Efficiency analysis of GEM detector with boron converter

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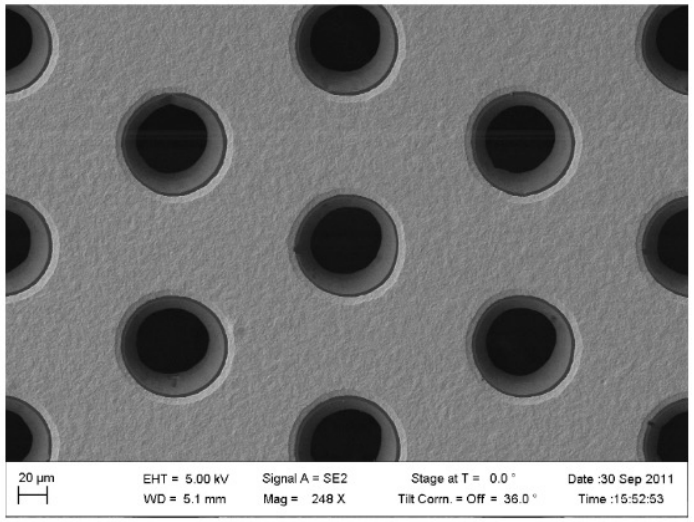
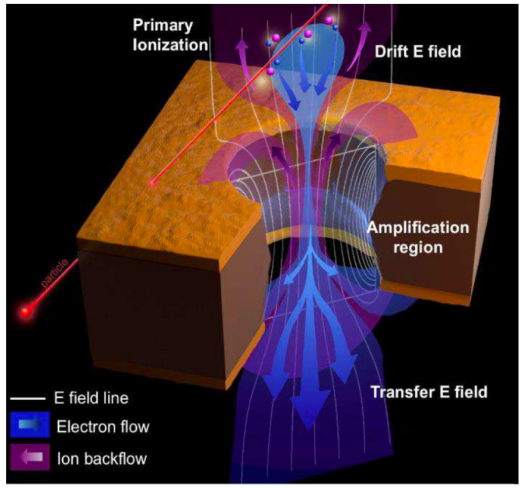
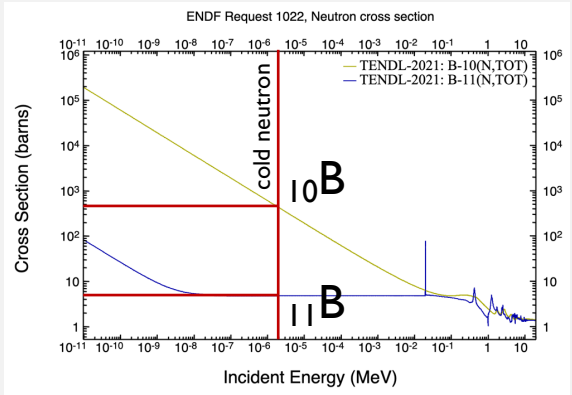
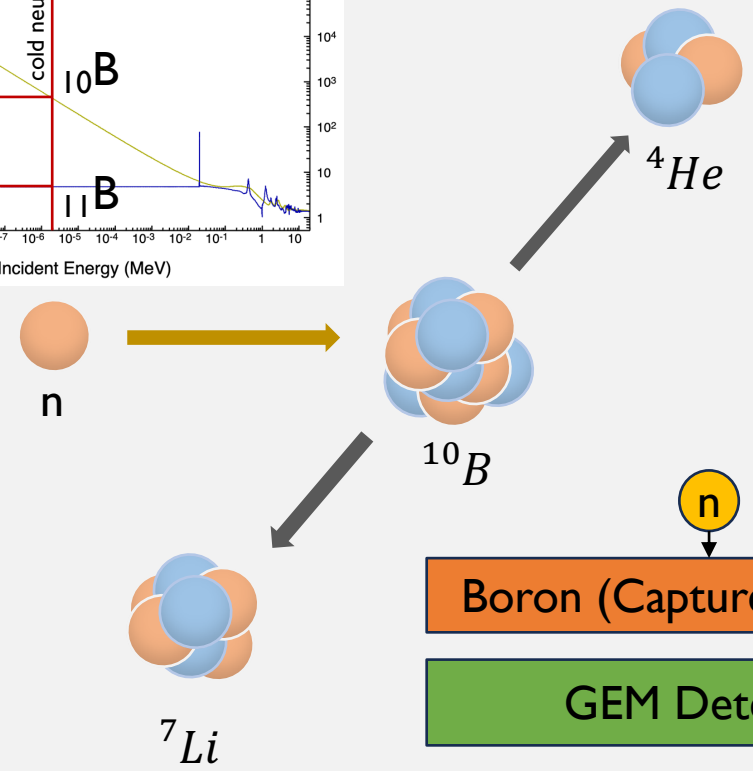
Gas Electron Multiplier & n Capture Process

- GEM foil = 50 μm polyimide film + 5 μm copper layer on each side
- The primary electrons are generated in the drift area
- The strong electric field in micro-holes makes electron avalanches









$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He + 0.48\ MeV\ \gamma + 2.31\ MeV(94\%)$

$E_\alpha = 1.47\ MeV,\ E_{Li} = 0.84\ MeV$

$\rightarrow {}^{7}Li + {}^{4}He + 2.79\ MeV(6\%)$

$E_\alpha = 1.78\ MeV,\ E_{Li} = 1.0\ MeV$

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)

