JLAB12 Activity report 2017

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1 Introduction

The JLAB12 group of LNF participates in the physics program carried on by the CLAS collaboration in the Hall B of the Jefferson Laboratory (JLab).

The 2017 activity of the group has been mainly devoted to the construction of a Ring Imagning CHerenkov (RICH) detector to improve the particle identificaton (PID) capabilities of the CLAS12 detector.

The detector is composed by an aerogel radiator, an array of multianode photomultiplier tubes (MAPMTs) for the Cherenkov light detection and a mirror system to direct the large angle photons onto the photodetectors. All these elements are contained in a large trapezoidal box, of approximate height of 3.5 m and large base of about 4 m.

The assembly of the detector went on for almost the whole 2017 and has been completed by mid of December. All the phases of the assembly have been performed and supervised by the physicist, engineers and technicians of LNF, with the help of the JLab crew. The RICH has been installed in CLAS12 in January 2018.

2 The RICH mechanical structure

The RICH mechanical box is made by structural elements (two lateral panel, the lower base and the two upper angular blocks) in aluminum and a number of other elements (frontal and back panels, top panel, reinforcement ribs) in carbon fiber. Its construction has been awarded in 2014 by the *Tecnolgie Avanzate srl* (Veroli, Italy), started in 2015, has been completed in 2016 with an assembly test. All the material has been shipped to JLab at the beginning of 2017.

Since many of the inner components of the RICH require special care in the handling and storing, the assembly of the RICH has been done in a large clean room at JLab. The external frame of the detector, made by the lateral aluminum panels and by the carbon fiber top and bottom panels, has been assembled first. Then the closing frontal and backward panels have been installed to verify their perfect match with the external frame and then removed to allow the installation of the inner components. The Fig. 1 shows the RICH fully assembled on its supporting structure.

3 The RICH mirror system

The RICH includes spherical and planar mirrors in order to contain the Cherenkov photons inside the detector and to direct them toward the photodetectors. The spherical mirror, with a radius of 4 m, is segmented in 10 submirrors assembled on a support anchored to the RICH mechanical structure. The planar mirrors are installed on the panels forming the mechanical structure: four on the sides, one on the bottom and two on the front of the RICH.

Figure 1: *The RICH fully assembled on its supporting structure in the clean room.*

3.1 The planar mirrors

The seven planar mirrors of the RICH are produced by the *MediaLario Technologies* (Bosisio Parini, Lecco, Italy). They have a sandwich structure made by two skins of thin glass with an aluminum core. The four lateral mirrors have skins of 1.6 mm thickness, while the two frontal ones, being in the CLAS12 acceptance, have a 0.7 mm thickness.

The technical specification required for the mirrors were: *i)* a high reflectivity in the wavelength range between 300 and 600 nm and above 90% at 400 nm, in order to maximize the number of detected Cherenkov photons; *ii)* a surface accuracy with local slope below 0.3 mrad, in order to preserve the emission angle of the photons. The Company produced for each mirror a passport including measurements of the surface shape taken with a Coordinate Measureming Machine (CMM) in a grid of points with 1.5 cm step and reflectivity measurements. The results of a sample of the measurements have been checked by using a CMM at LNF and a spectrophotometer in Ferrara. A good agreement with the passport data has been found.

An example of the reconstructed slope profile for the mirror A1L is shown in Fig. 2. To qualify the mirror surface, the parameter used is the fraction of surface with slope above the

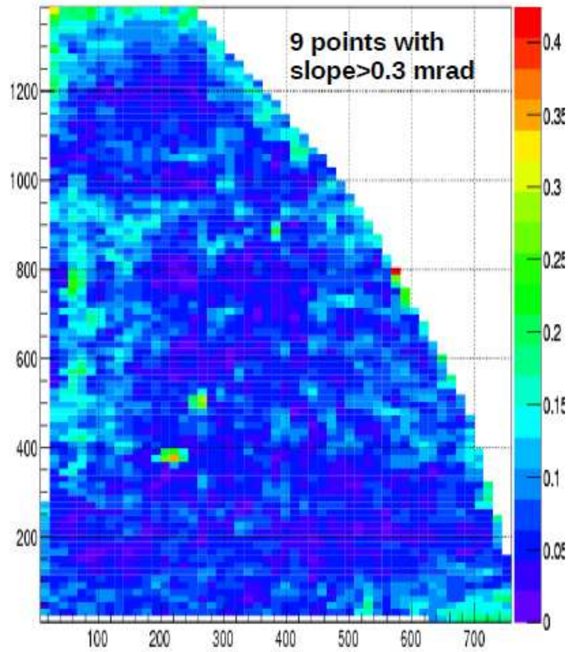

Figure 2: *The slope profile, shown by the color scale in mrad, of the mirror A1L measured with a CMM.*

specification. All the mirrors have this fraction at the level of few percent.

