A Ring Imaging Cherenkov Detector for CLAS12

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Abstract

The energy increase of Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) to 12 GeV promises to greatly extend the physics reach of its experiments. This will include an upgrade of the CEBAF Large Acceptance Spectrometer (CLAS) to CLAS12, offering unique possibilities to study internal nucleon dynamics. For this excellent hadron identification over the full kinematical range of 3 - 8 GeV/c is essential. This will be achieved by the installation of a Ring Imaging CHerenkov (RICH) detector. A novel hybrid imaging design incorporating mirrors, aerogel radiators and Hamamatsu H8500 multianode photomultiplier tubes is proposed. Depending upon incident particle track angle, Cherenkov light will either be imaged directly or after two reflections and passes through the aerogel. The detector design is described, along with preliminary results on individual detector components tests and from recent testbeam studies.

Keywords: RICH, Ring Imaging Cherenkov, CLAS12, MAPMT, Multianode Photomultiplier Tube, H8500, Aerogel, PID

1. Jefferson Lab 12 GeV Upgrade and CLAS12

Jefferson Lab (JLab) (VA, USA) is currently undergoing an upgrade program which involves the increase in energy of its electron accelerator from 6 GeV to 12 GeV. The upgrade will also see the enhancement of detector capabilities in the existing experimental halls, including Hall B's CEBAF Large Acceptance Spectrometer (CLAS) [1] which will be upgraded to CLAS12 (see Fig. 1). CLAS12 will receive polarised beams of

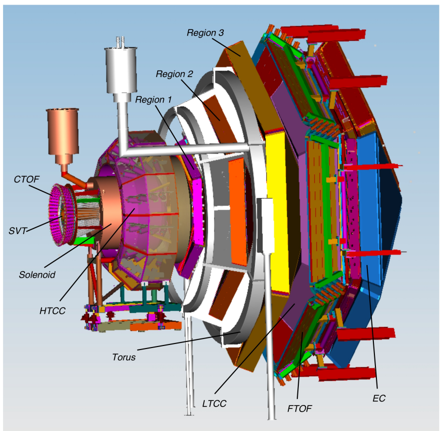

Figure 1: The CLAS12 detector [2]. The RICH detector will be positioned in place of the Low Threshold Cherenkov Counter (LTCC).

maximum energy 11 GeV and luminosity up to 10^{35} cm^{-2} s^{-1}, providing a world-leading facility for the study of electron-nucleon scattering at these kinematics, with close to full angular coverage. The physics program is extremely broad [2, 3], but in particular will focus upon three-dimensional imaging of the nucleon through the mapping of generalised parton and transverse momentum dependent distributions at high x_B with unprecedented precision. Other topics include quark hadronisation processes in the nuclear medium and spectroscopy studies. Efficient hadron identification is demanded across the entire kinematical range and, in particular, a π/K separation of $\sim 4\,\sigma$ up to 8 GeV/c is the goal. Currently charged Particle IDentification (PID) in CLAS12 is performed by Time-Of-Flight (TOF) detectors, Low and High Threshold Cherenkov Counters (LTCC, HTCC). These will not provide the necessary separation across the range of 3 - 8 GeV/c however and thus a RICH detector has been proposed for installation into the forward region of CLAS12, replacing the LTCC.

2. RICH Design

Since the RICH detector must fit into the original CLAS12 carriage there are several constraints imposed upon its design. Six radial sectors are required, each with projective geometry, limited gap depth of 1.2 m and ~ 4.5 m^2 entrance windows. There is also a strict low material budget to minimise influence on the TOF detectors positioned behind the RICH. Simulation studies favour a hybrid imaging Cherenkov detector design incorporating aerogel radiators, visible light photon detectors, and a focussing mirror system [4, 5]. The focussing mirror system (see Fig. 2) will be used to reduce the detection area instrumented by photon detectors to ~ 1 m^2 per sector, minimising costs and influence on the TOF system.

