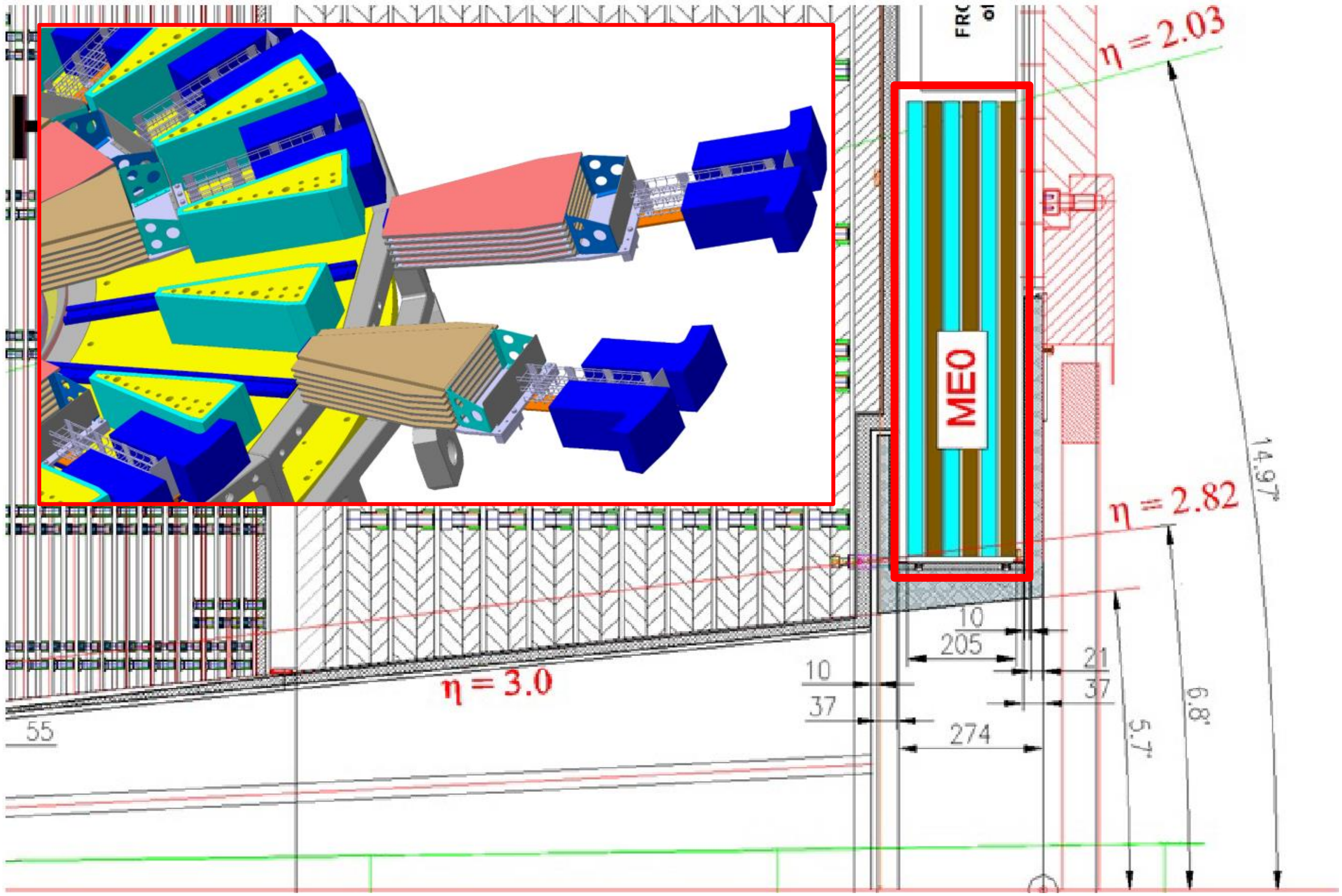
ME0 Ageing and Neutron Detector

Woojong Kim

서울시립대학교
UNIVERSITY OF SEOUL

ME0 Aging Test

Motivation



Expected accumulated charge on ME0 7.9 C/cm^2
(after 10 HL-LHC years)

CMS (Compact Muon Solenoid)

- General purpose experiment at the Large Hadron Collider (LHC) at CERN.
- Measures proton-proton and heavy-ion collisions.

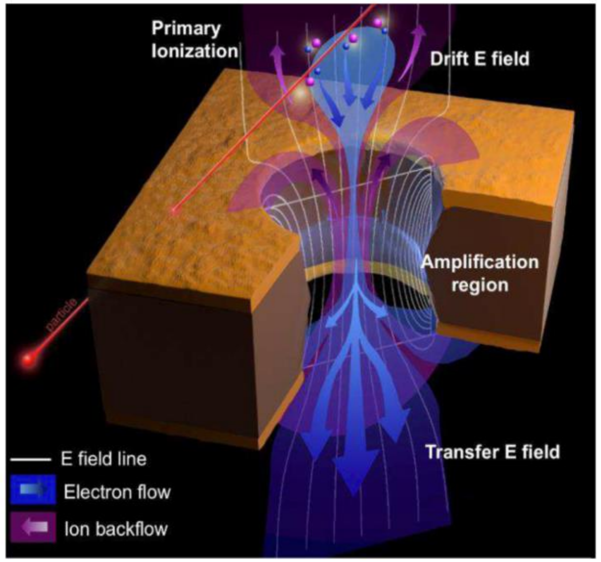
High Luminosity LHC (HL-LHC)

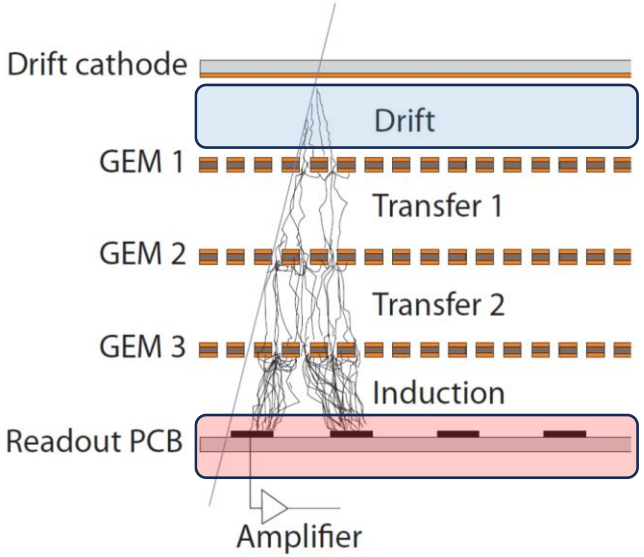
- Integrated Luminosity: 10x original
- Center of Mass Energy: Increase to 14 TeV.
- Proton-Proton Interactions: Up to 200 interactions per bunch crossing every 25 ns.
- Challenges: Longevity validation and completion of muon chambers

Gas Electron Multiplier

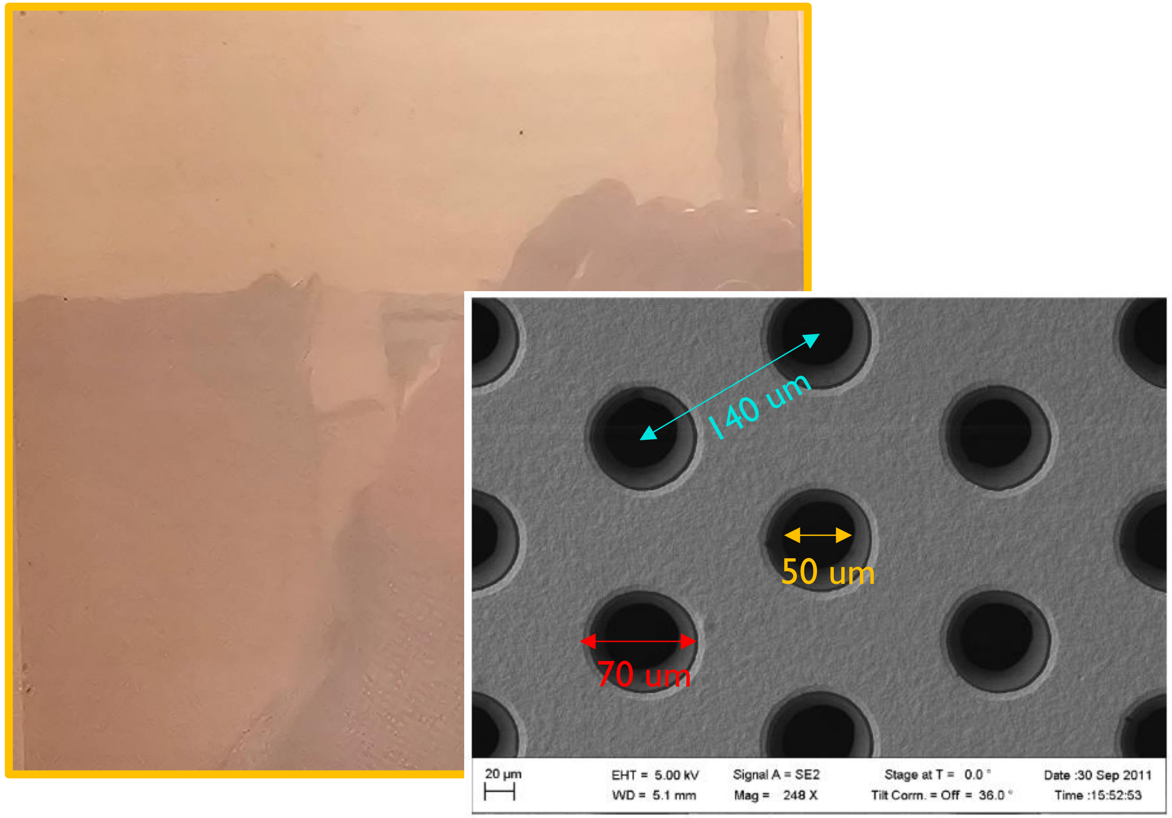
- **Drift area**
  - The primary electrons are generated
  - Accelerate the electrons sufficiently

- The strong electric field in micro-holes makes electron avalanches
- We use the GEM foil with micro pattern readout board and Ar/CO_2 gas (70/30)



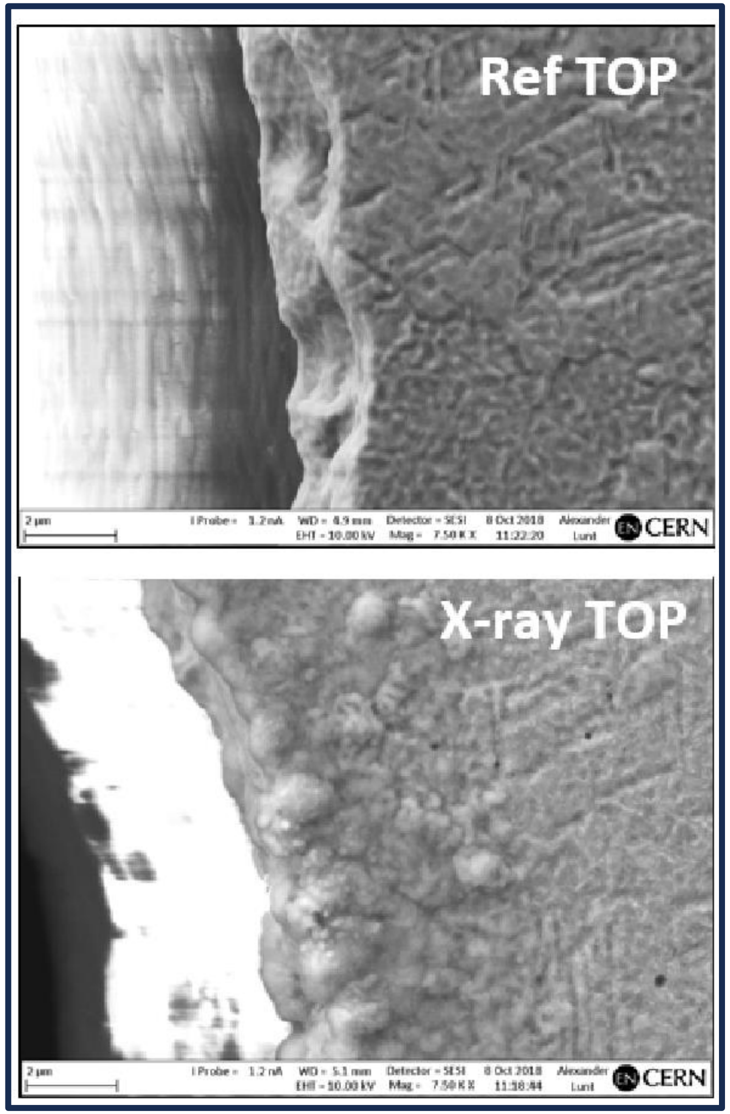


- **GEM foil**
  - 50 μm polyimide film +
    5 μm copper layer on each side
  - Many holes exist for electron amplification



Aging Effect

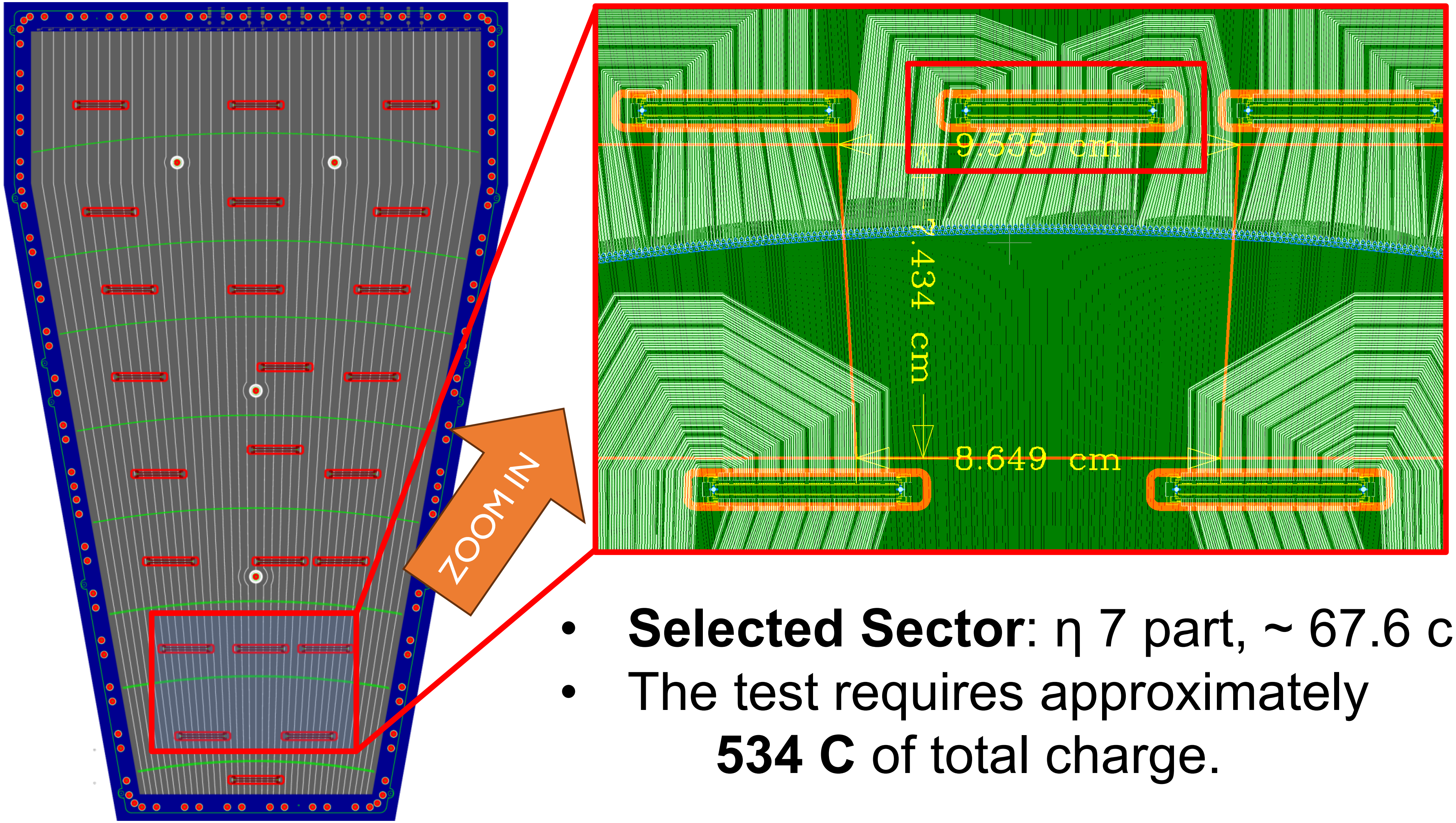
[1]



- **Ageing**: Permanent degradation in detector performance
- **Primary cause**: Polymerization of gas fragments produced during electron avalanches. Polymers accumulate on sensitive surfaces
- **Effect**: Insulation damage and electric field interference. Causes loss of gain, discharge, dark current, or reduced signal uniformity.

[1] Fallavollita, F, D Fiorina and J A Merlin. "Advanced Aging Study on Triple-GEM Detectors". *Journal of Physics: Conference Series* 1498, (2020.4.1): 012038.

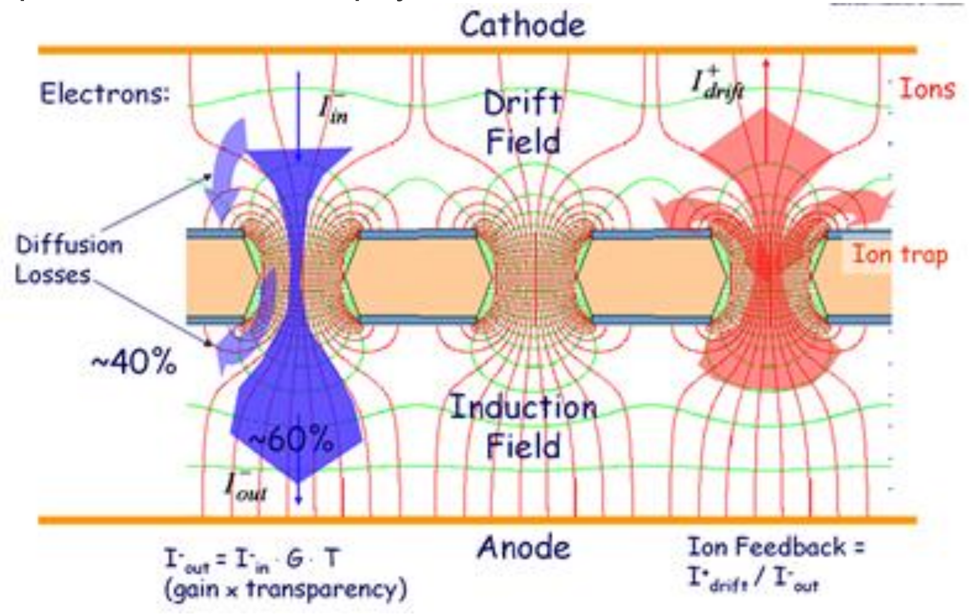
Aging Sector



- **Selected Sector**: η 7 part, ~ 67.6 cm².
- The test requires approximately **534 C** of total charge.