The lateral mirrors have been shipped to JLab in July and the frontal ones in September. Then they have been assembled on the RICH. A picture of the two planar mirrors installed on the frontal panel of the RICH can be seen in Fig. 3.

After the assembly, the alignment of the mirrors has been done by the JLab Survey Group using a CMM. The first step of the procedure was to check that each pair of mirrors installed on the same lateral panel or on the frontal panel formed a plane. Then, it was verified that the position of the mirrors within the RICH reference frame agreed with the CAD model. At the end of the process, the planar mirrors were aligned at better than 0.5 mrad.

3.2 The spherical mirrors

The spherical mirrors have been produced by the *Composite Mirror Applications Inc.* (CMA, Tucson, USA), which already produced mirrors for other physics experiments such as LHCb. They are made by a sandwich of two skins and a honeycomb core in carbon fiber. 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, delivered to JLab in 2016. They have been tested in the first half of 2017 by performing a reflected spot size measurement with a point-like light 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. All the mirros have a D_0 below 1.5 mm.

The mirrors have been then shipped to the *Evaporated Coatings Inc.* (ECI, Willow Grove,

Figure 3: *Two planar mirros installed on the frontal panel of the RICH.*

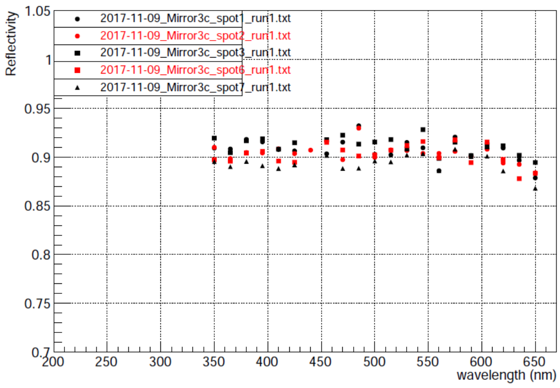

Figure 4: *The reflectivity of the spherical mirror 3c measured in few sample spots as a function of the wavelength.*

USA) to perform the deposition of the reflecting coating. During the process of the first two mirros, a problem in the surface has been reported by the ECI that prevented from obtaining a coating with high reflectivity and high uniformity. Thus, the mirrors have been shipped back to CMA for further inspection. They indeed recognized that the surface process of the mirrors was not properly done, so that they proceeded to resurface all the mirrors. Though free of charge for INFN, the resurfacing process caused a delay in the completion of the RICH assembly of more than one month, making impossible to be ready to install the detector before the beginning of the data taking of the CLAS experiment, in the middle of November. Thus, a new installation schedule has been arranged with the JLab management, that foresees the RICH installation in the first week of January 2018.

After the resurfacing, the mirrors have been sent back to ECI for the coating, which was now of high quality. The reflectivity of the final mirrors have been measured at JLab in a random grid of point. An example of the results for the mirror $3c$ is shown in Fig. 4. The reflectivity is around 90% in the whole wavelength range of interest from 300 to 900 nm.

