Neutron Detector with Ceramic GEM

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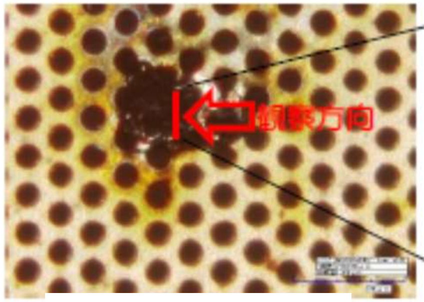
at WG2 in AFAD
Melbourne
2023.4.13

New GEM

- One big issue is that serious damage occurs in GEM foils.
  - Large charge stores in large capacitance of GEM foil.
  - Small discharge (trigger)
    − > Large discharge − > Serious damage (Carbonization)



Broken GEM

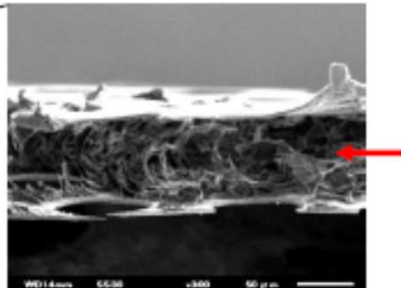


Image with SEM

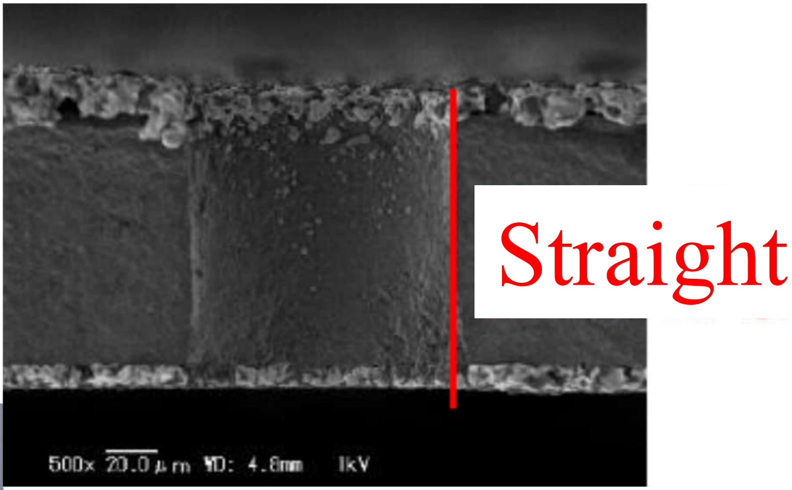
- To avoid serious damage
  - Ceramic GEM
    - There is no hydrogen.
    - It is also good for neutron detector.

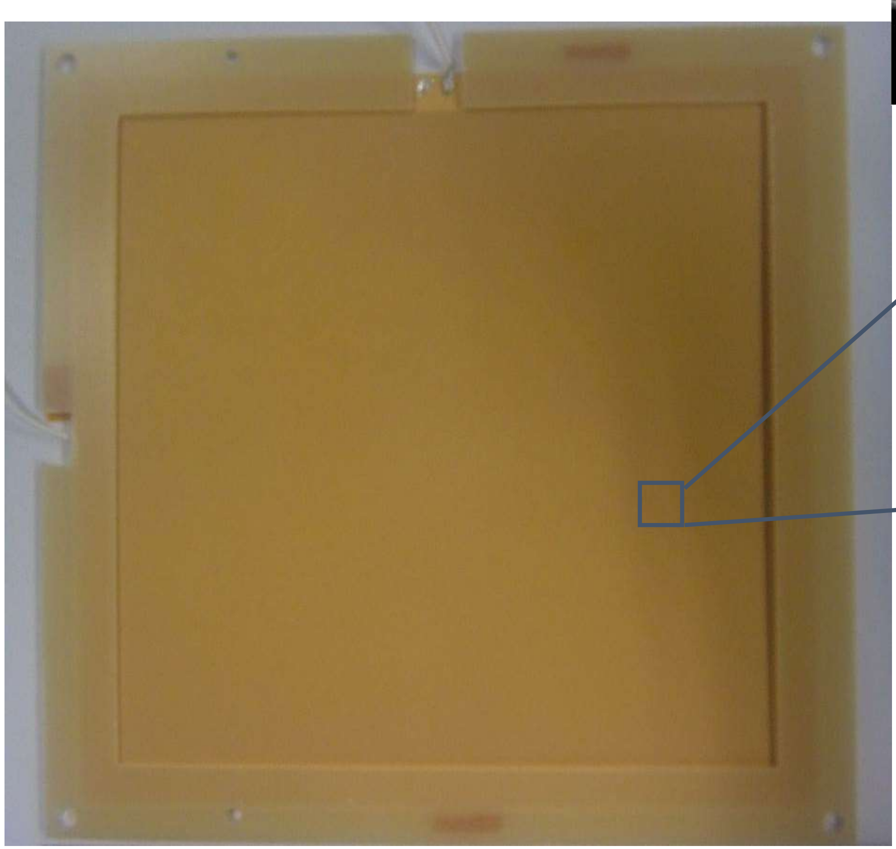
Two types of ceramic GEM

- Low Temperature Co-fired Ceramic (LTCC)
  - Temperature is relatively lower to make ceramic.
  - Gold electrodes on both surfaces
  - Unfortunately, there is small amount of boron.
    - It is not good for boron coated GEM

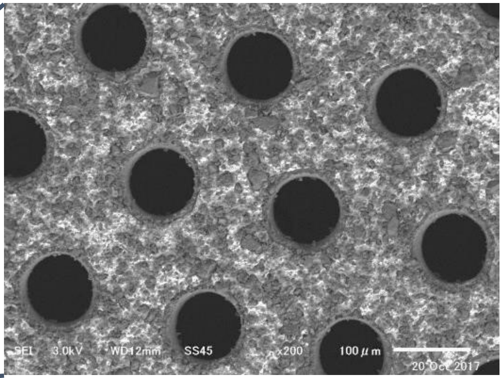
- High Temperature Co-fired Ceramic (HTCC)
  - There is no boron.
  - Platinum electrodes on both surfaces
  - This one should be used for boron coated GEM.

LTCC-GEM





LTCC-GEM



LTCC GEM (normal GEM)

- Size : 10 cm×10 cm
- Hole diameter : 100 μm (70 μm)
- Hole pitch : 200 μm (140 μm)
- Thickness : 100 μm (50 μm)
- Material of Electrode : Au (Cu)

Neutron detector system

One Ethernet cable for digital data transfer

All cables and pipes can be connected from one side.

HV cables

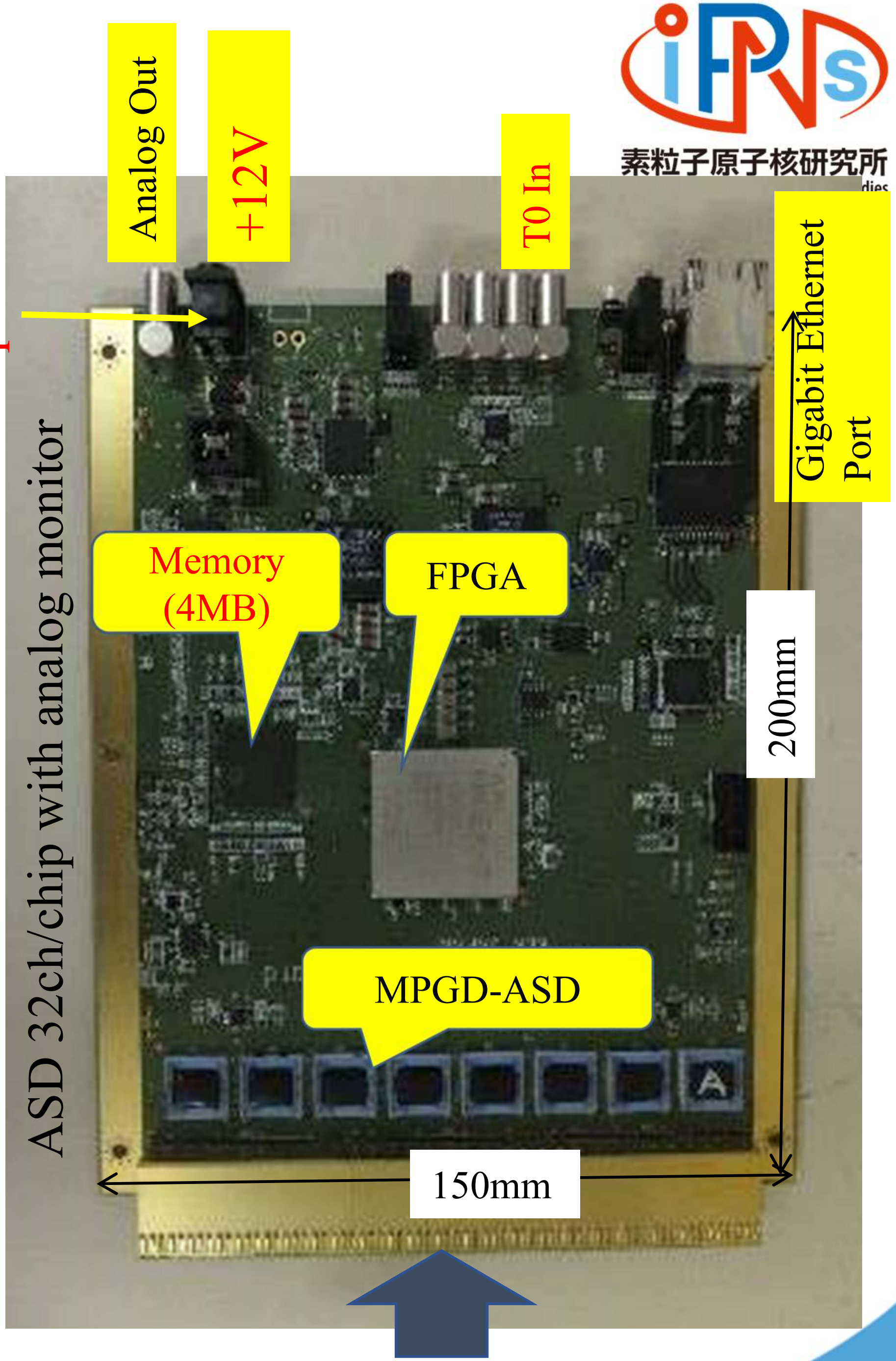
Two gas pipes for inlet and outlet

Active aria

Electronics aria

Commercial AC adapter can be used.

