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The CLAS12 large area RICH detector

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ABSTRACT

A large area RICH detector is being designed for the CLAS12 spectrometer as part of the 12 GeV upgrade program of the Jefferson Lab Experimental Hall-B. This detector is intended to provide excellent hadron identification from 3 GeV/*c* up to momenta exceeding 8 GeV/*c* and to be able to work at the very high design luminosity-up to 10^{35} cm^2 s^{-1}. Detailed feasibility studies are presented for two types of radiators, aerogel and liquid C_6F_{14} freon, in conjunction with a highly segmented light detector in the visible wavelength range. The basic parameters of the RICH are outlined and the resulting performances, as defined by preliminary simulation studies, are reported.

1. Introduction

At the Thomas Jefferson National Accelerator Facility (Newport News, VA) Hall-B currently houses the CLAS detector [1], which will be modified and upgraded to CLAS12 to meet the basic requirements for the study of the structure of nucleons and nuclei with the CEBAF 12 GeV upgraded electron beam. The major focus of the Hall-B physics program at 12 GeV, starting in 2014, will be the study of the internal dynamics and 3-dimensional imaging of the nucleon and quark hadronization processes [2].

Important observables that will be extensively investigated are Transverse Momentum Distribution functions (TMDs) describing partonic spin–orbit effects and Generalized Parton Distribution functions (GPDs), containing information about the spatial distribution of quarks and the relation (by a sum rule) to the elusive partonic orbital momenta. Several experiments have been already approved by the JLab12 PAC to study kaon versus pion production in hard exclusive and semi-inclusive scattering, providing access to the flavor decomposition of the two sets of non-perturbative distribution functions.

The main features of CLAS12 include a high operational luminosity of 10^{35} cm^{-2} s^{-1}, an order of magnitude higher than the present setup, and operation of highly polarized beam and nucleon targets. The conceptual design of the CLAS12 detector is shown in Fig. 1. The central detector with the high-field (5 T) solenoid magnet is used for particle tracking at large angles. The forward spectrometer detects charged and neutral particles in the polar angle range between 5 and 40°. It employs a 2 T torus magnet and retains the six sector symmetry of CLAS. In the base equipment, hadron identification is achieved by Cherenkov and time-of-flight counters. Such detectors do not provide an as efficient kaon identification at large momenta, from 3 to 8 GeV/*c*, as a RICH detector. There the semi-inclusive kaon yield is one order of magnitude smaller than the pion yield, see Fig. 2, thus the required rejection factor for pions is around 1:1000 (corresponding to 4.7 sigma pion–kaon separation). Moreover the base equipment detectors do not allow the separation of kaons from protons in the 5–8 GeV/*c* momentum interval. Improved particle identification and event reconstruction can be achieved in this momentum range by replacing the existing low-threshold Cherenkov counter (LTCC) with a RICH detector without any impact on the baseline design of CLAS12.

2. The CLAS12 RICH

To fit into the CLAS12 geometry, the RICH should have a projective geometry with six sectors that cover the space between the torus cryostats and covering scattering angles from 5 to 40°, see Fig. 3. Being downstream to the torus magnet at more than 5 m from the interaction point, the RICH has to cover a large surface, each sector spanning an area of the order of 4 m^2. Being constrained between detectors which are already in the construction phase, the gap depth cannot exceed 1 m. The proposed solution is a proximity focusing RICH.

A setup similar to the one adopted in Hall-A [3], with a freon (C_5F_{12} or C_6F_{14}) radiator and a CsI-deposited multi-wire proportional chamber as a UV-photon detector, does not achieve the required pion rejection factor at momenta greater than 3 GeV/*c*.

