The μPIC-based neutron imaging detector (μNID) for energy-resolved neutron imaging at J-PARC

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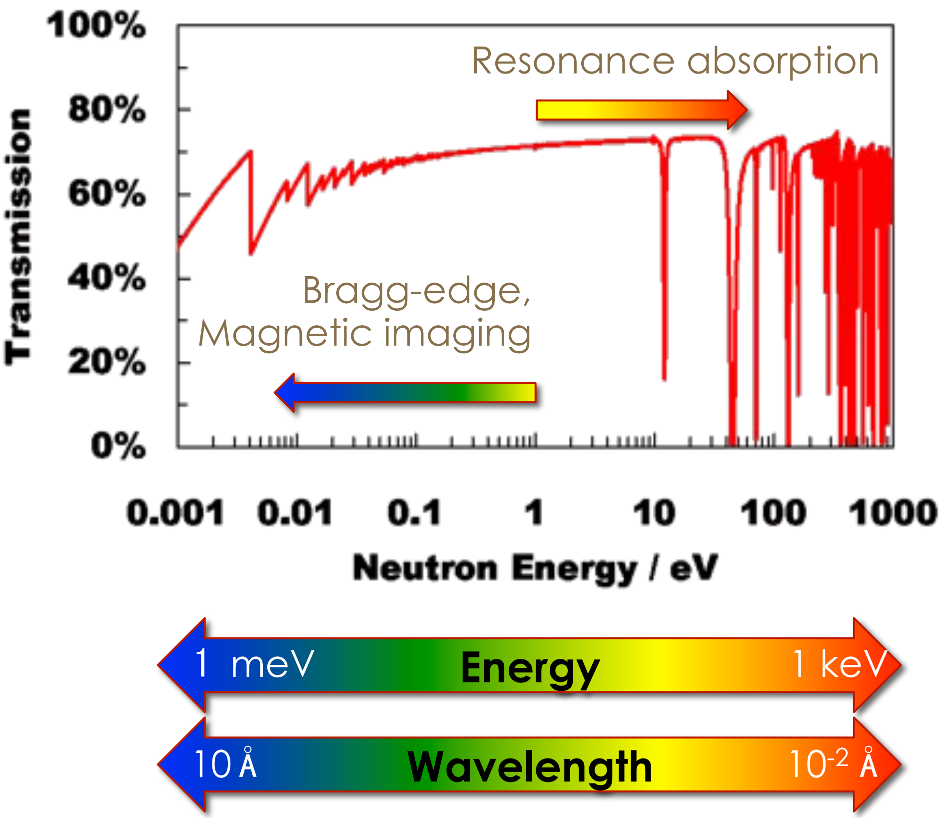
Outline

- (Brief) Intro to energy-resolved neutron imaging
- Current status of the μNID at RADEN
- Ongoing development
  - 215μm pitch MEMS μPIC
  - μNID with boron converter

Energy-resolved neutron imaging at RADEN

Energy-dependent neutron transmission



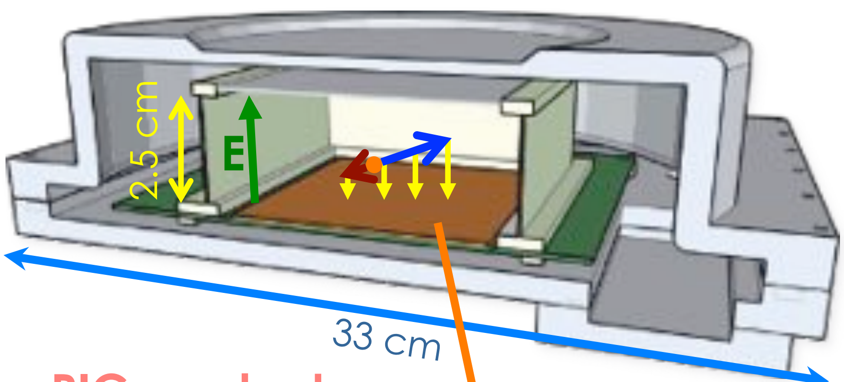
- Energy-dependence → quantitative information on macroscopic distribution of microscopic quantities
- Pulsed neutrons → wide energy range, accurate energy determination by time-of-flight
- Use time-resolved imaging detectors at RADEN:
  - Sub-mm spatial resolution
  - Sub-μs time resolution
  - Mcps count rate
  - Strong background rejection

μPIC-based Neutron Imaging Detector (μNID)

µPIC-based neutron imaging detector (µNID)

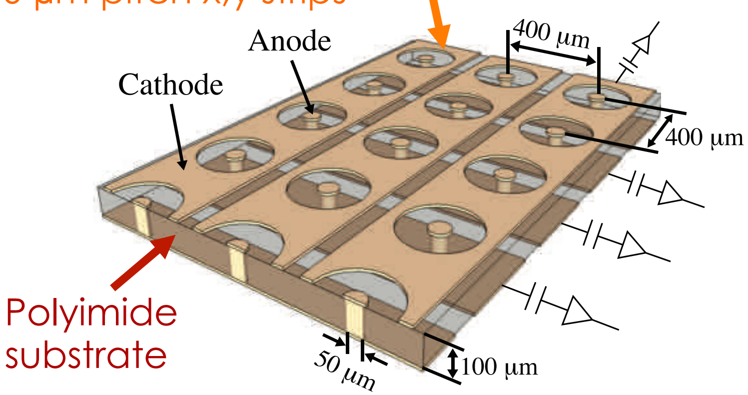
Neutron detection via n + ^{3}He → p + t

Overall track length ~4 mm in gas



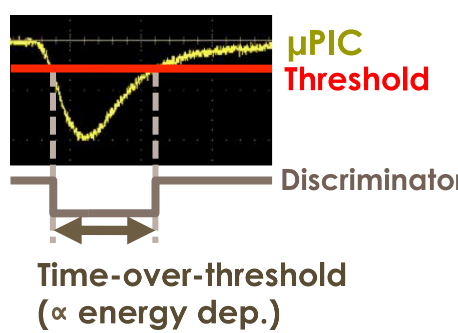
µPIC readout

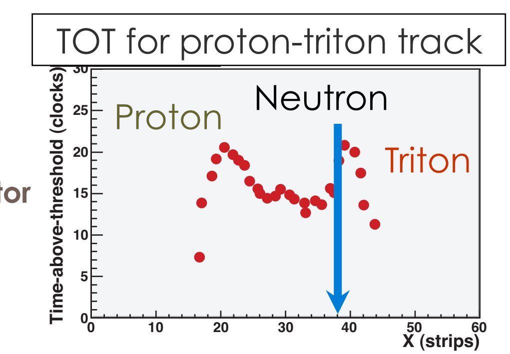
10 cm x 10 cm area,
400 µm pitch x,y strips



