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eRD10 Progress Report:

R&D Proposal for (Sub) 10 Picosecond Timing Detectors at the EIC

Period Reported: FY2015
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Abstract

Our group has been investigating the possibility of pushing TOF detector resolutions down to a resolution of about 10 ps, an order of magnitude improvement from the 100 ps which is the typical resolution for existing detectors in large experiments today. Such an improvement makes a TOF quite an attractive option as part of a suite of PID detectors that would be needed to deliver key physics measurements at an EIC. We have identified multi-gap Resistive Plate Chambers (mRPC) and MCP-PMT's with a thick fused silica Cerenkov window as promising technologies. Currently our group has focused on building a glass mRPC with many gaps. With this detector, we have achieved 18 ps resolution, which we believe is better than any published result form mRPCs. In addition, we have started simulations to begin to understand the role of a TOF in an EIC detector, written part of the code to simulate the detailed micro-physics of a mRPC using Garfield++, and helped with the planning for future MCP-PMT development that would enable a very high-performing TOF detector (sub-10 ps).

Section 1: What was promised, achieved, and not achieved?

Cosmic ray test stand with 36 gap glass mRPC

The UIUC cosmic ray test stand system is composed of scintillators for generating a trigger, drift chambers for tracking muons, and a gas cylinder for accommodating prototype detectors. Two 36 gap prototype MRPCs are placed inside of the gas cylinder. The mRPCs are constructed in 4 stacks of 9 gaps each. The gaps are 105 um thick, and are separated by 210 um thick glass. Three drift chambers are located on top and two drift chambers are located at bottom of the gas cylinder. Two lead blocks are placed under the cylinder and above the bottom scintillator to range out lower momentum muons. Figure 1 shows the prototype mRPCs and the UIUC cosmic ray test system. 97% of Freon R134a and 3% of SF_6 gas are mixed and flowed into the cylinder with a flow rate of 100cc/min. All this work was done by our post-doc Ihnjea Choi, who is funded through the EIC R&D program.

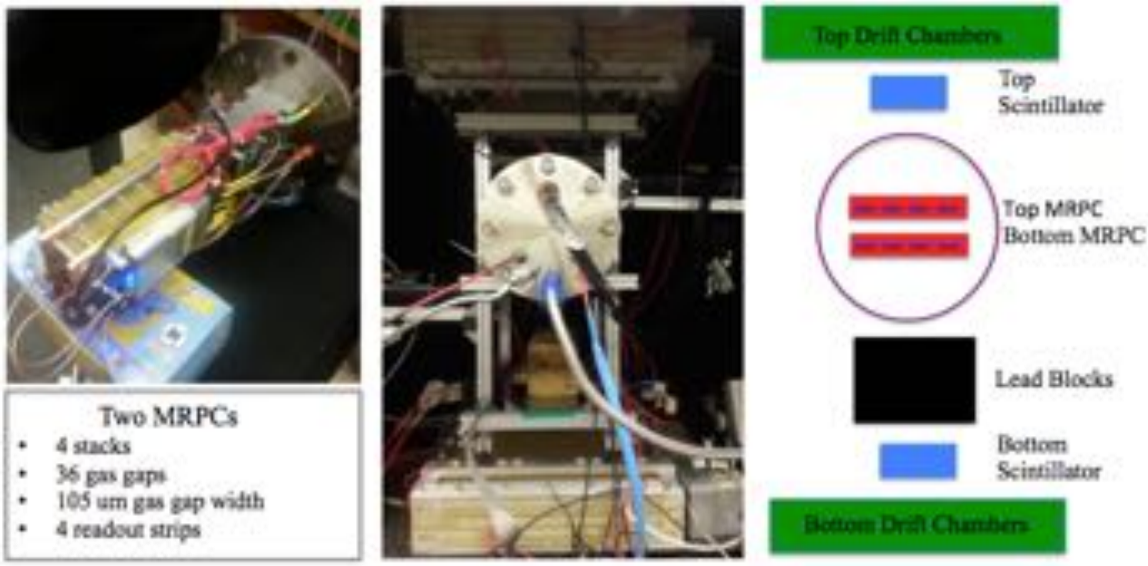

Fig. 1: Left picture shows the two prototype MRPCs, middle picture shows the cosmic ray test stand at UIUC, and the diagram on the right side shows the test stand system.

