NUCL SCI TECH (2017) 28:102
DOI 10.1007/s41365-017-0244-5

Simulation of a new hybrid MPGD with improved time resolution and decreased discharge probabilities using Garfield++

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Received: 7 March 2016 / Revised: 4 July 2016 / Accepted: 14 October 2016 / Published online: 8 June 2017

Abstract In this work, a new hybrid MPGD consisting of two GEM foils and a metallic mesh was proposed. Based on the simulation studies, this design can significantly reduce the rise time of signal and has a better performance in respect of particle identification compared with the triple GEM design. The gain with various voltages setting was computed in order to provide us references for future experiment. The simulation results also show that the time and space resolution compared to the triple GEM detector are also improved. The time and space resolution of hybrid detector with Ar/CO_2(70/30) and Ar/isobutane(95/5) were investigated for various drift electric field intensities. This new hybrid detector shows excellent potential for both fundamental research and imaging applications.

Keywords Hybrid MPGD · Particle discrimination · Simulation · Garfield++ · Rise time · Gain · Time and space resolution · Discharge

Supported by the National Natural Science Foundation of China (Nos. 11135002, 11275235, 11405077 and 11575073).

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1 Introduction

The Micro-Pattern Gaseous Detector has been developed for nearly 30 years since it was born for meeting the requirements for fine spatial and timing resolution and the ability to withstand high particle fluxes. Nowadays, GEM detectors [1] and Micromegas detectors [2], which have improved space resolution and rate capabilities once again, are still the most widely used MPGDs playing a fairly important role in fundamental research and applications in nuclear and particle physics. They are used in many laboratories all over the world, but the most critical issue of them has been so far the detector discharge. In this paper, the main subject is to find a best scheme for designing a new hybrid MPGD having not only fine spatial and temporal resolution but also very low discharge probabilities.

GEM detectors and Micromegas detectors are widely used in cosmic muon scattering tomography and neutron imaging. The background whose largest contribution is from X-rays has a great impact on the imaging effect, so reducing the background is especially important. These two kinds of detectors, moreover, are widely used in particle physics experiments as track detectors. X-rays affect the track reconstruction of high energy particles which pass through the detector. Therefore, distinguishing X-rays and charged particles is meaningful for fundamental research and imaging applications. In Lanzhou University, we did experiments to discriminate between X-rays of ^{55}Fe and cosmic muons with triple GEM detector based on rise time. The rise time of an incident particle consists of three parts. The first part of the rise time is the distribution of primary electron–ion pairs resulted from energy deposition of incident particle in the drift region. Charged particle deposits energy along its track and produces electron–ion pairs over the whole track. As a contrast, X-ray loses its energy in a small region. Different ways of depositing energy present differently on the time characters of signals. We just discriminate cosmic muon which deposits energy along its track and X-ray based on this part of time contribution. The second part of the rise time is the drift time of electrons in the induction region. The third part is the rise time of the electronics. For the better result of discrimination, the last two time should be as short as possible. The result represented that we could distinguish 97% of the cosmic muons from X-rays at best [3]. It is not the ideal result because of the induction gap of our triple GEM detector (4 mm) that induces a long rise time. For further optimization, reducing the thickness of induction region to 100 µm with a Micromesh from Micromegas detector can decrease the intrinsic rise time. However, the discharge between readout and Micromesh has always been the main problem of Micromegas plaguing the entire relative researchers. So far, the primary two methods to reduce the impact of discharges in Micromegas are letting GEM foil preamplify primary electrons and making resistive coating on the strips [4]. In this article, the GEM foil as preamplifier is the subject investigated. The properties of the new hybrid detector that we designed were simulated with Garfield++ [5]:

1. Rise time of hybrid device compared to GEM device.
2. Gain of hybrid detector with different gas mixtures.
3. Other properties of hybrid detector with different gas mixtures in variable drift electric fields.
4. Discharge probabilities of hybrid detector.

All the simulated results provide references so as to construct the new hybrid detector that optimize discrimination efficiency and avoid discharge. In a large sense, this work may provide other researchers a MPGD design method with reference data of gain, discharge probabilities, space resolution and time resolution of hybrid detector with different gas mixtures and variable electric field intensities.

