中国科学技术大学
University of Science and Technology of China

RPC 2022
XVI Workshop on Resistive Plate Chambers and Related Detectors

R&D of prototype inner TOF-MRPC at CSR External-target Experiment

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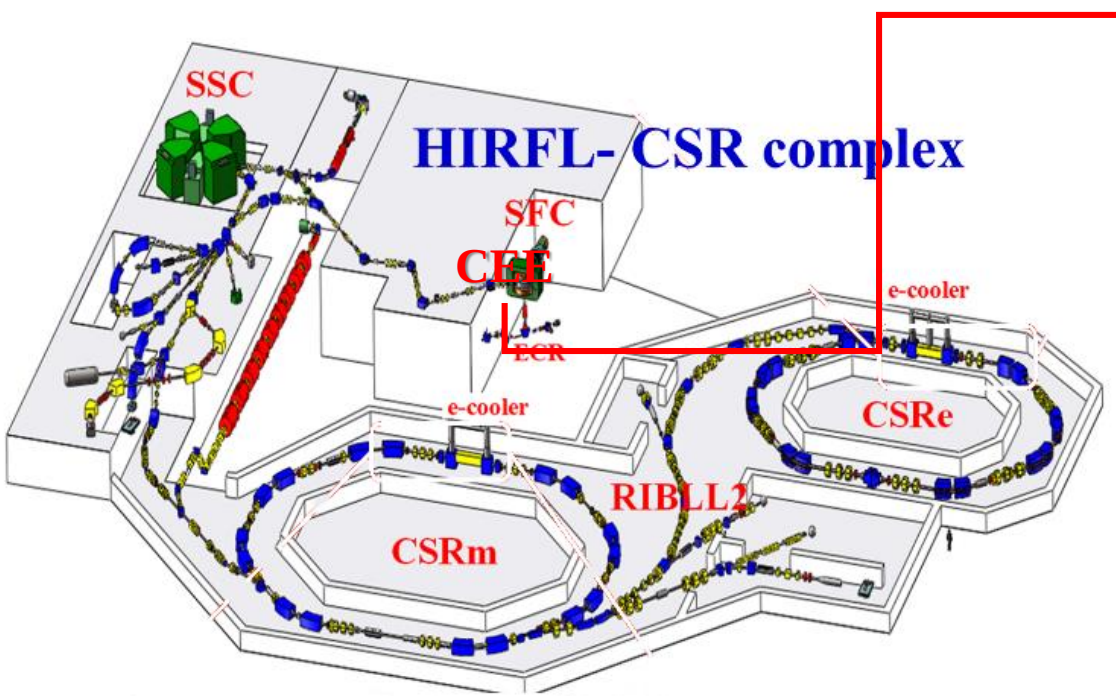
Outline

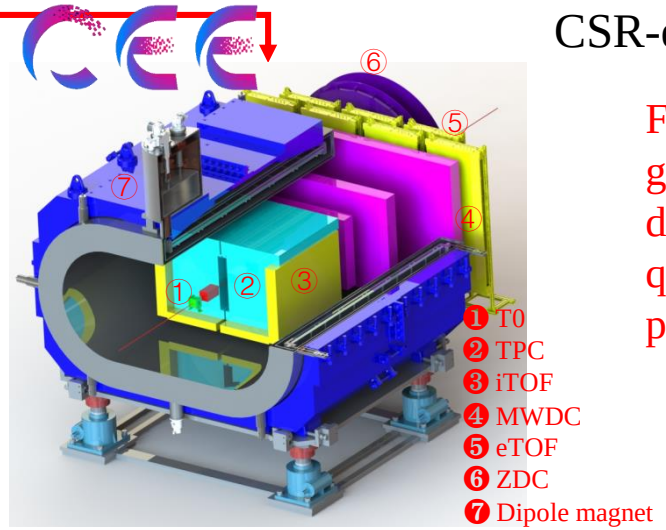
- **Motivation**
- **Design of high time resolution MRPC**
  - **Prototype of iTOF MRPC**
  - **Cosmic ray test system**
  - **Preliminary results**
- **Signal transmission simulation**
- **Summary**