The preliminary results on ongoing Monte Carlo studies, based on a GEANT3 toolkit with simplified geometry and optical surface

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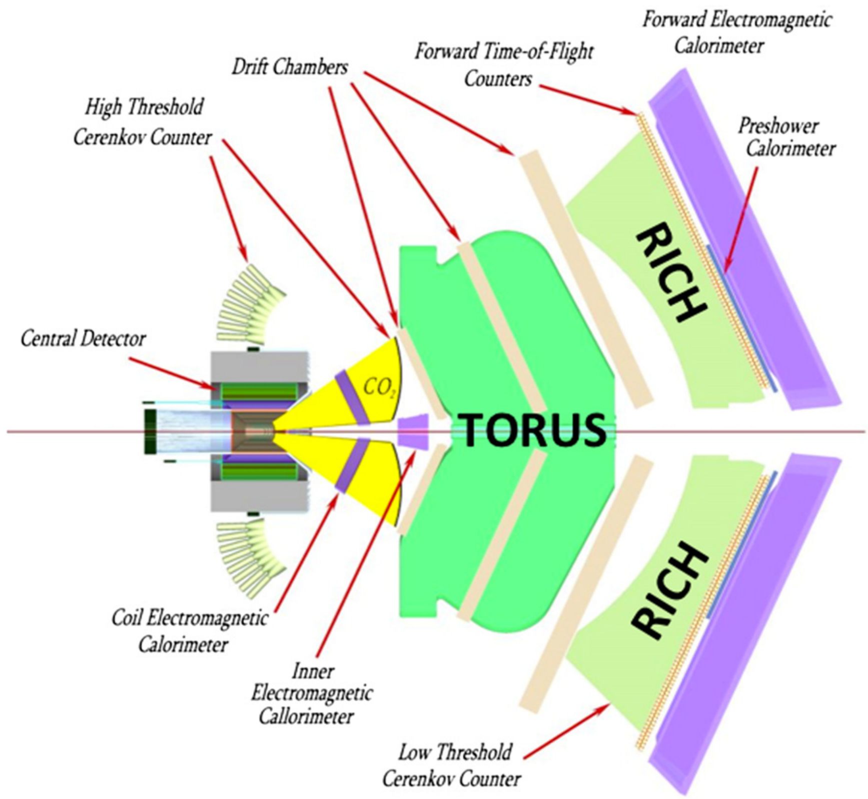

Fig. 1. Schematic of the CLAS12 detector. Improved particle identification can be achieved by replacing the existing low-threshold Cherenkov counter with a RICH detector.

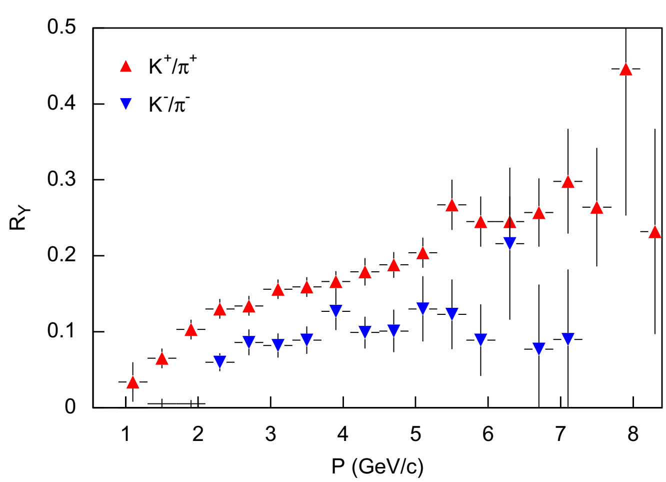

Fig. 2. Semi-inclusive kaon versus pion yield ratio R_Y.

