Development of Neutron Detector with GEM

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UCANS-I
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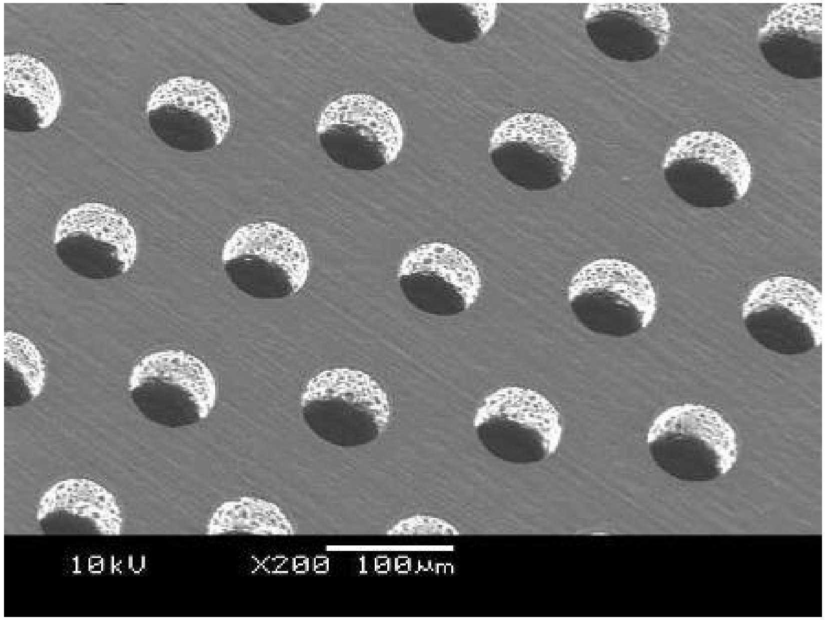
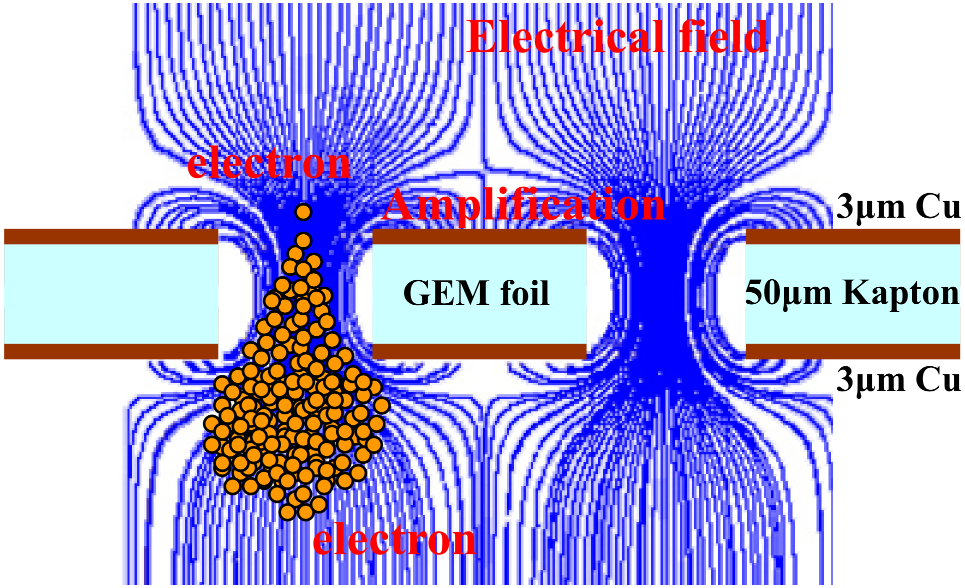
- Introduction
  - GEM
  - Application to Neutron Detector
  - Detector system
- Performance study with Neutron Beam
  - Research reactor
  - Pulsed neutron sources
- Energy selective neutron radiography
- Summary & future prospect

GEM (Gas Electron Multiplier)

Double side flexible printed circuit board

Electric field

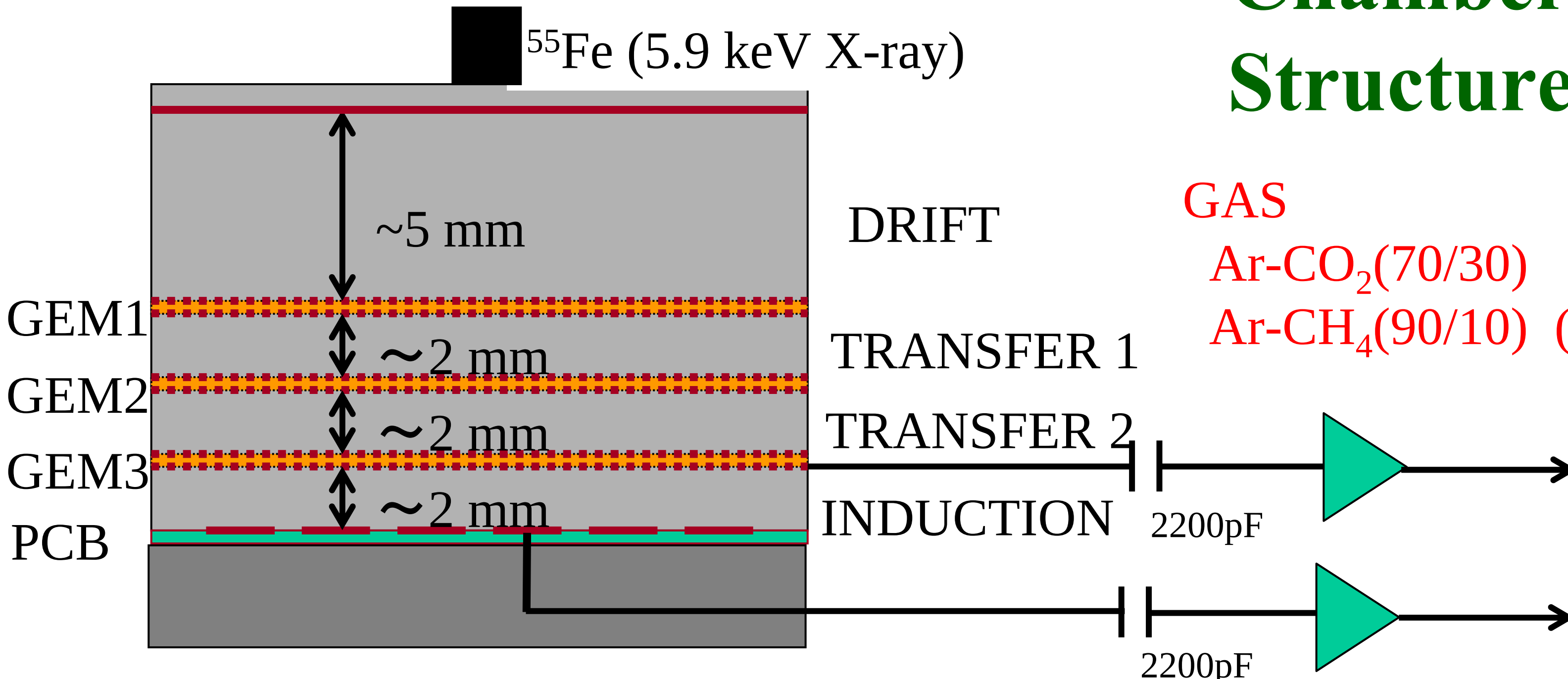




Hole diameter 70µm
Hole pitch 140µm
Thickness 50µm
Cu thickness 5µm

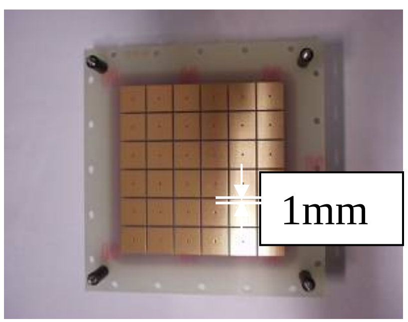
Developed by F.Sauli (CERN) in 1997.
NIMA 386(1997)531

Chamber Structure

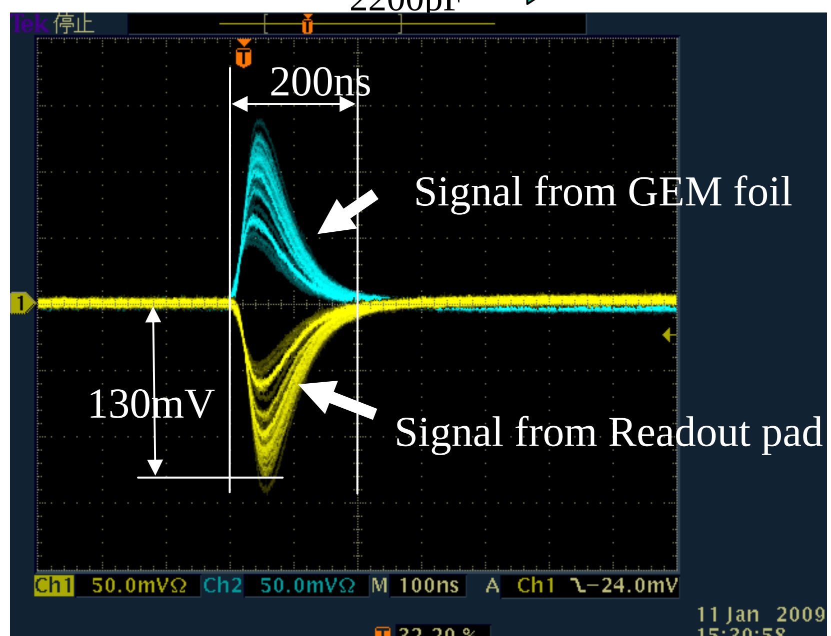


GAS
$Ar\text{-}CO_2(70/30)$
$Ar\text{-}CH_4(90/10)$ (P-10)

PCB

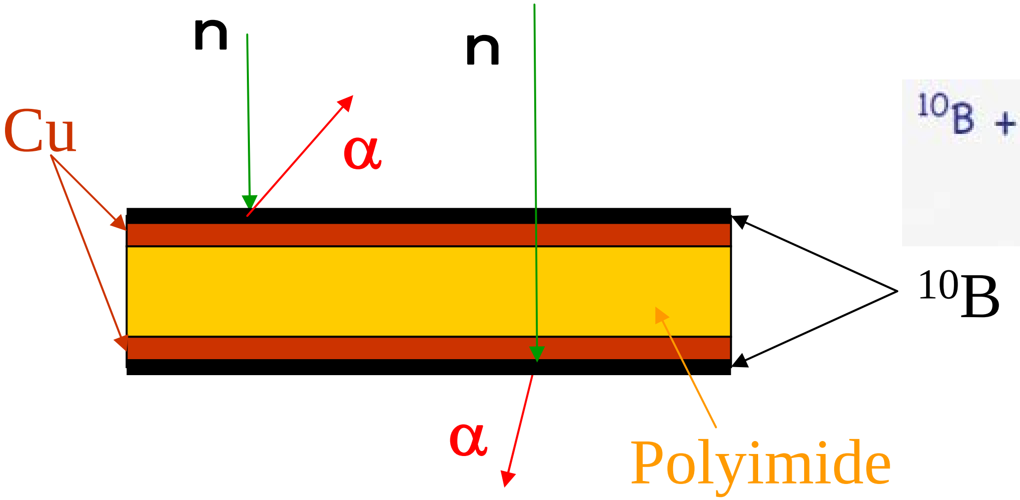


□15mm×15mm
36＝6×6



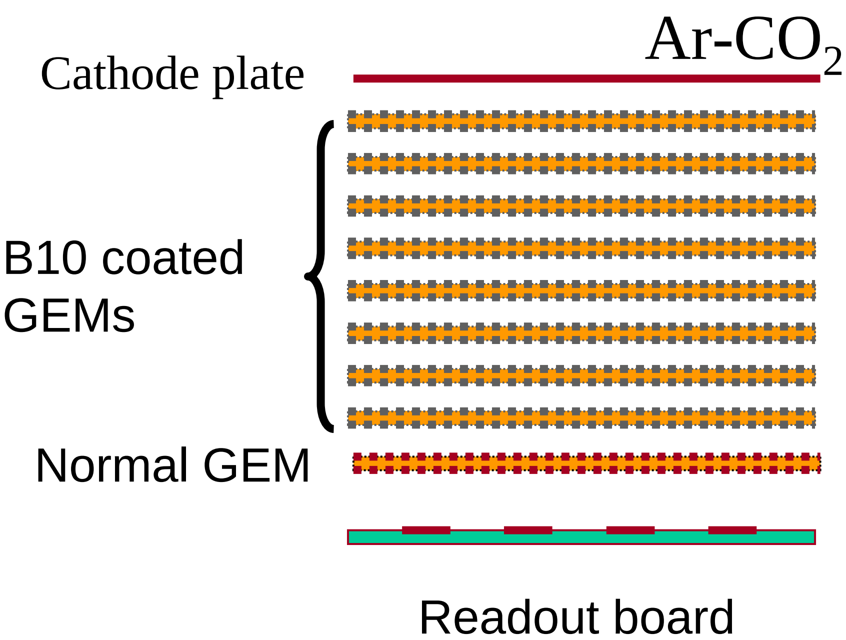
Others
X-Y Strips 0.8mm pitch 120+120
□6mm×6mm pads 256ch = 16x16

