PROCEEDINGS OF SCIENCE

The dRICH detector at the ePIC experiment

Luisa Occhiuto,[a,*] P. Antonioli,[b] L. Barion,[c] F. Bellini,[d,b] R.S. Bhadauriya,[e] A. Bressan,[f] A. Calivà,[g] M. Capua,[a] C. Chatterjee,[f] M. Contalbrigo,[c] S. Dalla Torre,[f] A. De Caro,[g] D. De Gruttola,[g] L. Dello Stritto,[g] D. Elia,[h] S. Fazio,[a] T. Ghosh,[e] S. Kumar,[h] A. Mastroserio,[i,h] F. Noferini,[b] C. Pecar,[l] R. Rath,[b] C. Ripoli,[g] M. Ruspa,[m] E. Tassi,[a] S. Vallarino,[n] G. Volpe[o,h] and A. Vossen[l]

[a] *Università della Calabria & INFN Gruppo Collegato di Cosenza, Rende (Cosenza), Italy*
[b] *INFN Sezione di Bologna, Italy*
[c] *INFN Sezione di Ferrara, Italy*
[d] *Università di Bologna, Italy*
[e] *M. S. Ramaiah University of Applied Sciences, Bangalore, India*
[f] *Università di Trieste & INFN Sezione di Trieste, Italy*
[g] *Università di Salerno & INFN Gruppo Collegato di Salerno, Italy*
[h] *INFN Sezione di Bari, Italy*
[i] *Università di Foggia, Italy*
[l] *Duke University, Durham, NC, USA*
[m] *Università del Piemonte Orientale & INFN Sezione di Torino, Italy*
[n] *INFN Sezione di Genova, Italy*
[o] *Università di Bari, Italy*

E-mail: `locchiuto@cs.infn.it`

ePIC will be a general-purpose detector designed to enable the entire physics program of the Electron-Ion Collider (EIC) at BNL, USA. Several key physics measurements depend on efficient Particle Identification (PID). The PID system of ePIC covers a wide pseudorapidity ($-3.3 < \eta < 3.5$) and momentum range. Several technologies have been identified to serve such a purpose. In the forward region ($1.5 < \eta < 3.5$) a Dual Ring Imaging Cerenkov detector (dRICH) will be employed to provide efficient and continuous hadron PID from 3 GeV/c to 50 GeV/c and to support the electromagnetic calorimeter by pion rejection in the lower momentum region. The dRICH comprises two different radiators, aerogel and gas (C_2F_6), to cover the entire momentum range. SiPM based photosensors are placed in six spherical sectors to detect Cherenkov photons which are focused by six corresponding spherical mirrors. Here we introduce the dRICH detector and discuss results from simulation studies, with a special focus on the separation power for pions and kaons and its dependency on the particle momentum and pseudorapidity.

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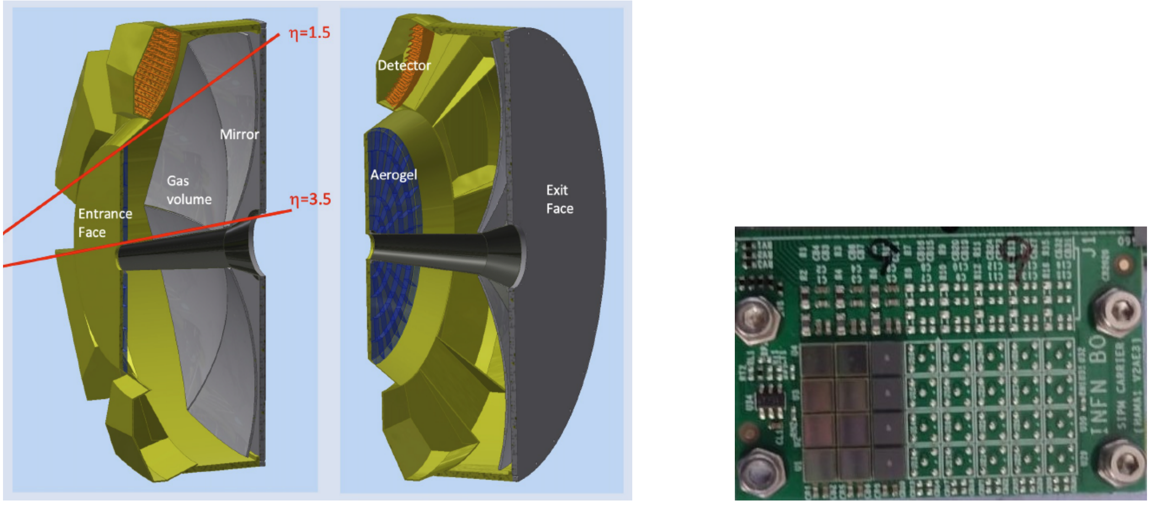
[*] Speaker