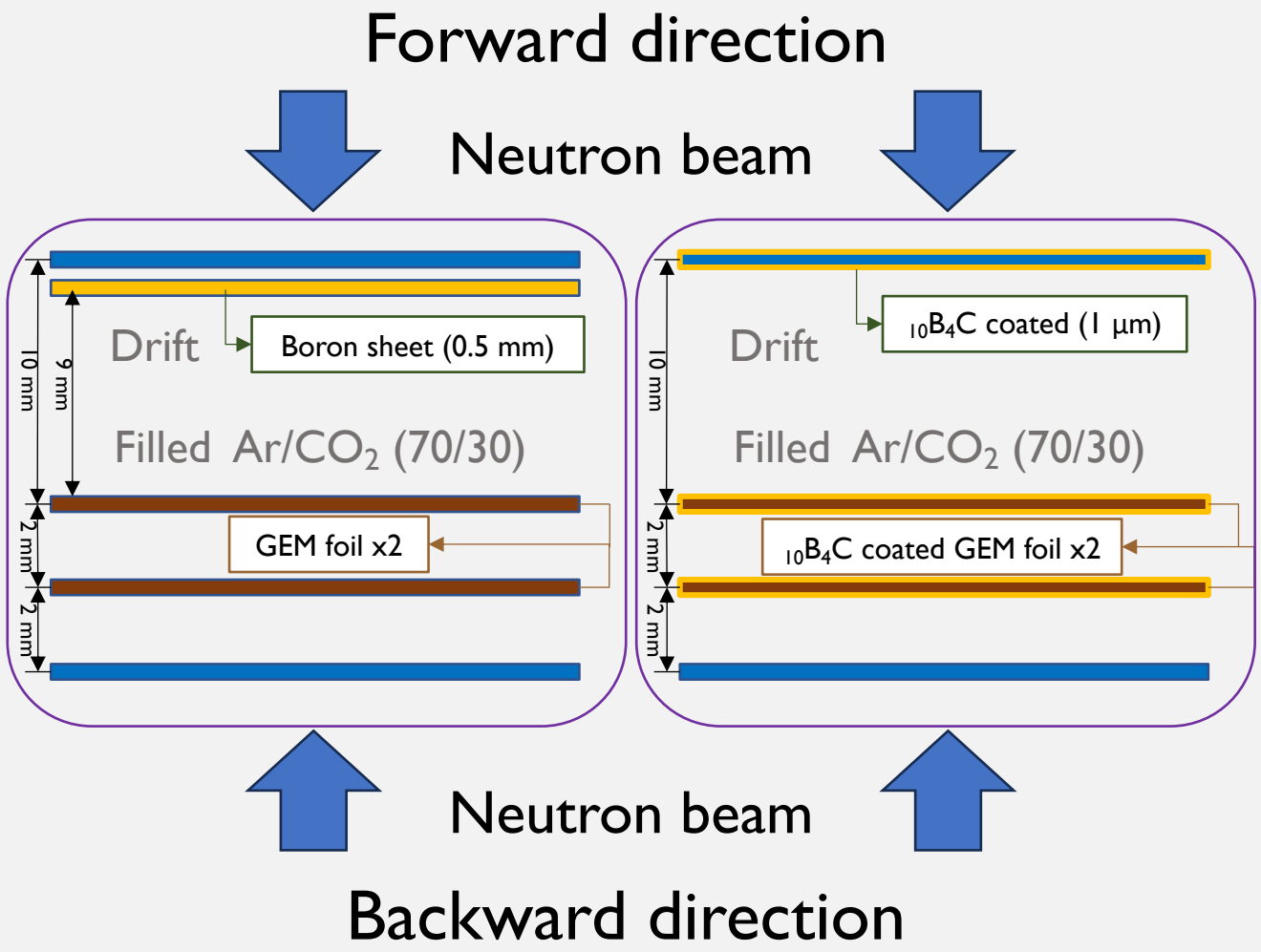
Variations on geometry

- 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 μm)
- Foil coating [Pure $_{10}B$ as B_4C]
  - Both of all GEM foils and cathode plate are coated (T =1 μm)

