Photoproduction of isolated photons with a jet at HERA. Status update

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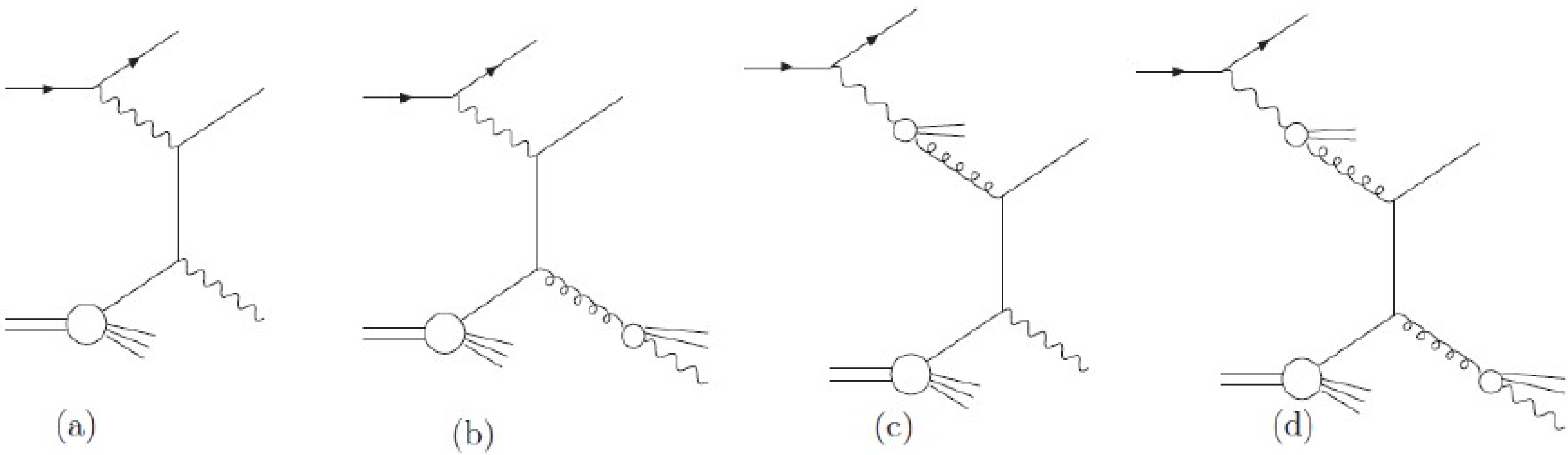
Introduction



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 two new variables:
  - x_p – measures longitudinal momentum transfer from proton – sensitive to PDF and modelling of parton in proton – interesting to see LMZ description of this with k_T-factorisation.
  - $\Delta\Phi$ – the azimuthal difference between the photon and the jet, sensitive to higher order processes.

- Study of three regions of x_γ – longitudinal momentum transfer from photon, resolved- and direct-enhanced:

$$x_\gamma < 0.7,\ x_\gamma < 0.8 \text{ and } x_\gamma > 0.8$$

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

$0.2 < y_{JB} < 0.7$

| 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

$Q^2<1$ GeV^2

$0.2<y_{JB}<0.7$

Particle type 29

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

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

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

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. The box diagram is included together with $2 \rightarrow 3$ subprocesses:

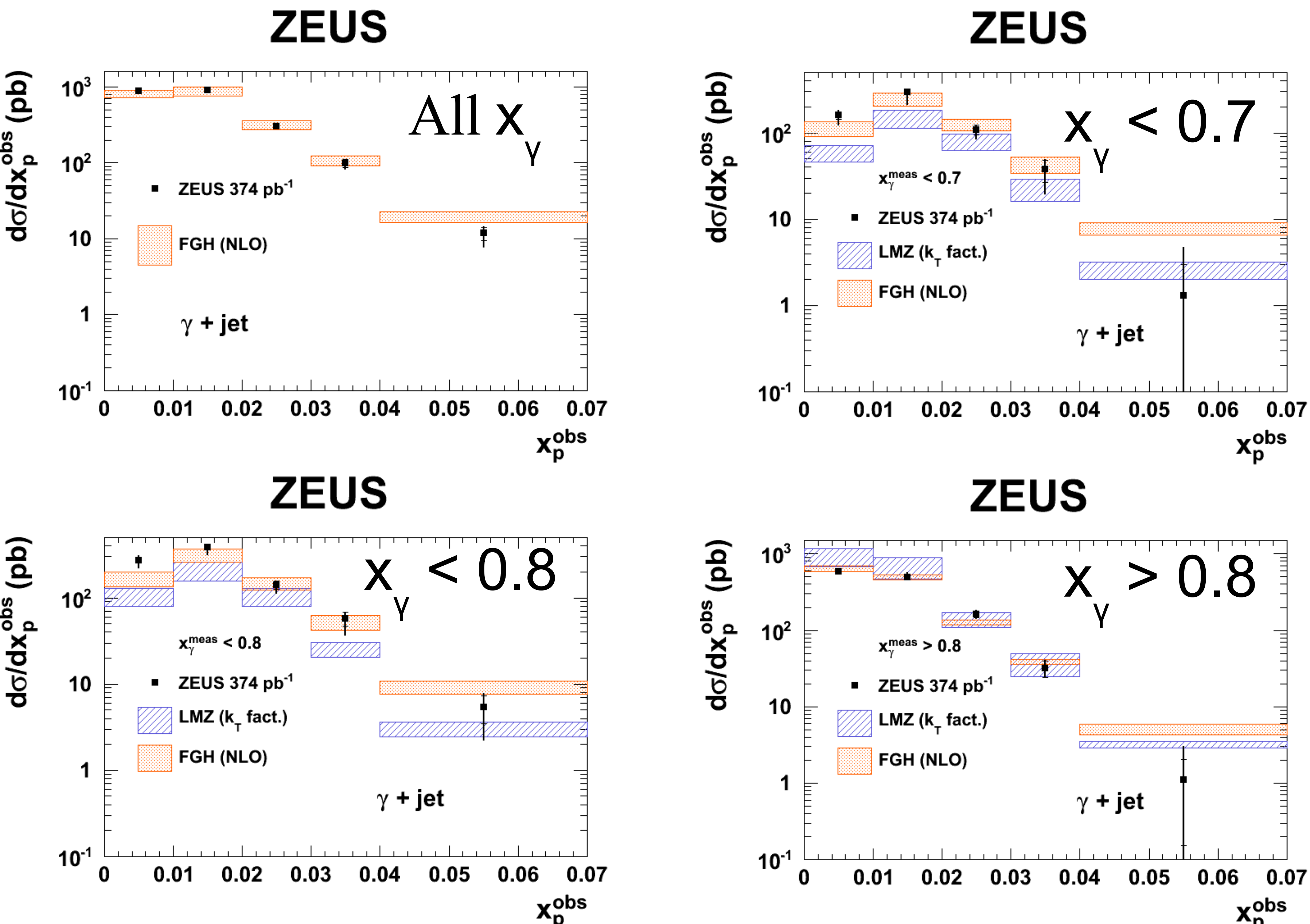
$\gamma(k_1) + q(k_2) \rightarrow \gamma(p_1) + g(p_2) + q(p_3)$

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

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

Now $gq \rightarrow \gamma q$ process is also included except several distributions. Waiting for the update.

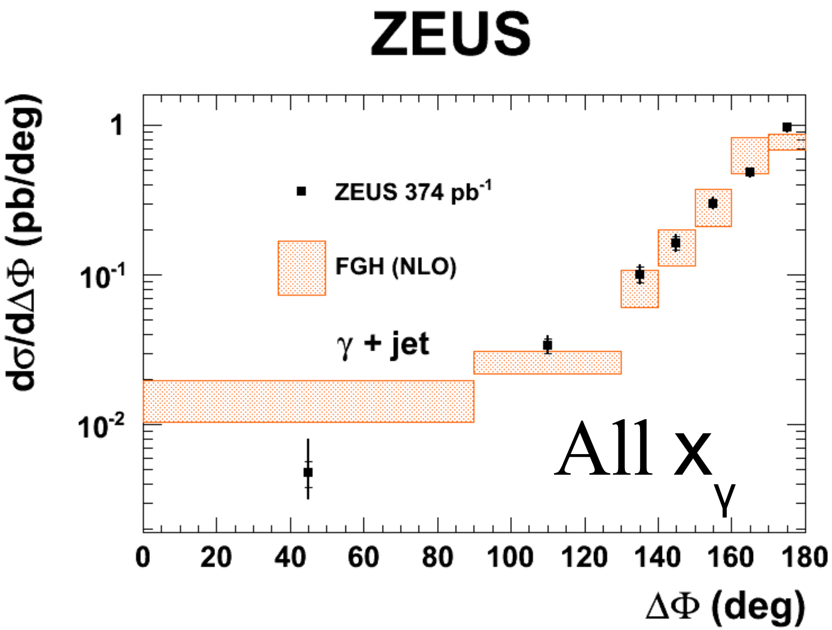
Cross sections. x_p

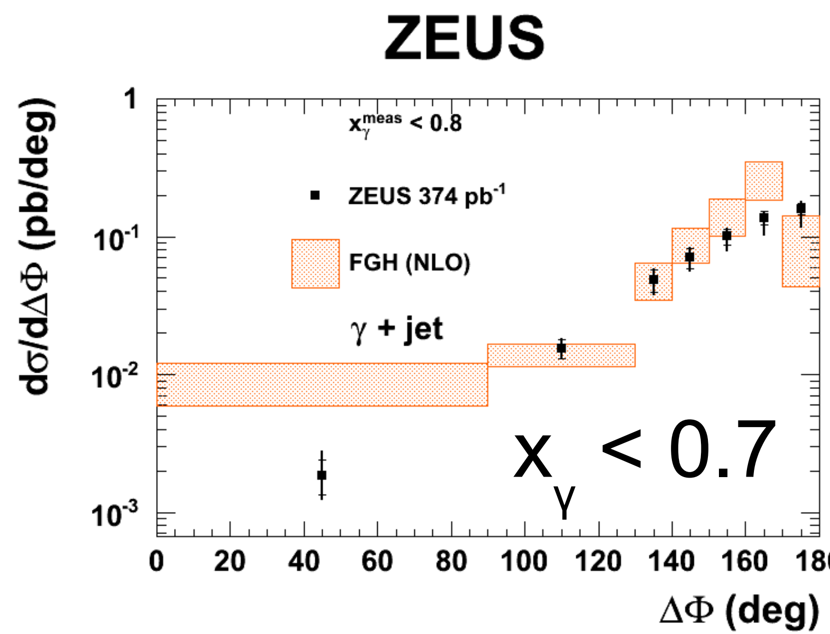


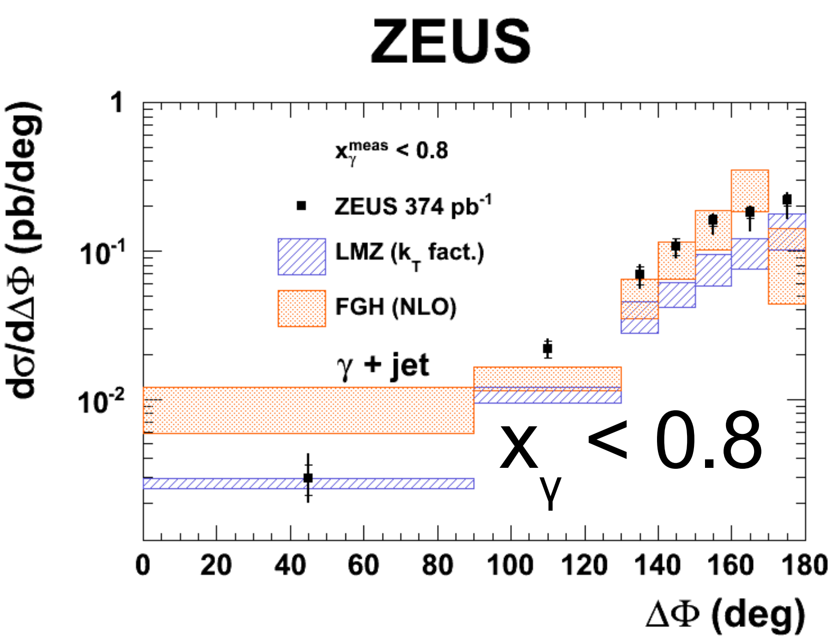
Reasonable description of data by theory. New hadronisation corrections are applied to theory. Only resolved had. corr. is used in $x_\gamma < 0.7$, $x_\gamma < 0.8$ regions and direct in $x_\gamma < 0.8$.

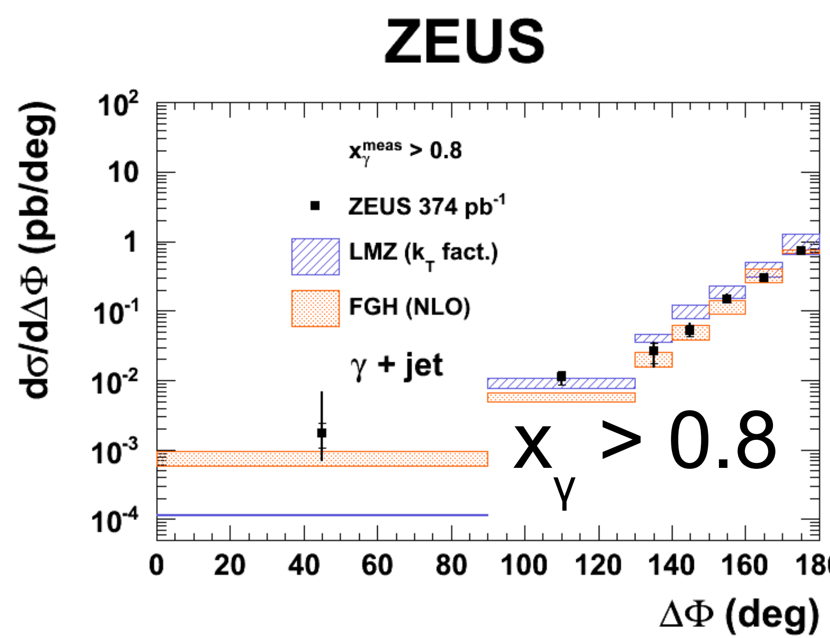
Inner and outer error bars – statistical uncertainties and statistical and systematic in quadrature.

Cross sections. ΔΦ





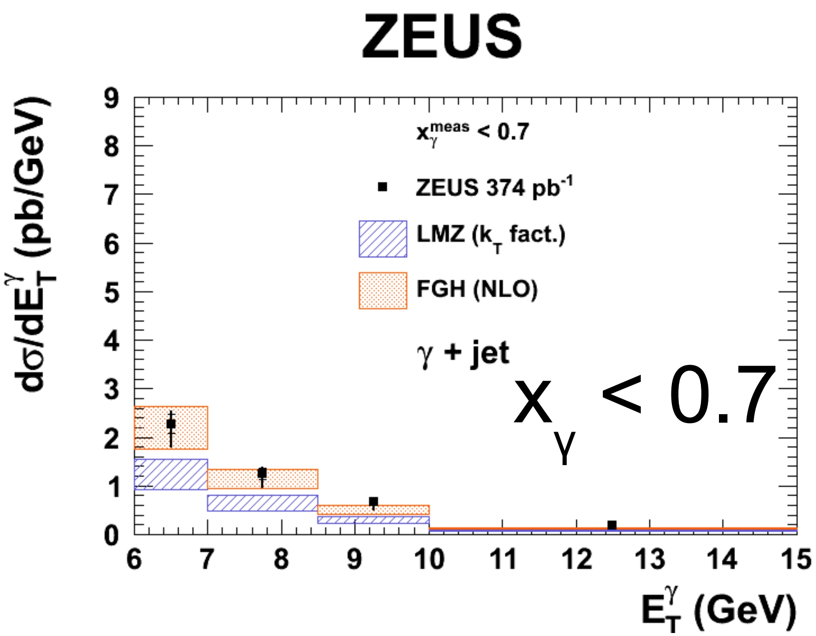


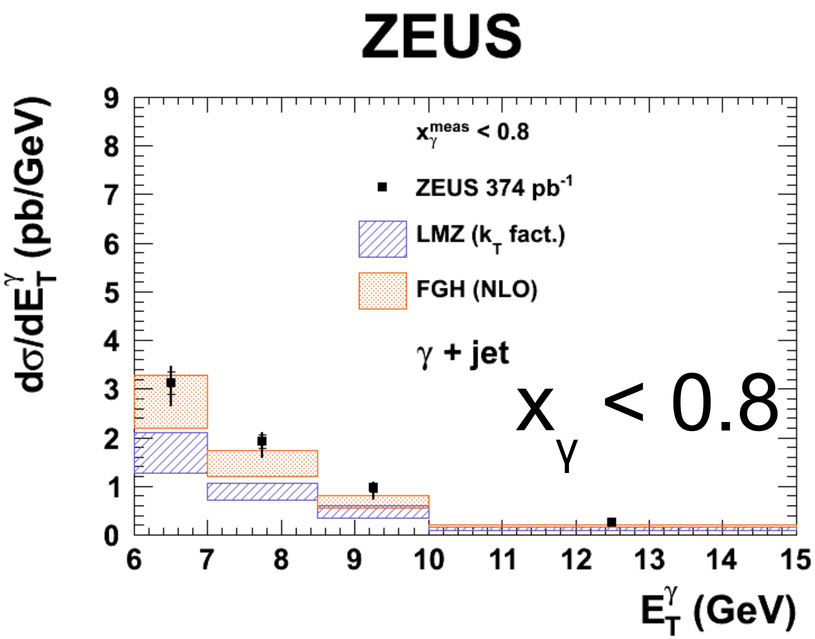


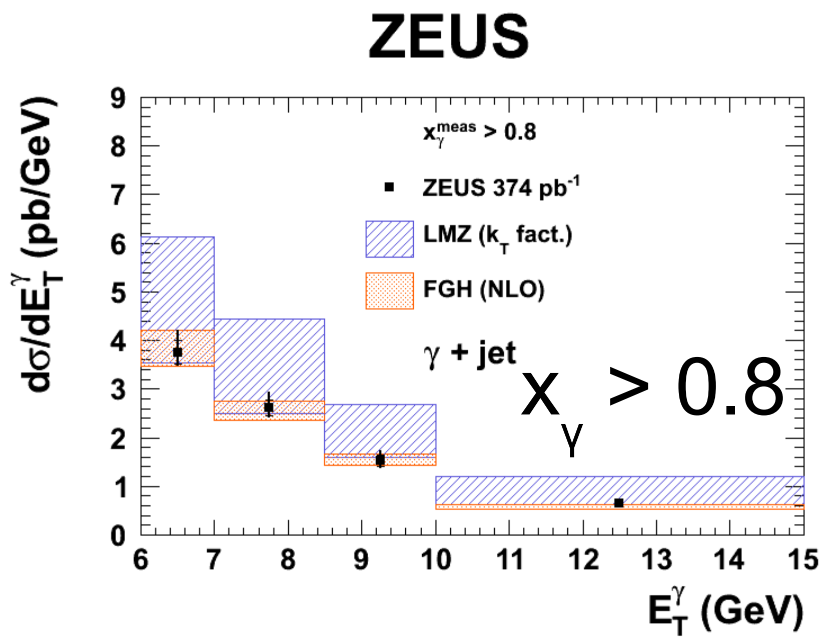
Reasonable description by theory, however there is an overestimation in the 0-90º bin that is coming from $x_\gamma < 0.7$ range in FGH and underestimation in 90-170º in LMZ in low x_γ region.

Cross sections. E_T^γ

FGH describes data within errors. LMZ tends to underestimate low x_γ region.

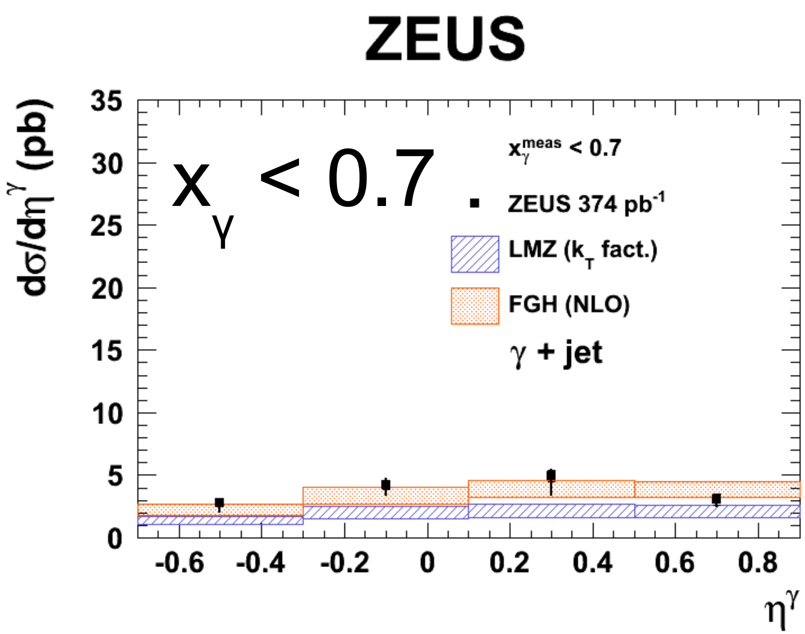


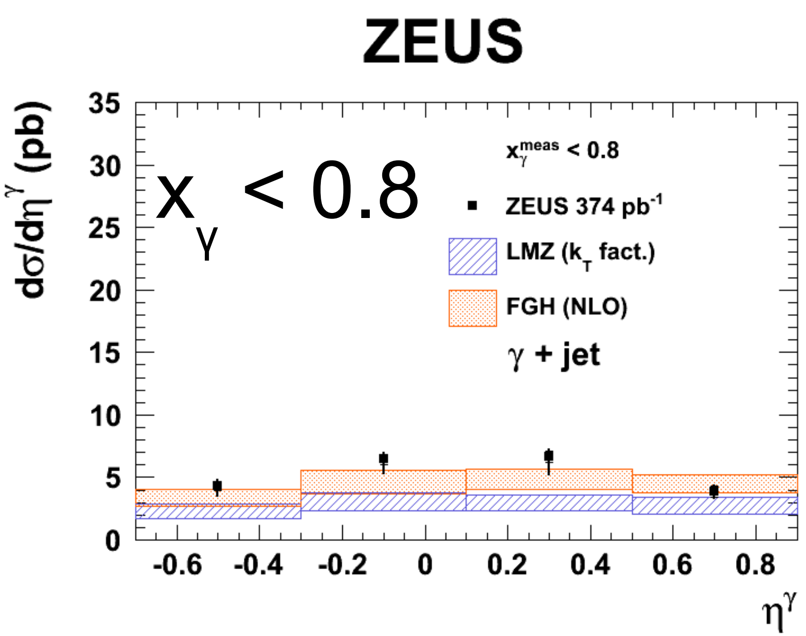


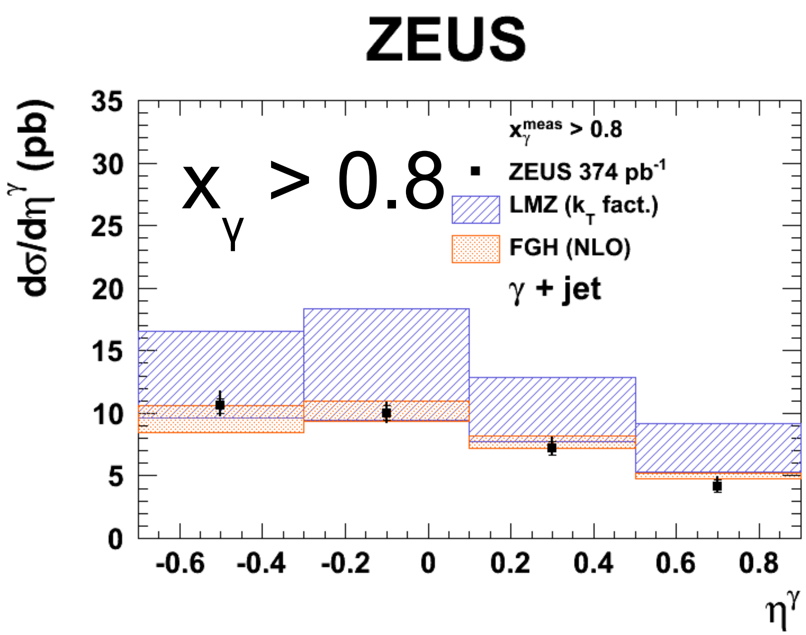


Cross sections. η^{γ}

FGH describes data within errors. LMZ tends to underestimate low x_{γ} region.

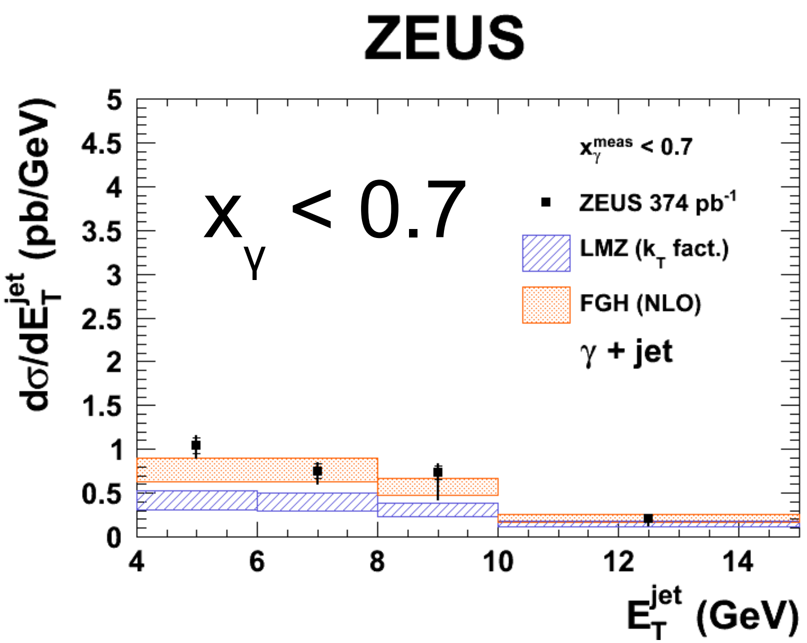


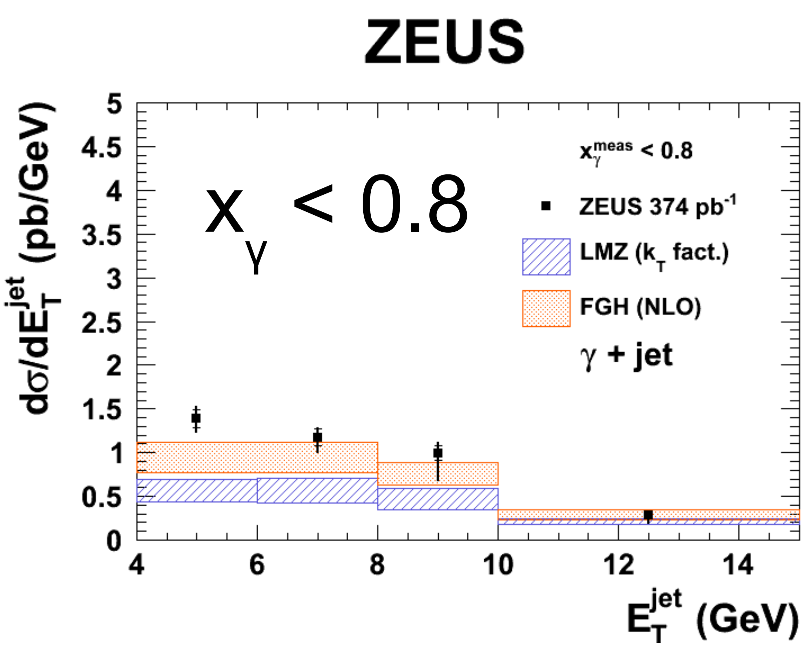


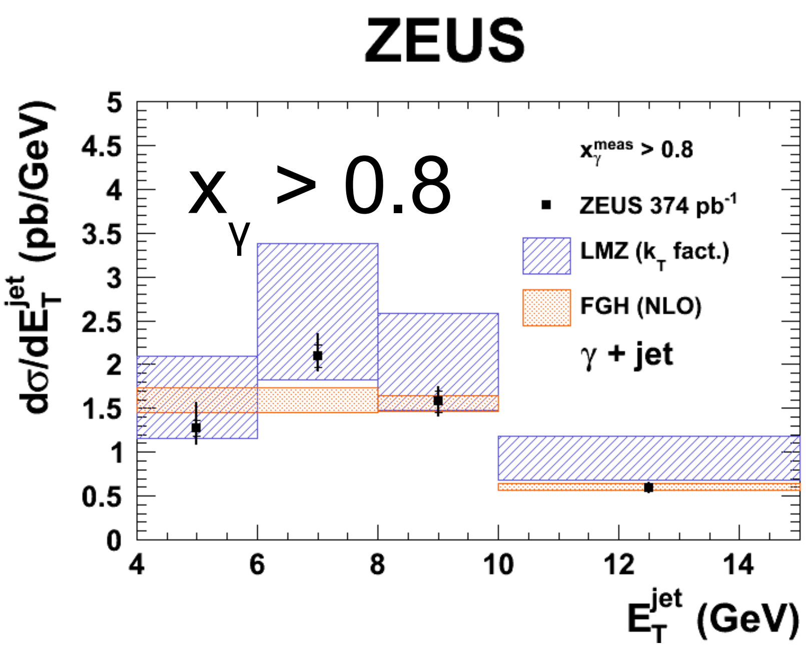


Cross sections. E_T^{jet}

First two FGH E_T^{jet} (4-6 and 6-8 GeV) bins are combined due to singularity.
Reasonable description of data.
LMZ tends to underestimate low x_γ region.

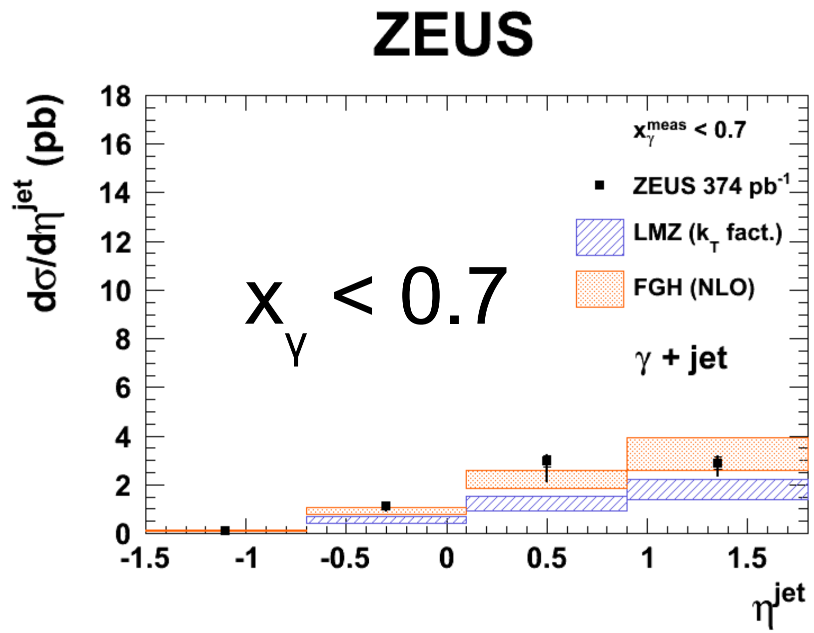


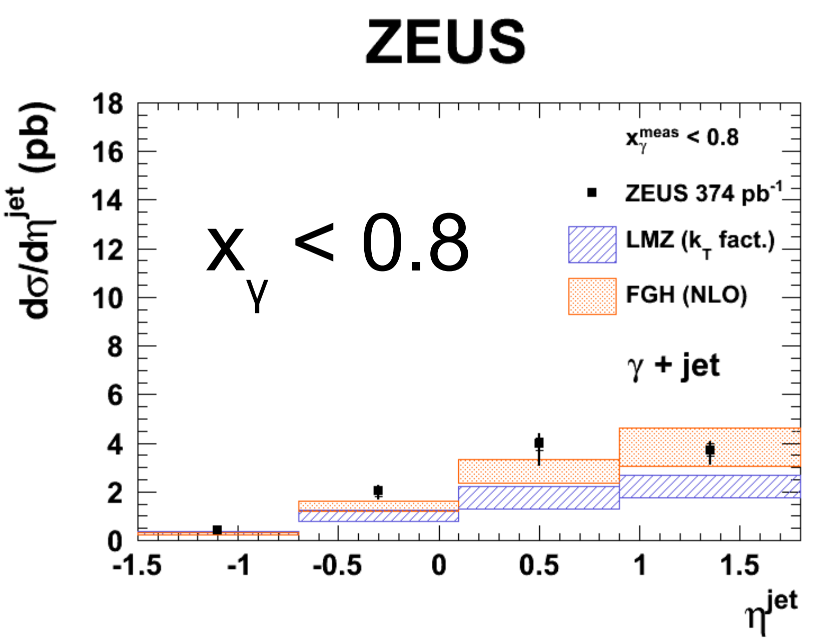


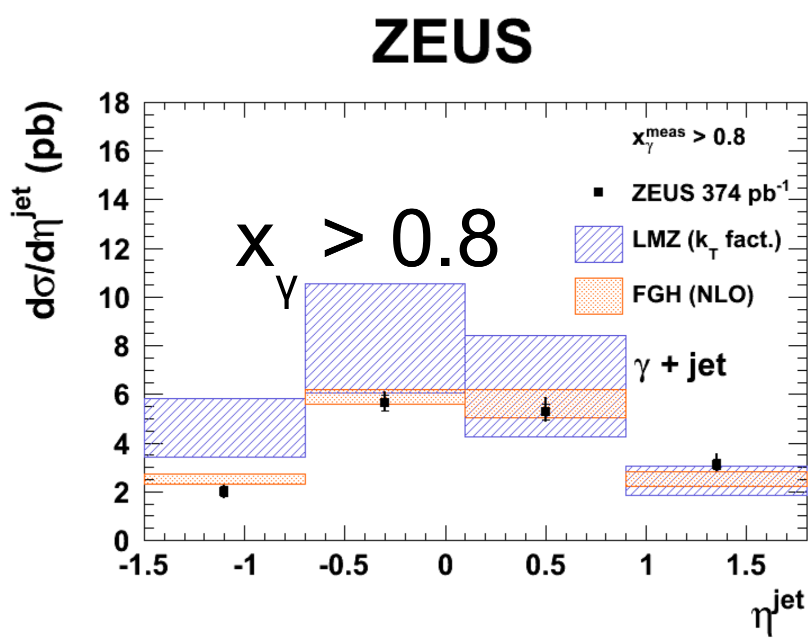


Cross sections. η^{jet}

Apart from overestimating low η^{jet} FGH describes data within errors. LMZ tends to underestimate low x_γ region.







Consistency check

	x_γ>0.8			x_γ<0.8			Sum			All x_γ		
	FGH	LMZ	Data	FGH	LMZ	Data	FGH	LMZ	Data	FGH	LMZ	Data
η^{jet}	13.49	16.47	13.13	7.1	4.34	8.47	20.59	20.81	21.6	22.47	20.34	22.16
E_T^{jet} *	12.52	16.06	12.83	6.74	4.18	8.52	19.26	20.24	21.35	20.9	19.31	21.76
η^γ	12.97	16.72	12.97	6.97	4.31	8.53	19.94	21.03	21.5	21.58	20.82	21.58
E_T^γ	12.9	16.72	13.22	6.92	4.29	8.71	19.82	21.01	21.93	21.48	20.53	22.44

* - bin 15 < E_T^{jet} < 35 GeV is not included in this sum.

There is an agreement within errors between the sum of different ranges of x_γ and the full x_γ range in theories and data.

Conclusion

Cross section comparison with FGH and LMZ in $x_\gamma < 0.8$ range shown, new hadronisation corrections applied.

Both theories provide good description within errors in $x_\gamma > 0.8$, but there is an overestimation in $0 < \Delta\Phi < 90^\circ$ bin that is mostly likely coming from $x_\gamma < 0.7$ region. LMZ tends to underestimate low x_γ region.

Future plans

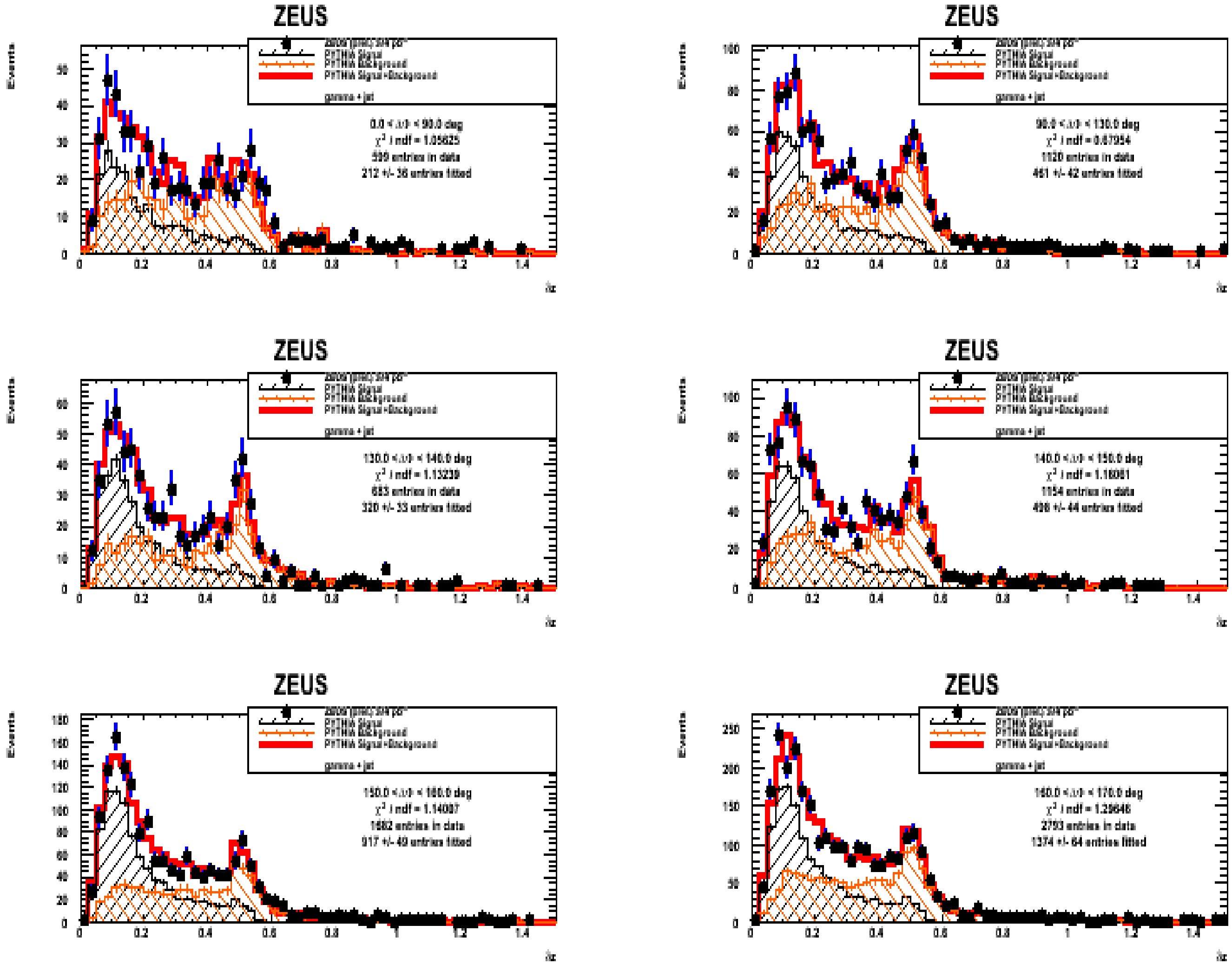
Reach agreement on corrections between analyses.

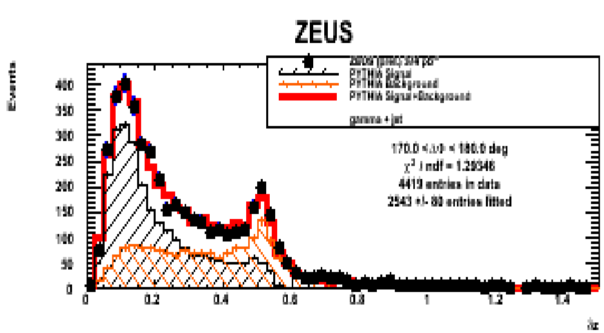
Obtain and add the rest of LMZ predictions.

DIS contamination study.

Backup slides

<δZ> Fits in ΔΦ bins. All x_γ





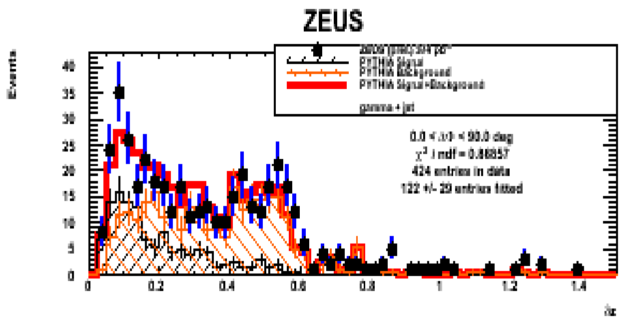
First bin 0 < ΔΦ < 90º:

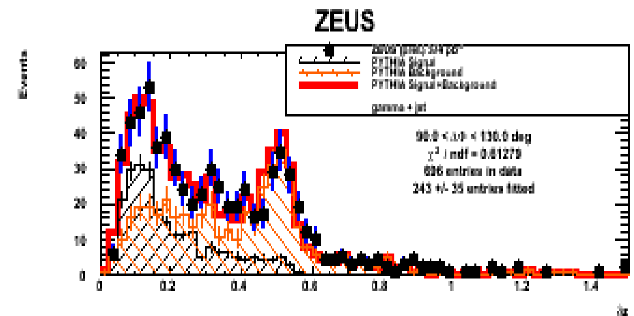
χ^2 / n.d.f. = 1.05625

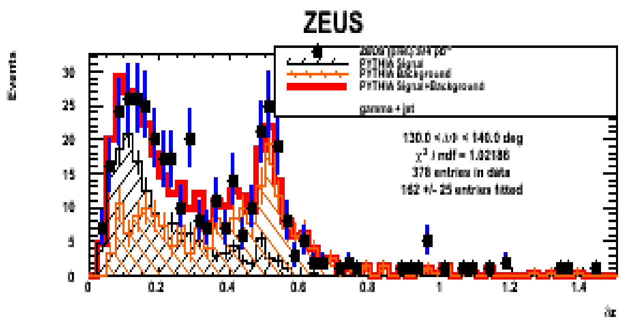
fitted photons 212 ± 36

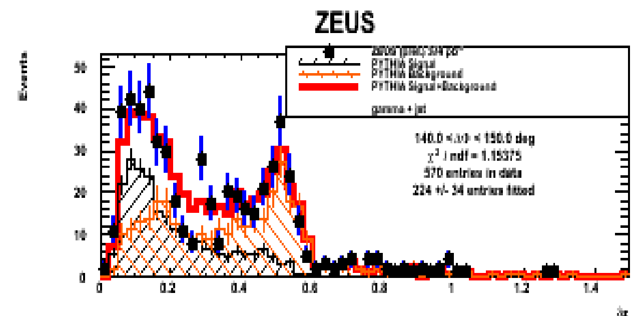
Bin looks good

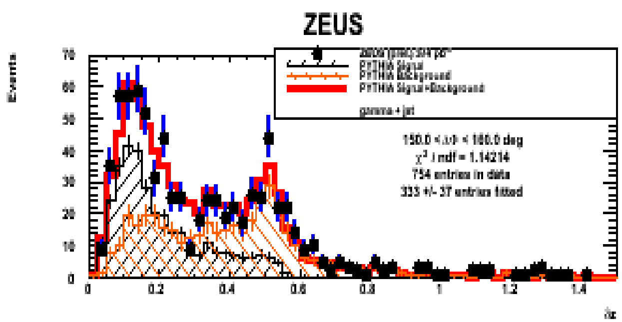
$\langle\delta Z\rangle$ Fits in $\Delta\Phi$ bins. $x_{\gamma} < 0.7$

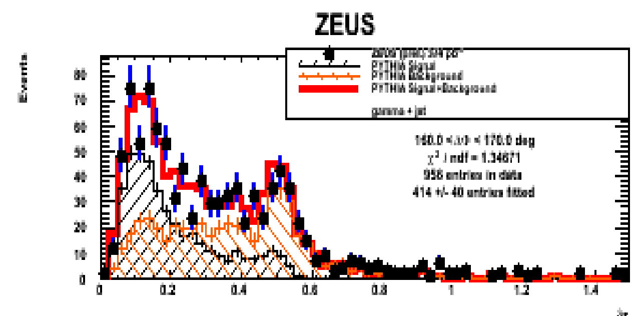


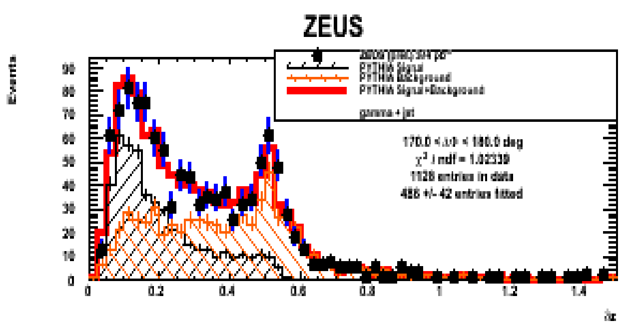












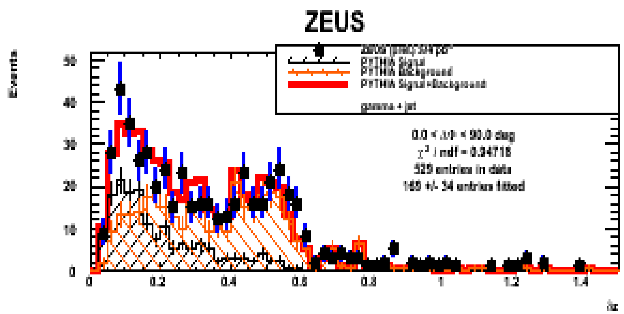
First bin $0 < \Delta\Phi < 90^{o}$:

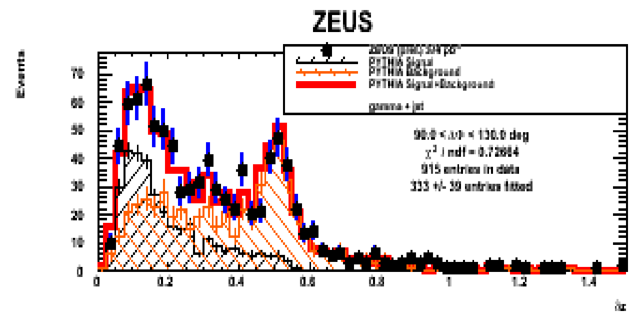
χ^2 / n.d.f. = 0.86857

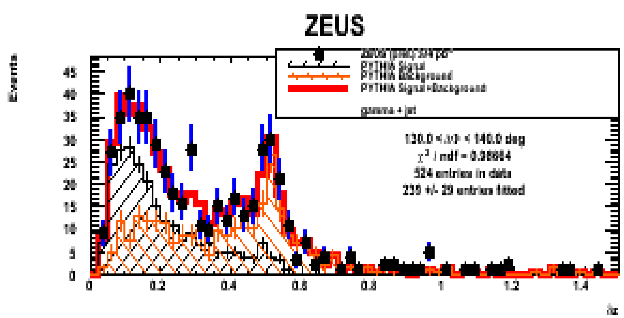
fitted photons 122 ± 29

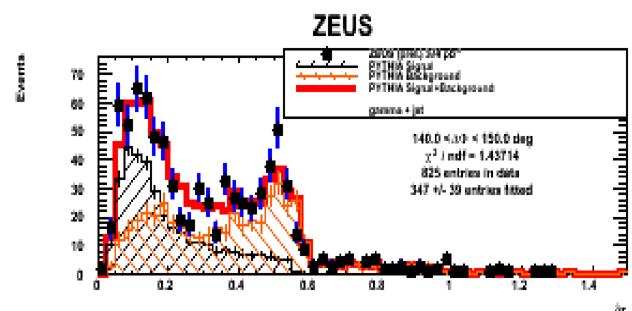
Bin looks good

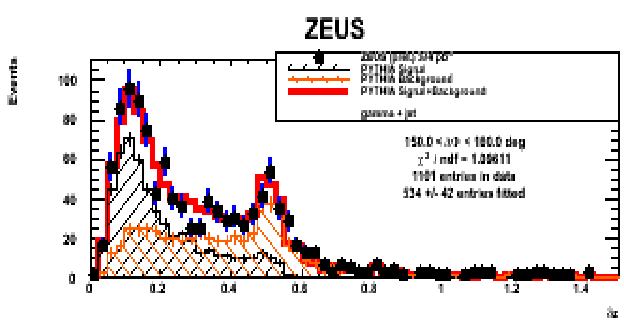
<δZ> Fits in ΔΦ bins. $x_\gamma < 0.8$

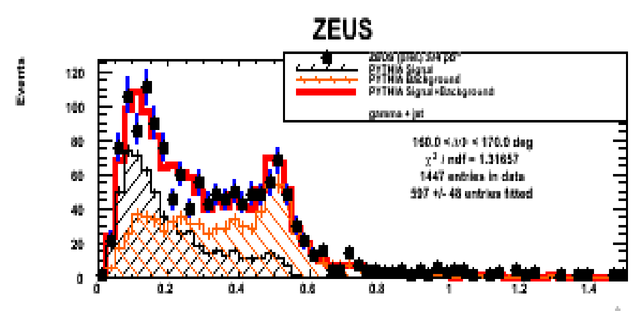


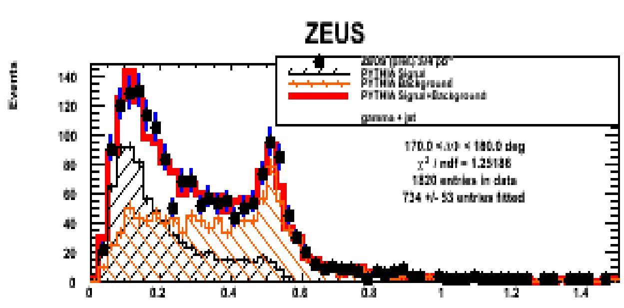






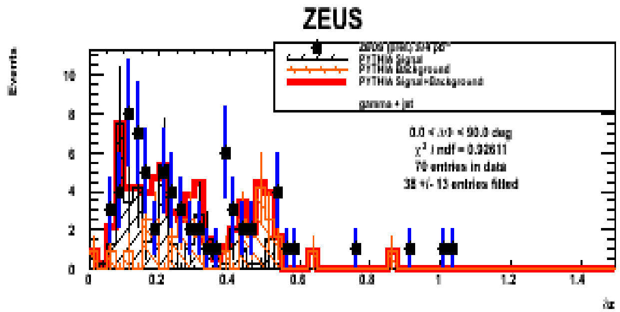


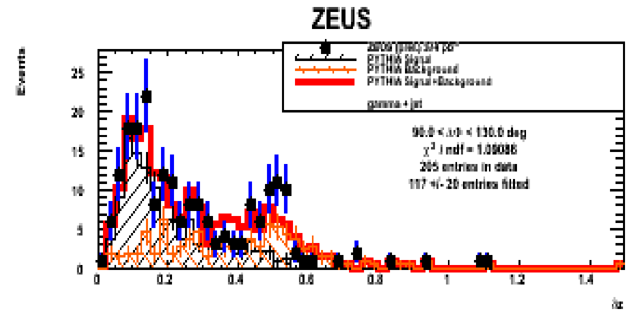


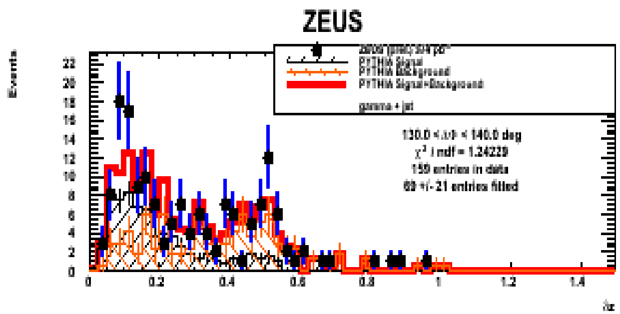


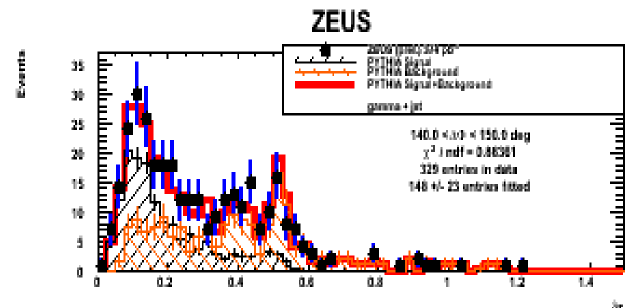
First bin 0 < ΔΦ < 90º:
χ^2 / n.d.f. = 0.94718
fitted photons 169 ± 34
Bin looks good