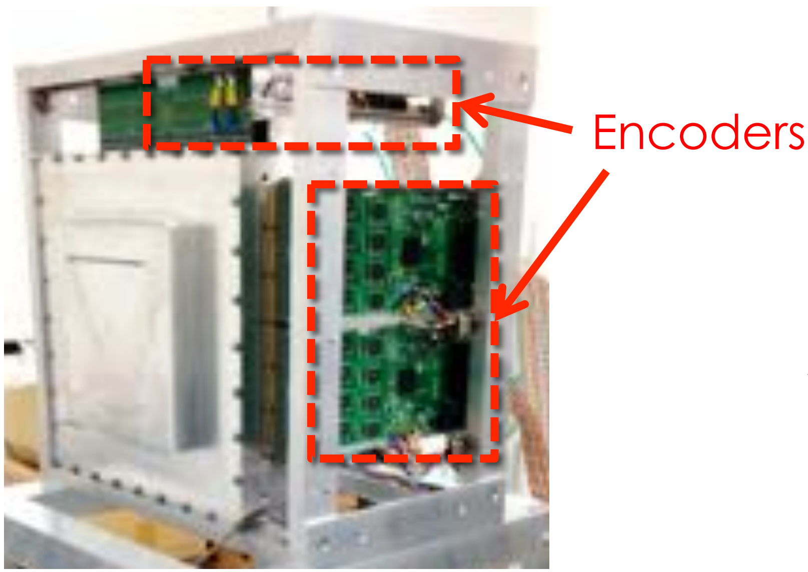
- Gaseous time-projection-chamber
  - CF_4-iC_4H_{10}-^{3}He (45:5:50) at 2 atm
  - µPIC micropattern readout
  - Compact ASIC+FPGA data encoder front-end
- 3-dimensional tracking of decay pattern + time-over-threshold
  - Accurate position reconstruction
  - Strong gamma rejection

Digital encoder with time-over-threshold (TOT)

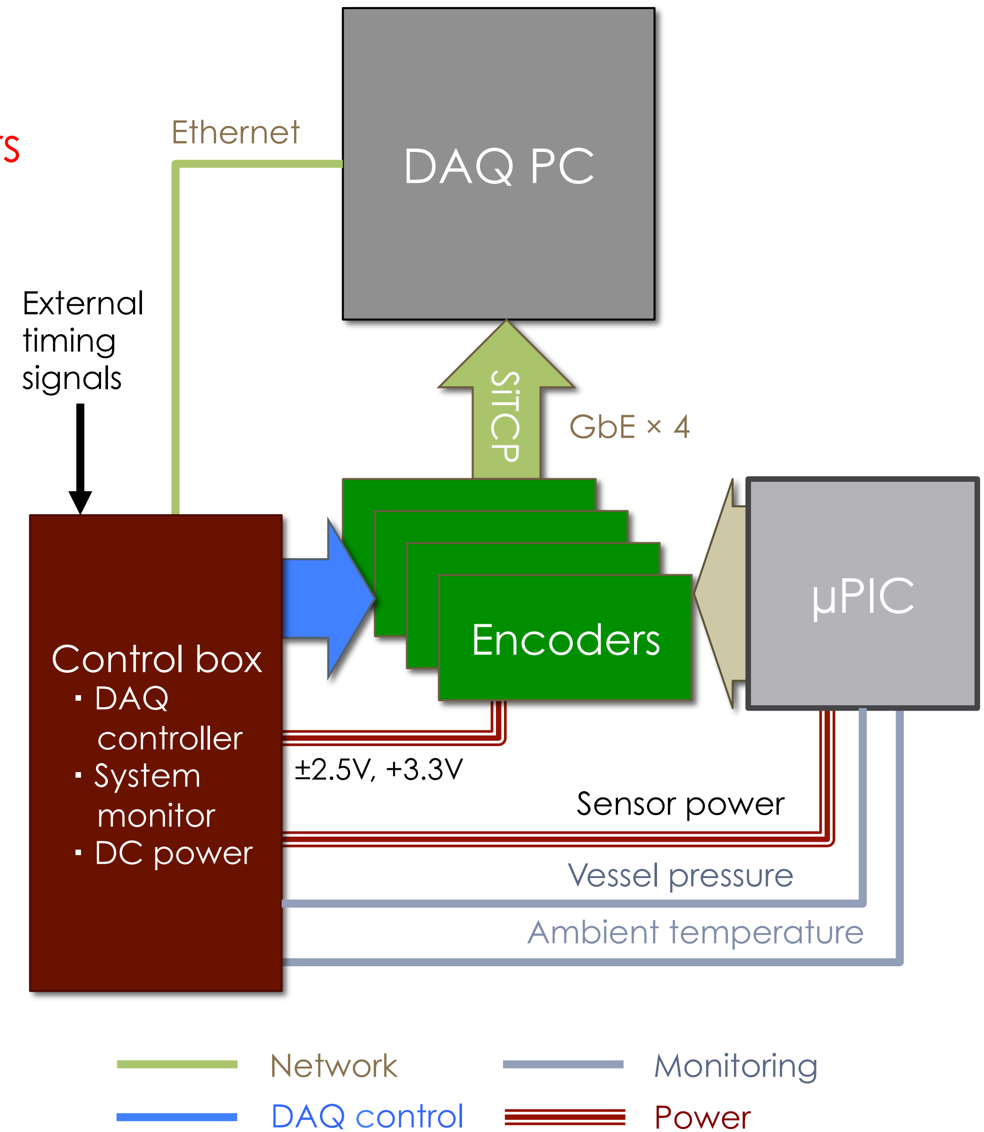




μPIC-based neutron imaging detector (μNID)



- FPGA-based encoders for high-speed data acquisition
- Data transfer via Gigabit Ethernet with SiTCP
- FPGA-based system controller



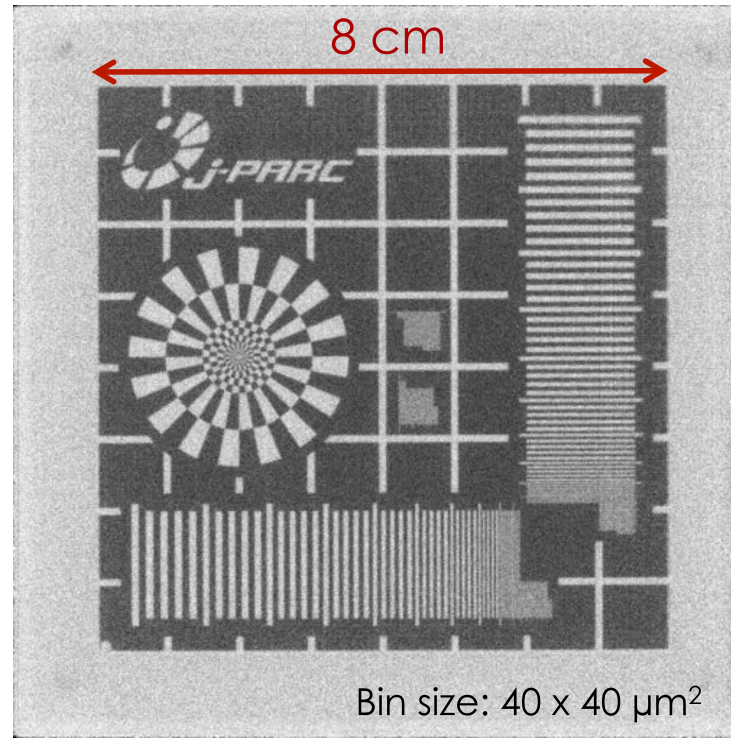
µNID performance and usage at RADEN

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

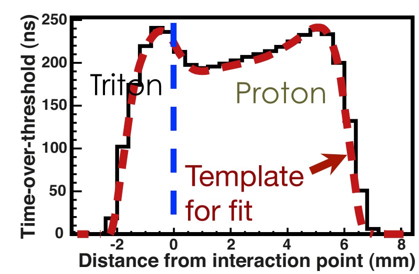
Detector usage at RADEN (2018A)	
µNID	34 days
CCD camera	20 days
Other counting-type	36 days

