Further studies of the photoproduction of isolated photons with a jet at HERA

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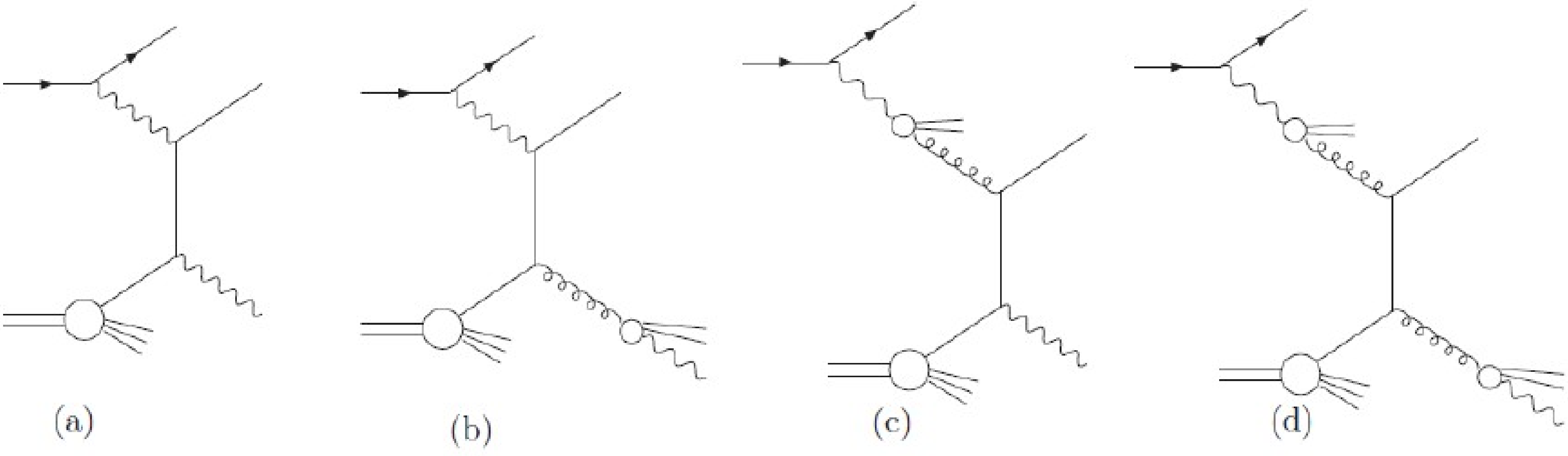
Introduction



(a) (b) (c) (d)

A prompt photon is one that emerges directly from a perturbative QCD process. LO diagrams are illustrated above:
(a) direct, in which the entire incoming photon interacts,
(c) resolved, in which a parton from the photon interacts.

Higher order pQCD processes occur and also "fragmentation" processes (b, d).

Motivation

- Prompt (isolated, high p_T) photons are a useful tool to study and test QCD.

- Their measurements are more precise than hadronic jets.

- Prompt photons can be used to measure and constrain the pdfs of proton and photon.

- Looking at three new variables: x_p, $\Delta\Phi$ and $\eta^{\gamma} - \eta^{jet}$.
- Study of three regions of x_{γ} – longitudinal momentum transfer from photon, resolved- and direct-enhanced:

$x_{\gamma} < 0.8$ and $x_{\gamma} > 0.8$

and to remove more of the remaining direct component:

$x_{\gamma} < 0.7$

Theory

FGH (Fontannaz, Guillet and Heinrich) - the LO and NLO diagrams and the box-diagram term are calculated explicitly. Fragmentation processes calculated in terms of fragmentation function.

LMZ (Lipatov, Malyshev and Zotov) - k_T-factorisation method makes use of unintegrated parton densities in the proton. Fragmentation terms are not included.

Analysis procedure

- Apply cleaning photoproduction cuts.
- Use Zufos as photon candidates.
- Find accompanying hadronic jet.
- Subtract the background using $<\delta Z>$ quantity – it is broader for background than for signal. Perform a statistical subtraction. It is done for every bin of every measured variable.
- Calculate acceptance corrections, cross-sections.

Data Samples

Data: HERA II 04p, 04/05e, 06e, 06p, 07p (Common Ntuples v06d) 374 pb^{-1}

MC Signal: 04p, 05e, 06e, 06p, 07p (CN v06b PYTHIA) Direct, Resolved

MC Background: 04p, 04/05e, 06e, 06p, 07p (CN v06b PYTHIA - Heavy Flavour Group, Jet – Sebastian's + Filtered) Direct, Resolved

Cuts

Event Selection

Trigger HPP16 on

$0.2 < y_{JB} < 0.7$

$|\text{Zvtx}| < 40$ cm

|BCAL time|<10 ns

Cal $p_T < 10$ GeV

No SINISTRA electron with Prob > 0.9 and Yel < 0.7

Prompt Photon Selection

Tufo[0] =31

$-0.7 < \eta^{zufo} < 0.9$

$6 < E_T^{zufo} < 15$ GeV

$E^{zufo}/E^{jet} > 0.9$

ZufoEemc/ZufoEcal>0.9

track isolation in cone 0.2

$x_\gamma < 0.7$, $x_\gamma < 0.8$ or $x_\gamma > 0.8$

Jet Selection

$-1.5 < \eta^{jet} < 1.8$

$4 < E_T^{\ jet} < 35$ GeV

Truth level selection

$Q^2 < 1\ \text{GeV}^2$

$0.2 < y_{JB} < 0.7$

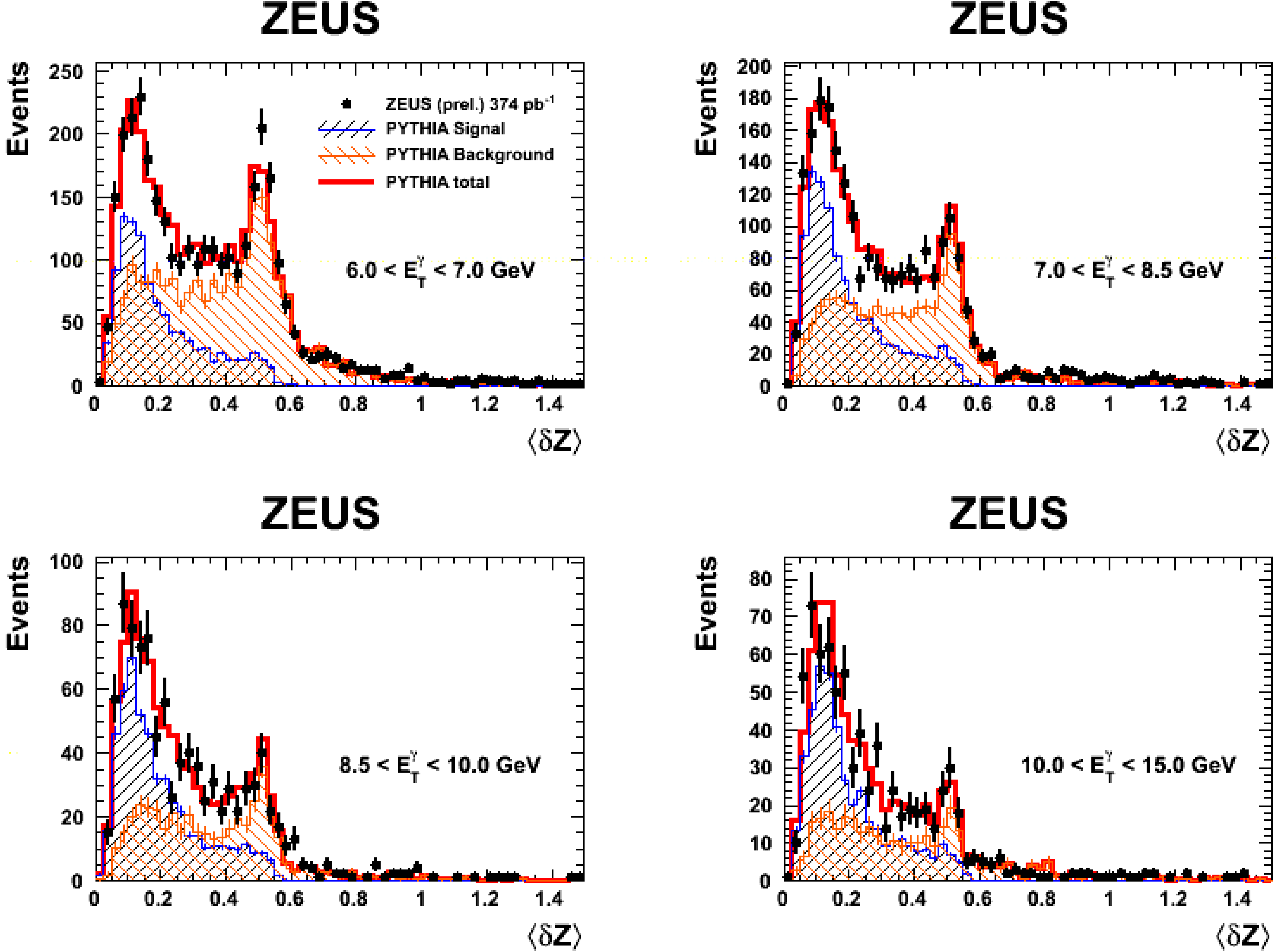
Particle type 29

$-0.7 < \eta^{particle} < 0.9$

$6 < E_T^{particle} < 15$ GeV

$E^{particle}/E^{jet} > 0.9$

Signal extraction



<δZ> energy weighted mean width of the electromagnetic cluster in Z direction:

$$\langle \delta Z \rangle = \sum_i E_i |Z_i - Z_{\mathrm{cluster}}| \Big/ (w_{\mathrm{cell}} \sum_i E_i)$$

Distributions of <δZ> in bins of E_T^γ showing the fitted signal and background.

Components. Chi**2 per degree of freedom in bins of examined variables is typically 1.1.

A model of
50% PYTHIA Direct,
40% Resolved,
5% each of resolved and direct radiative (“fragmentation”).

The radiative events are obtained from the background.
They are discarded from the background before it is used in the fits.

A systematic uncertainty allows for uncertainties in this model.

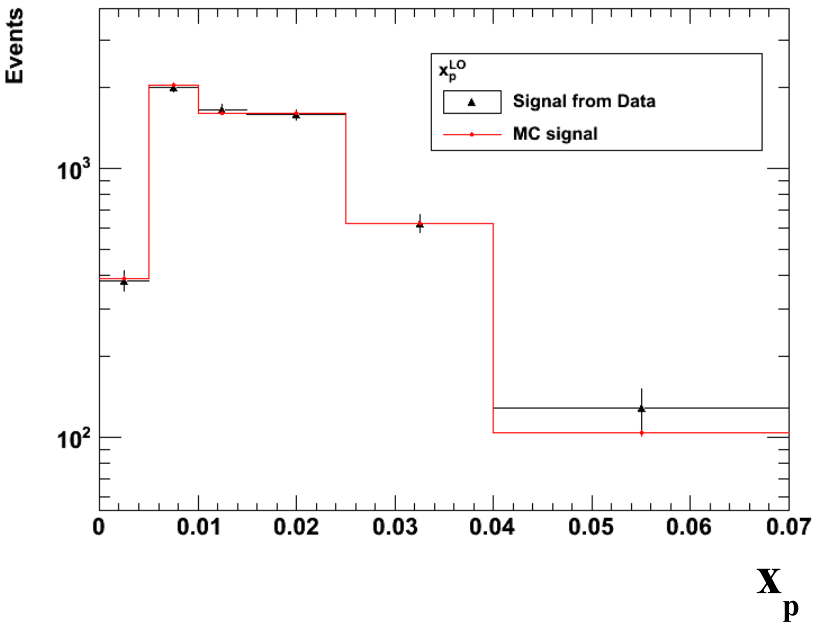
However different x_γ regions have different ratio of direct and resolved. Current 50/40/5/5 is obtained from $0.0 < x_\gamma < 1.0$ fit of PYTHIA MC signal to signal extracted from data. This ratio is further modified using detector-level PYTHIA predictions, so it is multiplied on ratio of what PYTHIA predicts is in e.g. $0.0 < x_\gamma < 0.7$ to the number of events in $0.0 < x_\gamma < 1.0$. Thus subregion ratios are:

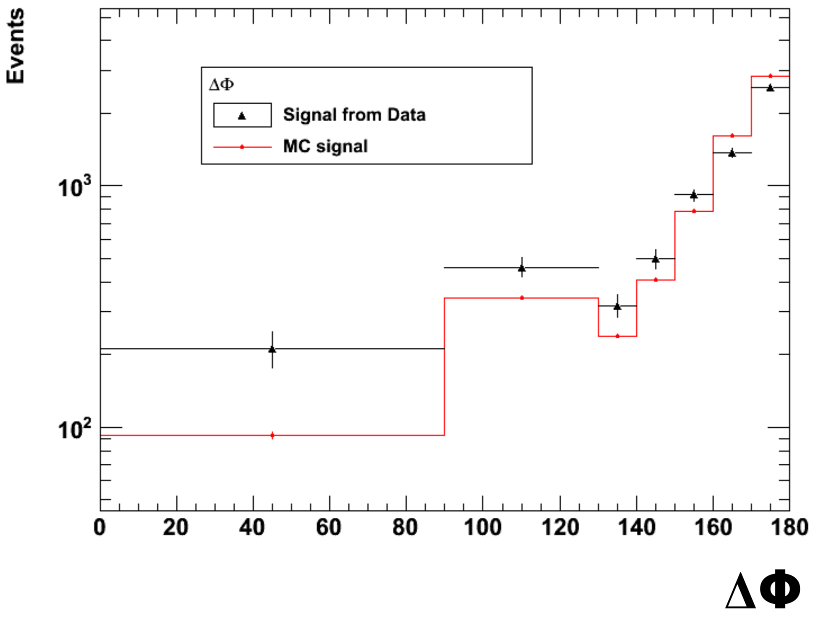
$0.0 < x_\gamma < 0.7$: 10/75/5/10

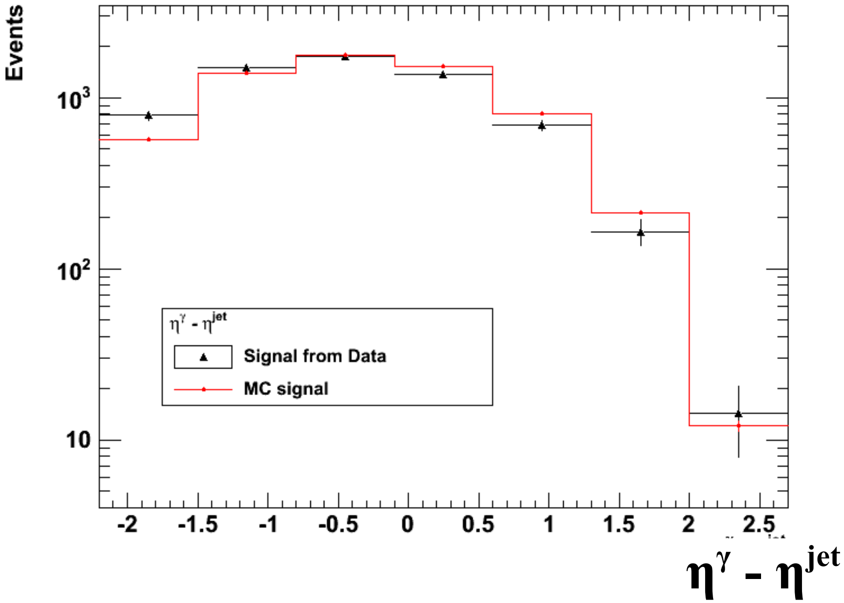
$0.0 < x_\gamma < 0.8$: 16/69/6/9

$0.8 < x_\gamma < 1.0$: 82/13/4/1

Control plots. All x_γ





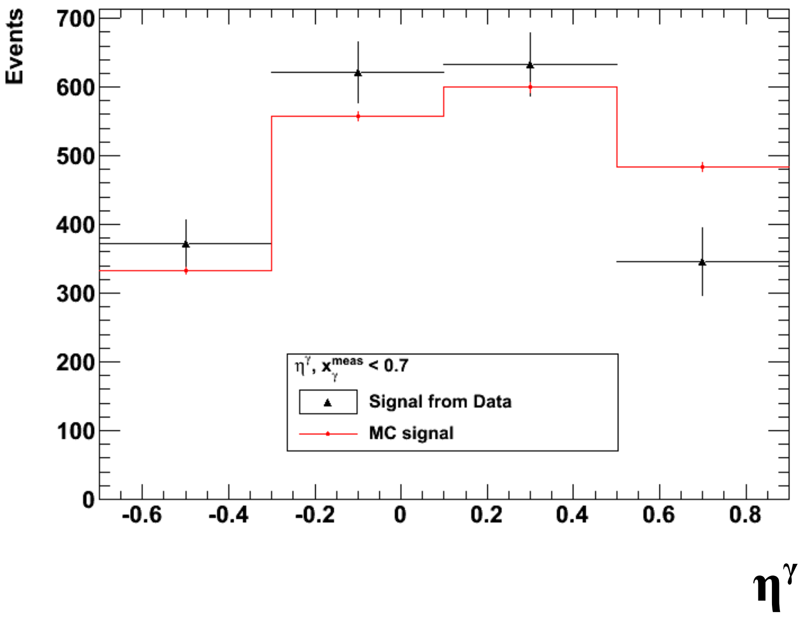


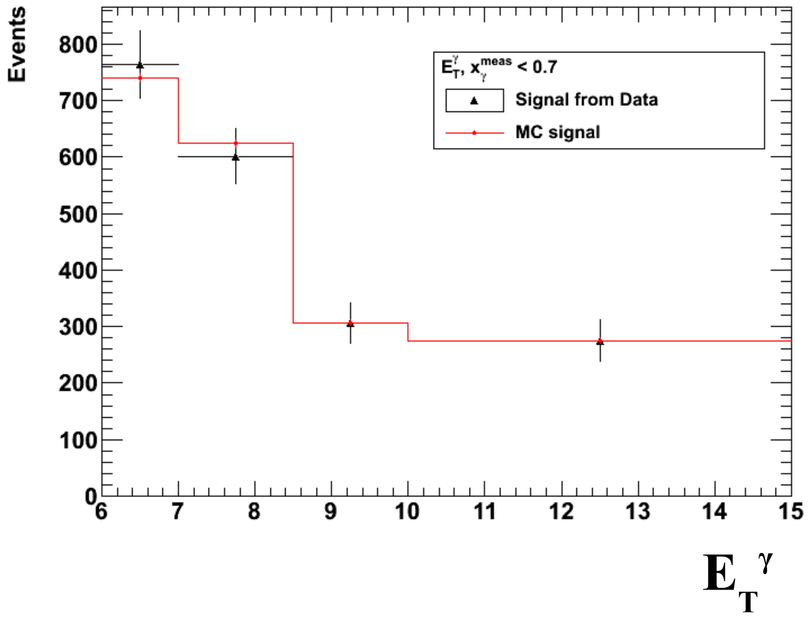
Signal from Data is signal extracted with deltaz fits.

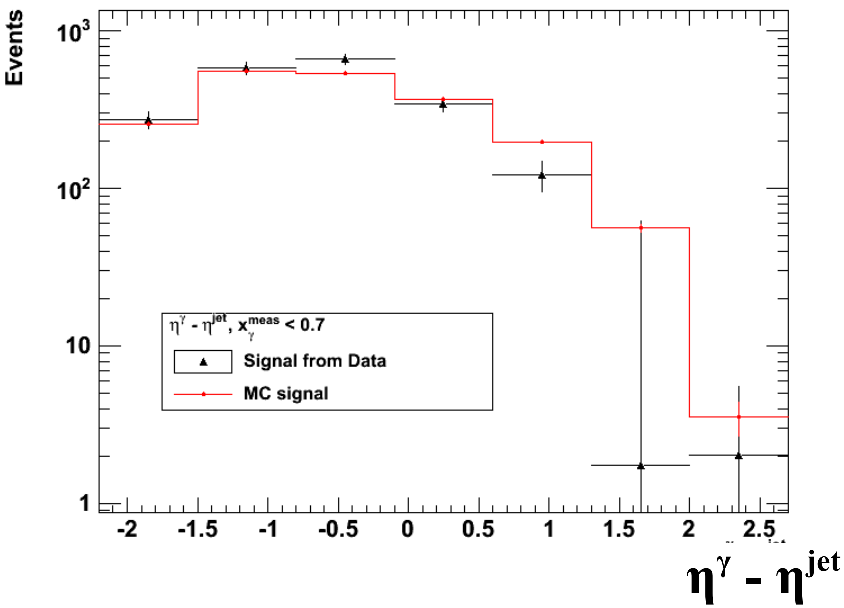
MC is normalized to signal from data.

Reasonable description of data by PYTHIA MC.

Control plots. $x_\gamma < 0.7$







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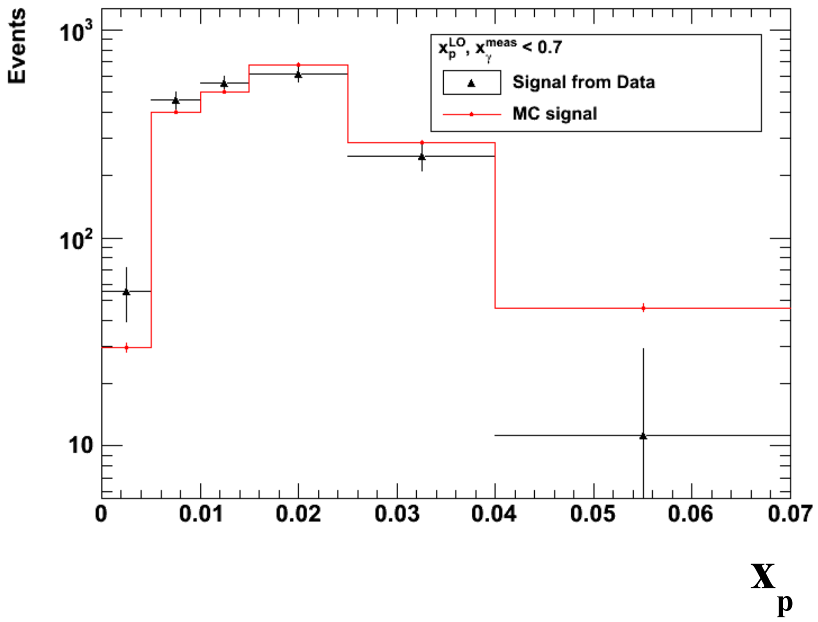
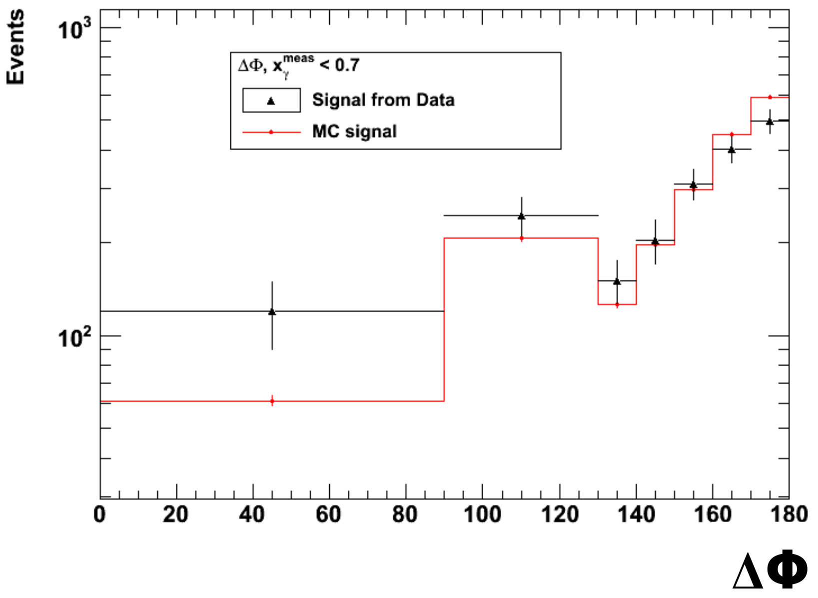
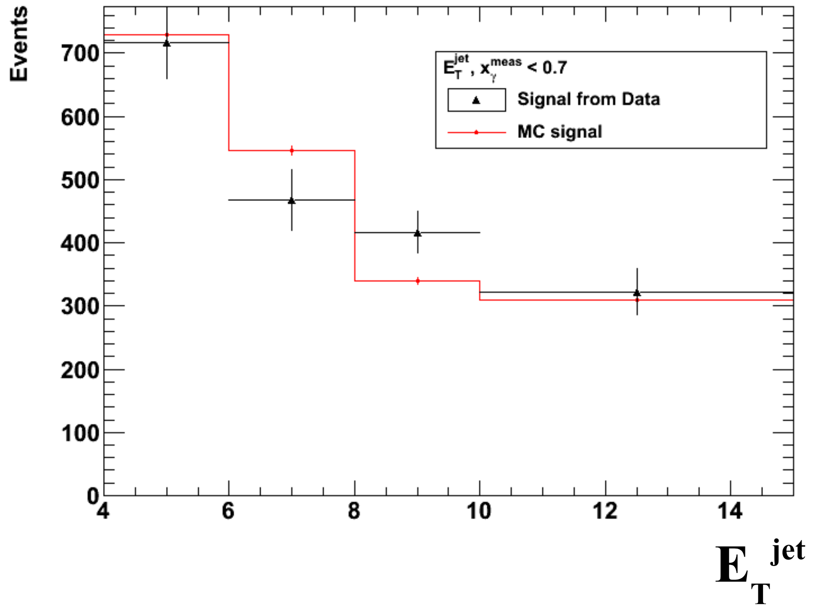
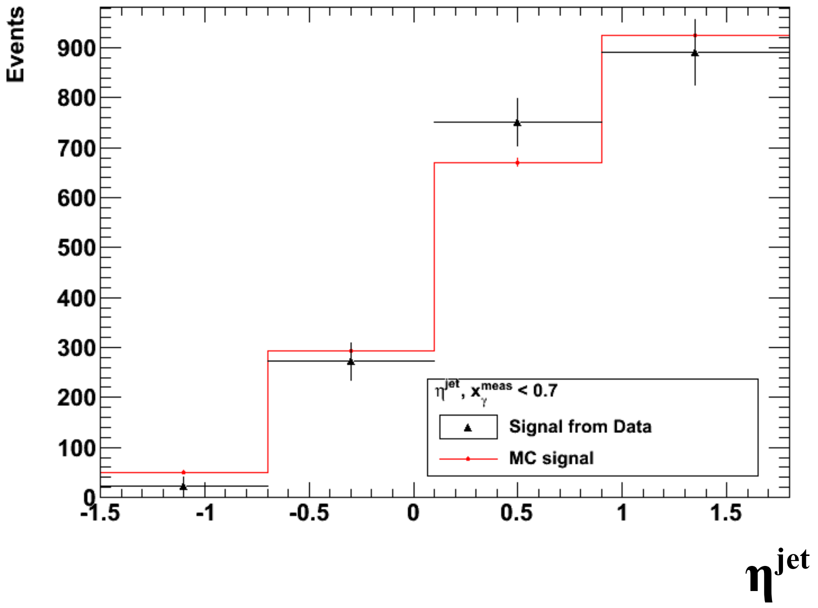


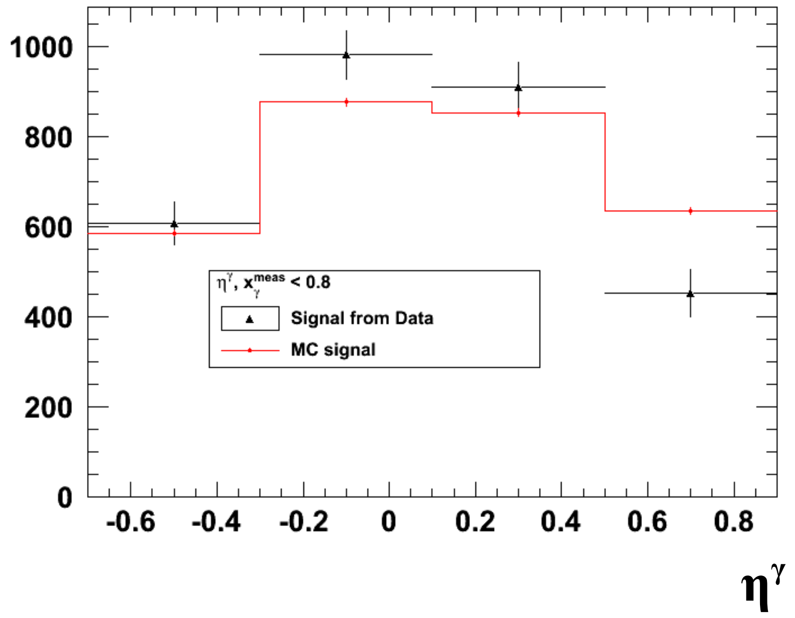


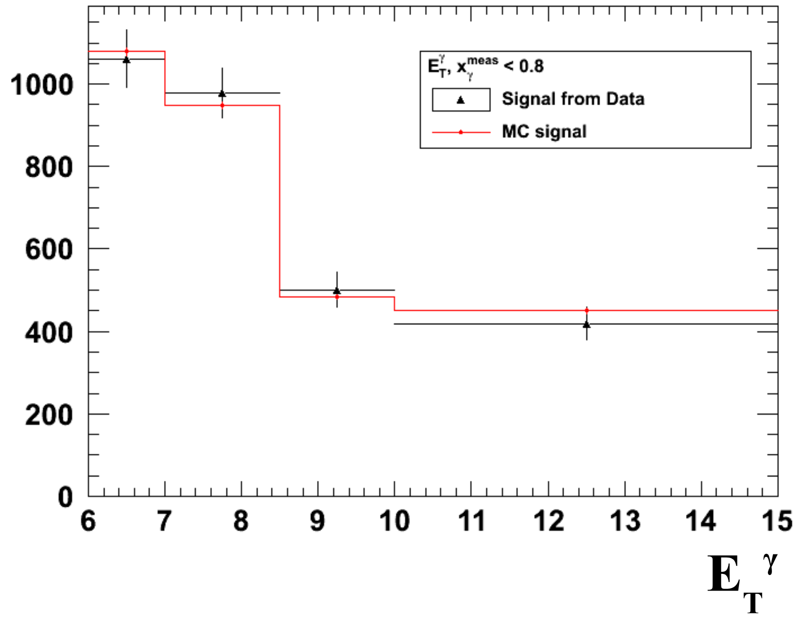


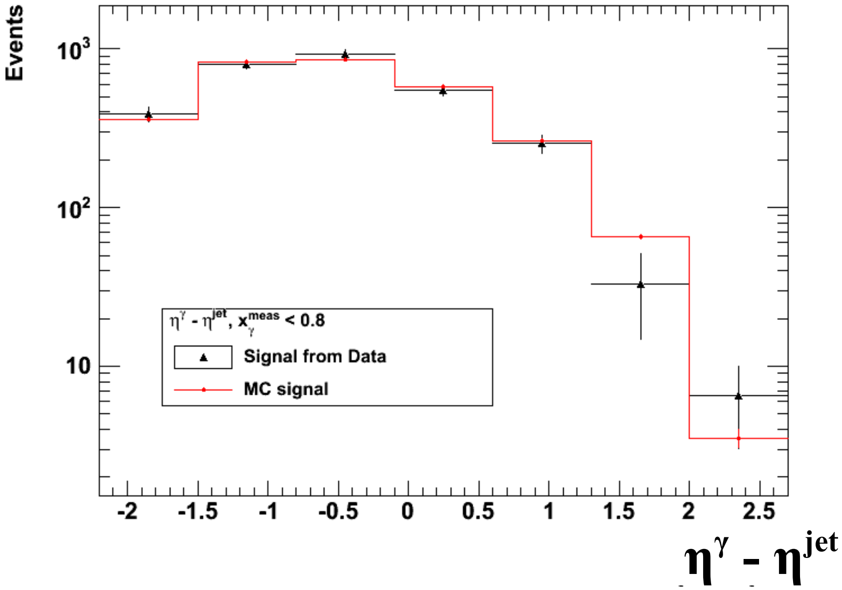


Reasonable description of data.

Control plots. $x_\gamma < 0.8$

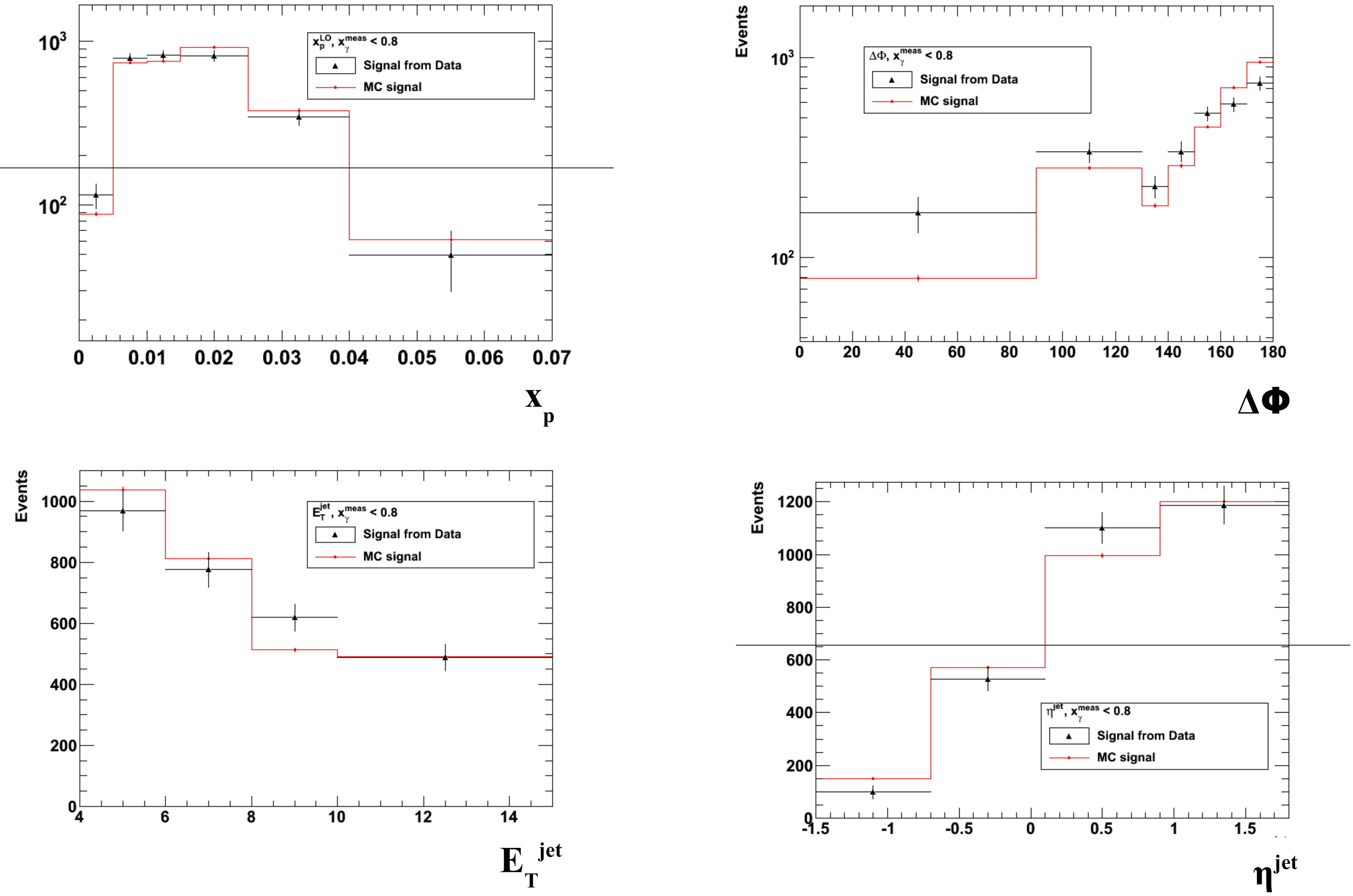






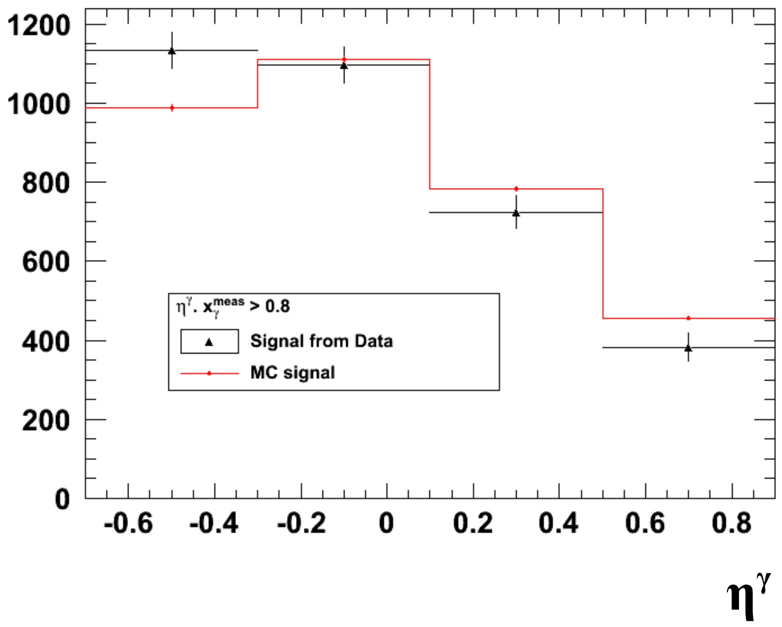
Reasonable description of data by PYTHIA MC.

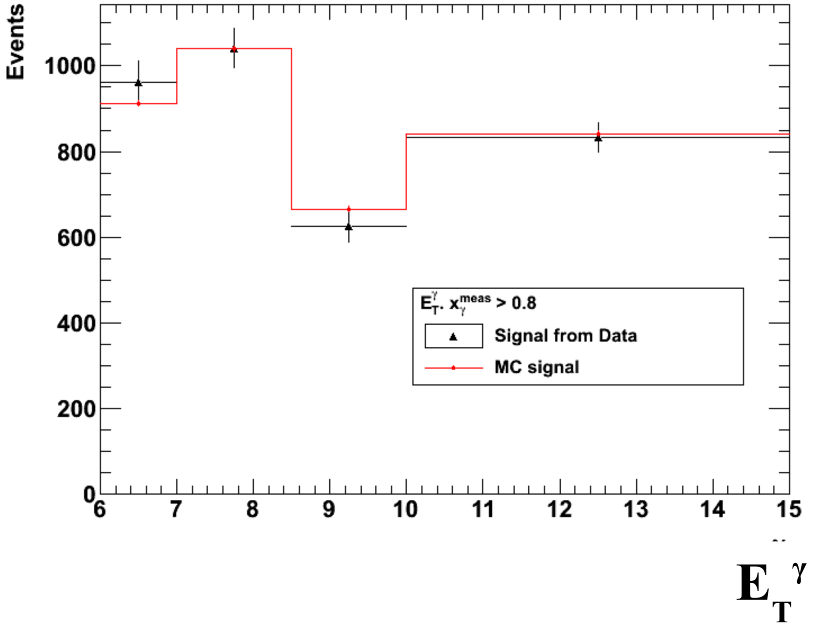
Control plots. $x_\gamma < 0.8$

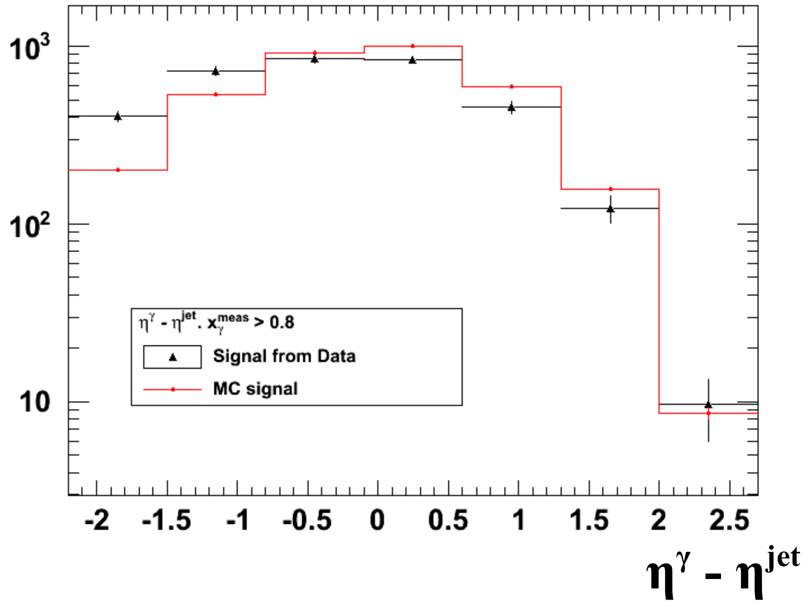


Reasonable description of data.

Control plots. $x_\gamma > 0.8$

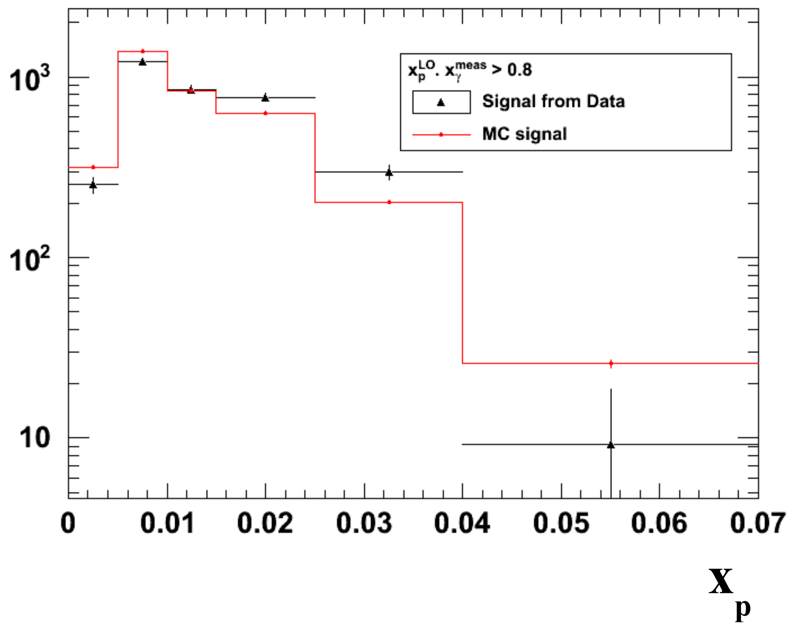


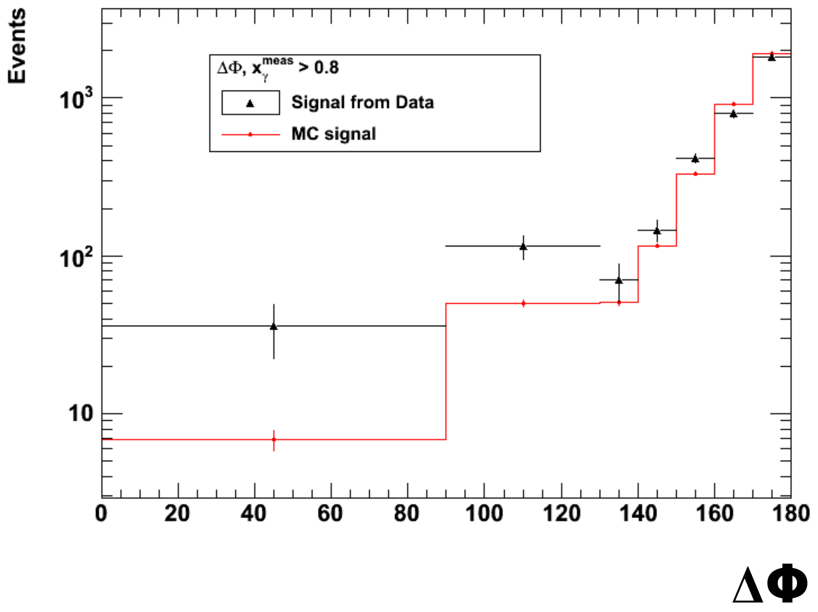


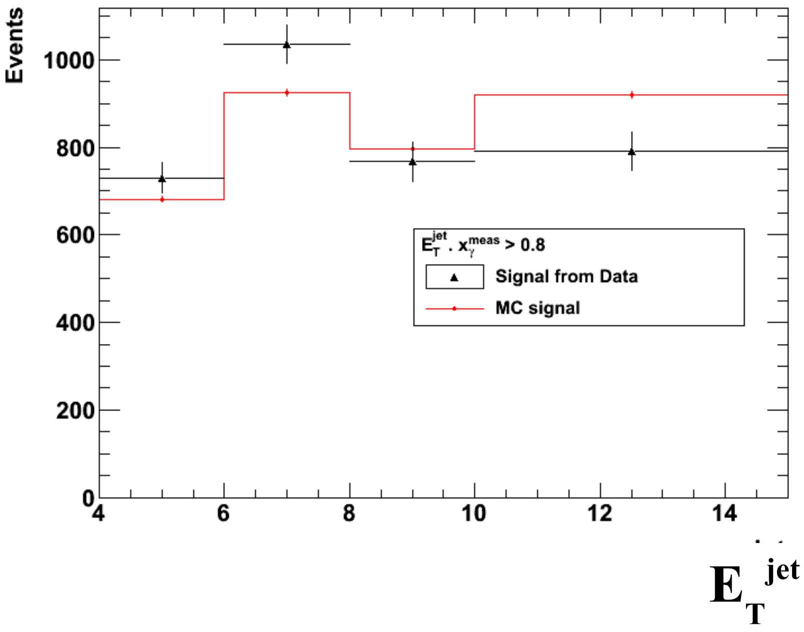


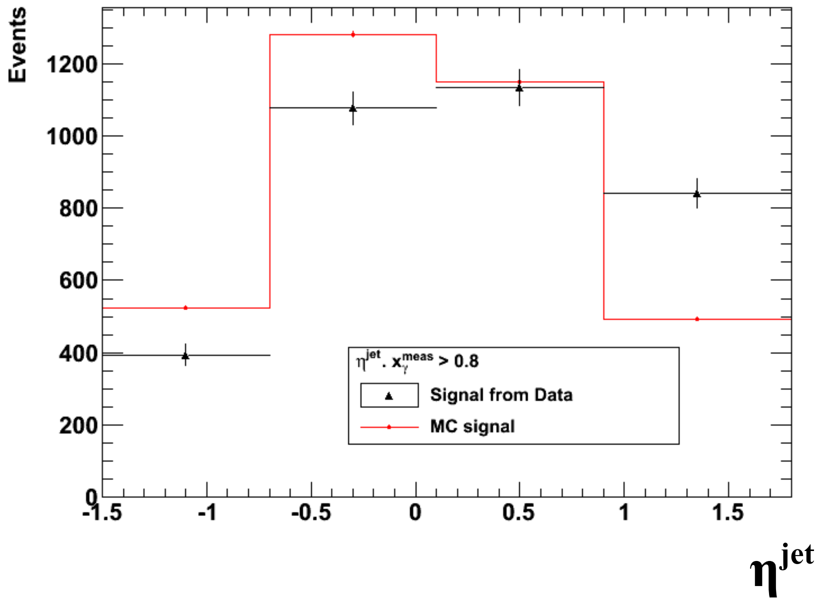
Reasonable description of data by PYTHIA MC.

Control plots. $x_\gamma > 0.8$



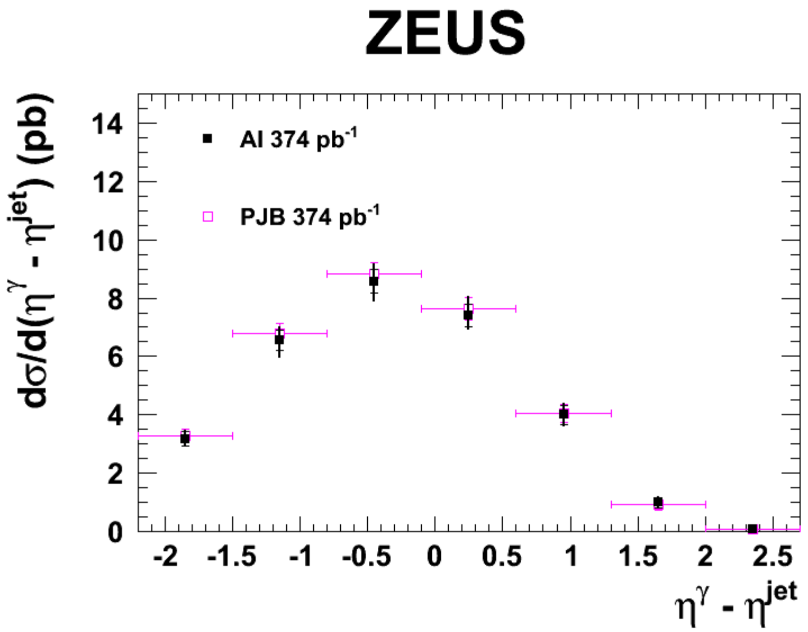


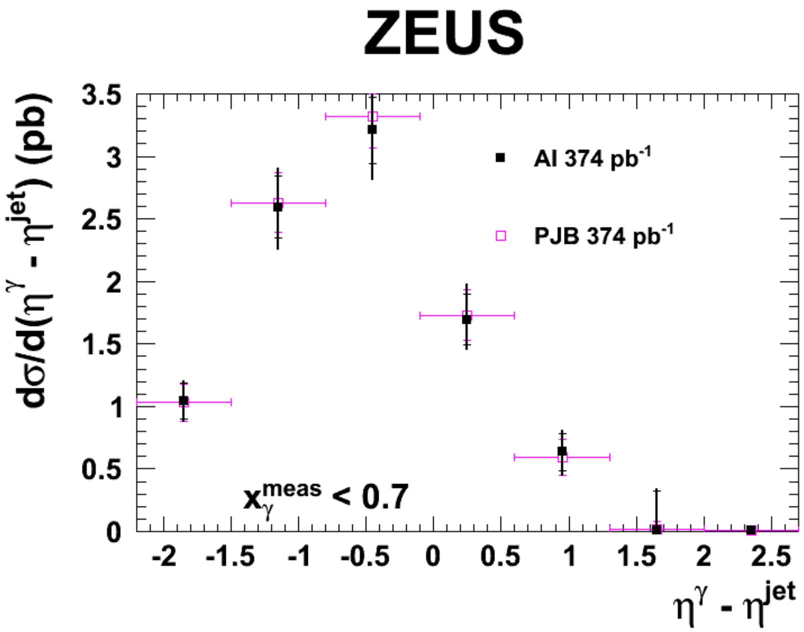


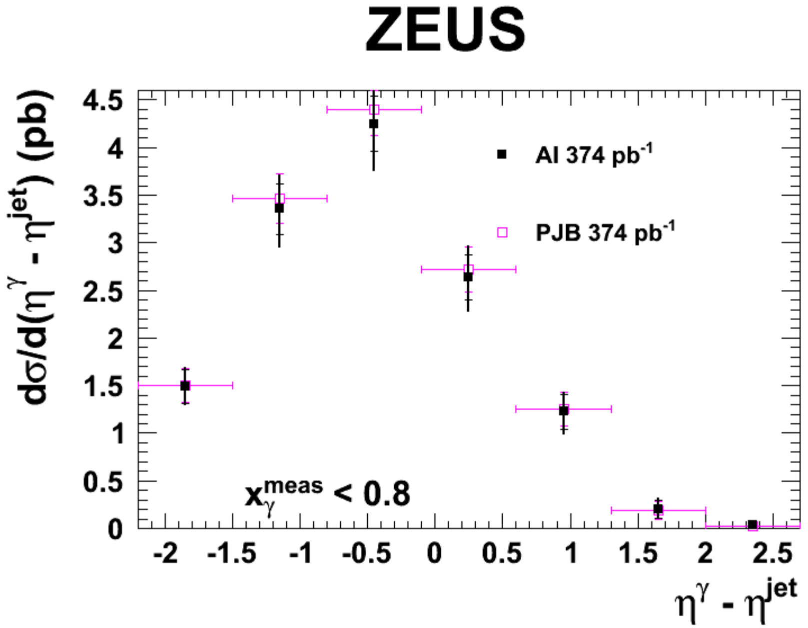


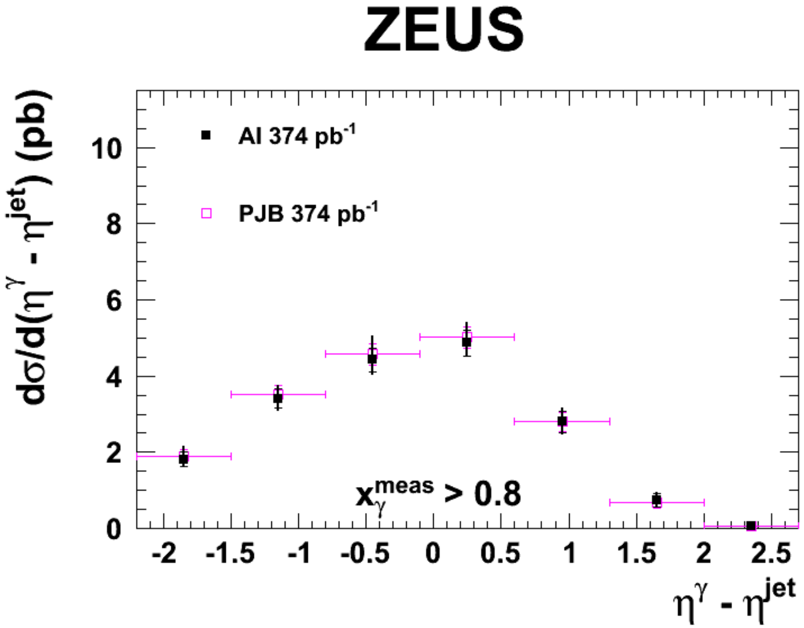
Reasonable description of data.

Comparison between analyses



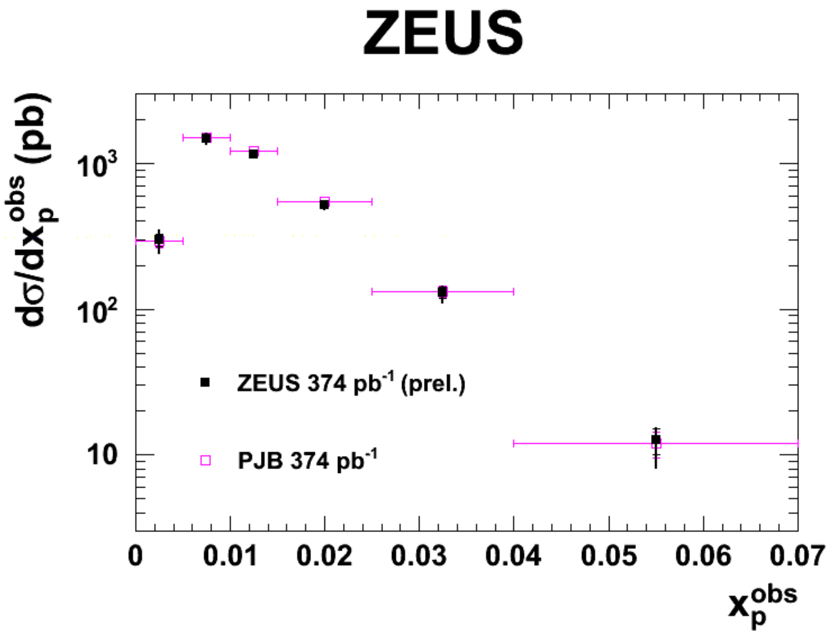


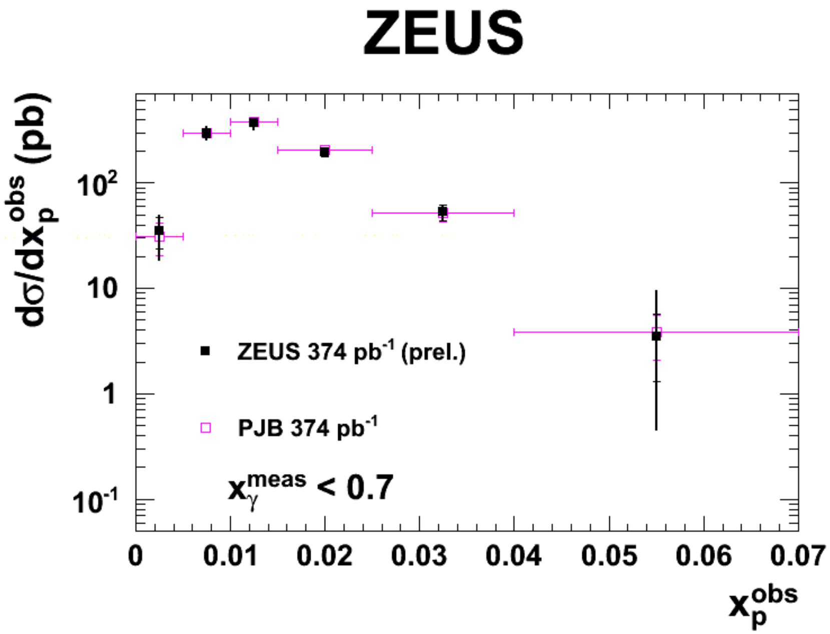


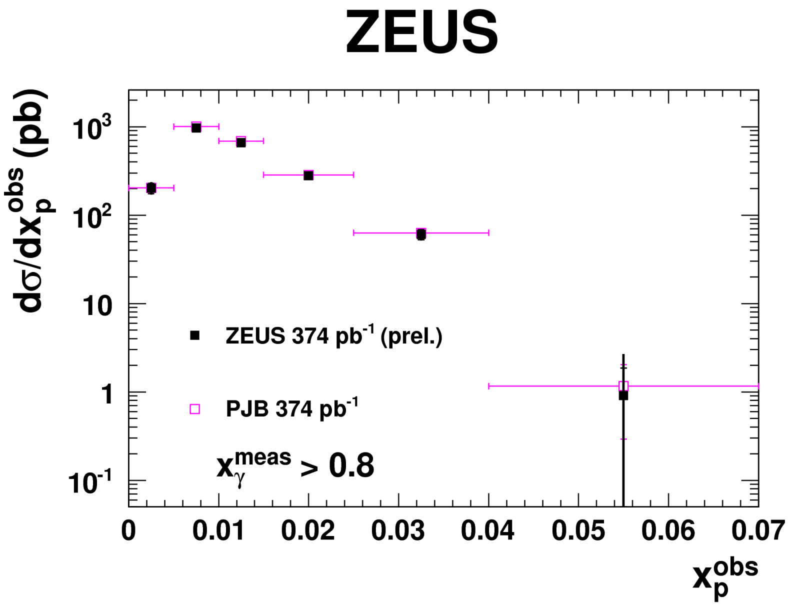


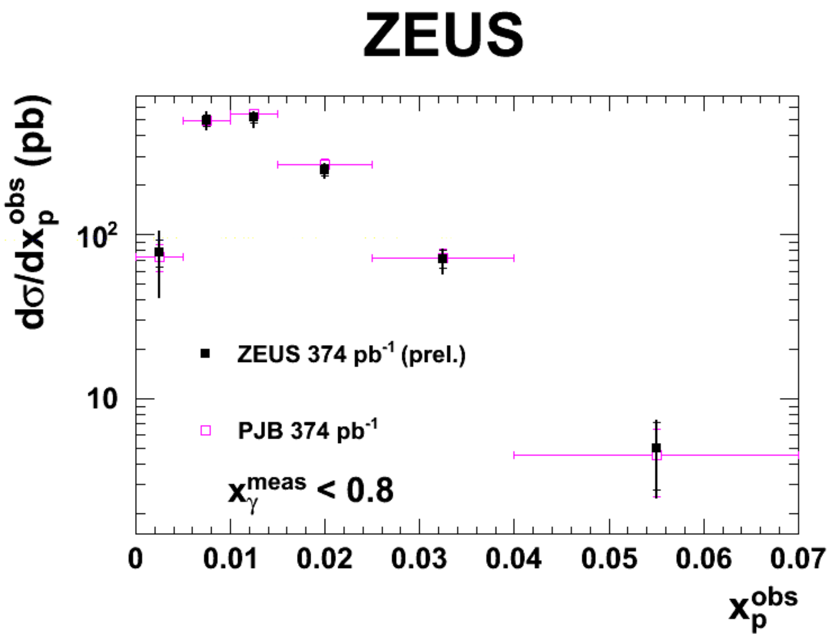
Good agreement between analyses.

Comparison between analyses









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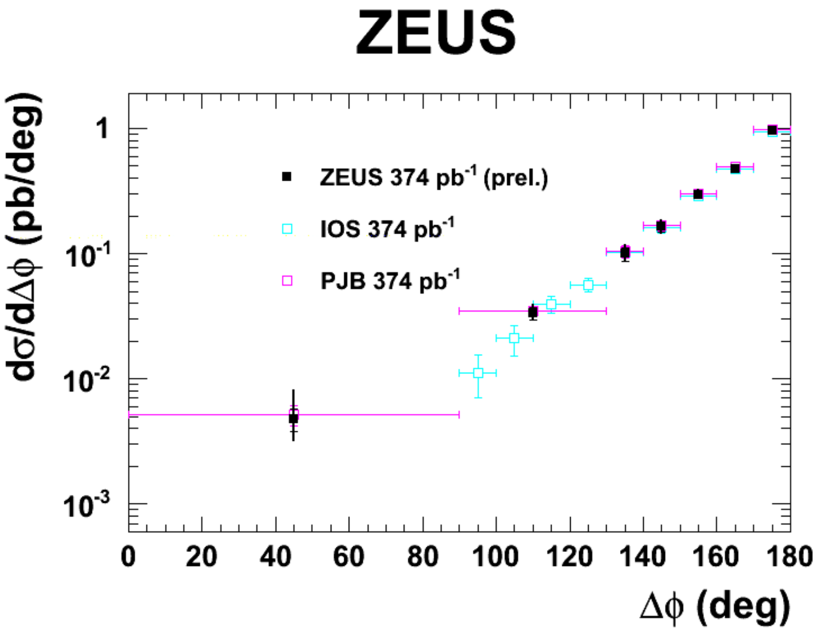

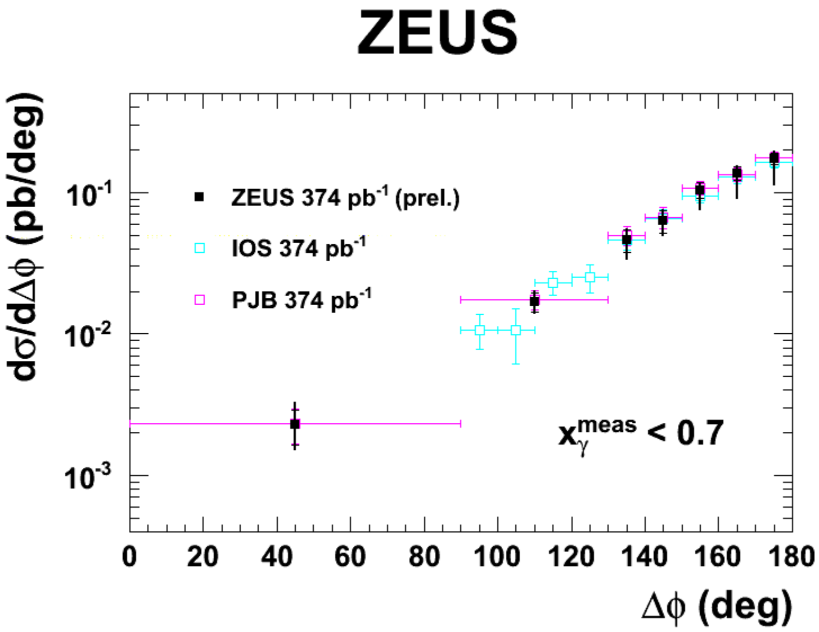

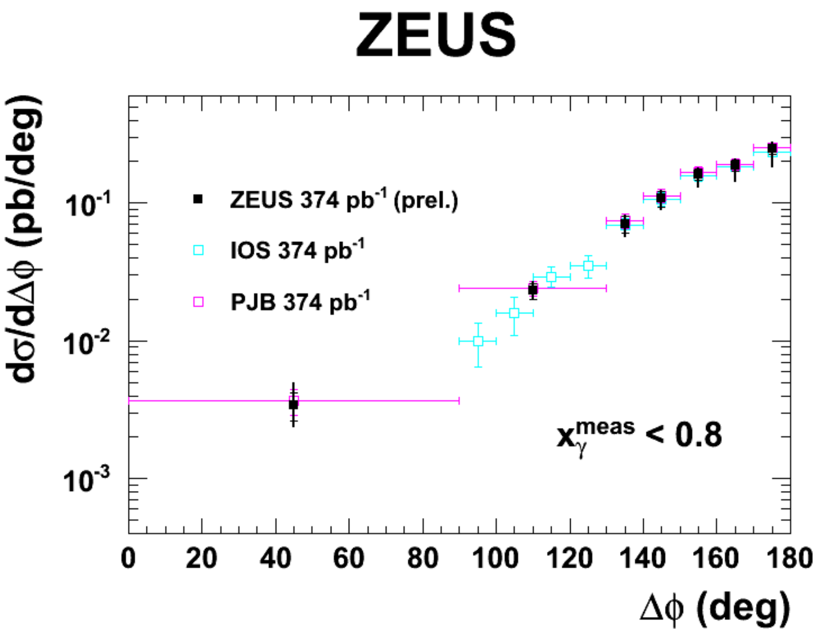

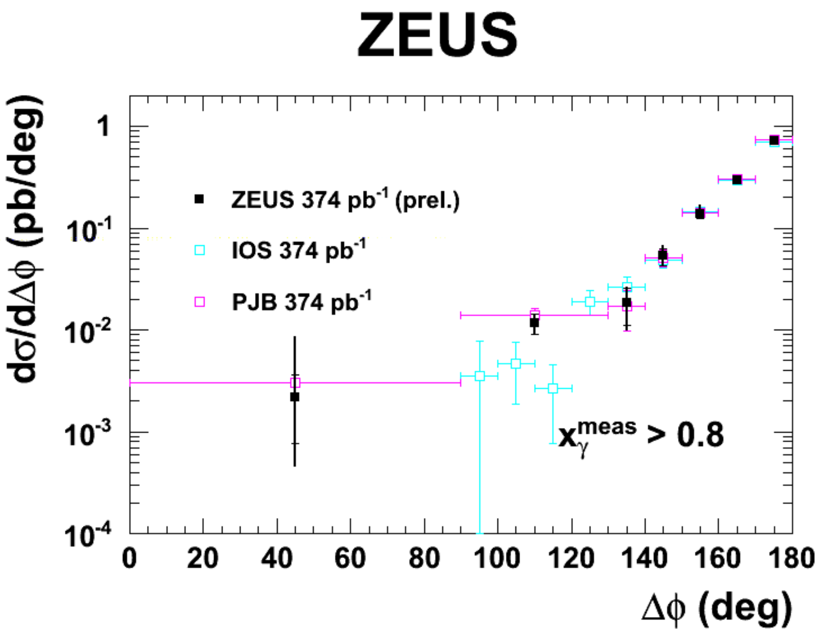

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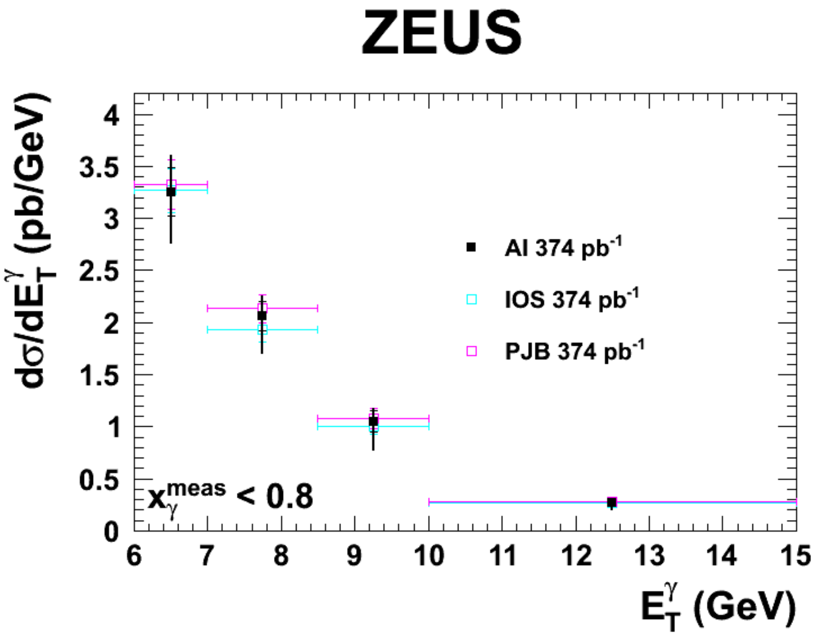
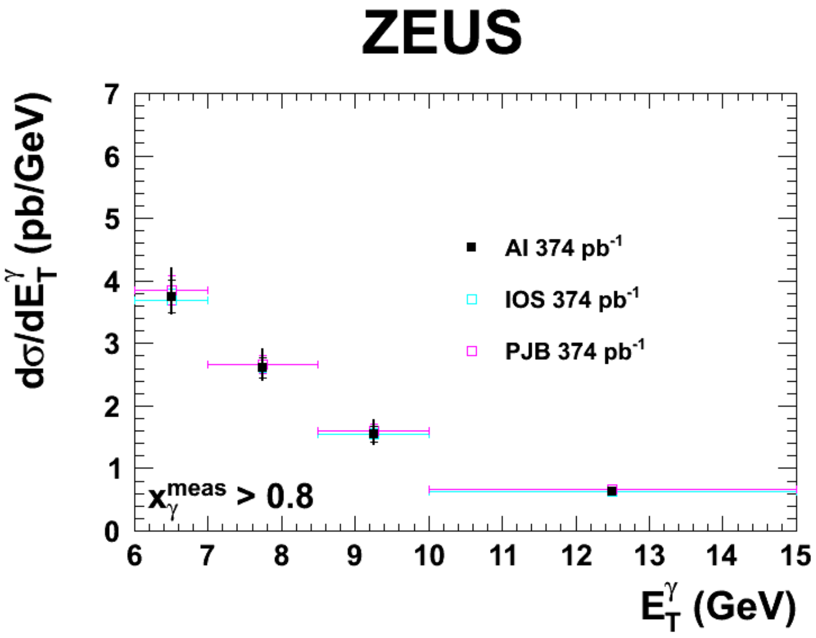
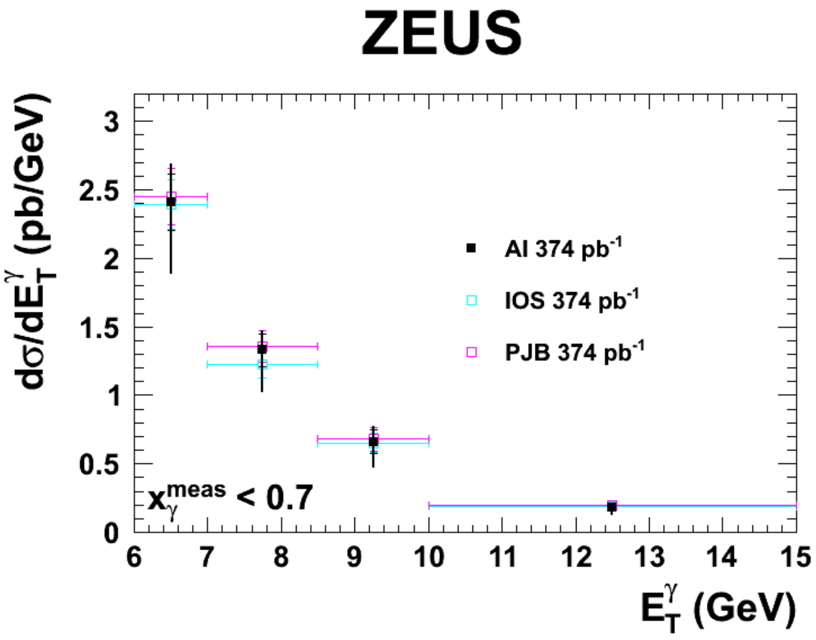
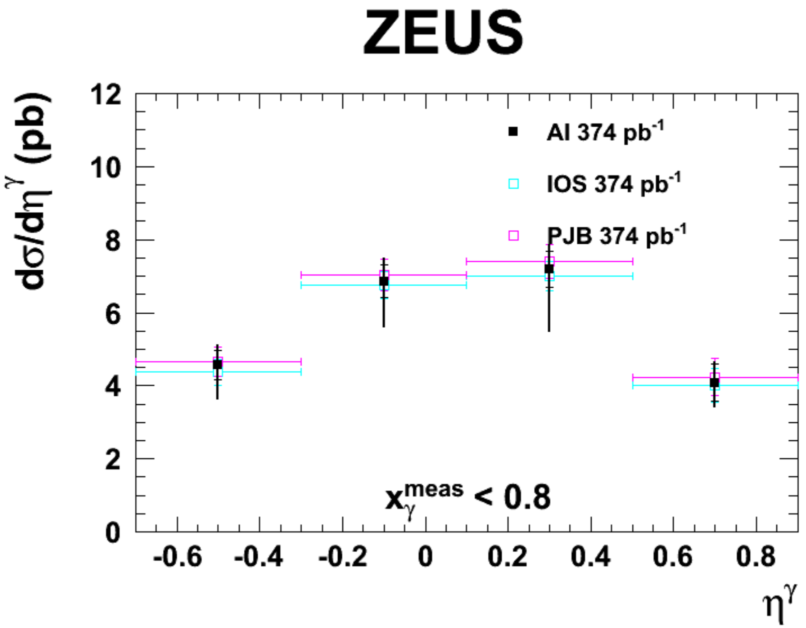


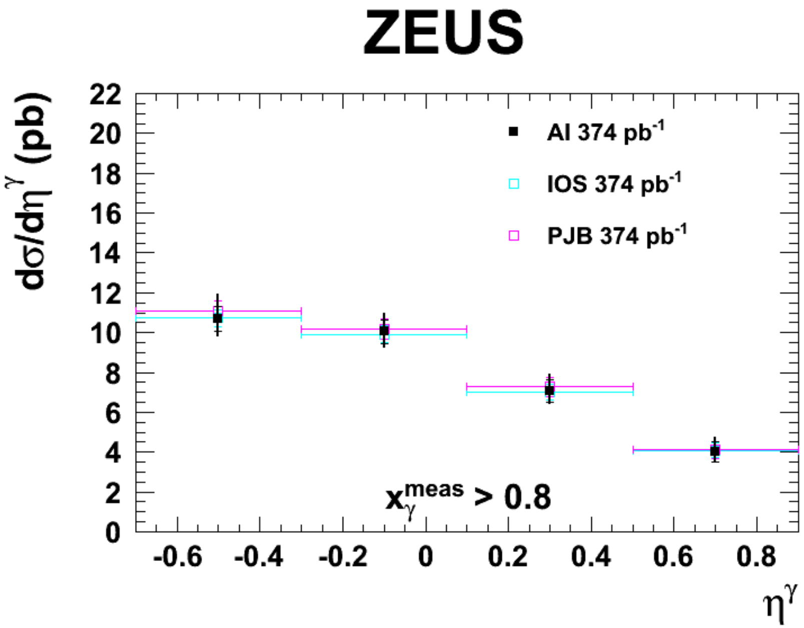


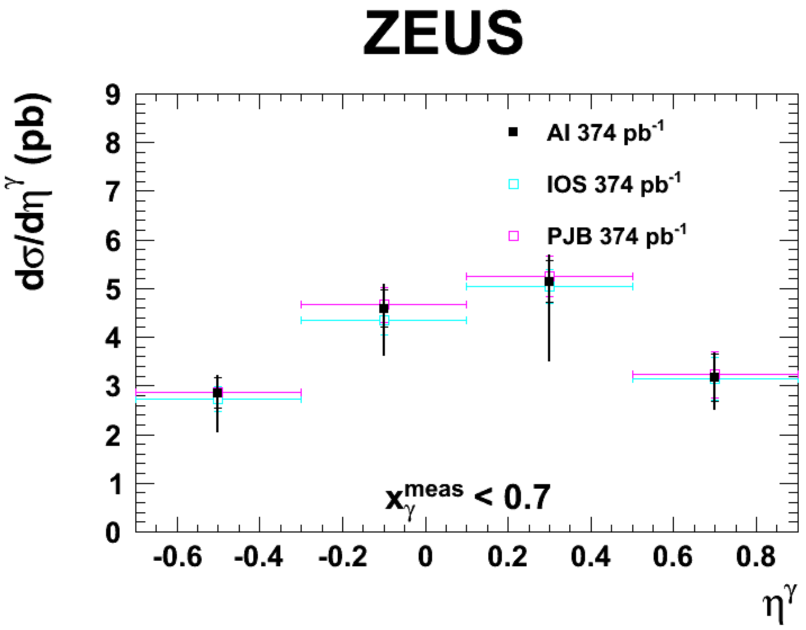


Reasonable agreement between analyses.

Comparison between analyses







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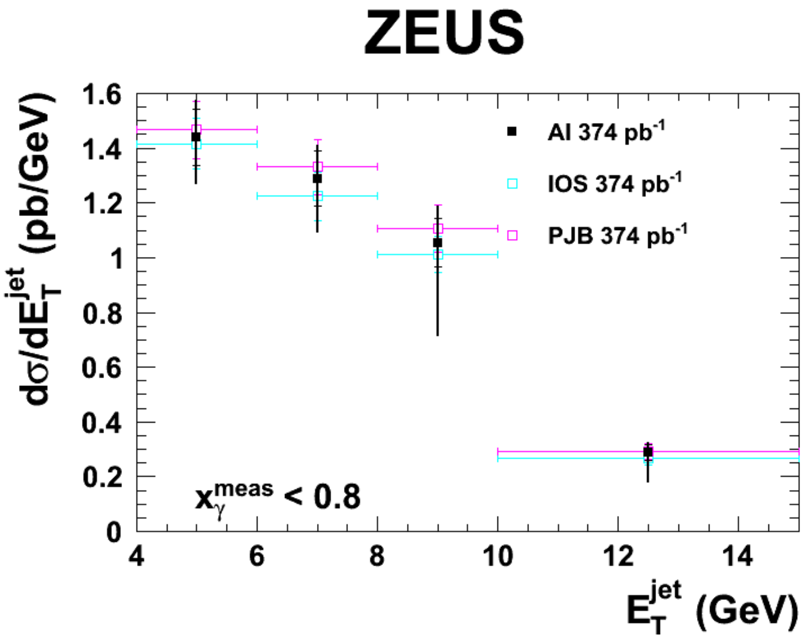

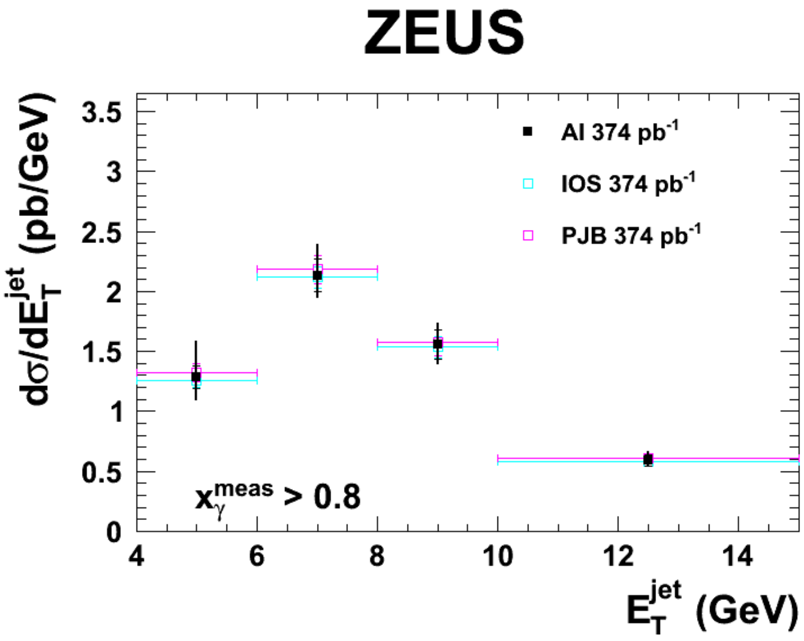

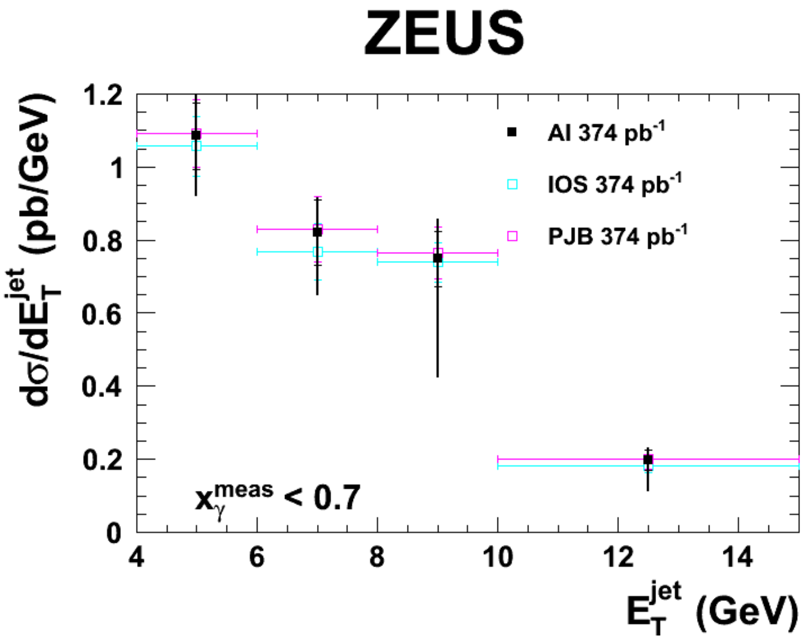

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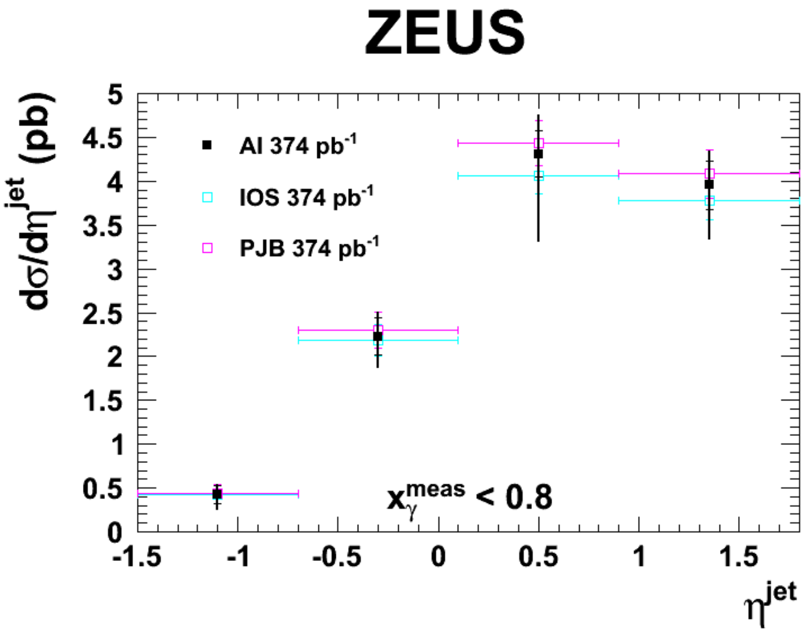
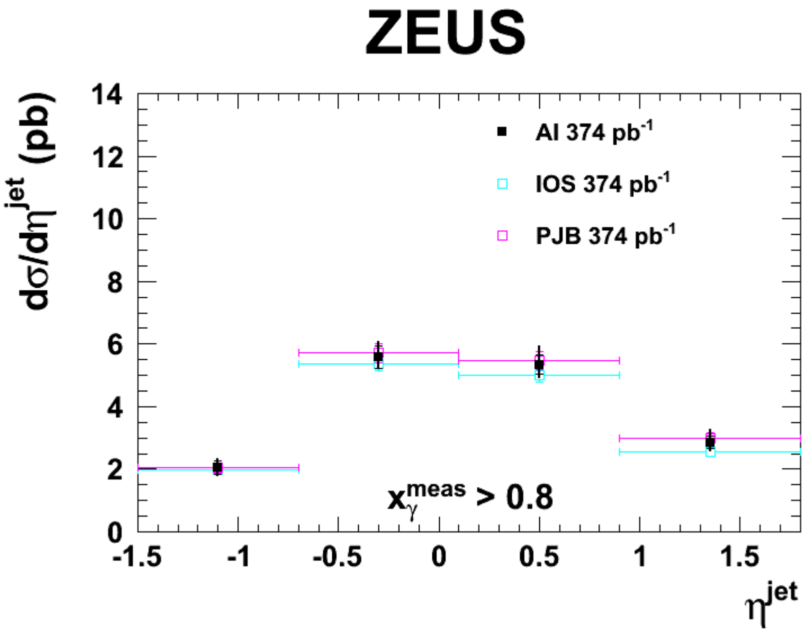
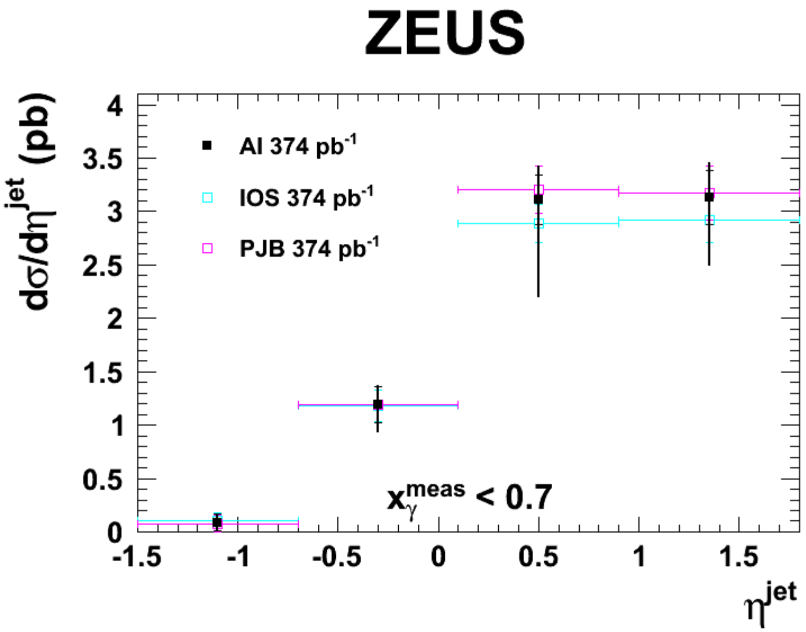
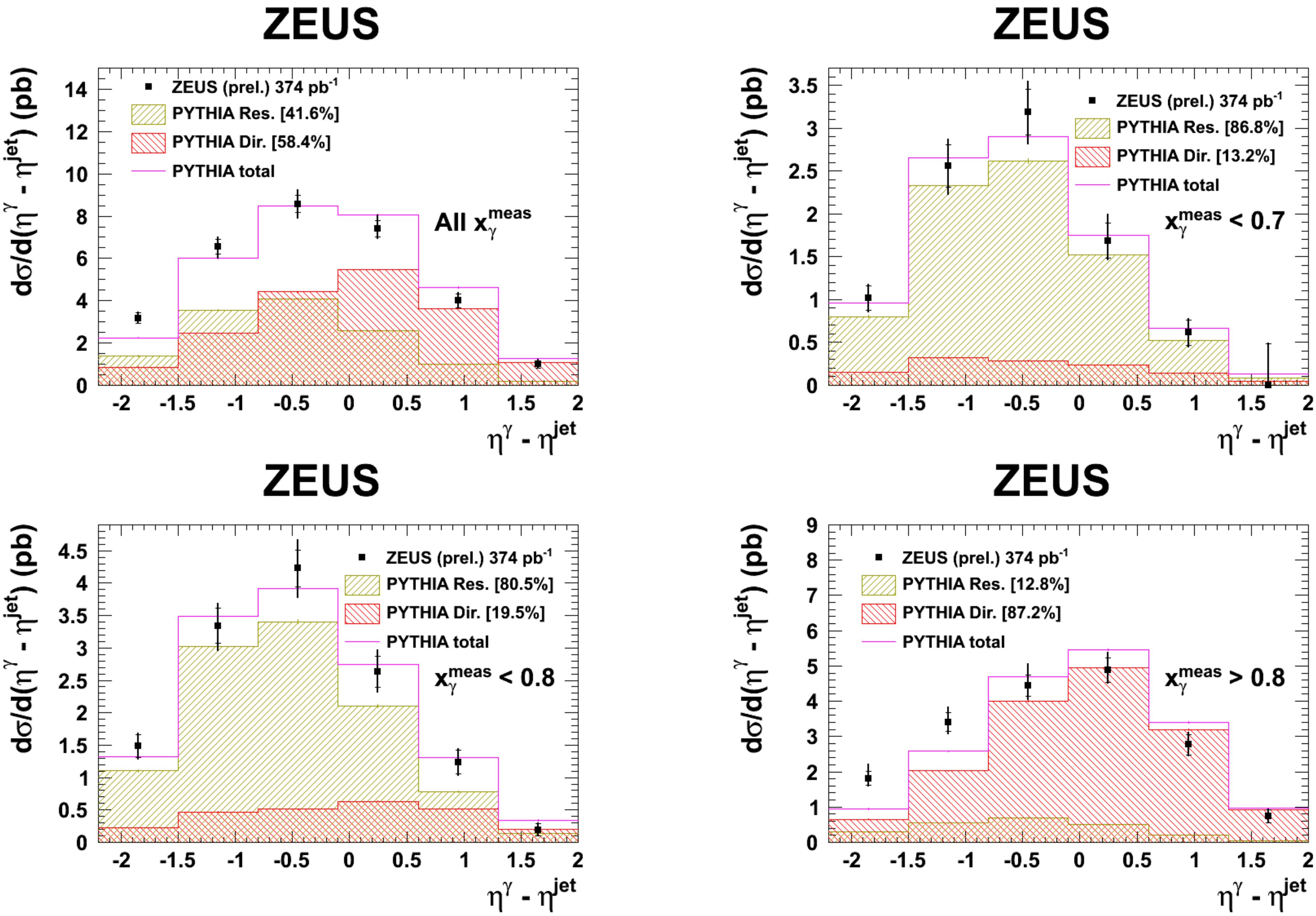






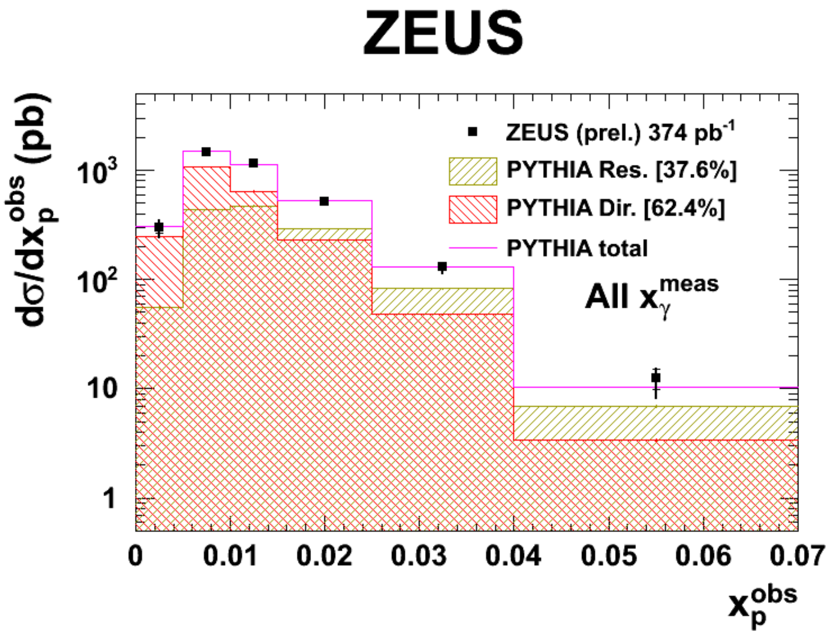
Reasonable agreement between analyses.

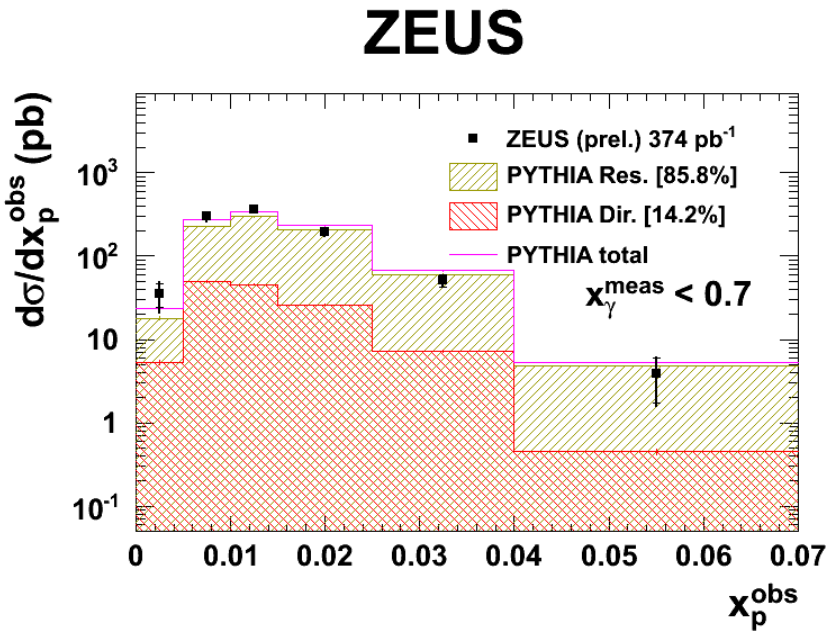
PYTHIA. Cross sections. $\eta^{\gamma} - \eta^{jet}$

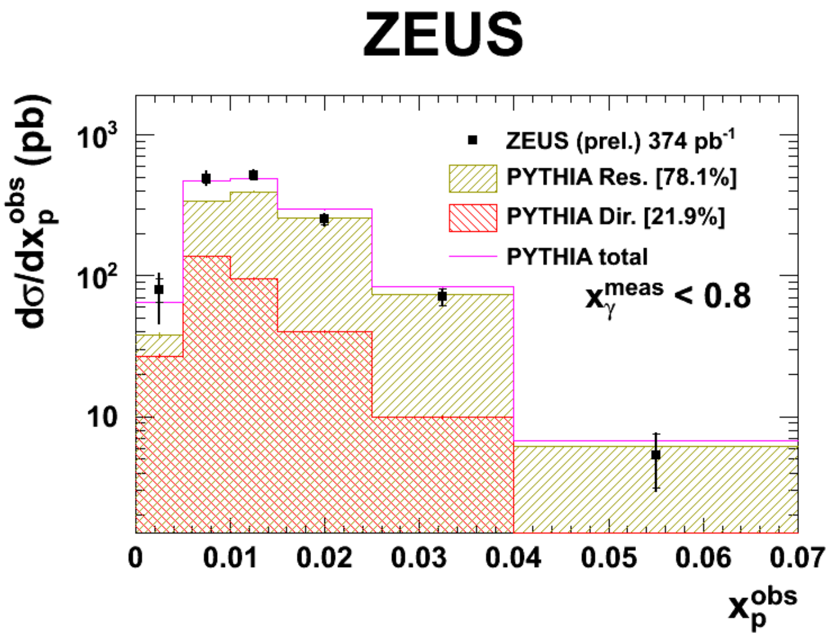


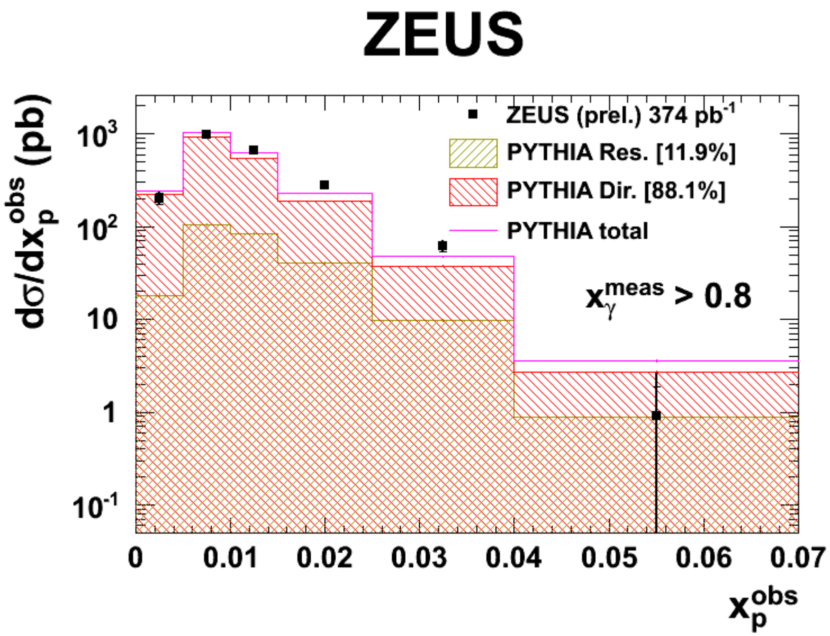
PYTHIA Direct and Resolved has Direct Fragmentation and Resolved Fragmentation included, respectively, then normalised to data.

PYTHIA. Cross sections. x_p



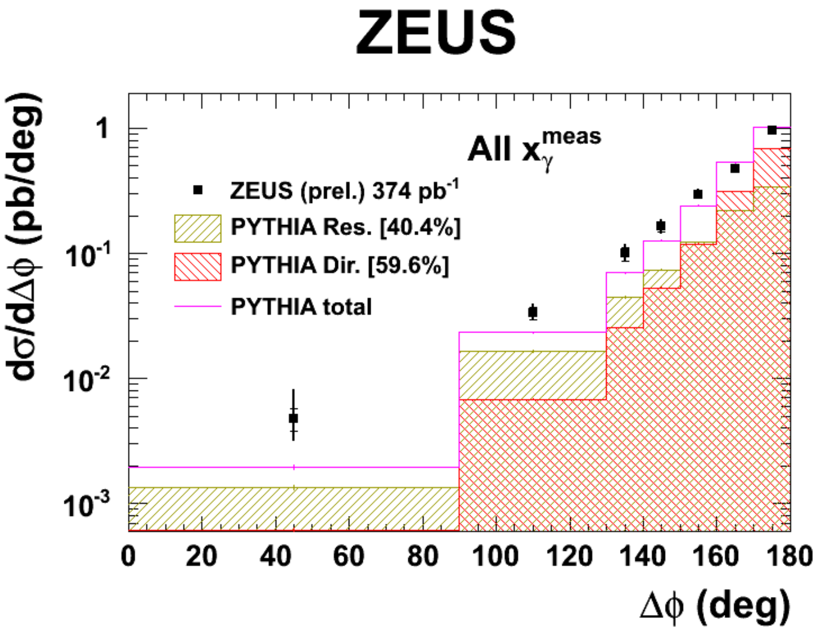


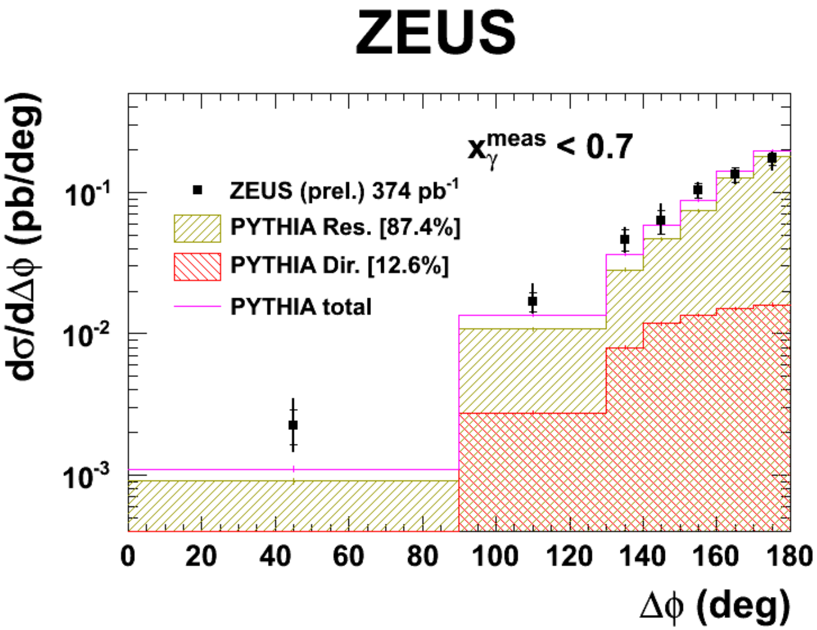


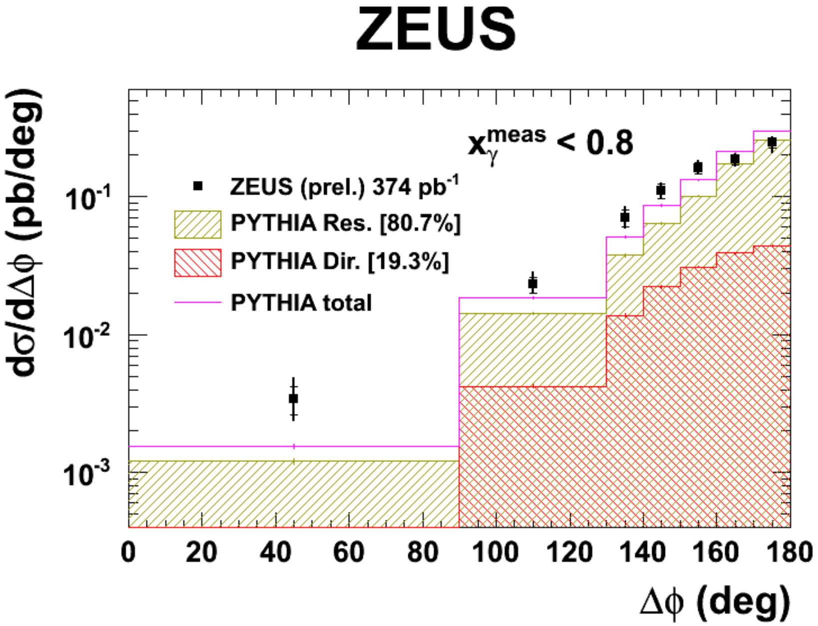


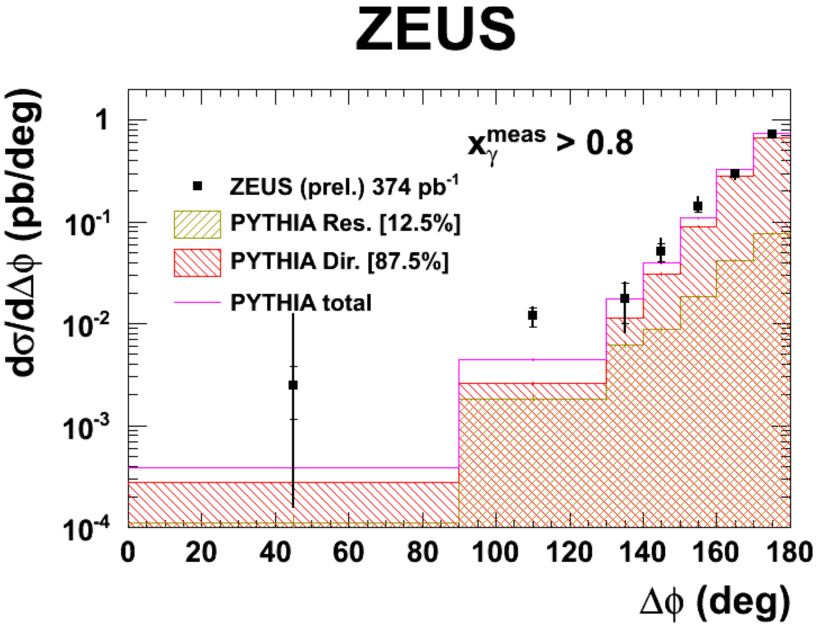
Reasonable description of data by MC.

PYTHIA. Cross sections. ΔΦ



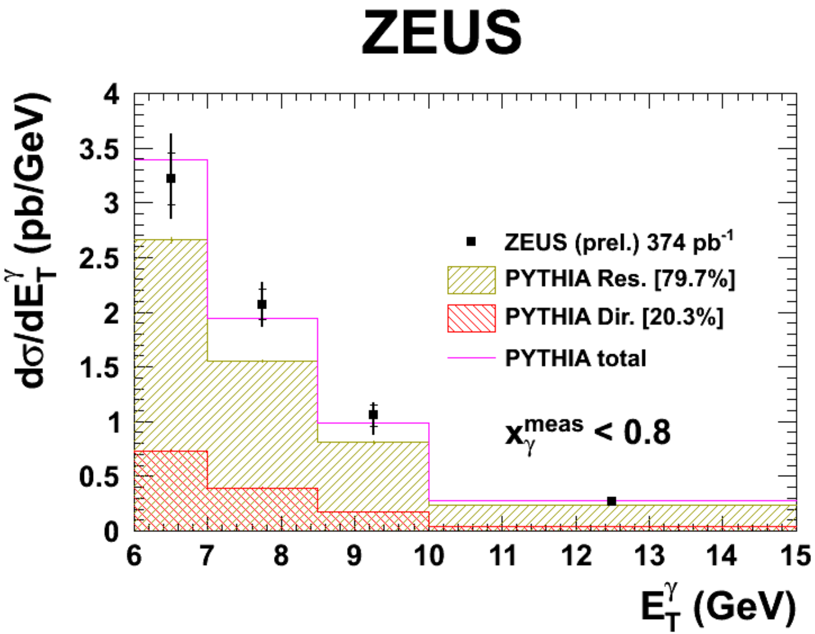


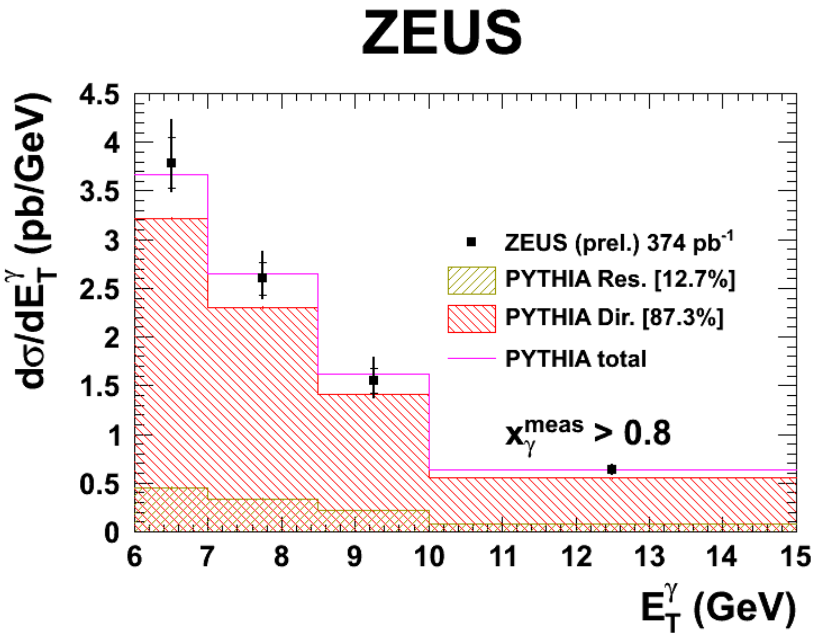


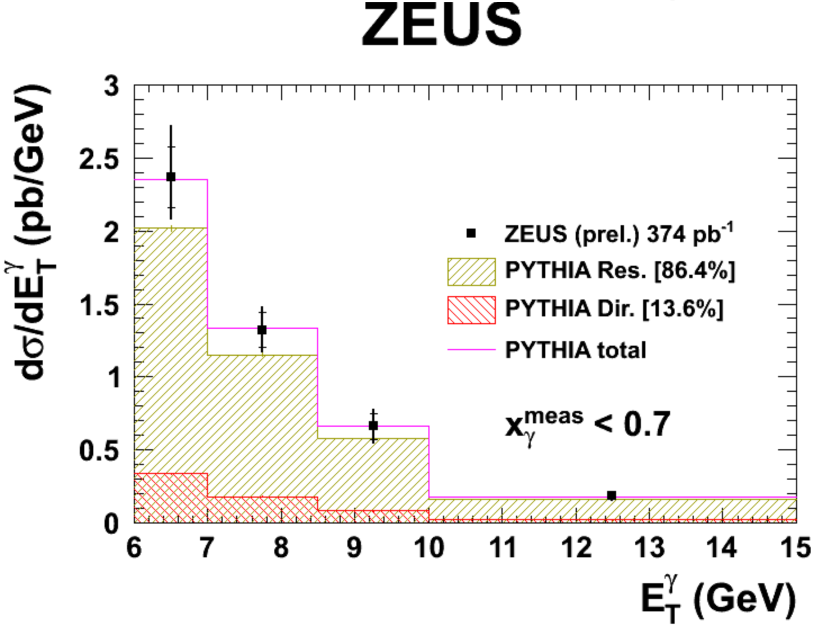


Reasonable description of data by MC. Low ΔΦ is underestimated.

PYTHIA. Cross sections. E_T^γ

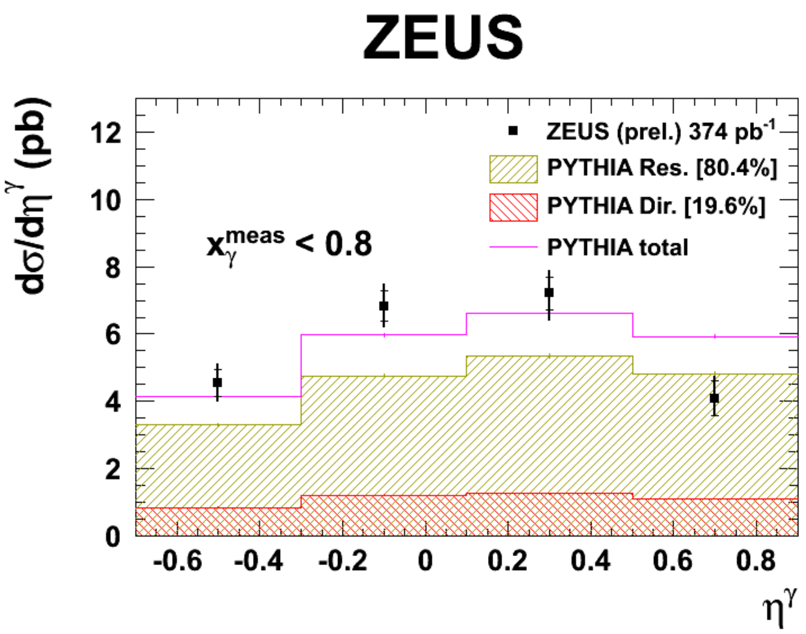


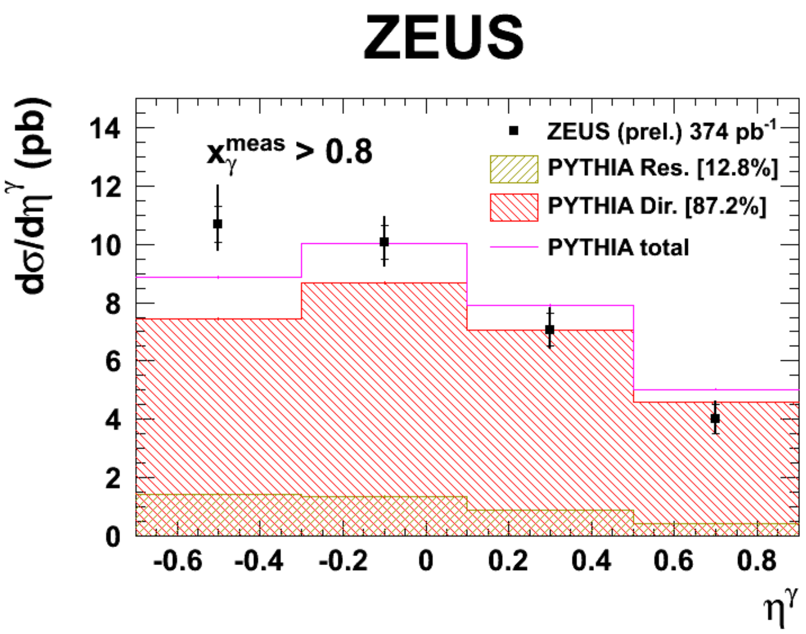


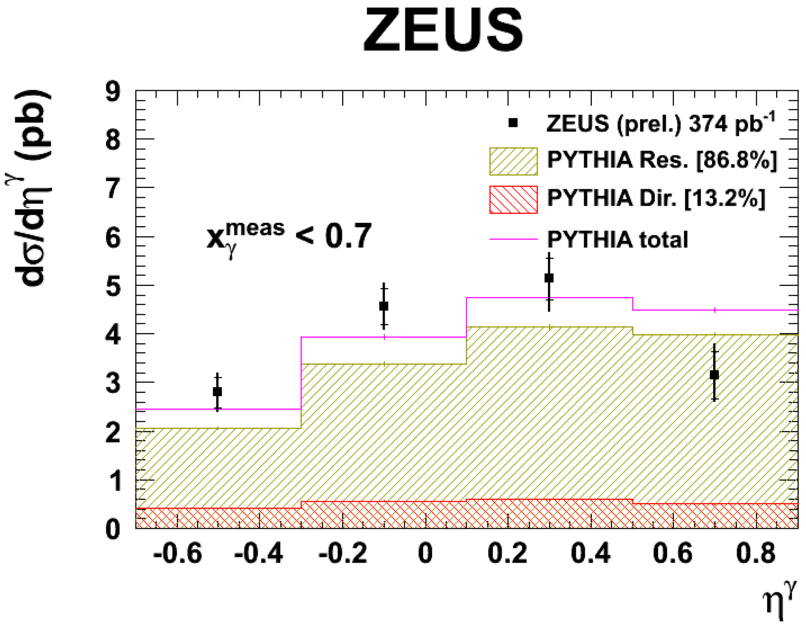


Reasonable description of data by MC.

PYTHIA. Cross sections. η^{γ}

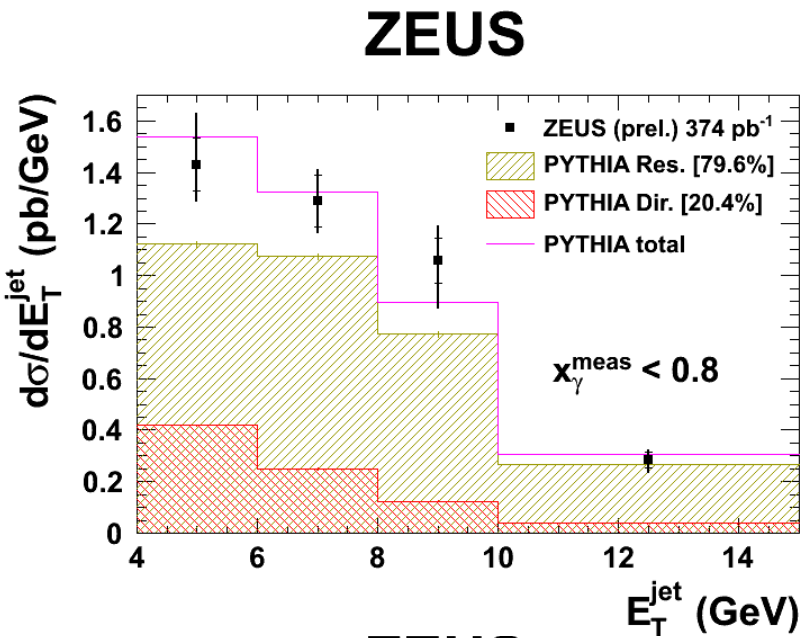


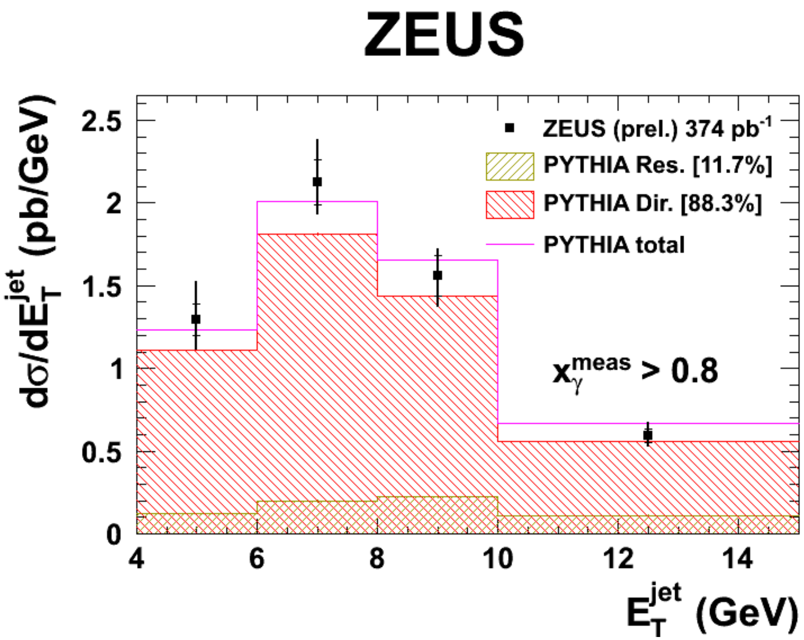


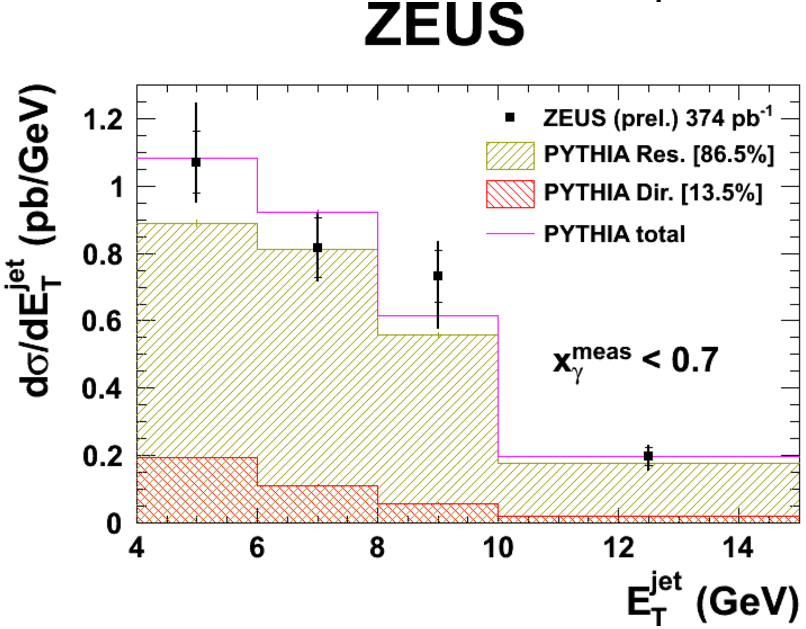


Reasonable description of data by MC.

PYTHIA. Cross sections. E_T^{jet}

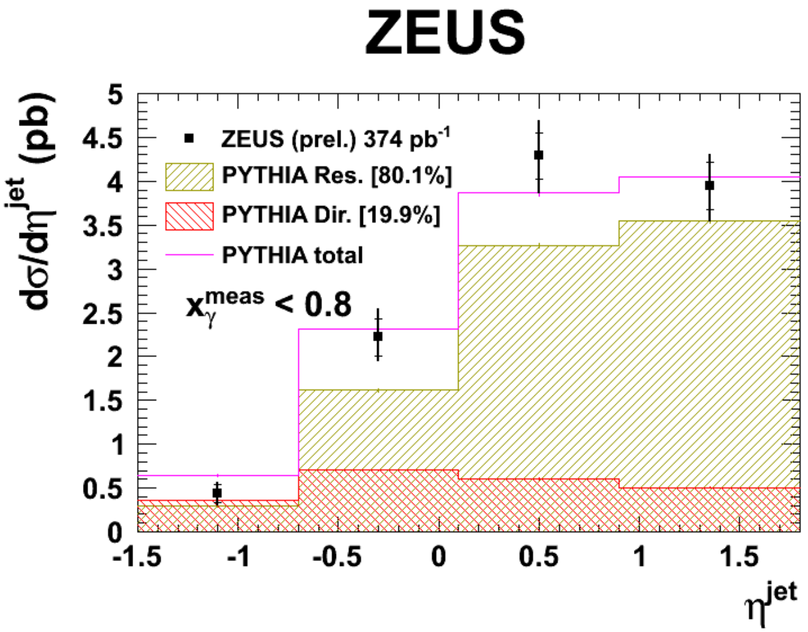


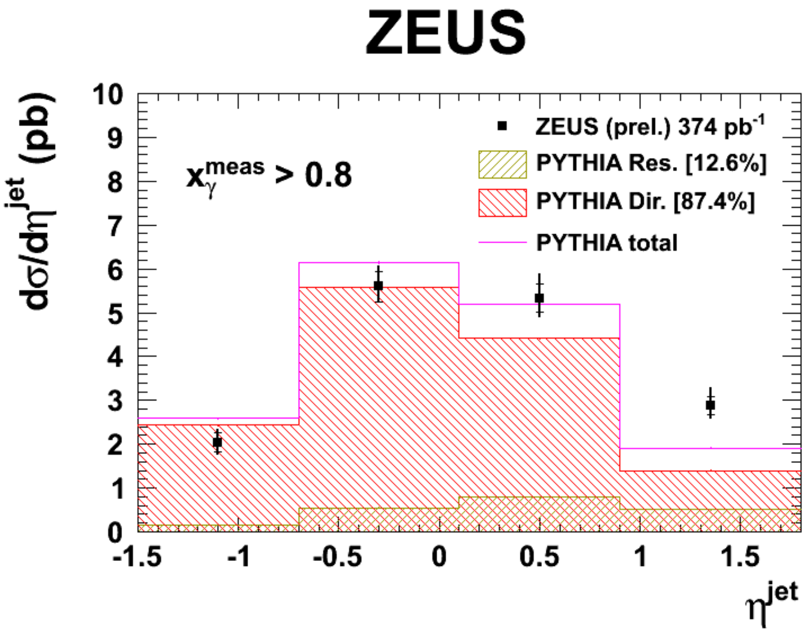


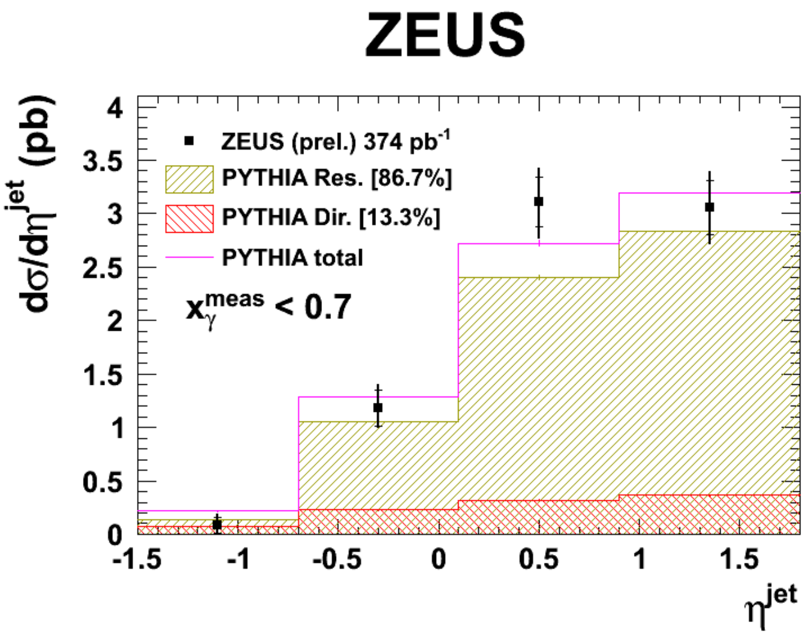


Reasonable description of data by MC.

PYTHIA. Cross sections. η^{jet}







Reasonable description of data by MC.

Corrections

Reweighting is included in systematics.

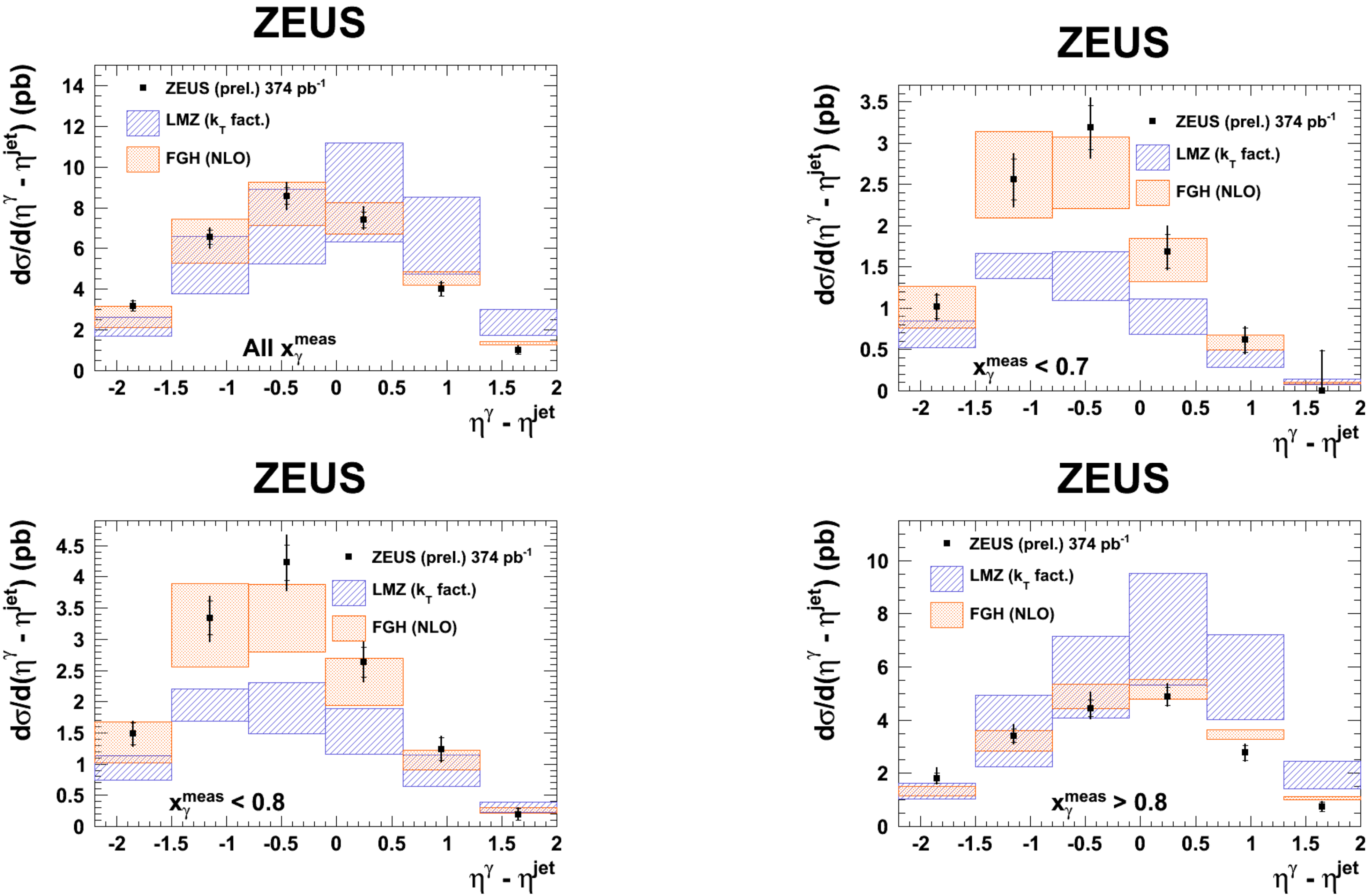
Hadronisation are applied to theory as they stand, without uncertainties.

E-gamma is corrected by 1.1 factor as in the main analysis.

Energy scale variations are the same as in the main analysis: vary E-gamma by 2% and independently vary E-jet by sqrt(x**2 + 2**2), where x = 1.5, 2 or 4 depending on E-jet value and 2 comes from electron scale.

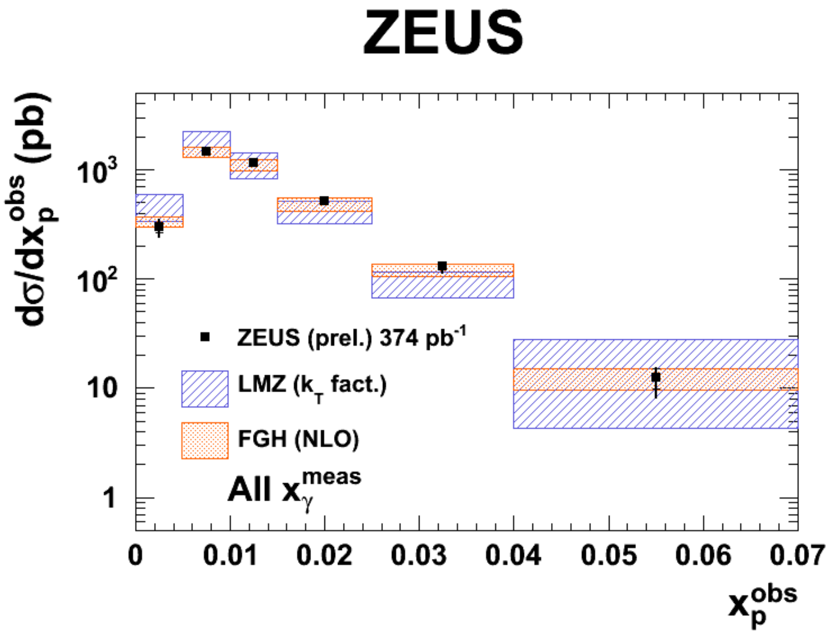
DIS contamination corrections are applied to data.

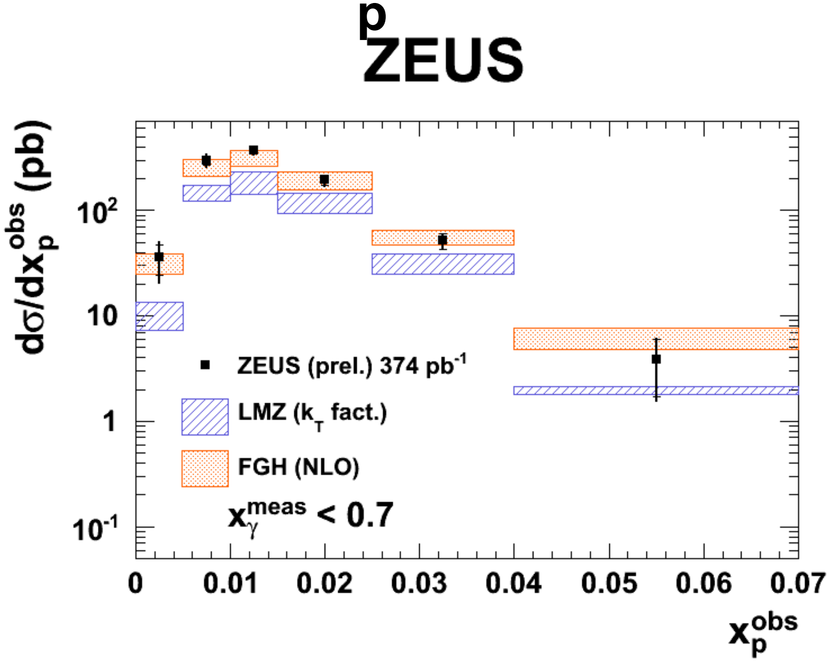
Theory. Cross sections. η^γ - η^{jet}

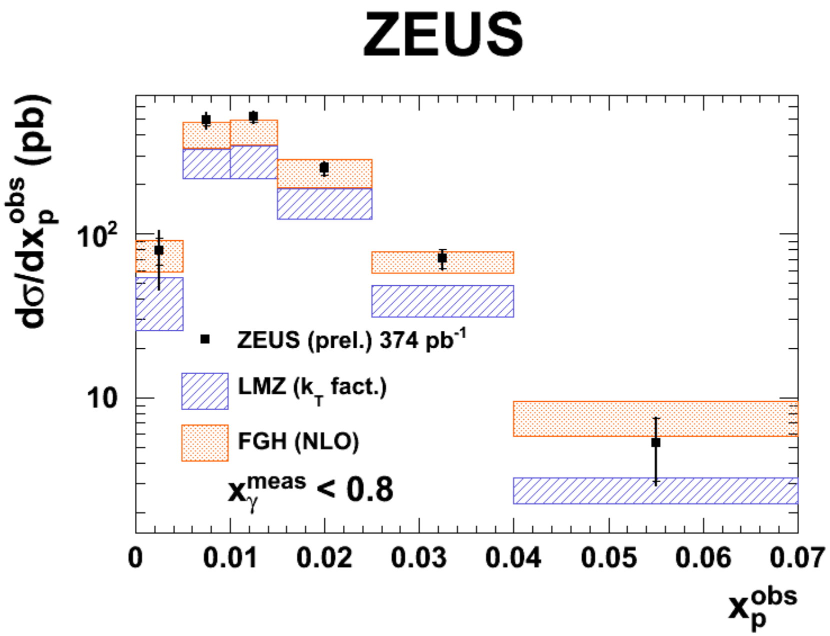


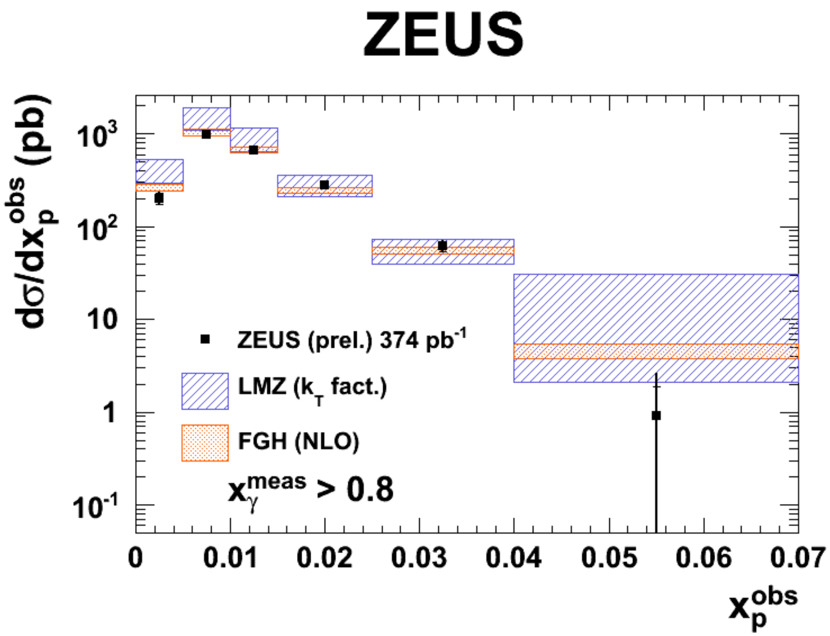
Reasonable description of data by theory. LMZ tends to underestimate low x_γ (more so x_γ<0.7, e.g. fifth bin) and overestimate high x_γ at high η^γ - η^{jet}.

Theory. Cross sections. x_p



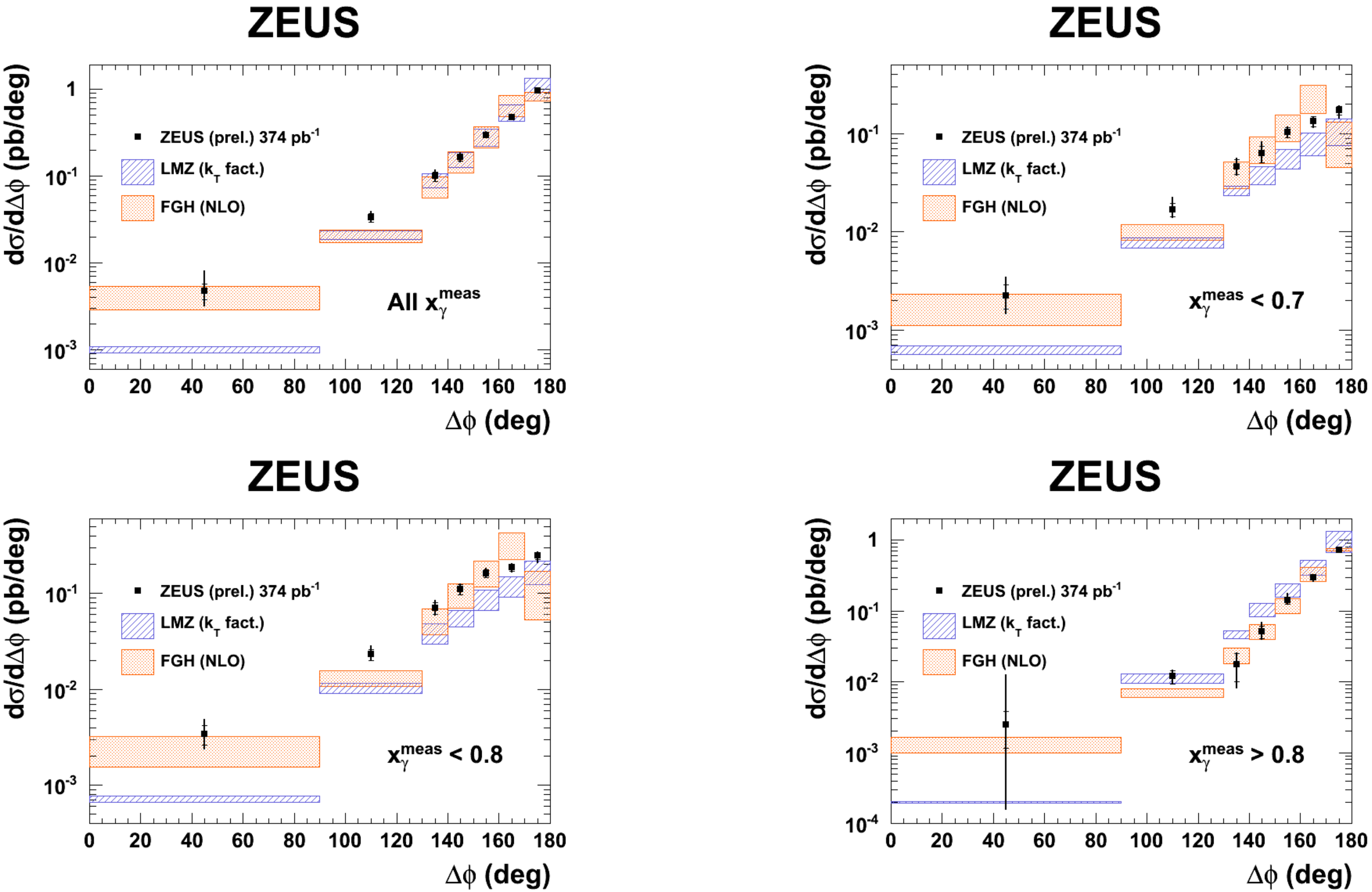






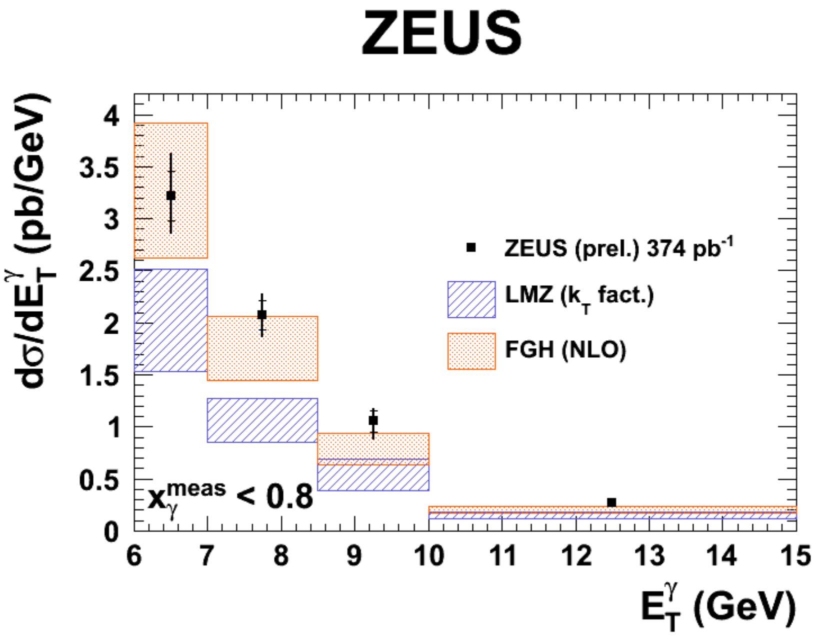
Reasonable description of data by theory. In x_γ<0.7 LMZ underestimates first bin, while agrees with data in it within errors in x_γ<0.8.

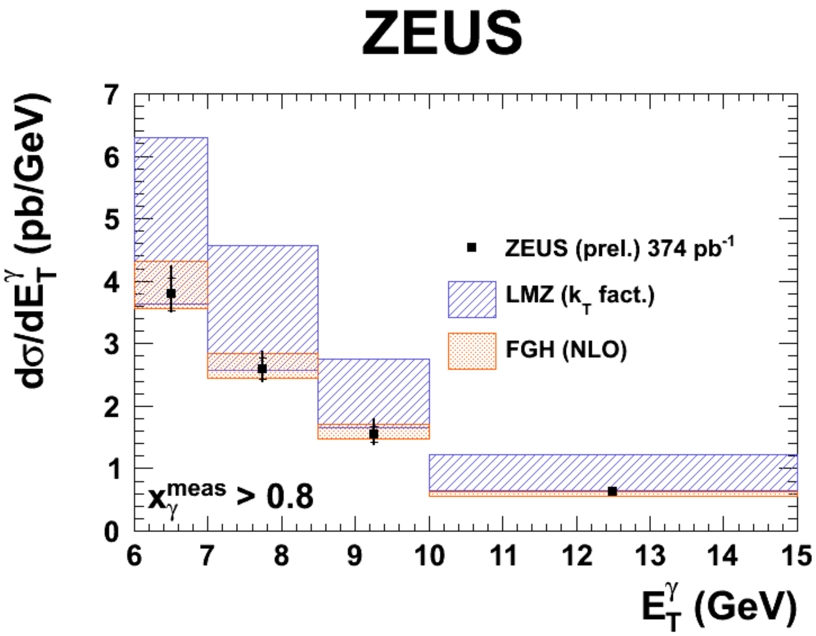
Theory. Cross sections. ΔΦ

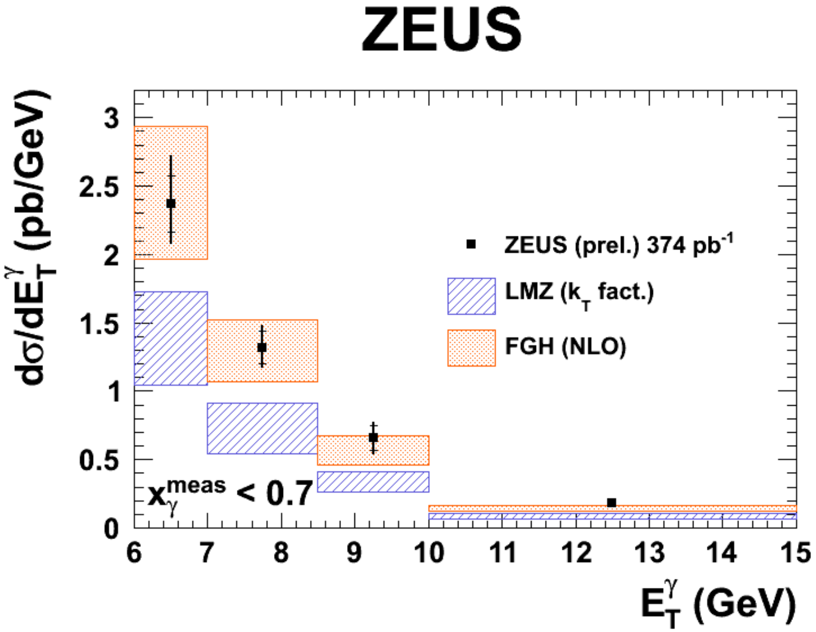


Reasonable description of data by theory. LMZ tends to underestimate low x_γ and overestimate high x_γ.

Theory. Cross sections. E_T^γ



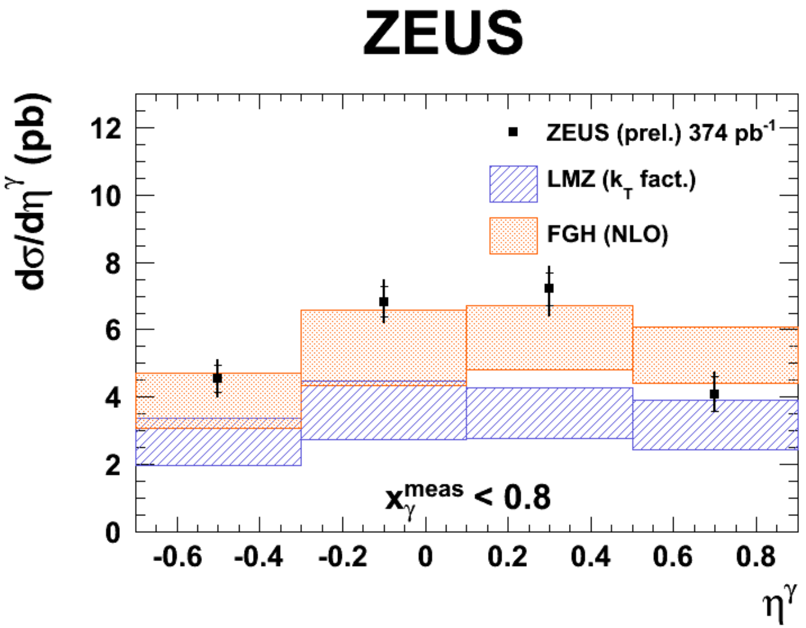


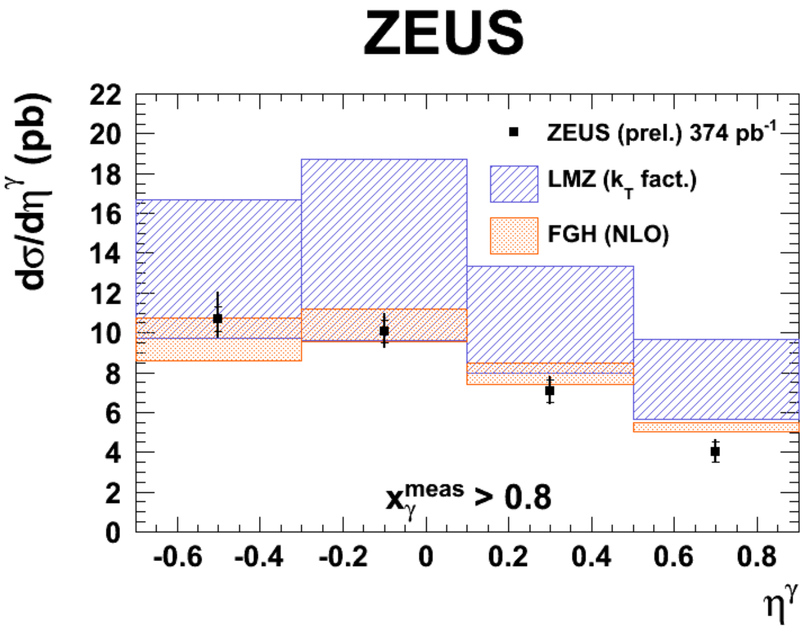


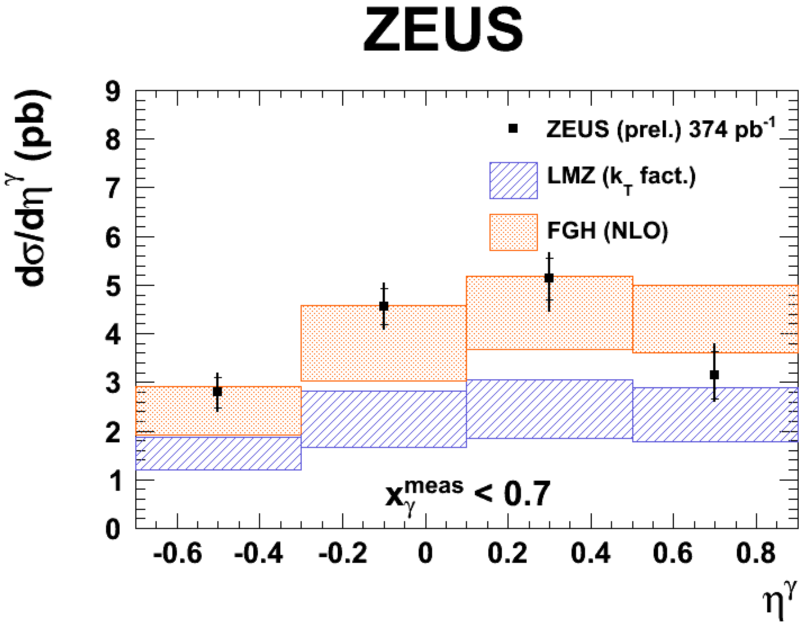
Reasonable shape description of data by theory.

LMZ tends to underestimate low x_γ region.