Weekly Gain Test

F.Murtas, “Applications of triple GEM detectors beyond particle and nuclear physics” 2014 JINST 9 C01058

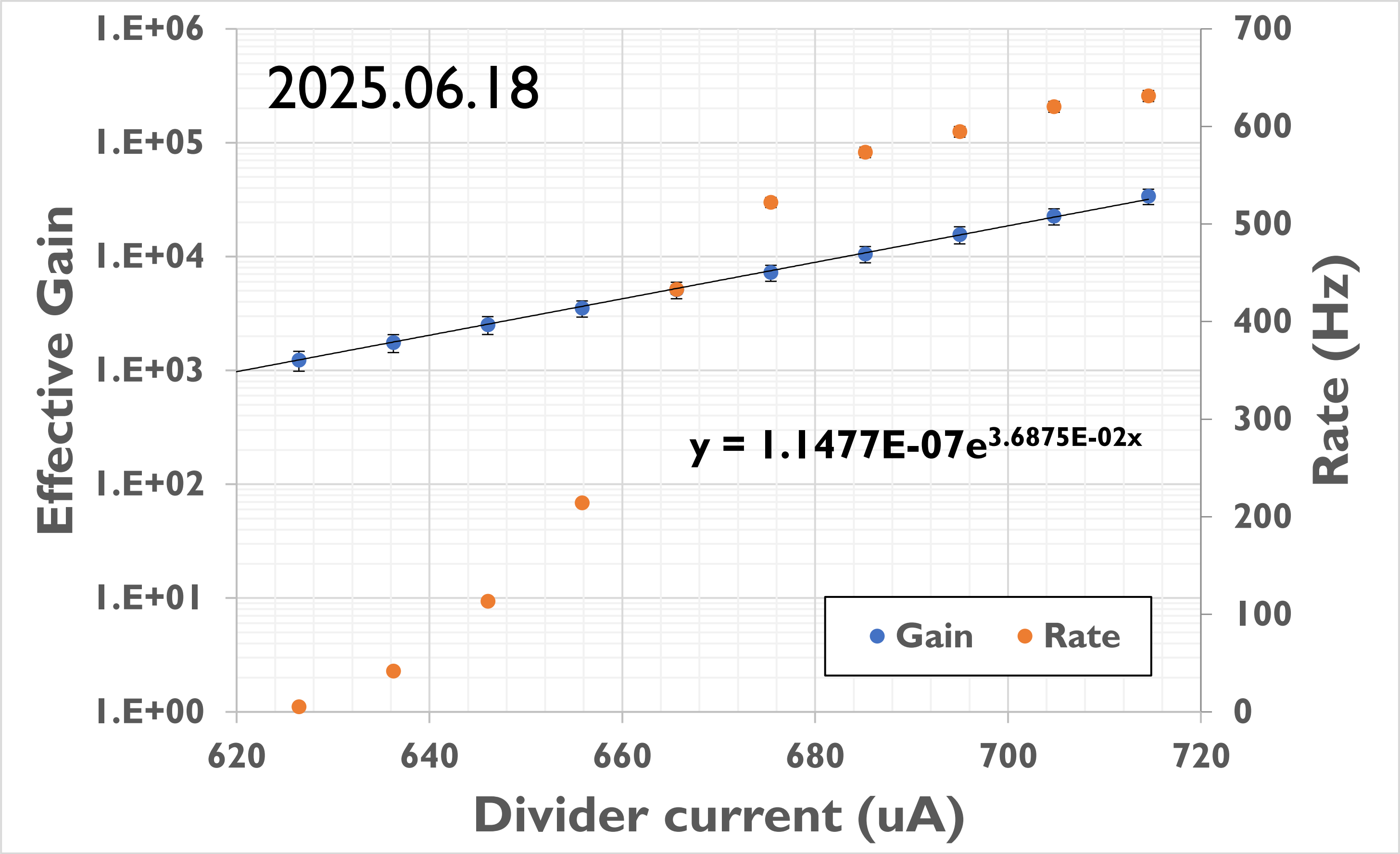


- **Weekly Gain Test**:
  Check the status of the detector.
- **Gain Calculation**:

$$Q/(R \times N_{primary} \times q_e)$$

- **Equipment Utilized**:
  - **Current Measurement Equipment**:
    Keithley 6400 picoammeter.
  - **Counting Equipment**:
    ORTEC 142pc and ORTEC 474.

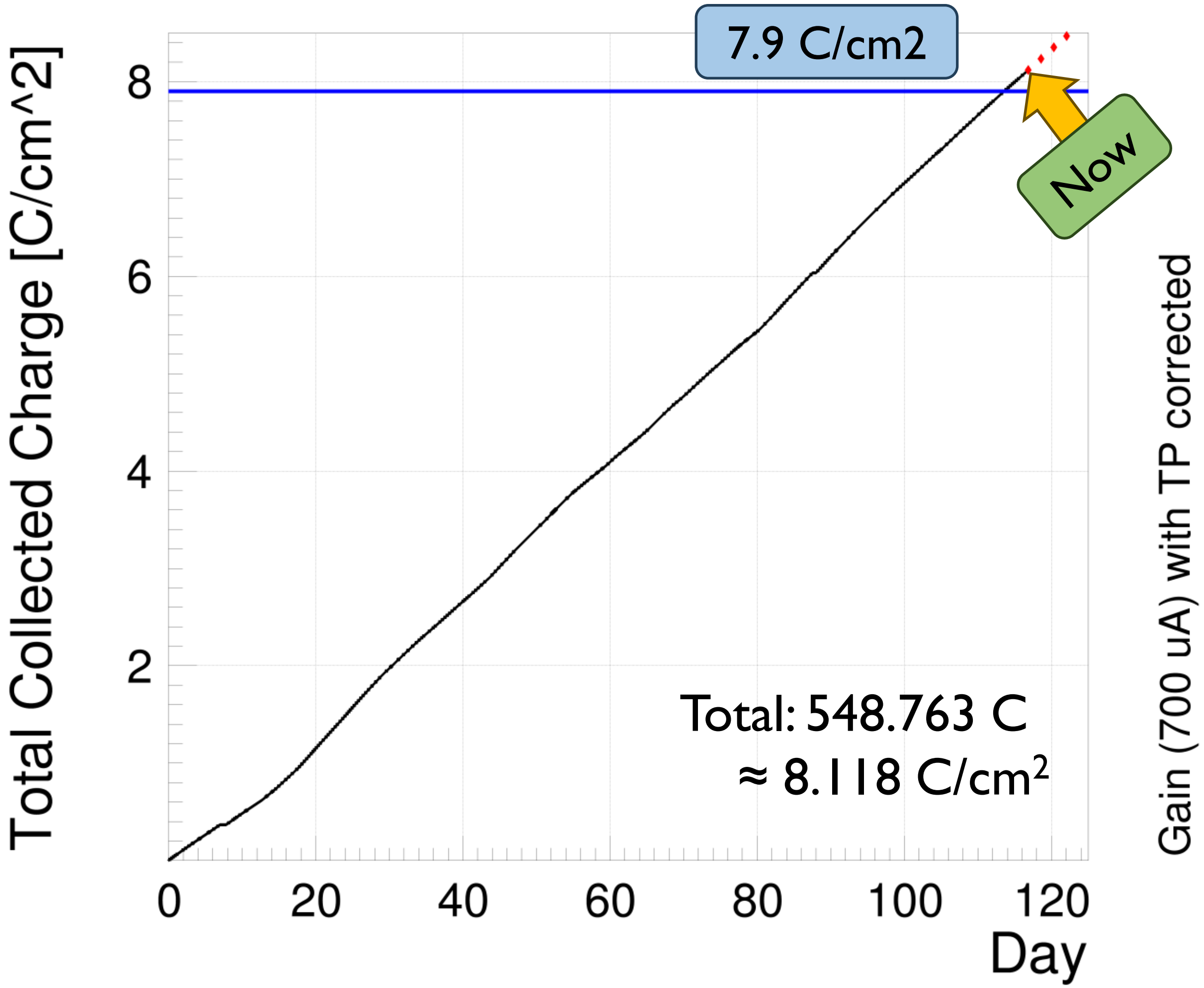
Effective Gain Test



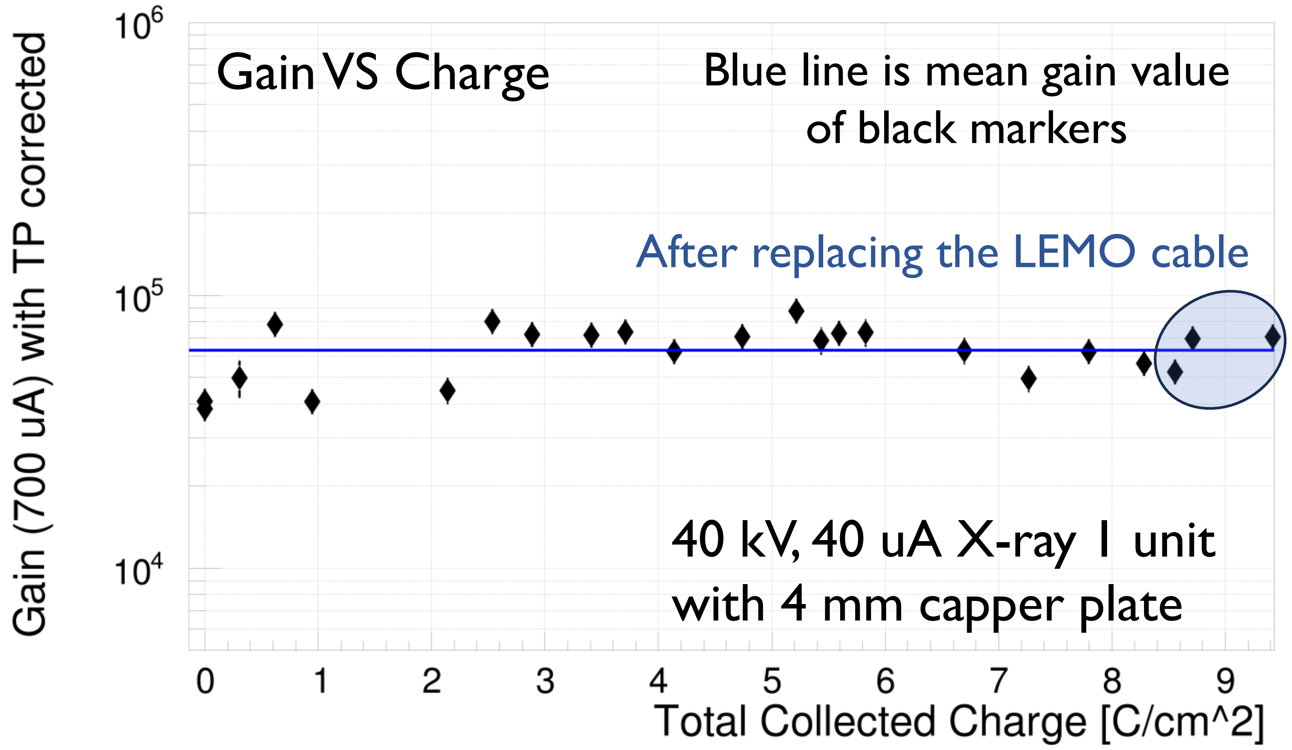
The Plateau is not visible properly.
The current are measured low overall.

- ORTEC 474 (timing filter amp)
  - Integrate : 100 ns
  - Differential : 100 ns
- Gain test setup:
  - 40 kV, 40 uA X-ray
  - 4 mm copper
- Effective gain (with TP)
  - 700 uA : ~1.862 x 10^4

ME0 Summary

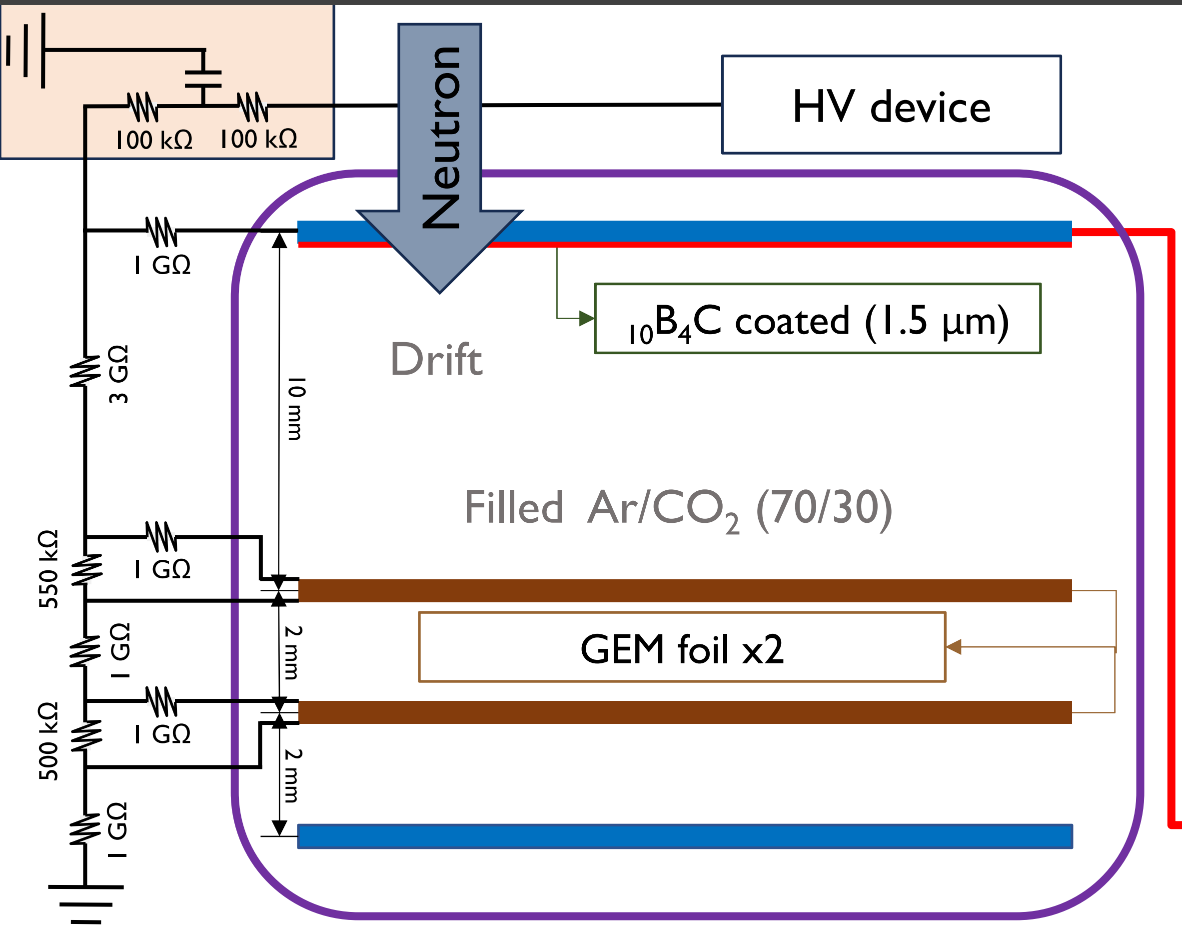


- ME0 SF1 aging test is complete.



Neutron GEM Detector

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.

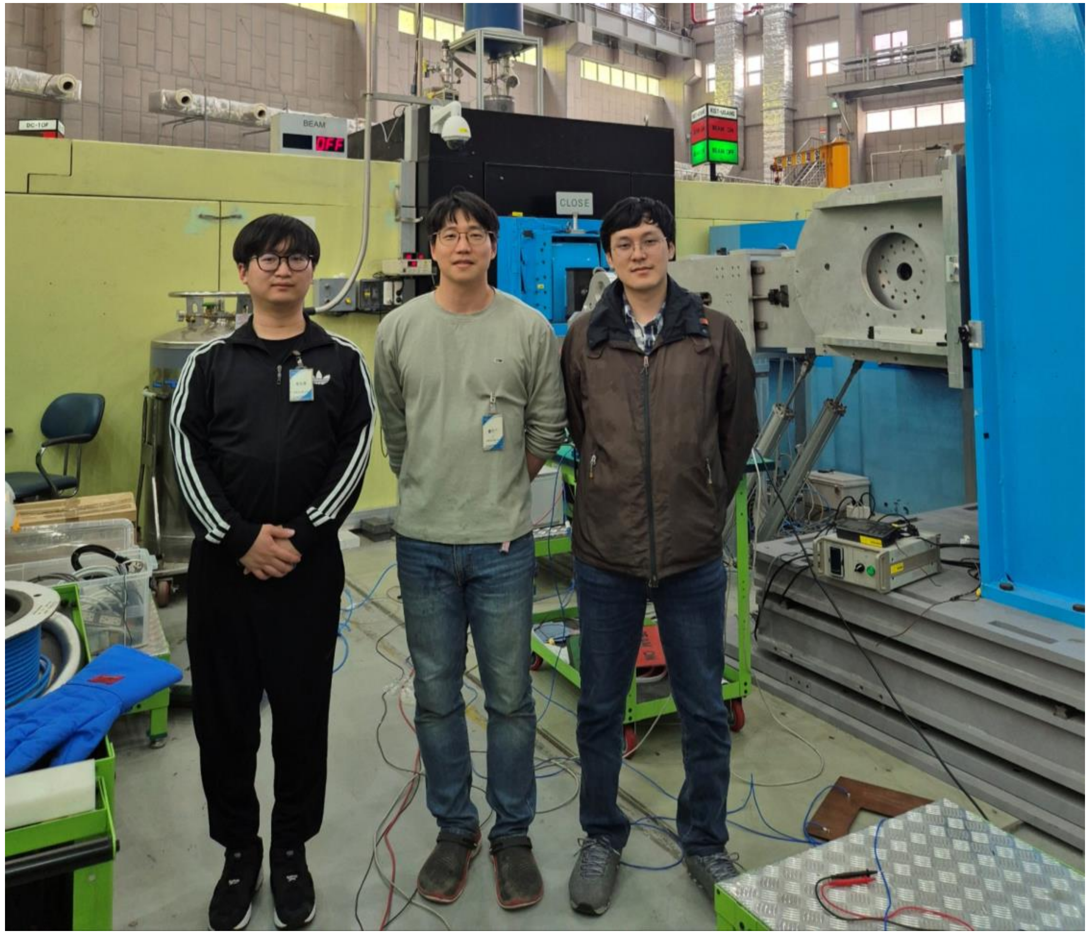
- GEANT4 confirms that drift coating is enough for neutron detection.

