JLAB12 Activity report 2022

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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 main task completed during 2022 is the assembly, installation and commissioning of the second module of the RICH detector of the CLAS12 spectrometer. In parallel, the study of the performance of the first module was carried out and a new release of the reconstruction software has been developed and tested for the upcoming reprocessing of all the CLAS12 data taken so far.

2 The CLAS12 RICH

The CLAS12 *Ring Imaging CHerenkov* (RICH) detector of the CLAS12 spectrometer in the Hall B of the Jefferson Laboratory is composed by two modules covering about one third of the acceptance od CLAS12. The first module was installed in January 2017, just before the beginning of the CLAS12 data taking. The second module was installed during this year, on time for the beginning of CLAS12 oparation with polarized targets.

Each module is composed by an aerogel radiator, an array of multianode photomultiplier tubes (MAPMTs) for the Cherenkov light detection and a mirror system. 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 radiator is composed by tiles with squared shape 20×20 cm^2 as well as smaller pentagonal, trapezoidal or triangular tiles to accomodate with the detector shape. The total number of tiles is 102, assembled in two sections: the forward angle one made by one layer with 2 cm thickness and the large angle one made by two layers with 3 cm thickness each. In order to prevent possible damage of the aerogel due to humidity absorption, the internal volume of the RICH is continuously fluxed with nitrogen.

The mirror system is composed by 10 carbon fiber spherical mirrors and 7 glass planar mirrors, for a total surface of about 10 m^2. The goal of the mirror system is to contain as much of the produced Cherenkov photons inside the detector and to direct them toward the photodetector array.

The photodector array uses 391 multi-anode photomultipliers (MAPMT) Hamamatsu H12700, composed by a matrix of 8×8 matrix of pixel with about 6 mm pixel size, with a total of 25024 independent readout channels.

The readout electronics is based on the MAROC3 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 prompt logic pulses from an adjustable threshold discriminator. The MAROC3 is configured and read out by a FPGA optically linked with the data acquisition node. The front-end electronics is organized in compact units

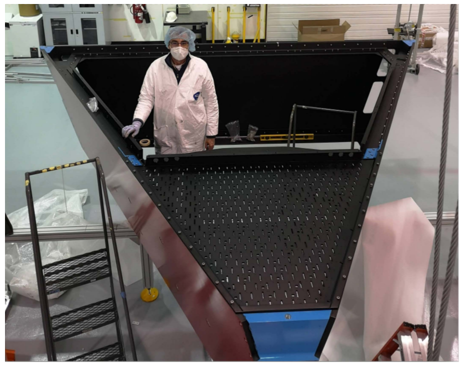

Figure 1: *The RICH external frame fully assembled.*

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 detector is also instrumented with a number of sensors to monitor the temperature on the electronic panel and the internal humidity level. Interlocks are set on the temperature sensors, so that the electronics is turned off if the temperature exceeds the safety level. In additions, alarms are set on the humidity sensors, segnaling possible malfunctions of the nitrogen supply system.

3 Assembly of the second RICH module

The assembly of the second RICH module, delayed because of the covid pandemic, could start only in January 2022 and was completed during three sessions of work by INFN personnel from LNF and Ferrara with the support of JLab technicians and physicists. The work followed a very tight scheduled, in part imposed by the delay in the delivery of the spherical mirrors, that arrived at JLab only around mid May, in order to be have the module installed in CLAS12 and commissioned by the first week of June, when the restart of the operation of CLAS12 was planned. All the tasks described in the next sections have been planned and completed under the coordination and responsibility of LNF personnel.

3.1 The mechanical structure

The first step has been the assembly of the detector external frame on the assembly structure already used for the first module. This external frame is composed by several large panels in aluminum and carbon fiber, constructed using the sandwich technique with two thin layers glued on a honeycomb core, allowing to greatly reduce the weight without compromising the rigidity. In Fig. 1 the frame fully assembled is shown.

3.2 The readout system

The readout system is assembled on a light carbon fiber panel, with trapezoidal shape, height of about 1.2 m and width of about 1.4 m.

The tests to verify the functionality of and to characterize the components of the readout system (photomultipliers, front-end boards, optical connections, DAQ modules) have been started during 2021 and finished by the early months of 2022. Then, in March the assembly of the readout system was started and proceeded in stages, to ensure the proper installation of each elements and to allow full test of the system.