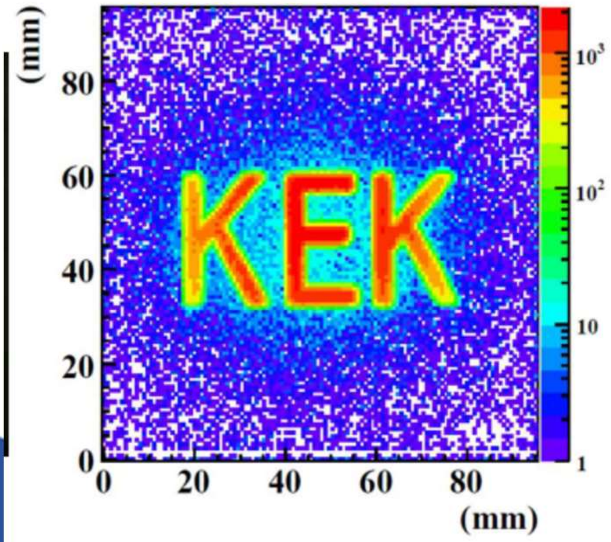
ASD 32ch/chip with analog monitor

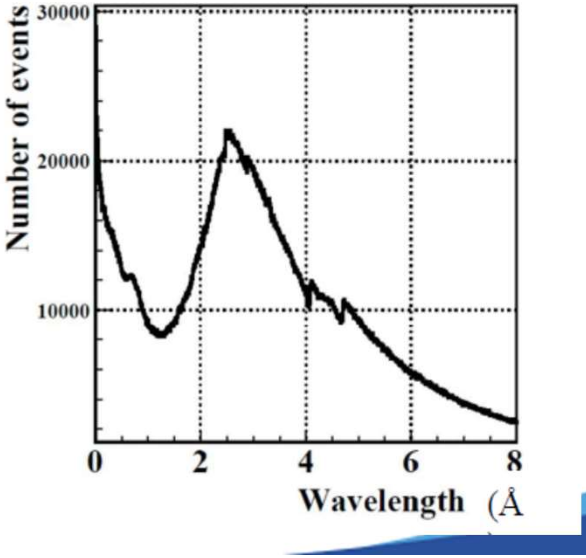


256 signal inputs

Two applications

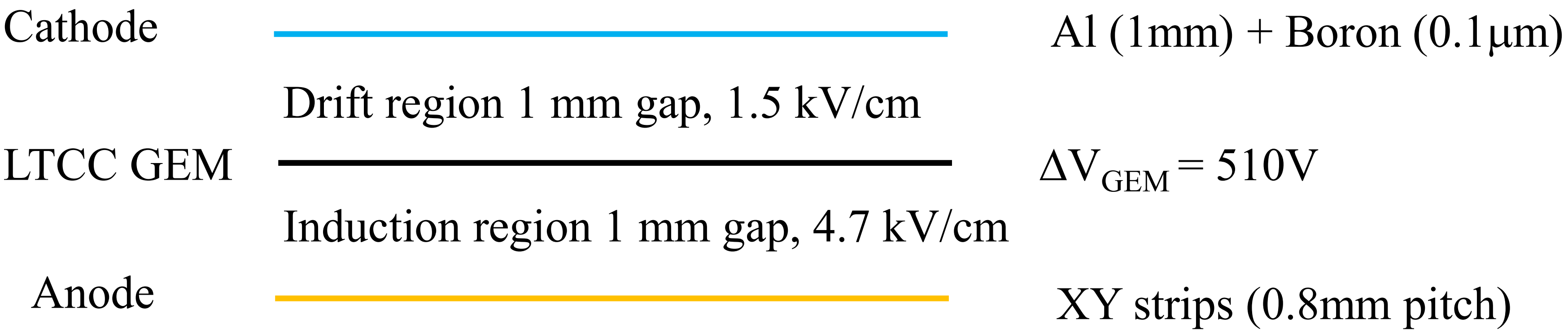
- Beam monitor
  - Simple structure is better.
  - Moderate efficiency is good enough in most of cases.
  - Boron coated cathode + single GEM structure
- Detector for energy selective neutron radiography
  - Higher efficiency is desired especially for small pulse neutron sources.
  - Several boron coated GEMs should be stacked.





Beam monitor

- Boron coated cathode + single GEM structure
- One register chain is used to provide each voltage for each part with single HV supply.



Cathode — Al (1mm) + Boron (0.1μm)

Drift region 1 mm gap, 1.5 kV/cm

LTCC GEM — $\Delta V_{GEM} = 510V$

Induction region 1 mm gap, 4.7 kV/cm

Anode — XY strips (0.8mm pitch)