For forward scattered particles ($\theta < 12^\circ$) with momenta p = 3 - 8 GeV/c a proximity imaging method will be used, where the Cherenkov cone is imaged directly. For larger incident particle angles of $12^\circ < \theta < 35^\circ$ and intermediate momenta of p = 3 - 6 GeV/c the Cherenkov light will be focussed by an ellip-

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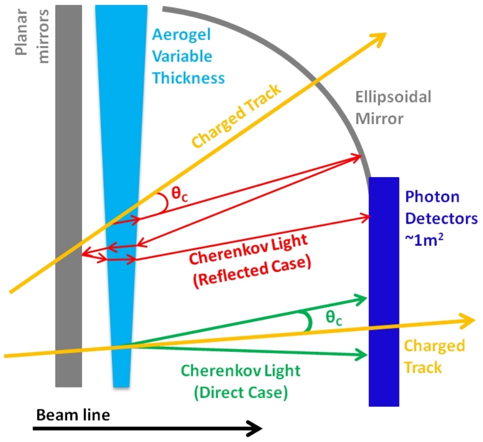

Figure 2: The hybrid RICH design concept - Cherenkov light is imaged directly for incident particle tracks of angles < 12°, and after two reflections and passes through the aerogel radiator for particle tracks with incident angles between 12 ° and 35 °.

tical mirror, followed by two further passes through the radiator material and a reflection from planar mirrors before detection. The Cherenkov light will be produced from a thicker amount of aerogel material than it will be reflected through, to compensate yield losses whilst obtaining a focalised ring. The case will also exist where Cherenkov rings are imaged partly by both the direct and reflected light cases simultaneously. For momenta below 3 GeV/c the TOF system will provide the necessary π/K identification for polar angles up to 40°.

The RICH detector is simulated within the CLAS12 Geant4 framework. This also allows the development of pattern recognition algorithms, which involve maximum likelihood methods and ray tracing ansätze. Results from simulations imply that, to achieve the $\sim 4\,\sigma$ π/K goal up to 8 GeV/c, of the order of 7 detected photons per ring are required in the direct light case.

Several characterisation studies of the individual RICH components are underway, a subset of which is described below.

3. Photon Detectors and the Hamamatsu H8500 MAPMT

There are several requirements limiting the choice of photon detector which have been confirmed through the simulation studies [4], for example the granularity of the photon detection plane. Due to the imaging aspect of the RICH and since multiple photon detectors will be tiled into large arrays, it is crucial that the photon detector provides an active area with minimal deadspace. The photon detector must also efficiently detect single photon level signals and, due to the aerogel radiator material, should be sensitive in visible light wavelengths.

MultiAnode PhotoMultiplier Tubes (MAPMTs) exist as promising candidates for the CLAS12 RICH and the currently selected photon detector is the flat-panel Hamamatsu H8500 MAPMT, which offers an adequate compromise between detector performance and cost. The H8500 MAPMT comprises an 8×8 array of pixels, each with dimensions 5.8 mm × 5.8 mm, into an active area of 49.0 mm × 49.0 mm and outer dimensions of 52.0 mm × 52.0 mm. Furthermore, the device has a very high packing fraction of 89 %. Although the H8500 MAPMT is not advertised as the optimal MAPMT for single photon detection purposes, several units have been successfully used by the CLAS12-RICH group in a testbeam of a small-scale RICH prototype at the CERN T9 beamline in 2011. Results demonstrated sufficient capabilities of the H8500 to detect Cherenkov light. For example, a mean of ~ 11 photoelectrons per event (Cherenkov ring with 56.8 % coverage) were obtained using a Novosibirsk tile of refractive index n = 1.05 and thickness 3 cm, and with a mixed hadron beam set at 10 GeV/c.

Laser scanning facilities have been setup for in-depth characterisations of MAPMTs. One topic which has been studied extensively includes the uniformity of the H8500 response. For example Fig. 3 shows the normalised single photoelectron signal efficiency response of an H8500 pixel and its surrounding area, obtained from a sub-mm precision laser scan. The signal efficiency is defined as the fraction of the single photoelectron distribution which lies above a 2σ pedestal cut. The pixel response demonstrates a dependency upon the dynode structure of the MAPMT, where there exist periodic drops in signal efficiency when the laser strikes dynode support structures. The magnitudes of these drops are however small, with ~5 % less relative signal efficiency compared to when the laser strikes dynode chain openings, and are not a concern for the CLAS12 RICH. Such studies are further described in [6], and they may also be used to study the PMT response in deadspace areas and to evaluate the true active areas of the pixels.

