Example J- PARC Commissioning Imaging BL22

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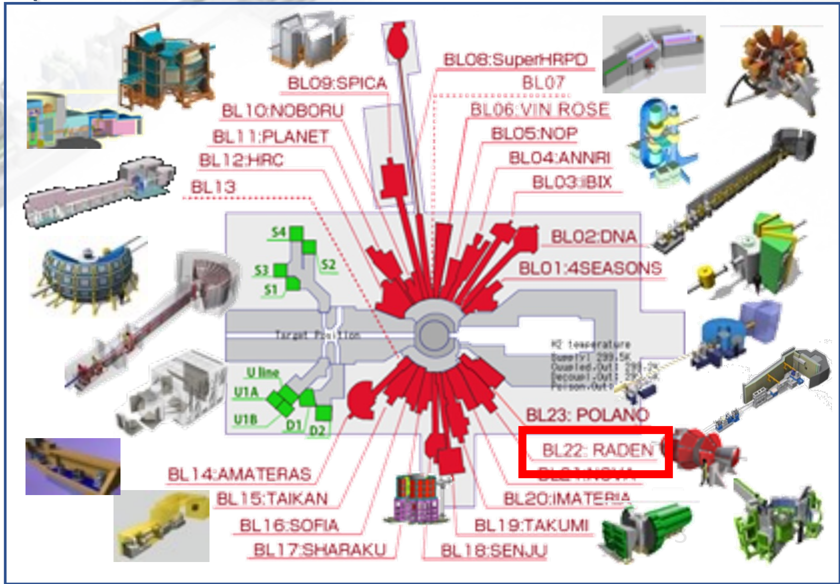
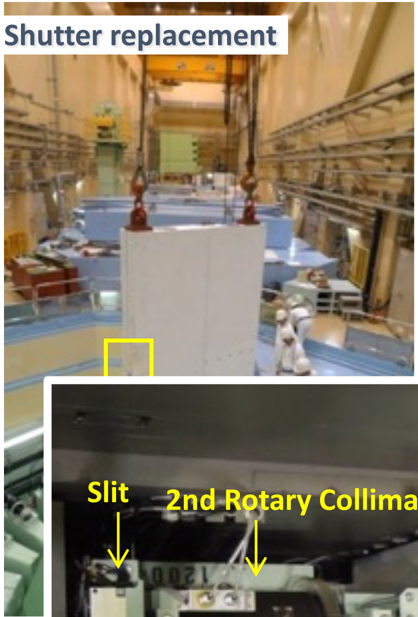
Introduction of RADEN Energy-Resolved Neutron Imaging System

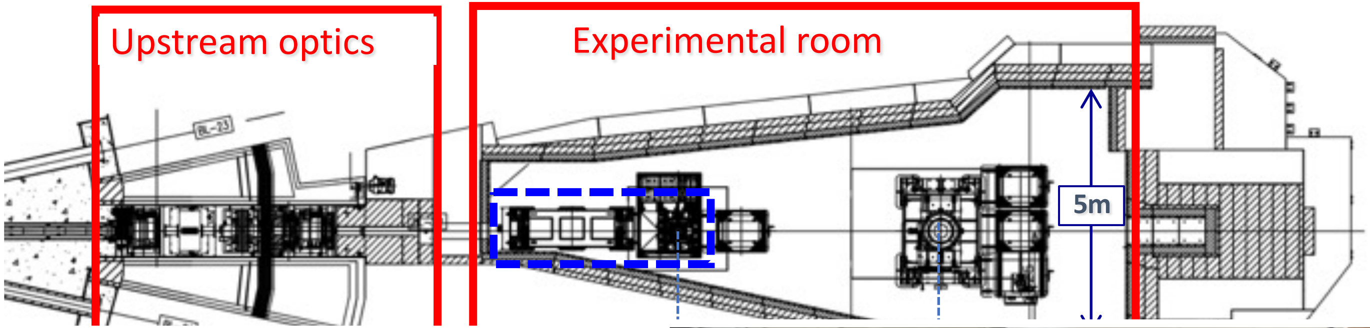
The world first instrument dedicated to the pulsed neutron imaging

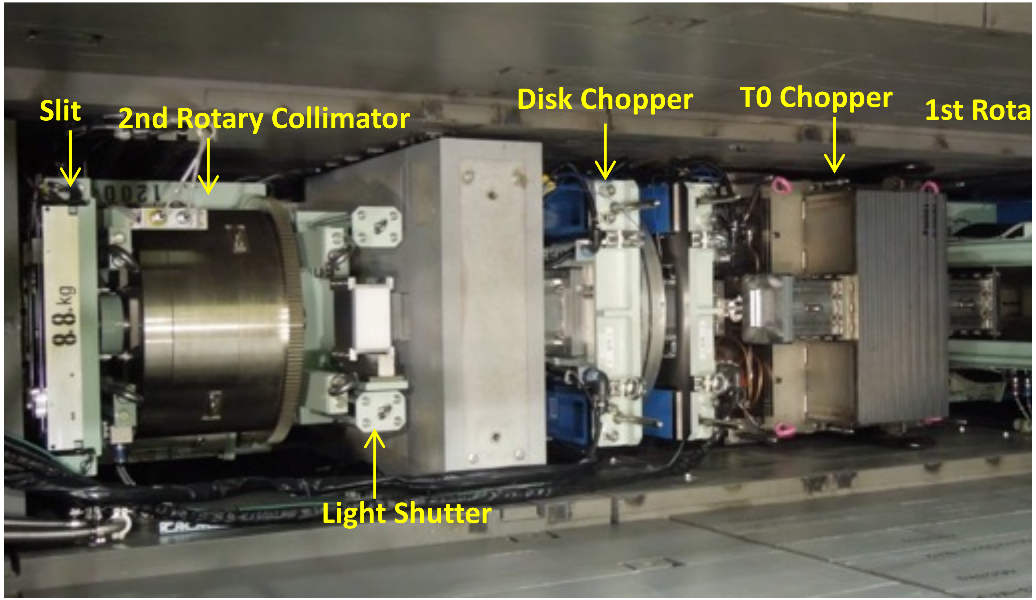
- ✓ Pioneering facility for Energy-resolved neutron imaging fully using short-pulsed neutrons' nature
  - Bragg edge imaging
  - Resonance absorption imaging
  - Pulsed polarized neutron imaging
- ✓ Leading neutron radiography & tomography facility in Japan
  - Fine spatial resolution (> 10 μm)
  - Large FoV (300 x 300 mm^2)
  - Flexible sample positioning
  - Wide space for sample environment
  - In-situ/in-operando imaging
- ✓ Development environment of pulsed neutron imaging technique and related devices
  - Phase contrast/dark field imaging
  - Detector test and development

