Development of two-dimensional gaseous detector for energy-selective radiography

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TIPP2011 Chicago, USA

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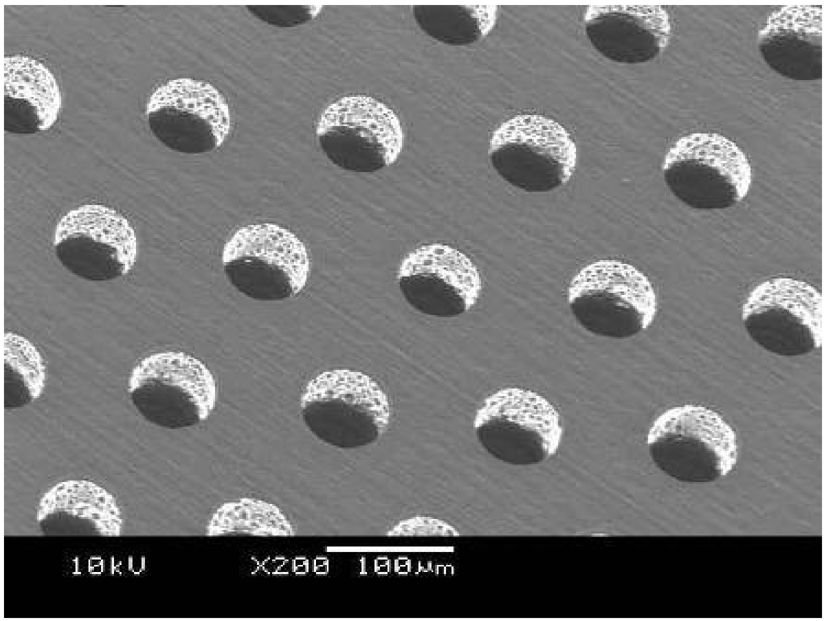
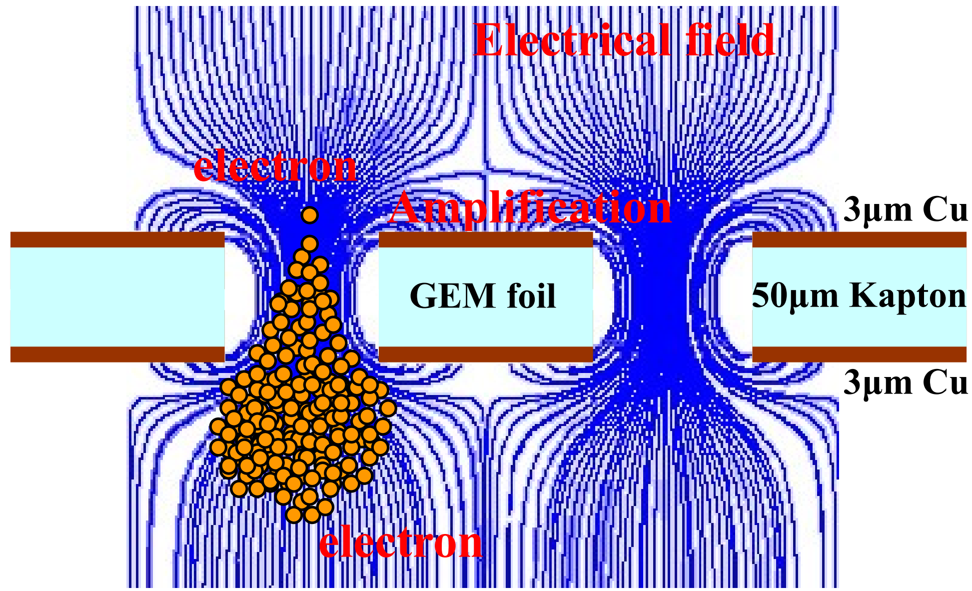
- Introduction
  - GEM
  - Application to Neutron Detector
  - Detector system
- Performance studies with pulse neutron beam
  - Basic test
  - Energy selective neutron radiography
- Summary

GEM (Gas Electron Multiplier)

Double side flexible printed circuit board



Electric field



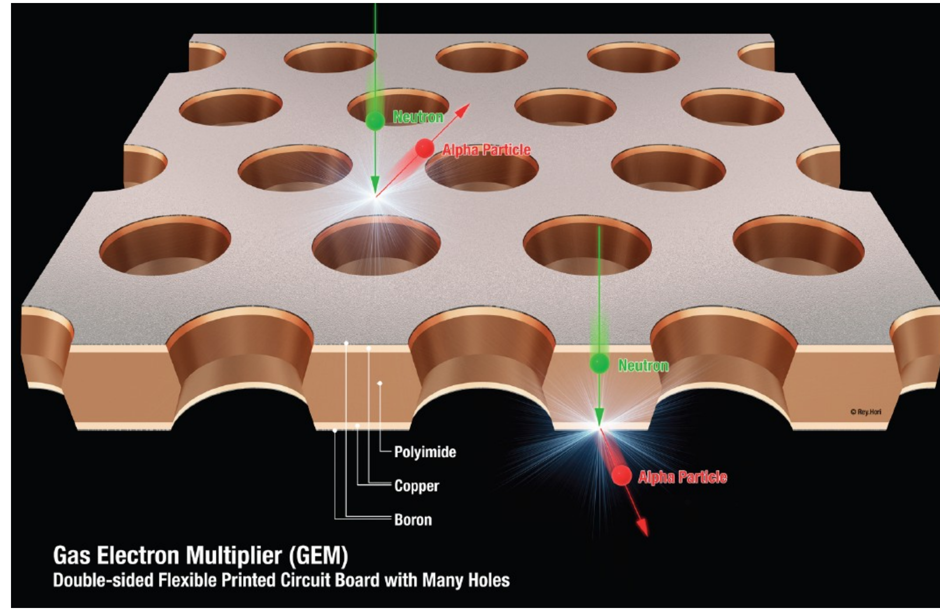
Hole diameter	70µm
Hole pitch	140µm
Thickness	50µm
Cu thickness	5µm

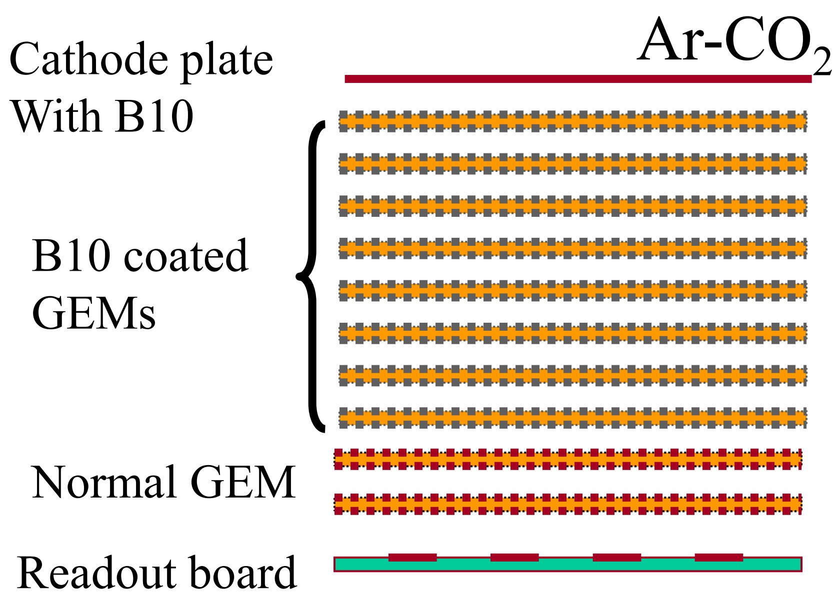
Developed by F.Sauli (CERN) in 1997.
NIMA 386(1997)531

Application to Neutron Detector

$$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.792\ \mathrm{MeV} \qquad 3840\ \mathrm{b}$$

$$^{7}Li^{*} + \alpha + 2.310\ \mathrm{MeV}$$



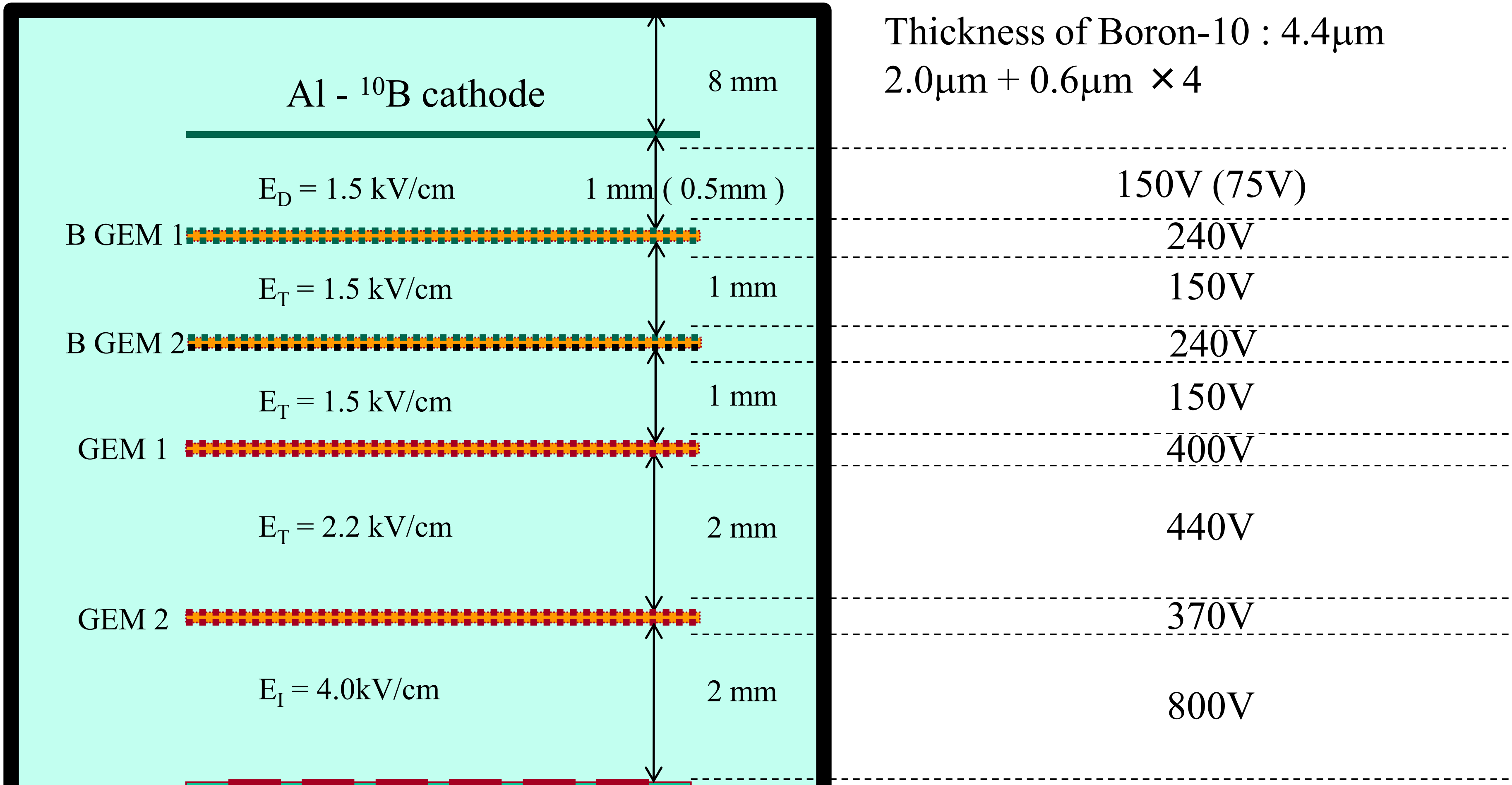


- Expensive ^{3}He Gas is not necessary.
  - No pressure vessel
- Free readout pattern
- High resolution
  - Position and **Time**
- Insensitive against g-ray
- Capability against high counting rate

