J-PARC MLF用の
中性子ビームモニターと
オンラインシステム

H. Ohshita (KEK, IMSS)

講演内容

- 開発の背景
- Gas Electron Multiplier (GEM)
- 中性子の検出原理
- 中性子ビームモニターnGEM
- 外観図
- FPGAブロック図・データフォーマット
- イベント選別アルゴリズム
- n-γ弁別による測定例
- 中性子感度と一様性
- BL21のビーム形状と中性子強度
- Redisを用いたオンラインシステム
- デモンストレーション
- まとめ

開発メンバー：

NOVA（BL21）グループ
大友季哉、池田一貴、本田孝志、金子直勝、鈴谷健太郎（JAEA）
KENS-DAQグループ
佐藤節夫、瀬谷智洋、坂口将尊
オンラインシステム開発
安芳次、森山健太郎（CROSS）
（株）Bee Beans Technologies
石綿将邦、岩瀬和也

開発の背景（2010年頃）

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 particularly, detectors irradiated by neutron beam directly

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

- For example, a traditional ^{3}He 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: ~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 × ~50 mm

A Gas Electron Multiplier (GEM) is known to have a high rate capability (more than 10^{7} Hz/cm^{2})

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

We developed a GEM-based neutron beam monitor.

開発の背景(現在)

- Our motivation

Online monitoring to check the experimental status,
to judge the statistics, to satisfy our mental
Online analyzing to get the physical quantity

- Our target

To realize online monitor system for the BL21 whole detectors,
we developed the system using Redis Queue (ADARA [1] at SNS is similar system).

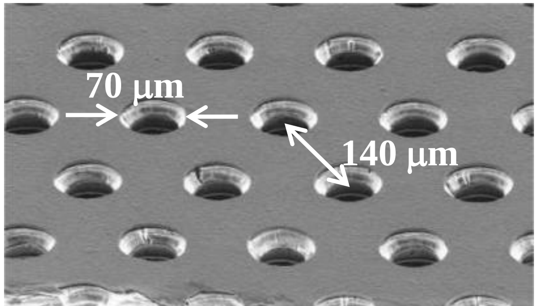
In the future plan, we'd like to realize online analyzing system.

Since Redis Queue has higher flexibility, using Redis Queue helps us to realize the system.

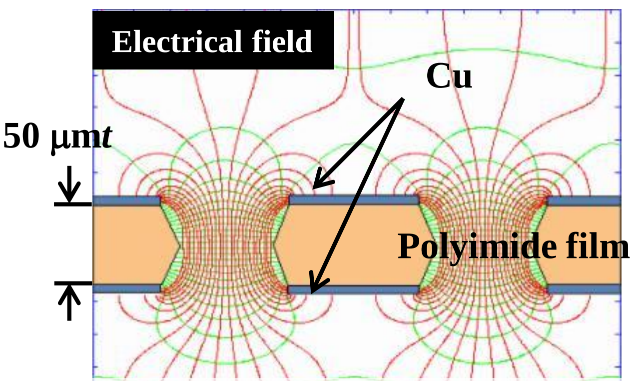
Gas Electron Multiplier (GEM)

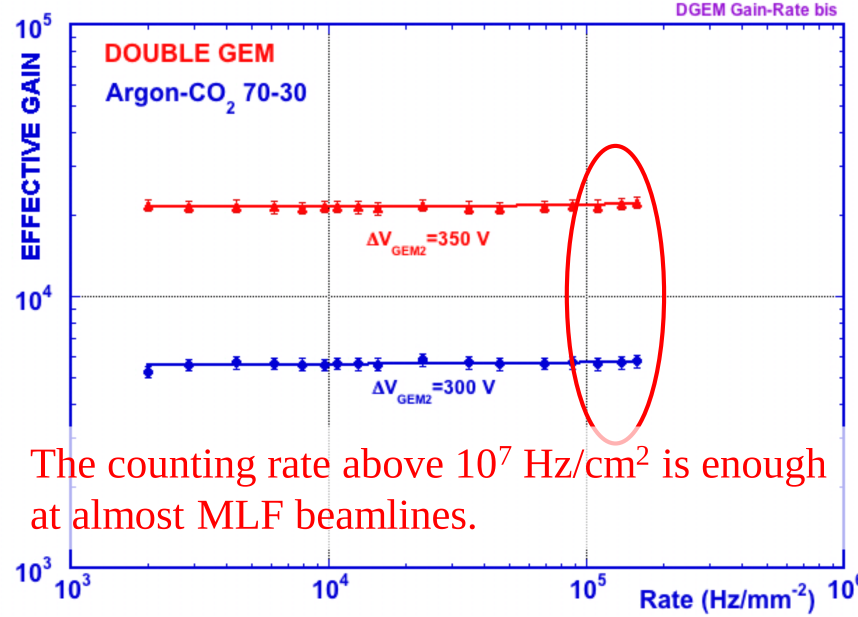
- One of Micro Pattern Gas Detectors (MPGDs), developed by F. Sauli
- Good high counting rate capability, stable operation under the intense radiation environment

F. Sauli, Nucl. Instr. and Meth. A **386** (1997) 531.
http://gdd.web.cern.ch/GDD/



50 μm*t* polyimide film with Cu-clad





The counting rate above 10^7 Hz/cm^2 is enough at almost MLF beamlines.

Signal generation mechanism

1. Primary electrons come into the higher electrical field of a GEM hole.
2. Secondary electrons are created by the gas amplification in the GEM hole.
3. Secondary electrons drift toward the anode electrode and induce charge on the anode electrode.

The main characteristics and performances of GEM detectors are:

- **Operation in most gas filling, including pure noble gases**
- **Proportional gains above 10^5**
- **Energy resolution 18% FWHM at 5.9 keV X-rays**
- **Space localization accuracy 60 μm rms or better**
- **Rate capability above 10^5 counts/mm^2·sec**
- **Active areas up to 1000 cm^2**
- **Flexible detector shape and readout patterns**
- **Robust, Low cost**

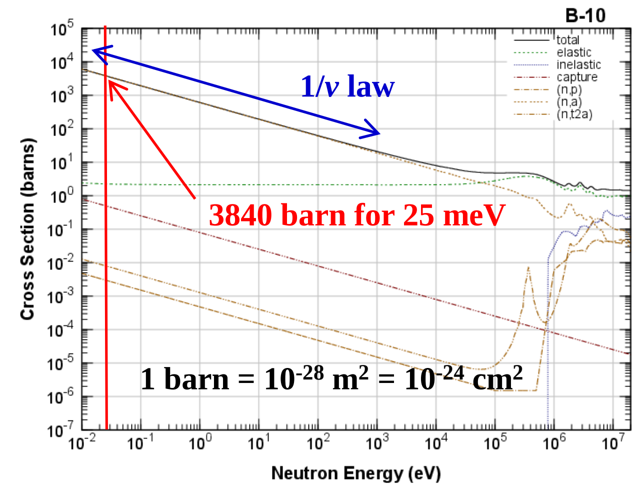
中性子の検出原理

- To detect charged particles from the following neutron nuclear reactions

$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.79$ MeV (6%)
$^{10}B + n \rightarrow {}^{7}Li^{*} + \alpha + 2.31$ MeV (94%)
$^{7}Li^{*} \rightarrow {}^{7}Li + 0.48$ MeV (prompt γ)