Used physics model

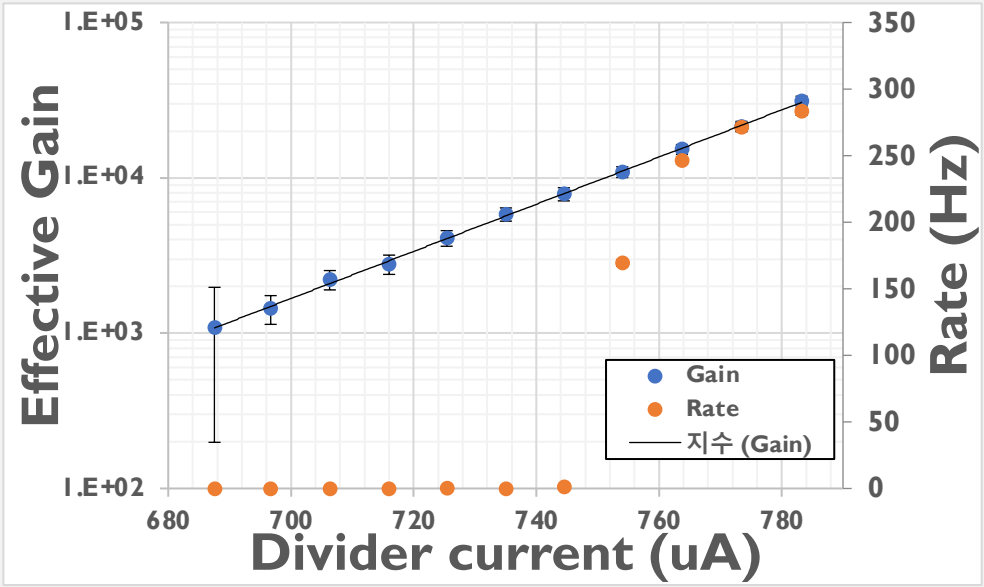
- QGSP BIC HP

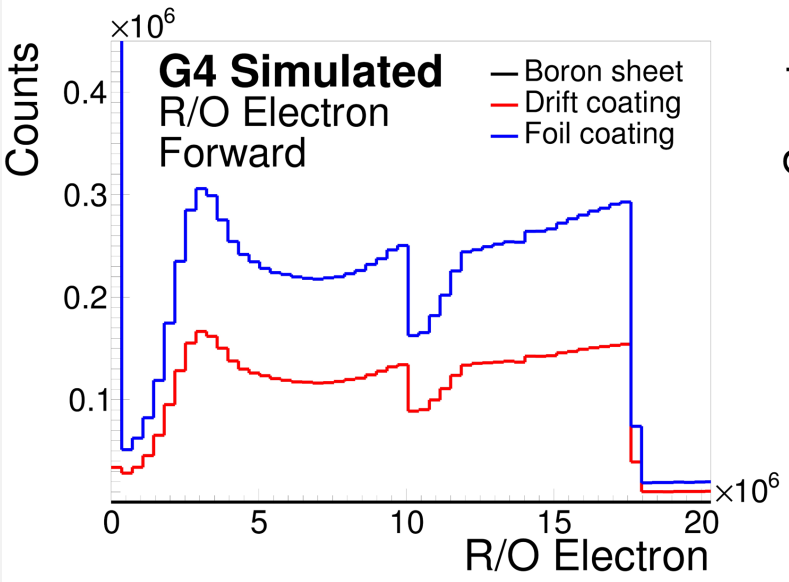
Variations on direction

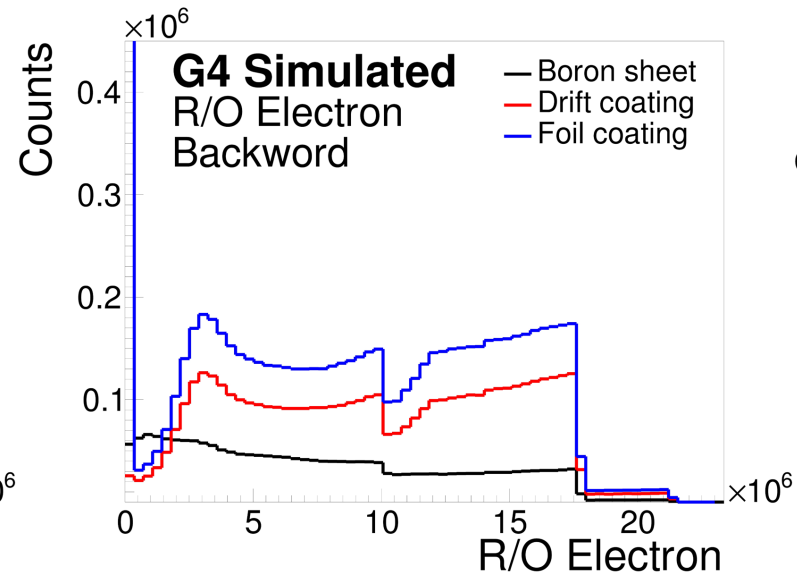


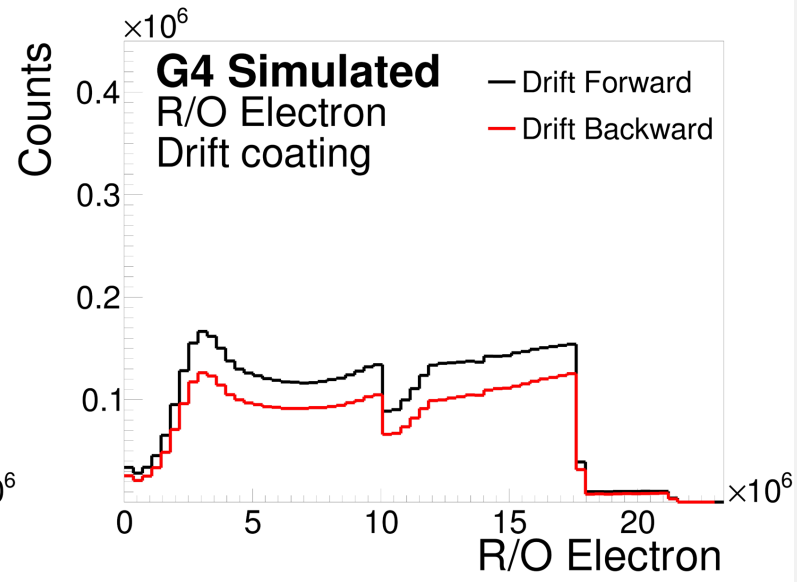
Geant4 Simulation [Result]

- The number of neutrons: 100 million (10 meV)
- 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









Beam Test

HANARO Beam Specification

- *HANARO (High-flux Advanced Neutron Application ReactOr)*

- Bio-REF specifications
  neutron energy : 10~12 meV (Cold)

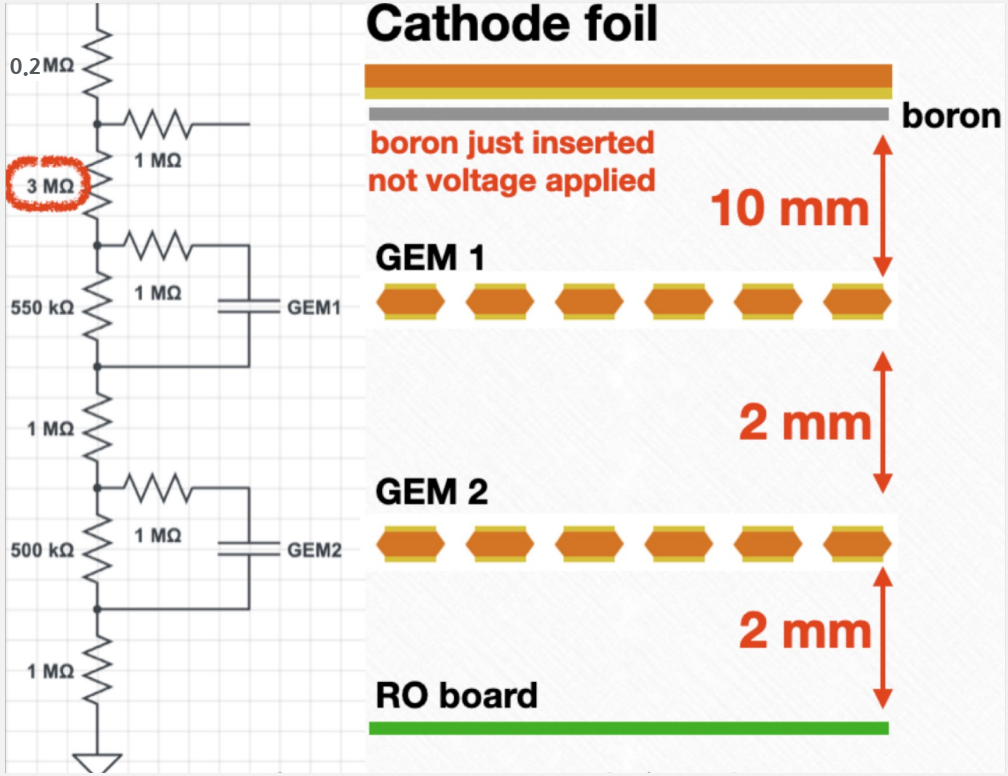
- Used profile
  - 22 MW (30MW max.)
  - X-width: 4 cm, Y-width: 0.5 cm
  - Flux: 4.8 x 10^6 Hz/cm^2
  - Neutrons fluence: ~ 9.5 x 10^6 Hz

Boron Coating on the Foils

Coating

Coating problem is nearly resolved.

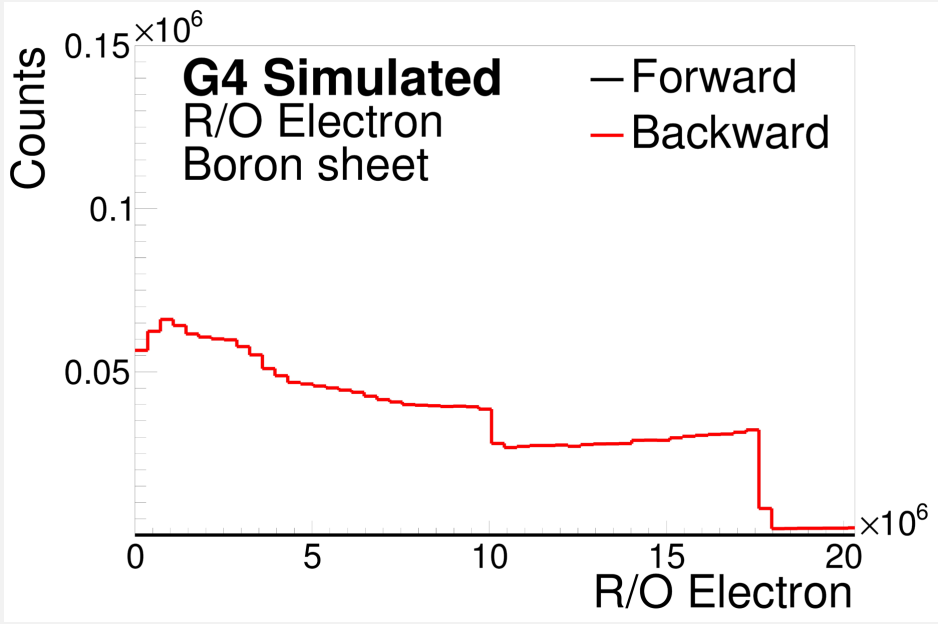
Boron GEM Structure [boron sheet]