HANARO Beam Specification

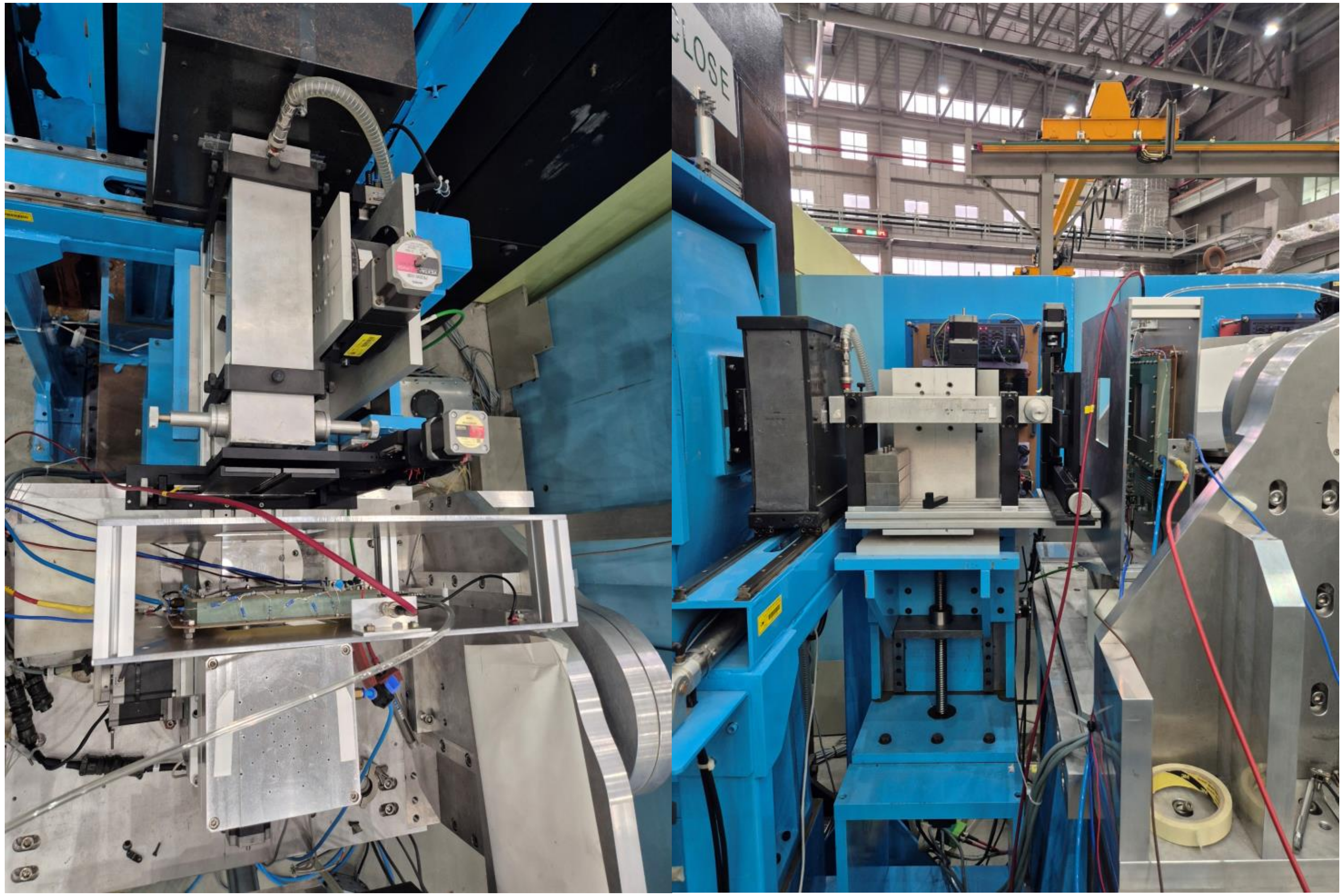
- *HANARO*
  (*High-flux Advanced Neutron Application ReactOr*)

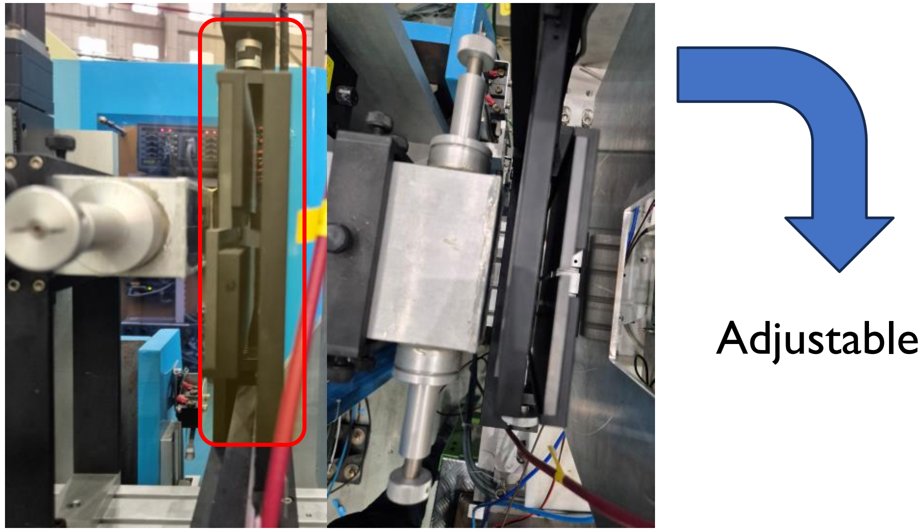
- Bio-REF specifications
  neutron energy : 4.5 Å (Cold Neutron)
  ~4.03 meV

- Profile
  - 30MW max
  - Fluence: 4.8×10^6 Hz/cm^2 $_{(max)}$



Detector Setup





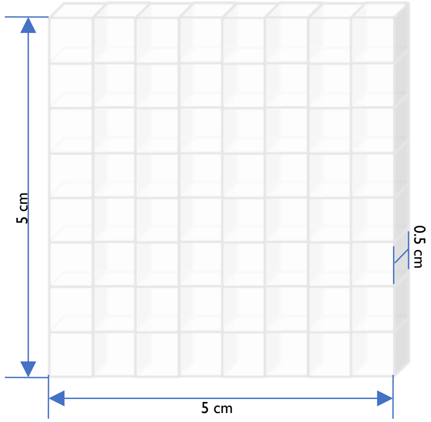
Adjustable slit

- Counting is using ORTEC's preamp and shaper from GEM's 2nd foil bottom AC signal

- Imaging is using APV25 chipset

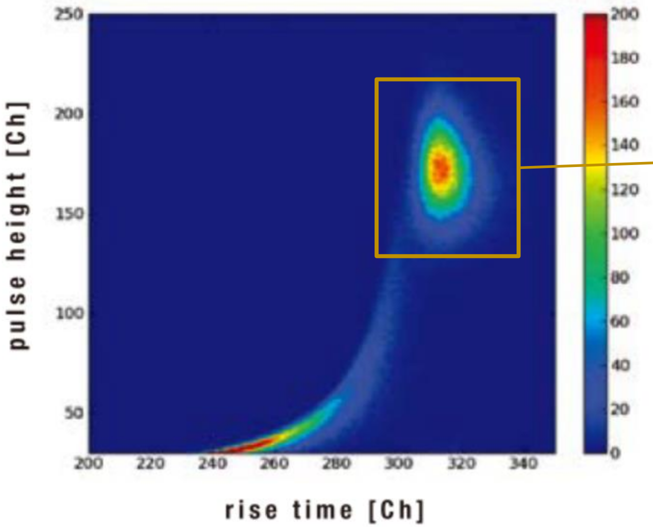
LiCAF Detector & Efficiency

LiCAF Scintillator

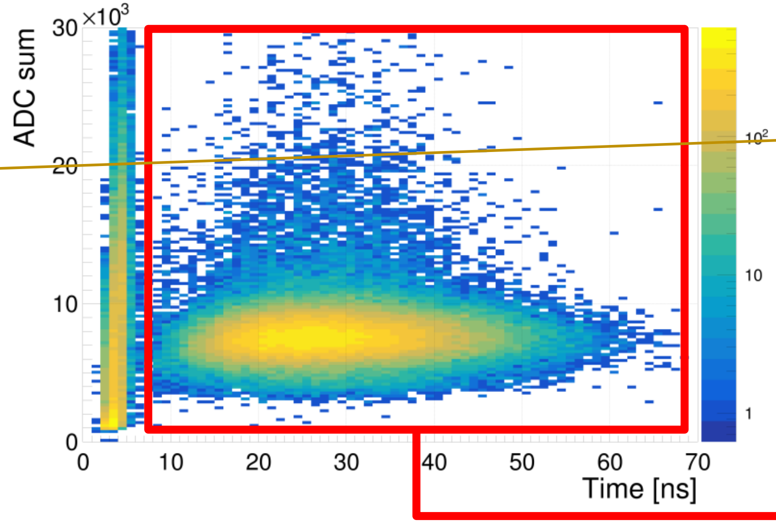


64ch PMT

Scintillator	Number of ^{6}Li atoms per cm^3	Intrinsic thermal neutron efficiency (%)
GS20 Ø50 mm×2 mm	~1.58×10^{22}	100
High-doping Ce:LiCAF 10 mm×10 mm×2 mm	~0.5×10^{22}	35±5
Low-doping Ce:LiCAF 10 mm×10 mm×2 mm	~0.5×10^{22}	32±5
High-doping Ce:LiCAF Ø50.8 mm×2 mm	~1×10^{22}	82±5



LiCAF ADCsum-rise_time AmBe taken



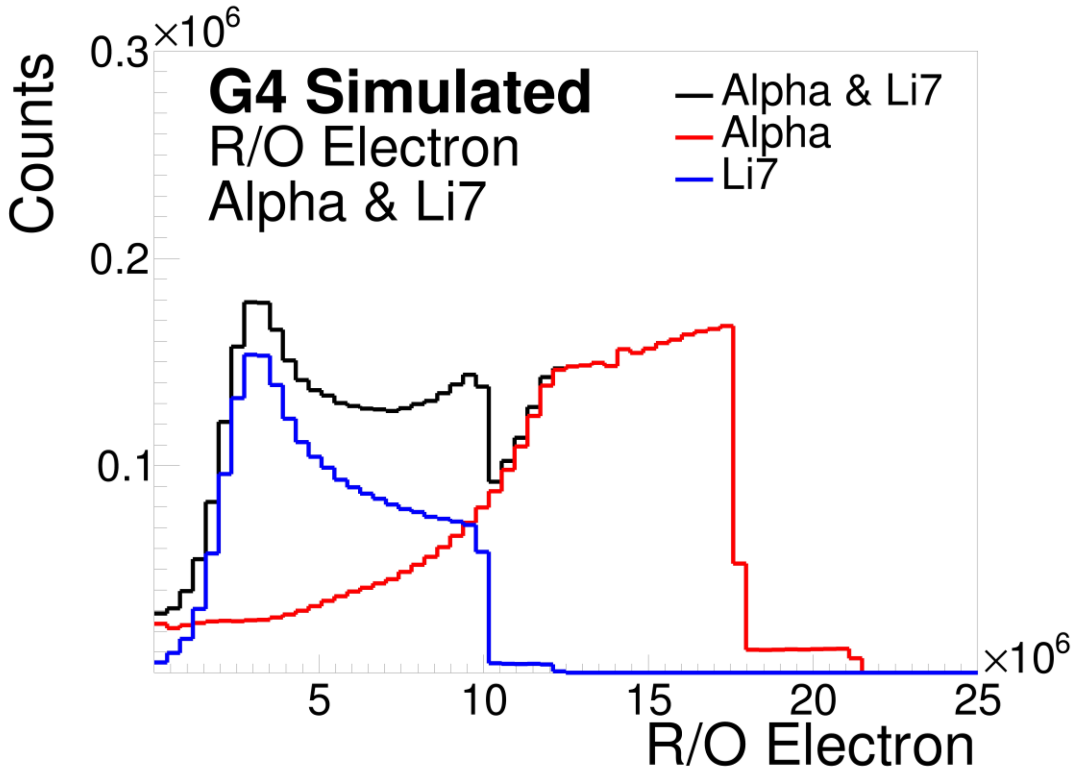
Li capture neutron and decays into H-3 and alpha.

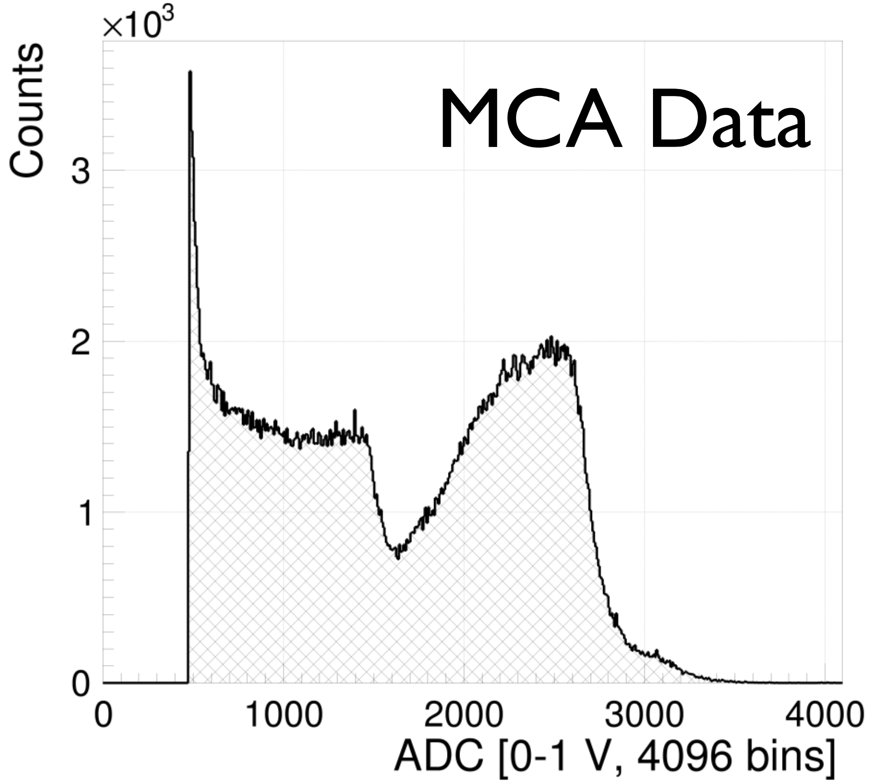
Unlike gamma, 3H and alpha makes broad pulse signal, so they have longer rise time.

$$^1_0n + ^6_3Li \longrightarrow ^3_1H\ (2.73MeV) + ^4_2He\ (2.05MeV)$$

Neutron Events

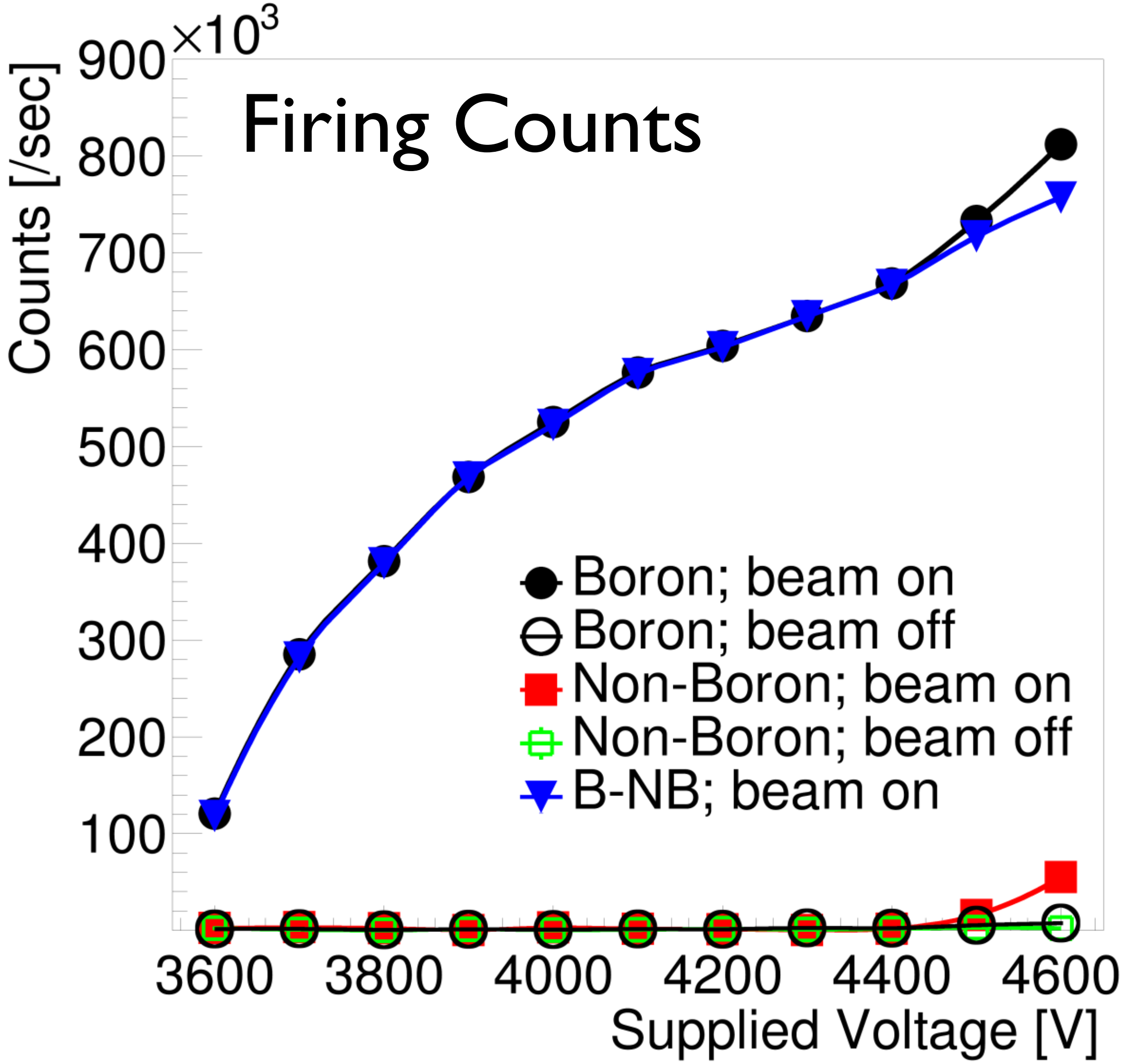
MCA Test: Alpha & Li7 R/O electron





We can find Li7 and Alpha signal !!!

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.

BGEM Efficiency

Data taken used LiCAF with ~4 meV neutron

50 s Data Analysis		Rate [Hz]	Rate/cm^2
Gamma	24,893	498	24,893
Neutron	115,010	2,300	115,010
Total	139,903	2,798	139,903

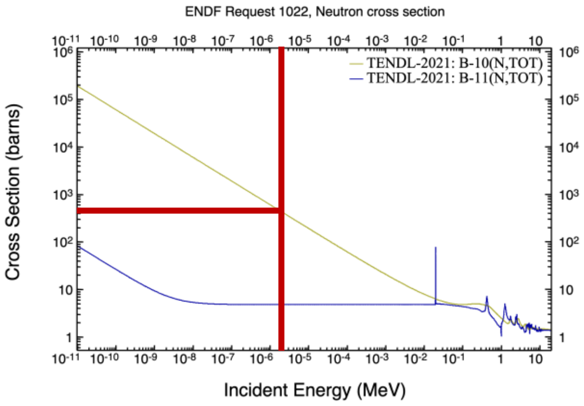
Data taken used BGEM with ~4 meV neutron

Voltage	Threshold	Beam off (Hz)	Beam on (Hz)	On - Off
4400 V	30	1265.0	1699.8	434.8
4400 V	40	124.6	352.9	228.3
4400 V	50	24.2	232.5	208.3
4400 V	60	1.2	201.2	200.0
4400 V	70	0.7	188.8	188.1

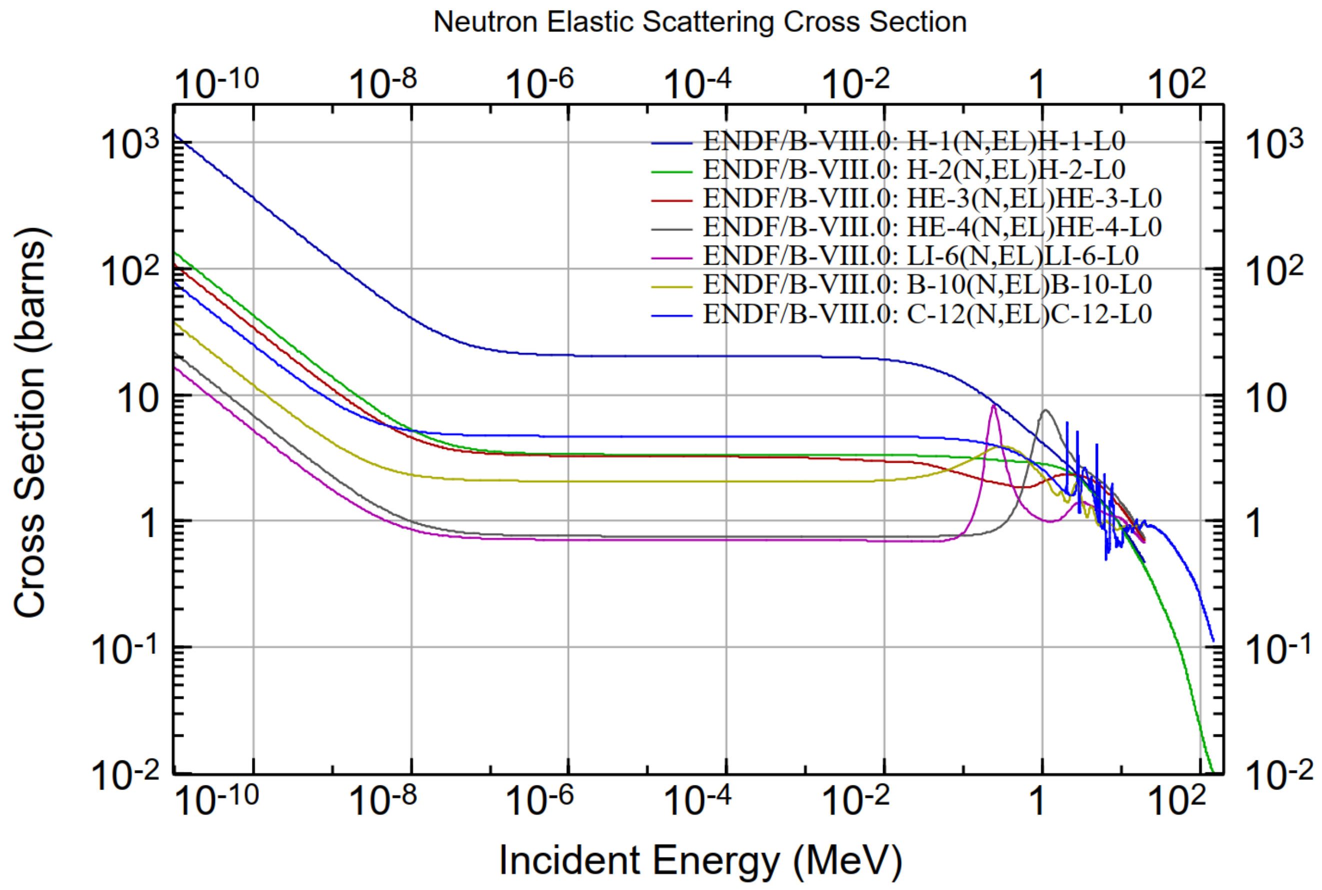
Geant4 Simulation data with 10 meV neutron

Direction of Neutron	Forward		Backward	
Signal Caused by	α, Li	α	α, Li	α
Sheet	0.00%	0.00%	1.64%	1.19%
Cathode	5.81%	3.66%	4.48%	2.80%
Cathode + Foil	10.79%	6.64%	6.44%	3.95%

- Select results with high event to noise ratio : 200 Hz
- Reference neutrons Rate uesd LiCAF: 2300 Hz
- Approximate detection efficiency : 8.69 %



Neutron Moderator



- The lower the neutron energy, the higher the chance of detection.
- For use as a moderator, it needs to react strongly with neutrons while avoiding neutron capture
- KRISS uses carbon blocks and HANARO uses liquid hydrogen tanks to slow down the fast neutron.

