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LHC-B Ring Imaging Cherenkov Detector

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Abstract

The progress towards the realisation of the LHC-B Ring Imaging Cherenkov detector is reported.

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1 Introduction

This paper reports on the development of the Ring Imaging Cherenkov (RICH) detector for LHC-B. The LHC-B experiment is a proposed single arm spectrometer for the LHC optimised for B physics. Particle identification is crucial for the study of B-physics and CP violation at the LHC. The many B-meson decay modes to be studied makes it necessary to have π/K separation over a momentum range of $1 < p < 150$ GeV/c. This reduces the background of the selected final state and, in addition, provides an efficient flavour tag of the signal B-meson. The overall concept and performance of LHC-B is discussed in more detail elsewhere in these proceedings [1].

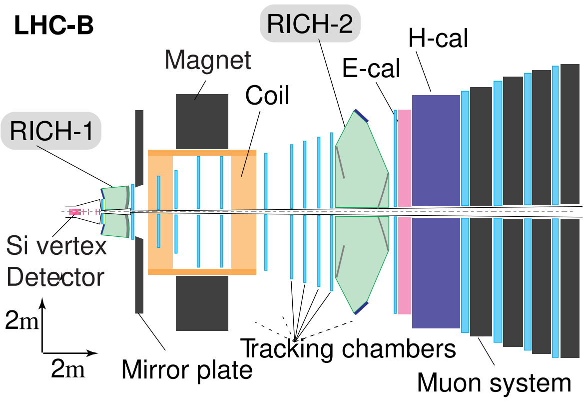

Figure 1: The LHC-B spectrometer

RICH detectors meet the experimental criteria for particle identification in the required momentum range. It is proposed to use two RICH detectors in the LHC-B experiment, see fig 1. The upstream detector (RICH1), fig. 2, has a combined gas and aerogel radiator and is situated in front of the dipole magnet. The aerogel radiator is placed against the entrance window of the second gaseous (C_4F_{10}) radiator. A spherical mirror with a radius of curvature of 190 cm is tilted by $\approx$ 250 mrad to reflect the Cherenkov light onto an array of photodetectors situated outside the experimental acceptance. The downstream RICH (RICH2), fig. 2, uses CF_4 as its radiator with a spherical mirror with a radius of curvature of 820 cm tilted by 370 mrad. An additional flat mirror is tilted by 240 mrad to bring the Cherenkov photons out of the acceptance of the experiment.

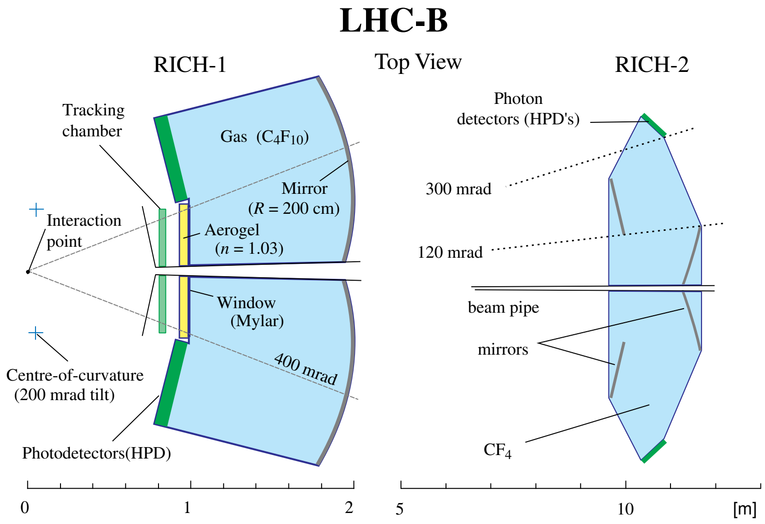

Figure 2: Layout of the LHC-B RICH detectors(note different scales).

Each RICH detector has two photodetector planes giving a total area of 2.9 m^2. The chosen detector technology must have a high quantum efficiency, a spatial resolution of at least 2.5×2.5 mm^2 and to have a fast readout consistent with 25 ns bunch crossing of the LHC. Two candidate technologies exists [3]: hybrid photodiodes (HPDs) and multianode photomultipliers. These detectors are commercially available but not in designs that meet the experimental needs of LHC-B. A program of R&D is currently underway on the development of a HPD with a large active area.

2 HPD development

Two complimentary approaches to the development of the HPDs are being investigated: the 'pixel HPD', which uses the bump bonding of a silicon pixel detector to a readout chip, and the 'pad HPD' where a silicon pad detector is readout using routing lines wire-bonded to front-end chips around its circumference.

