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The RICH detector for CLAS12 at Jefferson Lab

L.L. Pappalardo (on behalf of the CLAS12-RICH Collaboration)

Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, 44122 Ferrara, Italy

Abstract. The CLAS12 spectrometer at JLab will offer unique possibilities to study the 3D nucleon structure in terms of TMDs and GPDs in the poorly explored valence region, and to perform high precision hadron spectroscopy. A large area ring-imaging Cherenkov detector has been designed to achieve the required hadron identification capability in the momentum range 3–8 GeV/c. The detector, based on a novel hybrid imaging design, foresees an aerogel radiator and an array of multi-anode photomultipliers. The detector concept and preliminary results of test-beams on a prototype are presented.

1. The CLAS12 spectrometer at JLab

The Jefferson Lab main facility is currently undergoing a major upgrade program which will lead to a doubled energy of the electron beam (from 6 GeV to 12 GeV), an increased luminosity, the construction of a new experimental hall (Hall D) and the enhancement of the detector systems in the existing halls. The large acceptance CLAS12 spectrometer, located in Hall B, will benefit from highly polarized electron beams of energies up to 11 GeV. It will be operated at luminosities as high as 10^{35} cm^{-2} s^{-1}, thus providing unique conditions for the study of electron-nucleon scattering in this kinematic regime [1]. The physics program is broad [2]. Particular attention is devoted to the 3D imaging of the nucleon through the study of generalized and transverse momentum dependent parton distributions (GPDs and TMDs) in the poorly explored *valence region* (high Bjorken x) [3]. Other topics include quark hadronisation processes in the nuclear medium and hadron spectroscopy. At least three of the approved experiments require an efficient hadron identification in the 3-8 GeV/c momentum range. Given the one order of magnitude larger flux of pions with respect kaons, a pion rejection factor of about 1:500 is required to limit the pion contamination in the kaon sample to a few percent level. The CLAS12 baseline includes already some PID detectors: a time-of-flight system (TOF), able to identify hadrons with momenta up to 3 GeV/c, and two Cherenkov gas detectors of high (HTCC) and low (LTCC) threshold. The latter two reach the required pion rejection factor only at the edge of the available phase space (hadron momenta above 7 GeV/c) and are not able to distinguish kaons from protons. To achieve the needed hadron identification, a ring-imaging Cherenkov detector (RICH) has been proposed. The RICH will substitute the LTCC in at least two of the six radial sectors of the CLAS12 spectrometer.

2. The RICH concept

Based on in-depth simulation studies, the best configuration for the RICH detector is a non-conventional proximity-focusing design, based on a wall of aerogel radiator tiles, an array of visible light photon

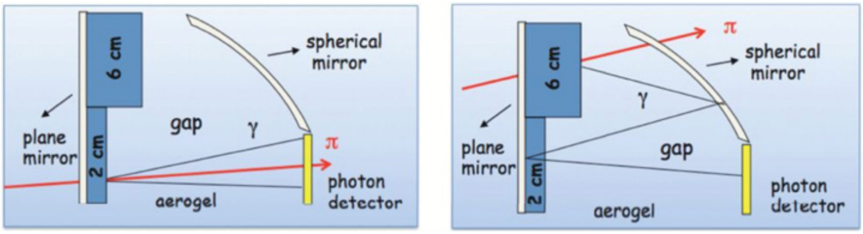

Figure 1. The CLAS12 RICH hybrid optics design. Left: direct light detection; Right: reflected light detection.

detectors, and a mirror system (Fig. 1). The latter is essential to reduce (to about 1 m^2 per sector) the area covered by the photon detectors, thus minimizing costs and the material-budget impact on the detectors positioned behind (TOF and Calorimeters). For forward scattered particles ($\theta < 13^o$), with momenta in the range 3–8 GeV/c, the Cherenkov light will be directly detected by the photon detector array (Fig. 1 left). For particles with larger incident angles ($13^o < \theta < 35^o$), with intermediate momenta of 3-6 GeV/c, the Cherenkov light will be double-reflected by a spherical and a planar mirror and focused onto the photon detector array after two passages through the 2 cm thick portion of the aerogel wall (Fig. 1 right). The photon yield losses, caused by absorption and scattering in the radiator material, will be compensated by the use of a thicker (6 cm) aerogel for these tracks[1].

