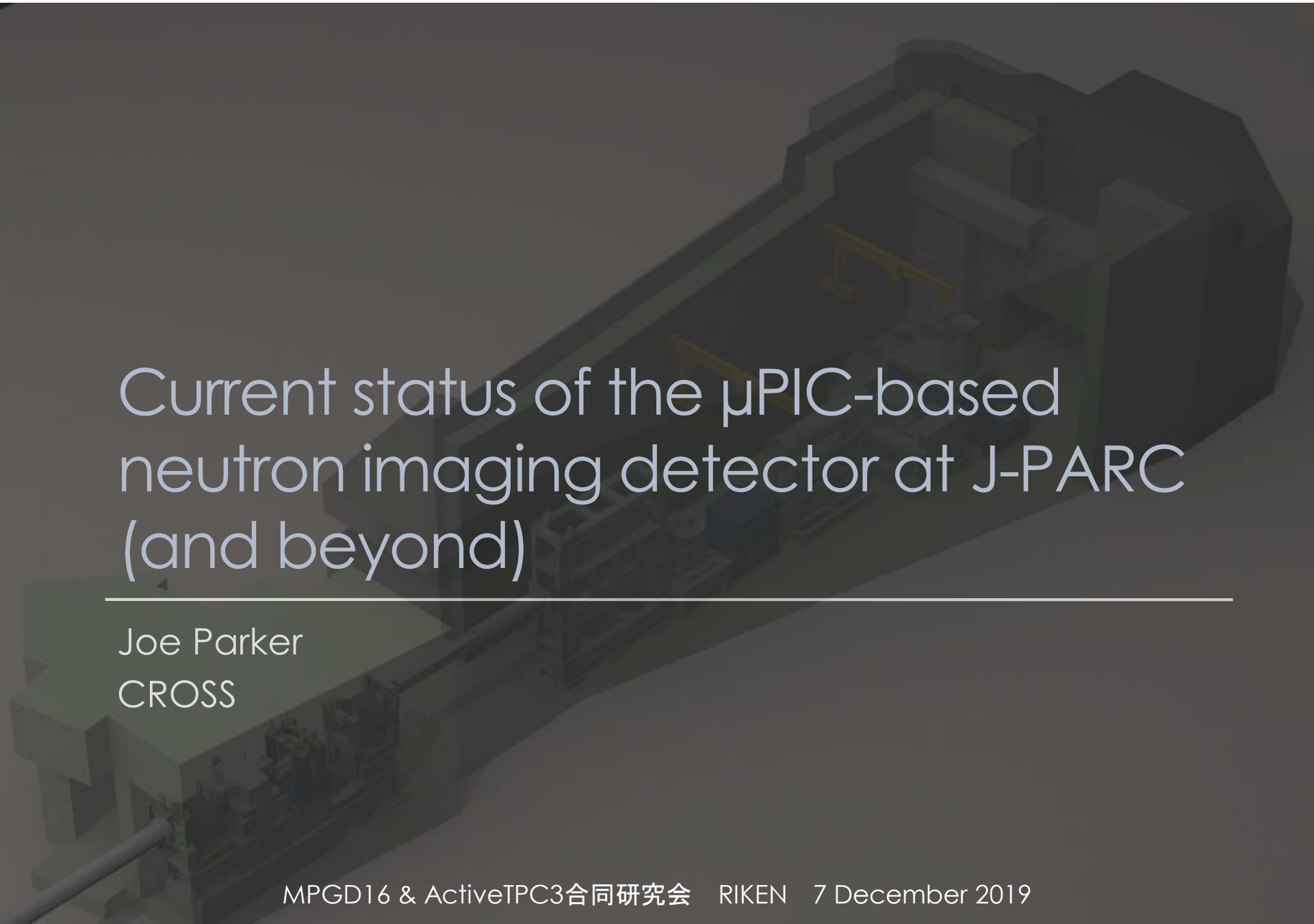


# Current status of the μPIC-based neutron imaging detector at J-PARC (and beyond)

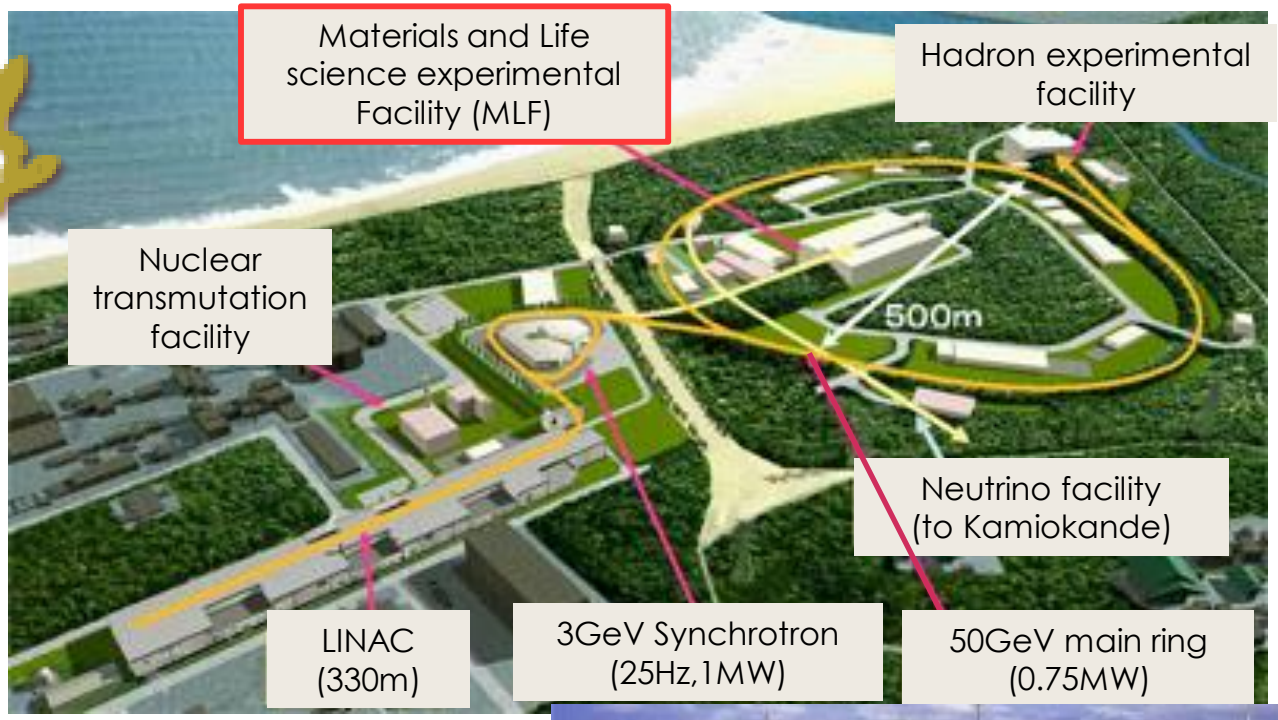
Joe Parker
CROSS

MPGD16 & ActiveTPC3合同研究会　RIKEN　7 December 2019

# RADEN and μNID development members

| | | |
|---|---|---|
| **CROSS** | Joe Parker (μNID Lead Developer) | |
| | Hirotoshi Hayashida | Yoshihiro Matsumoto |
| **JAEA/J-PARC Center** | Takenao Shinohara | Tetsuya Kai |
| | Kenichi Oikawa (BL10) | Masahide Harada (BL10) |
| | Takeshi Nakatani | Yusuke Tsuchikawa |
| | Kosuke Hiroi | Yuhua Su |
| **Nagoya University** | Yoshiaki Kiyanagi | |
| **Kyoto University** (μNID development) | Toru Tanimori | Atsushi Takada |

