

Commissioning test of a Neutron Beam Monitor for the High-Intensity Total Diffractometer at J-PARC

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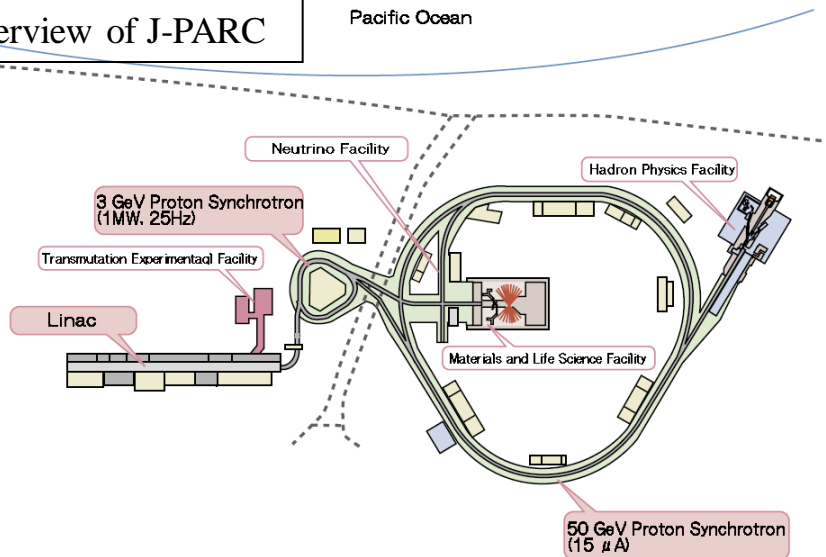
Now, this system keeps using as
a neutron beam monitor at MLF in J-PARC.

Contents

- Japan Proton Accelerator Research Complex (J-PARC)
- J-PARC history
- MLF, High-Intensity Total Diffractometer (BL21)
- Motivation
- Detector configuration
- Prototype detector
- Data transfer rate
- DAQ middleware
- Experimental setup
- Operation condition
- Typical wavelength-spectrum distribution
- Beam profiles
- Position resolution
- Summary

Japan Proton Accelerator Research Complex (J-PARC)

A overview of J-PARC



J-PARC is a joint project between two organizations, Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK).

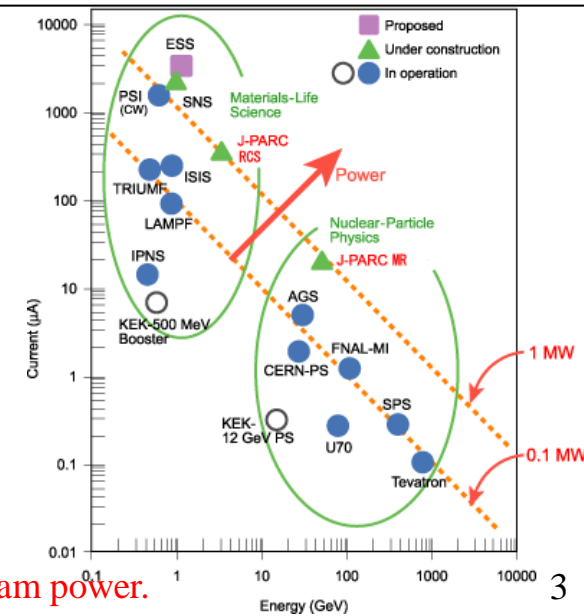
The facility is located in Tokai-Mura in Japan.

J-PARC consists of 3 accelerators, a linear accelerator, a rapid cycle synchrotron (RCS, 3 GeV) and a 50 GeV (Max) synchrotron.

The usage of various secondary particle beams (neutrons, muons, kaons, neutrinos, etc.)

The major scientific goals in J-PARC are nuclear-particle physics and materials and life sciences.

The beam power of several facilities



J-PARC is the world highest beam power, and will reach 1 MW beam power.

J-PARC history

History of J-PARC

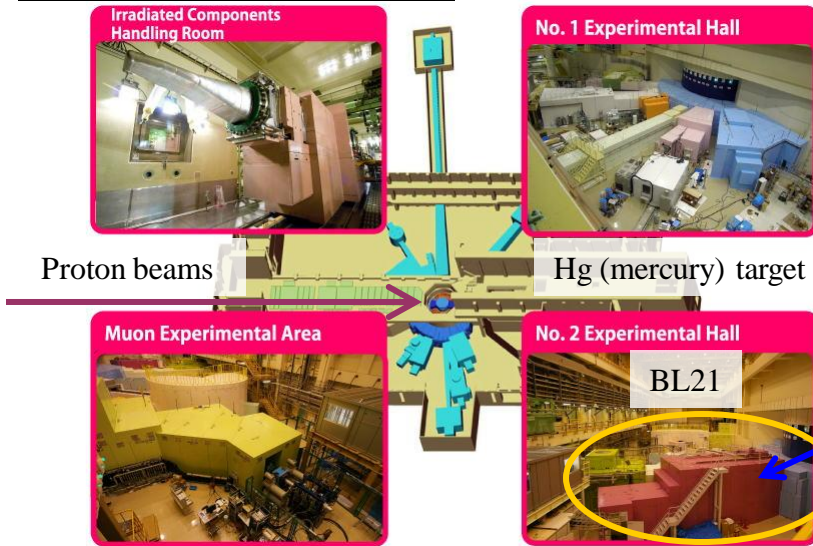
2001	The construction of J-PARC started.
2008/5	Neutron beams have been obtained.
2008/9	Muon beams have been obtained.
2009/2	Kaon beams have been obtained.
2009/4	Neutrino beams have been obtained.
2009/11	A steady operation of 120 kW at 3 GeV Proton Synchrotron.
2009/12	Operation of 300 kW at 3 GeV Proton Synchrotron has been succeeded.