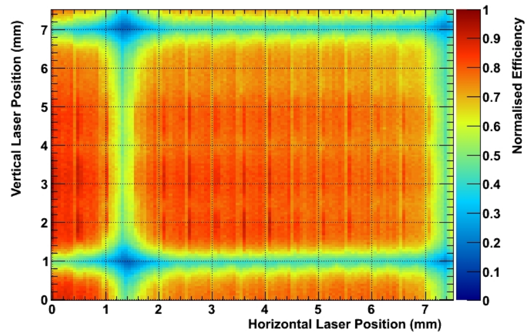

Figure 3: Normalised signal efficiency map of an H8500 pixel scanned in 0.04 mm steps, with a 633 nm laser beam focused to a diameter of 0.1 mm at single photoelectron light level.

Further characterisation tests performed include studies devoted to: crosstalk, where magnitudes of < 5 % are extracted; single photoelectron signal losses (defined as the fraction of the single photoelectron distribution lying below a $3\,\sigma$ pedestal threshold), which is minimised to ~ 12 % through operation at -1075 V close to the suggested maximum operating voltage; response uniformity within pixel areas as a function of incident photon angles, which is unaltered up to tested angles of 30° and pixel to pixel gain variations, which again did not cause concern for the RICH.

4. Prototype Studies at Testbeams

Testbeam studies of a prototype RICH detector were performed in 2012 with the T9 beamline in the CERN-PS East Area, which provides secondary particles - mostly pions and kaons - with selectable polarity and momenta from 0 - 15 GeV/c. The prototype consisted of two setups, dedicated to study direct and reflected light imaging cases individually. Gaseous Electron Multipliers (GEM) chambers were used for particle tracking and a beam threshold Cherenkov counter, which was provided in the T9 beam area, was set for kaons and pions to be below and above threshold respectively and used in offline kaon/pion separation analyses. Furthermore, a second smaller scale RICH prototype incorporating silicon photomultiplier arrays as photon detectors was included in the testbeams, however the results are not presented here.

For the direct light imaging case the prototype geometry was matched as close as possible to the CLAS12 RICH geometry and a schematic of the setup is shown in Fig. 4. Novosibirsk aerogel tiles, of dimensions 6 cm × 6 cm, were

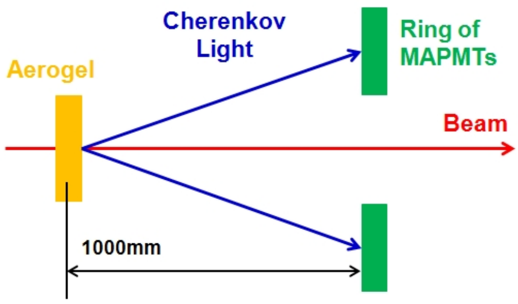

Figure 4: Diagram illustrating the proximity imaging setup of the testbeam prototype (side view).

used as Cherenkov radiators. Several thicknesses (t = 2 cm - 4 cm), transparencies and refractive indices (n = 1.04 - 1.06) were tested and their corresponding impact on the RICH prototype performance are under study. The radiator was placed at 1 m from a ring of 28 H8500 MAPMTs, which could be moved radially for imaging of differing ring radii. Both standard borosilicate and UV-extended window type MAPMTs were tested, to study yield differences and Rayleigh scattering resolution smearing effects. For readout of the MAPMTs the Multianode ReadOut Chip MAROC3 electronics [8] were used and, although the chip offers a sparsified readout mode, the entire charge spectrum of all channels was recorded to accurately study the MAROC3 and H8500 responses.