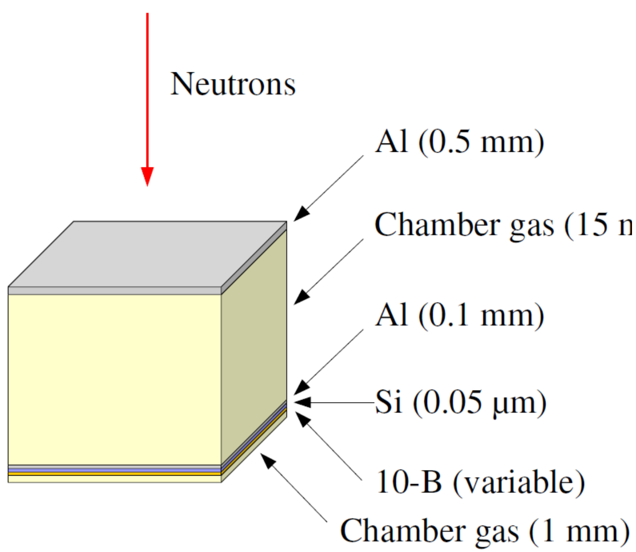
$^{3}He + n \rightarrow {}^{3}H + p + 0.765$ MeV (5330 barn)
$^{6}Li + n \rightarrow {}^{3}H + \alpha + 4.78$ MeV (940 barn)

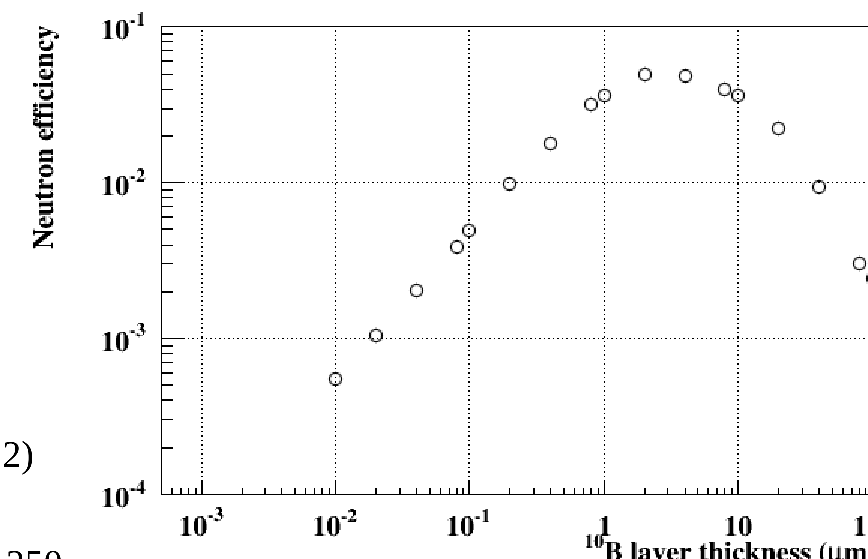
JENDL-4.0 nuclear data library



K. Shibata, et al., J. Nucl. Sci. Technol. **48** (2011) 1.

Geant4-based simulation





The Geant4-based simulation conditions are:
- Version 9.6
- Used with high precision neutron model (G4NDL 4.2)
- Reconstructed as ^{10}B lined gaseous detector

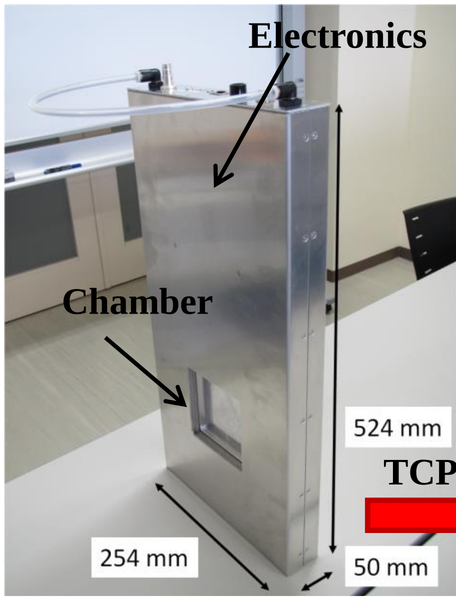
S. Agostinelli, et al., Nucl. Instr. and Meth. A **506** (2003) 250.

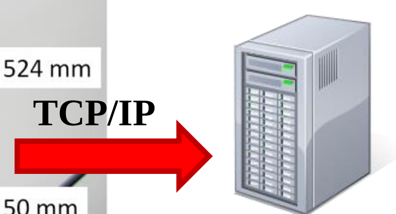
中性子ビームモニターnGEM

- Two-dimensional neutron detector for J-PARC MLF

* The nickname “nGEM” means “it’s made with Nippon technologies”.

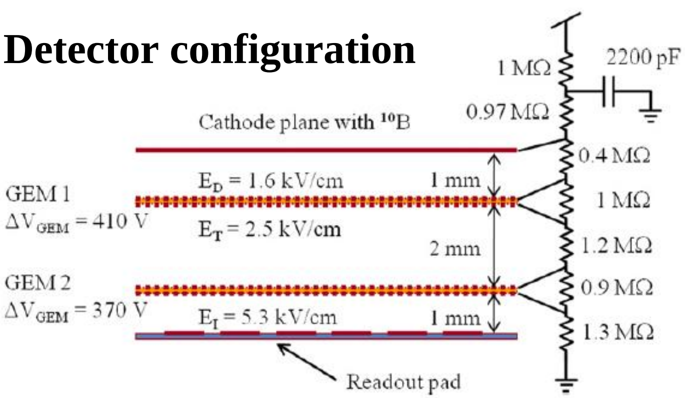
- Supported by the technologies of the KEK detector technology project such as SiTCP, ASIC-FE2007, DAQ-MW





Web site of the KEK detector technology project, http://rd.kek.jp.
T. Uchida, et al., IEEE Trans. Nucl. Sci. **NS-55** (2008) 2698.
Y. Fujita, et al., presented at the IEEE NSS 2007.
K. Nakayoshi, et al., Nucl. Instr. and Meth. A **600** (2009) 173.

