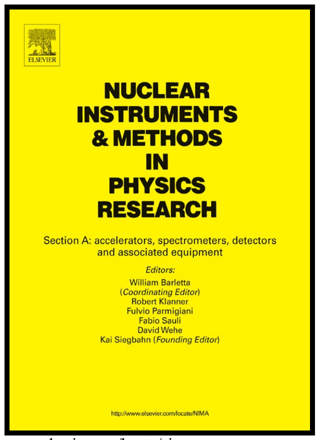

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PII: S0168-9002(17)30020-7
DOI: http://dx.doi.org/10.1016/j.nima.2017.01.020
Reference: NIMA59575

To appear in: *Nuclear Inst. and Methods in Physics Research, A*

Received date: 8 November 2016
Revised date: 10 January 2017
Accepted date: 11 January 2017

The large-area hybrid-optics RICH detector for the CLAS12 spectrometer

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Abstract

A large area imaging Cherenkov detector is under construction to provide hadron identification in the momentum range between 3 and 8 GeV/c for the CLAS12 exeperiment at the new 12 GeV electron beam of the Jefferson Laboratory (JLab). The detector adopts a hybrid optics solution with aerogel radiator, light planar and spherical mirrors and highly-segmented photon detectors. Cherenkov photons will be imaged either directly (for forward tracks) or after two mirror reflections (large angle tracks). The status of the detector construction is here reported.

Key words: RICH, Cherenkov detectors, Aerogel, Multi-Anode PMTs, mirrors

1. Introduction

With the upgrade of the Countinuous Electron Beam Accelerator Facility (CEBAF) to a maximum energy of 12 GeV, high polarization and high intensity, the Jefferson Laboratory will offer the unique opportunity to study the nucleon structure with a statistical precision never reached so far in a wide phase space [1]. In Hall B of the Laboratory, the new CLAS12 spectrometer, now under completion, will allow the detection of charged and neutral hadrons in a wide kinematical region at a luminosity as high as 10^{35} cm^{-2}s^{-1}. The physics program is broad [2], with particular attention to the 3D imaging of the nucleon in the valence region. At least three already approved experiments require efficient hadron identification in the $3 \div 8$ GeV/c momentum range.

The CLAS12 baseline comprises a time-of-flight system (TOF) and two Cherenkov gas detectors of high (HTCC) and low (LTCC) threshold installed in six azimuthal sectors. These systems are able to efficiently separate kaons from pions only below 3 GeV/c and close to the upper limit (around 7 GeV/c) and are not able to distinguish kaons from protons. Thus, a Ring-Imaging Cherenkov detector (RICH) has been proposed, replacing at least two symmetric LTCC sectors, to achieve the needed hadron identification and accomplish the physics program.

2. The CLAS12 RICH concept

The design of the detector is challenging because of the complicated geometry imposed by the constraints given by the existing CLAS12 detector. In addition, its large size (about 5 m^2 entrance window) imposes to reduce the area instrumented with photodetectors in order to contain the costs at an affordable level. Simulation studies [3, 4] demonstrated that the best configuration is a non conventional proximity focusing design, incorporating an aerogel radiator, visible light photodetectors and a mirror system (see left plot in Fig. 1). For forward scattered particles ($\theta < 13^o$) with momenta p = $3 \div 8$ GeV/c, a proximity imaging method with thin (2 cm) aerogel, gap length of about 1 m and direct Cherenkov light detection will be used. For larger incident particle angles ($13^o < \theta < 25^o$) and intermediate momenta of p = $3 \div 6$ GeV/c, the Cherenkov light will be reflected by a spherical mirror, undergo two further passes through the thin aerogel radiator and a reflection from planar mirrors before detection. The longer path of light allows the use of thick (6 cm) aerogel to compensate yield losses in the thin radiator.

Testbeam studies with a large size prototype of the RICH have been performed at the T9 experimental hall at CERN. The tested direct light detection configuration reproduced the geometry of the CLAS12 RICH, and a clear π/K separation up to 8 GeV/c momenta has been obtained [9]. For the re-

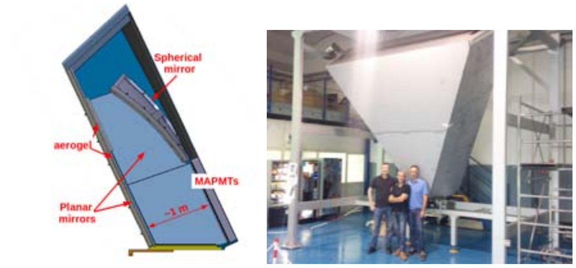

Figure 1: Drawing of the RICH (left) and the RICH mechanical structure after the assembly test (right).

flected light case, the prototype reproduced the concept of the CLAS12 RICH, in particular allowing the effect of Cherenkov photons that pass through the aerogel twice to be studied. No significant degradation in the Cherenkov angle resolution was found [10], except that the number of detected photons per ring was reduced by 60%, as expected. These results validated the CLAS12 RICH concept.