Chamber structure

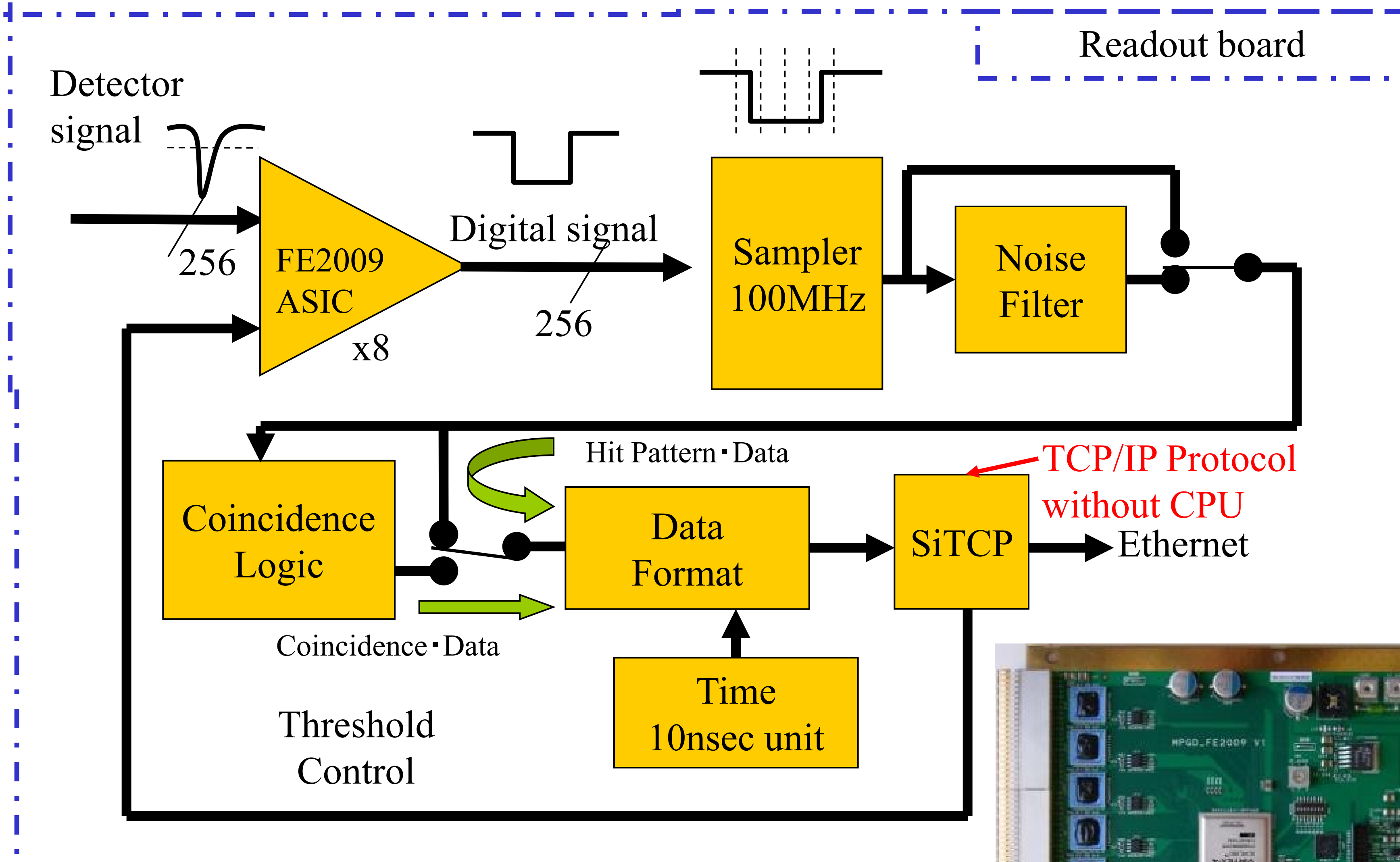
Ar/CO_2 = 70:30

Thickness of Boron-10 : 4.4μm
2.0μm + 0.6μm ×4

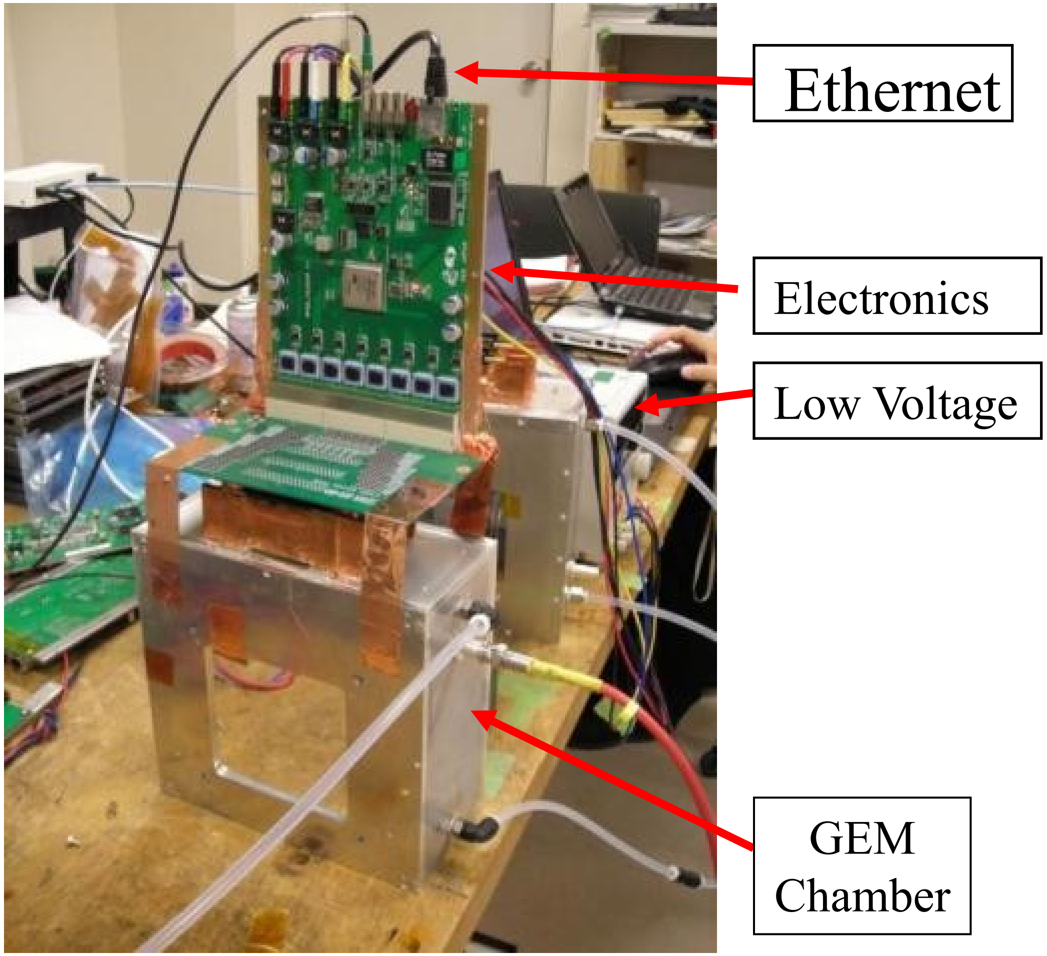


X(120) +Y (120) strips
0.8mm pitch

Block diagram for readout board



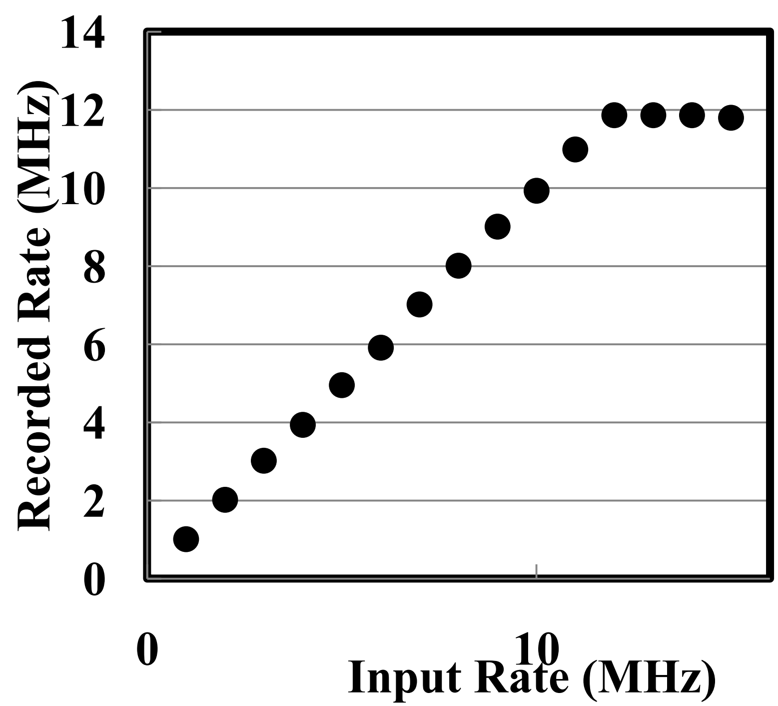
Present Detector System



Compact and Portable System

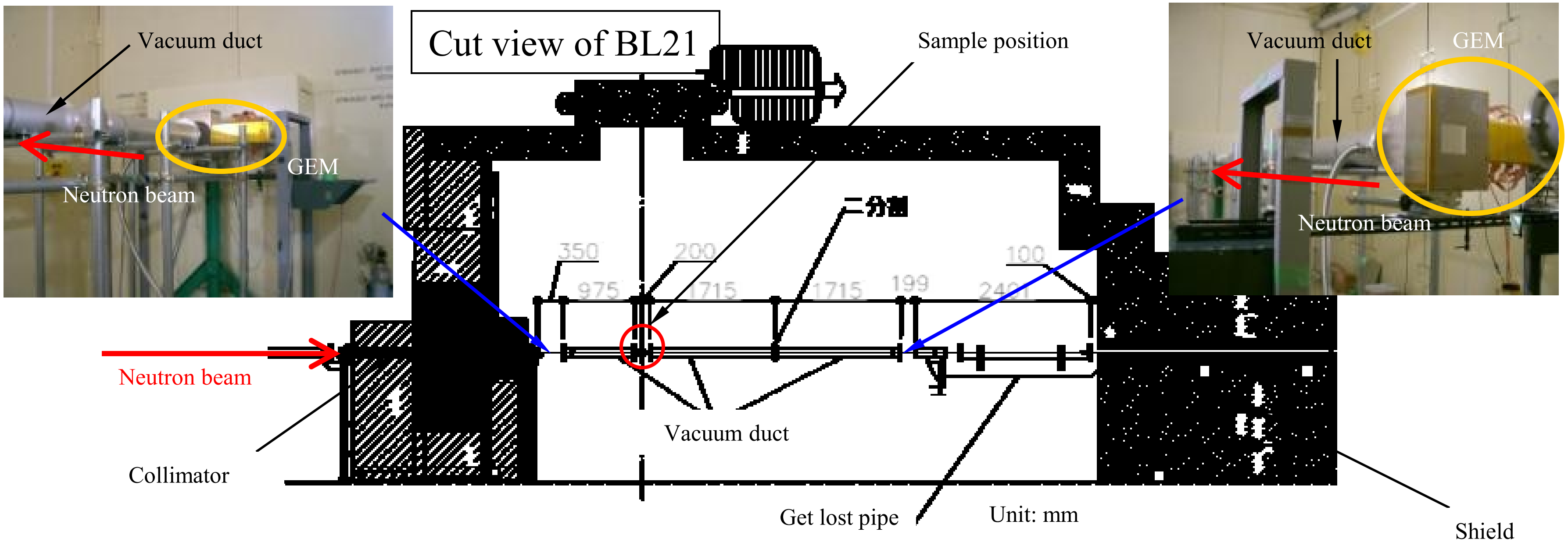
T.Uchida et. al., "Prototype of a Compact Imaging System for GEM detectors," was published on IEEE TNS 55(2008)2698.

- I/F
  - One HV cable
  - Three LV cables
  - One Ethernet cable
- Electronics
  - 8 ASIC chips + 1 FPGA
- FE2009 ASIC : KEK-DTP
- Data transfer and Control through Ethernet
  - SiTCP by T. Uchida (KEK)
  - Using Note-PC



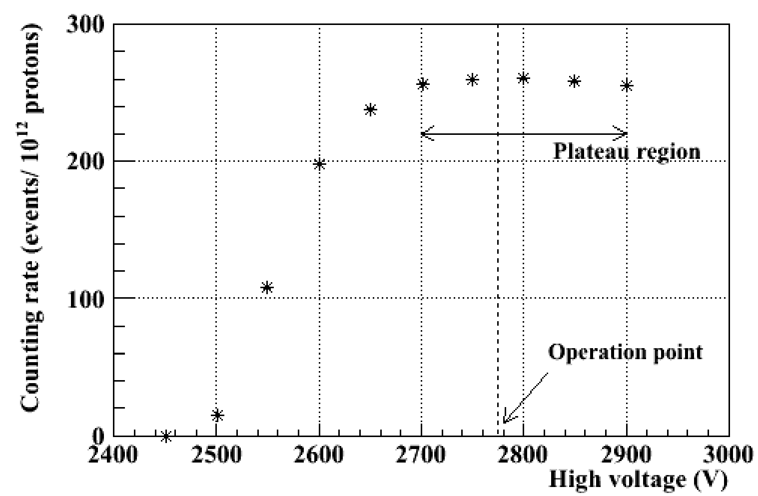
Several test experiments at the pulsed neutron sources in J–PARC MLF (BL21, BL10), Hokkaido University and RAL ISIS (ROTAX)

Experimental setup



A neutron irradiation test was performed at BL21 in MLF of J-PARC.

The Plateau curve as a function of supplied high voltage

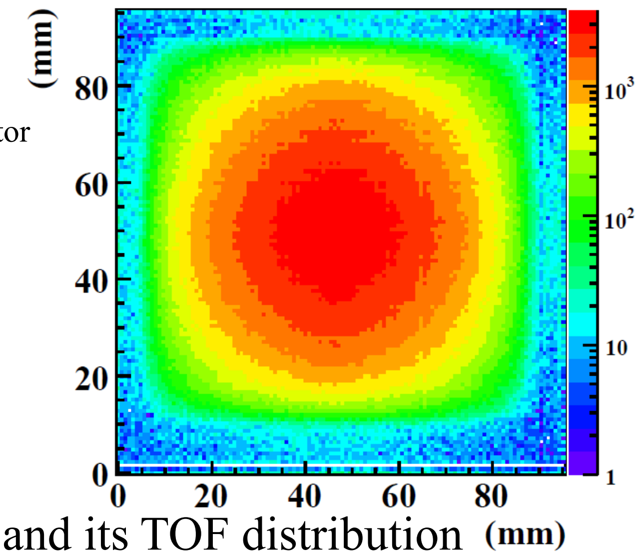


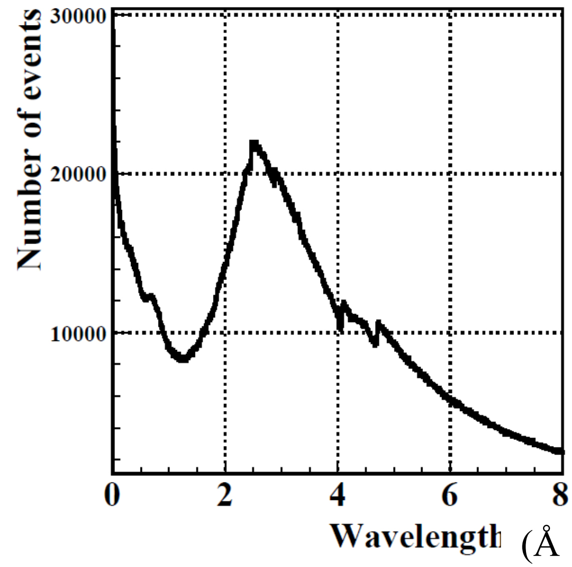
Data samples

The beam profile and its TOF distribution

L = 18789 mm ~ 18.8 m

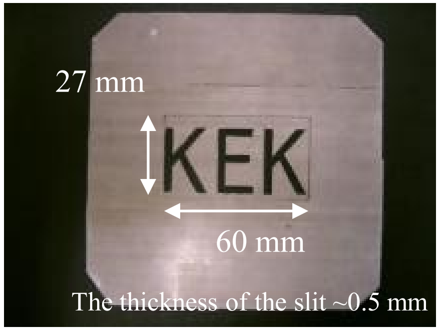
L: distance from the source to the detector



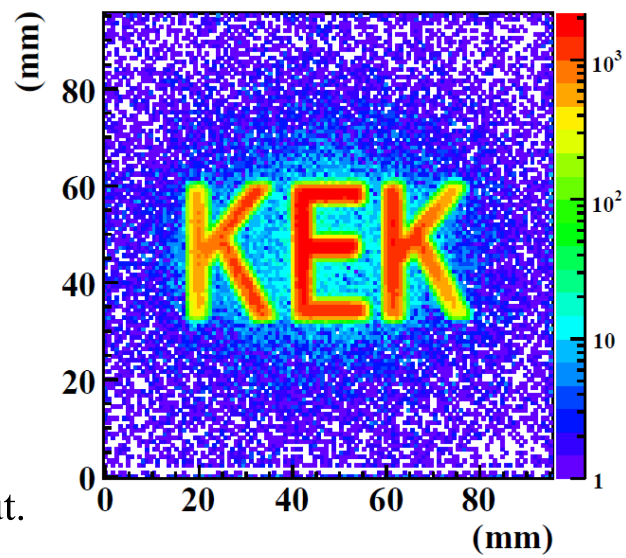


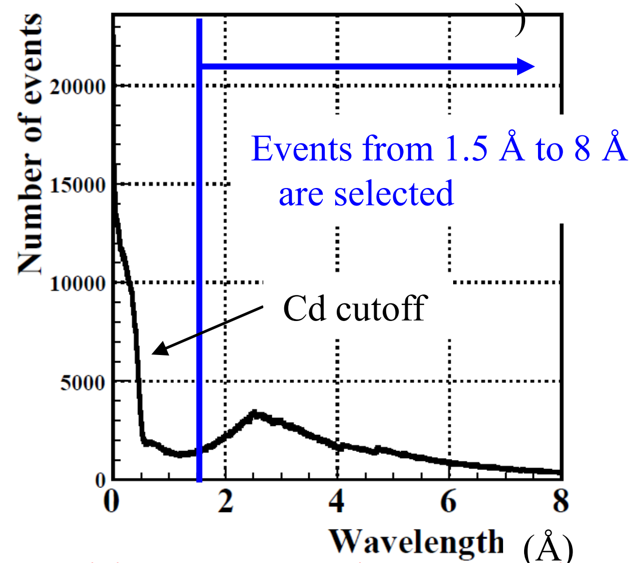
An image of a cadmium slit and its TOF distribution

L = 18789 mm



This image is produced with a wavelength cut.

