螺鈿における
計数型イメージング検出器開発の現状

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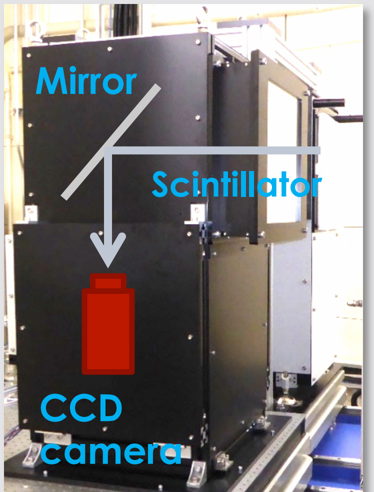
CROSS

平成30年度中性子イメージング専門研究会　京都大学複合原子力科学研究所　27 December 2018

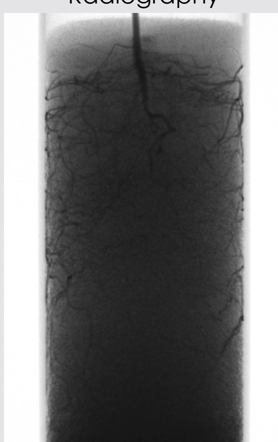
Neutron imaging at RADEN

Conventional



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

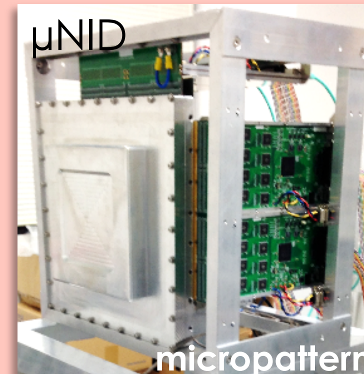
Radiography



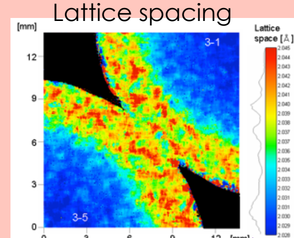
Sample: Roots of soybean plant (Nakazono, Nagoya U.)

Energy-resolved

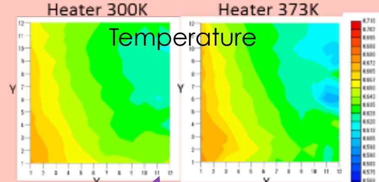
- Event-type detectors: sub-mm spatial and sub-μs time resolutions, neutron energy via TOF
- Energy-dependent neutron transmission: macroscopic distribution of microscopic quantities