Detector configuration

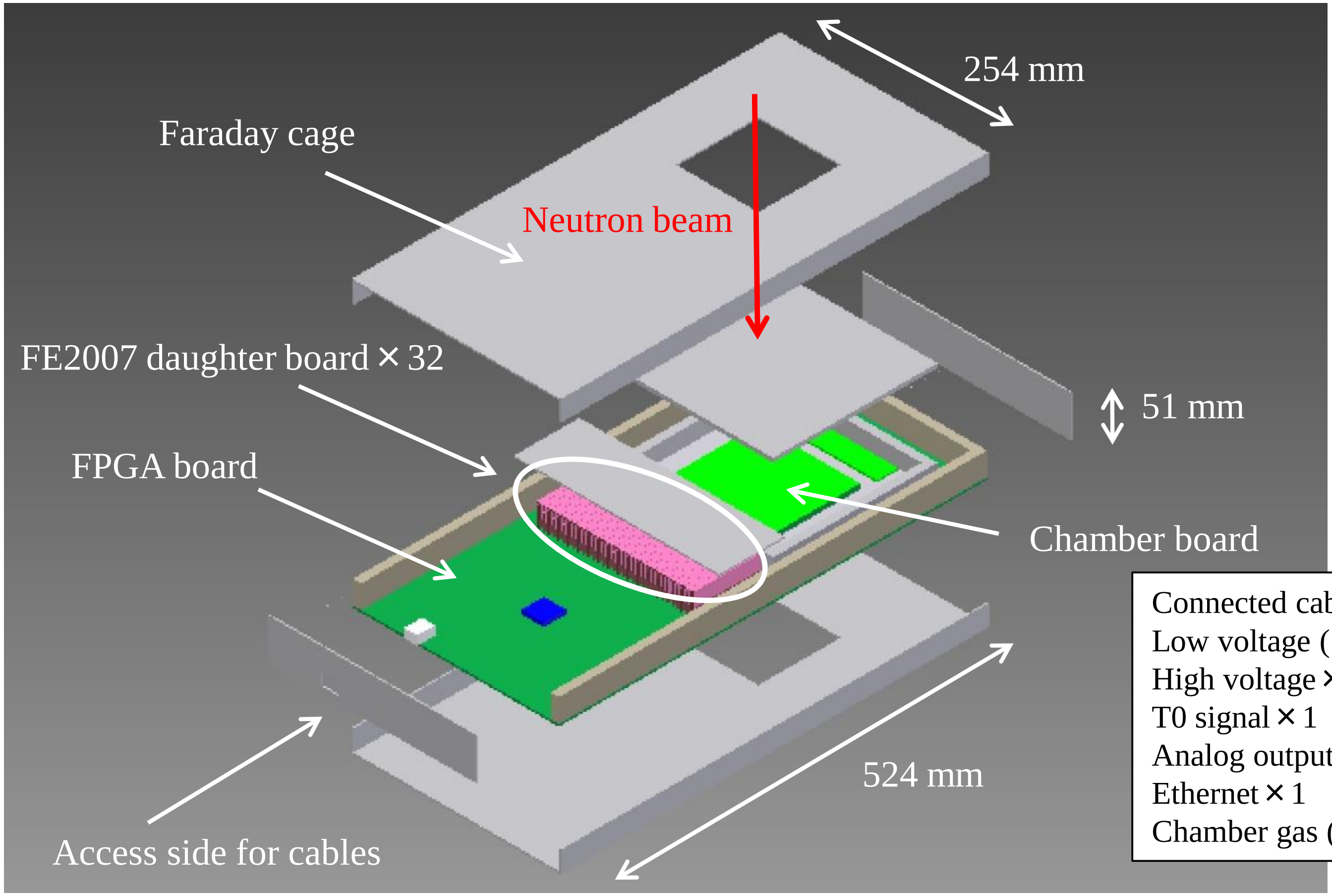


The main characteristics and performances of nGEM are:

- Gas flow radiation detector that can measure charged particles from a n(^{10}B, α)^{7}Li nuclear reaction
- Thermal neutron efficiency between 0.5% and 5% (depending on ^{10}B layer thickness)
- Data taking rate over 1 MHz (limited by Gigabit Ethernet) Available for list-mode, not histogram-mode
- Minimum time step of 5 ns
- Position resolution approximately 0.85 mm (FWHM)
- Operation voltage near 2700 V (negative)
- Ar/CO_2 (7:3) gas mixture
- Active area of 100 mm ×100 mm
- 128 ch ×128 ch readout channels with 0.8 mm pitch

外観図

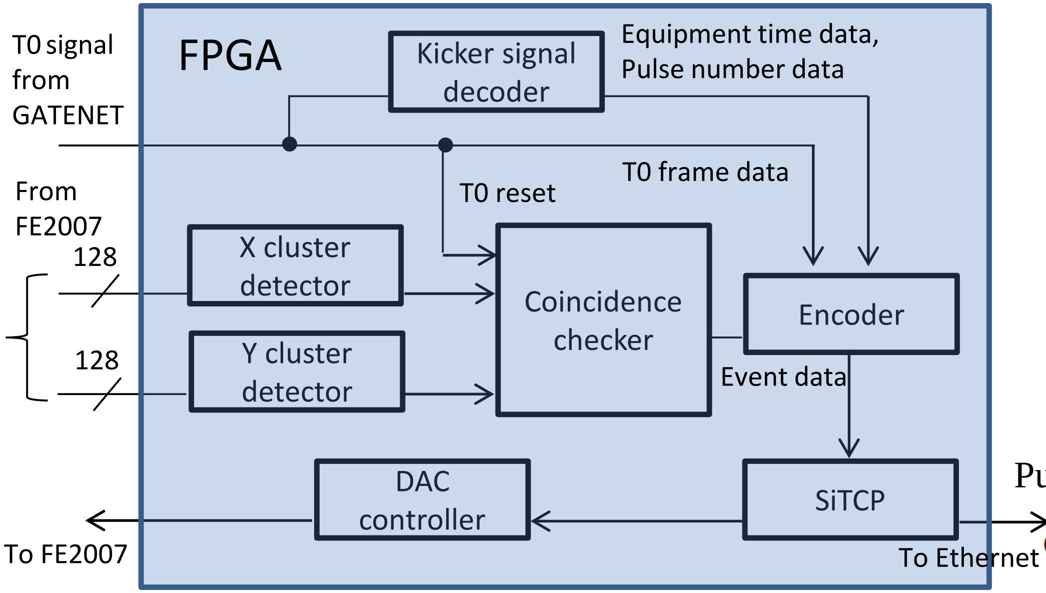
nGEM is a built-in system having a gas chamber and an electronics.
All signal lines from the readout pad are wired inside the printed circuit board.
FE2007 daughter board is able to exchange.
We can stack some 100 mm×100 mm GEMs in the chamber stand
(The height of the chamber: ~20 mm, Gas flow system only).



Connected cables and tubes are:
Low voltage (±5 V)×1
High voltage×1
T0 signal×1
Analog output×1
Ethernet×1
Chamber gas (input and output) ×2

FPGAブロック図・データフォーマット

- Composed of “kicker signal decoder”, “cluster detector” and “ coincidence checker”



SiTCP is able to handle Gigabit Ethernet.
TCP is used for data transfer,
UDP is used for control access.

T0 frame data (16 byte)

0x4E	FL(12)	EL(20)	TL(24)	0x4F	EC(32)	T0ID(24)

FL: Frame loss count
EL: Event loss count
TL: Total loss count
EC: Event count in FIFO
T0ID: T0 tag

Equipment time data (16 byte)

0x4C	S(30)	SS(15)	US(11)	0x4F	R(32)	T0ID(24)

S: Time count from UTC, unit: s
SS: Small time count (30.5176 µs/count)
US: Ultra small time count (25 ns/count)
R: No use
T0ID: T0 tag

Pulse number data (16 byte)

0x4B	C(8)	M(8)	R(8)	K(32)	0x4F	R(32)	T0ID(24)

C: Crate number
M: Module number
K: Pulse ID
R: No use
T0ID: T0 tag

Event data (16 byte)