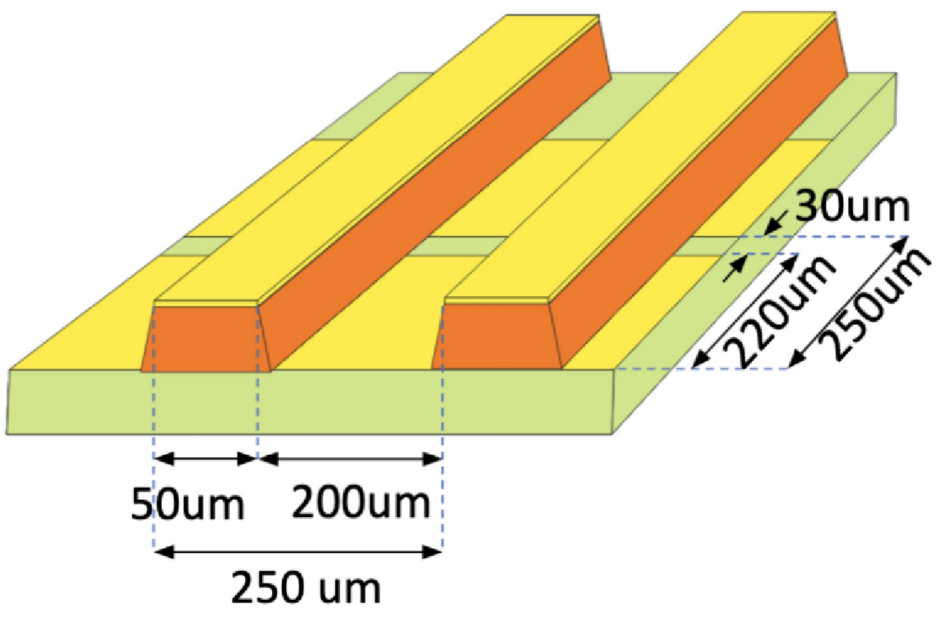
Filter resistance 200 kΩ in voltage supply part, Total resist. is 6.25 MΩ

- The B-GEM detector consists of two GEM foils and a neutron converter
  - Drift gap: 10 mm (3 MΩ)
  - Boron sheet: 0.5 mm with (^{11}B : ^{10}B, 4 : 1)