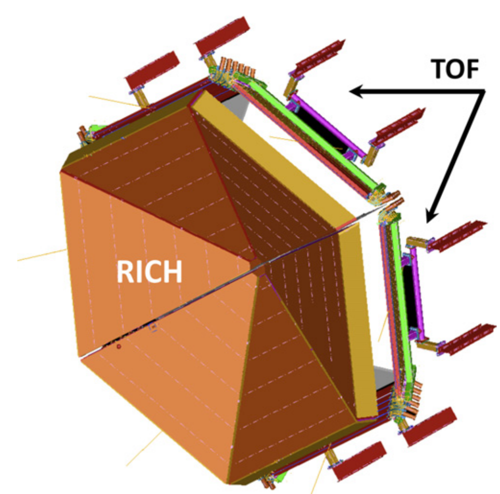

Fig. 3. Sketch of the six-sectors RICH layout, downstream of the CLAS12 torus and in front of the time-of-flight counter wall.

description, show that RICH requirements can be met by using aerogel as radiator and detecting light in the visible wavelength range. With respect to the use of freon in the UV region, such a solution offers a suitable refractive index, a lower chromatic error and a higher quantum efficiency in photon detection. The RICH performance has been studied as a function of the aerogel refractive index and thickness, as well as the photon detector pad size (minimum spatial resolution) for several geometrical configurations compatible with CLAS12. For aerogel, a now standard 40 mm transmission length (at a refractive index of 1.03 and 400 nm wavelength) has been assumed.

The study shows that, using a 3 cm thick aerogel with a refractive index of 1.03, a pion–kaon separation greater than 4 sigma up to 8 GeV/c momentum can be achieved if the detector pad size is less than 1×1 cm^2, see Fig. 4. The corresponding average number of detected photo-electrons is expected to be around 10, see Fig. 5. Although for larger aerogel thickness the number of photo-electrons increases, the also increased uncertainty on the photon emission point dominates the Cherenkov angle resolution and reduces the performance in pion–kaon separation. An increased number of photo-electrons could also be obtained with an increased aerogel refractive index, however, the RICH performance does not improve in the high-momentum range of interest, since at large refractive indexes the aerogel transparency is reduced (limiting the gain in photo-electrons) and the Cherenkov