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

Image of Gd test target



Fine spatial resolution using template fit to TOT distribution



μNID control software/analysis GUI

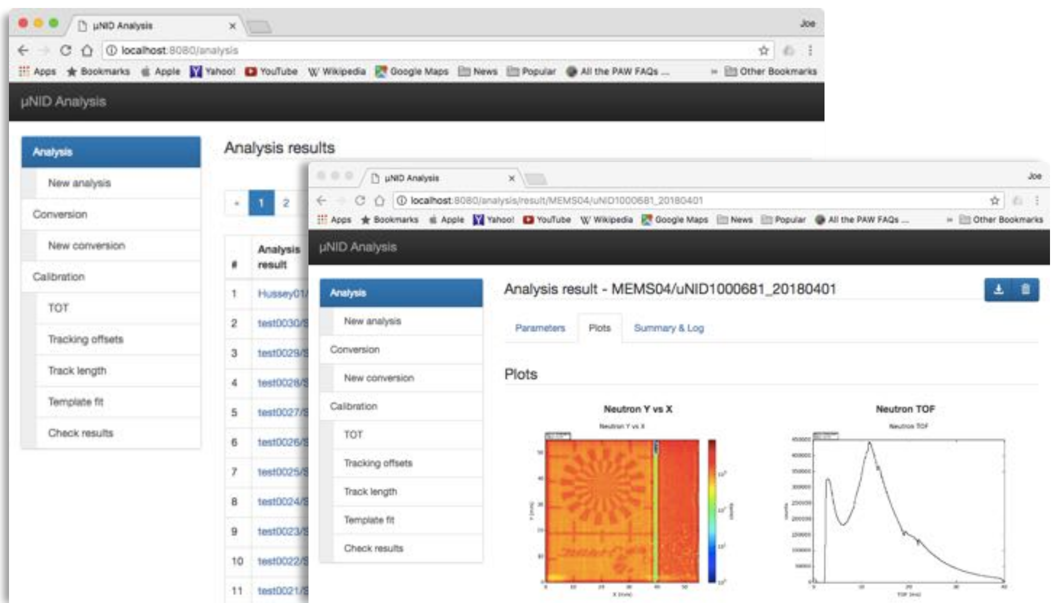
- New DAQ controller hardware and detector control software
  - Based on DAQ middleware
  - Full integration into beam line control system
  - In use since March 2018
- New browser-based UI for offline analysis
  - First update with simplified interface, better data visualization, etc.
  - In use since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

Software frameworks at the MLF

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

DAQ Middleware – Detector control and data collection (KEK)

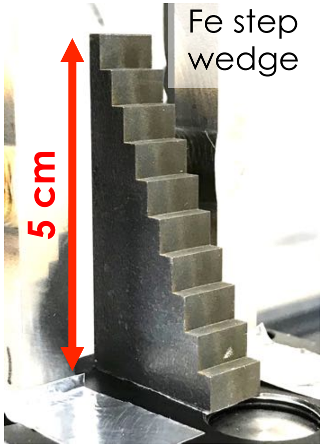
μNID analysis GUI

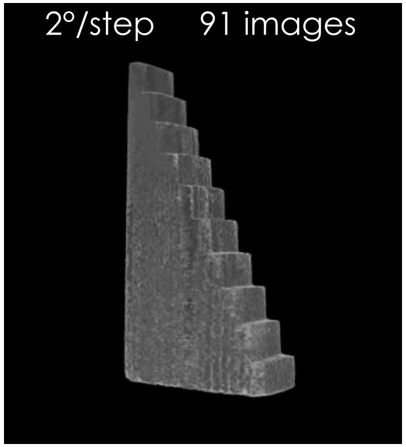


Automated measurements

- 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

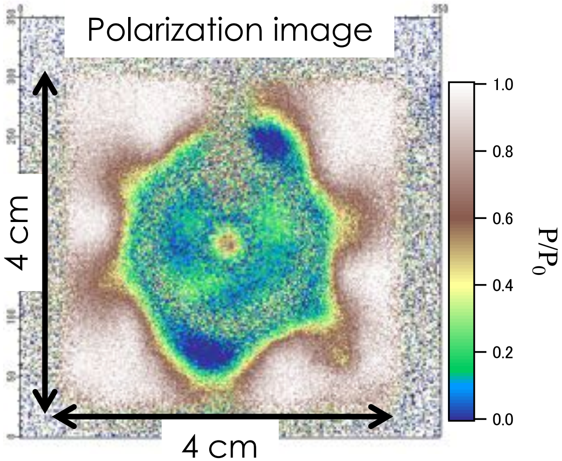
Computed tomography





Magnetic imaging of running motor

Model electric motor (provided by Hitachi)

