Imaging with glass GEM and dynamic time-over-threshold pulse processing method

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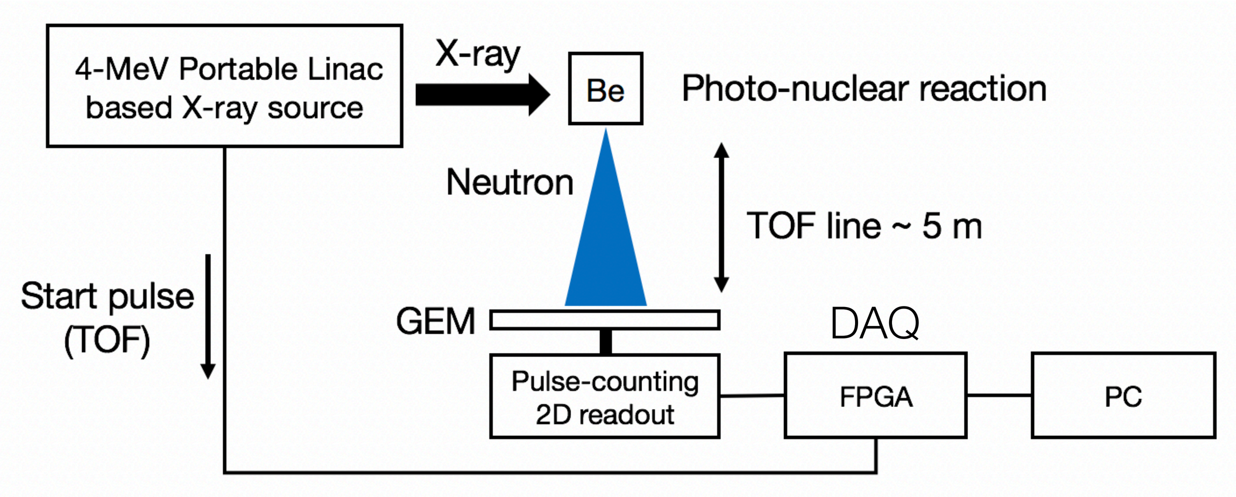
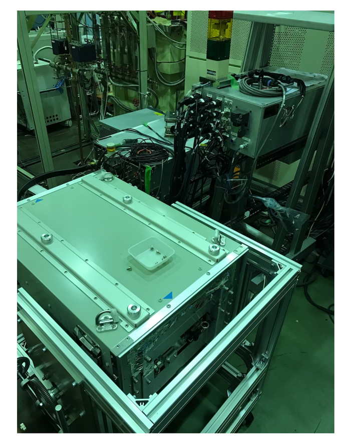
1. Background

- We are developing the energy-resolved neutron imaging system for the on-site nuclear fuel debris analysis.
- After the Fukushima Daiichi incident, there should be a lot of unaccountable nuclear melted fuel debris in the plant. In terms of nuclear security control, characterization and quantification of nuclear materials in debris is very important. Neutron imaging simultaneously with the neutron resonance spectroscopy is promising for this application.
- The goal of this research is to develop a dedicated pulse-counting 2D readout system for G-GEM, which will be integrated with neutron TOF measurement system in a near future. In this presentation, we report on results of a preliminary readout system tested with X-ray. The system is composed of G-GEM, charge-division, and dynamic time-over-threshold pulse processing method.