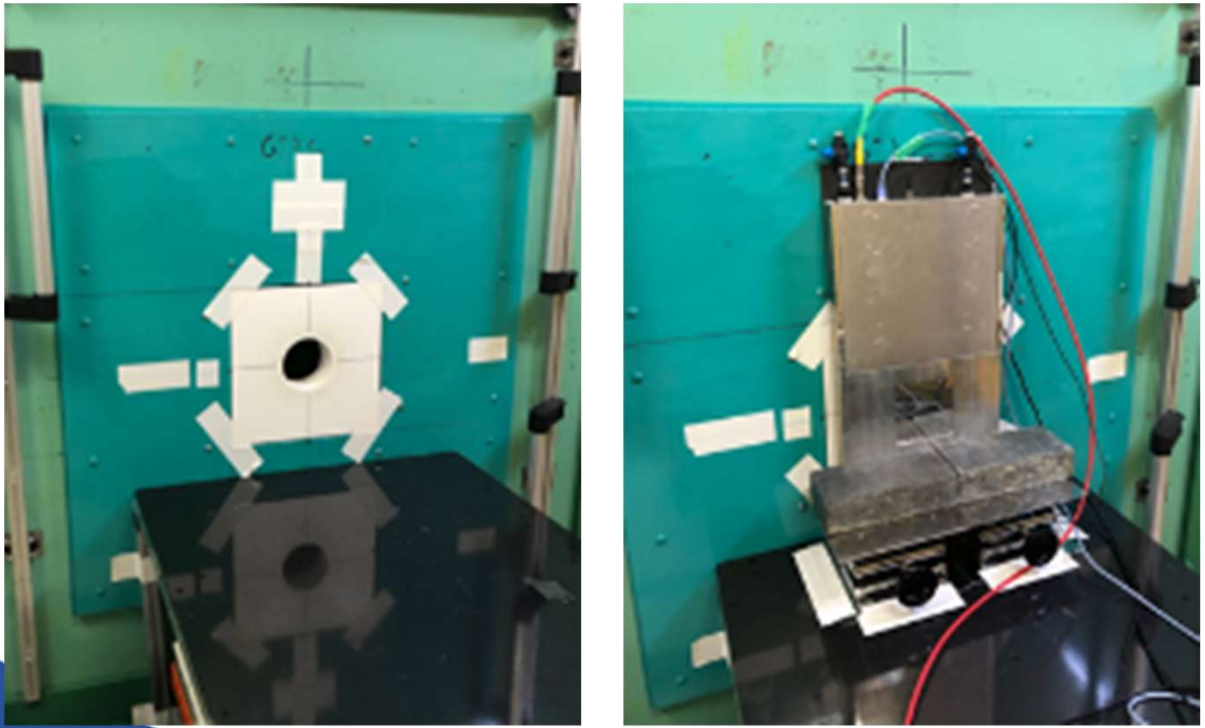
Beam monitor for BNCT

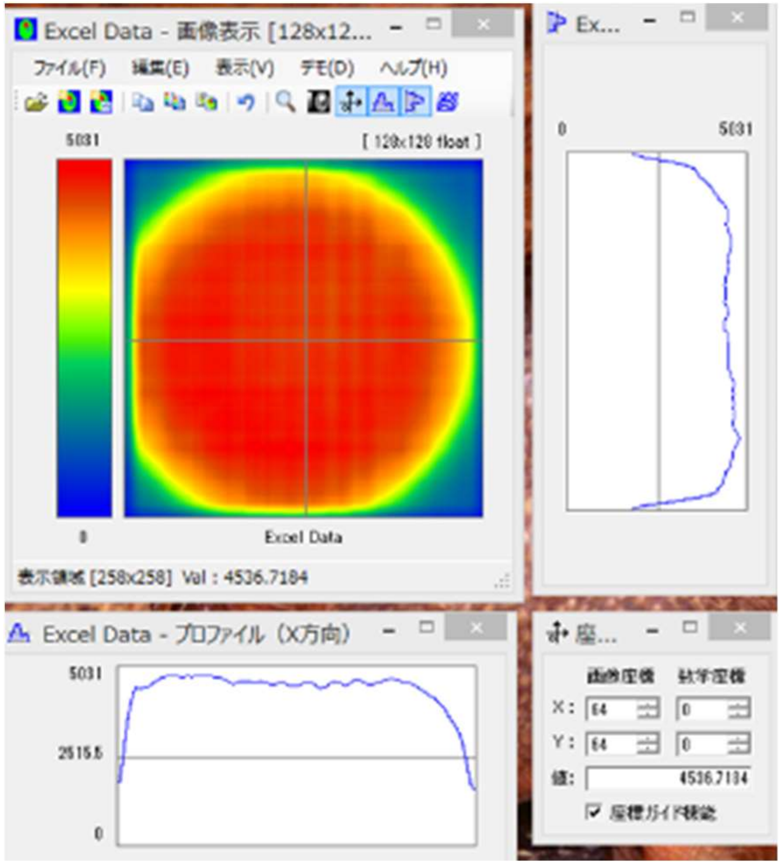
KURNS Prog. Rep. 2021(2022)45

Institute for Integrated Radiation and Nuclear Science,

Kyoto University

Small nuclear plant for various experiments





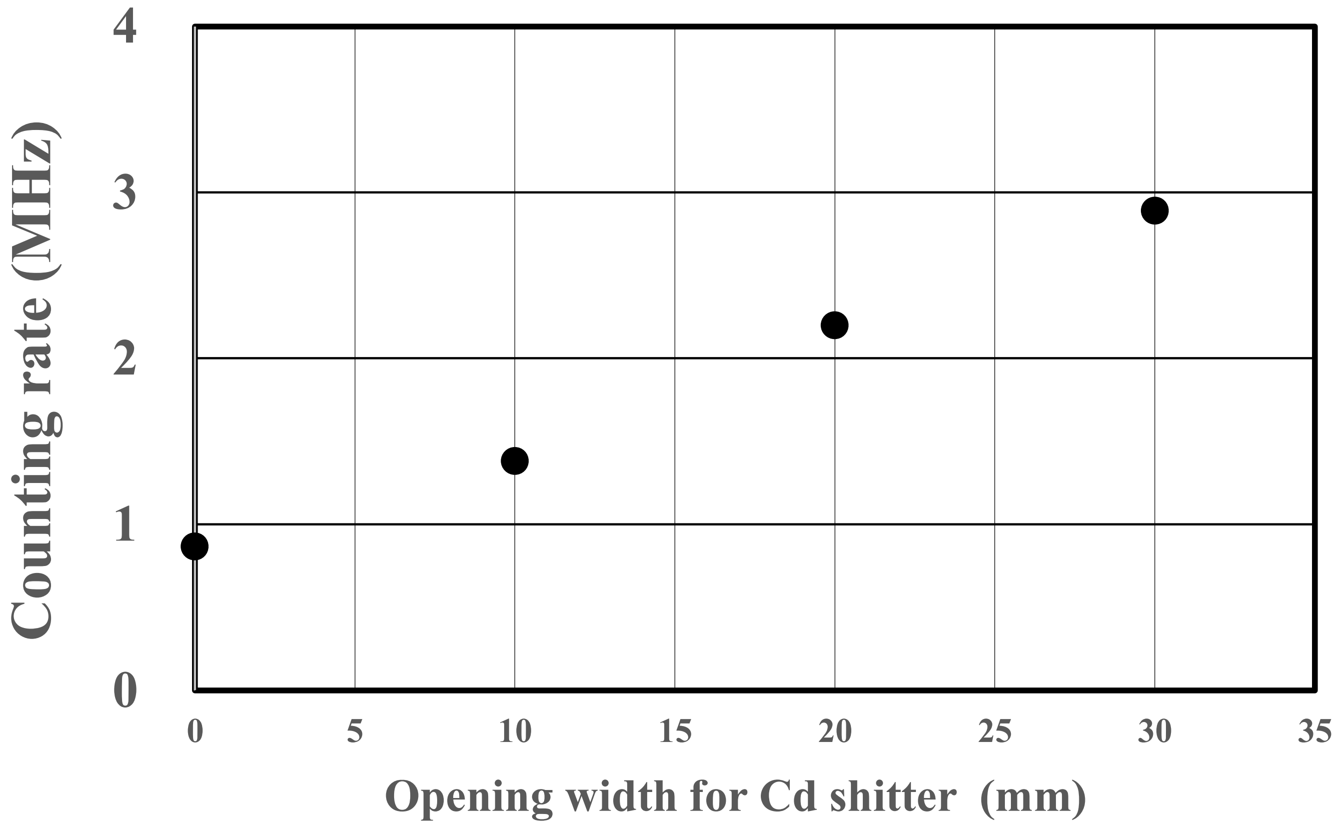
表示領域 [258x258] Val : 4536.7184

X: 64 0
Y: 64 0
値: 4536.7184

RUN39 @ 100µA 1327V 10min acquisition

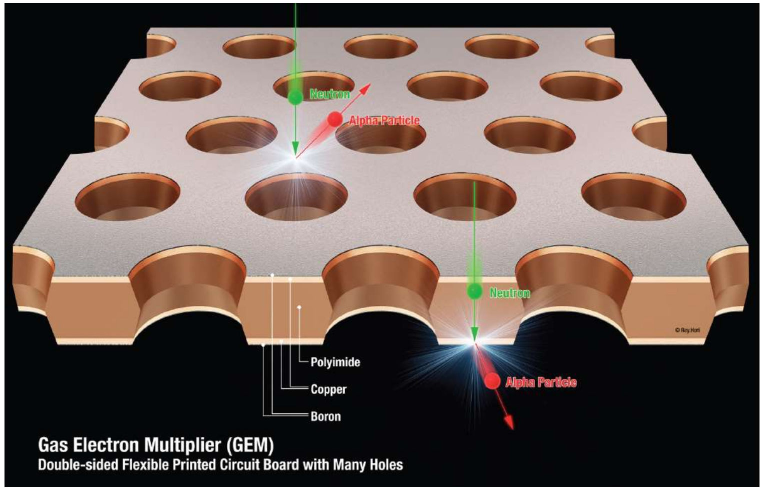
※ 5×5 smooth filter＋

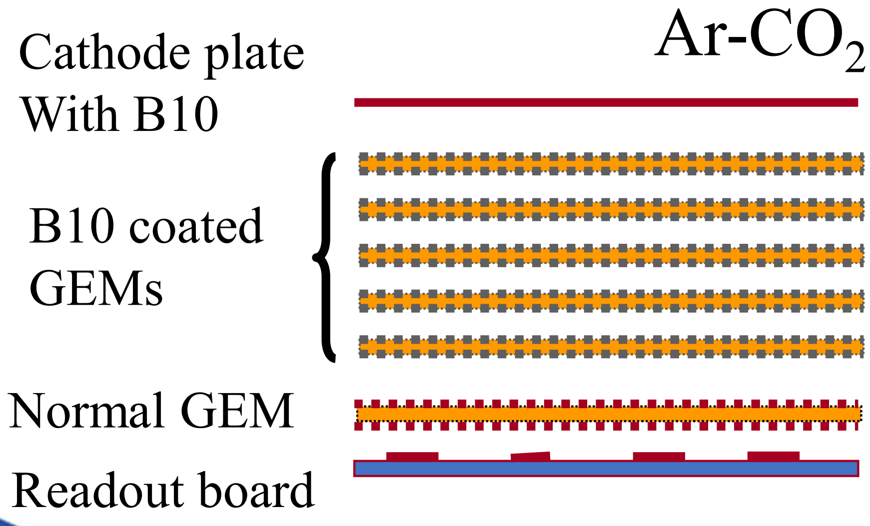
Counting rate



The detector system can count neutrons up to 3MHz at least.

Higher efficiency for thermal neutron





Ar-CO$_2$

Cathode plate
With B10

B10 coated
GEMs

Normal GEM

Readout board

Expensive ^{3}He Gas is not necessary.
 No pressure vessel

Free readout pattern

High resolution
 Position and **Time**

Insensitive against g-ray

Capability against high counting rate

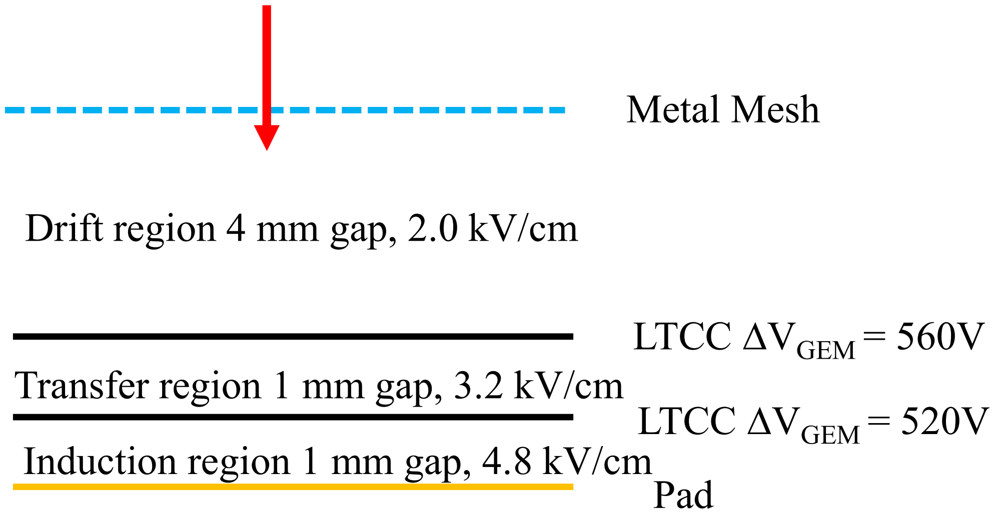
Boron coated GEM

- We have tried to produced boron coated GEM for many years.
  - It is not easy for us.
  - Finally, a test production of boron coated GEM just started.
- Just one smaller sample (10cm × 5cm) is available, now.
  - Natural boron
- Boron-10 cathode (10cm × 10cm) is also produced.
- Both samples were tested.

Suitable voltage in Boron GEM

- First step: Pulse height measurement without HTCC GEM
- Second step: Pulse height measurement with HTCC GEM as changing the voltage in HTCC.
- Then, compare the pulse height with/without HTCC GEM

X ray from Fe-55



Metal Mesh

Drift region 4 mm gap, 2.0 kV/cm

LTCC $\Delta V_{GEM} = 560V$

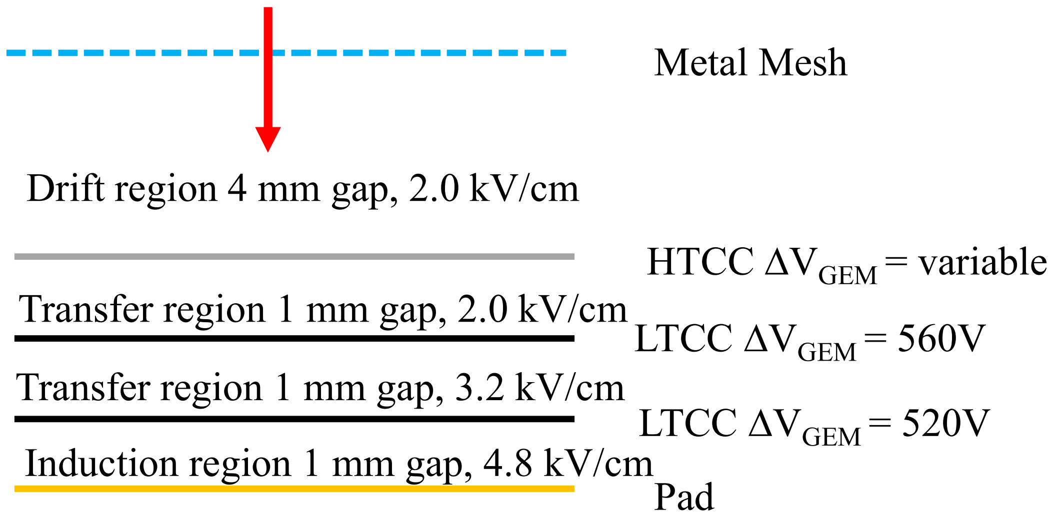
Transfer region 1 mm gap, 3.2 kV/cm

LTCC $\Delta V_{GEM} = 520V$

Induction region 1 mm gap, 4.8 kV/cm

Pad

X ray from Fe-55



Metal Mesh

Drift region 4 mm gap, 2.0 kV/cm

HTCC ΔV_{GEM} = variable

Transfer region 1 mm gap, 2.0 kV/cm

LTCC $\Delta V_{GEM} = 560V$

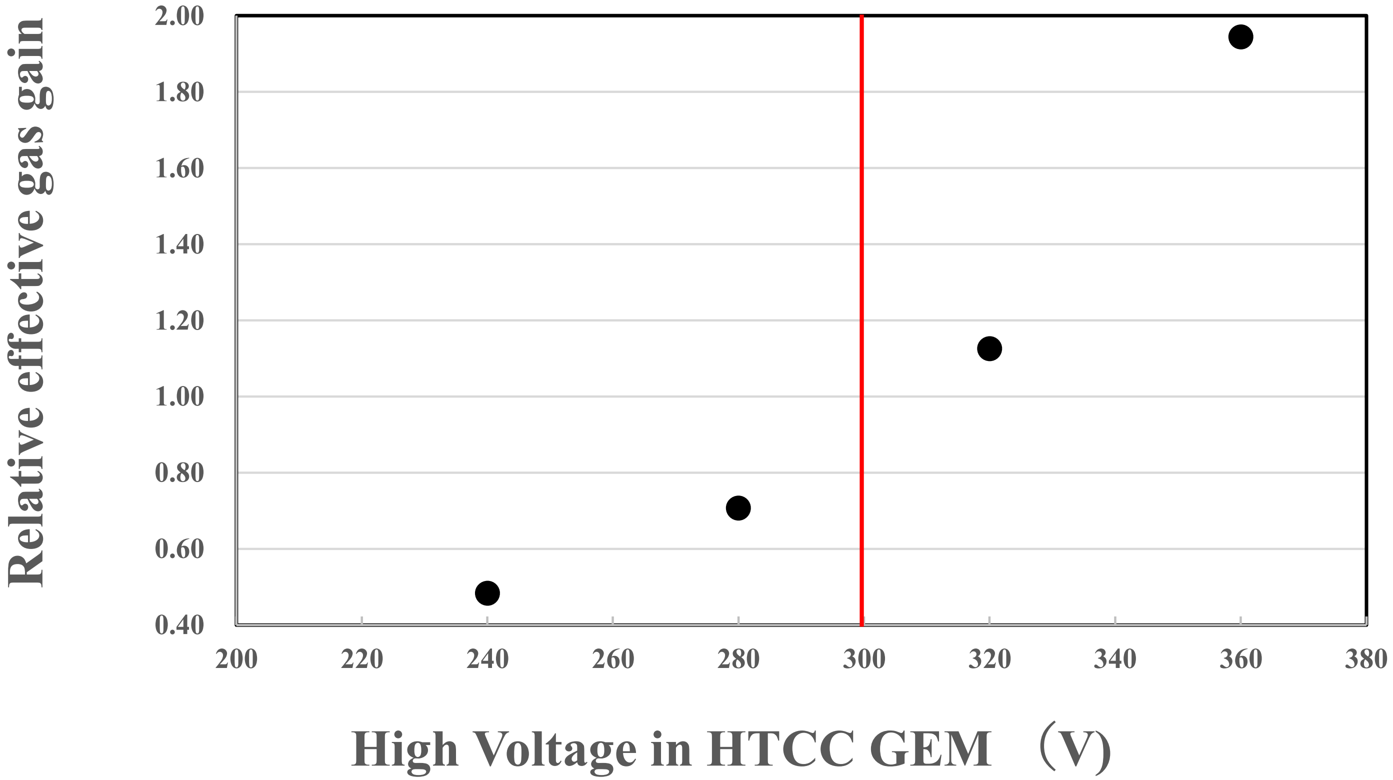
Transfer region 1 mm gap, 3.2 kV/cm

LTCC $\Delta V_{GEM} = 520V$

Induction region 1 mm gap, 4.8 kV/cm

Pad

Result



- Effective gas gain is around one in boron GEM with 300V.

