Development of High Precision and Eco-friendly MRPC TOF Detector for EIC

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Abstract

New generation of Multi Gap Resistive Plate Chamber (MRPC) can reach an intrinsic timing resolution of around 20 ps on par with e.g. Low Gain Avalanche Detector (LGAD) sensors and could be a cost effective solution to complement the time of flight system for the EIC Project Detector and/or the second detector in places where large area and moderate position resolution is needed. We are proposing to develop an accurate modelization software for MRPC simulation. We will use the software to optimize the MRPC design and study the replacement of the traditional gases with eco-friendly gases. We will also develop a time correction method based on machine learning to further improve the timing resolution. Combining cosmic-ray and beam tests with prototype MRPC modules using integrated front-end electronics, we will demonstrate a eco-friendly MRPC detector system with a total timing resolution of 20 ps or better.

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1 Introduction

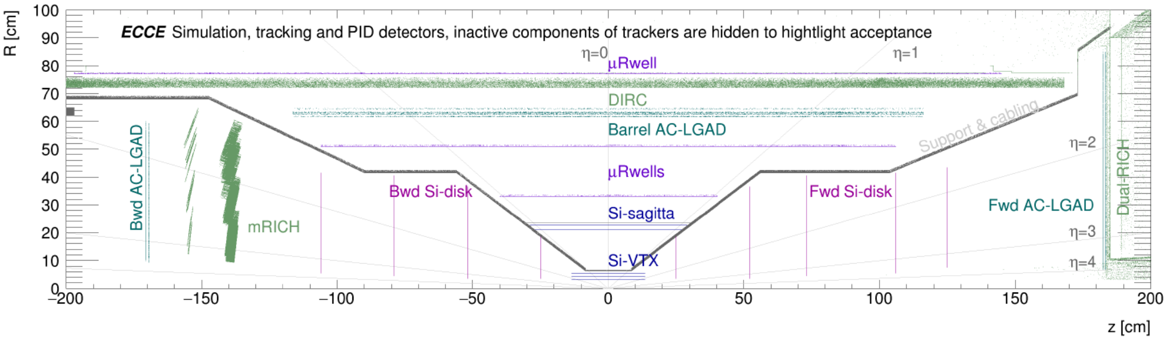


Figure 1: Tracking and PID detectors in ECCE detector proposal.

Precision timing detectors have wide applications in high-energy physics experiments. They have been used to identify particles using time-of-flight (TOF) information, and to improve tracking and/or calorimeter performance by incorporating the timing information of charged particle tracks. A TOF detector with a 20 ps time resolution can separate π/K up to 6 GeV/c after a 4 m flight path. Such detectors have been included in the reference detector design in the Electron-Ion Collider (EIC) Yellow Paper [1], and in all the three submitted detector proposals by ATHENA, CORE, and ECCE. For example, in the ECCE proposal which has been selected as the reference design for the EIC project detector at IP6 (Detector-1), a single layer of AC-coupled Low Gain Avalanche Detector (AC-LGAD) with a nearly 4π acceptance is included for TOF PID and tracking (see Fig. 1).

A main advantage of AC-LGAD is that it can provide both precise timing down to a few tens of picoseconds and spatial resolutions down to a few tens of microns. However, the cost of developing and building large area AC-LGAD detectors is quite expensive. Therefore, alternative solutions with cheaper development and construction cost are worth considering, especially in places where precise spatial resolution is not required.

Among various technologies, the Multigap Resistive Plate Chamber (MRPC) has been proven to be a reliable and cost-effective solution to precision timing measurement at RHIC and LHC experiments [2–4]. The timing resolution of these existing detector systems is on the order of 100 ps, with contributions from the intrinsic resolution of the MRPC itself, the readout electronics, as well as the start time (T_0). Prototypes of new generation MRPC can achieve 20 ps or better intrinsic resolution in cosmic-ray tests using standard gas. However, their actual performance in realistic high-energy experimental environments have not been studied. Another potential issue with the current operating MRPC detectors is the usage of greenhouse gases which might be forbidden to use in EIC. Several eco-friendly gas replacements have been studied with low rate tests but only 60 ps or worse time resolution have been achieved with ultra high voltages [5].

In this proposal, we will describe our plan to develop a MRPC detector system which can achieve a 20 ps timing resolution when operating the MRPCs in a realistic experimental environment using integrated front-end electronics and eco-friendly gases. Such a MRPC detector system can be considered as an option for the TOF PID in the EIC Detector-1 and/or the second detector at IP8.

1.1 Previous MRPC R&D

MRPC were invented in 1990s [6, 7] and then have successfully used in multiple particle physics experiments, such as in ALICE [8] and RIHC-STAR [9]. These first-generation MRPCs already have very good efficiencies and their time resolution are typically in the range of 50 to 100 ps. Future experiments, such as ALICE and CMS at CERN, CEE at IMP [10], CBM at FAIR [11] and SoLID at Jefferson Lab (JLab) [12], put a strict requirement of operating the MRPC under a very high rate background (up to 25kHz/cm^2), and in the meantime, still maintain very high detection efficiencies and precise time resolution.

The high rate requirement can be archived by employing 400μm thick low-resistive silicate glasses with a bulk resistivity of 10^{10} Ω, so-called black glasses, as demonstrated by the second generation MRPC developed by Tsinghua University [12–14] (Tsinghua). Even under an extremely high rate (70 kHz/cm^2), the beam-test shows that Tsinghua's MRPC still has very high detection efficiency (90%) with a time resolution better than 80 ps. We stress that the EIC detector is generally not a high-rate environment so MRPC with regular glasses are sufficient (10 times cheaper). However, at a very forward region for measurements of extreme physics processes (e.g. detecting jet or fragments in eA collisions), a high-rate and precise-timing detector may be needed to reduce the pile-up effect and maintain high detection efficiency.