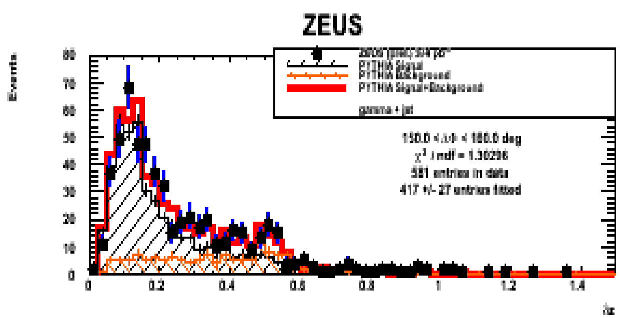
<δZ> Fits in ΔΦ bins. $x_\gamma > 0.8$

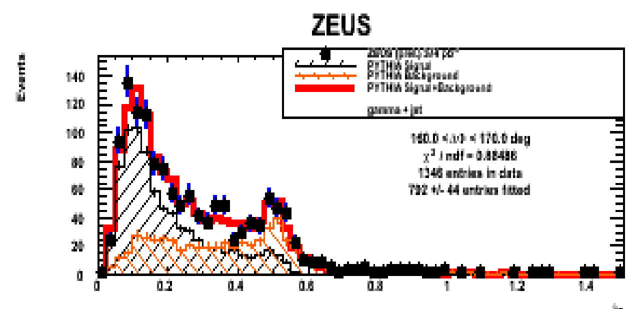


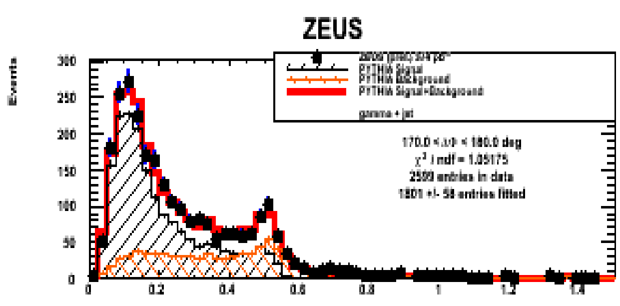






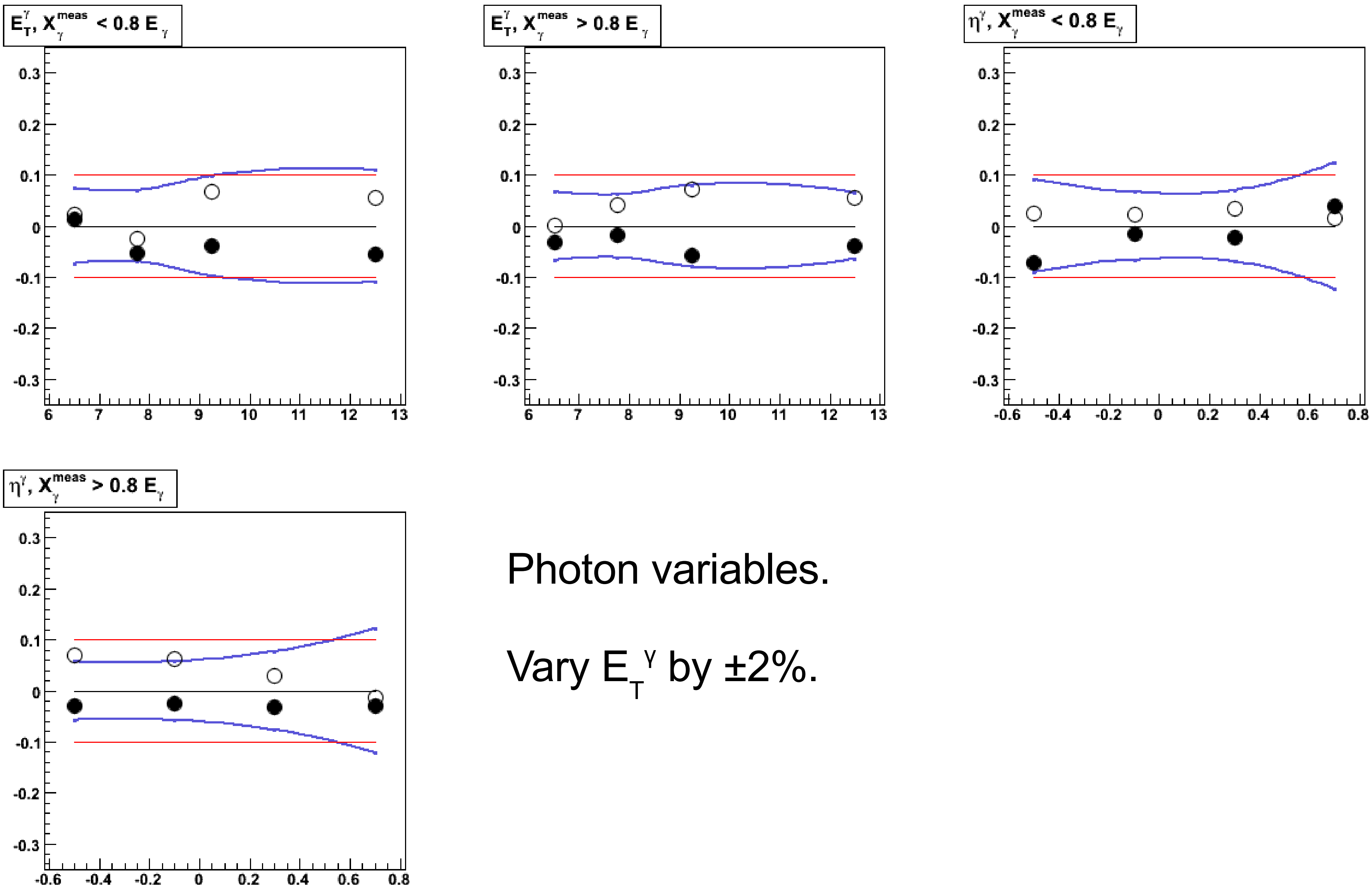






First bin 0 < ΔΦ < 90º:
χ^2 / n.d.f. = 0.92611
fitted photons 38 ± 13
Small statistics

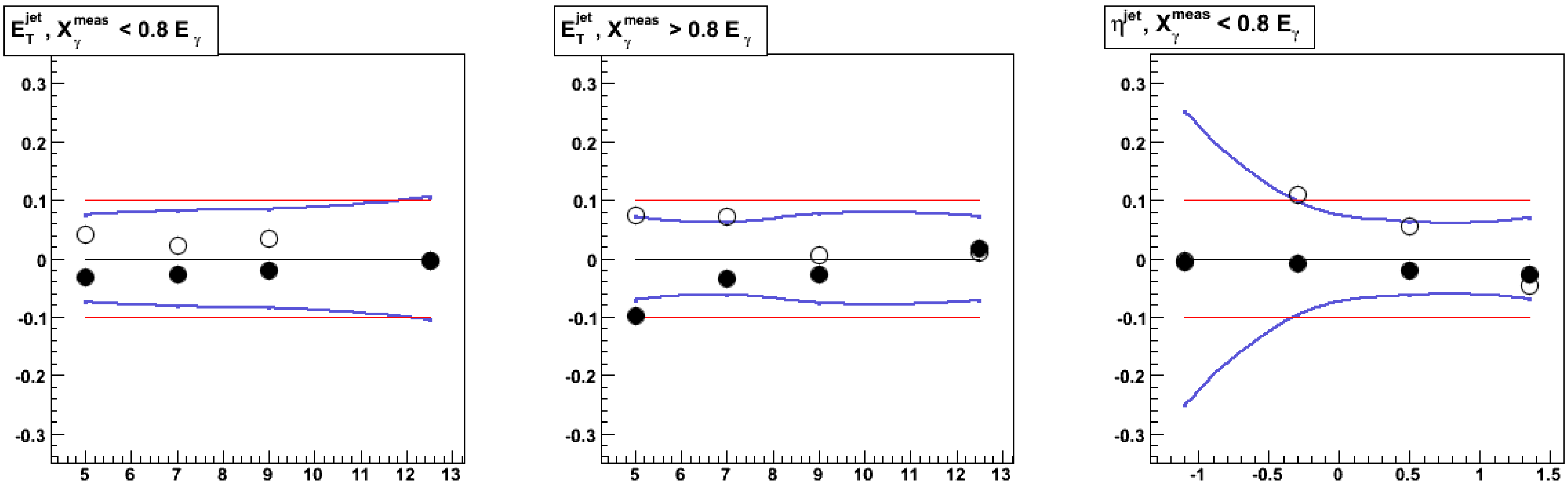
Major sources of systematics. E_T^γ variation

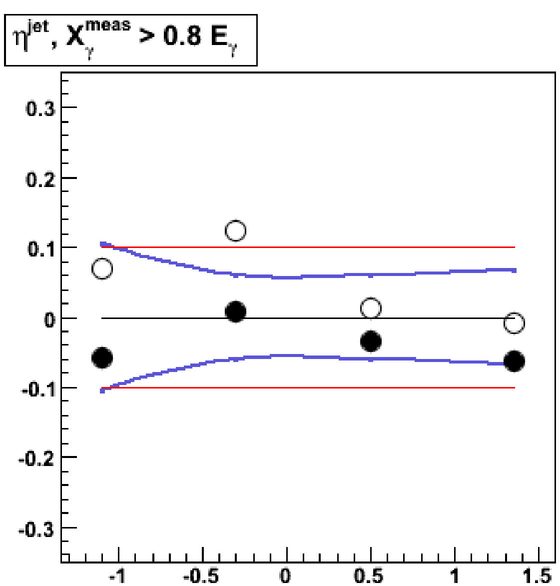


Photon variables.

Vary E_T^γ by ±2%.

Major sources of systematics. E_T^γ variation

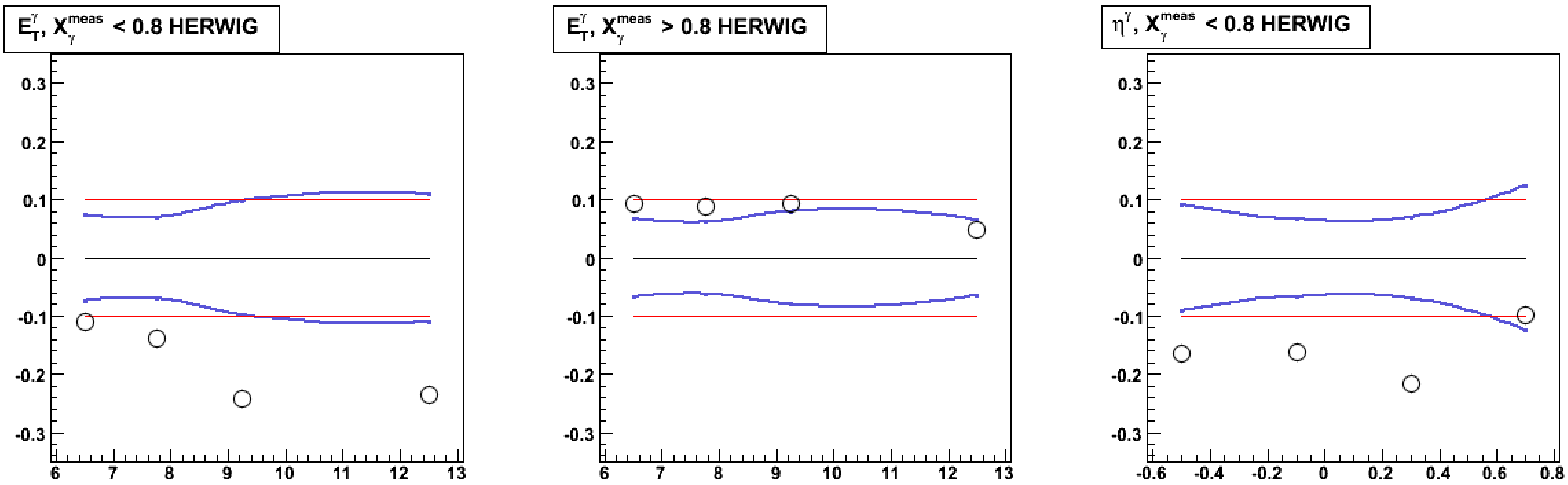


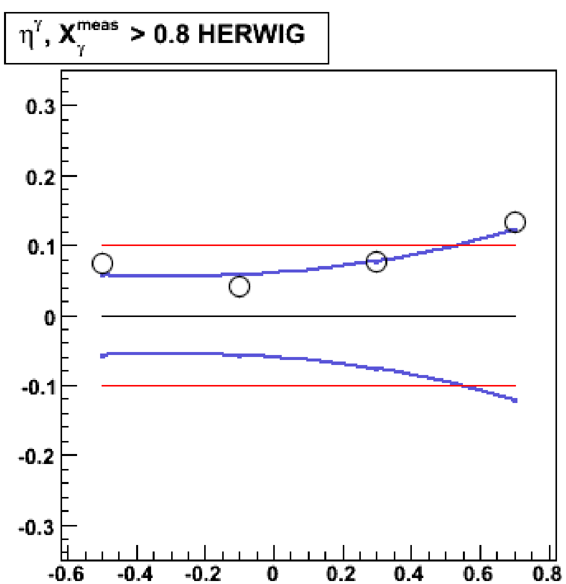


Jet variables.

Vary E_T^γ by ±2%.

Major sources of systematics. HERWIG



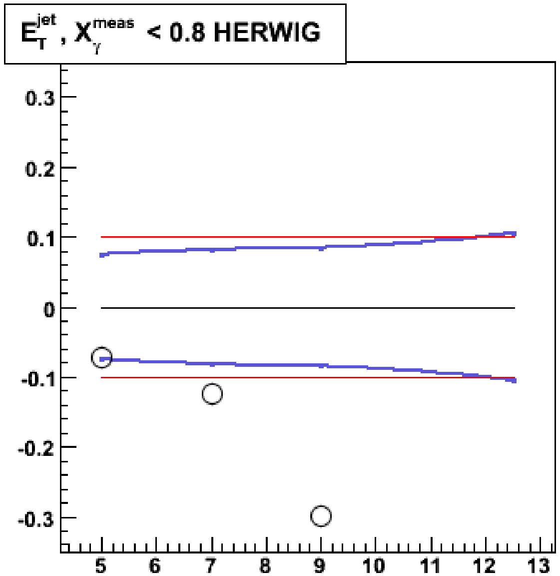


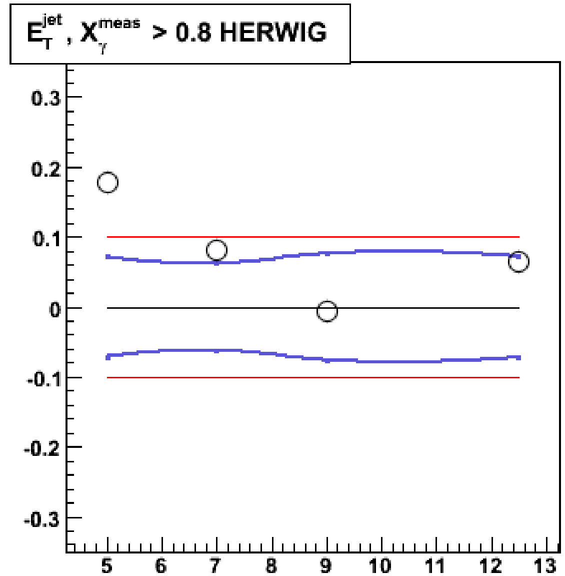
Photon variables.

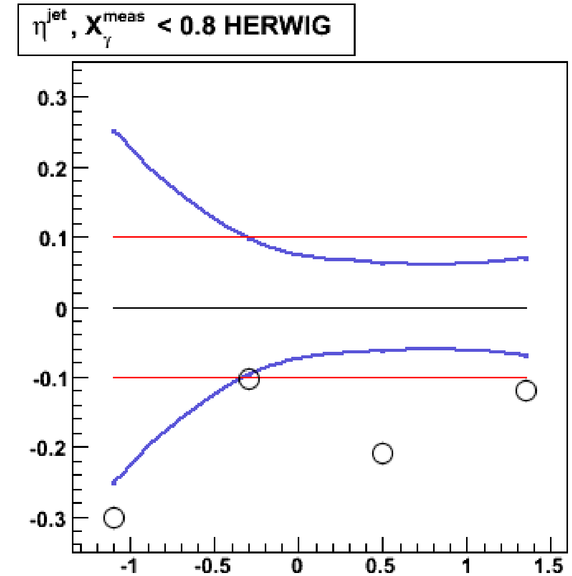
Use HERWIG model (signal and background) instead of PYTHIA for

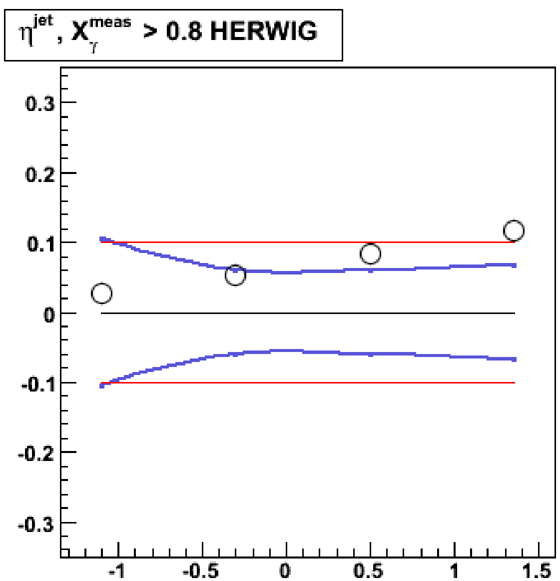
- <δZ> fits
- acceptance corrections calculation
- direct/resolved ratio determination

Major sources of systematics. HERWIG







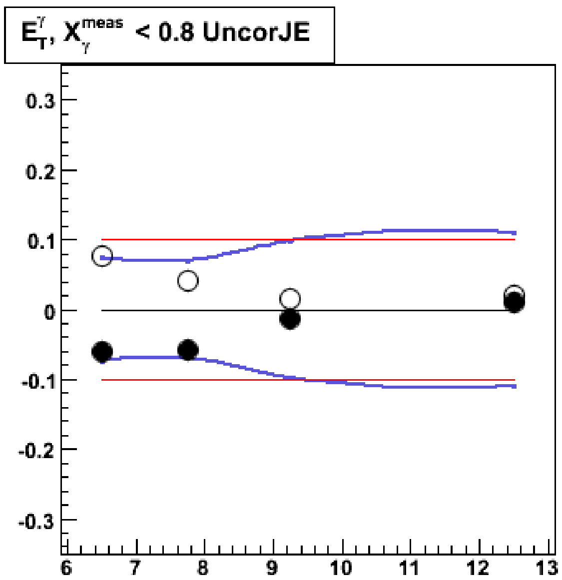


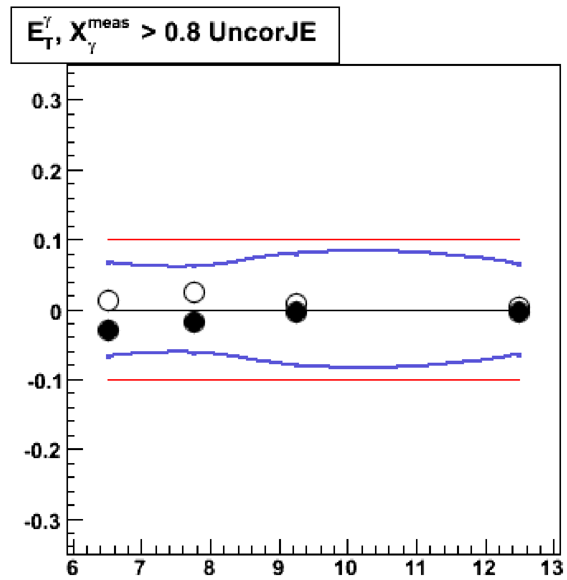
Jet variables.

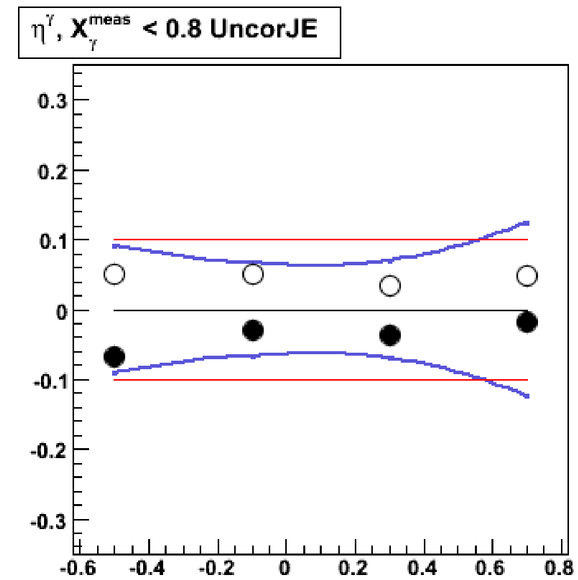
Use HERWIG model (signal and background) instead of PYTHIA for

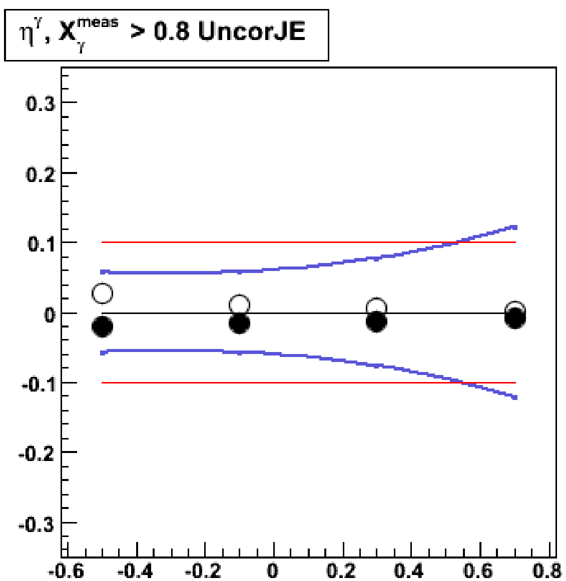
- <δZ> fits
- acceptance corrections calculation
- direct/resolved ratio determination

Major sources of systematics. Jet energy









Photon variables.

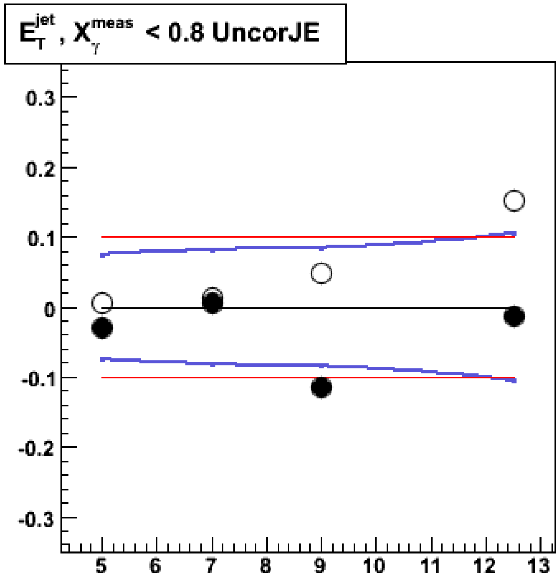
Vary jet energy independently from gamma energy:

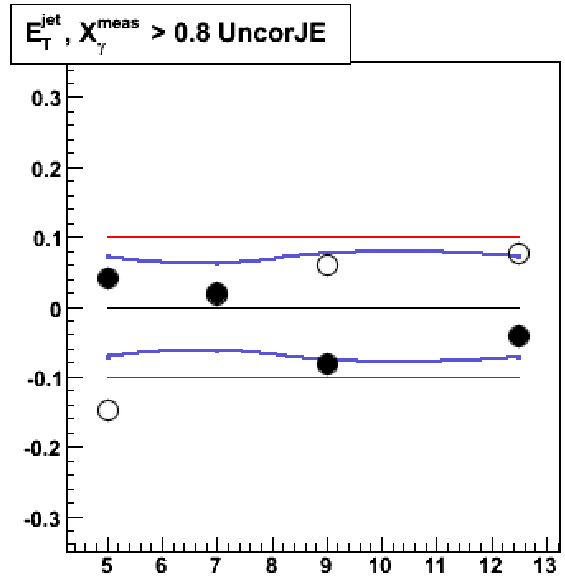
If JetEt ≤ 6 GeV by sqrt(4.*4. + 2.*2.))

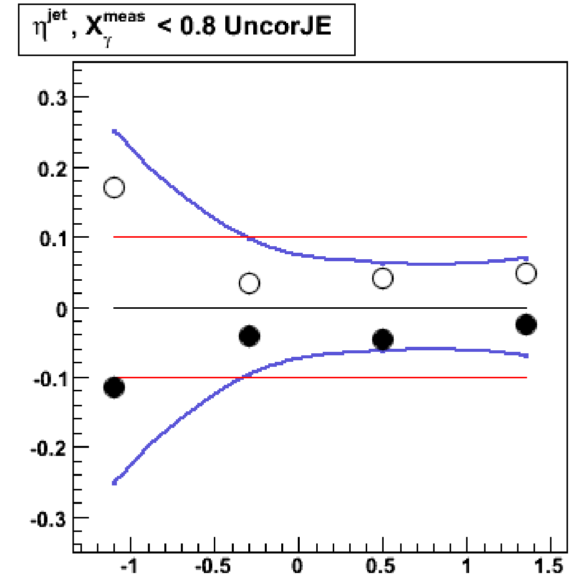
If 6 < JetEt ≤ 10 GeV by sqrt(2.*2. +2.*2.))

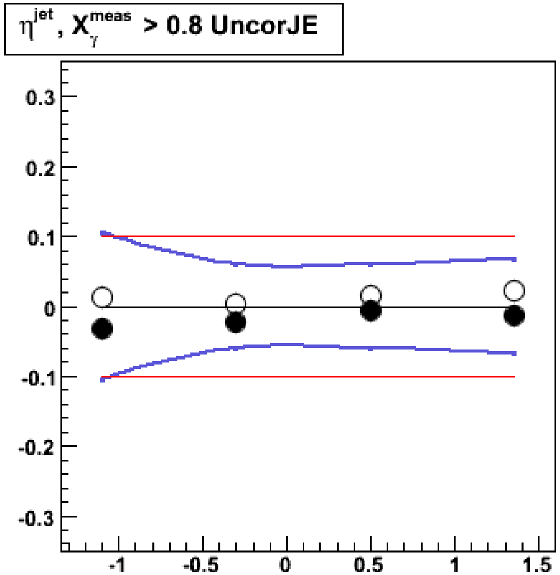
If JetEt > 10 GeV vary by sqrt(1.5*1.5 + 2.*2.))

Major sources of systematics. Jet energy









Photon variables.

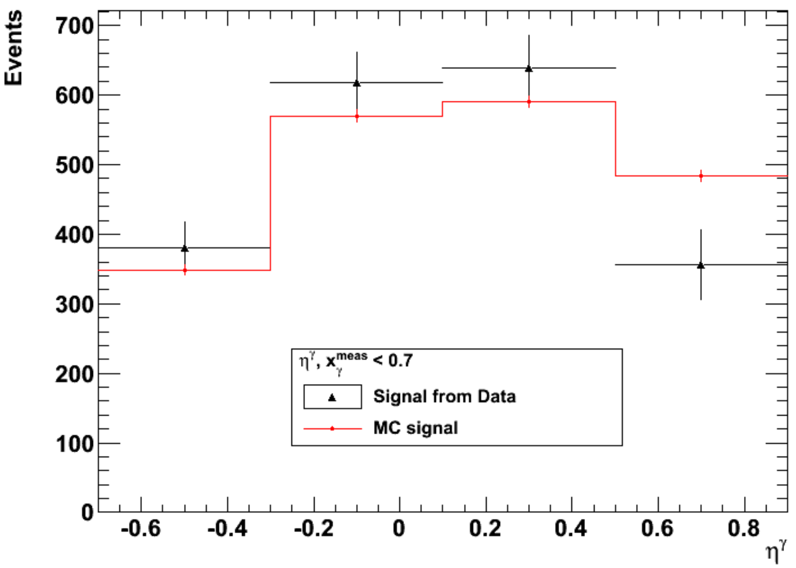
Vary jet energy independently from gamma energy:

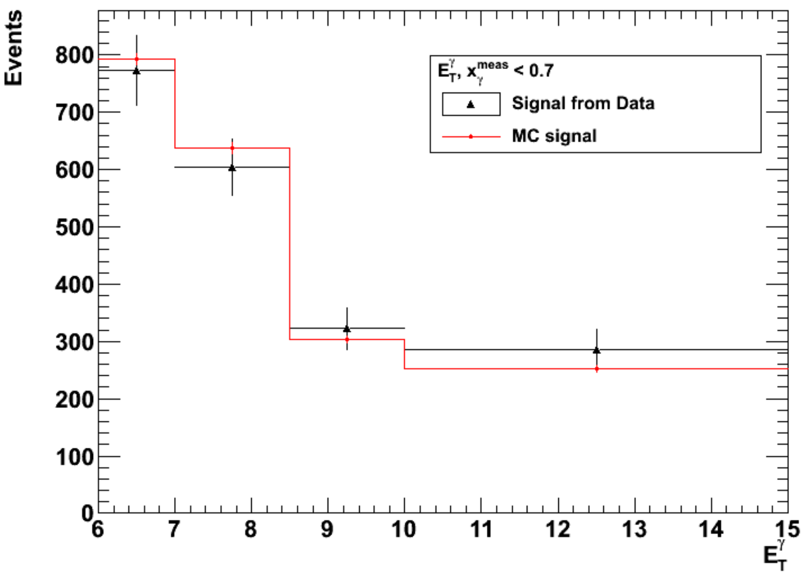
If JetEt ≤ 6 GeV by sqrt(4.*4. + 2.*2.))

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

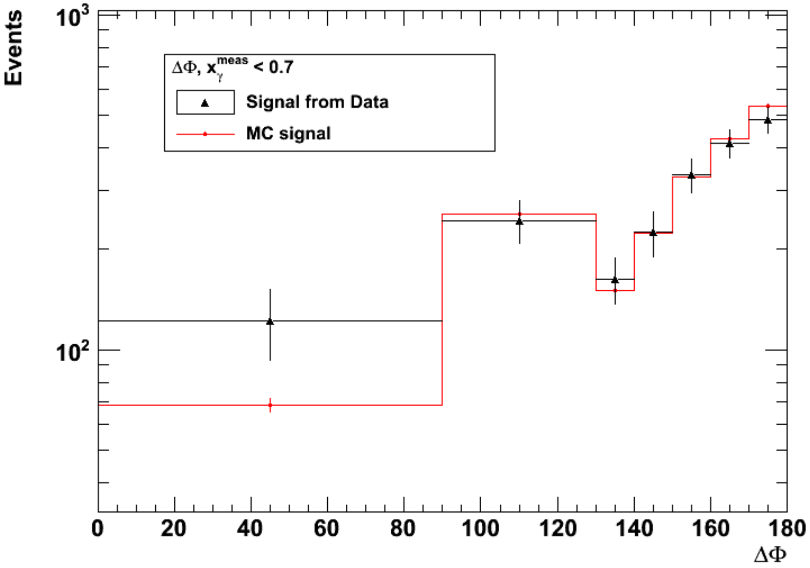
If JetEt > 10 GeV vary by sqrt(1.5*1.5 + 2.*2.))

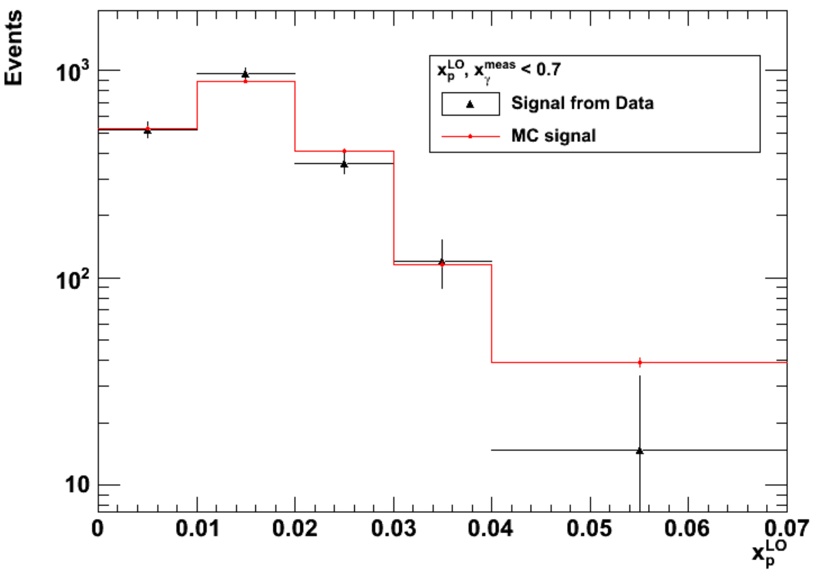
Control plots. $x_\gamma < 0.7$

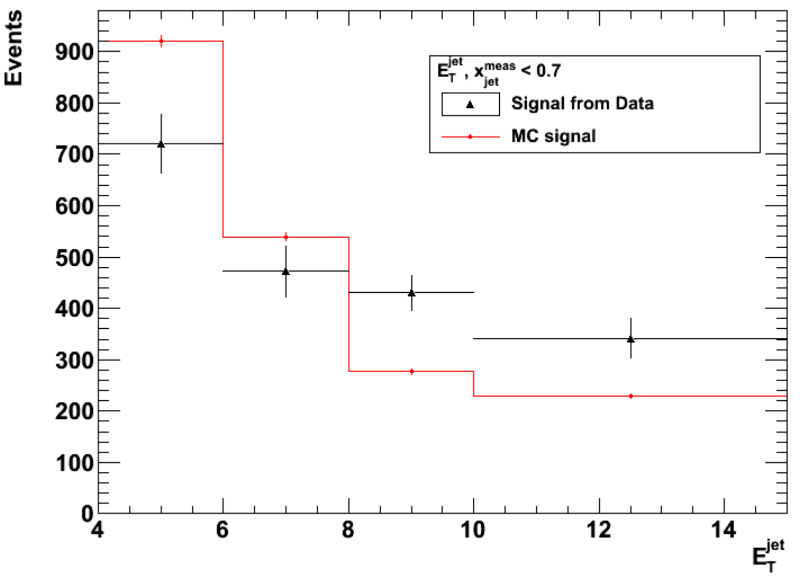


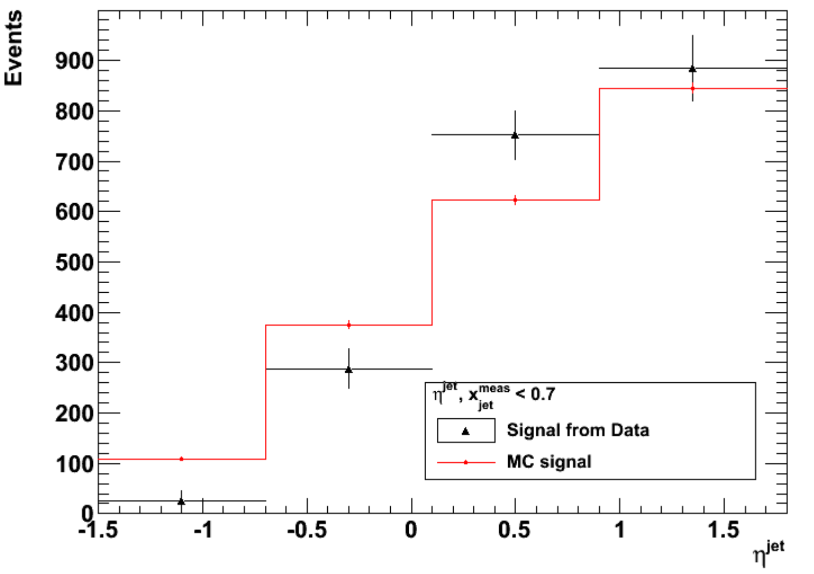


Control plots. $x_\gamma < 0.7$

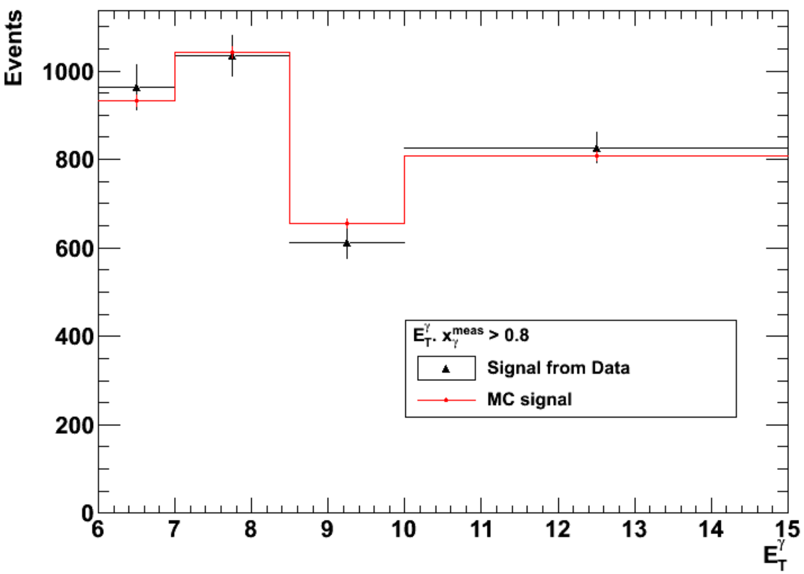


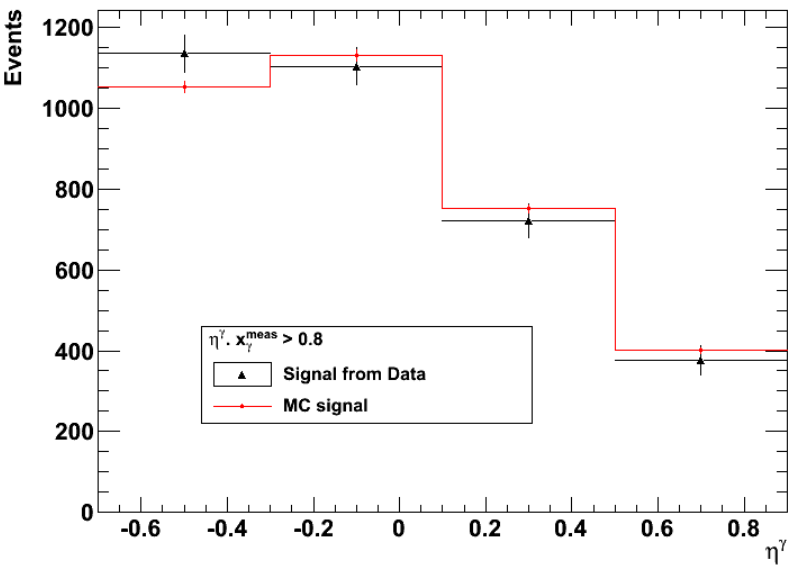




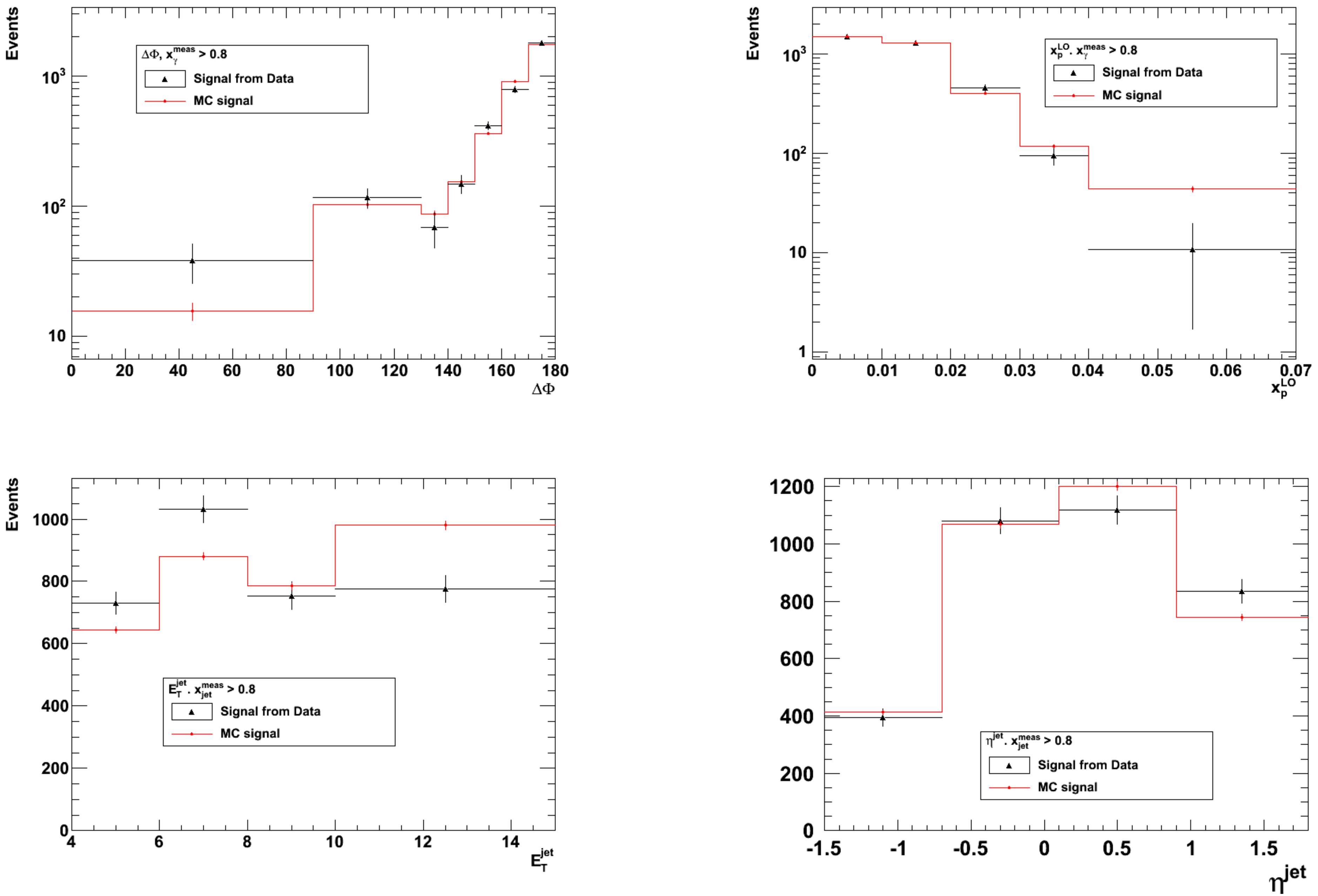


Control plots. $x_\gamma > 0.8$



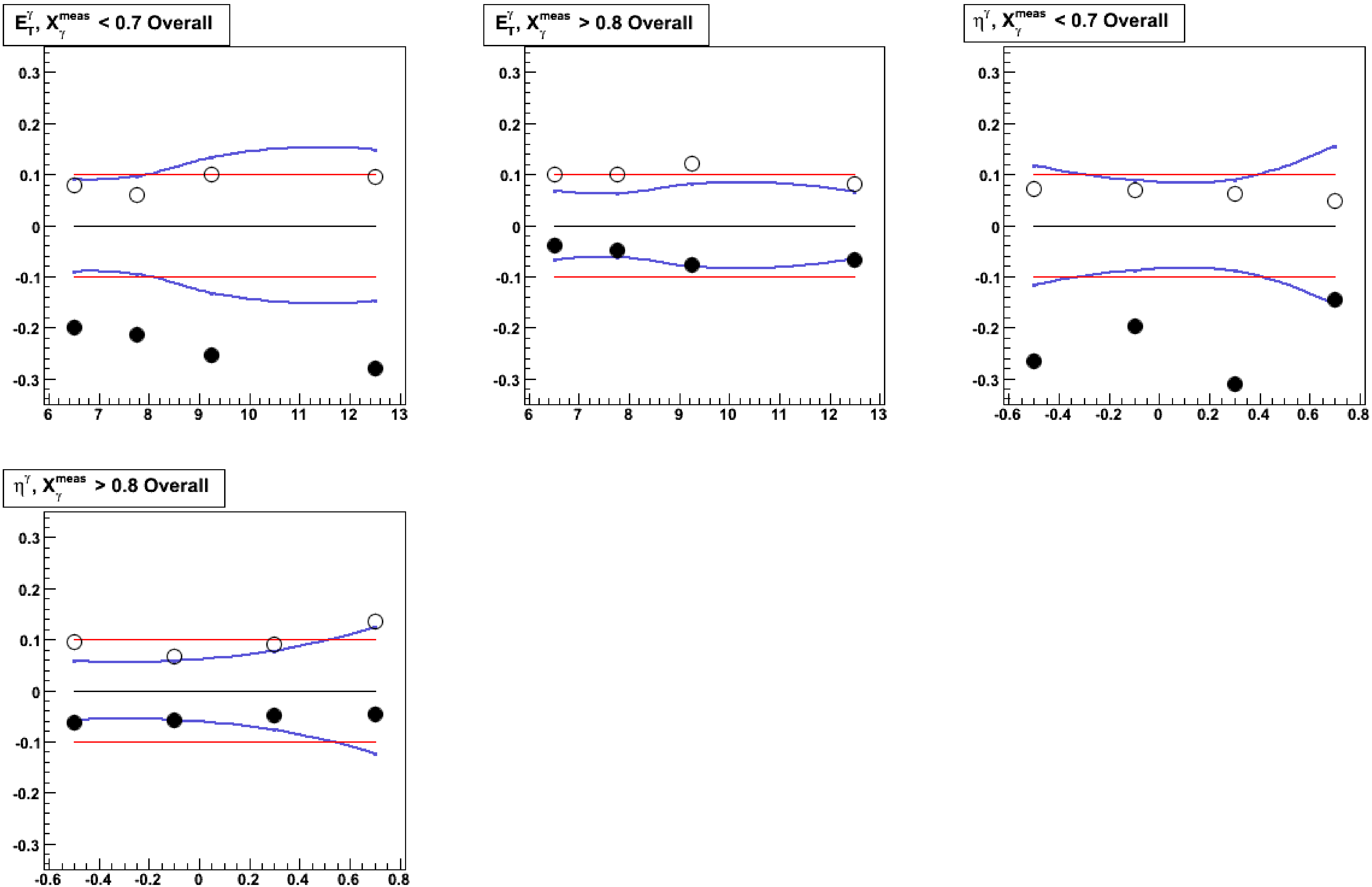


Control plots. $x_\gamma > 0.8$

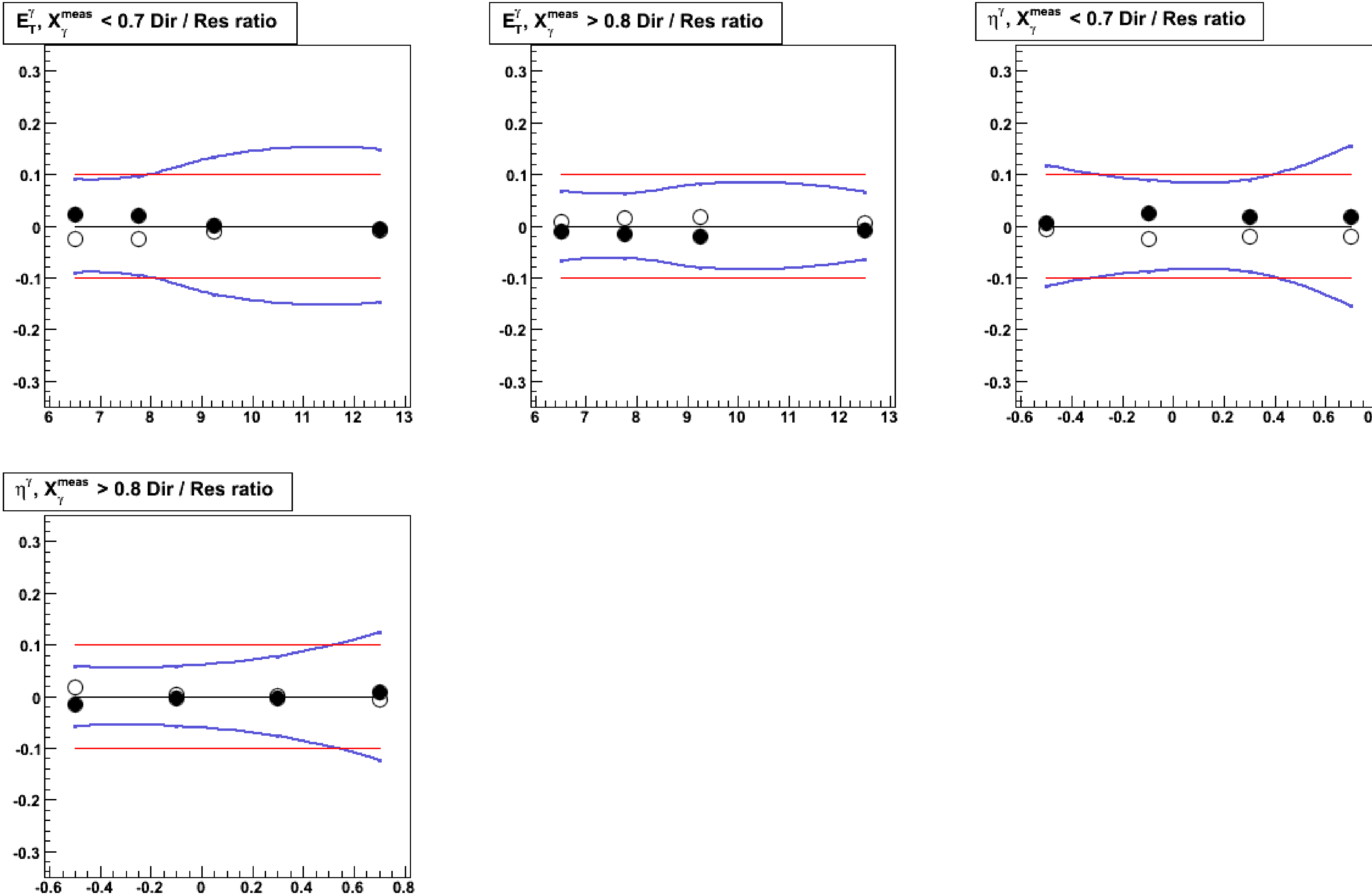


Systematic uncertainties

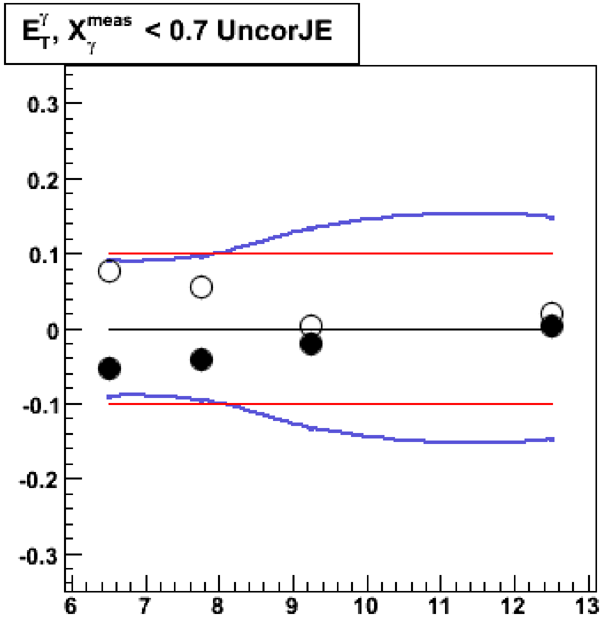
$x_\gamma < 0.7$

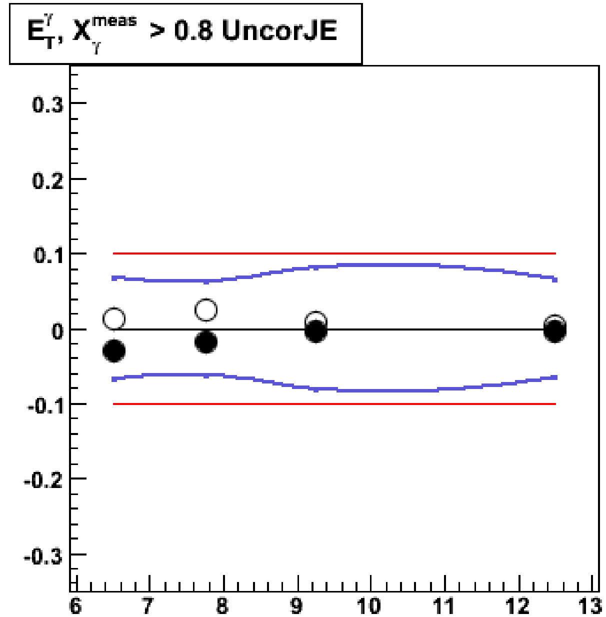


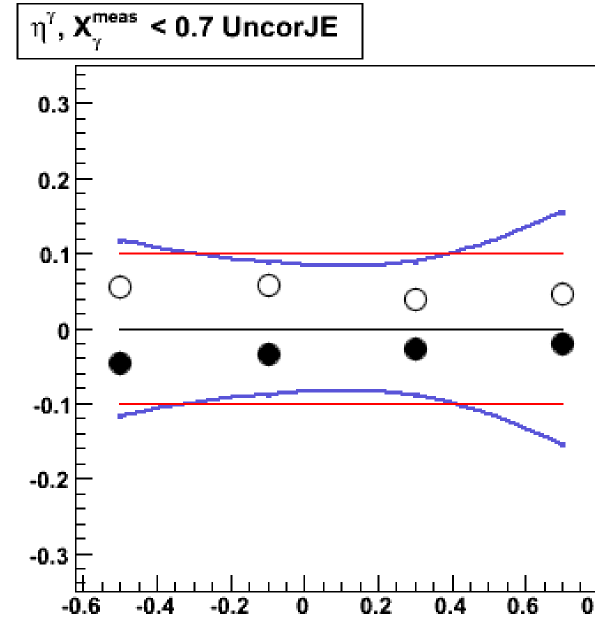
E_T^γ, X_γ^{meas} < 0.7 Overall
E_T^γ, X_γ^{meas} > 0.8 Overall
η^γ, X_γ^{meas} < 0.7 Overall
η^γ, X_γ^{meas} > 0.8 Overall