- Better direction: **Backward**

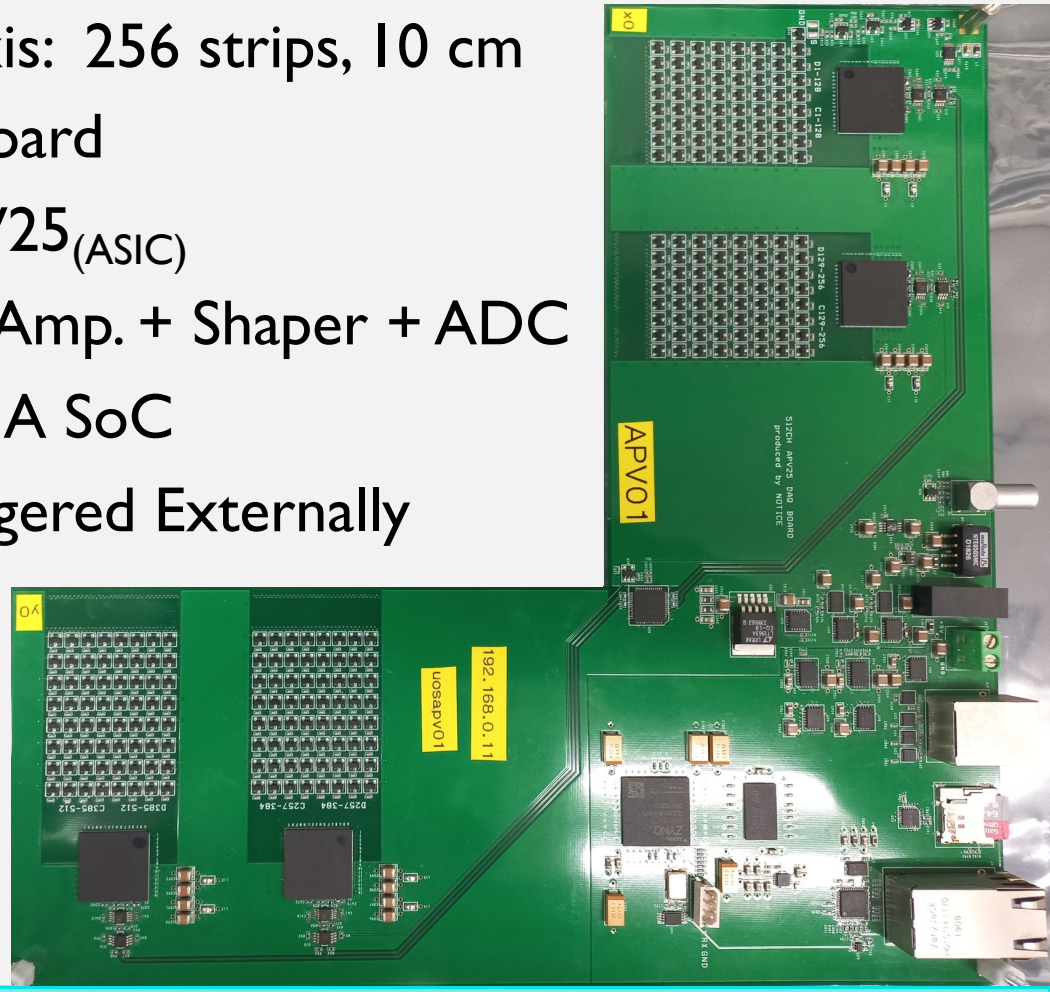


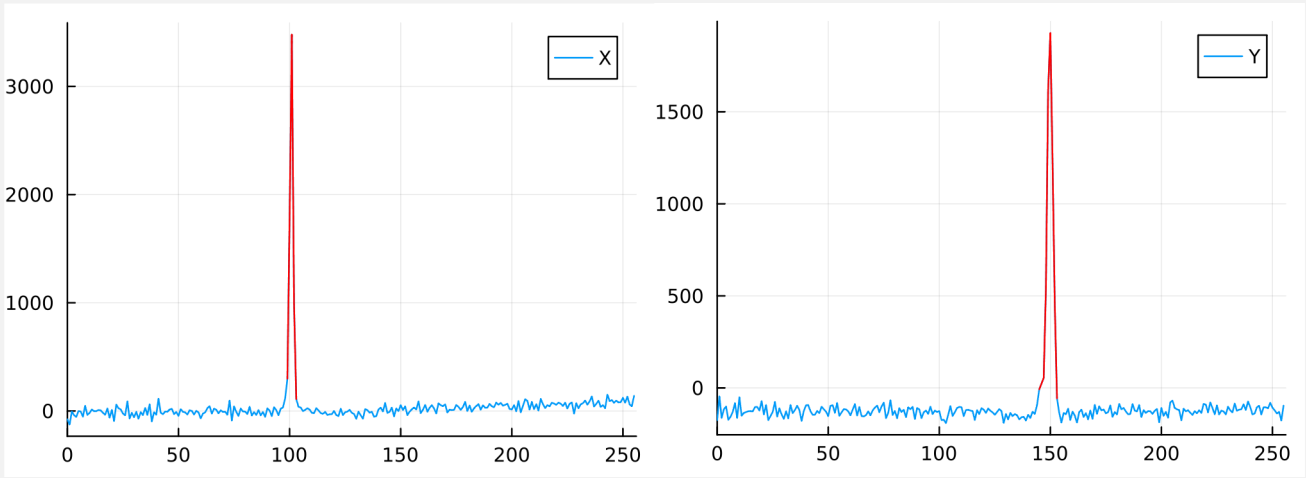
Data Acquisition



- Read-out board
  - X-axis: 256 strips, 10 cm
  - Y-axis: 256 strips, 10 cm
- DAQ board
  - $APV25_{(ASIC)}$
    - Amp. + Shaper + ADC
  - FPGA SoC
  - Triggered Externally

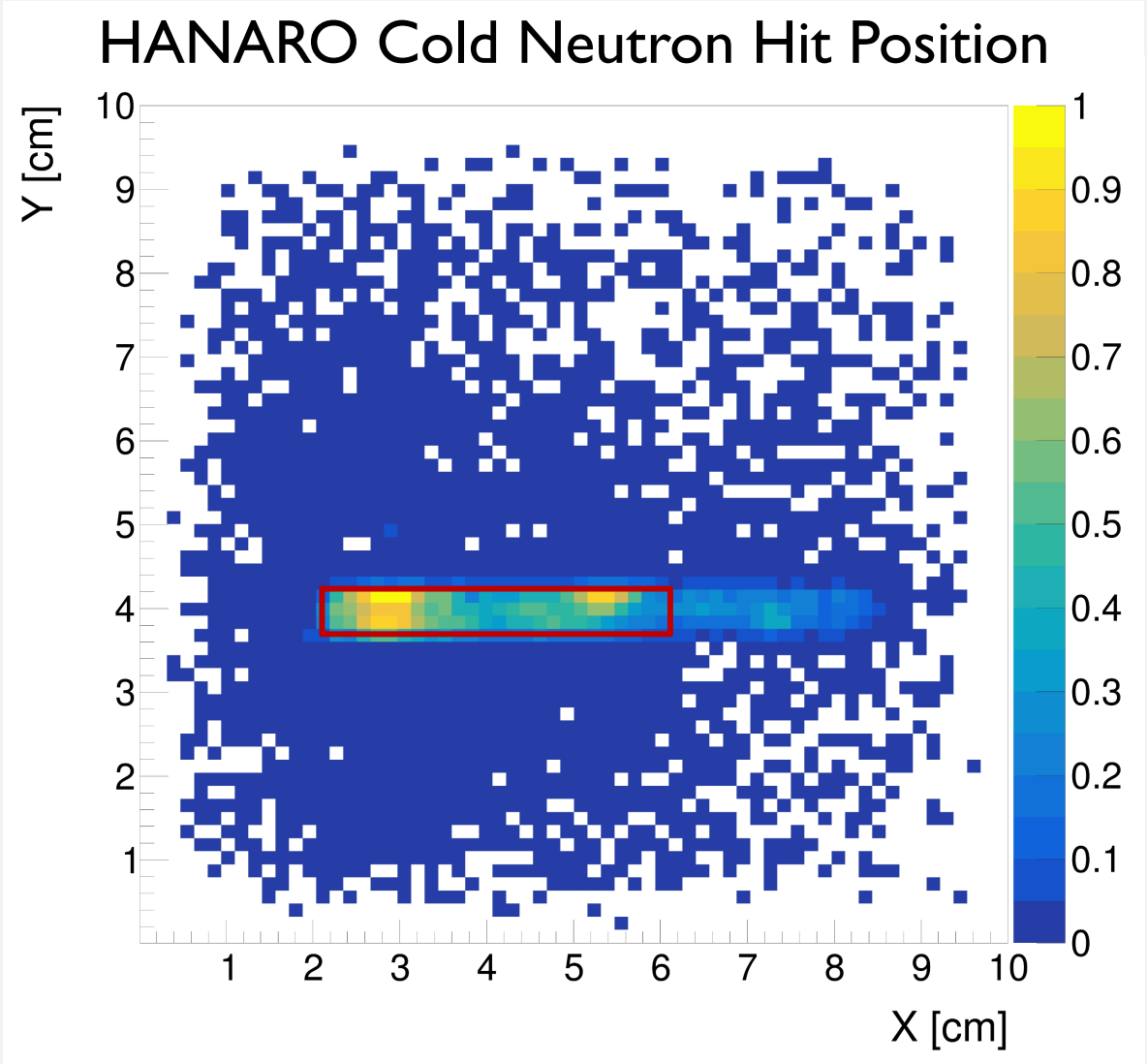
DAQ board





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.]
- 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