Application to Neutron Detector



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

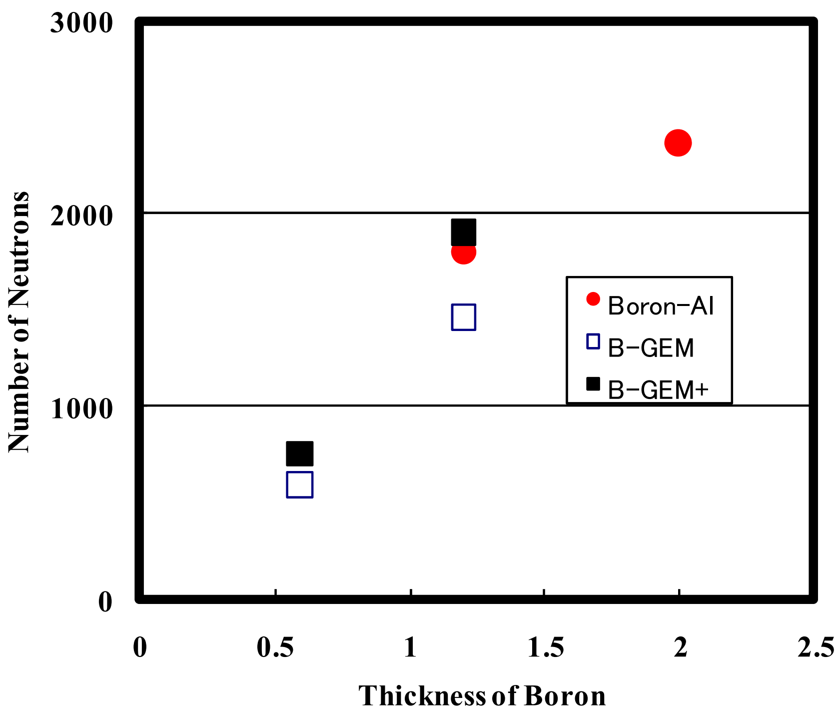
${}^{7}Li^{*} + \alpha + 2.310\ MeV$

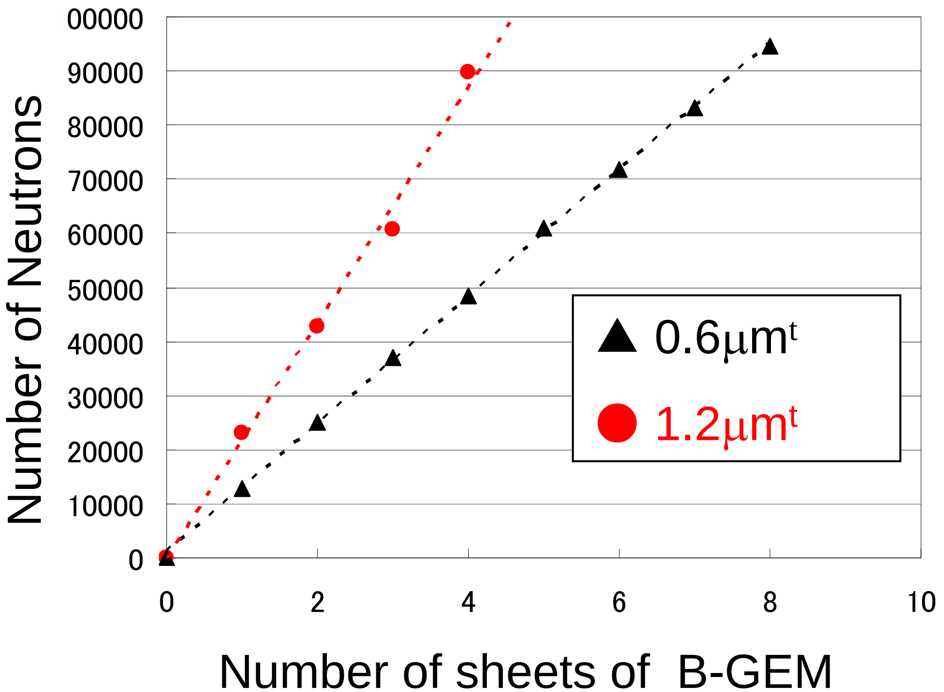


- No need of expensive ^{3}He Gas
  - No need of pressure vessel
- Free readout pattern
- High resolution
  - Position and **Time**
- Insensitive against γ-ray
- Capability against high counting rate

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.

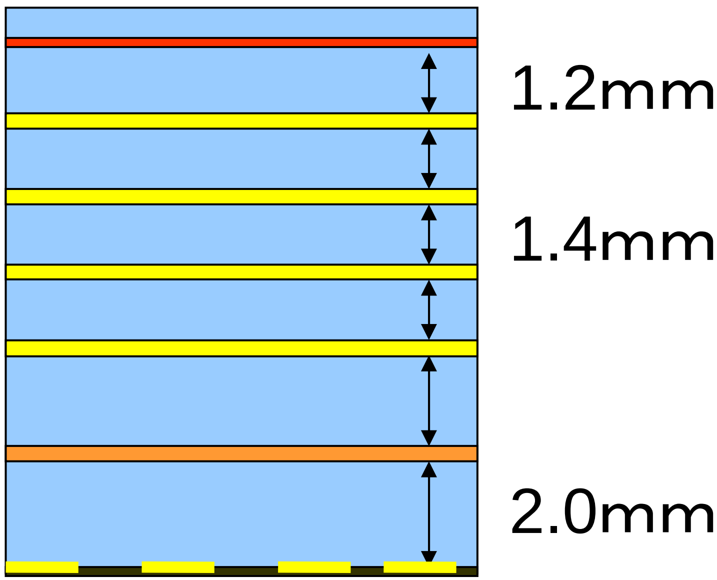
Chamber Structure for Beam Test

Boron coated Aluminum Foil

4 Boron coated GEM foils

100μm thick GEM

0.8mm pitch X-Y strips 120+120



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)

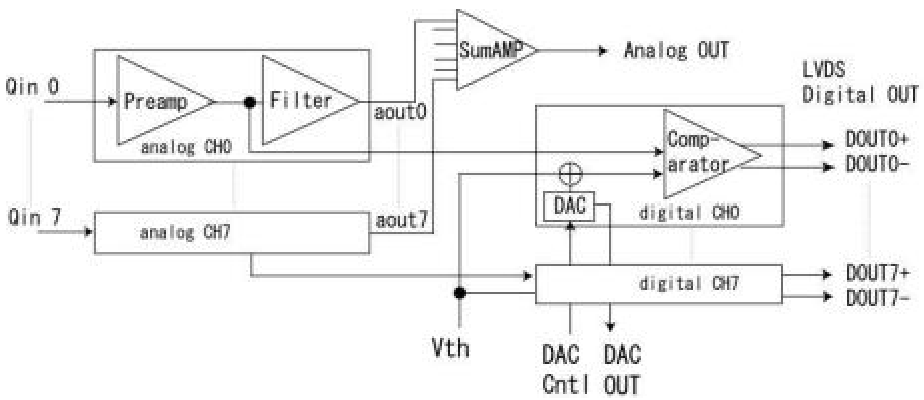
E_I=6.3kV/cm

Thickness of Boron Layer : **1.2μm**

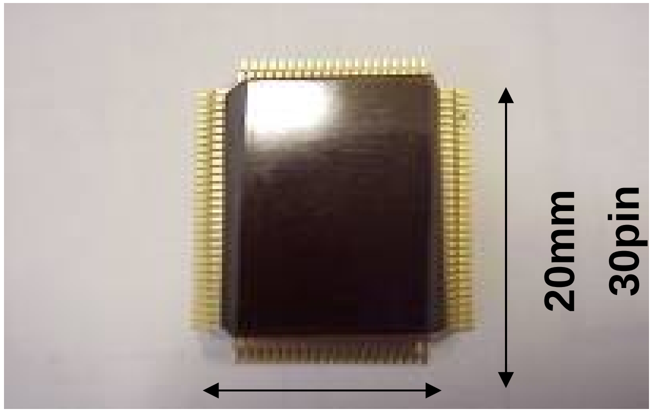
In total 1.2μmx9=10.8μm

Electronics : ASIC FE2007

KEK DTP ASIC Group Y.Fujita



8ch/chip

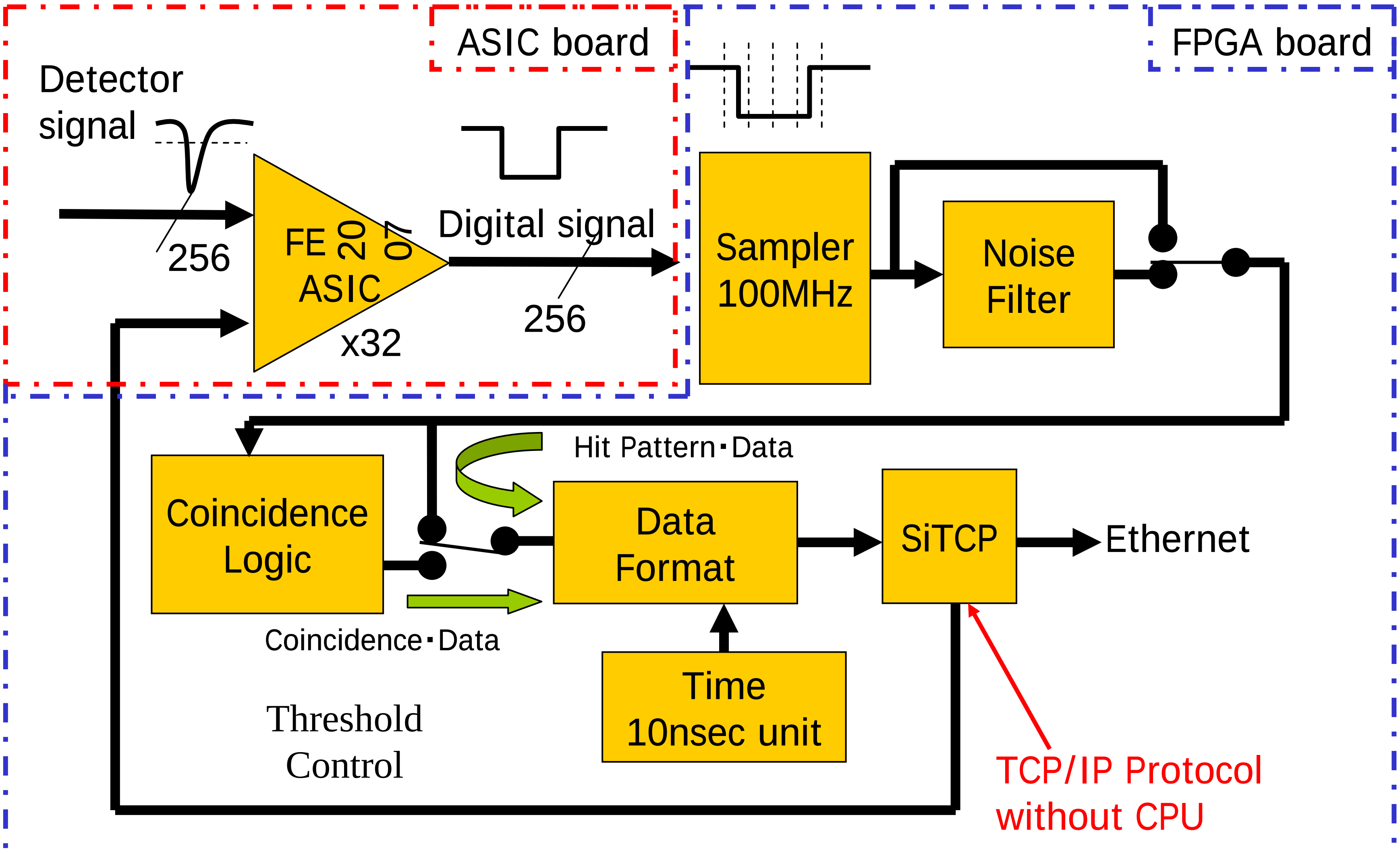


14mm
20pin

ASIC board
64ch/board

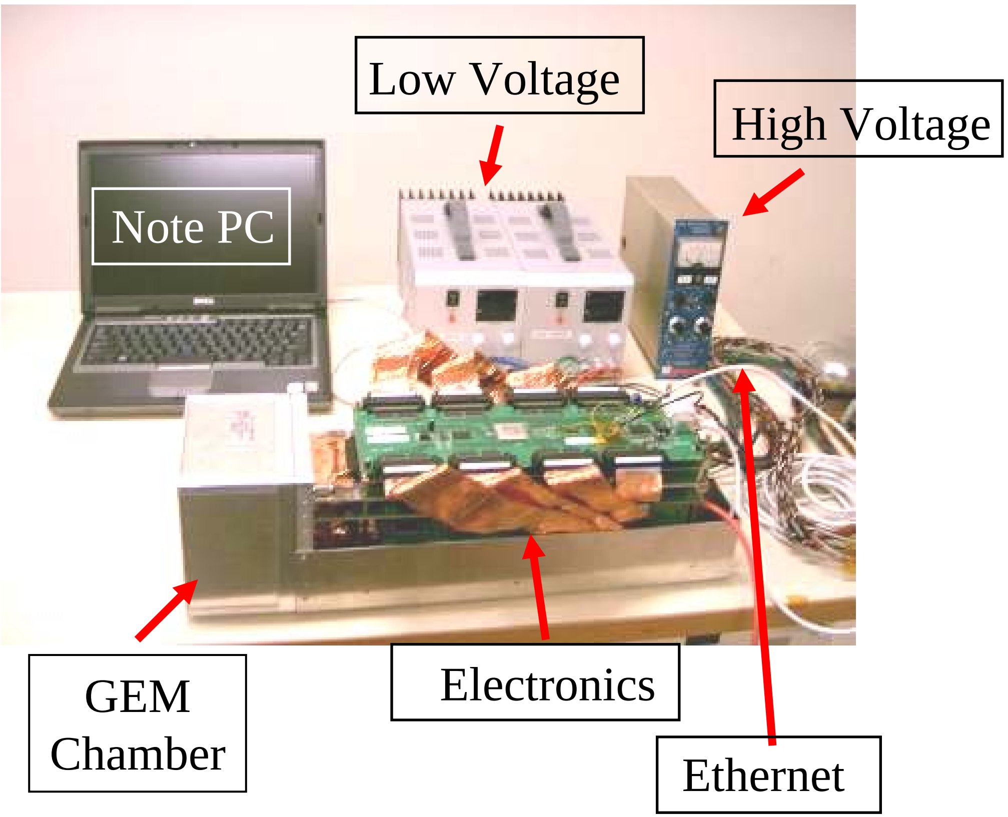
FPGA board

Block diagram for readout board



Present Detector System

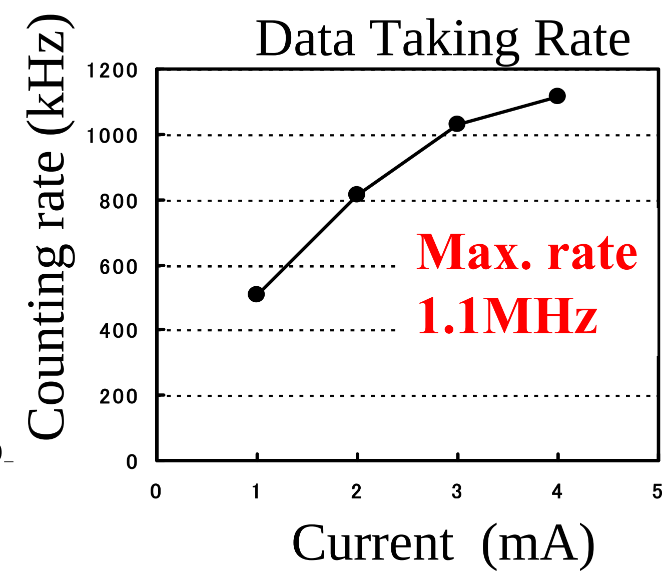
Detector size 150mm × 150mm × 510mm



Compact and Portable System

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

- I/F
  - One HV cable
  - Five LV cables
  - One Ethernet cable
- Electronics
  - Four ASIC boards
  - One FPGA board
- FE2007 ASIC : Y. Fujita (KEK)
- Data transfer and Control through Ethernet
  - SiTCP (by T. Uchida)
  - Using Note-PC