Motivation



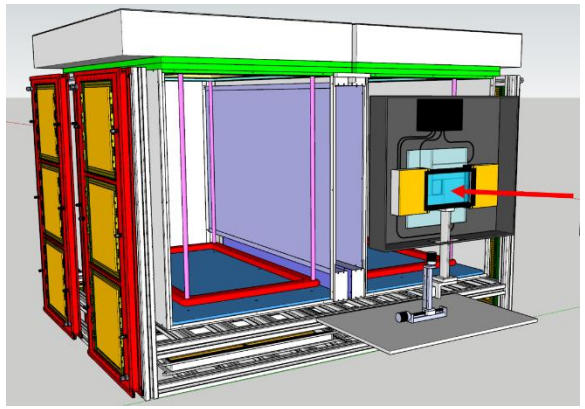
Heavy-Ion Research Facility at Lanzhou (HIRFL-CSR)

- ✓ Provides various ion beam with incident energy in the range of 0.5~1.2GeV/u (can be as heavy as uranium)



CSR-external Target Experiment，CEE

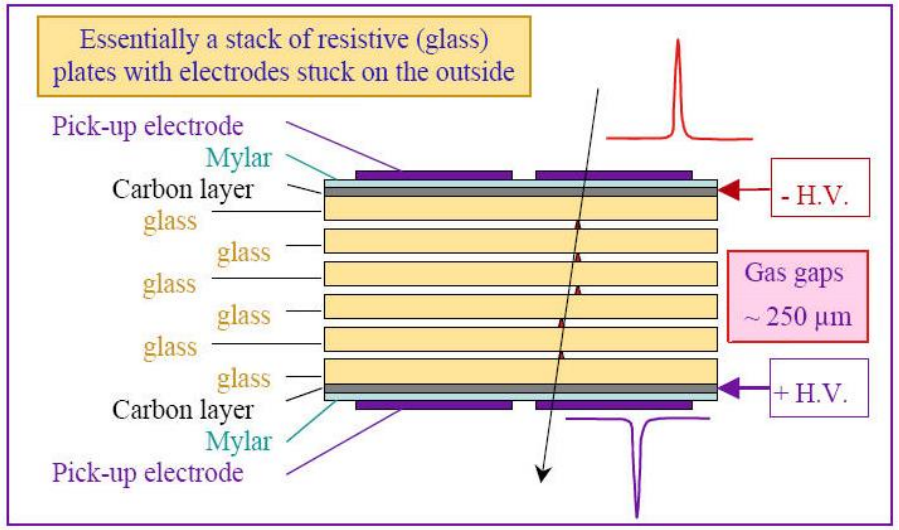
Fix target
goals to study the bulk properties of dense matter and to understand the quantum chromo-dynamic (QCD) phase diagram



Requirements：
Time resolution:
30-40ps
Occupancy:
10%-15%
Particle flux:
50 Hz/cm^2
Efficiency:
>95%

How to improve the time resolution of MRPC

MRPC(Multi-gap Resistive Plate Chamber)



[Nucl. Instrum. Meth. A 374.CERN-PPE-95-166 (1995): 132-136]

- High time resolution (~60 ps)
- Cheap and can be made in large areas
- Not affected by magnetic fields
- High granularity

$$\sigma_{MRPC} = \sqrt{\frac{d_{gap}}{N_{gap}\lambda}\frac{U}{(\alpha-\eta)d_{gap}v}}$$

d_{gap}: gap width N_{gap}: gap quantity

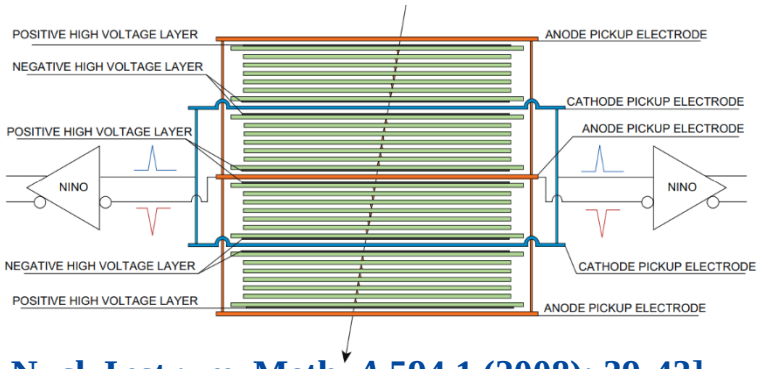
λ: the number of clusters per unit length