System overview

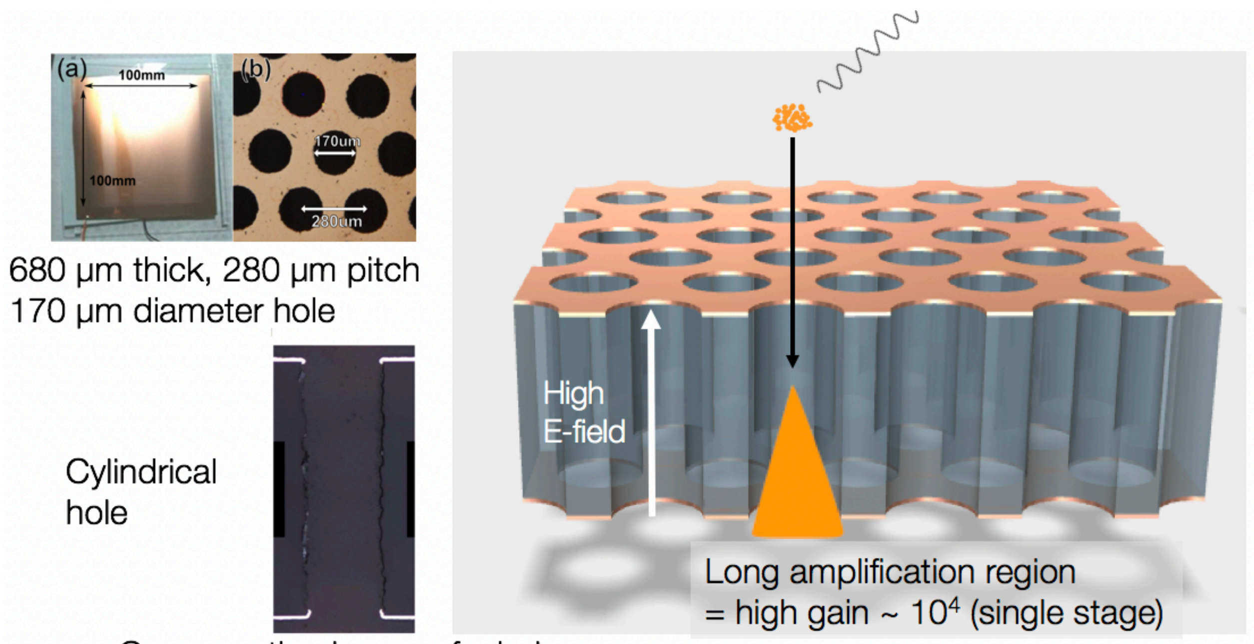


4-MeV portable X-band Linac based X-ray source

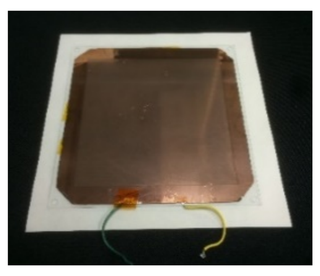
2. Glass gas electron multiplier

Glass gas electron multiplier (Glass GEM, or G-GEM) [1][2]

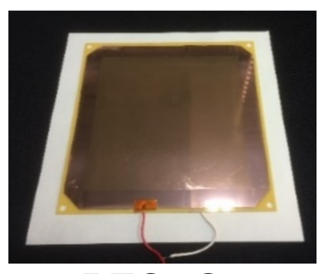
- Made of photosensitive etchable glass (PEG3, PEG3C)
- Fine structure: high aspect-ratio cylindrical holes by photolithography technique
- Low volume resistivity glass: Preventing surface charging-up in high-rate condition
- Single stage gain of greater than 10^4 : Large signal, High gas scintillation photon yield
- High resolution imaging capability [3]