3. Status of the detector

3.1. The mechanical structure

The mechanical structure of the detector must combine a low material budget with the high rigidity necessary to preserve the performance of the inner optical systems.

The six sector segmentation of the CLAS12 spectrometer is driven by the presence of the toroidal magnetic field coils. The region between two adjacent sectors, corresponding to the shadow of the torus coils, is a zero acceptance area. Thus, a design that combines aluminum (for the elements inside the torus coil shadow) and carbon fiber (for the elements inside of the CLAS12 acceptance) has been developed. In addition, for the larger elements, such as the aluminum lateral panels and the carbon fiber top and frontal closing panels, a sandwich technique has been adopted, with two thin layers (tipycally 1 mm) and a honeycomb core. This allowed the weight of the mechanical structure to be reduced by about 40% with respect to the existing LTCC modules.

The RICH mechanical structure was fabricated by *Tecnologie Avanzate srl* [11], a company specialized in aeronautic construction. The structure was recently completed and an assembly test successfully performed (see right plot in Fig. 1). The test was completed with a detailed laser tracker survey, in order to verify the compliance with the engineering drawings. Negligible discrepancies, at a level of few mm or less, have been found, basically in agreement with the Finite Elements Analysis (FEA) of the expected deformations.

The structure was then dismounted, packed, and is ready to be shipped to JLab.

3.2. The aerogel

The best radiator for CLAS12 RICH hadron identification in the few GeV/c momentum range is silica aerogel, successfully used as radiator material for RICH detectors in several particle physics experiments [5] and planned for future use [6].

The CLAS12 RICH utilizes about 120 large size tiles of 20×20 cm^2 area and refractive index $n = 1.05$ produced by the Budker and Boreskov Insititutes for Nuclear Physics at Novosibirsk (Russia), assembled on the RICH in two sections. The first section, with 2 cm thickness tiles, is installed on the frontal planar mirrors. The second section, made by two layers of 3 cm thickness tiles, is installed on the carbon fiber entrance panel.

The production started with the challenging 3 cm thick tiles, the largest ever mass-produced at this refractive index. They are difficult to produce since they entail such a large volume that must be made without cracks or bubbles, require long times for chemical clean up, etc. About 50% of the tiles have been completed to date. All of them have scattering lengths greater than 43 mm and transparency coefficient A_0 above 0.95 (see [7] for their definition). A detailed report on the acceptance and characterization tests is given in these proceedings [8]. The production of the 2 cm thickness tiles is currently starting.

3.3. The mirrors

The optical system of the RICH is made of ten spherical mirrors and seven planar mirrors. In order to have similar single photon resolution in both direct and reflected light configurations, the optical system of the RICH must contribute for no more than 1 mrad, corresponding to a average angular reflection error less than 0.5 mrad RMS.

The spherical mirrors have been produced by the *Composite Mirror Application Inc.* [12] company, which already produced mirrors for other physics experiments such as LHCb [13]. These mirrors are made by two carbon fiber layers with a honeycomb core. Compared to the LHCb mirrors, an improvement of about 20% in the areal density has been achieved (the equivalent radiation length is about 1% X_0). All the spherical mirrors have been produced and tested by performing a reflected spot size measurement when the mirror is illuminated by a point-like source. For a perfect mirror, when the source and the screen are at its center of curvature, the reflected spot would be a point. Thus, one can define the so-called D_0 of the mirror as the diameter of the circle containing 95% of the reflected light. The smaller the D_0, the better the mirror. The CLAS12 RICH optical specifications required a $D_0 < 2.5$ mm. As an example, in Fig. 2 we show the reflected spot measured for one of the mirrors. Here, a CCD camera and an optical fiber of about 1 mm diameter as light source have been used, both mounted on a stepper motor that allowed the spot size to be scanned at different positions along the mirror axis. When the source and the screen are far from the mirror center, one basically sees the shape of the mirror (left plot), while closer to the center the spot gets smaller (right plot). A parabolic fit of the data allows the extraction of the final D_0 value of the mirror, as shown in Fig. 3. After the size of the optical fiber source is unfolded, all the ten mirrors had measured D_0 values between 1.0 and 1.5 mm.

