STATUS OF THE µNID NEUTRON IMAGING DETECTOR AT THE J-PARC MLF

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μNID DETECTOR DEVELOPMENT MEMBERS

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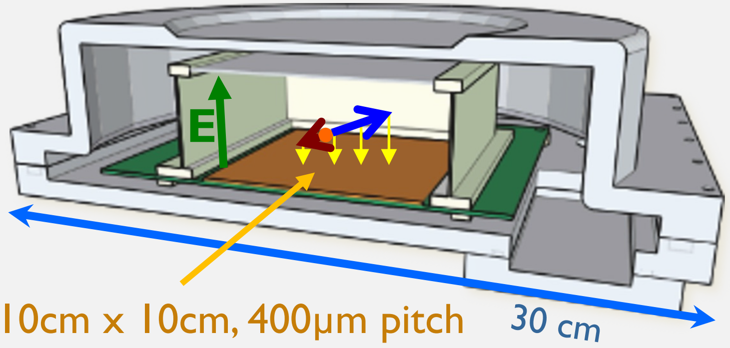
JAEA	Takenao Shinohara	Tetsuya Kai
	Kenichi Oikawa	Masahide Harada
	Yusuke Tsuchikawa	Kosuke Hiroi
	Yuhua Su	
Hokkaido University	Yoshiaki Kiyanagi	
Kyoto University	Toru Tanimori	Atsushi Takada

μNID: μPIC-based Neutron Imaging Detector

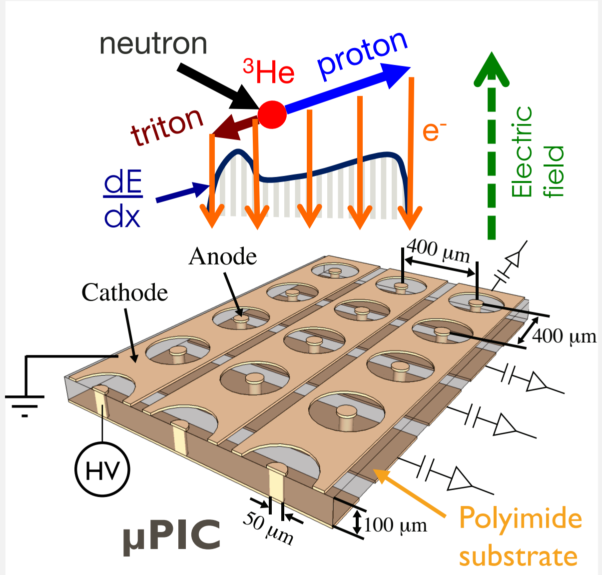
TPC in aluminum pressure vessel

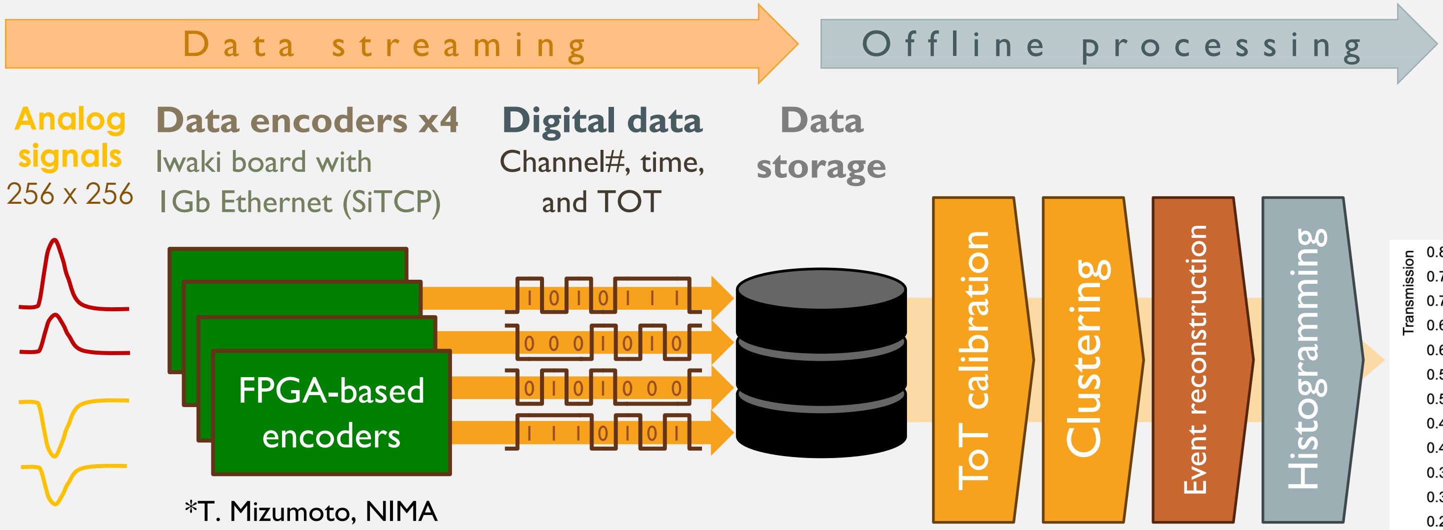


- μTPC optimized for pulsed neutron imaging (event-based)
- Neutron conversion with ^{3}He gas or ^{10}B thin film
- Triggerless, streaming data acquisition for high rate
- Specialized algorithms for clustering and event reconstruction

→ accurate position/time, strong BG rejection

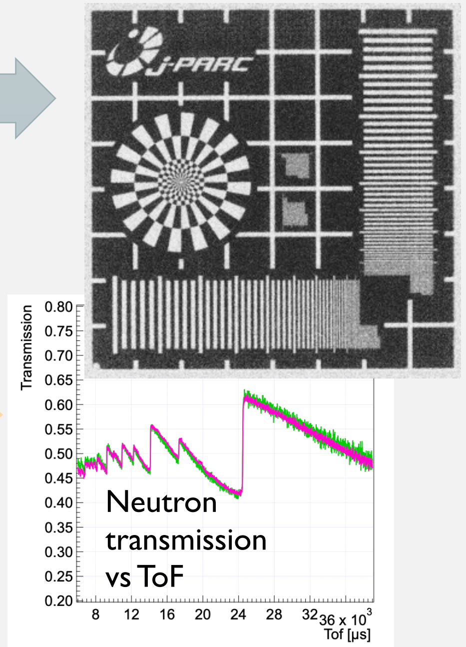
μNID data acquisition and data processing





*T. Mizumoto, NIMA 800, 40-50 (2015)

Neutron transmission image



μNID PERFORMANCE

Two versions: **μNID** and **BμNID**

(Detector systems mfd. by BeeBeans Technologies)

μNID

- ^{3}He gas converter (26% efficiency)
- 100μm spatial resolution / 4.6 Mcps count rate

Prioritize efficiency/ spatial resolution

BμNID (Boron-μNID)

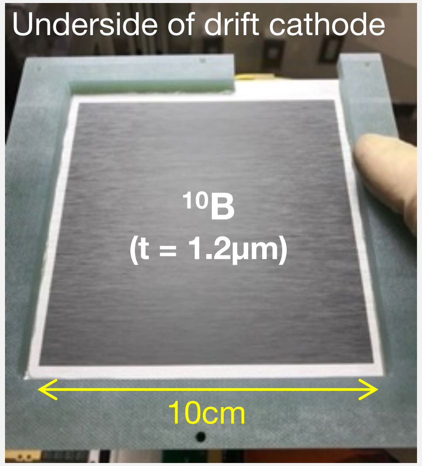
- ^{10}B thin-film converter (~5% efficiency)
- 300μm spatial resolution / 10 Mcps count rate

