XVII conference on Resistive Plate Chambers and Related Detectors
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A TOF-tracker MRPC for simultaneous measurements of timing and position at the π20 beamline of J-PARC

Ryotaro Koike

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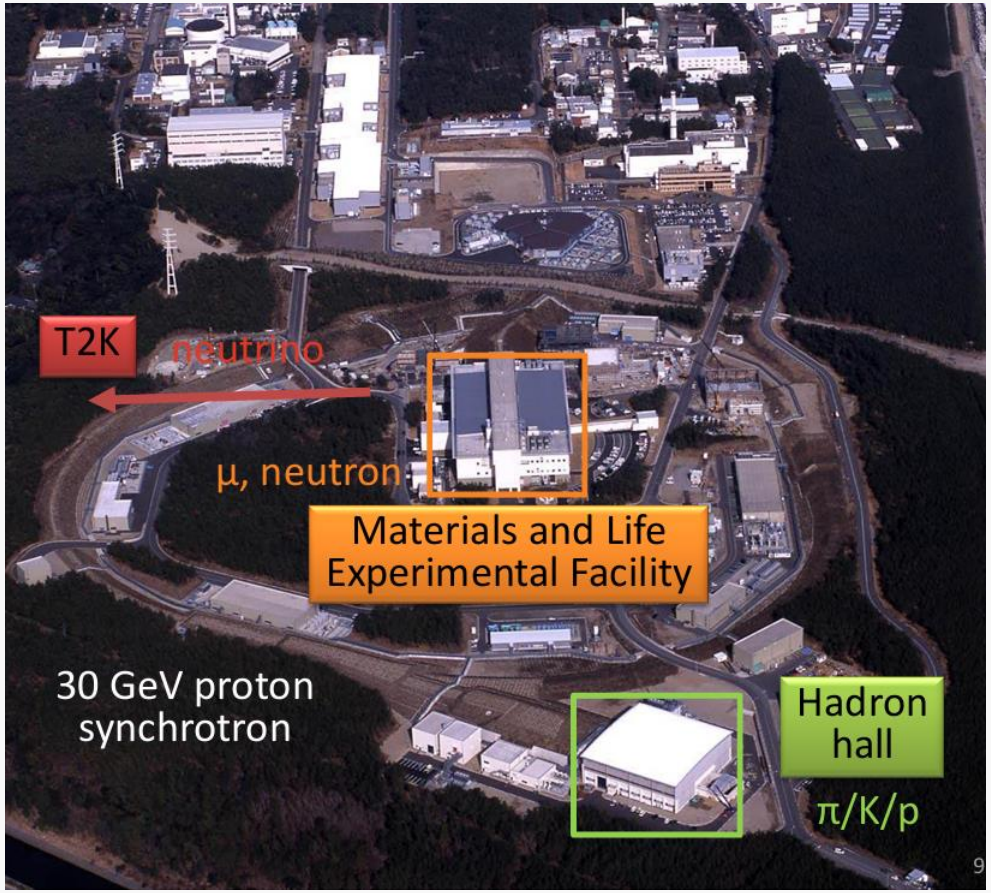
Experiments at J-PARC

@ J-PARC $\pi 20$ beam line
($20\,\mathrm{GeV/c}$ π^- beam)

We will utilize MRPCs for various experiments

- J-PARC (Japan Proton Accelerator Research Complex)
  Hadron hall high momentum beam line
  current : p beam @ 30 GeV/c
  future : $\pi^{\pm}/K^{\pm}/p/\bar{p}$ beam @ 2-20 GeV/c ($\pi 20$)



- Ξ baryon spectroscopy (E97)
- Charmed baryon spectroscopy (E50)
- I=3 dibaryon search (E79)
- GPD study using Exclusive Drell-Yan reaction
  $\pi^- p \to \gamma^* n \to \mu^+\mu^- n$

MARQ spectrometer

@ J-PARC $\pi 20$ beam line
($20\,\mathrm{GeV/c}$ π^- beam)

Multi purpose Analyzing system for Resonance and Quark dynamics is a future spectrometer at the $\pi 20$ beam line

TOF MRPC

Stop timing counter in TOF system
Identify π, K, p $< 1.7\,\mathrm{GeV/c}$ by TOF measurement

Total Coverage： 11 m^2
Time Resolution：60 ps
Efficiency： 99 %

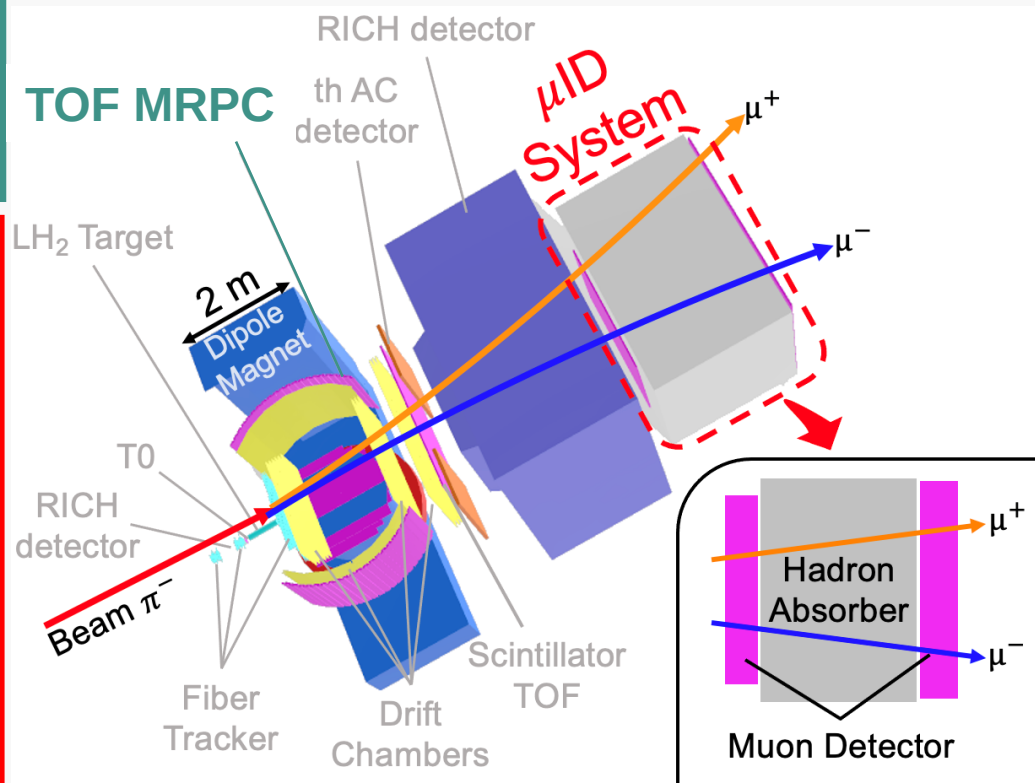
TOF-tracker MRPC

Upstream detector in μID system
Identify the desired $\mu^+\mu^-$ by rejecting random combinatorial muon pairs

Size： 2.4 m × 1.8 m
Time Resolution：100 ps
Position Resolution：1 mm
Efficiency： 99 %

exclusive Drell-Yan reaction

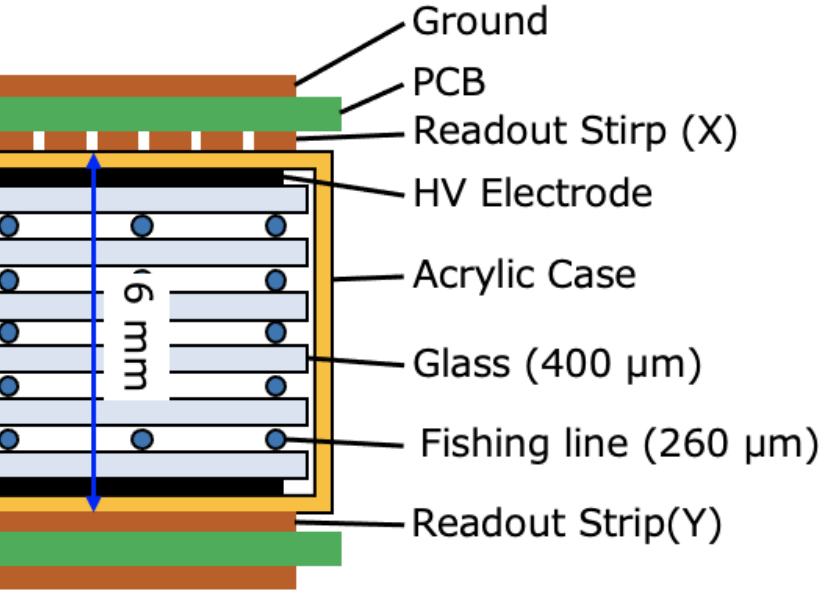
$$\pi^- p \rightarrow \gamma^* n \rightarrow \mu^+\mu^- n$$

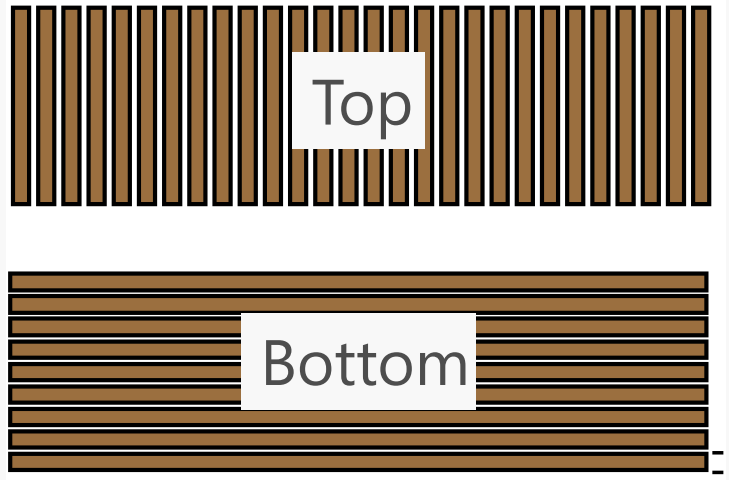


TOF-tracker MRPC prototype

- **Orthogonal pattern of strips**
  Vertical strips on one side and horizontal strips on the other side
  to enable precise measurements of both position and timing