In the last ten years, several R&D works have shown that a 20 ps level intrinsic time resolution on MRPC detectors can be achieved by reducing the thickness of each gas layer down to 100 μm and stacking more layers. The most recent MRPC designed for the ALICE-TOF upgrade showed an intrinsic time resolution of 25 ps [15, 16] at a low rate using regular glasses and the time resolutions become 36 ps and 50 ps at 2 kHz/cm^2 and 100 kHz/cm^2 when using the black glasses [17]. In a previous EIC R&D project (EIC RD2013-5 [18]) a thin-gas-gap MRPC prototype developed by members of the collaboration (UIUC and BNL) provided an 18 ps time resolution with the cosmic ray (25 ps in-beam at 80Hz/cm^2). However, these results were obtained with greenhouse gasses, which might be forbidden to use at EIC. Their performance in a realistic experimental environment has not been demonstrated yet.

1.2 Sealed MRPC

Tsinghua University has a long history of developing and constructing MRPC for RICH-STAR [19, 20], CBM, CEE, NICA [21], SoLID and EicC [22]. In the recent year, a brand new generation (gen-3) of MRPC has been developed (Fig 2) and it contains 32-gap with a gap thickness of 104μm [23, 24]. Black glasses are used when a high-rate measurement is required, otherwise regular glasses are used. The new MRPC also has a sealed structure [25] which can dramatically reduce the amount of greenhouse gas released to the atmosphere (20 cc/minute/cm^2). Such an achievement is extremely important for environmental protection point of view before eco-friendly gas replacements are identified.

Based on simulation, the intrinsic resolution of this sealed MRPC (sMRPC) can be as low as 10 ps [26] (see Fig. 8). To accommodate such a high resolution MRPC, the front-end electronics is thus planned to be a fast amplifier and a charge digitizer, in order to record the waveforms of signals from the MRPC detector. The timing performance was studied in a cosmic ray test using two identical sMRPC with gas mixture of 90% Freon (R-134a), 5%

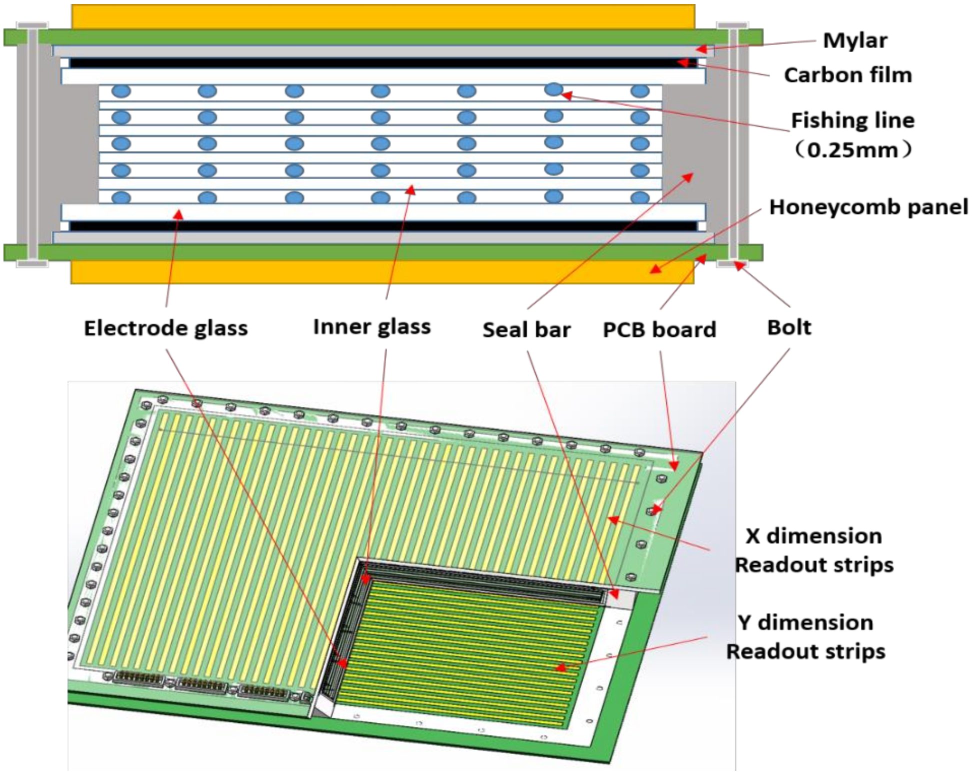
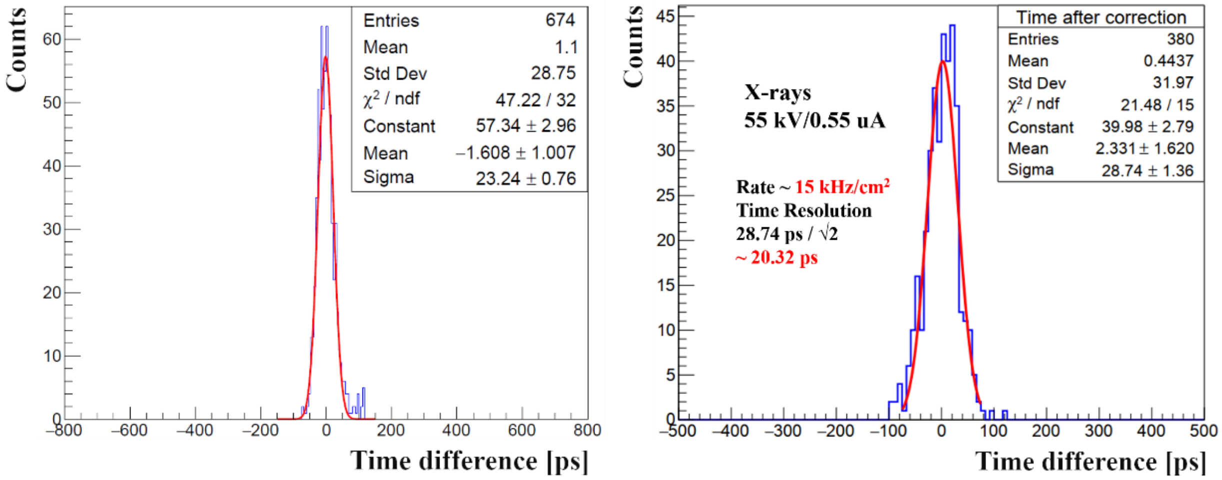


