JLAB12 Activity report 2024

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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 LNF group is involved in the data taking and analysis of the CLAS experiment and in the operation of the two modules of the Ring Imaging Cherenkov (RICH) detector of the CLAS12 spectrometer, that was completed in 2022. In 2024, the group also started to work on the preparation of the run wil transversely polarized target.

2 CLAS data taking

During the 2024, two experiments took data in the Hall B of the Jefferson Laboratory with the CLAS12 spectrometer.

The first one, called *Run Group K*, ran from January to March and was performed with an electron beam with energy of 6.4 and 8.5 GeV on an unpolarized liquid hydrogen target and was the continuation of a run taken in 2018. The goal of the experiment is the study of nucleon resonances, the search of the hybrid baryons and the measurement of the Deeply Virtual Compton Scattering (DVCS).

The second one, called *Run Group E*, ran from March to May and was performed with an electron beam with energy of 10.5 GeV on unpolarized liquid hydrogen and deuterium targets as well as various solid nuclear targets from carbon to lead. The goal of this experiment is the study of the quark propagation and hadron formation in nuclear matter and the measurement of the nucleon partonic functions in nuclei.

One of the main goal of the CLAS Collaboration has been the processing of the data taken in 20222 and 2023 with the longitudinally polarized liquid NH_3 and ND_3 targets by the *Run Group C* experiment. Being the first data taken with polarized target, a careful calibration of the detector and a detailed assessment of its performance has been done. The final approval has been given by the review committee [1]. The processing of the data has been started on December of 2024 and has been completed by the beginning of 2025.

3 CLAS data analysis

The physcists of the LNF group have been involved in the review of several analyses carried out by the CLAS Collaboration on the data taken with the unpolarized liquid hydrogen in 2018 and 2019. In particular, a major effort was dedicated to the measurement of the Beam Spin Asymmetry (BSA) in the Semi-Inclusive electroproduction of K^+ in the Deep Inelastid Scattering (SIDIS)

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[1] Marco Mirazita is member of the so-called pass-2 cooking review committee

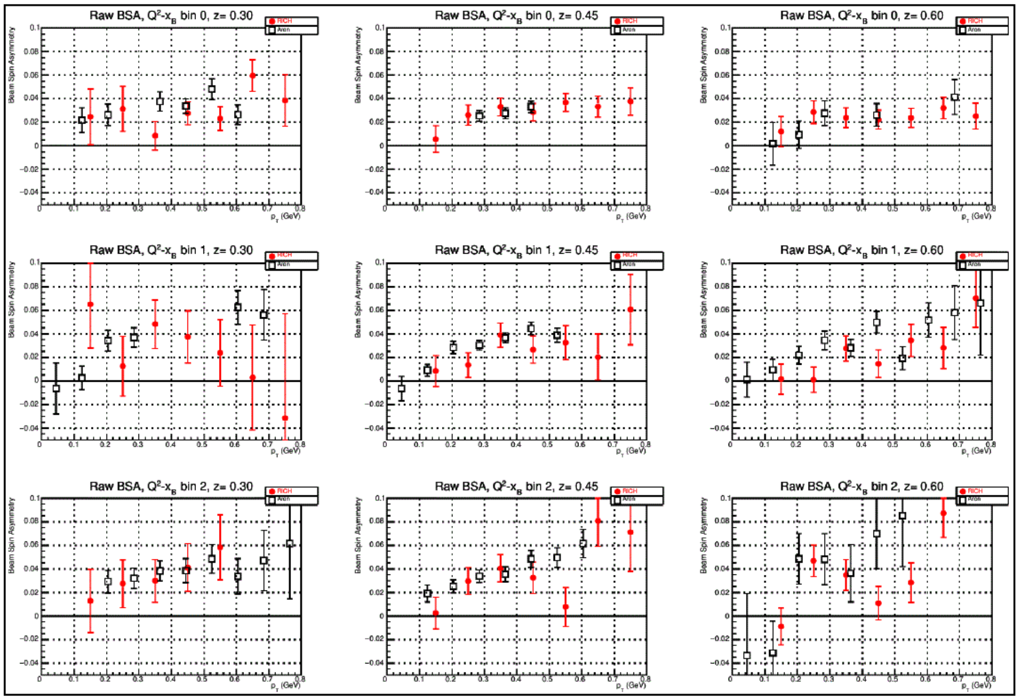

Figure 1: *The K^+ BSA measured using the FTOF PID (black empty squares) and the RICH PID (red full circles) as a function of the kaon p_T. Each row is one bin in the Q^2-x_B plane, each column is one bin in z.*