A. Introduction

With the design and construction of the world's first polarized Electron-Ion Collider (EIC)[1] in the United States, with a variable centre of mass energy (20-141 GeV) [2] and a large range of nuclear species (from proton to U), new perspectives open up for research in subnuclear physics. The primary goal of the EIC will be to explore advanced phenomena of quantum chromodynamics (QCD) and probe the internal structure of protons, nuclei, and the origin of their spin.
One of the major challenges for the EIC will be particle identification (PID) [3]. In the proposed ePIC detector, PID of pions, kaons, and protons will cover a wide range in pseudorapidity ($-3.3 < \eta < 3.5$). The challenge of PID is significant as it requires a greater than 3σ K/π separation in the backward, central, and forward regions, respectively up to a momentum of 9, 6, and 50 GeV/c [4]. In the forward region, to achieve an efficient coverage over such a wide momentum range, a dual Ring-Imaging Cherenkov (dRICH) is proposed. It consists of two different radiators, C_2F_6 gas (n = 1.0008) and aerogel (n= 1.02-1.03).
SiPMs are the technology of choice for detecting Cherenkov light in the dRICH. They have many advantages: ability to detect light at the single photon level, high single photon detection efficiency up to ~ 50 % [5], excellent single photon timing resolution of the order of 100 ps [6], and are insensitive to magnetic field. On the other hand, SiPMs are prone to dark current, and therefore noise from dark count rate (DCR), which can be further increased by radiation damage [7].
Photosensors will be positioned on six spherical tiles with a total surface area of ~ 3 m^2 and used to detect photons focused by an array of six spherical mirrors, as illustated in Figure 1.



(a) 3D mechanical model of the dRICH apparatus. **(b)** SiPM board.

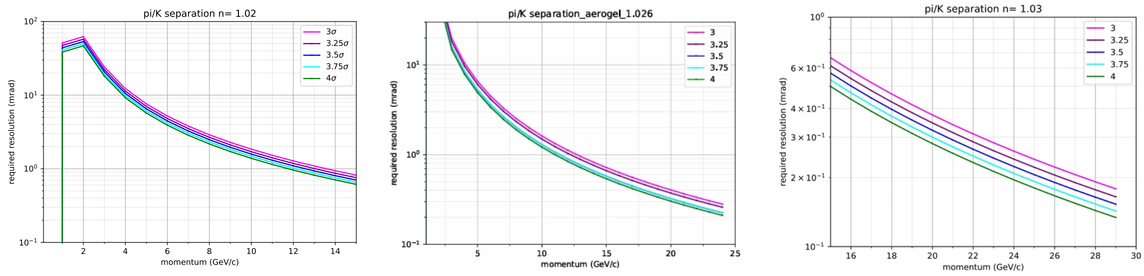
Figure 1: dRICH schematic on the left and SiPM board on the right.

Because these sensors will operate in a moderate radiation environment during the experiment, it is important to study their radiation tolerance. Estimates indicate that, at the position of the dRICH photosensors, the equivalent neutron fluence will be of $\sim 1 - 5 \times 10^7$ particles/cm^2 for every fb^{-1} of integrated luminosity. The measurements requiring the largest statistics data at EIC will demand an integrated luminosity of up to 100 fb^{-1}, corresponding to a delivered equivalent

neutron fluence of $\lesssim 10^{10}$ particles/cm^2 [8]. To keep the dark current at an acceptable level below 100 kHz/mm^2, SiPMs must be operated at low temperatures. In addition, radiation damage can be mitigated through periodic thermal treatment of the sensors, a process known as annealing.
The carrier board used for the radiation tolerance study has been designed at the Italian National Institute for Nuclear Physics (INFN) to accommodate 3×3 mm^2 SiPM photosensors in a 3×4 matrix arrangement, as shown in Figure 1. Each of the 3 rows of this matrix mounts a different type of SiPM four Hamamatsu S13360-3050 [5] in the first row, four Hamamatsu S13360-3075 [5] in the second row, and four Hamamatsu S14160-3050 [9] in the third row.

B. Performance studies

The dRICH operation is based on the properties of Cherenkov light [10] which is emitted by charged particles that pass through a medium with a speed greater than the speed of light in the medium itself. This light radiation can be captured and analyzed to infer the speed of the incoming particles and, knowing the momentum from the ePIC spectrometer, its mass.
The required Cherenkov angle resolution for various values of pion-kion separation in terms of standard deviation is shown in Fig.2: the nominal case (n = 1.02), the case evaluated with a refractive index of n = 1.026, and the case with n = 1.03.
Optical tuning has been performed for the most challenging pseudorapidity ($\eta > 2.5$) region.