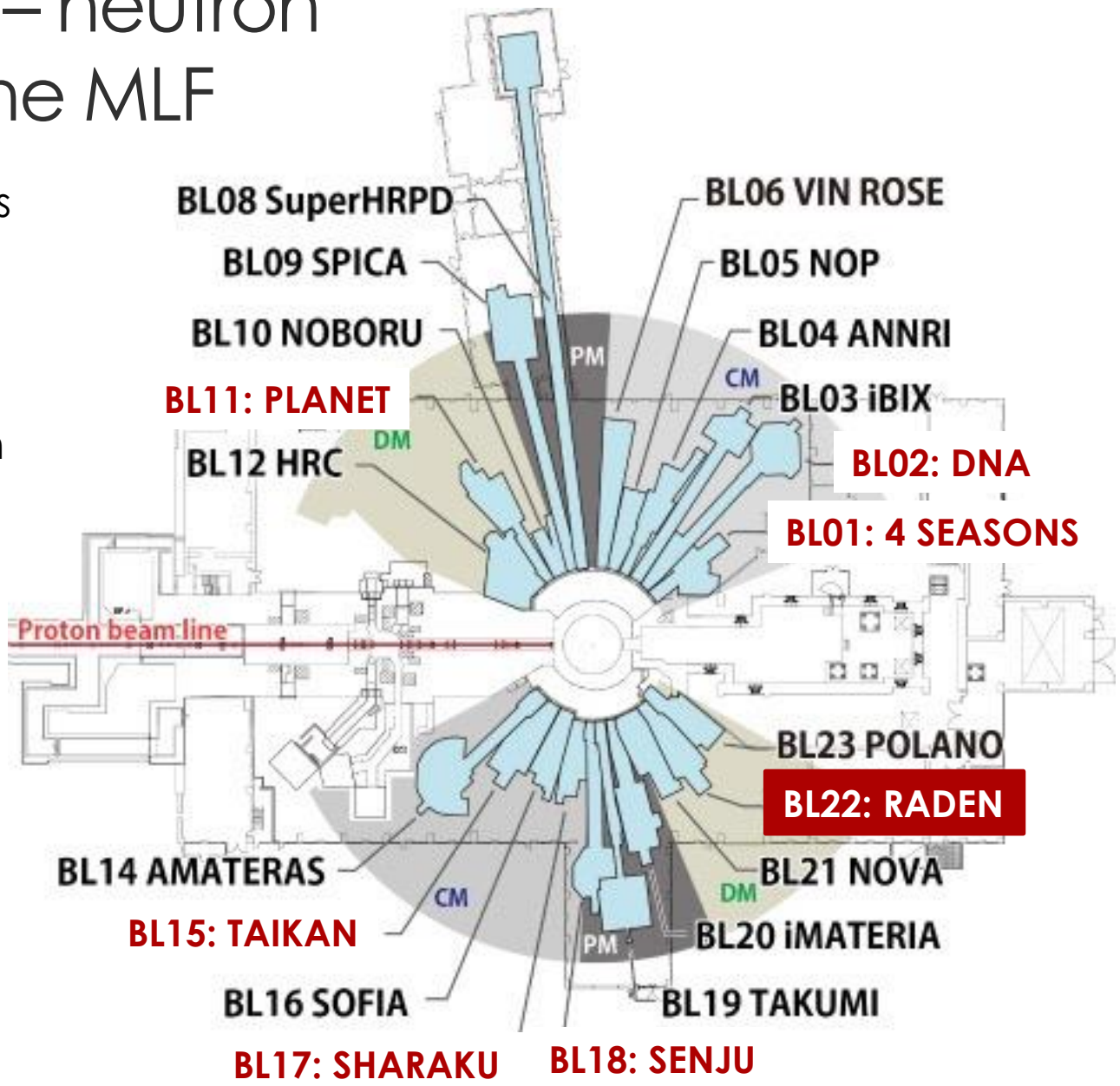
# J-PARC (Japan Proton Accelerator Research Complex)


MLF is currently operating at 500kW (successful tests at 1MW in July 2018, June 2019)

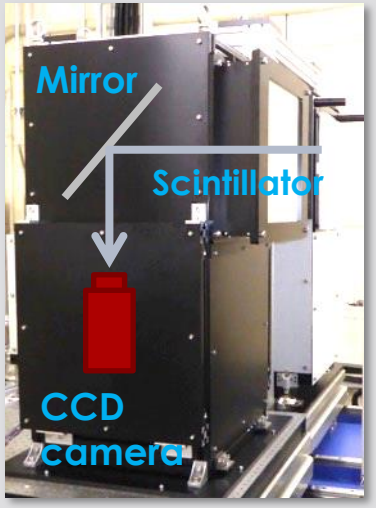
# BL22/RADEN – neutron imaging at the MLF

- 7 public beam lines operated by JAEA/CROSS
- BL22/RADEN is dedicated neutron imaging beamline
- In user operation since 2015



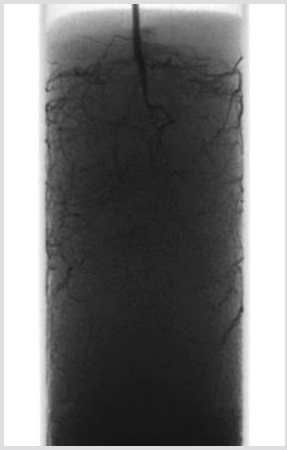
# Neutron imaging at RADEN

## Conventional




- CCD camera detectors: 50-300μm spatial resolution, no TOF
- Radiography and computed tomography

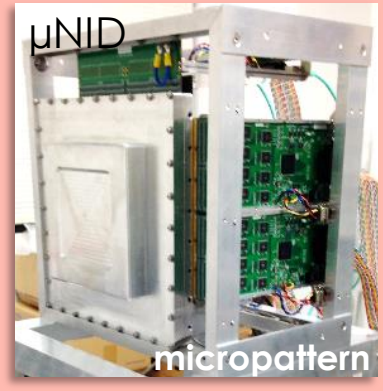
Radiography

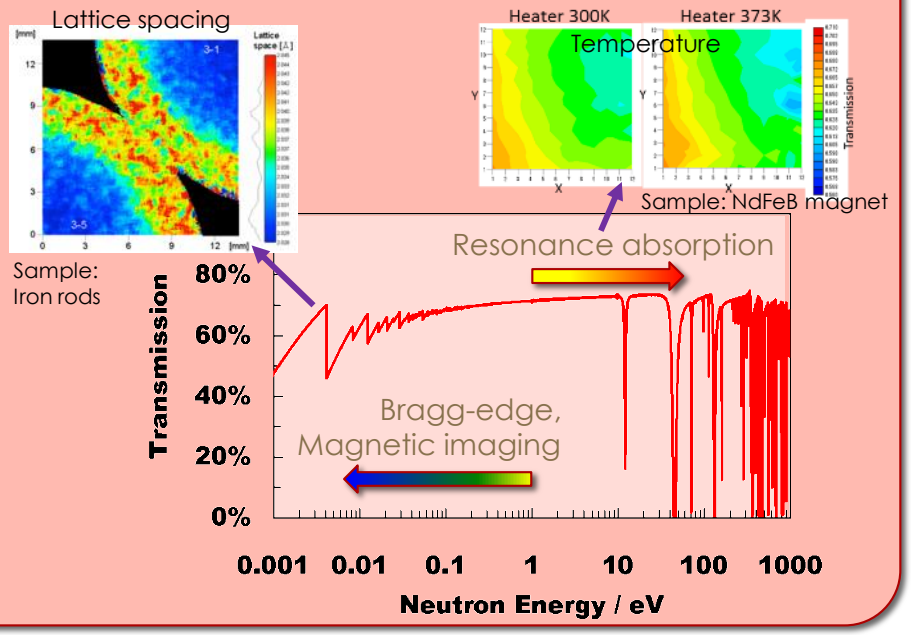


Sample: Roots of soybean plant (Nakazono, Nagoya U.)