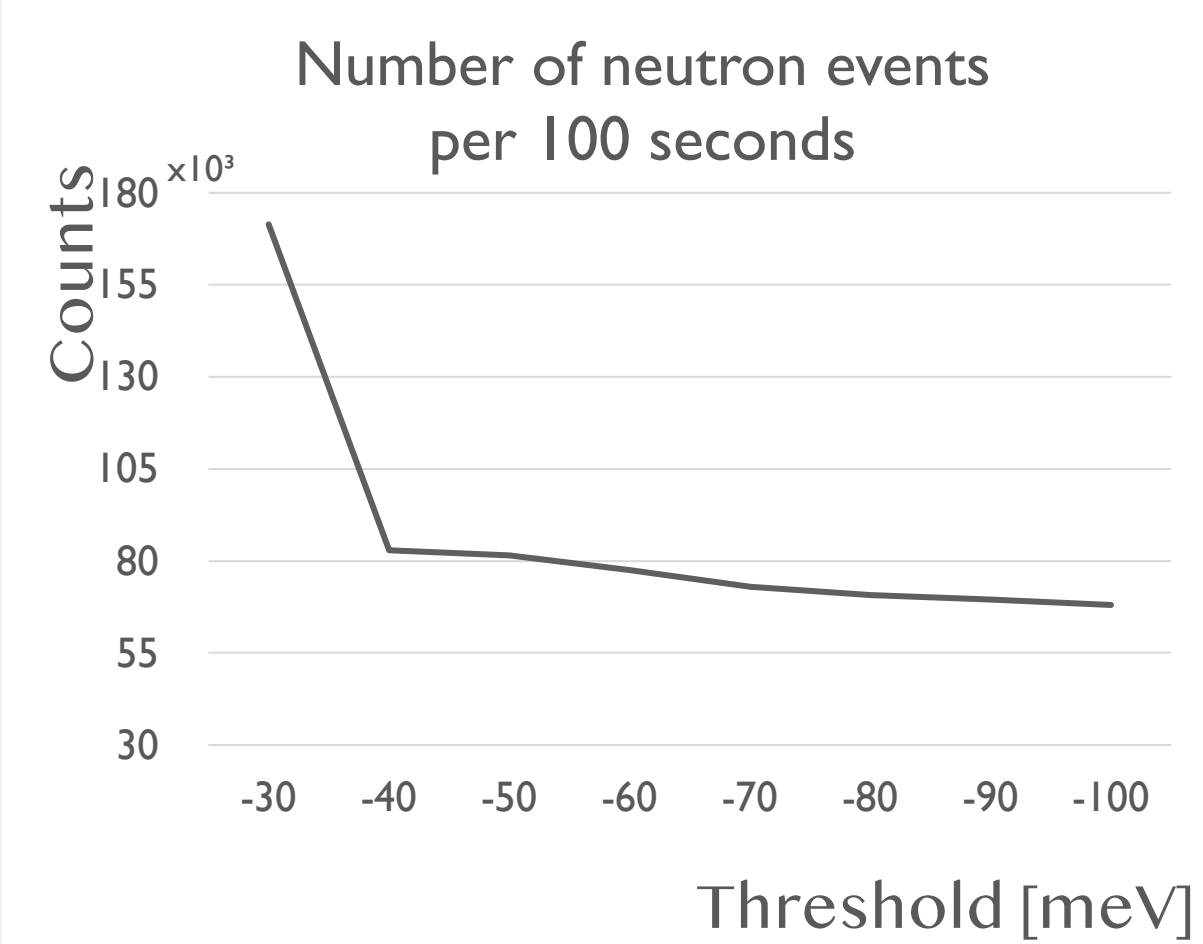


HANARO Experiment Results

- Measurements were performed for 100 seconds at each threshold.
- Y-axis: beam on counts – beam off counts

Threshold	Efficiency	Threshold	Efficiency
-30 mV	0.01798 %[1]	-70 mV	0.00765 %
-40 mV	0.00869 %	-80 mV	0.00742 %
-50 mV	0.00855 %	-90 mV	0.00729 %
-60 mV	0.00813 %	-100 mV	0.00714 %

[1] Due to beam-induced noise



Summary

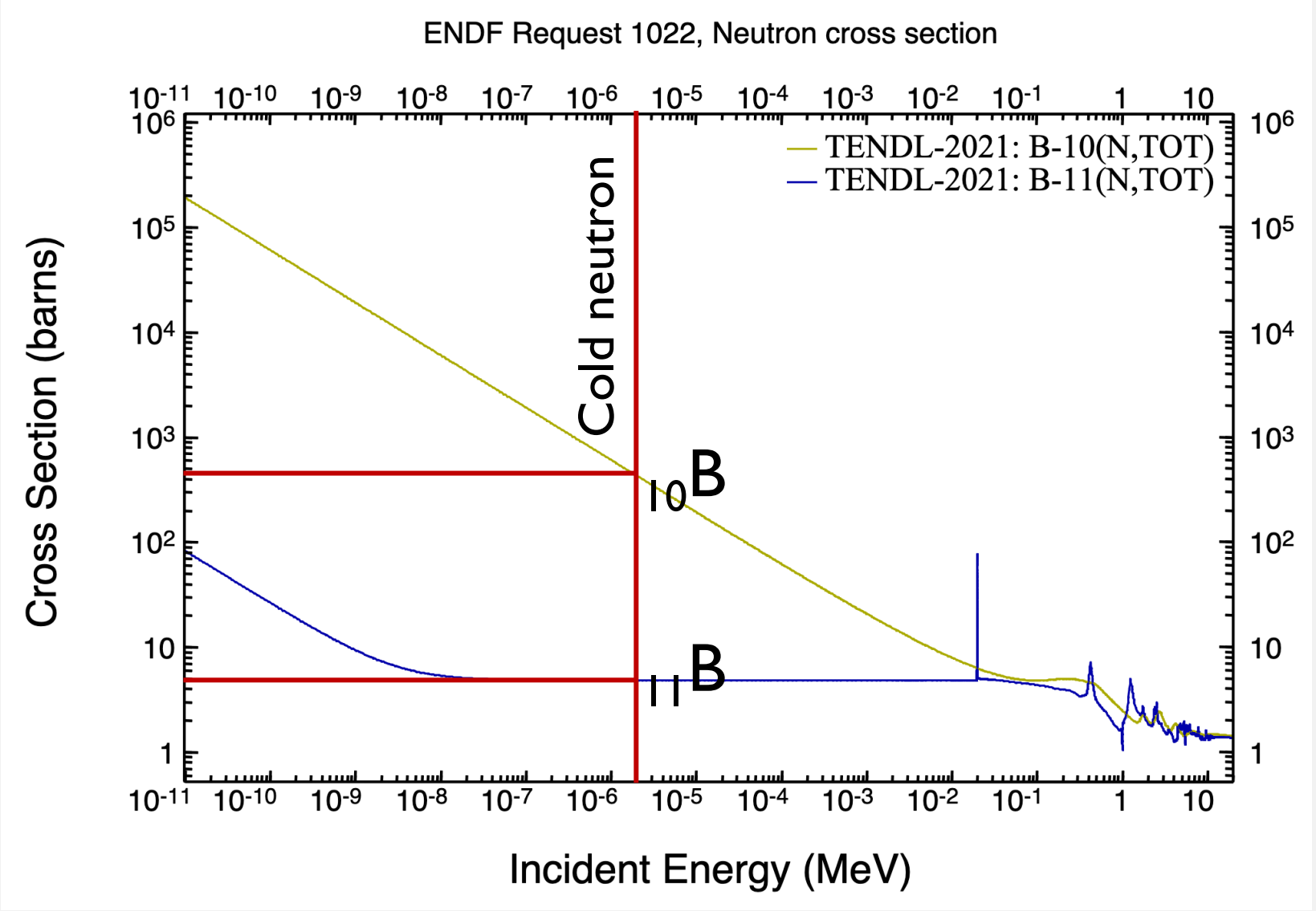
A beam test with GEM detector with boron sheet$_{(\text{natural proportion})}$ is done.
The beam was backward direction, selected by geant4 simulation results.