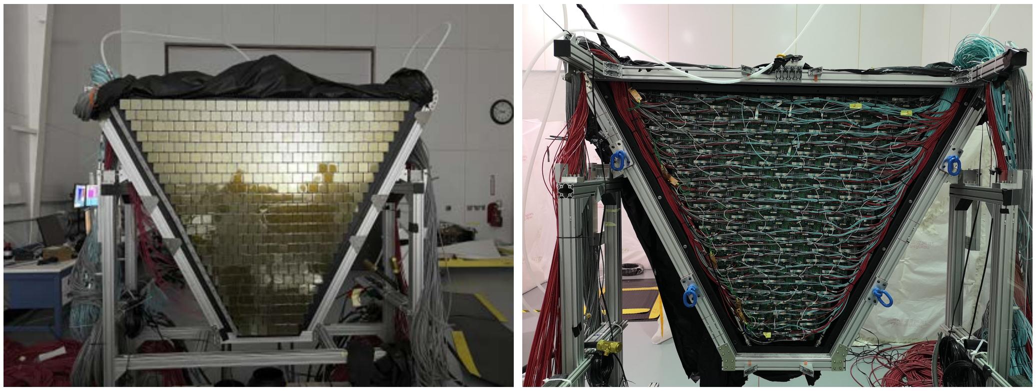

Figure 2: *The RICH electronic panel from the MAPMT (left) and front-end (right) side.*

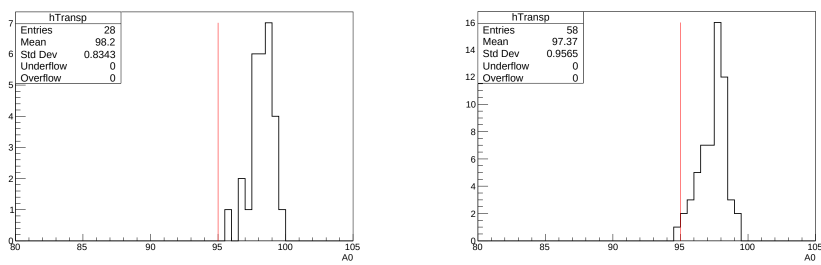

Figure 3: *Transparency of the aerogel tiles with 2 cm (left) and 3 cm (right) thickness.*

After the completion of the assembly, the readout system was completed by installing and testing the cooling and the temperature monitoring systems.

In Fig. 2 the electronic panel fully assmebled is shown, as seen from the MAPMT (left) and front-end electronic (right) side.

3.3 The aerogel radiator

Each tile was accompanied by a passport reporting a number of optical parameters measured by the russian producer before the shipment to JLab. During the installation of the first module, each aerogel tile has been tested to carefully cross-check the passport results and no major discrepancies were found. Because of the covid pandemic, the test of the aerogel of the second module has not been possible, therefore we had to rely on the passport measurements only. The optical properties of the second module aerogel has been found of comparable, if not slightly better, quality than the one of the first module. As an example, in Fig. 3 we show the transparency of the tiles with 2 and 3 cm thickness. The red lines indicate the minimum value requested.

In order to prevent the absorption of humidity and moisture, the assembly of the aerogel has been performed inside a dedicated area with controlled low humidity. The 2 cm thickness section has been installed on top ot the two frontal mirrors, while the 3 cm section was installed directly on the upper half of the frontal closing panel of the RICH detector. The radiator sections completed are shown in Fig. 4. After the assembly, each section was wrapped with plastic sheets, sealed and

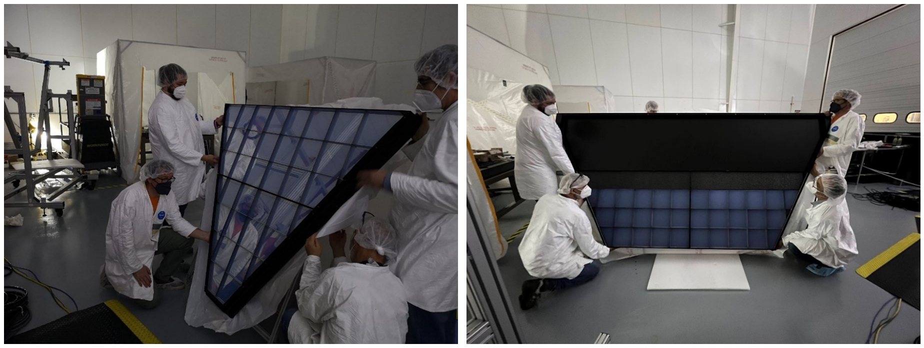

Figure 4: *The two sections of 2 cm thickness aerogel tile assembled on the frontal mirrors (left) and the 3 cm section assembled on the frontal closing panel (right).*