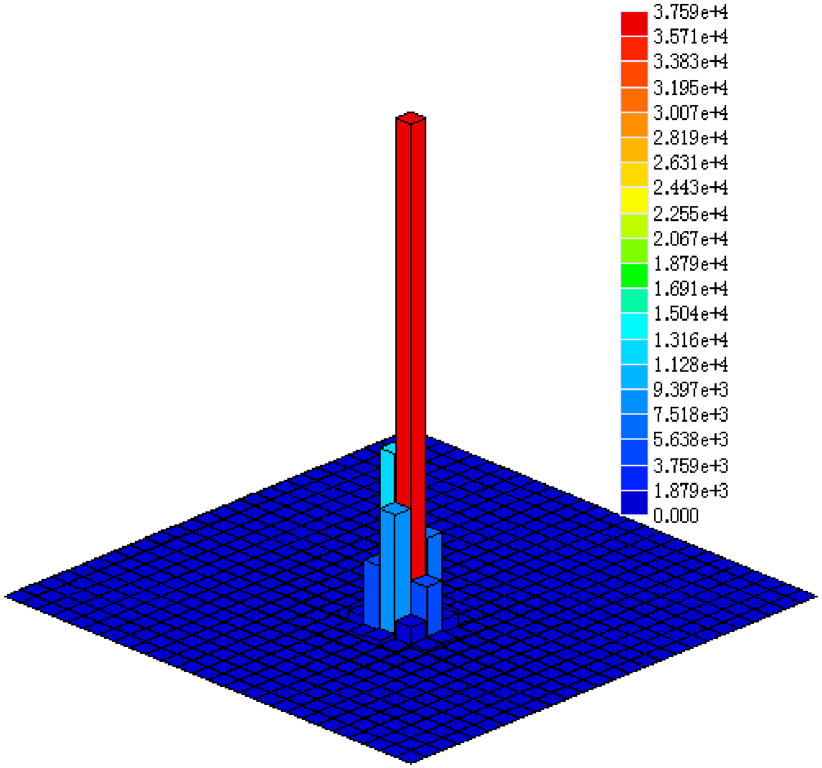


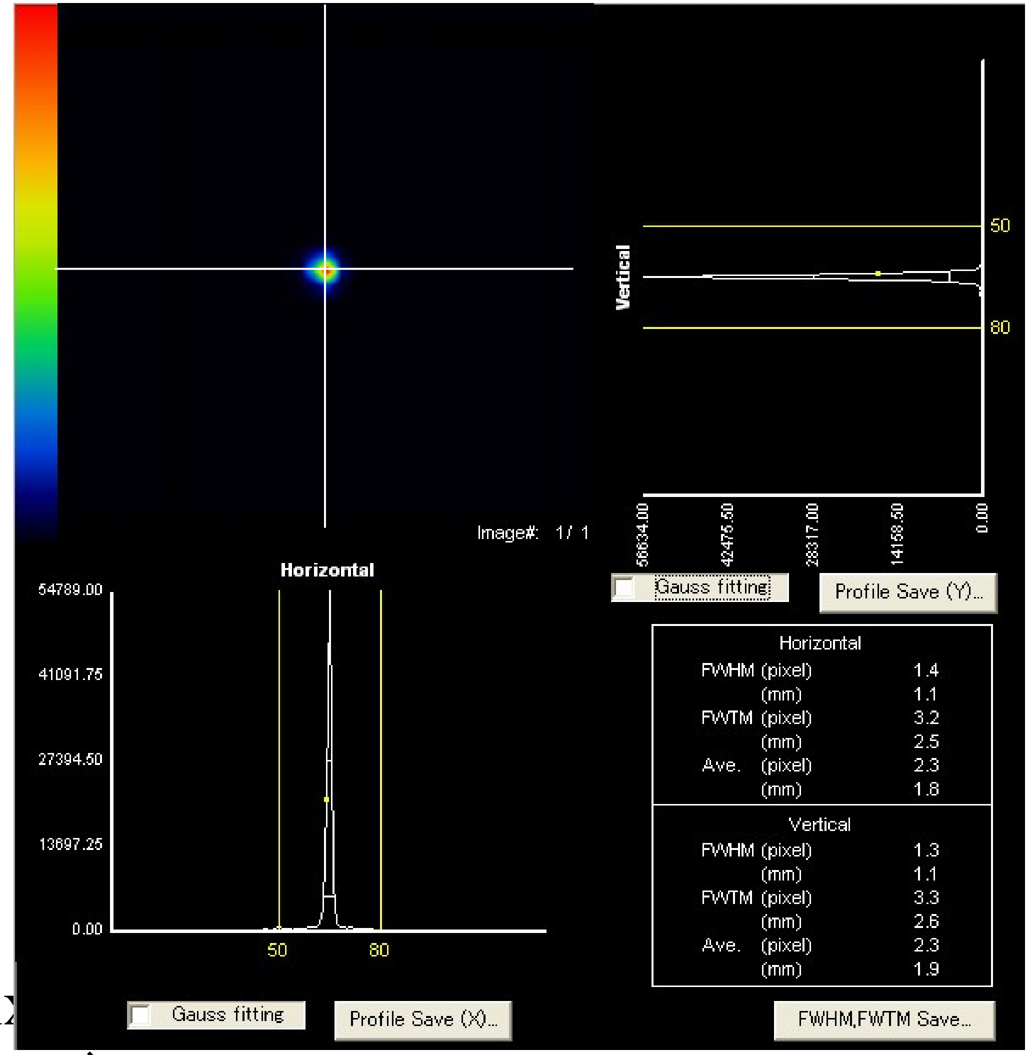


Our system can obtain a 2D image and its TOF at the same time.

Position resolution at ROTAX in ISIS of RAL

Pin-hole 0.5mm$^{\phi}$



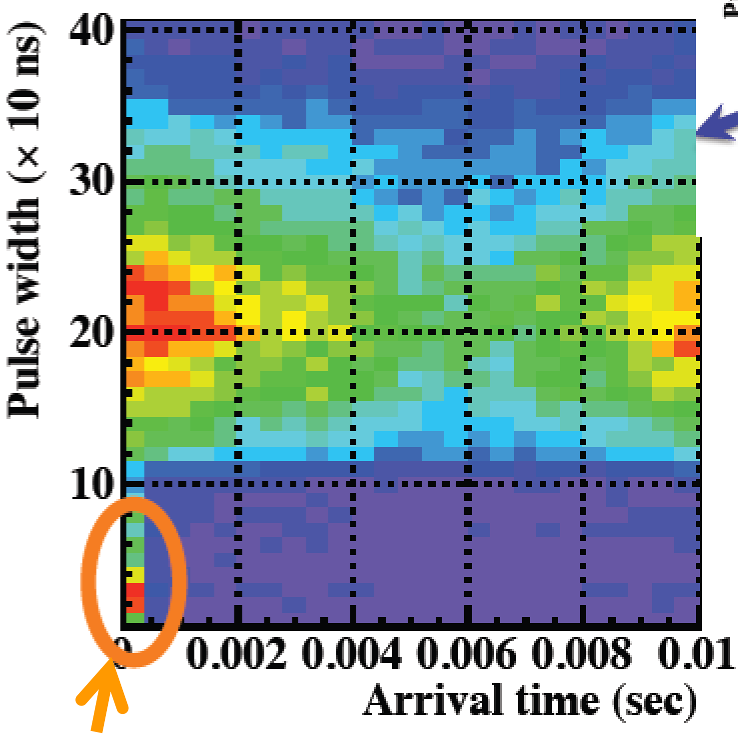


FWHM（H） 1.1mm（1.4pix

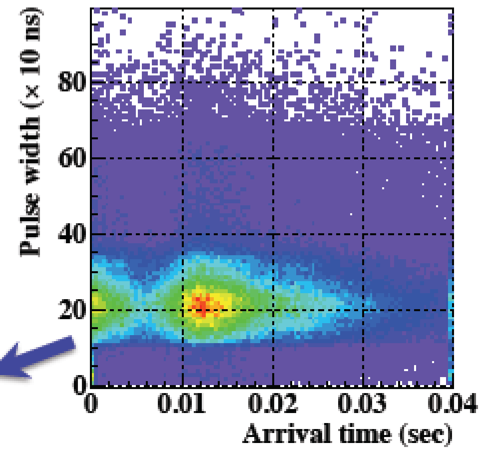
FWHM（V） 1.1mm（1.3pixel）

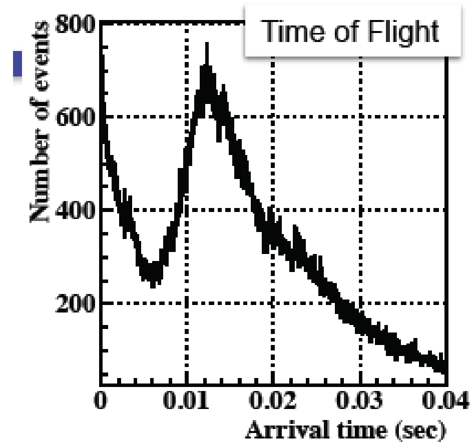
Capability to reject gamma ray

at BL21 in J-PARC



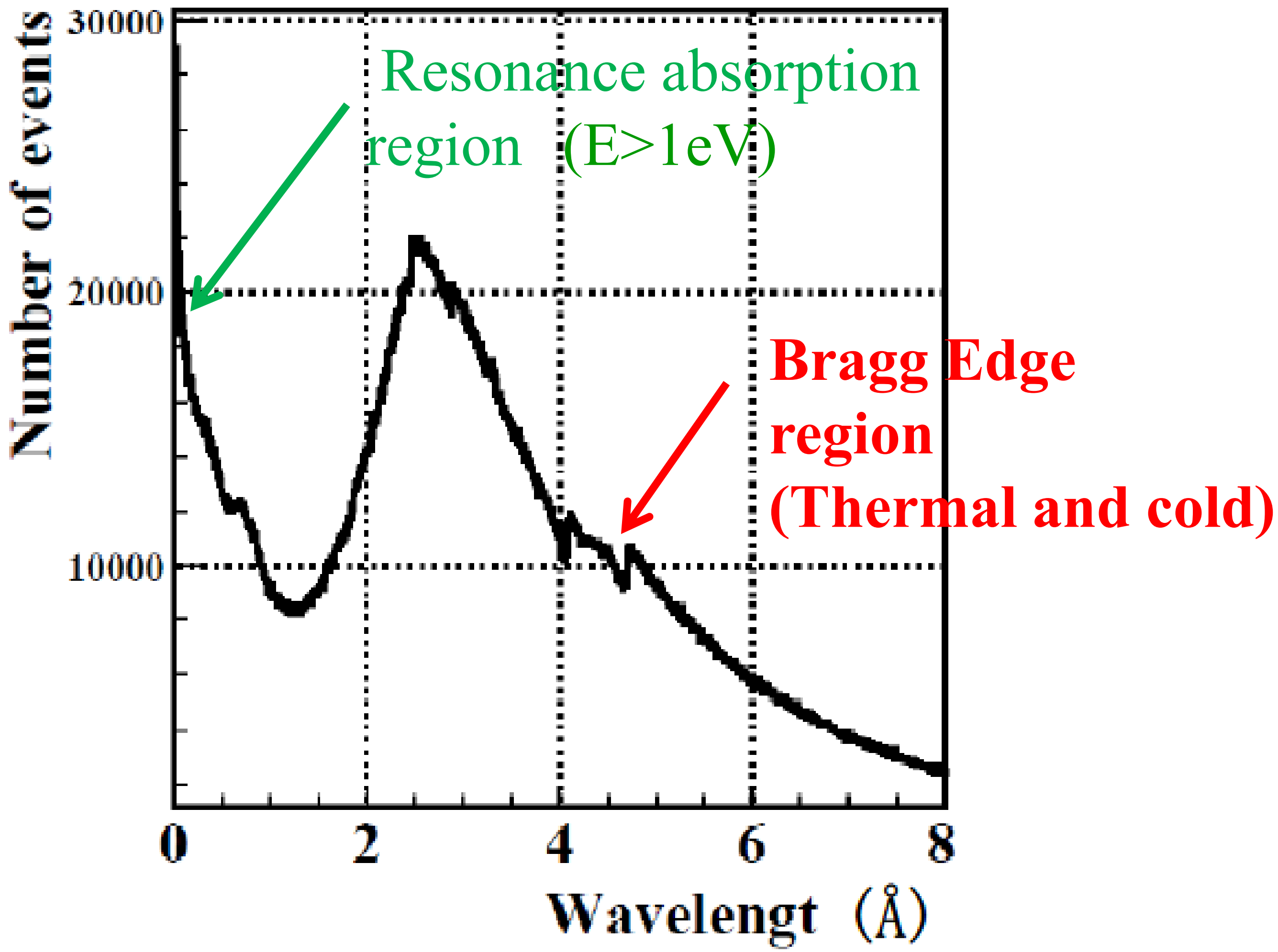
Gamma ray





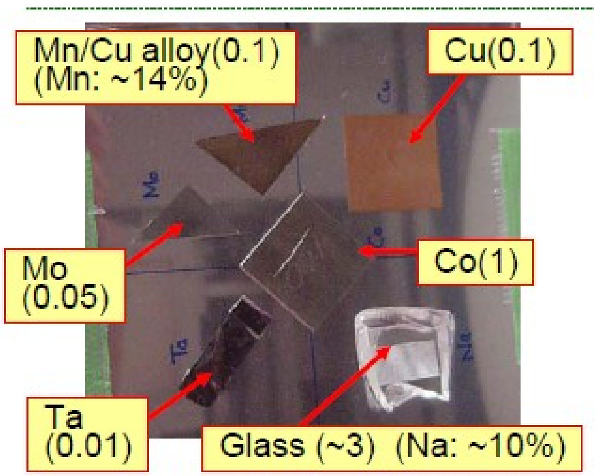
- Gamma ray can be rejected further using pulse width (pulse height) information, if necessary.

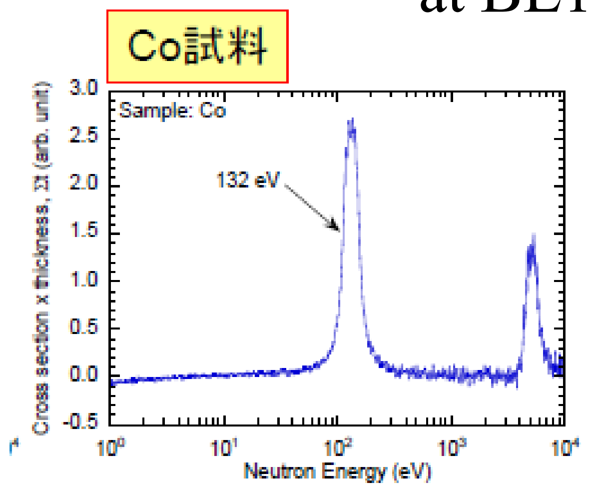
Energy Selective Neutron Radiography



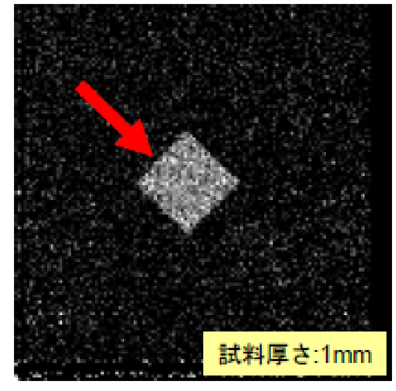
Resonance absorption imaging

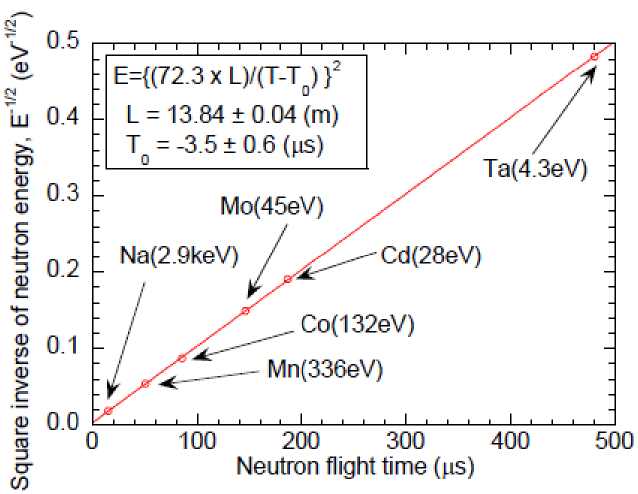
By T. Kai (JAEA) et al.
at BL10 in J-PARC

