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for the Cosmic-Ray γ Group
Kyoto University

Development of a Neutron Imaging Detector Based on the μ PIC Micro- Pixel Gaseous Chamber

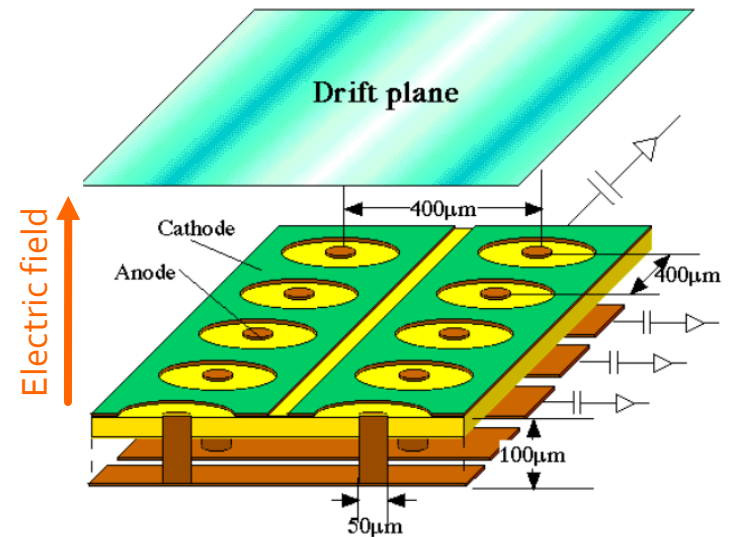
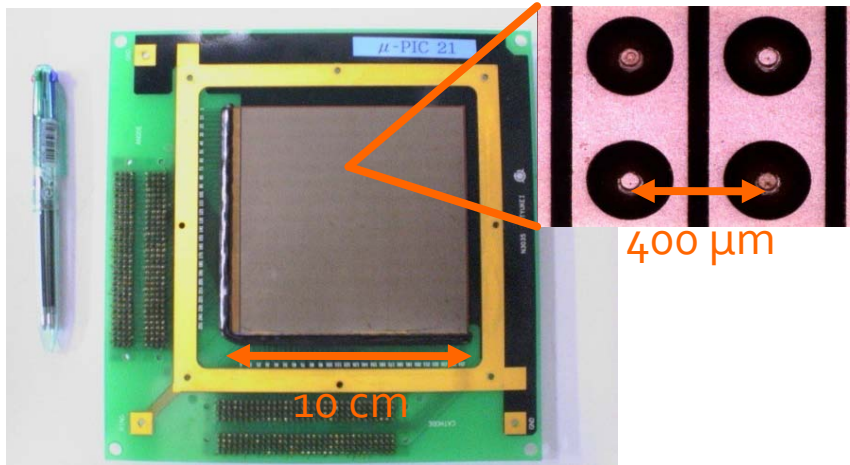


NID Project Team @ 京大

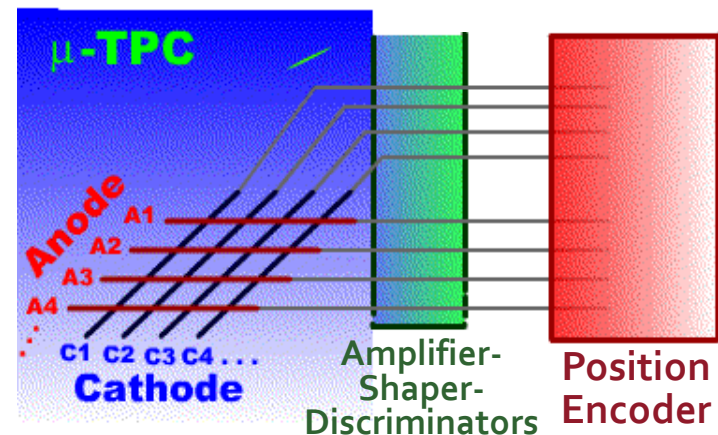
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S. Kurosawa, K. Miuchi, H. Nishimura, J. D. Parker,
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μ PIC (Micro-Pixel Gaseous Chamber)

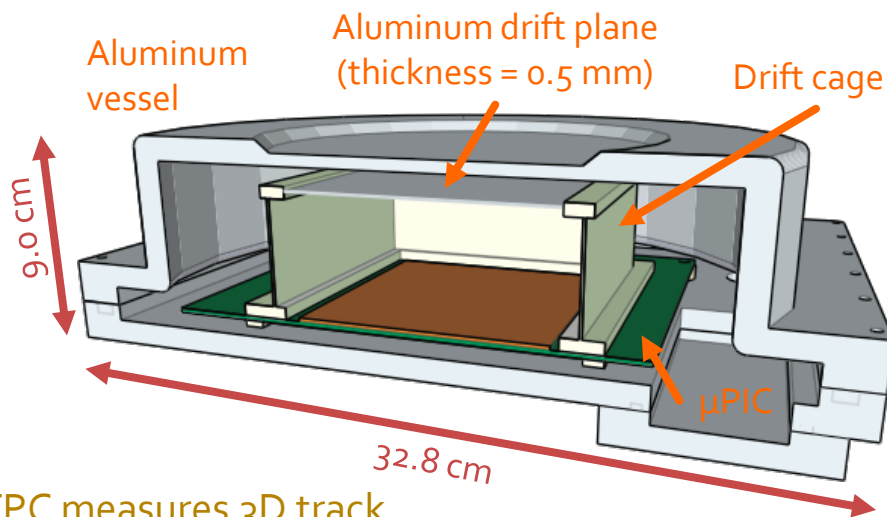
μ PIC ($10 \times 10 \text{ cm}^2$)



- Anode pitch: 400 μm .
- 256 \times 256 strip read-out ($10 \times 10 \text{ cm}^2$ size).
- Maximum gain: ~ 15000 .
- Energy resolution: 22% @ 5.9 keV.
- Gain uniformity: $\sim 4\%$ (σ).
- > 1 month stable operation at gain of ~ 6000 .