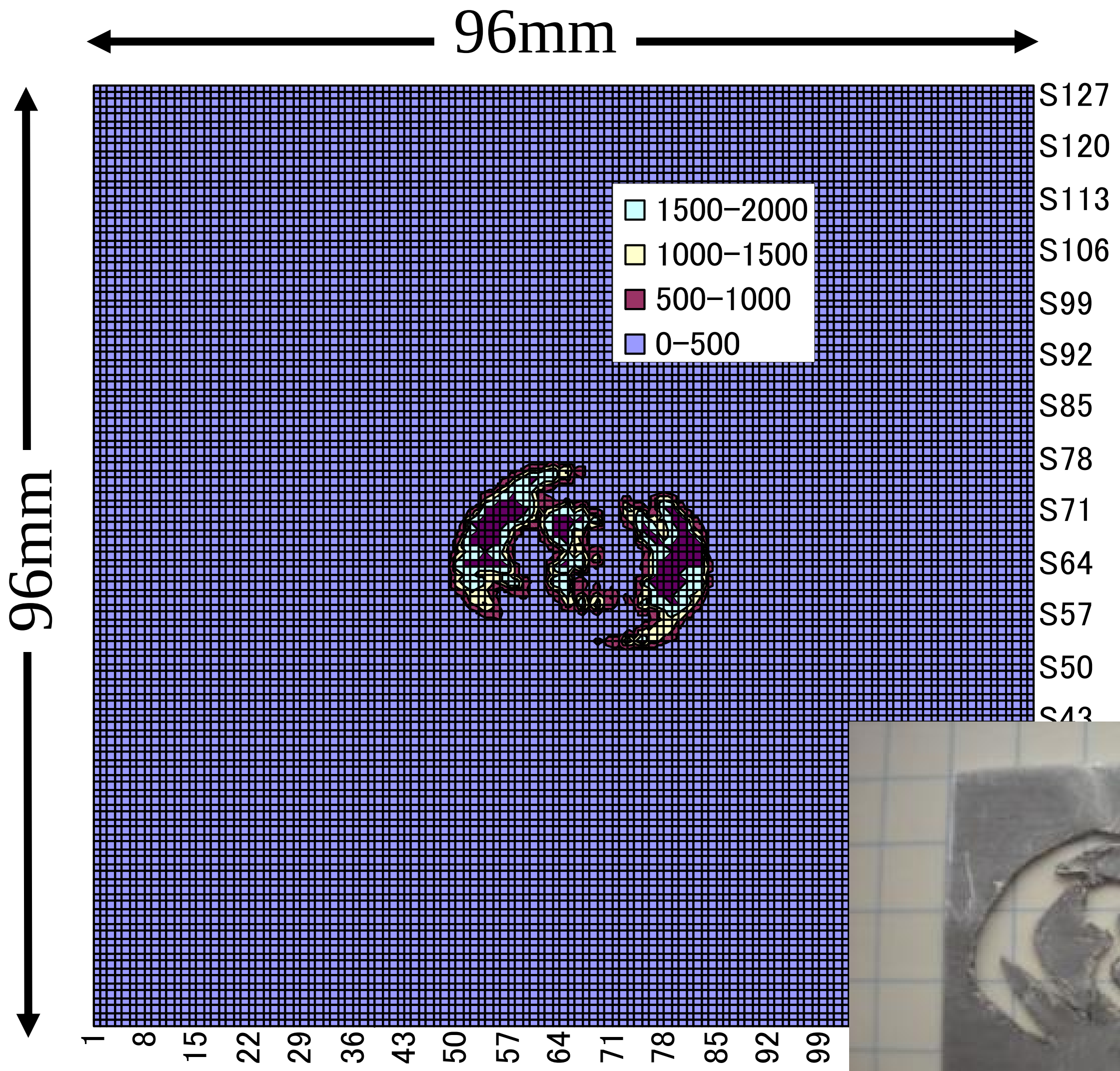
Test experiment
at JRR3 research reactor
in JAEA

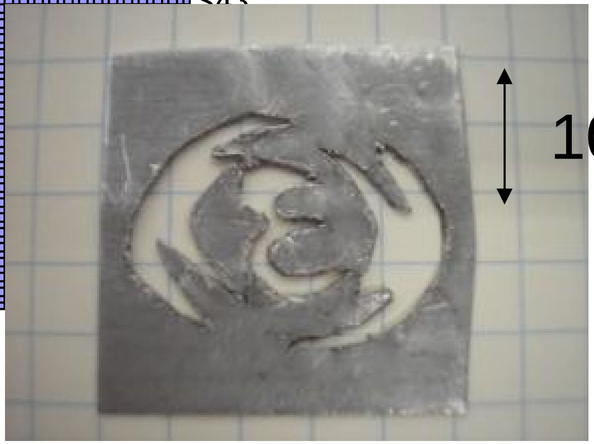
Detection Efficiency

- 1mm $^{\phi}$ 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

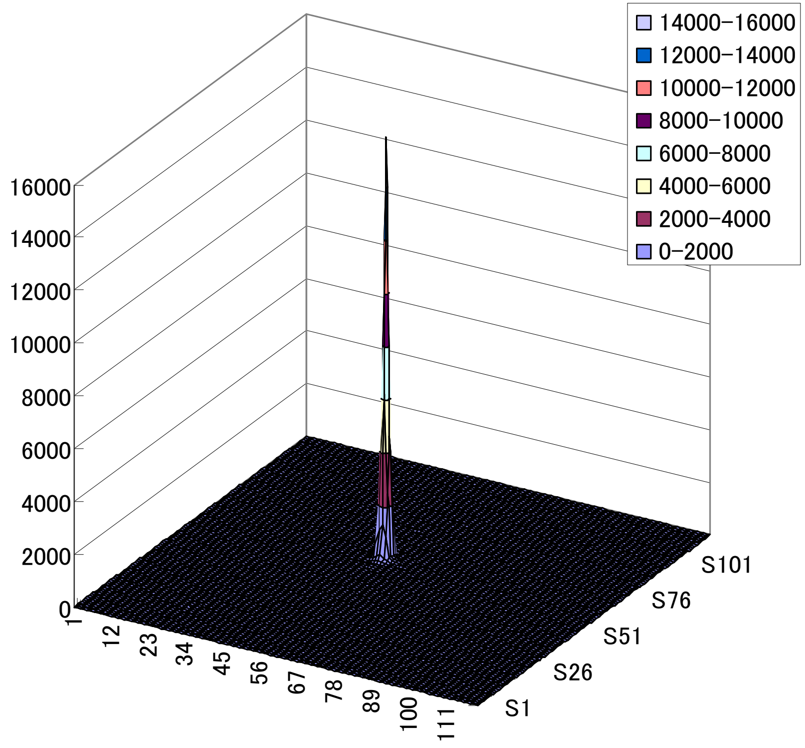
Two Dimensional Image

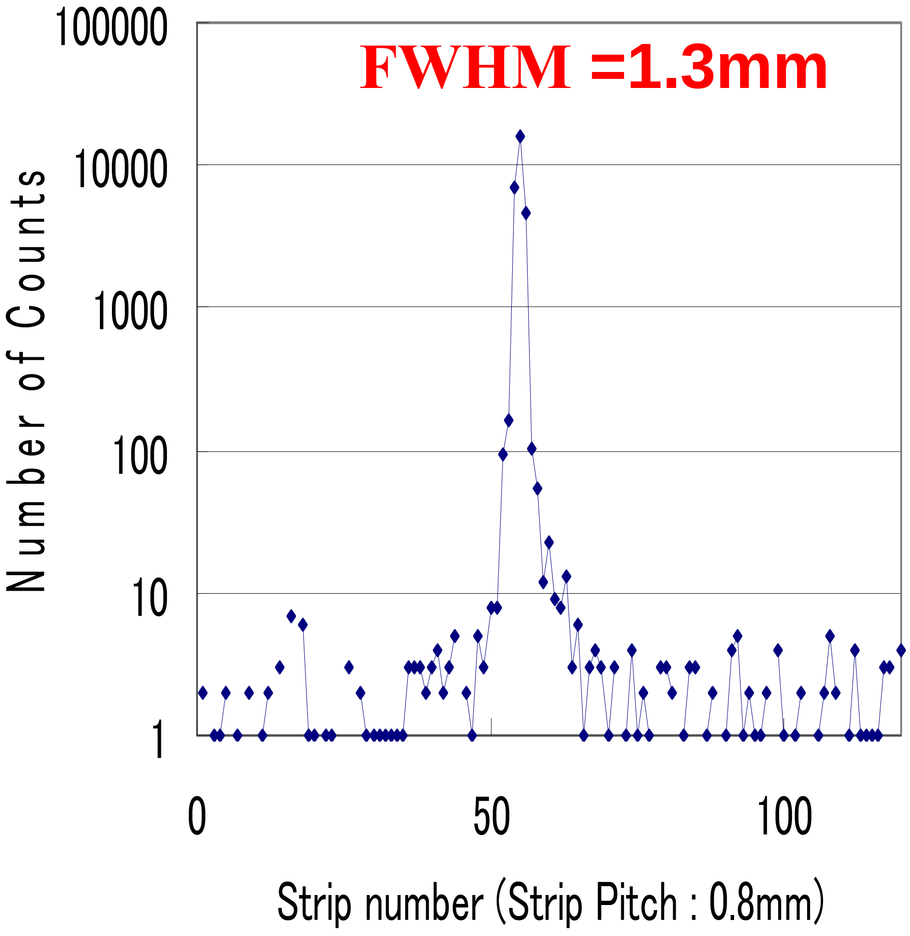




Position Resolution

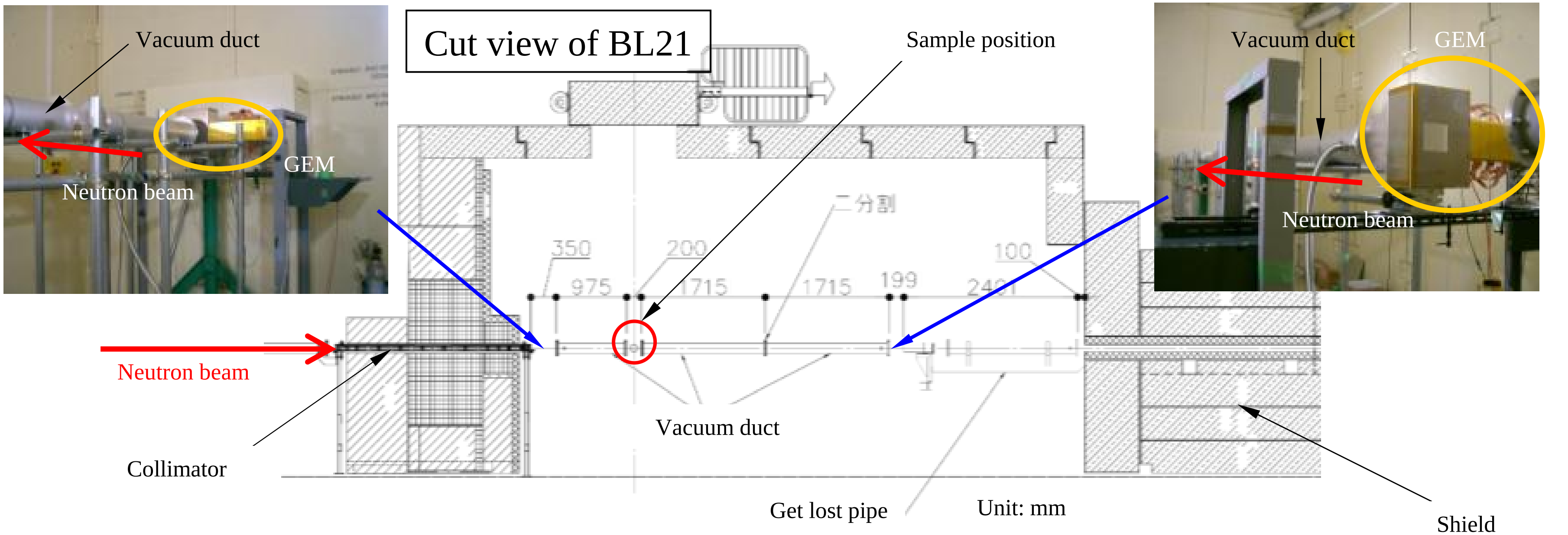
0.5mm$^{\phi}$ Pine Hole





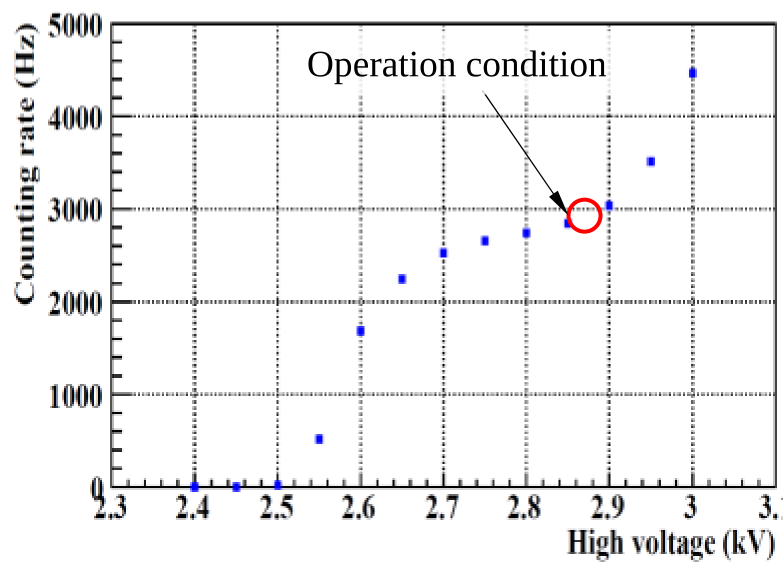
Test experiment at the pulsed neutron source in J–PARC

