PROGRESS REPORT OF eRD11 PROJECT – RICH DETECTOR FOR THE EIC'S FORWARD REGION PARTICLE IDENTIFICATION

The eRD11 Collaboration

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Abstract

The eRD11 R&D program is aiming to investigate the technology to be used for a Ring Imaging Cherenkov (RICH) detector for the hadron particle identification in the forward region of the future Electron-Ion Collider (EIC). Both the dual-radiator RICH option and a modular RICH concept are being investigated and the associated special optics design will be carried out. In particular, a newly developed Large-Area Picosecond Photo-Detector (LAPPD) using renovated Micro-Channel Plate (MCP) technology is being carefully evaluated as the readout of the RICH detector. If feasible, the excellent timing resolution provided by this new readout will greatly improve the PID capability of the RICH detector. In addition, the semiconductor photocathode and the GEM-based readout option will be investigated when more funds are available. The main goal of this project is to determine the best detector technology and to provide a conceptual design of the RICH detector for the EIC. The report covers the progress during the first three months of the project from Oct 1, 2014 to Dec 31, 2014.

1. What was planned for this reporting period?

Two tasks of the original proposal are supported by the EIC R&D funds: tests of the Large Area Picosecond Photo-Detector (LAPPD) and the detector simulation. More specifically, the milestones for FY2015 are following:

Tests of LAPPD (MCP-PMT)

- Photon detection efficiency, position resolution, rate capability.
- Radiation hardness, magnetic field effects.
- Timing resolution.

Detector Simulation

- Implementation of optical components in MEIC-GEMC, simulation in standalone mode to study requirement on optical qualities of aerogel and Fresnel lens.
- Evaluate response to physics events, such as phase-space and occupancies.
- Estimate background levels in a realistic EIC environment.

2. What was achieved?

2.1. Tests of LAPPD (MCP-PMT)

We received the first 6×6 cm^2 MCP-PMT unit, Tube #28, from Argonne National Laboratory at the end of October. A dark box has been setup in the Lab F-117 at Jefferson Lab. As shown in Figure 1, a Hamamatsu picosecond light pulser (PLP-10) is used as an ultrashort pulsed light source with a central wavelength at 405 ns. It has an average 60 ps pulse width and the repetition rate can go up to 100 MHz. We keep the laser output amplitude constant so that the pulse shape remains stable. In order to change the light intensity, we installed two neutral density filter wheels with which we can remotely change the transmission level up to three orders of magnitude. For the position sensitivity scan, we use a pin-hole design to limit the laser spot to be less than 2 mm on the surface of MCP-PMT and we move the MCP-PMT for the position scan using a 2-D stage with a travel of 5 cm in both X and Y directions. Another fast PMT is installed in the dark box to monitor the light yield and it can also be used as a trigger.