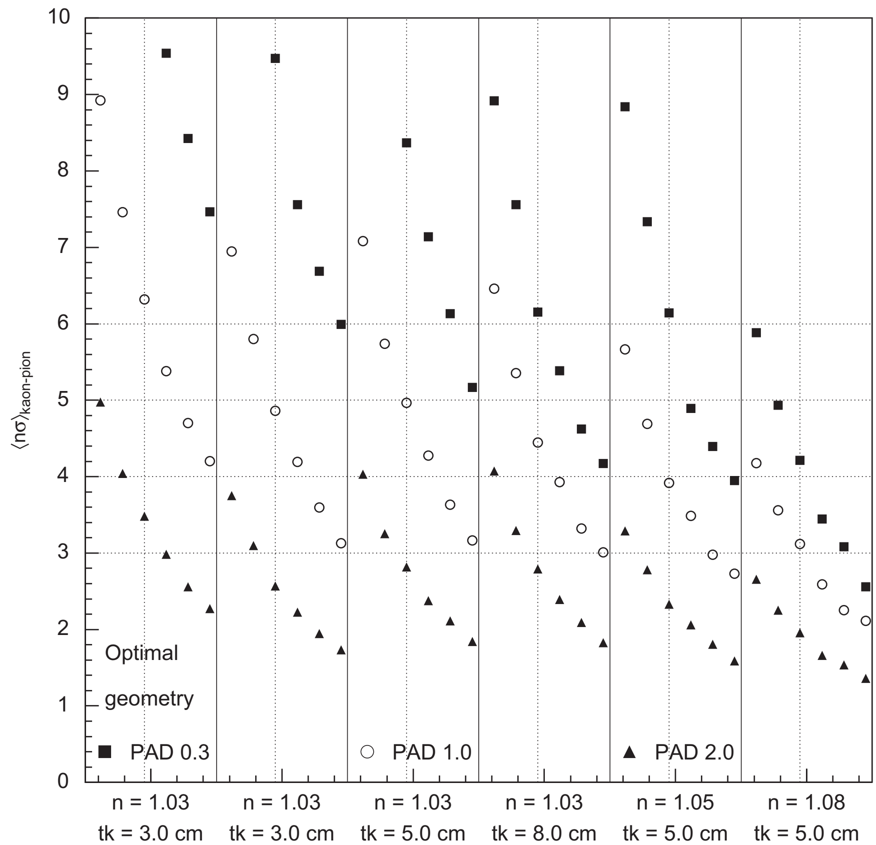

Fig. 4. Preliminary results of MC simulations of the CLAS12 RICH performance for different detector configurations. The study is performed for various refractive indexes (from 1.03 up to 1.08) and thicknesses (from 3 up to 8 cm) of the aerogel radiator, indicated on the horizontal axis. The optimal geometry corresponds to a photon detector extended to a region close to the beam-pipe not covered in the standard design. For each configuration, the average number of sigmas in pion–kaon separation is plotted in the 5–8 GeV/*c* momentum range, at intervals of 0.5 GeV/*c*. Three photon detector pad sizes are considered (2×2, 1×1 and 0.3×0.3 cm^2), indicated by the different symbols.

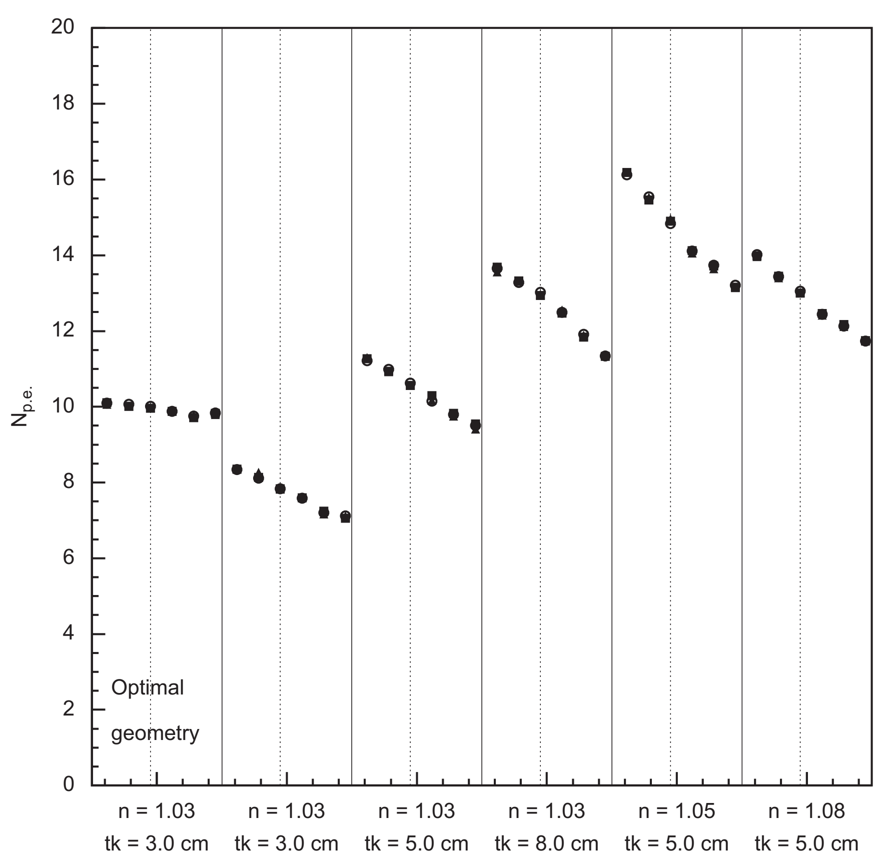

Fig. 5. The average number of photo-electrons is plotted in the 5–8 GeV/*c* momentum range, at intervals of 0.5 GeV/*c*, for different detector configurations. See Fig. 4 for detailed explanations.