Test trial of boron GEM

- Boron cathode (nB 1μm) + Boron GEM (nB 1μm both sides)
  + LTCC GEM

Boron Cathode

Drift region 1 mm gap, 1.5 kV/cm

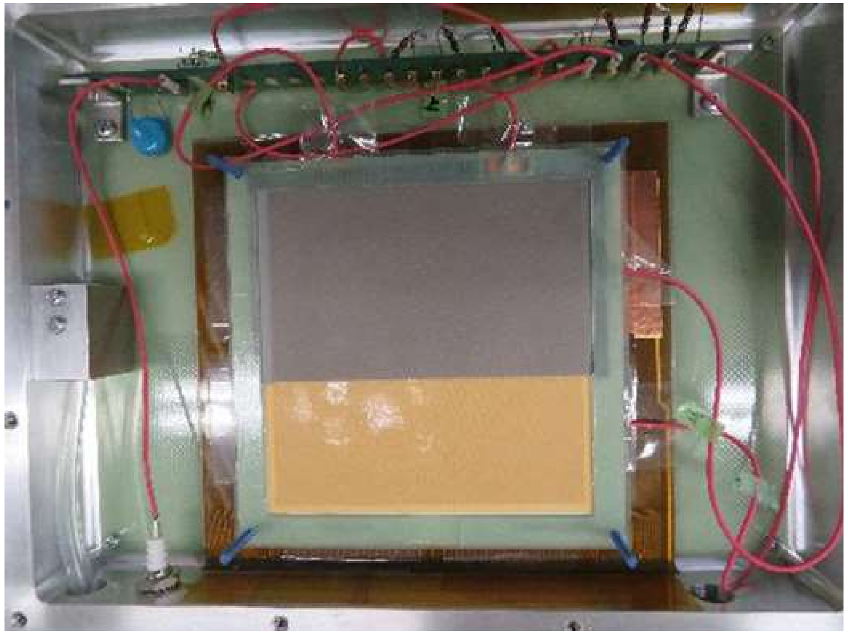
Boron GEM $\Delta V_{GEM} = 300V$

Transfer region 1 mm gap, 1.5 kV/cm

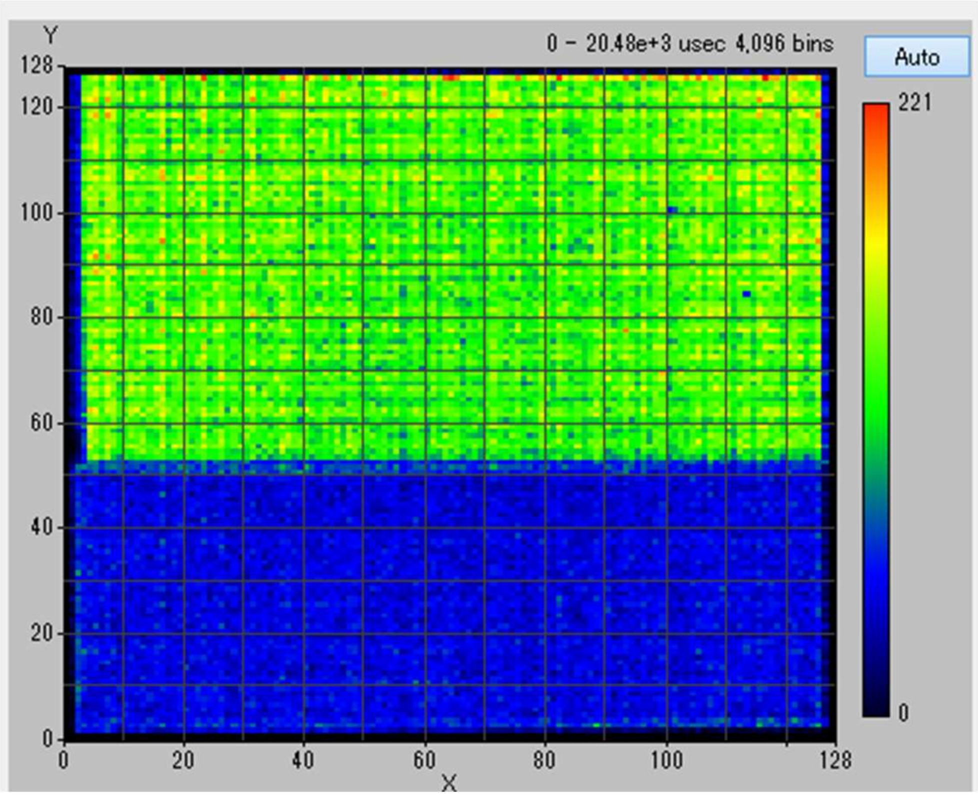
LTCC GEM $\Delta V_{GEM} = 510V$

Induction region 1 mm gap, 4.7 kV/cm

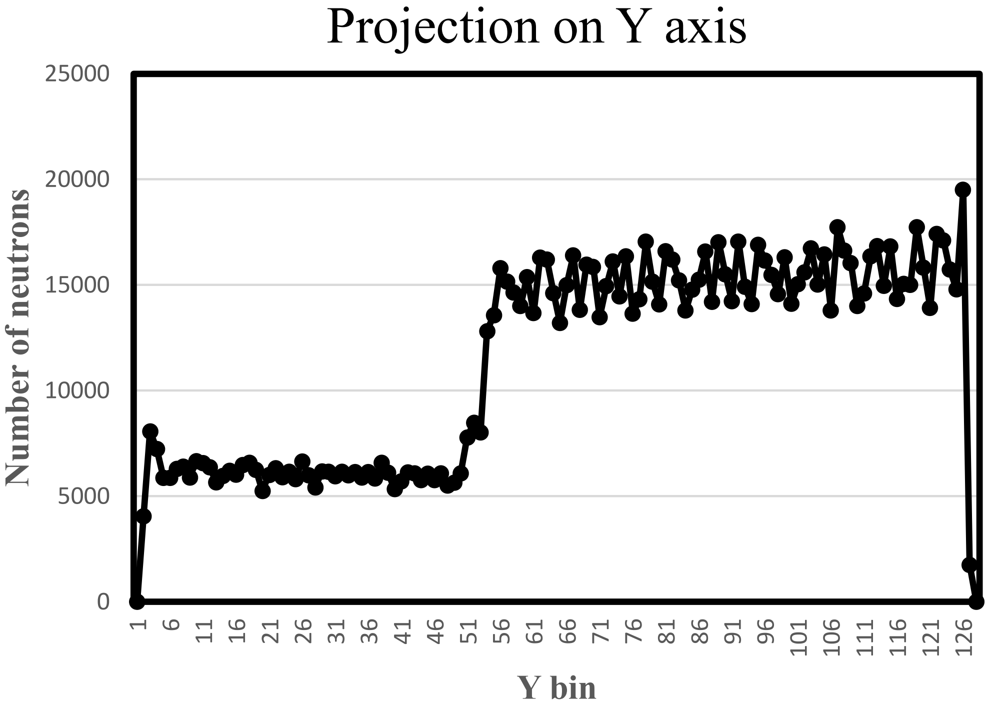
Anode XY strip



A beam test for the thermal neutron at Hokkaido University



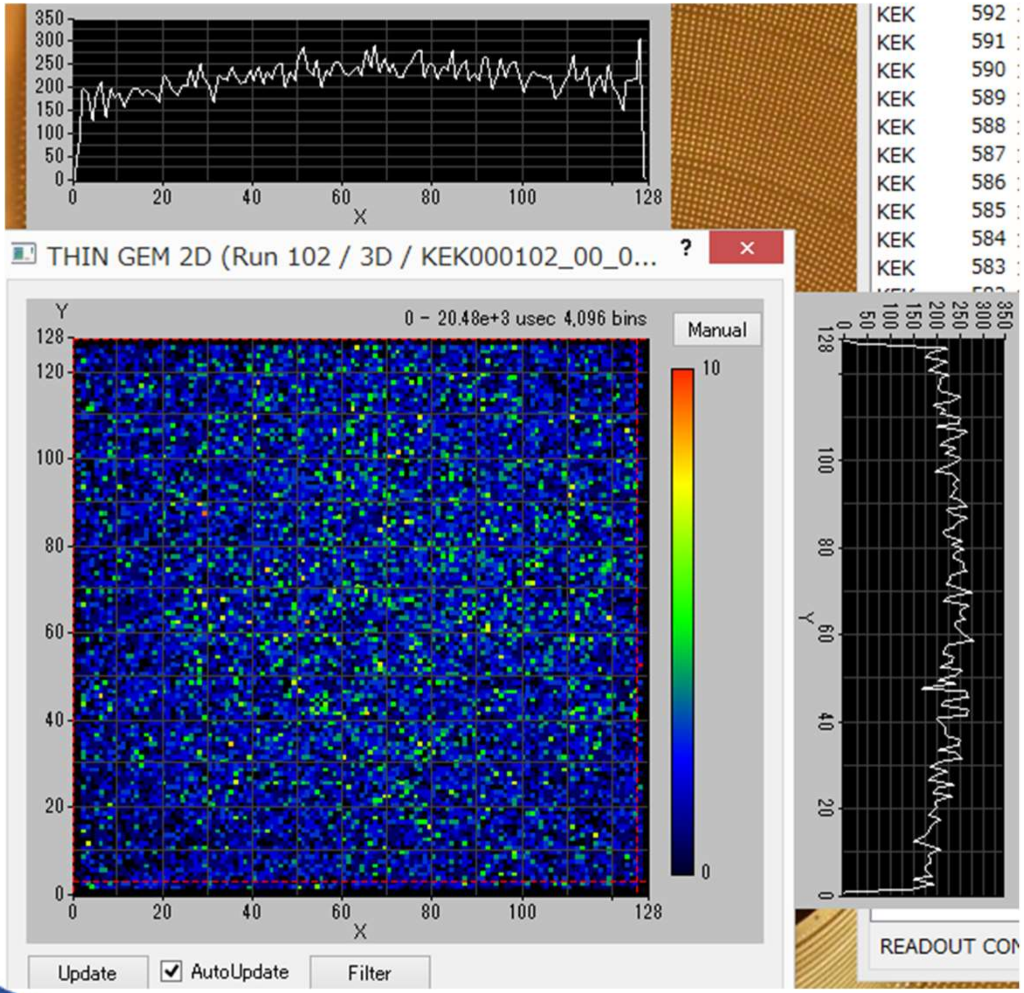
10 min measurement



Efficiency becomes higher by factor 3 as compared with a part of the boron cathode only.
Boron is really coated on the both surfaces of GEM.

B10-cathode

- B10 (2μm) cathode + LTCC GEM



THIN GEM 2D (Run 102 / 3D / KEK000102_00_0...

0 – 20.48e+3 usec 4,096 bins

16h46min measurement 0.47Hz

Cd-252 radioactive source

	Number of counts in 30 min	Rate (Hz)
Without source	19	0.011
nB	149	0.083
B10	846	0.47

