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

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MPGD16 & ActiveTPC3合同研究会　RIKEN　7 December 2019

RADEN and μNID development members

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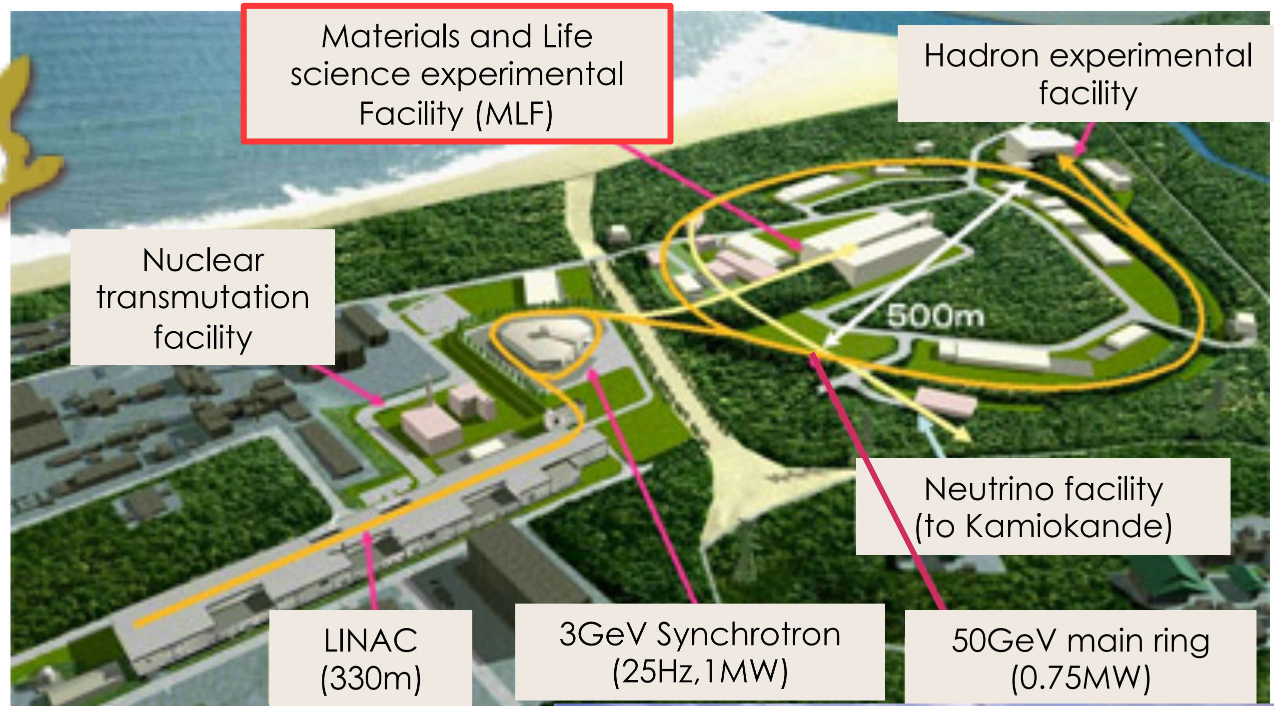
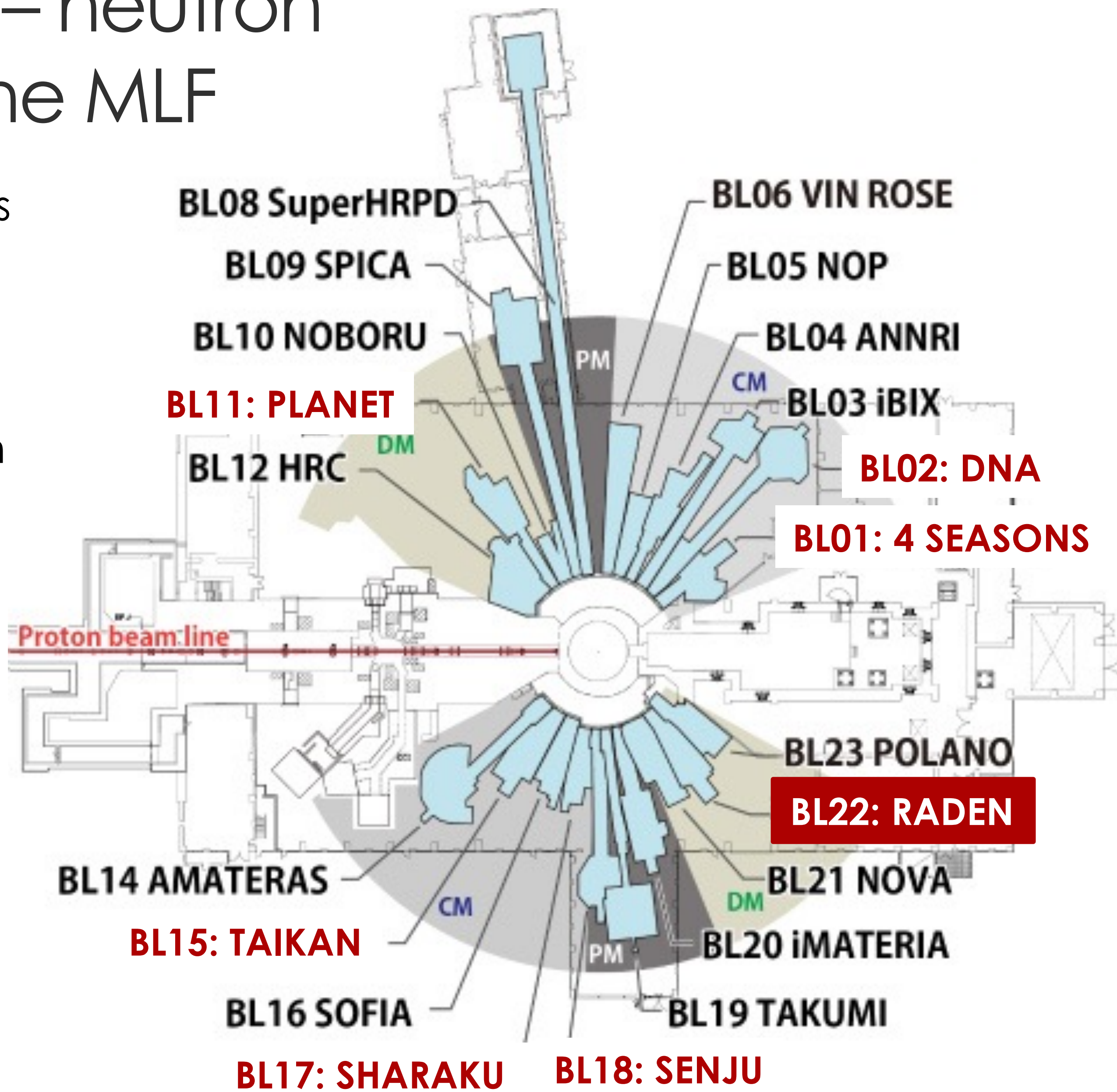
J-PARC (Japan Proton Accelerator Research Complex)