## Energy-resolved

- Event-type detectors: sub-mm spatial and sub-μs time resolutions, neutron energy via TOF
- Energy-dependent neutron transmission: macroscopic distribution of microscopic quantities

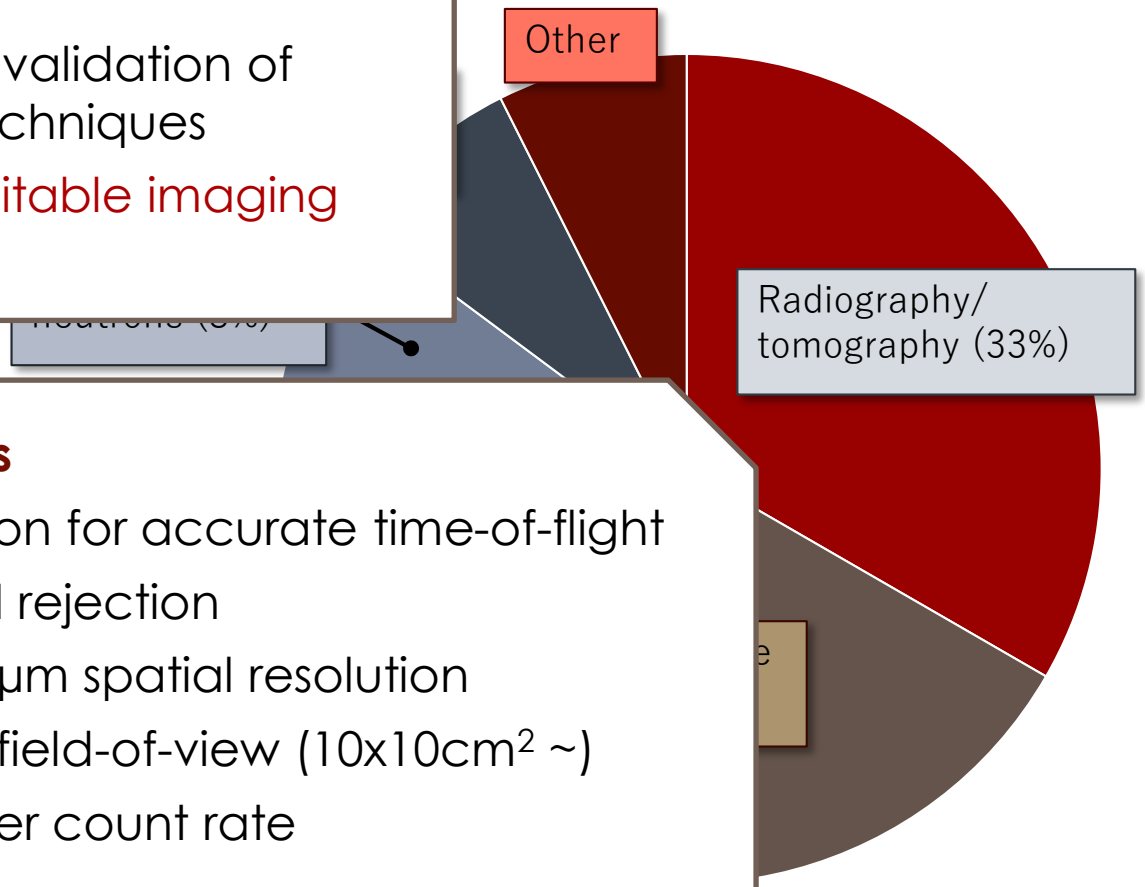


# Beam-time utilization at RADEN

- Energy-resolved

urement types for JFY 2015-6




**Ongoing R&D (at RADEN and around the world)**

- Development and validation of energy-resolved techniques
- Development of suitable imaging detector

**Detector requirements**

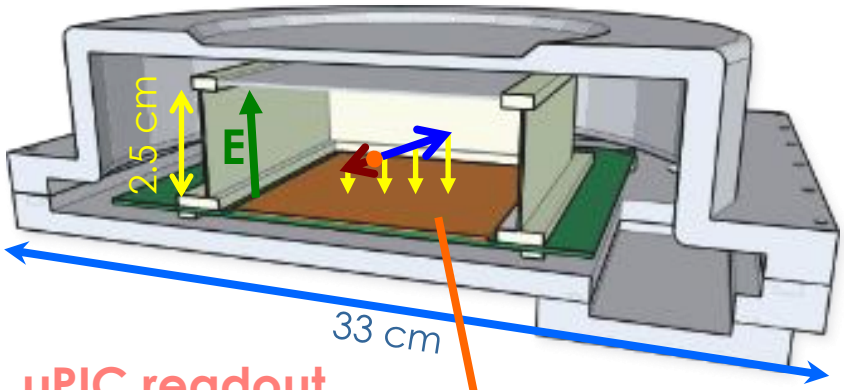
- Sub-μs time resolution for accurate time-of-flight
- Strong background rejection
- Sub-mm to sub-100μm spatial resolution
- Moderate to large field-of-view (10x10cm$^2$ ~)
- Mcps-order or higher count rate

# μPIC-based neutron imaging detector (μNID)

# μPIC-based neutron imaging detector (μNID)

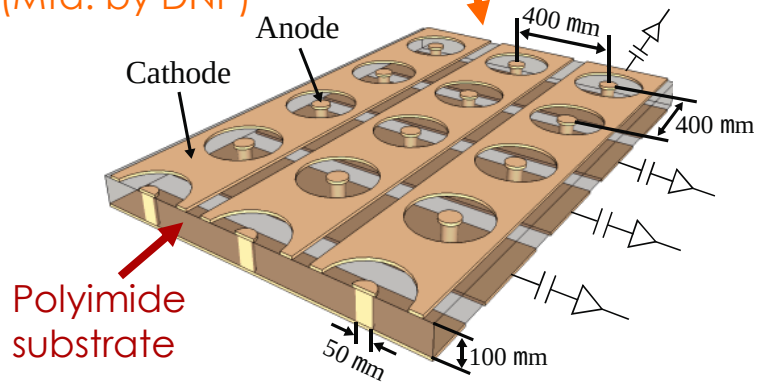
**Neutron detection via n + $^3$He → p + t**

Overall track length ~4 mm in gas



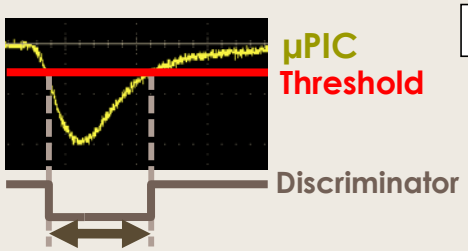

**μPIC readout**

10 cm x 10 cm area,
400 μm pitch x,y strips
(Mfd. by DNP)

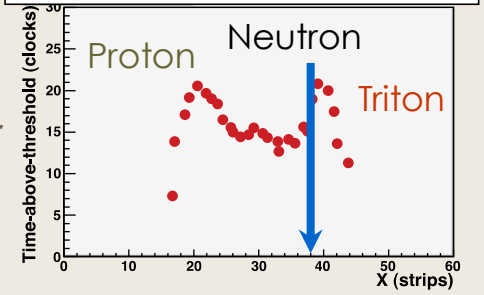



- Gaseous time-projection-chamber
  - $CF_4$-$iC_4H_{10}$-$^3$He (45:5:50) at 2 atm
  - μPIC micropattern readout
  - Compact ASIC+FPGA data encoder front-end
- 3-dimensional tracking (2D position + time) with time-over-threshold
  - Accurate position reconstruction
  - Strong gamma rejection

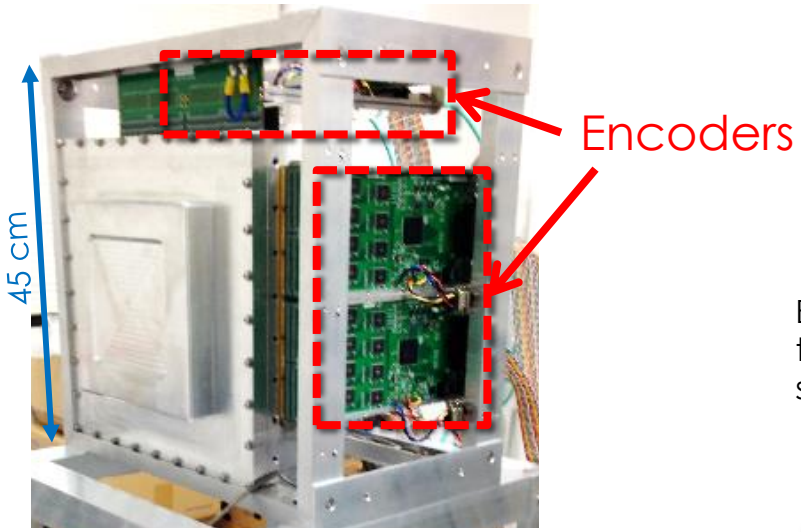
Digital encoder with time-over-threshold (TOT)