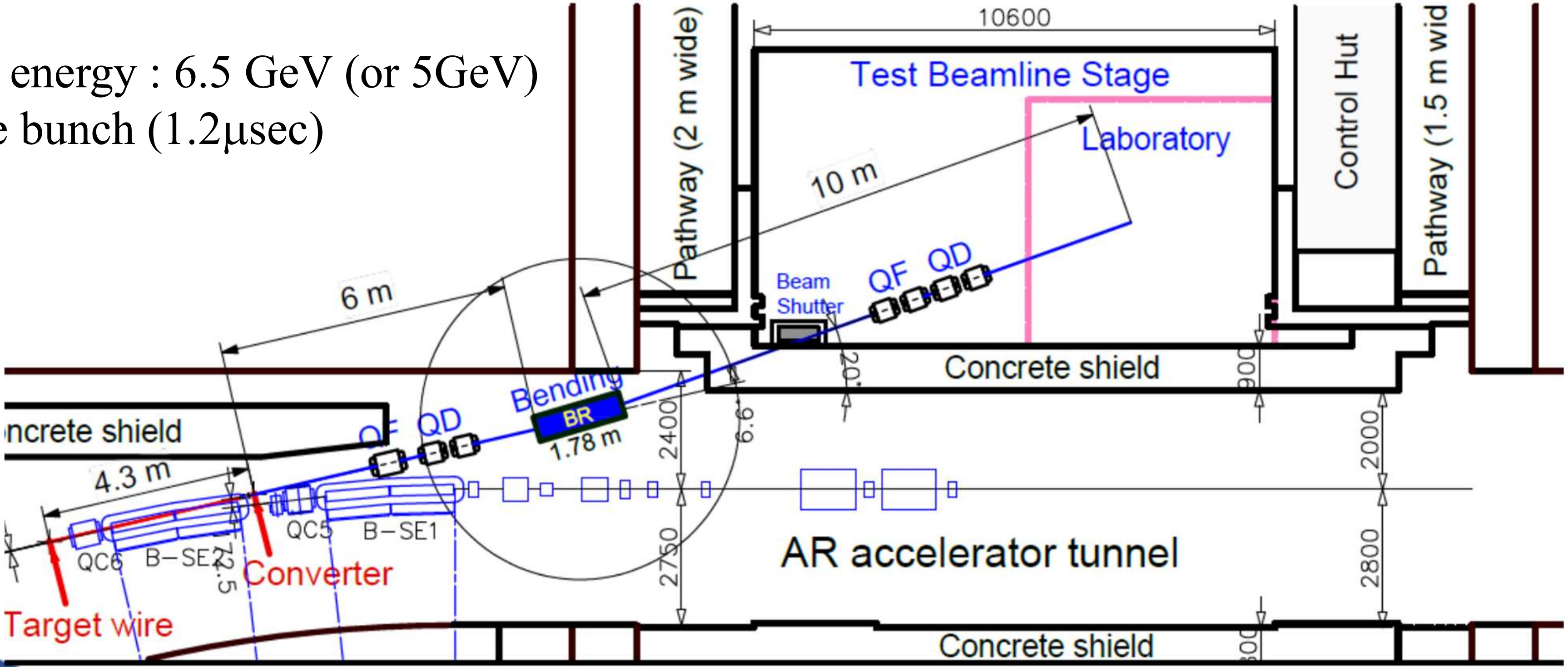
Different topic

New test beam line in KEK

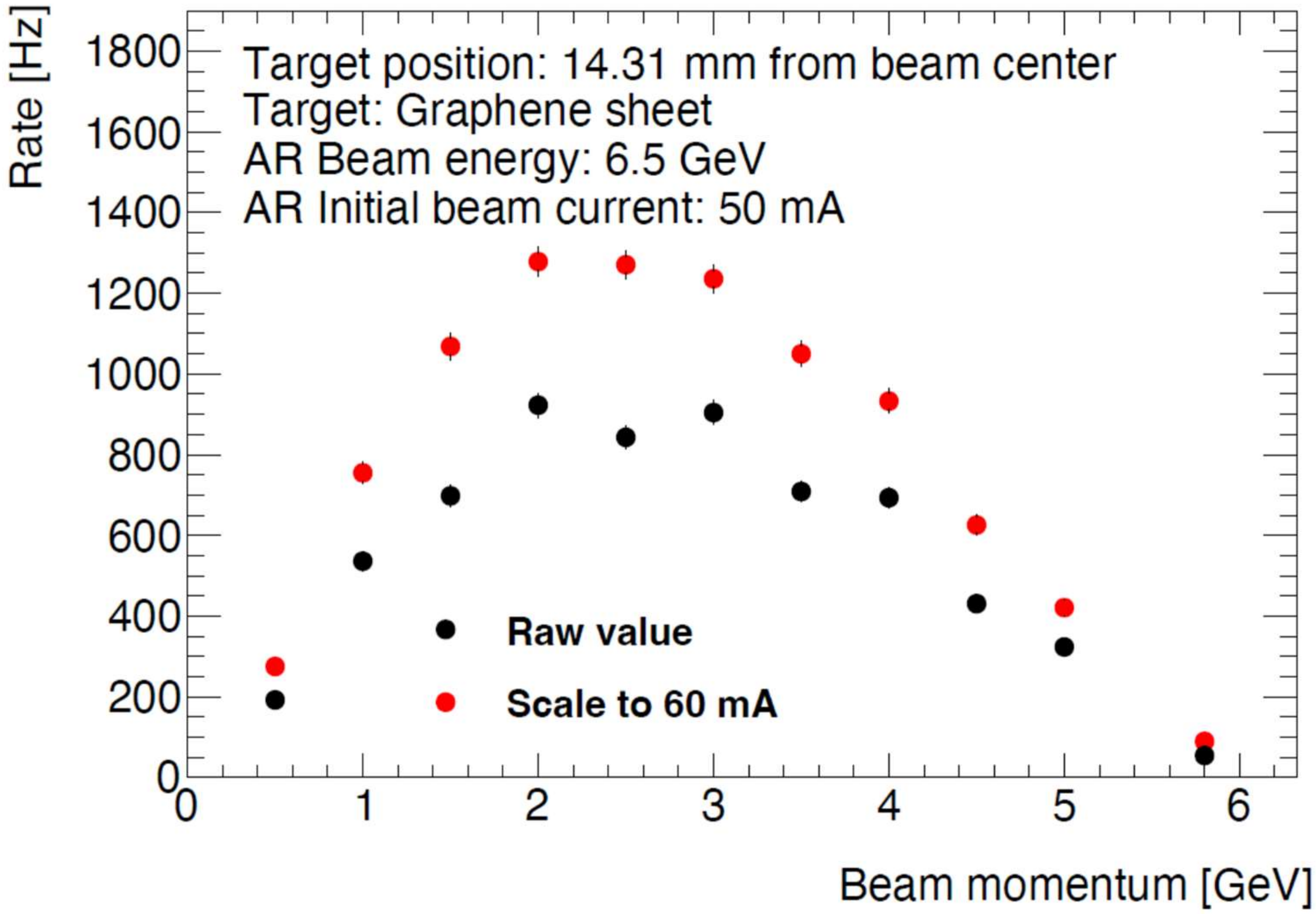
New test beam line in KEK

- New test beam line was constructed at AR (one of photon factory ring in KEK).
- A few GeV electron beam is available for users from this year.

Beam energy : 6.5 GeV (or 5GeV)
Single bunch (1.2μsec)



Available beam rate


Target position: 14.31 mm from beam center
Target: Graphene sheet
AR Beam energy: 6.5 GeV
AR Initial beam current: 50 mA

- It is not so strong (~1 kHz so far). Even so, I suppose it is useful for various detector tests.

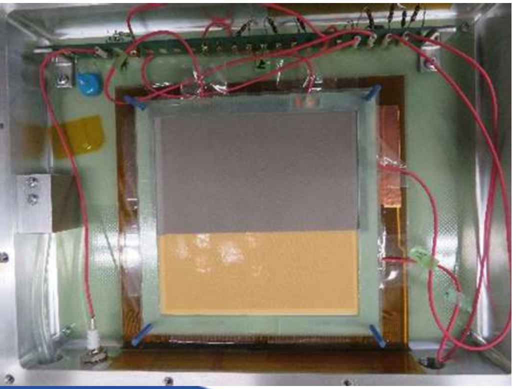
Summary

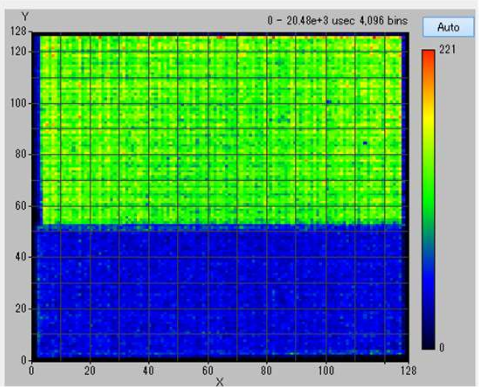
- Ceramic GEM is working fine without serious damage.
- Our detector system is compact and simple.
  - Neutron beam monitor is a good application.
- Boron coated GEM comes soon.
  - A test sample is working.
  - B10 is also available for sputtering.
- A new test beam line (a few GeV electron) is available for users in KEK from this year.

Backup

Neutron detector with ceramic GEM

Shoji Uno (KEK)





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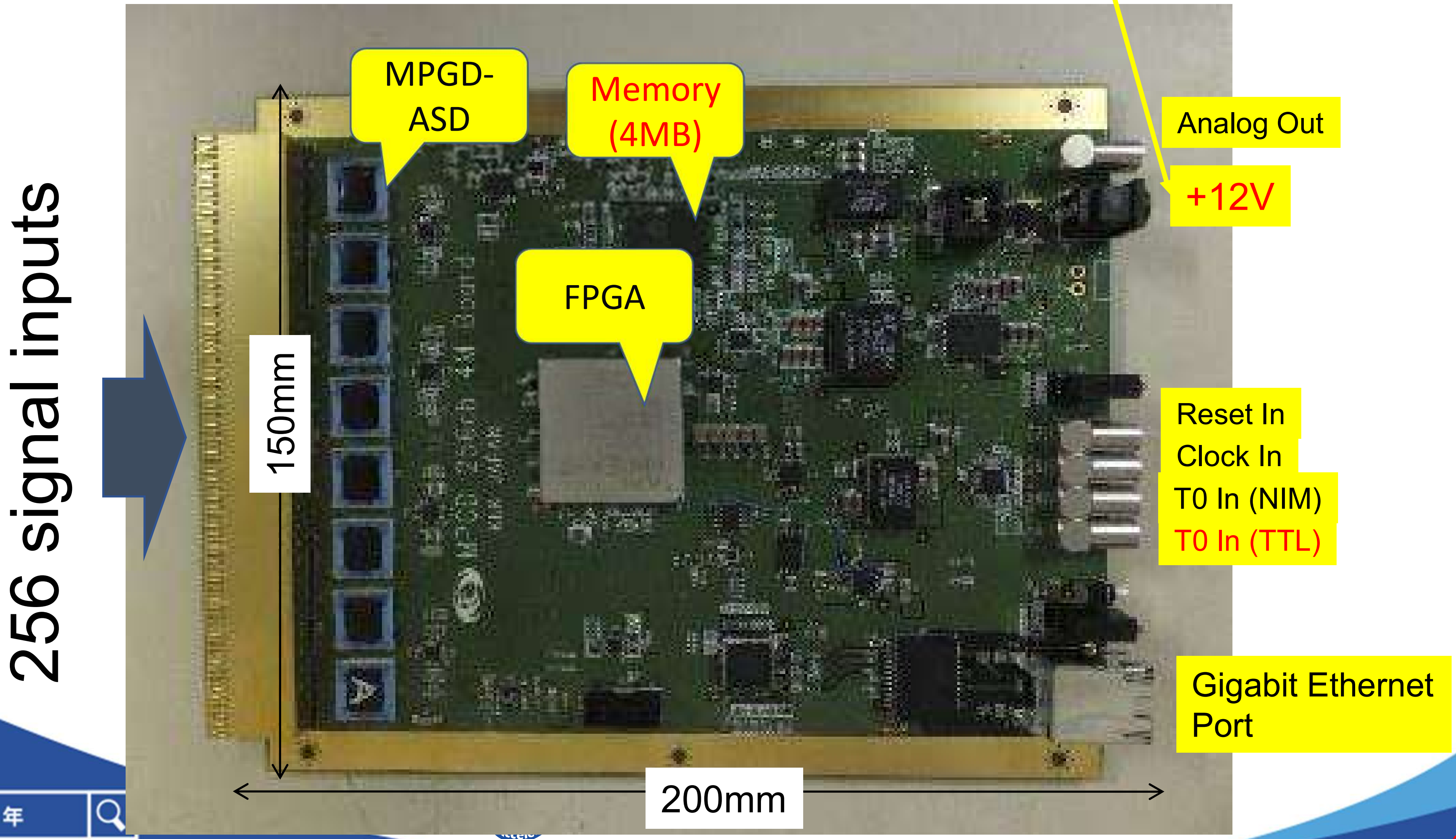
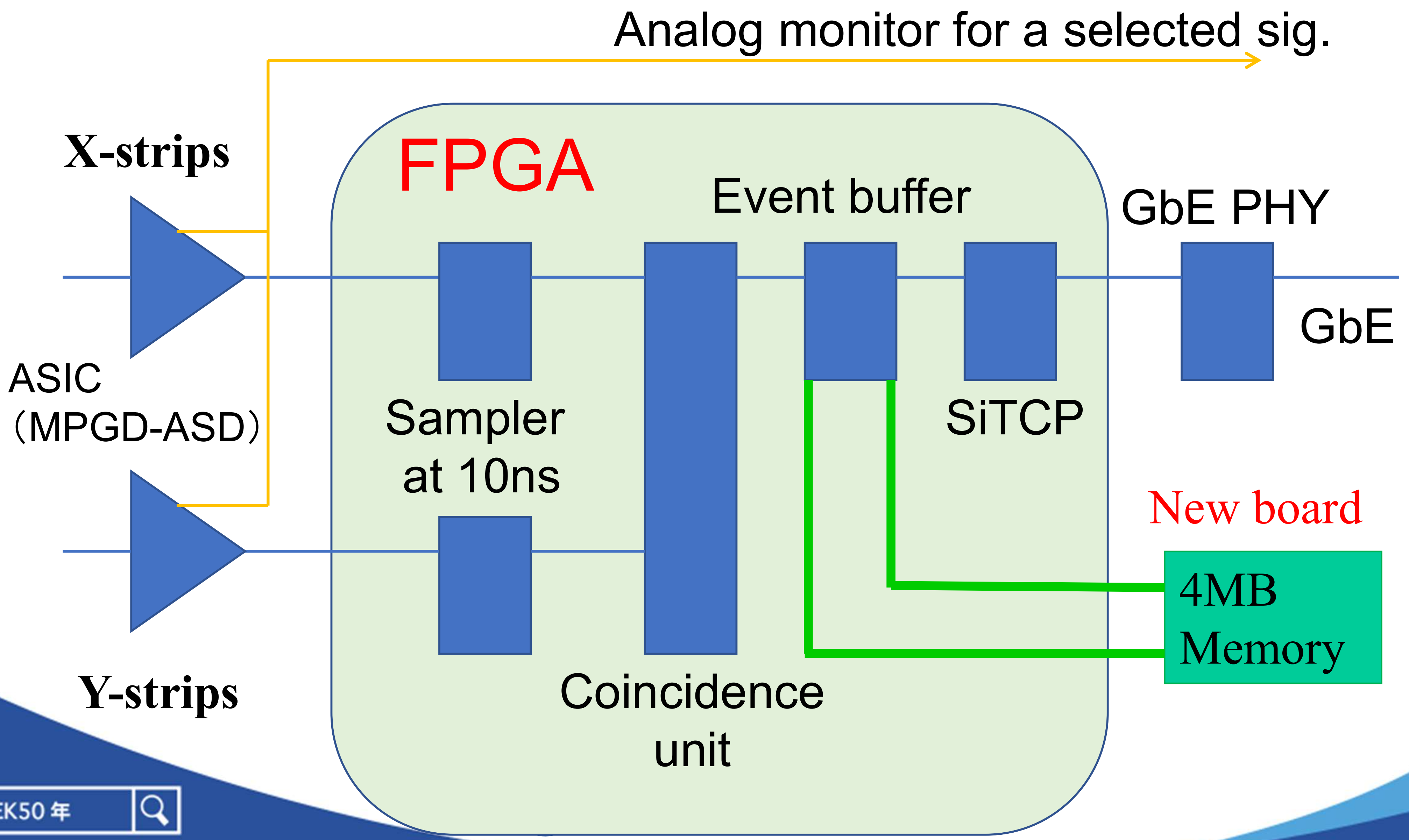
- A new test beam line (a few GeV electron) is available for users in KEK from this year.