J-PARC is ready to start some physics experiments.

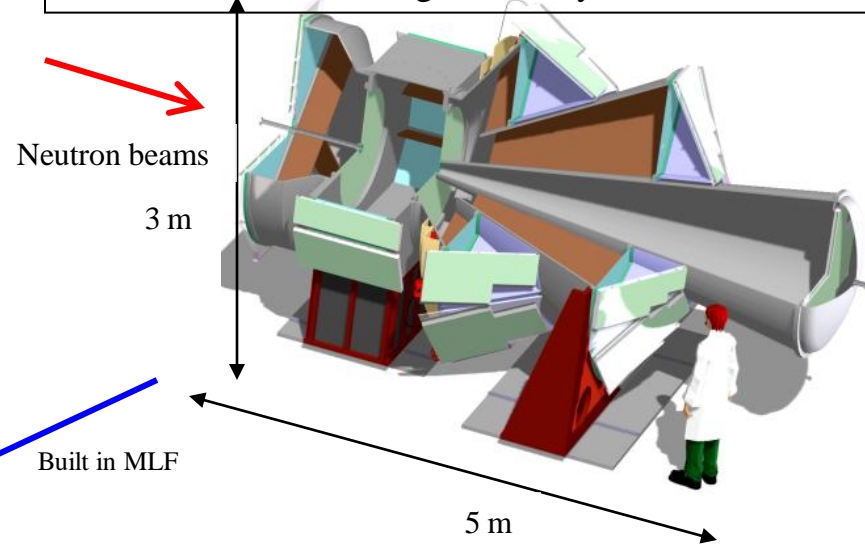
For materials and life sciences, the neutron and muon facilities have already been started the user program.

MLF, High-Intensity Total Diffractometer (BL21)

A schematic view of MLF



A schematic view of High-Intensity Total Diffractometer



Materials and Life Science Facility (MLF) at J-PARC is aimed at materials structure science and structural biology.

-23 neutron beam lines and 4 muon beam lines are equipped.

One of the world highest intensity pulsed neutron source; 5×10^8 n/s @ 1MW

High-Intensity Total Diffractometer (BL21) will research for the nature of hydrogen storage material.

- Neutron diffraction from samples is measured by the detector.
- One of the powder diffraction machine

BL21 has approximately 1400 Position Sensitive Detectors (PSDs) and two neutron beam monitors.

- PSDs are ^3He gas detectors and they are put around the vacuum chamber.
- For material structure analysis, it is important to measure the number of incident neutrons.

Motivation

A large amount of neutrons is expected in MLF with 1 MW operation.

We need to develop a new detector instead of a traditional detector.

- In particular, detectors irradiated by neutron beam directly

For more good statistical precision, we need to use a high-counting detector.

- For example, a traditional ^3He detector is limited by approximately 20 k cps.

But, our detector will reach approximately 1 M cps (after described).

To check the relative position between the neutron beam spot and the sample position, we need a two-dimensional (2D) detector.

Performance requirements of BL21 neutron beam monitor are summarized;

- Neutron sensitivity: $\sim 0.1\%$ (The value is decided by the limitation of the data transfer rate.)
- Data transfer rate: ~ 1 MHz
- Position resolution: ~ 1 mm (FWHM)
- Wavelength separation capability
- Active area: ~ 50 mm \times ~ 50 mm

A Gas Electron Multiplier (GEM) is known to have a high rate capability (more than 10^7 Hz/cm²)

A GEM is one of the few detector which satisfies all the requirements.

We developed a GEM-based neutron beam monitor.

Detector configuration

For neutron detection, the ^{10}B -coated Al plate is used.

- The thickness of ^{10}B is approximately $0.02\text{ }\mu\text{m}$.

For gas amplification, two “standard” GEMs are used.

- Their foil thickness are $50\text{ }\mu\text{m}$.

All our GEMs are purchased from SciEnergy Co., Ltd
(<http://www.scienergy.jp/>).