Theory. Cross sections. η^{γ}



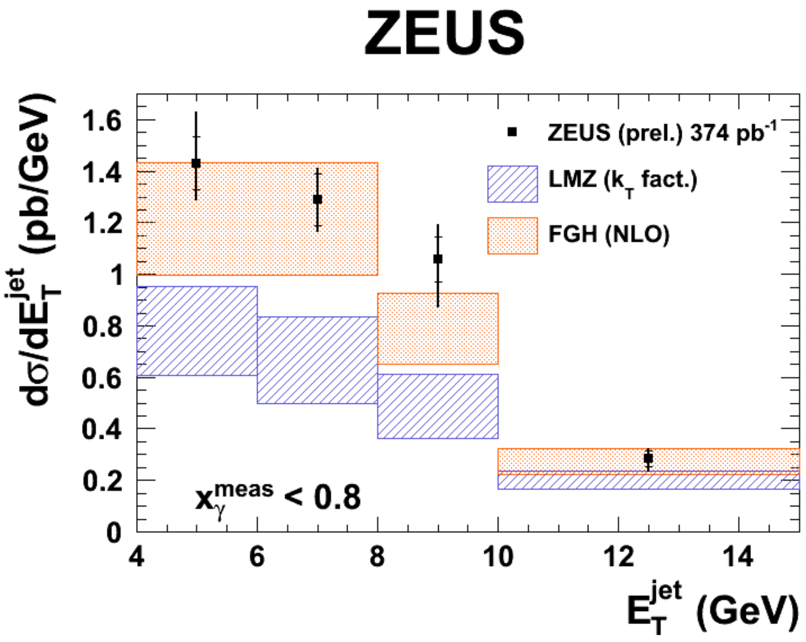


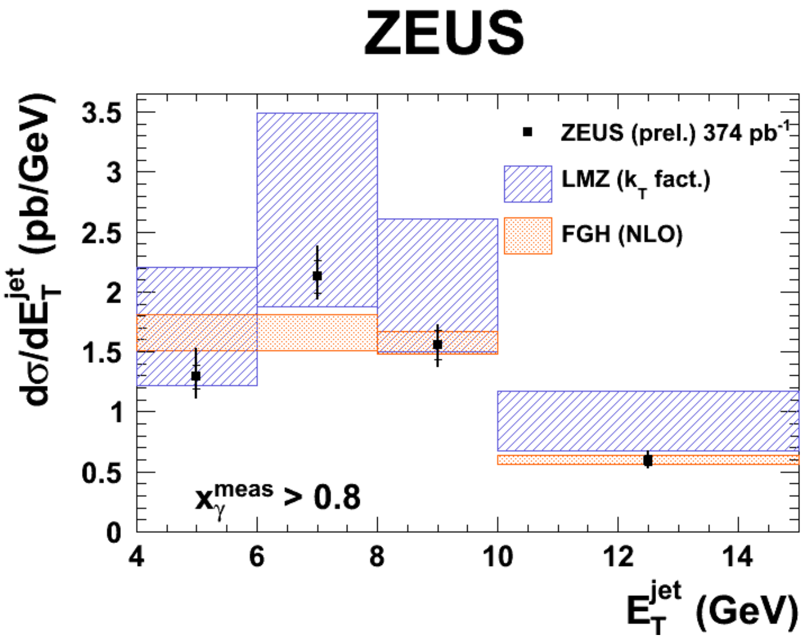


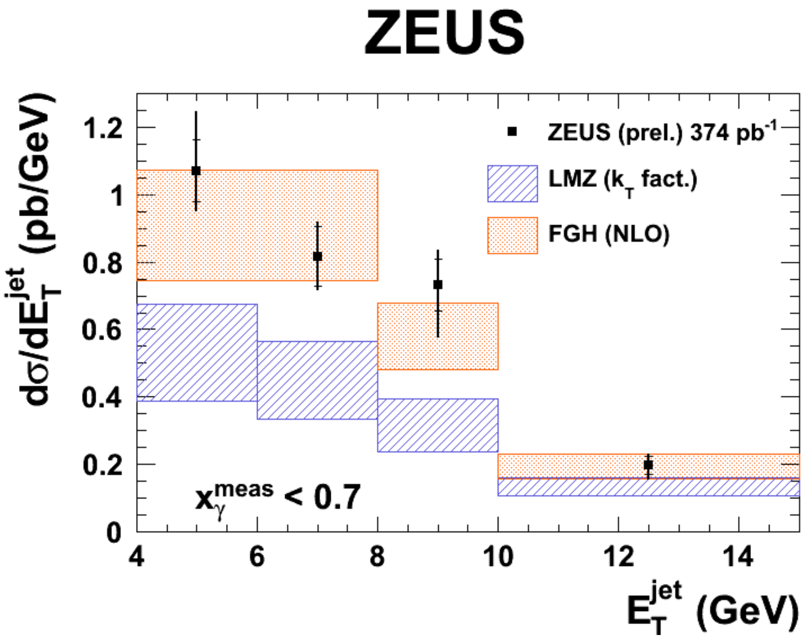
Reasonable shape description of data by theory.

LMZ tends to underestimate low x_{γ} region.

Theory. Cross sections. E_T^{jet}



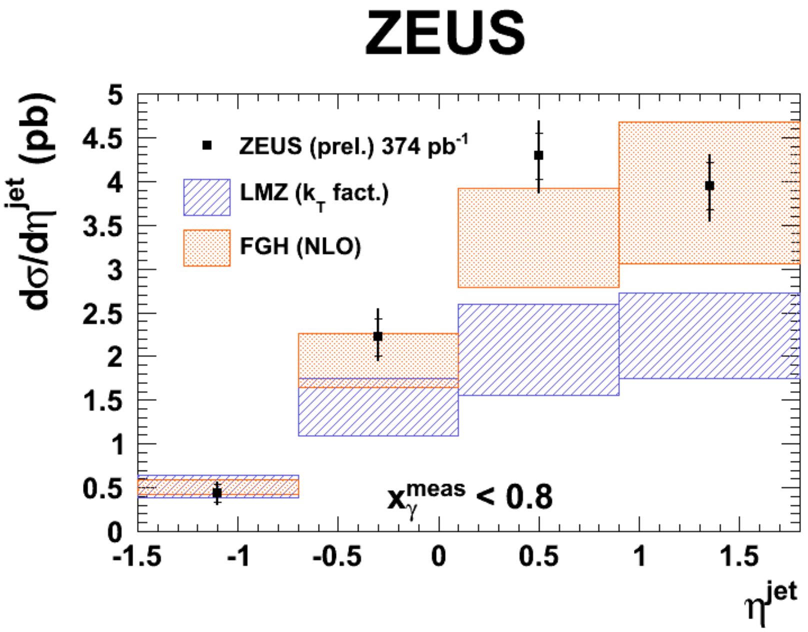


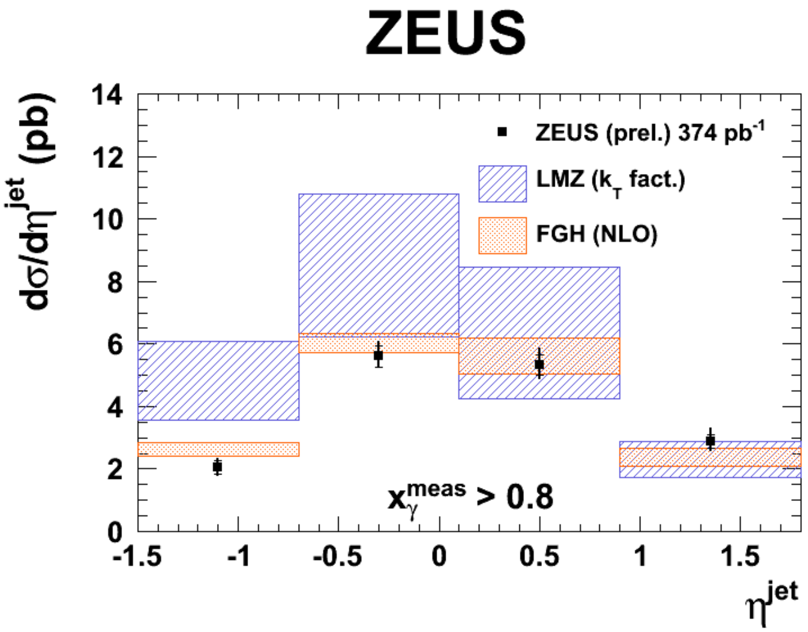


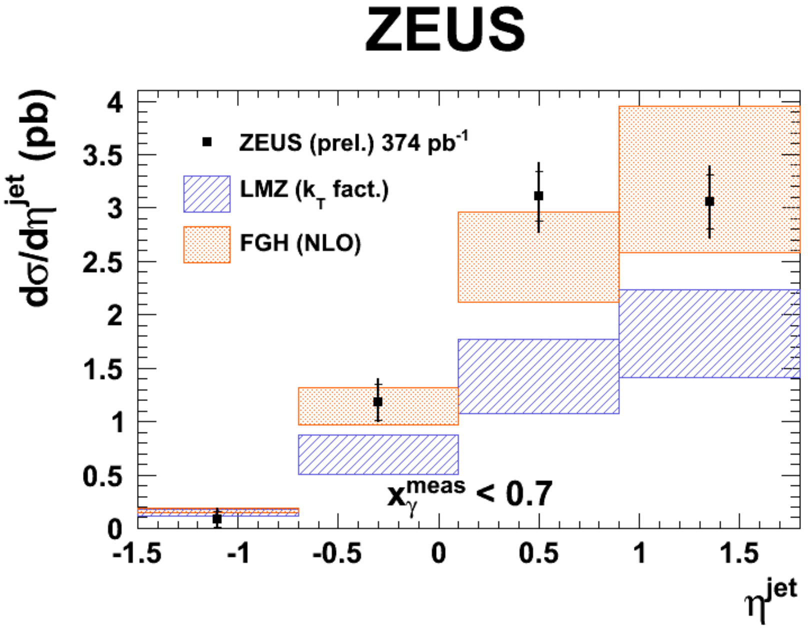
Reasonable shape description of data by theory.

LMZ tends to underestimate low x_γ region.

Theory. Cross sections. η^{jet}







Reasonable shape description of data by theory.

LMZ tends to underestimate low x_γ region and overestimate low η^{jet} at high x_γ.

Conclusion

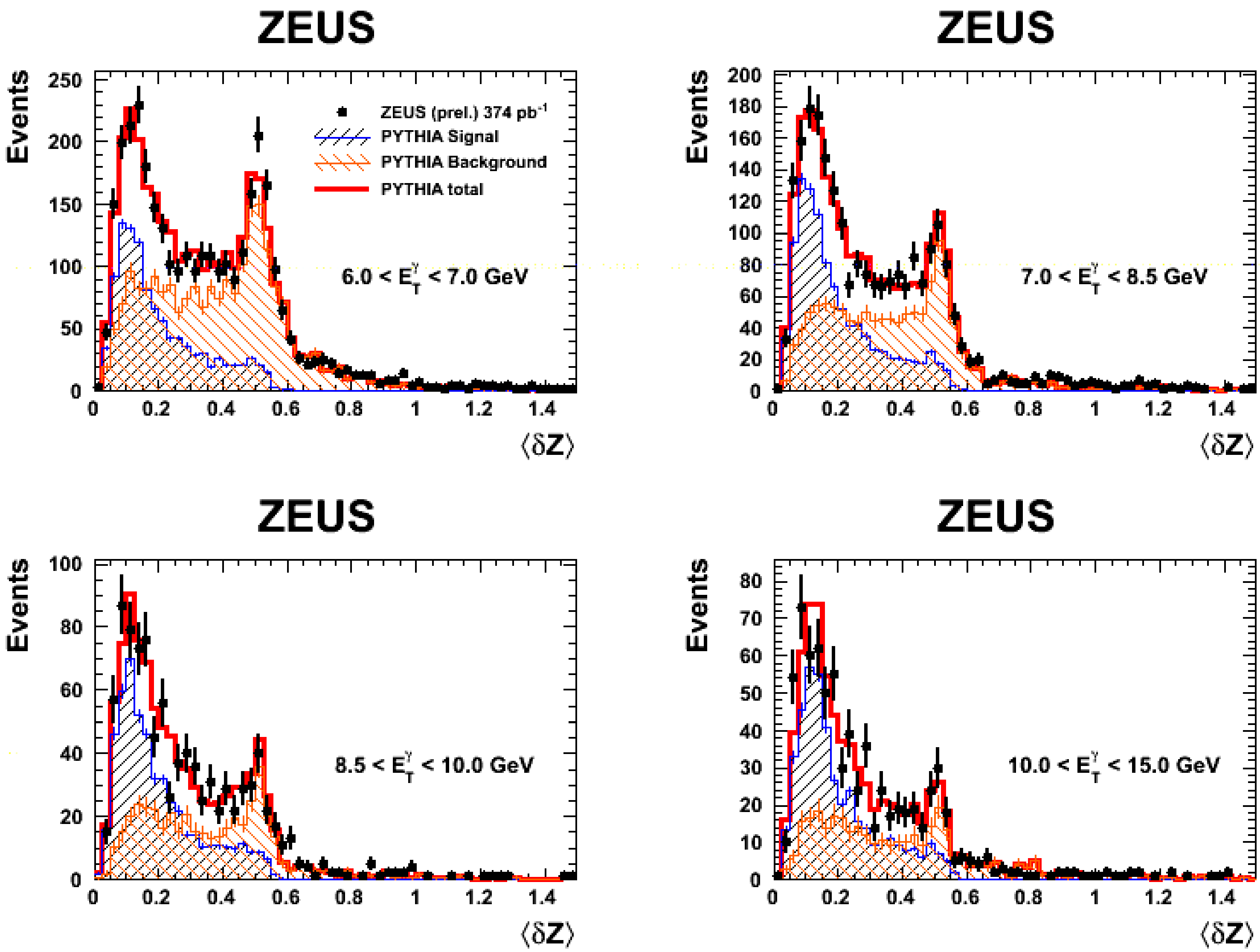
Complete set of photoproduction cross sections has been calculated for prompt photons with an accompanying jet.

Reasonable description by theory is available.

FGH reproduces well measured experimental distributions.

LMZ has a tendency to be too high at high x_γ^{meas}, but too low at low x_γ^{meas}, which is confirmed in $x_\gamma^{meas}<0.7$ region.

Plots to be made preliminary



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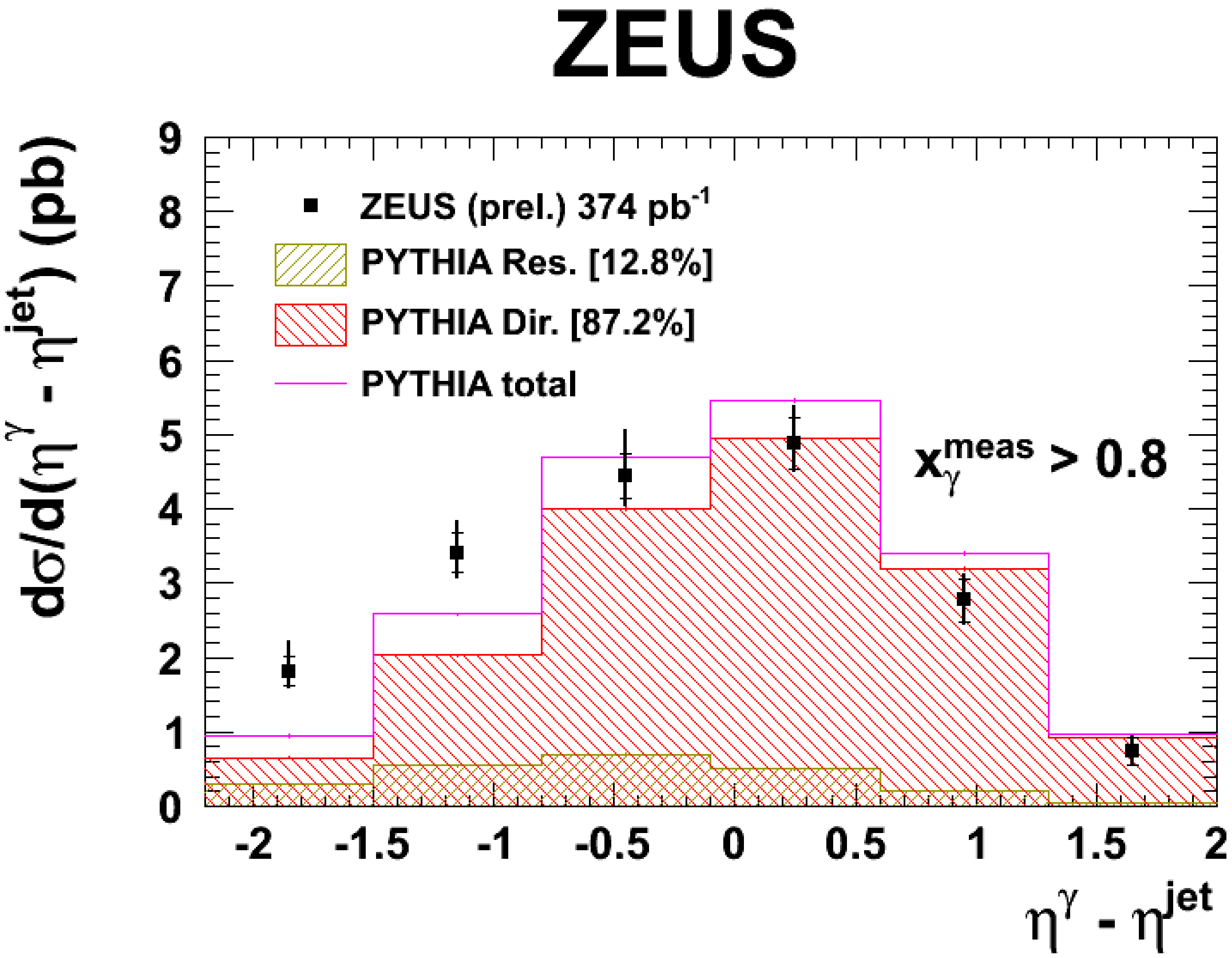

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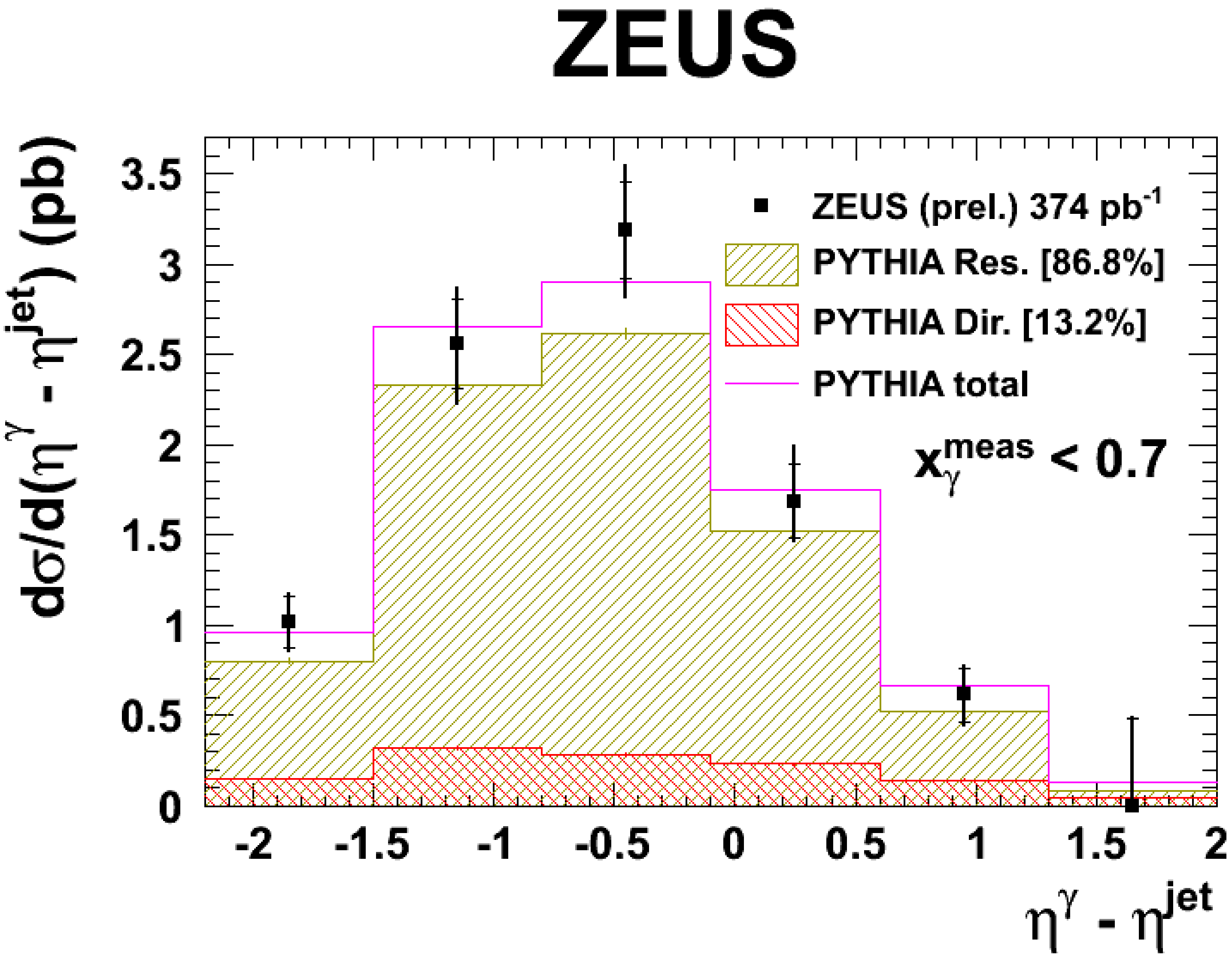

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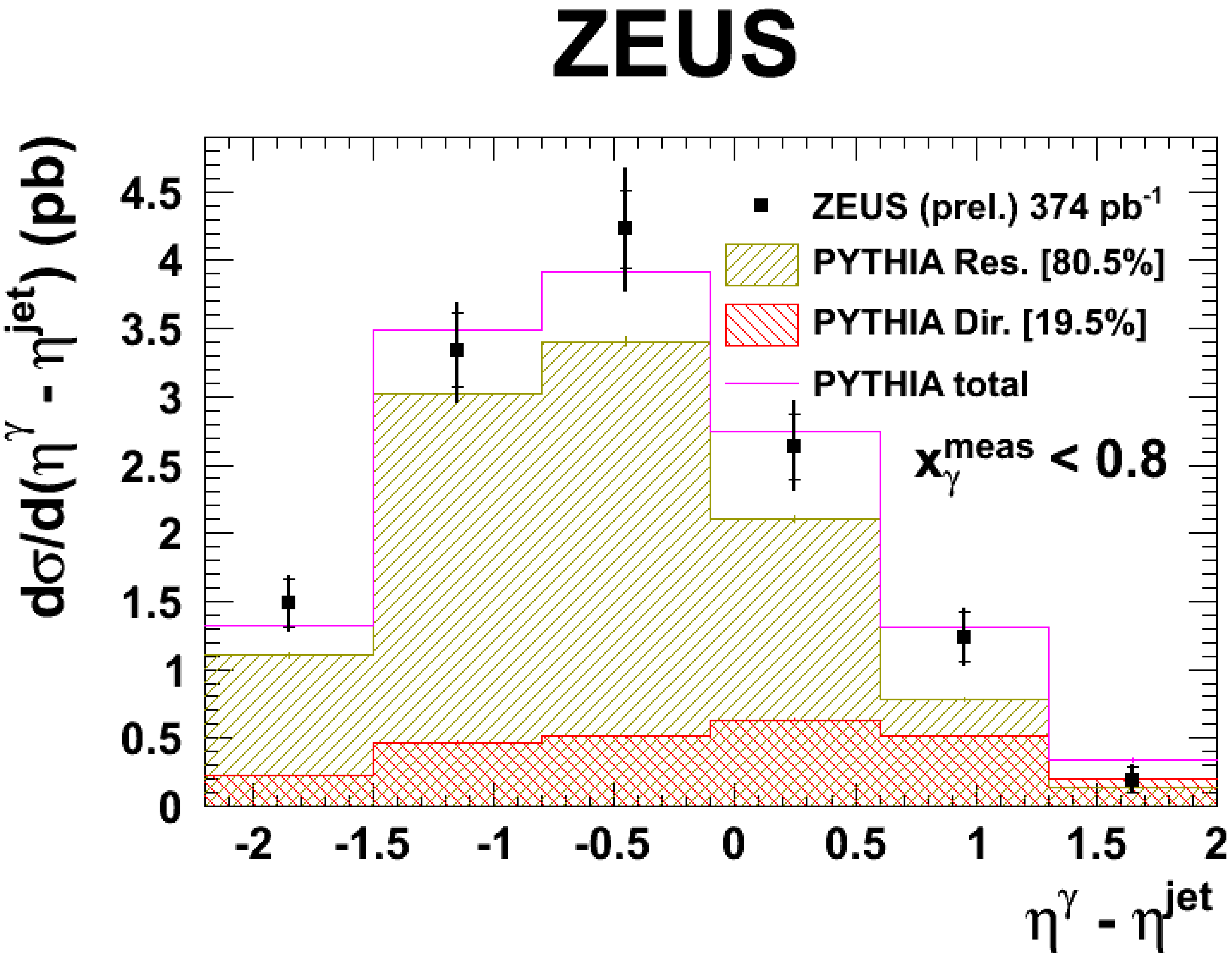

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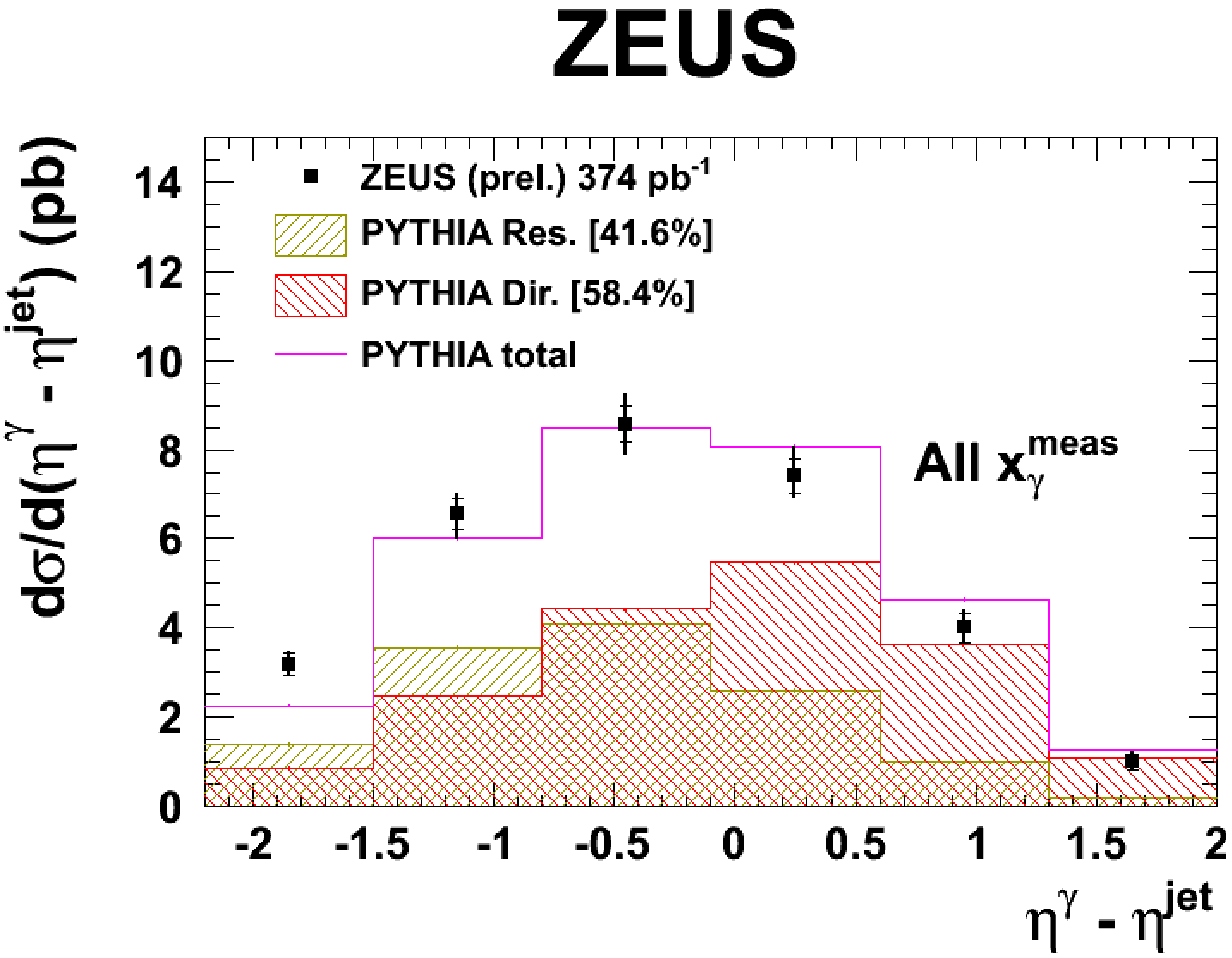

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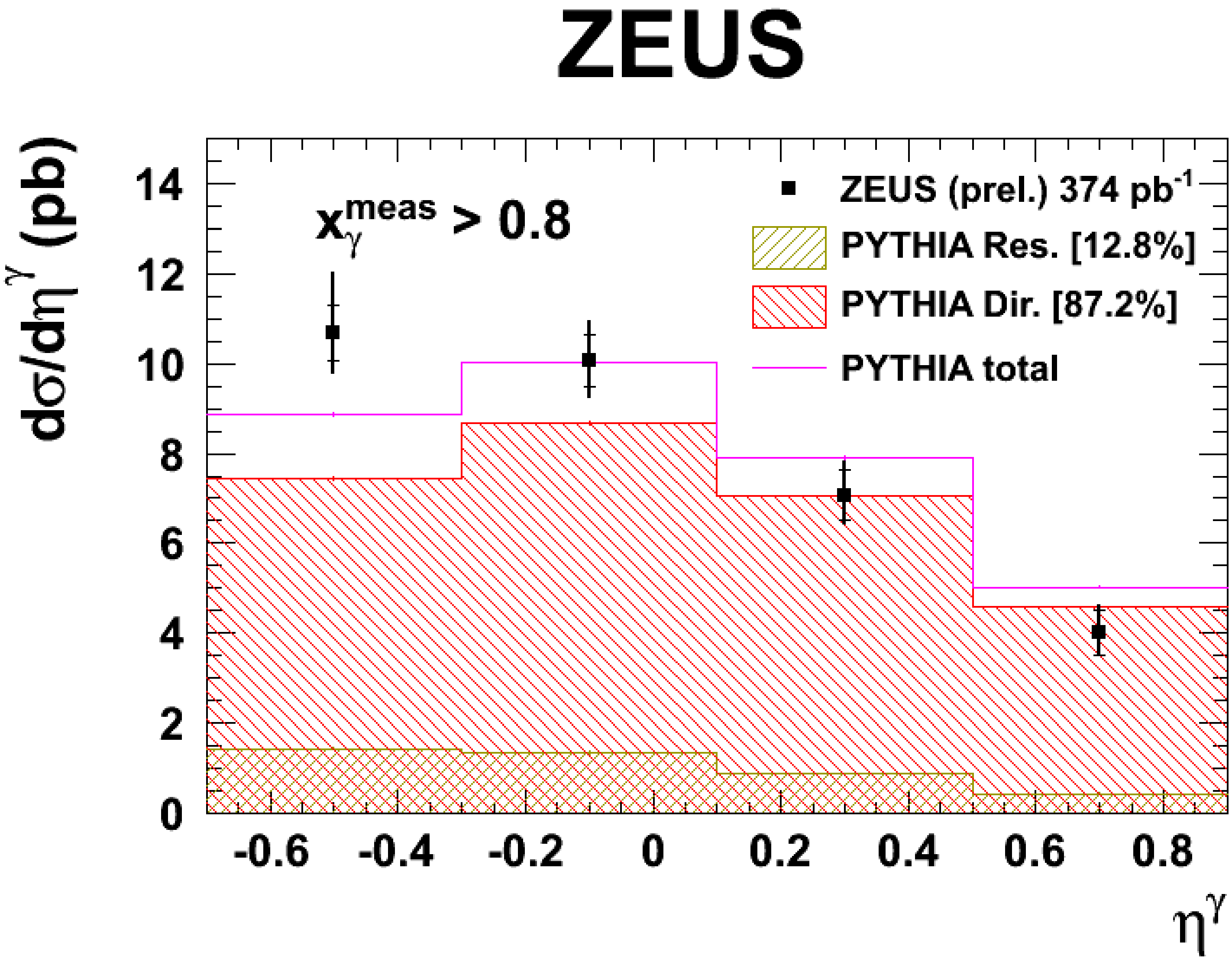

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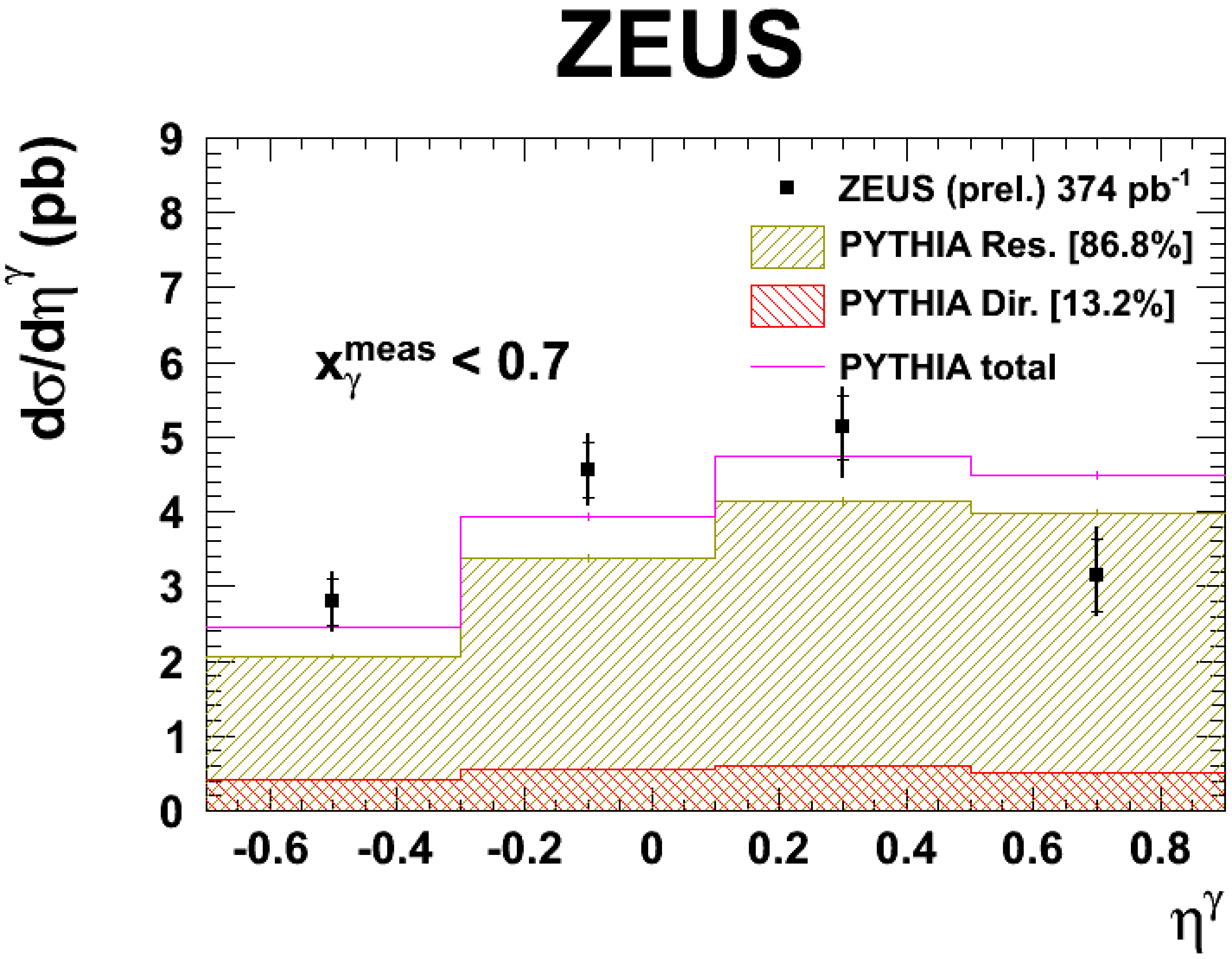

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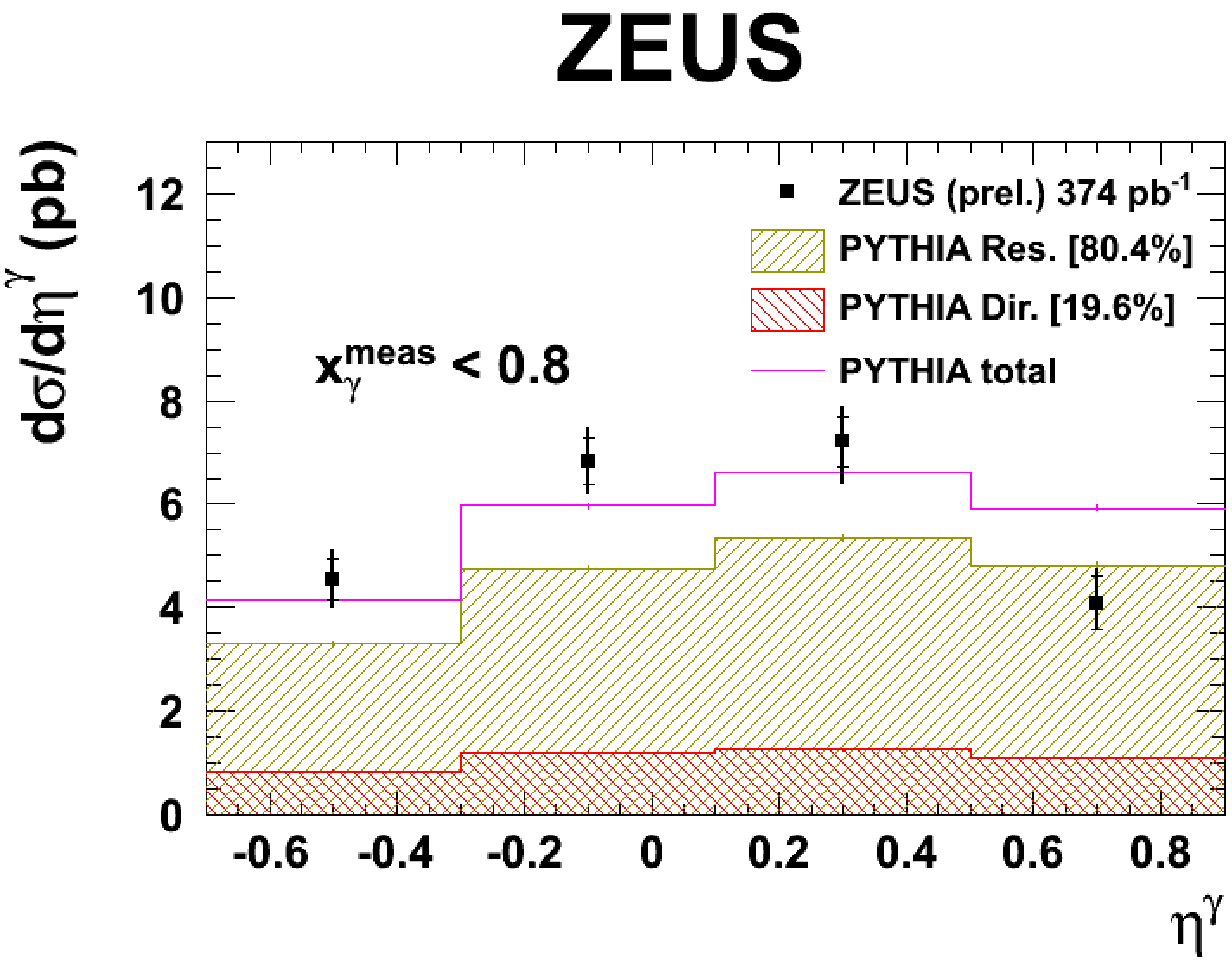

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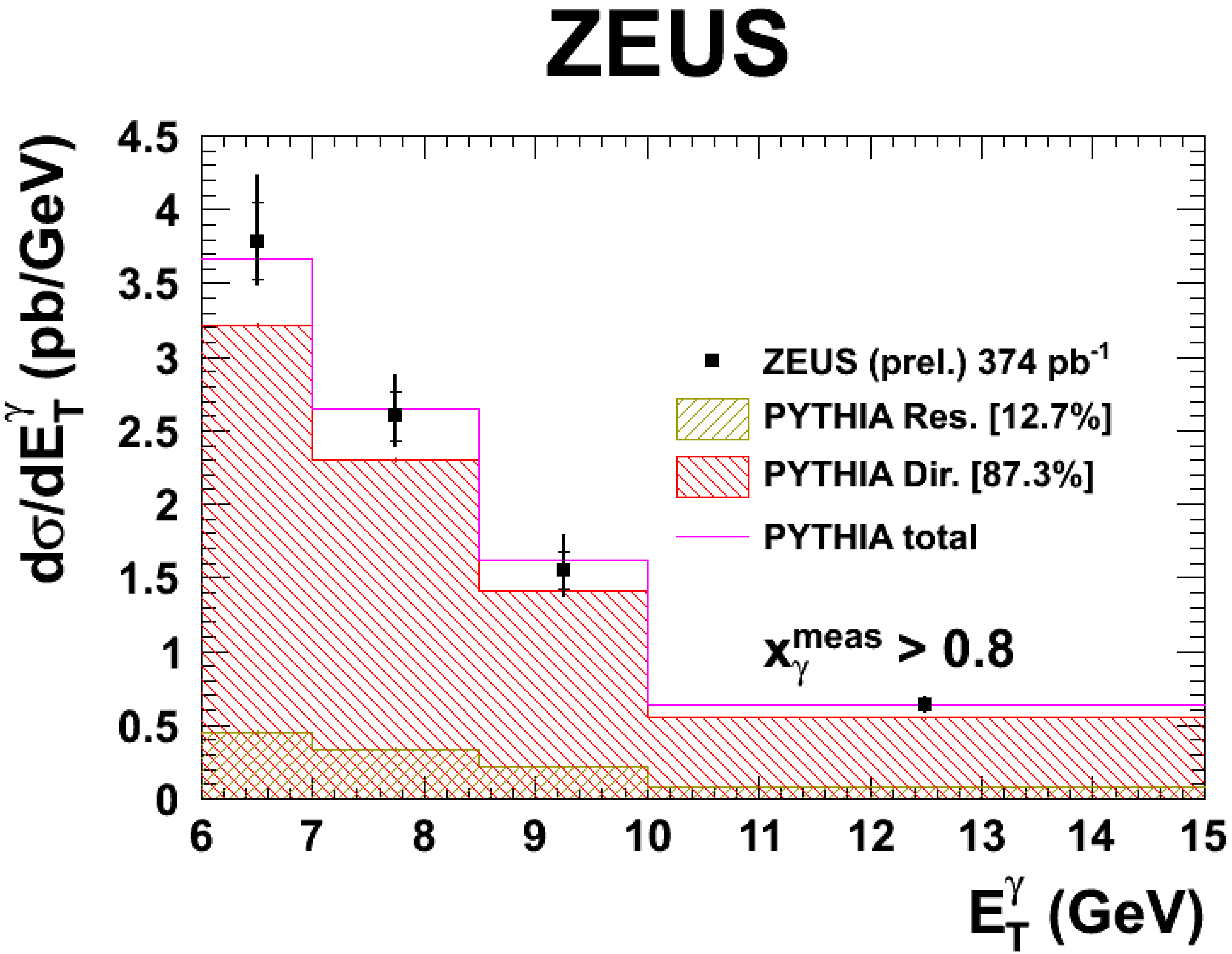

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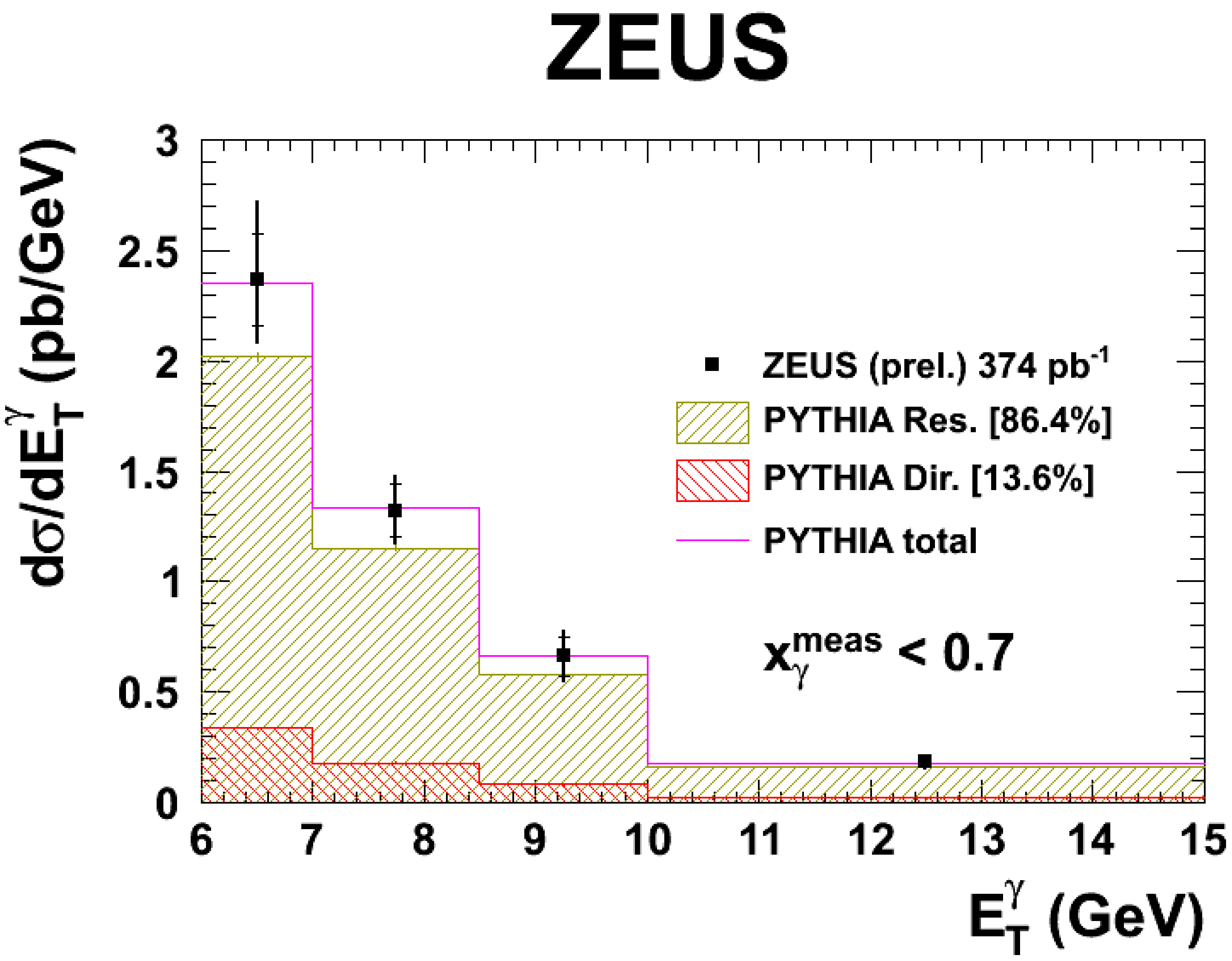

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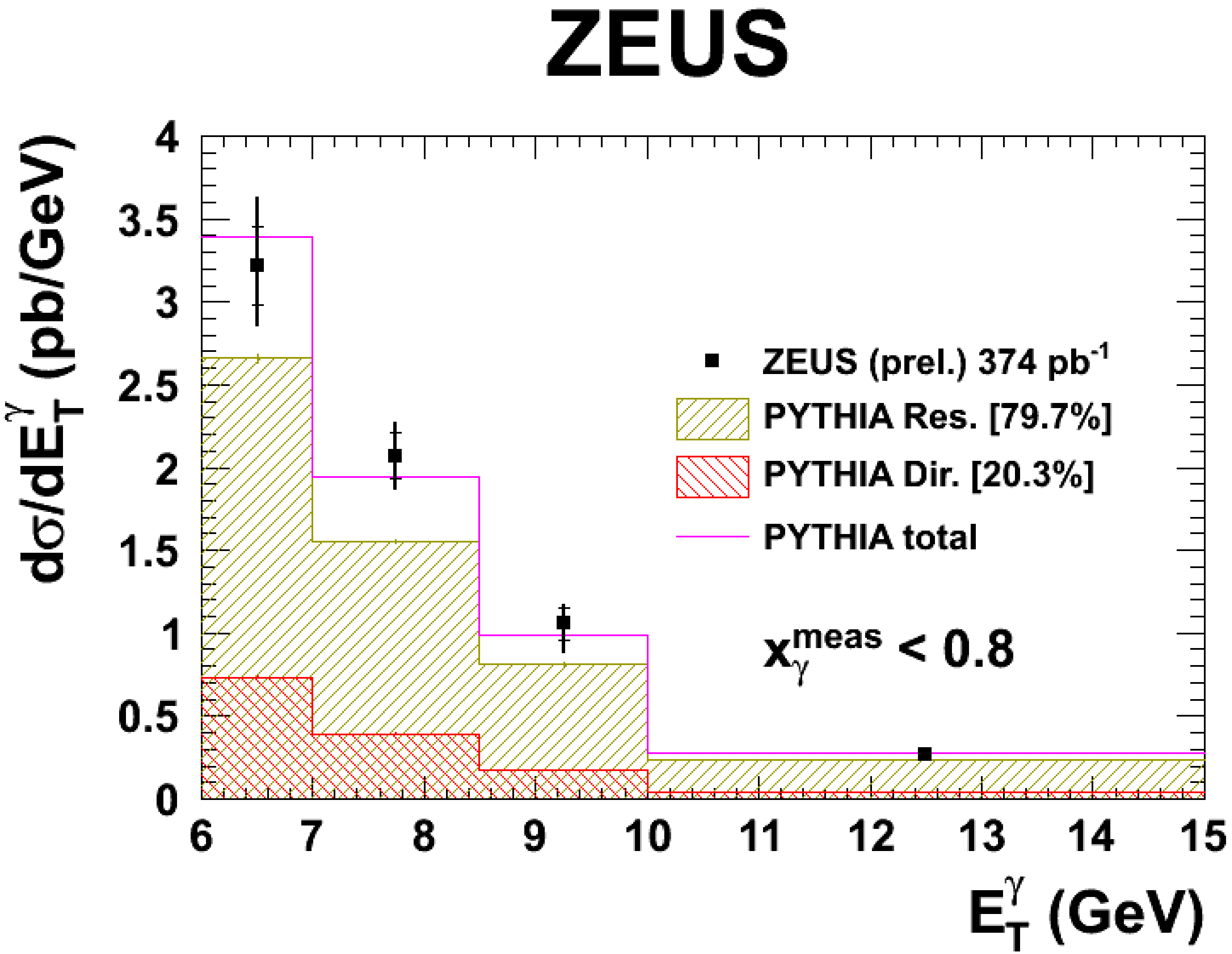

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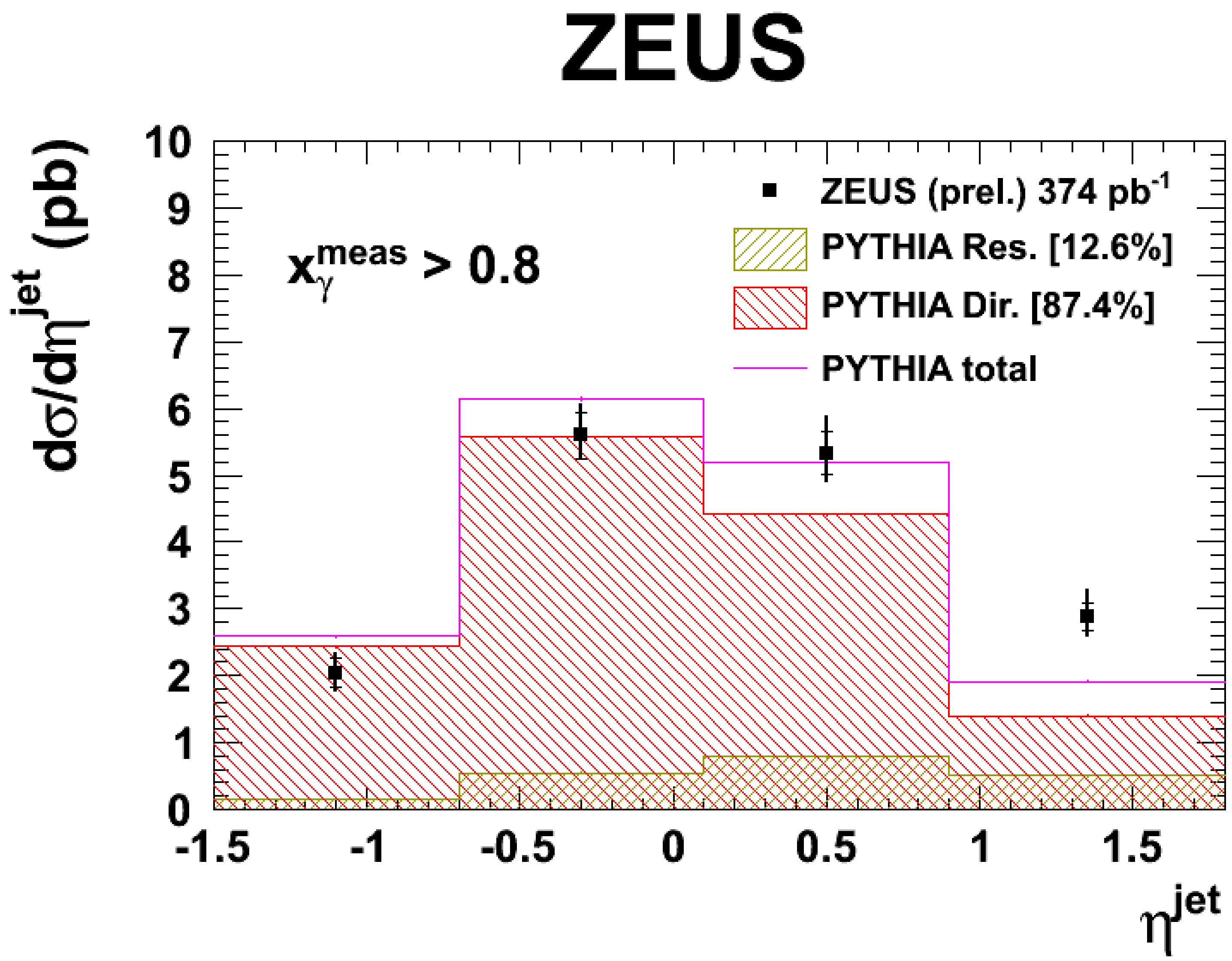

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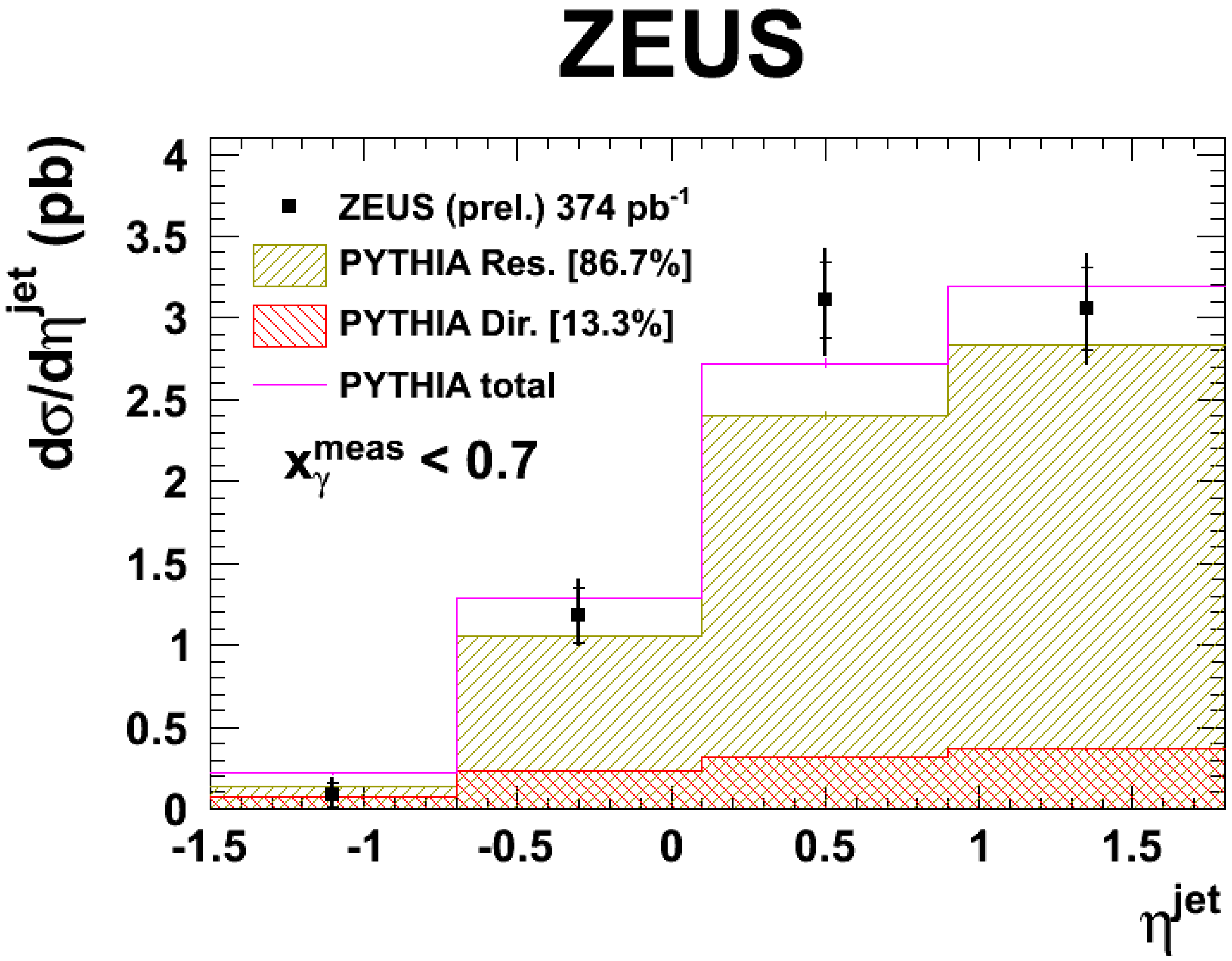

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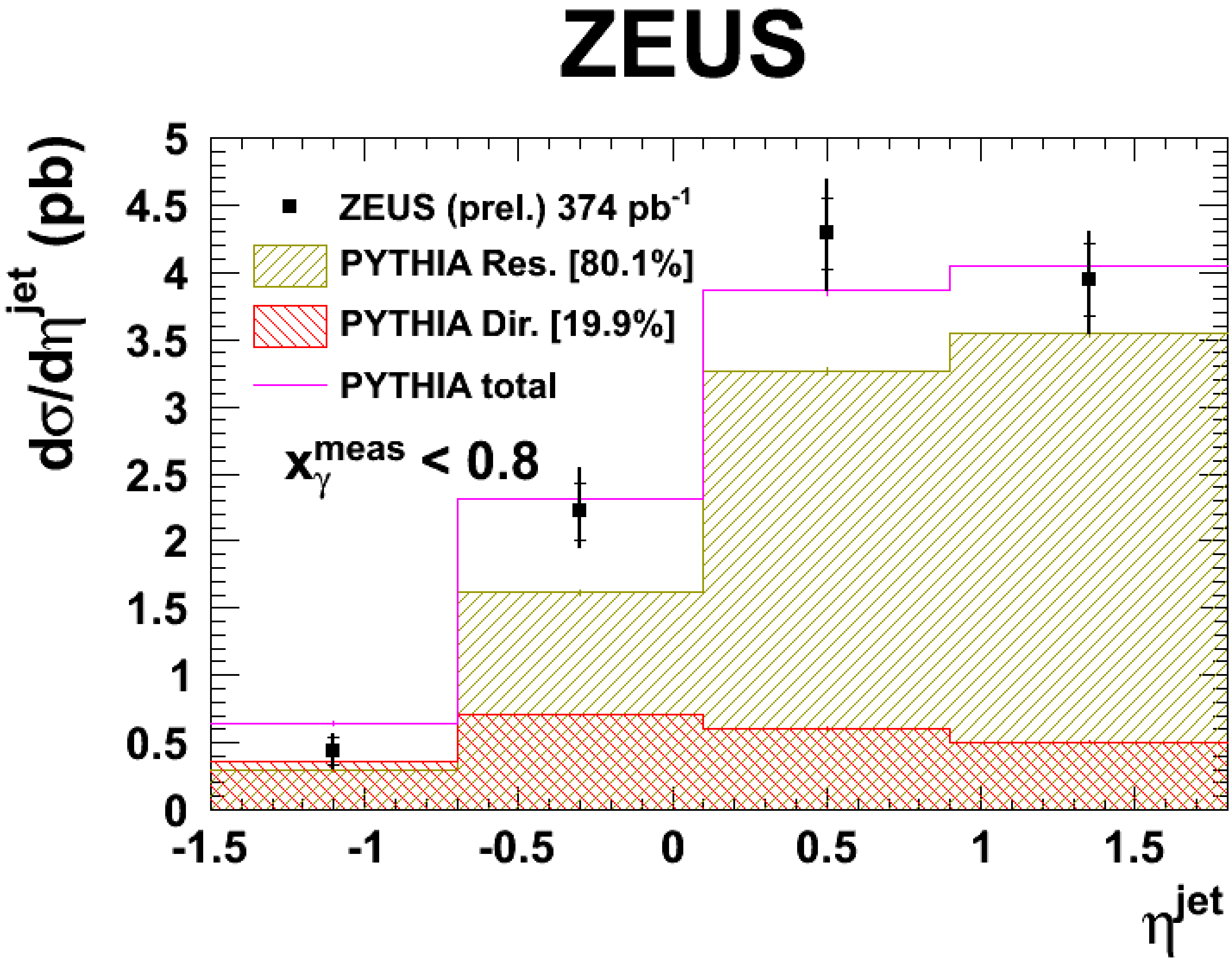

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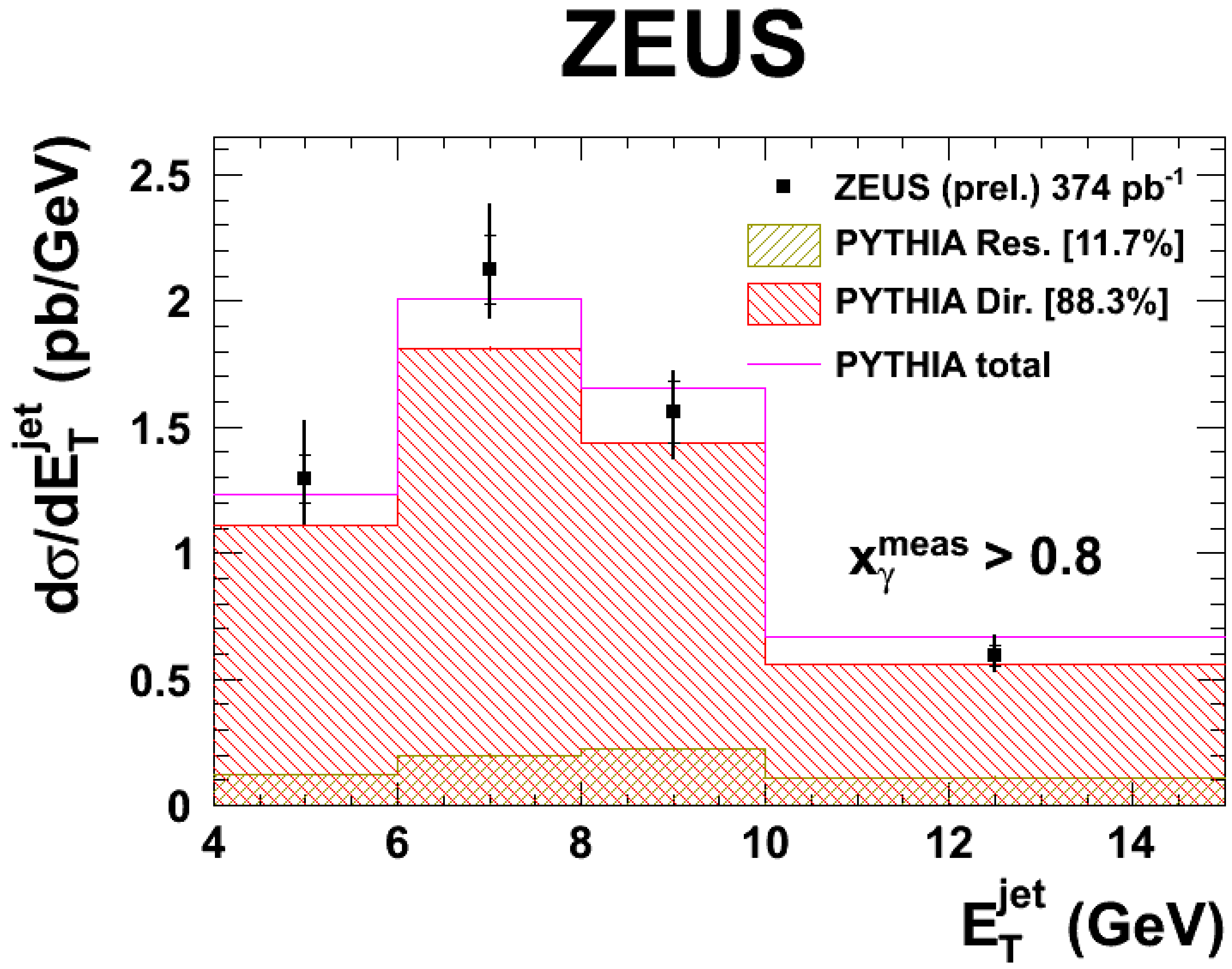

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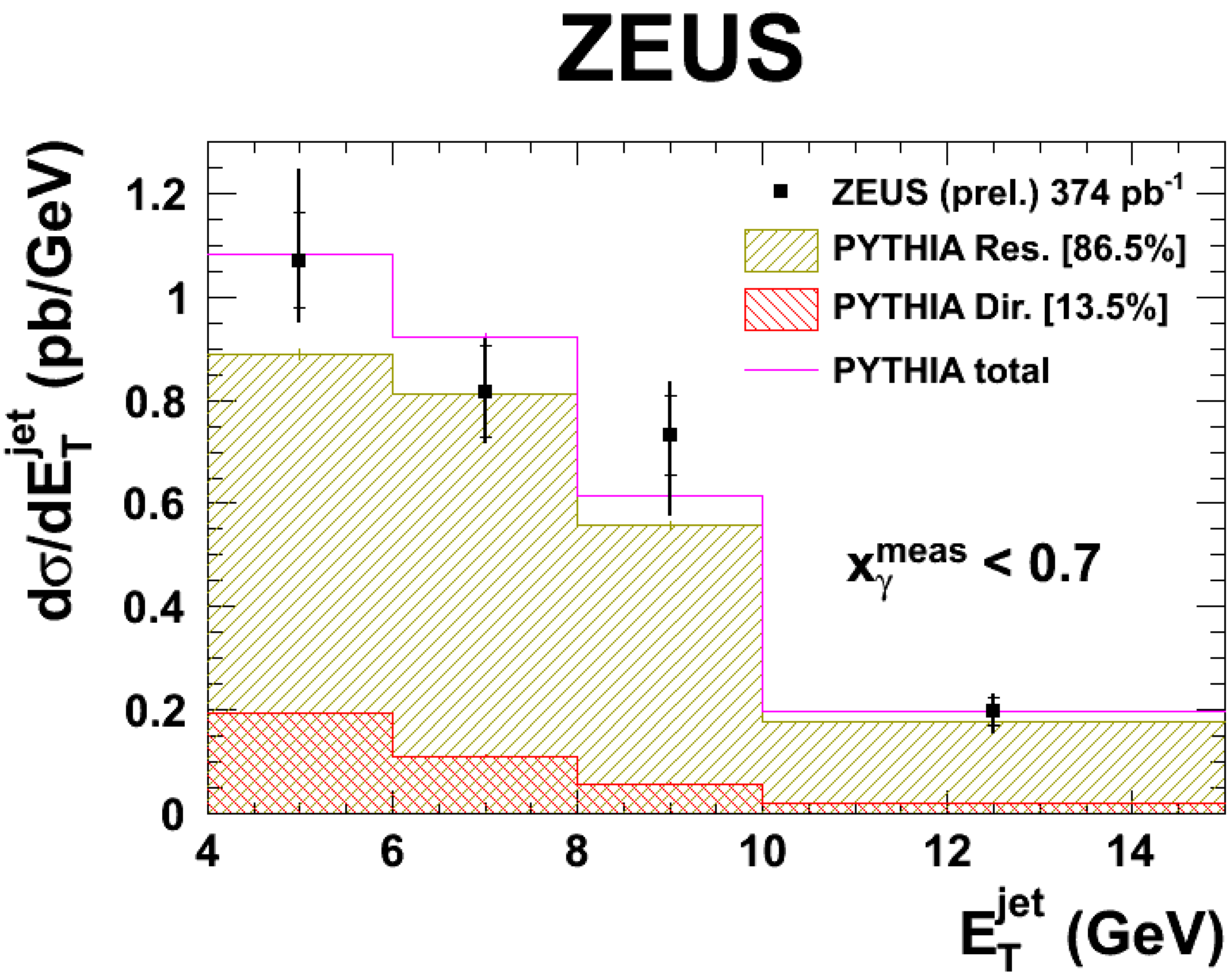

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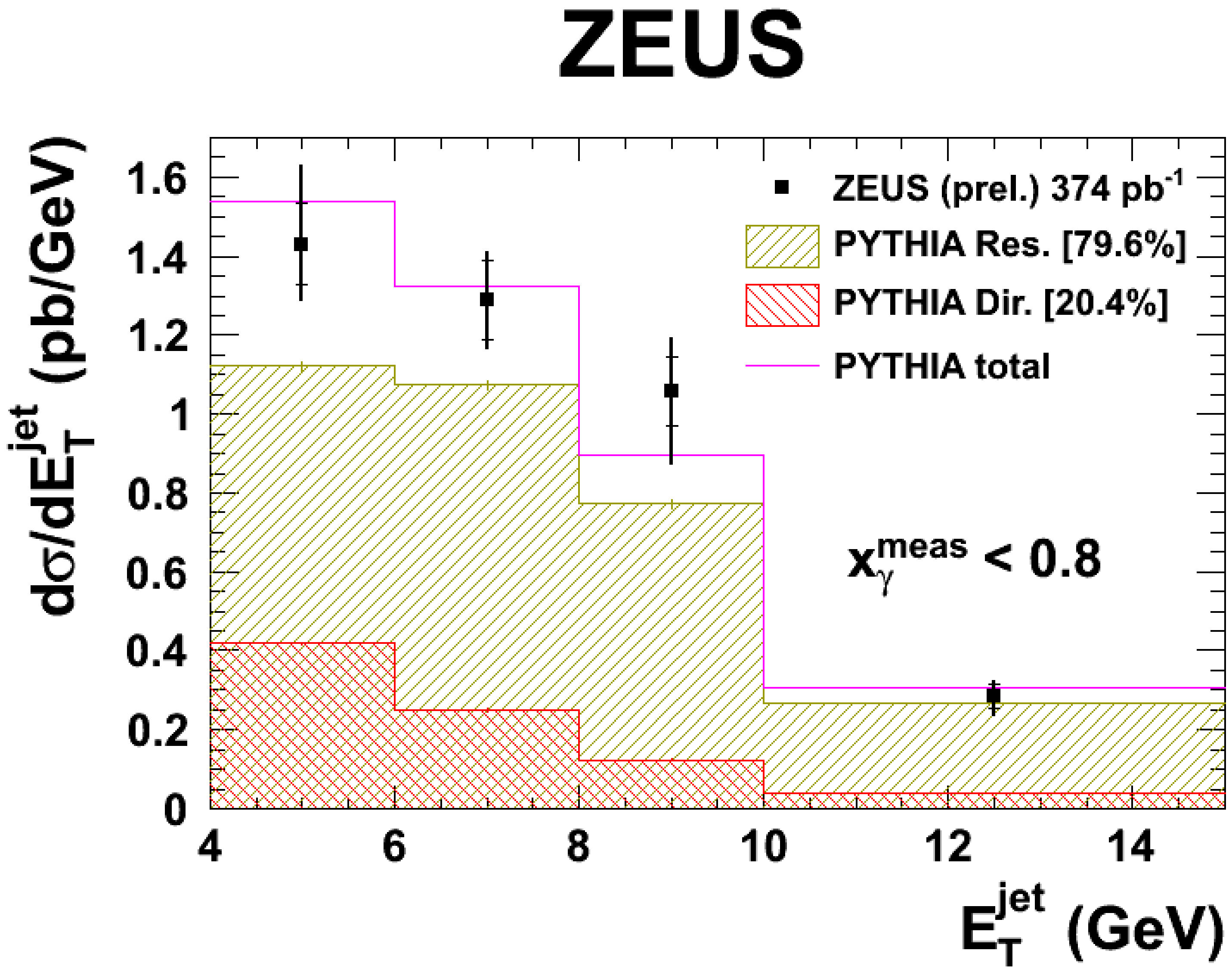

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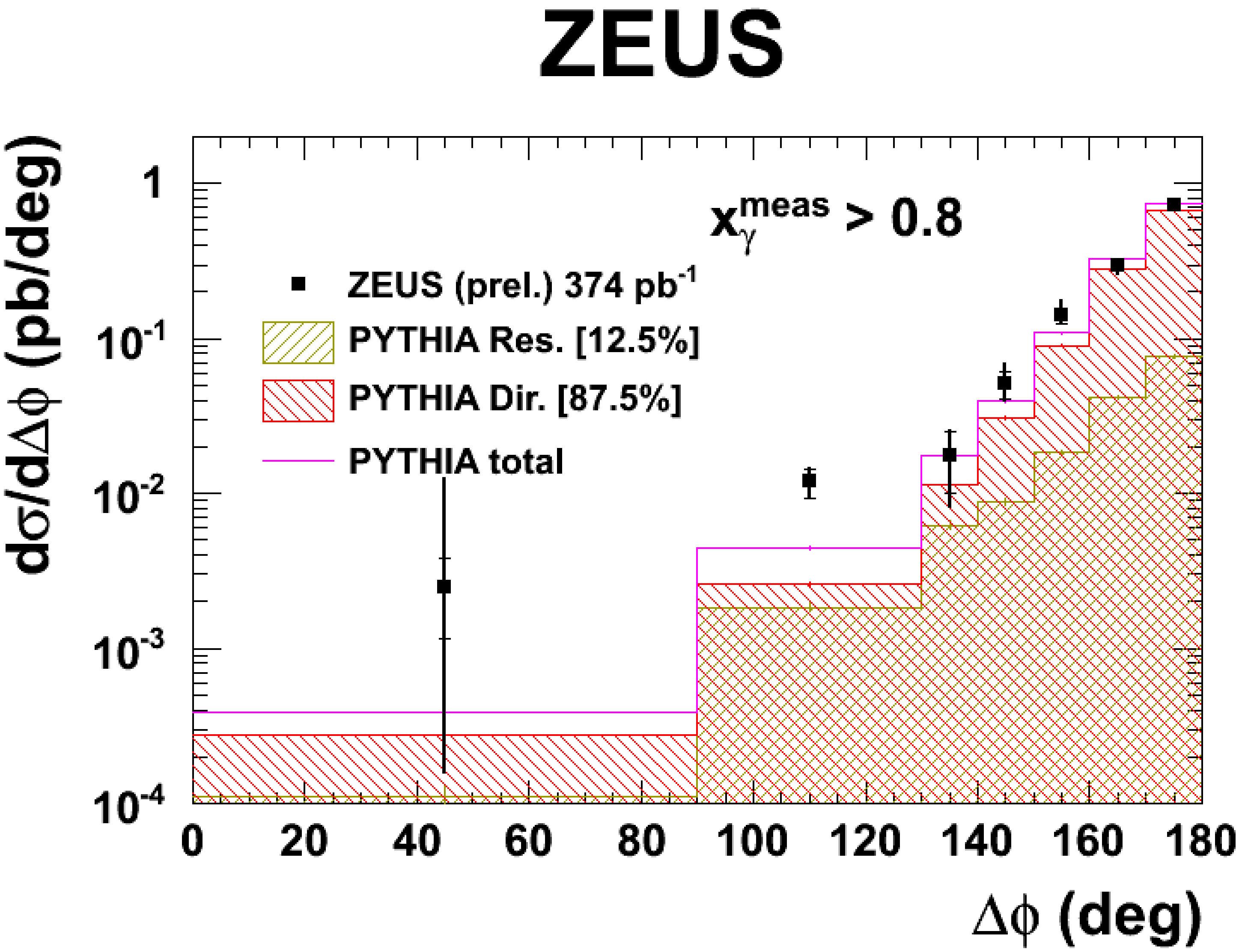

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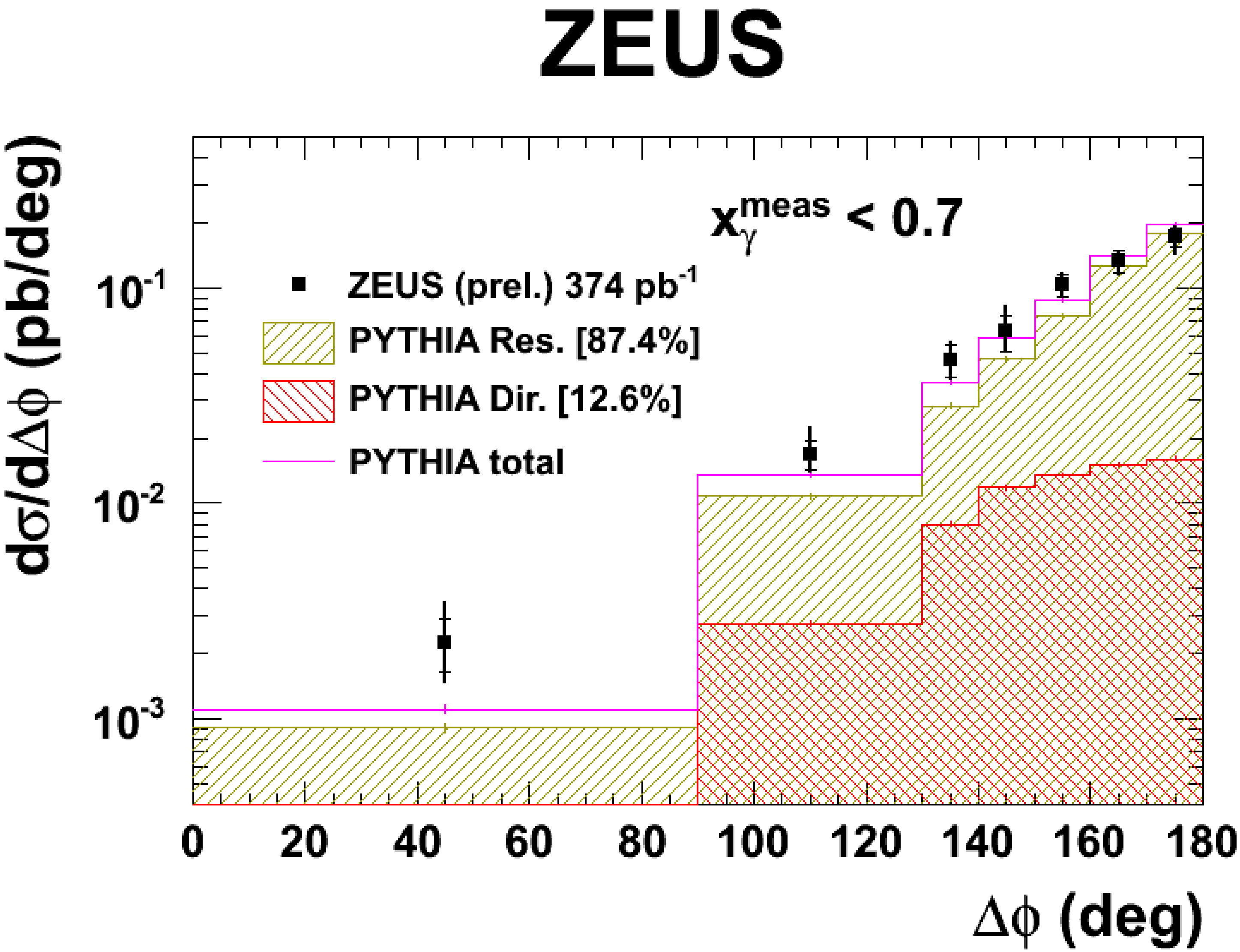

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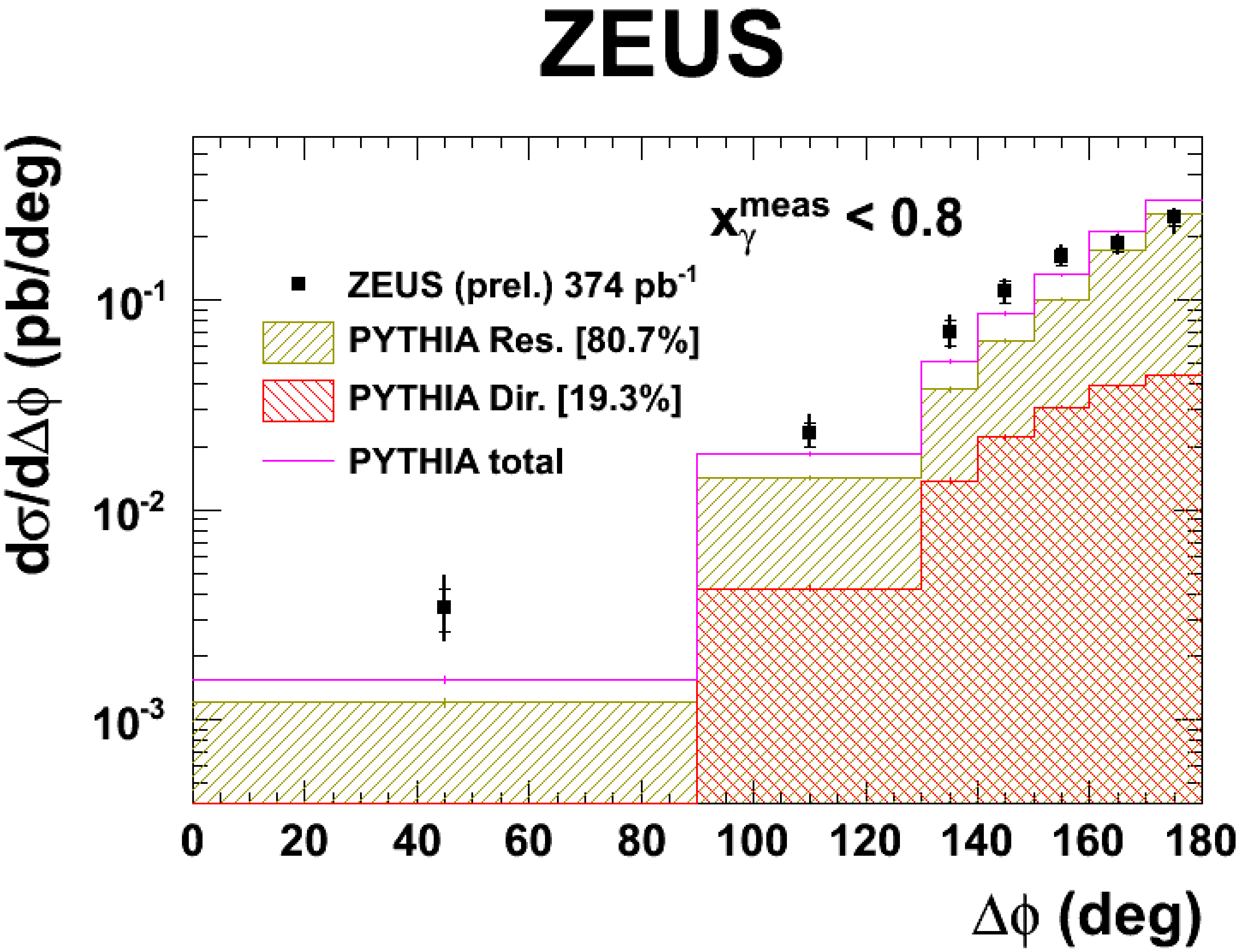

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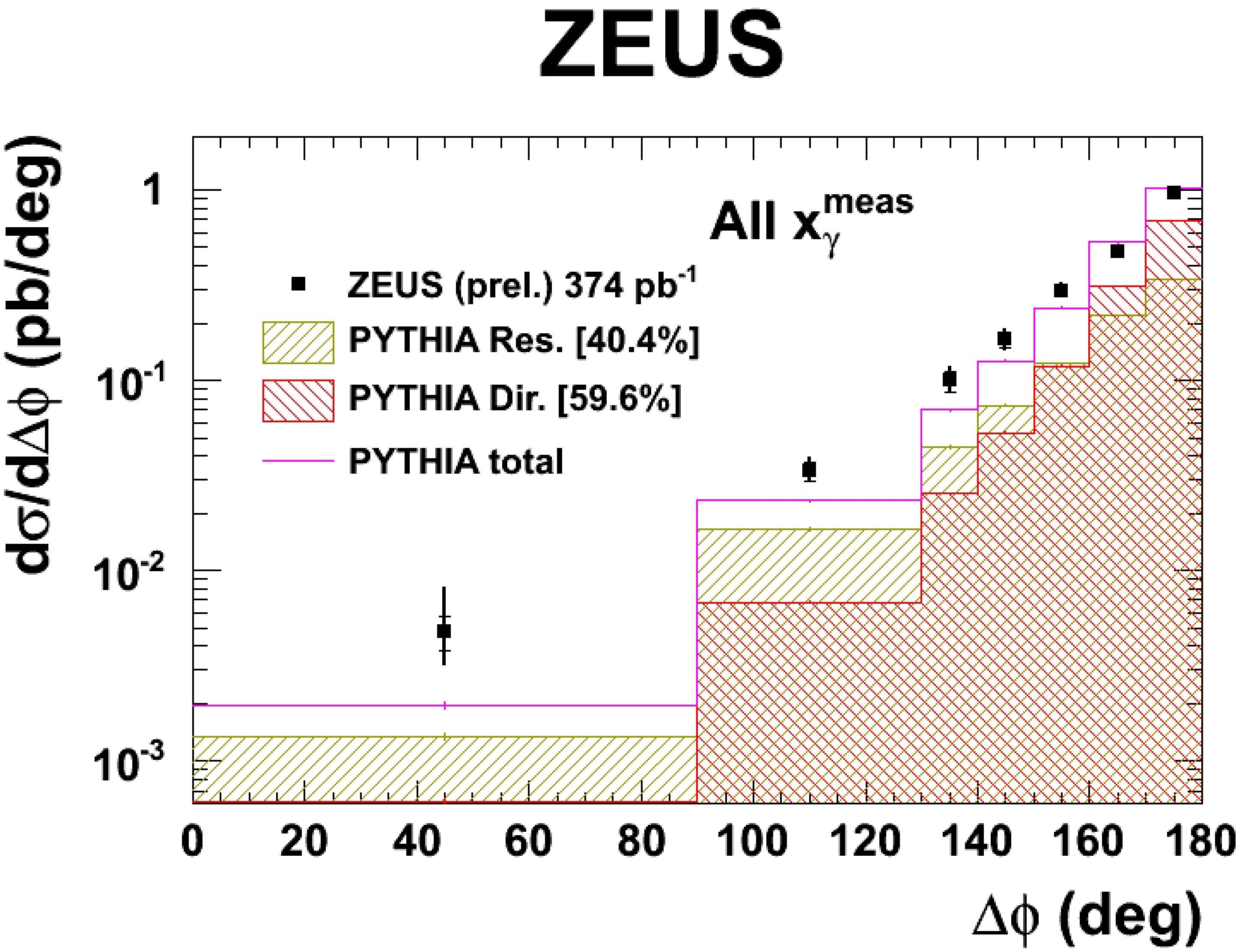

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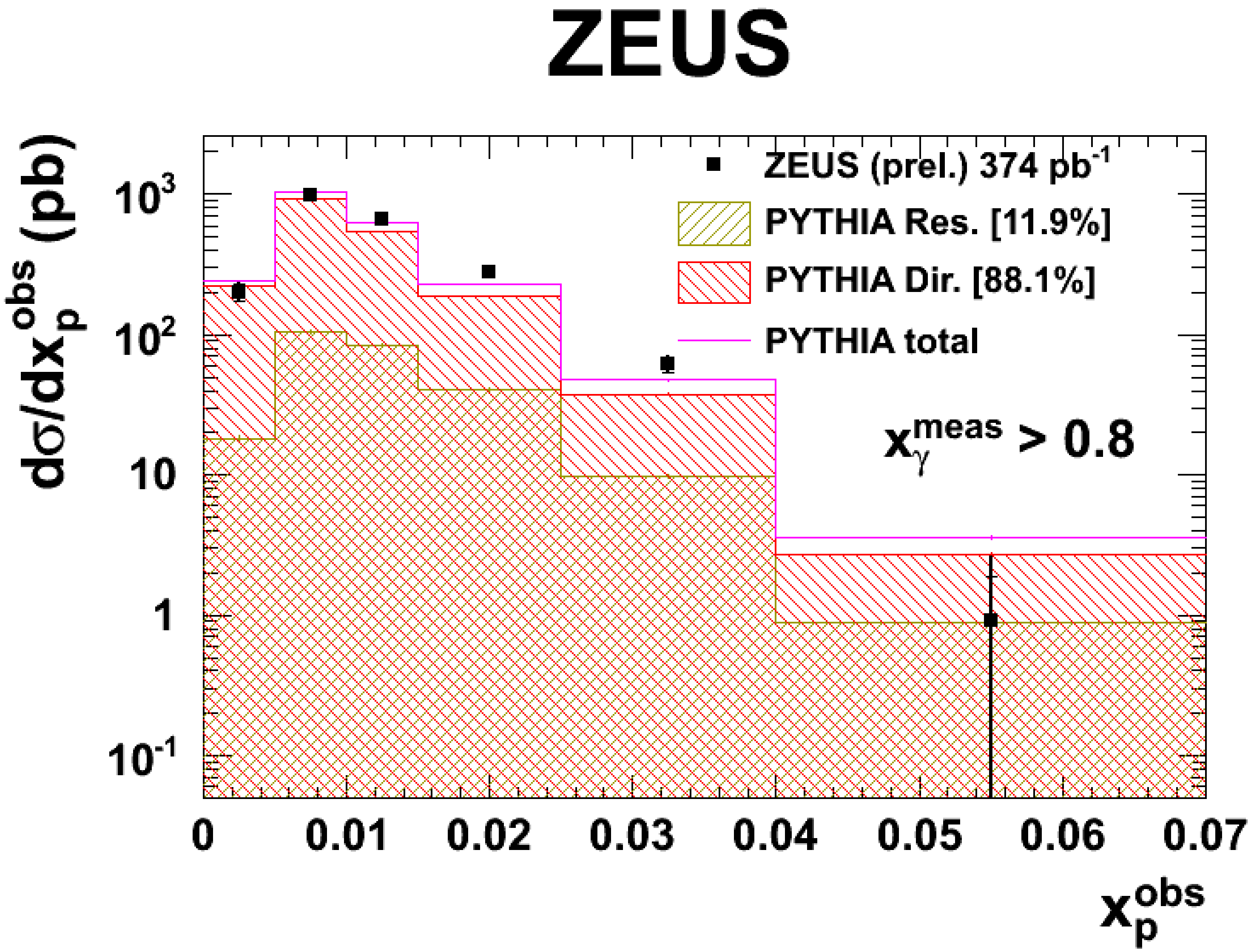

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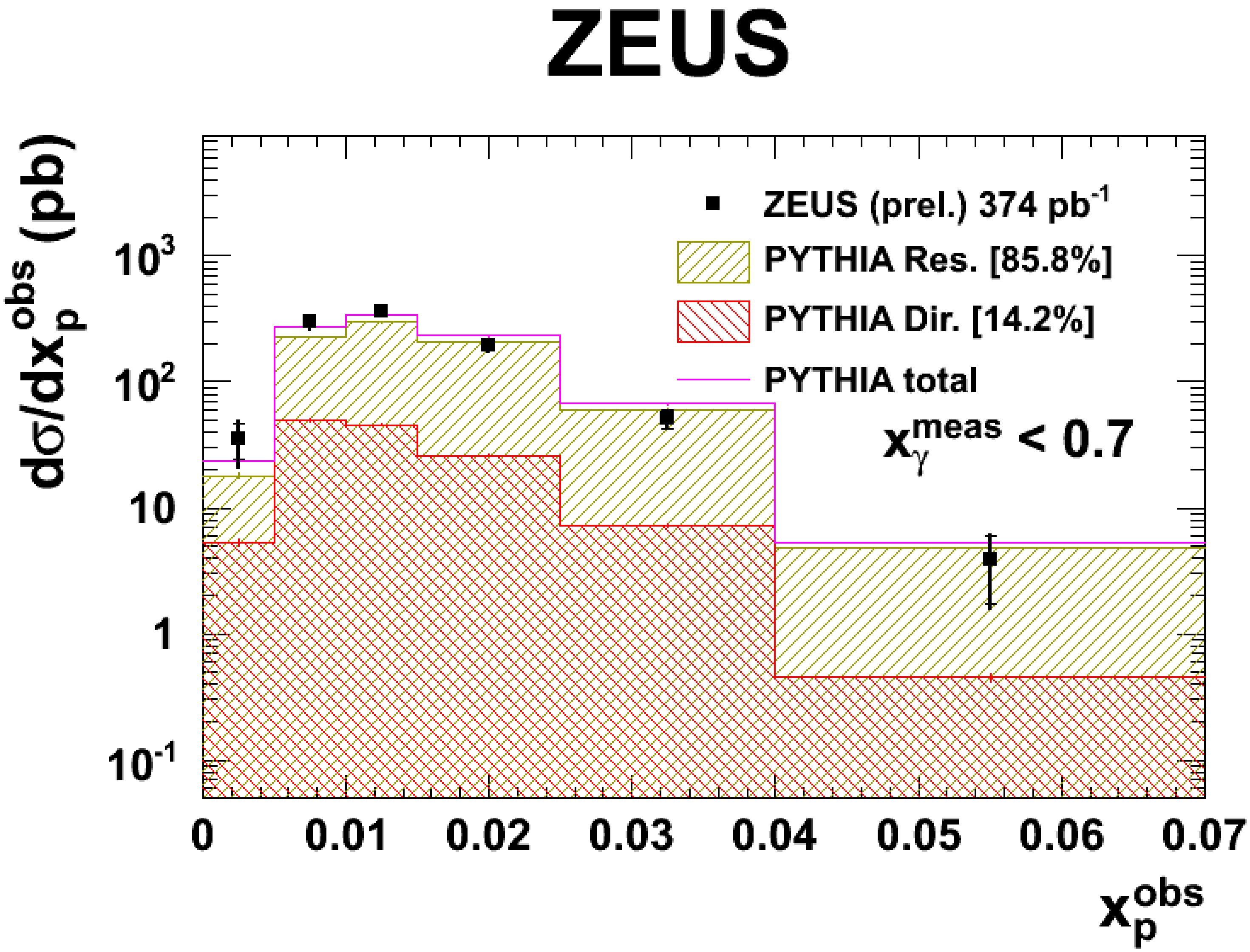

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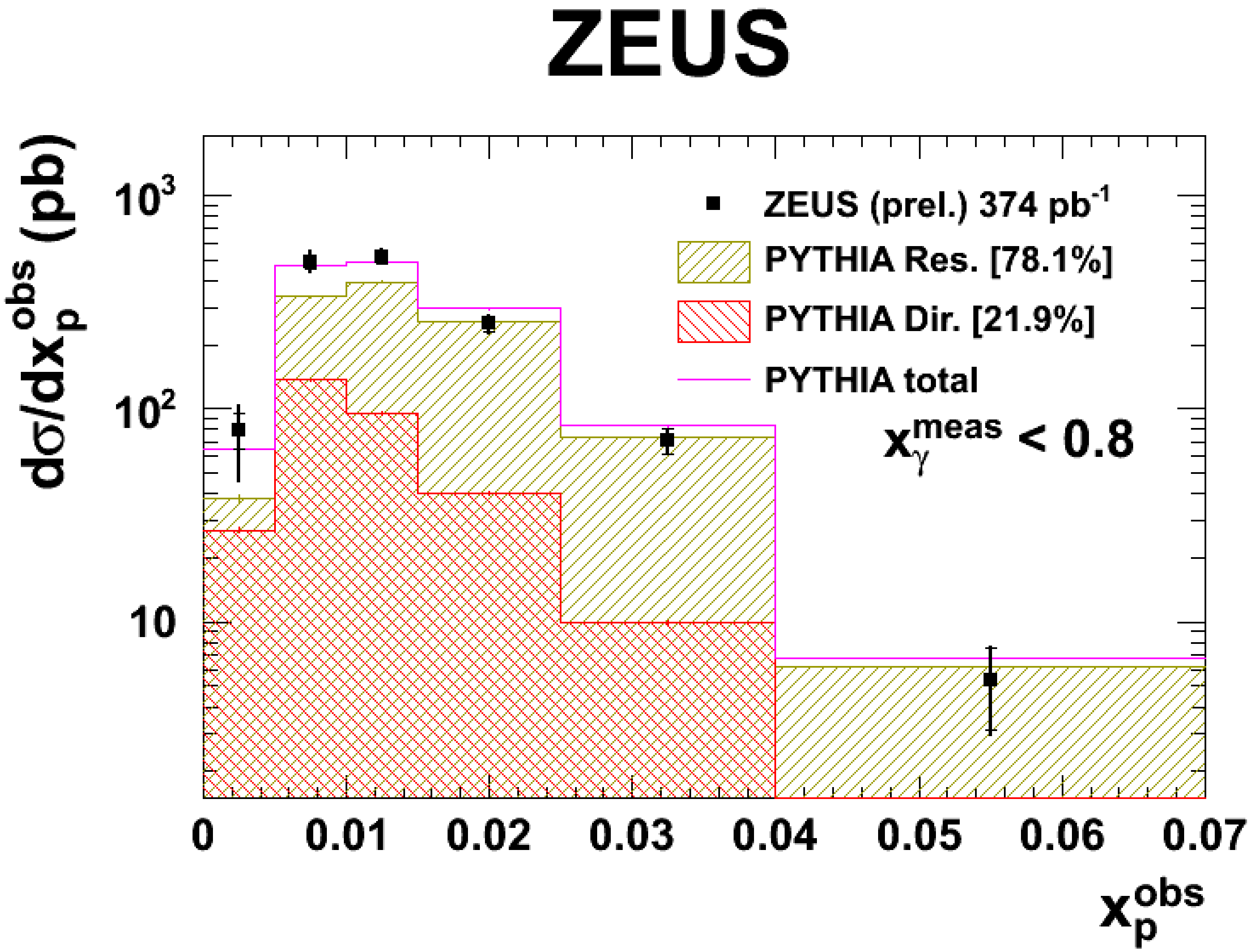

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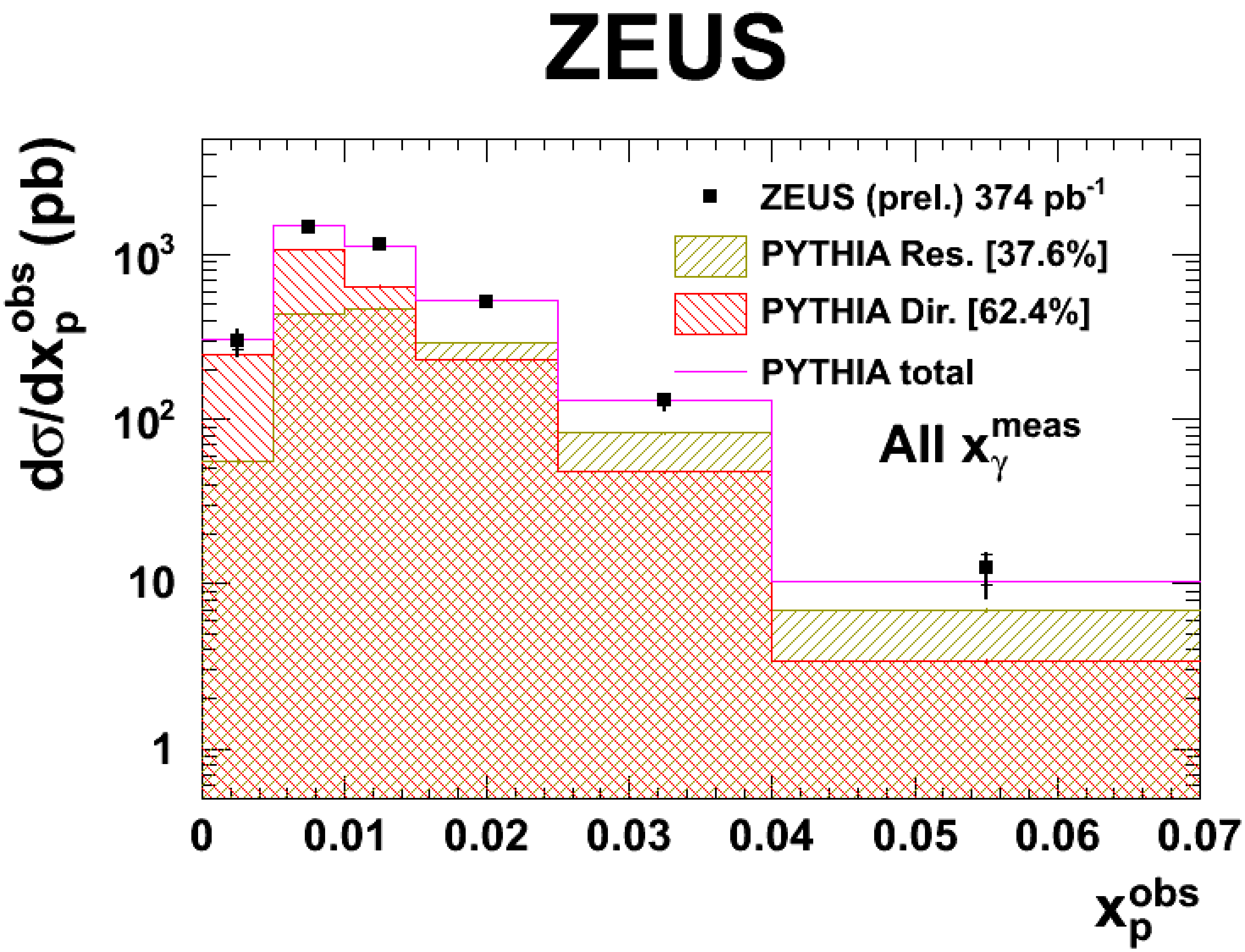

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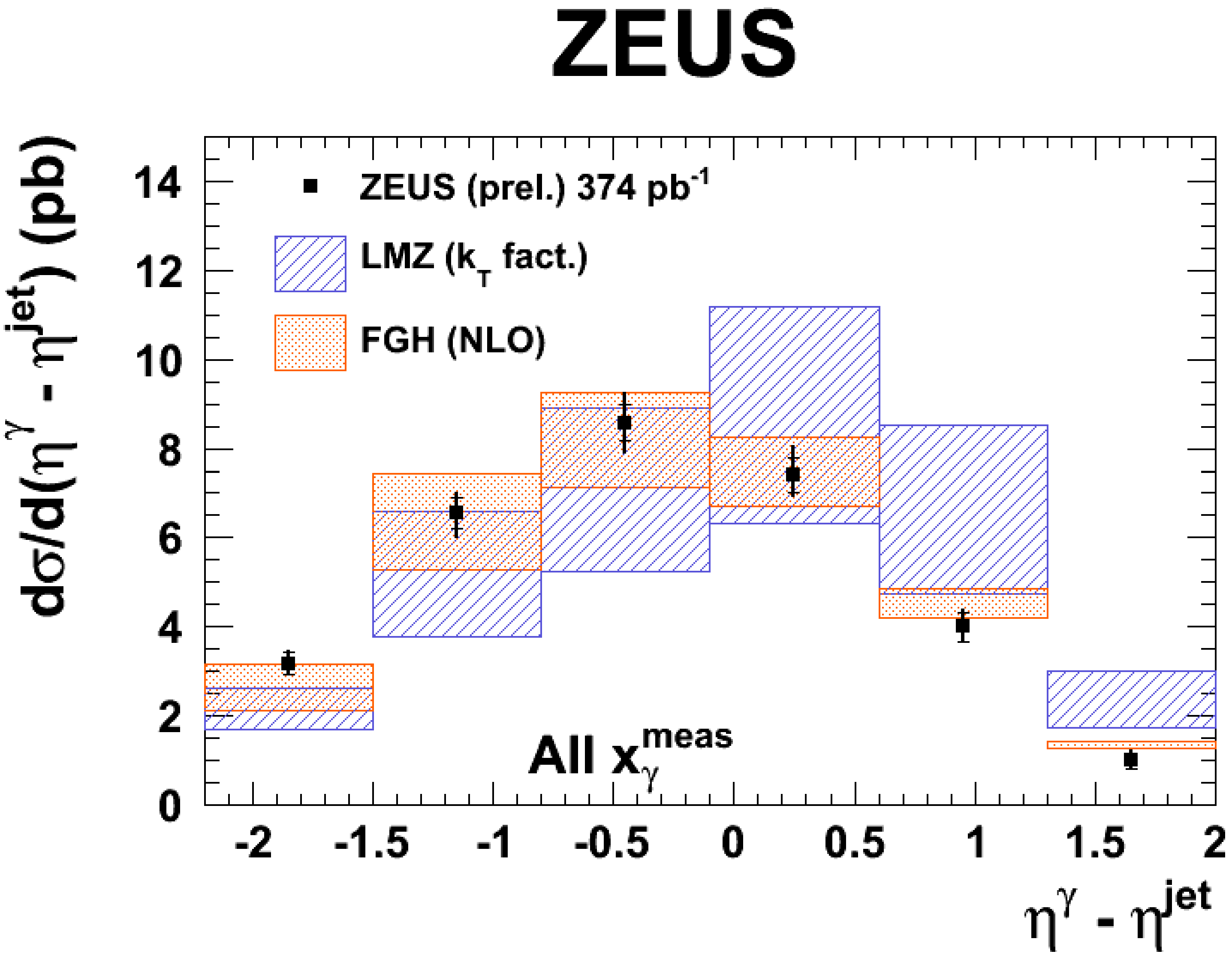

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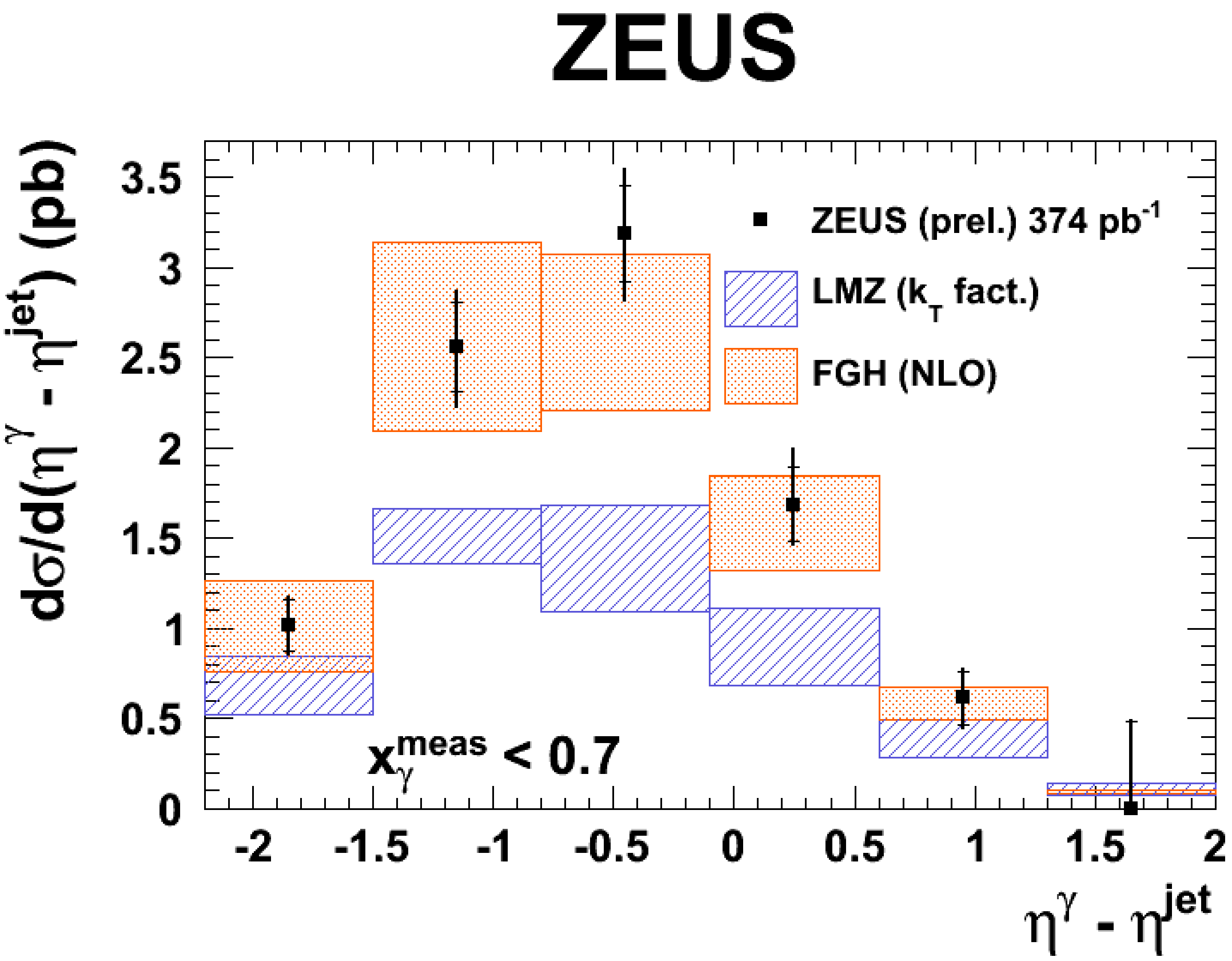

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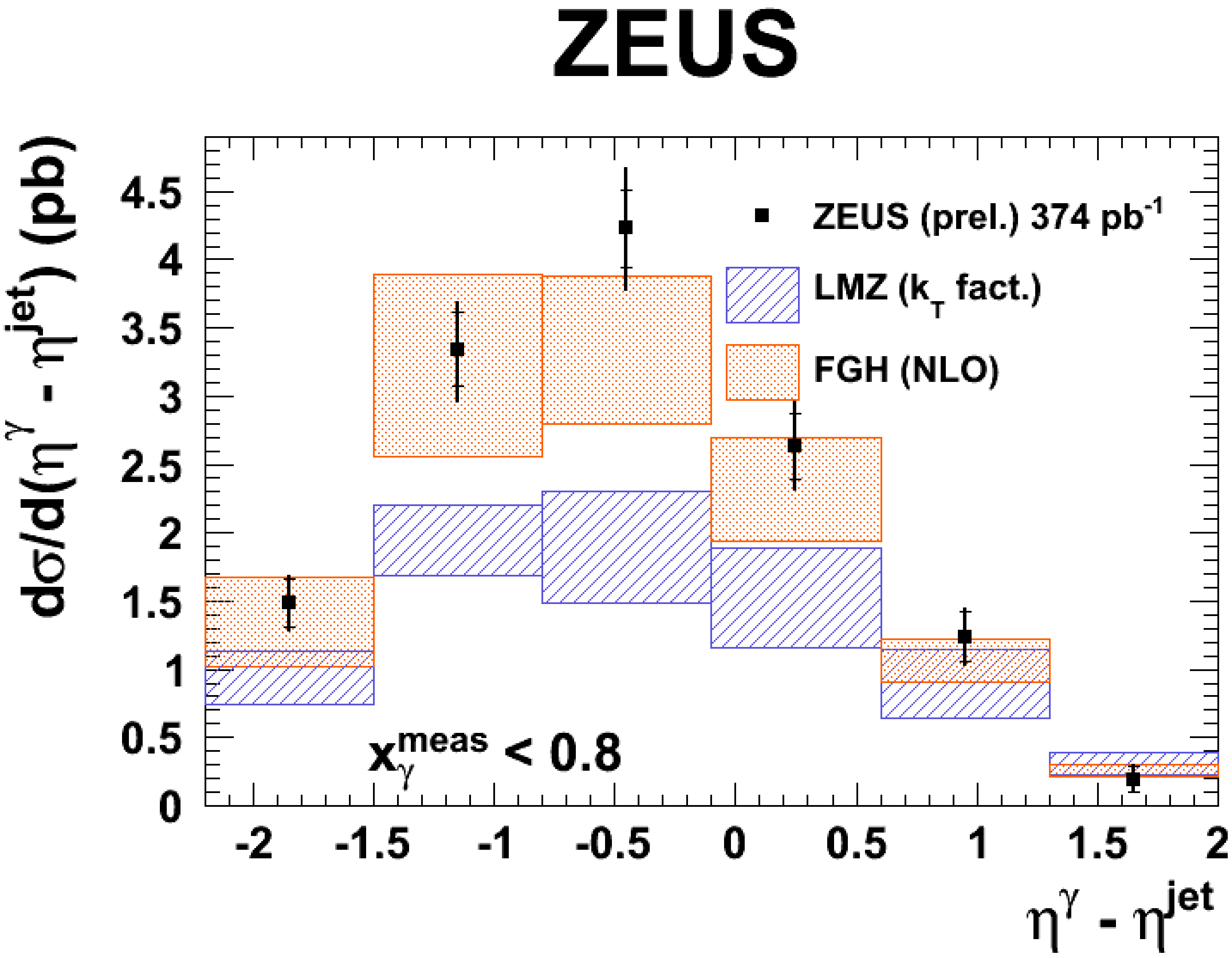

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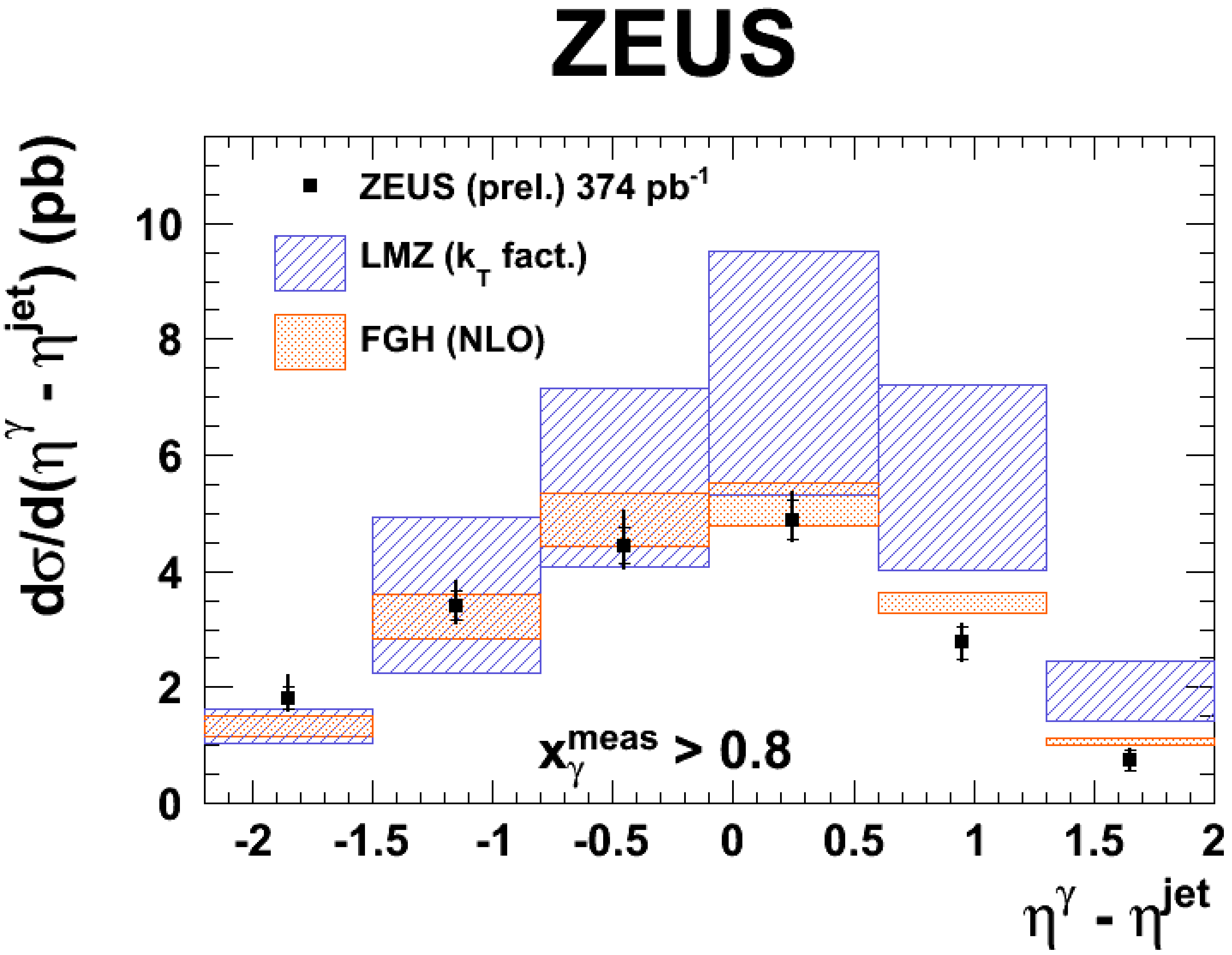

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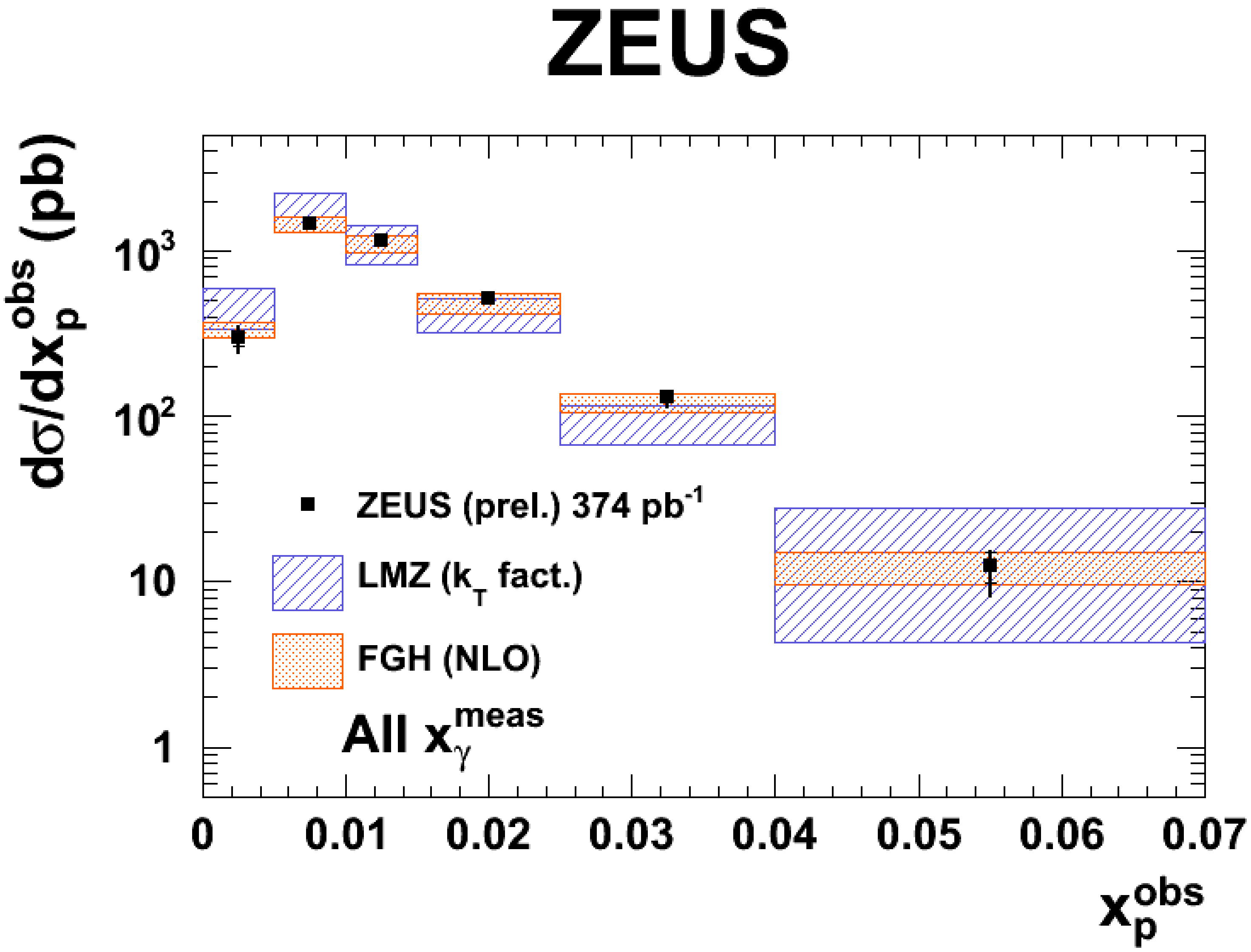

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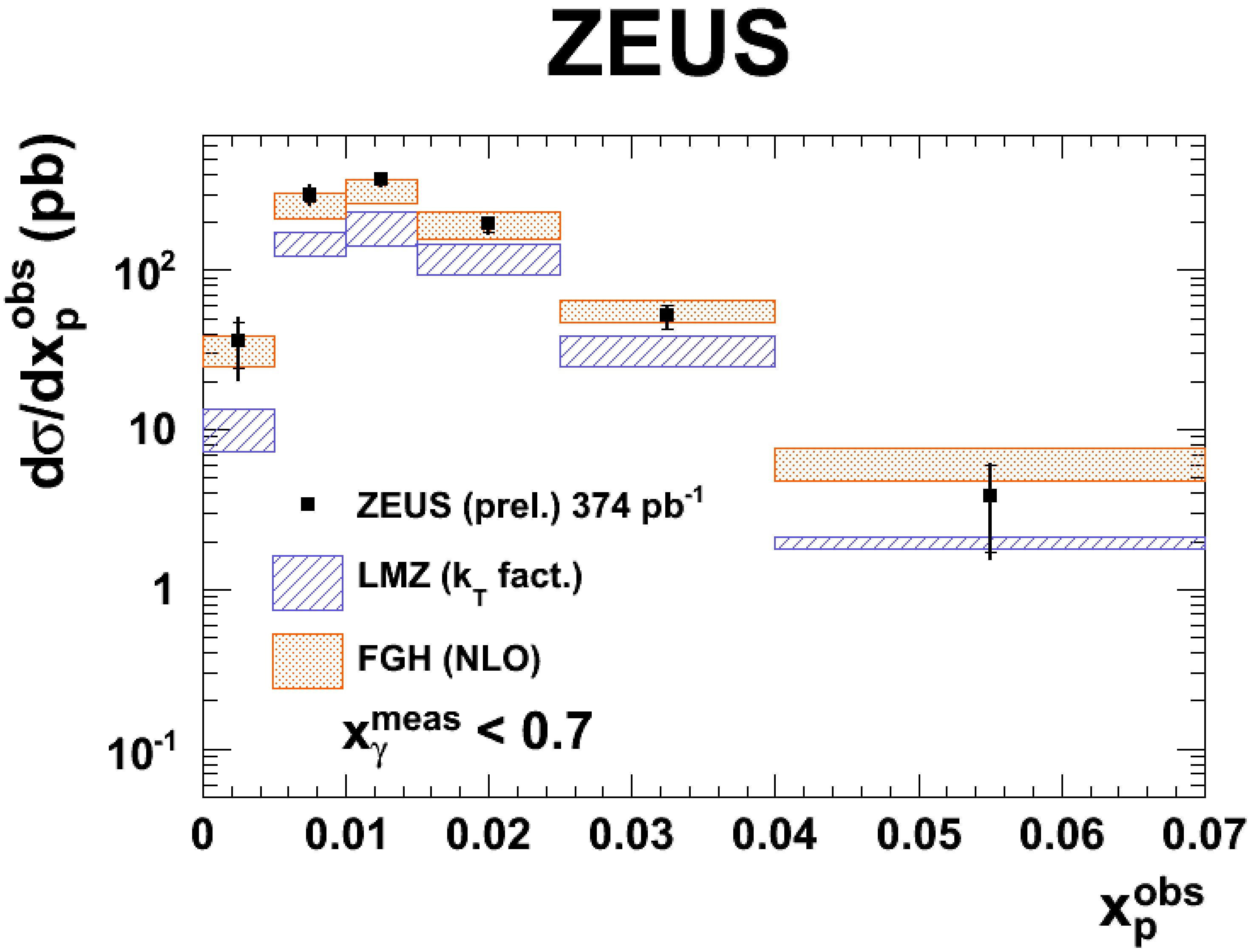

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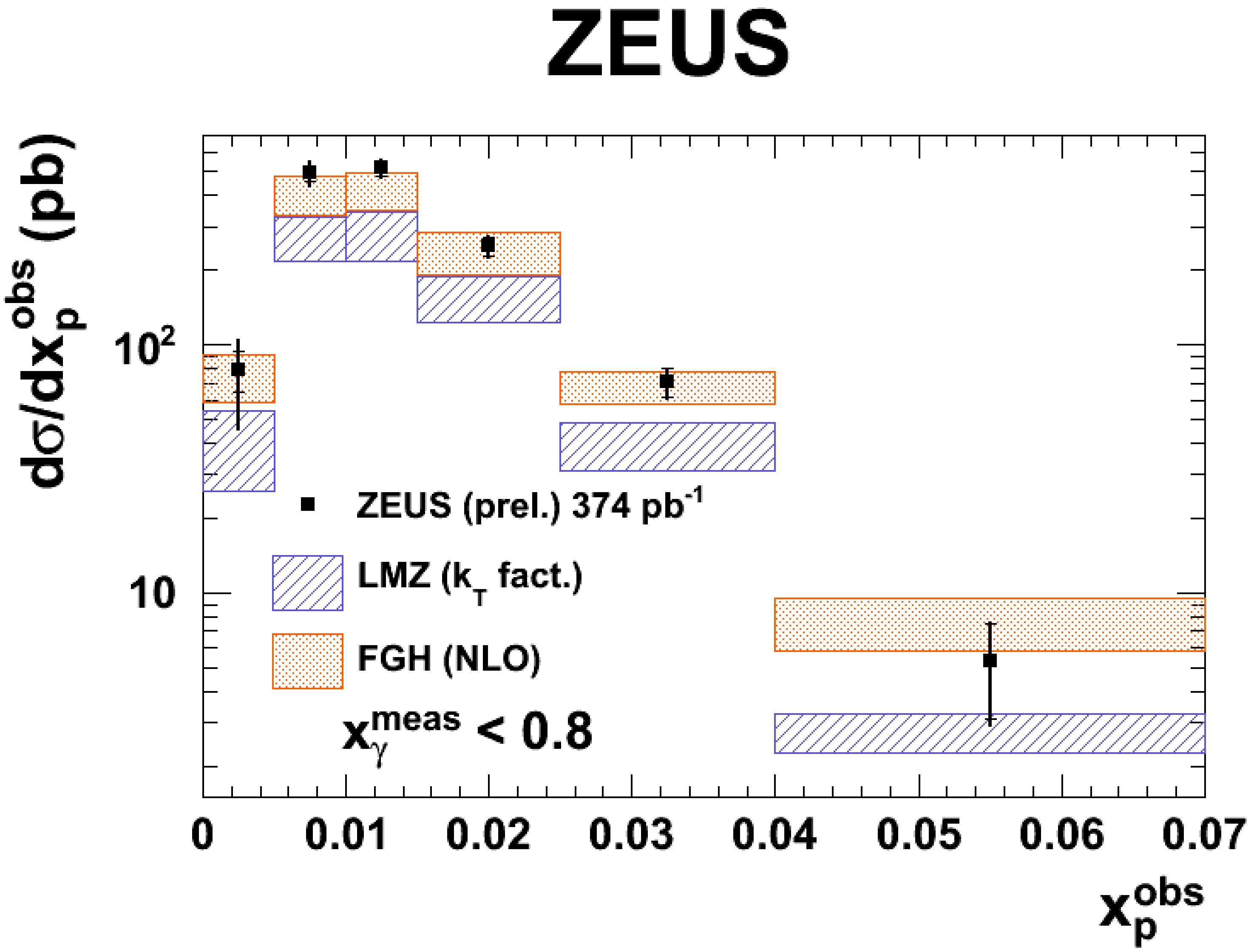

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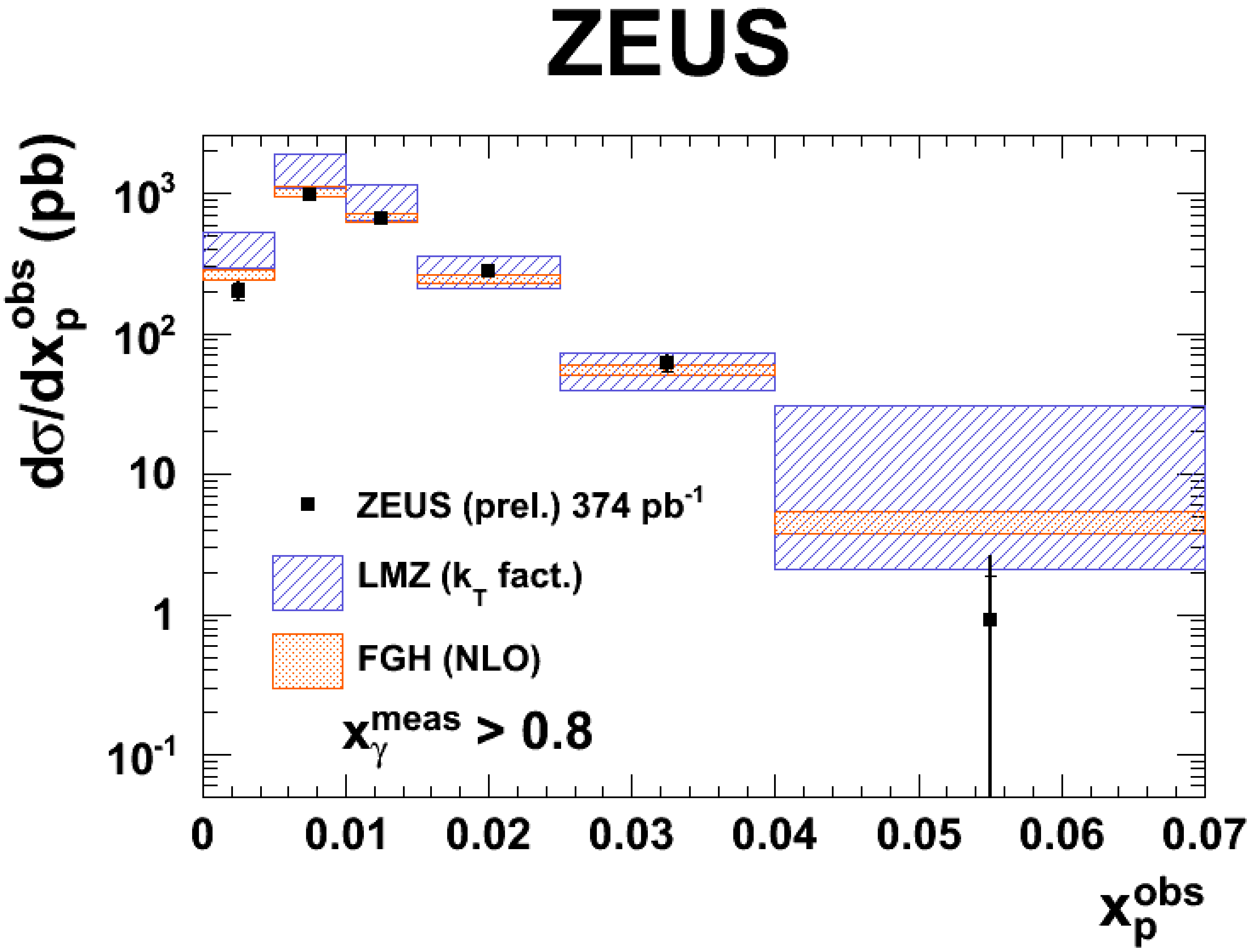

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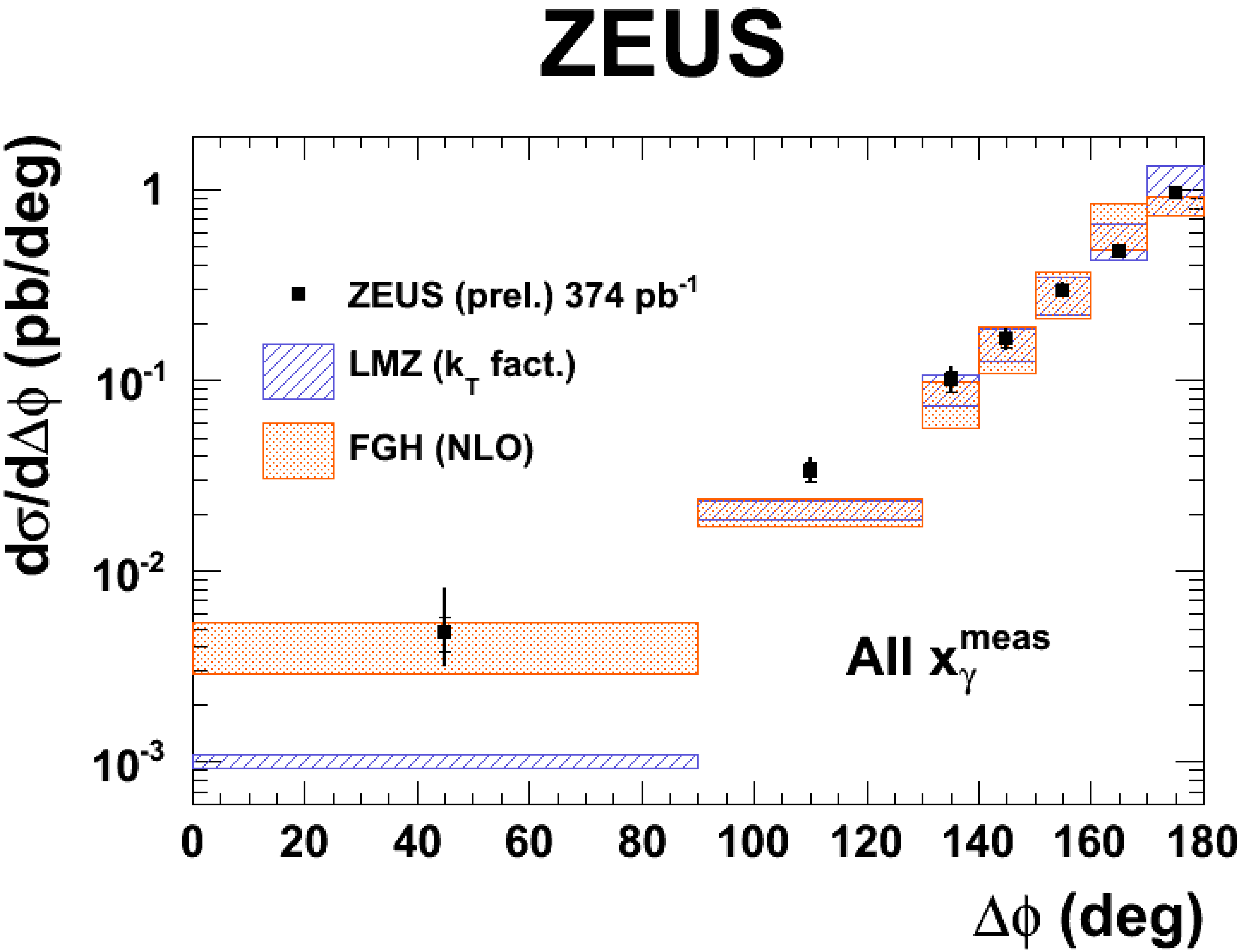

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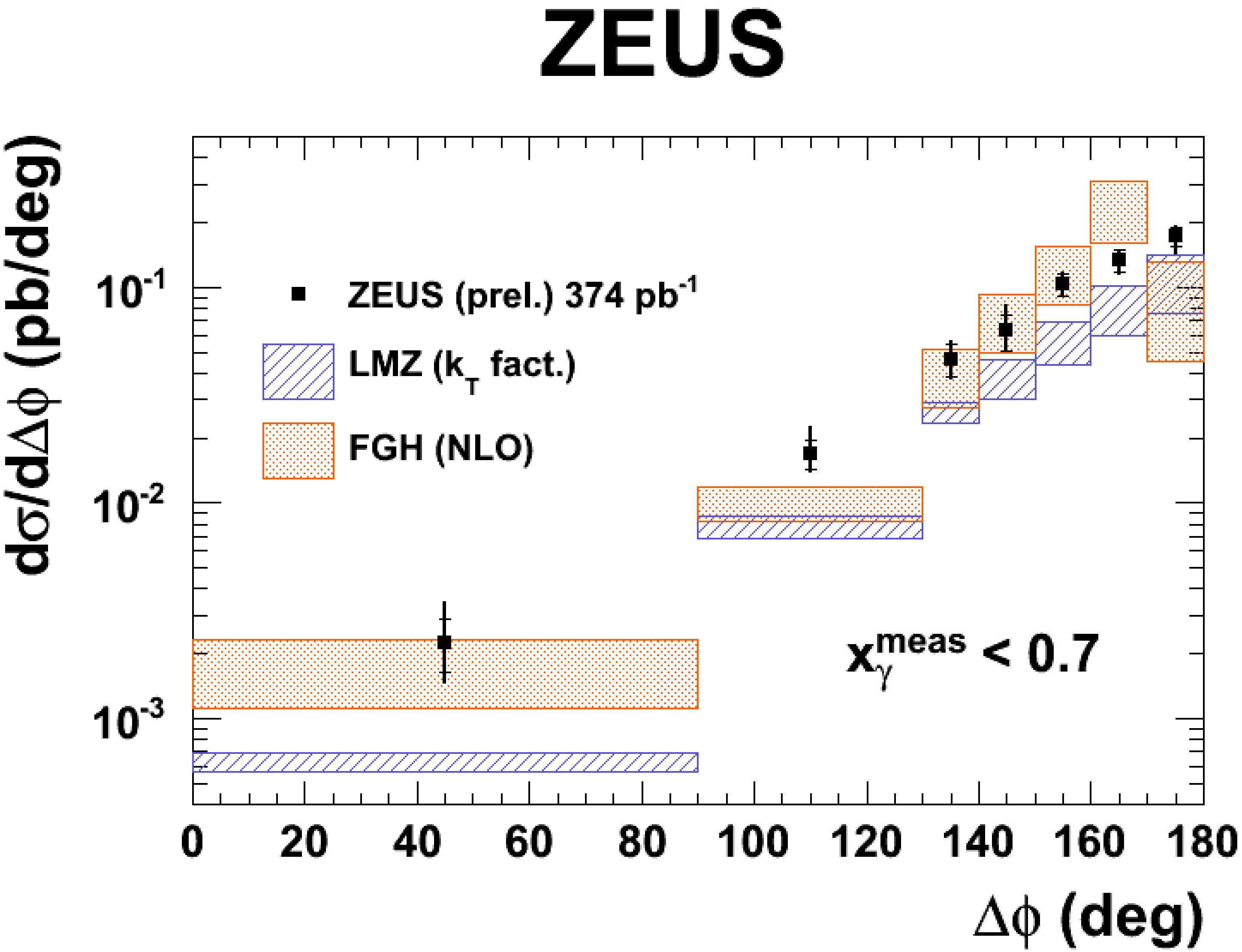

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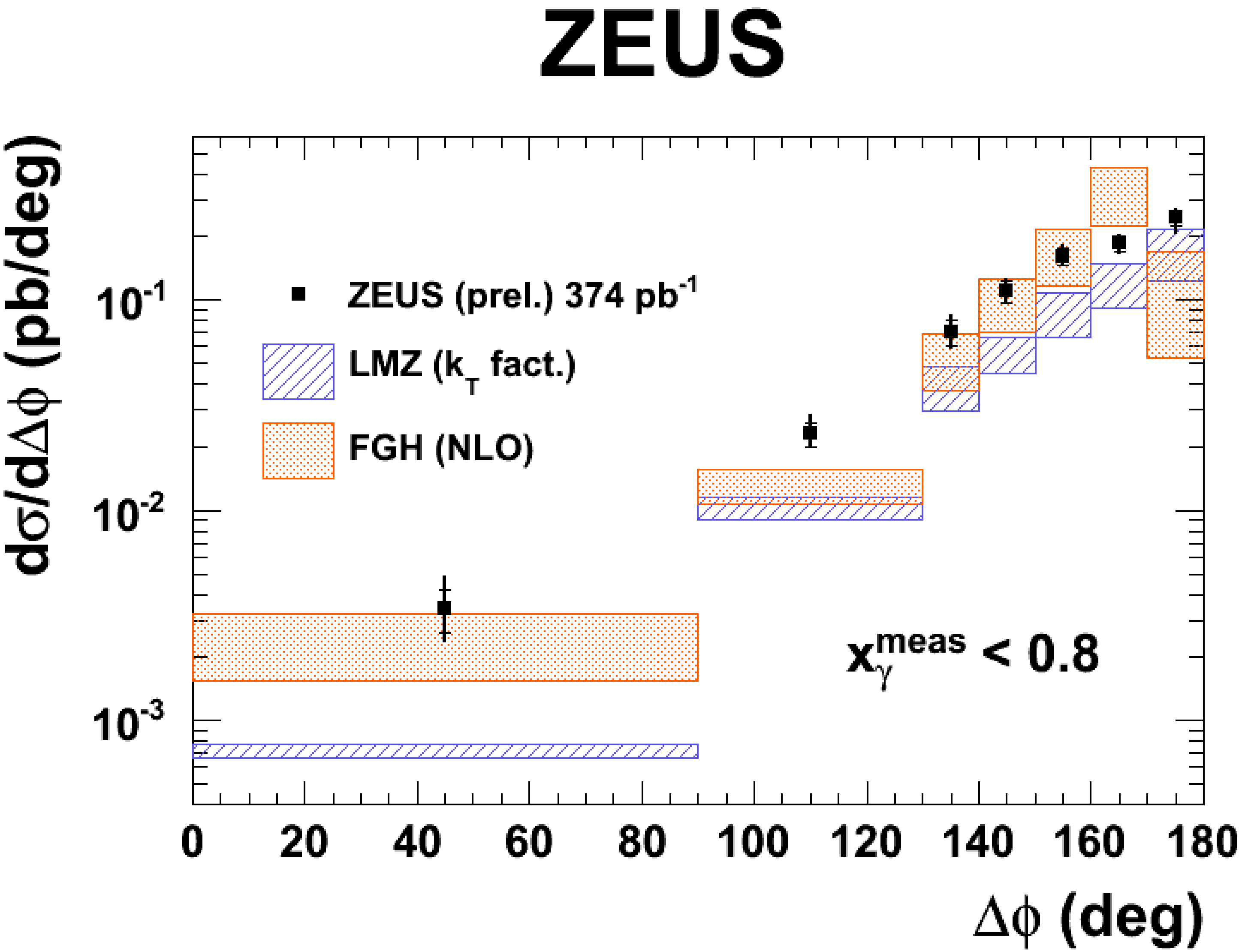

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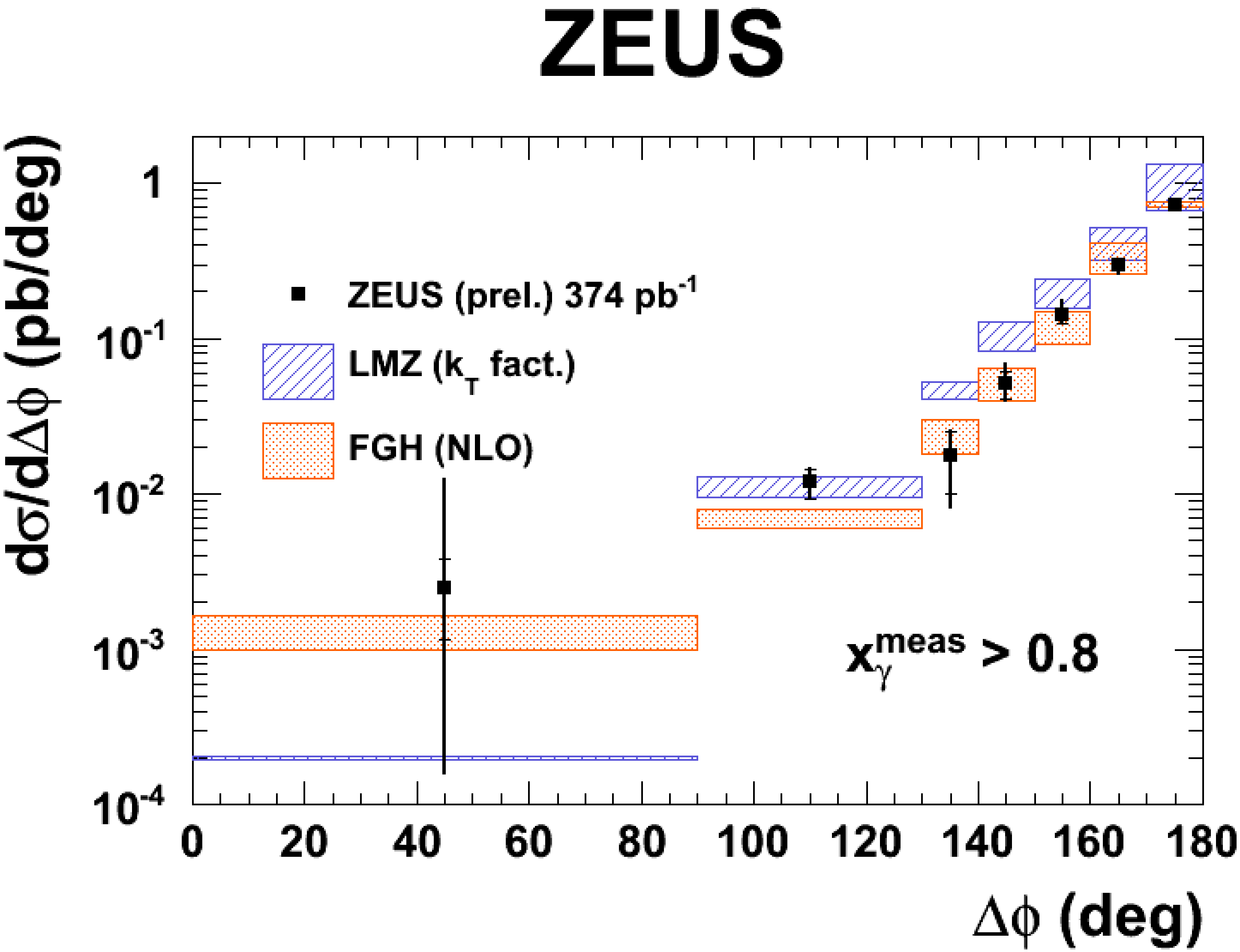

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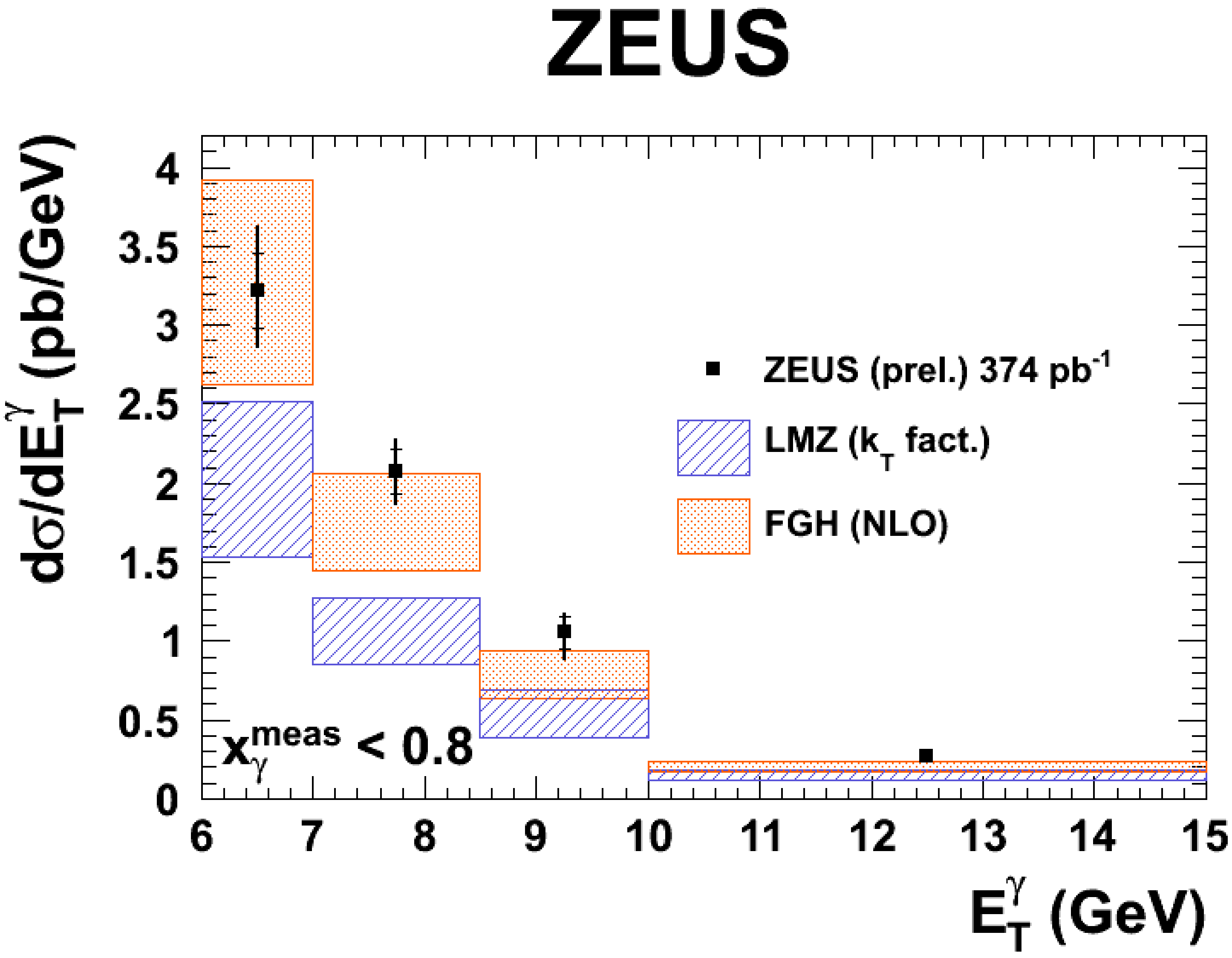

