Neutron Detection with Gadolinium and GEM Detector

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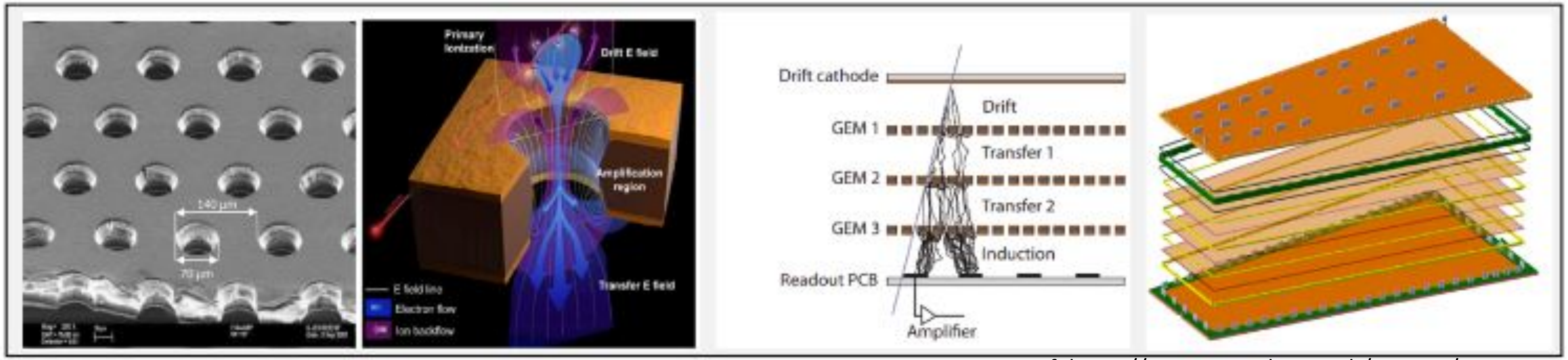
Gas Electron Multiplier (GEM)



Ref: https://ep-news.web.cern.ch/content/gems-cms

GEM FOIL

- GEM foil is a key material of GEM.
- 50 μm Polyimide resin, 5 μm Cu
- Pitch - $140\ \mu m$
- Outer hole - $70\ \mu m$ / Inner hole - $50\ \mu m$
- Strong electron field in the region of the holes

Triple GEM CHAMBER

- Three foils installed in the chamber and Ar-CO_2 70:30 mixed gas(other gas available)
- Particles passing through, ionize the gas
- Electrons from the ionization are multiplied passing through the holes
- Ionization will occur anywhere in the chamber, but electrons from ionization in the drift volume will be amplified three times by three GEM foil so that the signal can be read on the strip

Motivation of GEM based Neutron Detector Development

Ref: http://inspirehep.net/record/832378/plots

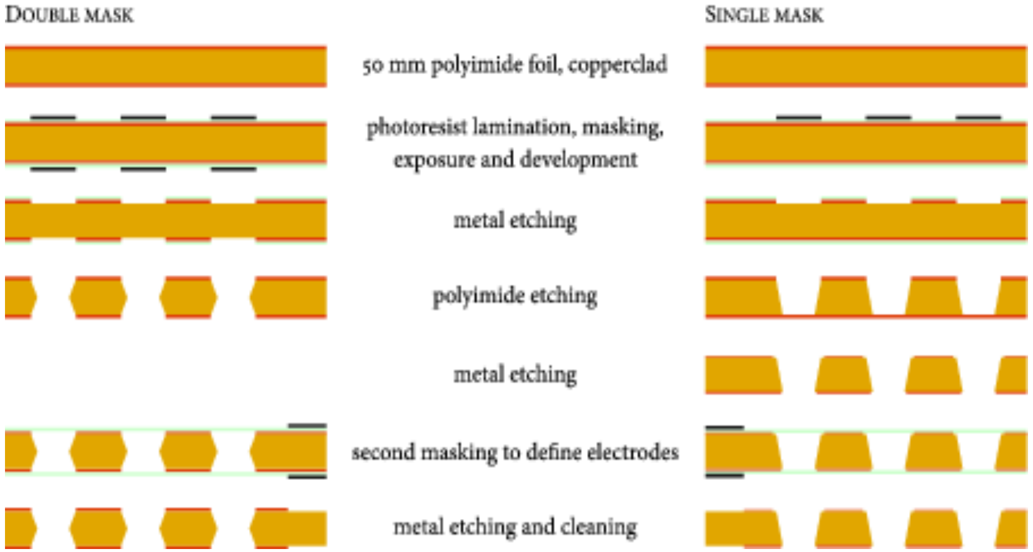
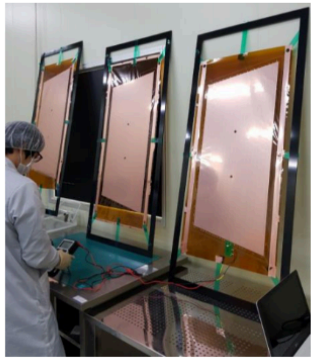