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

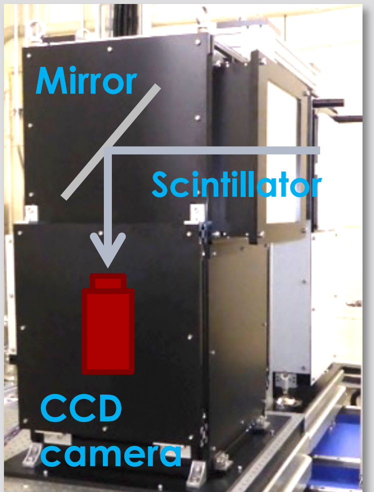
BL22/RADEN – neutron imaging at the MLF

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



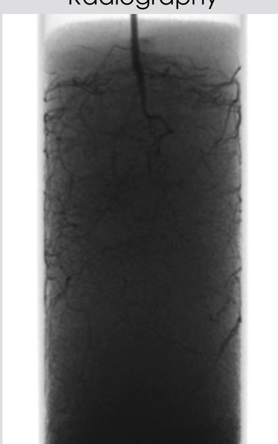
Neutron imaging at RADEN

Conventional



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

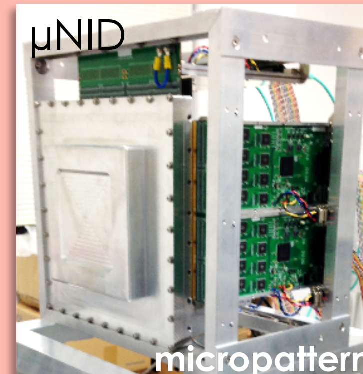
Radiography



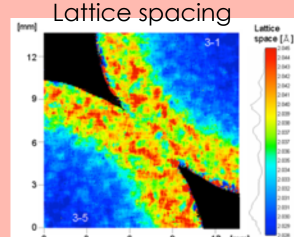
Sample: Roots of soybean plant (Nakazono, Nagoya U.)

