The First Year of the HERA-B RICH

K. Lau[1], I. Arinyo[2], M. Atiya[3], J. Bastos[4], D. Broemmelsiek[5], J. Carvalho[4], P. Conde[2], D. Dujmic[6], R. Eckmann[6], L. Garrido[2], A. Gorisek[7], M. Ispiryan[1], I. Ivanouchenkov[4], S. Karabekyan[8], S. Korpar[7], P. Krizan[7], R. Miquel[2], D. Peralta[2], R. Pestotnik[7], J. Pyrlik[1], S. Ramachandran[1], K. Reeves[6], J. Rosen[4], R. Schwitters[6], M. Selover[6], D. Skrk[7], A. Stanovnik[7], M. Staric[7], T. Zivko[7]

[1]University of Houston, Houston, USA
[2]University of Barcelona, Spain
[3]BNL, Upton, USA
[4]University of Coimbra, Portugal
[5]Northwestern University, Evanston, USA
[6]University of Texas, Austin, USA
[7]University of Ljubljana & J. Stefan Institute, Slovenia
[8]DESY, Hamburg, Germany

Abstract

The operational experience of the RICH detector for the first year at HERA-B is described. The design criteria, detector components, and reconstruction software are reviewed. The results show that the main design goals have been achieved.

I. Introduction

HERA-B is an internal target experiment at the proton storage ring, HERA, at DESY [1]. Beauty hadrons are produced by 920-GeV protons interacting with eight wire targets placed inside the beam-pipe. The high hadronic interaction rate produces about one billion beauty hadrons per year, providing a statistically important sample for CP violation studies.

CP violation in the beauty system is a large effect according to the standard model. The signal is particularly clean in the decay B to J/ψ and K_S because there is only one decay amplitude involved. The asymmetry in the decay of B and its antiparticle to the $J/\psi\ K_S$ final state is directly related to one of the basic parameters in the standard model; the time-integrated asymmetry is proportional to $\sin(2\beta)$. The small beauty production cross section and small BR of B to J/ψ and K_S necessitate a high-rate detector with large acceptance.

The HERA-B detector is a fine-grained forward spectrometer constructed around the beam-pipe to measure the final states of interest. The geometric acceptance of the detector covers about 90% of the solid angle in the CMS frame. A schematic of the detector is shown in Figure 1. The protons, entering from the right, interact with 8 wire targets positioned inside the beam-pipe. The particles produced in an interaction are first tracked by 8 layers of silicon strip detector, deployed within 1 cm of the beam during data-taking, with high spatial resolution [2]. This silicon vertex detector provides recognition and determination of interaction and decay vertices of the event. Beauty particles are short-lived, and travel typically about 1 cm in the lab before they decay.

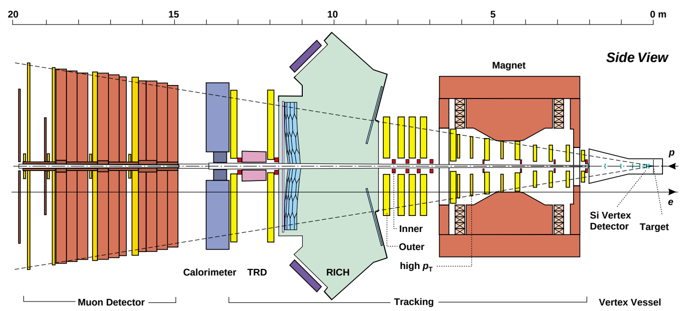

Figure 1: Schematic of the HERA-B detector

The tracking of charged particles is furnished by the Inner tracker which covers the small angle tracks, and the Outer tracker which covers the rest of the acceptance. The charged particles are momentum analyzed by the magnetic field generated by a dipole magnet, which provides a transverse momentum kick of 0.61 GeV/c.

Electrons and photons are analyzed by an electromagnetic calorimeter (ECAL) constructed with tungsten (inner) and lead-scintillator sandwiches.

An important part of the CP violation measurement is the tagging of the beauty decays. Beauty hadrons are produced in pairs with opposite flavors. The flavor the decayed B can be inferred from the flavor of the companion B which decays most of the time according to the standard $b \rightarrow c \rightarrow s$ chain, resulting in a kaon. The charge of the kaon in the decay of the companion B provides the tagging for the decayed B.

The main function of the RICH in HERA-B is to identify kaons for flavor tagging.

II. The HERA-B RICH

A. Design Criteria

The HERA-B RICH was optimized for flavor tagging of B decays. The production kinematics calls for a gas radiator and a fine granularity photon detector. The expected number of photons for relativistic charged particles is 34, well above the minimum required for flavor tagging. Details of the components are given in the following subsections.