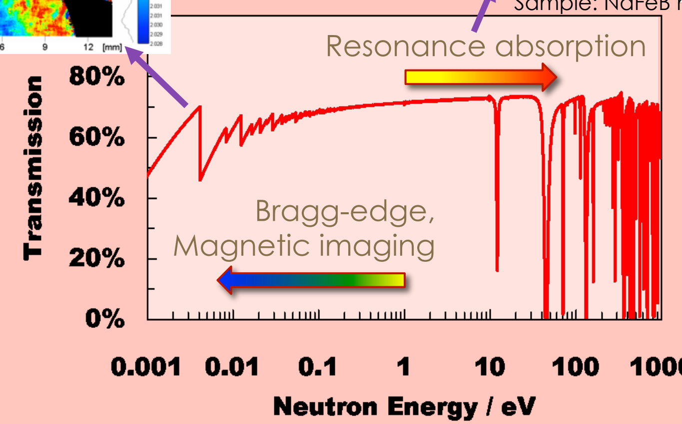
Lattice spacing



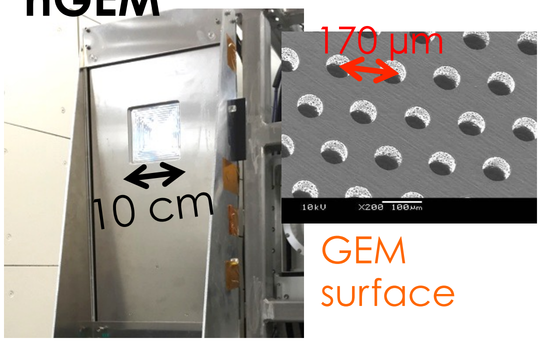
Sample: Iron rods

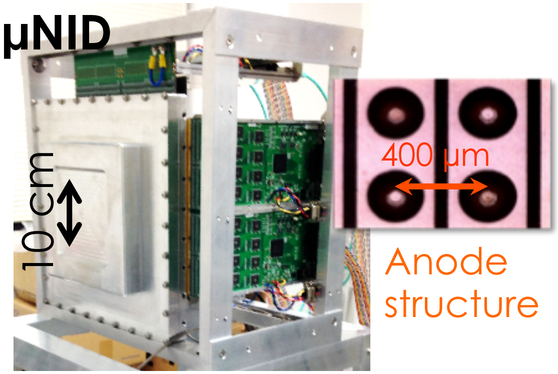


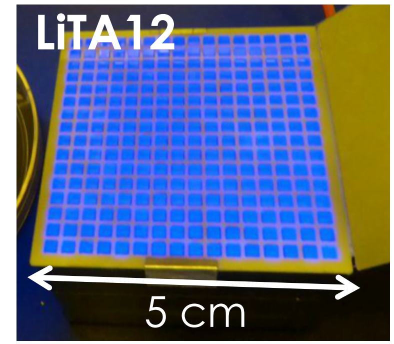
Sample: NdFeB magnet



Event-type detectors at RADEN

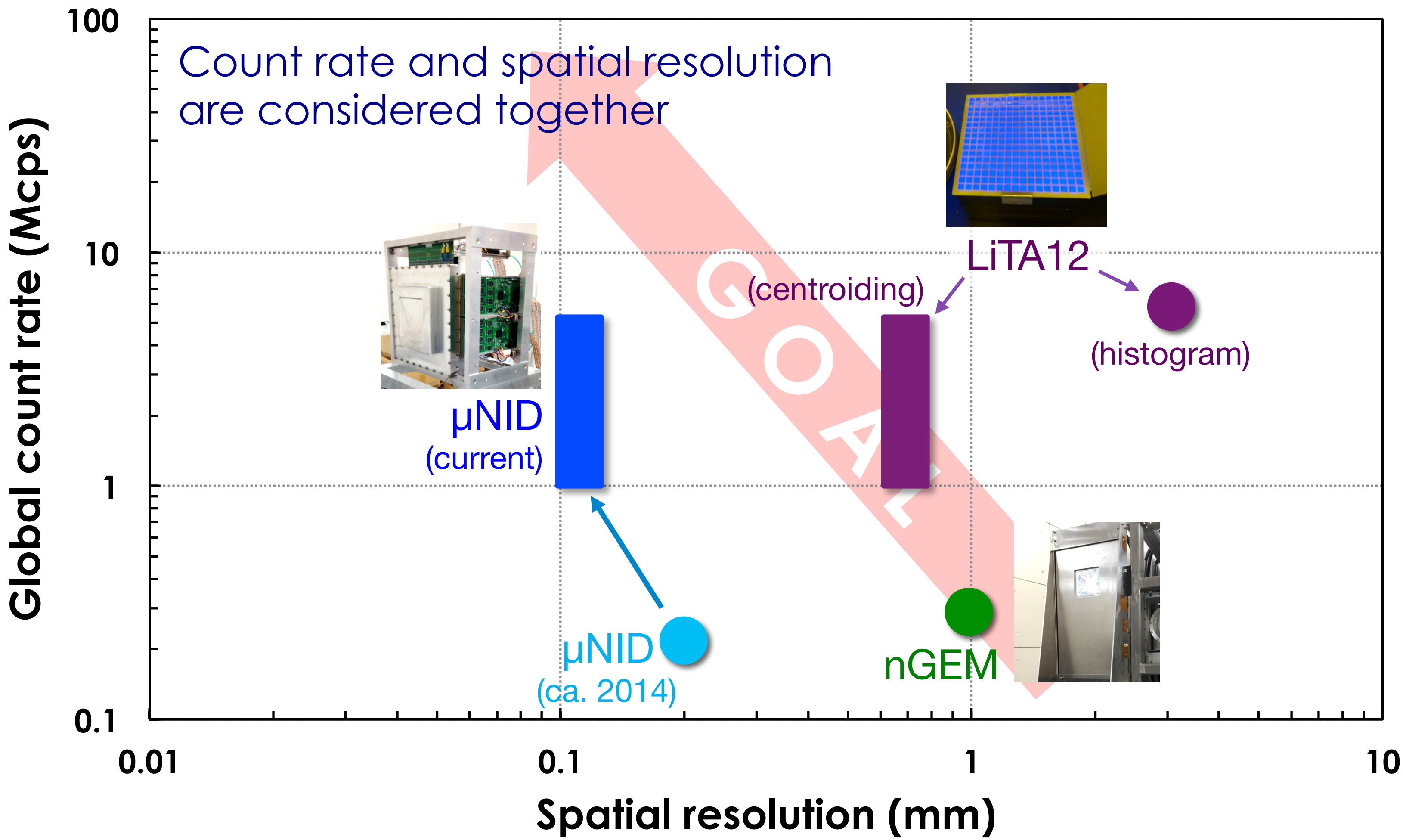




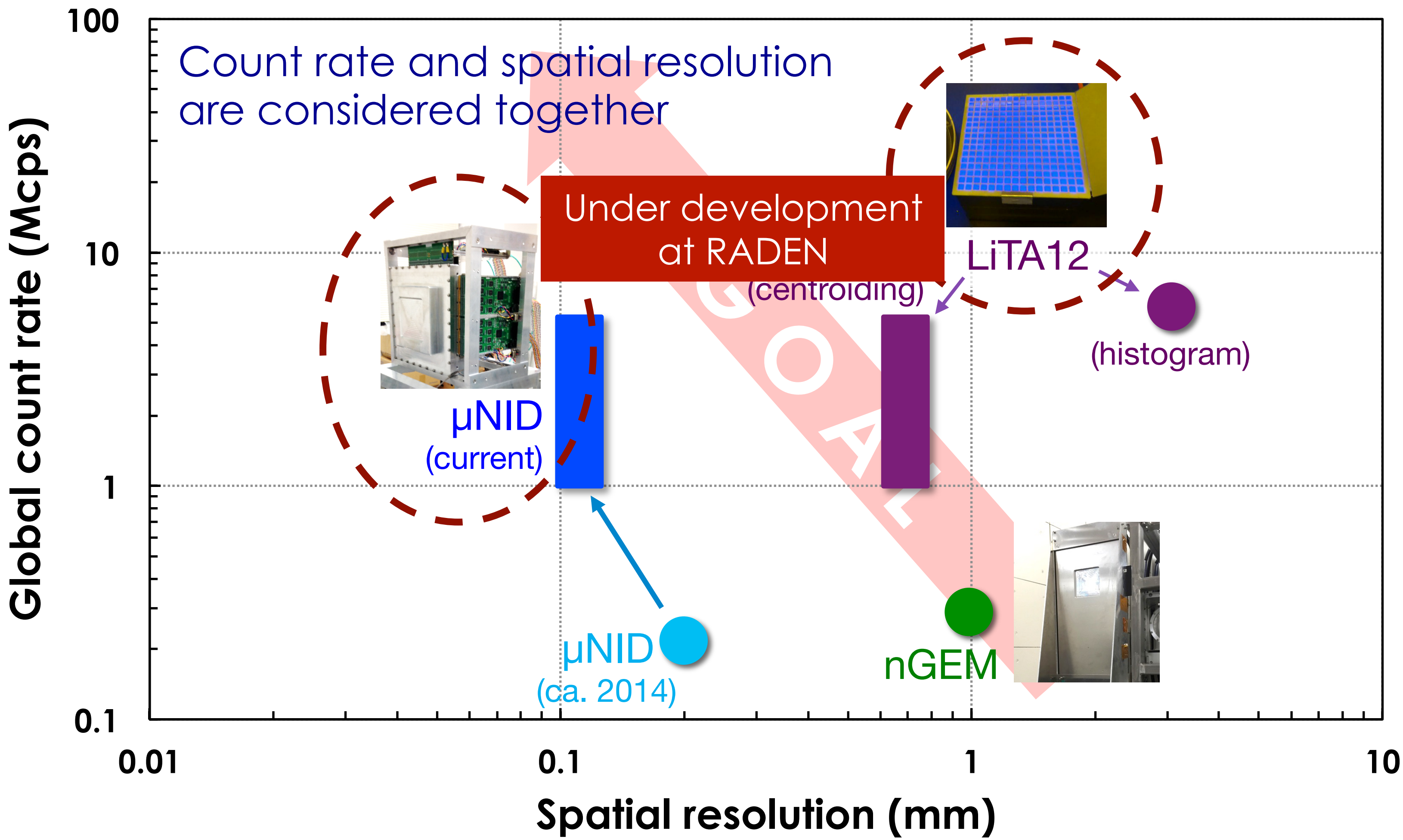


	nGEM	μNID	LiTA12
Detector type	Micropattern	Micropattern	Scintillator
Converter material	^{10}B	^{3}He	^{6}Li
Active area	10 cm x 10 cm	10 cm x 10 cm	5 cm x 5 cm
Spatial resolution	1 mm	0.1 mm	3 mm/0.7 mm
Time resolution	10 ns	250 ns	40 ns
Efficiency (thermal)	10%	26%	23%
Global peak count rate	0.2 Mcps	>1 Mcps	6 Mcps
Gamma sensitivity	10^{-4}	$< 10^{-12}$	low