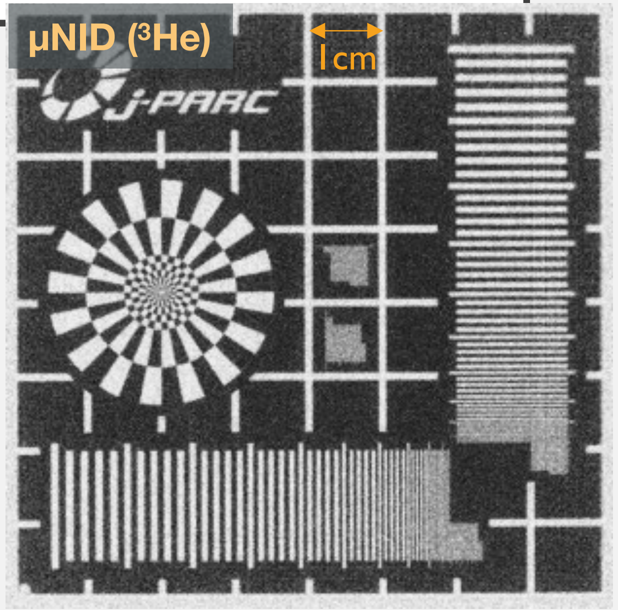
Prioritize count rate/ measurement statistics

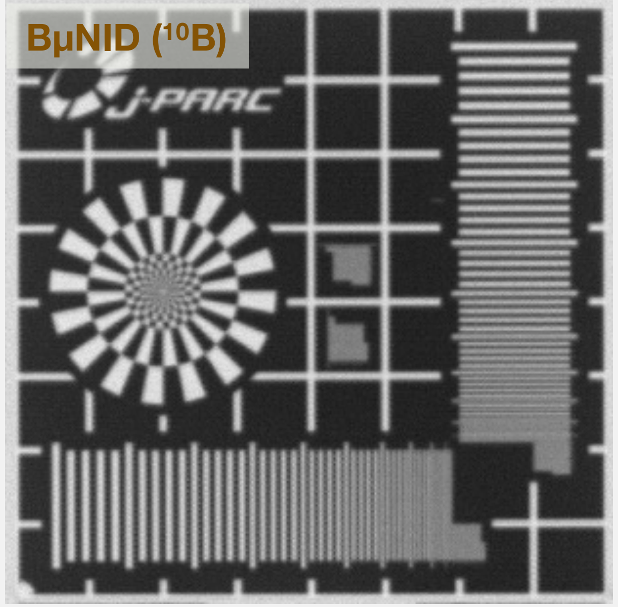
	μNID (^{3}He)	BμNID (^{10}B)
Active area	10 x 10 cm^{2}	
Filling gas	CF_4:iC_4H_{10}:^{3}He (45:5:50)@2 atm	CF_4:iC_4H_{10} (90:10)@1.6 atm
Spatial resolution*	0.1 mm	0.3 mm
Time resolution	250 ns	~10 ns
Efficiency @25.3meV	26%	~5%
Effective count rate**	4.6 Mcps (0.044 Mcps/cm^{2})	10 Mcps (0.101 Mcps/cm^{2})

* Line-width at which line-pair contrast falls to 10%

** Measured global neutron rate at count loss of 1%



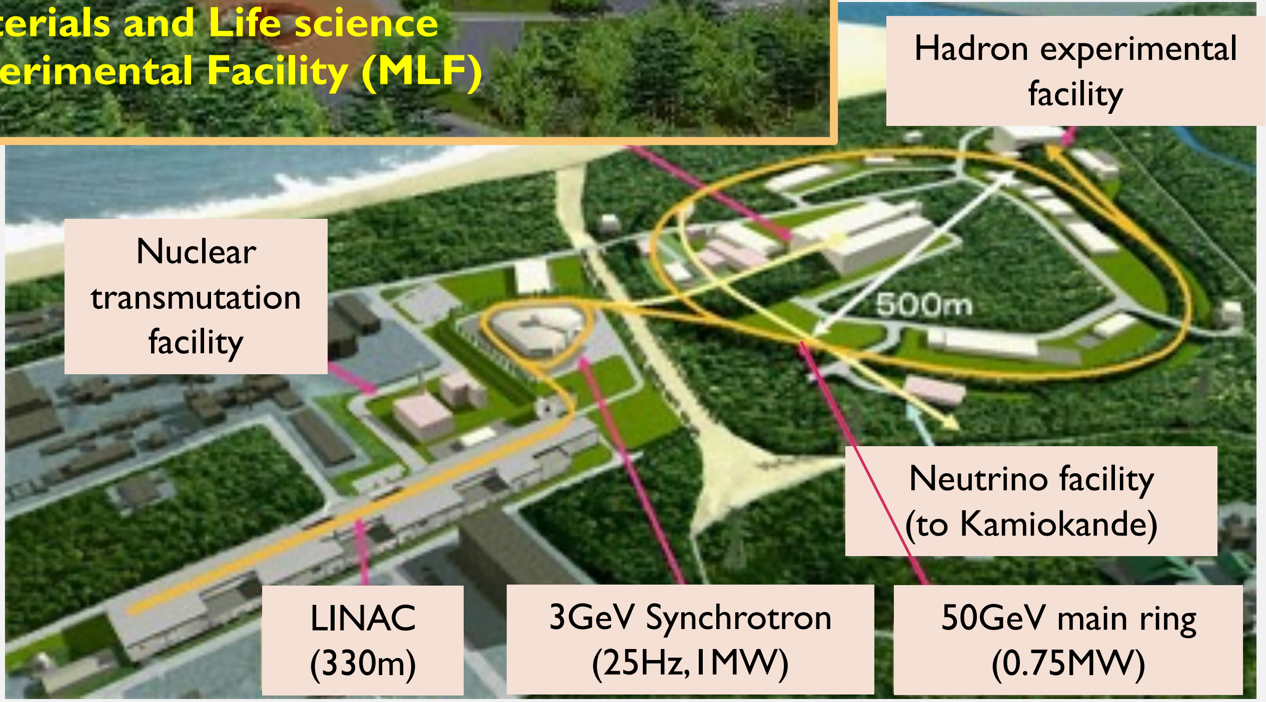




μNID AT THE J-PARC MLF

Japan Proton Accelerator Research Complex (J-PARC)