Fig 1. Double Mask and Single Mask



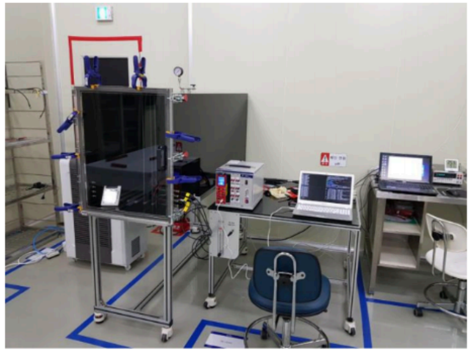
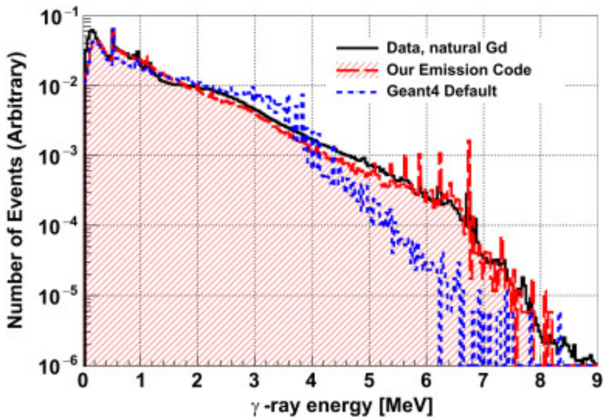


Fig 2. Facilities in MECARO

- Korean Company, MECARO produces GEM foils with double mask technique.
- MECARO produces GEM foils for CMS phase 2 upgrade
- University of Seoul works with MECARO and contribute to the GEM Foil Production and Detector R&D
- Applications of GEM are studied, like Muon Telescope and Neutron Detector
- Dawon Medacs, Medical Center that was developing neutron beam for BNCT wanted us to take a 2D profile of the beam.
- Therefore, our team wanted to explore the neutron detection with GEM.

Experiment Settings

Reference: D. Pfeier, F. Resnati, J. Birch, et al. First measurements with new high-resolution gadolinium-GEM neutron detectors. *Journal of Instruments*. **2016**. 11 P05011



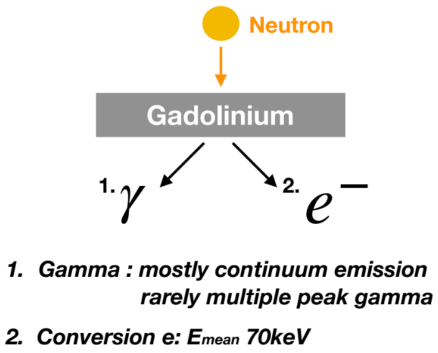


Fig 1. Neutron Capture Cross Section & Capture Process (Simple Diagram)

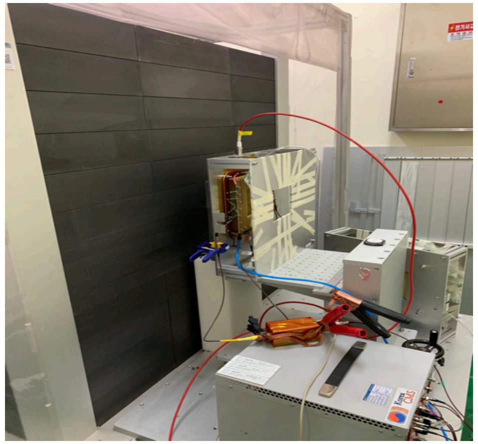
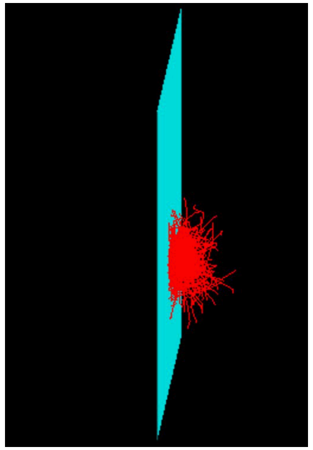