Current performance of event-type detectors at RADEN



Current performance of event-type detectors at RADEN

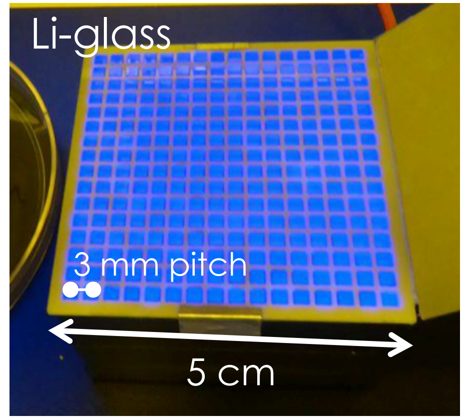


Development of counting-type detectors at RADEN

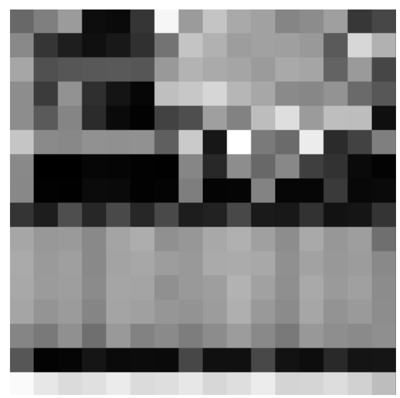
- Development of Li-glass detector
  - Improve spatial resolution using super resolution techniques
- Improvement of standard μNID
  - Optimization of analysis code, improved ease-of-use
  - Integration into RADEN control system
- New μNID development
  - Small-pitch MEMS μPIC for improved spatial resolution
  - μNID with boron converter for increased rate

LiTA12 with super resolution methods

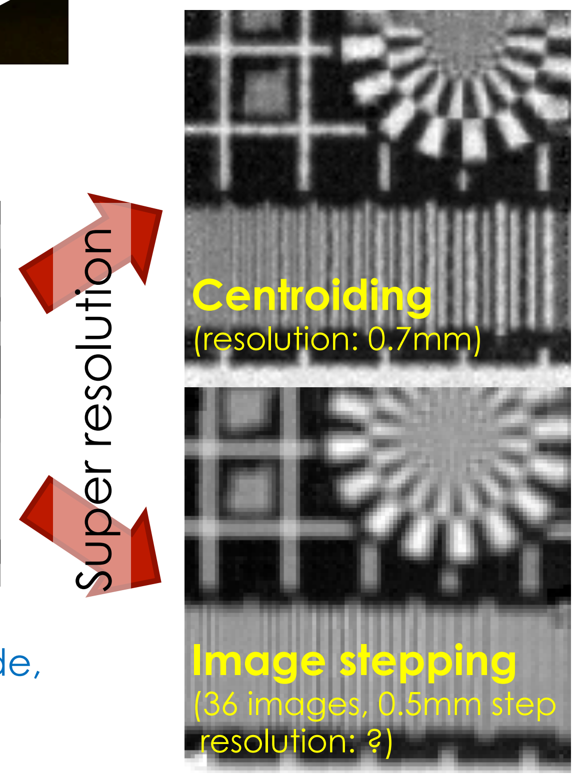
- Centroiding with single scintillator (T.Kai et al., Physica B, 2018)
  - Pixels replaced with 1mm thick plate, event mode
  - Spatial resolution improved to ~0.7 mm
- Image stepping
  - Pixels, histogram mode
  - Composite multiple images taken at sub-pixel shifts
  - Spatial resolution may be improved → Develop reconstruction procedure



Area	5 cm x 5 cm
Spatial res.	3 mm
Time res.	40 ns ~
Eff. (thermal)	23%
Count rate	6 Mcps



Gd test chart
(pixel, histogram mode, resolution: 3mm)



- New FPGA boards for event readout mode
- Data analysis software, integrated control software now in preparation

Development of counting-type detectors at RADEN

- Development of Li-glass detector
  - Improve spatial resolution using super resolution techniques
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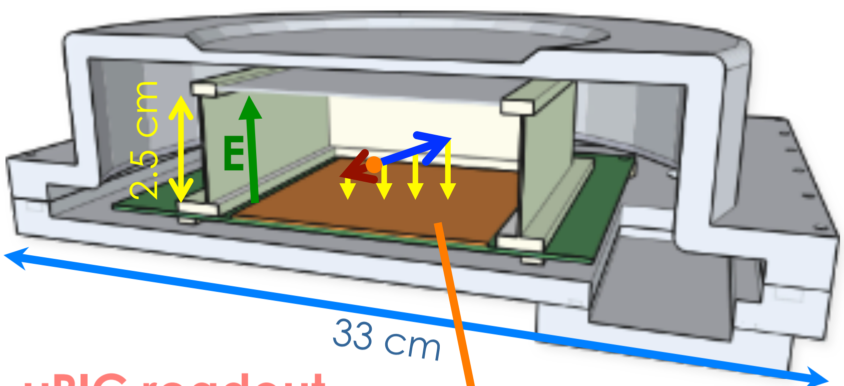
µPIC-based neutron imaging detector (µNID)

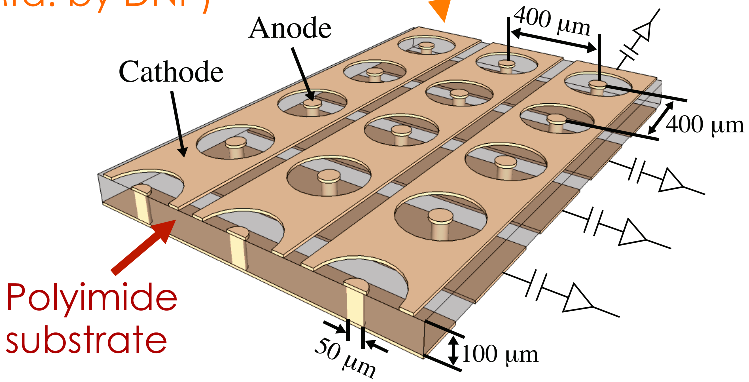
Neutron detection via n + ^{3}He → p + t

Overall track length ~4 mm in gas



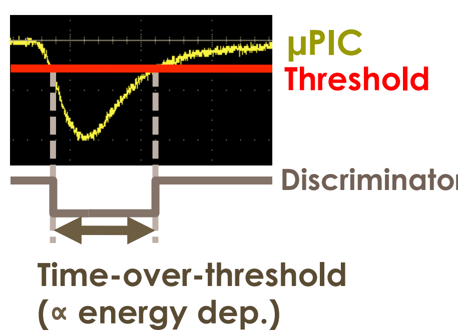
µPIC readout

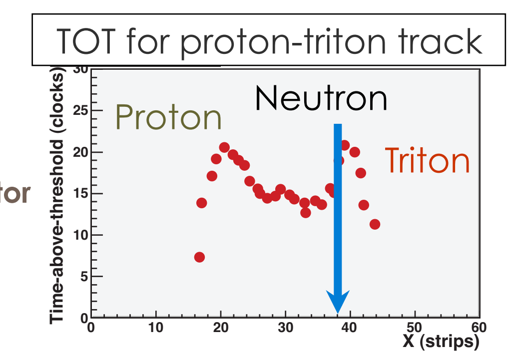
10 cm x 10 cm area,
400 µm pitch x,y strips
(Mfd. by DNP)