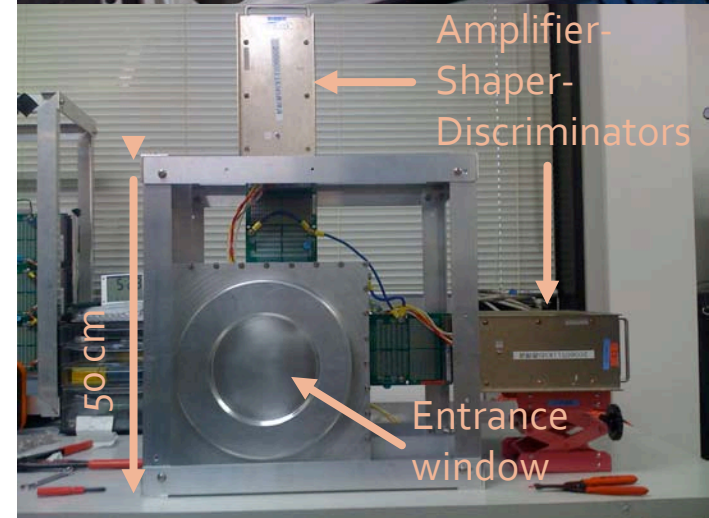
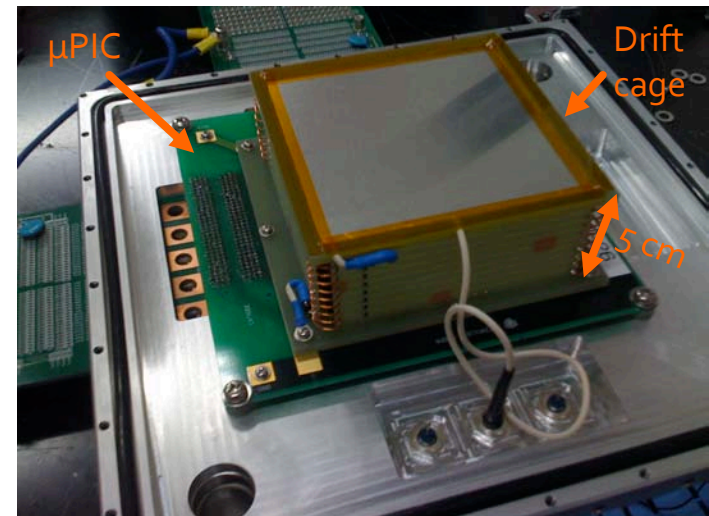


Neutron imaging detector (NID) prototype

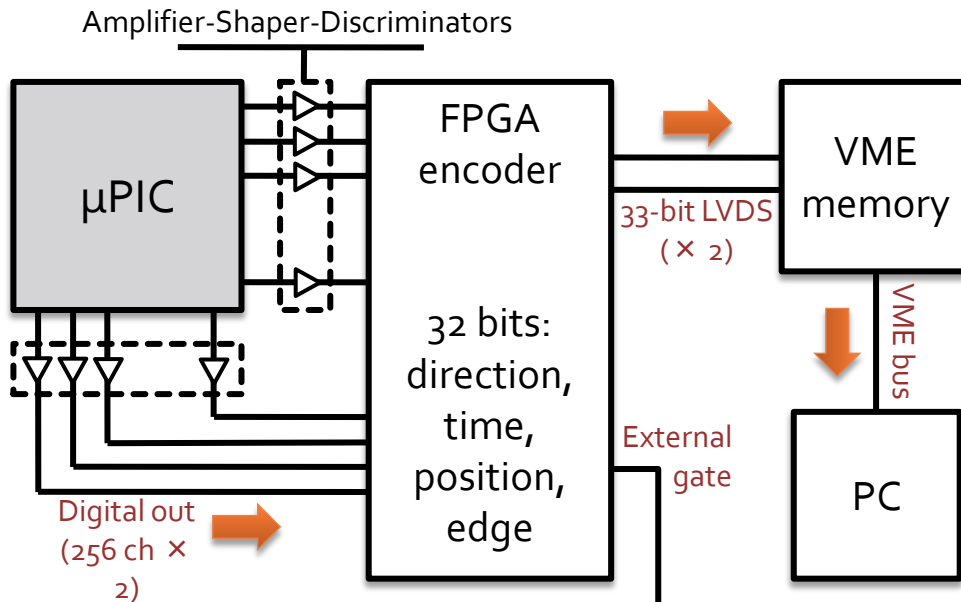


TPC measures 3D track of proton-triton pair.