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



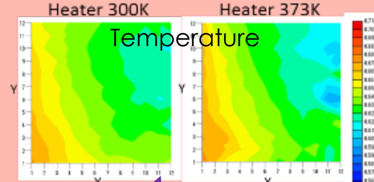
Lattice spacing



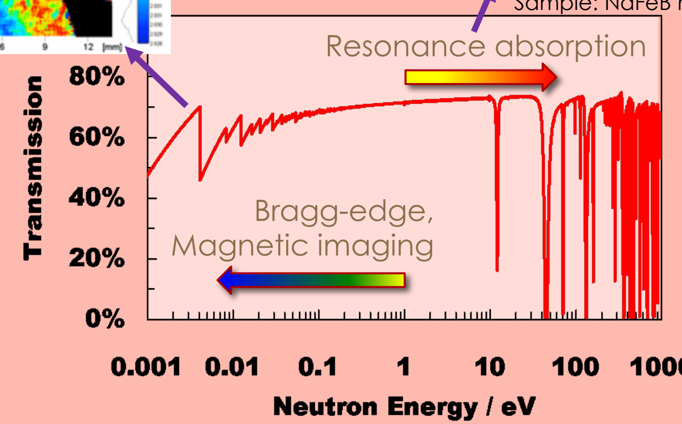
Sample: Iron rods

Heater 300K Heater 373K

Temperature

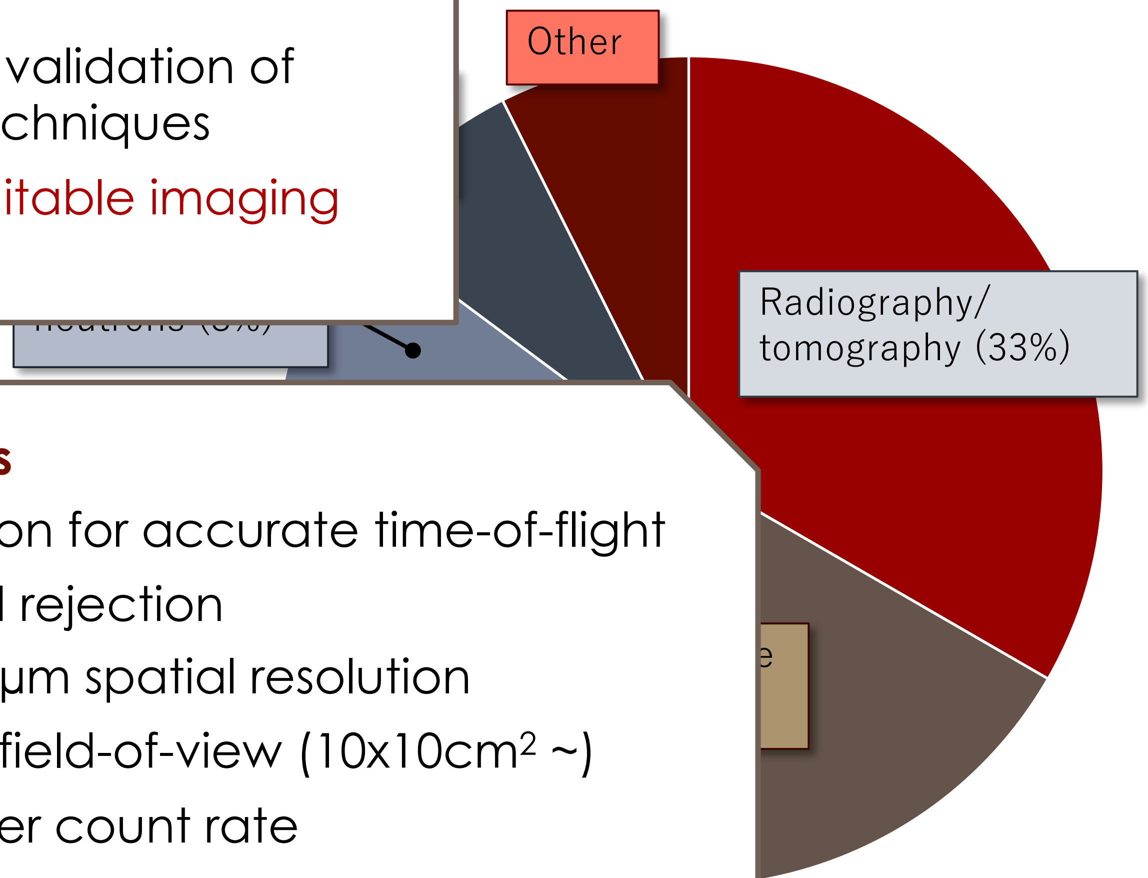


Sample: NdFeB magnet



Beam-time utilization at RADEN

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

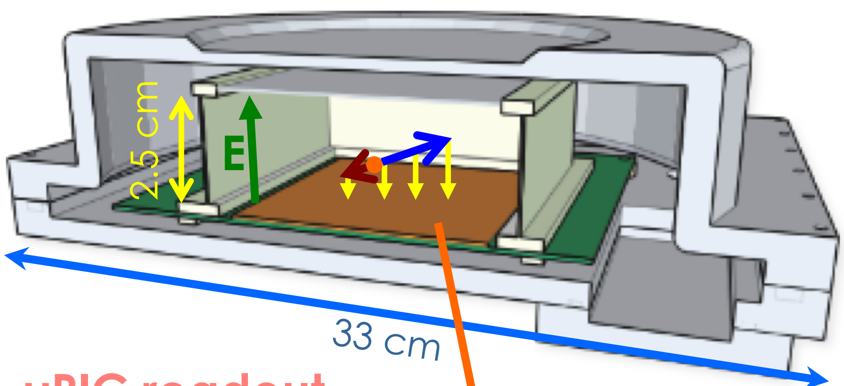
- Sub-μs time resolution for accurate time-of-flight
- Strong background rejection
- Sub-mm to sub-100μm spatial resolution
- Moderate to large field-of-view (10x10cm^2 ~)
- Mcps-order or higher count rate

µPIC-based neutron imaging detector (µNID)

μPIC-based neutron imaging detector (μNID)

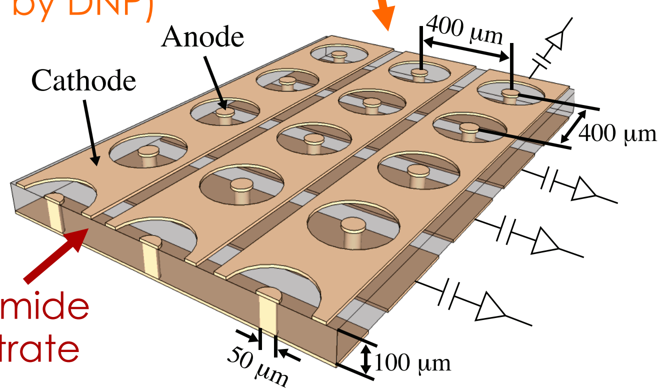
Neutron detection via n + ^{3}He → p + t

Overall track length ~4 mm in gas



μPIC readout

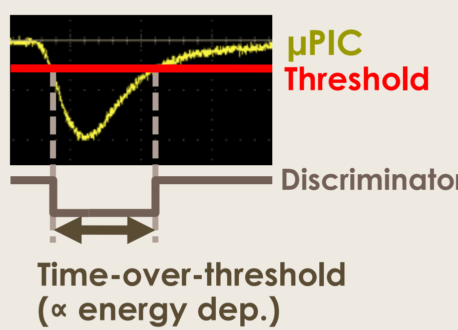
10 cm x 10 cm area,
400 μm pitch x,y strips
(Mfd. by DNP)

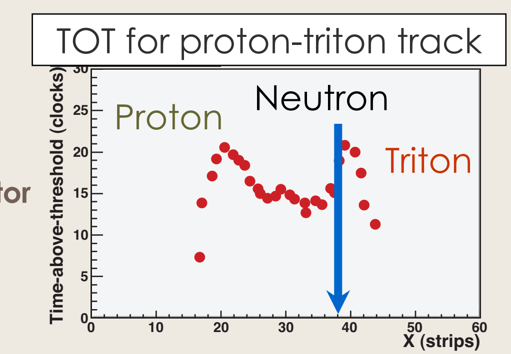


Polyimide substrate

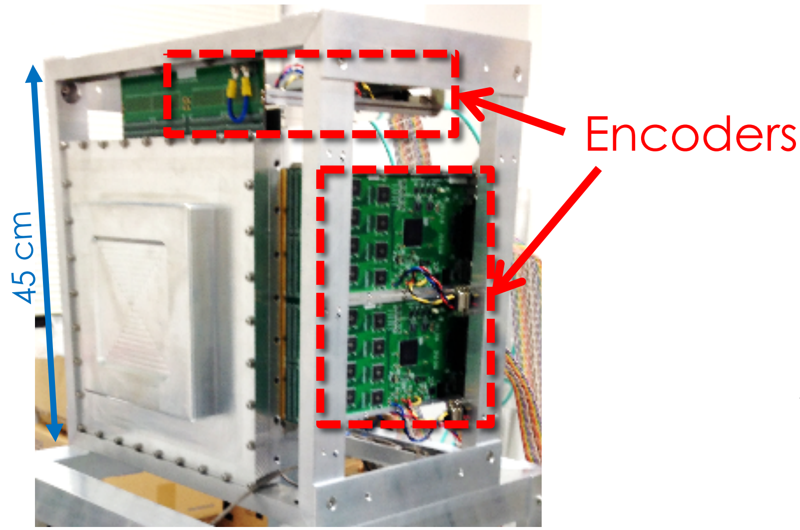
- Gaseous time-projection-chamber
  - CF_4-iC_4H_{10}-^{3}He (45:5:50) at 2 atm
  - μPIC micropattern readout
  - Compact ASIC+FPGA data encoder front-end
- 3-dimensional tracking (2D position + time) with time-over-threshold
  - Accurate position reconstruction
  - Strong gamma rejection

Digital encoder with time-over-threshold (TOT)