A LMH6881 differential preamplifier evaluation board is connected to the sides of the readout strips on each MRPC with 3 cm long cable and mounted next to the detector. This amplifier has a gain bandwidth product (GBP) of 2.8 GHz, and the gain can be set to 28 V/V. The output signals from the preamplifiers are connected to the DRS4 waveform digitizer inside the gas chamber. Time and voltage values are recorded by the DRS4 with a sampling speed of 5 GHz. Signals from the drift chambers are also recorded by DRS4's for reconstructing the cosmic ray tracks.

Positive and negative CAEN high voltage modules are connected to the MRPC electrodes. It provides a combined high voltage up to 30kV (+-15kV). In the results shown, +10kV and -10kV were applied to the both MRPCs.

Results from 36 gap mRPC

Oscillations from reflections were observed at the tail side of signals and it made it difficult to fit the whole signal using a template to determine the time. These reflections come late enough that they do not affect the leading edge of the pulse, so a Leading Edge Discrimination method was used to determine the detector hit time. Time T_1 is marked when a signal crosses over a certain threshold value in the top MRPC and T_2 is similar but in the bottom MRPC. The threshold value was set as lowest as possible to reduce any time uncertainty. The sigma of the pedestal (which tell us the noise level) was 1.1 mV and the threshold value was set to three times the RMS value of the pedestal.

The time resolution was measured by subtracting the two measured time values, $\Delta T = T_1 - T_2$. Figure 2 shows the distribution of this time difference ΔT. A time resolution of 25 ps was measured without a time slewing correction. Some backgrounds are noticeable under the main peak. We suspect that those backgrounds are due to either cross-talk with neighboring channels, or from streamer events.

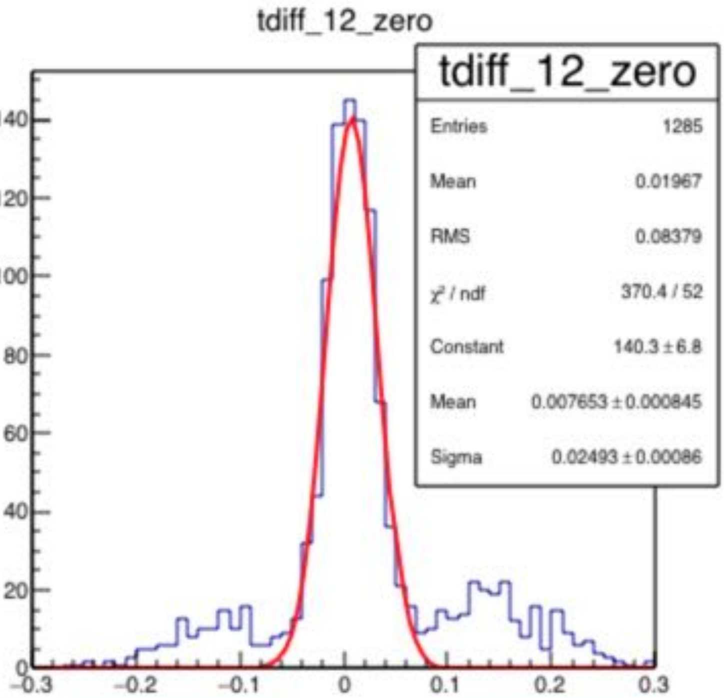

Fig. 2: The distribution of time difference between two MRPCs, in ns. Bump structures under the peak are being investigated.

Angles of incident muons on the MRPCs were reconstructed separately with the position information from the drift chambers. Tilt angles of muon tracks produce an additional time uncertainty in the time resolution measurement due to their path length difference between the readout strips in the MRPCs. Figure 3 shows estimated time uncertainty inherited from the path length differences between two MRPCs. This angular smearing is accounted for in Fig. 2.