An example ring image obtained with the direct light setup is shown in Fig. 5, where the beam momentum was 8 GeV/c and the radiator had refractive index n = 1.04 and thickness 2 cm. Such images were used online as a check that ring properties behaved as expected - for example that radii increased with aerogel refractive index as is demonstrated in Fig. 6, where the refractive index is increased to n = 1.06. Moreover, in the online data analysis, π/K separation has already been observed. For example Fig. 7 displays Cherenkov ring radii distributions extracted from 3-parameter (ring centre and radius) ring fits to

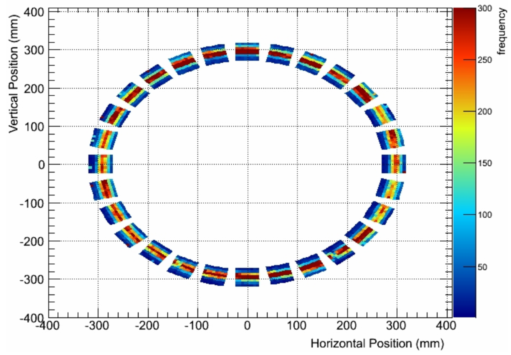

Figure 5: Direct light case testbeam prototype ring image, obtained beam momentum 8 GeV/c, aerogel refractive index 1.04 and thickness 2 cm.

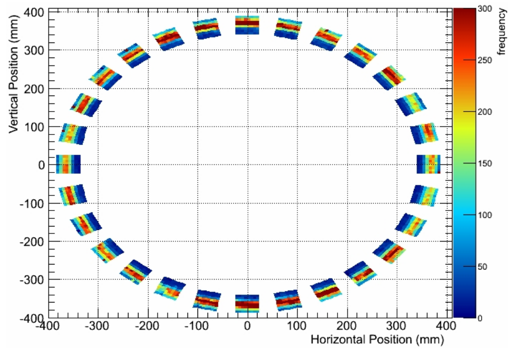

Figure 6: Direct light case testbeam prototype ring image, obtained beam momentum 8 GeV/c, aerogel refractive index 1.06 and thickness 2 cm.

the data obtained with a beam momentum 6 GeV/c, aerogel refractive index n = 1.05 and thickness 2 cm. The beam threshold

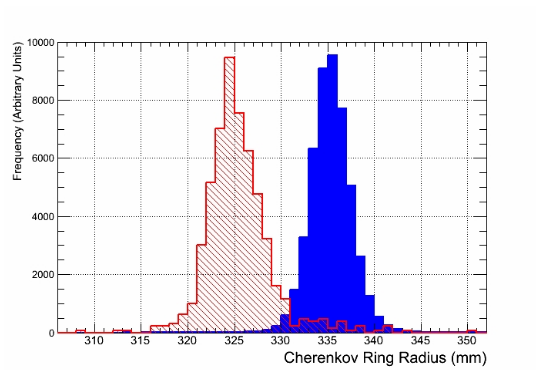

Figure 7: Cherenkov ring radii obtained for 6 GeV/c pions (blue/filled) and kaons (red/hatched), with the direct light testbeam setup and an aerogel radiator of n = 1.05 and thickness 2cm.

Cherenkov counter was used as an offline kaon trigger, and corresponding kaon and pion events are shown in the red/hatched and blue/filled histograms respectively. The kaon distribution has been subject to an amplitude scaling factor of 77, which is in rough agreement with the expected T9 beam composition at this momentum and negative polarity [7].

Currently investigations are underway to extract final light yield and ring resolution results, which are also converging with simulation comparisons. Due to the similarity of the geometries, for the direct light imaging case the testbeam results may be extrapolated for CLAS12 RICH performance projections, and also be used for model inputs in the simulations.