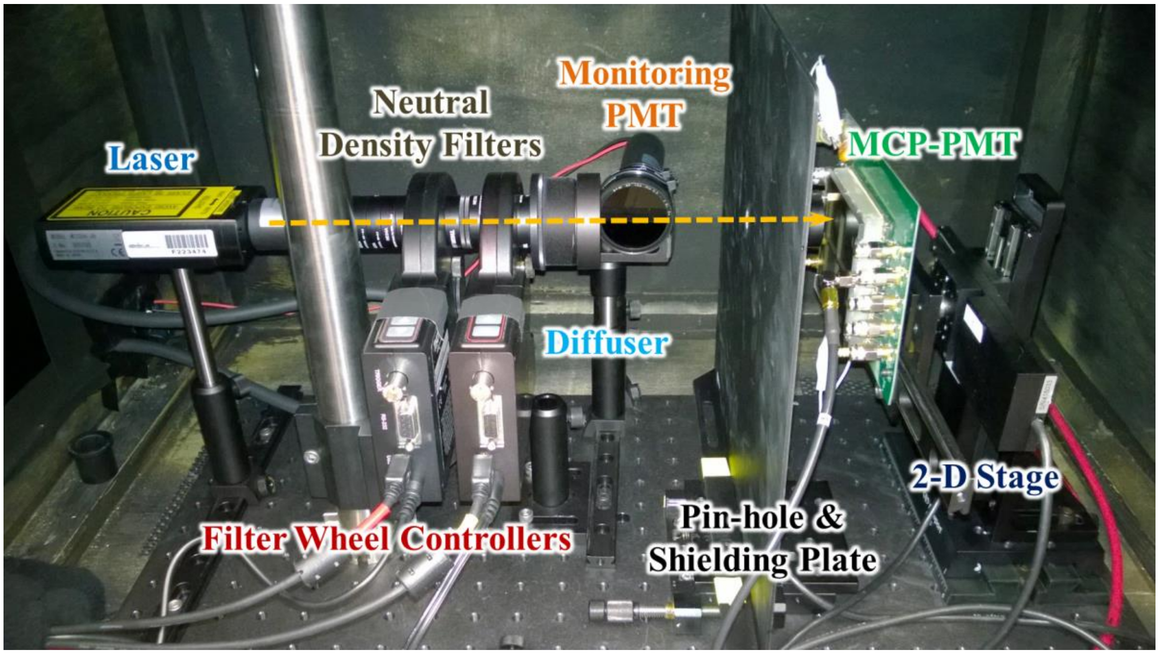

Figure 1 Optics setup for the MCP-PMT tests.

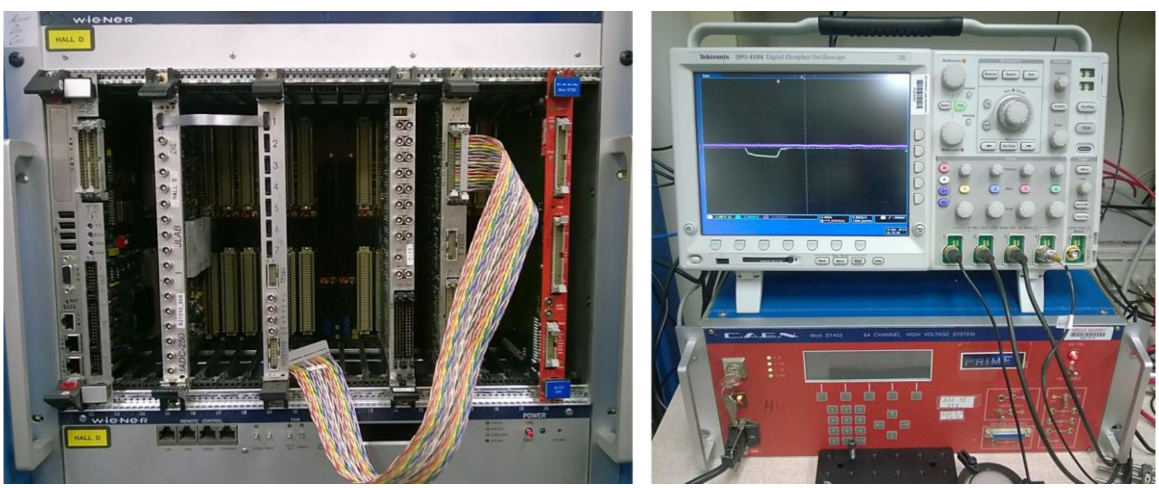

Figure 2 DAQ system: (Left) VME based system, (Right) 5 GS/s Oscilloscope and high voltage.

As shown in Figure 2, a 32-channel CAEN high voltage source is used to power both the MCP-PMT and the monitoring PMT. The signals are currently being read out by a 5 GS/s oscilloscope and collected by a LabVIEW program. The filter wheels and 2-D stage are controlled by the same program as well. A complete set of VME DAQ hardware including a CAEN V792 QDC and CAEN 32-Channel 25 ps TDC is also available and will be used for future tests.

