Performance Evaluation of a TOF-Tracker MRPC for Volcano Muography

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Previous TOF-Tracker MRPC Prototype and Related Results
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Summary

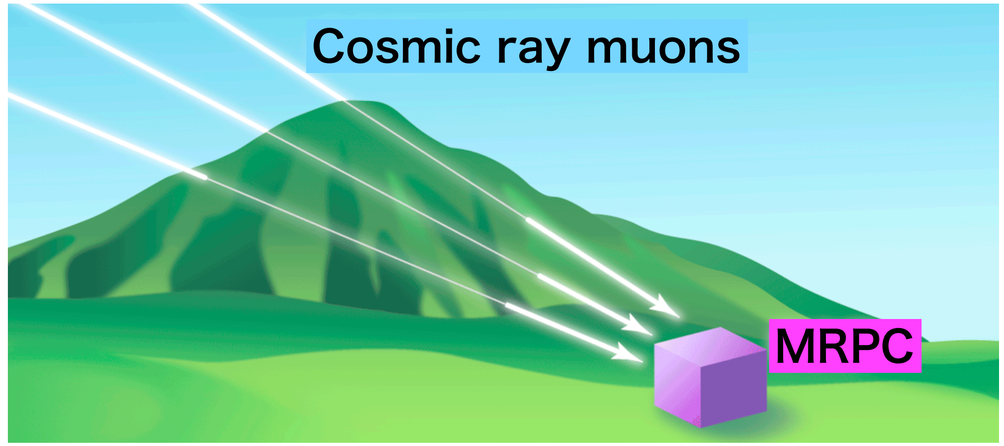
MRPCs for Volcano Muography and Hydological Monitoring

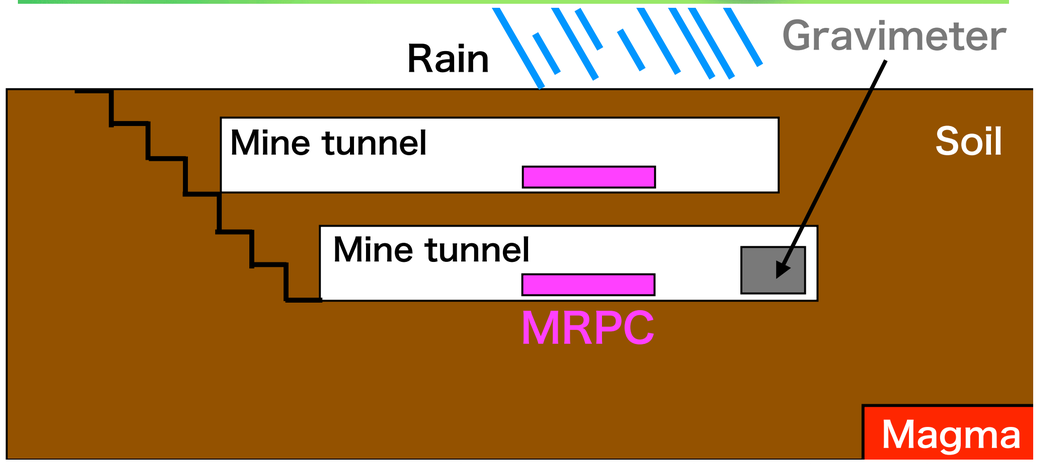
- We aim to image internal volcanic structures using cosmic-ray muons detected by TOF-tracker MRPCs

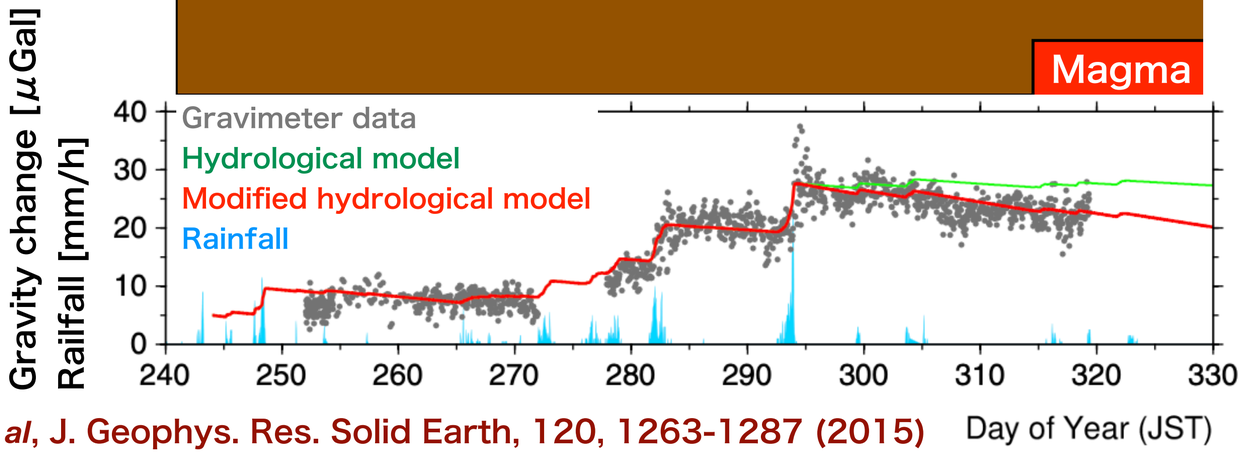
- Gravimeters can monitor magma movement
  → Changes in soil water content act as background (ex. Rainfall)

- We also plan to apply muography to estimate water movement in soil

We are developing large-area, sealed MRPCs for outdoor muography





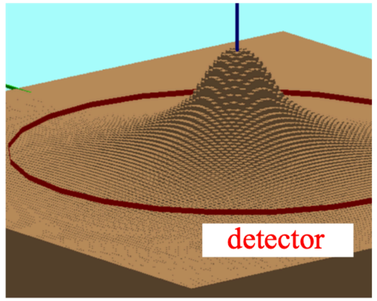


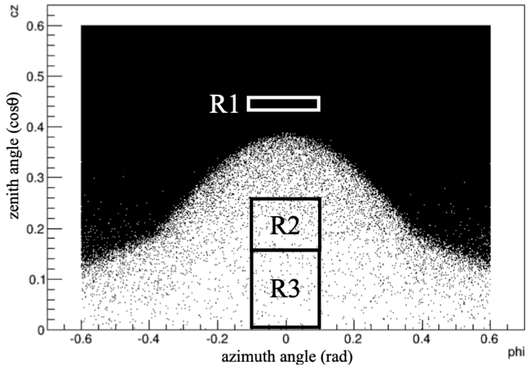
T. Kazama *et al*, J. Geophys. Res. Solid Earth, 120, 1263-1287 (2015)

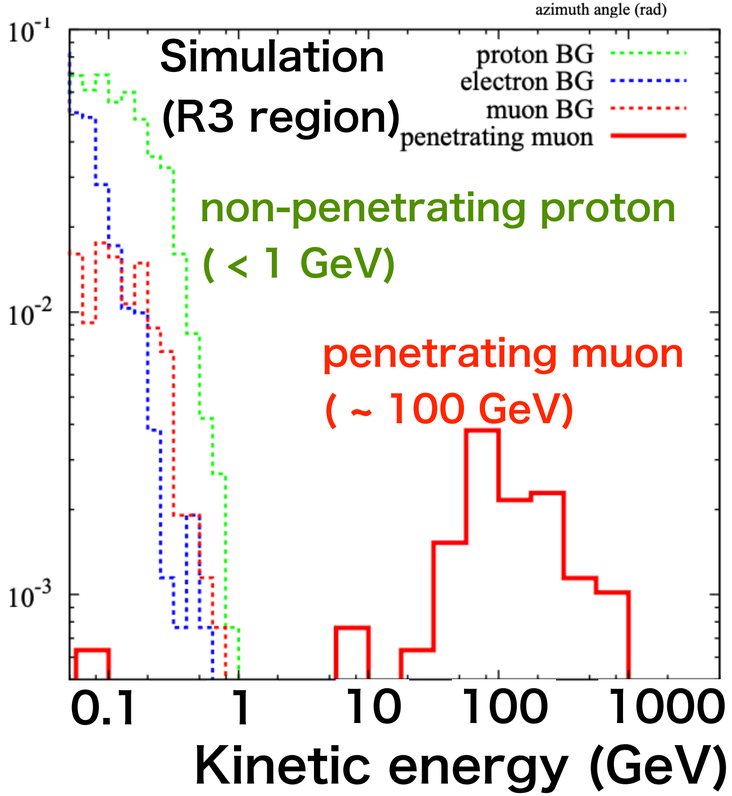
Development Goal

Geophys. J 206 1039 (2016), [Nishiyama:2016bgl]

