J-PARC-ESS Workshop
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The neutron source characterization at BL10, NOBORU

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Contents

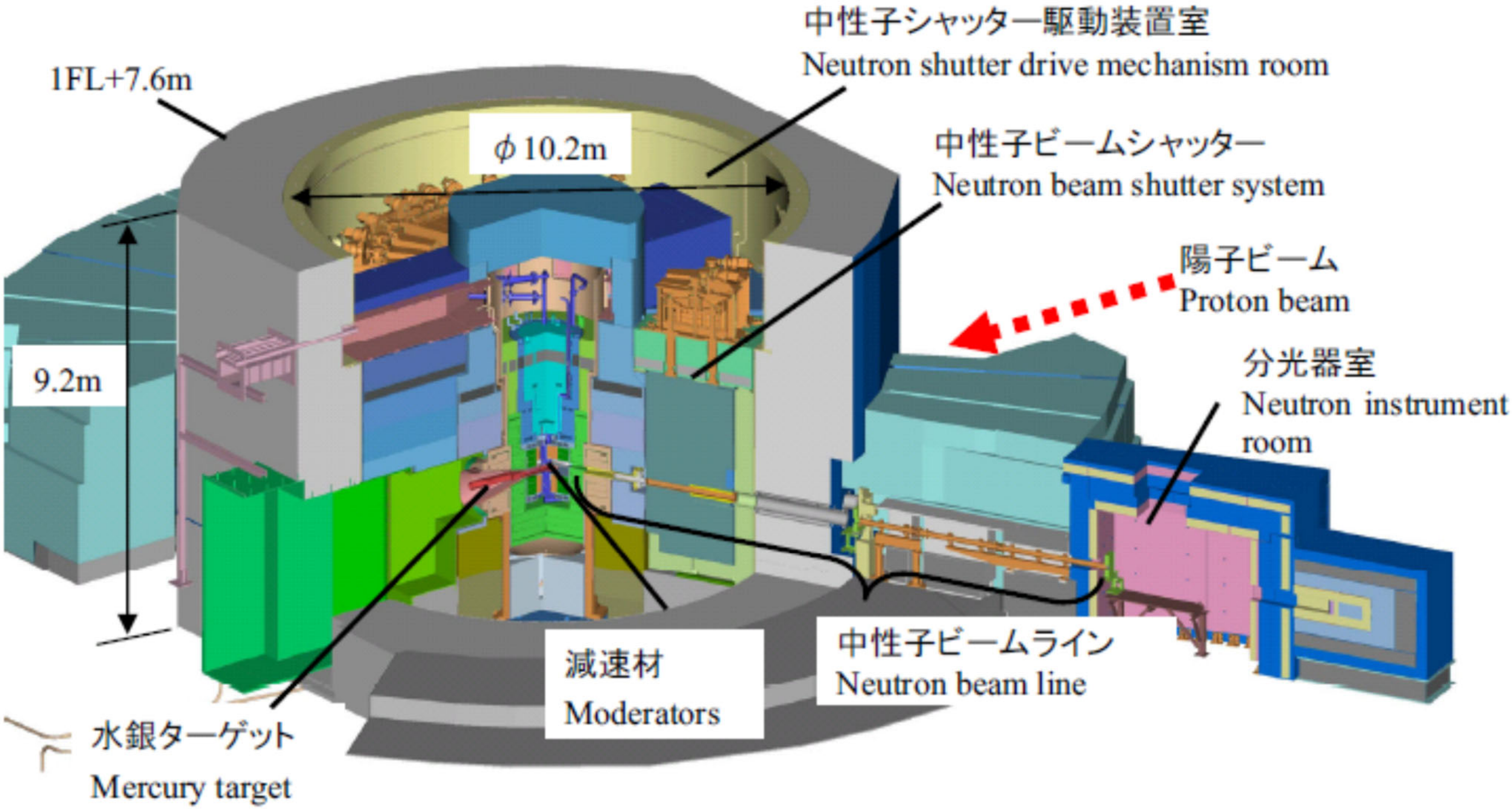
Introduction

Introduction

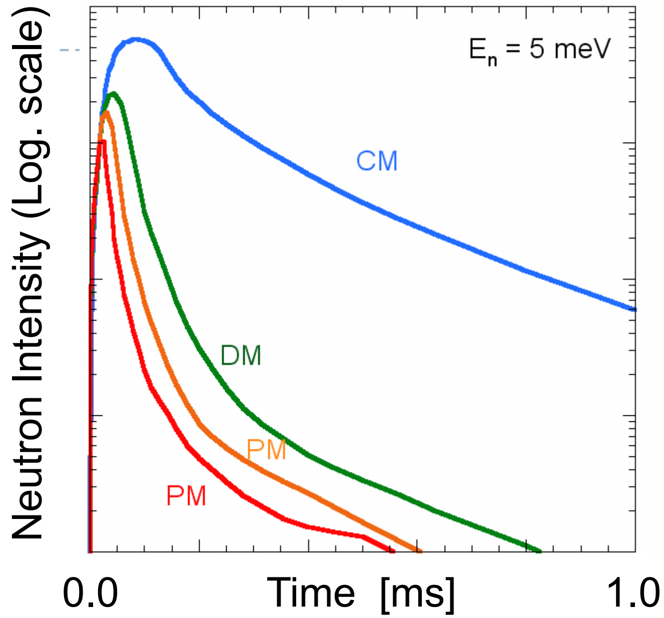
- The spallation neutron source at MLF in J-PARC has been designed by particle transport codes (NMTC/JAM, PHITS, MCNP and MCNPX) on viewpoint of neutronics.
- The validation is one of the most important works to check reliability of the calculations.
- The purpose of this study is the validation of neutronics calculation at MLF spallation neutron source in J-PARC.

Spallation Neutron Source at MLF in J-PARC

- •3GeV proton beam
- •Mercury Target
- •Supercritical hydrogen moderator



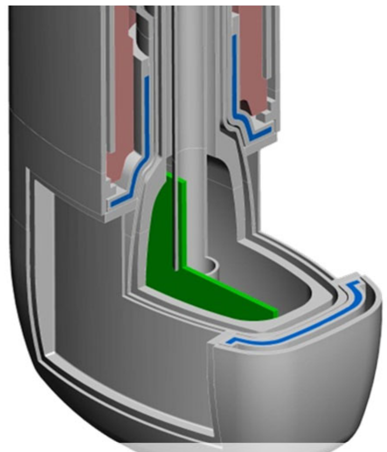
Liquid moderators



Poisoned decoupled moderator (PM)

Sharp pulse

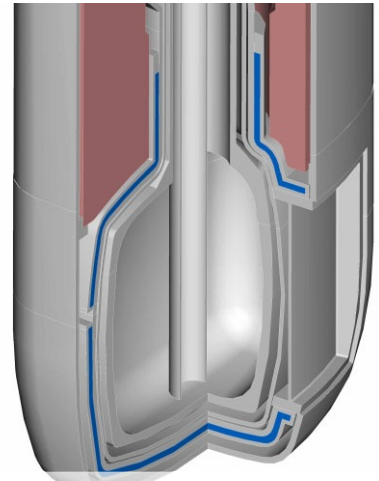
Port: 6



Decoupled moderator (DM)

High intensity & sharp pulse

Port: 6



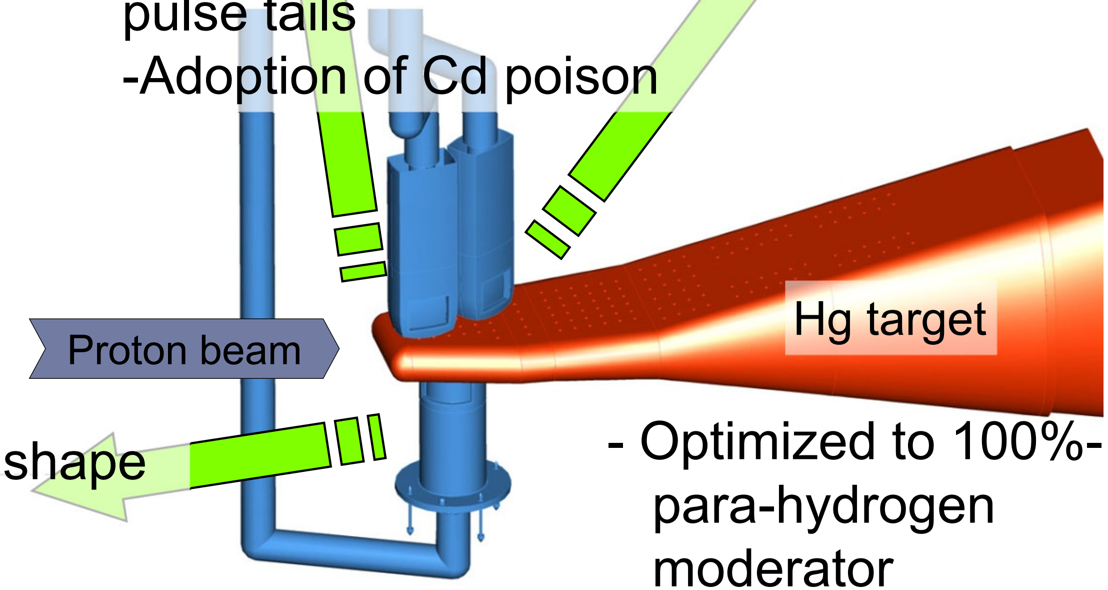
-Adoption of Ag-In-Cd (AIC) decoupled (E_d=1eV)
-Optimized decoupler arrangement for sharp pulse tails
-Adoption of Cd poison

Coupled moderator (CM)

Port: 11

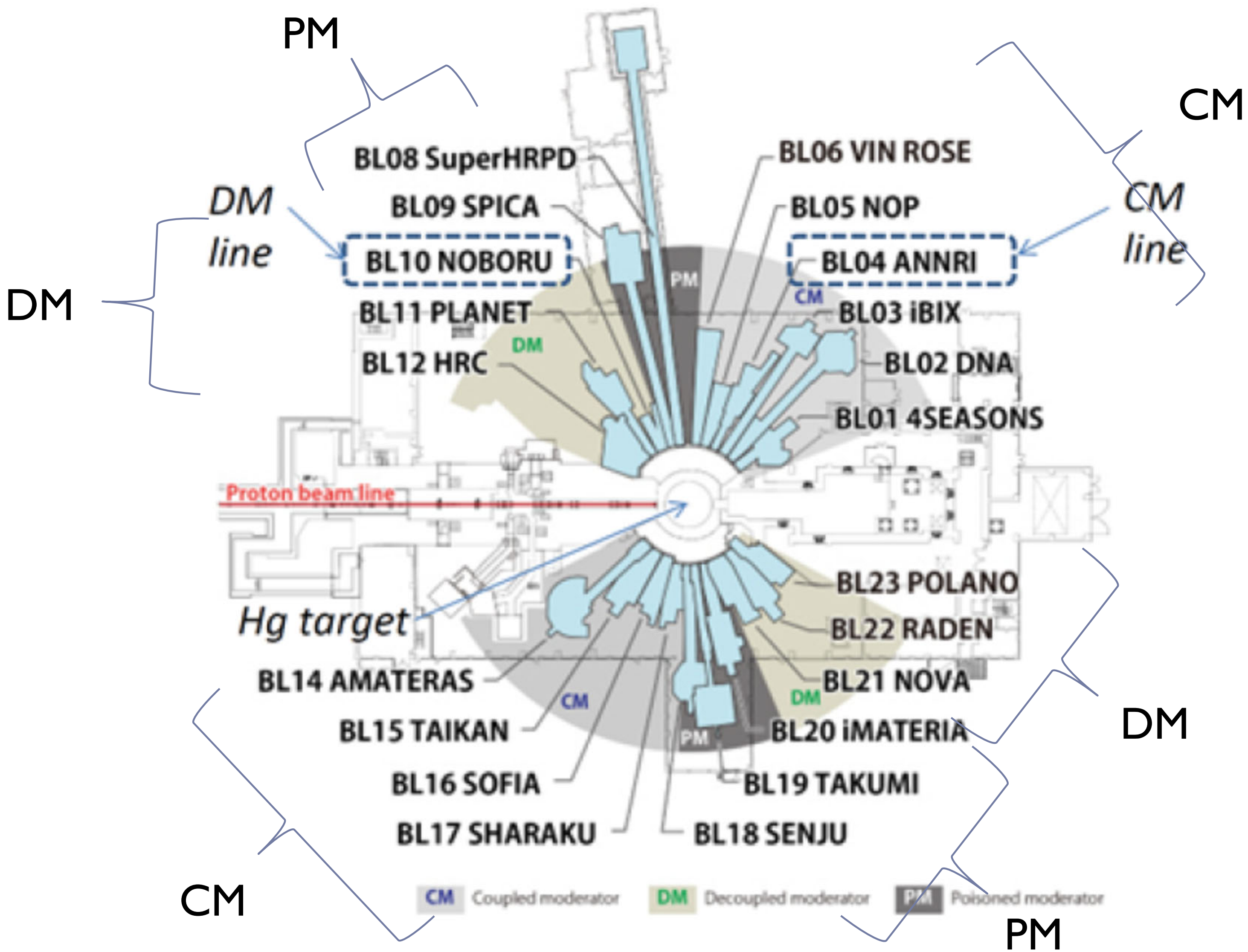
High intensity

- Large volume and Cylindrical shape
- Large extraction angle



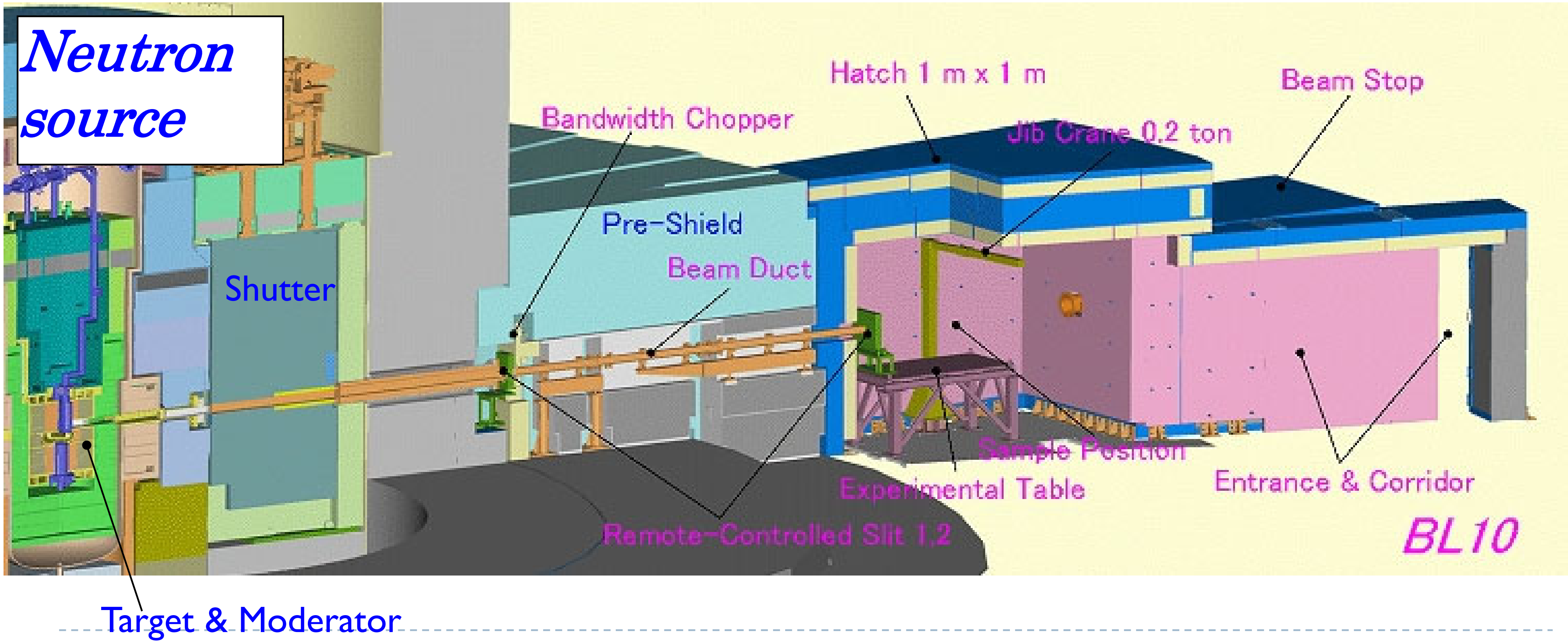
- Optimized to 100%-para-hydrogen moderator

Beam line arrangement and BL10



BL10, NOBORU

NeutrOn Beam-line for Observation and Research Use (NOBORU)
The aims of BL10 are to confirm the neutron characteristics and to do various test.
The largest sample (Fe in 10 x10 x 10 cm3) can be used.
Sample position is 14m in distance from moderator. Neutron beam line size is 10 x 10 cm^2 and the largest among the neutron beam ports. Several components are installed.