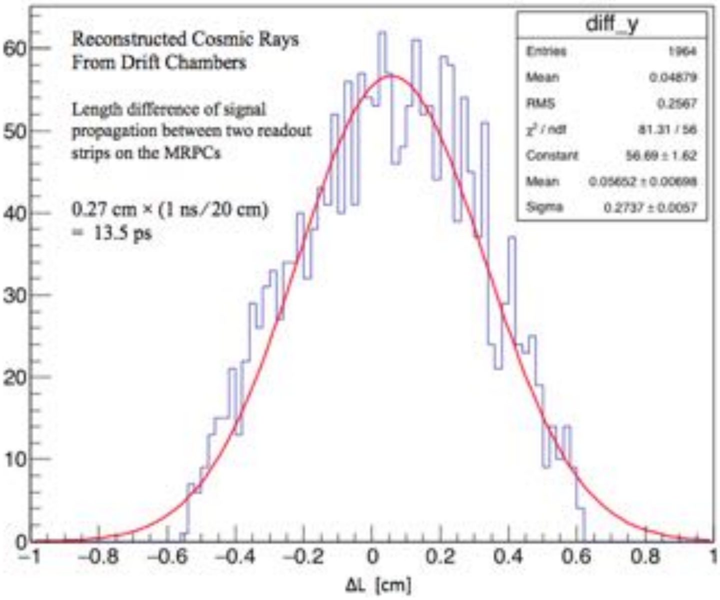

Fig. 3: The distribution of length differences between the hit points on the top and bottom MRPCs due to the varying angles of cosmic ray muons on the detectors.

Assuming the two detectors are identical, we measure a time resolution of ~18 ps for each detector. We believe the best published result is 20 ps. Note that we currently still have many studies remaining, including improvements that should be possible. For instance, we have not done any slewing corrections. The HV was set rather high to get higher efficiency, but it may be too high if there are substantial percentages of streamers. The study of this glass mRPC is still very actively in progress, and we hope to have updates by the July meeting.

Electronics

The DRS4 digitizers have been tested to ~2 ps resolution, which is more than adequate. Over the last year we have identified some TI amplifiers which have also worked well. So far we have looked into the LMH6554, LMH6881, and the LMH5401. These are fully differential amplifiers capable of 2.4-8.0 GHz GBP. They can be configured for 50 ohm single-ended input and output. On the output a wide-band balun is required for the conversion, and several are available on the market.

Using the stock evaluation amplifier boards from TI is adequate for our initial studies, but a custom preamp board will be necessary since the evaluation boards are rather large and cannot fit together along the edges of our mRPC signal PCB. Andrey has begun a SPICE calculation incorporating an mRPC detector model coupled to the TI LMH5401 preamp. An example calculation is shown in fig. 4. This modelling will also be useful for determining the right resistor settings for the impedance matching to the mRPC to reduce reflections. Currently at UIUC they have tried using a variable resistor to determine the optimal setting, and the SPICE calculation can help with confirming their study.

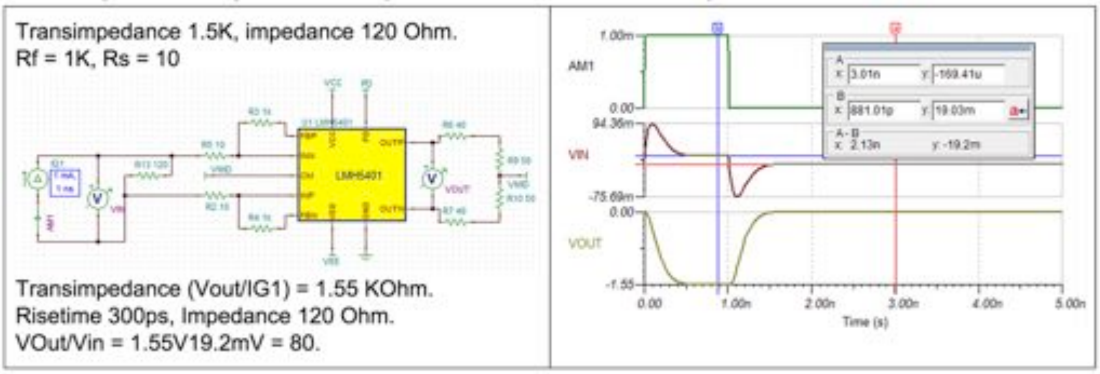

Fig. 4: Worksheet showing a SPICE calculation of an mRPC coupled to a LMH5401 amplifier.

