서울시립대학교
UNIVERSITY OF SEOUL

AFAD
Asian Forum for Accelerators and Detectors

Neutron Detection Study from Beam test of Boron GEM detector

Woojong Kim

Inkyu Park, Jason Sang Hun Lee, Hyupwoo Lee,
Minjae Kwon, Donghyun Song, Myeonghun Choi

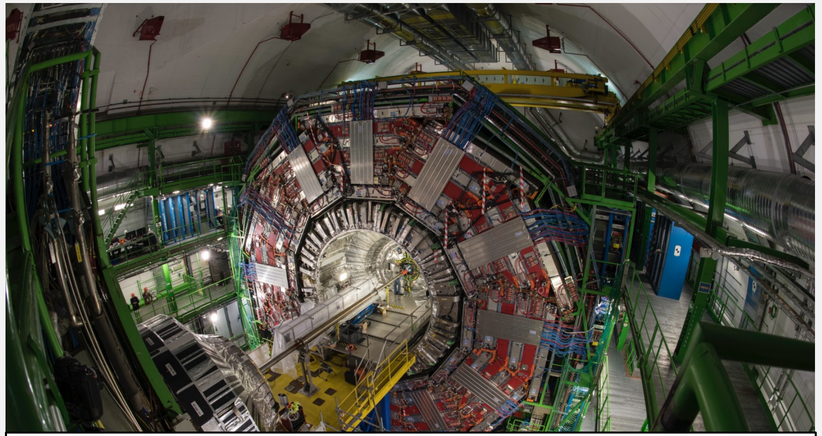
University of Seoul

Asian Forum for Accelerators and Detectors, 18 Apr 2024
WG2: Detector technology development

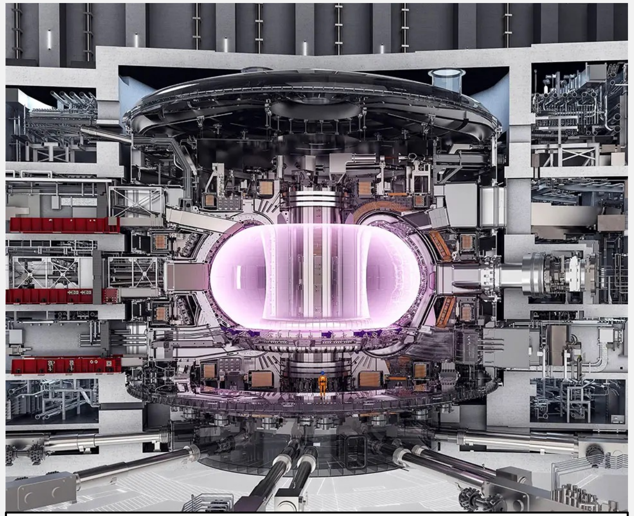
Motivation

- Neutron detectors are vital for sites requiring extensive neutron monitoring, such as fusion power plants. However, traditional neutron detectors are very expensive.
- This project aims to offer a cost-effective and scalable alternative to traditional neutron detector.
- The Gas Electron Multiplier (GEM) detector was selected for this purpose due to its suitability for large-scale implementation.

Our experiment is designed to evaluate the effectiveness of the Boron GEM in detecting neutrons.

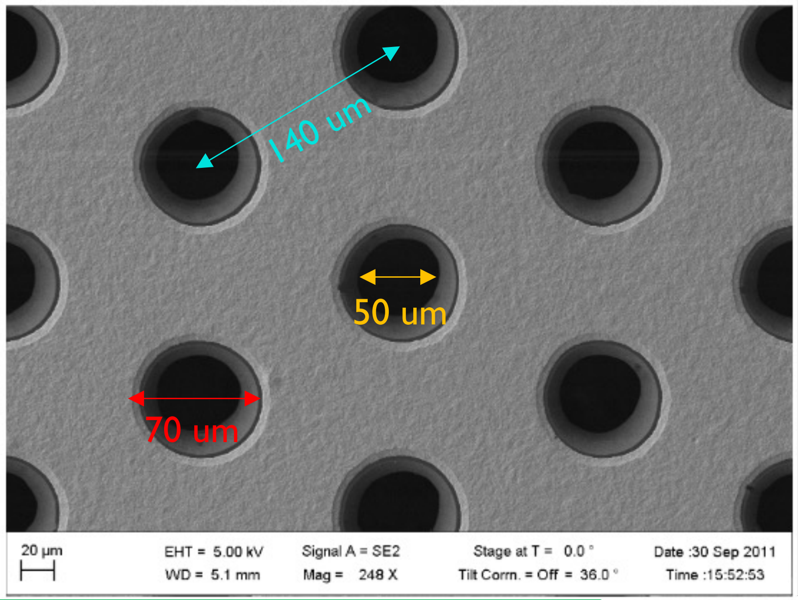


Compact Muon Solenoid
Gas Electron Multiplier Detector

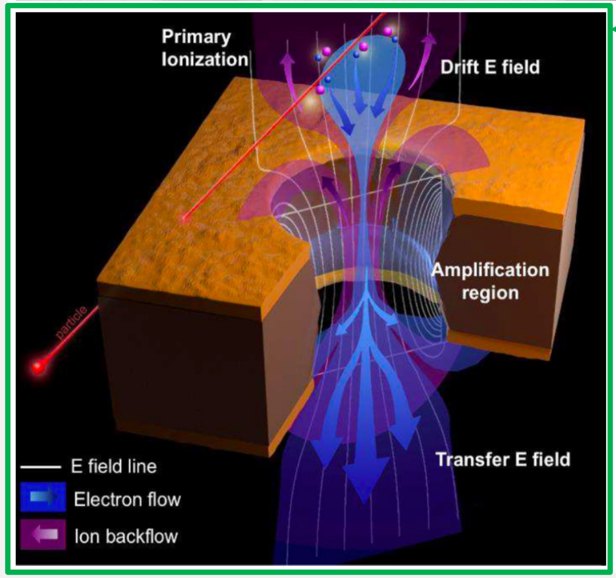


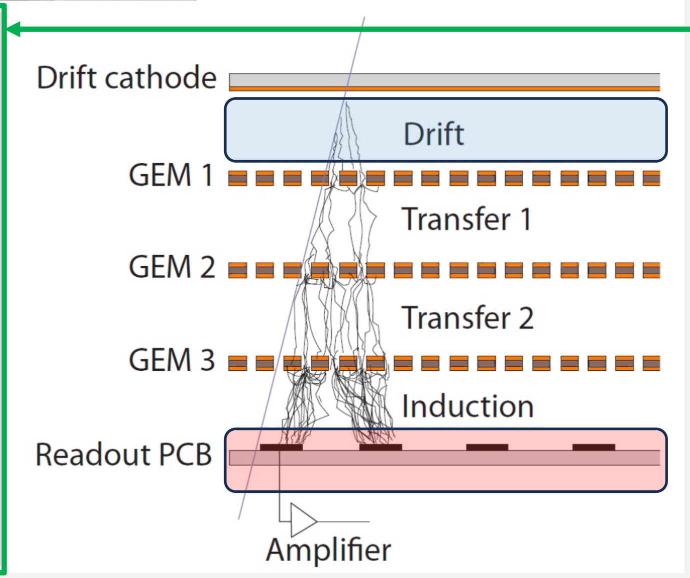
International Thermonuclear
Experimental Reactor

Gas Electron Multiplier



- GEM foil
  - 50 µm polyimide film + 5 µm copper layer on each side
  - Many holes exist for electron amplification
- Drift area
  - The primary electrons are generated
  - Accelerate the electrons sufficiently



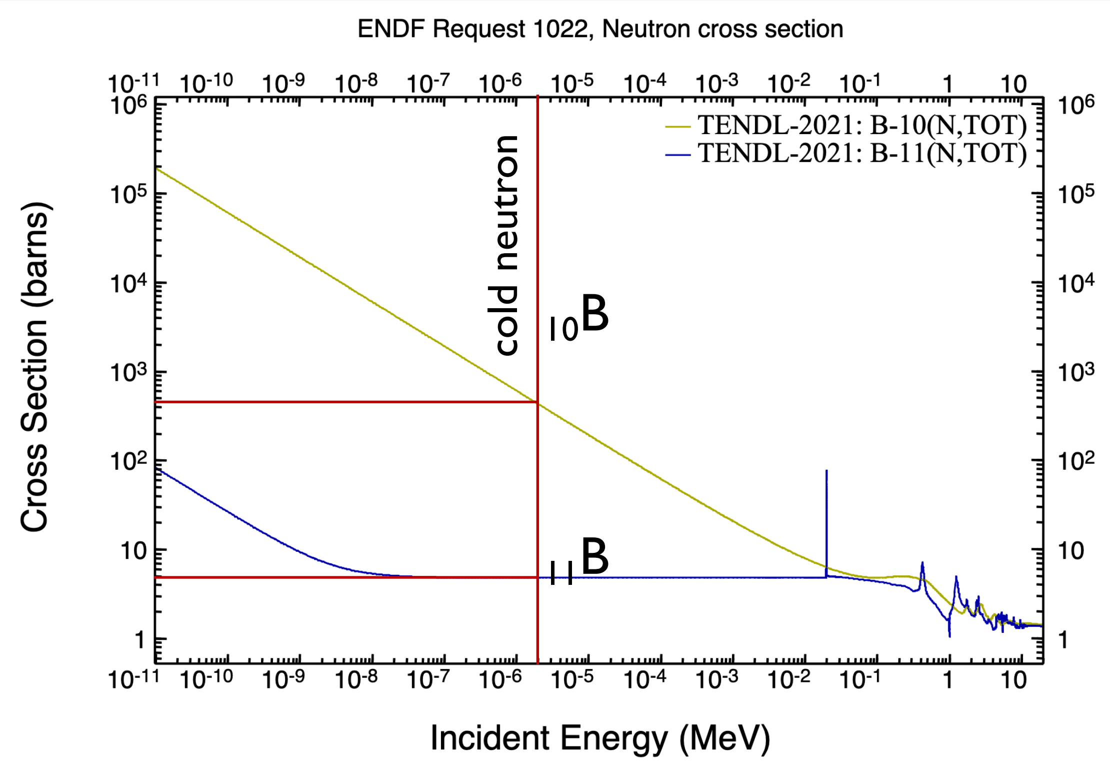


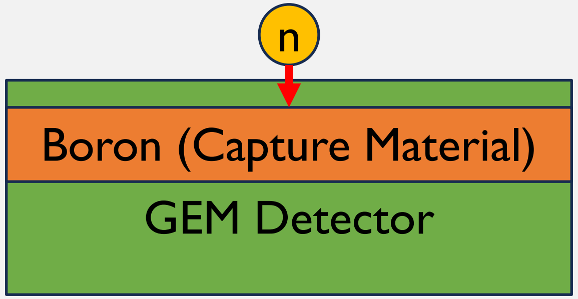
- The strong electric field in micro-holes makes electron avalanches
- We use the GEM foil with micro pattern readout board and Ar/CO2 gas (70/30)

