Introduction to PHENIX RICH detector

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1 Introduction and Working principle

The RICH was installed and operated since the RHIC-2000 run till the end. The working principle of the RICH is following. When a charged particle entered into a medium, it interacts with the medium through electromagnetic interaction, yielding ionization of the medium and/or electromagnetic emission (photons) from the medium. The photons emitted from various locations of the medium interfere each other and cease in a short distance. This is depicted in the left top figure of the Fig. 1. On the other hand, if the injected particle travels through the medium with a speed faster

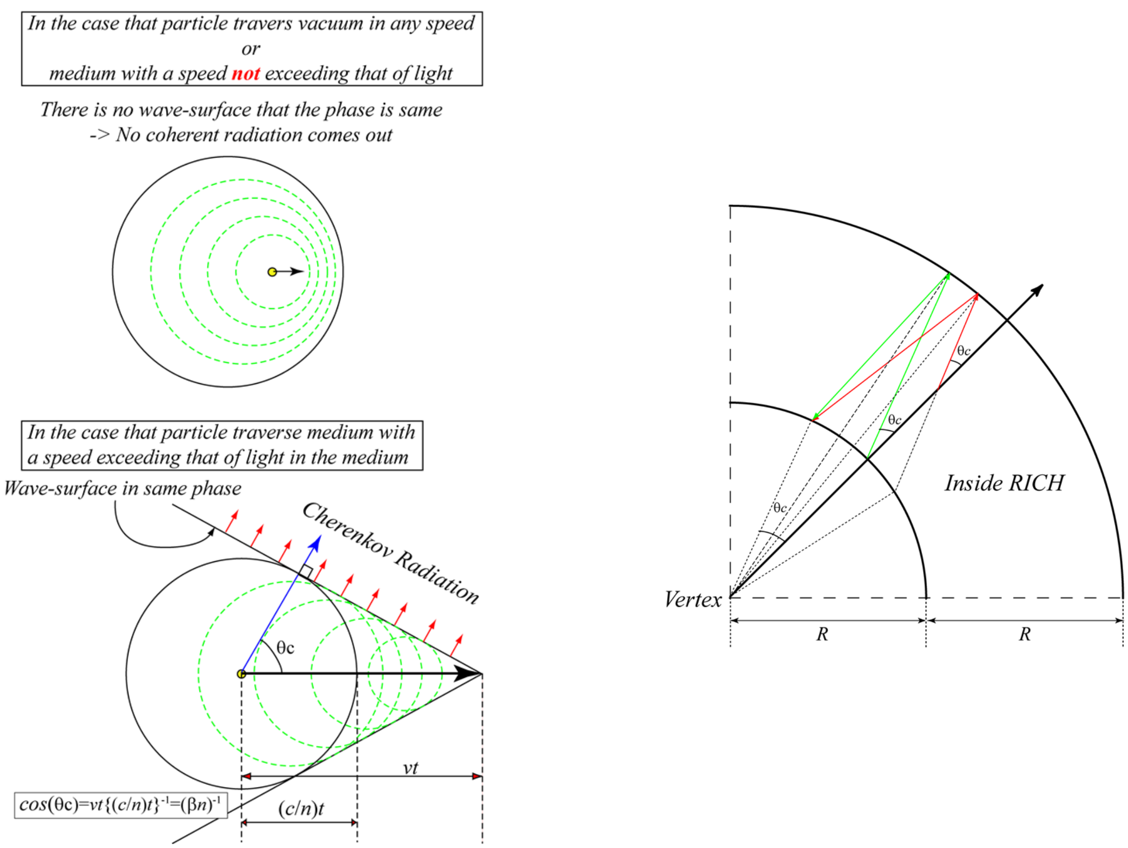

Figure 1: Left: Principle of Cherenkov radiation. Right: Optics for ring imaging.

than the speed of light of the medium, the phases of these photons become coherent at a certain angle with respect to the particle, and therefore can be transmitted to a distance as depicted in the left bottom figure of the Fig 1. This is the Cherenkov radiation. The phenomena was first discovered by P. A. Cherenkov, and theoretically interpreted by I. M. Frank and I. E. Tamm within the classical electromagnetic dynamics. The three physicists won the Nobel Prize of 1958. The condition of Cherenkov radiation and the emission angle (Cherenkov angle) θ_c are thus written as:

$$\beta > \frac{1}{n}, \quad \cos\theta_c = \frac{1}{n\beta}$$

where n is the refraction index of the medium, and the β is the speed of incident charged particle, respectively. The number of photo-electrons produced per unit path length of a particle with charge ze under an ideal condition is written as:

$$\frac{d^2N}{dEdx} = \frac{\alpha z^2}{\hbar c}\sin^2\theta_c = \frac{\alpha^2 z^2}{r_e m_e c^2}\left(1 - \frac{1}{\beta^2 n^2(E)}\right) \approx 370 z^2 \sin^2\theta_c(E)\,\mathrm{eV}^{-1}\mathrm{cm}^{-1}$$

In practical, the number of photons will be reduced due to several efficiencies, such as quantum efficiency of photon detection and/or light collection efficiency.