- HANARO is used for cold neutron source
- The neutron beam profile is well imaged as setup of slits
  - 43 minutes of exposure = # of neutrons ~25 x 10^9
- The efficiency is measured as $8.69\times10^{-3} \pm 3\times10^{-5}_{(\text{stat.})}$ [%]
  - with -40 mV threshold.

The B_4C Drift-coated GEM detector will be built and tested at HANARO.

Backup

Neutron cross section

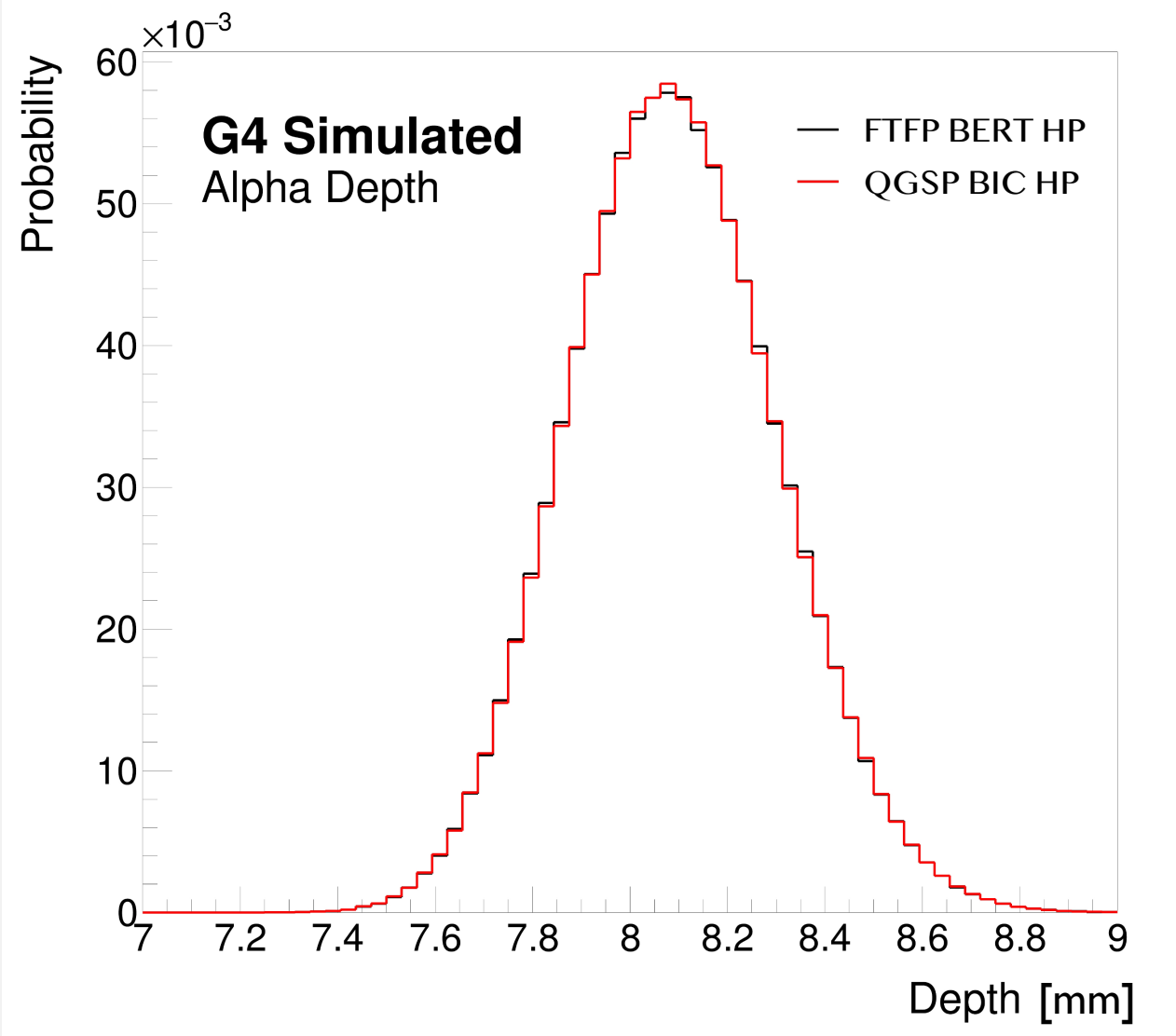


Geant4 Simulation [Alpha]

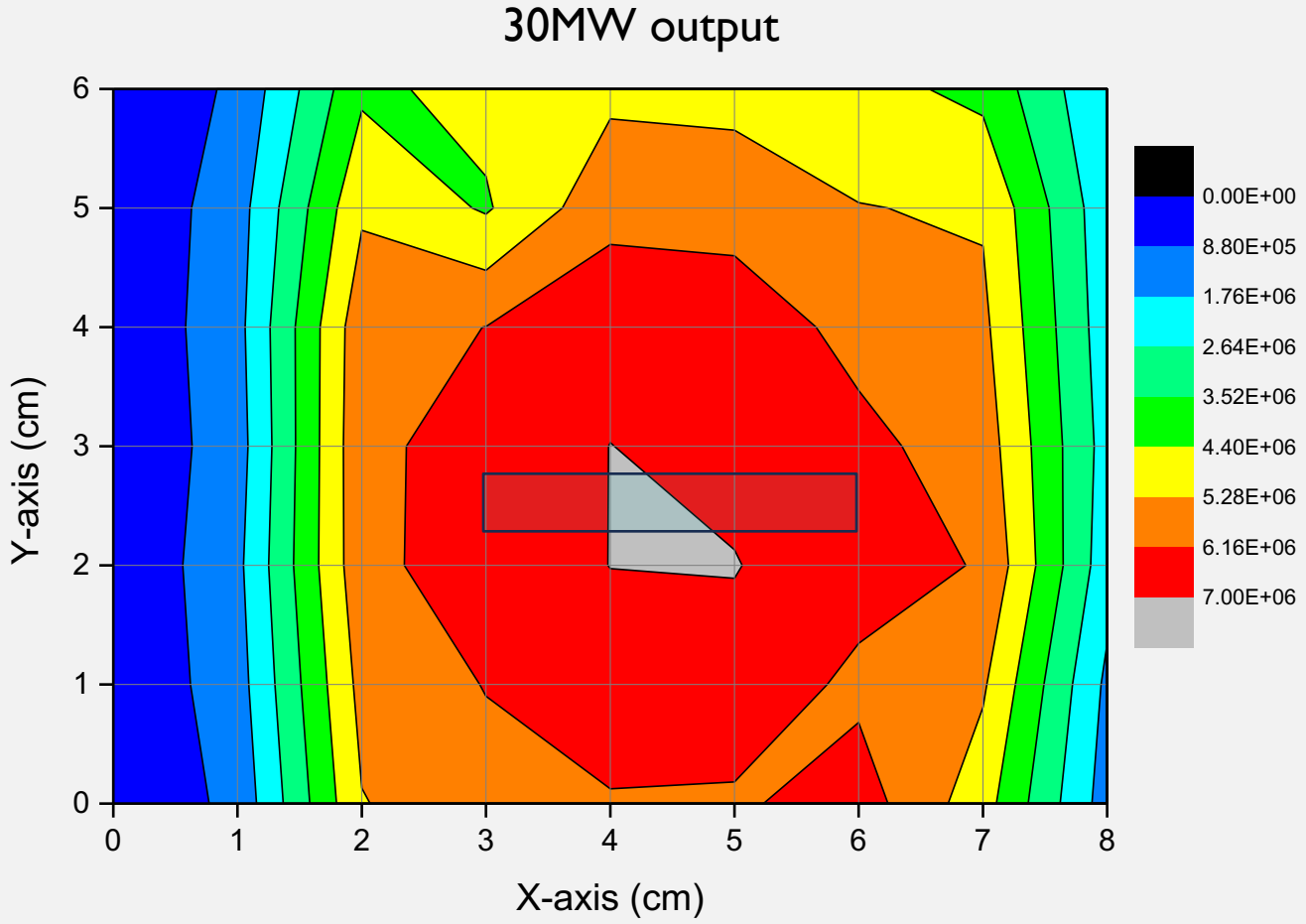
- Geant4 simulation by two physics models
  - FTFP BERT HP
  - QGSP BIC HP