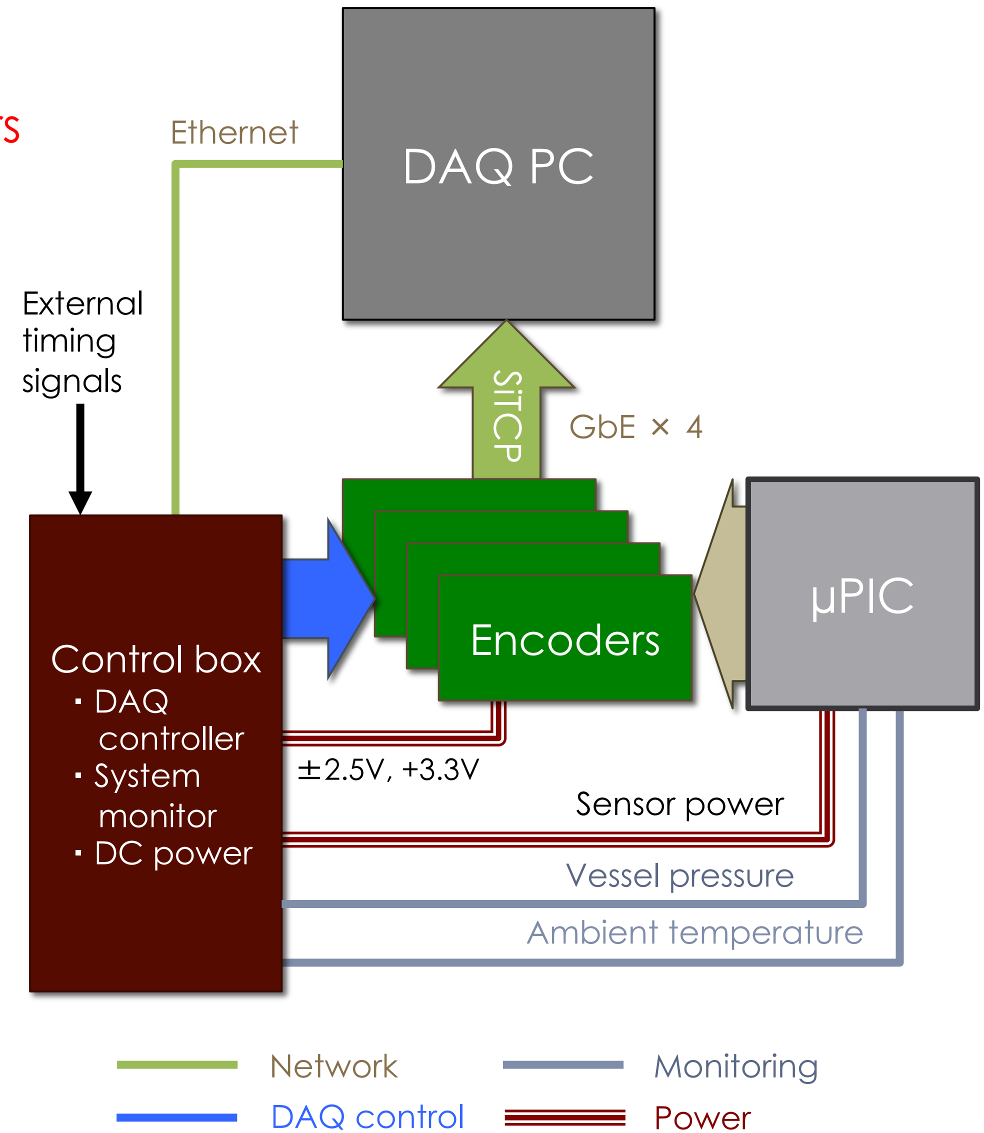




μPIC-based neutron imaging detector (μNID)



- 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)



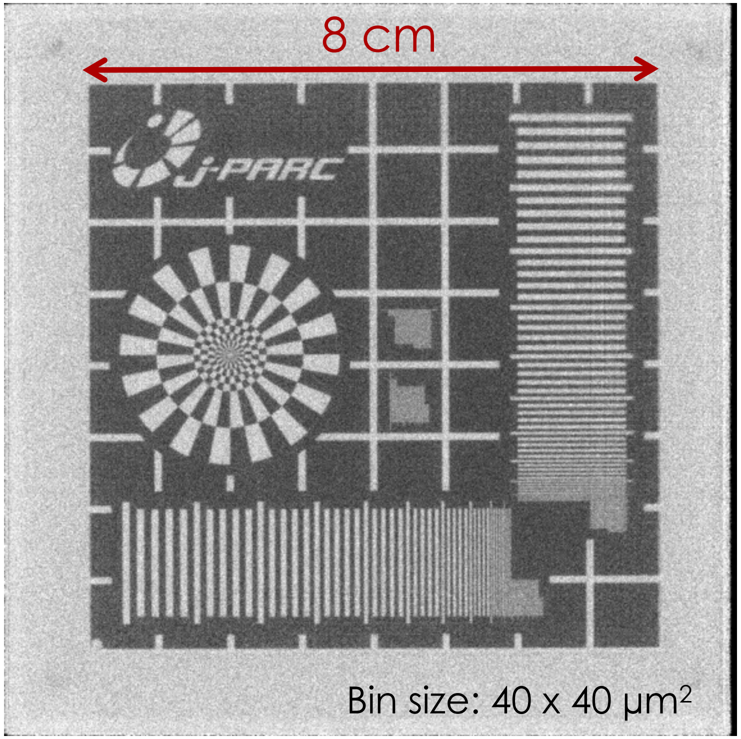
μNID performance and usage at RADEN

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

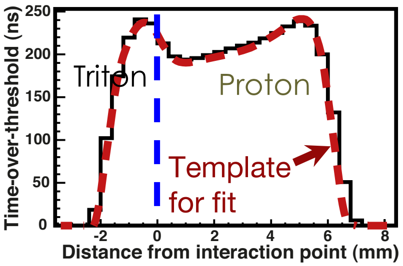
Usage at RADEN	2018A	2019A
μNID	34 days	30 days
Other event-type	36 days	25 days

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

Image of Gd test target



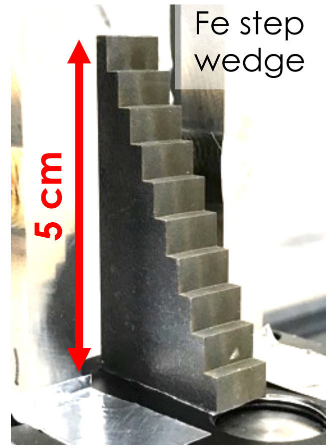
Fine spatial resolution using template fit to TOT distribution

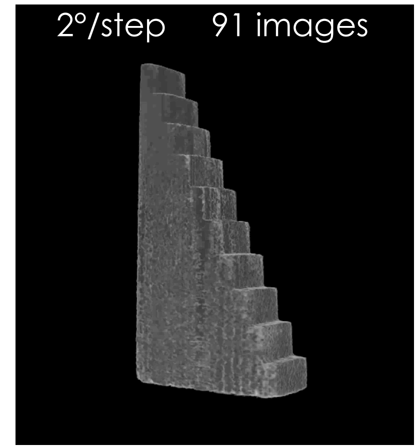


Automated measurements

- 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

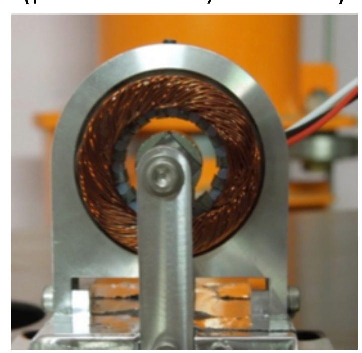
Computed tomography (CT)

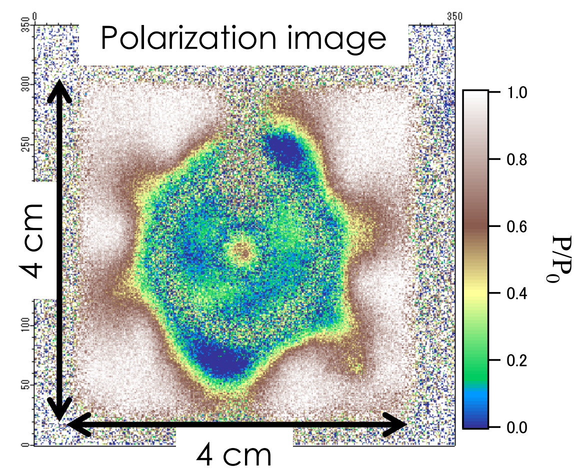




Magnetic imaging of running motor

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)