Calculations

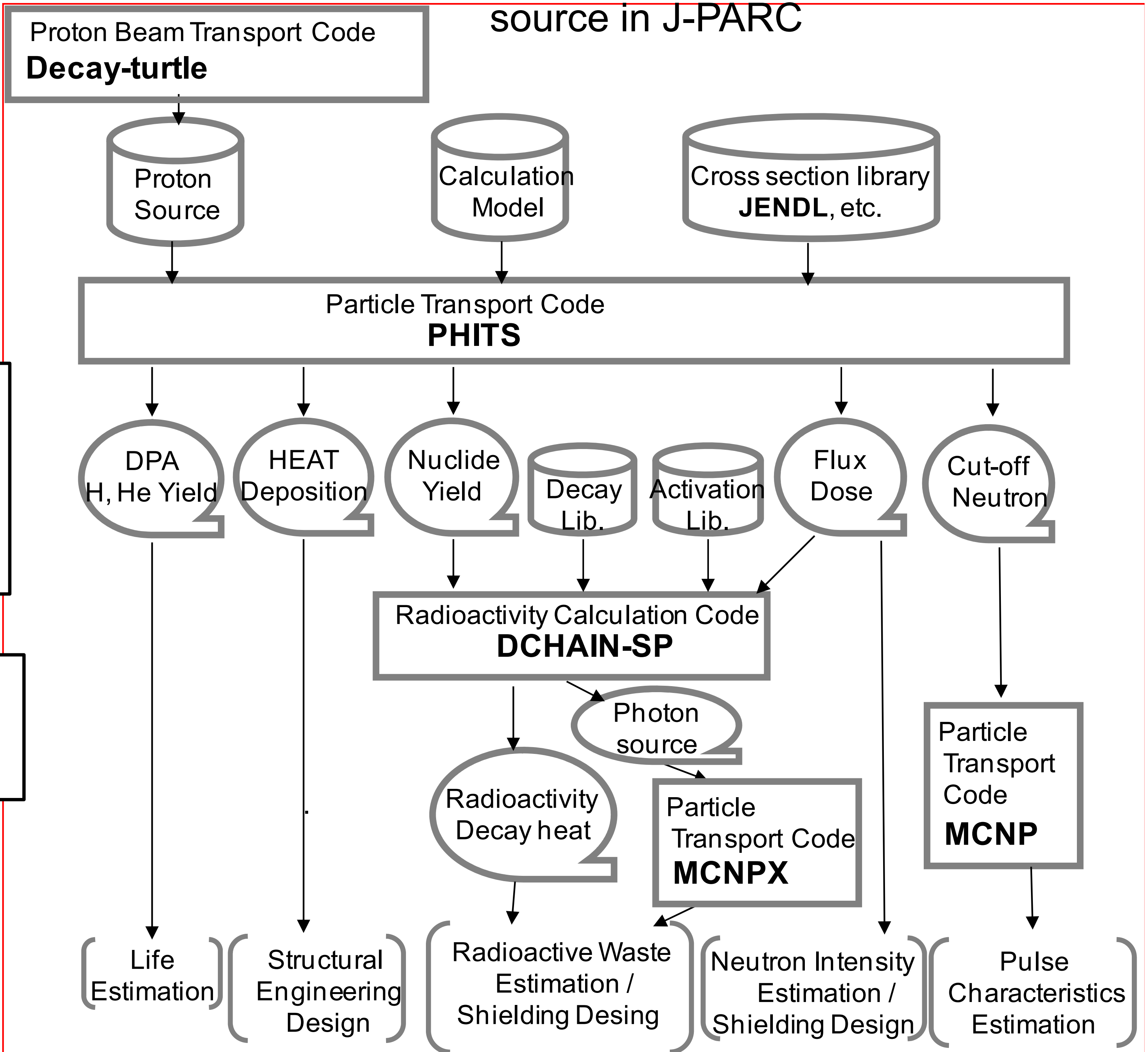
Code System

For the spallation neutron source in J-PARC

PHITS:
Particle and Heavy Ion Transport Code

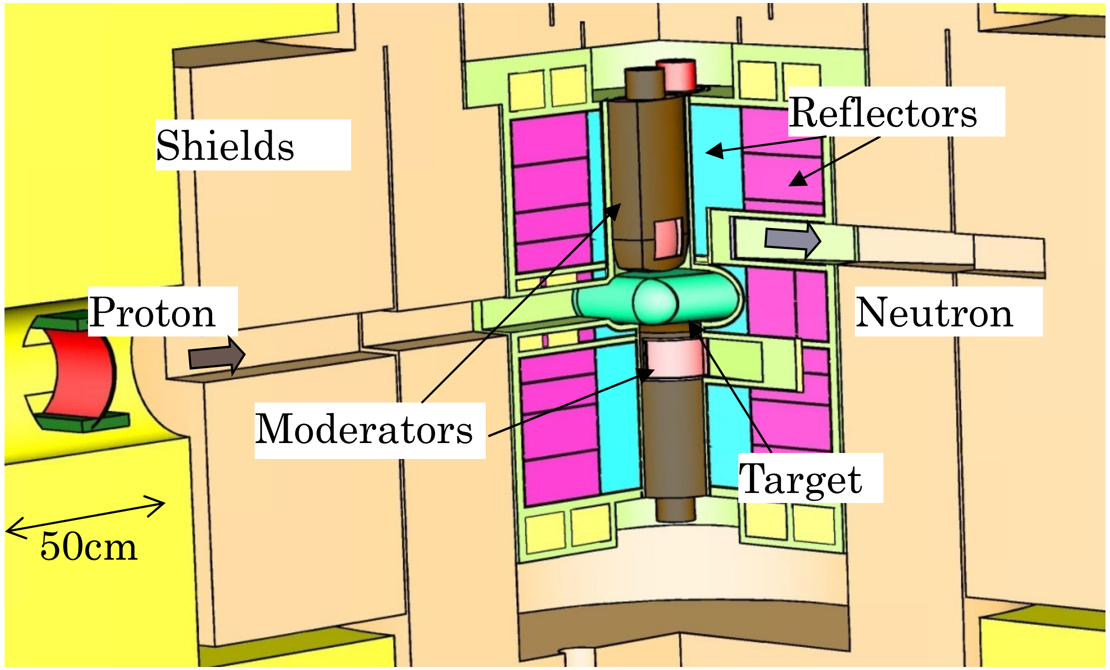
Large model size (>15m),
Large model number (>2000)
Large attenuation of neutron flux (>10 decades)
Large cases (~2000)

Around 2008,
MPI parallel computing system was used
Pentium IV 2.8GHz (2 core) X 36
Xeon 3.0 GHz (4 core) X 1



Calculation model and calculation parameter

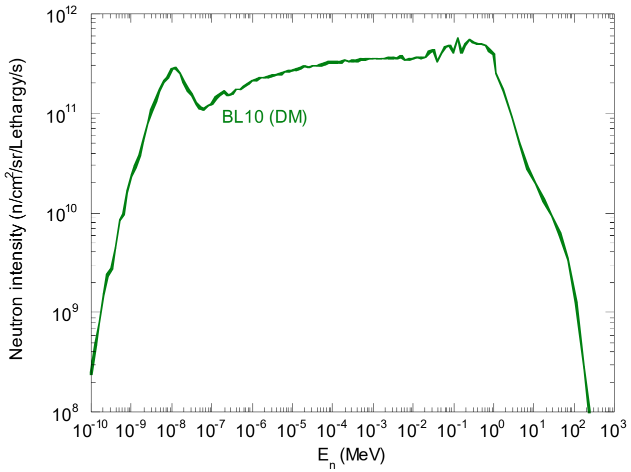
3 D view of JSNS design

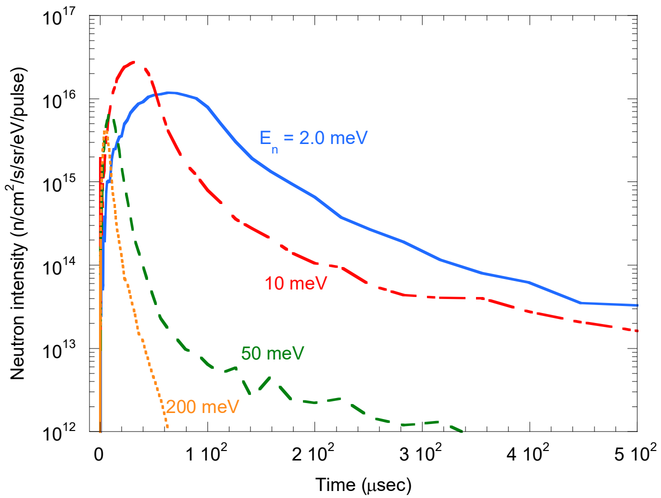


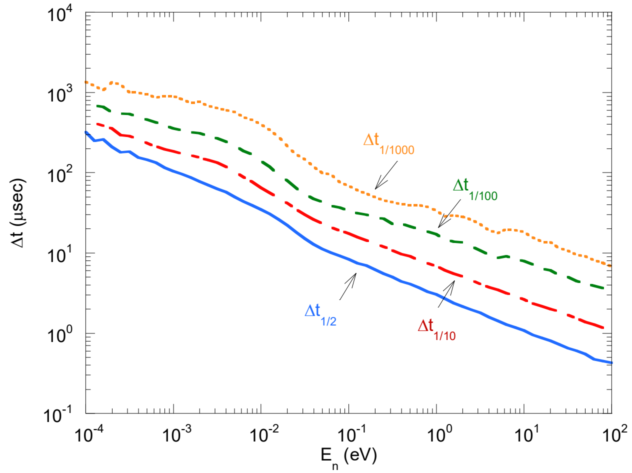
Item		Calculation condition
Proton Beam		
	Power	1MW at the proton beam window
	Operation time	5000 hours / year
	Profile	Emittance : 81 π mm mrad
		Gaussian + Uniform
		Footprint : 180 x 70 mm^2
	Repetation rate	25Hz
Proton Beam window		
	Material & thickness	Al-alloy (A5083), 2.5mm^t x 2 plates
	Coolant	H_2O
Target		
	Material, density	Mercury, 13.6 g/cm^3
	Vessel material	316L stainless steel
	Coolant	D_2O
Moderator		
	Type & number	Coupled (CM) 1
		Decoupled (DM) 1
		Decoupled Poisoned (PM) 1
	Material property	Super-critical hydrogen, 20K, 1.5MPa,0.07g/cm^3
	Vessel material	Al-alloy (A6061, A5083)
	Coolant	H_2O
Reflector		
	Material & size (Inner)	Beryllium, 50 cm (Dia.) x 100 cm (Hei.)
	Material & size (Outer)	Iron, 100 cm (Dia.) x 100 cm (Hei.)
	Coolant material., fraction	D_2O, about 10% (channel width: 5mm)
	Vessel material	Al-alloy (A5083)
Water-cooled shield		
	Material	304 stainless steel
	Coolant material, fractio	H_2O, about 10%
Air-cooled shield		
	Material	Steel
	Coolant material	Air
Neutron beam line		
	Number	23

Calculation results

Neutron flux and pulse shape for providing at the neutron beam port







Nuclear heat generation

Precise treatment were considered
1, Photon energy deposition via electron energy deposition
2, Energy-balanced neutron kerma factor
3, Decay heat

Energy conservation was consistent.

Component		Nuclear Heating (kW)
Target	Mercury & Vessel	493.0
Reflector	Reflector & Vessel	193.9
Shielding block	Water-cooled shielding block	133.8
Proton beam window	Window assembly	1.4
Poisoned moderator	H_2 & H_2 Vessel	1.1
	Water-cooled outer Vessel	4.4
Decoupled modearator	H_2 & H_2 Vessel	1.0
	Water-cooled outer Vessel	4.9
Coupled modearator	H_2 & H_2 Vessel	1.4
	Water-cooled outer Vessel	5.2
Total		874.7

Dose rate
DPA
Radioactive materials
and so on.

Measurements and validations

Measurement list

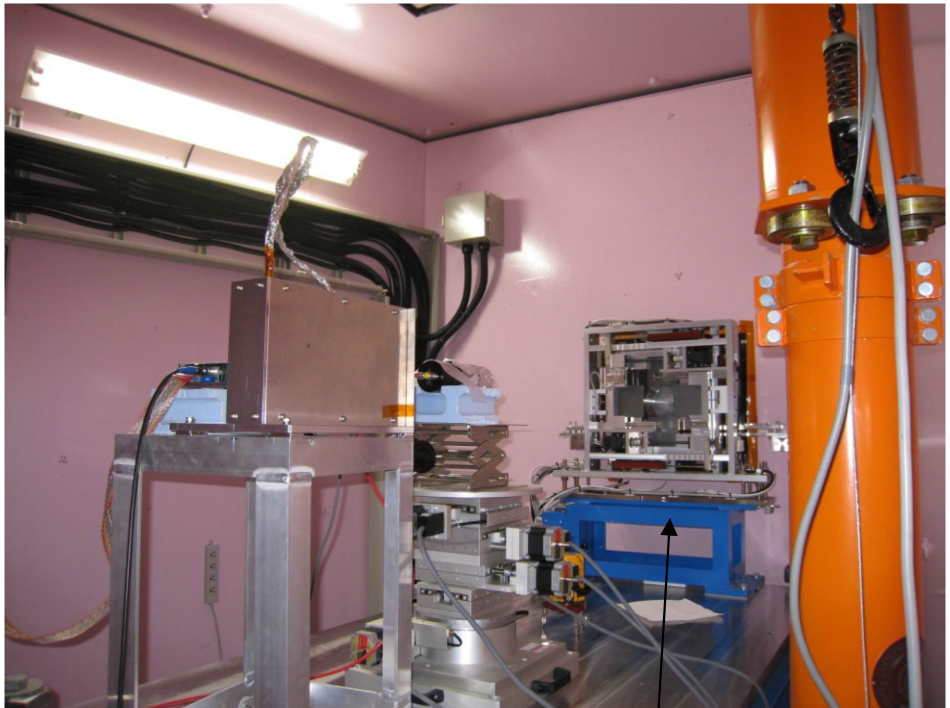
- First neutron measurement
- Neutron intensity
  - Thermal-cold neutrons
  - High energy
- Pulse shape
  - Thermal-cold neutrons
  - High energy
- Spatial distribution on moderator surface
  - Thermal-cold neutrons
  - High energy

Pictures of neutron measurement at BL10

Counting detectors
1/2 inch He-3 detector (Eff~1)
He-3 monitor (Eff:10^{-1},10^{-2},10^{-3},10^{-4},10^{-5})

