Development of Micro-Pattern Gaseous Detectors for Nuclear Reaction Studies

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Abstract: One of the frontiers of today's nuclear physics research is the synthesis of Super Heavy Elements (SHE). Fusion-fission dynamics, namely the competition between quasi fission and fusion is one of the key challenges to optimize the SHE. To have an insight into the dynamics, one requires the study of fission fragment mass and angular distribution near barrier energies for heavy-ion induced fission reactions. Recent successful installation of linear accelerators in India offers a unique opportunity to study the dynamics of nuclear reactions and formation process of SHE. For the effective utilization of these current, as well as upcoming facilities, development of novel detectors to study reaction dynamics, formation process of SHE with heavier projectiles and higher beam energies is needed. Gaseous detectors have undergone a rapid improvement in terms of spatial, temporal and energy resolution, rate capability, radiation hardness, ion feedback etc., ushering in a new genre of micro-structured devices based on semi-conductor technology, commonly known as Micro-Pattern Gaseous Detectors (MPGDs). Although many of the MPGD structures were primarily developed for high-rate tracking of charged particles in high energy physics experiments, stability of operation, simplicity of construction and relatively low cost make these detectors suitable for other applications, such as low-energy nuclear physics experiments. The present activities encompass a detailed evaluation of the operational conditions of Micromesh-Multi Wire and THGEM-Multi Wire hybrid detector operated in low-pressure isobutane gas with a view to optimizing their use in the detection of charged particles and fission fragments.

1. Introduction.

Nuclei with the magic number of nucleons (neutron or proton) show extra stability as the outer nuclear shell is fully filled up [1]. Due to this nuclear shell effect, elements having atomic number higher than 103, called Super Heavy Elements (SHE), do exist [2]. Example of these elements are

Rutherfordium (atomic number 104), Dubnium (105), Seaborgium (106) etc. Theoreticians predict that the super heavy element with neutron magic number N = 184 and proton number Z = 114/120/126 will be a stable element [3 -5]. Since currently it is not possible to produce the element with N = 184 (as that would require highly neutron rich targets and projectiles which are not available in nature), 210Po with magic number N = 126 can be studied extensively to explore the survival of nuclear shell effects around the excitation energy around 40 MeV, beyond which one would expect the shell effects to vanish [6 -7]. It is also well-known that the production cross section of SHE through the fusion of two heavy nuclei faces a dramatic drop because of quasi-fission. To understand the contribution of quasi-fission, it is necessary to develop thorough understanding of the fusion-fission reactions. The fission fragment mass distribution can be used as an experimental probe to enhance knowledge of the fusion-fission process and to look for the presence or absence of shell effects in nuclei.

In order to carry out a successful experiment in this regard, we need to measure Z, A of the emitted particles (from dE/dx, time-of-flight measurements), their energy and its dependence on angle (measurement of energy and position), as well the cross section (count of scattered particles). Simultaneous measurements of velocity, energy and angular distributions of the two correlated reaction products can give information about the contributions of the different types of reactions, as well as dynamics of fission. In such studies, it is essential to separate the fission fragments from compound nuclear reaction from those following elastic, quasi-elastic and non-compound fission reactions. For the detection of the fission fragments, position sensitive gas detectors Multi Wire Proportional Counters (MWPCs) are generally used [8]. Working at low operational gas pressure, these detectors provide time, position and information on energy loss. Major advantages of such detectors are their high gain in a compact shape. These detectors can be made to cover large surface area, if needed. This type of detector with a thin-walled windows have been fabricated in the Variable Energy Cyclotron Centre (VECC) and used successfully to study different fission reactions in which very good time (0.7 nSec) and position (1.5 mm) resolutions were achieved [7].

The central anode plane of MWPC detectors is the main charge multiplication region. Since the gain is inversely proportional to the radius, the usage of thin 10 µm wires suits best for MWPCs. However, this makes the detectors highly fragile, and prone to tear. Therefore, these detectors can not be considered to be portable. The present work is motivated towards adding this much needed attribute to this kind of detector, maintaining all the advantages of the older design as much as possible. In particular, time of arrival, position and energy loss information should be of a similar quality, as obtained from the older detector.