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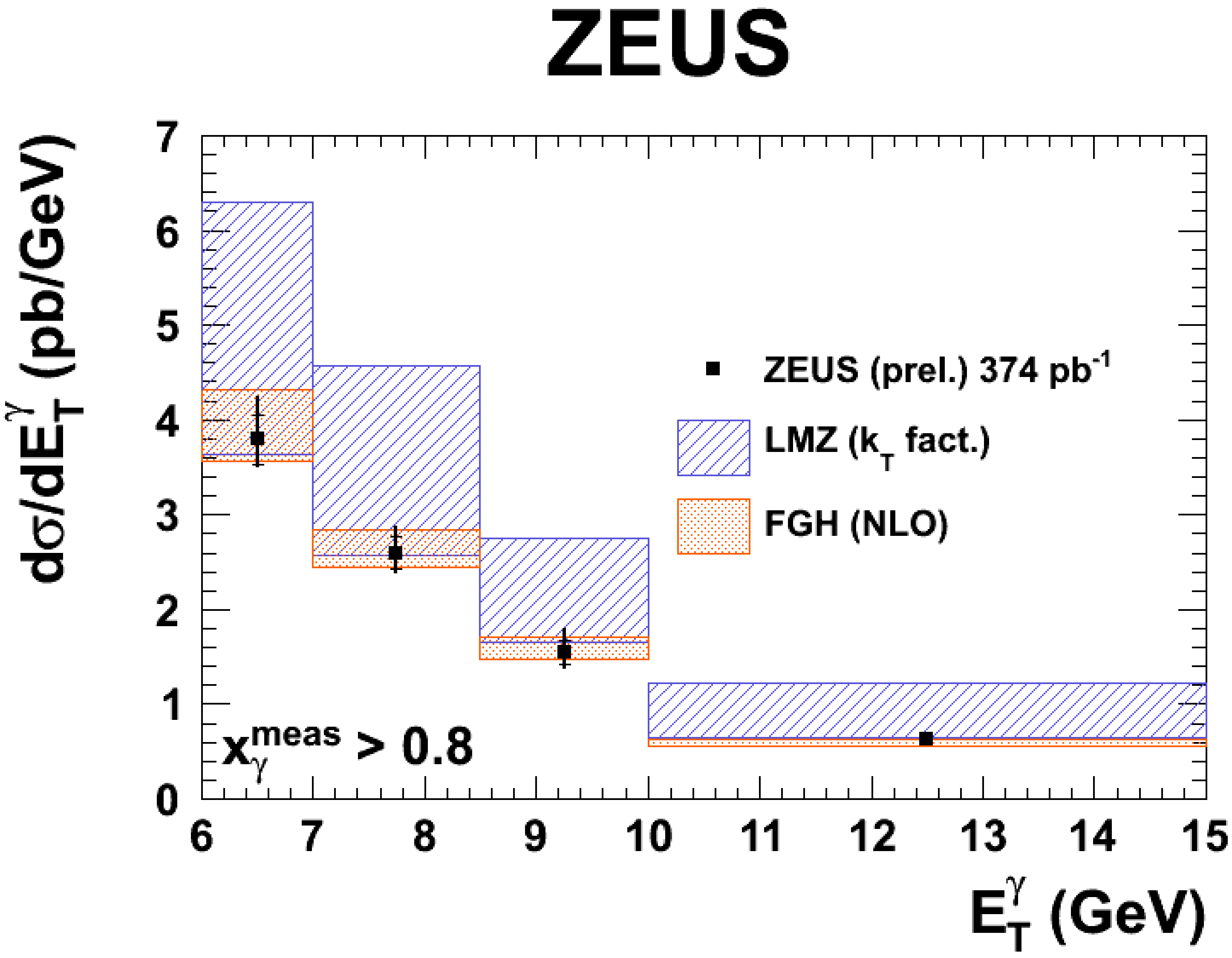

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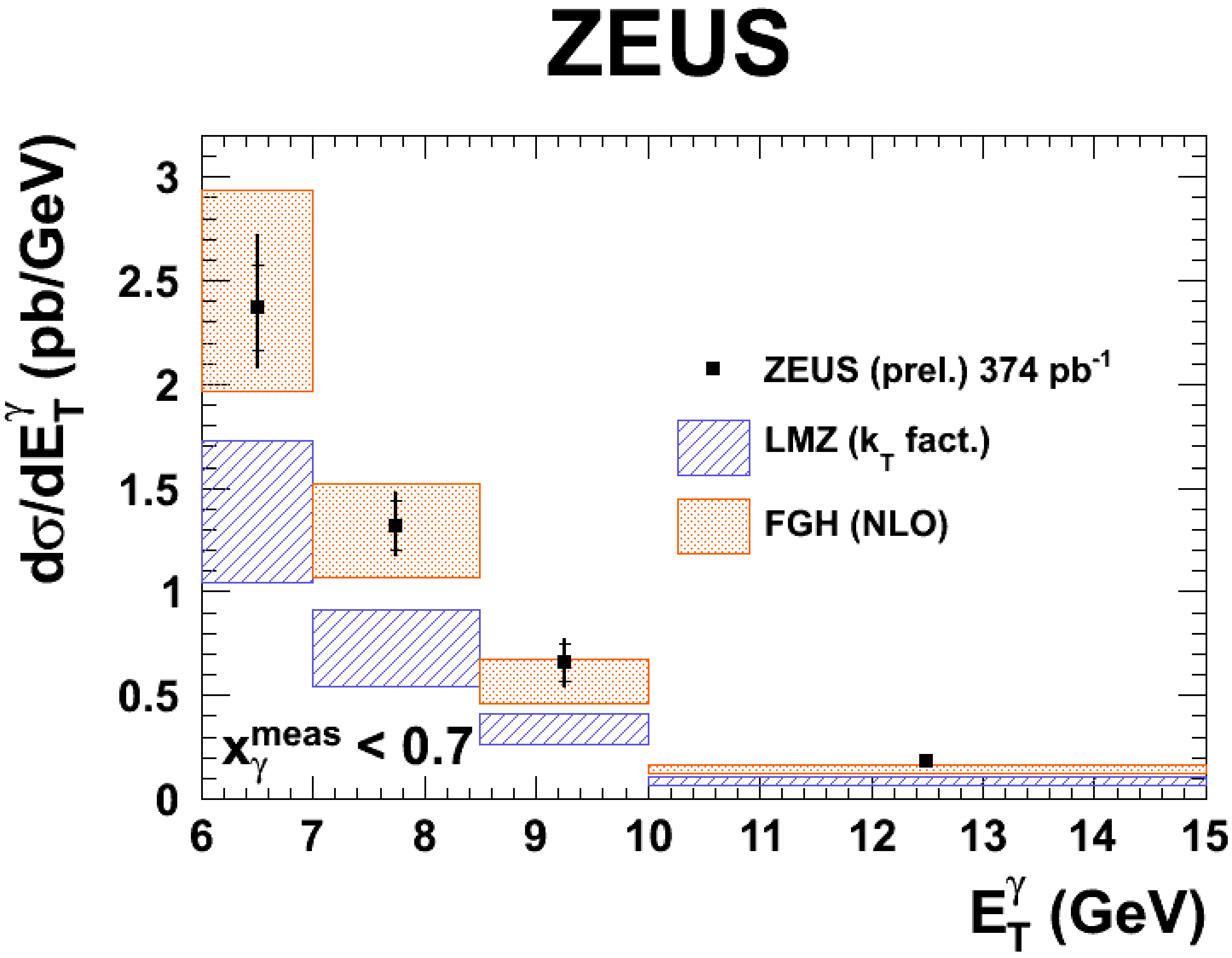

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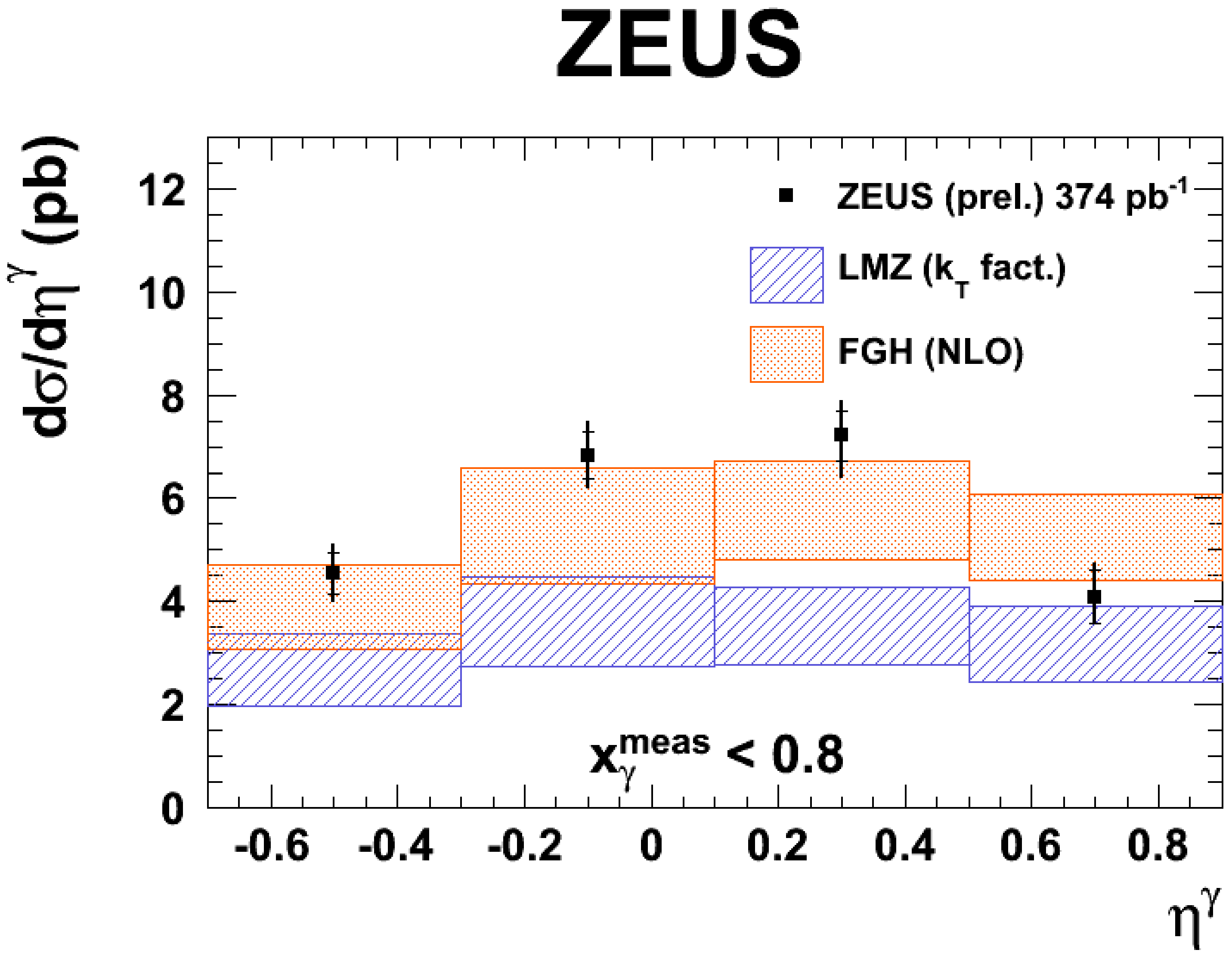
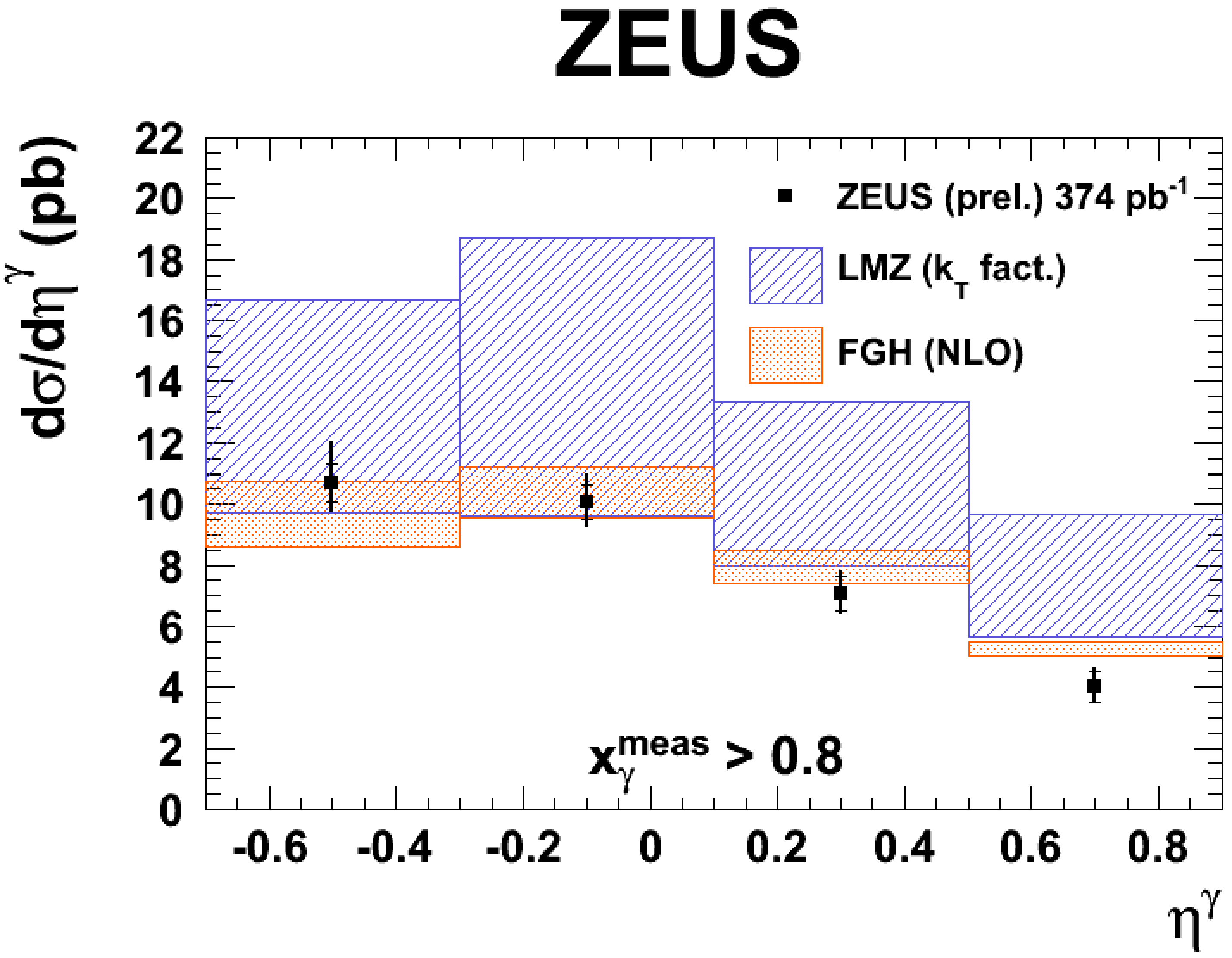
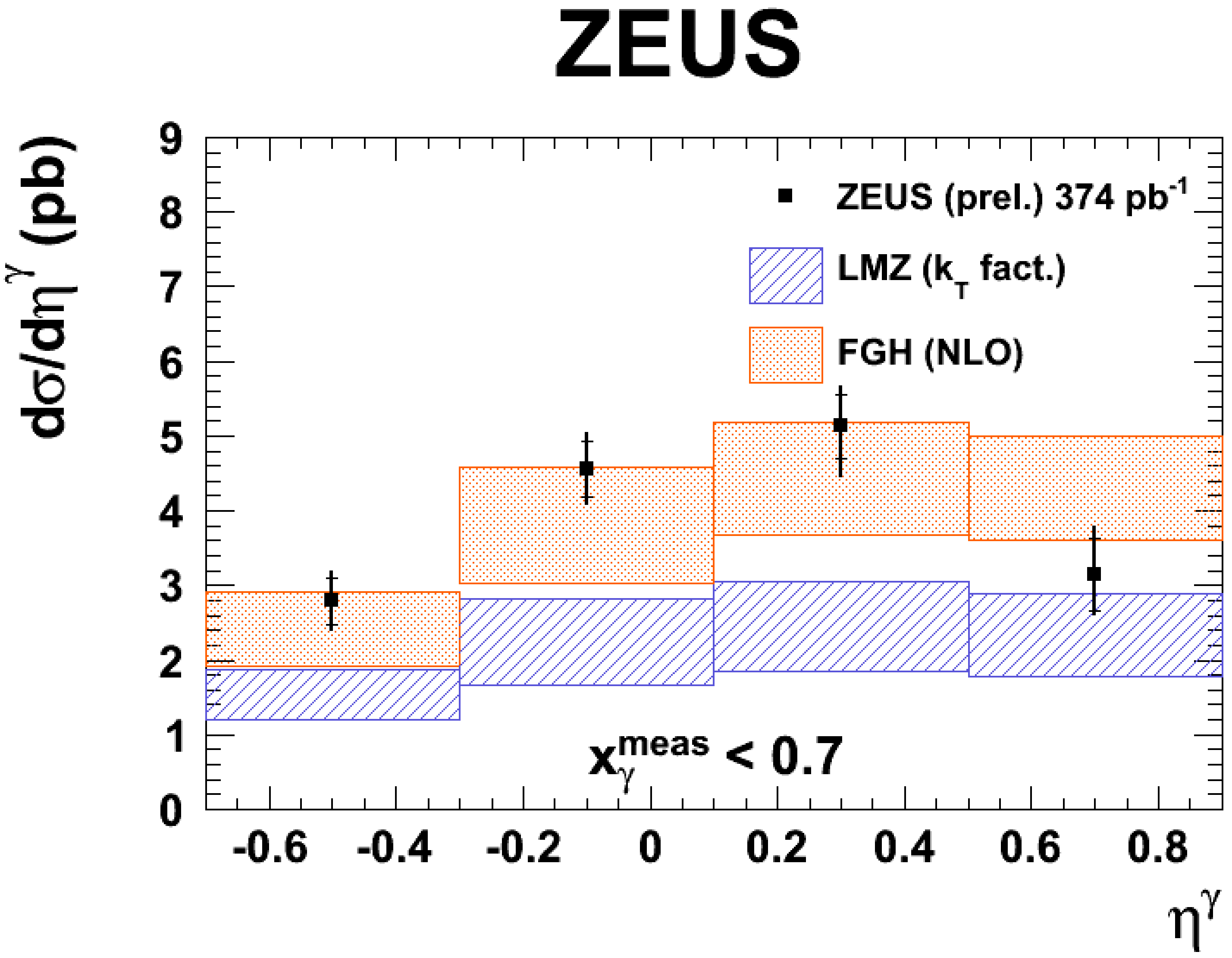


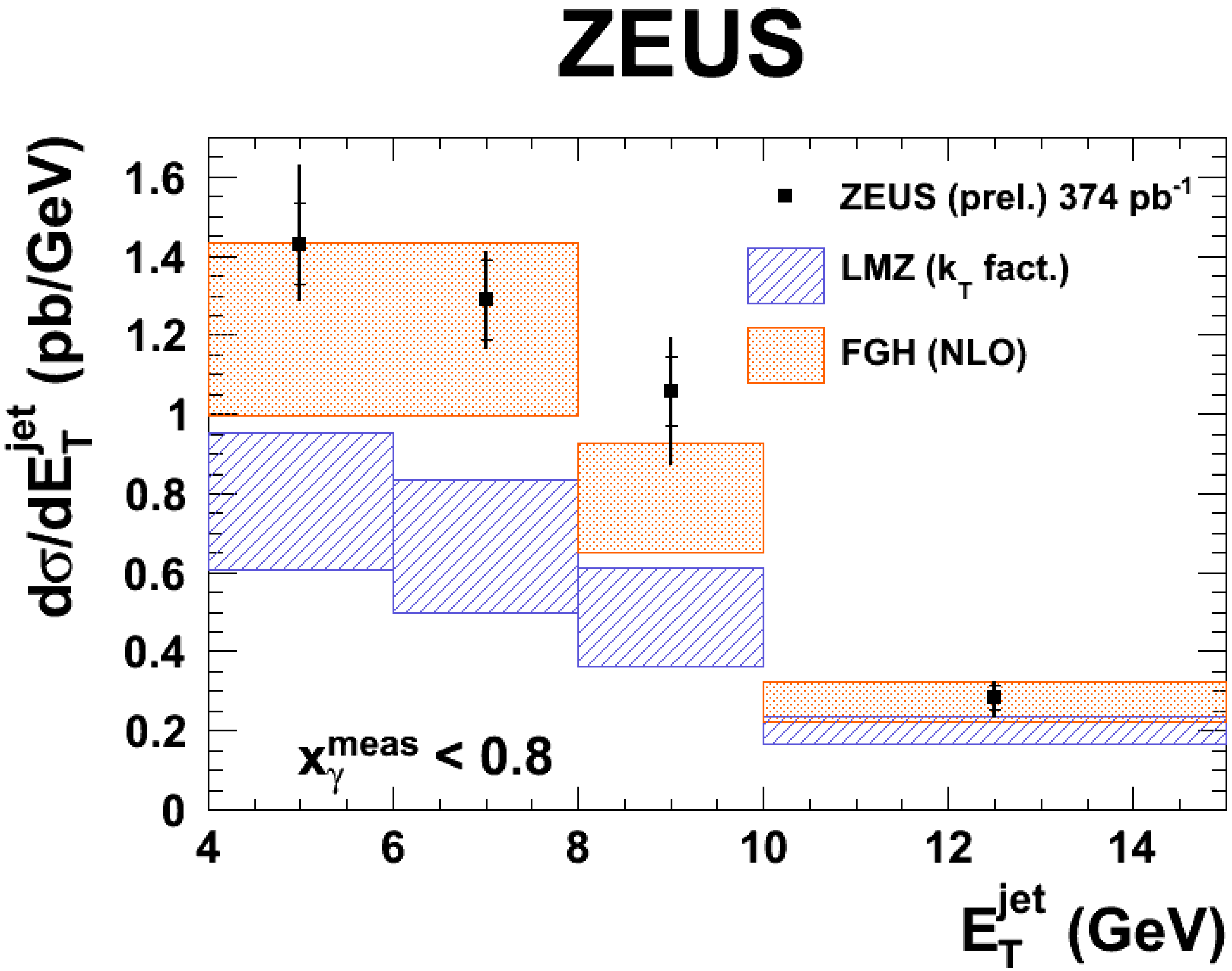
Plots to be made preliminary



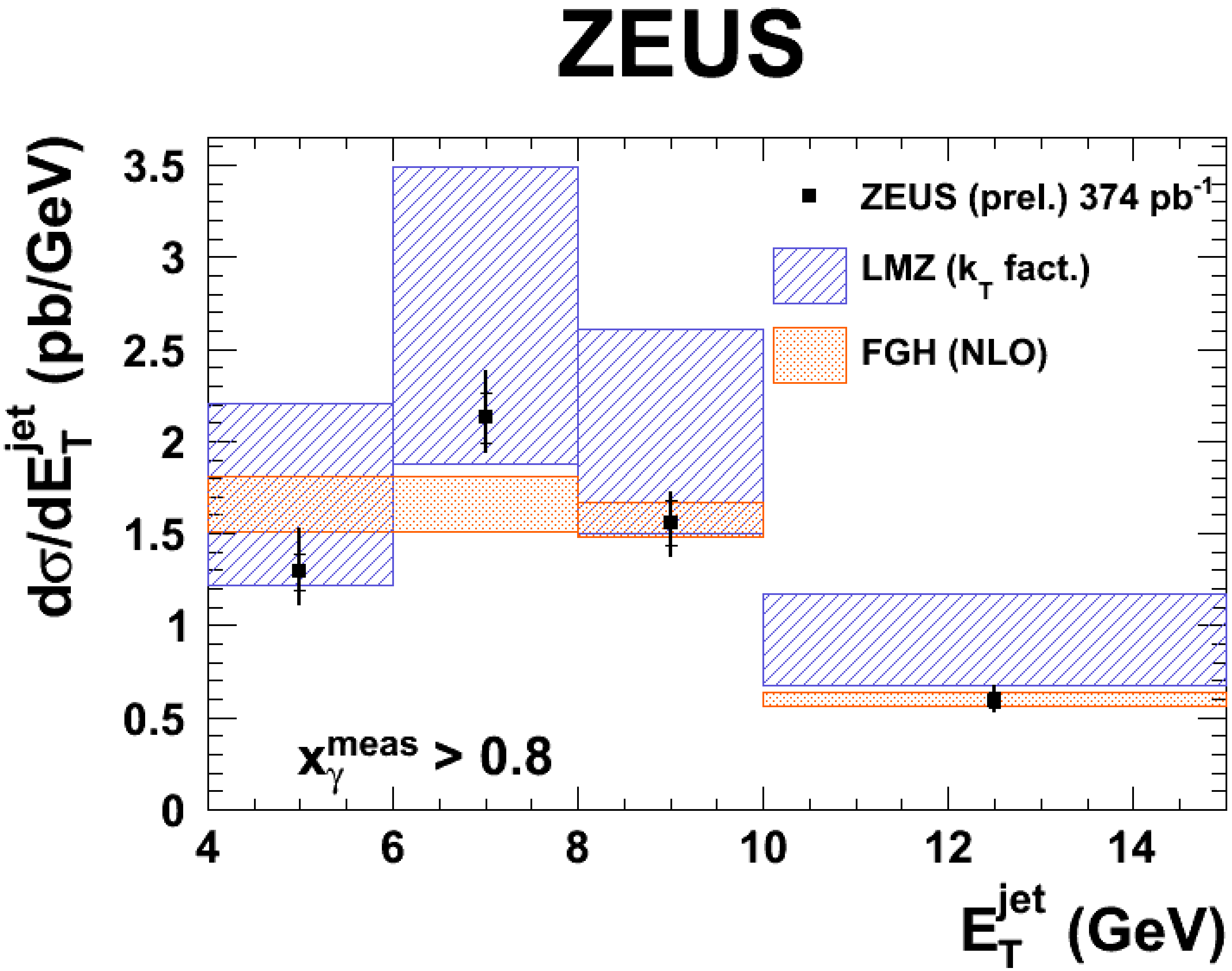
Plots to be made preliminary



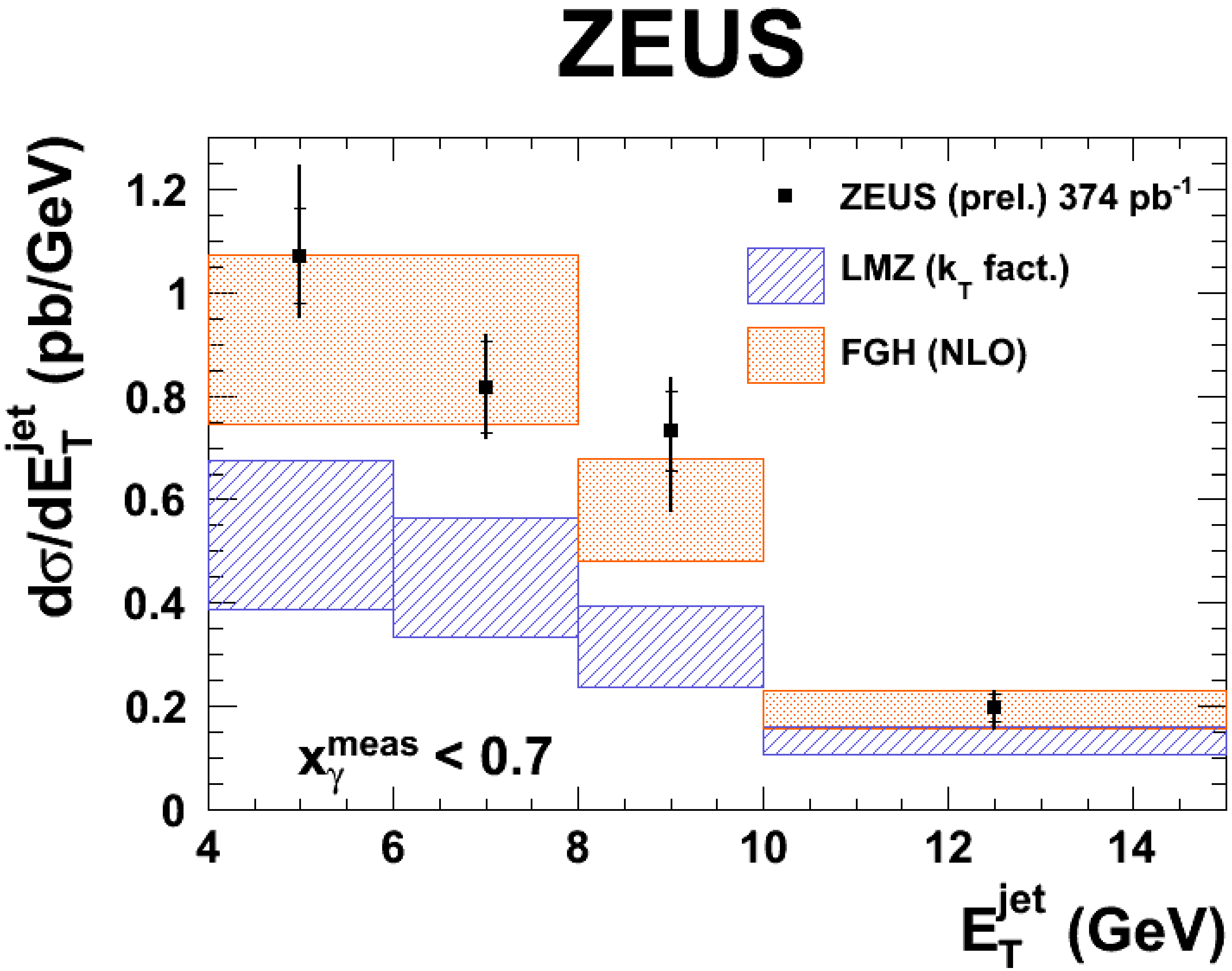
Plots to be made preliminary



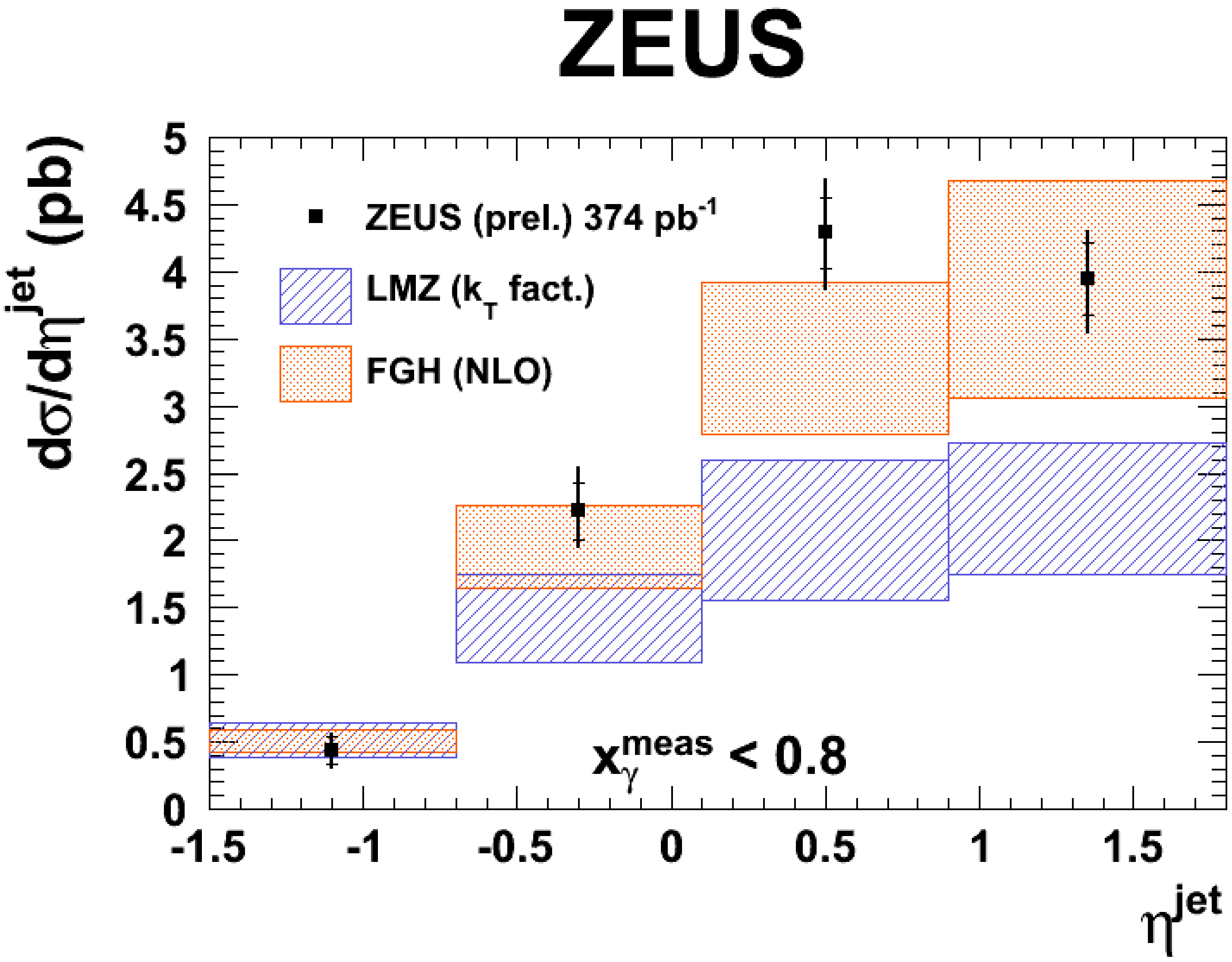
Plots to be made preliminary



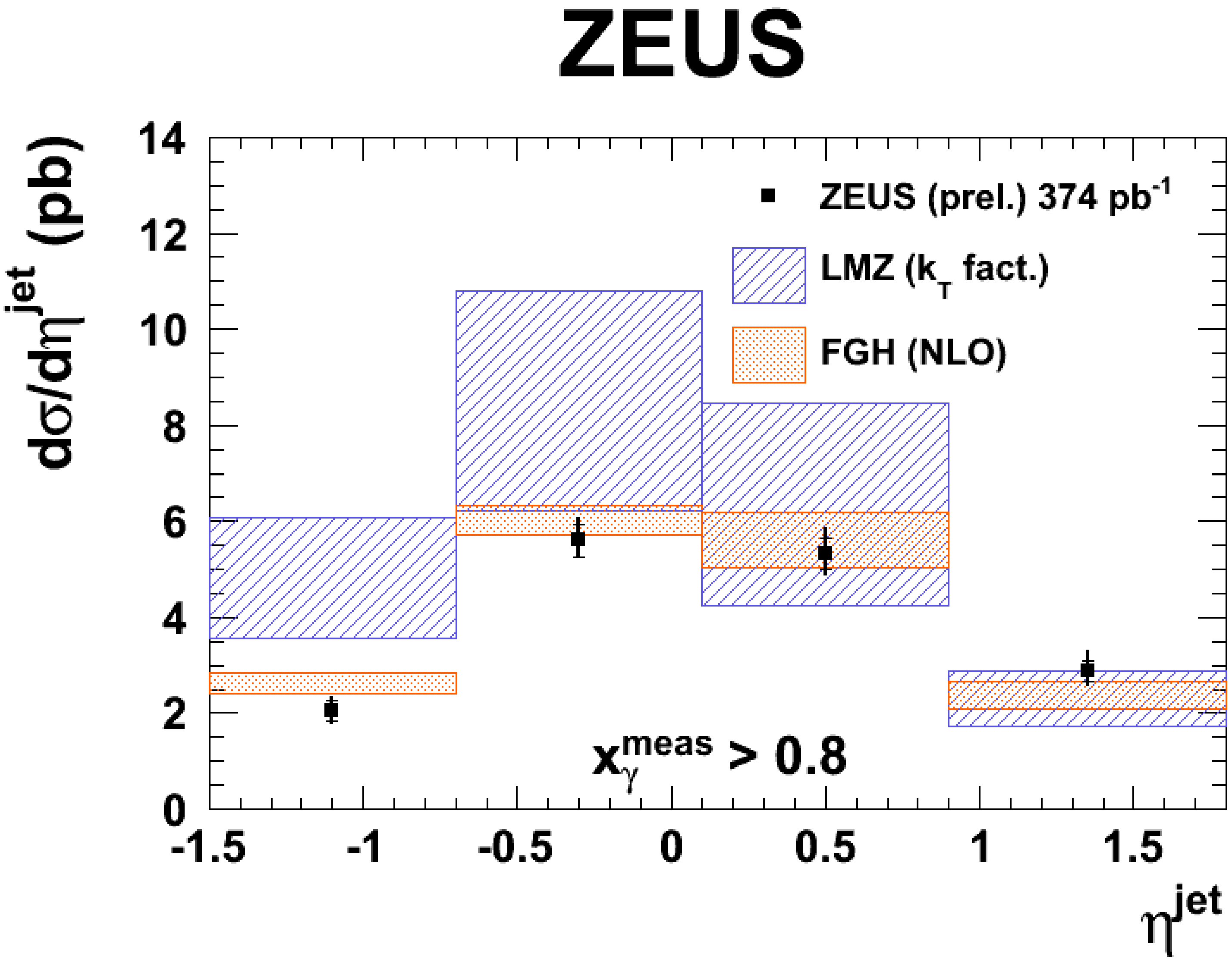
Plots to be made preliminary



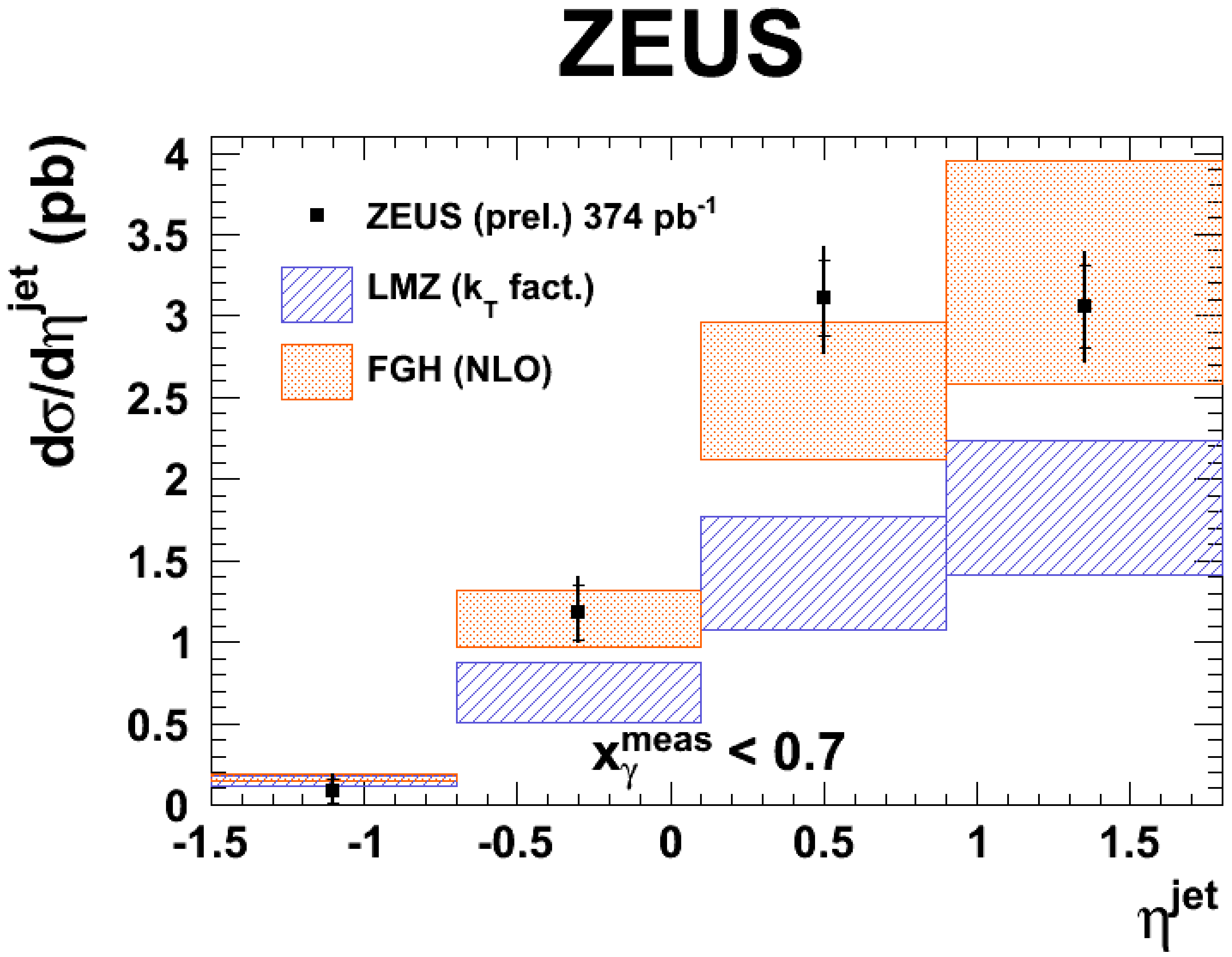
Plots to be made preliminary



Plots to be made preliminary



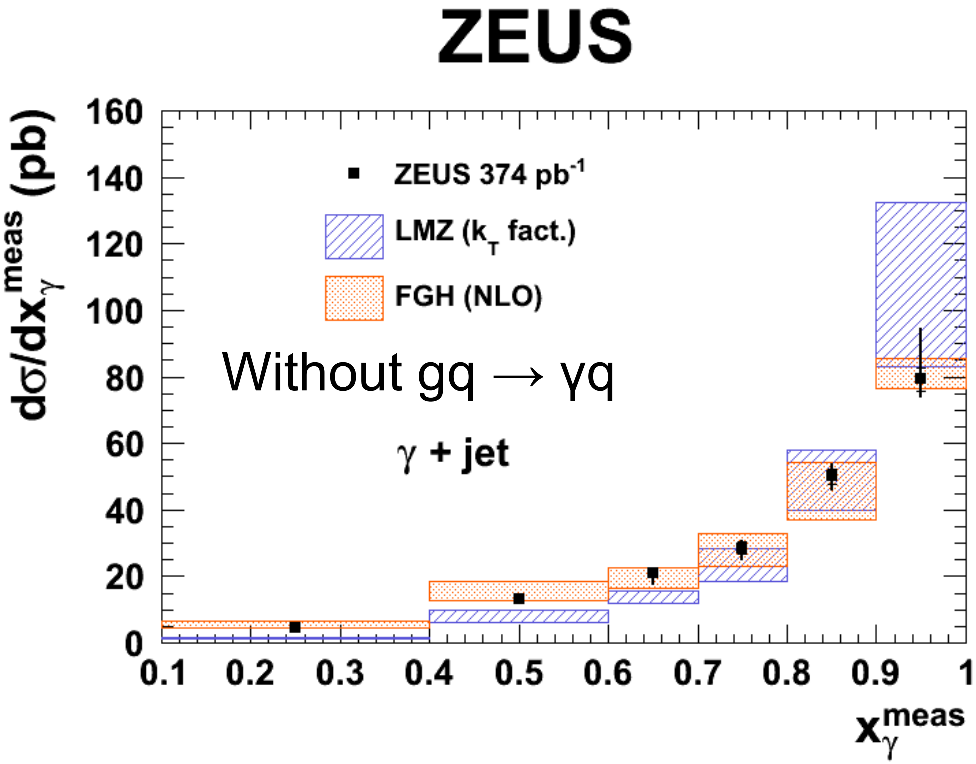
Plots to be made preliminary

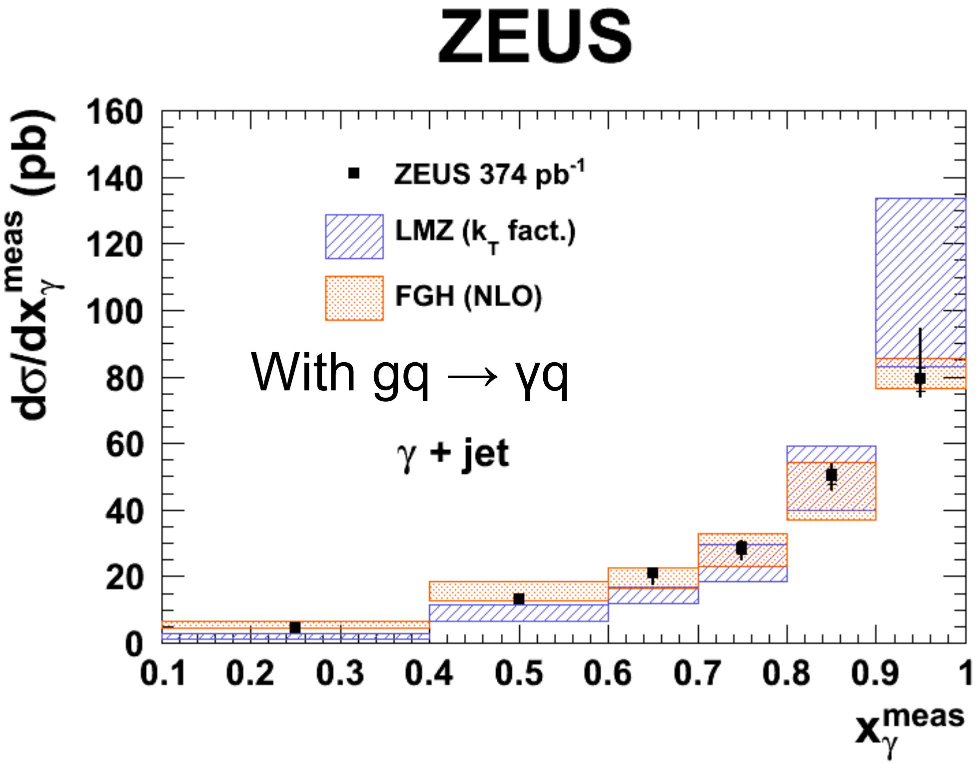


Backup slides

Update of LMZ theory
$\Delta\Phi$ study
Resolutions
Fits in bins
Acceptance, purity, efficiency
Systematics

Update of LMZ theory





Published paper arXiv:1312.1539 has LMZ predictions where box diagram is included together with 2 → 3 subprocesses:

$\gamma(k_1) + q(k_2) \rightarrow \gamma(p_1) + g(p_2) + q(p_3)$

$\gamma(k_1) + g^*(k_2) \rightarrow \gamma(p_1) + q(p_2) + \text{qbar}(p_3)$

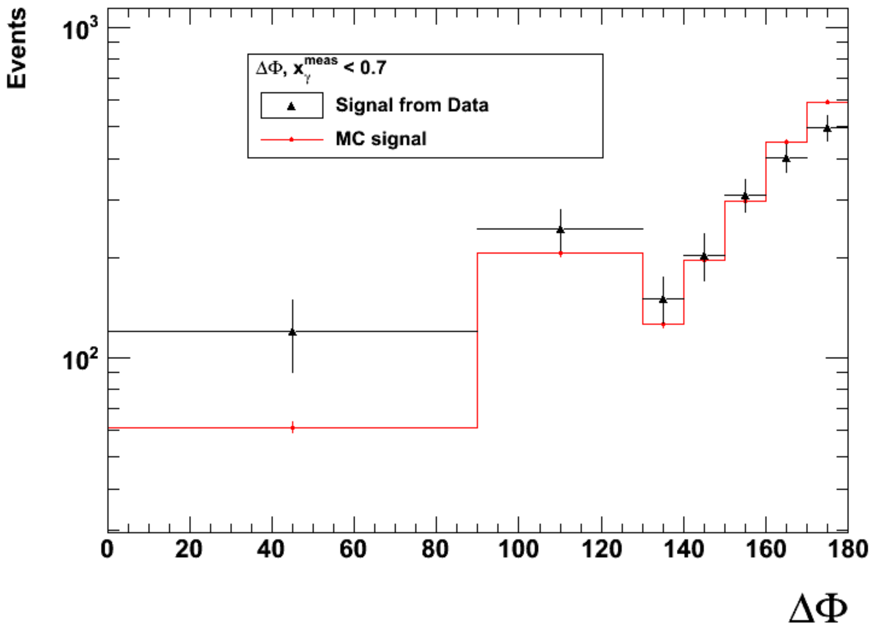
$\gamma(k_1) + g(k_2) \rightarrow \gamma(p_1) + g(p_2)$.

Now gq → γq process is also included.

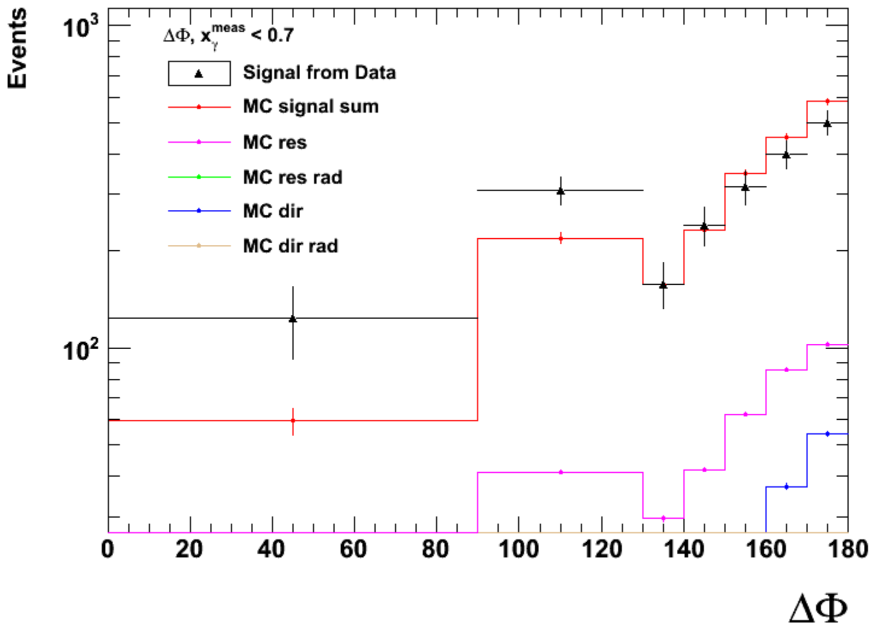
ΔΦ study

Comparison with HERWIG. No reweighting

PYTHIA



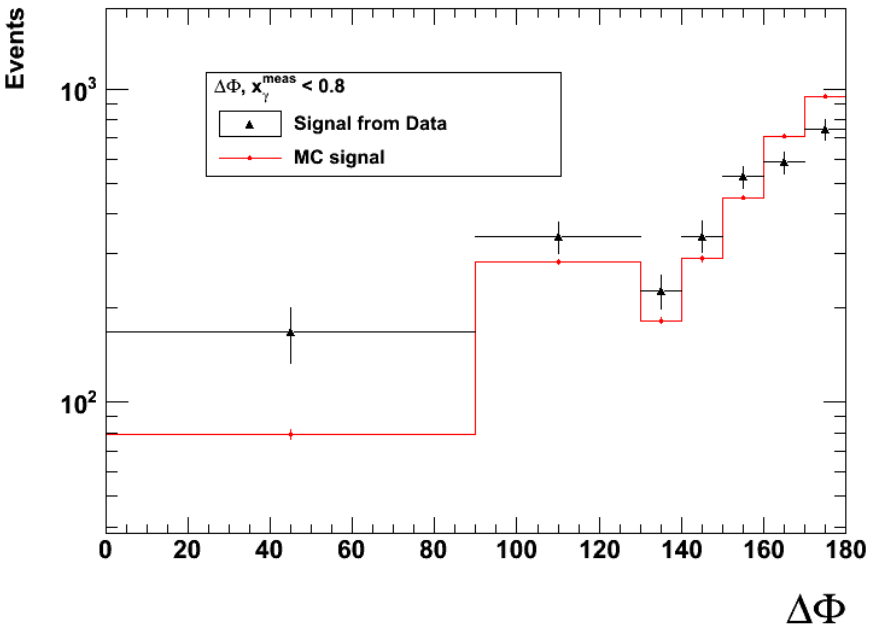
HERWIG



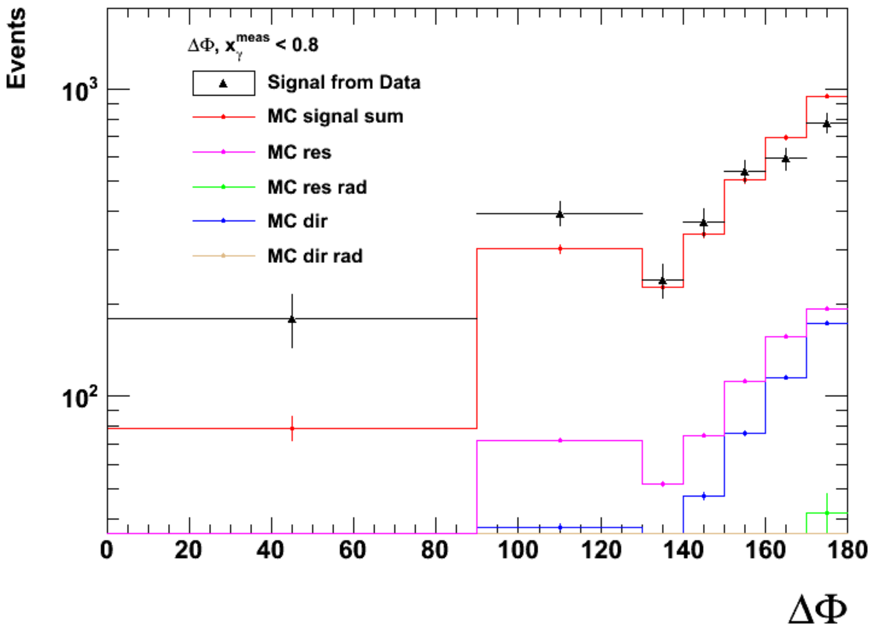
In some bins HERWIG fits better, in some worse. No significant improvement compared with when using PYTHIA.

Comparison with HERWIG. No reweighting

PYTHIA



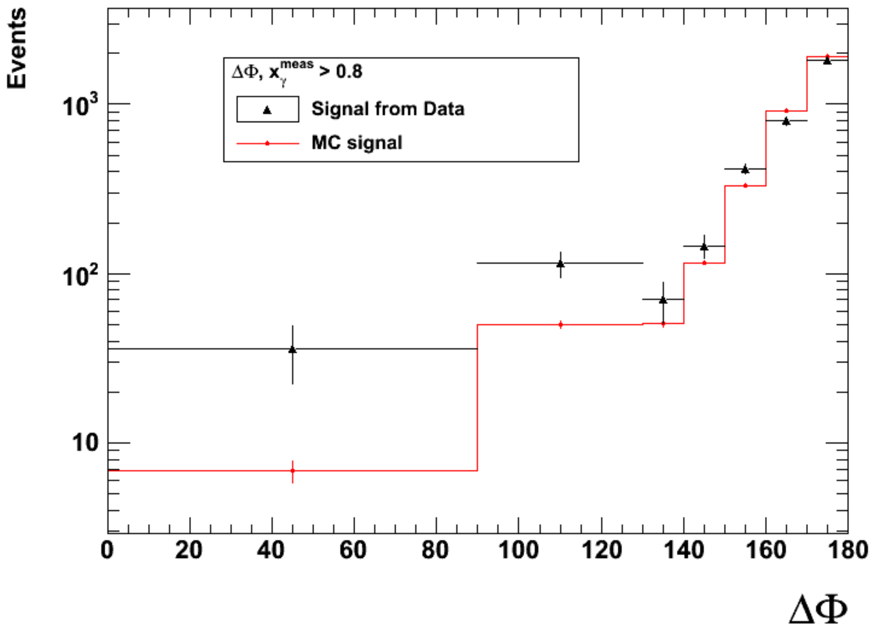
HERWIG



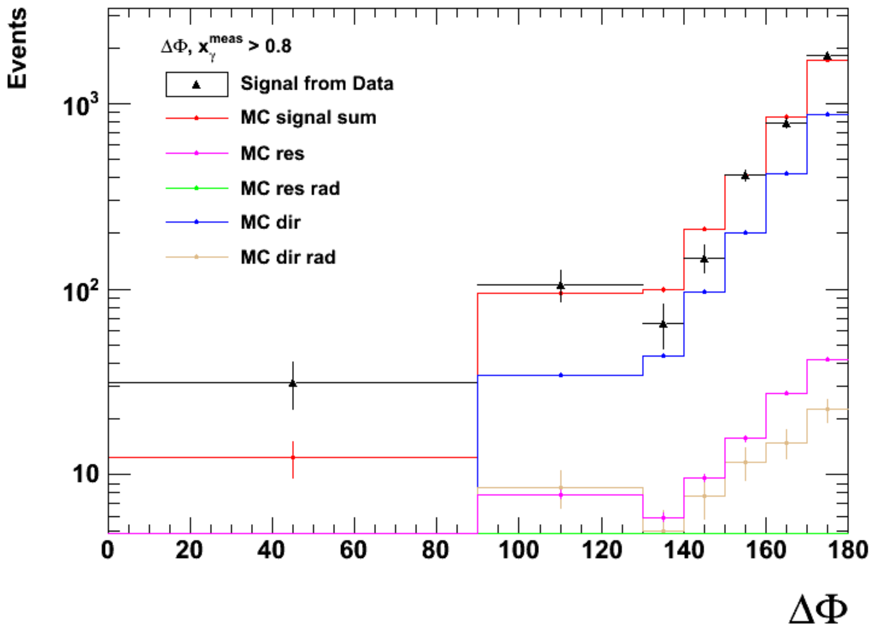
In some bins HERWIG fits better, in some worse. No significant improvement compared with when using PYTHIA.

Comparison with HERWIG. No reweighting

PYTHIA



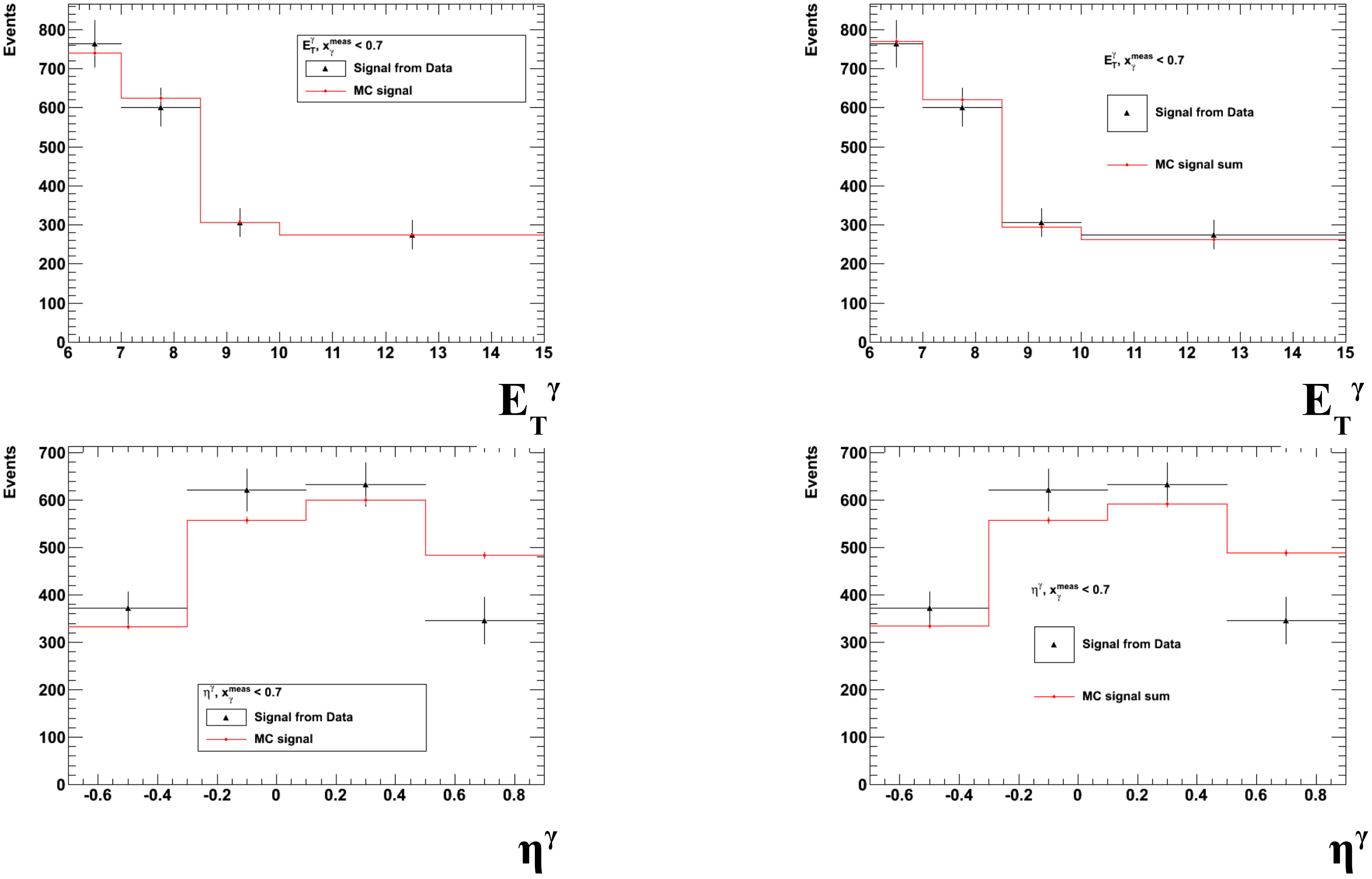
HERWIG



In some bins HERWIG fits better, in some worse. No significant improvement compared with when using PYTHIA.

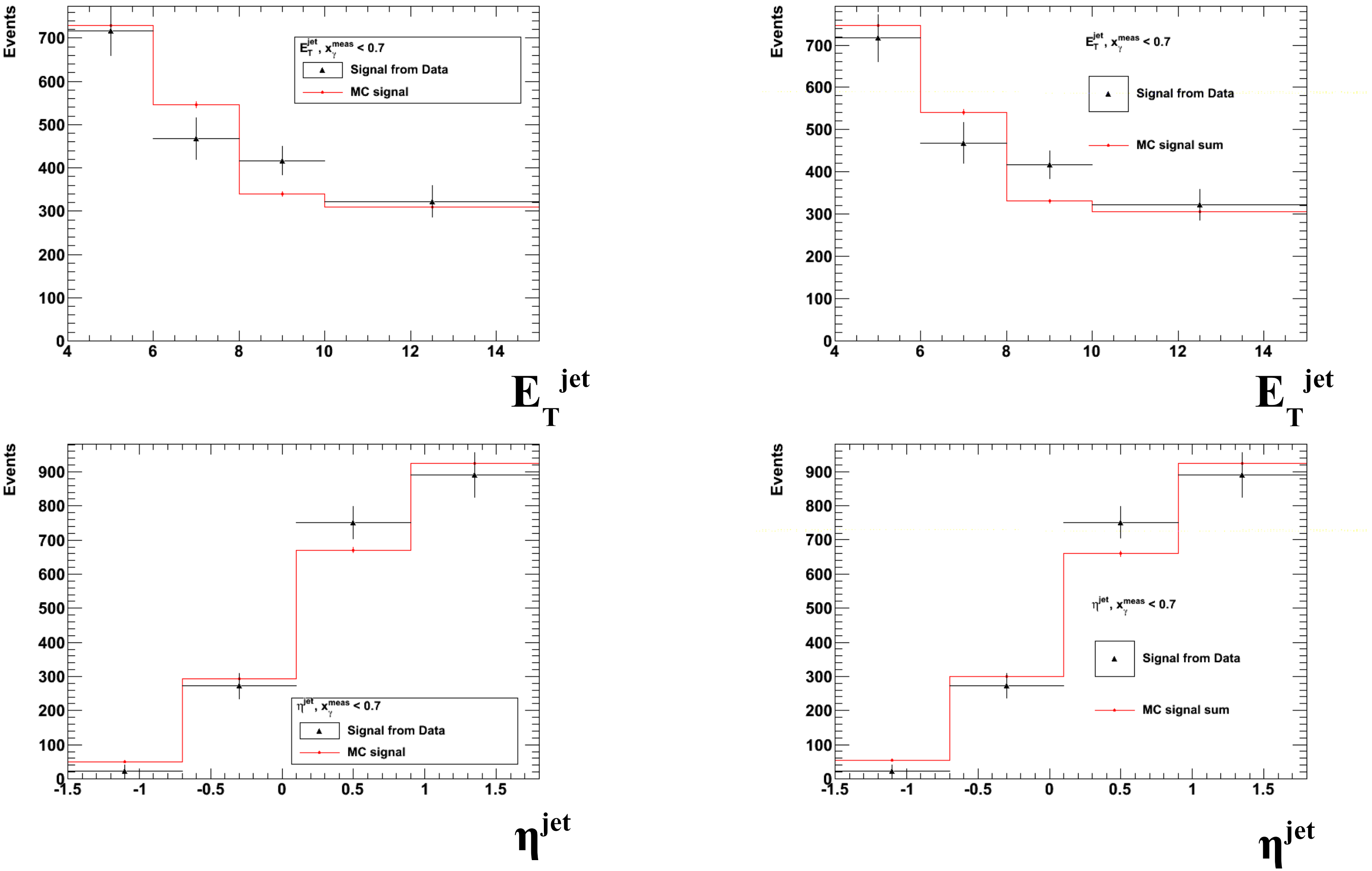
$\Delta\Phi$ reweighting. $x_\gamma < 0.7$

Before reweighting **After reweighting**



$\Delta\Phi$ reweighted using function determined from seven bins:
weight = $a*\Delta\Phi + b$
No significant changes in distributions.

$\Delta\Phi$ reweighting. $x_\gamma < 0.7$



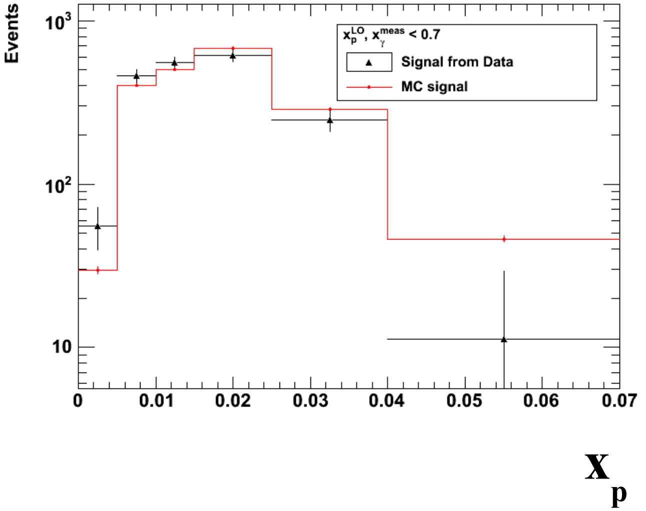
Before reweighting

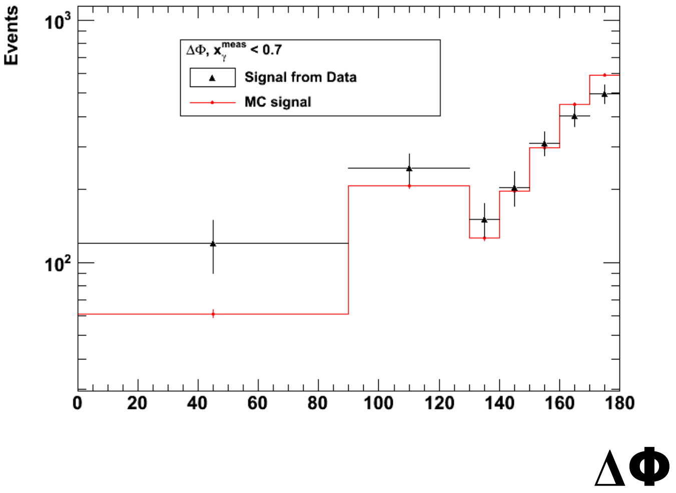
After reweighting

No significant changes in distributions.

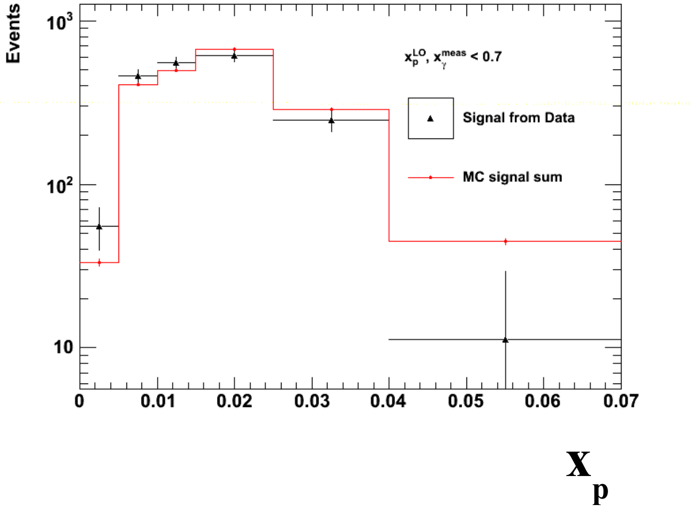
$\Delta\Phi$ reweighting. $x_\gamma < 0.7$

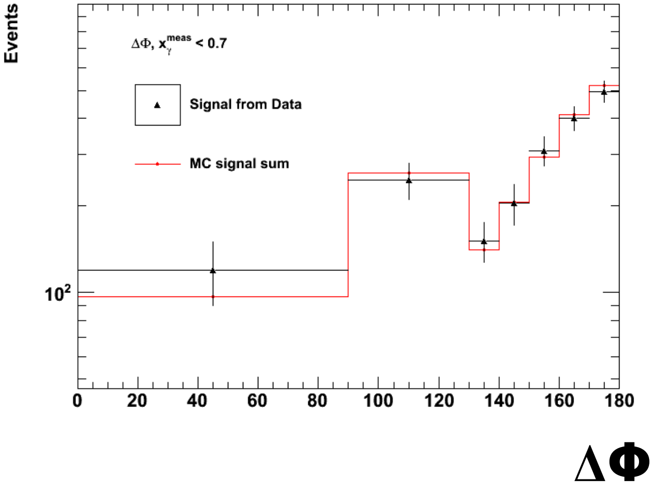
Before reweighting





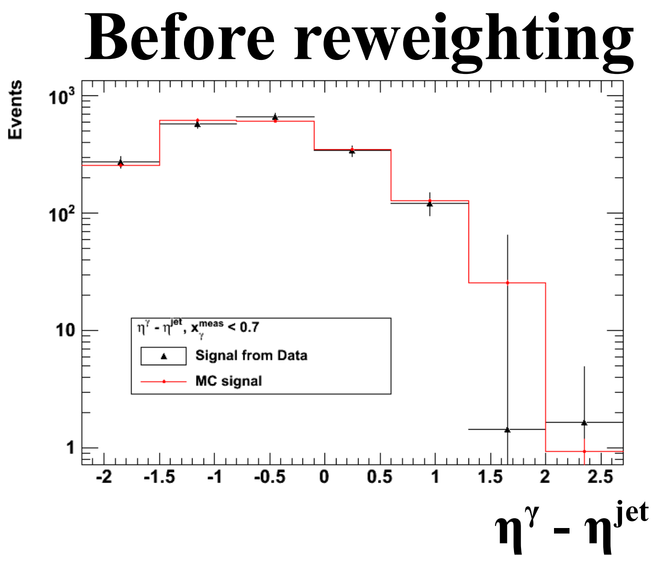
After reweighting

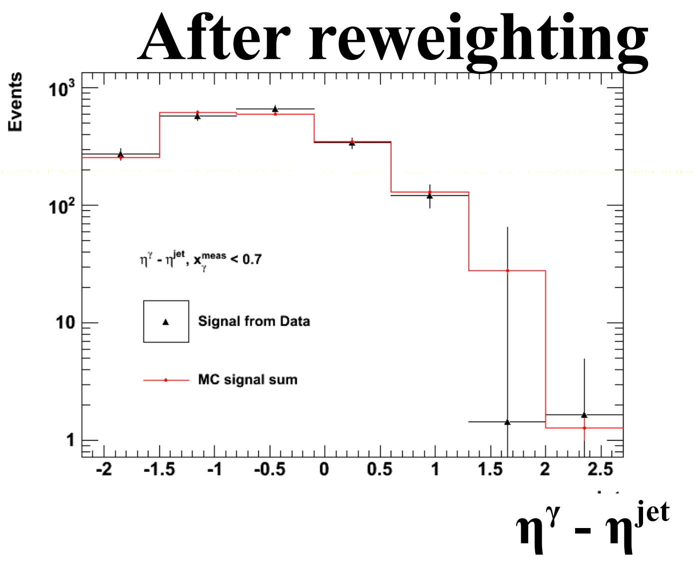




x_p does not show noticeable changes. $\Delta\Phi$ improves.

ΔΦ reweighting. $x_\gamma < 0.7$


Before reweighting


After reweighting

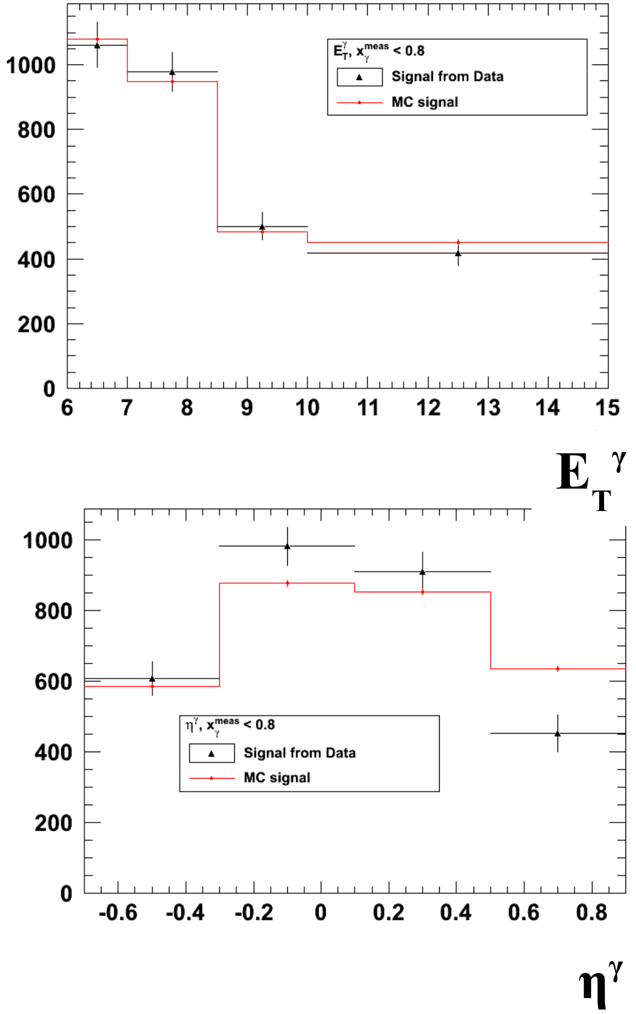
Typical change in numbers – E_T^γ

relative difference, Et-jet and eta-jet reweighted [%]	stat. error [%]	syst. error up [%]	syst. error down [%]
1.75495	8.88493	7.90227	19.87959
0.04484	9.43463	6.01201	21.46577
-0.89667	13.55742	9.99940	25.49549
-1.23823	15.57437	9.52430	27.96578

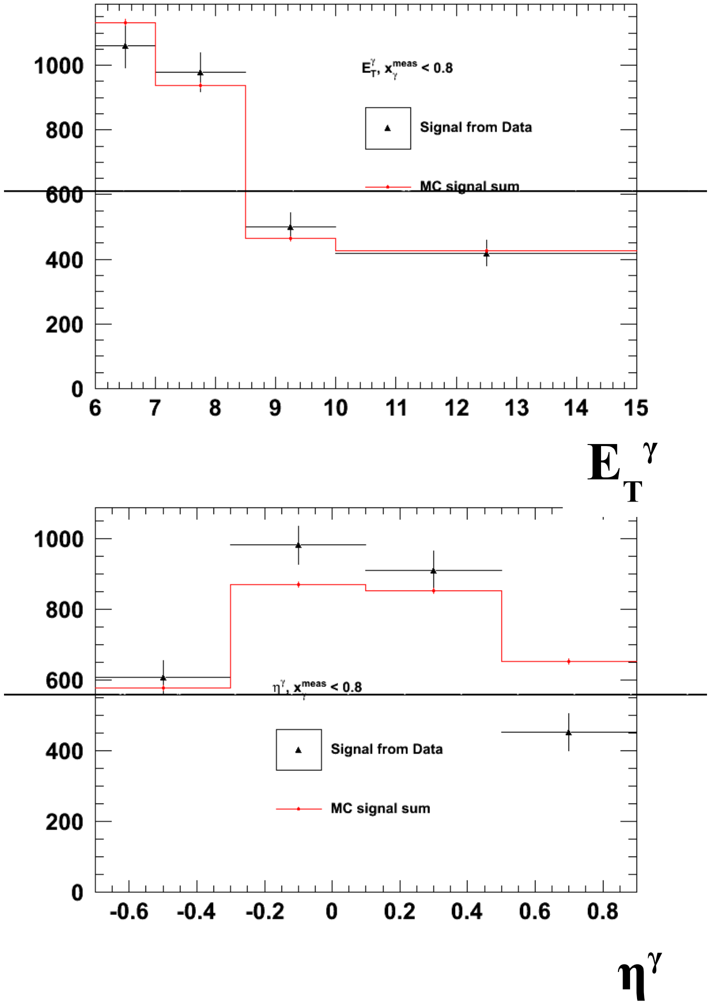
Reweighting ΔΦ gives small changes in control plots and cross-section numbers.

ΔΦ reweighting. $x_\gamma < 0.8$

Before reweighting

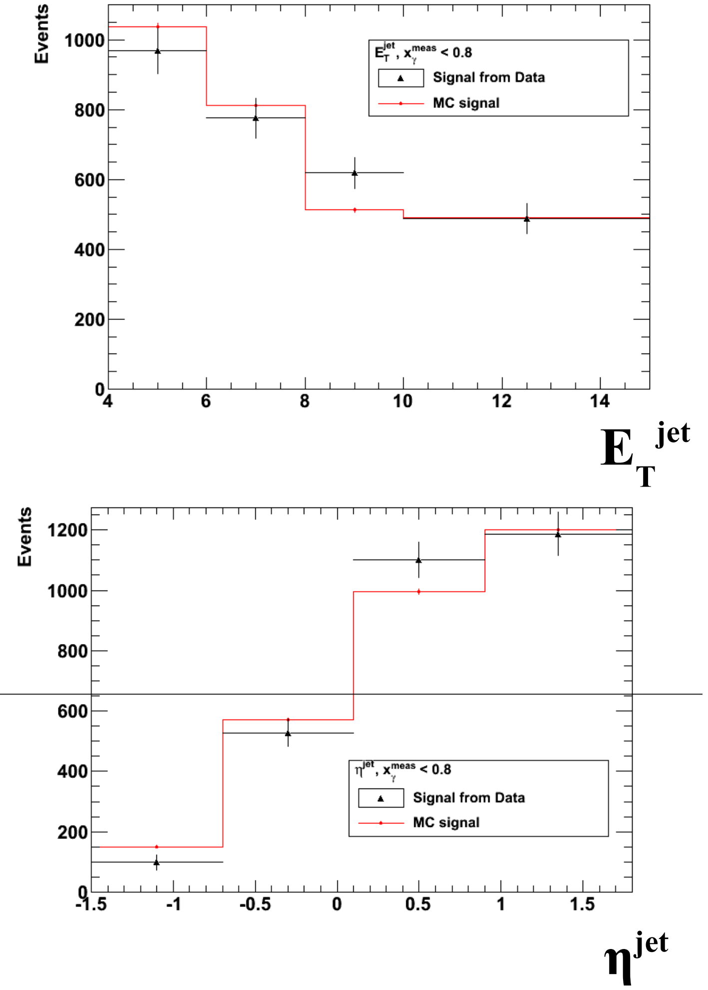


After reweighting

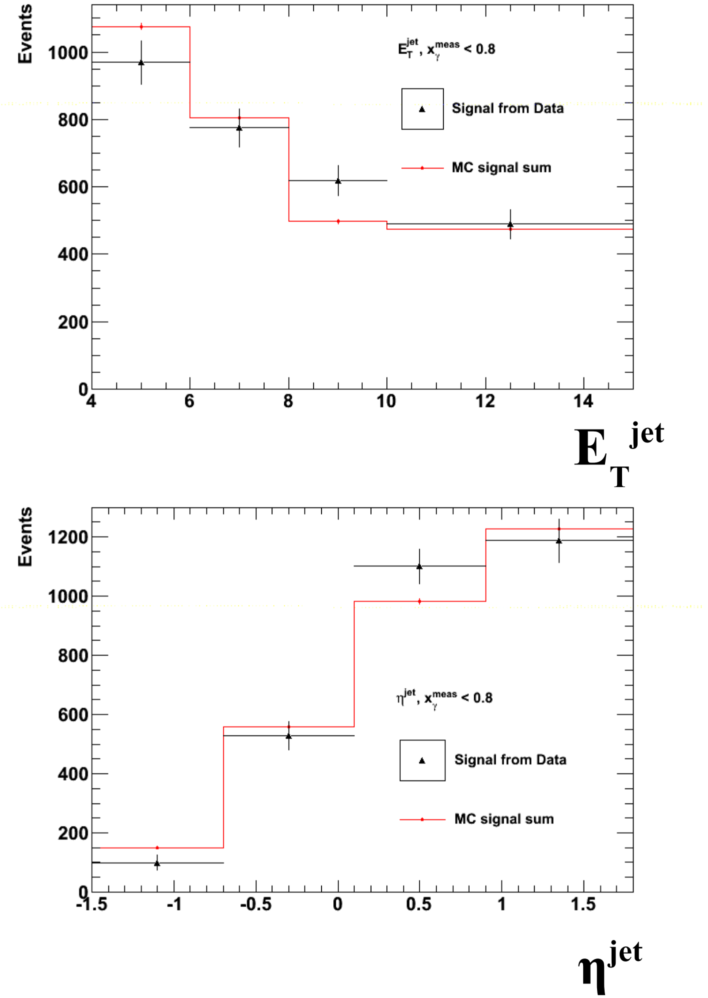


ΔΦ reweighting. $x_\gamma < 0.8$

Before reweighting

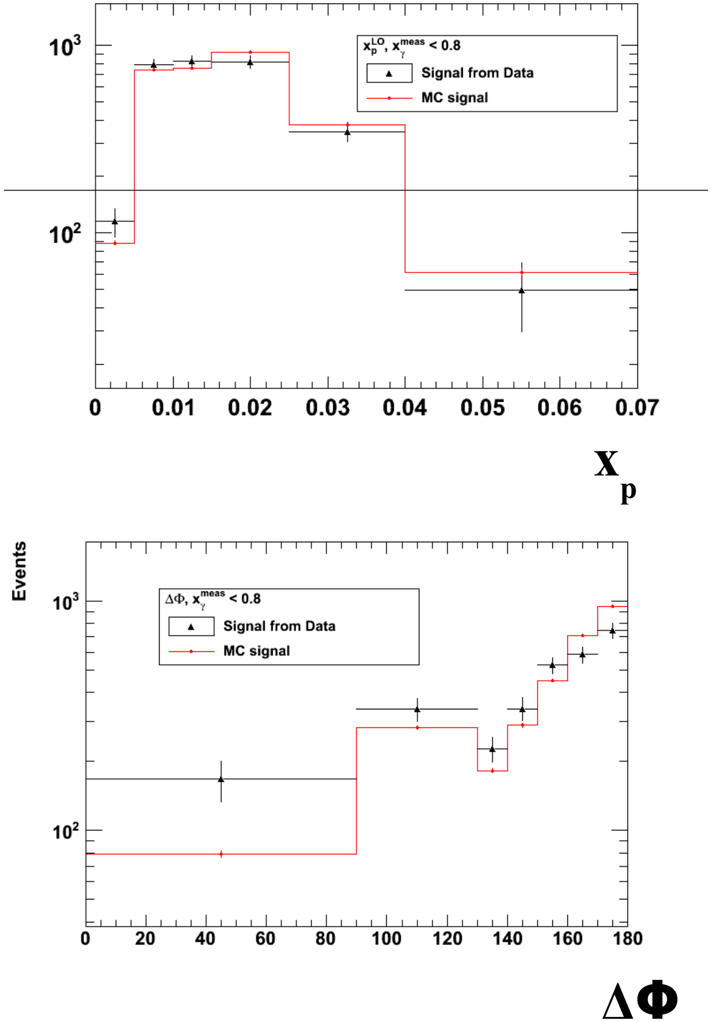


After reweighting

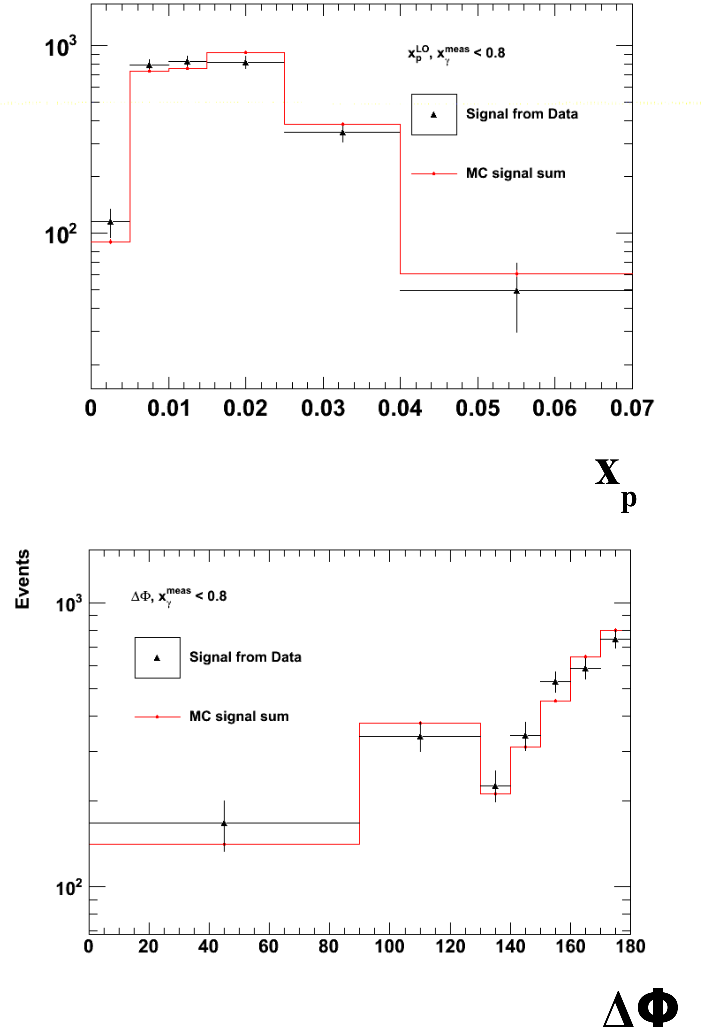


ΔΦ reweighting. $x_\gamma < 0.8$

Before reweighting

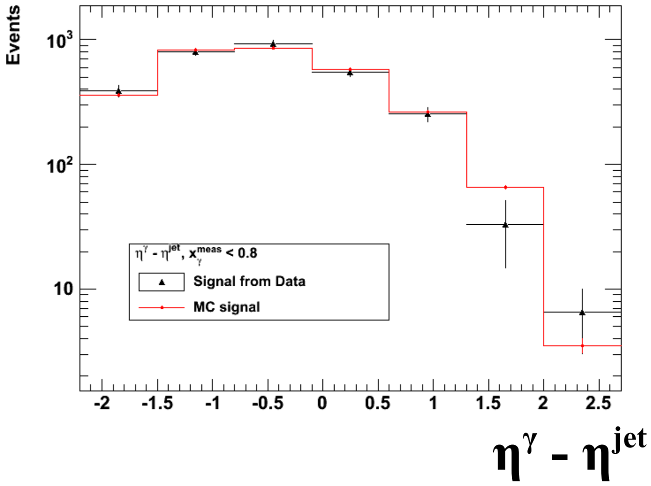


After reweighting

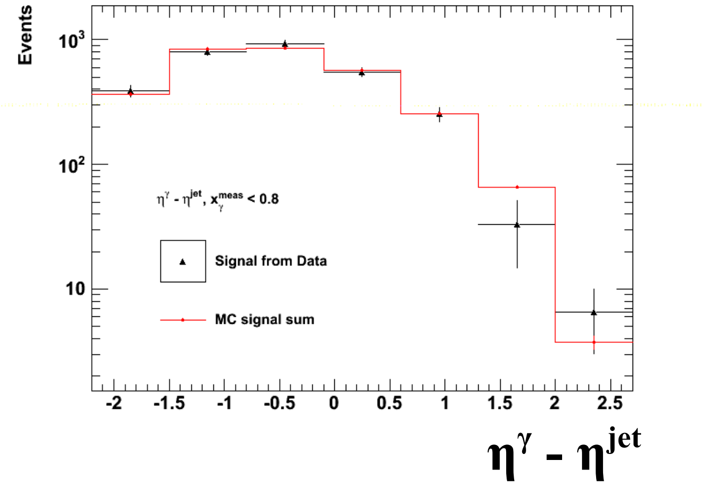


ΔΦ reweighting. $x_\gamma < 0.8$

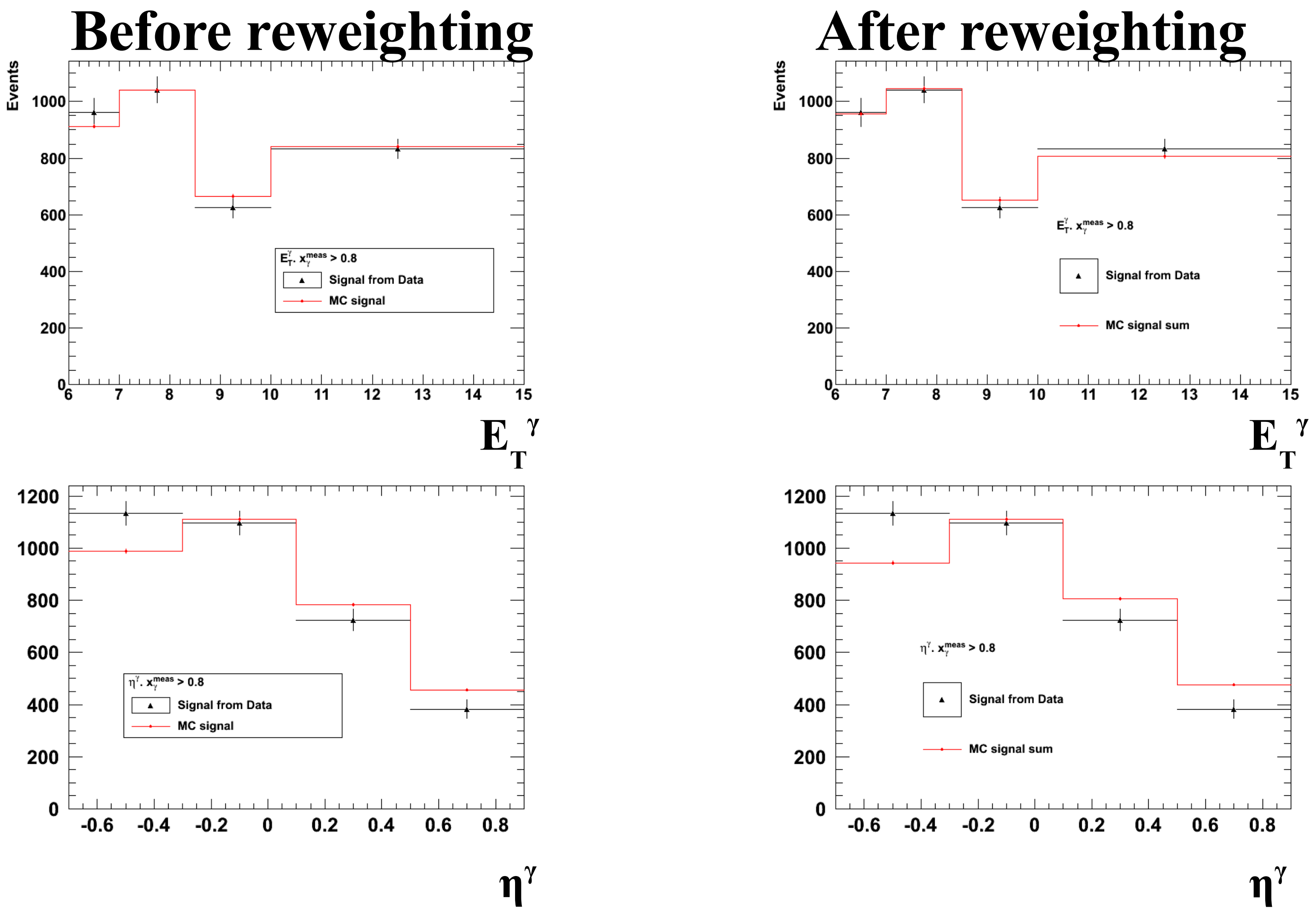
Before reweighting



After reweighting



ΔΦ reweighting. $x_\gamma > 0.8$

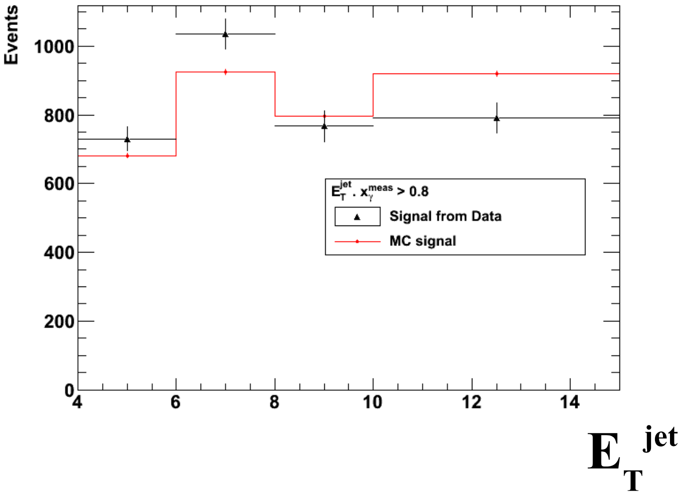


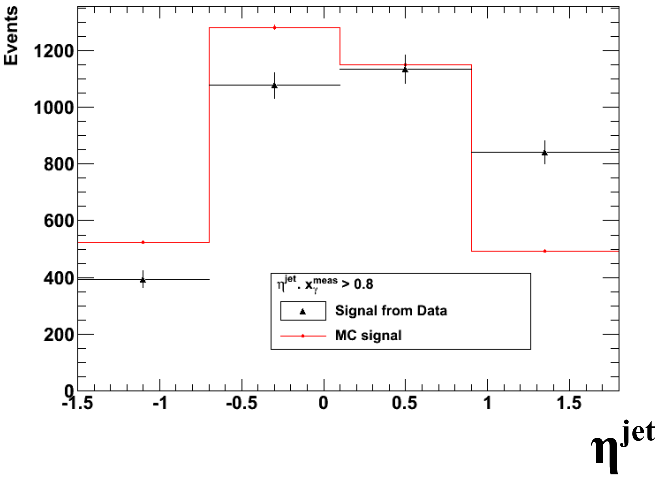
Before reweighting

After reweighting

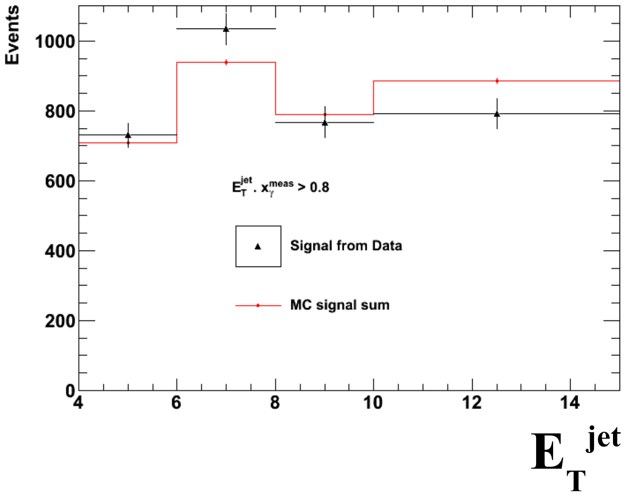
$\Delta\Phi$ reweighting. $x_\gamma > 0.8$

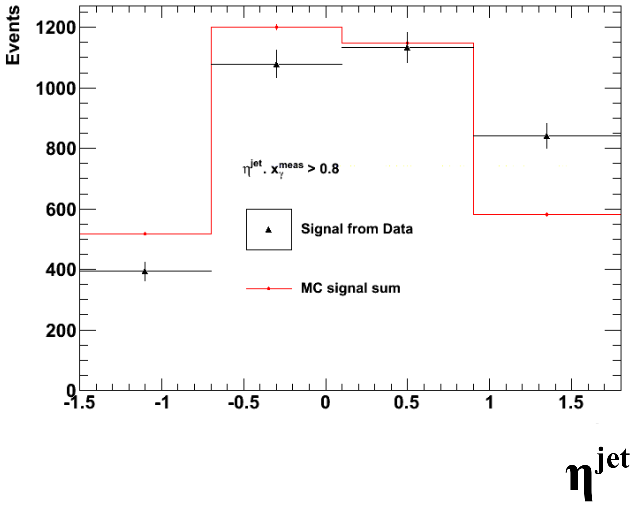
Before reweighting



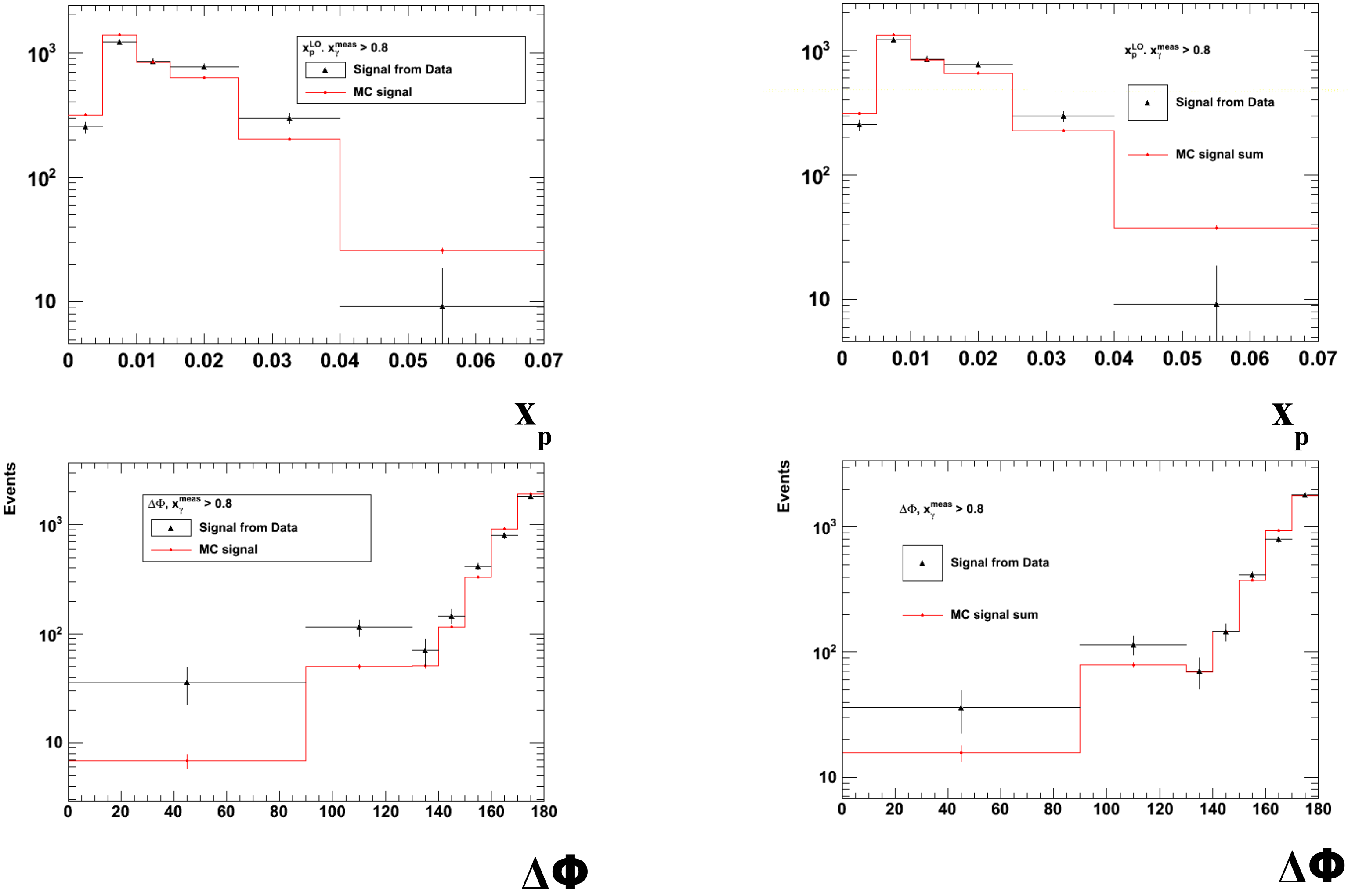


After reweighting





ΔΦ reweighting. $x_\gamma > 0.8$

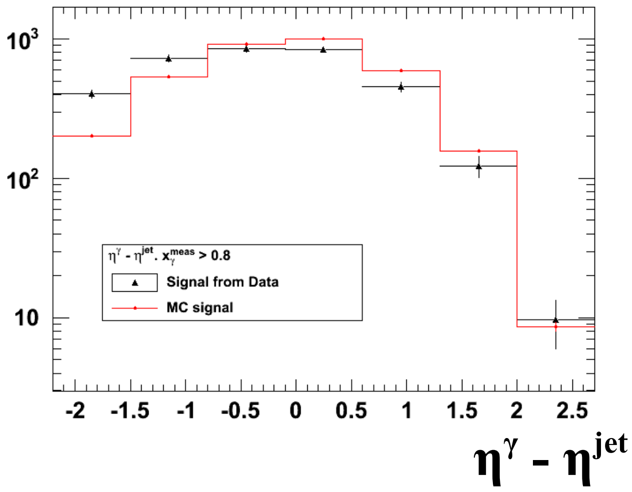


Before reweighting

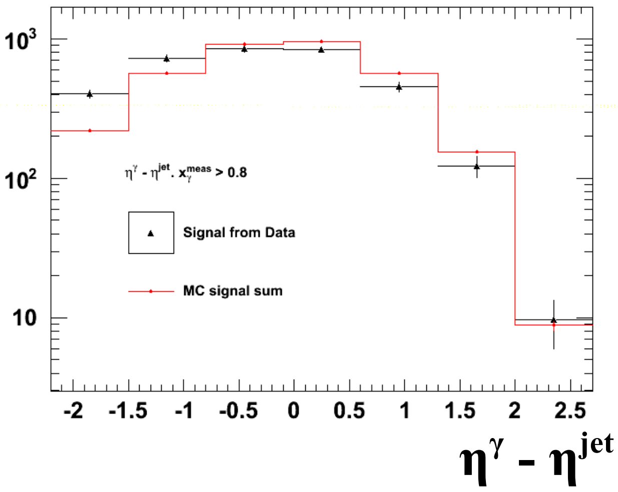
After reweighting

ΔΦ reweighting. $x_\gamma > 0.8$

Before reweighting

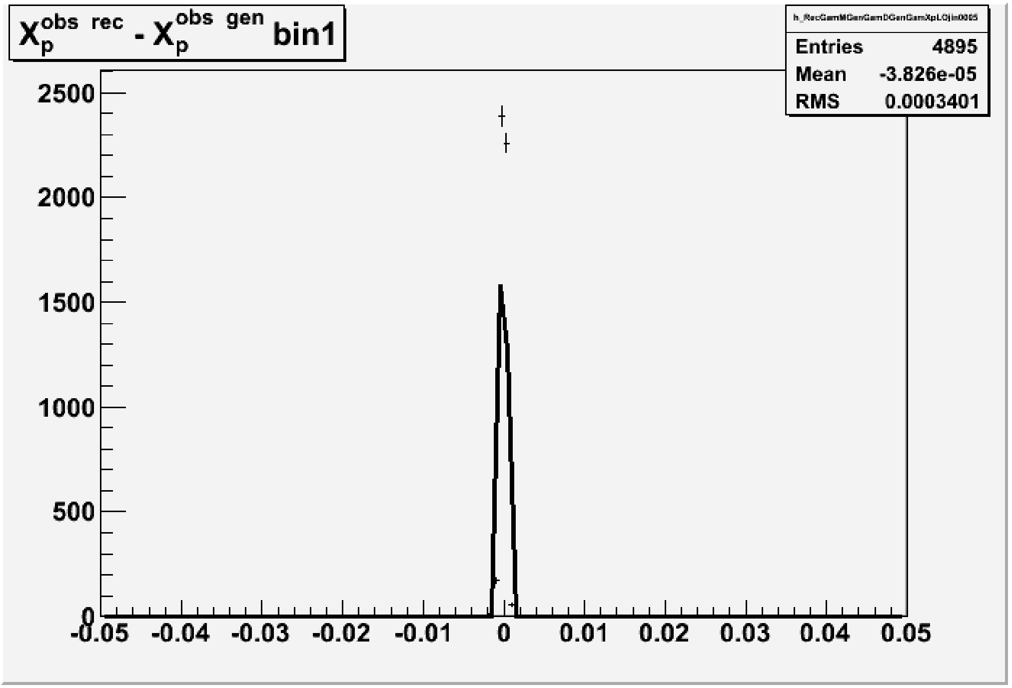


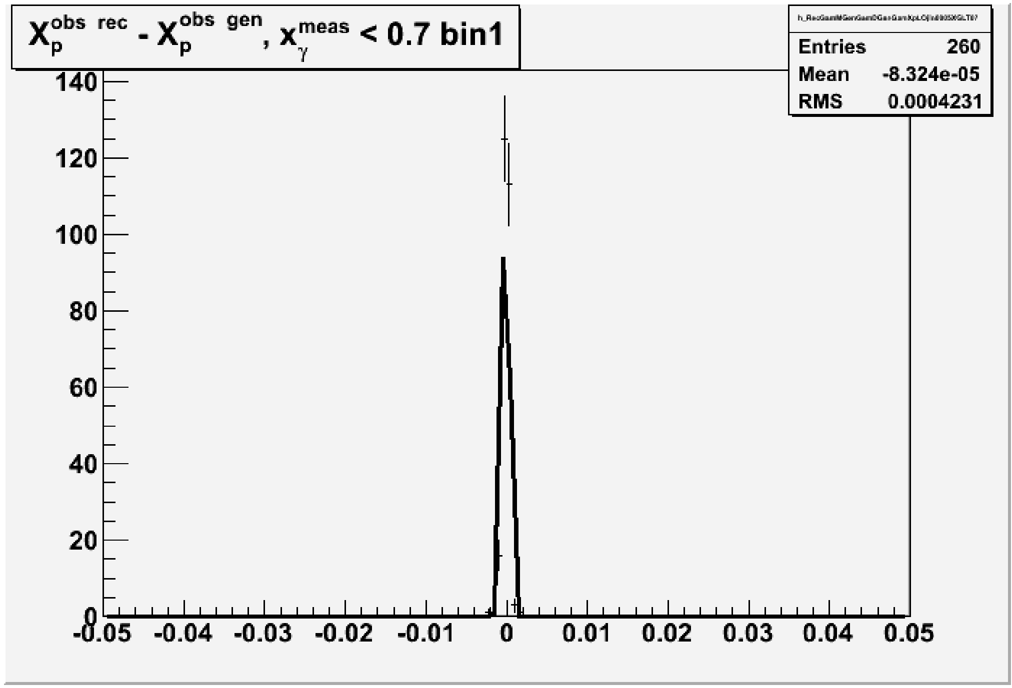
After reweighting



Resolutions

X_p^{obs} [0.000, 0.005]





Bin 1 all xgamma

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.42991e+03   6.48816e+01   1.66664e-01   8.66247e-07
  2  Mean        -3.05014e-05   5.72072e-06   1.79417e-08   5.30990e+00
  3  Sigma        3.77224e-04   4.44118e-06   9.29957e-06   7.23346e-03
```

Bin 1 xgamma<0.7

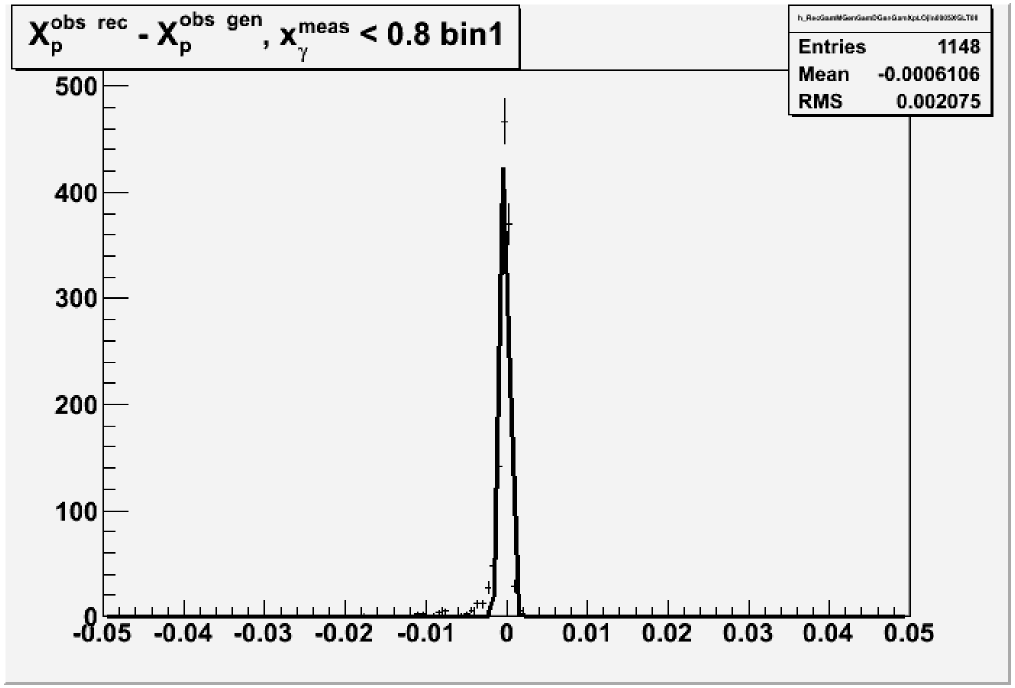
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.66720e+02   1.34388e+01   1.47131e-02   1.05662e-07
  2  Mean        -6.78001e-05   2.94067e-05   3.53288e-08   5.97504e-02
  3  Sigma        4.03659e-04   1.99591e-05   1.52039e-05   1.62969e-04
```

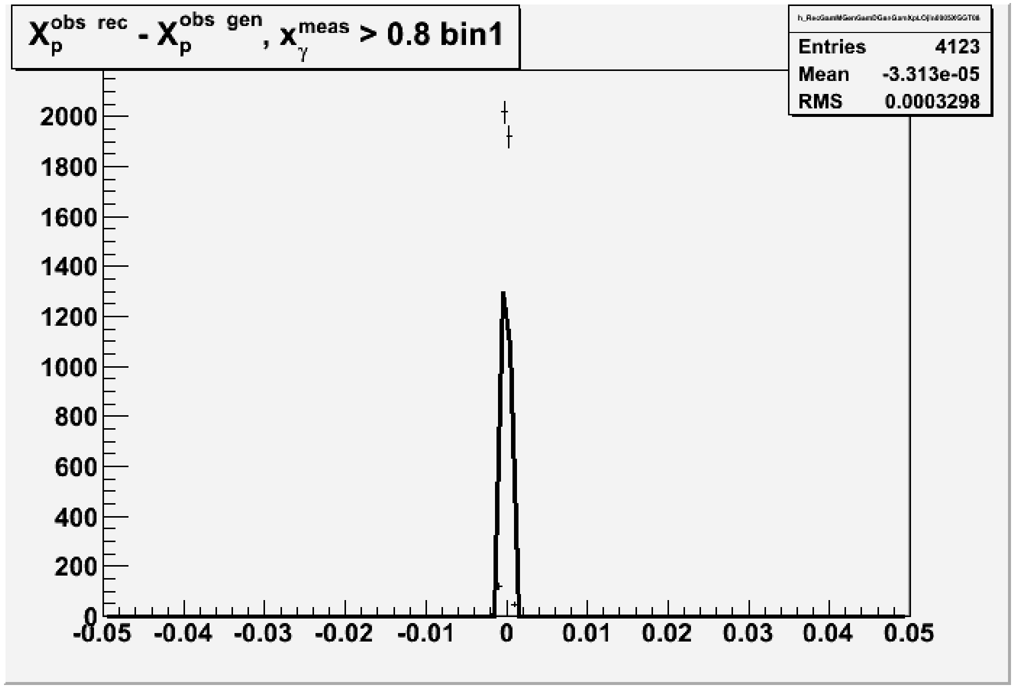
X_p resolution = $(X_p^{rec} - X_p^{gen})$

Using combined direct and resolved sample

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.000, 0.005]



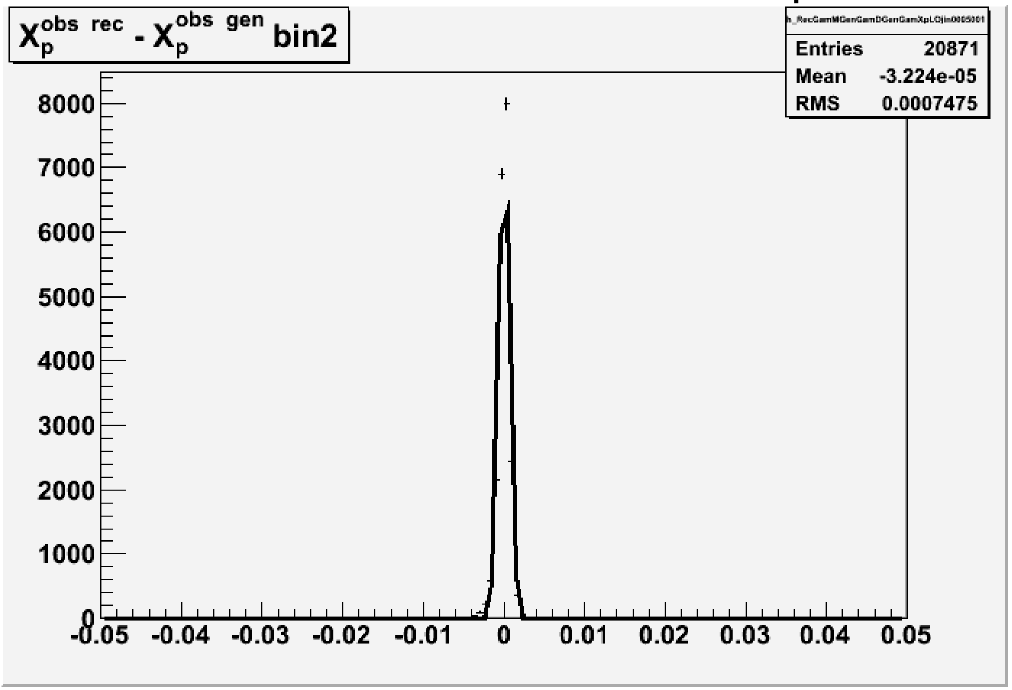


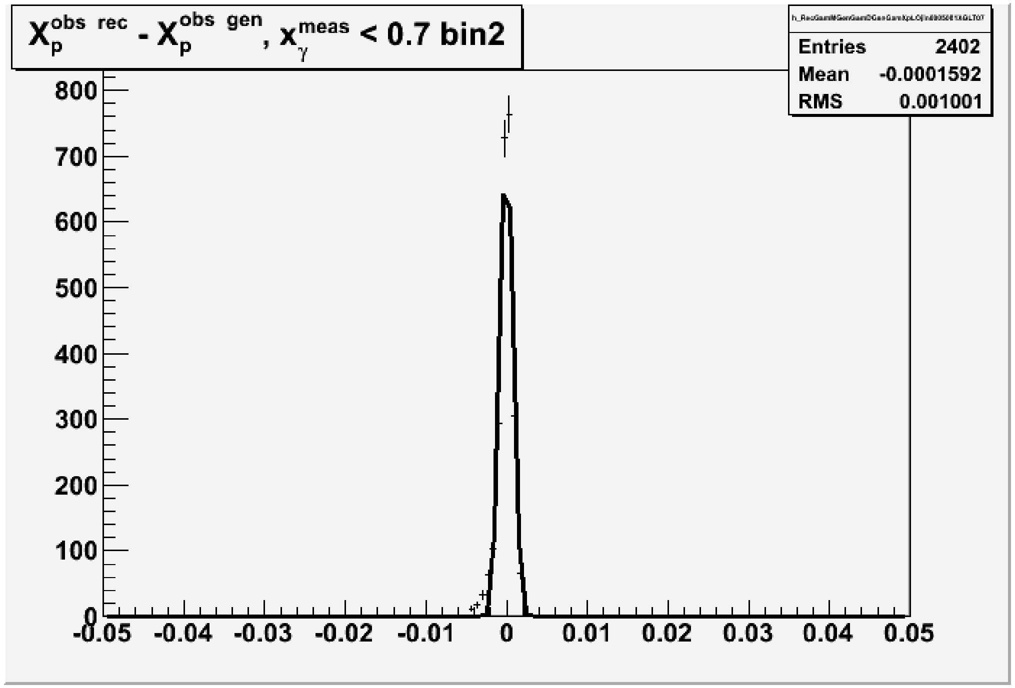
```
Bin 1 xgamma<0.8
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME        VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     4.98818e+02   2.28923e+01  -1.14771e-03  -4.17710e-07
  2  Mean        -6.42327e-05   1.70358e-05  -2.51085e-09   3.13151e-01
  3  Sigma        4.02464e-04   1.15926e-05   3.28309e-07  -4.38162e-04
```

```
Bin 1 xgamma>0.8
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME        VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     2.93951e+03   6.08236e+01   1.23885e-01   3.97480e-07
  2  Mean        -2.47133e-05   5.99279e-06   1.52900e-08  -1.20283e+01
  3  Sigma        3.71934e-04   4.79097e-06   8.19702e-06   7.18874e-03
```

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.005, 0.01]





Bin 2 all xgamma

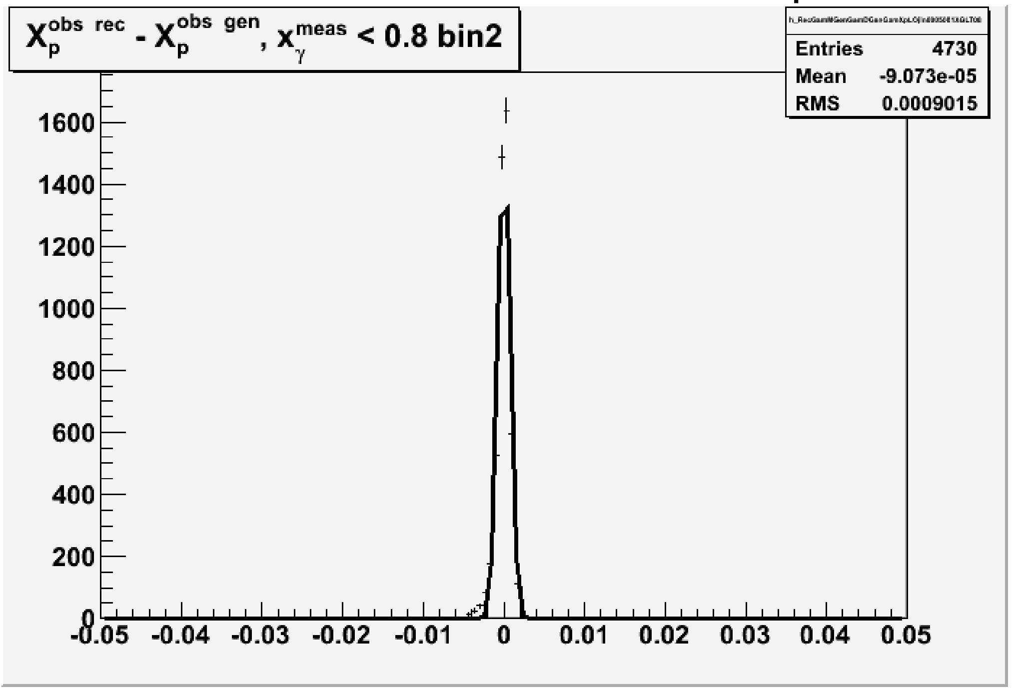
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     8.21382e+03   7.79816e+01   7.20418e-01   3.89603e-07
  2  Mean        2.61928e-05   4.70030e-06   5.74257e-08   1.11578e+00
  3  Sigma       6.54704e-04   4.17476e-06   1.77101e-05  -2.40027e-03
```

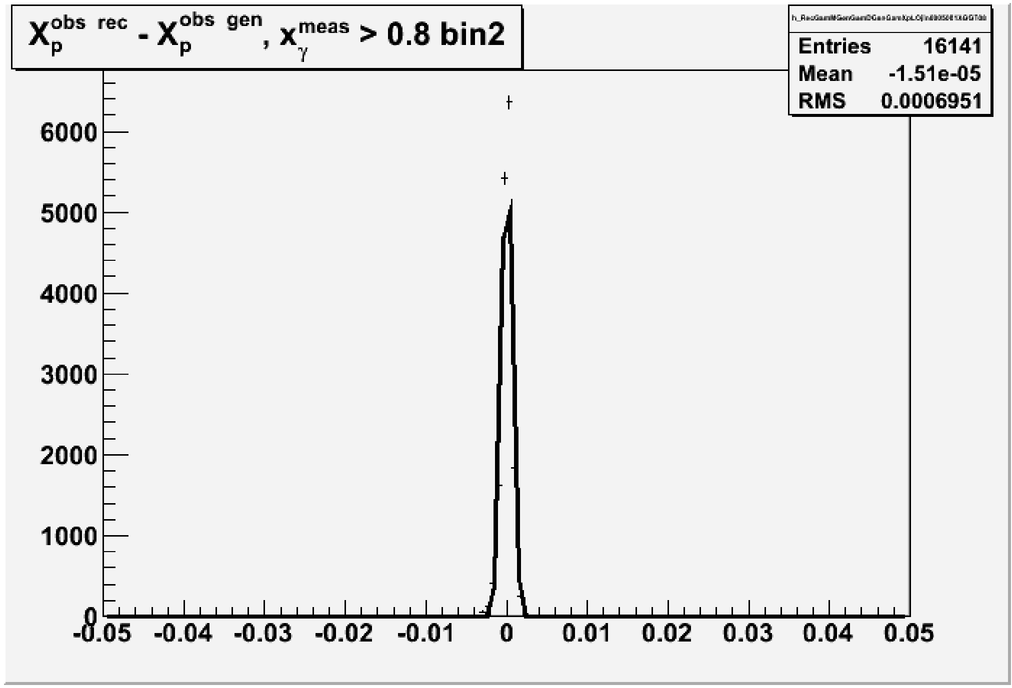
Bin 2 xgamma<0.7

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     7.76426e+02   2.22362e+01  -3.66209e-02   1.37097e-06
  2  Mean       -2.08548e-05   1.69466e-05   9.02917e-09   4.70596e-01
  3  Sigma        7.75178e-04   1.50999e-05   9.69806e-06   1.33518e-03
```

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.005, 0.01]





Bin 2 xgamma<0.8

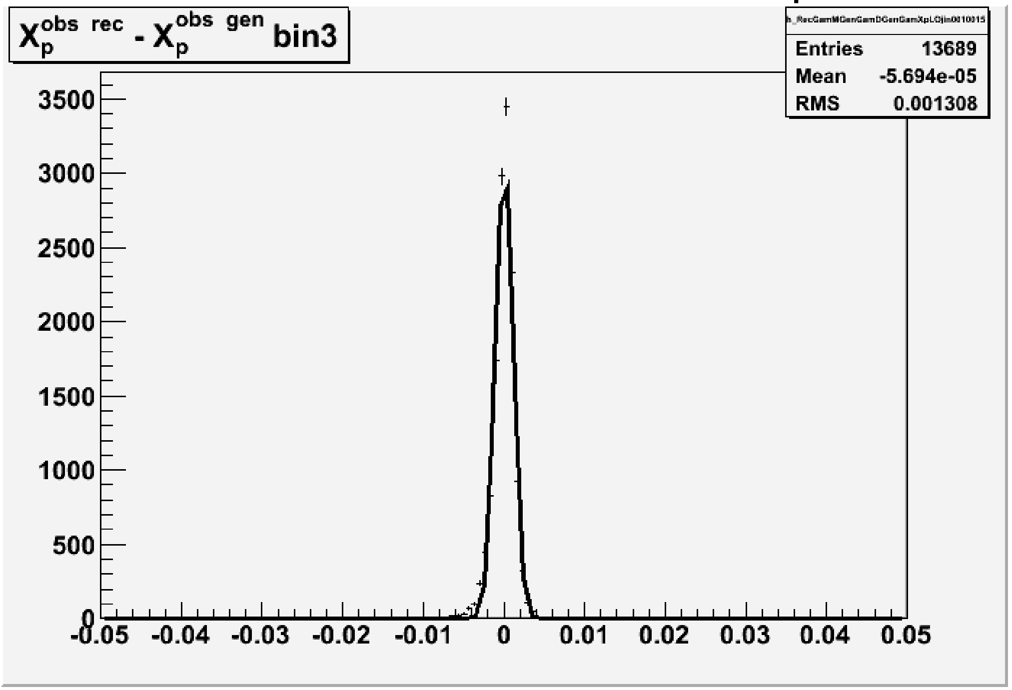
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.65954e+03   3.39637e+01  -7.25783e-03   1.23199e-07
  2  Mean         1.10100e-05   1.10724e-05  -1.84226e-09   1.82110e-01
  3  Sigma        7.22179e-04   1.01482e-05   3.84360e-07  -1.25495e-04
```

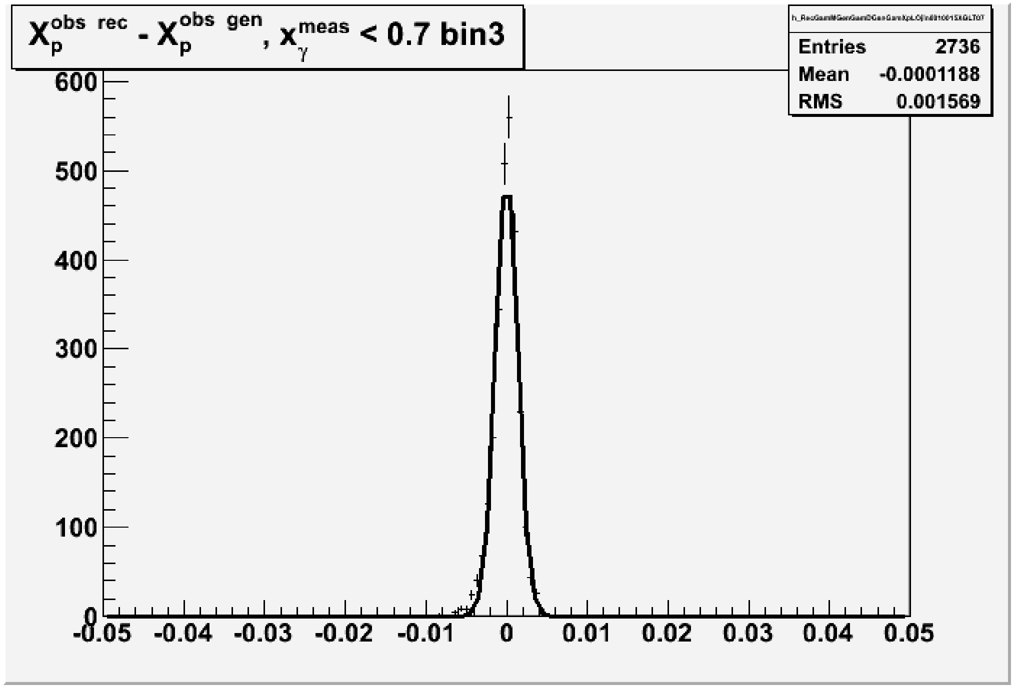
Bin 2 xgamma>0.8

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     6.56554e+03   7.01798e+01   5.20356e-01   7.47578e-08
  2  Mean         2.94890e-05   5.18129e-06   5.04961e-08  -1.30750e-01
  3  Sigma        6.37105e-04   4.53443e-06   1.62198e-05  -4.12401e-04
```

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.01, 0.015]





Bin 3 all xgamma

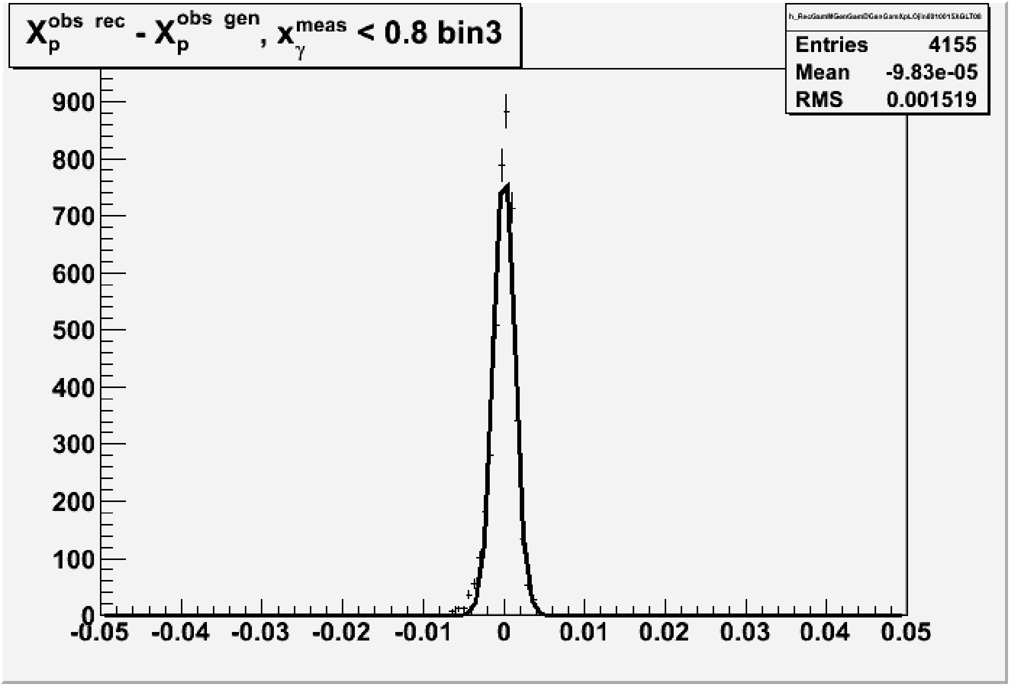
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.14655e+03   3.84545e+01   3.25043e-01   2.21949e-06
  2  Mean         4.93773e-05   1.01186e-05   1.14412e-07   1.09395e+00
  3  Sigma        1.10758e-03   9.46374e-06   2.13245e-05   1.84520e-02
```

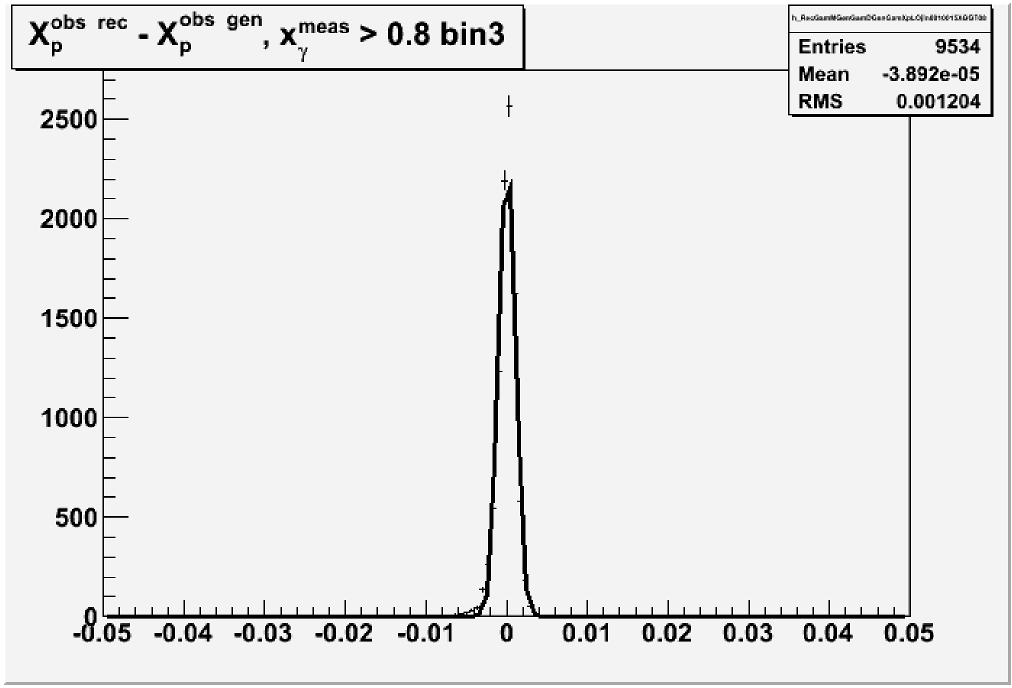
Bin 3 xgamma<0.7

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     5.01690e+02   1.33971e+01   4.94146e-02  -1.18459e-06
  2  Mean        -3.22348e-06   2.87615e-05   1.37392e-07  -1.78176e+00
  3  Sigma        1.39432e-03   2.54537e-05   2.02975e-05  -2.34797e-03
```

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.01, 0.015]





Bin 3 xgamma<0.8

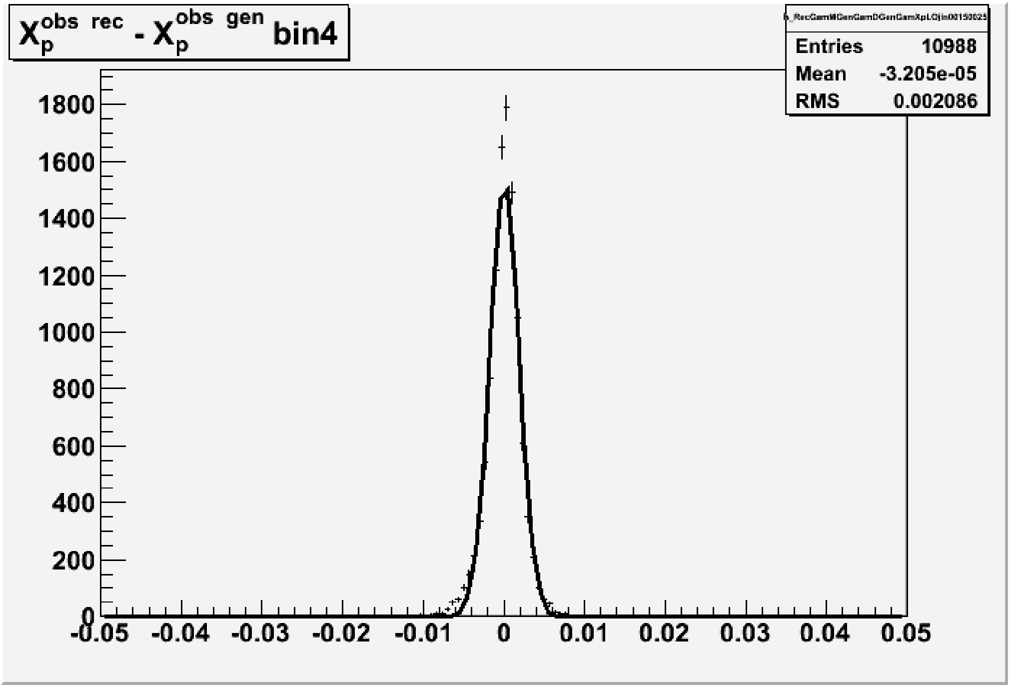
```
 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     8.00274e+02   1.79648e+01   8.73962e-02   2.85000e-06
  2  Mean        3.05518e-05   2.25305e-05   1.43684e-07  -2.11744e+00
  3  Sigma       1.31543e-03   2.08543e-05   2.27425e-05  -1.76297e-02
```

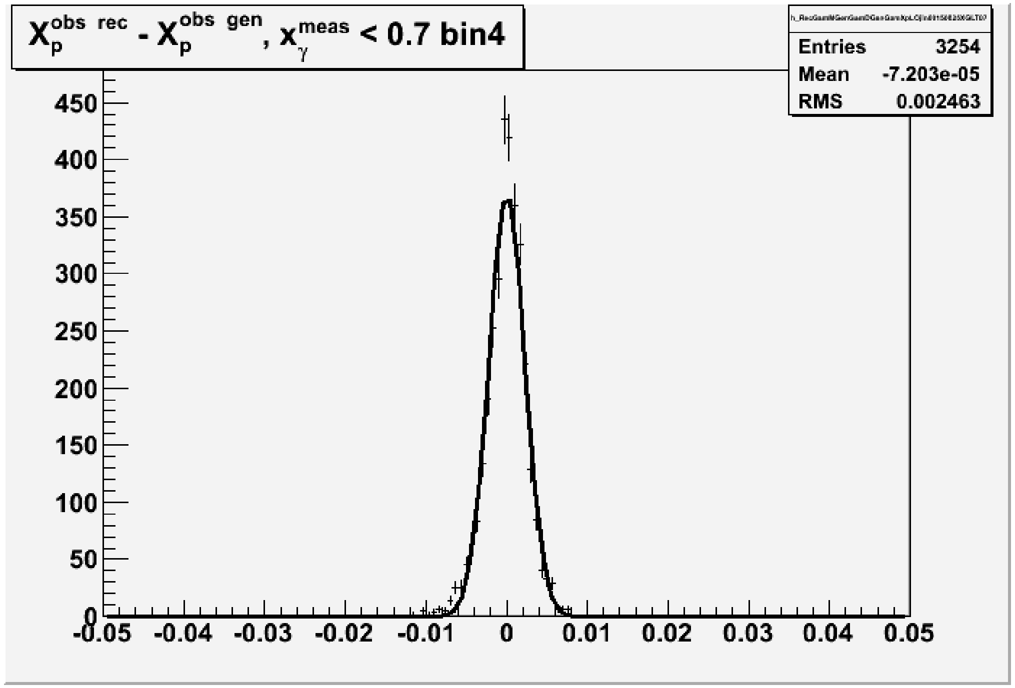
Bin 3 xgamma>0.8

```
 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE       DERIVATIVE
  1  Constant     2.36953e+03   3.39942e+01   2.26760e-01   4.94535e-07
  2  Mean        4.89237e-05   1.11709e-05   9.86326e-08   1.19110e-01
  3  Sigma       1.03064e-03   1.01439e-05   1.95317e-05  -2.68604e-03
```

Sigma is smaller than half of the bin width 2.5e-3

X_p^{obs} [0.015, 0.025]





Bin 4 all xgamma

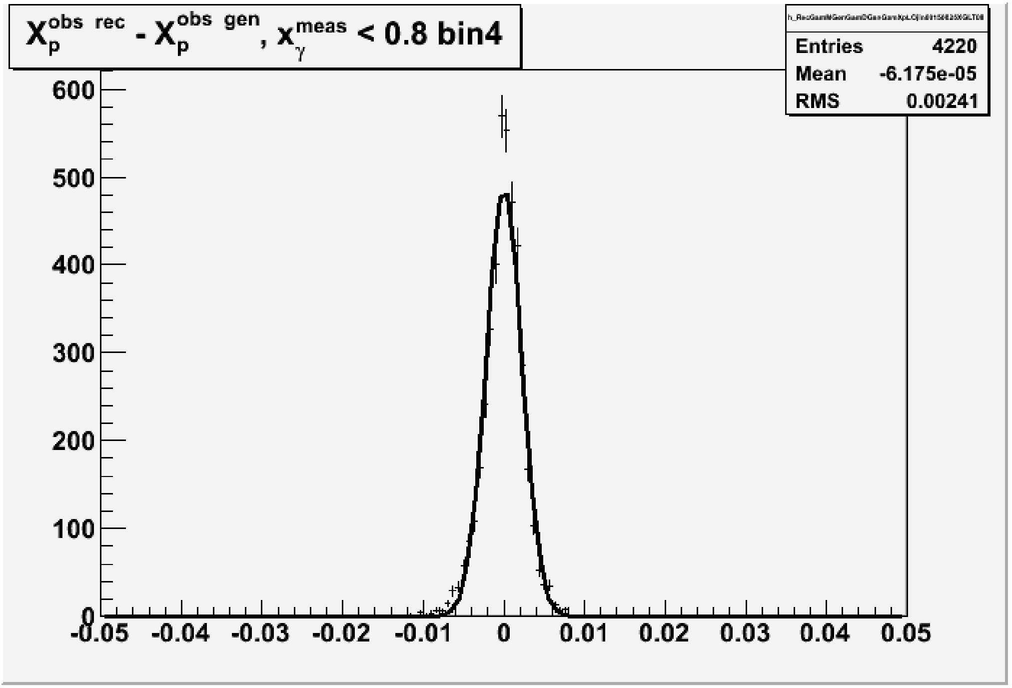
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant    1.54098e+03   2.13405e+01   1.55571e-01   3.64472e-09
  2  Mean        7.50015e-05   1.80382e-05   1.83637e-07   1.02389e-01
  3  Sigma       1.81887e-03   1.79015e-05   2.19374e-05   1.49996e-04
```

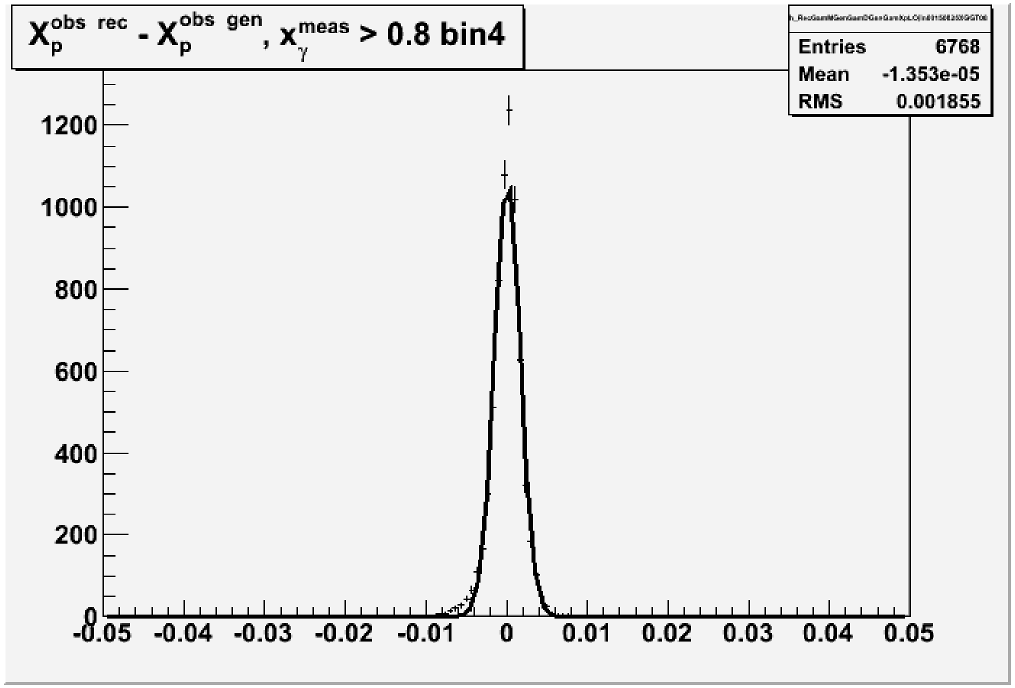
Bin 4 xgamma<0.7

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant    3.72557e+02   9.23611e+00   3.58017e-02  -1.20559e-07
  2  Mean        1.92889e-05   4.11250e-05   2.15192e-07  -1.76778e+00
  3  Sigma       2.23736e-03   3.85156e-05   2.07718e-05  -1.62965e-02
```

Sigma is smaller than half of the bin width 5e-3

X_p^{obs} [0.015, 0.025]





Bin 4 xgamma<0.8

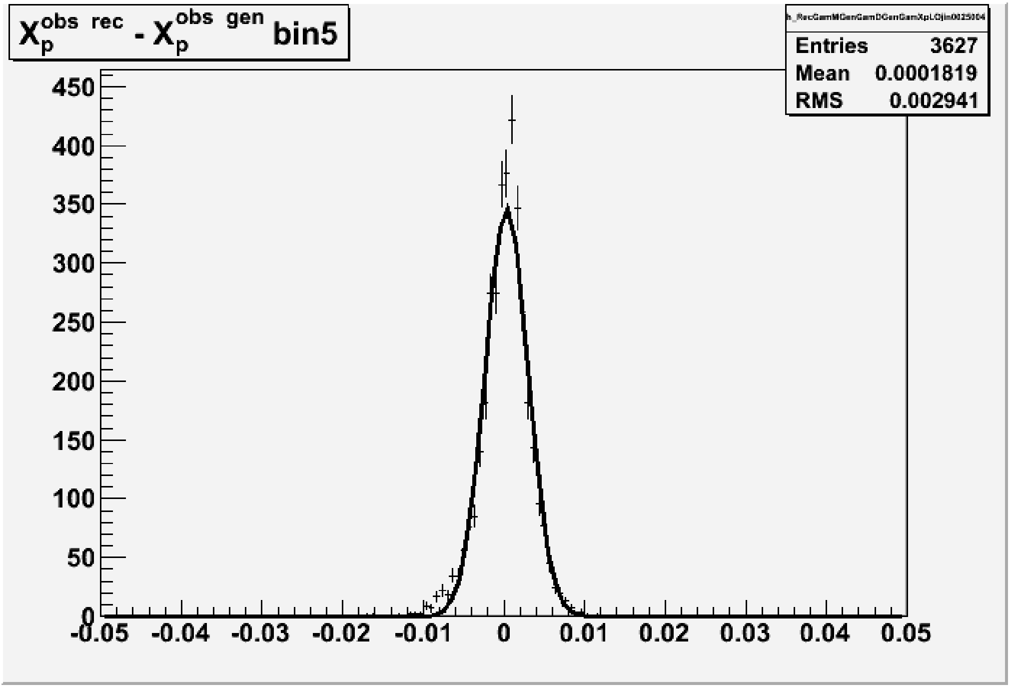
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME        VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     4.91593e+02   1.07522e+01   4.59186e-02   2.17360e-07
  2  Mean         1.68938e-05   3.55693e-05   2.05952e-07  -1.47014e+00
  3  Sigma        2.20328e-03   3.36577e-05   2.03739e-05  -1.44726e-02
```

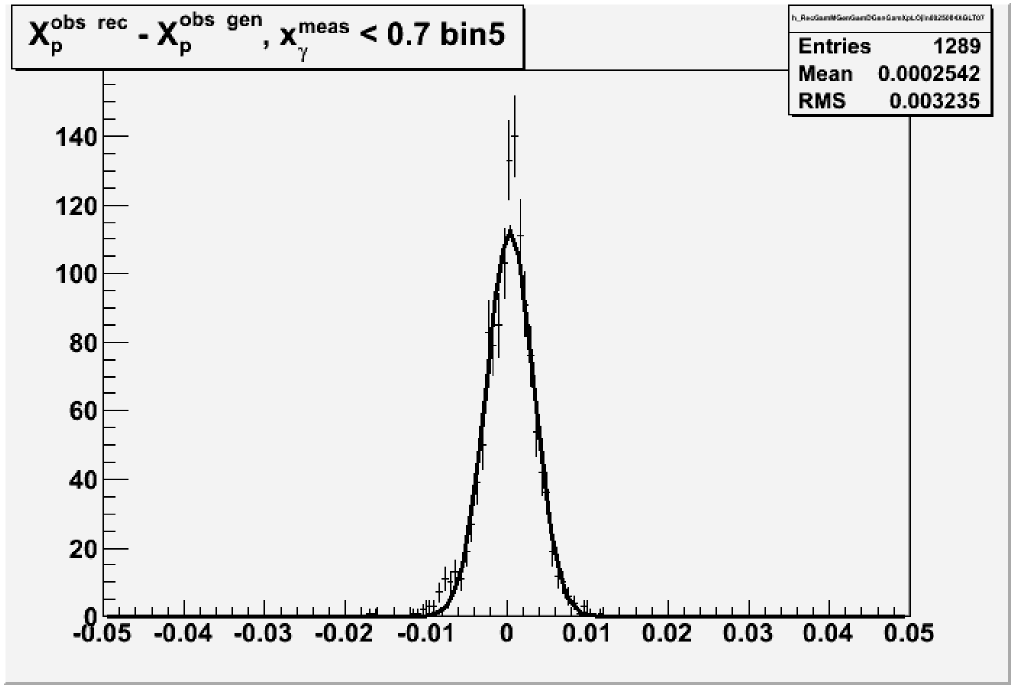
Bin 4 xgamma>0.8

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME        VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     1.07600e+03   1.88279e+01   1.06018e-01  -2.38406e-08
  2  Mean         8.71798e-05   2.01260e-05   1.58405e-07   2.82818e-02
  3  Sigma        1.60767e-03   1.98442e-05   2.12385e-05  -1.94644e-04
```

Sigma is smaller than half of the bin width 5e-3

X_p^{obs} [0.025, 0.04]





Bin 5 all xgamma

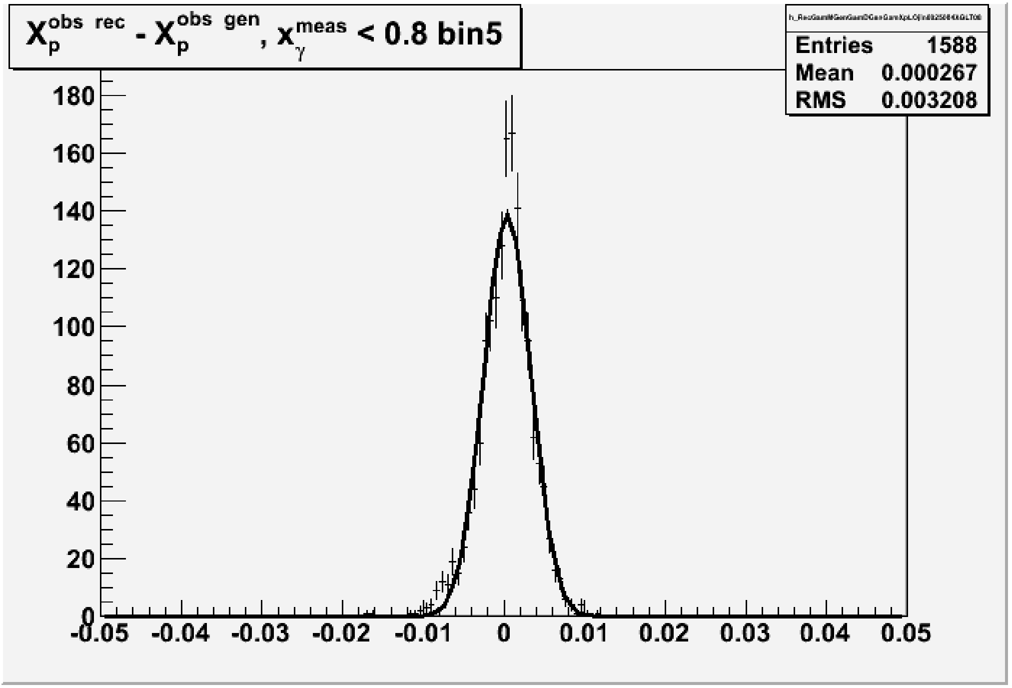
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.46469e+02   8.12778e+00   3.36024e-02   1.36913e-07
  2  Mean         3.31789e-04   4.60861e-05   2.59952e-07  -2.91644e-02
  3  Sigma        2.67939e-03   4.35380e-05   2.10652e-05  -5.78447e-04
```

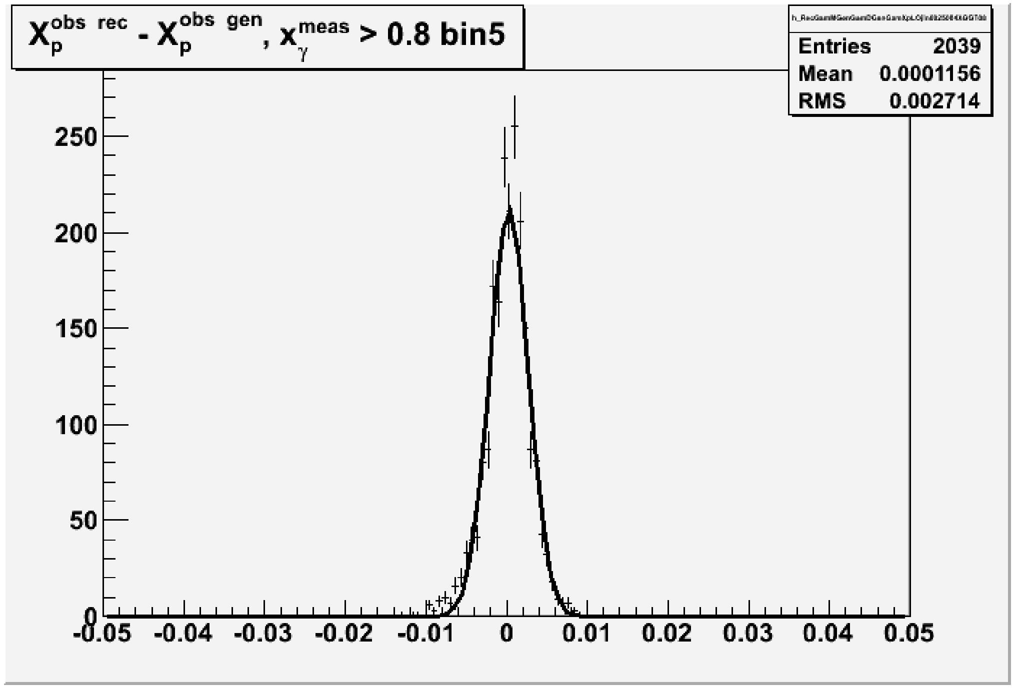
Bin 5 xgamma<0.7

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.12190e+02   4.26518e+00   1.11093e-02  -1.60398e-06
  2  Mean         4.15577e-04   8.50744e-05   2.91292e-07  -3.88660e-01
  3  Sigma        2.93789e-03   7.43798e-05   2.06055e-05  -4.42537e-03
```