- Active volume: $10 \times 10 \times 5 \text{ cm}^3$.
- Gas mixture: Ar-C₂H₆-³He (up to 2 atm total pressure).
- Position resolution: $< 0.4 \text{ mm}$.
- Time resolution: $\sim 1 \mu\text{s}$ (for neutron event).
- Detection efficiency: up to $\sim 30\%$ (for thermal neutrons).

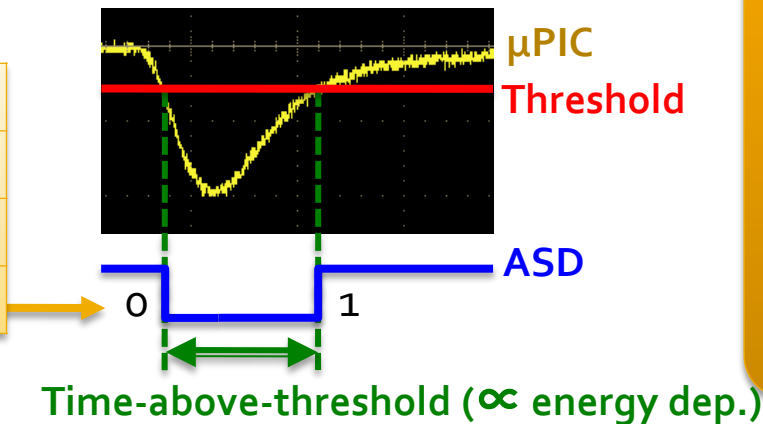


X-ray mode 8



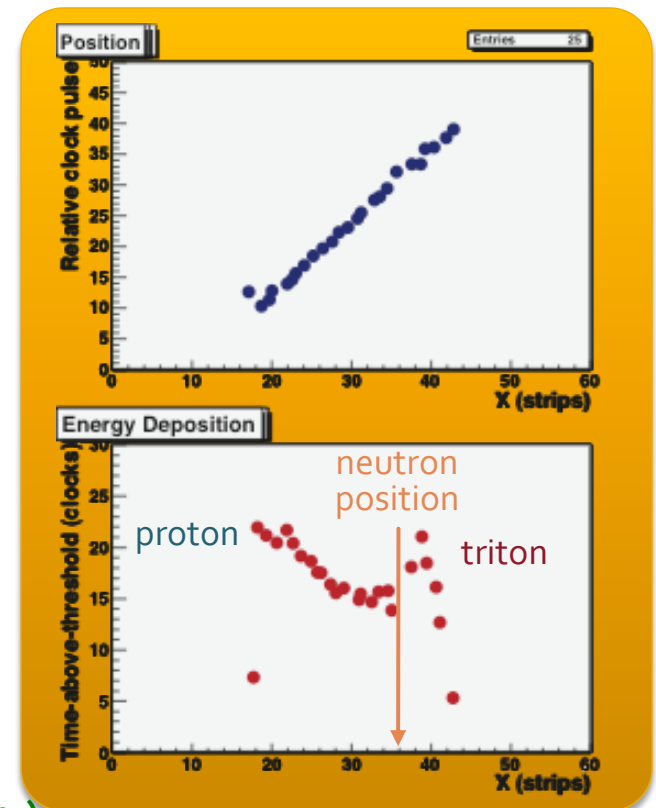
Data structure

1 bit	orientation
20 bits	time
10 bits	strip no.
1 bit	edge



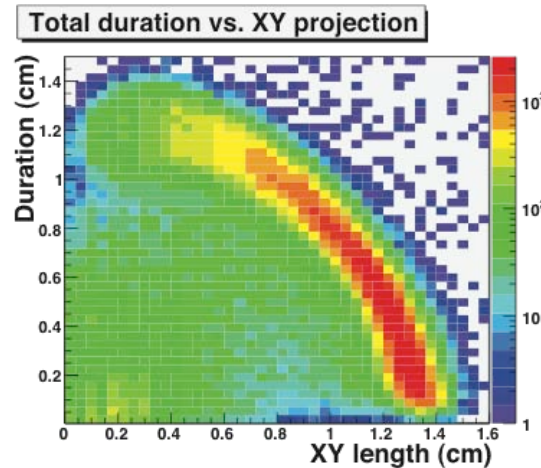
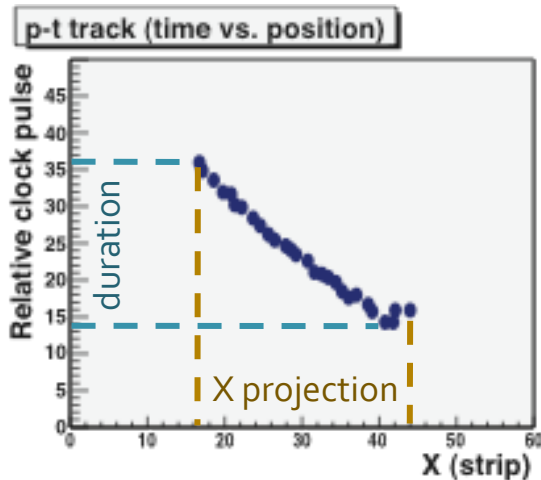
Proton and triton ID from pulse-width distribution.

> 2 × improvement in position resolution.