Rock thickness of R3: 600-900 m



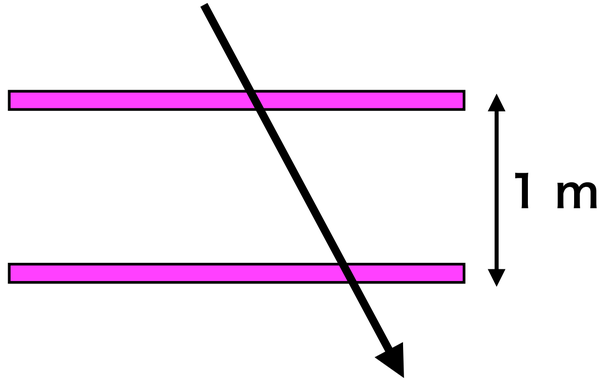




- **Time-of-flight measurement for suppression low-energy proton background**

  Time of flight over a distance of 1 m:

  - 1 GeV/*c* proton: 4.58 ns
  - 100 GeV/*c* muon: 3.34 ns



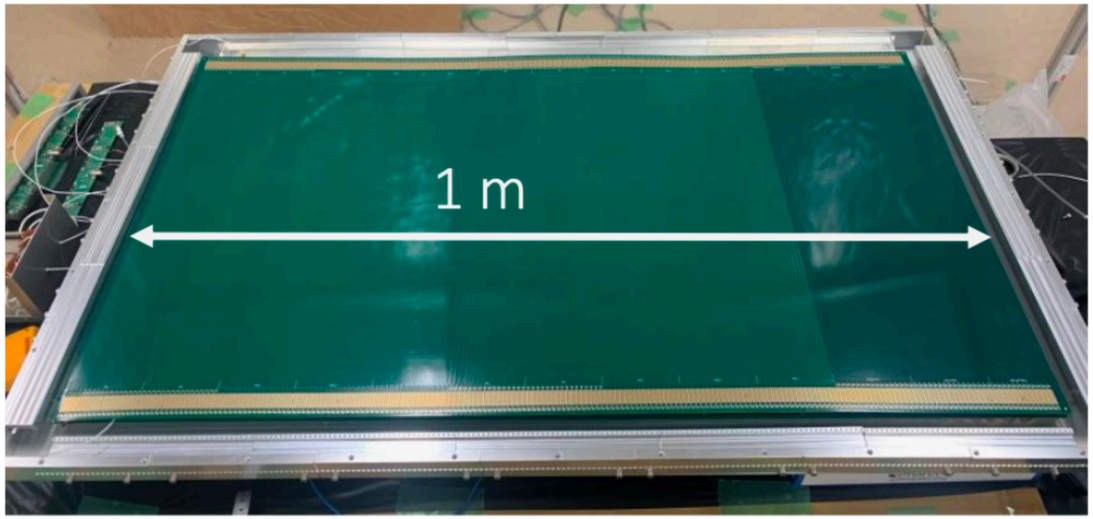
- **Strip segmentation and orthogonal arrangement → Two-dimensional position measurement**
- **An 8 cm x 8 cm high-resolution TOF-tracker MRPC developed by Blanco *et al*.** JINST 7 (2012) P11012, [Blanco:2012df]
- **Outdoor operation**

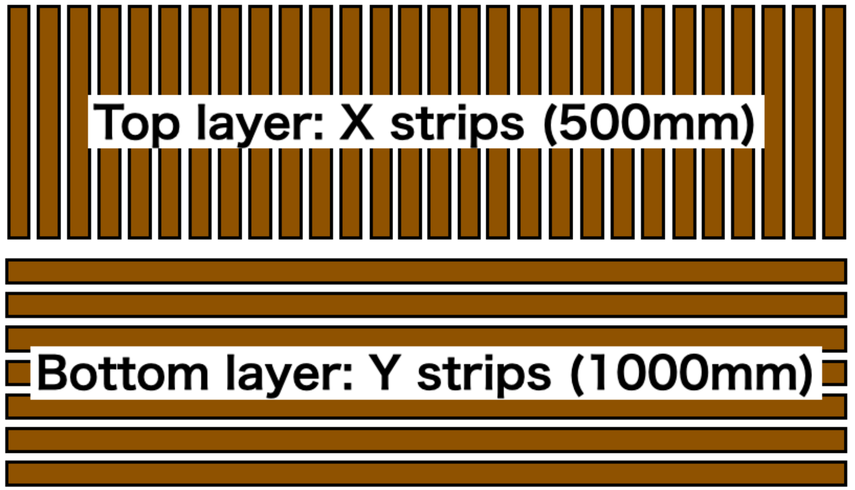
Our goals
- Time resolution: 70 ps
- Position resolution: 0.2 mm
- Large active area (~ 1 m²)
- Sealed chamber design

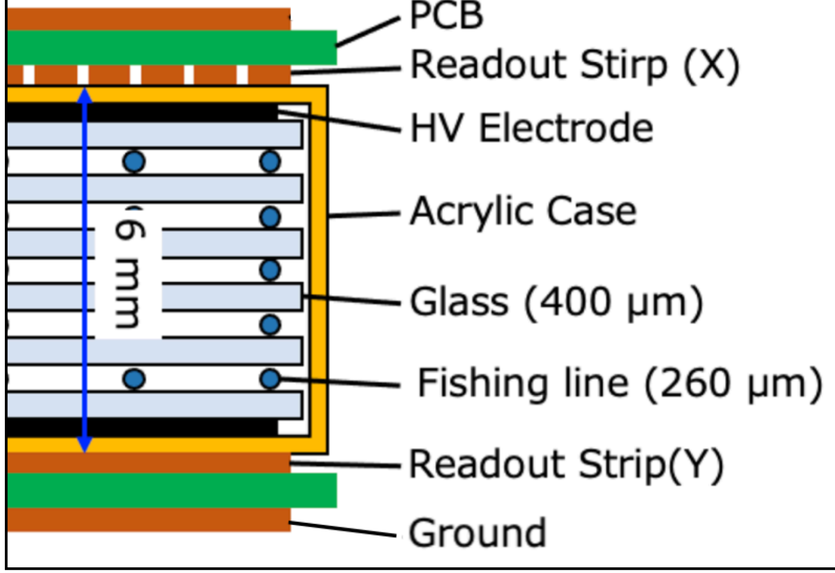
Presented at RPC 2024

NIM A **1056**, 168580 (2023), [Uda:2023iqw]
NIM A **1077**, 170517 (2025), [Tomida:2025cki]

Prototype TOF-tracker MRPC







- **Orthogonally arranged X and Y readout strips**
- **Strip widths: 1.15mm, 1.35mm, 1.60mm, 3mm ,4mm**
- **Strip pitch: 5mm**

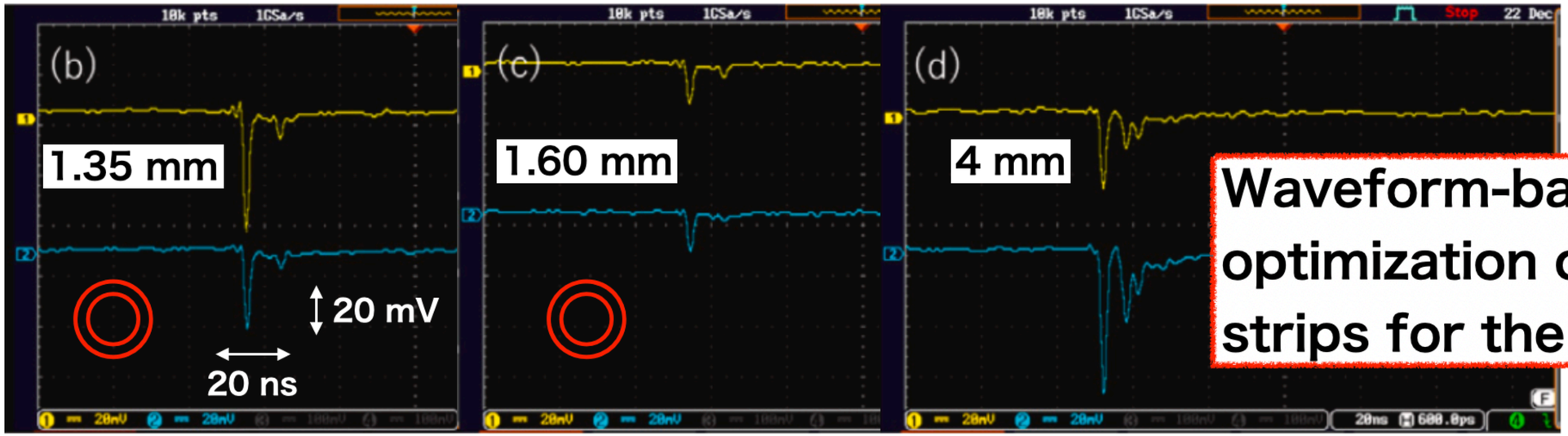
  → expected position resolution: < 1.4 mm $\left(= 5/\sqrt{12} \right)$