Electronics board

Commercial
AC adapter can be used.



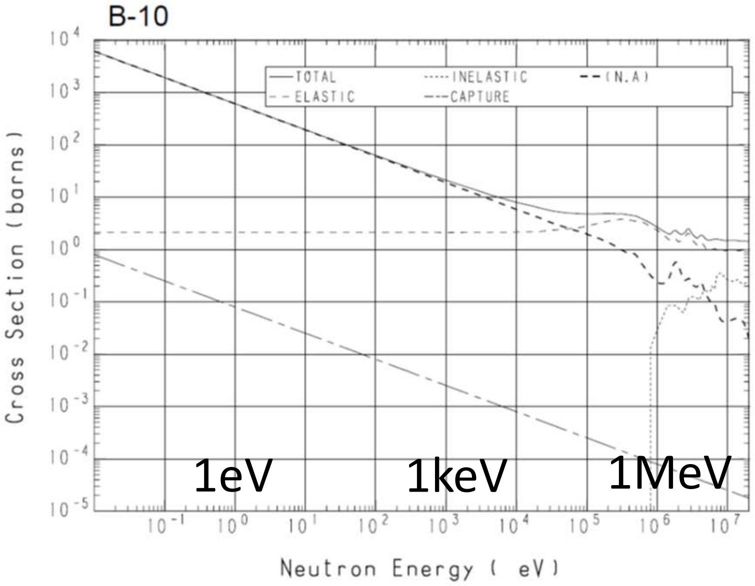
Block diagram



Neutron detection

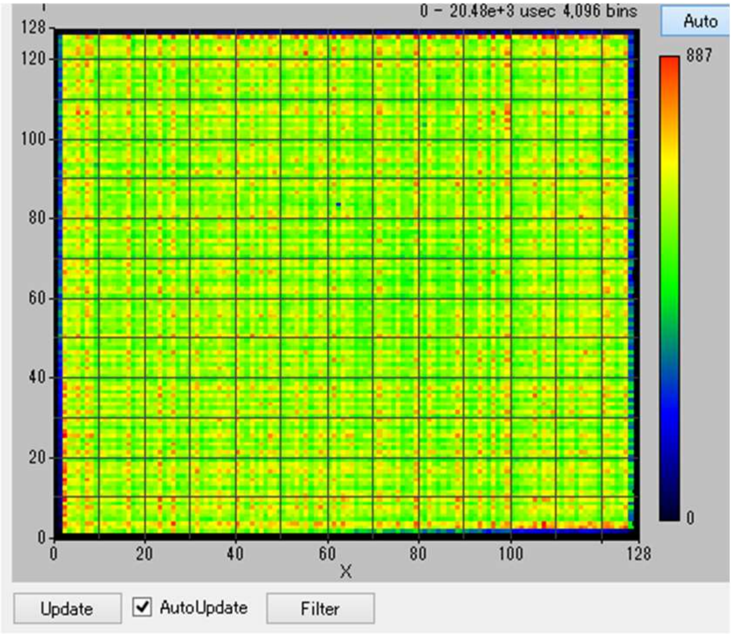
- Thermal (or cold) neutron : Boron
  - n +^{10}B → Li + α   σ = 3840 b for 25 meV neutron
    - Large cross section
    - Large ionization loss in gas volume for α (Li nuclei)

- High energy neutron (MeV) : Hydrogen
  - Cross section for Boron becomes small.   σ ~ 1/√E
  - Hydrogen is good target.
    - Proton comes out.
      - Still, larger ionization loss than electron from gamma.
    - Plastic contents large amount of Hydrogen.
    - PET : Polyethylene terephthalate

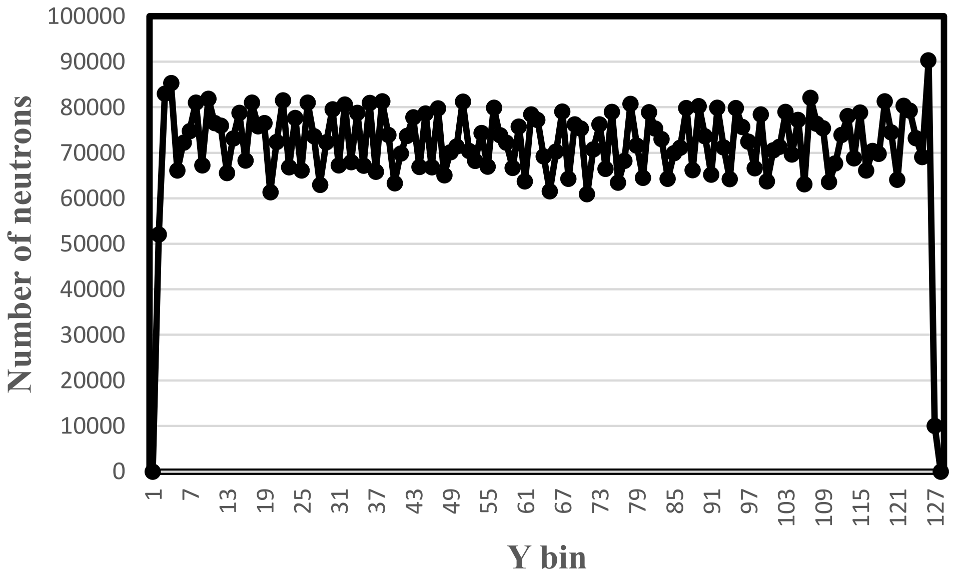


KEKの標準B-cathode

- 構成
  - KEKの標準ボロンカソード（B10 2μm厚） ＋ LTCC

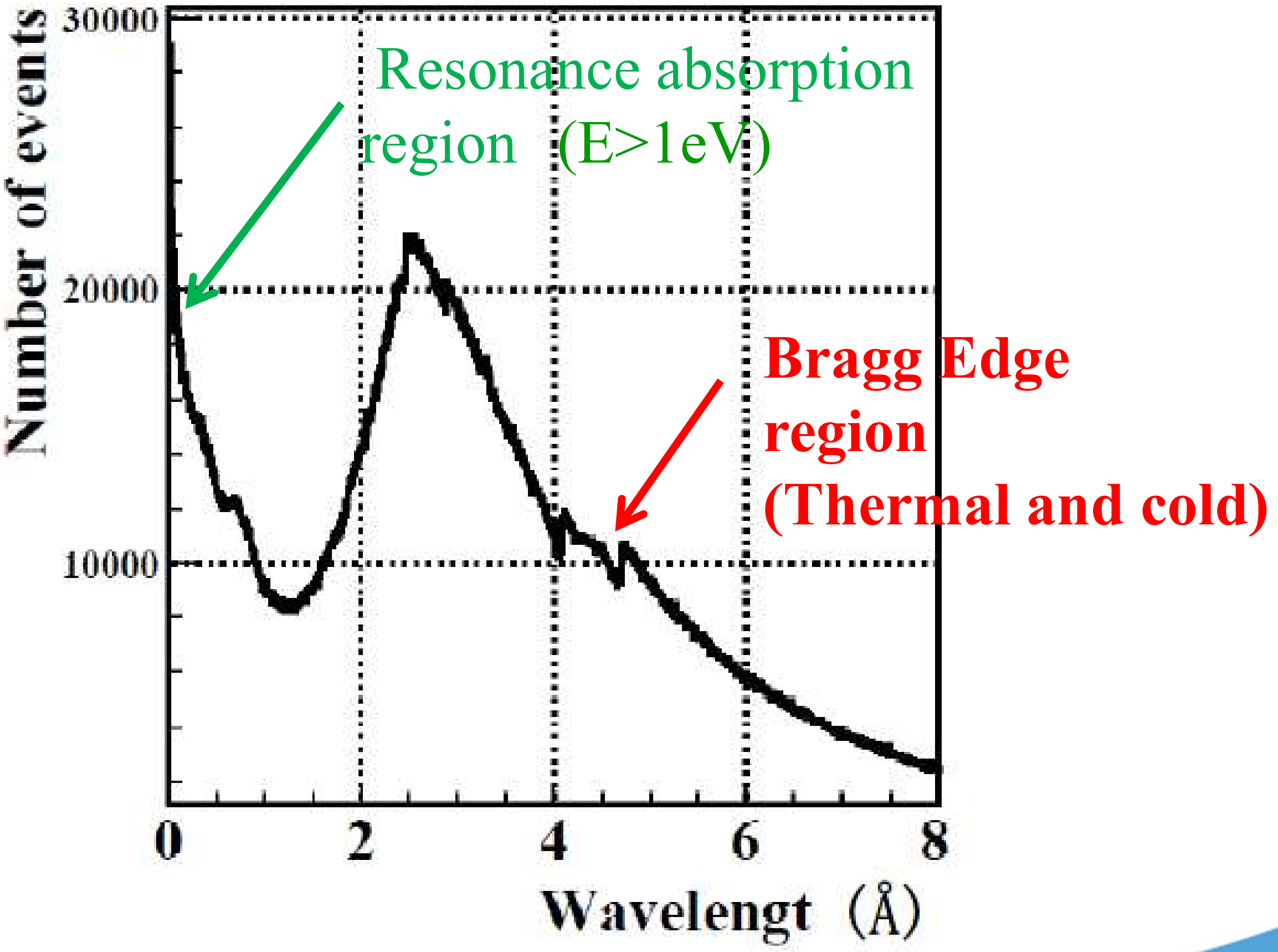


6min測定



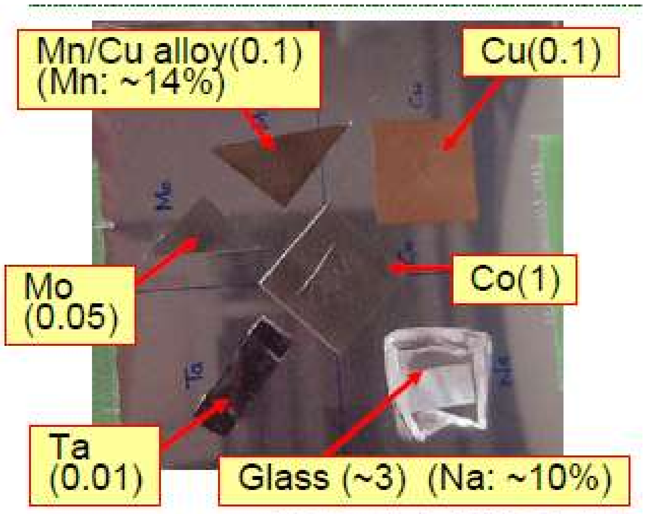
都産技研の1面の厚みは、
2μm x (6, 000/10x5)/(75, 000/6) ＝ 0. 48μm相当