Proton-triton track length

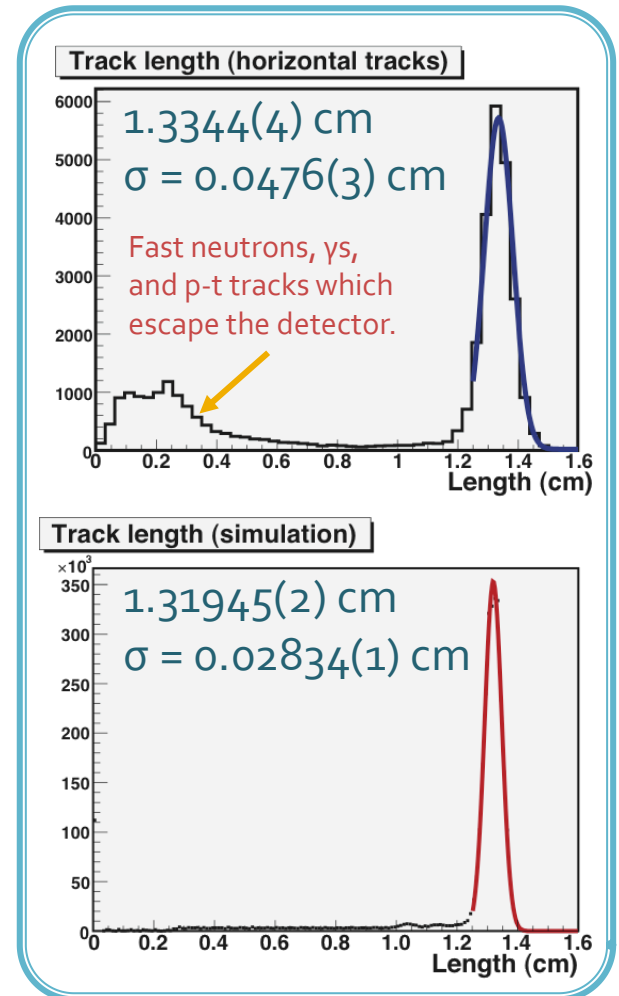
- Data taken at Kyoto U. Tandem van de Graaff.
- Neutrons from ${}^7\text{Li}(p,n){}^7\text{Be}$ reaction ($T_p = 3 \text{ MeV}$).
- Gas mixture: Ar(82.8%)-C₂H₆(9.2%)-³He(8%) at 1 atm.
- Gas gain: ~1000.



2D width from strips + time → 3D track

Time-to-distance: duration × drift velocity × 10 ns/clock pulse

Drift velocity: ~34 μm/ns.