3. Radiator and photon detectors

Aerogel, whose refractive index is intermediate between those of gases and liquids, is an ideal radiator material for RICH ID for hadrons with momenta of a few GeV/c. It is an amorphous solid network of SiO_2 nanocrystals with a very low macroscopic density. A systematic characterization has been carried out on a variety of aerogel samples from different manufacturers. The aerogel from the Budker and Boreskov Catalysis Institutes of Novosibirsk [4], that conjugates high-transparency with a considerable geometrical (area and thickness) flexibility, was found to be the best for our scopes. Precise measurements of the aerogel transmittance are being performed, using a Lambda 650 S PerkinElmer spectrophotometer, on a broad range of light wavelength (from 900 nm down to 200 nm). The optical quality uniformity is checked by performing measurements in different points of each aerogel tile. Noteworthy, during the prototyping, the production technique and the resulting quality of the Novosibirsk aerogel has significantly improved in time, reaching a clarity parameter as low as $0.0050\,\mu m^4\,cm^{-1}$ for a $n = 1.05$ refractive index. The chromatic dispersion, i.e. the dependence of the refractive index on the light wavelength, needs to be measured carefully as it constitutes one of the largest contributions to the Cherenkov angle resolution. This requires, in turn, precise measurements of the aerogel refractive index. One of the standard techniques is the so-called *prism method*, which allows to measure the refractive index through the Snell-Descartes formula [5]. This method was applied by focusing on the aerogel surface monochromatic beams of different wavelengths extracted from the spectrophotometer, and detecting the refracted light with a CCD camera. Preliminary results are shown in 2 (left). Due to local inhomogeneities, the refractive index may slightly vary throughout the tile. A refractive index gradient map, obtained with the *gradient method* [6] for a $n = 1.05$ tile from Novosibirsk, is shown in Fig. 2 (right). The observed variations are generally smaller than those due to the chromatic dispersion.

Dedicated simulation studies [7] have shown that the required Cherenkov angle resolution is ensured if the spatial resolution of the photon detectors is less than 1 cm. The Hamamatsu H8500 multianode

[1] The required resolution on the Cherencov angle is ensured by the longer path of the light and the focusing of the mirrors.

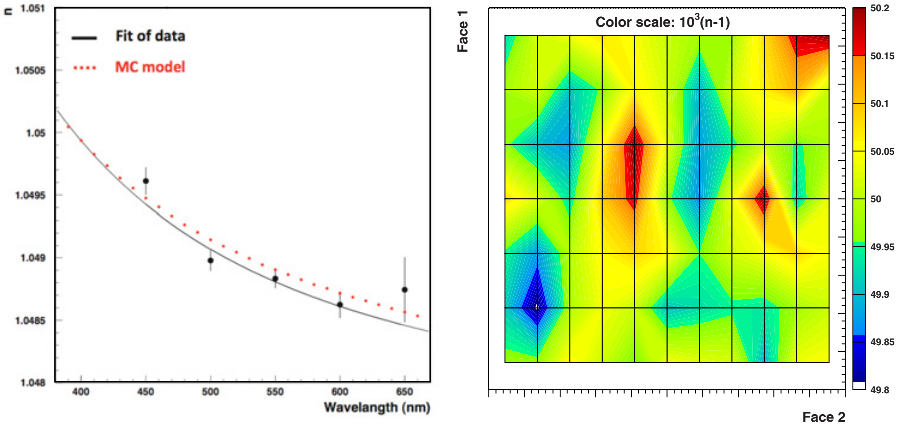

Figure 2. Left: aerogel chromatic dispersion measured with the *prism method*. The continuous line is a fit of the data based on the Sellmeier formula. The data points are compared with the dispersion model used in input to the RICH Monte Carlo (dotted lines). Left: refractive index gradient map obtained with the *gradient method*.

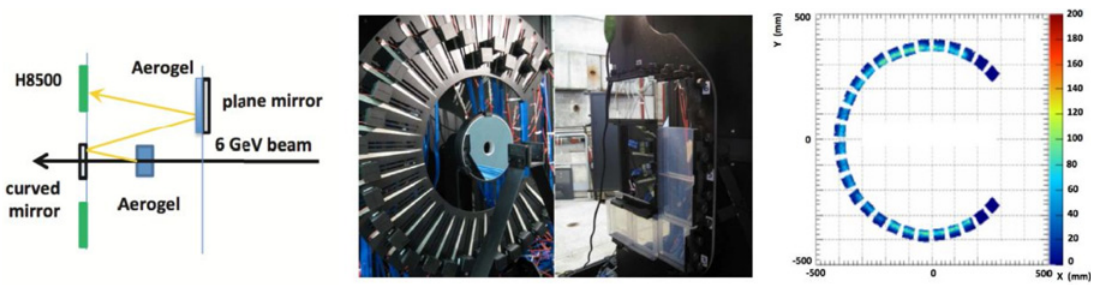

Figure 3. Reflected light configuration of the test-beam prototype. Left: side view diagram illustrating the setup. Center: photo of the detector plane together with the spherical mirror, and of the plane mirror array partially covered by the aerogel tiles. Right: the Cherenkov ring coverage is 60% for n = 1.05.