During recent times, Micro-Pattern Gaseous Detector (MPGD) [9] design and applications have made significant progress towards achieving excellent time, position and energy resolution. Semiconductor fabrication technologies used in the production of many of these detectors lead to very robust designs, as well. Here, we have made an attempt to evaluate two such MPGDs, namely MicroMesh Detector [10] and Thick Gaseous Electron Multiplier (THGEM) [11], for their suitability in replacing the anode wire plane.

2. Numerical Framework:

The simulation work has been carried out using Garfield [12] simulation framework which has interfaces to other software packages such as nearly Exact Boundary Element Method (neBEM) [13], HEED [14] and Magboltz [15]. In the present work, three types detectors were investigated:

- **Multi-Wire Proportional Counter (MWPC):** The MWPC consists of five wire planes which include one anode (A), two sense wire planes (X, Y), two cathode wire (C) planes. A schematic diagram of the numerical model of the MWPC-based detector is shown in figure 1a. The design parameters are listed in table 1. The two cathode wire planes are shorted and connected to a charge sensitive pre-amplifier. This gives the provision to get the energy loss signal. The signals from X and Y wire planes are taken using delay line chips. Since the avalanche are localized near the anode wire, the timing is faster and, therefore, timing signal is taken from anode using fast pre-amplifier.

- **Micromesh Multi-Wire Hybrid Detector:** It consists of five wire planes, one micromesh plane, two sense wire planes (X, Y) and two cathode wire planes. In this case, electron multiplication is occurred near to the micromesh wire plane and, the timing signal is taken from the micromesh. The two cathode wire planes are shorted and connected to a charge sensitive pre-amplifier. This gives the provision to get the energy loss signal. The signals from X and Y wire planes are taken using delay line chips. A schematic diagram of the numerical model of the MWPC-based detector is shown in figure 1b and the design parameters are listed in table 1.

- **THGEM Multi-Wire Hybrid Detector:** It consists of four wire planes, two sense wire planes (X, Y) and two cathode (C) planes. In place of anode wire, double-sided single THGEM detector is used. A THGEM electrode is made of a sub-mm thick double-sided printed-circuit board (Cu-clad on both surfaces). In this case, electron multiplication occurs inside the THGEM holes and, the timing signal is taken from the bottom of the THGEM. The two cathode wire planes are shorted and connected to a charge sensitive pre-amplifier. This gives the provision to get the energy loss signal. The signals from X and Y wire planes are taken using delay line chips. A schematic diagram of the numerical model of the MWPC-based detector is shown in figure 1c and the design parameters are listed in table 1.