Sigma is smaller than half of the bin width 7.5e-3

X_p^{obs} [0.025, 0.04]



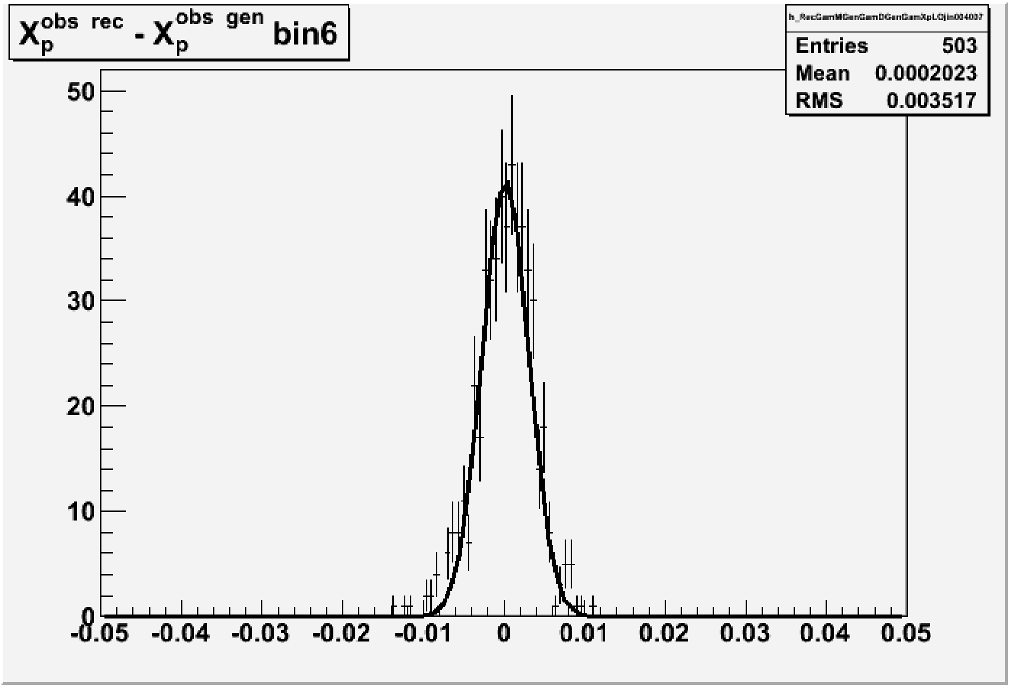


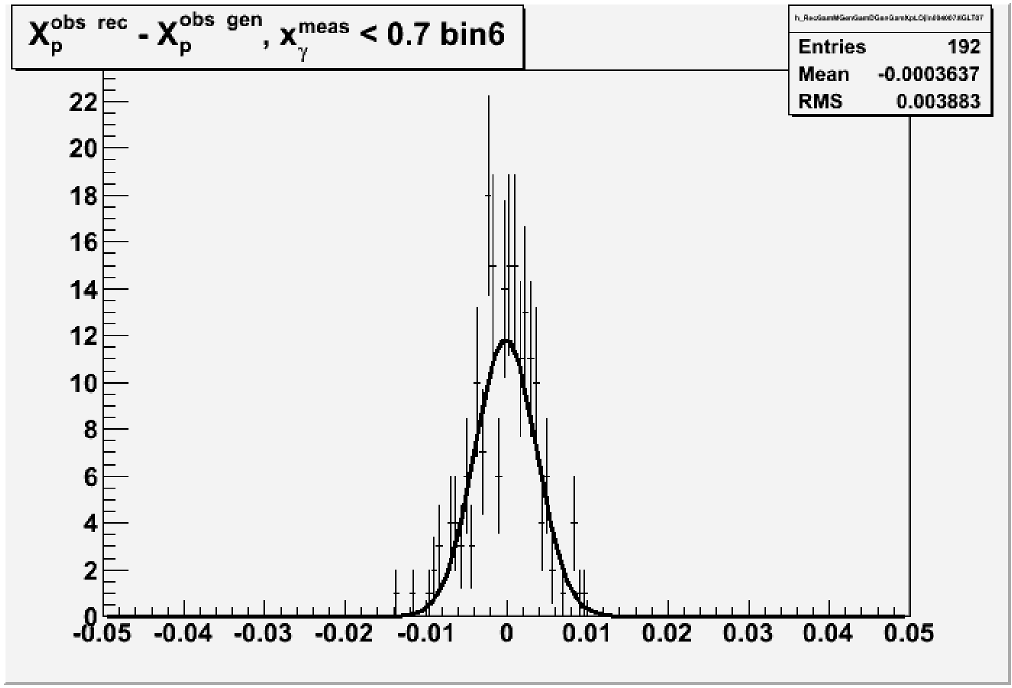
```
Bin 5 xgamma<0.8
 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.38448e+02   4.70994e+00   1.30533e-02   1.92442e-06
  2  Mean        4.09821e-04   7.70704e-05   2.77859e-07   1.46454e-01
  3  Sigma       2.94334e-03   6.62563e-05   1.95437e-05  -1.11068e-03
```

```
Bin 5 xgamma>0.8
 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     2.11890e+02   6.78594e+00   2.42163e-02   1.08848e-07
  2  Mean        2.84730e-04   5.64270e-05   2.77684e-07   2.28183e-03
  3  Sigma       2.42784e-03   5.48177e-05   2.49522e-05  -8.35136e-05
```

Sigma is smaller than half of the bin width 5e-3

X_p^{obs} [0.04, 0.07]



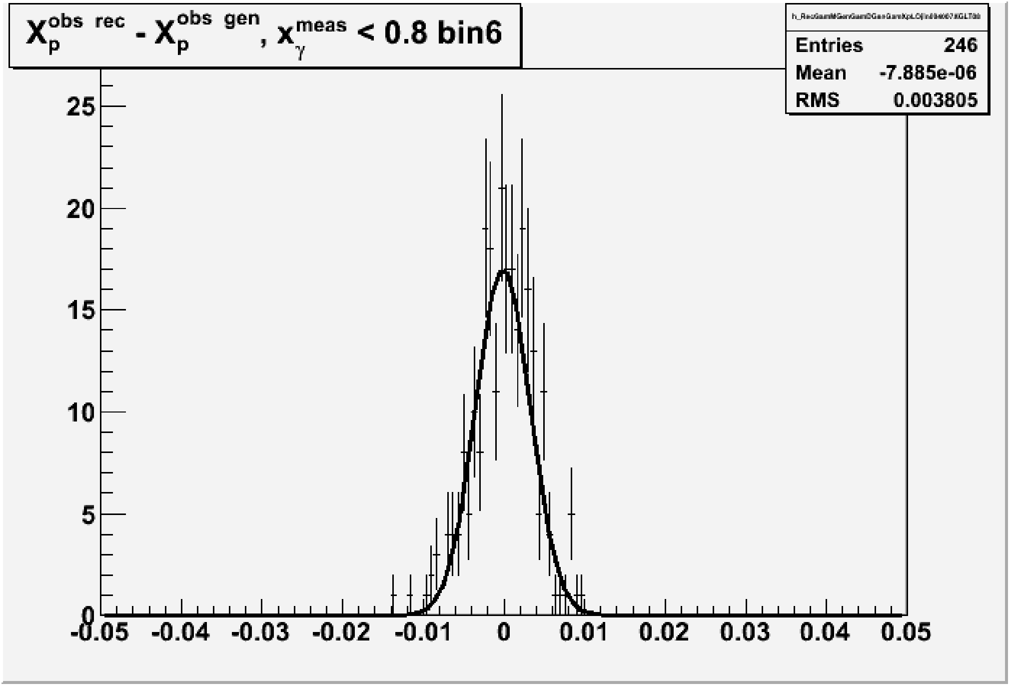


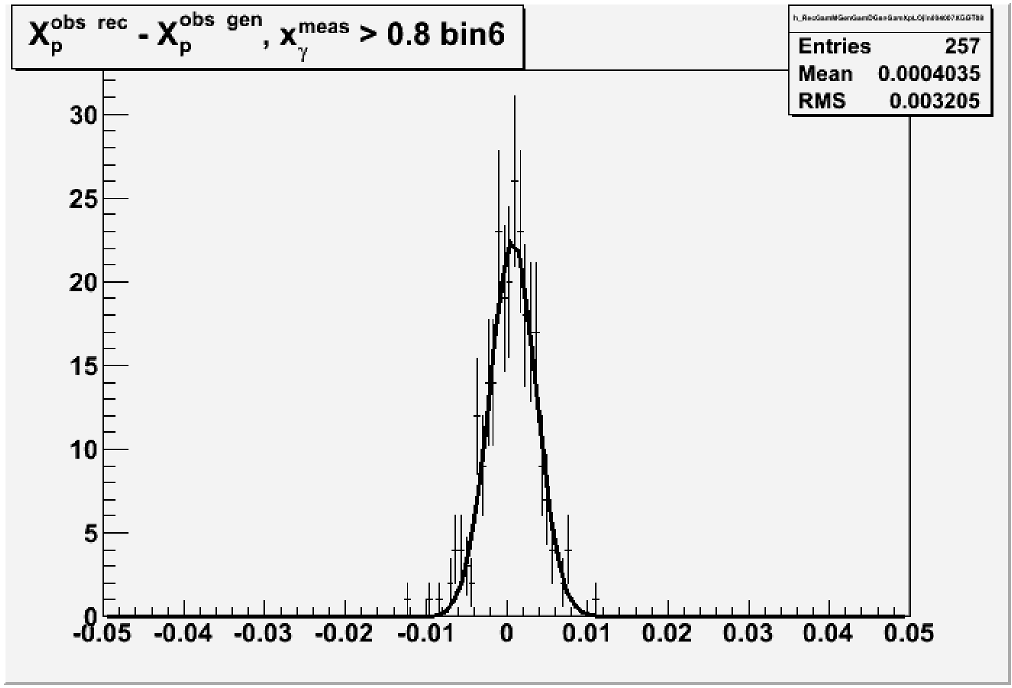
```
Bin 6 all xgamma
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant    4.13827e+01   2.61888e+00   7.03529e-03  -1.03395e-05
  2  Mean        1.93856e-04   1.53005e-04   4.97575e-07   2.21759e-01
  3  Sigma       2.89694e-03   1.25114e-04   3.26503e-05   5.09021e-04
```

```
Bin 6 xgamma<0.7
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant    1.18659e+01   1.37090e+00   2.56658e-03  -9.75237e-05
  2  Mean       -1.16935e-04   3.40573e-04   8.84882e-07  -1.08033e-01
  3  Sigma       3.77296e-03   3.71202e-04   5.90881e-05  -1.30371e-03
```

Sigma is smaller than half of the bin width 1.5e-2

X_p^{obs} [0.04, 0.07]





Bin 6 xgamma<0.8

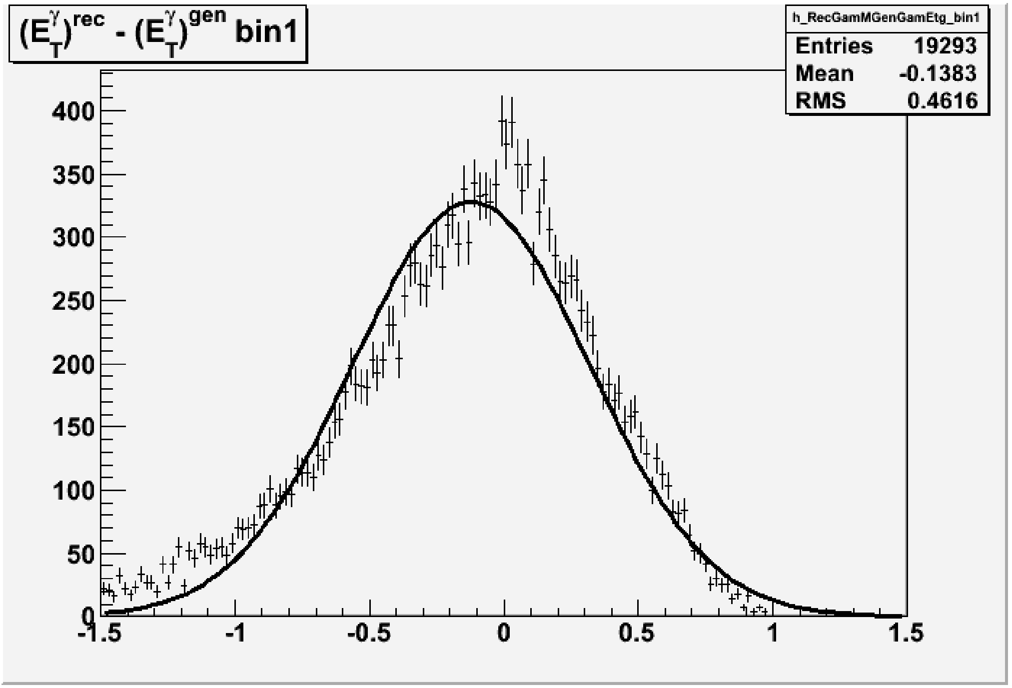
```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME        VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     1.70520e+01   1.60947e+00   3.26665e-03  -2.39973e-08
  2  Mean        -1.21900e-04   2.66288e-04   6.63059e-07  -1.27515e-03
  3  Sigma        3.36944e-03   2.33193e-04   4.07981e-05  -3.64682e-05
```

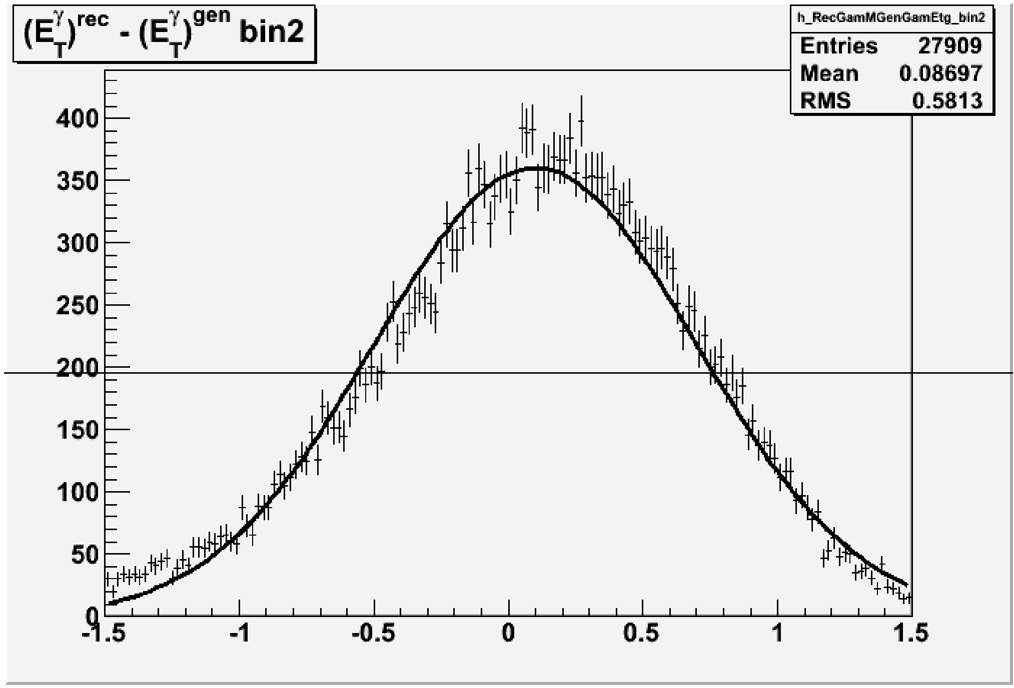
Bin 6 xgamma>0.8

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME        VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     2.23976e+01   1.96577e+00   3.19644e-03  -9.27844e-07
  2  Mean         7.63388e-04   1.97529e-04   4.33119e-07  -3.73103e-03
  3  Sigma        2.88539e-03   1.89081e-04   3.33978e-05  -3.20225e-04
```

Sigma is smaller than half of the bin width 1.5e-2

E_T^{γ}





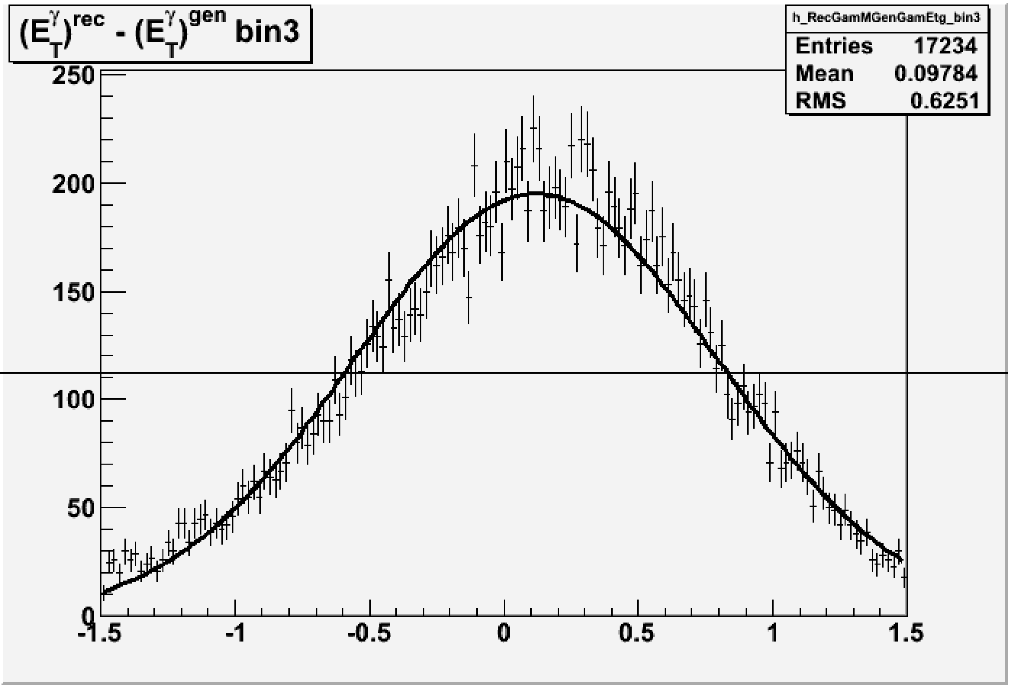
Et-gamma bin 1 6-7 GeV

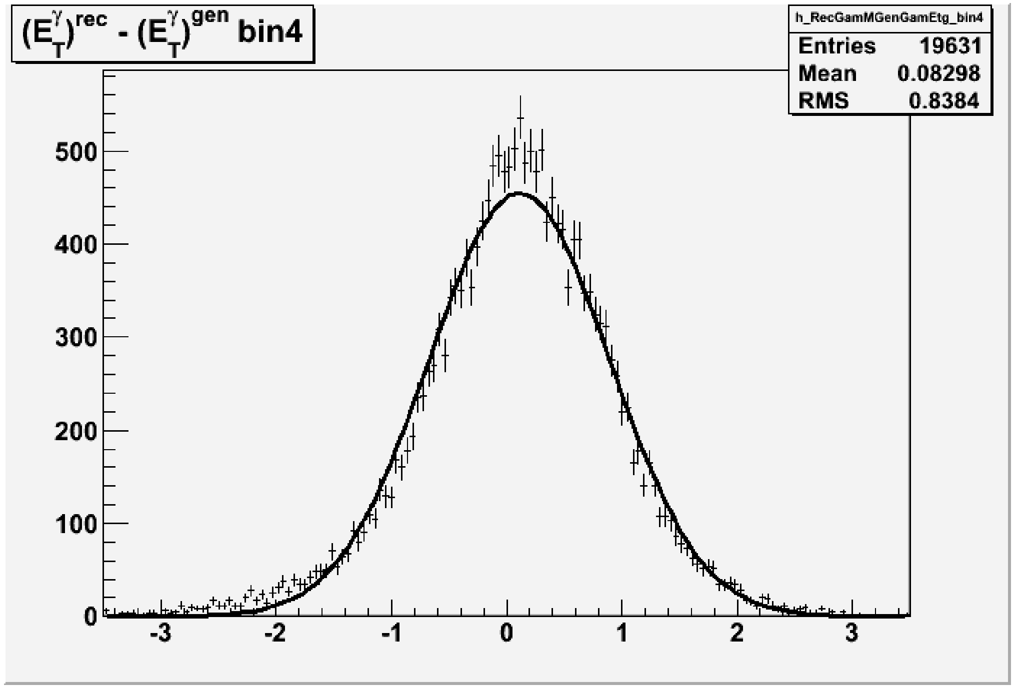
```
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     3.27702e+02   3.20542e+00   3.47882e-02  -7.01878e-08
   2  Mean        -1.22138e-01   3.77843e-03   4.81933e-05   4.82123e-03
   3  Sigma        4.41526e-01   2.92983e-03   2.19759e-05   4.17799e-03
```

Et-gamma bin 2 7-8.5 GeV

```
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     3.60049e+02   2.86062e+00   2.08193e-02   1.01728e-05
   2  Mean         1.00122e-01   3.91316e-03   3.63748e-05   1.54568e-02
   3  Sigma        5.99332e-01   3.33108e-03   1.36055e-05   3.99502e-02
```

E_T^γ





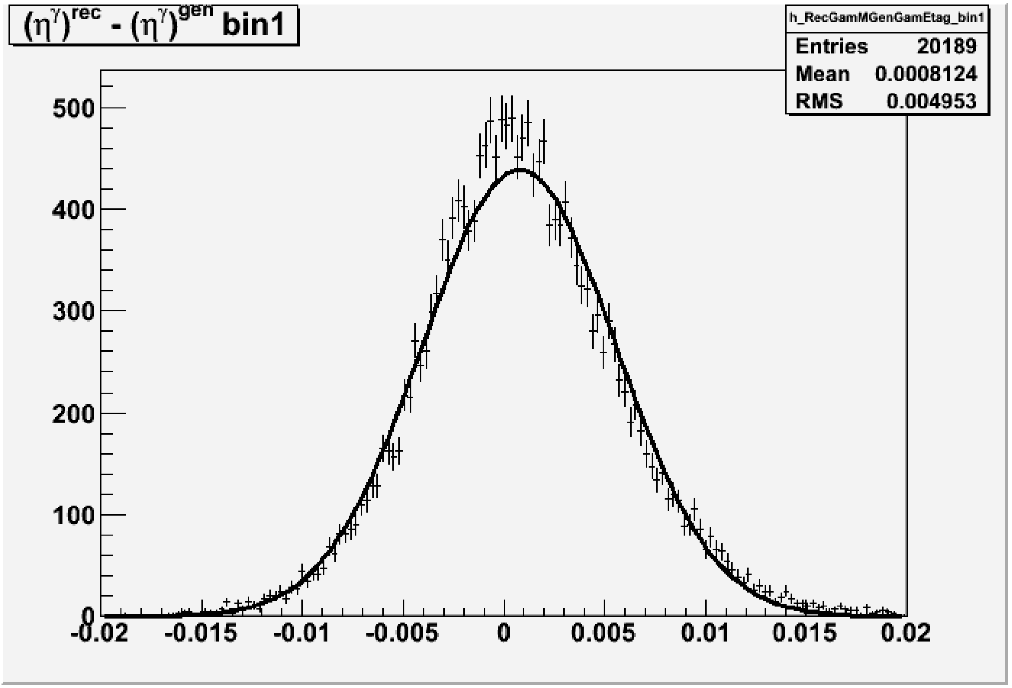
Et-gamma bin 3 8.5-10 GeV

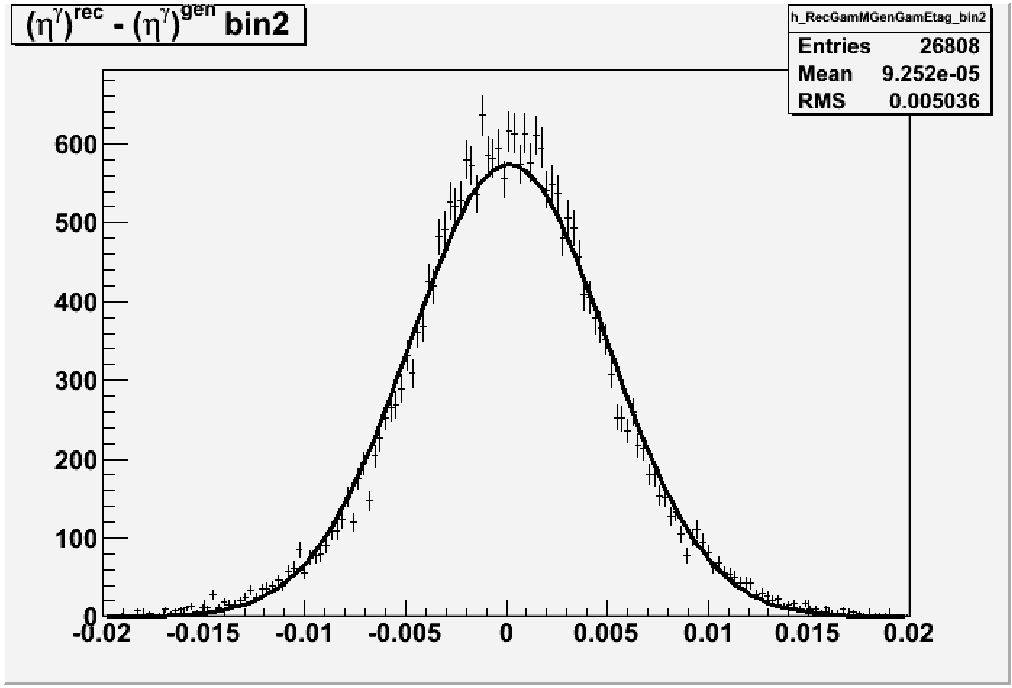
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.94830e+02   2.02391e+00   1.02555e-02   2.49426e-06
  2  Mean         1.19608e-01   5.84831e-03   3.89967e-05  -8.17443e-03
  3  Sigma        6.78153e-01   5.46140e-03   1.42415e-05   4.91577e-02
```

Et-gamma bin 4 10-15 GeV

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     4.54830e+02   4.40023e+00   3.46320e-02   5.52029e-08
  2  Mean         1.10019e-01   5.71464e-03   5.96292e-05  -5.34553e-05
  3  Sigma        7.82829e-01   5.03383e-03   1.61580e-05  -6.10192e-04
```

η^{γ}

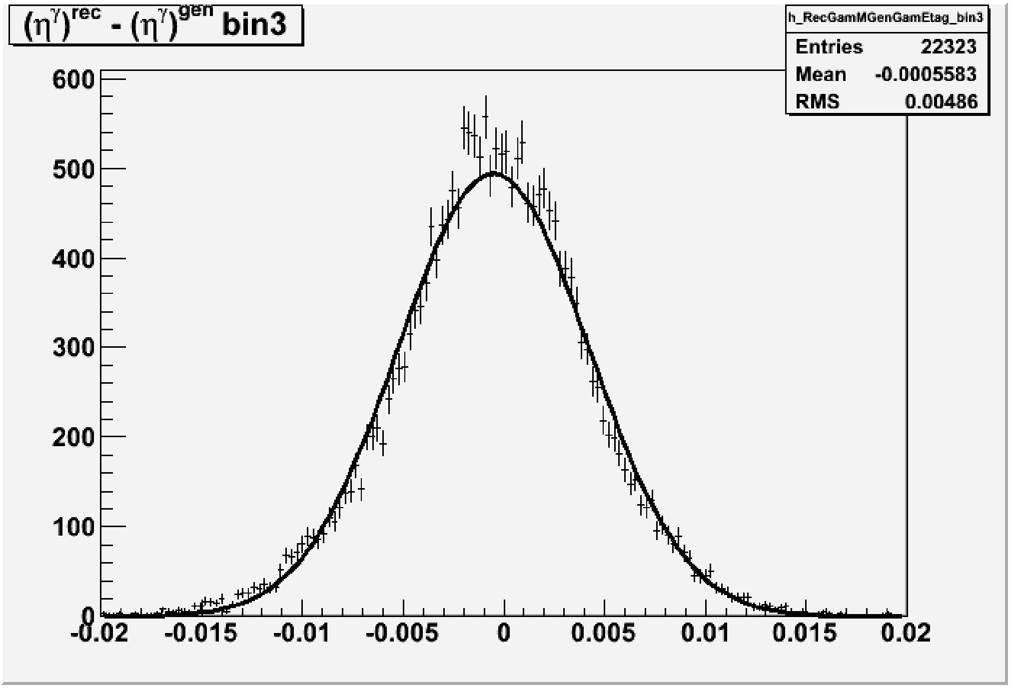


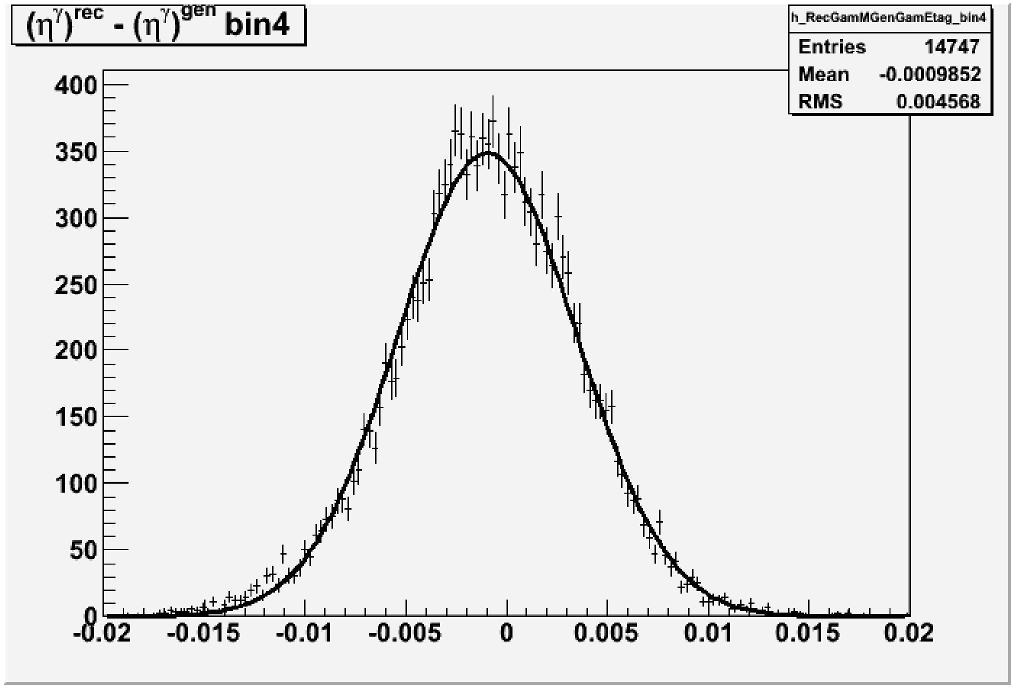


```
eta-gamma bin 1  -0.7 - -0.3
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     4.38918e+02   4.07804e+00   2.79365e-02  -2.48809e-06
   2  Mean         7.57454e-04   3.46157e-05   3.05650e-07  -3.84218e-01
   3  Sigma        4.79769e-03   2.87523e-05   1.33339e-05  -6.33114e-03
```

```
eta-gamma bin 2  -0.3 - 0.1
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     5.73582e+02   4.67629e+00   3.43706e-02   1.61663e-09
   2  Mean         1.16785e-04   3.01218e-05   2.92970e-07  -1.54977e-03
   3  Sigma        4.88681e-03   2.61145e-05   1.28751e-05  -4.84215e-04
```

η^γ

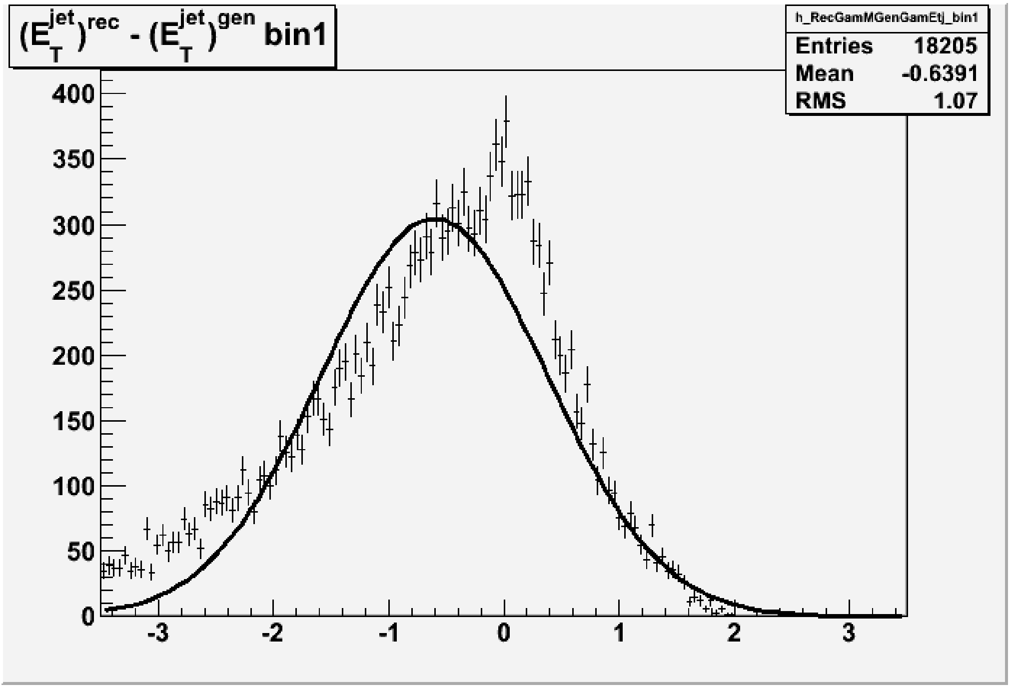


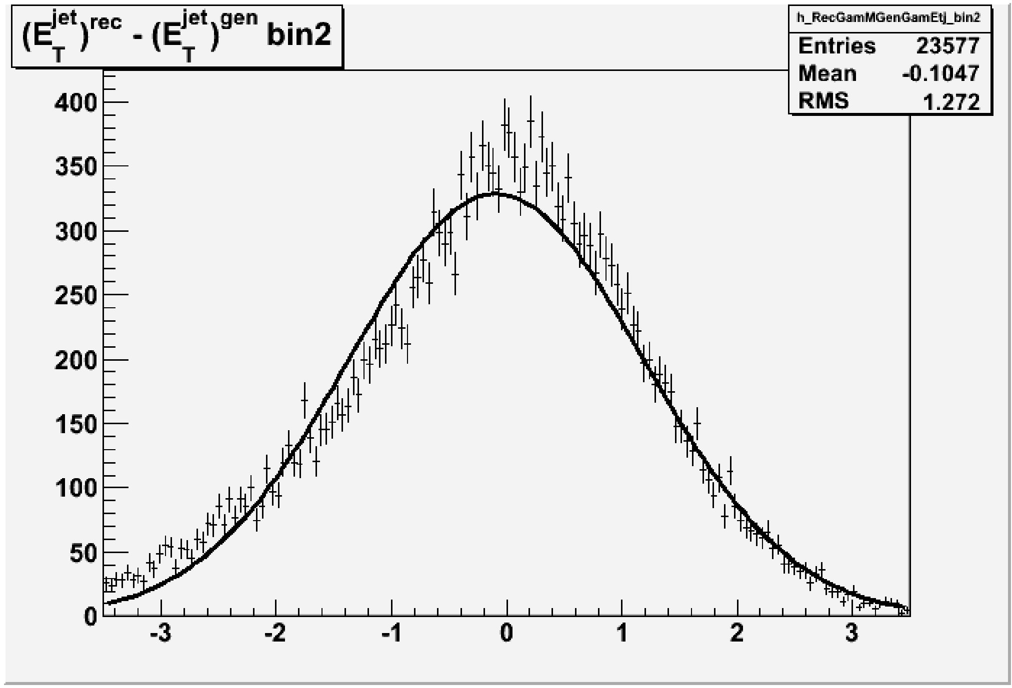


```
eta-gamma bin 3  0.1 - 0.5
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     4.93811e+02   4.37249e+00   2.94379e-02  -3.35021e-09
   2  Mean        -5.11674e-04   3.20137e-05   2.82094e-07   1.39417e-02
   3  Sigma        4.72933e-03   2.71316e-05   1.26630e-05  -4.29873e-04
```

```
eta-gamma bin 4  0.5 - 0.9
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     3.48008e+02   3.69358e+00   2.01588e-02   5.32939e-09
   2  Mean        -9.51076e-04   3.72973e-05   2.57850e-07   5.63752e-02
   3  Sigma        4.44198e-03   2.95146e-05   1.18315e-05  -1.64368e-03
```

E_T^{jet}

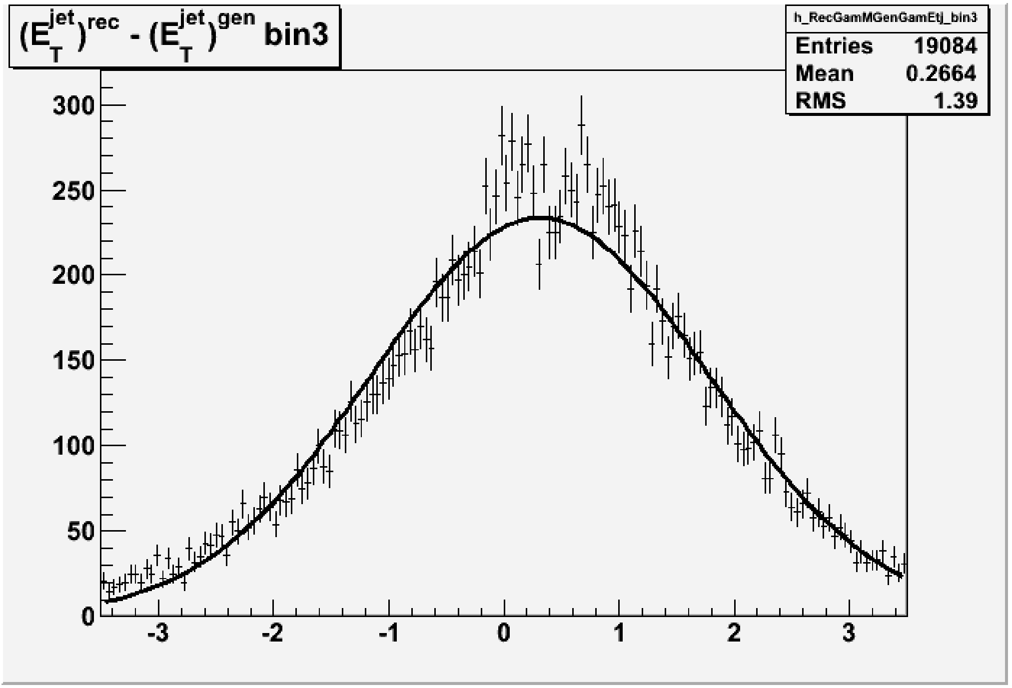


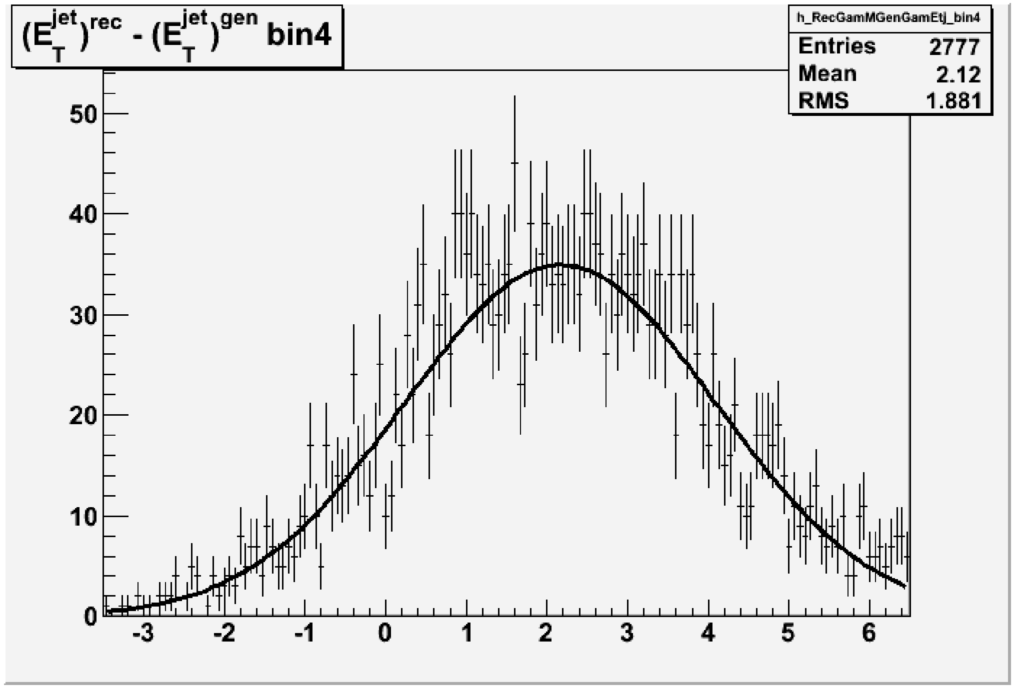


```
Et-jet bin 1  4-6 GeV
 EXT PARAMETER                                    STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.04385e+02   3.19077e+00   4.50033e-02   1.46444e-05
  2  Mean        -6.04500e-01   1.04726e-02   1.48769e-04   4.77472e-03
  3  Sigma        9.82548e-01   7.03803e-03   2.70514e-05   2.83814e-02
```

```
Et-jet bin 2  6-8 GeV
 EXT PARAMETER                                    STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.28564e+02   2.85321e+00   2.35626e-02  -6.09853e-07
  2  Mean        -9.07747e-02   9.24810e-03   9.43752e-05  -4.99215e-04
  3  Sigma        1.28065e+00   7.52477e-03   1.57251e-05   2.81820e-04
```

E_T^{jet}





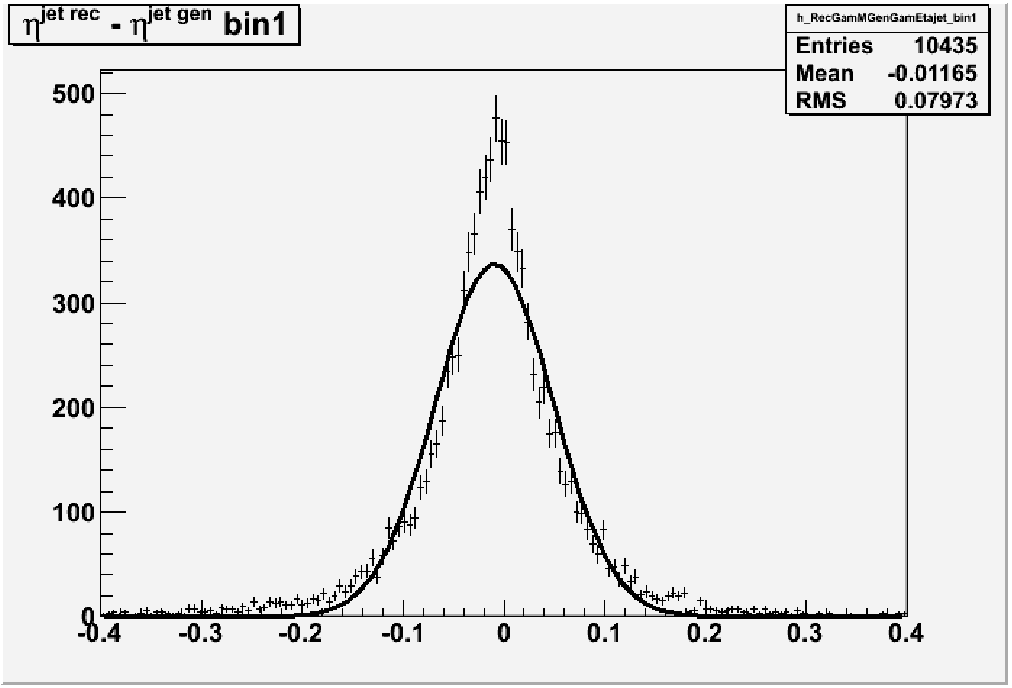
Et-jet bin 3 8-10 GeV

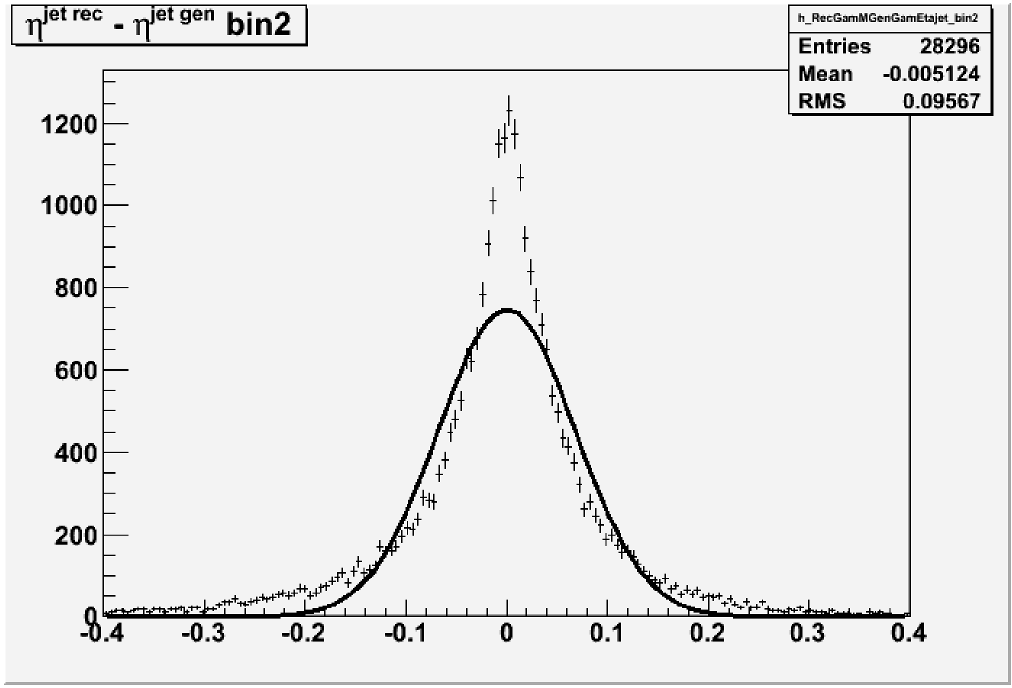
```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     2.33311e+02   2.31854e+00   2.65851e-04  -3.05957e-06
  2  Mean        3.15174e-01   1.15921e-02  -2.37934e-06   1.23656e-03
  3  Sigma        1.46647e+00   1.10598e-02  -9.50434e-07   3.40900e-03
```

Et-jet bin 4 10-15 GeV

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     3.49136e+01   9.18027e-01   4.20176e-03  -6.22006e-07
  2  Mean        2.16482e+00   4.14644e-02   2.45550e-04  -1.77093e-06
  3  Sigma        1.93003e+00   3.68521e-02   2.92600e-05  -1.83937e-04
```

η^{jet}

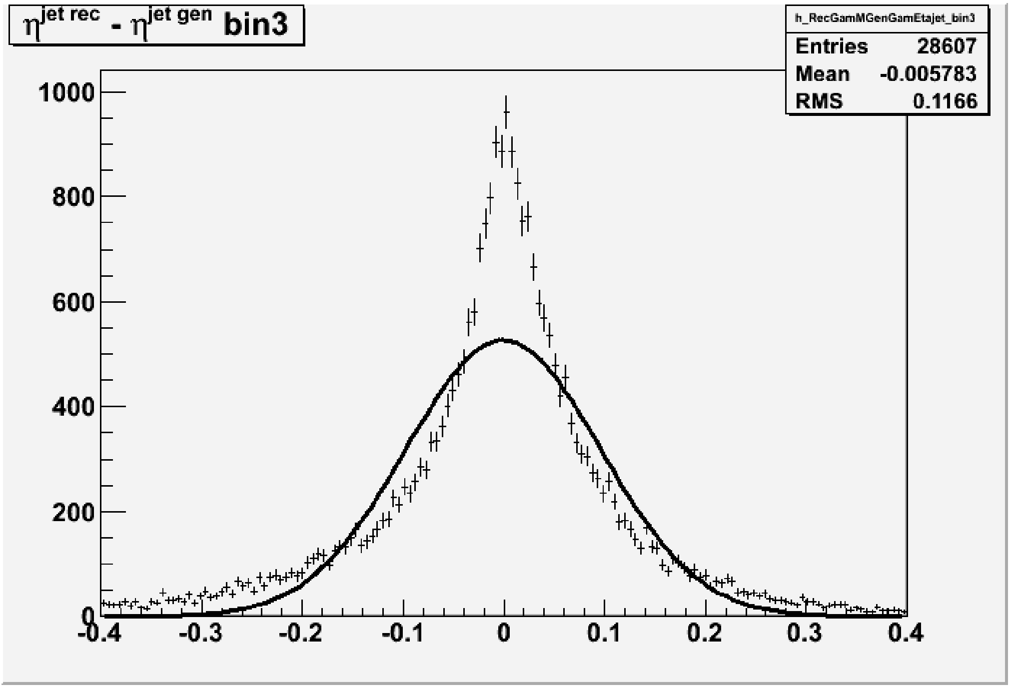


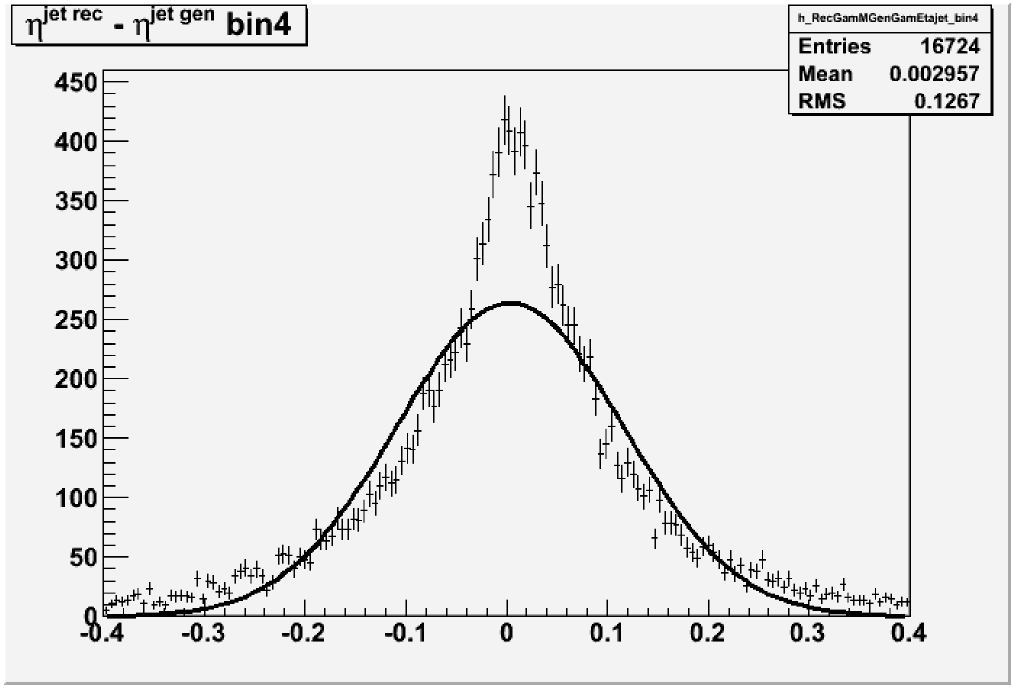


```
eta-jet bin 1  -1.5 - -0.7
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     3.37007e+02   5.42331e+00   5.25134e-02   9.54943e-08
   2  Mean        -9.37708e-03   6.07661e-04   9.10719e-06  -1.00334e-04
   3  Sigma        5.84455e-02   7.17790e-04   3.34403e-05  -6.49342e-04
```

```
eta-jet bin 2  -0.7 - 0.1
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     7.47076e+02   8.54617e+00   1.44084e-01  -8.21194e-07
   2  Mean         1.56216e-04   4.41915e-04   1.30773e-05  -4.61492e-03
   3  Sigma        6.78048e-02   6.38872e-04   4.37908e-05  -1.11525e-02
```

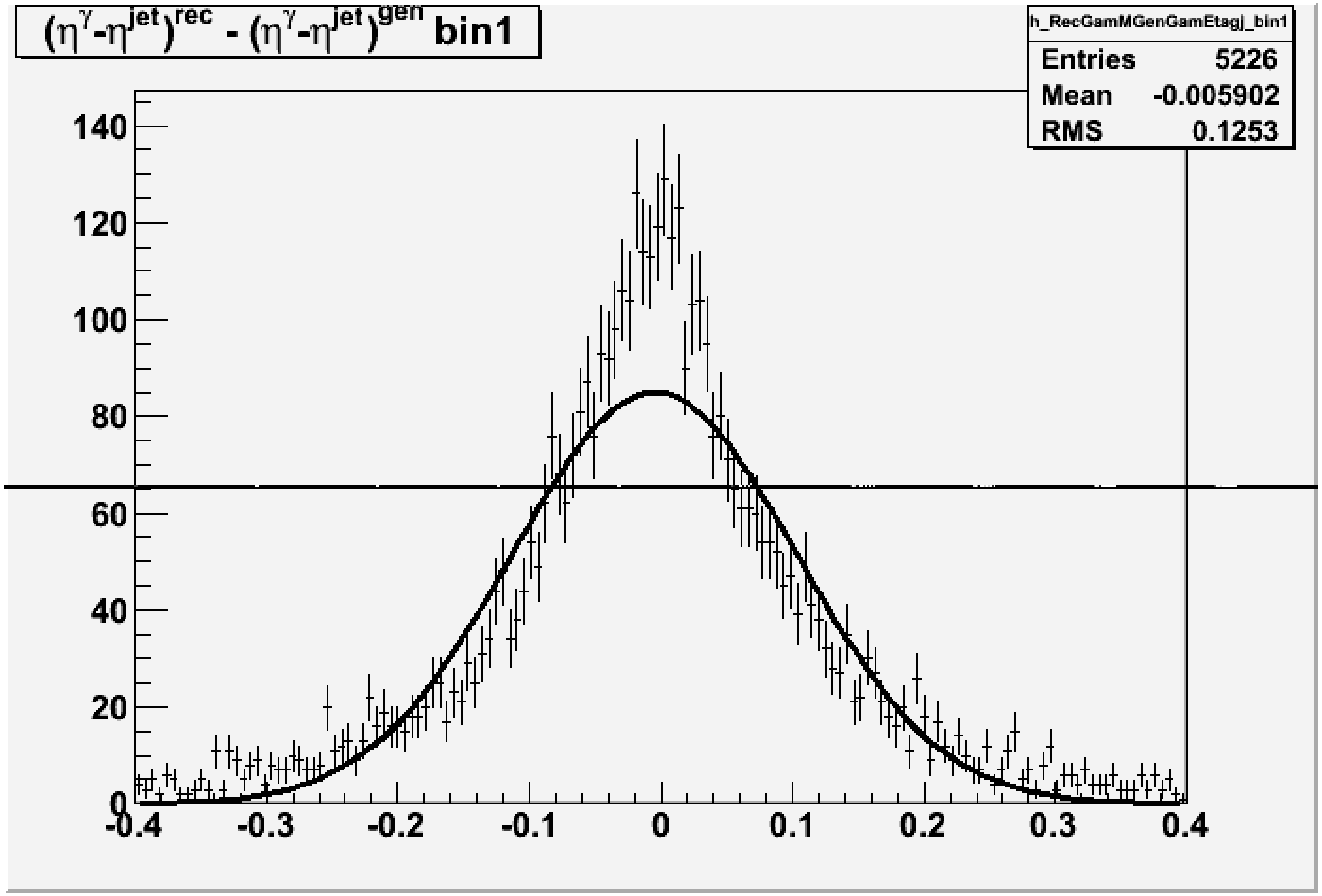
η^{jet}





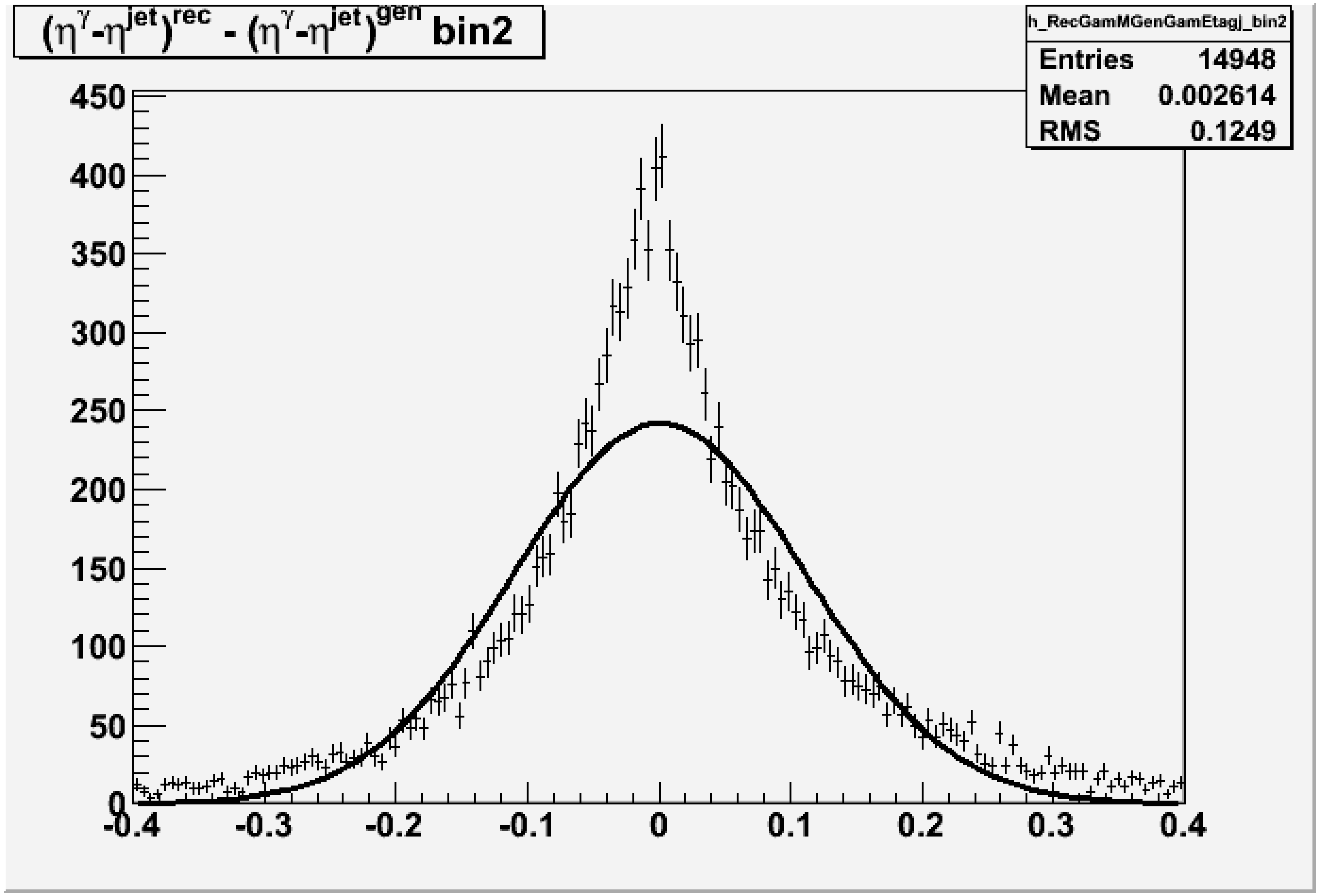
```
eta-jet bin 3  0.1 - 0.9
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     5.26778e+02   6.16052e+00   9.78760e-02   1.70495e-06
   2  Mean        -6.78126e-04   6.37637e-04   1.79128e-05  -1.06764e-02
   3  Sigma        9.63795e-02   9.38856e-04   4.61530e-05  -7.71493e-04
```

```
eta-jet bin 4  0.9 - 1.8
  EXT PARAMETER                                STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     2.64294e+02   3.62951e+00   4.11459e-02  -3.02551e-08
   2  Mean         3.34736e-03   9.54947e-04   1.74989e-05  -1.83859e-04
   3  Sigma        1.12125e-01   1.21713e-03   3.82986e-05  -1.12778e-03
```



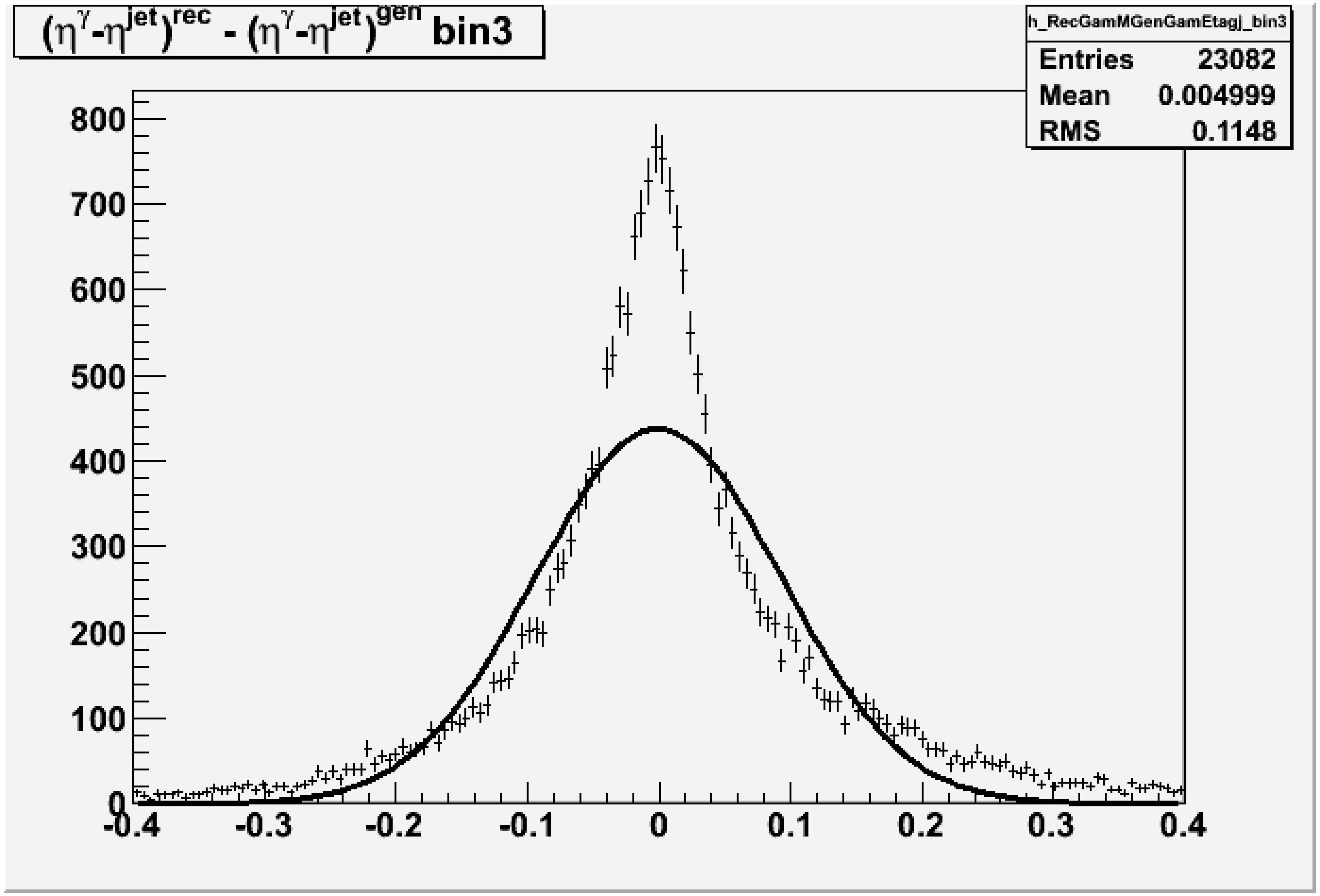
Etagj bin 1 -2.2 - -1.5

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     8.49221e+01   2.01954e+00   1.30907e-02   1.50704e-06
  2  Mean        -4.86008e-03   1.65077e-03   1.66988e-05   9.58249e-04
  3  Sigma        1.08156e-01   1.98173e-03   3.64756e-05  -4.20981e-04
```



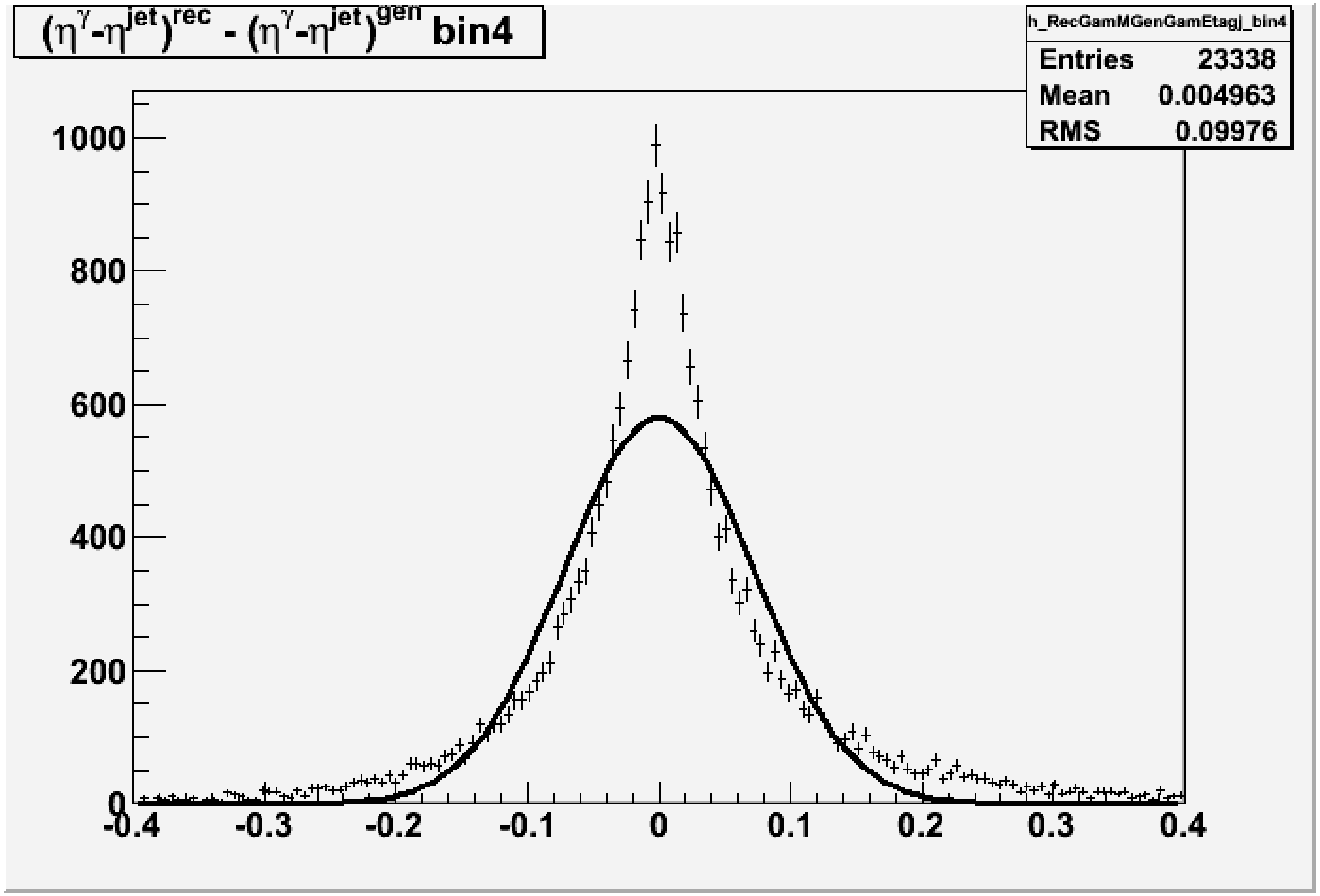
Etagj bin 2 -1.5 - -0.8

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     2.41795e+02   3.52997e+00   3.84856e-02   1.21391e-06
  2  Mean        6.64909e-04   1.00204e-03   1.76394e-05   2.47990e-03
  3  Sigma       1.10590e-01   1.28279e-03   3.92126e-05  -7.51846e-04
```



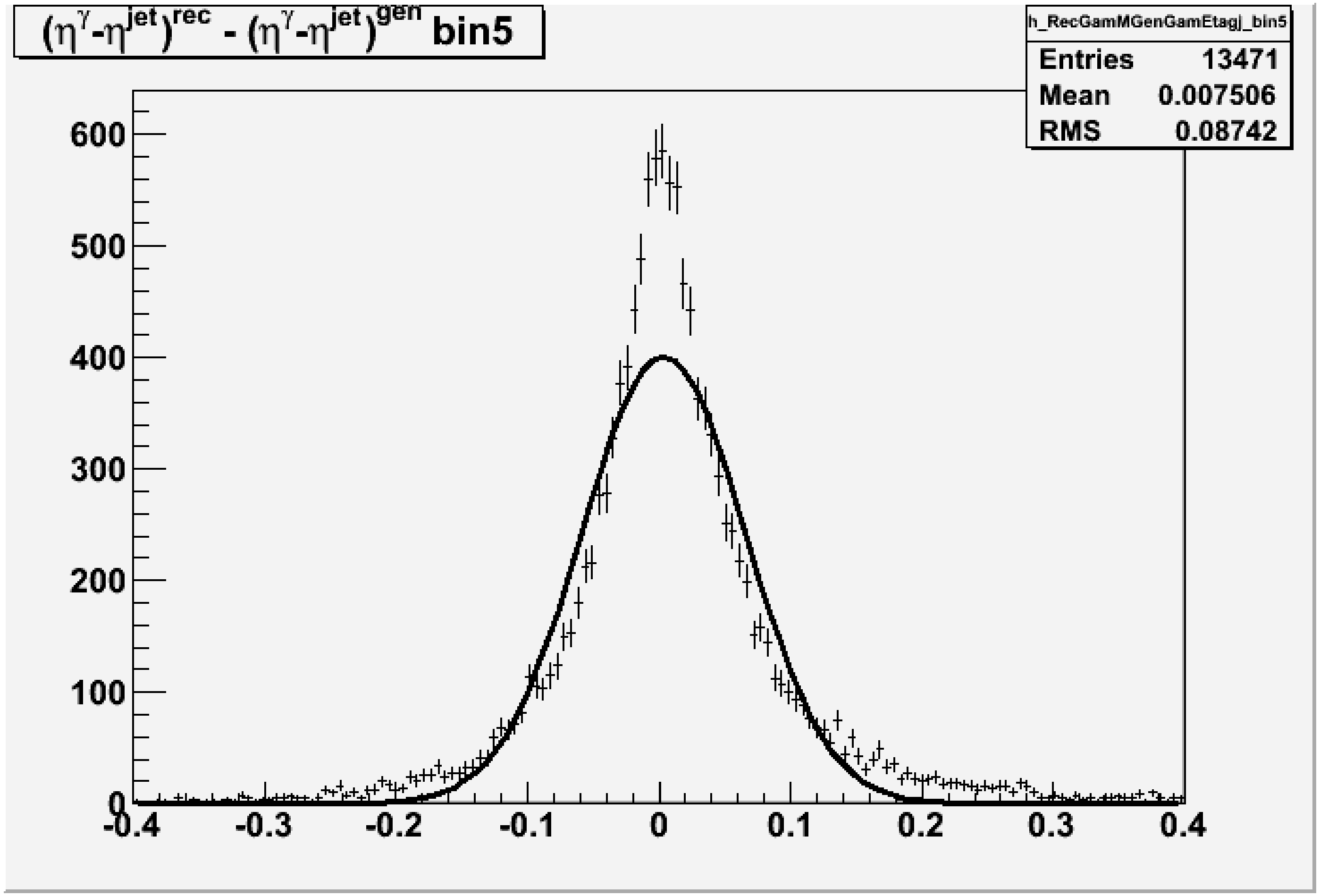
Etagj bin 3 -0.8 - -0.1

```
 EXT PARAMETER                                    STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     4.37937e+02   5.83834e+00   8.32580e-02   2.27838e-06
  2  Mean        -4.51158e-04   6.88916e-04   1.77016e-05   1.85273e-02
  3  Sigma        9.30955e-02   1.04293e-03   4.71217e-05   1.65675e-03
```



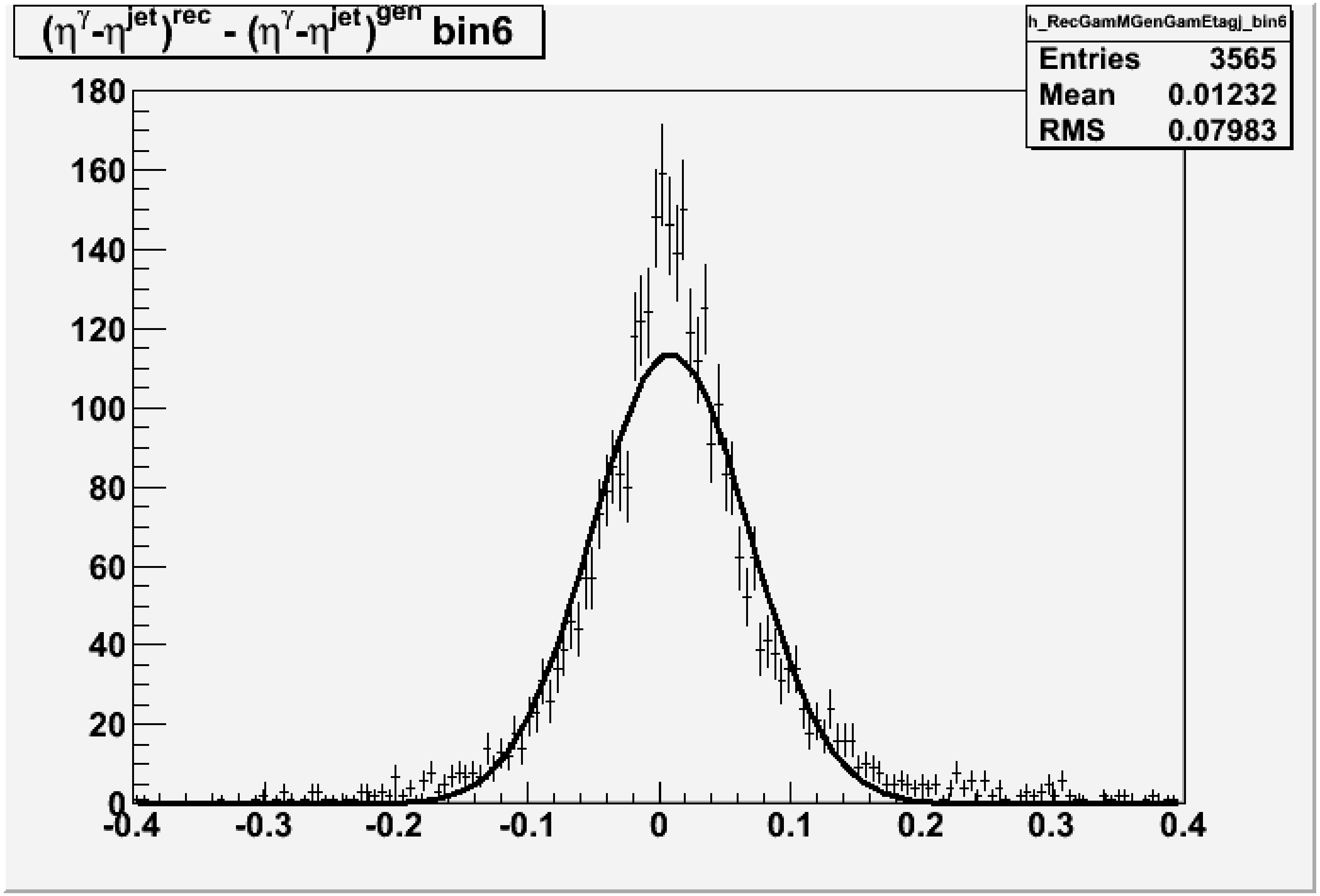
Etagj bin 4 -0.1 - 0.6

```
  EXT PARAMETER                                     STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     5.79960e+02   7.33584e+00   1.12130e-01  -4.73901e-07
   2  Mean        4.33125e-05   5.14843e-04   1.38842e-05   1.16150e-03
   3  Sigma       7.18110e-02   7.49049e-04   4.43598e-05  -5.49420e-03
```



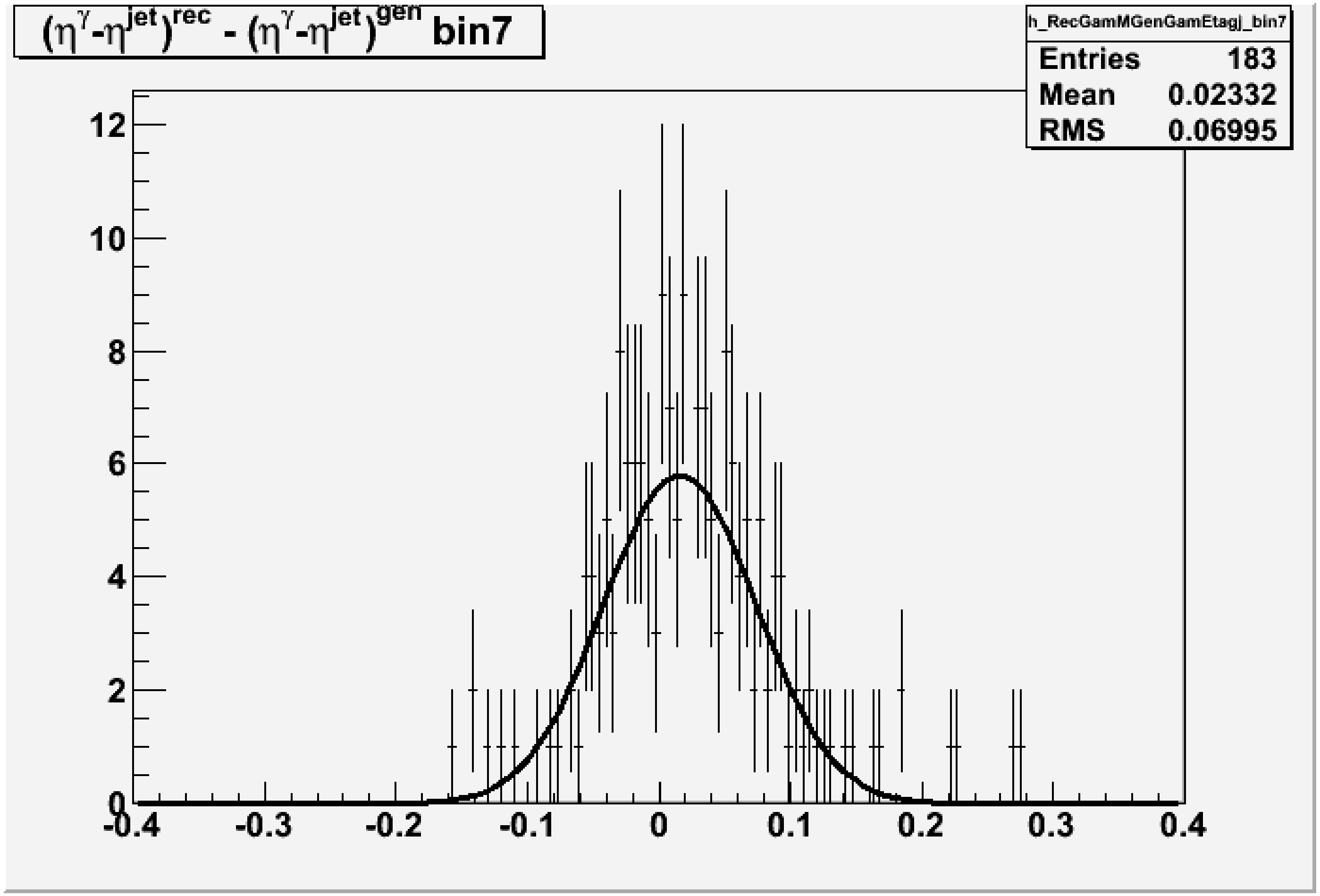
Etagj bin 5 0.6 - 1.3

```
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE           ERROR          SIZE      DERIVATIVE
  1  Constant     4.01023e+02   6.03318e+00   6.92054e-02   8.12116e-07
  2  Mean        3.52589e-03   5.74523e-04   1.06822e-05   7.15449e-04
  3  Sigma       6.18994e-02   7.33709e-04   3.74906e-05   4.95875e-04
```



Etagj bin 6 1.3 - 2.0

```
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     1.13482e+02   2.99982e+00   1.69995e-02  -2.82929e-07
  2  Mean        8.78328e-03   1.06312e-03   8.94403e-06  -3.44386e-04
  3  Sigma       5.97034e-02   1.17076e-03   3.15288e-05  -4.17598e-04
```

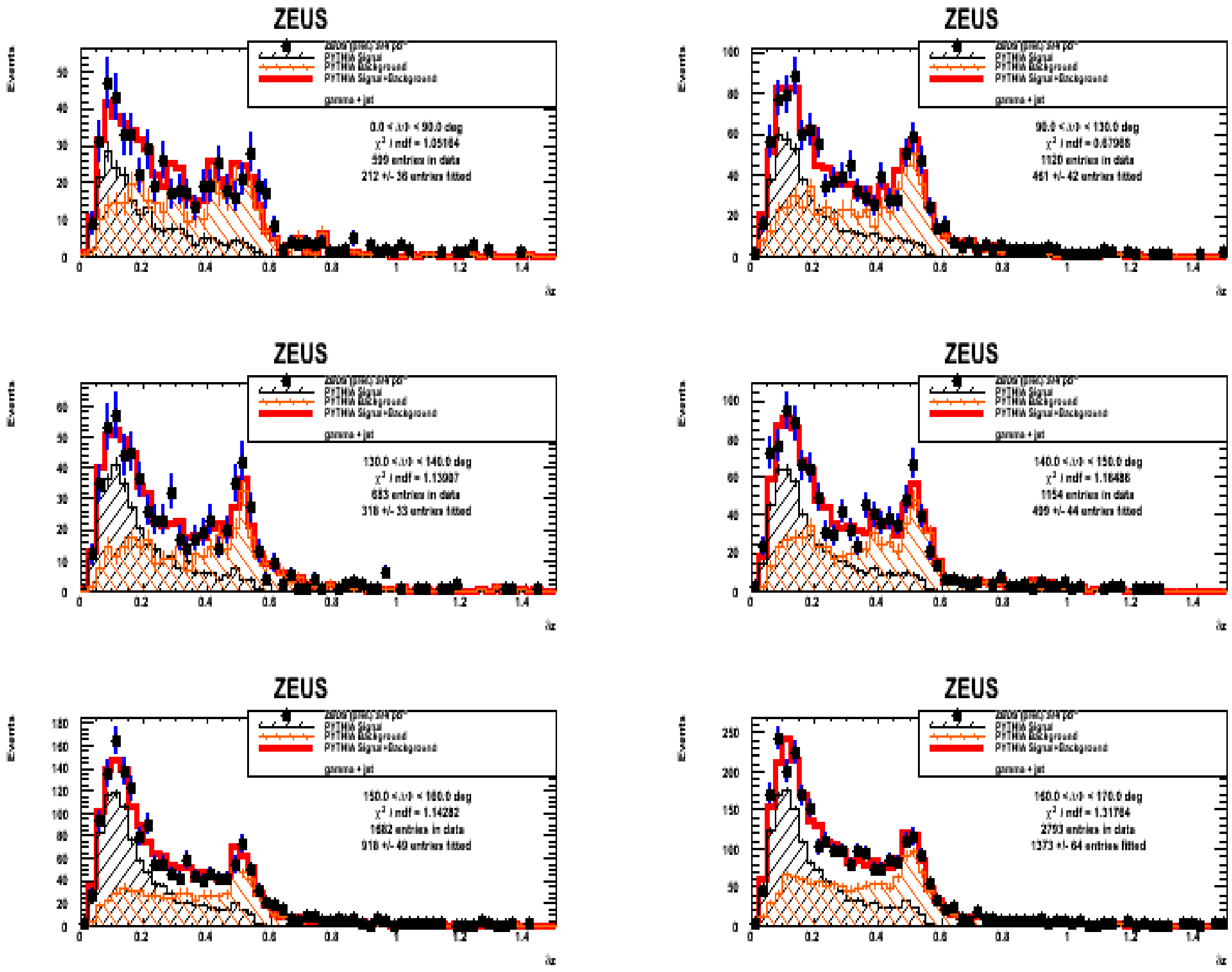


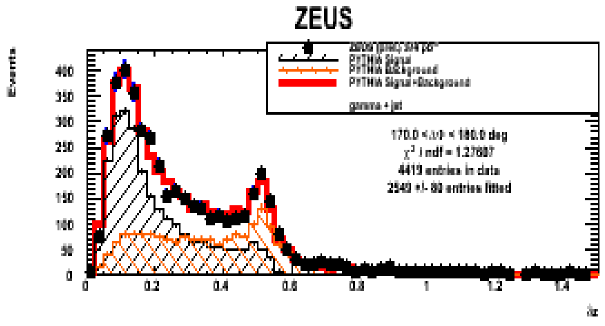
Etagj bin 7 2.0 - 2.7

```
 EXT PARAMETER                                    STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Constant     5.80244e+00   7.06648e-01   1.34605e-03  -1.72641e-04
  2  Mean        1.58550e-02   5.21723e-03   1.44991e-05  -1.13238e-02
  3  Sigma       5.78610e-02   6.01639e-03   5.93949e-05  -7.85405e-04
```

Fits in bins

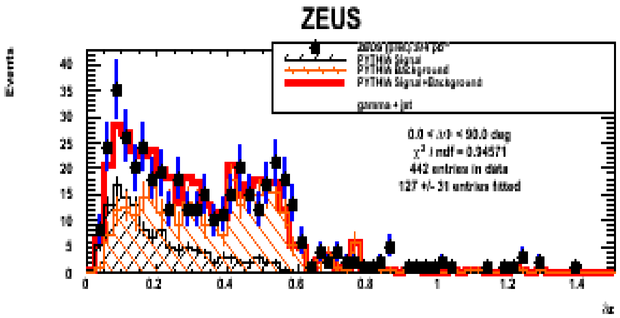
<δZ> Fits in ΔΦ bins. All x_γ

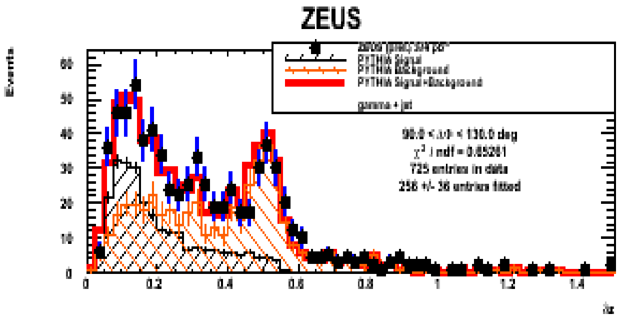


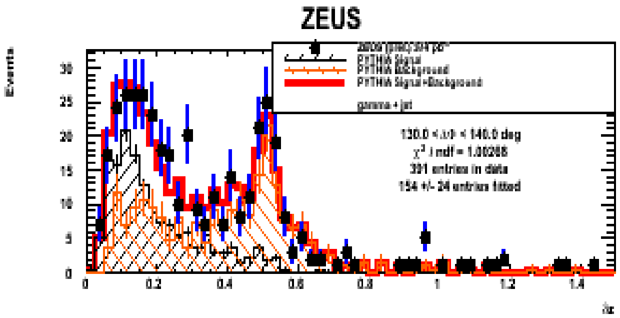


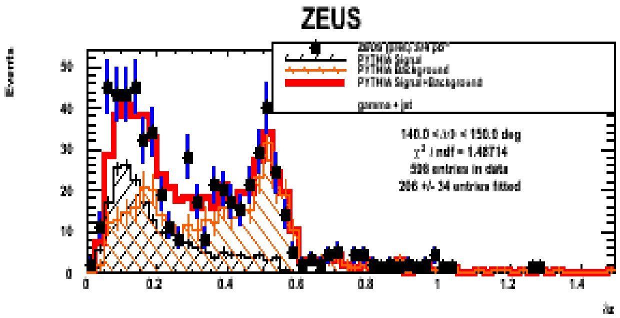
First bin 0 < ΔΦ < 90º:
χ^2 / n.d.f. = 1.05625
fitted photons 212 ± 36
Bin looks good

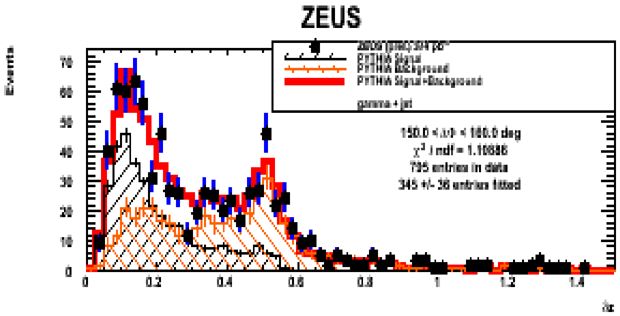
<δZ> Fits in ΔΦ bins. $x_\gamma < 0.7$

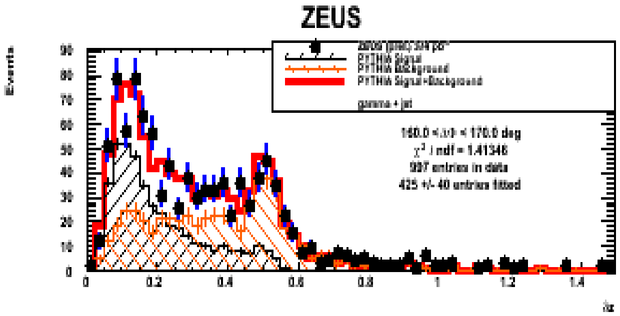


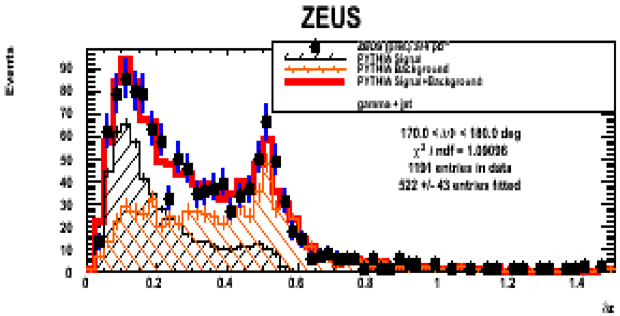






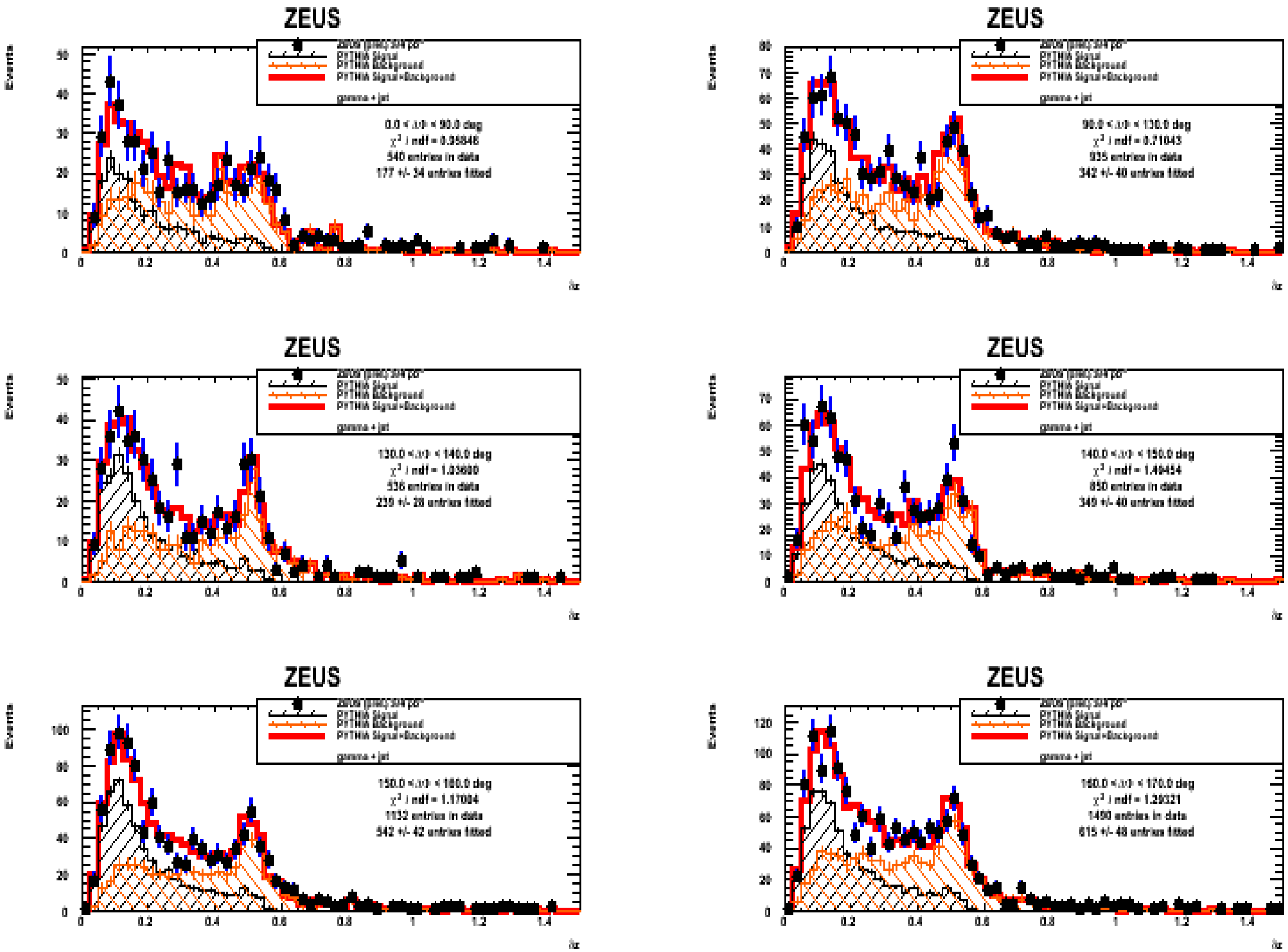


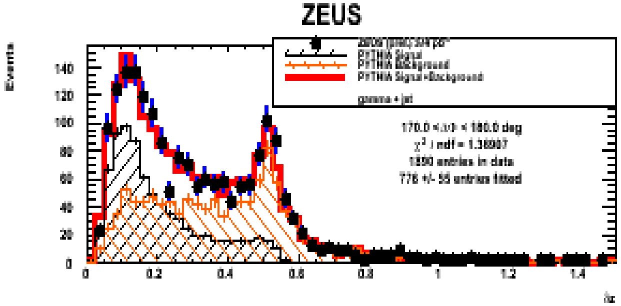




First bin 0 < ΔΦ < 90º:
χ^2 / n.d.f. = 0.86857
fitted photons 122 ± 29
Bin looks good

<δZ> Fits in ΔΦ bins. $x_\gamma < 0.8$





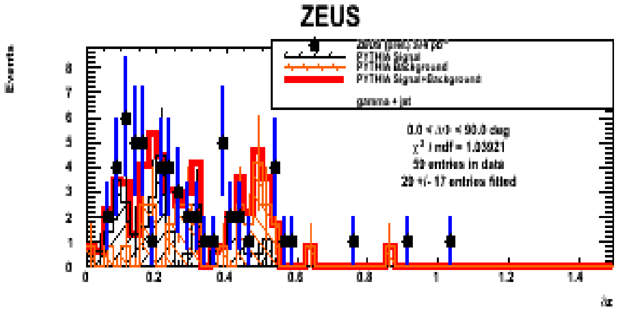
First bin 0 < ΔΦ < 90º:

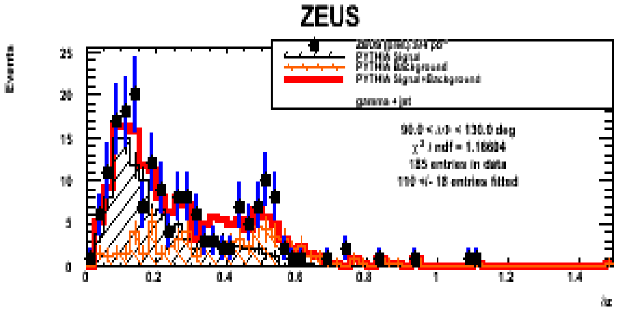
χ^2 / n.d.f. = 0.94718

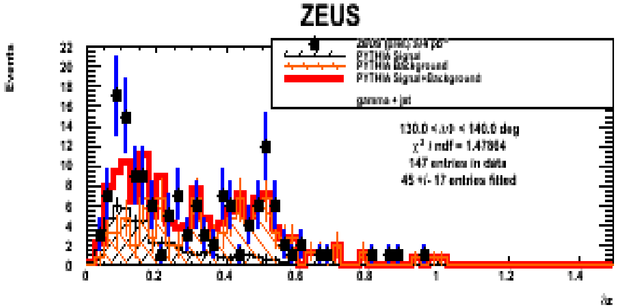
fitted photons 169 ± 34

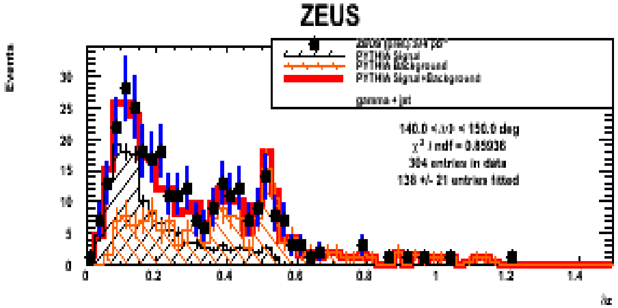
Bin looks good

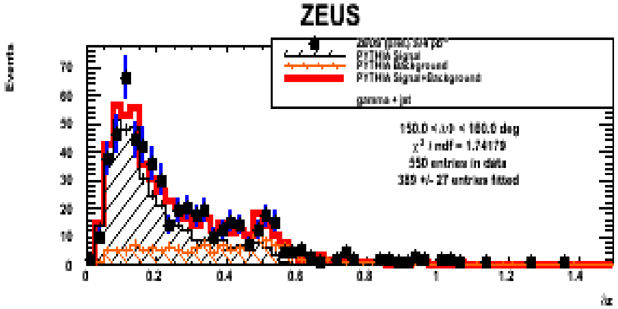
<δZ> Fits in ΔΦ bins. $x_\gamma > 0.8$

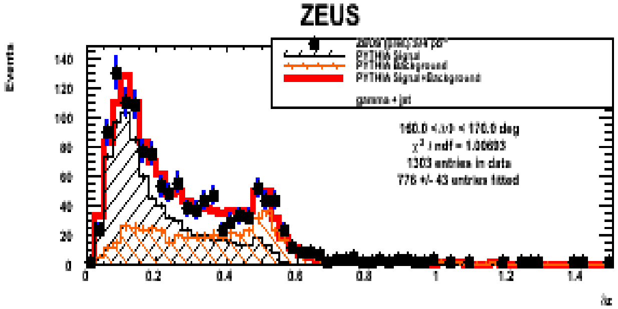


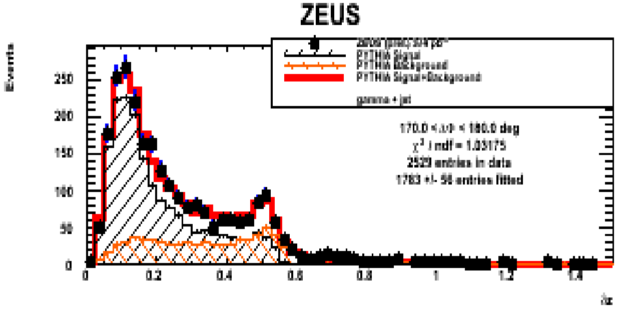






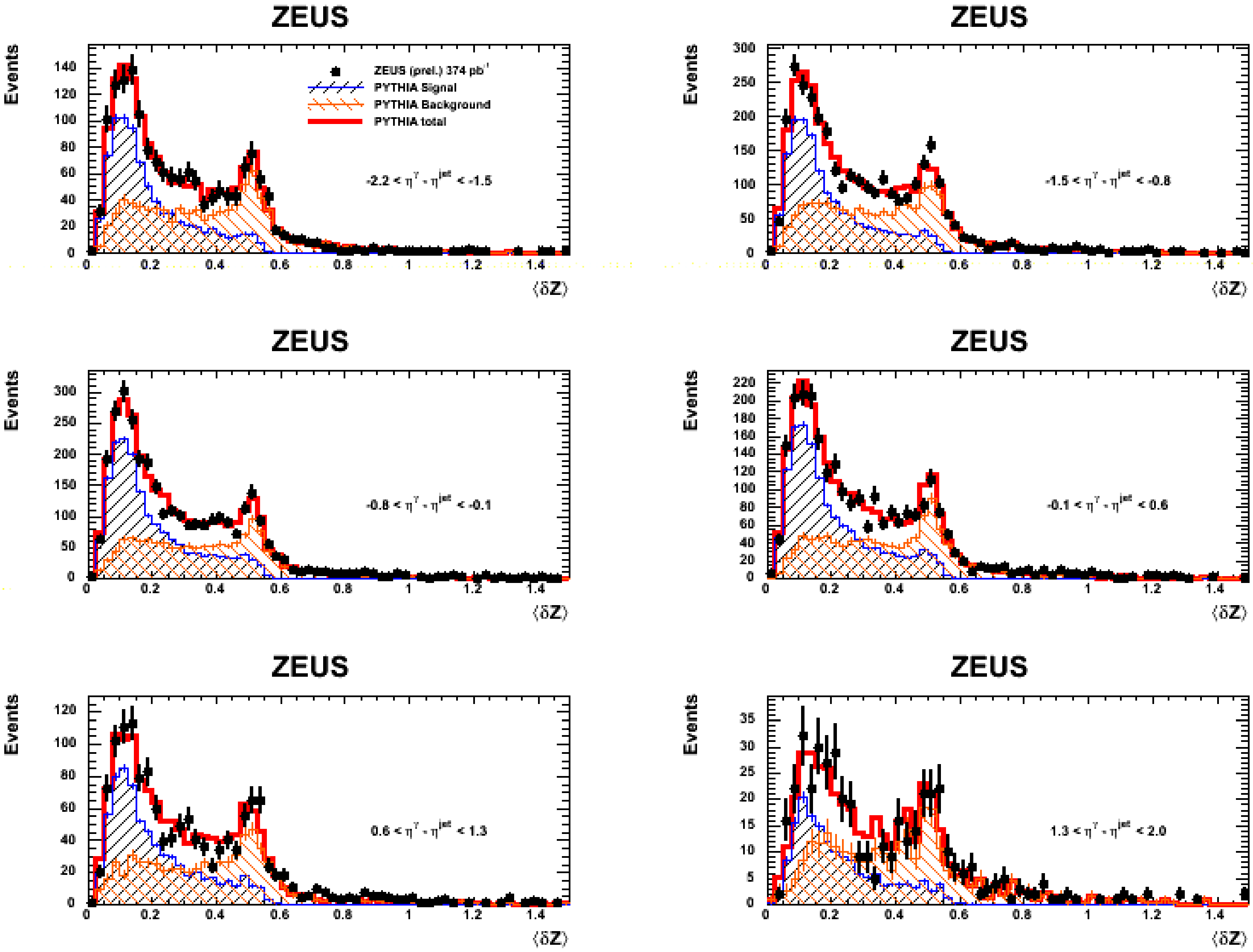




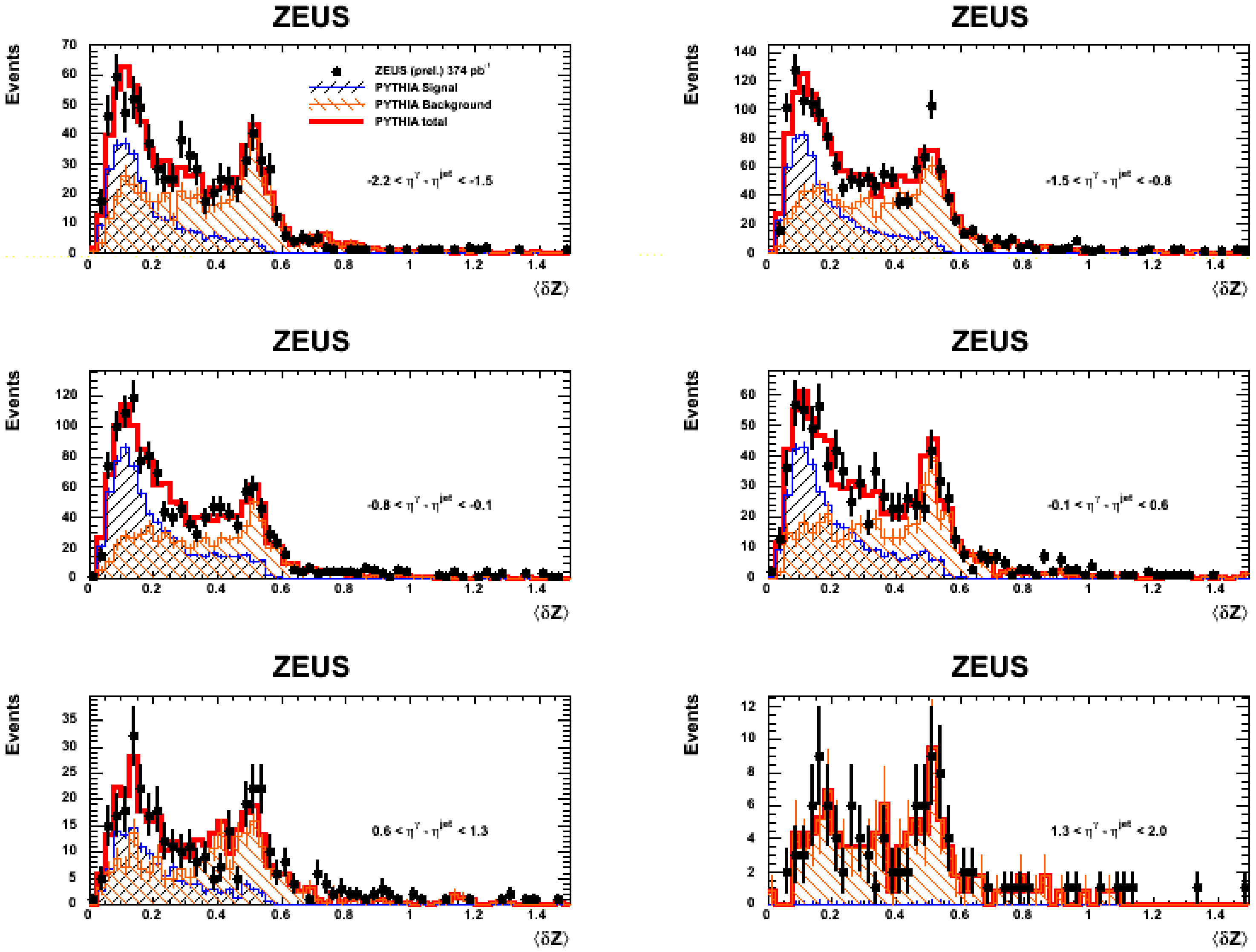


First bin 0 < ΔΦ < 90º:
χ^2 / n.d.f. = 0.92611
fitted photons 38 ± 13
Small statistics

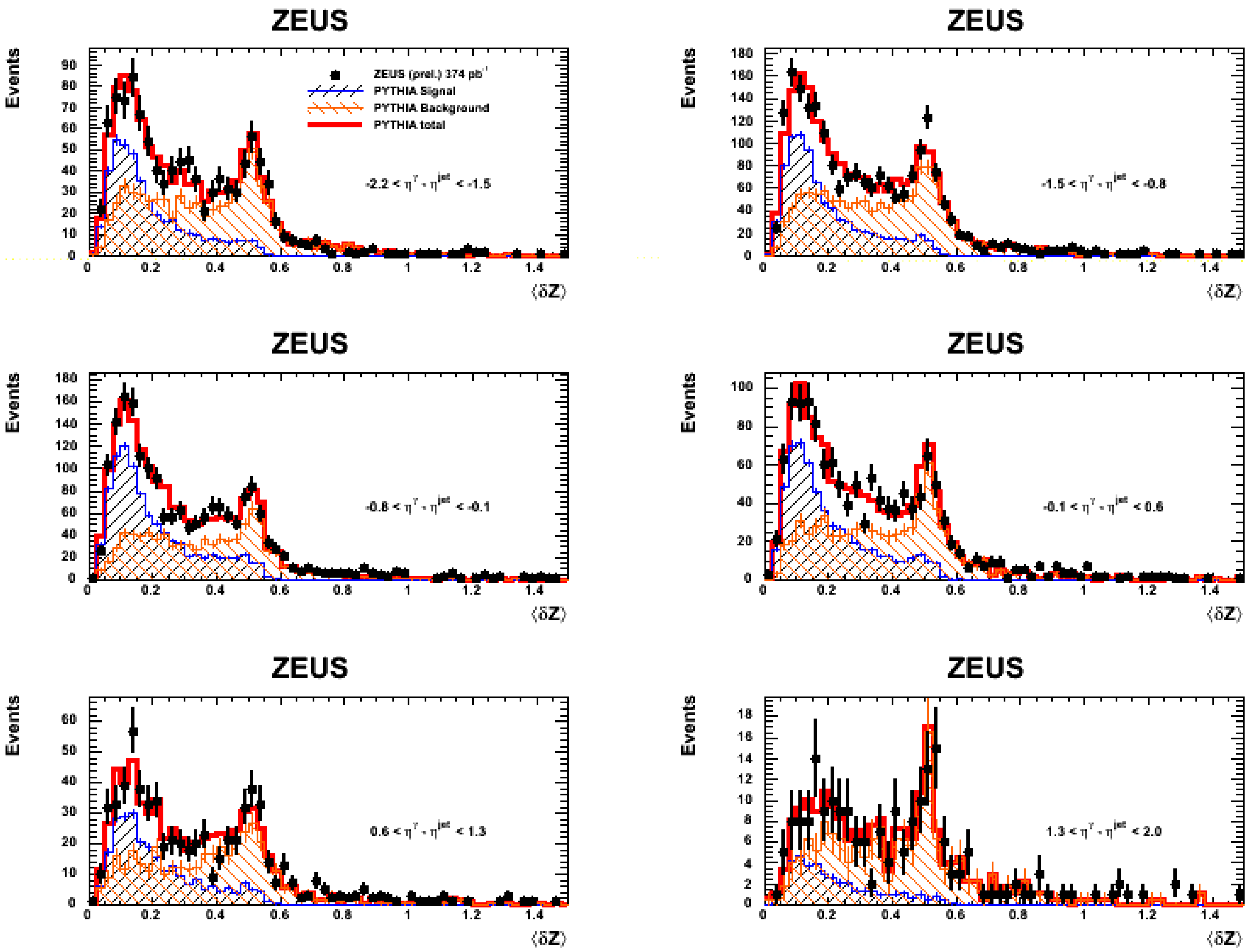
<δZ> Fits in $\eta^{\gamma} - \eta^{jet}$ bins. All x_{γ}



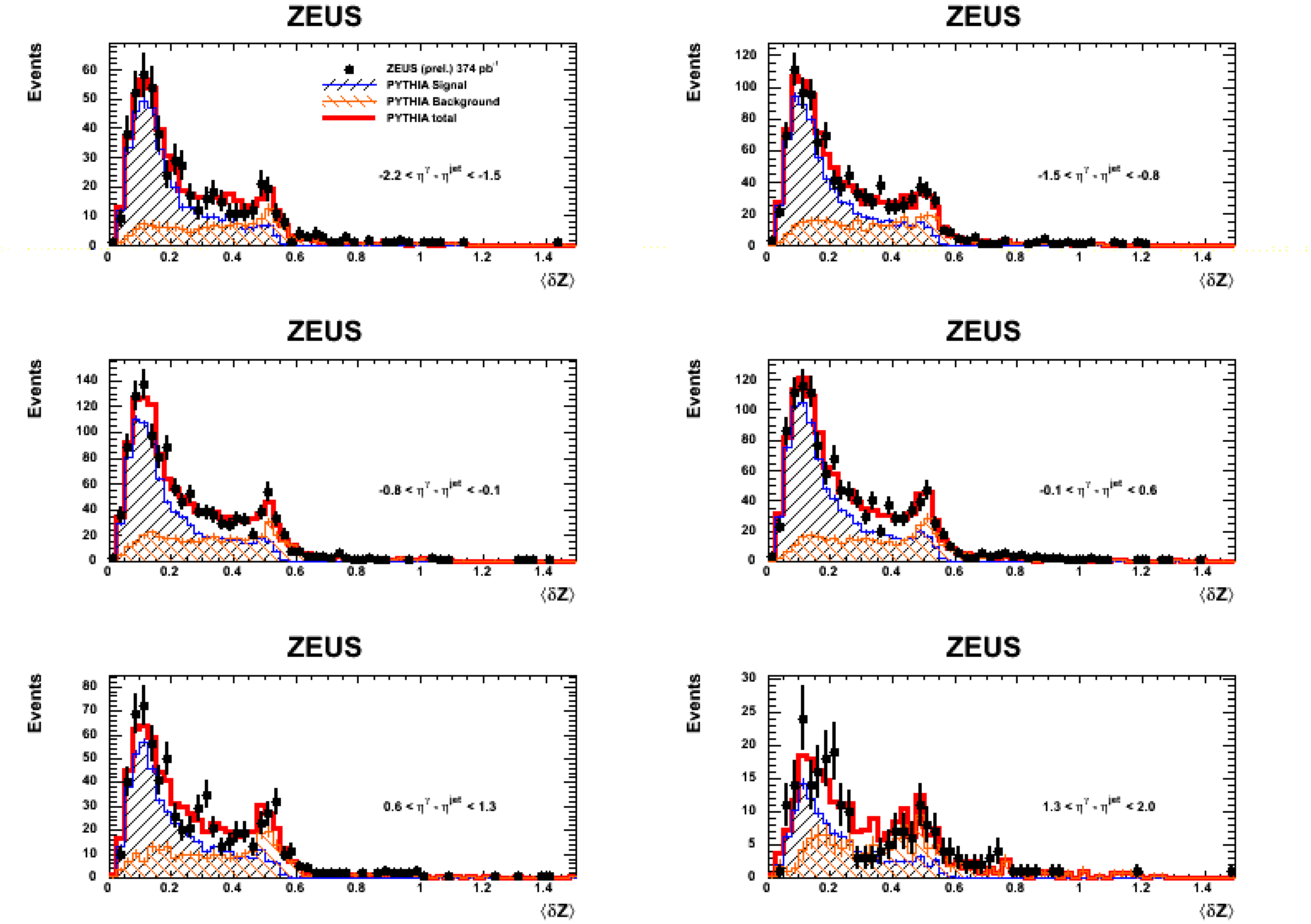
$\langle\delta Z\rangle$ Fits in η^{γ} - η^{jet} bins. $x_{\gamma} < 0.7$



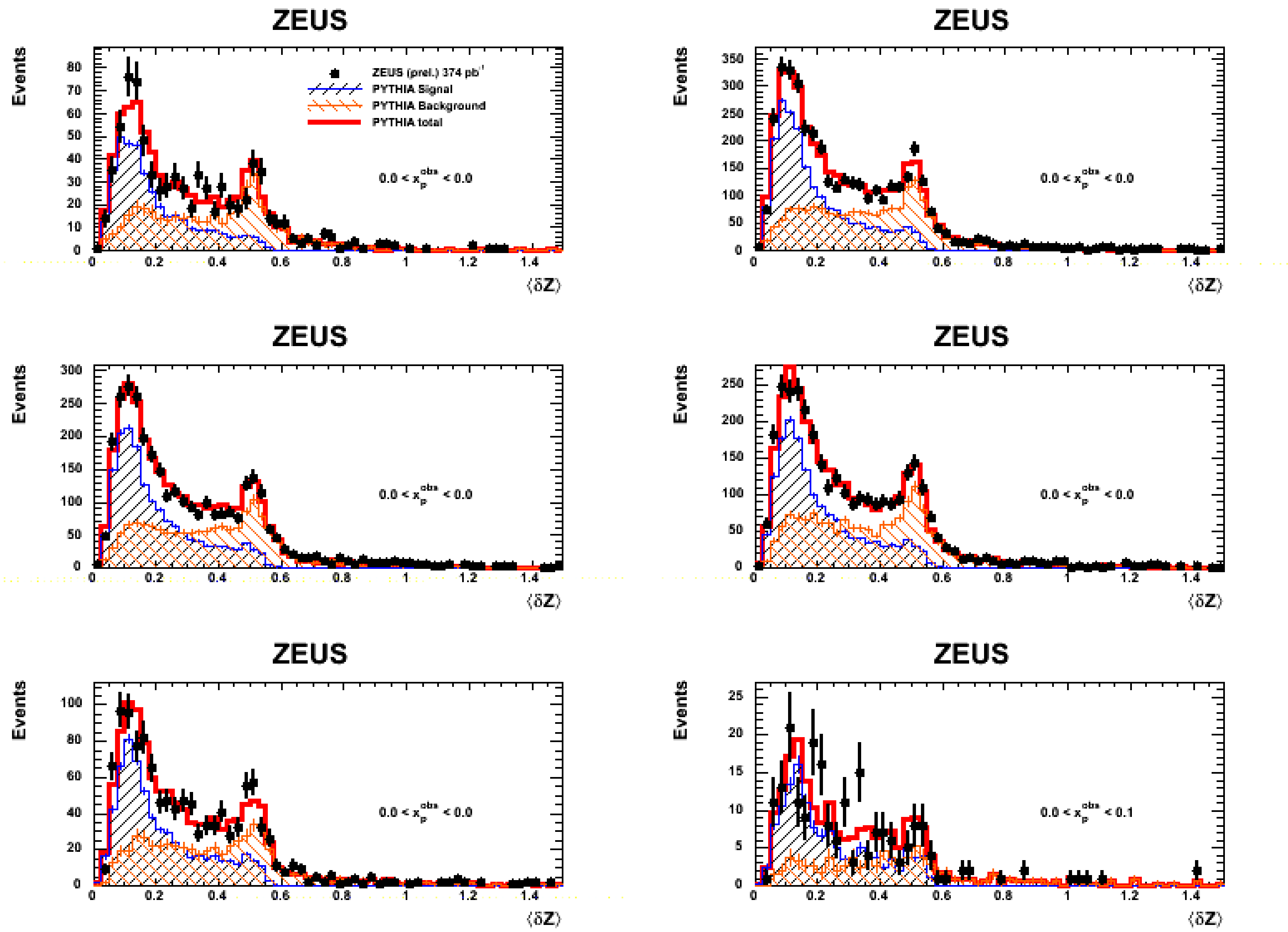
<δZ> Fits in η^γ - η^{jet} bins. x_γ < 0.8



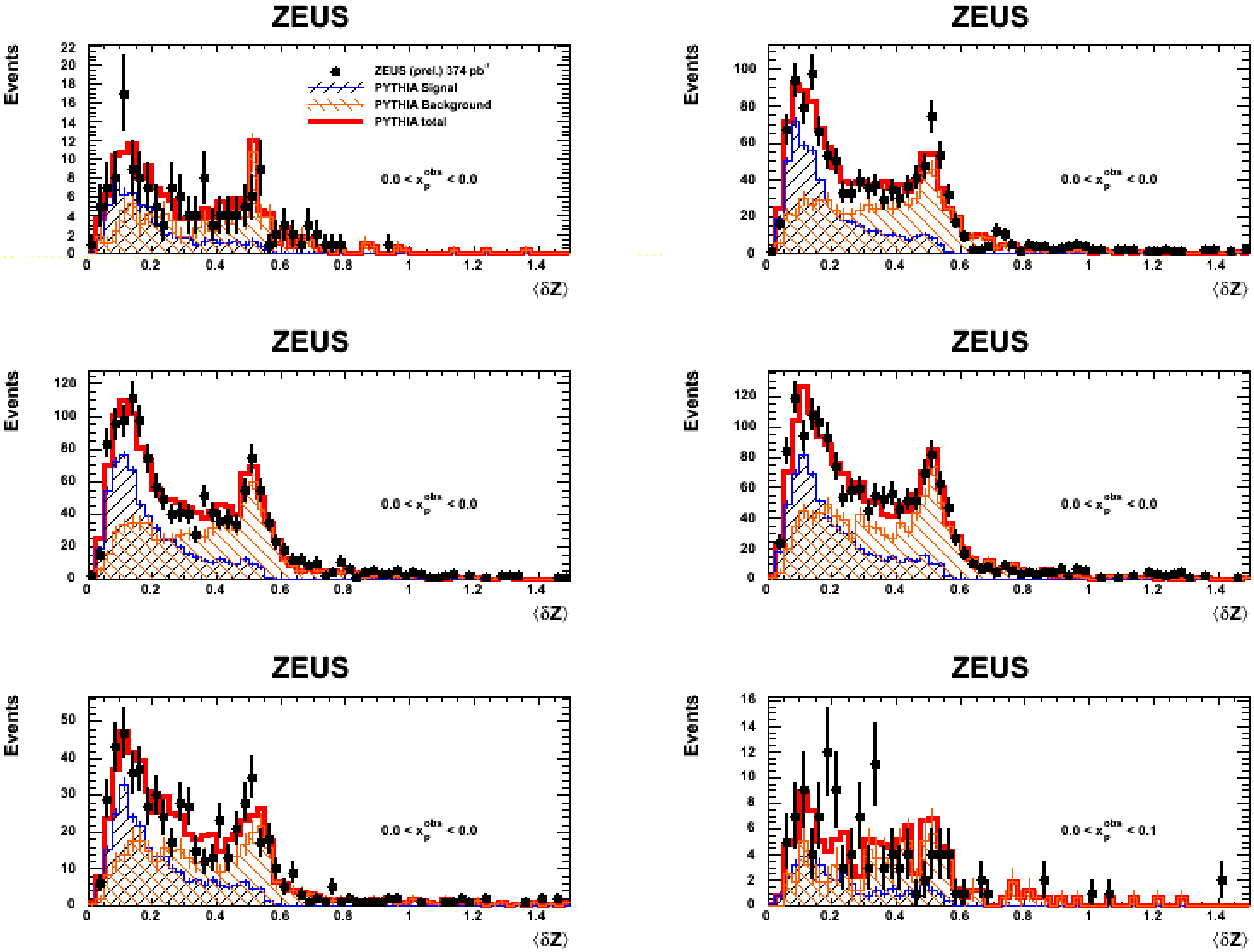
<δZ> Fits in η^{γ} - η^{jet} bins. x_{γ} > 0.8



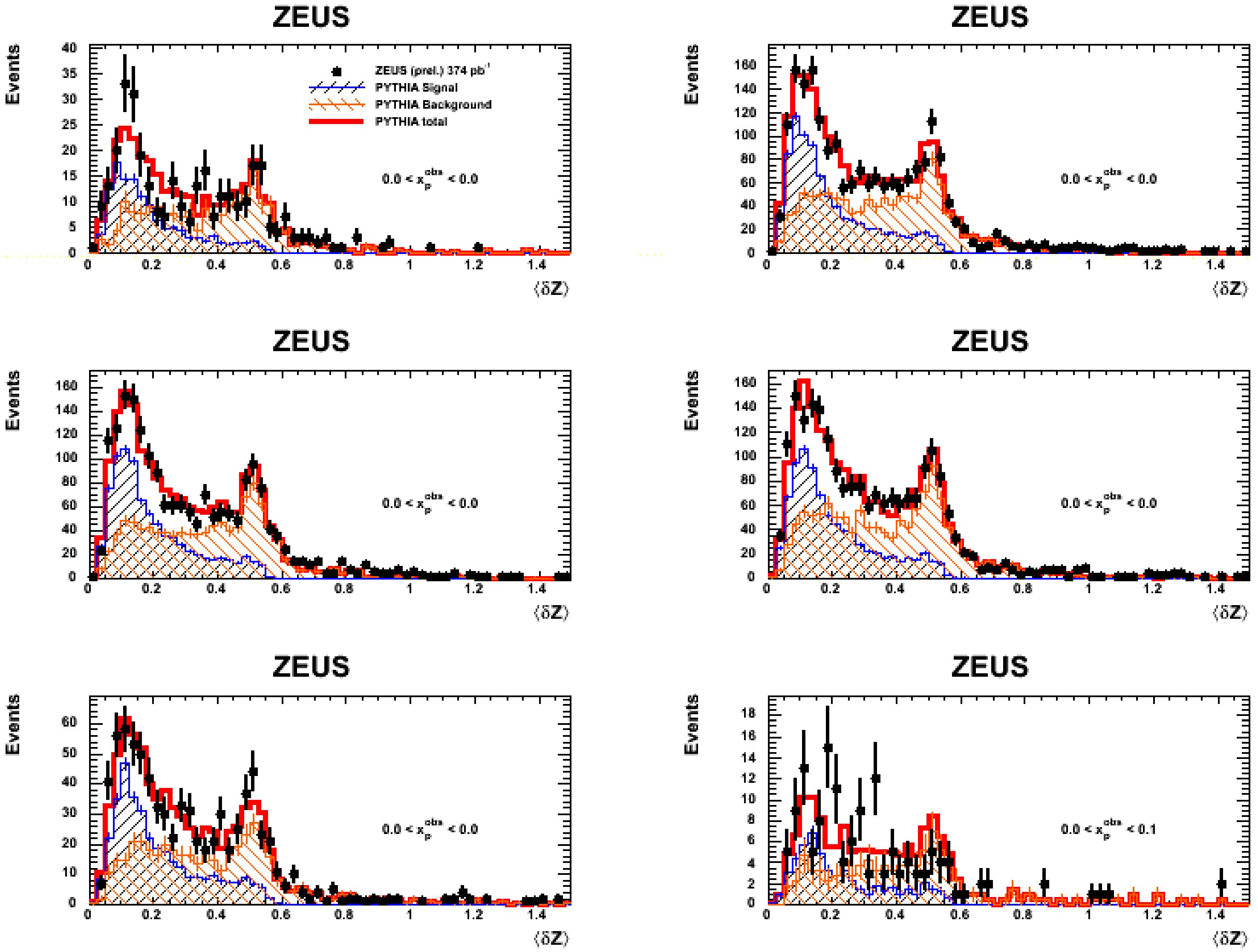
<δZ> Fits in x_p bins. All x_γ



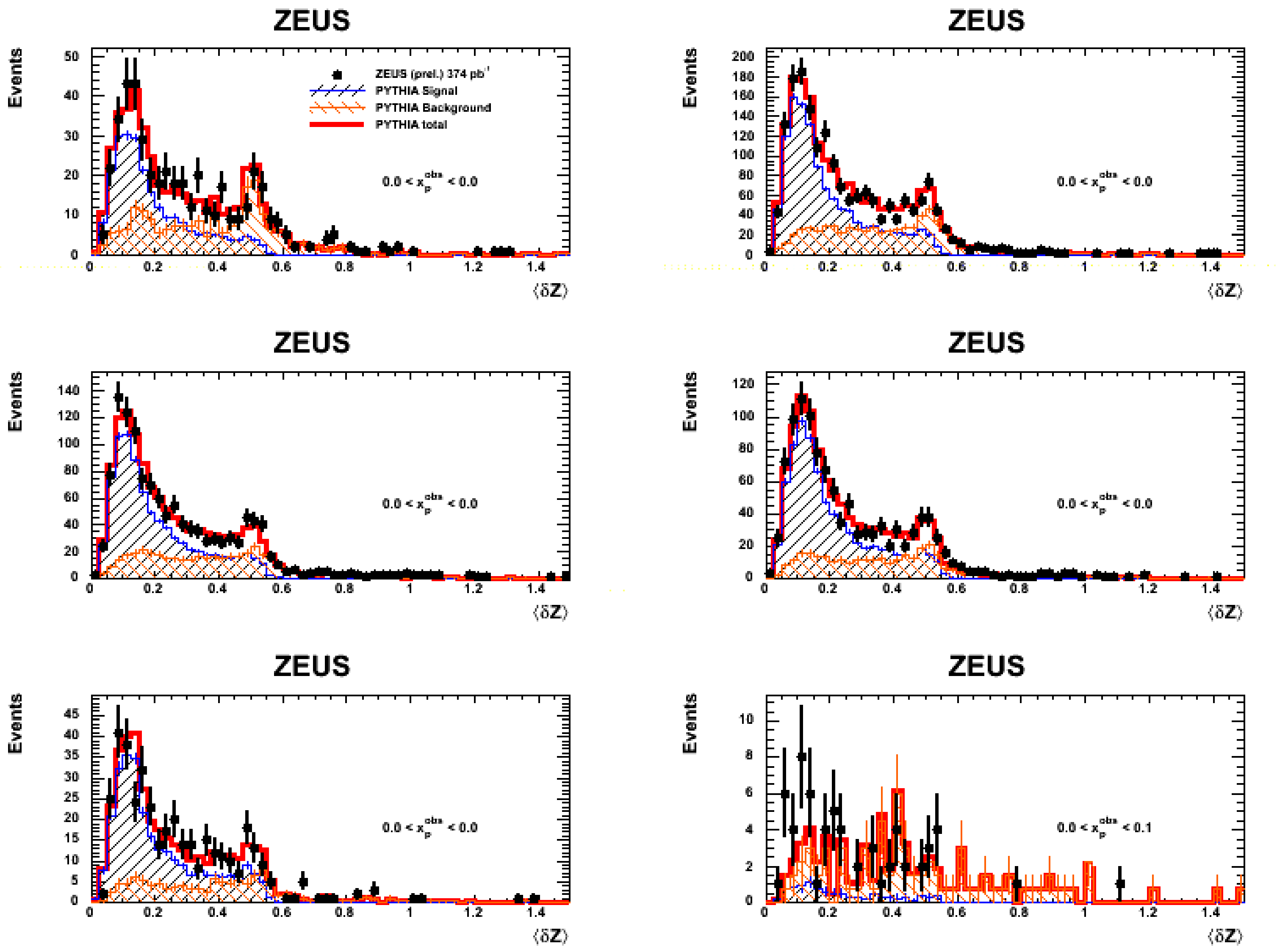
<δZ> Fits in x_p bins. $x_\gamma < 0.7$



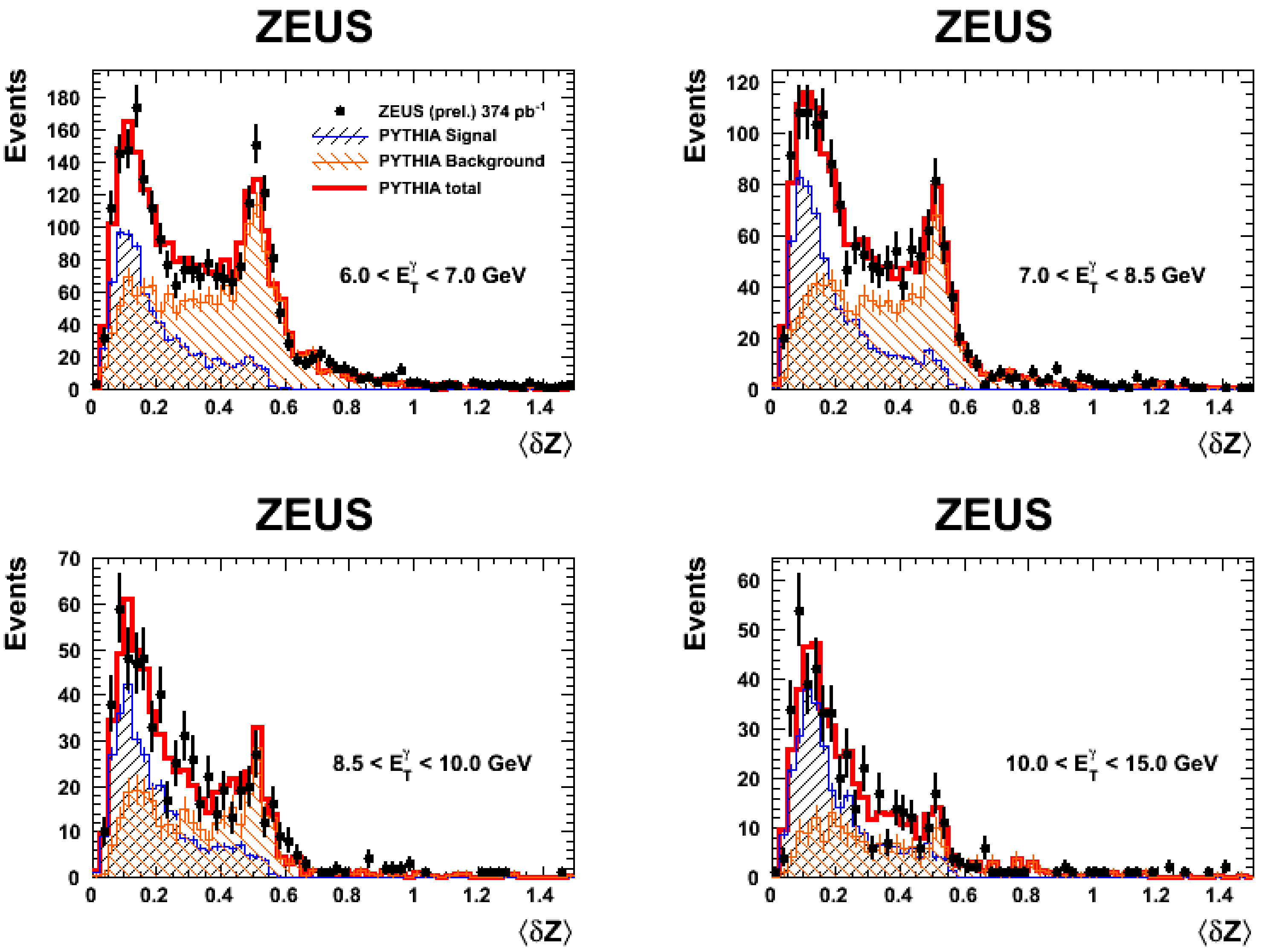
<δZ> Fits in x_p bins. $x_\gamma < 0.8$



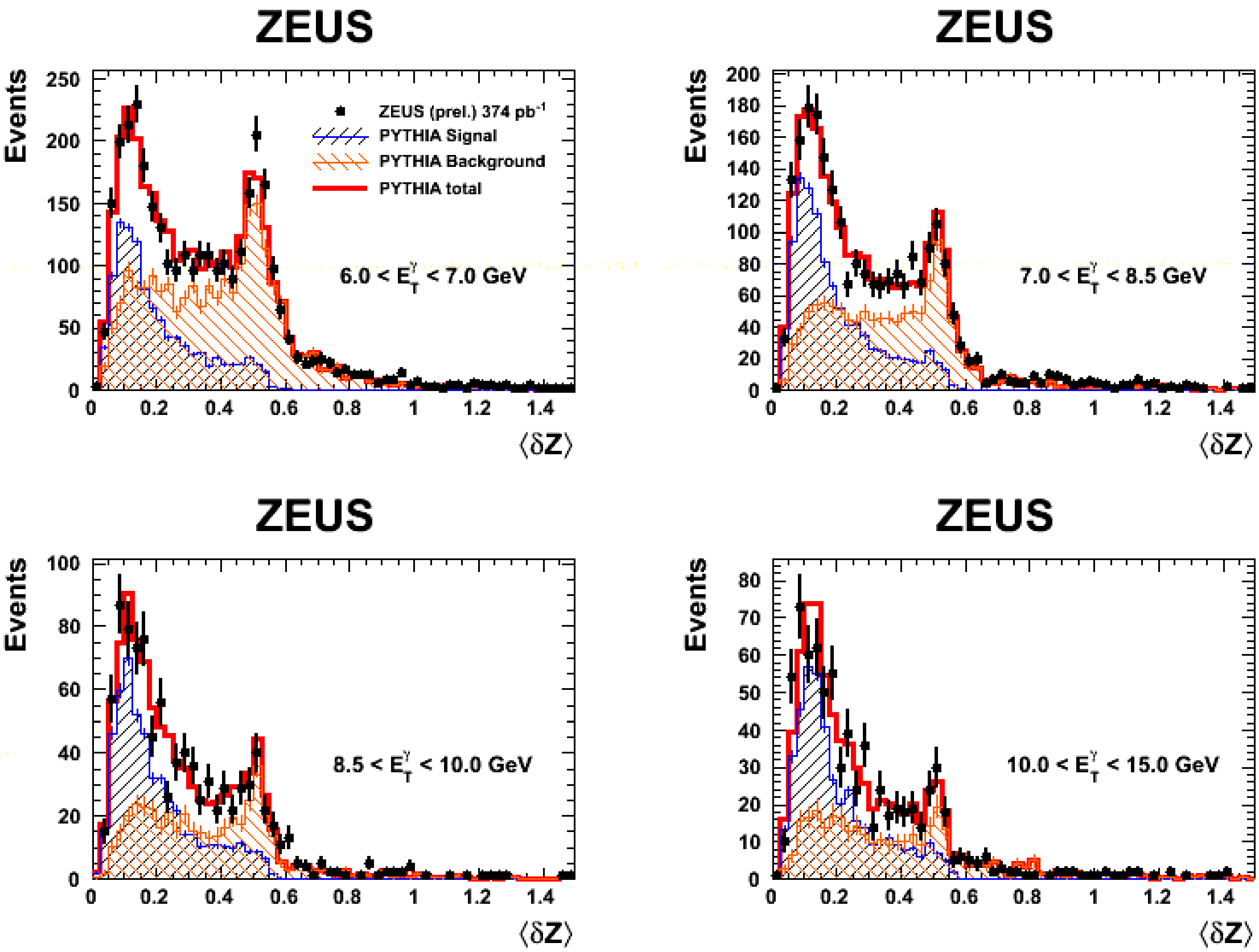
<δZ> Fits in x_p bins. x_γ > 0.8



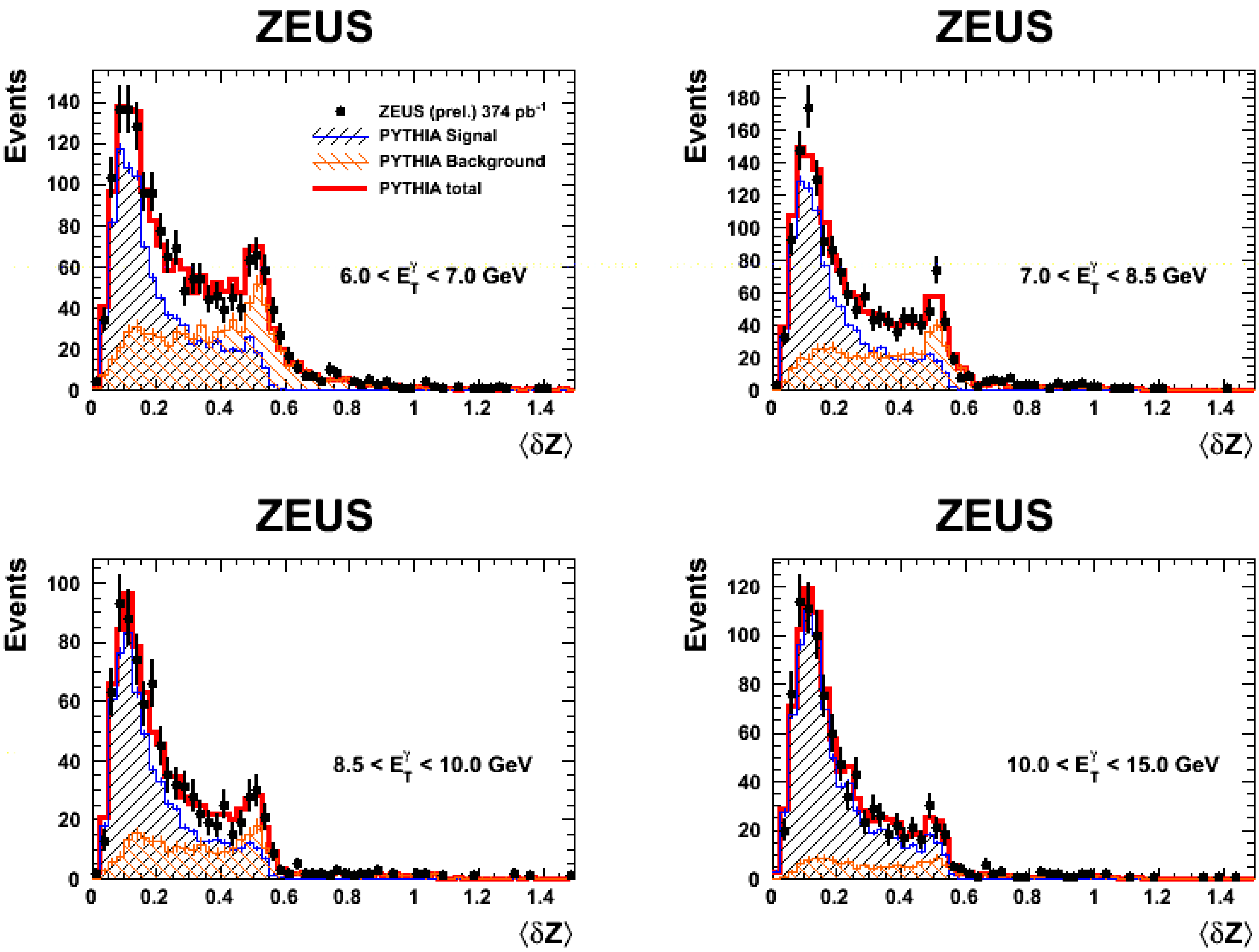
$\langle\delta Z\rangle$ Fits in E_T^{γ} bins. $x_{\gamma} < 0.7$



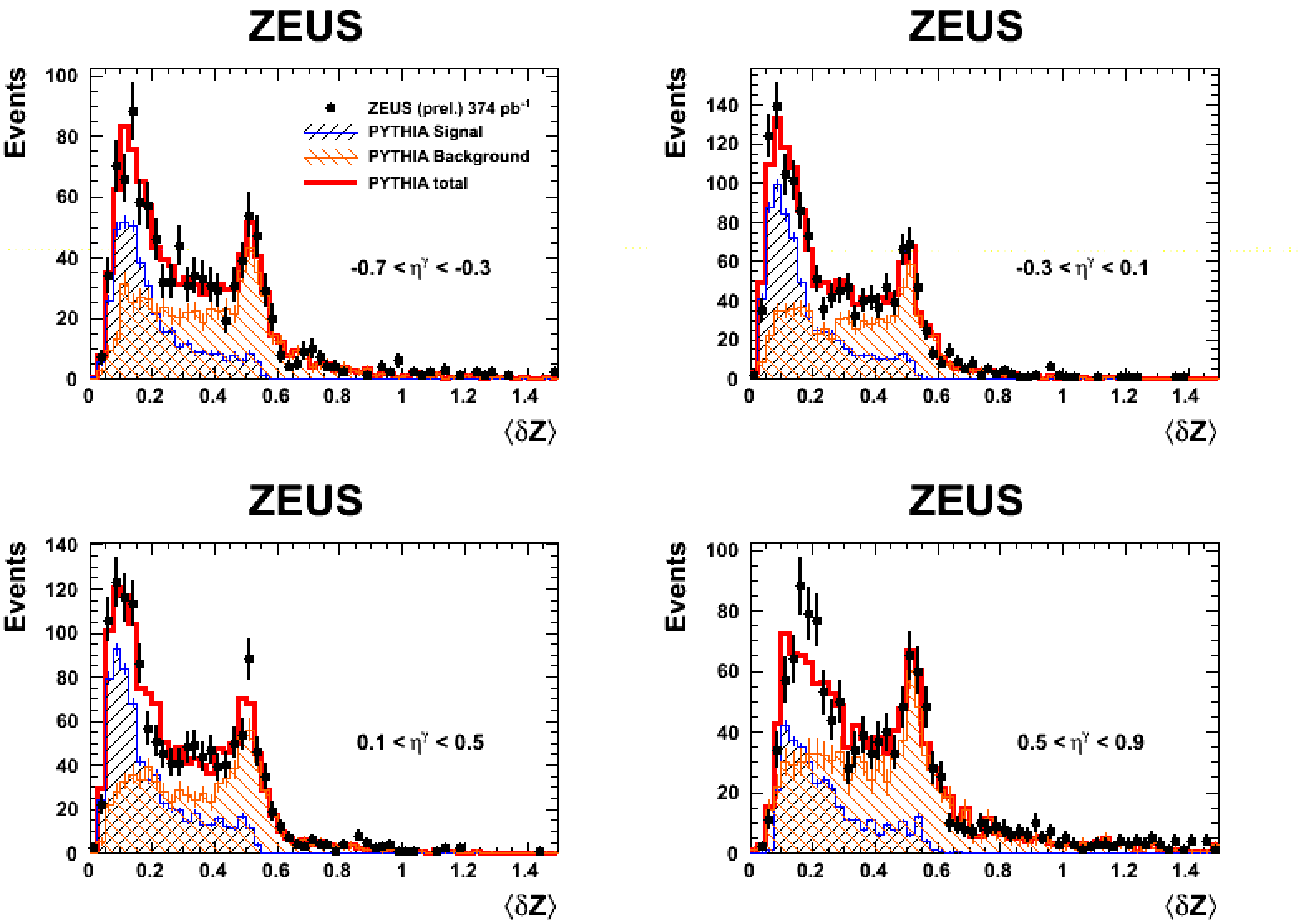
<δZ> Fits in E_T^γ bins. $x_\gamma < 0.8$



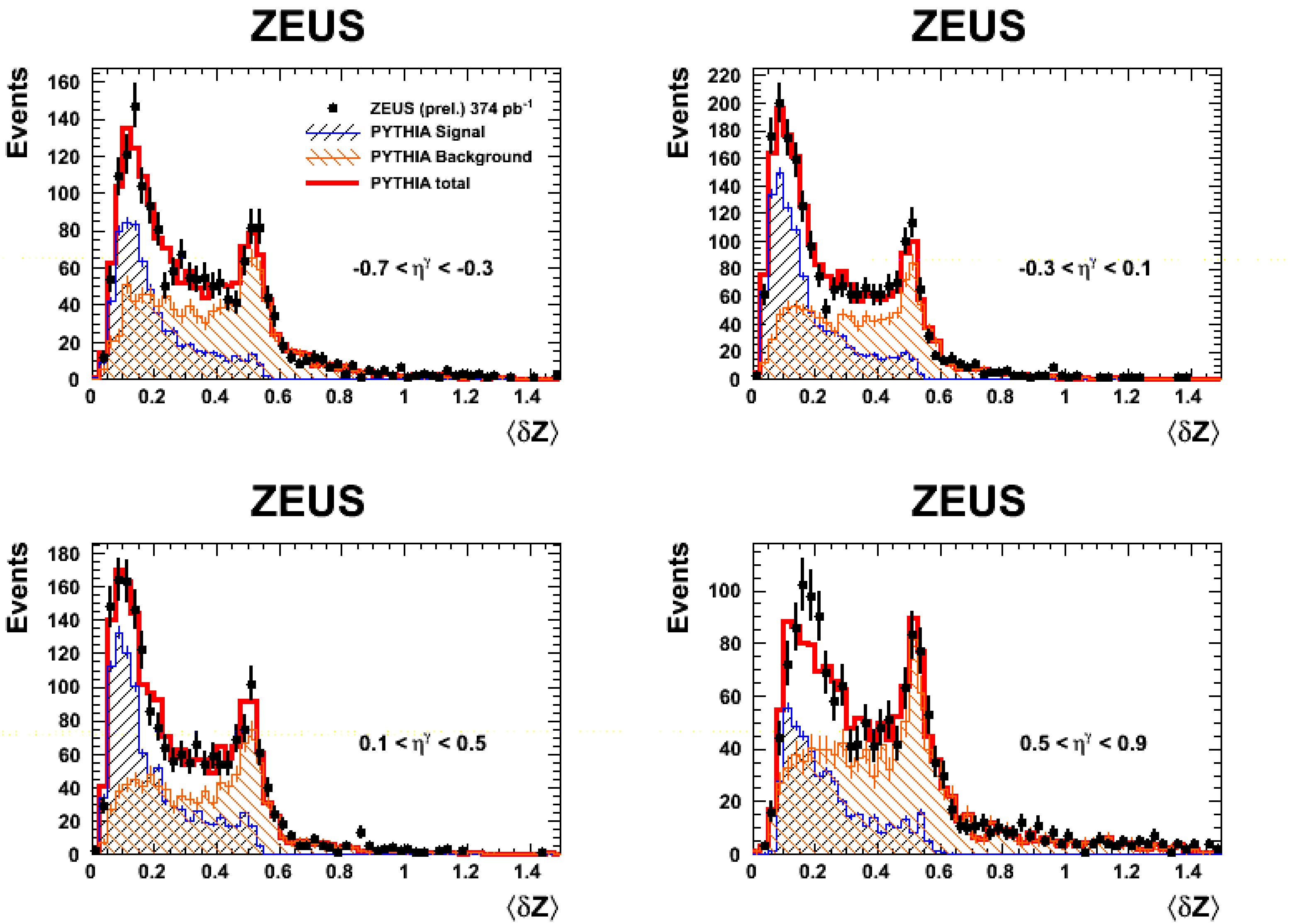
<δZ> Fits in E_T^γ bins. $x_\gamma > 0.8$