- 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 of decay pattern + time-over-threshold
  - Accurate position reconstruction
  - Strong gamma rejection

Digital encoder with time-over-threshold (TOT)





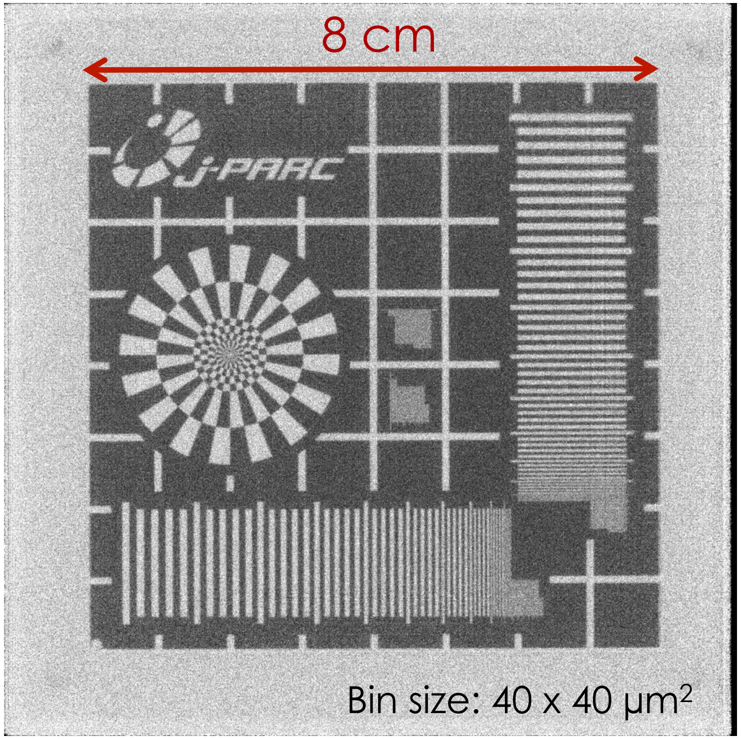
μNID performance and usage at RADEN

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

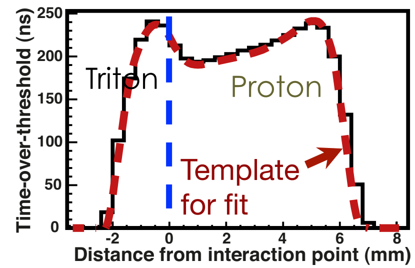
At RADEN, μNID used primarily for:

- Magnetic imaging with polarized neutrons
- Phase-contrast imaging
- Bragg-edge transmission imaging

Image of Gd test target

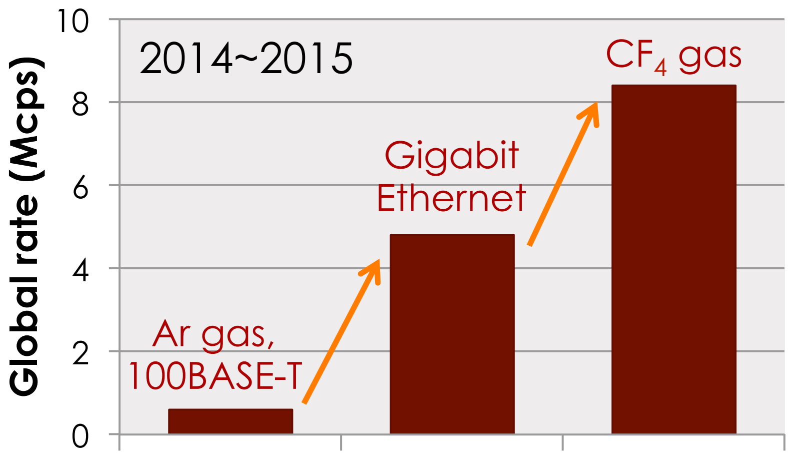


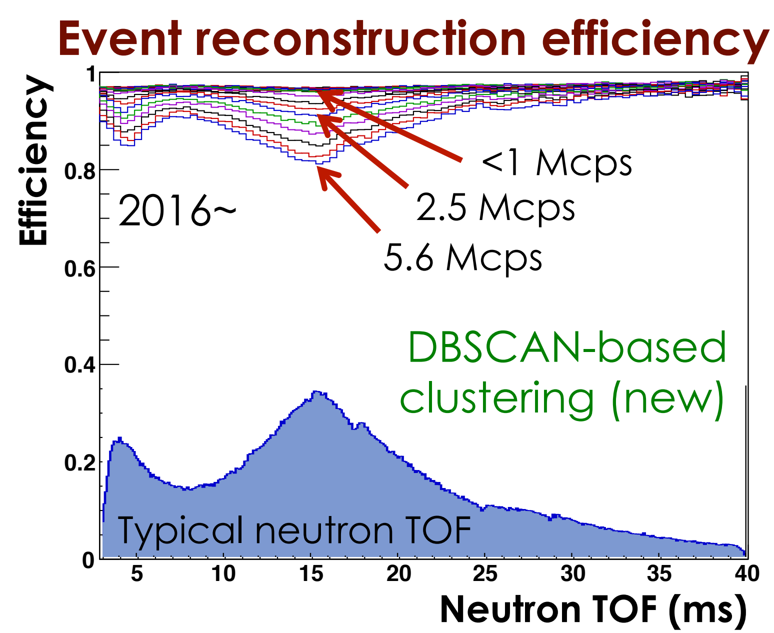
Fine spatial resolution using template fit to TOT distribution



Initial development at RADEN

- Upgraded data encoder hardware and optimized gas mixture for increased rate
  - Increased peak rate from 0.6 Mcps to 8 Mcps
- Usable rate limited by event pile-up in offline analysis
  - Optimized clustering algorithm for rate > 1 Mcps
- Additional improvements with optimized gas mixture
  - Improved spatial resolution from 0.2 to 0.1 mm
  - Increased thermal neutron efficiency from 18% to 26%





μNID control software/analysis GUI

- New DAQ controller hardware and detector control software
  - Based on DAQ middleware
  - Full integration into beam line control system
  - In use since March 2018
- New browser-based UI for offline analysis
  - In use since April 2018
  - First update with simplified interface, better data visualization, etc., in October 2018