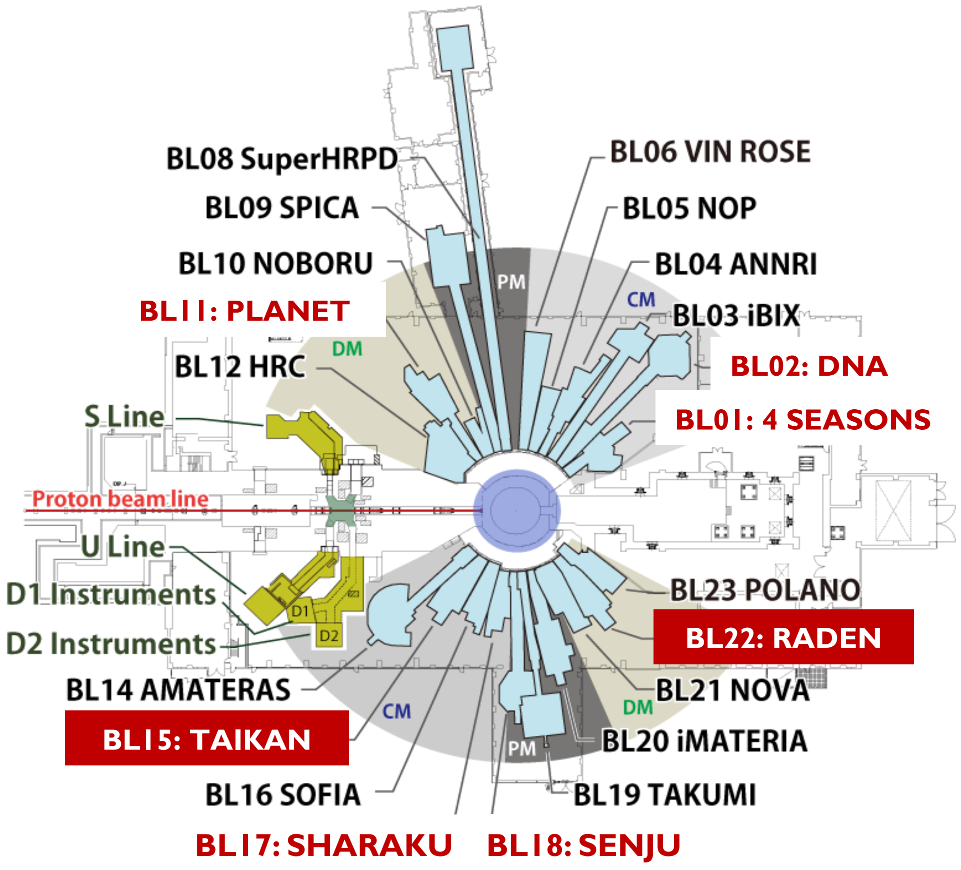
- Located in Tokai-mura, Ibaraki-prefecture
- Operated jointly by JAEA and KEK
- MLF neutron facility
  - Pulsed spallation neutron source (liquid mercury)
  - 1 MW, 25 Hz operation (currently 700kW due to target trouble)
  - 21 neutron instruments
  - Includes 7 public beamlines operated by JAEA
  - User selection and support for public beamlines provided by CROSS



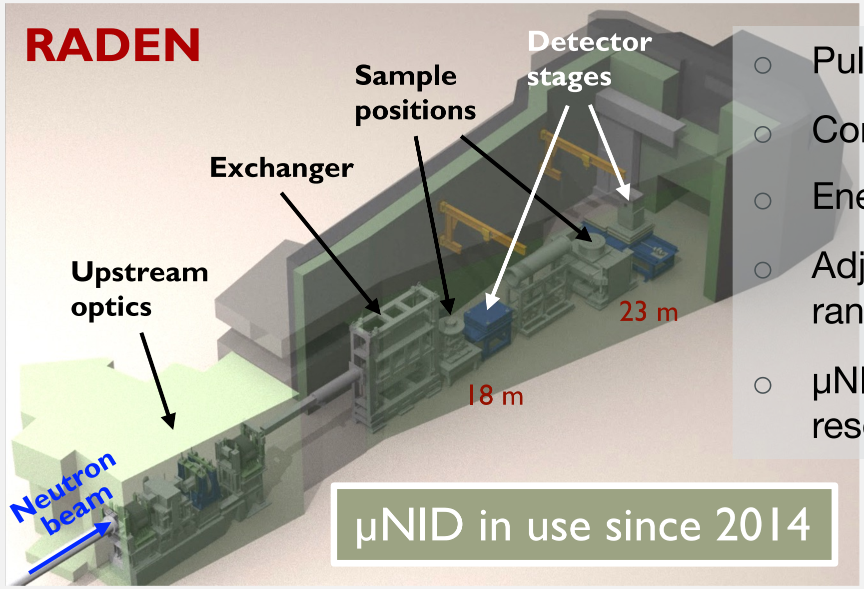
µNID AT THE MLF

Overhead view of the MLF

- Pulsed spallation neutron source (energy via ToF)
- 21 neutron instruments (w/ 7 public beamlines)