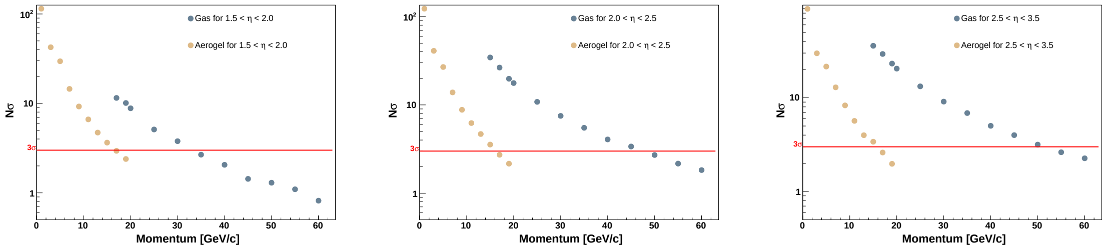
(a) Required Aerogel resolution with n=1.02.

(b) Required Aerogel resolution with n=1.026.

(c) Required Aerogel resolution with n=1.03.

Figure 2: Required resolution for a given π/K separation for aerogel.

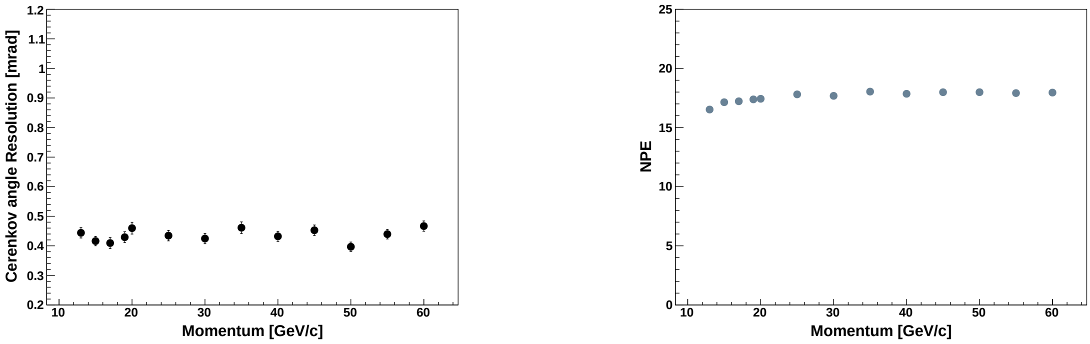
Detailed Simulation studies have been carried out. Figure 3 shows the $N\sigma$ separation as a function of momentum, for both aerogel and gas radiators, across three different pseudorapidity ranges.



(a) **(b)** **(c)**

Figure 3: Nσ separation in different pseudorapidity ranges.

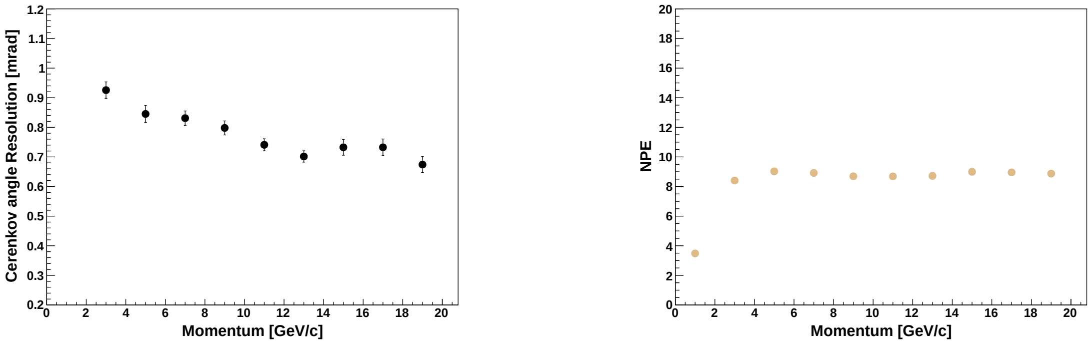
It can be observed that a greater than 3σ separation is achieved up to about 15 GeV/c for aerogel, while for gas, this separation can be reached up to 50 GeV/c. Figure 4 shows that for the gas, a resolution of about 0.4-0.5 mrad per particle is achieved with a detected photon count of 16-17. For the aerogel, at the nominal refractive index n=1.02, the resolution and the number of detected photons are 0.7-0.8 mrad and 9, respectively, see Fig. 5.



(a) Cerenkov angle resolution.

(b) Number of photon detected.

Figure 4: Cerenkov angle resolution and number of photons detected for gas in the $2.0 < \eta < 2.5$ range.