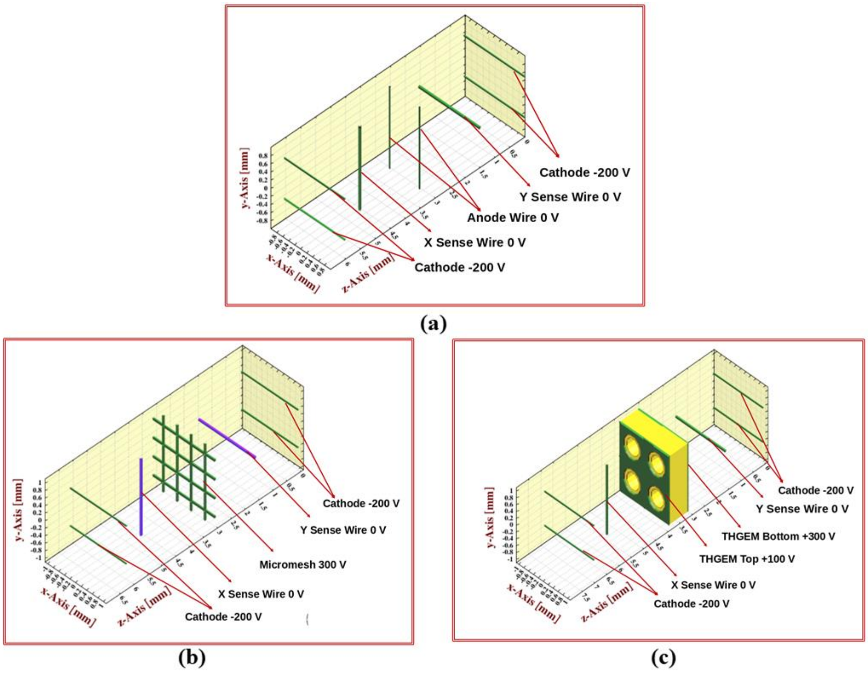

Figure 1: Numerical model for (a) Multi Wire Proportional Counter, (b) Micromesh Multi-Wire Hybrid Detector and (c) THGEM Multi-Wire Hybrid Detector

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Table 1: Design Parameters of the MWPC, Micromegas Multi-Wire Hybrid Detector and THGEM Multi-Wire Hybrid Detector

Parameters	MWPC	Micromesh Multi-Wire Hybrid Detector	THGEM Multi-Wire Hybrid Detector
Cathode Wire Diameter	20 µm	20 µm	20 µm
Cathode Wire Pitch	1 mm	1 mm	1 mm
Anode Wire Diameter	12.5 µm		
Anode Wire Pitch	1 mm		
X and Y Sense Wire Diameter	50 µm	50 µm	50 µm
X and Y Sense Wire Pitch	2 mm	2 mm	2 mm
Gap between Cathode Wire to Sense Wire	1.5 mm	1.5 mm	1.5 mm
Gap between Sense Wire to Anode Wire	1.5 mm	1.5 mm	1.5 mm
THGEM Thickness			0.8 mm
THGEM Hole Diameter			0.5 mm
THGEM Hole Rim			0.1 mm
THGEM Hole Pitch			1 mm
Gap between Sense Wire to THGEM Top Surface			1.5 mm
Gap between Sense Wire to THGEM Bottom Surface			1.5 mm
Micromesh Wire Diameter		50 µm	
Micromesh Wire Pitch		450 µm	
Gap between Sense Wire to Micromesh		1.5 mm	

Primary electron clusters were generated along a track within the drift gap. Drift of the primary-electrons and the avalanche of secondary electrons were simulated. In parallel, the drift lines of the ions were also traced. The current induced onto different electrodes have been calculated by means of the Shockley-Ramo theorem. The current pulse was then convoluted with the readout electronics response function. Note that similar framework was used in the past successfully for simulating the signal from THGEM-based detectors using different pre-amplifiers [16].

3. Results & Discussion

3.1 Multi Wire Proportional Counter based Detector

A single electron avalanche and corresponding secondary ion drift lines of a MWPC-based detector is shown in figure 2. The voltage configuration for this case is shown in figure 1. The electrons are found to multiply very close to the anode wire, whereas the ions produced there are collected on the cathode wires, comparable, but more on upper side ($z > 3$) and less on the lower side ($z < 3$).

In the present work, the preliminary focus is to estimate the timing signal and position signal using a fast pre-amplifier of rising time < nSec. For the MWPC-based detector, the anode signal (which is the timing signal) and the position signal for a track of 10 primary electrons are shown in figure 3 for different voltage configurations. The three different voltage configurations are listed in table 2. Amplitude of the X and Y position signals are equal and ~30% of the anode signal. It was also observed that the increase of anode voltage, as well as cathode voltage, increase the position signal significantly