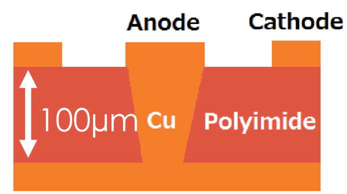
New μNID development

- Small-pitch MEMS μPIC
- μNID with Boron converter

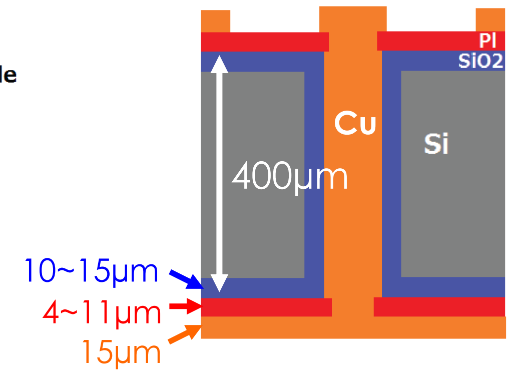
215μm-pitch MEMS μPIC for improved spatial resolution

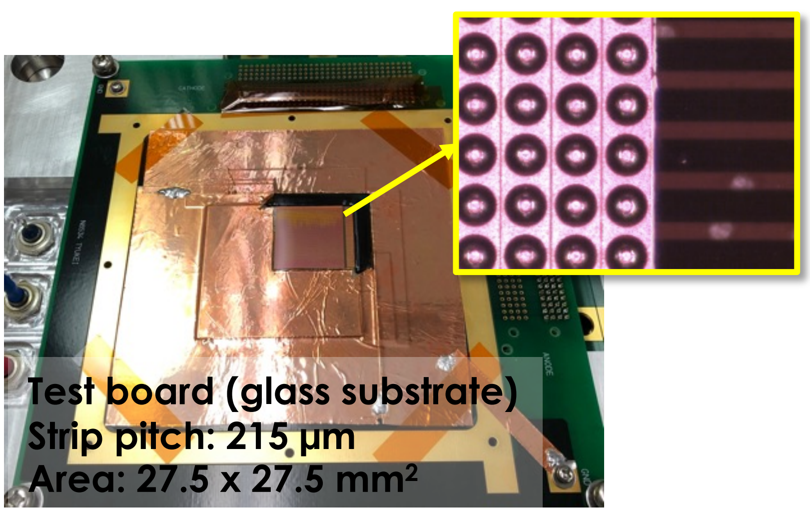
- 215μm pitch μPIC on silicon, glass substrates using MEMS manufacturing (DNP)
- Gain stability measured at RADEN
  - Silicon shows poor stability
  - Glass similar to PCB μPIC

Current PCB μPIC (400 μm pitch)