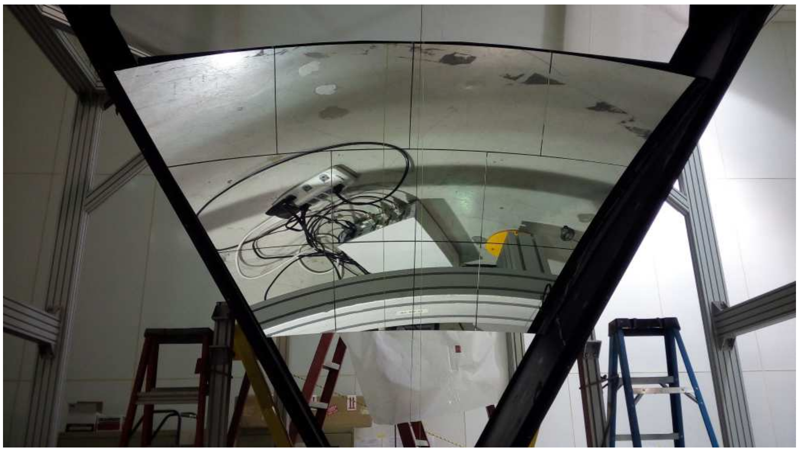

Figure 5: *The 10 spherical mirrors assembled on the RICH.*

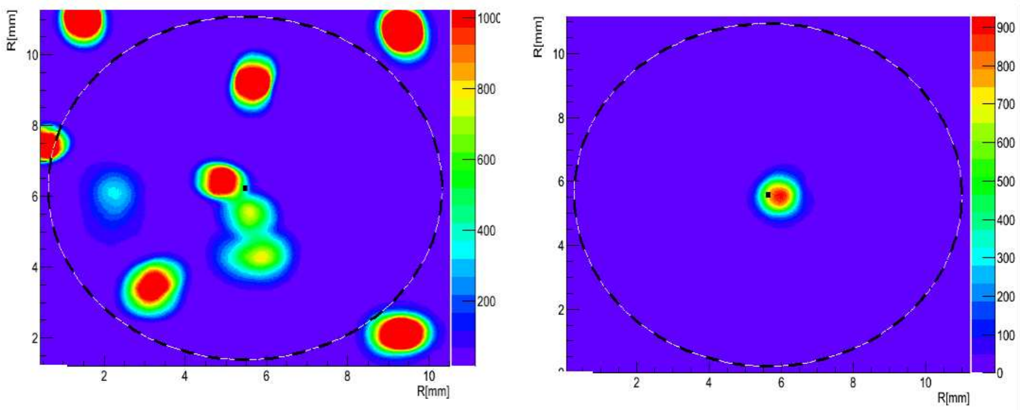

Figure 6: *The spots reflected by the spherical mirror fully assembled before (left) and after (right) the alignment of the 10 mirrors.*

The 10 spherical mirrors have then been installed in the RICH, as shown in Fig. 5. The relative alignement between the mirrors has been obtained by using the same setup used for the measurement of the D_0. The pointlike source illuminated the whole mirror system. Before the alignment, each mirror produces a reflected spot in a different position on the camera, as shown by the left plot in Fig. 6. After the alignment, the 10 reflected spots overlap, as shown in the right plot of Fig. 6, and the D_0 of the system was about 1.5 mm, consistent with the biggest D_0 measured on the individual mirrors.

4 The aerogel radiator

The CLAS12 RICH utilizes large size aerogel tiles with refractive index $n = 1.05$ produced by the Budker and Boreskov Insititutes for Nuclear Physics at Novosibirsk (Russia). There are 76 squared 20×20 cm^2 tiles. Then, to match the trapezoidal shape of the RICH, 10 tiles have pentagonal shape, 14 are trapezoidal and 2 triangular. They are assembled on the RICH in two sections. The first section, with 2 cm thickness tiles, is installed on the frontal planar mirrors. The second

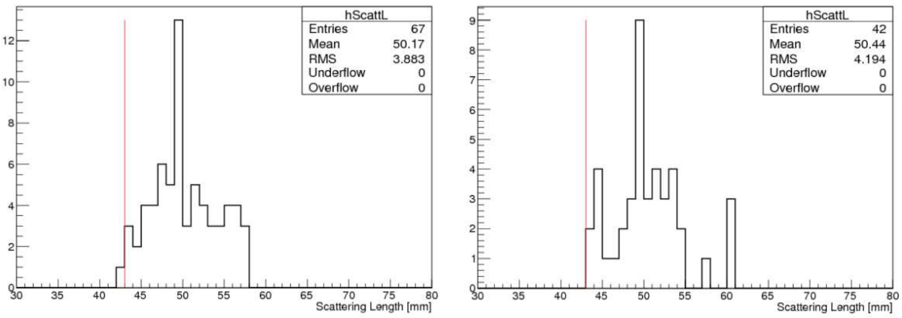

Figure 7: *The distribution of the scattering length taken from the passport data for the squared tiles with 3 cm (left) and 2 cm (right) thickness.*