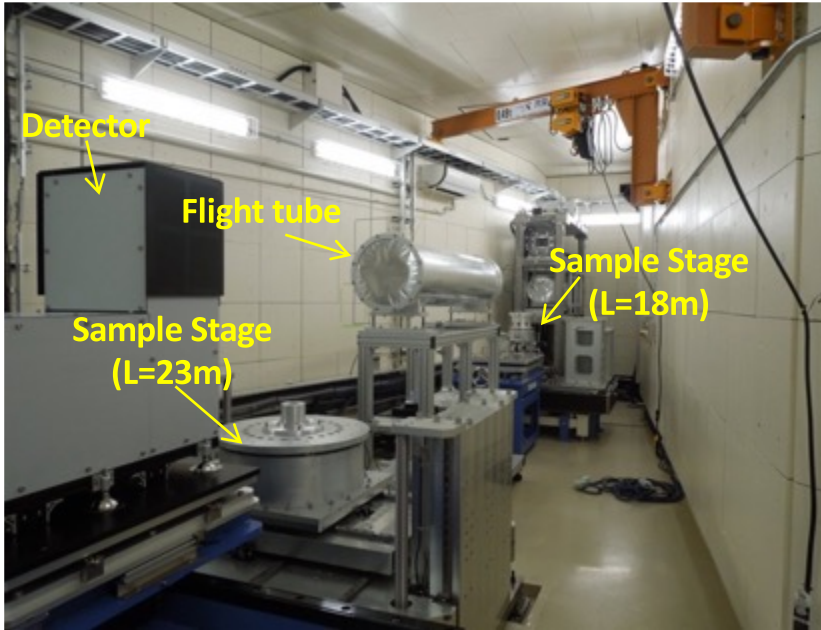


Structure of RADEN instrument









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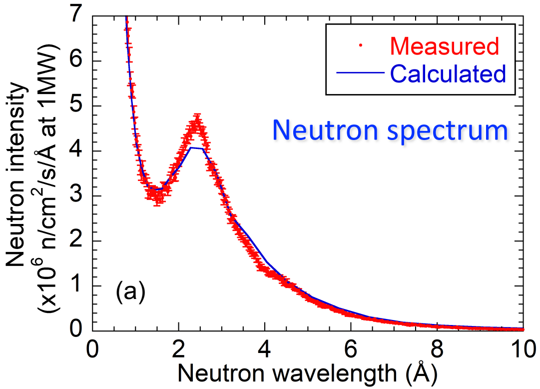
Specification of RADEN

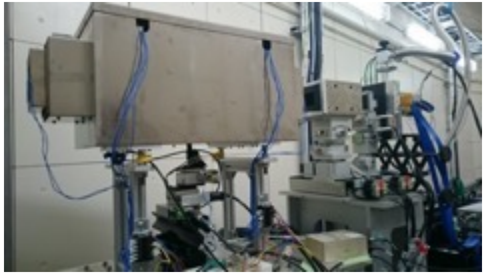
Review of Scientific Instruments, 91, 043302 (2020)

https://mlfinfo.jp/ja/bl22/

Beam line number: BL22,
Moderator type: Decoupled liquid H_2

- ✓ Neutron flux :
  - 1.7×10^7 n/sec/cm^2@L/D=180 (E< 0.45 eV)
  - 1.1×10^8 n/sec/cm^2@L/D=180 (E< 1 MeV)
- ✓ Wavelength resolution:
  - $\Delta\lambda/\lambda$ = 0.26% @L=18m , **0.20% @L=23m**
- ✓ Wavelength range:
  - **λ < 8.8 Å @L=18m** , < 6.9 Å @L=23m
- ✓ Field of View:
  - < 300 x 300 mm^2 (Camera type)
  - < 100 x 100 mm^2 (Event type)
- ✓ Spatial resolution:
  - > **10 µm** (Camera type) , > **100 µm** (Event type)
- ✓ Imaging detector systems:
  - **Event type** and **Camera type** detectors
- ✓ Sample environment:
  - Stages: large, medium, small, portable
  - Sample heater: infrared heating, electric heating





ToF Polarimetry system

Talbot-Lau interferometer

Available options

- ✓ **ToF Polarimetry system**:
  - Magnetic field imaging
- ✓ **Talbot-Lau interferometer**:
  - Phase contrast imaging
  - Dark field imaging
- ✓ **Diffraction detector, Gamma-ray detector**
  - Neutron diffraction measurements
  - Prompt gamma-ray analysis (PGA)

Neutron imaging detectors at RADEN

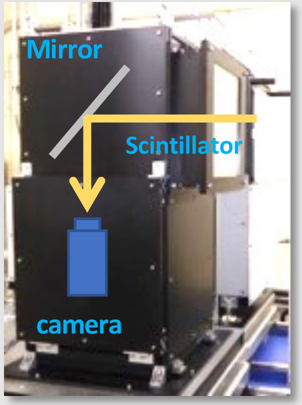
Conventional imaging radiography/tomography — Camera type

Single-mirror camera system

Standard System
- Andor iKon-L, EMCCD
- Δx >30μm
- No TOF

Short-time/energy selective system
- **sCMOS + Image intensifier**
- **Δx >50μm**
- **Synchronized imaging (<25Hz)**
- **Energy selection by ToF gate**

Automated system for CT
Scintillator : ZnS/LiF, GOS



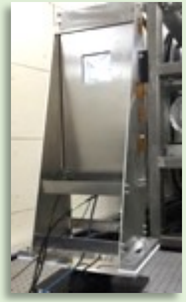
High-resolution system

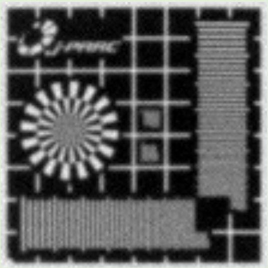
- **Hamamatsu sCMOS (ORCA Flash)**
- **Magnification = x1 and x2**
- **Δx > 10μm**
- **No TOF**
- **Automated system for CT**
- **Scintillator : P43, GAGG**

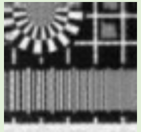
Event type — Energy-resolved neutron imaging

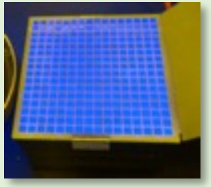
nGEM

- Micro-pattern
- ^{10}B (10% eff.)
- FOV: 10 × 10 cm^2
- **Δx=1mm**, Δt=15ns,
- Count rate < 0.5 Mcps







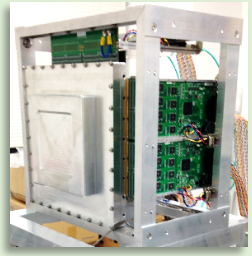


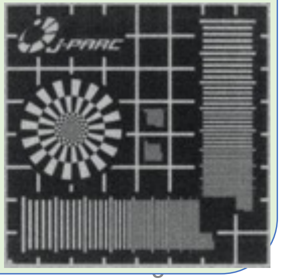
LiTA12

- Li-glass scint. (23% eff.)
- FOV: 5 × 5 cm^2
- **Δx=3mm**, Δt=40ns,
- Count rate = 6 Mcps