Experimental setup



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

The Plateau curve as a function of input high voltage

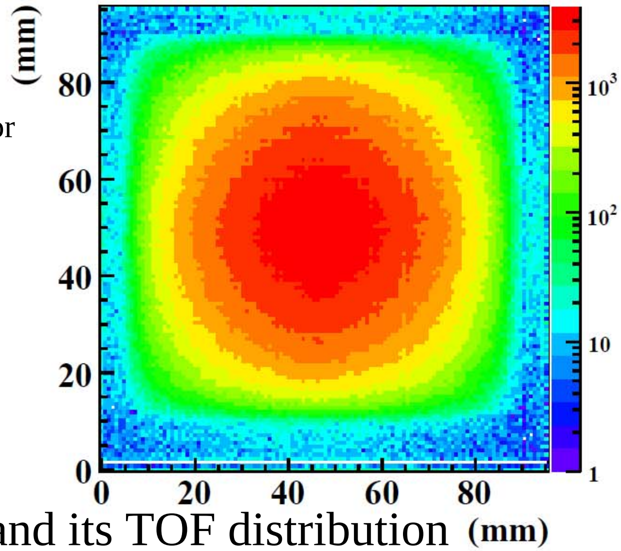


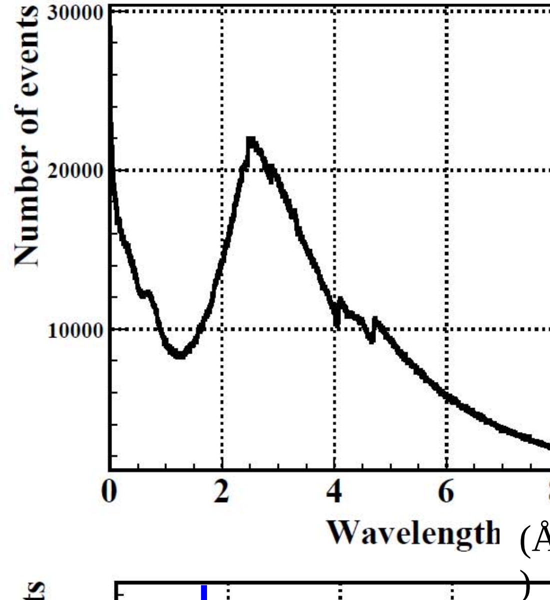
Data samples

The beam profile and its TOF distribution

L = 18789 mm ~ 18.8 m

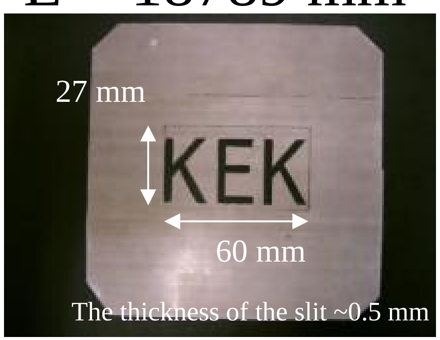
L: distance from the source to the detector



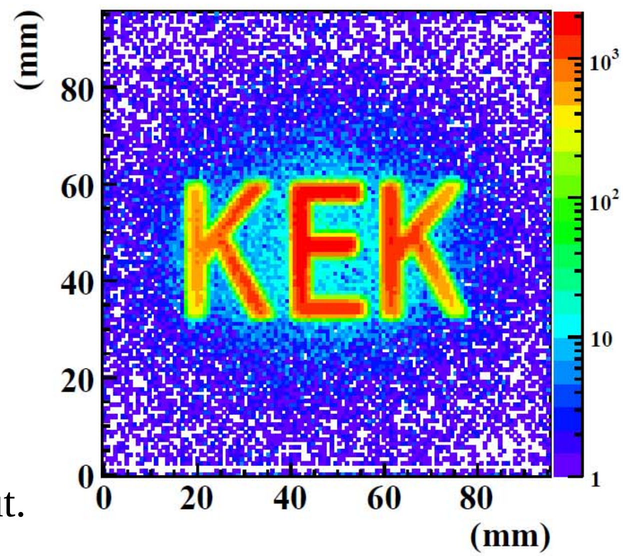


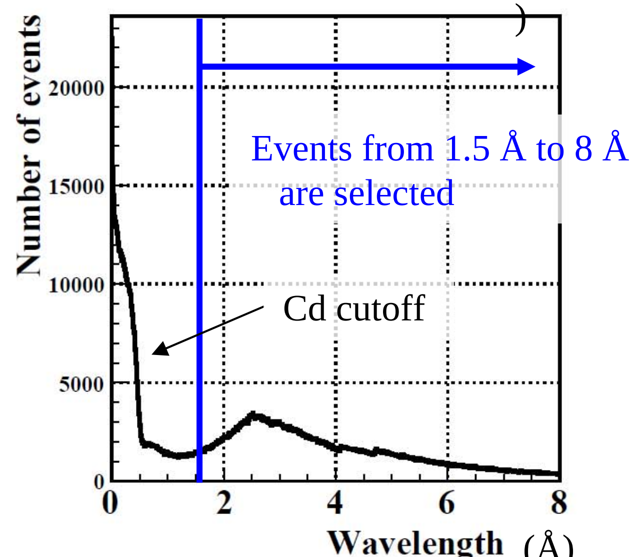
An image of a cadmium slit and its TOF distribution

L = 18789 mm



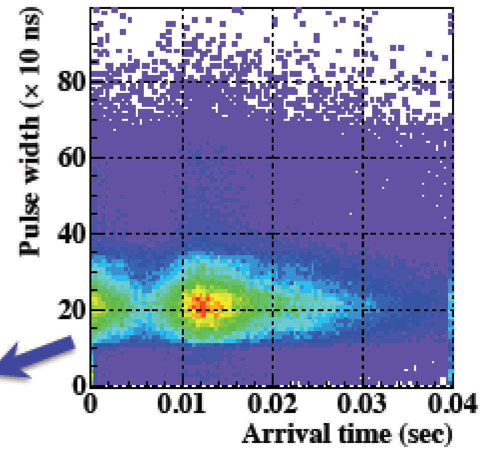
This image is produced with a wavelength cut.

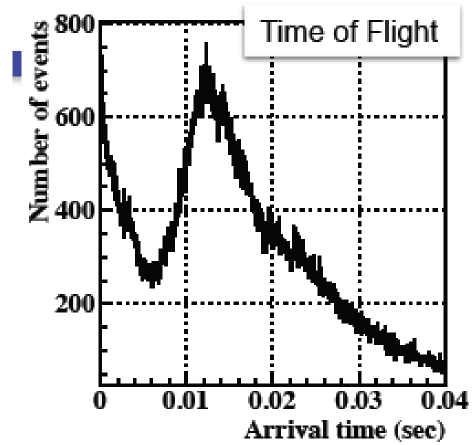


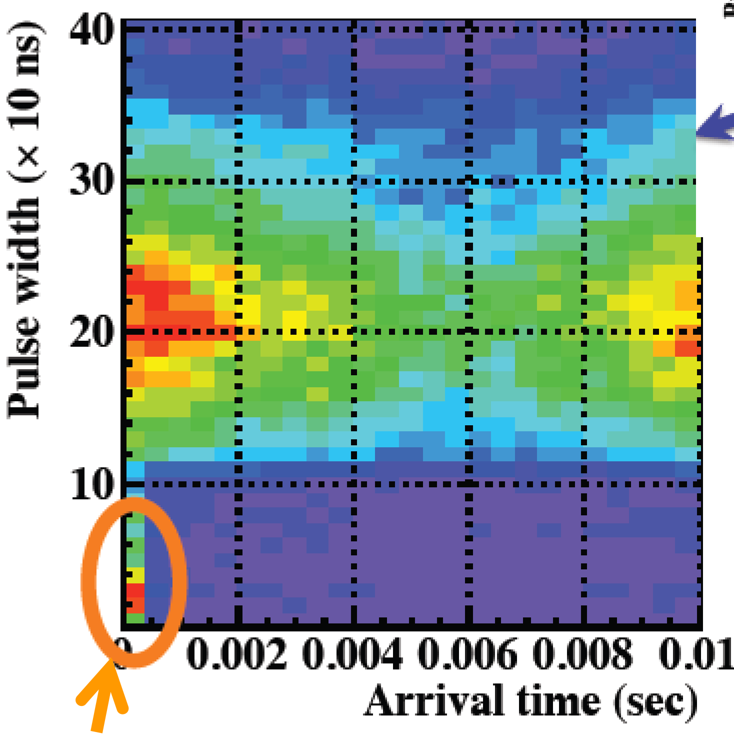


Our system can obtain a 2D image and its TOF at the same time.

Capability to reject gamma ray







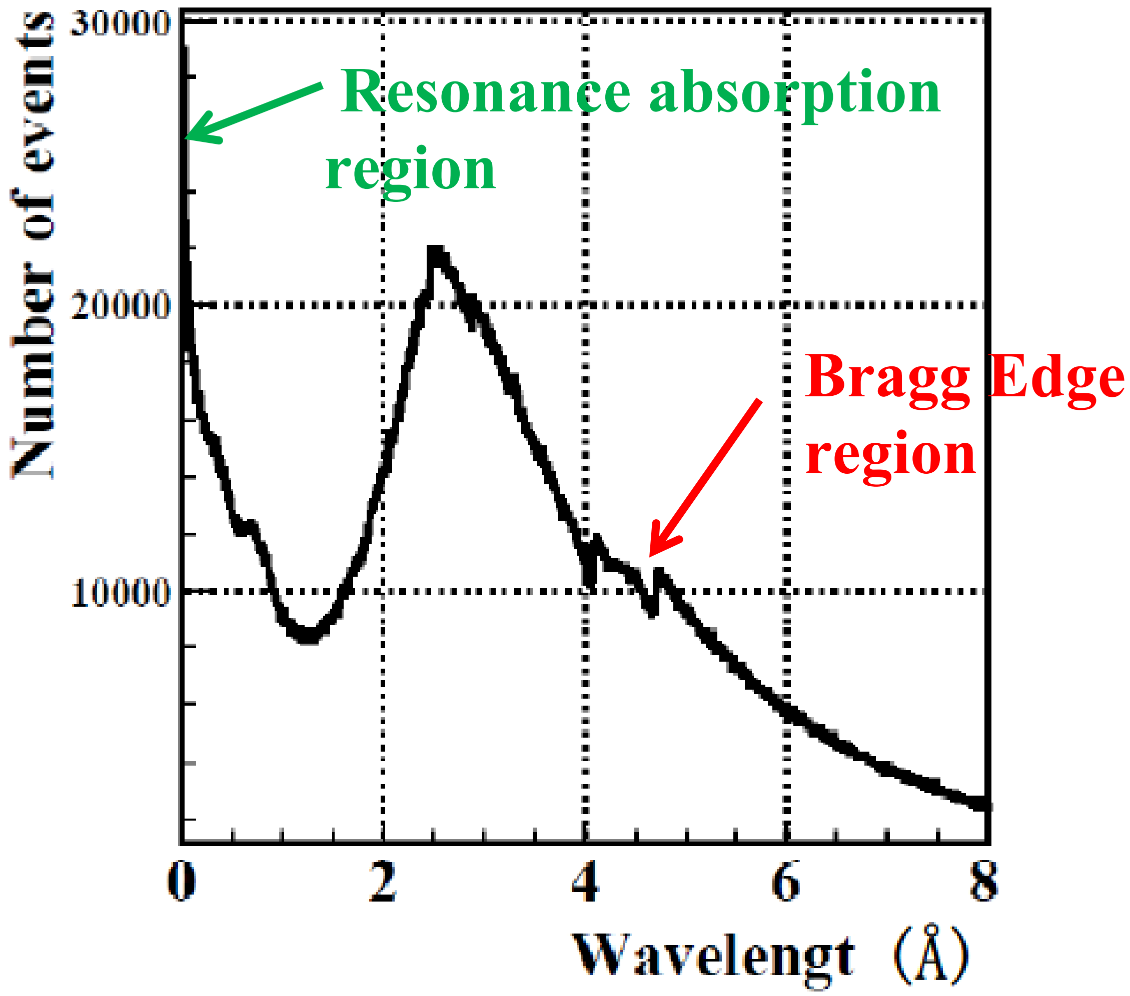
Gamma ray

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

Energy Selective Neutron Radiography

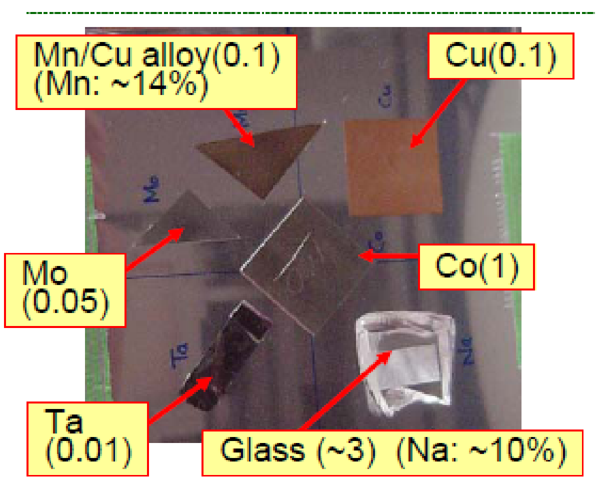
- Resonance absorption region
  - E>1eV
  - BL10 in MLF of J-PARC
- Bragg edge region
  - E : Cold or Thermal
  - Hokkaido University

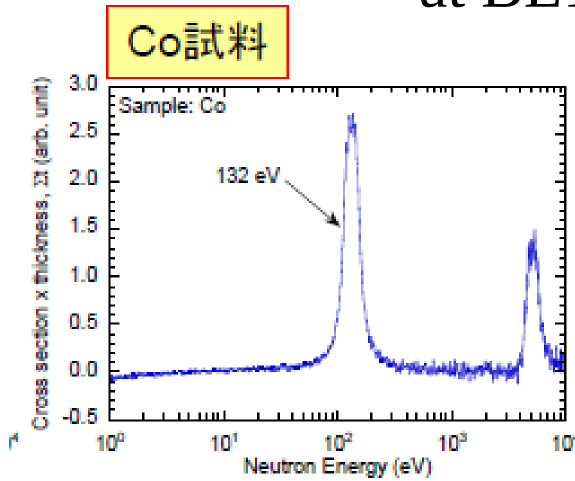
Energy Selective Neutron Radiography



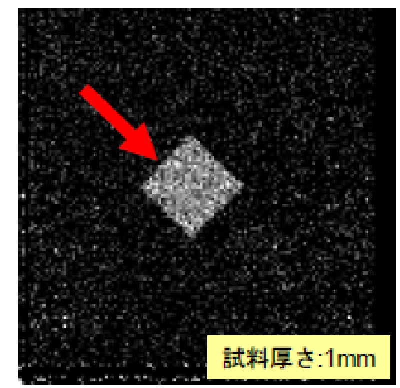
Resonance absorption imaging

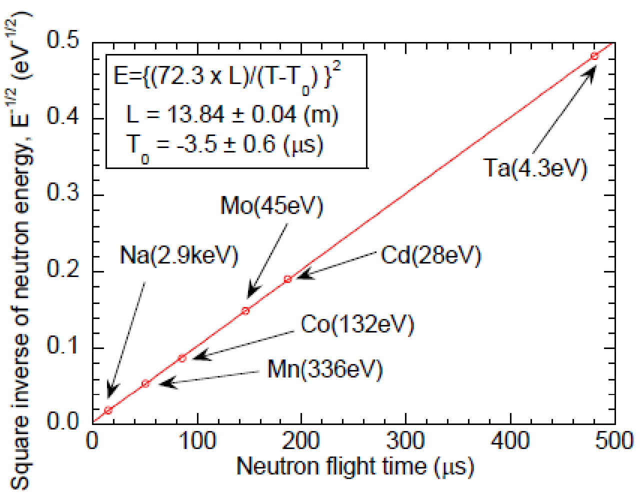
By T. Kai (JAEA) et al.
at BL10 in J-PARC