Developed a prototype TOF-tracker MRPC which has a 500 mm × 1000 mm active area



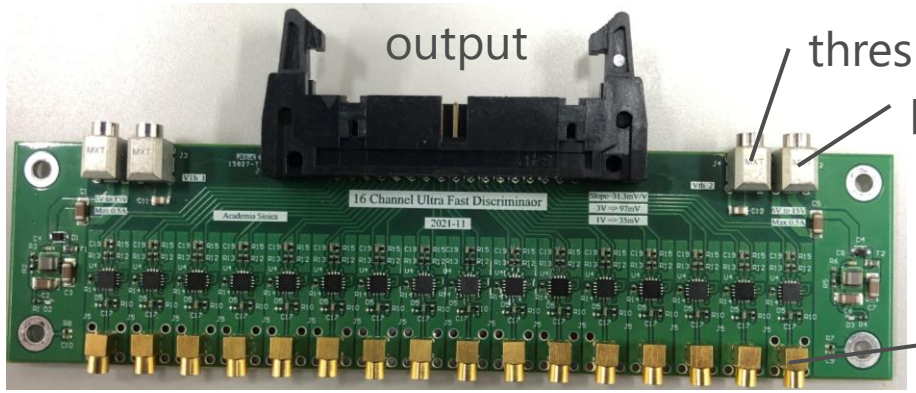


Configuration

- gas gap : 260 μm * 5 gaps
- R134a : butane : SF6 = 90 : 5 : 5
- Strip pitch : 5 mm
  → position resolution better than $5/\sqrt{12} = 1.4$ mm
- strip width : 1.35 mm, 1.60 mm
- Ground is printed on the opposite side of PCB from strips

Dedicated electronics and methods

Discriminators (Academia Sinica)

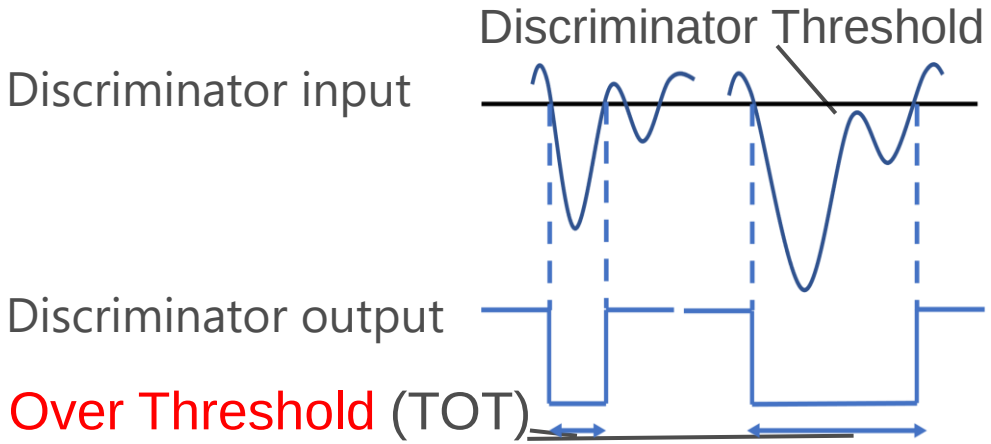


Width-varying output depending on the input width

Time Over Threshold (TOT)

Width of the discriminator output.

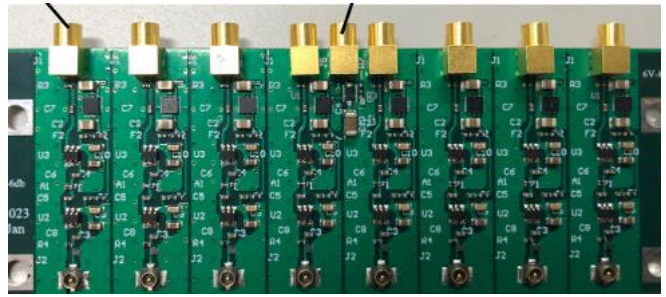
A representative of charge.



Amplifiers (Academia Sinica)

fast.

gain : ×~300

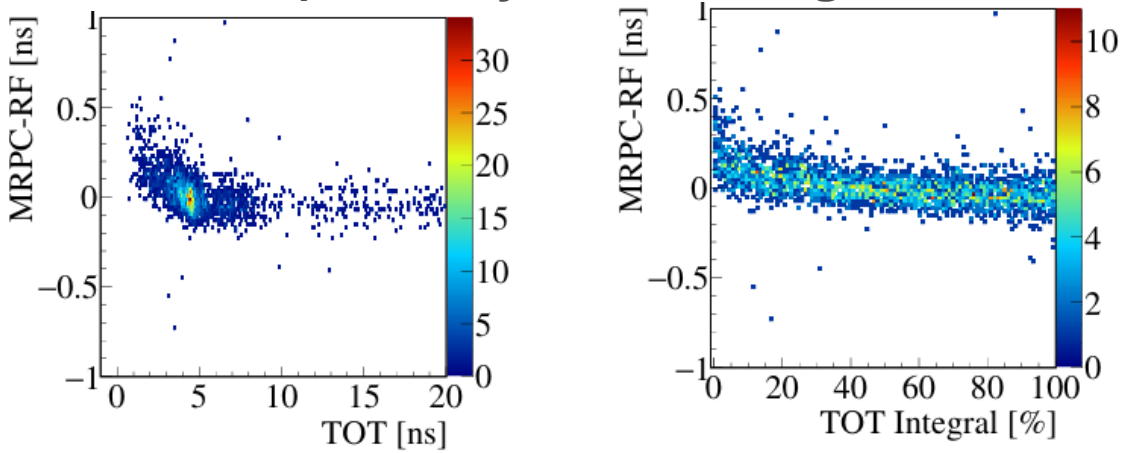


Slewing correction with TOT integral

A slew. corr. method that can be done only with TDC.

TOT integral = percentile of a tot in a tot distribution

Subtract the dependency on TOT integral

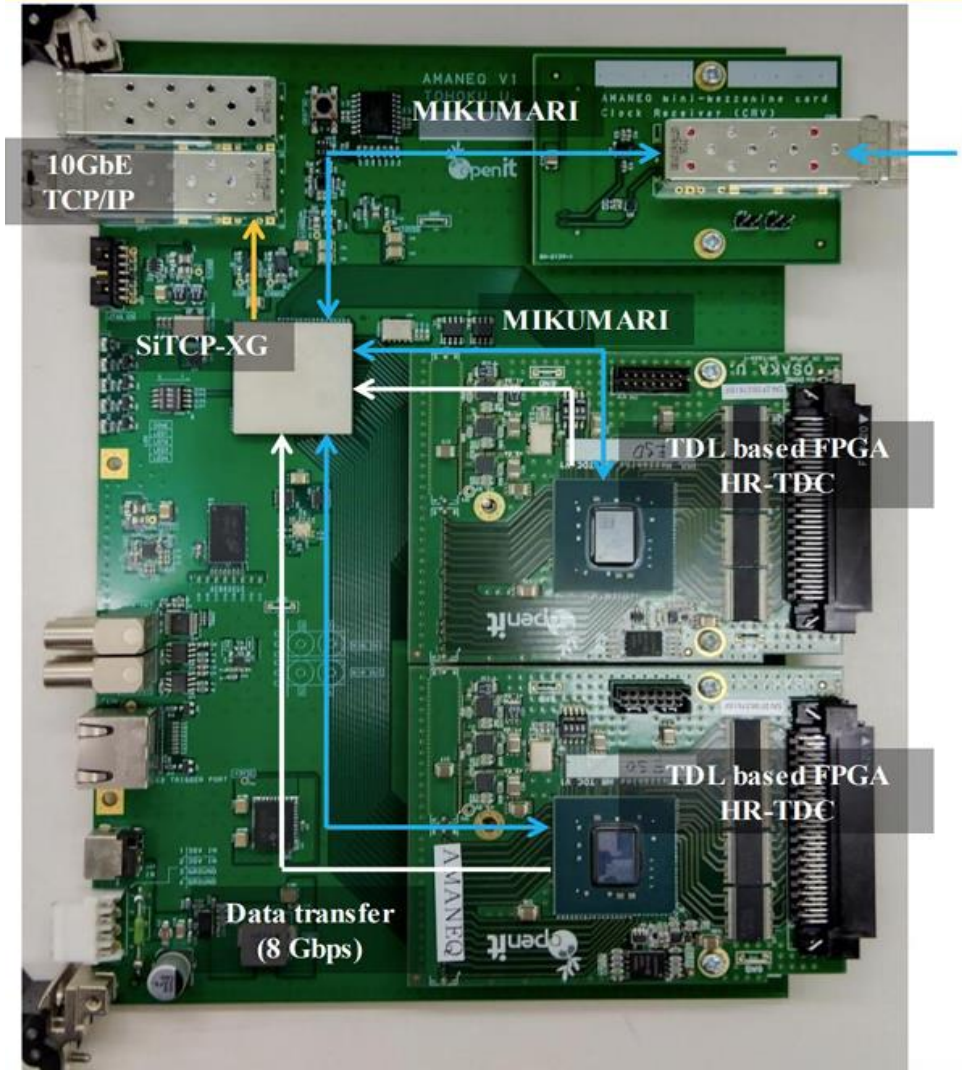


R. X. Yang, C. Li, Y. J. Sun et al., JINST 12 C01012 (2017).

Dedicated electronics and methods

HUL HR-TDC

https://openit.kek.jp/project/HUL/HUL
https://openit.kek.jp/project/StrHRTDC



Modulated clock
from upstream (distributer) module

- FPGA-based High Resolution TDC
- Time Resolution : ~25 ps
- A Peculiar issue

some very narrow signals (TOT < 1 ns) of MRPCs are not within the acceptance of this TDC