Li-glass scintillator

^{3}He detector



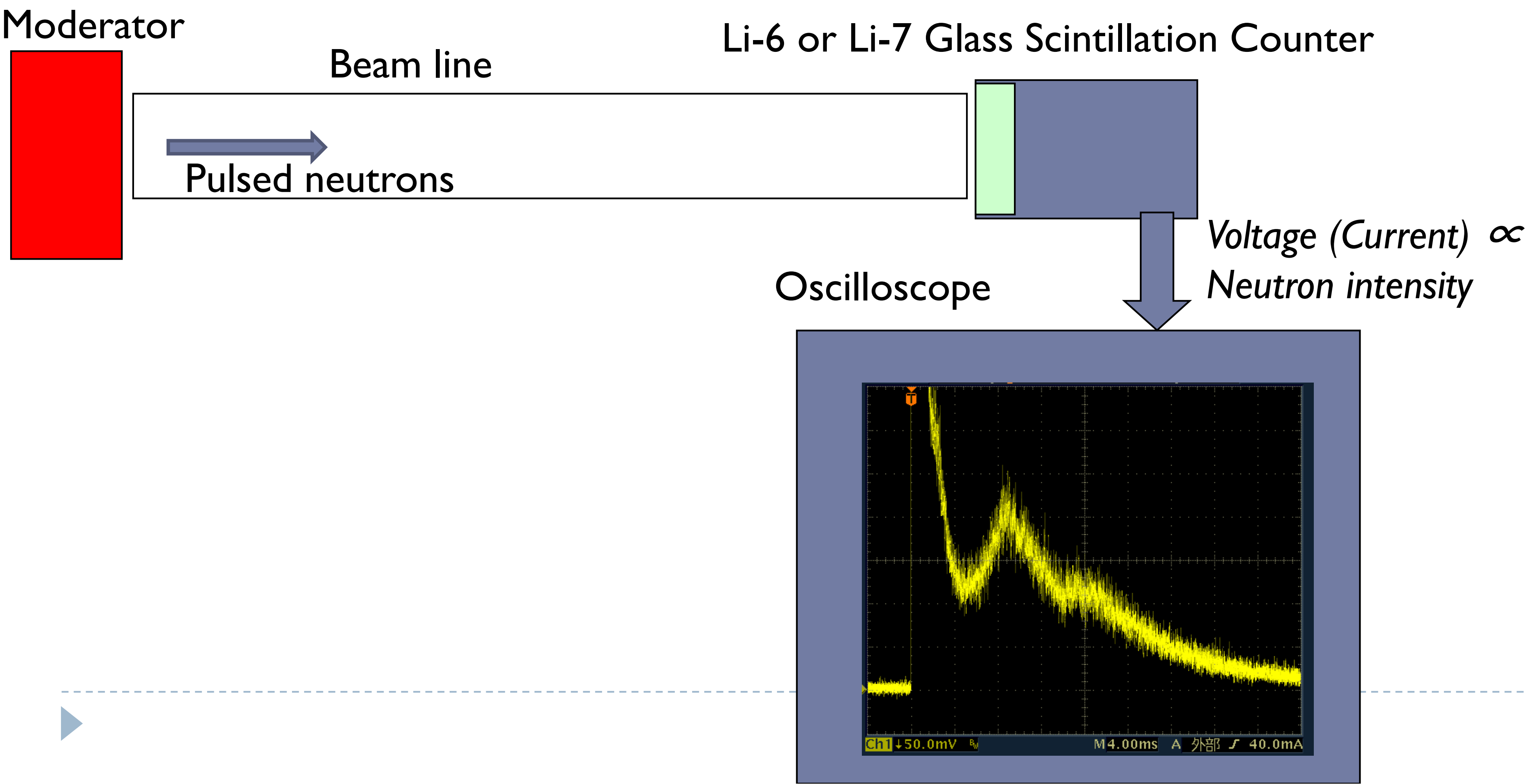
Beam stop

Neutron beam entrance

First Neutron Measurement

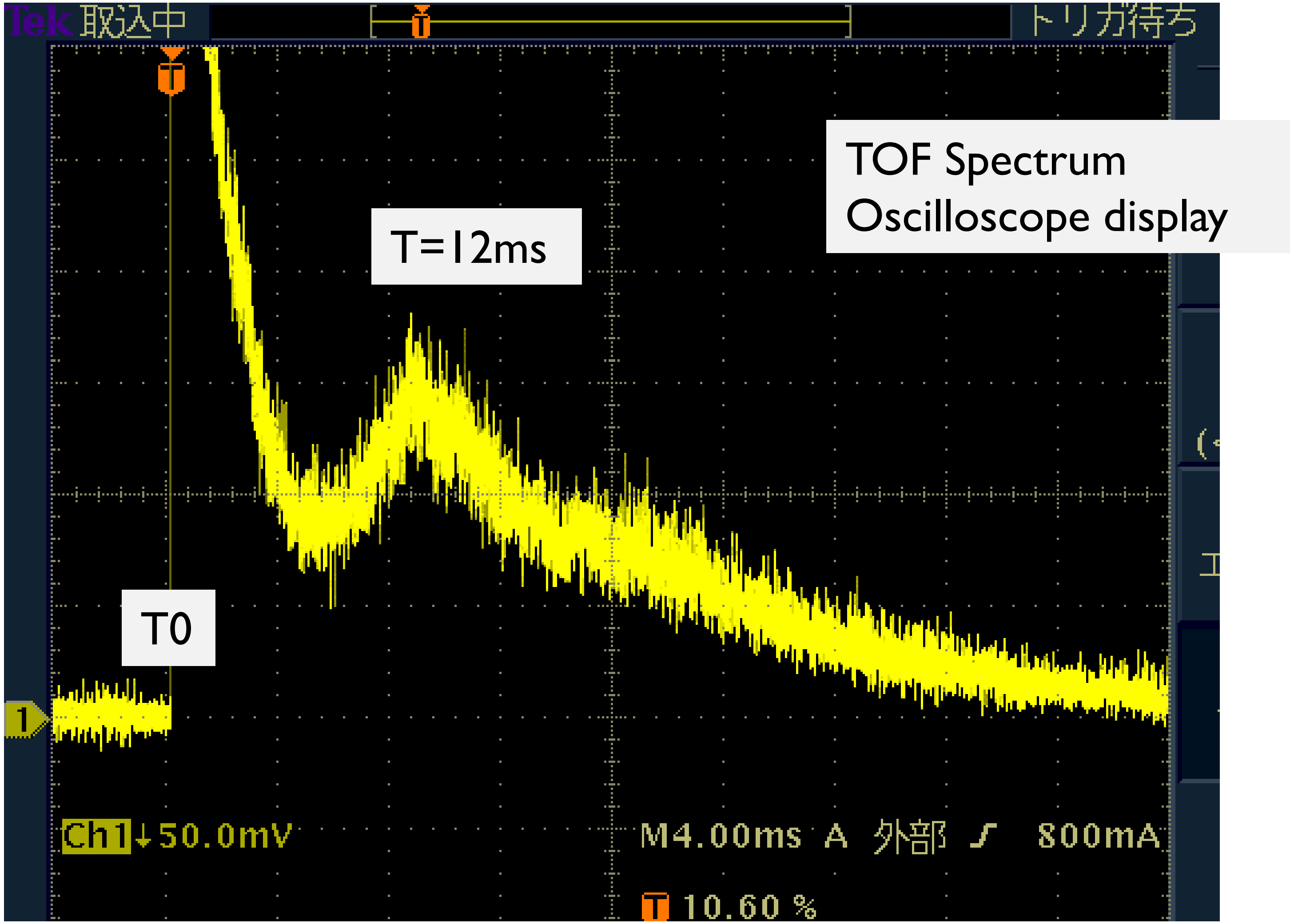
First direct beam was measured by CTOF method at the sample position at BL10.

CTOF: Current Time of Flight



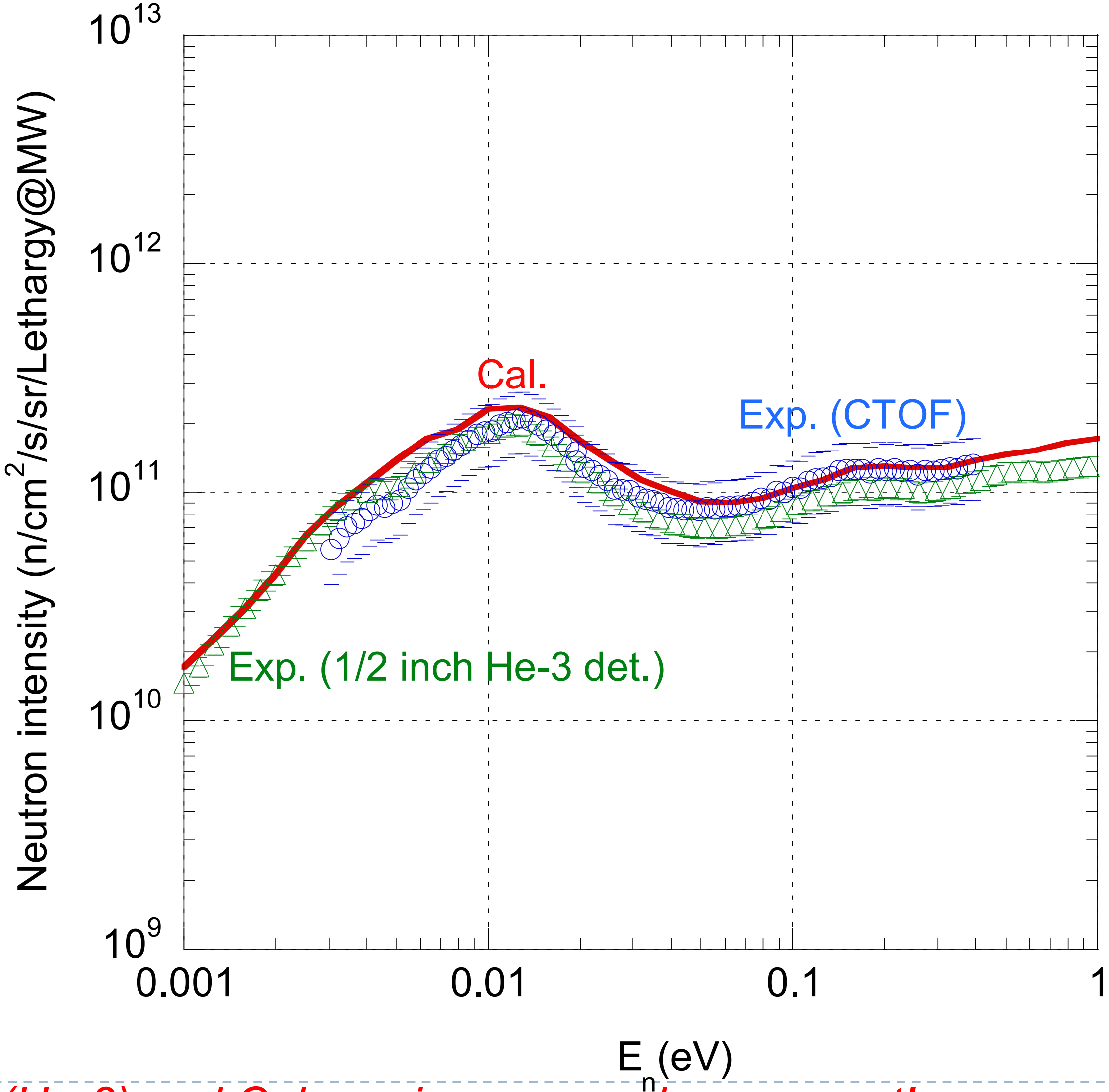
On May 30, 2008

The first neutron beam



Only 1 shot !

Measurement of neutron spectral intensity



Time of flight

- Measuring time
  6 minutes CTOF
  1 hour ½" He-3
  at 20 kW

- Exp(CTOF)-Exp(He-3):
  Good agreement

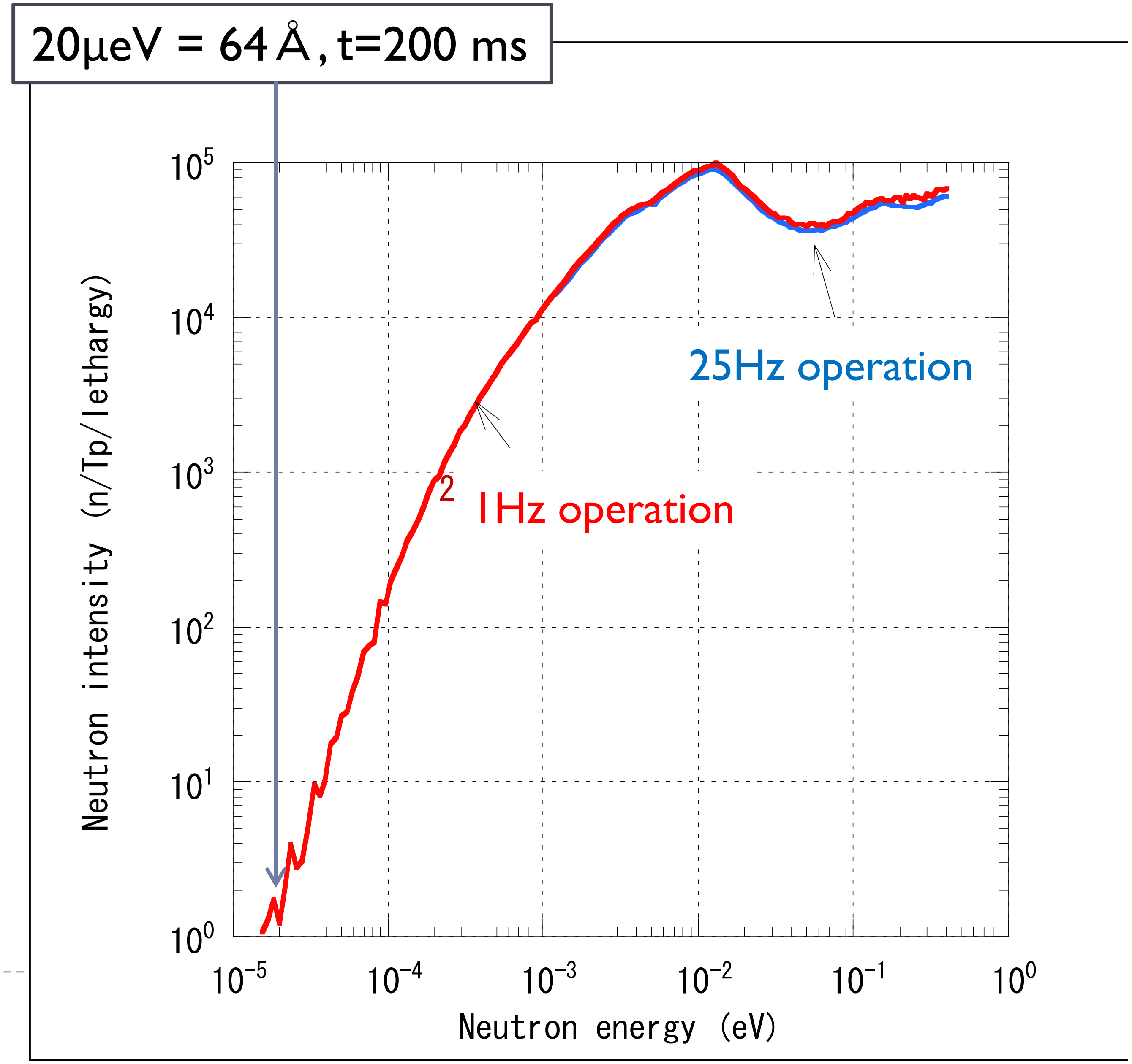
- Exp(CTOF)-Cal :
  Good agreement

- Experimental error :
  within 30 % :CTOF
  within 10 % :He3 detector

Exp (He-3) and Cal. are in very good agreement!
(without any parameter adjustment nor normalization).

Ultra-cold neutrons

- Neutron measurement in 1Hz operation was performed.
- Lower neutrons around 20 μeV could be measured.