BGEM Efficiency

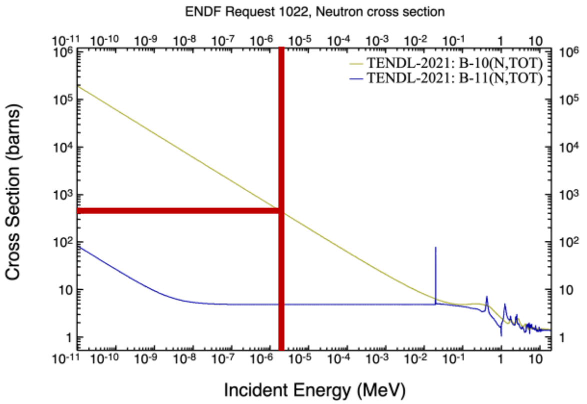
Data taken used LiCAF with ~4 meV neutron

50 s Data Analysis		Rate [Hz]	Rate/cm^2
Gamma	24,893	498	24,893
Neutron	115,010	2,300	115,010
Total	139,903	2,798	139,903

Data taken used BGEM with ~4 meV neutron

Voltage	Threshold	Beam off (Hz)	Beam on (Hz)	On - Off
4400 V	30	1265.0	1699.8	434.8
4400 V	40	124.6	352.9	228.3
4400 V	50	24.2	232.5	208.3
4400 V	60	1.2	201.2	200.0
4400 V	70	0.7	188.8	188.1

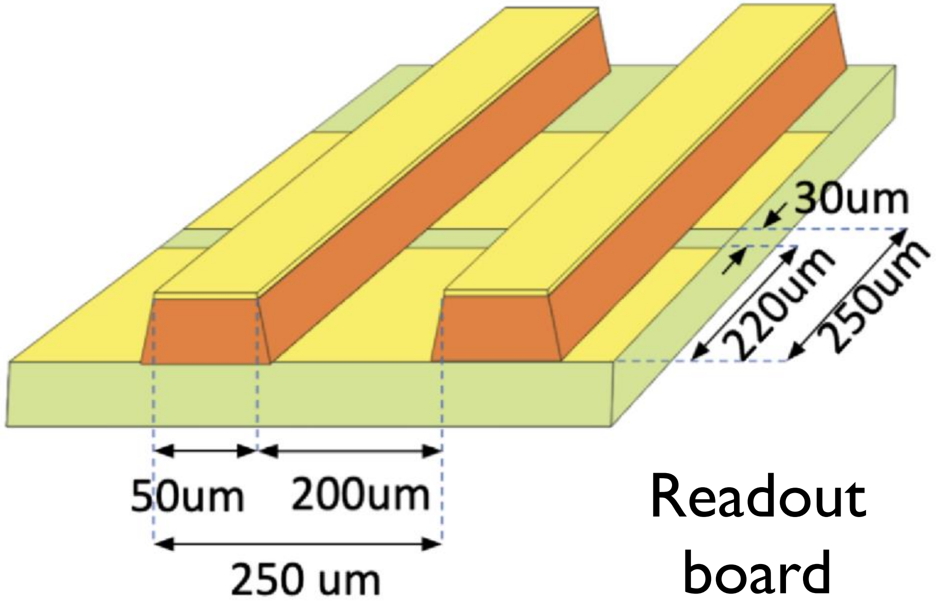
- Select results with high event to noise ratio : 200 Hz
- Reference neutrons Rate uesd LiCAF: 2300 Hz
- Approximate detection efficiency : 8.69 %



Geant4 Simulation data with 4 meV neutron

- Predicted Efficiency : 8.997 %
- Experimental Results : 8.69 %
- Experimental Error : ± 0.20 %

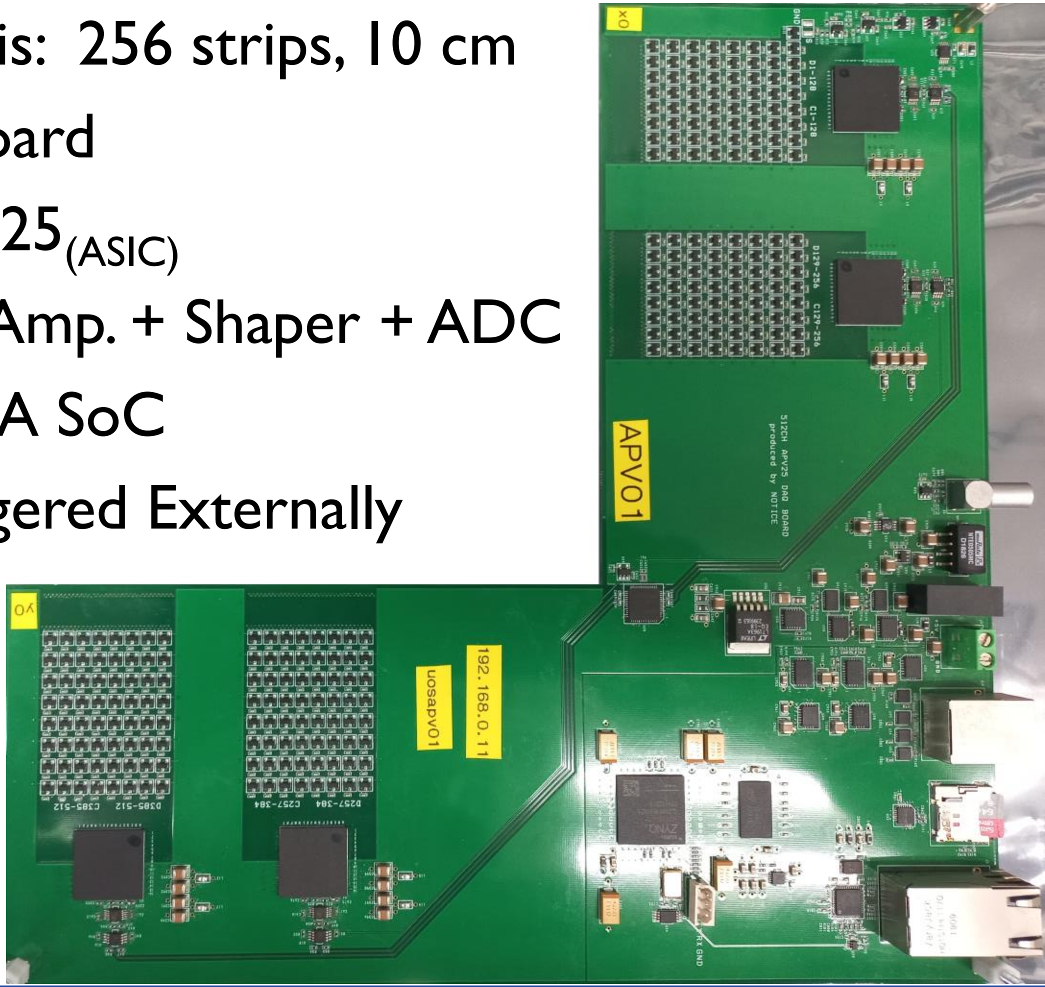
Data Acquisition

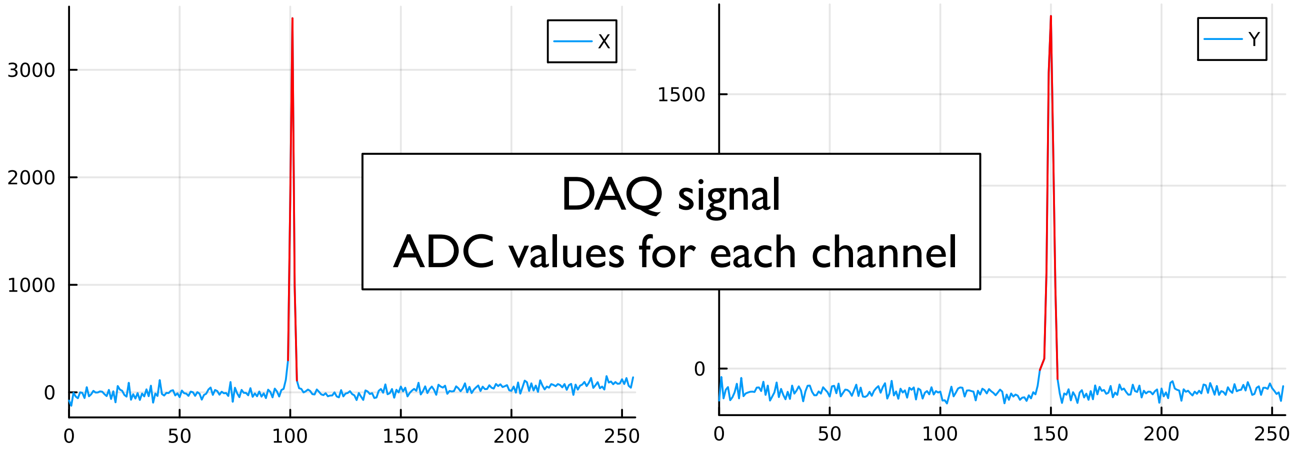


Readout board

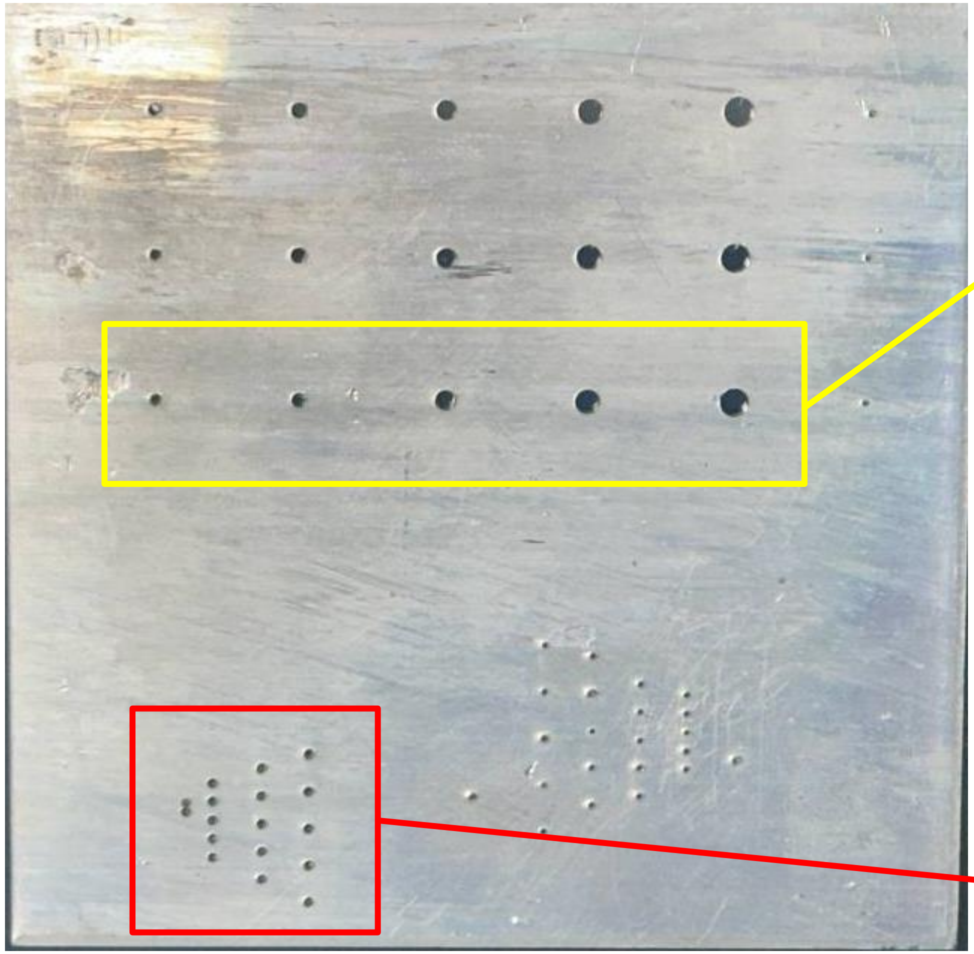
- Read-out board
  - X-axis: 256 strips, 10 cm
  - Y-axis: 256 strips, 10 cm
- DAQ board
  - APV25$_{(ASIC)}$
    - Amp. + Shaper + ADC
  - FPGA SoC
  - Triggered Externally

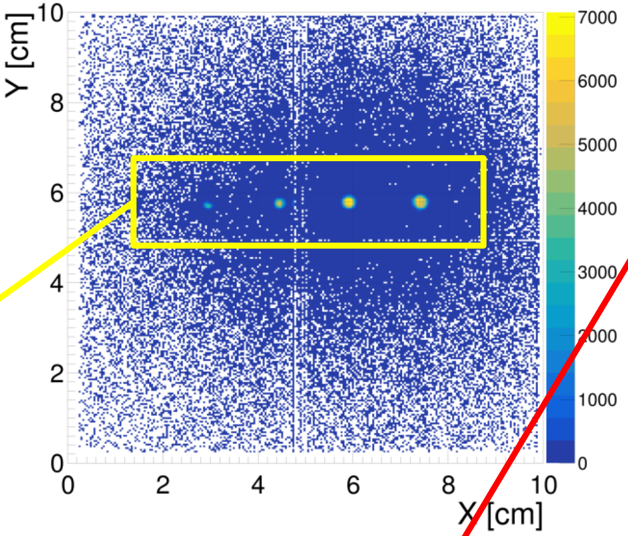
DAQ board

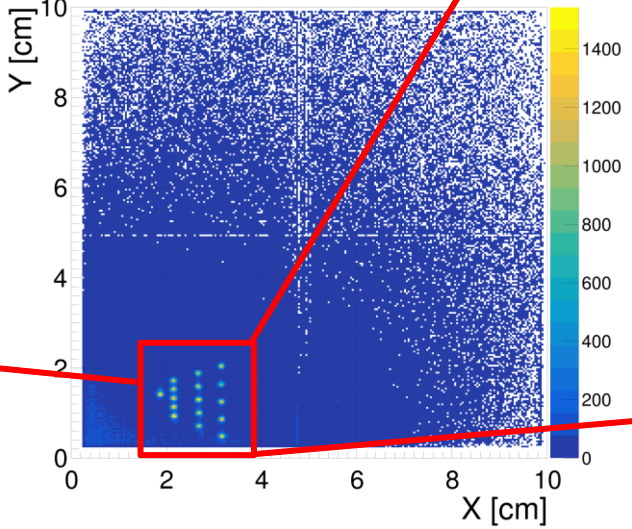




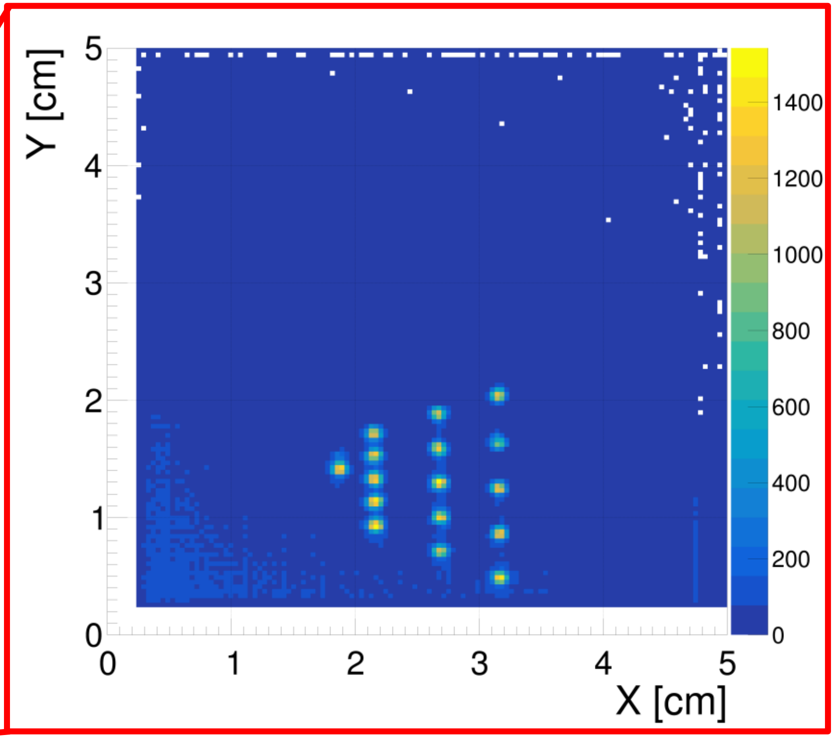
BGEM Imaging







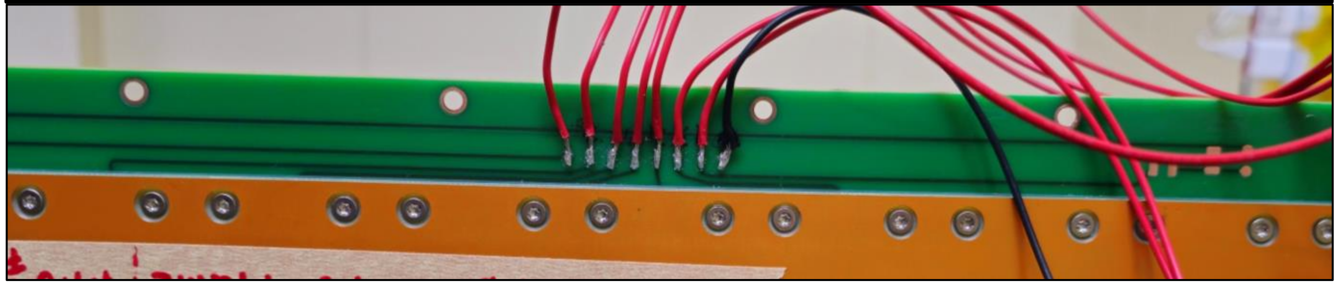
The beam window was small, so data from all holes could not be received at once.