Fig 2. GEM and Graphite blocks in KRISS

Thermal neutron field at the Korea Research Institute of Standards and Science (KRISS). The field was produced with high rate ^{241}Am-Be Source and a high purity graphite blocks. Ref [3]

The reference thermal neutron flux by He3 detector at the measurement point is $67\ n/s \cdot cm^2$

The flux of epi-thermal neutron is $1\ n/s \cdot cm^2$



GEANT4 simulation. 70keV electrons couldn't go through the Kapton window of our GEM chamber. Red lines are 70 keV electrons

Fig 3. GEANT4 Simulation Electron through Kapton

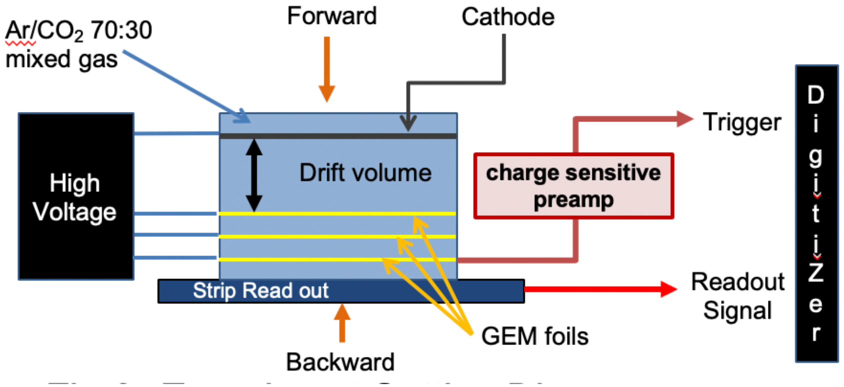
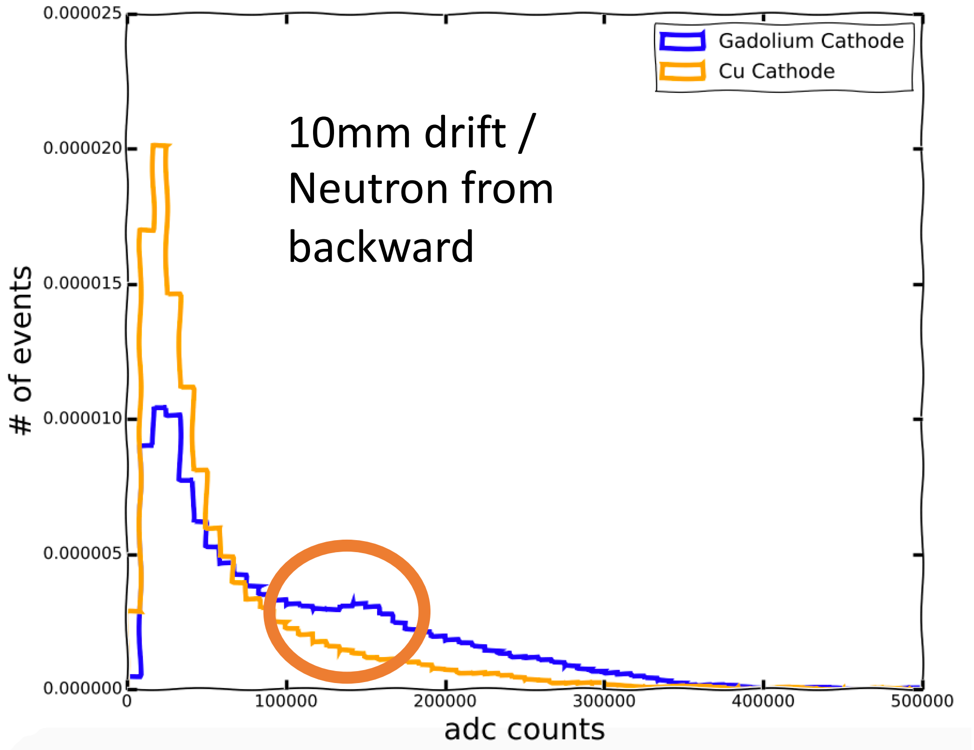