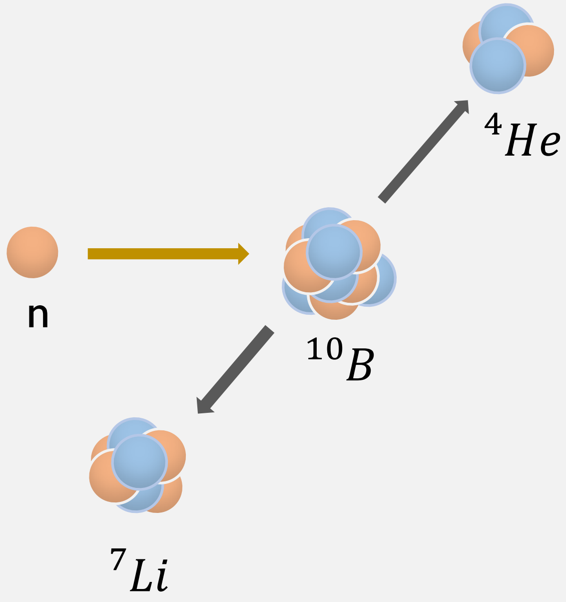
Neutron Capture Process

- Almost all neutron interacts with B-10
- After capture process
  - Li-7, Alpha and gamma occurred (mainly)
  - alpha$_{[E=1.47\ \mathrm{MeV}]}$ is easy to detected

- The initial signal is strong enough.
  Two GEM foils are used.







^{10}B + n -> ^{7}Li + ^{4}He + 0.48 MeV γ + 2.31 MeV(94%)

E_α = 1.47 MeV, E_{Li} = 0.84 MeV

-> ^{7}Li + ^{4}He + 2.79 MeV(6%)

E_α = 1.78 MeV, E_{Li} = 1.0 MeV

GEANT4 Simulation

GEANT4 Simulation [Setup Variation]

Variations on active material

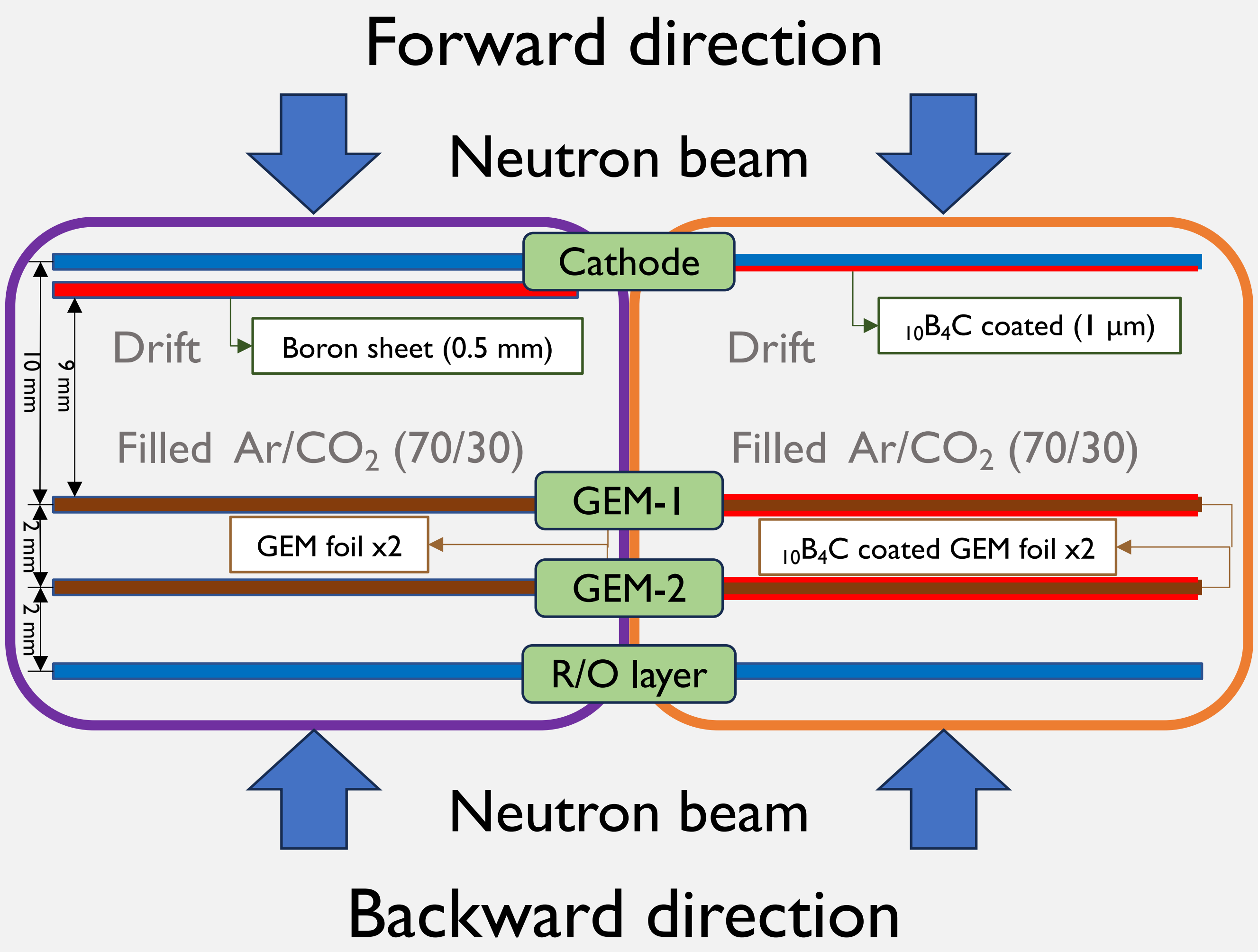
- Boron with natural proportion ($_{10}B$:$_{11}B$=1:4)
- Pure $_{10}B$ (5 x cross-section of natural B)

Variations on geometry

- **Boron sheet** [natural proportion]
  - Boron sheet at the drift area (T=0.5 mm)
- **Drift coating** [Pure $_{10}B$ as B_4C]
  - Coated cathode plate (T=1.5 μm)
- **Drift+Foil coating** [Pure $_{10}B$ as B_4C]
  - Both of all GEM foils and cathode plate are coated (T =1.5 μm)

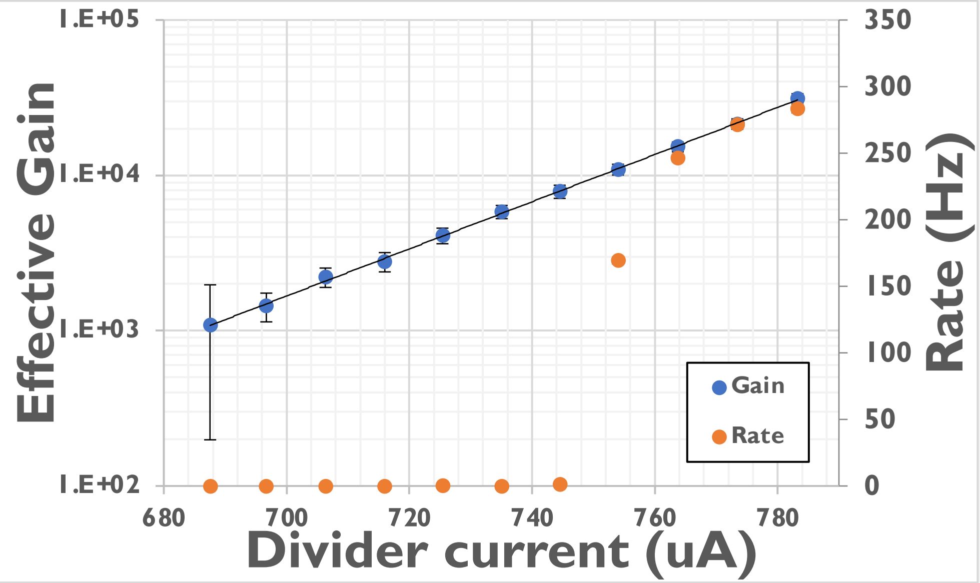
This simulation was conducted to test the usefulness of the boron convertor