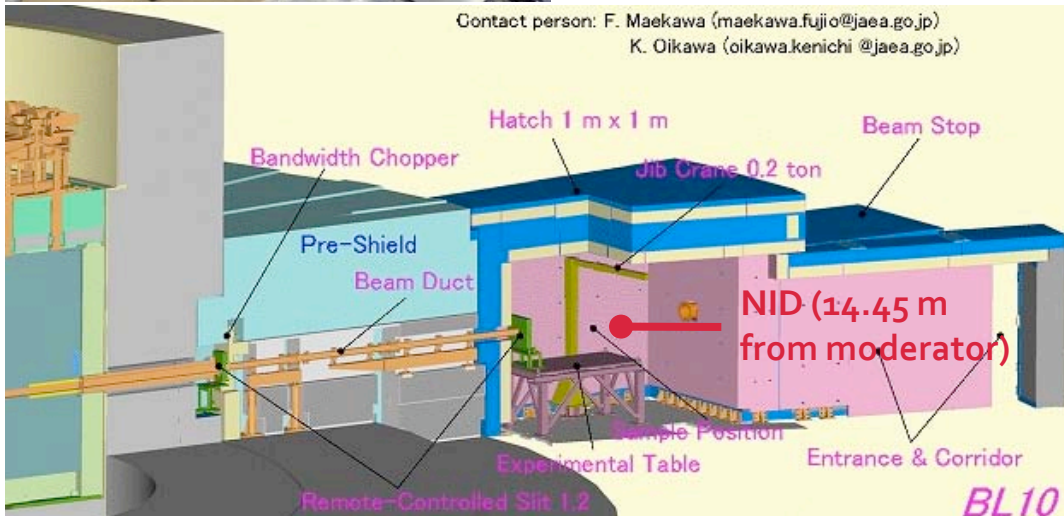


Test experiment at J-PARC



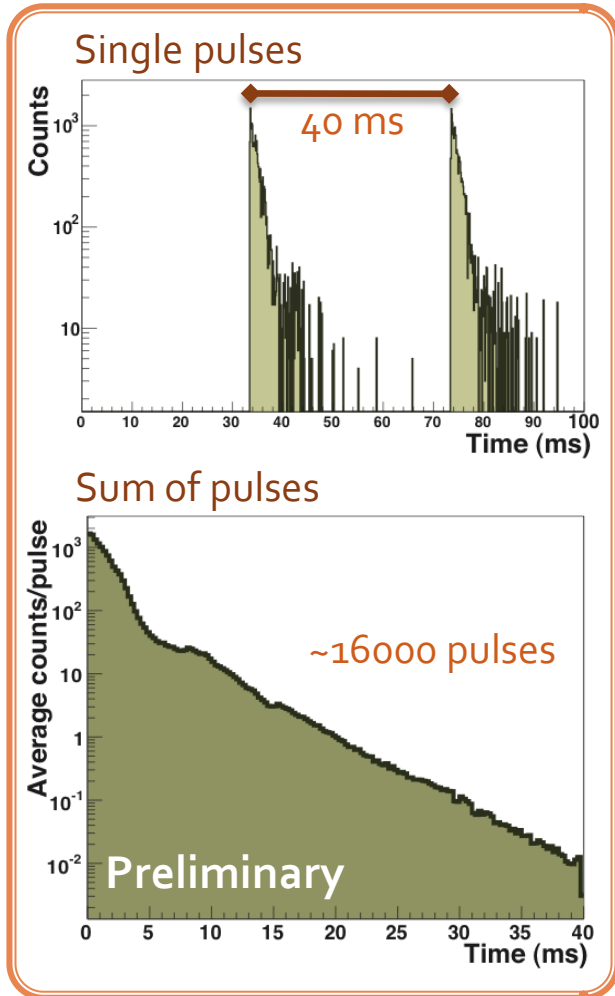
Experiment objectives

- Rate dependence of DAQ.
- Position resolution.
- Selection of neutron energy by time-of-flight.
- Demonstrate SANS and radiography.

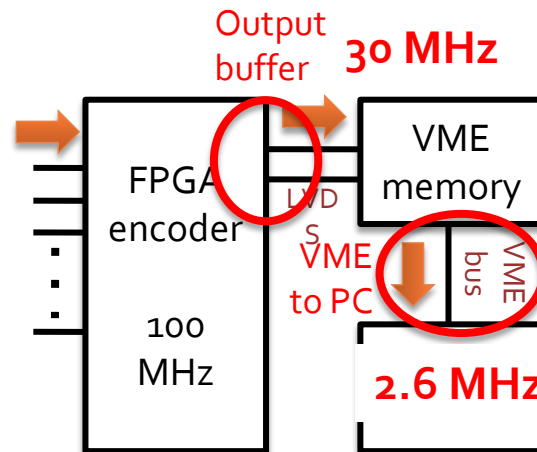


- Gas mixture: Ar(63%)- C_2H_6 (7%)- 3He (30%) at 2 atm.
- Detection efficiency: ~30%.

Neutron pulses and DAQ rate



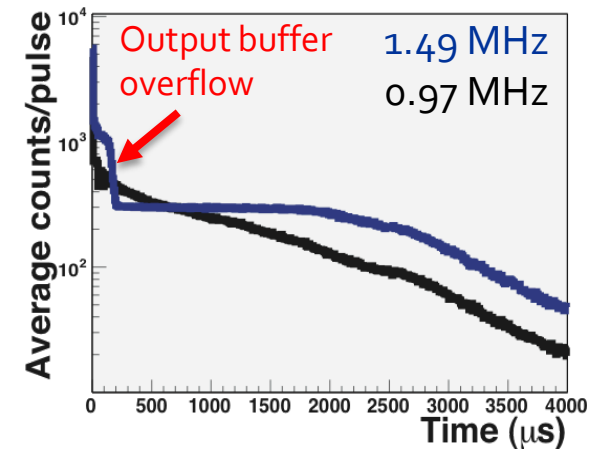
DAQ bottlenecks



- Encoder output buffer (limits DAQ rate).
- VME-to-PC data transfer (limits DAQ live time).

Data rates observed at J-PARC

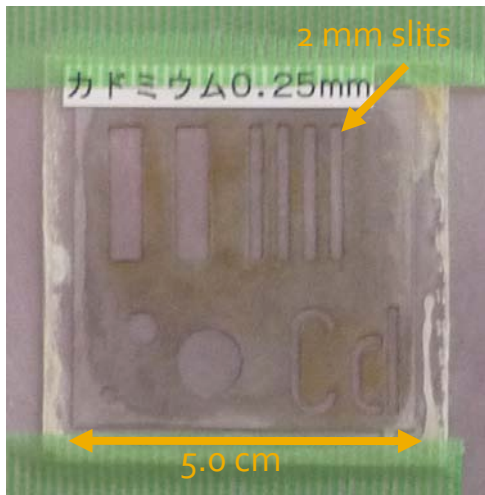
- 100 kHz ~ 1.5 MHz.
- ~70 MHz peak rate.



Max. rate ~1.4 MHz.

DAQ live time ~20% at 1.49 MHz.

