Current status of the thick-GEM TPC for the J-PARC E15 experiment

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J-PARC E15 Experiment

search for K-pp bound state using $^3\text{He}(K^-,n)$ reaction

$K^- \to 3\text{He}$

Formation

$K^- \text{pp}$ cluster

Decay

neutron

Mode to decay charged particles

$\Lambda$, $p$, $\pi^-$

exclusive measurement by

Missing mass spectroscopy and

Invariant mass reconstruction

at J-PARC
J-PARC E15 Setup

K1.8BR Beam Line

Cylindrical Detector System

mass resolution for K-pp

\begin{align*}
\text{invariant mass} & \quad \sigma = 19\text{MeV}/c^2 \ (\sigma_{\text{CDC}} = 250\mu\text{m}) \\
\text{missing mass (for 1.3GeV/c neutron)} & \quad \sigma = 9.2\text{MeV}/c^2 \ (\sigma_{\text{ToF}} = 150\text{ps})
\end{align*}
measurement of mesonic decay-mode of K⁻pp

important to measure not only non-mesonic decay mode but also mesonic decay mode

Thick-GEM TPC improves z-resolution
TGEM-TPC
for the J-PARC E15 exp.
TGEM-TPC for the J-PARC E15 exp.

- TGEM-TPC is located at the center of Cylindrical Detector System
  - located between CDC and target-chamber
  - cover the CDC acceptance of AUVA
  - minimum materials in the acceptance
  - 1mm spatial resolution in the z-direction

TGEM-TPC filled with P10 gas at atmospheric pressure
completed TGEM-TPC

field strip
- double sided
- FPC
- 8mm strip
- 10mm pitch

Gas connector
Field Cage 300mm
HV connector

R/O pad size 4mm × 20mm

# of pad = 4 × 4 × 9 = 144

TGEM

R/O

2 cm

28 cm

8mm

10mm

non-necessity of support-structure!
making of Field Cages

Large FPC board

sticking support frames on the FPC

soldering resistors (1MΩ)

rolling up the FPC

Inner and Outer field cages

uniting the two cages

completed
HV & Readout

HV connector (LEMO, max. 15kV)

150mm

prehamp attachment (test)

readout pad

readout with TGEM

to reduce detector capacitance, one side of TGEM is divided into 3 parts
Readout Electronics is the same as that of CDC

preamp cards and cables are attached

TDC’s in the counting room

LVDS→ECL converters at the exp. hall

Chip: CXA3183Q
(SONY, low noize ASD IC, \( \tau = 16 \text{nsec} \), \( \tau = 80 \text{nsec} \))

Output: LVDS differential

Gain: 0.8V/pC at preamp

4x4=16ch

We measure only time info. with the TPC!
limit of HV module: 15kV
GEM HV: 4kV
drift length: 30cm

maximum drift-field voltage: ~350V/cm

We choose P10 (Ar/CH₄=90/10) for the TGEM-TPC gas

gas

expected resolution

$$\sigma_x^2 = \sigma_0^2 + \frac{C_d^2 \cdot z}{N_{eff}}$$

- $\sigma_x$: total resolution
- $\sigma_0$: resolution w/o diffusion
- $C_d$: diffusion constant
- $z$: drift distance
- $N_{eff}$: effective number of electrons

$\phi$-direction resolution is limited by pad size, e.g.,
$20.0/\sqrt{12} = 5.8\text{mm}$
So we use only z-direction info.

- $E = 150\text{V/cm}$
  $\rightarrow C_{dl} = 0.34\text{mm}$, $C_{dt} = 0.60\text{mm}$
- $\sigma_{0l} = 0.5\text{mm}$
- $\sigma_{0t} = 0.2\text{mm}$
- $N_{eff} = 38.7 \times 0.4(\text{cm}) = 15.5$

<table>
<thead>
<tr>
<th>$z$ (cm)</th>
<th>$D_l$ (mm)</th>
<th>$D_t$ (mm)</th>
<th>$\sigma_l$ (mm)</th>
<th>$\sigma_t$ (mm)</th>
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<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
<td>0.20</td>
</tr>
<tr>
<td>10</td>
<td>1.09</td>
<td>1.89</td>
<td>0.57</td>
<td>0.52</td>
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<tr>
<td>20</td>
<td>1.54</td>
<td>2.67</td>
<td>0.63</td>
<td>0.71</td>
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<tr>
<td>30</td>
<td>1.88</td>
<td>3.27</td>
<td>0.69</td>
<td>0.85</td>
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</table>
Thick GEM (TGEM)

goal: gain $\sim 10^4$ with stable operation
What is TGEM?

Thick-GEM is …

- cost-effectively fabricated from double-clad G10 plates, using standard printed circuit board (PCB) techniques
- holes are mechanically drilled (and, if necessary, the hole’s rim is chemically etched to prevent discharges)
- a robust, simple to manufacture, high-gain gaseous electron multiplier
- easy to operate and feasible to cover large areas, compared to the standard foil GEM
TGEM prototypes

**goal**

- gain $\sim 10^4$ @ P10, NTP (double TGEMs)
- stable operation for a month, with gain fluctuation within $\sim$a few ten % for a month & a few % for a day

many groups have reported TGEMs work successfully, but actually it’s NOT so easy to operate TGEM with high gain stably!