B. Radiator

The radiator is a tank of 100 m^3 of C_4F_{10} under atmospheric pressure. The kaon threshold, based on the refractive index of 1.00135, is 9.6 GeV/c. The Cherenkov photons are emitted at 53 mrad for $\beta = 1$ particles. Near threshold, the RICH provides more than 10 σ separation of kaons from pions. The K/π separation stays more than 3 σ up to 50 GeV/c. Most of the kaons from B decays are below 50 GeV/c.

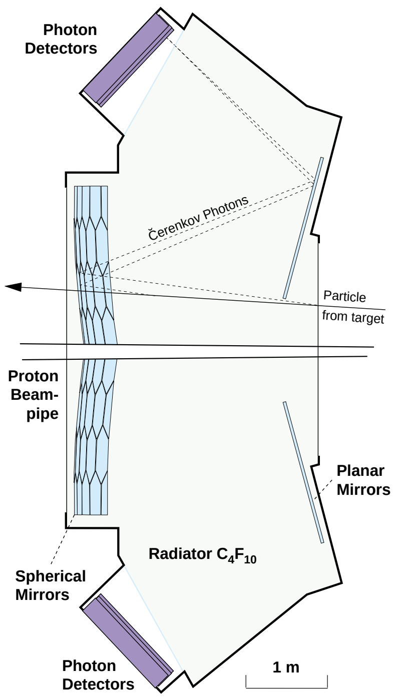

Figure 2: Schematic of the HERA-B RICH.

C. The Optics

The optics of the RICH follows the conventional design of employing a spherical mirror to focus the Cherenkov light onto a photon detector located at the focal surface. The HERA-B RICH is unique that the mirror is split in the mid-plane and, with the aid of two planar mirrors, reflects the light onto two photon detectors deployed above and below the beam-line. A schematic of the optical system is shown in Figure 2. The spherical mirrors are composed of 80 hexagonal mirrors with a radius of curvature of 11.4 m. The radius of a $\beta = 1$ ring on the photon detector is about 30 cm.

D. The Photon Detector

The Cherenkov photons are detected by multianode PMTs. The PMT option was taken after it was demonstrated unequivocally that the less costly TMAE option is not viable; the aging of TMAE was found to be too rapid under HERA-B running condition [3]. Two kinds of Hamamatsu multianode PMTs are used in the system, 16-channel models (R5900-00-M16) in the inner region and 4-channel models (R5900-03-M4) in the outer region. The cell sizes in the two regions are dictated by the desire to keep the occupancy below 10% at the highest interaction rate. The photon detector comprises 1500 M16s and 750 M4s, deployed as shown in Figure 3.

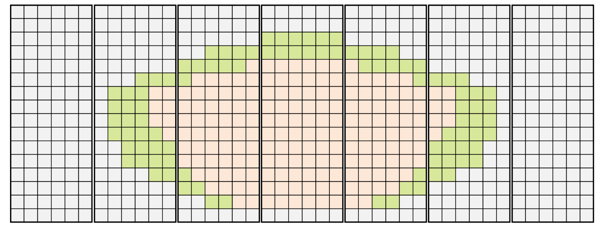

Figure 3: Distribution M16 (orange), M4 (green) PMTs on the upper photon detector (gray areas are left uninstrumented).

Each photon detector element contains a two-lens telescope which focuses light entering a cell onto the light-sensitive pixel areas of the PMT, 4.5mm $\times$ 4.5mm for the M16 (see Figure 4), 9mm $\times$ 9mm for the M4. Four PMTs of each kind are mounted on a base board which houses the voltage dividing circuits and signal interfaces. The 16-channel electronic readout cards, four for the M16 base board, one for the M4 base board, are plugged into the back. The PMT generates fast short pulses which are discriminated by the readout electronics. The digital output signals are sent to nearby front-end driver boards for further processing. A picture of the M16 PMT-Base assembly is shown in Figure 5. The high voltage for the PMTs is supplied by a CAEN 527 system, distributed via 160 channels, each serving a group of 8–20 PMTs by daisy-chaining 2–5 baseboards.