2 The new hybrid detector and simulation method

The structure of our hybrid detector is shown in Fig. 1. It consists of two GEM foils and a metallic mesh which is used in Micromegas detector as Micromesh. So the hybrid detector is a kind of combination of GEM detector + Micromegas detector. The primary electrons produce by incident particle ionization will be multiplied with large gains in GEM1, GEM2 and induction region between Micromesh and PCB-readout. In Garfield++, the detector could be built as we require and the electric field could be identified by setting voltages on the cathode, GEMs, Micromesh, and PCB-readout. The voltage on PCB-readout usually is 0 and the others are negative voltages. In the process of the simulation of signal, gain, drift time and transverse diffusion, the primary electrons would be placed at one spatial point of the drift region, firstly. Secondly, they would drift and avalanche in GEMs and induction region. Finally, we could get the information as follows: the signal induced by electrons on PCB-readout, total number of electrons multiplied, the position of PCB-readout where the electrons arrive and the time when they reach PCB-readout. The number of total multiplied electrons is gas gain of detector, and the deviation of time and position represents the time resolution and spatial resolution, respectively. In the process of the simulation of muon and X-ray, the incident particles, muons or X-rays, provided by the class TrackHeed, would produce primary electrons in the drift region. The rest is like mentioned before. The total number of electrons multiplied from each X-ray was counted, and the energy spectrum of X-rays could be obtained.

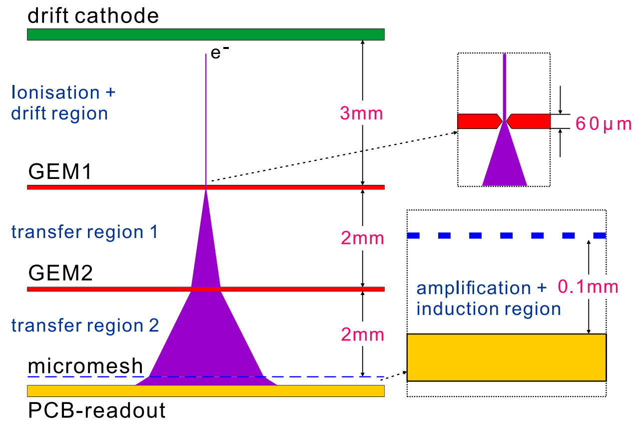

Fig. 1 (Color online) Structure of the new hybrid detector

In Garfield++, there is a coefficient r which represents penning transfer rate. Different gas mixtures have different penning transfer rate. Therefore, r to the working gas mixture should be first identified. Ar/CO_2(70/30) and Ar/isobutane(95/5) are the common gas mixtures which are most frequently used in GEM and Micromegas detectors. We also used these two kinds.

For Ar/isobutane(95/5), a Micromegas detector set with same structure as the prototype for the COMPASS and CLAS12 experiments [4] represents different gain values under different penning transfer r. Comparing with experimental data, we could find in Fig. 2 that $r = 0.5$ is the best choice of this kind of gas mixture under normal temperature and pressure. For Ar/CO_2(70/30) the penning transfer $r = 0.56$, which was investigated by other researchers [6].

In order to prove that the simulation setting is correct, the energy spectrum of the Micromegas detector was computed with a ^{55}Fe 5.9 keV X-ray virtual source, as shown in Fig. 3. The energy resolution is about 14.2%, the

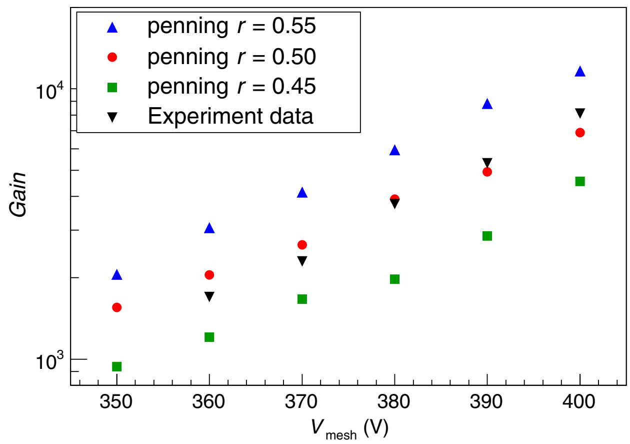

Fig. 2 (Color online) Penning transfer testing of Micromegas detector. The Exp.Data is from the COMPASS and CLAS12 experiments [4], and it was the biggest gain among the ten different prototypes of Micromegas