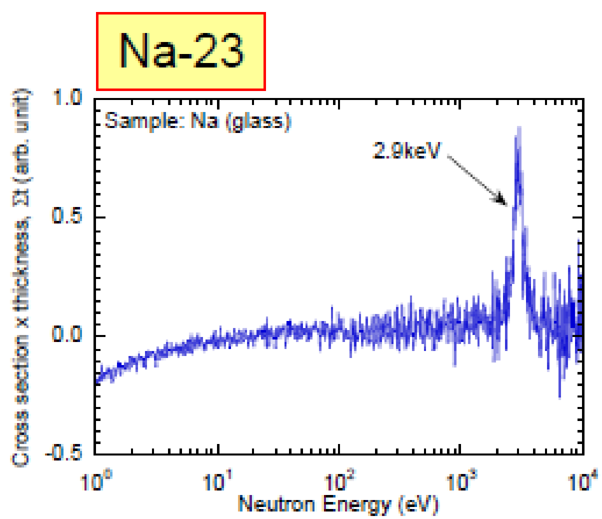




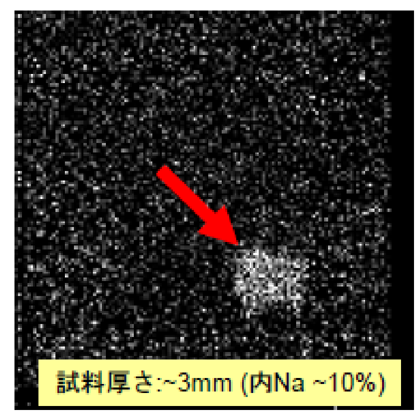
Co試料(9.29-11.8 μs)



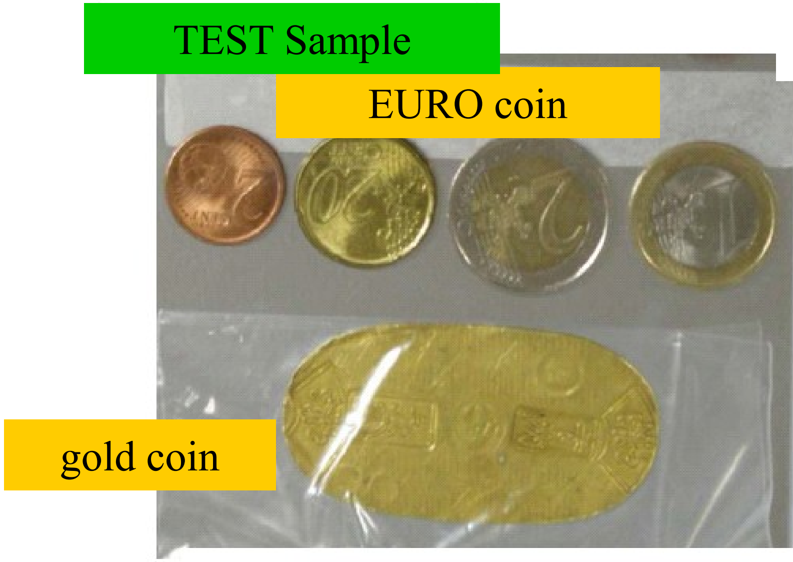




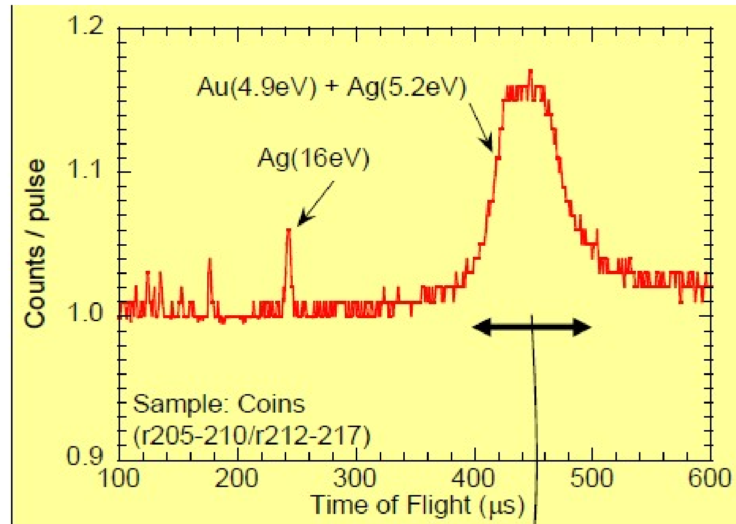
Na試料(14.5-15.5 μs)

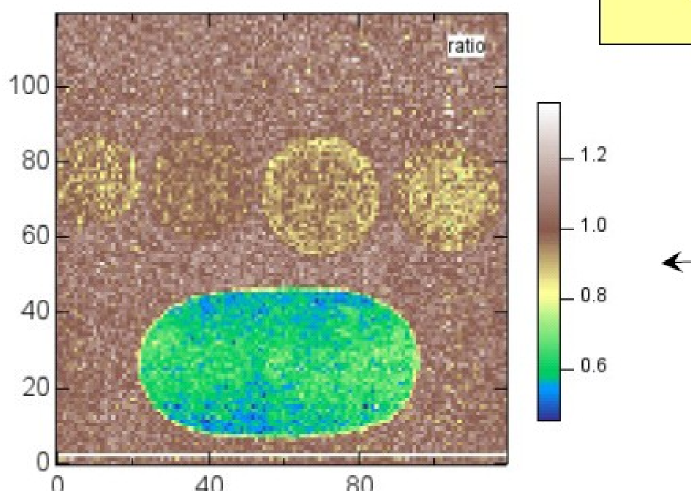


One more demonstration



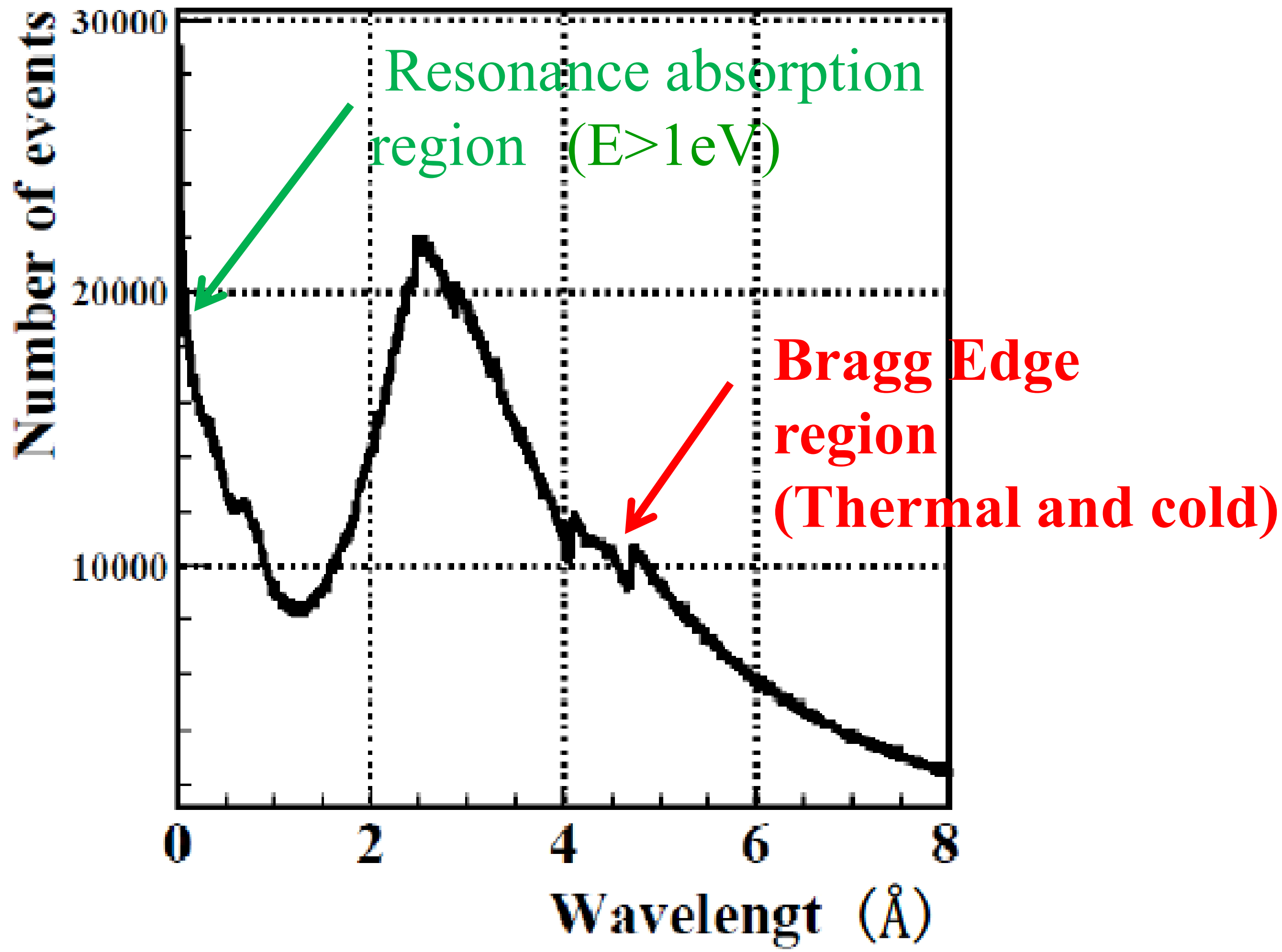
Ratio of ToF spectrums with/without sample