High energy neutrons (1)

Reaction rate

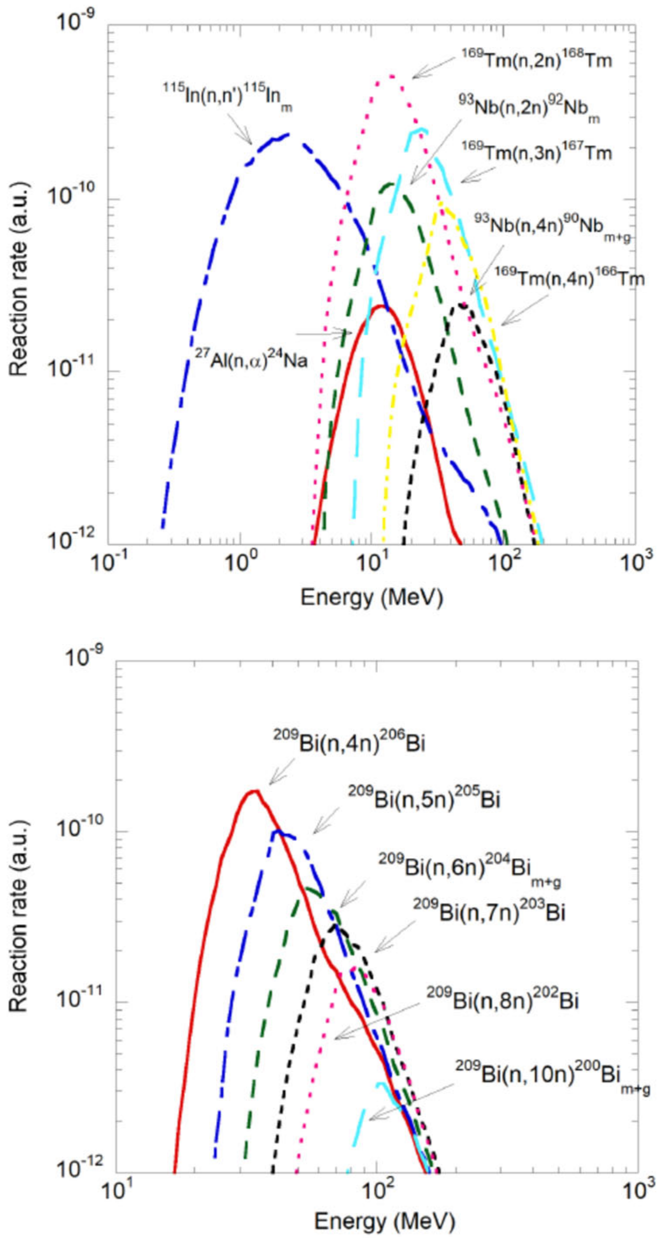
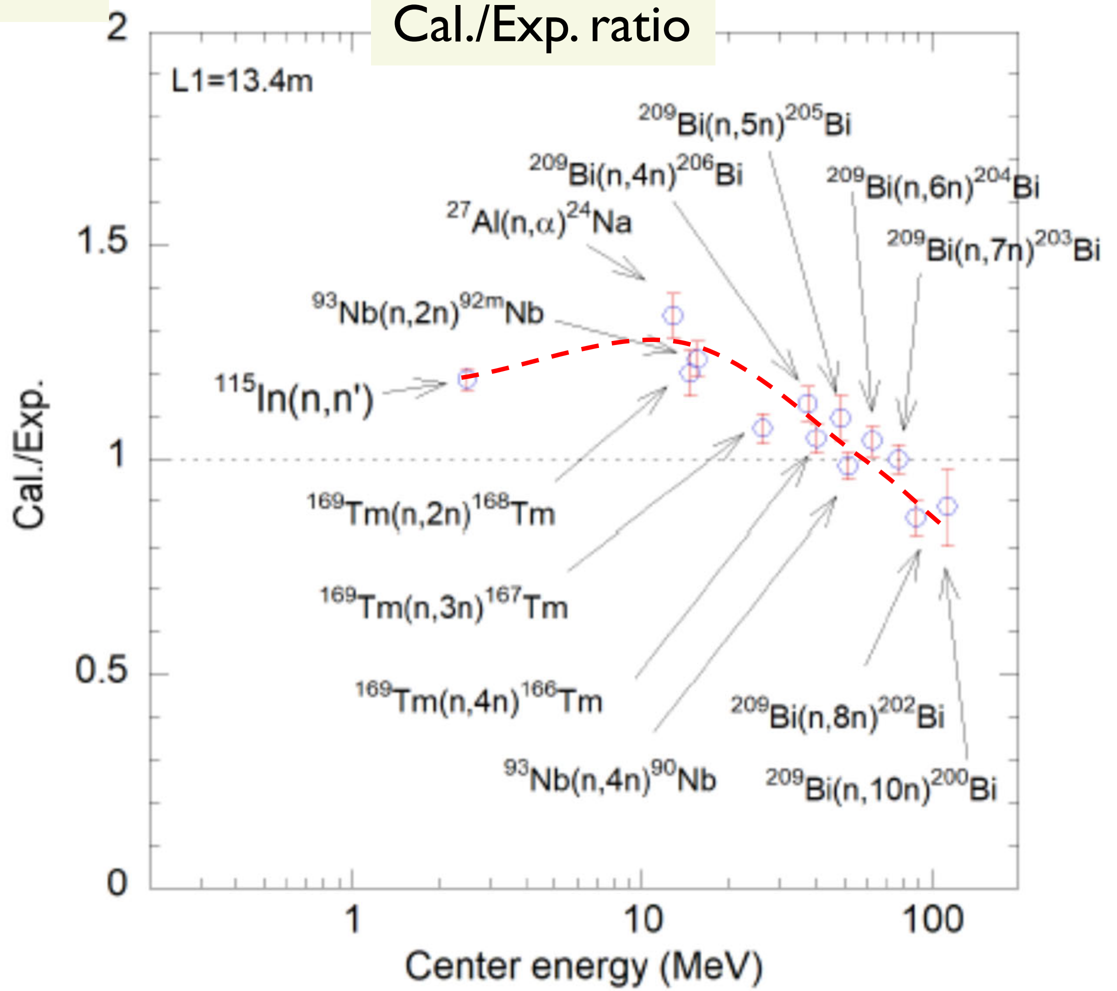


Figure 11: Neutron energy dependence of each reaction rate.

The foil activation method with the threshold energy reactions was used.

Cal./Exp. ratio



C/E: 0.8～1.2

Pulse shape measurement

- Sample: mica and diamond
- The detector was located at 170°

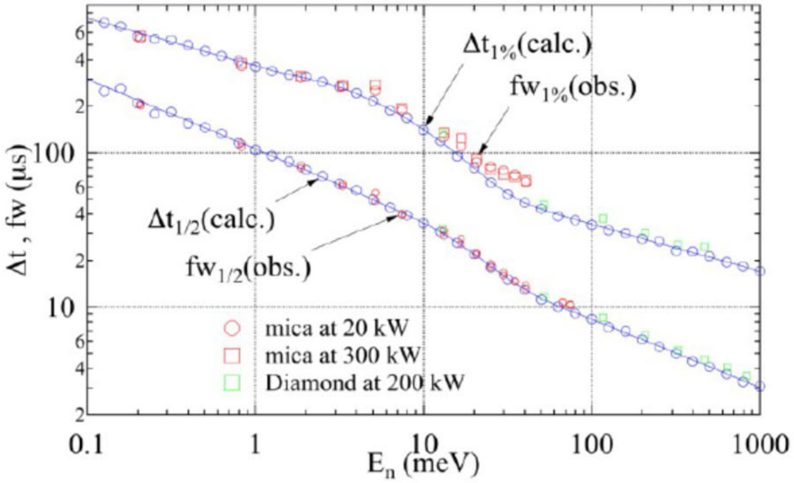


Fig. 3. Pulse width at half and 1 % maximum of observed
...nes of DM of JSNS.

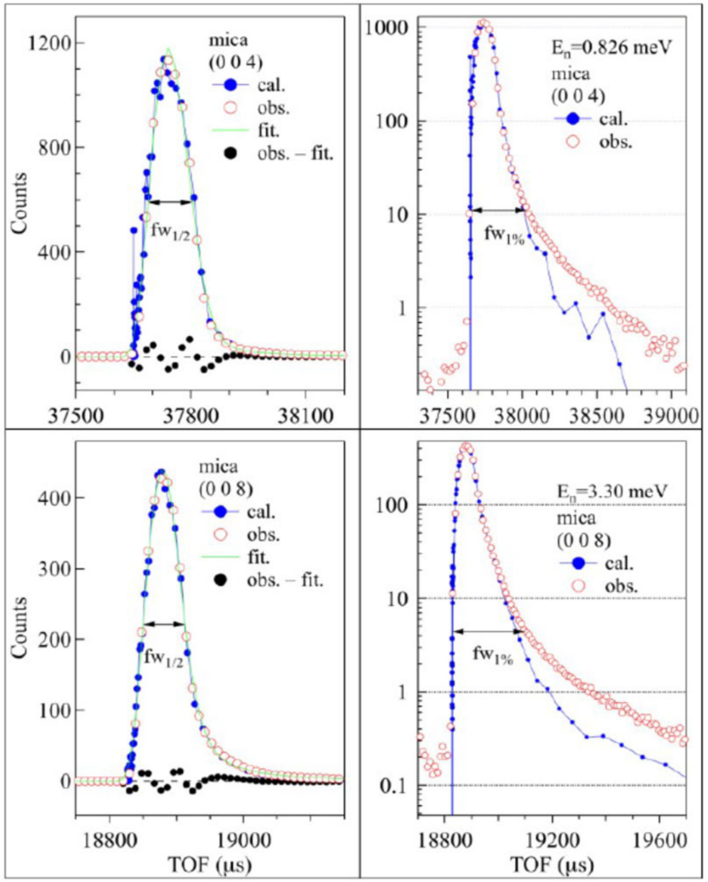


Fig. 1. Example of pulse shapes of the cold neutrons. Bragg peaks of (004) and (008) of mica are represented.

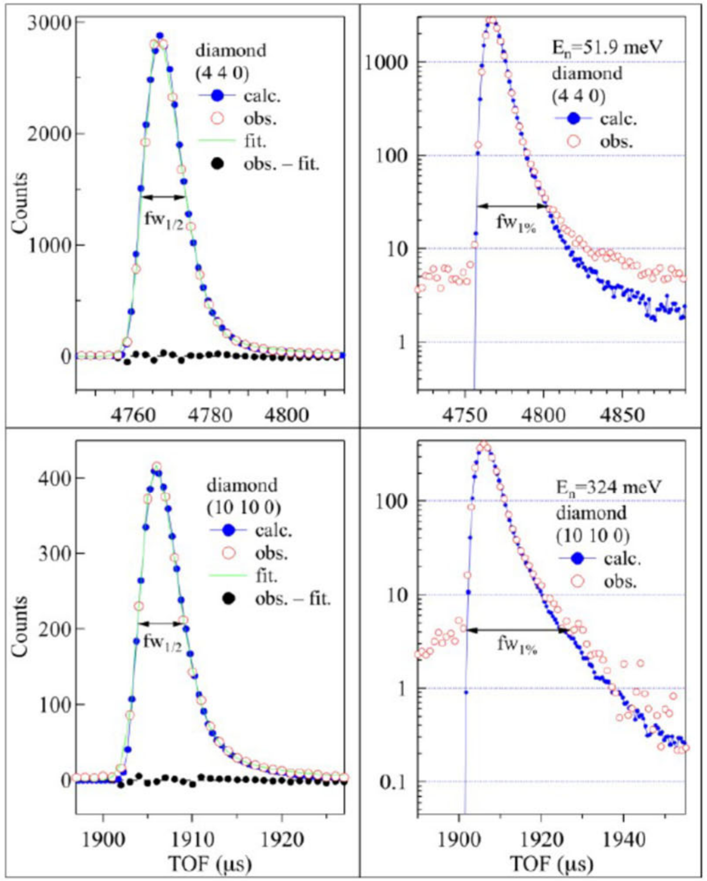
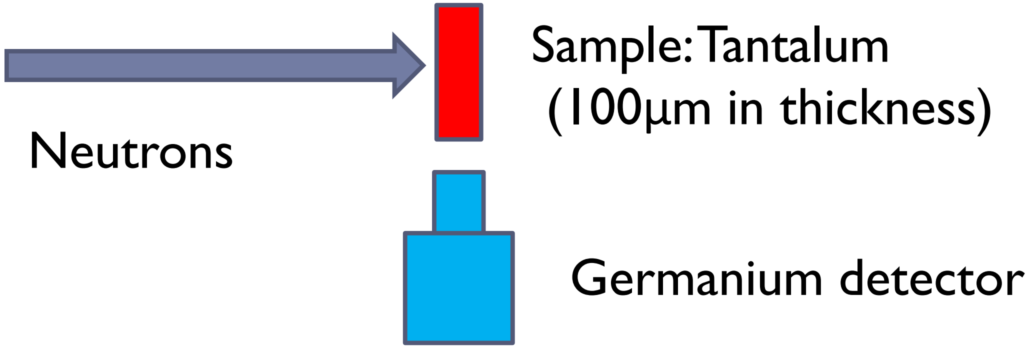
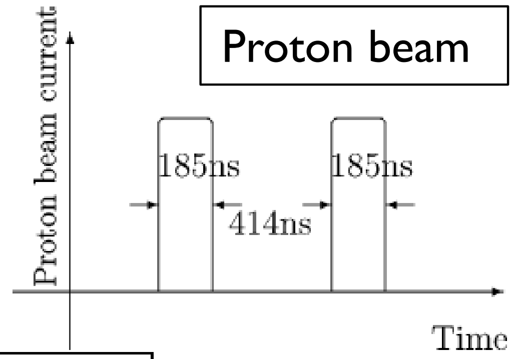


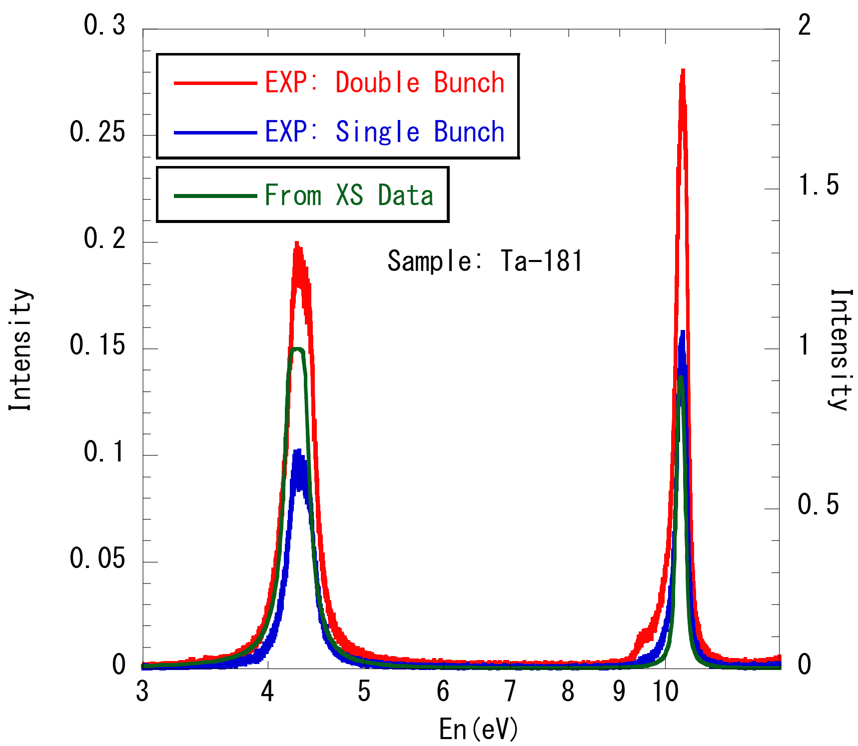
Fig. 2. Example of pulse shapes of the thermal and epithermal neutrons. Bragg peaks of (440) and (10 10 0) of diamond are extracted.