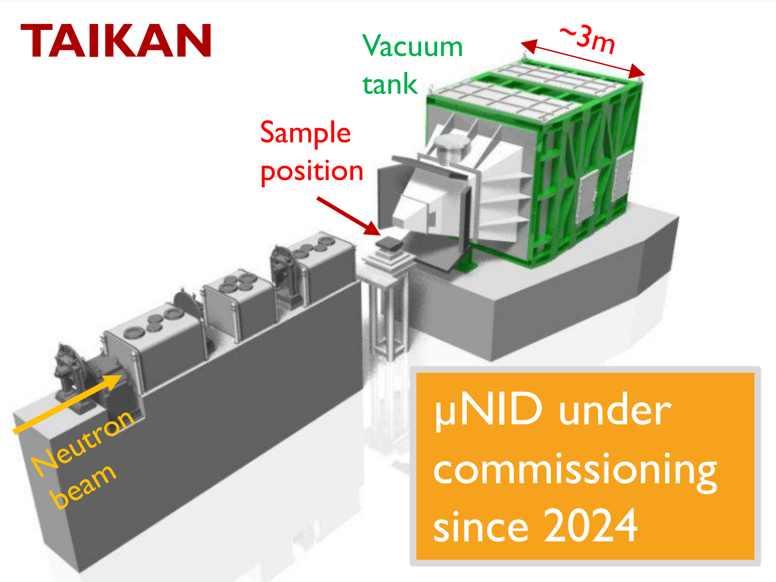


*Public neutron beamlines shown in red

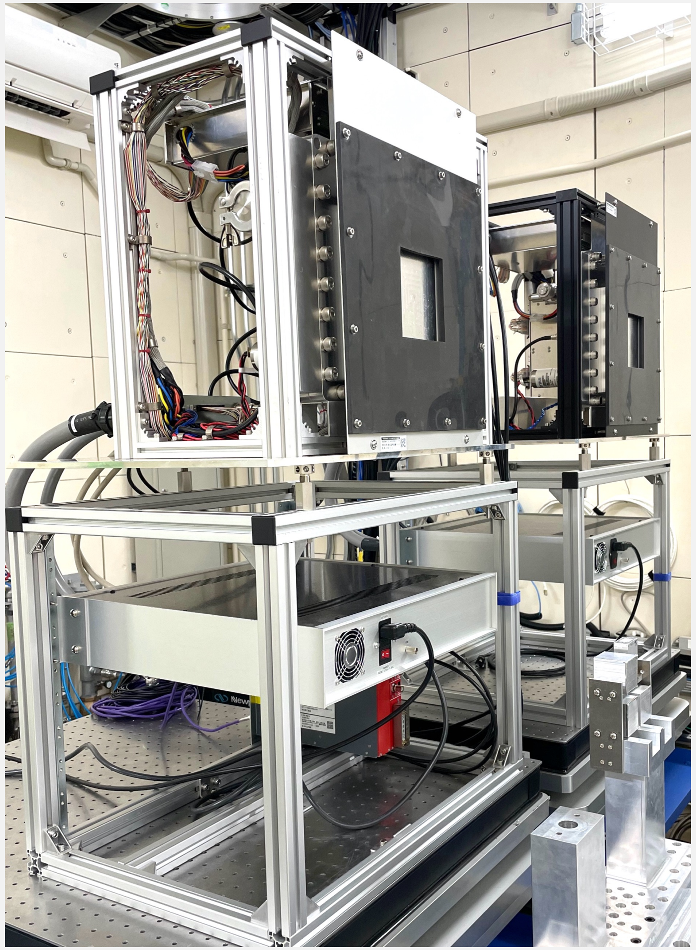


- Pulsed neutron imaging instrument
- Conventional radiography/CT
- Energy-resolved neutron imaging
- Adjustable optics for wide L/D range and beam size
- µNID is main detector for energy-resolved neutron imaging

- Small- and wide-angle neutron scattering instrument (wide Q range)
- Polarized neutrons (optional)
- Banks of ^{3}He tubes for wide angular coverage
- µNID as forward SANS detector (for very small-angle scattering)



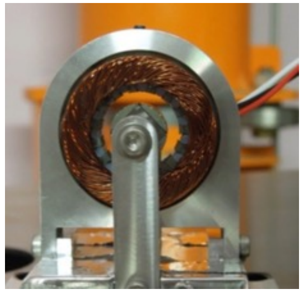
Energy-resolved neutron imaging at BL22 RADEN



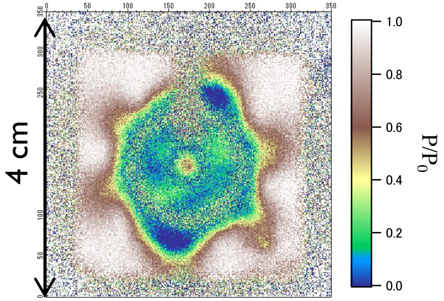
μNID (foreground) and BμNID (background) at RADEN

Magnetic imaging of running motor using polarized neutrons

Model electric motor (provided by Hitachi)

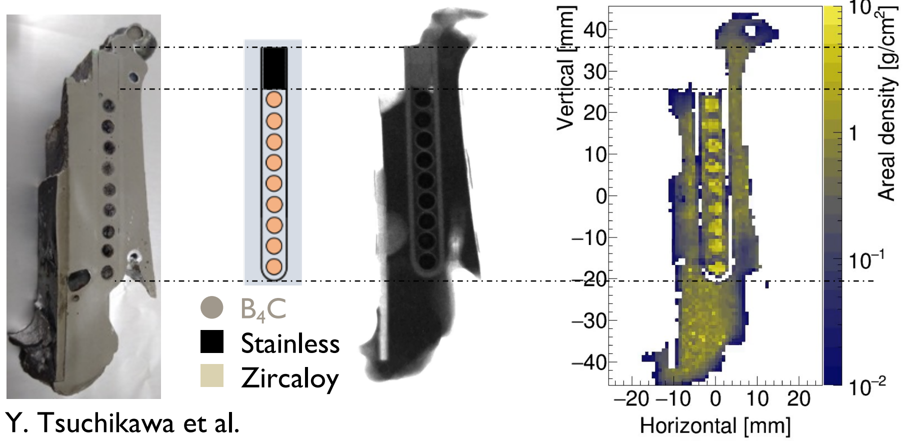


Polarization image



K. Hiroi et al., J. Phys.: Conf. Series 862 (2017) 012008

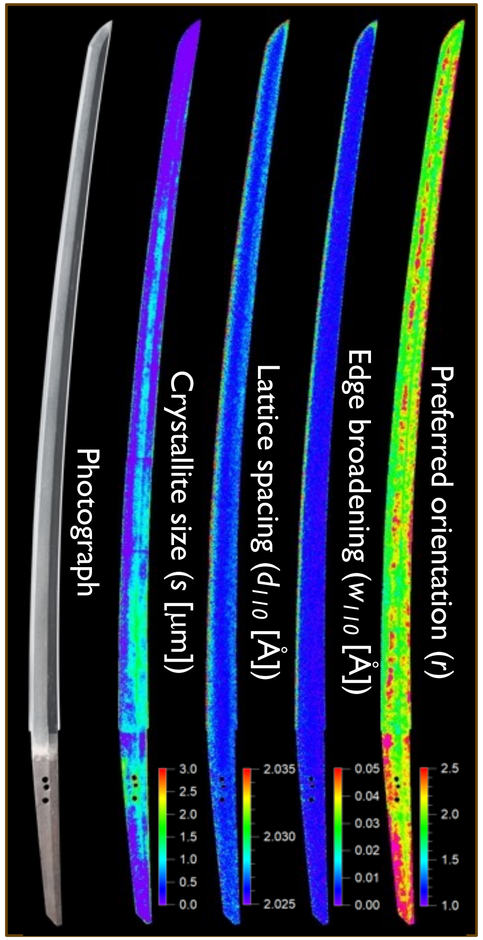
Boron areal density in simulated reactor melt using epithermal neutrons



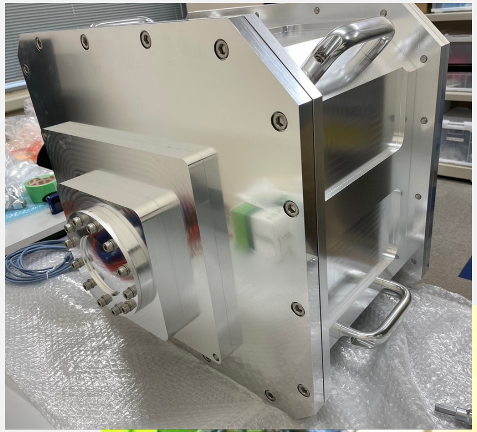
Y. Tsuchikawa et al.

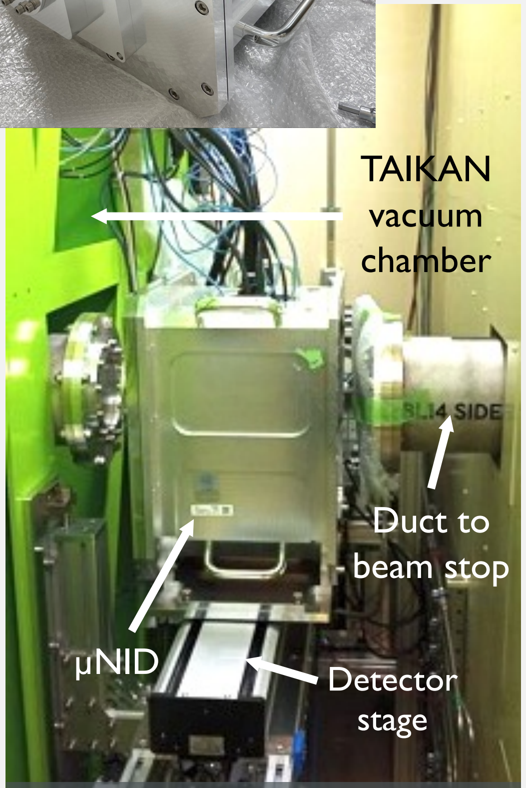
Crystallographic study of a Japanese sword using Bragg-edge imaging

