THE LARGE-AREA CLAS12 RING-IMAGING CHERENKOV DETECTOR

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The CLAS12 deep-inelastic scattering experiment at the 12 GeV JLab facility will offer unique possibilities to study the 3D nucleon structure in terms of TMDs and GPDs in the yet poorly explored valence region, and to perform precision measurements in hadron spectroscopy. A large area ring-imaging Cherenkov detector has been designed to achieve the required hadron identification capability in the momentum range from 3 GeV/c up to 8 GeV/c at a luminosity as high as 10^{35} cm^{-2}s^{-1}. The proposed solution foresees aeogel radiator and multi-anode photomultiplier tubes together with a novel hybrid imaging design. Cherenkov light will either be imaged directly (forward tracks) or after two mirror reflections (large angle tracks). The detector design, individual detector components tests and preliminary results of test-beam studies are here reviewed.

Keywords: RICH detector, Aerogel, MA-PMTs

1. The CLAS12 Experiment

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 Bs CEBAF Large Acceptance Spectrometer (CLAS)[1] which will be upgraded to CLAS12 (see Fig. 1). CLAS12 will receive polarised beams of maximum energy 11 GeV and luminosity 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.[2] The physics program is extremely broad,[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 unprecedented high Bjorken x. Other

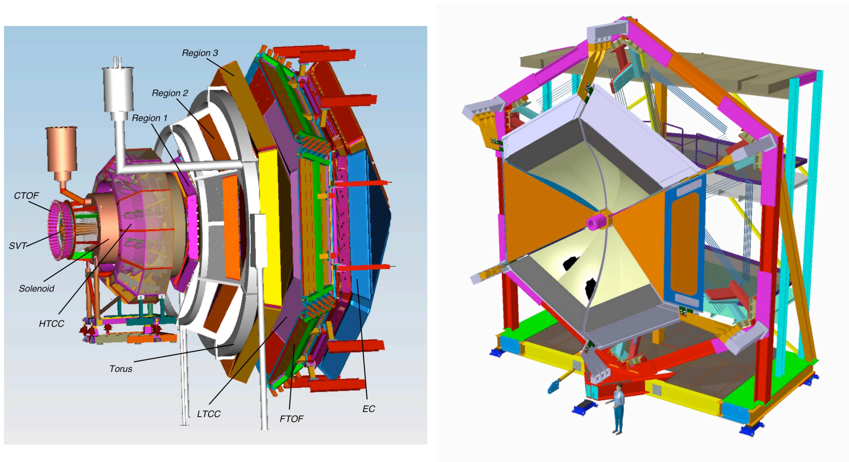

Fig. 1. Left: The CLAS12 detector. Right: The two-sector baseline RICH detector positioned in place of the Low Threshold Cherenkov Counter (LTCC) in the very forward section of the spectrometer.

topics include quark hadronisation processes in the nuclear medium and spectroscopy studies. In particular three approved experiments demand an efficient hadron identification across the entire momentum range, from 3 to 8 GeV/c, up to scattering angles of 25 degrees. Given the one order of magnitude larger flux of pions with respect kaons, a π rejection power of about 1:500 is required to limit the pion contamination in the kaon sample to a few percent level. For a 90% kaon identification efficiency, this corresponds to a separation of 4σ in the Cherenkov angle distributions. In CLAS12, the time-of-flight system is able to efficiently identify hadron up to 2.5-3.5 GeV/c momentum, decreasing with the distance of the impact point from the beam axis (i.e. the TOF scintillation slabs length). The threshold Cherenkov gas detectors become effective in rejecting pions only close to the upper limit of hadron momenta (around 7 GeV/c) and are anyhow not able to distinguish kaons from protons. A ring-imaging Cherenkov detector (RICH) has been proposed for installation into the forward region of CLAS12, replacing one of the Cherenkov gas detectors, to achieve the wanted 4σ separation from 3 GeV/c up to 8 GeV/c, without affecting the baseline layout of the CLAS12 spectrometer.

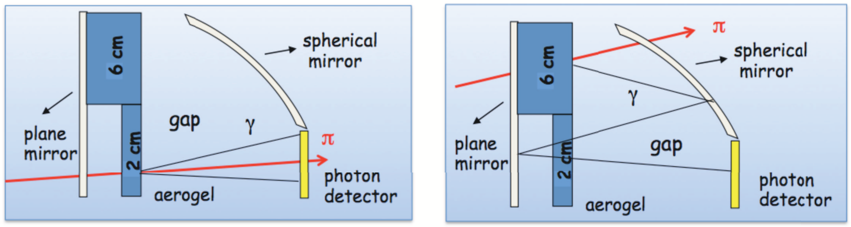

Fig. 2. The CLAS12 hybrid optics design.