$\alpha-\eta$: Effective Townsend coefficient

v: Electron drift velocity

U: Factor of avalanche statistics

[Journal of Instrumentation 12.03 (2017): C03029]



[Nucl. Instrum. Meth. *A* 594.1 (2008): 39-43]

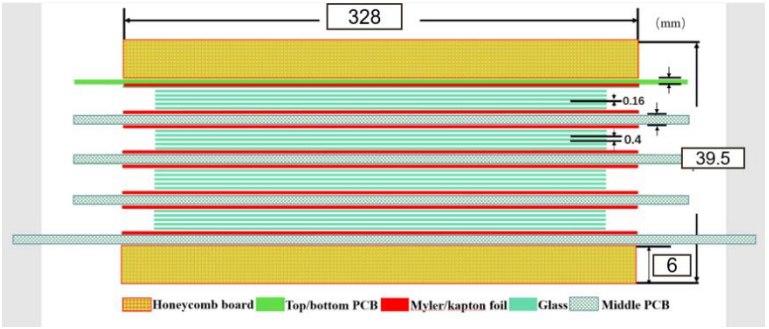
The way to get higher precision time resolution:

- Reduce gap thickness
- More gaps
- Improve the time resolution of front end electronics(FEE)
- Choose a good working gas

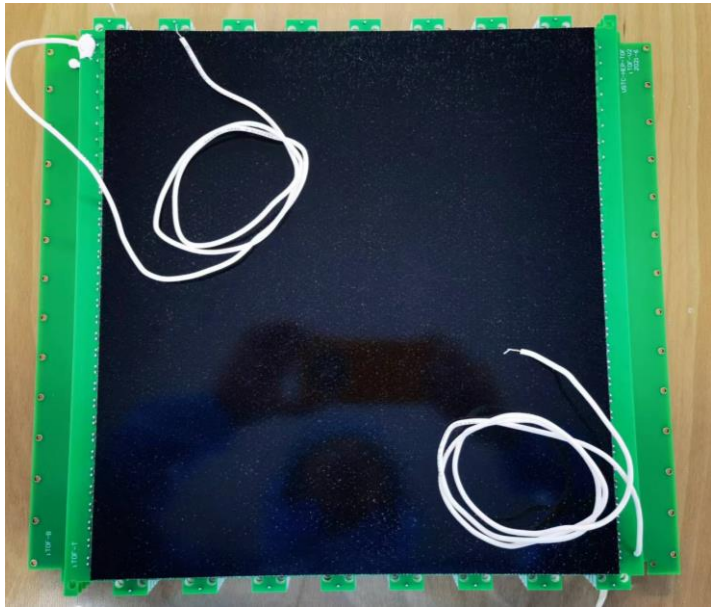
High precision time resolution MRPC designed by CERN

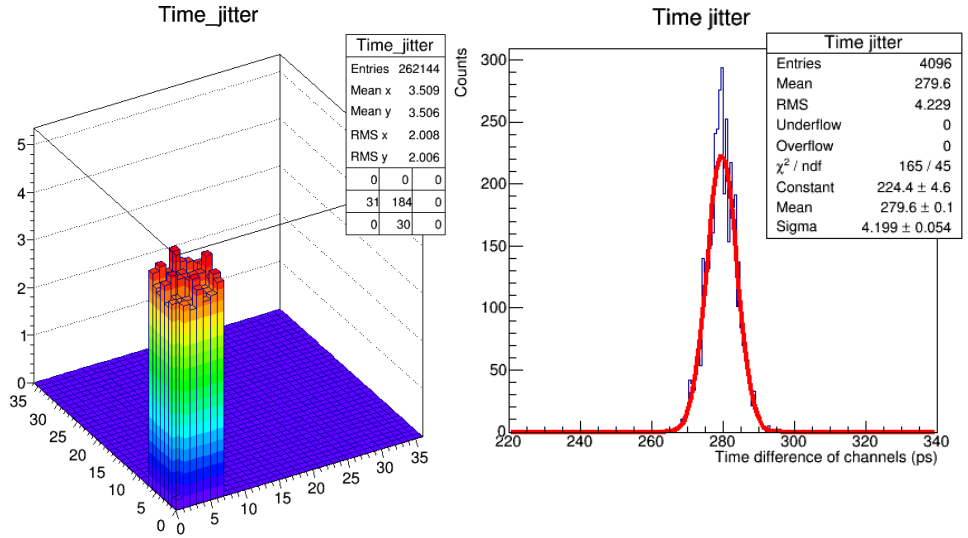
- 4×6 gaps
- 0.16mm gap width
- Waveform sampling readout
- 20ps time resolution
- 95% efficiency