The TDC may purely drop such signals, or store an incorrect timing information

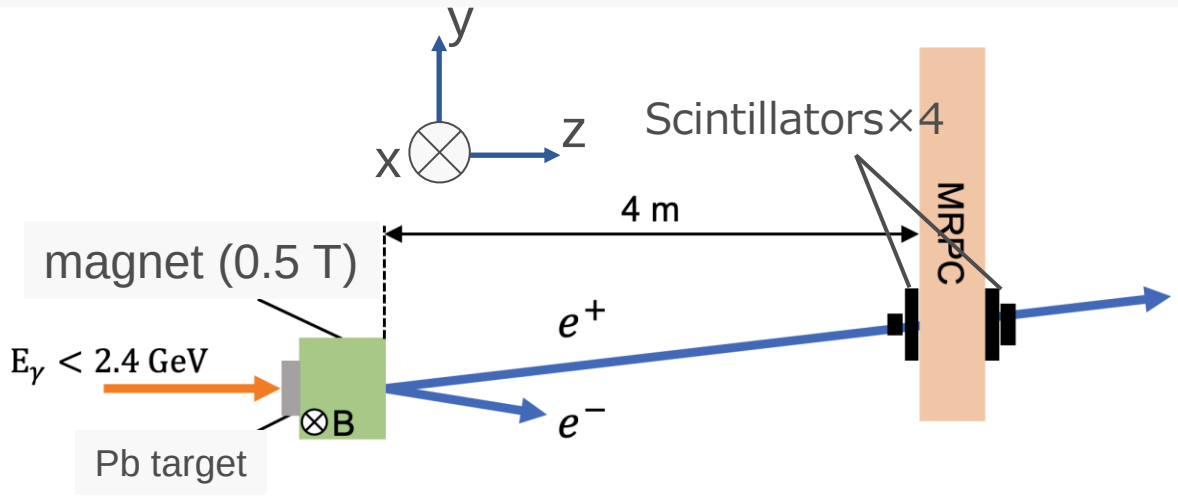
→ We can avoid this issue by stretching signal width

Beam test

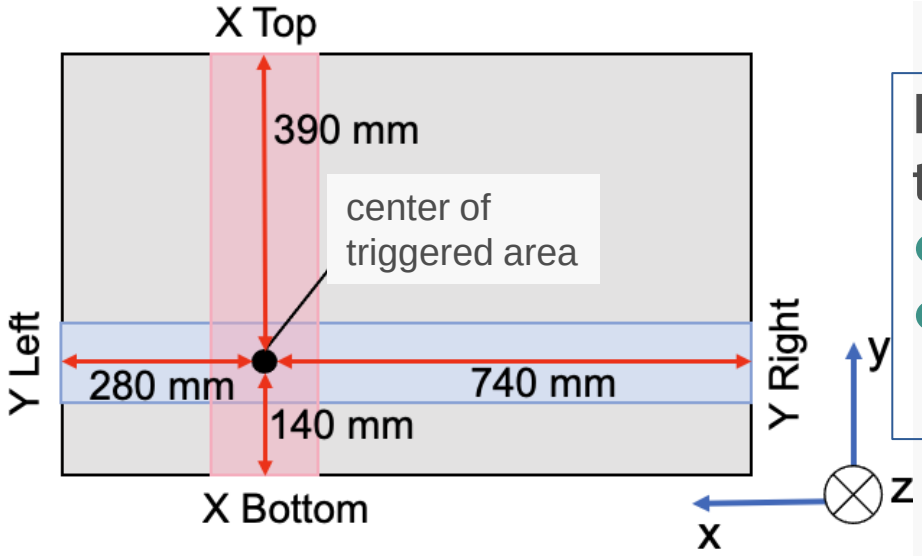
@SPring-8 LEPS2

Setup for timing measurement

Side view



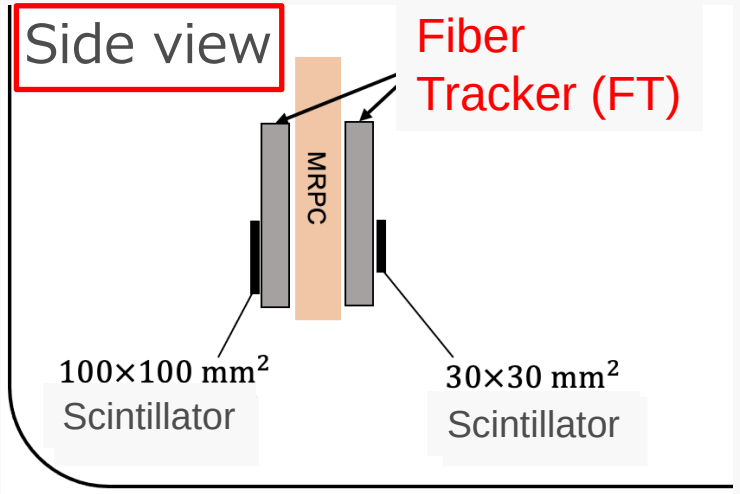
Upstream View



Evaluated time resolution from time difference, $\mathrm{MRPC} - \mathrm{RF}$

- $\sigma_{\mathrm{RF}} \sim 14$ ps
- with a FPGA based HR-TDC ($\sigma_{\mathrm{HR-TDC}} \sim 25$ ps)

Setup for position resolution



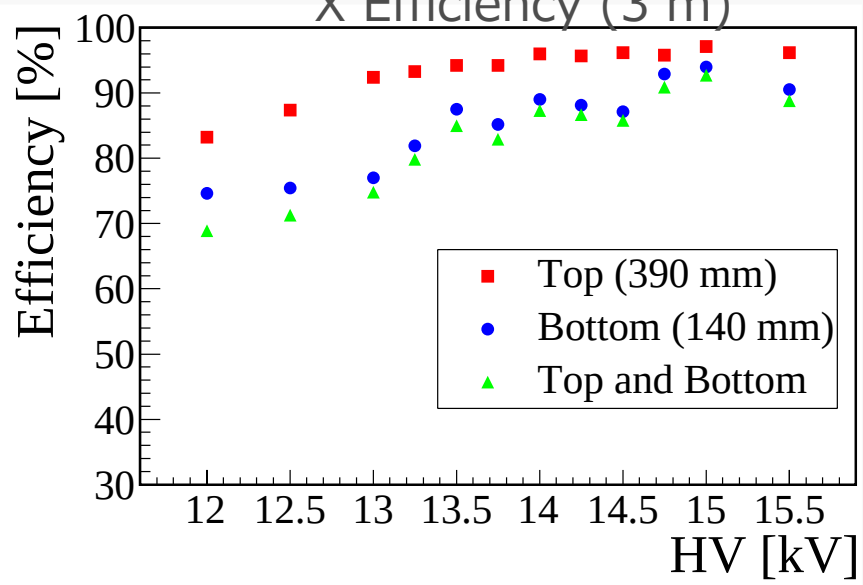
Evaluated position resolution using FTs as reference

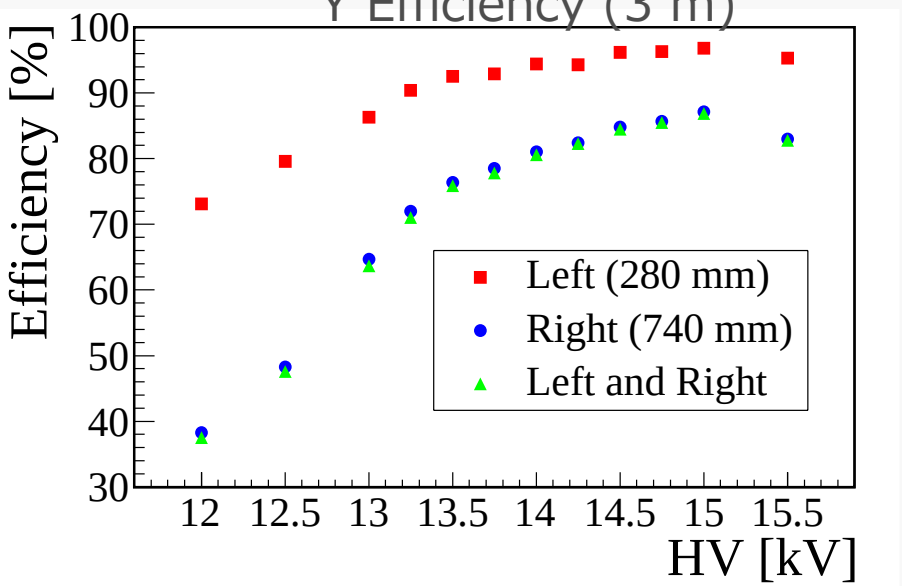
- $\sigma_{\mathrm{FT}} \sim 0.2$ mm

- Signal readout from both ends of a strip
- X strips: positive signals, Y strips : negative signals

Results: efficiency

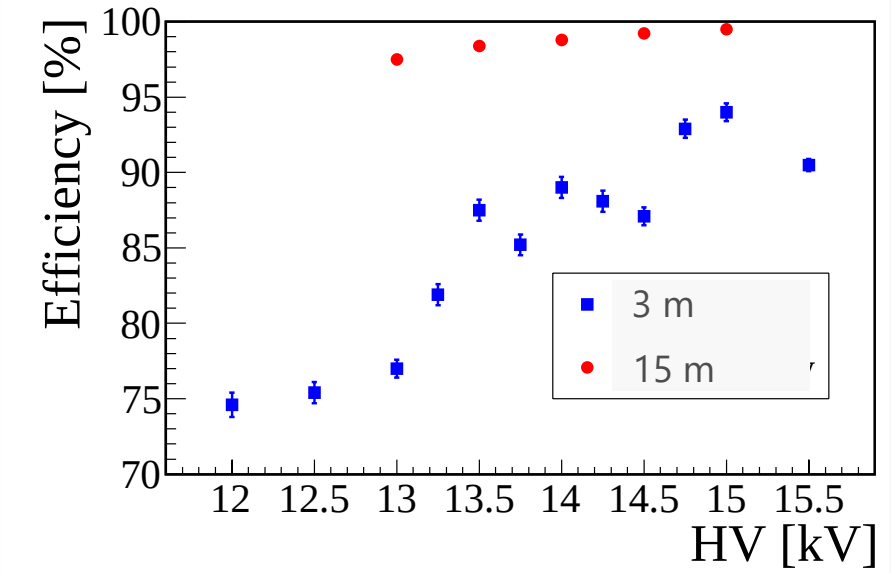
Vth (X) = 21mV
Vth (Y) = -53 mV





Longer cables

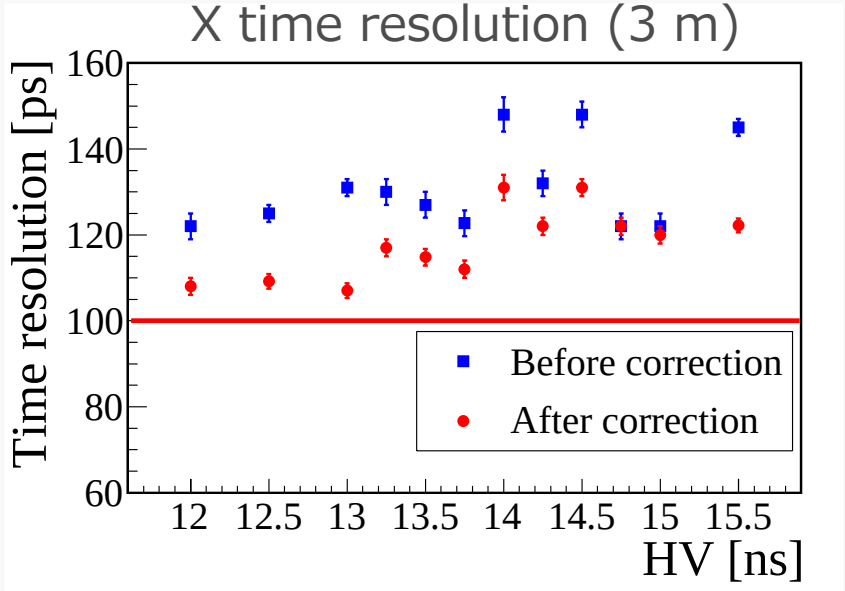
Efficiency for different cable lengths (X)

