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The large-area hybrid-optics CLAS12 RICH: Assembling, commissioning and first data-taking

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ABSTRACT

The first module of a Ring Imaging Cherenkov detector has been recently installed on the CLAS12 spectrometer at the Jefferson Laboratory (JLab) to provide the experiment with kaon identification in the momentum range between 3 and 8 GeV/c. The detector adopts a hybrid optics solution with aerogel radiator, light planar and spherical mirrors and highly-segmented photon detectors. We report here on the assembly and installation of the RICH and we show the first preliminary results obtained during the commissioning of the detector and the first physics data taking.

1. Introduction

The Continuous Electron Beam Accelerator Facility (CEBAF) and associated experimental equipment at Jefferson Lab (JLab) comprise a unique facility for nuclear physics research whose upgrade was completed in 2017. The upgraded facility will accelerate high current and a high polarized electron beams to 11 GeV for experiments in the existing Halls A, B and C. In addition, a 12 GeV beam is provided to a new experimental hall, Hall D, to generate a 9 GeV tagged photon beam. The upgrade includes beam line and equipments in the existing halls.

In the Hall B, the new CLAS12 spectrometer [1] has been installed, which allows detection of charged and neutral particles in a wide kinematic range with maximum instantaneous luminosity of the order of 10^{35} cm^{-2}s^{-1}. The physics program of CLAS12 is broad and covers many aspects of the hadron physics: nucleon structure, baryon and meson spectroscopy and search for exotic states [2].

CLAS12 is a magnetic spectrometer based on a toroidal field produced by six superconducting coils that naturally divide the spectrometer in six independent sectors. Each sector is instrumented with several subdetectors. Three regions of Drift Chambers allow the measurement of the charged particle momentum, while threshold Cherenkov counters, time-of-flight (TOF) detectors and electromagnetic calorimeters are used for particle identification.

The last component of CLAS12 that was installed is the first module of a Ring Imaging Cherenkov (RICH) detector, that was designed to allow the identification of kaons against protons and pions in the momentum range between 3 and 8 GeV/c. The installation of a second module in the opposite sector is foreseen for the beginning of the CLAS12 operation with polarized targets.

2. The CLAS12 RICH

In the CLAS12 kinematic regime, the expected production ratio of kaons to pions is about 1 to 10. Therefore, in order to keep the contamination of misidentified kaons at a few percent level, a pion to kaon rejection power of the order of 1:500 is required.

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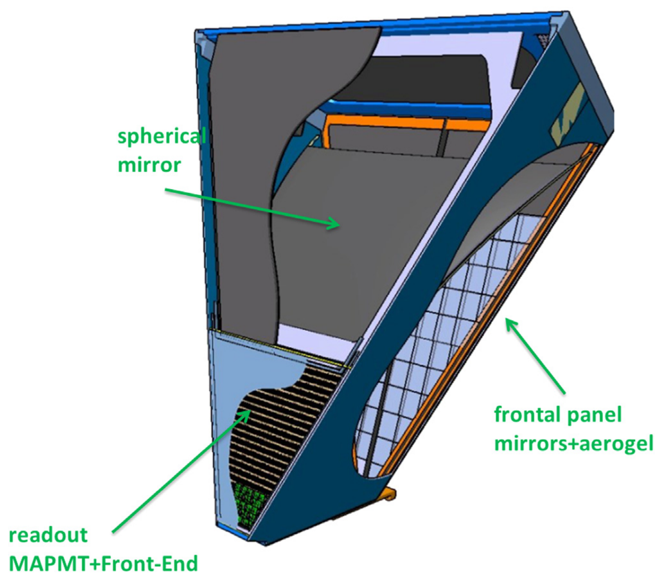

Fig. 1. A schematic drawing of the CLAS12 RICH.

The design of a RICH detector with these performances within the CLAS12 constraints was challenging, because of the peculiar trapezoidal shape and the stringent requirements in terms of material budget imposed by the downstream TOF and calorimeters detectors. Therefore, an effort was made in order to reduce the inactive material as much as possible. In addition, its large size (about 5 m^2 entrance window) imposed to reduce the area instrumented with photodetectors in order to contain the costs at an affordable level.