Prototype of inner TOF



Gap	width	0.160mm
	quantity	4 × 6
Glass thickness		0.55mm
Readout strip		(7mm + 3mm) × 32 Double end readout
Impedance		30Ω

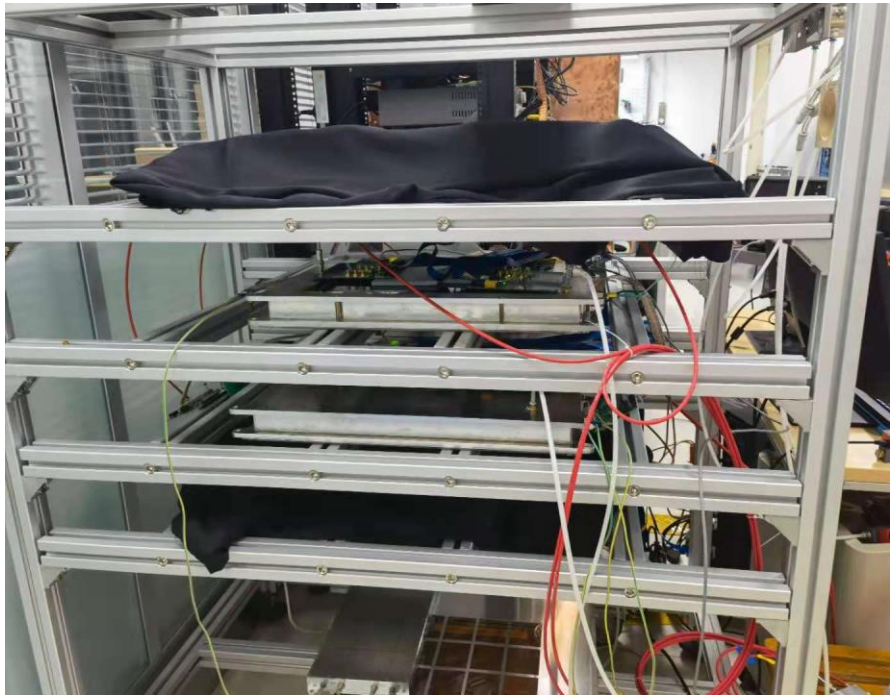




[IEEE Transactions on Nuclear Science 68.8 (2021): 1976-1983]

