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

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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

TPC measures 3D track of proton-triton pair.

- Active volume: $10 \times 10 \times 5 \text{ cm}^3$.
- Gas mixture: Ar-$\text{C}_2\text{H}_6$-$^3\text{He}$ (up to 2 atm total pressure).
- Position resolution: < 0.4 mm.
- Time resolution: $\sim 1 \mu\text{s}$ (for neutron event).
- Detection efficiency: up to $\sim 30\%$ (for thermal neutrons).
Proton and triton ID from pulse-width distribution.

> 2 × improvement in position resolution.

Data structure:

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

μPIC

Threshold

Time-above-threshold (≠ energy dep.)
Data taken at Kyoto U. Tandem van de Graaff.
- Neutrons from $^7$Li(p,n)$^7$Be reaction ($T_p = 3$ MeV).
- Gas mixture: Ar(82.8%)-$C_2H_6$(9.2%)-$^3$He(8%) at 1 atm.
- Gas gain: ~1000.

$\sigma = 0.0476(3) \text{ cm}$

Fast neutrons, $\gamma$s, and p-t tracks which escape the detector.

$\sigma = 0.02834(1) \text{ cm}$

2D width from strips + time $\rightarrow$ 3D track

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

Drift velocity: $\sim 34 \mu\text{m/ns}$. 
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: $\text{Ar}(63\%)-\text{C}_2\text{H}_6(7\%)-\text{He}(30\%)$ at 2 atm.

Detection efficiency: $\sim30\%$. 
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).

**Data rates observed at J-PARC**
- 100 kHz ~ 1.5 MHz.
- ~70 MHz peak rate.
- 1.49 MHz
- 0.97 MHz

**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)

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

Position from midpoint 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.
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)
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

Preliminary

q vs Neutron wavelength

Preliminary

q projection (6 < λ < 10 Å)
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 × 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.