Position resolution



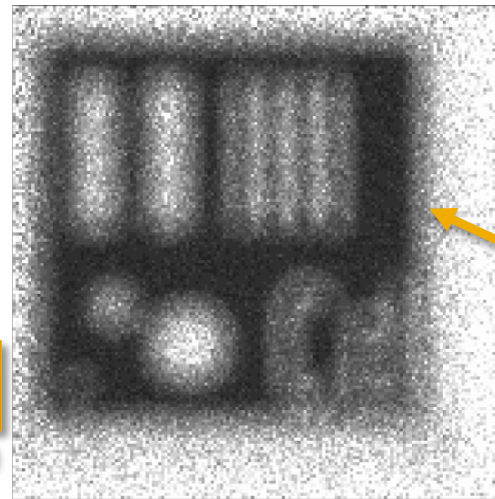
0.25-mm Cd test chart

DAQ rate: ~1.2 MHz

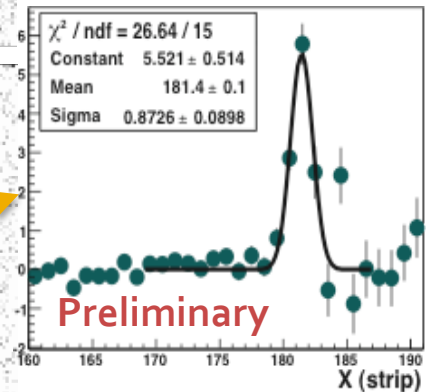
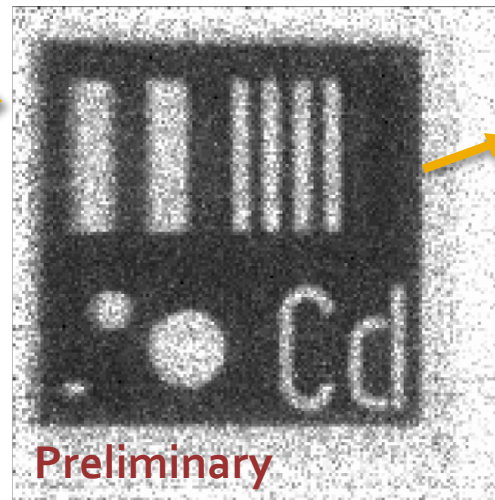
Exposure time: 8.9 min
(with live DAQ)

No proton ID

plus
proton
ID

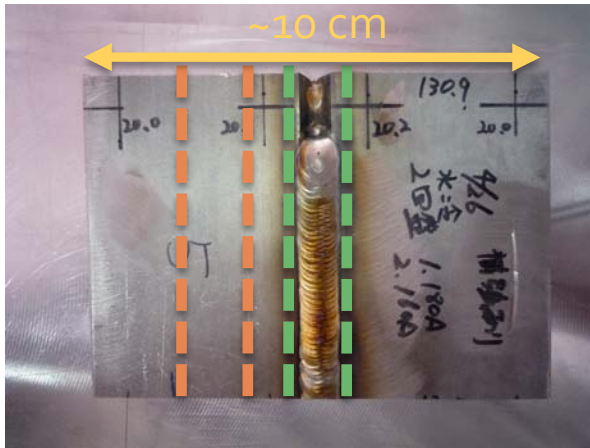


Proton ID from pulse-width distribution.
Corrected neutron interaction point.