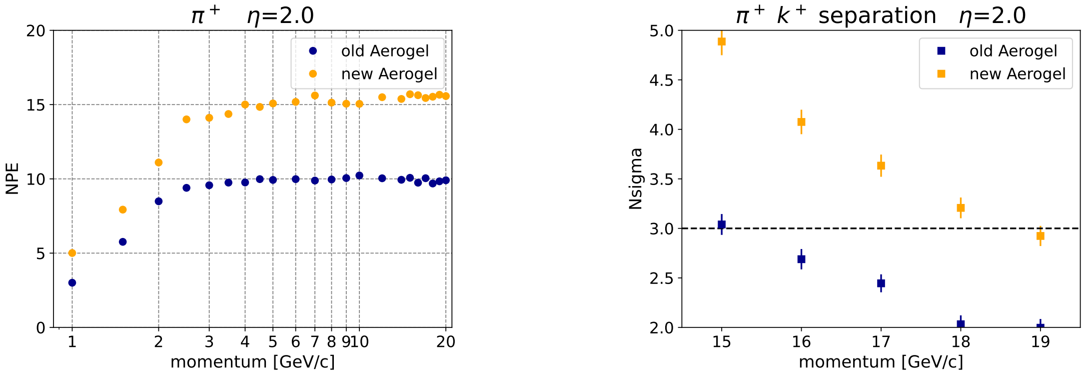
(a) Cerenkov angle resolution.

(b) Number of photon detected.

Figure 5: Cerenkov angle resolution and number of photons detected for n=1.02 aerogel in the $2.0 < \eta < 2.5$ range.

Because a complete reconstruction algorithm is not yet available, to simulat PID at ePIC lookup tables (LUT) for both aerogel and gas have been implemented. A particle is simulated with a specific momentum and pseudorapidity. The LUTs provide the probability that the dRICH has correctly identified or wrongly identified the particle at a given fixed momentum and pseudorapidity. The simulated particle in ePIC is identified based on the corresponding LUT probability. Using LUTs we have estimated that, for the aerogel, the identification efficiency is about 95% above 12.5 GeV/c, while the pion-kaon mis-identification probability is negligible up to 12.5 GeV/c.
To improve the performance of the detector and achieve higher efficiency, optimization studies were conducted on the refractive index of the aerogel, initially increasing it [11] to n=1.026, Fig. 6 and

subsequently to n=1.03, Fig. 7

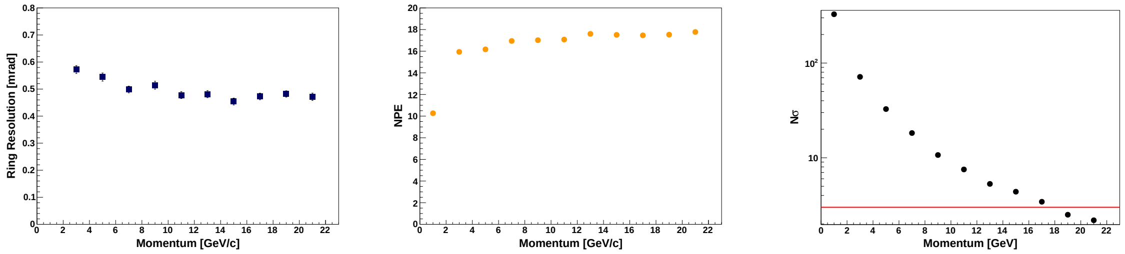


(a) Number of photons detected

(b) N*sigma* separation

Figure 6: Number of photons detected and Cerenkov angle resolution for aerogel with n=1.026

Fixing η = 2.0, we observed that we achieve a 3σ separation at approximately 17 GeV/c with a refractive index of n=1.03, as shown in Fig. 7, with overall results similar to those obtained for n=1.026. The resolution also remains comparable, with values between 0.5 and 0.6 mrad. The number of photons detected is higher than the nominal n=1.02, on the other hand this could lead to a loss of acceptance due to the increase in the ring size.



(a) Cerenkov angle resolution.

(b) Number of photons detected.

(c) Nσ separation

Figure 7: Cerenkov angle resolution and Number of photons detected for aerogel with n=1.03 at 2.0 pseudorapidity.

C. Conclusions

the dRICH detector will provide ePIC with PID in the region of the forward endcap, the direction of the outgoing hadron beam. The dRICH can achieve a 3σ π/K separation up to momenta slightly above 50 GeV/c in the forward region. The aerogel with a refractive index of n = 1.026 generates a higher number of NPE compared to the one with n = 1.02, providing better 3σ resolution. The LUTs are consistent with the results obtained for Nσ separation. In absense of a complete reconstruction algorithm, LUTs will provide quicker means of accounting for PID effects in event reconstruction within the ePIC framework.

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