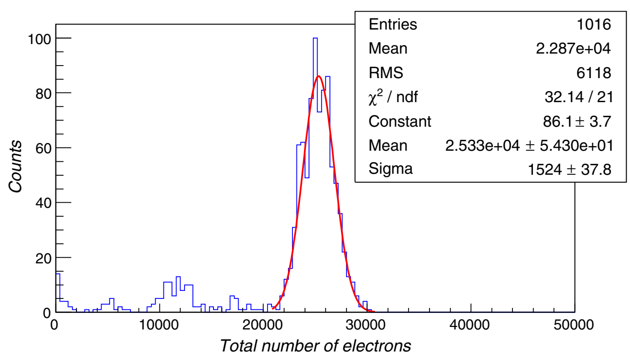

Fig. 3 (Color online) Energy spectrum of ^{55}Fe 5.9 keV X-ray

escape peak of Argon atom and full photo-electron peak of ^{55}Fe are distinguished completely, which demonstrates the simulated gain should be credible.

3 Results and discussion

3.1 Rise time

Based on the result of simulation, the current signal caused by the avalanches of primary electrons in a double GEM device is shown in Fig. 4a. The forming time of the signal is about 50 ns which is too long for particle discrimination. We reconstructed the detector with an extra Micromesh set 100 μm above the PCB-readout, i.e., the new hybrid detector. Figure 4b shows the current signal of this hybrid device. The forming time is about four times shorter than before. The shortening of forming time means that using the new hybrid detector is a right way to improve on distinguishing between muons and X-rays in our experiment. The forming time of the simulated current

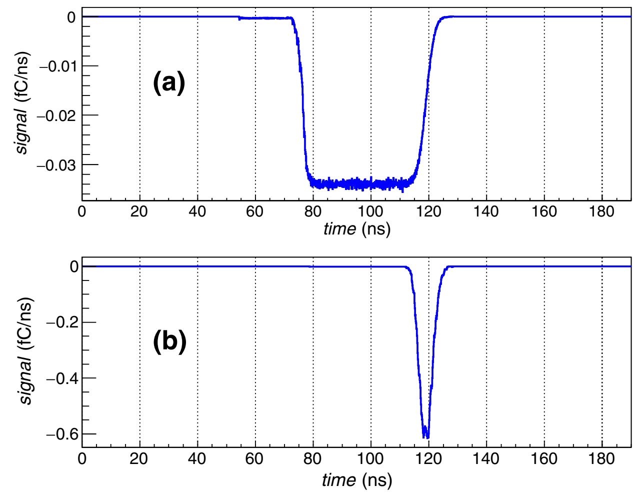

Fig. 4 (Color online) **a** The current signal of double GEM device; **b** the current signal of hybrid detector. The thickness of the induction region of double GEM device is 2 mm. The working gas mixture of these two devices is Ar/CO_2(70/30)

signal just reflects the rise time of the amplified voltage signal in the experiment, and the two incident particles were just discriminated by setting an appropriate threshold of the rise time to get the respective results. If the rise time is reduced as the simulation illustrated, the discrimination by hybrid detector will be better than the performance of our triple GEM detector.

In order to further prove the reduction of rise time of voltage signals in the experiment, the simulation of voltage signals induced by one 4 GeV incident muon and one 5.9 keV incident X-ray, respectively, in single GEM device and single GEM + Micromesh device was executed. The result is illustrated in Fig. 5. The blue signals (up) are the induced current signals and the red signals (down) are the voltage signals, which are the corresponding current signals convoluted by a preamplifier with time constant of 25 ns. In the single GEM, the rise time of muon sample (b) is nearly twice the amount of the rise time of X-ray sample (a). In view of fluctuation, this ratio is not big enough. However, in the single GEM + Micromesh detector, the rise time of muon sample (d) is almost five times the amount of the rise time of X-ray sample (c), which proves that hybrid device is the optimized resolution of discriminating between X-rays of ^{55}Fe and cosmic muons.