We also are testing various transient voltage suppressors. These will protect the amplifiers from accidental surges, which can occur if the 20 kV HV trips, for instance. These will be incorporated into the final design, along with low noise voltage regulators. The boards will be laid out and produced at BNL once Andrey completes the final design.

Simulations

Work has been done by a UIUC student, Chong Han, to study the performance of a psTOF wall with a RICH to determine the EIC sensitivities of semi-inclusive DIS measurements with transversely polarized protons. This effort will be a multi-year ongoing effort, and we expect that more consolidation with other EIC PID efforts will occur.

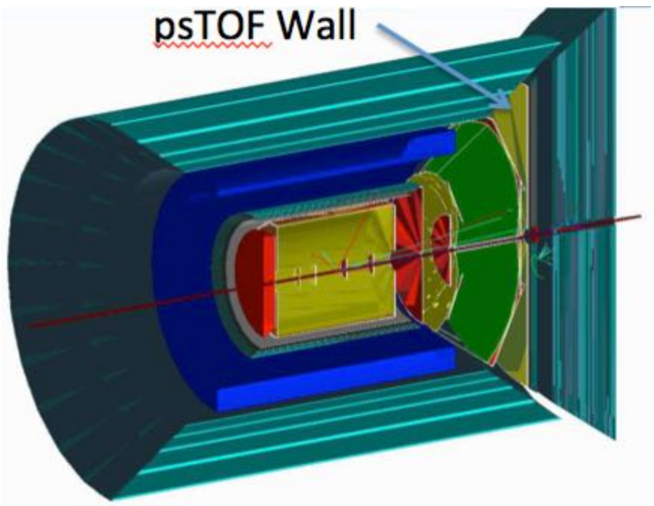

Fig .5: Implementation of a psTOF wall in the forward region of the ePHENIX GEANT4 simulation.

We have also written parts of a Garfield++ based code for detailed detector simulations. Such a study will be incredibly helpful in shrinking the incredibly large parameter space of mRPC parameters that we need to explore when optimizing the detector response. By parameters we mean such things as gas type, HV setting, gap thickness. This effort has been slowed down by lack of manpower, but we have recently identified a master's student at Howard who will start working on it immediately.

With TOF detectors, there is ultimately a question of where one can get a start time. There are quite a few options that we have suggested in the past:

1. If the RMS of the bunches in the electron beam is much shorter than 3 mm (10 ps), then one can use the beam RF clock along with a precise determination of the vertex to extract a start time. This method will depend entirely on the collider design, unfortunately.
2. One can place TOF everywhere and use the start time from the electron. This requires a precise vertex measurement and tracking.
3. Outgoing remnants of the hadron beam can be timed. At the LHC much work has been done to develop fast timing detectors to tag outgoing proton remnants from diffractive events at the 10 ps level, and such techniques could be applied at an EIC. More study needs to be done to determine the acceptance needed to time the forward going remnants (and even whether they determine the start time well since they may have lost significant energy). This is a technique that might be easier to do in e+A collisions than in e+p.
4. In relatively high multiplicity events, one can try to bootstrap the start time by assuming all particles are pions (since that is the dominant production), and then iteratively converging on a common start time that is consistent with all the measured particles in the event. This technique will probably succeed for high multiplicity events, and potentially fail for low multiplicities.

Most of the above options will need to be simulated to determine if they will actually work, and we will need to do this over the coming year.

Section 2: What are the future plans?

We have joined in the formation of the EIC PID consortium to help pool resources, share knowledge, and coordinate efforts. We have contributed a TOF section under this consortium, and the joint proposal is to be submitted to the EIC R&D program. Under this new consortium we have also started to work more closely with the eRD11 effort with LAPPD MCP-PMT development, and expect that in the next year we will devote more of our time to the LAPPD effort, assuming that some funding is allocated for production of MCP-PMTs from Argonne.