Y. Matsumoto, et al.



µNID commissioning at BL15 TAIKAN

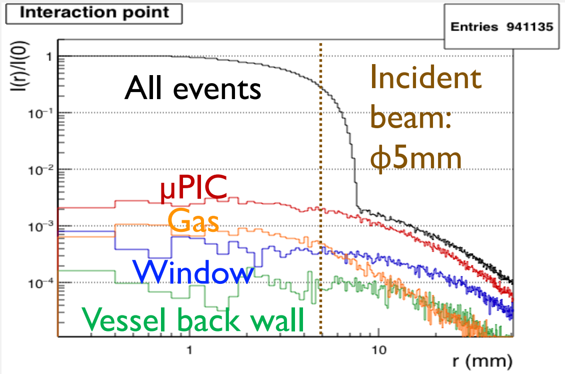


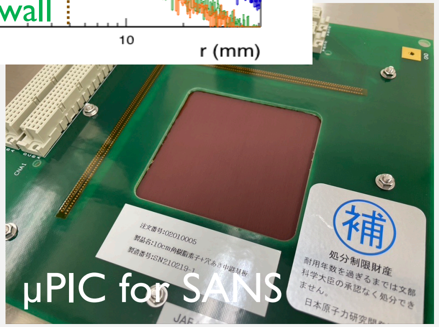


µNID installed at TAIKAN

- µNID as forward SANS detector
- Optimized vessel and µPIC for reduced scattering / improved dynamic range
- Installed in BL15 last December

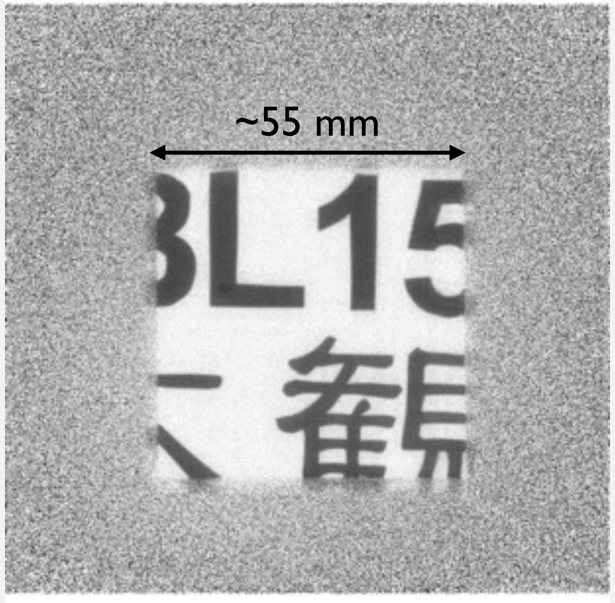
GEANT4 simulation of neutron scattering in µNID





µPIC for SANS

Image from first on-beam test



Remaining commissioning items

- Finish integration into TAIKAN experiment control system
- Automate data processing

Detector improvements

- Improve efficiency with new drift cage

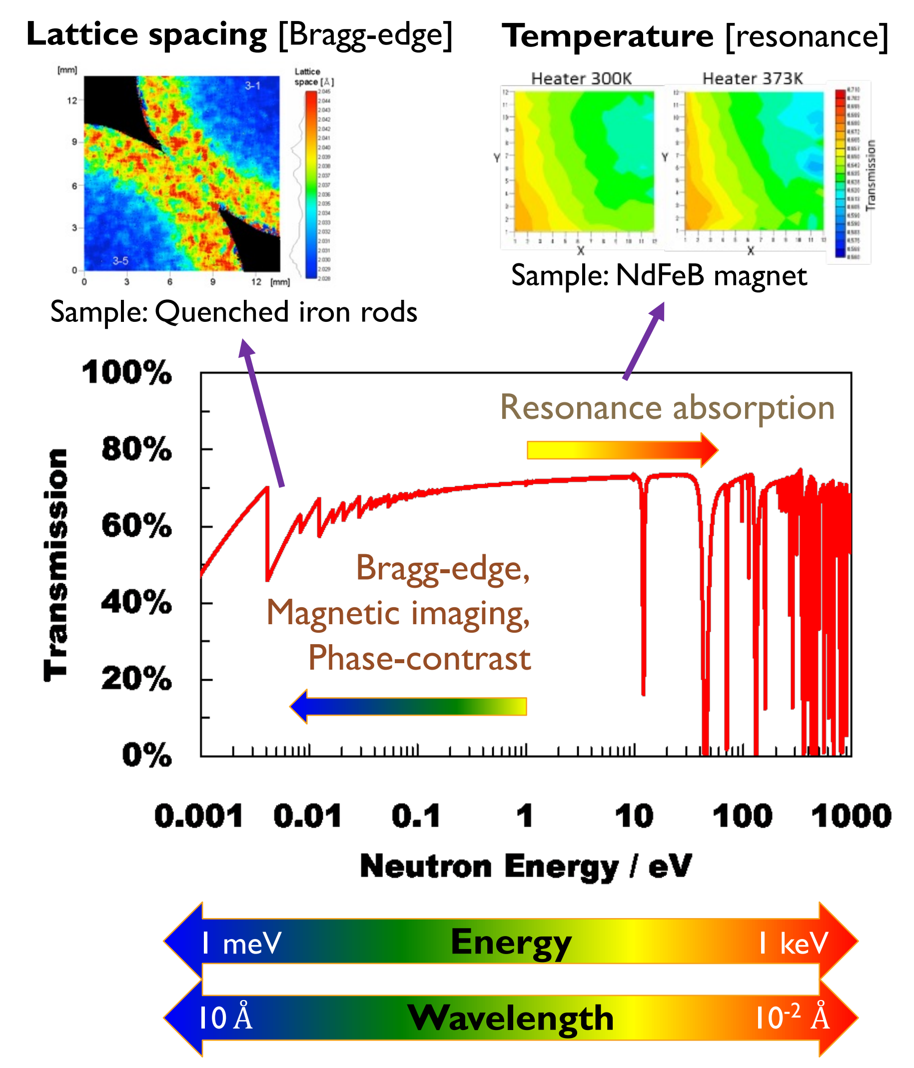
Recent activities

- Front-end readout electronics upgrade
- Vessel optimization for small-pitch μPIC
- Boron converter development
- Round robin measurement with ISIS

μNID development focus for RADEN

Energy-resolved neutron imaging → measure macroscopic distribution of microscopic quantities