Imaging data with around 450µsec ToF

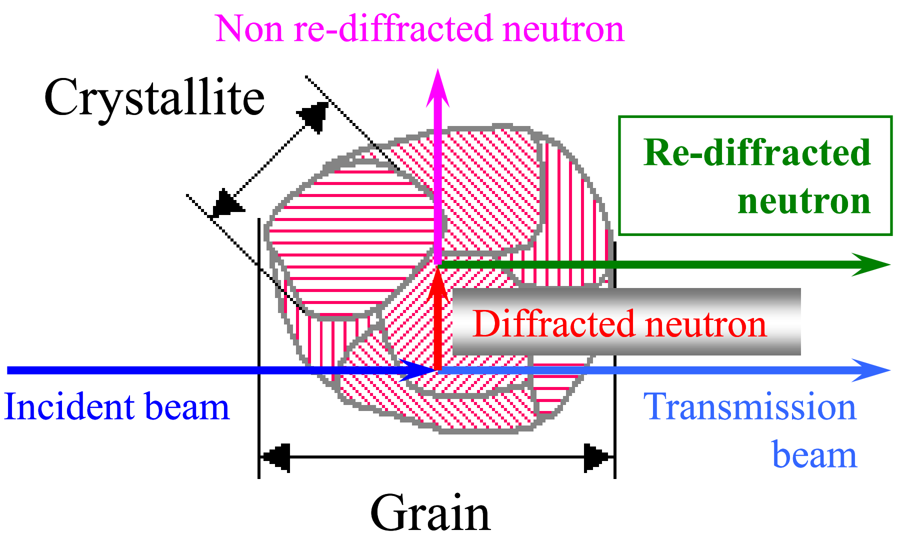
Energy Selective Neutron Radiography



Extinction function for microstructure

H.Sato of Hokkaido University

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



Sabine function

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

E_B: Bragg component; E_L: Laue component

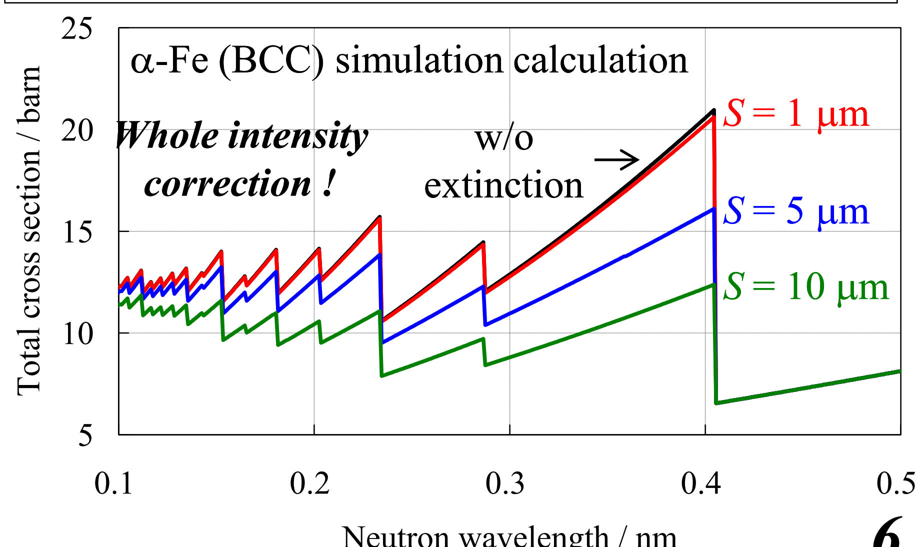
$$E_B = \frac{1}{\sqrt{1+x}}$$

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

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

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

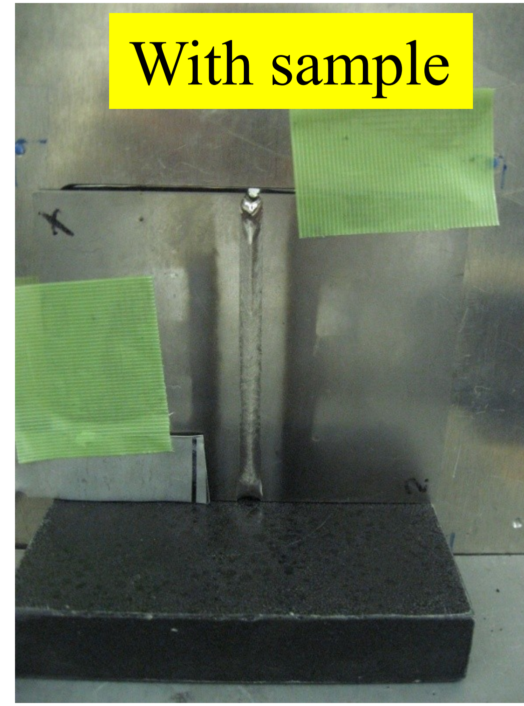
○ : Refinement parameter

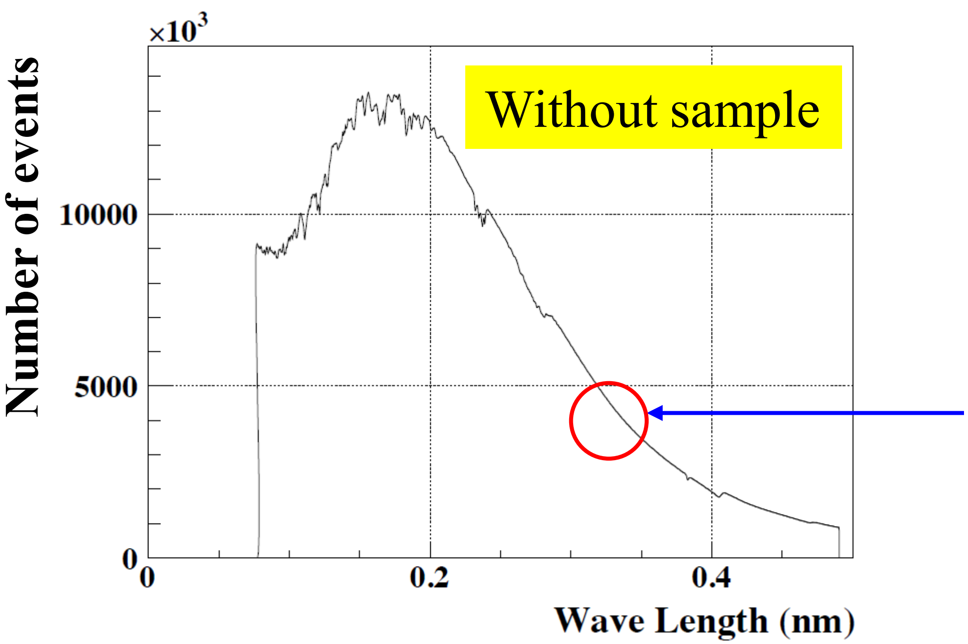


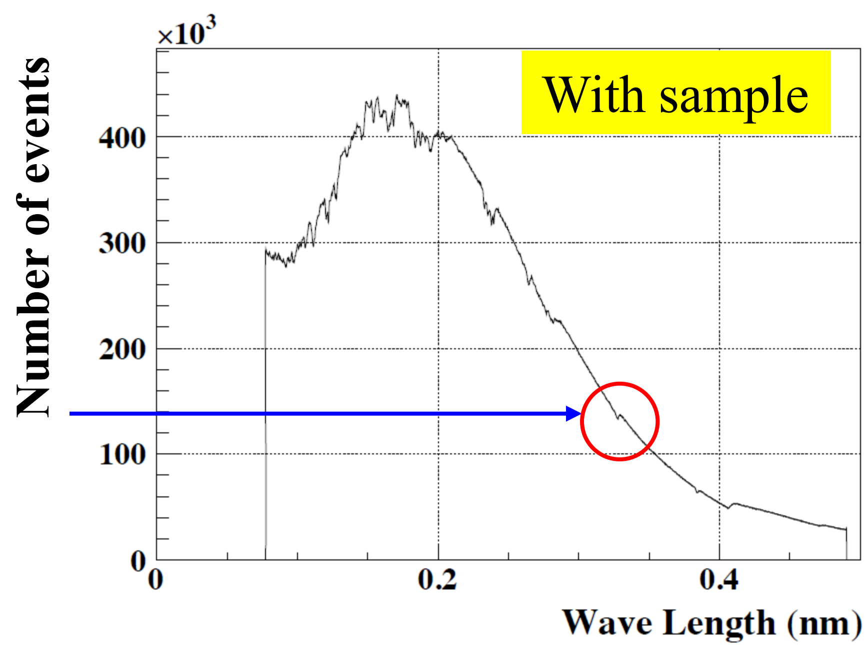
Visualized microstructure parameter

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

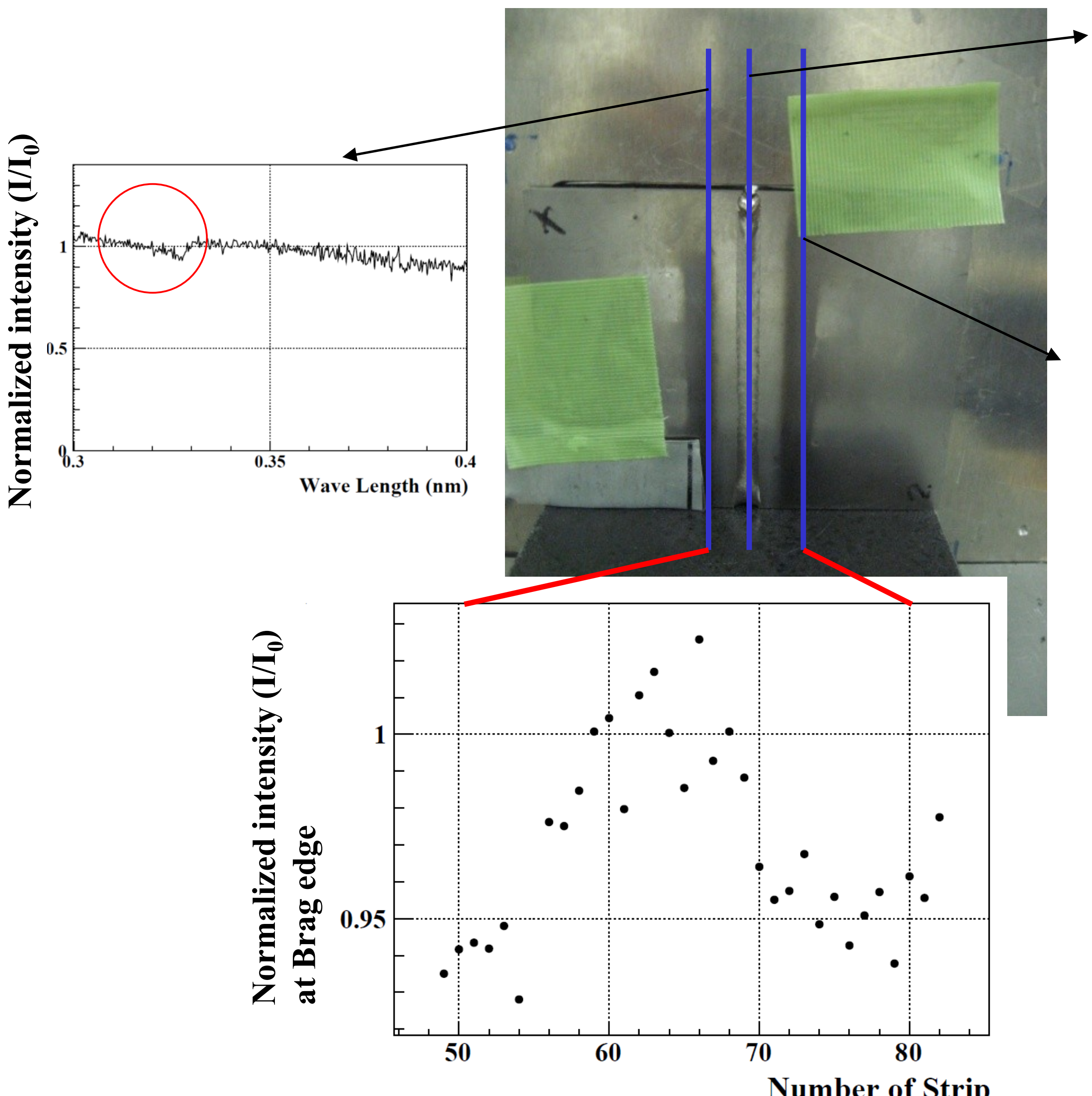
Nb plate with welding
at ROTAX

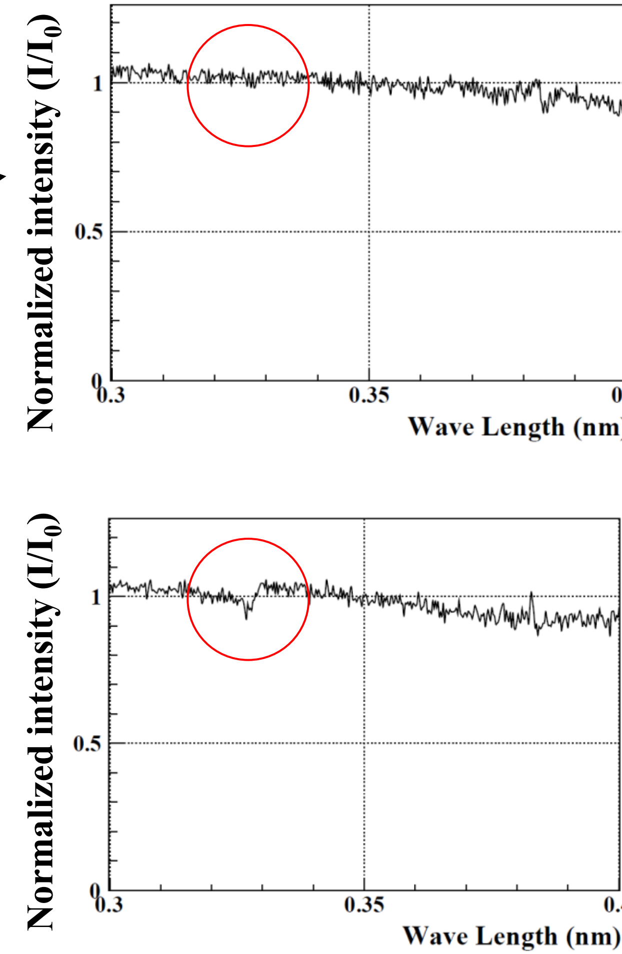






Bragg edge at welding region





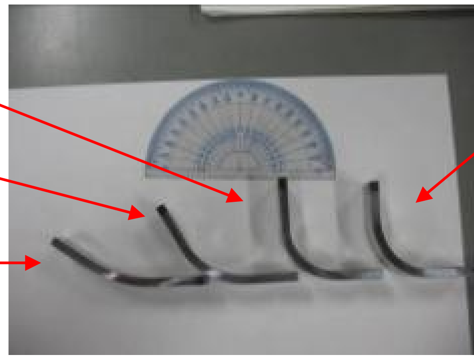
Imaging for bended iron plates at LINAC in Hokkaido University

Sample

90° Bend

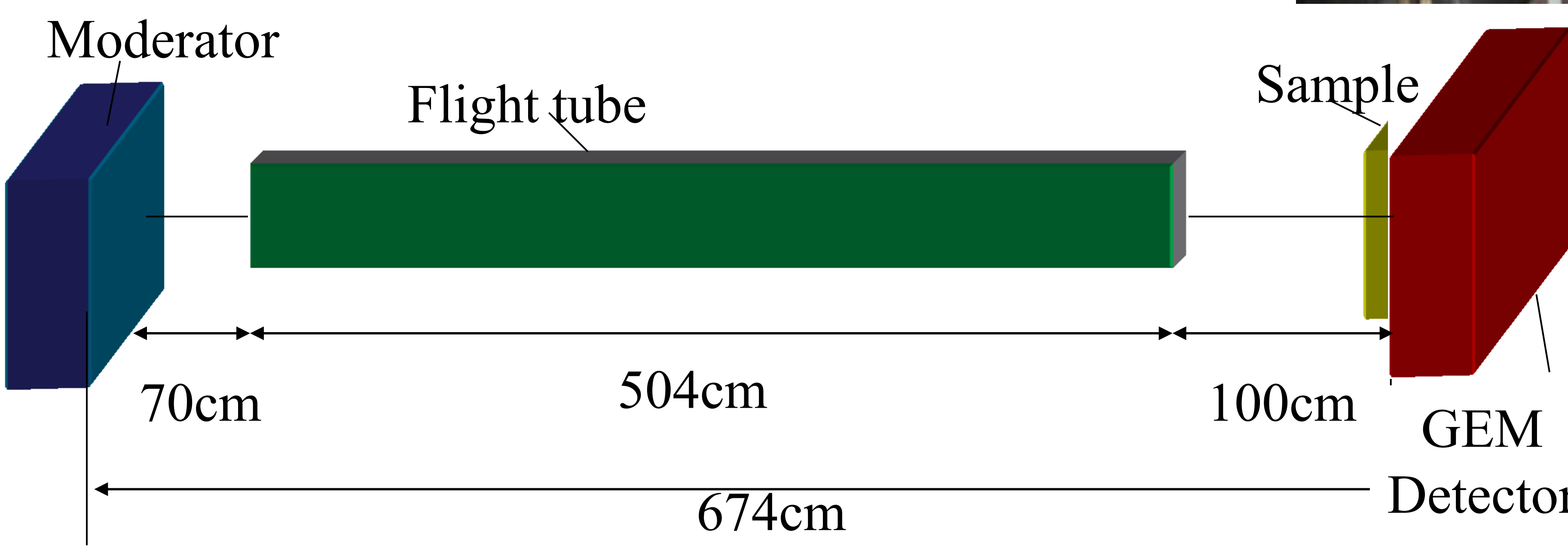
60° Bend

30° Bend



90° Bending and Re-flattening

+Reference (without bending)



Results

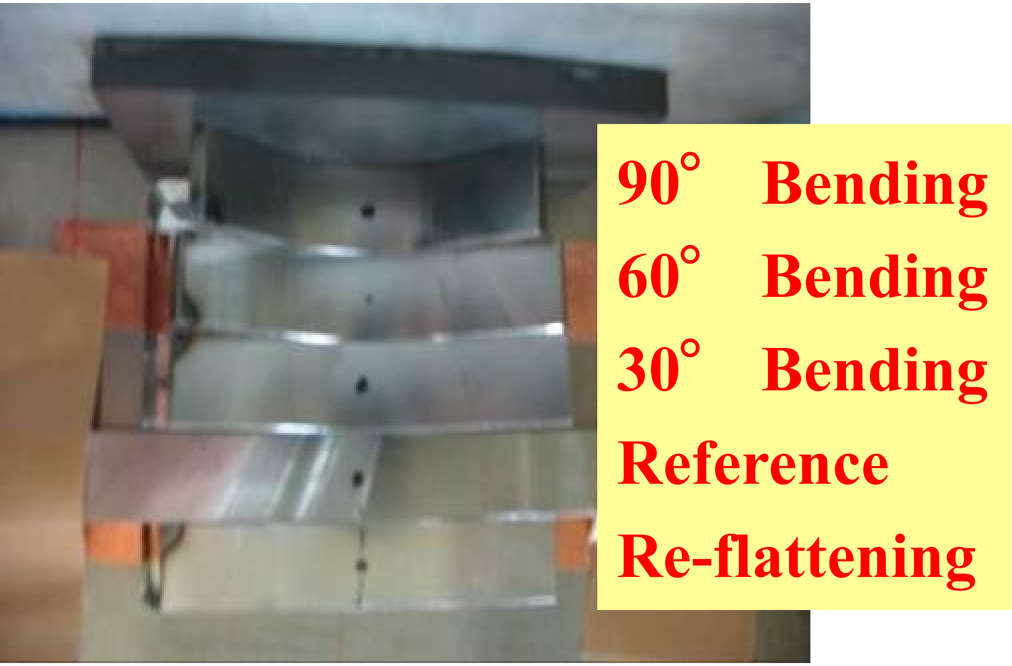
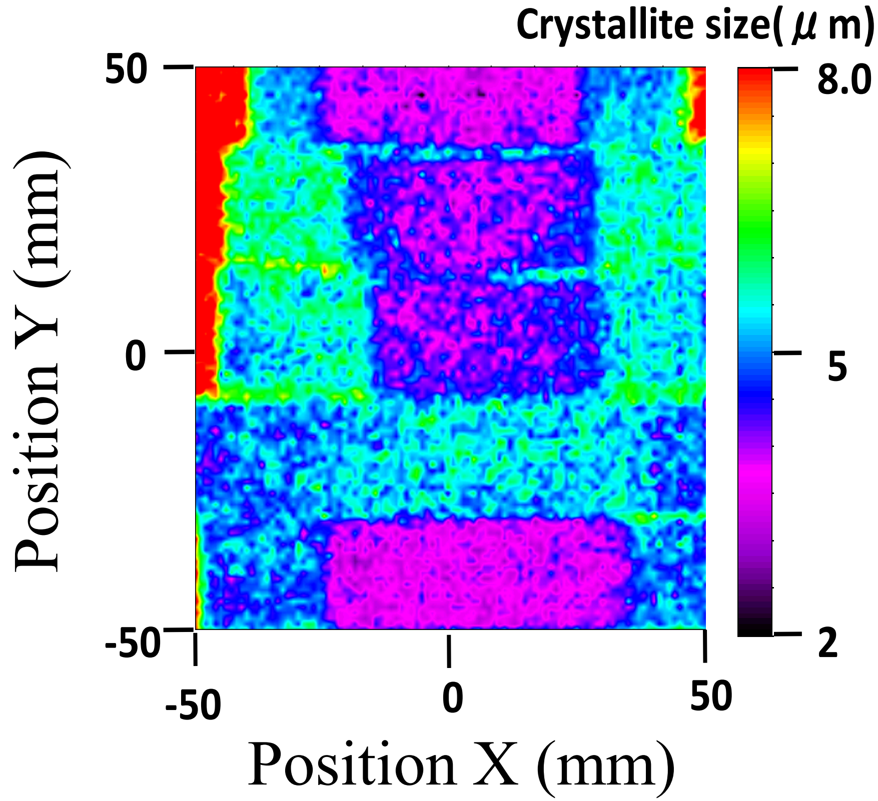


Photo of iron plates



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.