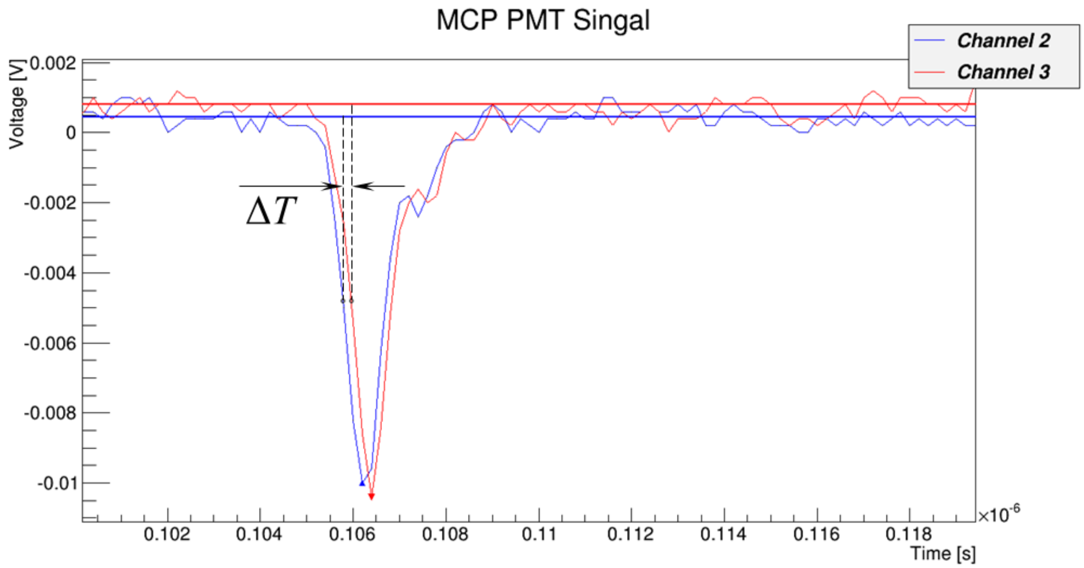

Figure 3 MCP-PMT Signals from both ends of a strip captured by the oscilloscope.

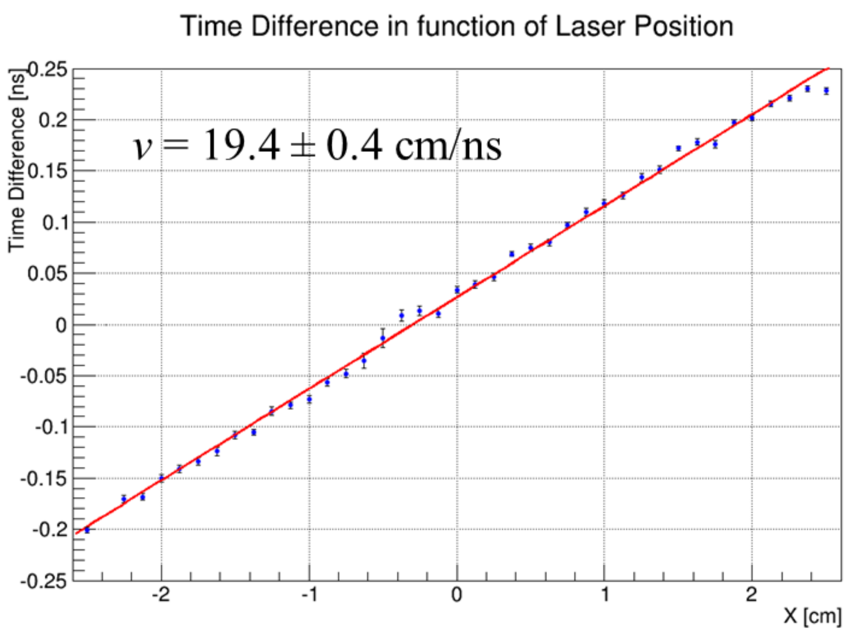

Figure 4 Speed of signal in transmission line measured through a position scan.