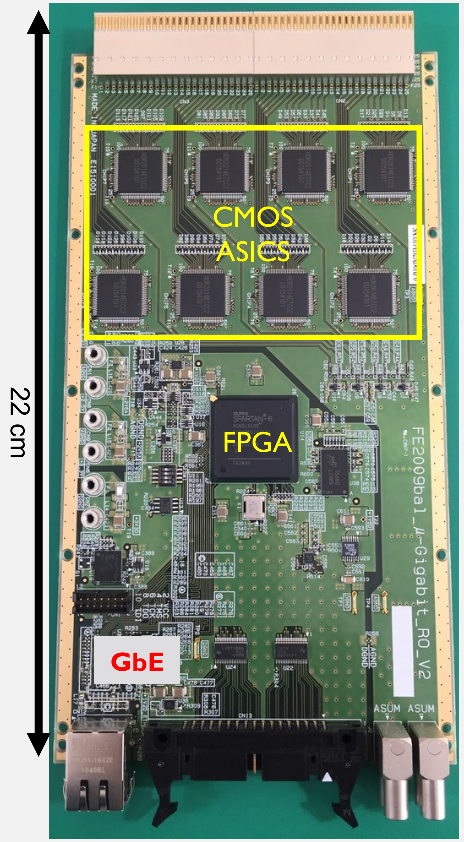
1) User experiments are moving toward *in situ, in operando* measurements (heating, bending/stretching, battery charging/discharging, etc.)
   - Requires good process time resolution (short measurement times)
   - Typical measurement times are several hours to acquire sufficient statistics
   - Combine improvements in rate performance with sparse data analysis techniques
2) Improvement of spatial resolution towards smaller or more intricate samples (cultural artefacts, fuel cells, etc.)



Front-end electronics upgrade

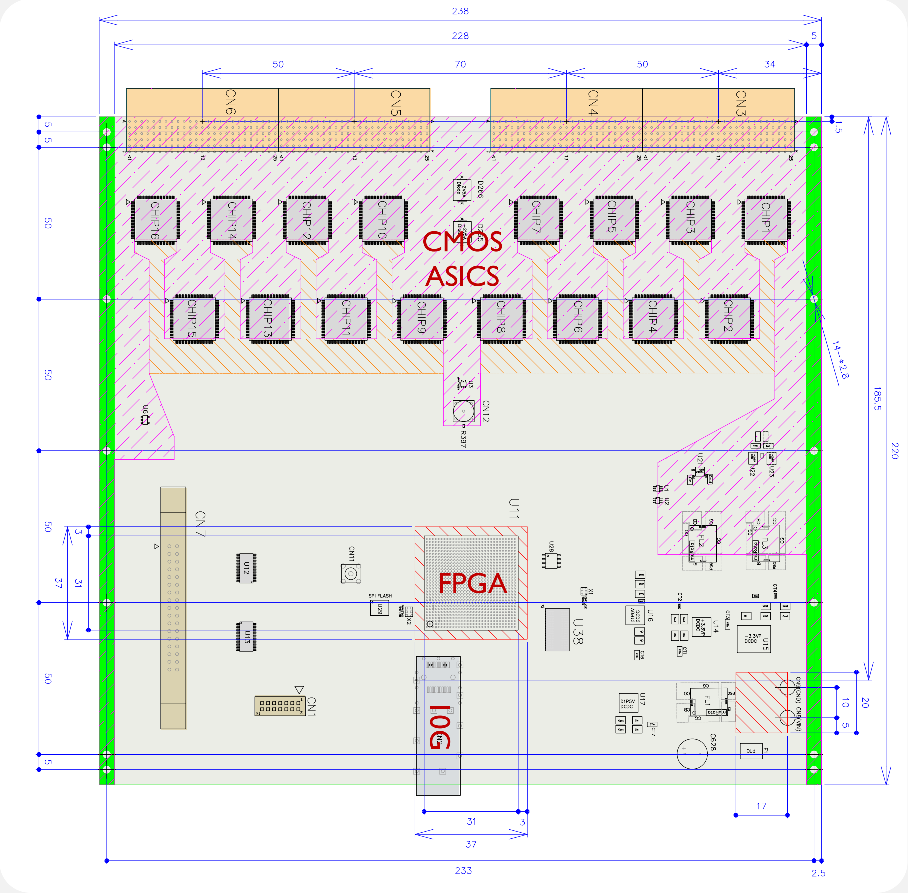
- Upgrade to 10G to accommodate future network infrastructre upgrades and data rate increases
- Utilize larger FPGA to carry out some preprocessing and speed up offline data processing

Current μNID readout board 3rd gen



- Custom ASICS (8 x 16 ch)
- Spartan6 FPGA
- Gigabit Ethernet data transfer
- 4 modules per detector
- ~10 years old

New μNID readout board

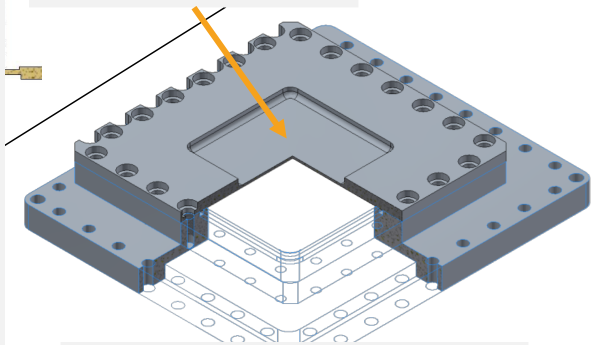


- Same custom ASICS (16 x 16 ch)
- Kintex7 FPGA
- 10G data transfer
- 2 modules per detector
- First test board to be completed by March (from BBT)

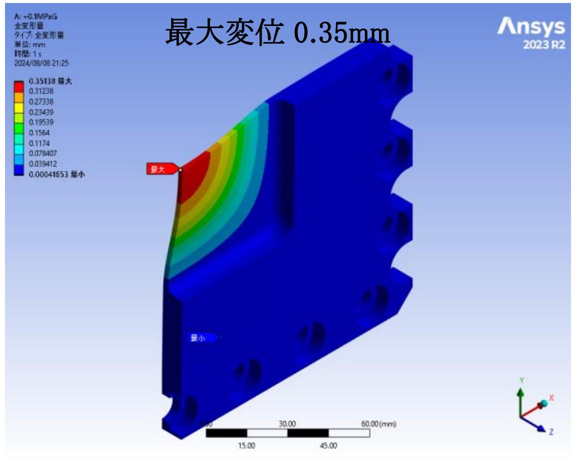
NEW PRESSURE VESSEL FOR SMALL-PITCH μPIC

- Small-pitch μPIC (215μm pitch) provides improved spatial resolution (currently 39% for BμNID, 19% for μNID)
- Objective: reduce thicknesses of entrance and exit windows for reduced scattering
- Design check and manufacture by Metal Techology Co., Ltd. (MTC)
  - Use A5083-O for entrance window, reduced from 3mm to 2.2mm
  - Exit window reduced from 10mm to 3mm
  - Detachable window allows future upgrades
- New vessel is awaiting testing (probably next fiscal year)