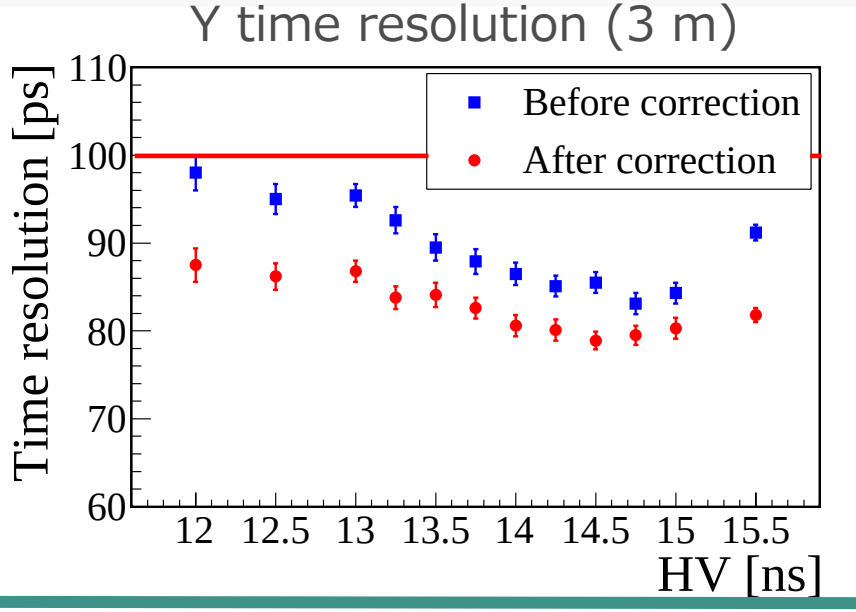


- Stretching signal by extending cables (3 m → 15 m) resulted in a good Efficiency
- Now developing a discriminator with stretcher
- 95+ % efficiency was achieved

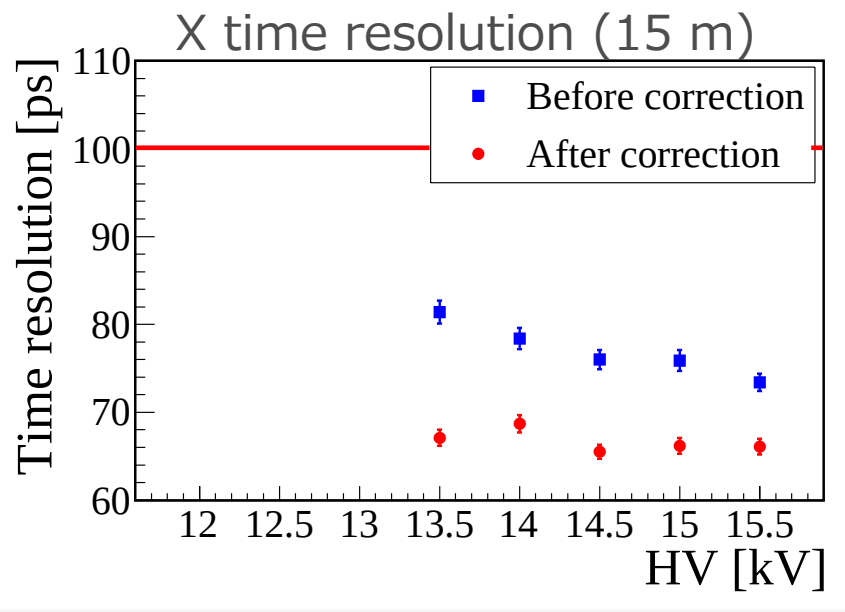
Results: time resolution

Vth (X) = 21mV
Vth (Y) = -53 mV





Longer cables

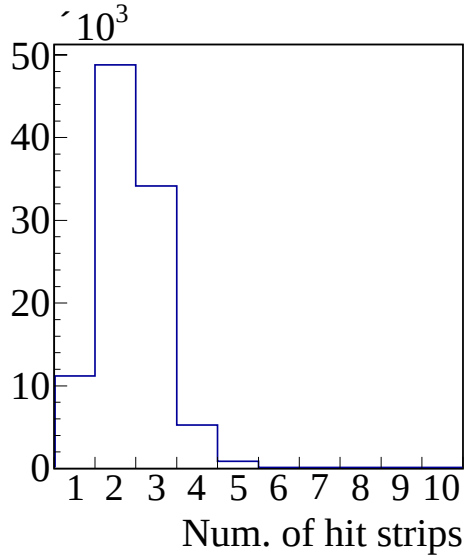


- Slewing correction was done with TOT integral
- Significant improvement again by stretching signals
- X : 66.0 ± 1.0 ps, Y : 79.8 ± 1.2 ps
  (target : 100 ps)
- Precise time resolution was achieved on both side

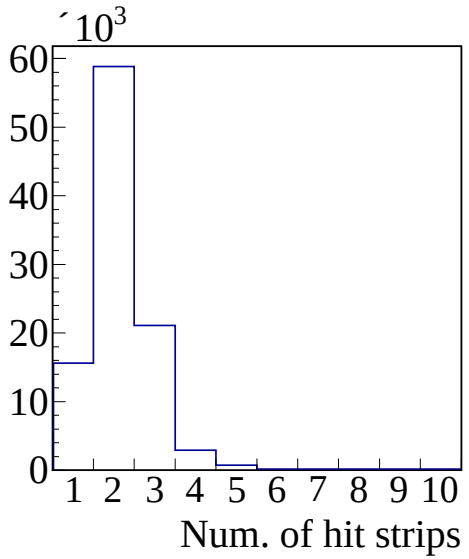
Number of hit strips and Position determination

X strips (15 m cables)

X Top (390 mm from trigger position)

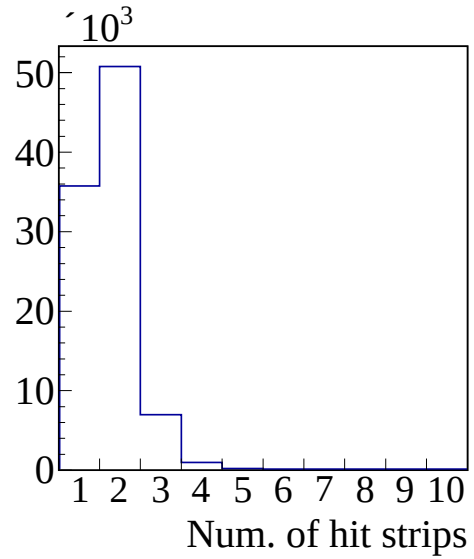


X Bottom (140 mm from trigger position)

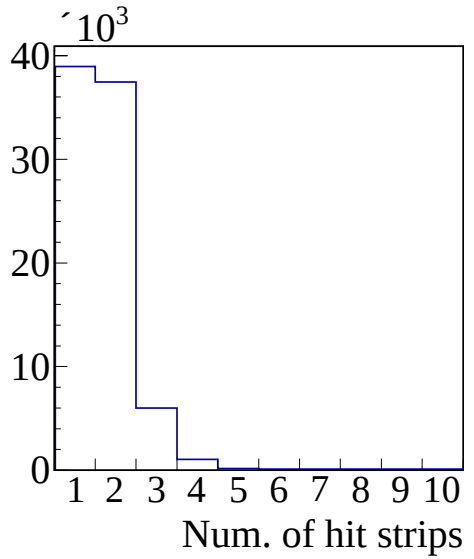


Y strips (3 m cables)

Y Left (280 mm from trigger position)



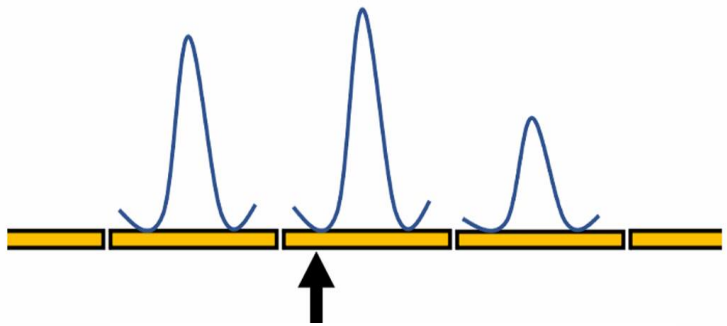
Y Right (740 mm from trigger position)



Usually several strips fire.