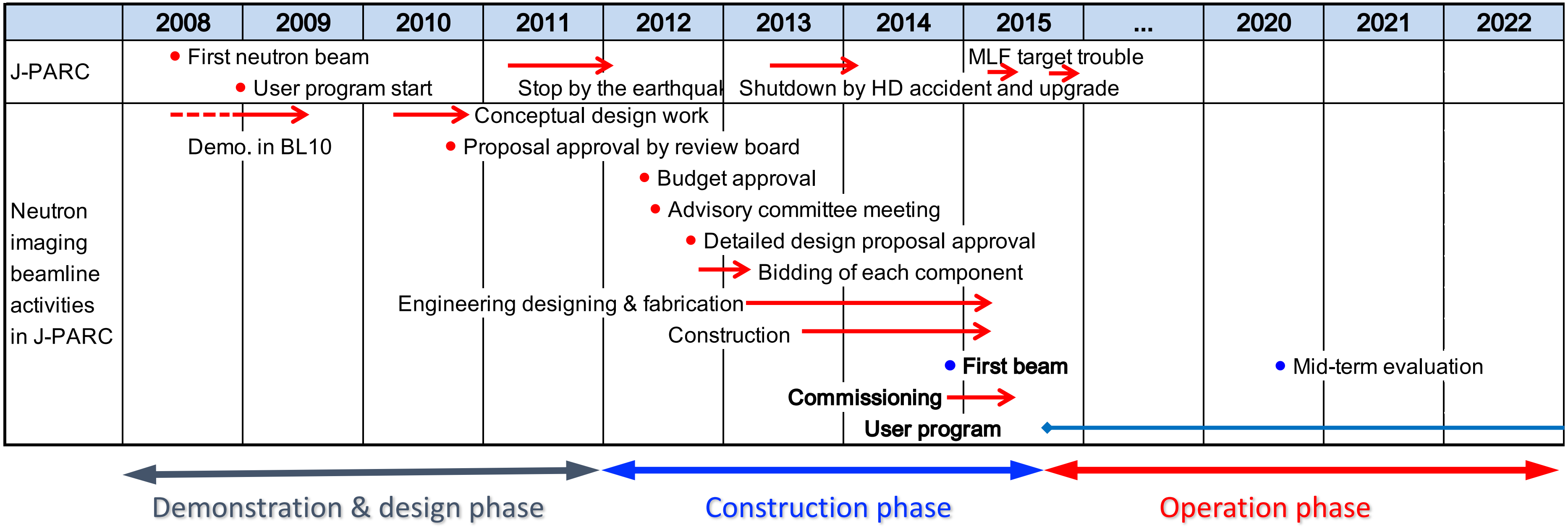
μNID

- Micro-pattern
- ^{3}He (26% eff.)
- FOV: 10 × 10 cm^2
- **Δx=0.1mm**, Δt=0.25μs
- Count rate = 1 Mcps





RADEN history



RADEN is a relatively young instrument in MLF.

- ✓ Most of instruments in MLF were in user operation phase at the time of RADEN construction.
- ✓ Fortunately most of characterization methods of devices and neutronic performances were established already.
- ✓ Device control software was ready.

-> Time for the commissioning was relatively short, and RADEN started to accept user programs quickly.

Commissioning history

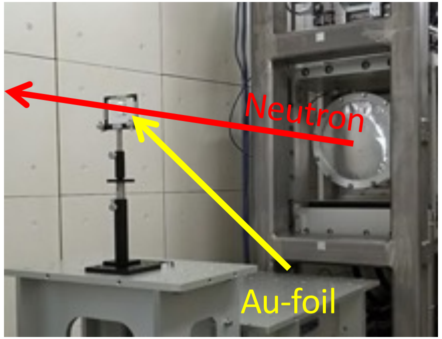
Beam power			Event & Milestone	Beam characterization	Device performance	Detector performance	Demonstrations
300kW	2014	Nov.	**Nov. 4th: Interlock test & radiation inspection** **Nov. 7th: First beam**	Flux measurement (Gold foil activation method) #1 Beam size measurements (CCD) **Flux measurement (Gold foil activation method)** #2	Slit center position check Filter performance (3He monitor) Disk chopper phase check (3He monitor)	Scintillator test Uniformity, Luminosity, Spatial resolution	first CT test (CCD)
		Dec.		Pulse width measurements #1 Material: synthetic mica spatial uniformity measurements (3He monitor, scanning)	Filter performance (LiTA)	LiTA test HV scan, Count rate, Threshold nGEM test HV scan, Count rate	Bragg edge (nGEM)
	2015	Jan.	**T0 chopper installation**				
400kW		Mar.	**First user experiment (Friendly user)**	Beam size measurements (reconfirmation, CCD) L/D measurements (3He monitor, CCD)	T0 Chopper Phase delay adjustment and performance check Talbot-Lau interferometer Alignment & performance check	Continuing scintillator and counting detector performance test	Resonance absorption test (thermometry, LiTA) Phase imaging (CCD)
		Apr.			Polarization analysis system Alignment & performance check	uNID test HV scan, Count rate	
500kW			**Apr. 30th: Beam operation terminated due to the target trouble.**	Back ground measurements **Pulse width measurements** #2 Material: $La^{11}B_6$, Natural Mica Detector: 3He counter		uNID, LiTA, nGEM test Count rate, Spatial resolution	Resonance absorption (LiTA) Polarization imaging (nGEM, uNID)
500kW		Oct.	**Oct. 31st: Beam operation resumed.**			Scintillator test Luminosity check ThinGEM test	Imaging demonstration
		Nov	**Nov.9th: First "official" user program start** **Nov.20th: beam operation terminated due to the target trouble again.**				

Commissioning results

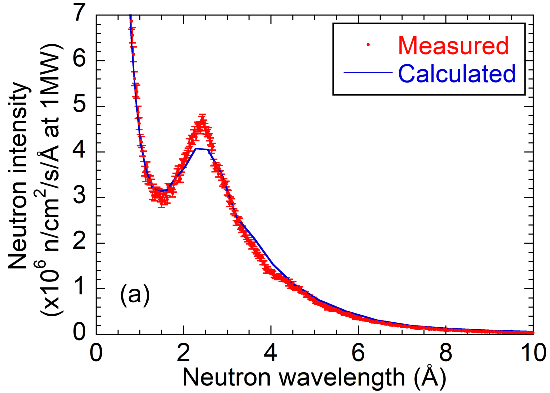
Neutron intensity

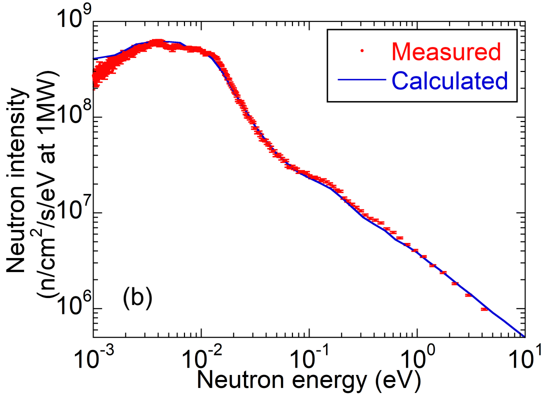
Gold foil activation method

- ✓ We did several times with changing Gold foil positions and beam collimation conditions.
- ✓ Gold foils (1.5 x 1.5cm^2, t=50µm) were irradiated at L=18.2m and 14.4m.
- ✓ w/ and w/o Cd cover
- ✓ T0 chopper: ON and OFF
- ✓ Gamma-ray measurements of ^{198}Au