photomultipliers (MAPMTs), being an effective compromise between detector performance and cost, have been selected for the CLAS12 RICH. They consist of an array of 8×8 pixels of 5.8 mm^2, and have a total active area of 49.0 mm^2, corresponding to a 89% packing factor. The quantum efficiency of these devices peaks at 400 nm and well matches the spectrum of light transmitted by the aerogel. Furthermore, the response is fast enough (less than 1 ns rise time) to largely suppress the background. Although the H8500 MAPMT is not advertised as the optimal MAPMT for single photon detection purposes, several units have been tested in a small-scale proximity imaging RICH prototype at the CERN T9 beam line. These devices demonstrated to be capable to detect in average 12 photoelectrons per Cherenkov ring, using a 3 cm thick aerogel of $n = 1.05$ refractive index. A laser scanning facility has been implemented for in-depth characterizations of the MAPMTs [8].

4. The RICH prototype and projected performances

A large-size prototype of the RICH detector was constructed to test the main features of the final RICH detector. Test-beam studies were performed on the prototype at the T9 beam line at CERN, using hadron beam particles of 6–8 GeV/c momentum. The Hamamatsu H8500 MAPMTs were equipped with a readout electronics based on the MAROC3 chip. Two gaseous electron multipliers chambers

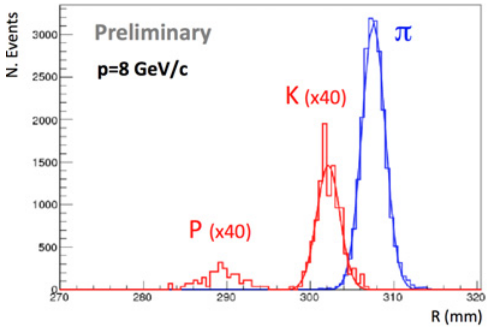

Figure 4. Cherenkov ring radius distributions for 8 GeV/c pions (blue) compared with those of kaons and protons (red), in the direct light configuration.

(GEM) were used to track the beam particles and a threshold Cherenkov gas counter was used to tag beam pions. In order to study both the direct and reflected light imaging modes separately, two setups were assembled inside a large ($1.6 \times 1.8 \times 1.6\,\mathrm{m}^3$) light-tight box. Several aerogel tiles with different thicknesses, transparencies and refractive indices (from $n = 1.04$ to $n = 1.06$) were employed to test their impact on the CLAS12-RICH performance. For the direct-light configuration a circular array of 28 MAPMTs was used. The main scope of the reflected-light configuration (Fig. 3) was to study the Cherenkov light yield loss in the double passage through the aerogel and its impact on the Cherenkov angle resolution. The Cherenkov light is first reflected by a spherical mirror and then by a semi-circular array of eight $11.5\,\mathrm{cm}^2$ planar mirrors, each coupled with a 2 cm thick aerogel tile. Preliminary results of the data analysis show a clear π/K separation up to 8 GeV/c (the maximum beam momentum) for the direct-light case (Fig. 4). In the reflected-light case, no significant degradation of the Cherenkov angle resolution was observed beyond that expected for the 60% light yield loss. These preliminary results not only validate the CLAS12 RICH concept, but also allow to extract the final light yield and the ring resolution to be implemented in the CLAS12 RICH simulation, embedded in the CLAS12 Geant4 framework. The description of the different optical elements in the simulation is thus based on both laboratory characterizations and test-beam studies on the prototype. The peculiar optical configuration of the RICH demands for a smart and robust pattern recognition algorithm; the current development is based on maximum likelihood methods and the ray tracing approach. The preliminary results indicate that a clear hadron separation, with a 1:500 pion rejection factor, can be achieved in the full momentum range (3–8 GeV/c) ensuring the fulfillment of the approved physics program.

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