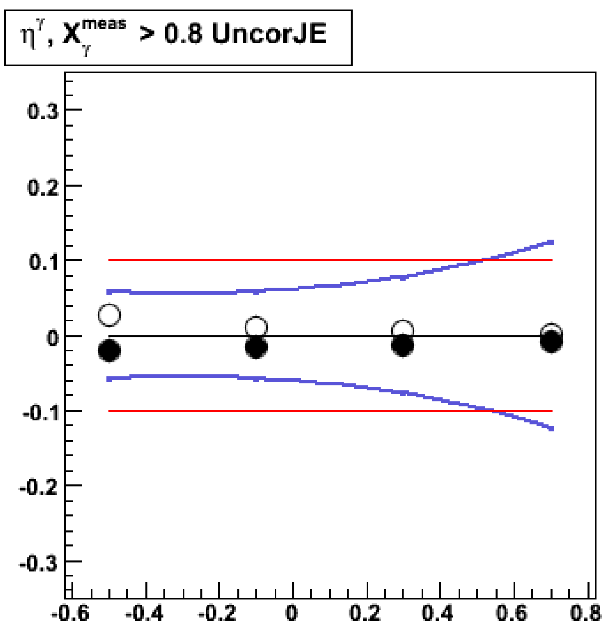


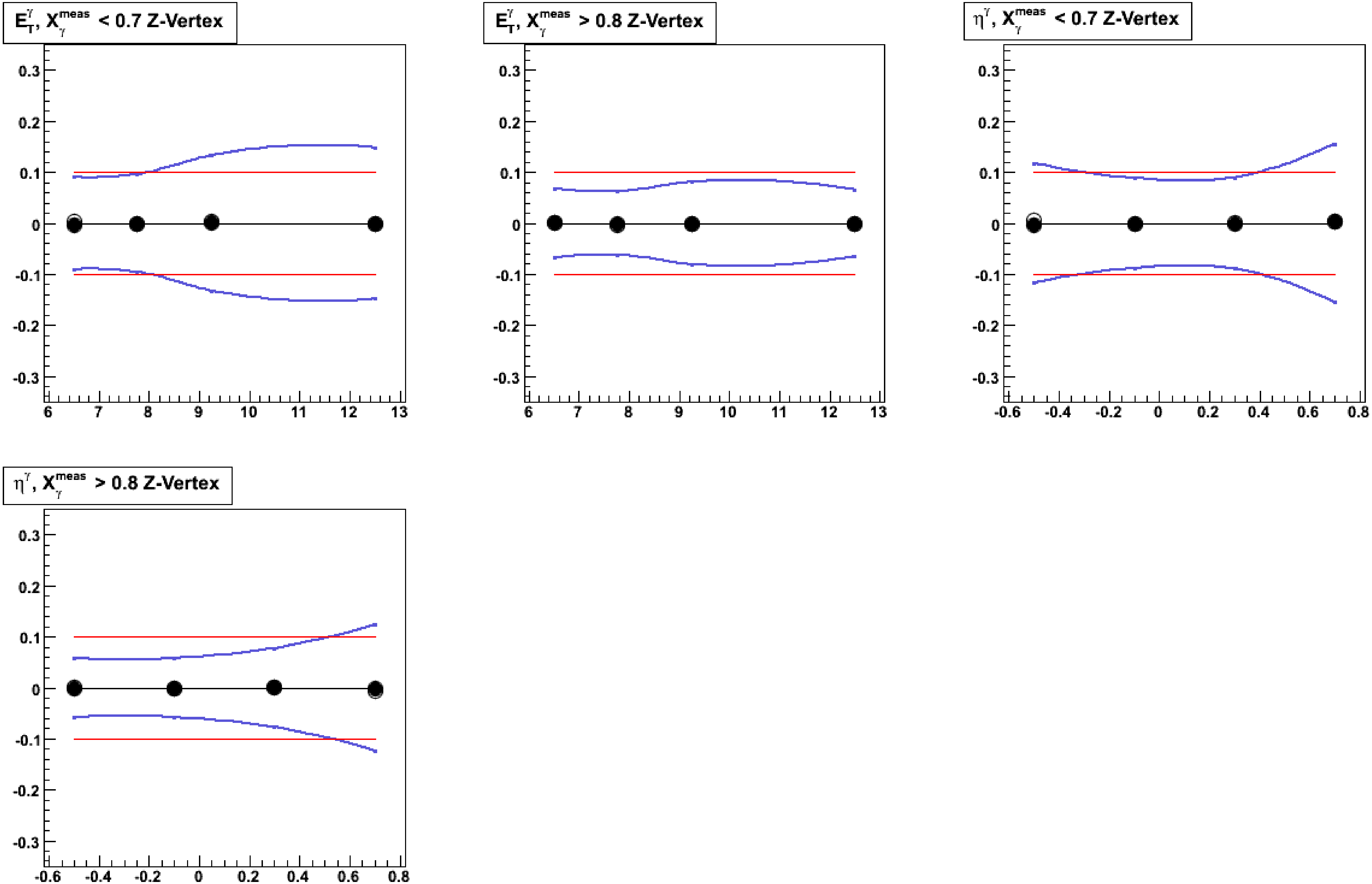
E_T^{γ}, X_{γ}^{meas} < 0.7 Dir / Res ratio
E_T^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio
η^{γ}, X_{γ}^{meas} < 0.7 Dir / Res ratio
η^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

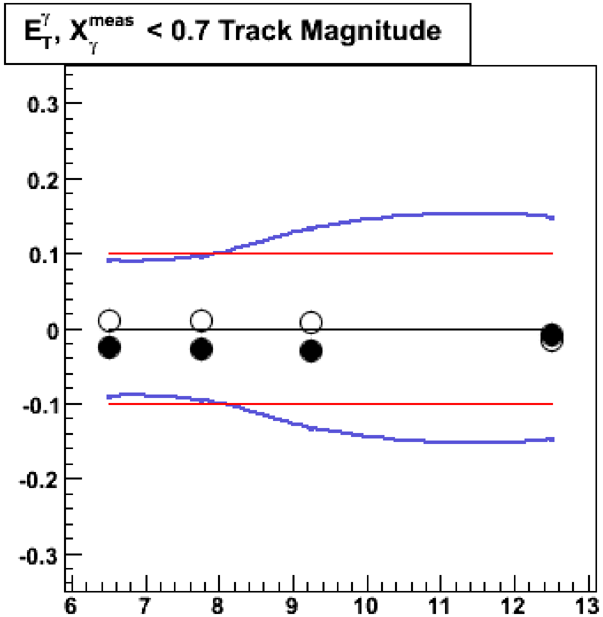

E_T^{γ}, X_{γ}^{meas} < 0.7 UncorJE

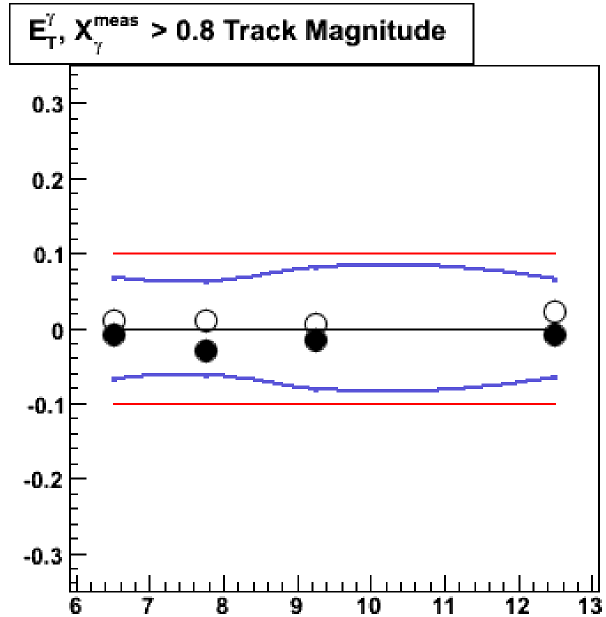

E_T^{γ}, X_{γ}^{meas} > 0.8 UncorJE

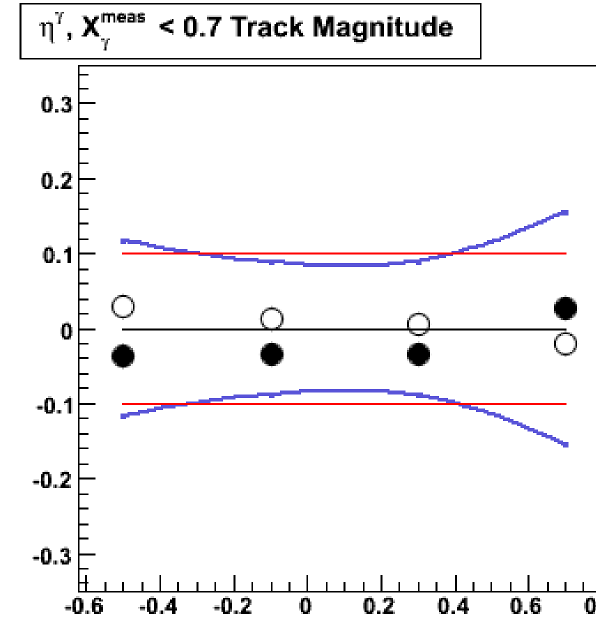

η^{γ}, X_{γ}^{meas} < 0.7 UncorJE

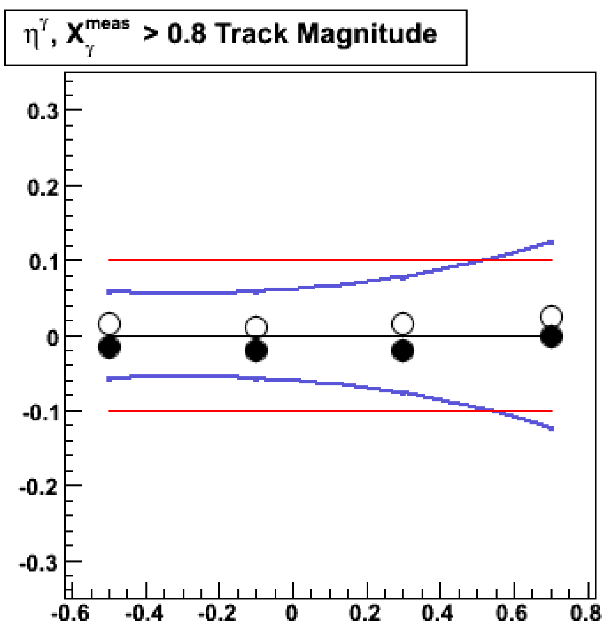

η^{γ}, X_{γ}^{meas} > 0.8 UncorJE

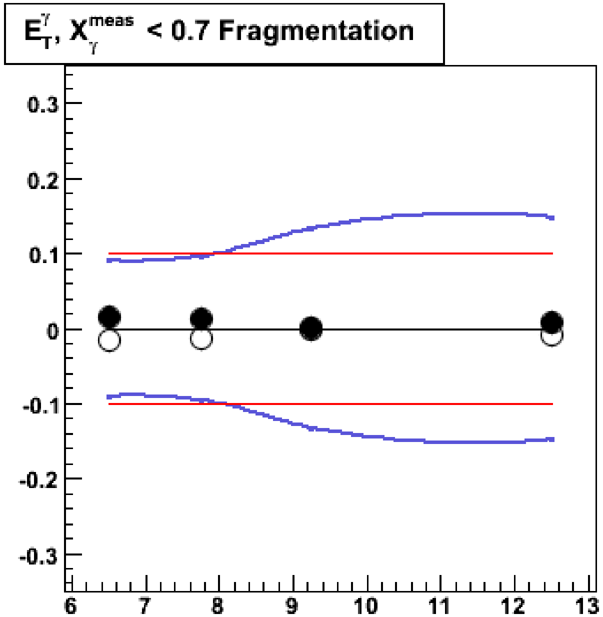

E_T^γ, X_γ^{meas} < 0.7 Z-Vertex
E_T^γ, X_γ^{meas} > 0.8 Z-Vertex
η^γ, X_γ^{meas} < 0.7 Z-Vertex
η^γ, X_γ^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

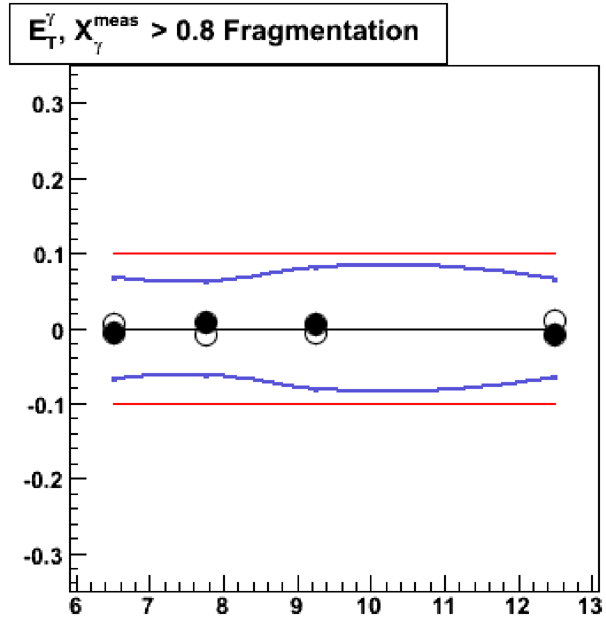

E_T^γ, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

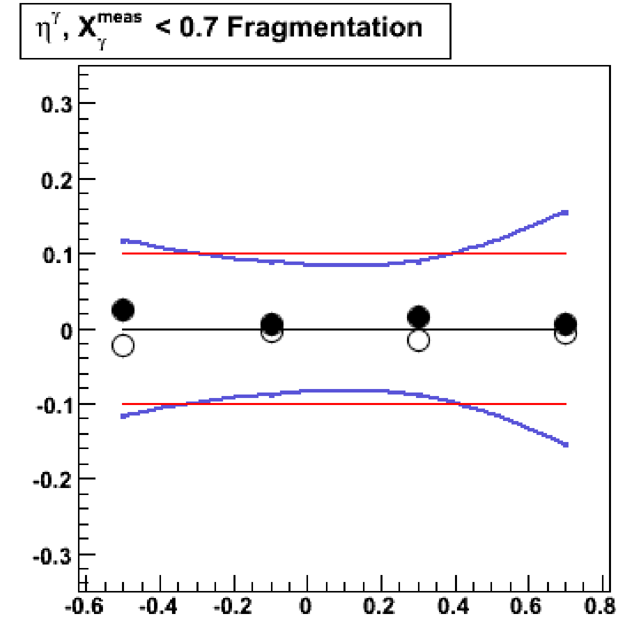

E_T^γ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13

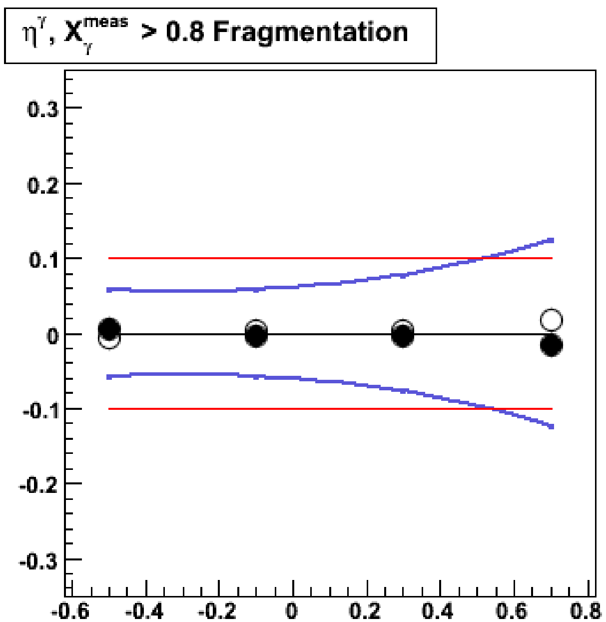

η^γ, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

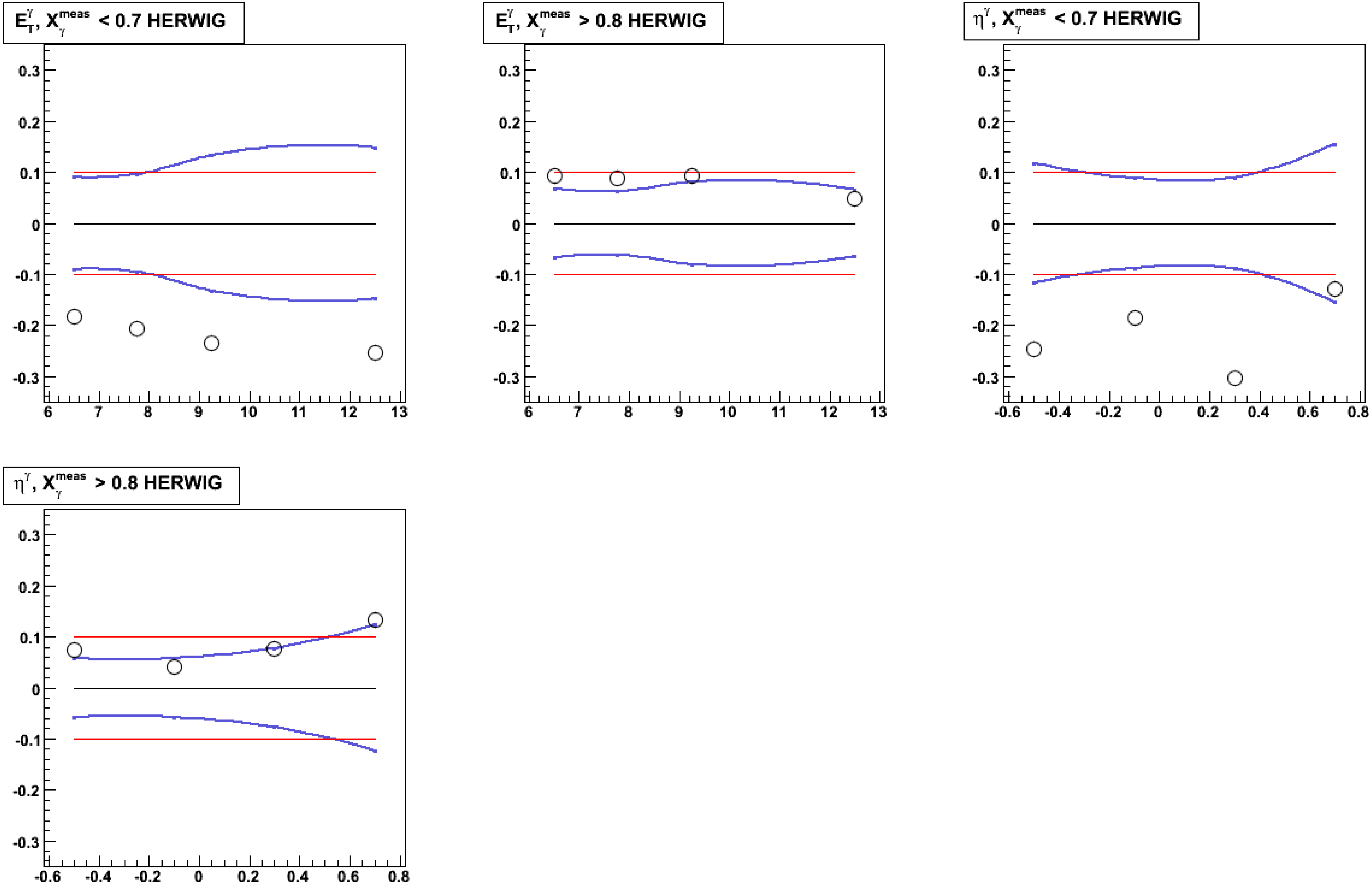

η^γ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8


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

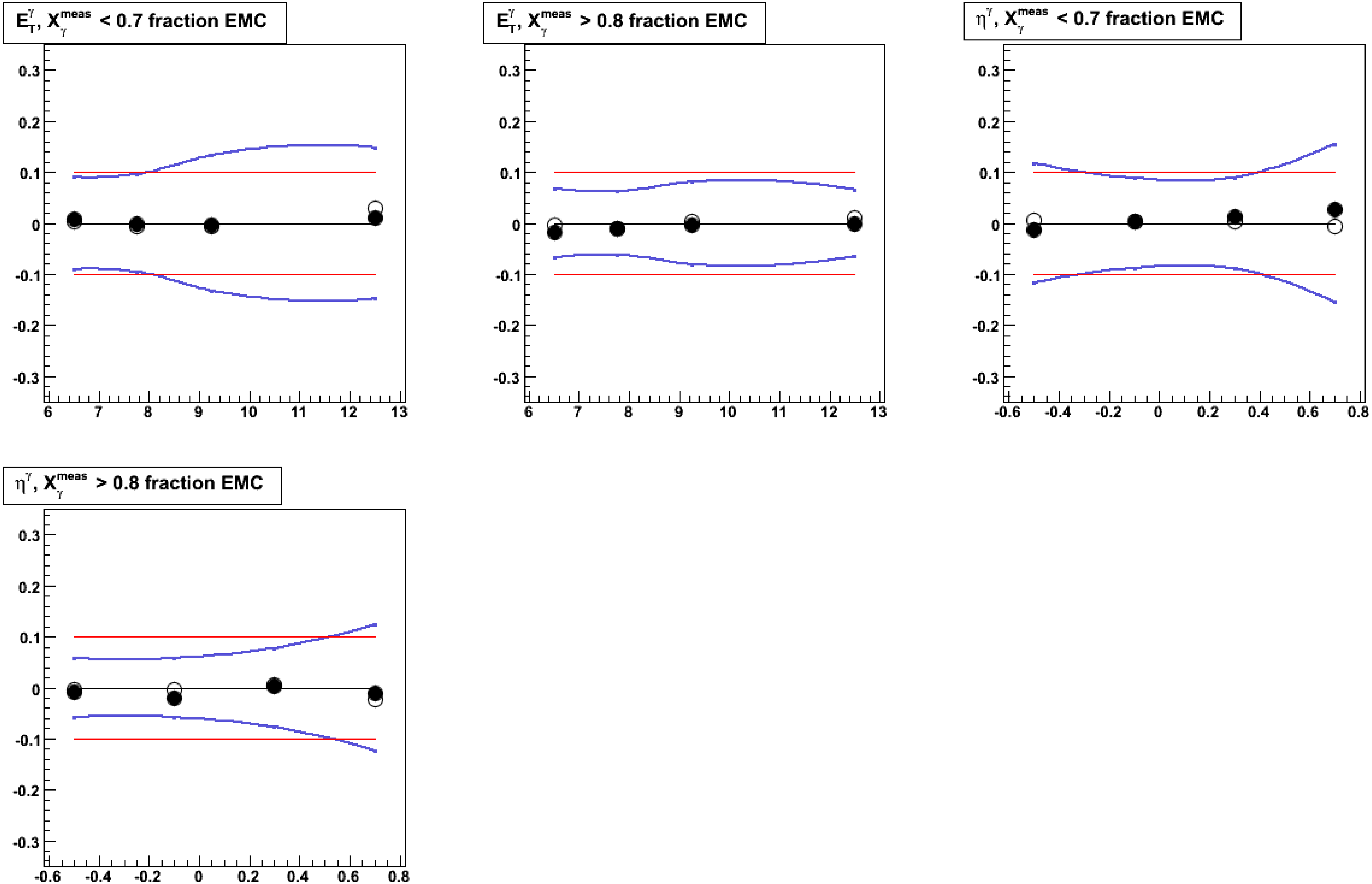

E_T^{γ}, X_{γ}^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6
7
8
9
10
11
12
13


η^{γ}, X_{γ}^{meas} < 0.7 Fragmentation
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

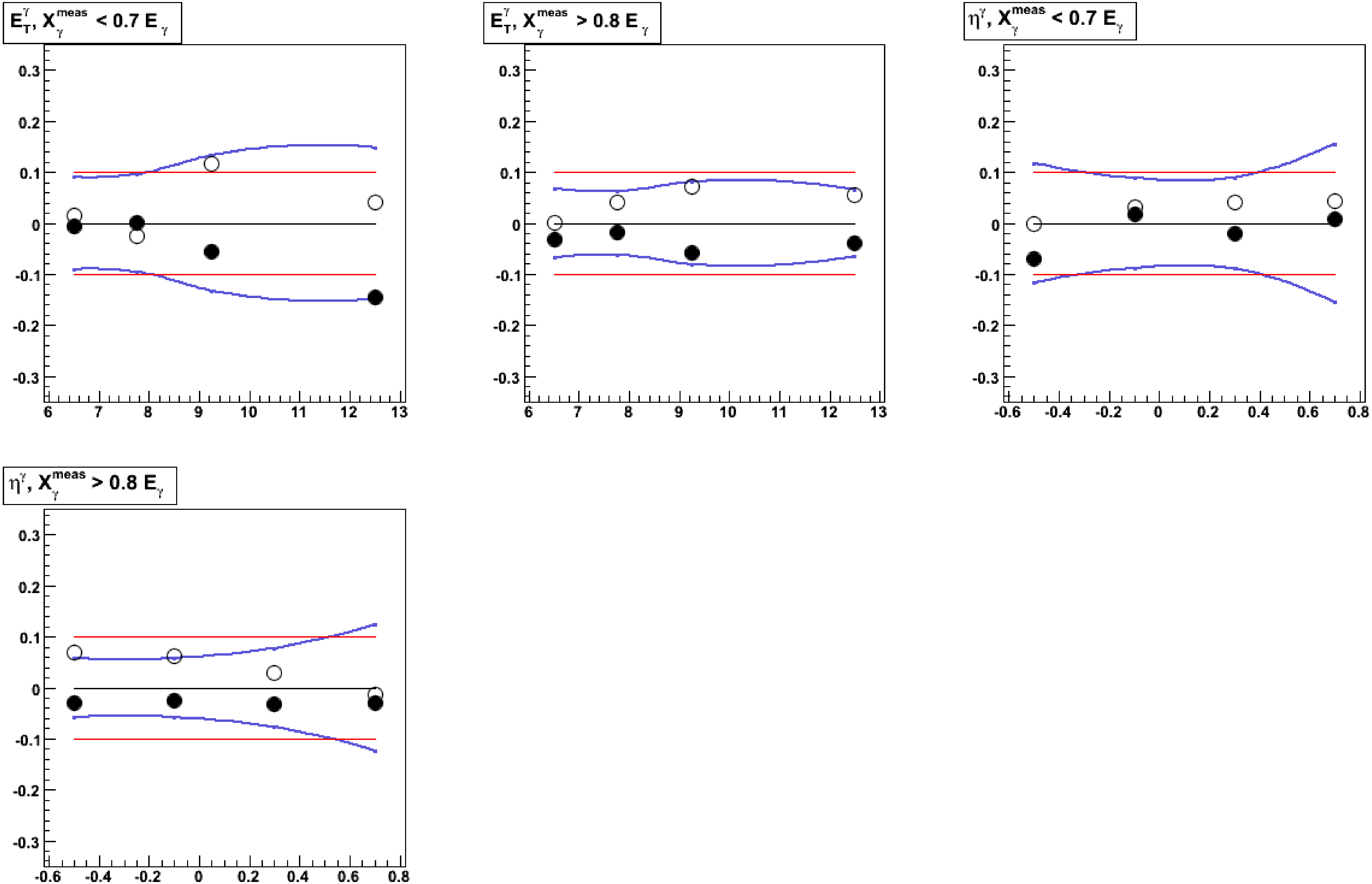

η^{γ}, X_{γ}^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8



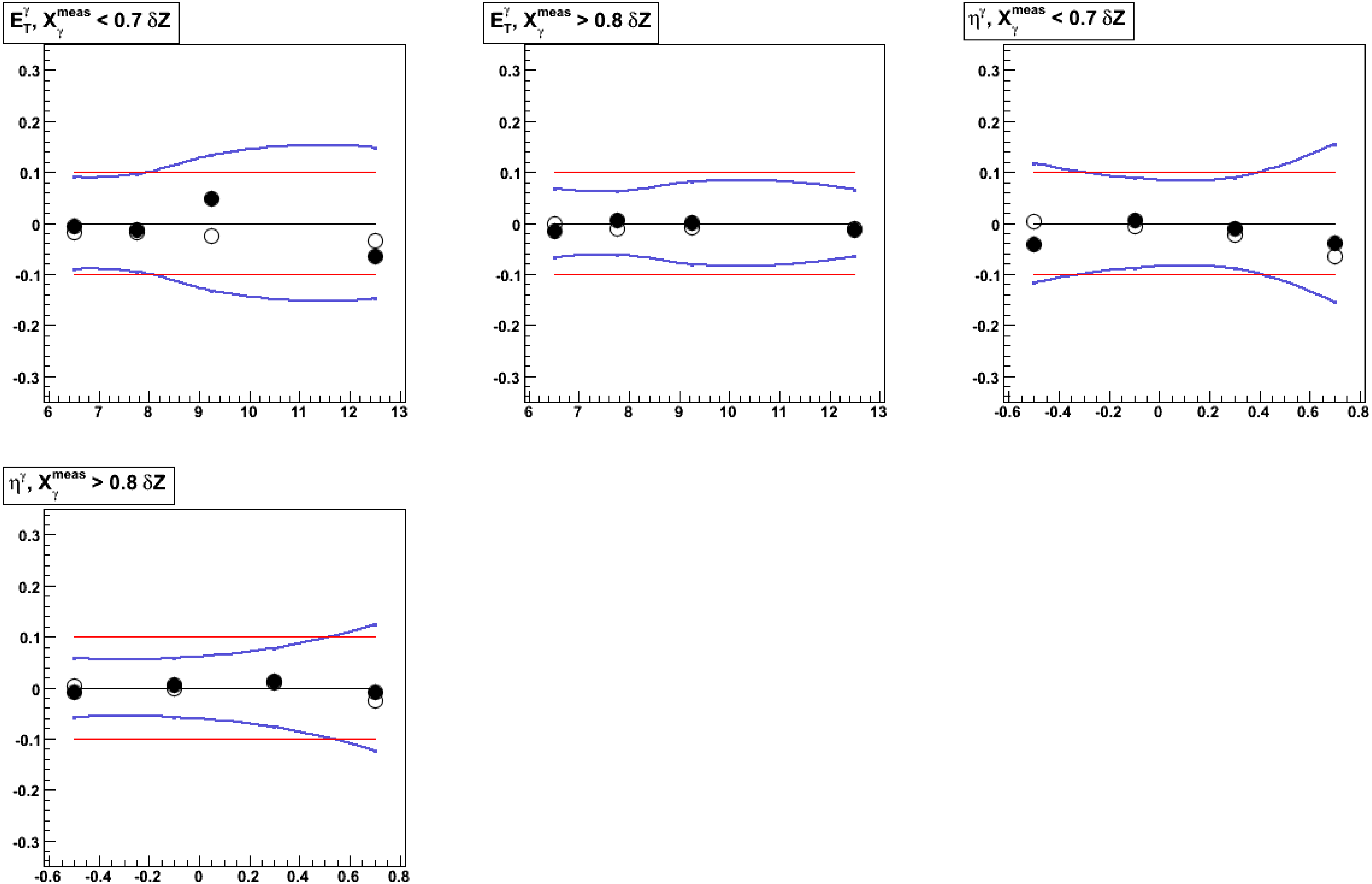
E_T^γ, X_γ^{meas} < 0.7 HERWIG
E_T^γ, X_γ^{meas} > 0.8 HERWIG
η^γ, X_γ^{meas} < 0.7 HERWIG
η^γ, X_γ^{meas} > 0.8 HERWIG



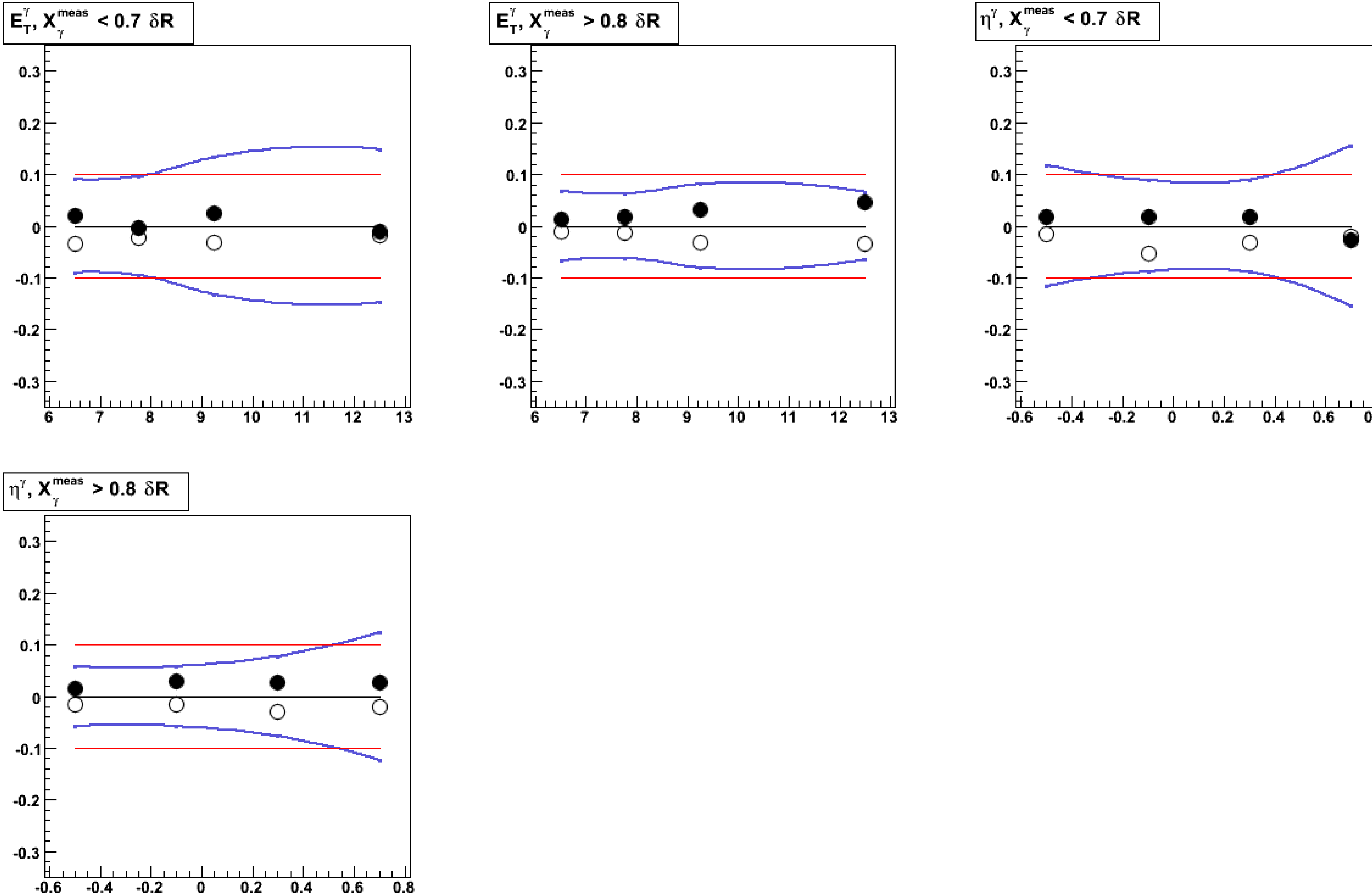
E_T^{γ}, X_{γ}^{meas} < 0.7 fraction EMC
E_T^{γ}, X_{γ}^{meas} > 0.8 fraction EMC
η^{γ}, X_{γ}^{meas} < 0.7 fraction EMC
η^{γ}, X_{γ}^{meas} > 0.8 fraction EMC



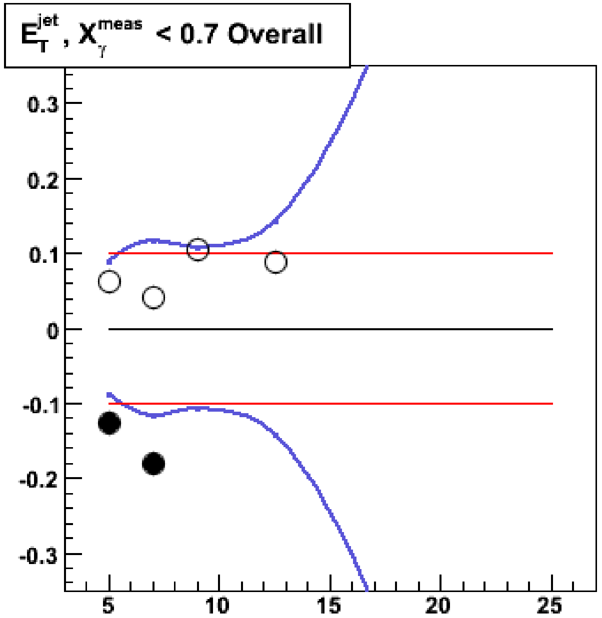
E_T^γ, X_γ^{meas} < 0.7 E_γ
E_T^γ, X_γ^{meas} > 0.8 E_γ
η^γ, X_γ^{meas} < 0.7 E_γ
η^γ, X_γ^{meas} > 0.8 E_γ

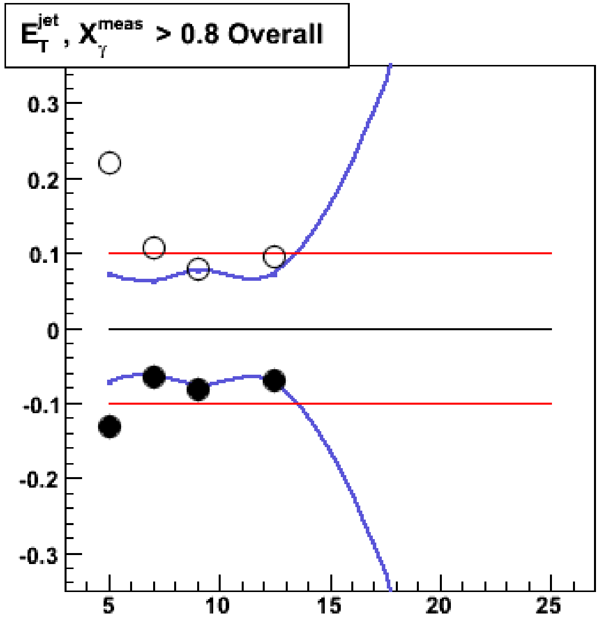


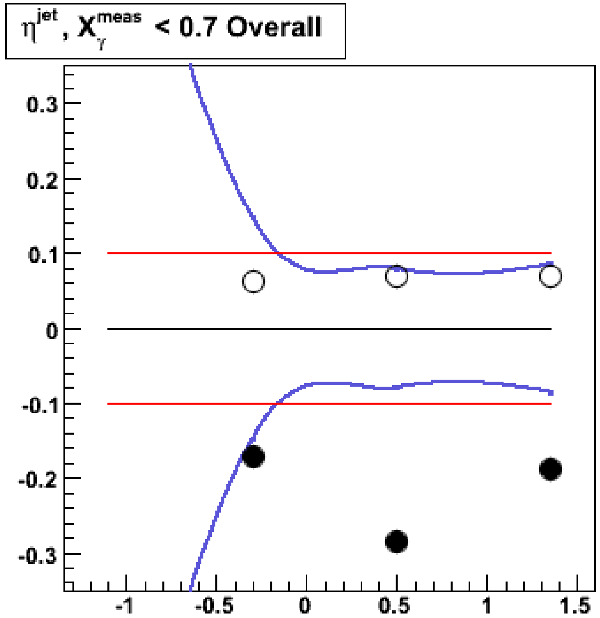
E_T^γ, X_γ^{meas} < 0.7 δZ
E_T^γ, X_γ^{meas} > 0.8 δZ
η^γ, X_γ^{meas} < 0.7 δZ
η^γ, X_γ^{meas} > 0.8 δZ

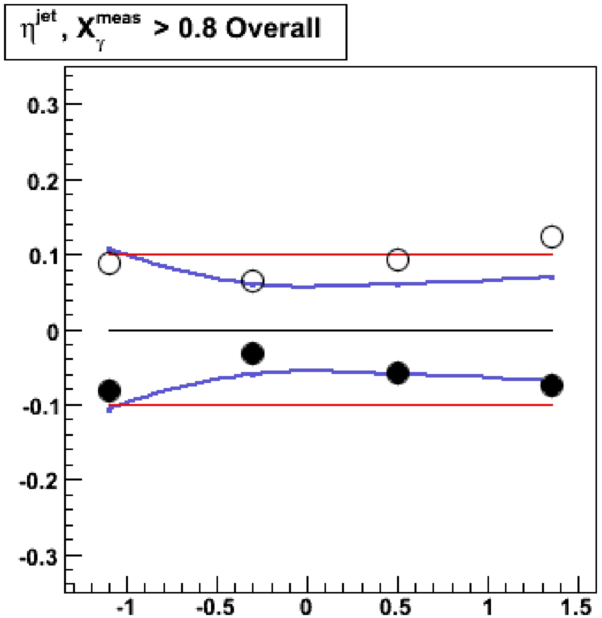


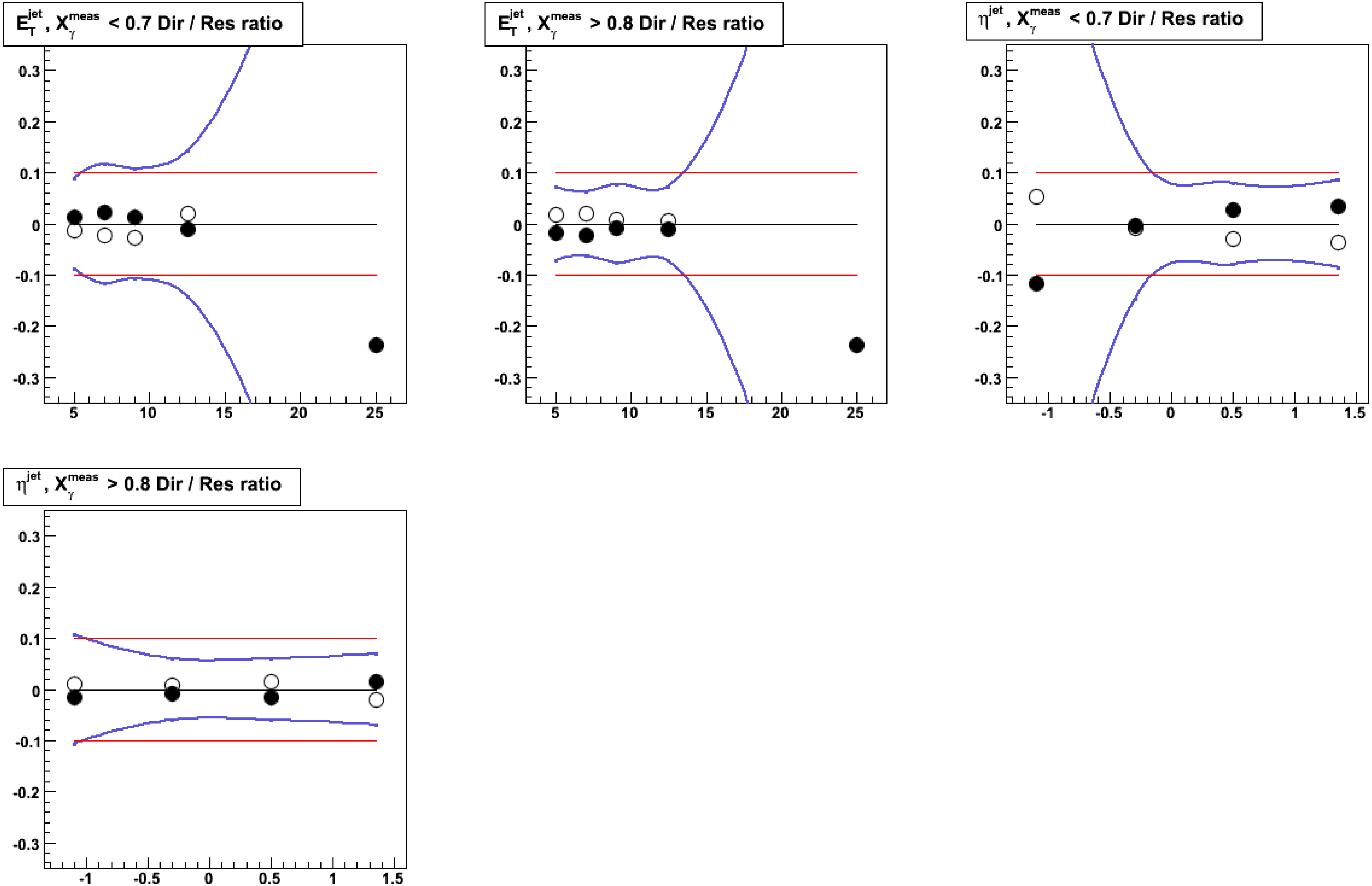
E_T^{γ}, X_{γ}^{meas} < 0.7 δR
E_T^{γ}, X_{γ}^{meas} > 0.8 δR
η^{γ}, X_{γ}^{meas} < 0.7 δR
η^{γ}, X_{γ}^{meas} > 0.8 δR

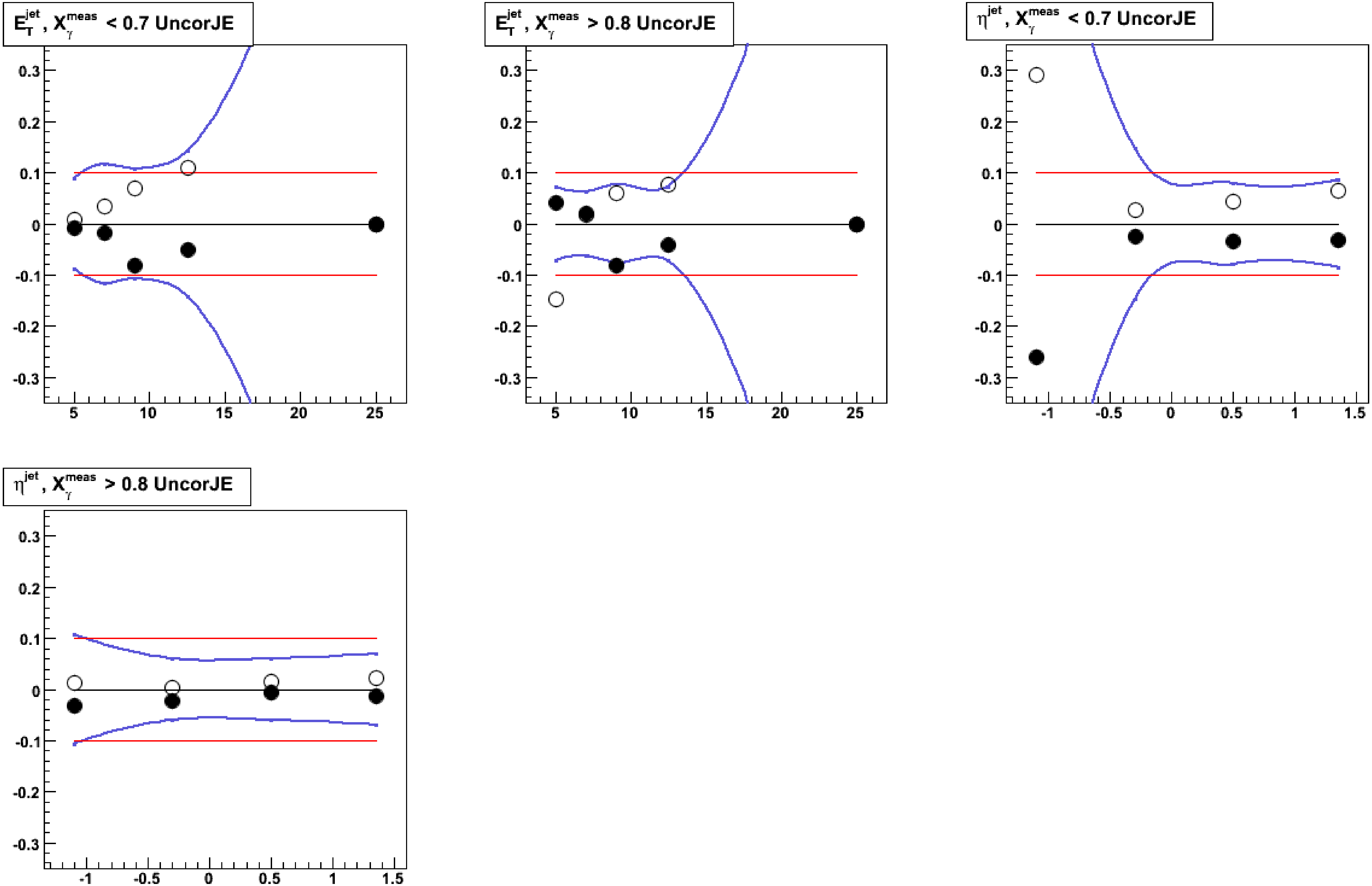

E_T^{jet}, X_γ^{meas} < 0.7 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25

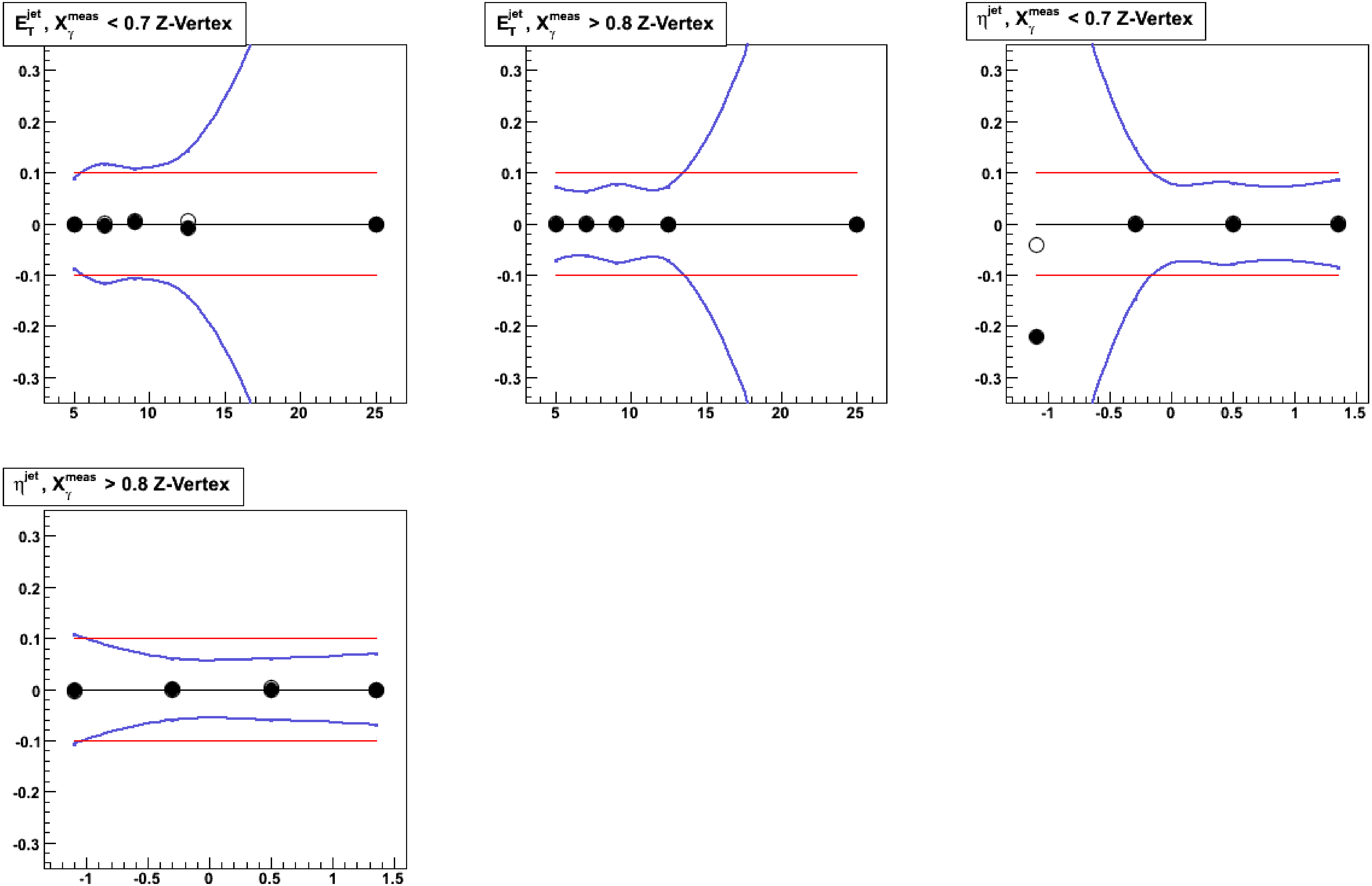

E_T^{jet}, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25

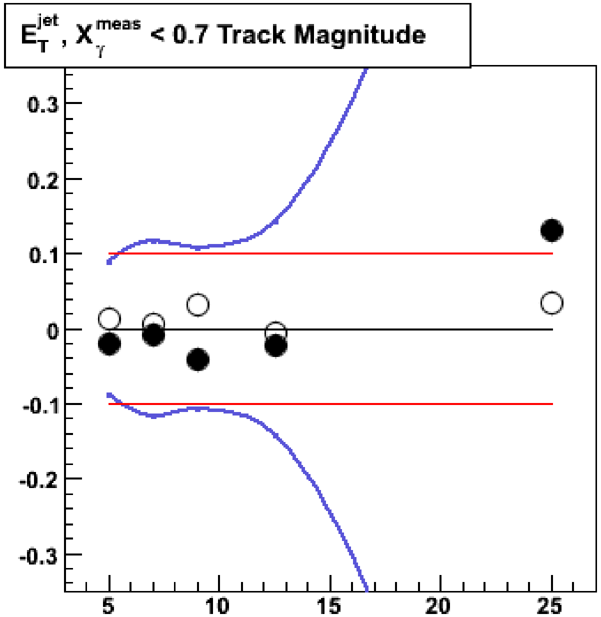

η^{jet}, X_γ^{meas} < 0.7 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

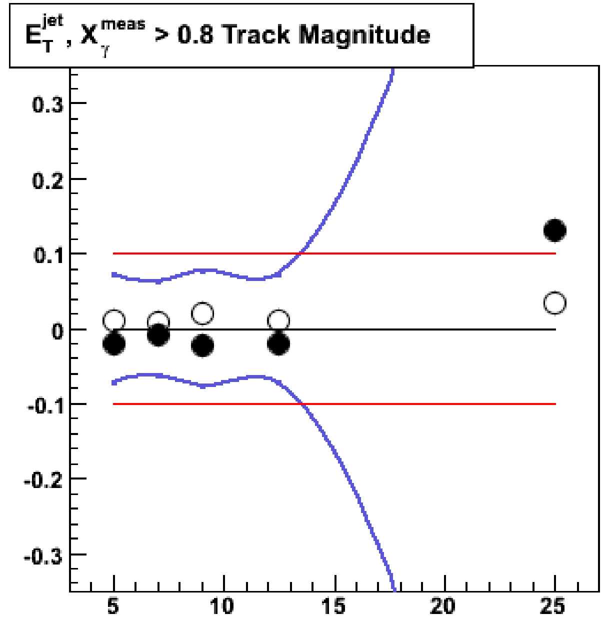

η^{jet}, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

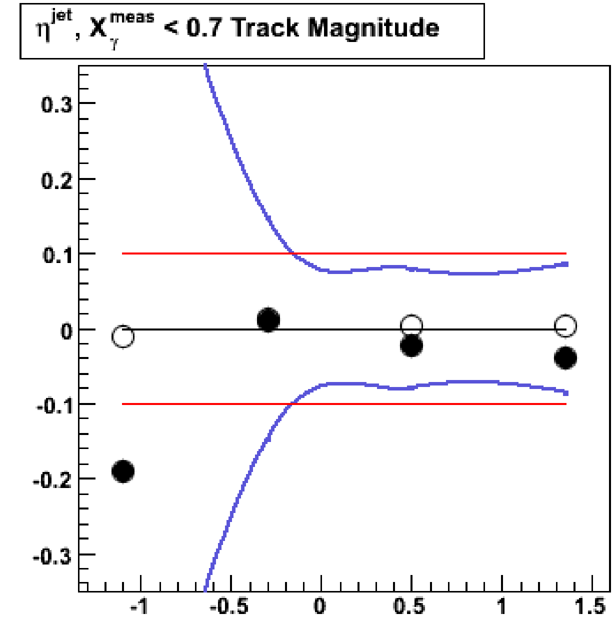

E_T^{jet}, X_γ^{meas} < 0.7 Dir / Res ratio
E_T^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio
η^{jet}, X_γ^{meas} < 0.7 Dir / Res ratio
η^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio

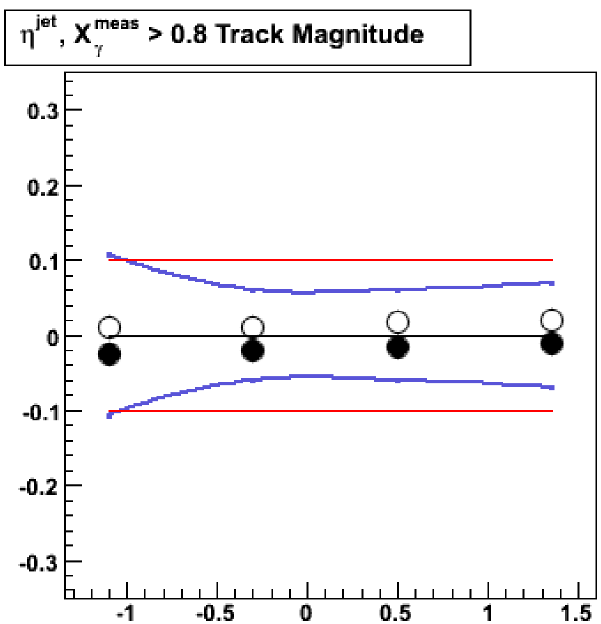

E_T^{jet}, X_γ^{meas} < 0.7 UncorJE
E_T^{jet}, X_γ^{meas} > 0.8 UncorJE
η^{jet}, X_γ^{meas} < 0.7 UncorJE
η^{jet}, X_γ^{meas} > 0.8 UncorJE

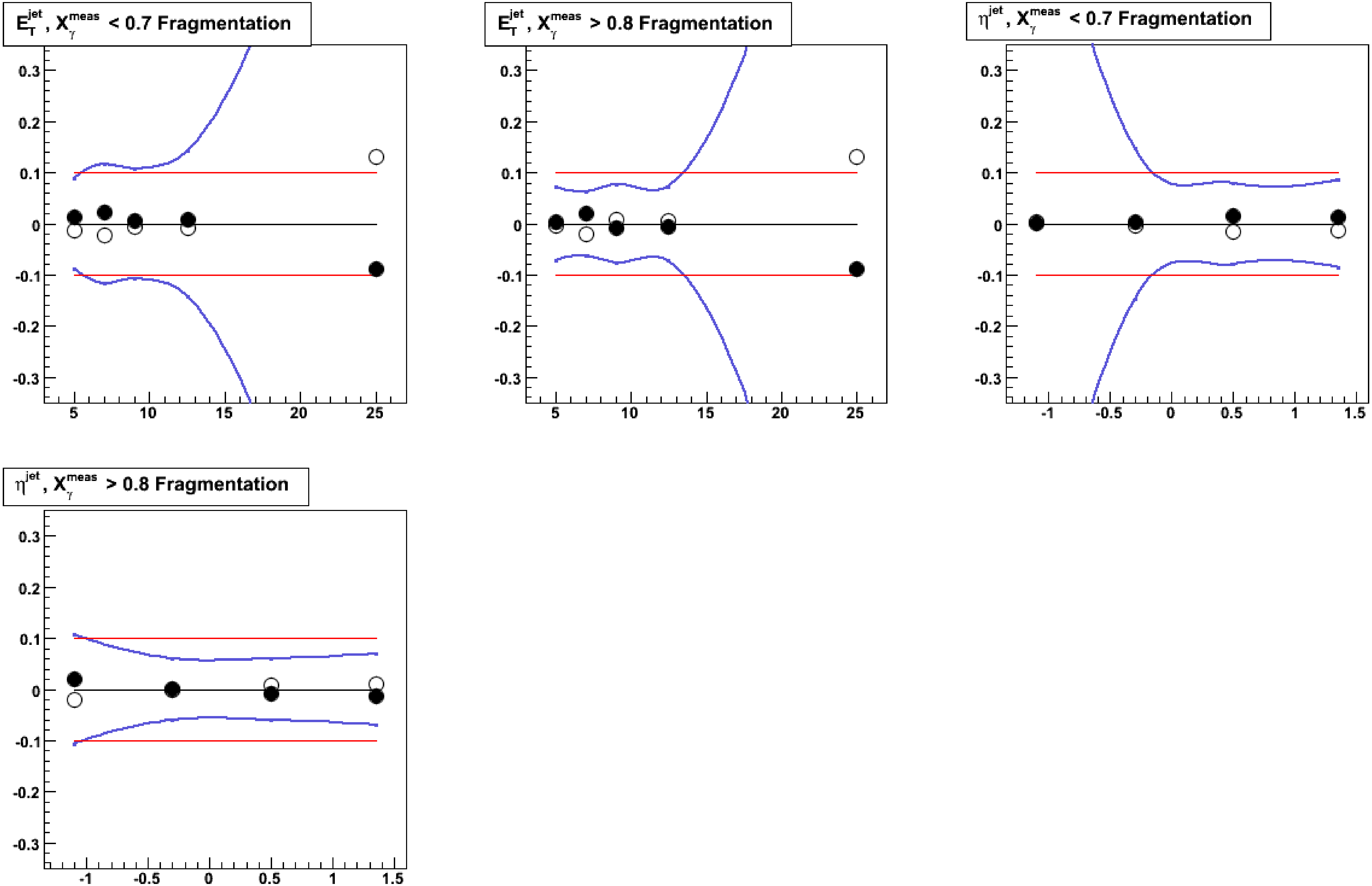

$E_T^{jet}, X_\gamma^{meas} < 0.7$ Z-Vertex
$E_T^{jet}, X_\gamma^{meas} > 0.8$ Z-Vertex
$\eta^{jet}, X_\gamma^{meas} < 0.7$ Z-Vertex
$\eta^{jet}, X_\gamma^{meas} > 0.8$ Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25
-1
-0.5
0
0.5
1
1.5


E_T^{jet}, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25

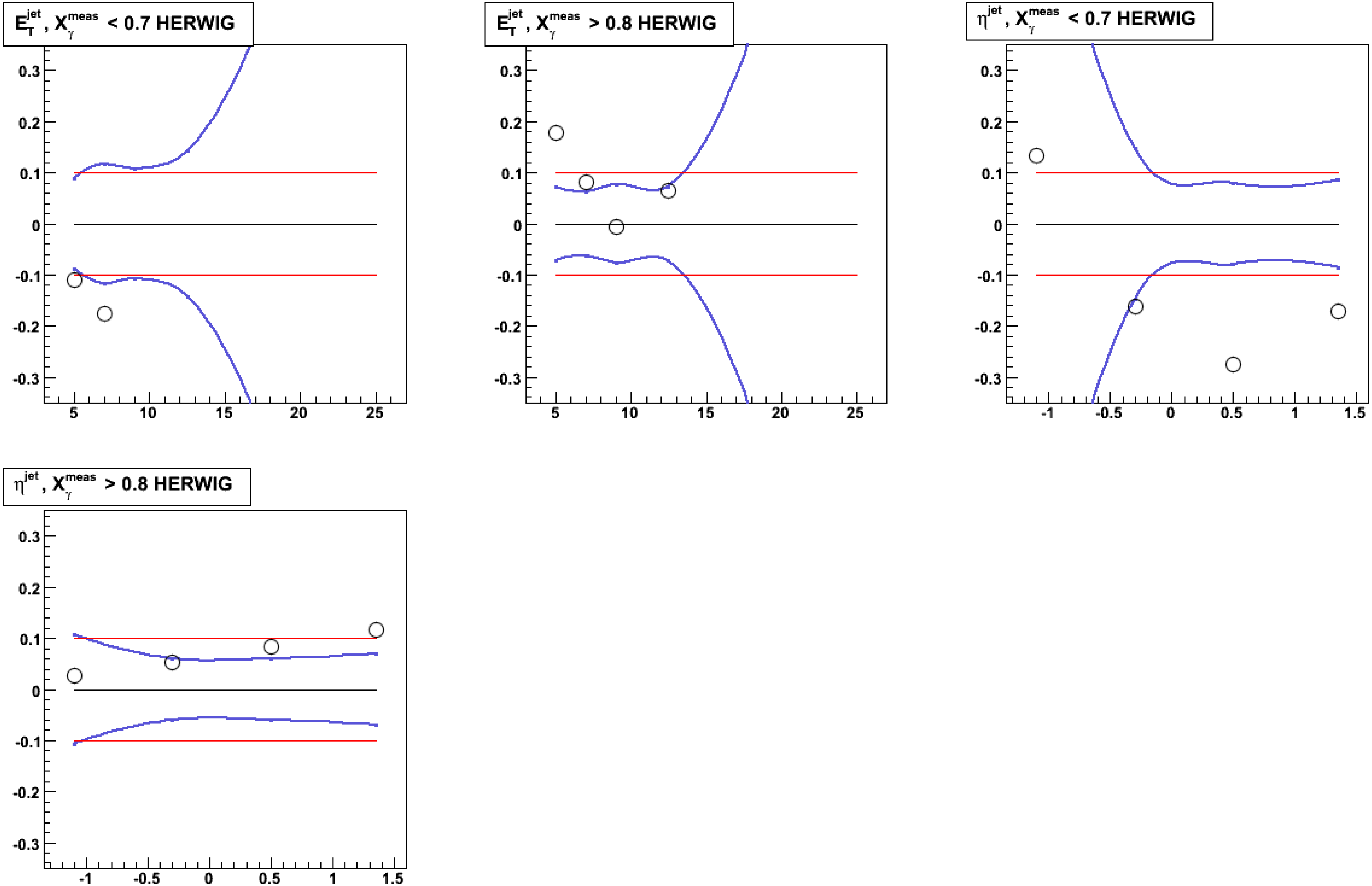

E_T^{jet}, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25

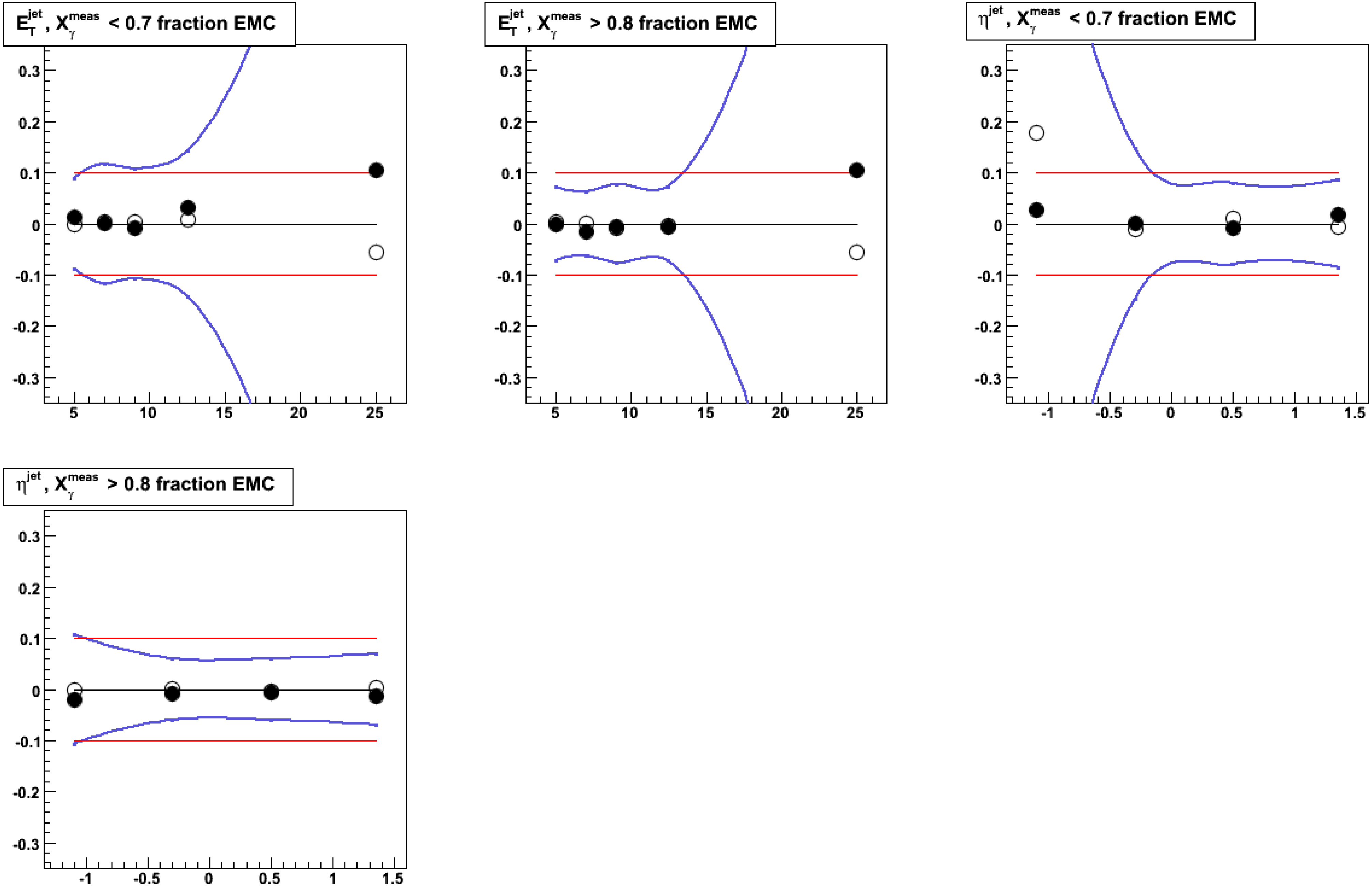

η^{jet}, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5

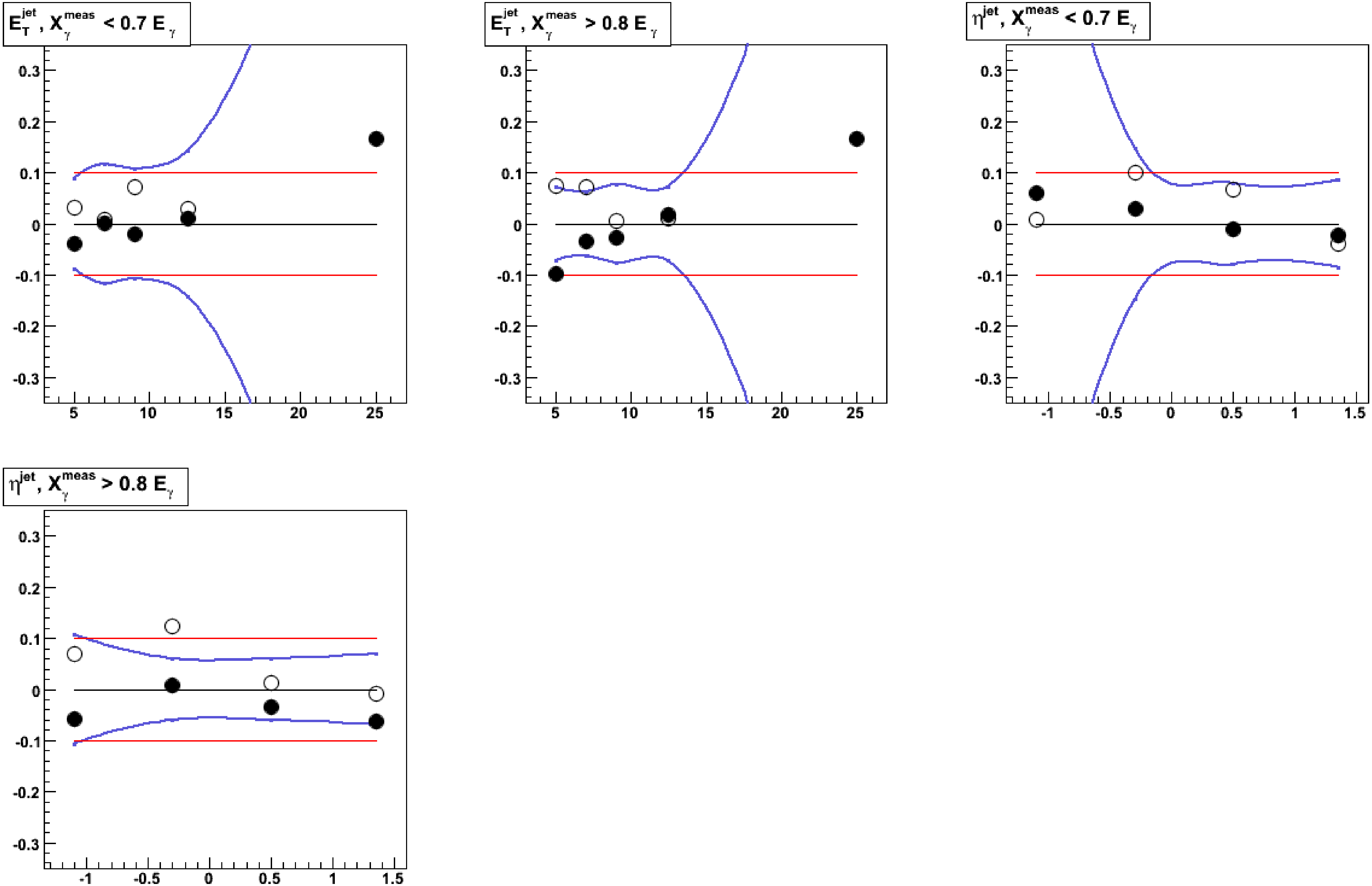

η^{jet}, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1
-0.5
0
0.5
1
1.5



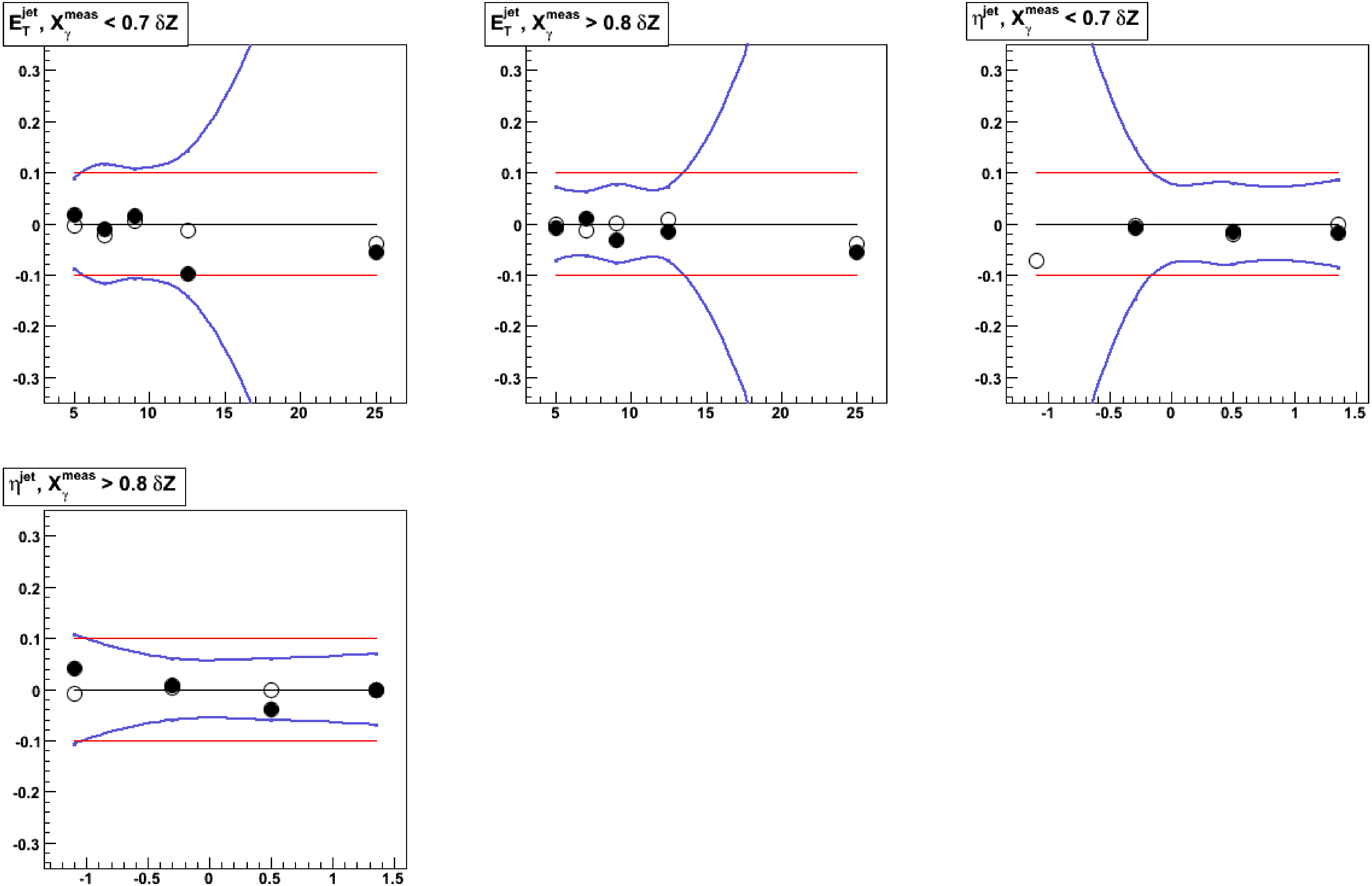
E_T^jet, X_γ^meas < 0.7 Fragmentation
E_T^jet, X_γ^meas > 0.8 Fragmentation
η^jet, X_γ^meas < 0.7 Fragmentation
η^jet, X_γ^meas > 0.8 Fragmentation


E_T^{jet}, X_γ^{meas} < 0.7 HERWIG
E_T^{jet}, X_γ^{meas} > 0.8 HERWIG
η^{jet}, X_γ^{meas} < 0.7 HERWIG
η^{jet}, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25
-1
-0.5
0
0.5
1
1.5

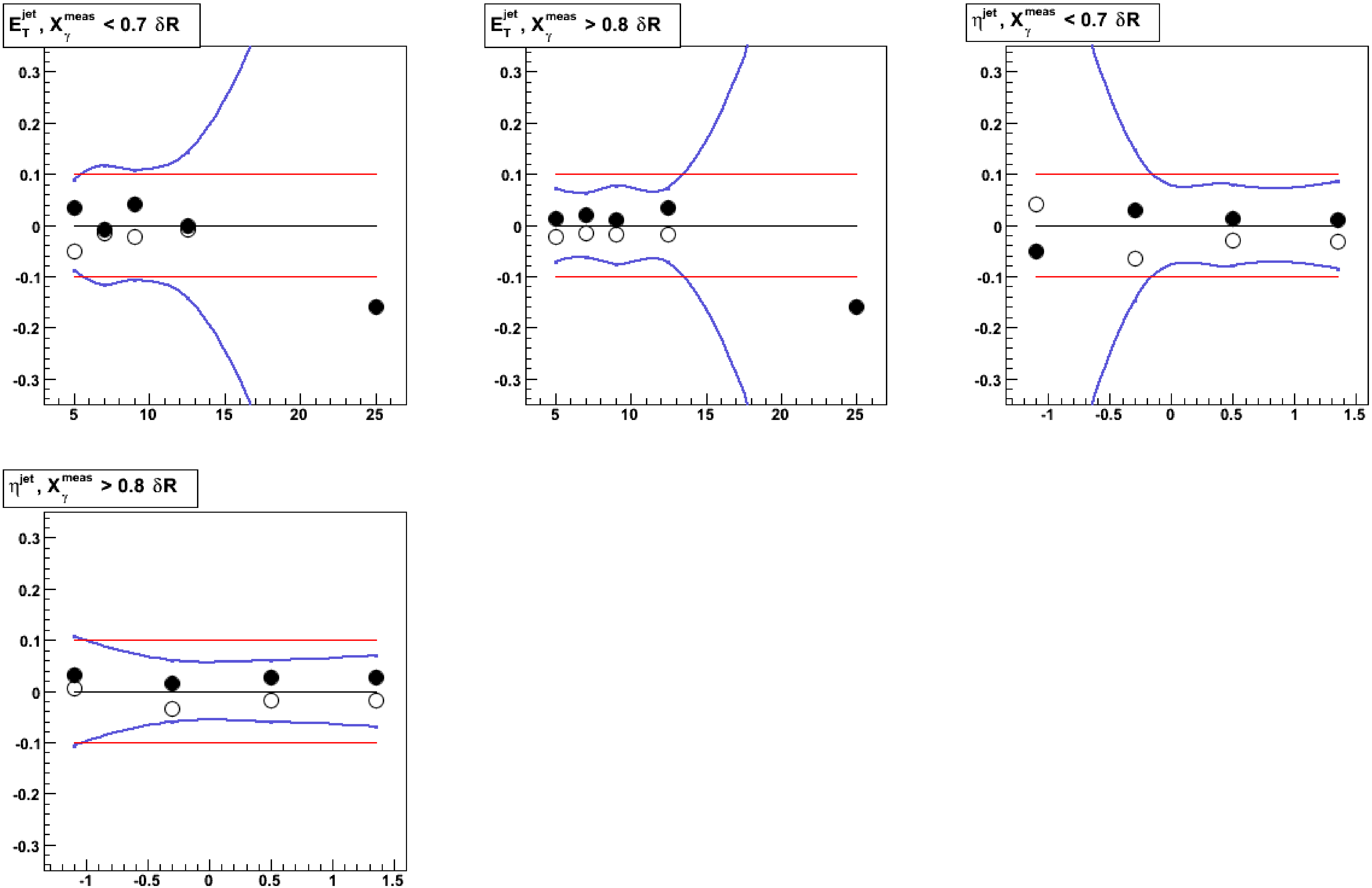

E_T^{jet} , X_γ^{meas} < 0.7 fraction EMC
E_T^{jet} , X_γ^{meas} > 0.8 fraction EMC
η^{jet} , X_γ^{meas} < 0.7 fraction EMC
η^{jet} , X_γ^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5
10
15
20
25
-1
-0.5
0
0.5
1
1.5



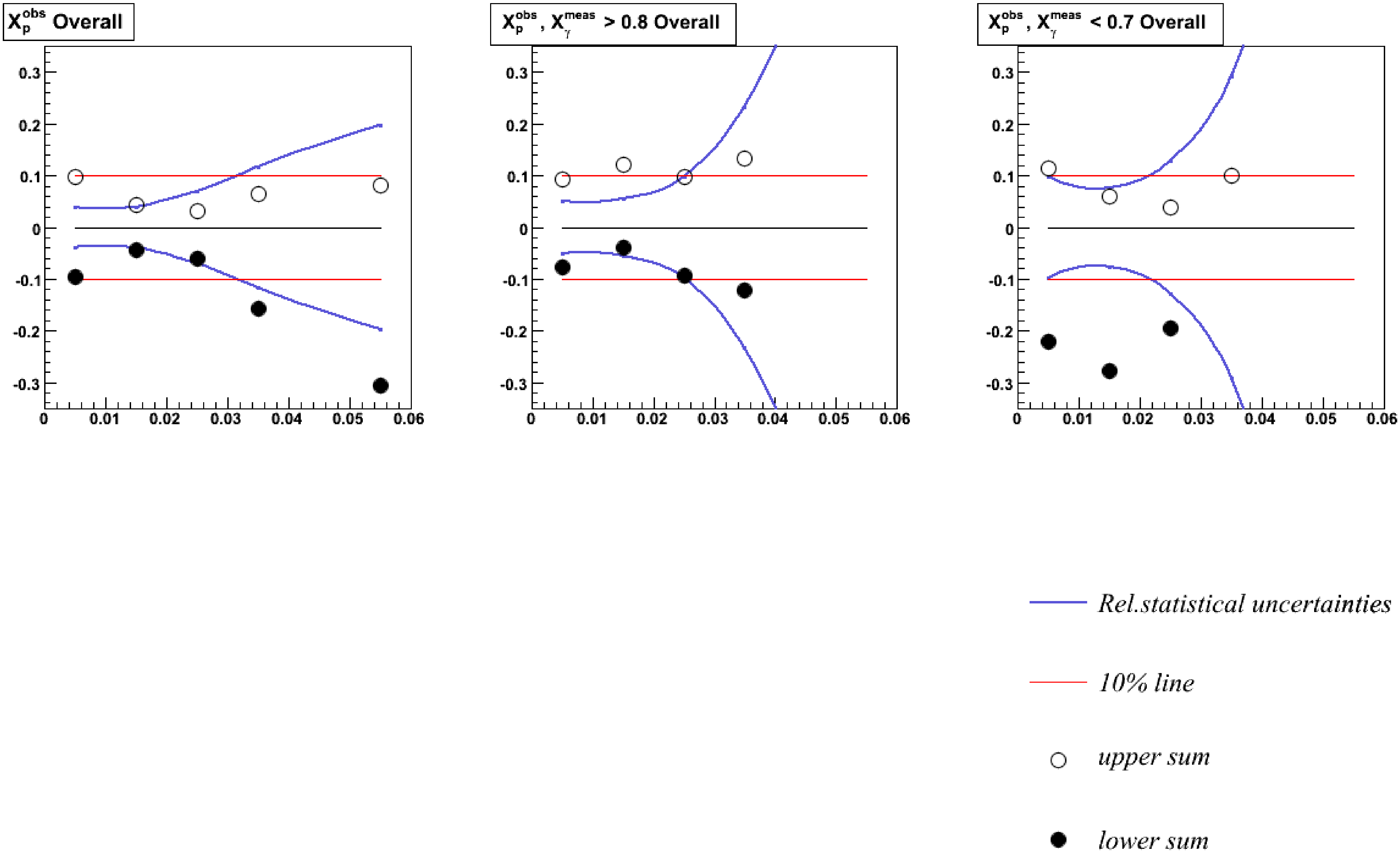
E_T^jet , X_γ^meas < 0.7 E_γ
E_T^jet , X_γ^meas > 0.8 E_γ
η^jet, X_γ^meas < 0.7 E_γ
η^jet, X_γ^meas > 0.8 E_γ

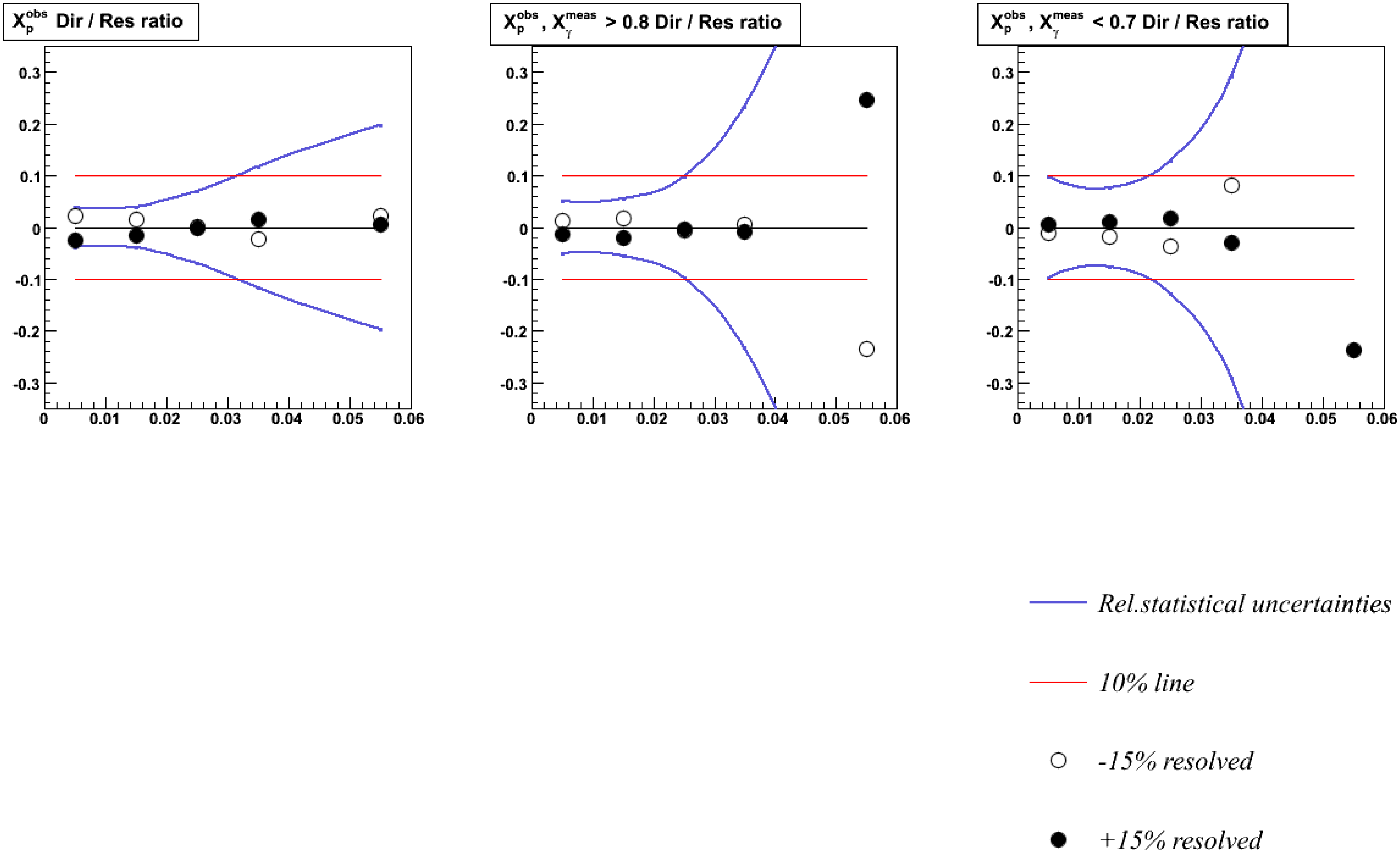


E_T^{jet}, $X_\gamma^{meas} < 0.7$ δZ
E_T^{jet}, $X_\gamma^{meas} > 0.8$ δZ
η^{jet}, $X_\gamma^{meas} < 0.7$ δZ
η^{jet}, $X_\gamma^{meas} > 0.8$ δZ

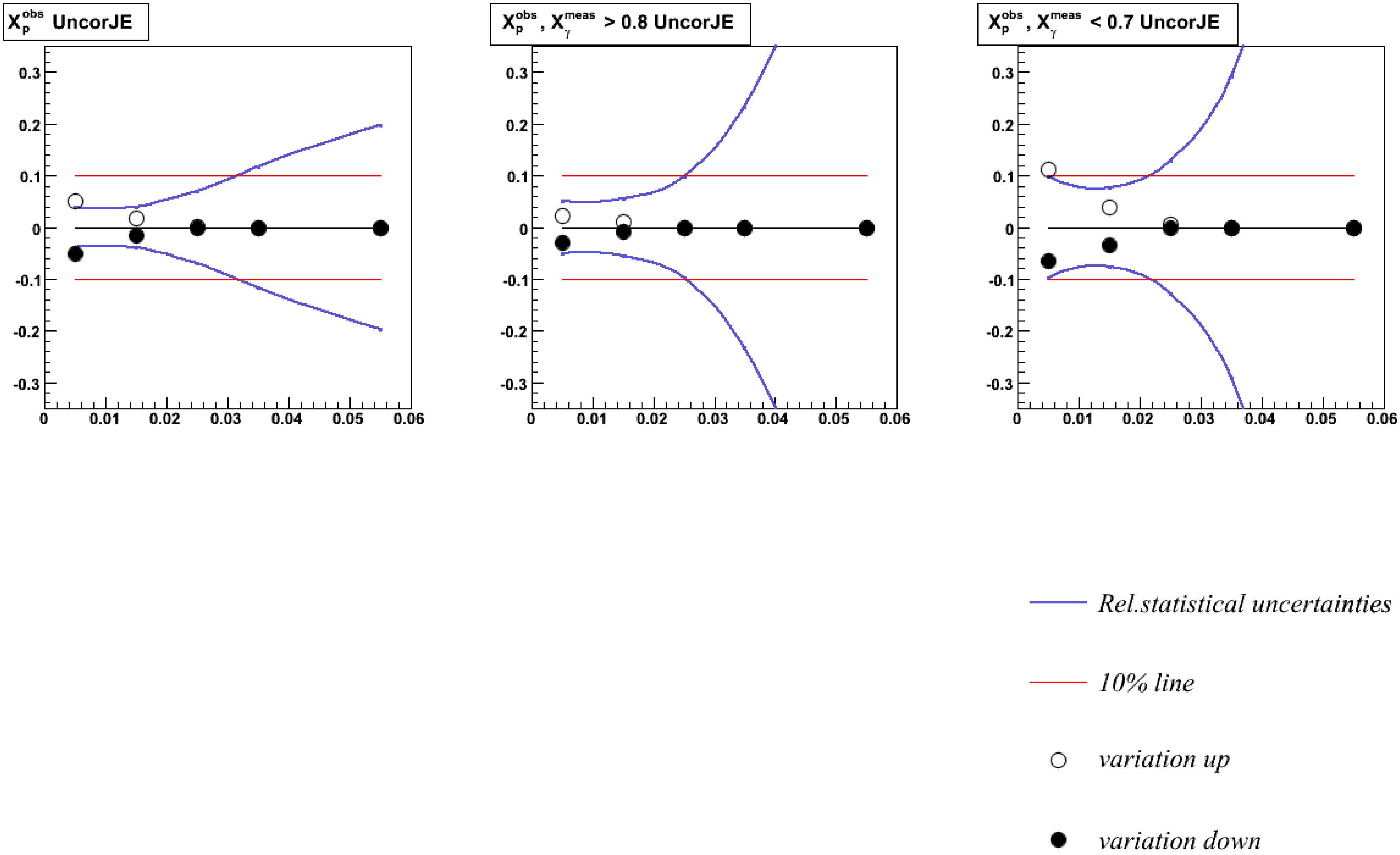


E_T^{jet}, X_γ^{meas} < 0.7 δR
E_T^{jet}, X_γ^{meas} > 0.8 δR
η^{jet}, X_γ^{meas} < 0.7 δR
η^{jet}, X_γ^{meas} > 0.8 δR

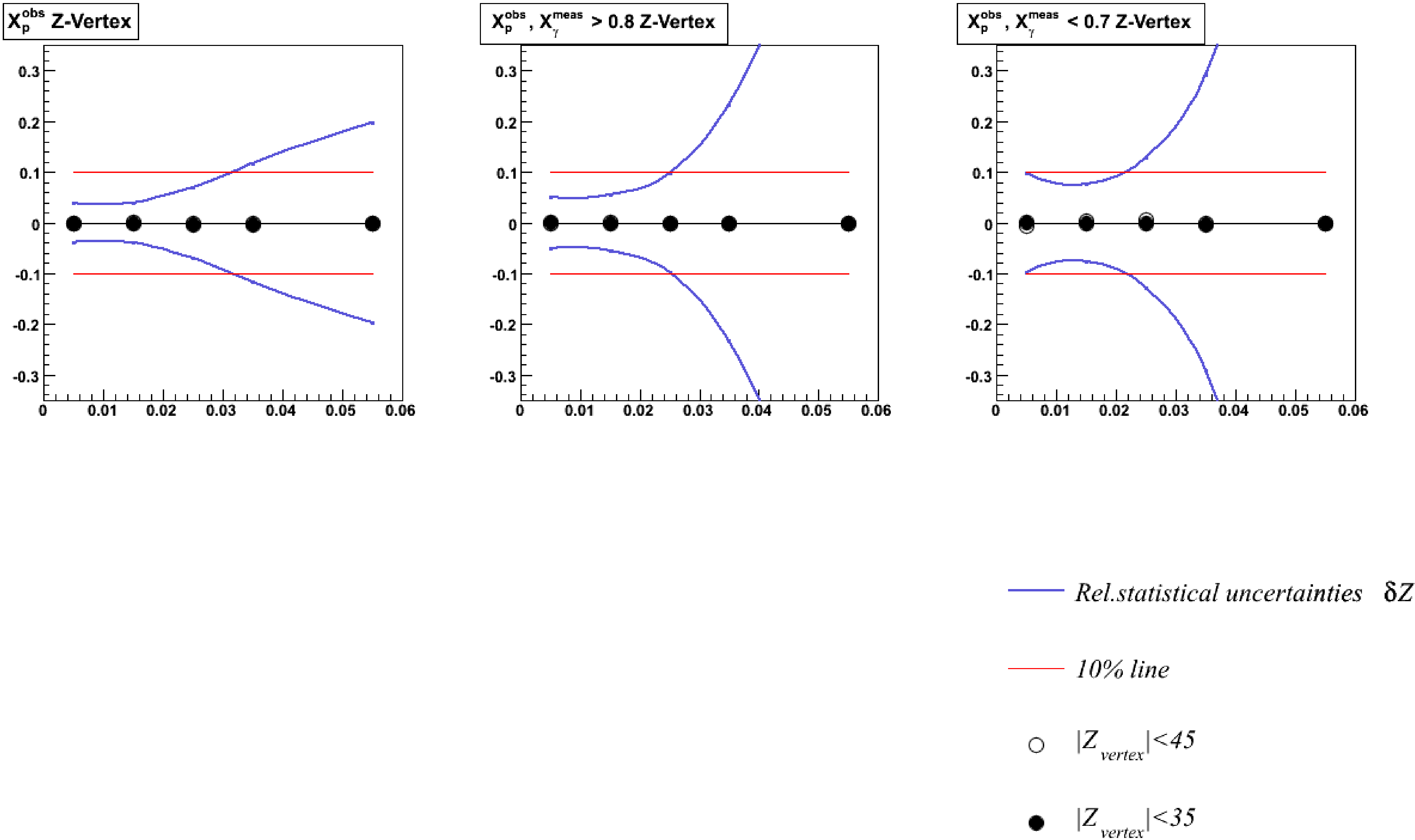

X_p^{obs} Overall
X_p^{obs}, X_γ^{meas} > 0.8 Overall
X_p^{obs}, X_γ^{meas} < 0.7 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
upper sum
lower sum



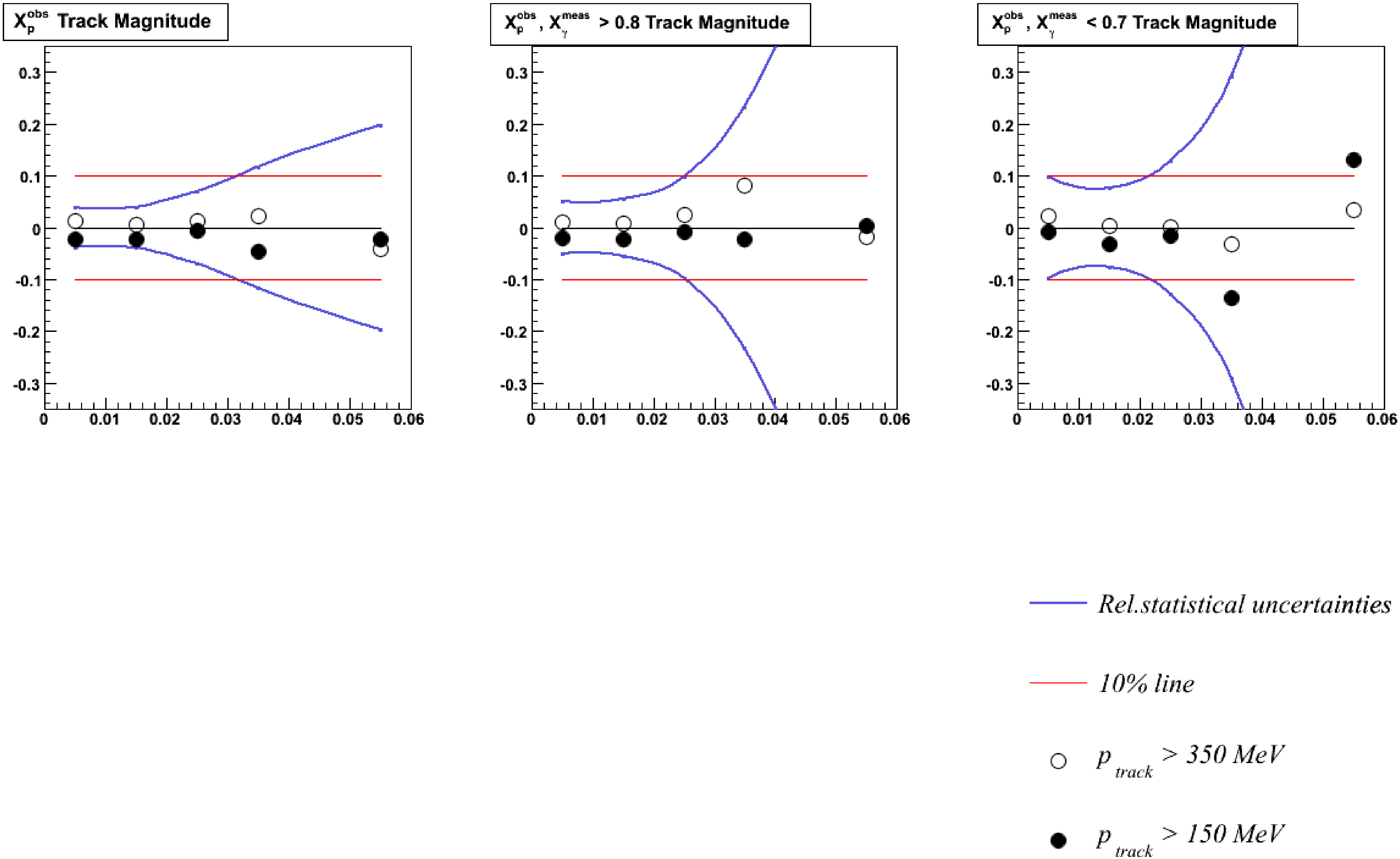
X_p^{obs} Dir / Res ratio
X_p^{obs}, X_γ^{meas} > 0.8 Dir / Res ratio
X_p^{obs}, X_γ^{meas} < 0.7 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
-15% resolved
+15% resolved

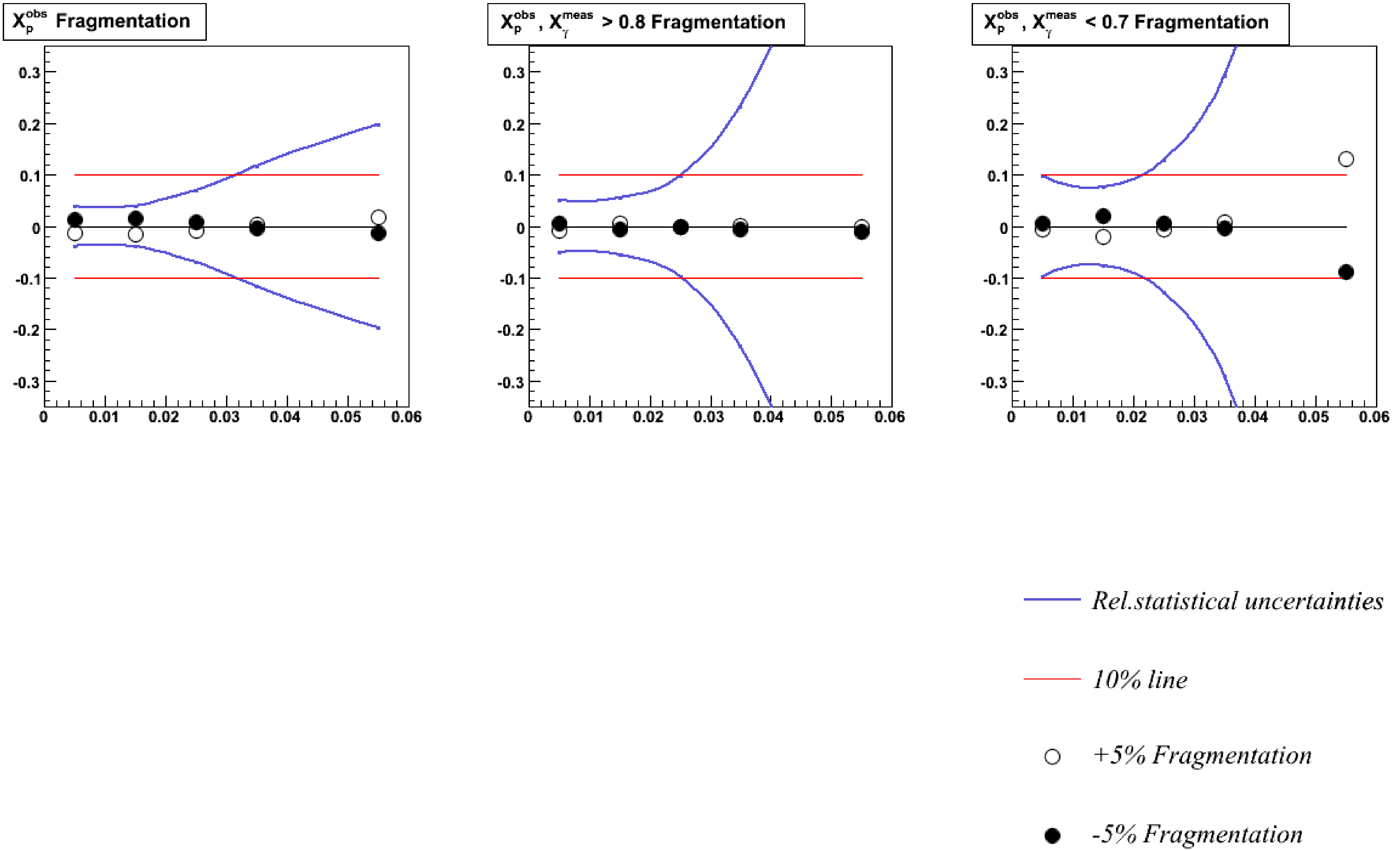


X_p^{obs} UncorJE
X_p^{obs}, X_γ^{meas} > 0.8 UncorJE
X_p^{obs}, X_γ^{meas} < 0.7 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties
10% line
variation up
variation down

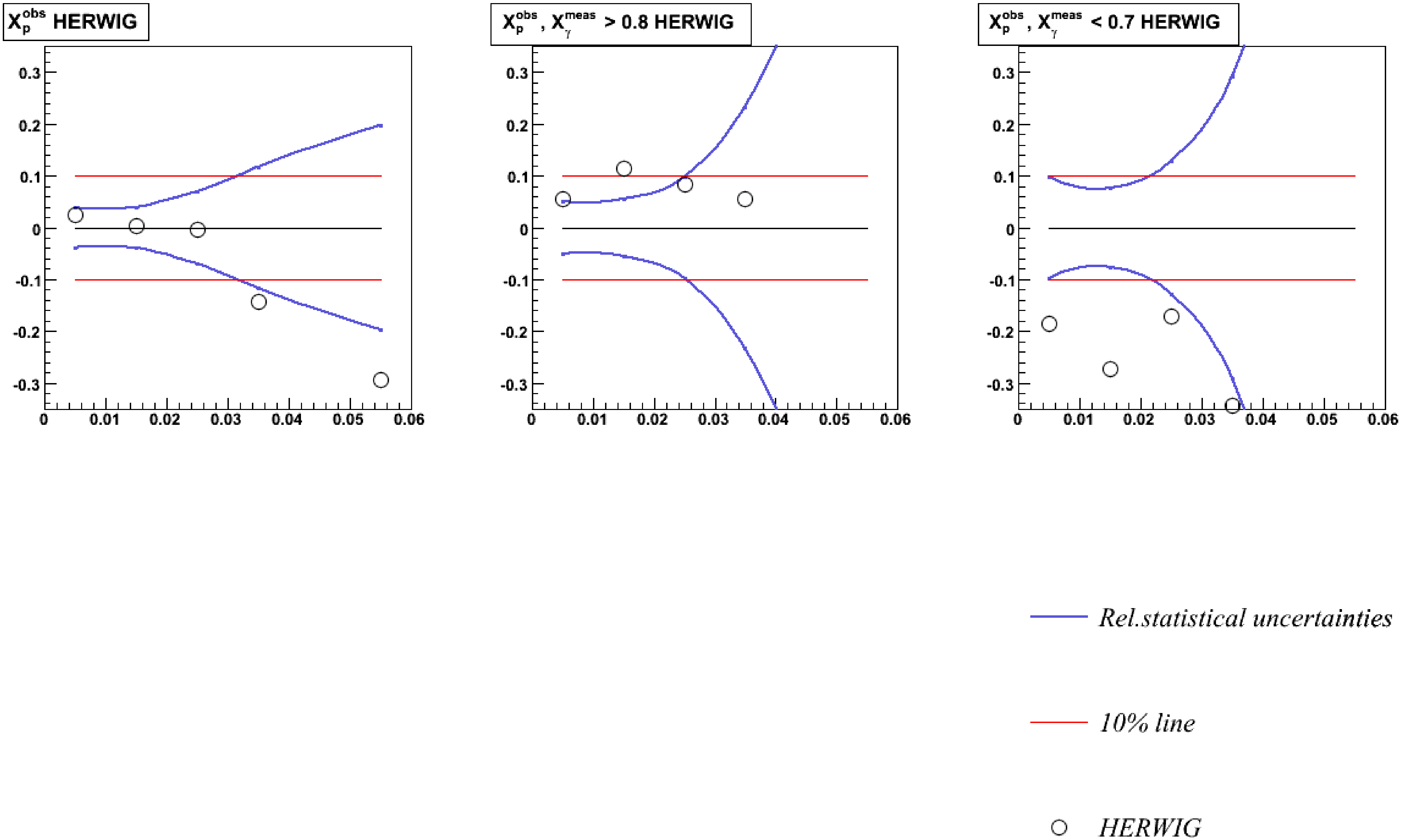


X_p^{obs} Z-Vertex
X_p^{obs}, X_γ^{meas} > 0.8 Z-Vertex
X_p^{obs}, X_γ^{meas} < 0.7 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties δZ
10% line
$|Z_{vertex}|<45$
$|Z_{vertex}|<35$