Summary

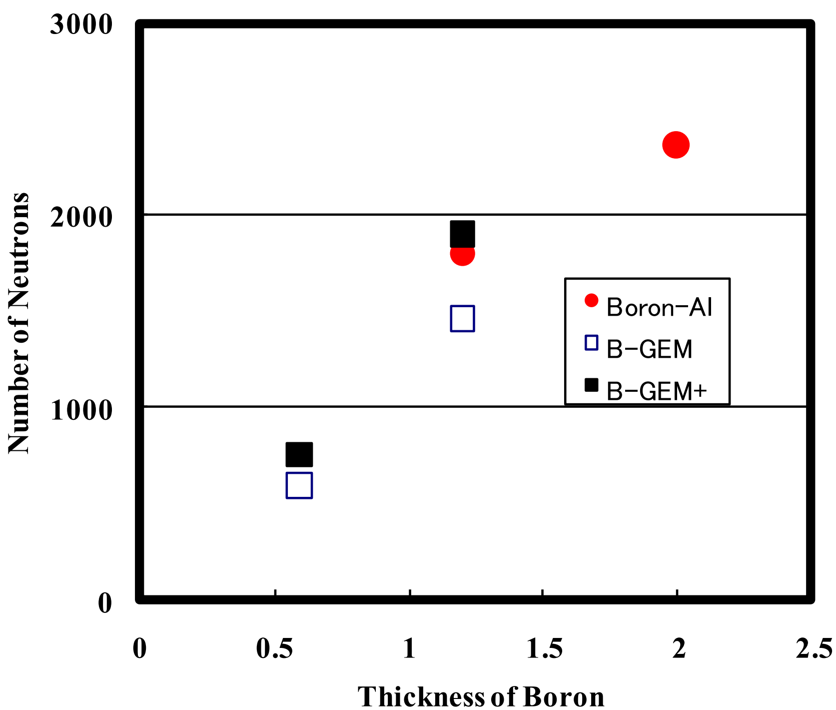
- **Neutron detector with Boron coated GEM was constructed.**
  - **Boron converter**
  - **Gas amplification at GEM**
  - **Two-dimensional readout with X-Y strips**
  - **High speed compact readout system**

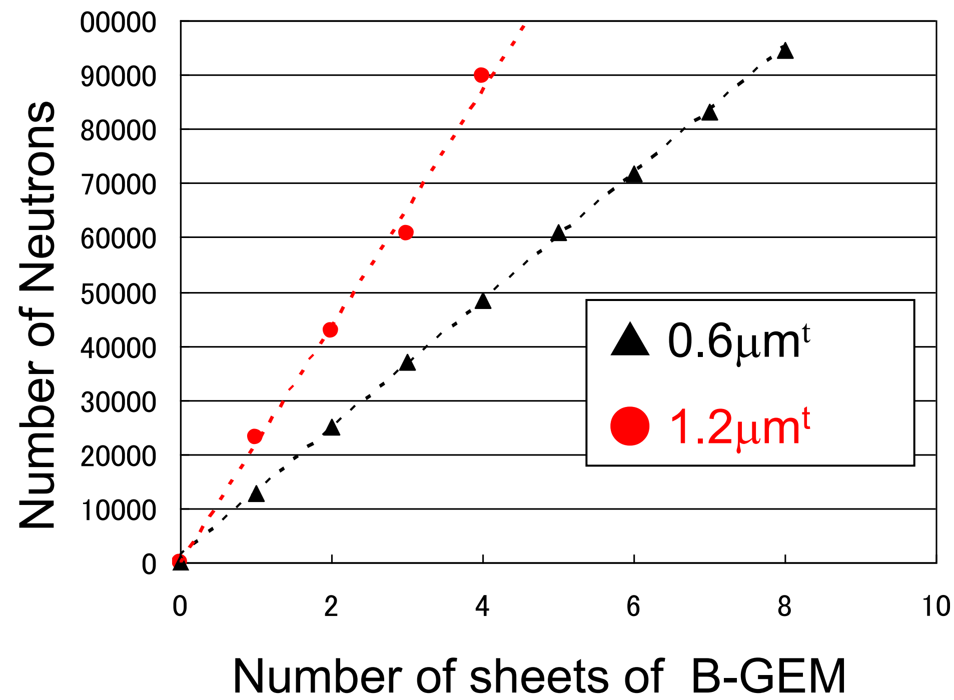
- **Test experiments were performed at several pulsed neutron sources.**
  - Good position resolution without distortion
  - Two dimensional position and flight time can be obtained simultaneously.
  - Gamma ray can be rejected further using the pulse width (pulse height).
  - **Good performance for the energy selective radiography is demonstrated.**

Backup

Thickness of Boron and Number of B-GEM foils

Using ^{252}Cf radiation source

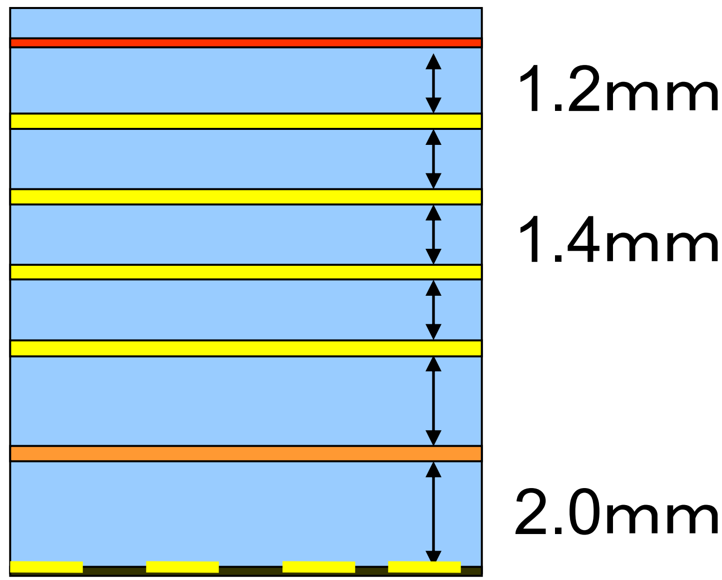




Saturation was observed in thicker Boron layer.

Higher efficiency could be obtained for more B-GEM foils.

Chamber Structure for Beam Test



Gas: Ar-CO_2(70/30)

E_D=1.5kV/cm

ΔV_{GEM}=220V(B-GEM)

E_T=1.5kV/cm（B-GEM）

ΔV_{GEM}=560V(100μmGEM)

E_I=6.3kV/cm

Thickness of Boron Layer : **1.2μm**

In total 1.2μmx9=10.8μm

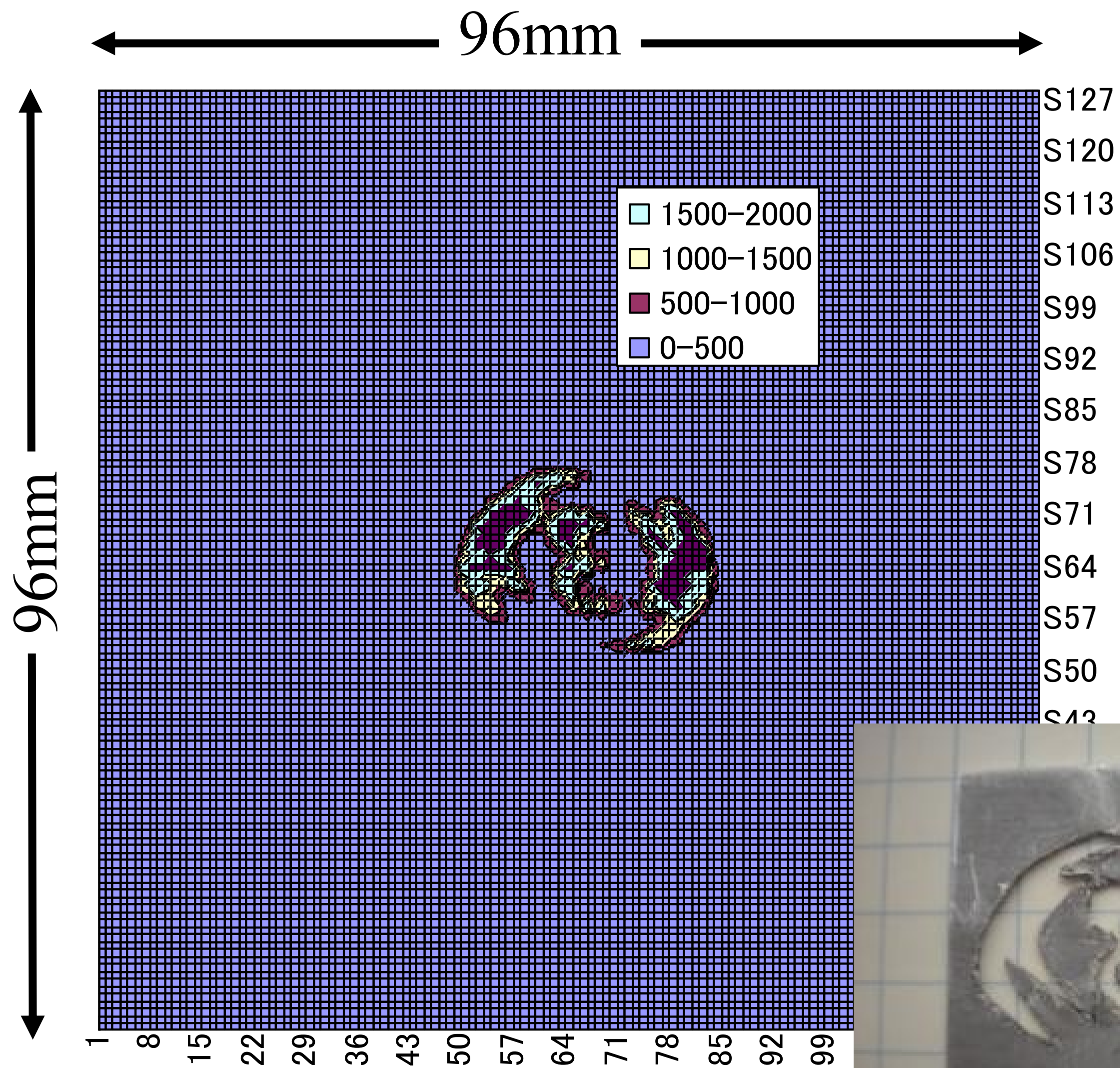
Test experiment at JRR3 research reactor in JAEA

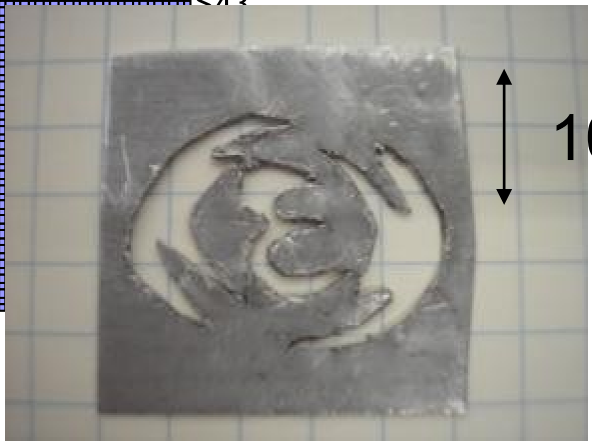
Detection Efficiency

- 1mm$^{\varphi}$ Pin Hole
- ^{3}He Counter with 1inch 10atm
  - 61405 counts/100sec
- Boron-GEM Foil
  - 18599 counts/100sec
- Detection Efficiency
  - 30% at 2.2Å
    - with 4 GEM foils
    - Boron-10 : 1.2μm^{t}