Neutron energy spectrum





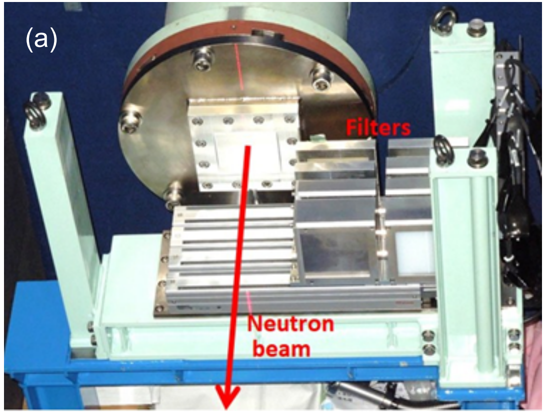
- ✓ Detector: Low efficiency ^{3}He monitor
- ✓ Detector position : ~15.5m
- ✓ Normalized by the result of Gold foil activation.
- ✓ Calculation: McStas simulation

-> Reasonable agreement with calculation in shape

Commissioning results

Neutron energy spectrum

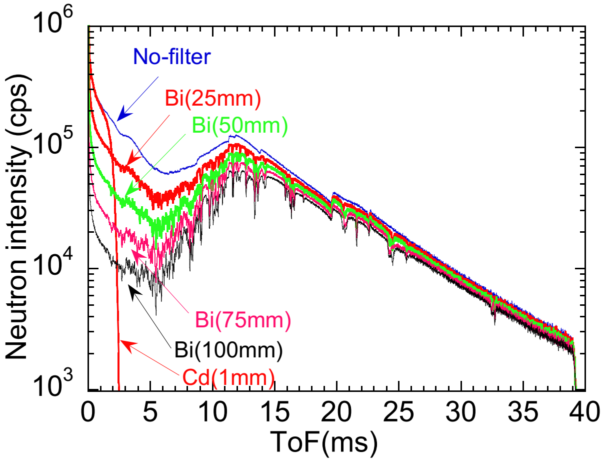
Filter performance test

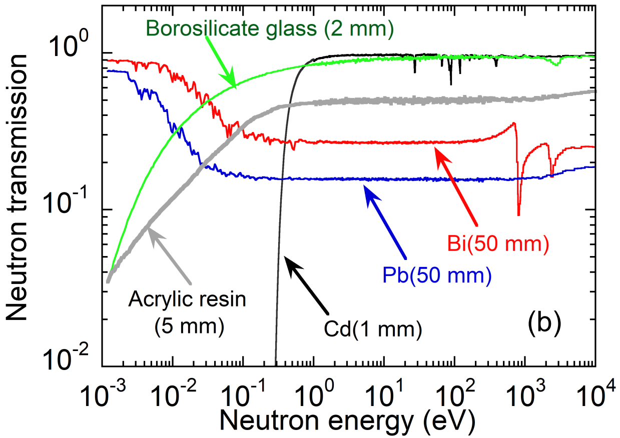


- ✓ Detector: ^{3}He monitor, LiTA, nGEM, μNID
- ✓ Detector position : 19m
- ✓ Changing filters

  Bi (25, 50, 75 mm), Pb (25, 50, 75 mm), Cd, Borosilicate glass, Acrylic resin

Filters are installed so as to reduce gamma-ray back ground at high-energy region or to conduct epi-thermal neutron imaging without thermal and cold neutrons.