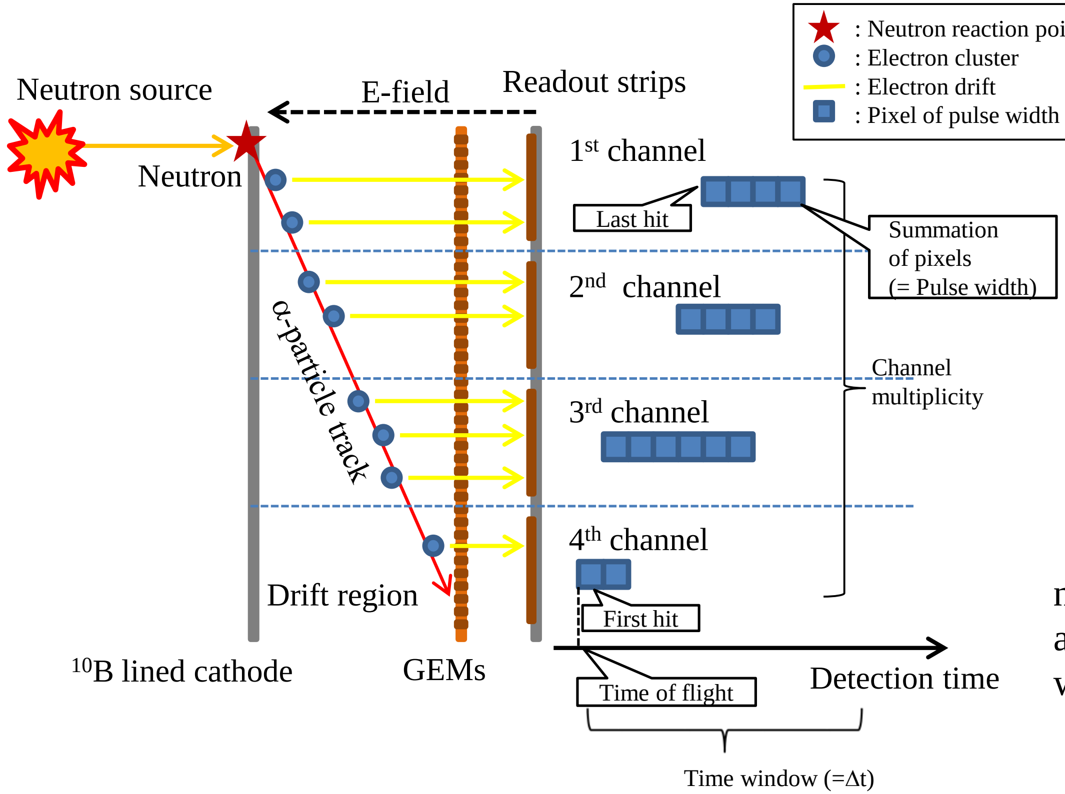
0x4C	TOF(28)	FX (7)	LX (7)	FY (7)	LY (7)	0x4F	DX (6)	SX (10)	DY (6)	SY (10)	T0ID(24)

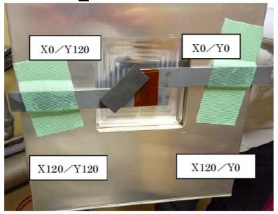
TOF: Time of flight, unit: ns
FX: First hit X channel, LX: Last hit X channel
FY: First hit Y channel, LY: Last hit Y channel
DX: Duration time on X hit channels, 5 ns/count
SX: Pulse width on X hit channels, 5 ns/count
DY: Duration time on Y hit channels, 5 ns/count
SY: Pulse width on Y hit channels, 5 ns/count
T0ID: T0 tag

イベント選別アルゴリズム

M. Shoji, et al., JINST **7** (2012) C05003.

- Based on the behavior of primary electron clusters
- Installed to the Field Programmable Gate Array (FPGA) chip for the online processing

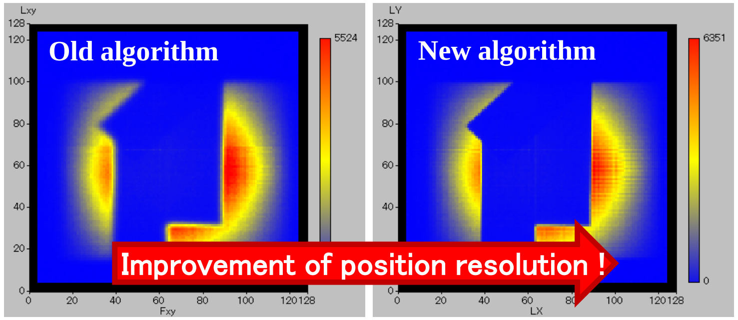




The 2D image with some sintered B_4C was measured.

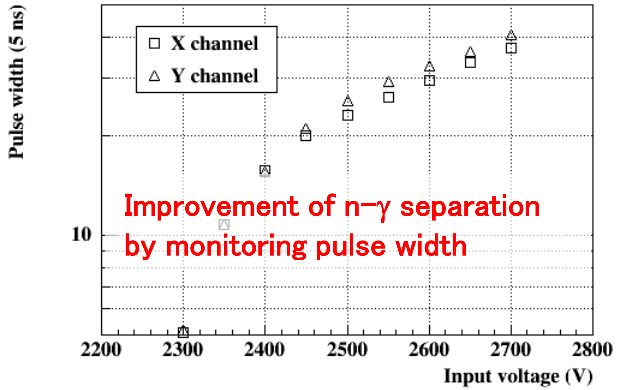
160 mm × 20 mm × 5 mm$t$ × 2

50 mm × 10 mm × 6 mm$t$ × 2



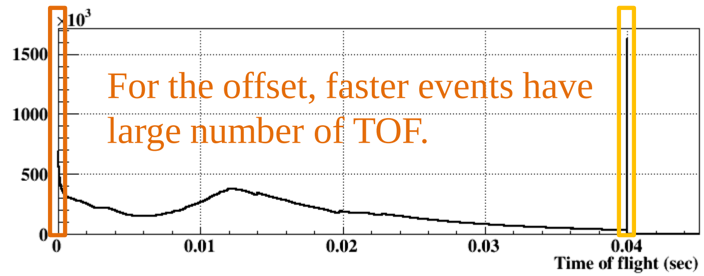
nGEM is also able to get the hit channel multiplicity and to apply special event selection algorithm with the time window cut.

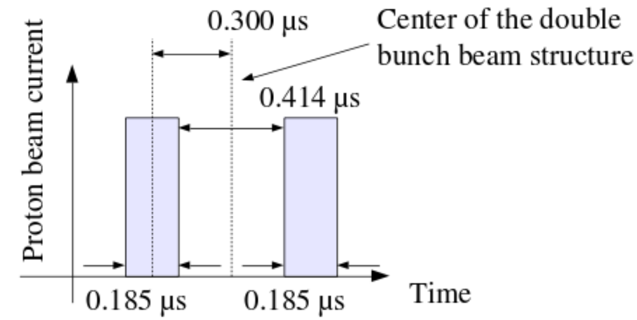
1. Primary electron clusters make along the track of an α particle, and then drift toward the anode electrode.
2. The latest arrival produces near the reaction point of the n(^{10}B, α)^{7}Li reactior
3. The pulse width is proportional to the amount of collected electron clusters.