Energy Selective Neutron Radiography

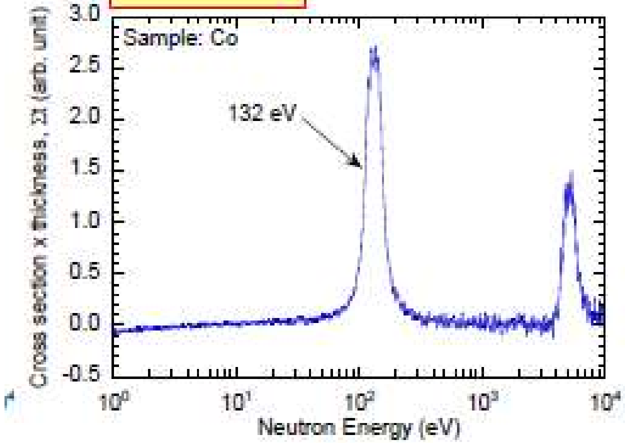


Resonance absorption imaging

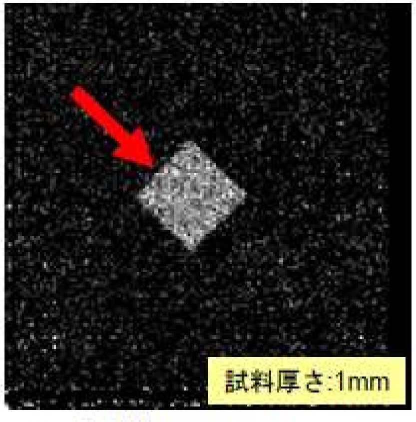
By T. Kai (JAEA) et al.
at BL10 in J-PARC

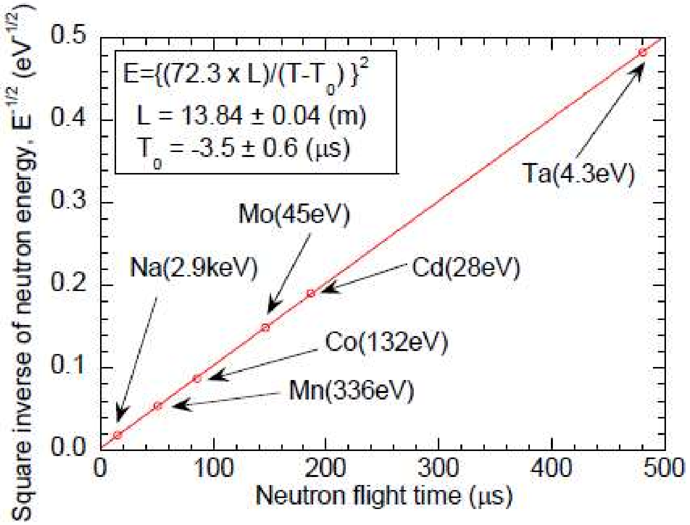


Co試料

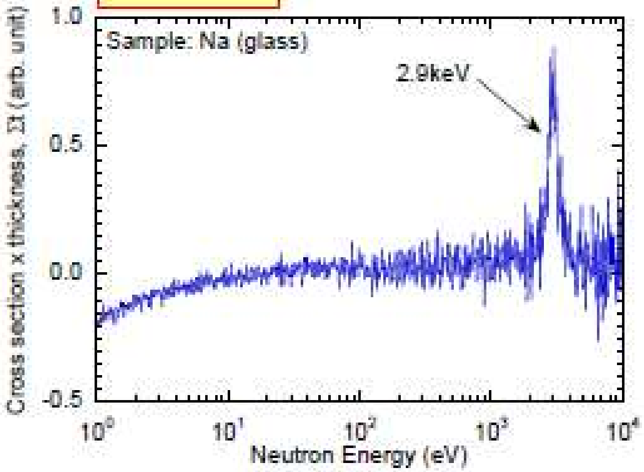


Co試料(9.29-11.8 μs)

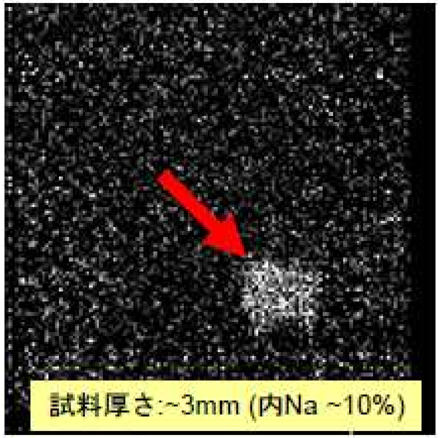




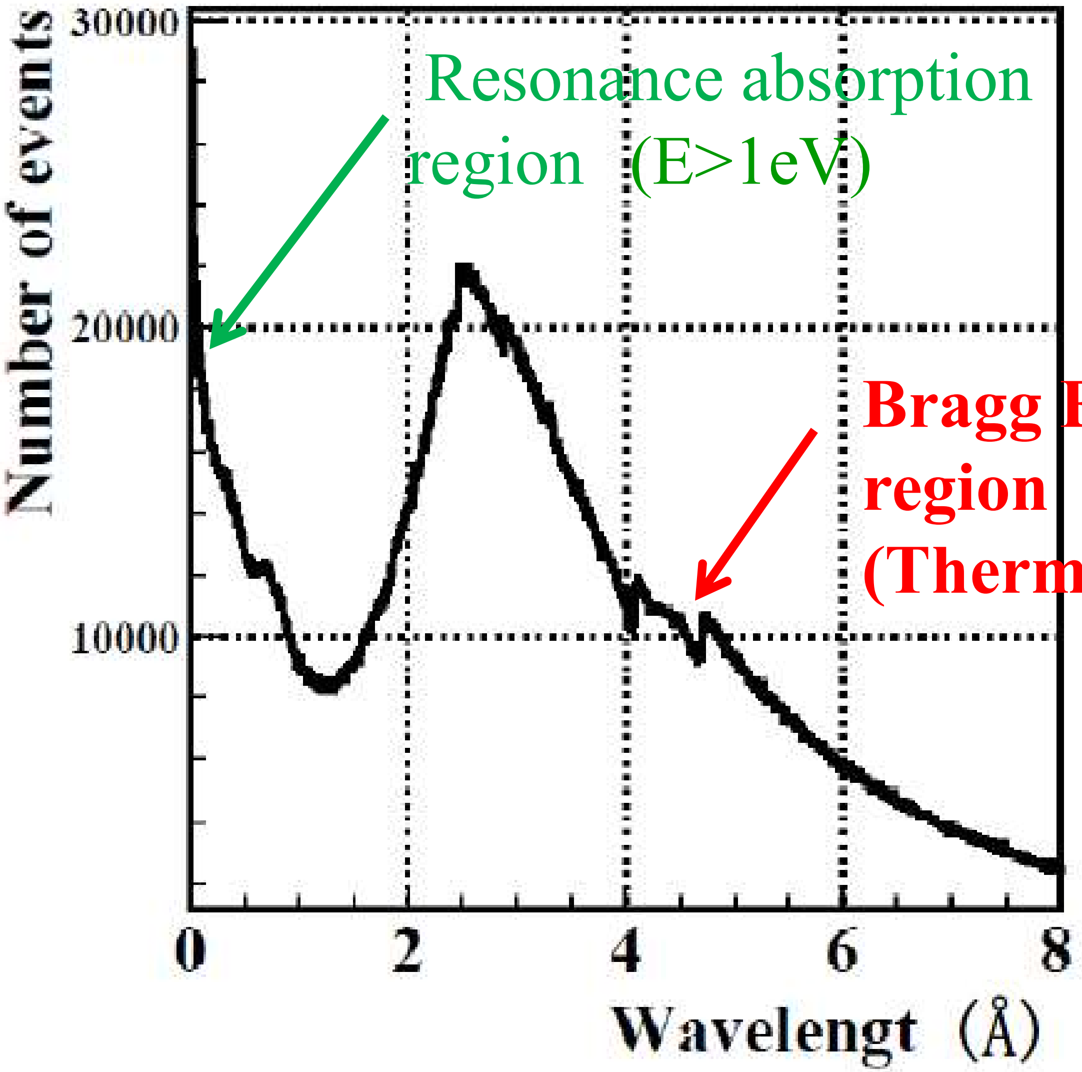
Na-23



Na試料(14.5-15.5 μs)



Energy Selective Neutron Radiography



Resonance absorption region (E>1eV)

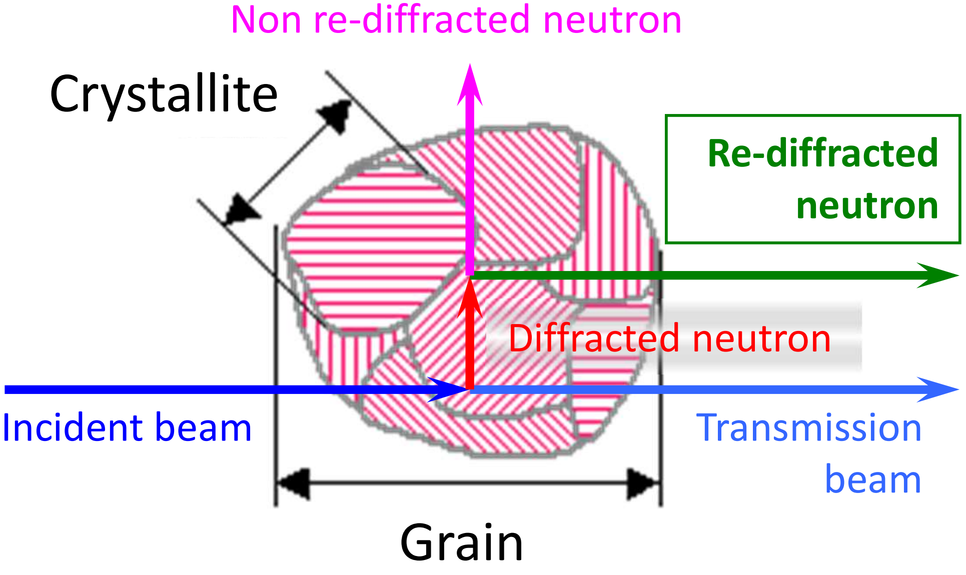
Bragg Edge region (Thermal and cold)