Chamber gas; $\text{Ar}/\text{CO}_2 = 70:30$

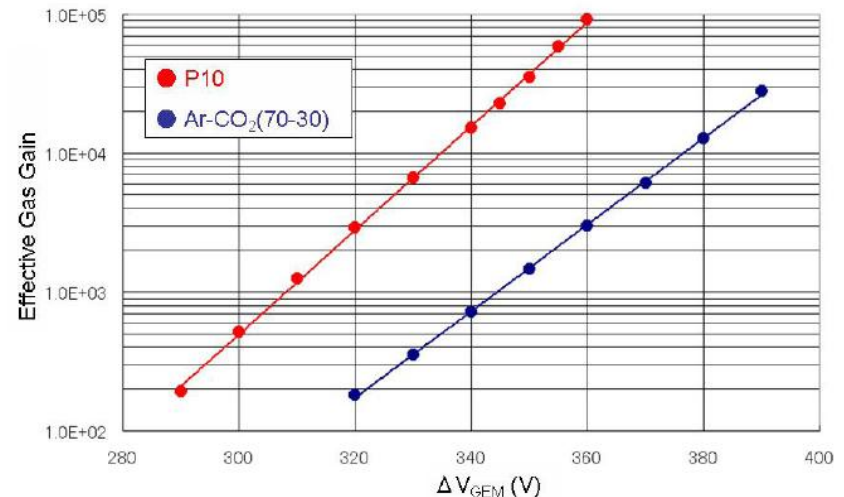
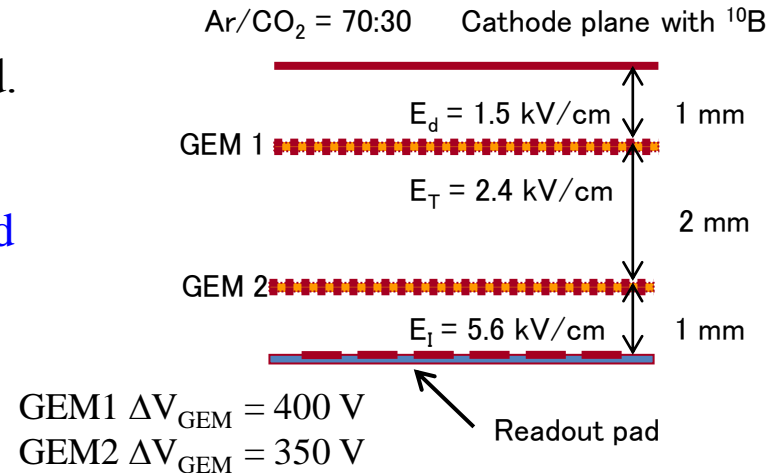
A readout pad is designed to output 2-dimensionally with 0.8 mm pitch.

For stable operation, input voltage to a GEM foil (ΔV_{GEM}) is different between two GEMs.

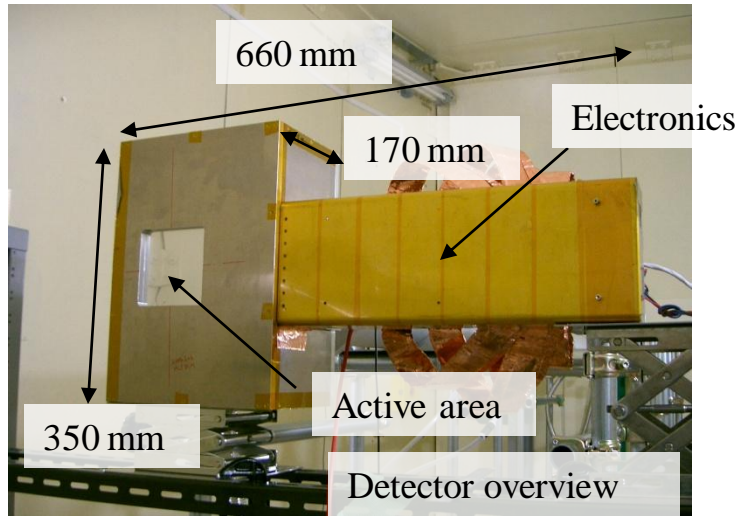
Effective gas gain is approximately 400.

- Effective gas gain as a function of ΔV_{GEM}
- Effective gas gain in this figure was obtained by triple-GEM.

A schematic cross-sectional view

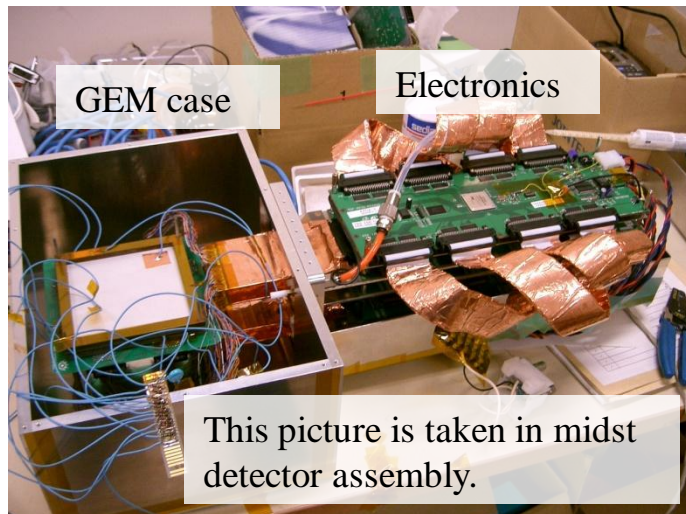


Prototype detector



Detector specification

- Detector size: 660 mm × 350 mm × 170 mm
- Active area: 100 mm × 100 mm
- Readout channel: 120 ch × 120 ch with 0.8 mm pitch
- T_0 input is equipped.