3.2 Gain

First of all, the gain in amplification region between Micromesh and readout should be calculated to identify the appropriate high voltage on Micromesh. Electrons placed in transfer region 2 drift into amplification region through Micromesh and multiply. The total electrons produced by

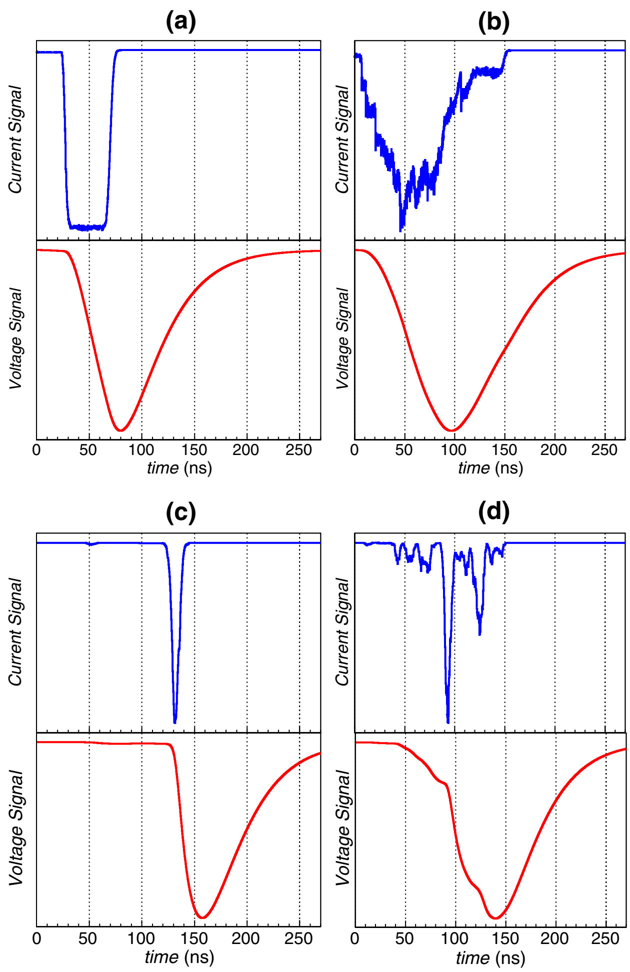

Fig. 5 (Color online) The *blue* signals (*up*) are the induced current signals and the *red* signals (*down*) are the voltage signals, which are the corresponding current signals convoluted by a preamplifier with time constant of 25 ns. **a** Signal of single GEM device produced by a X-ray sample; **b** signal of single GEM device produced by a muon sample; **c** signal of combination of single GEM and Micromesh produced by a X-ray sample; **d** signal of combination of single GEM and Micromesh produced by a muon sample. The thickness of the induction region of single GEM device is 2 mm. The working gas mixture of these two devices is Ar/CO_2(70/30)

avalanches of the primary electrons was computed as Fig 6 illustrates. For avoiding discharges of Micromegas, the high voltage on Micromesh should be as low as possible. However, it could not be too low, because the main signal should be induced by electrons produced under Micromesh in order to make the forming time of signal decrease. When gain is 20, 95% of signal induced by electrons produced under Micromesh. It is the lowest gain which could still work to reduce forming time. For Ar/isobutane(95/5), the voltage on Micromesh is about 195 V and for Ar/CO_2(70/30) 400 V.

The total gain of the hybrid detector which should be equal with our triple GEM detector is about 10,000. So the gain of double GEM in hybrid detector should be 500. For

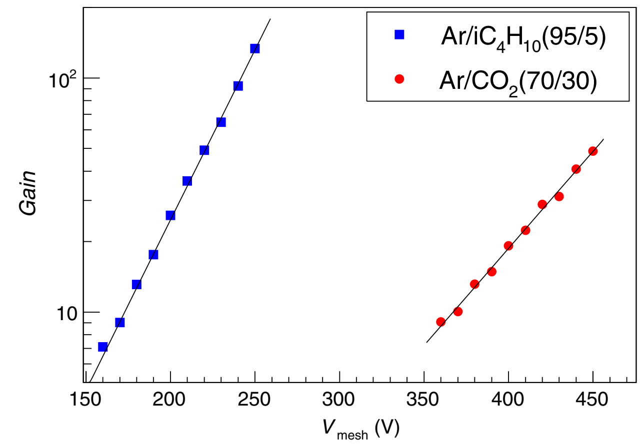

Fig. 6 (Color online) Gas gain in Micromegas for various mesh voltages

simplification, the voltages on two GEM foils were set by same value. The gain of double GEM is shown in Fig. 7. For Ar/isobutane(95/5), the bias voltage of single GEM foil is about 140 V and for Ar/CO_2(70/30) 275 V.