      → 2.4μm^{t} per one GEM foil

Two Dimensional Image



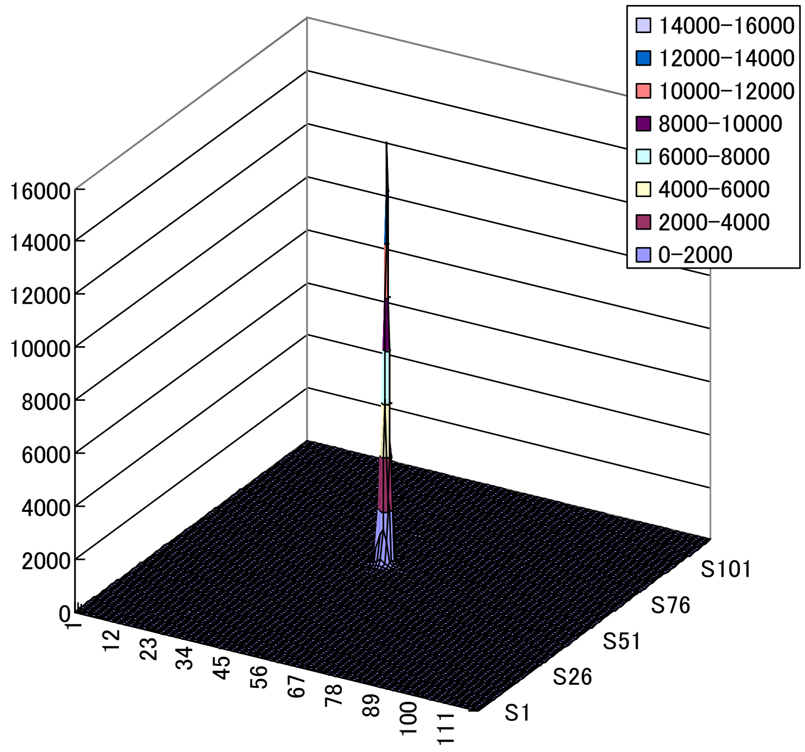


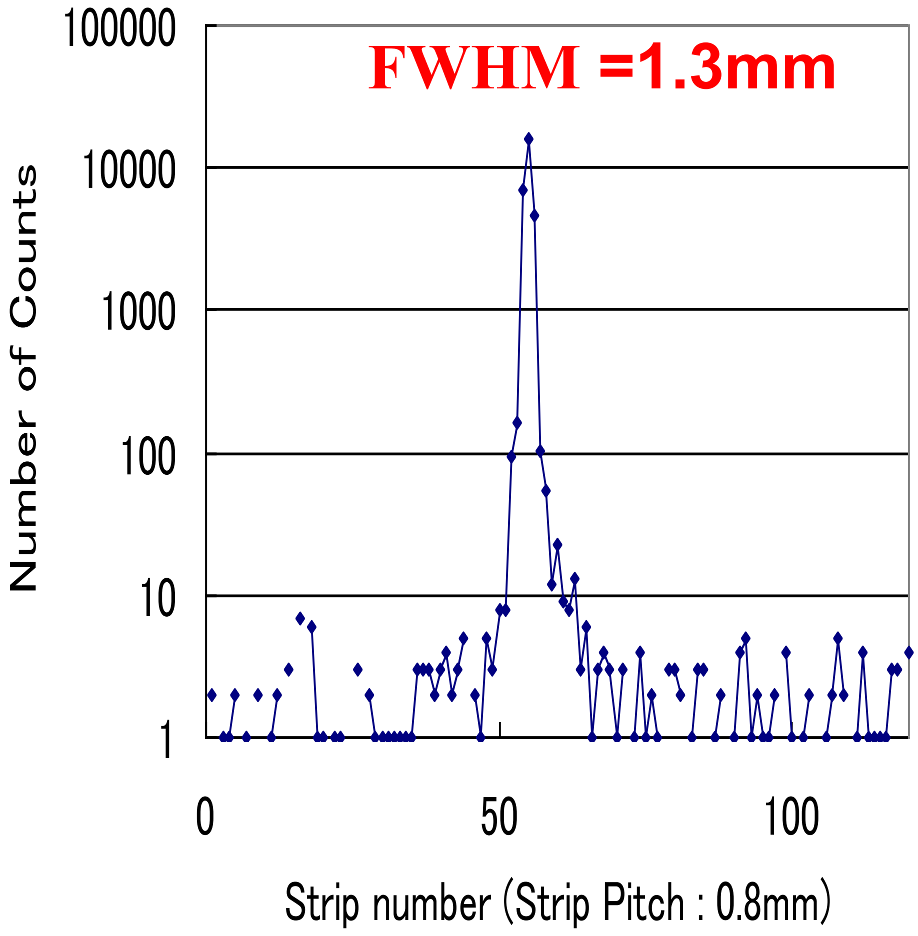
10mm

Cd Slit

Position Resolution

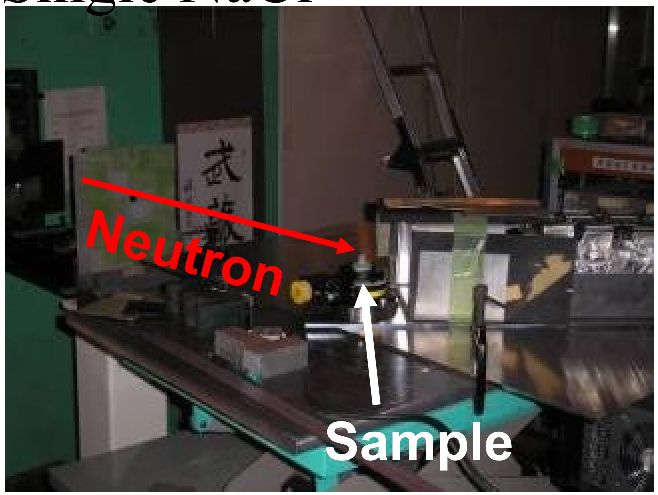
0.5mm$^{\varphi}$ Pine Hole

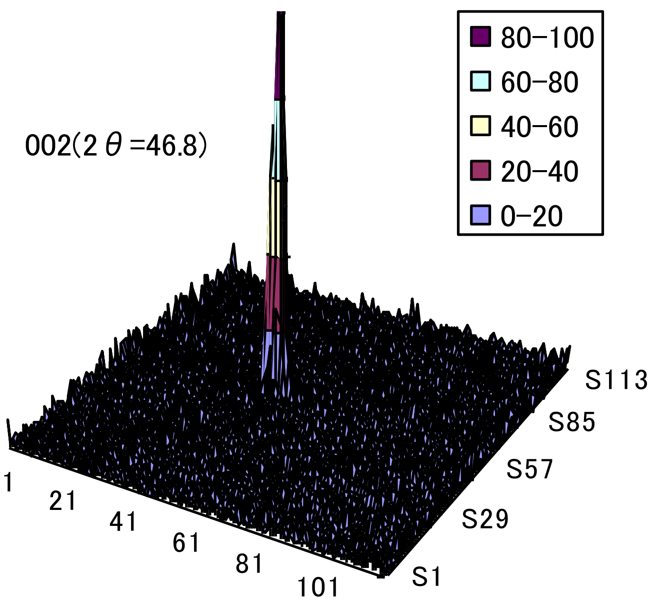




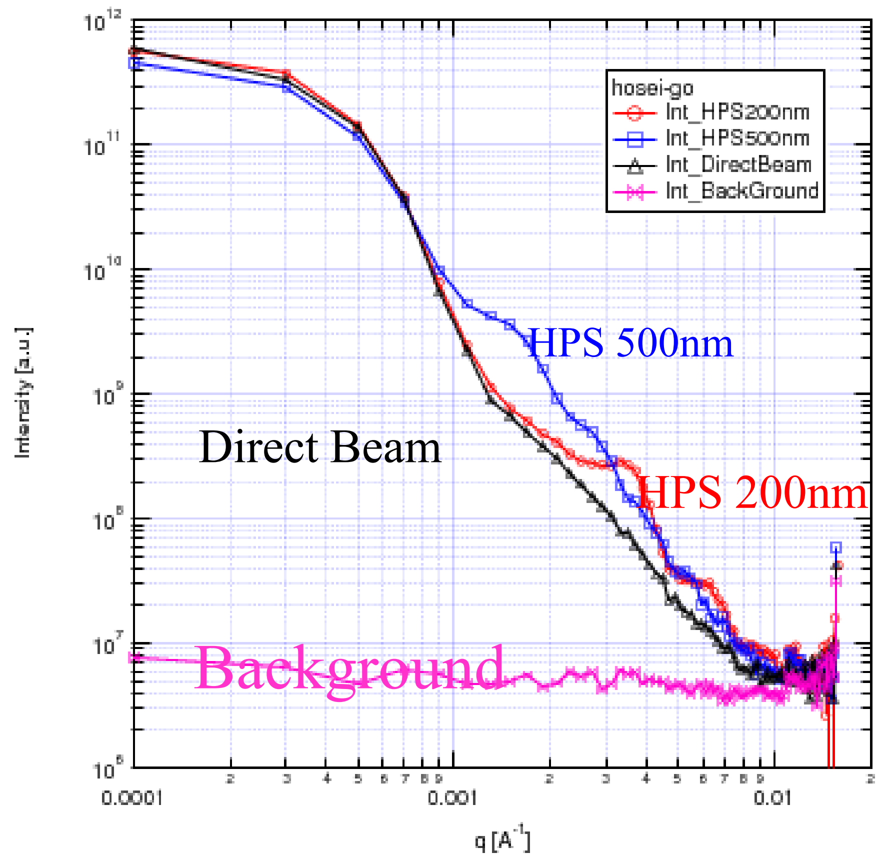
Sample test

Large angle scattering
Single NaCl

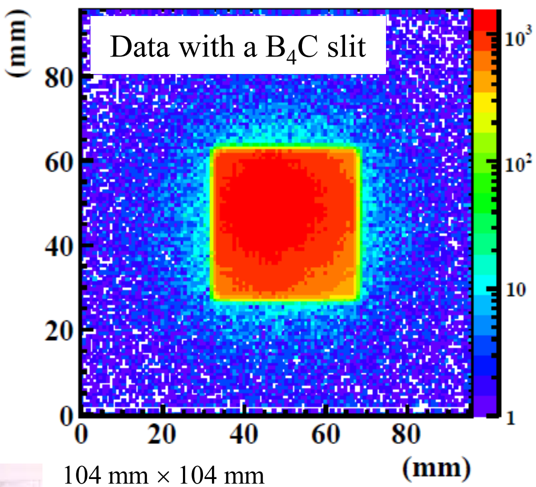


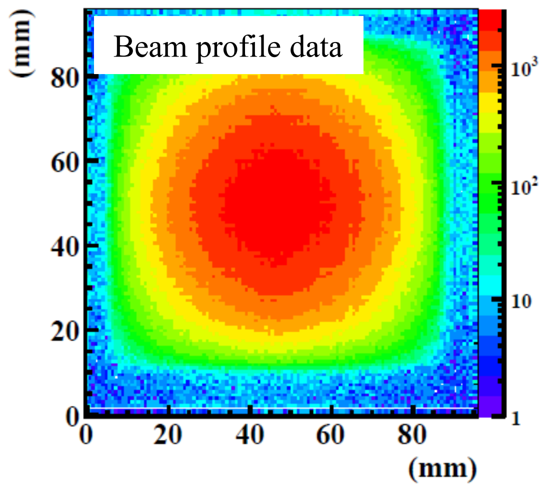


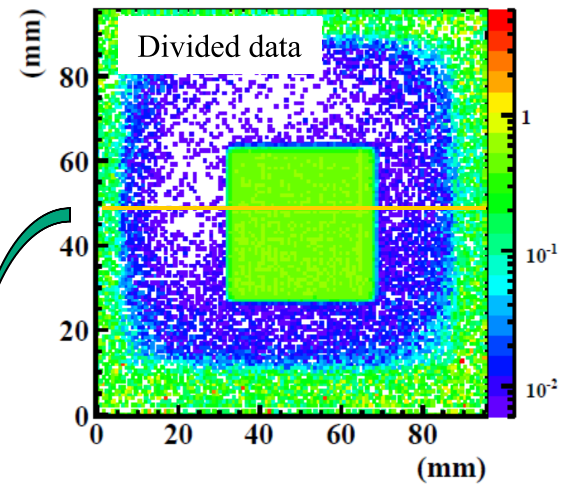
Small angle scattering
Hypresica (SiO_2)

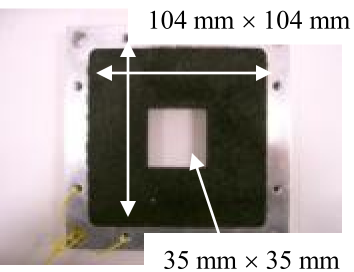


Position resolution



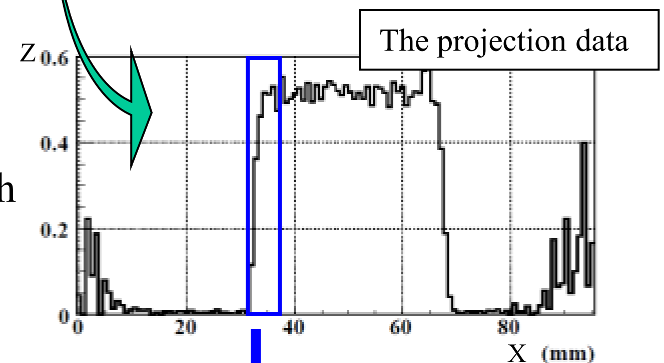






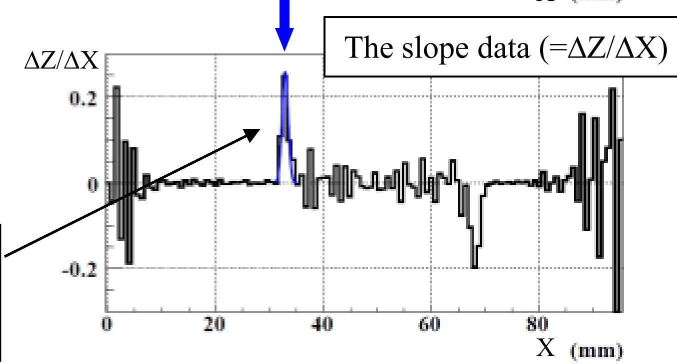
The B_4C slit (35 mm × 35 mm) was put in front of the GEM.

To compensate the beam profile, the data with the slit is divided by the beam profile data.



In the histogram of the slope (=ΔZ/ΔX), a sharp peak appears on the edge of the B_4C slit.

In order to estimate position resolution, the sharp peak is fitted by a gauss function.



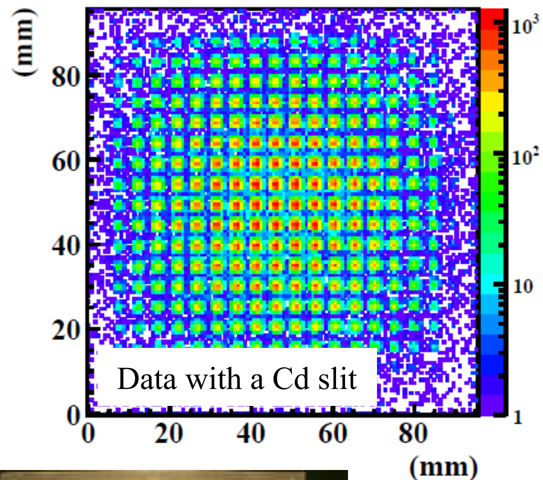
Constant:	0.26
Mean:	32.85
Sigma:	0.56

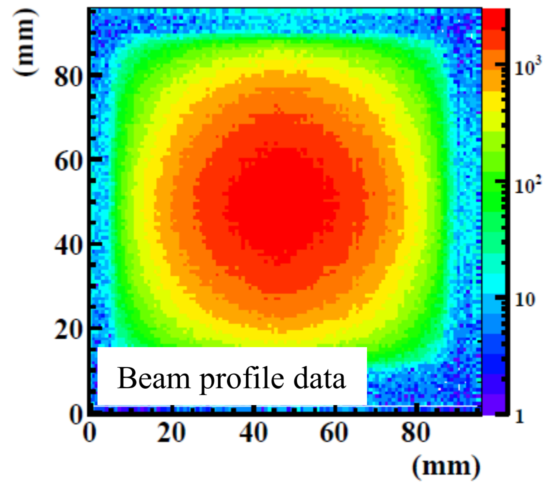
The position resolution; ~1.3 mm (FWHM)

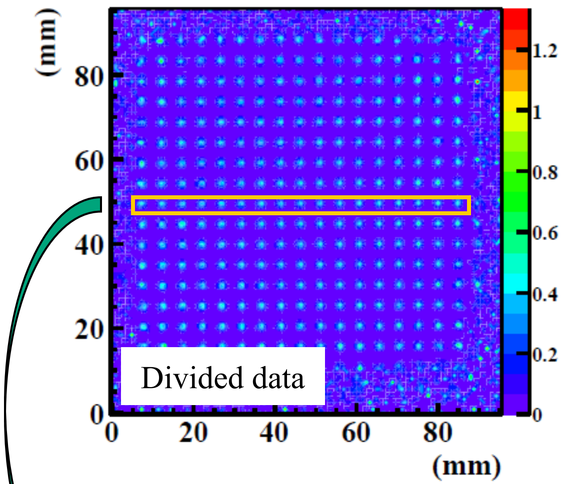
The correction of the beam divergence is not performed yet.

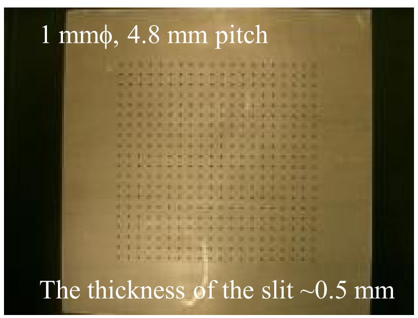
ΔZ/ΔX is obtained by subtracting the one from the adjacent one.

Uniformity (Neutron sensitivity, Imaging)



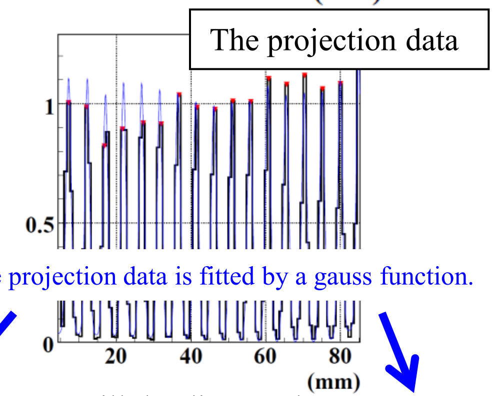






A cadmium slit (1 mmϕ, 4.8 mm pitch) was put in front of the GEM.

To compensate the beam profile, the data with the slit is divided by the beam profile data.



the projection data is fitted by a gauss function.

To estimate the uniformity of the neutron sensitivity, the peak area is used.

The peak area: 1.73 ± 0.30 (3σ)

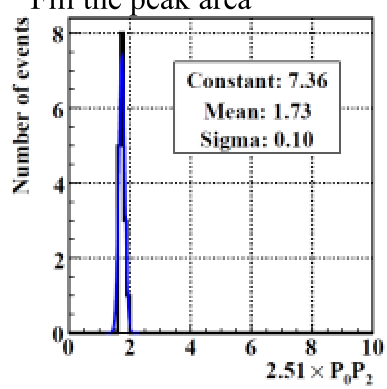
The dispersion of the neutron sensitivity is estimated at within 17%.

To estimate the distortion of the 2D image, the distance between the peaks is used.

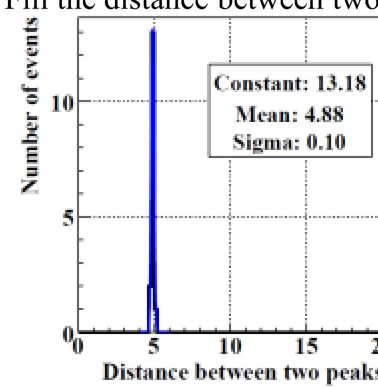
The distance between the peaks: 4.88 ± 0.10 mm

The distortion of the 2D image is very small.