Resolution from edge:
 $349 \pm 36 \mu\text{m} (\sigma)$

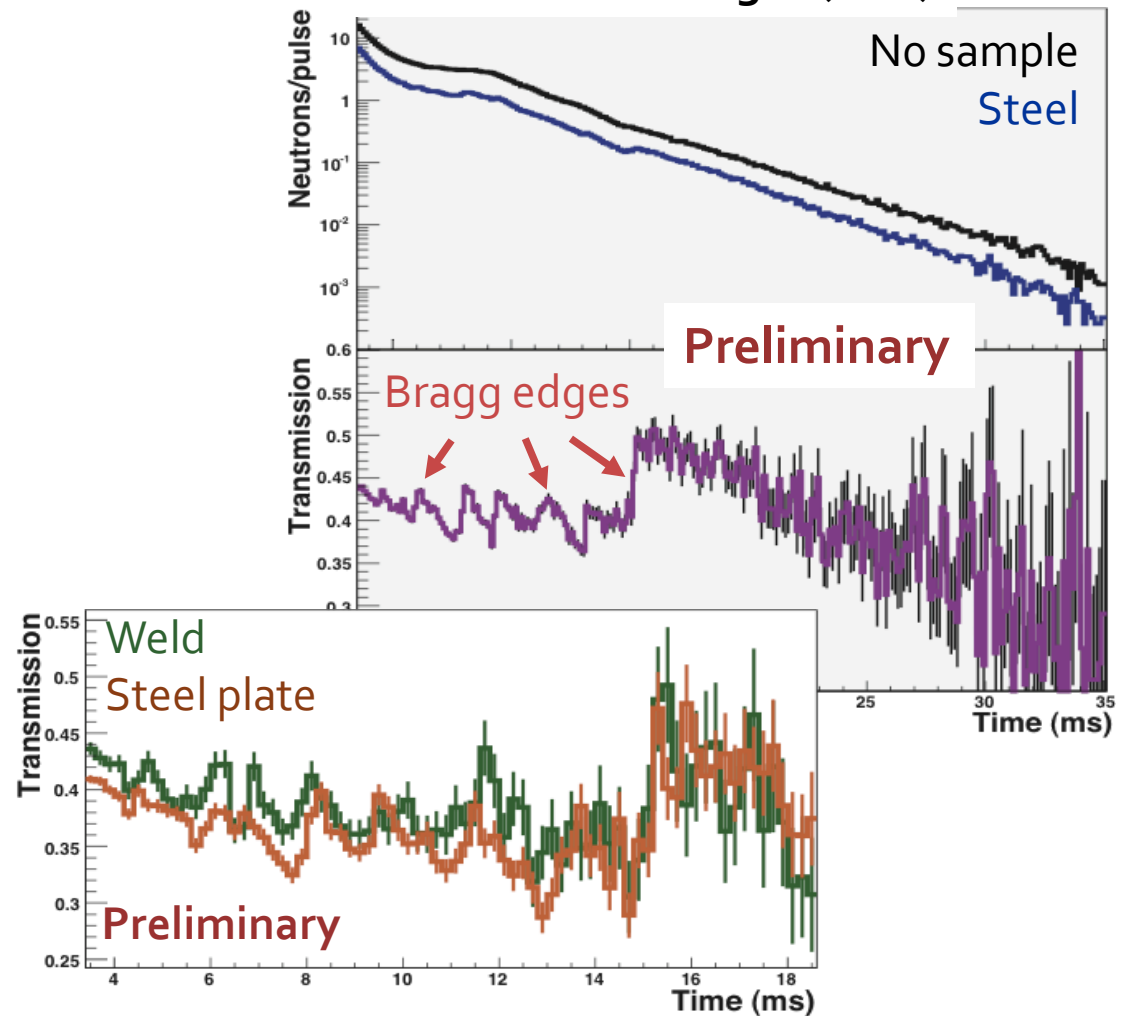
Radiography



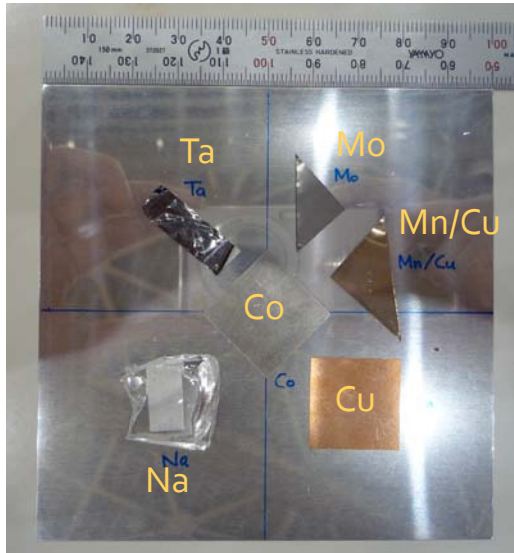
1-cm welded steel plate
DAQ rate: 972 kHz
Exposure time: 10.5 min

Bragg edges are clearly visible.

Neutron time-of-flight (TOF)



Resonance imaging

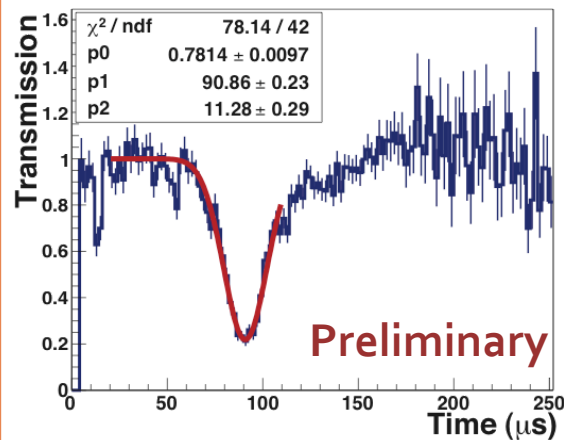


Assorted metals

DAQ rate: 1.48 MHz

Exposure time: 5.5 min

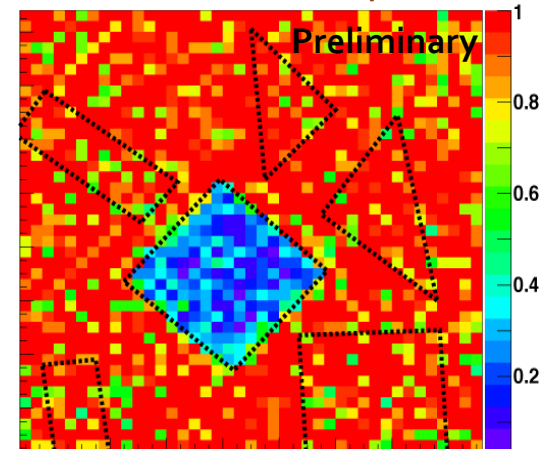
Transmission for ^{59}Co



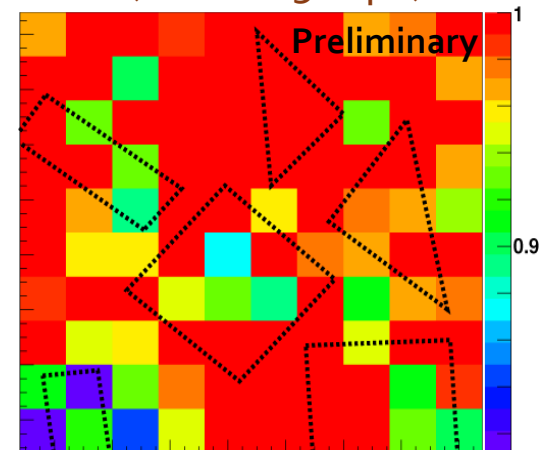
- Known resonance at 132 eV (TOF = 90.9 μs).
- Observed at $90.86 \pm 0.23 \mu\text{s}$.

Neutrons at resonance energy for selective imaging.