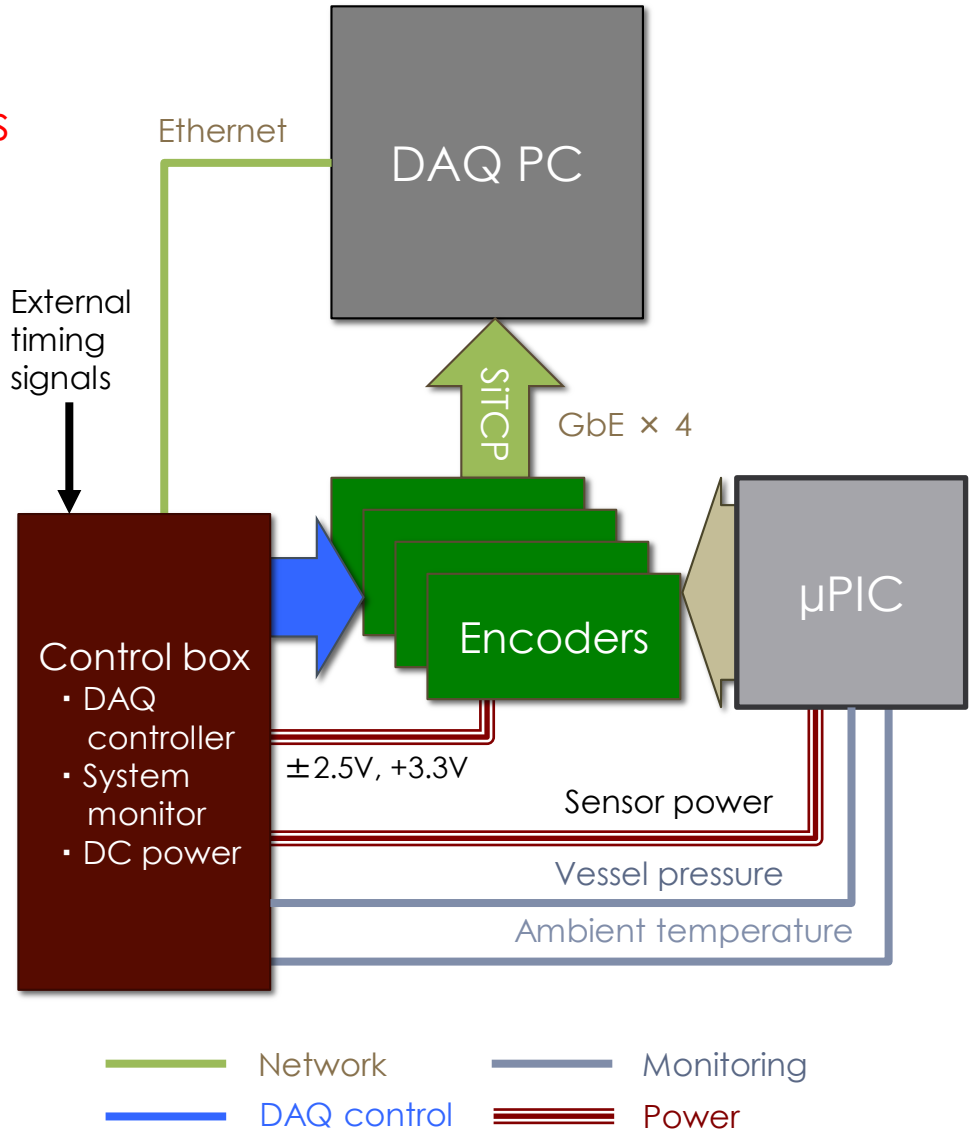

TOT for proton-triton track



# μPIC-based neutron imaging detector (μNID)




- High-speed FPGA-based encoders process signals from μPIC and send to PC via Ethernet (Kyoto U, KEK, OpenIT)
- DAQ controller synchronizes operation of encoders, controlled via PC (mfd. by BBT)
- Full integration into RADEN control system via DAQ-Middleware (software by BBT)



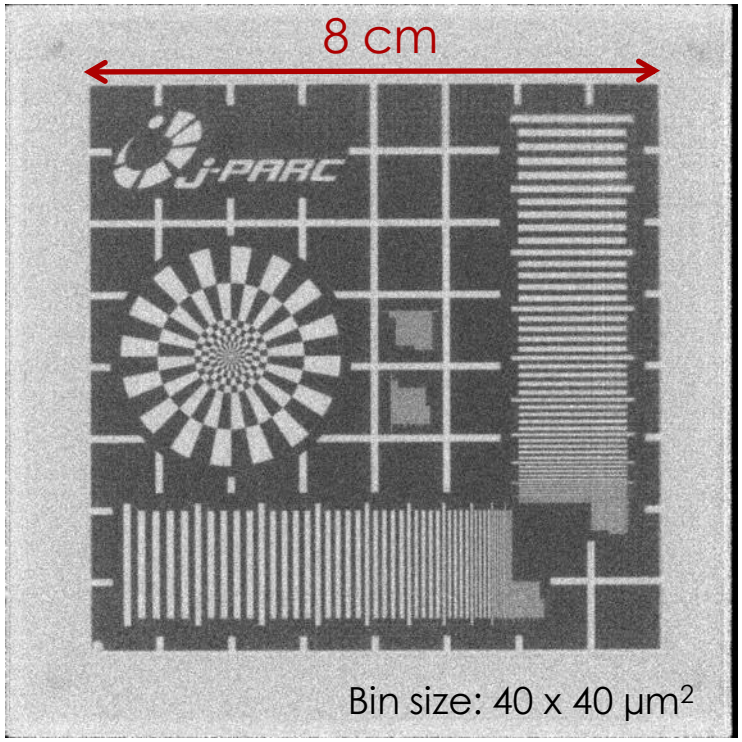
# μNID performance and usage at RADEN

| Base performance characteristics | |
|---|---|
| Active area | 10 x 10 $cm^2$ |
| Spatial resolution | 0.1 mm |
| Time resolution | 0.25 μs |
| γ-sensitivity | < $10^{-12}$ |
| Efficiency @25.3meV | 26% |
| Count rate capacity | 8 Mcps |
| Effective max count rate | > 1 Mcps |

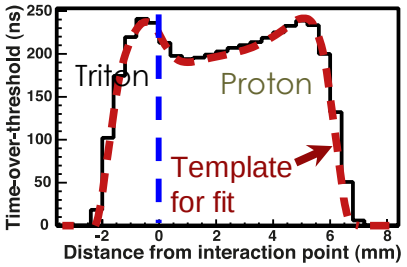
| Usage at RADEN | 2018A | 2019A |
|---|---|---|
| μNID | 34 days | 30 days |
| Other event-type | 36 days | 25 days |

μNID used primarily for Bragg-edge, magnetic imaging, and phase-contrast imaging measurements at RADEN