A compact 2D imaging detector

The system consists of four characteristic components;

(1) Micro Pattern Gas Detector, GEM

is used for gas amplification.

(2) Application Specific Integrated Circuit (ASIC)

is used for signal amplification and digitalization.

we call the ASIC “FE2007”.

Y. Fujita, et al., “Performance of Multi-Channel and Low Power Front-End ASIC for MPGD μ -PIC Readout”, IEEE NSS 2007.

(3) Hardware-based TCP processor (“SiTCP”)

is used for data transfer, and we call the device “SiTCP”.

T. Uchida, IEEE TNS 55 (2008) 1631.

“SiTCP” is written in FPGA.

“SiTCP” is able to transfer data to a hard disk via Ethernet network.

(4) DAQ middleware

is used for online monitor and data acquisition.

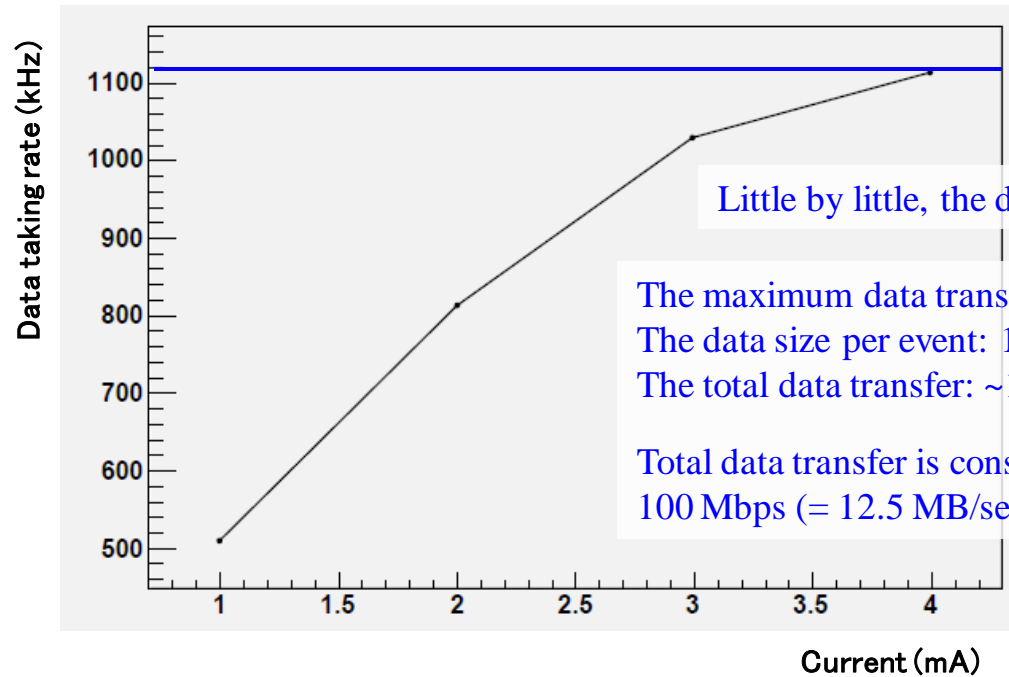
The system is not need a huge DAQ system like as a CAMAC system or a VME system.

Their technologies are developed in the KEK detector technology project (<http://rd.kek.jp>) .

Data transfer rate

In order to check the performance of “SiTCP”, we measured the data transfer rate.

- with X-ray irradiation
- Readout electronics are exactly the same.
- The number of incident x-rays is proportional to the beam current.



Little by little, the data transfer rate becomes saturated.

The maximum data transfer rate: ~1.1 MHz

The data size per event: 10 byte

The total data transfer: ~11 MB/sec ($\approx 1.1 \text{ MHz} \times 10 \text{ byte}$)

Total data transfer is consistent with the limit of 100 Mbps (= 12.5 MB/sec) Ethernet specifications.

We found that our system has a enough data transfer capability.

DAQ middleware

DAQ middleware is a standard tool for MLF in J-PARC.

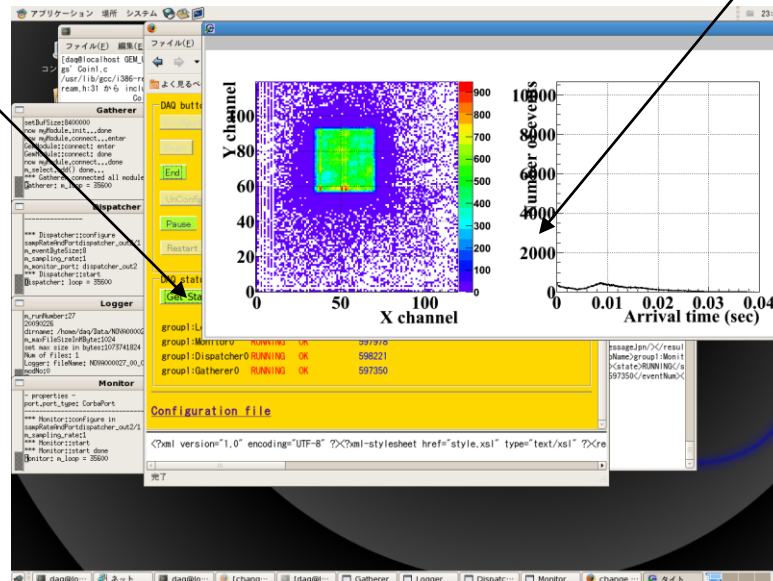
Users are able to take data without regard for the difference of detectors and to control the detectors from a web browser.