An engineering undergraduate student, Rodrigo Mendez, from Universidad Tecnica Federico Santa Maria, Chile, partially sponsored by the EIC R&D fund arrived at Jefferson Lab at the end of November and is actively working on testing the MCP-PMT. Yi Qiang and Carl Zorn from Jefferson Lab are also working on the tests as their contributions to the project. A position scan has been performed to extract the speed of the signal in the readout transmission line by measuring the time difference of signals reaching both ends of a strip, as shown in Figure 3. The result is presented in Figure 4. A very good linear response of the time difference as a function of position is seen and the speed is measured to be 19.4 ± 0.4 cm/ns which is consistent with our expectation. We also performed scans of high voltage to find optimal operation condition, measurements of gain and Photon Detection Efficiency. The data are still under analysis and will be reported later.

2.2. Detector Simulation

The simulation is built within the GEant4 Monte-Carlo (GEMC) simulation framework. GEMC is written in C++ and based on Geant4 libraries to simulate the passage of particles through matter. The simulation parameters (geometry, materials, fields, sensitivity, *etc.*) are defined externally and can be stored in local files or in databases. Users can build a completely customized hit process routine for individual detectors with analog or digital output. It can be used for a single detector simulation and then seamlessly merged into a whole detector simulation [1][2]. A post-doctoral researcher, Liang Xue, and a graduate student, Cheuk-Ping Wong, from Georgia State University partially sponsored by the EIC R&D fund are the main persons working on the simulation. Zhiwen Zhao, a researcher from Old Dominion University is also helping on the simulation as his contribution to the project.

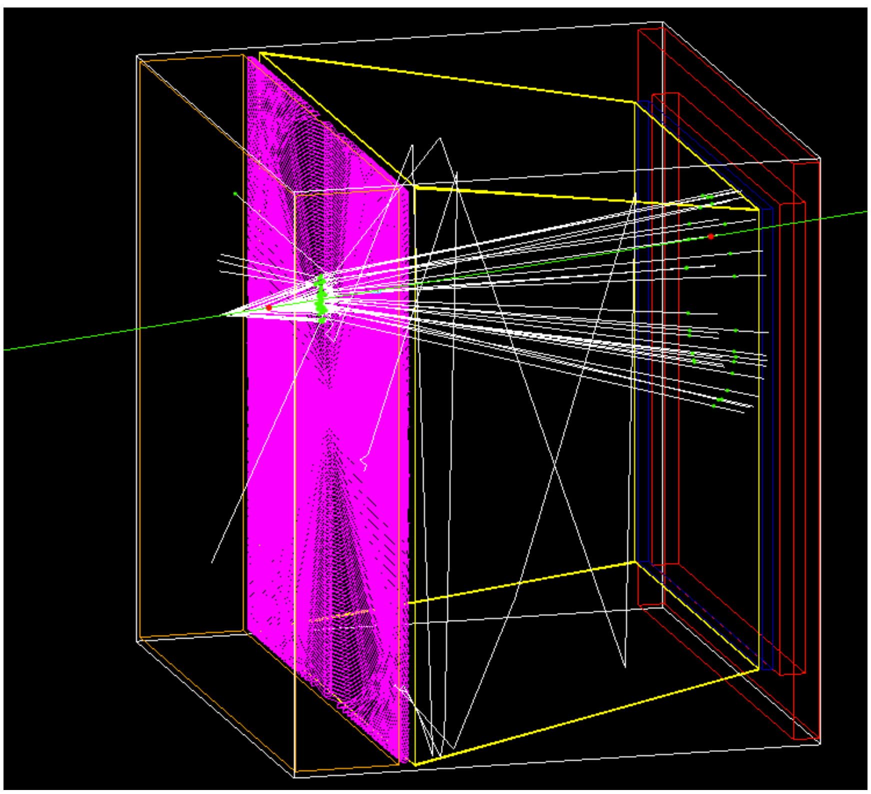

Figure 5 Implementation of a modular counter unit in GEMC framework. Visible are the aerogel, Fresnel lens, mirrors, photosensor, and read-out.