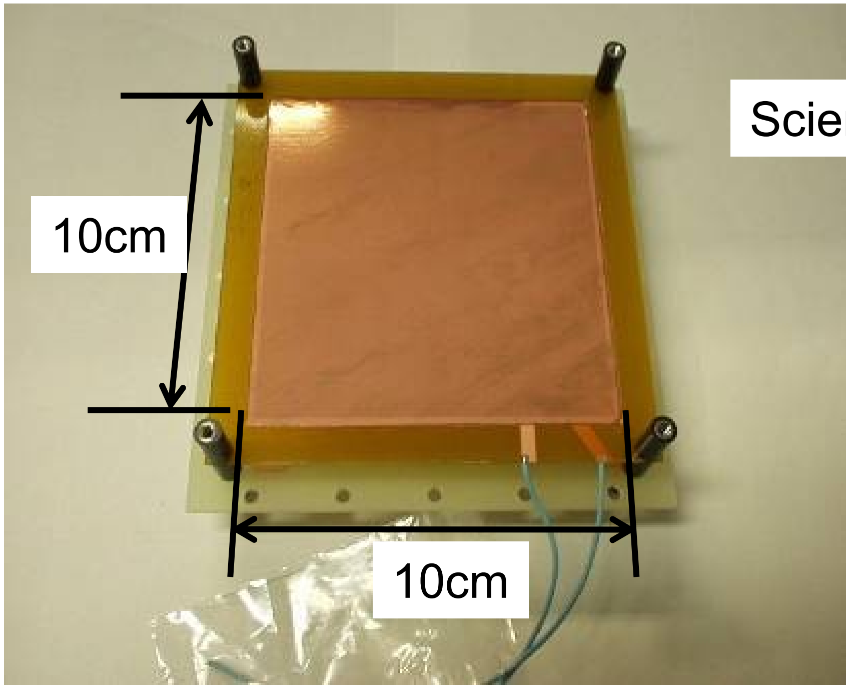
Fill the peak area



Fill the distance between two peaks

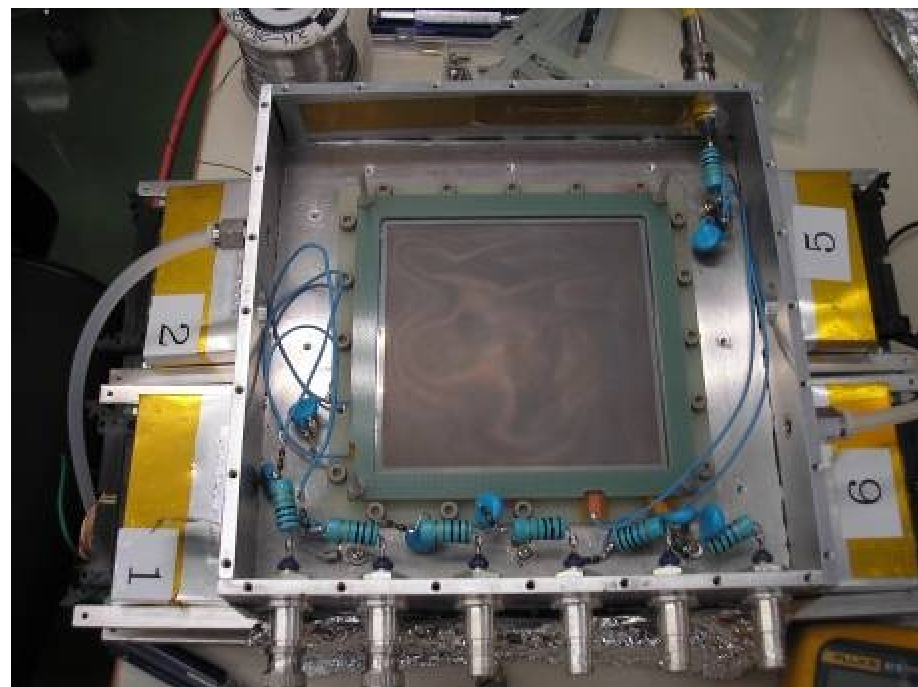


GEM Foil & Test Chamber



Sciencergy Co., Ltd. (Japanese company)

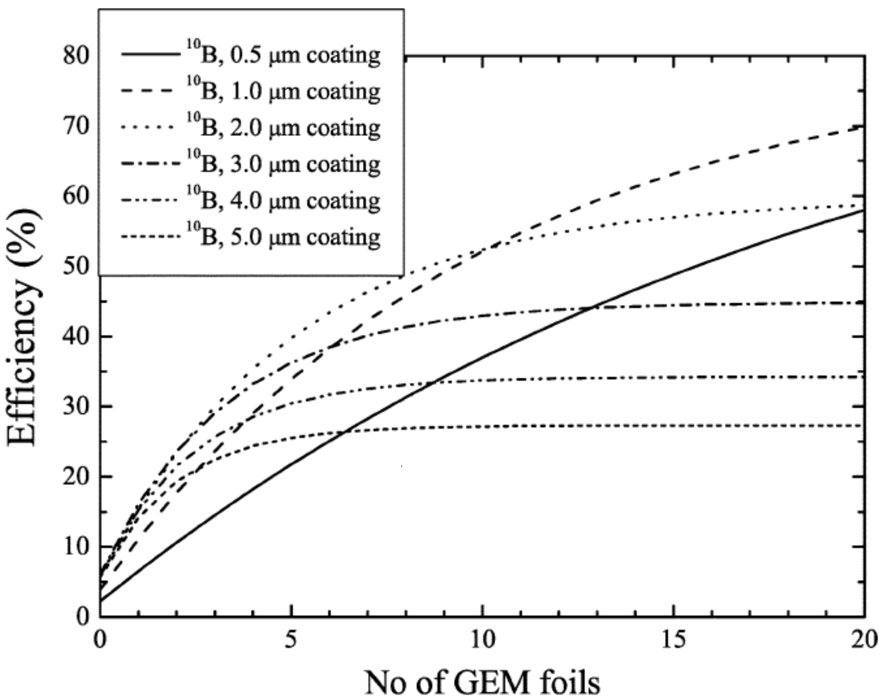
Boron coated GEM
Enriched B-10 Purity > 99%



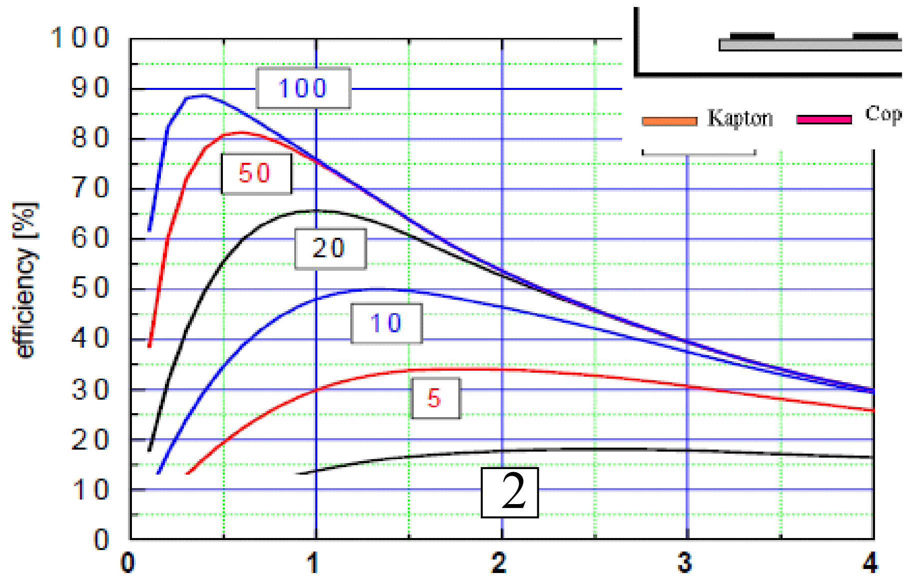
Standard GEM Foil
without Boron coating

Hole diameter	70µm
Hole pitch	140µm
Thickness	50µm
Cu thickness	5µm

Simulation study



No. of GEM foils



Thickness of ^{10}B (μm)

Se-Hwan Park et. al.,
IEEE NS52(2005)1689

CASCADE
M. Klein

~32%X0.77＝ ~25%

~35%X0.77 = ~27%

0.77 : Fraction of Cu surface on GEM

Principle of neutron detection

n(^{10}B,α)^{7}Li reaction

Neutrons are detected by n(^{10}B,α)^{7}Li reaction.

In order to optimize our detector design, we performed a GEANT4-based simulation.

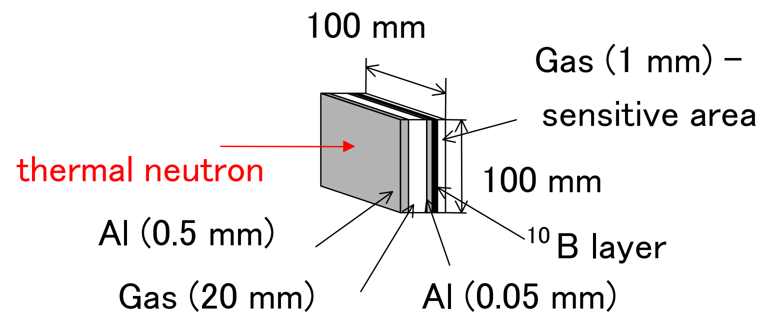
$$^{10}_{5}B + ^{1}_{0}n \rightarrow \begin{cases} ^{7}_{3}Li + ^{4}_{2}\alpha + 2.792MeV & (6\%) \\ ^{7}_{3}Li^{*} + ^{4}_{2}\alpha + 2.310MeV & (94\%) \end{cases}$$

$$^{7}_{3}Li^{*} \rightarrow ^{7}_{3}Li + 0.48MeV \ (\%)$$

The GEANT4-based simulation

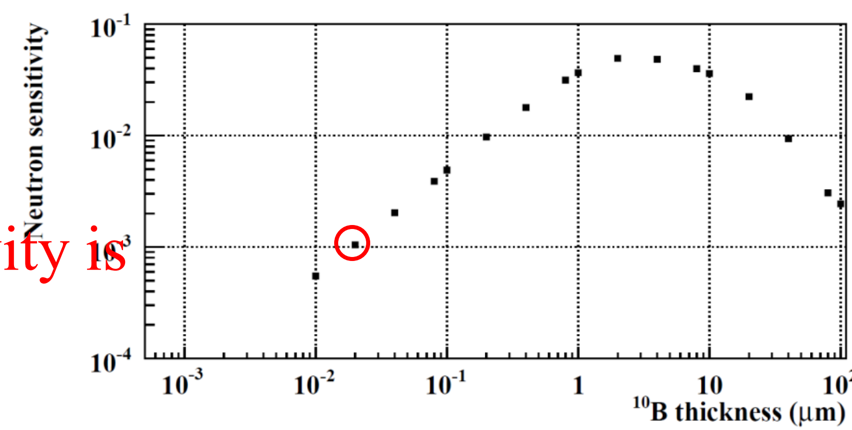
- 1.8 Å thermal neutrons shot into the detector at the normal incident.
- An event depositing energy in the gas is defined as a hit.

A schematic view of the Geant4-based simulation



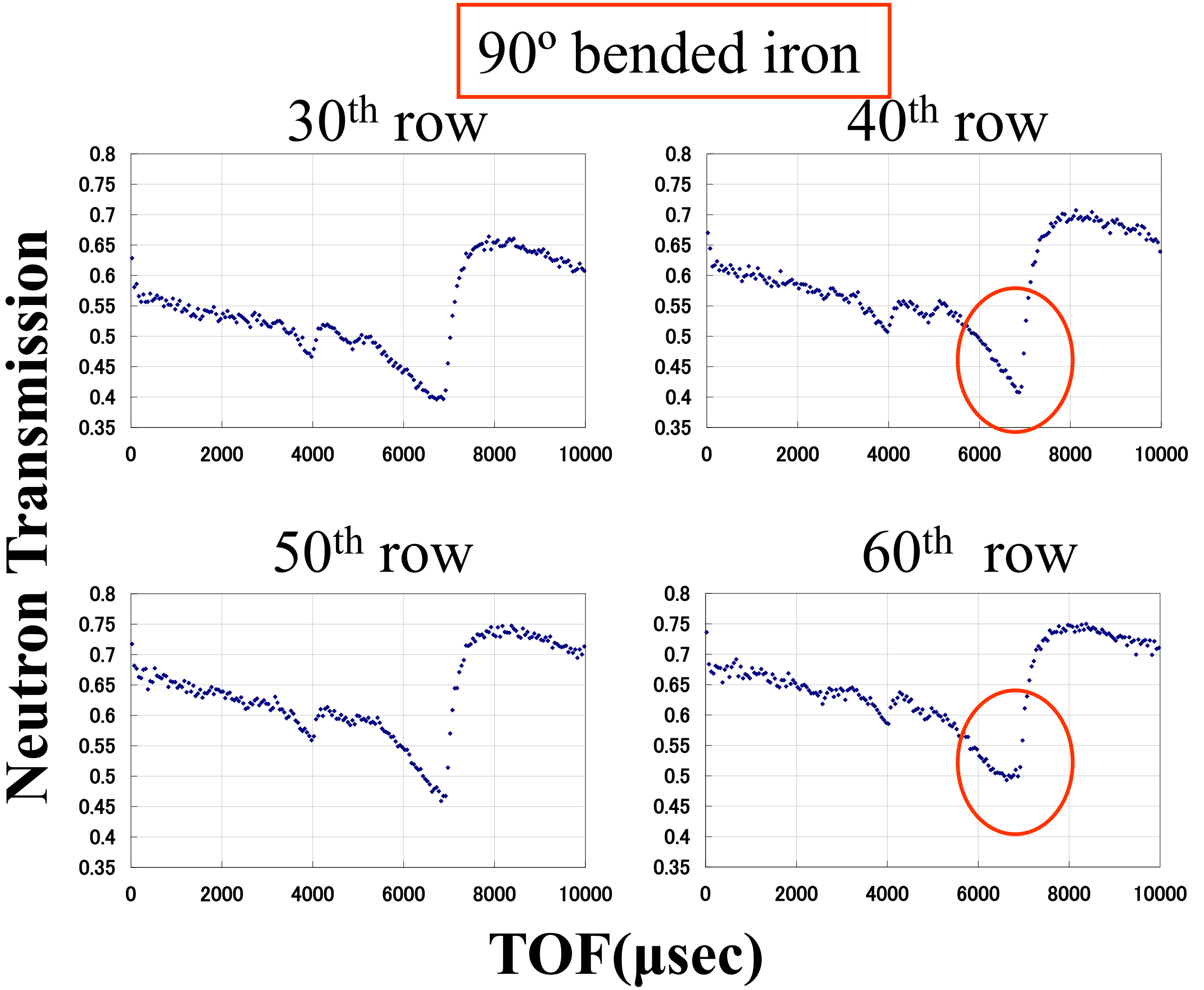
The neutron sensitivity as a function of ^{10}B thickness

- The neutron sensitivity reaches its maximum around 3 μm.
- Over the thickness, charged particles (α or ^{7}Li) can't enter into the gas volume.

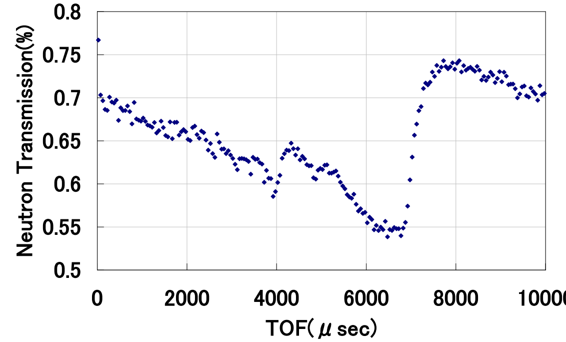


Approximately 0.1% neutron sensitivity is achieved by a 0.02 μm ^{10}B layer.

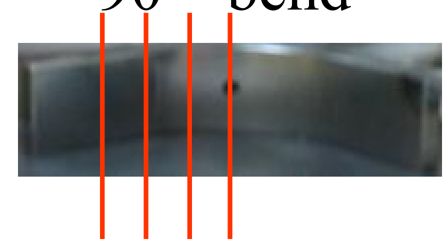
Transmission Spectrum for Bended Iron



Reference (40th row)



90° bend



30th → 60th row

Shapes of Bragg-edge are analyzed in a RITS code, which is developed by H. Sato.

→ Crystallite size bin by bin