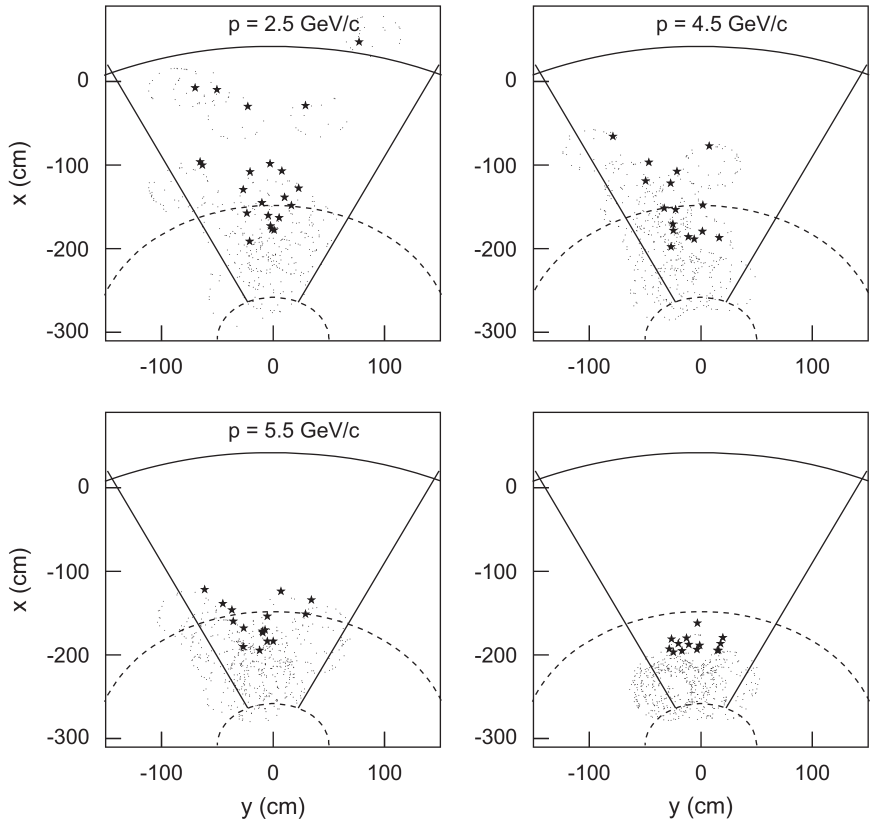

Fig. 6. Spatial distributions of the particle impact point at the RICH entrance (stars) and gamma impact point at the detector surface (dots) for few overlapping events. The plots distinguish among particles of increasing average momentum, from 2.5 up to 7.5 GeV/c, from top to bottom and left to right. High-momentum particles concentrate in a limited forward region close to the beam line, arbitrarily delimited by the two dashed arcs just for illustration.

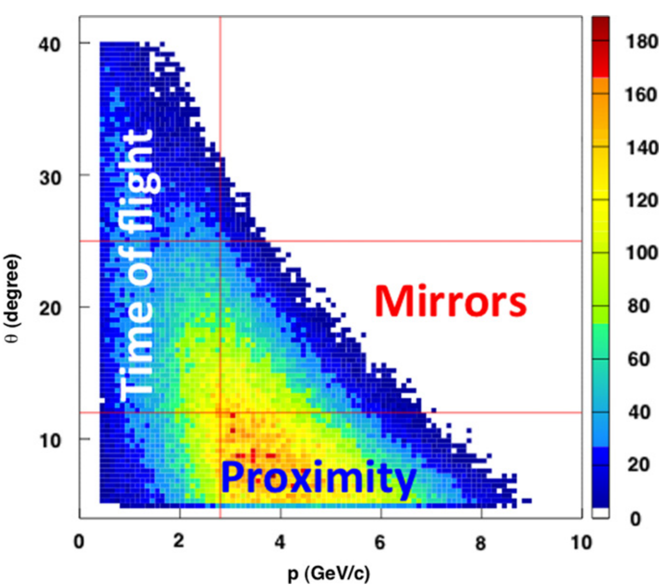

Fig. 7. Scattering angle versus momentum of the hadrons in the CLAS12 forward spectrometer. The TOF counters cover the low momentum region, a proximity focusing RICH is suitable for the high-momentum region at forward scattering angles, while at intermediate momenta and large scattering angles a mirror system could be the most effective option. The boundaries in scattering angle are arbitrarily defined by the two horizontal lines just for illustration.

angles of pion and kaon become closer. A larger aerogel thickness can be effective in the case of separated radiator layers or radiators with variable refractive index, and aerogels with increased transparency at large refractive indexes start to be available. The study of these options is ongoing.

