Development of a Precise Time and Position Resolutions TOF-tracker RPC for the $\pi$20 Beamline at J-PARC

Dept. of Phys. Osaka Univ.
Master Student

R. Uda
for the J-PARC E50 collaboration
TOF-tracker RPC for The Nucleon Structure Study

@J-PARC $\pi 20$ Beamline

Nucleon spin crisis

- Quark spin contribution to nucleon spin $\rightarrow$ approximately 30 %
- What is the remaining 70 % ?
- Measurement of the generalized parton distribution function

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Exclusive Drell-Yan reaction

$$\pi^- p \rightarrow \gamma^* n \rightarrow \mu^+ \mu^- n$$
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Identification

TOF-tracker RPC

Remove background muons from decays in flight of kaons and pions

Upstream muon detector

- Size: 1.8 m $\times$ 2.4 m
- Efficiency: more than 99 %
- Time resolution: $\sim$100 ps
- Position resolution: $\sigma$~1 mm
TOF-tracker RPCs Developed so far

Small TOF-tracker RPC
- 80 mm × 80 mm
- Strip pitch: 4 mm
- The orientation of the top and bottom readout strips was rotated by 90 degrees
- Read out channel by channel
- Time resolution: ~80 ps
- Position resolution: 40~70 µm

Large TOF-tracker RPC
- 1.5 m × 1.2 m
- Strip pitch: 2.5 mm
- The orientation of the top and bottom readout strips was rotated by 90 degrees
- X: group 31 strips, Y: group 10 strips
- Efficiency: 92 % (tracking), 72 % (timing)
- Time resolution: ~150 ps
- Position resolution: 1.3 mm (X), 8.1 mm (Y)
Prototype TOF-tracker RPC

- Size: 500 mm × 1000 mm
  - The maximum production size of readout board
- Number of gas gaps: 5 gaps, Gas gap: 260 µm
- 1 stack
- Strip pitch: 5 mm
- Several different widths of strips, Several ground configuration

Cross-sectional view of the readout strips

Readout Strip

X Direction

5 mm pitch × 204 strip

Y Direction

5 mm pitch × 106 strip
• Amplifier was developed with Academica Sinica in Taiwan (Gain ~ 800)
• The beam test was carried out with 9 strips (Strip width: 4 mm, Full ground) in Y direction
Beam Test

@SPring-8/LEPS2 Beamline

Time resolution evaluation

Scintillators×4
Trigger Area : 10×5 mm²

TOF-tracker RPC

1000 mm
500 mm

~1 GeV
~10 Hz/cm²

10 mm width
5 mm width

γ

Start timing of time information :
RF signal of accelerator
(Time resolution ~15 ps)

Time resolution of TDC (HUL) ~ 20 ps

Gas
R134a : butane : SF6 = 90 : 5 : 5

Pb target
Dipole Electromagnet

B

1000 mm
Beam Test

@SPring-8/LEPS2 Beamline

Time resolution evaluation

<table>
<thead>
<tr>
<th>500 mm</th>
<th>1000 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1 GeV</td>
<td>~10 Hz/cm²</td>
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</table>

TOF-tracker RPC

Scintillators × 4
Trigger Area : 10×5 mm²

Pb target

Dipole Electrode

Start timing of time information :
RF signal of accelerator
(Time resolution ~15 ps)

Time resolution of TPC (HUL) ~ 20 ps

Evaluate time resolution from the TOF between RPC and RF

R134a : butane : SF6 = 90 : 5 : 5
Beam Test

@SPring-8/LEPS2 Beamline

Position resolution evaluation

Measure y

500 mm

1000 mm

Pb target

Dipole Electromagnet

Fiber Tracker (FT)

Fiber scintillators

XUV each 4 Layer
Total 12 Layers

Position resolution
~ 0.25 mm
Beam Test

@SPring-8/LEPS2 Beamline

Position resolution evaluation

500 mm

1000 mm

Measure y

Fiber Tracker (FT)

Dipole Electromagnet

Fiber scintillators

XUV each 4 Layer Total 12 Layers

Position resolution ~ 0.25 mm

Compare y position measured at the RPC and FT
Time Walk Correction

\[ 20 \text{ DAQ: Only TDC} \]

- Discriminator Threshold
- Time Over Threshold (TOT)

\[
\begin{align*}
\text{Count} & \quad \text{integral} \\
\text{TOT [ns]} & \quad \text{TOT integral [%]} \\
\end{align*}
\]

\[
\begin{align*}
T \ [\text{ns}] & \quad T \ [\text{ns}] \\
\text{TOT [ns]} & \quad \text{TOT integral [%]} \\
\end{align*}
\]

BES-III RPC
JINST 12 C01012 (2017)
Time Resolution

Before correction

After correction

Time resolution: 113 ± 4 ps

Time resolution: 103 ± 3 ps

- Achieved required resolution (100 ps)
- Time resolution is the best at around 13.5-14 kV
- Similar voltage dependence to that of conventional TOF-RPCs
Position Resolution (Analysis On-Going)

1 strip
Center of strip

2 strips
Weighted by pulse height

More than 2 strips
Fitting with gaussian

Evaluate Pulse height using TOT integral

Left read out
$\sigma \sim 3.8 \pm 0.6 \text{ mm}$

Left read out
$\sigma \sim 3.4 \pm 0.2 \text{ mm}$

Left read out
$\sigma \sim 4.2 \pm 0.6 \text{ mm}$

Analysis on-going
Position Resolution (Analysis On-Going)

- Evaluate the hit position in single side
- Determine the hit position by averaging both sides
- Position resolution
  \[ \sigma \sim 3.8 \pm 0.2 \, \text{mm} \]
- Not achieved required resolution (1 mm)
- Worth than the expected resolution of single strip hit
  \[ \sigma \sim \frac{5}{\sqrt{12}} = 1.4 \, \text{mm} \]
- We will improve analysis methods of both the FT and RPC

Efficiency \( 97.3\pm0.6 \% \)
Summary and Future Work

Summary

• We are developing TOF-tracker RPC for the nucleon structure study experiment at J-PARC
• We have developed the prototype TOF-tracker RPC
  ➢ 500 mm × 1000 mm
  ➢ strip pitch : 5 mm
• We have performed the beamtest of the prototype RPC in SPring-8
  ➢ Efficiency : 97.6 ± 0.6 %
  ➢ Time resolution : 103 ± 3 ps
  ➢ Position resolution : 3.8 mm ± 0.2 mm, Analysis on-going

Future Work

• Increased the number of strips available for readout (amp noise suppression)
• Improvement of analysis method of position measurement