The RICH has seven planar mirrors to contain all the Cherenkov photons inside the detector: two frontal, four lateral and one on the bottom. They have been produced by the *MediaLario Technologies* [14] which has been producing glass

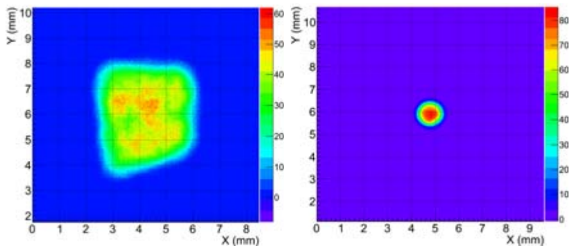

Figure 2: Typical results of the spot size measured far from the center (left) and at the center (right) for one of the spherical mirrors.

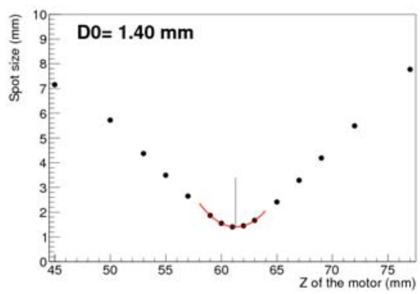

Figure 3: Spot size plotted as a function of the relative position of the stepper motor. The parabolic fit gives $D_0 = 1.4$ mm.

mirrors with sandwich structure for telescope applications for many years. To our knowledge, this is the first time that this technology has been utilized in nucler physics experiments. For the RICH frontal mirrors, being in the CLAS12 acceptance, thin glass layers of 0.7 mm have been used, obtaining an equivalent thickness of about 1% of X_0, similar to the carbon fiber mirrors. For the lateral mirrors, being in the torus coil shadow, thicker glass layers of 1.6 mm have been used. Two lateral and one frontal mirror have already been delivered and are now under tests. The accuracy of the surface of the mirrors has been measured by using a Coordinate Measuring Machine. An example of the typical results is shown in Fig. 4, from which one gets an accuracy of the surface of about $8\mu m$ RMS, which provides a contribution to the single photon resolution lower than 0.1 mrad. The reflectivity of the mirror has been also measured and found to be above 90% in the wavelength region between 300 and 600 nm.

3.4. The photodetectors

Early simulations [3] showed that the photodetectors must have a spatial resolution below 1 cm in order to obtain a contribution to the single photon angular resolution of about 2 mrad in the direct light configuration. The flat panel Hamamatsu H8500 Multi-Anode PMTs have been selected, since, although not advertised as the optimal choice in the single photon (SPE) regime, they showed adequate performances in several laboratory tests [15] and also at the CERN test beam [9]. Recently, the novel Hamamatsu H12700 has become available, with the same layout as the H8500, similar gain (typical value is 1.5 10^6

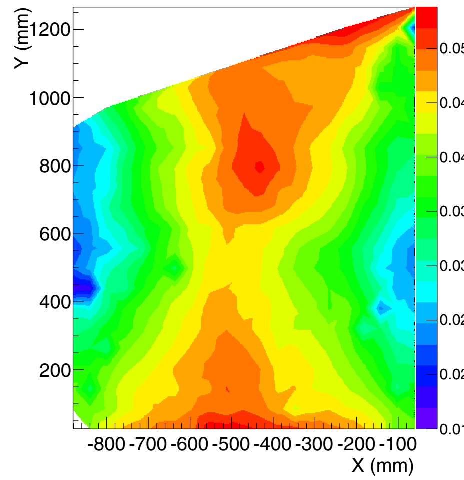

Figure 4: Surface accuracy measurement for one planar lateral mirror.

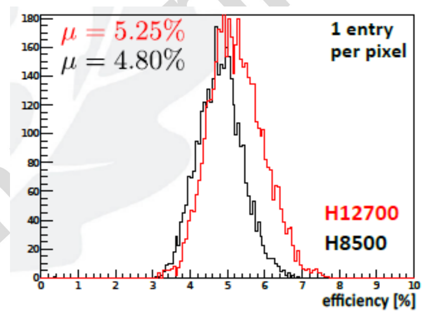

Figure 5: Comparison of the pixel single photon global efficiency between Hamamatsu H12700 (red) and H8500 (black).

at 1000 V) but optimized dynode structure for single photon detection.

The two devices have been extensively studied with a picosecond pulsed laser beam in the SPE region [16]. A quantitative comparison can be done by looking at the detection efficiency μ, defined as the ratio between the number of events above a 5 σ cut of the pedestal and the total number of events when a pixel is uniformly illuminated. The results are shown in Fig. 5: the H12700 has, on average, 10% better efficiency than the H8500.