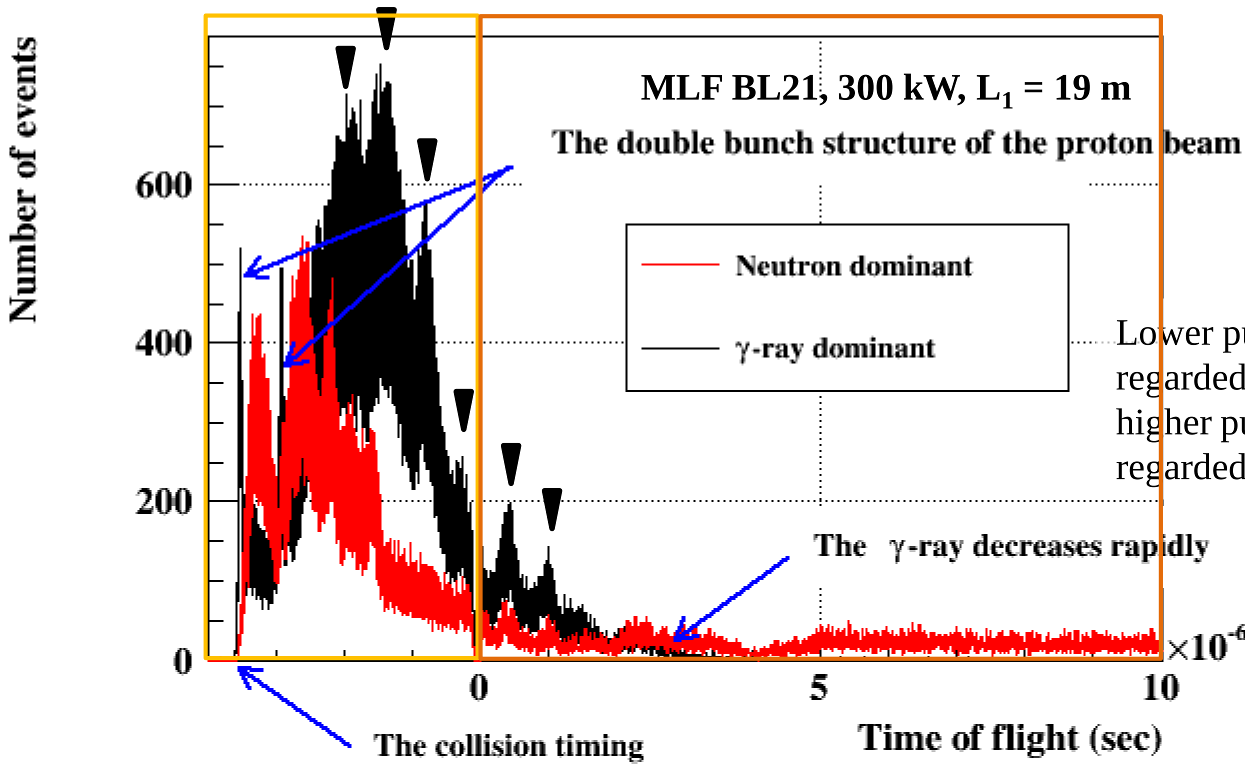


n−γ弁別による測定例

- Observation of the collision timing for the proton beam
  Double bunch structure, strange oscillation (?)







Lower pulse width events are regarded as a γ-ray component, higher pulse width events are regarded as a neutron component.

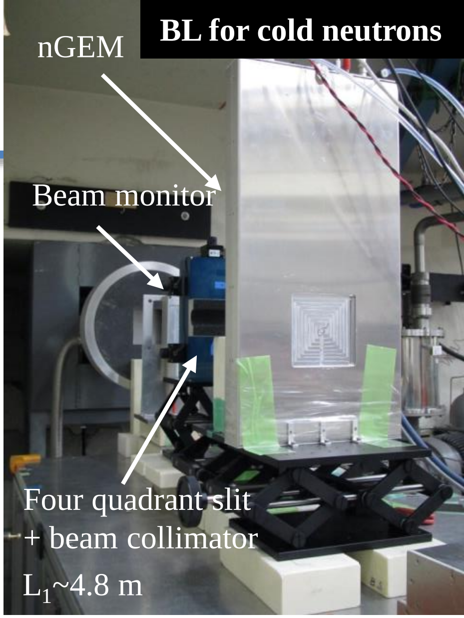
中性子感度と一様性

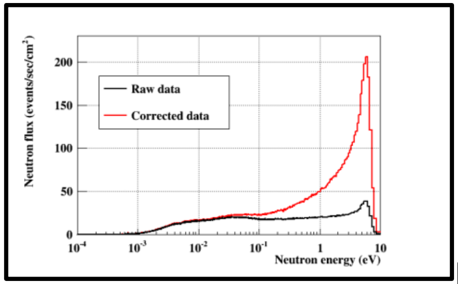
- Evaluated at Hokkaido Univ. 45 MeV electron LINAC
- Good agreement with the Geant4-based simulation

$$\text{Neutron efficiency } \varepsilon(E) = \frac{\text{Number of counts for nGEM}}{\text{Neutron flux}}$$

$$\text{Neutron flux } I_n(E) = \frac{N_{3He}(E) \times 50}{\varepsilon_{3He}(E)}$$

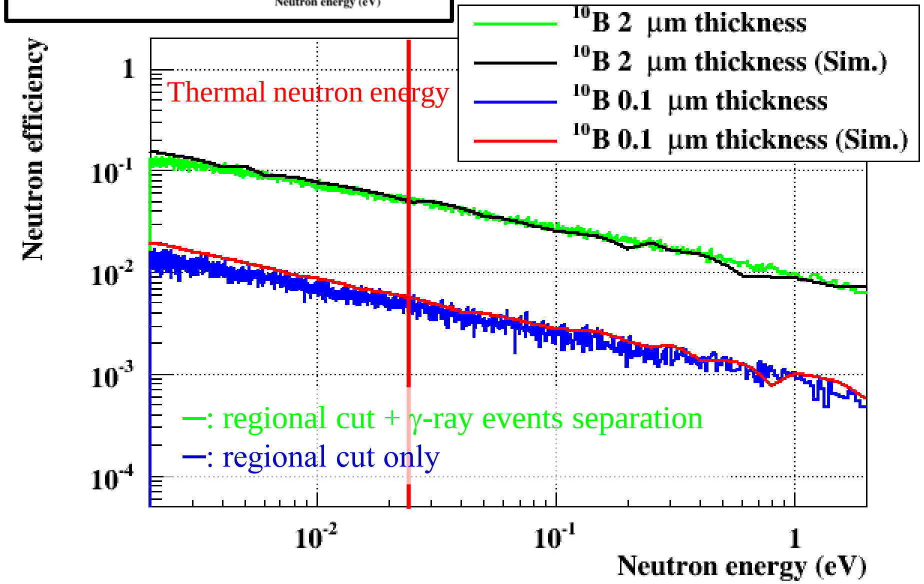
N_{3He} : Counting rate for 3-helium detector, ε_{3He} : Neutron efficiency for 3-helium detector





The neutron flux was measured by a 3-helium proportional counter (1-inch diameter, 3-helium partial pressure: 10 atm)

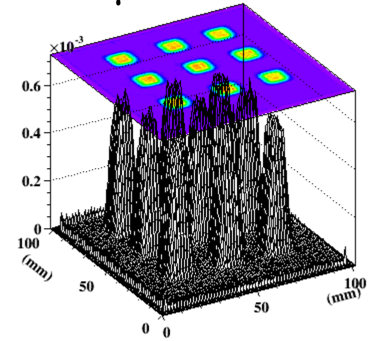
2.5×10^4 neutrons/cm²·sec (10^{-3} eV～0.5 eV, L=4.64 m)

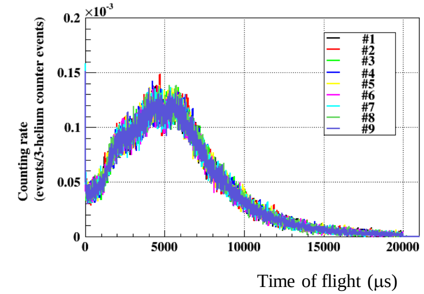


Beam power: ~30 µA, 50 Hz

Collimated beam size: 1 cm × 1 cm

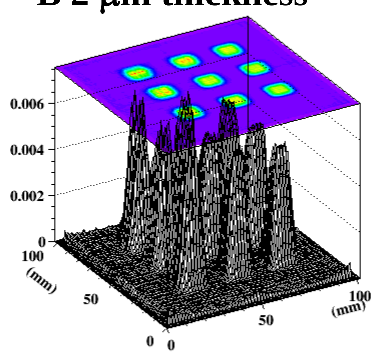
^{10}B 0.1 µm thickness

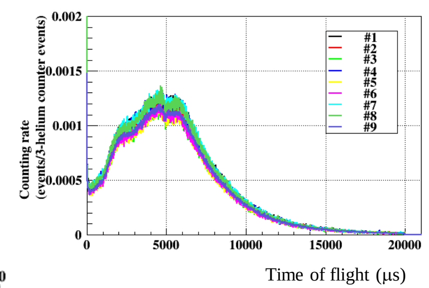




The standard deviation of total events: 0.8%

^{10}B 2 µm thickness





The standard deviation of total events: 4.3%

BL21のビーム形状と中性子強度

- Evaluated at the BL21 sample position
- Good agreement with the Monte Carlo (MC) simulation and the calculation