Fig 4. Experiment Setting Diagram

Tested Settings : Cathode(Gd/Cu), Drift Volume, Direction of Neutron Source, Effective Gain,

Results – Sensitivity for Neutron of Gadolinium

Sensitivity for Neutron of Gd



* area normalized as 1

Settings	Direction	Cu Cath.	Gd Cath.
Frequency [Hz]	Backward	12 ± 0.06	175 ± 0.02
	Forward	13 ± 0.06	83 ± 0.04

Table 1. * Frequency = # of Event / duration [s]
Background (without source) : 2Hz

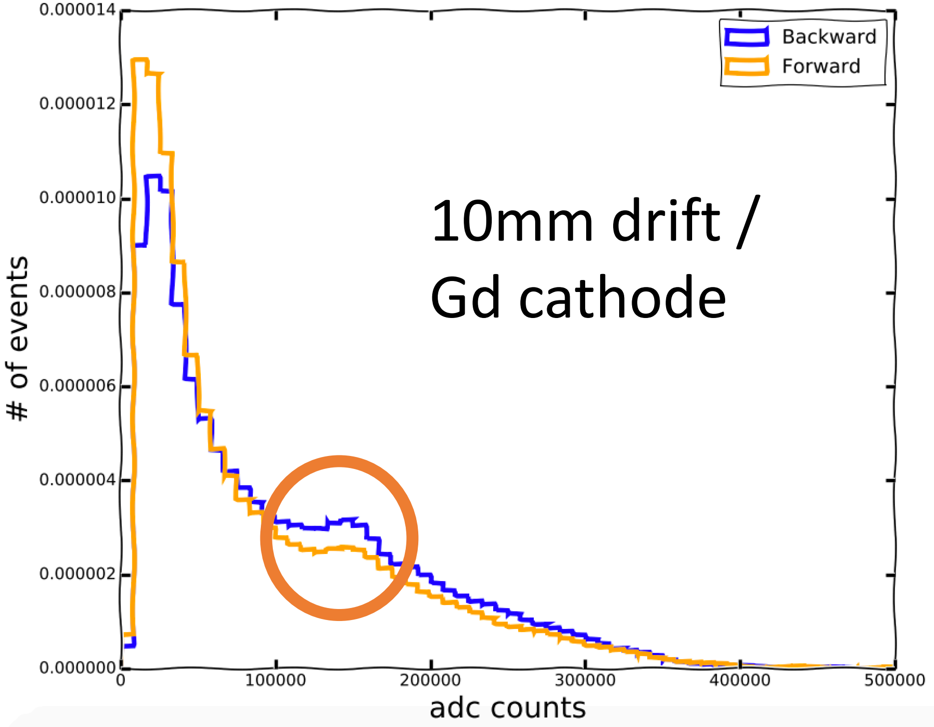
$Gain_{eff} \sim 10^5$

Gd cathode and Cu Cathode

The frequency difference at the same setting was up to 15 times, and the distribution shape looked different as above. Therefore we could see if the Gadolinium is sensitive to neutron

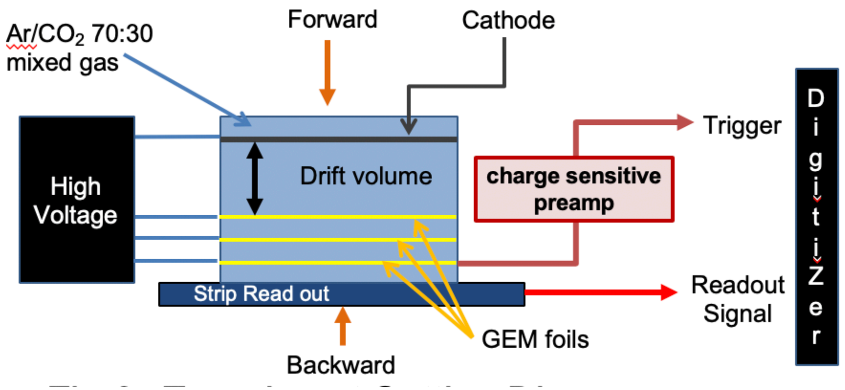
Results – Direction of Neutron

Direction of Neutron



$Gain_{eff} \sim 10^5$

The backward setting showed a small peak more clearly than the forward setting. So we decided to set the neutron goes from backward of the chamber for further experiments.