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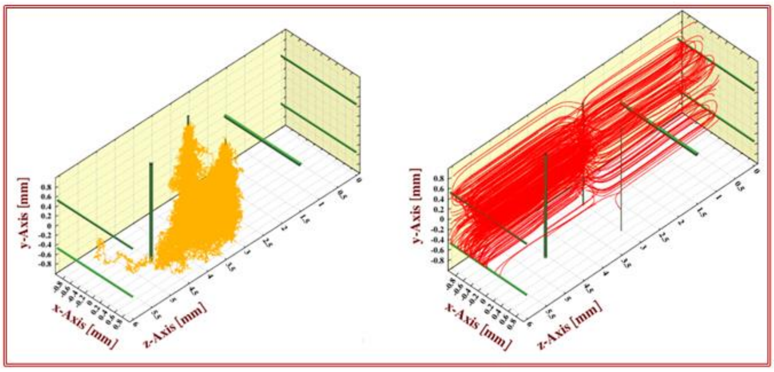
(figure 3). The rise time of anode signal is ~ 7 nSec while that of position signal is ~ 8 – 13 nSec. This result is in agreement with the previous experimental data [7].

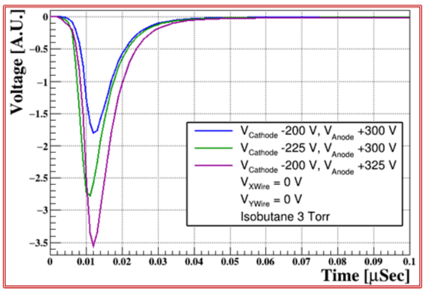
Table 2: Voltage configurations used for MWPC-based detector in isobutane gas of 3 Torr

Sr #	$V_{Cathode}$ [V]	V_{Anode} [V]	V_{XWire} [V]	V_{YWire} [V]
1.	-200	+300	0	0
2.	-225	+300	0	0
3.	-200	+325	0	0

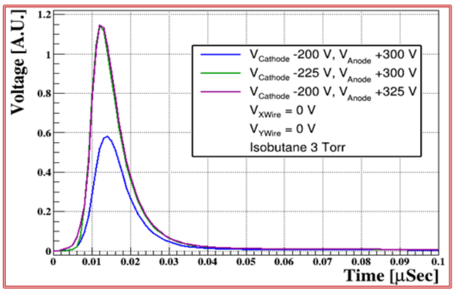


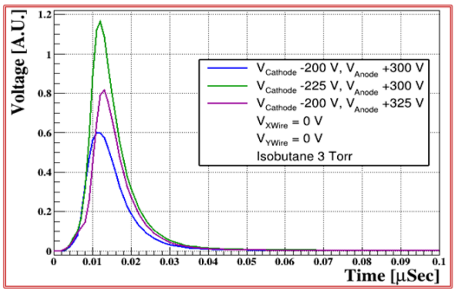
(a) **(b)**

Figure 2: (a) Single electron avalanche and (b) secondary ions drift for MWPC



(a)





(b) **(c)**

Figure 3: Simulated signal from fast pre-amplifier for MWPC-based detector: (a) anode, (b) X-position wire, (c) Y-position wire

In the next sections, we have replaced the anode wire with the Micromesh and THGEM detector. Since in the present report we are only considering the signal shape and rise time of the signal, the following parameters need to be kept in mind:

a) The rise time of the timing signal should be ~ 10 nSec
b) The rise time of the position signal should vary between 10 – 20 nSec.
c) It will be good to have position sense wire signal from both X and Y plane of similar amplitude and they should be strong enough for the detection over noise threshold

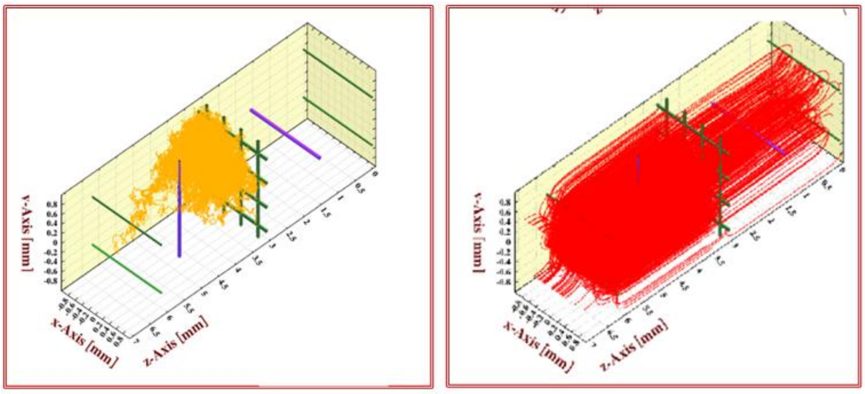
3.2 Micromesh Multi-Wire Hybrid Detector