Figure 2: Scheme layout of the sealed MRPC (sMRPC) developed at Tsinghua University [24]

iso-butane and 5% SF6, so called the standard gas. The waveforms of the sMRPC signals were measured with an amplifier with the bandwidth of 350MHz was used in this test and the waveform digitizer was CAEN DT5742 (based on DRS4-V5 Chip). A 10GS/s sampling rate Lecroy oscilloscope was also used in measuring the waveforms as reference. A time resolution of 16 ps was achieve for a sMRPC in the test after the time slewing correction, as shown in Fig. 3.(a). The time resolution under high rates was also studied by exposing the sMRPC with X-rays at 55kV and 0.55μA which gives a background rate of 15kHz/cm^2 during the cosmic ray test. The study shows that the time resolution reduces to about 20ps (Fig. 3.(b)). New analysis based on the deep learning method suggests that using the Long-Short-Term-Memory network (LSTM) can further improve the time resolution to around 16 ps [26, 27].

sMRPC was identified as a possible candidate of the ECCE TOF detector but because of its limited spatial resolution, it was replaced by AC-LGAD right before the proposal being submitted. Four modules had already been produced by then at Tsinghua and later shipped to University of Illinois at Chicago (UIC). Two modules were installed in FermiLab Test Beam Facility (FTBF) as shown in Fig. 4. However, due to lack of high-performance readout electronics, we were not able to obtain useful data before the beam was taken away. The detectors are now stored at UIC waiting for future beam test opportunities at FTBF or JLab.

With the mature technology and cost effectiveness, the sMRPC can be considered by the EIC TOF community as a good replacement/supplement of the AC-LGAD at certain location of the Detector-1 and possibly as a major TOF detector in Detector-2. With the



(a) Low rate

(b) High rate

Figure 3: The time difference between two identical MRPC after time-slewing correction [24]. Each MRPC has a resolution of $23.24/\sqrt{2} = 16.42$ ps at low rate and $28.74/\sqrt{2} = 20.32$ at high rate (15kHz/cm^2).

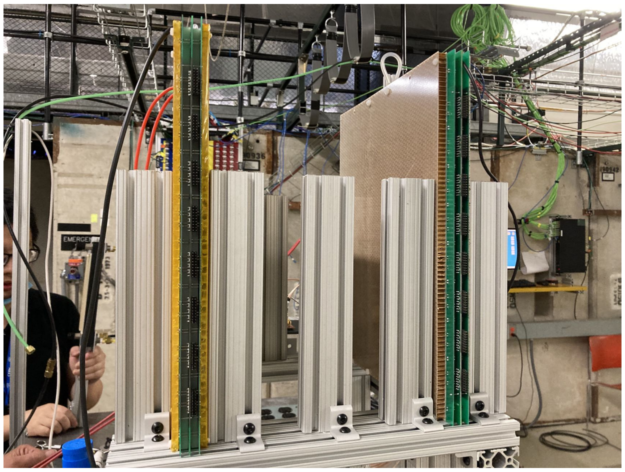


Figure 4: Two sealed MRPC were installed at FermiLab Test Beam Facility.

support from the EIC generic R&D plan, we plan to continue optimizing the design to meet the requirement of the EIC TOF system. We will also study and improve the in-beam performance of the sMRPC with eco-friendly gas. A time resolution between 10 to 20 ps which enable a clear π/K separation above 6 GeV/c will puts the sMRPC as a good candidate for EIC TOF system.

2 Deliverable

In this proposal, we focus on the software development of modeling MRPC on top of the simulation toolkit initially developed by Tsinghua [28, 29]. A reliable and efficient MRPC simulation toolkit is very beneficial for (but not limited to) the following studies:

- Optimize the geometry of the detector, for example, we can study the minimum layers of gas gaps that still can achieve the required time resolution. The material budget of the current sMRPC design is roughly at a 10% X_0 level mainly contributed by 33 glass layers which is not ideal for some regions in the EIC detector. Reducing sMRPC's thickness will minimize the impact on the downstream calorimeters and require less space in the barrel region of the EIC detector.

- Optimize the readout strip width and patterns which can improve the spatial resolution and potentially reduce the number of readout electronics channels which can significantly reduce the cost of the EIC TOF system.

- Investigate the replacements of the standard gas with more eco-friendly gasses and provide guidance for cosmic-ray and beam tests.

