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A ring imaging Cherenkov detector for CLAS12

Rachel Ann Montgomery *

SUPA School of Physics & Astronomy, University of Glasgow, Kelvin Building, University Avenue, Glasgow, Scotland G12 8QQ, United Kingdom

For the CLAS12-RICH collaboration

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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 on the 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.

1. Jefferson Lab 12 GeV Upgrade and CLAS12

Jefferson Lab (JLab) (VA, USA) is currently undergoing an upgrade programme 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 with a maximum energy of 11 GeV and a luminosity of up to $10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, providing a world-leading facility for the study of electron–nucleon scattering at these kinematics, with close to full angular coverage. The physics programme 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 $\sim 4\sigma$ at 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 $\sim 4.5\,\mathrm{m}^2$ entrance windows. 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 with photon detectors to $\sim 1\,\mathrm{m}^2$ per sector, minimising costs and influence on the TOF system.

For forward scattered particles ($\theta < 12^\circ$) with momenta of $p = 3$–8 GeV/c a proximity imaging method will be used, where the Cherenkov cone is imaged directly. For particles with larger incidence angles of $12^\circ < \theta < 35^\circ$ and intermediate momenta of $p = 3$–6 GeV/c the Cherenkov light will be focused by an elliptical 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 layer 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 the reflected light cases simultaneously. For momenta below

* Corresponding author.
E-mail address: r.montgomery.1@research.gla.ac.uk

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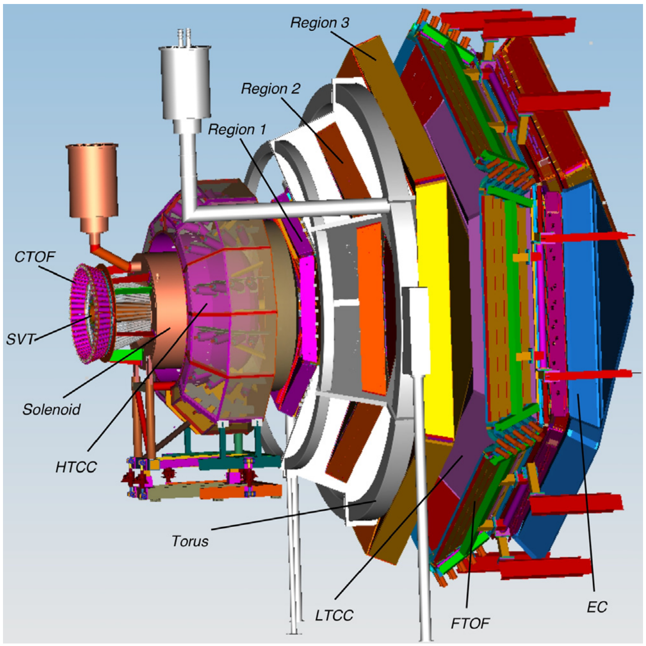

Fig. 1. The CLAS12 detector [2]. The RICH detector will be positioned in place of the Low Threshold Cherenkov Counter (LTCC).

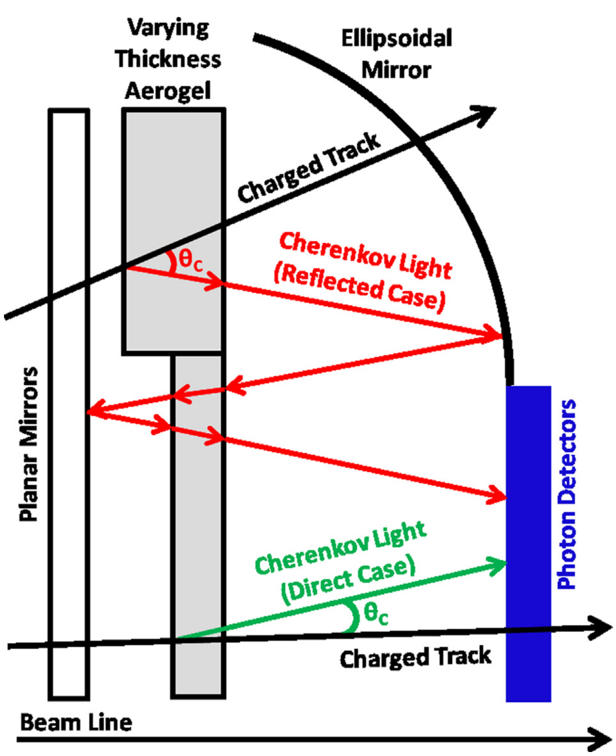

Fig. 2. The hybrid RICH design concept – Cherenkov light is imaged directly for incident particle tracks of angles $<12^\circ$, and after two reflections and passes through the aerogel radiator for particle tracks with incidence angles between 12° and 35°.

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 separation goal at 8 GeV/c, about 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 the 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 dead space. The photon detector must also efficiently detect single photon level signals and, due to the aerogel radiator material, should be sensitive in the 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, in an active area of 49.0 mm × 49.0 mm with 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 collaboration in a beam test experiment with a small-scale RICH prototype at the CERN T9 beam line [6] in 2011. The results demonstrated sufficient capabilities of the H8500 to detect Cherenkov light. For example, a mean value of ~ 11 photoelectrons per event (Cherenkov ring with 56.8% coverage) was obtained using a Novosibirsk tile [7], with a refractive index $n = 1.05$ and a thickness of 3 cm, in a mixed hadron beam set to 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

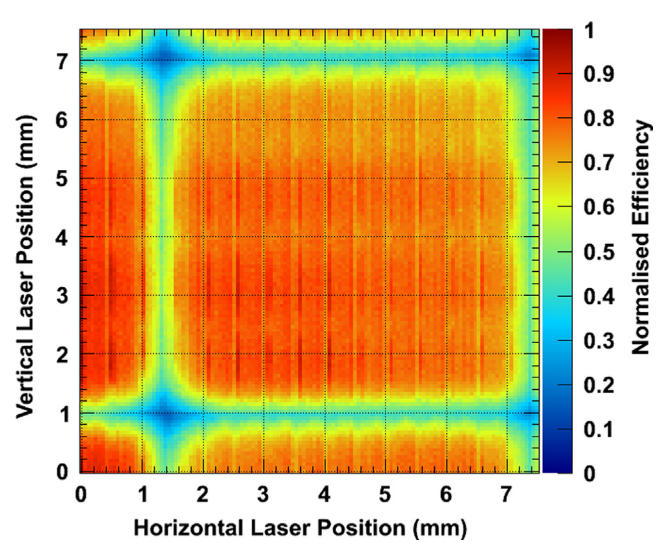

Fig. 3. Normalised signal efficiency map of an H8500 pixel scanned in 0.04 mm steps, with a 633 nm laser beam focused to a diameter of 0.1 mm at single photoelectron light level.