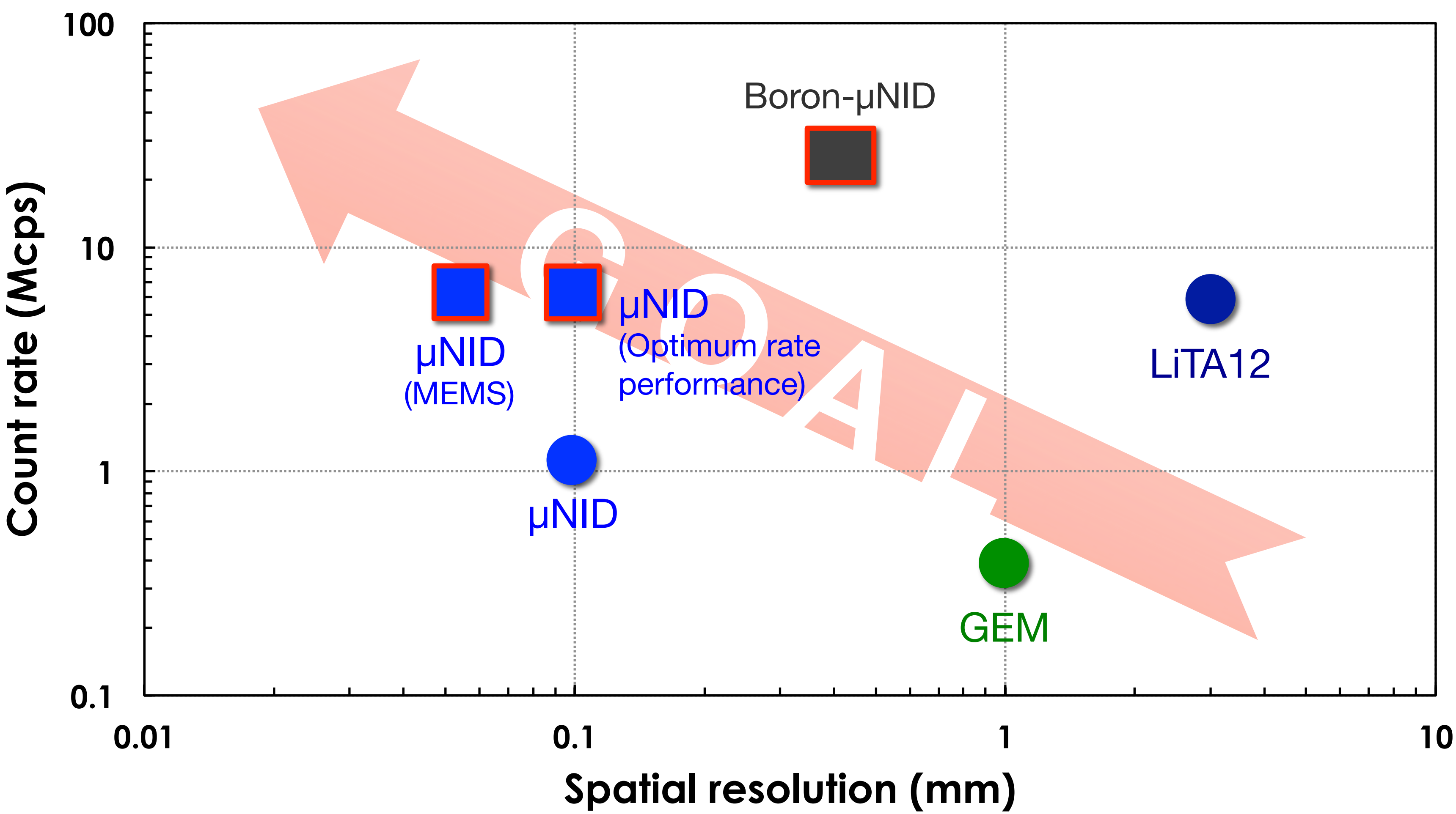


K. Hiroi et al., J. Phys.: Conf. Series 862 (2017) 012008

Ongoing development

- 215μm pitch MEMS μPIC for improved spatial resolution
- μNID with boron converter for increased rate performance

Current and projected performance of event-type imaging detectors at RADEN

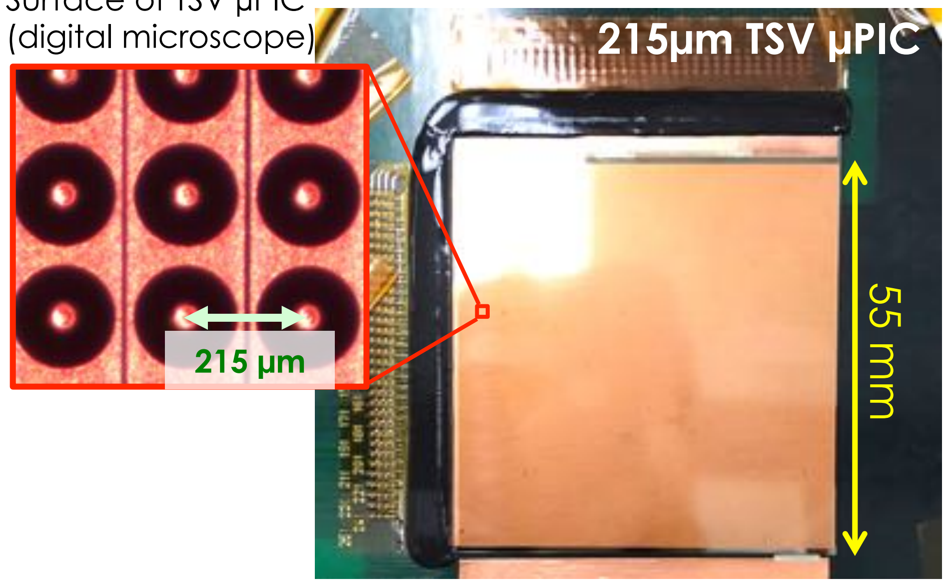


Small-pitch MEMS μPIC

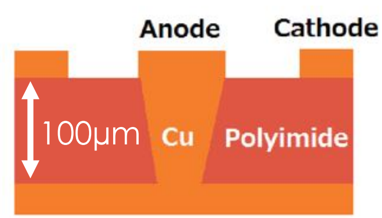
Small-pitch MEMS μPIC

- Improve spatial resolution with reduced strip pitch
- Develop small-pitch μPIC
  - Manufacture using MEMS on silicon substrate (by DaiNippon Printing Company, Ltd.) → Thru-silicon-via (TSV) μPIC
  - Successfully produced 215 μm pitch μPIC (down from 400 μm)
  - Small (14 x 14 mm²) and larger area TSV μPICs (55 x 55 mm²) tested at RADEN

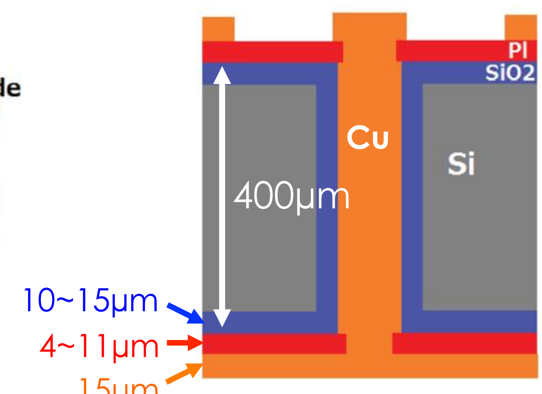
Surface of TSV μPIC
(digital microscope)



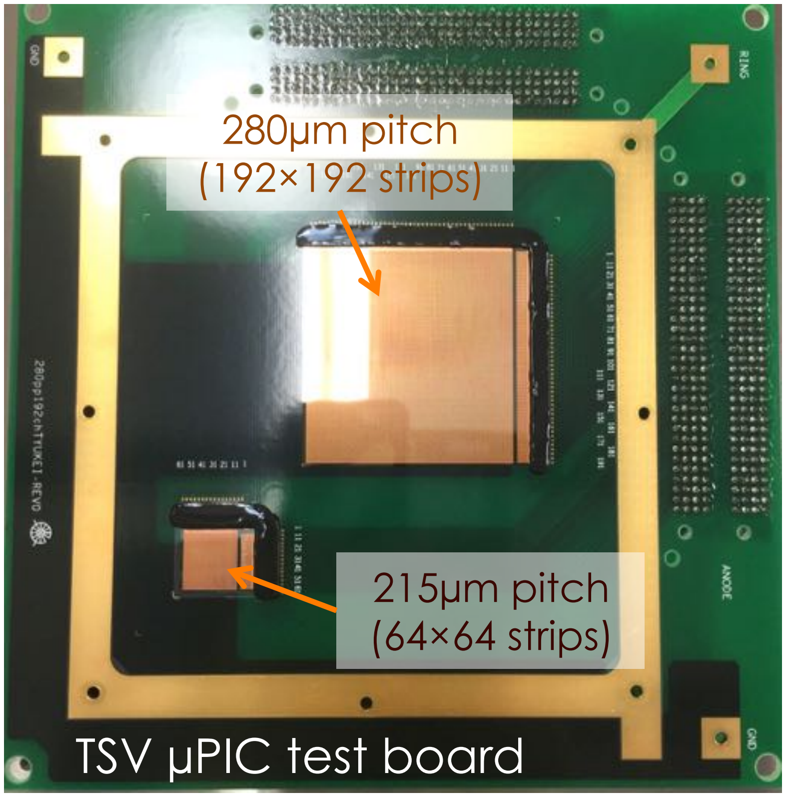
Current PCB μPIC (400 μm pitch)