- Generate realistic simulation data to be used to train the machine learning model which can be used in the online/offline data analysis to further improve the time resolution. Note that the development of the machine learning model is one of this proposal's goals.

To validate the simulation and the neural network correction method, we will perform the bench-top test with cosmic-ray and beam tests at Fermilab and/or JLab using the existing sMRPC at UIC (and future sMRPC sent from Tsinghua) with different gas mixtures. The beam test data will be analyzed using the trained machine learning model and the realistic time resolution in an experimental environment will be evaluated.

In the next few subsections, we will list the detailed tasks to carry out.

2.1 MRPC simulation

It is desired to have a digitization software that can well model the structure and performance of MRPC as well as allows us to further optimize the design based on the real experimental environment the detector is operated under. Ideally this MRPC software can work as a standalone package and can also be easily integrated into the EIC simulation framework for global detector design and optimization.

We propose to use the Geant4 simulation to simulate the charged particles from the physics events and backgrounds under the EIC experimental environment. The events will be fed into the MRPC simulation software which simulates the output signal from the sMRPC when a charged particle hits the detector.

Figure 5 shows an overview of the simulation procedure. The output of the Geant4 events provides information on the particle, e.g. hit location and energy deposition. The detector response is characterized by transport parameters such as Townsend (avalanche) coefficient α, attachment coefficient η, and electron drift velocity v. The parameters are obtained using

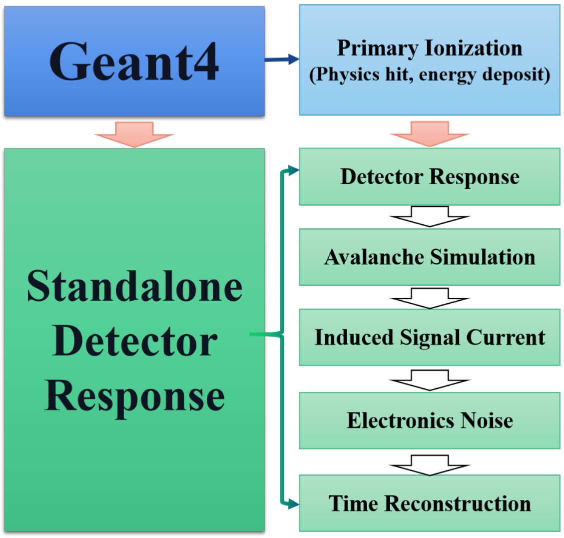


Figure 5: Schematic of the MRPC simulation

the Magboltz program [30] for a given electric field and the composition of the gas mixture. The electron multiplication (avalanche) process is simulated using a 1-Dimensional avalanche gas model developed by W. Riegler, C. Lippmann, and R. Veenhof [31]. In the simulation, an electron starts an avalanche that will grow until they reach to the end of the gas gap. Considering an electron at a position x in a gap, one can calculate the probability for an avalanche started with a single electron to contain n electrons at x+dx as:

$$P(n,x) = \begin{cases} k\frac{\bar{n}(x)-1}{\bar{n}(x)-k} & \text{(n=0)} \\ \bar{n}(x)(\frac{1-k}{\bar{n}(x)-k})^2(\frac{\bar{n}(x)-1}{\bar{n}(x)-k})^{n-1} & \text{(n>0)} \end{cases}$$

where the average number of electrons is $\bar{n}(x) = e^{(\alpha-\eta)x}$, and $k = \eta/\alpha$. α is the Townsend coefficient and η is the attachment coefficient, both from Magboltz. For each gas layer, the gap is divided into 200 steps, and for each step dx, the number of electrons with a probability for ionization and attachment is calculated. The same process is repeated over all electrons within a given gap until they reach the end of the gap. In addition, we employ an effective model based on the central limit theorem once the number of electrons is sufficiently large (n $>$ 200) to reduce computing time. In such a case, the number of electrons at $x + dx$ can be obtained by sampling a random number from a Gaussian with a mean of $\mu = n\bar{n}(dx)$ and $\sigma = \sqrt{n}\sigma(dx)$. Note that this 1-D model does not take into account that the growth of the avalanche is affected by space charge. The space charge effect stops exponential avalanche growth.

The induced current signal is then calculated using Ramo's theorem [32]:

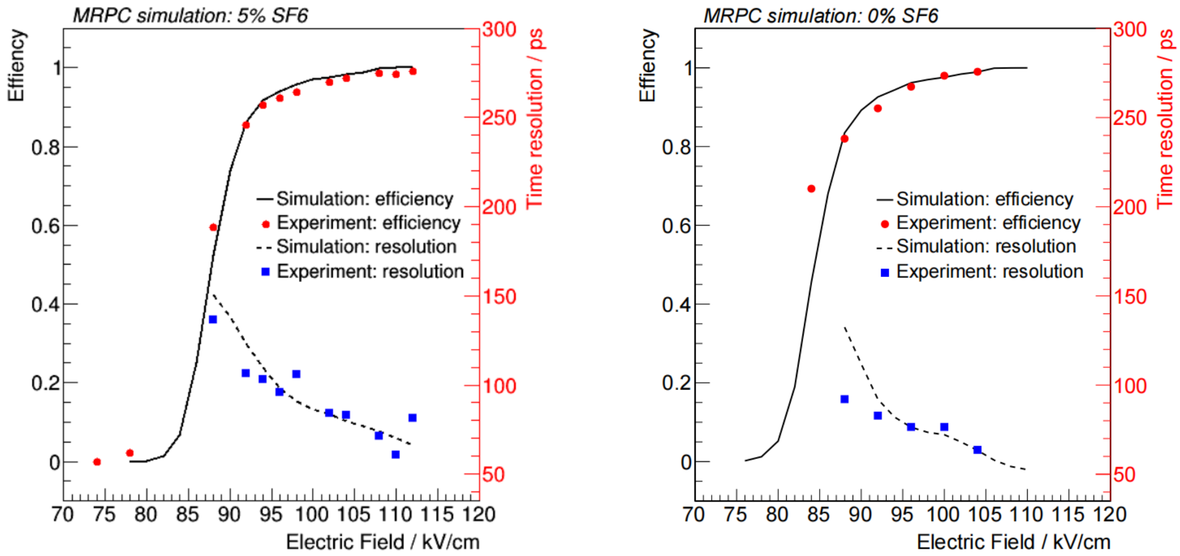
$$i(t) = E_W \cdot v \cdot e_0 \cdot N(t) \tag{1}$$