- NINO FEE + FPGA TDC
- Time jitter < 10 ps
- Uniformity ~ 2.4%

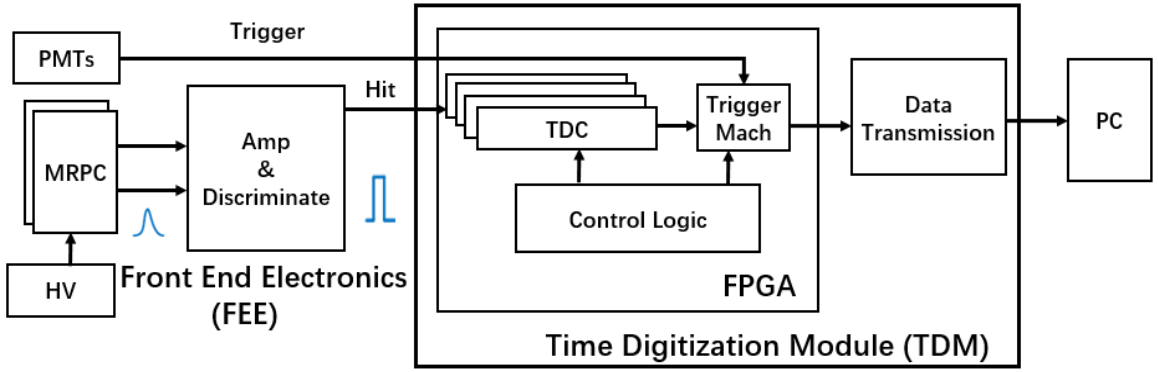
Cosmic ray test system

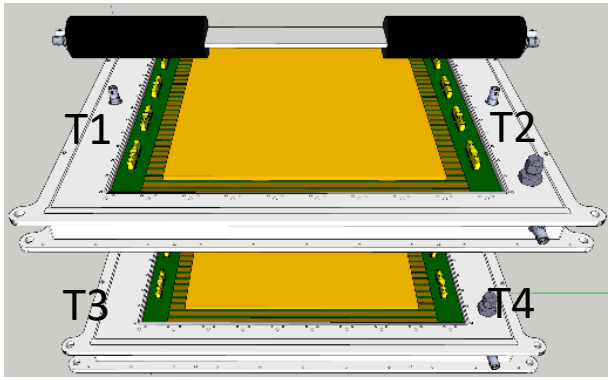


Working gas:
90% Freon + 5% Sulfur hexafluoride + 5% isobutene

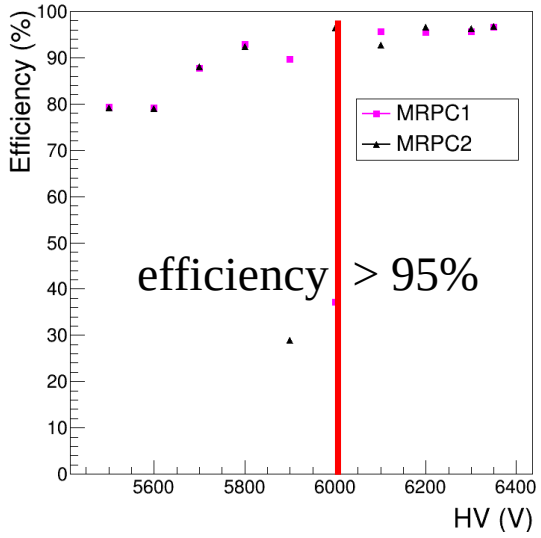
Trigger:
Plastic scintillator + PMT