A modular RICH detector is implemented in the GEMC framework as shown in Figure 5. It contains a block of aerogel (SiO_2), Fresnel lens, four sheets of mirrors, photosensor detector, and read-out electronics. The aerogel is 2 cm thick, 0.02 g/cm^3 density, and has a refractive index n = 1.025. The Fresnel lens is made of acrylic ($C_5H_8O_2$), has 100 grooves, and has a focal length of 8 cm. Four mirror segments are implemented at the front, back, top, and bottom to reflect optical photons generated by particle passing through aerogel. Photodetector and readout are created at the back to record Cherenkov rings. Also shown in Figure 5 is the event display with optical photons and ring generated by a 5 GeV negatively charged muon. On average, a 5 GeV negatively charged muon striking through can generate ~ 76 Cherenkov optical photons, and ~ 28 can arrive at photosensor at the back.

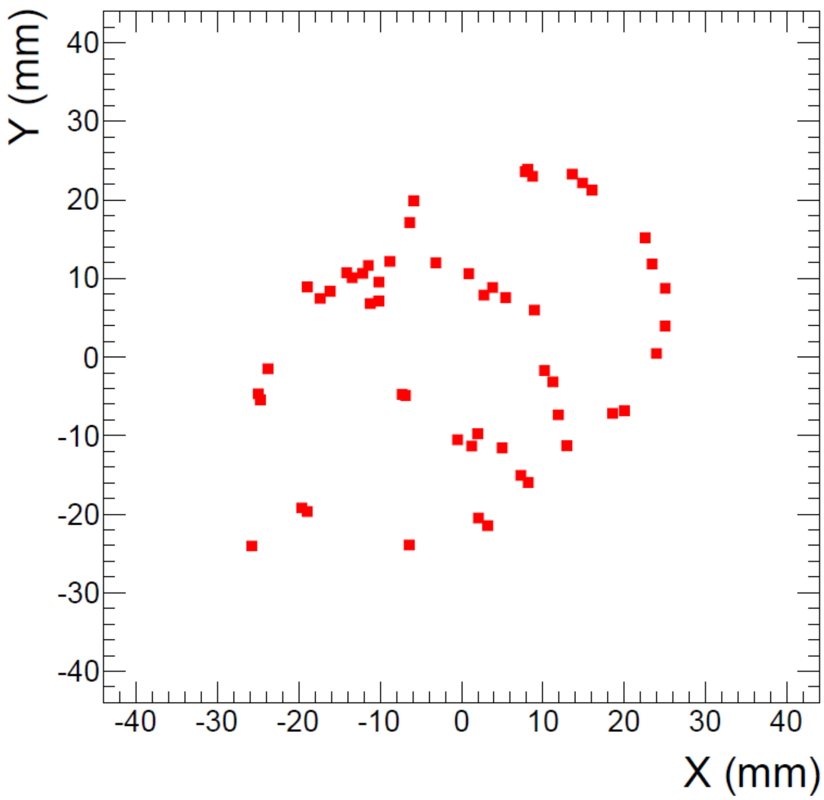

Figure 6 Cherenkov rings on the photosensor detector generated by muons.