Cross section image of a hole



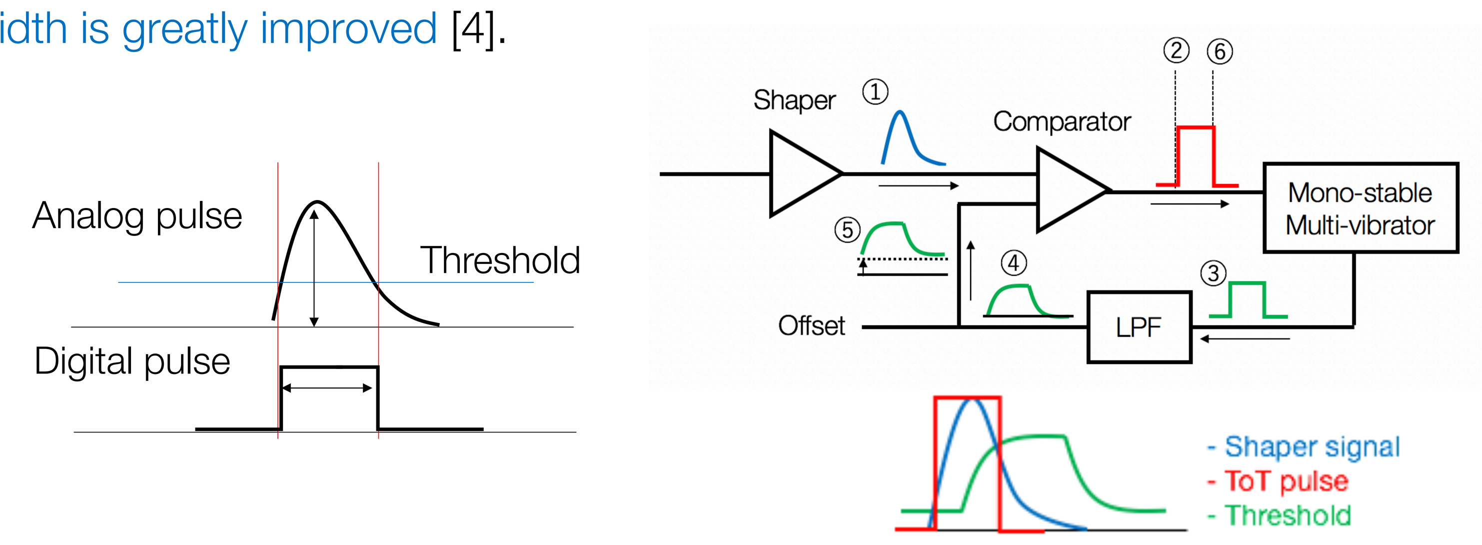
PEG3



PEG3C

3. Dynamic Time-over-Threshold method

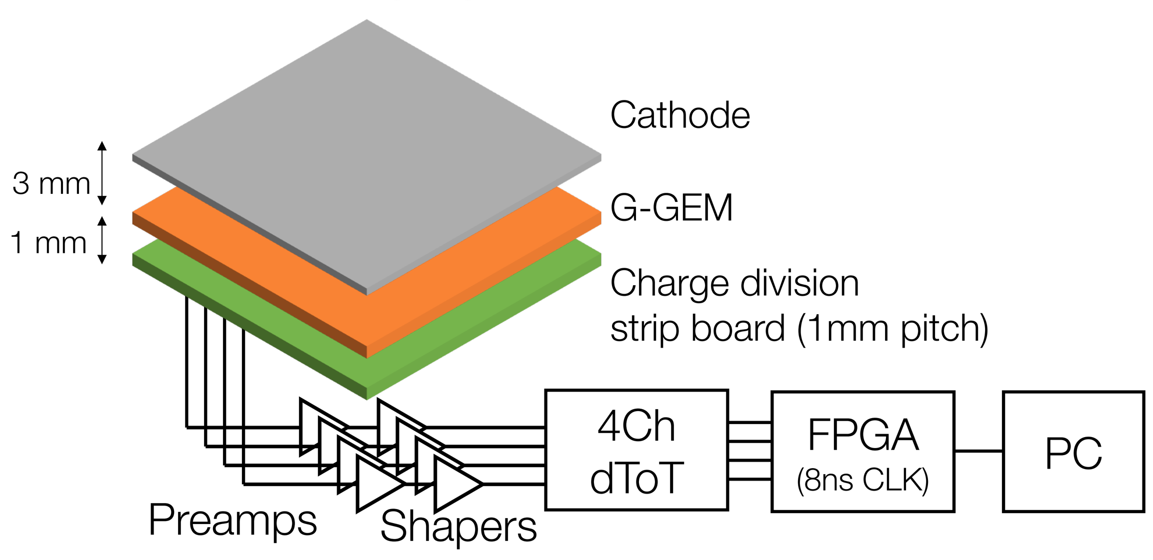
- The ToT (Time-over-Threshold) is a pulse processing method to convert an analog pulse to a digital pulse whose width is proportional to the original analog pulse height, measuring the time while the analog pulse is over the preset threshold.
- The ToT system is composed of simple circuit and hence promising for front-end circuits of multi-channel data acquisition system. In addition, ToT is easily combined with subsequent digital signal processing circuit such as FPGA.
- The dynamic ToT (dToT) is a modified method of ToT; The threshold is dynamically changed over time and the linearity between analog pulse height and digital pulse width is greatly improved [4].



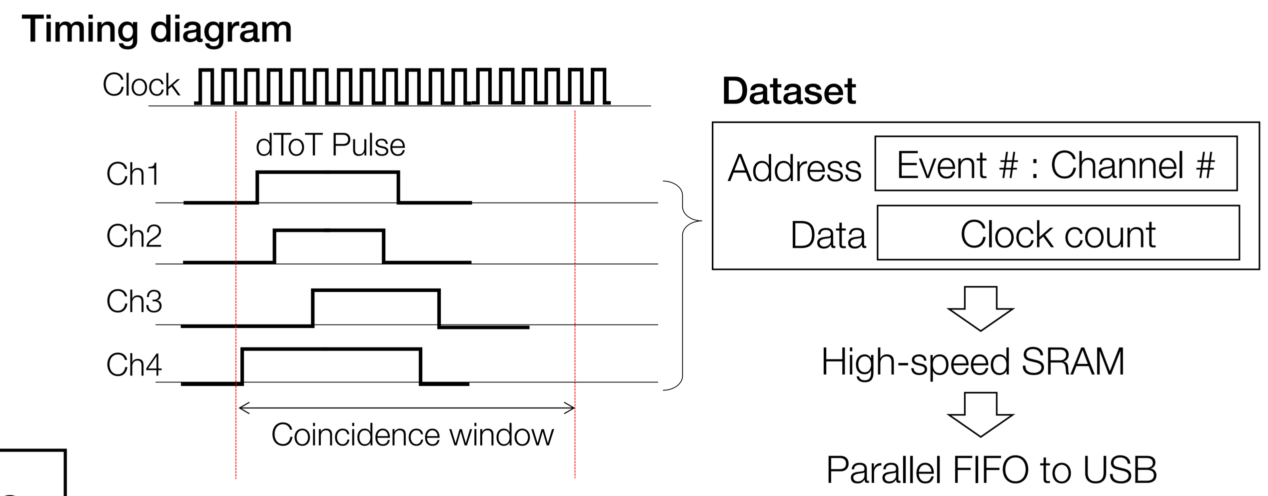
Normal ToT (Static threshold) Dynamic ToT (dynamic threshold)