where E_w is the weighting electric field, v is the electron drift velocity, e_0 is the electron charge, and $N(t)$ is the number of electrons at time t. The weighting field is calculated using the number of gas gaps, the width of gaps and other material plates, and the permittivity of the resistive plates. Lastly, the timing information is obtained using a leading edge discriminator.

In addition to the gas transport parameters, the simulation is further tuned to match the experimental test setup. A Gaussian noise in the signal processing is introduced with σ_{noise}, and an additional smearing factor for the timing of σ_{smear} is applied to match the simulation output with the data. Both the time and integrated charge are recorded for each particle that enters the MRPC volume. The time-walk correction is then performed to get the timing resolution. The time-walk correction function used can be defined as:

$$f(Q) = c_0 + \frac{c_1}{\sqrt{Q}}. \tag{2}$$

Fig. 6 shows the simulation results of the MRPC with two different gas mixtures. The detection efficiencies and time resolutions in the simulation agree very nicely with the experimental data from cosmic ray tests. It suggests that the simulation toolkit can reasonably model the MRPC and its performance.



(a) (b)

Figure 6: The MRPC simulation results were compared with experimental data for two different gas mixtures.

Deliverable#1: We will adopt Tsinghua's MRPC simulation tool and continue making improvements as the following:

- Implement an advanced version of the Magboltz program, so-called the Betaboltz program [33] which is believed to describe the gas properties better and is also constantly maintained and extended by a broader community.
- Implement the space charge effect into the simulation based on the work [34] which was not considered in the simulation. It can better simulate the detector inefficiencies.

- Implement a 3D electrostatic weighting field instead of using a 1D field, based on a previous study done by Tsinghua [35]. It can simulate the charge distribution in the anode plane.
- Implement the charge sharing effect among neighboring strip. The original simulation assumed the strip closet to the gravity center of the shower picks up all the charges. The improved algorithm can determine how each strip picks up a certain portion of the avalanche signal and generates different pulses on both ends depending on the hit location and shower developments.

This improved simulation tool will allow us to better understand the performance of the sMRPC and help us to optimize their structures to fit into the different locations of the EIC detector. For example, the number of gaps and gap sizes of the sMRPC can be optimized depending on the requirements of the physics measurements such as timing precision, position resolution, and rate capability. We can also optimize the pattern of the strips to further improve the performance (e.g. efficiency, timing and spatial resolutions), while reducing the number of readout channels.

Another possible consideration is to adopt *Garfield++* which is a powerful tool to simulate particle detectors based on ionization measurement in gases and semiconductors. It is believed that the ionization and avalanche processes in different gas mixtures could be better simulated in this tool. The detailed sMRPC structure will be implemented into the Garfield++ framework and the simulation results will be compared with the ones generated using Tsinghua's simulation tool.

2.2 Eco-friendly gas vs. gas recycling system

One of the key R&D items for MRPC is to identify an eco-friendly gas to replace the standard gas (90% Freon, 5% iC_4H_{10}, 5%SF6) which will be restricted to use in national labs. Many experimental studies [5,36–40] have been performed to identify some eco-friendly gases that can potentially replace the greenhouse gas. So far, a good replacement gas is a mixture of $C_3H_2F_4$ (R1234ze) and CO_2 (or SF6). Other possible candidates are Argonne+CO_2 mixtures. However, the studies are never concluded as these replacements always have pros and cons, for example, some gasses are extremely expensive (e.g. R1234ze), some have an impact on the detector systems (e.g., Helium) and most of them require ultra HV to reach good efficiencies and resolutions. The long-term stability effect among different gas replacements was also not studied in detail. The performance is also related to the designed structure of the MRPC and how the test was performed (e.g, cosmic-ray tests vs beam tests). Overall, most of previous studies focused on the detection efficiencies while the best time resolution with eco-friendly gases is 60 ps or worse [5].

Deliverable#2: We will use the simulation as guidance to study and identify a set of eco-friend gas as replacements for the standard gas used in sMRPC. We will also investigate an alternative solution which is to design a gas-recycling system that includes purification and compression of gasses released from MRPC.

An initial study was done at Tsinghua [41] to simulate the working gas performance in MRPC which was later included in the simulation tool. With the new sMRPC simulation tool to be developed (Section 2.1), we will implement different gas mixtures into the sMRPC simulation and study the variation of performance (efficiencies and time resolution) vs. high-voltage applied. Important transport parameters of working gas in sMRPC, e.g. Townsend coefficient, electron attachment coefficient, drift velocity, and diffusion coefficient, can be calculated by Magboltz or Betaboltz with given an electric field. The gas mixtures fully studied by other groups will be first implemented as starting points. Simulation results will be cross-checked with the test results reported by other groups which allows us to improve the simulation. Then we will continue to explore other possible gas mixtures and identify a list of possible candidates that could be cost-effective while remaining good performance. Finally, we would like to confirm the simulation study with a real beam test using these echo-friendly gasses.