We can extract more precise position information with multi hits;

- **Hit position ~ weighted average position with TOT integral**



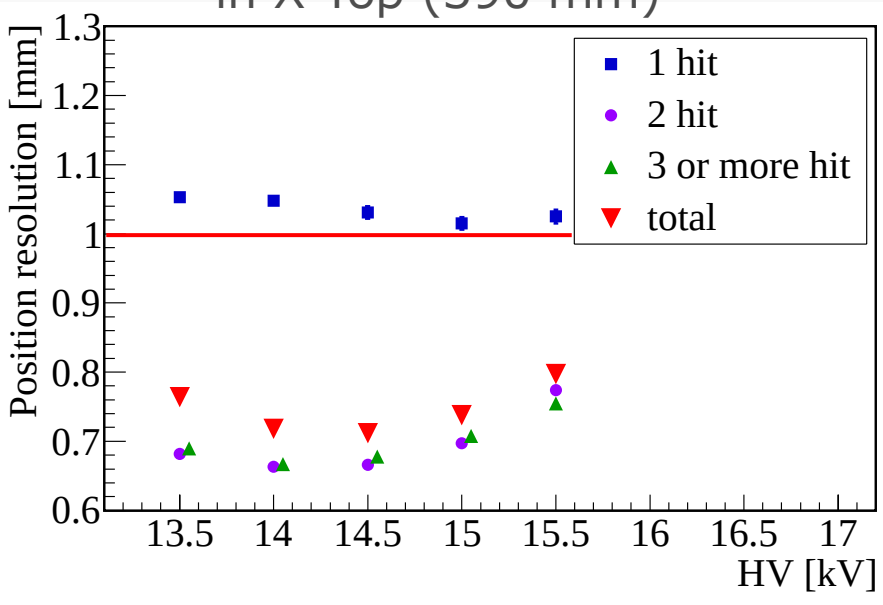
Results: Position resolution in X

Vth = 21 mV
cable length : 15 m

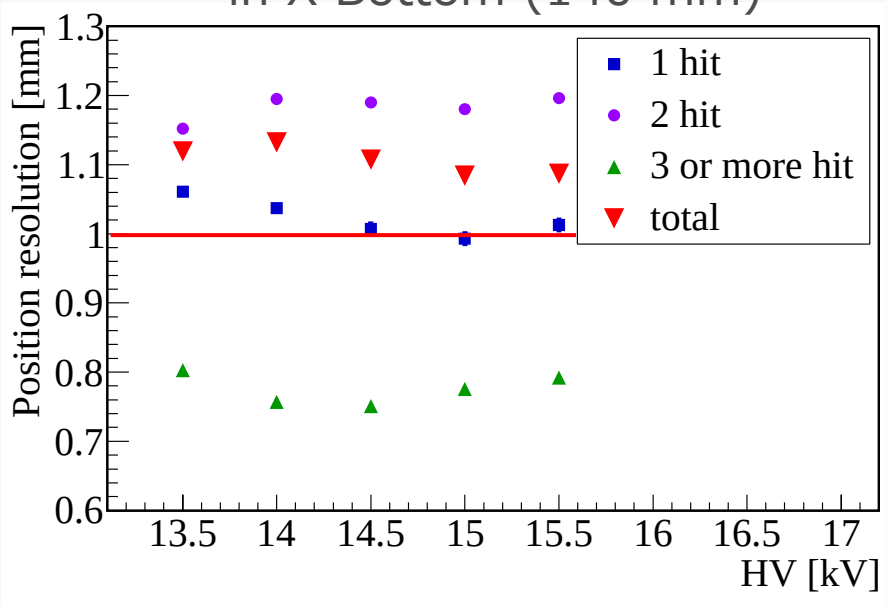
- X Top : **0.712±0.003 mm**、X Bottom : **1.107±0.003** mm （HV =14.5 kV）
  For X Top, the target (1 mm) was achieved
  For X Bottom, events with 2 hit strips gave a worse resolution
  (maybe because the propagation length was short and the TDC dropped some small-TOT hits)

- If we determine a hit position from the average of X Top and X Bottom;
  resolution : **0.767±0.003 mm**

Position resolution
in X Top (390 mm)



Position resolution
in X Bottom (140 mm)



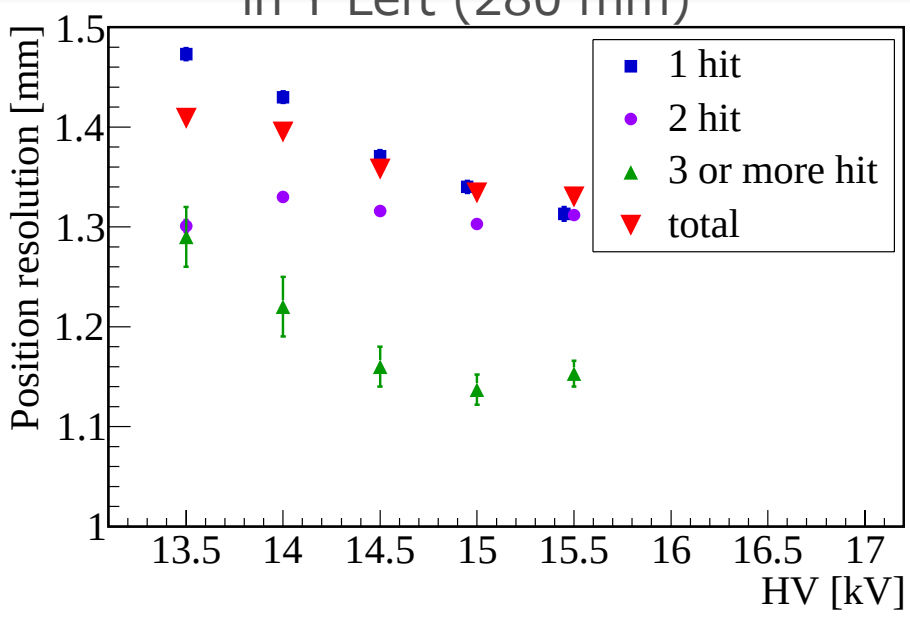
Results: Position resolution in Y

- Y Left : 1.358 ± 0.004 mm、Y Right : 1.257 ± 0.004 mm
  better than naively expected value (1.4 mm)

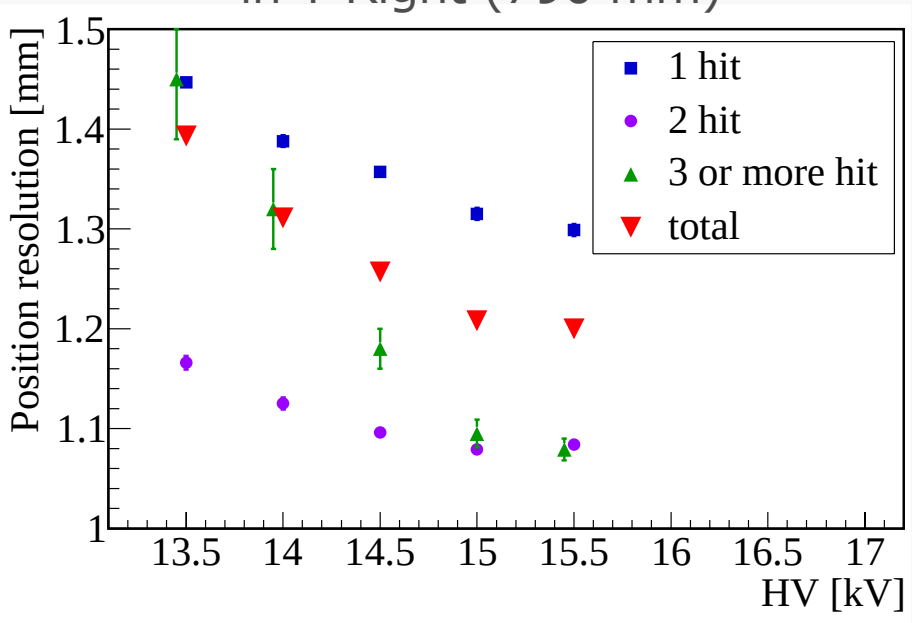
- They will improve if we extend the cable

- If we determine a hit position by the average of Y Left and L Right;
  resolution : 1.115 ± 0.003 mm (HV = 14.5 kV)

Position resolution
in Y Left (280 mm)

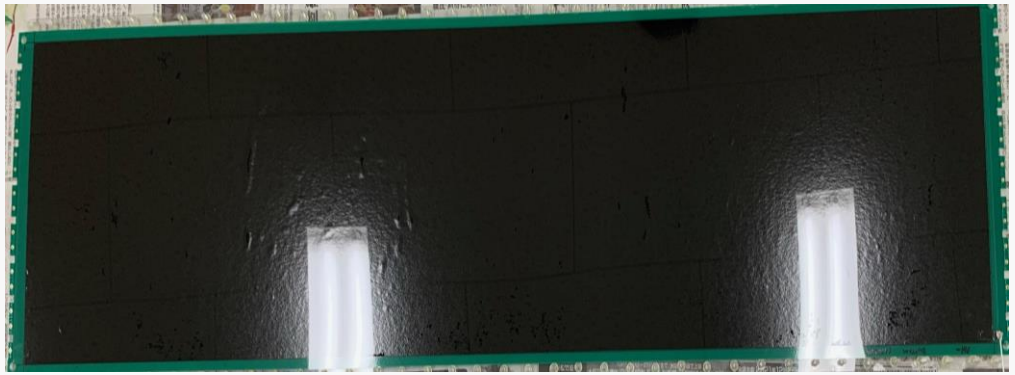


Position resolution
in Y Right (790 mm)



A problem we are facing

- In Japan, T-9188 carbon tape from EEEC have been used for MRPC electrodes
- The production has ended a few years ago.
  We can no longer purchase it.



T-9188 carbon tape

- We must find an alternative electrode towards the mass production of MRPCs
- Several attempts have failed so far
  - Badger Air-Opaque Airbrush (carbon spray used in Colombia) → could not make it work
  - Kontakt Chemie Graphit 33 (carbon ink used in Lyon) → problems with imports
  - diamond like carbon → expensive, hard to cover a large area
- Crisis in the feasibility of MRPCs in Japan?

New Electrode Candidates

Conductive coating on glass or mylar

Electrode for Reference

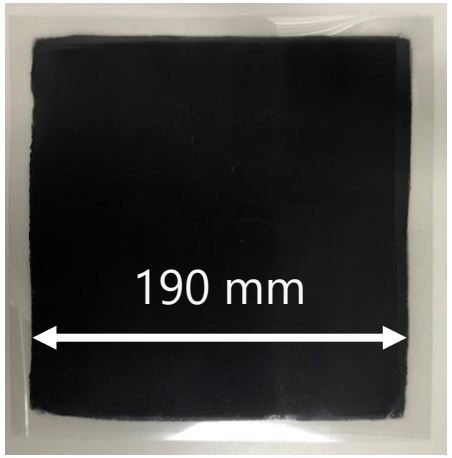
Carbon ink (used in Lyon)

graphit 33

from kontaktchemie

$\sim 2 \times 10^6\ \Omega/\mathrm{sq.}$

painted on mylar



unable to import.