- they use small TGEMs, e.g. $\sim$3x3cm$^2$
- most of them don’t discuss stability of TGEM

We have studied basic TGEM behavior and performance.
## TGEM prototypes @ RIKEN
produced by REPIC corp. and TOUKAI DENSHI KOUGYOU corp.

<table>
<thead>
<tr>
<th>No.</th>
<th>Electrode</th>
<th>Insulator</th>
<th>Thickness [µm]</th>
<th>Hole-diameter [µm]</th>
<th>Rim [µm]</th>
<th>×</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>200</td>
<td>300</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>200</td>
<td>500</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>–</td>
<td>5</td>
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<tr>
<td>4</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Cu</td>
<td>FR4</td>
<td>400</td>
<td>300</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>500</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>C</td>
<td>FR4</td>
<td>400</td>
<td>300</td>
<td>–</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>C</td>
<td>FR4/UV</td>
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<td>300</td>
<td>–</td>
<td>7</td>
</tr>
<tr>
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<td>C</td>
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<td>300</td>
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<td>2</td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>CEM3</td>
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<td>300</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
<td>FR4</td>
<td>600</td>
<td>300</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>C/Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>–</td>
<td>4</td>
</tr>
</tbody>
</table>

Total 40

size: 10cm x 10cm
many TGEM prototypes
Test bench setup

- **Test chamber**
- **Readout pad**

**Double GEM setup**

- **$^{55}\text{Fe}$**
- Drift mesh
- X-ray
- $e^-$
- TGEM 1
  - $\Delta V_{\text{GEM}}$
- TGEM 2
  - $\Delta V_{\text{GEM}}$
- R/O pad
  - $\rightarrow$ CS preamp

- **Double TGEMs**
- **Gas**: P10 at 1 atm, normal temperature
- **HV divider with resistive chain**

$\rightarrow$ Ratio of $\Delta V_{\text{GEM}}/E_{\text{trns}}/E_{\text{ind}}$ is const.
Results of TGEMs
Cu-electrode TGEM

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>200</td>
<td>300</td>
<td>50</td>
<td>~10³</td>
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<tr>
<td>2</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>200</td>
<td>500</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>–</td>
<td>~10⁴</td>
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<tr>
<td>4</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>30</td>
<td>over 2 × 10⁴</td>
</tr>
<tr>
<td>5</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>50</td>
<td>over 2 × 10⁴</td>
</tr>
<tr>
<td>6</td>
<td>Cu</td>
<td>FR4</td>
<td>400</td>
<td>300</td>
<td>100</td>
<td>over 2 × 10⁴</td>
</tr>
<tr>
<td>7</td>
<td>Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>500</td>
<td>–</td>
<td>~10³</td>
</tr>
</tbody>
</table>

Rim of 50,100µm: Weizmann method (drilling + masked etching)
Rim of 30µm: CERN method (drilling + resist etching)
w/o Rim (#3): w/ hydrogen peroxide - sulfuric acid etching

TGEMs with thickness of 400µm and hole diameter of 300µm achieve maximum gain of 10⁴
dependence on rim size

The limits of gain around $10^5$ is caused by rather limit (source = $^{55}\text{Fe}$).

\[
\Delta V_{\text{GEM}} \ (V) : \ E_{\text{trans}} \ (V/cm) : \ E_{\text{induct}} \ (V/cm)
\]

\[
\begin{align*}
1 & : 2.5 & : 7.5
\end{align*}
\]

TGEM with larger rims requires higher voltage, but enables higher gain
initial drop of gain is caused by charge-up (polarization?) of the insulator?

instability of TGEMs with rims is caused by charge-up of the insulator not metalized.

mismatch of the center of the etched and drilled holes and incomplete round-shape of rims cause the instability.
**long term stability (30\(\mu\)m rims TGEM, 10days)**

- TGEM with 30\(\mu\)m rims can be operated with gain of more than \(10^4\) for the long term @ P10, NTP
- Gain stability is within \(~50%/week \& ~10%/day\)

\[\text{relative gain} \approx 2.5 \times 10^4\]

\[\Delta V_{\text{GEM}} \text{ is turned up by hand}\]

\[\text{resolution(}\sigma\text{)} [\%]\]
To avoid the effects of rims, we are developing a new resistive-electrode TGEM (RETGEM) which has electrodes coated with graphite paint. RETGEMs have an advantage of being fully spark-protected.
Results of the first sample

It seemed that C-electrode TGEMs work excellent!!! However...
carbon TGEMs have no reproducibility at all !!!

only first 2 out of 11 samples of RETGEMs work !!!

- discharge from burrs arising from drilling process
  (but these can be removed using antistatic-brush)
- carbon attachment inside the holes caused by knot of FR4 fiber

→ now, we have been studying another insulator of CEM3 not FR4/G10
C/Cu-electrode Hybrid-TGEM

- In principle, if one side of electrode is resistive then that would be spark-protected.