2. RICH Design

Since the RICH detector must fit into the baseline of the CLAS12 spectrometer which is already under construction, 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 6 m^2 entrance windows. The material budget should minimise influence on the detectors (TOF and Calorimeters) positioned behind the RICH. Simulation studies favour a hybrid imaging RICH 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 about 1 m^2 per sector, minimising costs and influence on the TOF system. For forward scattered particles ($\theta < 12^o$) 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 $12^o < \theta < 35^o$ and intermediate momenta of p = 3 - 6 GeV/c the Cherenkov light will be focussed by an spherical 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, in attempt to compensate yield losses while exploiting the mirror focusing of the Cherenkov cone. For momenta below 3 GeV/c the TOF system will provide the π/K identification for polar angles up to 40^o.

3. Aerogel Radiator

The best radiator for RICH hadron ID in the few GeV momentum range is silica aerogel, an amorphous solid network of SiO_2 nanocrystals with a very low macroscopic density and a refractive index in between gases and liquids. It has been successfully used as radiator material for RICH detectors

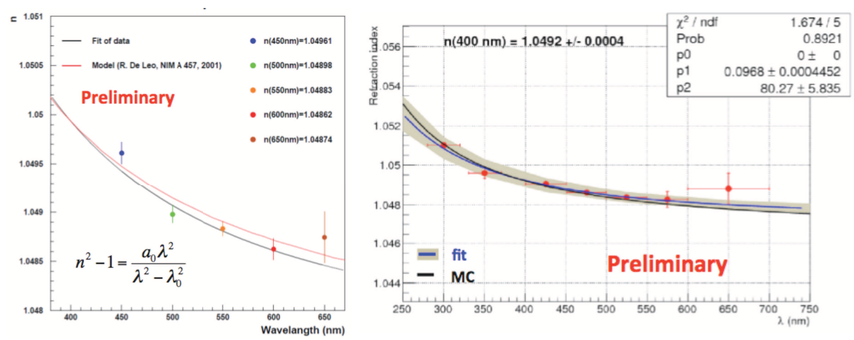

Fig. 3. Aerogel dispersion measured with the spectrometer beam and the prisma method (left) and with the prototype and 8 GeV/c pion beam by using optical filters (right) on two different tiles. The red and blue lines are fits of the data using the Sellmeier formula, with the gray band showing the uncertainty due to fitted parameter errors. The data points are compared with the dispersion model used in input to the RICH Monte Carlo simulations (black line).

in several particle physics experiments[6–9] and is planned for future use.[10]

A systematic characterization has been carried out in laboratory and during test beams on a variety of aerogel samples from different producers. The most studied has been the aerogel from the Budker and Boreskov Catalysis Institutes of Novosibirsk,[11] because it conjugates high-trasparency with flexibility in geometrical parameters (area and thickness).

Precise measurements of the aerogel transmittance as a function of the light wavelength are being performed using a Lambda 650 S PerkinElmer spectrophotometer. The uniformity of the optical quality has been checked by performing measurements in different points on the surface of each tile. During the prototyping phase, the production technique and the resulting quality of the aerogel has been significantly improved in time. Presently, a clarity of the order of 0.0050 $\mu\text{m}^4\text{cm}^{-1}$ for a n=1.05 refractive index has been achieved.

In order to study the chromatic dispersion, i.e. the dependence of the refractive index on the light wavelength, estimated to be among the largest contributions to the Cherenkov angle resolution, one needs precise measurements of the aerogel refractive index. Different methods were employed. The prism method allows to measure the refractive index through the Snell-Descartes formula.[13] The measurements were performed using the monochromatic beam extracted from the spectrophotometer, focused by a series of lenses and recorded by a CCD camera, see Fig. 3. As a second method, the dependence of the refractive index on the photon wavelength has been studied by applying optical filters just after the n=1.05 aerogel radiator in the prototype, with a 8 GeV/c pion beam. The set of available filters allowed to span the entire range of relevant wave-lengths, from 300 to 650 nm, in steps of 50 nm. At the reference wavelength of 400 nm, the measured n = 1.0492 ± 0.0004 refractive index is in agreement with the valued derived from the given aerogel density of $\rho = 0.230$ g/cm^3. The data points are consistent with the dispersion model used in input to the RICH simulations, in which the aerogel refractive index is derived as a combination of those of its air and quartz components.[14]