Tsinghua's sMRPC typically uses 20cc/minute of gas for a 1m^2 area MRPC and the gas are released into the atmosphere if not recycled. For the EIC Detector-1, the total TOF area is about 20m2. Assuming a whole year of running, 210 m^3 of the gas will be released into the air. While the standard gas is cost-effective but not environmentally friendly, these eco-friendly gas replacements are generally very costly and their effects on the environment are still unknown. CBM designs a gas-recycling system that will recapture the standard gas released by MRPC, and purify and mix the gasses for reuse. We will investigate the cost of such a recycling system for EIC compared with the cost of directly releasing echo-friendly gases into the air, and evaluate its impact on the entire detector system. The study would provide important input to the consideration of choosing MRPC as part of the TOF system in Detector-1 or future Detector-2.

2.3 Timing correction with machine learning

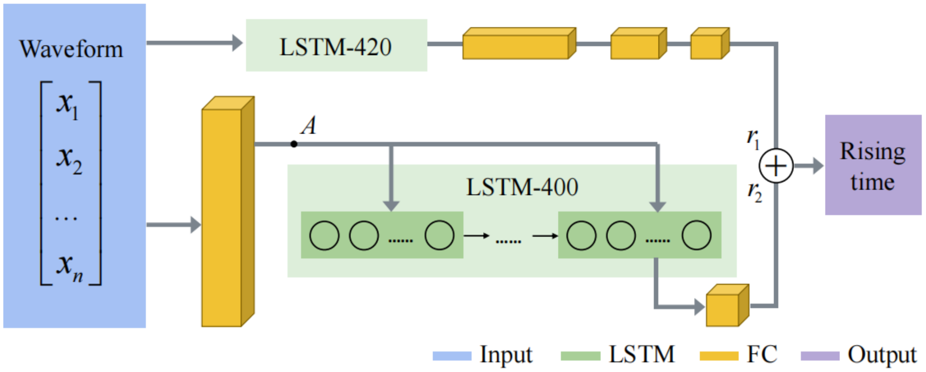
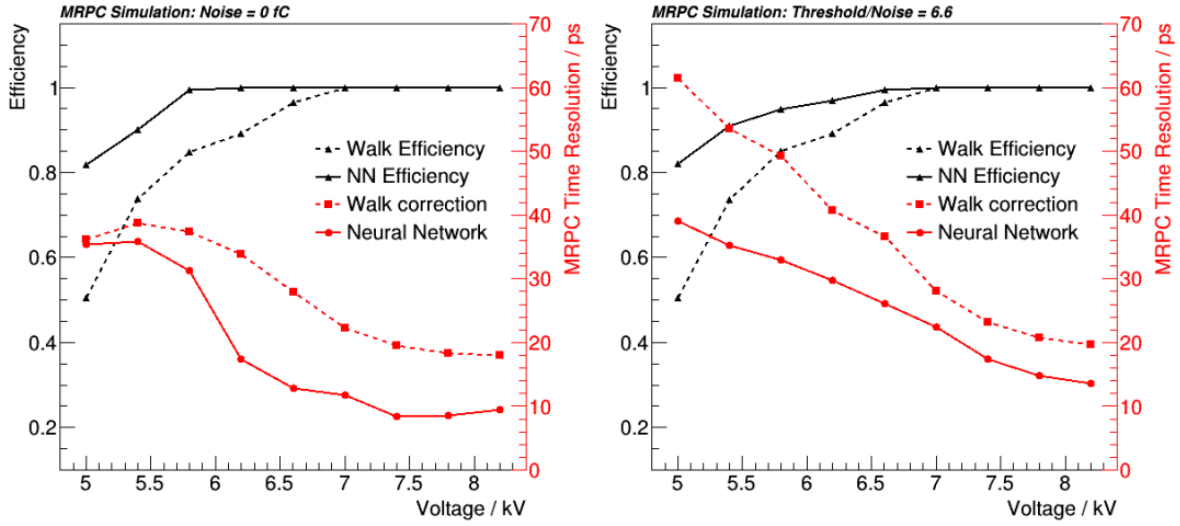


Figure 7: The framework of MRPC ComLTSM neural network [27, 28]

For typical timing measurement, a Time-Over-Threshold(ToT) method is commonly used due to the slow response of the front-end electronics and the easy implementation in discriminators. By setting a fixed threshold, this method measures the threshold crossing time (t_c) and the total time over threshold t_{tot}. t_c is regarded as the particle arriving time, and t_{tot} which is strongly related to the pulse height is used for the time walk correction of t_c (Eq. (2)). Such a two-point method is limited by the resolution of the TDC electronics, the variation of the incoming signals as well as the signal-to-noise ratio (SNR). In a large scale experiment, the time-walk correction is difficult during the online analysis or offline analysis where either the noises are high or the ADC information is not necessarily available.