Our most critical issue at the moment is that for various reasons, UIUC will not be able to co-support our post-doc Ihnjea, who has built the UIUC test stand and did all the studies with the glass mRPC. We absolutely need to fund him for another 6 months in order for him to continue his studies with the glass mRPC's. Among the items which still need to be addressed are the efficiency of the mRPC, and systematic studies of its performance for different HV and gas combinations. Besides this, we are excited about the possibility that the 3D printed mRPCs may make for easier to build as well as superior performing mRPCs. We expect them to have superior performance due to the smaller gas gaps that can be made, and because one can print thinner layers of 3D materials compared to what can be purchased in glass. In fact, glass thinner than 150 um becomes flexible (and very expensive), and thus we may be pushing the limits to what one can do with glass mRPCs.

Another aspect of extending Ihnjea's funding is that it will allow ample time for a UIUC student to train with him so that UIUC will have an experienced person to continue these mRPC studies into the future.

BNL will begin building Kapton and Mylar based mRPCs and test them in their test stand. The simulations work will continue as well over the next year. Over the long term, we plan to build a few prototypes at the scale we would consider for the EIC detector, and test them in test-beam to determine the best available mRPC technology. For the next year we also hope to build a few LAPPD style MCP-PMT based TOF detectors and get some initial measurements of their performance.

For more details on the future plans, please check the TOF chapter in the EIC PID proposal.

Section 3: Manpower

One post-doc was funded through the EIC R&D, Ihnjea Choi. So far we have received 1 FTE's worth of post-doc funding and nothing else (no materials, etc). Ihnjea has been 100% on the project since last summer, and is supervised directly by Matthias, and remotely by Mickey. There are a variety of UIUC students involved, all supervised by Matthias. Chong Han (undergraduate) has been doing simulations of using TOF+RICH for a SIDIS measurement in e+p (0.2 FTE), and was helped initially by Yakov Kulinich (0.1 FTE). Jun Hui See Toh has been making 3D drawings and investigating the available 3D printers and printing materials at UIUC (0.1 FTE).

Mickey has spent 0.3 FTE of his time on the project, and is trying to find more time to spend. Rob Pisani has set up the gas system at BNL (2 weeks FTE), and can spend more time as needed when the R&D at BNL ramps up. Andrey Sukhanov is just coming off the MPC-EX project and has spent 0.1 FTE so far, but going forward will be able to devote much more time to this project, at the level of 0.5 FTE for the next year. He will be the main designer of our preamp board. Most of the other BNL co-authors spend time at the advisory level.

Marcus from Howard University has spent 0.1 FTE on this project. He has recently found funding for a master's student, who will work during the summers on the Garfield++ simulation of the mRPC, as well as during the school year as his time allows. At that point his time investment will ramp up since he will be one of the main advisors for this student.

We have recently added Rusty Towell from Abilene Christian University as a collaborator. Over the next year we expect Rusty to contribute for two months over the summer at BNL, along with 3-4 undergraduate students that he will bring. He is also interested in starting a lab at ACU, and may also be able to contribute during the school year for some systematic studies.

Section 4: External Funding

The materials and equipment that were needed to construct the glass mRPCs and buy the 3D printed gas gaps at UIUC were funded through the university or through Matthias's NSF grant. Some travel for Ihnjea was also funded through this. The total was about $25K for this. Some other funding for materials at BNL were provided through Mickey's PECASE grant, around $5K, mostly for electronics and testing equipment. In the future years, this relatively low level of funding that is required for materials and hardware can probably be supported at UIUC. Mickey's PECASE funding is over and he will need some alternative for anything but minor costs in the future.

Various members of our group are pursuing funding through various sources for homeland security applications of the fast timing detectors we are creating. This funding will have some synergies with the EIC R&D funding, but will necessarily have to be geared toward the defense application. These pursuits are still in progress and have not yet been successful, but we wanted to mention this as a possibility.

Section 5: Publications

So far we have not published any of our results, but we have only been at this for one year. However, since we have possibly gotten perhaps the best timing resolution ever with mRPC's, we have already talked about publishing our results in NIM. This will probably happen in a few months, and before the mid-year EIC R&D meeting in January 2016.