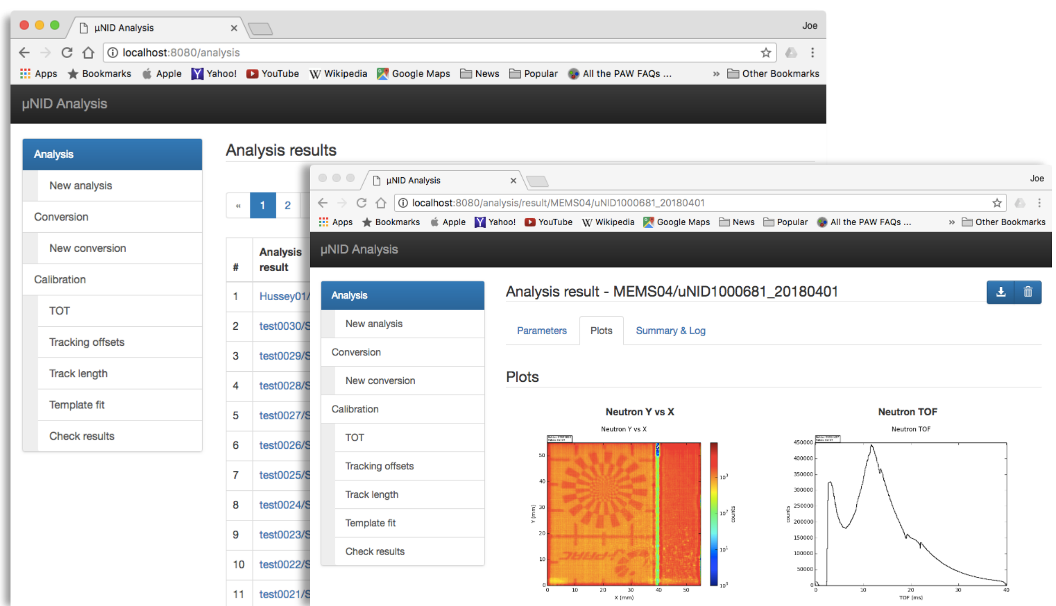
*DAQ controller and software by BBT

Software frameworks at the MLF

IROHA2 – Experimental device control system with web-based UI (MLF)

DAQ Middleware – Detector control and data collection (KEK)

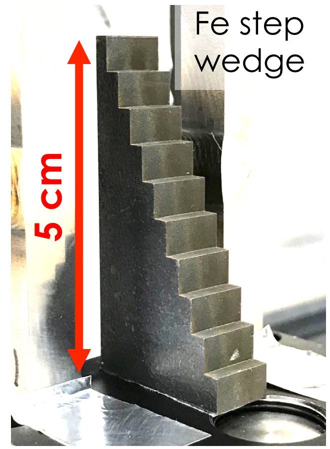
μNID analysis GUI

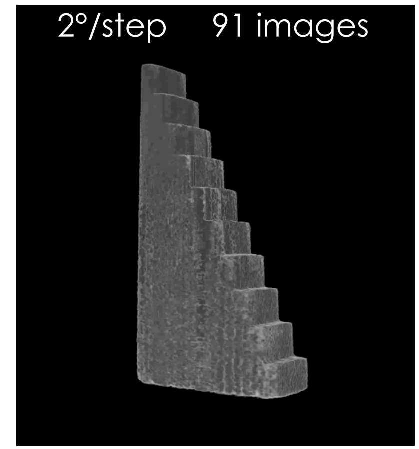


Automated measurements

- 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 info with motion/process frequency
    - Currently limited to cyclical processes

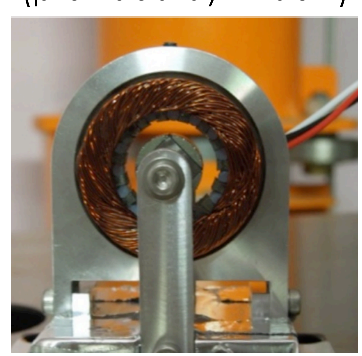
Computed tomography

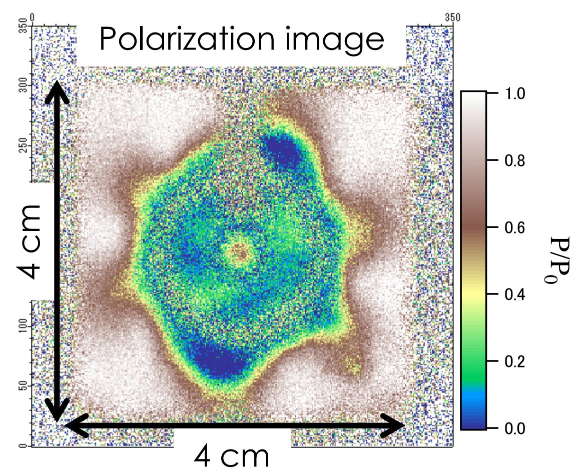




Magnetic imaging of running motor

Model electric motor (provided by Hitachi)





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

Continuing development with standard μNID

- Continue refinement of clustering, position reconstruction
- Update FPGA firmware for data encoders
  - Incorporate buffering for increased rate capacity above 10 Mcps
- Investigate new gas mixtures for increased efficiency, optimized event size
- Combine energy-resolved and conventional CT
  - Use feedback from energy-resolved CT to improve quantitativity of conventional CT
  - Combine resonance CT with conventional CT for improved visualization of isotopic density/temperature
  - Use Bragg-edge information from energy-resolved CT to guide conventional CT

Development of counting-type detectors at RADEN

- Development of Li-glass detector
  - Improve spatial resolution using super resolution techniques
- Improvement of standard μNID
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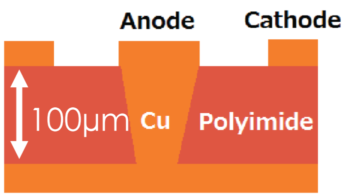
- New μNID development
  - Small-pitch MEMS μPIC for improved spatial resolution
  - μNID with boron converter for increased rate

Small pitch for improved spatial resolution

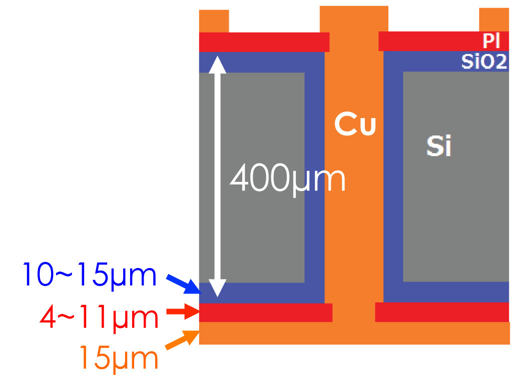
- Develop small-pitch μPIC with MEMS manufacturing
  - Produced 215 μm pitch μPIC (down from 400 μm)
  - Mfd. by DNP
- Tested at RADEN
  - Confirmed sufficient gain
  - Spatial resolution not improved as expected
  - Gain instability under neutron exposure

- **Spatial resolution**: optimize gas for shorter track length
- **Gain stability**: new MEMS μPIC with glass substrate prepared

Current PCB μPIC (400 μm pitch)