4. Experiment

4.1 Preliminary system



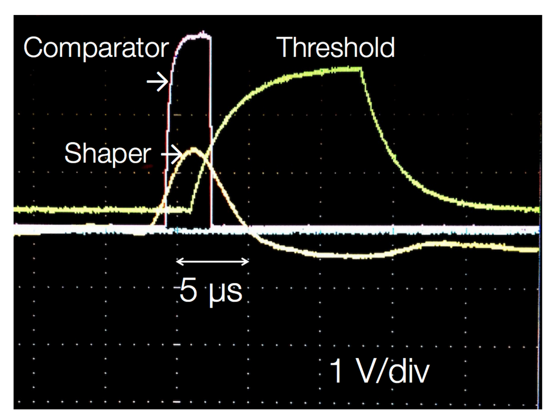
Charge division strip board has 1 mm pitch strips in X-Y directions. The sensitive area of the detector is 100 × 100 mm^2. The detector was flushed with Ar/CH4 95/5 in a gas flow mode.

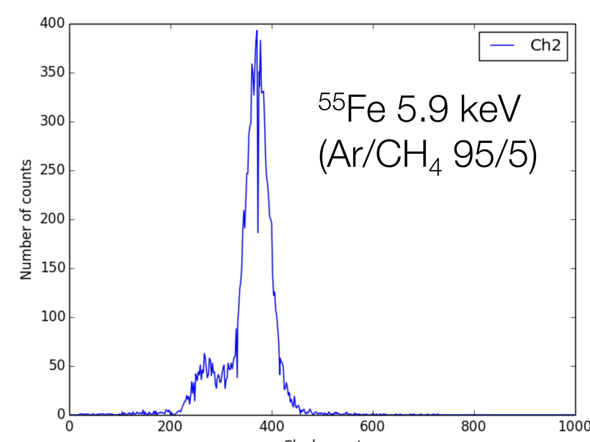


The FPGA is configured to…

1. Detect the positive edge of ToT pulse from each channel.
2. Detect a coincidence of all the 4 channels within a preset coincidence window duration.
3. Counting the clock (8 ns) for each channel.
4. Store the counts into the SRAM on the board by each event.
5. The data in SRAM is read through a parallel FIFO ⇔ USB module.

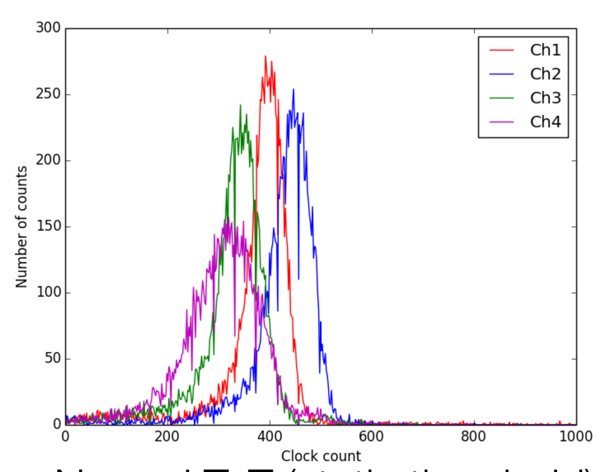
4.2 Spectrum measurement



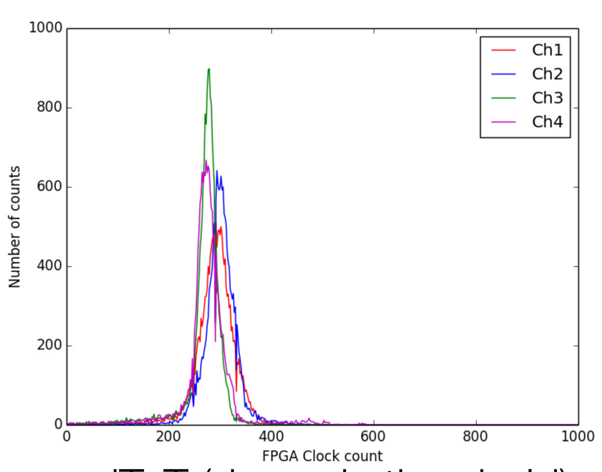


(Left) Shaper pulse, threshold, and comparator output.
(Right) Spectrum of Fe-55 from one of the 4 channels. The Ar escape peak was well separated from its main peak. The resolution at main peak was approximately 16 %.