Electronics:
FEE + TDM, with time resolution of 9 ps

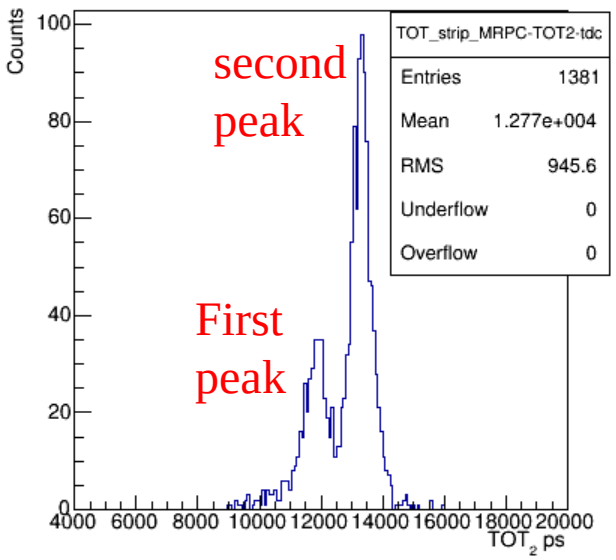


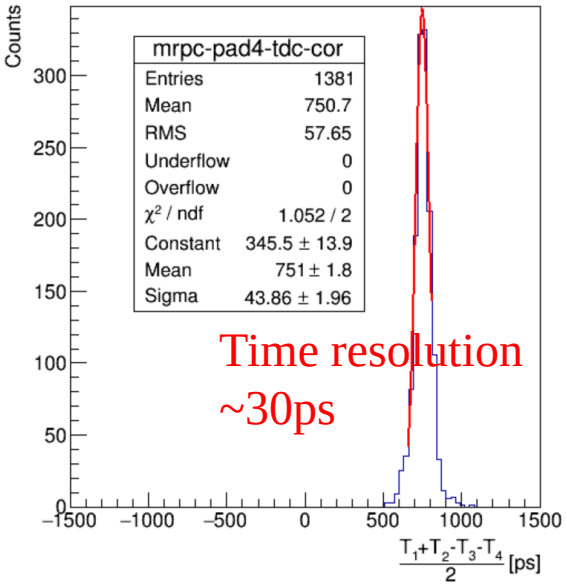


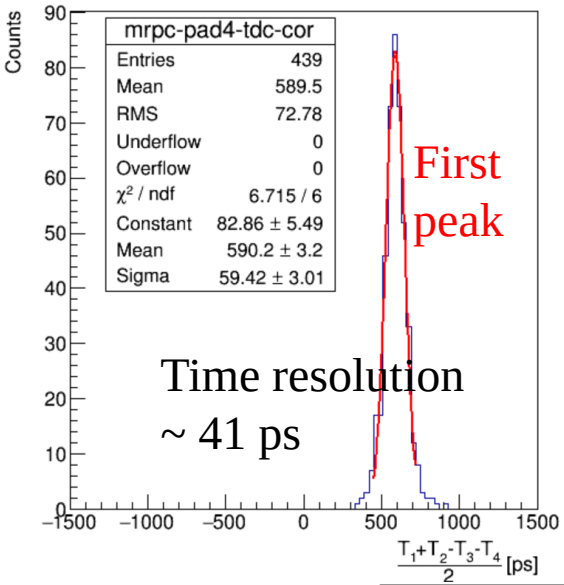
Cosmic ray test results

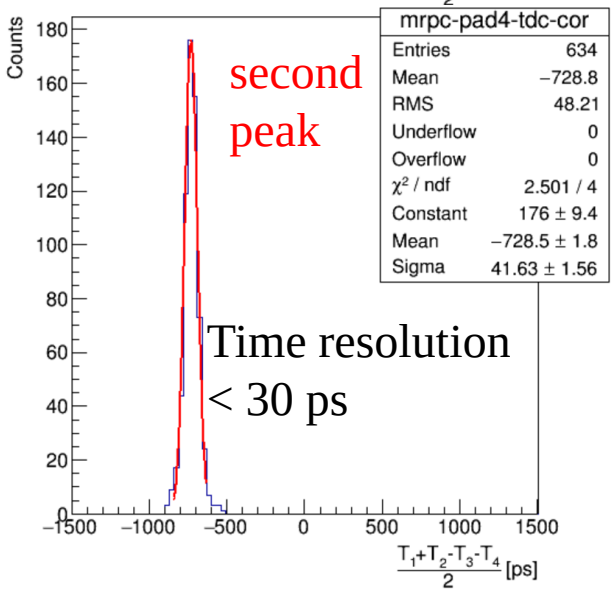


$$\sigma_t = Sigma/\sqrt{2}$$







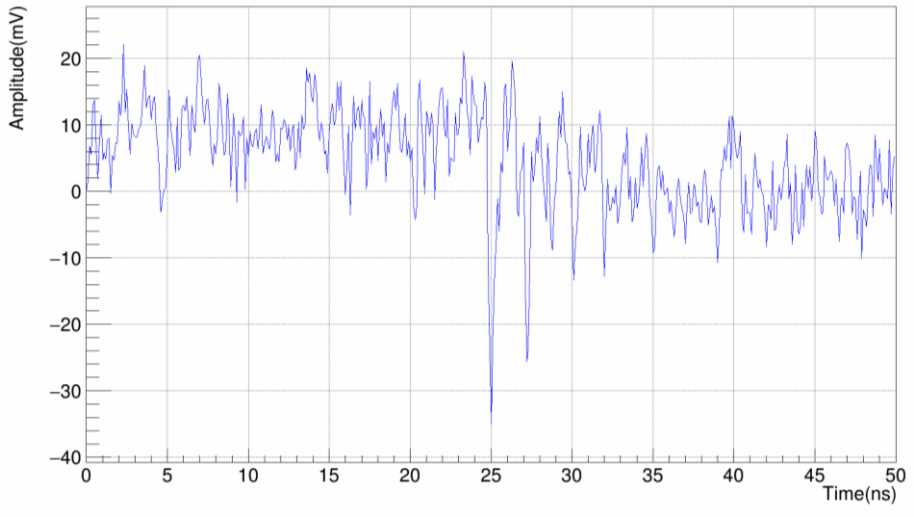