Other tests have been performed to study the dark noise rate. It has been found that, in some cases, the border pixels of a typical H12700 device show significant increases in dark current with respect to typical H8500 values. However, the dark noise rate remains at a level that doesn't represent a problem for the RICH application.

The production of the RICH photodetectors (about 80 H8500 and 320 H12700) has been completed. All the MAPMTs have been fully tested and characterization parameters have been extracted by using a detailed model developed at JLab [17].

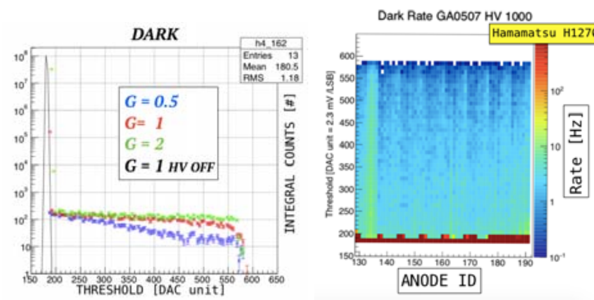

Figure 6: Left plot: Individual pixel dark noise rate measured as a function of binary discrimination threshold for different gain G. Right plot: dark noise rate measured for all the pixels of one MAPMT at gain 1 and different thresholds

3.5. The Front-End electronics

The RICH front-end electronics must ensure 100% efficiency at the 1/3 of a photoelectron level, gain spread compensation 1:4, and time resolution on the order of 1 ns to distinguish direct from reflected photon hits, while accepting trigger rates up to 20 kHz with a latency of $8\mu s$. This electronics is based on the MAROC3 chip [18], a 64 channel microcircuit dedicated to MAPMT pulse processing. Each channel offers a low impedence adjustable gain preamplifier followed by a highly configurable shaping section, and produces both prompt logic pulses from an adjustable threshold discriminator and pulse height measurements using a sample and hold structure. The MAROC is configured and read out by a FPGA optically linked with the data acquisition node. The current firmware version includes 1-ns precision hit timestamping.

The front-end electronics is organized in compact units (tiles) mechanically designed to fit the MAPMT dimensions and serving two or three MAPMTs each, thus allowing the tessellation of large surfaces with minimum dead space and material budget. The adequate light and gas tightness to work with single photons is obtained with a special adapter board equipped with tailored sealing o-rings.

Performance has been tested in the laboratory using both pulse generator and MAPMT devices. As an example, in the left plot of Fig. 6 the measured dark rate of one pixel of a H12700 MAPMT is plotted against the discriminating threshold for various preamplifier gain settings. The plot shows a large region of uniform response for preamplification gain bigger than 1 (allowing pixel non-homogeneity to be compensated) and a small slope vs threshold (thus making it easy to find the working point). The right plot of the figure shows the individual dark count rate for all the 64 pixels of one typical MAPMT at gain 1. The measured value of about 10 Hz/pixel is in agreement with the Hamamatsu specifications for that MAPMT.

Successful testbeam studies of the RICH electronics have been performed at Fermilab using 120 GeV/c proton beam. A small RICH prototype was made by a aerogel tile and four H8500 MAPMTs, for a total of 256 electronics channels. In the Fig. 7 a typical online monitor plot is shown, where one can clearly identify the Cherenkov ring at the center of the plot and, on the bottom left, the proton track cluster.

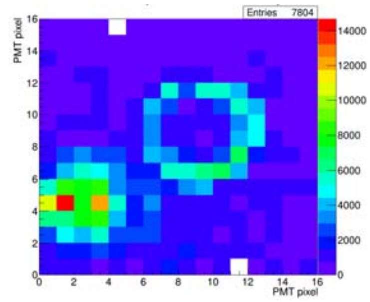

Figure 7: On line monitor plot during the Fermilab testbeam of the RICH electronics.

4. Conclusions

The first module of the CLAS12 RICH sector is under construction. The mechanical structure of the detector, comprising elements made of aluminum and carbon fiber, has been completed and a successful assembly test has been performed. The structure has now been dismounted and packed to be shipped to JLab. Delivery of the inner components of the detector has been either completed (MAPMTs) or is underway (mirrors and aerogel radiator tiles). Acceptance and characterization tests of these components are being performed upon arrival at JLab. The development of the readout front end electronics has been completed and successfully tested. Its final production is now underway.

The installation of the detector is expected for the summer 2017, ready for the beginning of CLAS12 data taking with unpolarized and longitudinally polarized targets. A second module is expected to be completed for the beginning of the CLAS12 operations with transversely polarized targets.

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