Simulation studies [3,4] and test of various prototypes with hadron beams [5] led to a non conventional proximity focusing geometry, incorporating an aerogel radiator, a system of planar and spherical mirrors and visible light photodetectors, in which the Cherenkov photons can be detected either directly or after reflections on the mirrors. A sketch of the detector is shown in Fig. 1.

2.1. The mechanical structure

The mechanical structure of the RICH, produced by the *Tecnologie Avanzate* [6] company, utilizes aluminum for the elements in the dead volume of CLAS12 and carbon fiber for the elements inside of the CLAS12 acceptance. For all the parts with large dimensions, the sandwich technique was used, in which two thin solid skins are glued together on a honeycomb core. The RICH mechanical structure was assembled on a frame especially designed to allow the installation of the internal components and of the closing panels. Special attention was devoted to the structure rigidity to minimize stress and misalignments of the delicate optical components (mirrors and aerogel) during the assembly, transportation and installation.

2.2. The radiator

In the few GeV/c momentum range, the best radiator option is silica aerogel, which is being used by several particle and nuclear physics experiments worldwide [7,8]. The aerogel radiator used in the CLAS12 RICH is made by 102 large tiles with nominal refractive index $n = 1.05$ produced by the *Budker and Boreskov Institute of Nuclear Physics* (Russia). In order to match the RICH geometry, the tiles were cut with squared 200×200 mm^2 as well as pentagonal, trapezoidal and triangular shape. The tiles are assembled in two separate sections. In the most forward section, the tiles have thickness of 20 mm and are installed on top of the frontal planar mirrors. In the large angle sections, two layers of

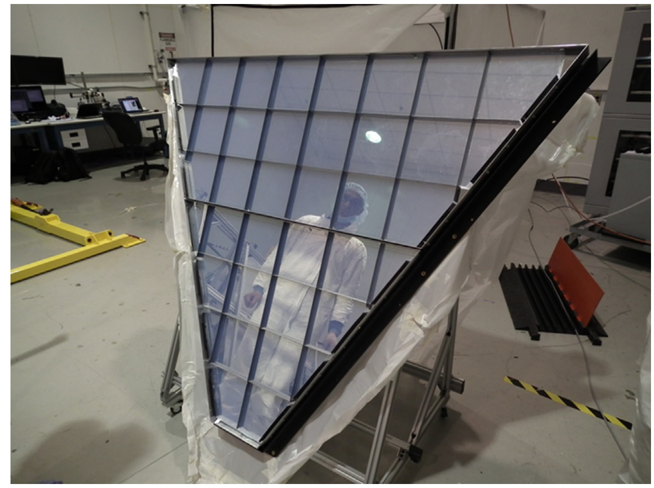

Fig. 2. The 20 mm thickness section of the aerogel.

30 mm thickness tiles are installed on the carbon fiber entrance panel of the RICH. Fig. 2 shows the 20 mm sections of the aerogel wall fully assembled.

A series of characterization measurements [9] was performed in order to determine the main optical and geometrical parameters of all the tiles. The results showed that all the tiles satisfied the required specifications. In particular, using the Hunt parametrization of the light transmission [10], we obtained, averaging over all the tiles, scattering length of $L_{scatt} = 50.5$ mm, transparency parameter $A_0 = 0.975$ and clarity parameter $C = 0.00512$ μm^4/cm. From these measurements, the expected photon yield for $\beta = 1$ particles was computed and the tiles with highest yield were installed where the more demanding rejection power is expected.

2.3. The mirror system

The mirror system is composed by 10 spherical mirrors, installed just before the exit panel of the RICH, and 7 planar mirrors installed on the entrance and lateral panels. The system was designed to minimize the photon loss and to direct as much as possible of the Cherenkov radiation toward the photodetectors. The mirror system as it is seen from the entrance panel is shown in Fig. 3.

The spherical mirrors, produced by the *Composite Mirror Applications* company [11], are made by two layers of carbon fiber glued on a honeycomb core and were coated with the reflecting layer by the *Evaporated Coatings Inc* [12]. The total area of these mirrors is about 3.5 m^2. The accuracy of the spherical surface was verified through the reflected spot size measurements, which also provides the average radius of curvature. All the mirrors exhibit a spot size smaller than 1.5 mm and a mirror-to-mirror variation in the radius below 0.5%, well within the required specifications.