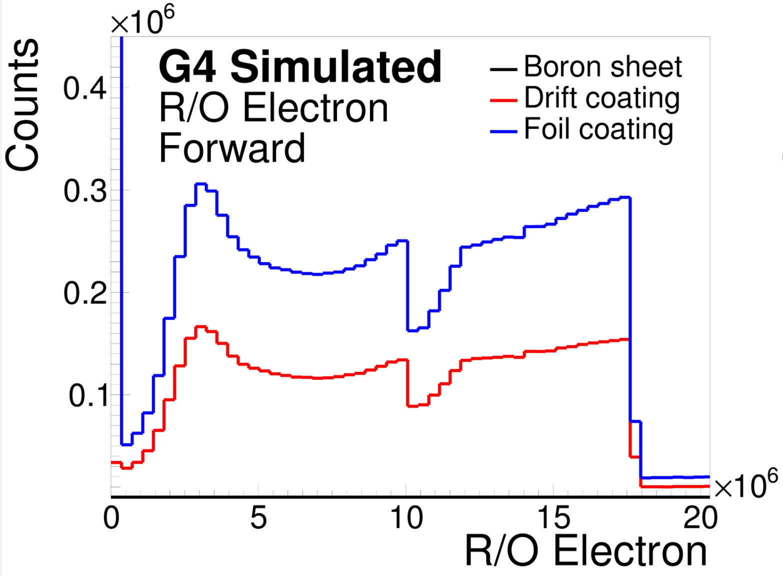
Variations on direction

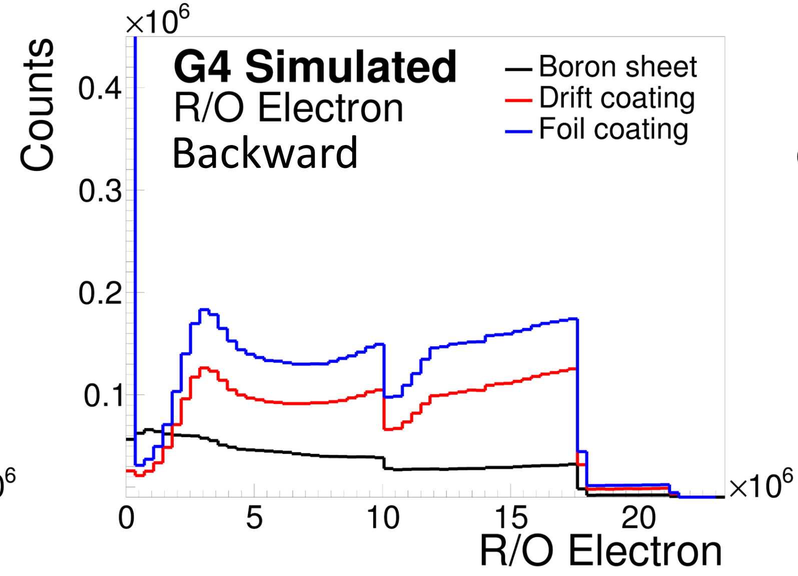


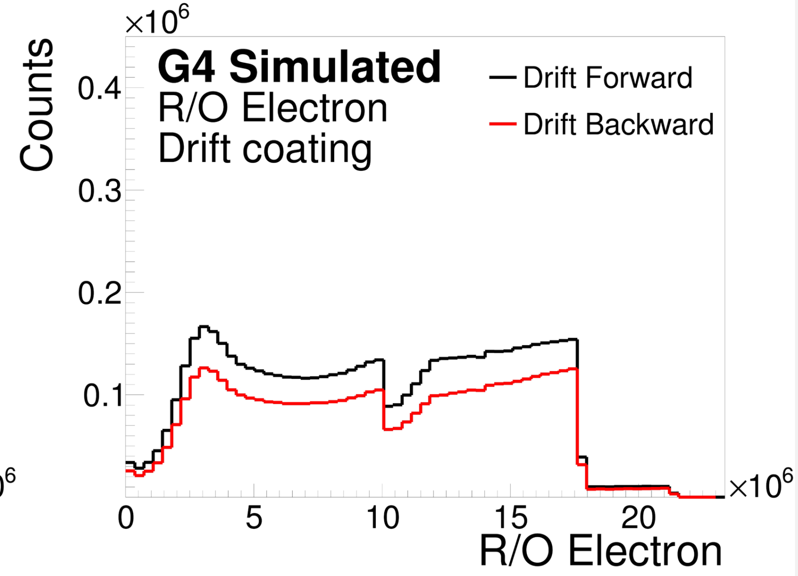
GEANT4 Simulation [Result]

- R/O Electron = energy loss / W factor x amplification rate (18) ^ number of sheets (2)
- Efficiency difference between setups
  - Boron sheet: Backward > Forward
  - Coating: Forward > Backward









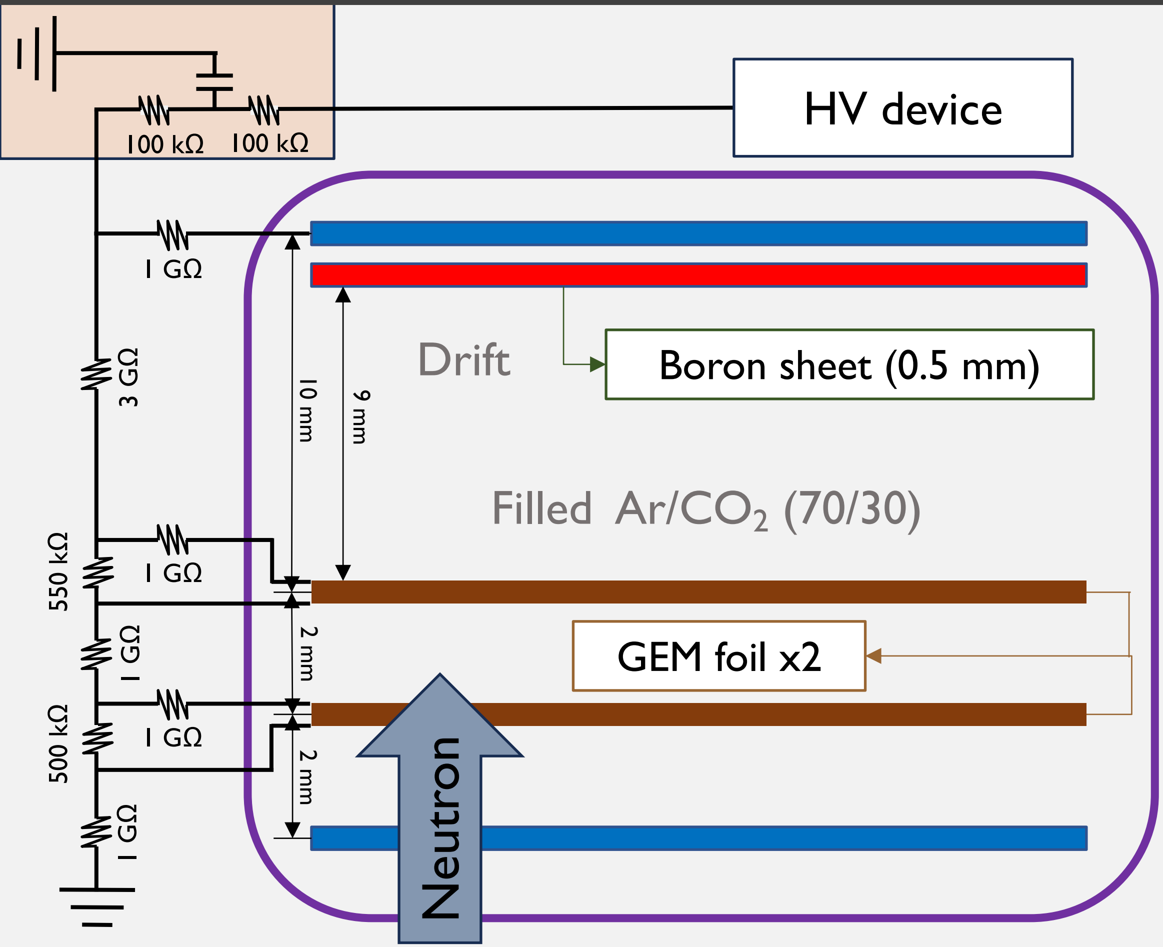
Cold Neutron Test

HANARO Beam Specification

- *HANARO (High-flux Advanced Neutron Application ReactOr)*
- Research reactor in Korea
- Bio-REF specifications
  neutron energy : 10~12 meV (Cold)

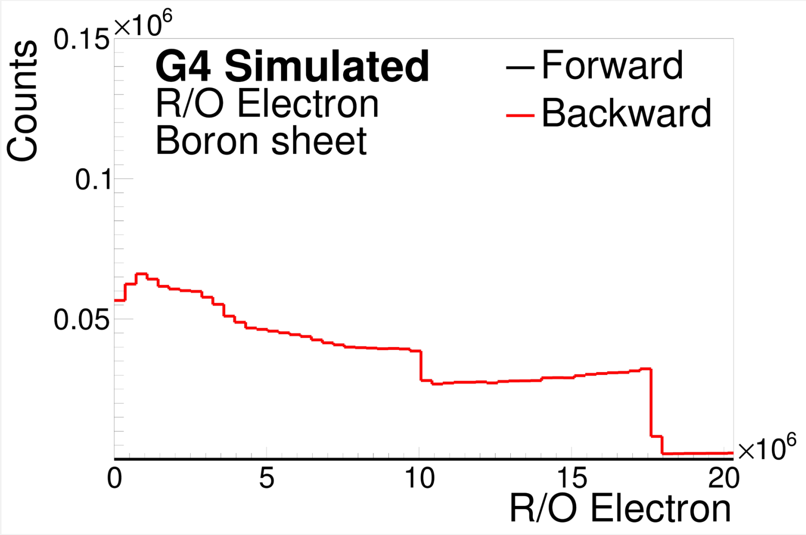
- Profile
  - 30 $MW_{(Max)}$
  - Maximum shaping slit
    - X-width: 4 cm
    - Y-width: 0.5 cm
  - Flux: 4.8×10^6 Hz/cm^2 $_{(for\ 30\ MeV)}$

Boron GEM Structure [boron sheet]