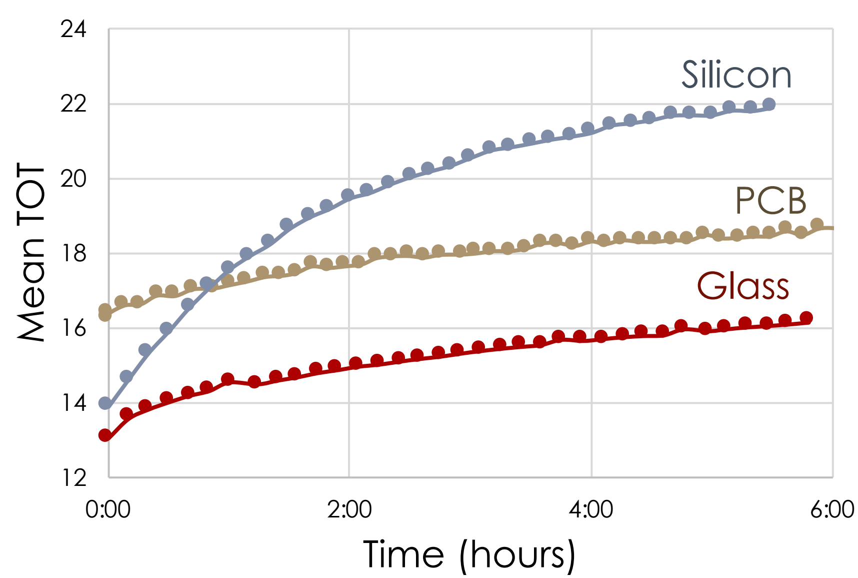


MEMS μPIC



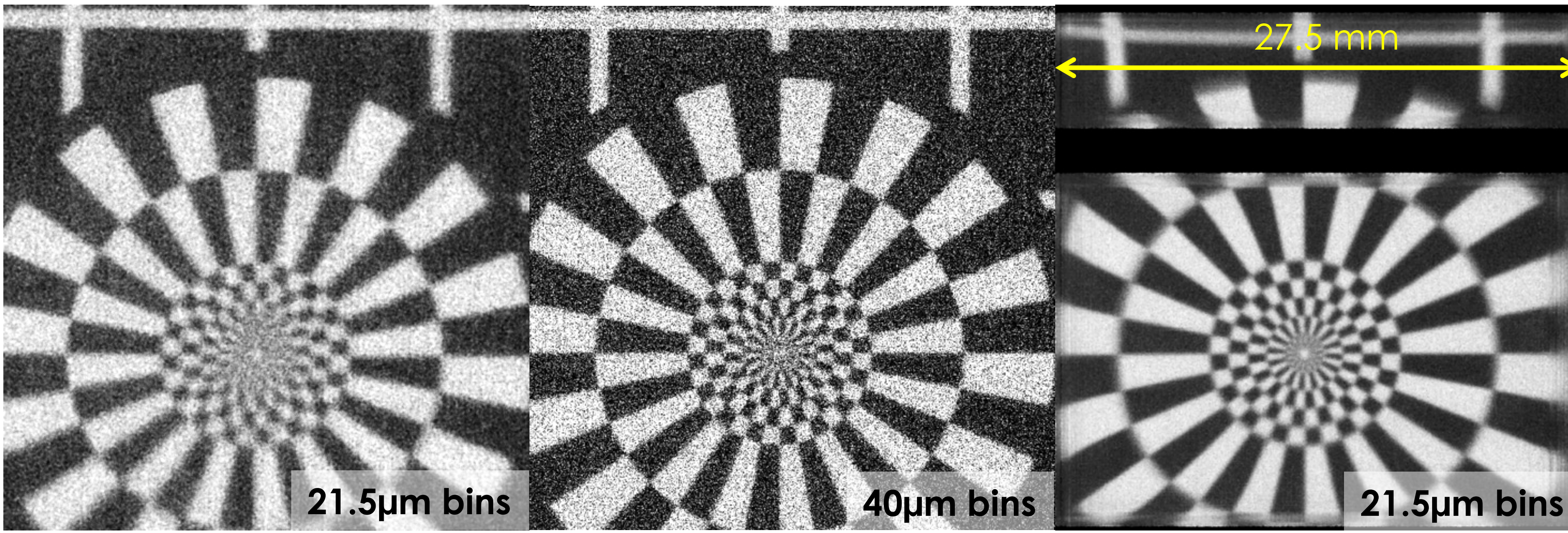


μPIC gain stability at RADEN



Imaging with the 215μm MEMS μPICs

215μm pitch Silicon substrate	400μm pitch PCB μPIC	215μm pitch Glass substrate

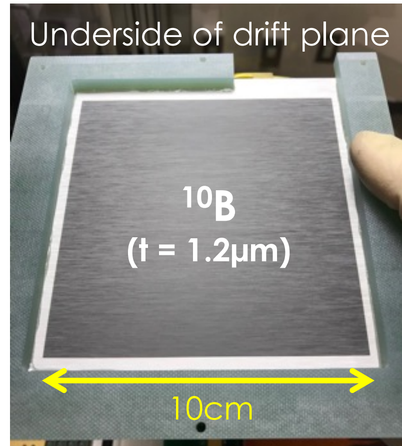


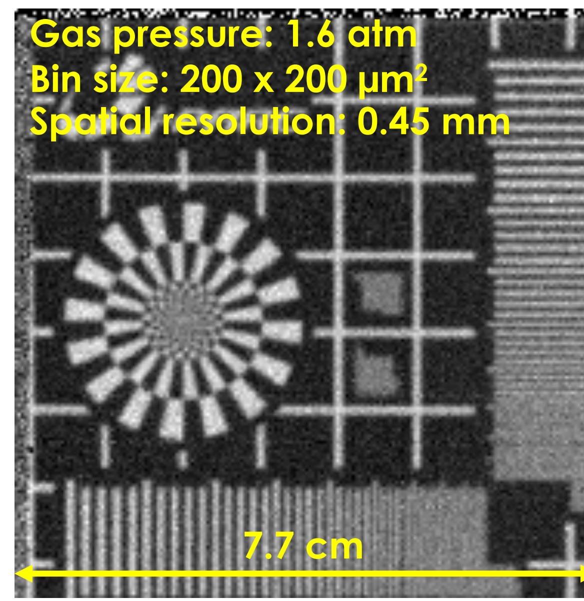
- Image quality for glass substrate looks good
- Resolution appears to be improved compared to PCB μPIC

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 → <u>low efficiency</u> (3~5%)





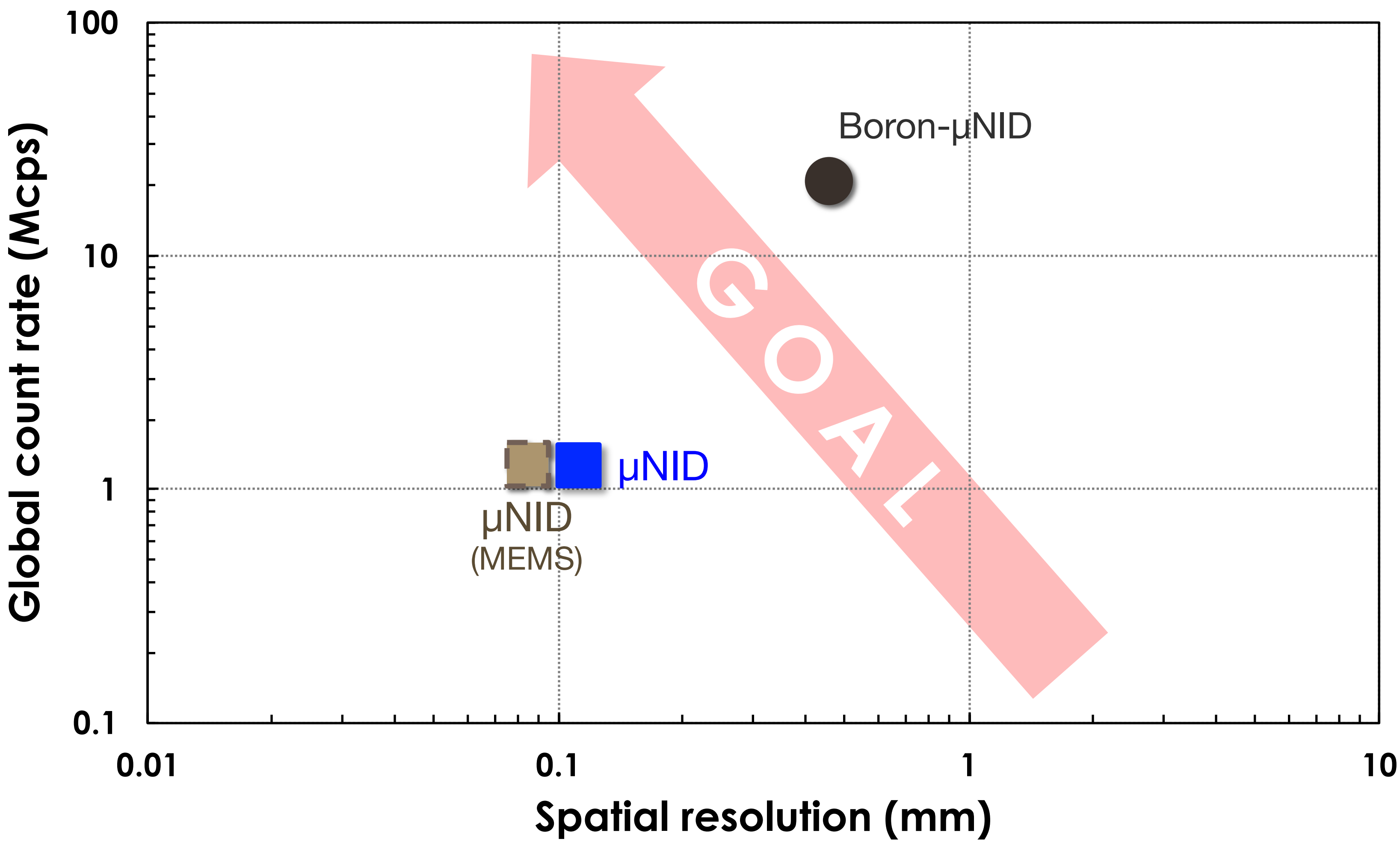
Initial testing at RADEN

- Maximum count rate of 22 Mcps <u>confirmed</u>
- Spatial resolution of 0.45 mm <u>confirmed</u>