region. The basic Particle Identification (PID) system of CLAS12 is the Forward Time-of-Flight (FTOF), which covers all the 6 sectors of the spectrometer but has limited kaon/pion rejection power, especially at larger momentum. On the contrary, the RICH detector has excellent kaon/pion rejection power but coverage limited to only one sector (the second sector was installed in 2022). To benefit of the higher statistics, the analysis was performed using the PID provided by the FTOF and the RICH information was used in several stages of the analysis, namely to:

- determine the limited kinematic region were the FTOF PID is reasonably reliable, i.e. P< 3 GeV/c;
- tune the kaon to pion production rate in the Monte Carlo event generator;
- validate the calculation of the pion contamination.

As a final cross check, the BSA measured with the FTOF has been compared with the results obtained by using the RICH detector. In Fig. 1 we show the comparison in the 3 bins in the Q^2-Bjorken-x plane and at fixed z (the fraction of the energy carried by the kaon) and as a function of the transverse momentum p_T of the kaon. The error bars of the FTOF results include statistical and systematic uncertainties, while the RICH results include only the statistical one (but the systematic one is expected to be small). The two results agree well, with the FTOF having better statistical precision while the RICH has larger kinematic coverage (due to the momentum cut P< 3 GeV/c).

The analysis is now under the final Collaboration review.

4 The RICH detector

Each module of the Ring Imaging Cherenkov (RICH) detector is composed by an aerogel radiator, an array of multianode photomultiplier tubes (MAPMTs) for the Cherenkov light detection and a mirror system.

The radiator is composed by 102 tiles 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.

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 photodector array uses 391 MAPMT Hamamatsu H12700 and H8500, each composed by a matrix of 8×8 matrix of pixel with about 6 mm pixel size, for a total of 25024 independent readout channels per module.

The readout electronics is based on the MAROC3 chip, a 64 channel microcircuit dedicated to MAPMT pulse processing. The MAROC3 is configured and read out by a FPGA optically linked with the data acquisition node.

4.1 RICH data taking

The RICH detector continued to take data regularly together with the CLAS12 spectrometer. Just before the begininning of the data taking in 2024, a new firmware has been installed on the FPGA controlling the Front End electronic, to improve the stability of the data acquisition and the speed of the inizialization.

Due to several failure of Low Voltage (LV) boards occured during the data taking over the last years, it was decided to replace the original CAEN system with a new MPOD crate. The replacement has been performed during the shut down in fall 2024. The new system has been tested by taking calibration data using dark noise of the Hamamatsu Multi-Anode PMTs (MAPMTs) and the scaler readout in self-triggering mode. As an example, in Fig. 2 we show the comparison of the pedestals measured with the old LV system before the replacement (in blue) and with the new LV system (in red). No appreciable differences have been found for this and all the other MAPMTs.

4.2 RICH simulations

A major achievement of the 2024 for the LNF has been the integration of the RICH detector in the CLAS12 `GEMC` simulation package. The geometry of the detector, that is defined by a mixture of native `Geant4` volumes and `STL` files axtracted from the CAD drawings, has been revised to simplify the description of the dead volumes in order to reduce the processing time and to fix minor residual overlaps. The Fig. 3 shows the two sectors of the detector in the simulation.

A major effort has been dedicated to the tuning of the properties of the active elements of the detector: aerogel radiator, spherical and planar mirrors, photomultipliers and readout electronics.

