THE LARGE-AREA CLAS12 RING-IMAGING CHERENKOV DETECTOR

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The CLAS12 deep-inelastic scattering experiments 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 solution proposed for the first module foresees aerogel 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 and two passes through aerogel (large angle tracks). The detector design, individual detector component tests and preliminary results of test-beam studies are here reviewed.

Keywords: RICH detector, Aerogel, MA-PMTs

1. The CLAS12 RICH Detector

Jefferson Lab (JLab) VA, USA, is currently undergoing an upgrade program which involves the doubling of the energy of its electron beam from 6 GeV to 12 GeV and the enhancement of detector capabilities in the existing experimental halls. In Hall B, the CLAS12 detector (see Fig. 1) 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.[1] The physics program is extremely broad,[2] but in particular will focus upon 3D imaging of the nucleon through the mapping of generalized and transverse momentum dependent parton distributions at unprecedented high Bjorken x.[3] In particular three approved experiments demand an efficient hadron identification across the momentum range from 3 to 8 GeV/c and scattering

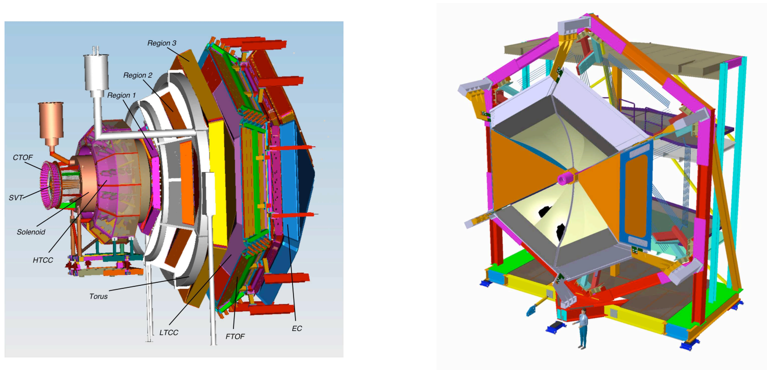

Fig. 1. Left: The CLAS12 detector. Right: The two-sector baseline RICH detector (orange) positioned in place of the low threshold Cherenkov counters in the forward section of the spectrometer.

angles up to 25 degrees. A pion rejection power of about 1:500 is required to limit the pion contamination in the kaon sample to a few percent level. The CLAS12 baseline comprises a time-of-flight system (TOF), able to efficiently identify hadrons up to a momentum of about 3 GeV/c, and two Cherenkov gas detectors of high (HTCC) and low (LTCC) threshold, reaching the needed pion rejection power only close to the upper limit of hadron momenta (around 7 GeV/c) and anyhow not able to distinguish kaons from protons. A ring-imaging Cherenkov detector (RICH) has been proposed, replacing the low threshold Cherenkov gas detector, to achieve the needed hadron identification without affecting the baseline layout of the CLAS12 spectrometer. At least two radial sectors are required to accomplish the physics program, each with projective geometry, limited gap depth of 1.2 m and about 5 m^2 entrance windows, see Fig. 1. Simulation studies favor a hybrid imaging RICH design incorporating aerogel radiators, visible light photon detectors, and a focusing mirror system.[4,5]

The focusing mirror system (see Fig. 2) will be used to reduce the detection area instrumented by photon detectors to about 1 m^2 per sector, minimizing costs and influence on the detectors (TOF and Calorimeters) positioned behind the RICH. For forward scattered particles ($\theta < 12^o$) with momenta p = 3 - 8 GeV/c, a proximity imaging method with thin (2 cm) aerogel and direct Cherenkov light detection will be used. 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 focused by a spherical mirror, undergo two further passes through the thin radiator material and a reflection from