DAQ middleware is available as an online monitor.

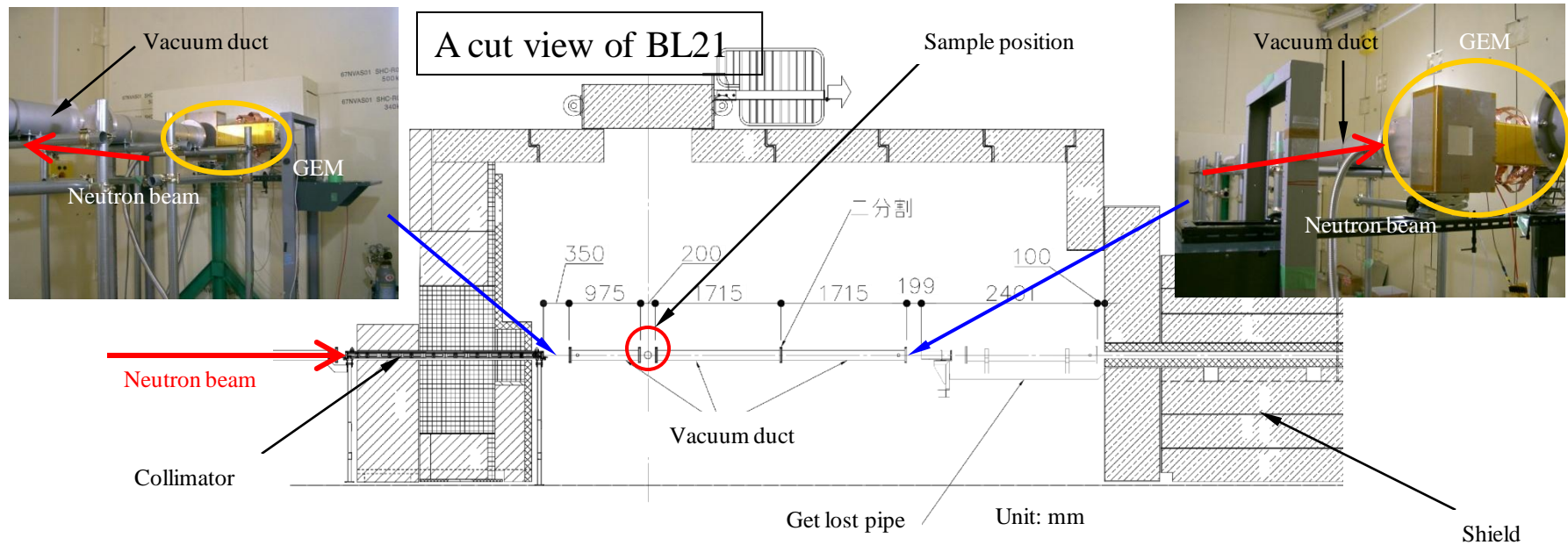
Control panel in a web browser

The 2D image and the TOF distribution are updated every additional 100 events.

A screen shot during data taking



Experimental setup



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

Some vacuum ducts were set instead of a vacuum chamber.

The GEM detector was set between the vacuum ducts.

Beam operation condition: 20 kW, 25 Hz

A chopper was not installed, a collimator was installed.

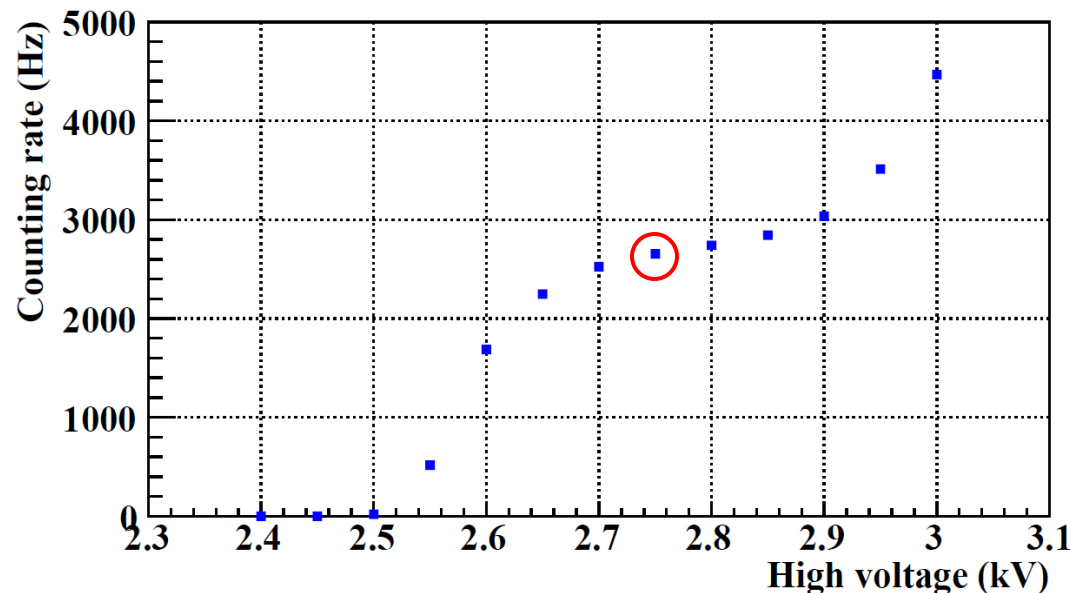
Some beam profiles and TOF distributions were measured.