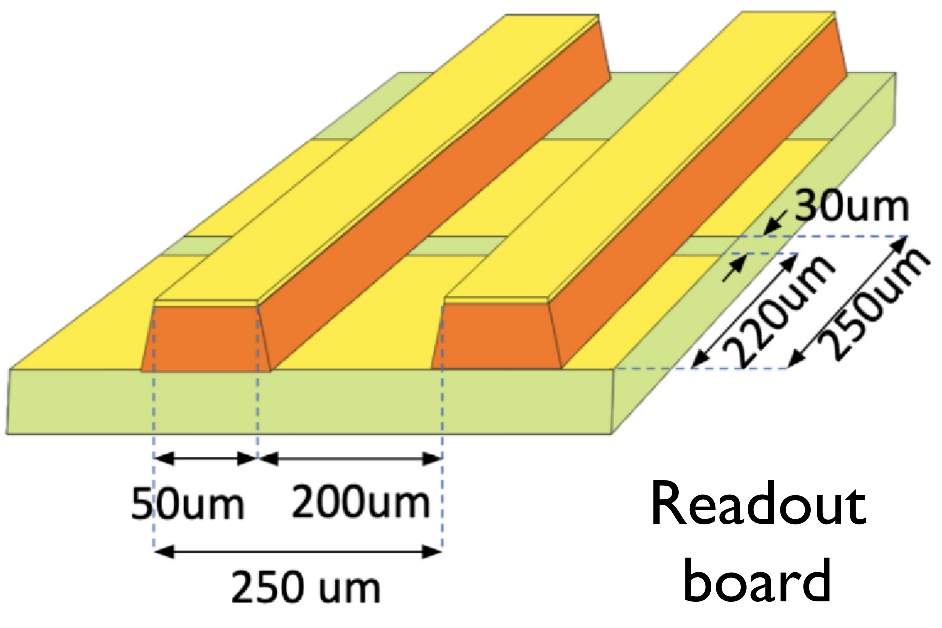


Filter resistance 200 kΩ in voltage supply part
Total resist. is 6.25 MΩ

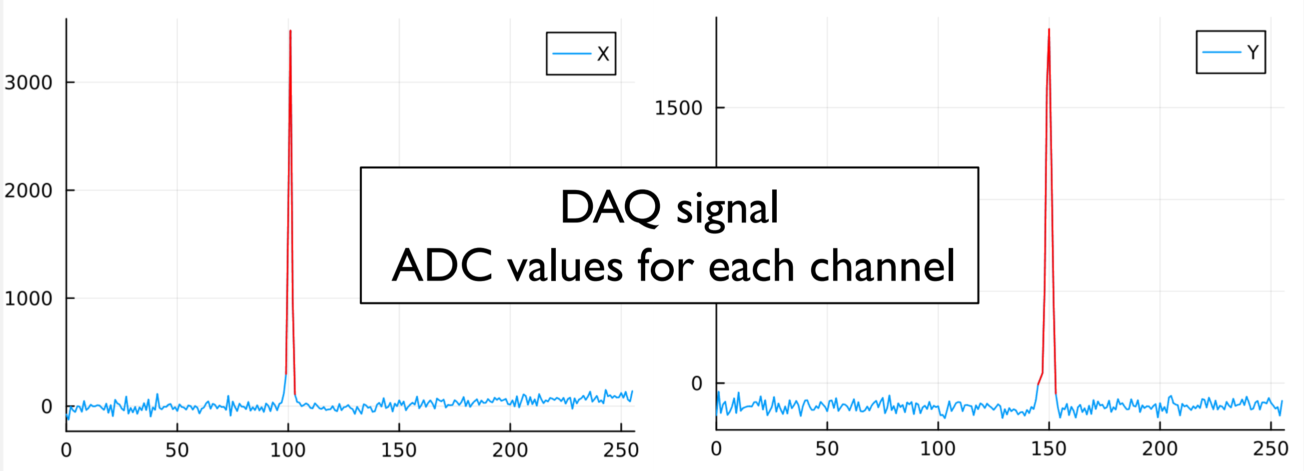
- Two GEM foils with boron sheet
  - Drift gap: ~9 mm
  - Boron sheet: 0.5 mm with (^{11}B : ^{10}B, 4 : 1)
    For neutron conversion
- Testing to ensure boron converter works
  - Before making a boron-coated GEM detector
- Better direction: **Backward**



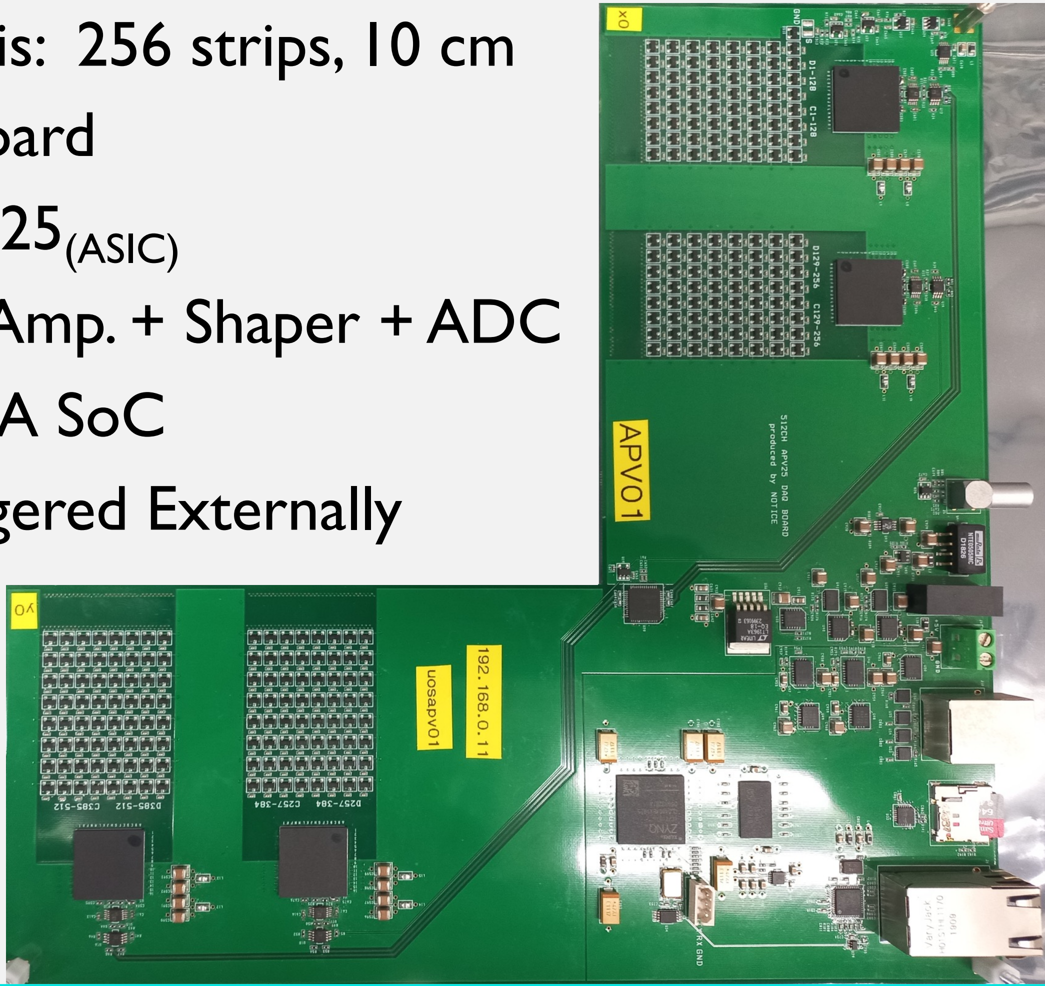
Data Acquisition



- Read-out board
  - X-axis: 256 strips, 10 cm
  - Y-axis: 256 strips, 10 cm
- DAQ board
  - APV25$_{\text{(ASIC)}}$
    - Amp. + Shaper + ADC
  - FPGA SoC
  - Triggered Externally