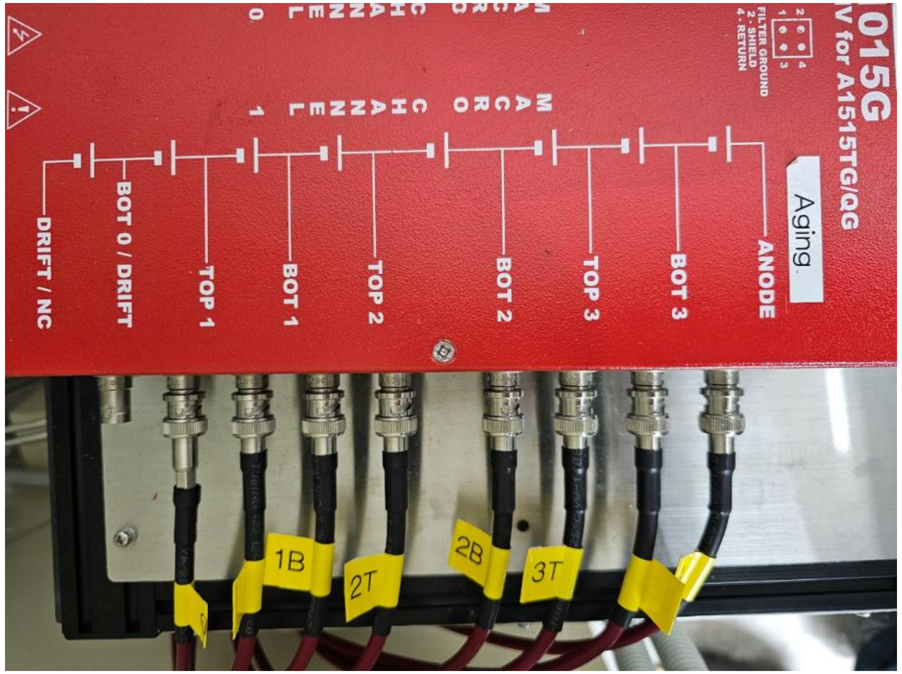


Backup

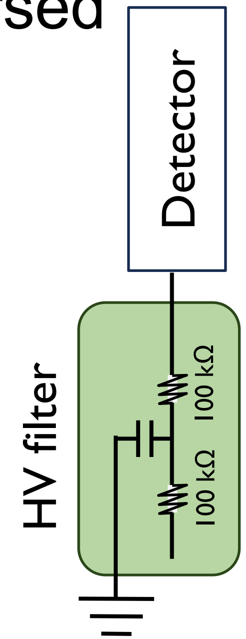
Detector Setup

Drift – G1B – G1T – G2B – G2T – G3B – G3T – Readout

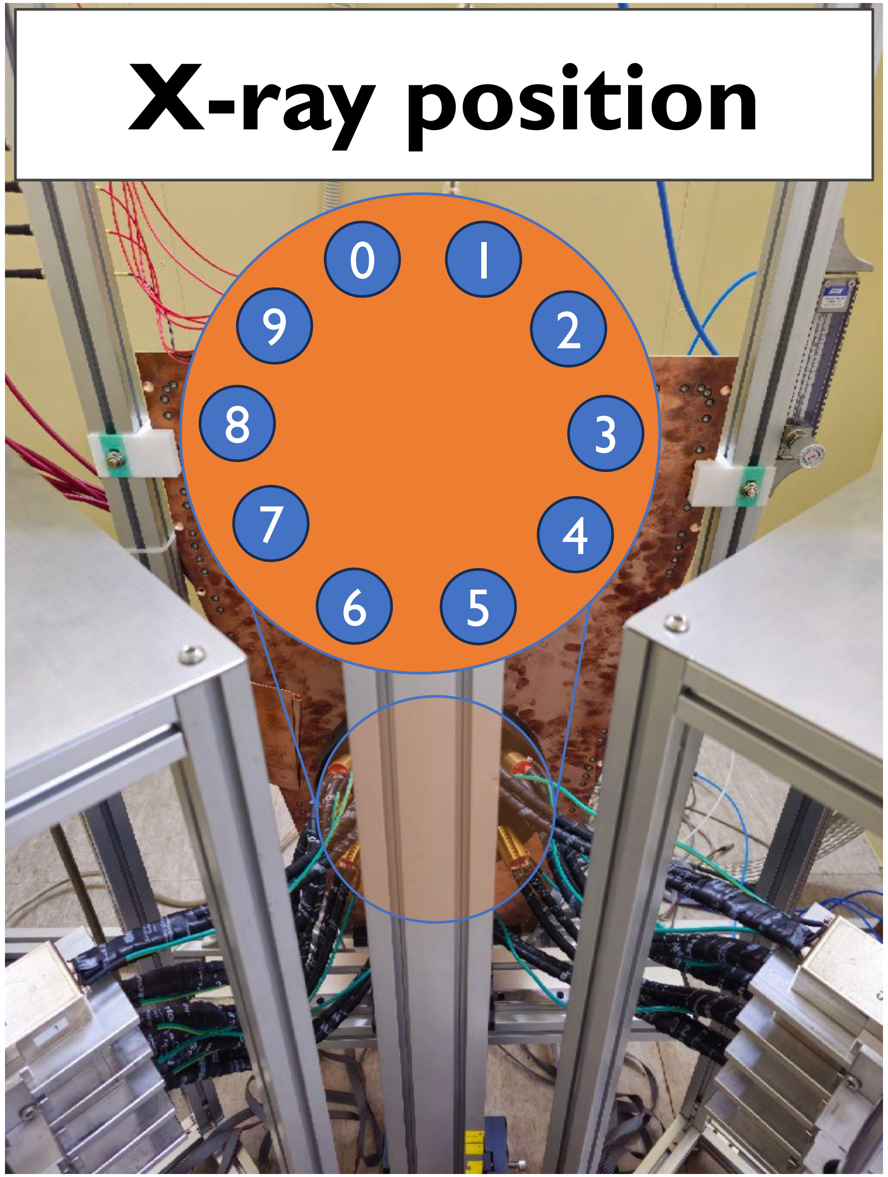




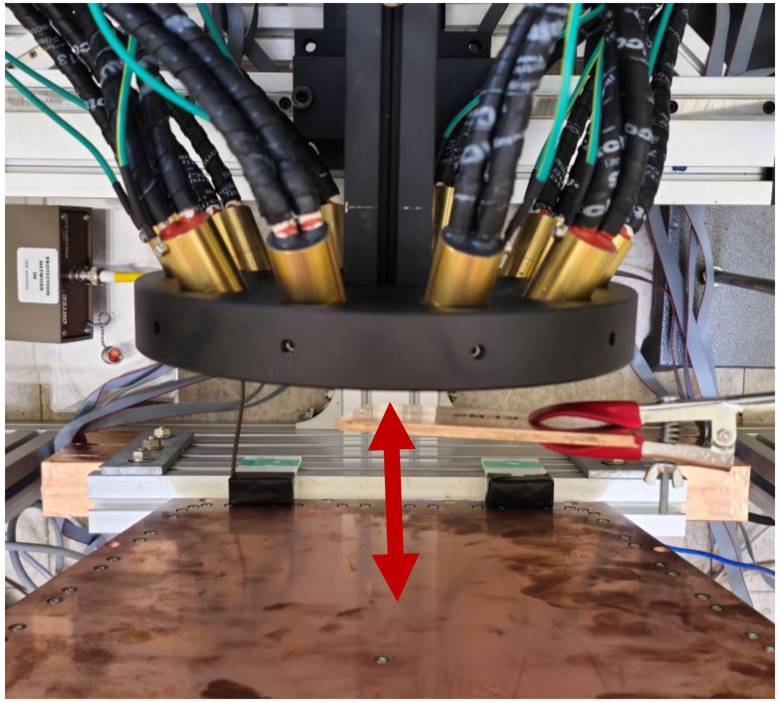
- **High Voltage (HV)**: component was powered separately for each section without using resistors. The prototypes of the ME0 HV line mask (top and bottom) are reversed
- **Aging**:
  Without HV filter
- **Gain Test**:
  With HV filter (200 kΩ)

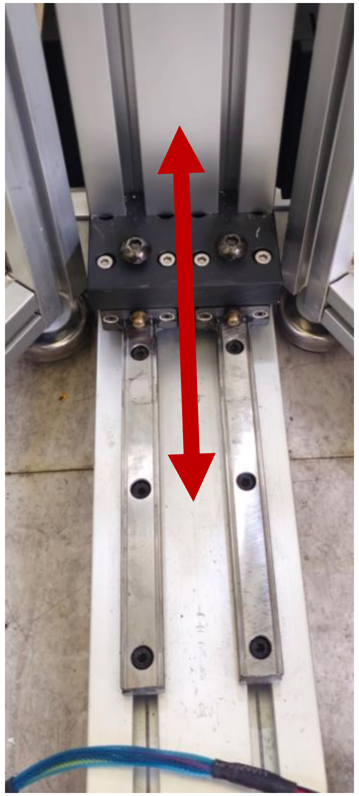


X-ray Setup

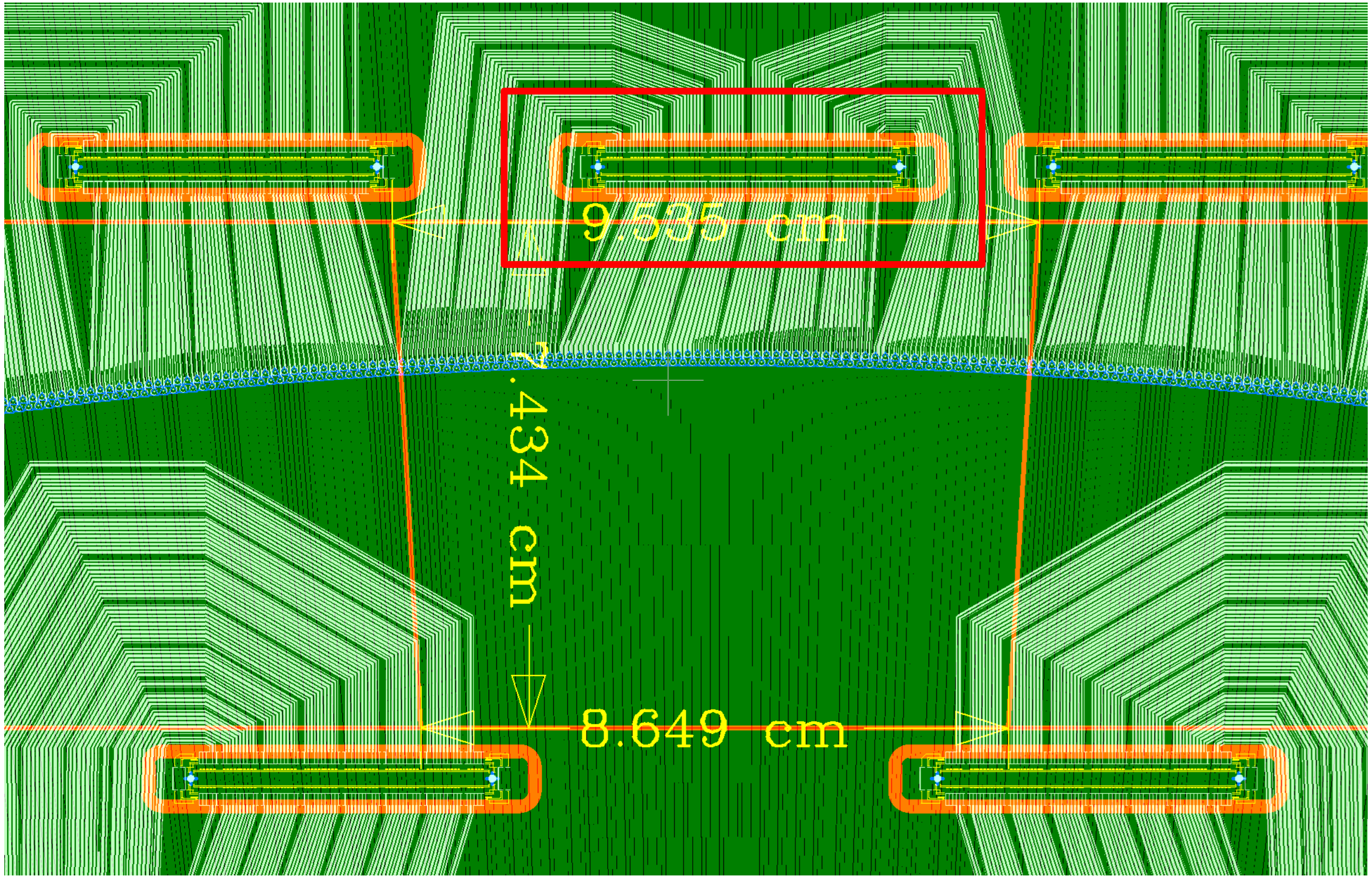


- X-ray is adjusted to the sector with the frame under the chamber.
- The X-ray focal length was adjusted.





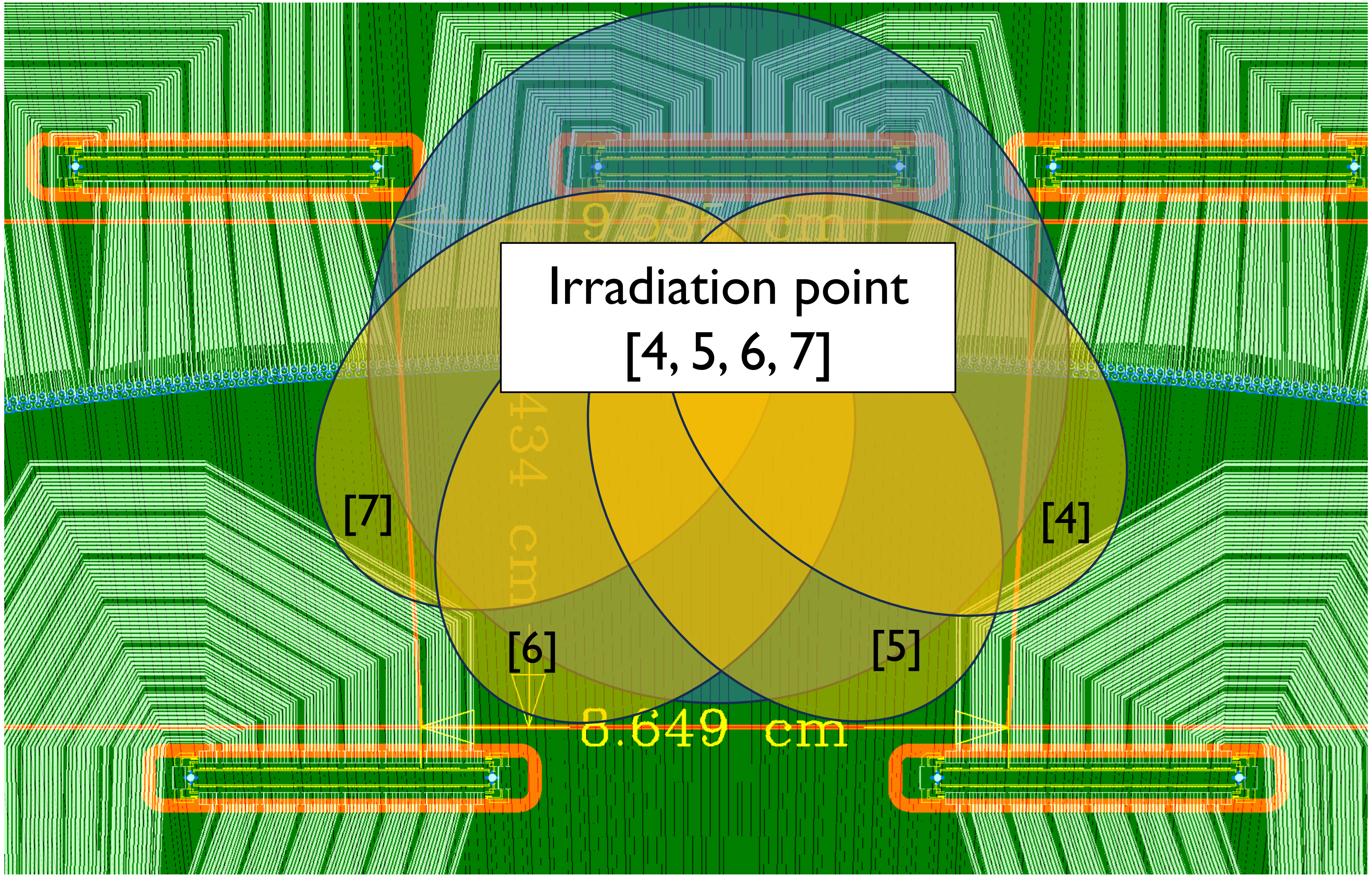
Aging Sector



- The ME0 have 24 readout sectors
- Each reading out have 128 strips
- Aging area is ~67.6 cm^2

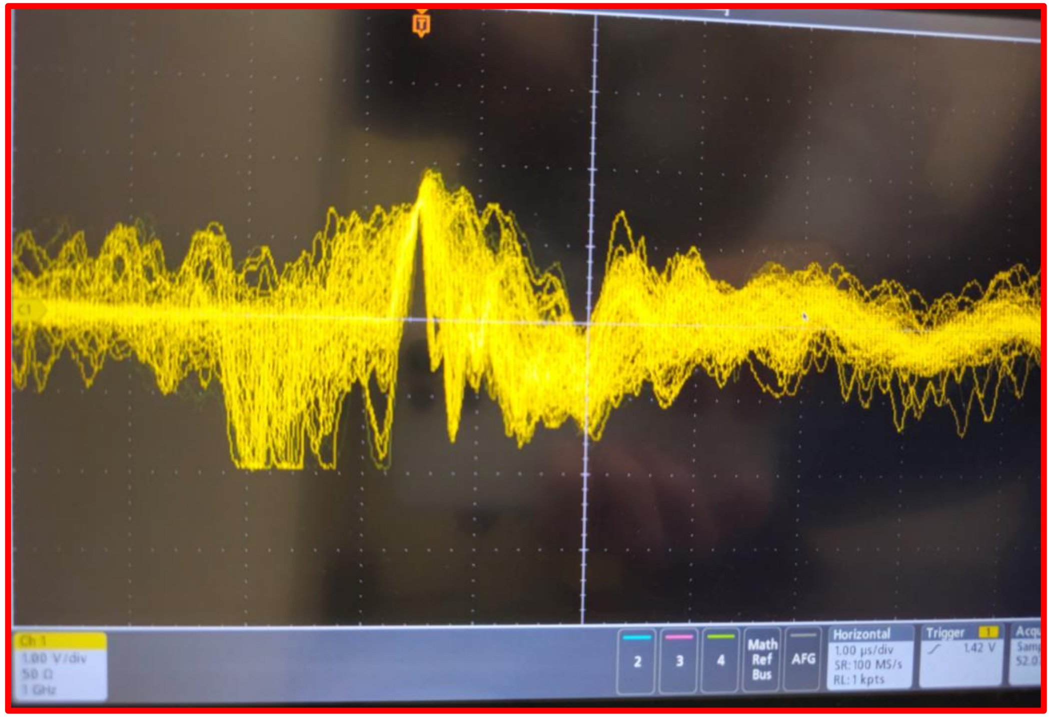
Expected accumulated charge on ME0 7.9 C/cm^2
Total ≈ 534 C