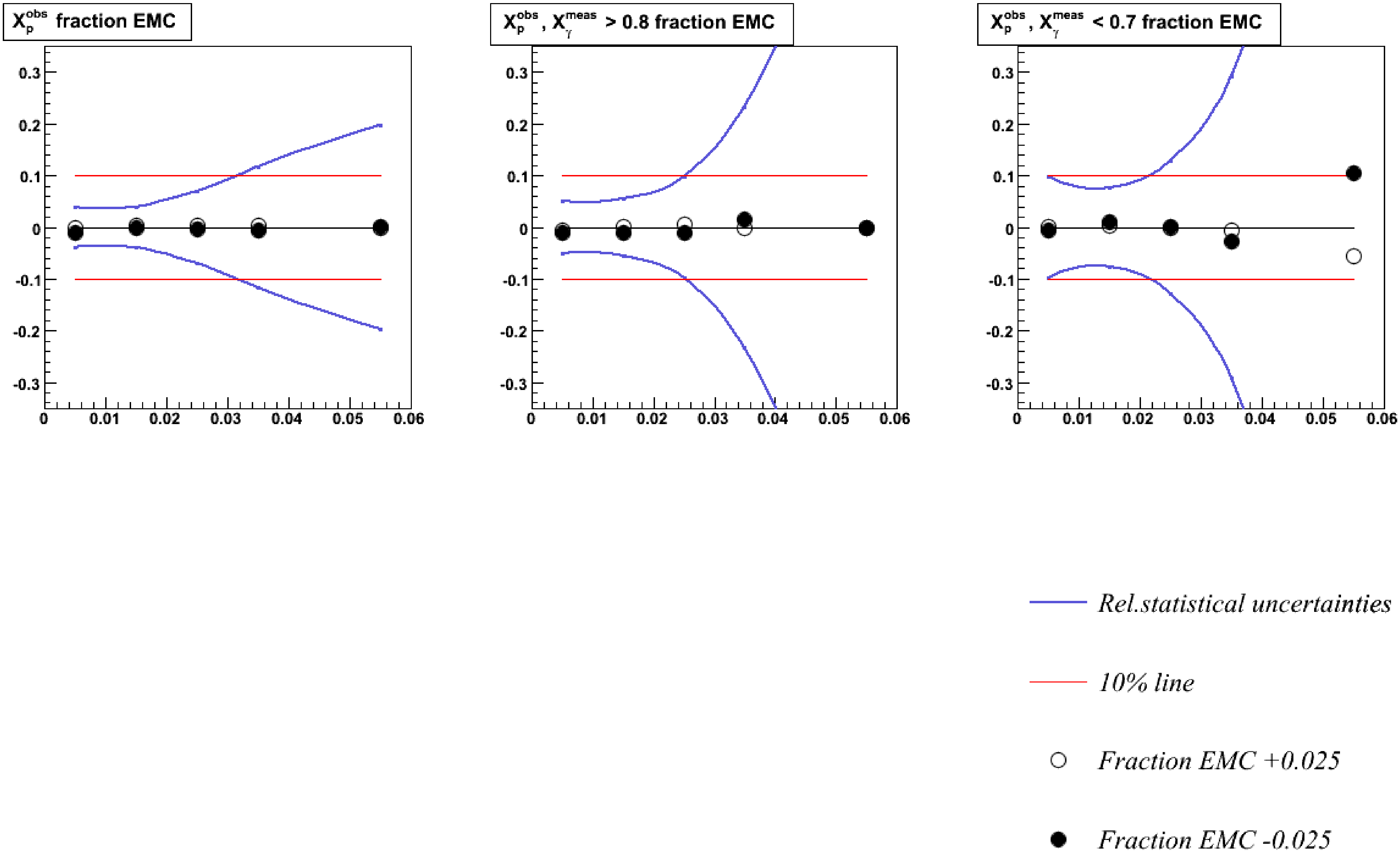

X_p^{obs} Track Magnitude
X_p^{obs}, X_γ^{meas} > 0.8 Track Magnitude
X_p^{obs}, X_γ^{meas} < 0.7 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties
10% line
p_{track} > 350 MeV
p_{track} > 150 MeV

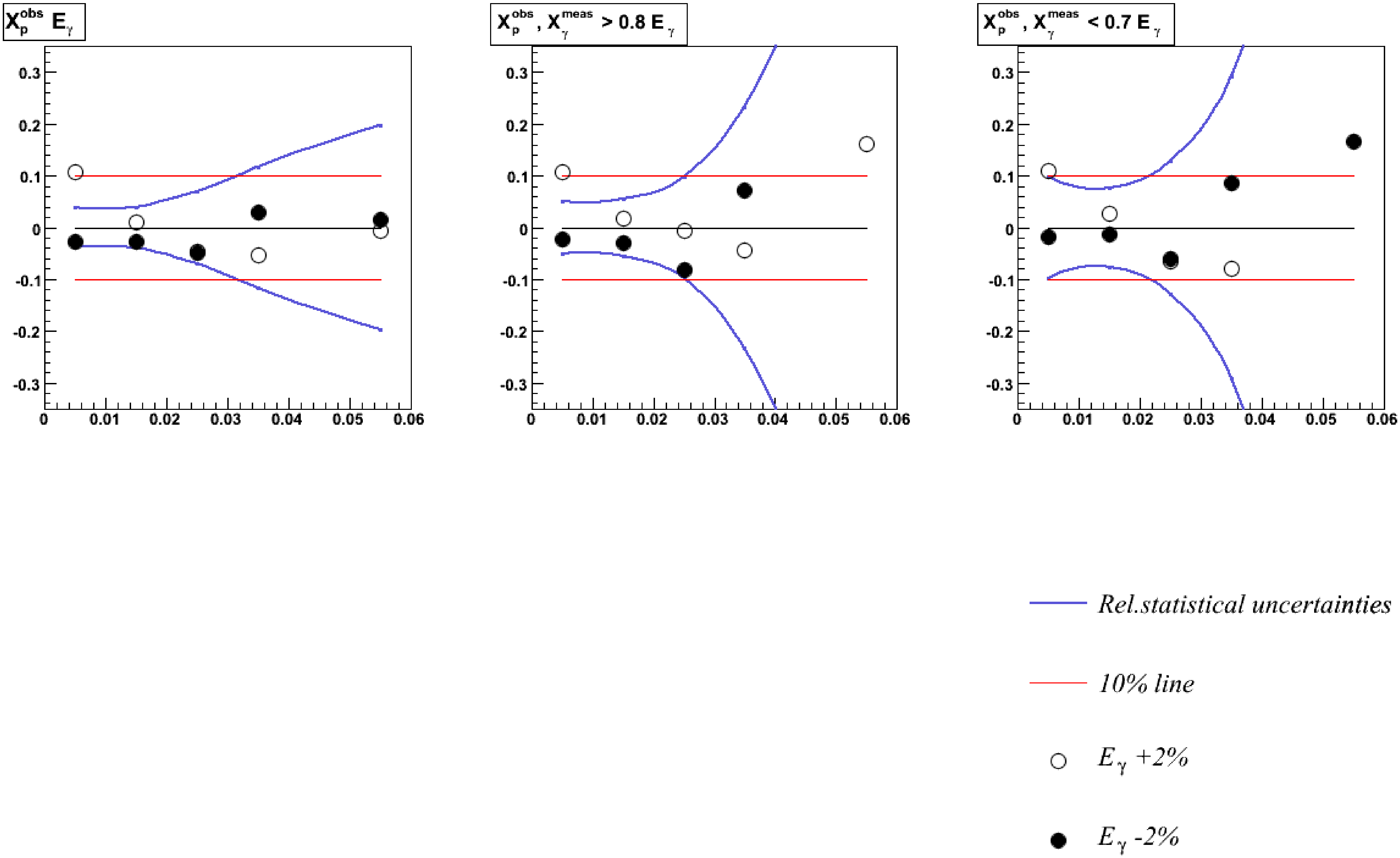


X_p^{obs} Fragmentation
X_p^{obs}, X_γ^{meas} > 0.8 Fragmentation
X_p^{obs}, X_γ^{meas} < 0.7 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
+5% Fragmentation
-5% Fragmentation

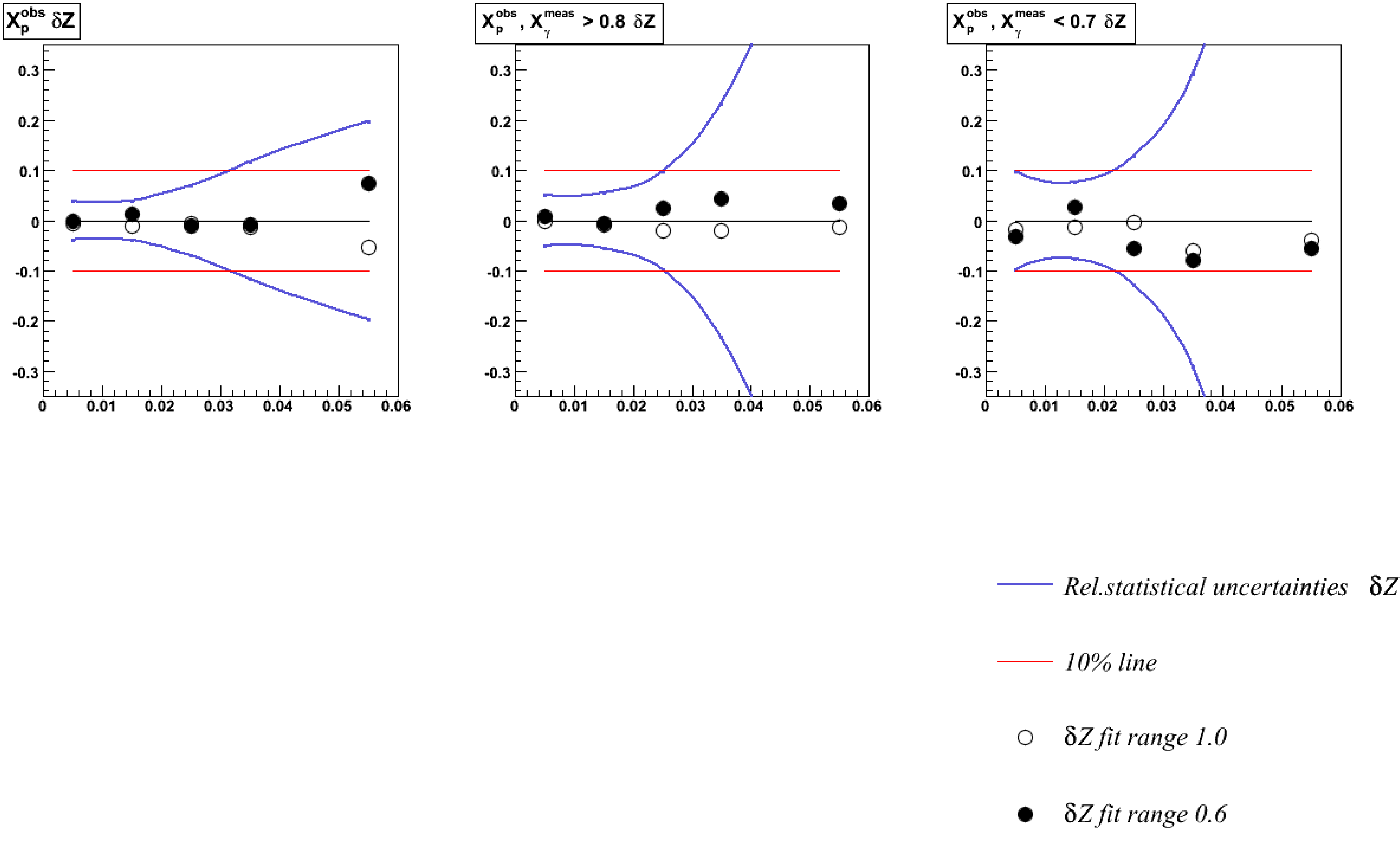


X_p^{obs} HERWIG
X_p^{obs}, X_γ^{meas} > 0.8 HERWIG
X_p^{obs}, X_γ^{meas} < 0.7 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
HERWIG

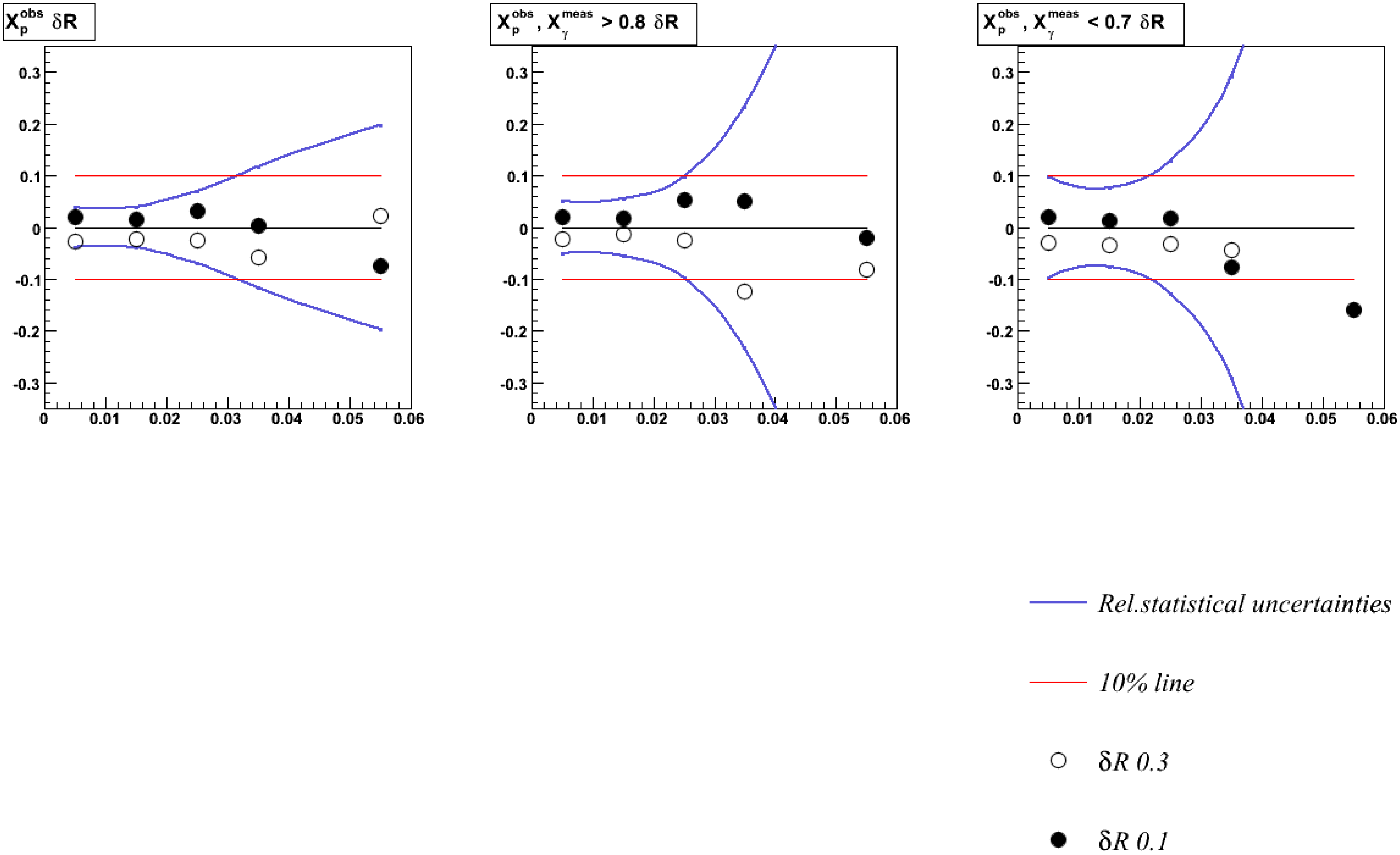

X_p^{obs} fraction EMC
X_p^{obs}, X_γ^{meas} > 0.8 fraction EMC
X_p^{obs}, X_γ^{meas} < 0.7 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
Fraction EMC +0.025
Fraction EMC -0.025

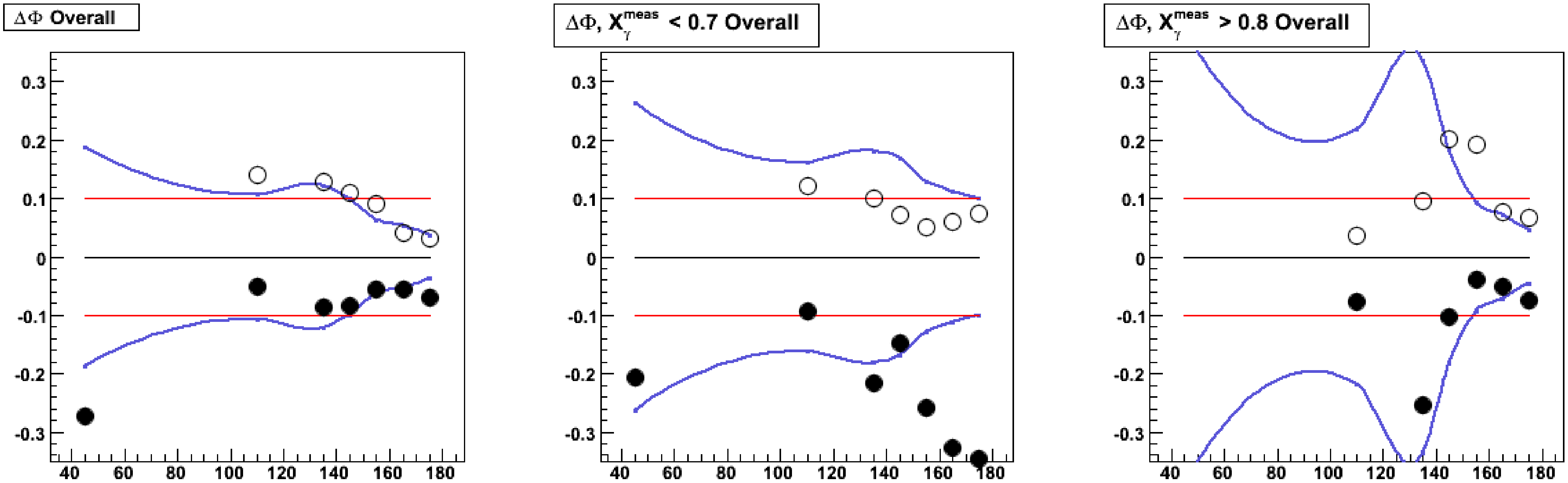


X_p^{obs} E_γ
X_p^{obs}, X_γ^{meas} > 0.8 E_γ
X_p^{obs}, X_γ^{meas} < 0.7 E_γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties
10% line
E_γ +2%
E_γ -2%

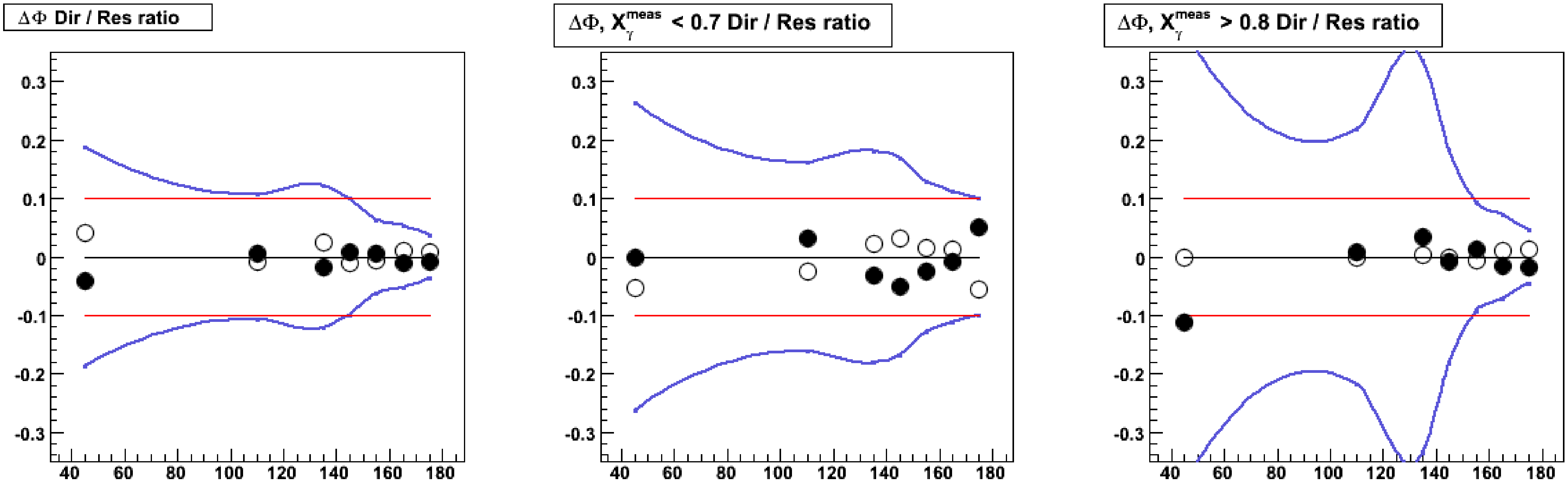


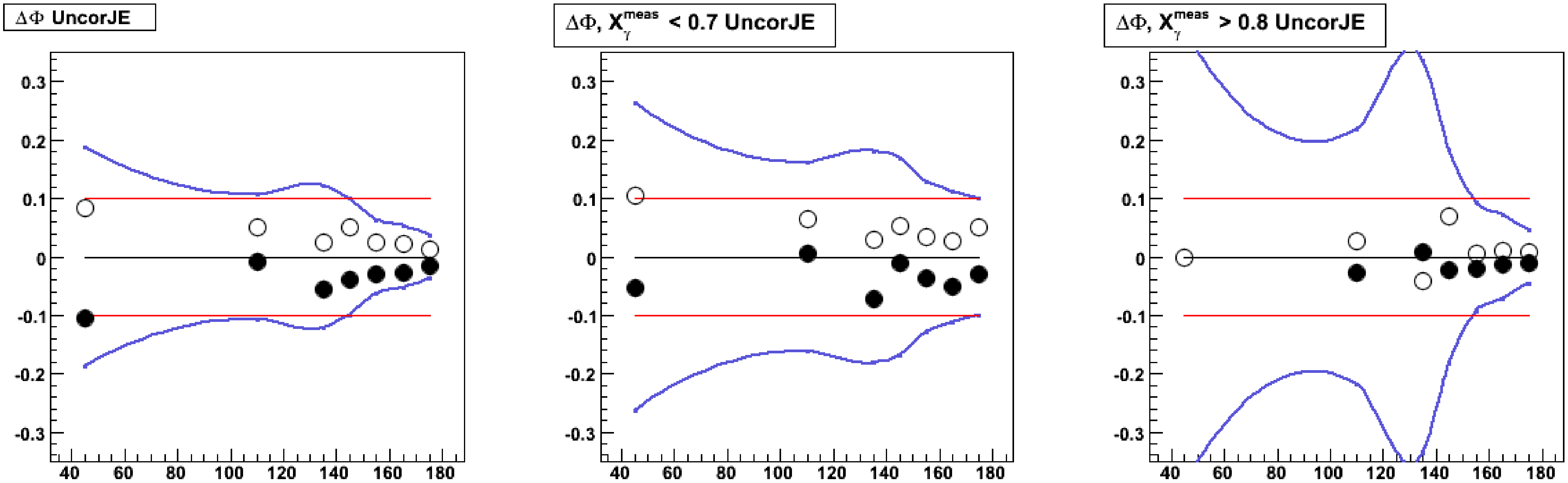
X_p^{obs} δZ
X_p^{obs}, X_γ^{meas} > 0.8 δZ
X_p^{obs}, X_γ^{meas} < 0.7 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties δZ
10% line
δZ fit range 1.0
δZ fit range 0.6

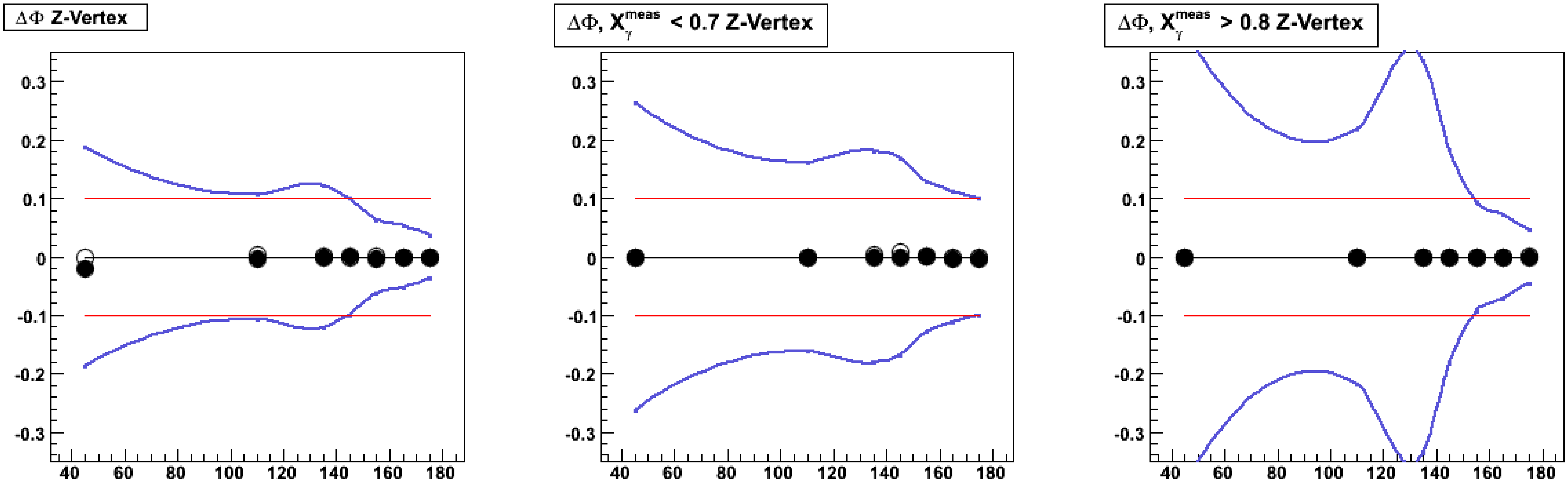

X_p^{obs} δR
X_p^{obs}, X_γ^{meas} > 0.8 δR
X_p^{obs}, X_γ^{meas} < 0.7 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties
10% line
δR 0.3
δR 0.1



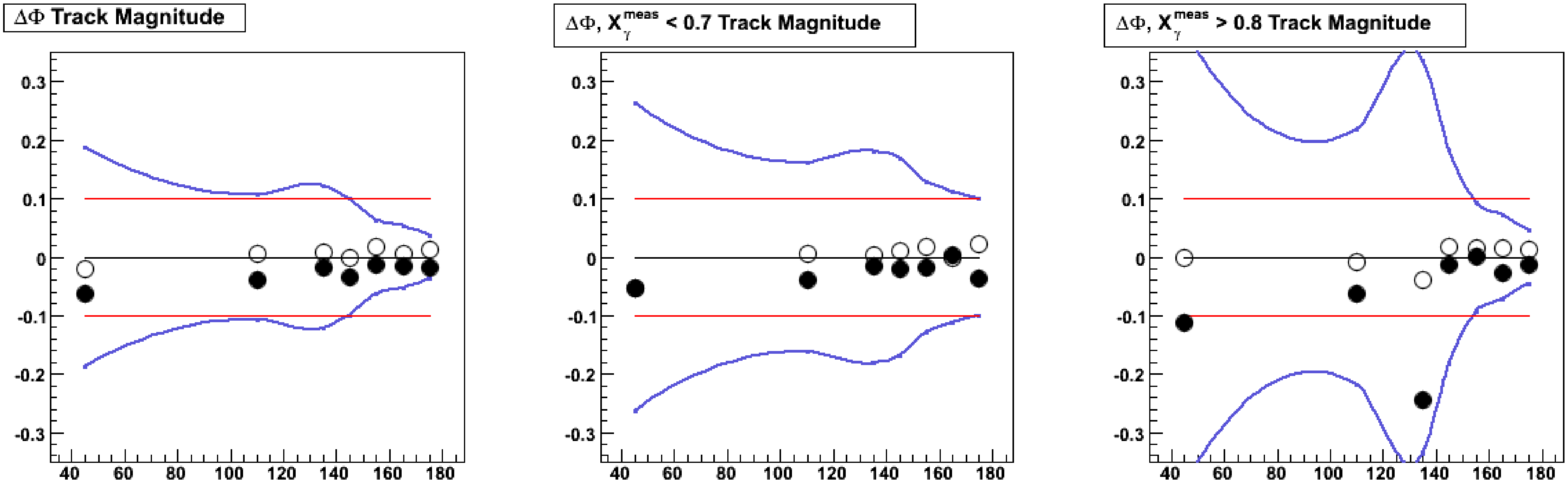
ΔΦ Overall
ΔΦ, X_γ^{meas} < 0.7 Overall
ΔΦ, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180

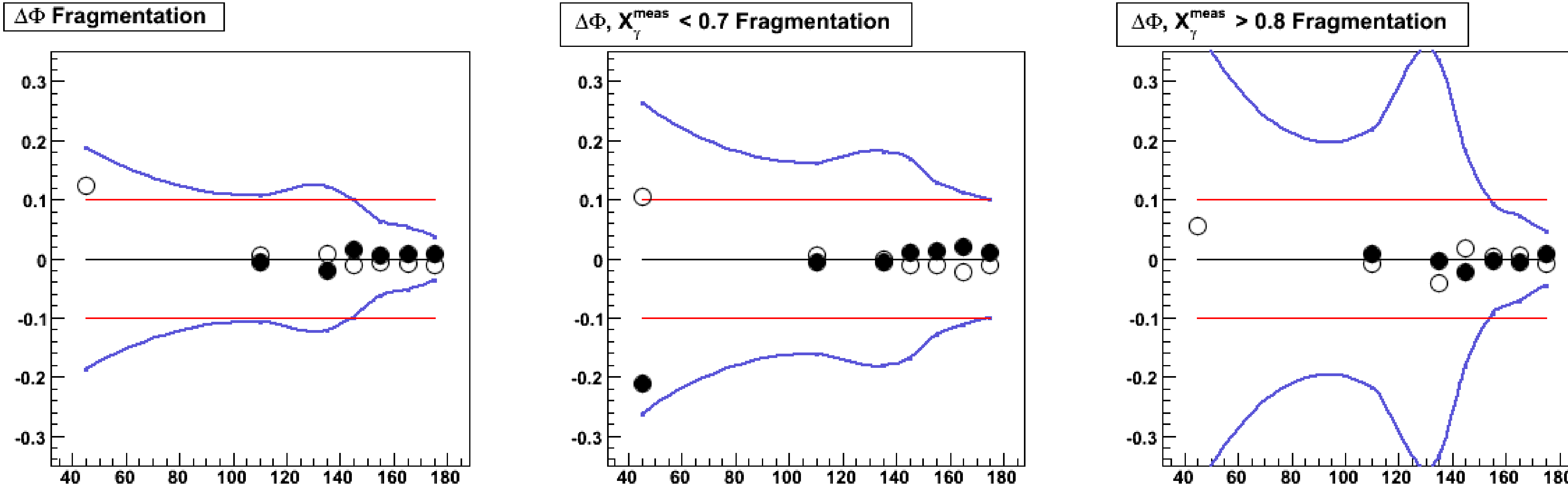

ΔΦ Dir / Res ratio
ΔΦ, X_γ^{meas} < 0.7 Dir / Res ratio
ΔΦ, X_γ^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180

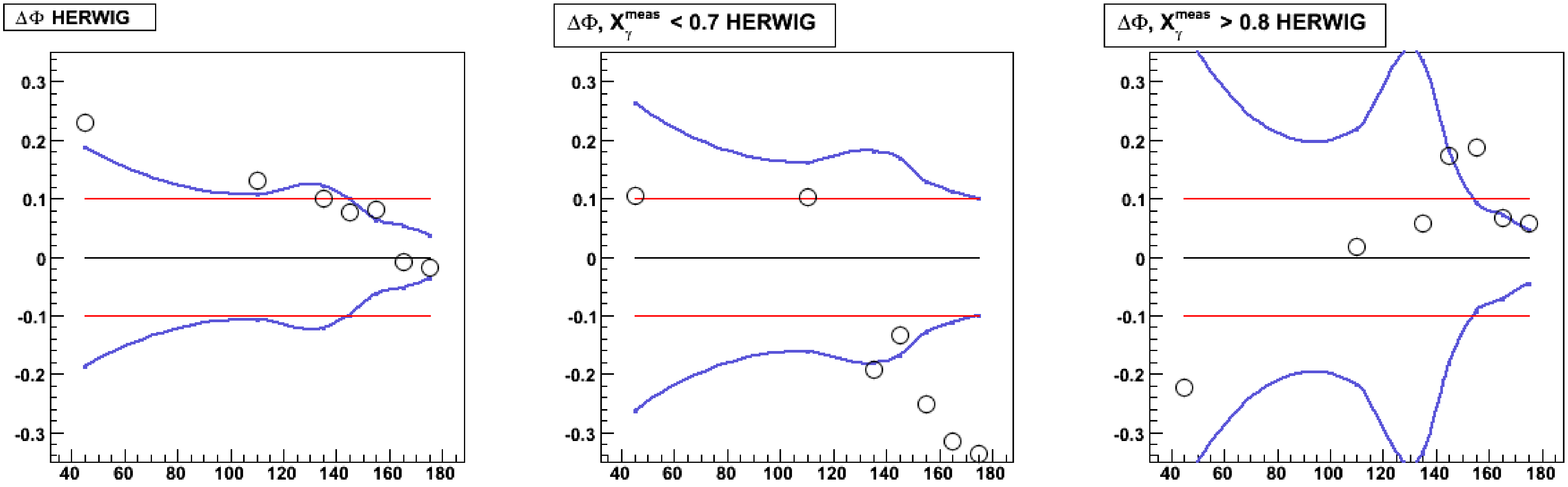

ΔΦ UncorJE
ΔΦ, X$_\gamma^{meas}$ < 0.7 UncorJE
ΔΦ, X$_\gamma^{meas}$ > 0.8 UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



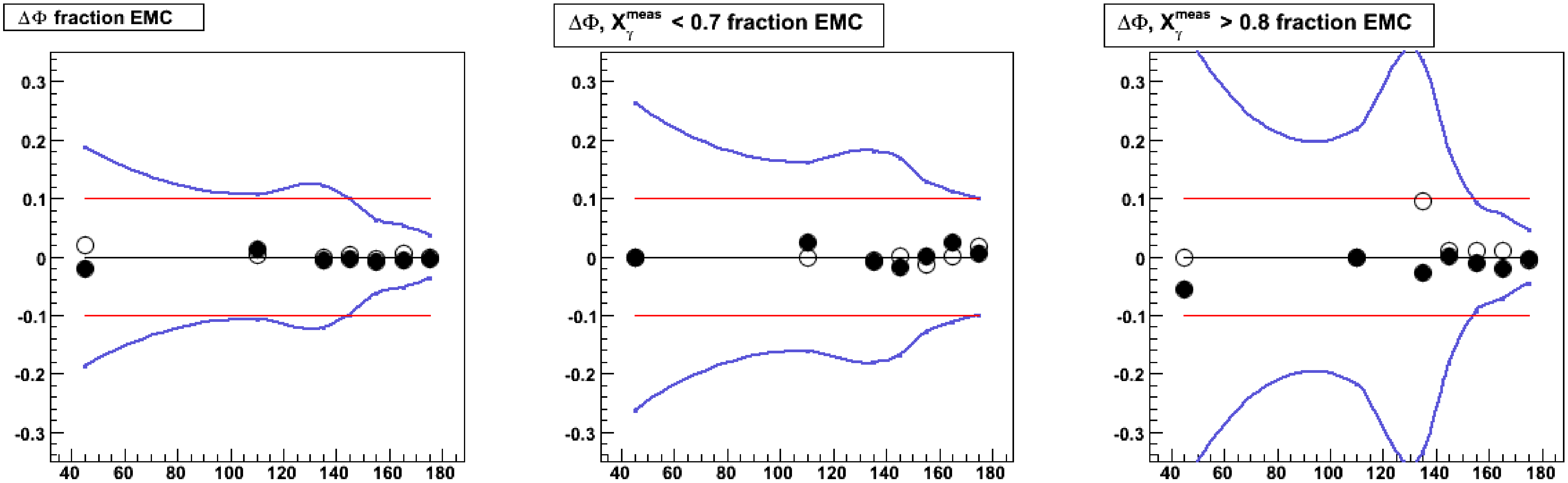
ΔΦ Z-Vertex
ΔΦ, X_{γ}^{meas} < 0.7 Z-Vertex
ΔΦ, X_{γ}^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180

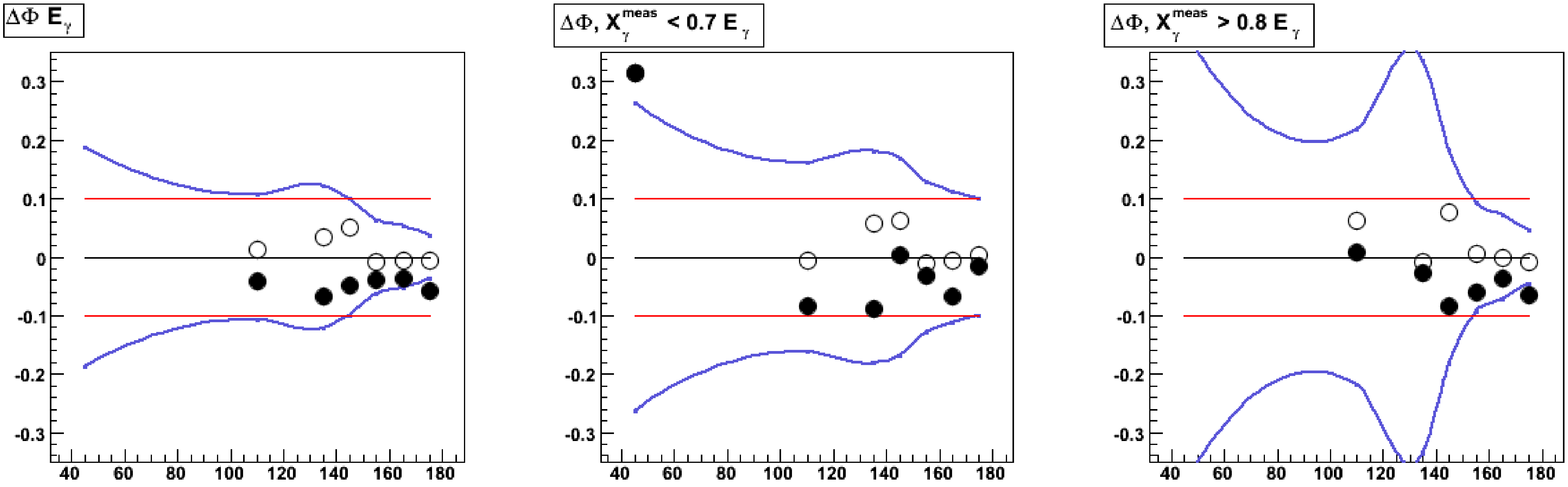

ΔΦ Track Magnitude
ΔΦ, X_{γ}^{meas} < 0.7 Track Magnitude
ΔΦ, X_{γ}^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180


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

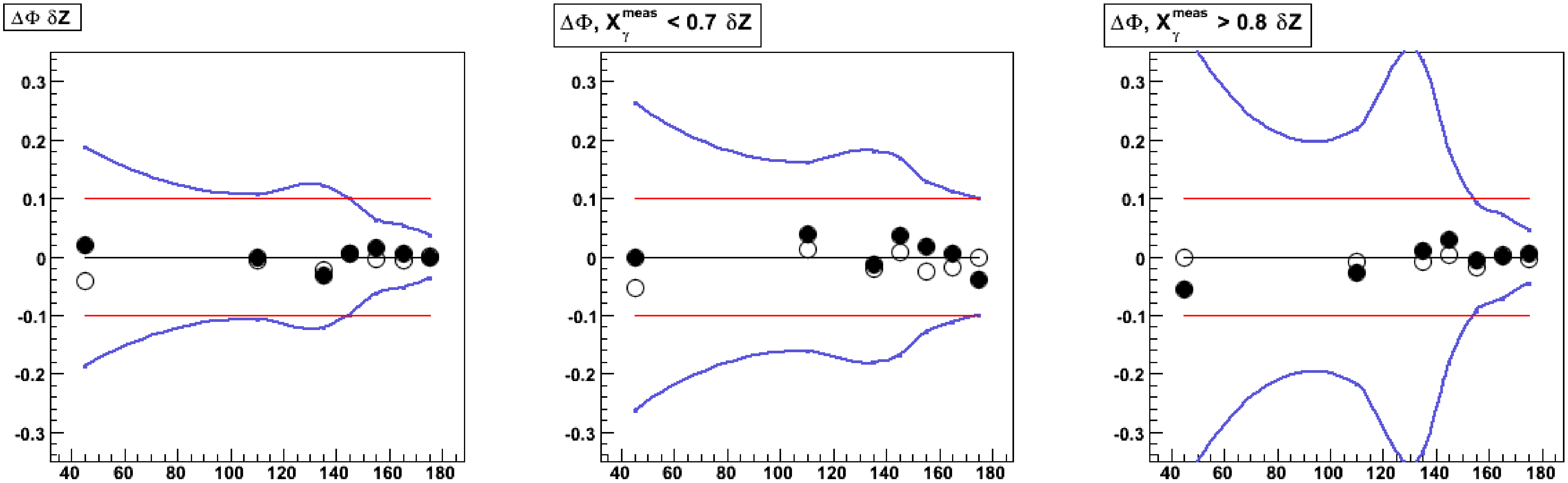


$\Delta\Phi$ HERWIG
$\Delta\Phi$, X_γ^{meas} < 0.7 HERWIG
$\Delta\Phi$, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180

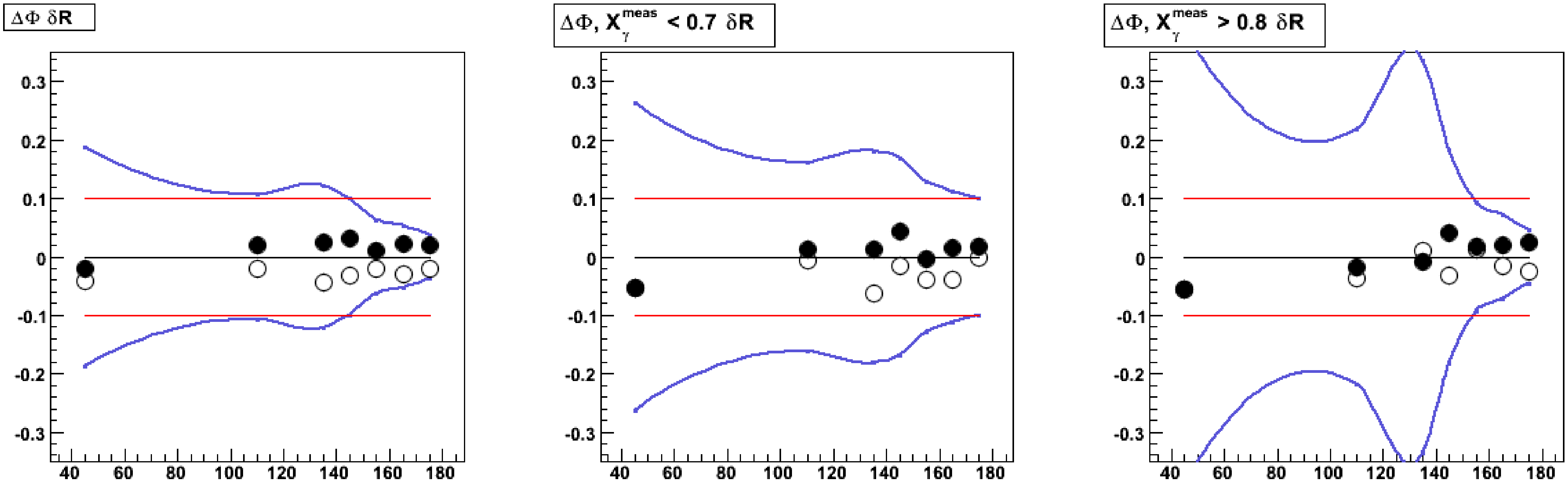

ΔΦ fraction EMC
ΔΦ, X_γ^{meas} < 0.7 fraction EMC
ΔΦ, X_γ^{meas} > 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180



ΔΦ E γ
ΔΦ, X γ meas < 0.7 E γ
ΔΦ, X γ meas > 0.8 E γ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180



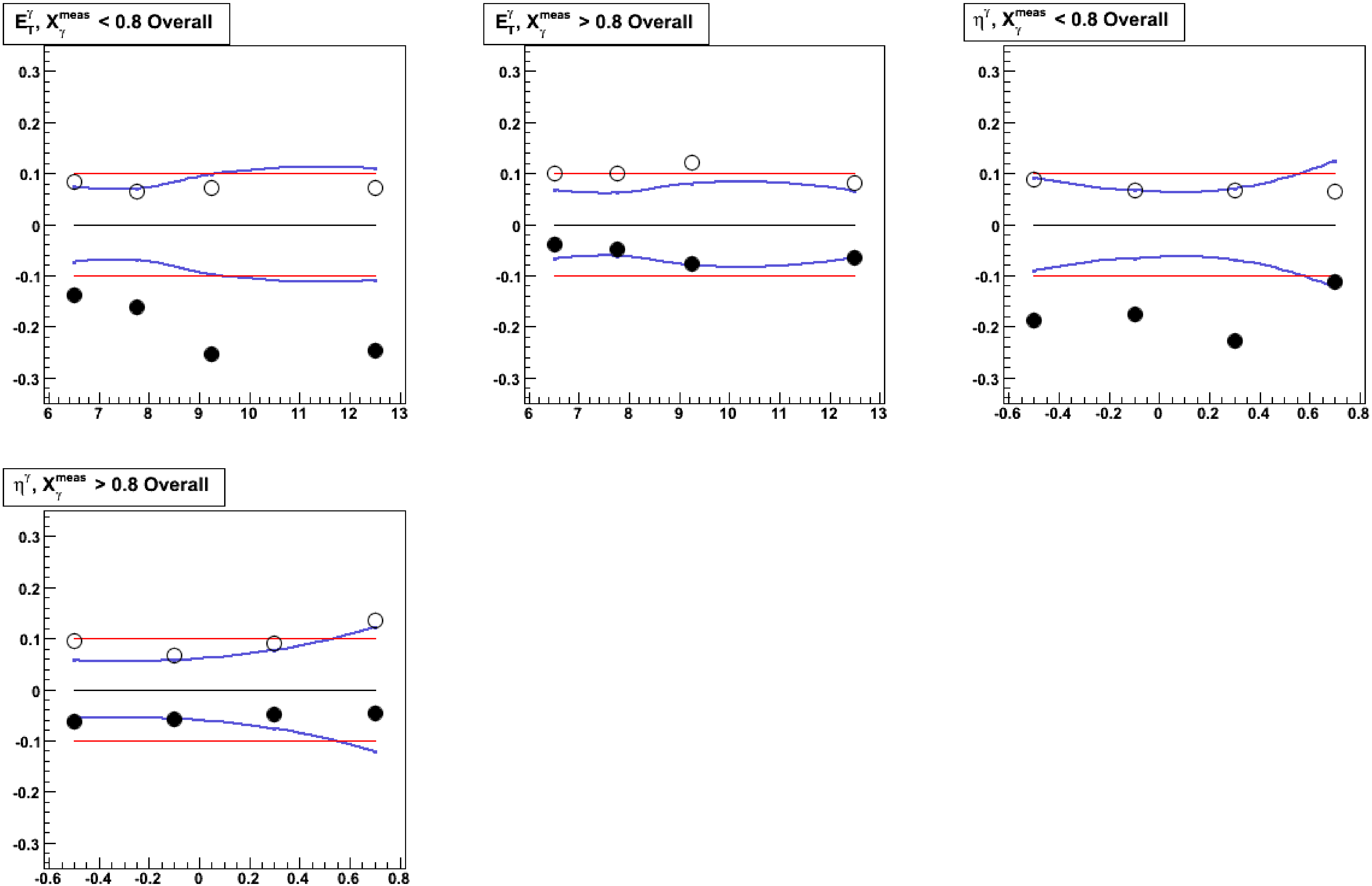
ΔΦ δZ
ΔΦ, X_γ^{meas} < 0.7 δZ
ΔΦ, X_γ^{meas} > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

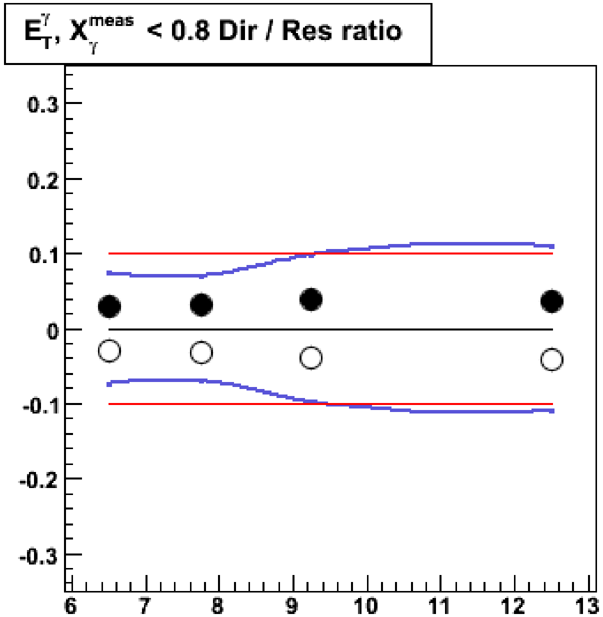


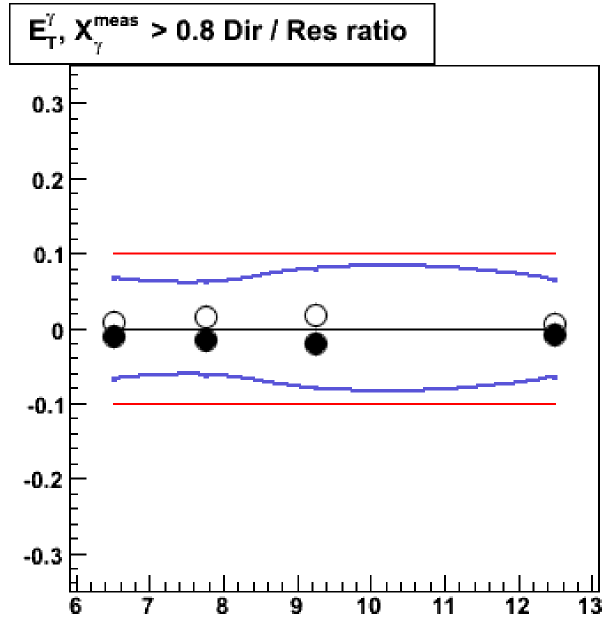
ΔΦ δR
ΔΦ, X_{γ}^{meas} < 0.7 δR
ΔΦ, X_{γ}^{meas} > 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