The Cherenkov photons are emitted in a form of cone as can be imagined from the Fig. 1. In order to measure the Cherenkov cone angle (thus the radius of the projected cone) better, the Cherenkov photons are often reflected at the mirror and focused onto the focal plane, which is at the half of the radial position of the mirror as shown in right figure of the Fig 1. The cone image will become a ring at the focal plane, thanks to the optics.

2 Technical details of PHENIX RICH detector

Figure 2 shows the schematic cross-sectional view of the RICH detector installed in PHENIX. The

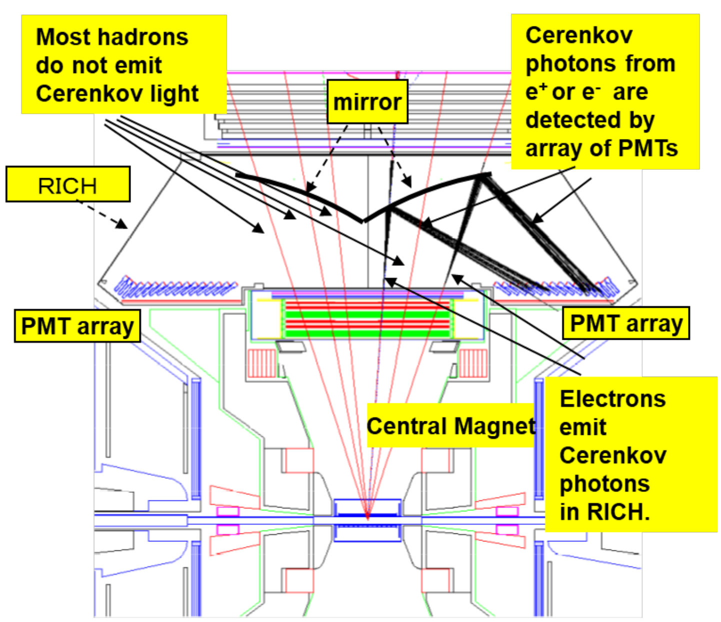

Figure 2: Schematic cross-sectional view of the RICH detector in PHENIX.

RICH is preceded by Drift Chamber and Pad Chamber 1 (West case), and followed by another Pad Chambers and EMCal, in the radial direction. The two gas vessels, each equipped with two PMT arrays and two 14 mirror arrays in north and south sides, are installed in east and west arm of the detector. The total number of mirrors is 56. Each PMT array consists of 1280 PMTs (16×80 in $z \times \phi$), thus the number of total PMTs is 5120. Each PMT is effectively covering $0.02(\eta) \times 0.02(\phi)$. The picture of PMT arrays is found in the left side of the Fig. 3, and the PMT arrays reflected onto the mirrors are seen in the right side of the same figure. A CO_2 was employed for the

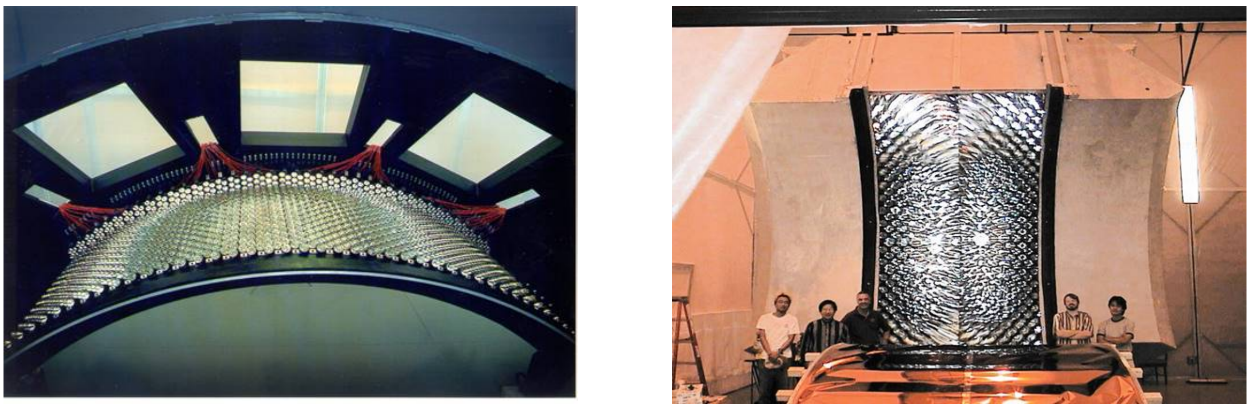

Figure 3: Left: PMT arrays inside the gas vessel. Right: PMT arrays are seen on mirrors as reflected images.

radiator gas throughout the data taking runs of PHENIX. The refractive index is $n = 1.00041$, corresponding to $\gamma_{th} = 35$. With this gas, electrons are exclusively identified in the momentum range of $p < 4.9\,\mathrm{GeV}/c$, ($\because 0.138(m_\pi) \times 35(\gamma_{th}) \approx 4.9$). More details including readout electronics can be found in the literature listed in the reference section.