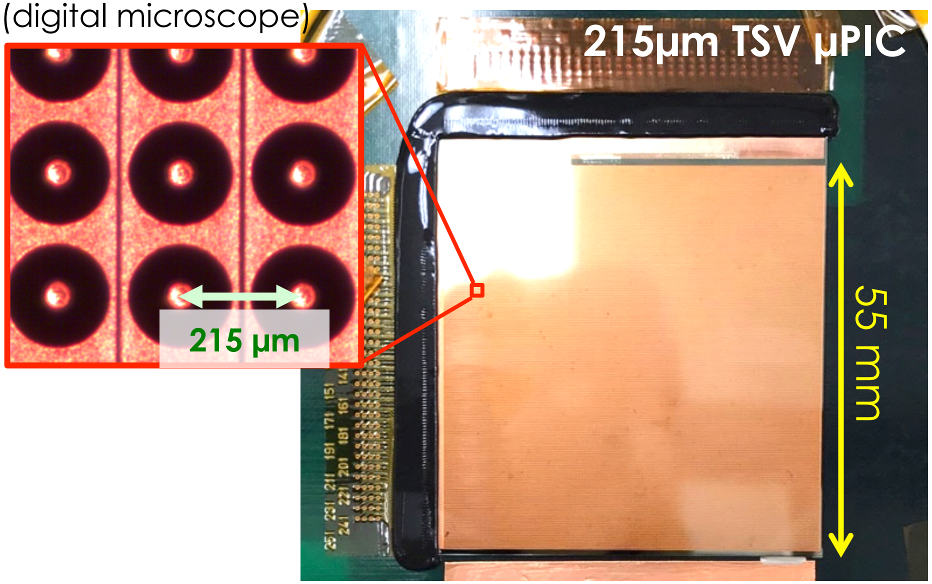


TSV* μPIC



* TSV = Thru-silicon-via

Surface of TSV μPIC (digital microscope)



MEMS μPIC with glass substrate (12/10)

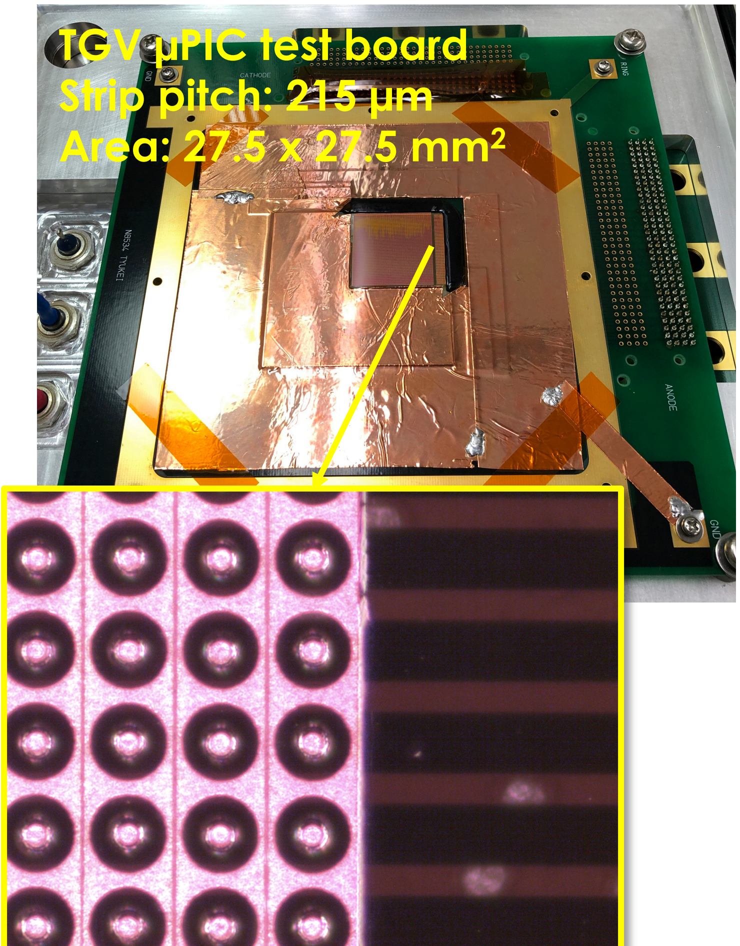
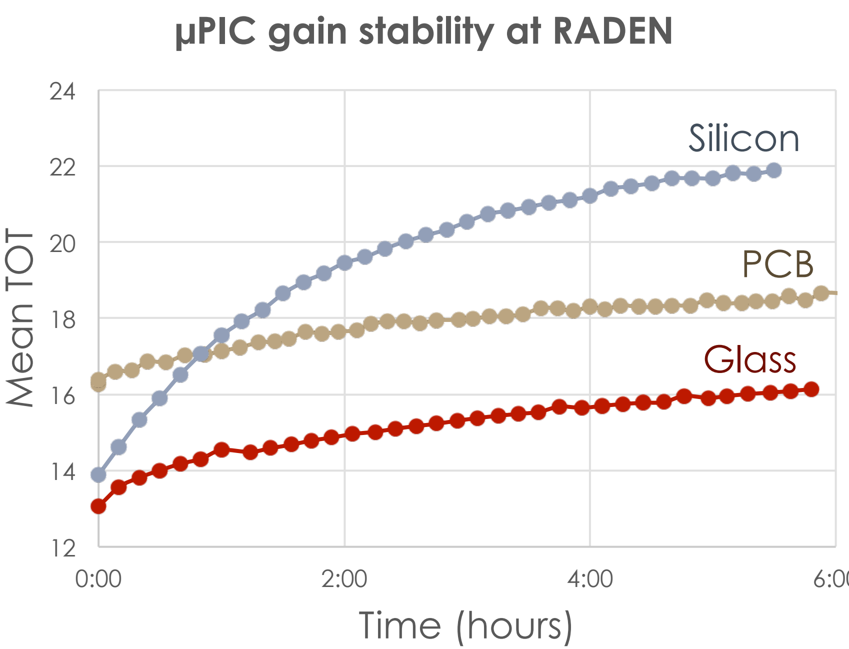


Image from digital microscope



- Initial testing performed at Kyoto U.
- Gain stability measured at RADEN
  - Improved over silicon substrate
  - Similar or slightly worse than PCB μPIC

