TPCs for neutron

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Outline

- nTPC: TPC as a fast neutron spectrometer
  - Working principle
  - Performance simulation
  - System design
  - Neutron beam test results
- nimTPC: TPC as a fast neutron imaging detector
  - Working principle
  - Simulation
nTPC Working Principle: Elastic Scattering with H

- Neutron energy: \( E_n = \frac{E_p}{\cos^2 \theta} = E_p \left(1 + \tan^2 \theta\right) = E_p \left(1 + \frac{1}{k^2}\right) \)

- Energy of recoil proton (\( E_p \)): total charge of all the pads
  
  other options: track length, \( dE/dx \) …

- Slope of proton track \( k \): track fitting
Initial energy of proton $E_{p0}$

Energy deposited in TPC $E_p$

$E_p = \sum E_{pad,i}$

Neutron's energy spectrum

$E_n = 5\text{MeV}$

$f(\theta) = \sin 2\theta$

Proton's recoil angle $\theta$
Simulation result of energy resolution and efficiency

<table>
<thead>
<tr>
<th>Neutron energy</th>
<th>Gas</th>
<th>Cutting angle</th>
<th>Energy resolution (FWHM)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5MeV</td>
<td>Ar-C$_2$H$_6$(50-50)</td>
<td>$&lt;30^\circ$</td>
<td>4.0%</td>
<td>1.6x10$^{-3}$</td>
</tr>
<tr>
<td></td>
<td>Ar-CH$_4$(70-30)</td>
<td>$&lt;30^\circ$</td>
<td>4.0%</td>
<td>6.3x10$^{-4}$</td>
</tr>
<tr>
<td>2.5MeV</td>
<td>Ar-C$_2$H$_6$(50-50)</td>
<td>$&lt;30^\circ$</td>
<td>4.9%</td>
<td>1.2x10$^{-3}$</td>
</tr>
<tr>
<td></td>
<td>Ar-CH$_4$(70-30)</td>
<td>$&lt;30^\circ$</td>
<td>5.6%</td>
<td>9.9x10$^{-4}$</td>
</tr>
</tbody>
</table>

**System Design**

### nTPC design parameters

<table>
<thead>
<tr>
<th>Detector</th>
<th>Size</th>
<th>(\Phi 30\text{cm} \times 50\text{cm} ) (TU-TPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Ar-CH(_4) (70-30) or Ar-C(_2)H(_6) (50-50)</td>
<td></td>
</tr>
<tr>
<td>Drift field</td>
<td>~200V/cm</td>
<td></td>
</tr>
<tr>
<td>Readout detector</td>
<td>3GEM</td>
<td></td>
</tr>
<tr>
<td>pad</td>
<td>ring, 5mm (\times) 2mm</td>
<td></td>
</tr>
</tbody>
</table>

| ASIC     | Shaping time | 80ns                                             |
|          | Gain         | 2mV/fC                                           |

| DAQ      | Sampling parameters | 12bit, 25MHz                                    |
|          | Triggering Mode    | Single trigger                                   |

<table>
<thead>
<tr>
<th>Data processing</th>
<th>Platform</th>
<th>Labview</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mode</td>
<td>Online</td>
</tr>
</tbody>
</table>

Based on: TU-TPC

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Neutron Beam Test - Setup

- Level Monitor
- DAQ
- DAQ Source
- CASA-GEM
- nTPC
- PE Collimator
- Paraffin Shield
- Target Position
- Beam Pipe

Neutron energy: 1.2MeV, 1.81MeV, 2.5MeV
Gas: Ar-CH₄(70-30)
Drift field: 176.5V/cm
Voltage over GEM: 350V
Readout channels: 448

@ Key Laboratory of Nuclear Data Measurement and Evaluation Technology, China Institute of Atomic Energy
Discrimination of Background Events (1)

Associated $\gamma$:  

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$^{28}\text{Si}$</th>
<th>$^{40}\text{Ca}$</th>
<th>$^{12}\text{C}$</th>
<th>$^{16}\text{O}$</th>
<th>$^{27}\text{Al}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inelastic $\gamma$ rays (MeV)</td>
<td>1.78</td>
<td>3.73</td>
<td>4.43/3.216</td>
<td>6.13/7.12</td>
<td>1.81/1.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$^{1}\text{H}$</th>
<th>$^{28}\text{Si}$</th>
<th>$^{35}\text{Cl}$</th>
<th>$^{40}\text{Ca}$</th>
<th>$^{56}\text{Fe}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture $\gamma$ rays (MeV)</td>
<td>2.23</td>
<td>3.44/1.95</td>
<td>6.11/6.64</td>
<td>6.14</td>
<td>7.64</td>
</tr>
</tbody>
</table>

**Discrimination method:**
- Starting position of track
- $(-dE/dx)_{ion}$

<table>
<thead>
<tr>
<th>Source</th>
<th>Discrimination method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{1}\text{H}$</td>
<td>Collision of scattering neutrons with working gas</td>
</tr>
<tr>
<td>$^{12}\text{C}$</td>
<td>Collision of incident neutrons with working gas</td>
</tr>
<tr>
<td>$^{40}\text{Ar}$</td>
<td>Collision of incident neutrons with working gas</td>
</tr>
<tr>
<td>$e^{-}$</td>
<td>Interaction of gamma with working gas</td>
</tr>
<tr>
<td>$^{1}\text{H}$</td>
<td>Edge protons</td>
</tr>
</tbody>
</table>
Discrimination of Background Events (2)