The planar mirrors, produced by the *Media Lario* company [13], are made by two thin layers of glass glued on a aluminum honeycomb core. Being in the acceptance of the detector, the frontal mirrors use very thin (0.7 mm) glass layers, while for the lateral ones thicker (1.6 mm) layers were used. This technology, used for the first time in nuclear physics experiments, allows to have mirrors with material budget comparable to the carbon fiber ones, but at much lower cost. The total area of the mirrors is about 6.5 m^2. The planarity of the mirror surface was measured by using a Coordinate Measuring Machine. Typically, the measured surface accuracy is of the order of few microns RMS, corresponding to a contribution to the angular resolution below 0.1 mrad, by far within the required specification of 0.3 mrad.

The characterization of both spherical and planar mirrors was completed by reflectivity measurements on several sample spots on the

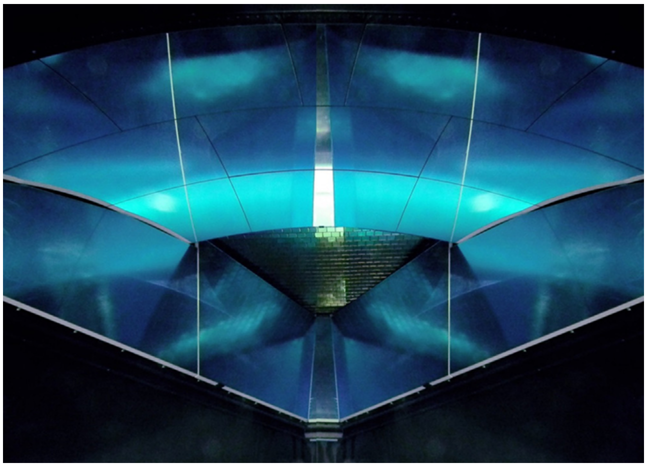

Fig. 3. The mirror system as it is seen from the RICH entrance panel.

mirror surface in the range of wavelengths of interest from 350 to 600 nm. For all the mirrors, we obtained on average a reflectivity between 88% and 90%.

2.4. Photodetectors and front end electronics

The RICH utilizes as photodetectors the Multi-Anode Photomultipliers (MAPMTs) Hamamatsu H8500 and H12700, because they have high detection efficiency in the visible and near UV region, fast response, high gain, large area and high packing fraction. Their capability as single photon detectors was extensively proven during laboratory tests [14,15]. In addition, their 8 × 8 pixel matrix matches with the chosen Front-End electronics, which is based on the 64 channel MAROC3 chip [16]. This chip offers a low impedance adjustable gain preamplifier followed by a highly configurable shaping section and produces prompt logic start and stop pulses from an adjustable threshold discriminator. 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 modular 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 gaskets.

The RICH readout system, composed by 138 tiles with 391 MAPMTs for a total of 25024 independent channels, is assembled on a carbon fiber panel and is placed in the bottom part of the exit face of the RICH. The MAPMTs plane is shown in Fig. 4.

The photodetectors and the readout electronics were extensively tested using cosmic rays detected by a tracking system installed on a dedicated trigger station inside a large dark box. The collected data have also been used to determine the working parameters for the physics data taking and to validate the maps to decode the readout channels.

2.5. Assembly and preliminary tests

The assembly phase of the detector was completed by the end of November 2017. Each inner element was installed on the mechanical structure after the completion of the characterization tests. The mirrors were the first elements installed, followed by the readout electronics. The aerogel was the last element installed, being the most sensitive to the external conditions. This assembly phase included also a detailed survey of the position and alignment of each inner element, in particular the mirrors, with respect to the mechanical structure of the detector.

Fig. 4. The plane of MAPMTs fully assembled.