**Image of Gd test target**



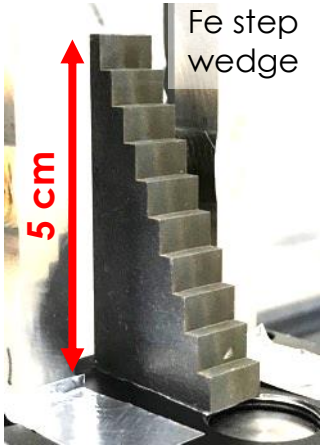

Fine spatial resolution using template fit to TOT distribution

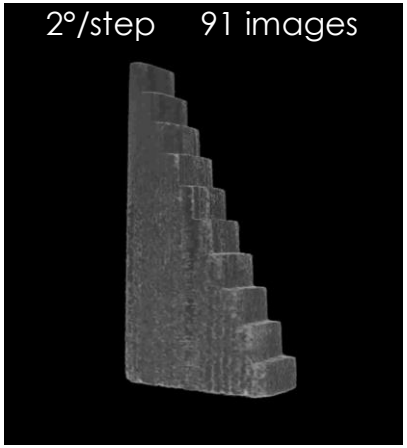


# Automated measurements

- Increased rate and integrated control
  - Perform complex measurements more easily
- Computed tomography with TOF
  - Quantify effects of scattering, beam hardening, etc.
  - Combine with energy-resolved imaging techniques
- Dynamic samples
  - Fold TOF with motion/process frequency
  - Currently limited to cyclical processes

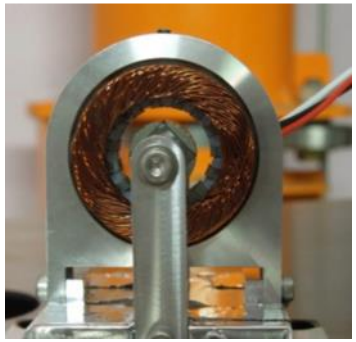
## Computed tomography (CT)

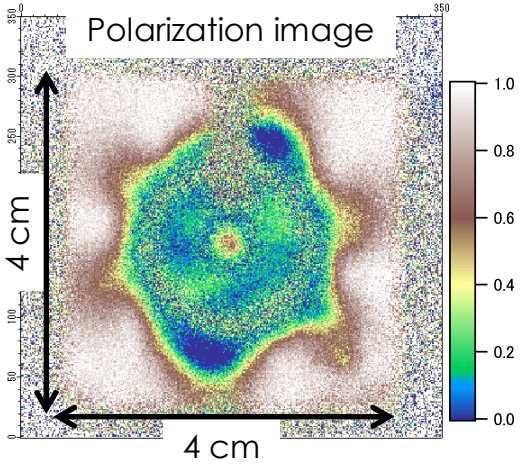



## Magnetic imaging of running motor

Model electric motor (provided by Hitachi)






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

# Continuing development of the μNID

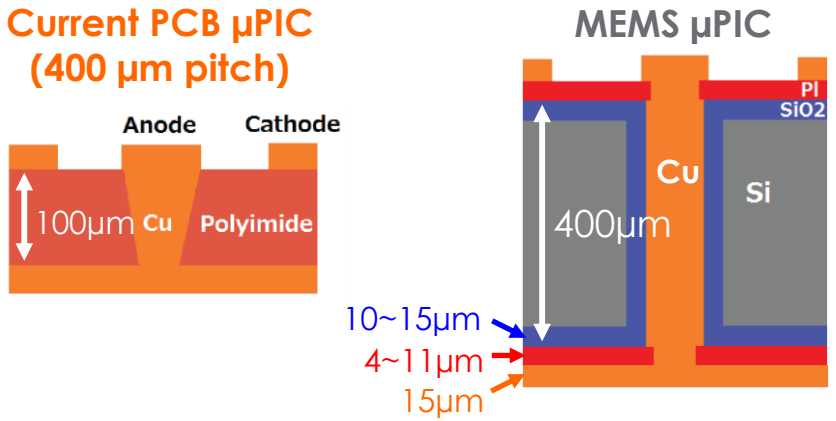
- Development since 2014
  - Upgraded encoders with Gigabit Ethernet (and 2Gb memory)
  - Optimized gas mixture and offline analysis for improved rate, spatial resolution
  - New DAQ control hardware/software for full integration into RADEN control system; GUI for offline analysis
- Continue refinement of clustering algorithm to utilize full hardware rate capacity (10 Mcps order) and improve offline processing speed (GPU processing)
- Upgrade FPGA encoder firmware to incorporate data buffering for increased rate capacity above 10 Mcps
- Investigate new gas mixtures for increased efficiency, optimized event size (increase stopping power)

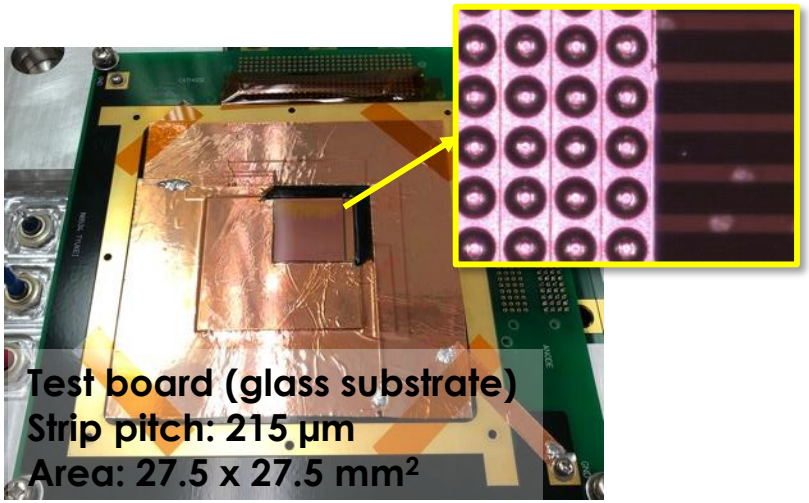
# New μNID development

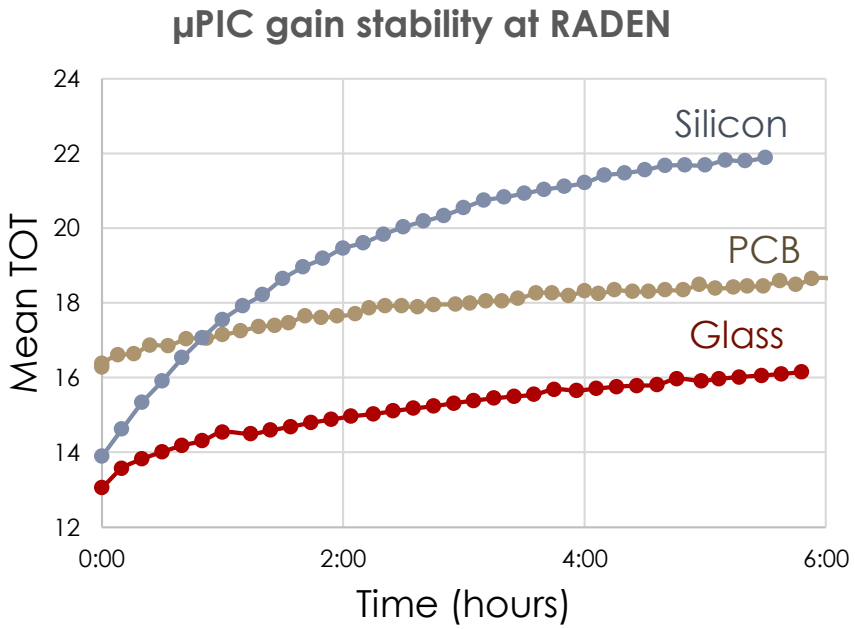
- Small-pitch MEMS μPIC
- μNID with Boron converter

# 215μm-pitch MEMS μPIC for improved spatial resolution

- 215μm pitch μPIC on silicon, glass substrates using MEMS manufacturing (DNP)
- Gain stability measured at RADEN
  - Silicon shows poor stability
  - Glass similar to PCB μPIC