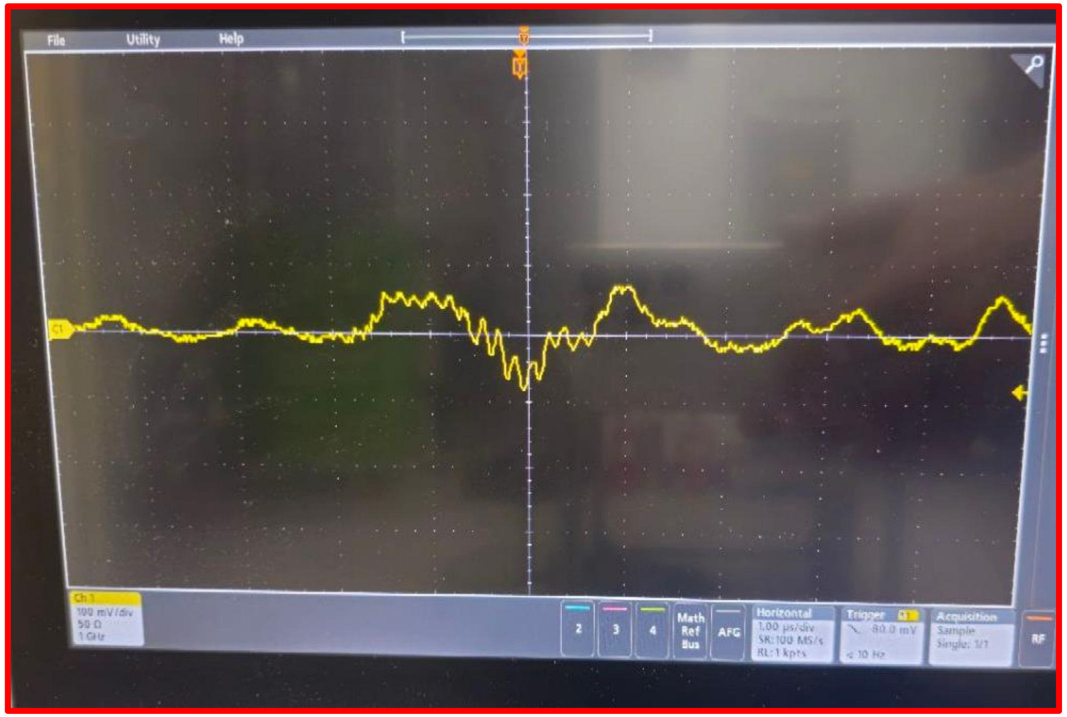
X-ray Setup



- **X-ray device**: Operates within the range of 20-80 kV and 40-100 μA.
- **Aging test**: The X-ray source operated at 40 kV and 80 μA.
- **Gain test**: The X-ray source operated at 40 kV and 40 μA, with a 4 mm copper plate used to block the beam for accurate counting.

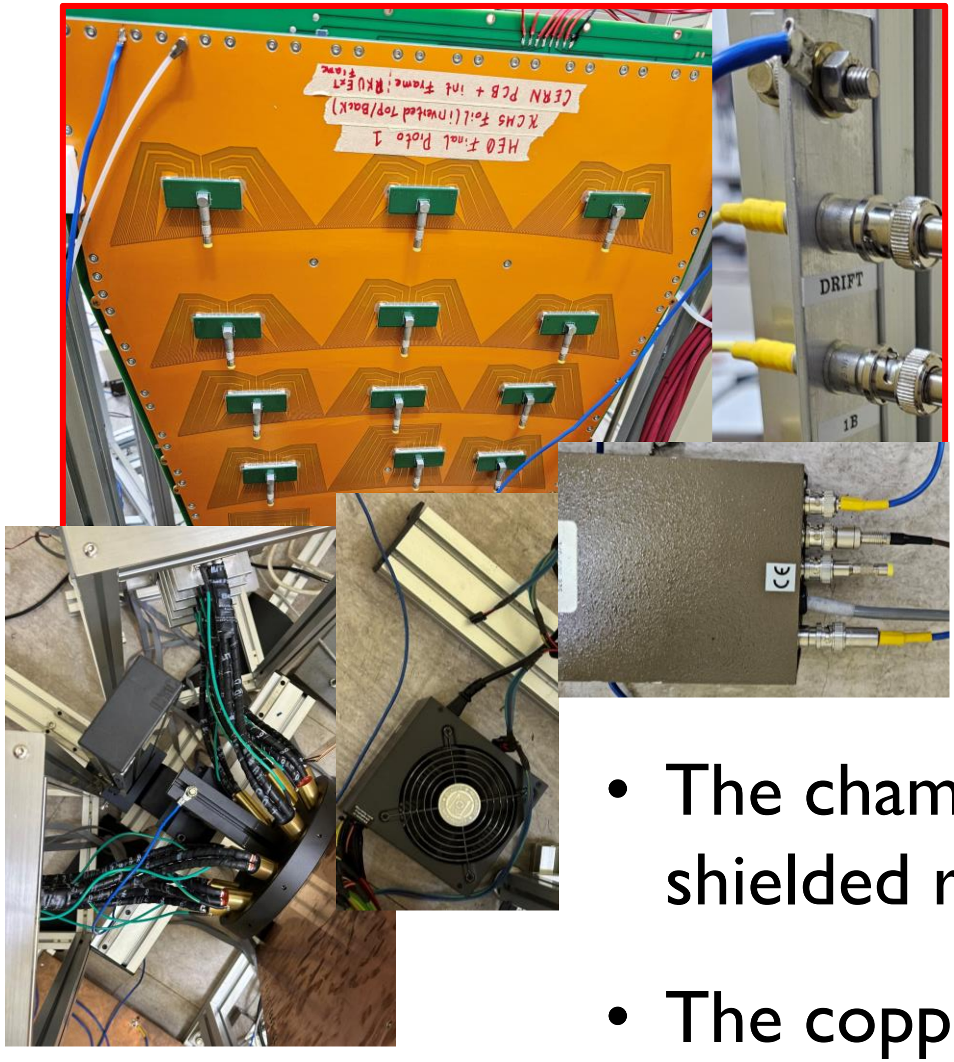
Noise Issue

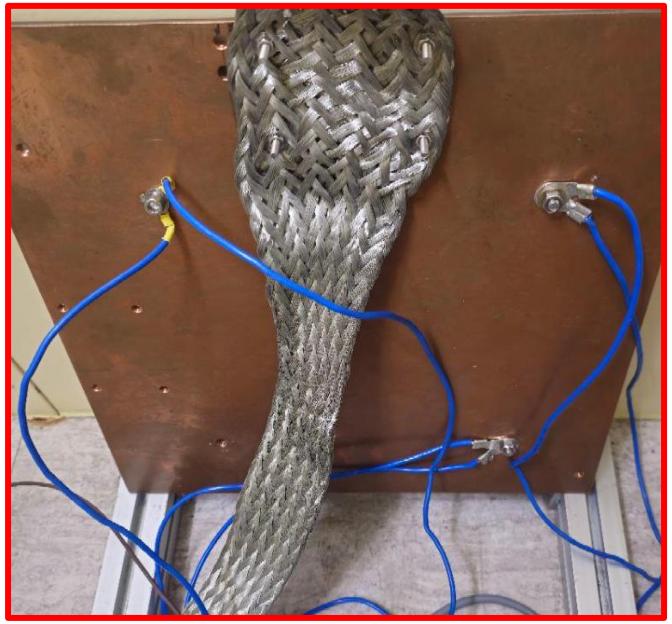


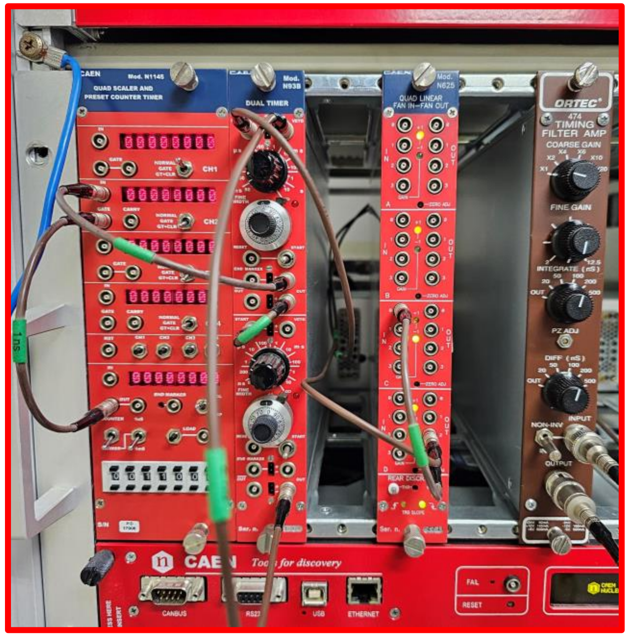


- Grounding work showed the effect of reducing noise.
- Tested at trigger level -100 mV
- Noise events measured ~3 per second

Noise Issue

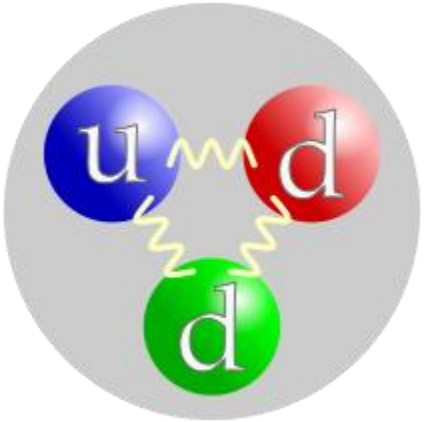




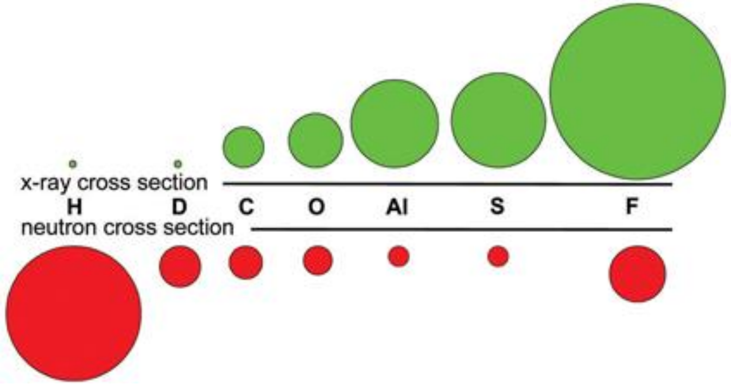


- The chamber and HV line, preamplifier, etc. inside the shielded room were connected to a copper plate.
- The copper plate was connected to a rack outside

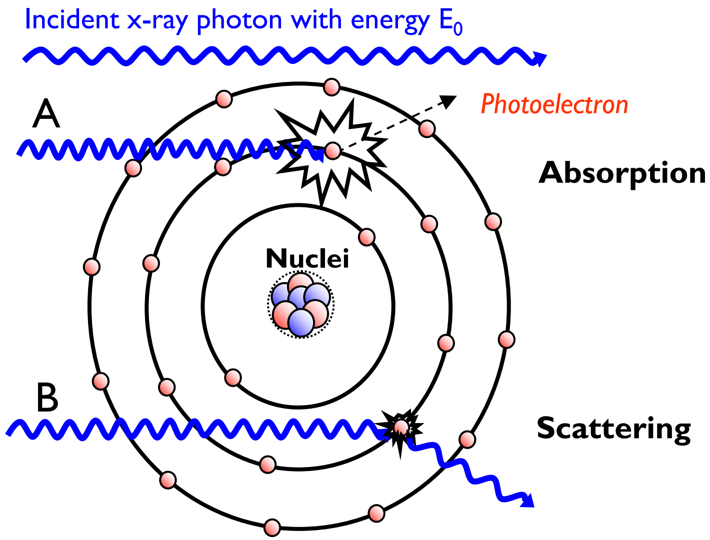
Neutron

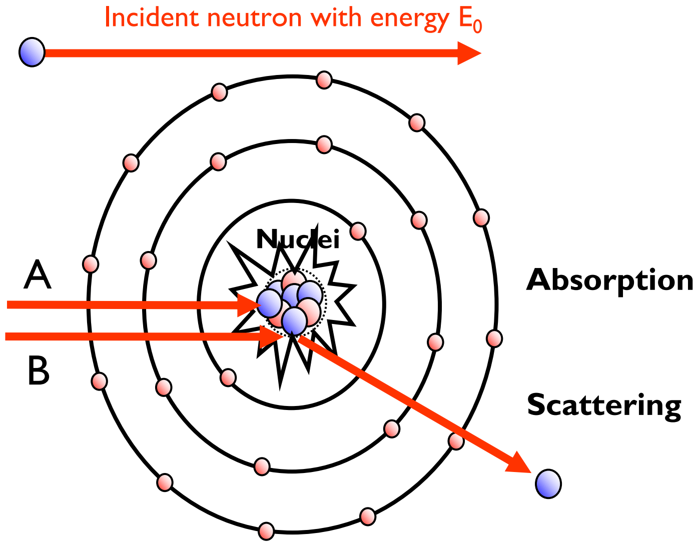


- Decay: $n \rightarrow p + e^- + \bar{\nu}_e$
- Lifetime: $878.4 \pm 0.5\ s$
- Electric charge: $(-2\ \pm 8) \times 10^{-22}\ e$



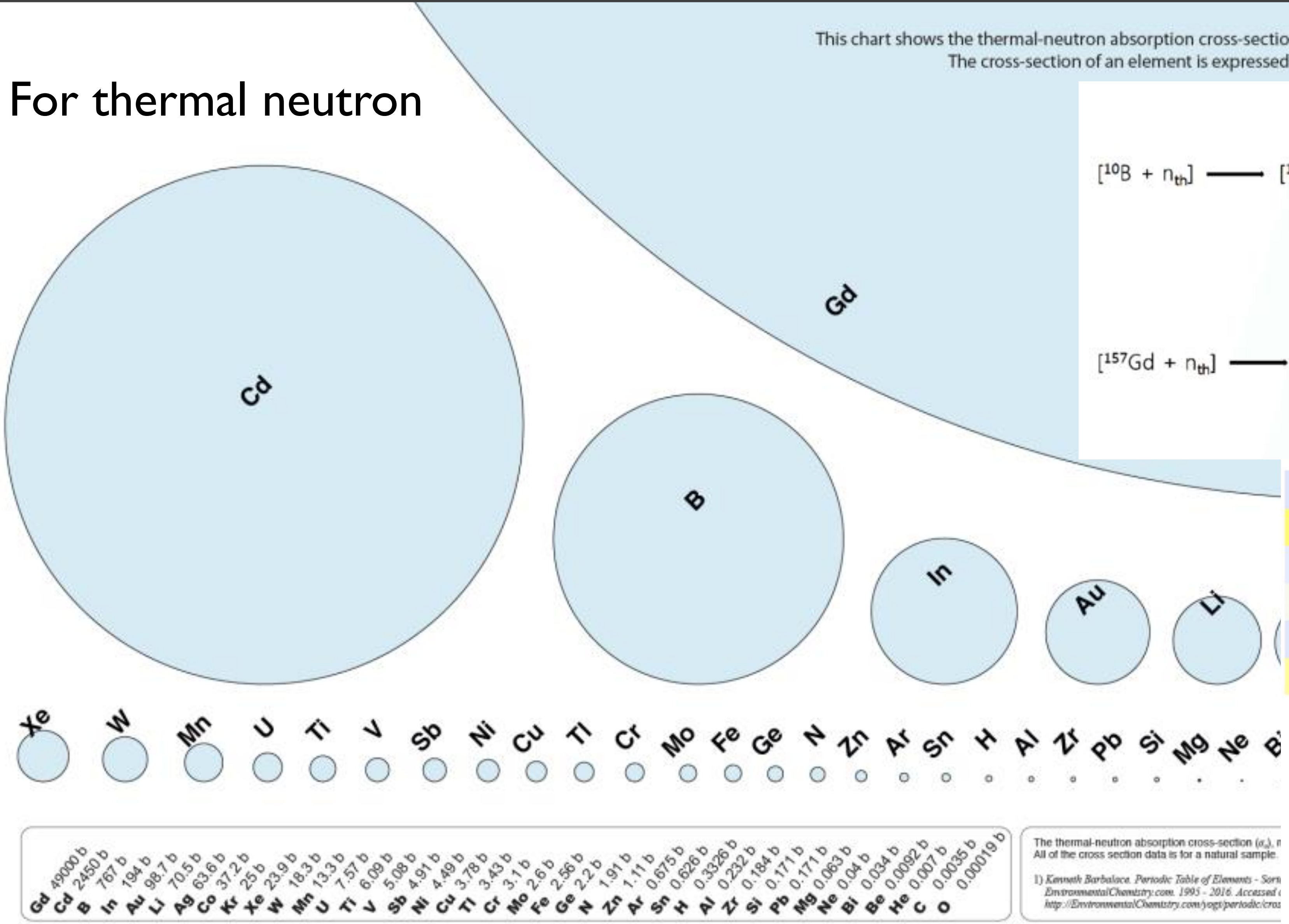
- The common means of detecting a charged particle by looking for a track of ionization, but does not work for neutrons directly.
- The commonly used method to detect neutrons is mainly neutron capture.