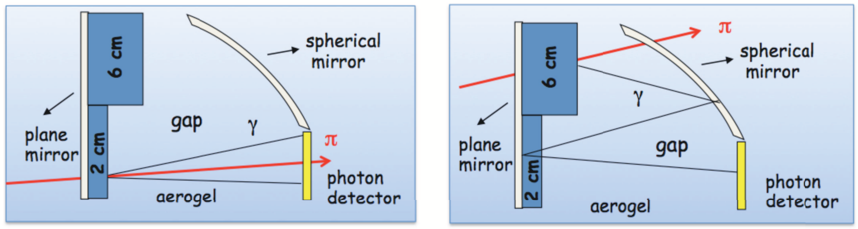

Fig. 2. The CLAS12 hybrid optics design (see text for details).

planar mirrors before detection. The longer path of light and the focusing mirror allows the use of a thick (6 cm) aerogel to compensate yield losses into the thin radiator.

2. The RICH Component Tests

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 in several particle physics experiments[6] and is planned for future use.[7] 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,[8] because it conjugates high-transparency 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. During the prototyping, the production technique and the resulting quality of the Russian aerogel has been significantly improved in time. Presently, a clarity of the order of 0.0050 $\mu m^4 cm^{-1}$ 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.[9] 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

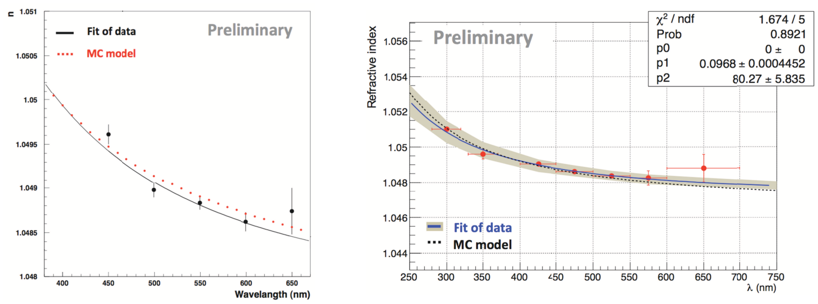

Fig. 3. Aerogel dispersion measured with the spectrometer beam and the prism method (left) and with the RICH prototype and 8 GeV/c pion beam by using optical filters (right) on two different aerogel tiles. The continuous lines are fits of the data using the Sellmeier formula, with the gray band showing 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 (dashed lines).

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 a RICH prototype tested with a 8 GeV/c pion beam (see next Section). The set of available filters allowed to span the entire range of relevant wavelengths, 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 ρ = 0.230 g/cm^3 and the relation $n^2 = 1 + 0.438\rho$. 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.[10] 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.[11]

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. The Hamamatsu H8500 multianode photomultiplier tubes (MAPMTs) have been selected as a candidate for the CLAS12 RICH, as being an effective 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

Fig. 4. Direct light configuration of the test-beam 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.

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 suppress the background.

Laser scanning facilities have been setup for in-depth characterizations of MAPMTs. The uniformity of the H8500 response has been extensively studied with a pico-second pulsed laser. 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 dead space areas, and to evaluate the true active areas of the pixels.[12] Further characterization 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 lost below the pedestal threshold, which is minimized to less than 15% through operation at 1040V high voltage or above.

3. The RICH Prototype and Projected Performances

Test-beam studies of a large-size prototype RICH detector were performed at the T9 beam line in the CERN-PS East Area, with hadron beam particles of 6-8 GeV/c momentum. The readout electronics was based on the MAROC3 chip and derived from Medical Imaging applications. Two gaseous 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 modes individually. The direct light case reproduces the CLAS12 geometry with a 1 m gap,