- The MC simulation with simple considerations of the geometry of the NOVA beam line, no physics reaction
- The neutron intensity at the sample position:

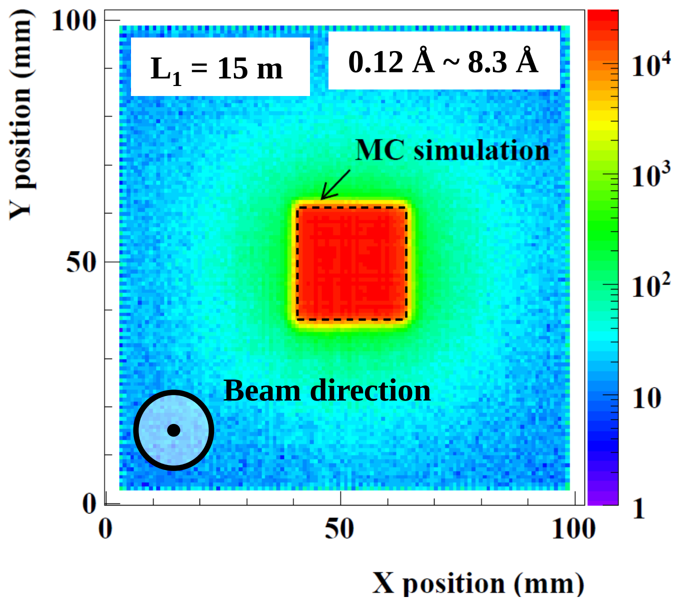
$$I(E) = i_{\mathrm{raw}}(E)/\varepsilon(E),$$

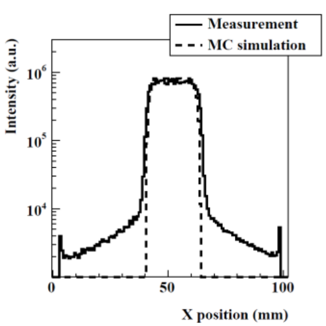
where $i_{\mathrm{raw}}(E)$: the raw distribution, $\varepsilon(E)$: the neutron efficiency obtained from the Geant4-based simulation

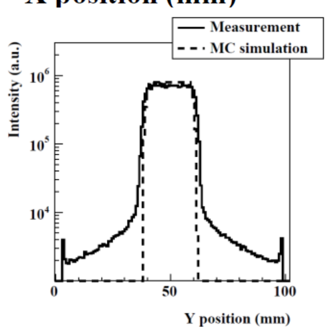
- The calculated neutron intensity:

$$I_{\mathrm{cal}}(E) = i_{\mathrm{cal}}(E) \times T_{r\ \mathrm{total}}(E) \times k,$$

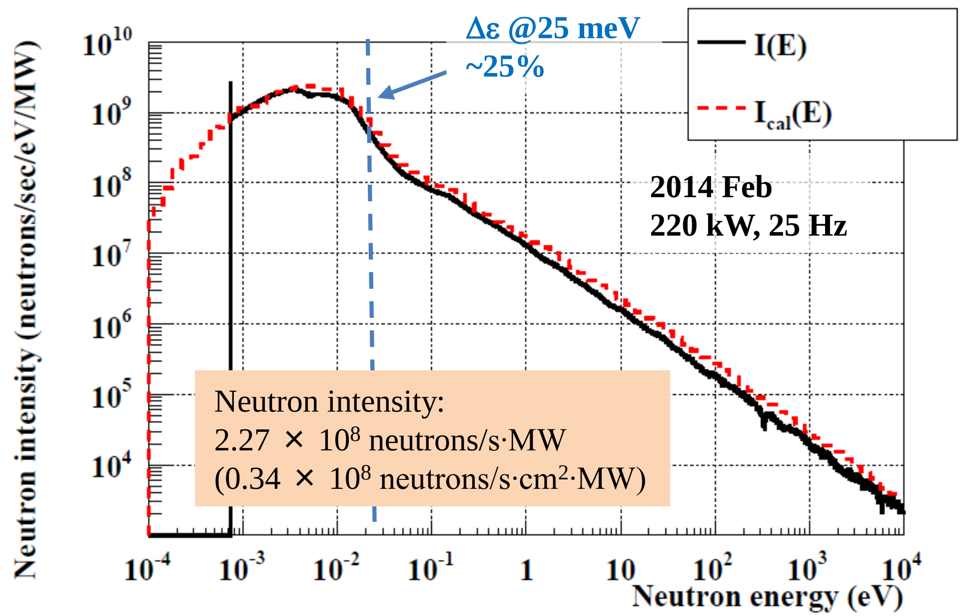
where $i_{\mathrm{cal}}(E)$: the calculation of the neutron intensity obtained from the JSNS group's study, $T_{r\ \mathrm{total}}(E)$: the total transmission of the NOVA beam line, k: other factors such as the type of cooling water and the existence of the muon target







Measurement: 25.6 mm × 26.4 mm
MC simulation: 23.2 mm × 23.2 mm

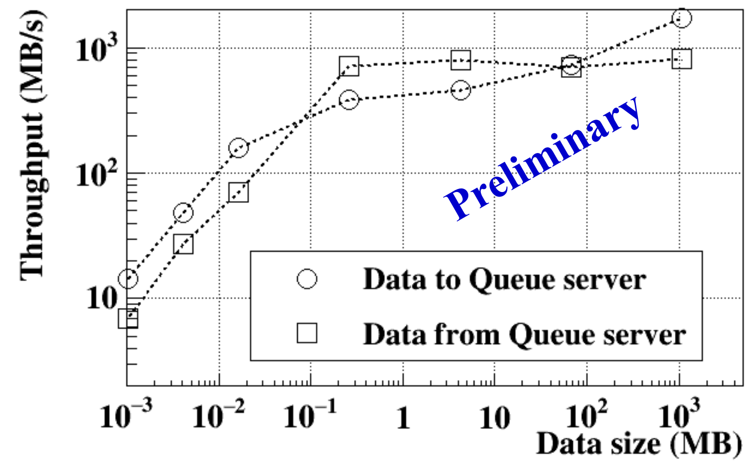


Redisを用いたオンラインシステム

The main characteristics of Redis are:

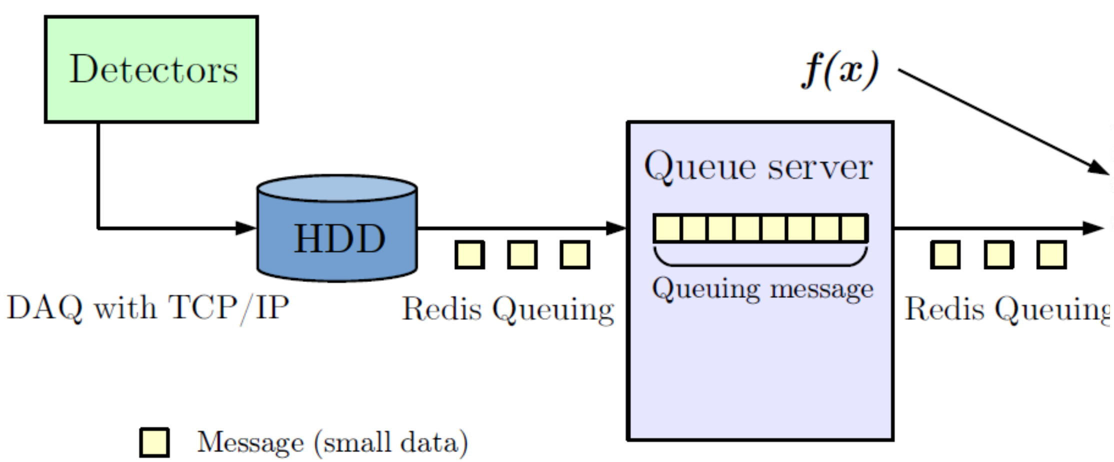
- One of middleware to realize message queuing
- Open source (BSD licenced)
- In-memory data structure store
- Used as database, cache and message broker
- Available for several data structures
- Computer library support such as C/C++, Python…