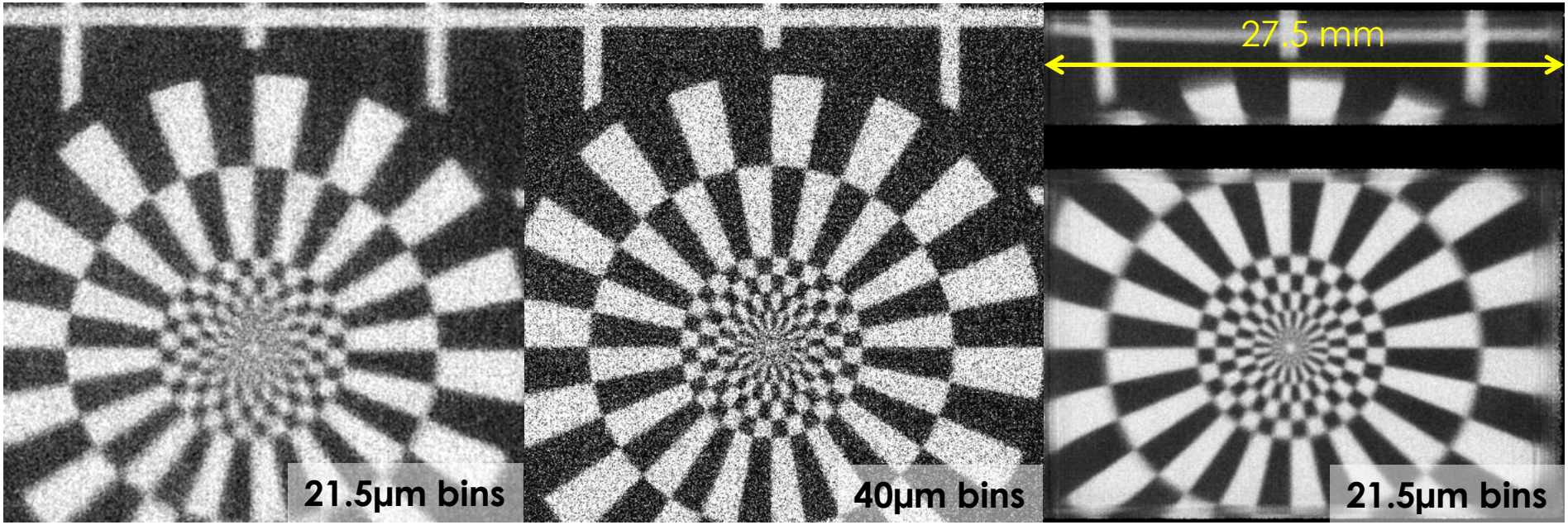



# Imaging with the 215μm MEMS μPICs

215μm pitch
Silicon substrate

400μm pitch
PCB μPIC

215μm pitch
Glass substrate

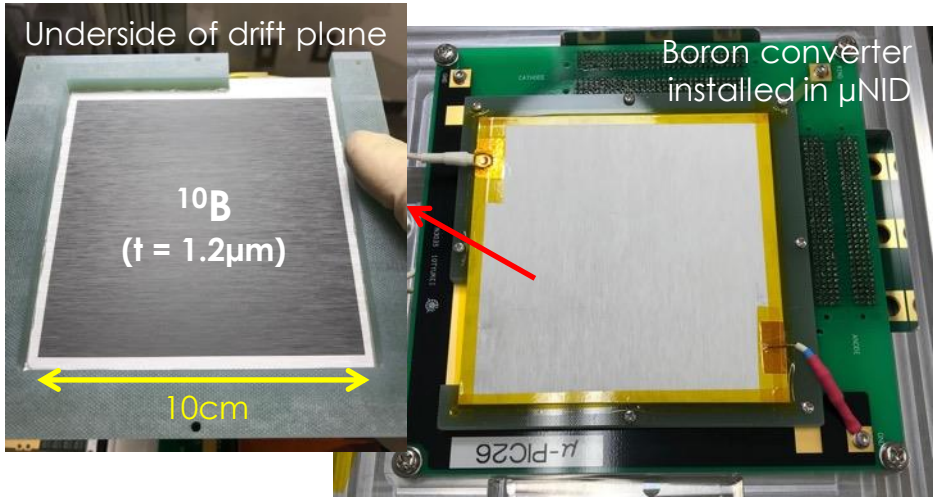


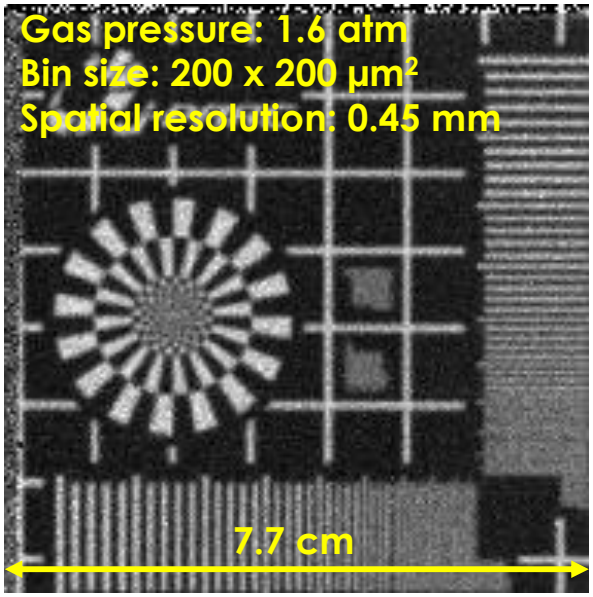

- Image quality for glass substrate looks good
- Resolution appears to be improved compared to PCB μPIC

Note: measurement statistics are different for each image

# Boron converter for increased rate

- 3x smaller event size compared to $^{3}He$
  - Trade-off in spatial resolution
- μNID with flat boron converter for proof-of-principle
  - Thin, 1.2μm $^{10}B$ layer → low efficiency (3~5%)



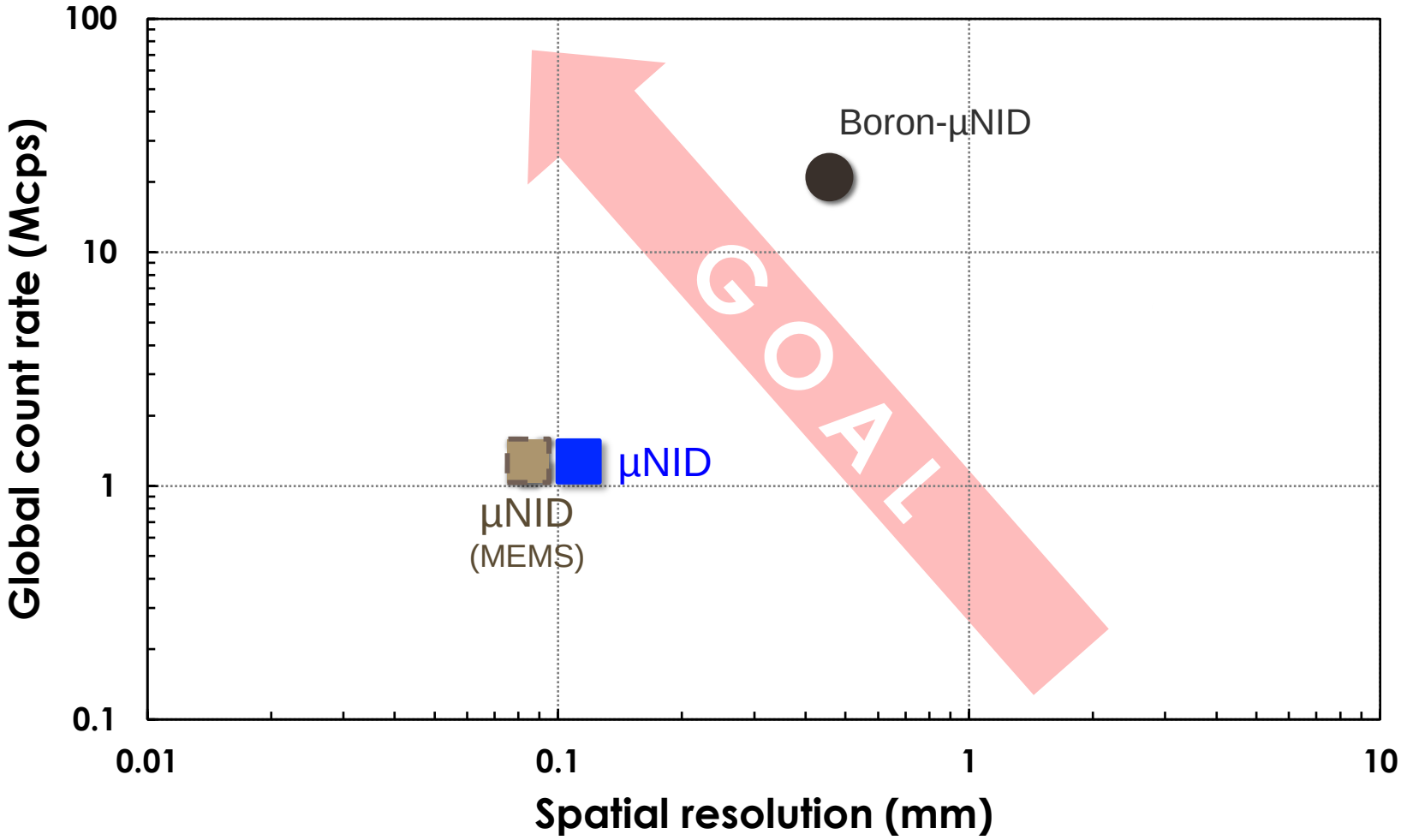

Initial testing at RADEN

- Maximum count rate of 22 Mcps confirmed
- Spatial resolution of 0.45 mm confirmed