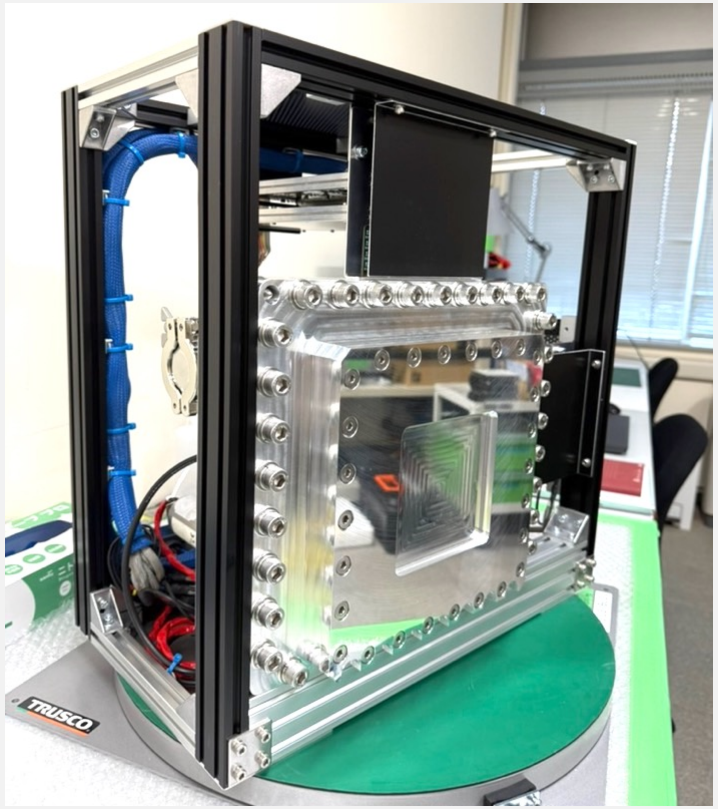
Entrance window:
3mm → 2.2mm



Exit window (not shown):
10mm → 3mm



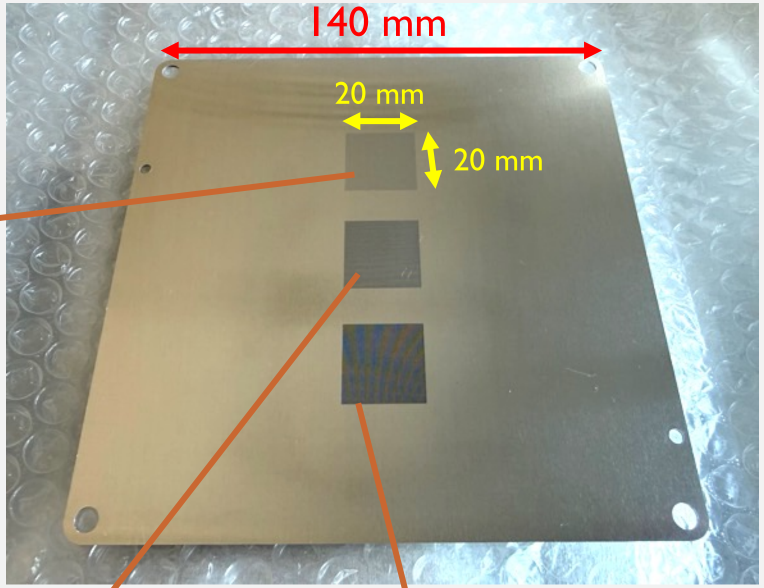
Strain simulation at +1 atm

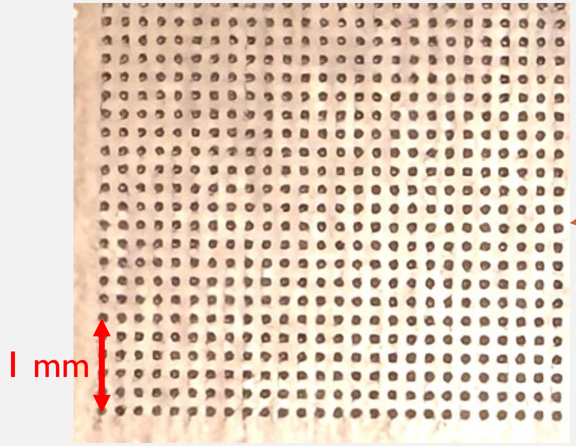


New vessel assembled and ready for testing

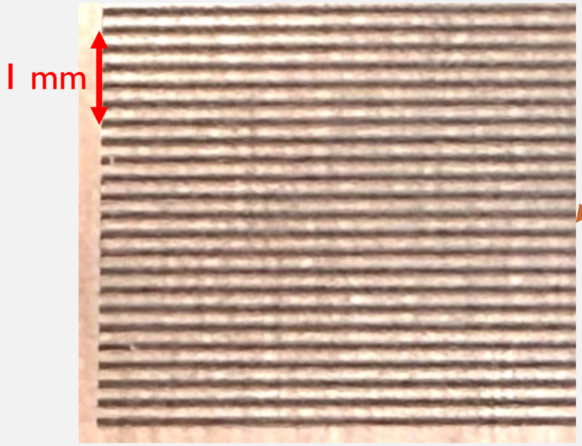
Boron converter development of improved efficiency

- 5% efficiency for current ^{10}B converter
- Objective: improve efficiency of ^{10}B converter using micropatterning to increase surface area
- Manufactured through Metal Techology Co., Ltd. (MTC)
  - Laser manufacturing
  - Dimples: ϕ100μm x 30μm depth x 200μm pitch
  - Grooves and crossed grooves: 100μm x 30μm depth x 200μm pitch
- Preparing for boron depostion (natural boron at first stage)
- Will test next fiscal year