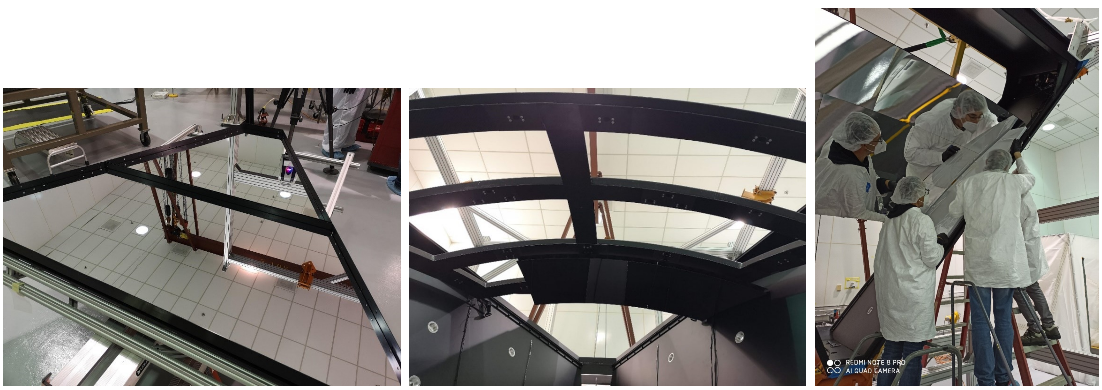

Figure 5: *Phasis of the assembly of the mirrors: the frontal mirrors (left), the spherical mirrors (center), the lateral mirrors (right).*

taken under continuous nitrogen flow till the final installation on the RICH.

3.4 The mirrors

The first step in the mirror assembly was the installation of the two frontal planar mirrors on the lower half of the frontal closing panel of the detector, in order to be able to proceed quickly with the installation of the aerogel on it. Then, the spherical mirrors have been installed on the supporting frame and finally the lateral mirrors have been installed on the lateral panels. The Fig. 5 shows various phasis of the mirror assembly.

Before installation, the reflectivity of each mirror has been measured in few sample spots in order to cross-check the vlaues provided by the producers. Also in this case, no major discrepancies have been found. After the completion of the mirror assembly, a careful survey of the full system has been performed in order to check the alignment of each mirror with respect to the nominal position. For the planar mirrors, this task has been performed by the JLab survey group. For the spherical mirrors, the alignment has been carried out using a dedicated set-up already used for the first module. This setup included a point-like light source and a photocamera mounted on a remotely-controlled moving system. When illuminated by the light source, each mirror produces on the camera (positioned on the center of curvature) a reflected spot in different position. The