Candidate ①

Fluoropolymer-base conductive coating

KP-8348-1 Black

from Kansaipolymer

$\sim 3 \times 10^4\ \Omega/\mathrm{sq.}$

painted on glass

Candidate ②

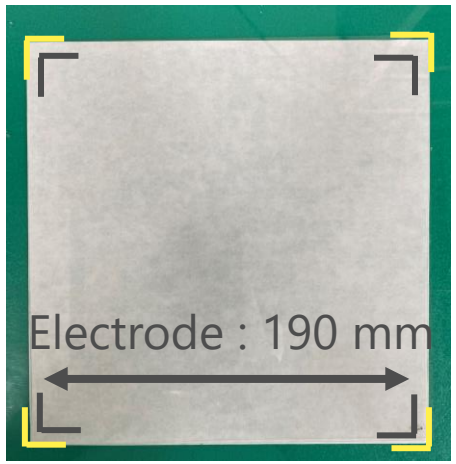
Nanocarbon dispersed polysiloxane

CS-6301

from Colcoat

$\sim 4 \times 10^6\ \Omega/\mathrm{sq.}$

painted on glass



Glass : 200 mm sq.

$\sim 3 \times 10^6\ \Omega/\mathrm{sq.}$

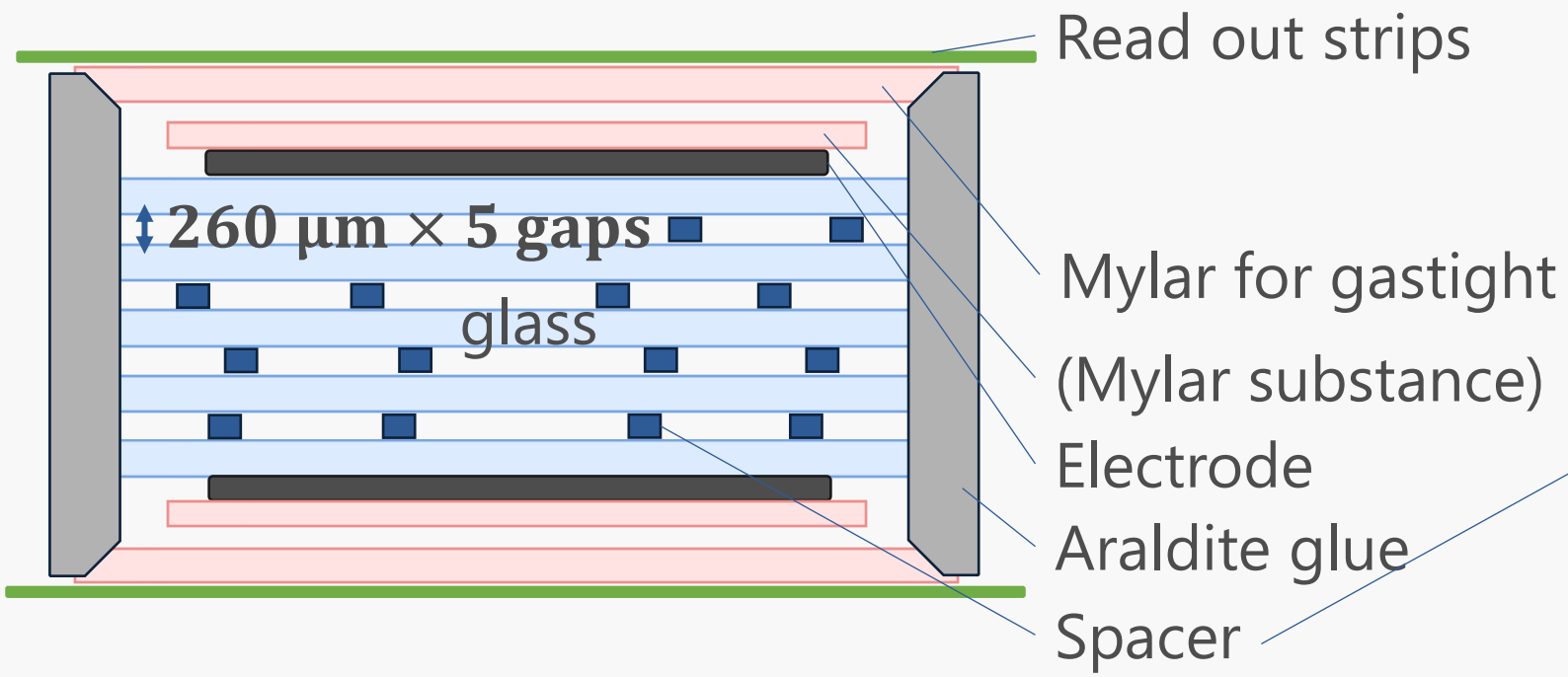
painted on mylar

(it's transparent)

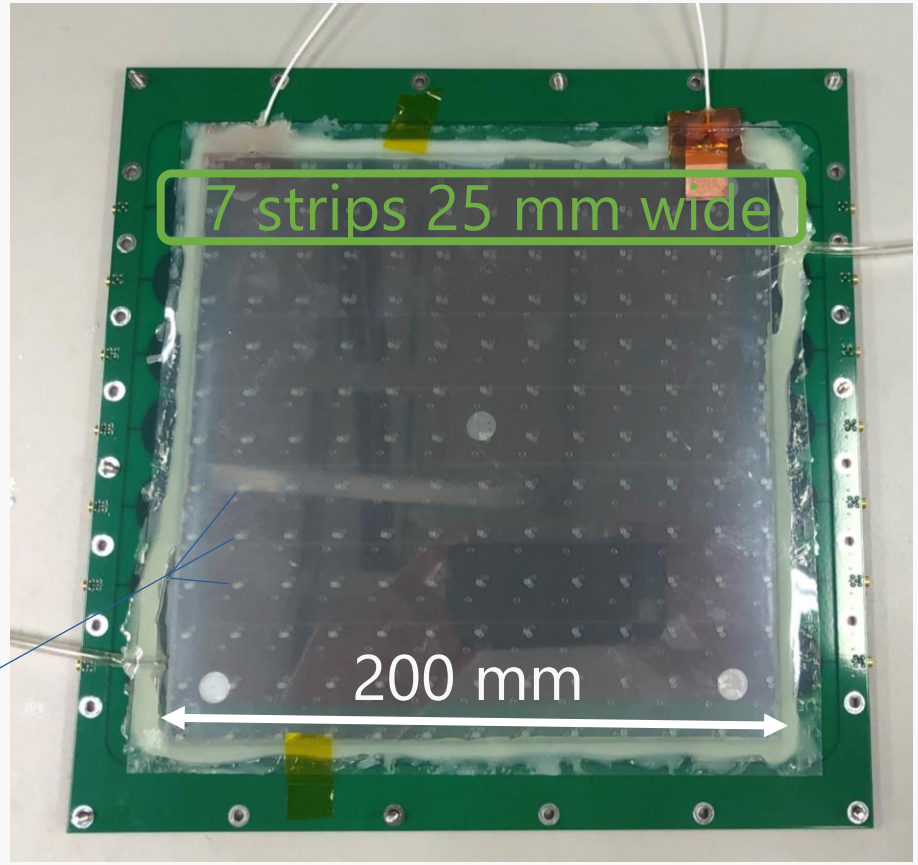
prototype

See Chia-Yu's slide for the spacer info.

- **Developed a $20 \times 20\ \mathrm{cm}^2$ prototype**
  - 2mm-diameter sticky pad spacer
  - Gas tight system inspired by Lyon group
- **Conducted a beam test**



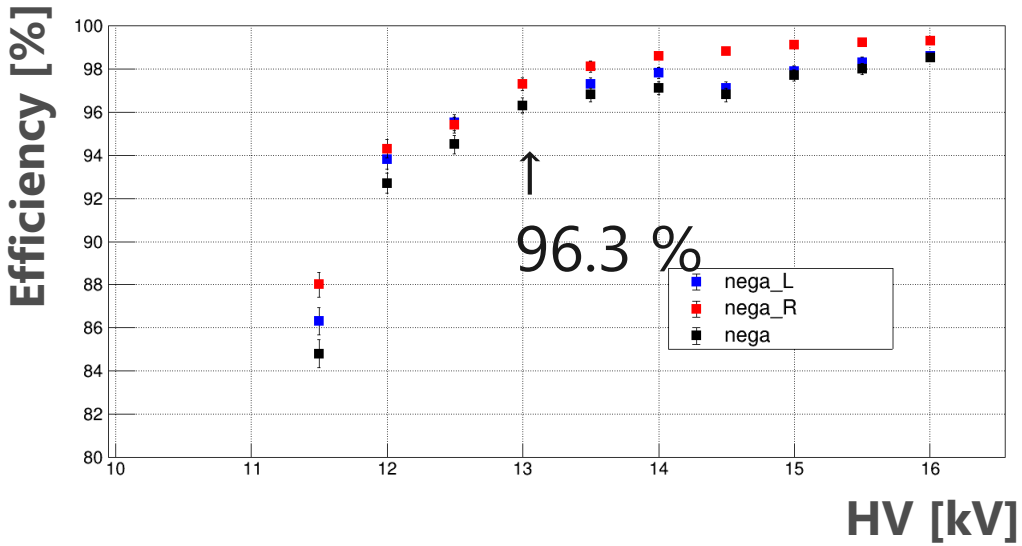
Cross section

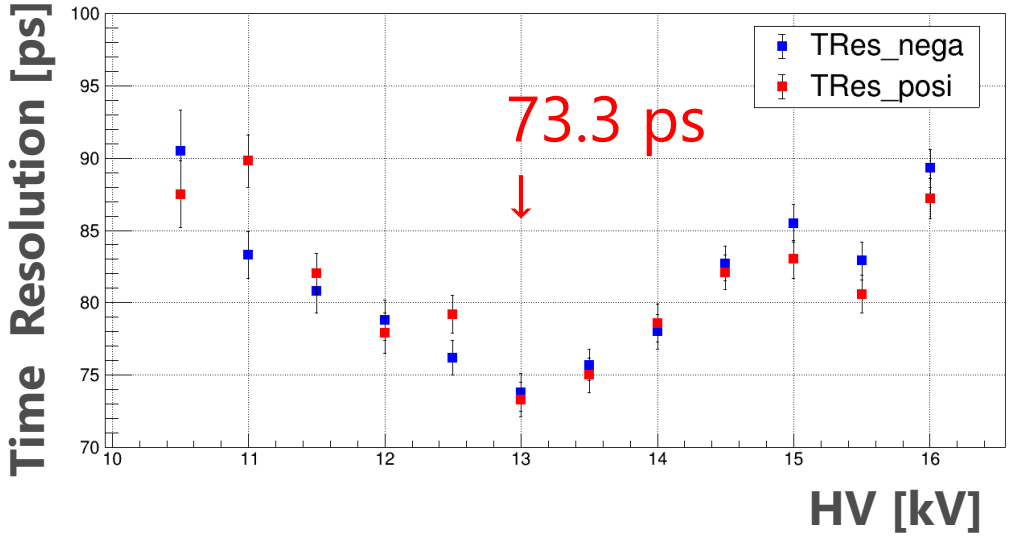


Front view.