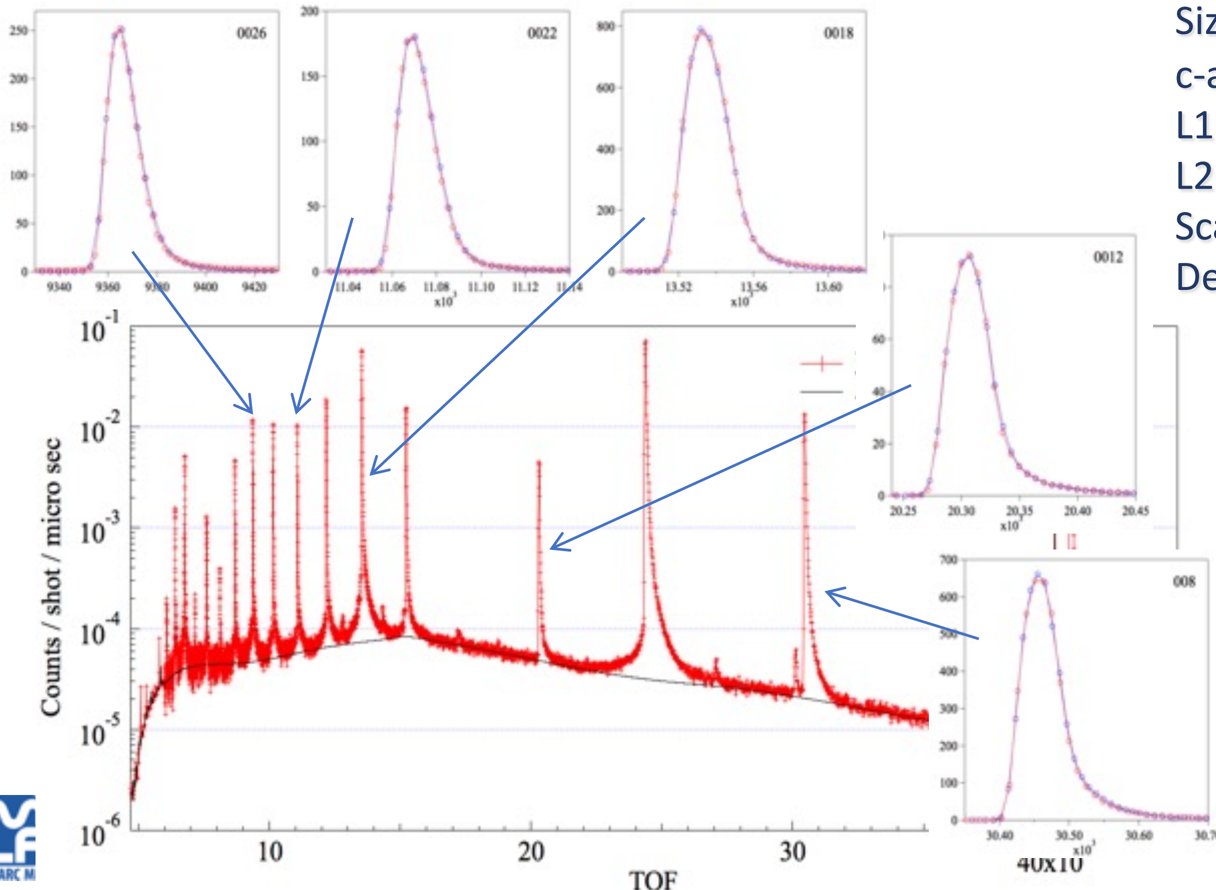




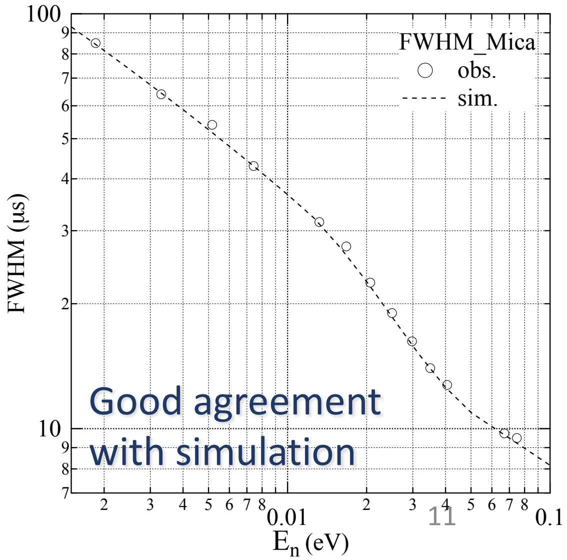
Commissioning results

Neutron pulse shape

Single crystal diffraction



Sample: natural mica single crystal
$KAl_2AlSi_3O_{10}(OH)_2$
Size: 50 mm x 10 mm x 1 mm (c-axis)
c-axis length : 20 Å
L1: 23m
L2: ~1.2m
Scattering angle 2θ~170°
Detector: ½ inch ^{3}He counter