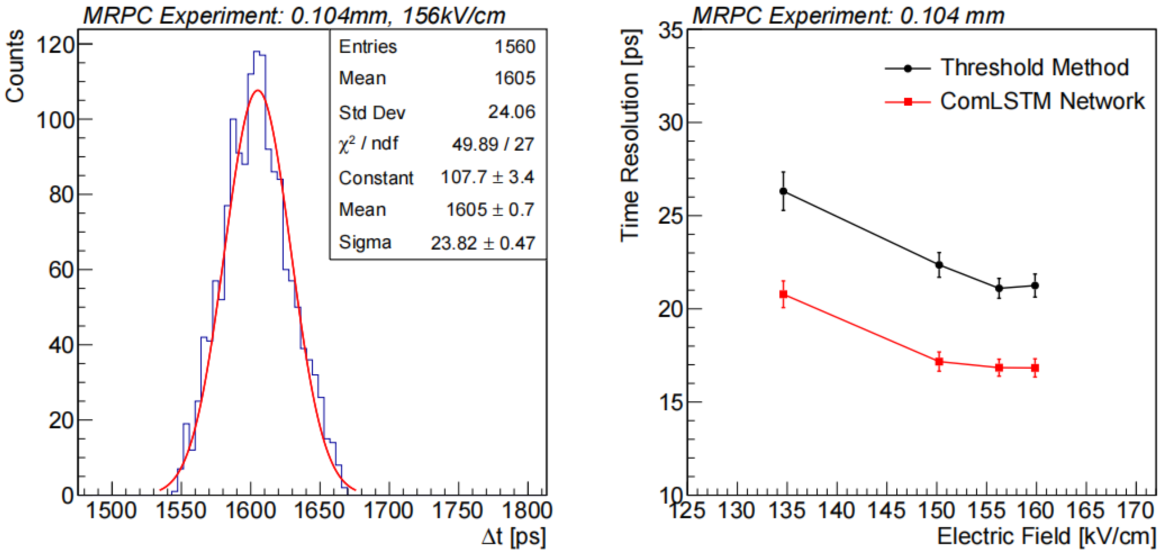
With high sampling rate front-end electronics, the waveform of the timing signal's rising edge could be captured, for example, a CAEN waveform digitizer DT5742 (based on DRS4-V5 Chip) can collect up to 8 samples of the raising edge from a MRPC signal. A time reconstruction method based on the neural network and machine learning algorithms has been developed by Tsinghua to take the full sampling waveform [26] to obtain precise t_c without additional corrections. The neural network (NN) is a powerful tool in solving non-linear pattern recognition problems and has more and more applications in the fields of particle physics. In this time reconstruction method, a fully connected network is proposed to learn the waveform patterns from the simulation data and then applied in the real experimental data to estimate the particle arrival time. A combined LSTM (ComLSTM) neural network takes several uniformly distributed points on the leading edge of the signal waveform as the input and outputs the length of the leading edge t_l (Fig. 7. By subtracting t_l from the peak time t_p, the estimated particle arriving time is $t_a = t_p - t_l$.



(a) (b)

Figure 8: The MRPC simulation results [26] using sMRPC (gen-3, 32-gaps, 104μm gap size). The plots show the timing resolution and efficiencies as functions of high-voltages obtained with the ToT method and the NN method. (a) are results with no noise added in the simulation and (b) has electronics noise added with a threshold/noise ratio equal to 6.6.

The power of adopting the NN method is demonstrated in Fig. 8 where the efficiencies and time resolutions of a 32-gap 104μm gap-size sMRPC are plotted as a function of high voltages. The curves obtained suggest that compared with the ToT method, the NN method is very effective to obtain higher time resolution at lower voltage even with noise presented in the simulation data. The study was validated by the cosmic-ray data shown in Fig. 9. A 16 ps time resolution can be obtained with the NN method compared with 23 ps using the ToT method.



(a) **(b)**

Figure 9: The MRPC cosmic-ray test results [27] using sMRPC (gen-3, 32-gaps, 104μm gap size). (a) shows the timing resolution obtained with the NN method (single MRPC resolution is $23.83/\sqrt{2} = 16.8$ ps). (b) compares time resolutions vs. working voltages using both the ToT method and the NN method.

Deliverable#3: We propose to improve the Tsinghua neural network method using a more powerful machine learning toolkit and study improvement of the timing resolution in the simulation data and the real data after corrected with the NN method.

Besides using the default ComLSTM model, we will also explore other modern machine learning toolkits to reduce the learning time and improve the models. With the update and improved Geant4 simulation for the current sMRPC design (Section 2.1), we can generate new sets of simulated data to be used to train the machine learning model. We will then apply the trained model to the future JLab beam-test data and evaluate the improvement of the timing resolution. An efficient NN method would enable a real-time correction of the timing measurement during the online data taking and allow us to reduce the data size by saving the time signal instead of waveform. It is extremely useful since the DAQ system of the EIC detector is going to be triggerless.

2.4 Cosmic and Beam test

Deliverable#4: To validate the simulation and adjust some of its parameters, we are planning to carry out cosmic and beam tests with the current existing prototype of sMRPC.

The timing performance of the new generation MRPC were only been evaluated with cosmic-ray or low-intensity narrow beam using a fast-sampling oscilloscope. However, instantaneous variations in flux will introduce voltage fluctuations and cause time-walk fluctuations. Currently the studies of MRPC performance under radiation background only two types of tests: (a) During cosmic-ray test, using low-energy x-ray expose to the entire detector plane where the secondary charged particles mostly stop in the first glass layer; or (b), Low/high energy beam hitting in a small spot of the detector while in the actual operation the entire detector plane are exposed to high-energy particle under high-rates. Due to the large amount of channels, fast front-end electronics as parts of the integrated DAQ system are used to collect the timing signal. The performance of the electronics system is going to be one of the major contribution to distort time information.