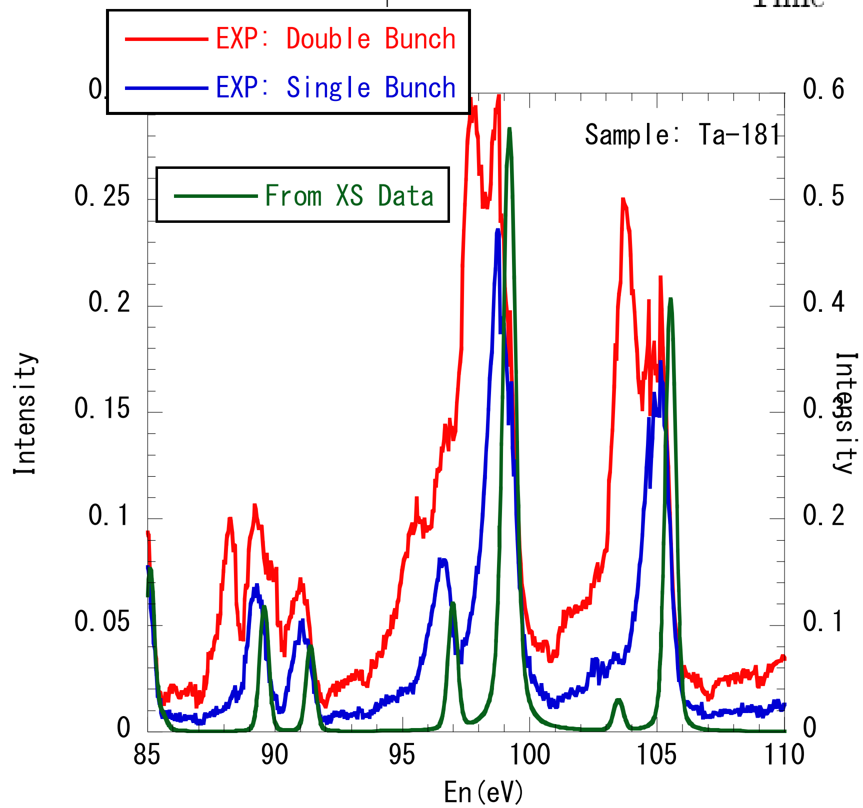
Good agreement

Pulse shape at eth-thermal region



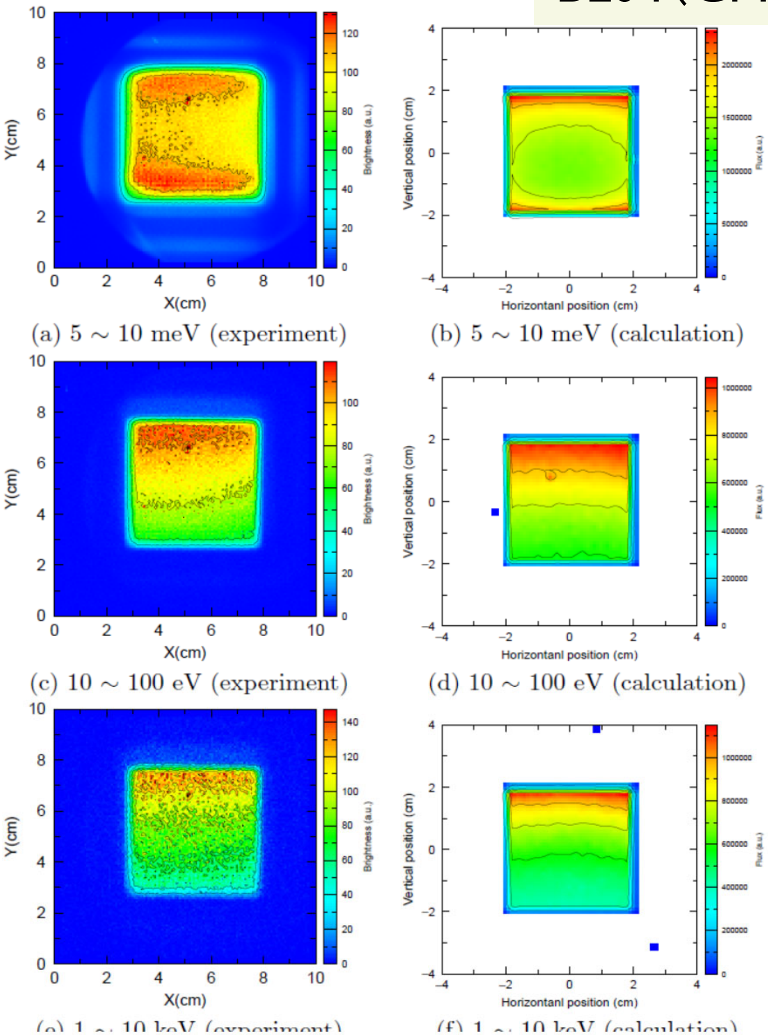




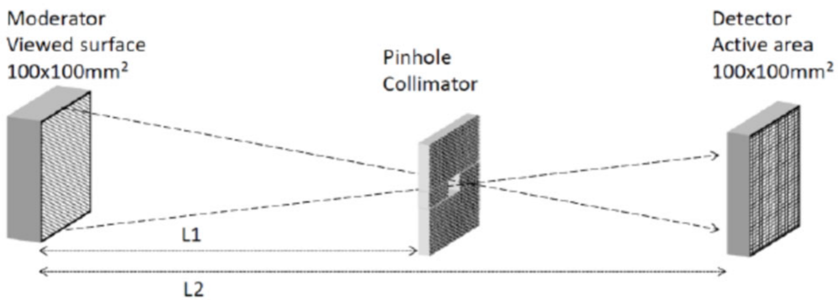


Spatial distribution

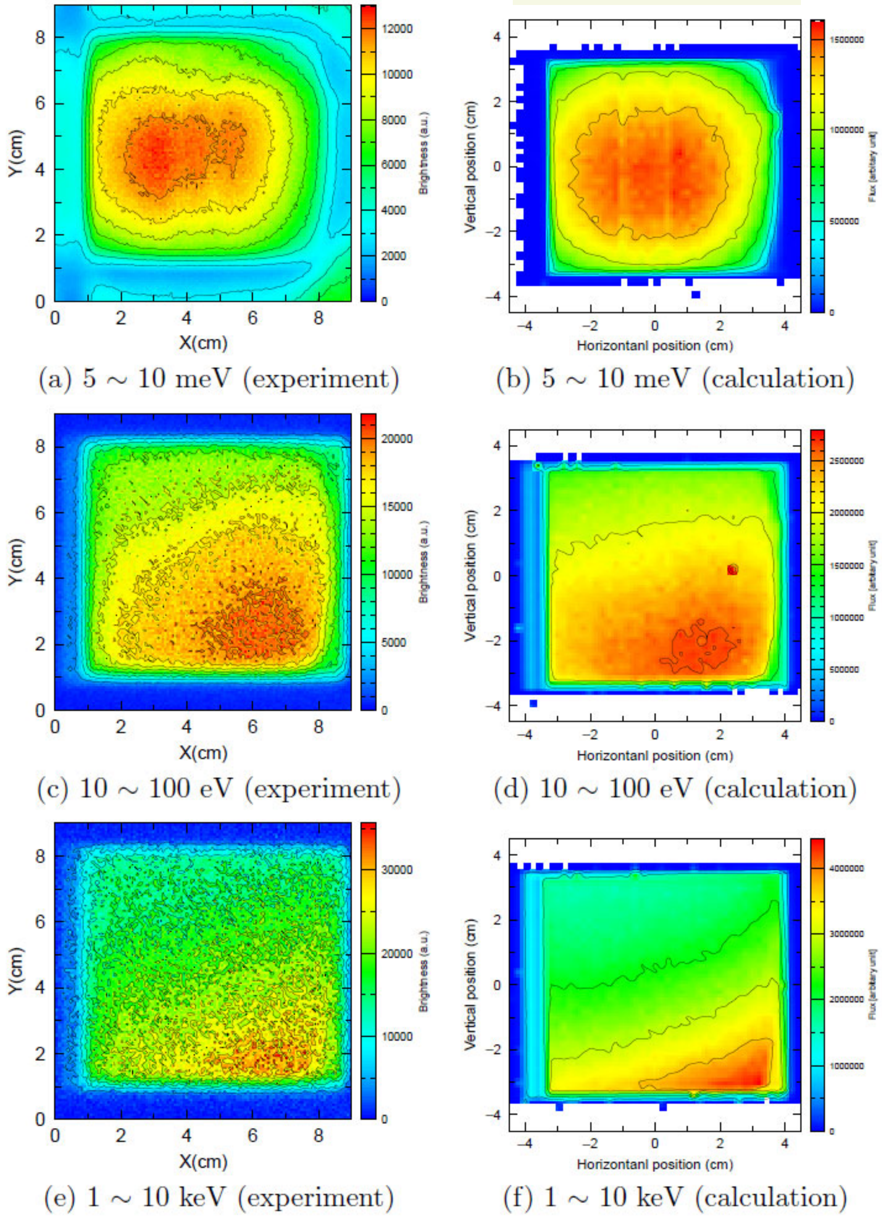
BL04(CM)



(a) 5 ~ 10 meV (experiment) (b) 5 ~ 10 meV (calculation)
(c) 10 ~ 100 eV (experiment) (d) 10 ~ 100 eV (calculation)
(e) 1 ~ 10 keV (experiment) (f) 1 ~ 10 keV (calculation)



BL10(DM)



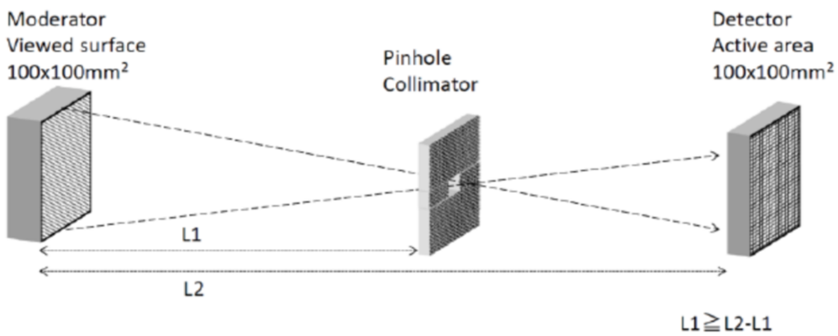
(a) 5 ~ 10 meV (experiment) (b) 5 ~ 10 meV (calculation)
(c) 10 ~ 100 eV (experiment) (d) 10 ~ 100 eV (calculation)
(e) 1 ~ 10 keV (experiment) (f) 1 ~ 10 keV (calculation)

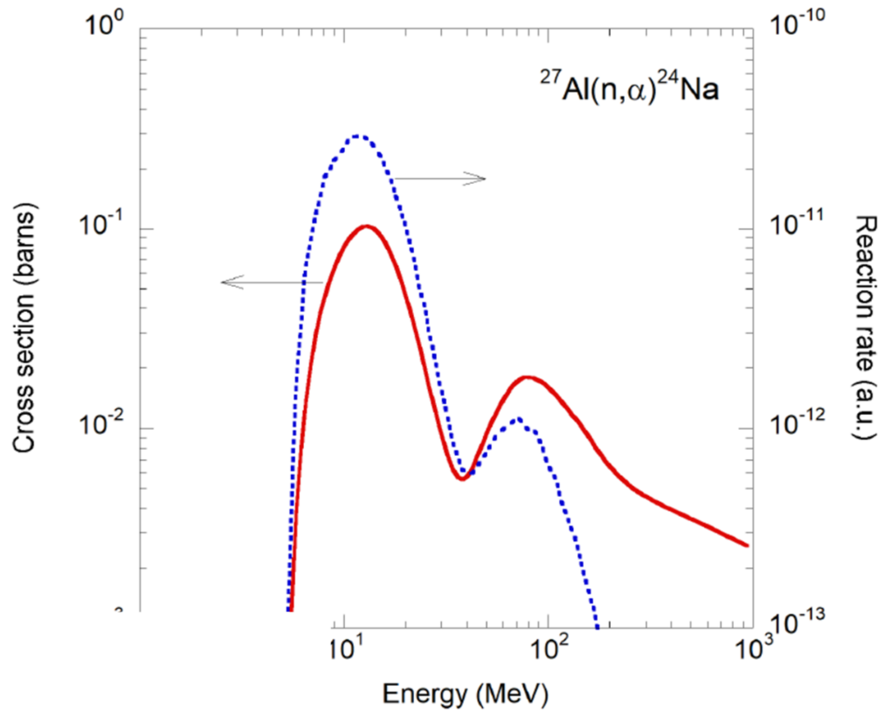
Figure 9: Measured and calculated brightness at BL10.

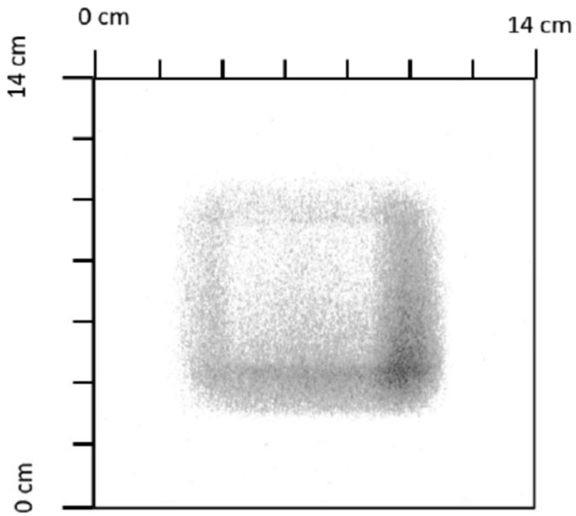
We could observe the spatial distribution.

Spatial distribution of high energy neutrons

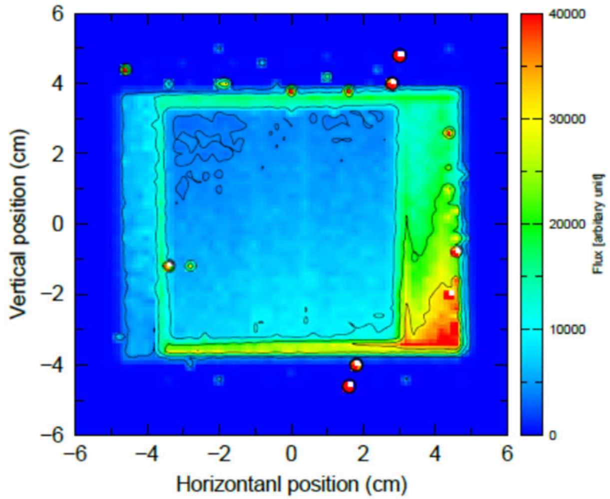
The $^{27}Al(n,\alpha)^{24}Na$ reaction was used.