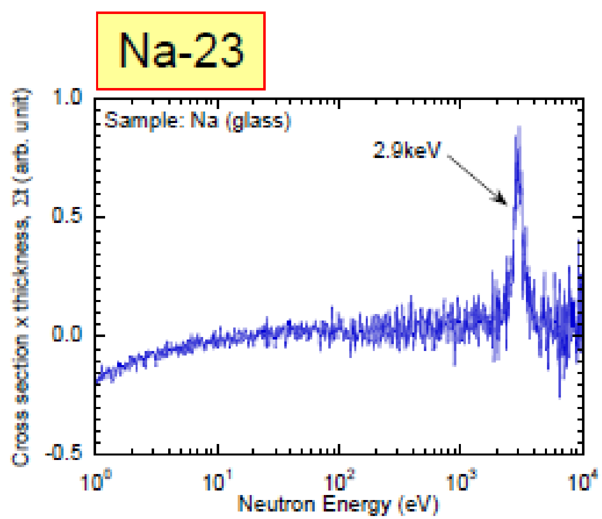




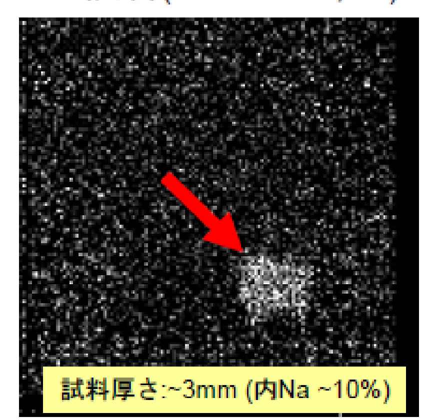
Co試料(9.29-11.8μs)



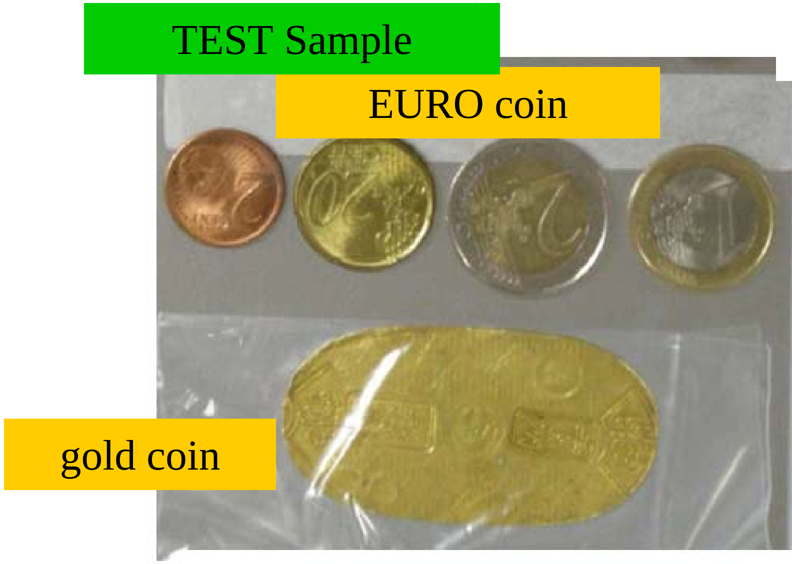




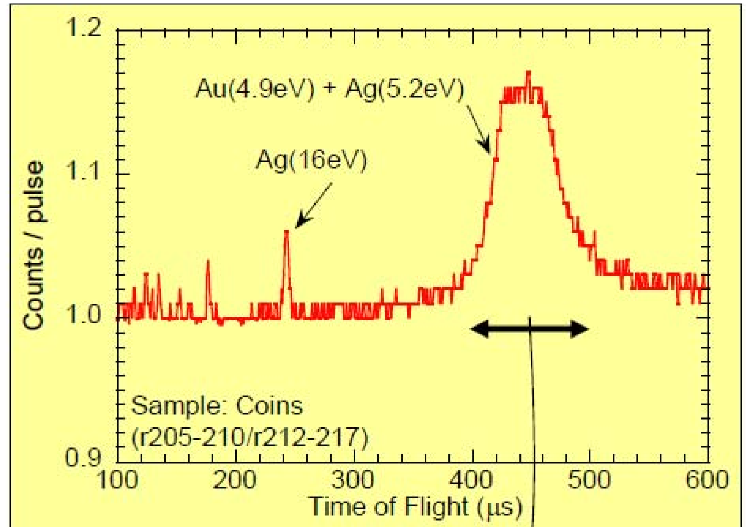
Na試料(14.5-15.5μs)

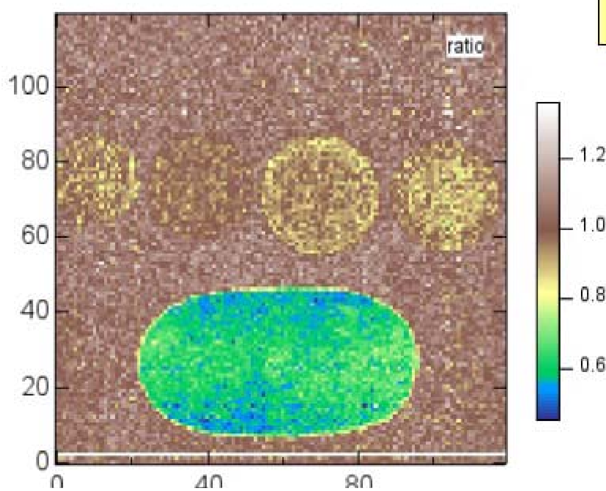


One more demonstration



Ratio of ToF spectrums with/without sample



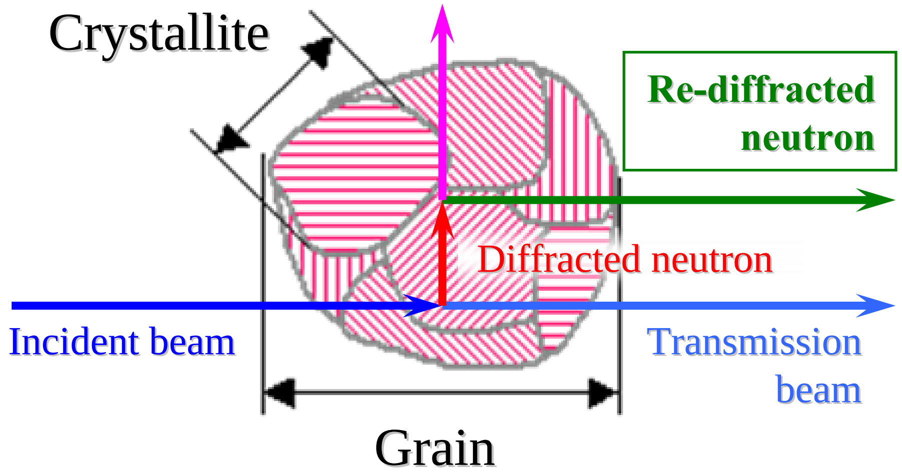


Imaging data with around 450μsec ToF

Extinction function for microstructure

H.Sato of Hokkaido University

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



Sabine function

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

↑ Bragg component ↖ Laue component

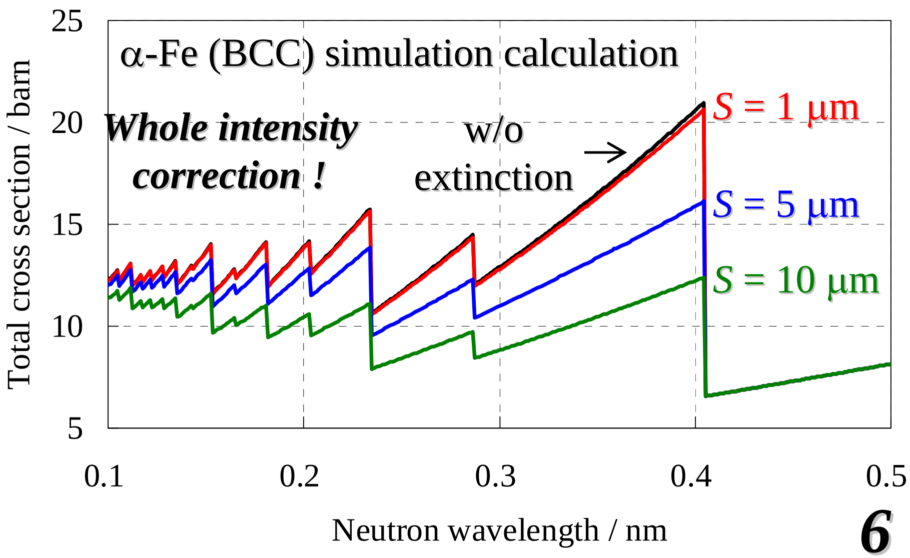
$$E_B = \frac{1}{\sqrt{1+x}}$$

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

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

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

○ : Refinement parameter



Visualized microstructure parameter

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

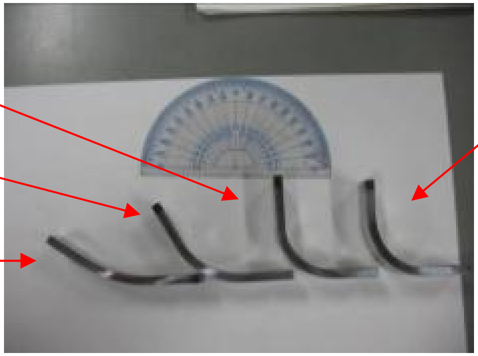
Imaging for bended iron plates at LINAC in Hokkaido University