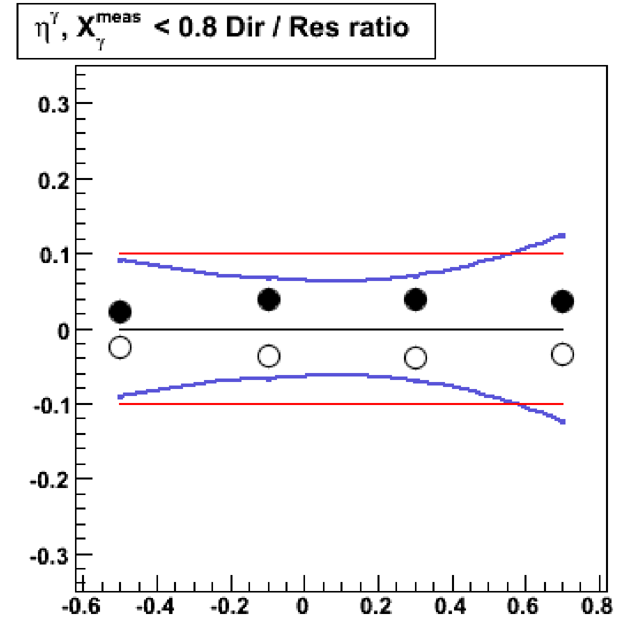
Systematic uncertainties

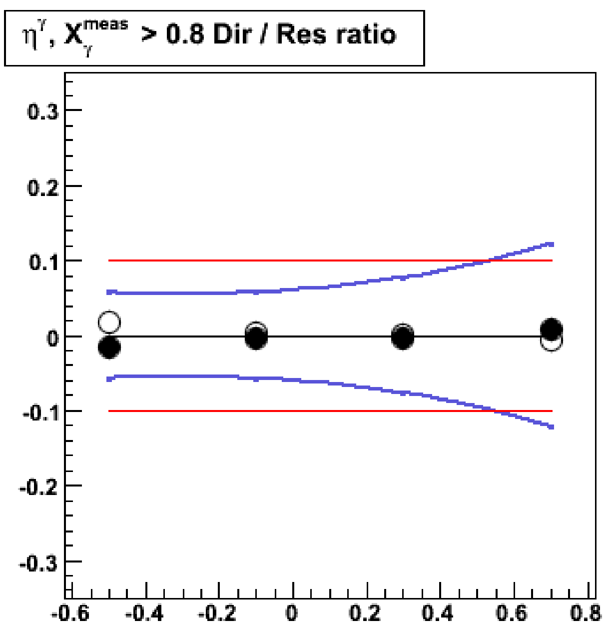
$x_\gamma < 0.8$

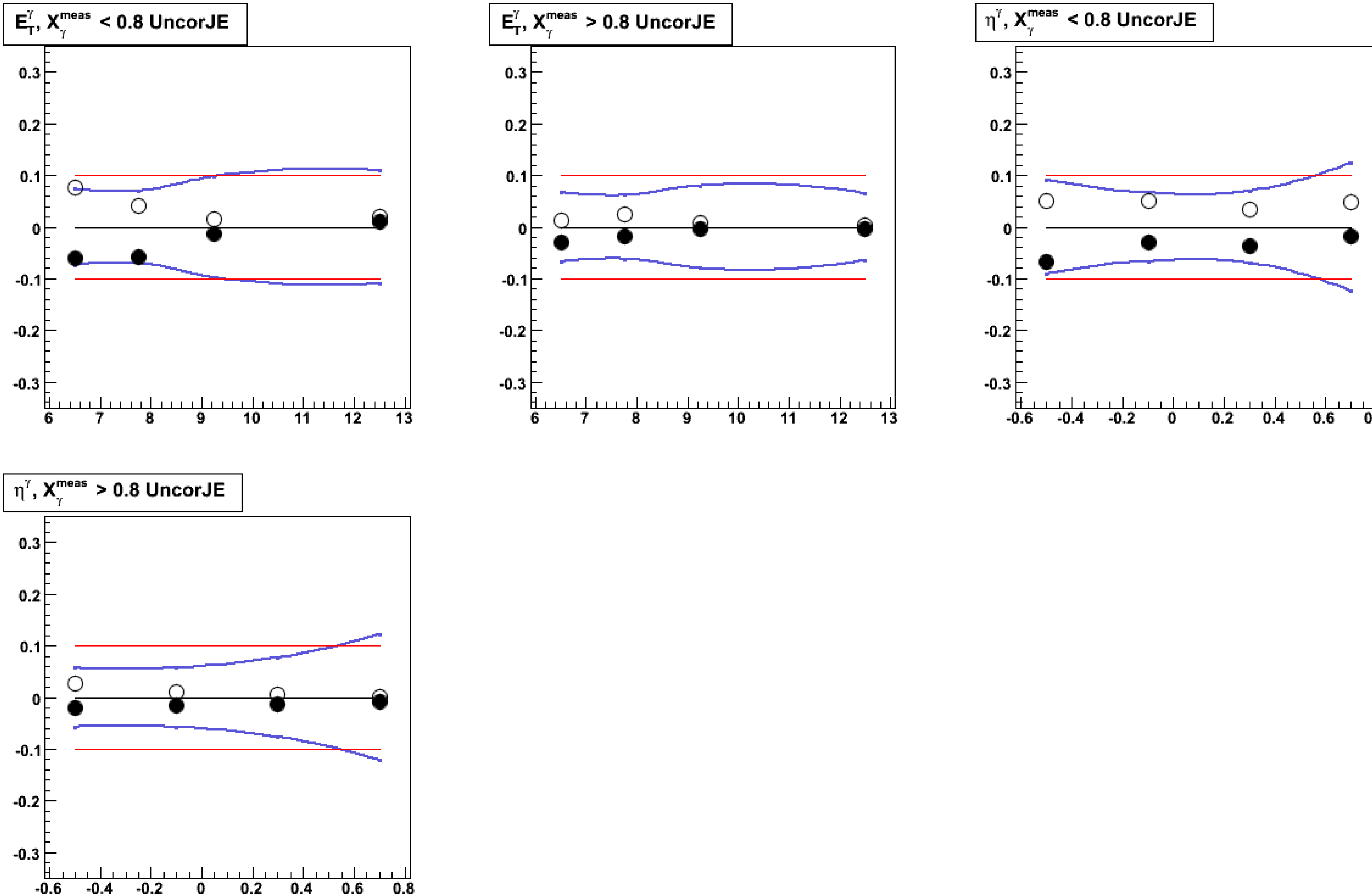

E_T^γ, X_γ^{meas} < 0.8 Overall
E_T^γ, X_γ^{meas} > 0.8 Overall
η^γ, X_γ^{meas} < 0.8 Overall
η^γ, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

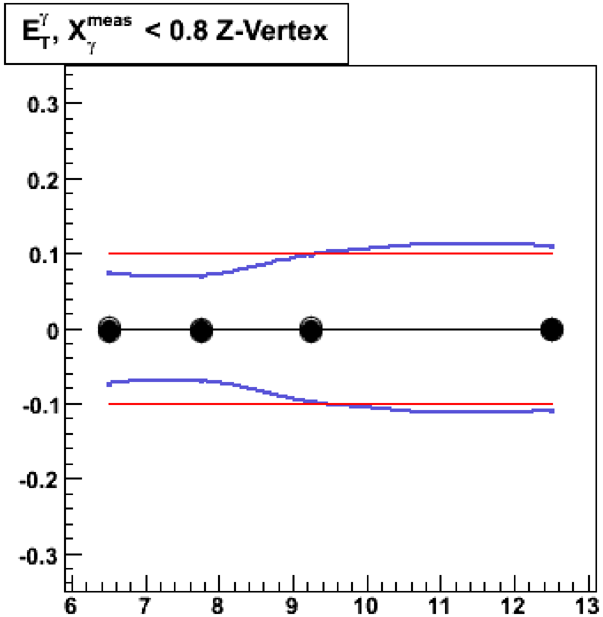

E_T^{γ}, X_{γ}^{meas} < 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13

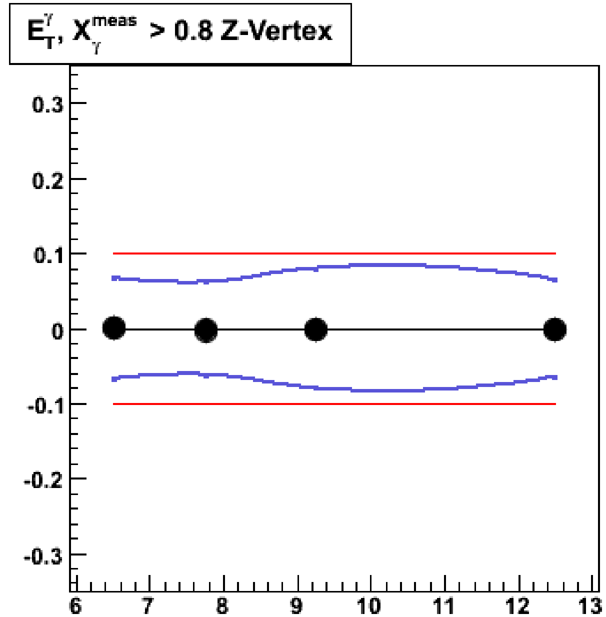

E_T^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13

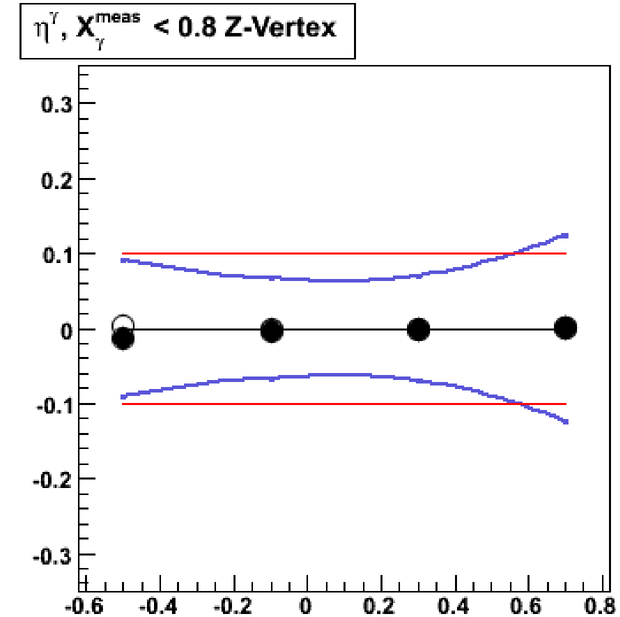

η^{γ}, X_{γ}^{meas} < 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

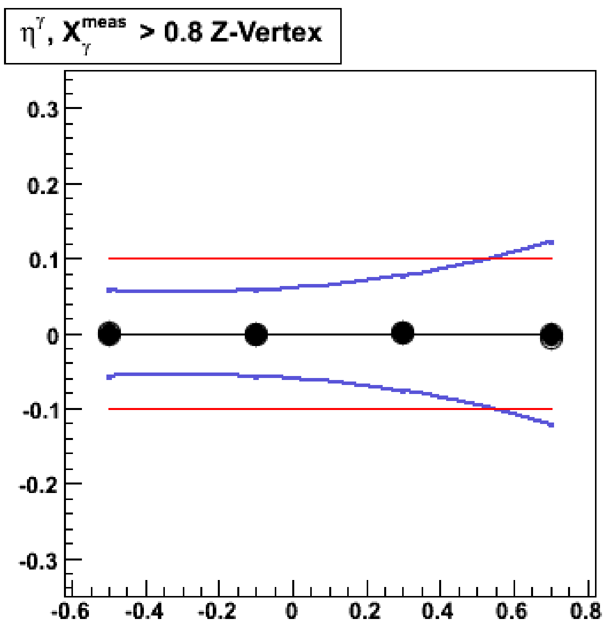

η^{γ}, X_{γ}^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

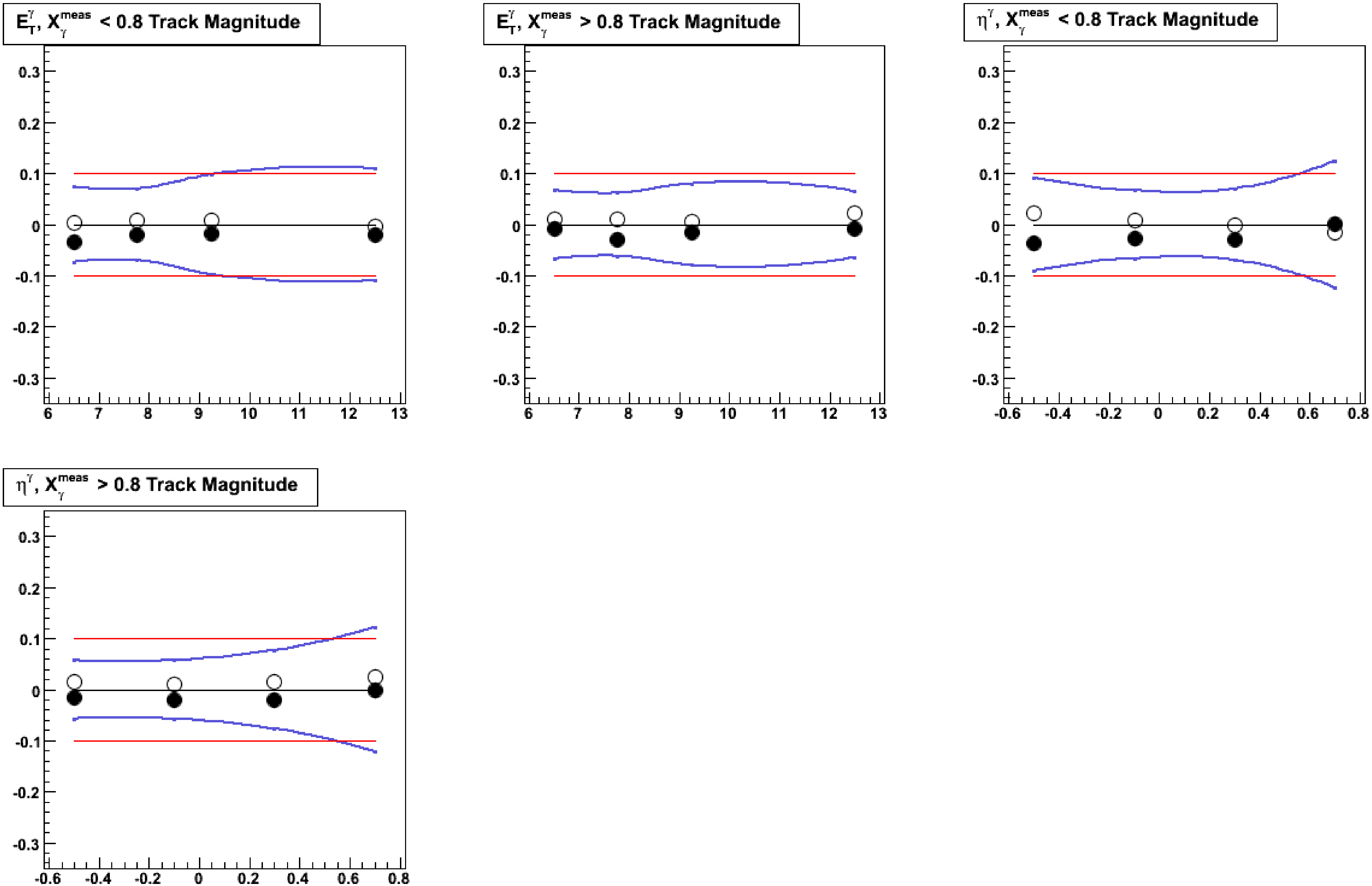

E_T^γ, X_γ^{meas} < 0.8 UncorJE
E_T^γ, X_γ^{meas} > 0.8 UncorJE
η^γ, X_γ^{meas} < 0.8 UncorJE
η^γ, X_γ^{meas} > 0.8 UncorJE

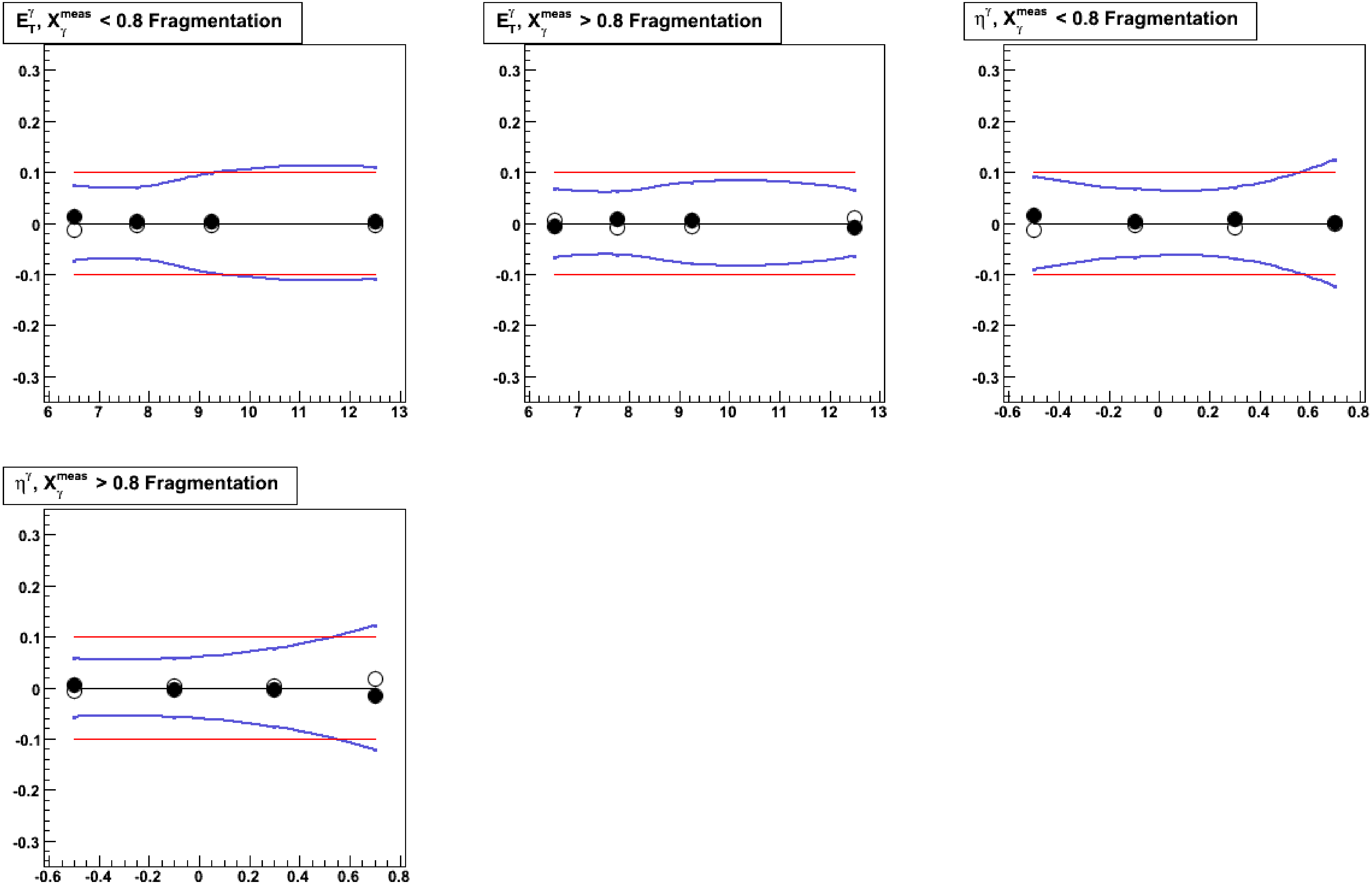

E_T^γ, X_γ^{meas} < 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13


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

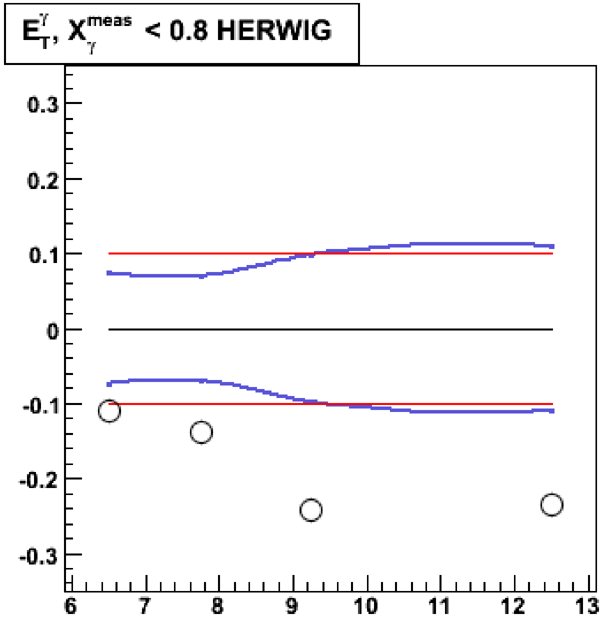

η^γ, X_γ^{meas} < 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

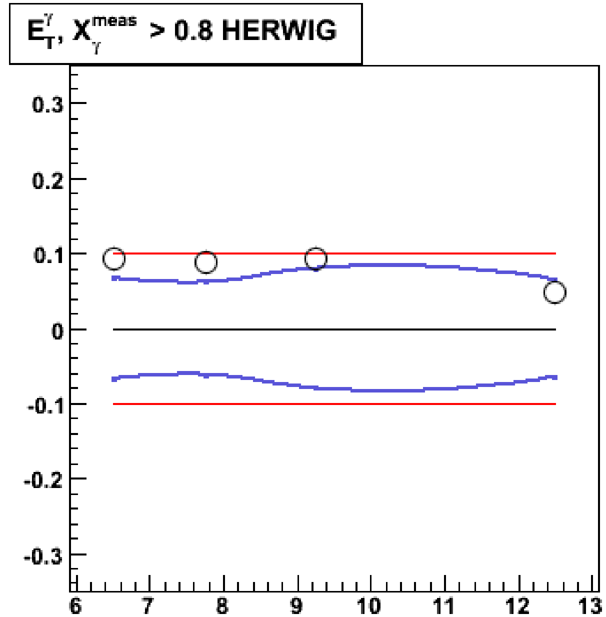

η^γ, X_γ^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

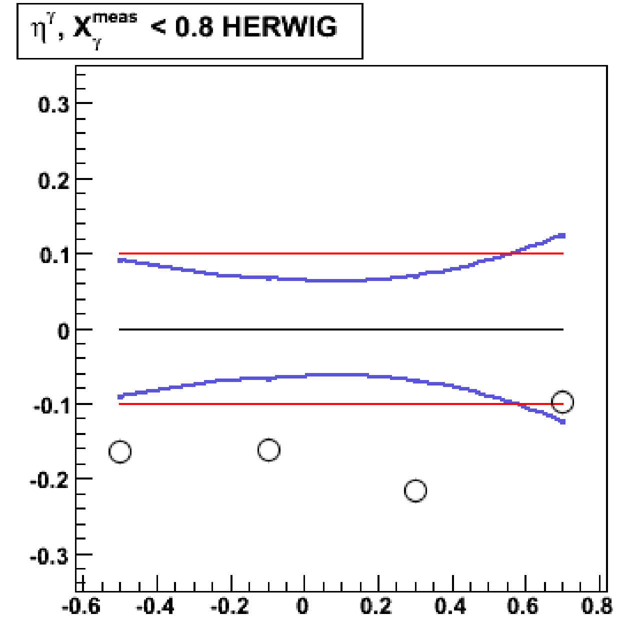

E_T^γ, X_γ^{meas} < 0.8 Track Magnitude
E_T^γ, X_γ^{meas} > 0.8 Track Magnitude
η^γ, X_γ^{meas} < 0.8 Track Magnitude
η^γ, X_γ^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

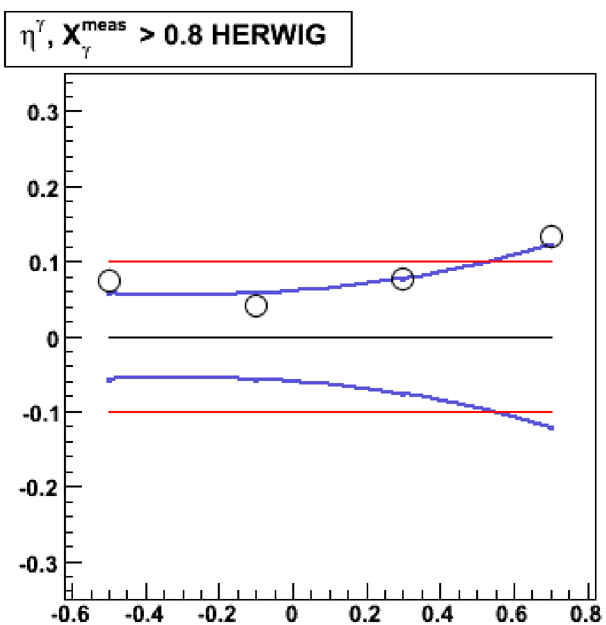


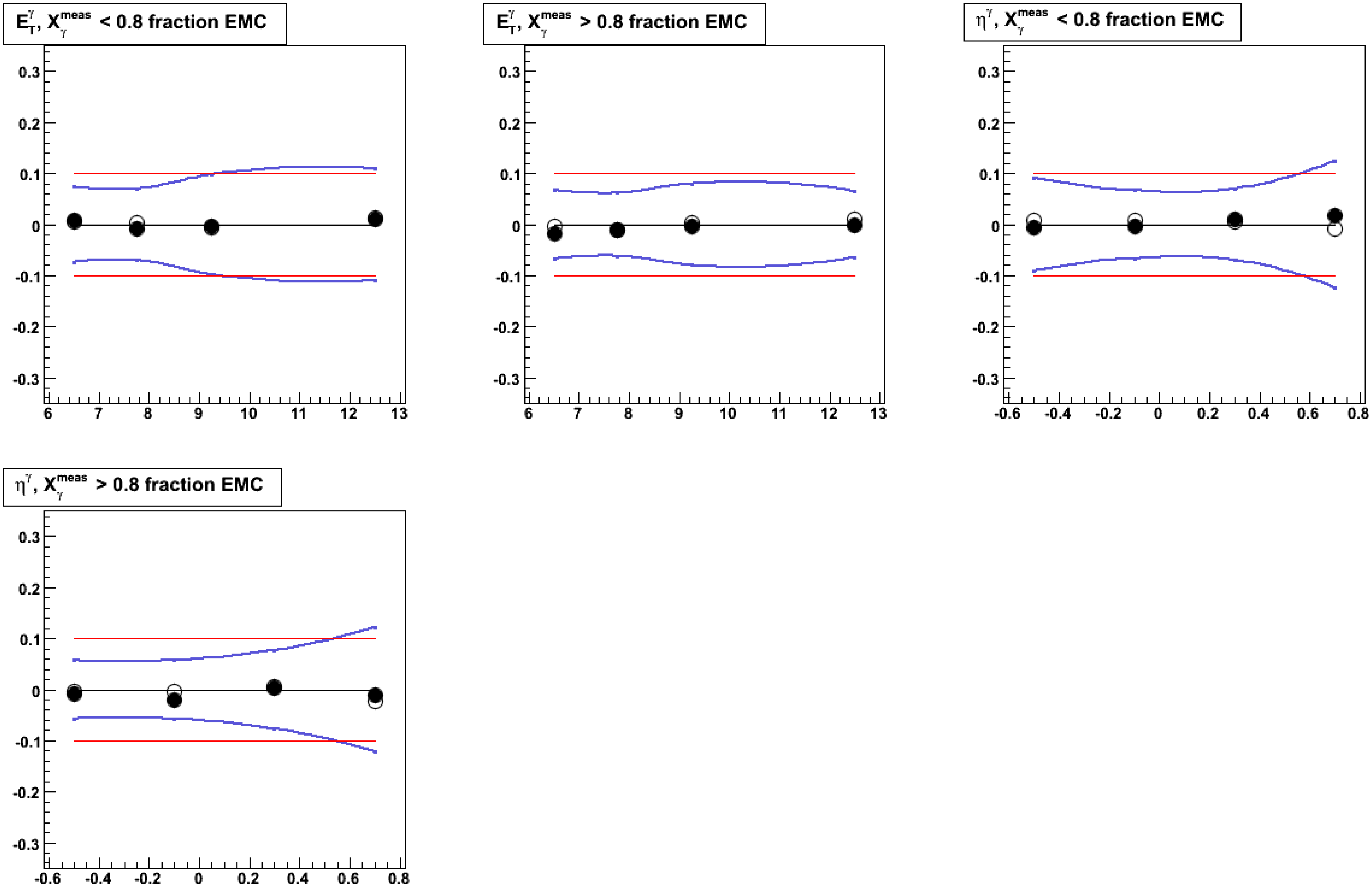
E_T^γ, X_γ^{meas} < 0.8 Fragmentation
E_T^γ, X_γ^{meas} > 0.8 Fragmentation
η^γ, X_γ^{meas} < 0.8 Fragmentation
η^γ, X_γ^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8


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

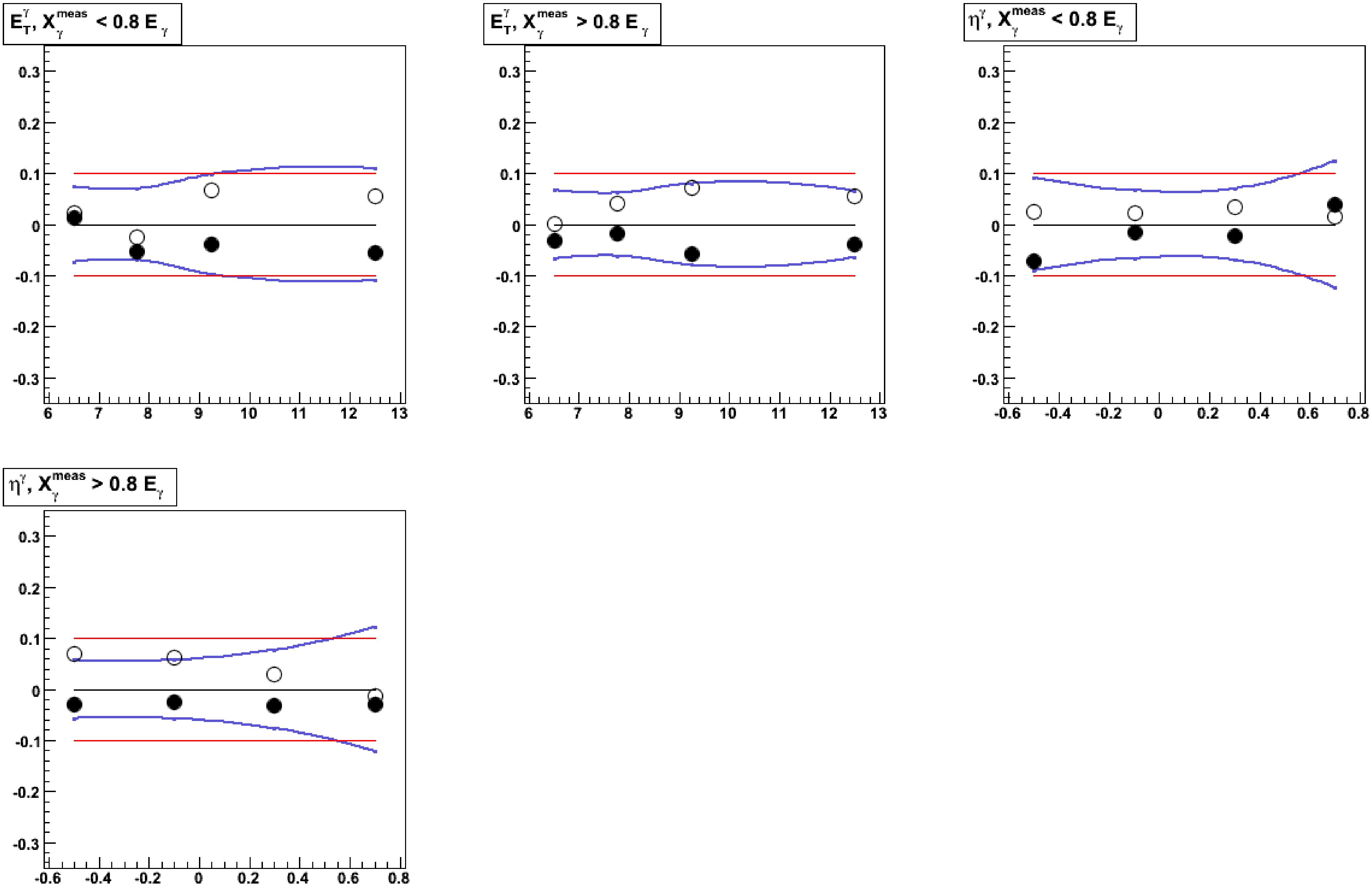

E_T^{γ}, x_{γ}^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
6 7 8 9 10 11 12 13

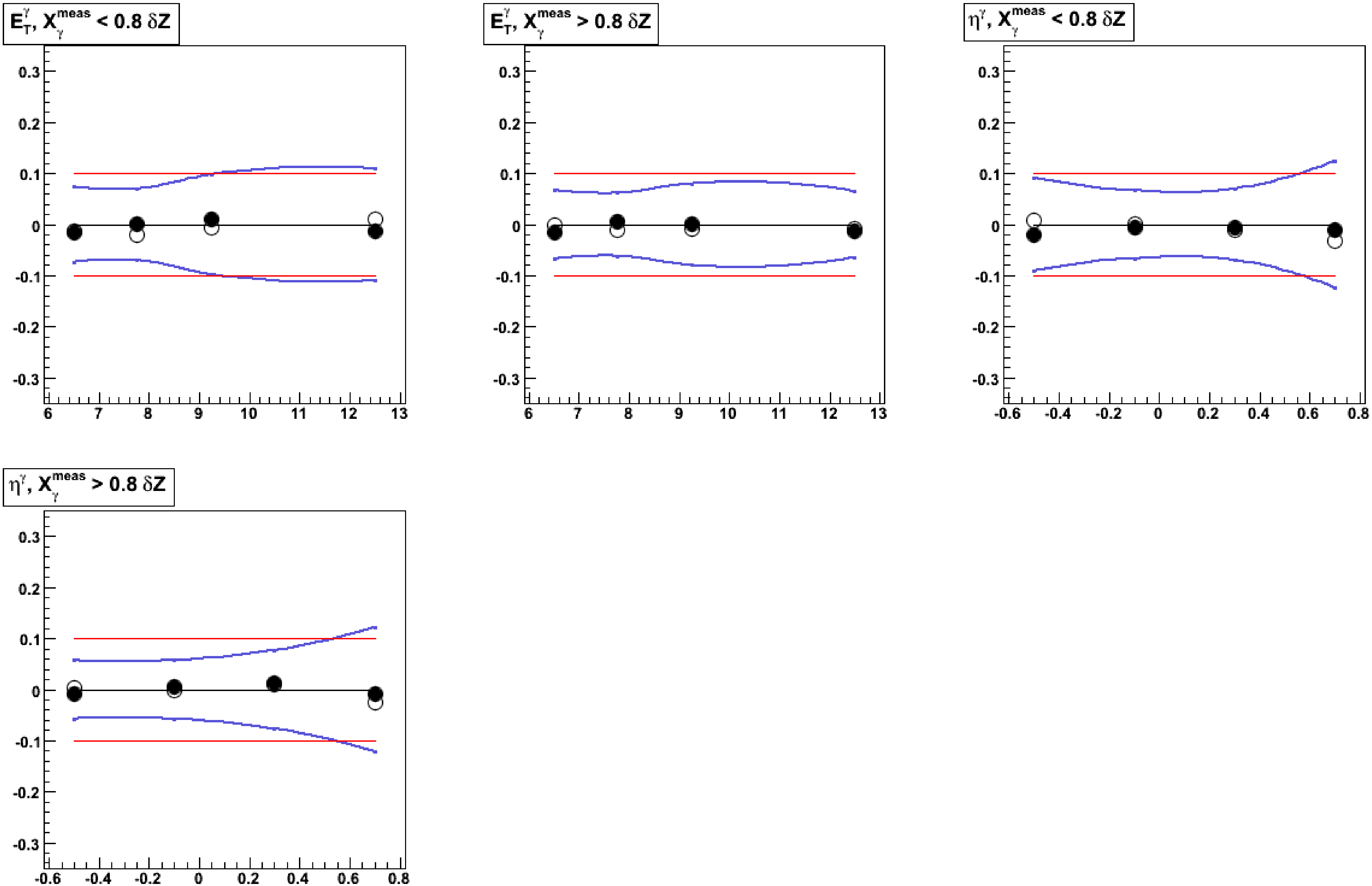

η^{γ}, x_{γ}^{meas} < 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

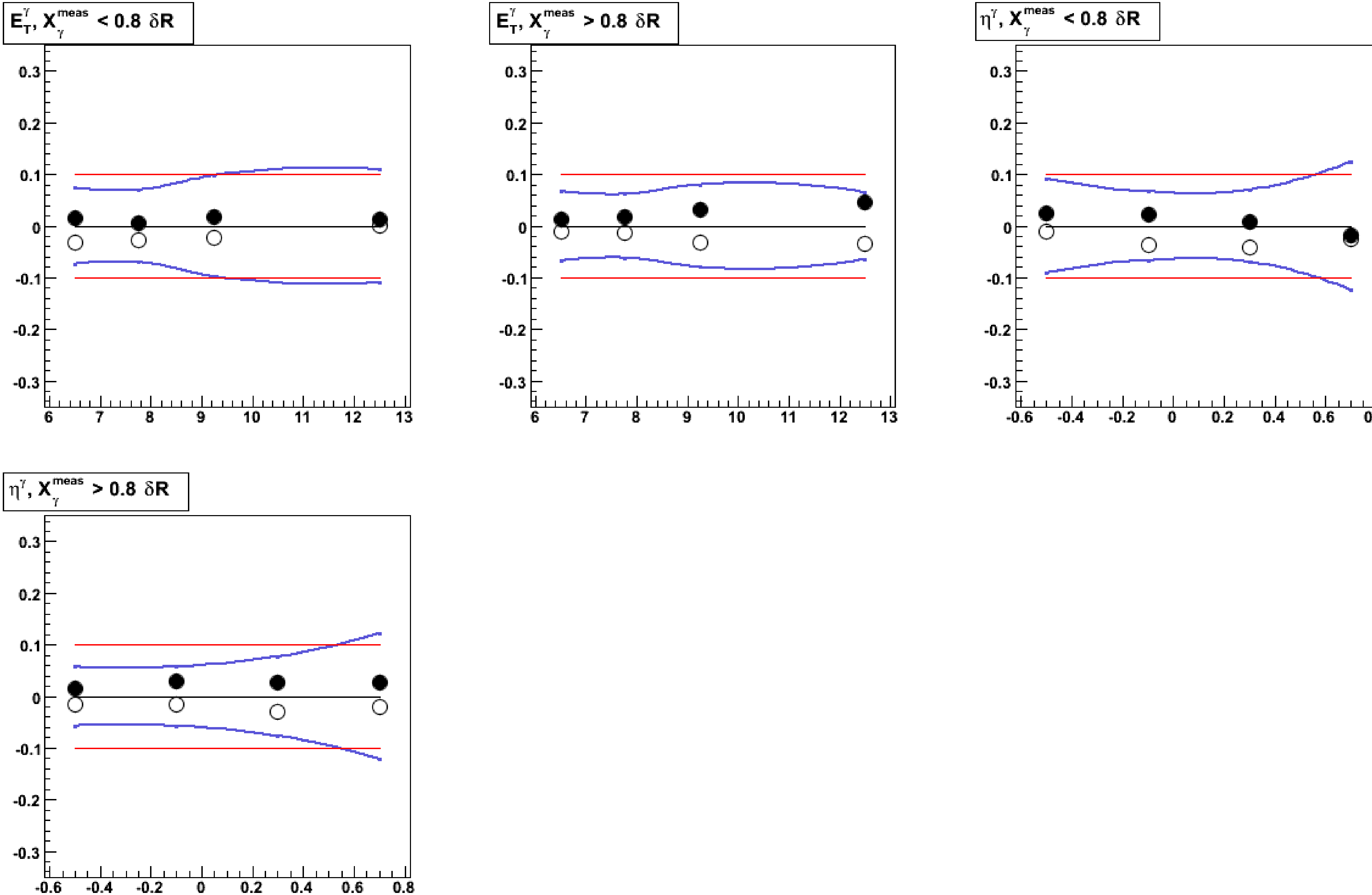

η^{γ}, x_{γ}^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8



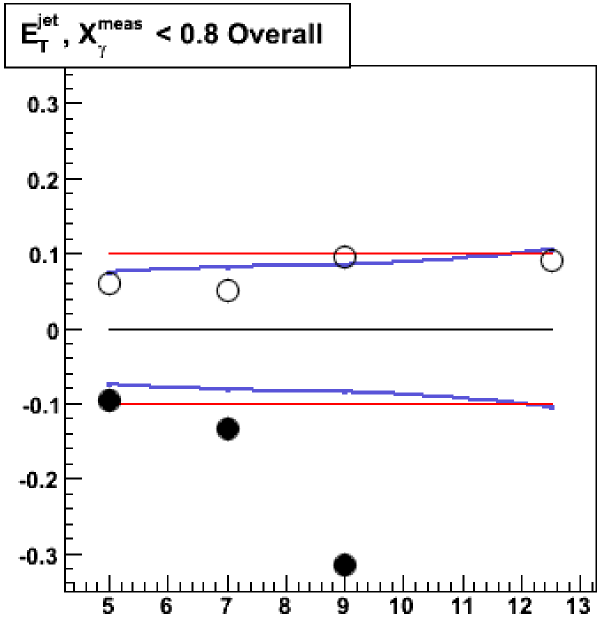
E_T^γ, X_γ^{meas} < 0.8 fraction EMC
E_T^γ, X_γ^{meas} > 0.8 fraction EMC
η^γ, X_γ^{meas} < 0.8 fraction EMC
η^γ, X_γ^{meas} > 0.8 fraction EMC

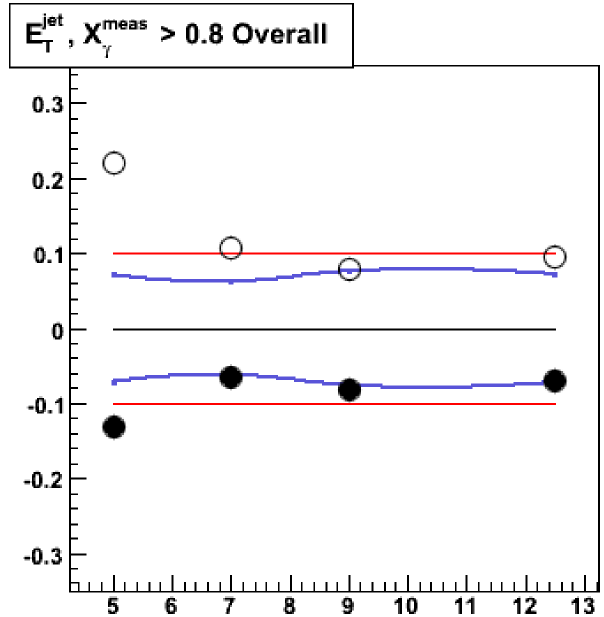

E_T^γ, X_γ^{meas} < 0.8 E_γ
E_T^γ, X_γ^{meas} > 0.8 E_γ
η^γ, X_γ^{meas} < 0.8 E_γ
η^γ, X_γ^{meas} > 0.8 E_γ

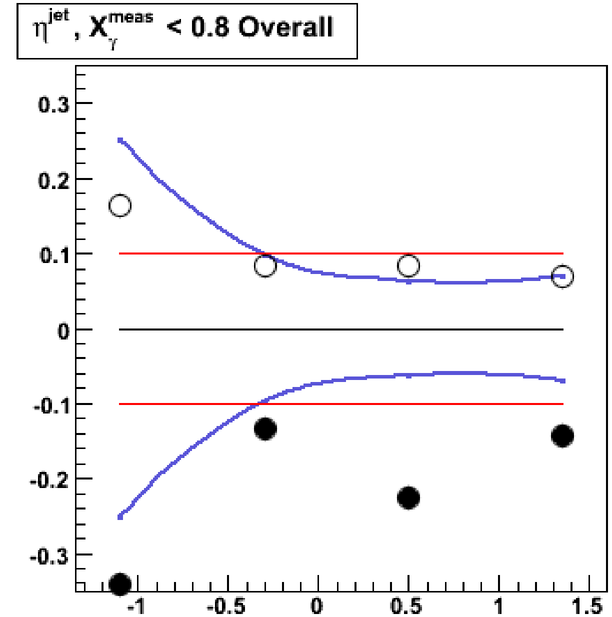

E_T^γ, X_γ^{meas} < 0.8 δZ
E_T^γ, X_γ^{meas} > 0.8 δZ
η^γ, X_γ^{meas} < 0.8 δZ
η^γ, X_γ^{meas} > 0.8 δZ

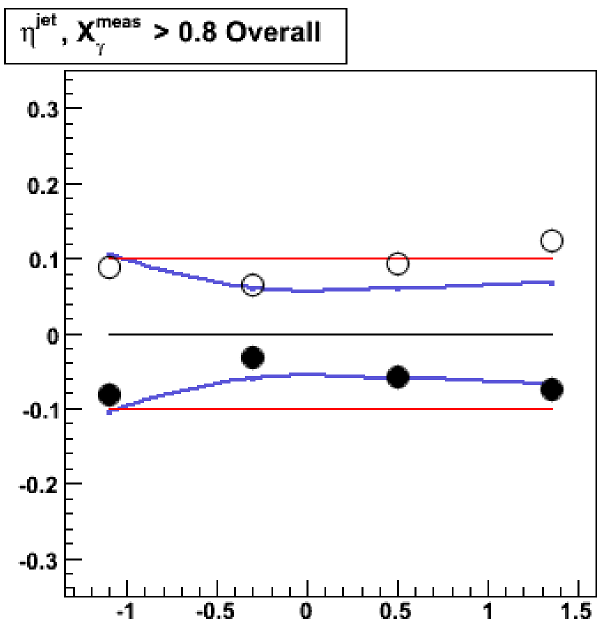


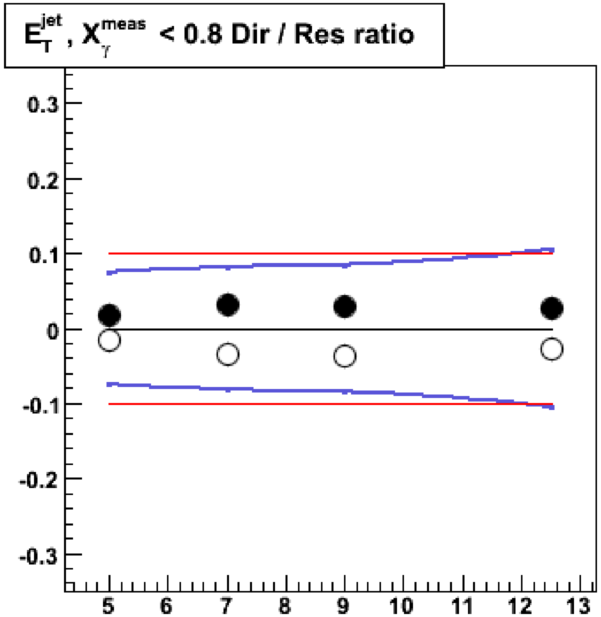
E_T^γ, X_γ^{meas} < 0.8 δR
E_T^γ, X_γ^{meas} > 0.8 δR
η^γ, X_γ^{meas} < 0.8 δR
η^γ, X_γ^{meas} > 0.8 δR

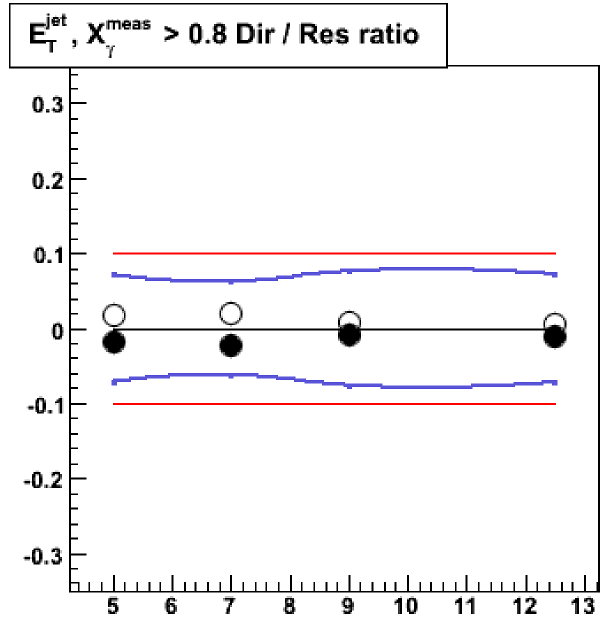

E$_T^{jet}$, X$_\gamma^{meas}$ < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

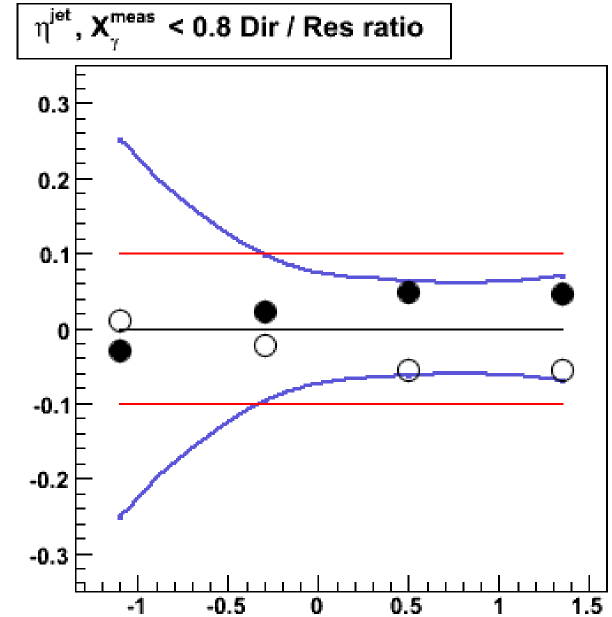

E$_T^{jet}$, X$_\gamma^{meas}$ > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

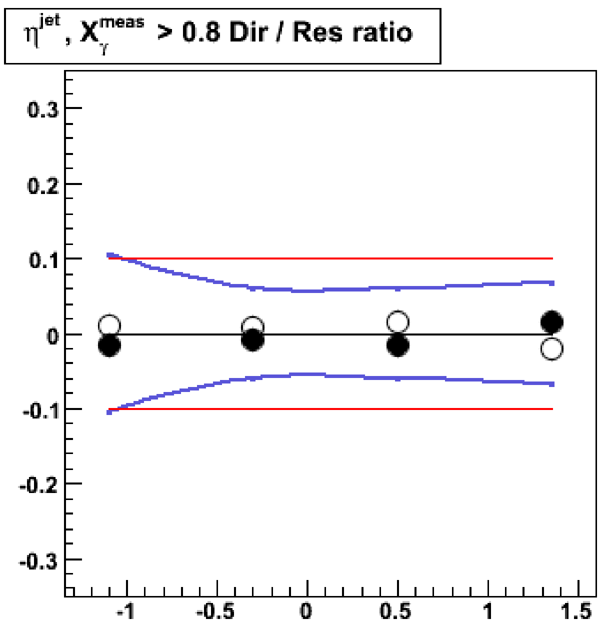

η^{jet} , X$_\gamma^{meas}$ < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5

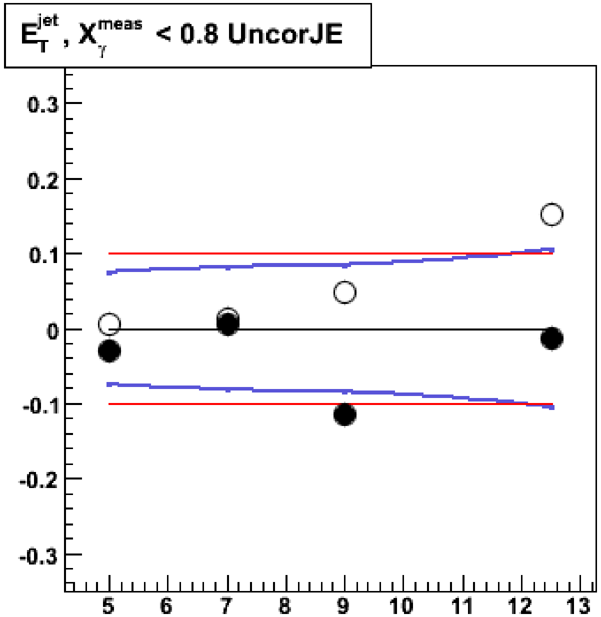

η^{jet} , X$_\gamma^{meas}$ > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5