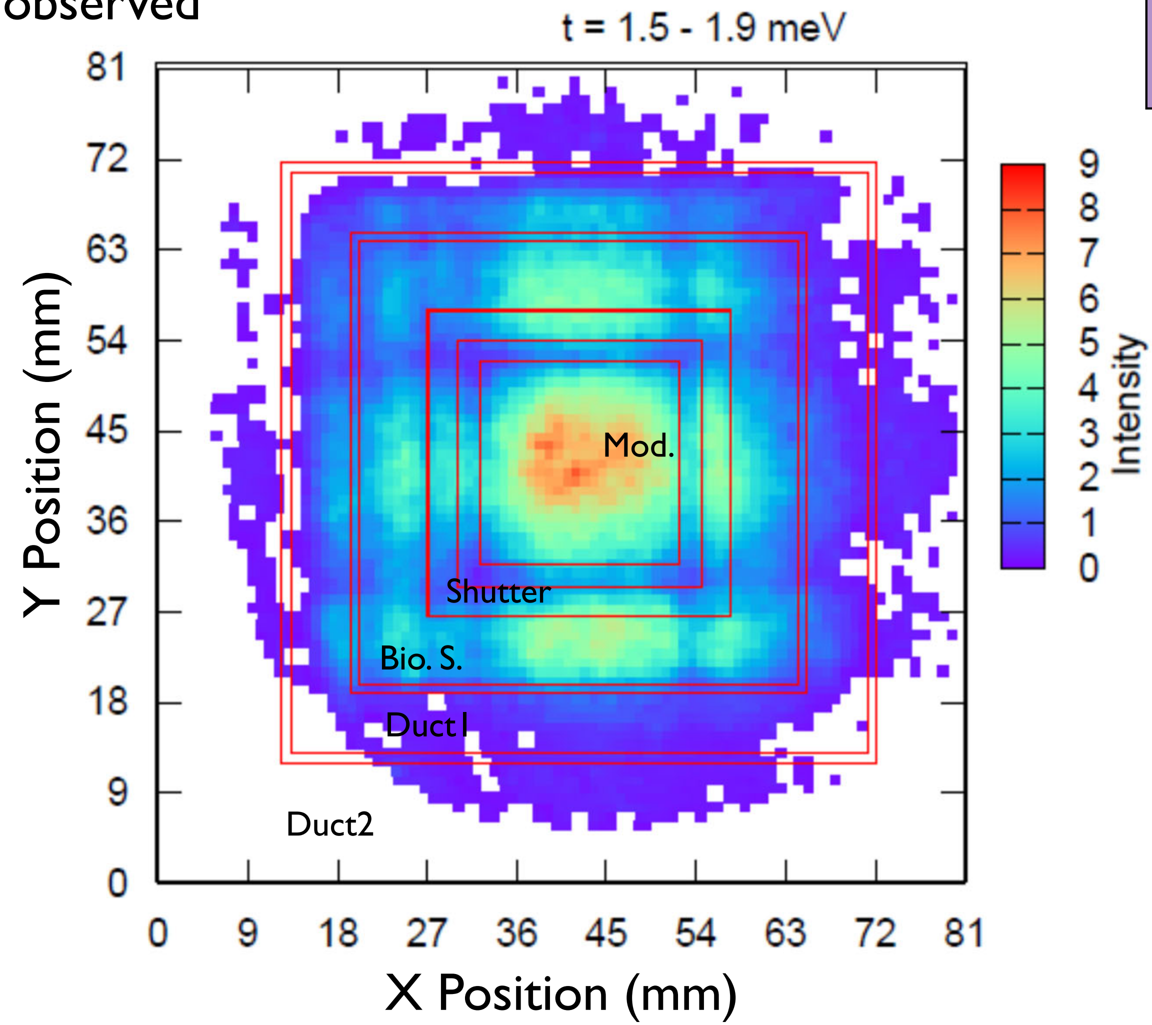
(a) experiment

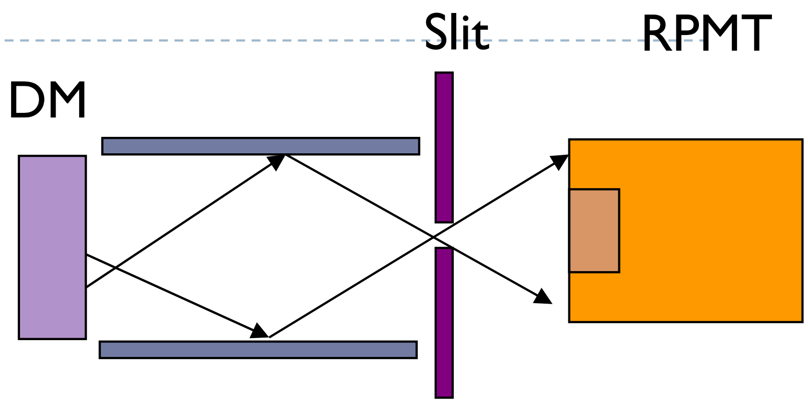


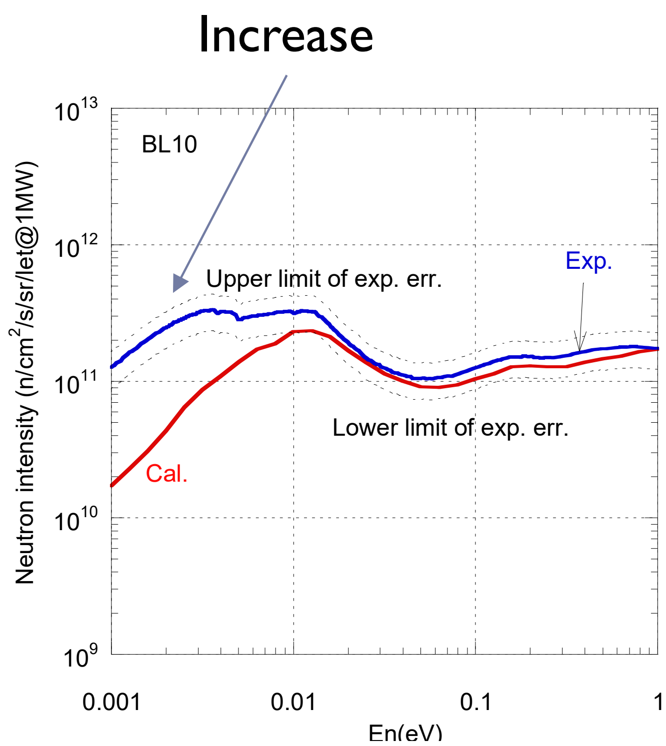
(b) calculation

Spatial distribution on moderator surface and neutrons reflection at ducts

・Neutron reflection in shutter, biological shields and so on can be observed

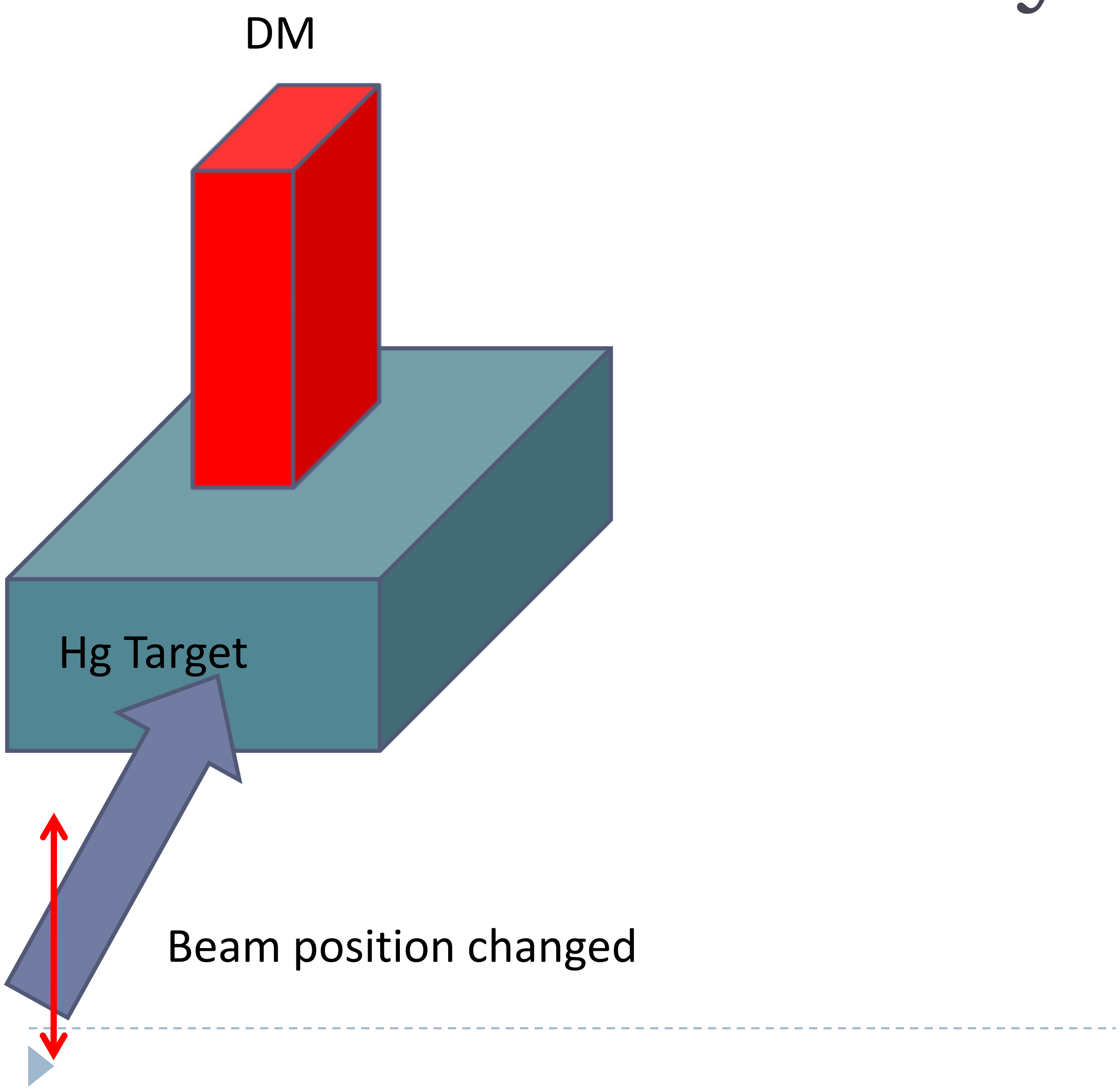


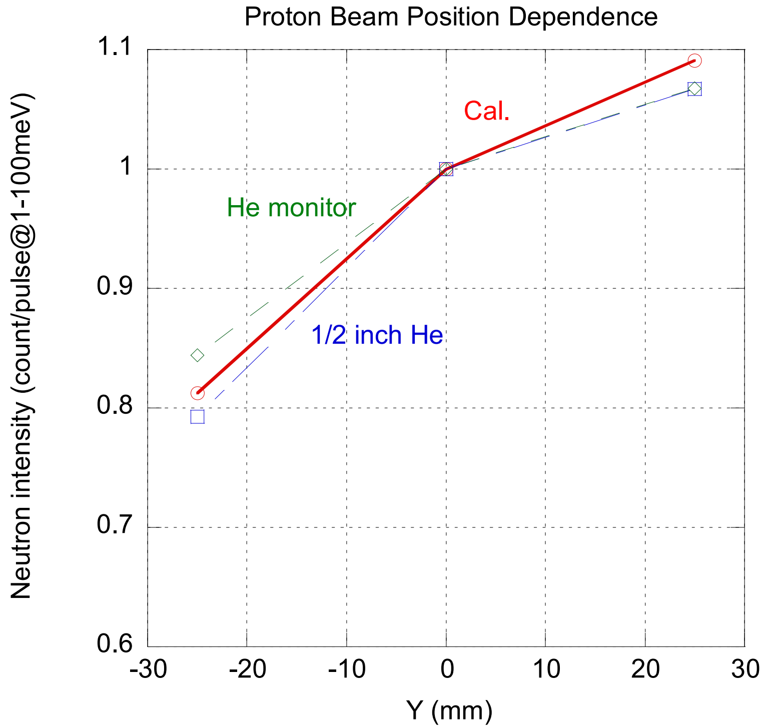


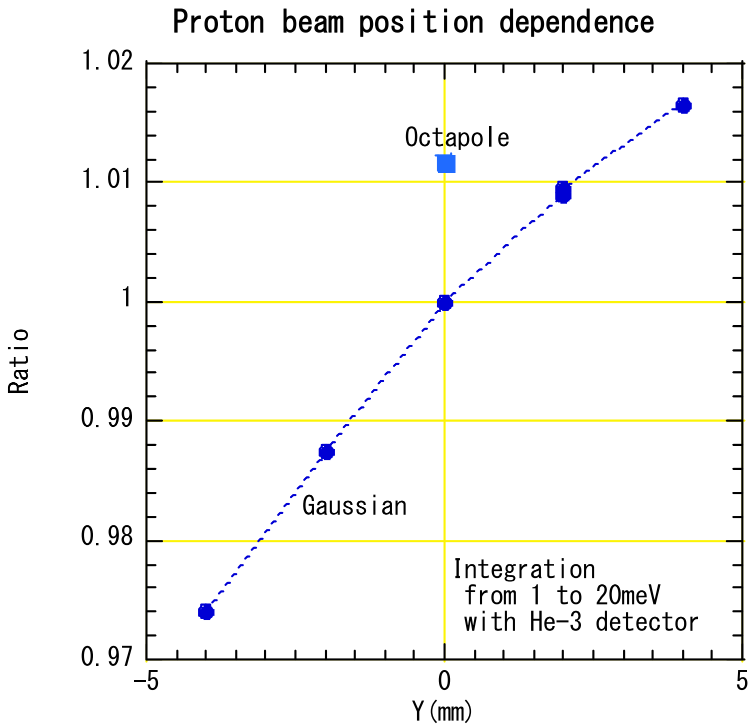


Other measurements

Proton beam position dependence on neutron intensity

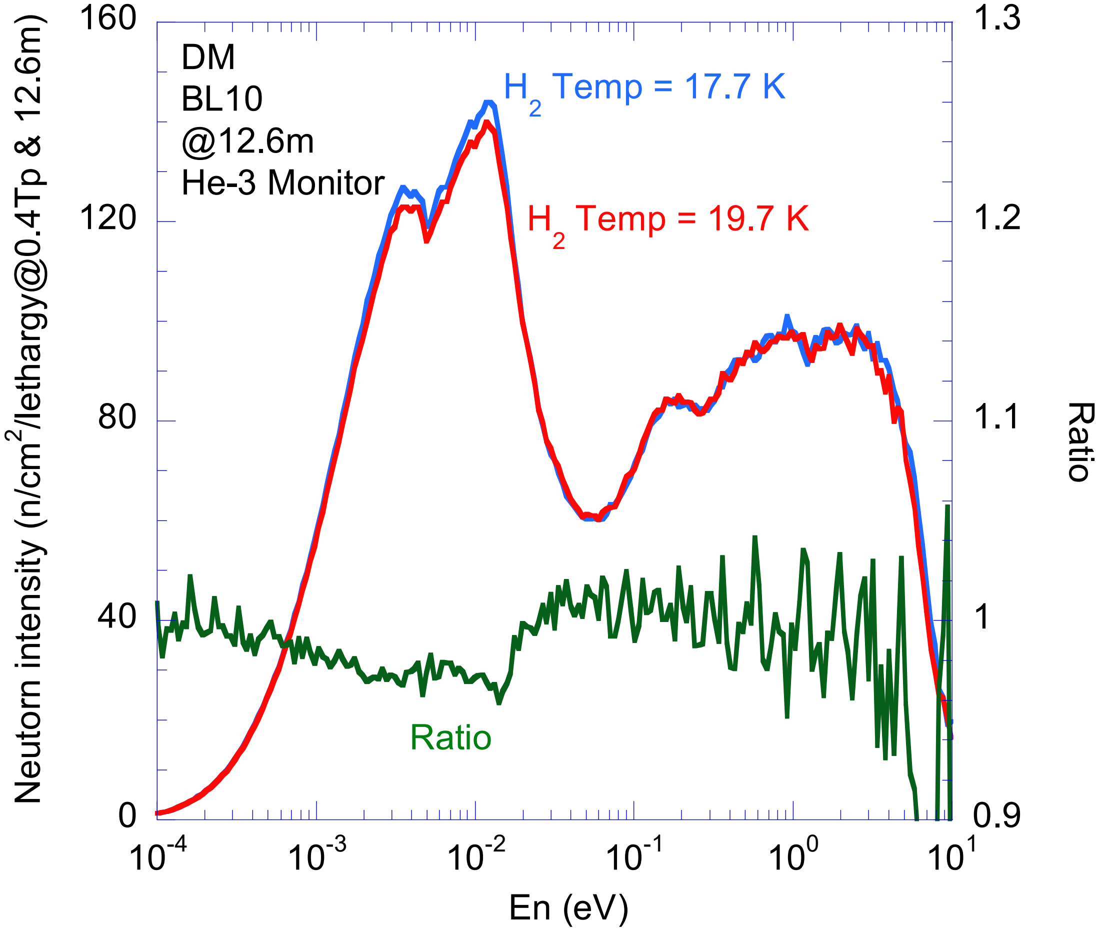






Liquid hydrogen temperature dependence on neutron spectral intensity

Spectral intensity change between 17.7K ad 19.7K

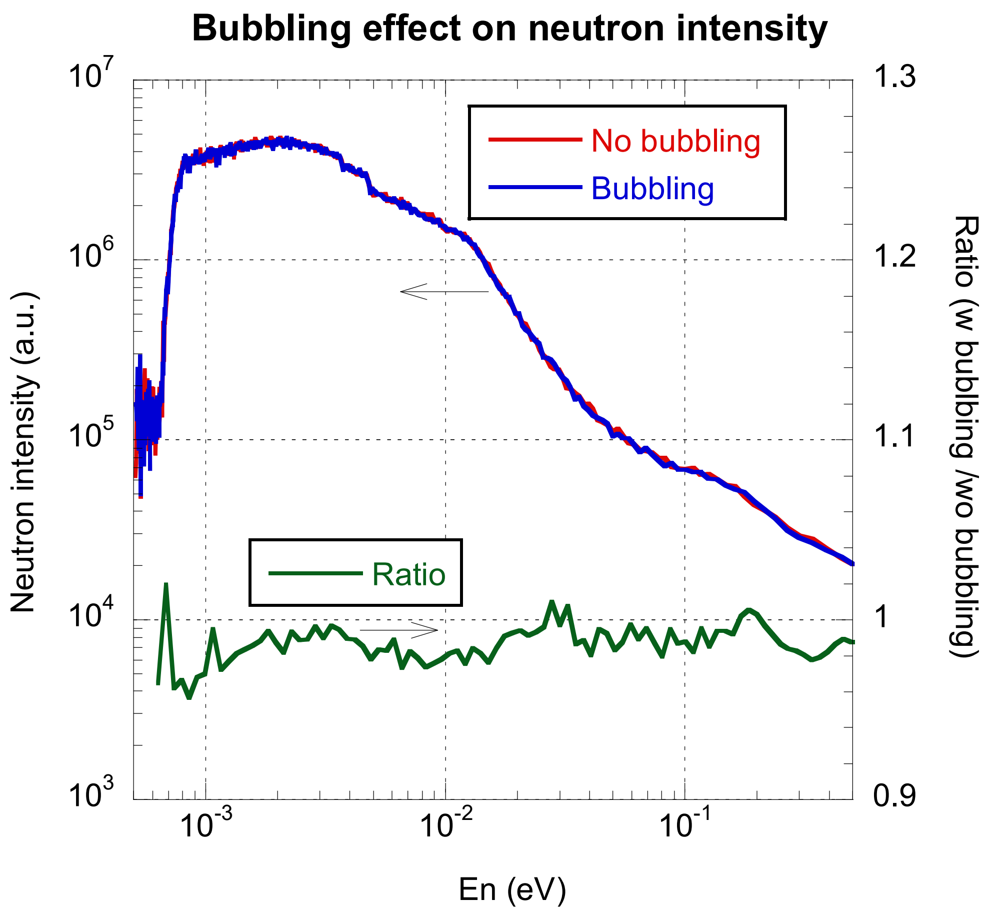


From calculation
DM
En<50meV 5%/2K
En>50meV 1%/2K

↓

Good agreement

Bubbling effect on neutron intensity

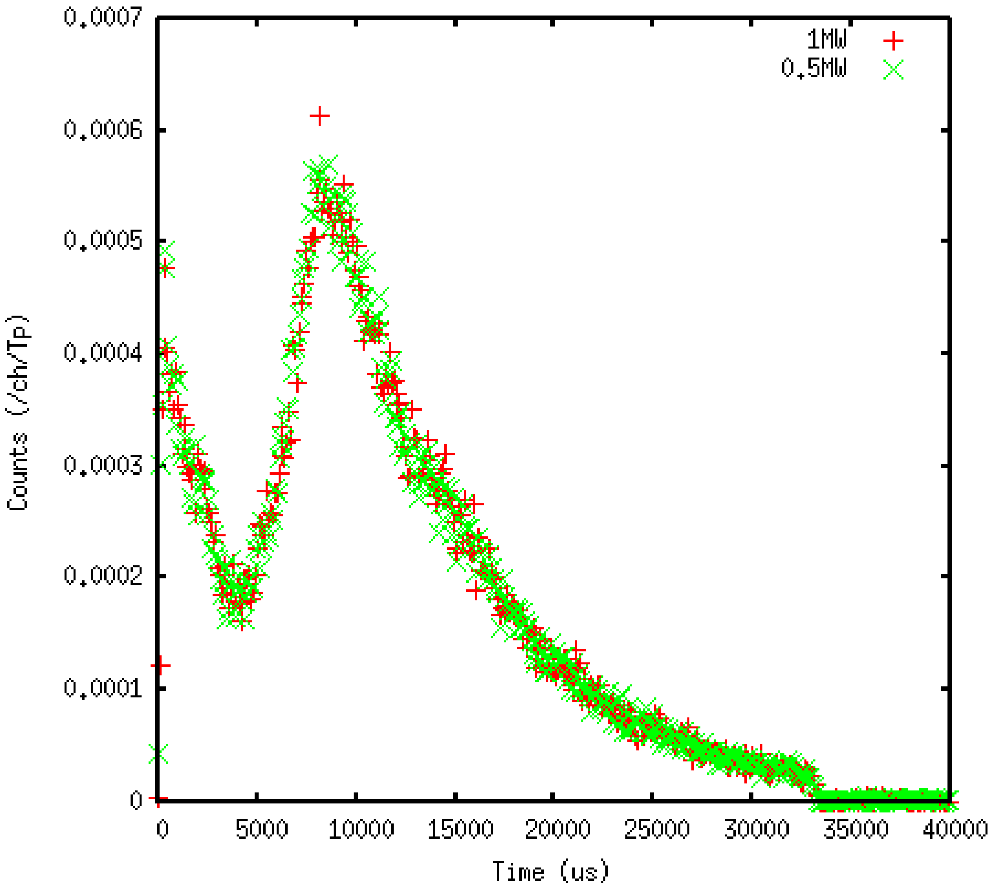


- Neutron intensity decreases or doesn't by the bubbling in the target system?
- Neutron intensity were measured at BL10 with the He-3 monitor (Eff:10^{-5})