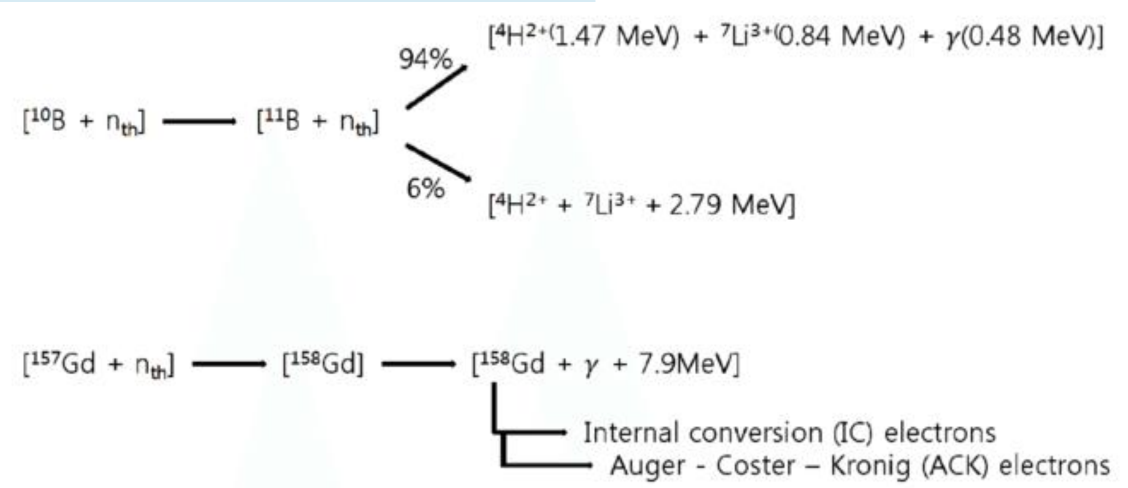


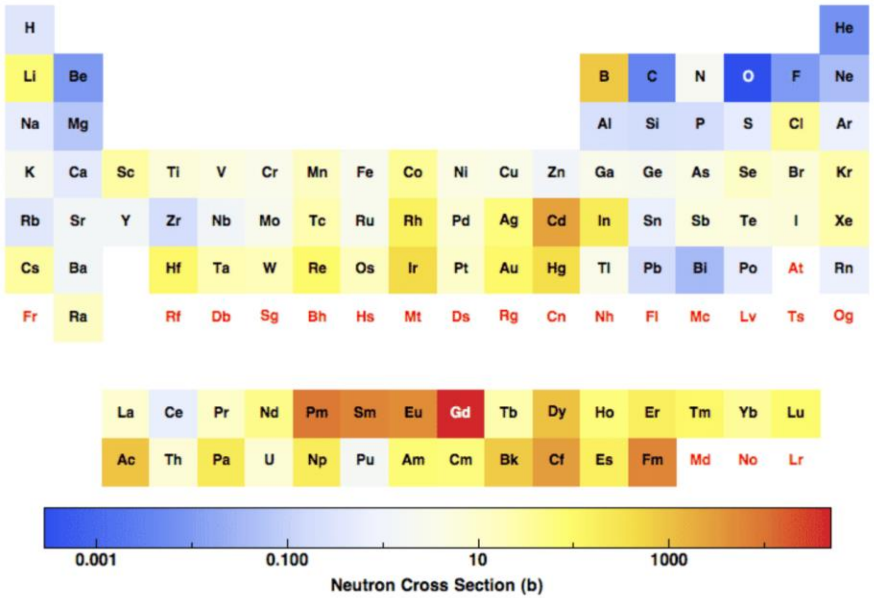


Neutron Cross Section

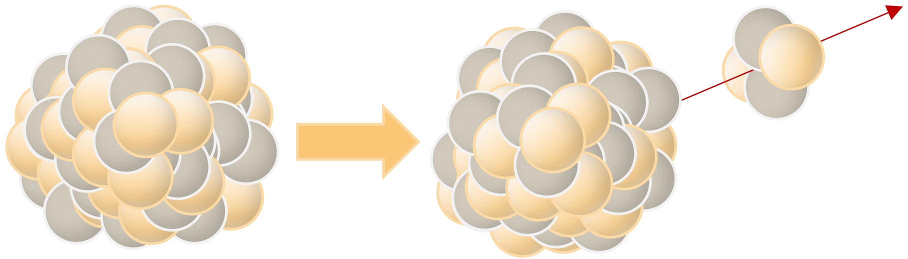
For thermal neutron



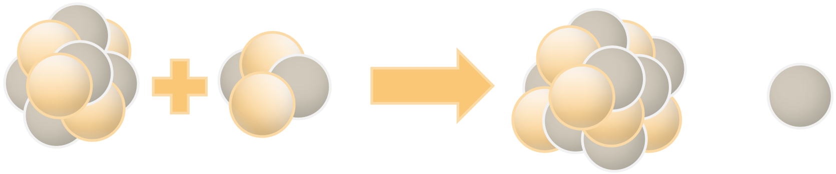




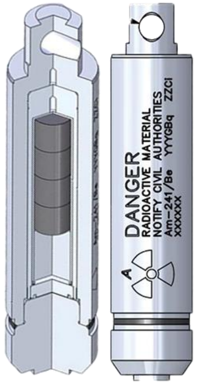
Source [AmBe]



^{241}Am $^{237}Np + \alpha$

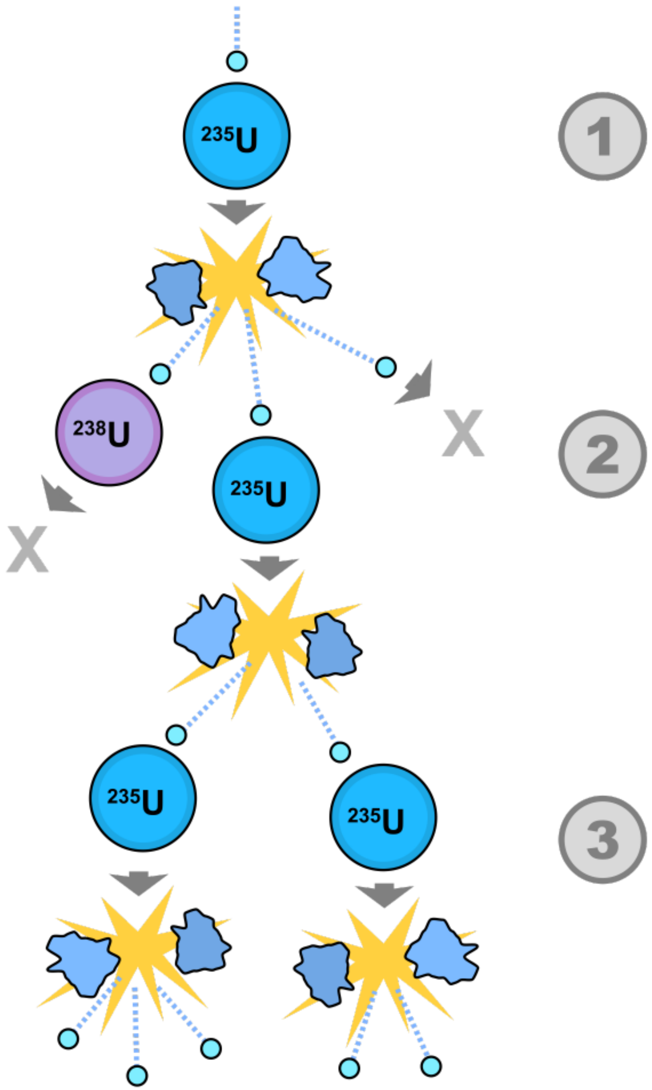


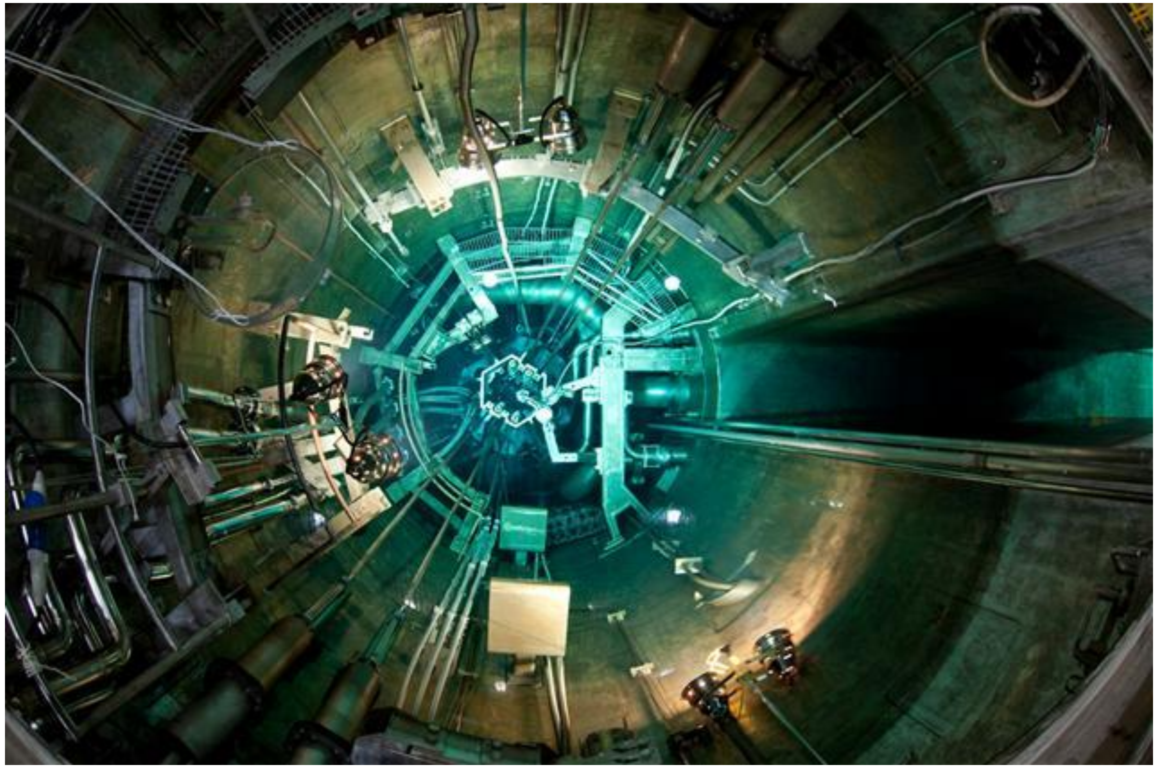
$^{9}Be + \alpha$ $^{12}C + {}^{1}n$



- AmBe ("ambee") sources are mix of ^{241}Am and ^{9}Be
- $^{9}Be + \alpha \rightarrow n + {}^{12}C^*$
  $^{12}C^* \rightarrow {}^{12}C + 4.44$ MeV γ
- Yield: 2.2×10^6 neutrons/s/Ci
- Half-life: 432.2 years
- Average neutron energy: 4.2 MeV (11 MeV max)
- 90 μCi(3.33×10^6 Bq) ~ 198 n/s

Source [Reactor]



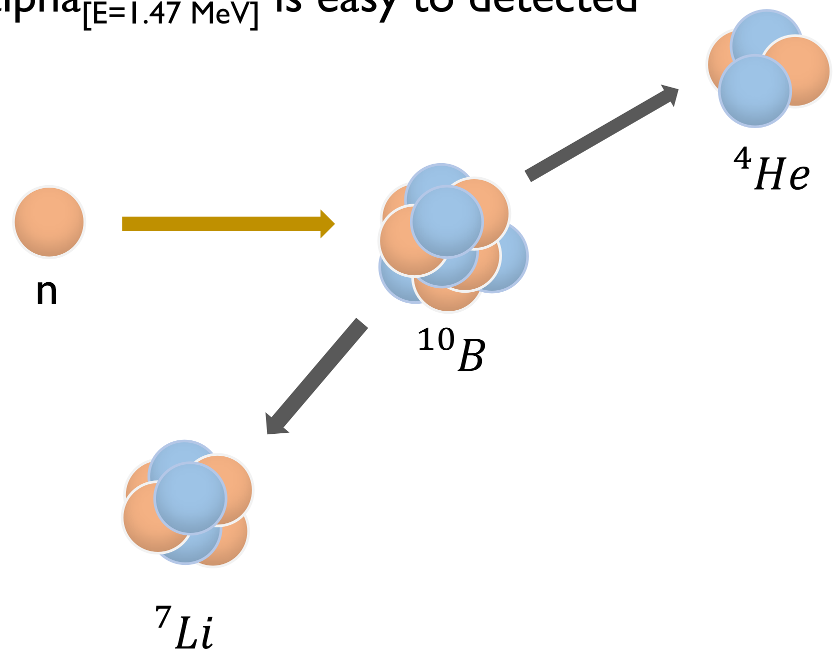


$$ {}_{92}U^{235} + n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n + \sim 200\ \text{MeV} $$

Fast neutron

n Capture Process

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



^{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

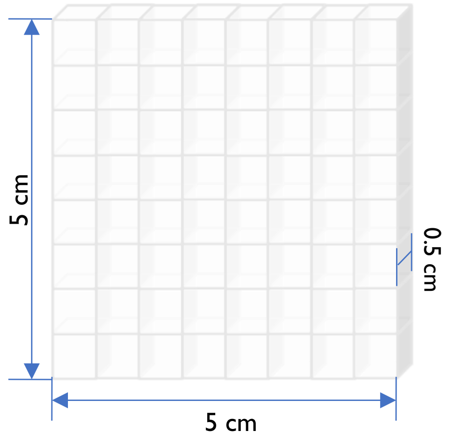
He-3 neutron capture process

- n + ^{3}He → ^{3}H + ^{1}H + 0.764 MeV
- ${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + e^{-} + \bar{\nu}_e$
- ${}^{3}_{1}\mathrm{H}$ half-life : 12.32 years

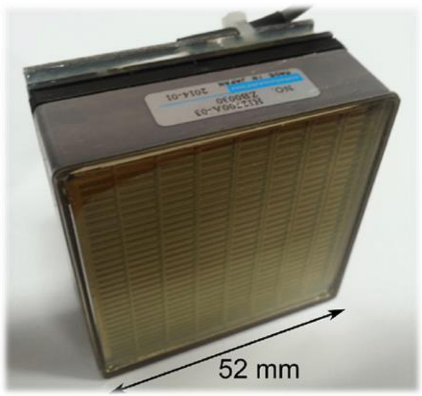
Li-6 neutron capture process

- n + ${}^{6}_{3}\mathrm{Li} \rightarrow {}^{3}_{1}\mathrm{H}(2.73\ \mathrm{MeV}) + {}^{4}_{2}\mathrm{He}(2.05\ \mathrm{MeV})$

LiCAF Scintillator



64ch PMT



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)

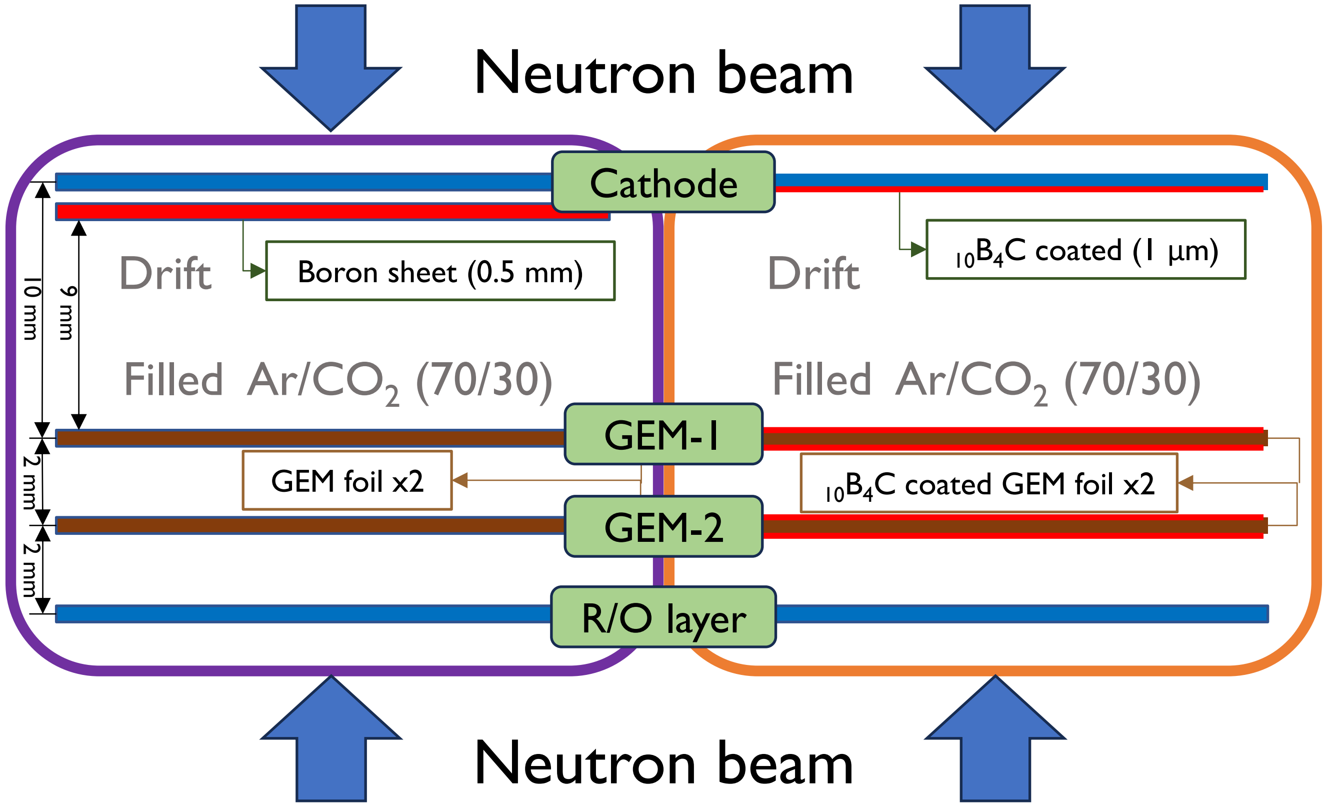
Variations on geometry

- **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

Forward direction



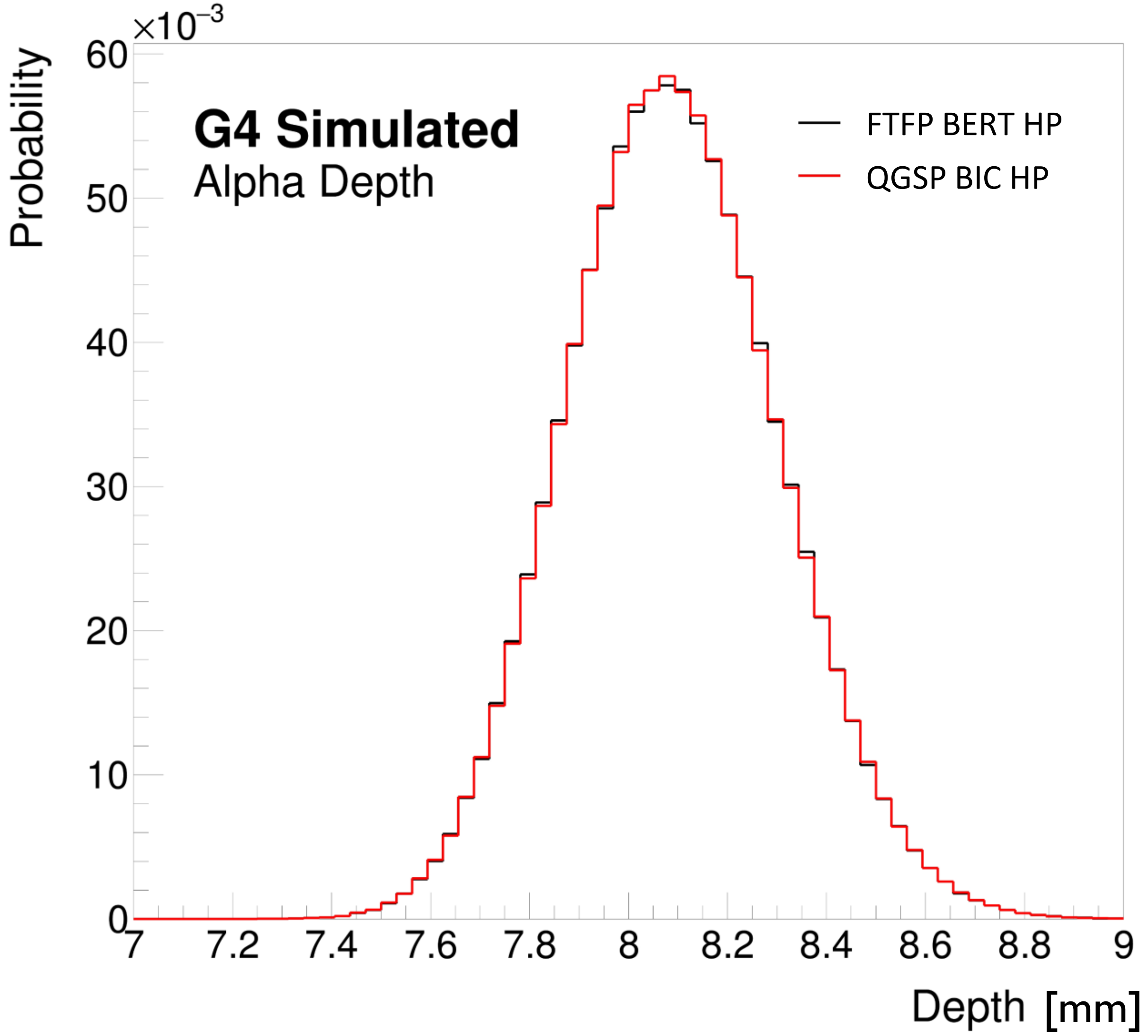
Backward direction

Geant4 Simulation [Alpha]