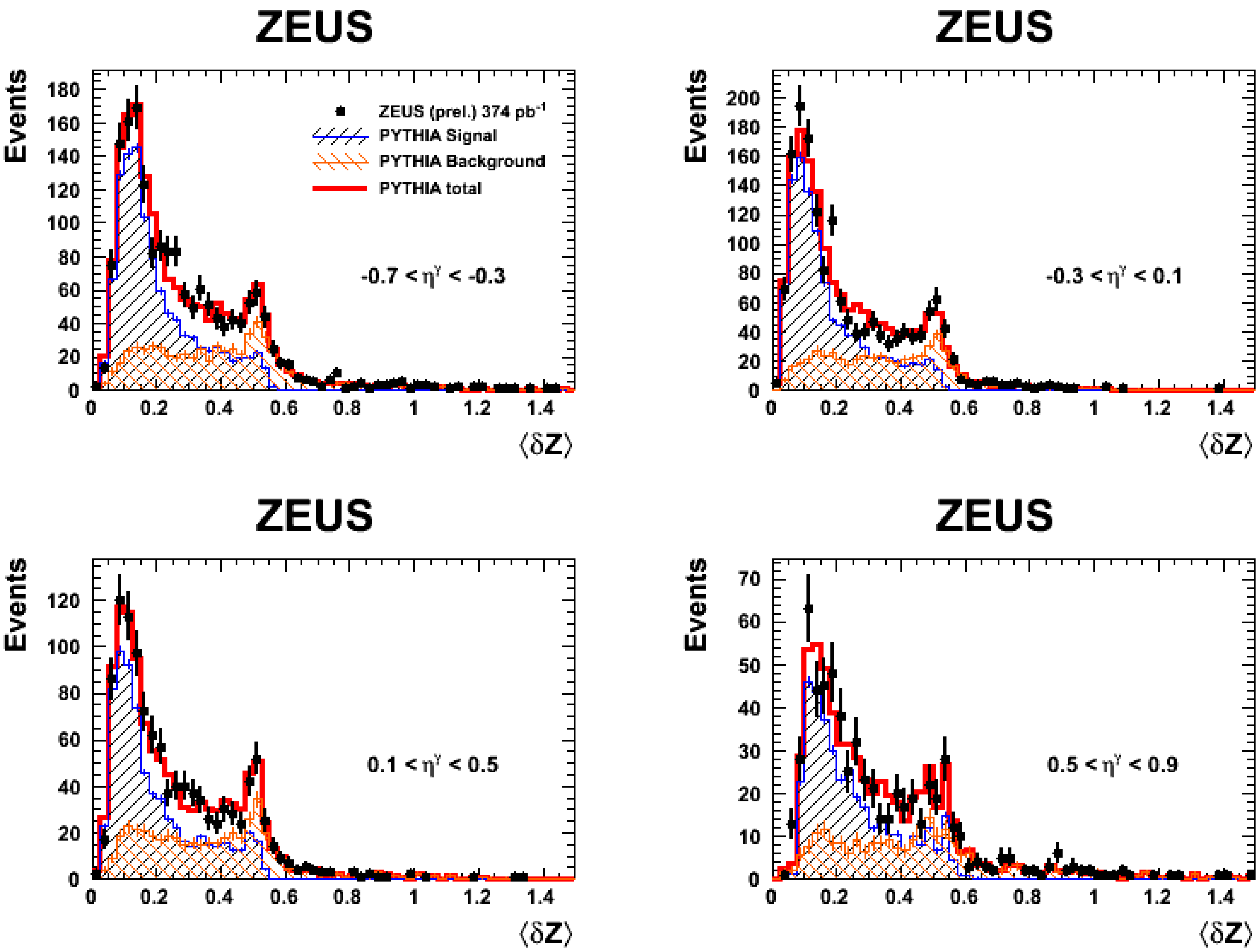
<δZ> Fits in η^γ bins. $x_\gamma < 0.7$



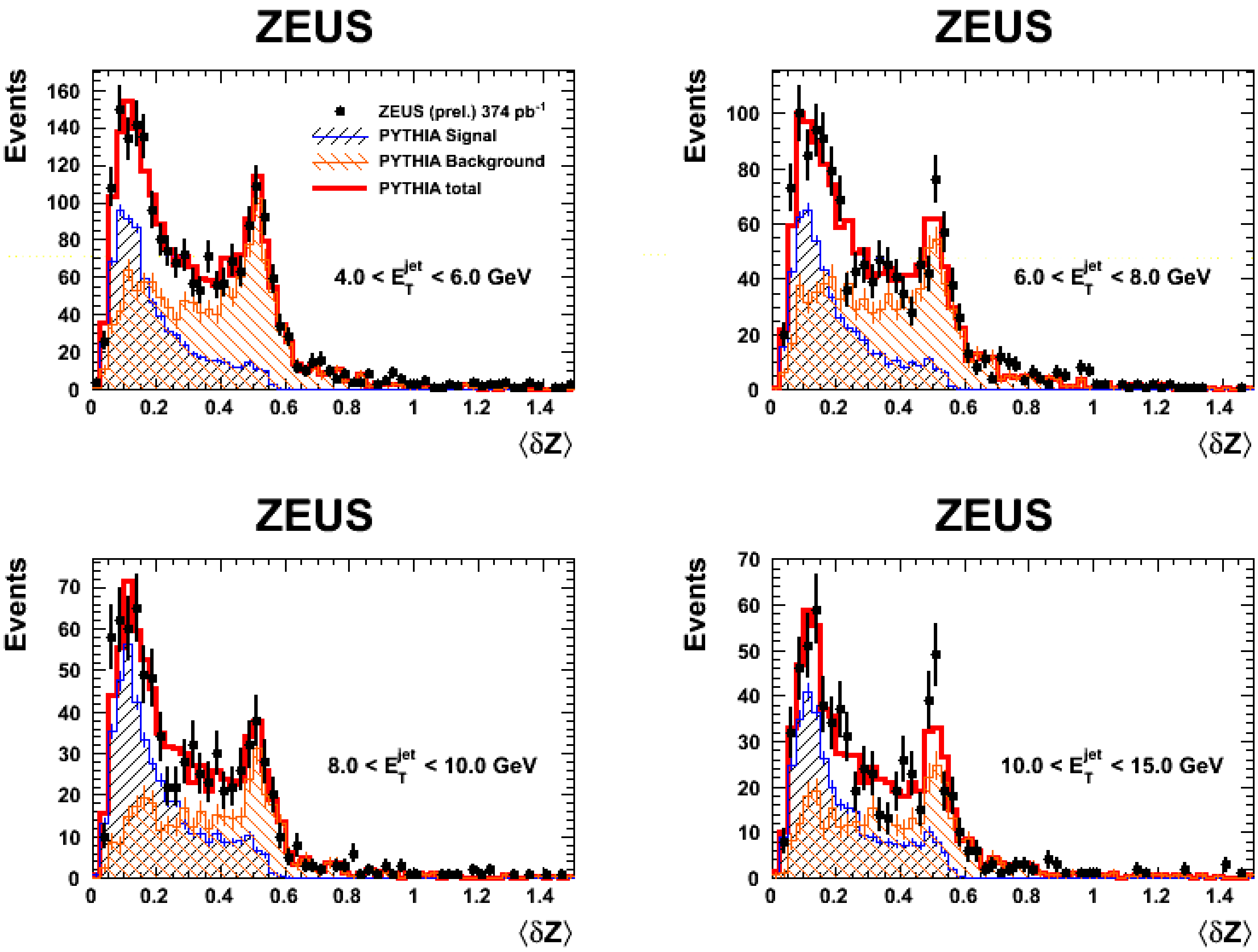
$\langle\delta Z\rangle$ Fits in η^{γ} bins. $x_{\gamma} < 0.8$



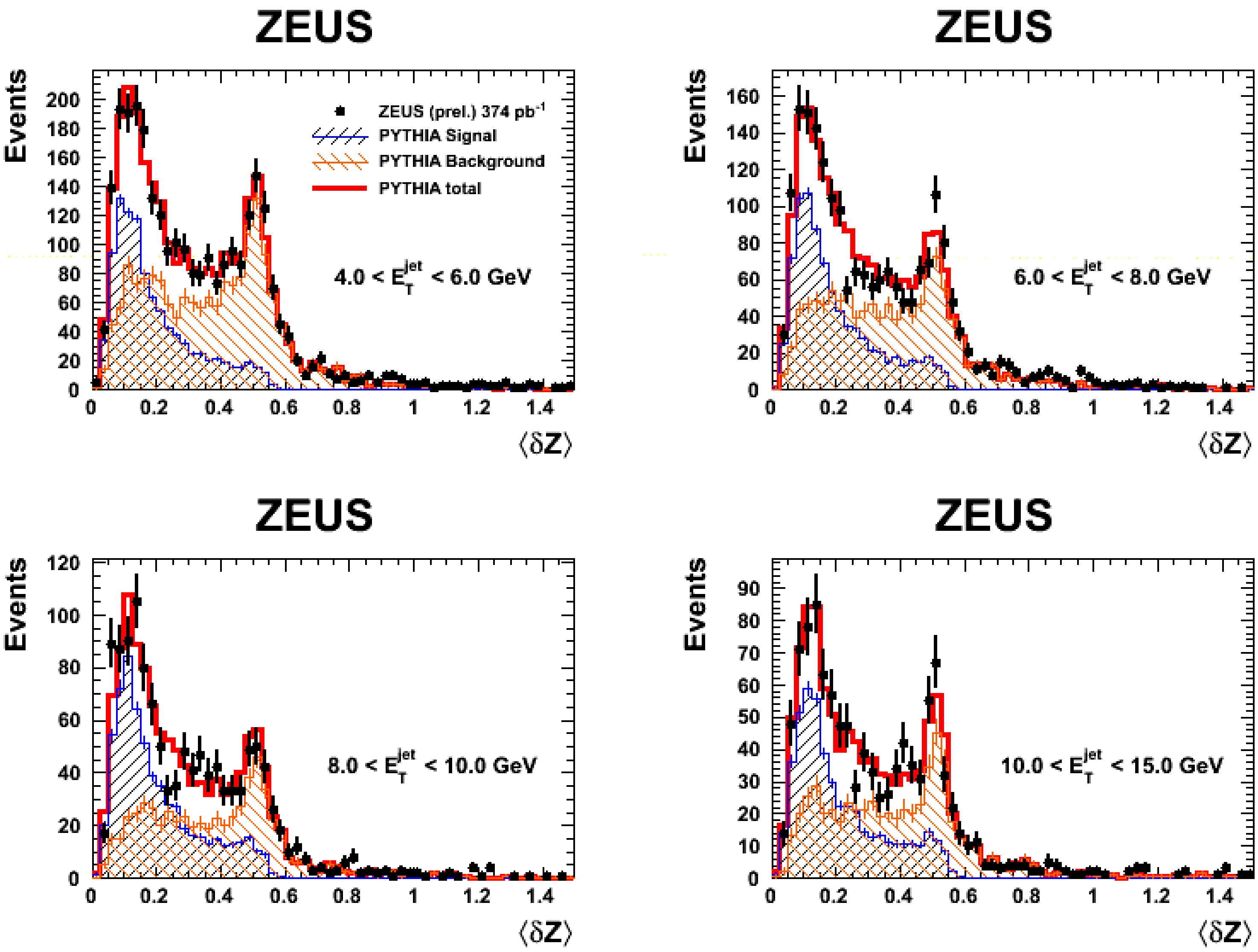
<δZ> Fits in η^γ bins. $x_\gamma > 0.8$



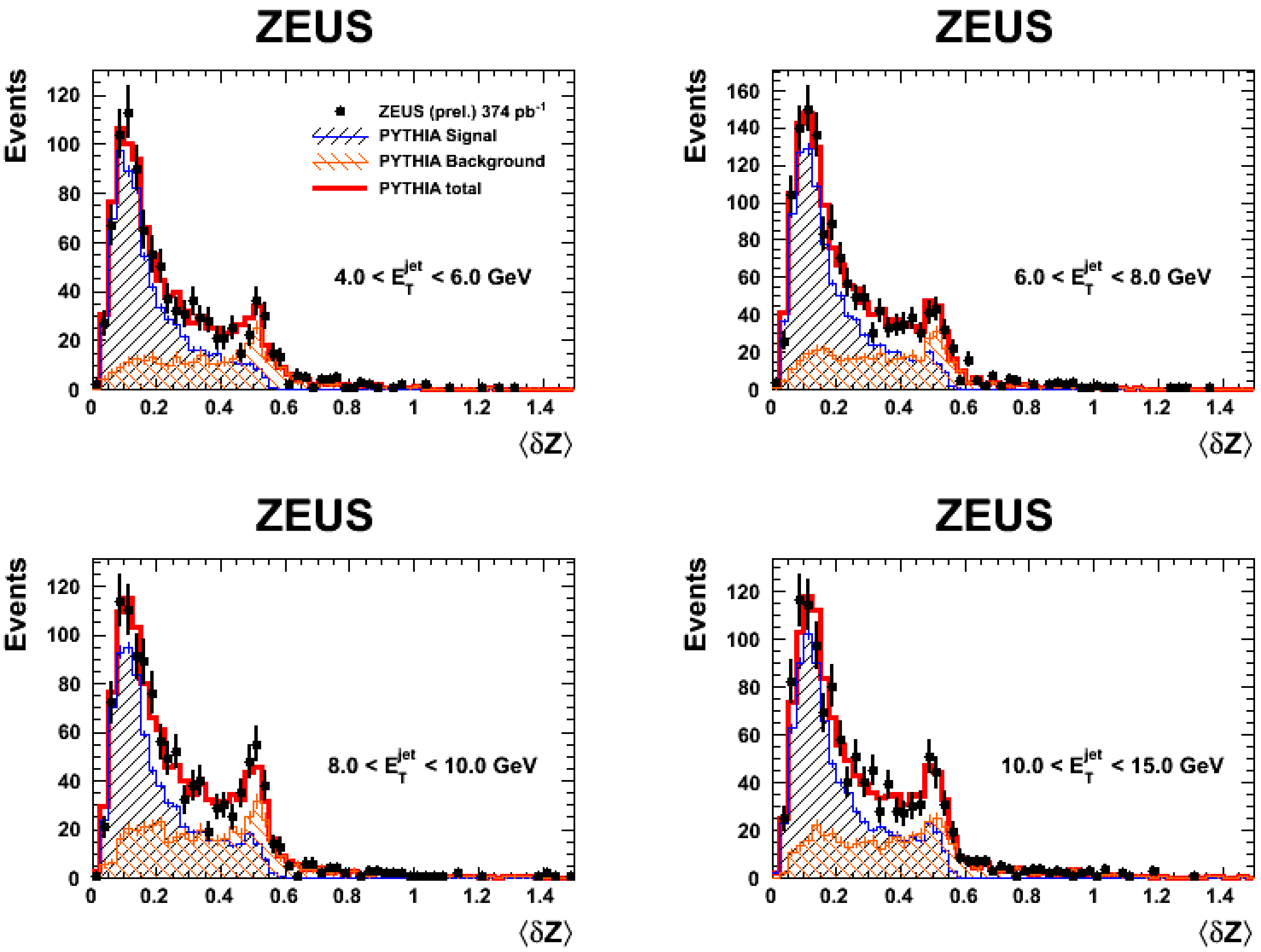
<δZ> Fits in E_T^{jet} bins. $x_\gamma < 0.7$



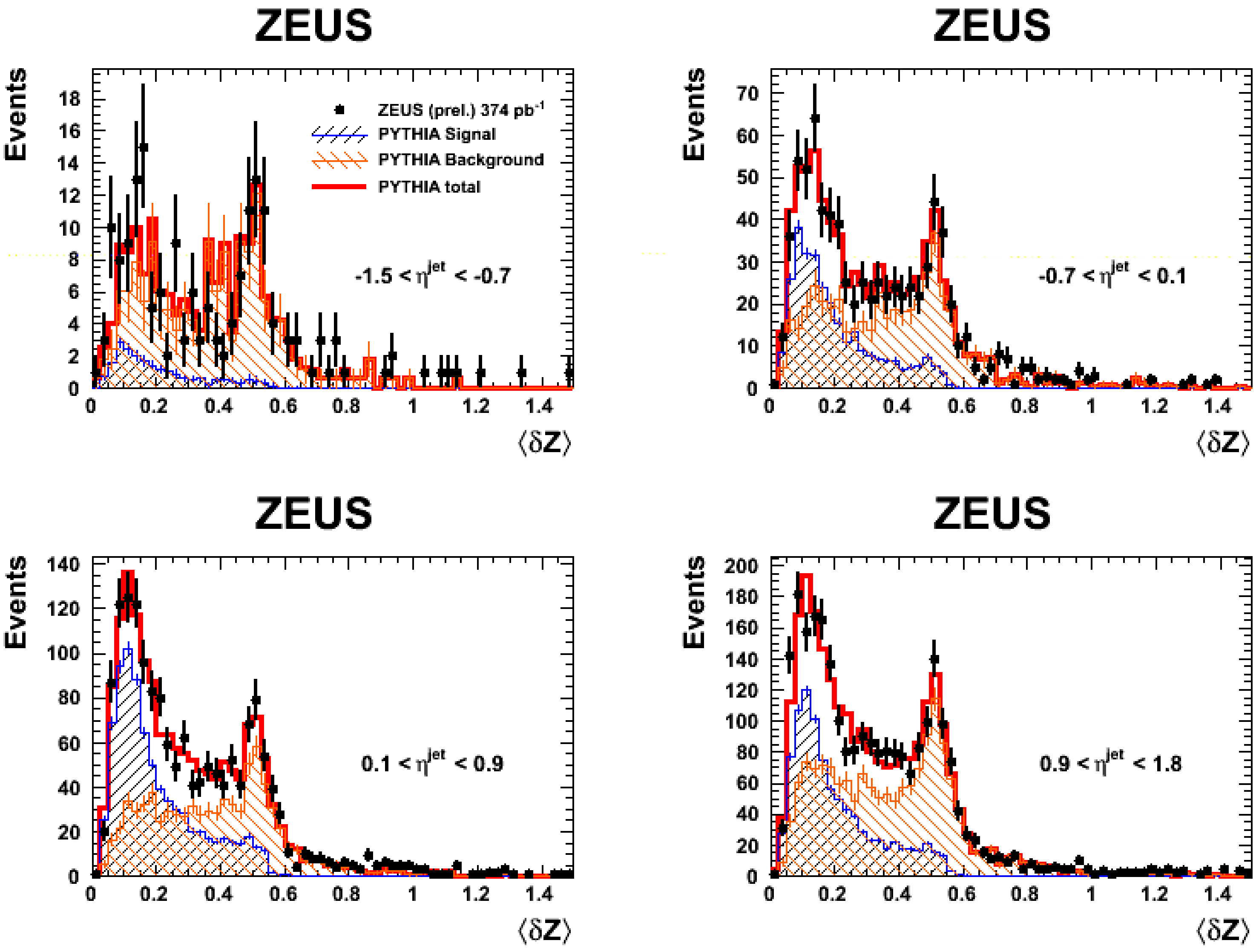
<δZ> Fits in E_T^{jet} bins. $x_\gamma < 0.8$



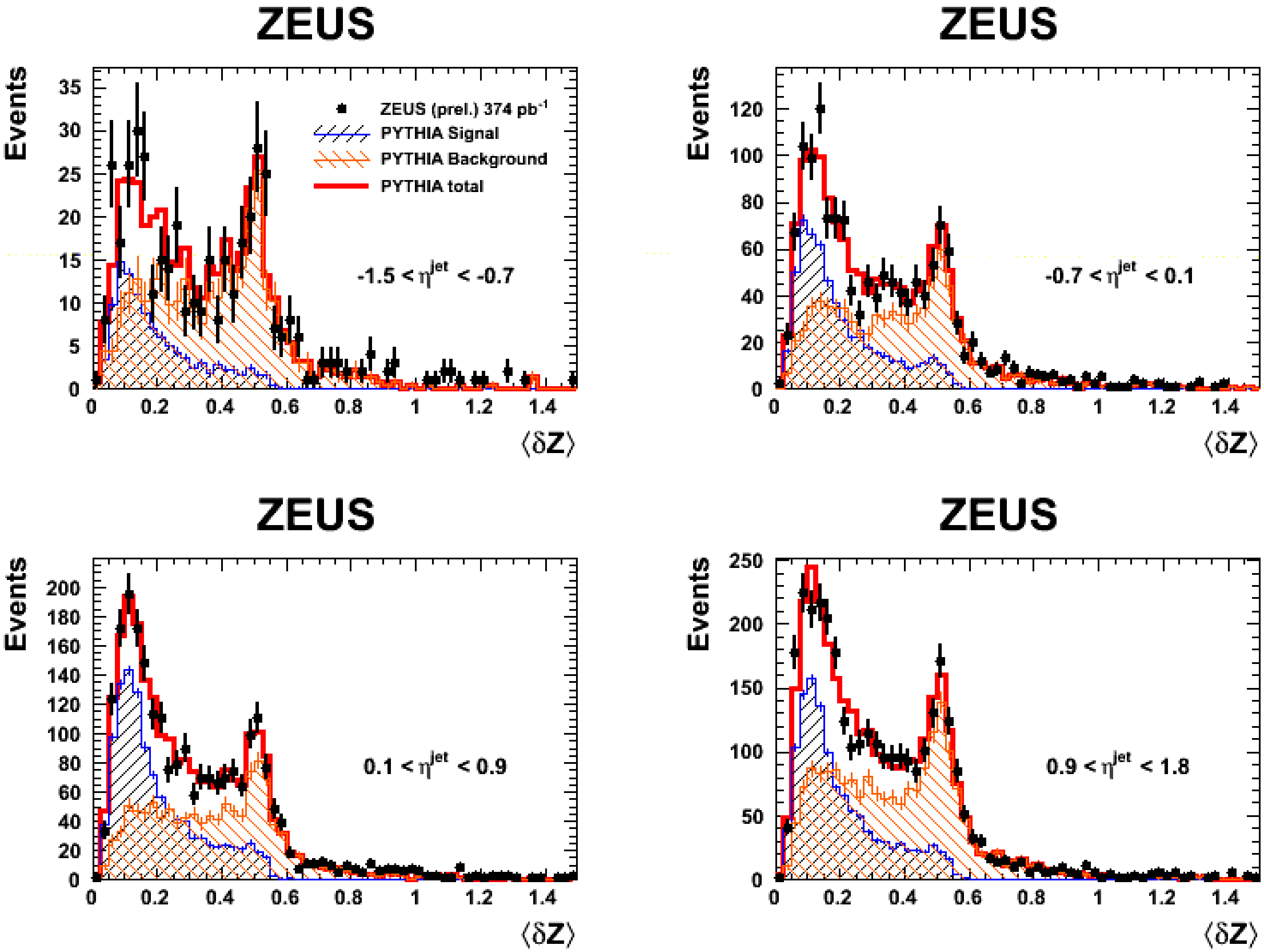
<δZ> Fits in E_T^{jet} bins. $x_\gamma > 0.8$



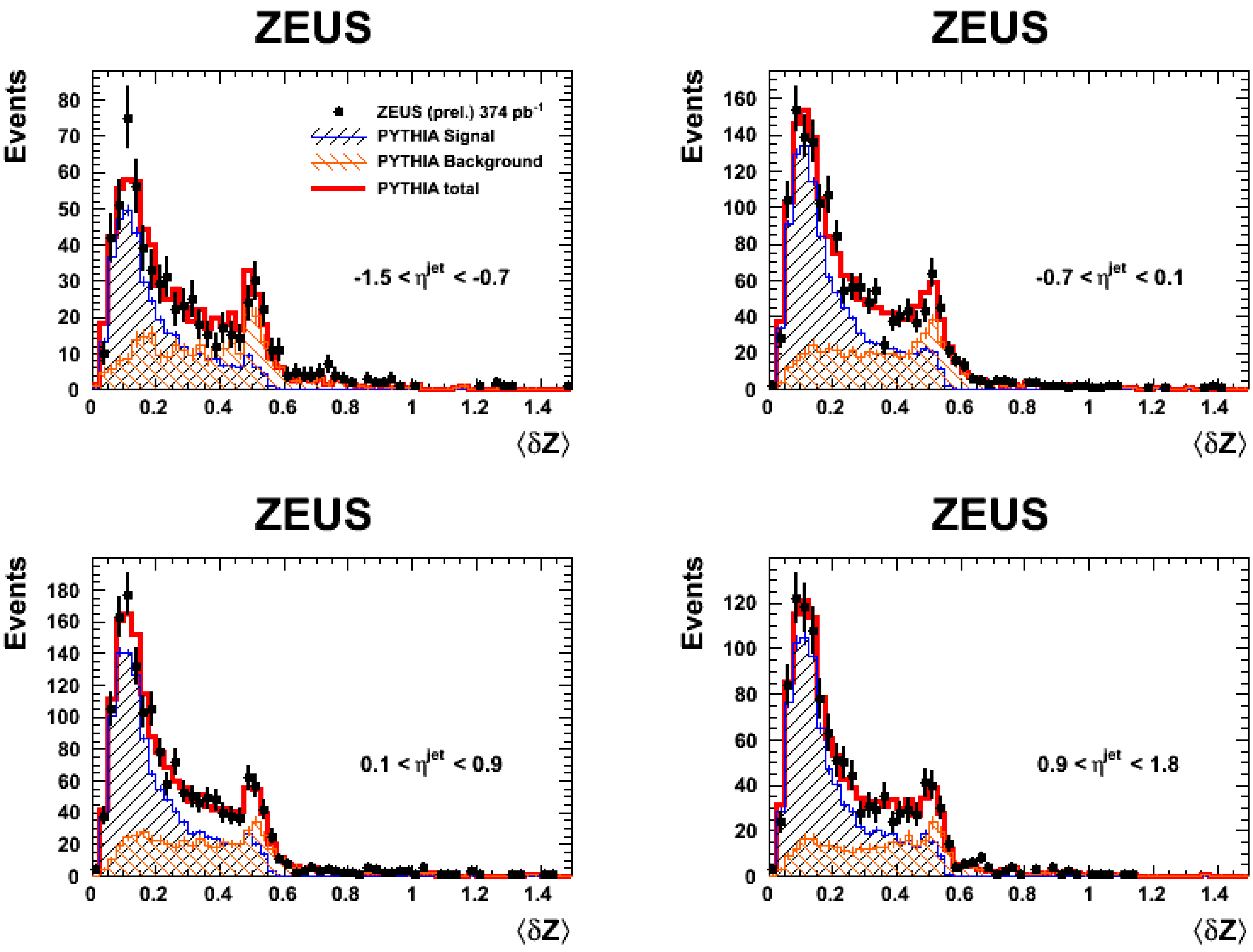
$\langle \delta Z \rangle$ Fits in η^{jet} bins. $x_\gamma < 0.7$



<δZ> Fits in η^{jet} bins. $x_\gamma < 0.8$

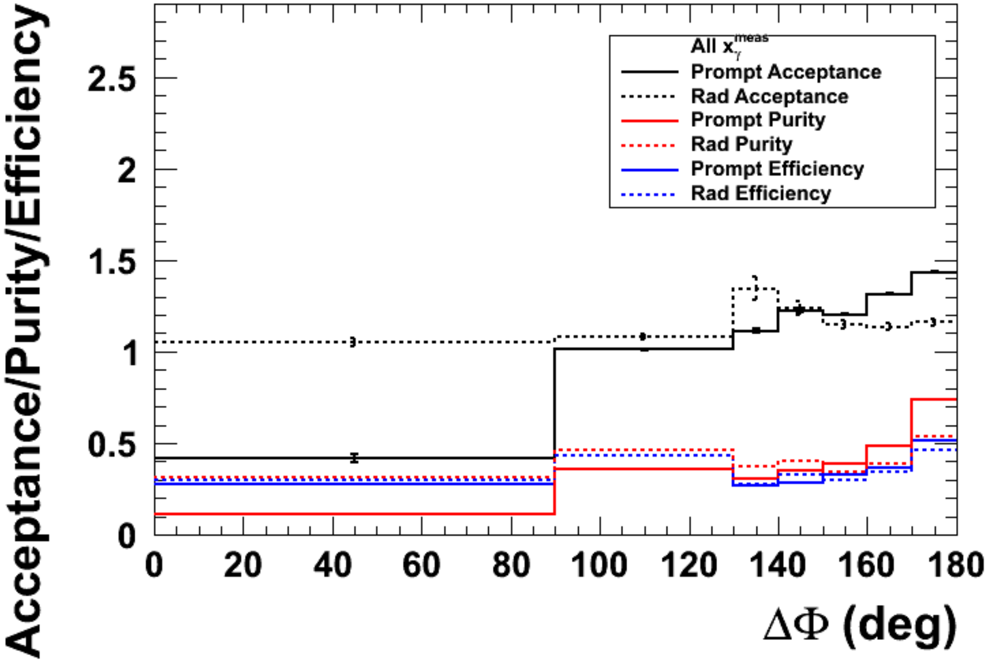


$<\delta Z>$ Fits in η^{jet} bins. $x_\gamma > 0.8$

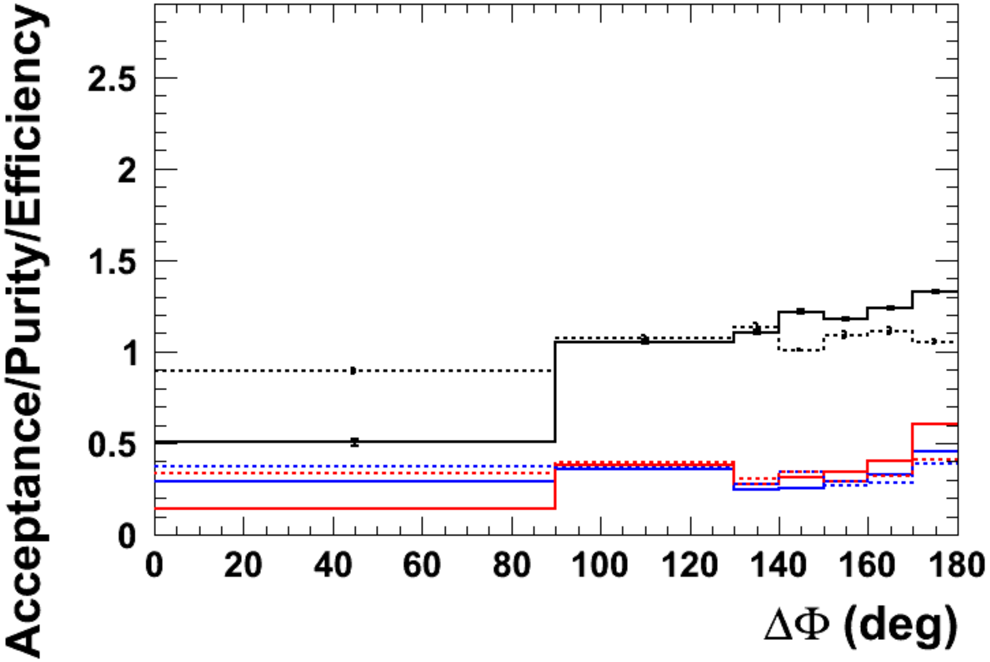


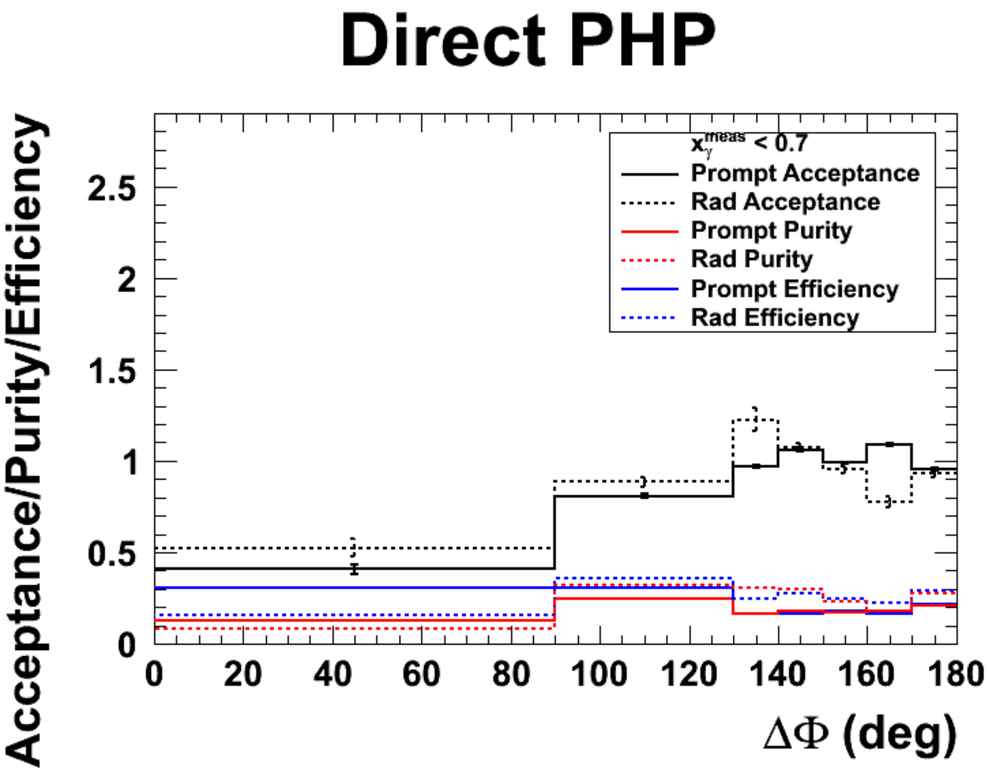
Acceptance, purity, efficiency

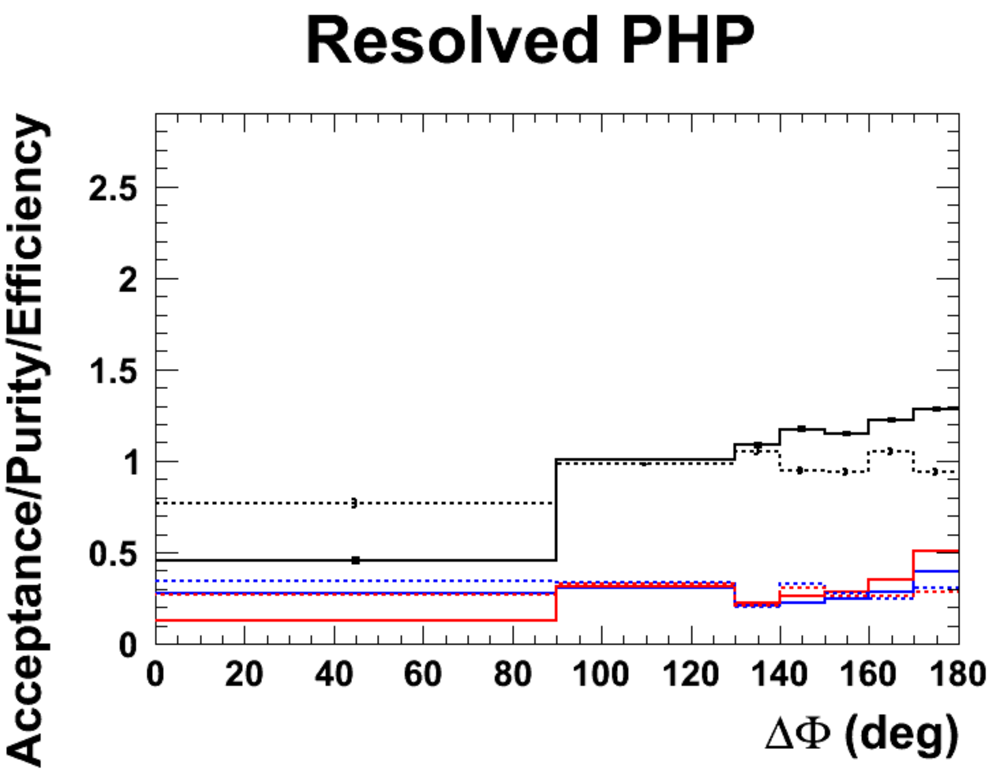
Direct PHP

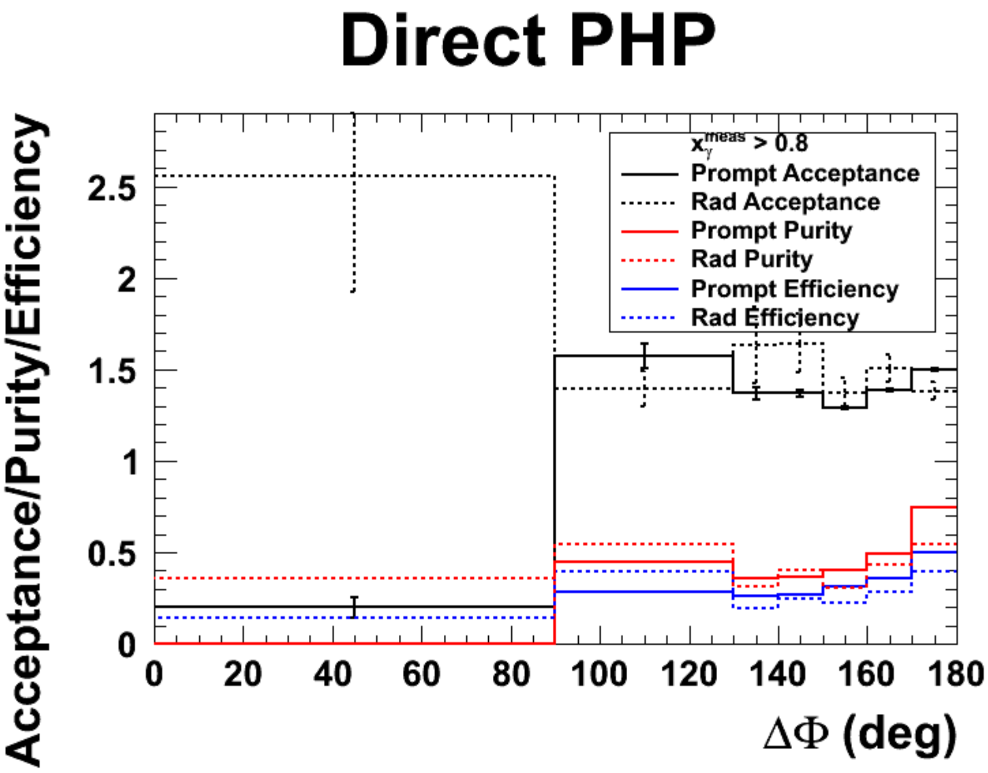


Resolved PHP

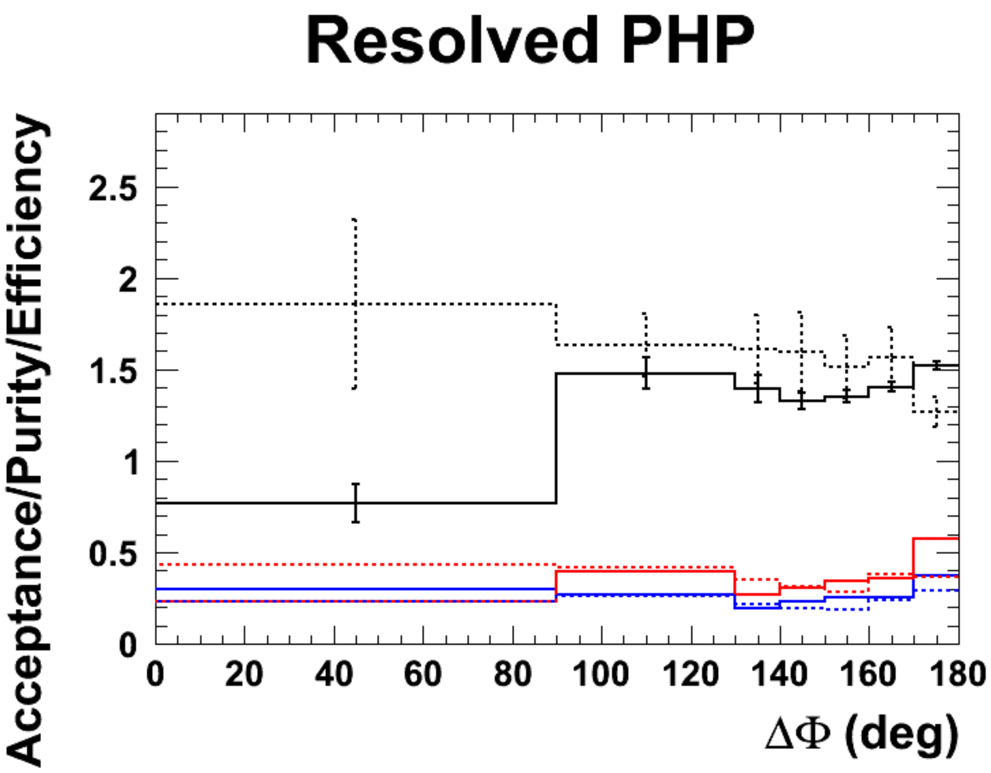



Direct PHP

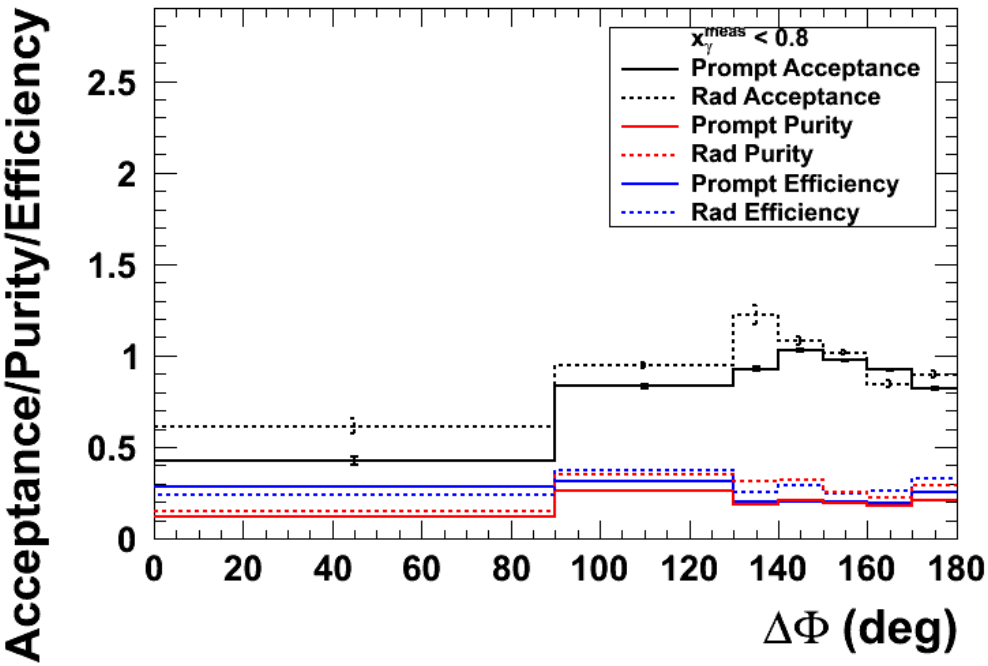

Resolved PHP



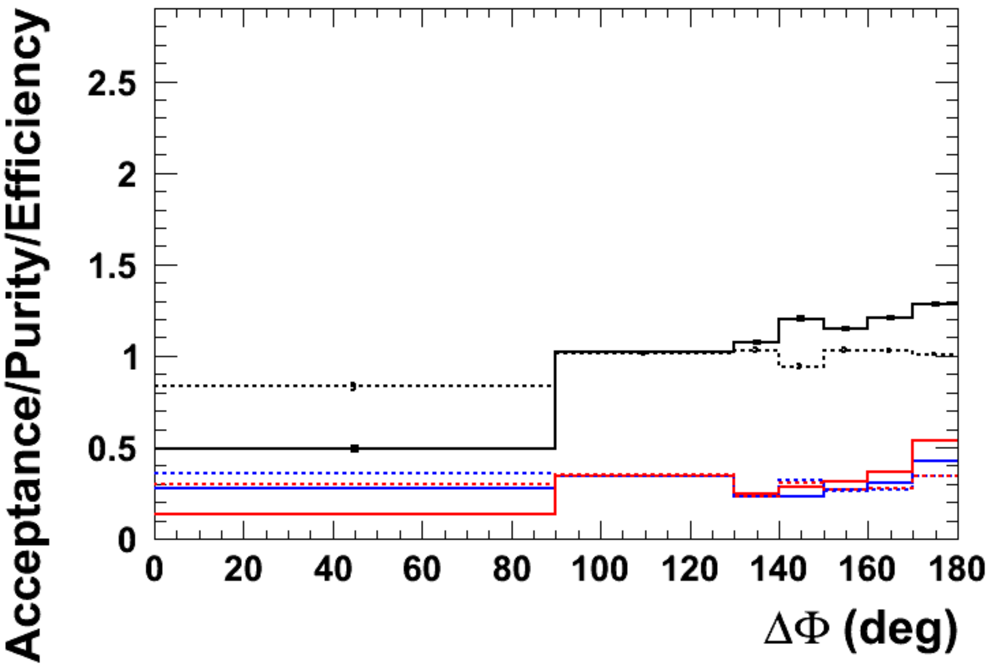
Direct PHP



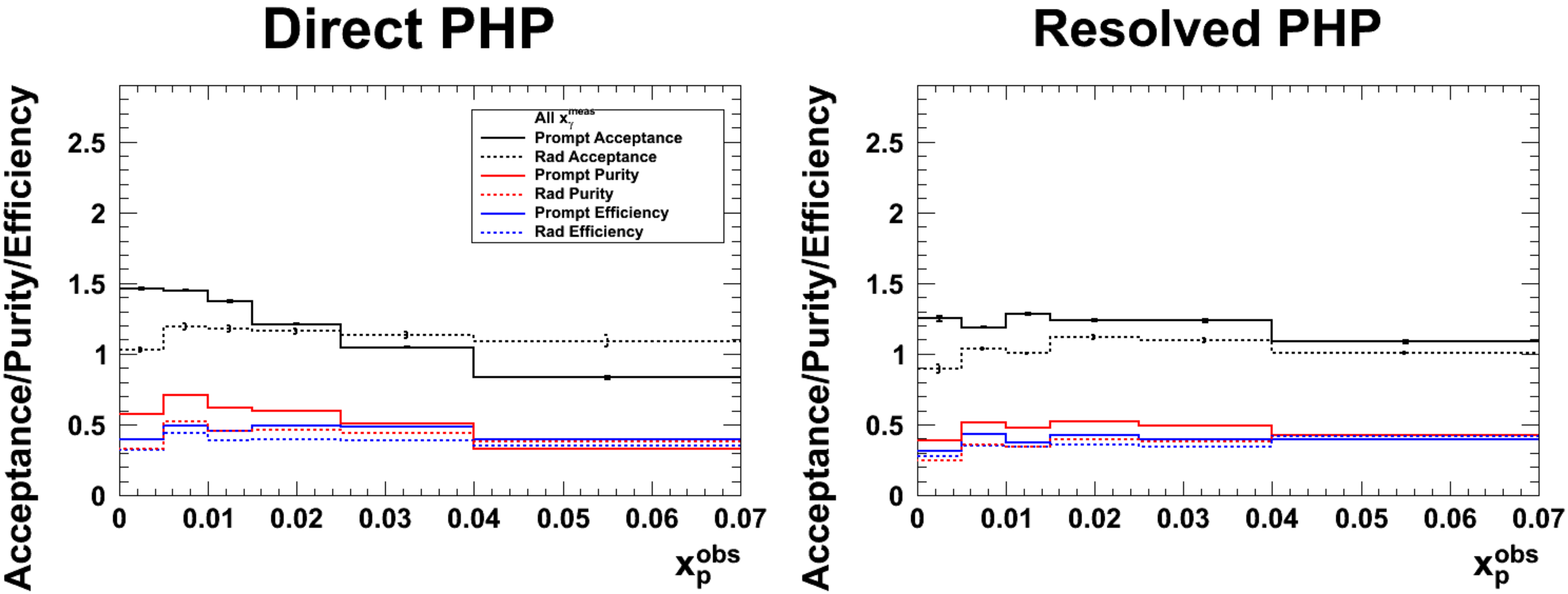
Resolved PHP



Direct PHP



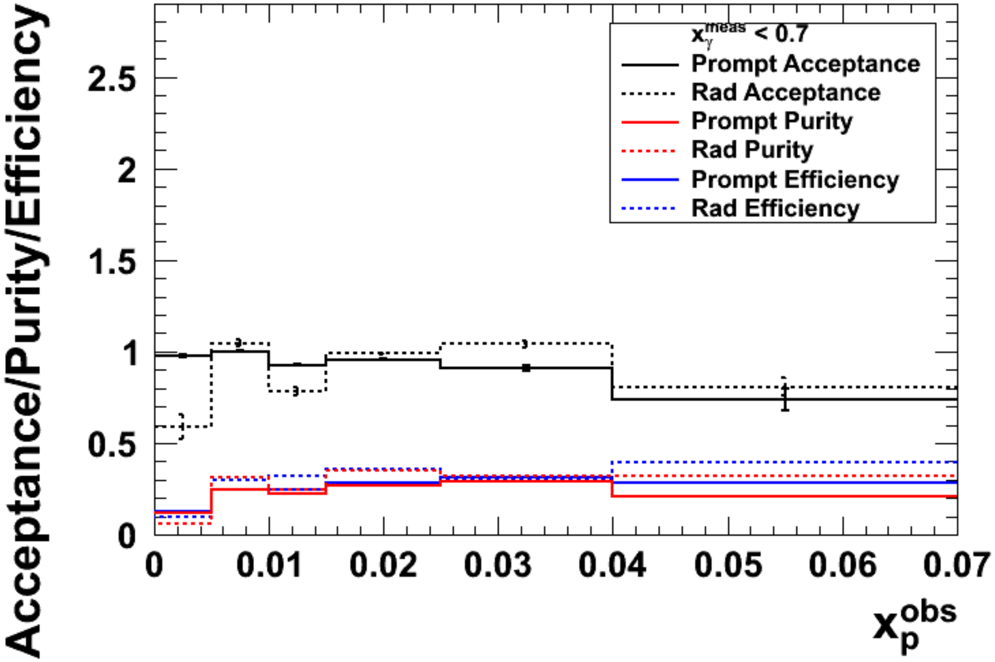
Resolved PHP



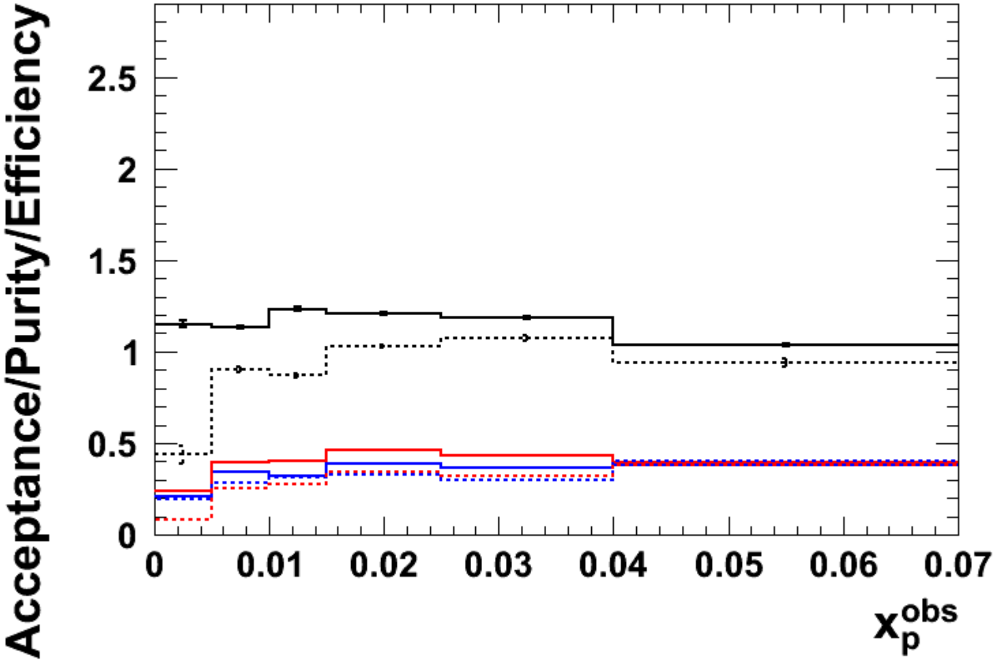
Direct PHP

Resolved PHP

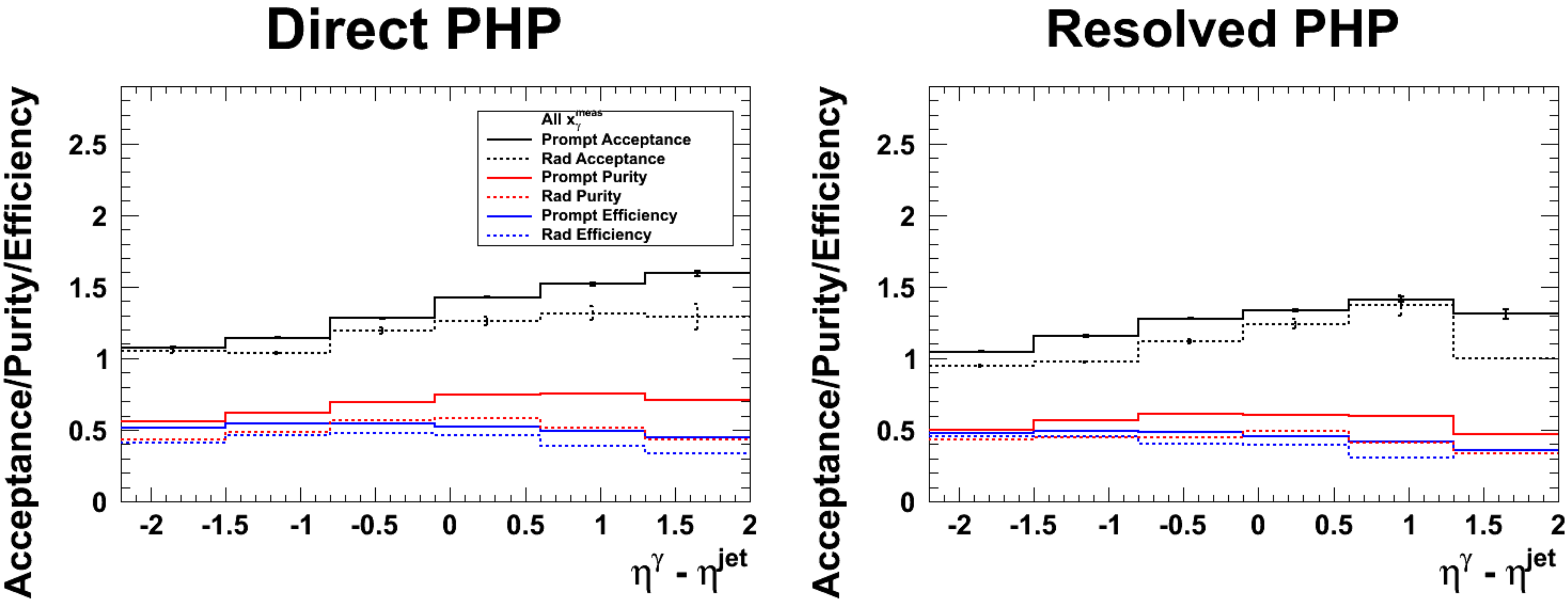
Direct PHP



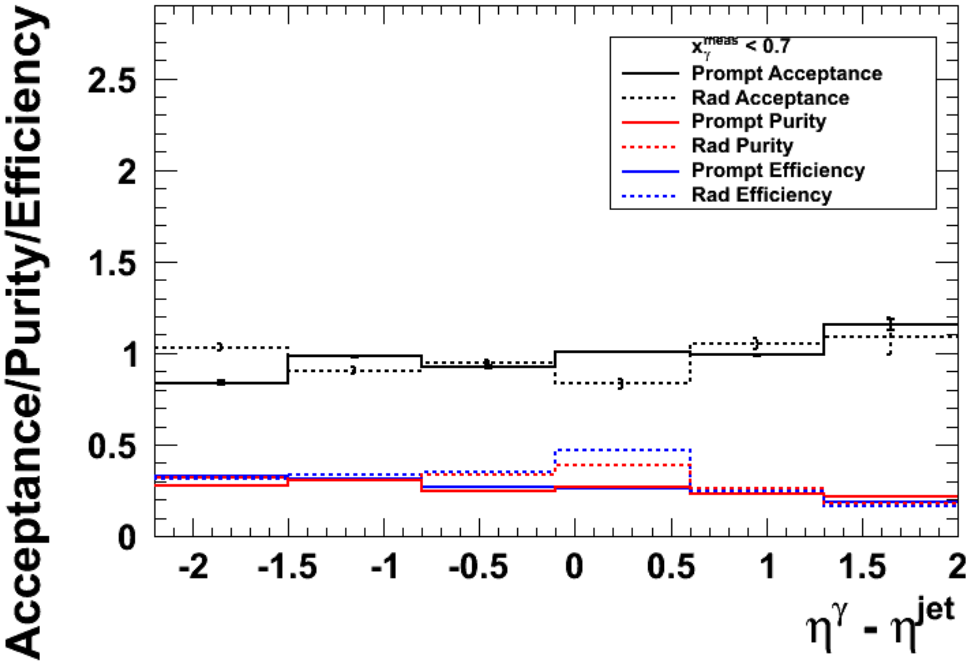
Resolved PHP



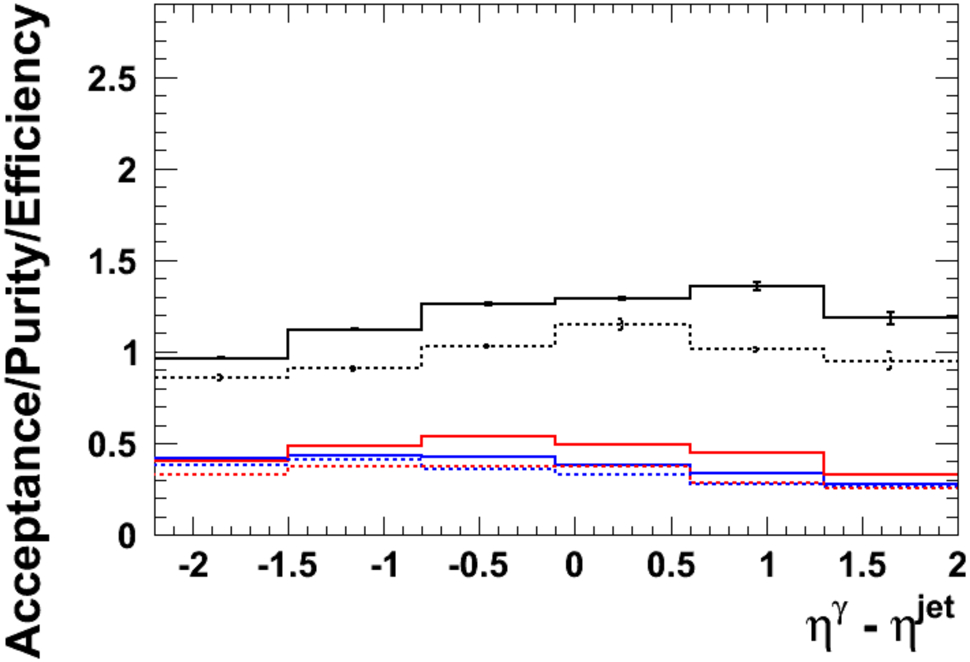
All x_γ


Direct PHP
Resolved PHP
Acceptance/Purity/Efficiency
η^γ - η^{jet}
All x_γ^{meas}
Prompt Acceptance
Rad Acceptance
Prompt Purity
Rad Purity
Prompt Efficiency
Rad Efficiency
0
0.5
1
1.5
2
2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

$x_\gamma < 0.7$

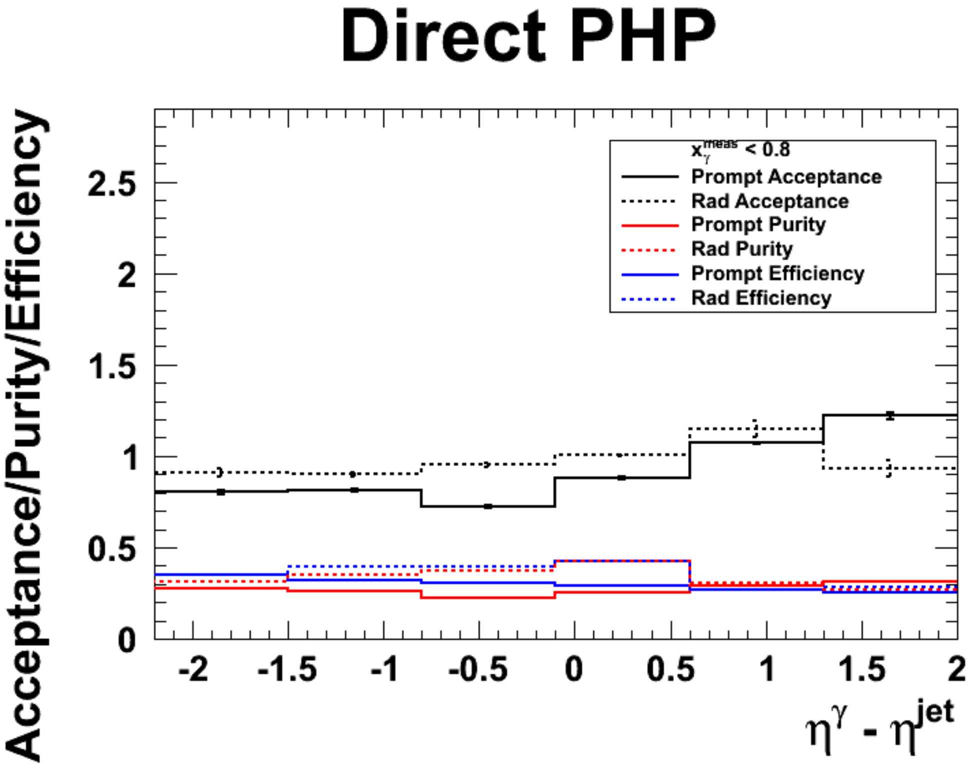


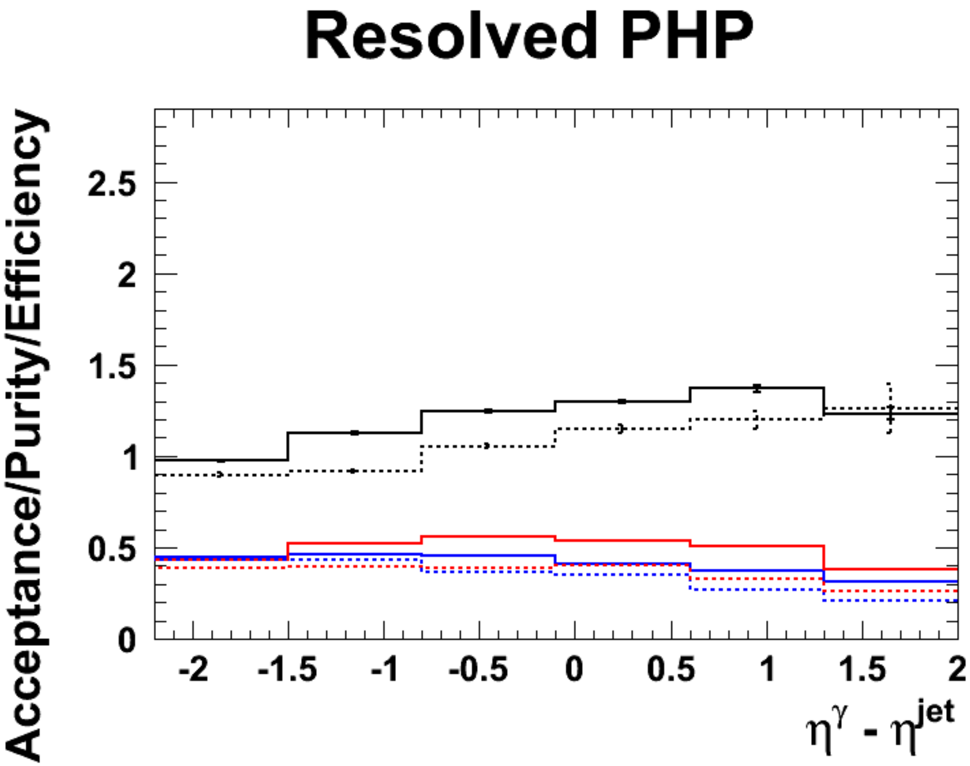
Direct PHP



Resolved PHP

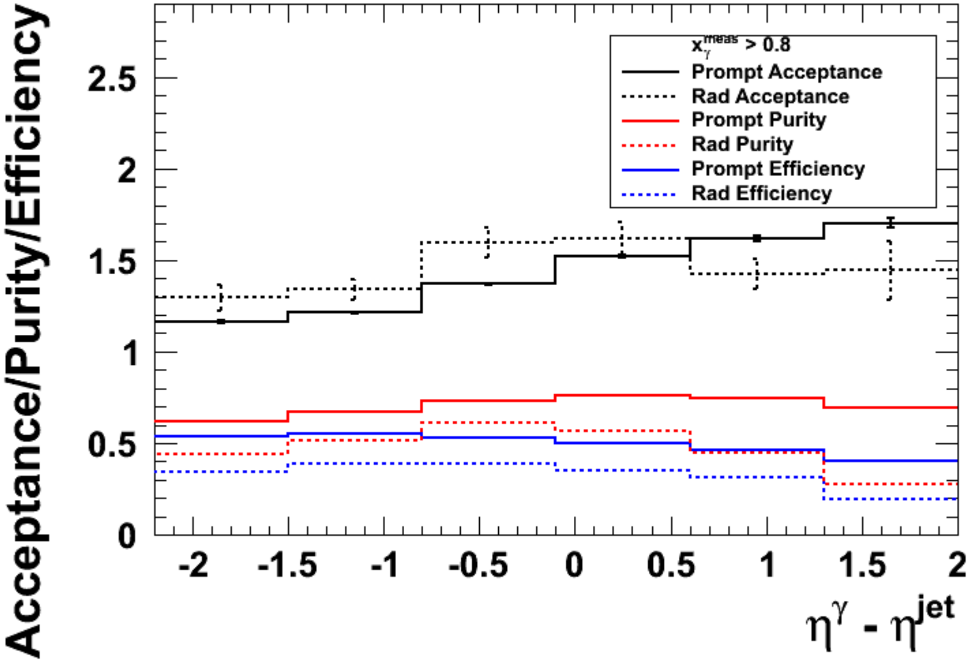
$x_\gamma < 0.8$


Direct PHP

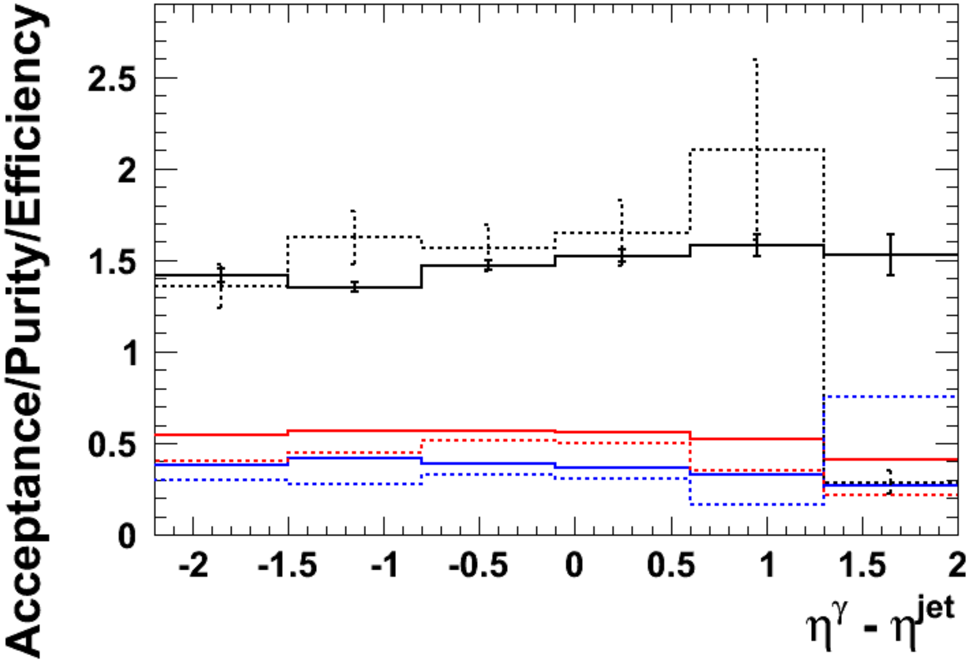

Resolved PHP

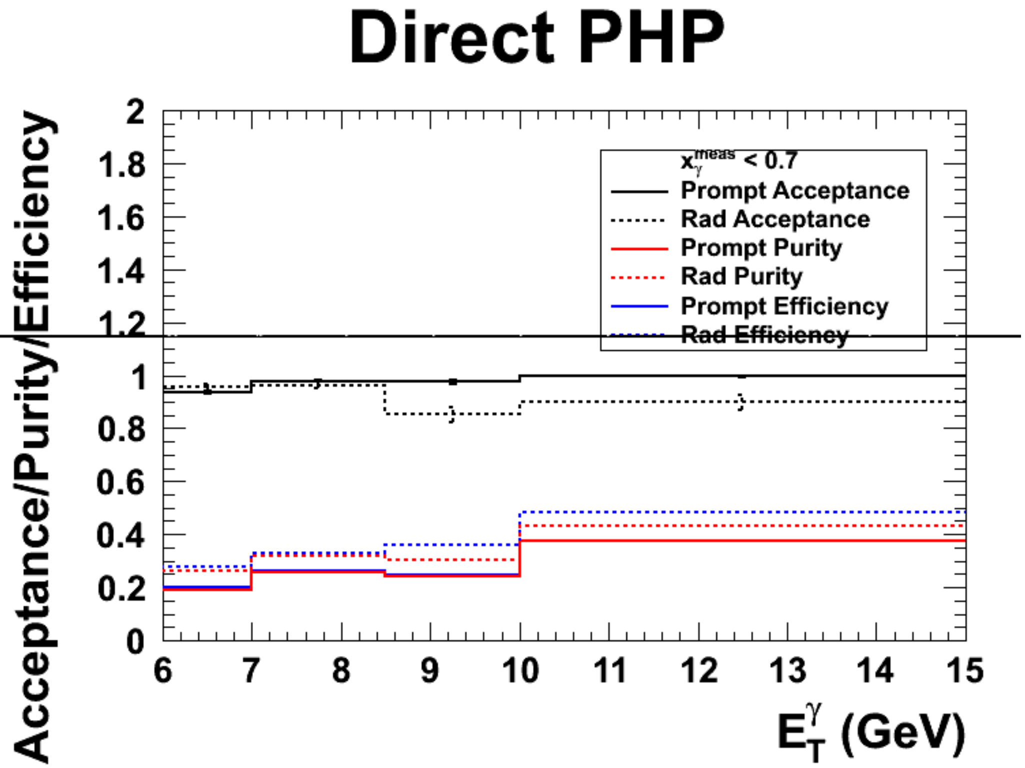
$x_\gamma > 0.8$

Direct PHP

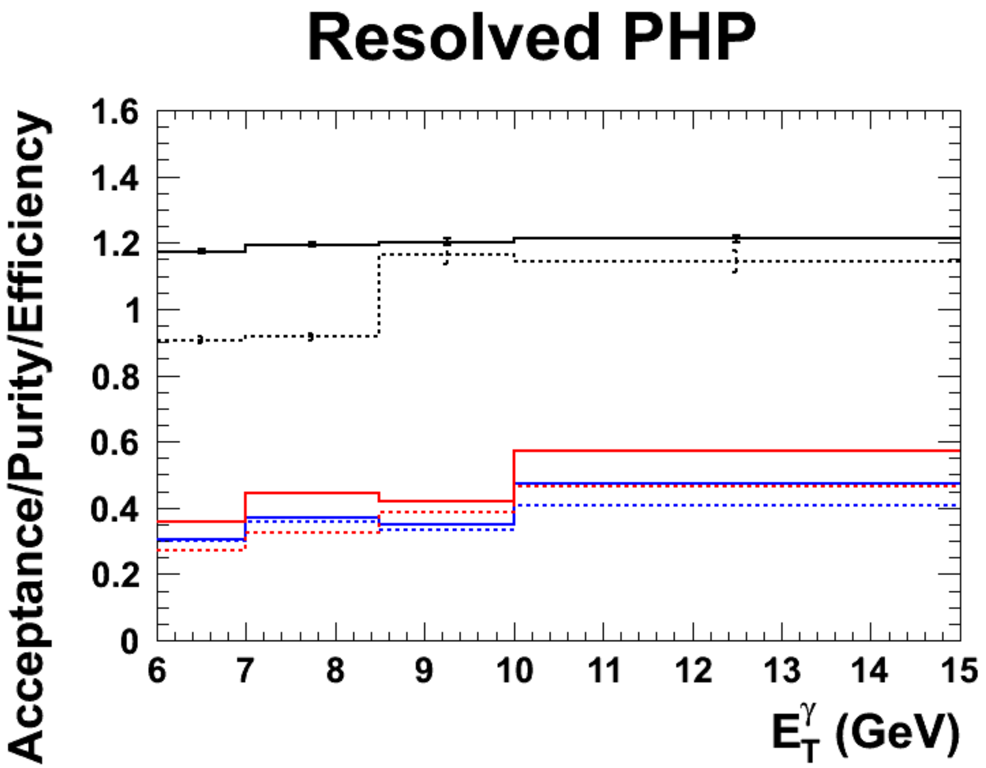


Resolved PHP



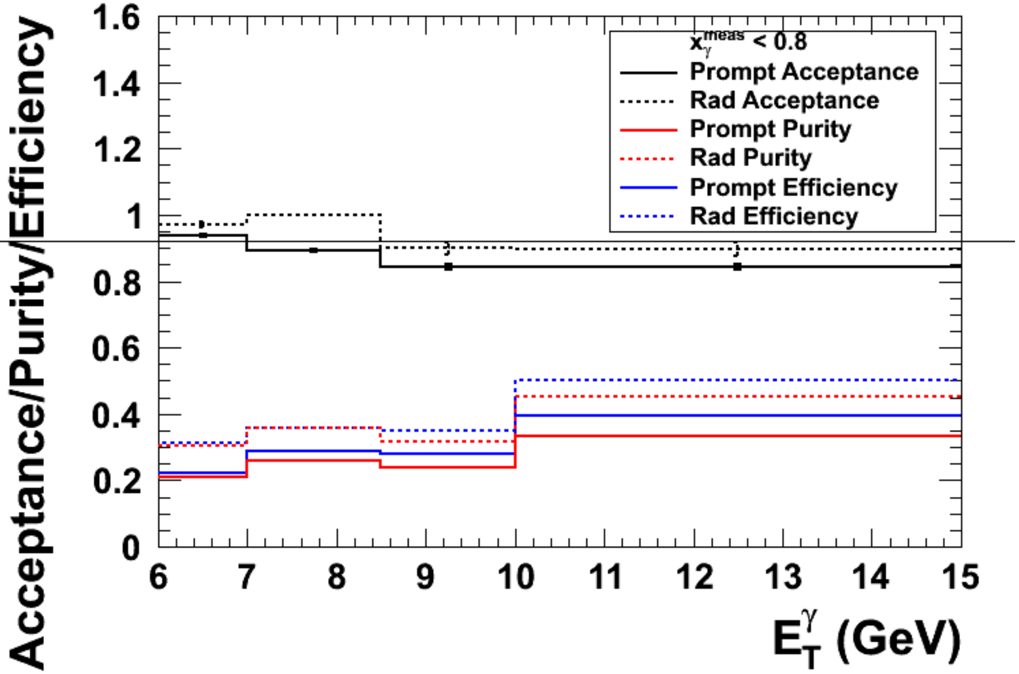


Direct PHP

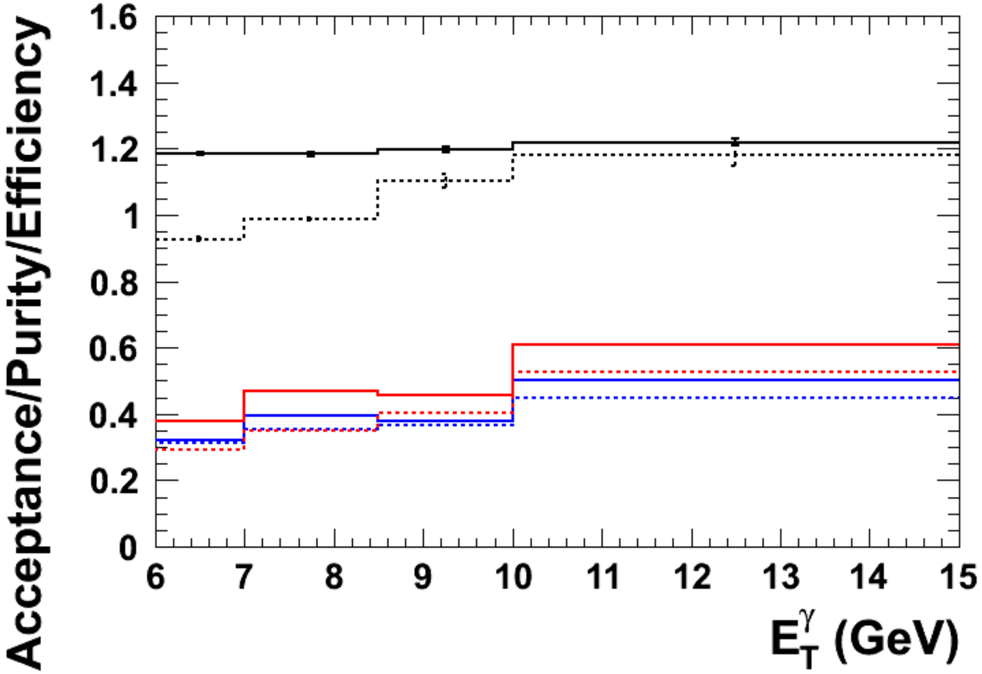


Resolved PHP

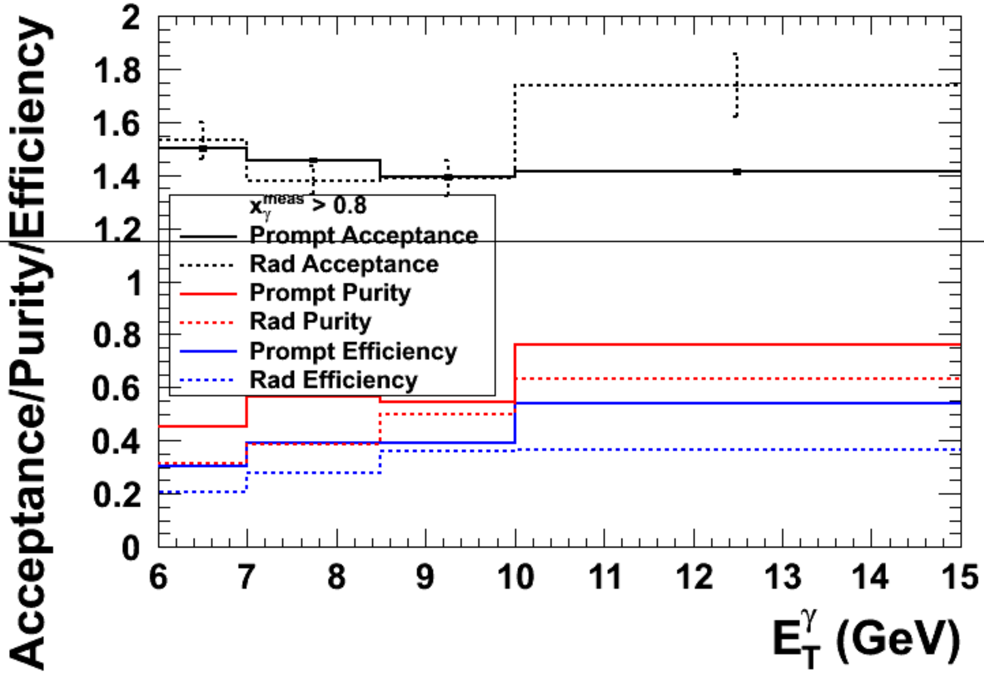
Direct PHP



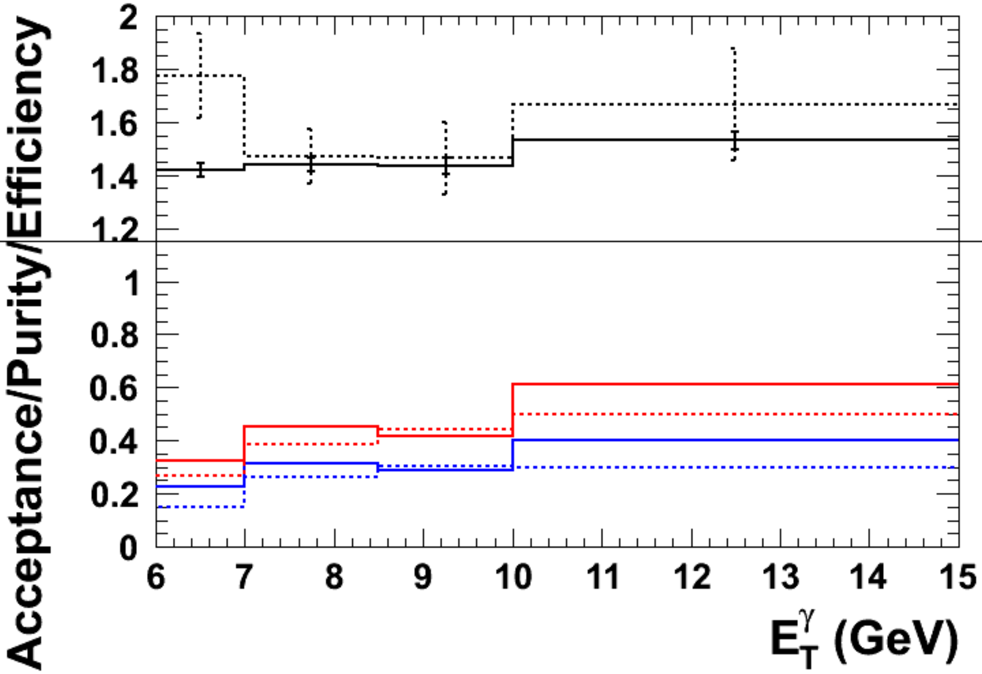
Resolved PHP



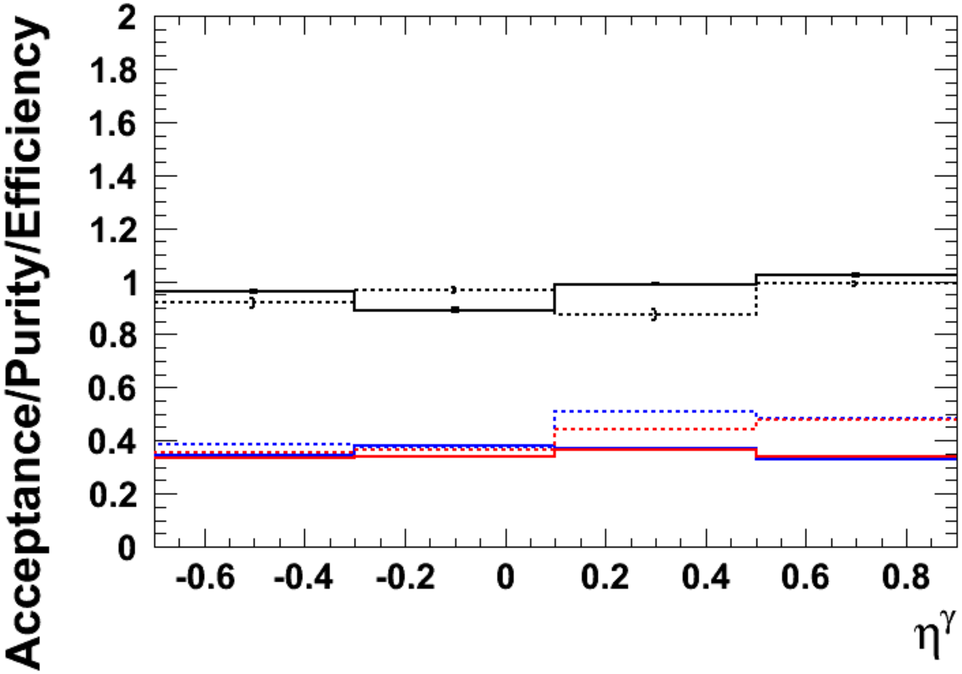
Direct PHP



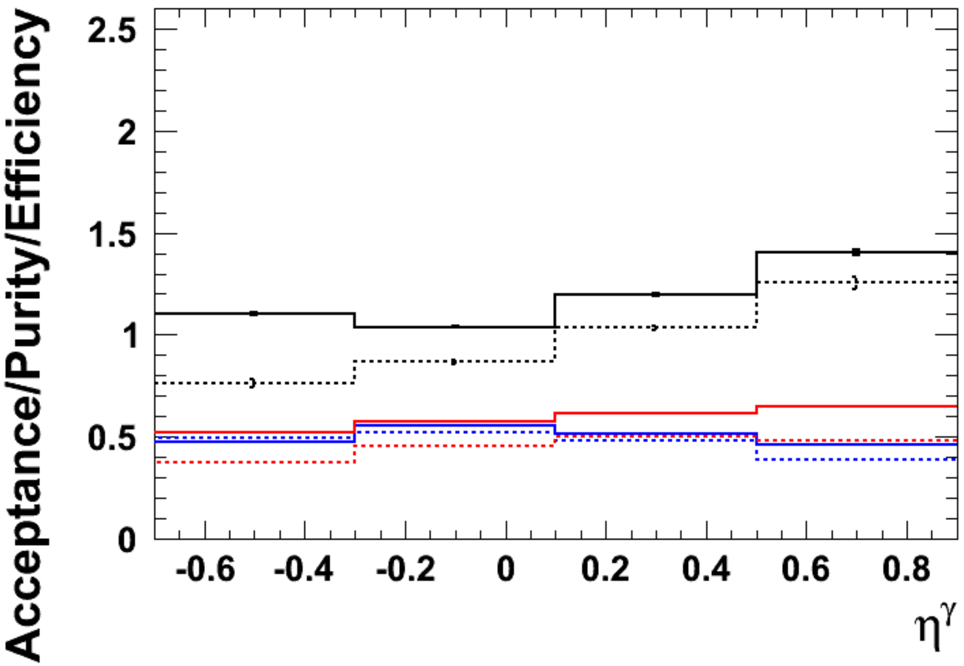
Resolved PHP



$x_\gamma < 0.7$

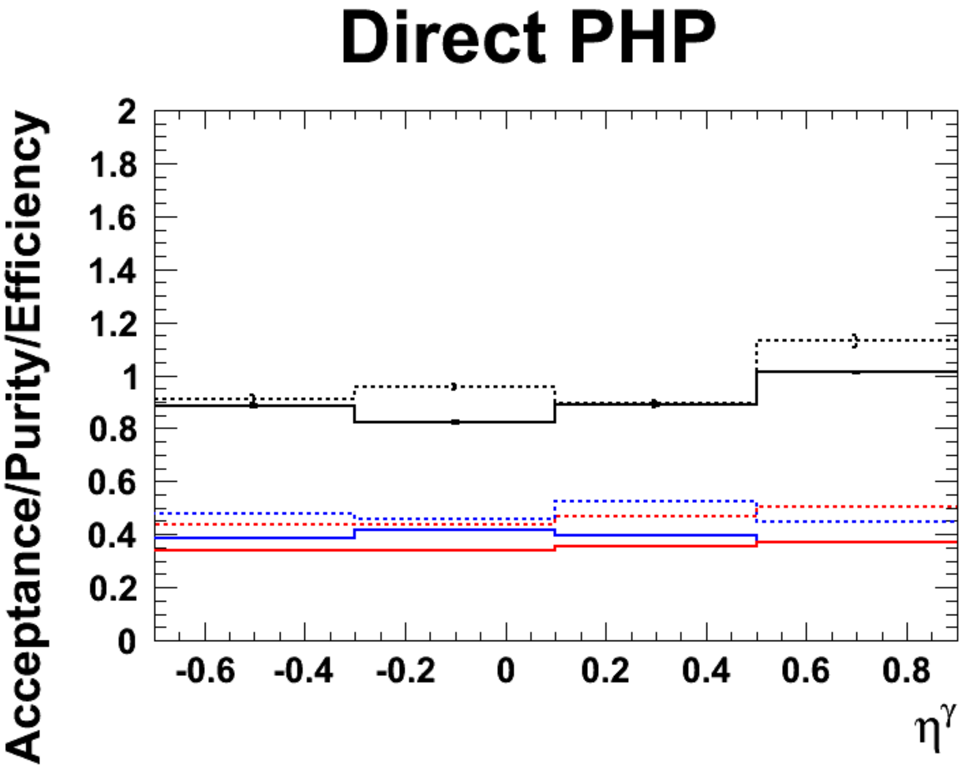


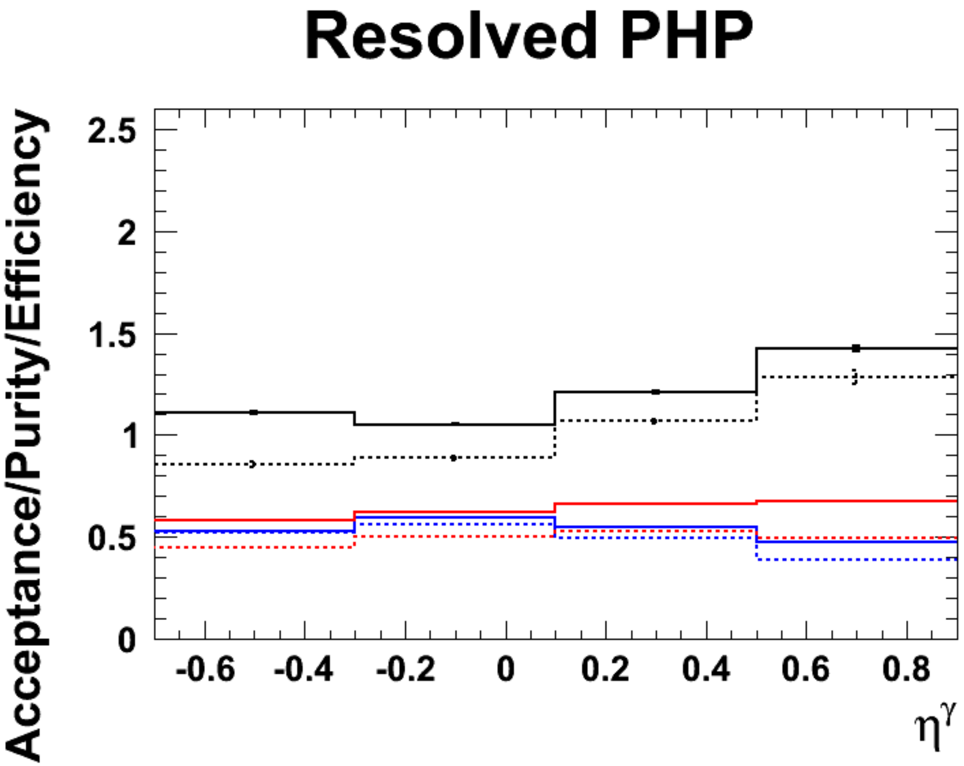
Direct PHP



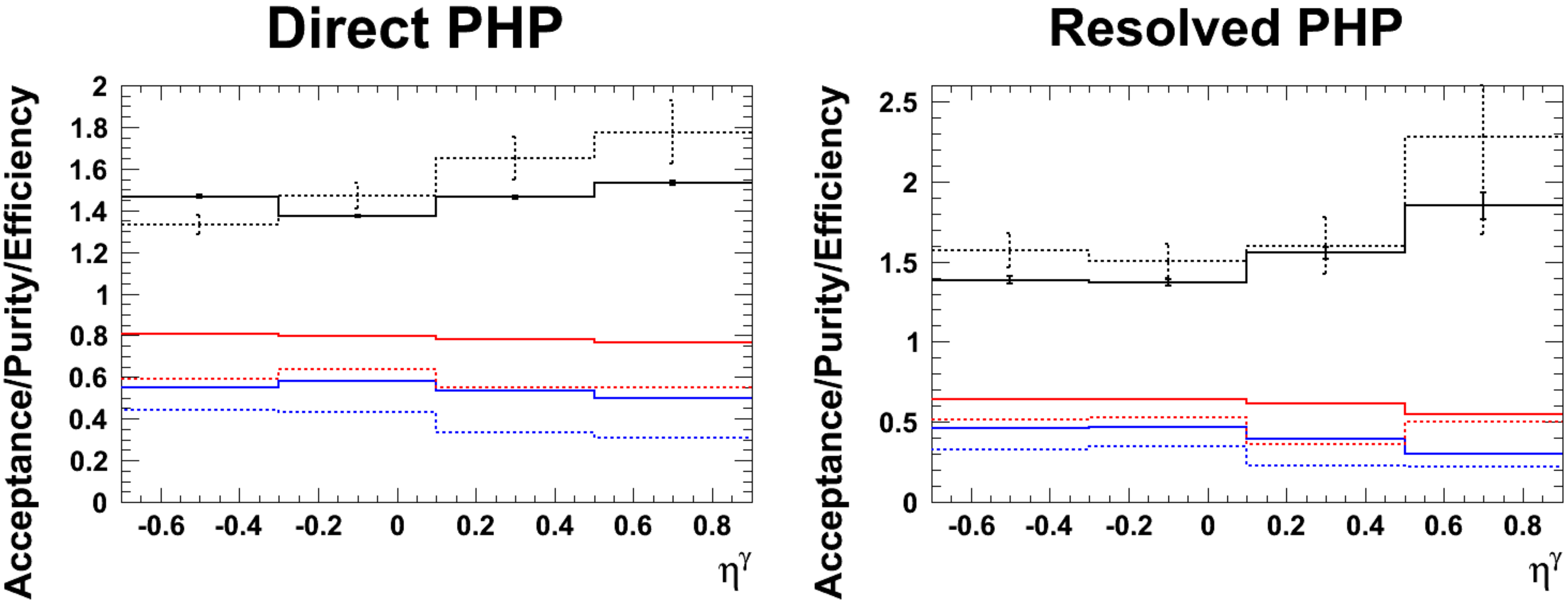
Resolved PHP

$x_\gamma < 0.8$

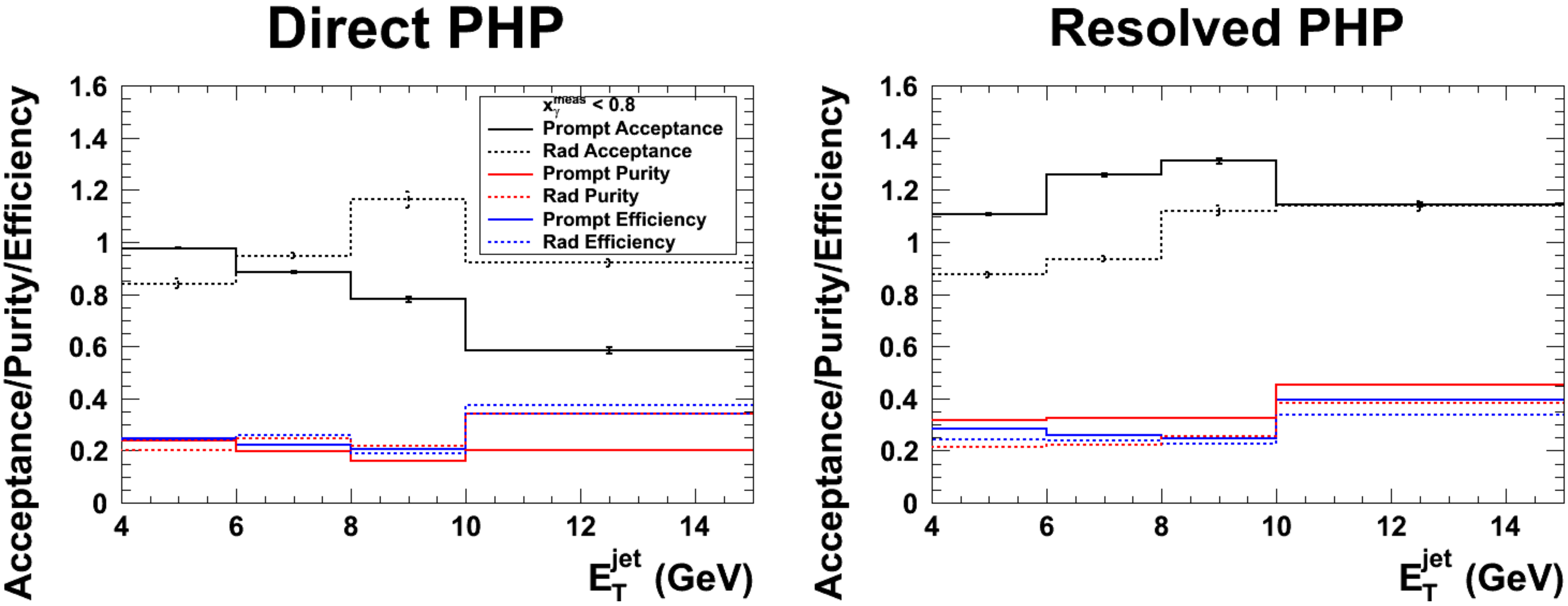

Direct PHP
Acceptance/Purity/Efficiency
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
η^γ


Resolved PHP
Acceptance/Purity/Efficiency
2.5
2
1.5
1
0.5
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
η^γ

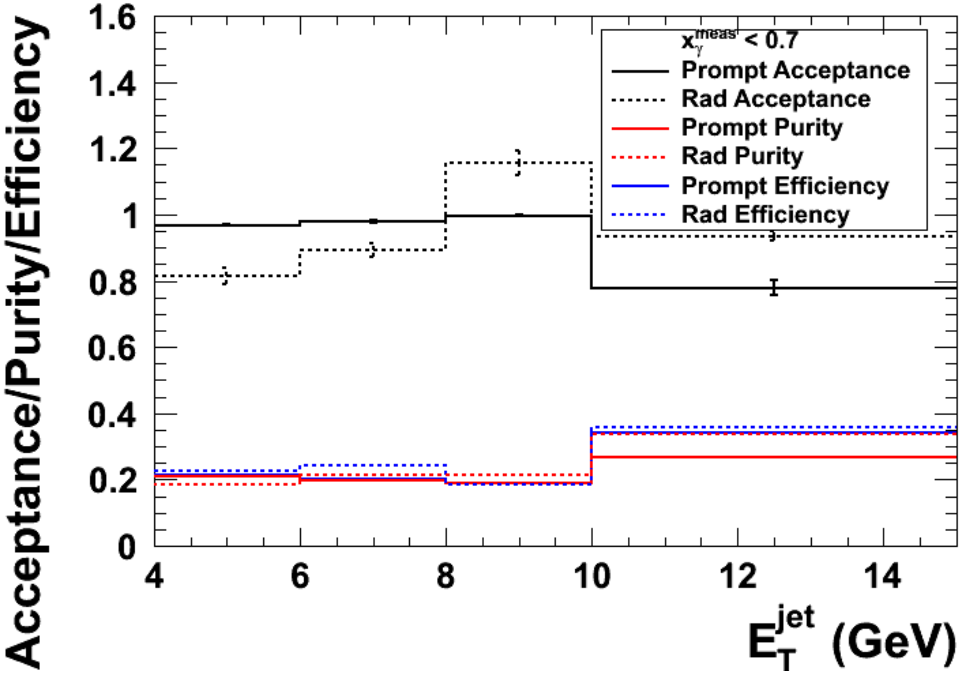
$x_\gamma > 0.8$


Direct PHP
Resolved PHP
Acceptance/Purity/Efficiency
Acceptance/Purity/Efficiency
η^γ
η^γ
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.5
1
1.5
2
2.5
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

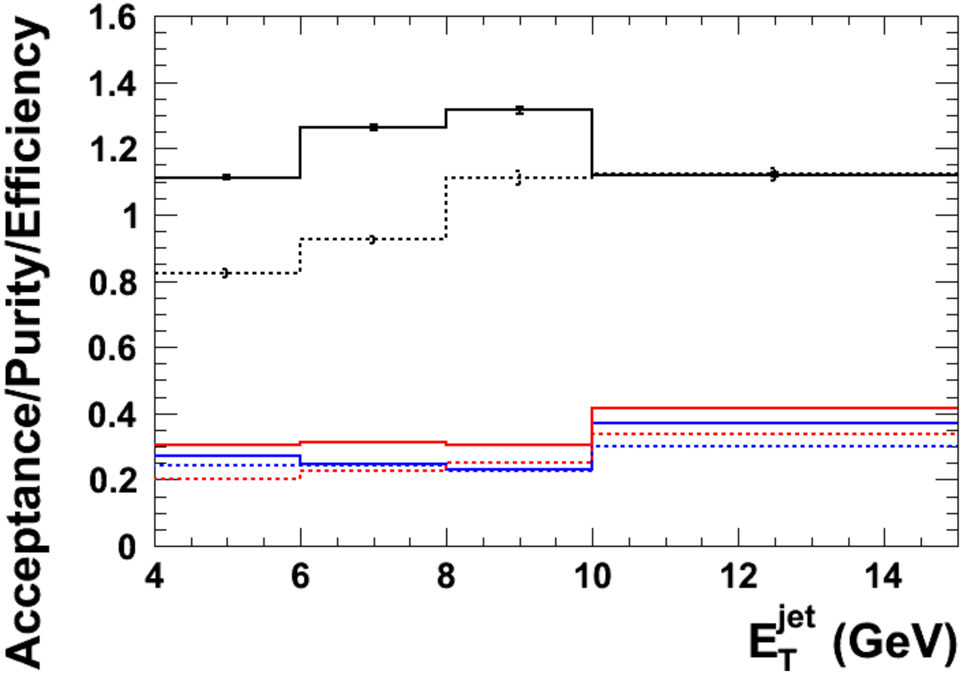
$x_\gamma < 0.8$


Direct PHP
Resolved PHP
Acceptance/Purity/Efficiency
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4
6
8
10
12
14
E_T^{jet} (GeV)
$x_\gamma^{meas} < 0.8$
Prompt Acceptance
Rad Acceptance
Prompt Purity
Rad Purity
Prompt Efficiency
Rad Efficiency

$x_\gamma < 0.7$

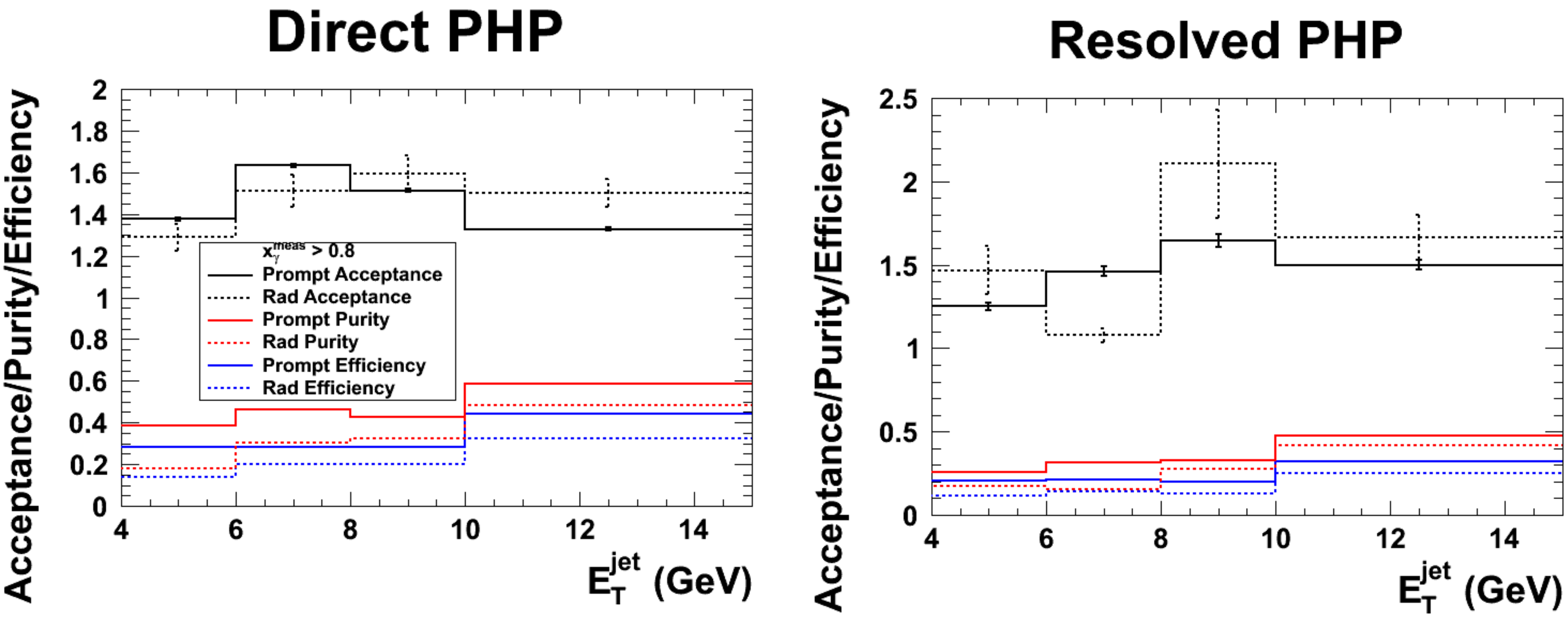


Direct PHP



Resolved PHP

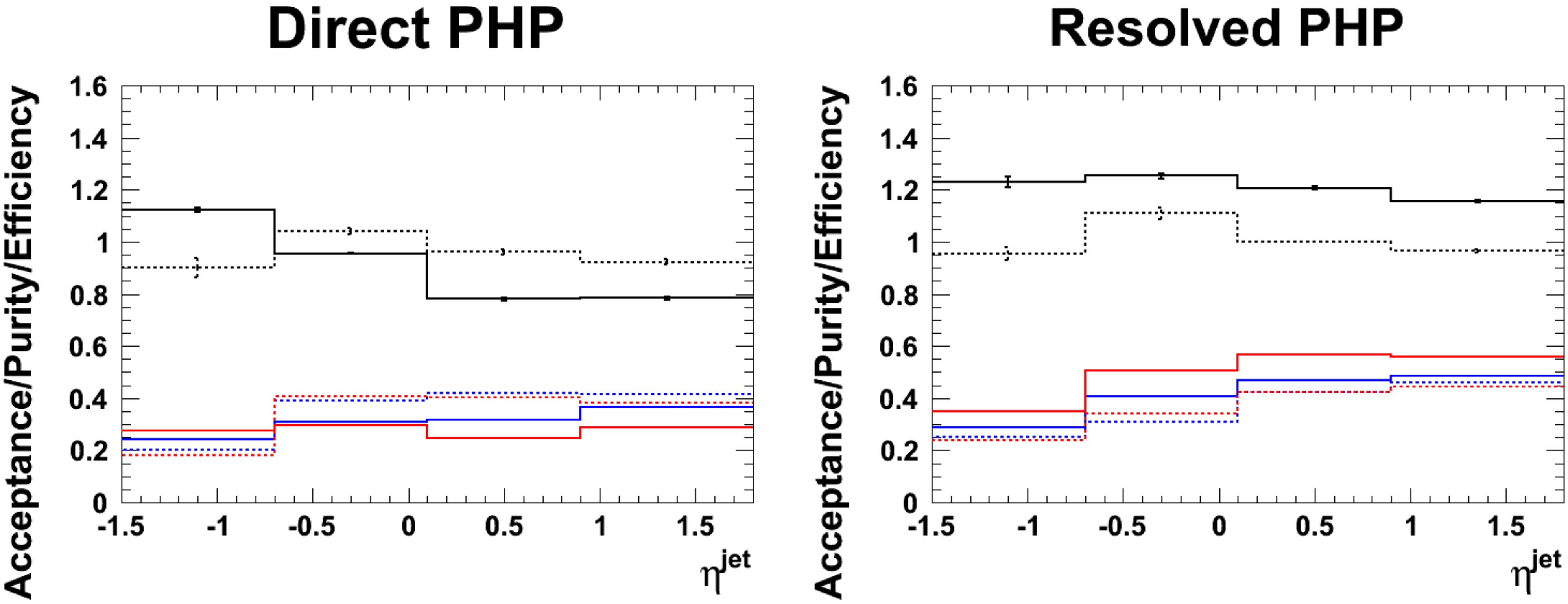
$x_\gamma > 0.8$



Direct PHP

Resolved PHP

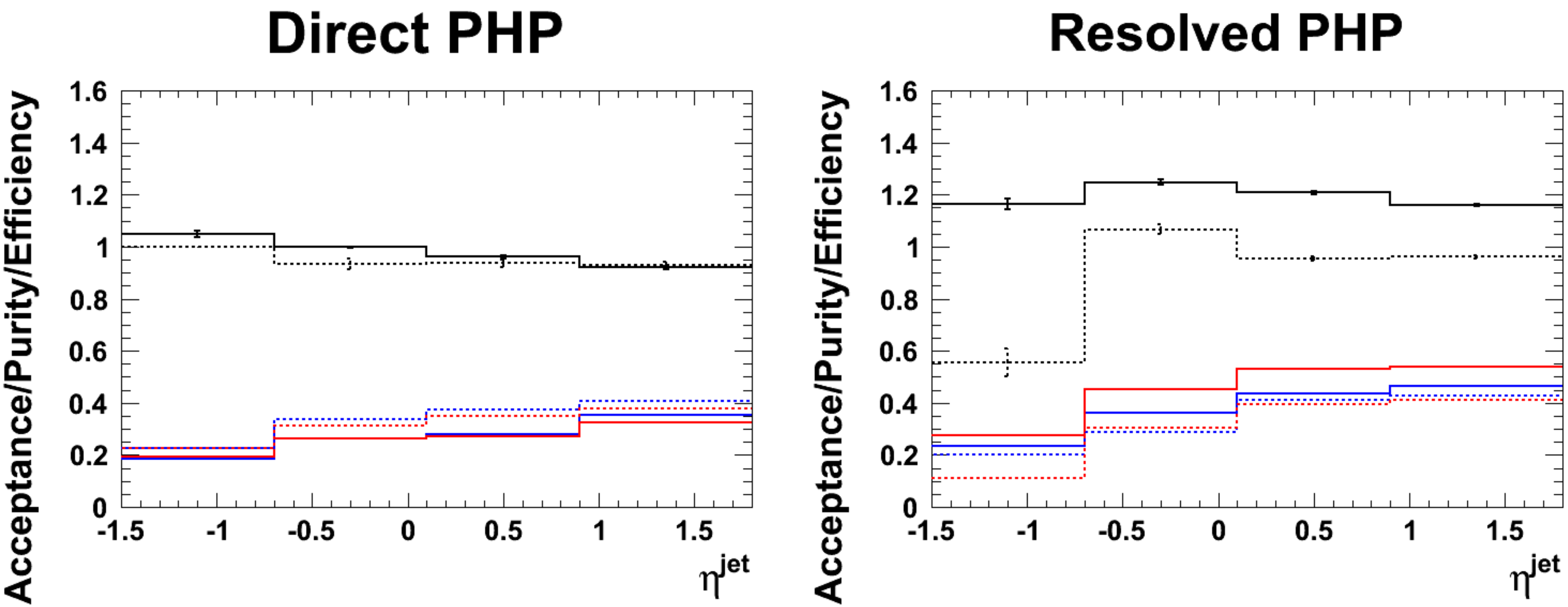
$x_\gamma < 0.8$



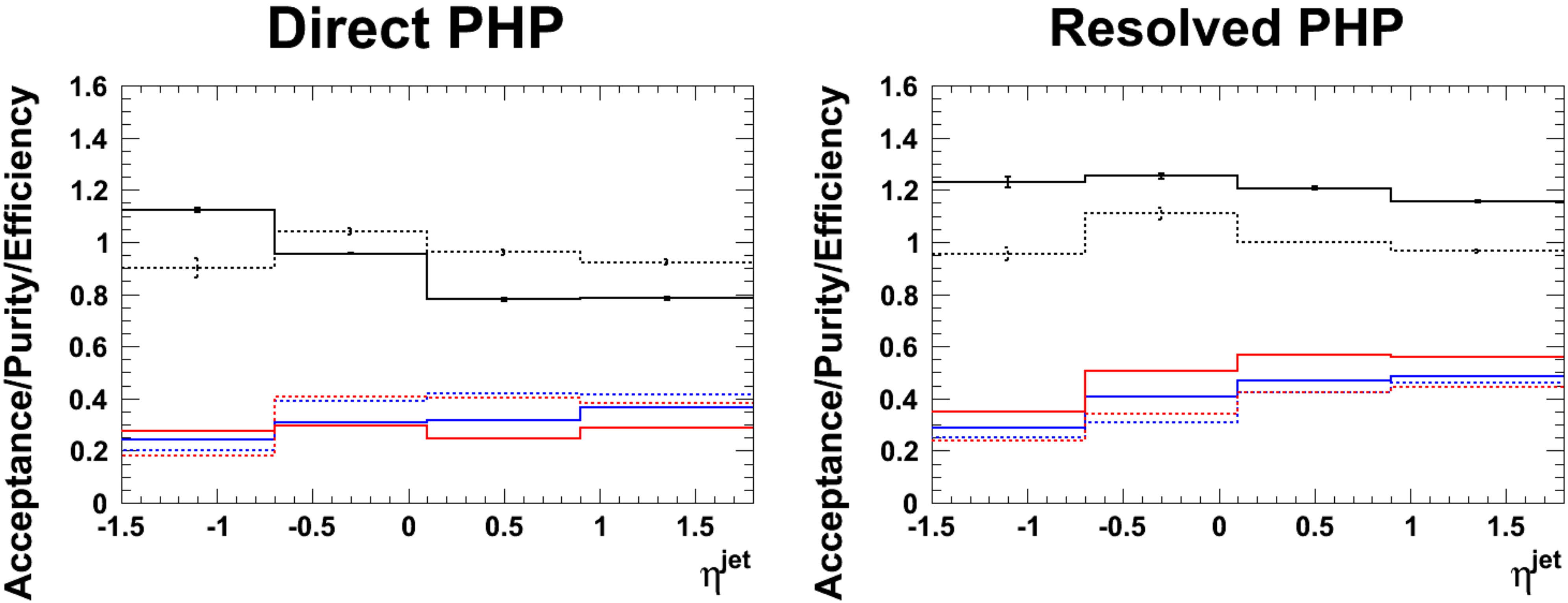
Direct PHP

Resolved PHP

$x_\gamma < 0.7$

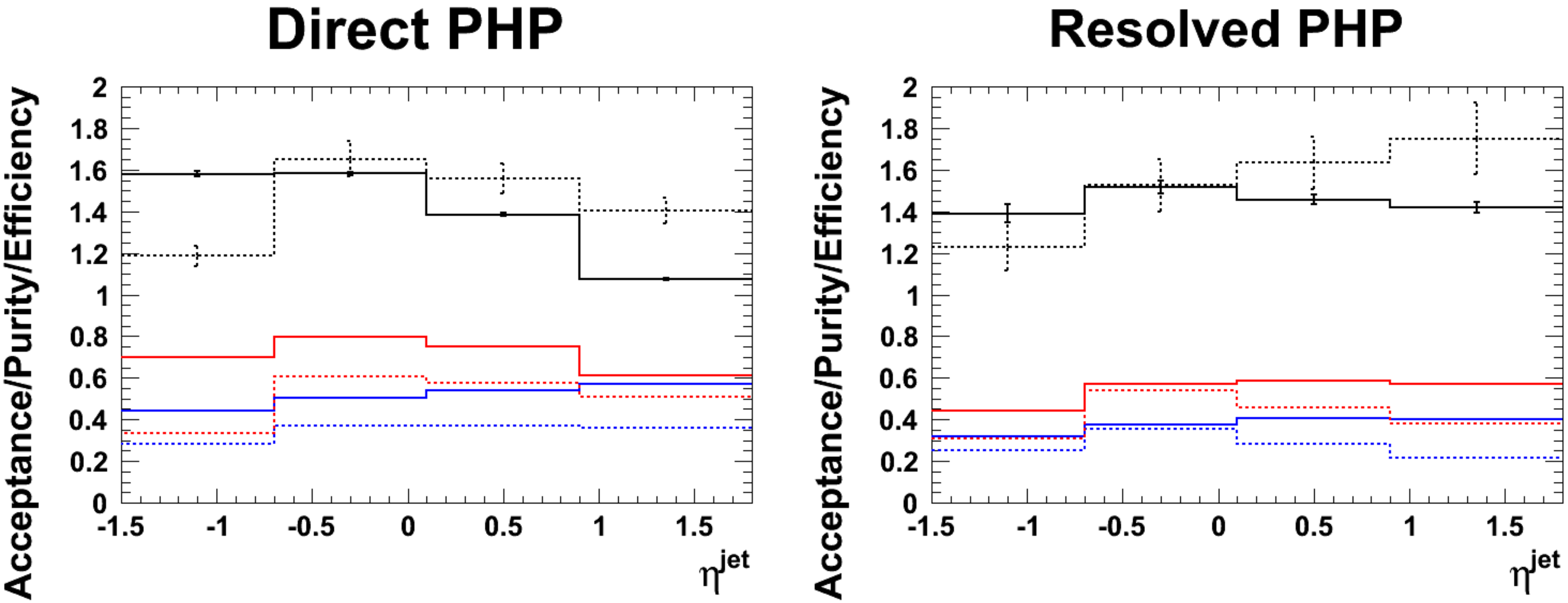

Direct PHP
Resolved PHP
Acceptance/Purity/Efficiency
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
-1.5
-1
-0.5
0
0.5
1
1.5
η^{jet}

$x_{\gamma} < 0.8$



Direct PHP
Resolved PHP
Acceptance/Purity/Efficiency
Acceptance/Purity/Efficiency
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
-1.5
-1
-0.5
0
0.5
1
1.5
η^{jet}
η^{jet}

$x_{\gamma} > 0.8$

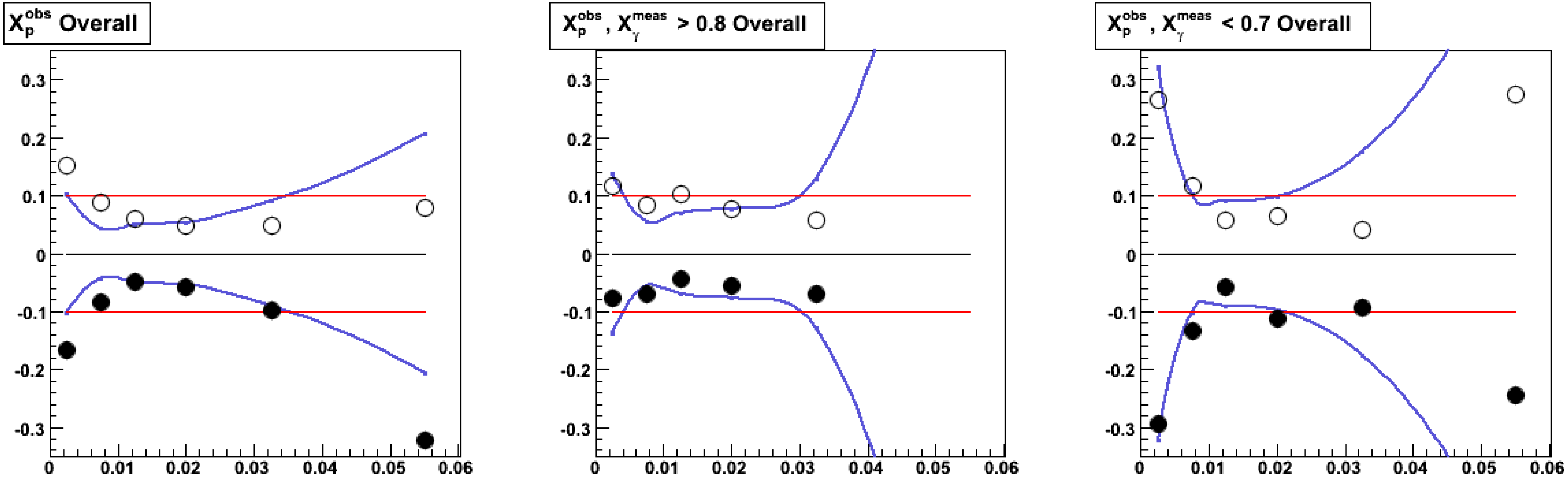


Direct PHP

Resolved PHP

Systematic uncertainties

$x_\gamma < 0.7$, $x_\gamma > 0.8$



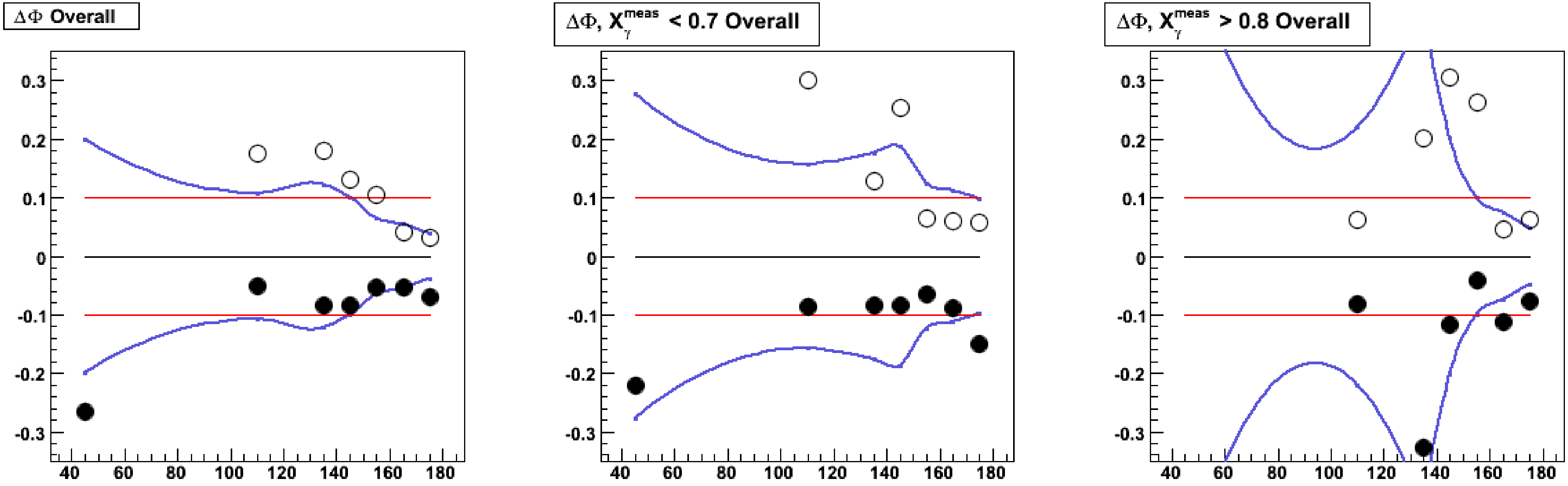
Overall systematics

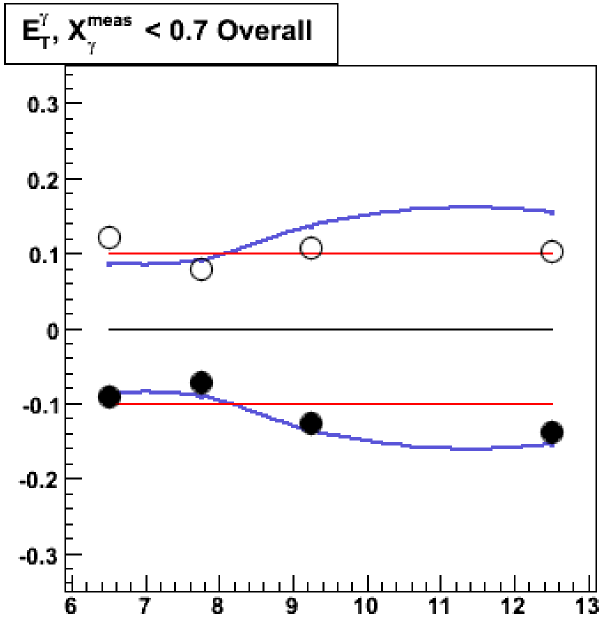
— *Rel.statistical uncertainties*

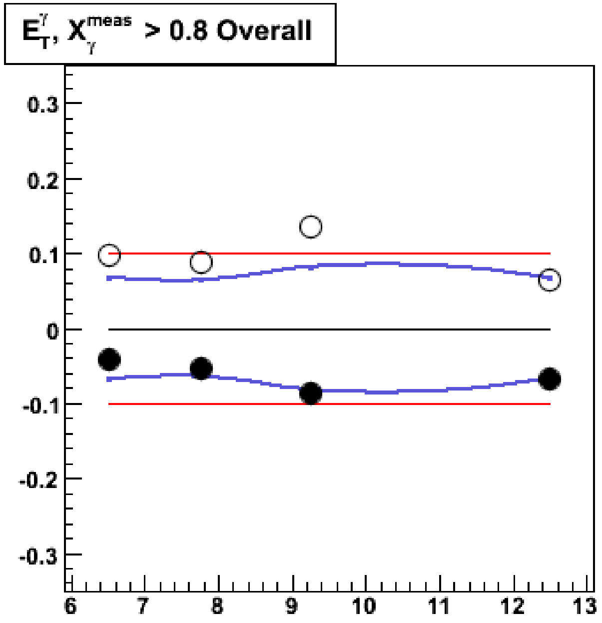
— *10% line*

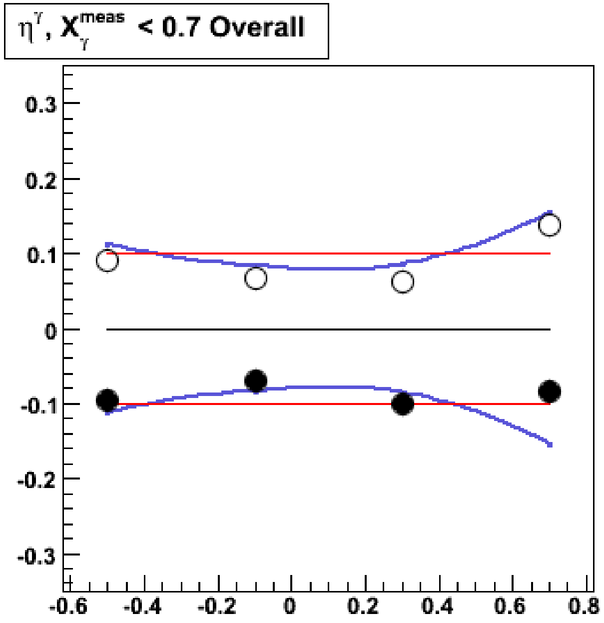
○ *upper sum*

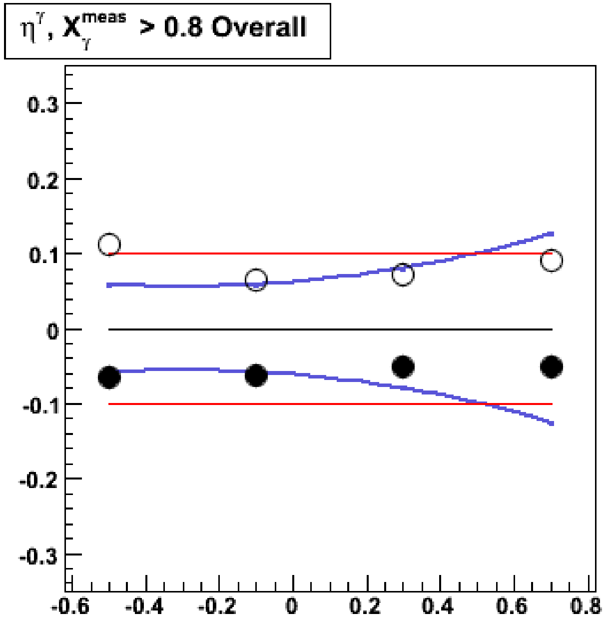
● *lower sum*


ΔΦ Overall
ΔΦ, X_γ^{meas} < 0.7 Overall
ΔΦ, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

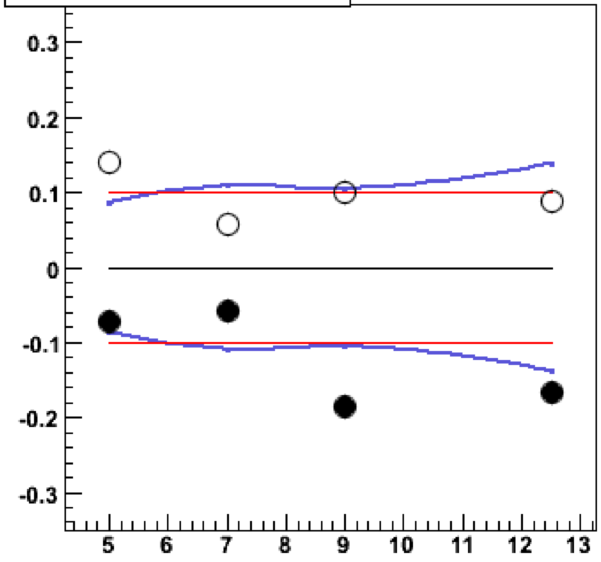

E_T^{γ}, X_{γ}^{meas} < 0.7 Overall


E_T^{γ}, X_{γ}^{meas} > 0.8 Overall

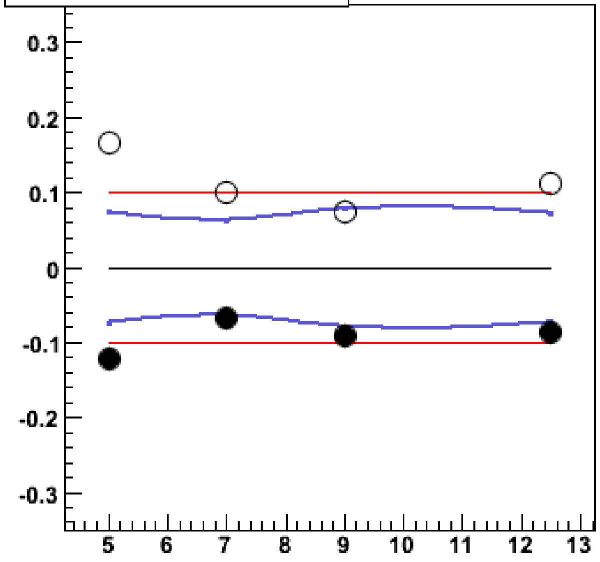

η^{γ}, X_{γ}^{meas} < 0.7 Overall


η^{γ}, X_{γ}^{meas} > 0.8 Overall

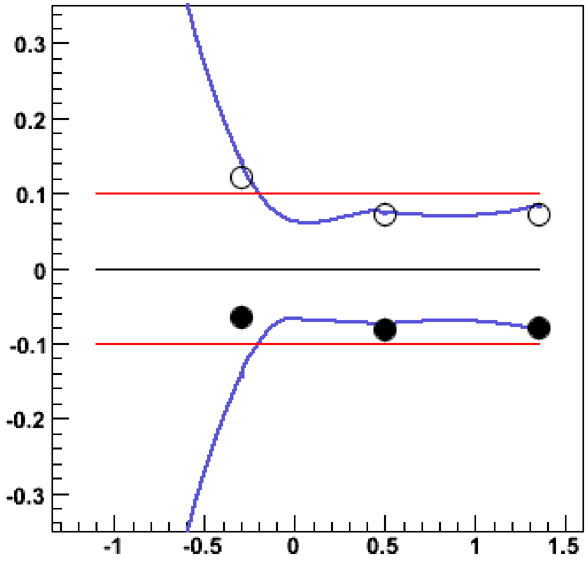
E_T^{jet} , X_γ^{meas} < 0.7 Overall



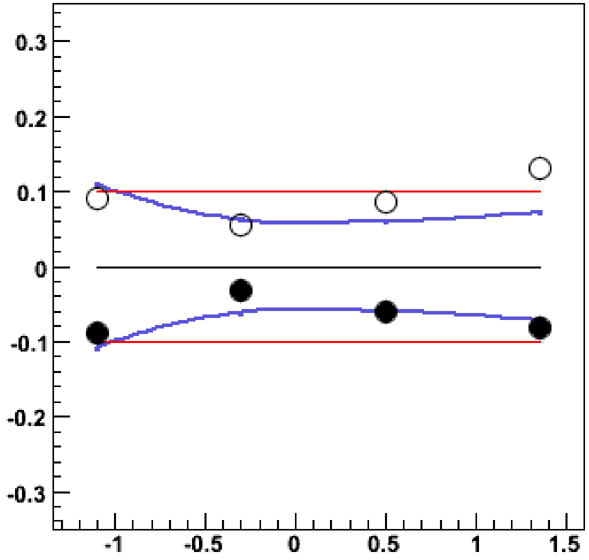
E_T^{jet} , X_γ^{meas} > 0.8 Overall

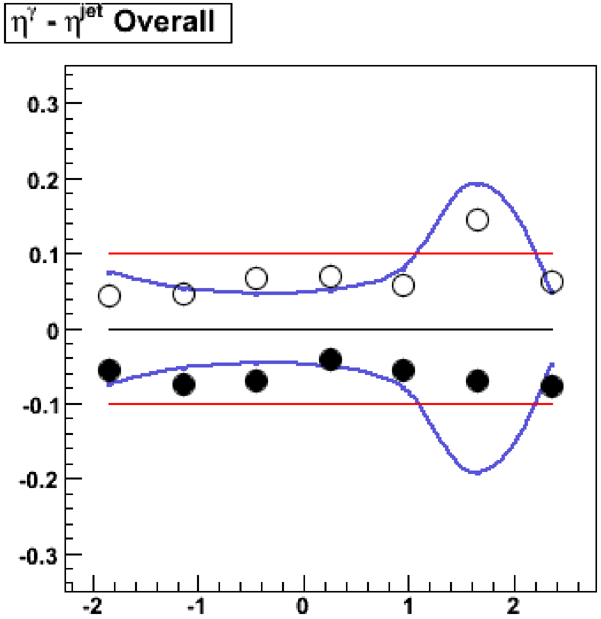


η^{jet} , X_γ^{meas} < 0.7 Overall

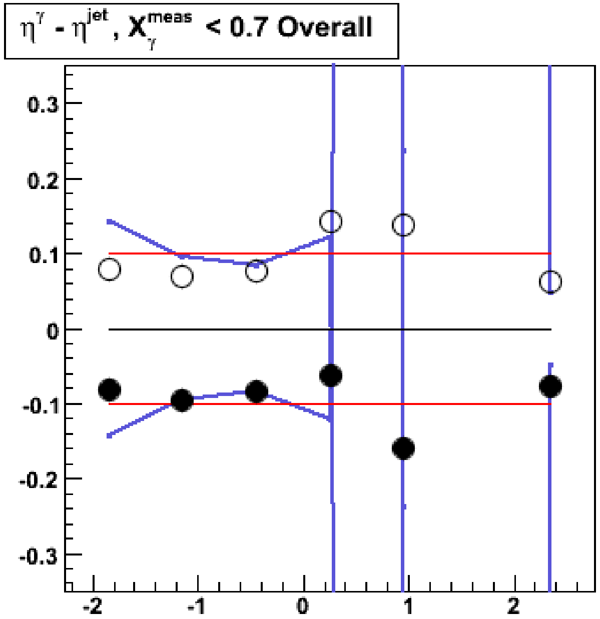


η^{jet} , X_γ^{meas} > 0.8 Overall

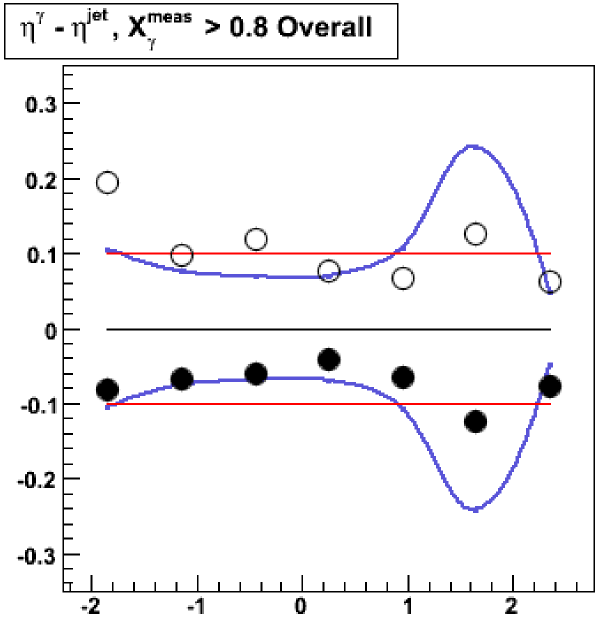




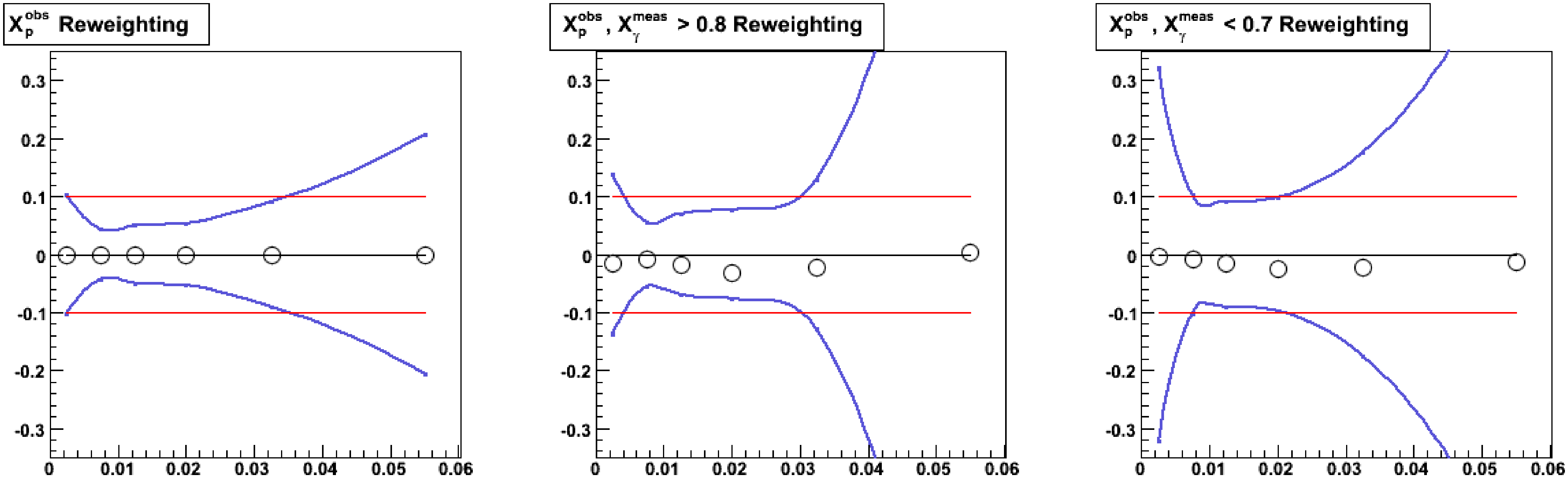
$\eta^{\gamma} - \eta^{jet}$ Overall



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.7$ Overall



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ Overall



Reweighting

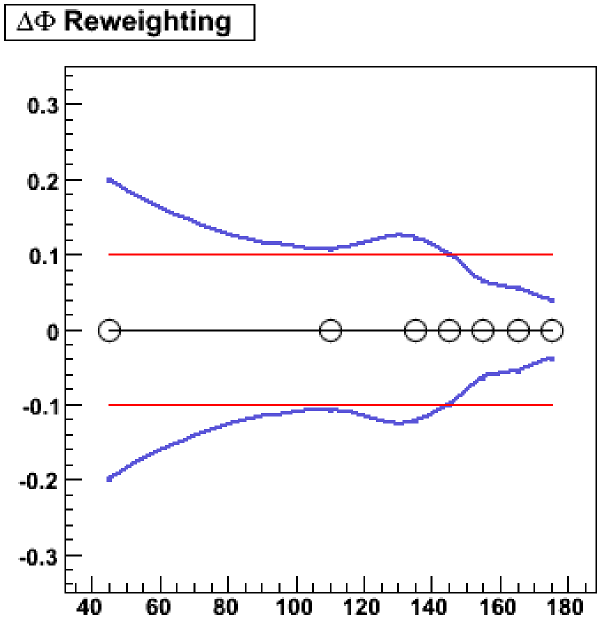
ΔΦ reweighted in x_γ<0.7 and x_γ>0.8 regions.

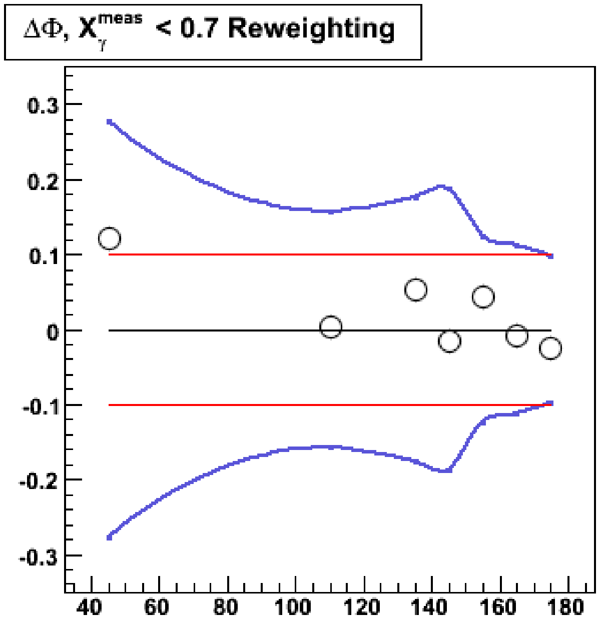
E_T^{jet} and η^{jet} reweighted in x_γ>0.8 region.