- 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

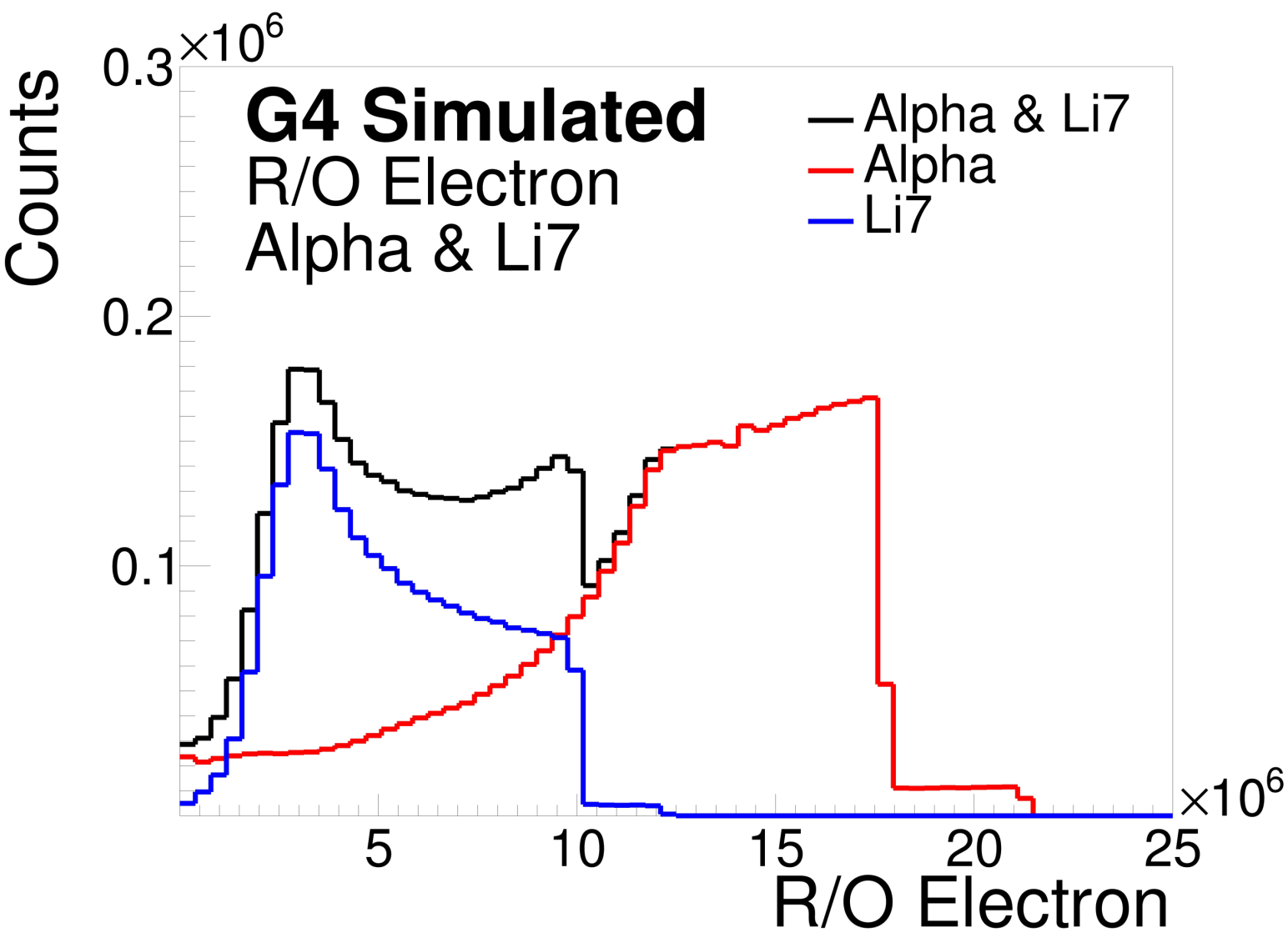


HANARO Neutron Beam Flux



- Total entering neutrons:
  ≈ 4 cm x 0.5 cm x 6.5 x 10^6 cm^2/s
  ≈ 1.3 x 10^7 / s
- If the number of neutrons is linearly proportional to the output.
  For 22 MW output:
  ≈ 9.5 x 10^6 / s

Alpha & Li7 R/O electron



Efficiency

threshold	Beam W/O	Beam W/	Signal	Efficiency
-30 mV	165773	337183	171410	0.01798 %
-40 mV	11849	94675	82826	0.00869 %
-50 mV	1083	82639	81556	0.00855 %
-60 mV	108	77569	77461	0.00813 %
-70 mV	67	72990	72923	0.00765 %
-80 mV	37	70783	70746	0.00742 %
-90 mV	38	69573	69535	0.00729 %
-100 mV	26	68066	68040	0.00714 %

- 2023.09.08
- Humidity : 59 %
- Temperature : 26 ℃
- Operating voltage : 4400 V
- Veto time : 2 us
- Running time : 100 s
- Total neutrons
  ≈ 9.5 x 10^8