forward / backward

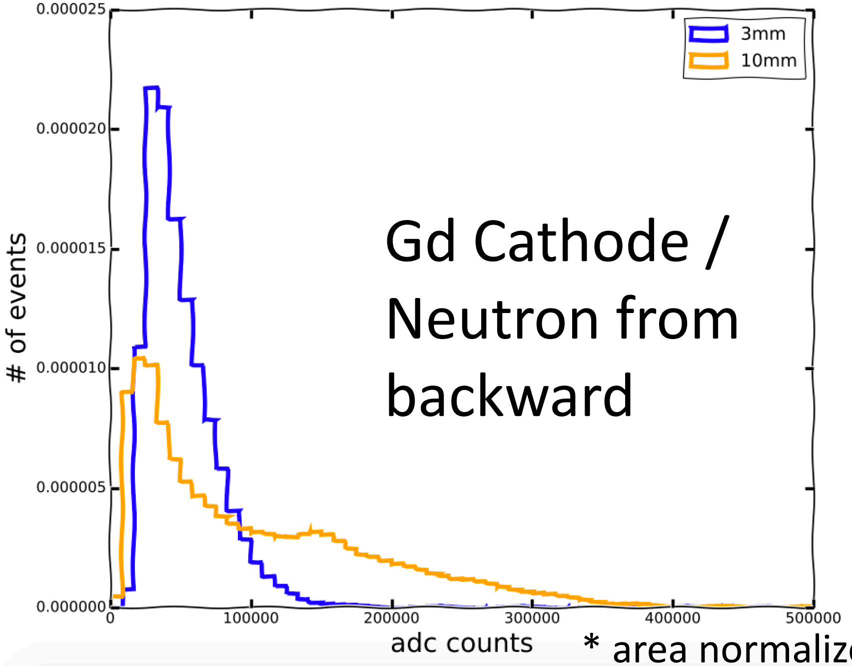
Forward indicates the window of the chamber is facing the neutron source so the neutrons go through the window and Gd sheet, therefore most of them will be captured by the surface of the Gd sheet out of the drift volume.

For **backward, the neutrons go through the readout board so most of them will be captured on the surface of the Gd sheet in the drift volume.**

We assumed that 70keV conversion electrons can't go through the Gd sheet.

Results – Electron Energy Deposition

Electron Energy Deposition



* area normalized as 1

Fig 1. 3mm and 10mm Drift Volume

Settings	3 mm	10 mm
Frequency [Hz]	**72** ± 0.72	**175** ± 0.02

Table 1. * Frequency = # of Event / duration [s]

Background (without source) : 2Hz

With a 3mm Gd-cathode chamber, we could measure 72Hz events which means it does detect neutron but due to the 3mm is too small for electrons to deposit their whole energy in the drift volume, we couldn't see the small peak which shows up for 10mm settings. The test was done to see the same result as the simulation results of the reference paper below.