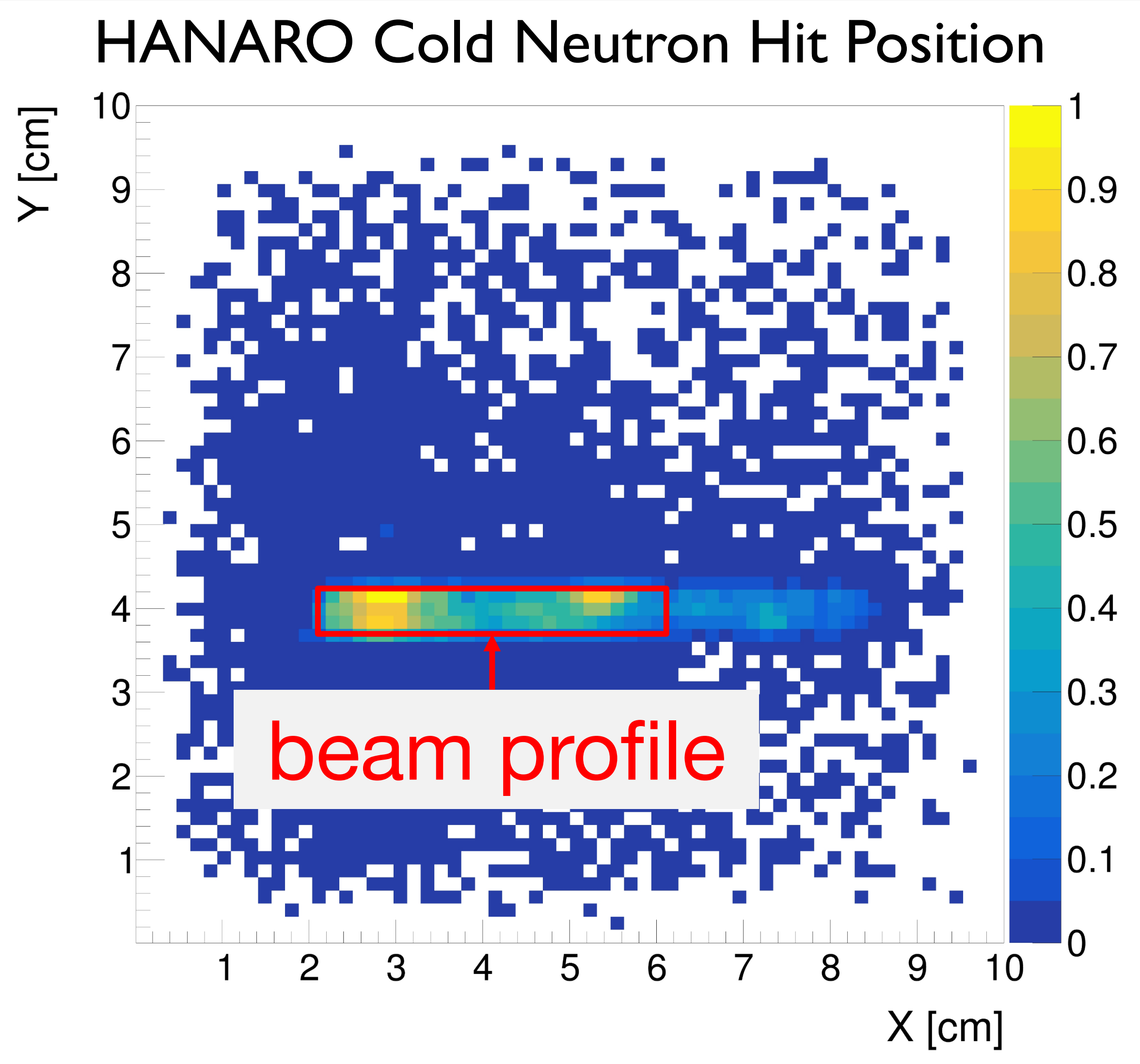
DAQ board



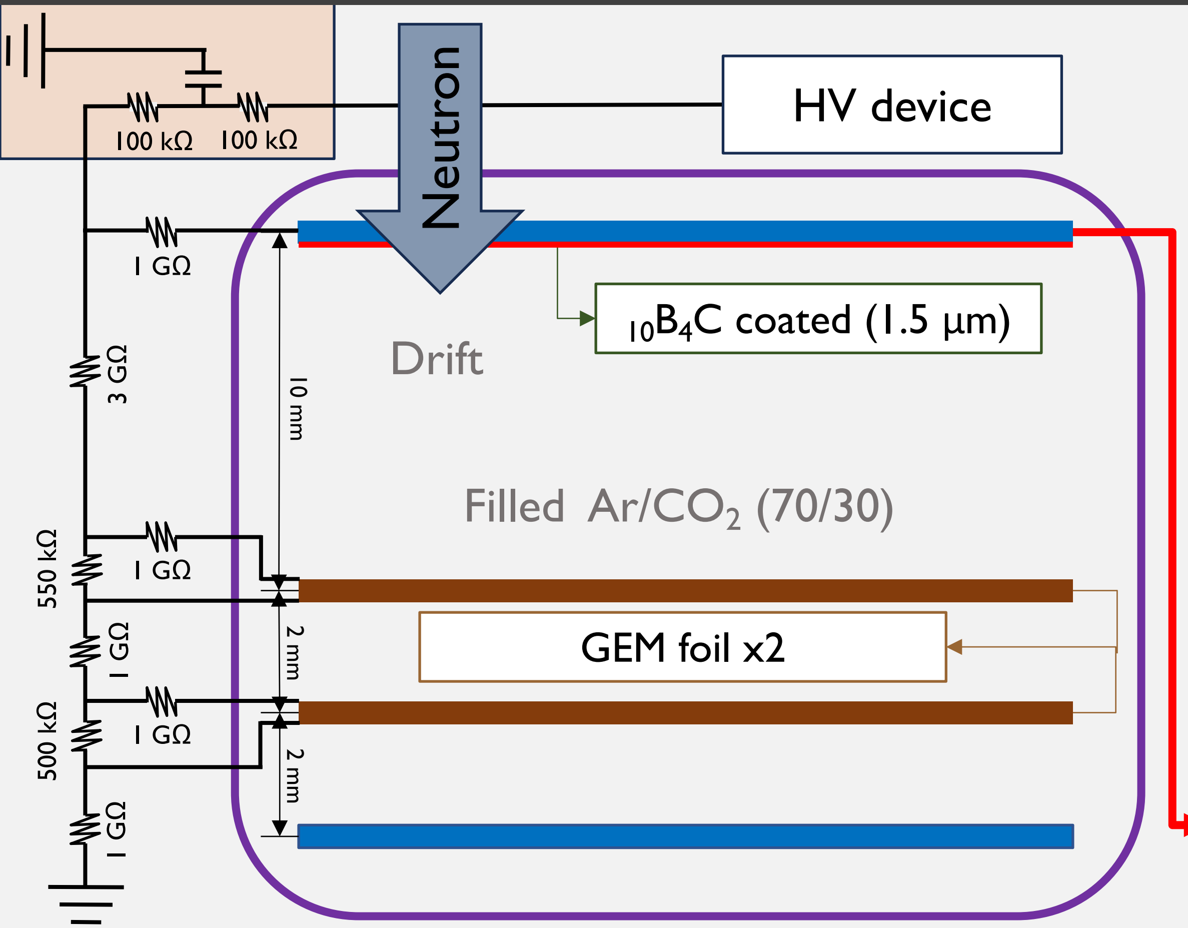
HANARO Experiment Results

- Total running time: 43 minutes.
  - Flux: 4.8 x 10^6 Hz/cm^2
  - Total # of neutrons: ~25 x 10^9 [est.]
  - 3600 V applied
- Beam profile (by slits)
  - X width = 4 cm
  - Y width = 0.5 cm
- Signal Selection
  - max(ADC) > 300
  - N_{strip} fired ∈ {1…30}
- Hit Position
  - *C.O.M. of strips with ADC

*center of mass



Boron GEM Structure [boron coated]



Filter resistance 200 kΩ in voltage supply part
Total resist. is 6.25 MΩ

- Two GEM foils and a coated cathode
  - Drift gap: 10 mm
  - Boron coating: 1.5 um with (^{10}B)
    For neutron conversion

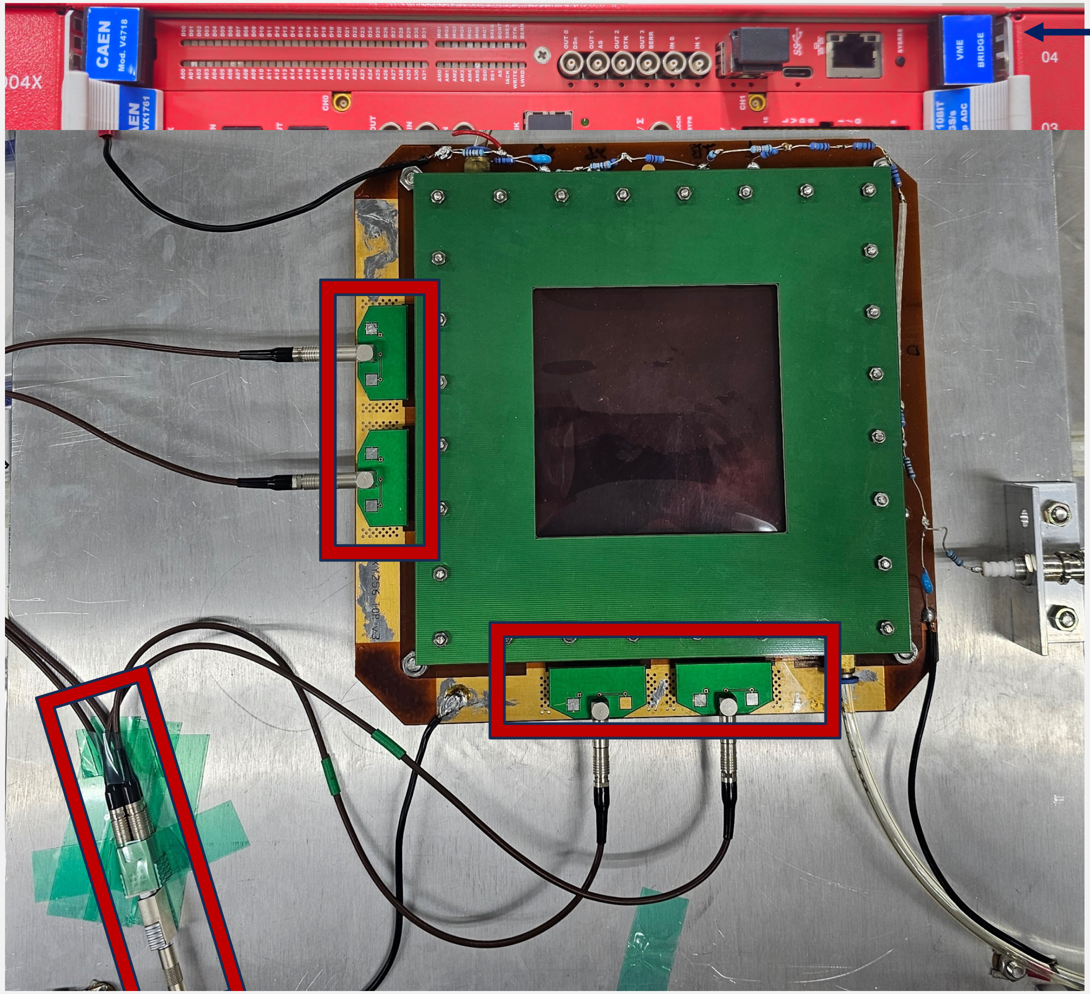
- The same structure without boron coating

To check for gamma events

- Coating GEM foil with boron can cause short circuits on both copper sides.

- GEANT4 confirms that drift coating is enough for neutron detection.

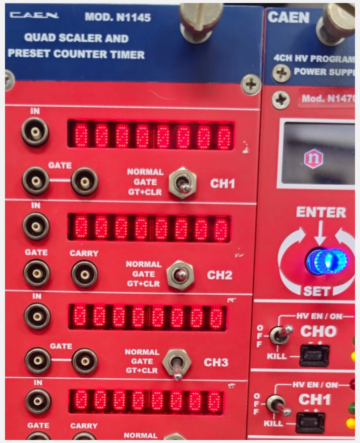
Data Acquisition



- Digitizer (0.25 ns step size)
  - 1 ch: shaper signal
  - 2 ch: R/O direct signal
  - 2 us window time