In place of fragile anode wire, a Micromesh has been used. A single electron avalanche and corresponding secondary ion drift lines of a Micromesh Multi-Wire Hybrid detector is shown in figure 4. For the given voltage configuration of Figure, the primary electrons are multiplied near the Micromesh wire planes. Almost 90% of ions move back to the top cathode wires, whereas the others are collected on the bottom cathode.

Table 3: Voltage configurations used for Micromesh Multi-Wire Hybrid detector in isobutane gas of 3 Torr

Sr #	$V_{Cathode}$ [V]	$V_{Micromesh}$ [V]	V_{XWire} [V]	V_{YWire} [V]
1.	-200	+300	0	0

As mentioned earlier, in the present work, the preliminary focus is to estimate the timing signal and position signal using a fast pre-amplifier of rising time < nSec. For the Micromesh Multi-Wire Hybrid based detector, the mesh signal (which is the timing signal) and the position signal for a track of 10 primary electrons are shown in figure 5 for the voltage configurations mentioned in table 3. Amplitude of the X position signal is ~ 50% of the Micromesh signal, whereas that of Y position signal is ~ 15%. The rise time of anode signal is ~ 9 nSec while that of position signal is ~ 10 – 15 nSec.



(a) **(b)**

Figure 4: (a) Single electron avalanche and (b) secondary ions drift for Micromesh Multi-Wire Hybrid Detector

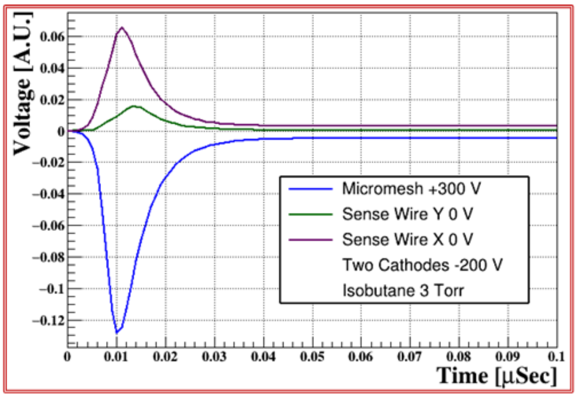


Figure 5: Simulated anode, X-position wire, Y-position wire signal from fast pre-amplifier for Micromesh Multi-Wire Hybrid Detector

3.3 THGEM Multi-Wire Hybrid Detector

A single electron avalanche and corresponding secondary ion drift lines of THGEM Multi-Wire Hybrid detector is shown in figure 6. For the given voltage configuration of figure 1c, a few of primary electrons are collected on the THGEM top surface whereas the others are multiplied inside the THGEM hole. Finally, the electrons are collected on the bottom of the THGEM. Almost 95% of ions move back to the top cathode wires, whereas the others are collected on the bottom cathode.

Table 4: Voltage configurations used for THGEM Multi-Wire Hybrid detector in isobutane gas of 3 Torr

Sr #	$V_{Cathode}$ [V]	V_{Top} [V]	V_{Bottom} [V]	V_{XWire} [V]	V_{YWire} [V]
1.	-200	+100	+300	0	0
2.	-200	+100	+500	0	0
3.	-300	+100	+400	0	0
4.	-300	+100	+500	0	0
5.	-200	+200	+500	0	0
6.	-100	+300	+600	0	0

An optimization of the voltage configuration was carried out to obtain a proper timing signal from the THGEM and position signal from X and Y wire. For this purpose, six different voltage configurations as listed in the table 4 were considered.