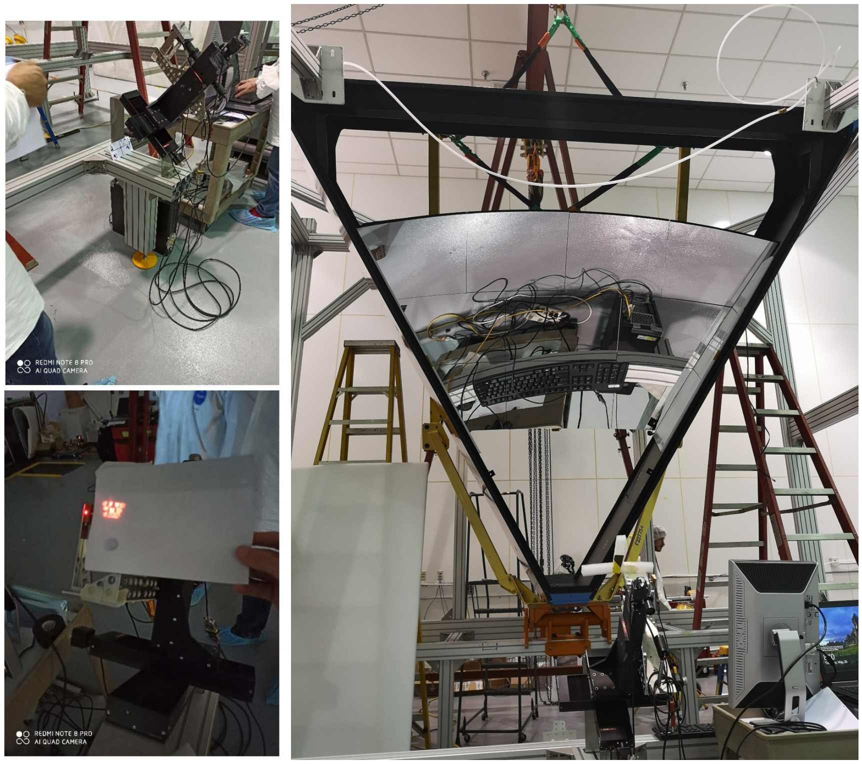

Figure 6: *The setup used for the spherical mirror alignment (top left), the reflected spots before the alignment (bottom left) and mirror after the alignment (right).*

alignment procedure consists in the adjustment of the mirror position and orientation so that all the reflected spots collapse in the same position. In Fig. 6 we show the setup for the alignment, a image of the reflected spots before the alignment and the full spherical mirror after the alignment.

4 Installation and commissioning of the second RICH module

After completion of the assembly, a final test of the whole detector was peformed in the last week of May in the assembly hall. The working parameters of the cooling system have been optimized by turning on the readout electronics and taking calibration data for several hours without interruption. The nitrogen supply system was also tested, studying the humidity level as a function of the nitrogen flow intensity. The slow controls, alarm and interlock systems have also been tested.

At the end of these tests, the detector was removed from the assembly structure and transferred to the transportation cart. The gantry crane was used to move the detector out of the assembly area and put it on the truck that transported the RICH down in the experimental hall. Once in the hall, the detector was taken from the truck, attached to the hall gantry crane, moved to the CLAS12 detector and installed. All these operations were completed under the responsibility of the JLab crew and with the supervision of INFN personnel. The Fig. 7 shows the two RICH modules installed in the forward carriage of the CLAS12.

The detector cabling was completed and the basic parameters and performance of the readout electronics (equalization gains and thresholds, pedestals, dark noise levels) have been measured and

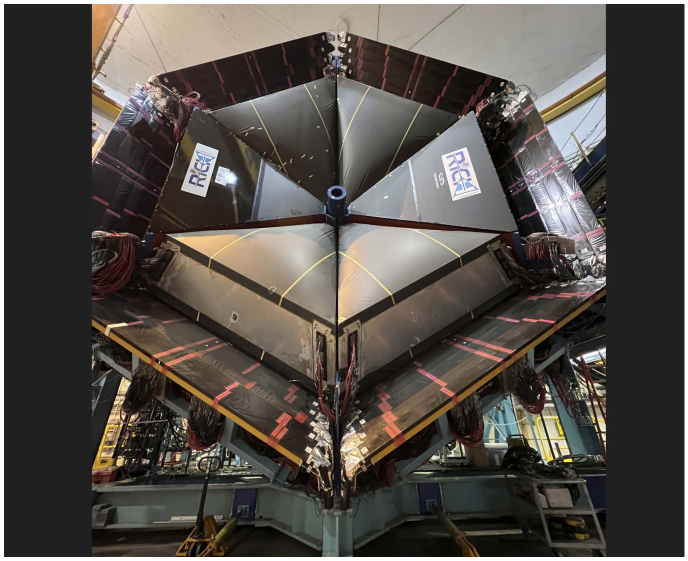

Figure 7: *The two RICH modules in the forward carriage of CLAS12.*

compared with the reference values obtained in the assembly hall. On June 3 the experimental hall was locked and on June 8 the CLAS12 data taking with the two RICH modules has started. In Fig. 8 we show a screenshot of the RICH monitoring system during the first days of data taking. The plots show the temperature measured on the FPGA (top left), event counting with the scaler readout (top right) and TDC readout counting and timing plots (bottom row).