$Gain_{eff} \sim 10^5$

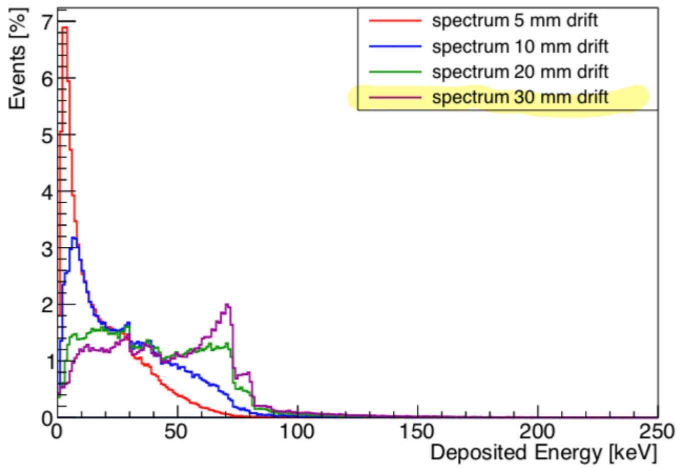
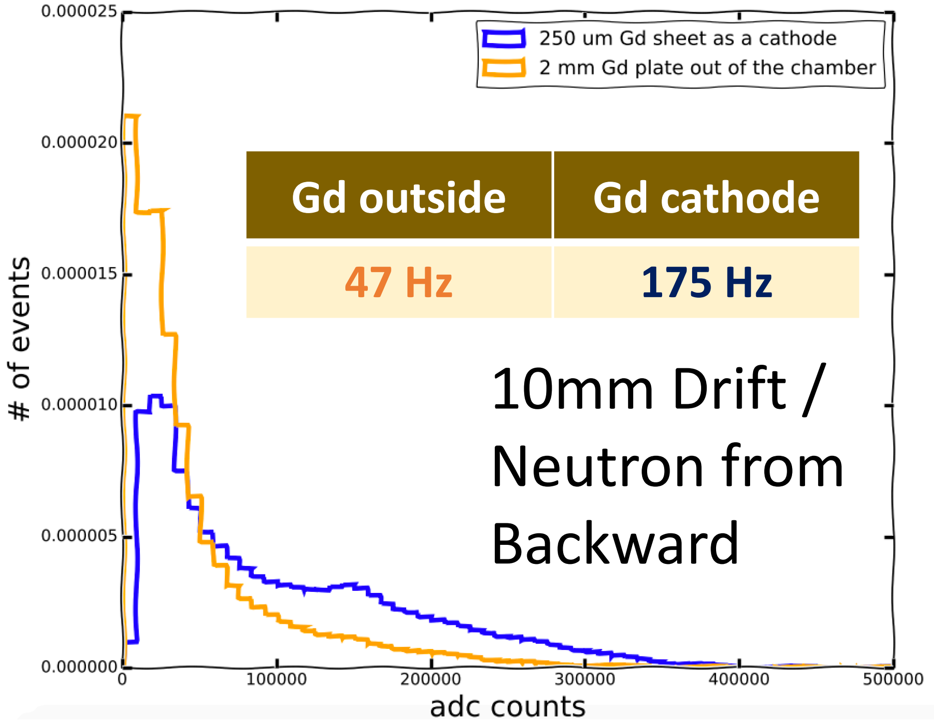


Fig 2. Simulation from Reference [1]

Results - Electron Peak

Electron Peak



Gd outside	Gd cathode
47 Hz	175 Hz

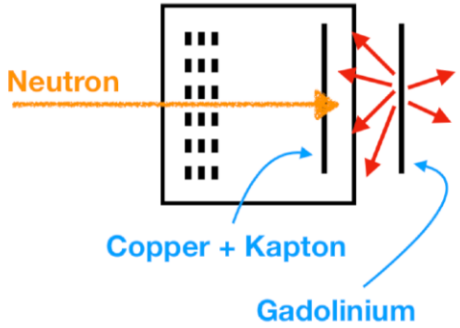
* area normalized as 1

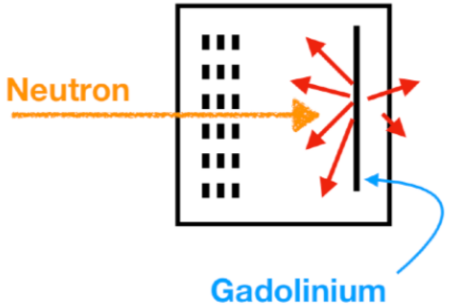
Settings	Gd outside	Cu Cath.	Gd Cath.
Frequency [Hz]	47 ± 0.06	12 ± 0.06	175 ± 0.02

Table 1. * Frequency = # of Event / duration [s]
Background (without source) : 2Hz
Neutron Direction : Backward

$Gain_{eff} \sim 10^5$

Gd-outside had 4 times higher frequency than the Cu-cathode option (Table 1.) which means it does detect neutron, but the small peak was reduced. This test was done to prove if the peak was from electrons as it can't go through our 250um Kapton.