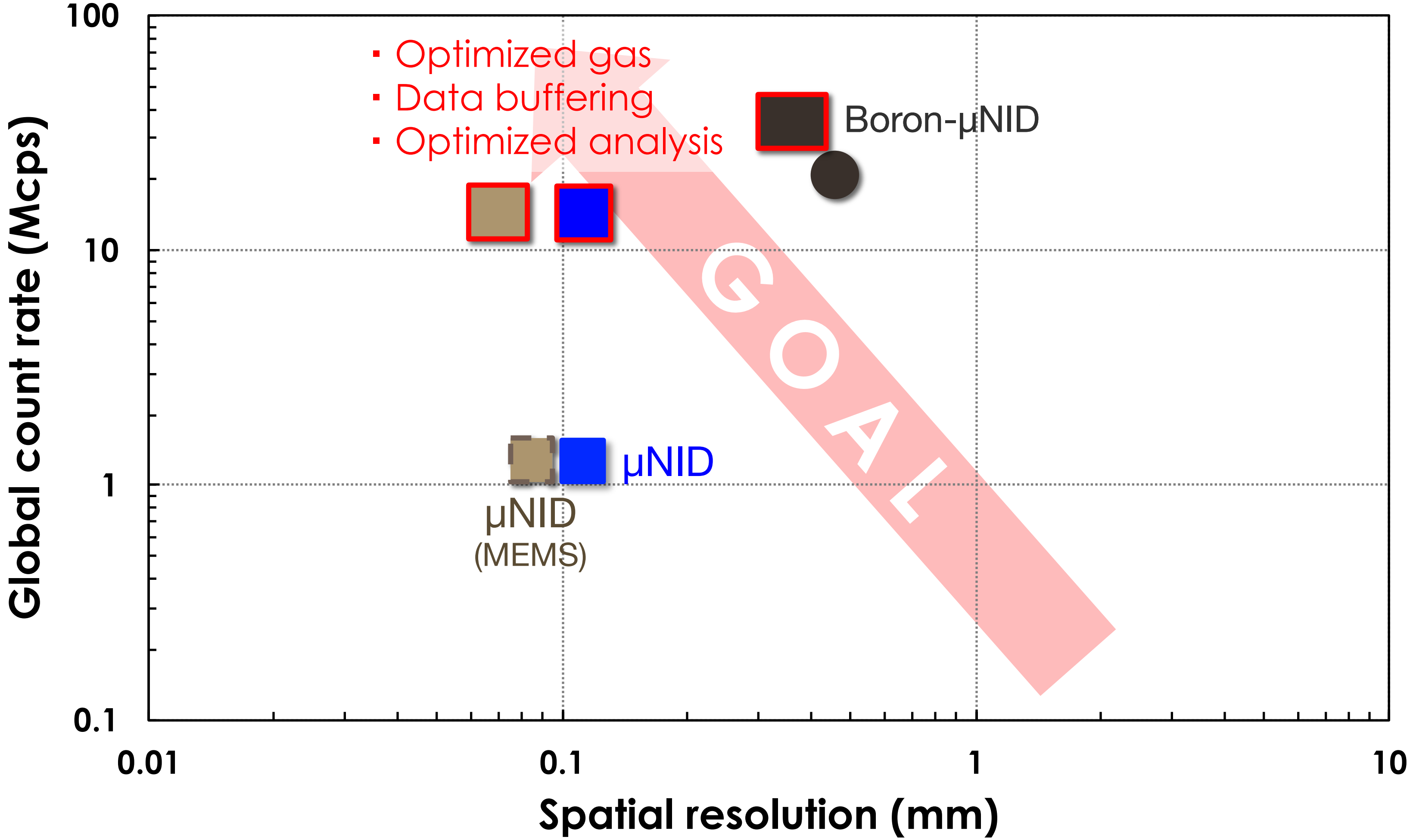
Next:

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

Performance of the μNID at RADEN



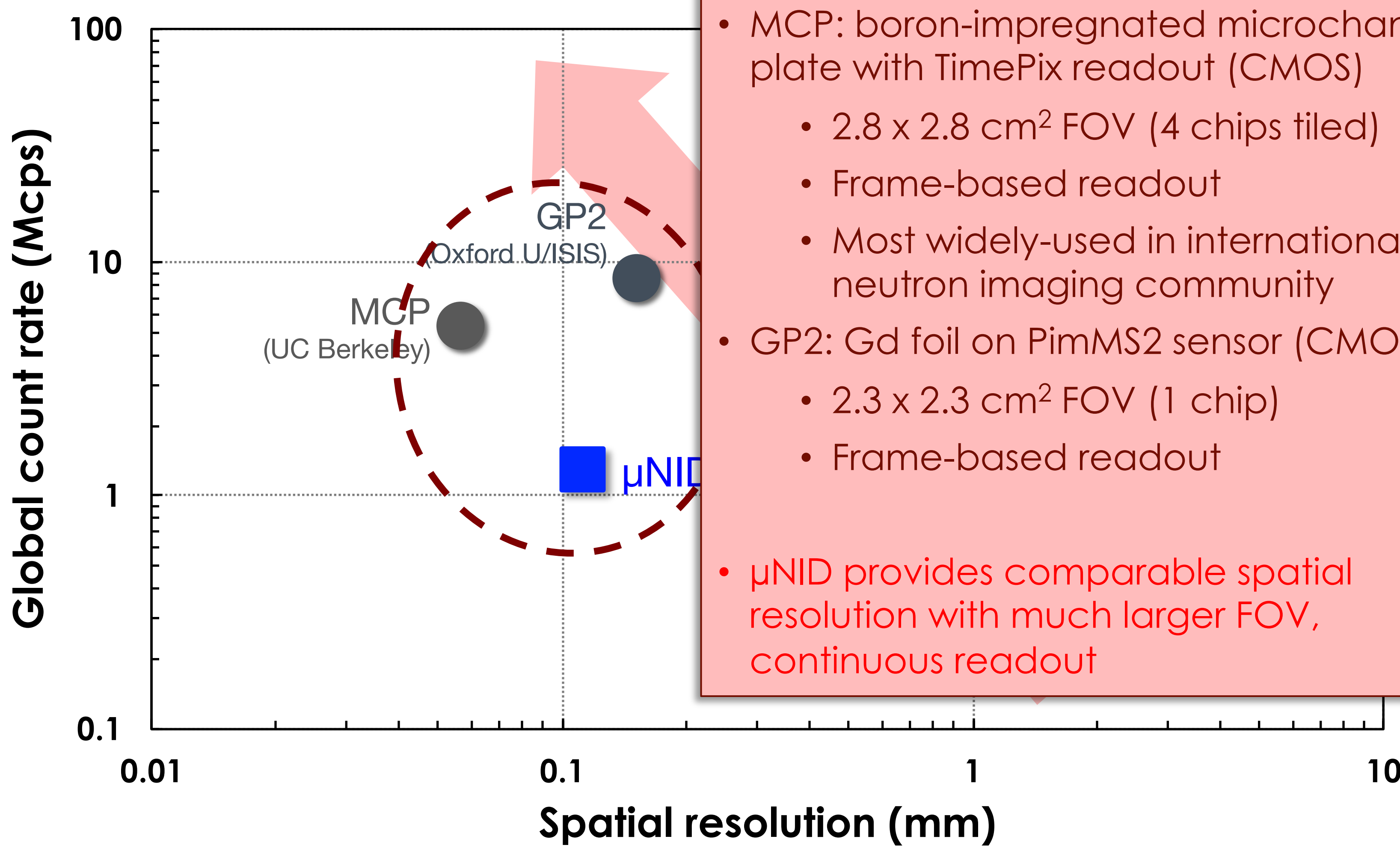
Current and projected performance of the μNID at RADEN