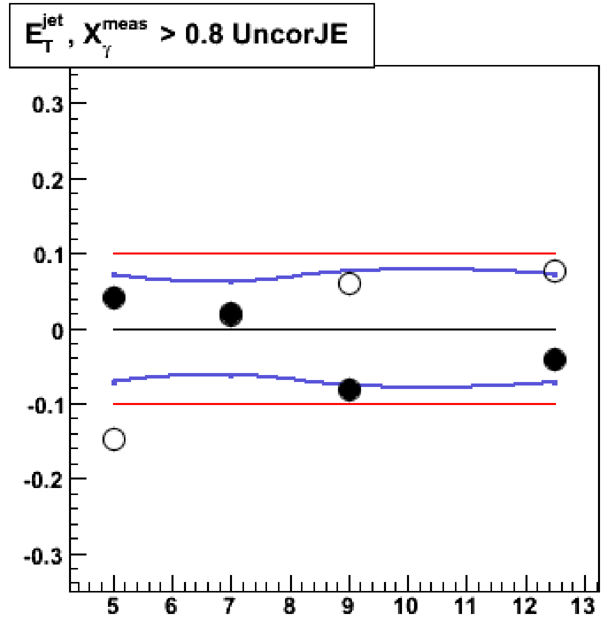

E_T^{jet}, X_γ^{meas} < 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

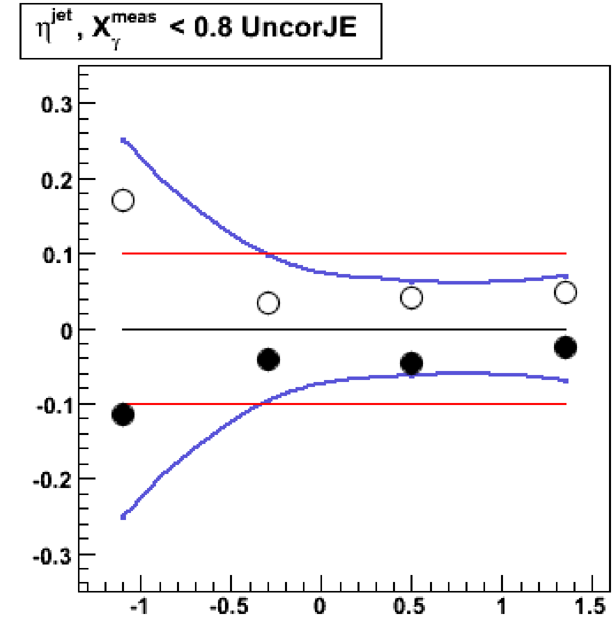

E_T^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13

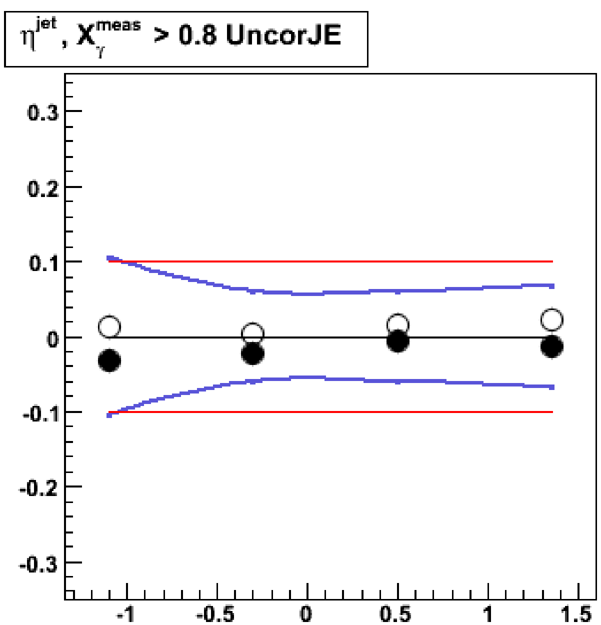

η^{jet}, X_γ^{meas} < 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5

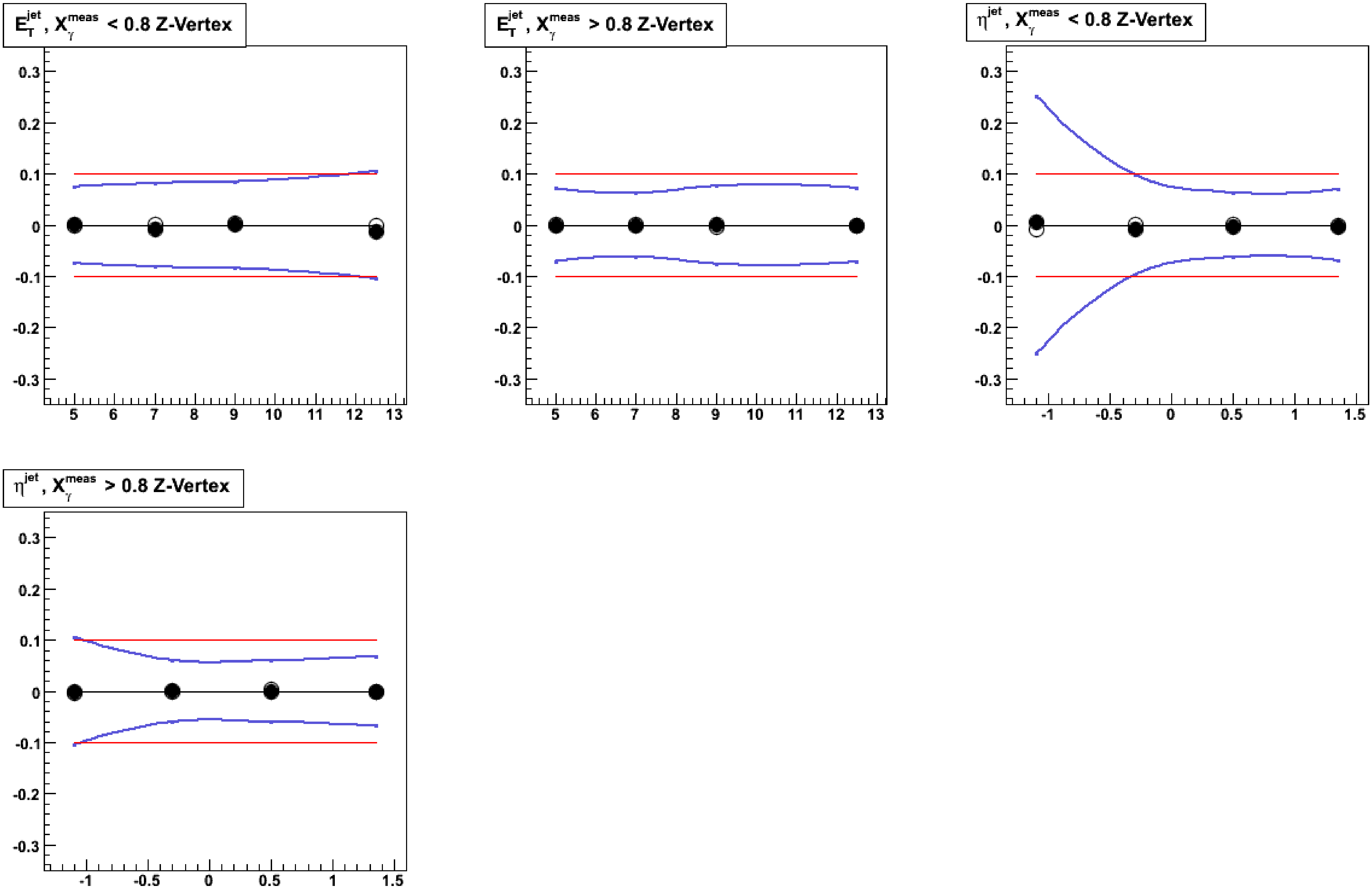

η^{jet}, X_γ^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5


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

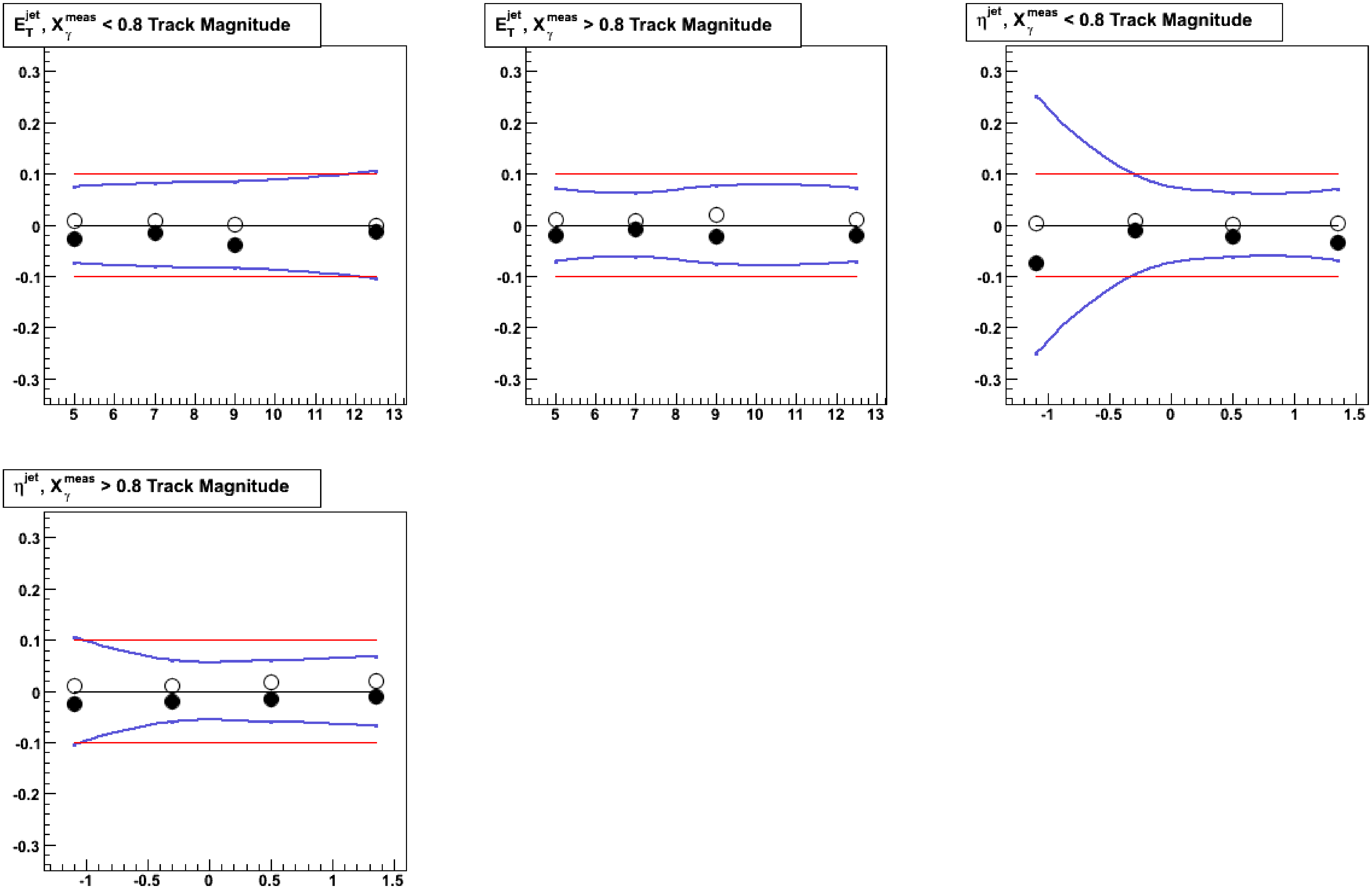

E_T^jet , X_γ^meas > 0.8 UncorJE
0.3 0.2 0.1 0 -0.1 -0.2 -0.3
5 6 7 8 9 10 11 12 13


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

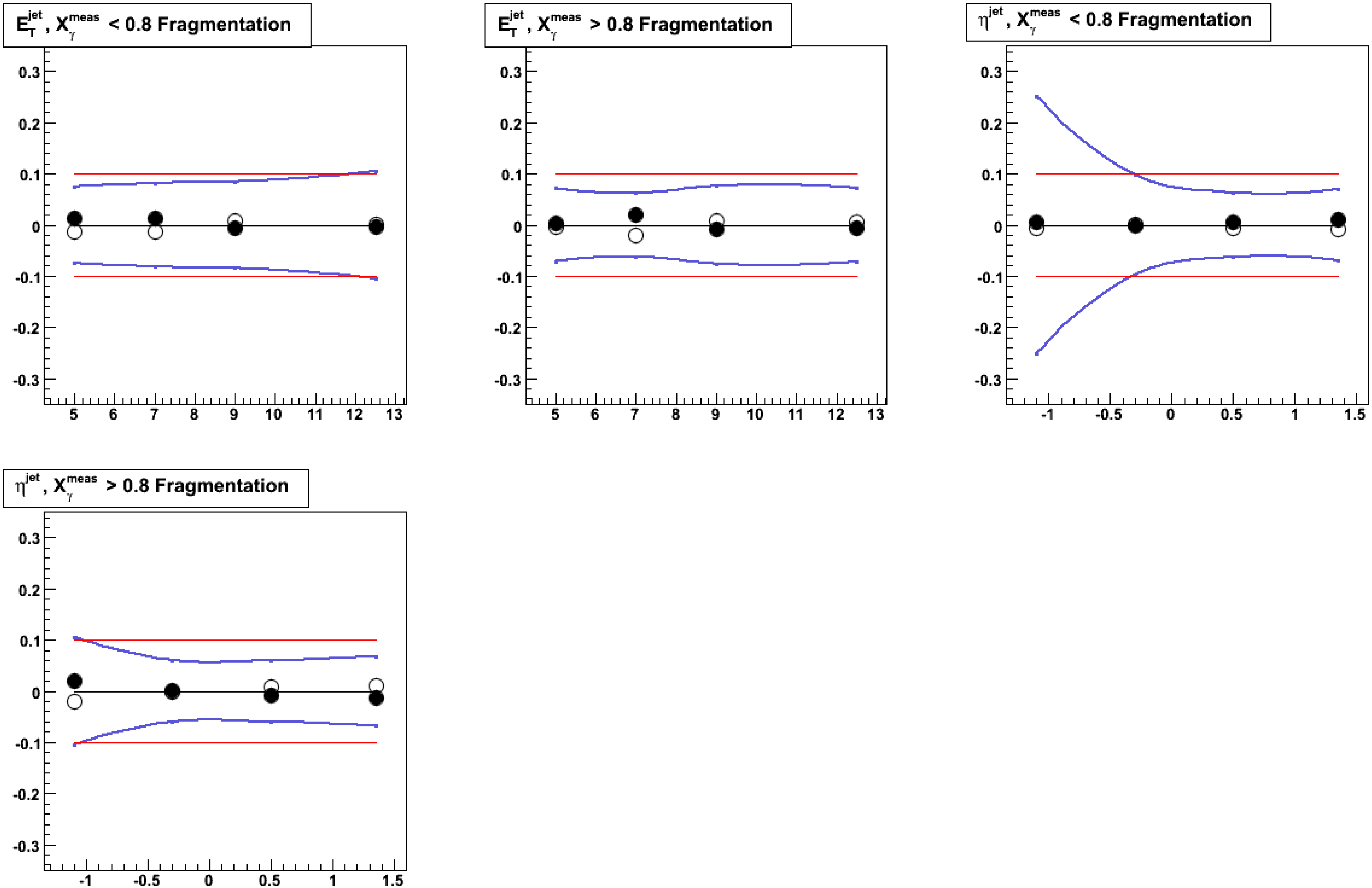

η^jet , X_γ^meas > 0.8 UncorJE
0.3 0.2 0.1 0 -0.1 -0.2 -0.3
-1 -0.5 0 0.5 1 1.5



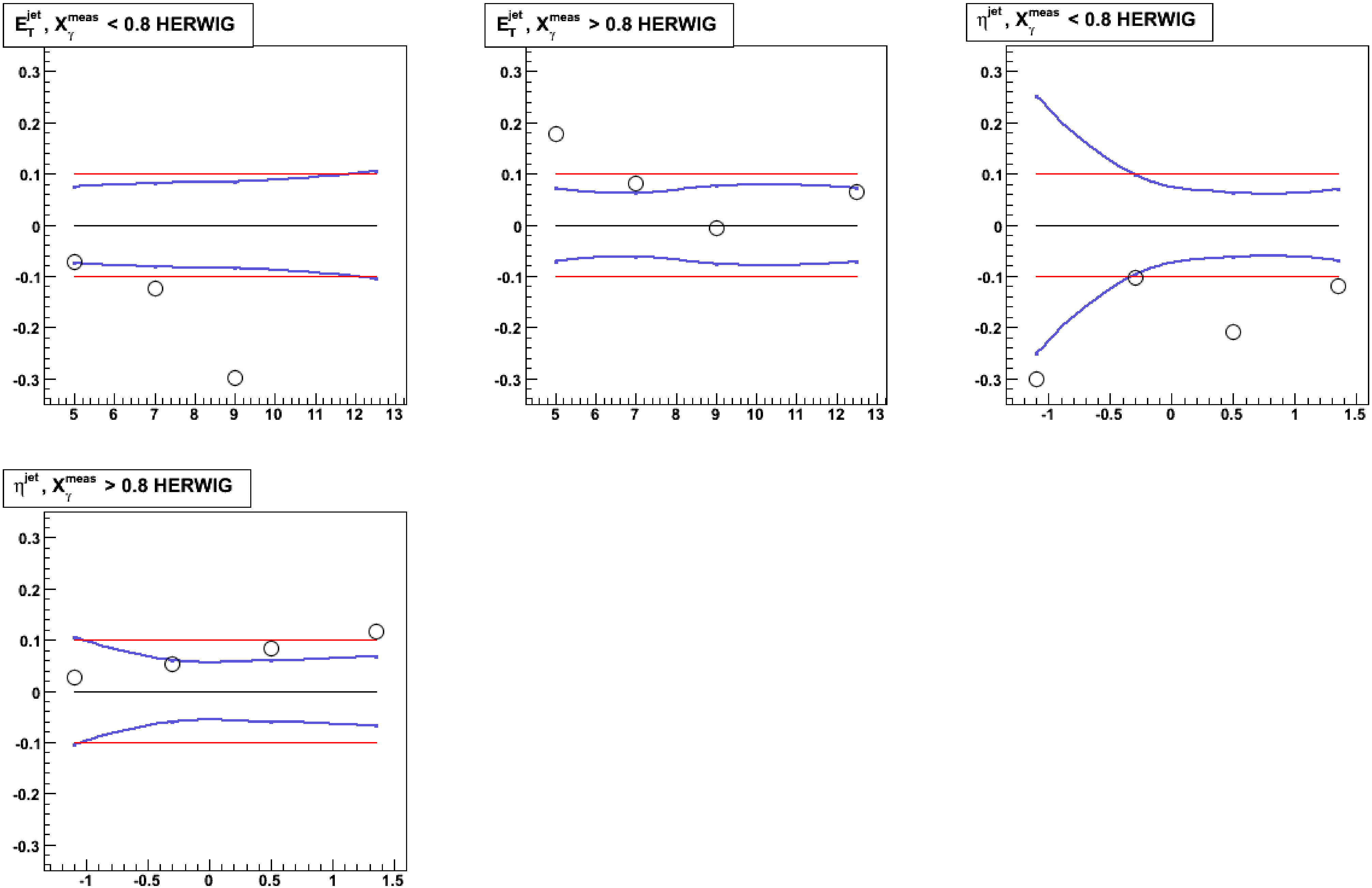
E_T^{jet}, X_γ^{meas} < 0.8 Z-Vertex
E_T^{jet}, X_γ^{meas} > 0.8 Z-Vertex
η^{jet}, X_γ^{meas} < 0.8 Z-Vertex
η^{jet}, X_γ^{meas} > 0.8 Z-Vertex

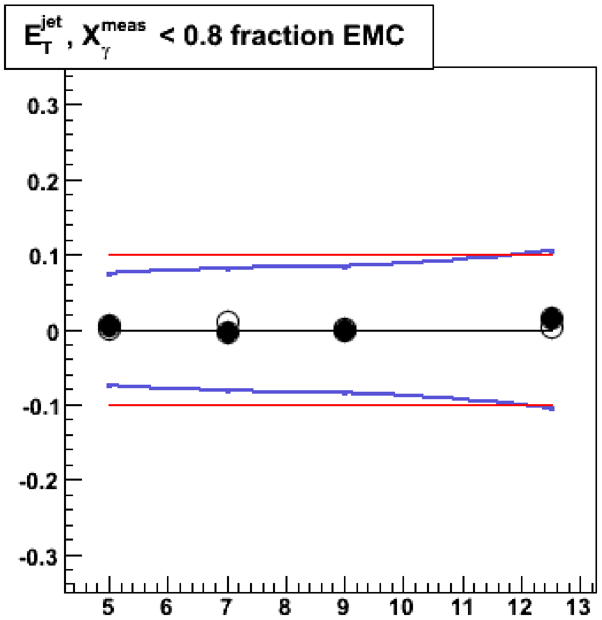


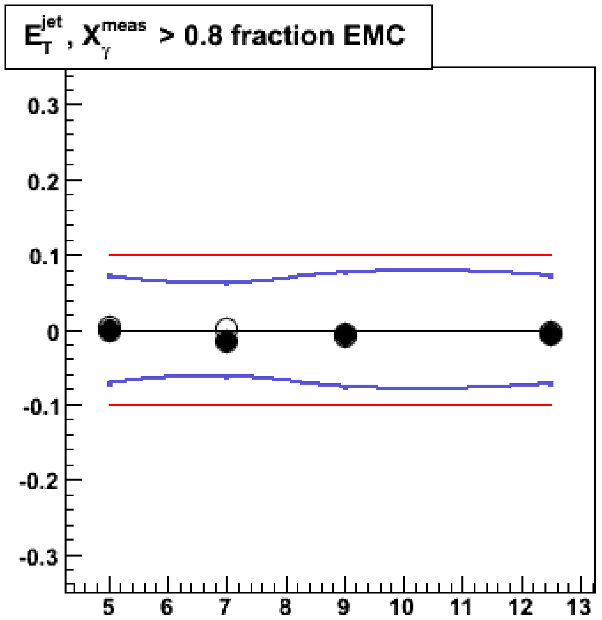
E_T^{jet}, X_γ^{meas} < 0.8 Track Magnitude
E_T^{jet}, X_γ^{meas} > 0.8 Track Magnitude
η^{jet}, X_γ^{meas} < 0.8 Track Magnitude
η^{jet}, X_γ^{meas} > 0.8 Track Magnitude

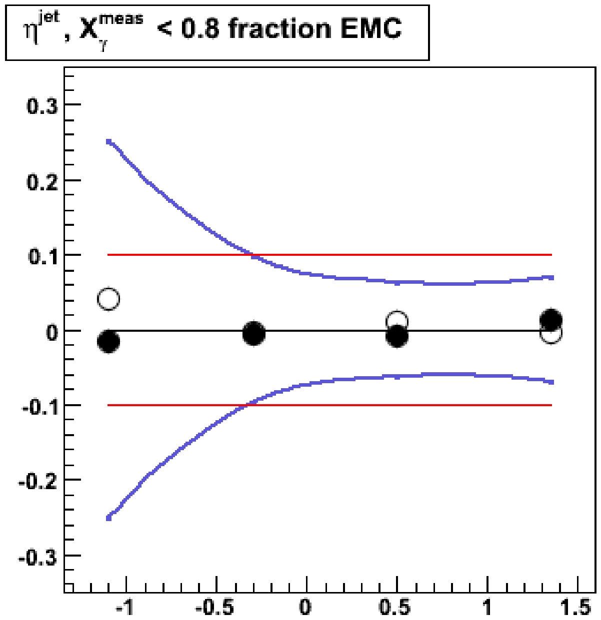


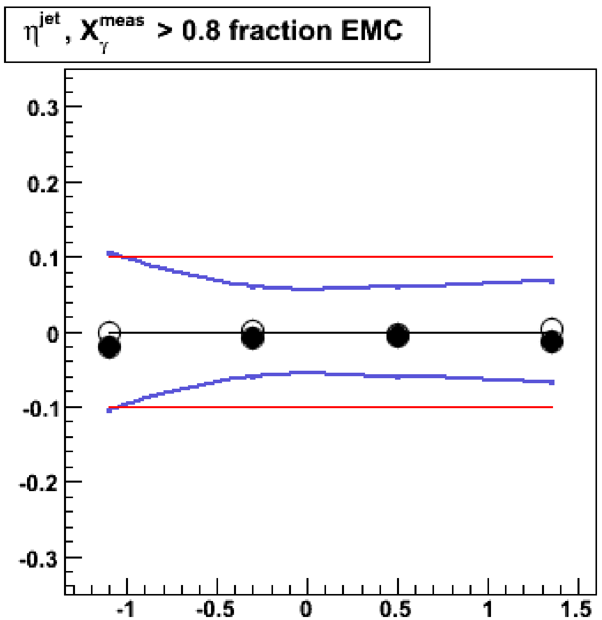
E_T^jet, X_γ^meas < 0.8 Fragmentation
E_T^jet, X_γ^meas > 0.8 Fragmentation
η^jet, X_γ^meas < 0.8 Fragmentation
η^jet, X_γ^meas > 0.8 Fragmentation

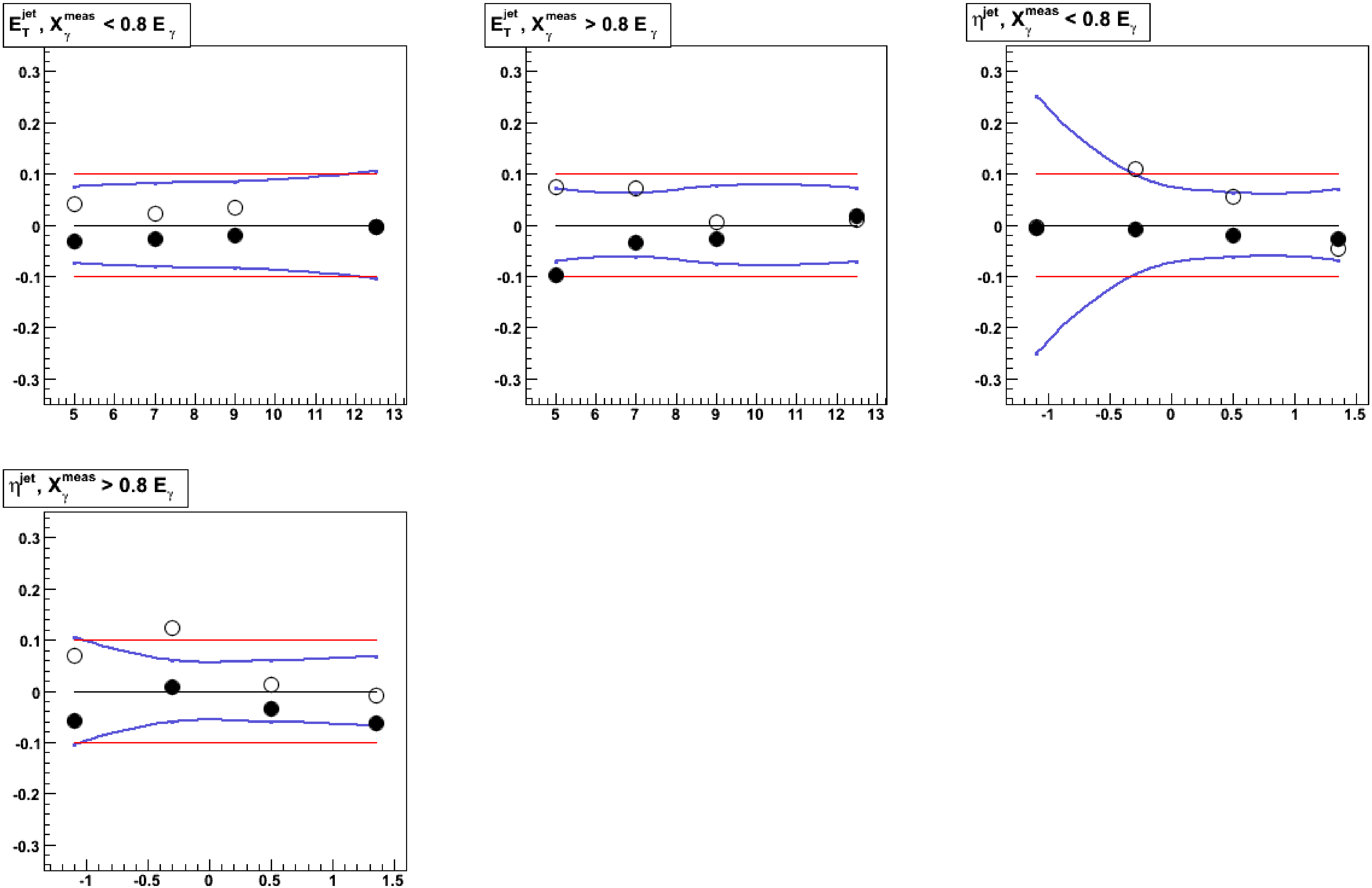

E_T^{jet}, X_γ^{meas} < 0.8 HERWIG
E_T^{jet}, X_γ^{meas} > 0.8 HERWIG
η^{jet}, X_γ^{meas} < 0.8 HERWIG
η^{jet}, X_γ^{meas} > 0.8 HERWIG

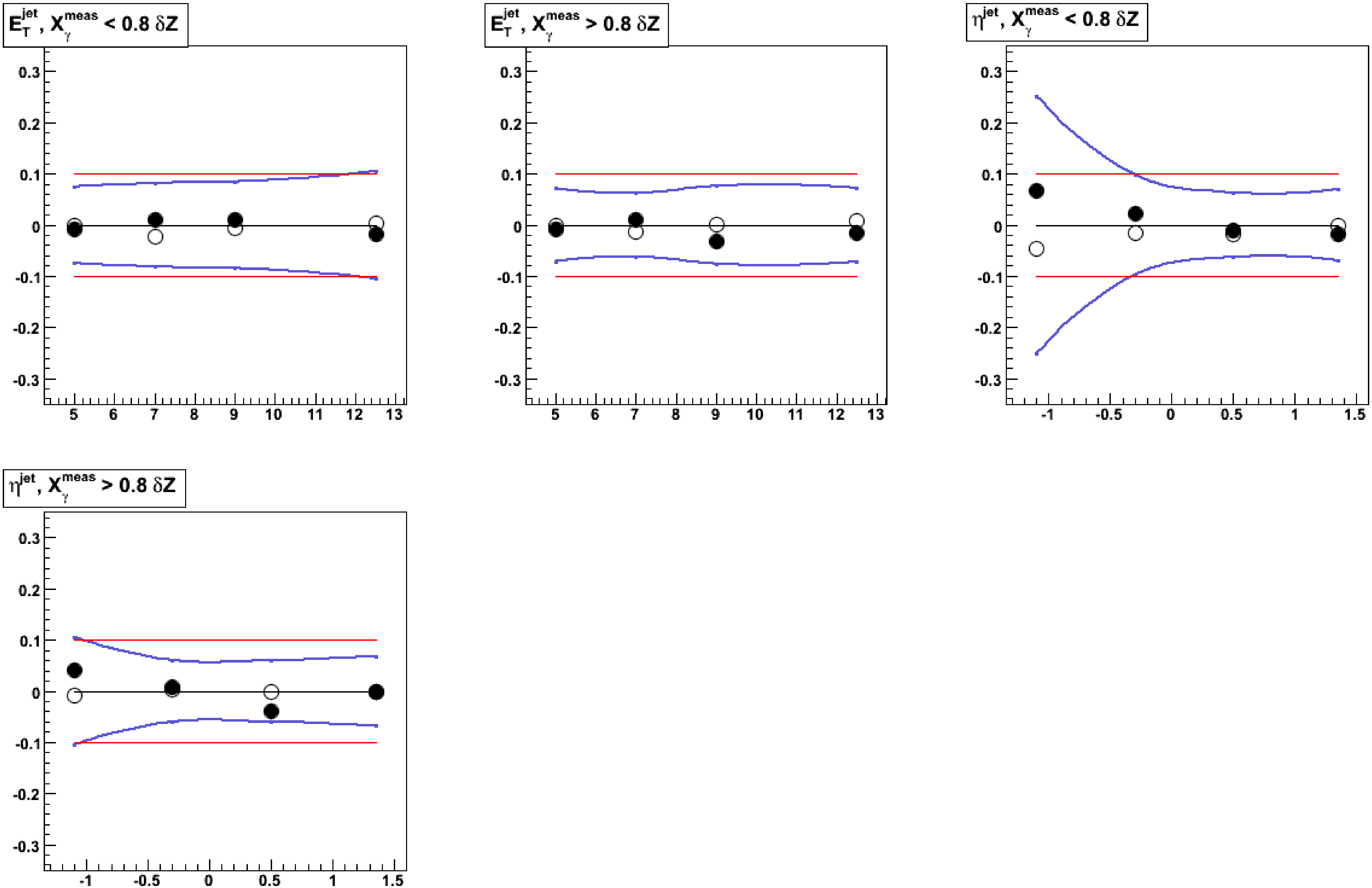

E_T^{jet} , X_γ^{meas} < 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13


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

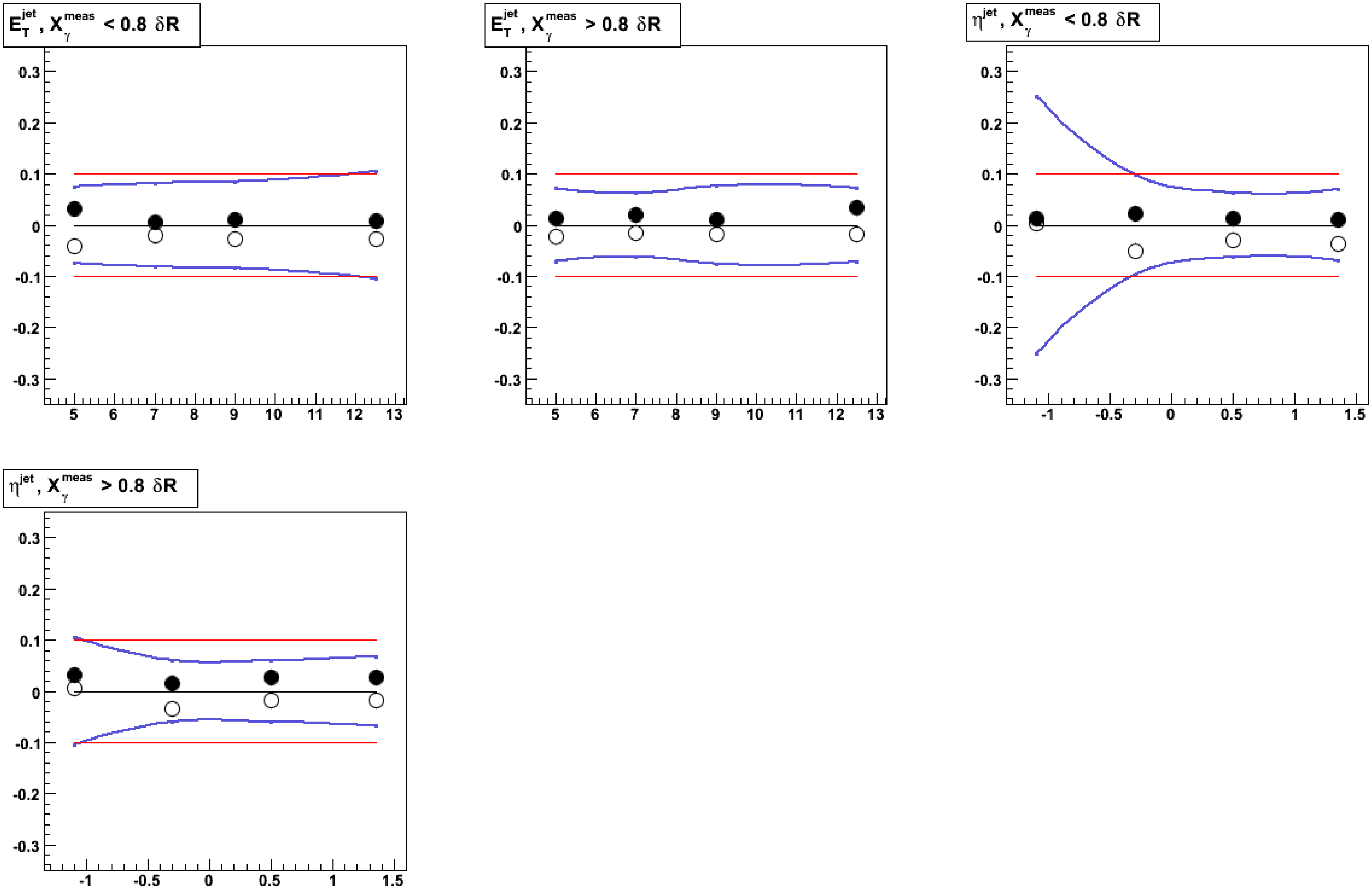

η^{jet} , X_γ^{meas} < 0.8 fraction EMC
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-1 -0.5 0 0.5 1 1.5


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

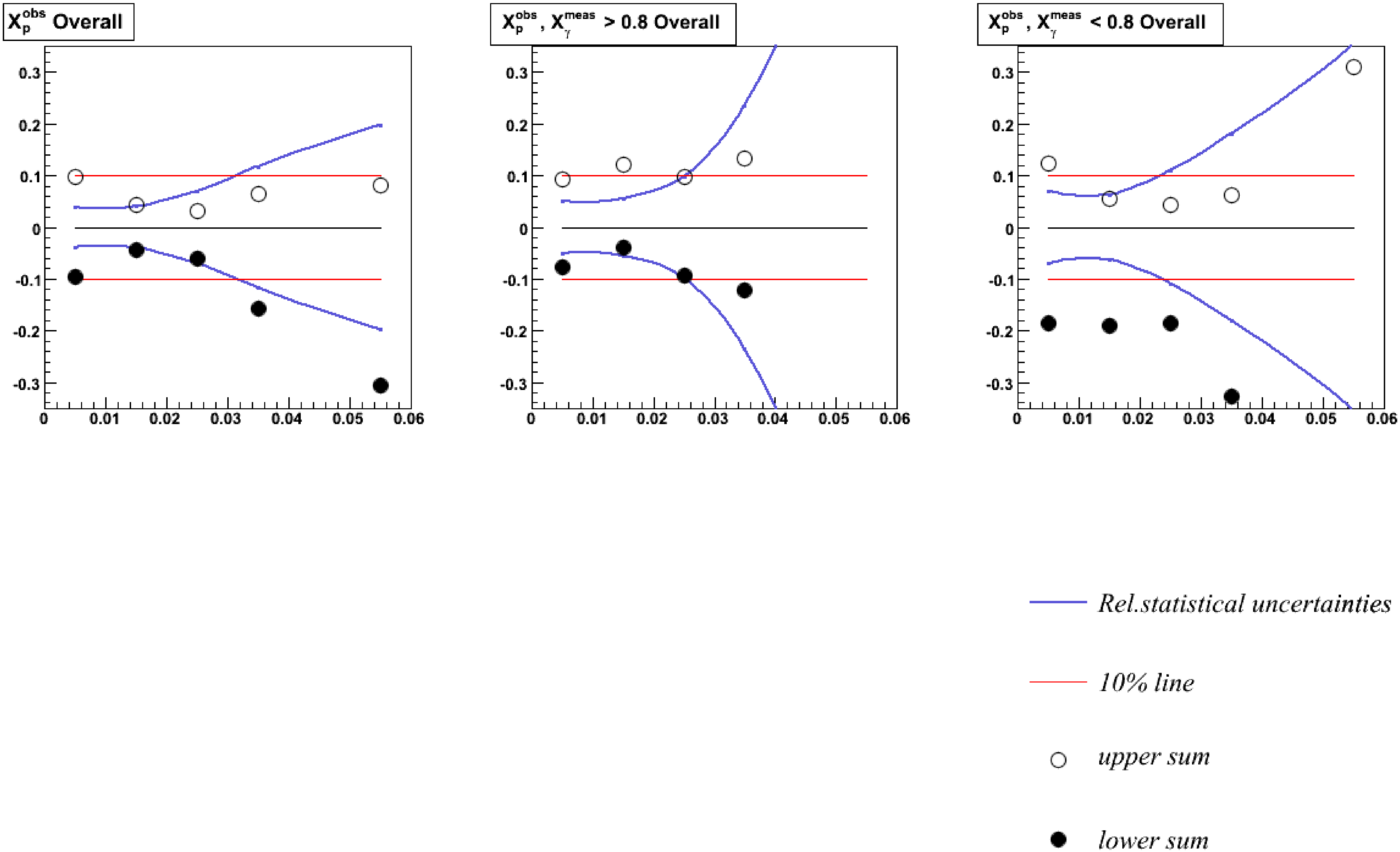

E_T^{jet}, X_γ^{meas} < 0.8 E_γ
E_T^{jet}, X_γ^{meas} > 0.8 E_γ
η^{jet}, X_γ^{meas} < 0.8 E_γ
η^{jet}, X_γ^{meas} > 0.8 E_γ

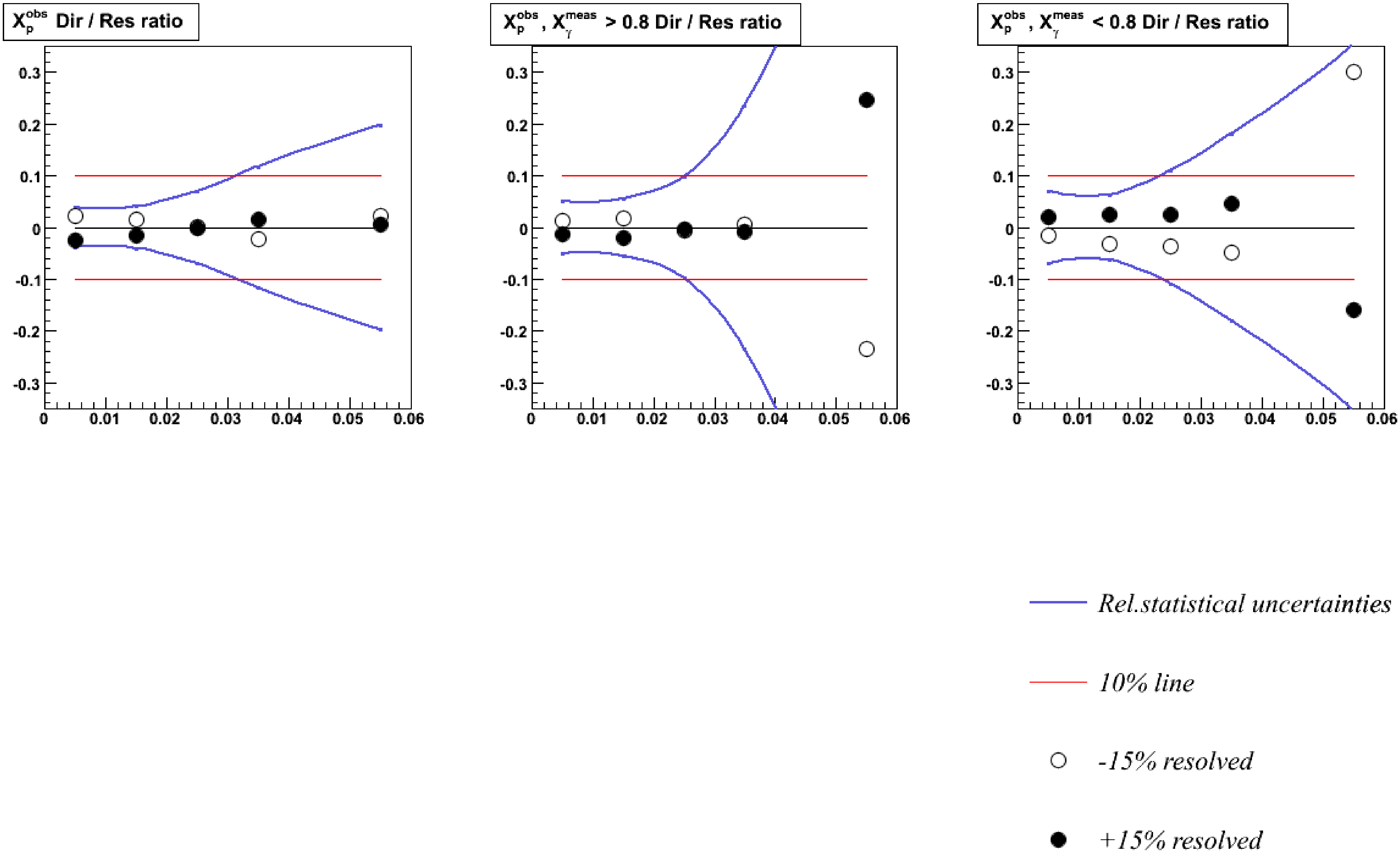


E$_T^{jet}$, X$_\gamma^{meas}$ < 0.8 δZ
E$_T^{jet}$, X$_\gamma^{meas}$ > 0.8 δZ
η^{jet}, X$_\gamma^{meas}$ < 0.8 δZ
η^{jet}, X$_\gamma^{meas}$ > 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
5 6 7 8 9 10 11 12 13
-1 -0.5 0 0.5 1 1.5

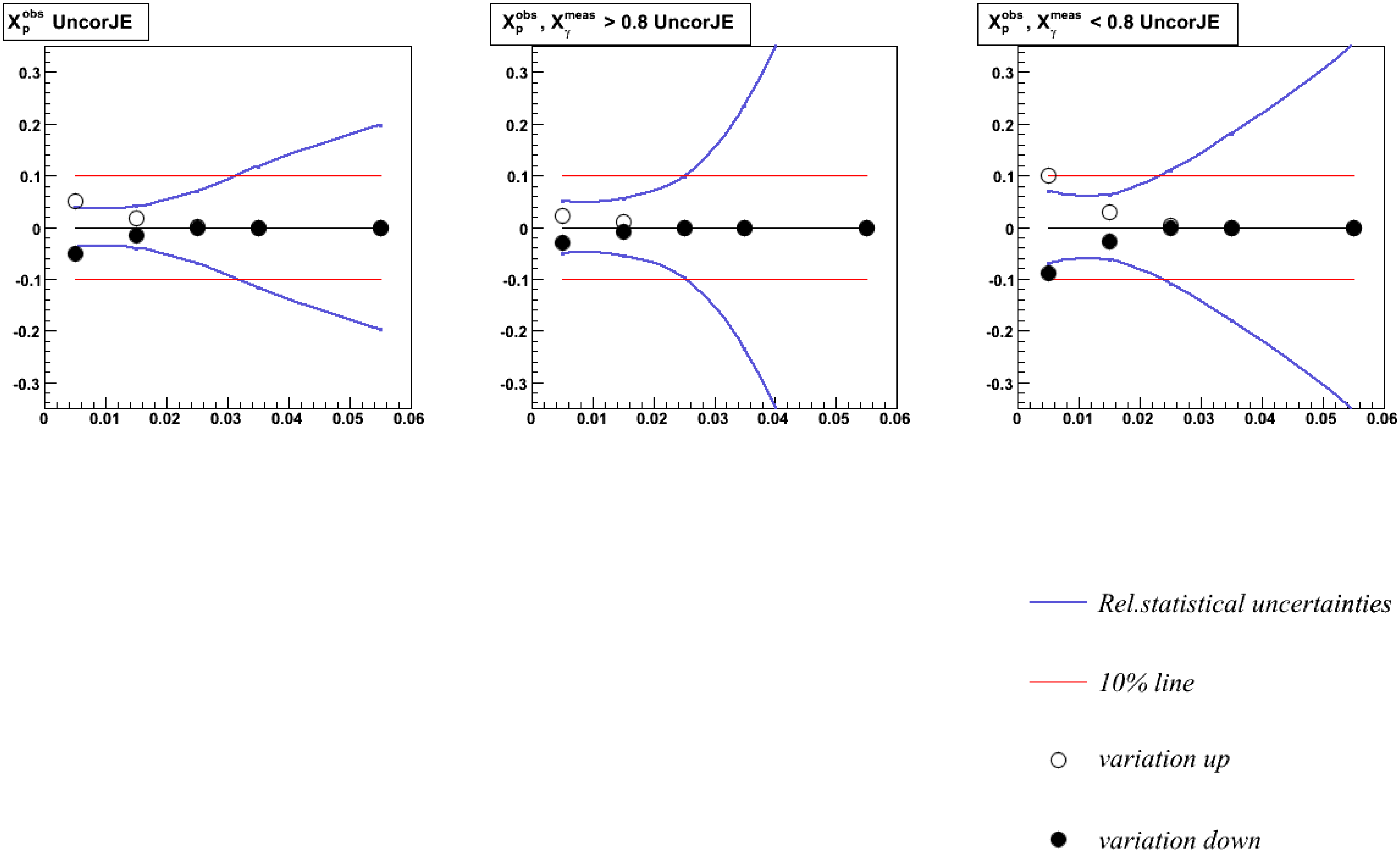


E_T^{jet}, X_γ^{meas} < 0.8 δR
E_T^{jet}, X_γ^{meas} > 0.8 δR
η^{jet}, X_γ^{meas} < 0.8 δR
η^{jet}, X_γ^{meas} > 0.8 δR

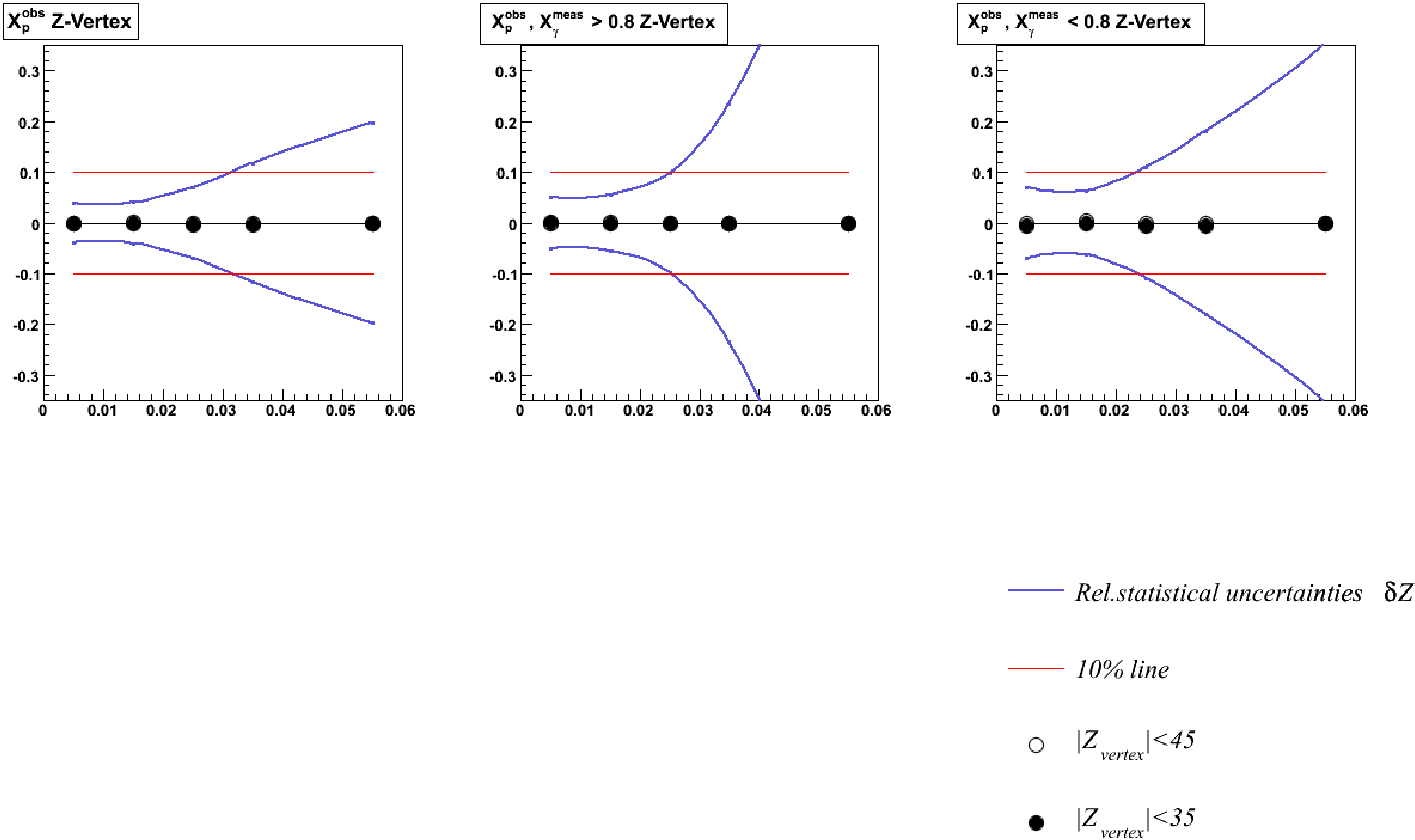

X_p^{obs} Overall
X_p^{obs}, X_γ^{meas} > 0.8 Overall
X_p^{obs}, X_γ^{meas} < 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties
10% line
upper sum
lower sum



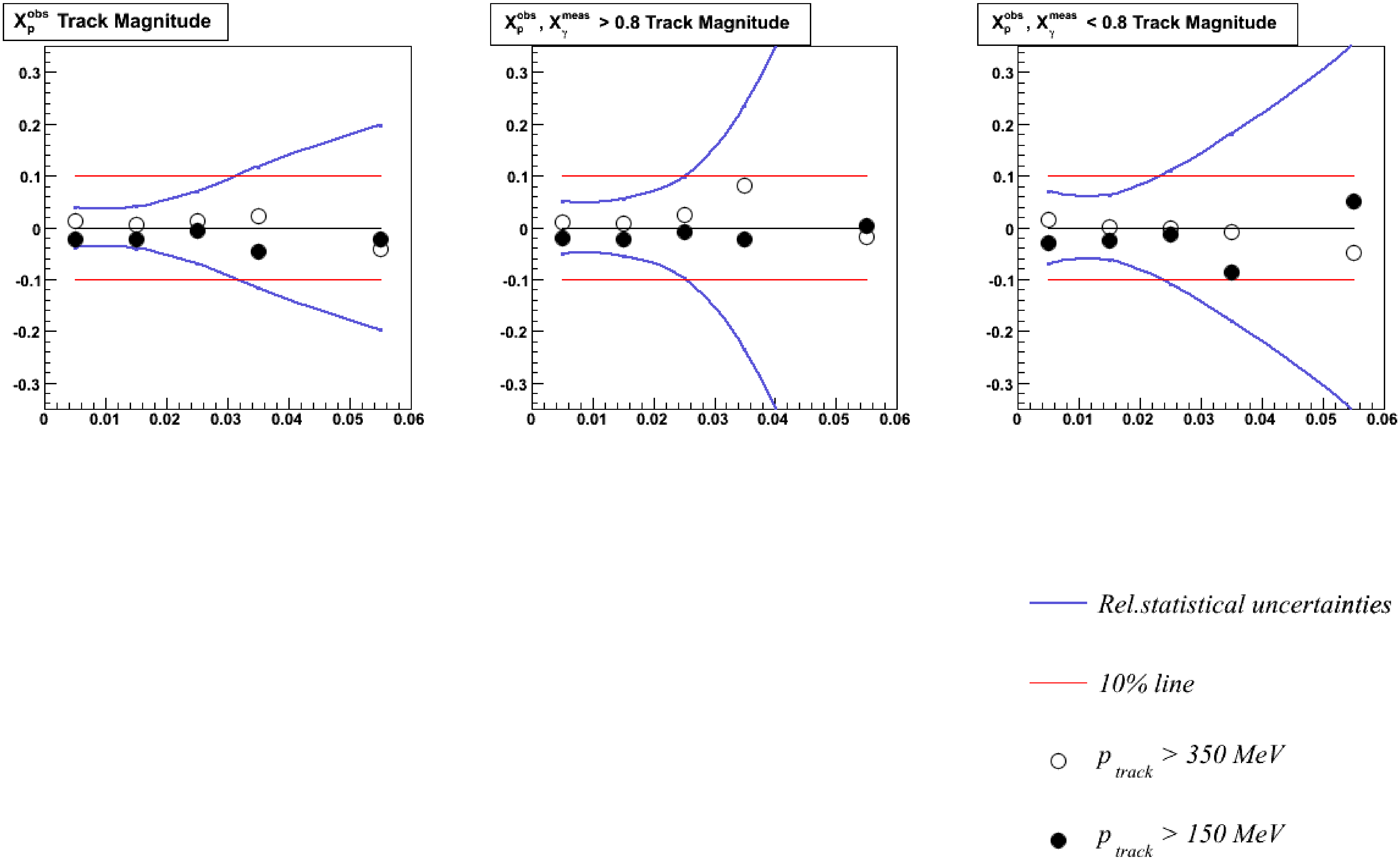
X_p^{obs} Dir / Res ratio
X_p^{obs}, X_γ^{meas} > 0.8 Dir / Res ratio
X_p^{obs}, X_γ^{meas} < 0.8 Dir / Res ratio
Rel.statistical uncertainties
10% line
-15% resolved
+15% resolved