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

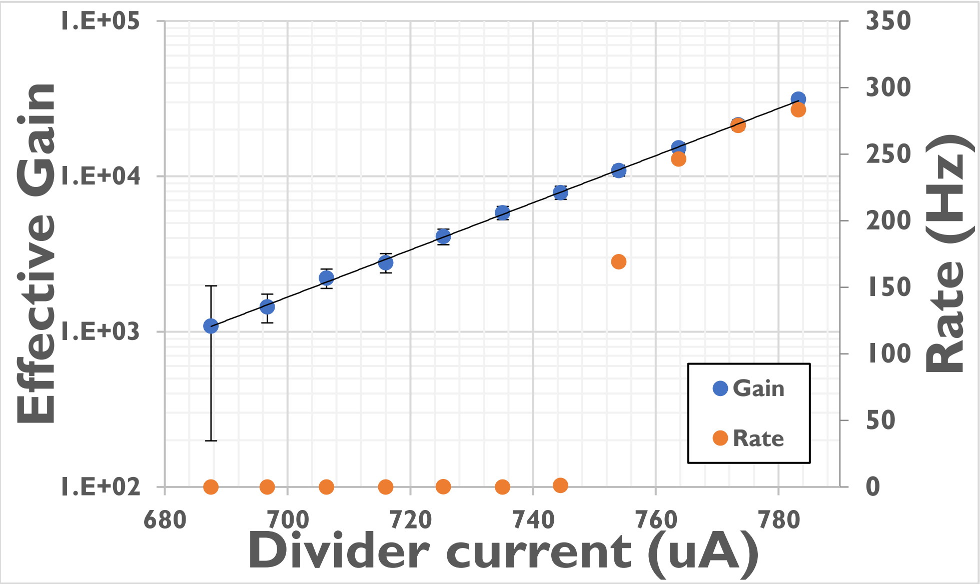
- Gas: Ar/CO_2 (70/30)
- Alpha energy: 1.78 MeV
  maximum energy after capture

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

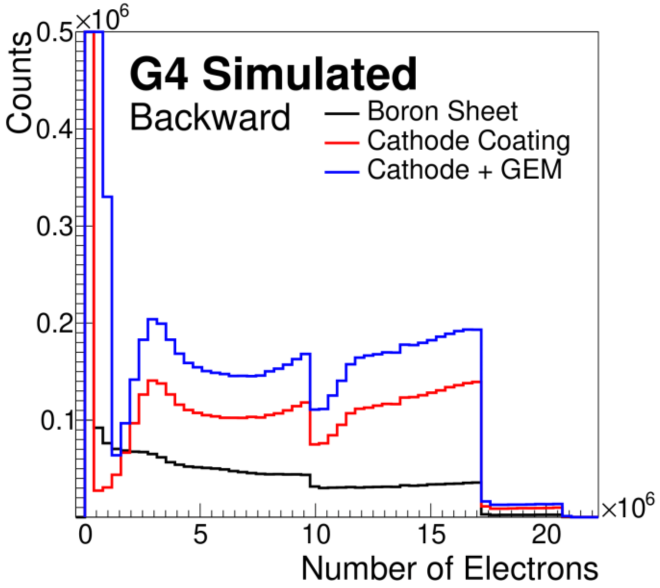


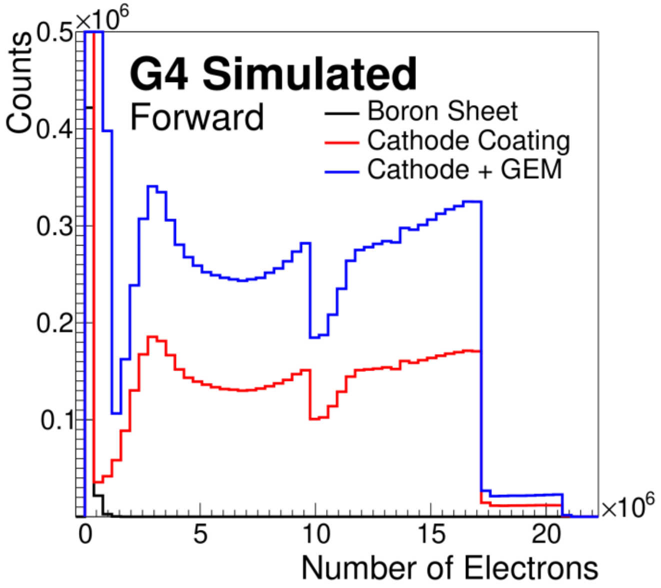
GEANT4 Simulation [Result]

- R/O Electron = energy loss / W factor x amplification rate (18) ^ number of sheets (2)
- 0.48 MeV gamma maximum number of electrons on readout plane is 2.11×10^6.



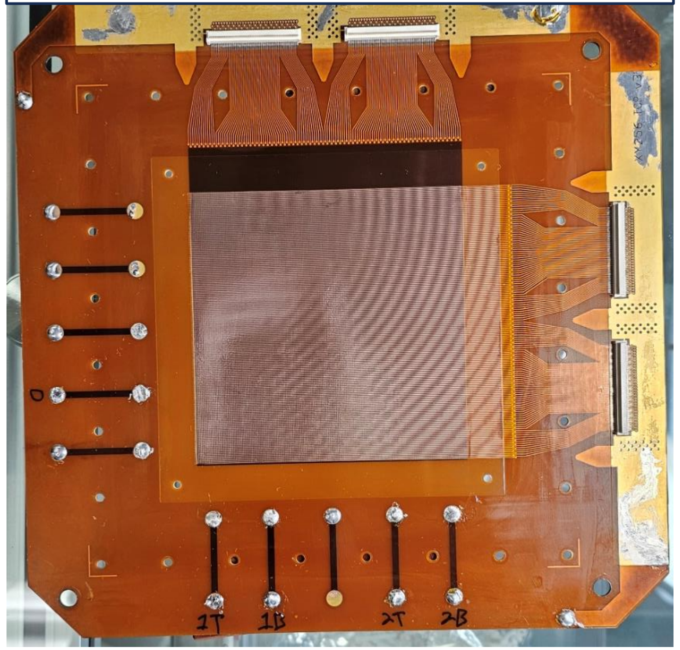
Direction of neutron	Forward		Backward	
Signal caused by	α, Li, e^-, γ	α	α, Li, e^-, γ	α
Sheet	0.00 %	0.00 %	1.64 %	1.19 %
Cathode	5.81 %	3.66 %	4.48 %	2.80 %
Cathode + Foil	10.79 %	6.64 %	6.44 %	3.95 %



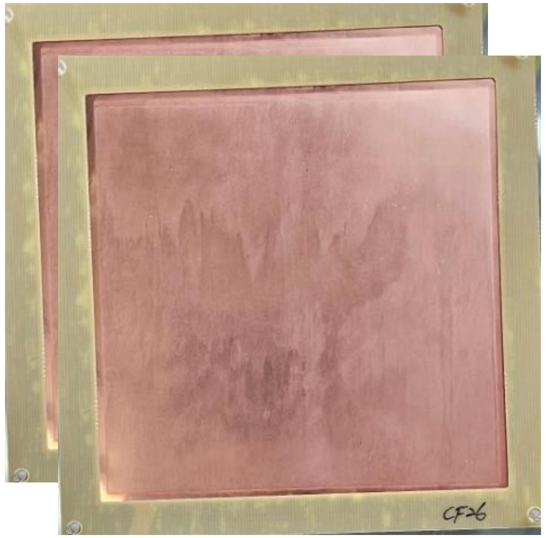


The Making Process

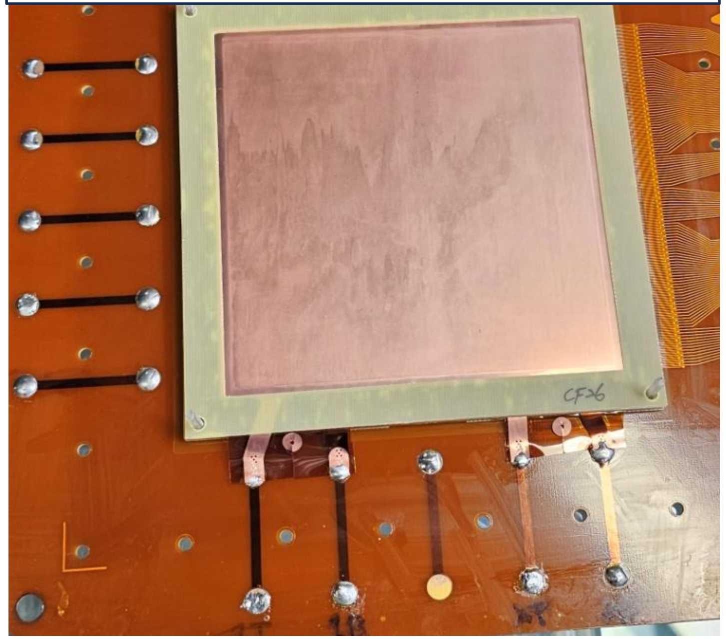
Readout board



2 GEM foil

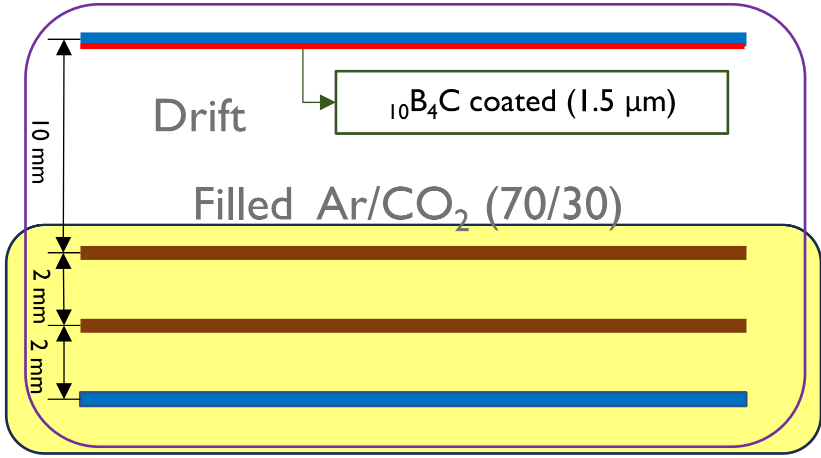


Attach the GEM foil to the board



Spacer

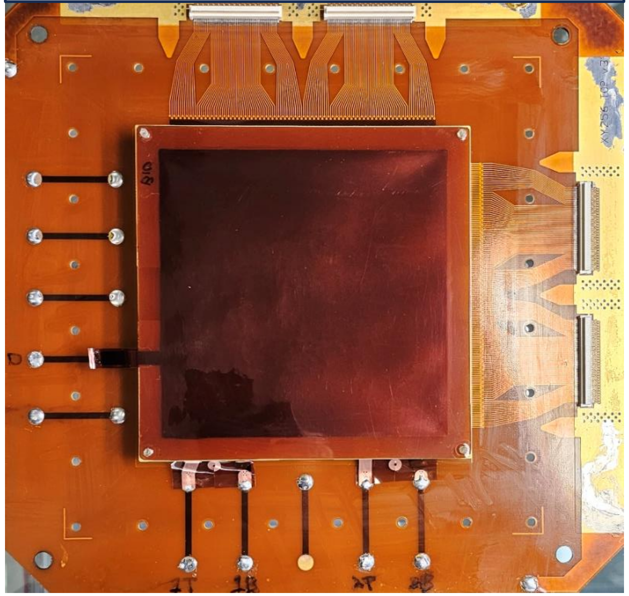
- Detector assemble readout-board and GEM foils with use spacer.
  - Each gap is 2 mm.



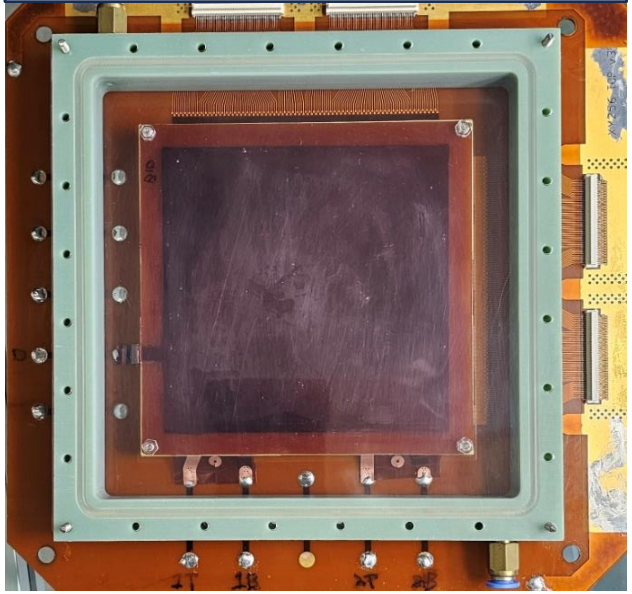
The Making Process

B4C coated cathode

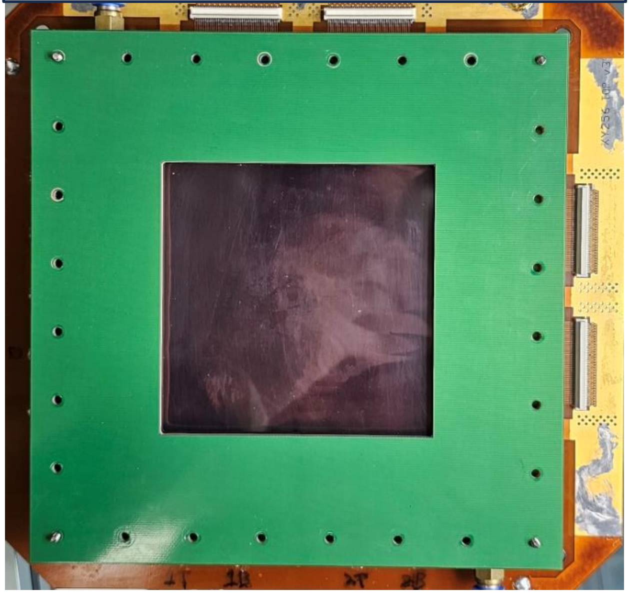
Attach the coated cathode

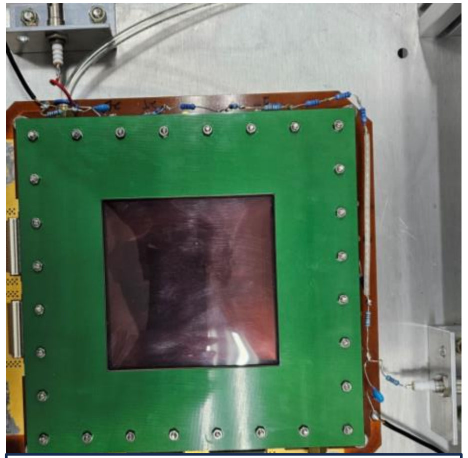


Attach the window film



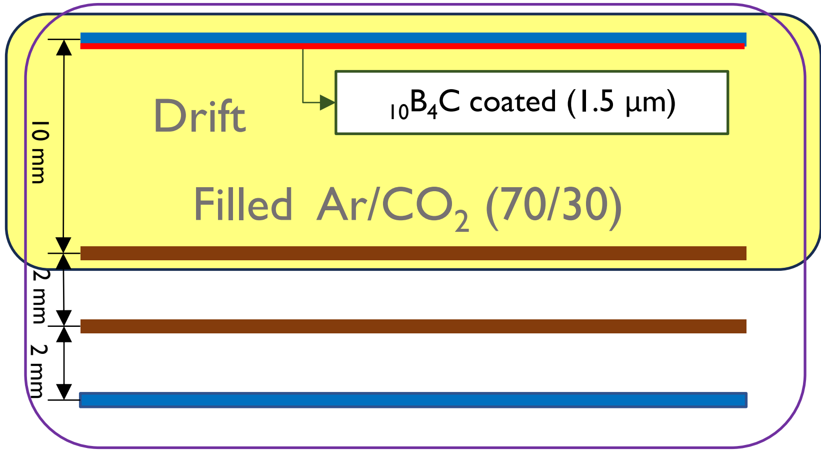
Casing detector





Assembled detector

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



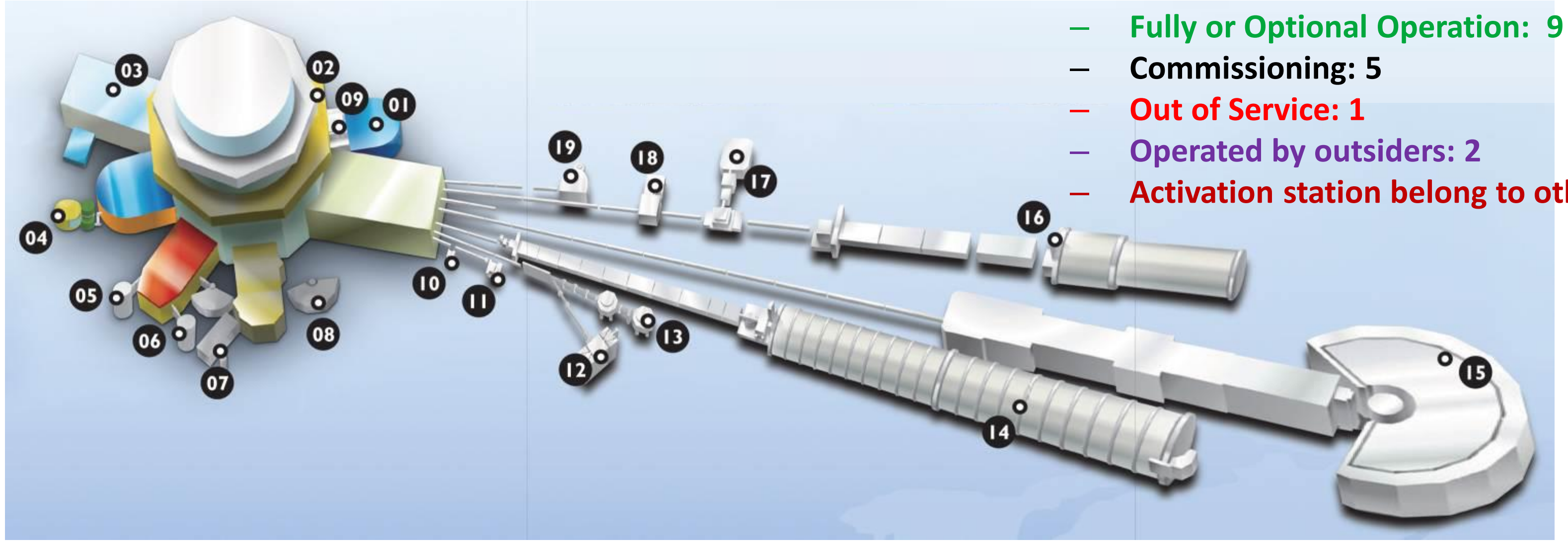
Boron Coating on the Foils

Coating

HANARO

2018 status total 19 instruments

- Fully or Optional Operation: 9
- Commissioning: 5
- Out of Service: 1
- Operated by outsiders: 2
- Activation station belong to other division:2



02 Ex-core Neutron irradiation Facility	10 Guide Test Station
09 Thermal Neutron Prompt Gamma Activation Analysis	11 Vertical type REFlectometer
01 Residual Stress Instrument	12 Cold Neutron Activation Station
08 High Resolution Powder Diffractometer	13 High Intensity Powder Diffractometer
07 Four Circle neutron Diffractometer	14 40m Small Angle Neutron Scattering instrument
06 Bio-Diffractometer	15 Disk-Chopper Time-of-Flight spectrometer
05 Bio-diffractometer with neutron image plate Camera	18 KIST Ultra-Small Angle Neutron Scattering instrument
04 Thermal neutron Triple-Axis Spectrometer	17 Bio-REFlectometer
03 Neutron Radiography Facility	16 18m Small Angle Neutron Scattering instrument
	19 Cold neutron Triple-Axis Spectrometer