2.1 Pixel HPD

The pixel HPD is being developed in close collaboration with DEP [4]. It is based on standard image intensifier technology that strongly focuses photoelectrons onto a segmented silicon pixel array. The feasibility of this approach has already been demonstrated with the 'IPSA-tube' [5]. Work is ongoing on a scale model prototype with an active photocathode diameter of 40 mm and an anode diameter of 11 mm. The anode is assembled with the LHC1 chip developed at CERN [6]. This chip contains a detector array of 2048 pixels, $50 \times 500\mu\mathrm{m}^2$ in size and it has a lowest achievable comparator threshold of $4000e^-$ with a spread of $1000e^-$. Unfortunately these detector properties are not compatible with the needs of LHC-B. In particular, the pixel dimension (50μm) is too small compared to the RICH granularity ($500 \times 500\mu\mathrm{m}^2$). Nor are the the threshold properties of the LHC1 chip compatible with LHC-B requirements, though recent development in pixel electronics have achieved comparator thresholds down to $1400e^-$ with an RMS of $90e^-$. The specific needs of LHC-B are being investigated.

2.2 Pad HPD

The pad HPD will be housed in a cylindrical glass envelope capped with a UV-glass entrance window with a K_2CsSb photocathode. A visible light photocathode deposition facility that allows a high vacuum seal of the HPD baseplate onto the metal flange of the glass envelope has been designed. The final assembly of this apparatus was performed at CERN at the end of 1997. The signal from the photoelectrons in the silicon sensor will be detected by front end chips placed around the edge of the sensor via wires bonded to the routing lines from the pad. Focussing electrodes, fixed in the glass envelope, will demagnify the image by a factor of 2.3. The 2048 pad silicon detector contains pads of dimensions $1\mathrm{mm}^2$. Successful tests have been performed on the sensor with photoelectrons up to 20 keV with (the non LHC speed) VA3 chip [7]. A signal/noise ratio of ≈ 10 has been achieved. Earlier tests with a 256 pad sensor had achieved a signal/noise ratio of ≈ 18. This difference is under investigation, but one possible reason for this degradation in performance is differences in the manufacturing of the wafer.

The SCT-128A [8] analogue chip which was developed for the ATLAS silicon tracker is being modified to achieve a noise level of $\sim 600e^-$. Additional modifications will be needed to meet the requirements of the pad HPD for LHC-B, in particular the multiplexing properties of the chip.

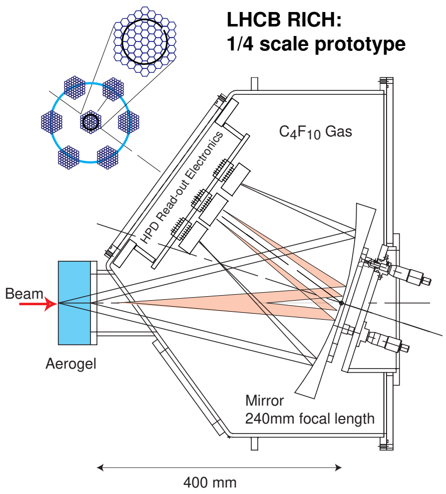

Figure 3: Configuration 1: the 1/4 scale prototype RICH vessel

3 RICH Prototype

A prototype of the downstream RICH detector was tested in the T9 test beam at the CERN SPS during the Spring and Summer of 1997. A planar array of seven 61-pixel HPD's from DEP were used to detect the

Cherenkov photons produced in aerogel, air and C_4F_{10} radiators. In configuration-1, fig. 3, of the prototype the light is focussed by a 240 mm focal length mirror which corresponds to a 1/4 scale of the RICH1 detector. A full scale prototype (configuration 2) was also used which has a 1143 mm mirror to focus rings from C_4F_{10} onto an array of six 61-pixel HPD's. This was achieved by adding extension arms to configuration 1.

The 61 pixel HPD has a silicon diode detector segmented as a hexagonal array with pad dimensions of 2 mm face-to-face. The HPD was operated at a high voltage of 12kV. Using a pulsed light emitting diode the complete readout and data acquisition chain was tested. The pedestal, the single, double and triple photoelectrons peaks were clearly visible with a signal/noise ratio of ≈ 5.7. Most of this noise is associated with the input capacitance of the feedthrough and printed circuit boards.

The test beam provides charged particles of either polarity and the momentum can be tuned in the range $2-15.5$ GeV/c. The particle type is identified by measuring the signal pulse height from a CO_2 threshold Cherenkov counter installed 30 m upstream from the prototype. The prototype vessel was aligned with the beam axis. Charged particles which provide the trigger are selected using using scintillation counters, two upstream and two downstream of the vessel. A photoelectron hit is defined to be a HPD pixel with a signal pulse height 4σ above the pedestal mean, where σ is the rms width of the pedestal peak.