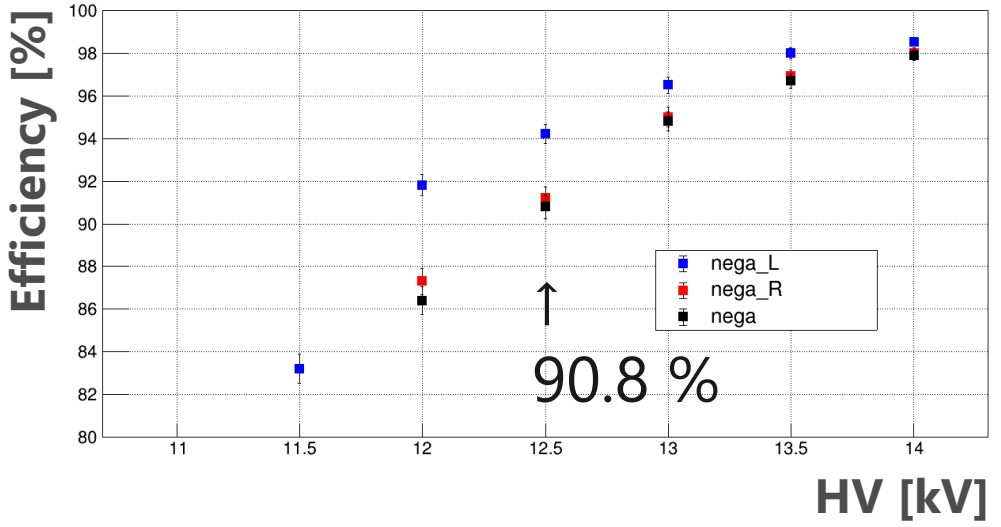
results

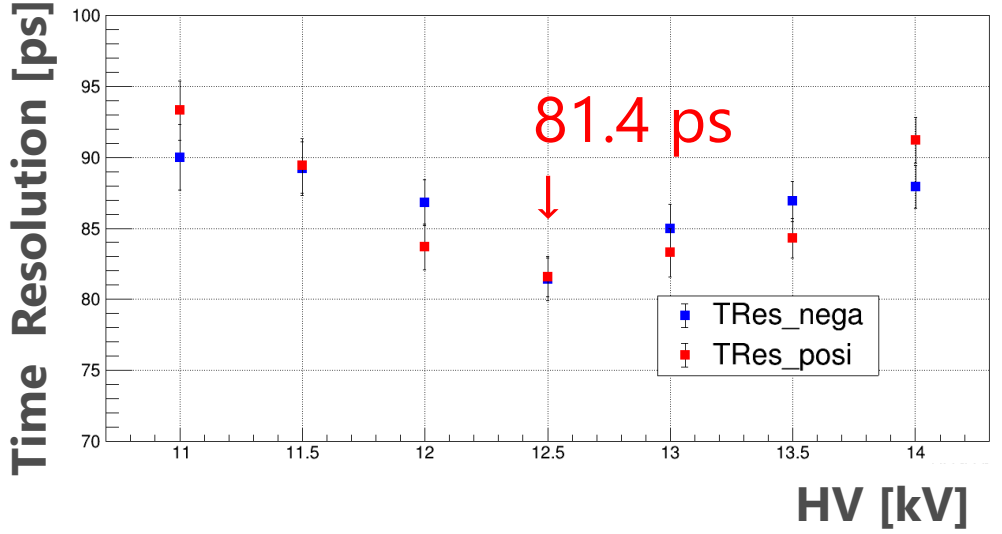
Electrode for Reference : graphit 33





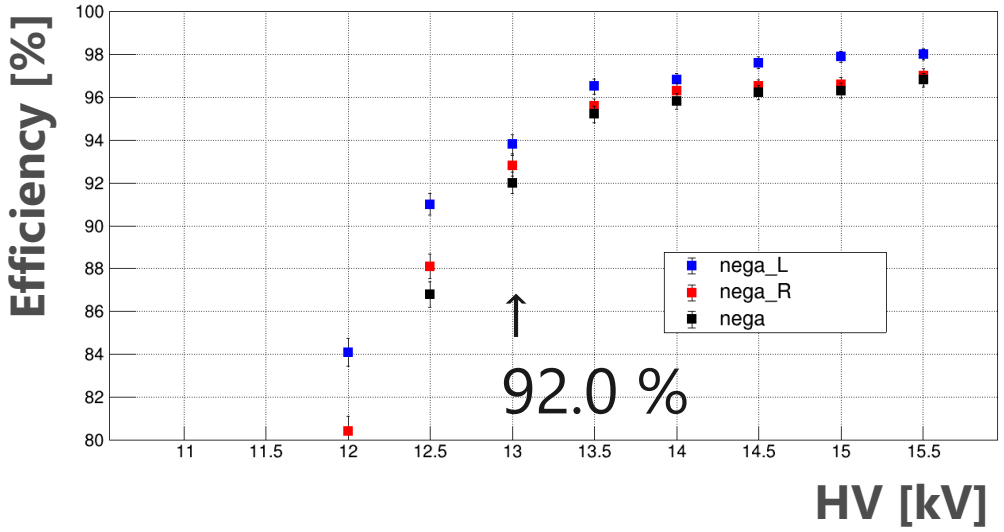
Candidate ① : KP-8348-1 Black

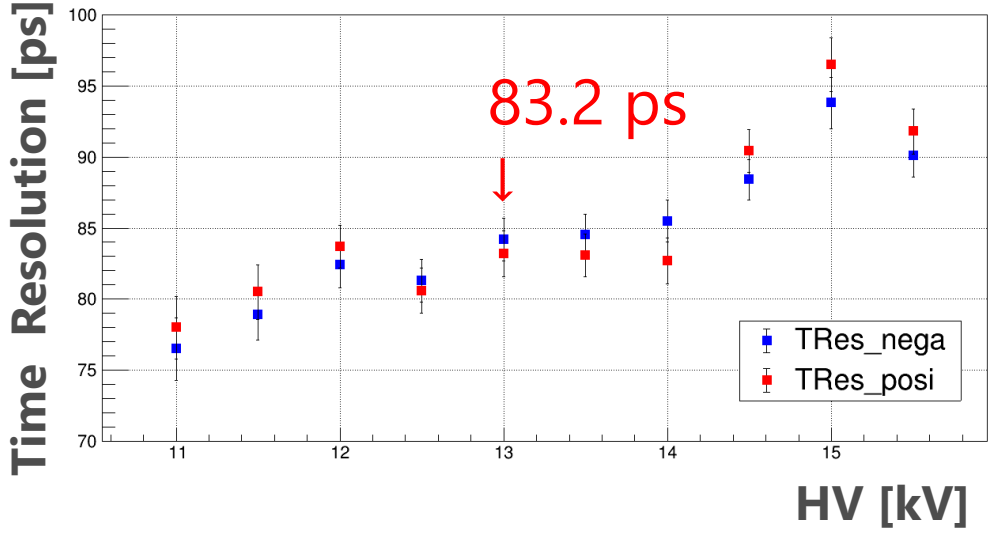




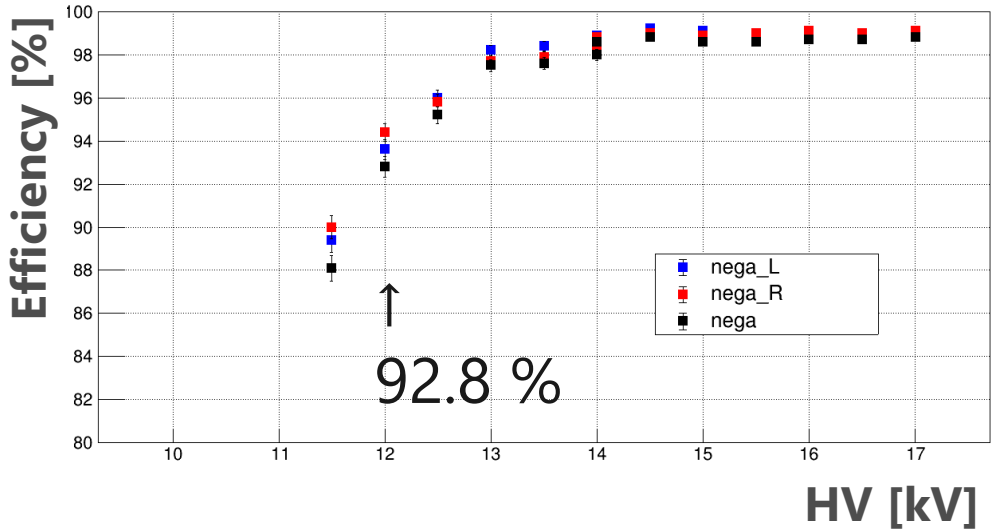
results

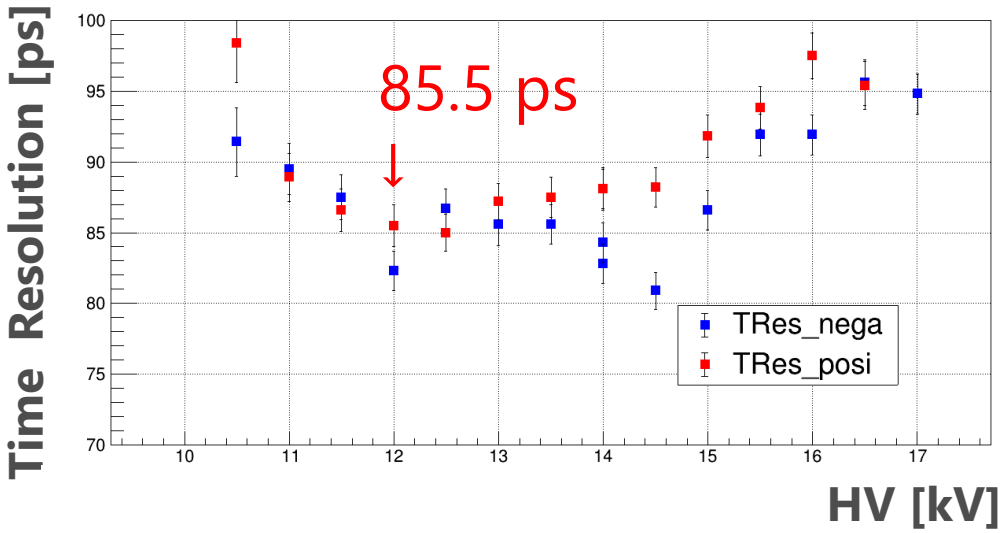
Candidate ② CS-6301(on glass)





Candidate ② CS-6301(on mylar)





Summary and Prospects

- **We developed a prototype TOF-Tracker MRPC for a cross section measurements of Exclusive Drell-Yan reaction**
  - 5 mm strip pitch
  - 500 mm × 1000 mm active area
- **Achieved good performances**
  - Efficiency : 95+ %
  - Time Resolution : $\mathbf{66.0 \pm 1.0\ ps}$ (X), $\mathbf{79.8 \pm 1.2\ ps}$ (Y)
  - Position resolution : $\mathbf{0.767 \pm 0.003\ mm}$ (X), $\mathbf{1.115 \pm 0.003\ mm}$
- **Also, we searched for alternative electrode candidates**
- **Promising candidates found**