- Neutron intensity integrated in the energy region from 1 meV to 100 meV with the bubbling decreases 0.55% compared with that without the bubbling.
  -> Negligible difference

Comparison of 0.5MW and 1MW operation Neutron absolute intensity and spectral intensity (Preliminary)

BL10 noboru

Spectrum by He-3 detector



2cases operation

- 0.5MW(506kW) operation
- 1.0MW(879kW) operation

Absolute value by Gold foil activation method

Below Cd cut-off energy

2.1×10^{-16} reaction/atom/s@506kW

→ 2.0×10^{-31} reaction/atom/p

3.6×10^{-16} reaction/atom/s@879kW

→ 2.0×10^{-31} reaction/atom/p

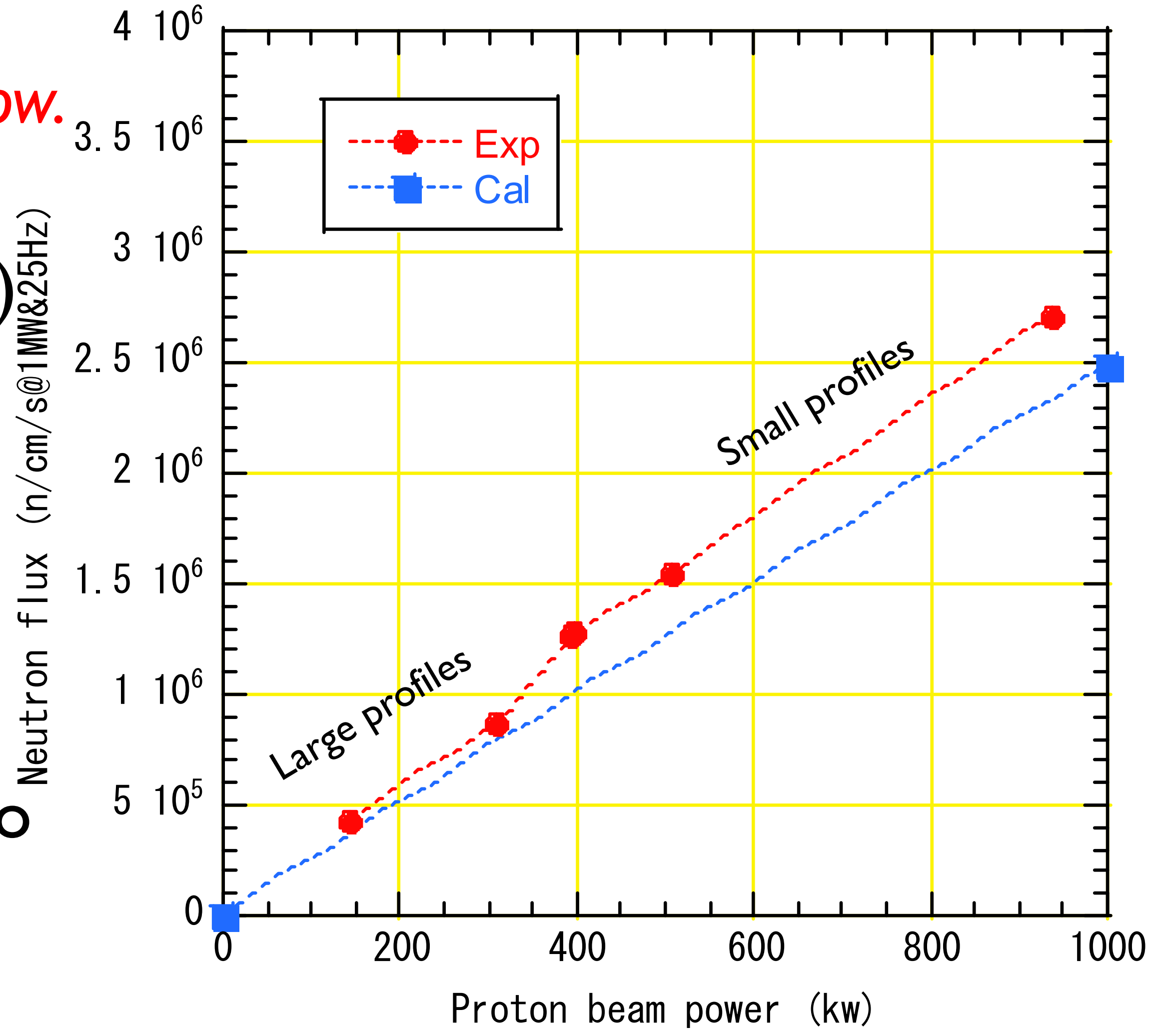
Linearity is good.

Absolute value of neutron intensity with gold foil activation method

- *1MW operation for 10 hours on July 3 was successful.*
- *500kW operation is sable now.*

- At sample position (13.4m) BL10 (Noboru) with collimators
- W/WO Cd cover

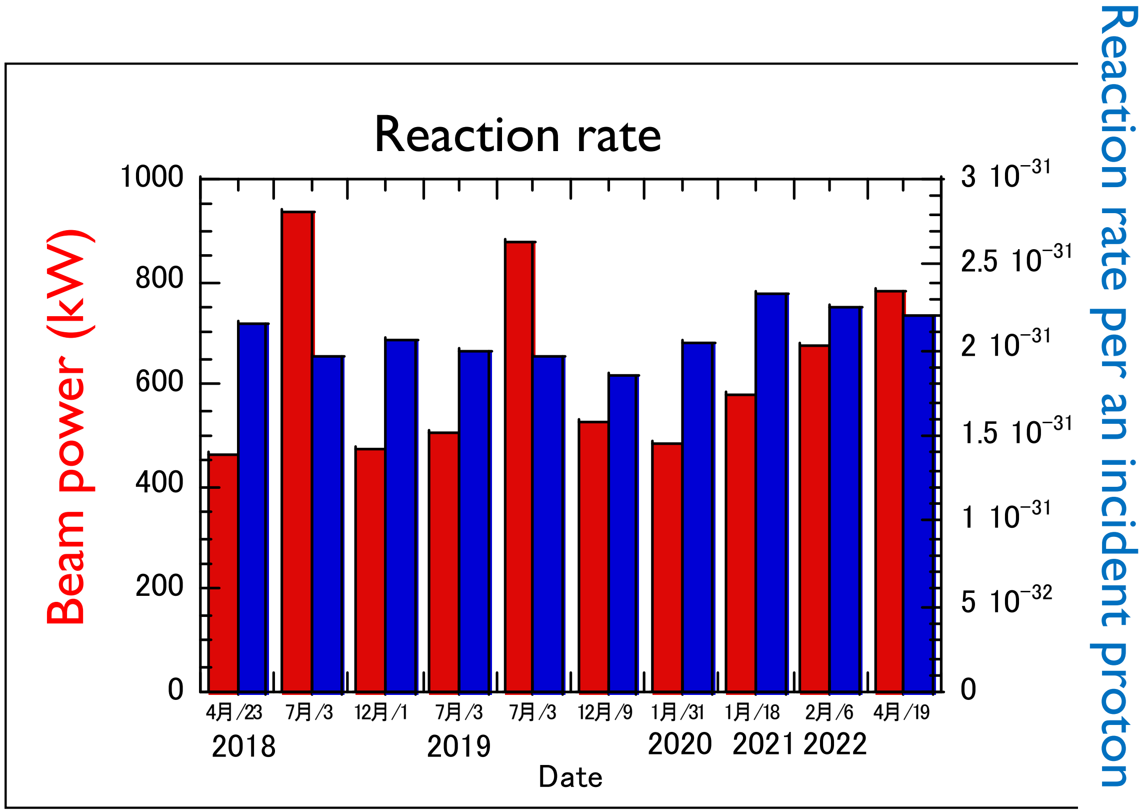
- Good agreement
- At 1MW operation with no collimator, 4.7×10^7 n/cm^2/s will be archived.