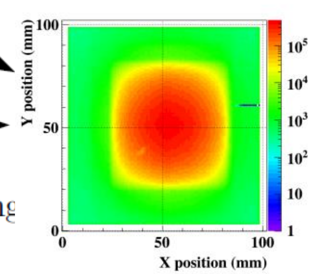
DELL Precision M4700
CPU: Intel® Core™ i7-3940XM 3.00 GHz
Thread: 8 (4 cores × 2)
Memory: 32 GB
HDD: SSD (SMB41) 512 GB



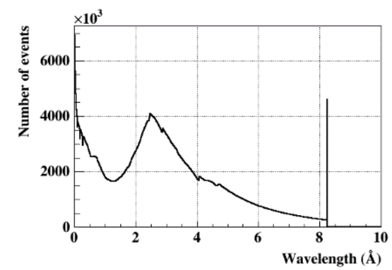
redis http://redis.io

Online data system (start version)





Beam profile



TOF distribution

Redisを用いたオンラインシステム

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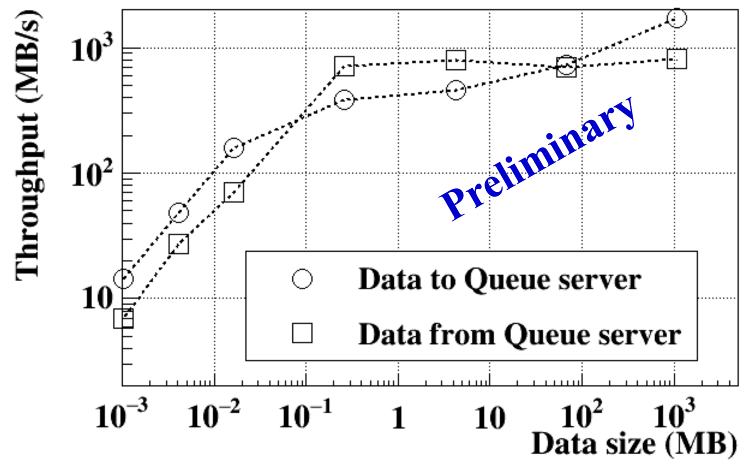
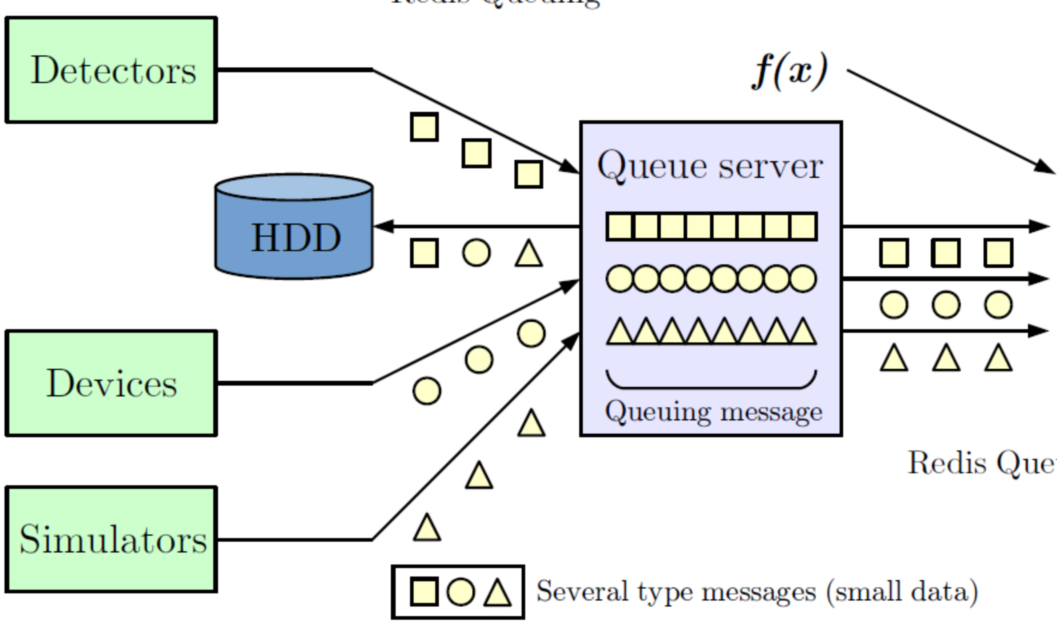
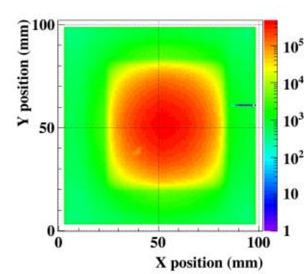
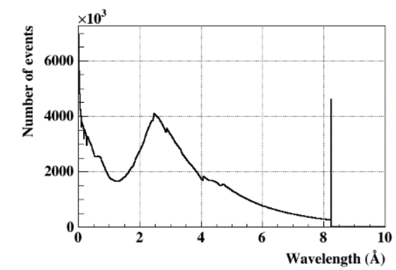


Online data system (target version)