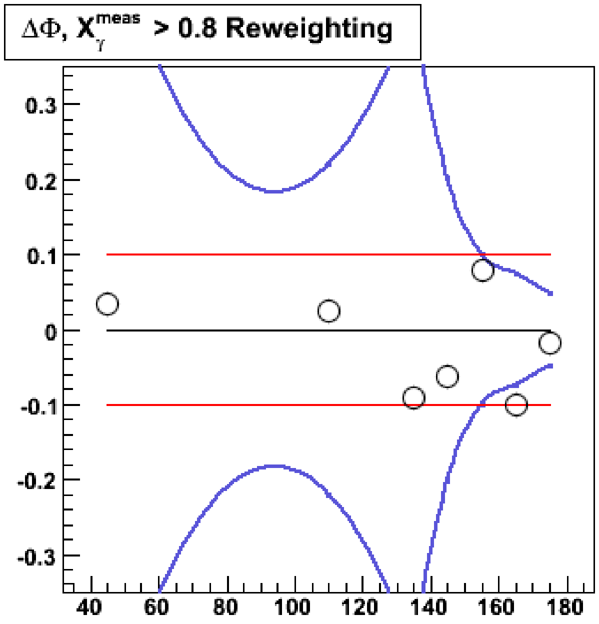
— *Rel.statistical uncertainties*

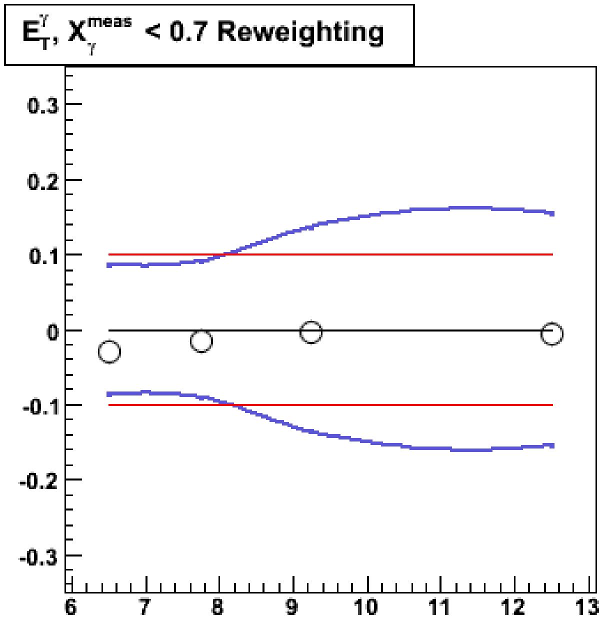
— *10% line*

○ *Reweighting*

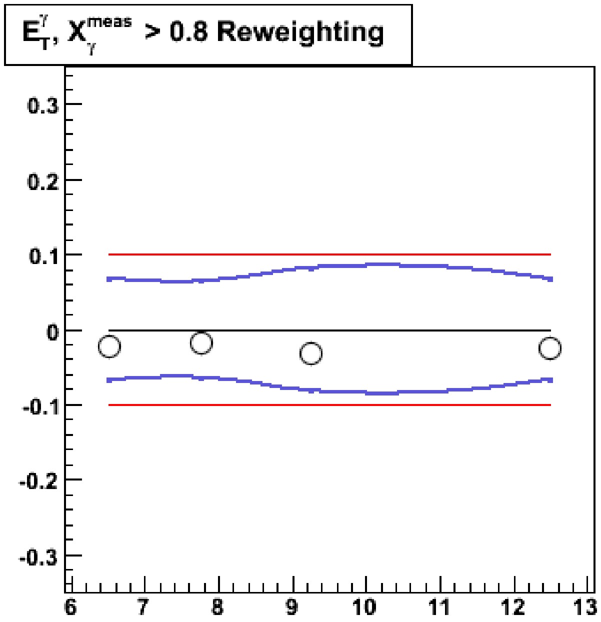

$\Delta\Phi$ Reweighting


$\Delta\Phi$, $X_\gamma^{meas} < 0.7$ Reweighting

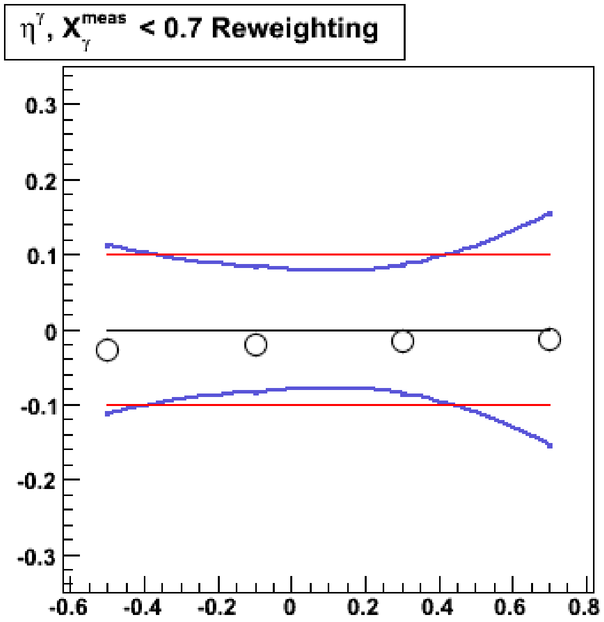

$\Delta\Phi$, $X_\gamma^{meas} > 0.8$ Reweighting



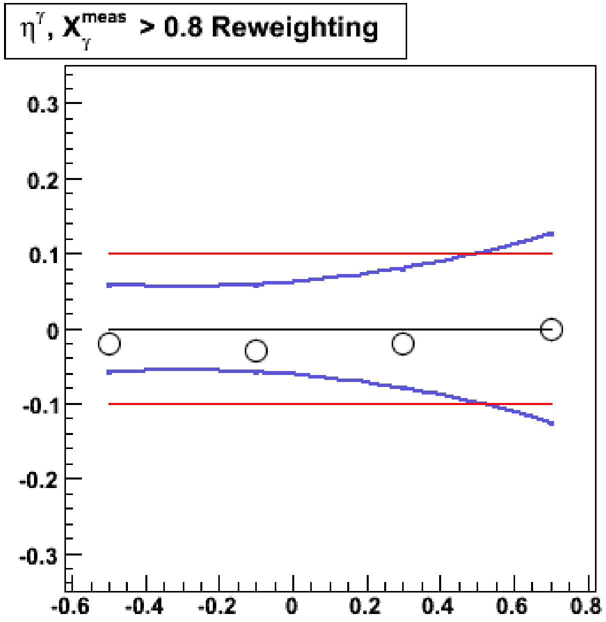
E_T^γ, X_γ^{meas} < 0.7 Reweighting



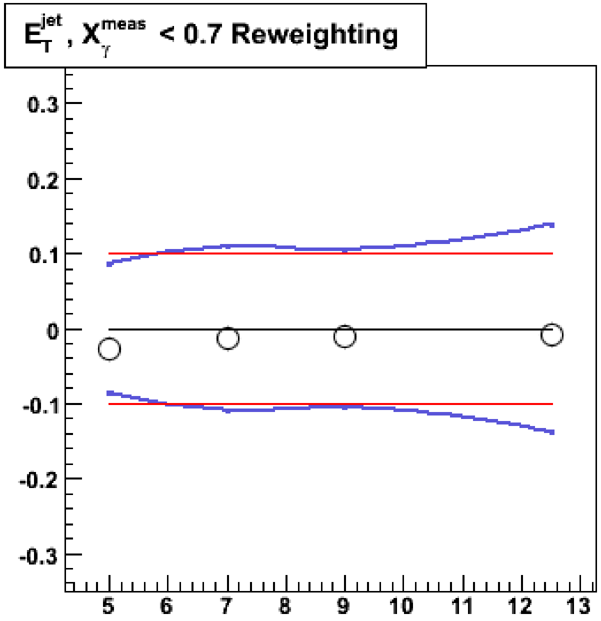
E_T^γ, X_γ^{meas} > 0.8 Reweighting



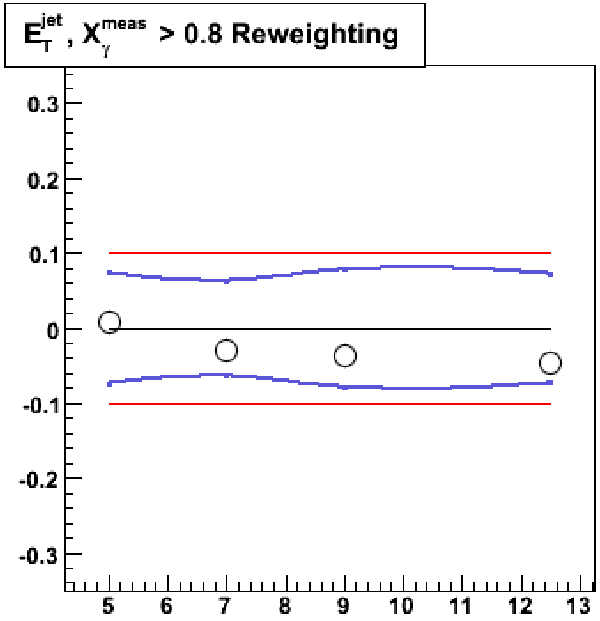
η^γ, X_γ^{meas} < 0.7 Reweighting



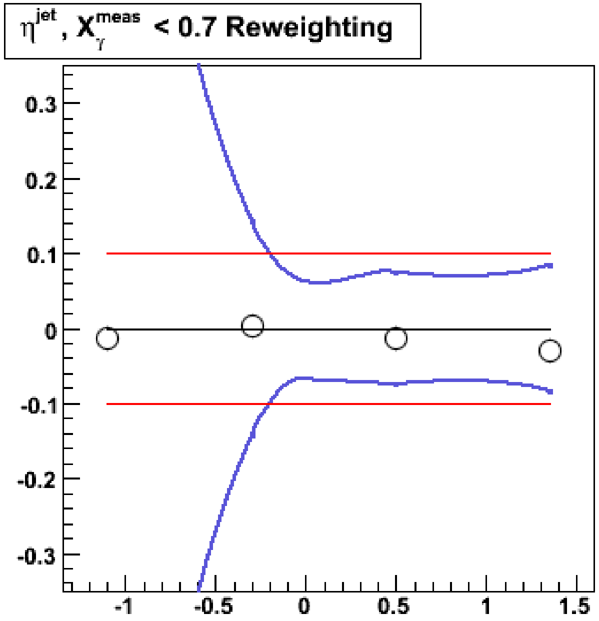
η^γ, X_γ^{meas} > 0.8 Reweighting



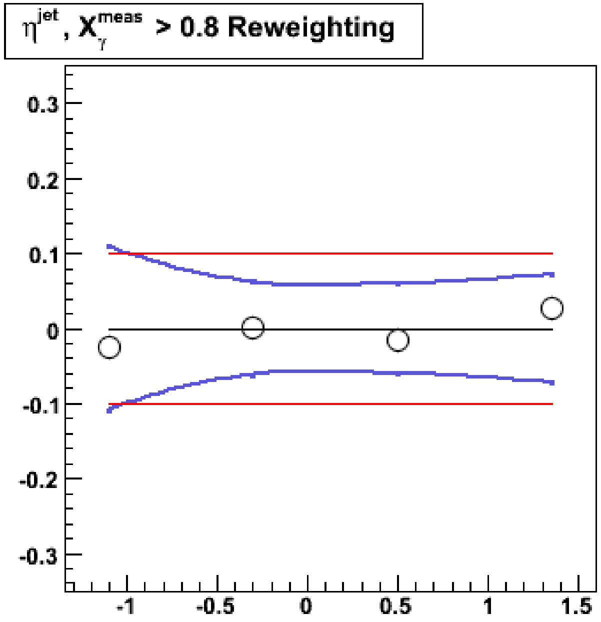
E_T^{jet}, X_γ^{meas} < 0.7 Reweighting



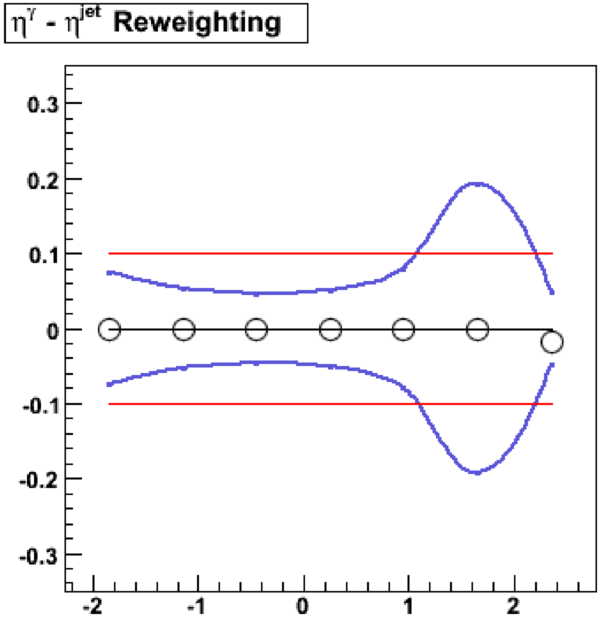
E_T^{jet}, X_γ^{meas} > 0.8 Reweighting



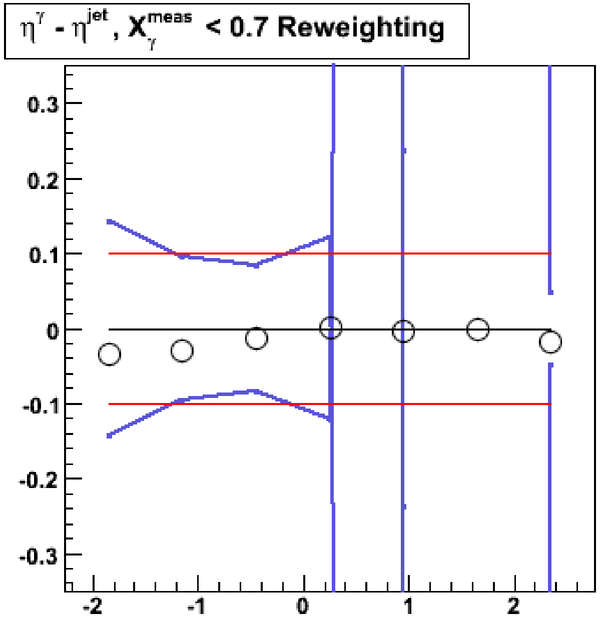
η^{jet}, X_γ^{meas} < 0.7 Reweighting



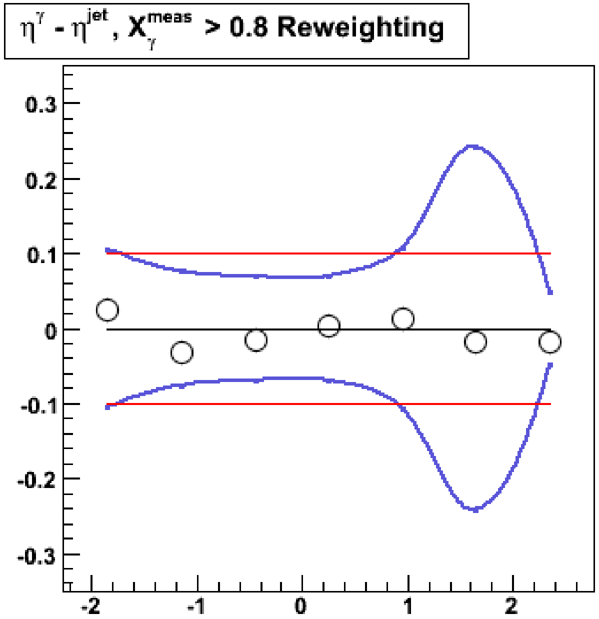
η^{jet}, X_γ^{meas} > 0.8 Reweighting



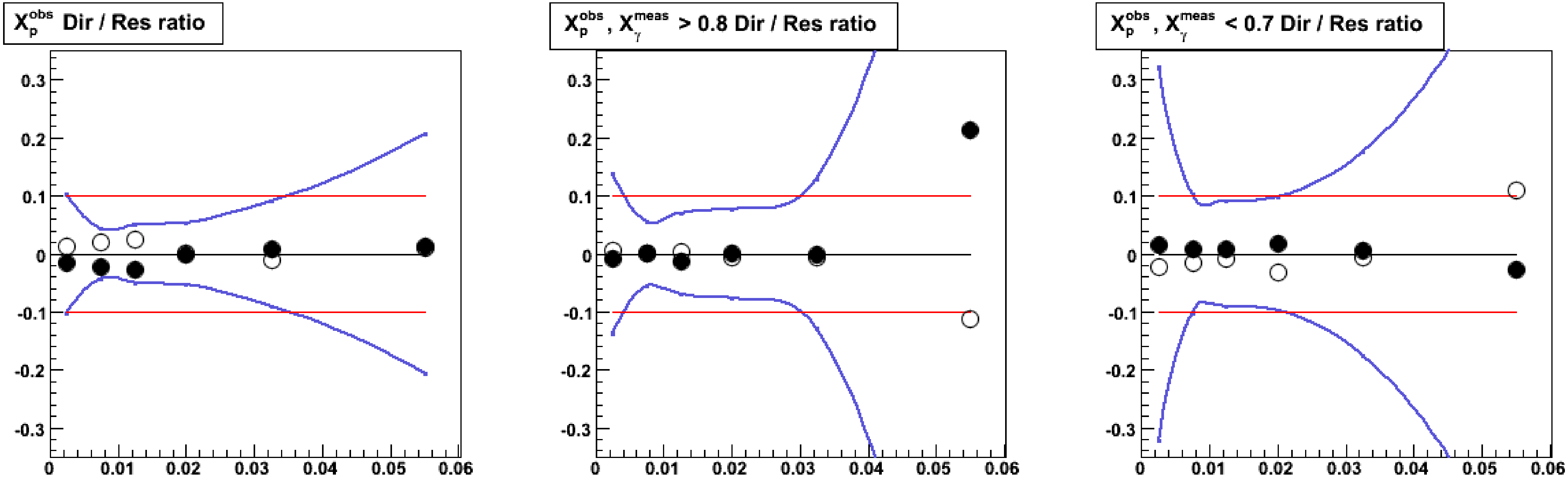
$\eta^{\gamma} - \eta^{jet}$ Reweighting



$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.7 Reweighting



$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 Reweighting



Systematic uncertainties: PYTHIA dir / res

Standard direct/ resolved ratio:
50% / 40%

Vary fraction of resolved by +-15%:

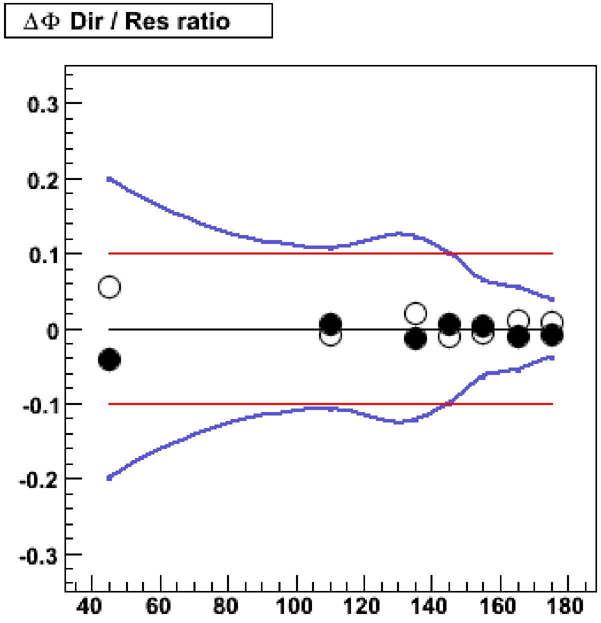
35% / 55%
65% / 25%

— *Rel.statistical uncertainties*

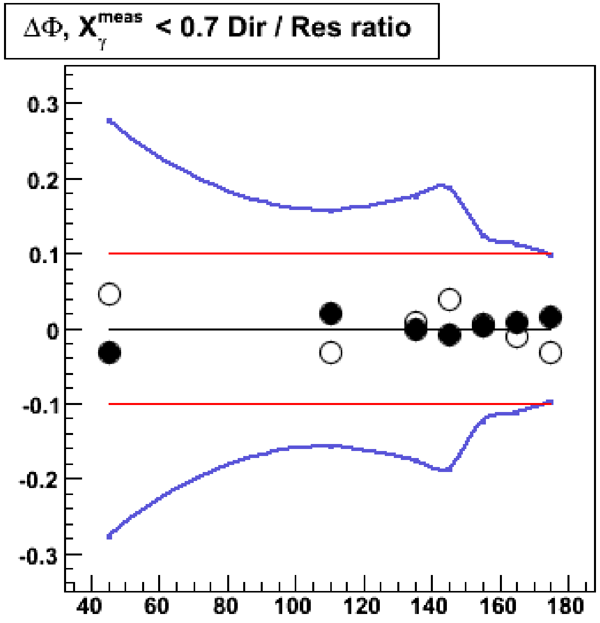
— *10% line*

○ *-15% resolved*

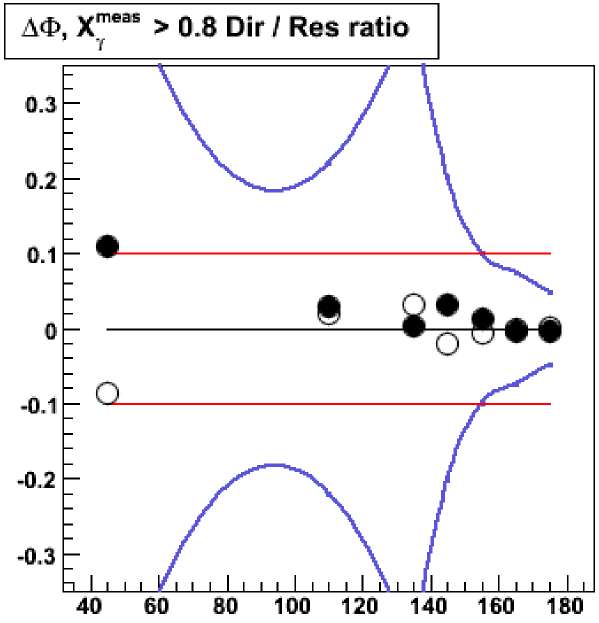
● *+15% resolved*



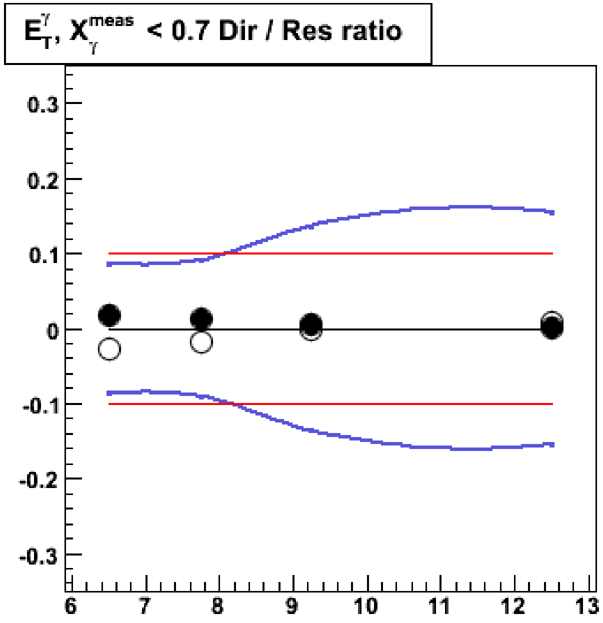
$\Delta\Phi$ Dir / Res ratio



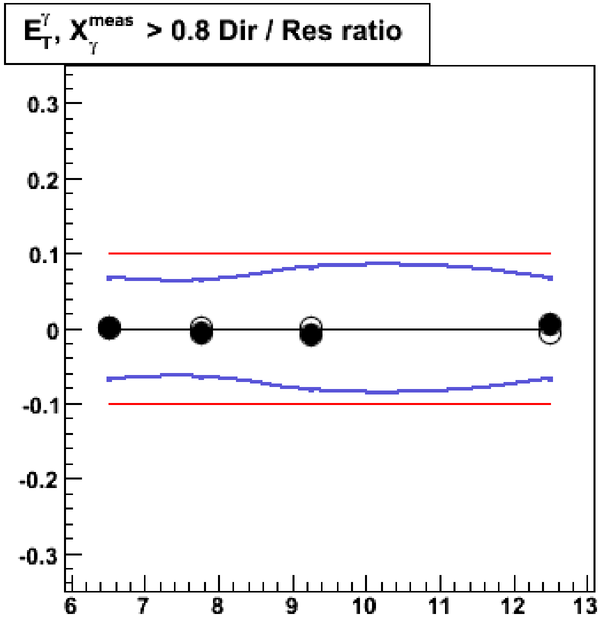
$\Delta\Phi$, X_γ^{meas} < 0.7 Dir / Res ratio



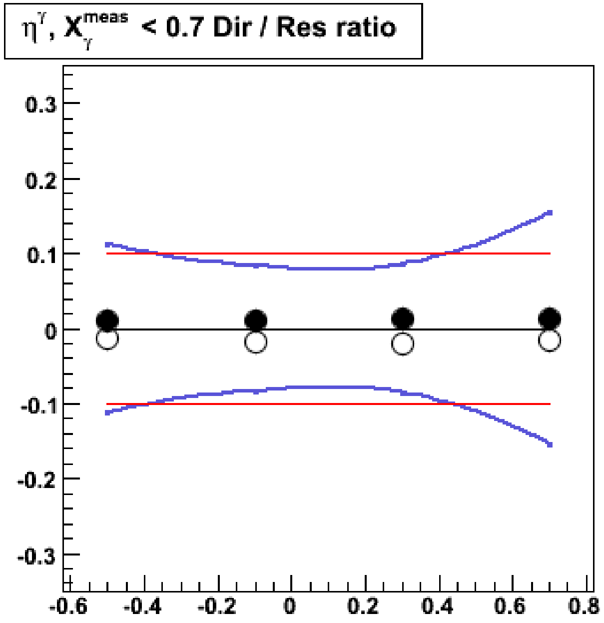
$\Delta\Phi$, X_γ^{meas} > 0.8 Dir / Res ratio



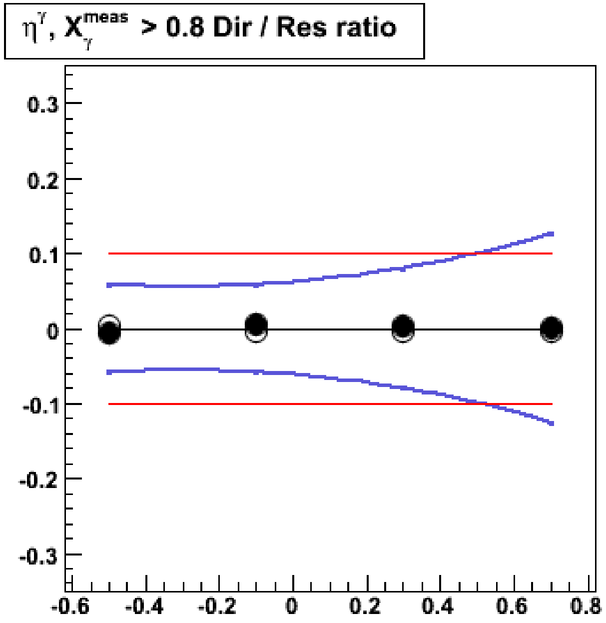
E_T^{γ}, X_{γ}^{meas} < 0.7 Dir / Res ratio



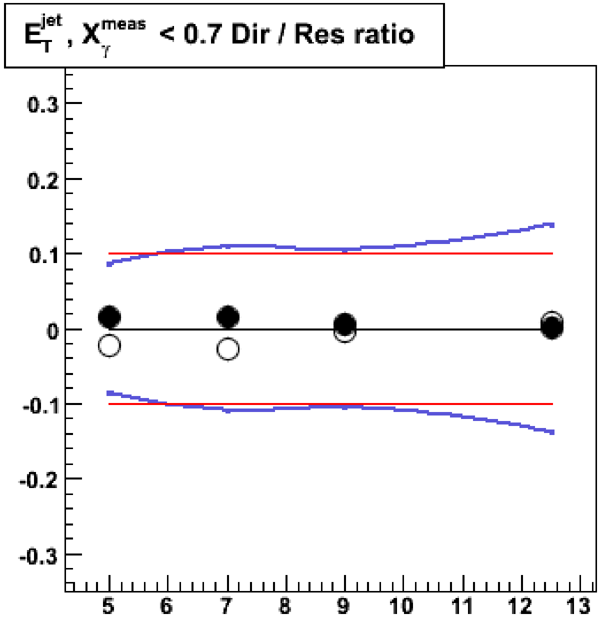
E_T^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio

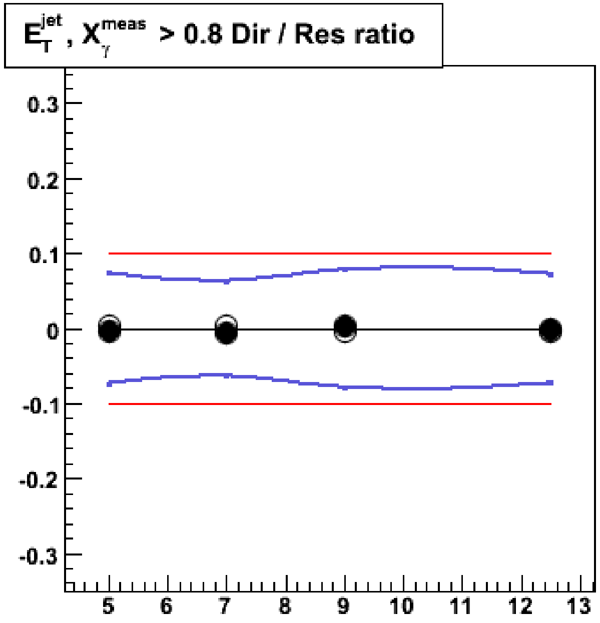


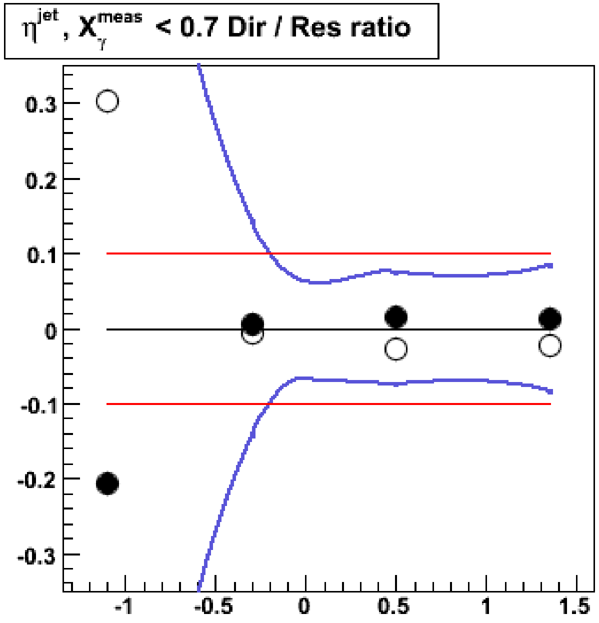
η^{γ}, X_{γ}^{meas} < 0.7 Dir / Res ratio

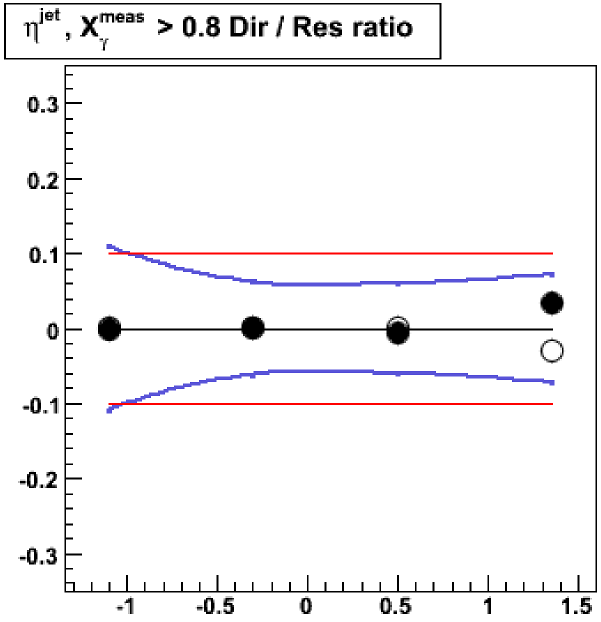


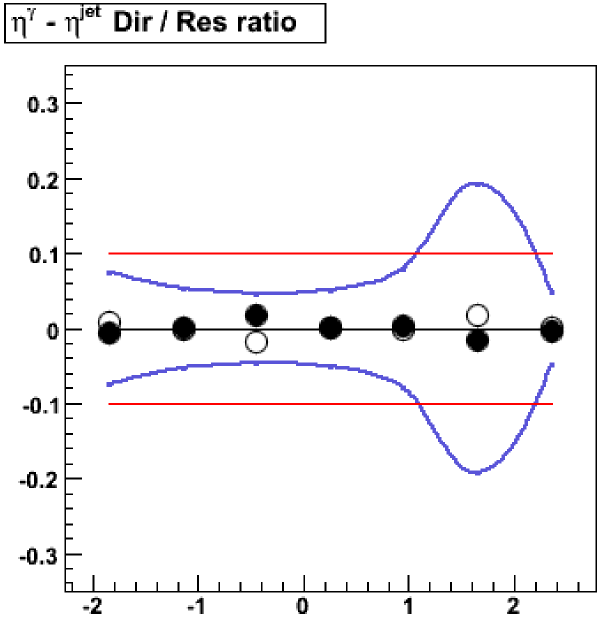
η^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio

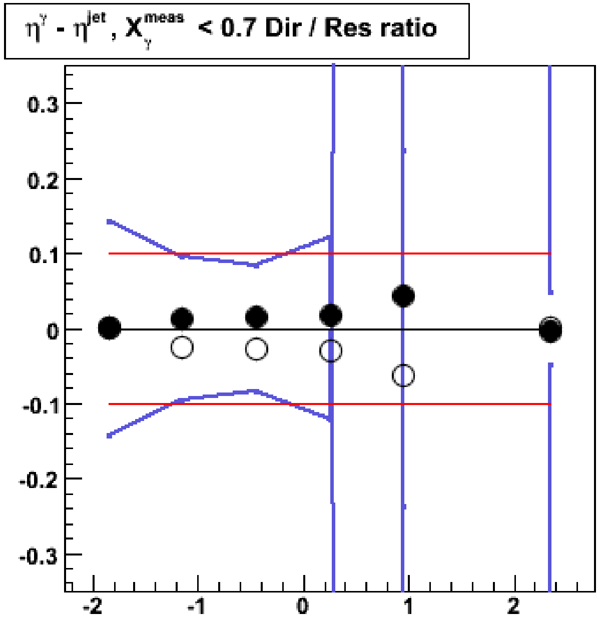

E_T^{jet}, X_{γ}^{meas} < 0.7 Dir / Res ratio

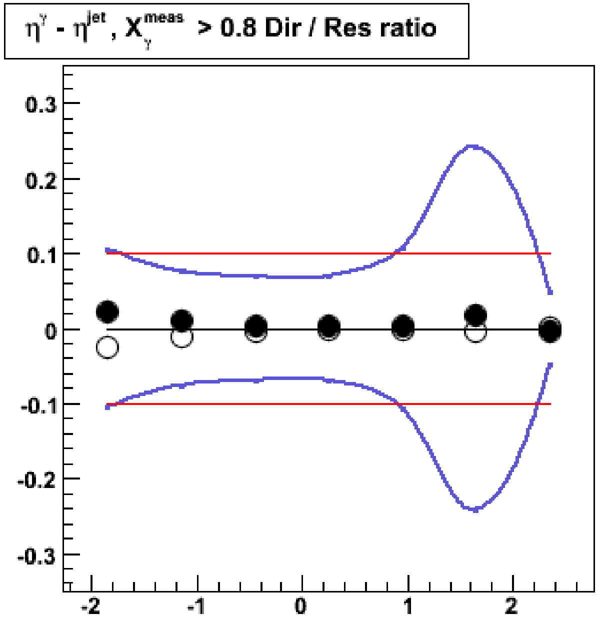

E_T^{jet}, X_{γ}^{meas} > 0.8 Dir / Res ratio

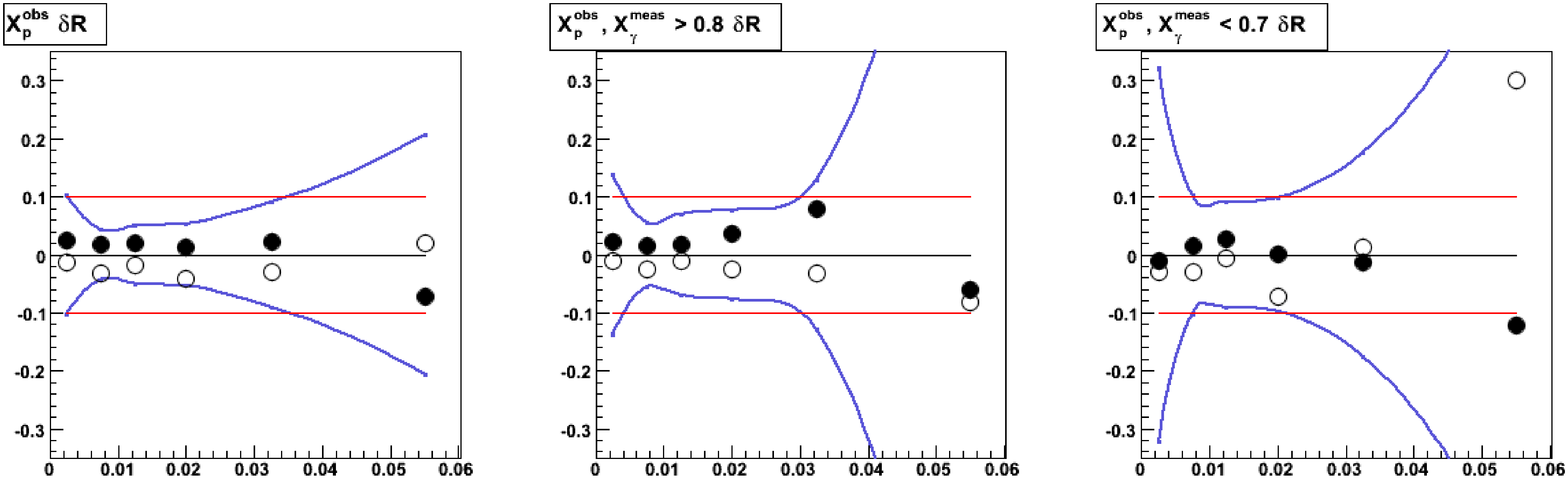

η^{jet}, X_{γ}^{meas} < 0.7 Dir / Res ratio


η^{jet}, X_{γ}^{meas} > 0.8 Dir / Res ratio


$\eta^{\gamma} - \eta^{jet}$ Dir / Res ratio


$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.7 Dir / Res ratio


$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 Dir / Res ratio



Systematic uncertainties: deltaR

Standard cut:

deltaR track isolation in cone 0.2

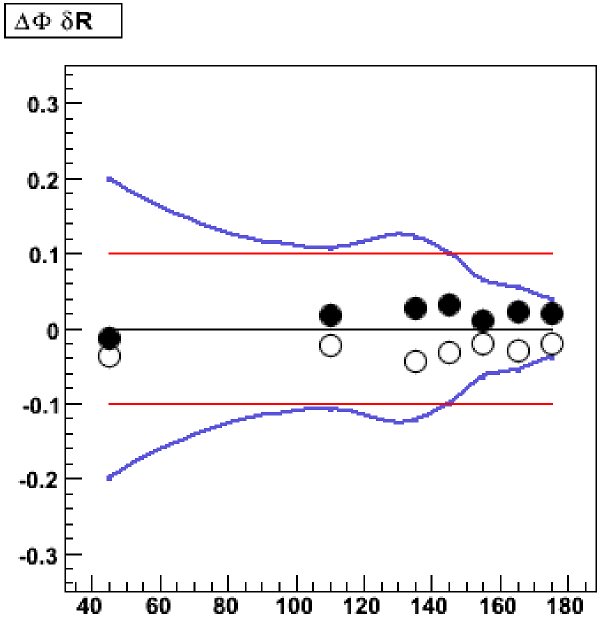
Vary cone radius by +-0.1

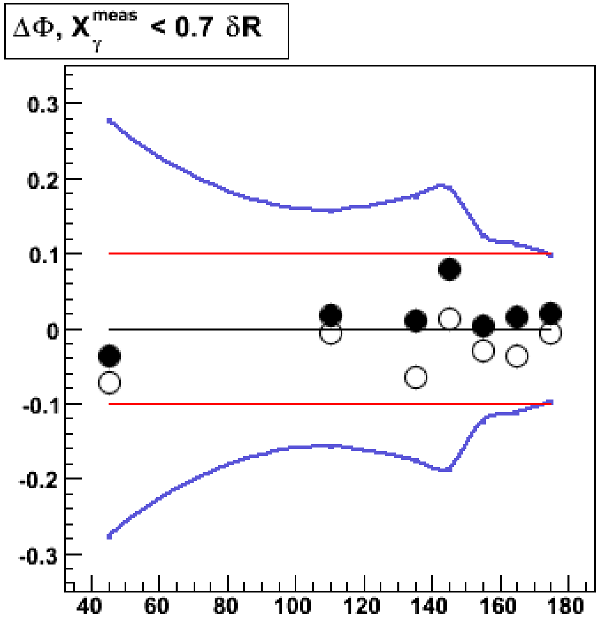
— *Rel.statistical uncertainties*

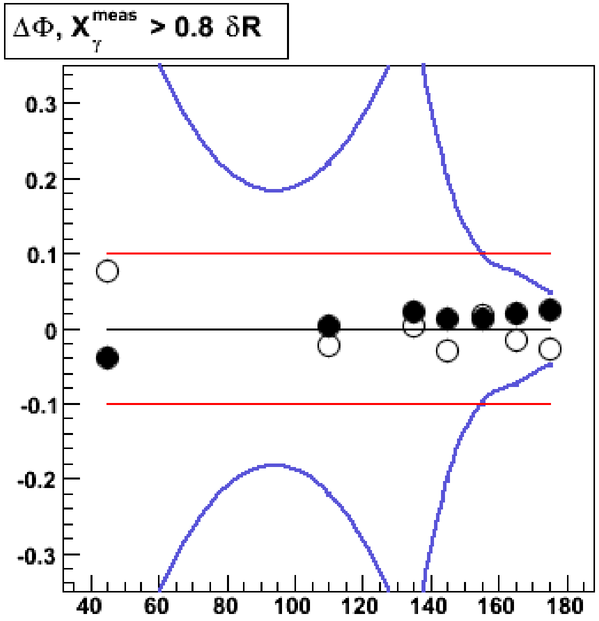
— *10% line*

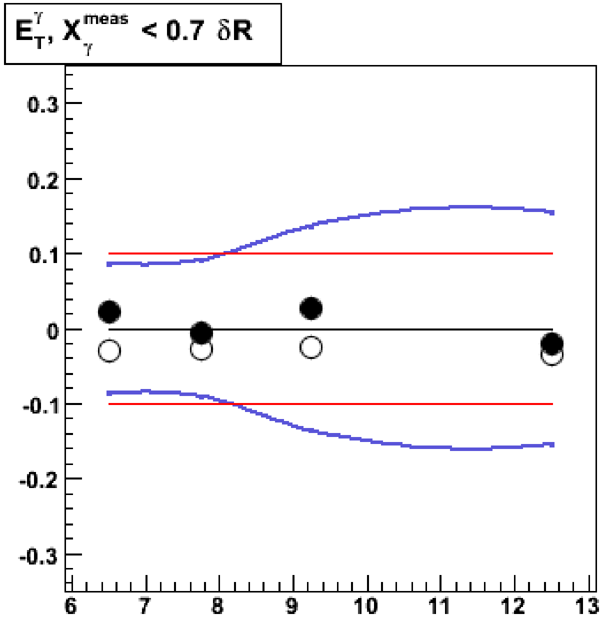
○ *δR 0.3*

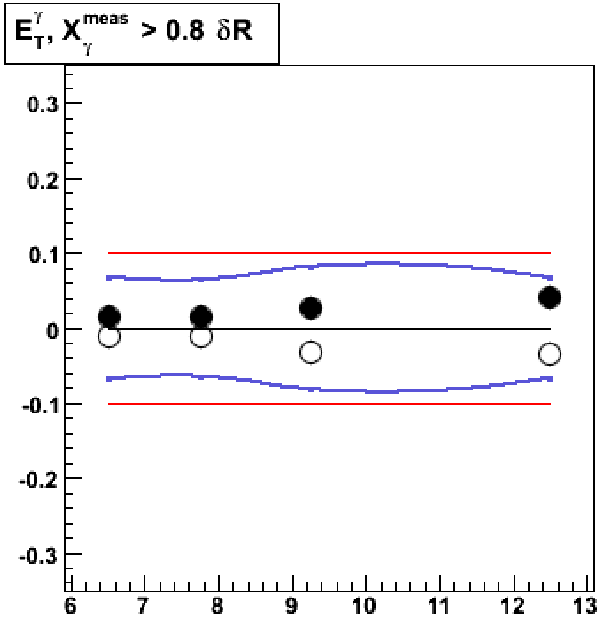
● *δR 0.1*

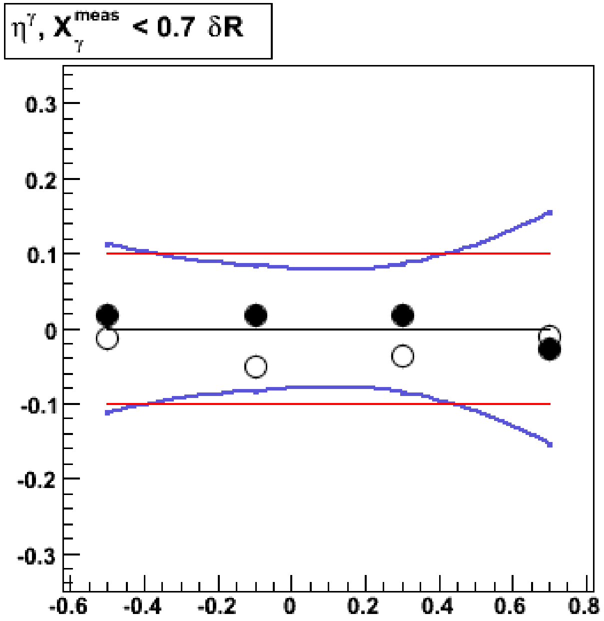

$\Delta\Phi$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

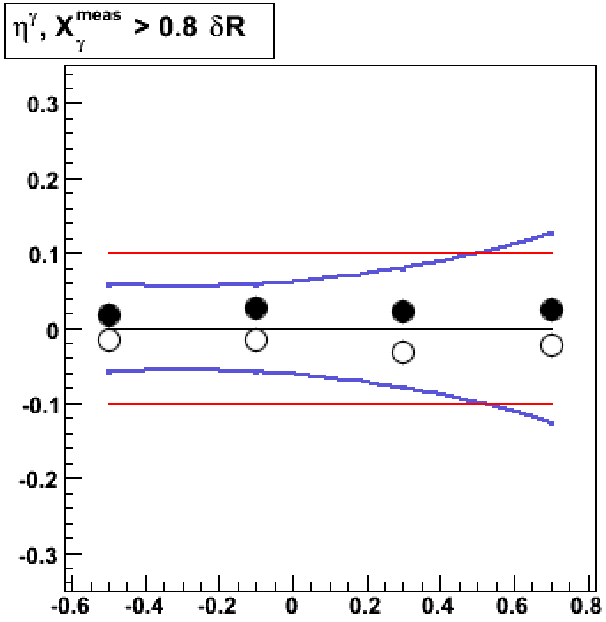

$\Delta\Phi$, $X_\gamma^{meas} < 0.7$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

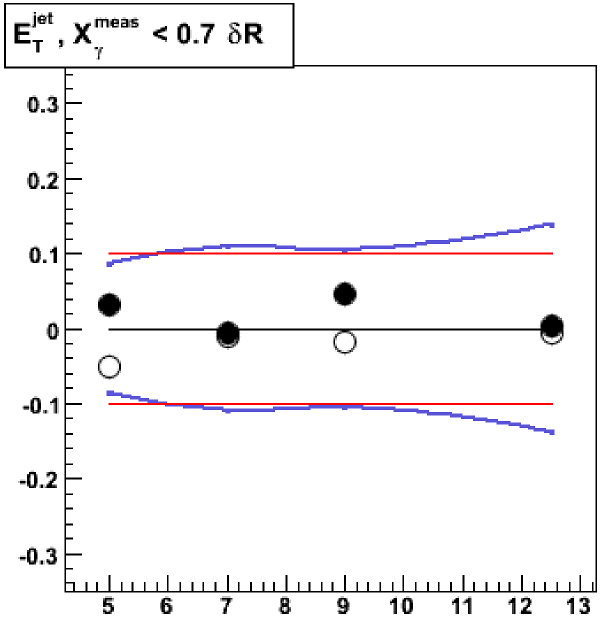

$\Delta\Phi$, $X_\gamma^{meas} > 0.8$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

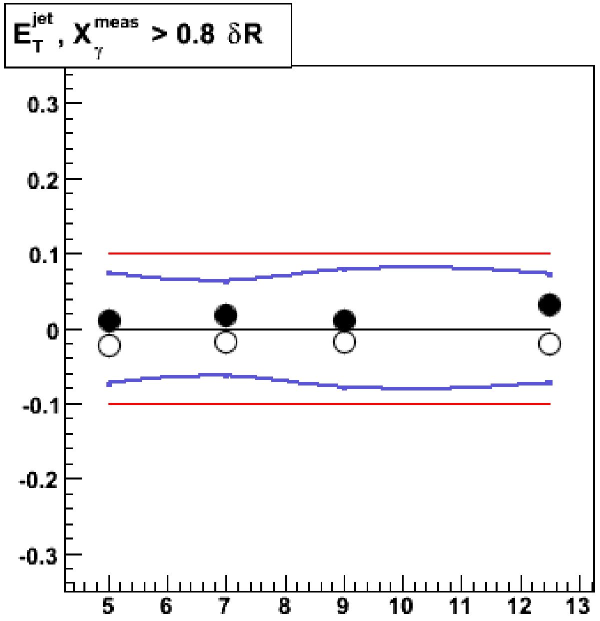

$E_T^\gamma, X_\gamma^{meas} < 0.7\ \delta R$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

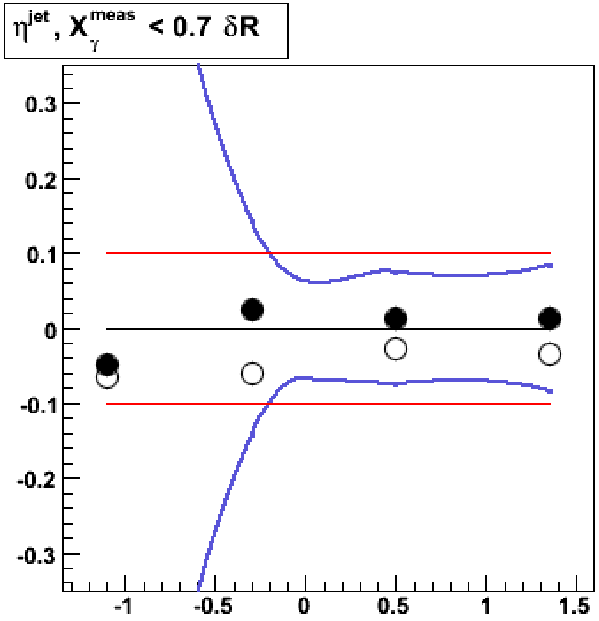

$E_T^\gamma, X_\gamma^{meas} > 0.8\ \delta R$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

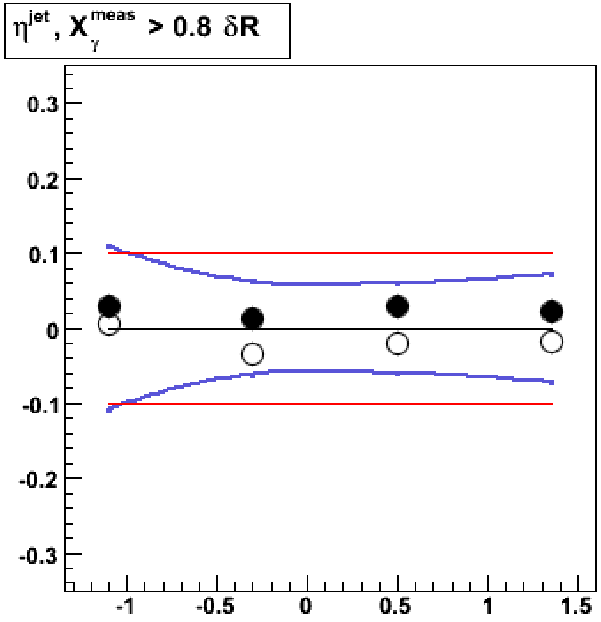

$\eta^\gamma, X_\gamma^{meas} < 0.7\ \delta R$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

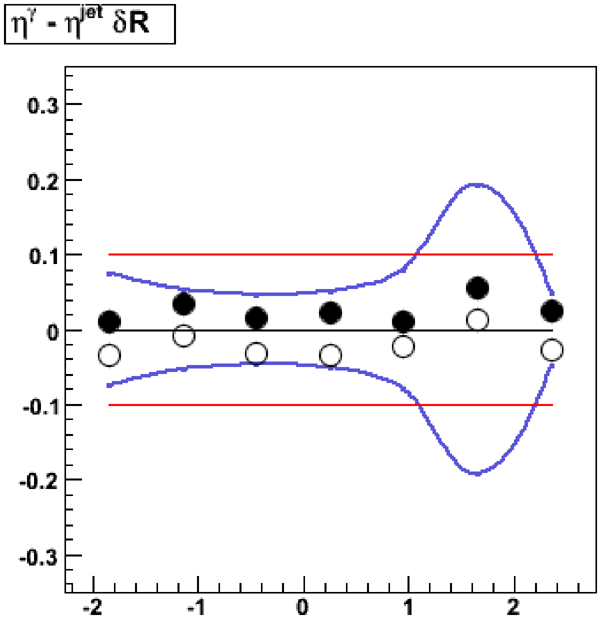

$\eta^\gamma, X_\gamma^{meas} > 0.8\ \delta R$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet}, $X_\gamma^{meas} < 0.7$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

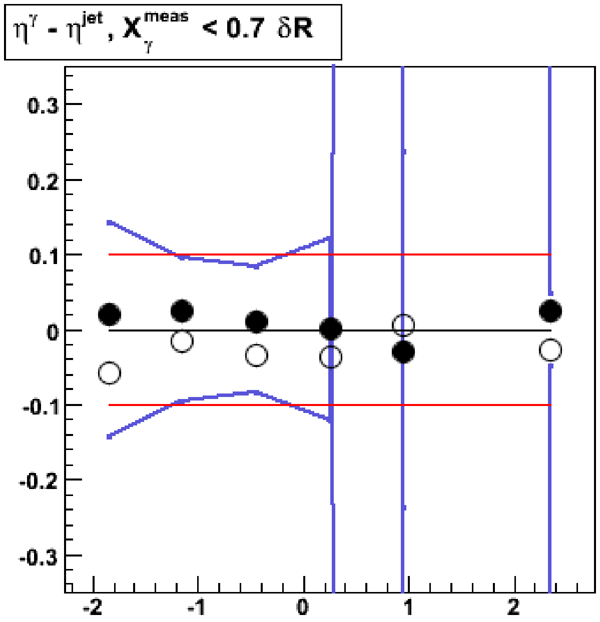

E_T^{jet}, $X_\gamma^{meas} > 0.8$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13


η^{jet}, $X_\gamma^{meas} < 0.7$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

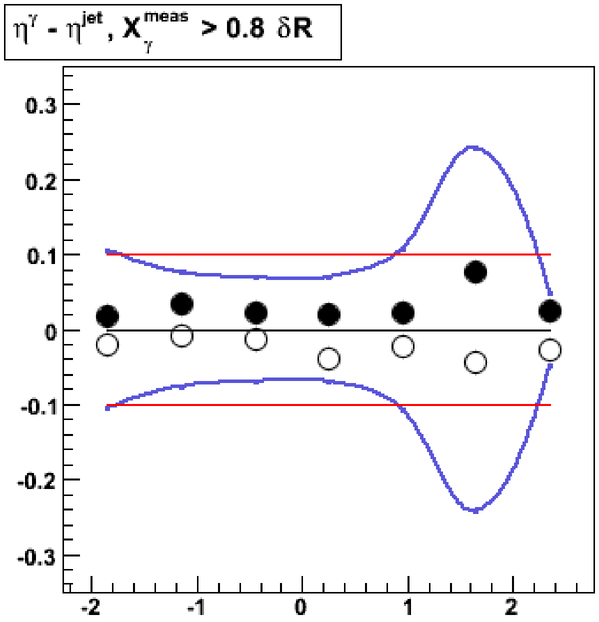

η^{jet}, $X_\gamma^{meas} > 0.8$ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5



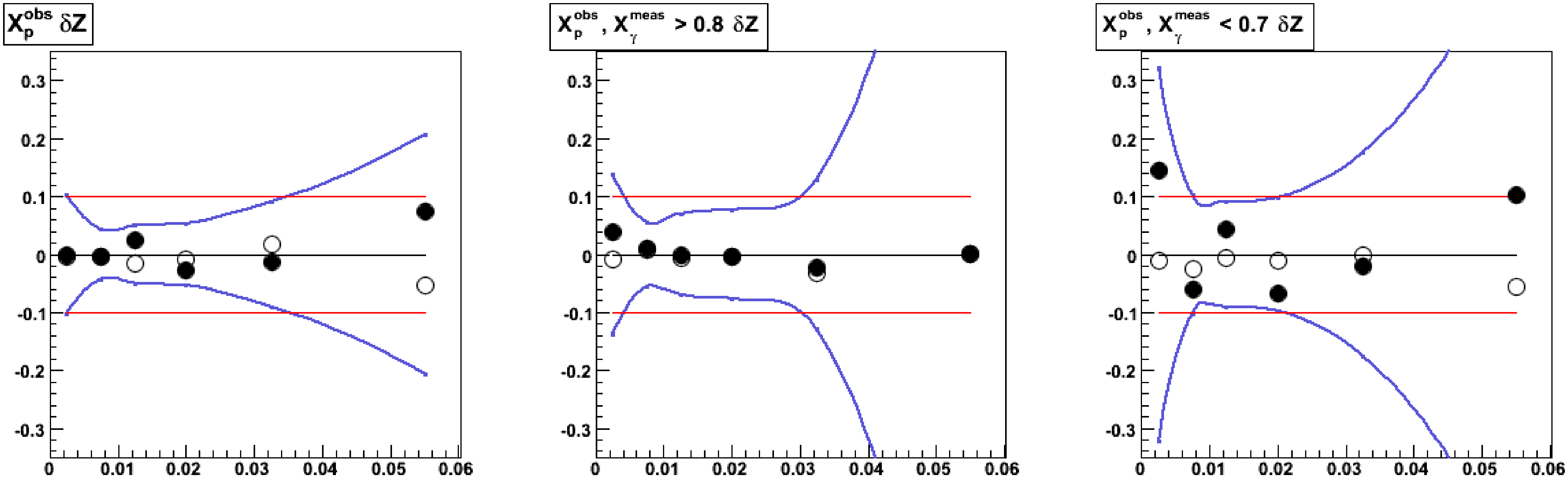
$\eta^{\gamma} - \eta^{jet}$ δR



$\eta^{\gamma} - \eta^{jet}, X_{\gamma}^{meas} < 0.7$ δR



$\eta^{\gamma} - \eta^{jet}, X_{\gamma}^{meas} > 0.8$ δR



Systematic uncertainties: deltaZ fit range

— *Rel.statistical uncertainties* δZ

— *10% line*

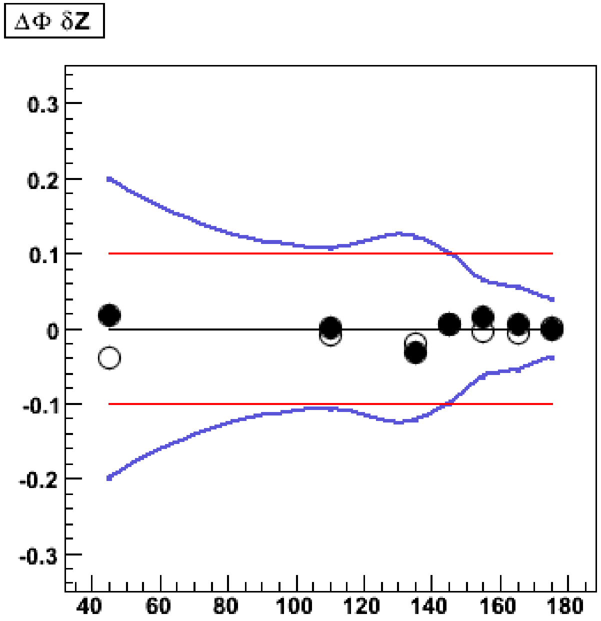
○ *δZ fit range 1.0*

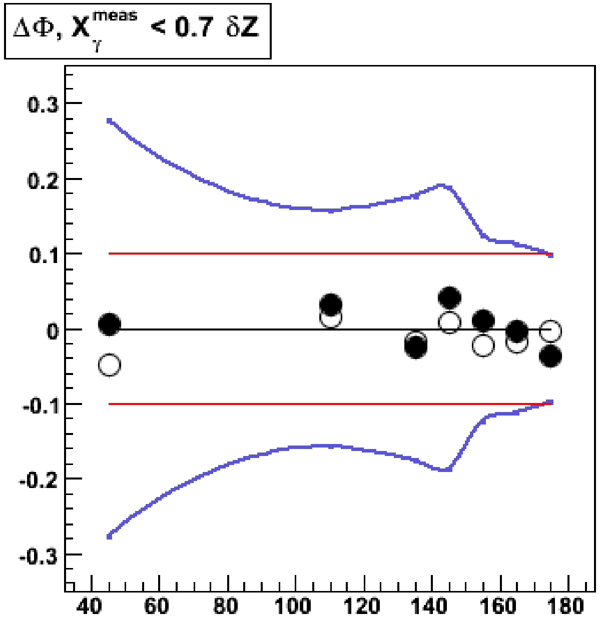
● *δZ fit range 0.6*

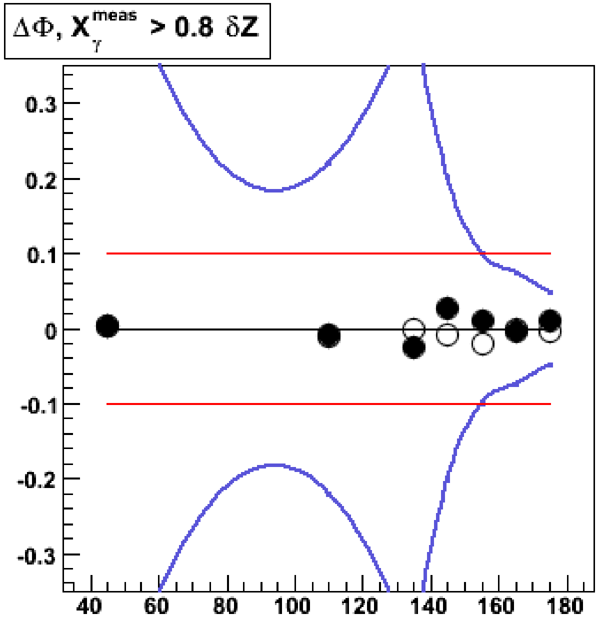
Standard range:

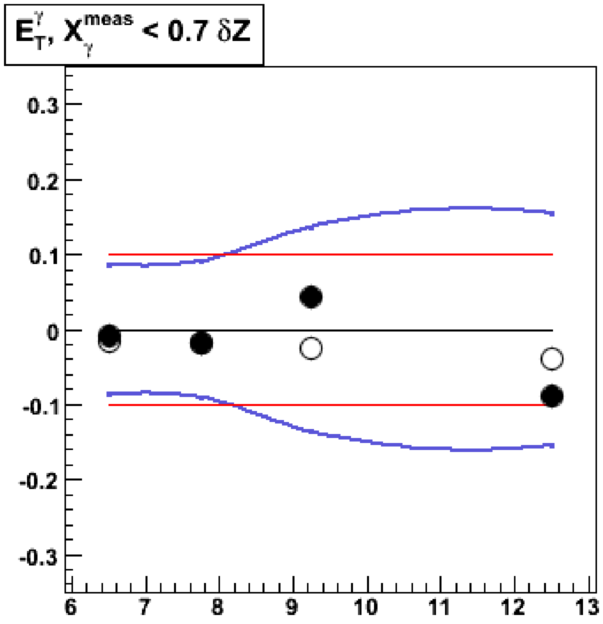
0.05 – 0.8

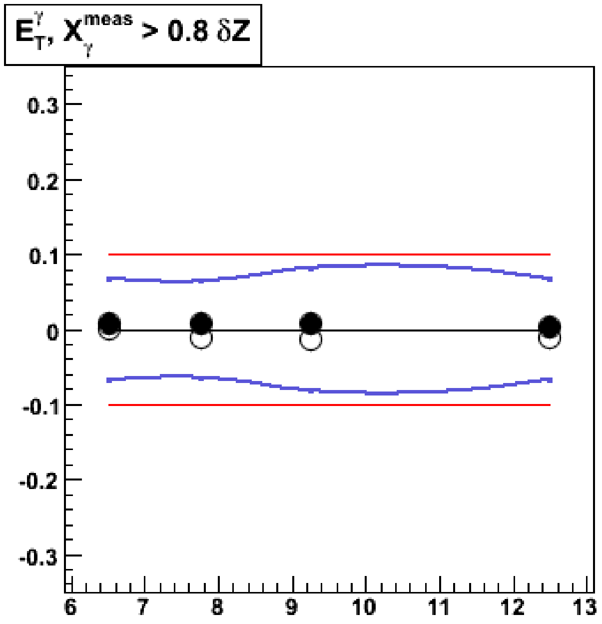
deltaZ upper limit variation between 0.6 and 1.0

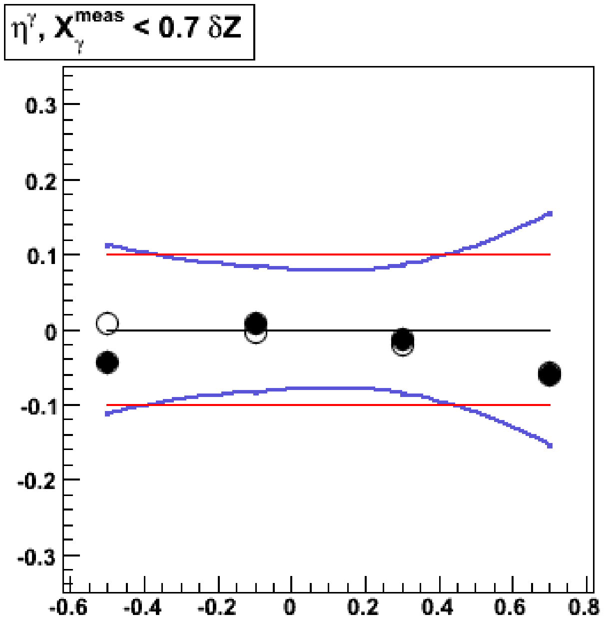

ΔΦ δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

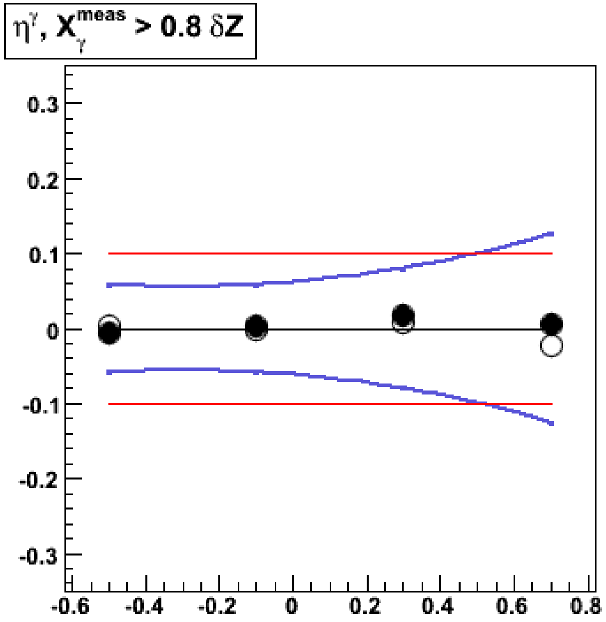

ΔΦ, X_{γ}^{meas} < 0.7 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

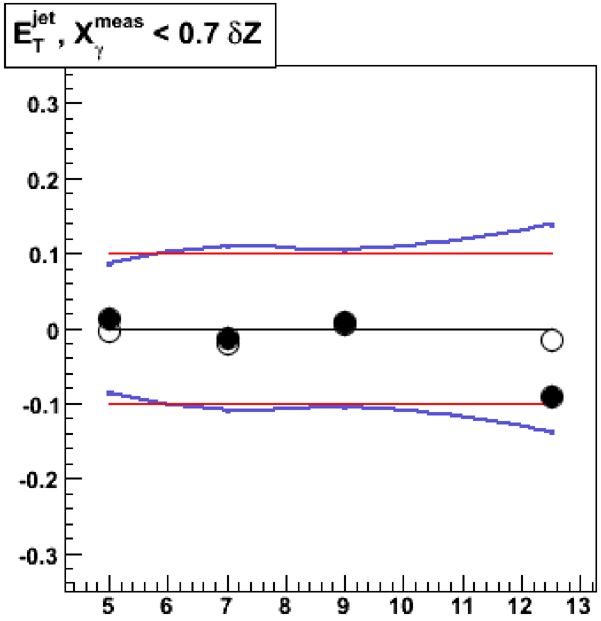

ΔΦ, X_{γ}^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


E_T^γ, X_γ^{meas} < 0.7 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

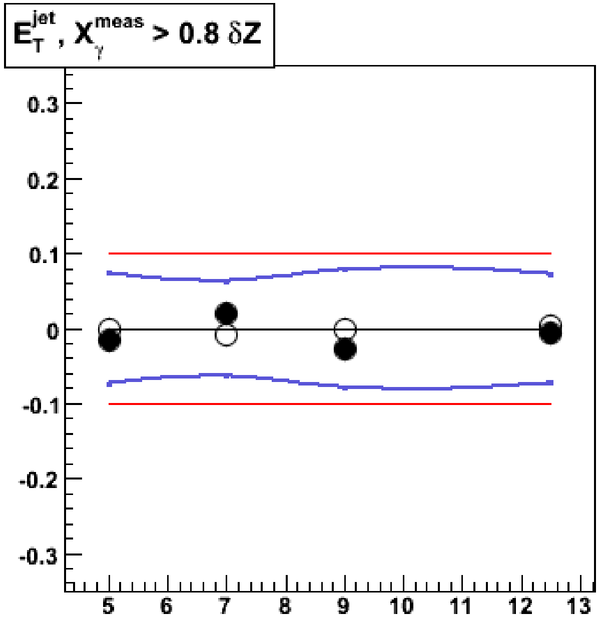

E_T^γ, X_γ^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


η^γ, X_γ^{meas} < 0.7 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

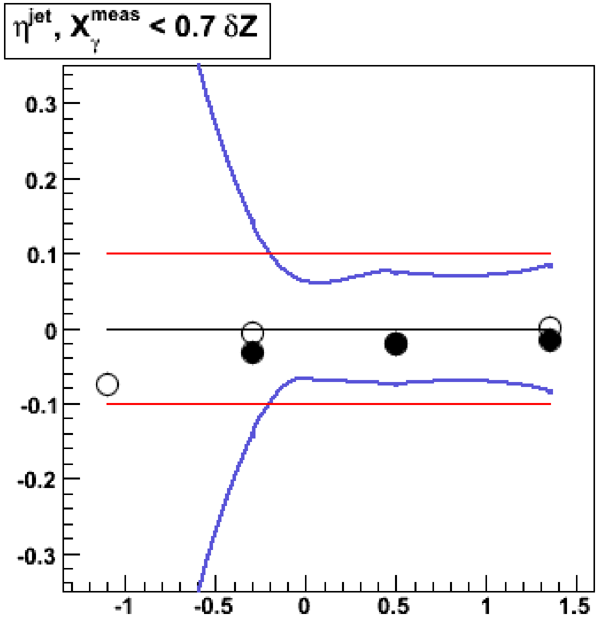

η^γ, X_γ^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8



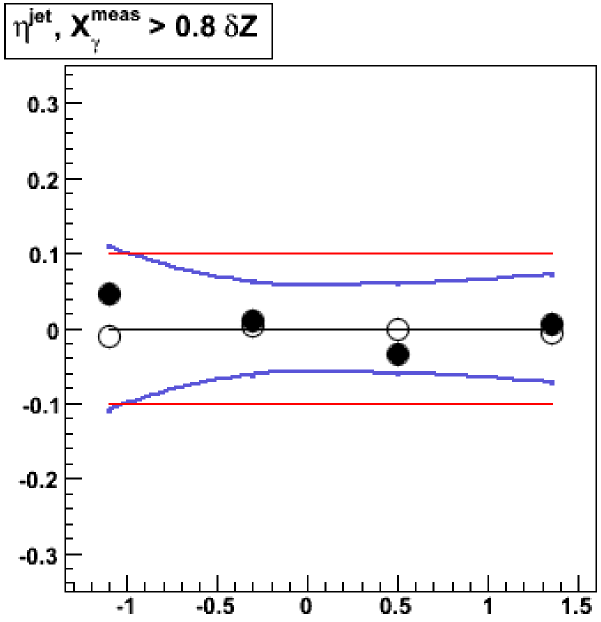
$E_T^{jet}, X_\gamma^{meas} < 0.7\ \delta Z$



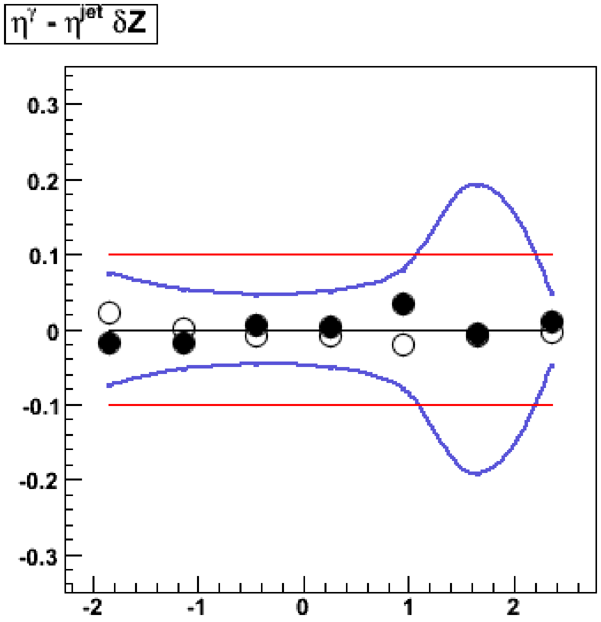
$E_T^{jet}, X_\gamma^{meas} > 0.8\ \delta Z$

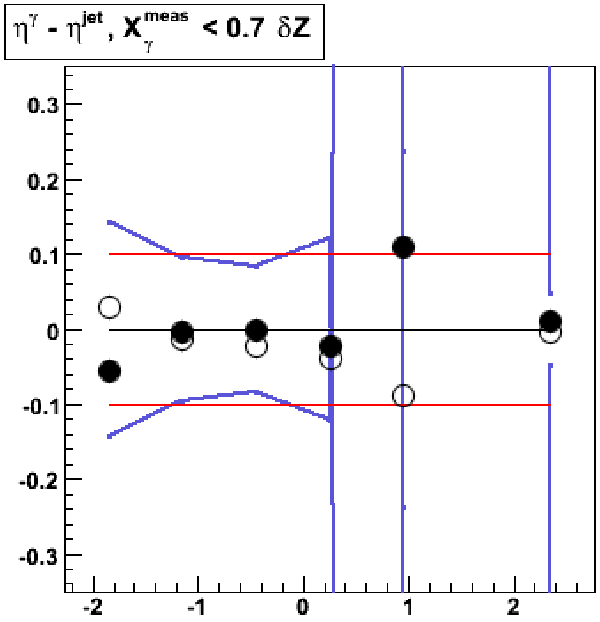


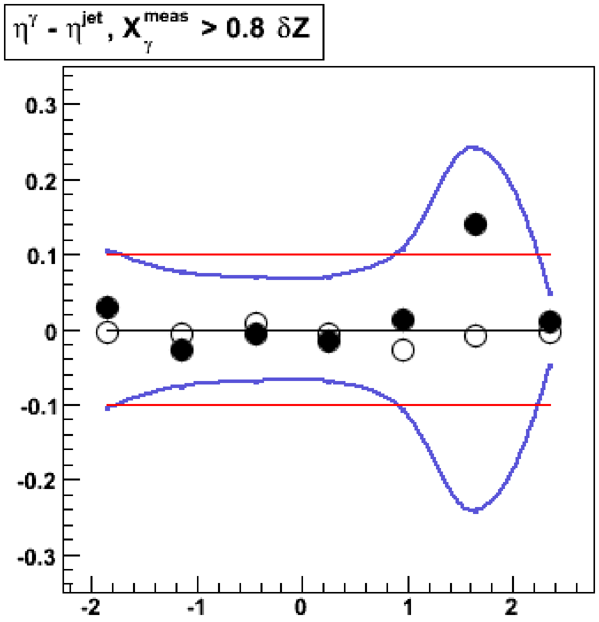
$\eta^{jet}, X_\gamma^{meas} < 0.7\ \delta Z$

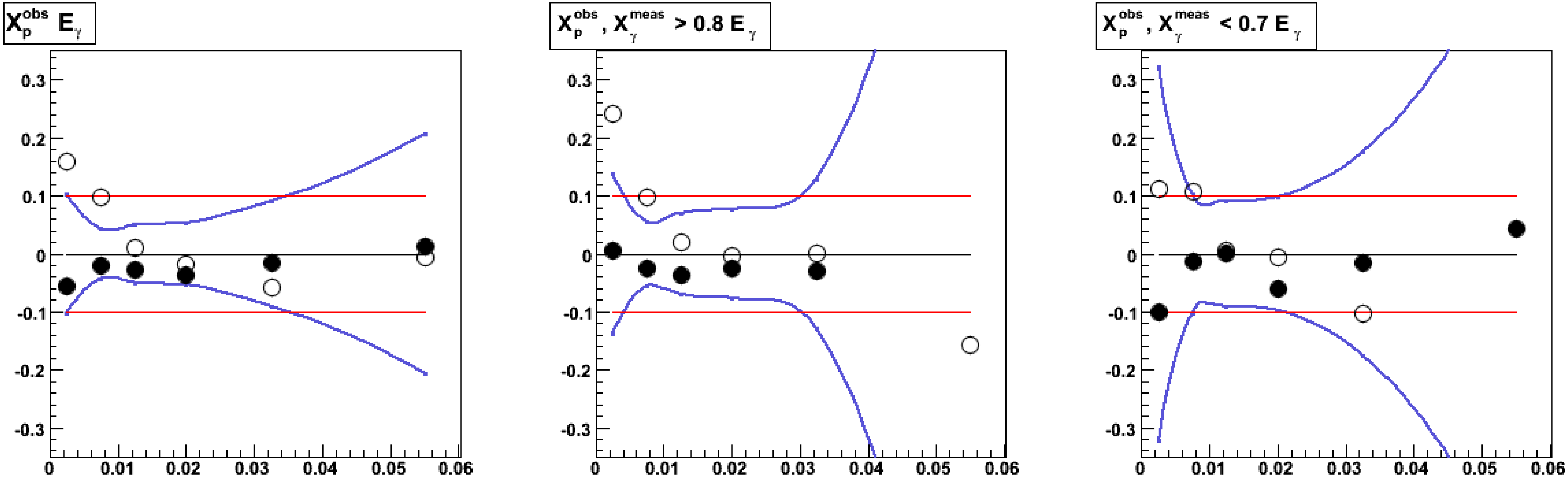


$\eta^{jet}, X_\gamma^{meas} > 0.8\ \delta Z$


η^γ - η^jet δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^γ - η^jet, X_γ^meas < 0.7 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^γ - η^jet, X_γ^meas > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



Systematic uncertainties: E^γ variation

Standard cuts:

- $6 < E_T^{zufo} < 15$ GeV

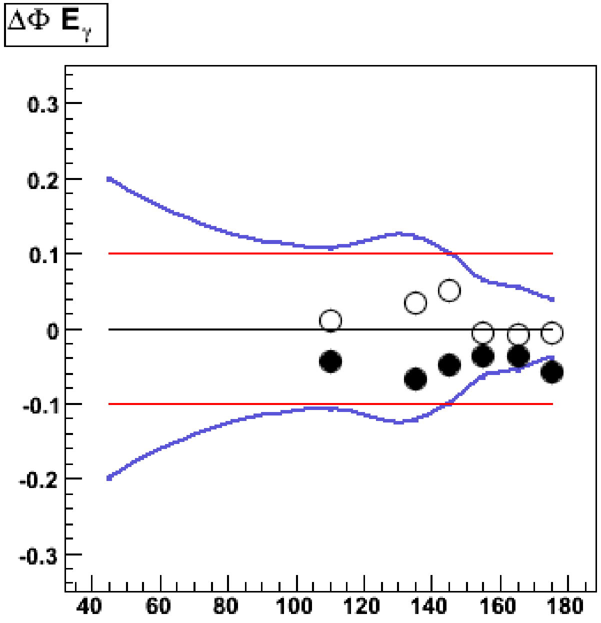
Vary E^γ by +- 2%

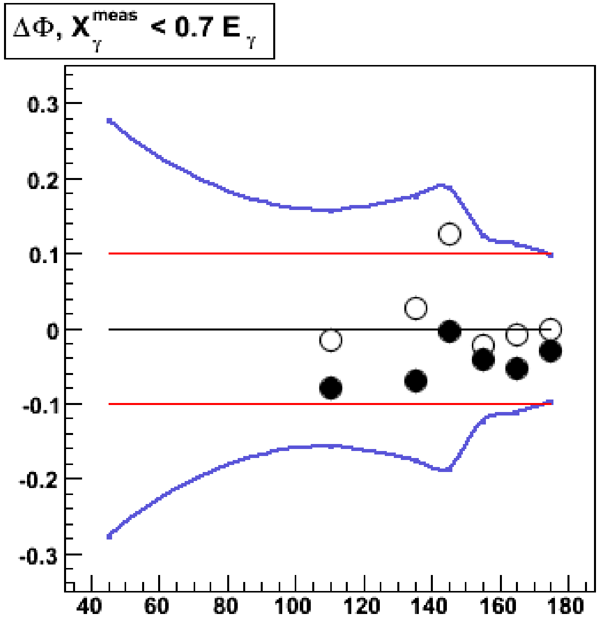
— *Rel.statistical uncertainties*

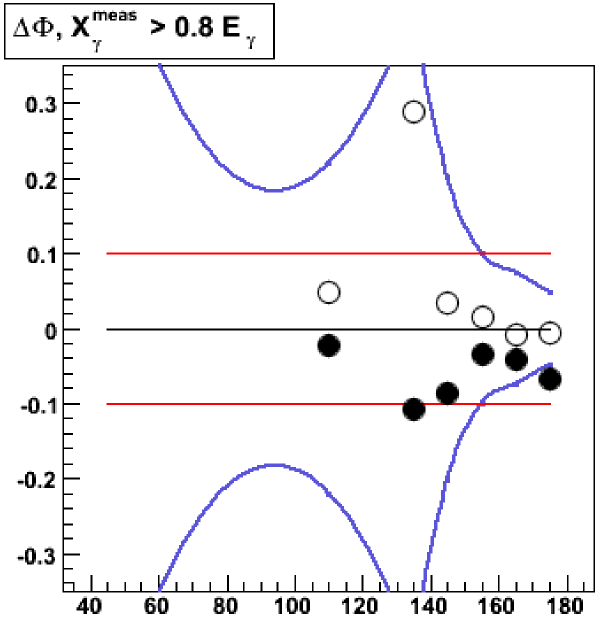
— *10% line*

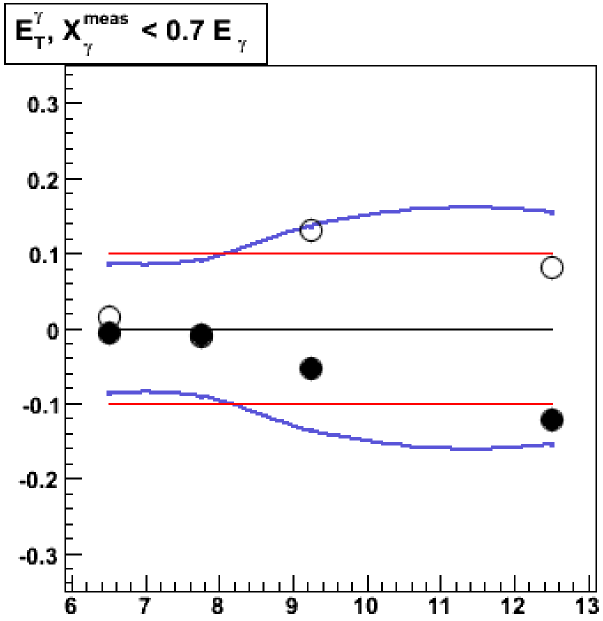
○ E_γ +2%

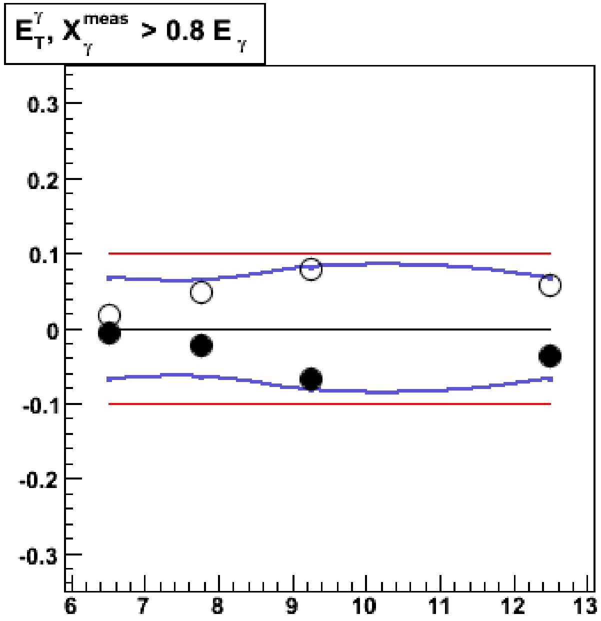
● E_γ -2%

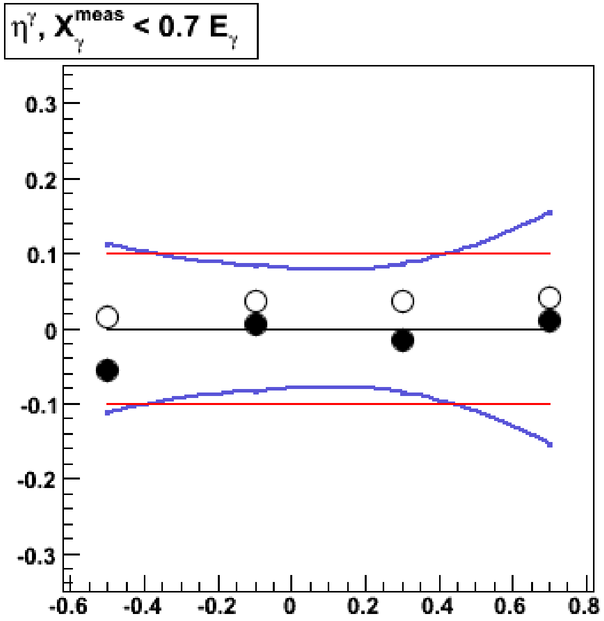

$\Delta\Phi$ E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

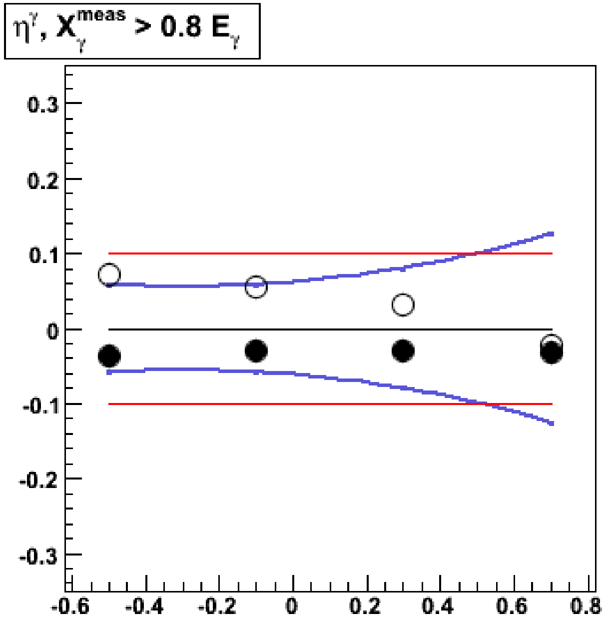

$\Delta\Phi$, $X_\gamma^{meas} < 0.7\ E_\gamma$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

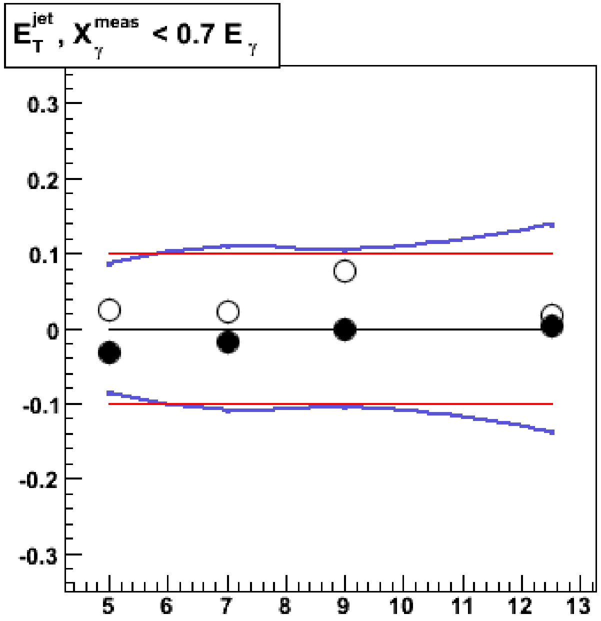

$\Delta\Phi$, $X_\gamma^{meas} > 0.8\ E_\gamma$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

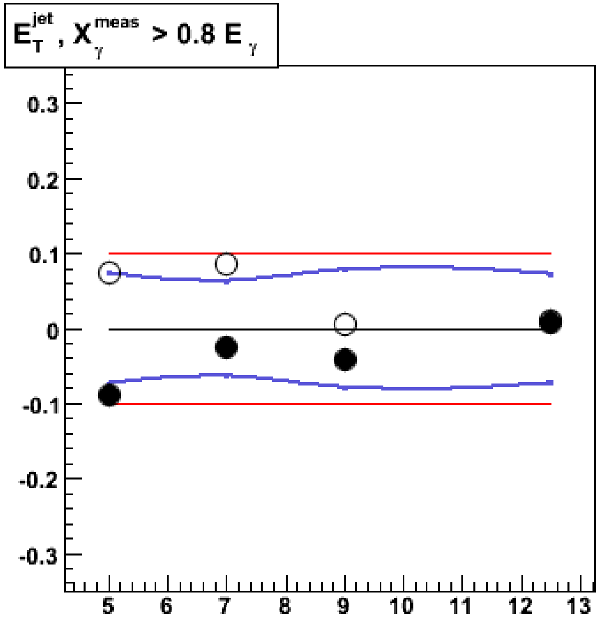

E_T^γ, X_γ^{meas} < 0.7 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

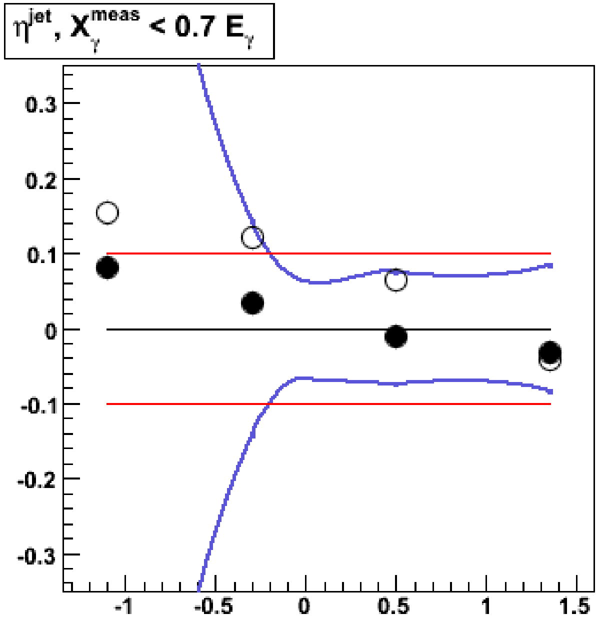

E_T^γ, X_γ^{meas} > 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

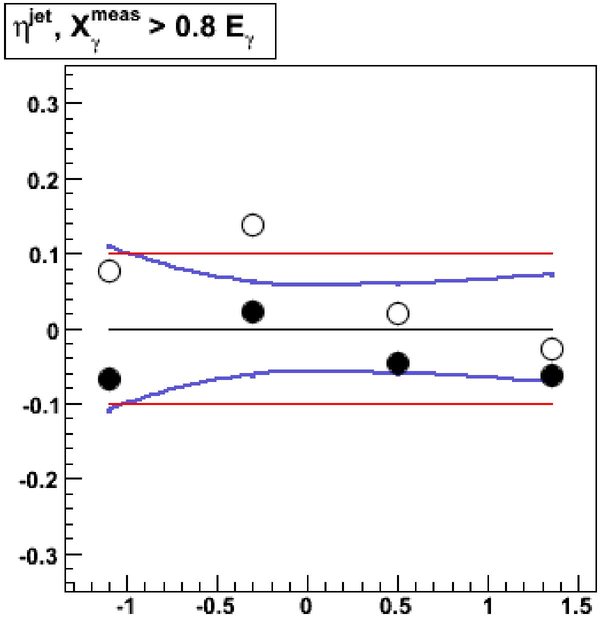

η^γ, X_γ^{meas} < 0.7 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

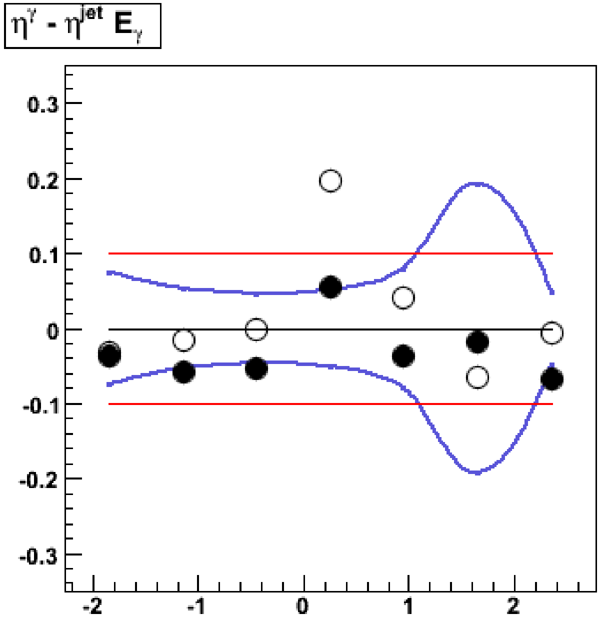

η^γ, X_γ^{meas} > 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet} , $X_\gamma^{meas} < 0.7\ E_\gamma$

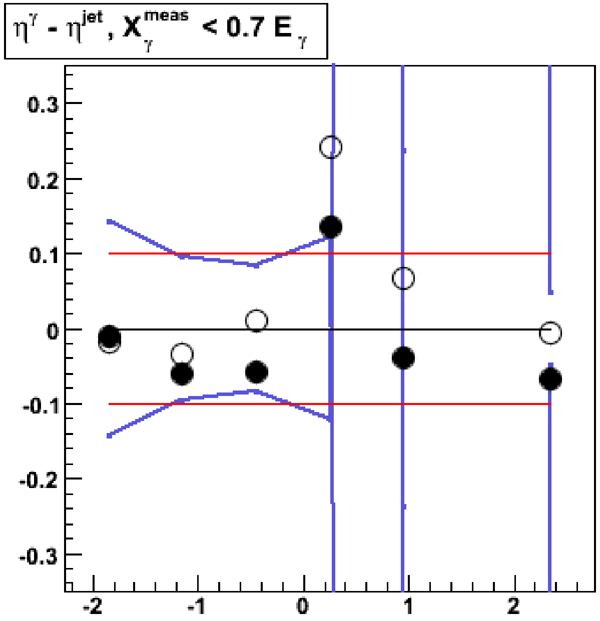

E_T^{jet} , $X_\gamma^{meas} > 0.8\ E_\gamma$


η^{jet}, $X_\gamma^{meas} < 0.7\ E_\gamma$

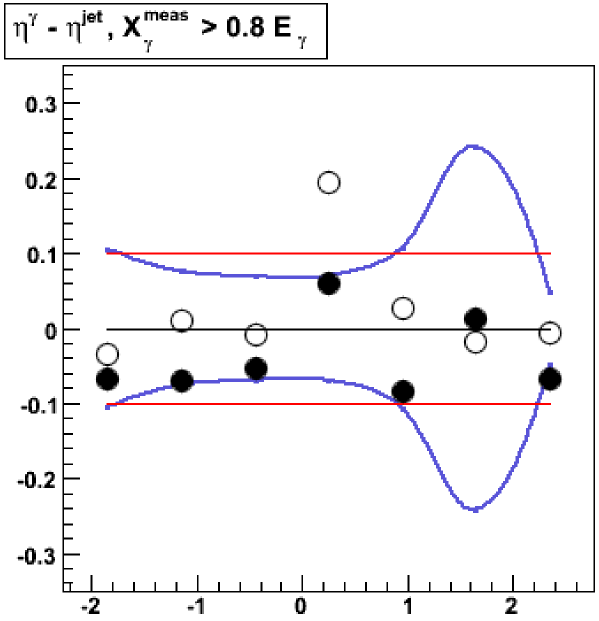

η^{jet}, $X_\gamma^{meas} > 0.8\ E_\gamma$



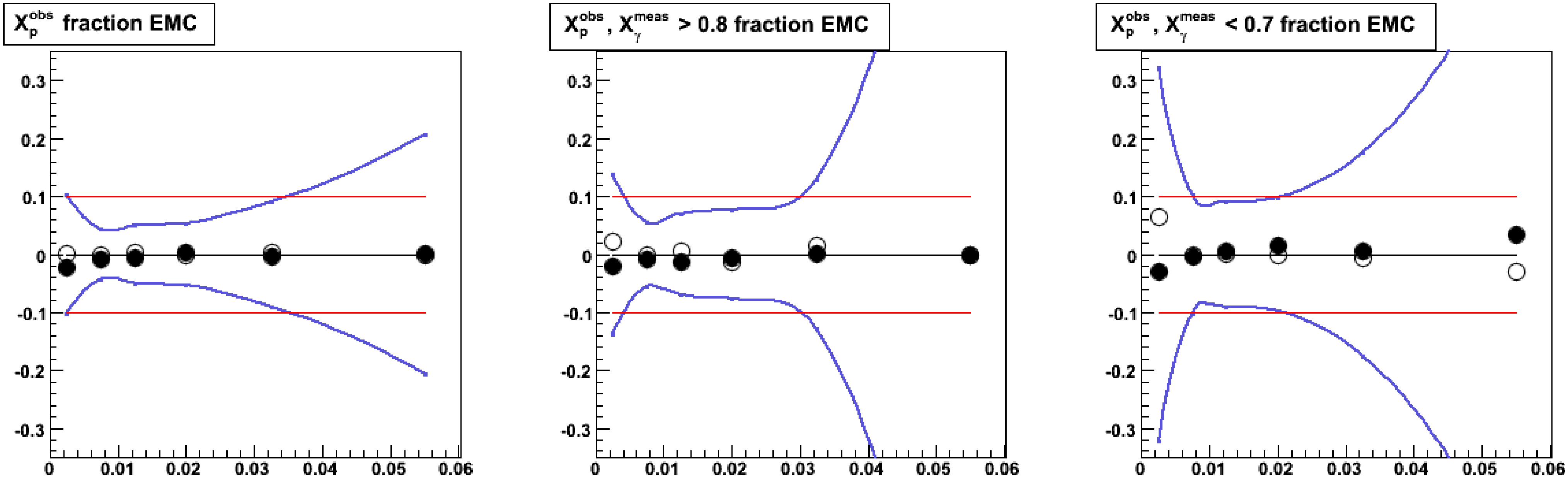
$\eta^{\gamma} - \eta^{jet}\ E_{\gamma}$



$\eta^{\gamma} - \eta^{jet},\ X_{\gamma}^{meas} < 0.7\ E_{\gamma}$



$\eta^{\gamma} - \eta^{jet},\ X_{\gamma}^{meas} > 0.8\ E_{\gamma}$



Systematic uncertainties: Fraction EMC

Standard cut:

- ZufoEemc/ZufoEcal>0.9

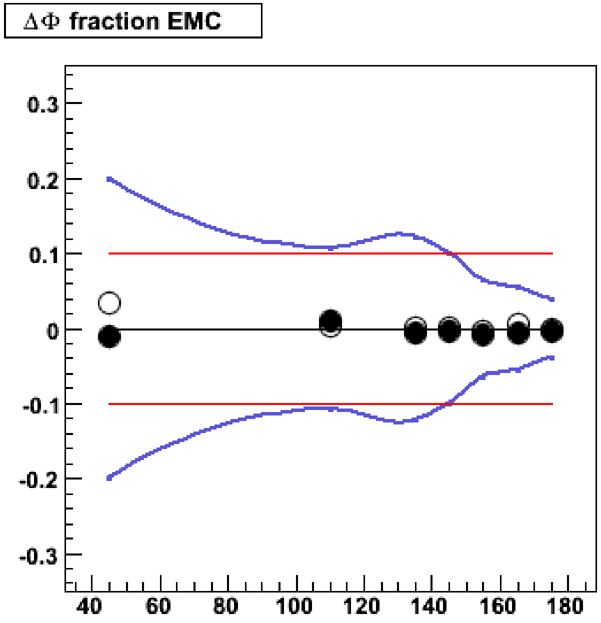
Vary the em fraction in the photon zufo by +-2.5%

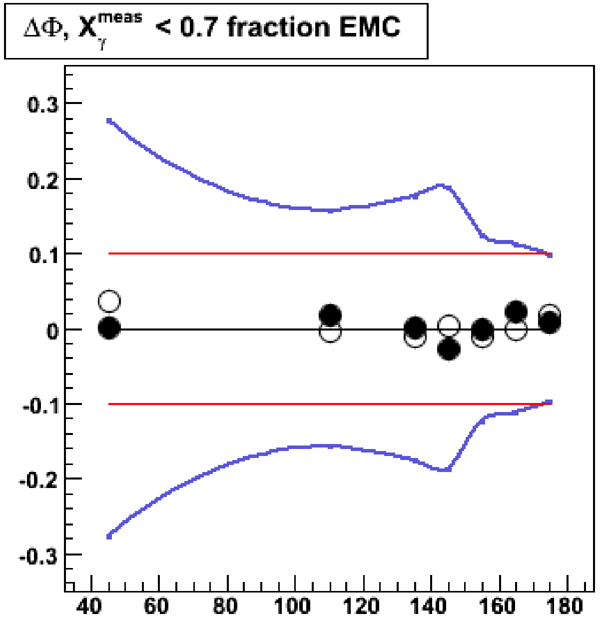
― *Rel.statistical uncertainties*

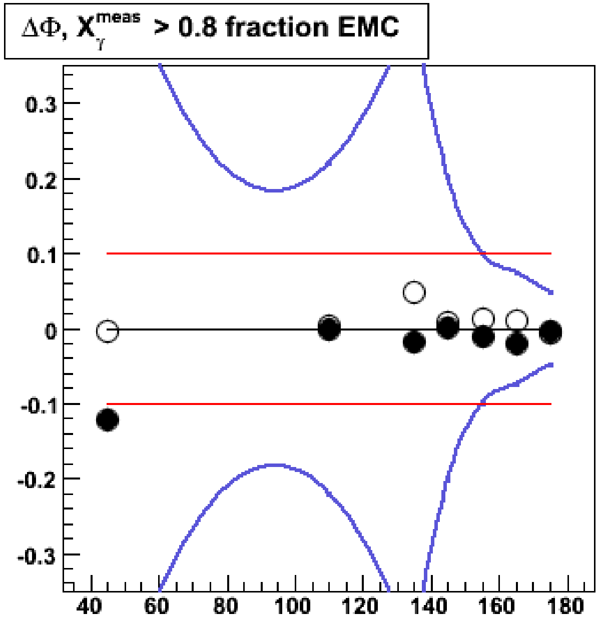
― *10% line*

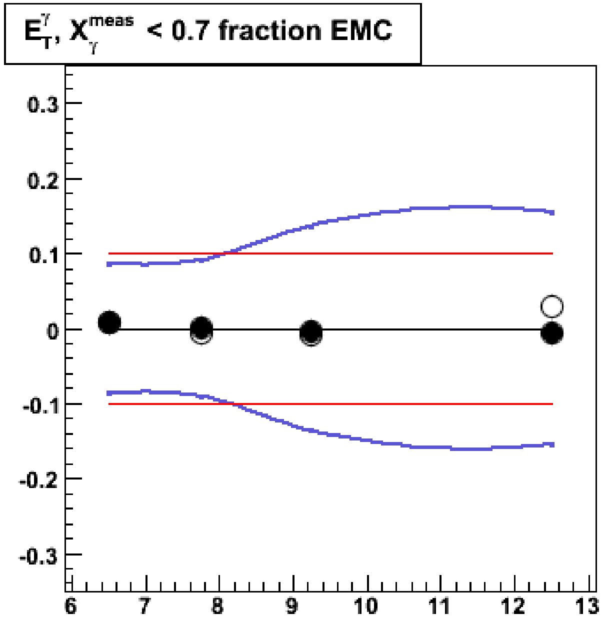
○ *Fraction EMC +0.025*

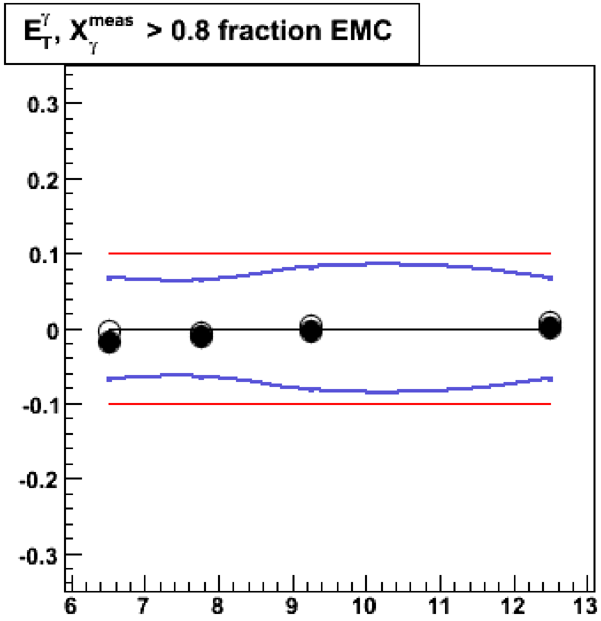
● *Fraction EMC -0.025*

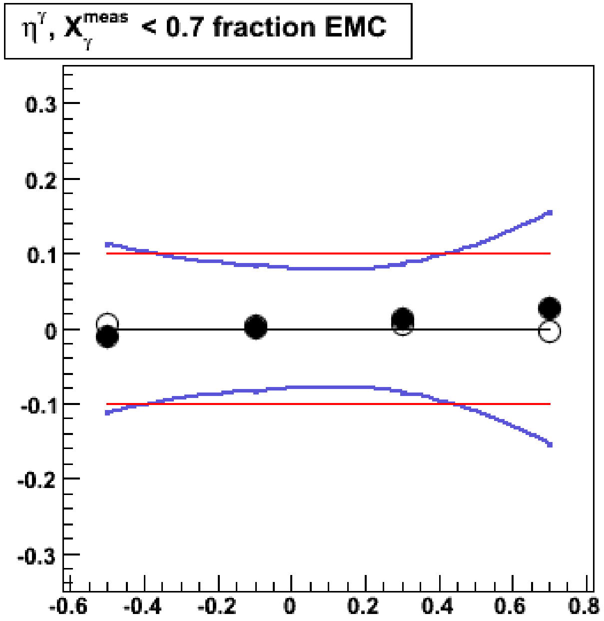

ΔΦ fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

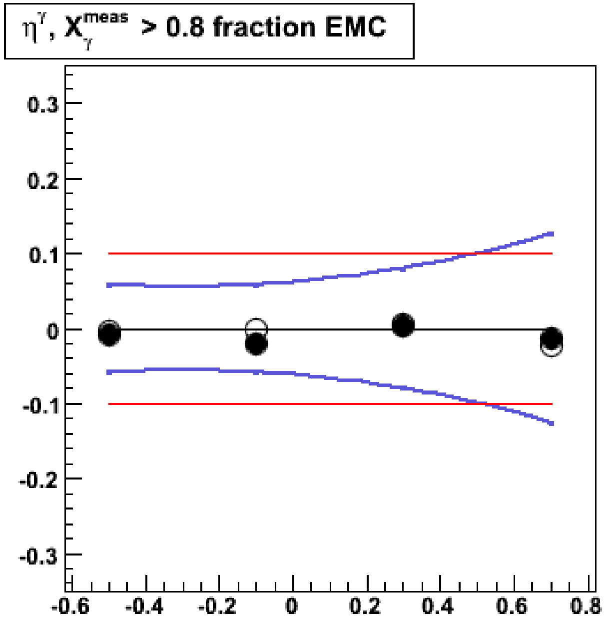

ΔΦ, X_{γ}^{meas} < 0.7 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

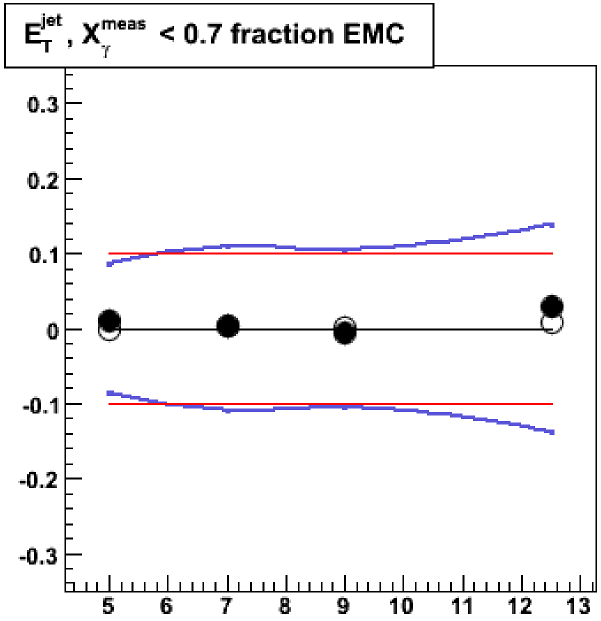

ΔΦ, X_{γ}^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

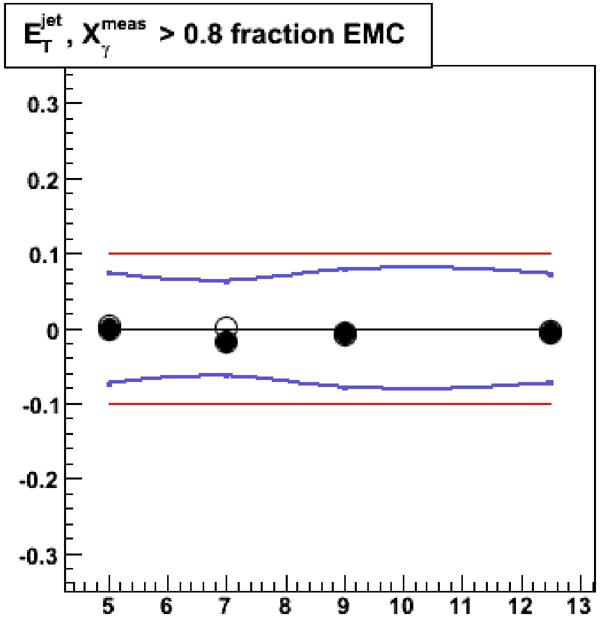

E_T^γ, X_γ^{meas} < 0.7 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

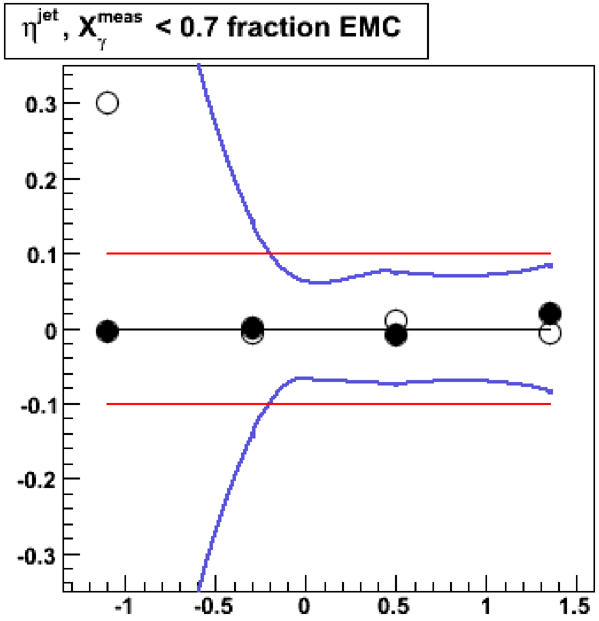

E_T^γ, X_γ^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

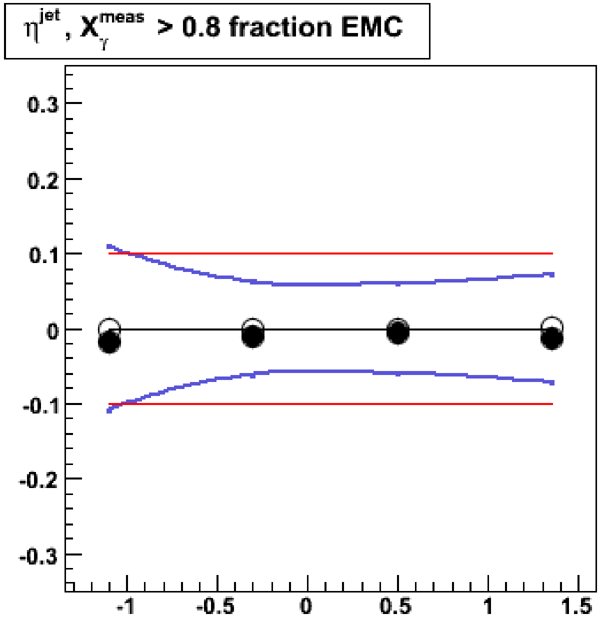

η^γ, X_γ^{meas} < 0.7 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

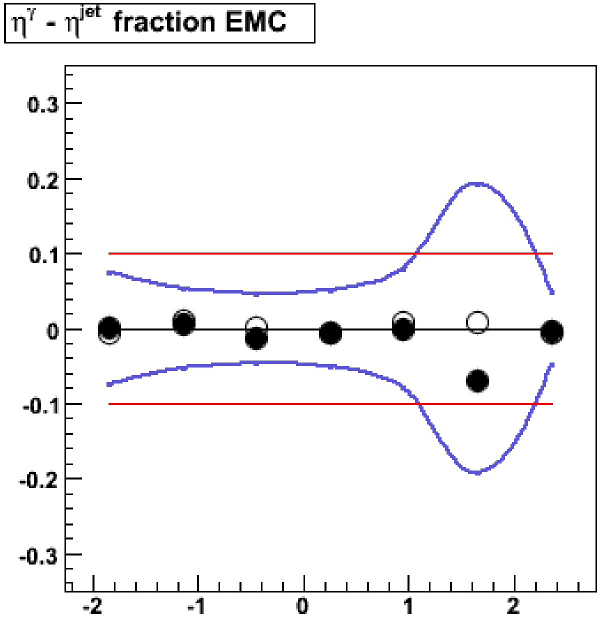

η^γ, X_γ^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

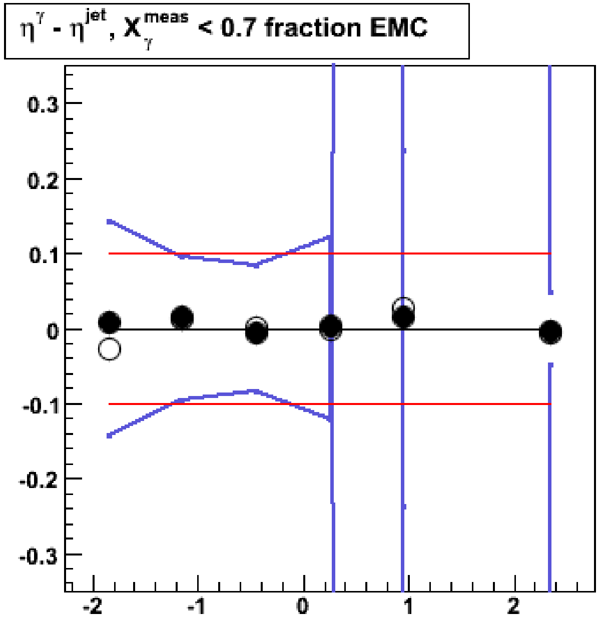

E_T^{jet}, X_γ^{meas} < 0.7 fraction EMC

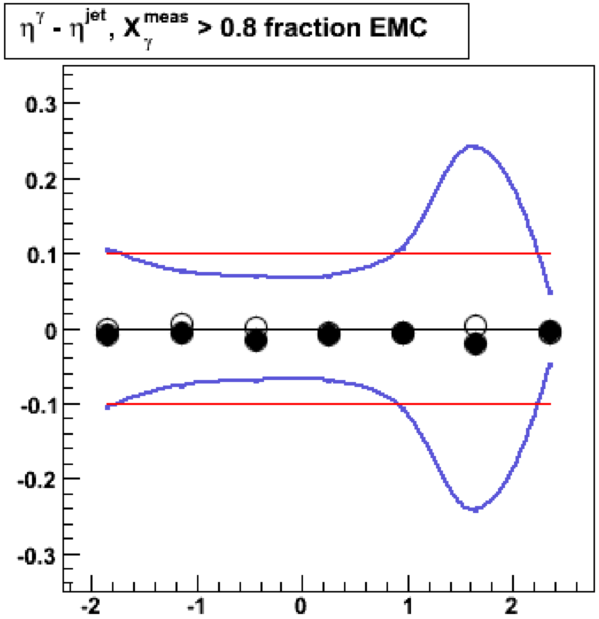

E_T^{jet}, X_γ^{meas} > 0.8 fraction EMC

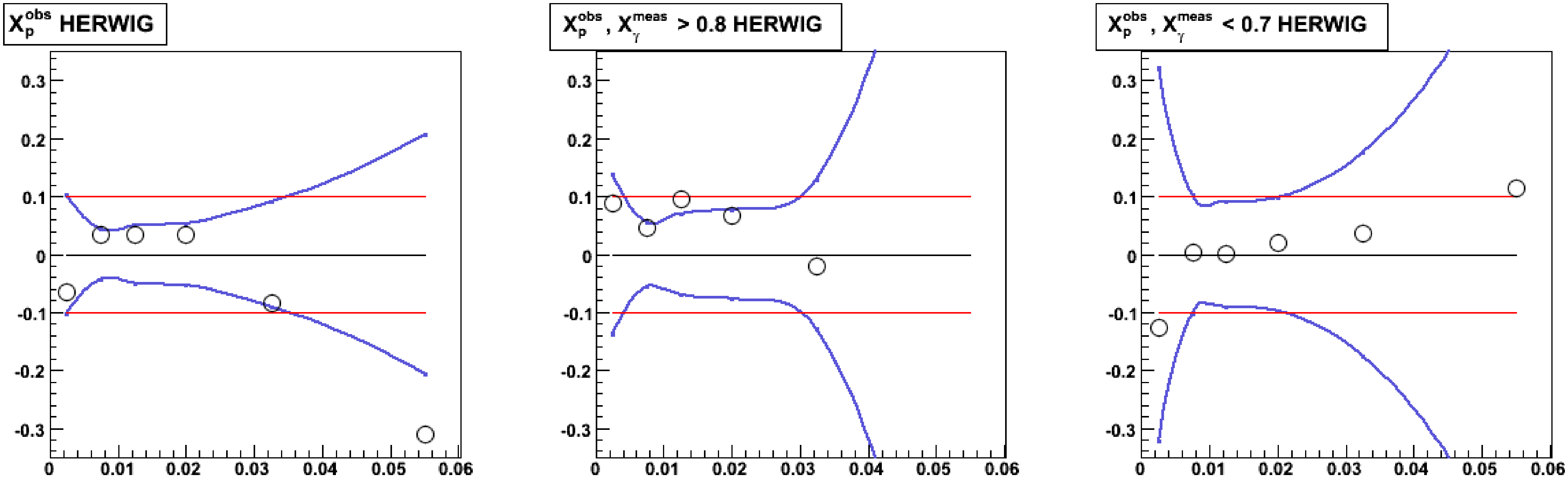

η^{jet}, X_γ^{meas} < 0.7 fraction EMC


η^{jet}, X_γ^{meas} > 0.8 fraction EMC


η^{γ} - η^{jet} fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} < 0.7 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



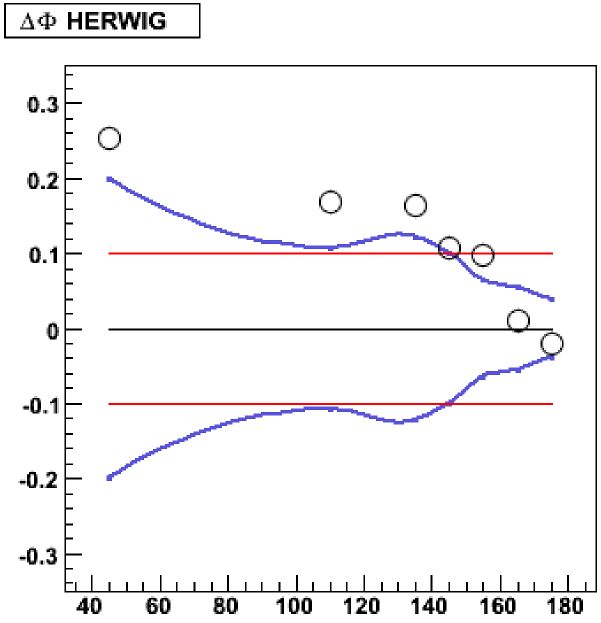
Systematic uncertainties: HERWIG

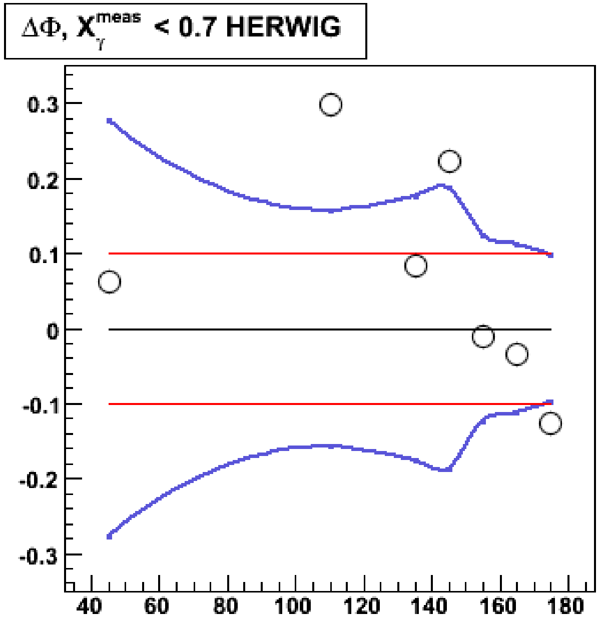
Use HERWIG signal and background instead of PYTHIA

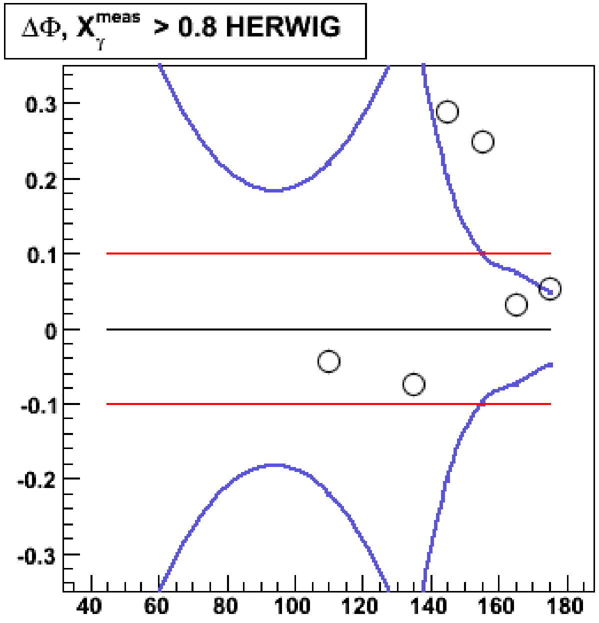
— *Rel.statistical uncertainties*

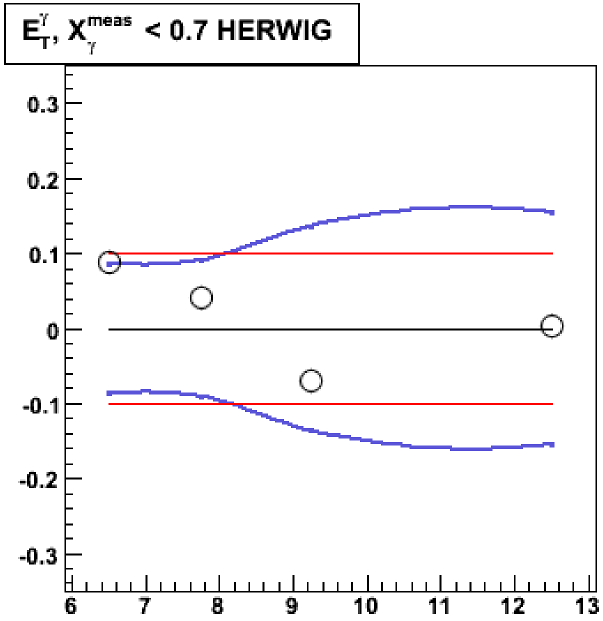
— *10% line*

○ *HERWIG*

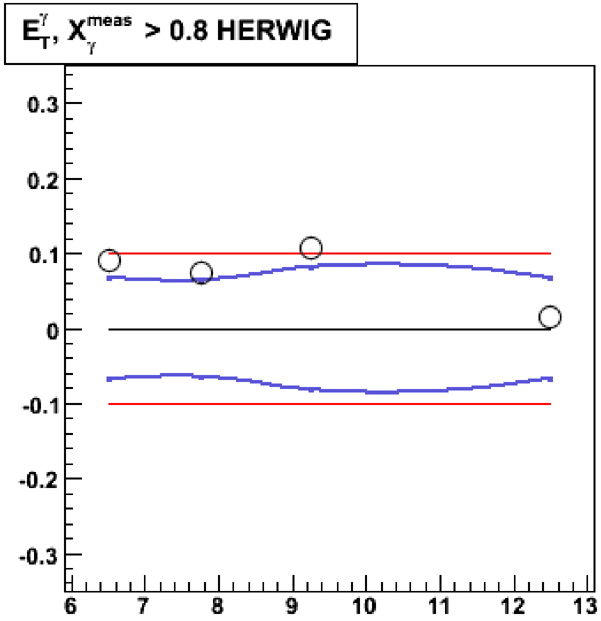

$\Delta\Phi$ HERWIG


$\Delta\Phi$, X_γ^{meas} < 0.7 HERWIG

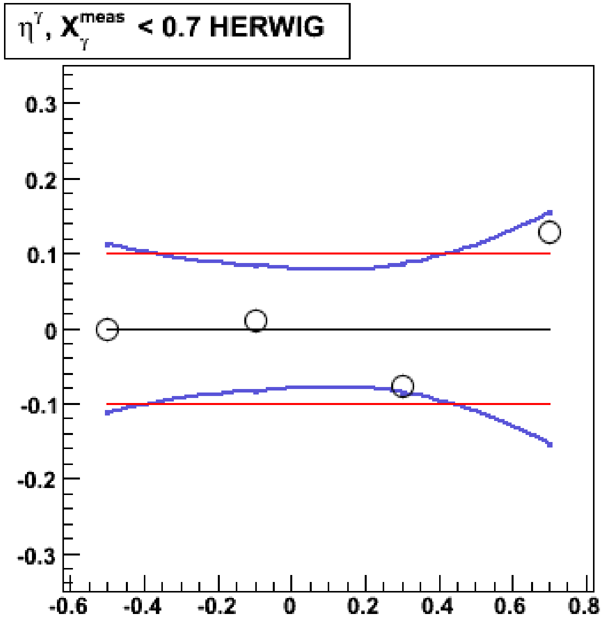

$\Delta\Phi$, X_γ^{meas} > 0.8 HERWIG



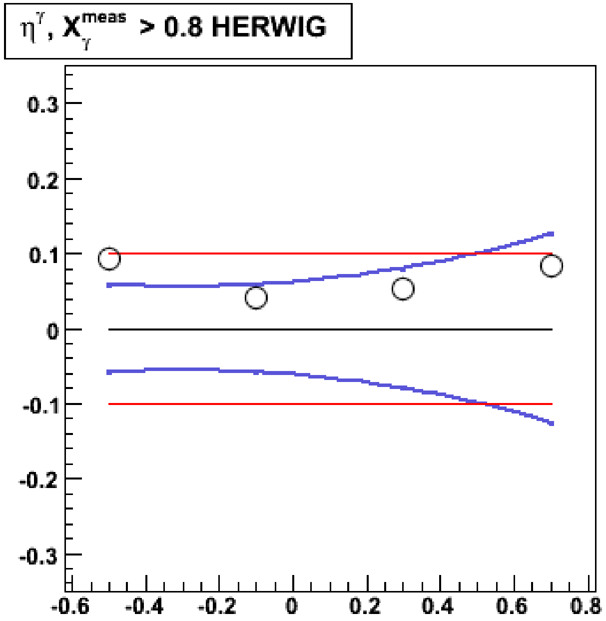
E_T^{γ}, X_{γ}^{meas} < 0.7 HERWIG



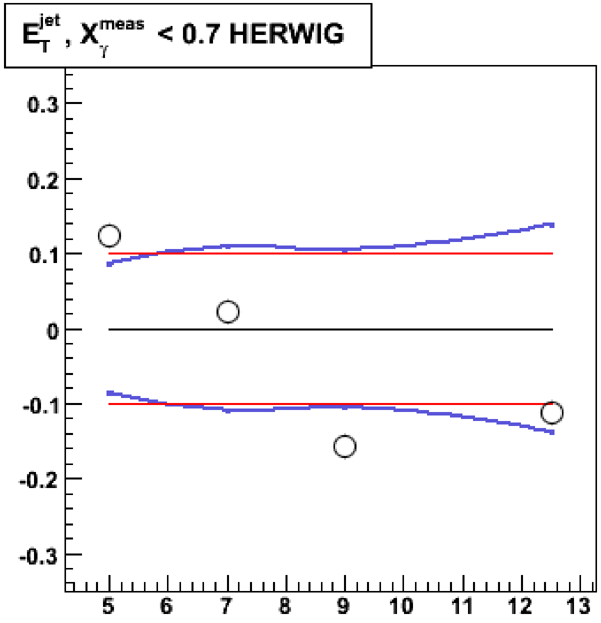
E_T^{γ}, X_{γ}^{meas} > 0.8 HERWIG

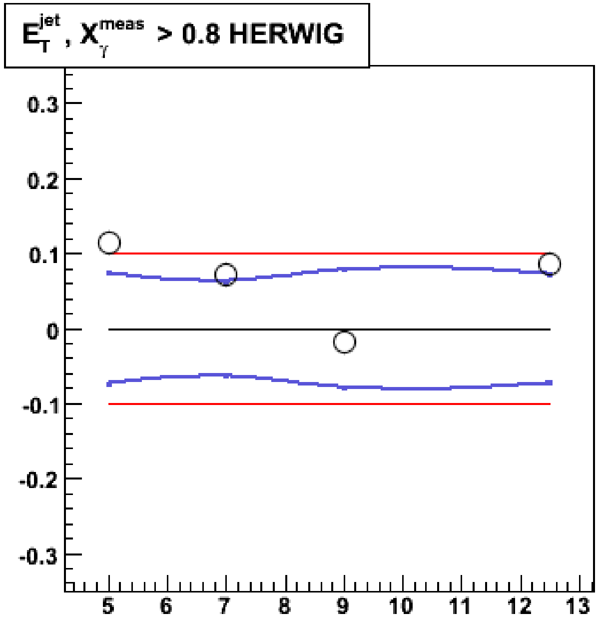


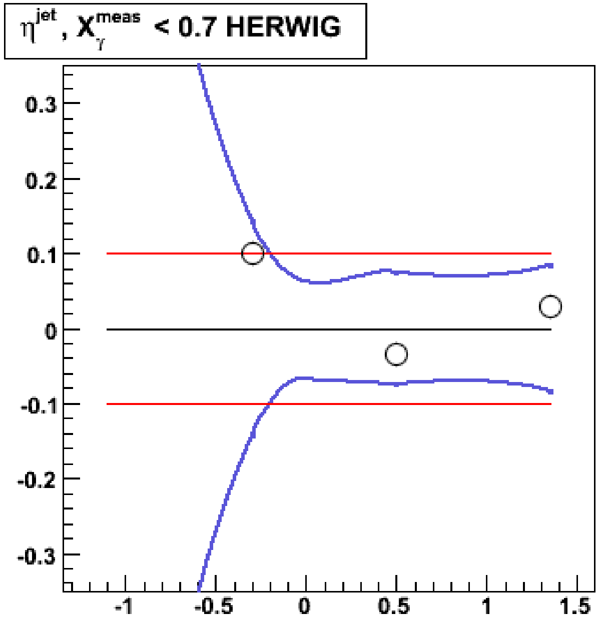
η^{γ}, X_{γ}^{meas} < 0.7 HERWIG

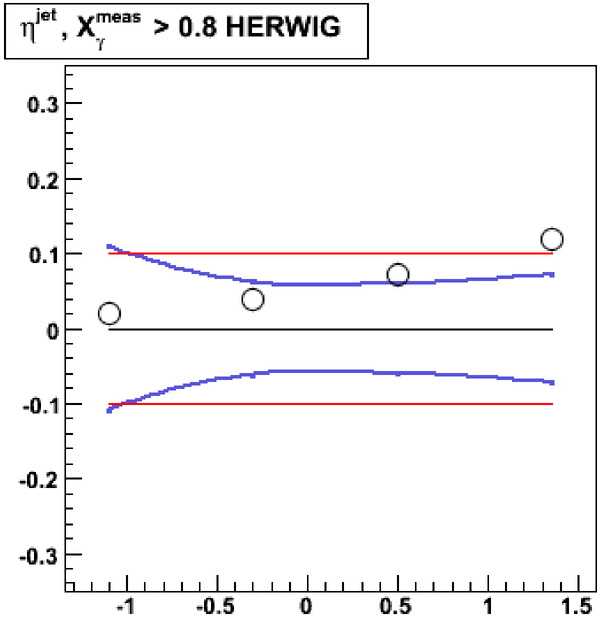


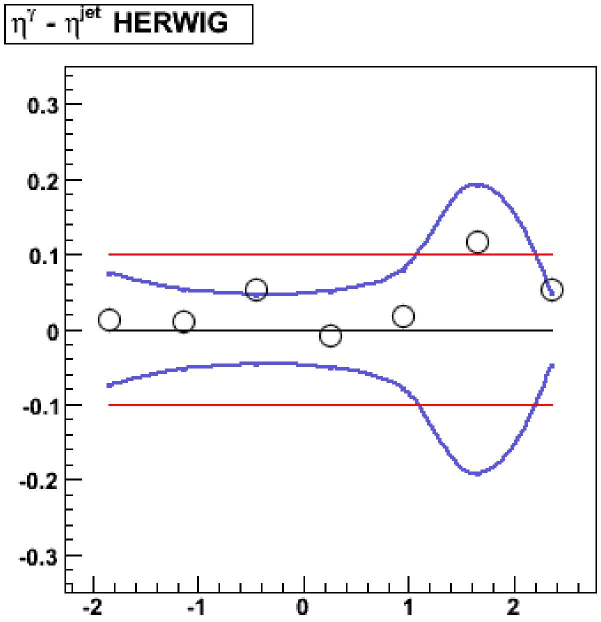
η^{γ}, X_{γ}^{meas} > 0.8 HERWIG

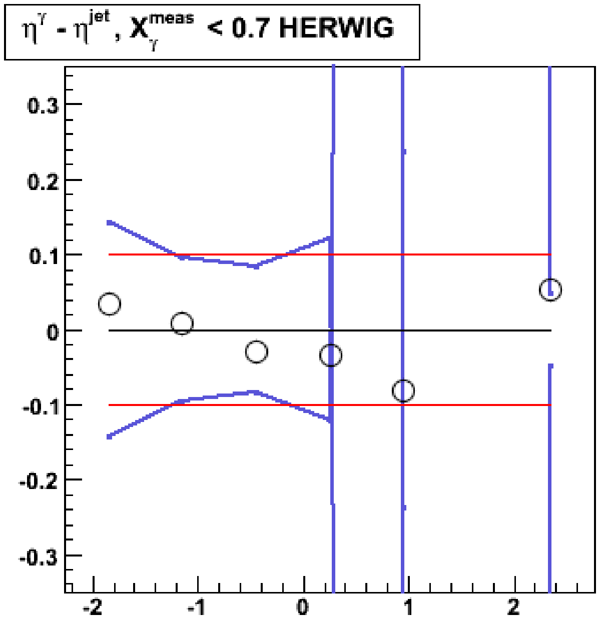

E_T^{jet}, X_γ^{meas} < 0.7 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

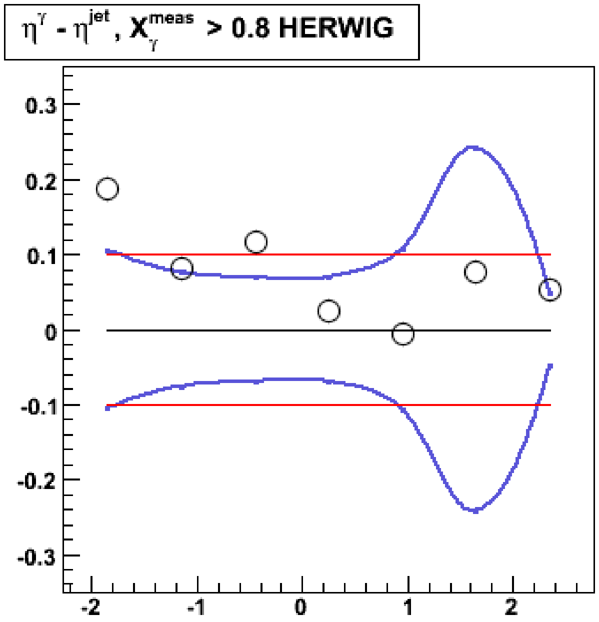

E_T^{jet}, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

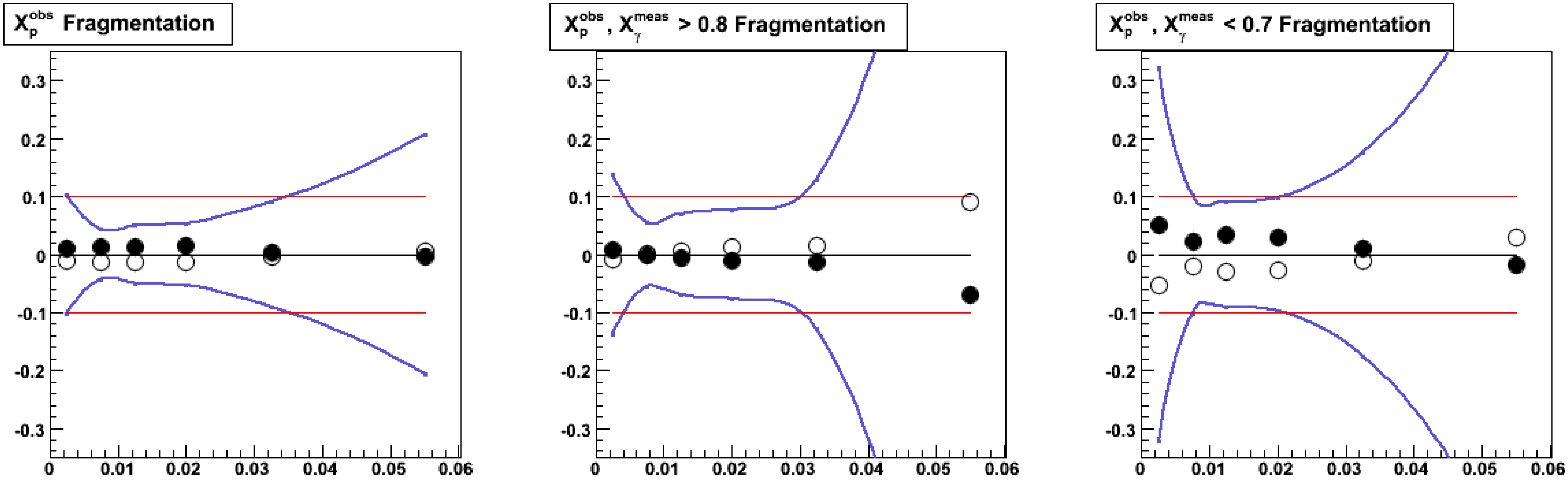

η^{jet}, X_γ^{meas} < 0.7 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^{jet}, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


$\eta^{\gamma} - \eta^{jet}$ HERWIG


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.7$ HERWIG


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ HERWIG



Systematic uncertainties: PYTHIA fragmentation

Standard value: 5% direct and 5% resolved fragmentation

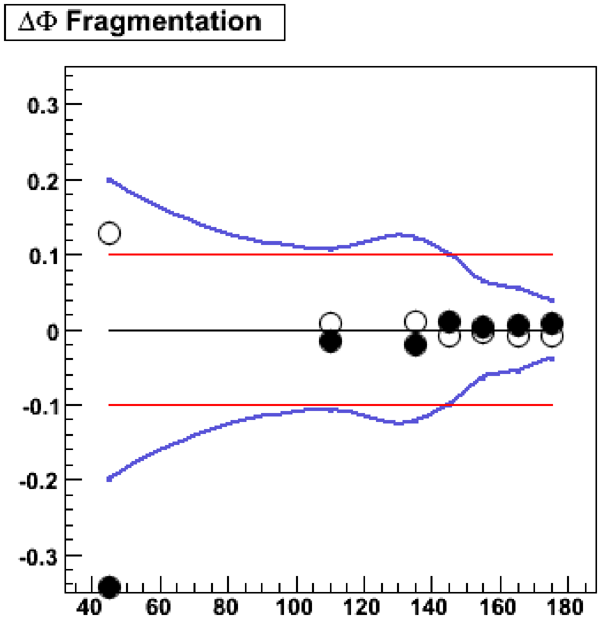
Vary fraction of fragmentation direct and resolved simultaneously by +-5%

Rel.statistical uncertainties

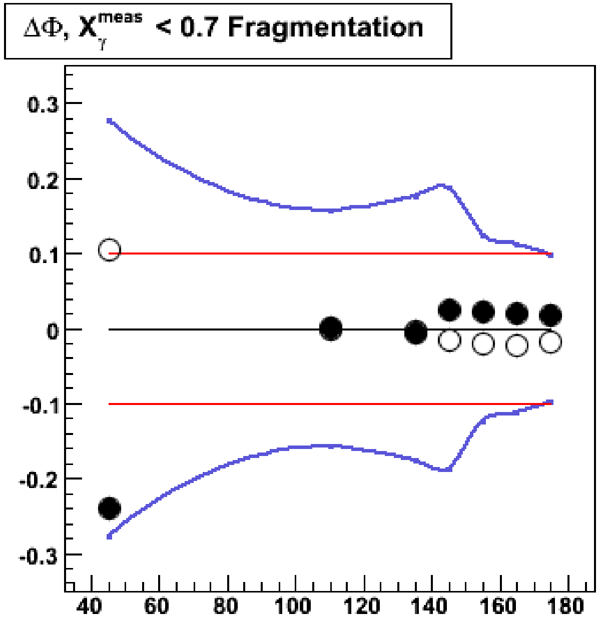
10% line

○ *+5% Fragmentation*

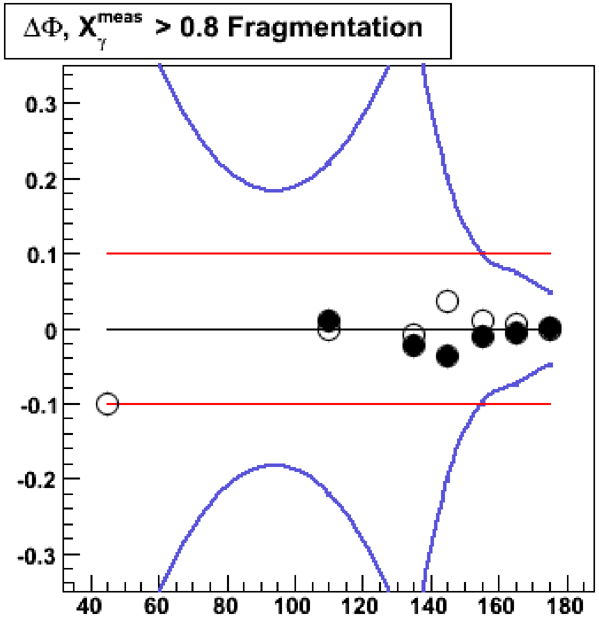
● *-5% Fragmentation*



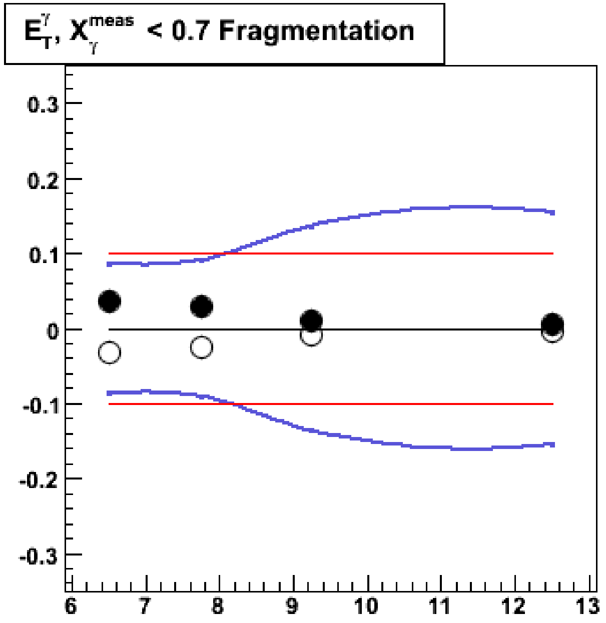
$\Delta\Phi$ Fragmentation



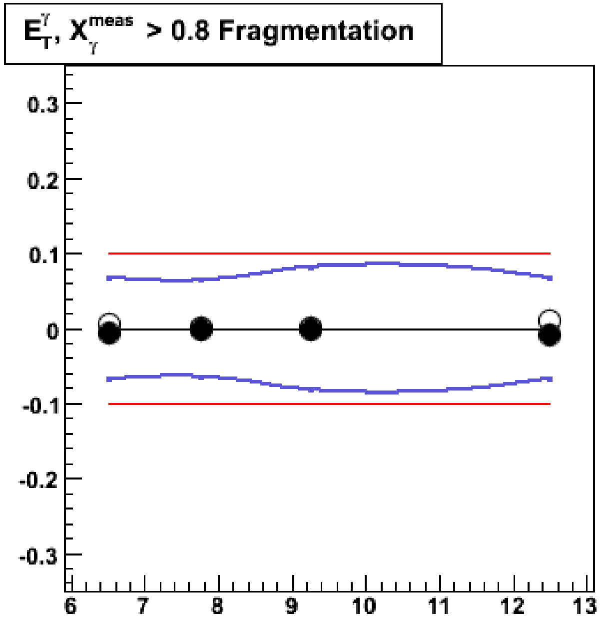
$\Delta\Phi$, X_{γ}^{meas} < 0.7 Fragmentation



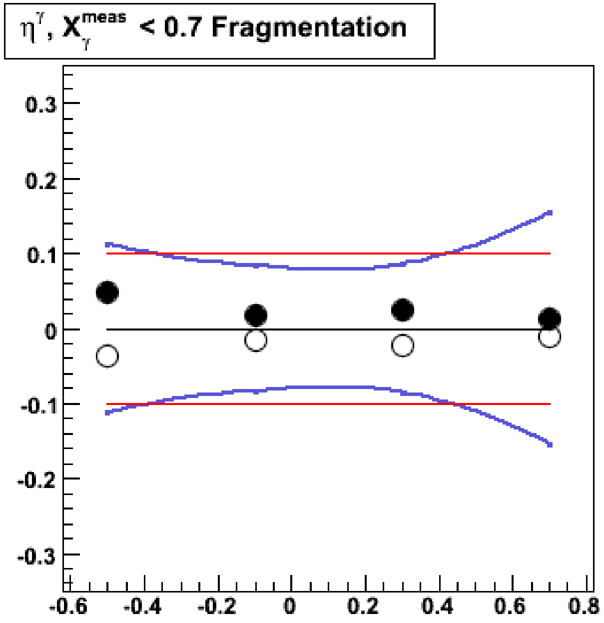
$\Delta\Phi$, X_{γ}^{meas} > 0.8 Fragmentation



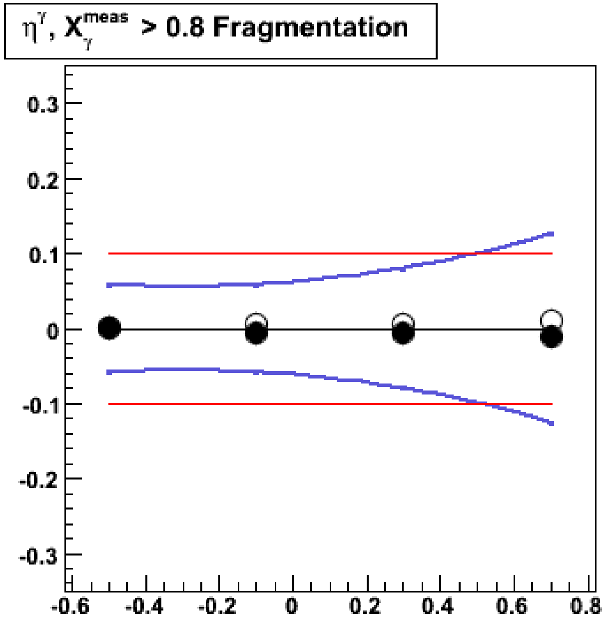
E_T^γ, X_γ^{meas} < 0.7 Fragmentation



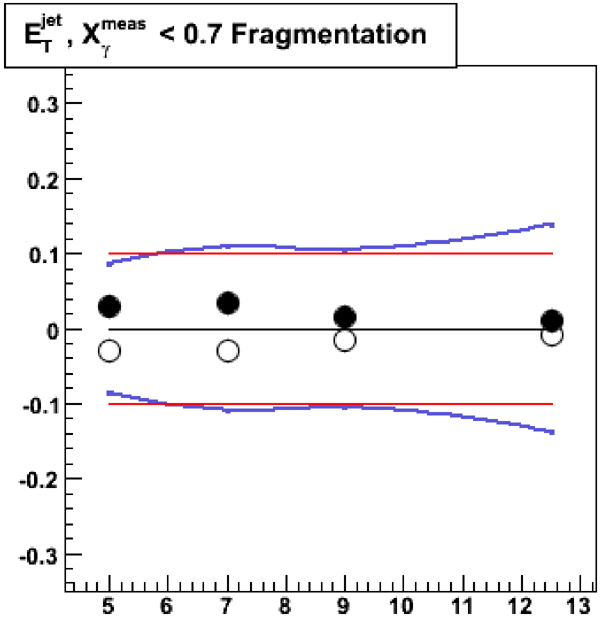
E_T^γ, X_γ^{meas} > 0.8 Fragmentation

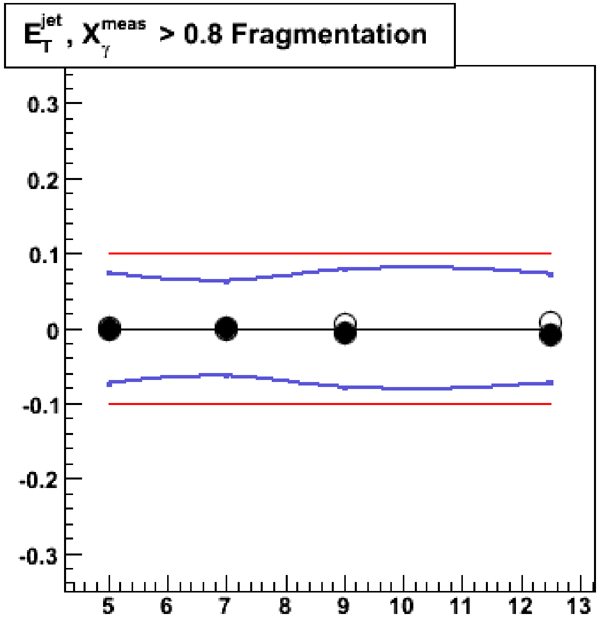


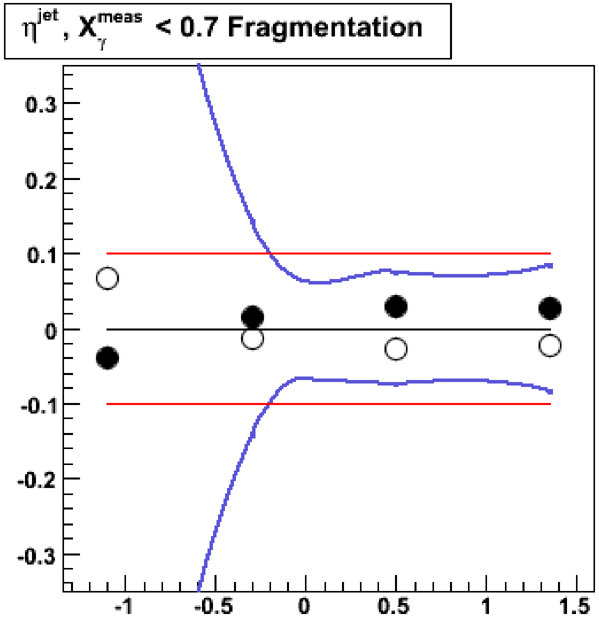
η^γ, X_γ^{meas} < 0.7 Fragmentation

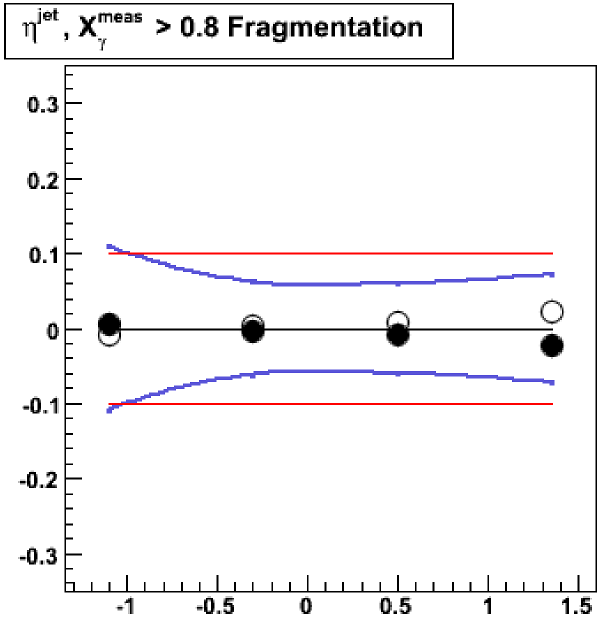


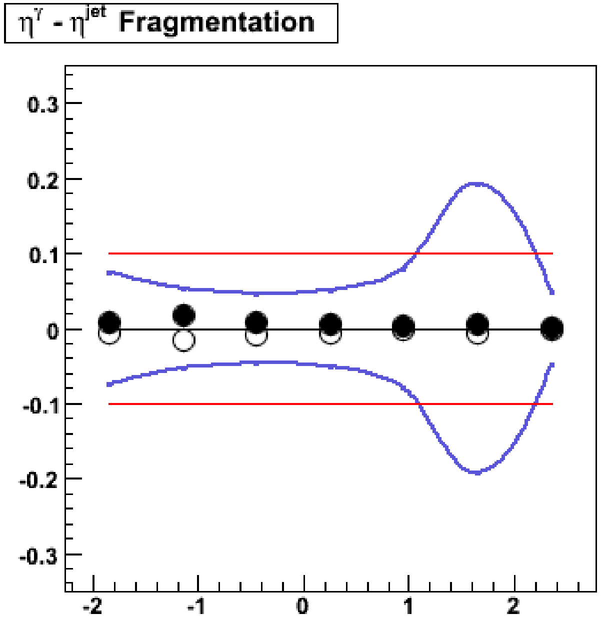
η^γ, X_γ^{meas} > 0.8 Fragmentation

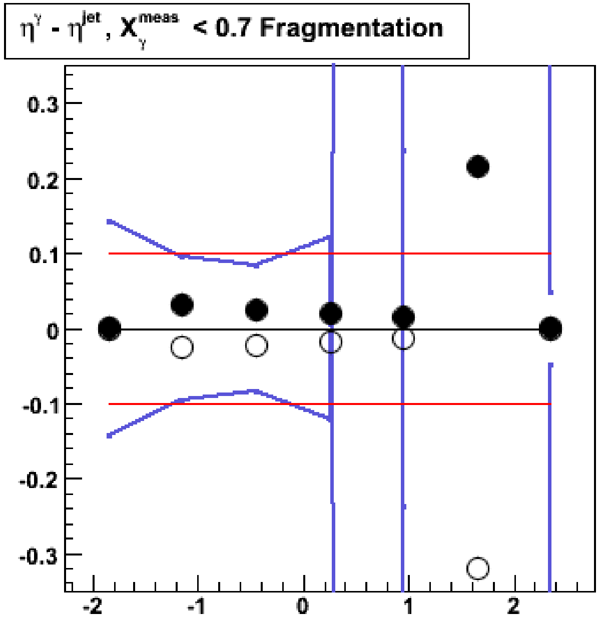

E_T^{jet}, X_γ^{meas} < 0.7 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