Sample

90° Bend

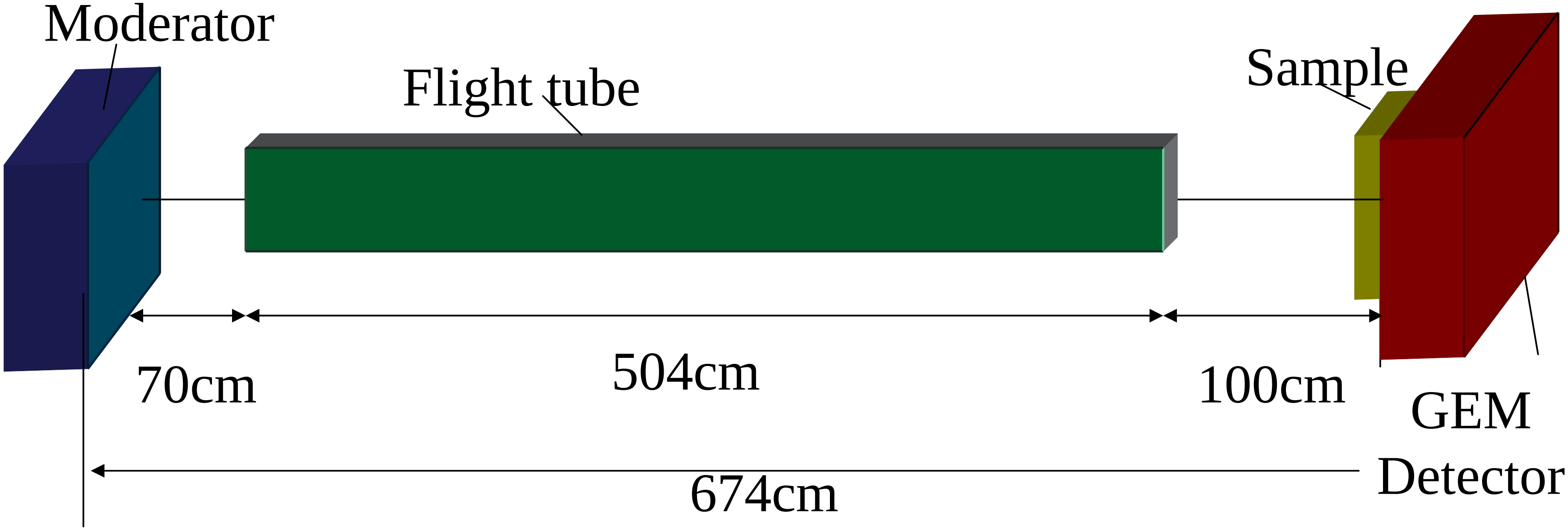
60° Bend

30° Bend

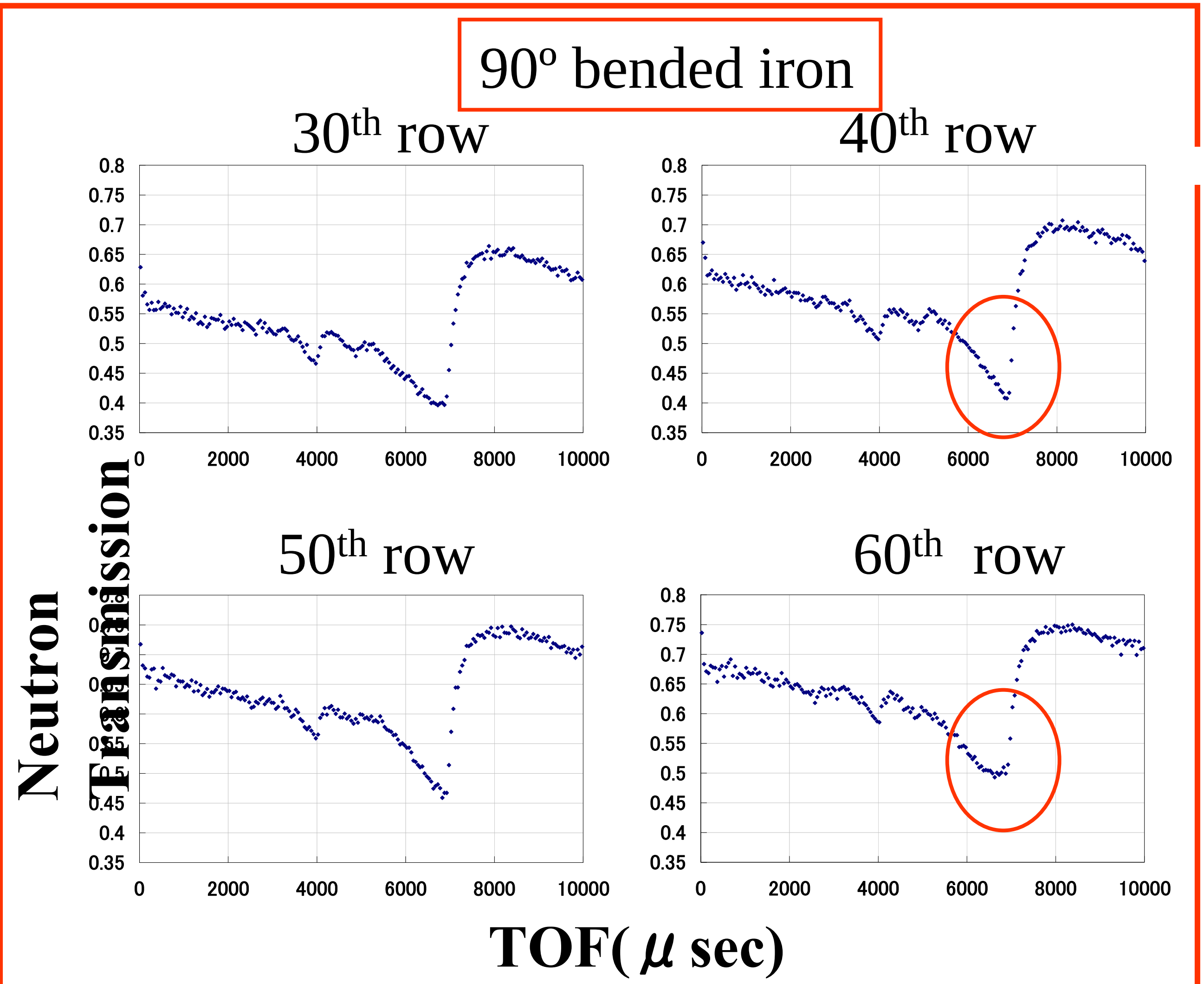


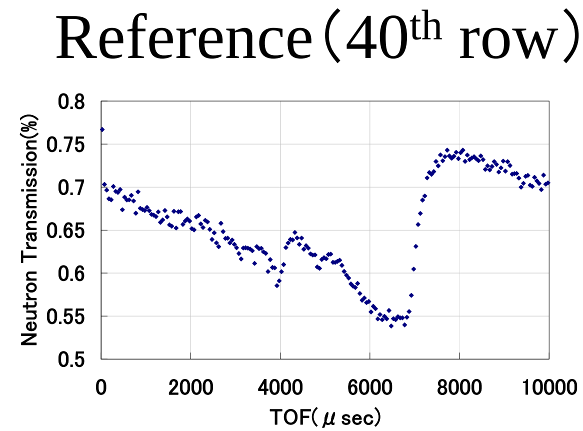
90° Bending and Re-flattening

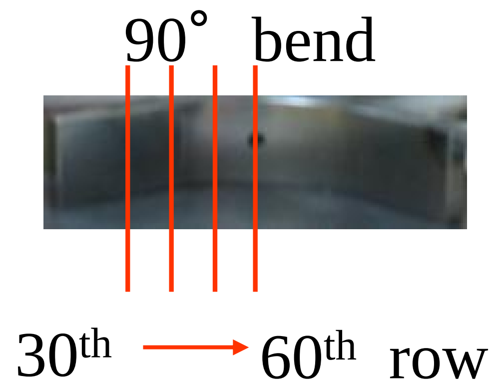
+Reference (without bending)



Transmission Spectrum for Bended Iron





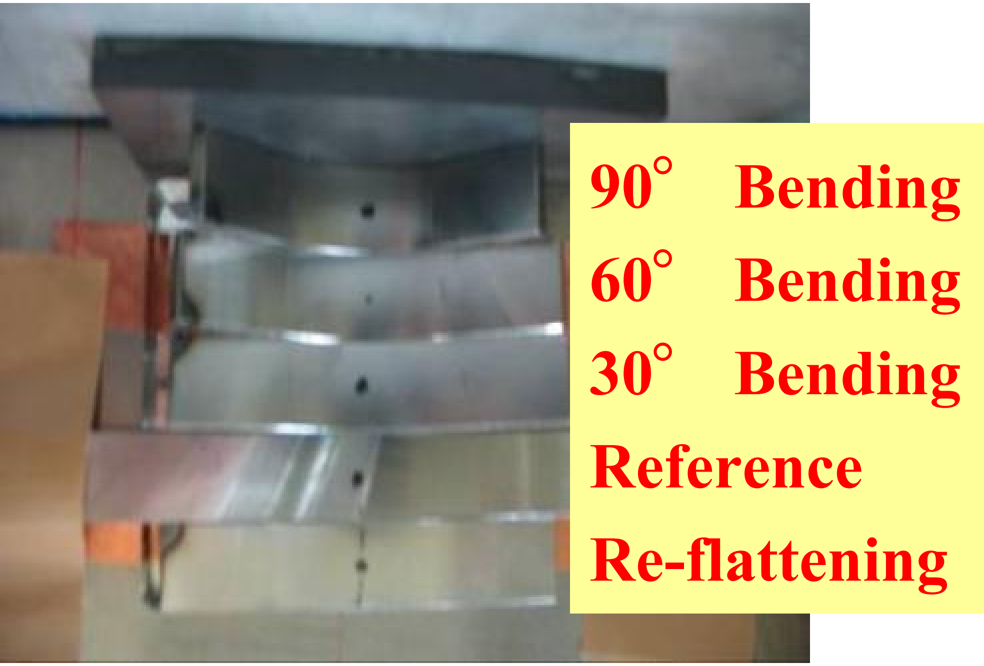


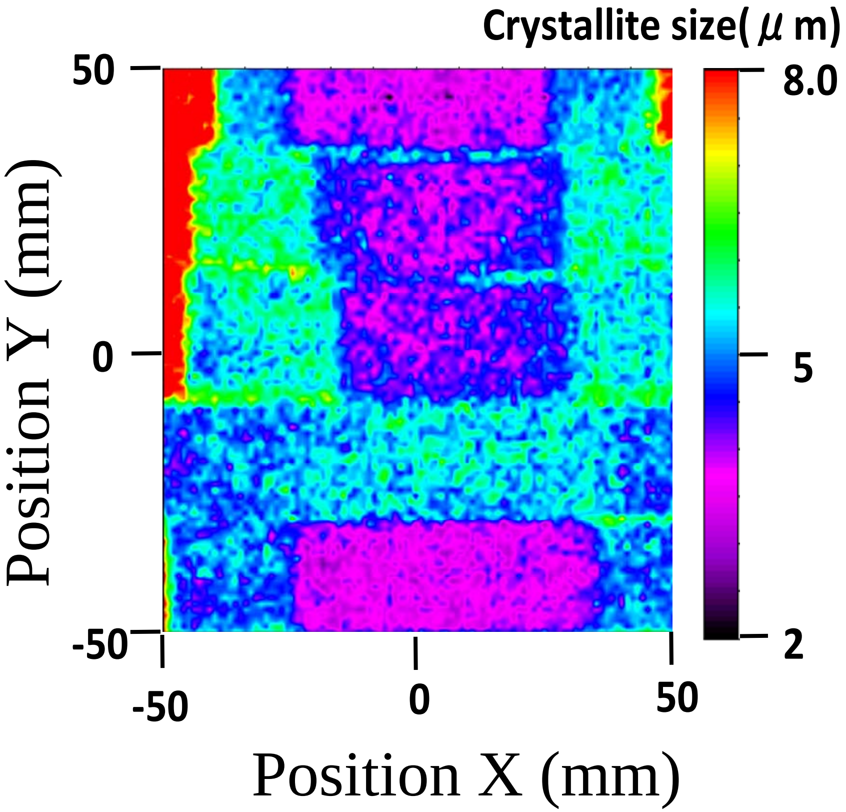
Shapes of Bragg-edge are analyzed in a RITS code, which is developed by H. Sato.

→ Crystallite size bin by bin

Results

Photo of iron plates





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

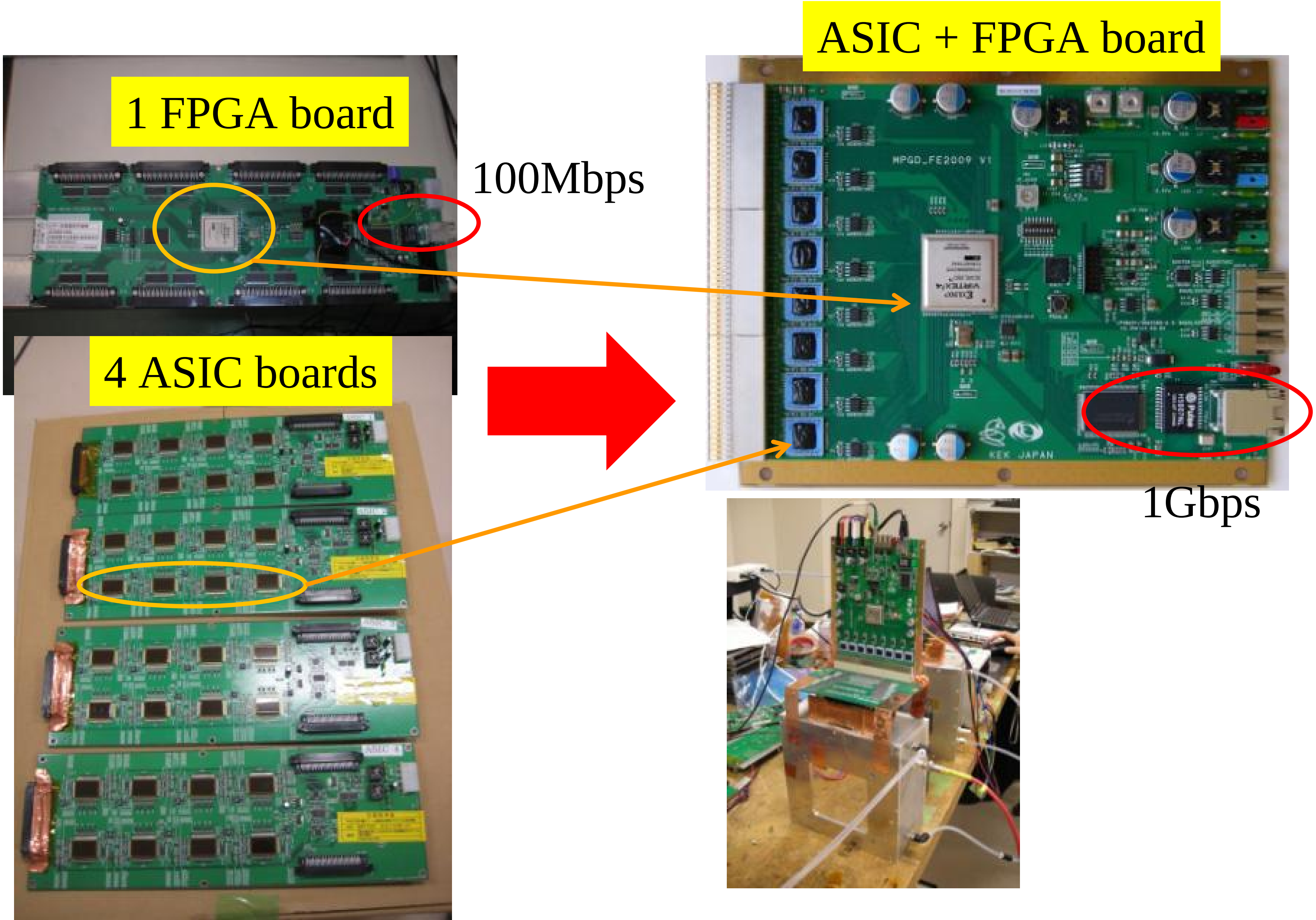
Visualization of microstructure for heavy material can be done even with rather weak pulsed neutron source (1kW).

Summary and Future Prospect

- Neutron detector with Boron coated GEM was constructed.
- Performance study was done with Neutron beam at JAEA.
  - Good position resolution without distortion
  - Good time resolution
- Test experiment at the pulsed neutron sources
  - 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.**
- Now, we are testing a new electronics board.
  - 100Mbps → 1Gbps Ethernet
  - More channels in one ASIC chip (8 → 32 channels)
  - 4 ASIC boards + 1 FPGA board

    → One compact board with ASIC chips and FPGA without cables

New readout board



Backup

Time resolution at MINE

Neutron Resonance Spin Echo Method
Modulated Intensity of Zero Effort (MIEZE)