- **Several different ground patterns**
- **Gas mixture - R134a : Butane : SF6 = 90 : 5 : 5**
- **Five 260 μm gas gaps**

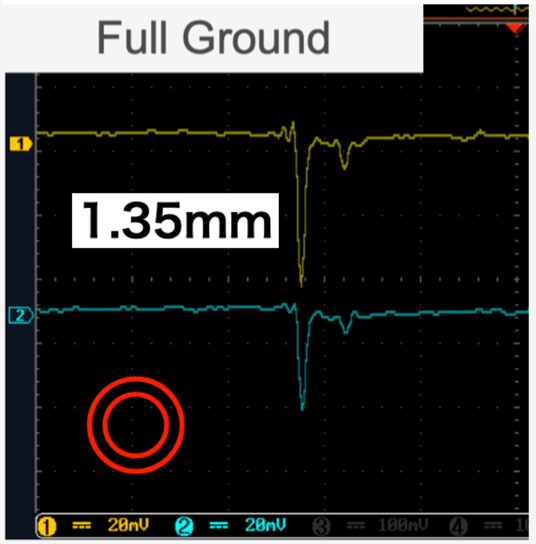
Presented at RPC 2024

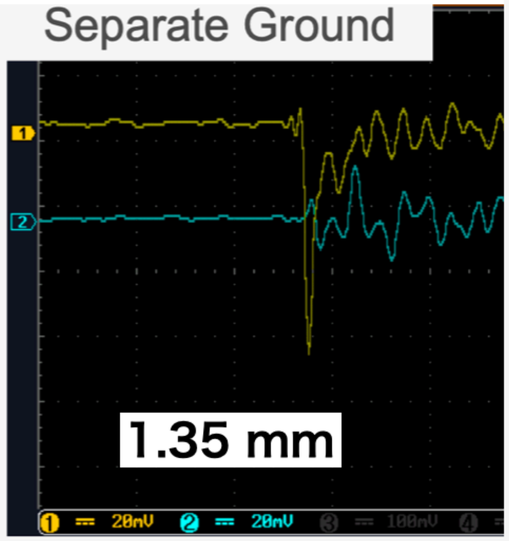
NIM A **1056**, 168580 (2023), [Uda:2023iqw]
NIM A **1077**, 170517 (2025), [Tomida:2025cki]

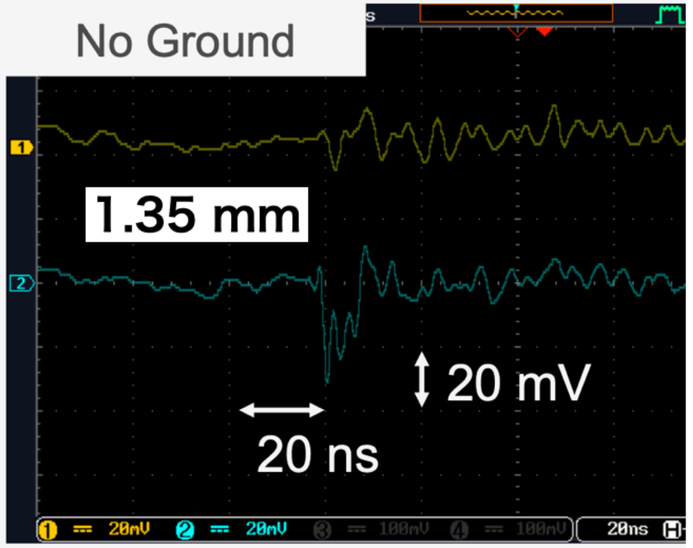
Results (Readout Strip)

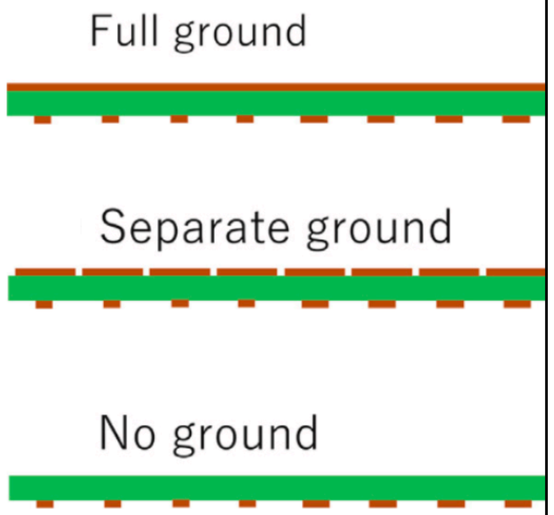


Waveform-based optimization of readout strips for the beam test







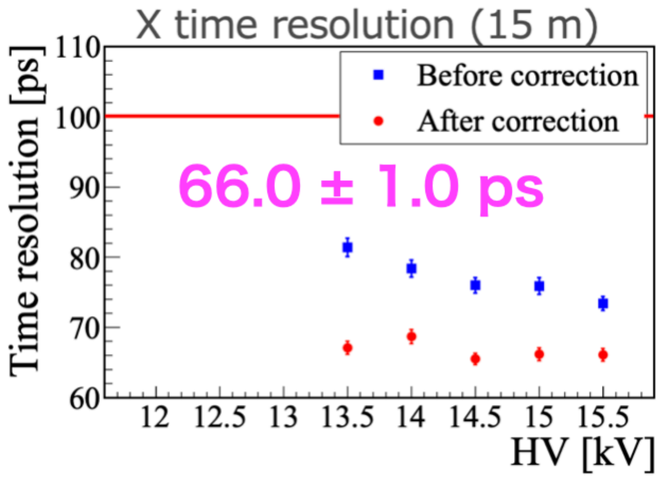


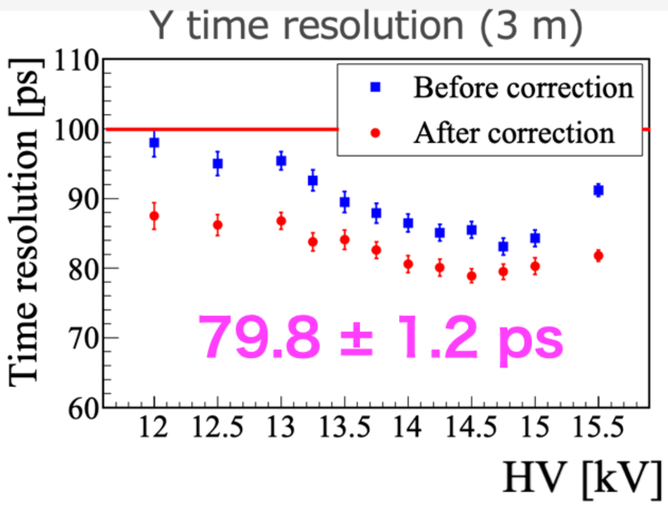
Presented at RPC 2024

NIM A **1056**, 168580 (2023), [Uda:2023iqw]
NIM A **1077**, 170517 (2025), [Tomida:2025cki]

Results (Time/Position Resolution)

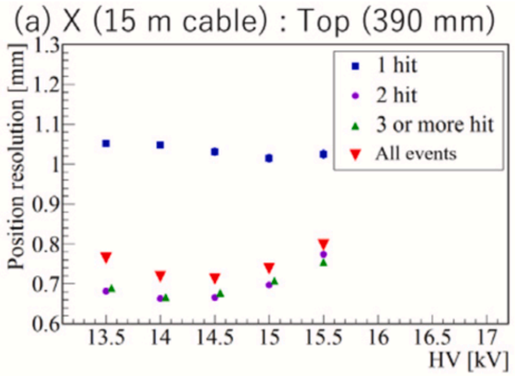
Signal stretching through cable extension for the X strips (3 m → 15 m)

