Ring Imaging Čerenkov detector of PHENIX experiment at RHIC

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Abstract

The RICH detector of the PHENIX experiment at RHIC is currently under construction. Its main function is to identity electron tracks in a very high particle density, about 1000 charged particles per unit rapidity, expected in the most violent collisions at RHIC. The design and construction status of the detector and its expected performance are described

The PHENIX experiment[1]at the Relativistic Heavy Ion Collider (RHIC) is currently under construction. When completed in 1999, RHIC will provide collisions of Au+Au ions at $\sqrt{s}$=200 GeV per nucleon. The primary goal of PHENIX is to detect a new state of matter, the quark gluon plasma, in heavy ion collisions. The PHENIX detector consists of 4 spectrometers, or "arms" and an inner detector. Two central arms are to measure charged hardons,

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photons and electrons at the mid-rapidity. They are placed in back-to-back fashion at the both side of the beam line, covering 70 to 110 degrees in polar angle (θ) and 90 degrees per arm in azimuth (ϕ). The other two arms are to detect muons in forward and backward angles. The inner detector is to measure the total multiplicity, vertex position, and the start timing of an event.

The PHENIX RICH is the primary device for electron identification in the PHENIX central arms. It is a threshold gas Čerenkov detector with a high angular segmentation to cope with the high particle density, about 1000 charged particles per unit rapidity, expected in the most violent collisions at RHIC. Its Čerenkov threshold for pions is 3.5 GeV/c (with ethane radiator) or 4.9 GeV/c (with CO_2 radiator), and thus most pions and heavier particles produce no signal in the RICH. Figure 1 shows a side view of the RICH detector, and illustrates its function. When an electron passes through the RICH gas volume, Čerenkov photons emitted from the electron are reflected by thin spherical mirrors and are focused on arrays of PMTs, forming a ring shaped pattern. The direction of the electron track is then measured from the position of the Čerenkov ring. A charged particle track, measured by tracking system of the central arm, is identified as an electron if its direction matches the direction measured from the ring. There are two identical RICH detectors, one for each of the two central arms. The detector is sandwiched by the inner and outer tracking stations of the PHENIX central arm, and occupies radial region between r = 2.575 m and r = 4.1 m from beam line.

Figure 2 shows a cut away view of one of the RICH detector. The gas vessel is fabricated from aluminum, and has a volume of approximately 40 m^3. The vessel houses two arrays of spherical mirrors and two arrays of photo-multiplier tubes (PMTs). The PMT arrays are placed behind the PHENIX central magnet so that particles from the collision vertex do not directly hit the arrays. The vessel is filled with ethane or CO_2 at 1 atm as Čerenkov radiator. The radiator length, from the entrance window to the surface of the mirror, varies from about 0.9 m at $\theta = 90$ degrees to 1.5 m at $\theta = 70$ degrees and 110 degrees. The entrance and exit windows (9 m^2 and 21 m^2) of the vessel are made of 125 micron thick aluminized Kapton. The windows are covered by a light absorber sheet and are supported against a small pressure of radiator gas (1/2" of water) by graphite epoxy rods. All the gas seals are made using GoreTex gaskets.

In order to minimize the gamma conversion and multiple scattering, the materials in the acceptance of the detector are kept small in radiation length. The radiation lengths of the windows, mirror panels, and mirror supports are 0.2 %, 0.4%, and 1.0 % respectively. The total radiation length of the RICH detector filled with ethane gas is about 2.1 %.

A RICH detector has two 16×80 arrays of Hamamatsu H3171S[2] PMTs with

UV transparent glass window for Čerenkov photon detection. A PMT has a gain greater than 10^7 with dark current less than 100 nA. The diameter of the photocathode is 25 mm and its quantum efficiency is about 20 % (5 %) at 300 nm (200 nm). Since there is a significant stray magnetic field from the central magnet at the place of PMTs, each PMT is housed in a magnetic shielding case. For the first 900 PMTs, the shielding case is made of soft iron and mu-metal. For the rest (4220 + spares), it is made of ferroperm[3], which has a better shielding capability. A Winstone cone with 50 mm entrance diameter is attached to each PMT to collect Čerenkov light. There are 5120 (= 2 (arm) $\times$ 2 (side) $\times 16(\theta) \times 80(\phi)$) PMTs in the RICH system. They are placed near the focal plane of the mirror so that Čerenkov photons with the same emission angles in θ and ϕ are detected by the same PMT. The angular segmentation of the PMT array is approximately 1 degree by 1 degree in θ and ϕ.