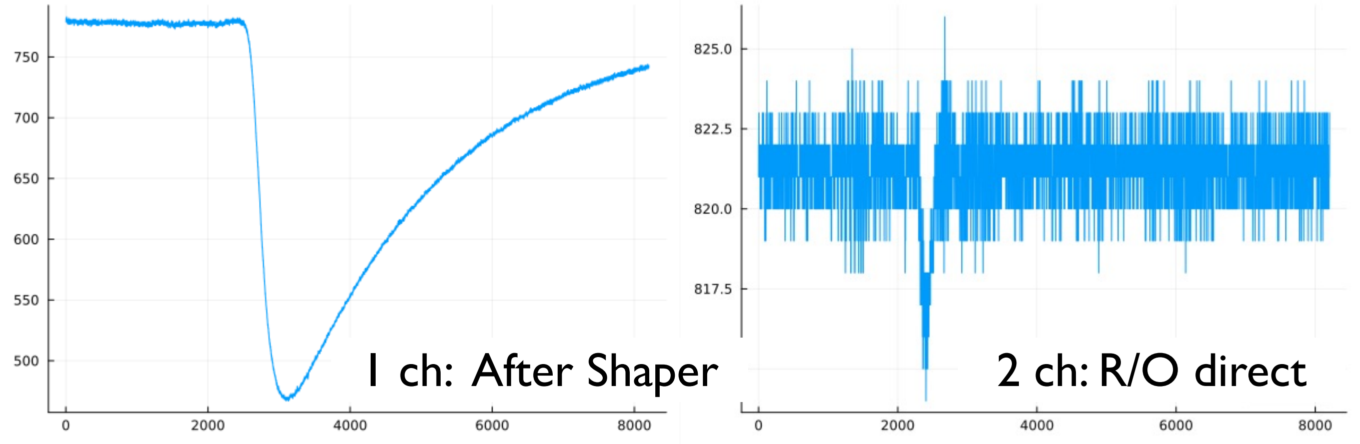
Input same signal

Counter



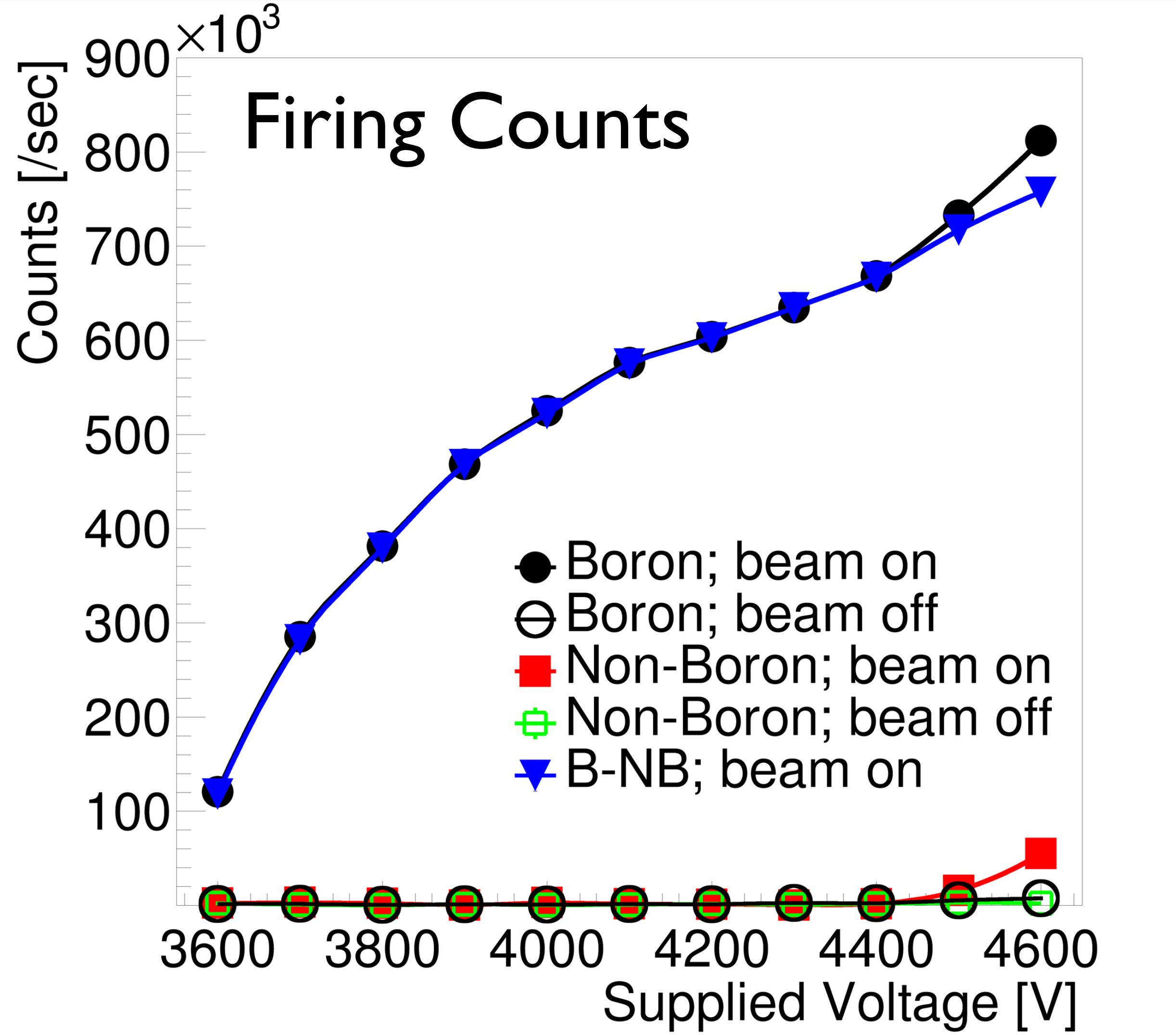
- Counter used to check for neutron events in the detector

Digitizer signal: ADC values over time



The 512ch of the readout board is combined into one.

Boron Coating vs Non-Boron



According to the plot, the signal is almost entirely due to neutrons.

- HANARO power: 27 MW
- Threshold: -30 mV
- Slit horizontal: 40 mm
- Slit vertical: 0.2 mm

  (B4C shaping slit)

- Beam on/off distinction is obvious.
- Above 4500 V, a gamma event of 0.48 MeV (from boron) is detected.
- The noise level is low despite the low threshold.

Next Plan & Summary

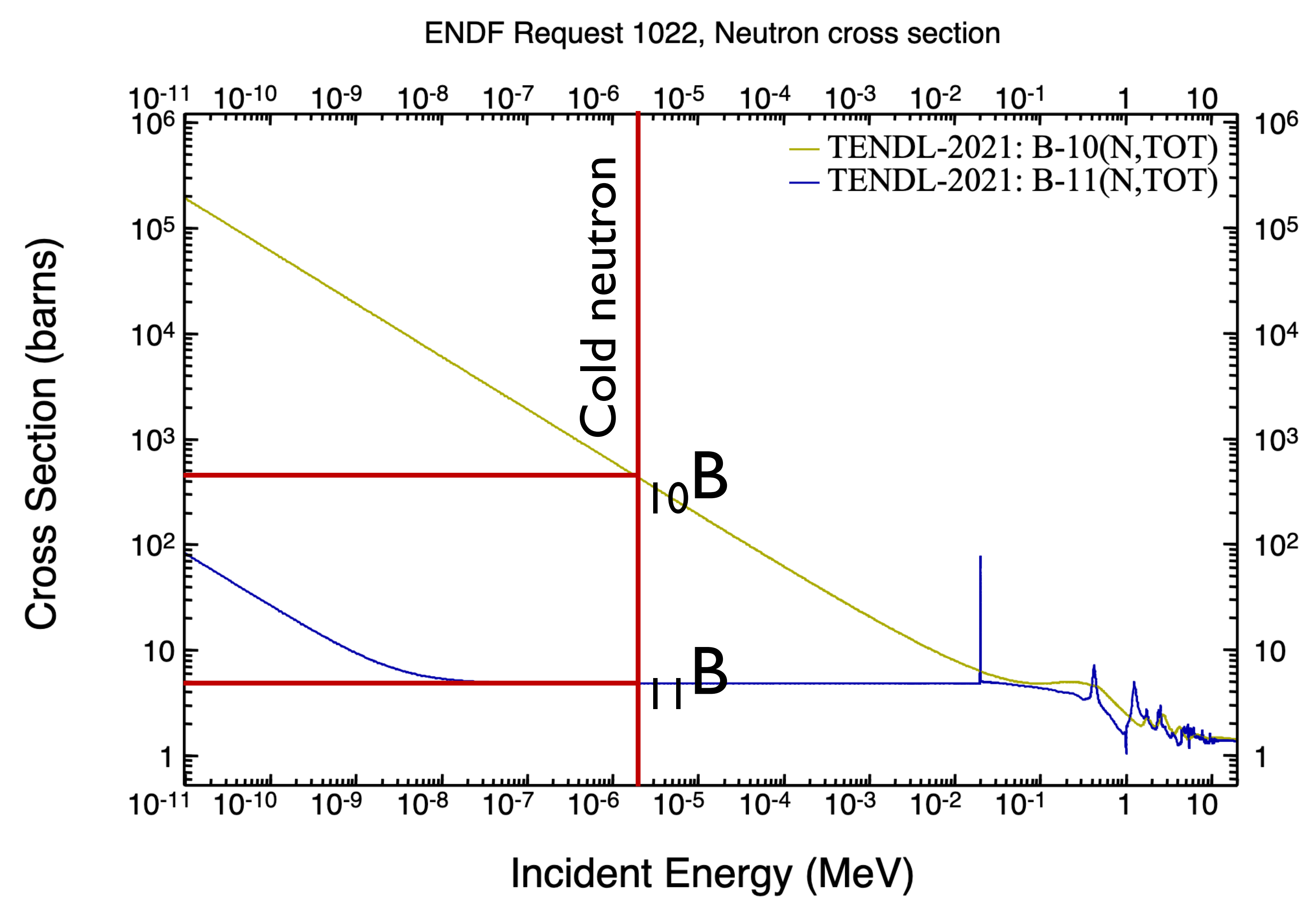
The Boron-GEM detector was developed and tested at HANARO for cold neutron detection.

- GEANT4 simulations have been completed to validate neutron efficiency calculations.
- The neutron detection capability of Boron GEM was demonstrated
- Future experiments at the RFT-30 cyclotron in Korea will use GEM detectors and Bonner spheres.

The efficiency of the B-GEM detector and the scale factor for neutron flux monitoring were determined by combining the results of the RFT-30 cyclotron experiment and GEANT4.