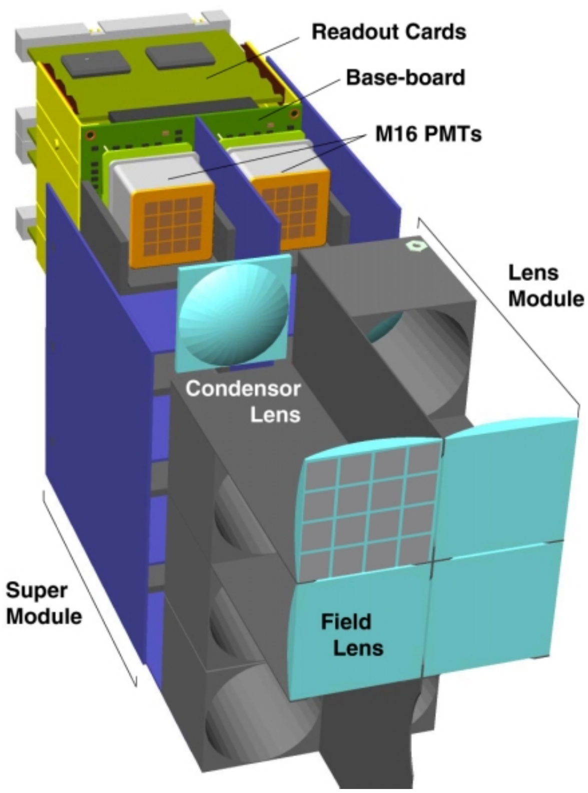

Figure 4: Schematic showing the elements of the photon detector.

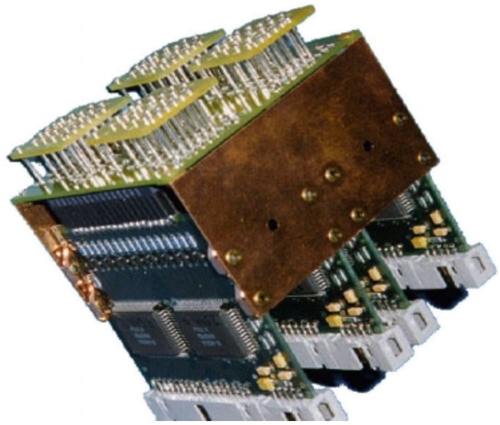

Figure 5. Picture of a M16 baseboard-readout card assembly.

The mechanical assembly of photon detectors is organized as seven supermodules shown in Figure 3. The supermodules follow the cylindrical surface that best approximates the actual focal surface.

III. COMMISSIONING & PERFORMANCE

The HERA-B RICH construction began in 1997. All the components were ready in the summer of 1998. A small Cherenkov ring was observed in August 1998 while the radiator tank was still filled with air. The RICH began its normal operation after C_4F_{10} was in place in January 1999. The RICH has been in operation since then.

A. *Event Display*

Data were taken with a mixture of C_4F_{10} and nitrogen since January 1999. The magnetic field was switched on in May 1999. An event, with the magnetic field on, is shown in Figure 6. As one can see in this low mutiplicity event, the RICH rings are clearly discernible; there are very few dead and noisy channels. The average number of photons per ring for $\beta=1$ particles is 34, in good agreement with our Monte Carlo expectation.

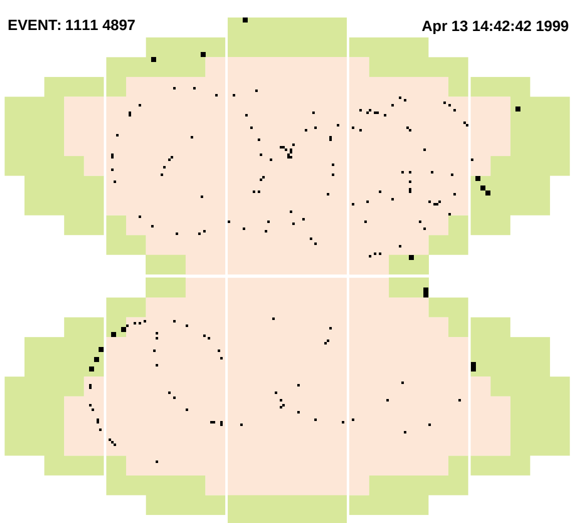

Figure 6: Typical event.

B. *Ring Reconstruction*

The hits in the two subdetectors are first joined together by the λ–ϕ parametrization. The λ–ϕ coordinates of each hit are the vertical and horizontal angles of each photon, relative to the beam axis, respectively. The optics is designed such that the hits from the Cherenkov light of a charged particle form a circle on the λ–ϕ plane with small spherical aberrations. An event with hits displayed in λ–ϕ coordinates is shown in Figure 7. Several computer programs have been written to reconstruct the rings from the hits alone. One method is based on the Hough transformation in which the intersection of circles centered at each hit is tallied; the Cherenkov ring centers are indicated by points of high intersection rate. A second approach is based on seeds constructed with three hits. A typical reconstructed event is shown in Figure 7.

C. *Ring Parameters*

The performance of the RICH is studied by analyzing the rings reconstructed from these stand-alone programs. One important parameter is the number of photons per $\beta=1$ particle. Several methods have been used. Visual scanning gives a result of 34 hits per track. Another method, based on reconstructed rings, also yields the same result.