Due to local inhomogeneities, the refractive index can change significantly (variations up to $\delta n \approx 10^{-3}$) throughout the tile. The prism method allows to determine the refractive index only in the proximity of the tile edges, whereas the test-beam measurements are time consuming. A complementary approach has been commissioned based on the gradient method.[12]

4. Photon detector

As confirmed by simulation studies,[4] the photon detector must provide a spatial resolution of less than 1 cm to not degrade the Cherenkov angle resolution. 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 8x8 array of pixels, each with dimensions 5.8mm x 5.8 mm, into an active area of 49.0mm x 49.0 mm with a very high packing fraction of 89%. The device offers a spectral response matching the spectrum of light transmitted by the aerogel, with a quantum efficiency peaking at 400 nm, and a fast response (less than 1 ns rise time) useful to control the backgrounds.

Laser scanning facilities have been setup for in-depth characterisations of MAPMTs. The uniformity of the H8500 response has been extensively studied with a pico-second pulsed laser, see Fig. 4. The typical gain variations in the pixel response, of the order of 1:2, can be easily compensated by the readout electronics. Sub-mm precision scan are used to study the PMT response in deadspace areas, and to evaluate the true active areas of the pixels.[16] Further characterisation tests performed include: crosstalk studies, where magnitudes of less than 5% are extracted with both blue and red laser wavelengths, and the fraction of single photoelectron signal losses to pedestals, which is minimised to less than 15% through operation at

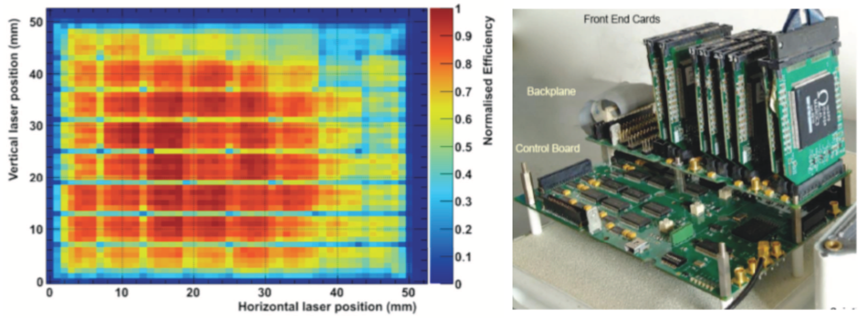

Fig. 4. Left: Normalised signal efficiency map of a H8500 MAPMT scanned with a 633 nm laser beam focused to a diameter of 0.1mm at single photoelectron light level. Right: Readout electronics based on the MAROC3 chip and derived from Medical Imaging.

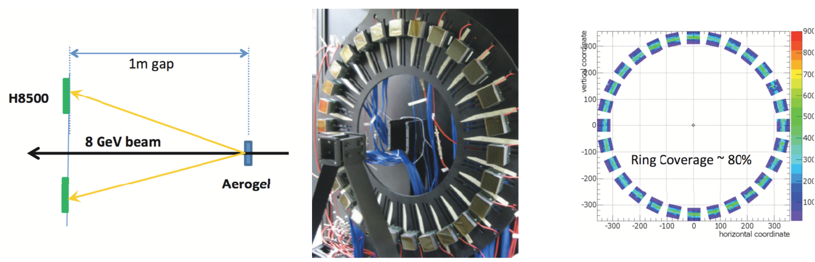

Fig. 5. Direct light configuration of the testbeam prototype. Left: Side view diagram illustrating the setup. Center: Photo of the detector plane. Right: The Cherenkov ring coverage is about 80% for a n=1.05 refractive index.

1040V high voltage or above, in the upper half of the bias voltage working interval.

5. RICH Prototype

Testbeam studies of a large-size prototype RICH detector were performed at the T9 beamline in the CERN-PS East Area, with hadron beam particles of 6-8 GeV/c momentum. Two gas electron multipliers chambers were used for beam particle tracking. A threshold Cherenkov gas counter, which was provided in the T9 beam area, was used to tag beam pions. Two setups were mounted inside a large (approximately 1.6x1.8x1.6 m^3) light-tight box, to study direct and reflected light imaging cases individually.

