A GEM-Based Time Projection Chamber for J-PARC Hadron Physics Program

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for the J-PARC E42/45 Collaboration

Outline
- Motivation (J-PARC Experiments)
- Introduction of HypTPC
- High-Rate Beam Test Results
J-PARC E42 Experiment

- Search for H-dibaryon via $^{12}$C(K-,K+) reactions

**Simulation**

\[ \sigma_{\Delta M} \sim 1 \text{ MeV} \]

\[ 90 \Lambda\Lambda \text{ events} \]

\[ \sigma_{\Delta M} \sim 5 \text{ MeV} \]

\[ 90 \Lambda\Lambda \text{ events} \]

KEK E522

- KURAMA Spectrometer
- Hyperon Spectrometer
- K1.8 Beam Line Spectrometer

**J-PARC E42**

- High Resolution
- High Statistics

- SC Magnet
- HypTPC

- K1.8 Beam Line in Hadron Hall, J-PARC
J-PARC Hadron Experiments with HypTPC

HypTPC - Main tracking device

H-Dibaryon Search

N* Baryon Spectroscopy

New Λ* Resonance Search near Λη Threshold
HypTPC
-Structure

[explosion view]

Gas Vessel

Target Holder

Field Cage

Gating Grid

Triple GEM

Pad Plane

E=130 V/cm
Field Cage Structure

- Drift length: 55 cm
- 1 atm P-10 gas, 130 V/cm
- Target inside drift volume for a large acceptance
- Beam slits to avoid charge build-up on the field cage in high rate beam.
Gating Grid Plane

- Gate operation to suppress the ion back flow

Between Drift & Amplification Region

Gate Operation with $V_{\text{Gate}} = \pm 25$ V
Triple GEM Layer

- Low ion back flow rate
- Triple GEM layers (50+50+100 μm)
- Gain ~$10^4$
- Segmented electrodes

**Gating wires**

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Potential</th>
<th>Electric Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 μm GEM</td>
<td>$V_{GEM}$</td>
<td>2 kV/cm</td>
</tr>
<tr>
<td>50 μm GEM</td>
<td>$V_{GEM}$</td>
<td>2 kV/cm</td>
</tr>
<tr>
<td>100 μm GEM</td>
<td>$1.5V_{GEM}$</td>
<td>3.1 kV/cm</td>
</tr>
</tbody>
</table>

**Amplification Region**

- 130 V/cm ($E_{Drift}$)
- 4.2 mm

**[Top view]**

- 500 mm

**[Side view]**

- 500 mm

**Target position**

- 143
## GEM Specification

<table>
<thead>
<tr>
<th></th>
<th>50 μm GEM</th>
<th>100 μm GEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Raytech</td>
<td>Raytech</td>
</tr>
<tr>
<td><strong>Insulator</strong></td>
<td>Polyimide (PI)</td>
<td>Liquid Crystal Polymer (LCP)</td>
</tr>
<tr>
<td><strong>Etching method</strong></td>
<td>Wet</td>
<td>Laser</td>
</tr>
<tr>
<td><strong>Cu thickness</strong></td>
<td>4 μm</td>
<td>9 μm</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
<td>140 μm</td>
<td>140 μm</td>
</tr>
<tr>
<td><strong>Inner diameter</strong></td>
<td>25 ± 10 μm</td>
<td>35 ± 10 μm</td>
</tr>
<tr>
<td><strong>Outer diameter</strong></td>
<td>55 ± 5 μm</td>
<td>65 ± 5 μm</td>
</tr>
</tbody>
</table>
Pad Plane

- 5768 readout pads
- Concentric configuration around the target
- 10 inner layers: 2.1-2.7 $\times$ 9 mm$^2$
- 22 outer layers: 2.3-2.4 $\times$ 12.5 mm$^2$
GET (General Electronics for TPCs)

- ZAP+AsAd
  - 4 AGET chips
  - Preamplifier (gain 120 fC-10 pC)
  - Shaper (peaking time 50 ns-1 μs)
  - Circular Buffer (sampling rate 1-100 MHz)
  - 12-bit ADC

- TPC 5768 Pads

- CoBo
  - Data processing
  - Data formatting

- MuTanT
  - Synchronous trigger

- MCH (μTCA Carrier Hub)

- μTCA crate

- HDD

- DAQ PC
  - Run control
  - Data flow management
  - Data storage

~2000 MB/s
10 GbE
25 MHz
1 GbE
~230 MB/s

HypTPC

E. Pollacco et al., NIMA 887 (2018) 81
HypTPC Commissioning at HIMAC

- To study the basic performance and the high rate capability of TPC

Submitted to NIMA
Beam Event

- Sampling freq.: 12.5 MHz
- Readout depth: 200
  \((80 \text{ ns} \times 200 = 16 \, \mu\text{s})\)
- \(\Delta = (\text{Max} + \text{Min})/2 - \text{Ped} > 20\)
- GEM frame region pads excluded
3D Track Reconstruction

At $E=130\,\text{V/cm}$ in P-10 gas,

Drift Velocity = **5.00 cm/μs**

$x,z \leftarrow$ Pad plane

$y \leftarrow$ Time
Pad Detection Efficiency

\[
\text{Efficiency} = \frac{\# \text{ of clusters with the size } \geq N}{\# \text{ of tracks}}
\]