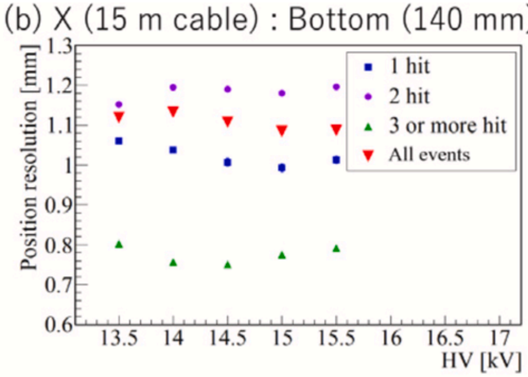


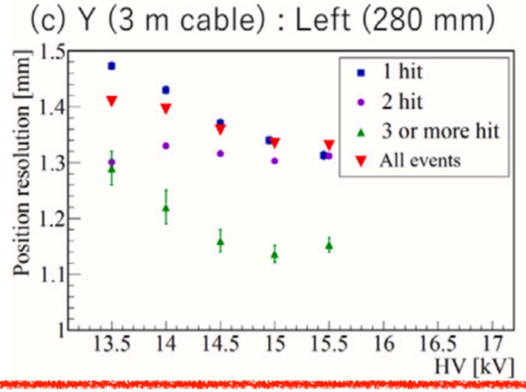


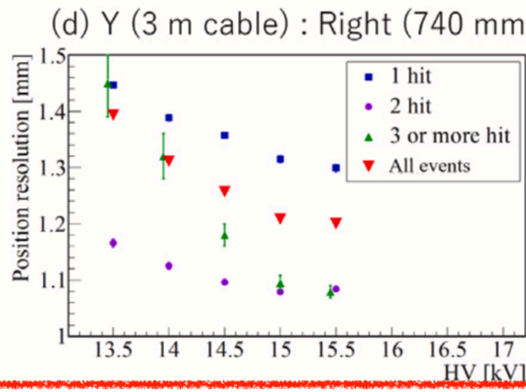
X(0.5m): 0.767 ± 0.003 mm,
Y(1m): 1.115 ± 0.003 mm

Strip: 1.35 mm, Full ground
Electrode: 1.4×10^7 (Ω/sq)



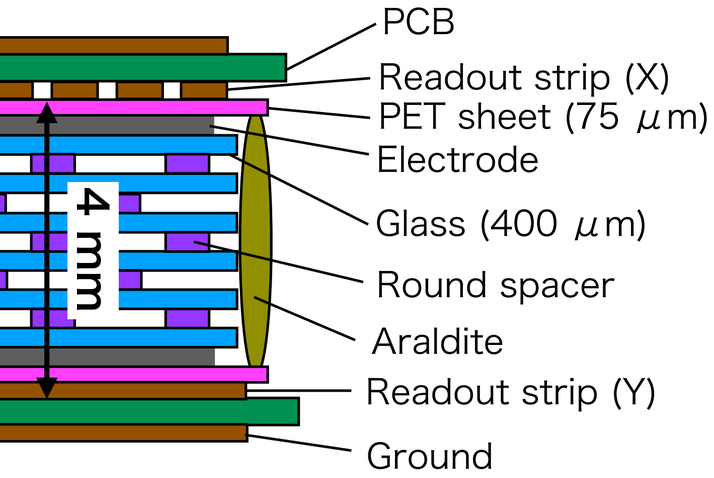






- Good time resolution
- Further improvement needed in position resolution

Updates from RPC 2024



	Spacer	Sheet resistance of electrode (Ω/sq)	Sealed structure
Old prototype	Fishing line 260 μm	10^7 (EEEC, T-9188)	Acrylic case
New prototype	**Round spacer 255 μm**	**10^5 (Colcoat, CS-6301)**	**PET sheet + Araldite**

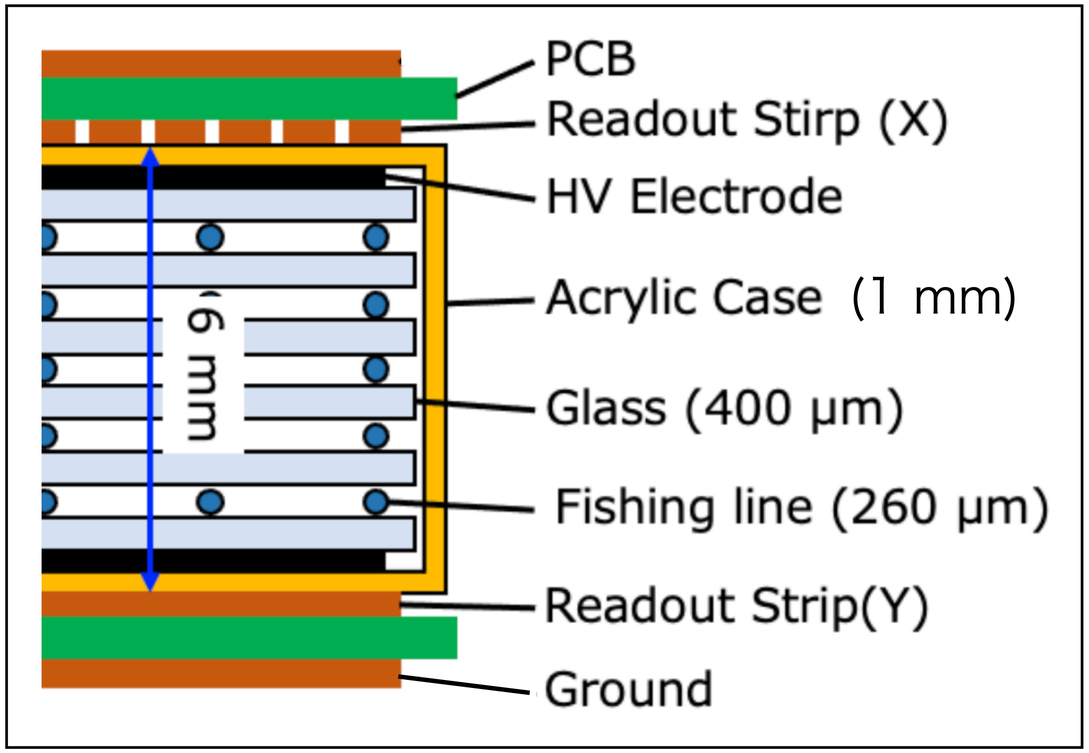
	Strip width (mm)	Cable length (m)	Amplifier
RPC 2024	1.35, 1.60	X(0.5m): 15 Y(1m): 3	Sensitive to noise
RPC 2026	**4**	X(0.5m): 15 **Y(1m): 15**	**Improved noise immunity**

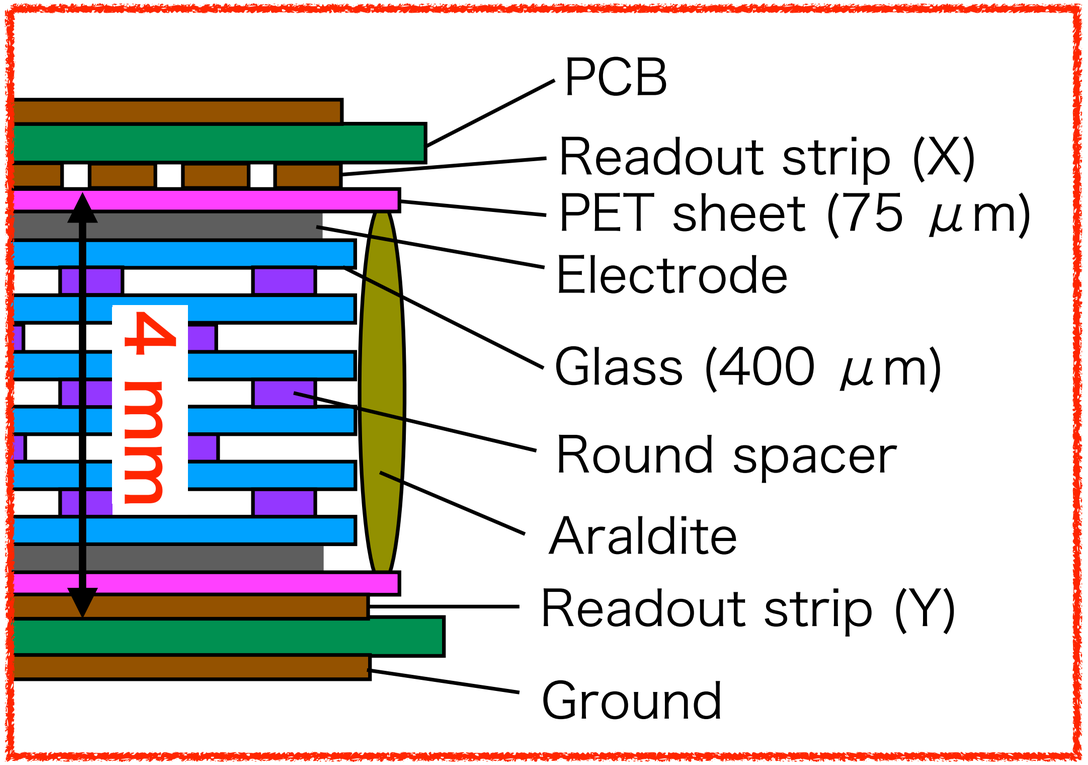
For details, see N. Tomida's talk on September 18.