The direct light case reproduces the CLAS12 goemetry with a 1 m gap, see Fig. 5. The aerogel support can host tiles of approximately 58x58 mm^2:

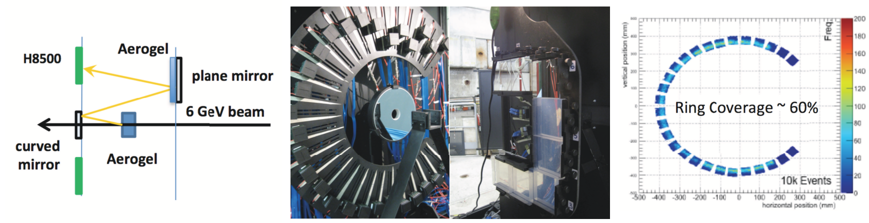

Fig. 6. Reflected light configuration of the testbeam prototype. Left: Side view diagram illustrating the setup. Center: Photo of the detector plane togetehr with the spherical mirror, and of the plane mirror array partially covered by the aerogel tiles. Right: The Cherenkov ring coverage is 60% for a n=1.05 refractive index.

several thicknesses, transparencies and refractive indices (in the range 1.04-1.06) were tested and their corresponding impact on the RICH prototype performance are under study. The Cherenkov light is detected by a circular array of 28 MAPMTs, alternated of the type H8500C with normal glass and H8500C-03 with UV glass for systematic studies. The MAPMTs are mounted on a circular support and can be radially moved so to intercept the Cherenkov ring produced with different opening angles depending on the choosen refractive index. The ring coverage varyies between about 90% to 60% for the minimum and maximum radial position, respectively.

The main aim of the reflected light case was the study of the concept of double reflection with multiple passes through the aerogel, in particular investigating the Cherenkov light yield loss and the contributions to the Cherenkov angle resolution. The prototype allowed to test all the optical components and validate their Monte Carlo description, even though the geometrical constraints of the prototype did not allow to reproduce the CLAS12 gap length and to put the MAPMTs on the mirror focal plane, see Fig. 6. The Cherenkov light were first reflected by a spherical mirror with focal length of $\tilde{1}$ m and then by a circular array of eight 11.5x11.5 cm^2 planar mirrors towards the MAPMTS wall. The supports of the planar mirrors are designed to allow the insertion of tiles of aerogel, in order to study their photon yield absorption. In this configuration, the ring coverage runs from about 75% to 50%, depending on the radial position.

In the early stages of data analysis, clear π/K separation has been obtained up to the maximum beam momentum of 8 GeV/c for the direct light case, see Fig. 7. In the reflected light case, no significant degradation of the Cherenkov angle resolution except for the expected 60% light yield loss were observed, see Fig. 7. Those preliminary results validate the CLAS12

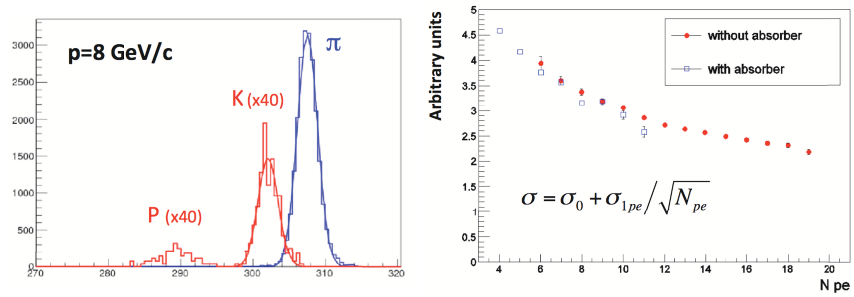

Fig. 7. Left: Cherenkov ring radius distributions for 8 GeV/c pions (blue) compared with those of hadrons without signal in the gas Cherenkov (red), in the direct light configuration. Right: Cherenkov angle resolution as a function of the photo-electron number in the reflected light configuration for the two cases with and without adsorber (aerogel) in front of the planar mirrors.

RICH concept. Currently investigations are underway to extract final light yield and ring resolution results, to be also used for model inputs in the CLAS12 RICH simulation.

6. CLAS12 RICH Expected Performances

The CLAS12 RICH detector is simulated within the CLAS12 Geant4 framework. The description of the different optical elements is based on laboratory characterizations and the prototype results. Pattern recognition algorithms, which involve maximum likelihood methods and ray tracing ansätze were developed as required by the hybrid optics. The preliminary results indicate that a clear hadron separation, with a 1:500 pion rejection power, can be obtained in the full 3-8 GeV/c momentum range for scattering angles up to 25 degrees, ensuring the completion of the approved physics program.

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