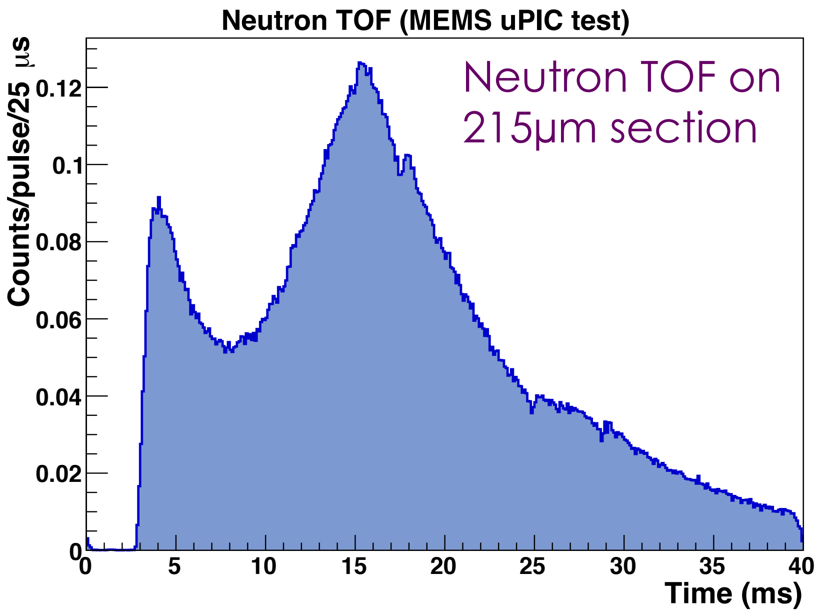


TSV μPIC



First test of TSV μPIC at RADEN (MPGD2016)



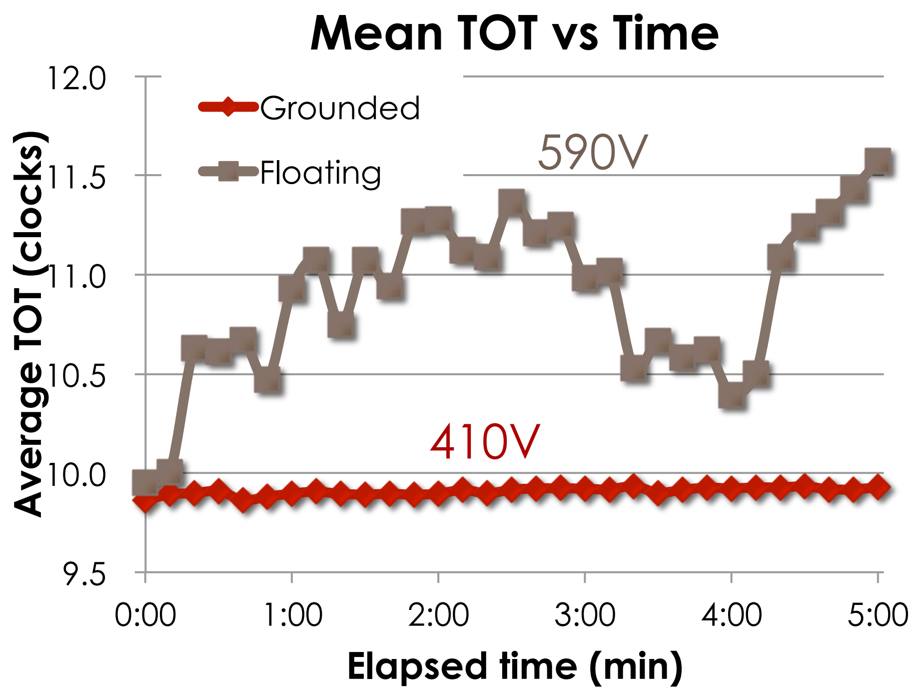


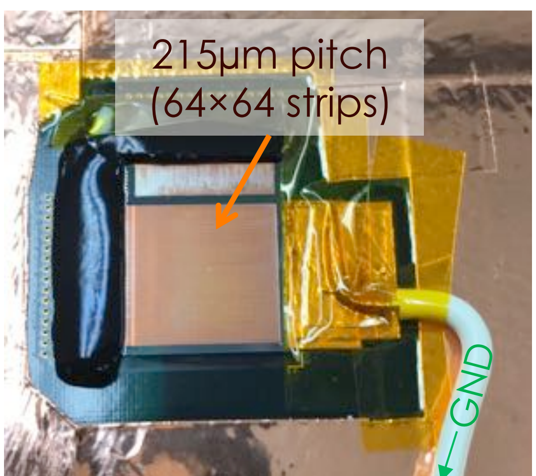
Gas filling used for test:
P10:CF_4:He (60:30:10) @2 atm

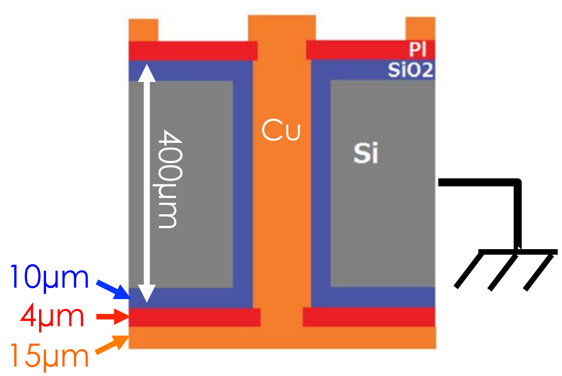
- No signal measured on 280μm section (gain too low)
- Signal confirmed on 215μm section
- Observed gain instability

Gain instability under irradiation (MPGD2017)

- TSV μPIC gain observed to increase with neutron exposure even for 15μm SiO_2 layer
- Tried grounding Si substrate