Operation condition

The plateau curve as a function of input high voltage

- The GEM has plateau region between 2.7 kV and 2.85 kV.
- Over 2.9 kV, a discharge event occurred.

We decided operating the GEM at 2.75 kV.



Typical wavelength-spectrum distribution (1)

The wavelength-spectrum distribution is derived from the TOF distribution.

The typical wavelength-spectrum distribution;
The histogram represents the measurement
The graph with a “+” symbol represents the calculation

As a calculation, we estimate the neutron reaction rate.

Neutron reaction rate R

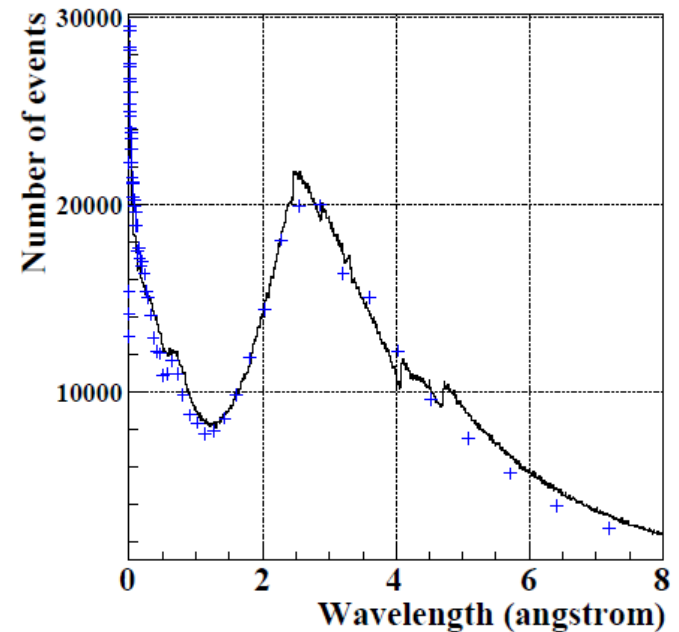
$$R = \int \phi(E) N \sigma(E) dE$$

where $\phi = \int \phi(E) dE$ is the neutron flux, N is the number of ^{10}B atoms in the neutron convertor, $\sigma(E)$ is the neutron cross section.

The neutron flux is used by the simulation results [*].

[*] M. Harada, “Pulse characteristics estimation for 23 neutron beam lines at JSNS”

http://j-parc.jp/MatLife/en/instrumentation/data/Pulse_paper.pdf



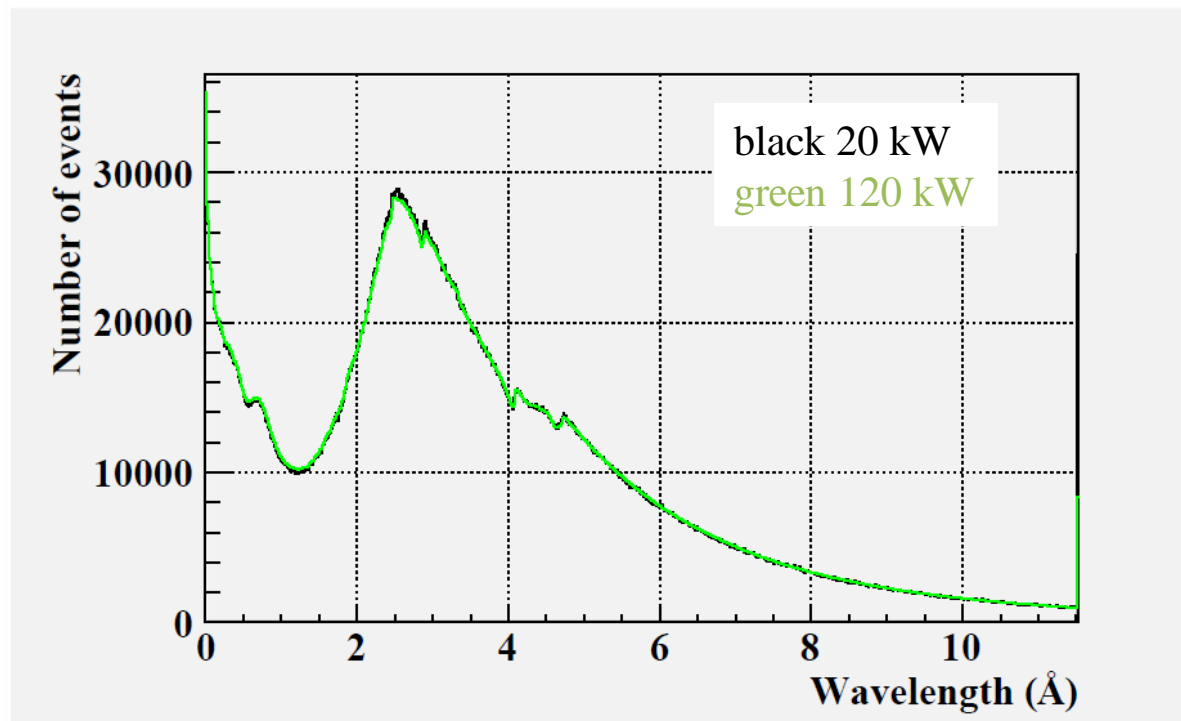
Since the difference between the measurement and the calculation is small,
we found that the wavelength-spectrum distribution is consistent.