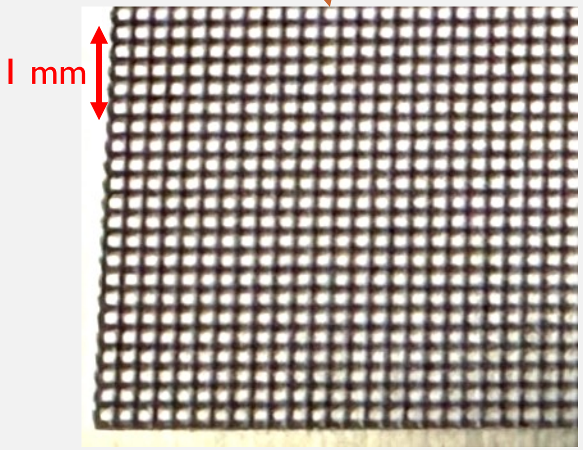




Dimples



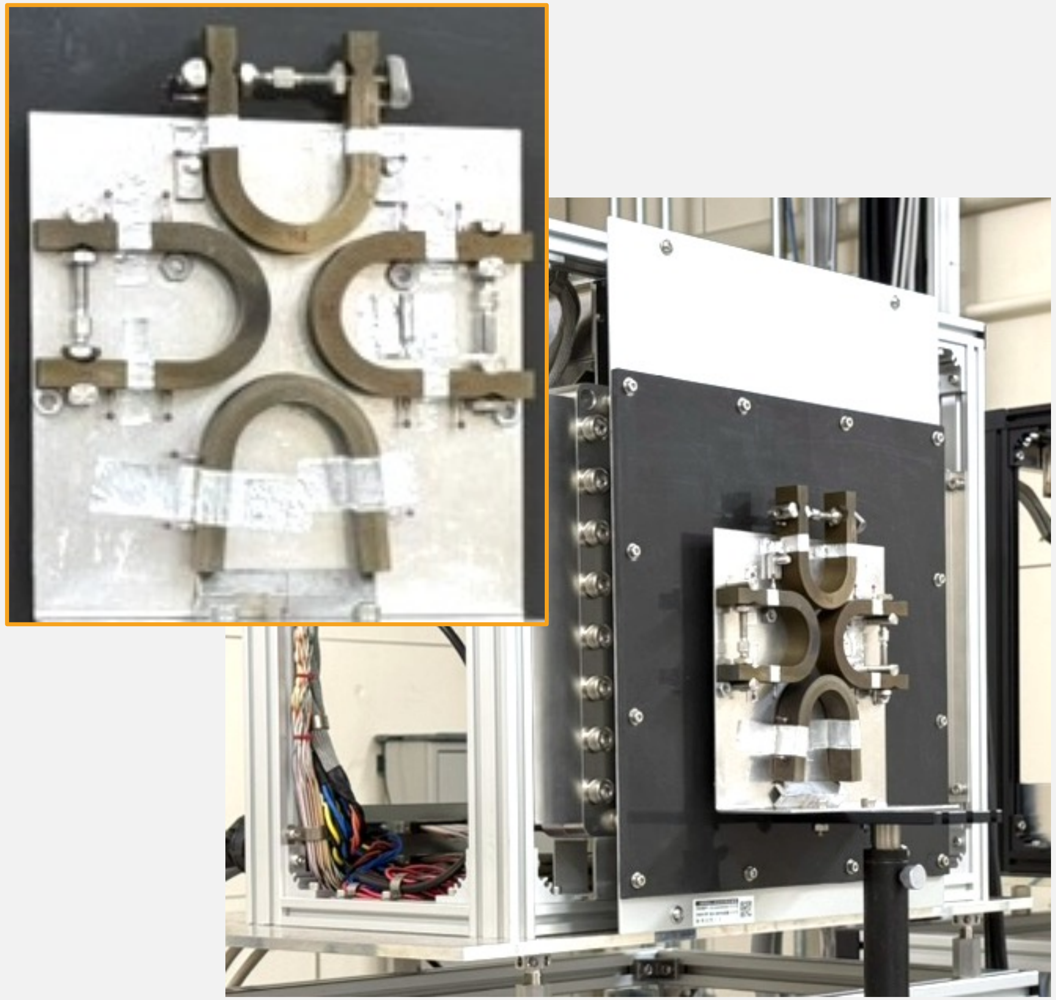
Grooves



Crossed grooves

ROUND ROBIN MEASUREMENT WITH ISIS

- Bragg-edge round robin samples developed at IMAT instrument of ISIS, UK (bent steel bars under tension/compression)
- Compare Bragg-edge spectra and strain analysis at different energy-resolved neutron imaging instruments
- Samples measured previously at ISIS and PSI (Switzerland), will also measure at VENUS (SNS, USA)
- IMAT instrument scientist (Ranggi Ramadan) participated
  - Interested in μNID for IMAT
  - Used both μNID and BμNID for measurements
  - May take μNID to ISIS next year (if beamtime is available)



Bragg-edge round robin samples mounted in front of μNID at RADEN

SUMMARY

- The µNID is a µPIC-based detector designed for event-based neutron imaging
- The µNID is in use at the RADEN (energy-resolved neutron imaging) and TAIKAN (neutron scattering) instruments within the MLF
- Development toward improved rate performance and spatial resolution is ongoing
  - Upgrading encoder board to use 10G data transfer and Kintex 7 FPGA
  - Optimizing pressure vessel for improved spatial resolution with small-pitch µPIC
  - Designing new ^{10}B converter for improved efficiency
- Adoption of the µNID being considered at IMAT instrument, ISIS, UK (some interest also shown by VENUS at SNS, USA)
  - Performed Bragg-edge round robin measurement at RADEN with IMAT instrument scientist
  - May take µNID to IMAT next year for test

NEXT YEAR: μNID FOR FAST NEUTRON IMAGING (TEST)

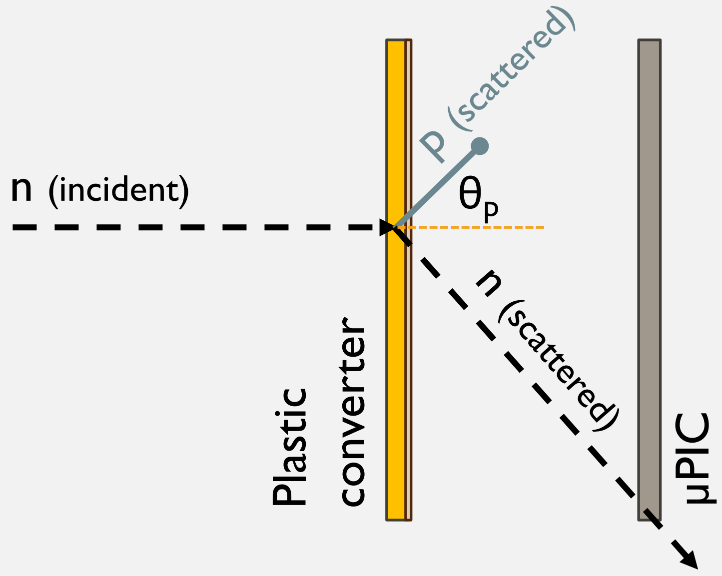
Thermal / cold / epithermal neutrons
(E < ~100 eV)

+ Well-established
– Poor penetration for large samples
– Limited isotope mapping

VS

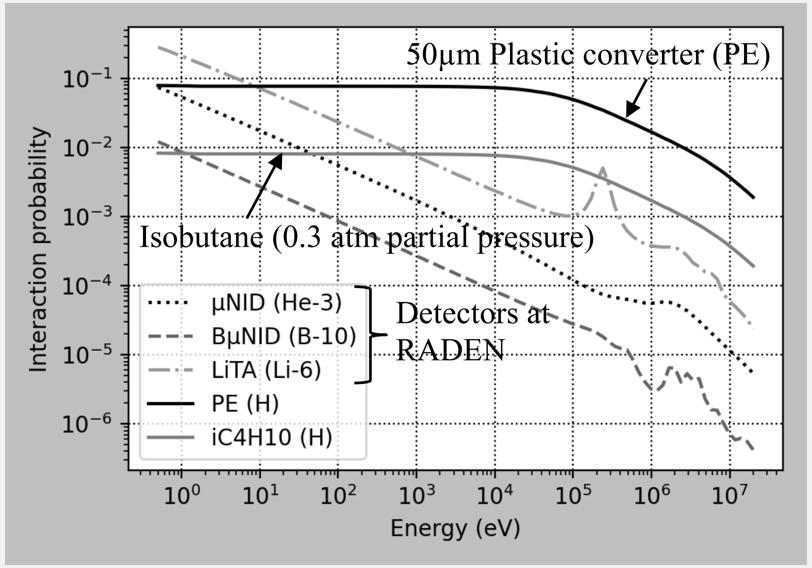
Fast neutrons
(E > ~100 eV)

+ High penetration
+ Isotope mapping
– Low detection efficiency
– Poor image quality



- Utilizing fast neutrons allows imaging of larger samples, more complete isotope mapping via neutron resonance absorption
- Difficulties include poor detection efficiency and degradation of image quality due to scattering in the sample

➢ A plastic converter (n-p scattering) can improve efficiency for fast neutrons by several orders compared to ^{3}He, ^{10}B, ^{6}Li
➢ Kinematics can be used to reject scattered neutron background
➢ Plan to perform proof-of-principal testing next fiscal year



THANK YOU FOR YOUR ATTENTION!