Gd plate with Cu Cathode and Gd cathode

Conclusion

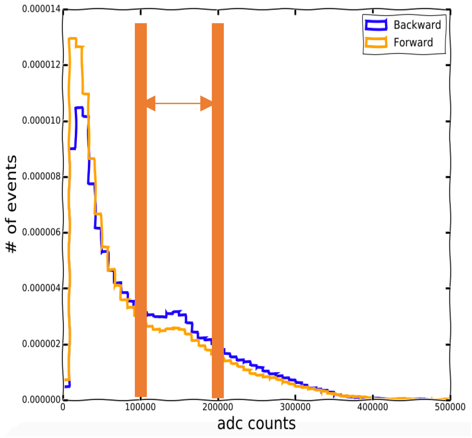


Fig 1. Electron Peak Region

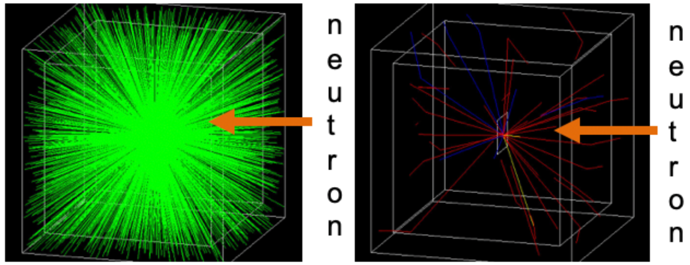


Fig 2. GEANT4 Simulation neutron beam toward Gadolinium sheet

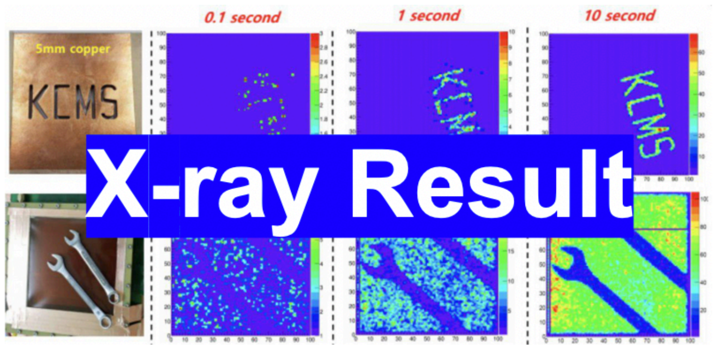


Fig 3. GEM 2D Imaging with X-ray Source

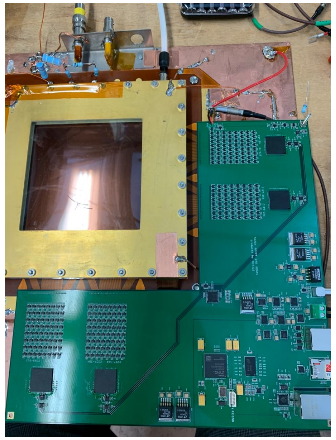


Fig 3. Picture of Developing 2D DAQ and GEM

We studied several settings of our GEM chamber with Gadolinium cathode and we could reproduce the results of the reference. Gadolinium was used as a neutron sensitive material to see if our GEM chamber can be utilized as a neutron detector.

The next study will be GEM based neutron 2D imaging application with position resolution less than 1cm using multiple channel readout. We should discriminate the electrons from gammas so the boron will be a better neutron sensitive material than gadolinium. We proved that the small peak comes from the electrons, so we will see if we could see an image using neutron absorber with the ADC counts cut on Fig 2. Fig 3 is the picture of our DAQ on development.

Thank you!
Danke!