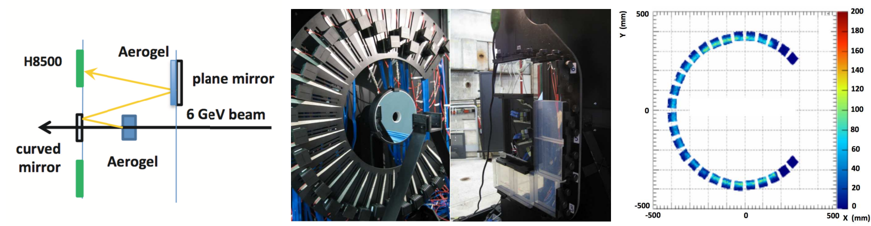

Fig. 5. Reflected light configuration of the test-beam prototype. Left: Side view diagram illustrating the setup. Center: Photo of the detector plane together with the spherical mirror, and of the plane mirror array partially covered by the aerogel tiles. Right: The Cherenkov ring coverage is 60% for a n=1.05 refractive index.

see Fig. 4. Several aerogel thicknesses, transparencies and refractive indexes (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 chosen refractive index. 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 did not allow to reproduce the CLAS12 reflected-light path length and to put the MAPMTs on the mirror focal plane, see Fig. 5. The Cherenkov light were first reflected by a spherical mirror with focal length of 0.9 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 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. 6. 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. 6. These preliminary results validate the CLAS12 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.

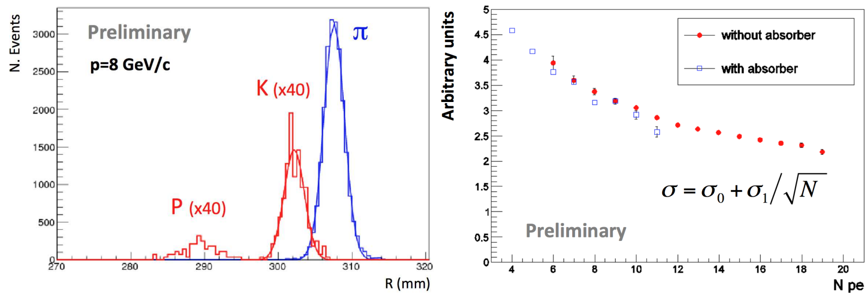

Fig. 6. Left: Cherenkov ring radius distributions for 8 GeV/c pions (blue) compared with those of hadrons without signal in the gas Cherenkov (red), in the direct light configuration. Right: Cherenkov angle resolution as a function of the photo-electron number in the reflected light configuration (at 6 GeV/c beam momentum) for the two cases with and without absorber (aerogel) in front of the planar mirrors.

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 test results. The peculiar hybrid optics demands for a smart and robust pattern recognition algorithm; the current development involves maximum likelihood methods and ray tracing ansätze. 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.

References

1. CLAS12 Technical Design Report, version 5.1 208 (2008).
2. V. D. Burkert *et al.*, *arXiv:1203.2373* **[hep-ex]** (2012)
3. H. Avakian *et al.*, *arXiv:1202.1910v2* **[hep-ex]** (2012)
4. M. Contalbrigo *et al.*, *Nucl. Instrum. Meth.* **A 639** (2011) 302.
5. A. El Alaoui *et al.*, *Physics Procedia* **37** (2012) 773.
6. R. De Leo *et al.*, *Nucl. Instrum. Meth.* **A 595** (2008) 19; A. Yu. Barnyakov *et al.*, *Nucl. Instrum. Meth.* **A 453** (2000) 326; R. Pereira *et al.*, *Nucl. Instrum. Meth.* **A 639** (2011) 37; R. Forty *et al.*, *Nucl. Instrum. Meth.* **A 623** (2010) 294.
7. T. Iijima *et al.*, *Nucl. Instrum. Meth.* **A 598** (2009) 138.
8. A. Yu. Barnyakov *et al.*, *Nucl. Instrum. Meth.* **A 639** (2011) 225.
9. T. Bellunato *et al.*, *Eur. Phys. J.* **C 52** (2007) 759.
10. R. De Leo *et al.*, *Nucl. Instrum. Meth.* **A 457** (2001) 52.
11. Y. Sallaz-Damaz *et al.*, *Nucl. Instrum. Meth.* **A 614** (2010) 184.
12. R. A. Montgomery *et al.*, *Nucl. Instrum. Meth.* **A 732** (2013) 366.