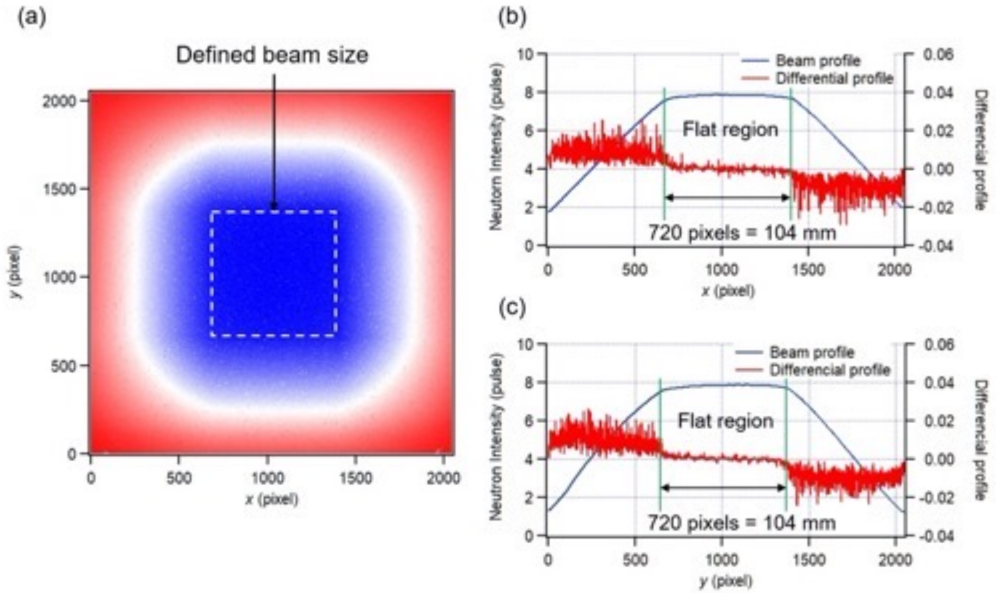


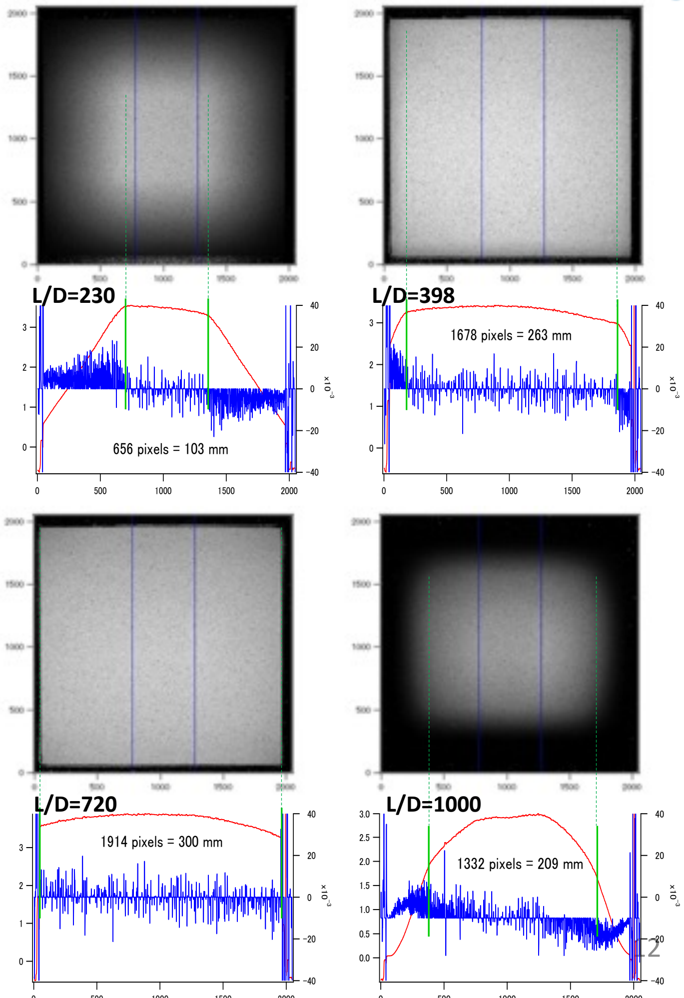
Good agreement with simulation

Commissioning results

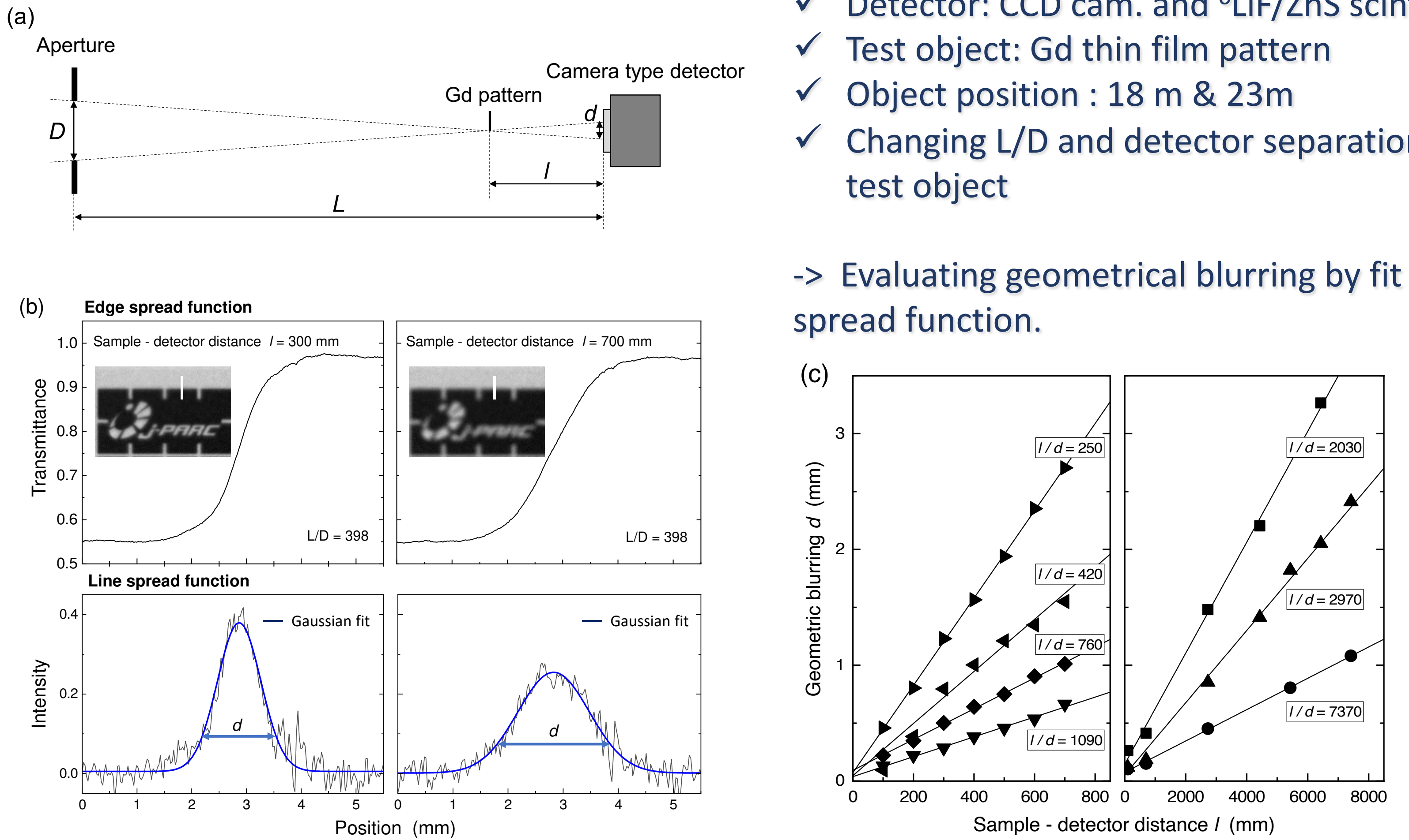
Neutron beam size

- ✓ Detector: CCD cam. and ^{6}LiF/ZnS scintillator
- ✓ Detector position : 23 m
- ✓ Changing L/D with changing collimation conditions.
- ✓ Prior to the measurements we took image of PE scattering so as to cancel scintillator inhomogeneity.





Commissioning results L/D



- ✓ Detector: CCD cam. and $^{6}LiF/ZnS$ scintillator
- ✓ Test object: Gd thin film pattern
- ✓ Object position : 18 m & 23m
- ✓ Changing L/D and detector separation from the test object

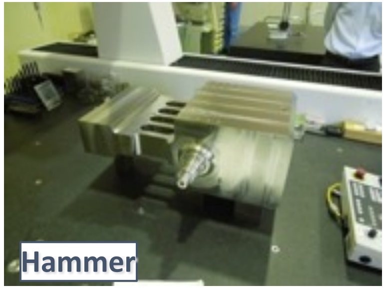
-> Evaluating geometrical blurring by fit it with line spread function.

Neutron beam size and L/D (summary)

	Collimator	100x100	50.1mmϕ at 3.1m	26.4mmϕ at 4.3m	15mmϕ at 8m	6mmϕ at 11.15m	5mmϕ at 8m	2mmϕ at 8m
L=23 m	L/D (calc.)	230	398	720	1000	1975	3000	7500
	L/D **(measured)**	**250**	**420**	**760**	**1090**	**2030**	**2970**	**7370**
	Beam Size (mm) (calc.)	100	250	300	144	100	173	181
	Beam Size (mm) **(measured)**	**104(H) 104(V)**	**255(H) 258(V)**	**300(H) 300(V)**	**154(H) 155(V)**	**116(H) 103(V)**	**194(H) 189(V)**	**205(H) 196(V)**