References

[1] D. Pfeier, F. Resnati, J. Birch, et al. First measurements with new high-resolution gadolinium-GEM neutron detectors. *Journal of Instruments.* **2016**. 11 P05011

[2] Fabio Sauli. Operating principles and applications. *Nuclear Instruments and Methods in Physics Research A.* **2016**. *805*, pg. 2-24

[3] Park H, Kim J, Choi KO. Neutron calibration facility with radioactive neutron source at KRISS. *Radiat Prot Dosimetry*. **2007**. 126, pg. 1-4

[4] D. Song, I. Park, J.S. Lee, et al. 2D Image using GEM. *Conference of Korea Physics Society.* **2018**. *P1-pa. 024**

[5] T. Yano. Measurement of gamma-ray production from thermal neutron capture on gadolinium for neutrino experiments. *Nuclear Instruments and Methods in Physics Research Section A:* 2017. 845, pg. 425-428

Backup

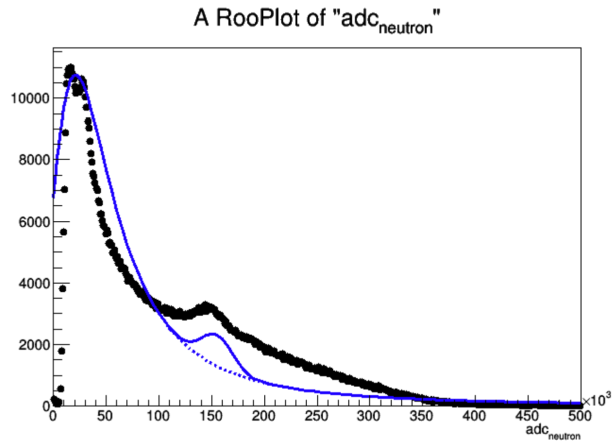


Fig 1. Somebody help me with fitting ….

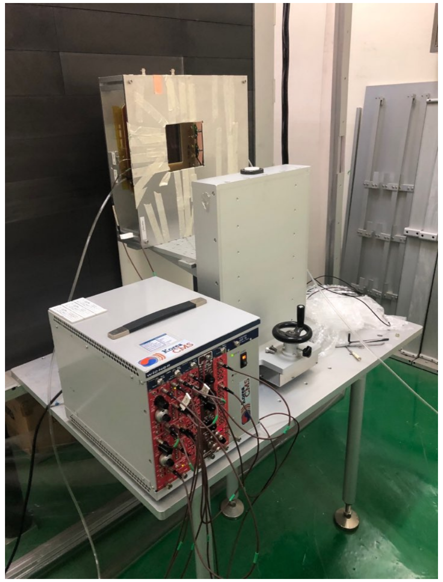


Fig 2. Settings at KRISS (Neutron Source AmBe)

FIg 3. BNCT researching medical center neutron beam facility

Fig 4. Picture of GEM with HV divider

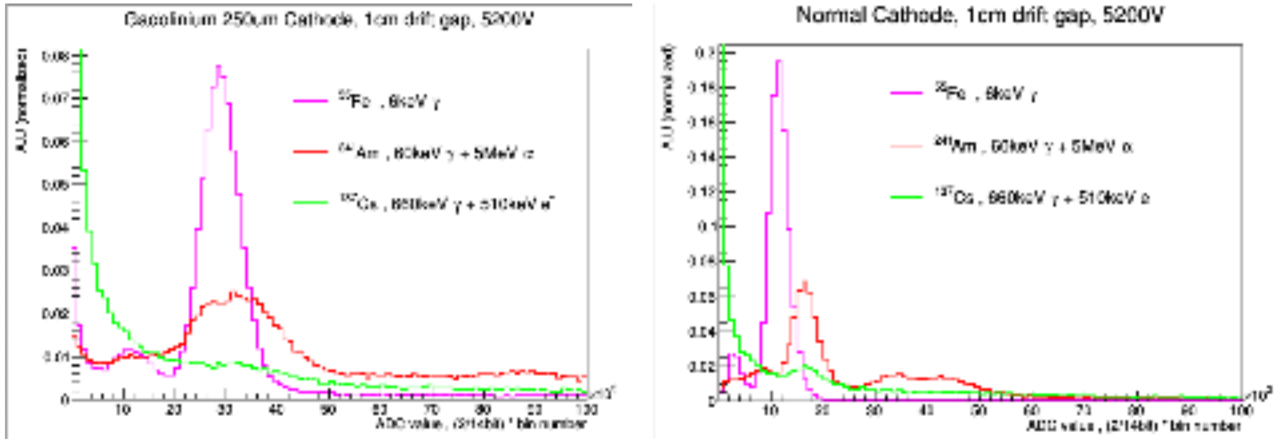


Fig 5. Calibration with several sources. Gd Cathode (left) Cu Cathode(right)