TGV μPIC – Thru-glass-via μPIC

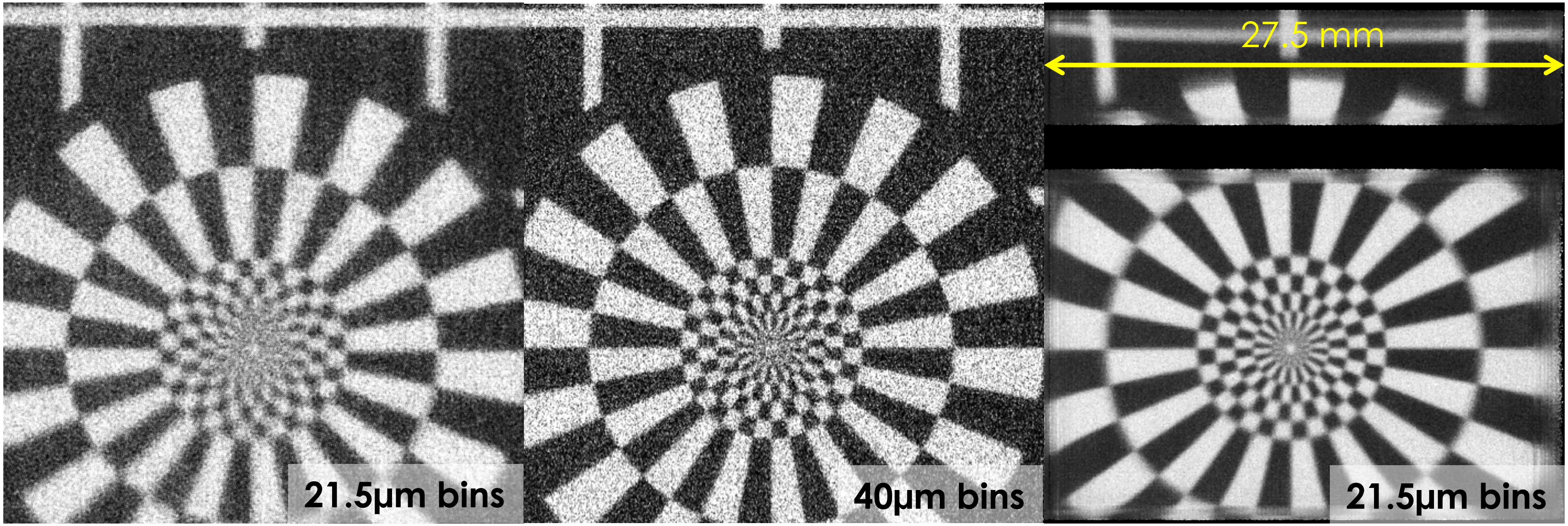
PRELIMINARY

Imaging with the 215µm MEMS µPICs

215µm pitch
Silicon substrate

400µm pitch
PCB µPIC

215µm pitch
Glass substrate

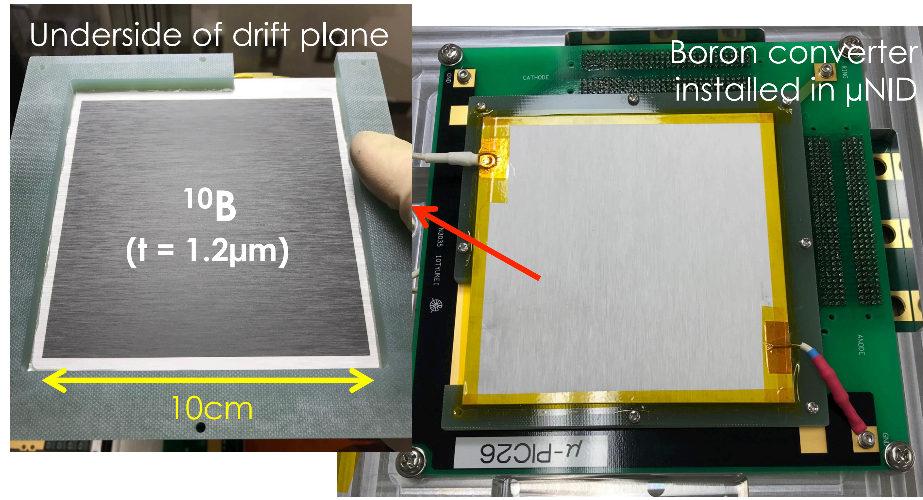


- Image quality with TGV µPIC looks good
- Resolution may be improved compared to PCB µPIC

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 initial testing
  - Thin, 1.2μm ^{10}B layer → low efficiency (3~5%)

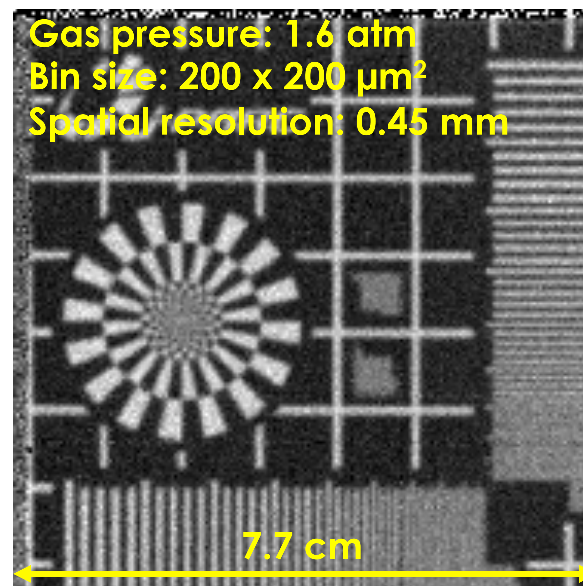


Initial testing at RADEN

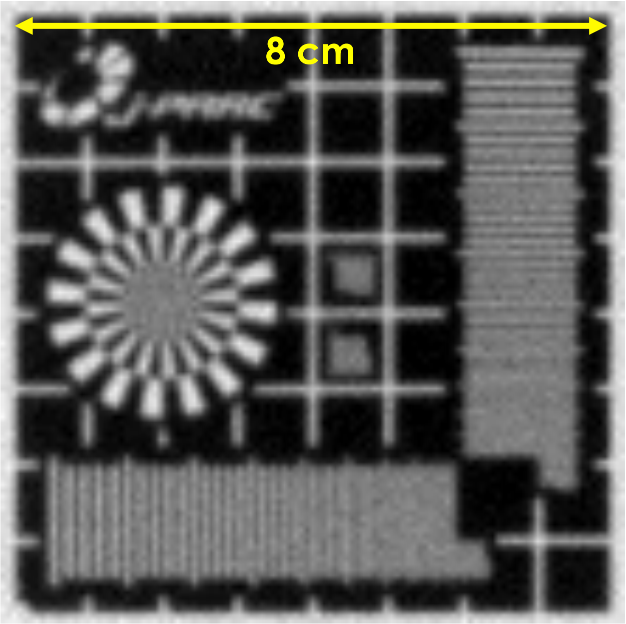
- Maximum count rate of 22 Mcps
- Spatial resolution of 0.45 mm

Next:

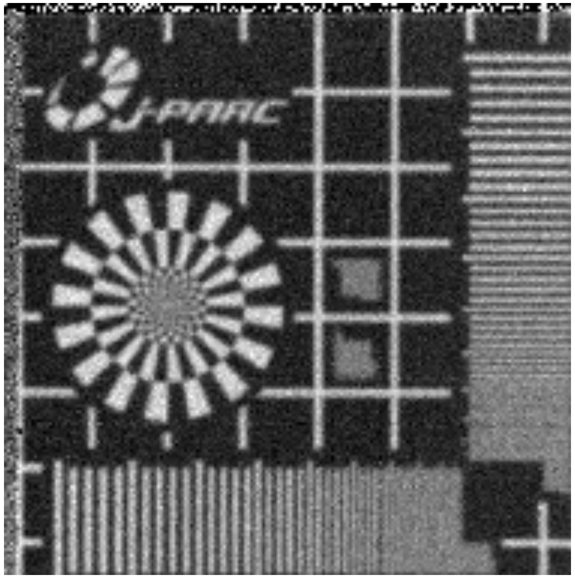
- Prepare dedicated Boron-μNID system
- Optimize gas for shorter track lengths
- Design new converter for increased efficiency



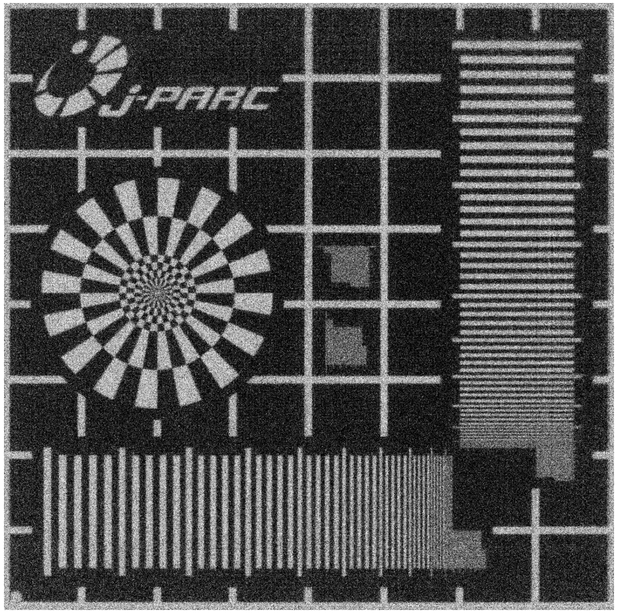
Comparison of imaging for nGEM, B-μNID, and μNID



nGEM
Spatial resolution: 1 mm

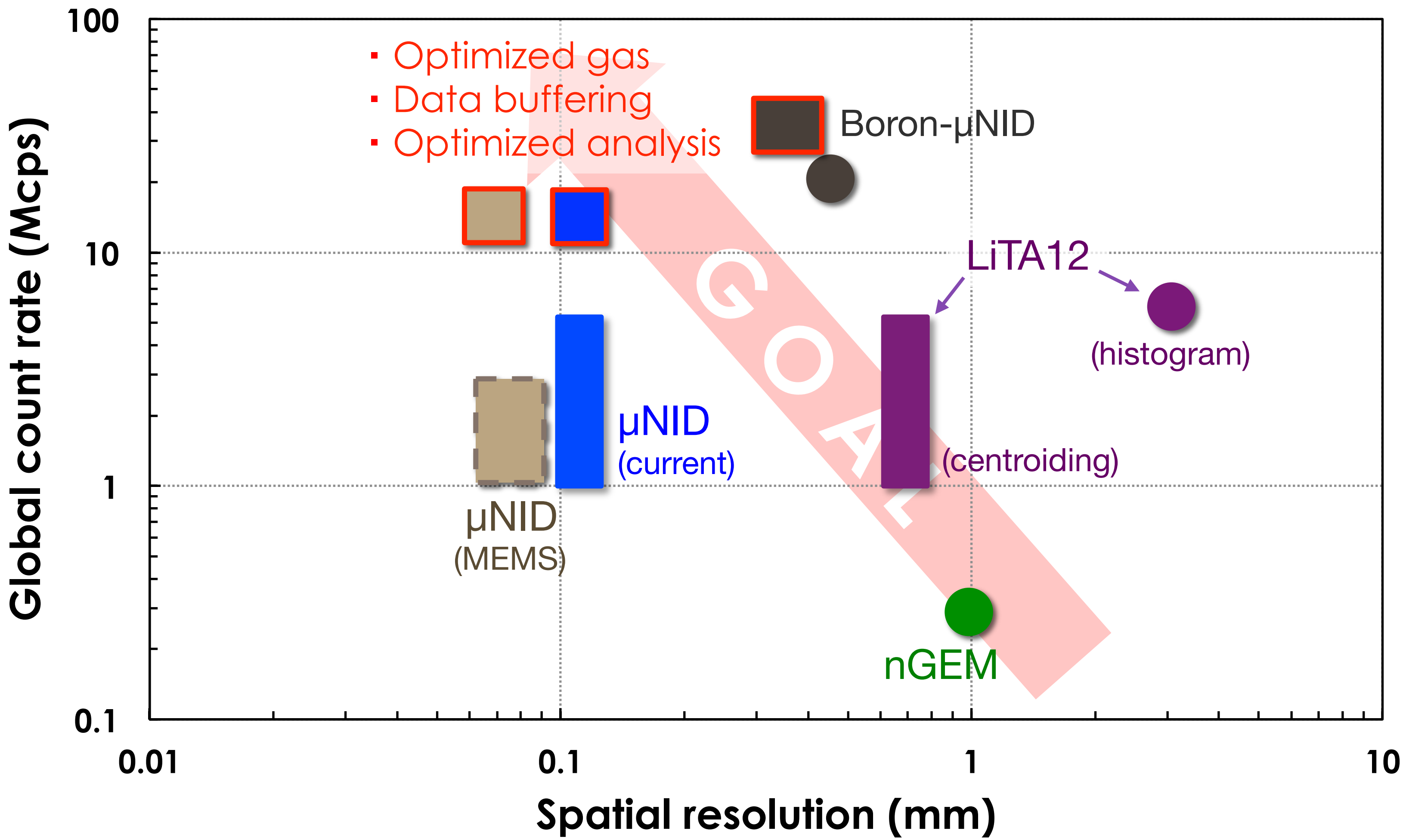


B-μNID (1.6atm)
0.45 mm



Standard μNID (^{3}He)
0.1 mm

Current and projected performance of event-type detectors at RADEN



Summary

- Development of detectors to meet the needs of energy-resolved neutron imaging at RADEN is ongoing
- LiTA12
  - Improved spatial resolution using super resolution techniques
  - Now preparing analysis/control software
- Standard μNID
  - Improved rate performance to over 1 Mcps
  - Fully integrated detector into RADEN control system
  - Begin study of energy-resolved CT with the μNID
- 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

RADEN and μNID development members

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	Takeshi Nakatani	Mariko Sagawa
	Kosuke Hiroi	Yuhua Su
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Kyoto University	Toru Tanimori	Atsushi Takada
(μNID development)	Taito Takemura	Mitsuru Abe
KEK	Setsuo Satoh	
(LiTA12 development)		