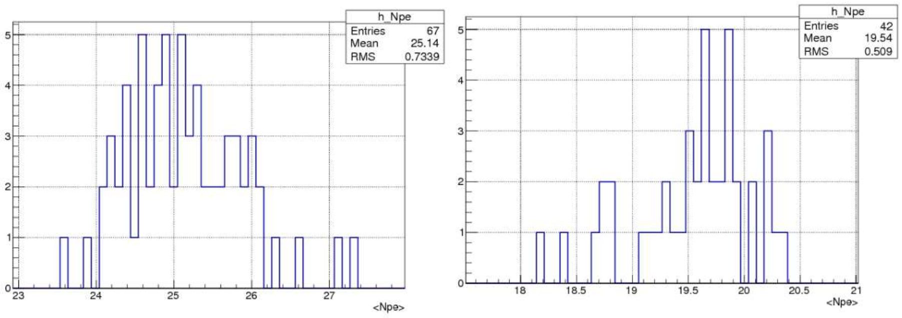

Figure 8: *The expected number of photoelectron for the squared tiles with 3 cm (left) and 2 cm (right) thickness.*

section, made by two layers of 3 cm thickness tiles, is installed on the frontal closing panel.

For each tile, the producer provided a passport with a number of characterization parameters, as the average density (from which the refractive index can be obtained), the scattering length at 400 nm, the transparency and the geometrical dimensions. In Fig. 7, we show the distribution of the scattering length L_{scatt} for the squared tiles with thickness of 3 cm (left) and 2 cm (right). All the data are above the minimum $L_{scatt} = 43$ mm, except for one tile which is sligthly below and was accepted as spare.

After delivery, the optical parameters have been measured at the Catholic University (Washington, USA) in order to verify the passport data. Differences of the order of 10^{-3} or less have been found, totally acceptable and well within the uncertainty of the measurements.

The tiles have been classified according to the expected number of photoelectrons (p.e.) calculated from the optical properties for a high momentum pion, taking into account the Cherenkov light emission spectrum and the quantum efficiency of the photodetectors [1)]. About 25 photons per charged particle are expected from the 3 cm tiles and about 20 from the 2 cm ones.

The criterium to place the tiles was to have the ones with higher p.e. yield at smaller polar angle and in the center of the panel. For the tiles with 3 cm thickness, the additional requirement that two tiles with similar average refractive index were placed one on top of the other, with the one with worst optical properties closer to the target, was also used. In Fig. 9 we show the aerogel fully installed on the frontal panels.

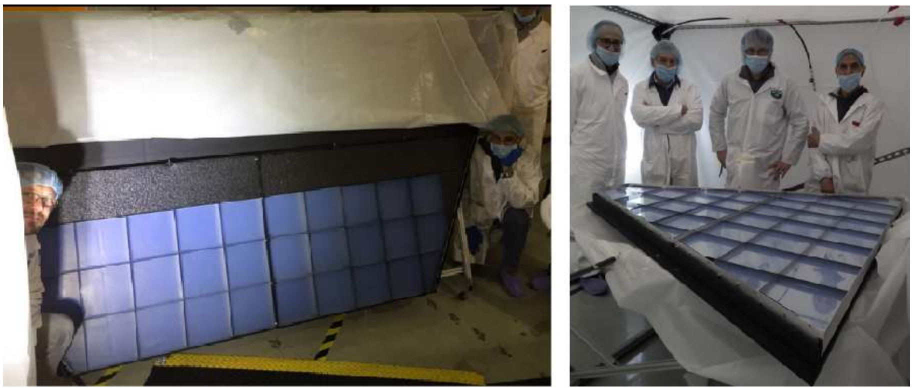

Figure 9: *The aerogel fully installed: the 3 cm tiles on the upper frontal panel (left) and the 2 cm tiles on the planar mirrors (right).*

Figure 10: *The electronic panel from the MAPMT (left) end readout electronics (right) side.*

5 The readout electronics

The Cherenkov photons are detected on an array of 391 Multi-Anode PhotoMultiplies (MAPMTs) Hamamatsu H8500 and H12700. The readout of the system is based on the MAROC3 [2] chip, 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. The MAROC is configured and read out by a FPGA optically linked with the data acquisition node.