The preliminary focus is to estimate the timing signal and position signal using a fast pre-amplifier of rising time < nSec. The signal calculation has been performed for the above mentioned six voltage configurations. THGEM top, bottom and X and Y position wire signals are plotted in figure 7. As in the case of earlier studies, the fast-timing signal and position signal for a track of 10 primary electrons are calculated. For the 5^{th} voltage configuration, the signal from the THGEM top, bottom and the both position wires look reasonable to work with. The THGEM top and bottom signal amplitude is same and the rise time of is ~ 15 nSec. For the same voltage configuration, the signal from X position wire is ~ 2% of the THGEM bottom signal whereas the signal from Y position wire is ~ 10%. The rise time of position signal is ~ 12 – 15 nSec.

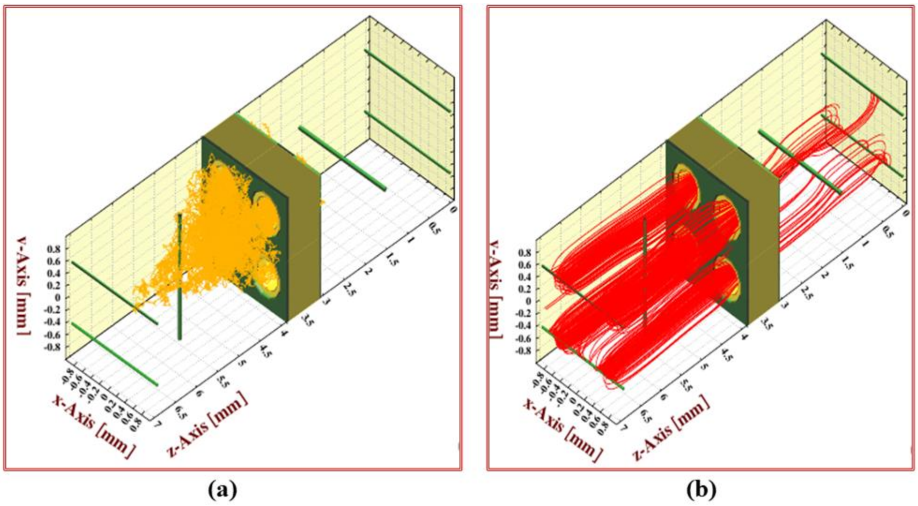


Figure 6: *(a) Single electron avalanche and (b) secondary ions drift for THGEM Multi-Wire Hybrid Detector*