The main aim of the reflected light case testbeam study was to investigate the Cherenkov light yield loss caused by multiple passes through aerogel. A schematic illustrating the testbeam prototype setup is shown in Fig. 8. A mirror, with focal

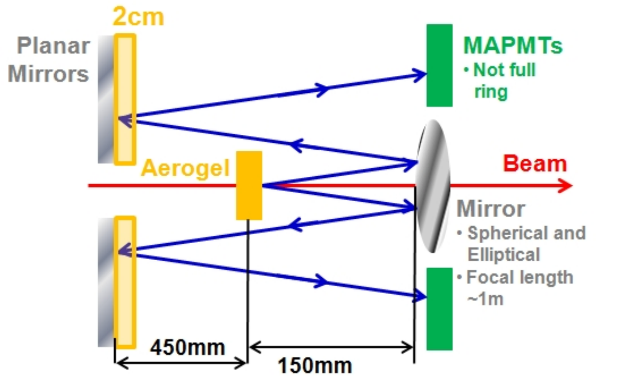

Figure 8: Diagram illustrating the setup of the reflected light case of the testbeam prototype (side view).

length ∼ 1 m, was used to reflect Cherenkov light radiated from the aerogel along the beam to a wall of 8 planar mirrors with aerogel tiles, called absorbers, placed in front of them. The Cherenkov radiators were as in the direct light setup, but with increased thicknesses used (6 cm - 8 cm). The aerogel absorbers were 10 cm × 10 cm × 2 cm Novosibirsk tiles of varying transparencies and refractive index n = 1.05.

Fig. 9 shows an example ring image obtained with no absorber tiles placed in front of the planar mirrors, a beam momentum of 6 GeV/c and radiator refractive index of n = 1.05 and thickness 6 cm. For the reflected light measurements less than

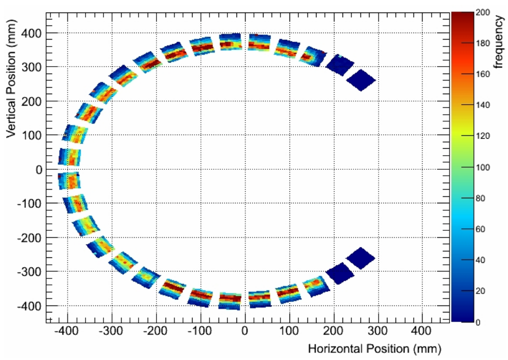

Figure 9: Reflected light case ring image, obtained with the testbeam prototype, without aerogel absorber tiles in front of the planar mirrors.

the full ring circumferences were instrumented, due to larger ring radii and setup shadowing effects. The corresponding image with absorbers before the planar mirrors is shown in Fig. 10. A lower Cherenkov yield (visible by colour scale) is extracted as a result of multiple passes through the aerogel absorbers. Nonetheless, the ring remains discernible and preliminary studies indicate that the yield is sufficient to perform a likelihood pattern recognition analysis.

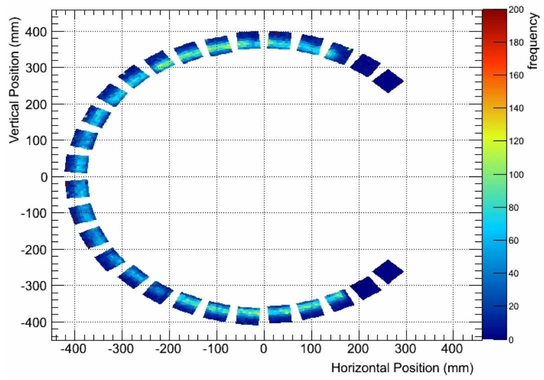

Figure 10: Reflected light case ring image, obtained with the testbeam prototype, with aerogel absorber tiles in front of the planar mirrors.

5. Summary

The installation of a RICH detector into CLAS12 for improved hadron identification over the 3 - 8 GeV/c momentum range will enhance its physics reach. A hybrid imaging design has been proposed, incorporating both proximity and reflected light imaging cases depending upon incident particle track angle. An in-depth characterisation program of candidate detector components, including H8500 MAPMTs and aerogel radiators, has been performed. Furthermore a large-scale testbeam prototype has been studied and currently extensive data analysis and simulation comparisons are ongoing, with further results on Cherenkov yield and ring resolutions to follow. From the prototype testbeam results it is decided that H8500 MAPMTs with standard Borosilicate glass windows only will be used in the CLAS12 RICH, since Cherenkov ring resolution degradations were observed with UV-extended window types. The writing of the technical design report is currently underway and the construction and installation of one complete RICH sector is planned for the beginning of CLAS12 data taking.

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