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

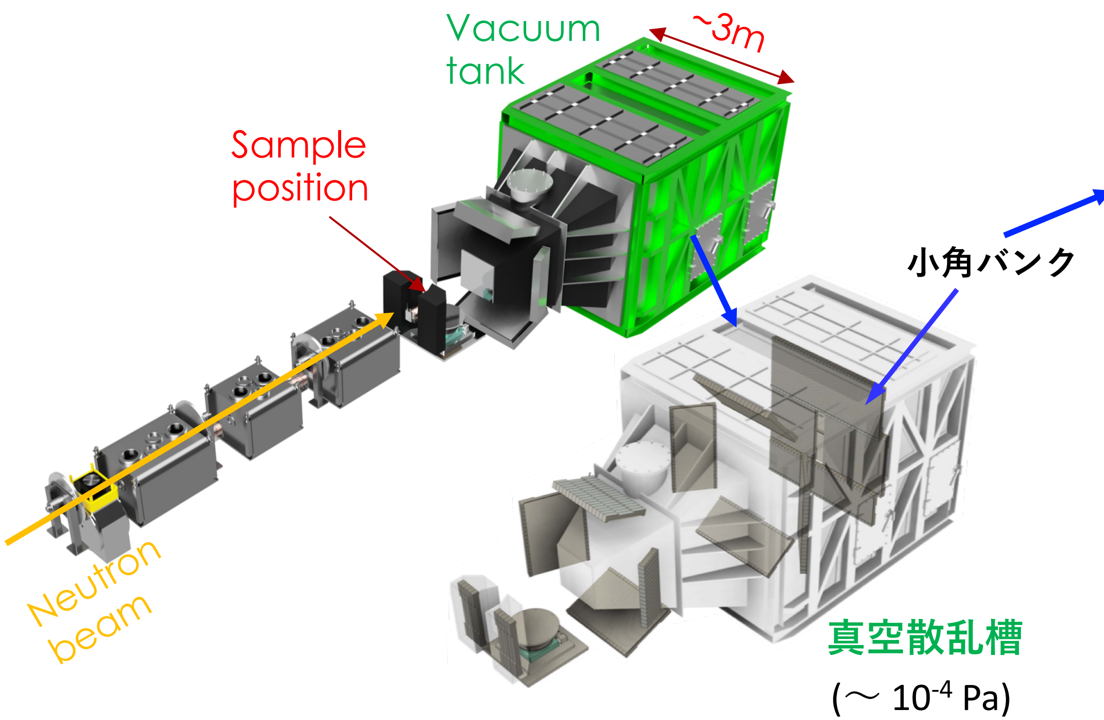


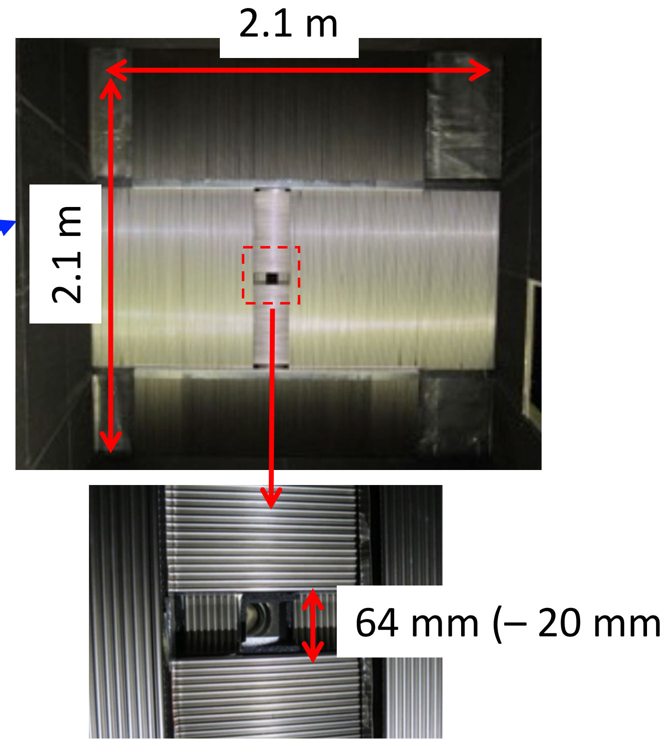
μNID vs MCP/GP2

- 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

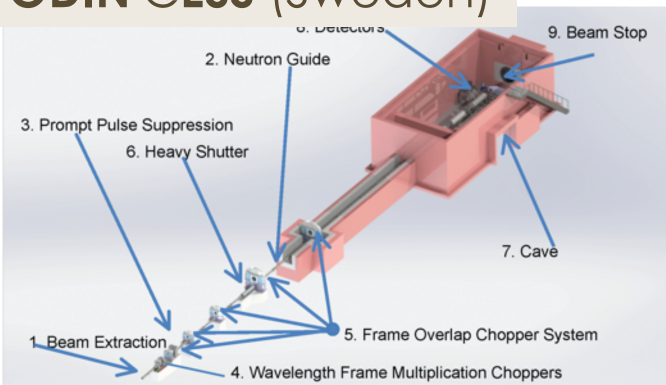




- Fine spatial resolution of μNID to measure very small-angle scattering
- Detector must be adapted for use in vacuum; may need to optimize detector design for reduced background
- SANS test at BL22 on 12/18; dedicated SANS detector next fiscal year

μNID at international facilities

ODIN @ESS (Sweden)

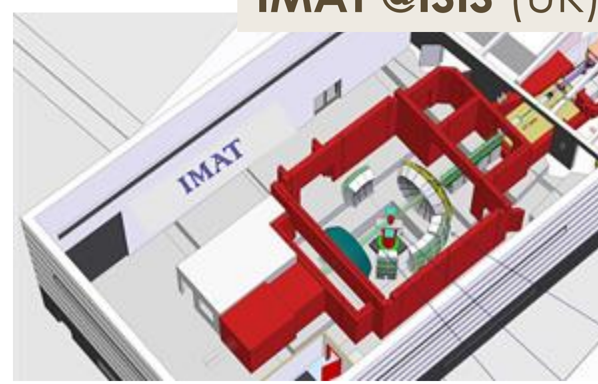


ESS under construction
User operation from 2023

VENUS @SNS (USA)

VENUS started construction

IMAT @ISIS (UK)



In operation since 2018

- 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

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