4.3 Energy resolution comparison



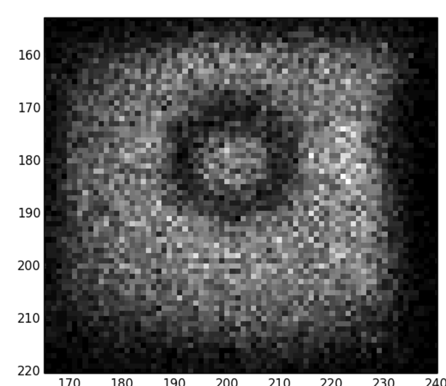
Normal ToT (static threshold)



dToT (dynamic threshold)

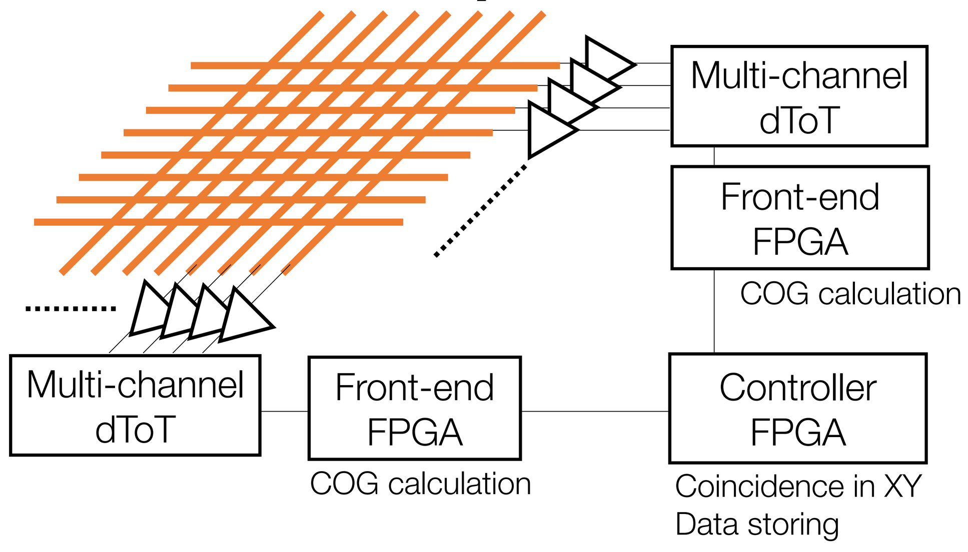
Spectra with both the dynamic and normal ToT. Fe-55 source was placed at the same position (the center of the detector). The Energy resolution was improved by dynamically changing the threshold.

4.4 Charge division imaging



Preliminary result of X-ray imaging (100×100 mm^2 area). The object was a metal washer which was placed at the detector window. The X-ray tube (10 kV/5uA) was used. The image was uniform and not distorted over the sensitive area.

4.5 Future development



To improve position resolution, individual readout system with center-of-gravity (COG) calculation is under development.

5. Conclusion

- Toward the nuclear fuel debris analysis, we are developing an energy-resolved neutron imaging system. We demonstrated a preliminary system which is composed of G-GEM, charge-division strip board, and 4-channel pulse counting readout based on dynamic time-over-threshold (dToT) method. The system was tested with X-ray for characterization of the readout. Better energy resolutions were obtained with dToT, compared with normal ToT. The X-ray imaging was also demonstrated.
- To improve the image resolution, development of individual strip readout system is ongoing, and it will be integrated with neutron TOF measurement to achieve energy-resolved neutron imaging.

References

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[2] Y. Mitsuya, T. Fujiwara, T. Fushie, T. Maekawa, H. Takahashi, Nucl. Inst. and Meth A 795 (2015) 156.
[3] T. Fujiwara, Y. Mitsuya, T. Yanagida, T. Saito, H. Toyokawa, and H. Takahashi, Japanese Journal of Applied Physics 55 (2016) 106401
[4] T. Orita, K. Shimazoe, H. Takahashi, Nucl. Inst. and Meth A (775 (2015) 154-161

Acknowledgement

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