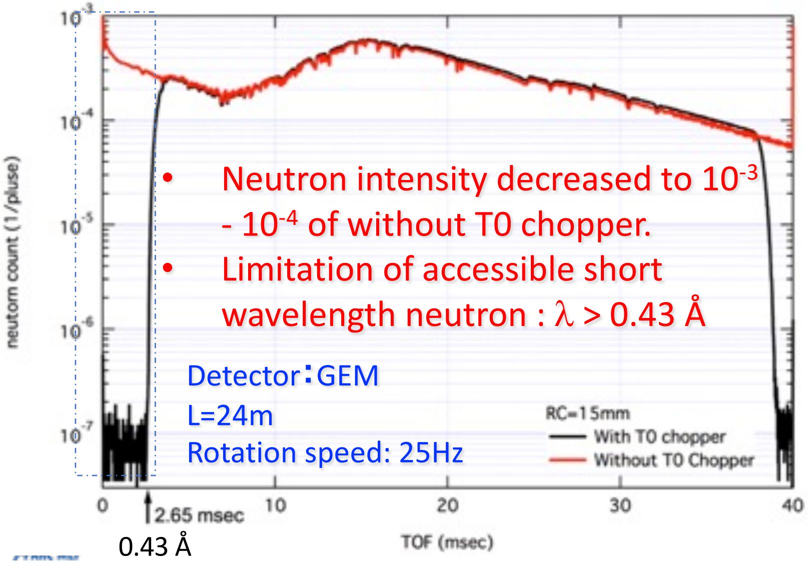
Commissioning results

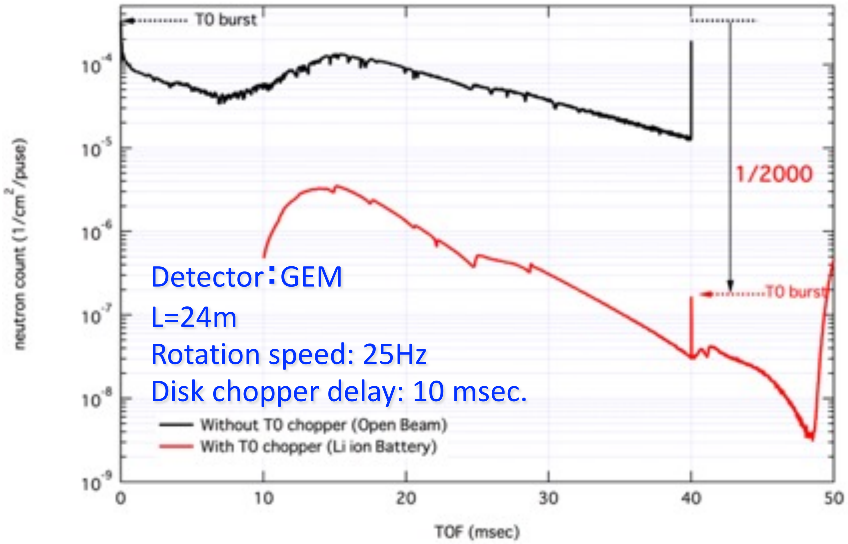
T0 chopper



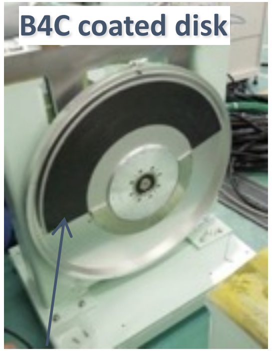
A T0 chopper is installed so as to eliminate flash gamma-ray and to suppress high-energy neutron back ground.

- ✓ Phase delay check
- ✓ Performance test
  - Transmission at around TOF=0
  - stopping power of prompt pulse





Commissioning results

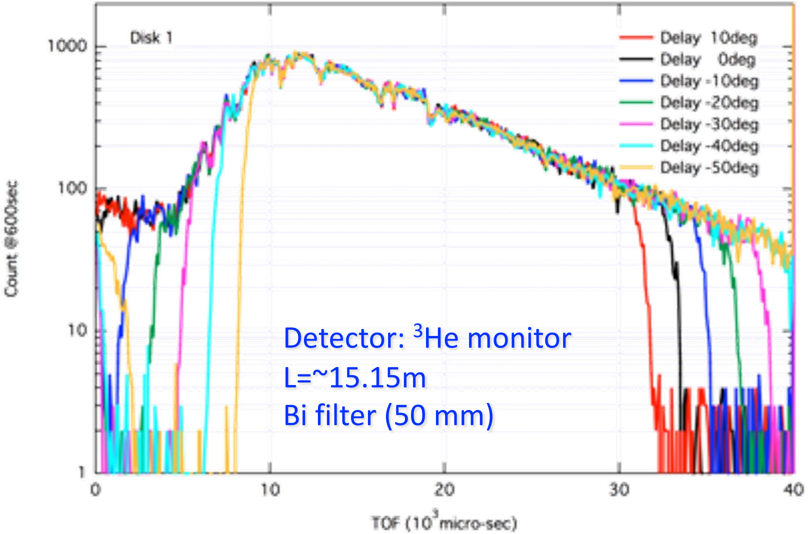


Opening angle of a disk = 190°

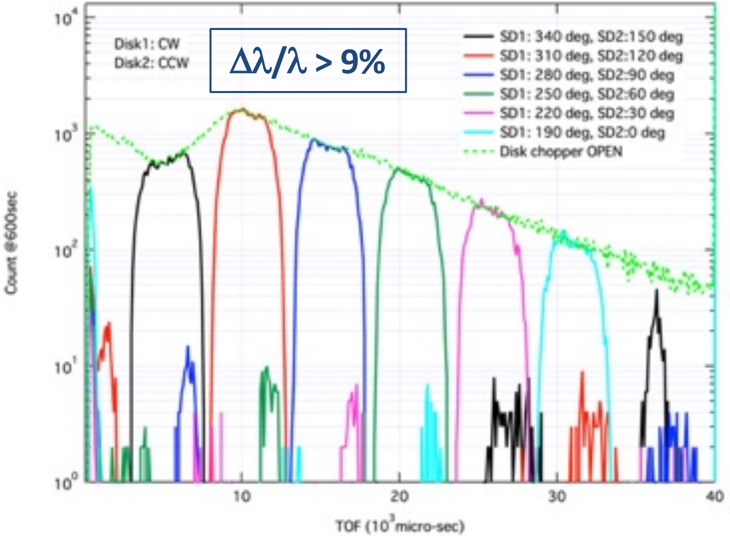
Double disk chopper

A double disk low-speed chopper is used to define band width and wavelength range.

- ✓ Phase delay check
- ✓ Performance test
  - Transmission
  - Frame overlap



Opening angle = 20 deg.

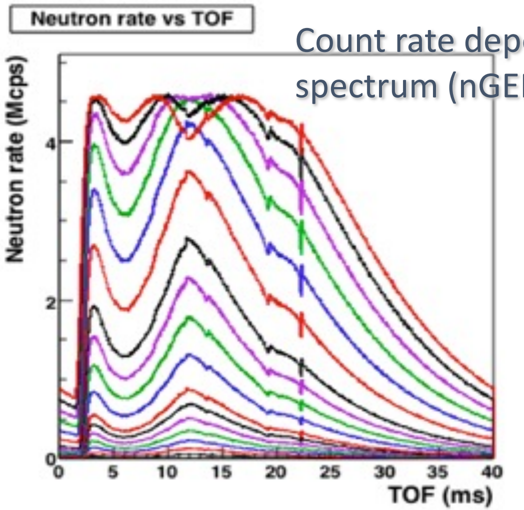


Commissioning results

Neutron detectors (event recording type)