Read points

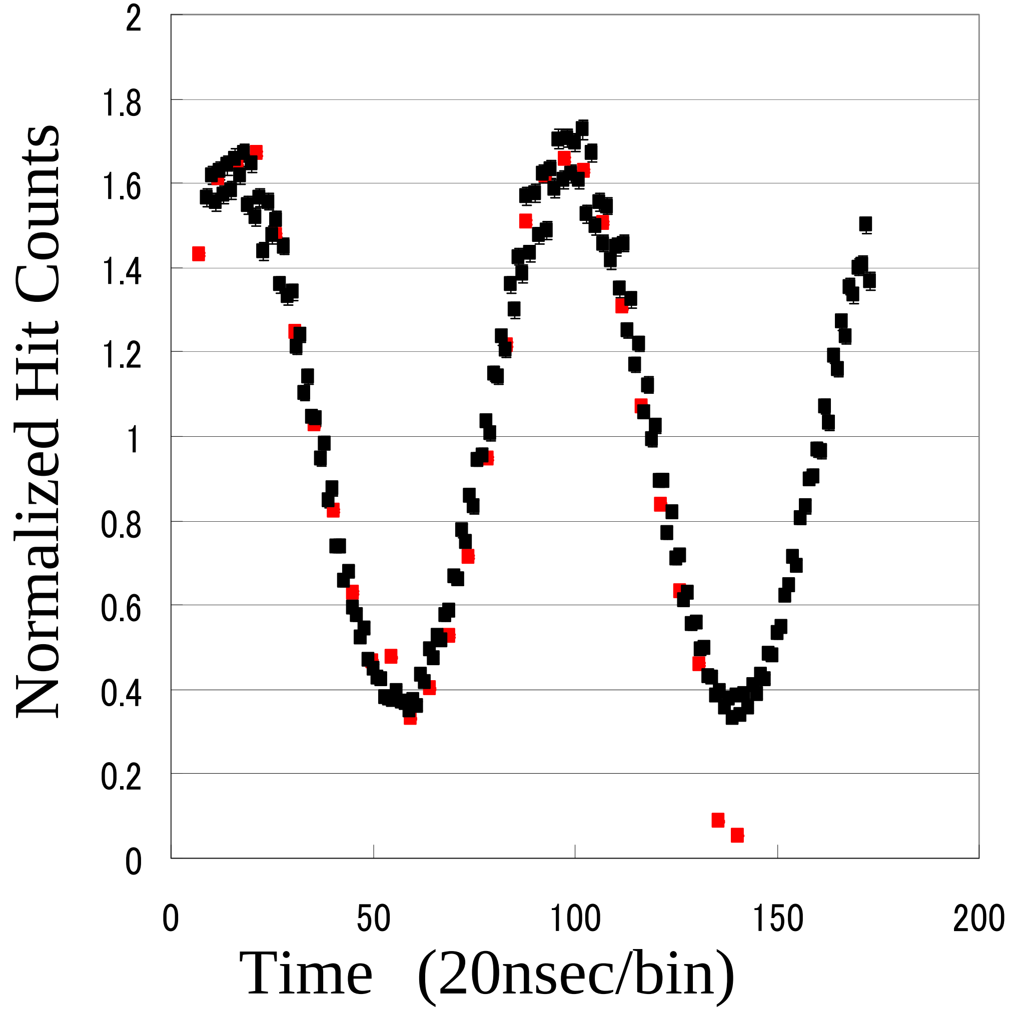
Li - Scintillator
＋
PMT(R3292)

PNSE：0.670±0.014
Frequency ：17.060±0.006 μ sec

Black Points

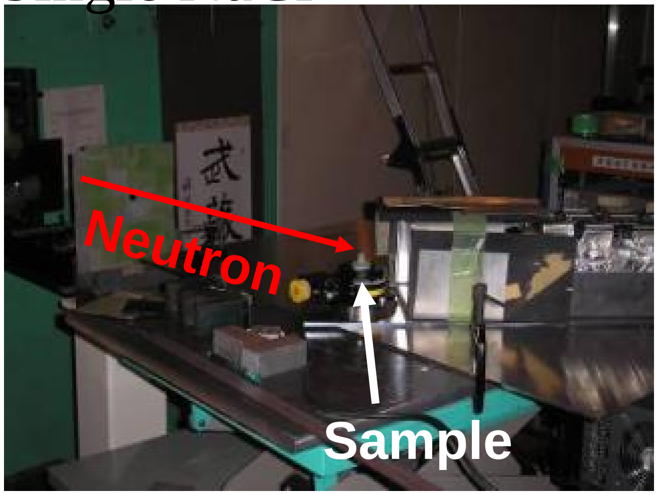
B10-GEM Chamber

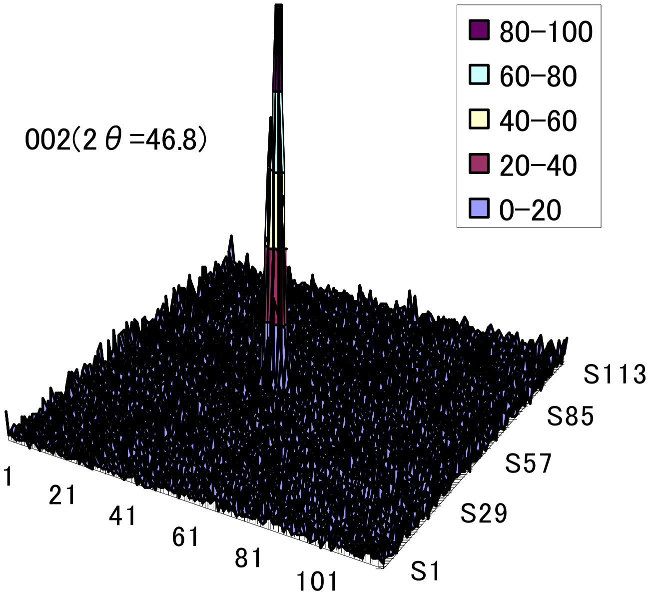
PNSE：0.650±0.007
Frequency ：16.700±0.004 μ sec



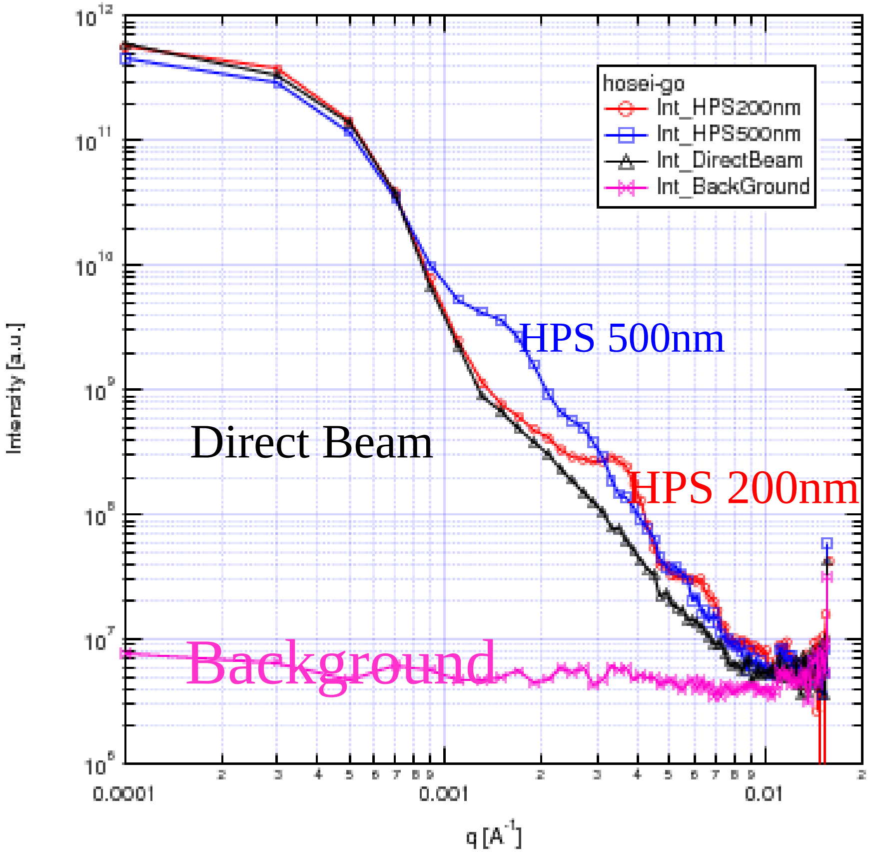
Sample test

Large angle scattering
Single NaCl

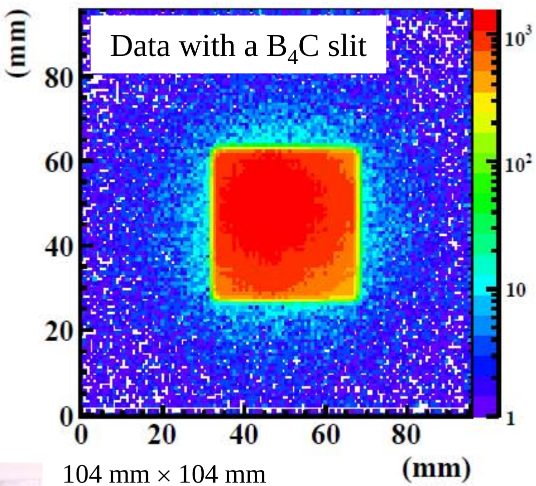


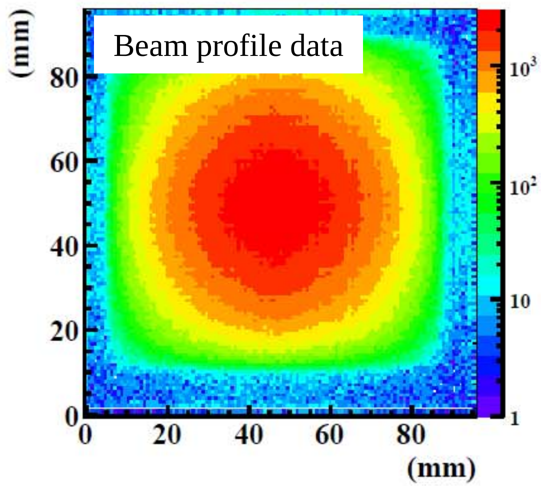


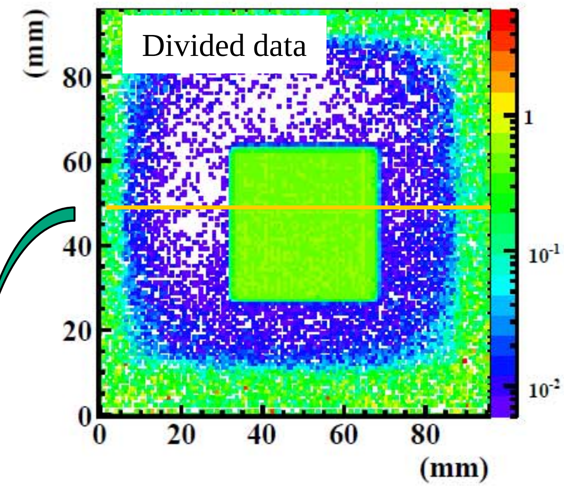
Small angle scattering
Hypresica (SiO_2)

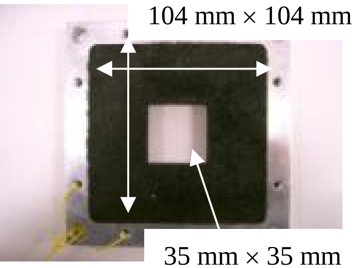


Position resolution



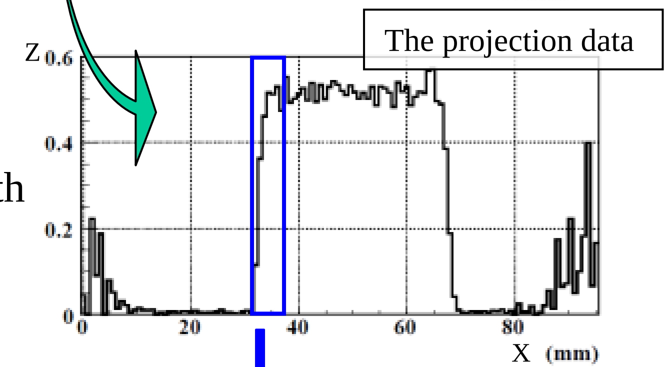






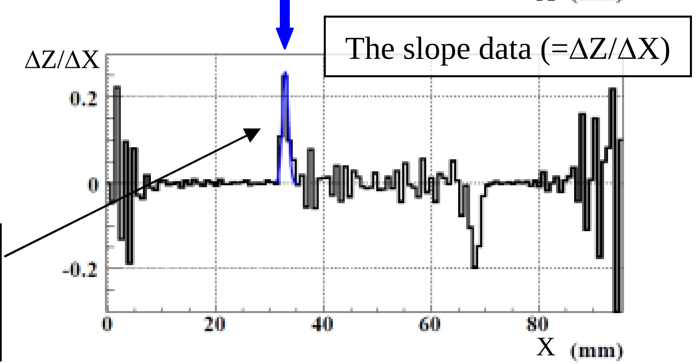
The B_4C slit (35 mm × 35 mm) was put in front of the GEM.

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.



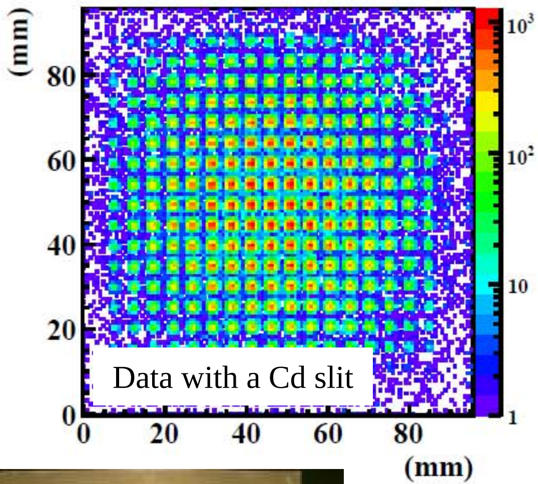
Constant: 0.26
Mean: 32.85
Sigma: 0.56

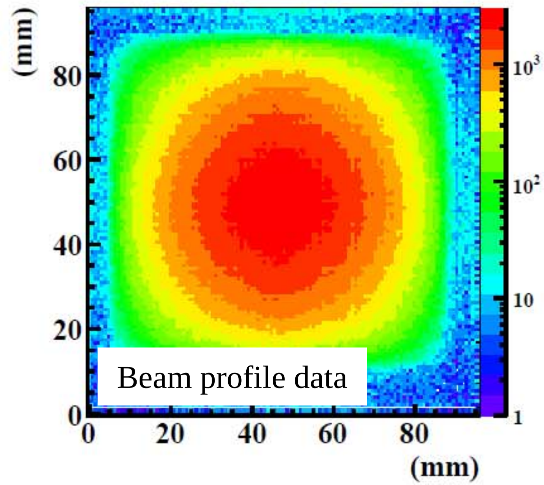
The position resolution; ~1.3 mm (FWHM)

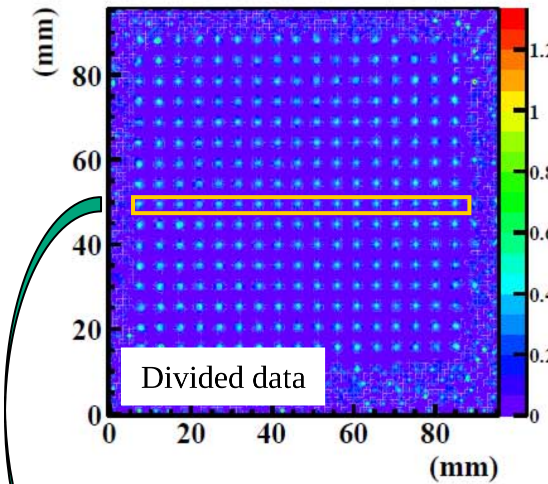
The correction of the beam divergence is not performed yet.

