Development of a Neutron Imaging Detector Based on the μPIC Micro-Pixel Gaseous Chamber
μPIC (Micro-Pixel Gaseous Chamber)

- Anode pitch: 400 μm.
- 256 × 256 strip read-out (10 × 10 cm² size).
- Maximum gain: ~15000.
- Energy resolution: 22% @ 5.9 keV.
- Gain uniformity: ~4% (σ).
- > 1 month stable operation at gain of ~6000.
Neutron imaging detector (NID) prototype

- Active volume: $10 \times 10 \times 5 \text{ cm}^3$.
- Gas mixture: Ar-$\text{C}_2\text{H}_6^{-}\text{He}$ (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).

TPC measures 3D track of proton-triton pair.
Data structure

<table>
<thead>
<tr>
<th>Bit(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Orientation</td>
</tr>
<tr>
<td>20</td>
<td>Time</td>
</tr>
<tr>
<td>10</td>
<td>Strip no.</td>
</tr>
<tr>
<td>1</td>
<td>Edge</td>
</tr>
</tbody>
</table>

Proton and triton ID from pulse-width distribution.

> 2 × improvement in position resolution.
Data taken at Kyoto U. Tandem van de Graaff.

Neutrons from $^7\text{Li}(p,n)^7\text{Be}$ reaction ($T_p = 3$ MeV).

Gas mixture: $\text{Ar}(82.8\%)-\text{C}_2\text{H}_6(9.2\%)-\text{He}(8\%)$ at 1 atm.

Gas gain: $\sim 1000$.

Fast neutrons, γs, and p-t tracks which escape the detector.

1.3344(4) cm
$\sigma = 0.0476(3)$ cm

1.31945(2) cm
$\sigma = 0.02834(1)$ cm

Time-to-distance: duration $\times$ drift velocity $\times$ 10 ns/clock pulse

Drift velocity: $\sim 34$ 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$_2$H$_6$(7%) - $^3$He(30%) at 2 atm.
- Detection efficiency: ~30%.

NID (14.45 m from moderator)
Neutron pulses and DAQ rate

Single pulses
- 40 ms

Sum of pulses
- ~16000 pulses

DAQ bottlenecks
- Encoder output buffer (limits DAQ rate).
- VME-to-PC data transfer (limits DAQ live time).
- Output buffer overflow
  - 0.97 MHz
  - 1.49 MHz

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)

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

Position from mid-point of p-t track.
Resolution: $960 \pm 105 \mu m (\sigma)$

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

No sample
Steel

Preliminary
Resonance imaging

Assorted metals
DAQ rate: 1.48 MHz
Exposure time: 5.5 min

Neutrons at resonance energy for selective imaging.

Transmission for $^{59}$Co

- Known resonance at 132 eV (TOF = 90.9 μs).
- Observed at 90.86 ± 0.23 μs.

$^{59}$Co (TOF = 90.9 μs)

$^{23}$Na (TOF = 19.6 μs)
Small-angle neutron scattering

Spherical SiO$_2$ nanoparticles
Diameter: ~200 nm.
Sample distance: 1666 mm.
Beam size: $4 \times 4$ mm$^2$.
DAQ rate: 520 kHz.
Exposure time: 35.0 min.

Preliminary
Position of diffraction peak depends on wavelength.
Peak is constant in $q$.

Distance from beam center

$q$ vs Neutron wavelength

$q$ projection ($6 < \lambda < 10$ Å)
Summary

- TPC based on micro-pattern gaseous detector and FPGA DAQ system.
  - Position resolution of < 0.4 mm; timing resolution of ~1 μs.
  - 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.
- μPIC system is available in $10 \times 10$ cm$^2$, $20 \times 20$ cm$^2$, and $30 \times 30$ cm$^2$.
  - Second 10-cm system built for JAEA.
  - Now setting up 20-cm neutron imaging detector for use at 京大.