Backup

Neutron cross section

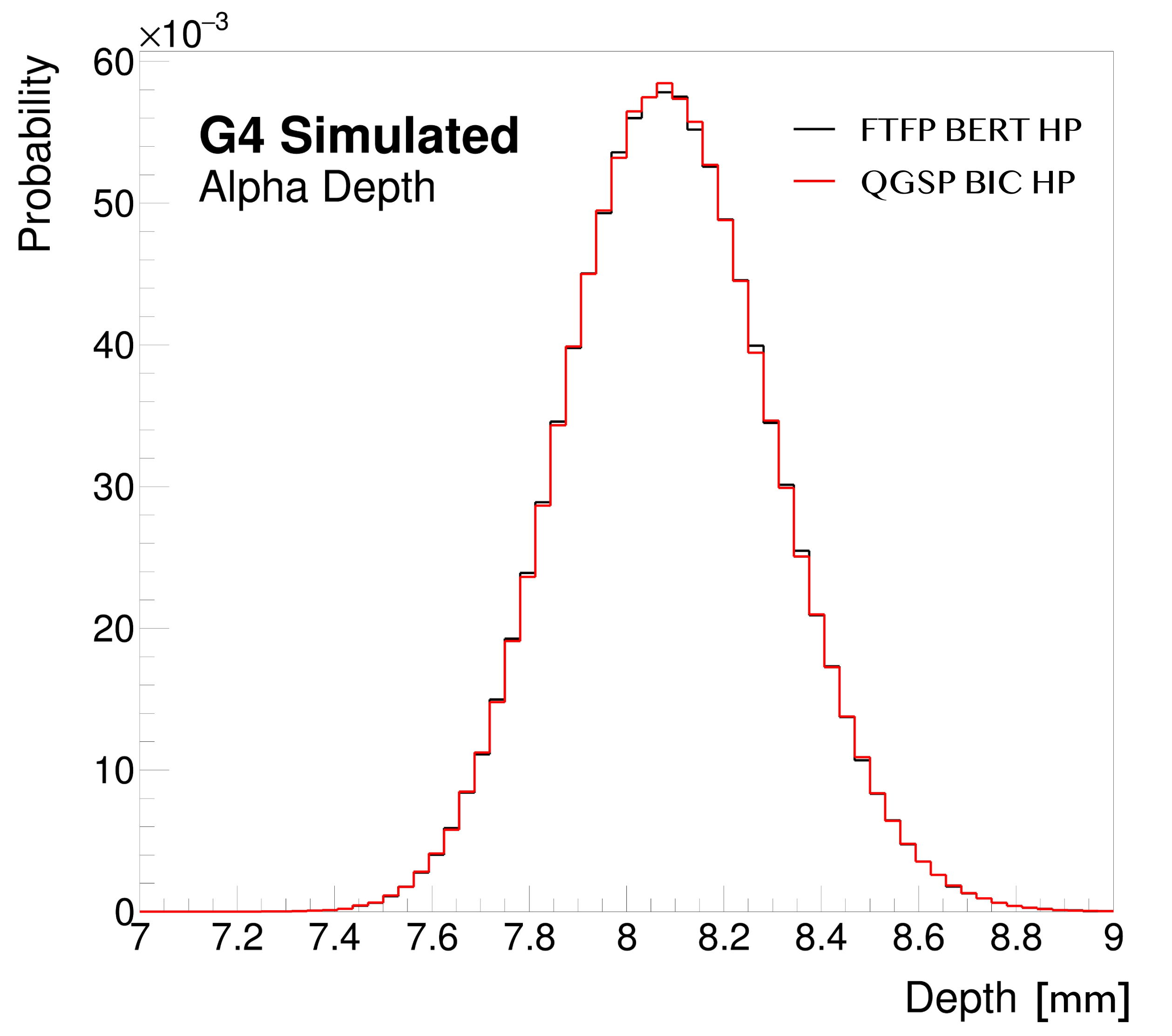


Geant4 Simulation [Alpha]

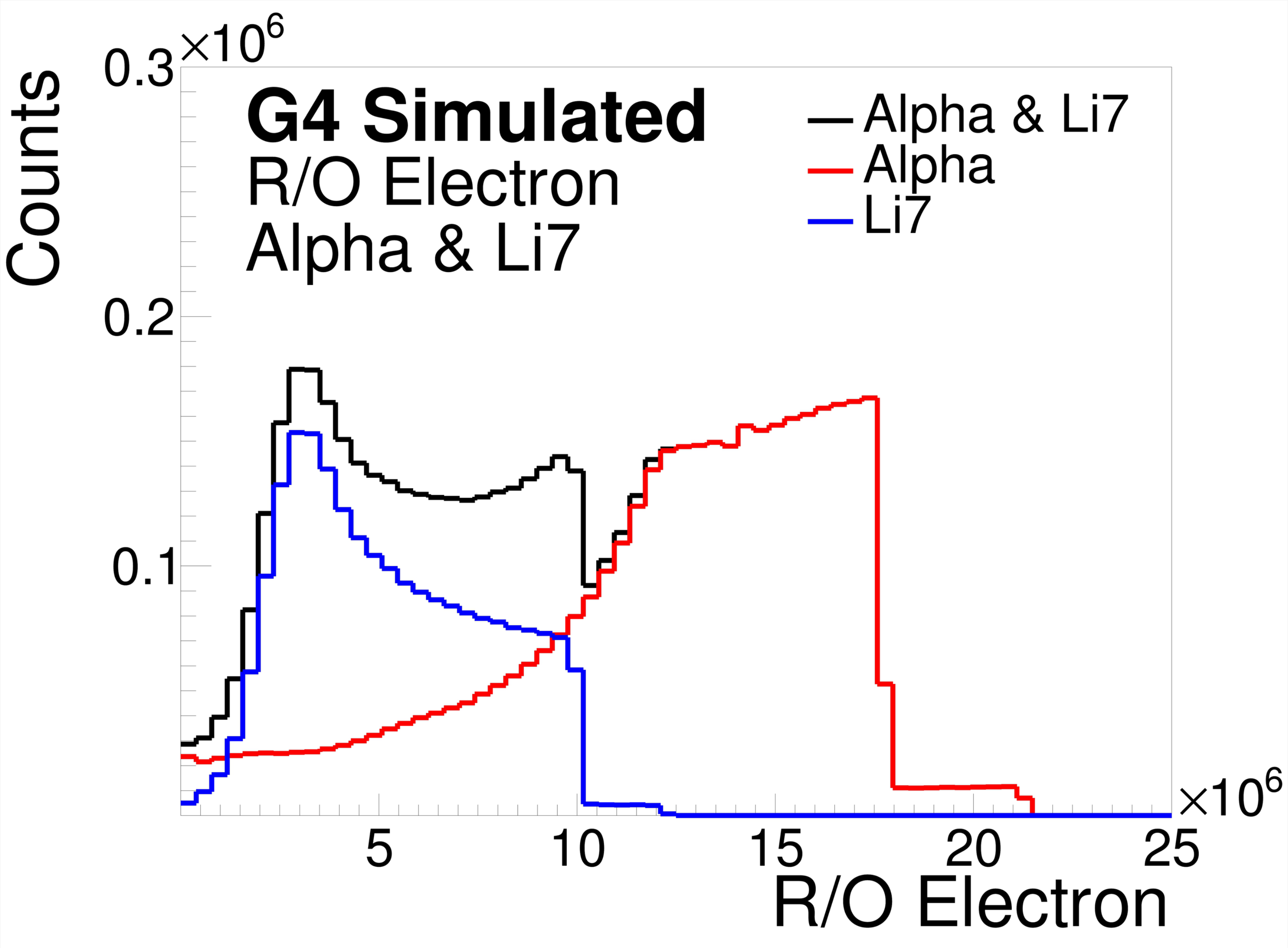
- Geant4 simulation by two physics models
  - FTFP BERT HP
  - QGSP BIC HP

- Gas: Ar/CO_2 (70/30)
- Alpha energy: 1.78 MeV
  maximum energy after capture

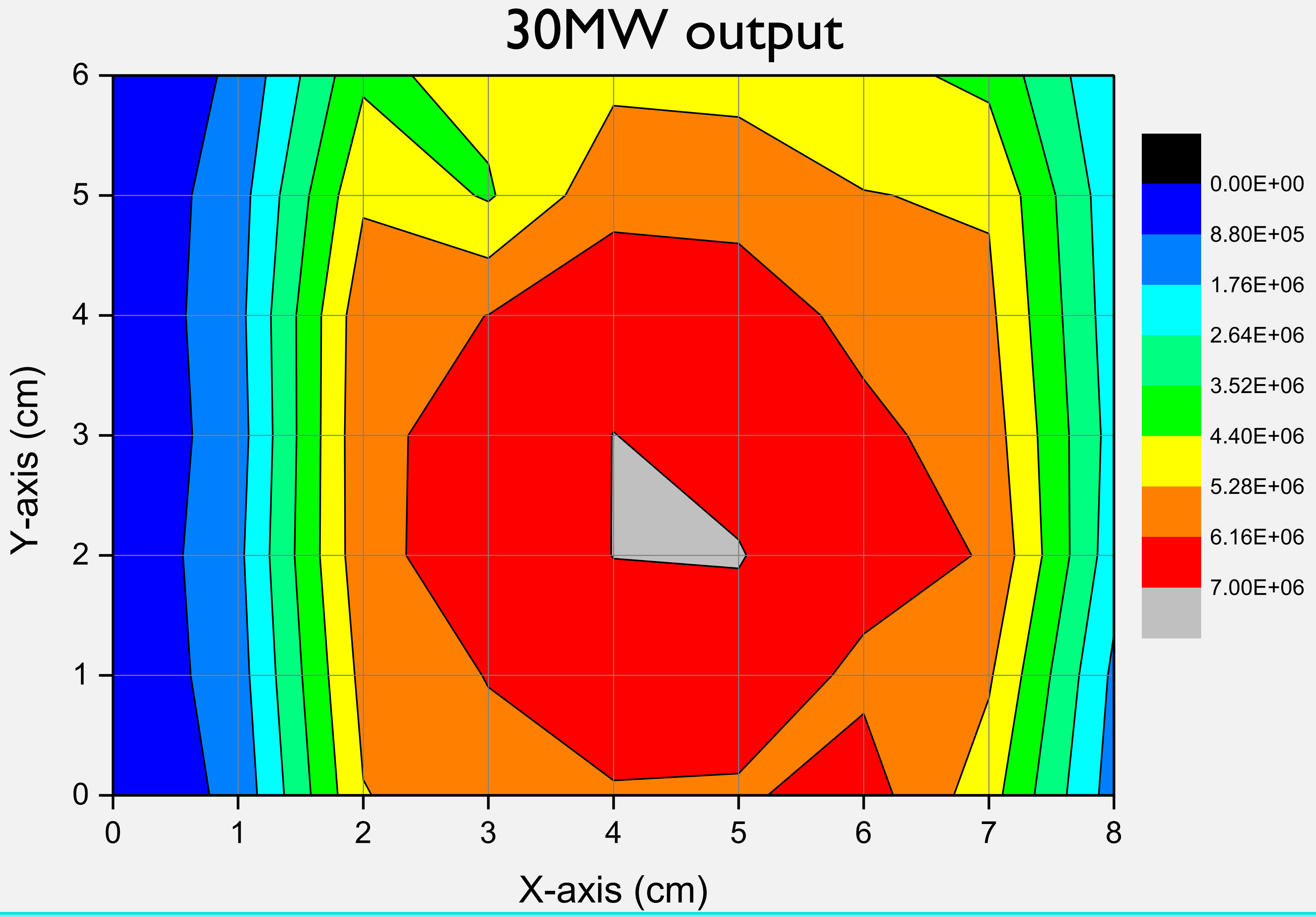
- Geant4 simulation result
  - Peak: 8.1 mm
  - Maximum: 9 mm