In conclusion, Ar/isobutane(95/5) need much lower voltage than the other one in order to reach the same gain. That may benefit the improvement of discharge problem, compared to Ar/CO_2(70/30).

3.3 Performance of time and spatial resolution

Drift time and transverse diffusion of electrons in triple GEM detector were simulated and the σ_t and σ_s represent the time resolution and spatial resolution, respectively, as shown in Fig. 8. Simulation of hybrid detector which has same gas mixture, drift electron field, drift height, distance between GEM and total gain as the triple GEM detector is illustrated in Fig. 8. The bias voltage of GEM foils and voltage on Micromesh are just the result indicated in

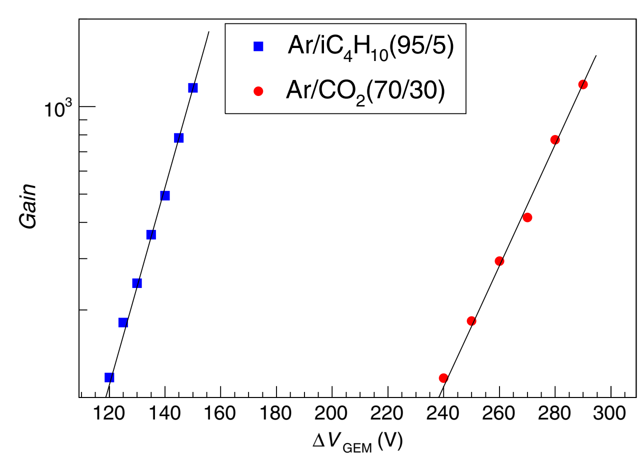

Fig. 7 (Color online) Gas gain in double GEM for various GEM bias voltages

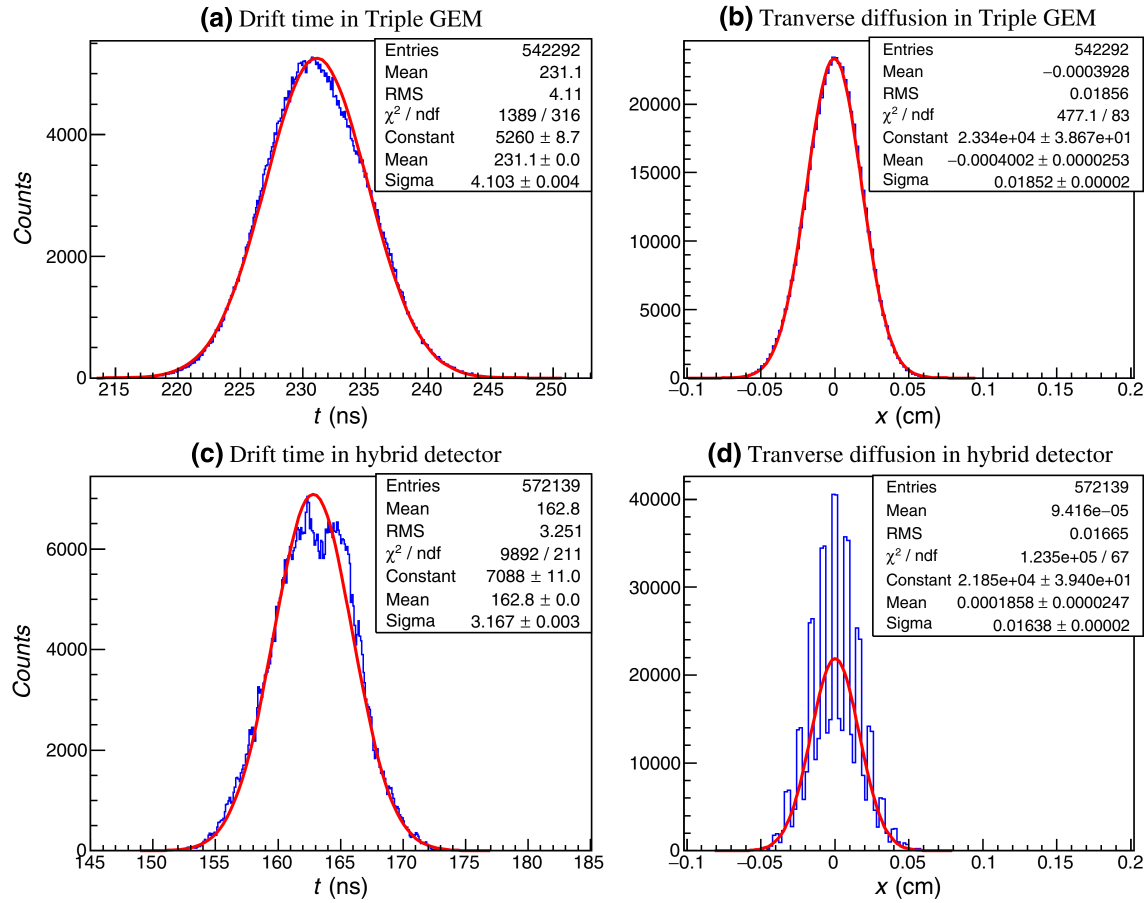

Fig. 8 Drift time and transverse diffusion of electrons in Triple GEM detector and hybrid detector. The t axis of drift time represents the time when all the electrons reach PCB-readout and the x axis of transverse diffusion represents the position of PCB-readout where they arrive. For triple GEM: $\sigma_t = 4.103$ ns, $\sigma_s = 185.2\,\mu$m. For hybrid detector: $\sigma_t = 3.167$ ns, $\sigma_s = 163.8\,\mu$m

Sect. 3.2. The σ_t and σ_s both are better than the triple GEM detector. Besides the reduction of forming time, the rise time would be further decreased because of the improvement of the σ of drift time. Moreover, the spatial resolution is also improved, which is also good for particle tracking.

For different gas mixtures, the temporal and spatial performances of hybrid detector with variable drift electric field intensities are shown in Table 1. Ar/CO_2(70/30) is better than Ar/isobutane(95/5) in terms of both σ_t and σ_s. When the drift E is 3 kV/cm, the σ_t reaches the minimum while the σ_s is low enough to our experimental goal. The accurate discharge rates for different gas mixtures and variable drift E are not clear currently. If discharge cannot be observed in detectors with this two gas mixtures, the gas with CO_2 will be our best choice and 3 kV/cm also the best drift E.