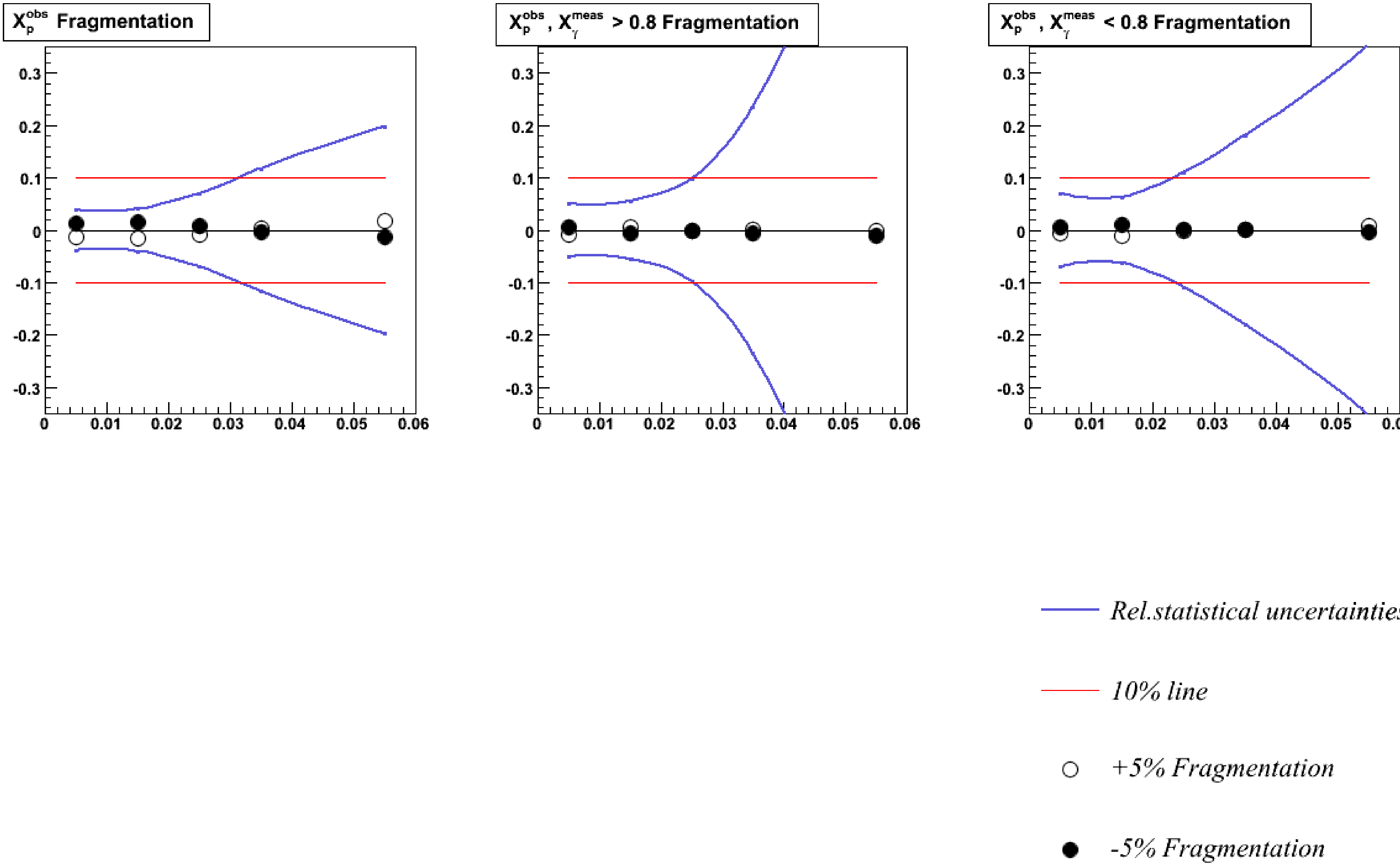
X_p^{obs} UncorJE
X_p^{obs}, X_γ^{meas} > 0.8 UncorJE
X_p^{obs}, X_γ^{meas} < 0.8 UncorJE
Rel.statistical uncertainties
10% line
variation up
variation down

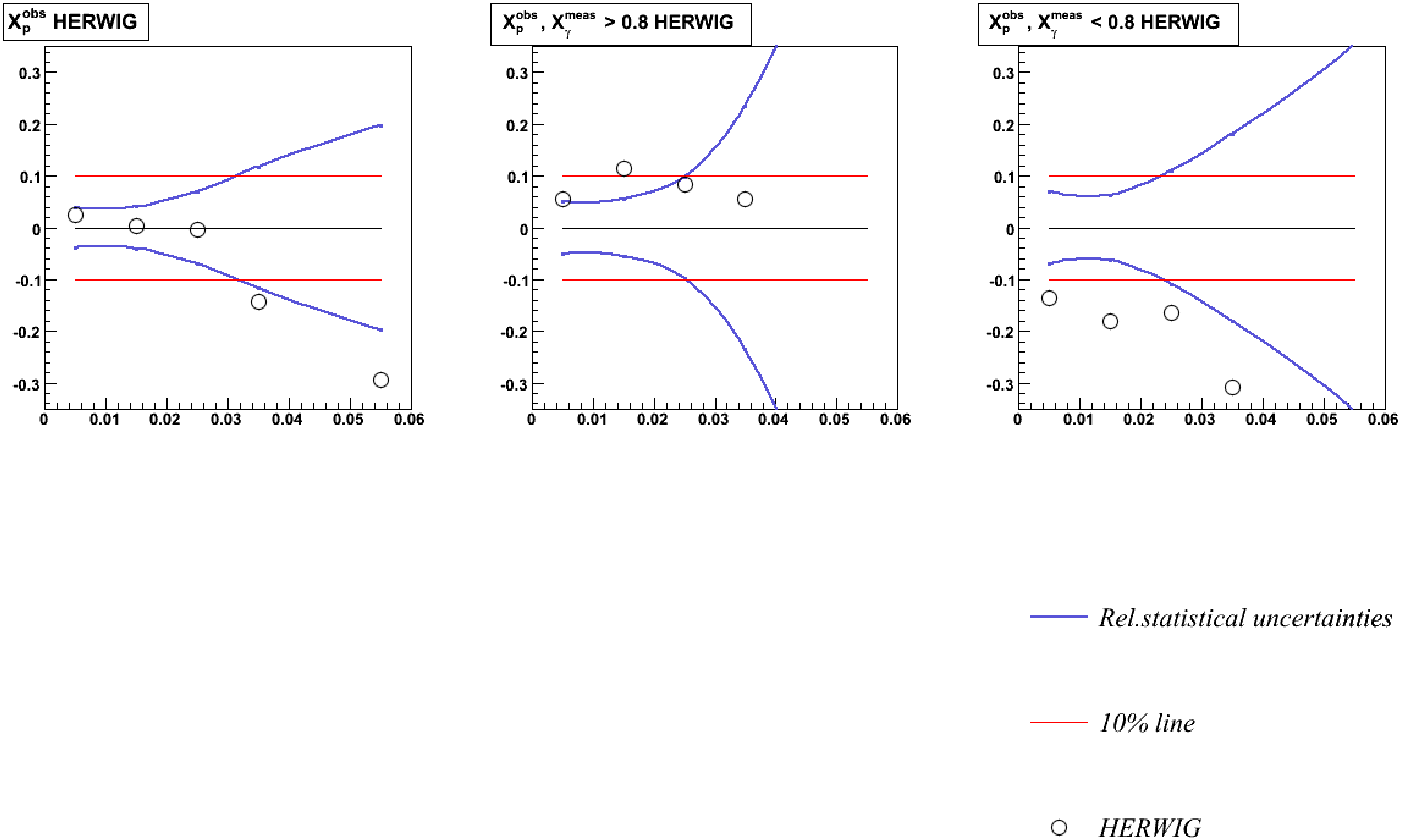


X_p^{obs} Z-Vertex
X_p^{obs}, X_γ^{meas} > 0.8 Z-Vertex
X_p^{obs}, X_γ^{meas} < 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties δZ
10% line
$|Z_{vertex}|<45$
$|Z_{vertex}|<35$

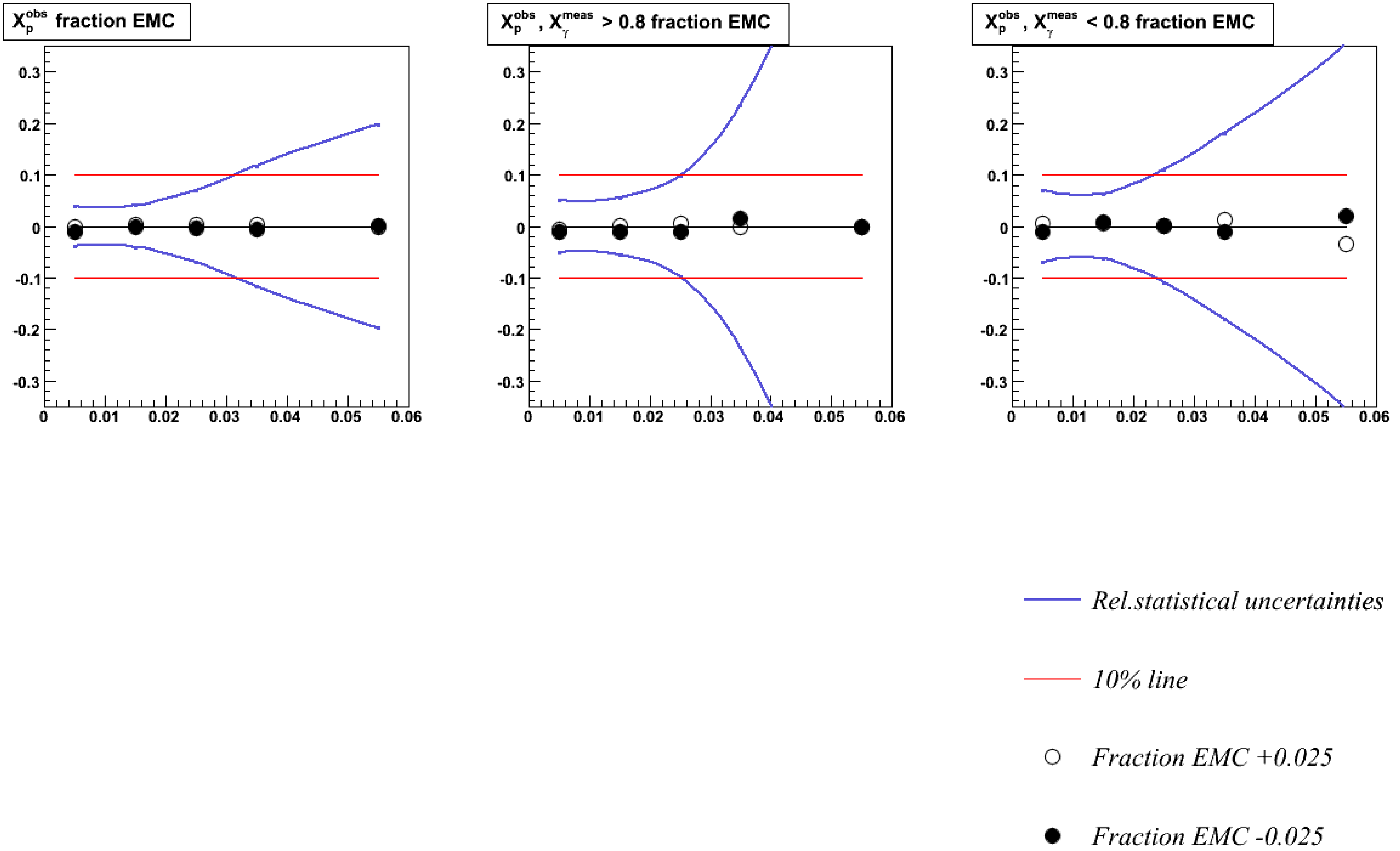


X_p^{obs} Track Magnitude
X_p^{obs}, X_γ^{meas} > 0.8 Track Magnitude
X_p^{obs}, X_γ^{meas} < 0.8 Track Magnitude
Rel.statistical uncertainties
10% line
p_{track} > 350 MeV
p_{track} > 150 MeV

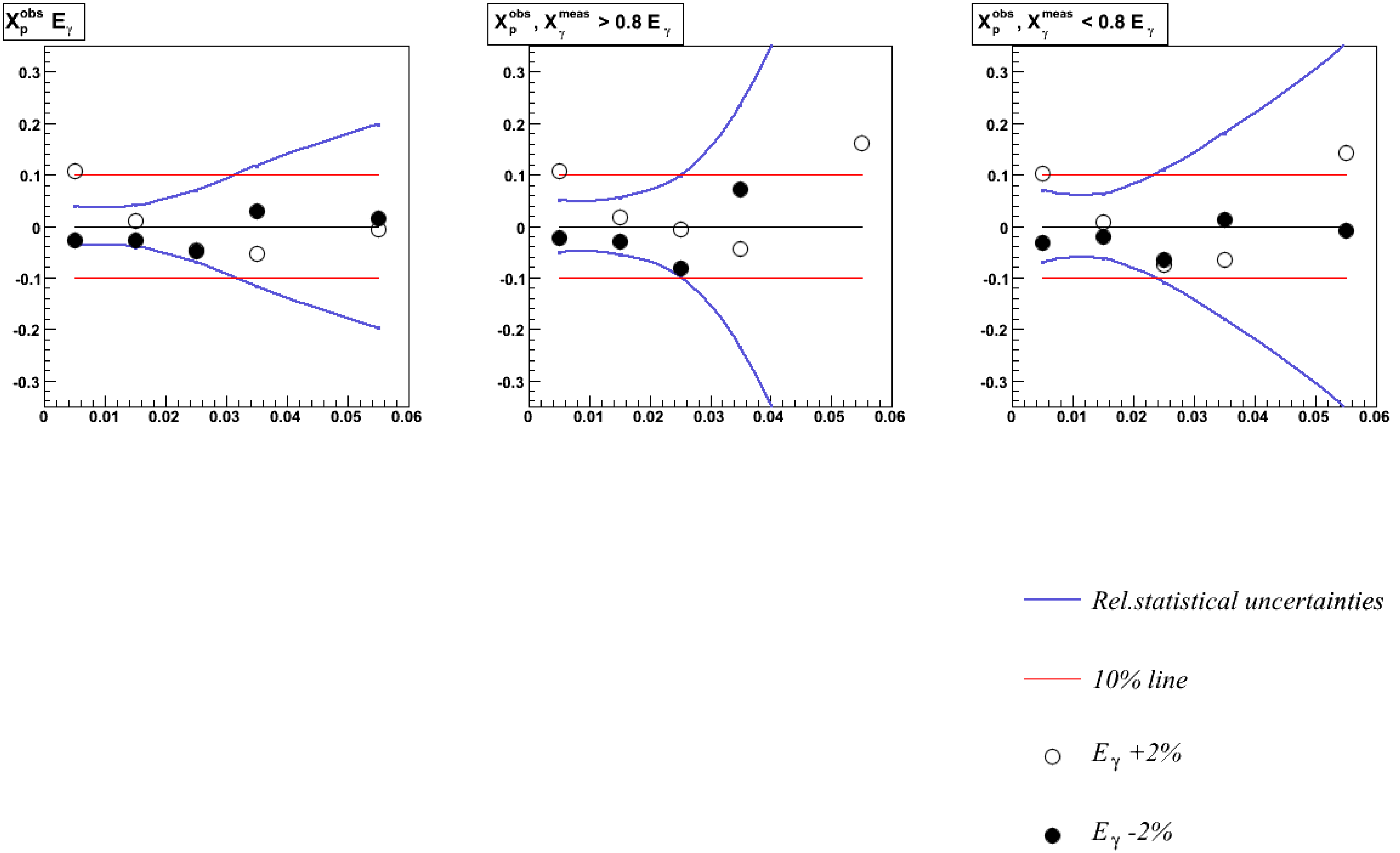

X_p^{obs} Fragmentation
X_p^{obs}, X_γ^{meas} > 0.8 Fragmentation
X_p^{obs}, X_γ^{meas} < 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
+5% Fragmentation
-5% Fragmentation



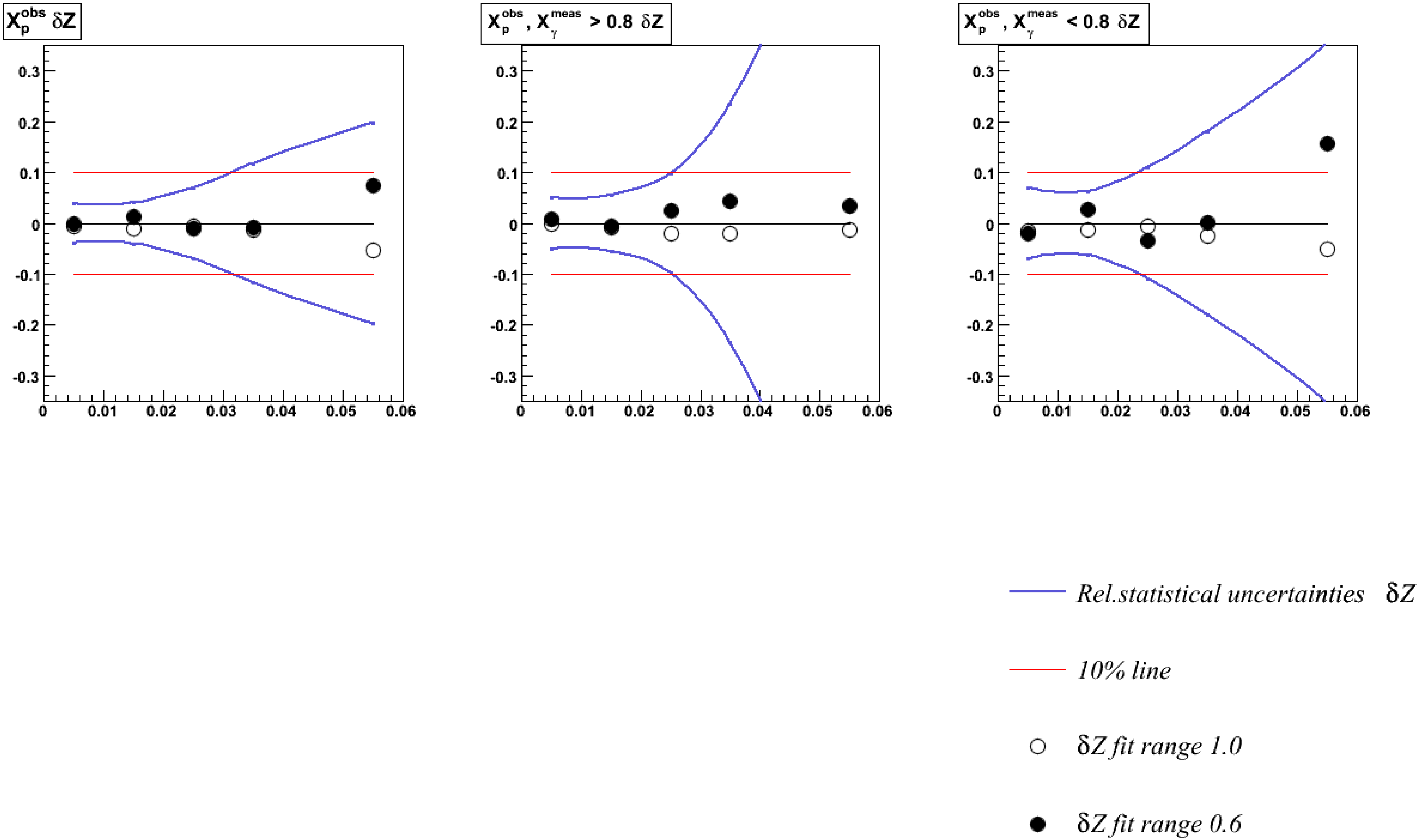
X_p^{obs} HERWIG
X_p^{obs}, X_γ^{meas} > 0.8 HERWIG
X_p^{obs}, X_γ^{meas} < 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
HERWIG



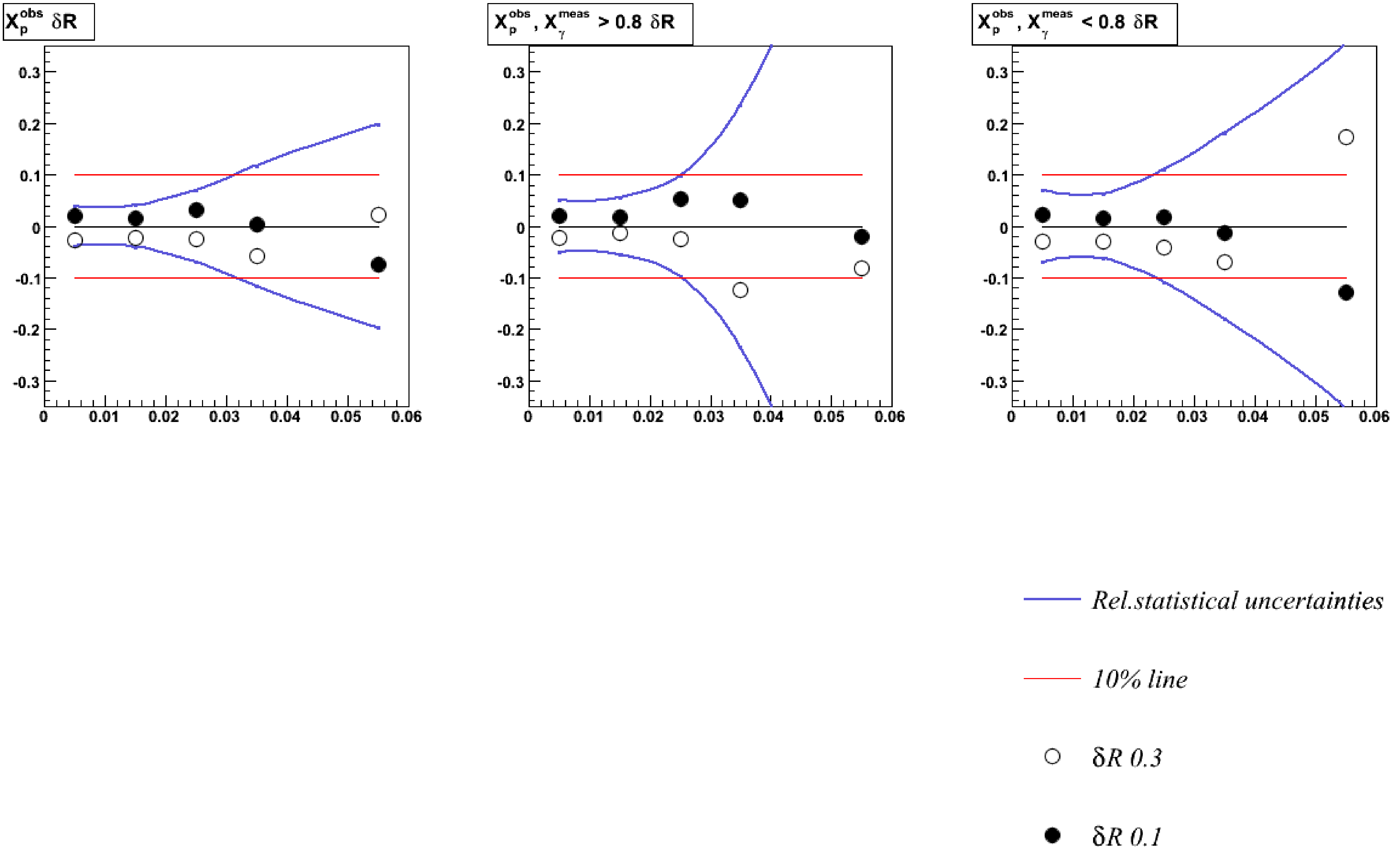
X_p^{obs} fraction EMC
X_p^{obs}, X_γ^{meas} > 0.8 fraction EMC
X_p^{obs}, X_γ^{meas} < 0.8 fraction EMC
Rel.statistical uncertainties
10% line
Fraction EMC +0.025
Fraction EMC -0.025

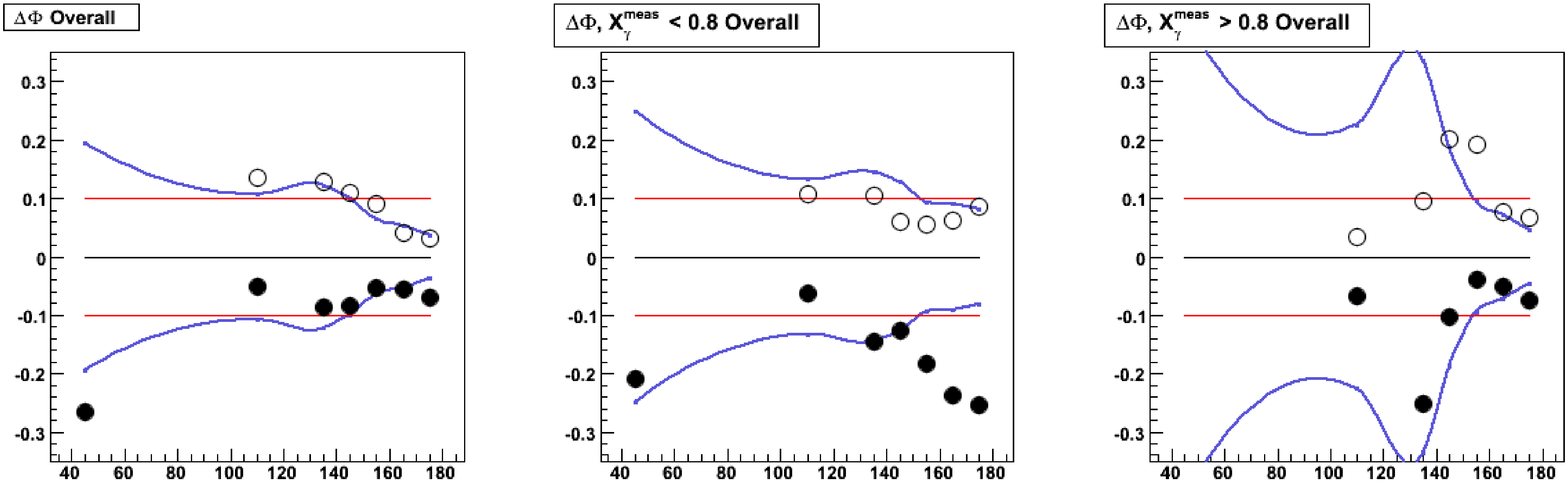


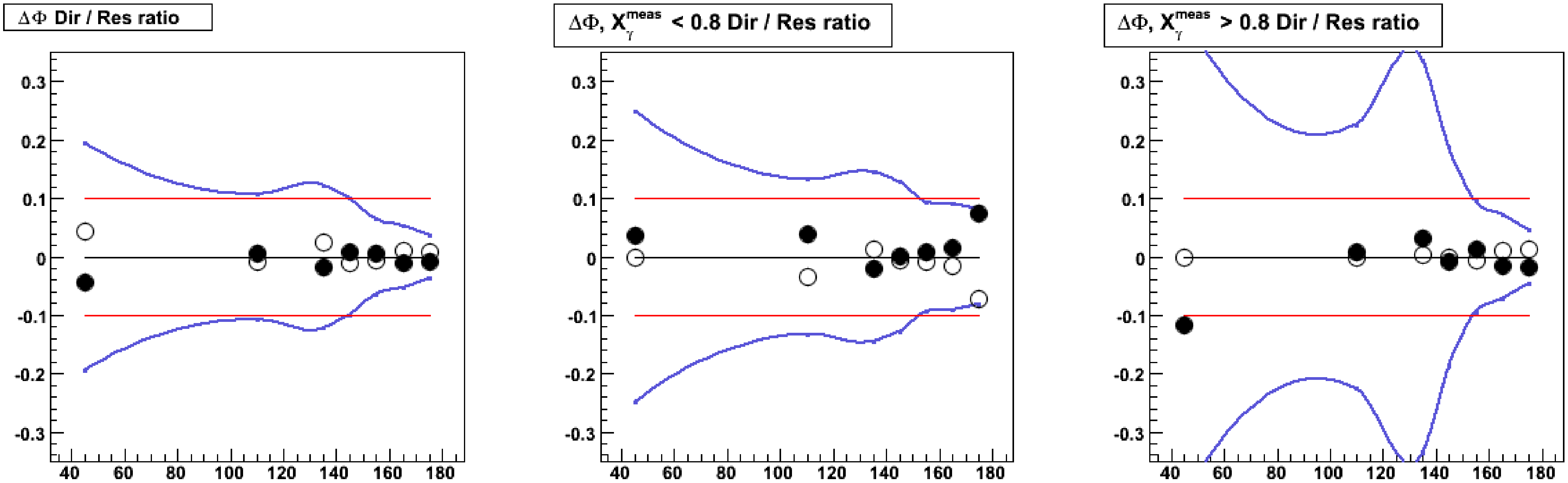
X_p^{obs} E_γ
X_p^{obs}, X_γ^{meas} > 0.8 E_γ
X_p^{obs}, X_γ^{meas} < 0.8 E_γ
Rel.statistical uncertainties
10% line
E_γ +2%
E_γ -2%



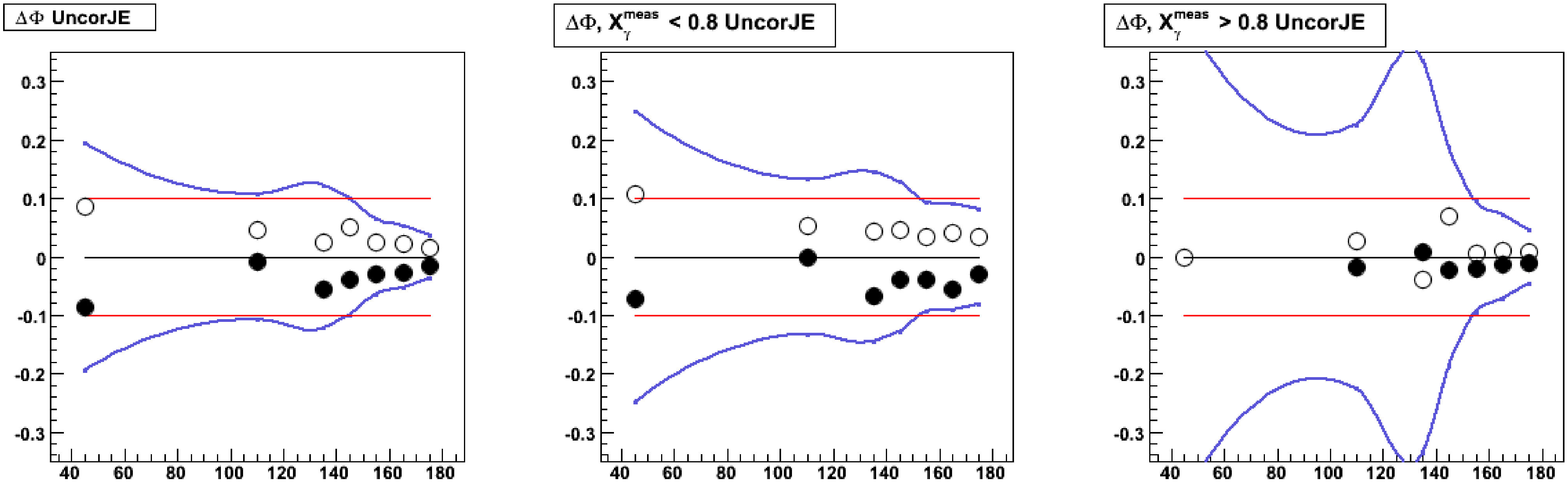
X_p^{obs} δZ
X_p^{obs}, X_γ^{meas} > 0.8 δZ
X_p^{obs}, X_γ^{meas} < 0.8 δZ
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0 0.01 0.02 0.03 0.04 0.05 0.06
Rel.statistical uncertainties δZ
10% line
δZ *fit range 1.0*
δZ *fit range 0.6*


X_p^{obs} δR
X_p^{obs}, X_γ^{meas} > 0.8 δR
X_p^{obs}, X_γ^{meas} < 0.8 δR
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
0.01
0.02
0.03
0.04
0.05
0.06
Rel.statistical uncertainties
10% line
δR 0.3
δR 0.1

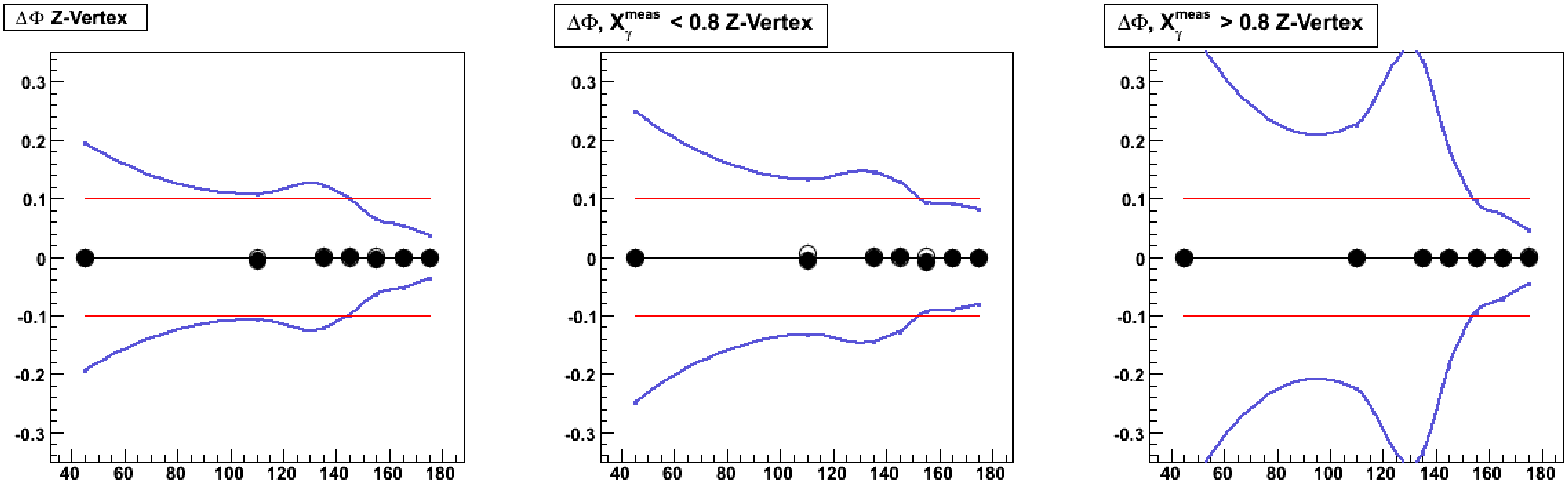

ΔΦ Overall
ΔΦ, X_γ^{meas} < 0.8 Overall
ΔΦ, X_γ^{meas} > 0.8 Overall
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



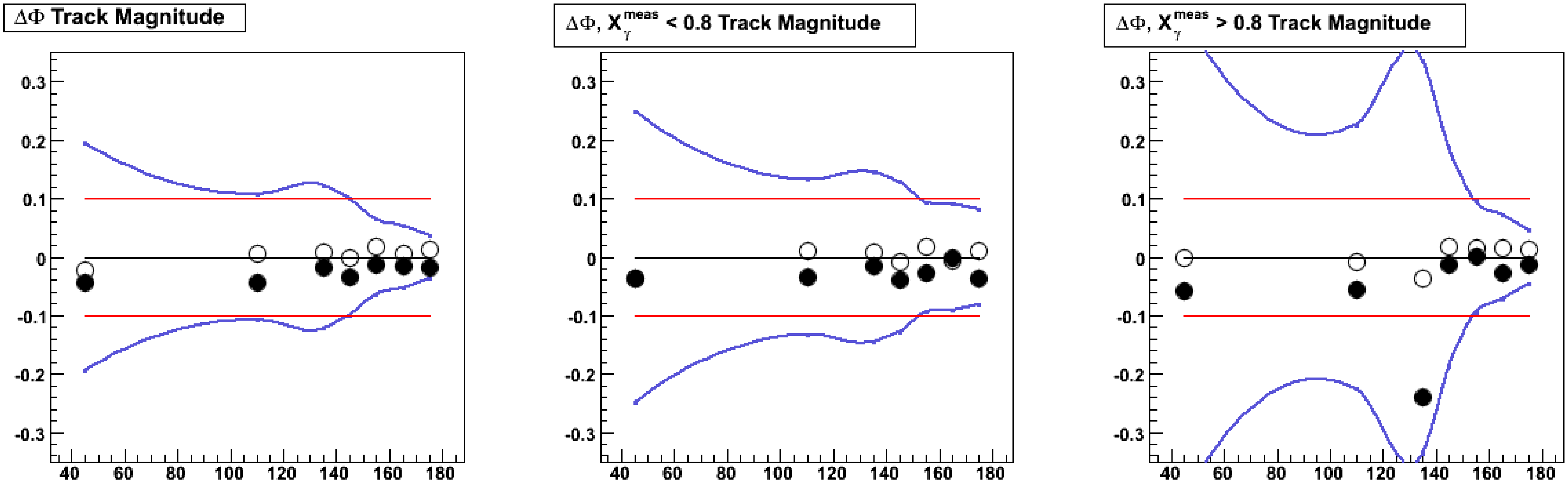
ΔΦ Dir / Res ratio
ΔΦ, X_γ^{meas} < 0.8 Dir / Res ratio
ΔΦ, X_γ^{meas} > 0.8 Dir / Res ratio
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40 60 80 100 120 140 160 180



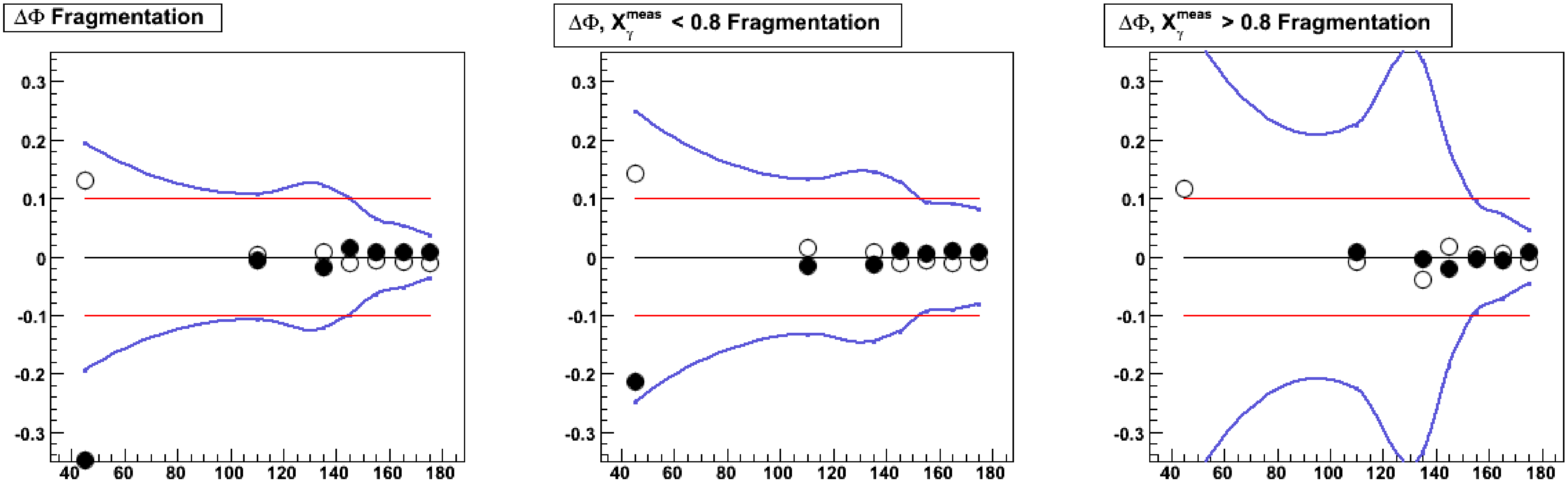
ΔΦ UncorJE
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180
ΔΦ, X_γ^meas < 0.8 UncorJE
ΔΦ, X_γ^meas > 0.8 UncorJE



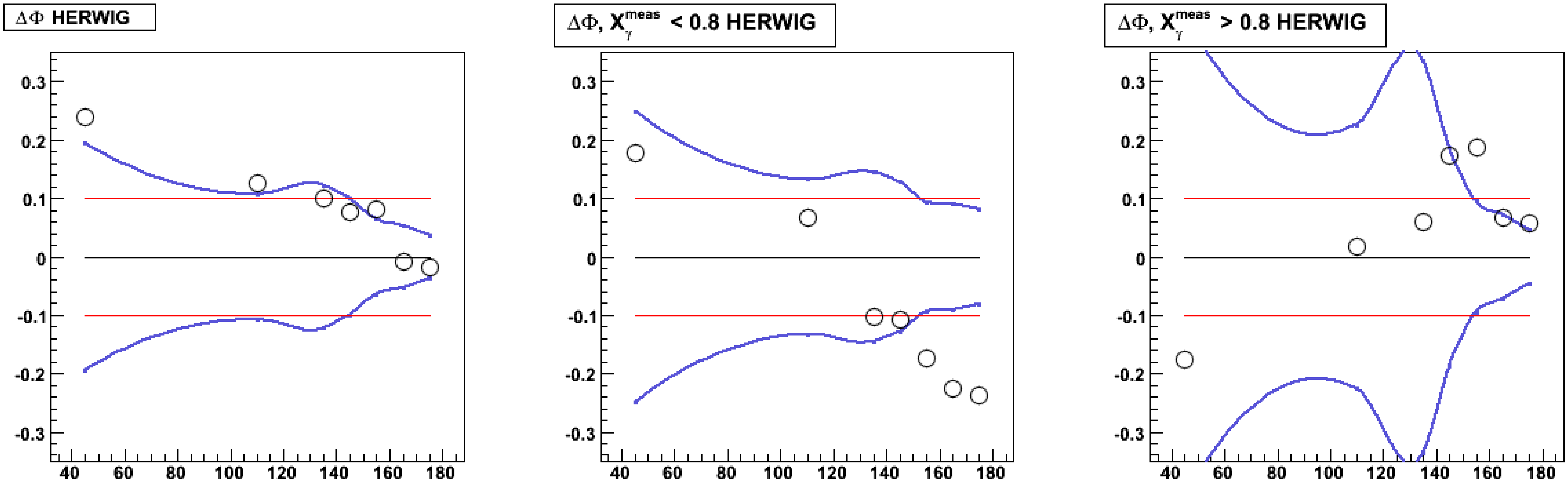
ΔΦ Z-Vertex
ΔΦ, X_γ^{meas} < 0.8 Z-Vertex
ΔΦ, X_γ^{meas} > 0.8 Z-Vertex
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



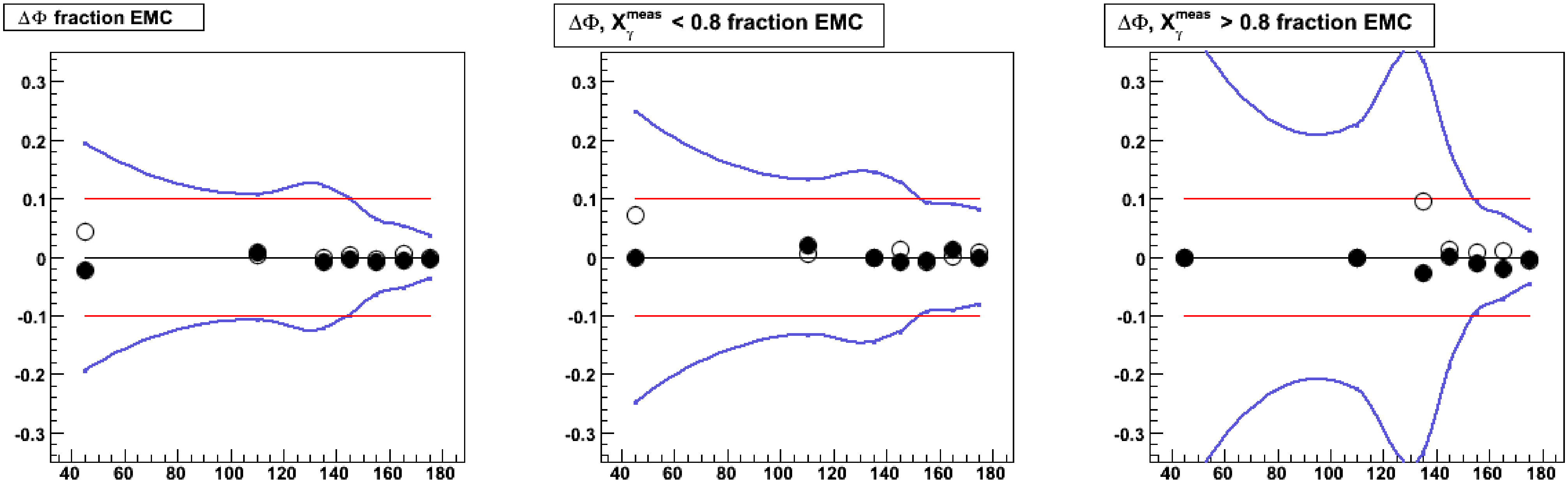
ΔΦ Track Magnitude
ΔΦ, X_{γ}^{meas} < 0.8 Track Magnitude
ΔΦ, X_{γ}^{meas} > 0.8 Track Magnitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



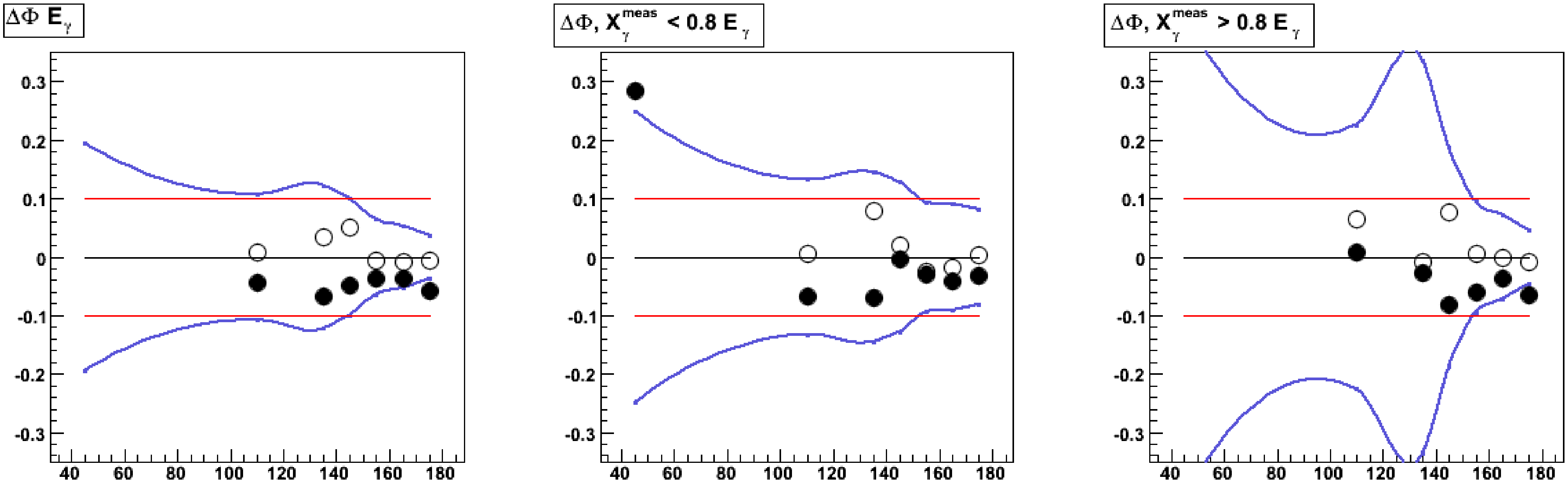
ΔΦ Fragmentation
ΔΦ, X_γ^{meas} < 0.8 Fragmentation
ΔΦ, X_γ^{meas} > 0.8 Fragmentation
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180

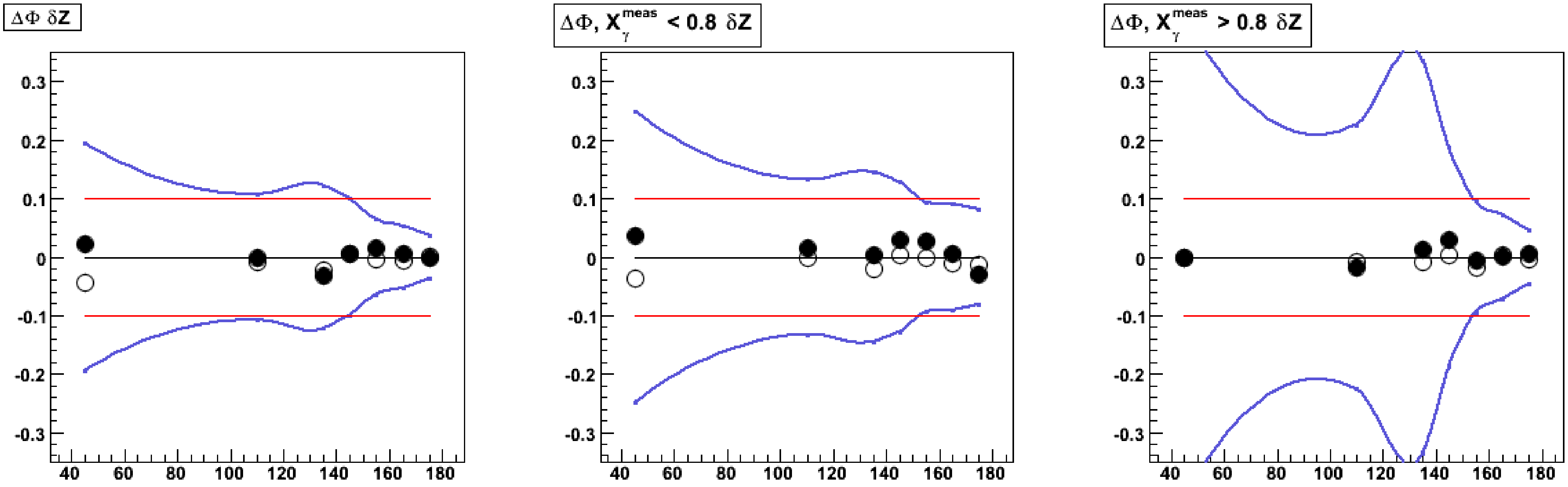


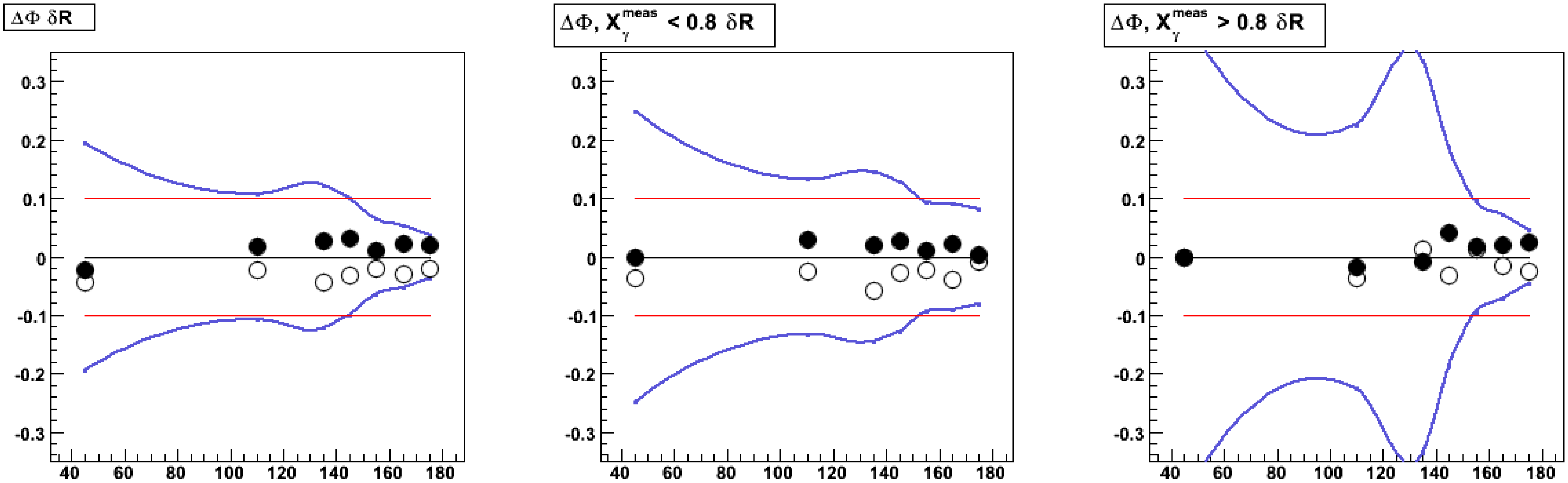
ΔΦ HERWIG
ΔΦ, X_γ^{meas} < 0.8 HERWIG
ΔΦ, X_γ^{meas} > 0.8 HERWIG
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
40
60
80
100
120
140
160
180



ΔΦ fraction EMC
ΔΦ, X_{γ}^{meas} < 0.8 fraction EMC
ΔΦ, X_{γ}^{meas} > 0.8 fraction EMC


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


ΔΦ δZ
ΔΦ, X_γ^{meas} < 0.8 δZ
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


ΔΦ δR
ΔΦ, X_γ^{meas} < 0.8 δR
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