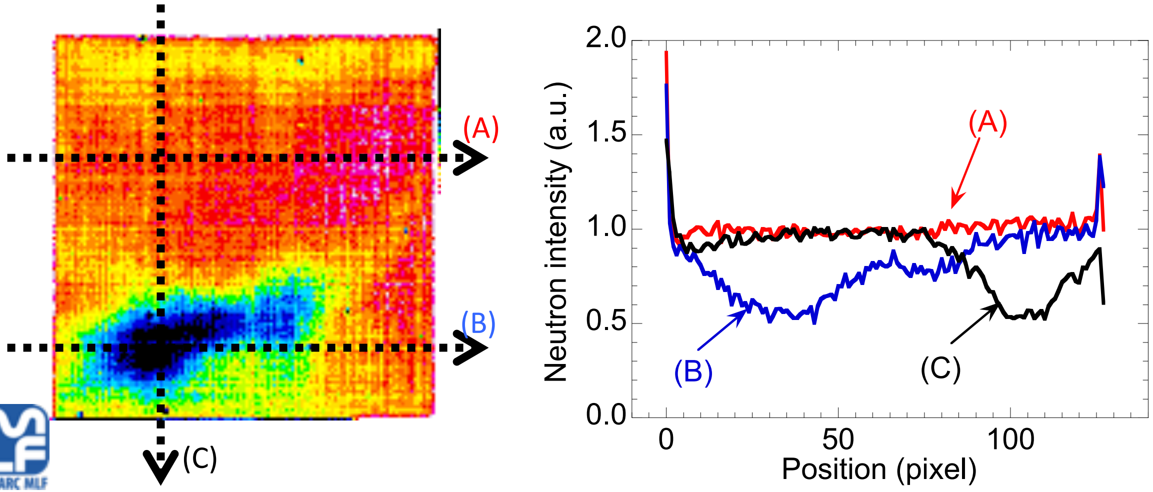
Test menu

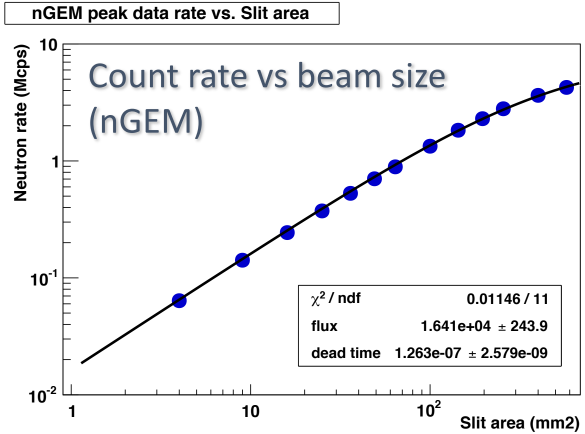
- ✓ Basic operation
- ✓ Maximum rate/linearity
- ✓ Spatial resolution/image uniformity
- ✓ Time (TOF) resolution
- ✓ Gamma sensitivity
- ✓ Detection efficiency



Count rate dependent spectrum (nGEM)

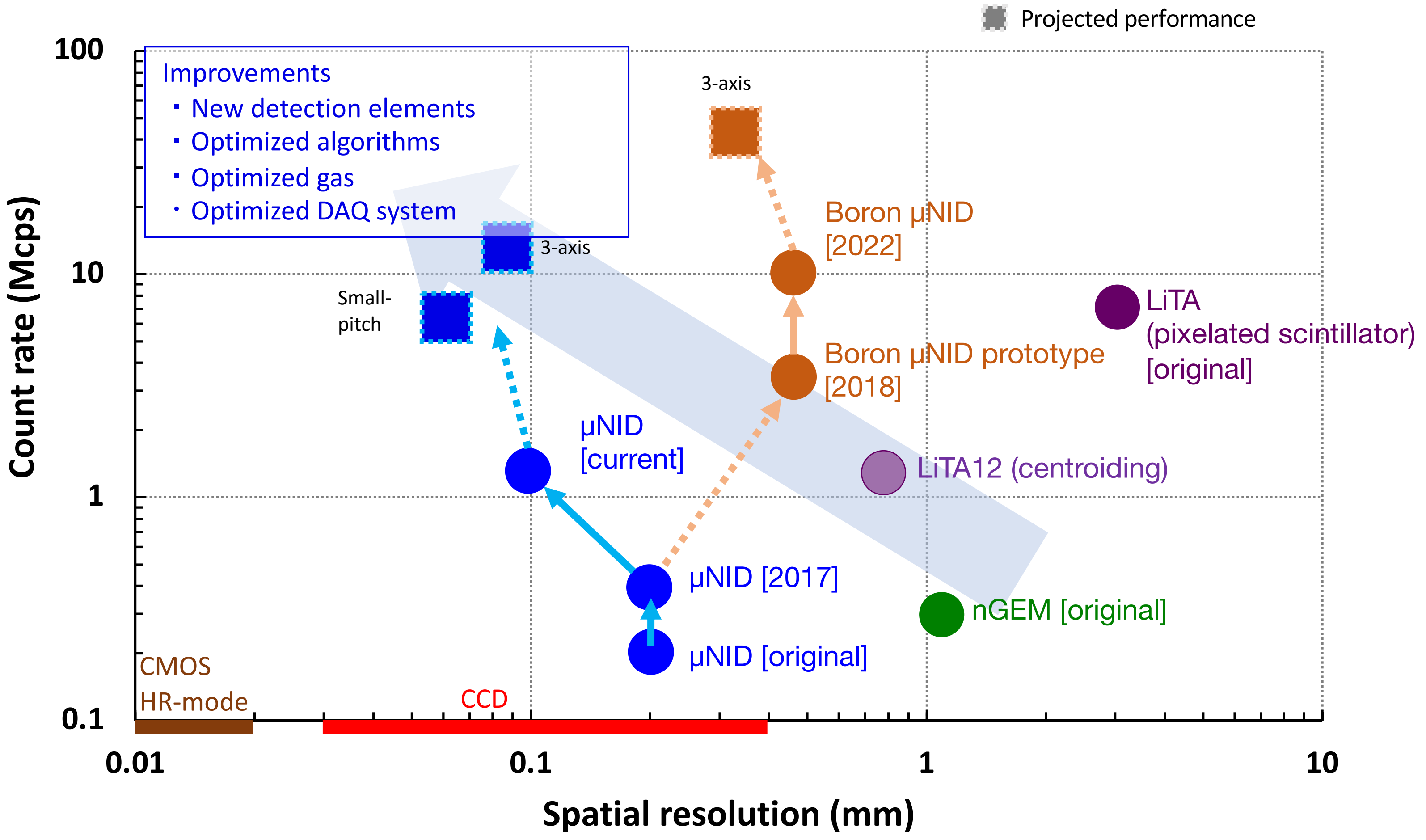
Uniformity of nGEM (bad example)





Count rate vs beam size (nGEM)

Detector performance: original, current and projected (summary)



Radiation dose inside the shield

Neutron dose rate measurements inside the shield with heavy shutter closed so as to come in the shield safely.

- Detector: REM counter
- Beam power: 300 kW
- Position: L=ca. 15m, on beam axis
- Blocker (light shutter): Open/Close

Shutter (BL22)	Blocker (BL22)	Shutter (BL21)	Neutron Dose rate in BL22
Close	Open	Open	0.80 μS/h
Close	Close	Open	0.05 μS/h

- ✓ 2.6 μSv/h at 1 MW is expected
- ✓ We decided to close blocker before entry
- ✓ Expected radiation source: penetration of shutter or neighboring beam line (BL21)

About RADEN Commissioning

- Commissioning team = Instrument group member
  Commissioning work has been done by RADEN instrument team.

- Instrument control -> iroha2 (python based software)
  Dr. Inamura will introduce and explain it.

- Special tools for commissioning?
  Pulse width : neutron diffraction measurements
  Neutron flux: Gold foil activation
  Spatial resolution and L/D: a test pattern made by Gd thin film
  We used several detectors for beam characterization.
  3He counter, monitor, 2D event type detectors, CCD cam, …

- Data storage -> We use our own storage system.

- Documented? -> No. But mostly summarized in our instrument paper (and written in the log-books).

Thank you for your attention.