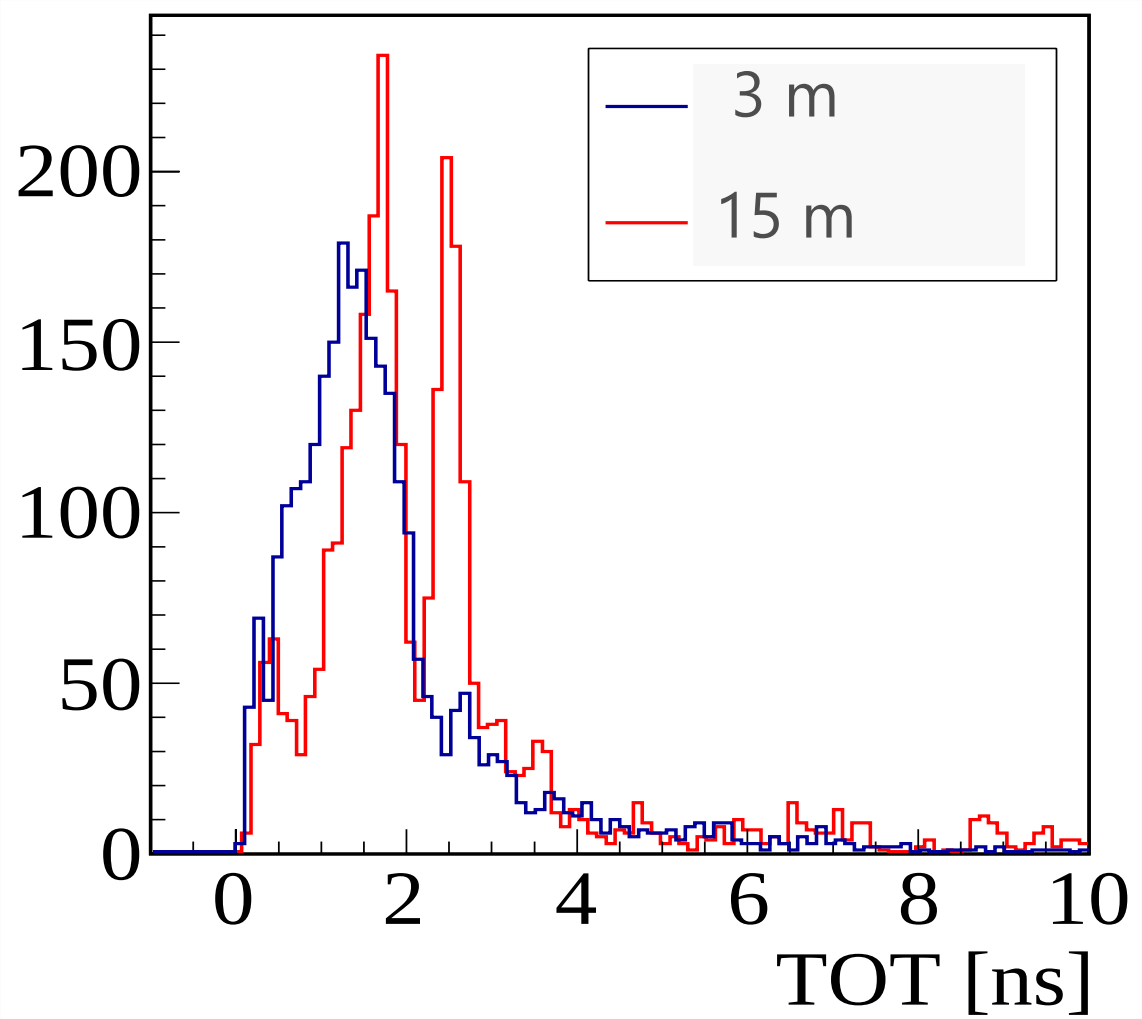
Summary and Prospects

- **We will develop discriminators with stretching functionality to properly capture the signals of MRPCs**

- **We will continue the evaluation of the new electrodes**
  - Large size
  - Reproductivity of resistivity

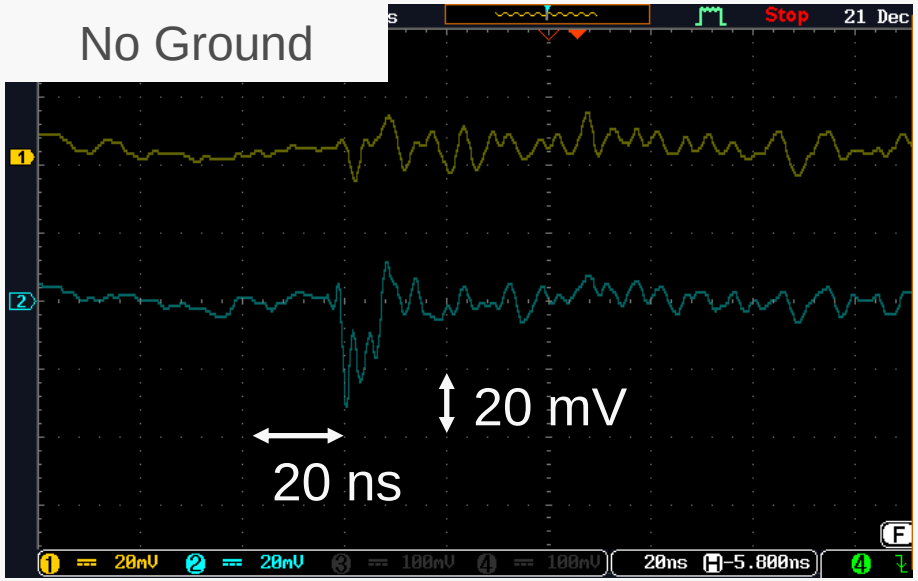
Backup

The effect of stretching signals

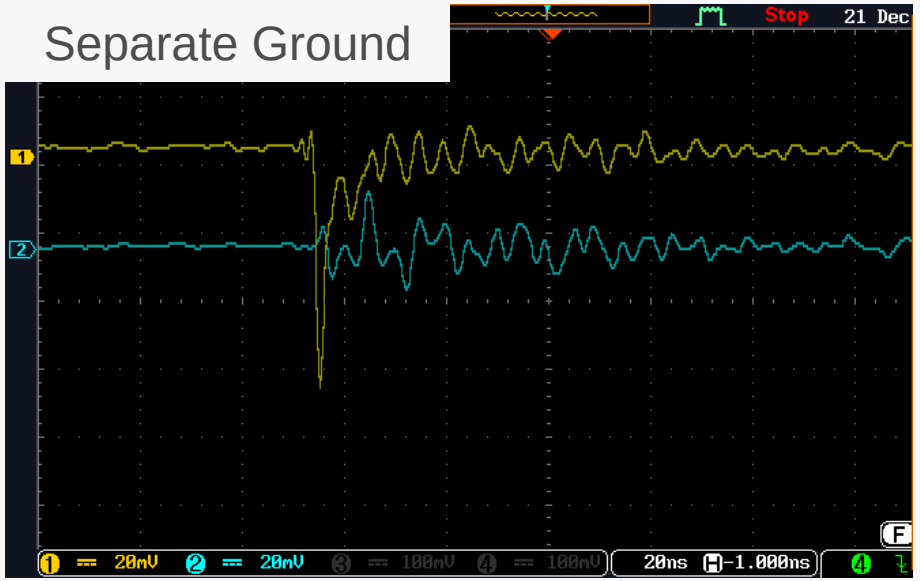


Signal shapes with different ground condition

No Ground



Separate Ground



Full Ground

Full ground resulted in the least reflection.

Previous studies by other groups

Small TOF-tracker RPC

JINST7(2012)P11012

- 80 mm × 80 mm
- Strip pitch : 4 mm
- Rotate the orientation of the top and bottom readout strips 90 degrees
- Read out channel by channel
- Time resolution : ~80 ps
- Position resolution : 40~70 μm

Large TOF-tracker RPC

JINST11(2016)C10002

- 1.5 m × 1.2 m
- Strip pitch : 2.5 mm
- 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)