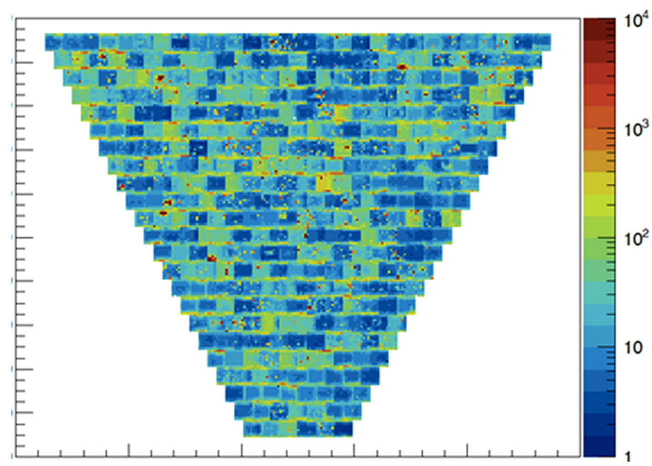

Fig. 5. Map of the dark rate (color scale) measured on the 25024 readout channel using the scaler readout . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Once the detector was sealed and before the transportation to the experimental hall, its functioning parameters were tested for several weeks in the assembly room. These tests included the two gas systems serving the RICH: the nitrogen system that must keep the internal humidity at few percent level to preserve the optical performance of the aerogel and the air cooling system of the readout electronics.

3. Commissioning and data taking

The detector was transported in the experimental hall and installed in CLAS12 at the beginning of January 2018. After completion, the first weeks of data taking were dedicated to the verification of the functioning of the detector through various tests performed without and with beam.

Tests without beam included pedestal measurements, dark noise runs, calibration runs with a Light Emitting Diode (LED) system. As an example, in Fig. 5 we show a map of the measured dark rate per channel by using the scaler readout. More than 99% of the 25024 readout channels show a dark rate below 100 Hz, and only few channels, typically on the border of the MAPMT, have dark rate larger than 10 kHz. These tests are periodically repeated in order to verify the stability of the performance of the detector.

Tests with beams included measurements of the counts as a function of the beam current, study of the time distributions, runs with straight

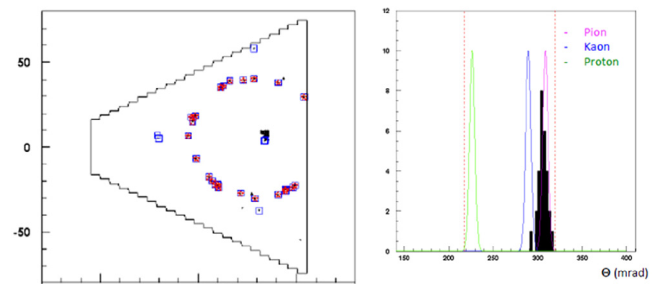

Fig. 6. Left plot: measured hit distribution for a typical event. Right plot: expected Cherenkov angle distributions for protons (green), kaons (blue) and pions (magenta) with the measured one (black). The red vertical lines indicate the expected signal region . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tracks to verify the alignments. More details are given in these proceedings [17].

A direct photon event reconstruction based on an analytic calculation [5] is currently under test. In the left plot of Fig. 6, we show one typical event with an almost complete direct ring for a track with $P = 4.3$ GeV/c. The black dots indicate the decoded hits, the blue squares the in-time hits and the red circles the ones accepted for the Cherenkov angle analysis. The results of the preliminary reconstruction is shown in the right plot of Fig. 6. Here, the two vertical red lines indicate the region of the accepted photons for the Cherenkov angle reconstruction, comprised between the two values $\theta_{min} = \theta(p) - 3\sigma_\theta(p)$ and $\theta_{max} = \theta(\pi) + 3\sigma_\theta(\pi)$. The green, blue and magenta distributions show the expected Cherenkov angle for protons, kaons and pions, respectively, while the black distribution represents the result of the RICH reconstruction algorithm.

A small variation in the measured Cherenkov angle is still possible, due to various effects that are not corrected yet (nominal 1.05 aerogel refractive index instead of the measured one, misalignments, etc.). Depending on the sign of these corrections, the black distribution could move either to the left (i.e. closer to the kaon peak) or to the right (i.e. closer to the pion peak). However, a clear identification of the particle that produced the ring will be possible in any case, thanks to the narrow distribution of the measured Cherenkov angles and to the low background level.

4. Conclusions

The first module of the RICH detector was installed inside the CLAS12 spectrometer in January 2018. The commissioning of the detector without and with beam was successfully completed without any major problem. Together with all the other detectors of CLAS12, the RICH has been run during the first part of the Run Group A data taking, which used the 10.6 GeV electron beam and an unpolarized liquid hydrogen target. The development of the reconstruction and particle identification software is still ongoing. For the special case of particles producing rings of directly detected photons, the preliminary analysis of the physics data indicates that the detector matches the expected performance.

Acknowledgments

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