3 Practical use of RICH for identifying electrons

Here we explains the typical way of using RICH for identifying electrons. Once a track of a charged particle is reconstructed, the projections of the track onto the RICH mirror and then to the PMT arrays are calculated. The radius of the ring for electrons can be estimated assuming most of electrons are relativistic, and one can draw the expected ring shape with some width (area), with respect to the track projection point. One then calculates the number of PMT hits, the distance between the PMTs and the track projection point, and the number of Cherenkov photo-electrons in the defined area, as depicted in the left side of the Fig 4, as quantities for defining cuts.

In case of PHENIX RICH, we defined a couple of ring areas and calculated number of PMT hits (n0, n1, n2, n3) and the number of Cherenkov photo-electrons (npe0, npe1, npe2, npe3). The ring shape parameters (chi2) were also calculated with respect to the ideal ring shape. The detailed information for these quantities are summarized here:

`https://www.phenix.bnl.gov/WWW/offline/wikioff/index.php/RICH_information_on_PMT_hits`

The right side of the Figure 4 shows the E/p ratio for all tracks and those with RICH association, as a function of track momenta. Here, E is measured by EMCal, and p is measured by

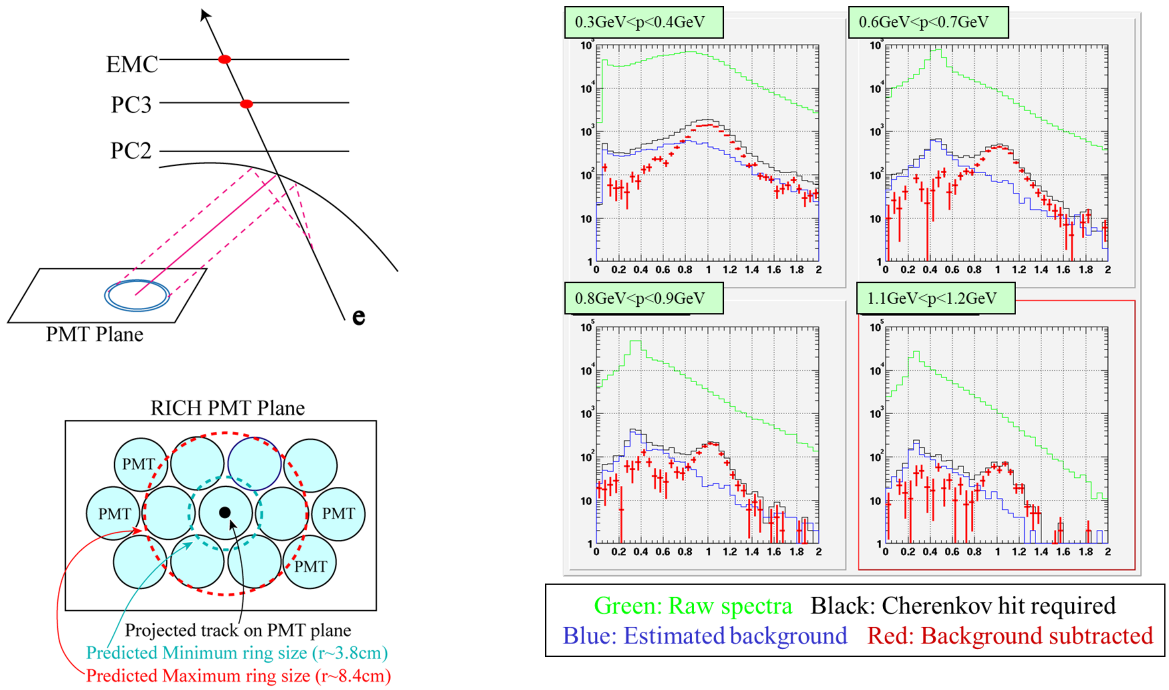

Figure 4: Left: Association of tracks with RICH hits. Right: E/p ratio with and without RICH association applied.

DC. After applying RICH association, clear peaks around $E/p = 1$ are seen which correspond to electrons. The "Estimated background" is the estimated contribution of random association of the tracks and RICH hits, and was estimated by so-called z-swap method. More analysis detail using RICH information can be found in analysis notes of single and pair electron analyses.

References

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