Hence, the actual performance of the MRPC needs to be evaluated with the integrated front-end electronics system using high-energy charged particles and background particles hitting a large area of the detector. We propose to use the 32-channel waveform digitizer based on SAMPIC [42] chips to evaluate the performances of these systems and be able to fully instrument the detectors.

Two MRPC detector planes will station at UIC and continuously measure cosmic ray data for software development, gas mixture study, and electronics tuning. Depending on the beam schedule, the setup will be moved to FTBF for real beam test. Both tests will exam the intrinsic time resolution of the MRPC with no or small background.

The experimental halls at JLab can offer large background parasitically to running experiment. We are proposing to setup two MRPC detector planes in the JLab experimental hall (e.g, Hall-C) and study its performance under high-energy radiation background with various rates. Results from both the cosmic-ray test and the beam tests will be used to iterate with the simulation works to fine tune the input parameters.

3 Timeline and milestones

Task	**Start**	**End**	**Milestone**
Software development	Oct 2022	Jan 2023	fully working codes
Eco-friendly gas	Jan 2023	July 2023	simulation and cosmic ray test agree with previous studies
Neural Network development	Jan 2023	April 2023	NN correction applied to simulation and cosmic-ray data
Cosmic-ray/Beam test	Oct 2022	June 2023	Prototype setup and data taking with cosmics and beam
Beam test analysis	June 2023	September 2023	Time resolution and efficiency studies with standard and eco-friend gas; Iterated with NN correction

Table 1: Timeline and Milestone.

The main tasks carried by the Tsinghua team is the development of the simulation software and the neural network correction method. The UIC team will focus on the eco-gas system, cosmic ray test and FTBF beam test where the later depends on the beam-time schedule. Both the Tsinghua team and the UIC team will work together on analyzing and comparing the real data with simulation data for different eco-friendly gasses. The JLab team will focus on assisting and carrying out the cosmic-ray test and the beam tests, as well as supervise the students on analyze the simulation data and the real data. While all tasks will be carried out by close collaboration among teams and some tasks are highly correlated, we are trying to give a rough timeline and the milestones given in Table 1.

4 Budget request

Tsinghua will have one full-time student working on the development of the simulation software (\$2K×3 months) and the neural network method (\$2K×3 month).Then the student will closely work with UIC and JLab teams on comparing the simulation data with real data and apply the correction with NN method (\$2K×6 month). The student will travel to US to participate the beam test at FTBF and JLab (2 months, \$10K). In a scenario of a nominal budget minus 40% is given, the student will find other support for traveling to US or just skip the trip.

UIC needs to purchase the MRPC gas-circulation system and different gas mixtures (\$25K). In addition, UIC will buy a HV supply (\$10K) and two SAMPIC modules (\$5K×2), as well as The cost for traveling to FTBF and JLab for beam tests is about \$10K. One FTE graduate student with 0.5 FTE (\$25K) supported by the project and the rest covered by other resources will work on the cosmic-ray and beam tests, perform data analysis and compare results with simulation data.

JLab will purchase the MRPC gas mixtures, gas-circulation system and other small accessories for the local beam test (\$10K).

	Software Development	Neural Network	Eco-friendly Gas	Cosmic& Beam Test	Sum
Tsinghua	\$9K	\$9K	-	\$10K	\$28K
UIC	-	-	\$25K	\$55K	\$80K
JLab	-	-	-	\$10K	\$10K
Total					\$118K

Table 2: Money Matrix.

In total, we request a budget of \$118K to support the tasks layed out in this proposal. Table 2 give the detailed breakdown of the budget to be shared among three teams for different tasks. Tsinghua takes the lead of the software development and the neural network implementation. All these are mainly labor cost. UIC will focus on setting up experiments (hence ”Eco-friendly Gas” goes to UIC) and perform cosmic ray and beam testing while helping improvement of the software by comparing real data and simulation data. Tsinghua and UIC will work together on studying the eco-friend gasses by performing both the simulation study and the experimental tests. For the ”Cosmic/Beam Test”, Tsinghua's cost is mostly the travel cost, UIC's cost will be mainly equipment and labor, and JLab's cost will be mainly the gases.

In a scenario of 80% of the requested budget is granted, Tsinghua will skip the trip to US ($10K less), UIC will purchase one SAMPIC module only and reduce the test beam time and thus the travel cost ($10K less).

In case of only 60% of the requested budget is given, we will skip the beam tests hence reduce the $10K for gas purchase at JLab, and reduce travel cost to zero.

Detailed tables in the following sections reflect different budget scenarios.

4.1 Detailed budget full funding

Tsinghua University	Graduate student 12 months	$18K
Tsinghua University	Travel	$10K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×2	$10K
UIC	Gas system and gas	$25K
UIC	Travel for beam test	$10K
JLAB	Gas supplies	$10K
Total		$118K

4.2 80 % budget scenario

Tsinghua University	Graduate student 12 months	$18K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×1	$5K
UIC	Gas system and gas	$25K
UIC	Travel for beam test	$5K
JLAB	Gas supplies	$10K
Total		$98K

4.3 60% budget scenario

Tsinghua University	Graduate student 12 months	$18K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×1	$5K
UIC	Gas system and gas	$25K
Total		$83K

5 Manpower

The 1 FTE of Tsinghua student will be located in China and supervised by Zhihong Ye, to work on developing the software and NN analysis, support test beam and test beam analysis The 1 FTE UIC student will be located at UIC and be supervised by Zhenyu Ye, and will mainly focus on eco-gas system, cosmic and beam test setup and analysis.

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