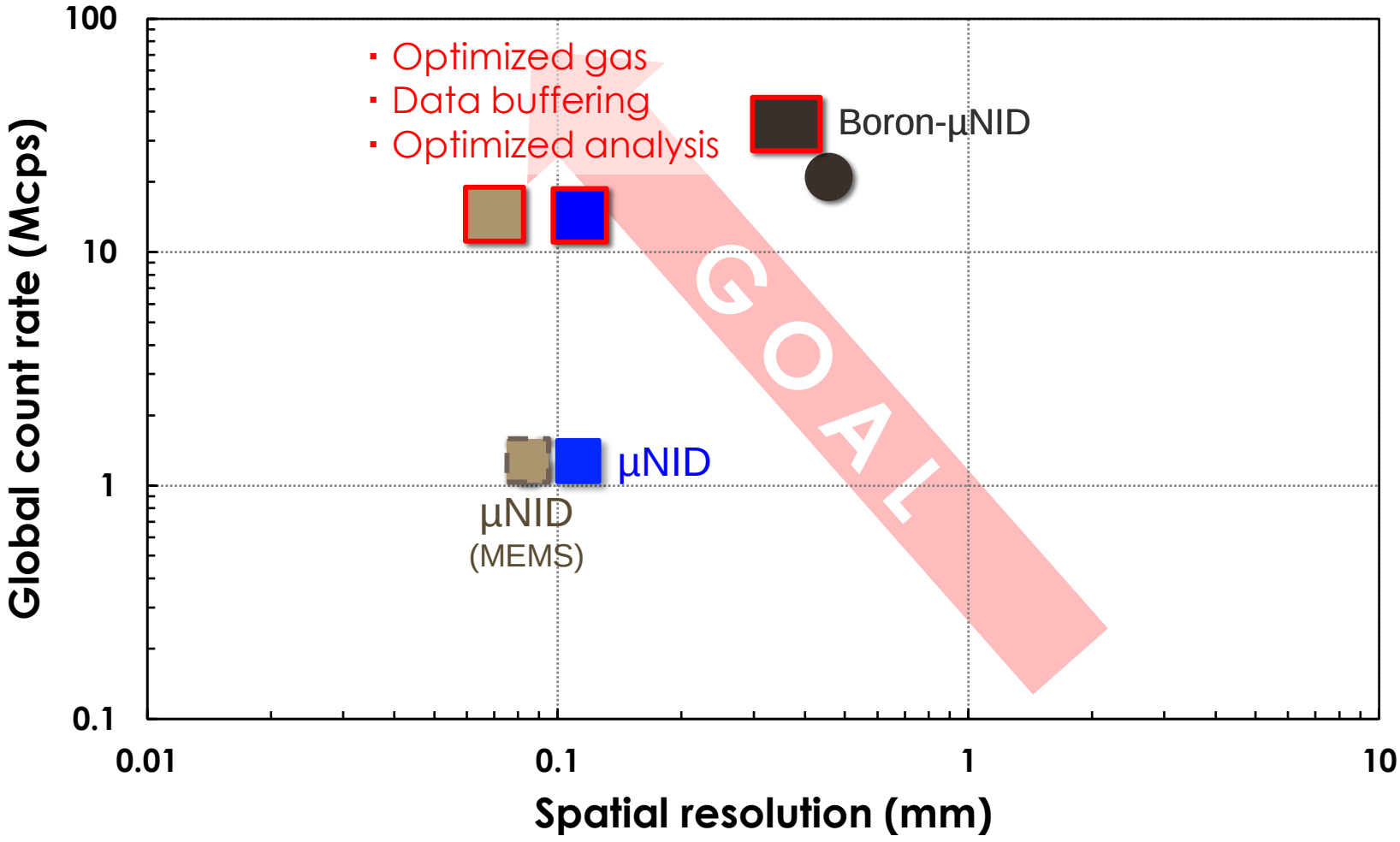
Next:

- Preparing dedicated Boron-μNID system
- Optimize gas for shorter track lengths
- Design new converter for increased efficiency

# Performance of the μNID at RADEN



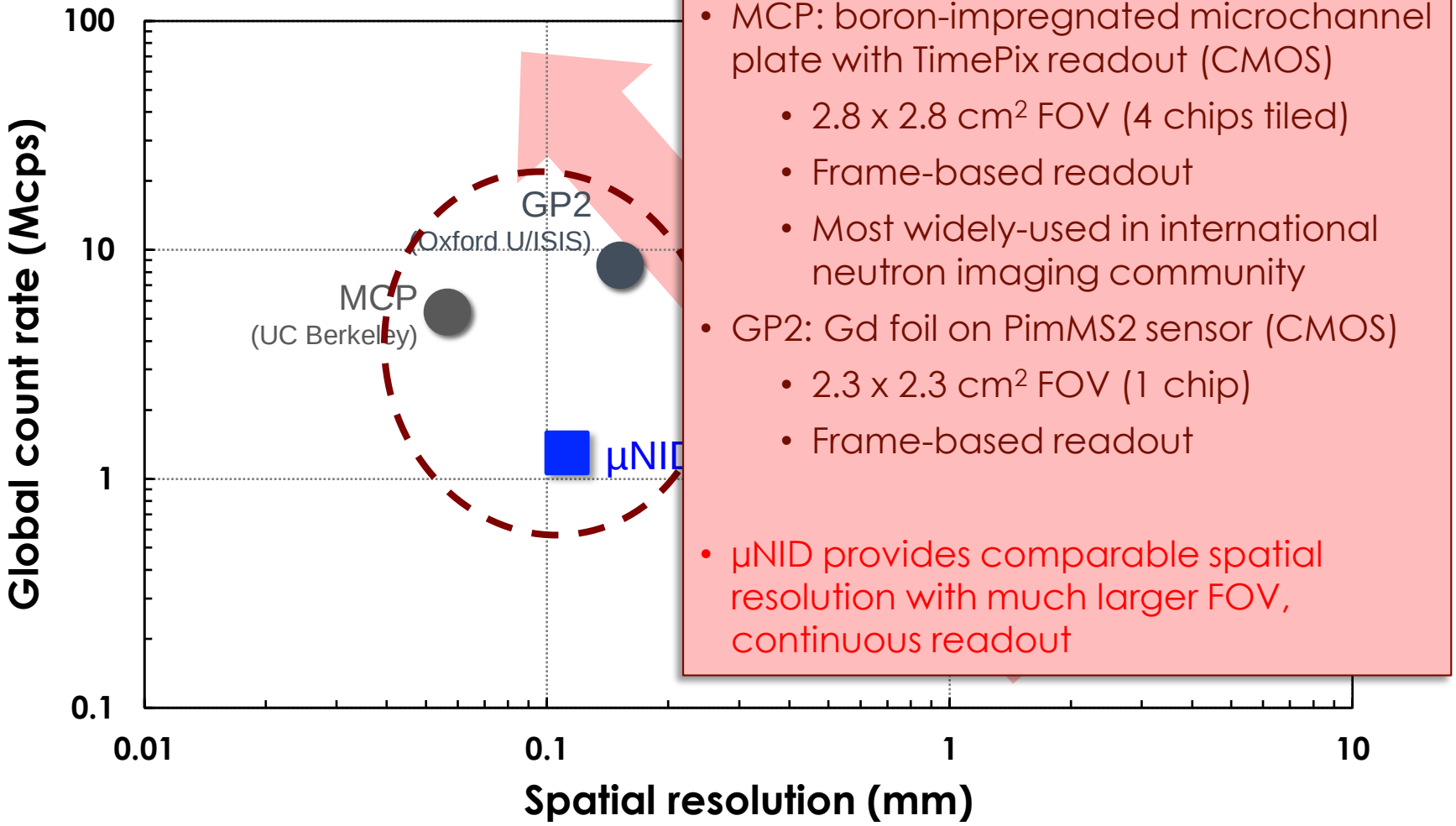
# Current and projected performance of the μNID at RADEN