The PMTs are first assembled into a 16 $\times$ 2 sub-array, called supermodule. After a supermodule is assembled, it is tested and the gain of all 32 tubes are measured. The gain of a tube is determined from the single photo-electron peak. After the gain measurement, the supermodule is "burn-in" at the nominal operating voltage for 3 weeks in a dark room. If any tube is failed during the "burn-in", it is replaced. (The failure rate has been less than 0.5 %.) After the "burn-in", the gain of the tubes are measured again, and then installed in the RICH gas vessel. Forty supermodules forms one 16 $\times$ 80 array of PMTs of one side of the RICH detector, which is shown in figure 3.

There are two mirror arrays in a RICH detector. One array consists of 2 $\times$ 12 spherically curved graphite-epoxy mirror panels, with total surface of 10 m^2. The radius of the reflecting surface of the mirror is 4.03 m. The substrate of a mirror panel consists of 1.25 cm of Rohacell foam sandwiched between two 0.7 mm thick graphite epoxy sheets. The substrate is manufactured by ARDCO[4]. The reflective surface is added to the substrate by replication, in which an aluminum layer is evaporated onto a highly polished glass master and then transferred to the graphite-epoxy substrate. This is accomplished by spacing the substrate 150 micron away from the glass mater, filling the gap with epoxy, curing the epoxy, and then separating the aluminum layer from the glass master. The replication is done by OPTICON[5]. The reflectivity of the mirror has been measured from a small sample produced by the same process. The reflectivity was found 83 % at 200 nm and 90 % at 250 nm.

The mirror panels are supported by a system of graphite-epoxy beams. A mirror panel is mounted to the support beams by three adjustable attachments so that the orientation of the mirror panel can be precisely adjusted. The alignment of the mirror panels were done in the following way. After all mirror panels and PMTs were installed, the RICH vessel was rotated up in the same orientation as on the PHENIX detector carriage. Then several optical targets were attached on the surface of each of mirror panels. Their positions were then measured by a computerized theodolite system (MANCAT). The mirror mounts were adjusted so that all optical targets are within 0.25 mm of the designed spherical surface.

A test beam experiment with a small prototype RICH was performed at KEK PS and BNL AGS. In the test, the figure of merit, N_0, of the device was determined about 120 per cm, and its timing resolution for a ring was about 250 psec r.m.s. Pion rejection of better than 10^4 with electron efficiency better than 99 % for an isolated track was obtained in the test.

In the very high particle density expected in heavy ion collisions at RHIC, the pion rejection factor is reduced due to ambiguities in association of a Čerenkov ring with a charged particle track. The photon conversions in the PHENIX detector produces background electrons into RICH active volume. Those electrons produce background hits in RICH PMT array. The background hits and high particle density reduces the e/π separation power of the RICH in Au+Au collisions. This effect has been studied by a detailed, GEANT3 based Monte Carlo simulation. Figure 4 shows estimates of pion rejection factor as a function of electron efficiency in central Au+Au collisions. Pion rejection of factor 200 to 1500 with electron efficiecy of 90 % to 75 % are expected.

The PHENIX RICH detector is in its final stage of construction. The assembly of the first RICH detector has been completed in October 1998. The entire RICH subsystem will be ready for its first operation in 1999.

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References

[1] PHENIX Conceptual Design Report, BNL, USA 1993, unpublished;
PHENIX collaboration, Nucl. Phys. A638 (1998) 565c

[2] Hamamatsu Photonics K.K., Hamamatsu 430, Japan

[3] Alloy of 1 % Al-iron developed by NKK Co., Japan.
T. Omori et al., J. Appl. Phys. 69 (1991) 5927.

[4] Advance Ratio Design Co. Inc, 2540 Green Street, Chester, PA 19013, U.S.A.

[5] OPTICON Corporation, 76 Treble Cove Rd, N. Billerica, MA 01862, U.S.A.

Fig. 1. A cut through view of PHENIX RICH detector.

Fig. 2. Cutaway view of one arm of the PHENIX RICH detector.

Fig. 3. One of the PMT arrays of the first PHENIX RICH detector. There is an identical PMT array in the oppsite side of the RICH.

Fig. 4. Expected performance of the PHENIX RICH in central Au+Au collisions at RHIC. Pion rejection factor vs. electron efficiency are plotted for ethane, CO_2, and freon 13. The simulation includes a shielding against background electrons that improves e/π separation by a factor 2.