Updates from RPC 2024

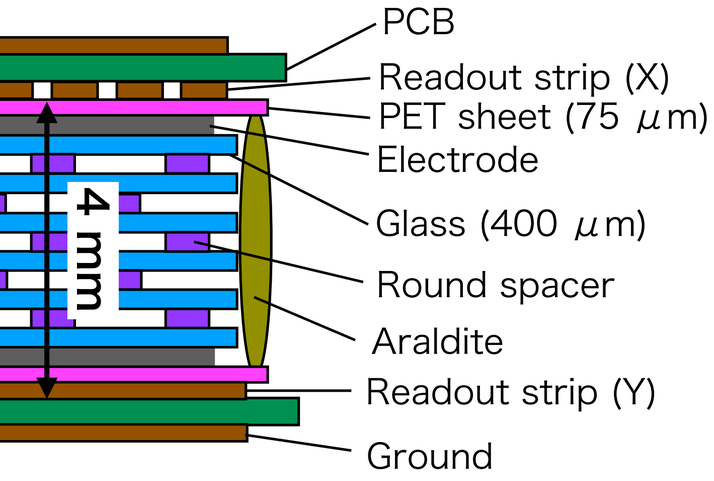
The distance between the readout strips was reduced (6 mm → 4 mm).

	Spacer	Sheet resistance of electrode (Ω/sq)	Sealed structure
Old prototype	Fishing line 260 μm	10^7 (EEEC, T-9188)	Acrylic case
New prototype	**Round spacer 255 μm**	**10^5 (Colcoat, CS-6301)**	**PET sheet + Araldite**





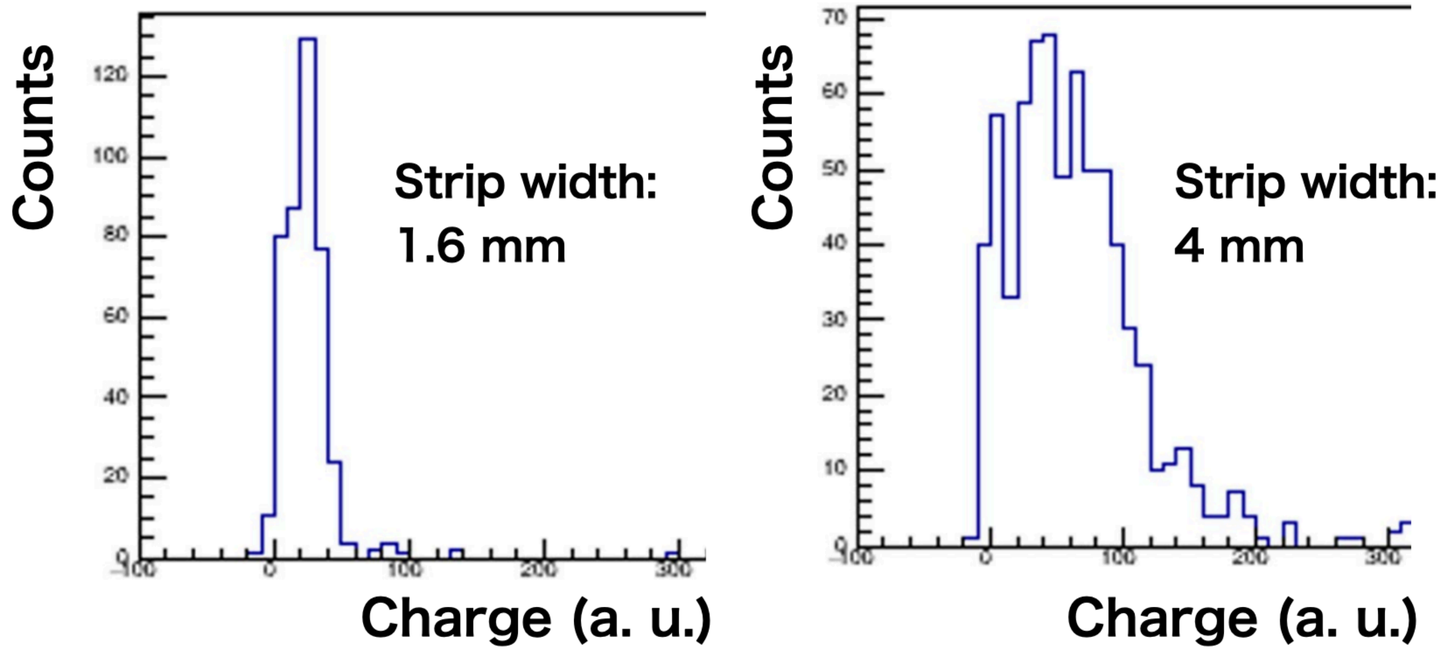
Updates from RPC 2024



	Spacer	Sheet resistance of electrode (Ω/sq)	Sealed structure
Old prototype	Fishing line	10^7	Acrylic case
New			

	Strip width (mm)
RPC 2024	1.35, 1.60
RPC 2026	**4**

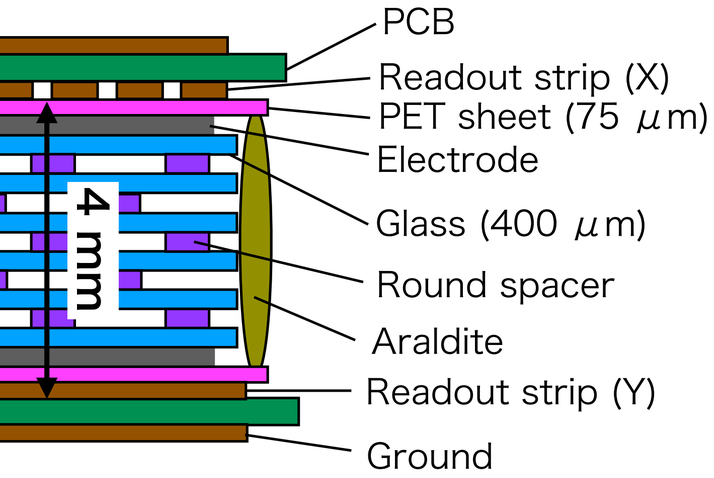
Evaluate using cosmic rays



Increase in induced charge with strip width from 1.6 mm to 4 mm

We chose 4-mm-wide strips

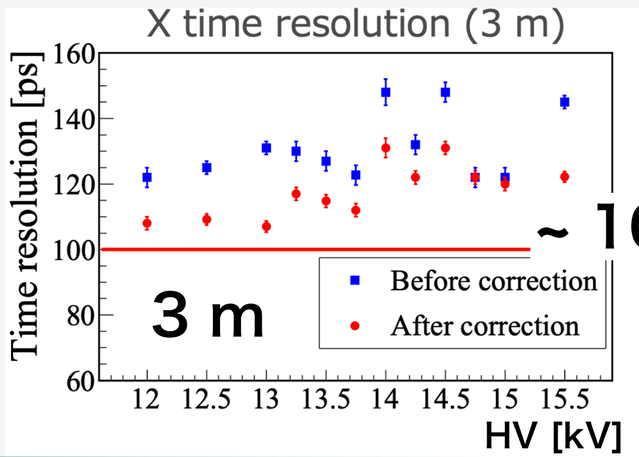
Updates from RPC 2



	Spacer
Old prototype	Fishing line 260 μm
New prototype	**Round spac 255 μm**

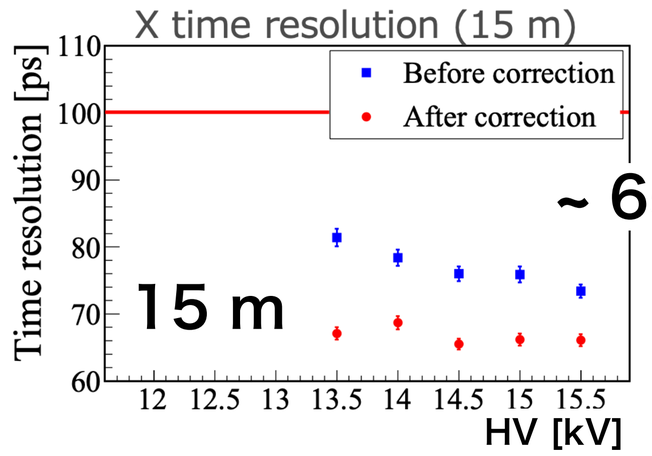
	Strip width (mm)	Cable length (m)
RPC 2024	1.35, 1.60	X(0.5m): 15 Y(1m): 3
RPC 2026	4	X(0.5m): 15 **Y(1m): 15**