Being a highly non-standard material, with non negligble surface and volume inhomogenities, a special care has been necessary in order to determine its optical parameters. The aerogel optical processes can be classified in three categories:

- Cherenkov photon generation, which is governed by the well known Cherenkov emission spectrum and by the variation of the refractive index with the photon wavelength;
- volume effects, including transmission or absorption of the photons inside the radiator, Rayleigh and forward scattering;

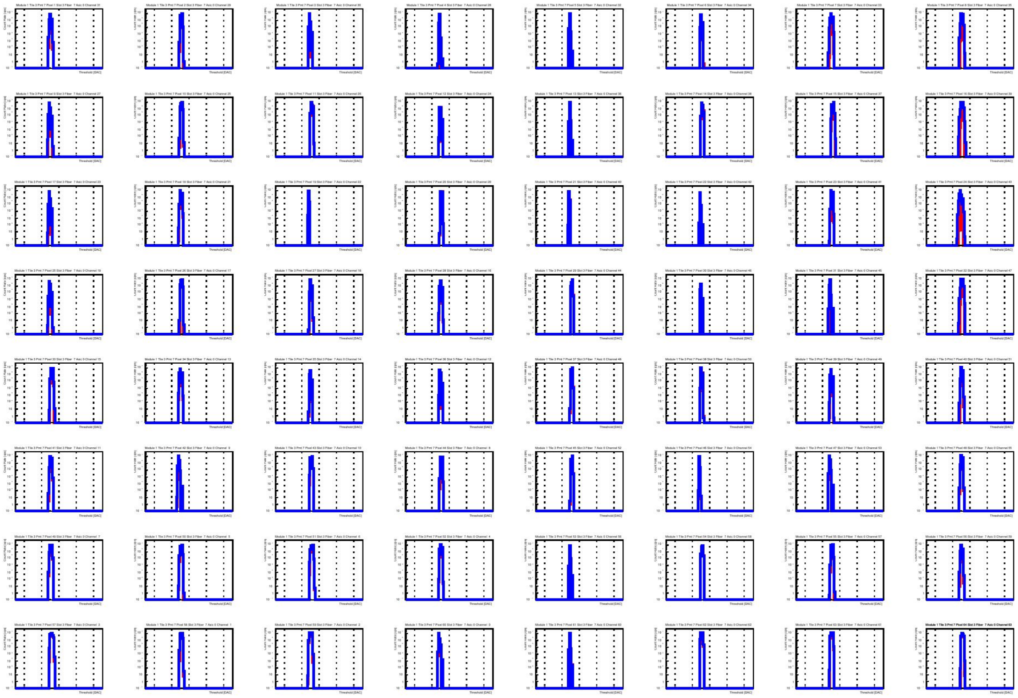

Figure 2: *Pedestals of the 64 channels of one MAPMT measured with the old (in blue) and the new (in red) LV supply system.*

- surface effects, including the refraction of the photons when they exit from the radiator volume and the smearing of the refracted angles due to the surface roughness.

For the mirrors, the basic properties to be determined are the reflectivity as a function of the photon wavelength and the smearing of the reflection angle due to the surface accuracy.

The `Geant4` simulation of optical photons allows the user to define a large number of parameters, as for example the refractive index dispersion, the scattering and absorption lengths, the average forward scattering angle of the radiator, the reflectivity and surface accuracy of the mirrors, etc.. All these parameters have been determined by the characterization measurements perfomed on the aerogel radiator before the assembly of the detector [1, 2]. As an example, in Fig. 4 we show the measured forward scattering angular distributions [2] (left plot) and the average reflectivity measured on the planar and spherical mirrors (right plot).

The photon hit digitization on the RICH readout system has been implemented in thre steps:

- simulation of the H1270 and H8500 Hamamatsu MAPMTs to single photons;
- simulation of the binary response of the MAROC3 readout chip, including charge to time conversion;
- the generation of the TDC response with a 1 ns time stamps provided by the FPGA of the readout system.