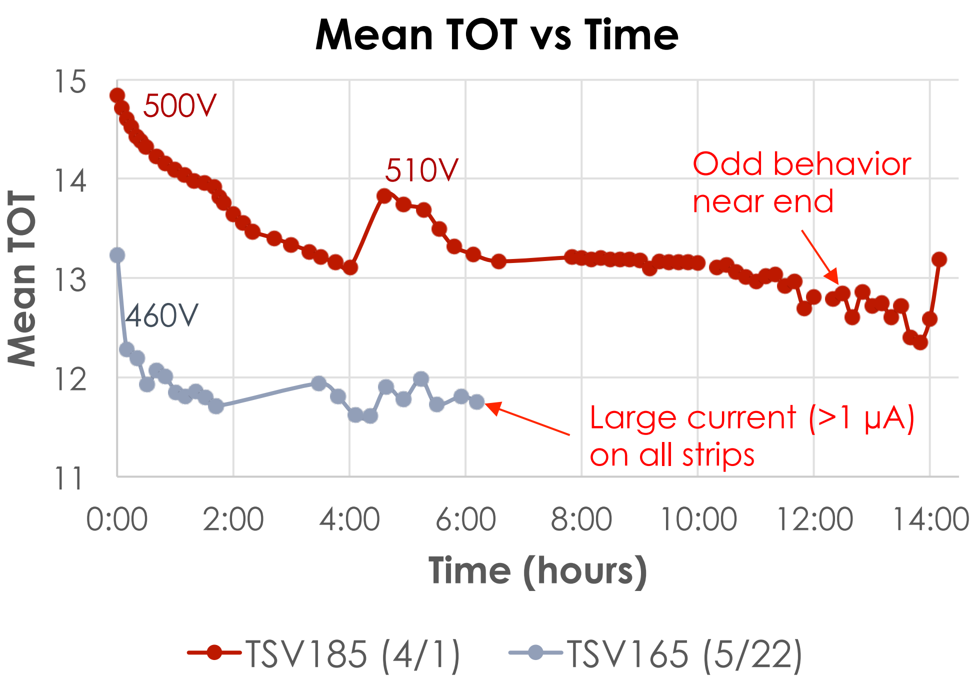


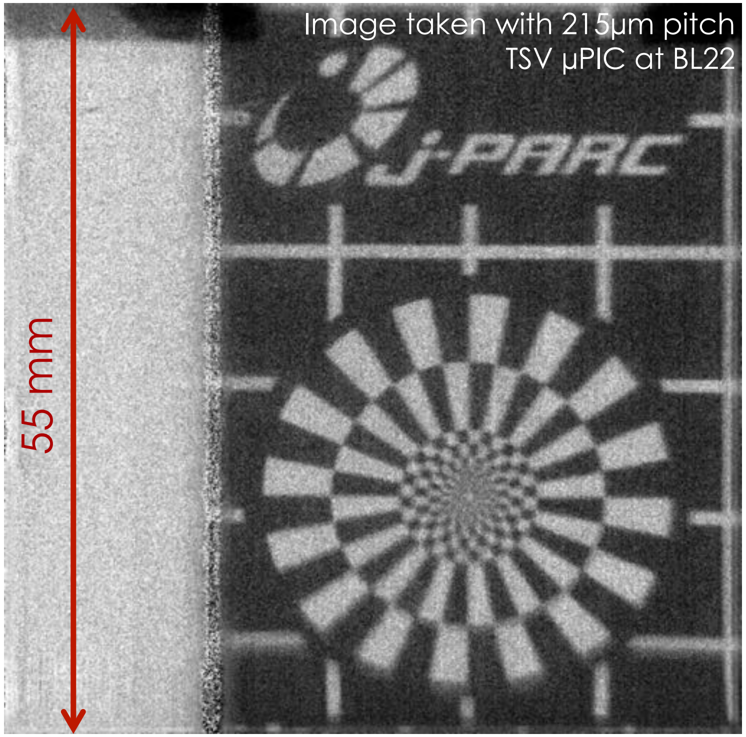
Grounding substrate appears to stabilize gain

Necessary anode HV was also reduced

Large-area TSV μPIC test at RADEN

- Imaging confirmed but spatial resolution not improved as expected (slightly worse than PCB μPIC)
- Gain instability under neutron exposure → improved by grounding substrate but not eliminated





- **Gain stability**: new MEMS μPIC with glass substrate (TGV μPIC)
- **Spatial resolution**: optimize gas for shorter tracks?

MEMS μPIC with glass substrate (12/10)

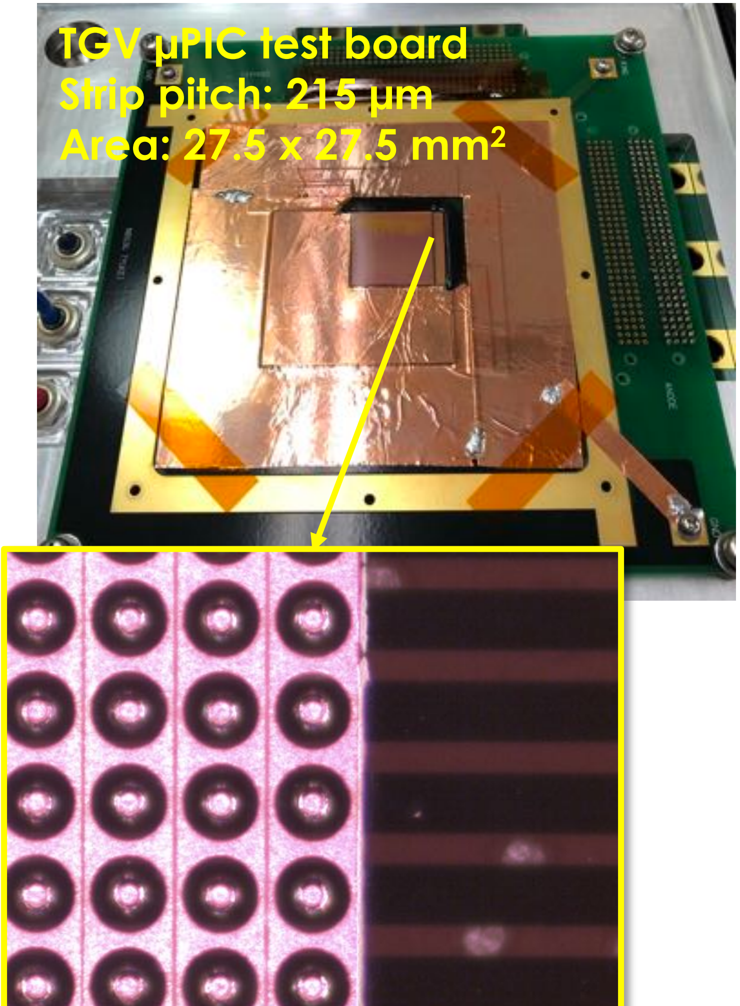
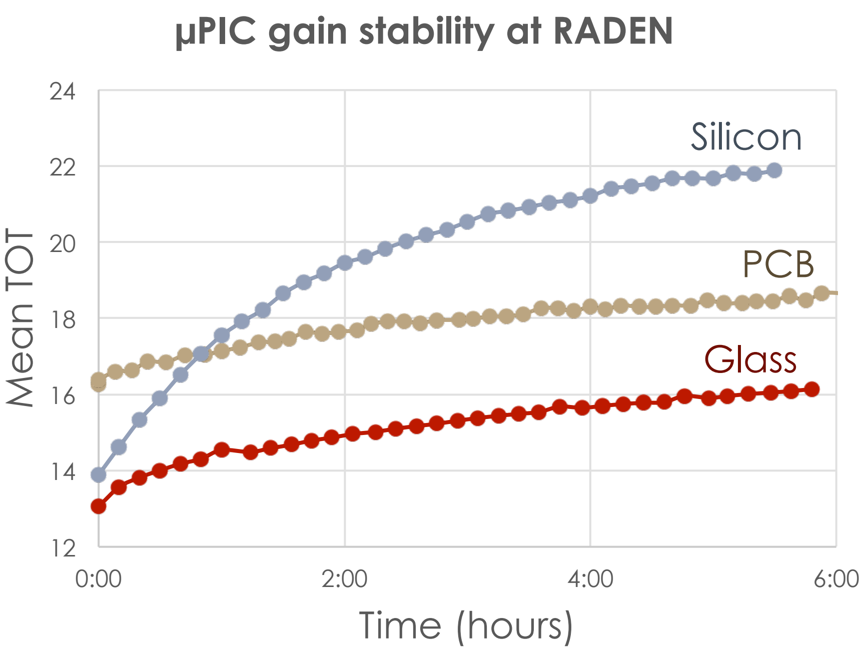