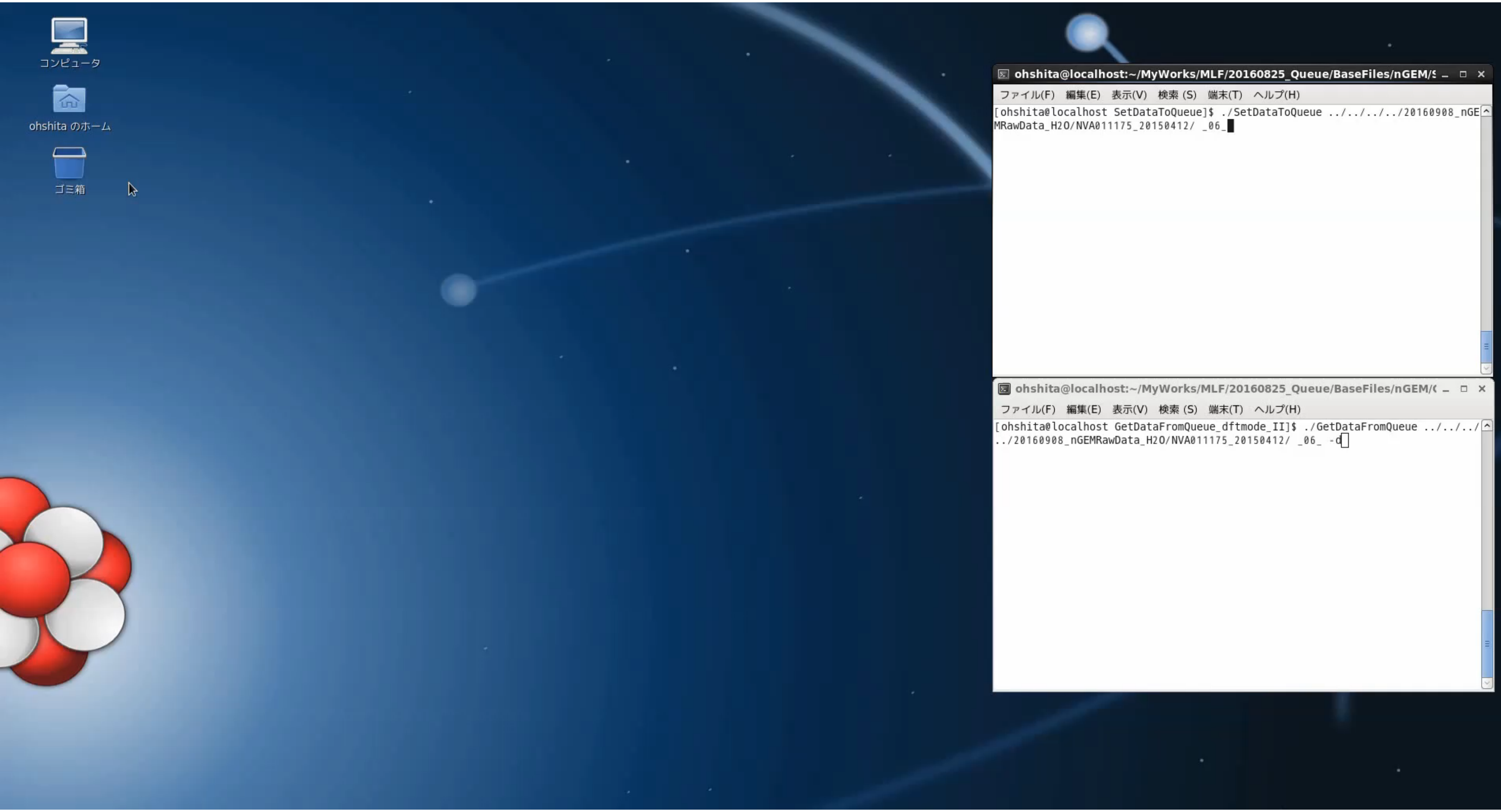


Beam profile



TOF distribution

デモンストレーション



コンピュータ
ohshita のホーム
ゴミ箱
ohshita@localhost:~/MyWorks/MLF/20160825_Queue/BaseFiles/nGEM/S
ファイル(F) 編集(E) 表示(V) 検索 (S) 端末(T) ヘルプ(H)
[ohshita@localhost SetDataToQueue]$ ./SetDataToQueue ../../../../20160908_nGEMRawData_H2O/NVA011175_20150412/ _06_
ohshita@localhost:~/MyWorks/MLF/20160825_Queue/BaseFiles/nGEM/G
ファイル(F) 編集(E) 表示(V) 検索 (S) 端末(T) ヘルプ(H)
[ohshita@localhost GetDataFromQueue_dftmode_II]$ ./GetDataFromQueue ../../../../20160908_nGEMRawData_H2O/NVA011175_20150412/ _06_ -d

まとめ

We developed the neutron detector with a GEM
and drove at BL21 in J-PARC for several years.

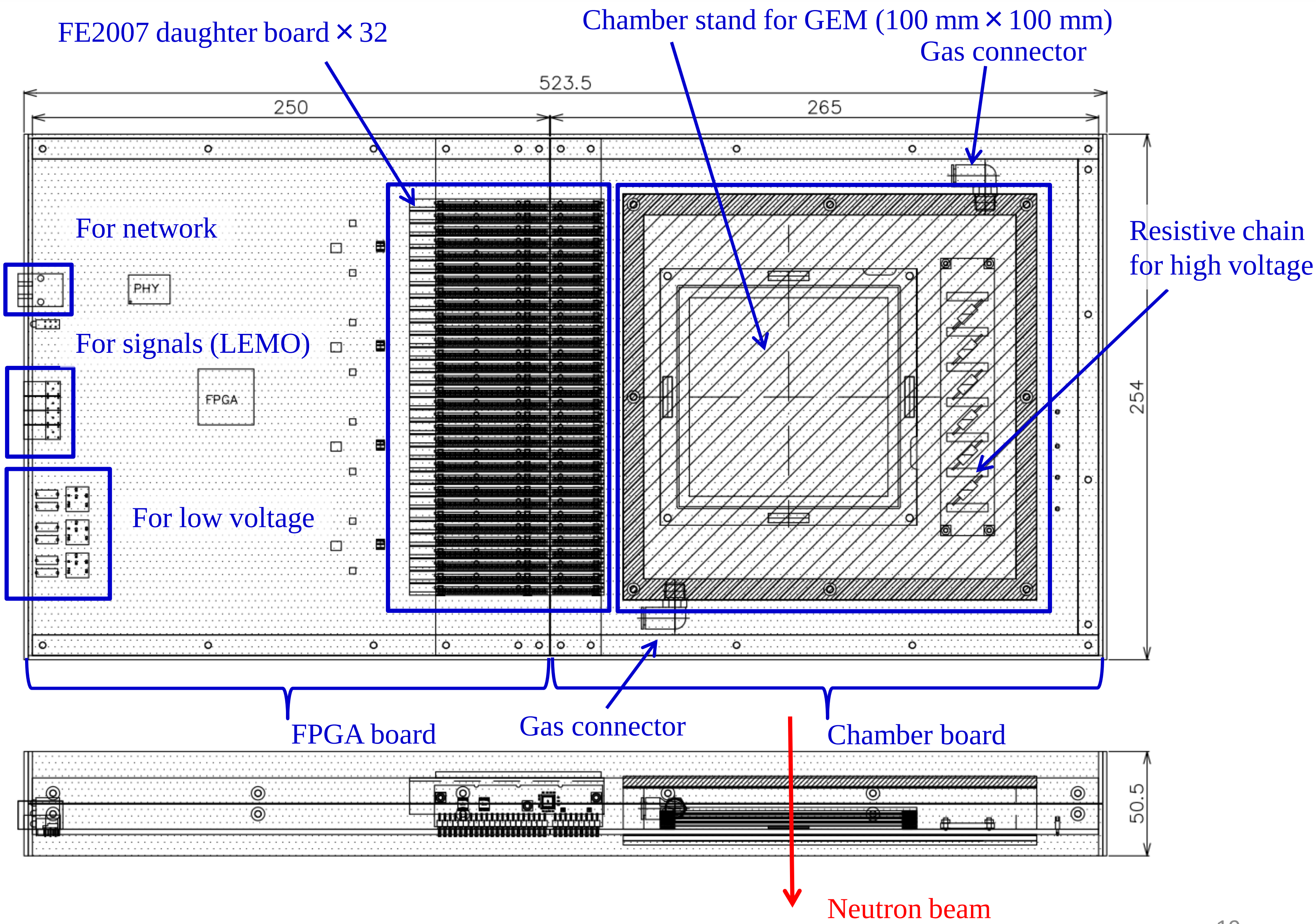
The GEM is going well for our initial purpose.

Our next target is to develop the online monitor system and the online analysis system.

Now, we developed the prototype of online monitor.
We will make adjustments at BL21 from next month.

Thanks for your attention !

内部構造図面



FE2007 daughter board × 32
Chamber stand for GEM (100 mm × 100 mm)
Gas connector
523.5
250
265
For network
PHY
For signals (LEMO)
FPGA
For low voltage
Resistive chain
for high voltage
254
FPGA board
Gas connector
Chamber board
50.5
Neutron beam

デモンストレーション（2）