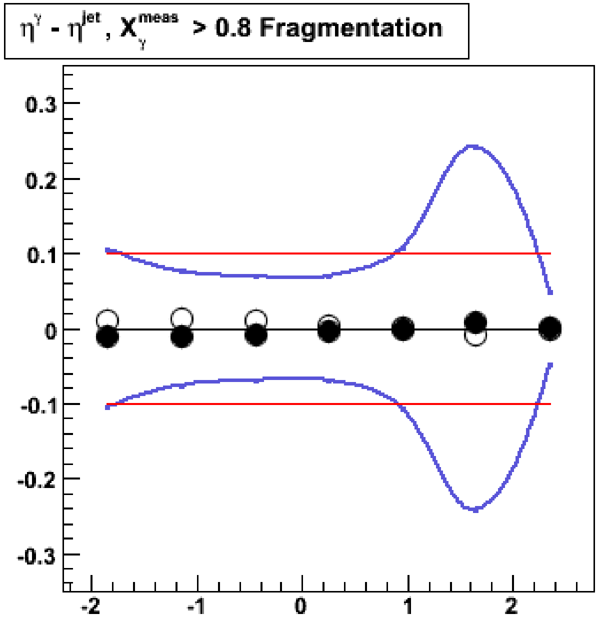

E_T^{jet}, X_γ^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

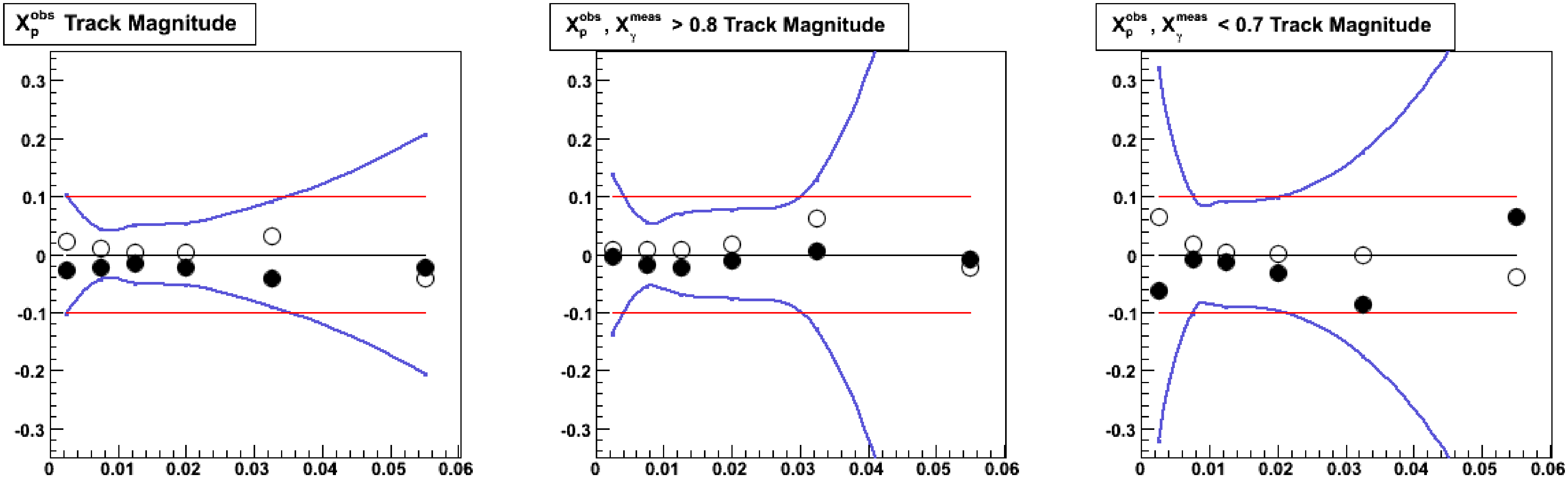

η^{jet}, X_γ^{meas} < 0.7 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5


η^{jet}, X_γ^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5


$\eta^{\gamma} - \eta^{jet}$ Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.7 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



Systematic uncertainties: Track momentum

Standard cut:

- Track momentum>250 MeV

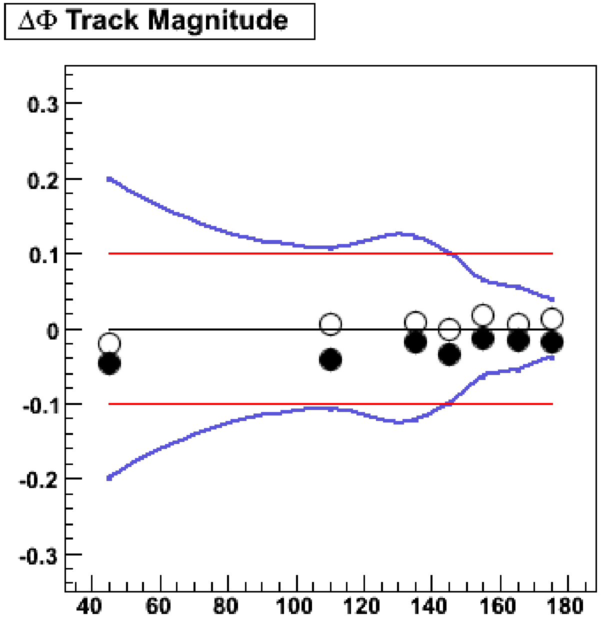
Vary track momentum by 100 MeV

Rel.statistical uncertainties

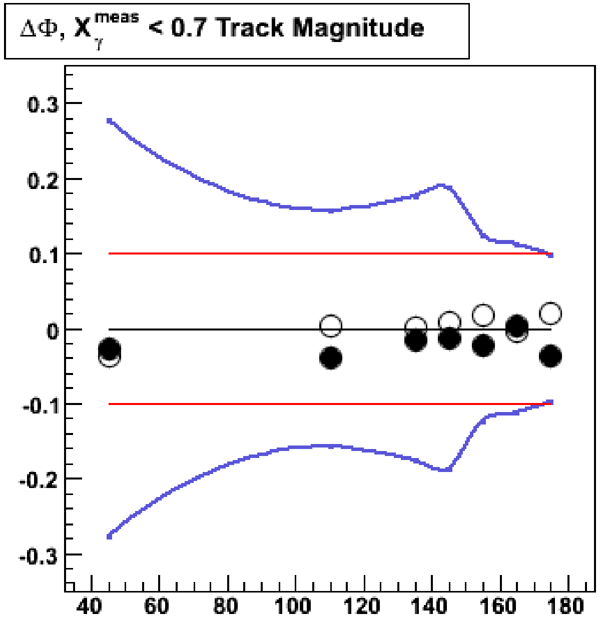
10% line

○ p_{track} > 350 MeV

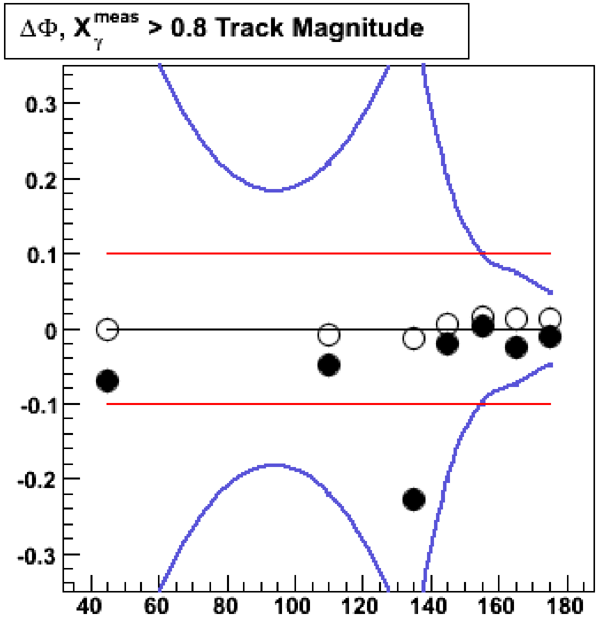
● p_{track} > 150 MeV



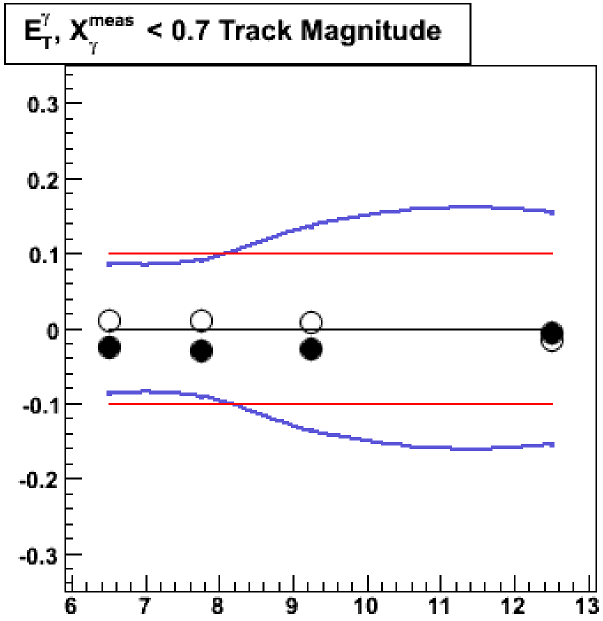
ΔΦ Track Magnitude

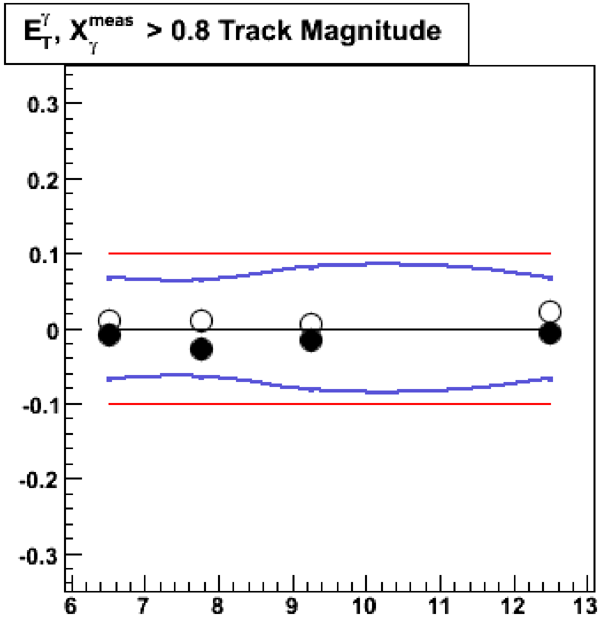


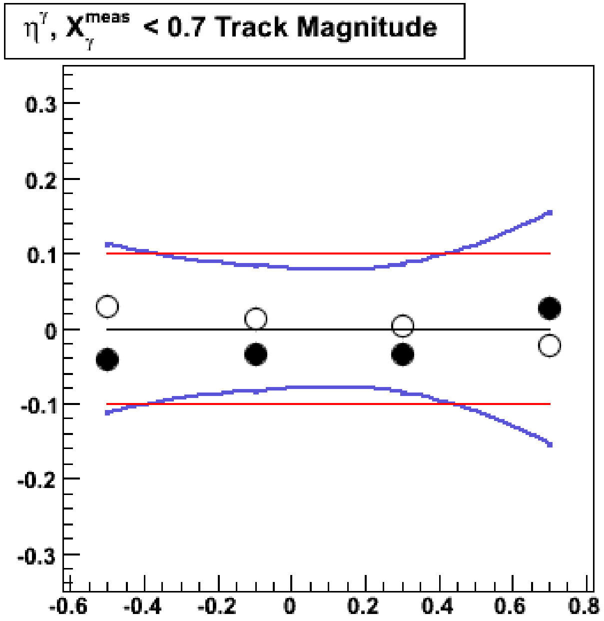
ΔΦ, X_{γ}^{meas} < 0.7 Track Magnitude

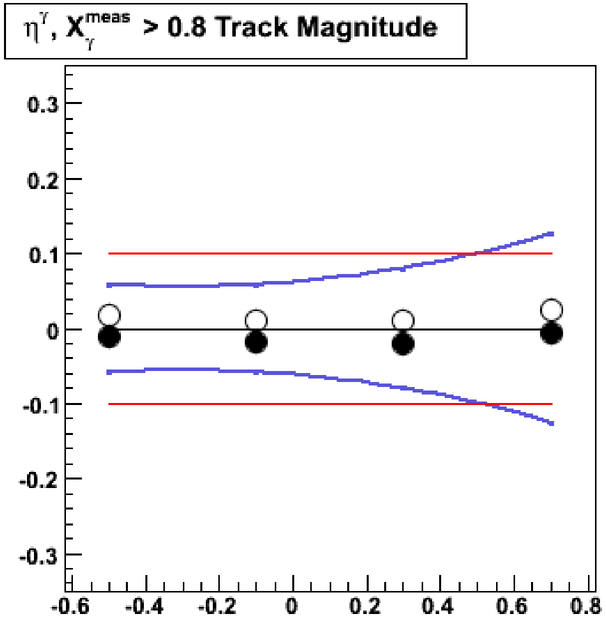


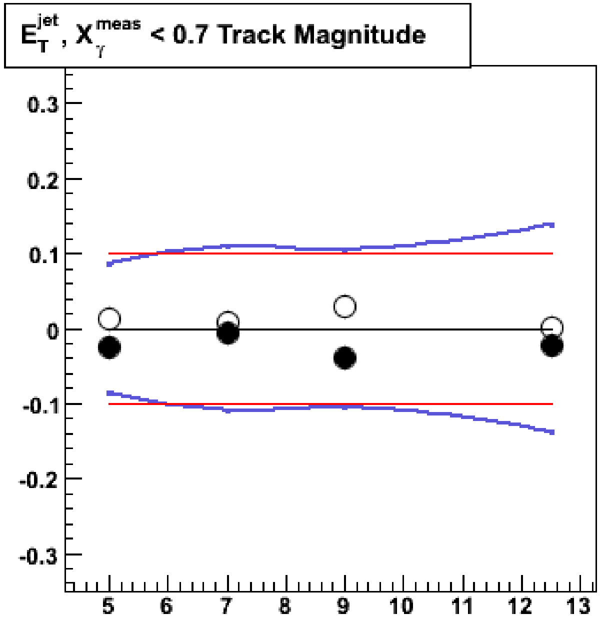
ΔΦ, X_{γ}^{meas} > 0.8 Track Magnitude

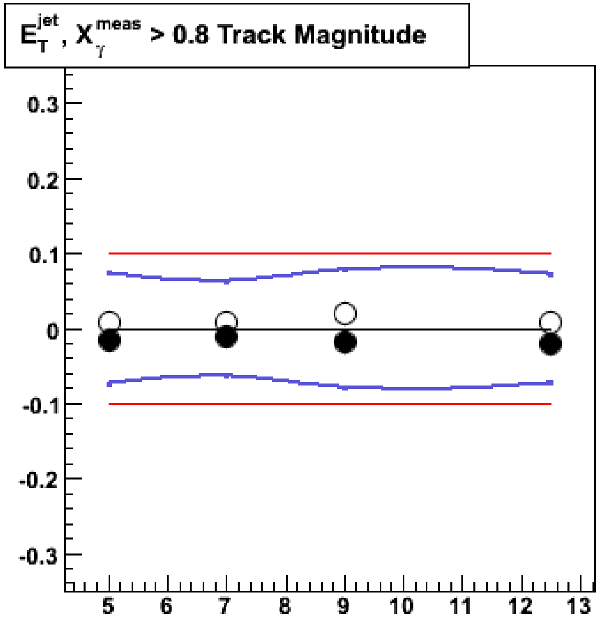

E_T^{γ}, X_{γ}^{meas} < 0.7 Track Magnitude

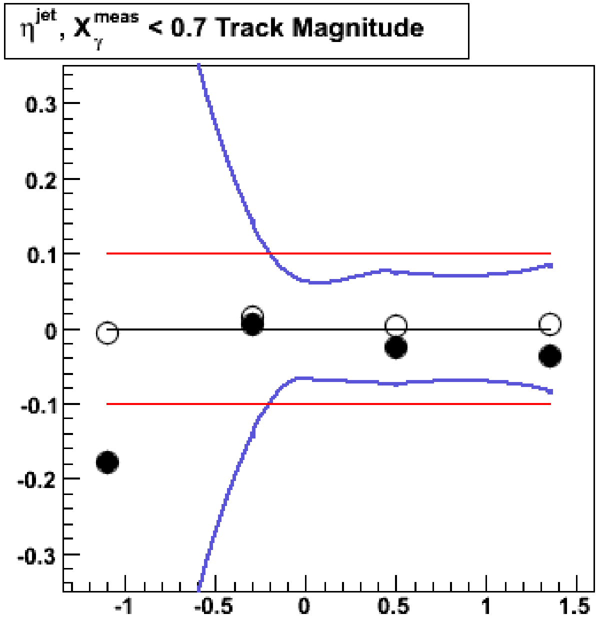

E_T^{γ}, X_{γ}^{meas} > 0.8 Track Magnitude

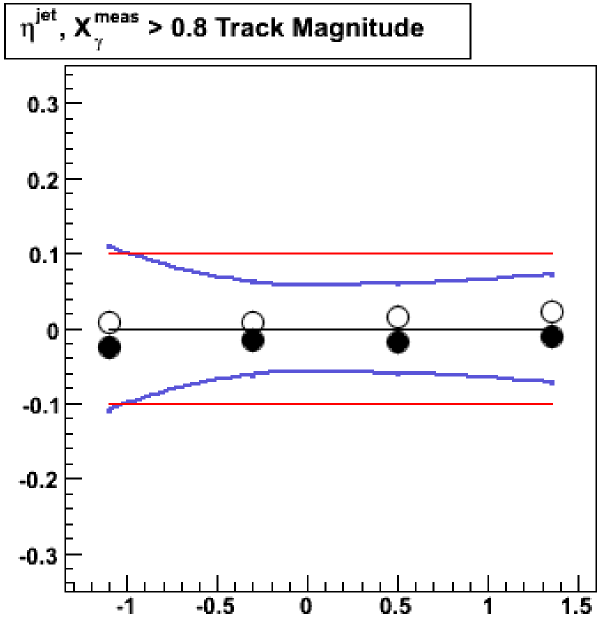

η^{γ}, X_{γ}^{meas} < 0.7 Track Magnitude

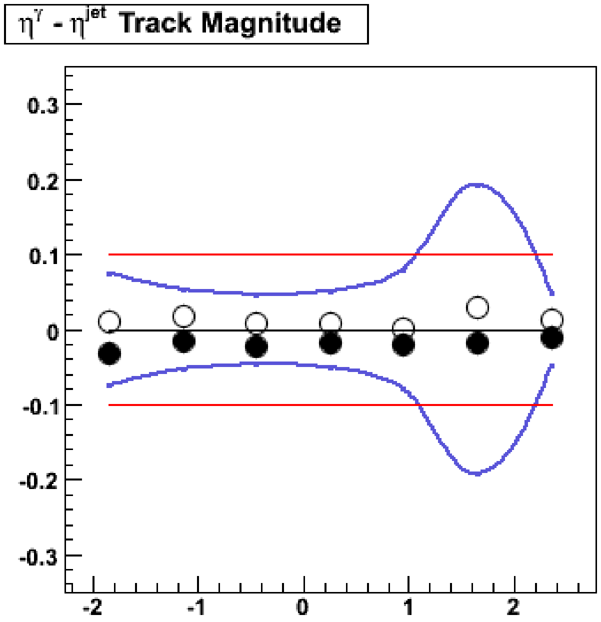

η^{γ}, X_{γ}^{meas} > 0.8 Track Magnitude


E_T^{jet}, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

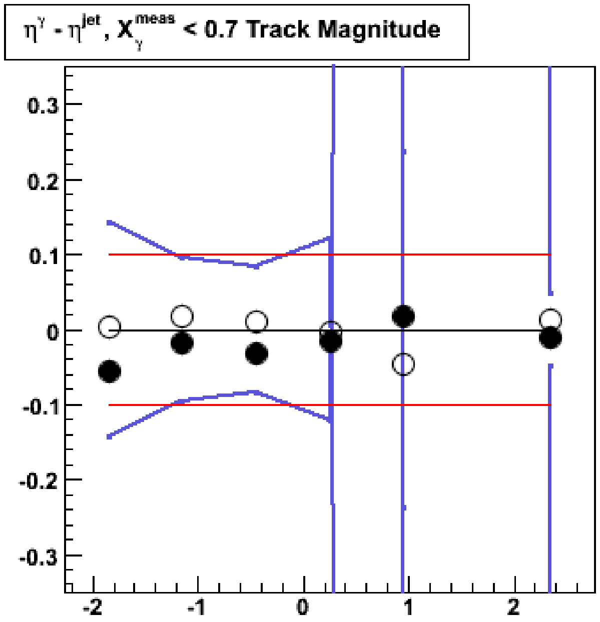

E_T^{jet}, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13


η^{jet}, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

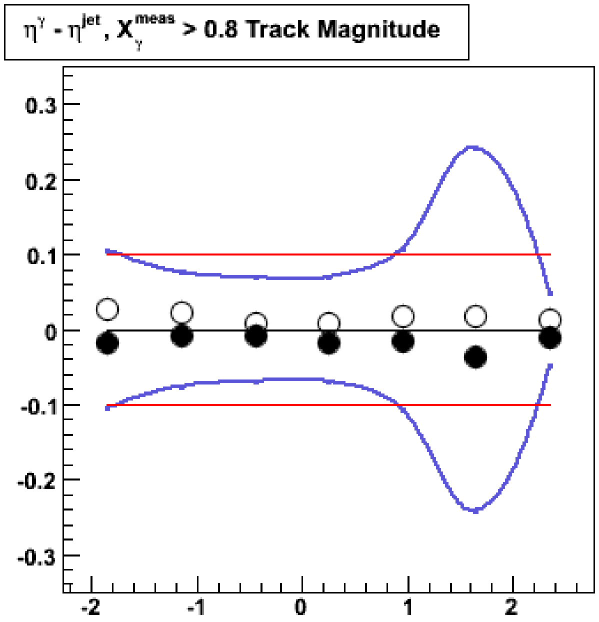

η^{jet}, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5



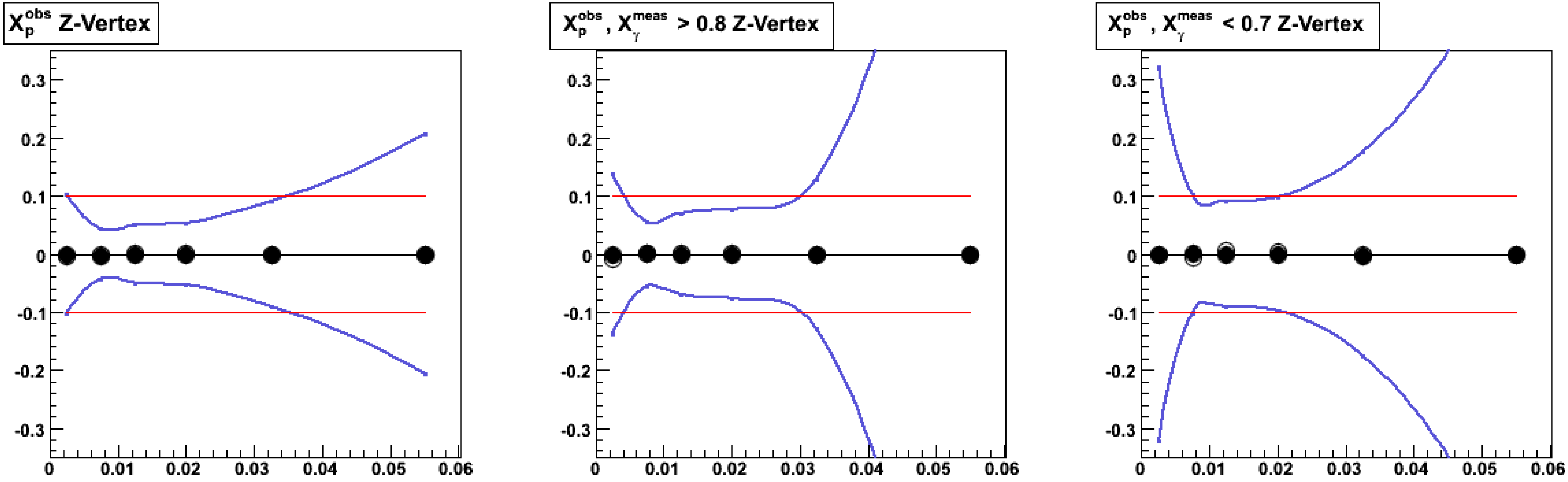
$\eta^{\gamma} - \eta^{jet}$ Track Magnitude



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.7$ Track Magnitude



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ Track Magnitude



Systematic uncertainties: Zvtx

Standard cut:

- | Zvtx |<40 cm

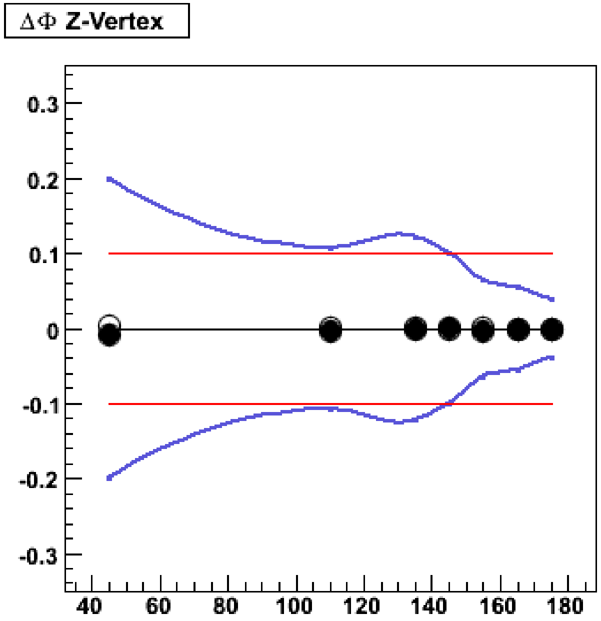
Vary z-vertex cut by +-5 cm

— *Rel.statistical uncertainties* δZ

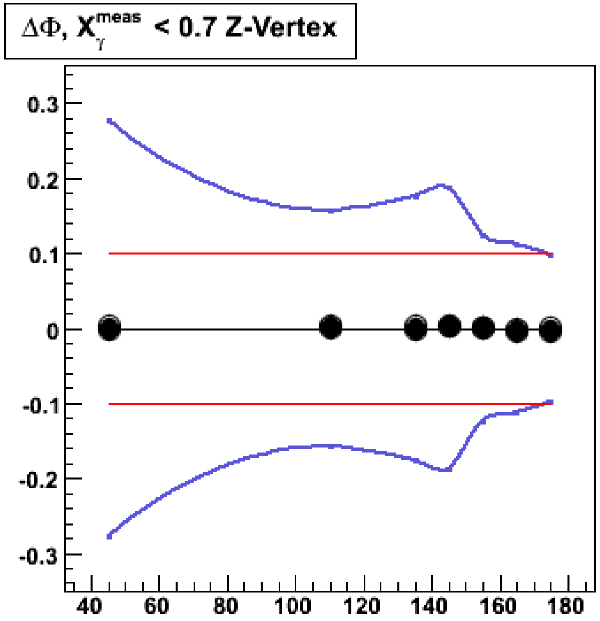
— *10% line*

○ $|Z_{vertex}|<45$

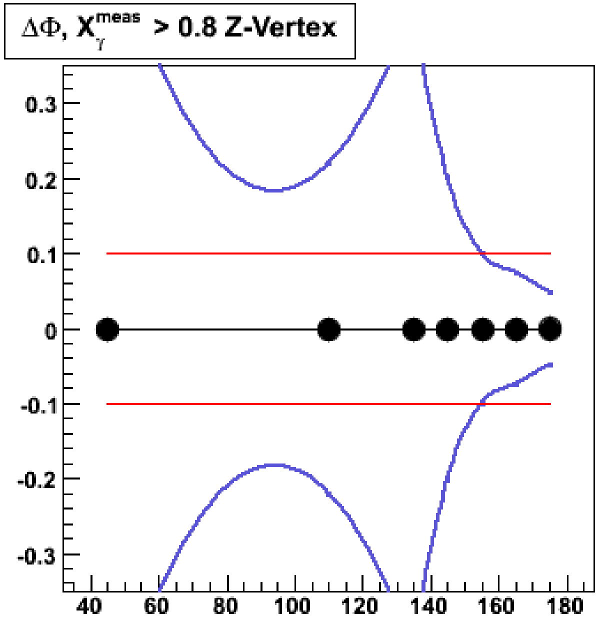
● $|Z_{vertex}|<35$



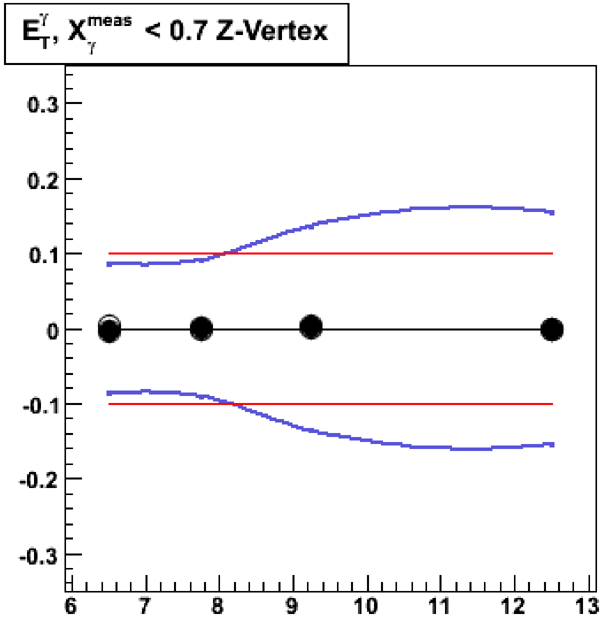
ΔΦ Z-Vertex

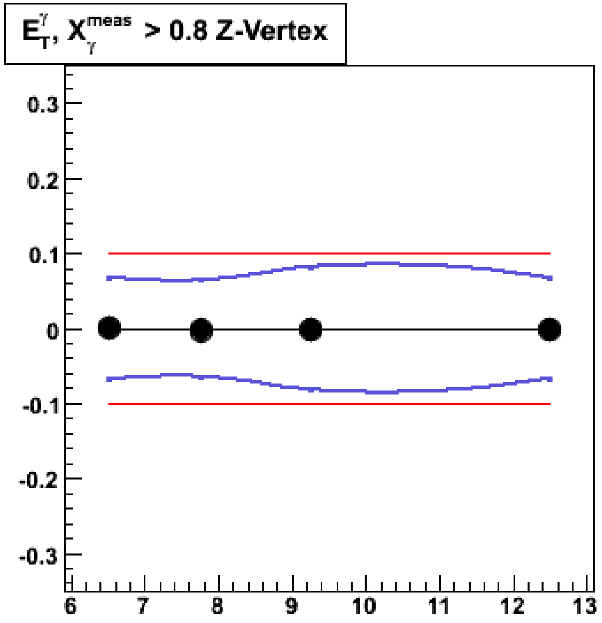


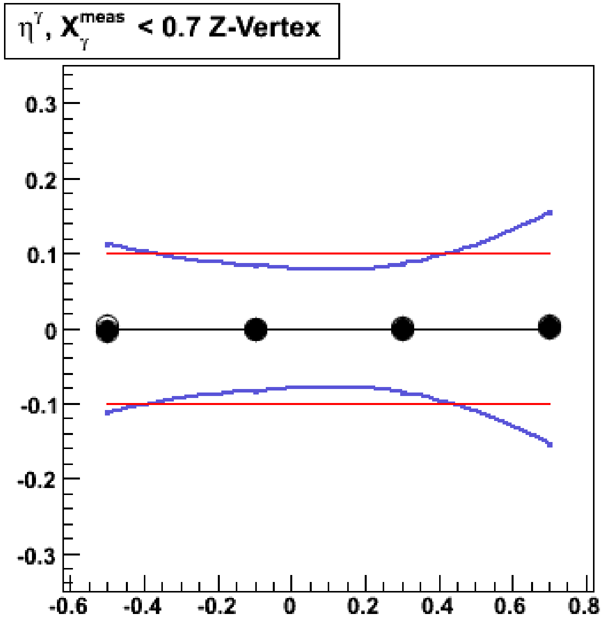
ΔΦ, X_{γ}^{meas} < 0.7 Z-Vertex

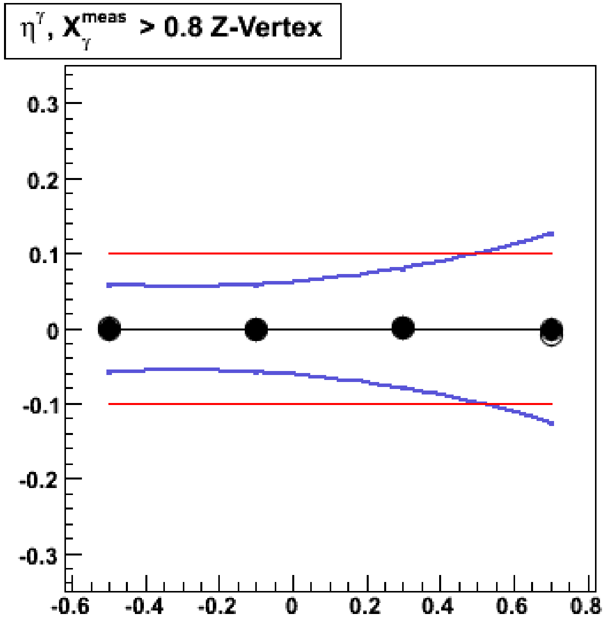


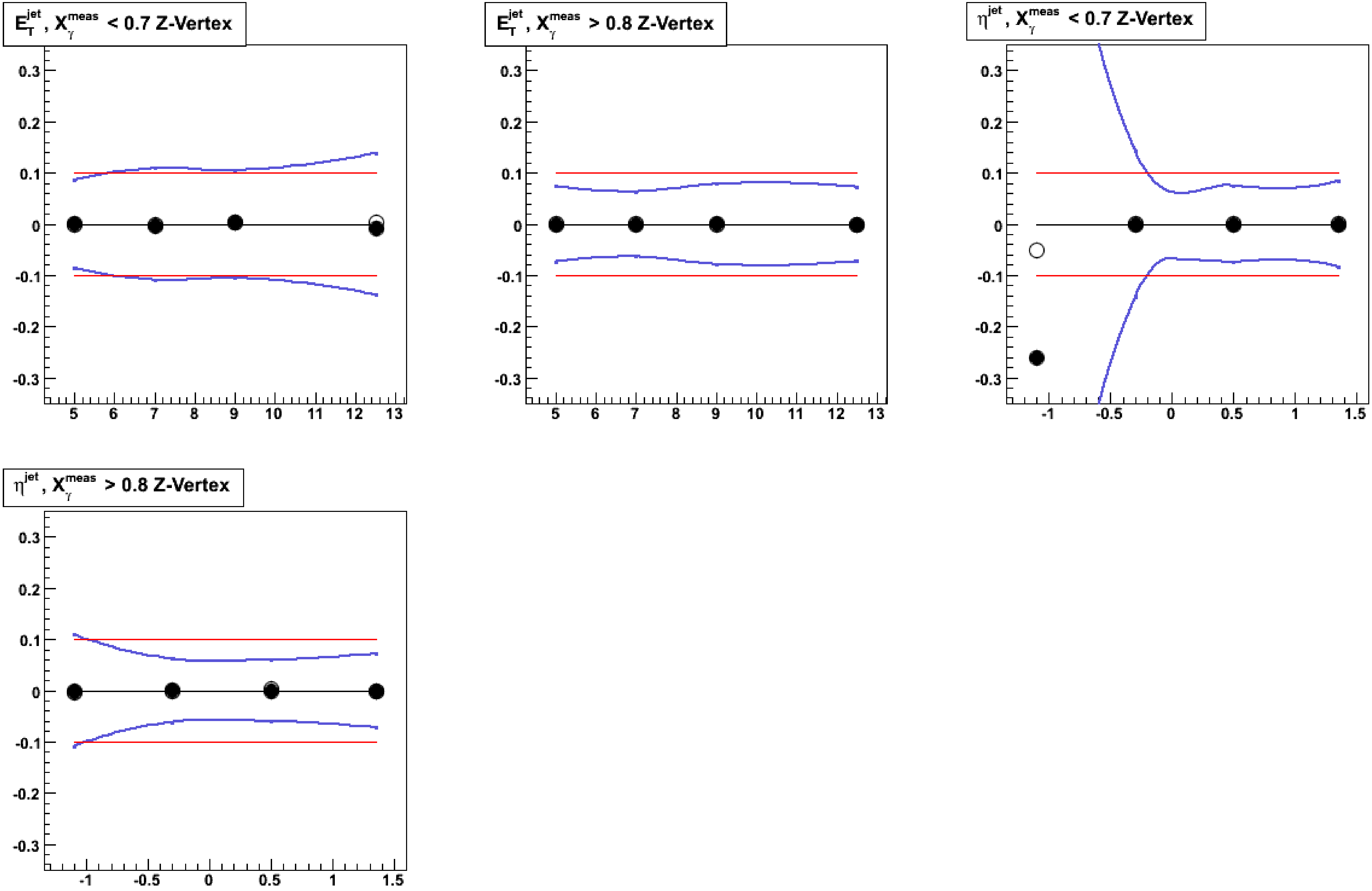
ΔΦ, X_{γ}^{meas} > 0.8 Z-Vertex

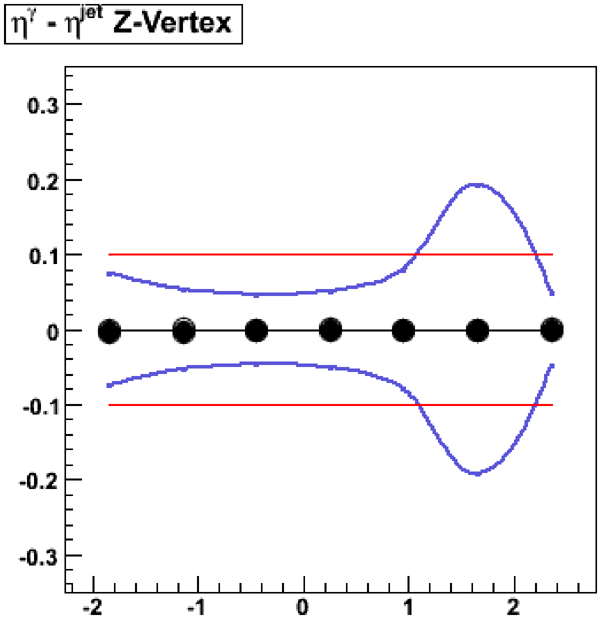

E_T^γ, X_γ^{meas} < 0.7 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


E_T^γ, X_γ^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

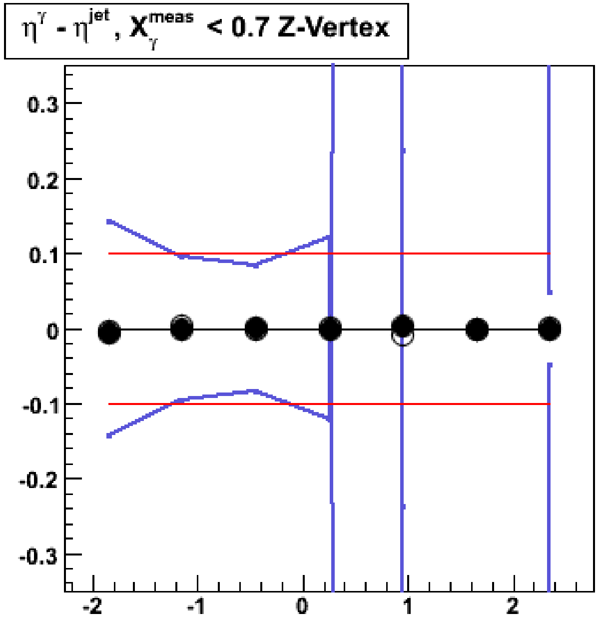

η^γ, X_γ^{meas} < 0.7 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


η^γ, X_γ^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

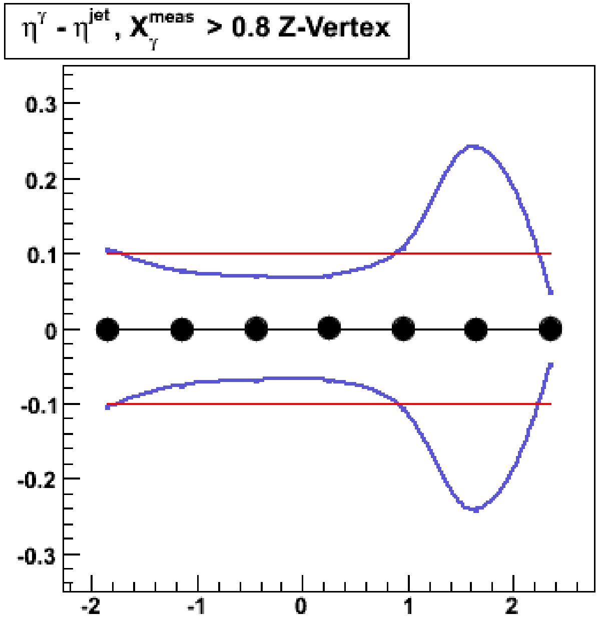




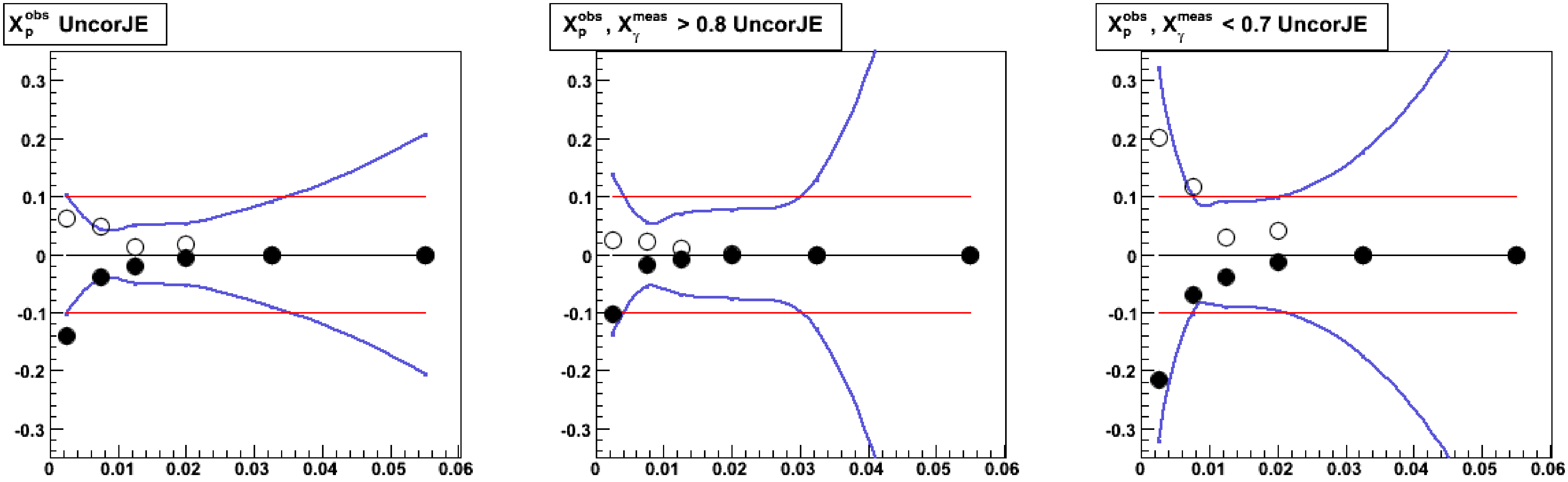
$\eta^{\gamma} - \eta^{jet}$ Z-Vertex



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.7$ Z-Vertex



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ Z-Vertex



Systematic uncertainties: E^{jet} variation

Standard cuts:

- $4<E_T^{\,jet}<35$ GeV

Vary jet energy independently from gamma energy:

If JetEt ≤ 6 GeV by sqrt(4.*4. + 2.*2.))

If 6 < JetEt ≤ 10 GeV by sqrt(2.*2. +2.*2.))

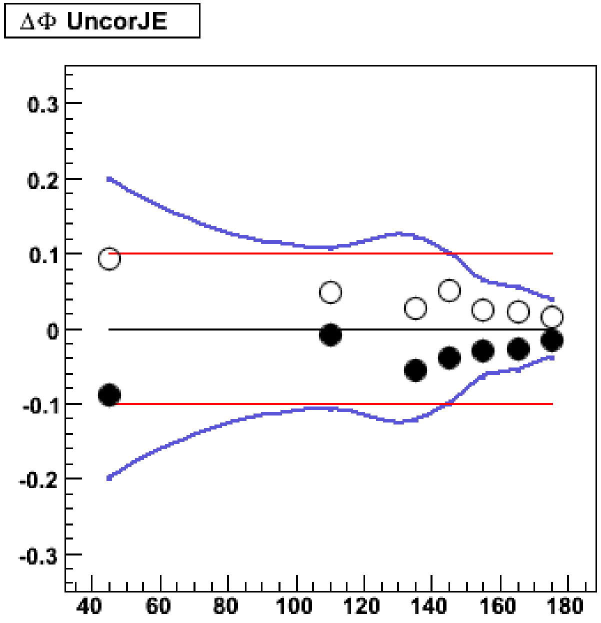
If JetEt > 10 GeV vary by sqrt(1.5*1.5 + 2.*2.))

— *Rel.statistical uncertainties*

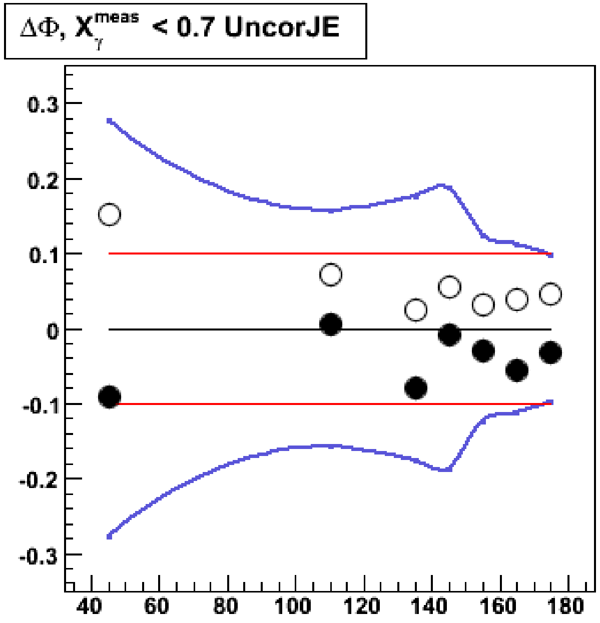
— *10% line*

○ *variation up*

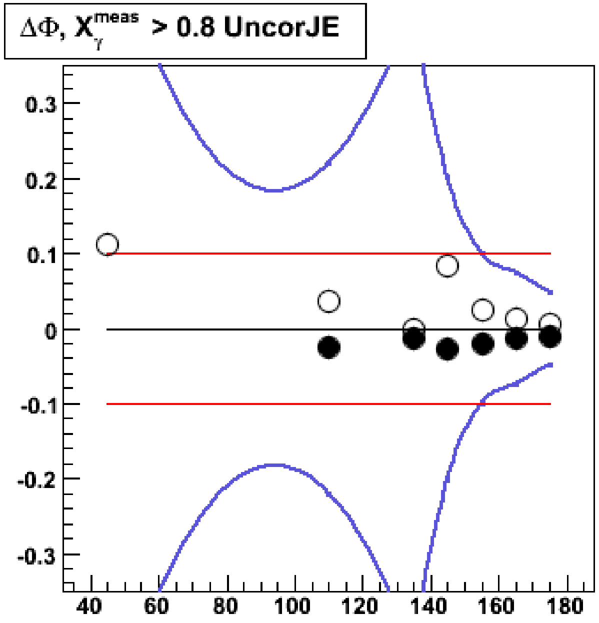
● *variation down*



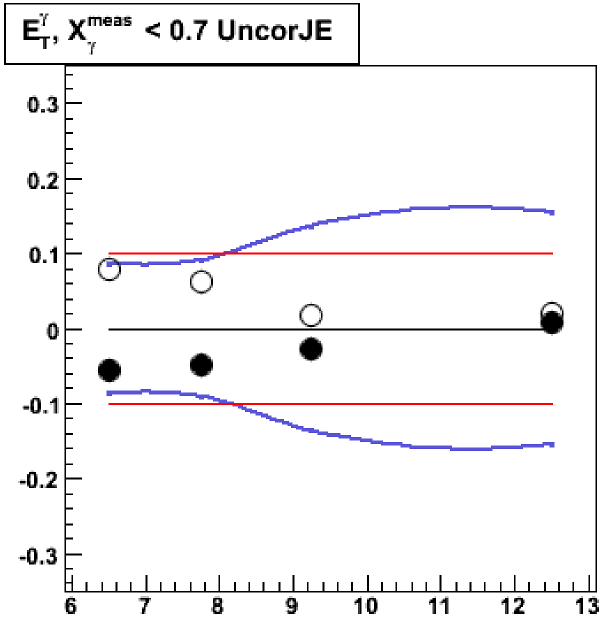
$\Delta\Phi$ UncorJE

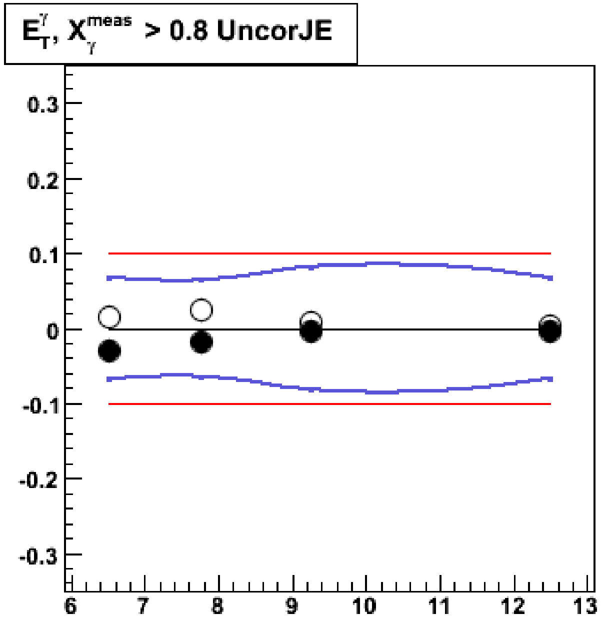


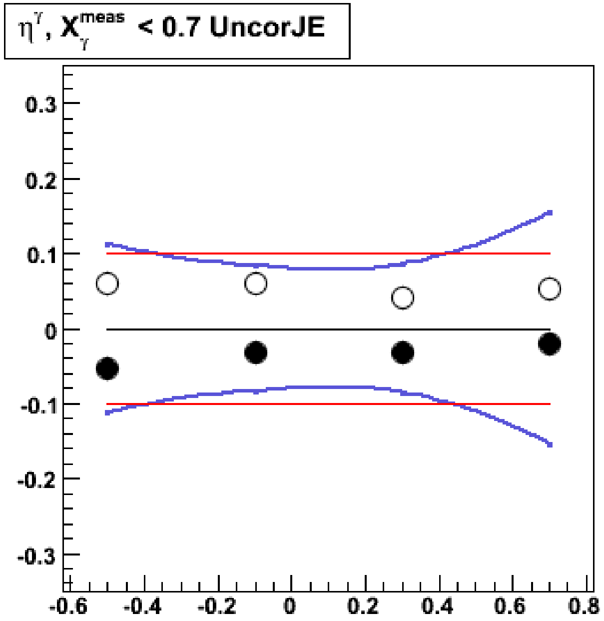
$\Delta\Phi$, X_γ^{meas} < 0.7 UncorJE

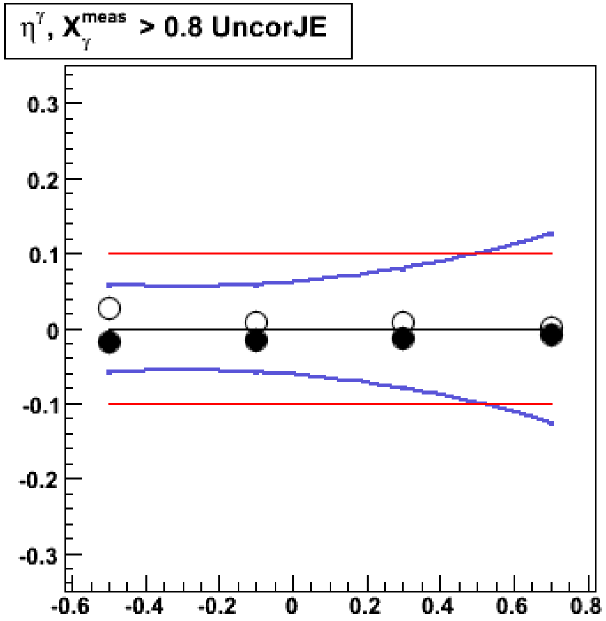


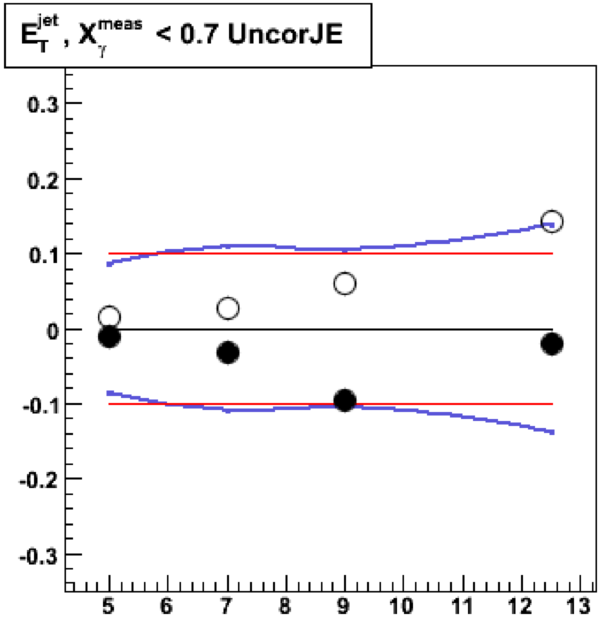
$\Delta\Phi$, X_γ^{meas} > 0.8 UncorJE

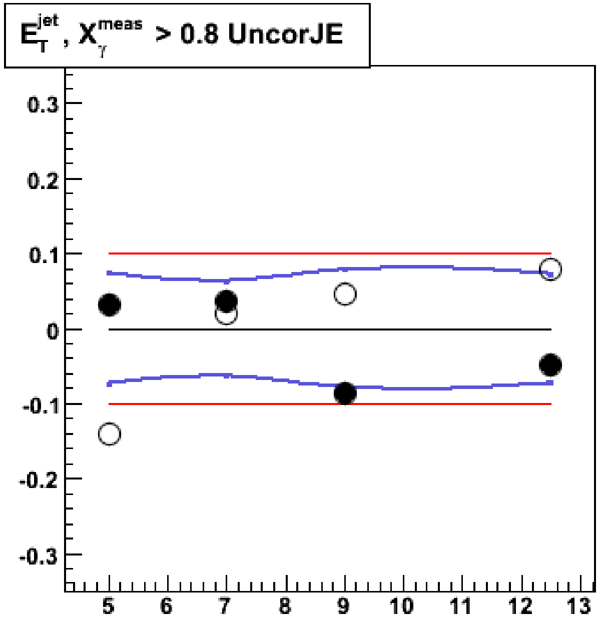

E_T^γ, X_γ^{meas} < 0.7 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


E_T^γ, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


η^γ, X_γ^{meas} < 0.7 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


η^γ, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet}, X_γ^{meas} < 0.7 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13


E_T^{jet}, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
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6
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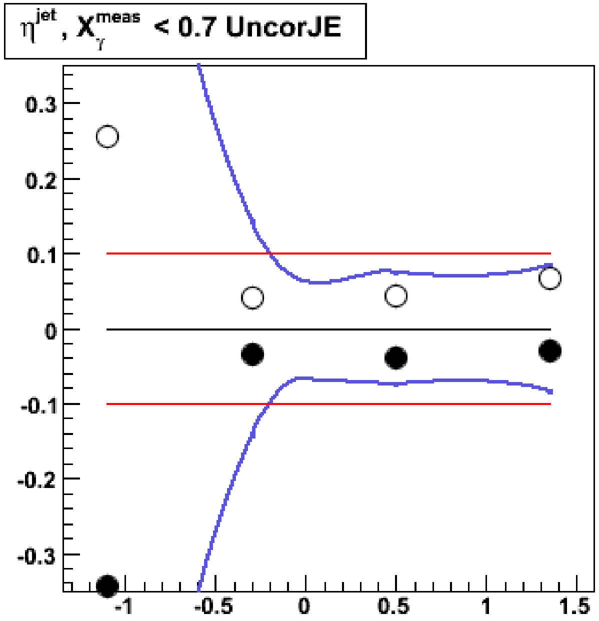
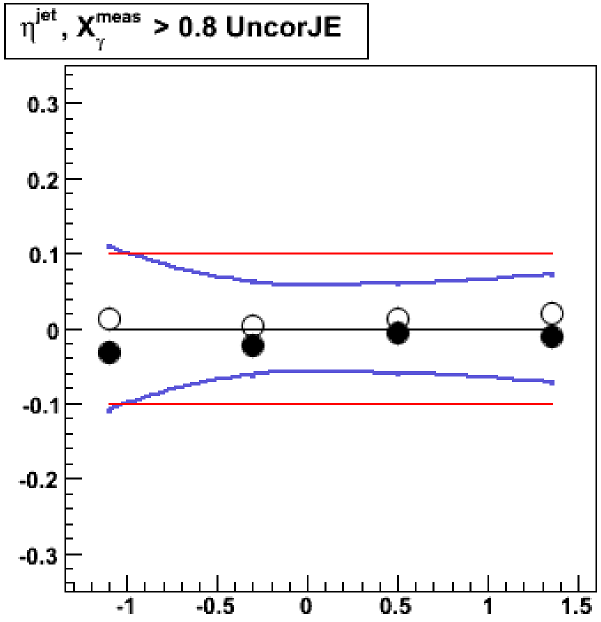
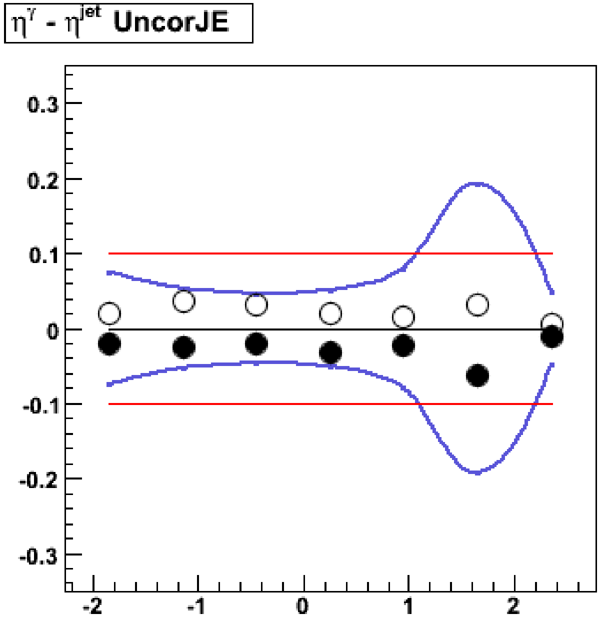
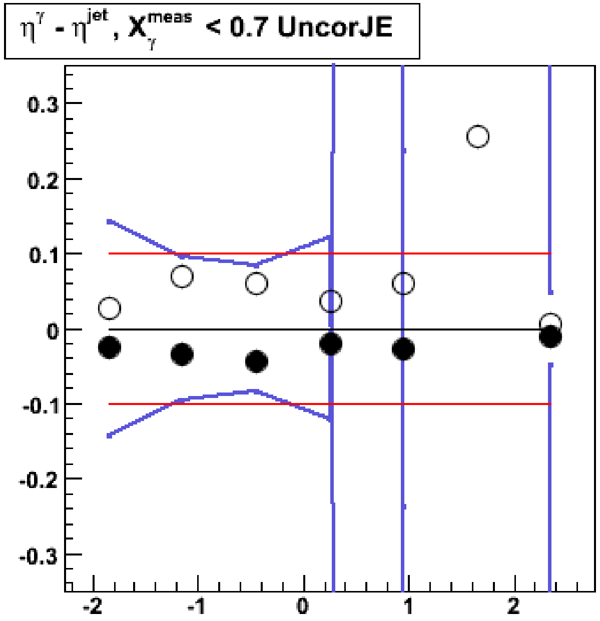
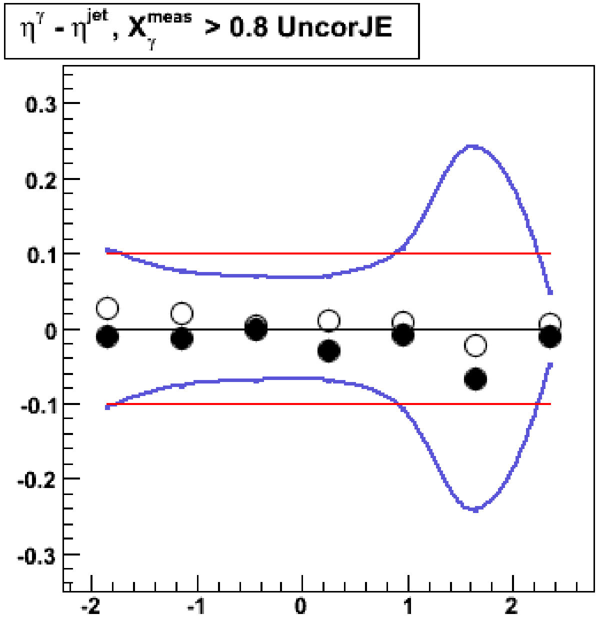
8
9
10
11
12
13


η^{jet}, X_γ^{meas} < 0.7 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^{jet}, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

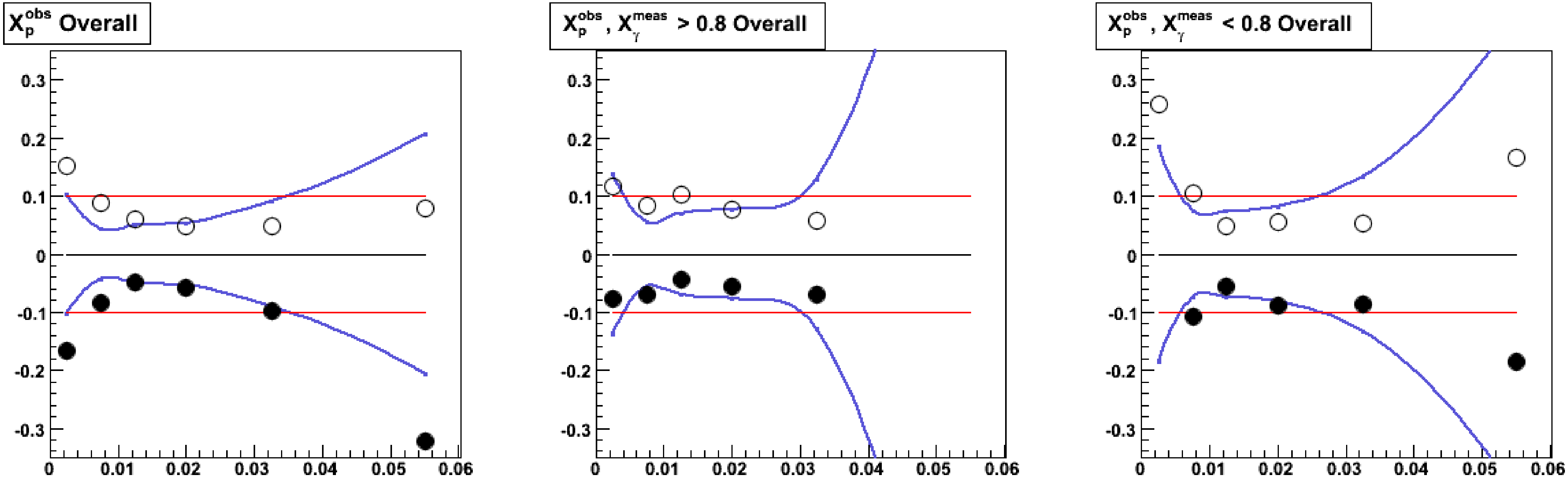

$\eta^{\gamma} - \eta^{jet}$ UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.7$ UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2

Systematic uncertainties

$x_\gamma < 0.8$, $x_\gamma > 0.8$



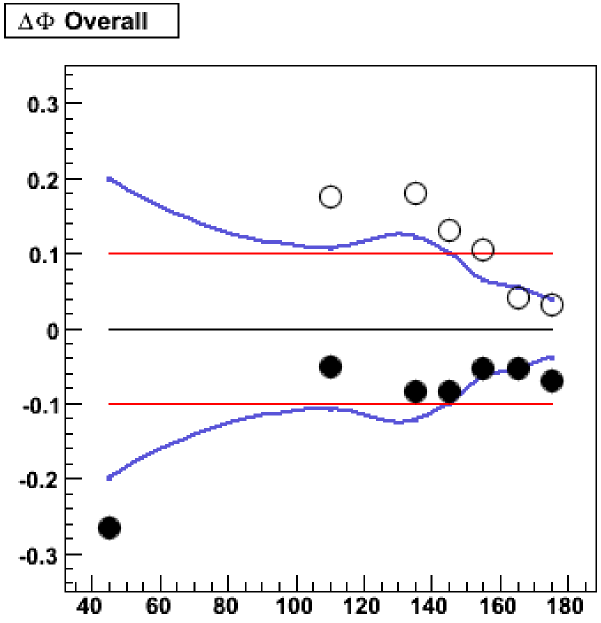
Overall systematics

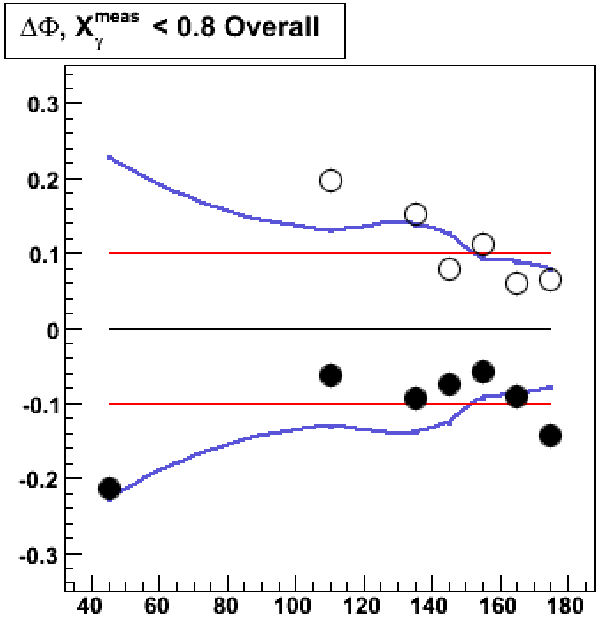
— *Rel.statistical uncertainties*

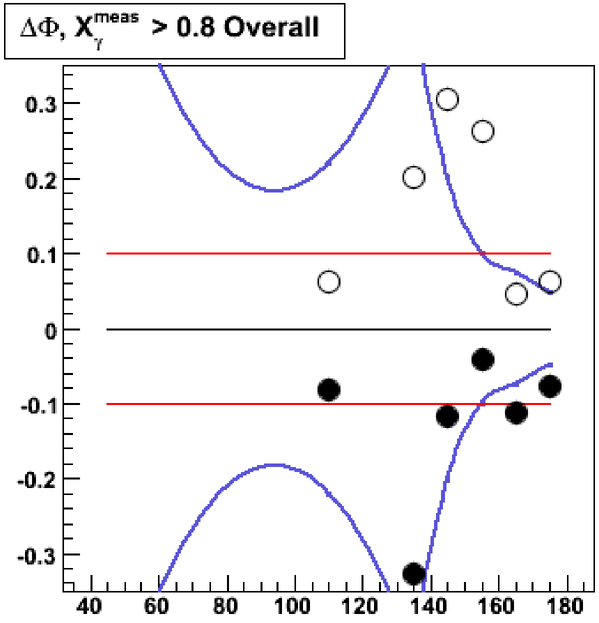
— *10% line*

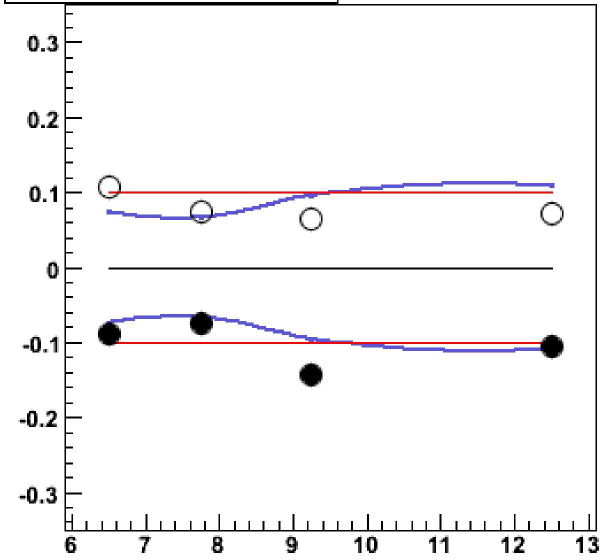
○ *upper sum*

● *lower sum*

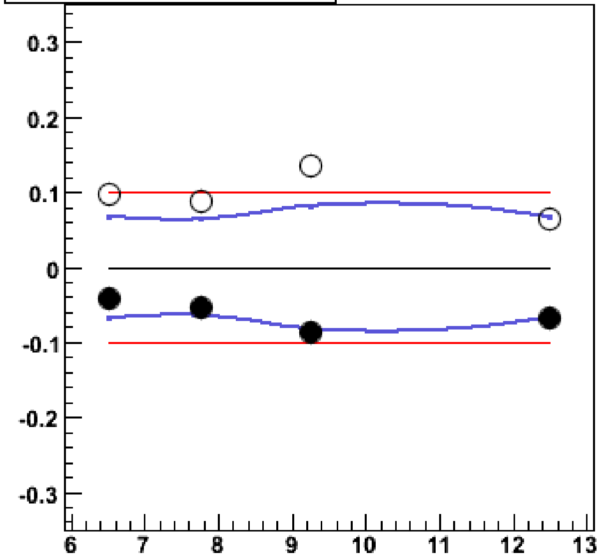

ΔΦ Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


ΔΦ, X_{γ}^{meas} < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

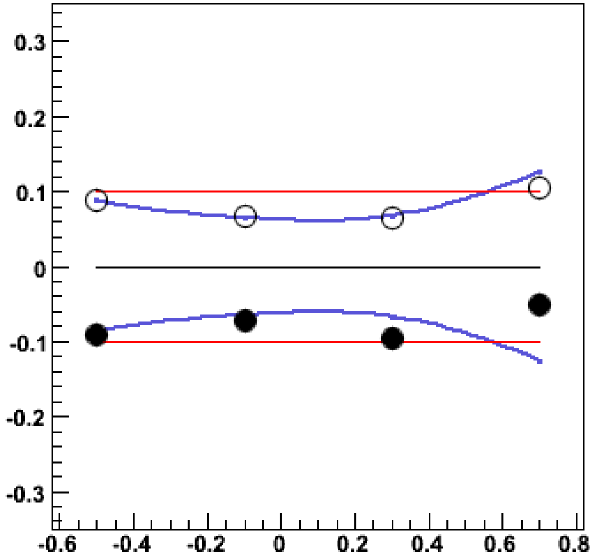

ΔΦ, X_{γ}^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



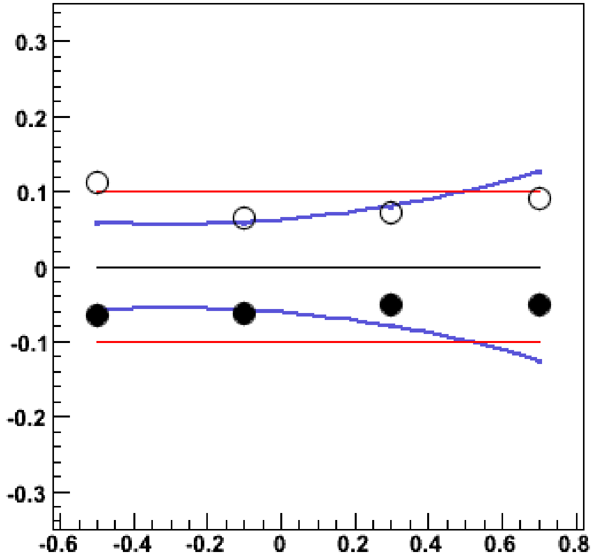
E_T^{γ}, X_{γ}^{meas} < 0.8 Overall



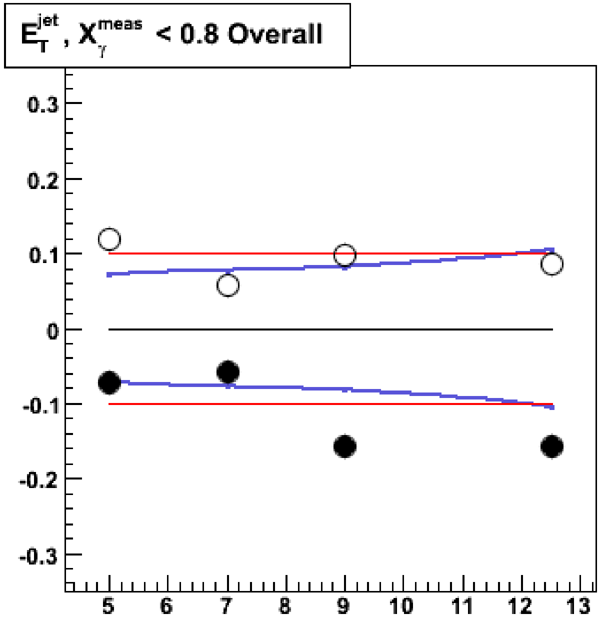
E_T^{γ}, X_{γ}^{meas} > 0.8 Overall

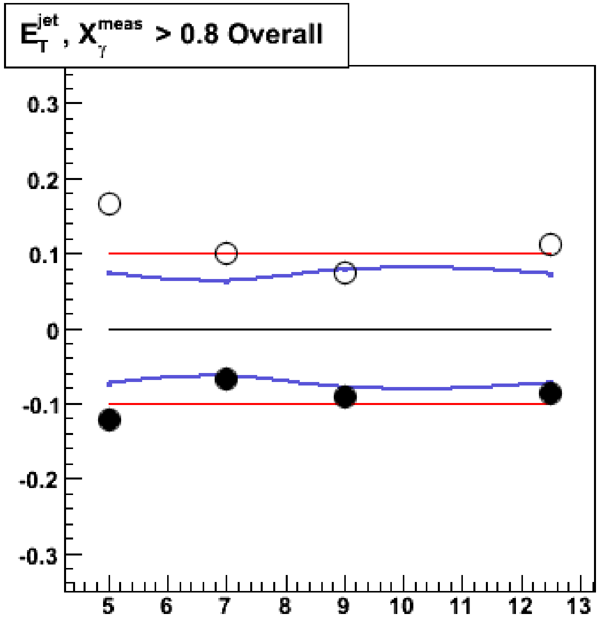


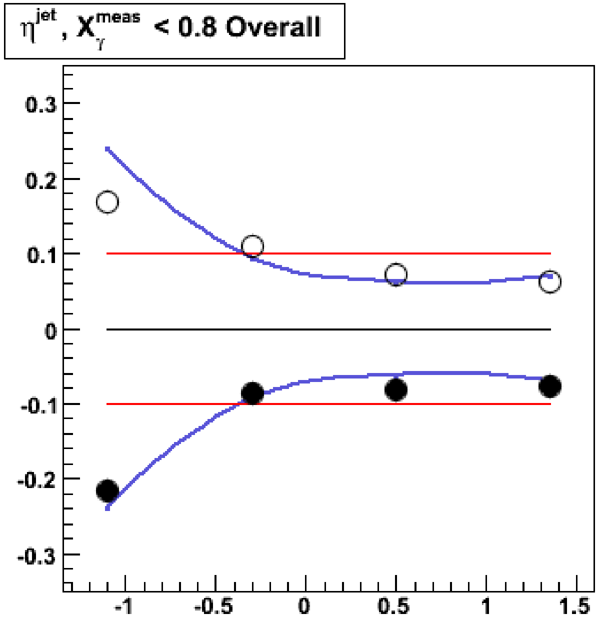
η^{γ}, X_{γ}^{meas} < 0.8 Overall

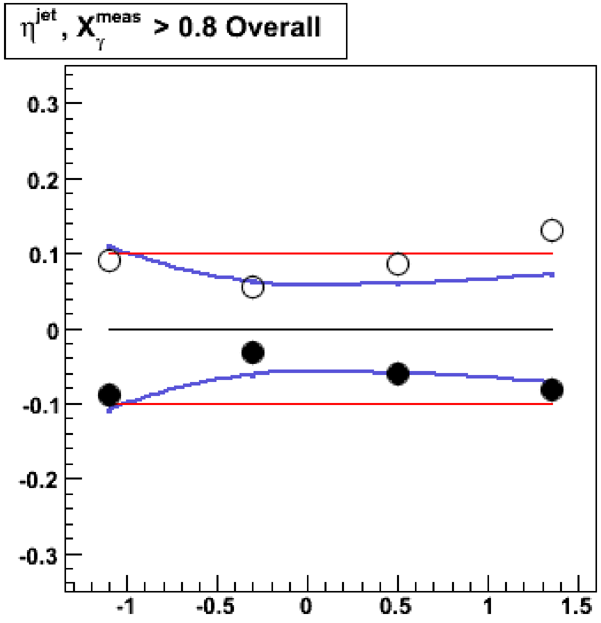


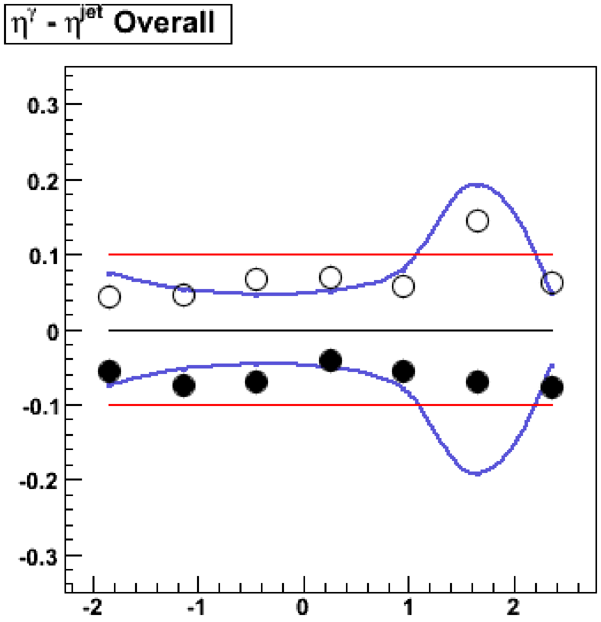
η^{γ}, X_{γ}^{meas} > 0.8 Overall

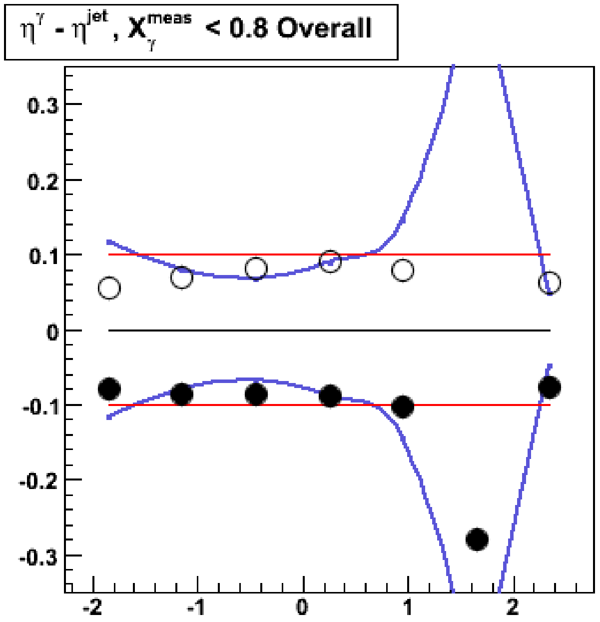

E_T^jet, X_γ^meas < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

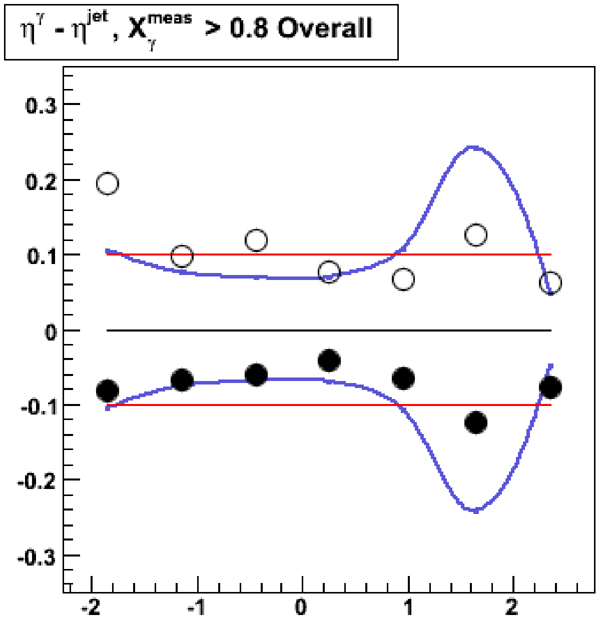

E_T^jet, X_γ^meas > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

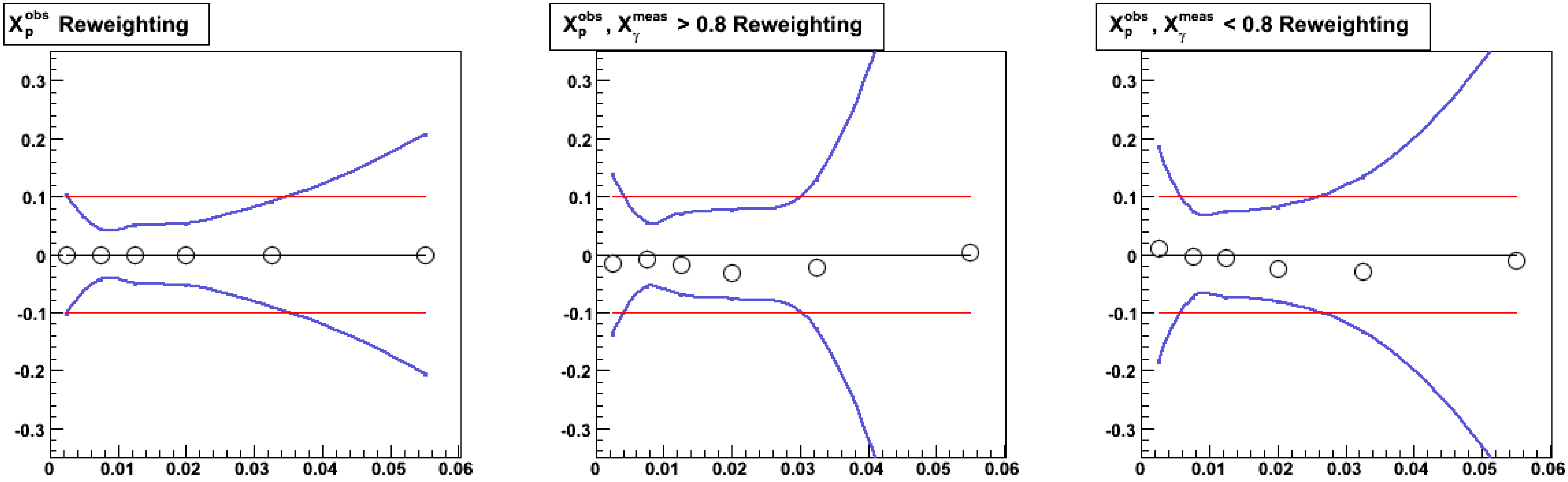

η^jet, X_γ^meas < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^jet, X_γ^meas > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^{γ} - η^{jet} Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



Reweighting

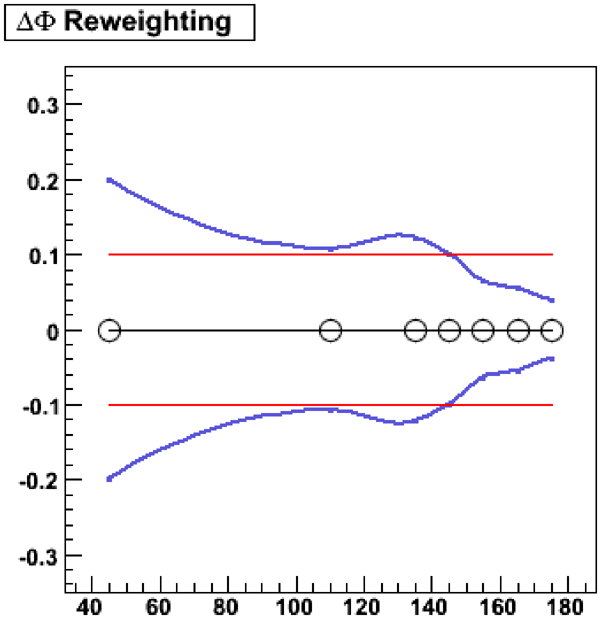
ΔΦ reweighted in x_γ<0.8 and x_γ>0.8 regions.

E_T^{jet} and η^{jet} reweighted in x_γ>0.8 region.

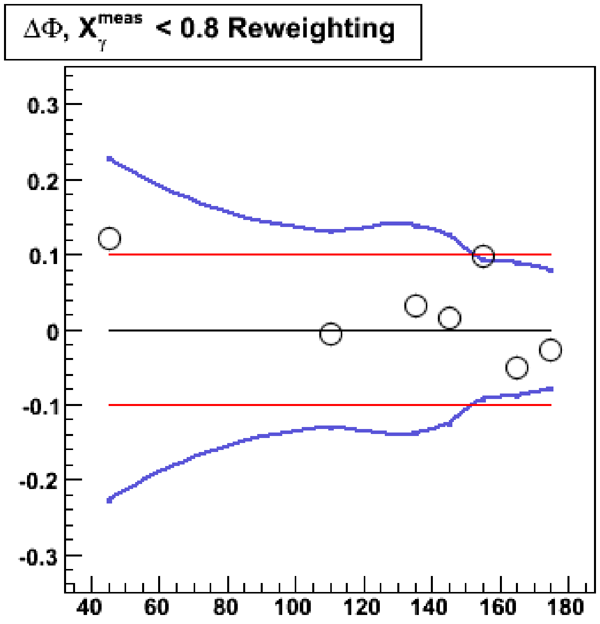
— *Rel.statistical uncertainties*

— *10% line*

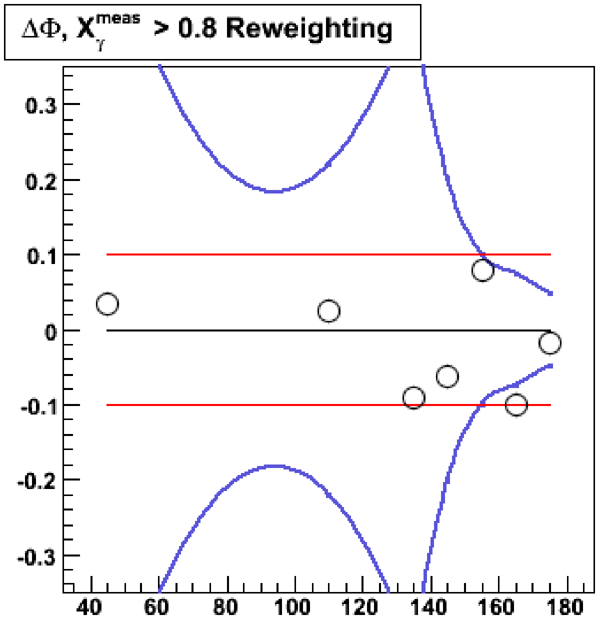
○ *Reweighting*



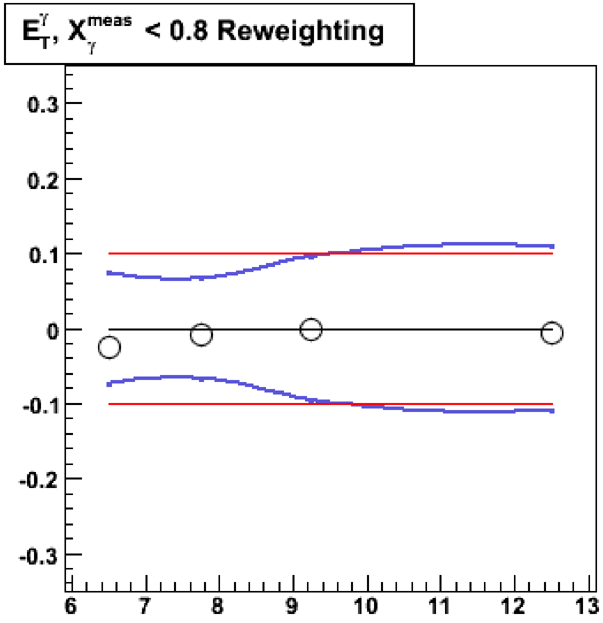
ΔΦ Reweighting

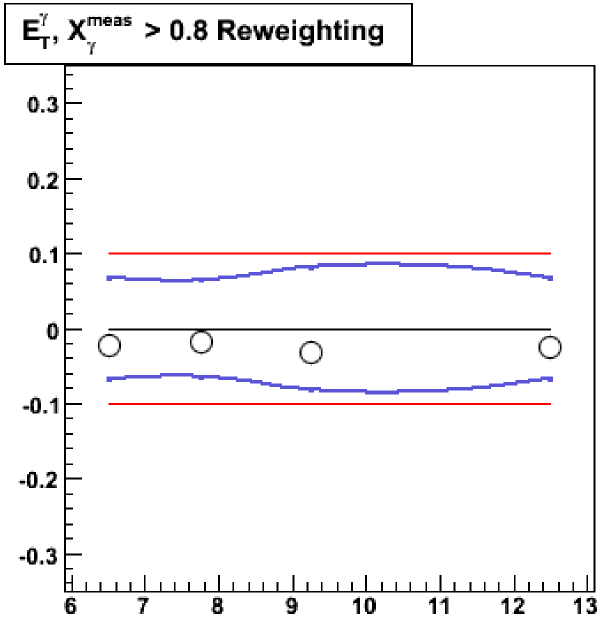


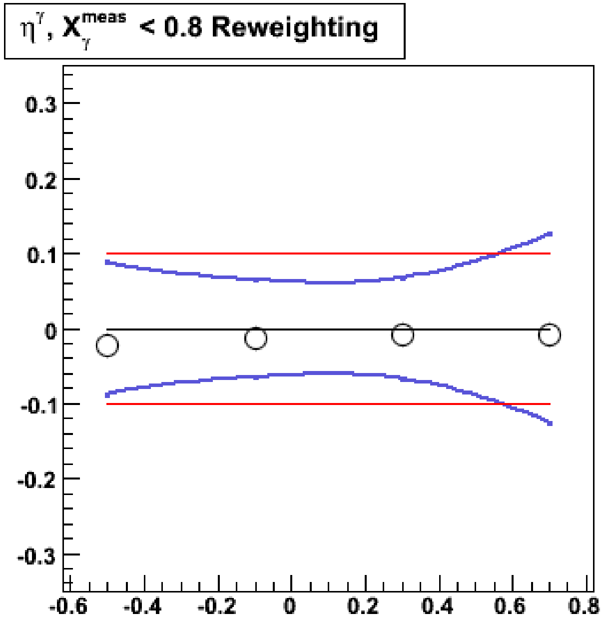
ΔΦ, X_{γ}^{meas} < 0.8 Reweighting

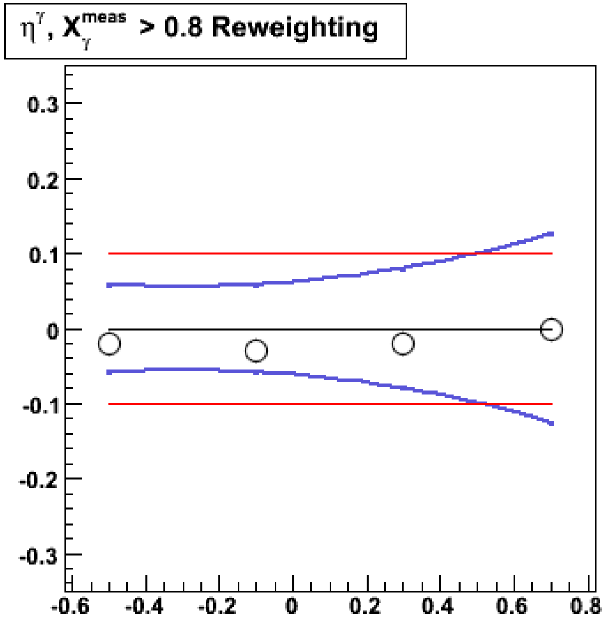


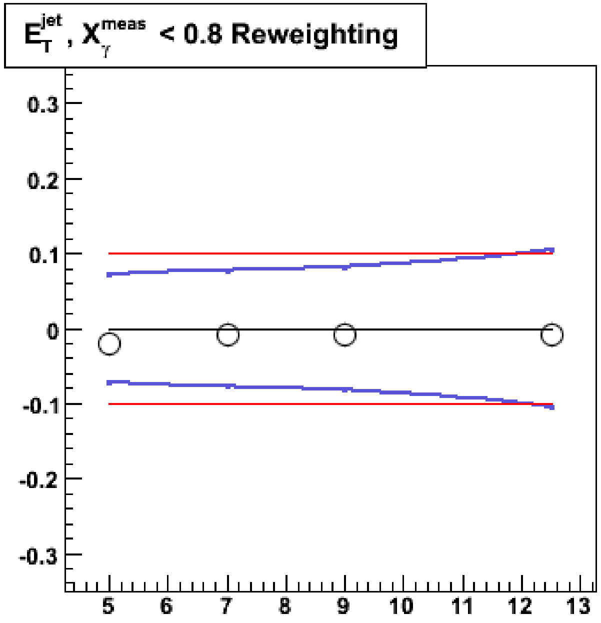
ΔΦ, X_{γ}^{meas} > 0.8 Reweighting


E_T^γ, X_γ^{meas} < 0.8 Reweighting
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

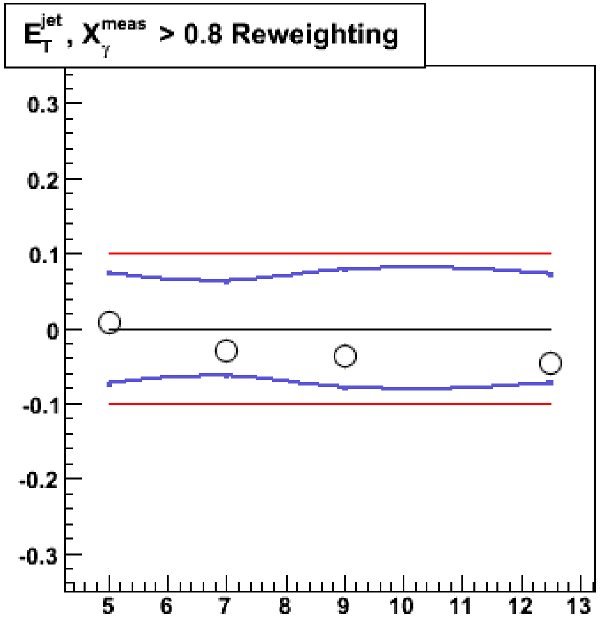

E_T^γ, X_γ^{meas} > 0.8 Reweighting
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


η^γ, X_γ^{meas} < 0.8 Reweighting
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

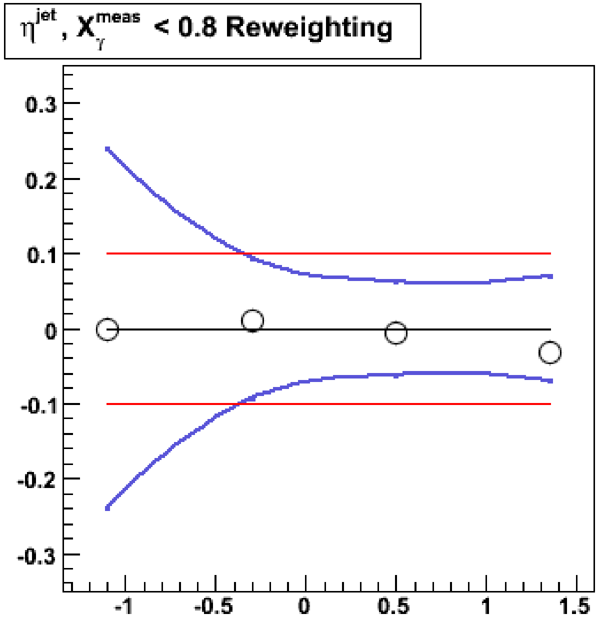

η^γ, X_γ^{meas} > 0.8 Reweighting
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8



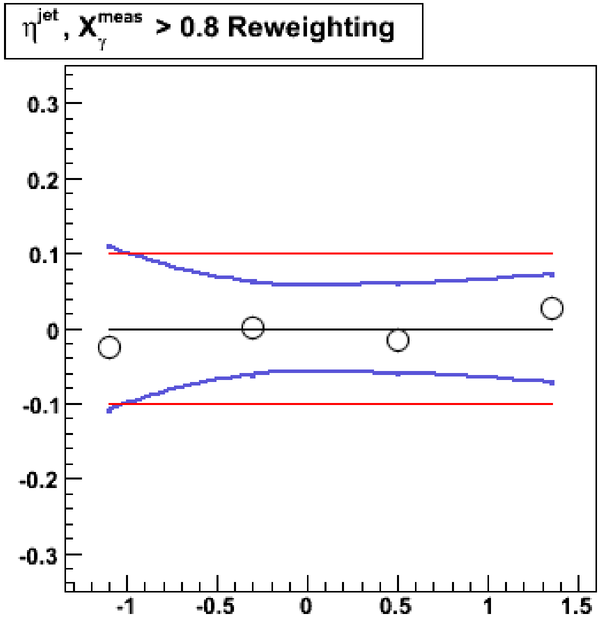
E_T^{jet}, X_γ^{meas} < 0.8 Reweighting



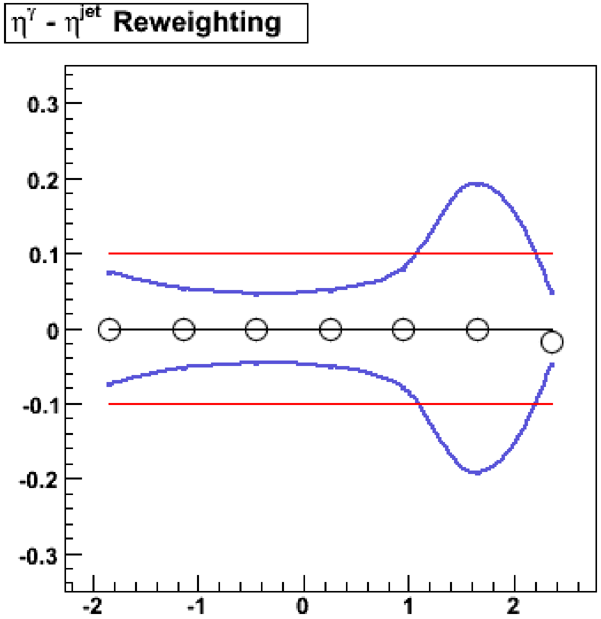
E_T^{jet}, X_γ^{meas} > 0.8 Reweighting



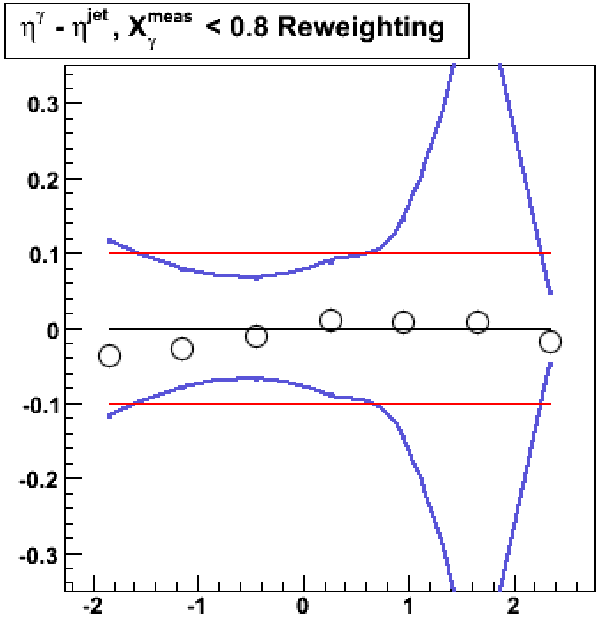
η^{jet}, X_γ^{meas} < 0.8 Reweighting



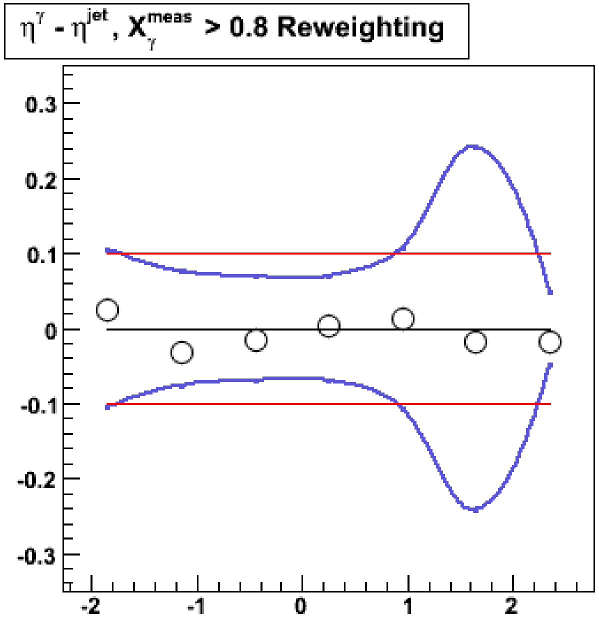
η^{jet}, X_γ^{meas} > 0.8 Reweighting



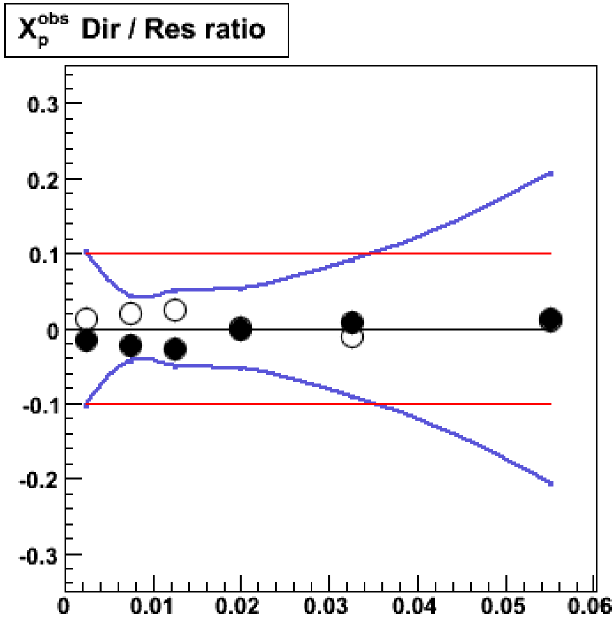
$\eta^{\gamma} - \eta^{jet}$ Reweighting

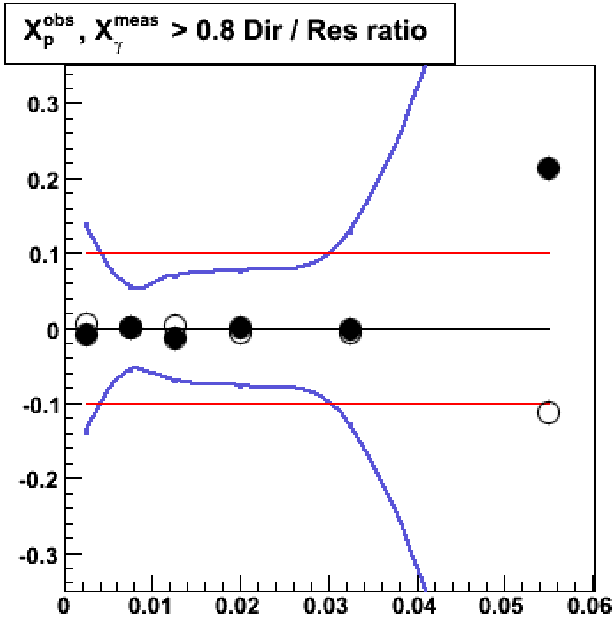


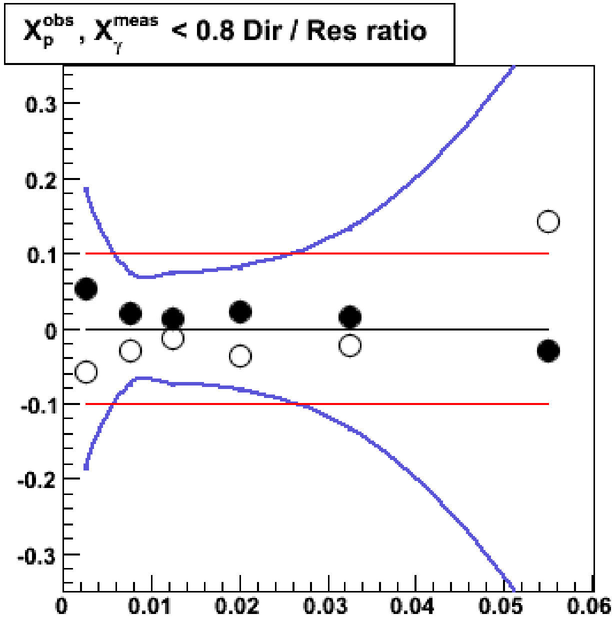
$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.8$ Reweighting



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ Reweighting


X_p^{obs} Dir / Res ratio


X_p^{obs}, X_γ^{meas} > 0.8 Dir / Res ratio


X_p^{obs}, X_γ^{meas} < 0.8 Dir / Res ratio

Systematic uncertainties: PYTHIA dir / res

Standard direct/ resolved ratio:
50% / 40%

Vary fraction of resolved by +-15%:

35% / 55%
65% / 25%

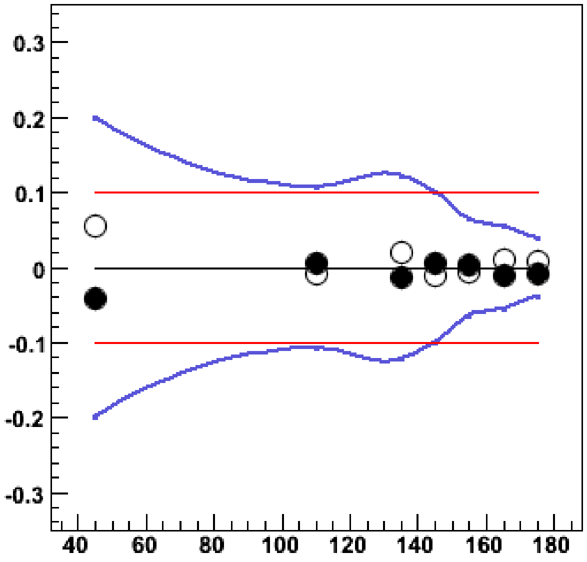
— *Rel.statistical uncertainties*

— *10% line*

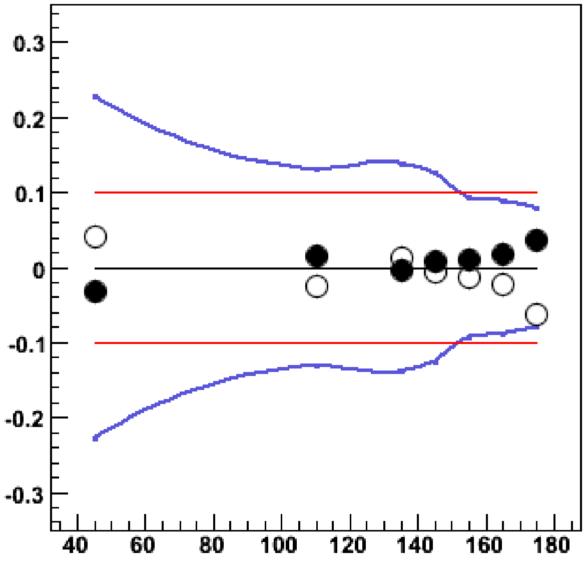
○ *-15% resolved*

● *+15% resolved*

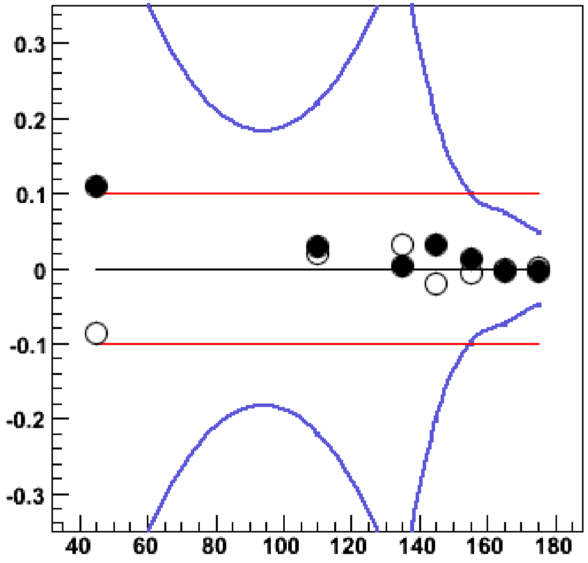
ΔΦ Dir / Res ratio

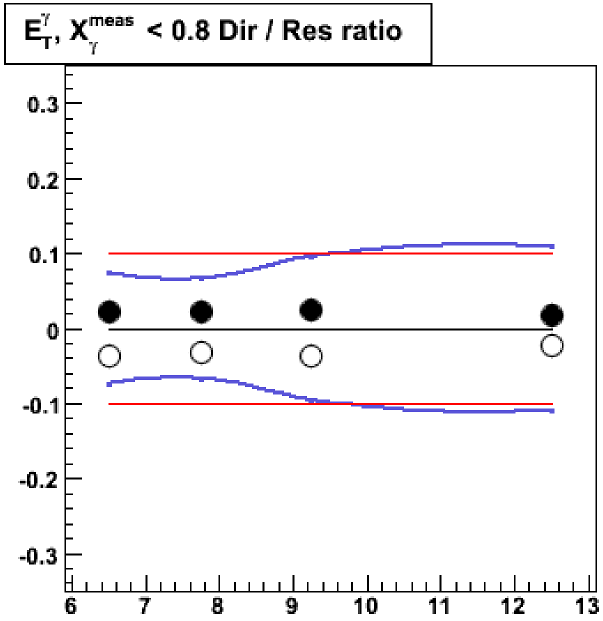


ΔΦ, X_{γ}^{meas} < 0.8 Dir / Res ratio

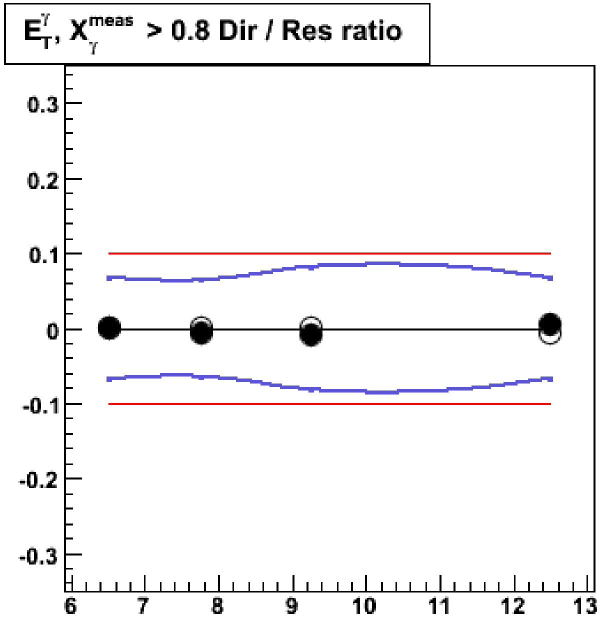


ΔΦ, X_{γ}^{meas} > 0.8 Dir / Res ratio

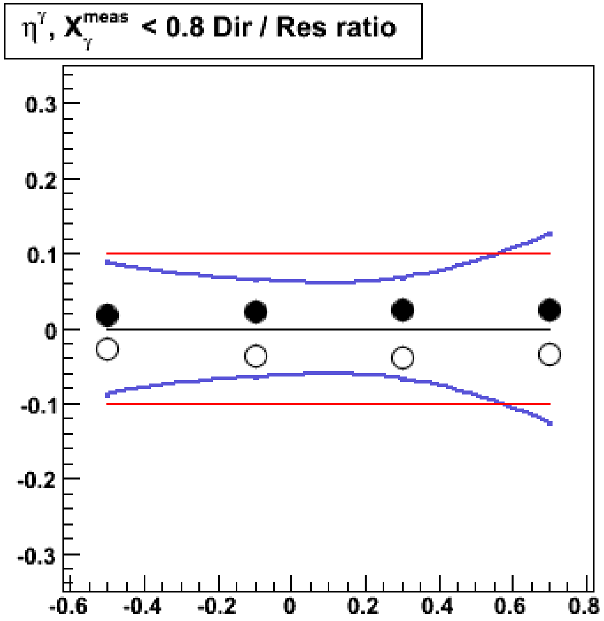




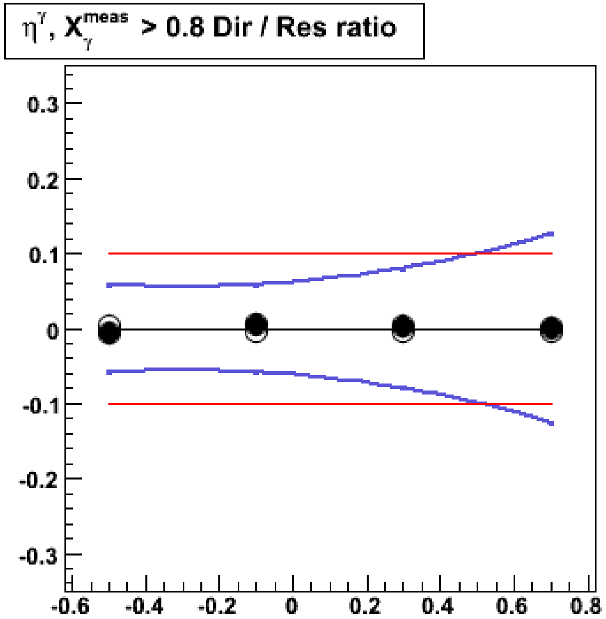
E_T^{γ}, X_{γ}^{meas} < 0.8 Dir / Res ratio



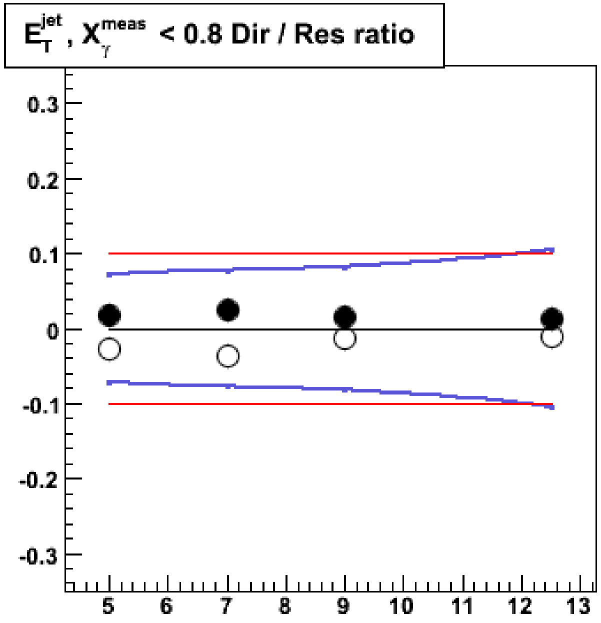
E_T^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio



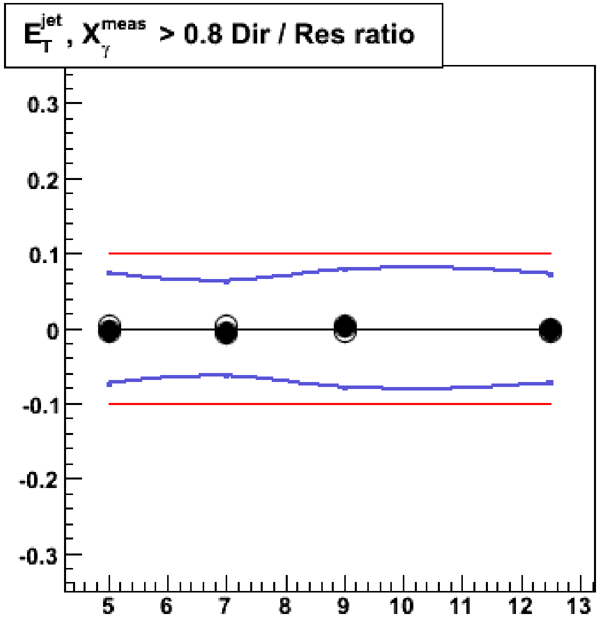
η^{γ}, X_{γ}^{meas} < 0.8 Dir / Res ratio



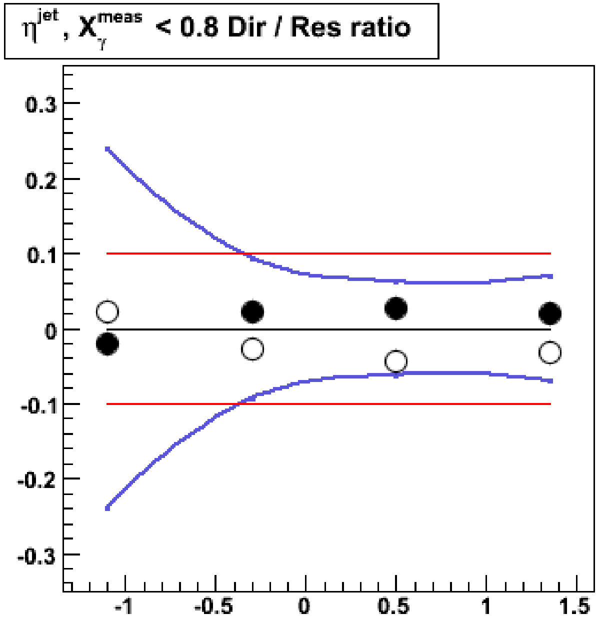
η^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio



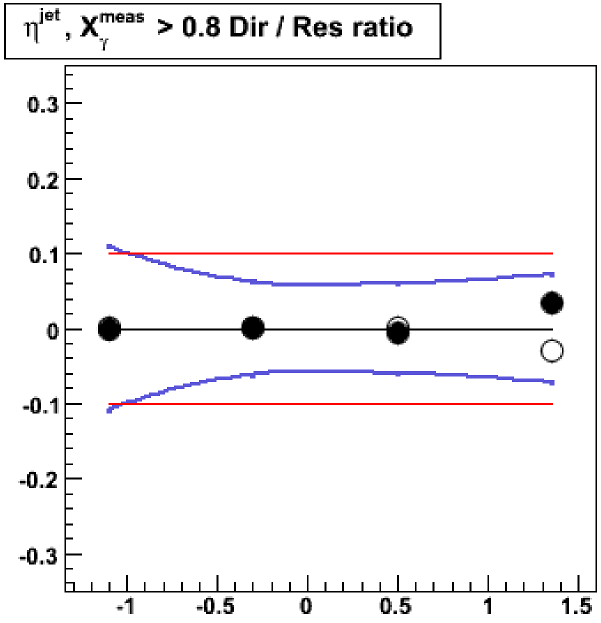
E_T^{jet}, X_γ^{meas} < 0.8 Dir / Res ratio



E_T^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio

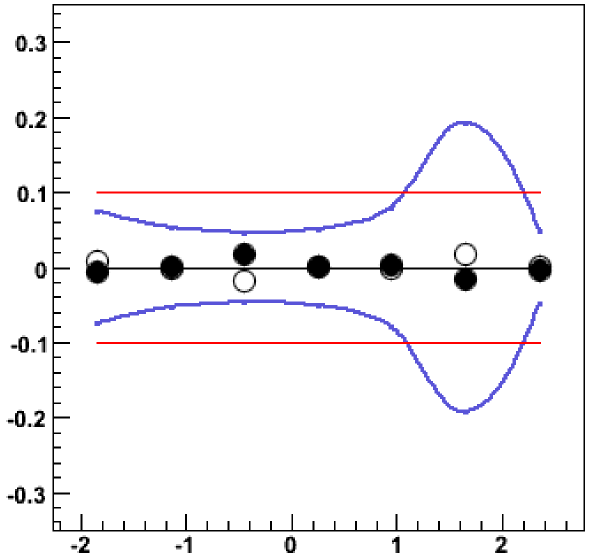


η^{jet}, X_γ^{meas} < 0.8 Dir / Res ratio

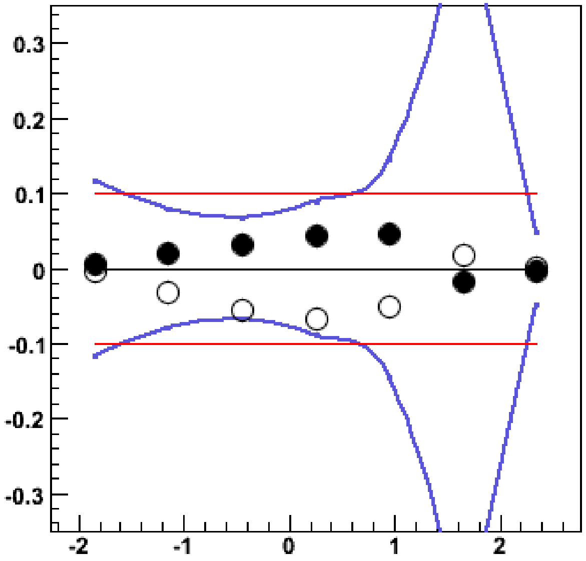


η^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio

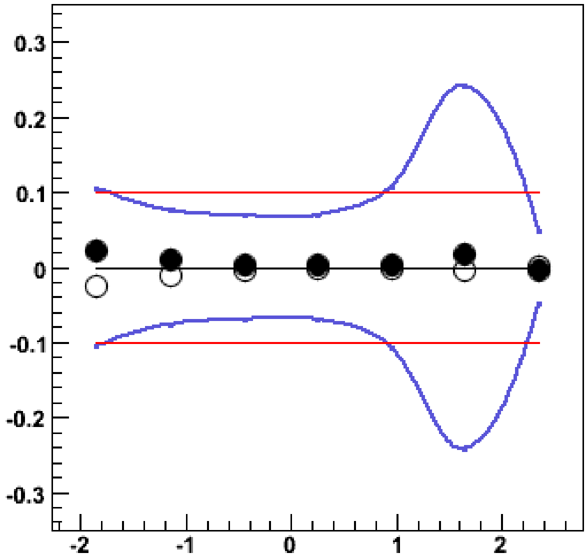
$\eta^{\gamma} - \eta^{jet}$ Dir / Res ratio

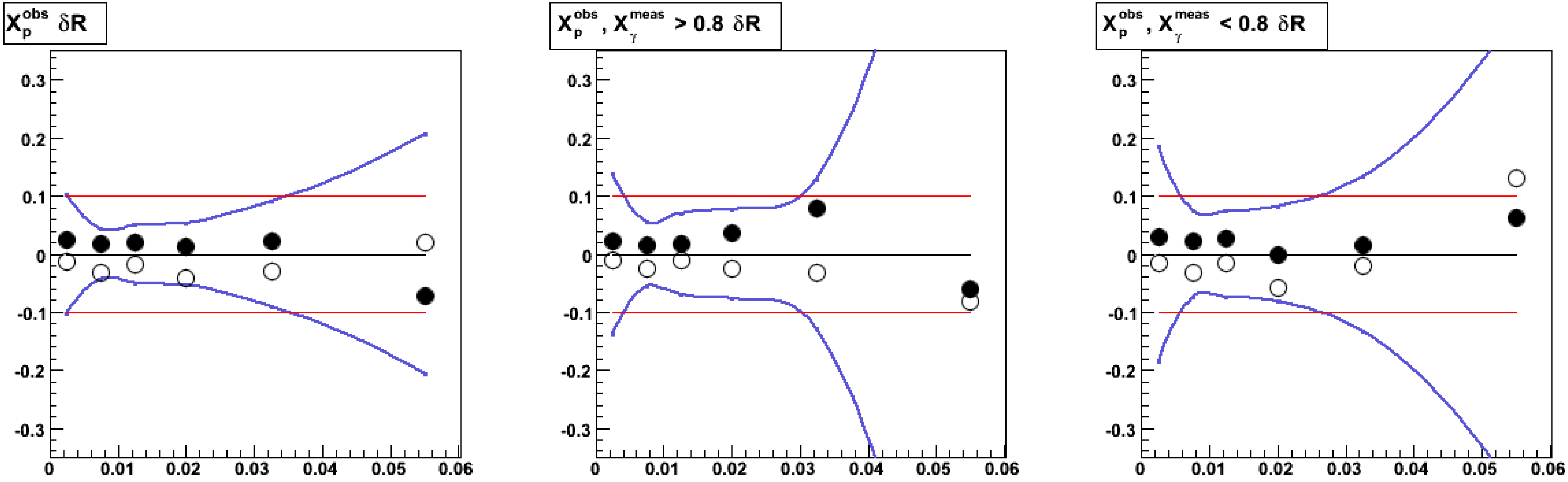


$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.8 Dir / Res ratio



$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 Dir / Res ratio





Systematic uncertainties: deltaR

Standard cut:

deltaR track isolation in cone 0.2

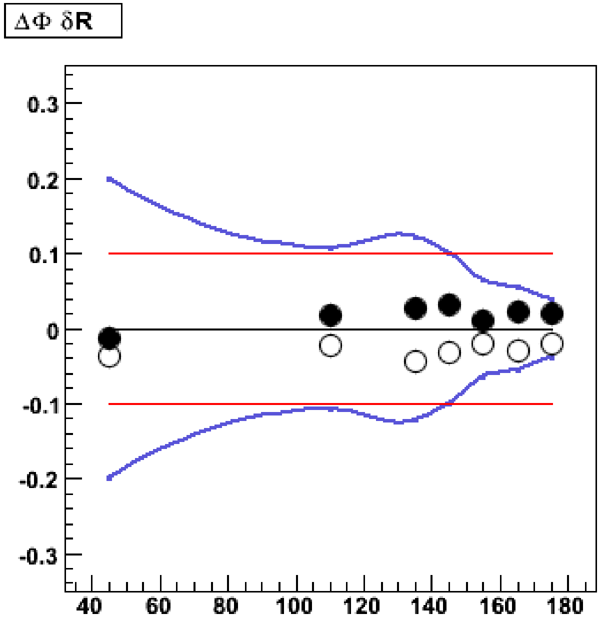
Vary cone radius by +-0.1

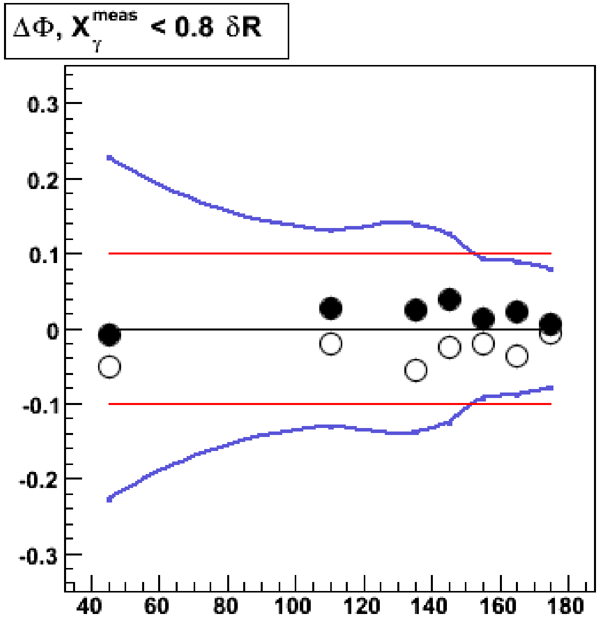
Rel.statistical uncertainties

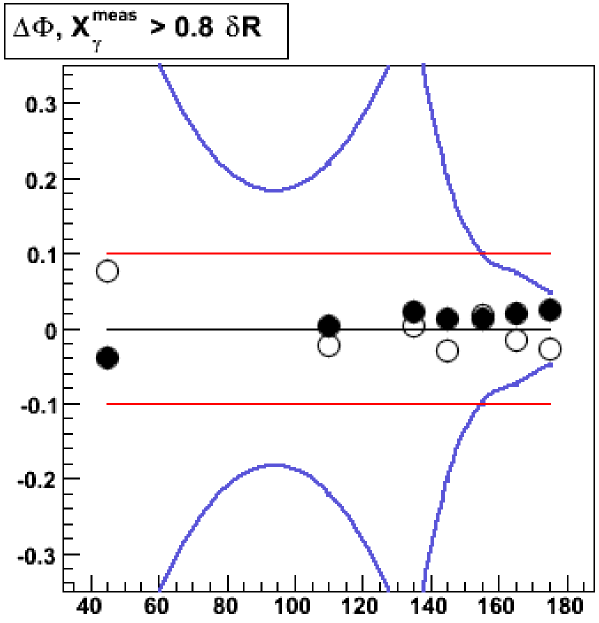
10% line

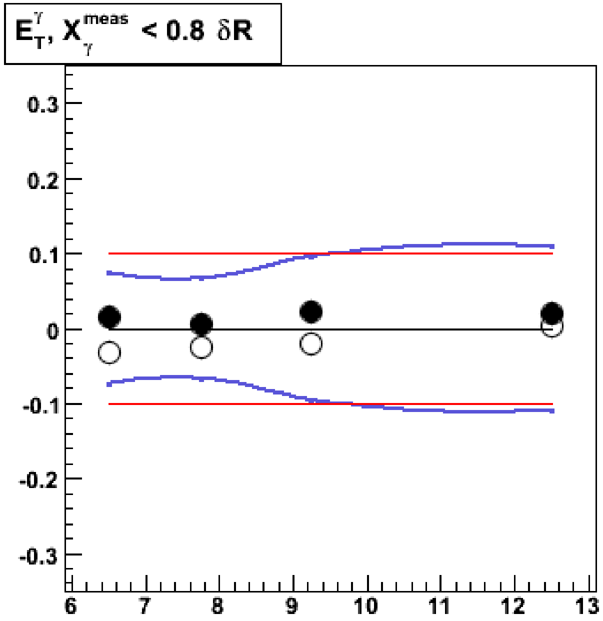
○ *δR 0.3*

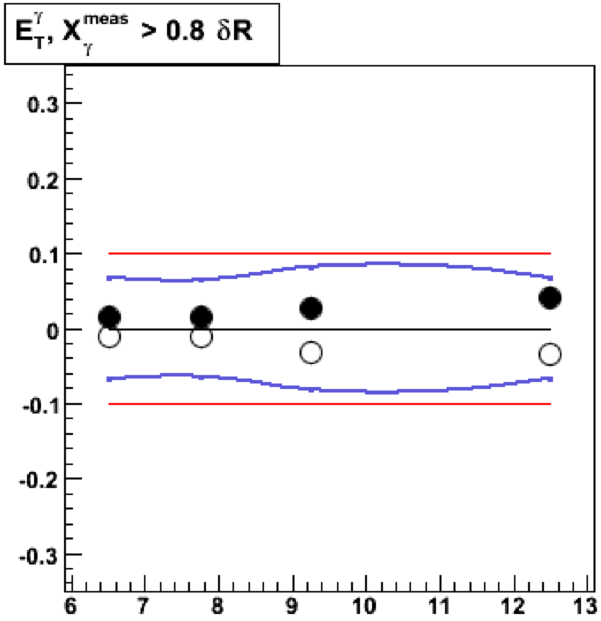
● *δR 0.1*


ΔΦ δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


ΔΦ, X_γ^{meas} < 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


ΔΦ, X_γ^{meas} > 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


E_T^γ, X_γ^{meas} < 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


E_T^γ, X_γ^{meas} > 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
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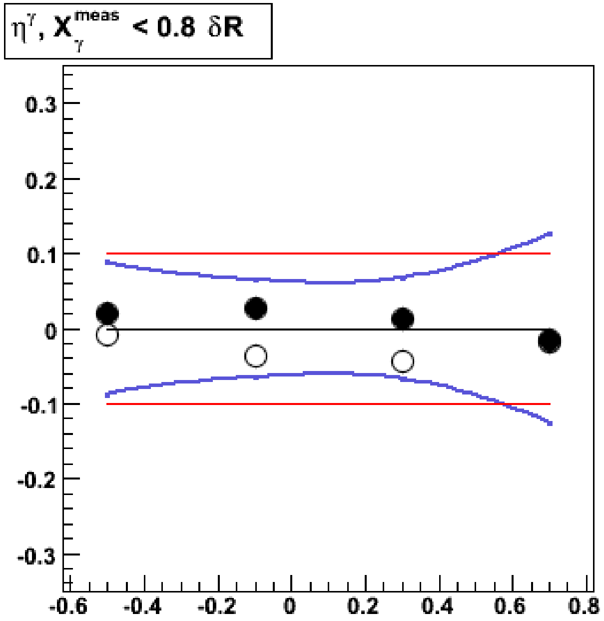
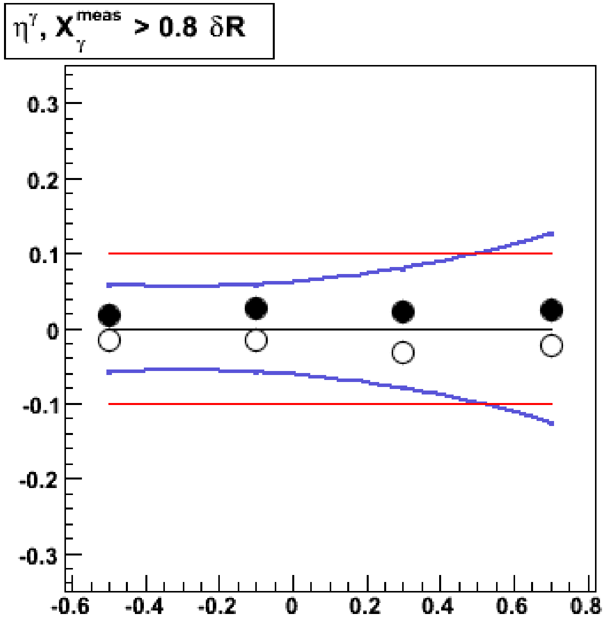
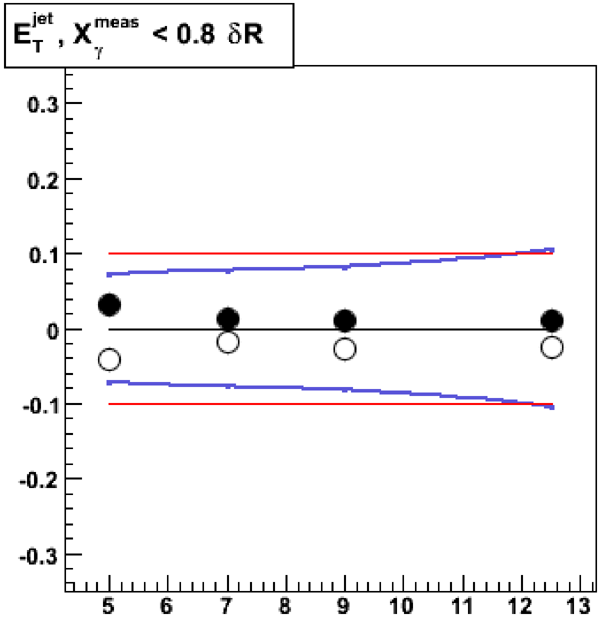
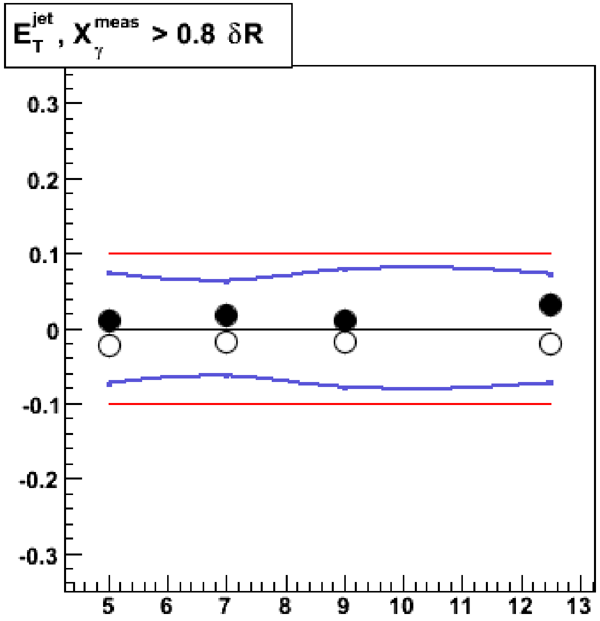
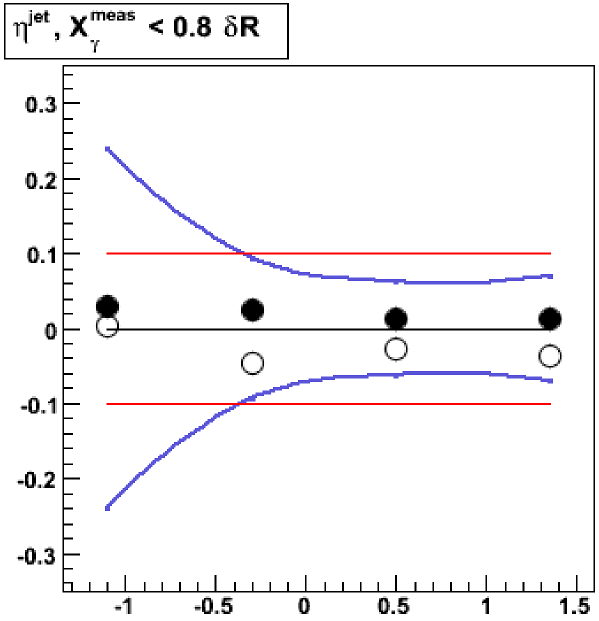
8
9
10
11
12
13

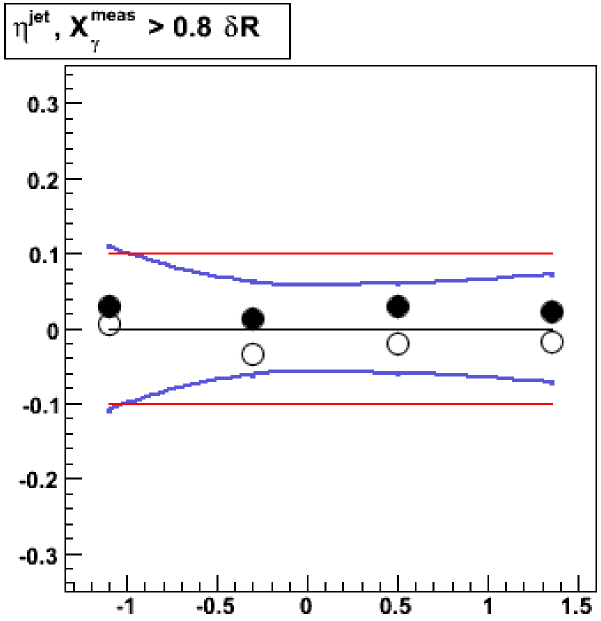

η^γ, X_γ^{meas} < 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

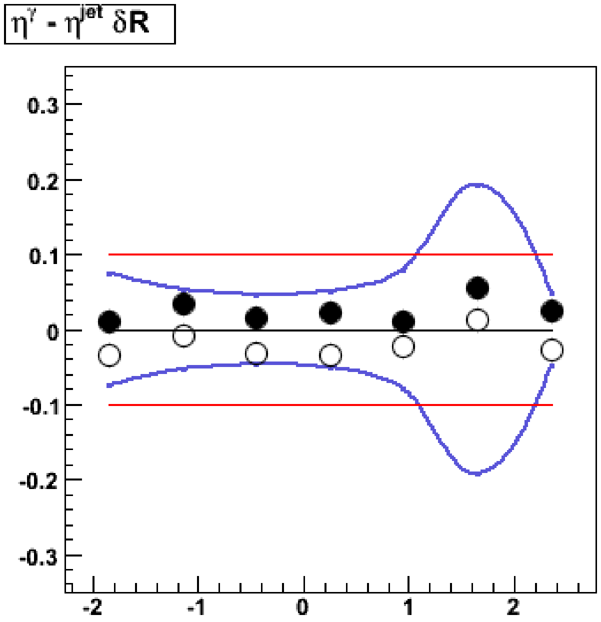

η^γ, X_γ^{meas} > 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet} , X_γ^{meas} < 0.8 δR

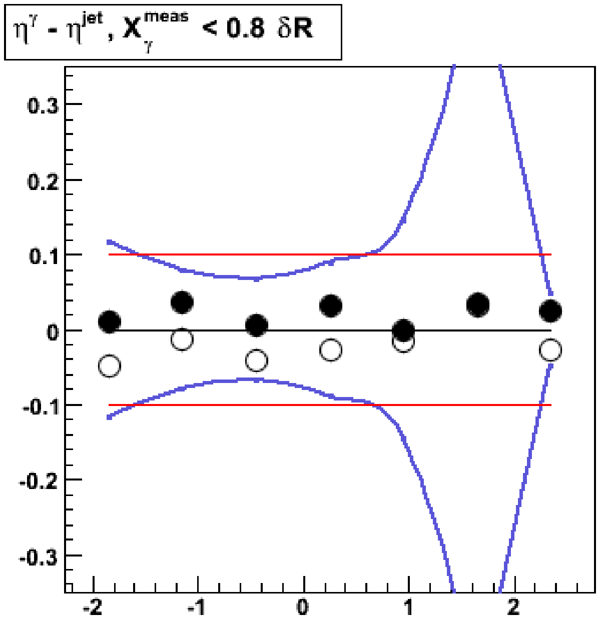

E_T^{jet} , X_γ^{meas} > 0.8 δR


η^{jet}, X_γ^{meas} < 0.8 δR

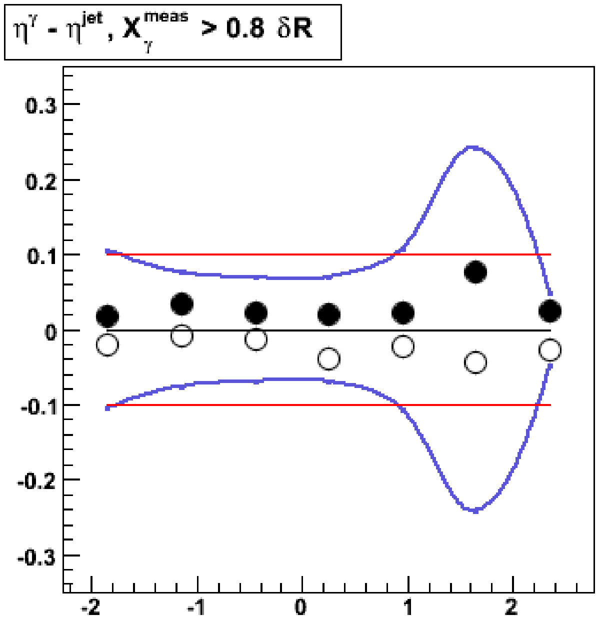

η^{jet}, X_γ^{meas} > 0.8 δR



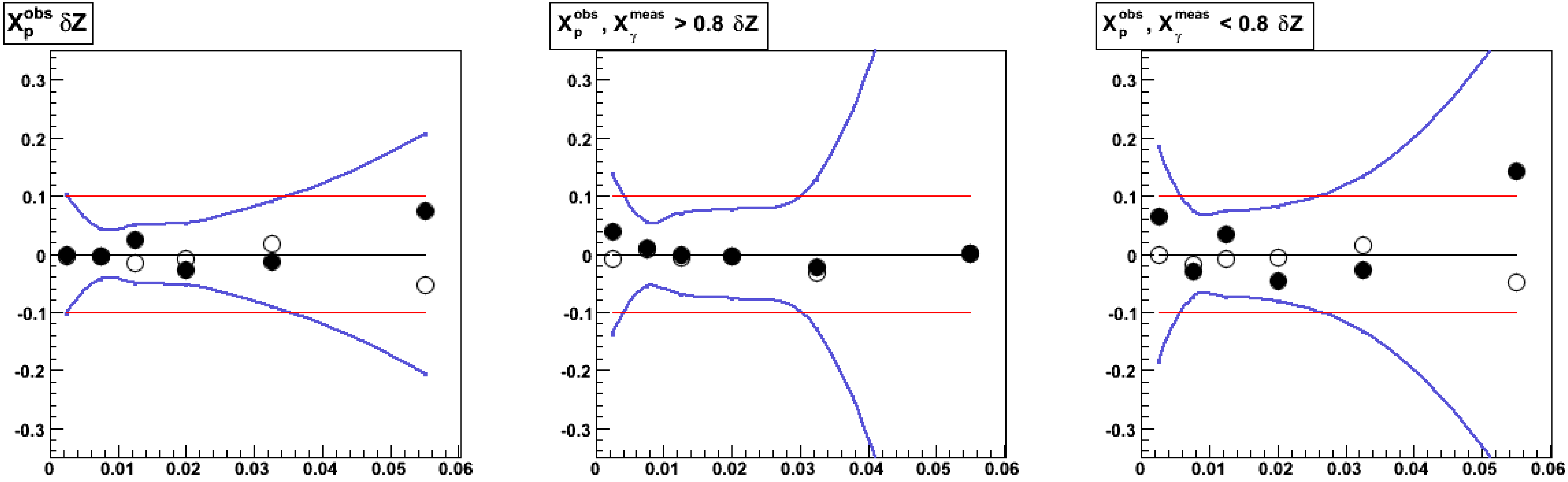
$\eta^{\gamma} - \eta^{jet}$ δR



$\eta^{\gamma} - \eta^{jet}, X_{\gamma}^{meas} < 0.8$ δR



$\eta^{\gamma} - \eta^{jet}, X_{\gamma}^{meas} > 0.8$ δR



Systematic uncertainties: deltaZ fit range

— *Rel.statistical uncertainties* δZ

— *10% line*

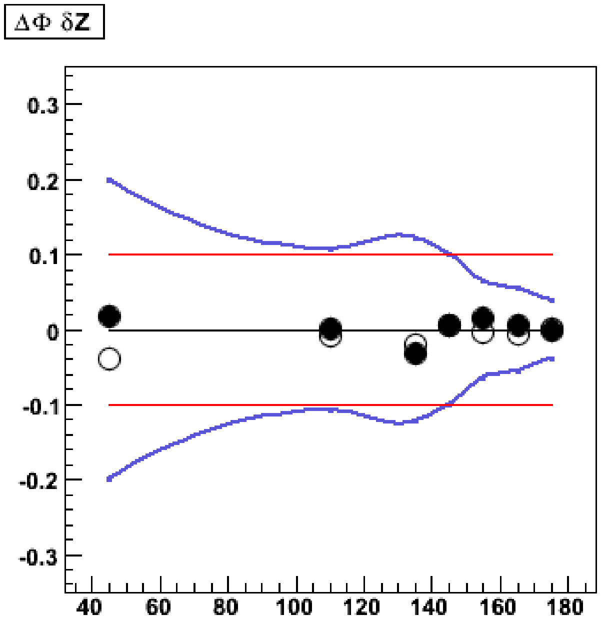
○ *δZ fit range 1.0*

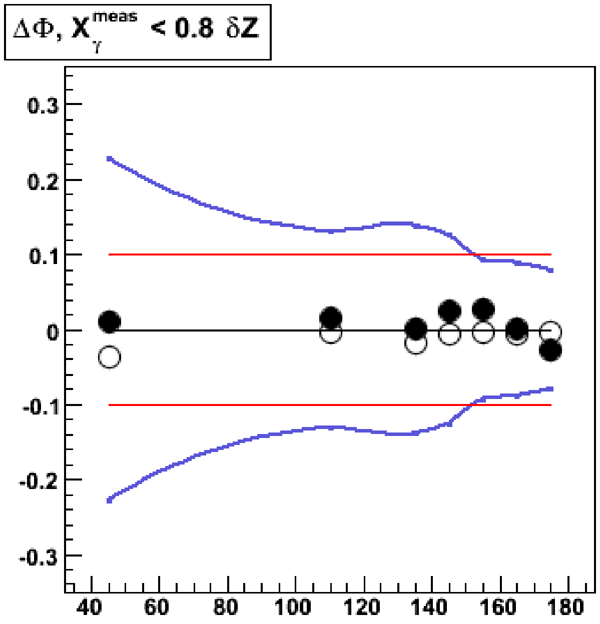
● *δZ fit range 0.6*

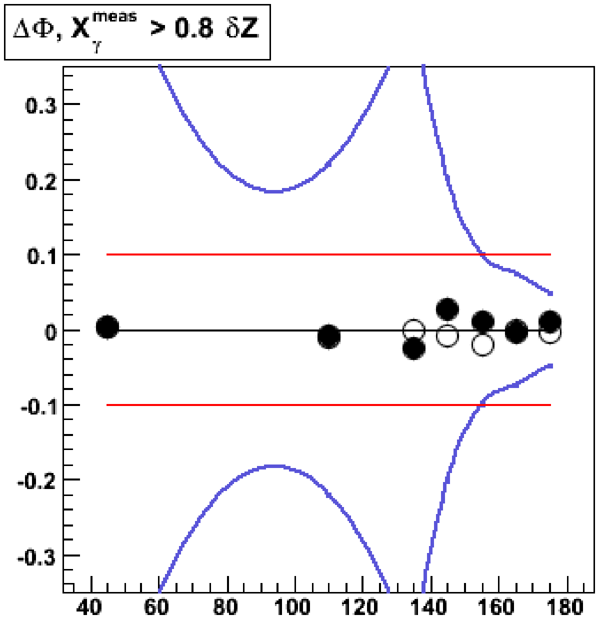
Standard range:

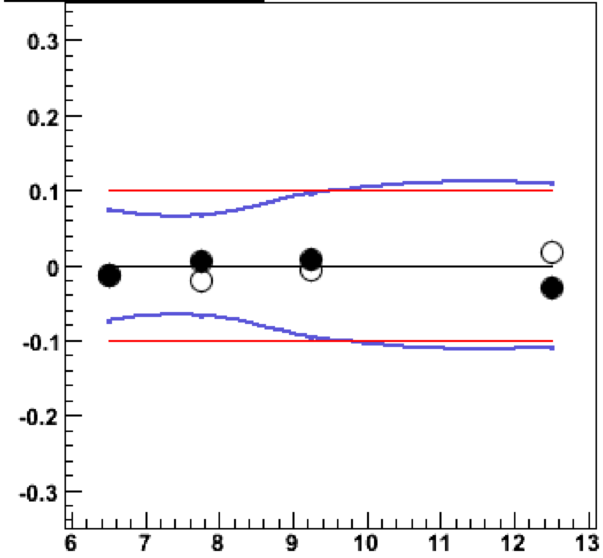
0.05 – 0.8

deltaZ upper limit variation between 0.6 and 1.0

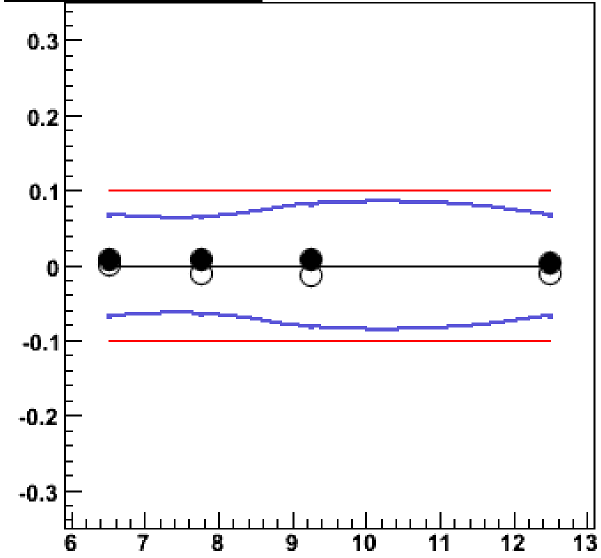

$\Delta\Phi$ δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


$\Delta\Phi$, X_{γ}^{meas} < 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