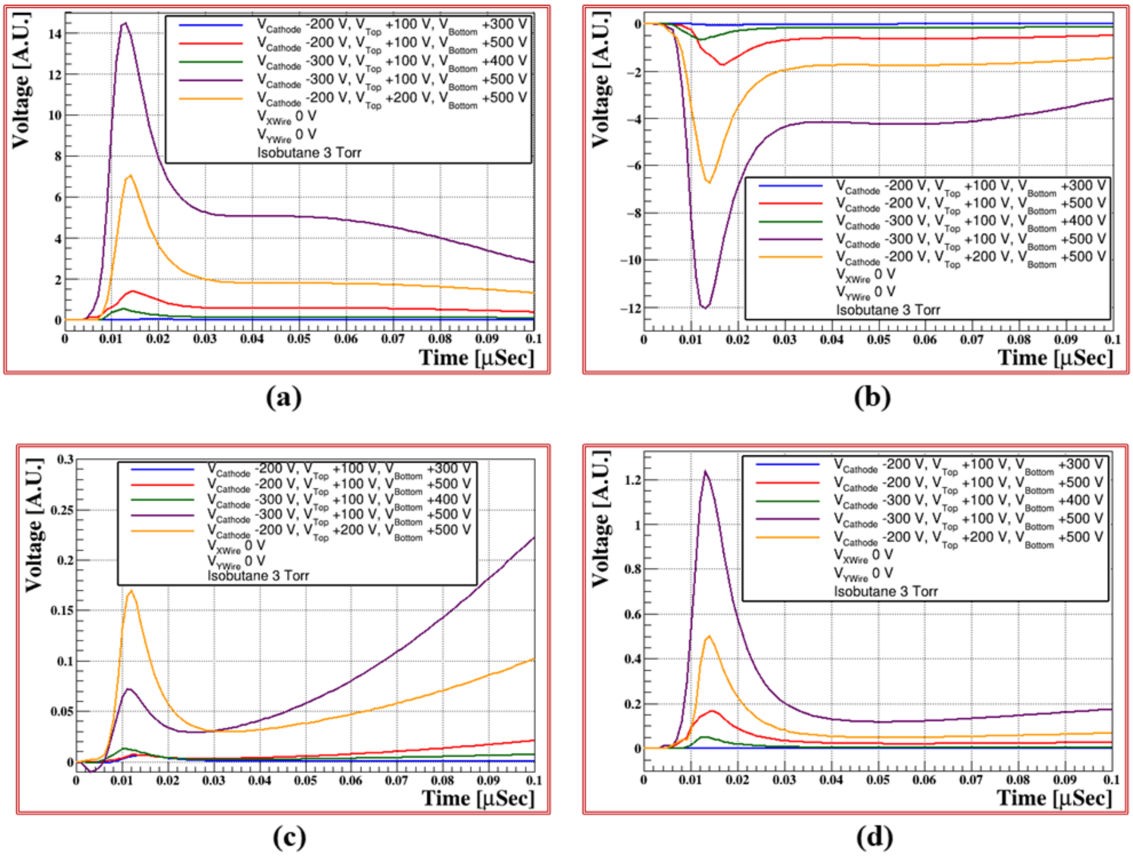


Figure 7: Simulated anode, X-position wire, Y-position wire signal from fast pre-amplifier for THGEM Multi-Wire Hybrid Detector

4. Summary and Conclusion

Several numerical studies have been carried out to evaluate the feasibility of replacing the anode wire plane by Micromesh, or a THGEM, suppression of photon feedback being an important advantage of the THGEM-based design. Both the design possibilities have yielded encouraging results. The simulations indicate that all necessary information will be preserved in the new detectors, and signals of acceptable characteristics will be observed from the pickup electrodes.

We plan to carry out further simulations to fine-tune the results obtained here. Finally, we will proceed with the building the detectors soon and testing them in Indian accelerator facilities.

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References

[1] Cohen B L, *Concepts of Nuclear Physics* (McGraw-Hill, New York, 1971)
[2] Oganessian Y T and Utyonkov V K, 2015 *Rep. Prog. Phys*. **78** 036301
[3] Christiansen J, 1952 *Z. Angew. Physik* **4** 326
[4] Itkis M G, Oganessian Yu Ts and Zagrebaev 2002 *Phys. Rev. C* **65** 044602
[5] Moller P and Sierk A 2003 *Nature* **422** 485
[6] Ghosh T K, Pal S, Sinha T, Chattopadhyay S, Golda K S, Bhattacharya P 2005 *Nucl. Instrum.and Meth*. A **540** 285
[7] Ghosh T K 2018 *Springer Proc. Phys*. **201** 15
[8] Charpak G and Sauli F 1979 *Nucl. Instrum. and Meth. A* **162** 405
[9] Sauli F, https://doi.org/10.1142/11882
[10] Giomataris, Y.; Rebourgeard, Ph.; Robert, J.P.; Charpak, G. (1996) *Nucl. Instrum. and Meth. A* **376** 1
[11] Chechik R, Breskin A, Shalem C and Mormann D 2004 *Nucl. Instrum. and Meth. A* **535** 303
[12] Veenhof R 1998 *Nucl. Instrum. and Meth*. A **419** 726
[13] Majumdar N and Mukhopadhyay S 2006 *Nucl. Instrum. and Meth. A* **566** 489
[14] Smirnov I B 2005 *Nucl. Instrum. and Meth. A* **554** 474
[15] Biagi S F 1999 *Nucl. Instrum. and Meth. A* **421** 234
[16] Bhattacharya P, Moleri L and Bressler S 2019 *Nucl. Instrum. and Meth. A* **916** 125