Slides in Koike's talk in RPC 2024



~ 100 ps

Longer cables

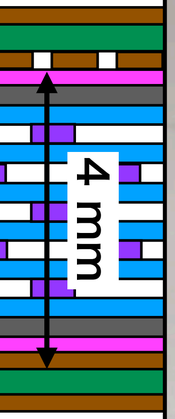


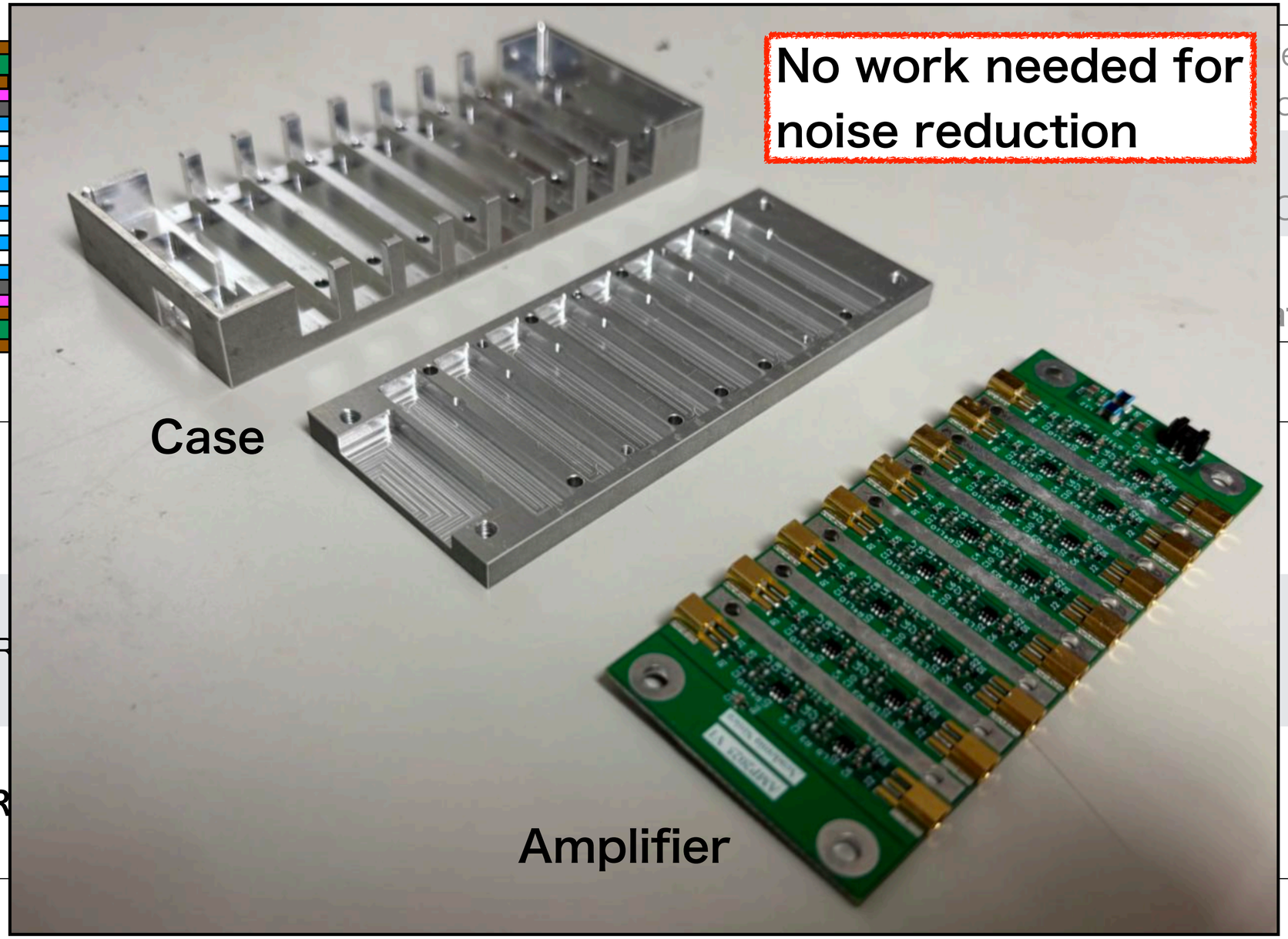
~ 65 ps

Significant improvement with longer cables (3 m → 15 m)

Because the charge is measured using TOT, narrow pulses (~ 1 ns) cannot be measured accurately.

Updates from RPC 2024

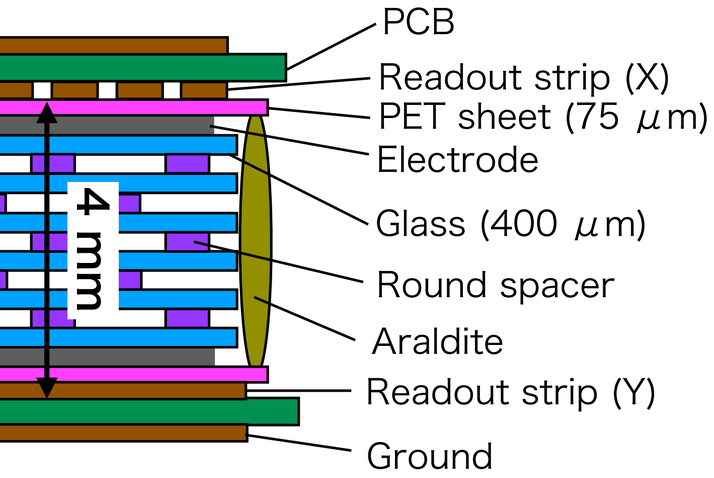




esistance of ode (Ω/sq)	Sealed structure
10^7 C, T-9188)	Acrylic case
10^5 t, CS-6301)	PET sheet + Araldite

	Amplifier
R	Sensitive to noise
R	**Improved noise immunity**

Updates from RPC 2024



	Spacer	Sheet resistance of electrode (Ω/sq)	Sealed structure
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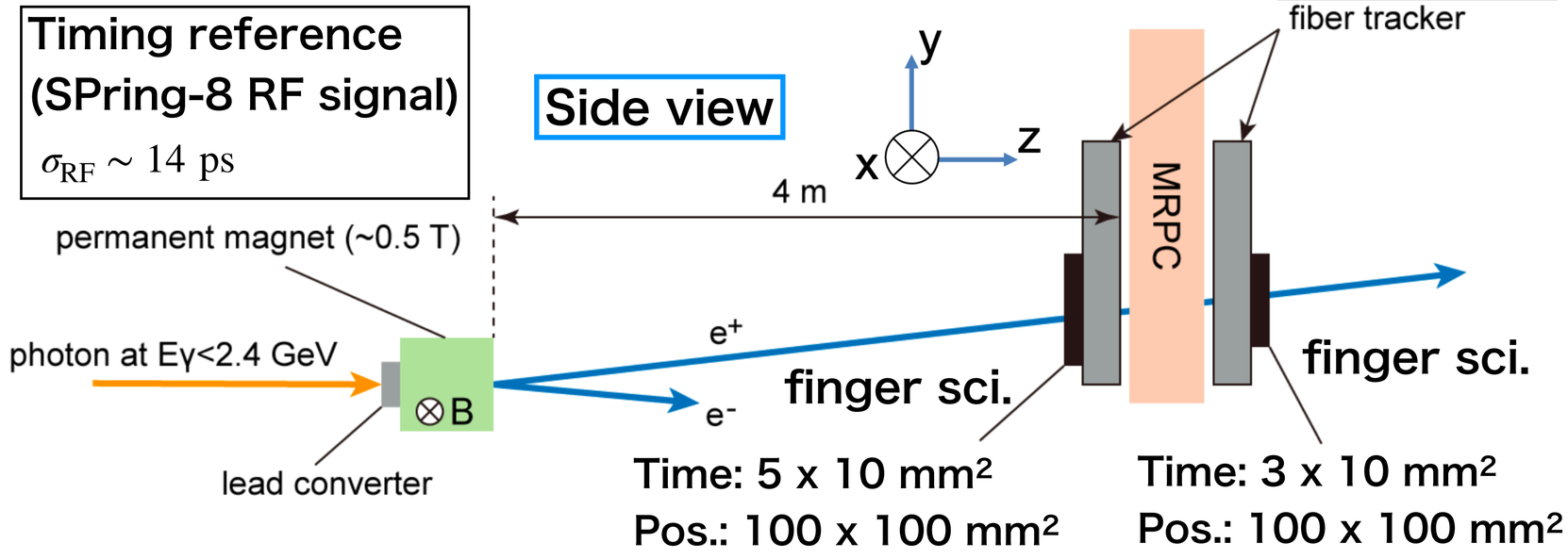
	Strip width (mm)	Cable length (m)	Amplifier
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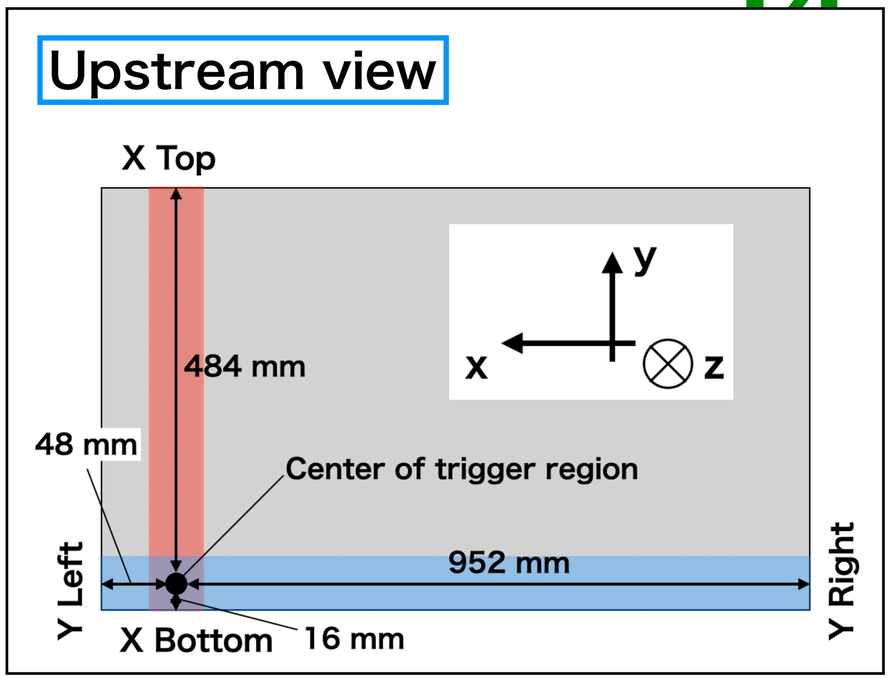
We evaluated the performance of the new configuration in a beam test.