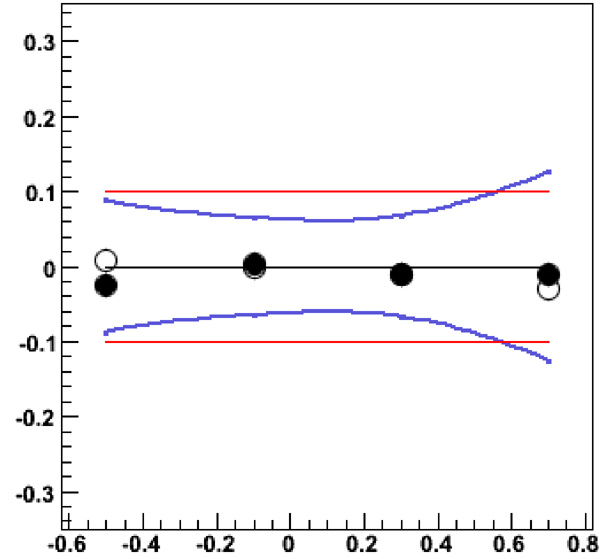

$\Delta\Phi$, X_{γ}^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



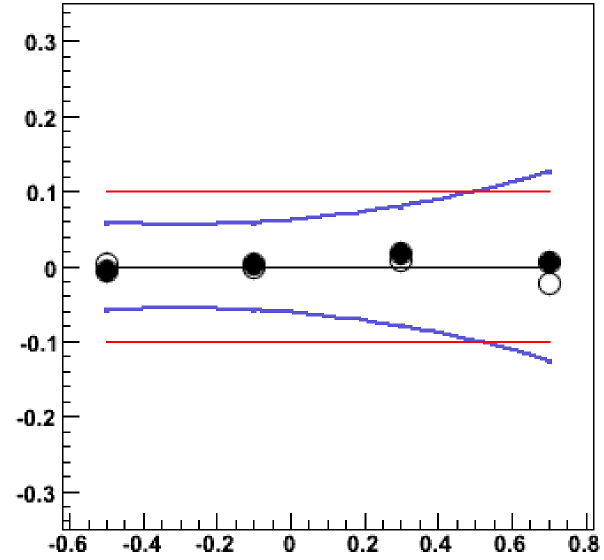
E_T^{γ}, X_{γ}^{meas} < 0.8 δZ



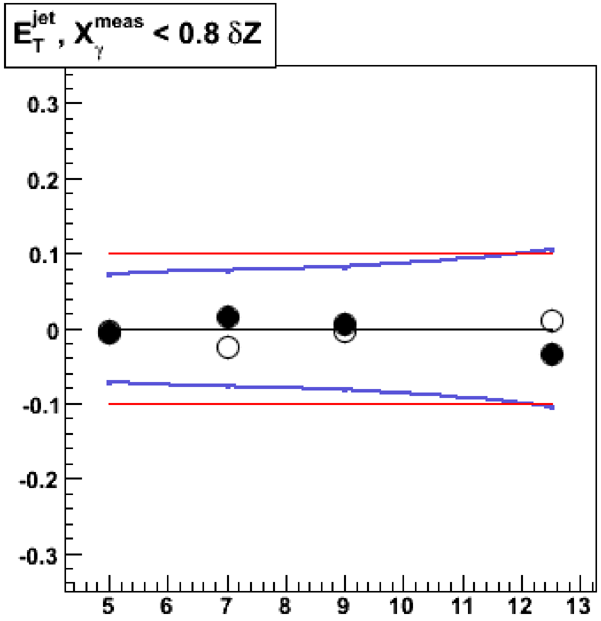
E_T^{γ}, X_{γ}^{meas} > 0.8 δZ

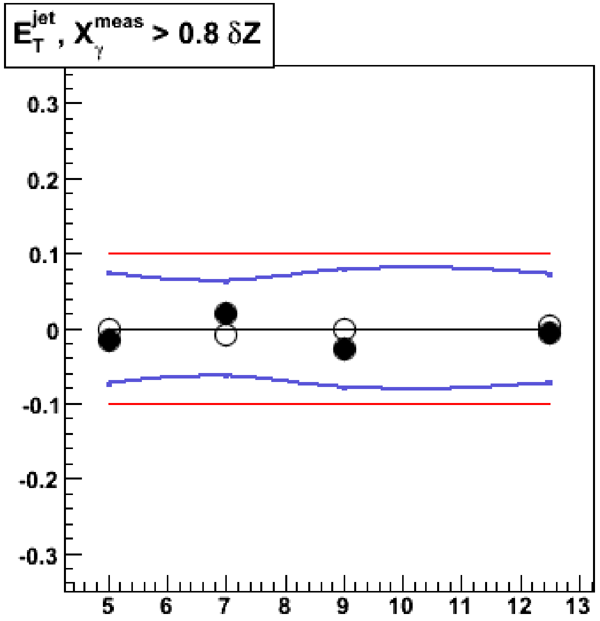


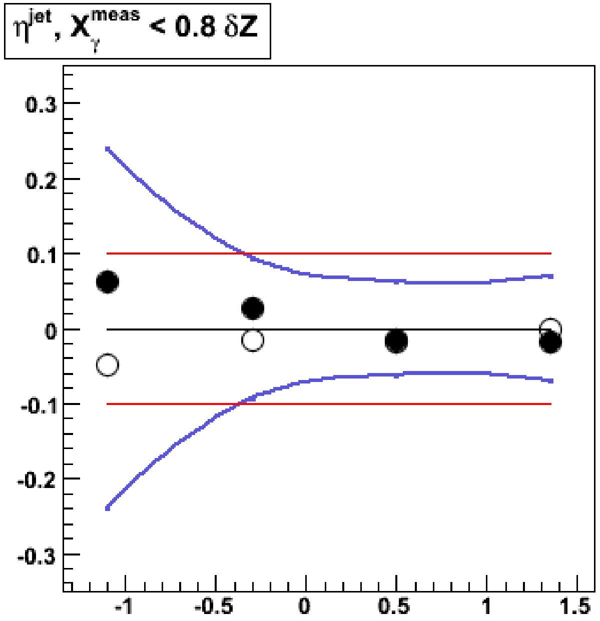
η^{γ}, X_{γ}^{meas} < 0.8 δZ

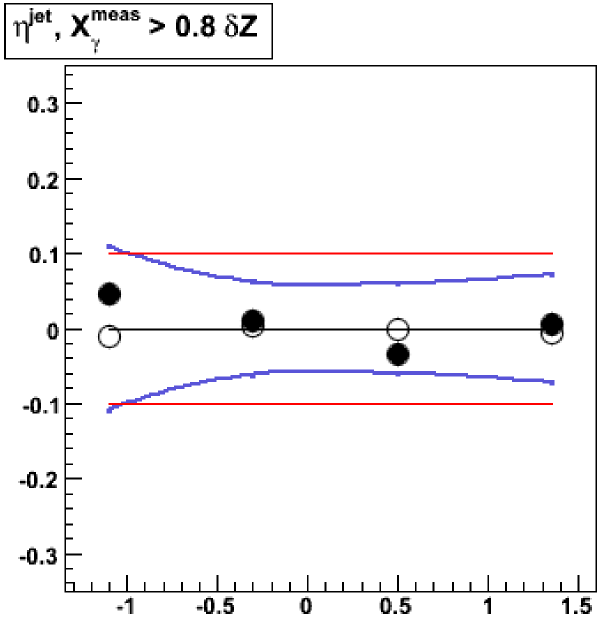


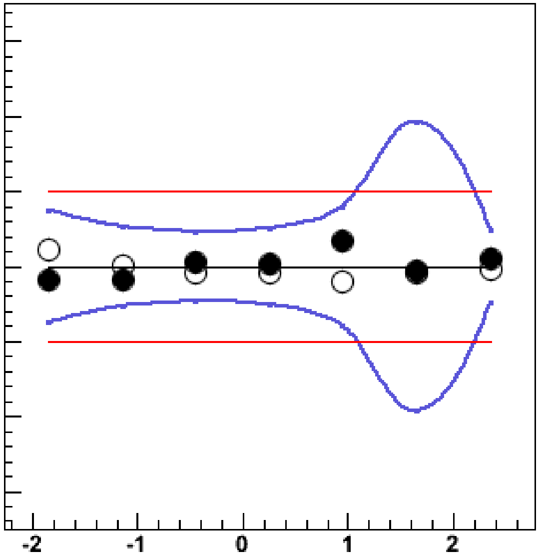
η^{γ}, X_{γ}^{meas} > 0.8 δZ


E_T^{jet} , X_γ^{meas} < 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13

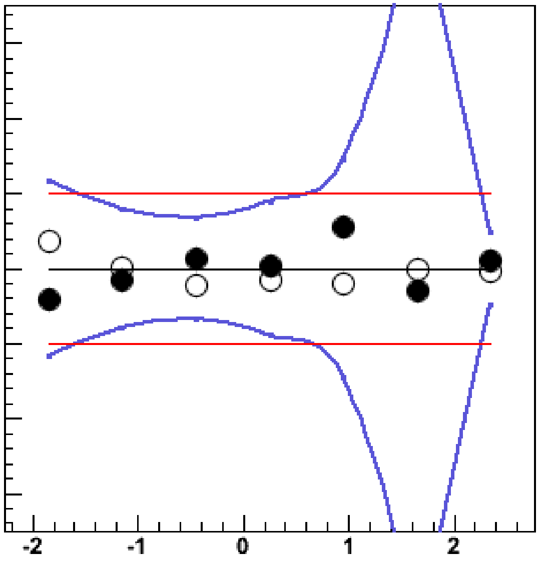

E_T^{jet} , X_γ^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13


η^{jet}, X_γ^{meas} < 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

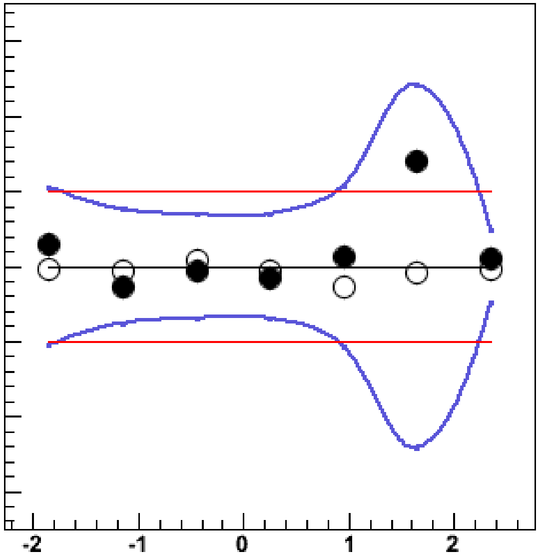

η^{jet}, X_γ^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5



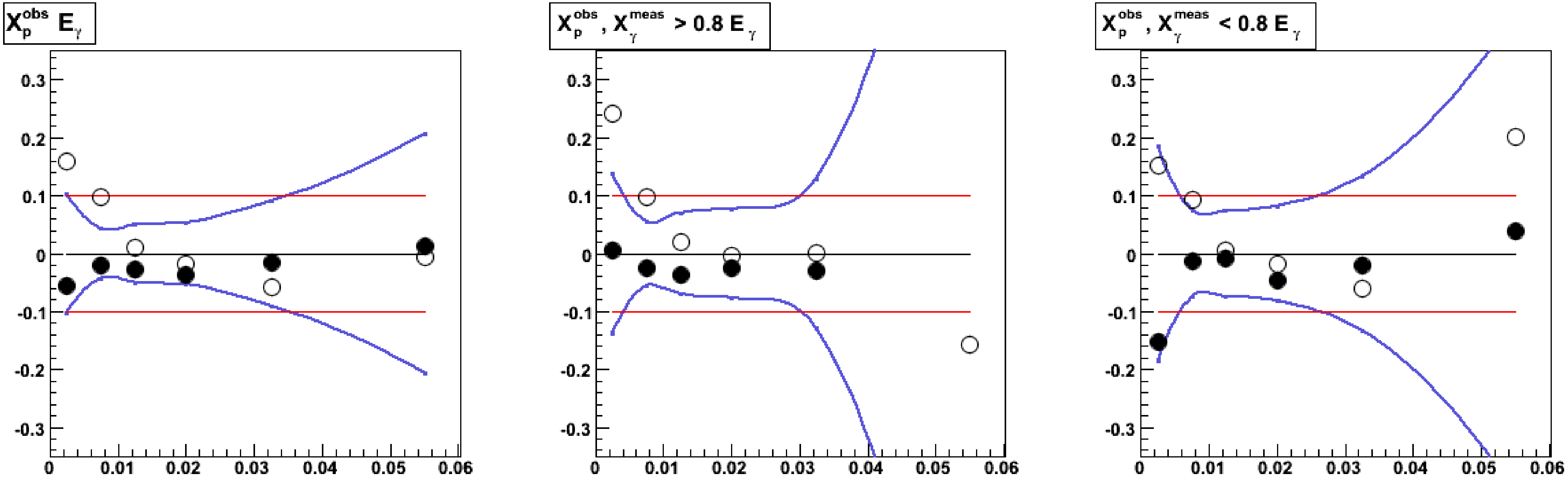
$\eta^{\gamma} - \eta^{jet}$ δZ



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.8$ δZ



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ δZ



Systematic uncertainties: E^γ variation

Standard cuts:

•$6<E_T^{zufo}<15$ GeV

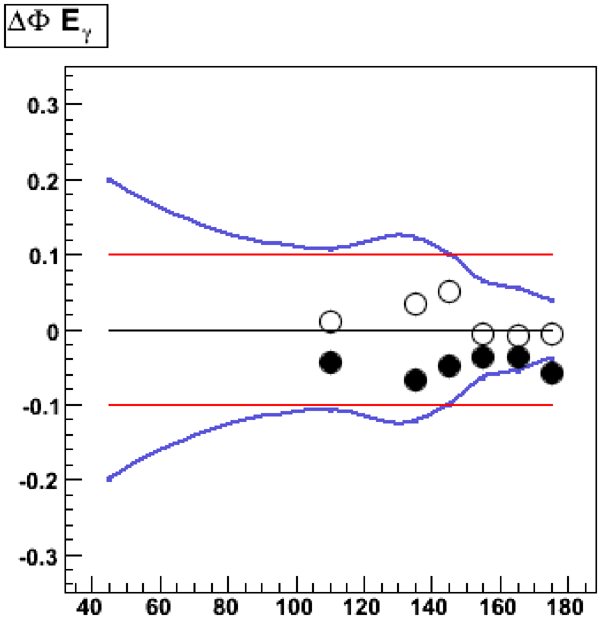
Vary E^γ by +- 2%

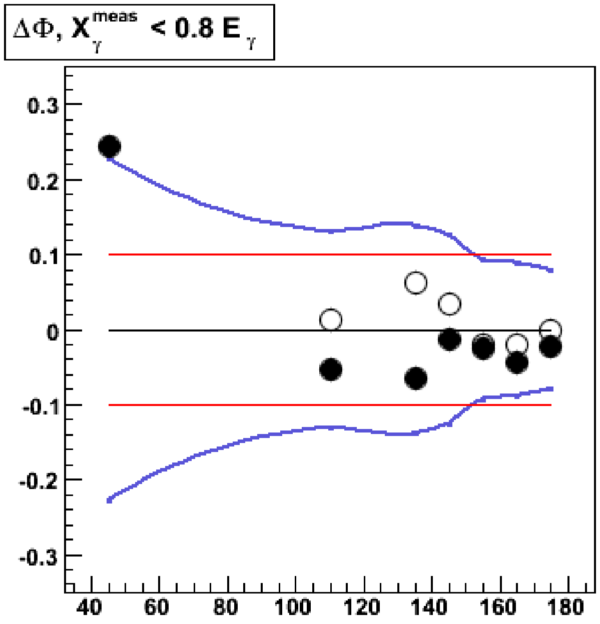
Rel.statistical uncertainties

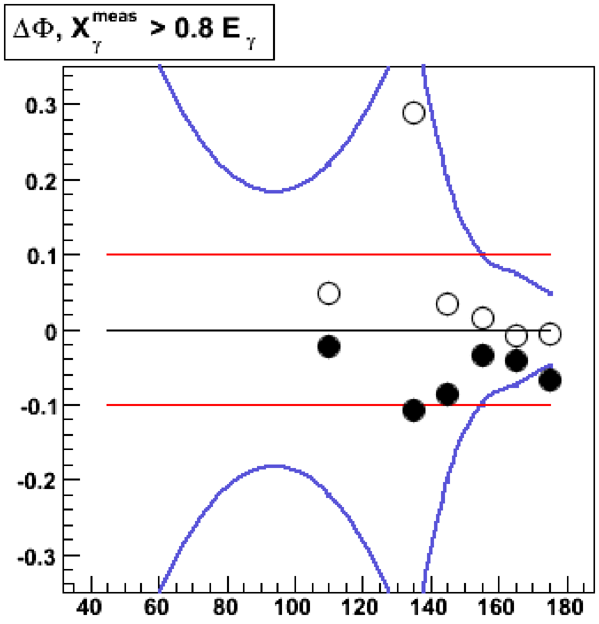
10% line

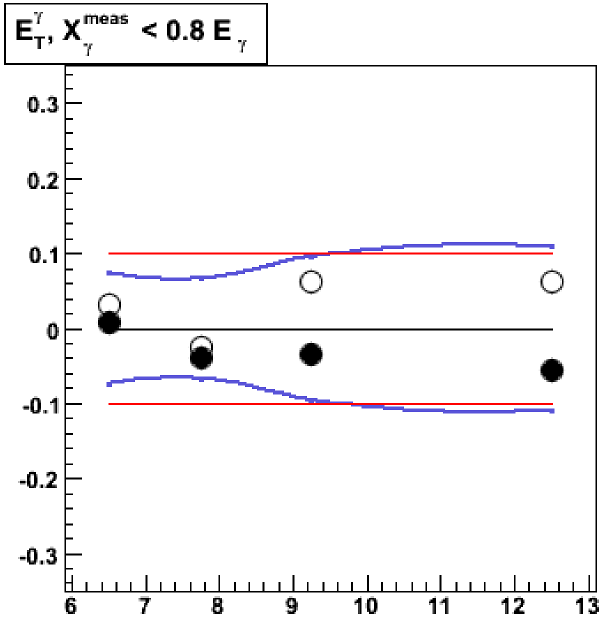
○ *E_γ +2%*

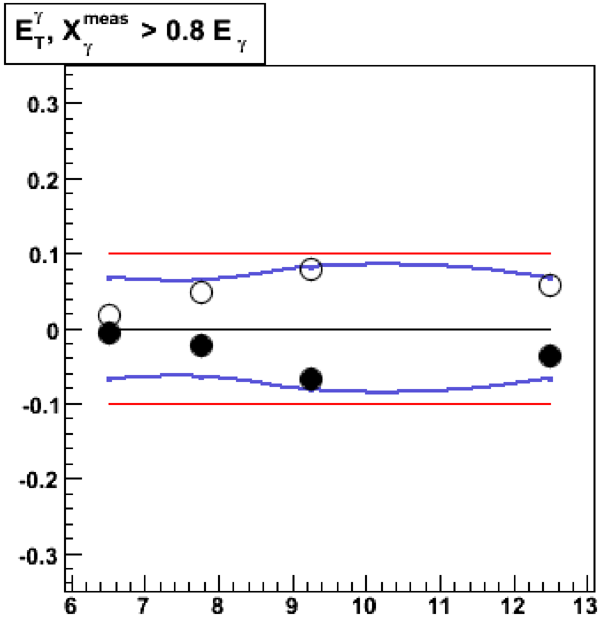
● *E_γ -2%*

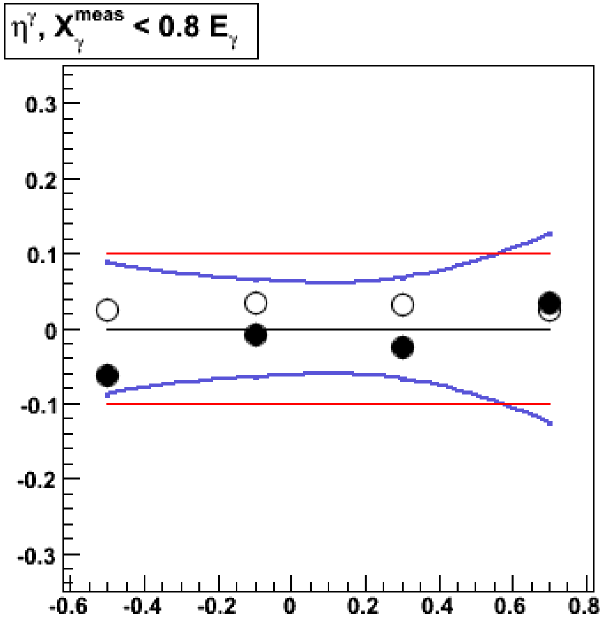

$\Delta\Phi\ E_{\gamma}$

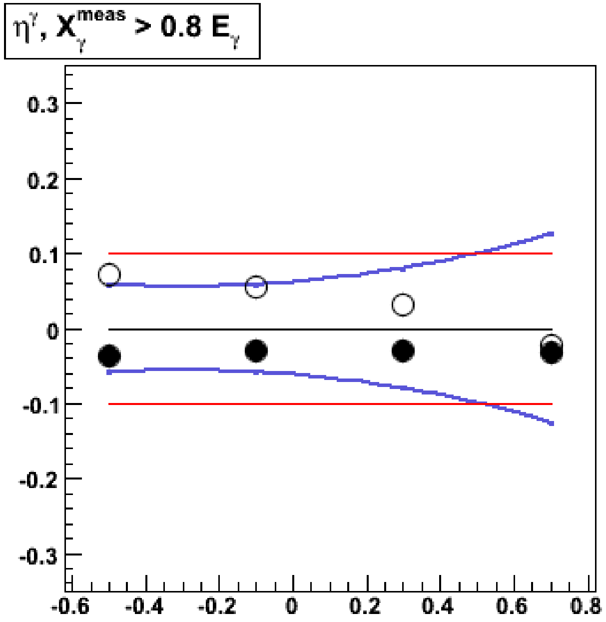

$\Delta\Phi,\ X_{\gamma}^{meas} < 0.8\ E_{\gamma}$

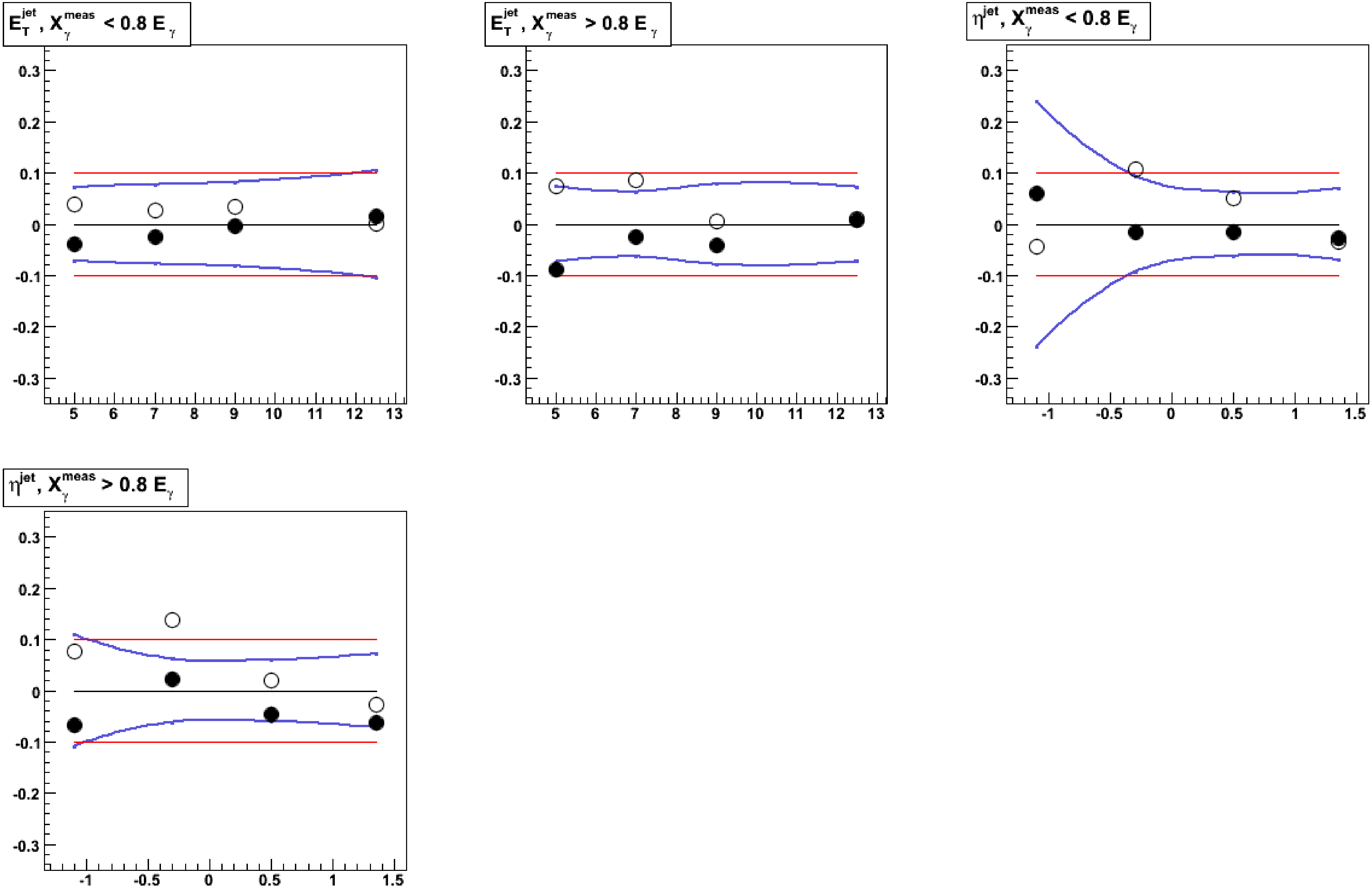

$\Delta\Phi,\ X_{\gamma}^{meas} > 0.8\ E_{\gamma}$

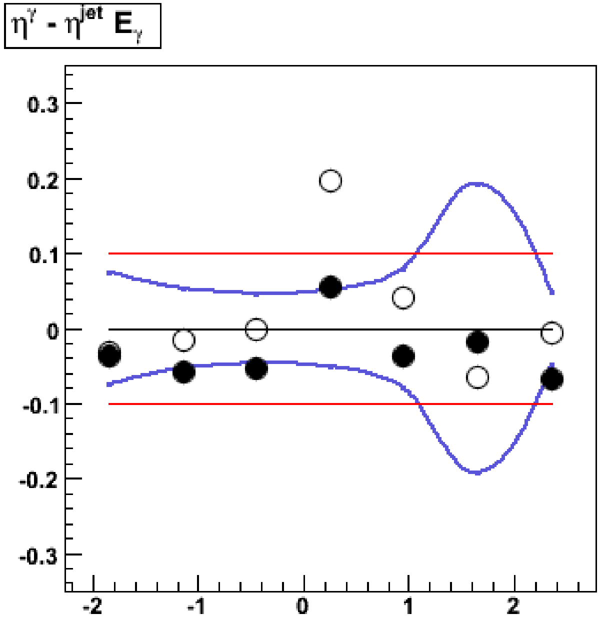

E_T^γ, X_γ^{meas} < 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

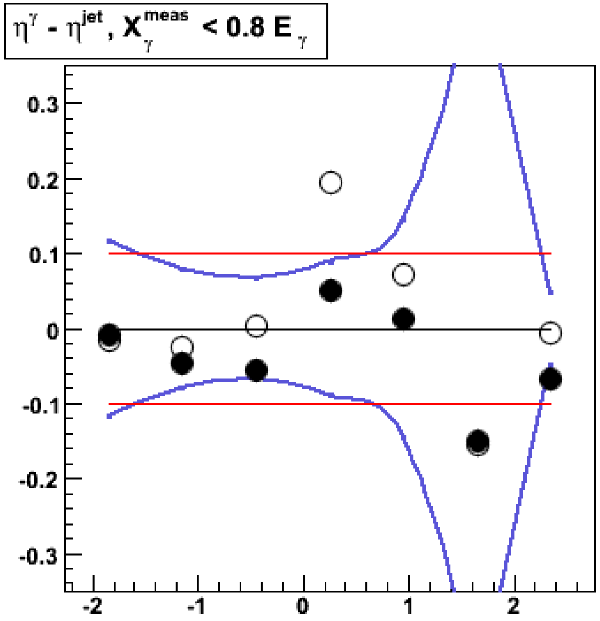

E_T^γ, X_γ^{meas} > 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

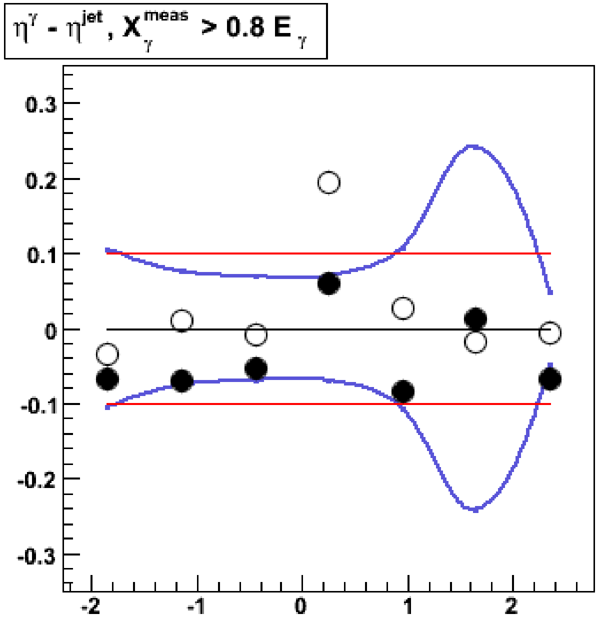

η^γ, X_γ^{meas} < 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

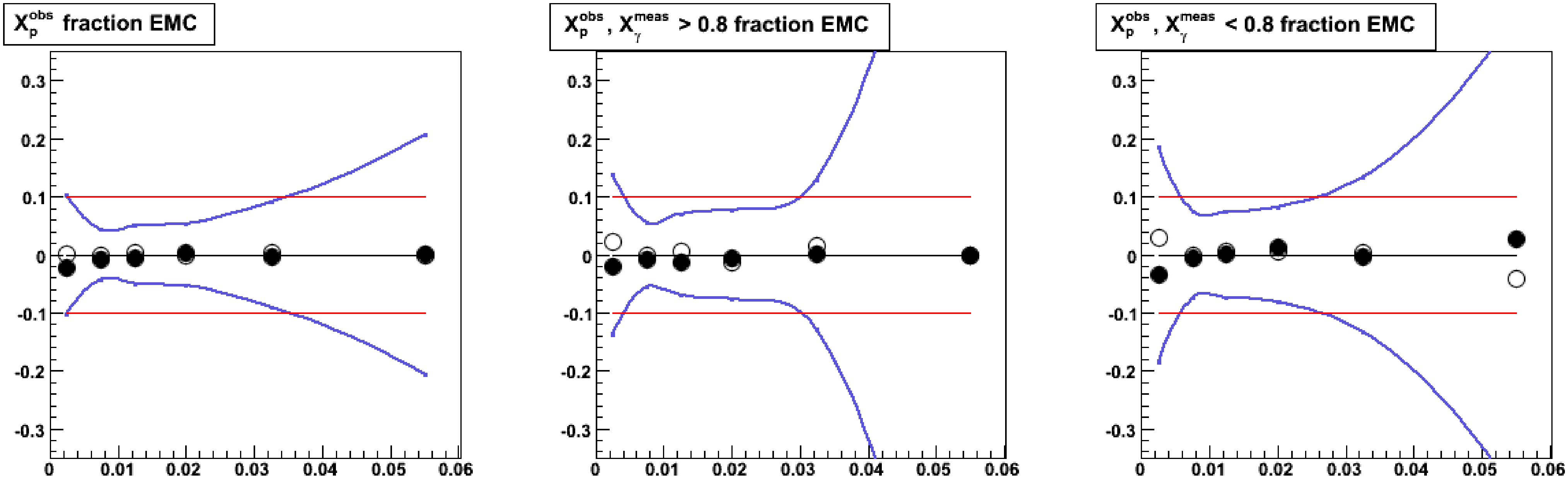

η^γ, X_γ^{meas} > 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet}, X_γ^{meas} < 0.8 E_γ
E_T^{jet}, X_γ^{meas} > 0.8 E_γ
η^{jet}, X_γ^{meas} < 0.8 E_γ
η^{jet}, X_γ^{meas} > 0.8 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13
-1
-0.5
0
0.5
1
1.5


η^{γ} - η^{jet} E_{γ}
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} < 0.8 E_{γ}
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} > 0.8 E_{γ}
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



Systematic uncertainties: Fraction EMC

Standard cut:

- ZufoEemc/ZufoEcal>0.9

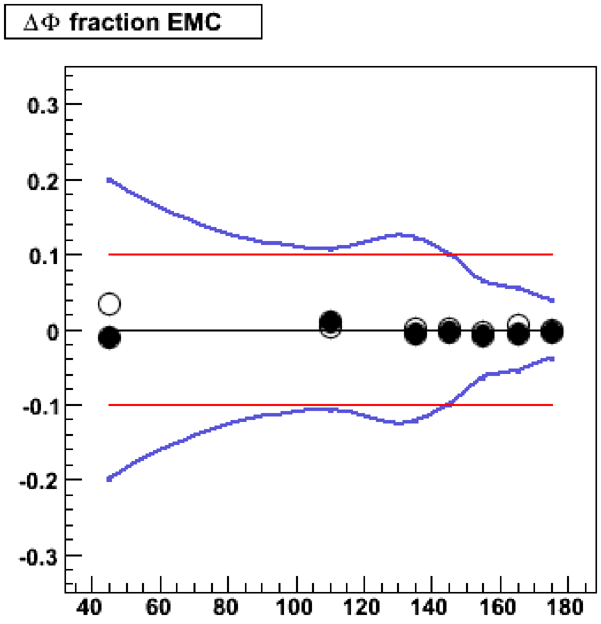
Vary the em fraction in the photon zufo by +-2.5%

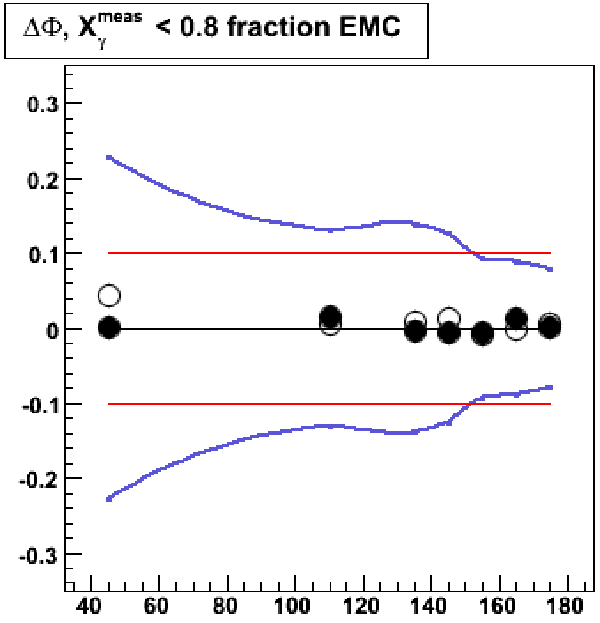
Rel.statistical uncertainties

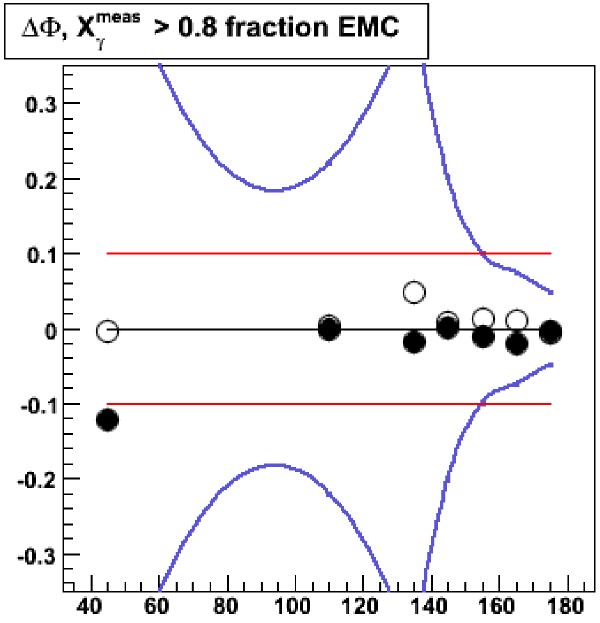
10% line

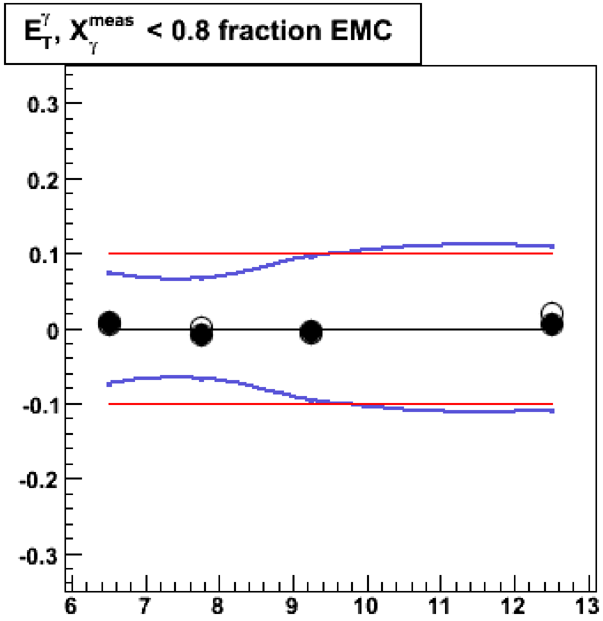
○ *Fraction EMC +0.025*

● *Fraction EMC -0.025*

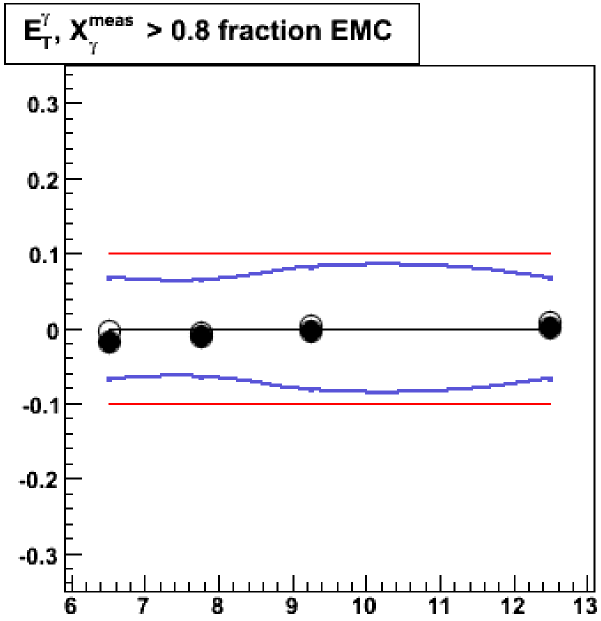

ΔΦ fraction EMC


ΔΦ, X_γ^{meas} < 0.8 fraction EMC

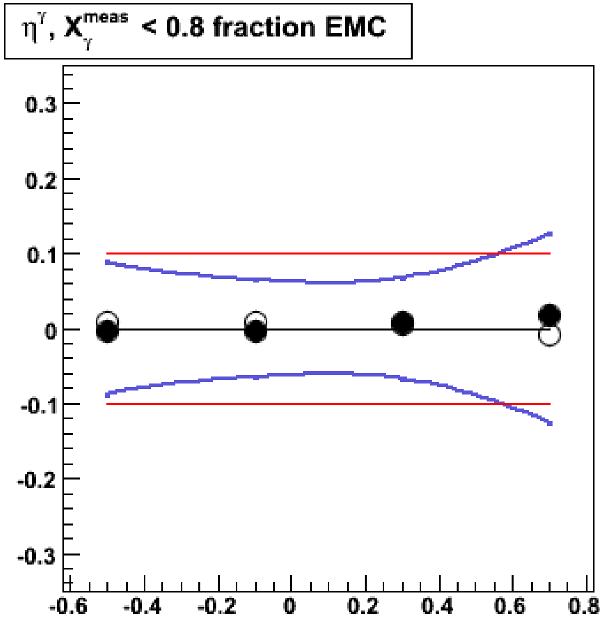

ΔΦ, X_γ^{meas} > 0.8 fraction EMC



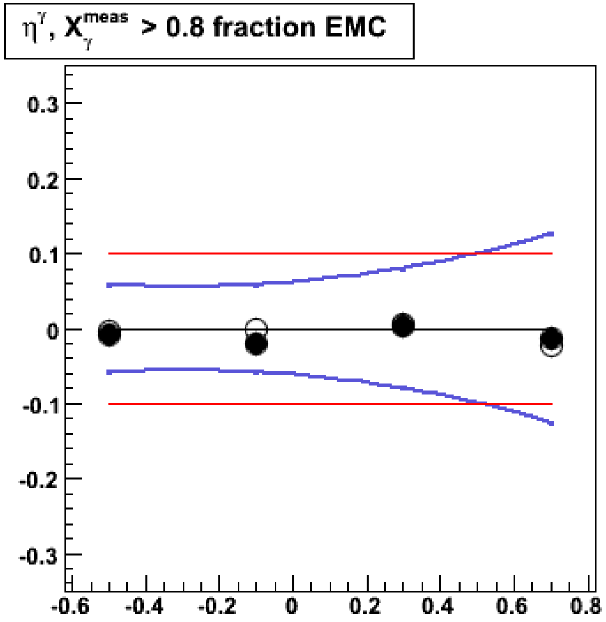
E_T^{γ}, X_{γ}^{meas} < 0.8 fraction EMC



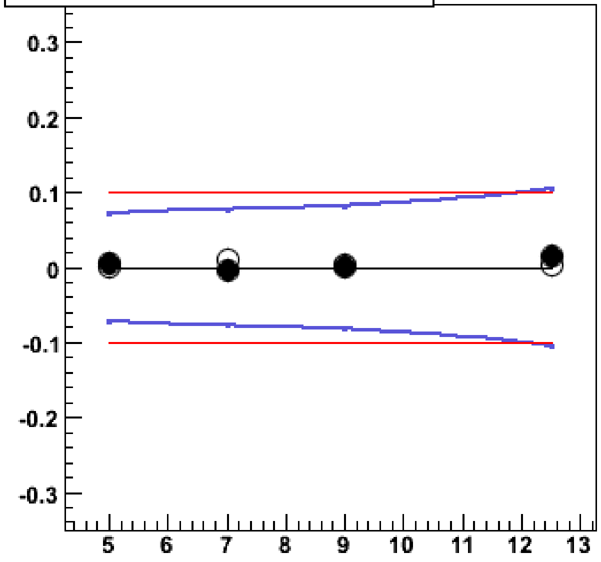
E_T^{γ}, X_{γ}^{meas} > 0.8 fraction EMC

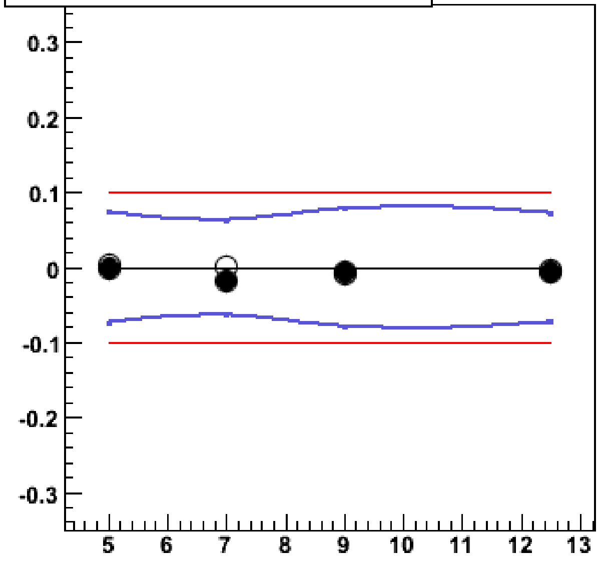


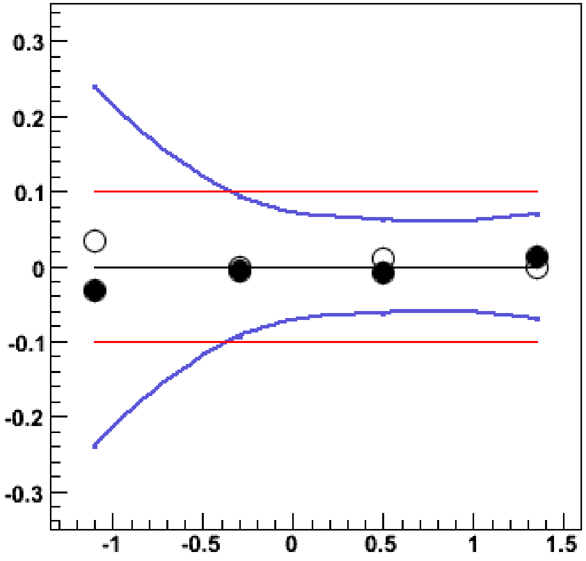
η^{γ}, X_{γ}^{meas} < 0.8 fraction EMC

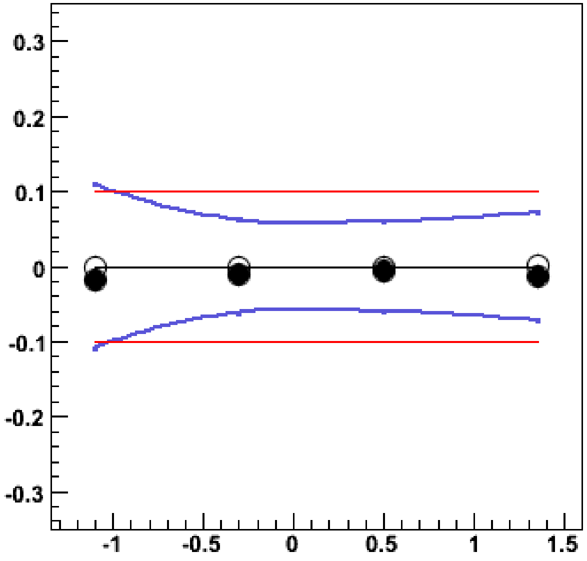


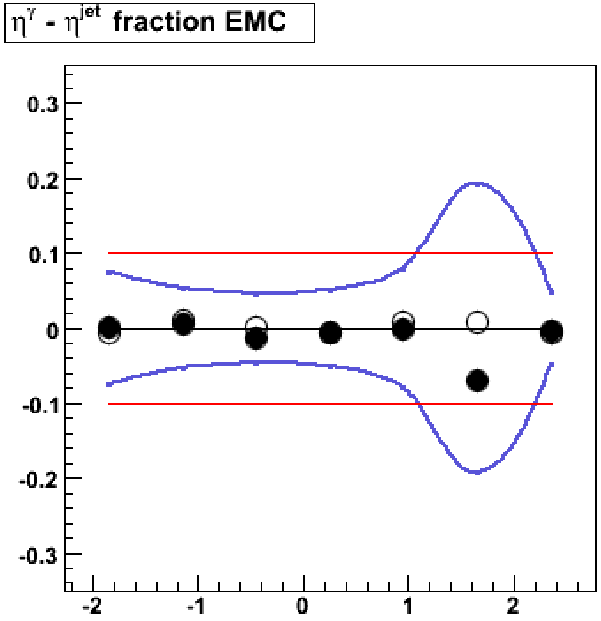
η^{γ}, X_{γ}^{meas} > 0.8 fraction EMC

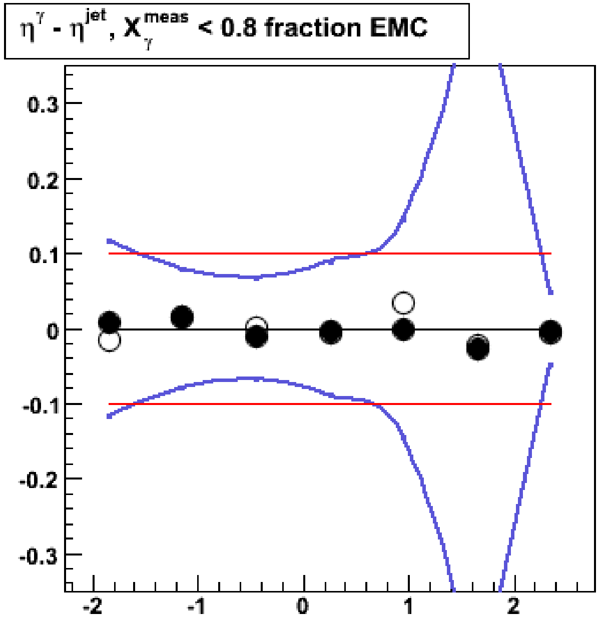

E_T^{jet}, X_γ^{meas} < 0.8 fraction EMC

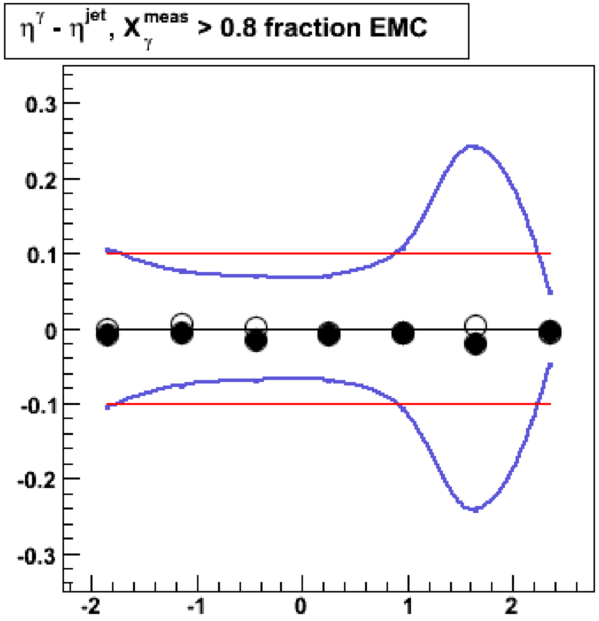

E_T^{jet}, X_γ^{meas} > 0.8 fraction EMC

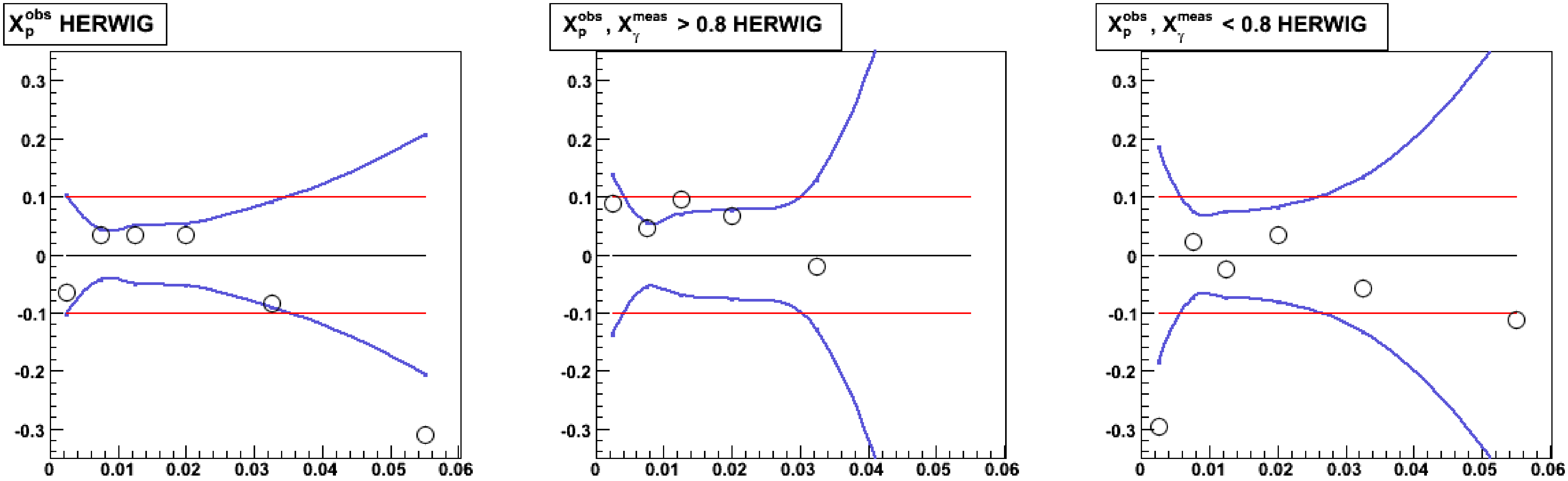

η^{jet}, X_γ^{meas} < 0.8 fraction EMC


η^{jet}, X_γ^{meas} > 0.8 fraction EMC


$\eta^{\gamma} - \eta^{jet}$ fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.8$ fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



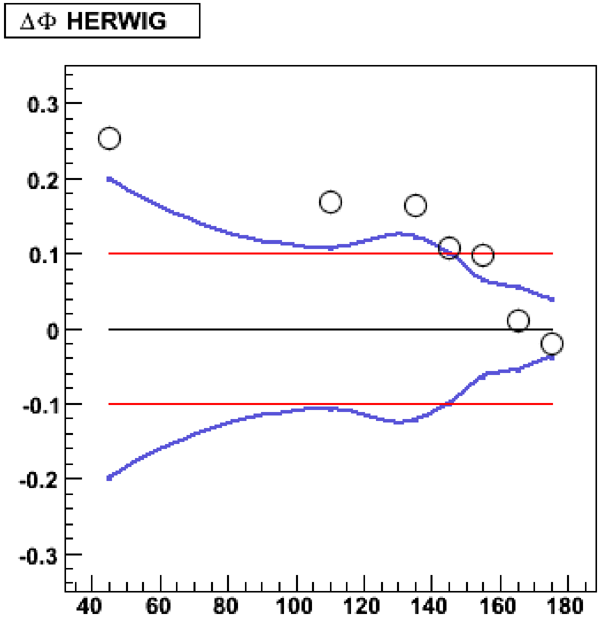
Systematic uncertainties: HERWIG

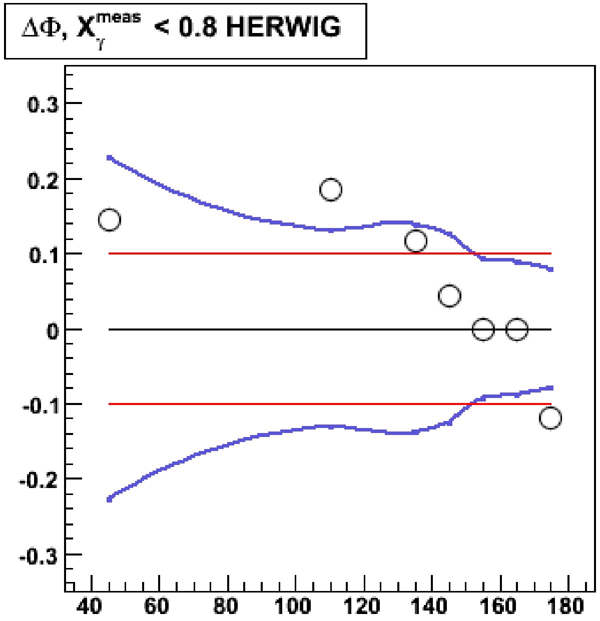
Use HERWIG signal and background instead of PYTHIA

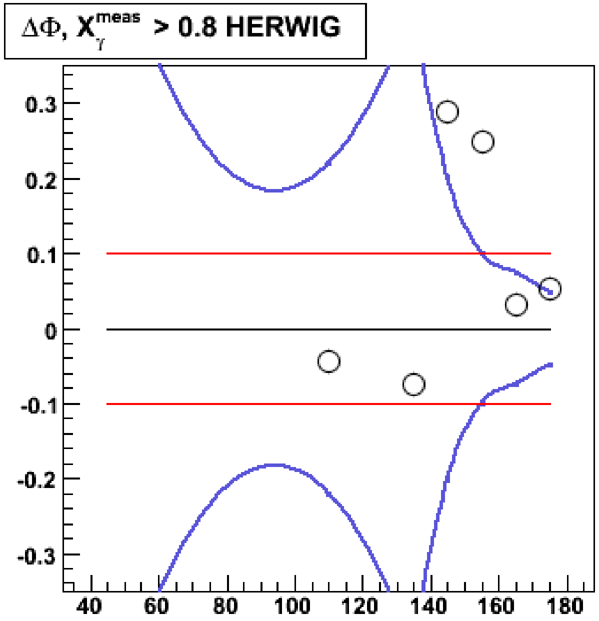
— *Rel.statistical uncertainties*

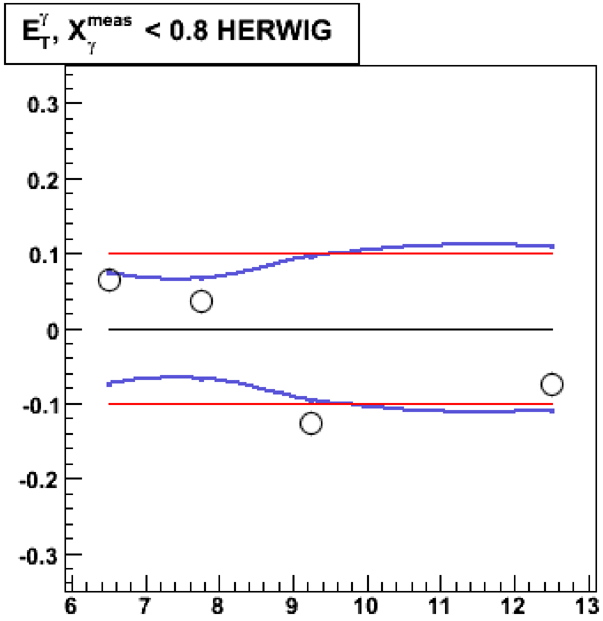
— *10% line*

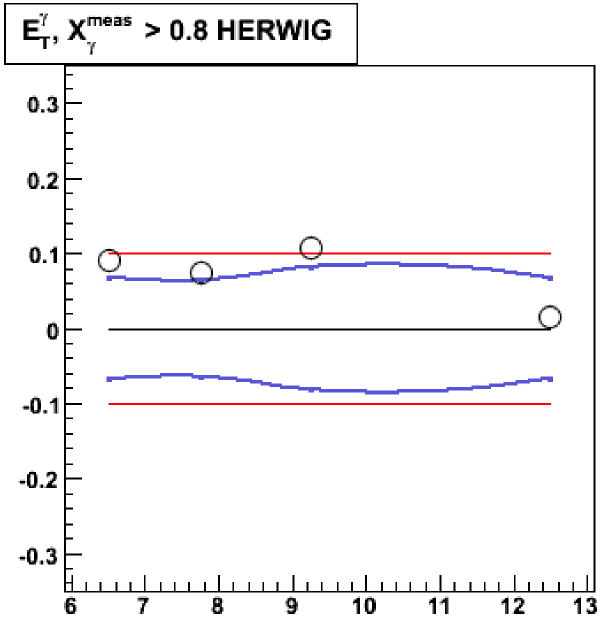
○ *HERWIG*

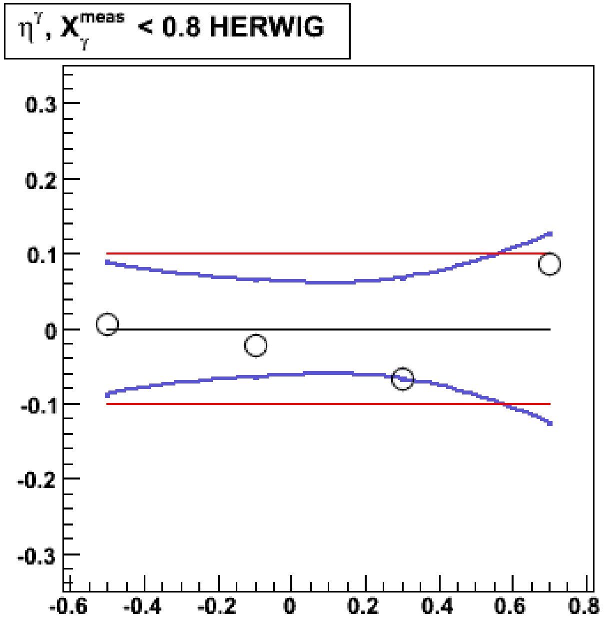

ΔΦ HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

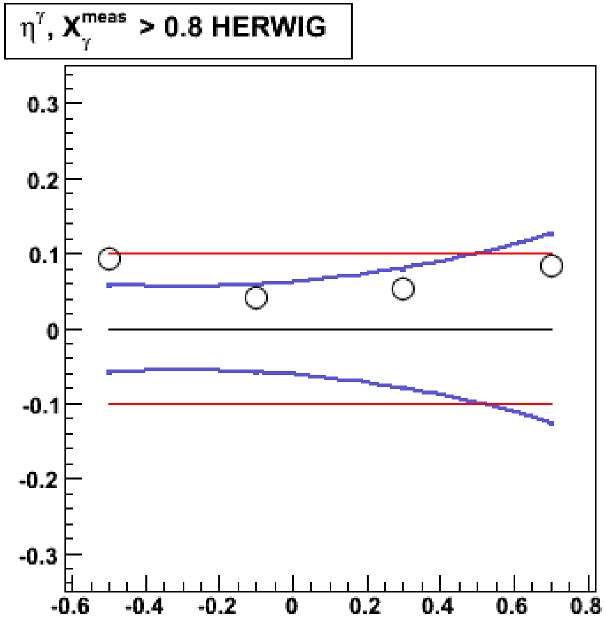

ΔΦ, X_γ^{meas} < 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

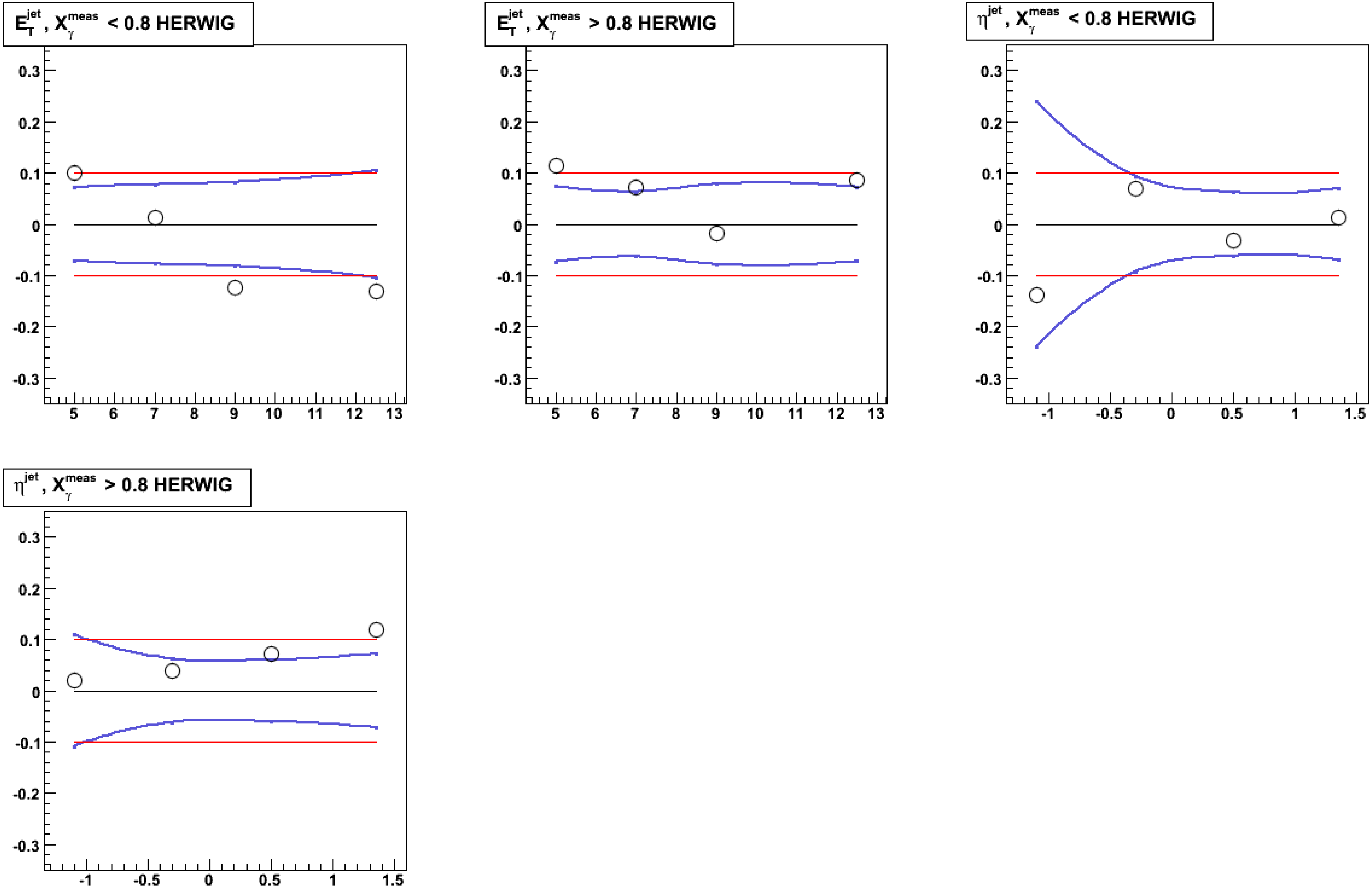

ΔΦ, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

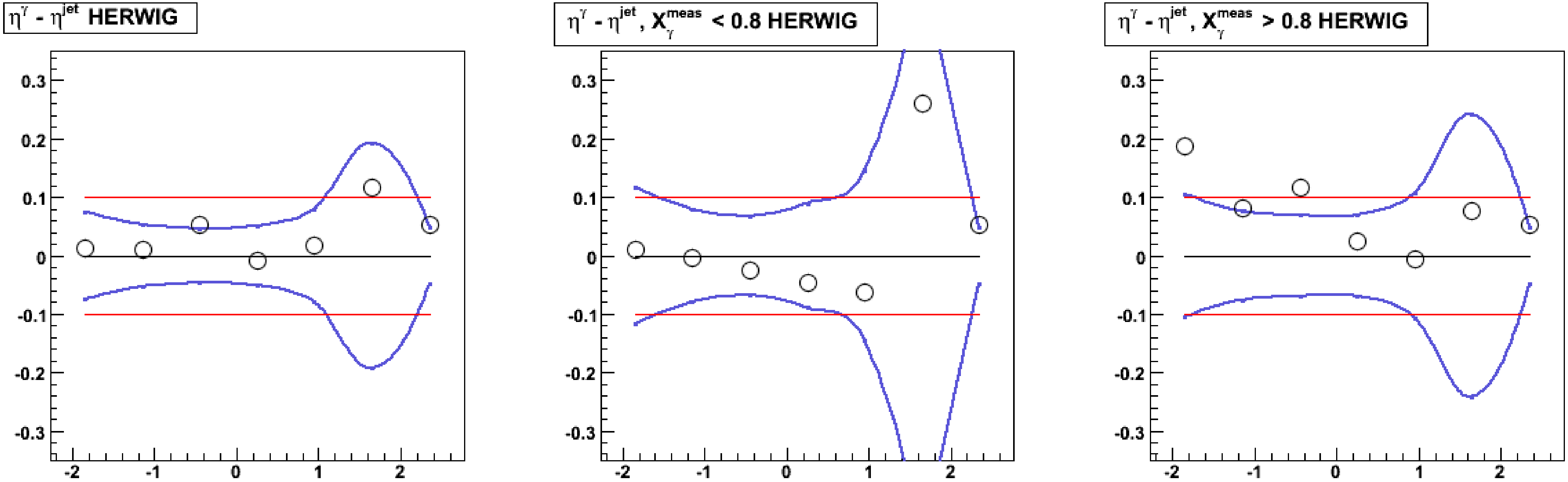

E_T^γ, X_γ^{meas} < 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

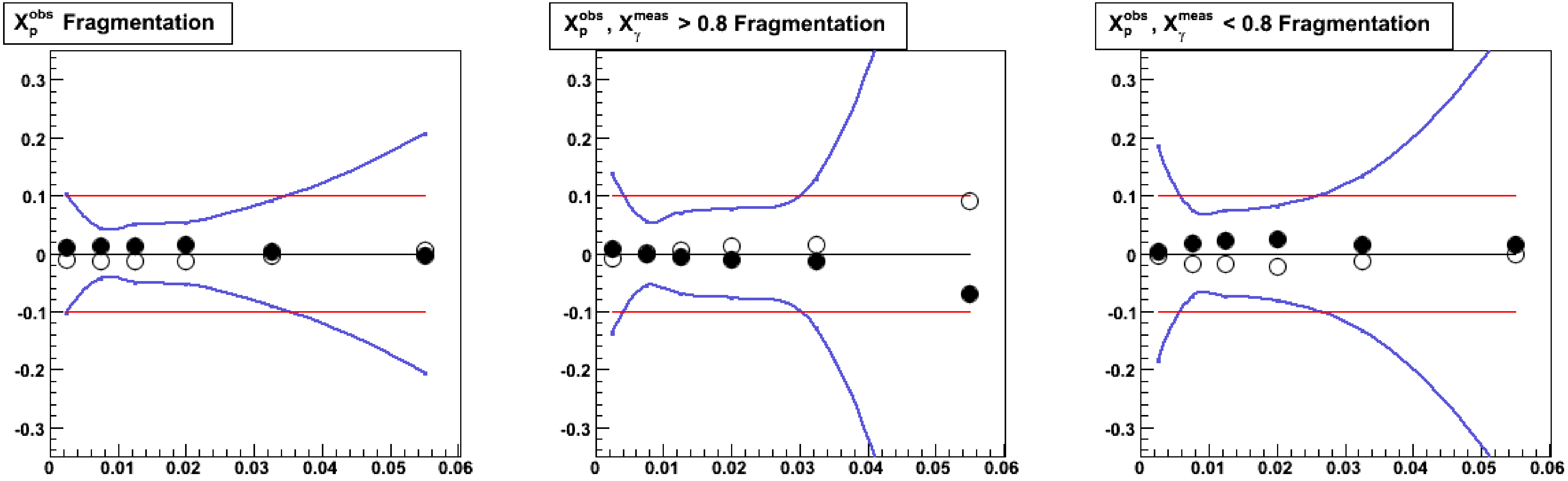

E_T^γ, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


η^γ, X_γ^{meas} < 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


η^γ, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet}, X_γ^{meas} < 0.8 HERWIG
E_T^{jet}, X_γ^{meas} > 0.8 HERWIG
η^{jet}, X_γ^{meas} < 0.8 HERWIG
η^{jet}, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
6
7
8
9
10
11
12
13
-1
-0.5
0
0.5
1
1.5


$\eta^{\gamma} - \eta^{jet}$ HERWIG
$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.8 HERWIG
$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2



Systematic uncertainties: PYTHIA fragmentation

Standard value: 5% direct and 5% resolved fragmentation

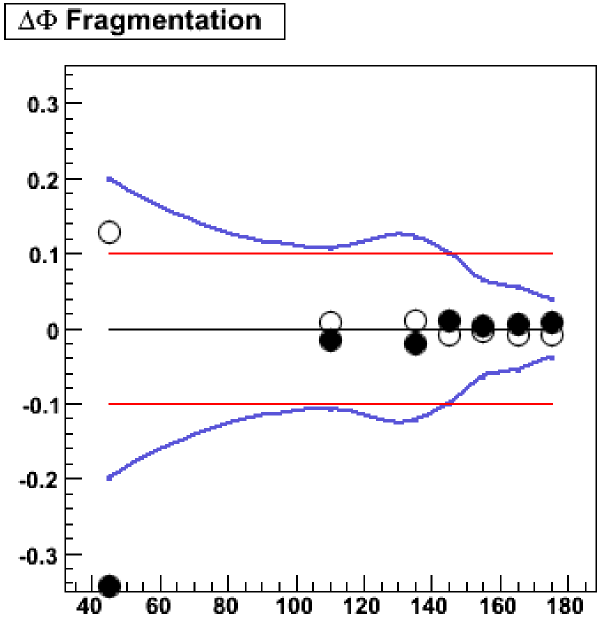
— *Rel.statistical uncertainties*

— *10% line*

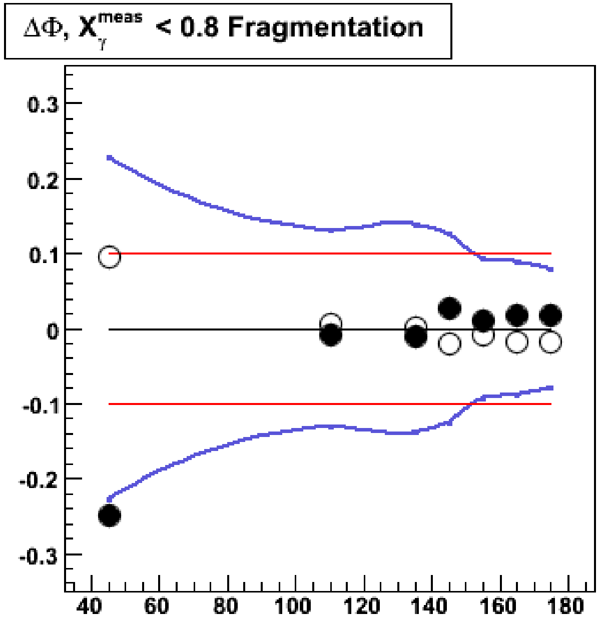
○ *+5% Fragmentation*

● *-5% Fragmentation*

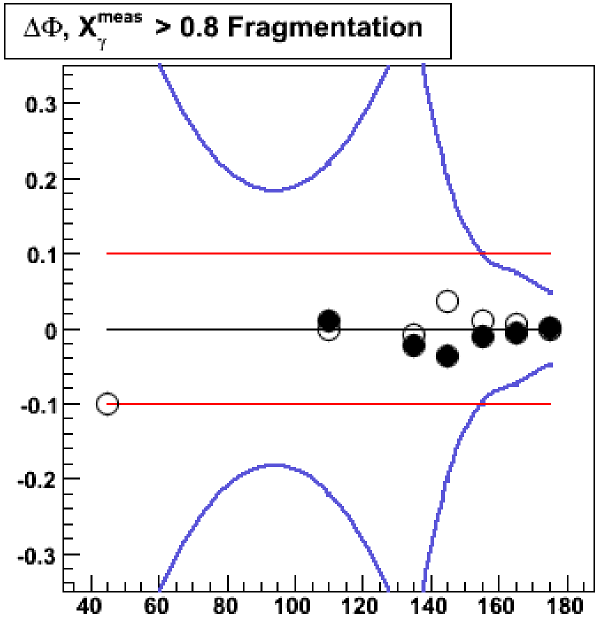
Vary fraction of fragmentation direct
and resolved
simultaneously by +-5%



ΔΦ Fragmentation

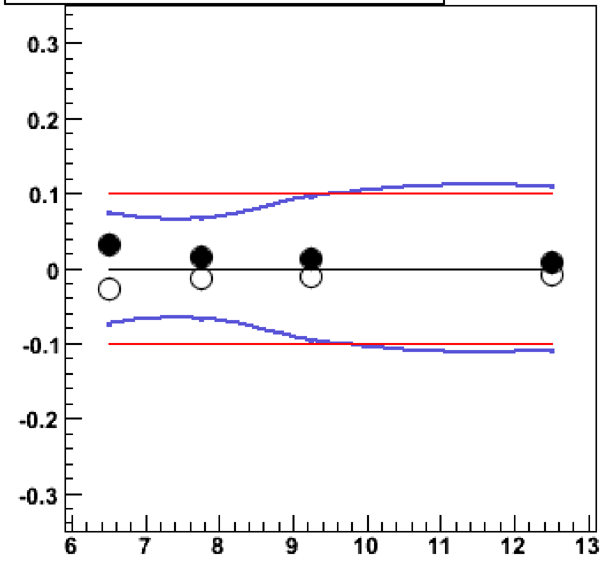


ΔΦ, X_{γ}^{meas} < 0.8 Fragmentation

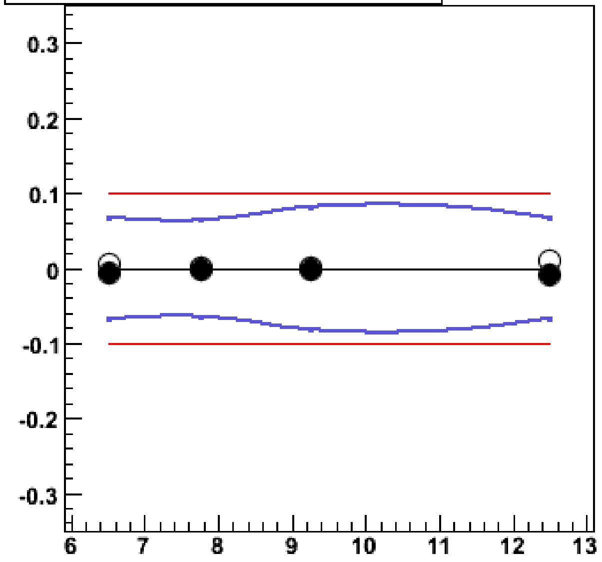


ΔΦ, X_{γ}^{meas} > 0.8 Fragmentation

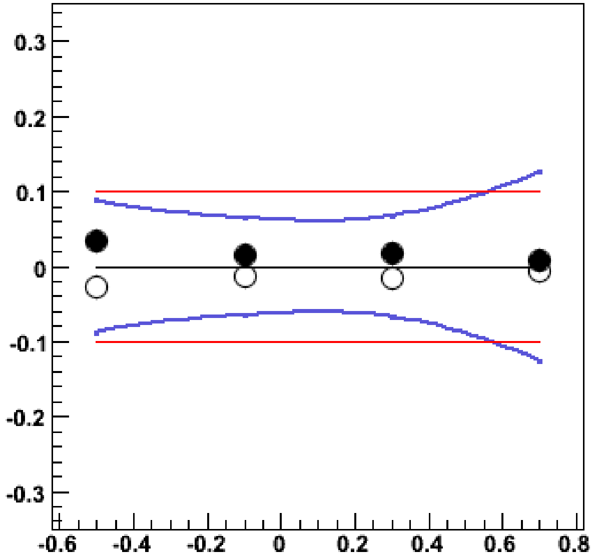
E_T^γ, X_γ^{meas} < 0.8 Fragmentation



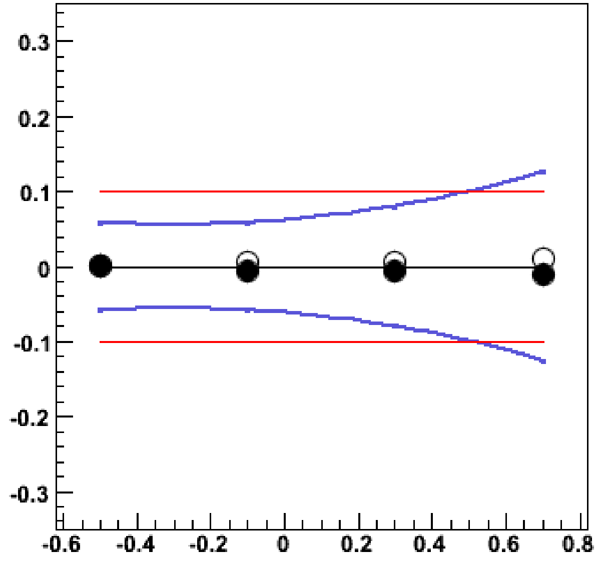
E_T^γ, X_γ^{meas} > 0.8 Fragmentation

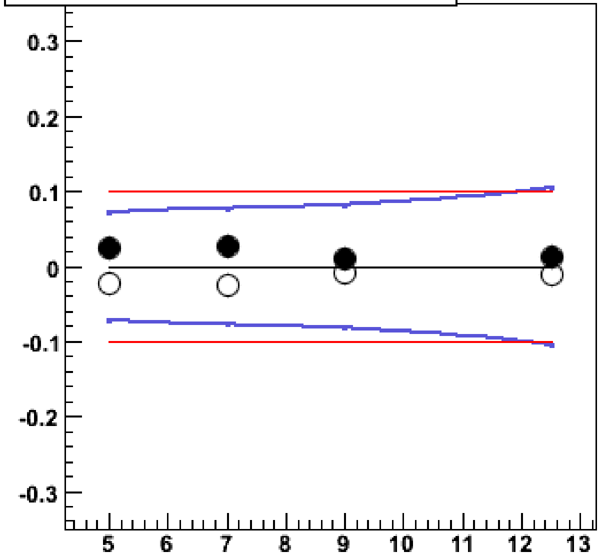


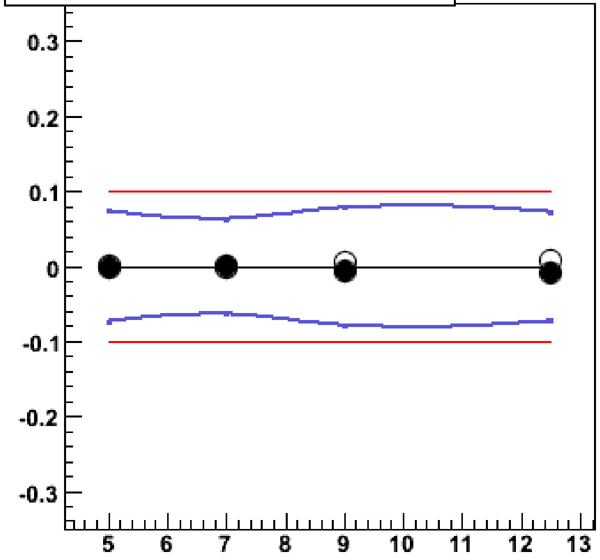
η^γ, X_γ^{meas} < 0.8 Fragmentation

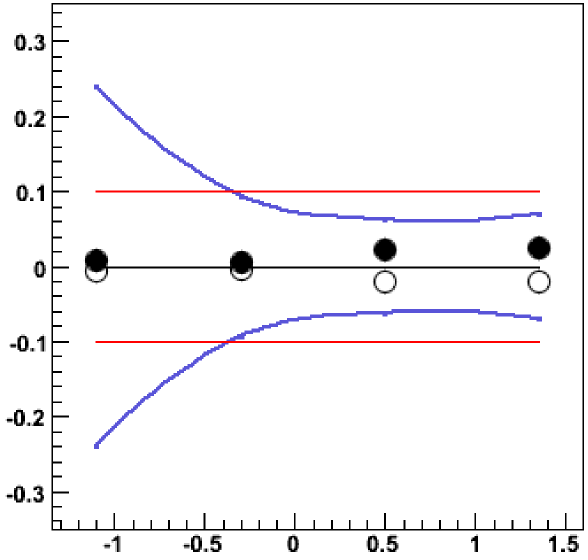


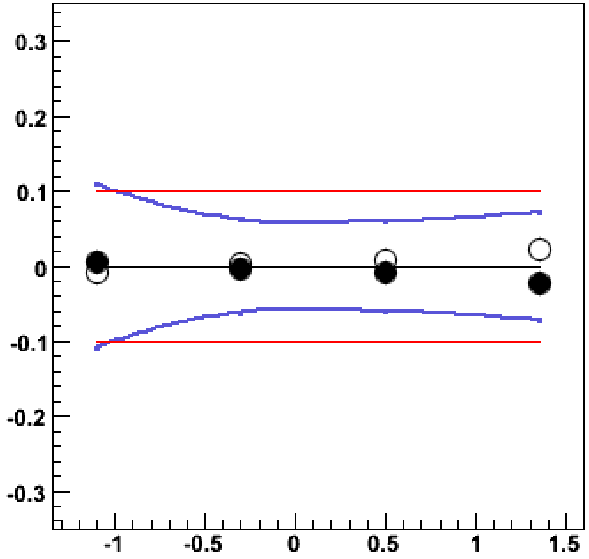
η^γ, X_γ^{meas} > 0.8 Fragmentation

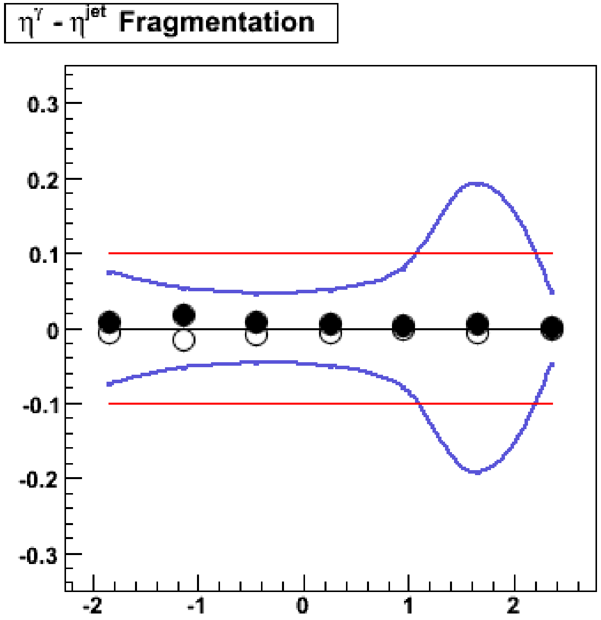



E_T^{jet}, X_γ^{meas} < 0.8 Fragmentation

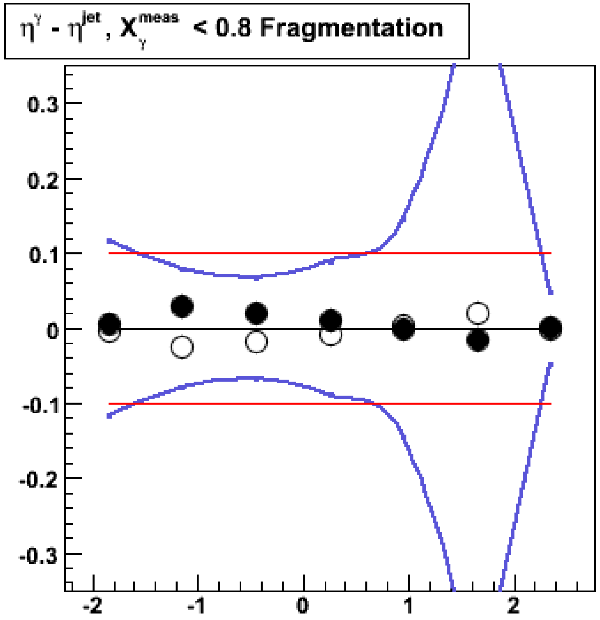

E_T^{jet}, X_γ^{meas} > 0.8 Fragmentation


η^{jet}, X_γ^{meas} < 0.8 Fragmentation

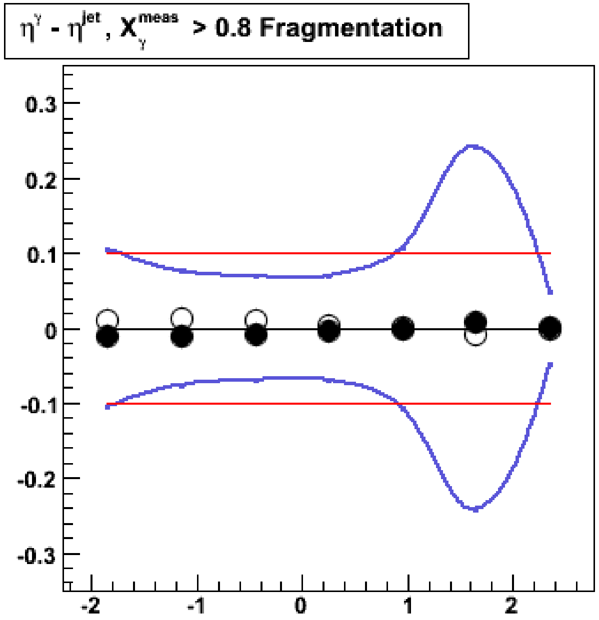

η^{jet}, X_γ^{meas} > 0.8 Fragmentation



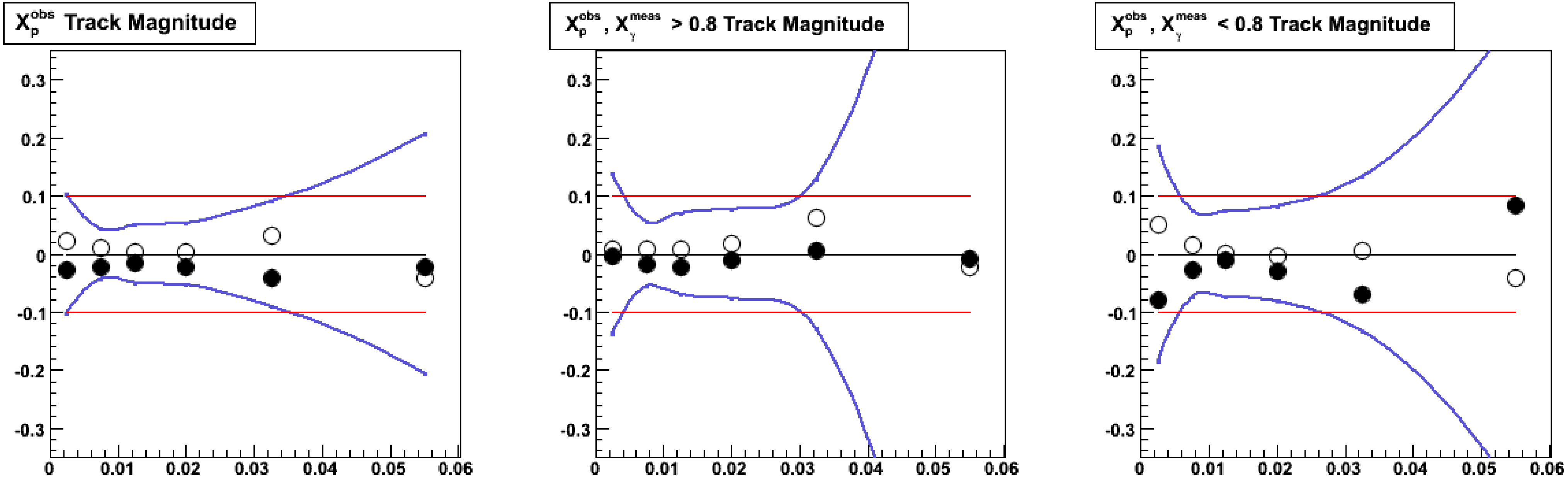
$\eta^{\gamma} - \eta^{jet}$ Fragmentation



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} < 0.8$ Fragmentation



$\eta^{\gamma} - \eta^{jet}$, $X_{\gamma}^{meas} > 0.8$ Fragmentation



Systematic uncertainties: Track momentum

Standard cut:

- Track momentum>250 MeV

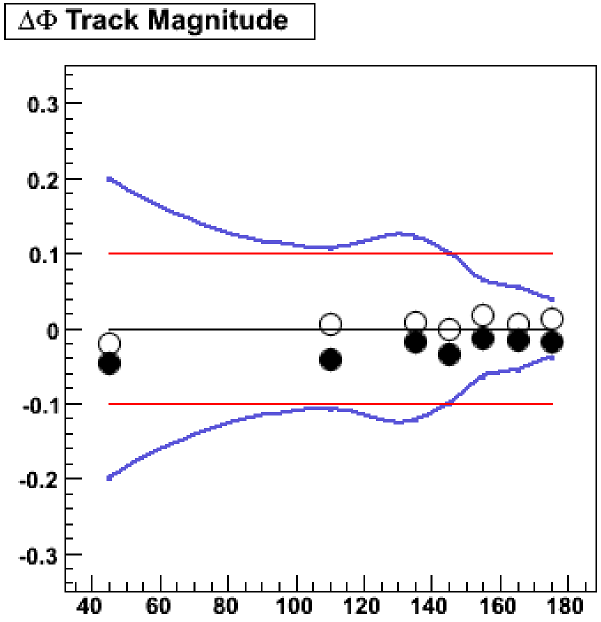
Vary track momentum by 100 MeV

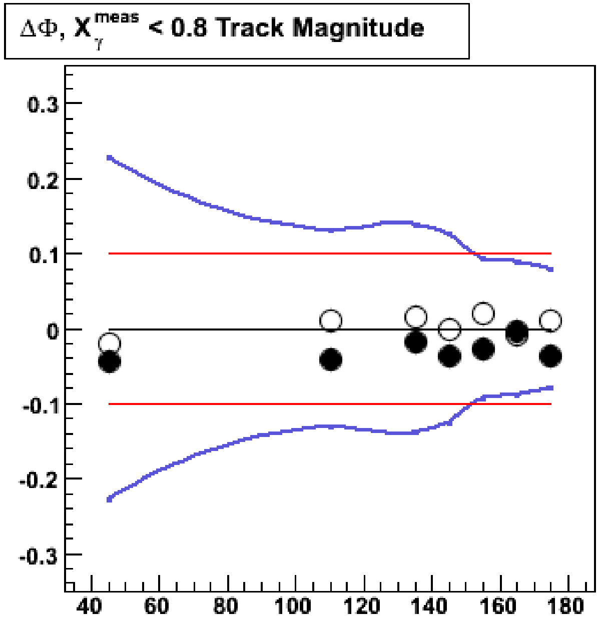
— *Rel.statistical uncertainties*

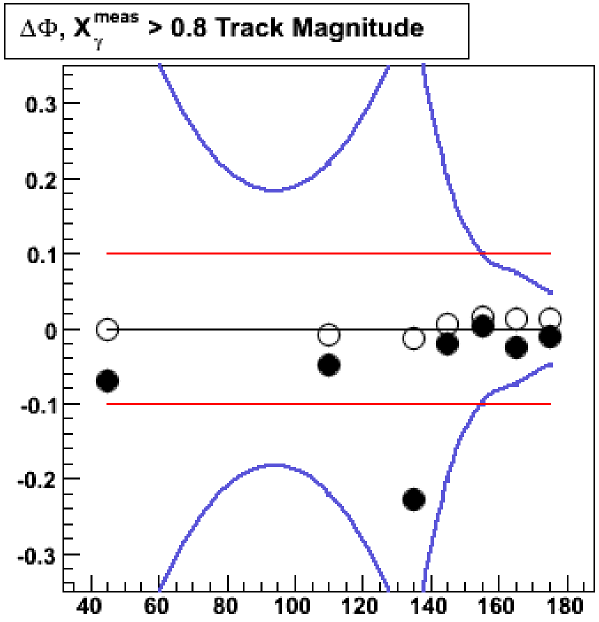
— *10% line*

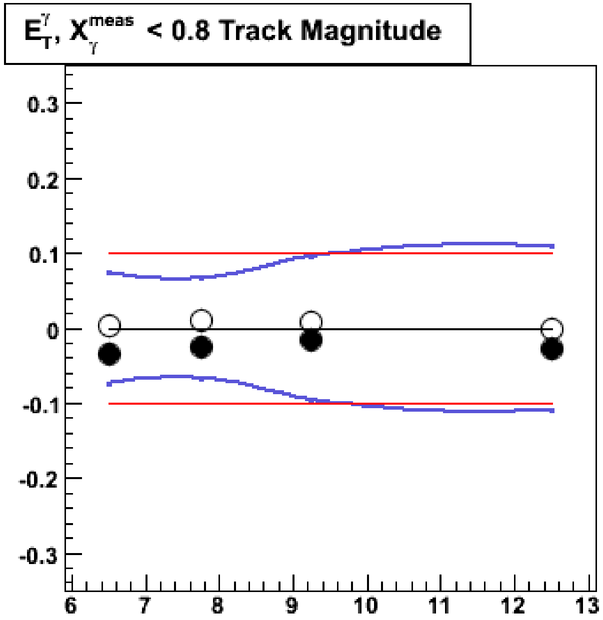
○ $p_{track} > 350$ *MeV*

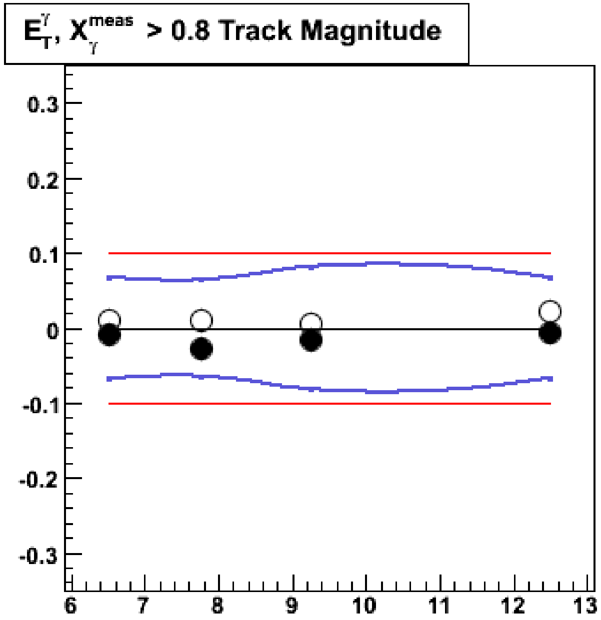
● $p_{track} > 150$ *MeV*

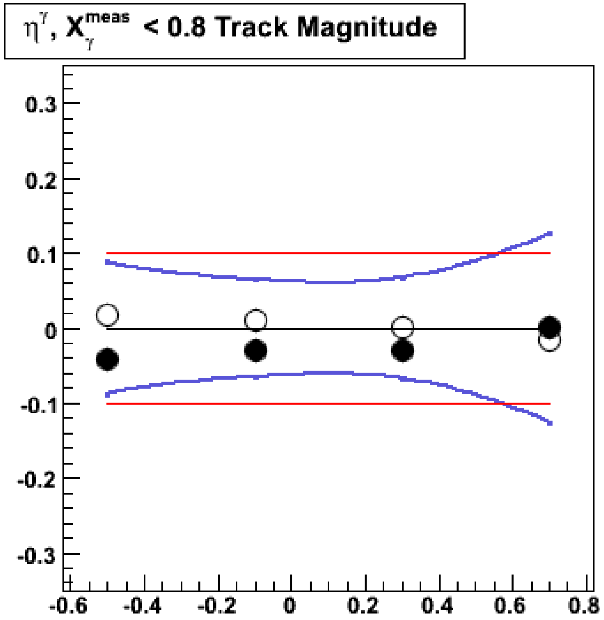

ΔΦ Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

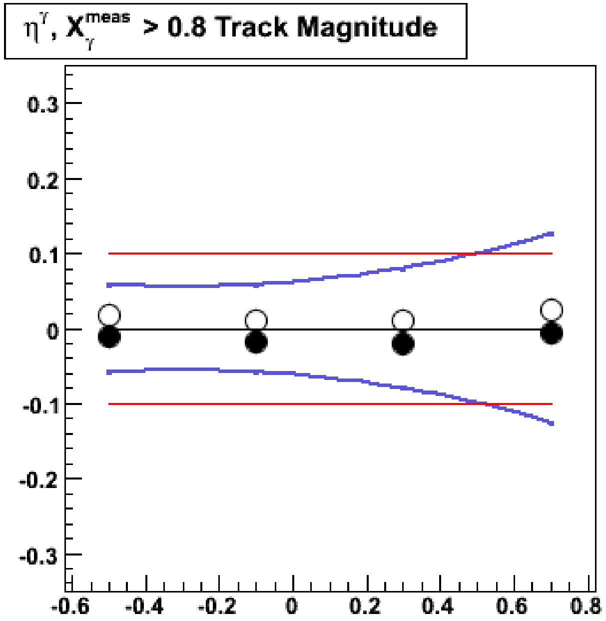

ΔΦ, X_γ^{meas} < 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

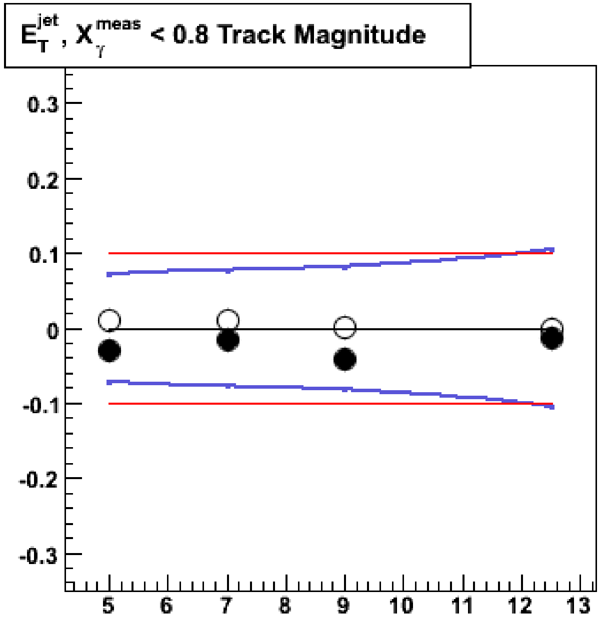

ΔΦ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

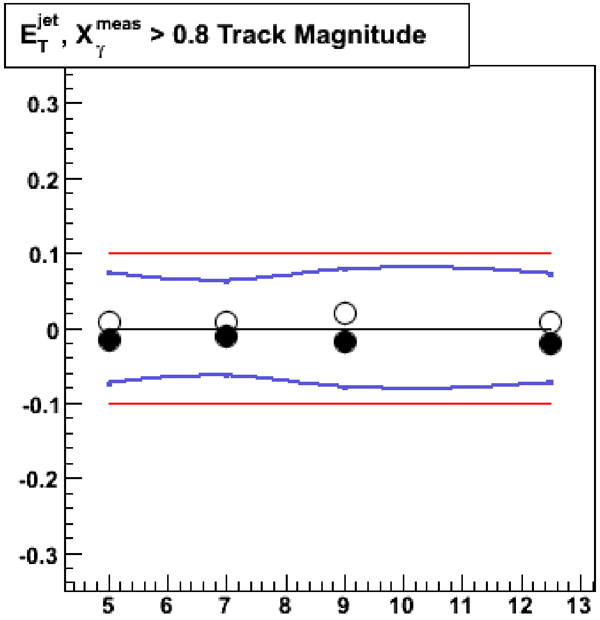

E_T^γ, X_γ^{meas} < 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

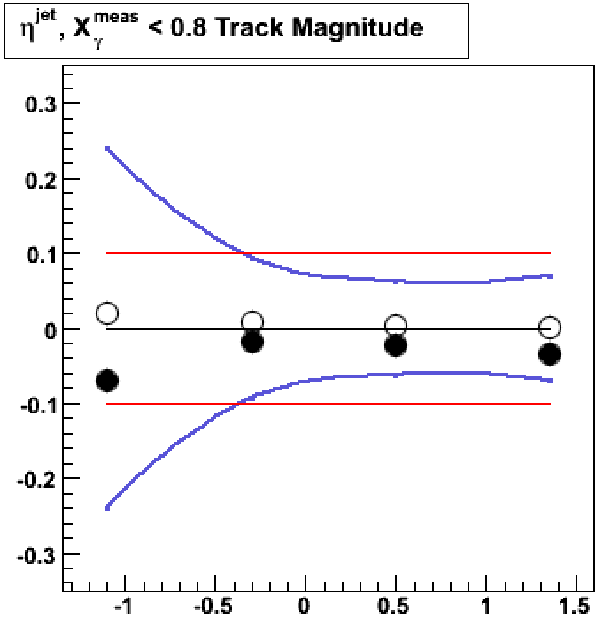

E_T^γ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

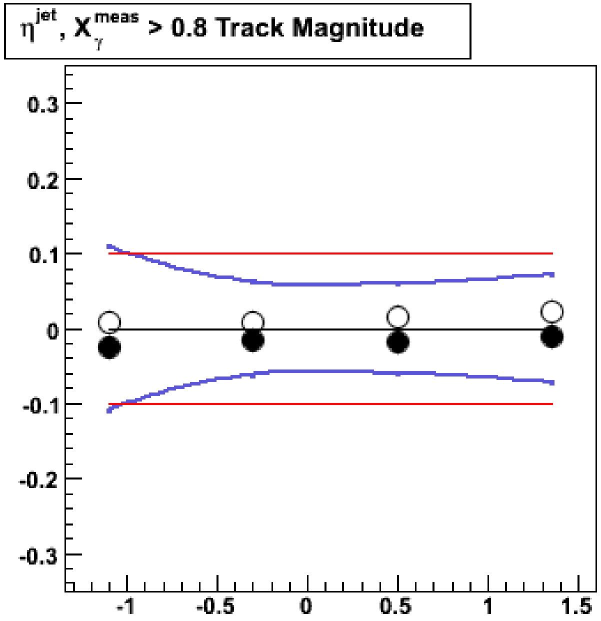

η^γ, X_γ^{meas} < 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

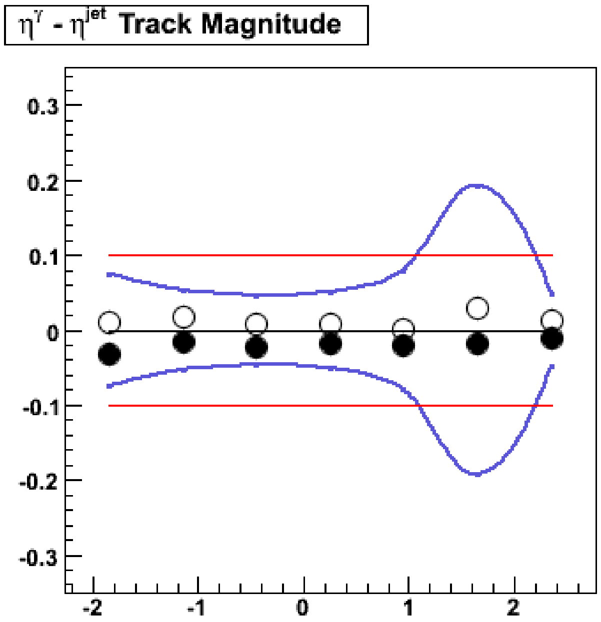

η^γ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


E_T^{jet}, X_γ^{meas} < 0.8 Track Magnitude

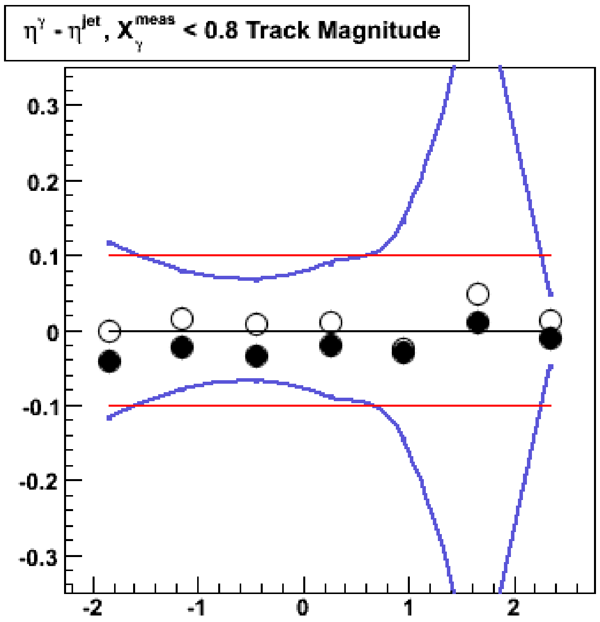

E_T^{jet}, X_γ^{meas} > 0.8 Track Magnitude


η^{jet}, X_γ^{meas} < 0.8 Track Magnitude

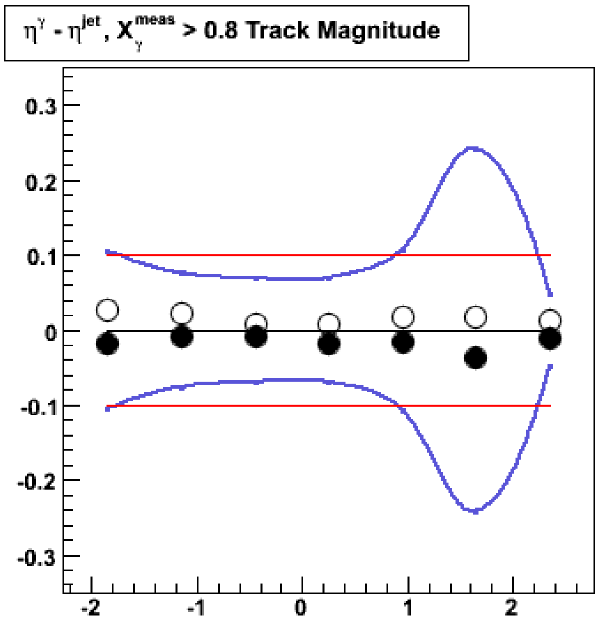

η^{jet}, X_γ^{meas} > 0.8 Track Magnitude



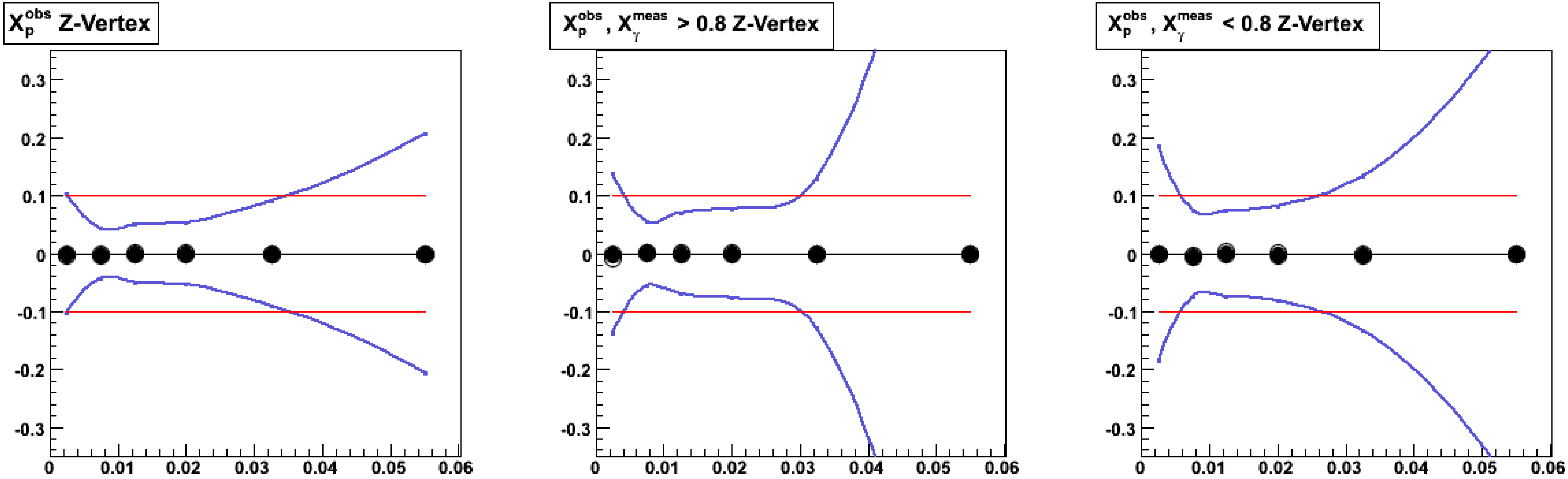
$\eta^{\gamma} - \eta^{jet}$ Track Magnitude



$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} < 0.8 Track Magnitude



$\eta^{\gamma} - \eta^{jet}$, X_{γ}^{meas} > 0.8 Track Magnitude



Systematic uncertainties: Zvtx

Standard cut:

- | Zvtx |<40 cm

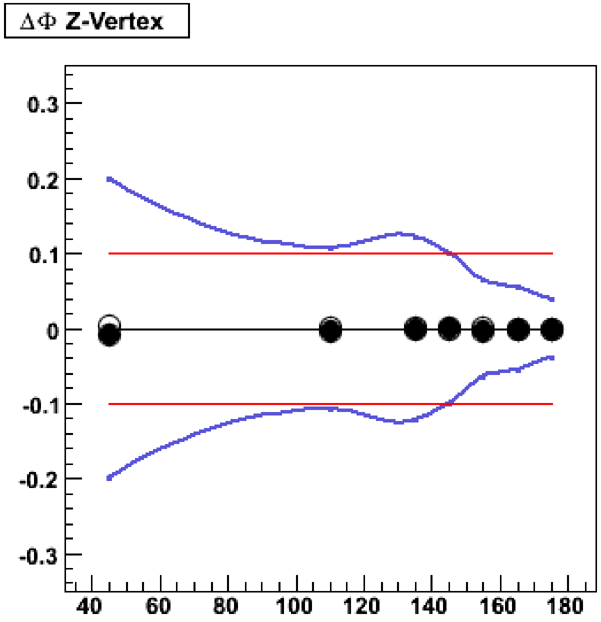
Vary z-vertex cut by +-5 cm

— *Rel.statistical uncertainties* δZ

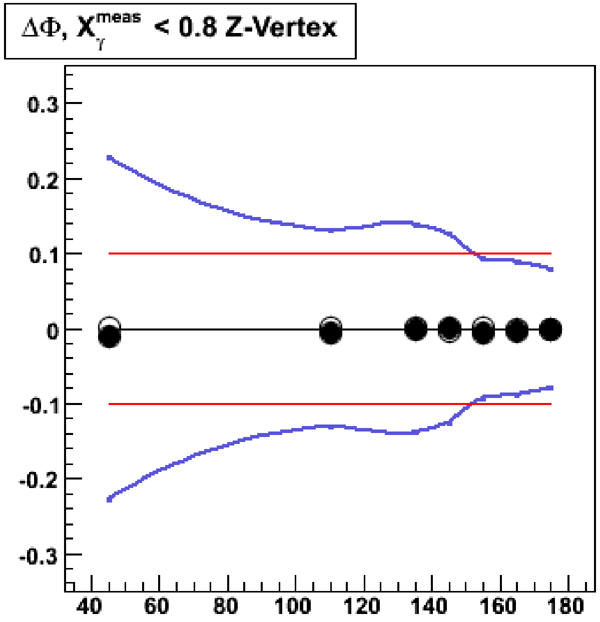
— *10% line*

○ $|Z_{vertex}|<45$

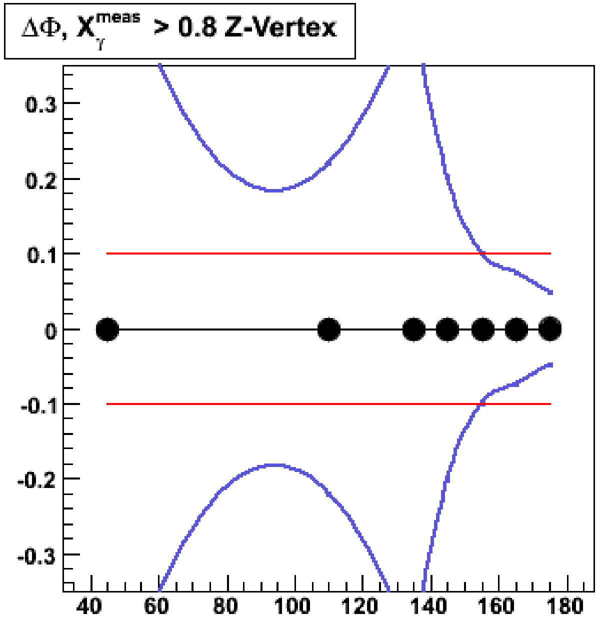
● $|Z_{vertex}|<35$



ΔΦ Z-Vertex

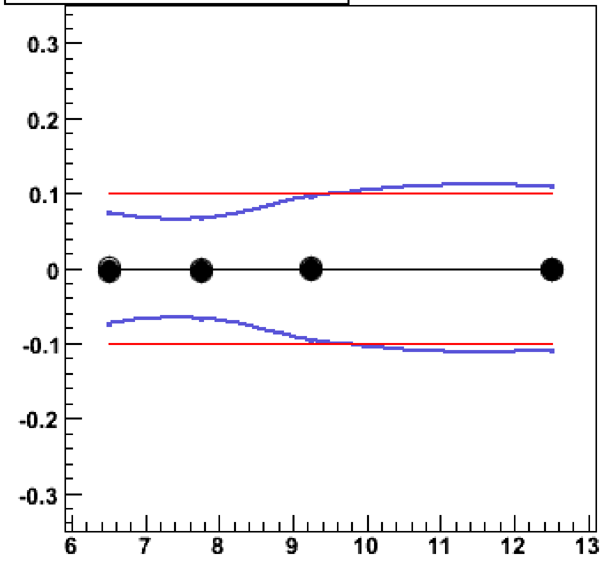


ΔΦ, X_{γ}^{meas} < 0.8 Z-Vertex

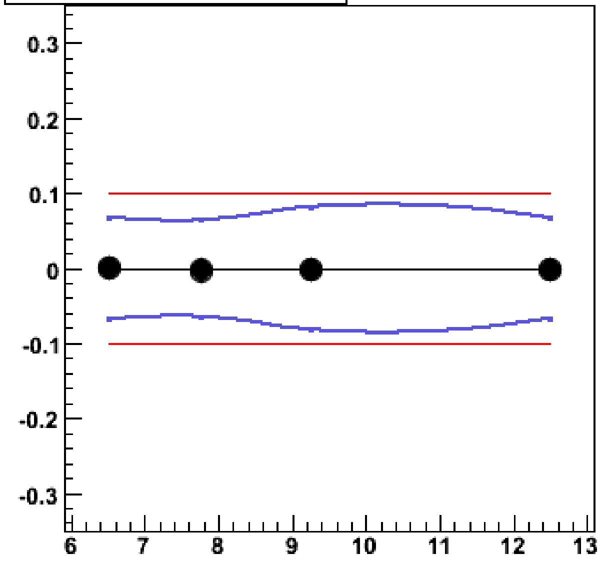


ΔΦ, X_{γ}^{meas} > 0.8 Z-Vertex

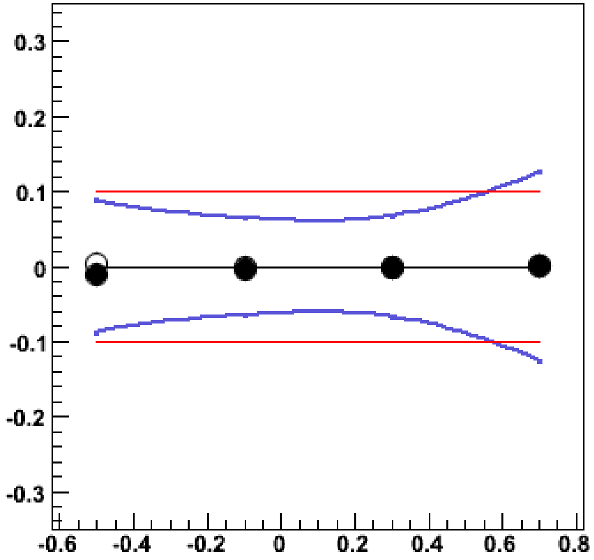
E_T^{γ}, X_{γ}^{meas} < 0.8 Z-Vertex



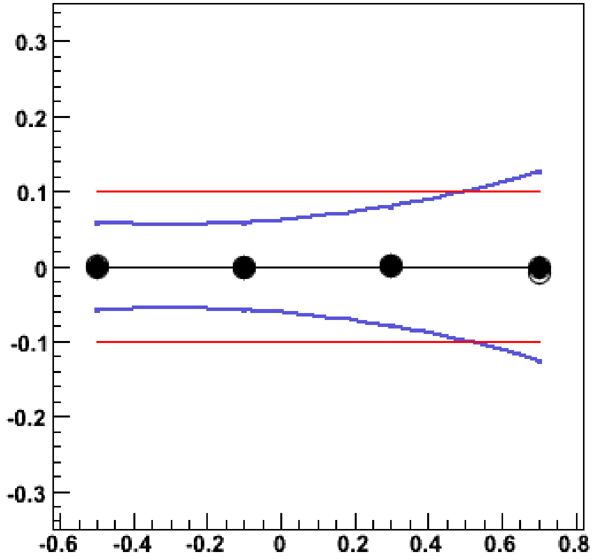
E_T^{γ}, X_{γ}^{meas} > 0.8 Z-Vertex

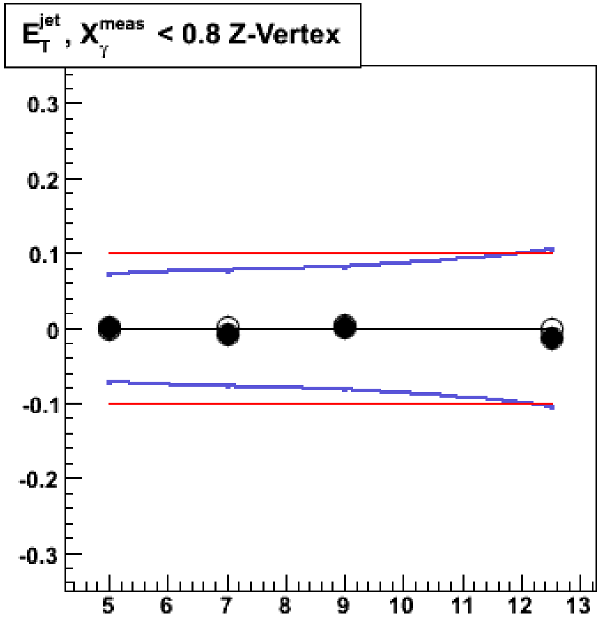


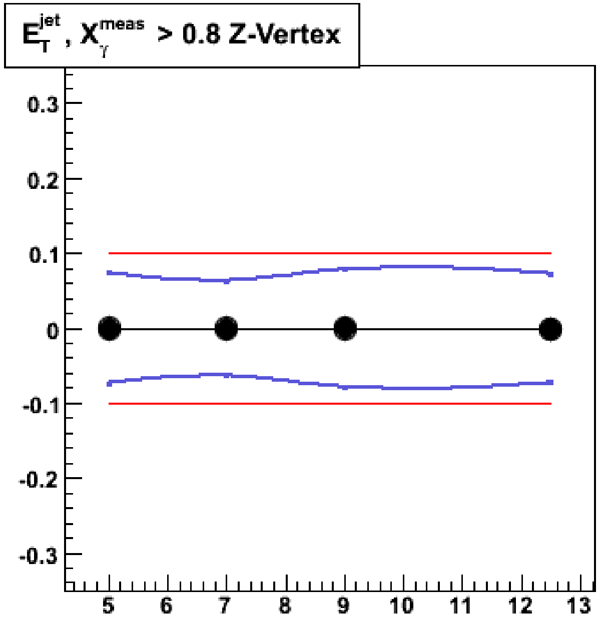
η^{γ}, X_{γ}^{meas} < 0.8 Z-Vertex

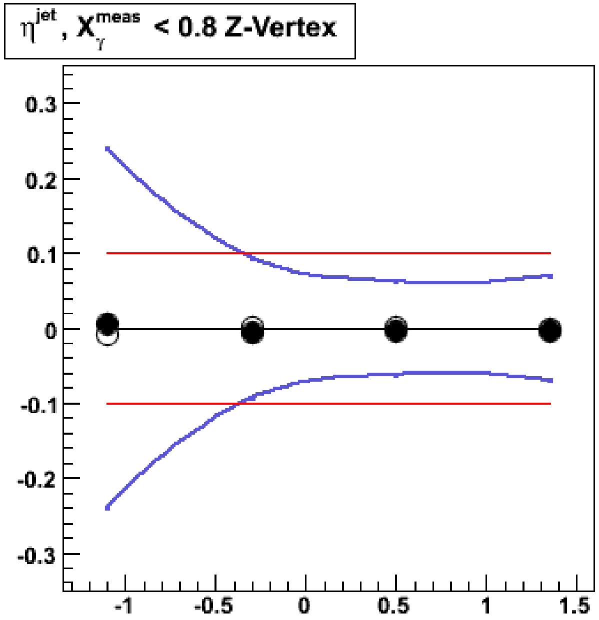


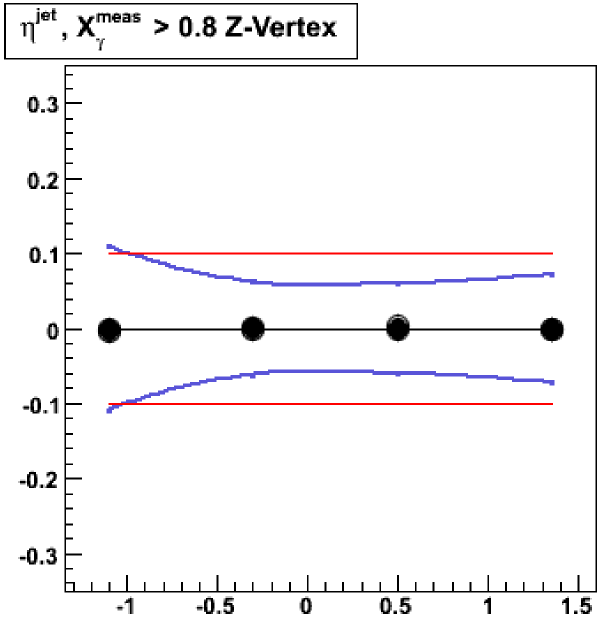
η^{γ}, X_{γ}^{meas} > 0.8 Z-Vertex

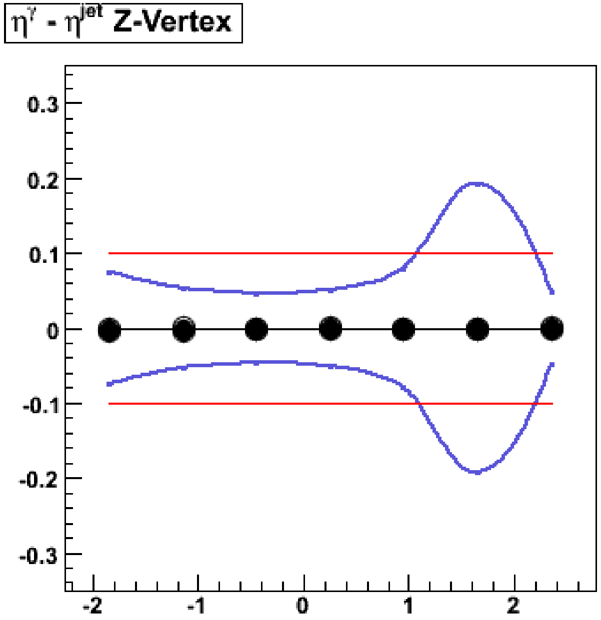



E_T^{jet}, X_γ^{meas} < 0.8 Z-Vertex

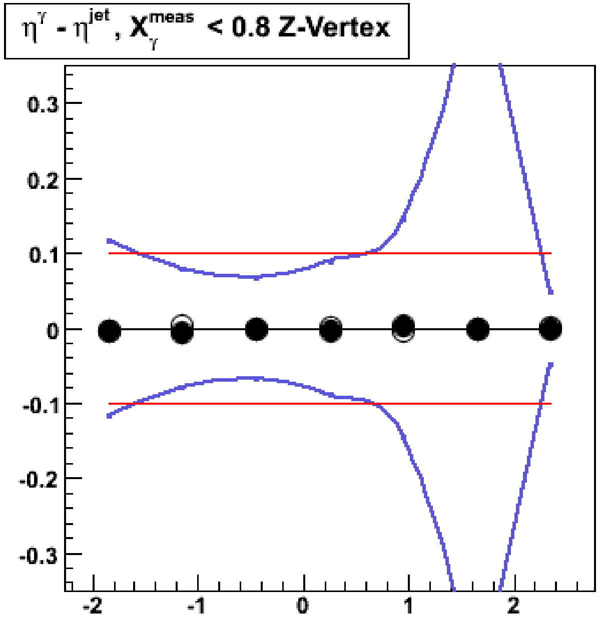

E_T^{jet}, X_γ^{meas} > 0.8 Z-Vertex


η^{jet}, X_γ^{meas} < 0.8 Z-Vertex

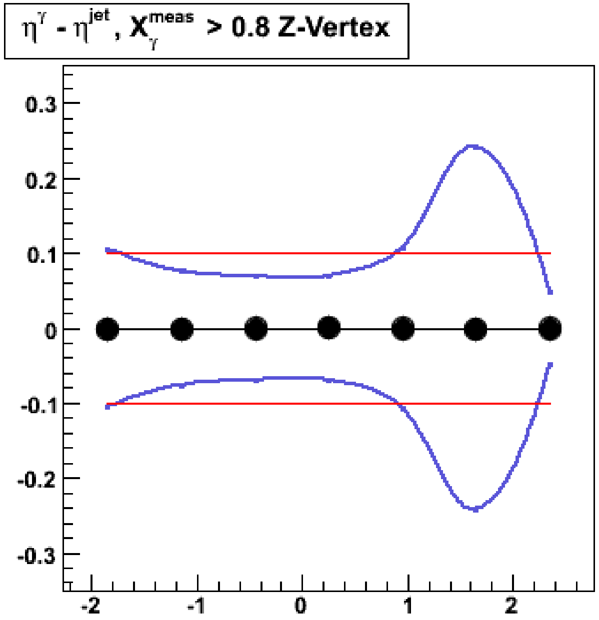

η^{jet}, X_γ^{meas} > 0.8 Z-Vertex



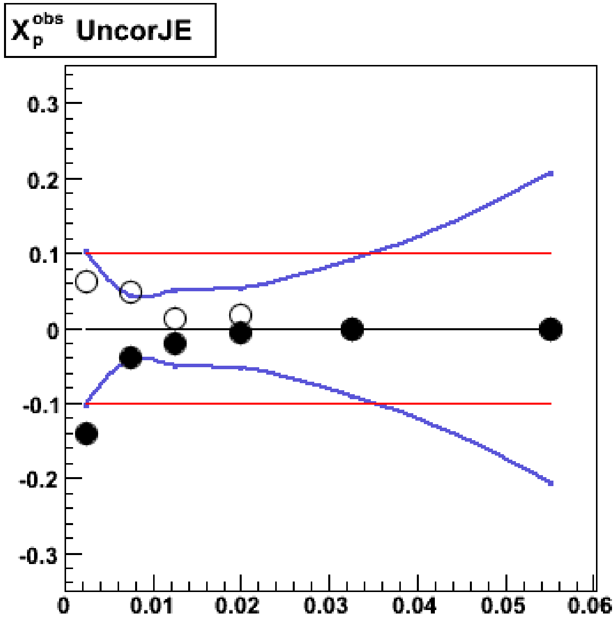
η^{γ} - η^{jet} Z-Vertex

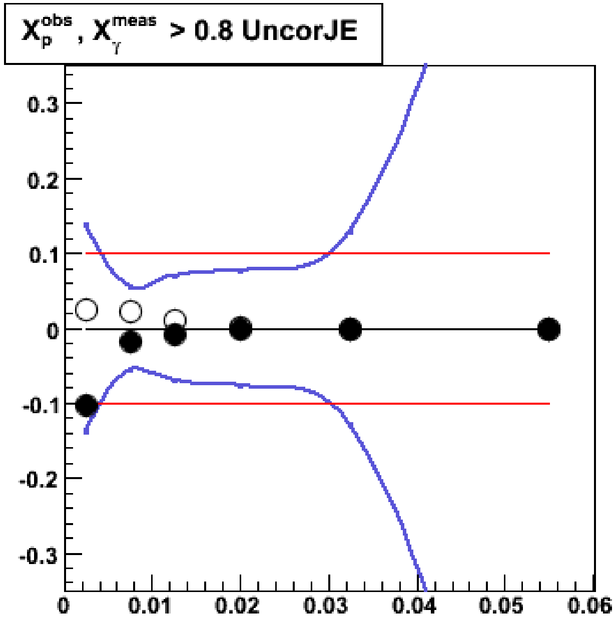


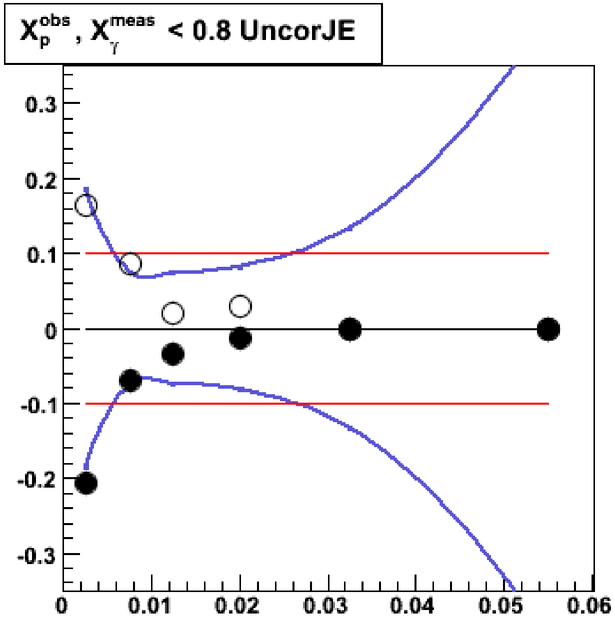
η^{γ} - η^{jet}, $X_{\gamma}^{meas} < 0.8$ Z-Vertex



η^{γ} - η^{jet}, $X_{\gamma}^{meas} > 0.8$ Z-Vertex







Systematic uncertainties: E^{jet} variation

Standard cuts:

- $4 < E_T^{jet} < 35$ GeV

Vary jet energy independently from gamma energy:

If JetEt ≤ 6 GeV by sqrt(4.*4. + 2.*2.))

If 6 < JetEt ≤ 10 GeV by sqrt(2.*2. +2.*2.))

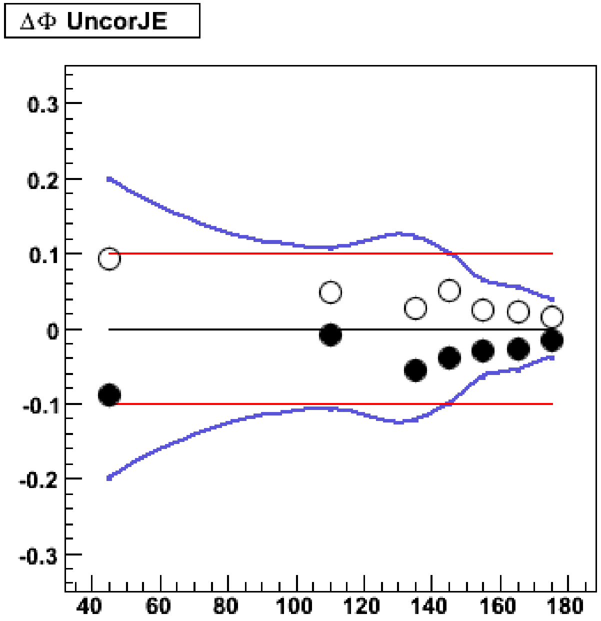
If JetEt > 10 GeV vary by sqrt(1.5*1.5 + 2.*2.))

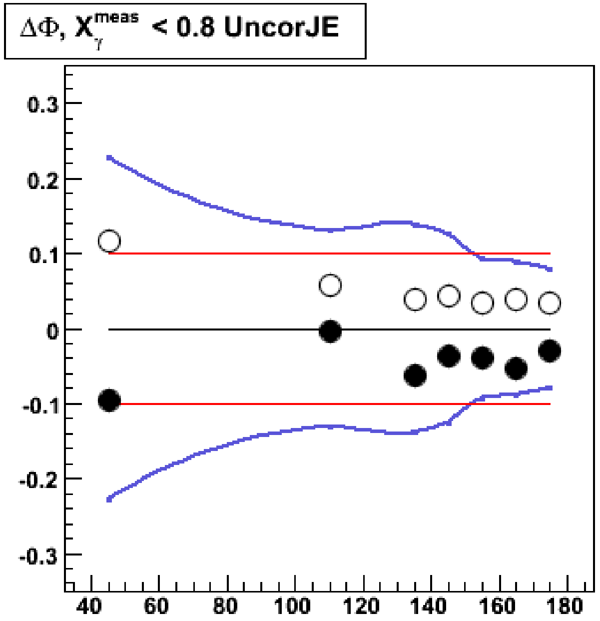
— *Rel.statistical uncertainties*

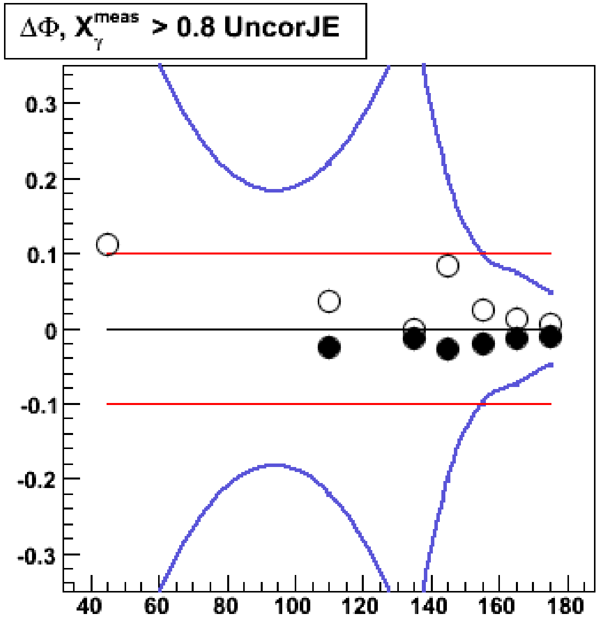
— *10% line*

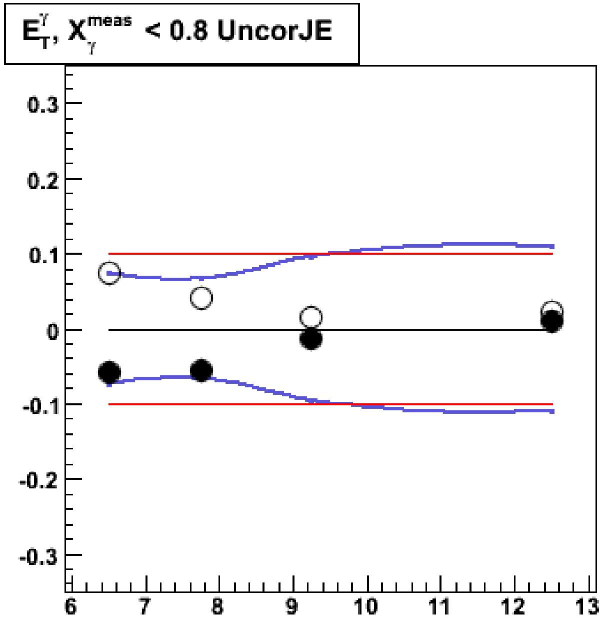
○ *variation up*

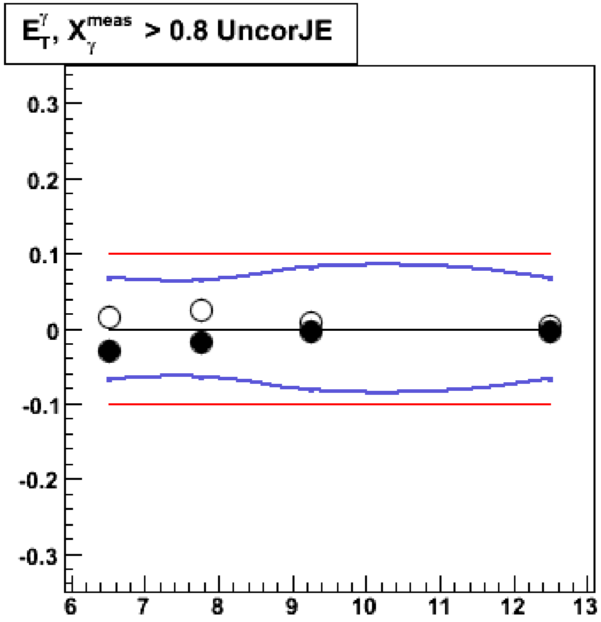
● *variation down*


ΔΦ UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


ΔΦ, X_γ^{meas} < 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


ΔΦ, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


E_T^{γ}, X_{γ}^{meas} < 0.8 UncorJE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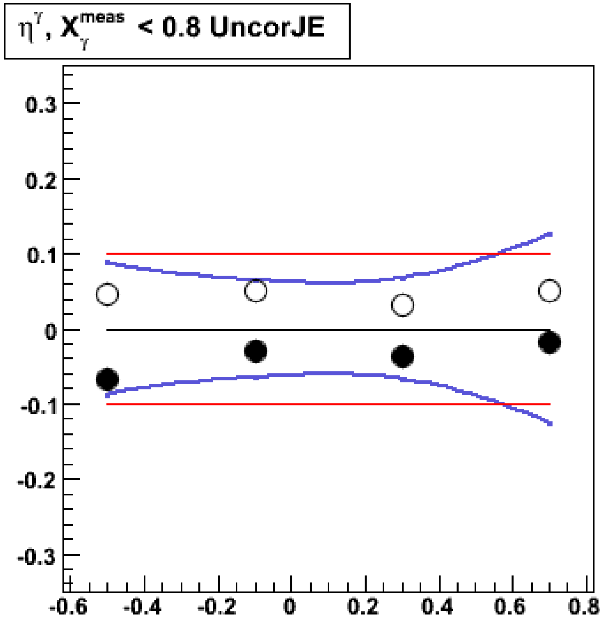
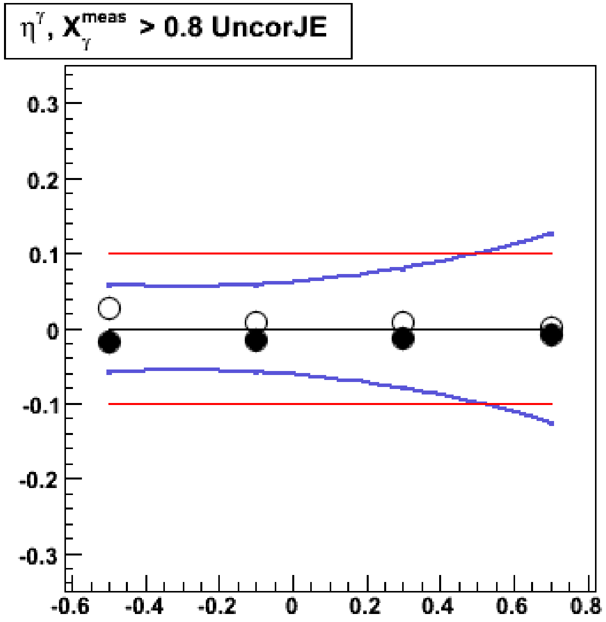
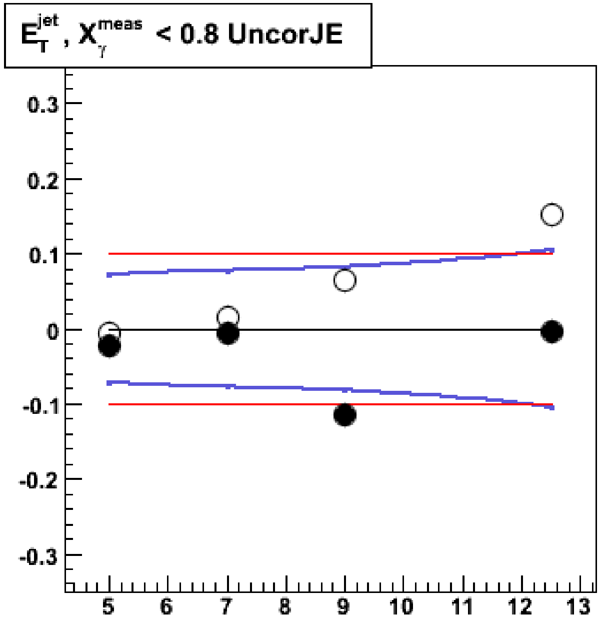

η^{γ}, X_{γ}^{meas} < 0.8 UncorJE


η^{γ}, X_{γ}^{meas} > 0.8 UncorJE


E_T^{jet}, X_γ^{meas} < 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
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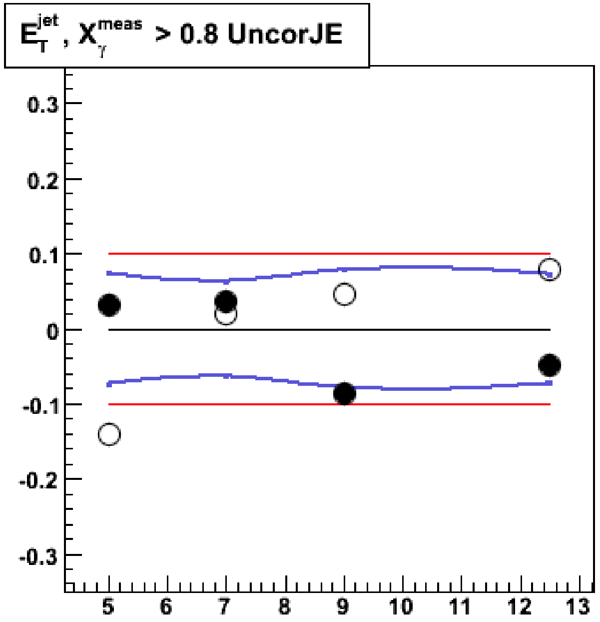
6
7
8
9
10
11
12
13


E_T^{jet}, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
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0
-0.1
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6
7
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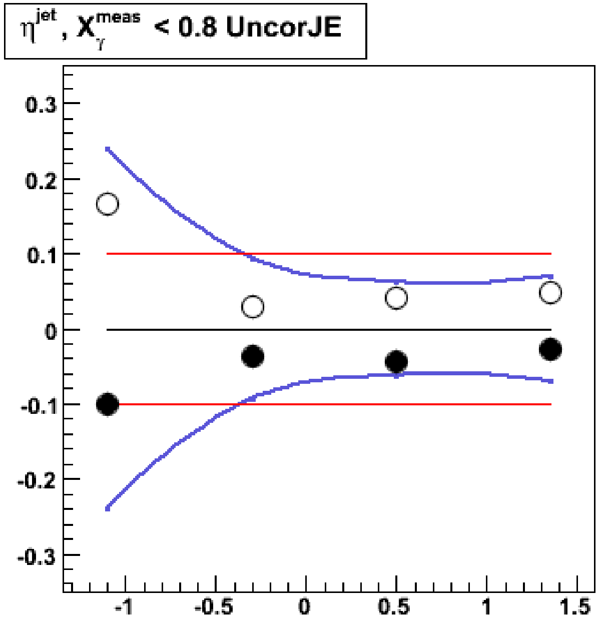
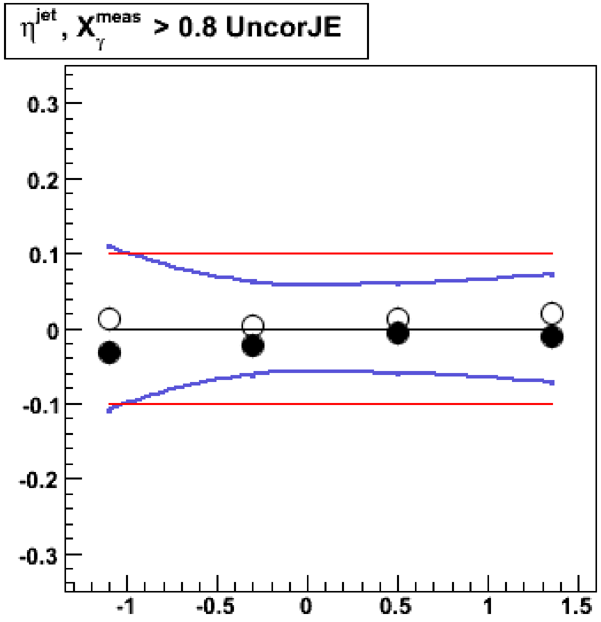
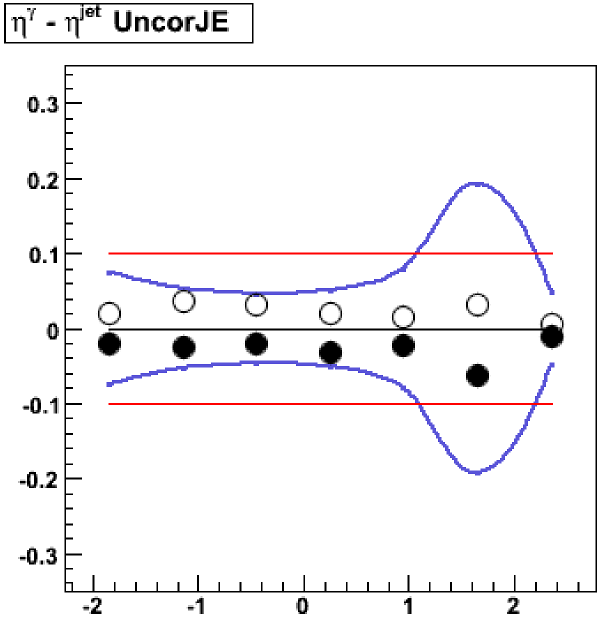
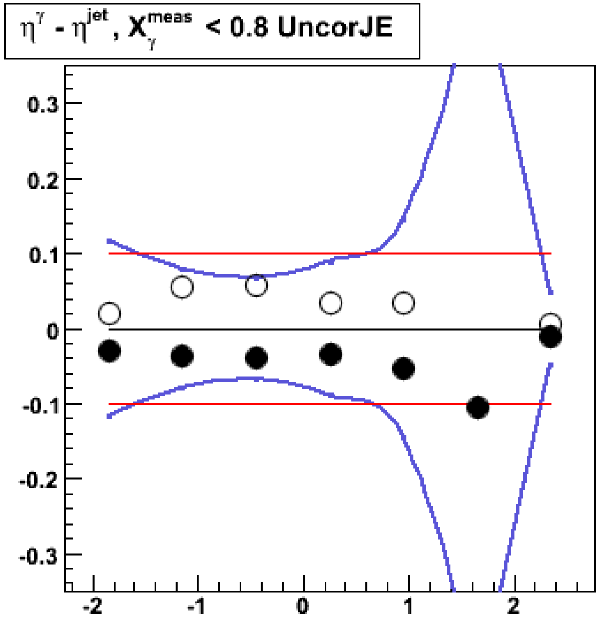
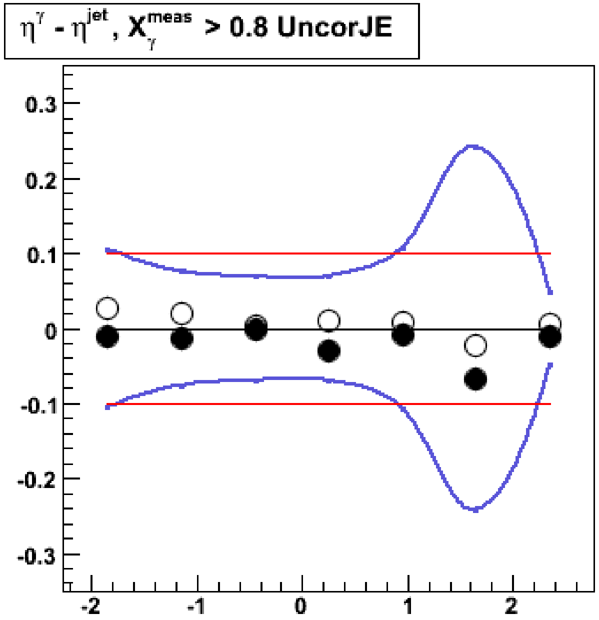
12
13


η^{jet}, X_γ^{meas} < 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^{jet}, X_γ^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5


η^{γ} - η^{jet} UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} < 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2


η^{γ} - η^{jet}, X_{γ}^{meas} > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-2
-1
0
1
2