5 Reconstruction of the RICH data and particle ID performance

In preparation of the installation of the second RICH module and of the reprocessing of all the data taken so far by the CLAS12 experiment planned for the beginning of 2023, in 2022 a major revision of the RICH software has been carried out. The LNF physiscists have been deeply involved in this work, which, besides the extension from one to two modules, essentially included:

- the revision of the output data structure;
- the revision of the calibration constant database;
- a revision of the calibration suite that uses the MAPMT dark counts to monitor the stability of the photosensor response;
- the development of the new software providing the reference values of the measured Cherenkov angle as a function of the various different photon detection topologies (e.g. no reflections, one reflection on a lateral mirror, two reflections with the first one on a spherical mirror, etc.);
- the development of the new software to monitor the detector performance in physics observables;
- the implementation of a fast Monte Carlo simulation of the detector;
- a re-analysis of old experimental data on hydrogen target to improve the alignment of the mirrors.

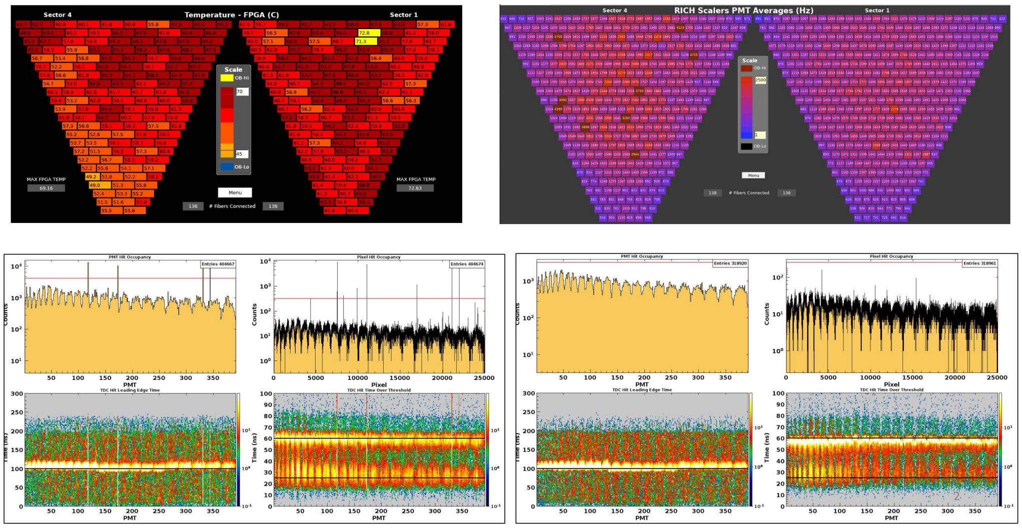

Figure 8: *RICH monitoring plots during normal CLAS12 data taking: FPGA temeperatures (top left), scaler readout counts per MAPMT (top right), TDC readout counts and time distributions per MAPMT and per channel (bottom).*

Few representative examples of the quality of the data obtained so far is shown in the next figures. In Fig. 9 we show the comparison of the reconstructed Chrenkov angle as a function of the momentum for photons detected with no reflections (blue points) or after one reflection on one of the lateral mirrors (green points). The left plot show the mean and the right one the sigma of the distributions. The agreement between the means in the two detection topologies is below 1 mrad, well within the desing goal. Also the single photon resolution below 5 mrad is in agreement with the expected performance

In Fig. 10 we show the missing mass distributions in $ep \to e'K^+X$ (left) and $ep \to e'K^-X$ (right) events. In black we show the results when the CLAS12 particle ID (i.e. without the RICH) is used, in red when the RICH ID is used. The main features we observe here are:

- in both histograms with CLAS12 ID we see a fake peak in the nucleon (for the K^+) and Δ (for the K^+) mass regions due to pions misidentified as kaons;
- these two fake peaks basically disappears with the RICH ID;
- the signal-to-background ratio in the Λ and Σ mass regions in the K^+ distribution is much higher with RICH ID, with both an increase in the total signal strength and a decrease in the background;
- an overall smaller number of Kaons with RICH ID, due to the higher contamination from misidentified pions in th CLAS12 ID histograms;

These two plots demonstrate the effectiveness of the RICH detector in identifying kaons with high efficiency and low contamination.