The study shows the importance of extending the photon detector to a region close to the beam-pipe not covered in the standard design, in order to catch the full Cherenkov ring of high-momentum particles. In this way the average number of photo-electrons versus the momentum of the particle is stable, and one gets the best performance up to 8 GeV/c momentum.

3. Photon detection options

In order to match a (less than) 1×1 cm^2 photon detector resolution, multi-anode photomultipliers (MA-PMTs) or silicon photomultipliers (SiPM) have been considered, although the recent development of hybrid photomultipliers for the BELLE upgrade [4] is being followed with interest.

Among MA-PMTs, the R7600 by Hamamatsu is optimized for single-photon detection and has been already in use with success [5]. However, light concentrators have to be developed to compensate the large dead area (around 51%) of this photomultiplier. It is not clear if the use of lens telescopes, as the ones used in the COMPASS RICH [5], can cope with the relatively large Cherenkov angles obtained with aerogels and the broad range of particle impact angles at the RICH surface due to the bending in the CLAS12 toroidal field. Although H8500 MA-PMT by Hamamatsu is not optimized for single-photon detection, it is being considered as a suitable option thanks to its excellent packing factor (89%). Several tests are ongoing on H8500 by various collaborations with promising results (see e.g. Refs. [6,7]).

The SiPM option can better cope with the fringe fields of the torus magnet, which are estimated to be of the order of 50 Gauss in the photon detector region. SiPMs are compact and robust devices, insensitive to external magnetic fields, and have high spatial resolution and quantum efficiency. However, to suppress the high dark-current counting rate, the DAQ system should be designed with tight (of the order of few nanoseconds) coincidence time-windows and a sub-nanosecond time resolution. In addition, SiPMs require light concentrators since the actual cost per unit of surface is higher than for MA-PMTs and cannot be used in all environments since they are highly sensitive to radiation damage [8].

Various types of photomultipliers are being tested, and a prototype is being realized to compare the photon detector options under the experimental conditions foreseen for CLAS12.

The use of aerogel as radiator and the detection of light at visible wavelengths is an expensive solution. Work is in progress to limit the area of photon detection to about 1 m^2 per sector. The approach is to instrument a limited area around the beam line to have direct detection in the forward region at high momenta, see Fig. 6. At large angles and lower momenta, where the requirements on RICH performance can be loosened, a system of focusing mirrors catch the light and reflect it toward the photon detector. Such a solution would better decouple the RICH from the downstream time-of-flight system (TOF), since the mirrors minimize the amount of material and the effect on TOF resolution, while the photon detector only covers a spatial region where a large fraction of particle momenta is above the TOF working range, see Fig. 7. The challenging task is to avoid multiple passages of the reflected Cherenkov photons through the radiator, which will cause a dramatic loss in light intensity due to the limited aerogel transparency.

4. Conclusions

In summary, unambiguous kaon identification is needed for a complete study of exclusive and semi-inclusive reactions in Hall-B with the CLAS12 detector. A significant improvement in the particle identification in the 3 to 8 GeV/c momentum range can be obtained by replacing the low-threshold Cherenkov counter with a proximity focusing RICH. Preliminary studies show that the use of an aerogel radiator (with $n=1.03$ and 3 cm thickness) and a photon detector for visible light with pixel sizes smaller than 1×1 cm^2 matches the requirement of greater than 4 sigma separation between pions and kaons (about 1:1000 pion rejection factor). Work is in progress to obtain a more realistic simulation based on GEANT4 toolkit with refined geometry and optical properties of the surfaces. A prototype is being built to verify the expected performances and test the most promising options for the photon detection and geometry configurations in order to minimize the total instrumented surface (and therefore the cost).

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