Beam Test Setup

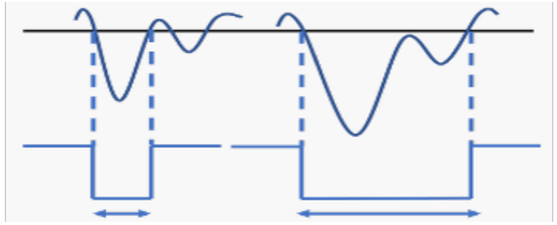
Timing reference
(SPring-8 RF signal)
$\sigma_{RF} \sim 14$ ps

Position ref.
$\sigma_{FT} \sim 0.2$ mm

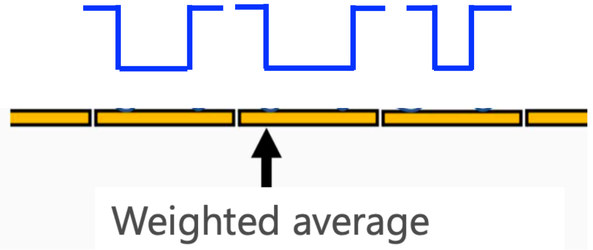




☆ Time-resolution measurement
- Triggered DAQ with HUL HR-TDC
- Time difference relative to the SPring-8 RF signal, $T_{MRPC} - T_{RF}$
- Single-strip readout
- Slewing correction using TOT instead of charge

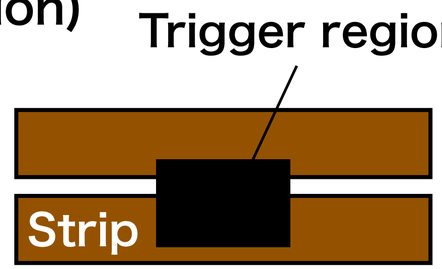


☆ Position-resolution measurement
- Streaming DAQ with AMANEQ HR-TDC
- Position residual relative to the fiber trackers $X_{MRPC} - X_{FT}$ $(X = x,\ y)$
- Position determination by TOT-weighted average

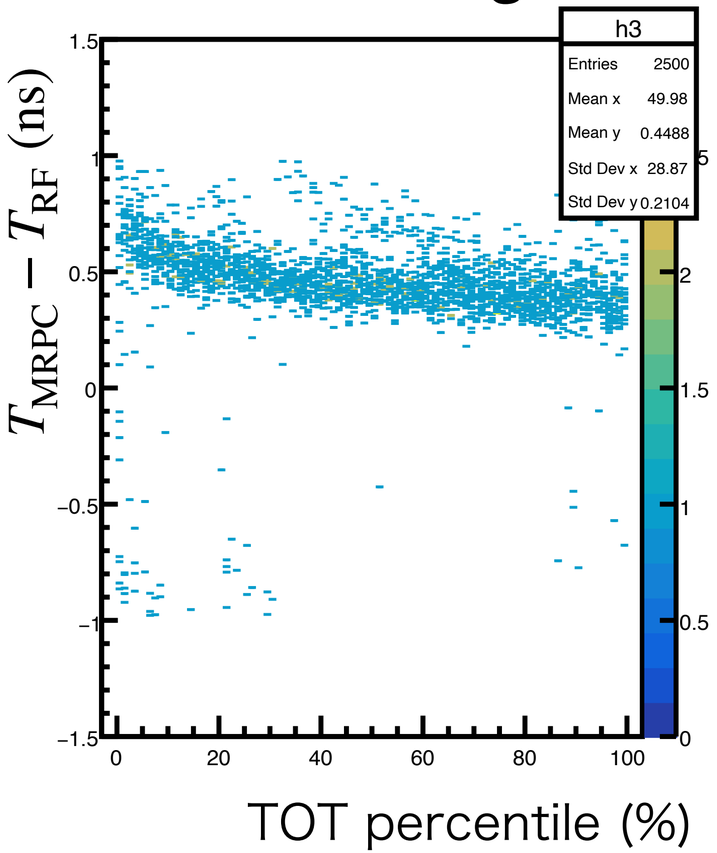


Result of Time Resolution

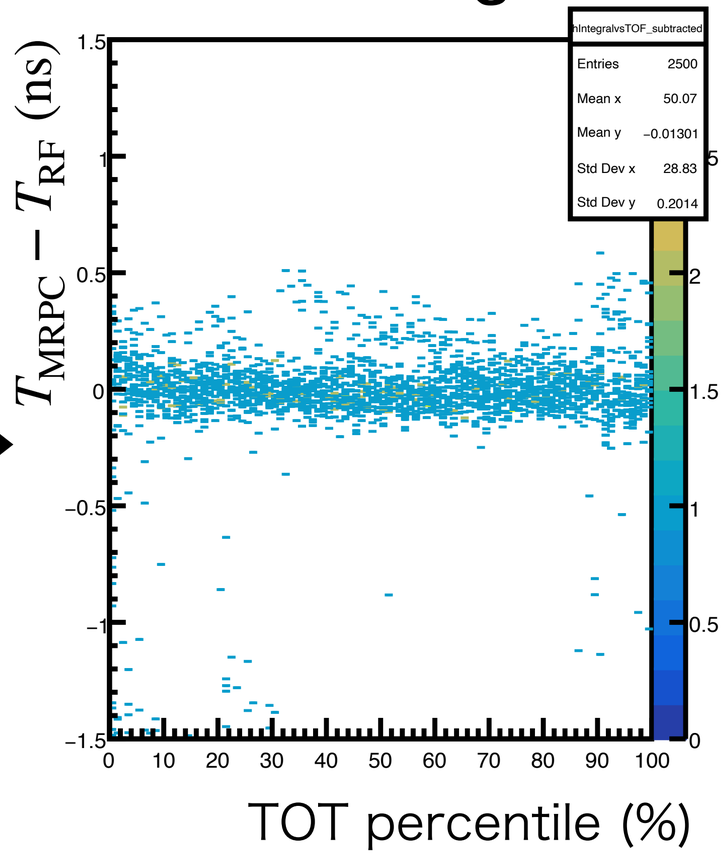
- Use 1 strip (1-m-long strip, 15-m-long cable) JINST **12**, no.01, C01012 (2017), [Yang:2017ydx]
- Slewing correction with TOT percentile (percentile of a TOT in a TOT distribution)
- Improvement compared with RPC 2024 result (79.8 ± 1.2 ps, 3-m-long cable)
- Eff. ~ 85 % → more than 15 % hit an adjacent strip