Alpha & Li7 R/O electron



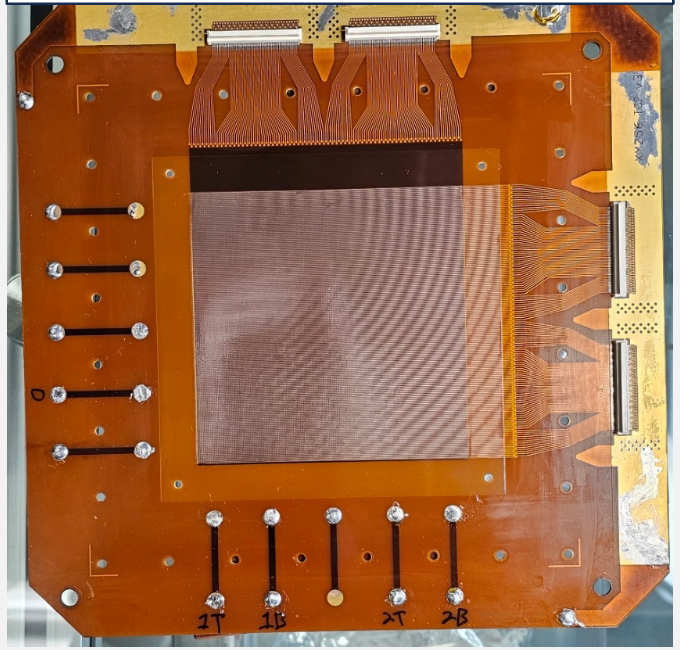
HANARO Neutron Beam Flux



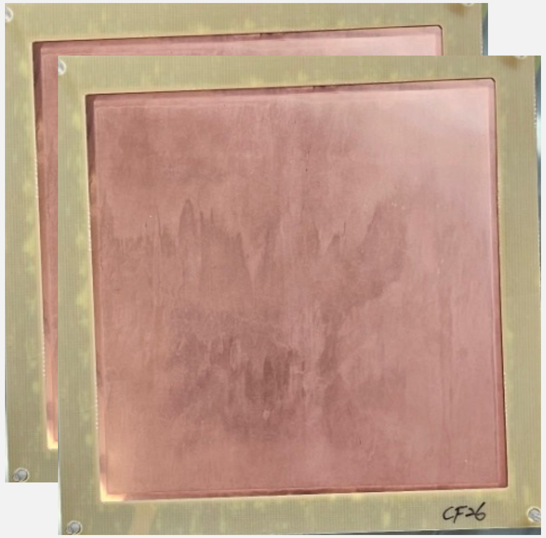
Detector Assemble

The Making Process

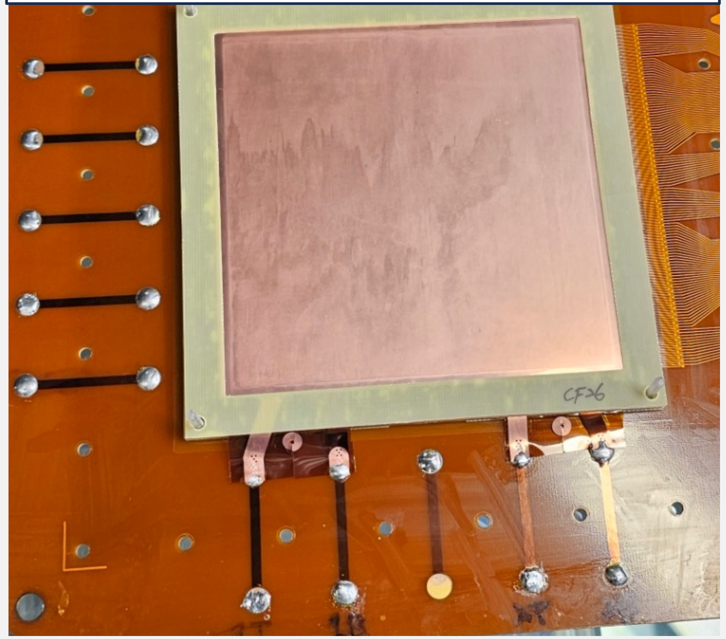
Readout board

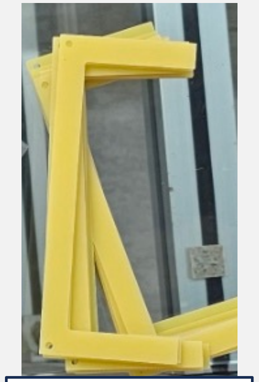


2 GEM foil



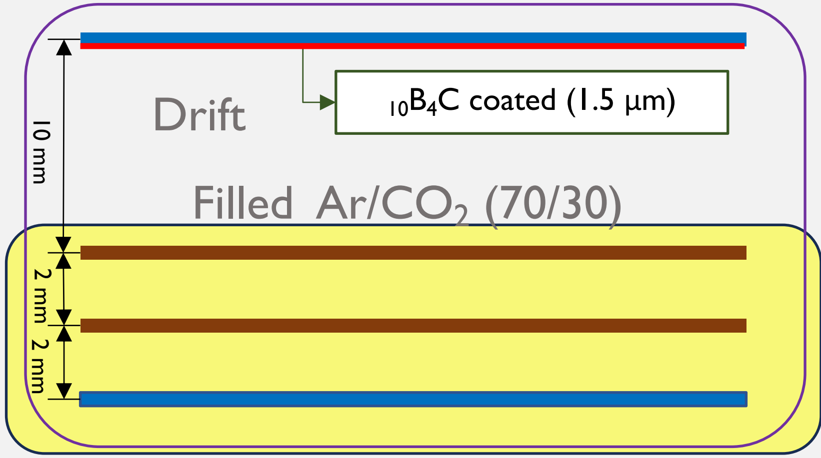
Attach the GEM foil to the board





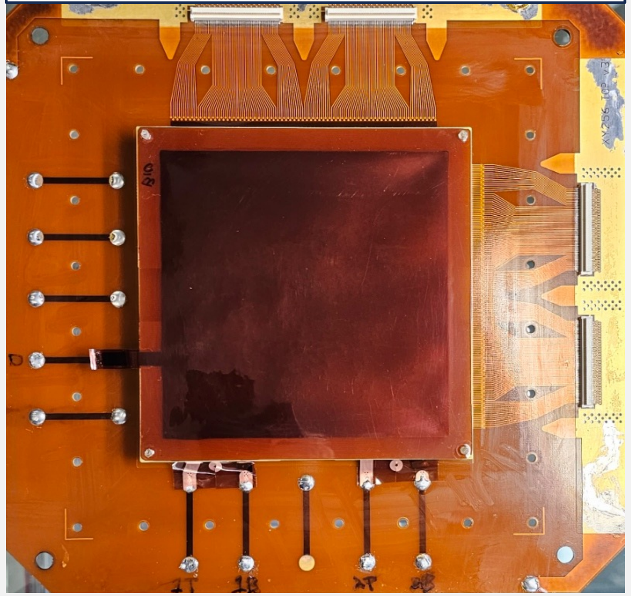
Spacer

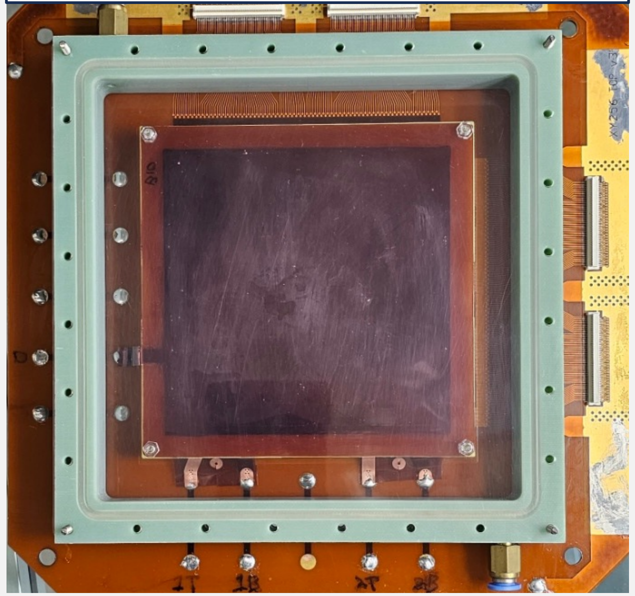
- Detector assemble readout-board and GEM foils with use spacer.
  - Each gap is 2 mm.

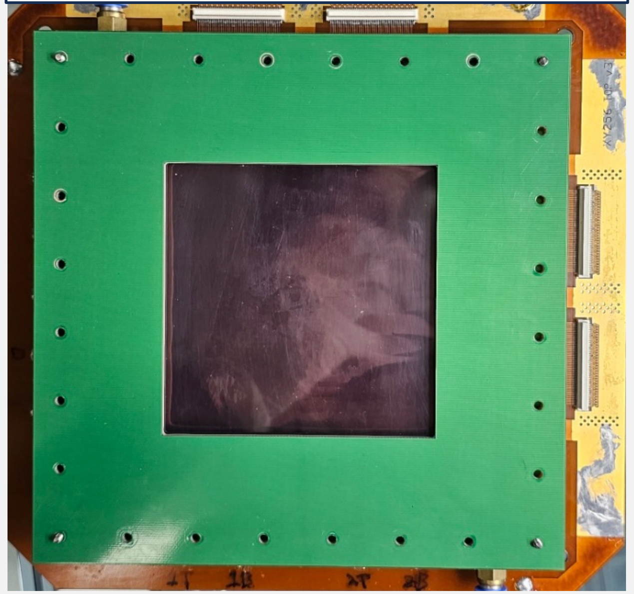


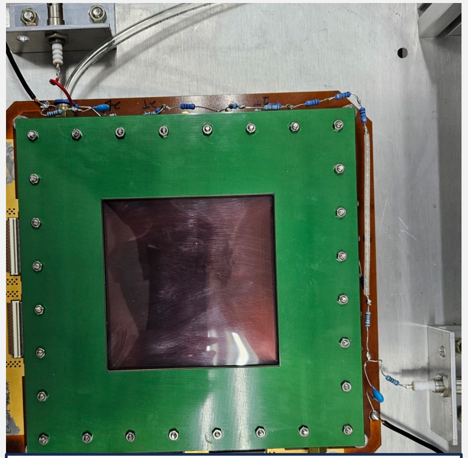
The Making Process


B4C coated cathode


Attach the coated cathode


Attach the window film


Casing detector


Assembled detector

- Insert a 10mm spacer between the cathode plate and the first GEM foil.
- Then cover the case and solder the circuit.