# μNID beyond RADEN

- Forward detector for SANS at MLF BL15/TAIKAN
- Interest from pulsed neutron imaging beamlines at facilities from abroad

# Performance of various neutron imaging detectors

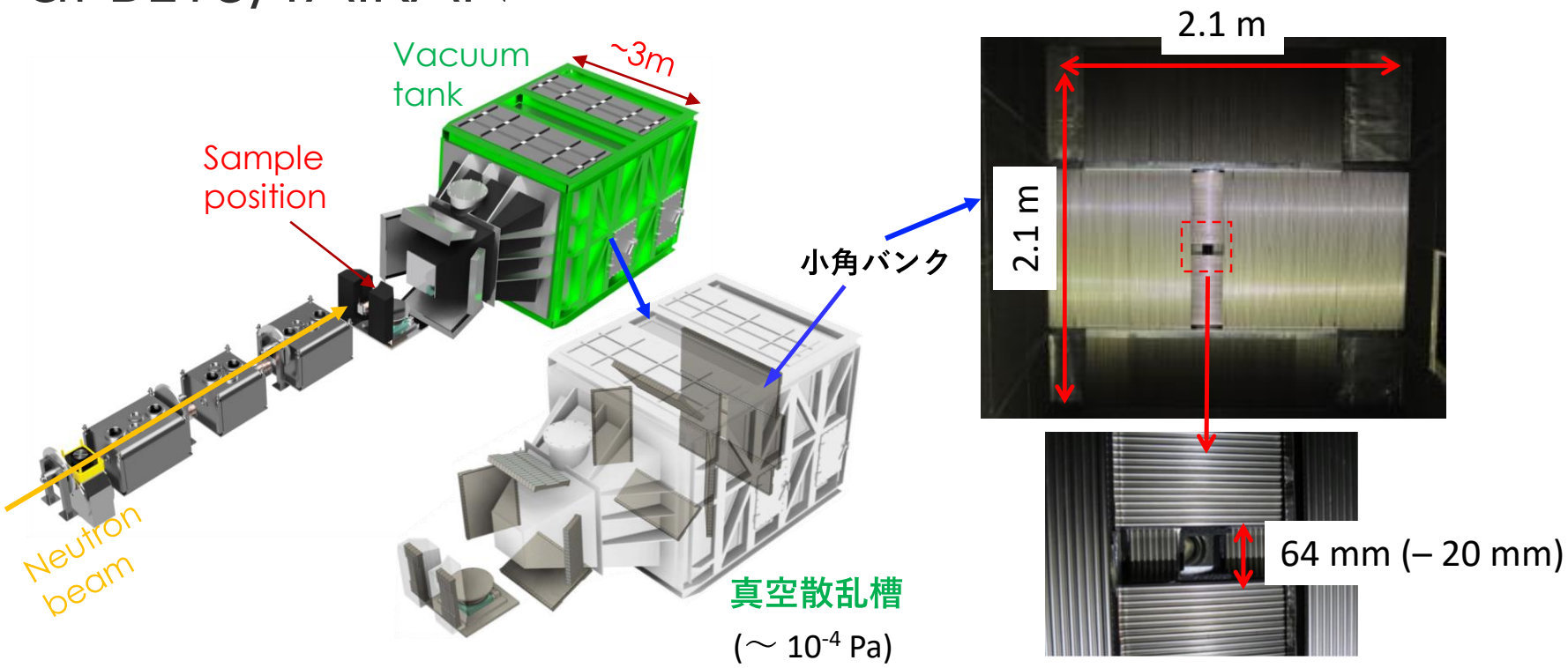



**µNID vs MCP/GP2**

- MCP: boron-impregnated microchannel plate with TimePix readout (CMOS)
  - 2.8 x 2.8 $cm^2$ FOV (4 chips tiled)
  - Frame-based readout
  - Most widely-used in international neutron imaging community
- GP2: Gd foil on PimMS2 sensor (CMOS)
  - 2.3 x 2.3 $cm^2$ FOV (1 chip)
  - Frame-based readout

- µNID provides comparable spatial resolution with much larger FOV, continuous readout

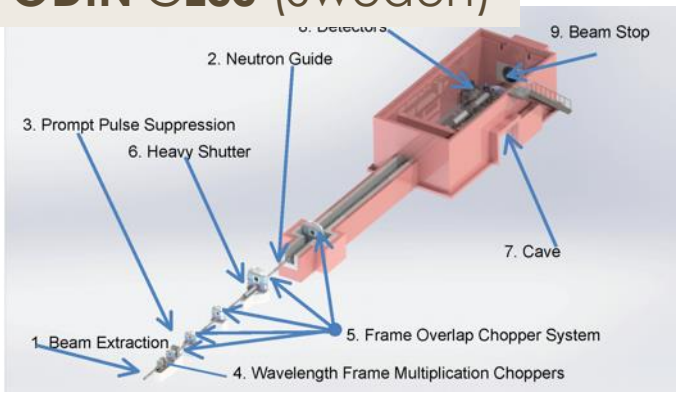
# μNID for small-angle neutron scattering (SANS) at BL15/TAIKAN




- Fine spatial resolution of μNID to measure very small-angle scattering
- Detector must be adapted for use in vacuum; may need to optimize detector design for reduced background
- SANS test at BL22 on 12/18; dedicated SANS detector next fiscal year

# μNID at international facilities

**ODIN @ESS** (Sweden)



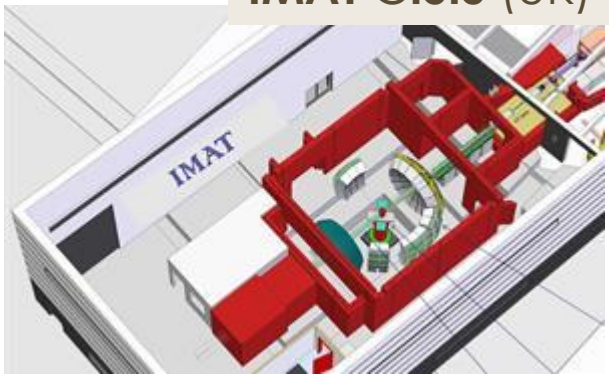

ESS under construction
User operation from 2023

**VENUS @SNS** (USA)

VENUS started construction

- Interest from other current and upcoming pulsed neutron imaging beam lines
- Test at ESS/ODIN test beam line, located at Helmholtz Zentrum Berlin, carried out in July 2019

**IMAT @ISIS** (UK)




In operation since 2018

# Summary

- Development of the μNID at RADEN is ongoing and its usage is steadily increasing
- Continuing development of standard μNID for improved rate performance, ease-of-use
- New μNID development
  - Promising test of small-pitch μPIC on glass substrate → prepare larger-area test element
  - Confirmed operation of μNID with boron converter → prepare dedicated Boron-μNID detector system
- μNID receiving significant interest from other pulsed neutron imaging facilities around the world
  - Carried out detector test at ESS/ODIN test beamline at HZB in July 2019