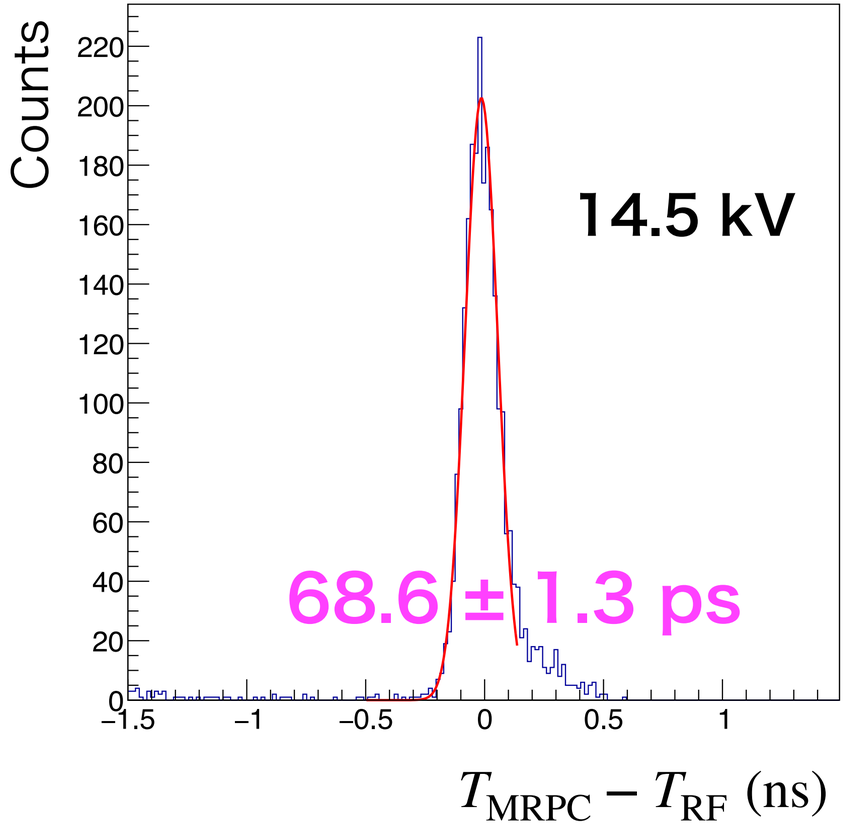


before slewing corr.



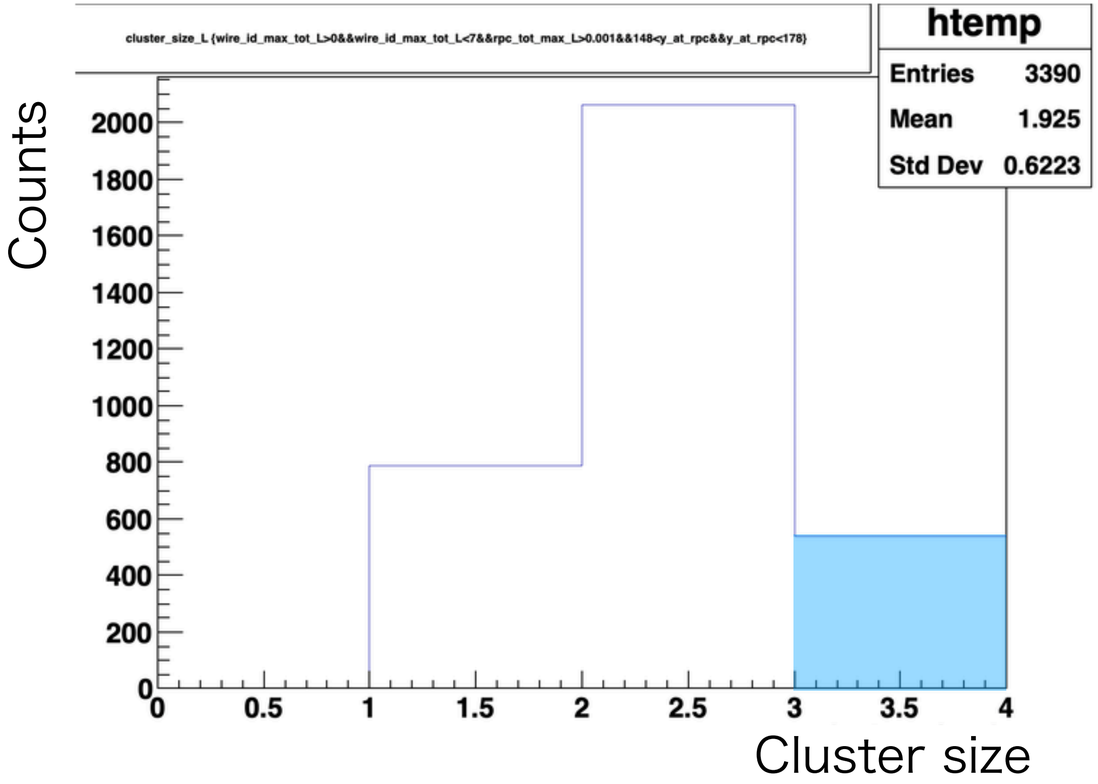
after slewing corr.

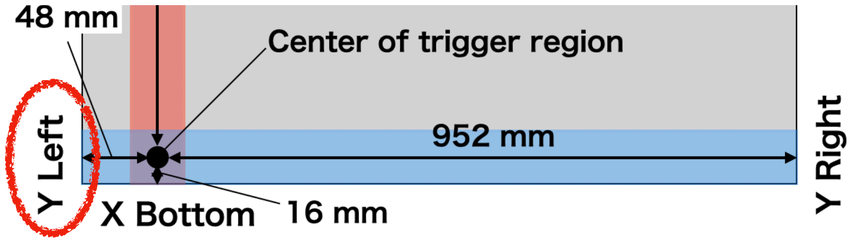




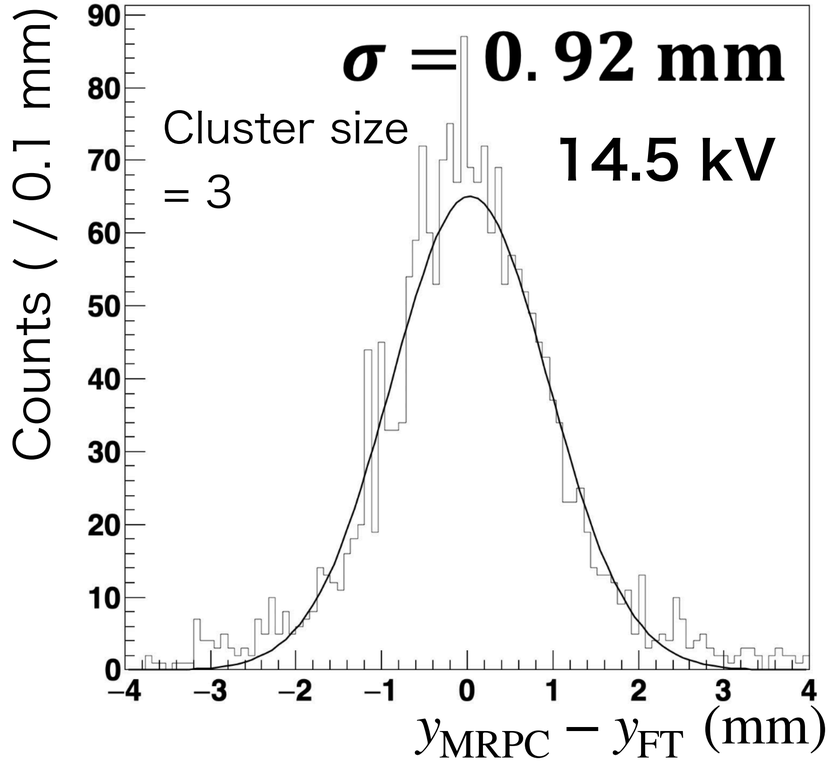
Result of Position Resolution

- Use 1-m-long strip a 15-m-long cable
- Signal readout only from the end closer to the trigger position
- A few 3-strips events (16 % of all events)
  → Narrow signals (~ 1 ns) may not be recorded





- Better than RPC 2024 result (σ > 1.1 mm), but below target



- Re-evaluation using charge information

Summary and Prospects

- We are developing a large-area, high-precision MRPC capable of measuring two-dimensional position and timing for volcanic imaging and terrestrial water storage monitoring.
- We conducted a beam test at the SPring-8/LEPS2 beamline to evaluate the timing and position resolutions of 1-m-long, 4-mm-wide strips using a new HV electrode and a 15-m-long cable.
- Both timing and position resolutions improved compared with the previous results, but the position resolution did not reach the target.

- Since the narrow signals (~ 1 ns) may not be properly recorded, cosmic-ray testing using a charge information is currently underway.
- We are constructing a small MRPC prototype to investigate the effect of readout-strip length.
- We plan to investigate differences in timing and position resolutions depending on the trigger position along the strip.

Thank you!

backup