- Hybrid-TGEM would have a possibility of reduction of carbon attachment inside the holes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Electrode</th>
<th>Insulator</th>
<th>Thickness [µm]</th>
<th>Hole-diameter [µm]</th>
<th>drill</th>
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</thead>
<tbody>
<tr>
<td>13</td>
<td>C/Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>Cu→C</td>
</tr>
<tr>
<td></td>
<td>C/Cu</td>
<td>FR4/UV</td>
<td>400</td>
<td>300</td>
<td>C→Cu</td>
</tr>
</tbody>
</table>
Results of C/Cu-electrode Hybrid TGEM

We tried 2 drilling directions, i.e. Cu → C and C → Cu

The 2 fabrication methods work similarly

<table>
<thead>
<tr>
<th>$E_{\text{drift}}$ (V/cm)</th>
<th>$\Delta V_{\text{GEM}}$ (V)</th>
<th>$E_{\text{trans}}$ (V/cm)</th>
<th>$E_{\text{induct}}$ (V/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\approx 2.5 \times 10^4$</td>
<td>2.5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

$\Delta V_{\text{GEM}}$ (V): $E_{\text{trans}}$ (V/cm) : $E_{\text{induct}}$ (V/cm)
hybrid TGEM can be operated with more than gain of $10^4$ for the long term @ P10, NTP

gain stability is within ~20%/week & ~5%/day
Summary

• We have been developing a **TGEM-TPC** for the J-PARC E15 upgrade

• **TGEM-TPC** was completed, and commissioning will be started soon

• **Cu electrode TGEM with 30µm rims** can be operated with gain of more than $10^4$ for the long term rather stably @ P10, NTP

• **C-electrode TGEM** is far from goal...

• **C/Cu electrode TGEM** can be operated with gain of more than $10^4$ for the long term stably @ P10, NTP
C electrode TGEM with CEM3 insulator

A cross section of CEM3 is very clean compared with that of FR4.

reduction of carbon attachment inside the holes

Now we are investigating reproducibility of CEM3 RETGEM

A disadvantage of CEM3 RETGEM is its flexibility

\[ \Delta V_{GEM}[V] \]

\[ \text{gain} \sim 2.5 \times 10^4 \]

Gain and resolution over time [h]
How to make Rims

There are 2 ways

**Weizmann method**
- **drilling + masked etching**
- **Advantage:** large rims can be made easily
- **Disadvantage:** difficult to center etched and drilled holes

**CERN method**
- **drilling + resist etching**
- **Advantage:** center of etched and drilled holes are the same
- **Disadvantage:** difficult to make large rims

It’s known that large rims cause instability of TGEMS, although those enable TGEMs to reach high gain.
**ET, EI dependence (Rim 30µm TGEM)**

- **Drift mesh**
- **TGEM 1**
- **TGEM 2**
- **R/O pad**

**Graphs:**
- Effective gain vs. \( E_T \) for various \( \Delta V_{GEM} \) values.
- Effective gain vs. \( E_I \) for various \( \Delta V_{GEM} \) values.

**Parameters:**
- \( E_T = 150 \text{ V/cm} \)
- \( \Delta V_{GEM} = 900, 940, 980, 1020, 1060 \text{ V} \)

**Materials:**
- \( ^{55}\text{Fe} \)
signals and goal of the studies

Double TGEM #4
P10, 1atm
$\Delta V_{\text{GEM}} = 983V$
$^{55}\text{Fe}$ X-ray

100ns
1mV
gain $\sim 2.0 \times 10^4$

$\text{gain} = \frac{t[s] \times (p.h.[V]/50[\Omega])/2}{1.6 \times 10^{-19} \times 227}$

raw signal

preamp

ADC

preamp out

ADC spectrum

goal for of TGEM study

in consideration of TPC operation,

- effective gain $\sim 10^4$
- long time stability of gain and resolution
**P/T correction of gain**

P/T correction function:

\[ f(P/T) = \alpha \exp(\beta P/T) \]

- **P/T**
- **correlation**
- **raw gain**
- **correction**
- **corrected relative gain**
after-treatment of C-electrode TGEM

We tried many items to make the C-electrode TGEMs work

- ethanol cleaning → ×
  - does not improve at all
- plasma etching → △
  - improves a little bit, but it’s not perfect
  - does not remove burrs of carbon
- removing burrs with resist-film and/or antistatic-brush → △
  - removes burrs, but does not improve
- steam cleaning → ×
  - does not improve at all
- polyimide etching → ?
  - effects are depend on material of the insulator
  - and also depend on etching time
- change insulator (FR4/UV → CEM3) → ?
  - CEM3 TGEMs work good, but that are after polyimide etching
    (we did not check the without the etching)

We have to study more
Outlook

• Nonagonal TGEMs (w/o rims and Cu-rim-30μm) and Hybrid-TGEMs for the TPC were produced, and studies have started now.

• Development of Carbon TGEMs will be continued in the year 2010.
Physics Motivation

deeply-bound kaonic nuclear states exist?

We need conclusive evidence!

T. Yamazaki, A. Dote, Y. Akiaishi