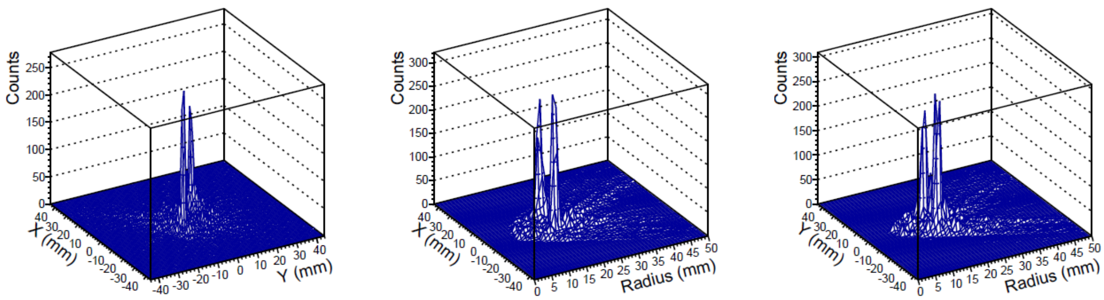

Figure 7 Left: Cherenkov radiation rings center calculated by combinatorial Hough Transform; Middle: X position and Cherenkov radiation ring radius calculated by combinatorial Hough Transform; Right: Y position and Cherenkov radiation ring radius calculated by combinatorial Hough Transform.

A ring finder algorithm (Hough Transform [3]) has been developed to identify the Cherenkov radiation rings on the photosensor detector. This algorithm performs a transform from the image space to parameter space. Any three data points on the photosensor detector defines a ring in the parameter space, a combinatorial calculation will give an enhancement at the real rings center in image space. Figure 6 presents the Cherenkov rings on the photosensor detector generated by muons, with the corresponding rings center and radius being calculated using a combinatorial Hough Transform as shown in Figure 7. Any quantum efficiency effect, non-uniformity and non-flatness in the aerogel or Fresnel lens are not considered in the calculation.

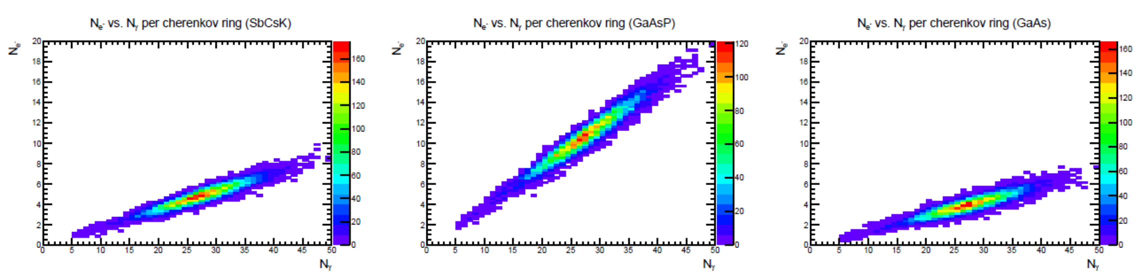

Figure 8 Electron photoproduction as a function of number of optical photons for bi-alkali crystals Sb-Cs-K (left panel), and semiconductor materials such as GaAs (middle panel), GaAsP (right panel).

Figure 8 shows photon electron production for bi-alkali crystals such as Sb-Cs-K, and semiconductor materials such as GaAs, and GaAsP. Typically, 5 GeV muons passing through the detector can produces 5 electrons for Sb-Cs-K, 11 electrons for GaAsP, and 3 electrons for GaAs.

3. Moving Forward

3.1. MCP-PMT

- Continue tests with VME DAQ system.

- Establish baseline measurements and extract gain and QE
- High rate test
- Magnetic field test
- Neutron radiation hardness test

3.2. Simulation

- Implement detector non-uniformity, non-flatness effects in simulation.
- Properly implement the quantum efficiency for different materials of photosensor detector, and study their photon electron production.
- Extend the detector simulation with gas radiators.
- Study PID requirements of angular and momentum coverages, provide constraints on magnetic field in the EIC solenoid.
- Study realistic background rates in GEMC framework.

3.3. Collaboration

A researcher from INFN will soon come to JLab partially supported by the EIC R&D fund to primarily work on the MCP-PMT tests with some supporting role for the simulation.

We are also working with the eRD10 (TOF) group to form a PID consortium. More progress will be reported in next January's meeting.

References

[1] GEant4 Monte-Carlo (GEMC), http://gemc.jlab.org
[2] EIC Software, https://eic.jlab.org/wiki/index.php/EIC_Software
[3] Hough Transform, http://en.wikipedia.org/wiki/Hough_transform