Track length (mm) vs. deposited energy (pC)

Deposited energy (pC) vs. recoil angle (Degree)

- (a) Track length (mm) vs. charge collected (pC)
  - $E_n = 2.5\text{MeV}$
  - 1. Normal Proton Events
  - 2. Edge Proton Events
  - 3. $^{40}$Ar and $^{12}$C Events
  - 4. Gamma Events

- (b) Deposited energy (pC) vs. reconstructed inclination angle with Z-axis (degree)
  - $E_n = 2.5\text{MeV}$
  - 1. Normal Proton Events
  - 2. Edge Proton Events
  - 3. $^{40}$Ar and $^{12}$C Events
  - 4. Gamma Events
Reconstruction of Neutron Spectrum

Deposited energy vs. recoil angle $\theta$

- **1.2MeV**
  - $E_n=1.2\text{MeV}$
  - Peak=22.8pC

- **1.81MeV**
  - $E_n=1.81\text{MeV}$
  - Peak=30.3pC

- **2.5MeV**
  - $E_n=2.5\text{MeV}$
  - Peak=39.7pC

Reconstructed neutron spectrum

- **Cut**: $\text{dep}>1\text{pC (} \sim 60\text{keV)}$, $\theta < 30^\circ$

Charge response vs. neutron energy

- **Equation**: $y = a + b \times x$
- **Adj. R-Square**: 0.99894
- **Value**
  - intercept: 7.31042 ± 0.49853
  - slope: 12.87288 ± 0.29654

Working gas: Ar-CH$_4$ (70-30)
Voltage of GEM: 350V
Cut of Recoil Angle: $\theta < 30^\circ$
Energy Resolution vs Detection Efficiency (1)

Cut: $\text{dep} > 1\text{pC}$ ($\sim 60\text{keV}$), $\theta < 30^\circ$

Cutting angle

Track fitting length (relative)

$E_n = 2.5\text{MeV}$

Energy resolution from $11.7\%$ to $9.1\%$ (FWHM)

Energy Resolution vs Detection Efficiency

Optimized results of the neutron energy resolution

<table>
<thead>
<tr>
<th>Neutron energy</th>
<th>recoil angle cutting</th>
<th>Track fitting part (ratio)</th>
<th>Starting position</th>
<th>Energy resolution (FWHM)</th>
<th>Detection efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 MeV</td>
<td>30°</td>
<td>0-1</td>
<td>$r_{st} &lt; 10\text{mm}$</td>
<td>Simulation: 15.7%</td>
<td>Experiment: 14.6%</td>
</tr>
<tr>
<td>1.81 MeV</td>
<td>30°</td>
<td>0.1-0.6</td>
<td>$r_{st} &lt; 5\text{mm}$</td>
<td>Simulation: 10.3%</td>
<td>Experiment: 8.3%</td>
</tr>
<tr>
<td>2.5 MeV</td>
<td>25°</td>
<td>0.1-0.4</td>
<td>$r_{st} &lt; 5\text{mm}$</td>
<td>Simulation: 7.0%</td>
<td>Experiment: 6.3%</td>
</tr>
</tbody>
</table>

Due to that the effective readout pads only covers about 45° angle range, the detection efficiency of the neutron-TPC could be improved further by add more channel.
Outline

• **nTPC: TPC as a fast neutron spectrometer**
  – Working principle
  – Simulation
  – System design
  – Neutron beam experiment results

• **nimTPC: TPC as a fast neutron imaging detector**
  – Working principle
  – Simulation
TPC for Fast Neutron Imaging: Working Principle

Event reconstruction:
(1) Time windows:
(2) $p \perp n$

- $p$: direction of track
- $n$: vector between positions of 2 events

Energy, direction of both $p$ and $p'$ measured:
Both energy and direction of $n_0$ can be determined.

Energy, direction of $p$, and start position of $p'$ measured:
Direction of $n_0$ limited to $<90^\circ$ in a plane.
TPC for Fast Neutron Imaging: Simulation

Φ30cm × 50cm TPC filled with Ar-C$_2$H$_6$ (50-50), no outer-ring neutron converters. 2MeV neutrons incidented from the axial direction.

① line-line
FWHM ~ 8.0% @ 2.5MeV

② line-point
FWHM ~ 8.9° @ 2.5MeV
Efficiency: 1.38 × 10$^{-5}$
Conclusion

• nTPC is developed as a fast neutron spectrometer;
• High energy resolution with relatively high efficiency;
• Energy resolution reach 7.0% (FWHM) @ 2.5 MeV;
• Detection efficiency > $10^{-5}$ @2.5MeV;

• nimTPC for fast neutron imaging is under developed;
• Angle resolution $\sim 4.8^\circ$ (FWHM) @2.5MeV in simulation;
• Total detection efficiency $\sim 1.7 \times 10^{-5}$@2.5MeV in simulation.
THANKS A LOT!!