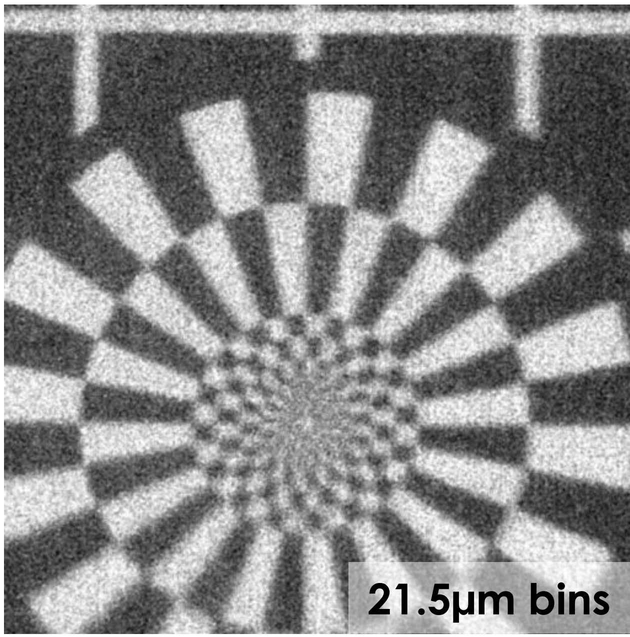
Image from digital microscope



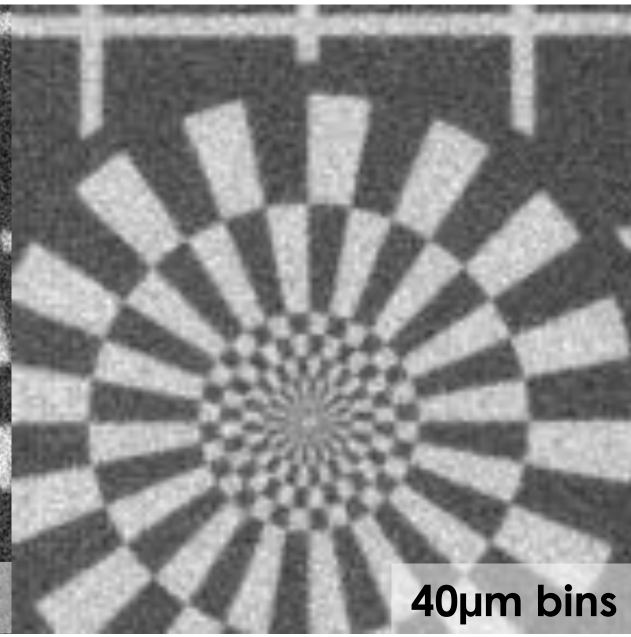
- Initial testing performed at Kyoto U. (Abe-san's talk)
- Gain stability measured at RADEN
  - Improved over silicon substrate
  - Slightly worse than PCB μPIC

Imaging with the 215µm MEMS µPICs

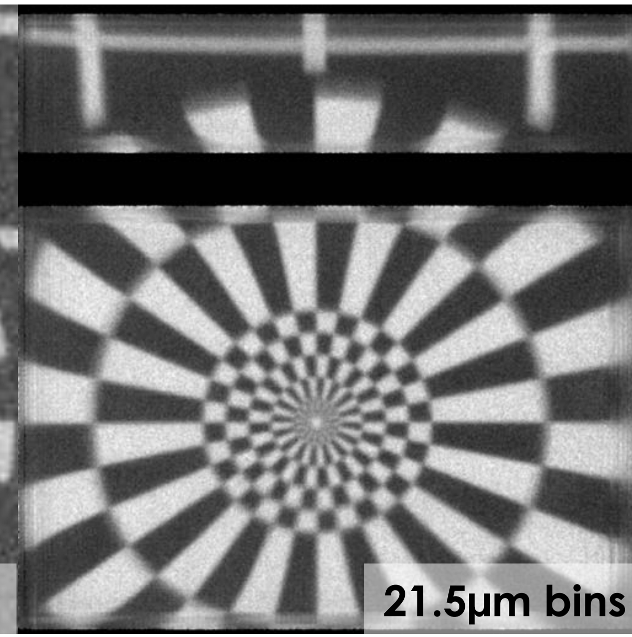
215µm TSV µPIC



400µm PCB µPIC



215µm TGV µPIC

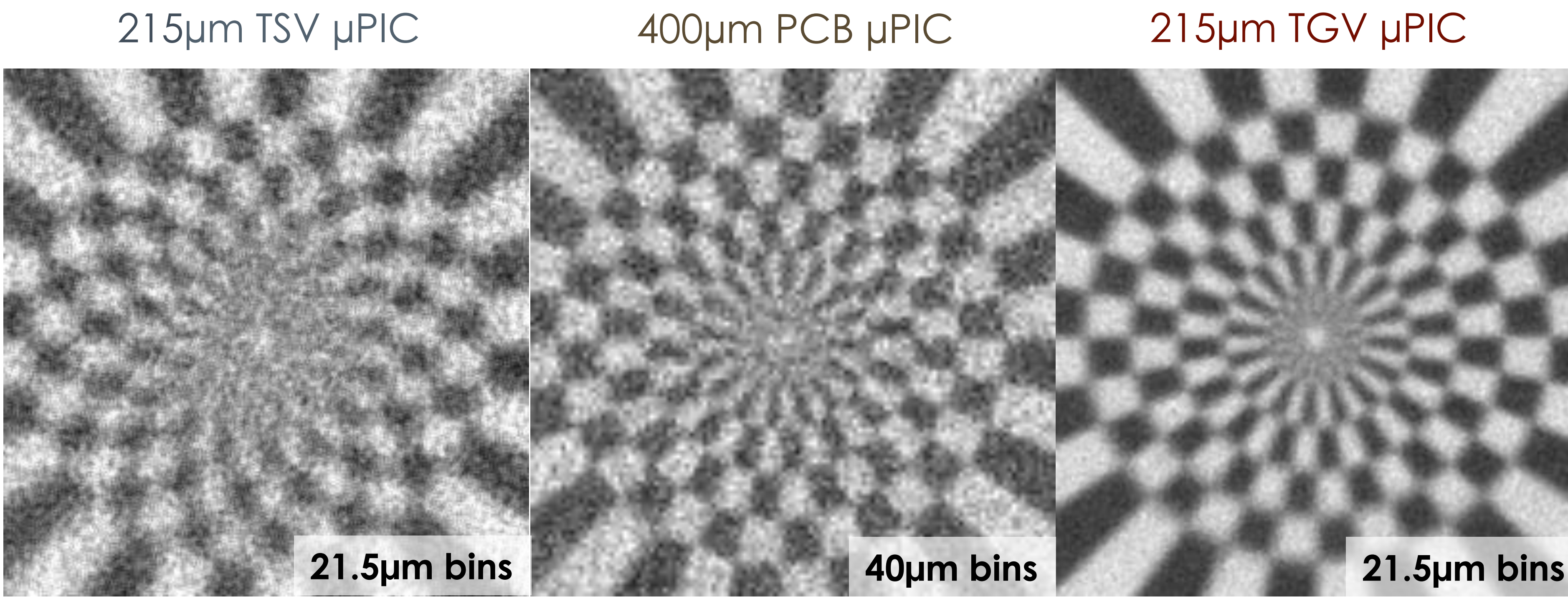


- Image quality with TGV µPIC looks good
- Resolution may be slightly improved compared to PCB µPIC