Typical wavelength-spectrum distribution (2)

We measured the wavelength-spectrum distributions at 20 kW and at 120 kW, respectively. The both distributions are normalized with the number of events.

The both distributions are almost same.

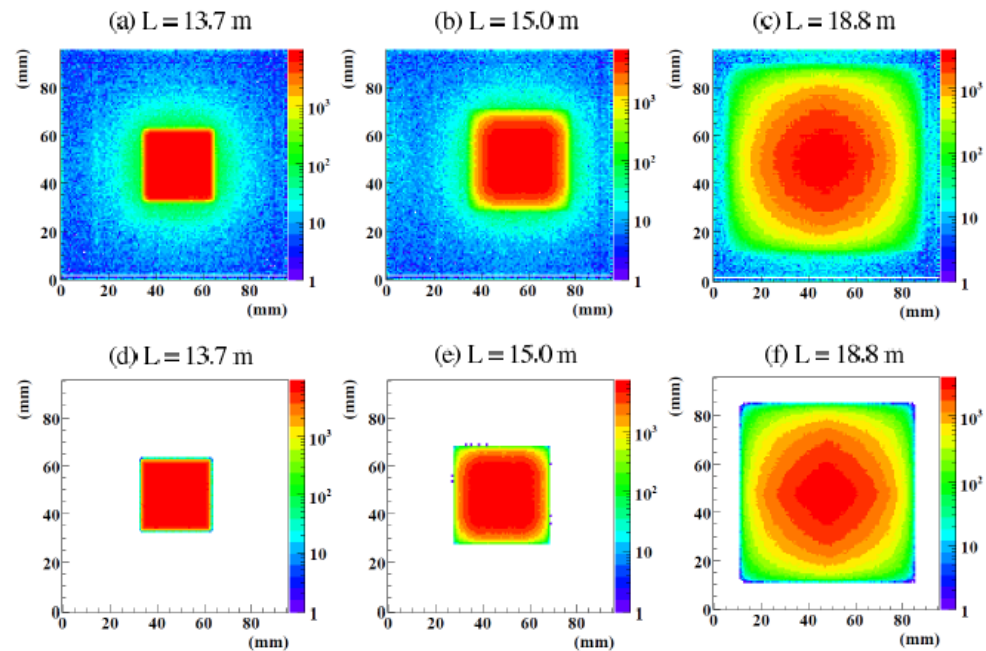
The GEM operated well without the counting loss in the higher neutron environment.



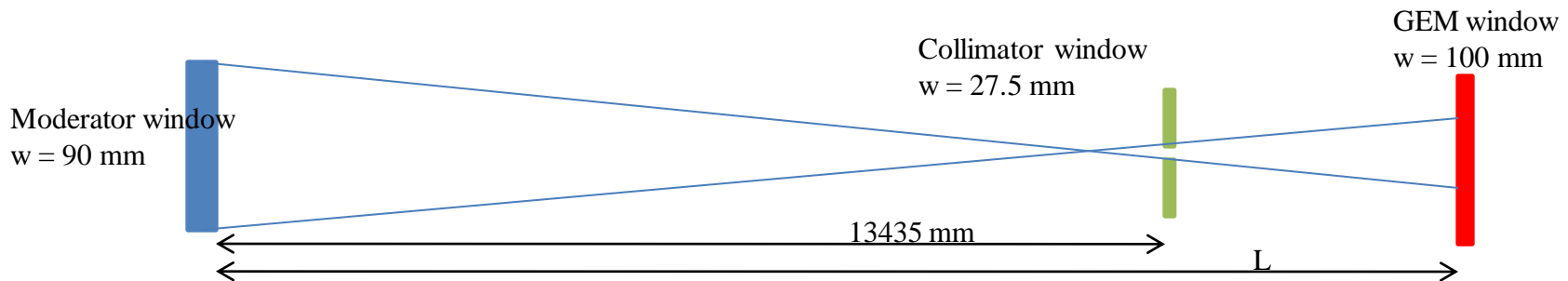
Beam profiles

Beam profiles were measured by changing the GEM's position.

Upper 3 figures represent the measurement.
Lower 3 figures represent a Monte Carlo (MC) simulation.