The MAPMT simulation has been implemented using the Hamamatsu data sheets, while the simulation of the RICH readout system has been tuned to the characterization measurements and to the CLAS12 experimental data. The Fig. 5 shows the simulation of a typical single photon

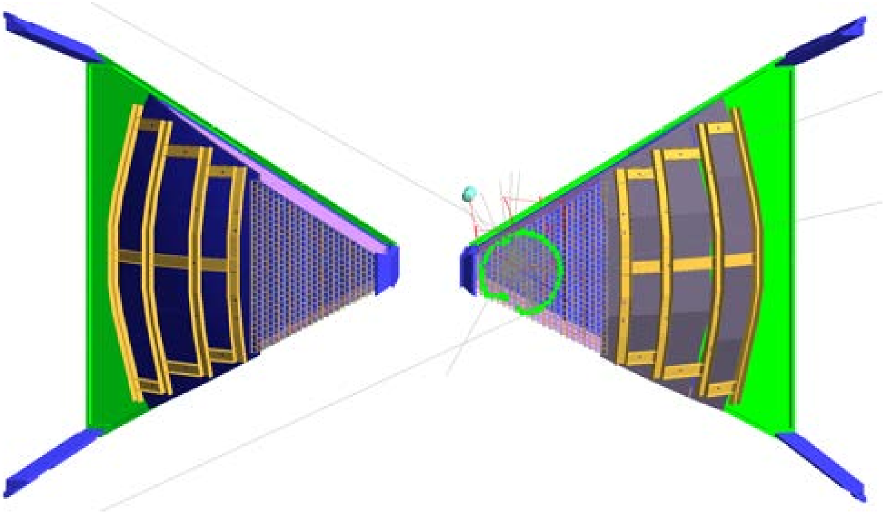

Figure 3: *The two modules of the RICH detector in the* `Geant4` *simulation of CLAS12.*

spectrum on a H12700 MAPMT (left plot) and the Time-over-threshold vs TDC time distribution (right plot).

A first test of the performance of the simulation with respect to the experimental data has been done by simulating SIDIS events $ep \rightarrow e'hX$ in CLAS12. In Fig. 6 we show the resolution of the reconstructed Cherenkov angle for particles crossing the tiles of the first section of the aerogel radiator. Only photons that are detected without reflections on the mirror system (direct photons) have been considered in this plot. The red points are simulated results, the blue points the best resust from the experimental data obtained so far. Filled and empty symbols refers to negative and positive charge particles, respectively. The agreement is fairly good.

5 Transversely polarized target

The *Run Group H* is dedicated to the data taking with a transversely polarized target and includes three experiments: the study of the SIDIS reactions with one or two hadrons in the final state and the DVCS measurement. The three experiments were originally submitted assuming a frozen spin *HD* target and have been approved with high rating under the condition that the *HD* target could be operated with a high energy electron beam. The tests performed showed that the heat produced by the beam significantly reduces the depolarization time to a level that is not manageable in normal experimental condition. Therefore the run group decided to switch to a conventional dynamically polarized NH_3 target, which imposes the removal of the existing central detector and solenoid of the CLAS12 spectrometer to install the cryostat of the target.

A proposal with the NH_3 target and the modified CLAS12 geometry will be presented to the Jefferson Lab PAC in July. The proposal foresees a novel recoil detector, mainly dedicated to the detection of the protons in the DVCS experiment, covering the polar angles above 35^o that go beyond the coverage of the CLAS12 forward spectrometer. The present design of this detector includes three layers of μRwell for tracking and an array of plastic scintillators for time of flight measurement. The LNF group is in charge for the design of the mechanical structure of the recoil detector.

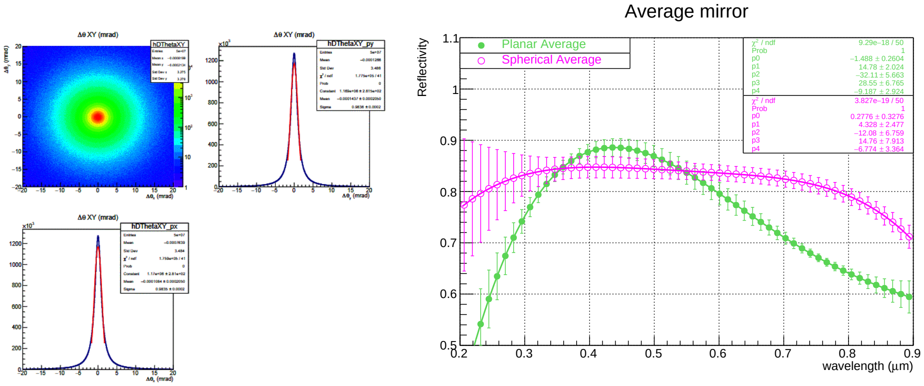

Figure 4: *Left plot: forward scattering angular distribution measured for one aerogel block. Righ plot: average reflectivity measured on the 7 planar (green full circles) and 10 spherical (pink empty circles) mirrors.*