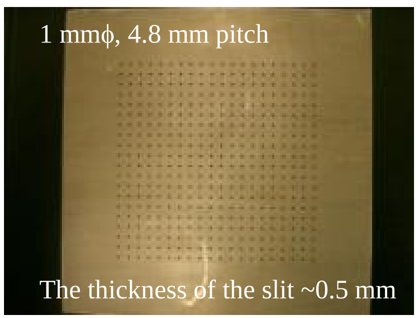
ΔZ/ΔX is obtained by subtracting the one from the adjacent one.

Uniformity (Neutron sensitivity, Imaging)



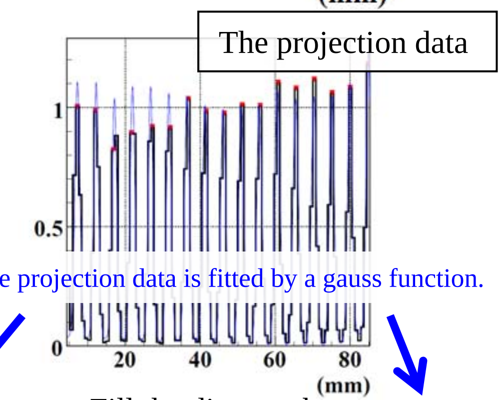






A cadmium slit (1 mmϕ, 4.8 mm pitch) was put in front of the GEM.

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)

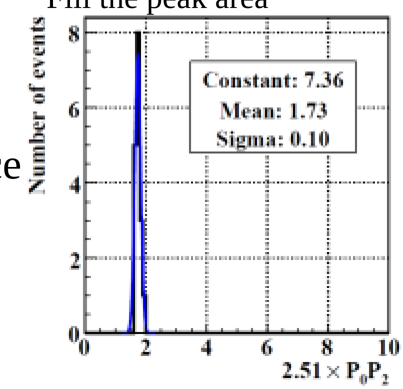
The dispersion of the neutron sensitivity is estimated at within 17%.

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

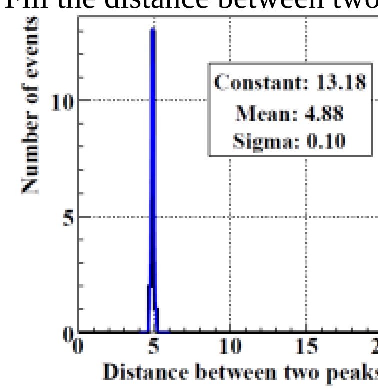
The distance between the peaks: 4.88 ± 0.10 mm

The distortion of the 2D image is very small.

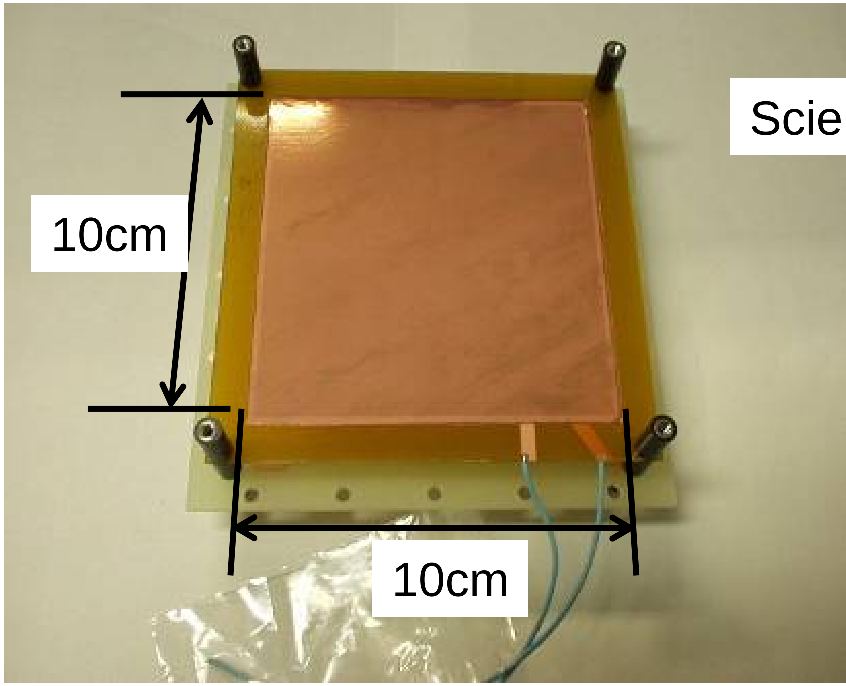
Fill the peak area



Fill the distance between two peaks



GEM Foil & Test Chamber

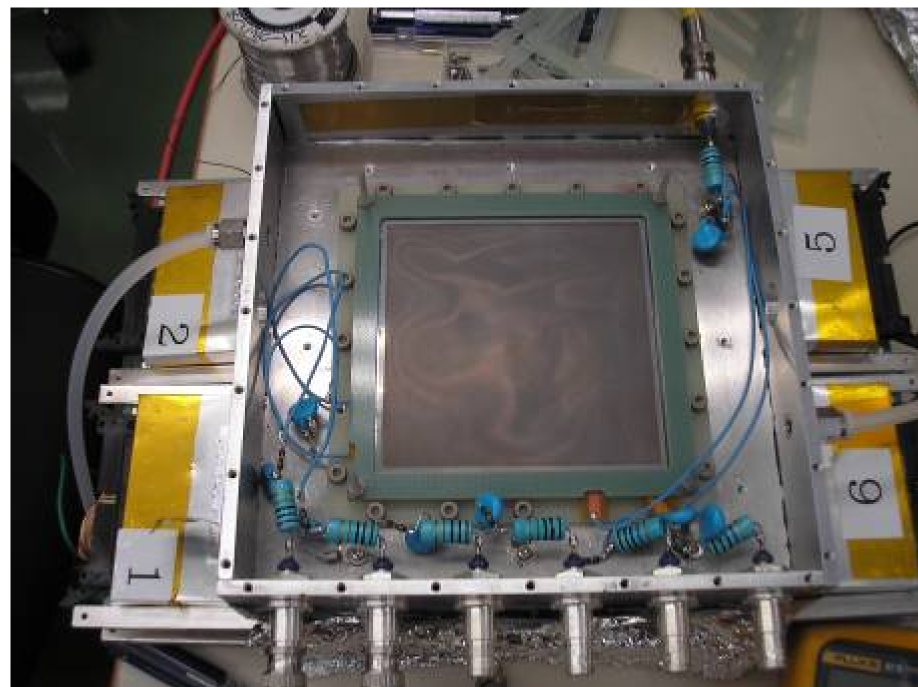


Scienergy Co., Ltd. (Japanese company)

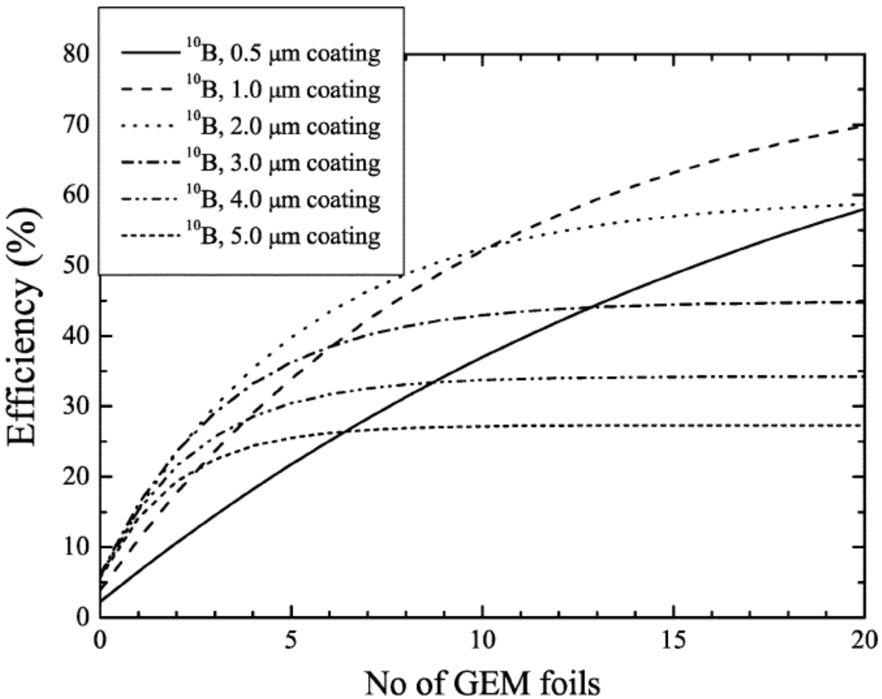
Standard GEM Foil
without Boron coating

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

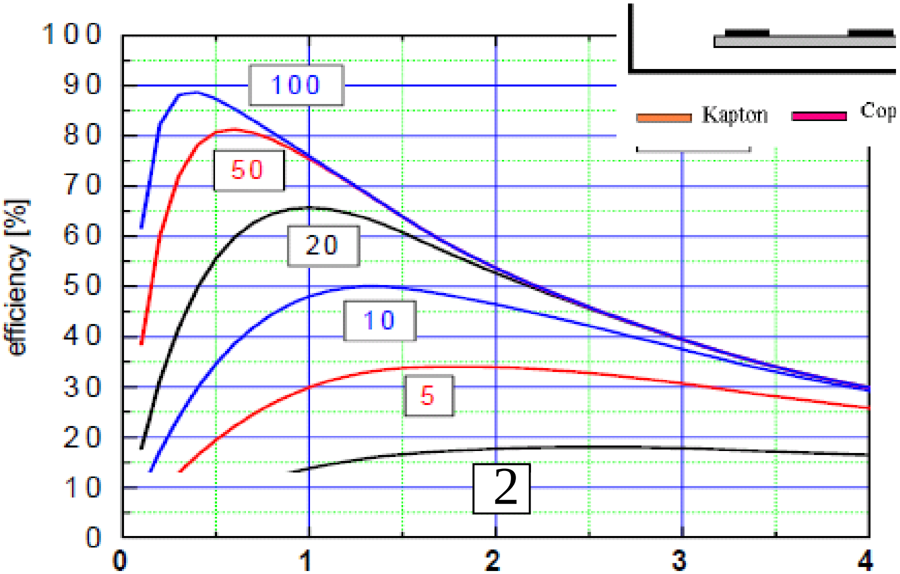
Boron coated GEM
Enriched B-10 Purity > 99%



Simulation study



No. of GEM foils



Thickness of ^{10}B (μm)

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

~32%X0.77＝ ~25%

CASCADE
M. Klein

~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.

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

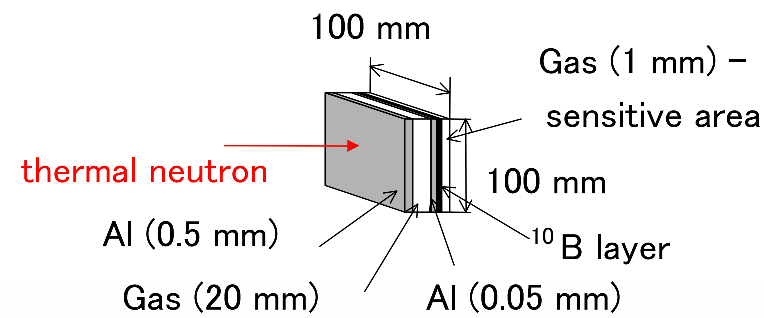
$$ {}^{7}_{3}Li^{*} \rightarrow {}^{7}_{3}Li + 0.48MeV $$

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

The GEANT4-based simulation

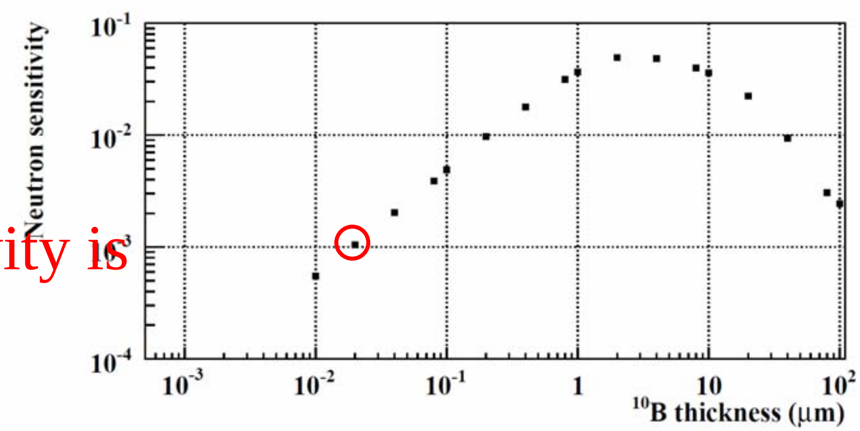
- 1.8 Å thermal neutrons shot into the detector at the normal incident.
- An event depositing energy in the gas is defined as a hit.

A schematic view of the Geant4-based simulation



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

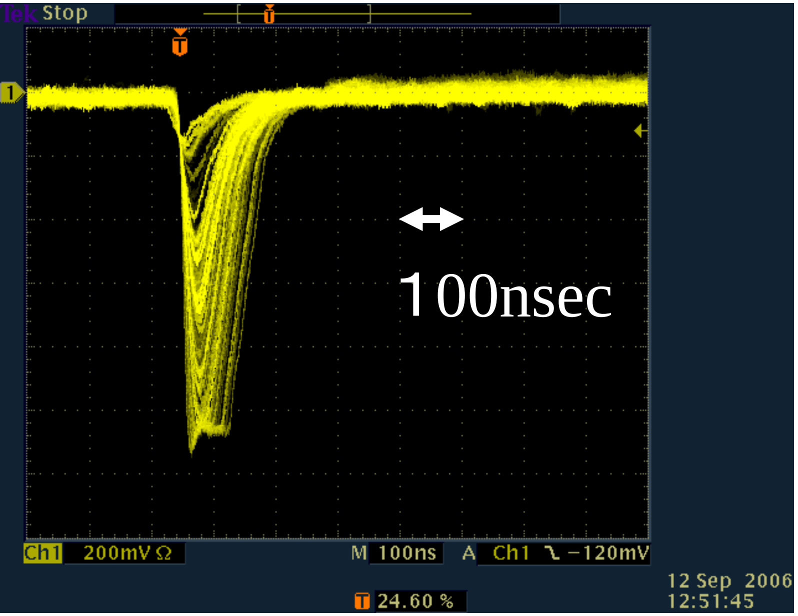
- The neutron sensitivity reaches its maximum around 3 μm.
- Over the thickness, charged particles (α or ^{7}Li) can't enter into the gas volume.



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

Signal Shape and Pulse Height Distribution

Neutron (2.2 Å)



200mV/div