Unfortunately, the alignment procedure developed so far was not able to properly handle the photons with more than one reflection, in particular when the first reflection occurs on the spherical mirror. For this reason, in the upcoming reprocessing of the data the photons with reflections on the spherical mirrrors will not be used in the particle identification, thus limiting the

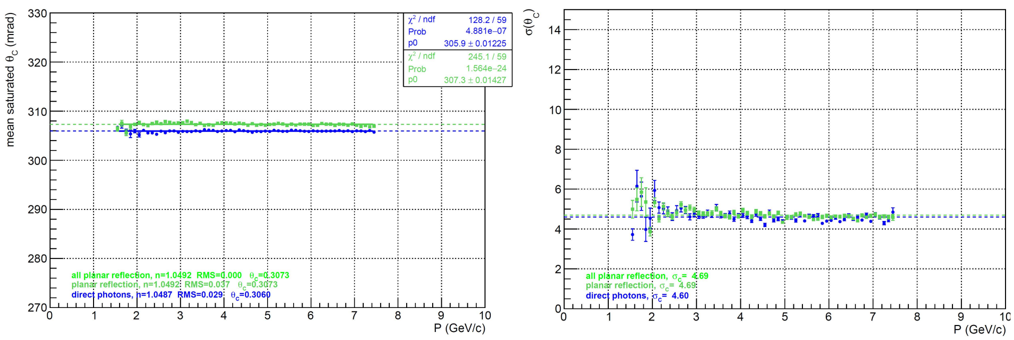

Figure 9: *Comparison between the Cherenkov angle mean for photons with no reflections (blue points) and those with one reflection on one of the lateral mirrors (green points) as a function of the momentum. The left plot show the mean of the distributions and the right one the sigma. Data for elctrons and negative pions.*

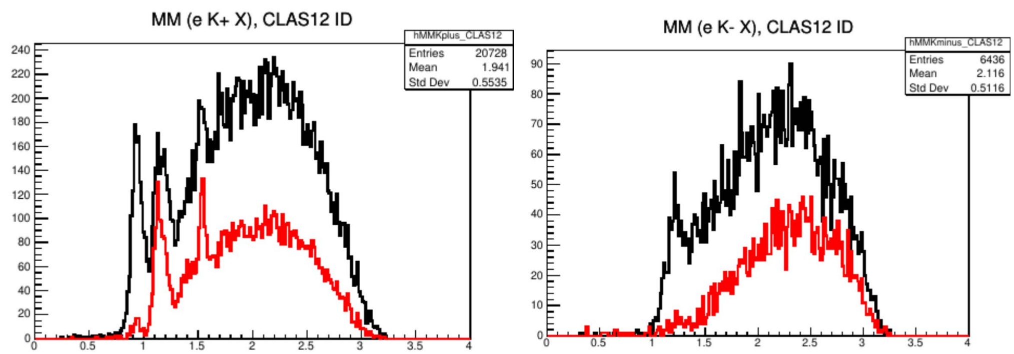

Figure 10: *Missing mass distributions for* $ep \to e'K^+X$ *(left) and* $ep \to e'K^-X$ *(right) events with CLAS12 (i.e. with the RICH, black histograms) or RICH (red histograms) ID.*

RICH acceptance to about 15^o for particles curved by the torus field toward the beam line and to about 23^o for oppositely charged particles.

To solve this issues, new alignment techniques are being explored, in particular exploiting machine learning and artificial inteligence tools. Once a better alignment will be obtained, the RICH data will be reprocessed to extend the particle identification to the full kinematic coverage.

6 Other activities

In the week from December 13 to 16, the *Workshop on kaons with CLAS12* has been organized in Frascati [1]. The workshop had a participation of about 20 person, half of them in person (from LNF and Ferrara in Italy, from JLab staff and Duquesne and Duke Universities in USA) and half of them by remote connection. It has been organized in four afternoon sessions, to allow people from USA to connect. Two sessions were dedicated to the physics with kaons, including ongoing studies and future perspective in exclusive and semi-inclusive kaon production on proton and nuclear targets, unpolarized as well as longitudinally polarized. Two sessions were dedicated to technical aspects connected to the RICH data analysis, with particular emphasis on possible applications of artificial intelligence and machine learning techniques to alignment studies, event reconstruction and particle identification.

References

1. https://agenda.infn.it/event/33338/