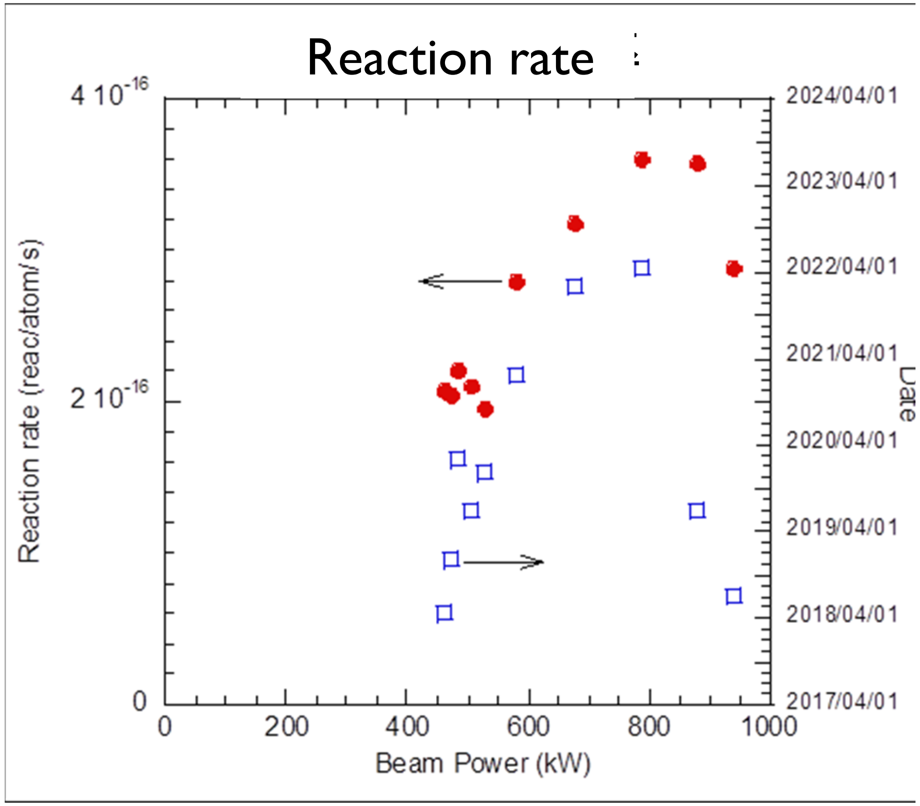
Fixed measurement (Gold foils)

We continue to measure neutron intensity with the gold foil and He-3 monitor

Reaction rate at each measurement

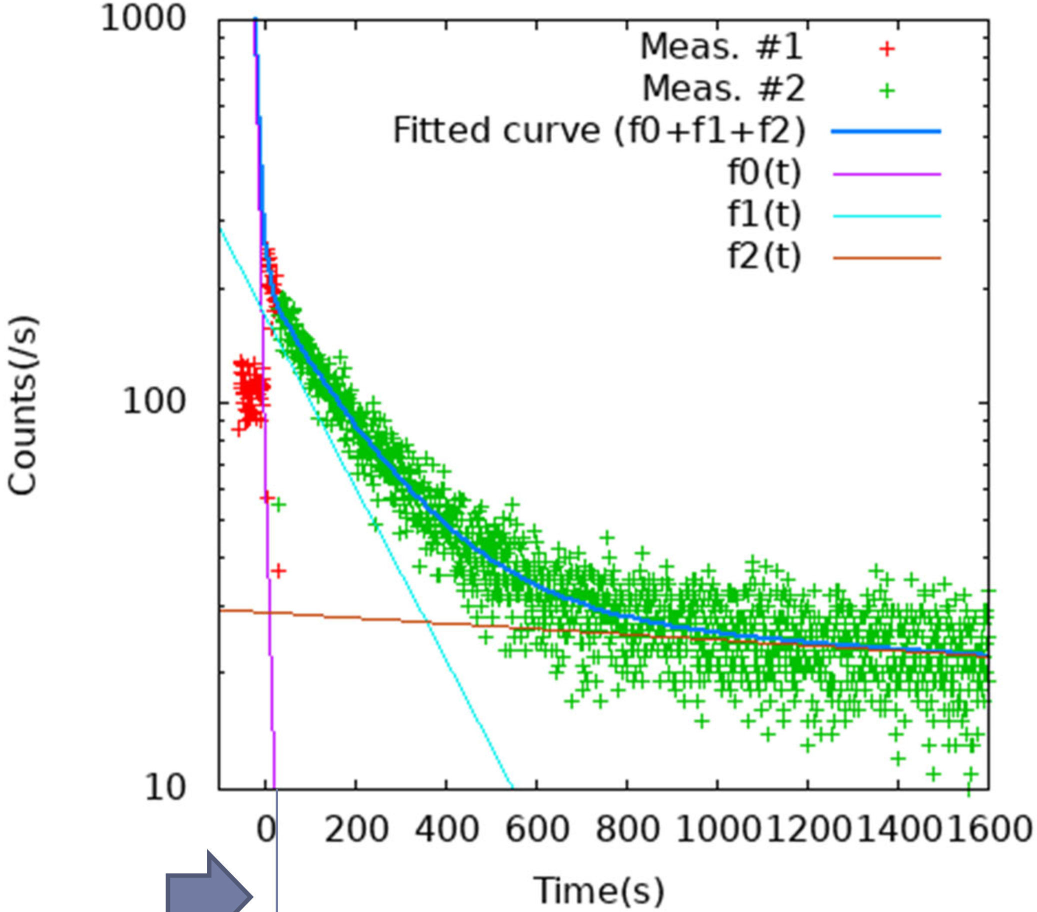


Reaction rate vs. Proton beam power



Neutron observation after the operation stop

Blocker opened



There events were confirmed as neutron detections from the pulse height data

These events ?

1, Delayed neutrons

2,The (γ,n) rection

ex. $^{9}Be + \gamma \rightarrow {}^{8}Be + n - 1.666MeV$

In operation

Operation stop

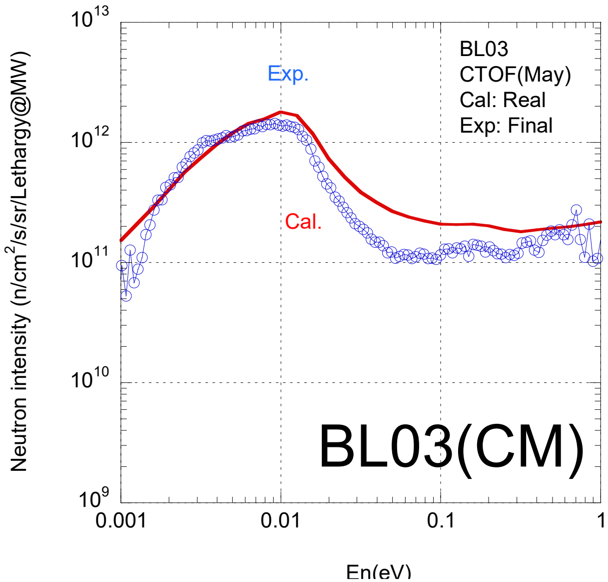
f0(t)=95.749*(1/2)^(t/6.5381)

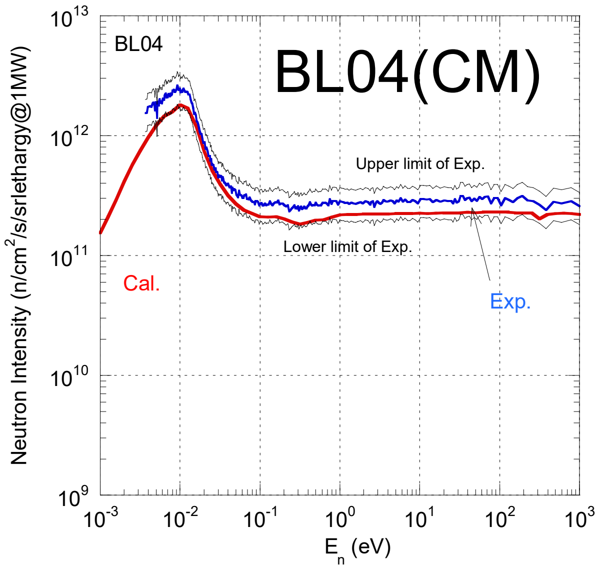
f1(t)=172.06*(1/2)^(t/134.41)

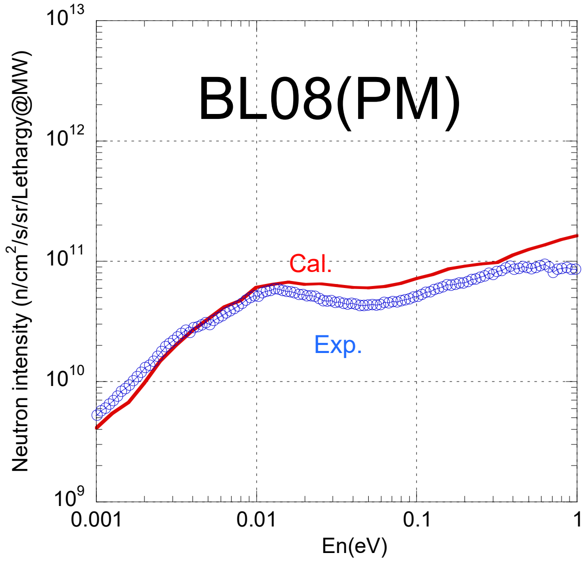
f2(t)=28.811*(1/2)^(t/4217.2)

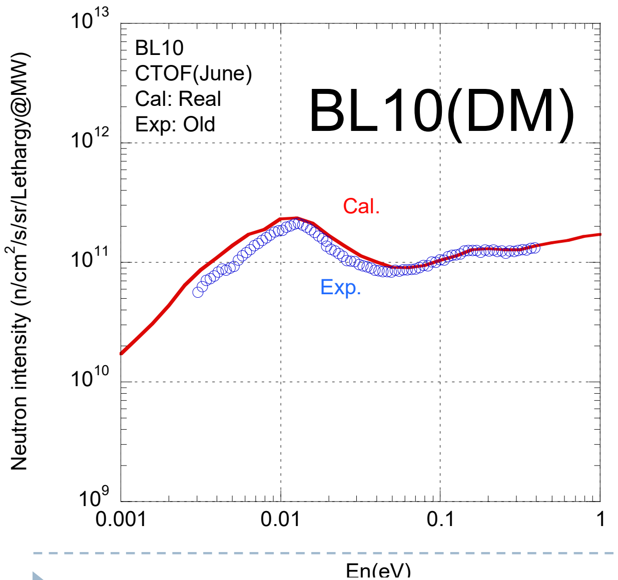
Measurements in other BLs

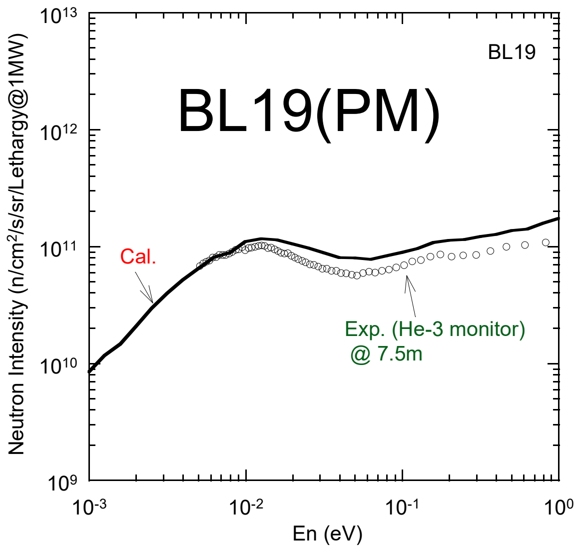
Neutron spectral intensity in other beam lines

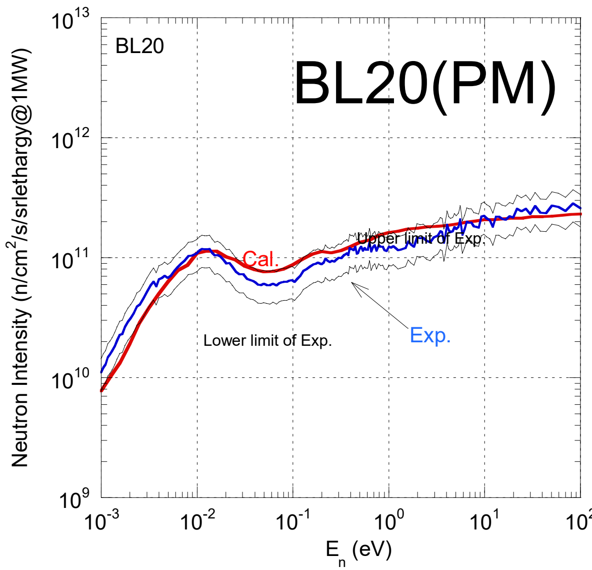








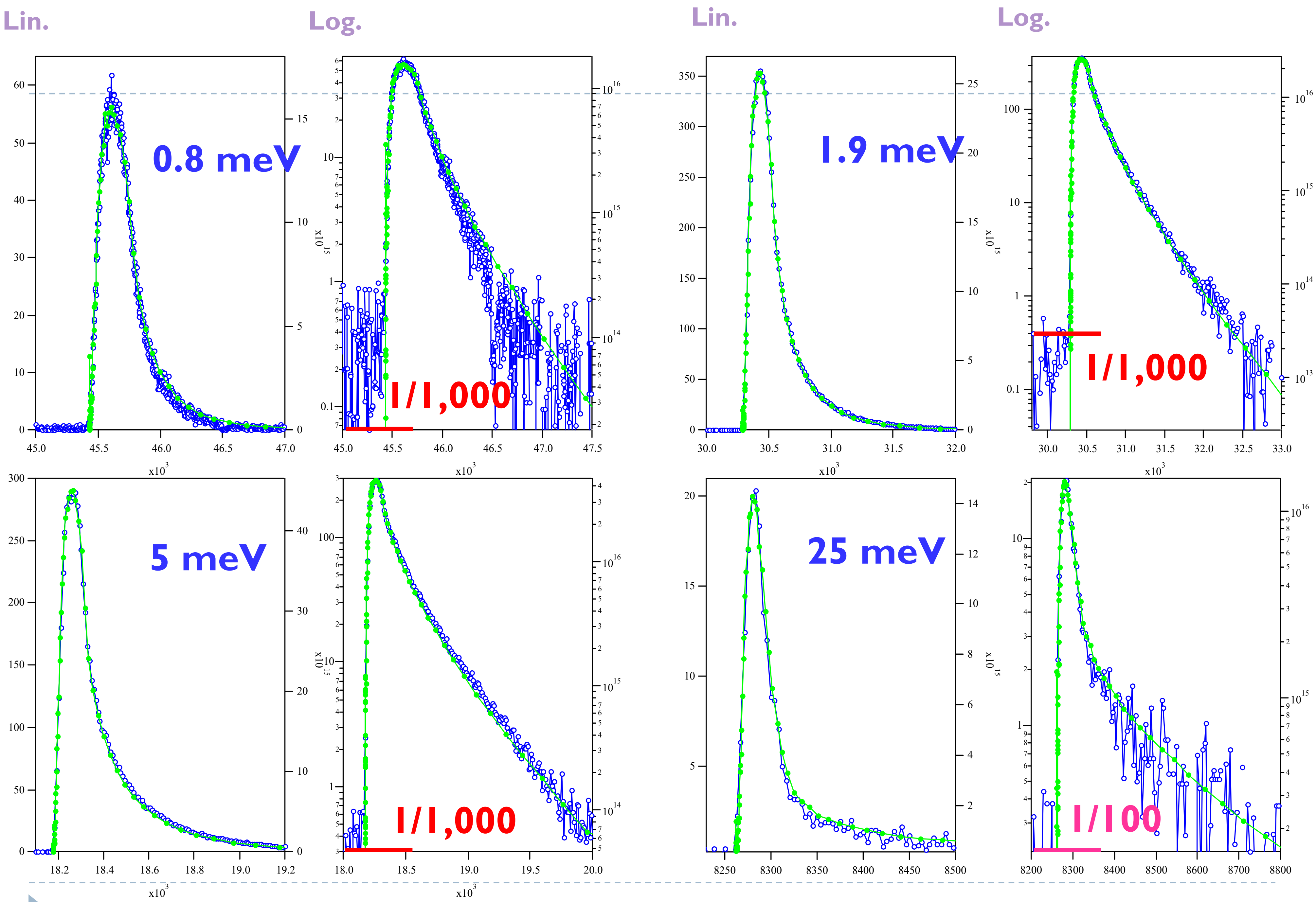




Good agreement within 20%

Pulse Shape Measured & Calculated

BL01 4Season (CM)



normalized at the peak

20%の精度でよいい一致

Summary

- The neutronics calculation at MLF spallation neutron source in J-PARC was validated and the good agreement was confirmed.
- Several measurement remained will be done.

References

- Main contents

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  - K. Oikawa, et al., Study on the pulse shape of thermal and cold neutrons provided by the decoupled moderator of JSNS, JPS Conf. Proc. (Internet), 1, p.014012_1 - 014012_4 (2014)
  - M.Harada, et al, Application and validation of particle transport code PHITS in design of J-PARC 1 MW spallation neutron source, Prog. Nucl. Sci. Technol. (Internet), Vol.2, 872-878, (2011).
  - M. Harada, et al., Shielding Design of a Neutron Beam Line "NOBORU" at JSNS/J-PARC, Prog. Nucl. Sci. Technol. (Internet), Vol.1, 94-97, (2011).
  - M. Harada, et al., Measurement of neutronic characteristics of JSNS, Proc. ICANS-19 (CD-ROM), 1-8, (2010).

- Spatial distribution at high energy region

  - M. Harad,a et al., to be prepared to submit to Nucl. Instrum. Meth. A

- Proton beam power dependence

  - M. Harad,a et al., to be presented in JSNS 2022 Autum

Thank you for your attention.