Note: measurement statistics are different for each image

PRELIMINARY

Imaging with the 215μm MEMS μPICs



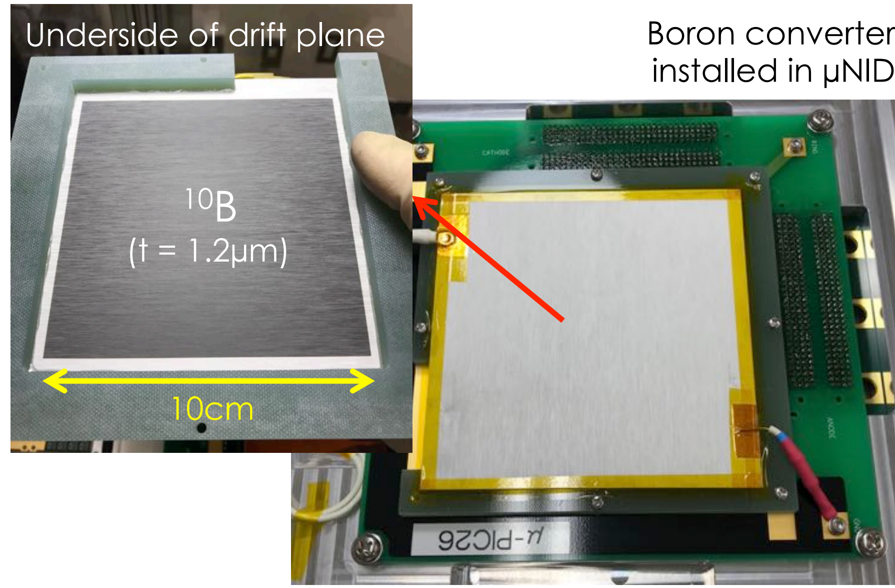
- Image quality with TGV μPIC looks good
- Resolution may be slightly improved compared to PCB μPIC

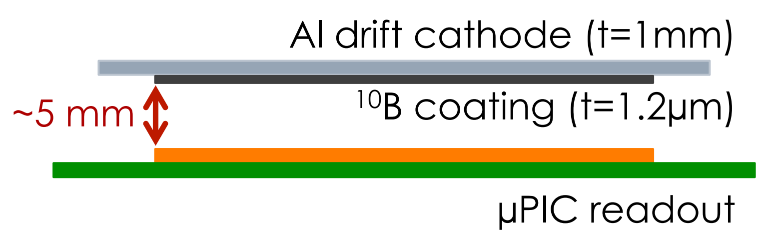
Note: measurement statistics are different for each image

μNID with boron converter

μNID with boron converter (B-μNID)

- Increase count rate capacity by reducing event size
  - ^{10}B (α,Li) for <u>3x smaller event size</u> than ^{3}He (p,t)
  - Trade-off in spatial resolution
- μNID with flat boron converter (for initial testing)
  - Thin, 1.2μm ^{10}B layer → <u>low efficiency</u> (3~5%)
- Need to consider ways to improve detection efficiency



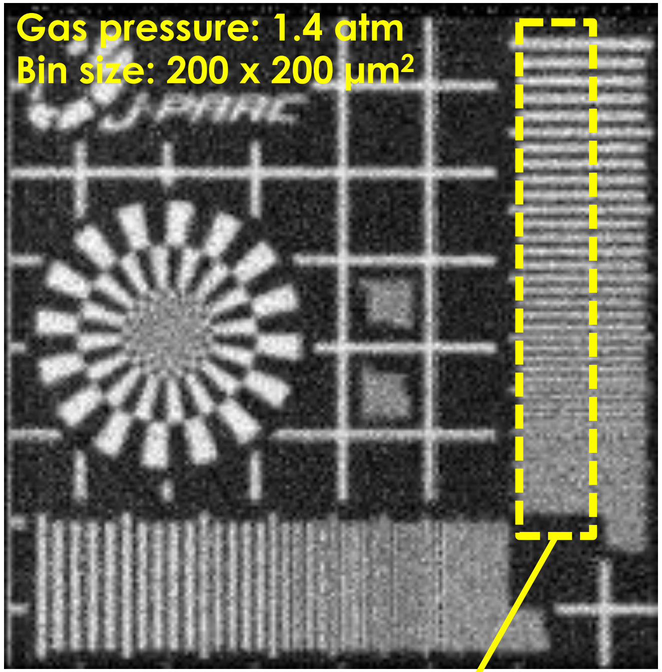


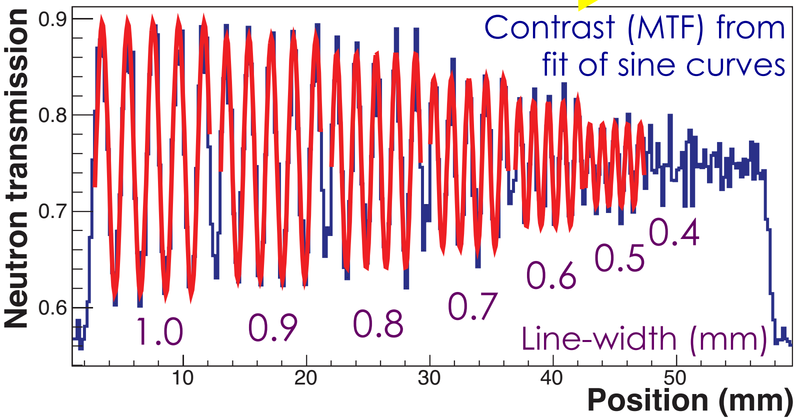
Expect 20~25 Mcps count rate and 0.4 ~ 0.5 mm spatial resolution

Spatial resolution study at RADEN

- Study of spatial resolution, event size vs. gas pressure (1.2 ~ 1.6 atm)
- L/D:1000, Exposure time: 15 mins
- Spatial resolution estimated from contrast of line-pairs (MTF)
- Maximum count rate at hardware limit: 22 Mcps @1.6 atm

Pressure (atm)	1.2	1.4	1.6
Average hits/ event	5.86	5.42	4.82
MTF @0.6mm	27%	36%	41%
Spatial resolution @10% MTF (mm)	0.50	0.48	0.45





Summary

- Standard μNID detector is in regular use at RADEN
  - Integration into RADEN control system greatly improved usability
  - Incremental improvements in spatial resolution, rate performance
- MEMS μPICs for improved resolution
  - TSV μPIC gain stability initially seemed to be improved with grounded substrate, but long-term operability may be adversely affected
  - Large-area TSV μPIC → image quality worse than PCB μPIC (gain instability?)
  - TGV μPIC → improved gain stability, good image quality
- μNID with boron converter for increased rate
  - Proof-of-principle study completed → confirmed peak rate of 22 Mcps and spatial resolution of 0.45 mm
  - Next: gas optimization for further reduced event size, increase efficiency of converter
  - Will make a new, dedicated Boron-μNID system for RADEN next year