Extinction function for microstructure

H.Sato of Hokkaido University

Sabine function

Primary extinction (re-diffraction) inside a crystallite (a mosaic block)



$$E_{hkl}(\lambda, F_{hkl}) = E_B \sin^2\theta_{hkl} + E_L \cos^2\theta_{hkl}$$

$\uparrow$ Bragg component $\nwarrow$ Laue component

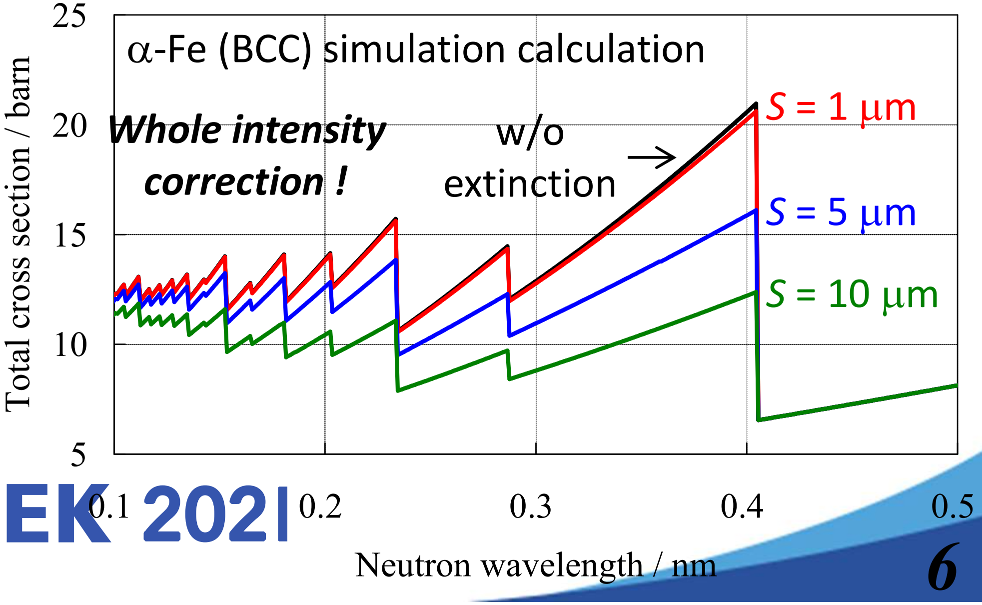
$$E_B = \frac{1}{\sqrt{1+x}}$$

$$E_L = 1 - \frac{x}{2} + \frac{x^2}{4} - \frac{5x^3}{48} + \cdots \quad \text{for} \quad x \le 1$$

$$E_L = \sqrt{\frac{2}{\pi x}}\left[1 - \frac{1}{8x} - \frac{3}{128x^2} - \frac{15}{1024x^3} - \cdots\right] \quad \text{for} \quad x > 1$$

$$x = \textcircled{S}^2 \left(\frac{\lambda F_{hkl}}{V_0}\right)^2$$

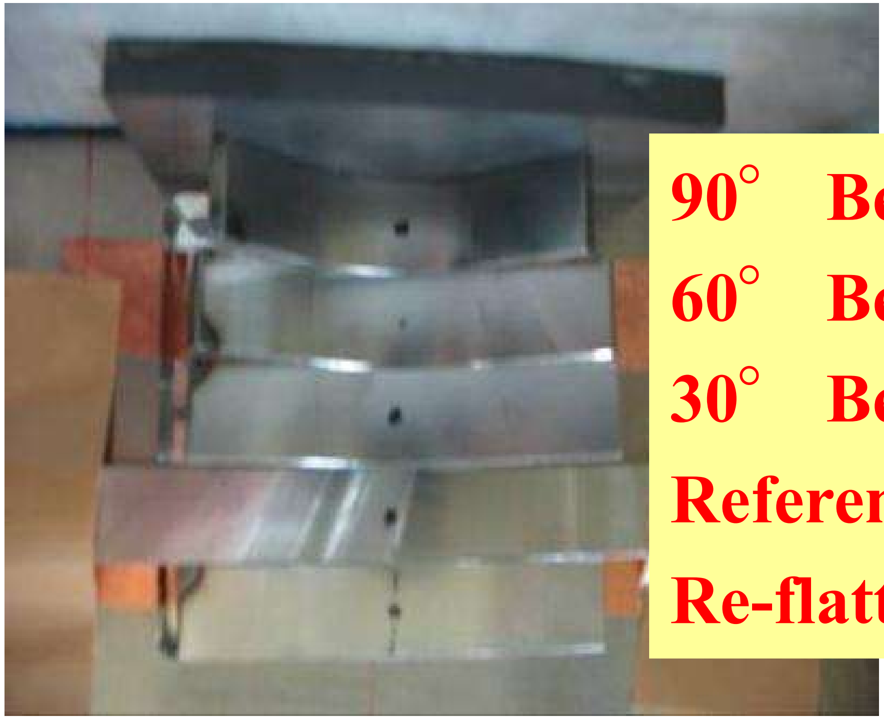
○ : Refinement parameter



Visualized microstructure parameter

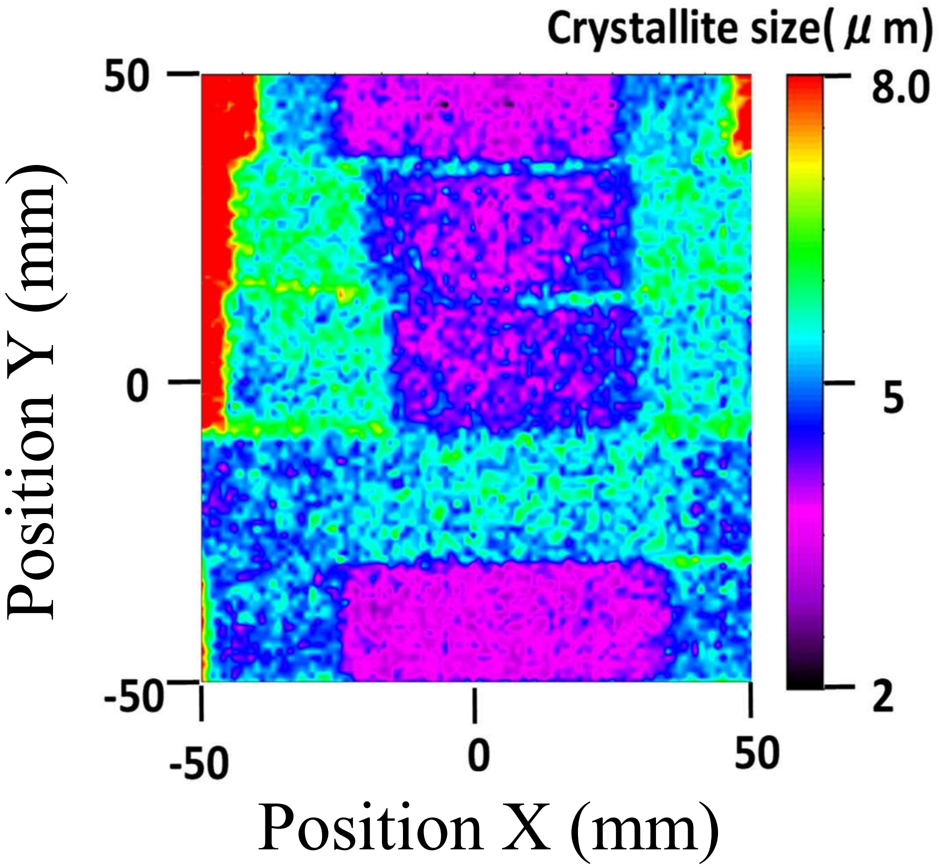
S **: Crystallite size along the beam direction**

Results



90° Bending
60° Bending
30° Bending
Reference
Re-flattening

Photo of iron plates

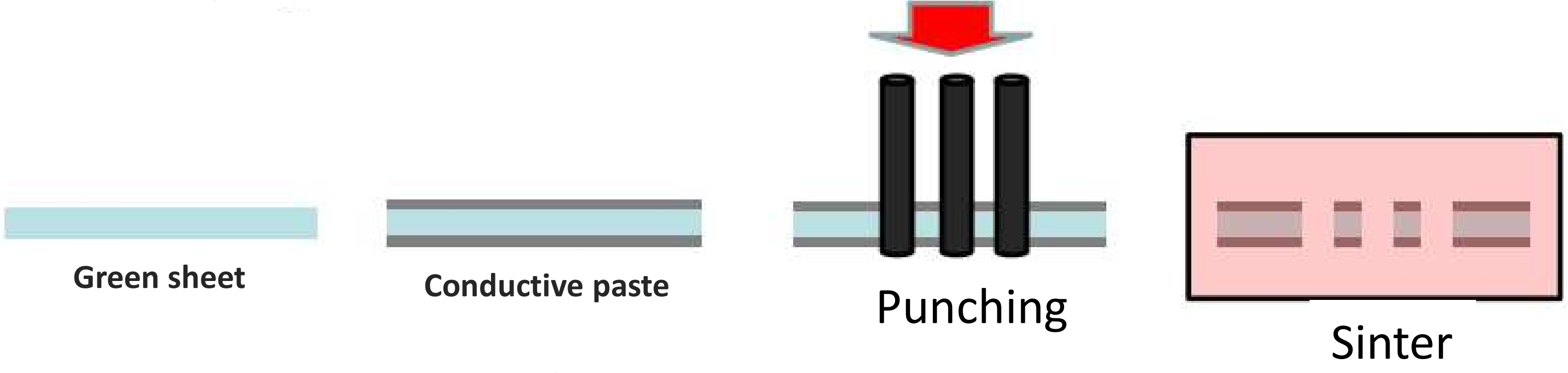


Two dimensional imaging of crystallite size in the bended iron plates can be done clearly.

Visualization of microstructure for heavy material can be performed with the gaseous neutron detector.

2.　Low Temperature Co-fired Ceramic (LTCC) GEM

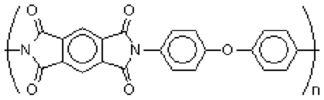
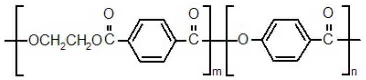
（1）Production process



- Simple
- Mask-less

No carbon and no hydrogen in ceramic.
It is better for the neutron detector.

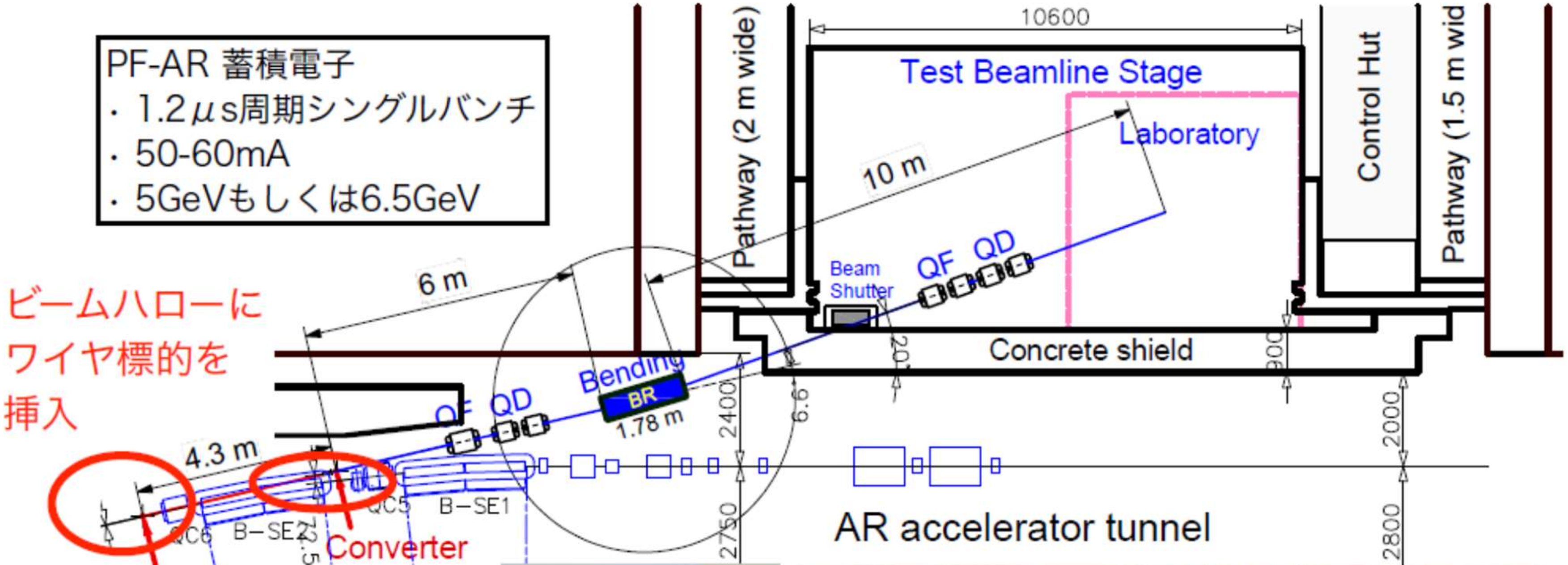
⑵ Strong against discharge

		Past		New
		Foil GEM		Ceramic GEM
		polyimide	LCP	LTCC
Material				CaO Si_2 + Al_2O B_2O_3
Voltage registance	kV・mm^{-1}	22	26-40	＞15
Ark discharge	Sec	135	186	＞300
Melting point	℃	＜800	＜450	＞800

測定器開発テストビームライン概要

PF-AR 蓄積電子
- 1.2μs周期シングルバンチ
- 50-60mA
- 5GeVもしくは6.5GeV

ビームハローにワイヤ標的を挿入



Target wire

Converter $\gamma \rightarrow e^+e^-$