Using RICH configuration 1, data were taken with a 10 GeV/c negatively charged beam with 18 mm thickness of aerogel. Fig. 4 shows an arc of a ring on the central HPD, whose radius is compatible with that expected from C_4F_{10}. The outer HPD's clearly exhibit a ring which originates from the aerogel radiator.

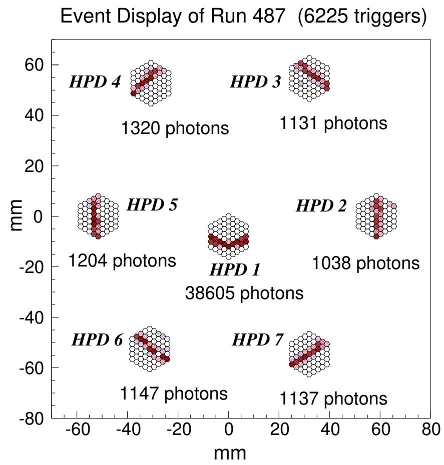

Figure 4: An event display from aerogel and C_4F_{10} radiators in RICH configuration 1, integrated over run 487.

The number of photoelectrons per triggered event was measured for all three radiators in the vessel. For this analysis a threshold of 3σ was set for individual pixels and multiple photoelectrons were taken into account. The mean number of photoelectrons are shown in table 1. The partial geometrical coverage of the aerogel and gas rings was calculated from simulation with $\approx 5\%$ uncertainity. The expected photoelectron yields was calculated from simulation which included the properties of the aerogel, mirror and photocathode efficiencies. The overall precision in the expected yield is estimated to be 15%. The comparison between observed and expected yields are given in table 1. The numbers from this preliminary analysis are compatible within 30%.

Radiator	Raw hits	Bkg. corr.	Eff. corr.	Ratio
Air	4.92	4.56	4.80	0.99
C_4H_{10}	7.85	7.49	33.55	1.07
Aerogel	1.79	1.31	10.71	0.72

Table 1: Observed number of photoelectrons per event for air, aerogel and C_4F_{10} radiators. The columns give the number of raw hits, the numbers after correction for background and for geometrical efficiency, and the comparison with the expected yield.

The full scale RICH1 prototype was studied using configuration-2. The longer focal length of the mirror means the C_4F_{10} ring now spans the outer 6 HPDs. The event display shown in fig. 5 is obtained from negatively charged 15.5 GeV/c momentum beam. The $K:\pi$ ratio of the triggering particles has been enhanced to $1:2$ using the threshold Cherenkov counter. Fig. 5 shows segments of two rings; an inner ring from the incident kaons and an outer ring from the pions. It can be seen that the number of hits observed in HPD 3 is lower than in HPD 4. (Similarly HPD 5 has fewer hits than HPD 2.) This is because HPD's 3 and 5 have mylar windows in front of their photocathodes which absorb the UV photons.

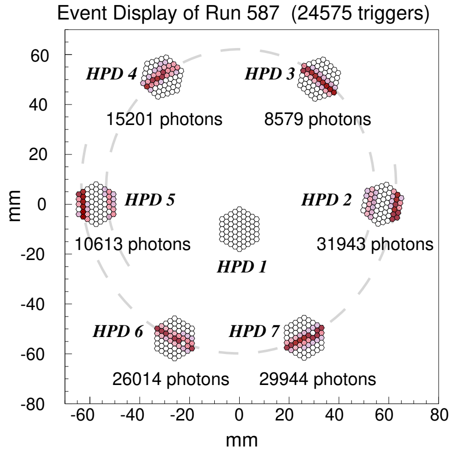

Figure 5: An event display showing π/K separation, using C_4F_{10} radiator in RICH configuration 2, integrated over run 587.

4 Summary

The major outstanding issue for the LHC-B RICH detector is the demonstration of a photodetector that matches LHC-B requirements. For the pixel HPD it is envisaged to produce and test a 80 mm diameter tube whilst a pixel chip is developed in parallel that meets the experimental needs. Test in 1998 are planned for the pad HPD using the 2048 pad detector under vacuum with the designed focussing and then eventually with a bialkali photocathode.

The RICH prototype tests have been successful. Clear Cherenkov rings from gas and aerogel radiators have been observed for the first time using HPD's as photon detectors. The preliminary measured photon yields are compatible within 30% of expectations based on simulations. Further analysis of the data is investigating the reconstruction resolution of the Cherenkov angle for each recorded hit from both the gas and aerogel radiators. Further prototype testbeam runs are being planned to study RICH 2. It is also planned to use the RICH prototype to test the various photodetectors as they become available.

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