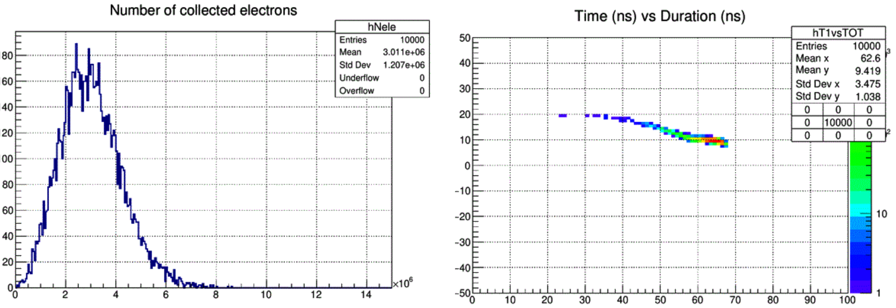

Figure 5: *Left plot: the simulated response to a single photon of one Hamamatsu H12700 MAPMT. Righ plot: simulation of the time-over-threshold vs TDC time of the MAROC3 chip readout.*

6 Conference organization

From 9 to 13 December 2024, the LNF hosted the *Science at the Luminosity Frontier: Jefferson Lab at 22 GeV* workshop [3], chaired by P. Rossi and M. Mirazita.

The workshop, part of a series of workshops dedicated to the development of the scientific case for a 22 GeV upgrade of the CEBAF accelerator at Jefferson Lab, was sponsored by the The ExtreMe Matter Institute (EMMI) of GSI and by the Jefferson Lab. It was organized in plenary sessions, dedicated to the following topics:

- Spectroscopy;
- Partonic structure and spin;
- Hadronization and transverse momentum;
- Spatial structure, Mechanical properties and emergent hadron mass;
- Nuclear dynamics;
- QCD confinement, fundamental symmetries and physics beyond the Standard Model.

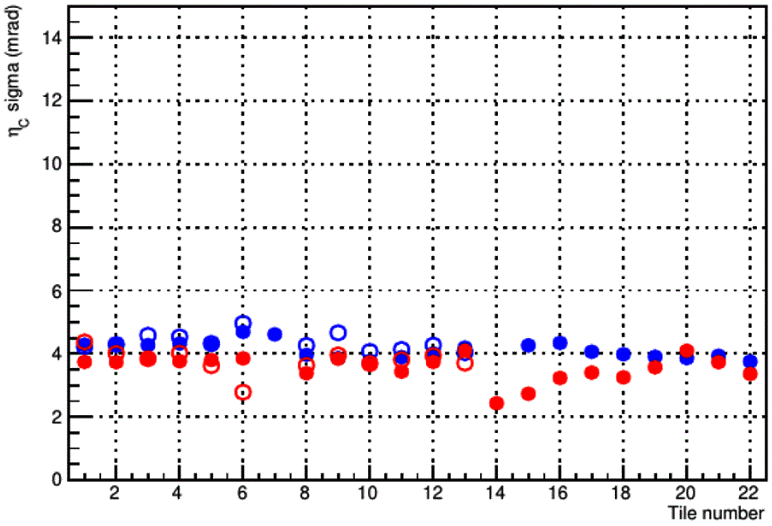

Figure 6: *Comparison of the direct photons Cherenkov angle resolution between experimental (blue circles) and simulated (red circles) data for the tiles of the second section of the aerogel radiator. Filled and empty symbols refer to negative and positive particles, respectively.*

It was attended by 91 participants from 13 countries, with 70 invited speakers, 8 of which were flash talks given by young physicists.

References

1. S. Anefalos Pereira *et al.*, Eur. Phys. J. A (2016) 52: 23
2. M. Contalbrigo *et al.*, Nucl.Instrum.Meth. A876 (2017) 168-172
3. https://agenda.infn.it/event/39742/