305 V, \sim 99%
Transverse Diffusion Coefficient, $D_T$

\[ \sigma_D(L) = \sqrt{\sigma_0^2 + D_T^2 L} \]

At $E=130$ V/cm, $B=0$ in P-10 gas,

$D_T = 0.57 \pm 0.02$ mm/$\sqrt{\text{cm}}$

\[ D_T(L) = \frac{\sigma^2}{2} + D_T^2 L \]

L=15 cm

L=30 cm

L=45 cm
Transverse Spatial Resolution, $\sigma_T$

$E=130$ $V/cm$, $B=0$, P-10 gas

$$\sigma = \sqrt{\sigma_{incl} \cdot \sigma_{excl}}$$

$\sigma_T = 400 - 700$ $\mu$m
Expected $\sigma_T$ under the B Field

$E=130 \text{ V/cm}, B=0, P-10 \text{ gas}$

$\sigma = \sqrt{\sigma_{\text{incl}} \cdot \sigma_{\text{excl}}}$

$\sigma_T^2 = \sigma_0^2 + \frac{D_T^2}{N_{\text{eff}}} e^{-AL} L$

with $D_T = 0.57 \text{ mm}/\sqrt{\text{cm}}$

$\sigma_0 = 199 \pm 40 \mu m$

$N_{\text{eff}} = 42.1 \pm 8.1$

$A = 0.55 \pm 0.42 \text{ m}^{-1}$

with $D_T = 0.18 \text{ mm}/\sqrt{\text{cm}}$

at $B = 1 \text{ T}$

$\sigma_T = 230 - 300 \mu m$
Vertical Spatial Resolution, $\sigma_y$

$E = 130\ \text{V/cm},\ B = 0,\ \text{P-10 gas}$

$$\sigma = \sqrt{\sigma_{\text{incl}} \cdot \sigma_{\text{excl}}}$$

$\sigma_y = 500 - 800\ \mu\text{m}$
Scattering Event

- Hough Transform from the \((z, x)\) plane

\[ r = z \cdot \cos \theta + x \cdot \sin \theta \]

\((z, x)\) Space

\((r, \theta)\) Hough Space
Vertex Distribution

CH$_2$ Target size: 3 cm (x) x 6 cm (y) x 2 cm (z)
Beam Rate Study

1 kHz

100 kHz

1 MHz

Triggered event

Before trigger

After trigger

ADC [ch]

Time bucket [80 ns]

ADC [ch]

Time bucket [80 ns]

ADC [ch]

Time bucket [80 ns]
Beam Event at High-Rate Beam

- Hough Transform from the \((z, y)\) plane
  \[ r = z \cdot \cos \theta + y \cdot \sin \theta \]

\((z, y)\) Space

\((r, \theta)\) Hough Space
TPC Performance at High-Rate Beam

- Pad Efficiency
- Spatial Resolution

![Graphs showing pad efficiency and spatial resolution vs. beam rate (Hz)]
Summary

- A time projection chamber (HypTPC) has been newly developed for the various hadron experiments at J-PARC.
- We confirmed the basic performance and the high rate capability of HypTPC in the proton beam test at HIMAC.
- The first physics experiment with HypTPC (E42) is envisioned in 2020.

Stay tuned!
Backup
Scattering Events at 1 MHz Beam

- Hough Transform from the \((z, y)\) space to separate the accidental beam events
  \[ r = z \cdot \cos\theta + y \cdot \sin\theta \]

- Hough Transform from the \((z, x)\) space to separate the scattered particle tracks
  \[ r = z \cdot \cos\theta + x \cdot \sin\theta \]
How To Attach GEM Frame

- Glue
- Metal mask
- GEM frame
- Slits for glue
- Metal mask
- Weight (glass plate + α)
Tension of 0.24 Pa with 12 cylinders
The HDDAQ (K1.8 beam line DAQ) was used for the data acquisition of the trigger counters and the SSDs. The GET (TPC DAQ) shares the trigger and busy signal with HDDAQ using MuTanT module.
DAQ Performance

- Due to the gate noise, the full readout mode was used.
- The data size/CoBo for each event in the full readout mode with 200 time buckets was 426 kB and the measured data transfer speed for each CoBo was ~420 Mbps.

- The HIMAC beam had a spill structure with ~1 sec length in every ~3.3 sec cycle.
- The beam rate was varied in a range of $10^3 - 10^6$ cps.
- We used the pre-scaled trigger rate of ~230 Hz with ~100 % DAQ efficiency.
Upstream SSD Beam Profile

\( \sigma = 5.4 \text{ mm} \)

\( \sigma = 5.5 \text{ mm} \)
Baseline Correction

![Graph showing baseline correction before and after](image-url)
Superconducting Magnet

- Helmholtz-typed Magnet
- NbTi($T_c$=9 K), Cu/SC = 2.4
- 1.5 T Max. @ 103 A
- $\Delta B_y/B_0<3\%$ in TPC volume
E Field Calculation

Staggered Field Strip

Non-staggered
GEM Q/A with Test Chamber
GEM Q/A with Test Chamber