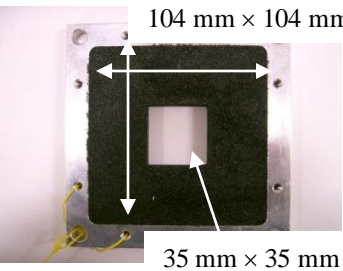
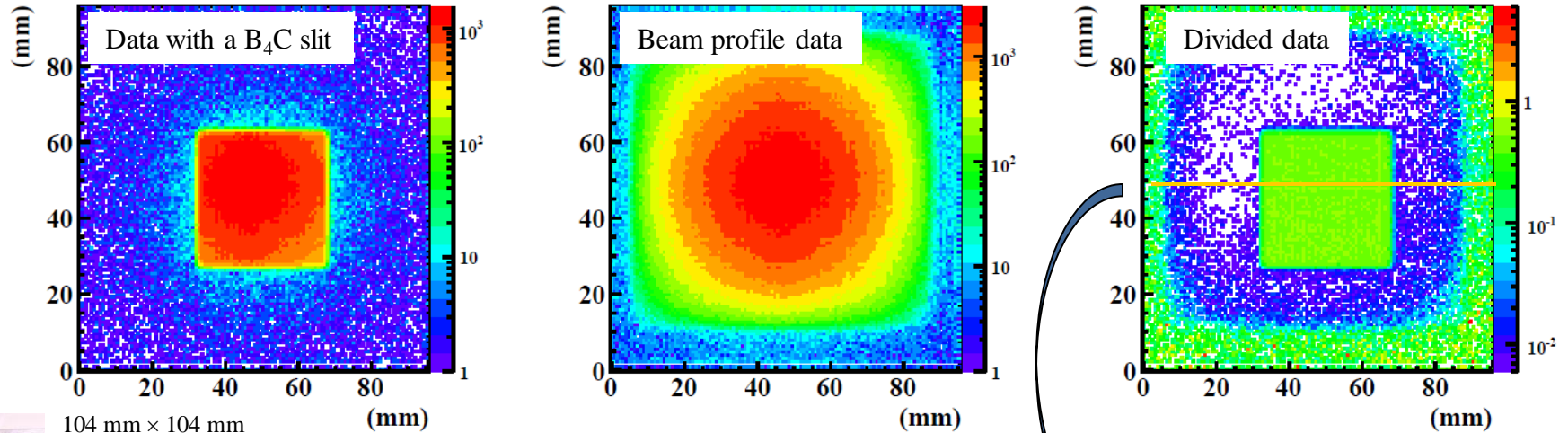
In the MC simulation, only the geometrical conditions such as the size and the position of the moderator, the collimator and the detector were considered.



- (1) An injection point in the moderator and an incident point in the collimator were selected at random
- (2) The line segment passing through these two points extends
- (3) A hit point in the detector is derived as a cross point between the line segment and the detector's position

The beam size and the beam pattern are explained as a geometrical characteristics.
The beam profiles agree with the MC simulation.

Position resolution



In order to estimate the position resolution, the B_4C slit (35 mm \times 35 mm) was put in front of the GEM.

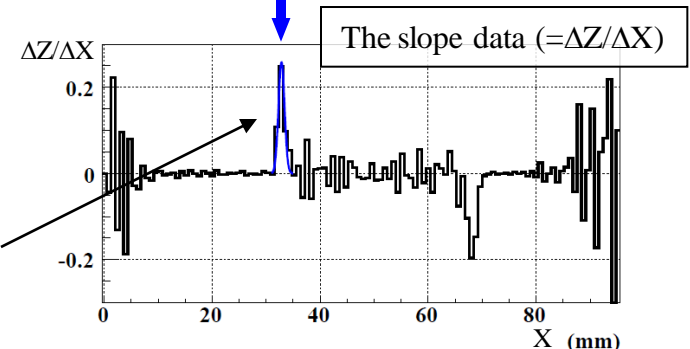
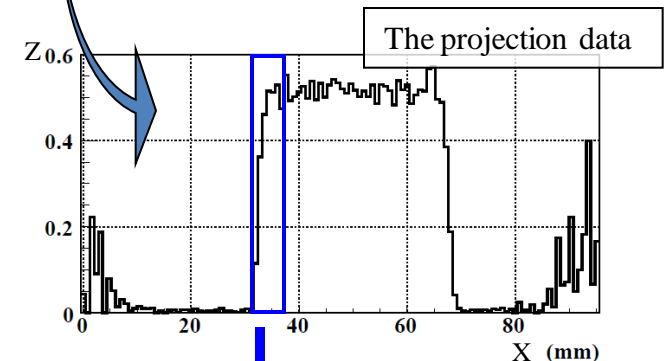
To compensate the beam profile, the data with the slit is divided by the beam profile data.

We performed edge analysis.

The histogram of the slope ($=\Delta Z/\Delta X$) is derived.

In the histogram of the slope, a sharp peak appears on the edge of the B_4C slit and the sharp peak is fitted by a gauss function.

The position resolution; ~ 1.3 mm (FWHM)



Constant:	0.26
Mean:	32.85
Sigma:	0.56

$\Delta Z/\Delta X$ is obtained by subtracting the one from the adjacent one. 16

Summary

We developed the neutron detector with a GEM
and performed the neutron irradiation test at BL21 in J-PARC.

The GEM operated well in the neutron irradiation test.

We will check a long term stability and a high rate capability from now.

If you are interested in our system, please contact us !
hidetoshi.ohshita@kek.jp

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The end