The front-end electronics is organized in compact units 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 MAPMTs and the readout electronics are installed on a carbon fiber panel, with the MAPMTs with higher gain placed at smaller polar angle. Pictures of the panel from the MAPMT (left) end electronics (right) side are shown in Fig. 10.

Test of the electronics have been performed taking cosmics data for several days before the installation of the system in the RICH, with a dark box specially design to fit with the electronic panel geometry. No major problems have been found during this data taking. The accumulated data have been used to define the configuration of the electronics once the RICH will be installed in CLAS12 and the physics data taking will begin.

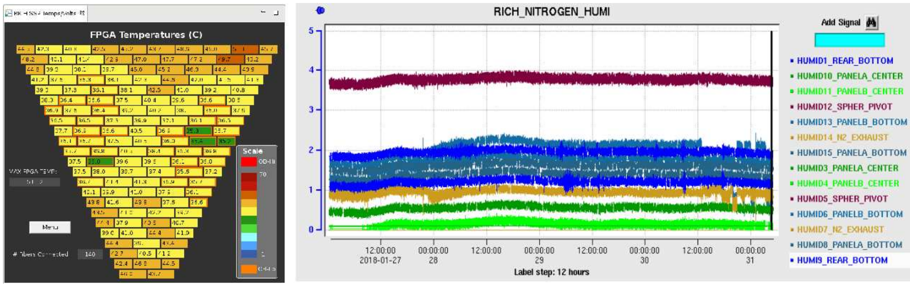

Figure 11: *Screenshots of the RICH slow controls: FPGA temperatures (left) and humidity (right).*

6 Completion of the assembly

The assmebly of the RICH has been completed in the first week of December 2017. All the internal components (mirrors, aerogel, electronics) have been installed. The detector has been also completed with the services and slow controls necessary to run it in the safest conditions.

The inner volume of the RICH was fluxed with dry nitrogen, to keep internal humidity at few percent level in order to preserve the optical properties of the aerogel. The nitrogen is fed inside the RICH by a number of gas ditributors designed and produced at LNF by using a 3D printer. The flow is controlled through a system which includes also a purge system that guarantees the purity of the gas. The humidity level is monitored by several sensors placed inside the detector and fed to the slow control. Alarms have been set in case of failure of the system and too high humidity levels are reached.

The cooling system of the readout electronics has been developed based on the test performed at LNF in 2016. It is composed by a oil-free and dry-air compressor capable of high flux connected to a large capacity tank. The distribution lines bring the cool air directly inside the small volume containing the electronics. The temperature is monitored in several points inside this volume. In addition, the FPGAs have internal temperature sensors. All these temperature sensors are connected to the slow control and to the interlock system. In case one or more of the sensors exceed the temperature limits, the interlock shuts down all the high and low voltages and prevent the powers to be turned on again until the temperatures are back at normal level.

An example of the slow control screenshots is shown in Fig. 11. The RICH has been successfully taken in running conditions, i.e. with electronics turned on and under the flow of the cooling air and of the nitrogen, for several days. The detector is now ready to be installed in CLAS12.

7 Publications

Publications on the RICH activity besides the CLAS Collaboration.

1. M. Mirazita *et al.*, "The large-area hybrid-optics RICH detector for the CLAS12 spectrometer", Nucl. Instrum. Meth. A **876**, 54 (2017).

2. I. Balossino *et al.*, "Cherenkov light imaging tests with state-of-the-art solid state photon counter for the CLAS12 RICH detector", Nucl. Instrum. Meth. A **876** (2017) 89.

3. M. Contalbrigo *et al.*, "Aerogel mass production for the CLAS12 RICH: Novel characterization methods and optical performance", Nucl. Instrum. Meth. A **876** (2017) 168.

References

1. S. Anefalo Pereira *et al*, Eur. Phys. J. **A 52**, 23 (2016).
2. S. Blin *et al.*, MAROC3 datasheet, October 2010, OMEGA website: http://omega.in2p3.fr