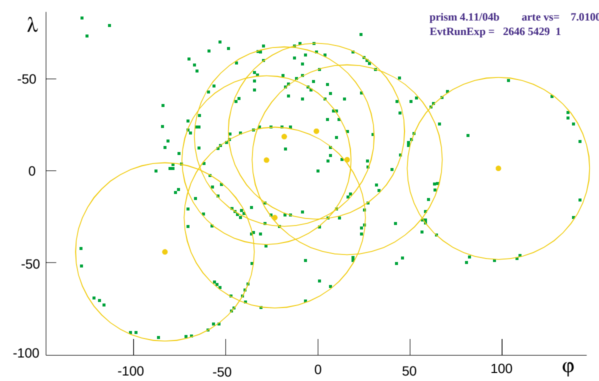

Figure 7: A typical reconstructed event with raw hits displayed.

Another parameter of interest is the angular resolution of each hit. The single-hit resolution is limited by the dispersion of the radiator gas and the cell granularity, each contributing to about 0.4 mrad. The single-hit resolution was studied by comparing the hits to the fitted center and radius. A plot of the hit position, relative to the best circle fit, is shown in Figure 9. The width of the peak, before applying optical corrections, is about 0.9 mrad. Monte Carlo simulation shows that the resolution can be improved to 0.6 mrad by applying optical correction.

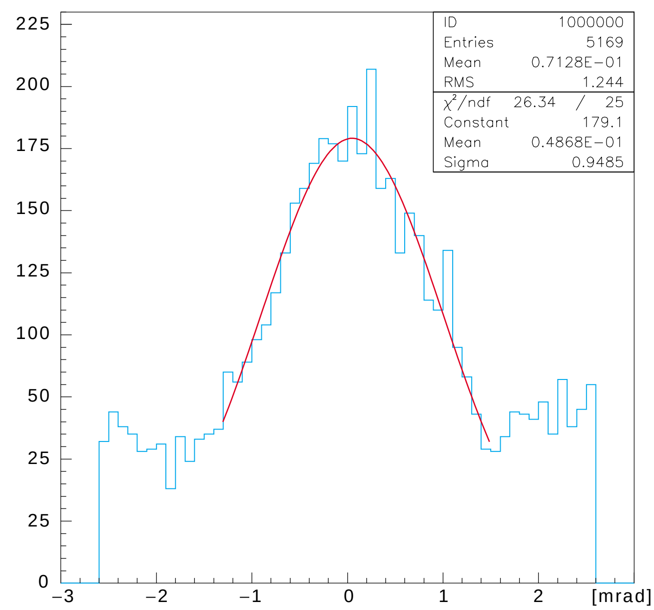

Figure 8: Distribution of deviation of hit position from expected position for reconstructed rings.

D. Particle Identification

Momentum measurement is needed for particle identification. We began this study by using the ECAL to provide a spatial point for the charged particle. The momentum of the charged particle is determined by requiring a vertex-constrained fit to the track angle determined by the RICH, after the magnetic bending. The preliminary results are shown in Figure 9, where the square of the Cherenkov angle θ^2 is plotted against $1/p^2$, the inverse-square of the momentum. A straight-line band for each particle species is seen, in agreement with expectation.

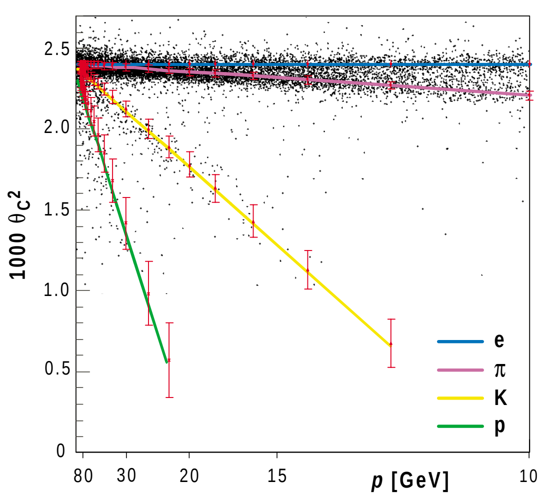

Figure 9: The square of the Cherenkov angle θ^2 versus $1/p^2$, the inverse-square of the momentum.

IV. Conclusions

The HERA-B RICH is operational, and has achieved its main design goals in its first year of operation. The system is robust, and shows no signs of aging under the high interaction rate conditions. We are beginning to extract useful physics results, such as particle identification, from the system.

V. Acknowledgments

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VI. References

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[2] See, e.g., S. Masciocchi, these proceedings.

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