^{59}Co (TOF = 90.9 μs)



^{23}Na (TOF = 19.6 μs)

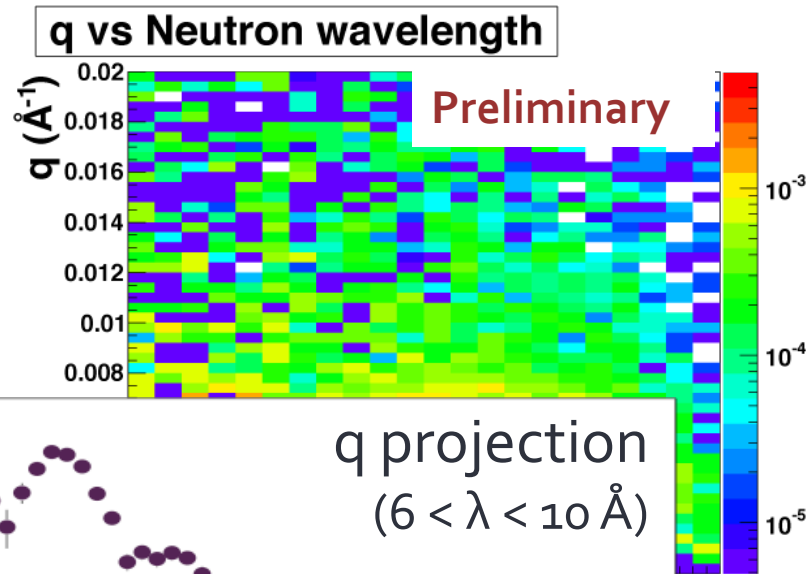


Small-angle neutron scattering

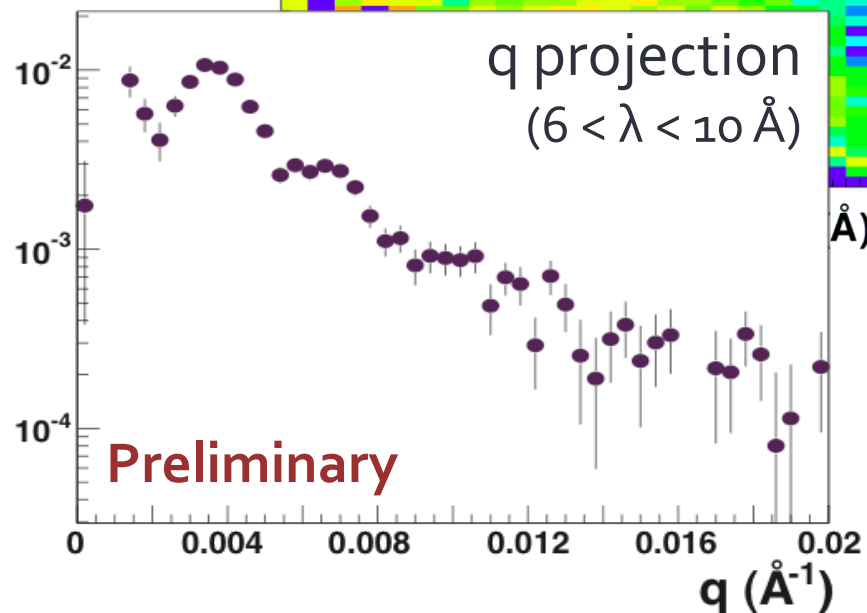
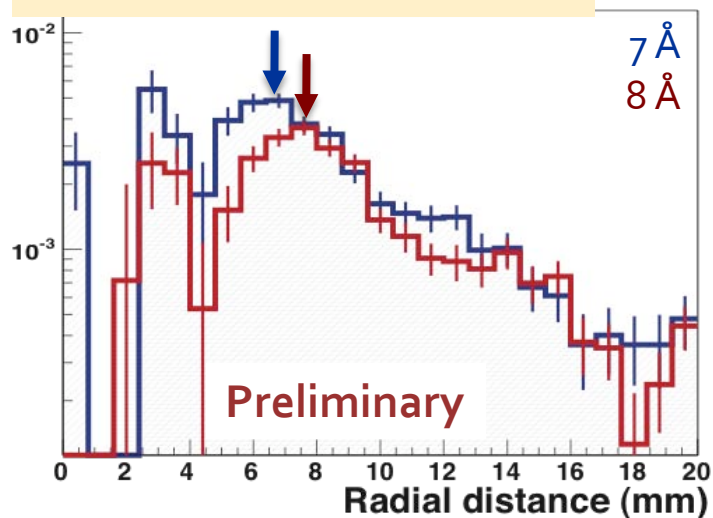


~1 cm

Spherical SiO₂ nanoparticles
Diameter: ~200 nm.
Sample distance: 1666 mm.
Beam size: 4 × 4 mm².
DAQ rate: 520 kHz.
Exposure time: 35.0 min.



Distance from beam center



Summary

- TPC based on micro-pattern gaseous detector and FPGA DAQ system.
 - Position resolution of < 0.4 mm; timing resolution of ~ 1 μ s.
 - High data rates.
- Strong rejection of background gammas and fast neutrons.
- Detector performance studied at J-PARC:
 - Confirmed good position resolution with DAQ X-ray mode 8.
 - Selection of neutron energy by time-of-flight.
 - Demonstrated application to SANS and radiography.
- μ PIC system is available in 10×10 cm², 20×20 cm², and 30×30 cm².
 - Second 10-cm system built for JAEA.
 - Now setting up 20-cm neutron imaging detector for use at 京大.