Table 1 Temporal and spatial performances

E (kV/cm)	Ar/isobutane(95/5)		Ar/CO_2(70/30)	
	σ_t (ns)	σ_s (μm)	σ_t (ns)	σ_s (μm)
0.5	5.472	376.6	5.342	172.4
1	5.634	339.9	3.167	163.8
2	6.098	412.6	2.153	190.5
3	5.326	380.9	1.968	205.4

3.4 Discharge probability

It was reported during the past study of Micromegas detector with a GEM foil as a preamplifier that the discharge rate would be about 100 times smaller than for a stand-alone Micromegas detector, and in some researches the discharge could even not be observed [7–9]. The discharge probability is further decreased when increasing the GEM high voltage at fixed total gain [4]. In our new hybrid detector, there are two GEM foils which make the total gain easily reach high value while the voltage on Micromesh is much lower than a stand-alone Micromegas and even lower than the past hybrid detector with only one GEM foil. We estimate that the discharge rate would be further reduced. Experiment of discharge rate will be initiated to prove this estimation.

4 Conclusion

The new hybrid detector has the capability to substantially decrease rise time of signal in order to completely distinguish cosmic muons and X-rays of ^{55}Fe. We infer that it can also be used in discriminating charged particles and photons. It shows outstanding performance in energy resolution. With double GEM foils, it can reach high gain when the voltage on the Micromesh is a very low value, which may decrease the discharge rate more than 100 times to the stand-alone Micromegas detector. Moreover, it has better time and spatial resolution compared with triple GEM detector. The double GEM + Micromesh combination appears to be an ideal device for distinguishing between charged particles and photons and thus improves muon and neutron imaging effect and tracking accuracy of charged in particle physics experiments.

The next step in the future is to build this hybrid detector and experimentally authenticate this simulation work. Then neutrons detection should be tested to distinguish recoil protons from X-rays based on rise time.

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