Working electric field:
129 kV/cm

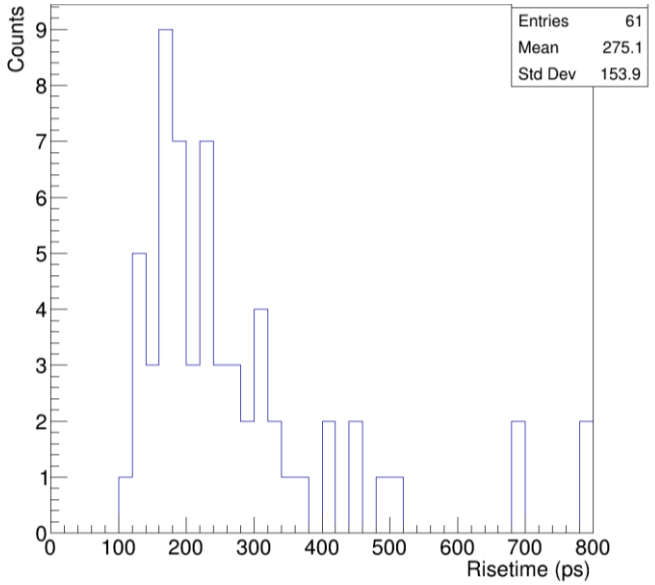
Threshold:
180 mV

MRPC raw signal

Signal of 4 × 6 gaps iTOF with gap thickness of 0.16mm at 125 kV/cm



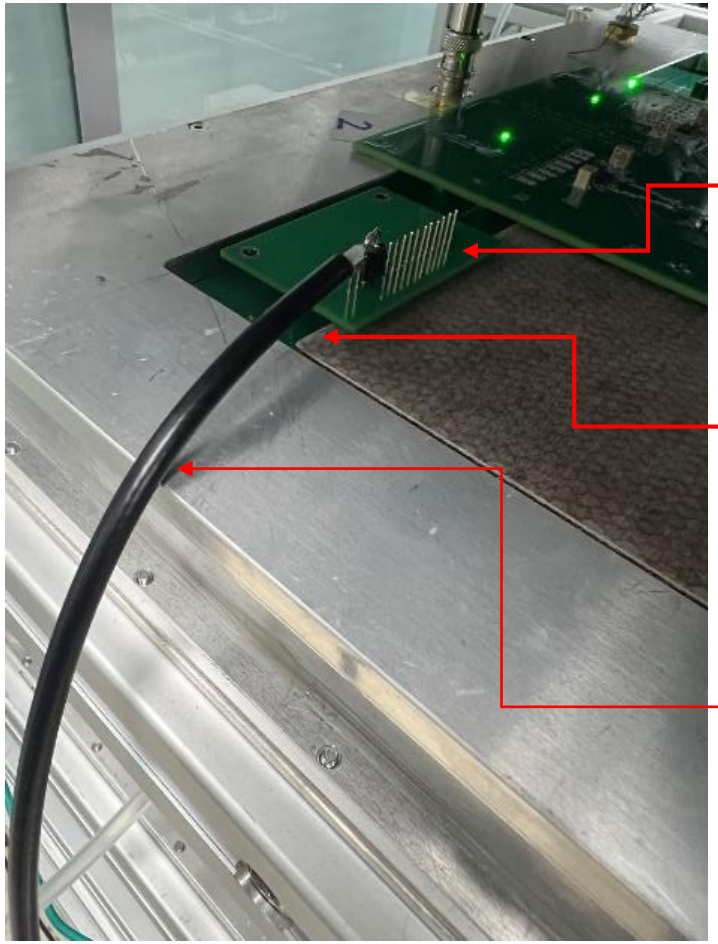
Reflection is significant



Bandwidth: 4GHz
Sampling rate: 10GS/s

Signal rise time: 275ps

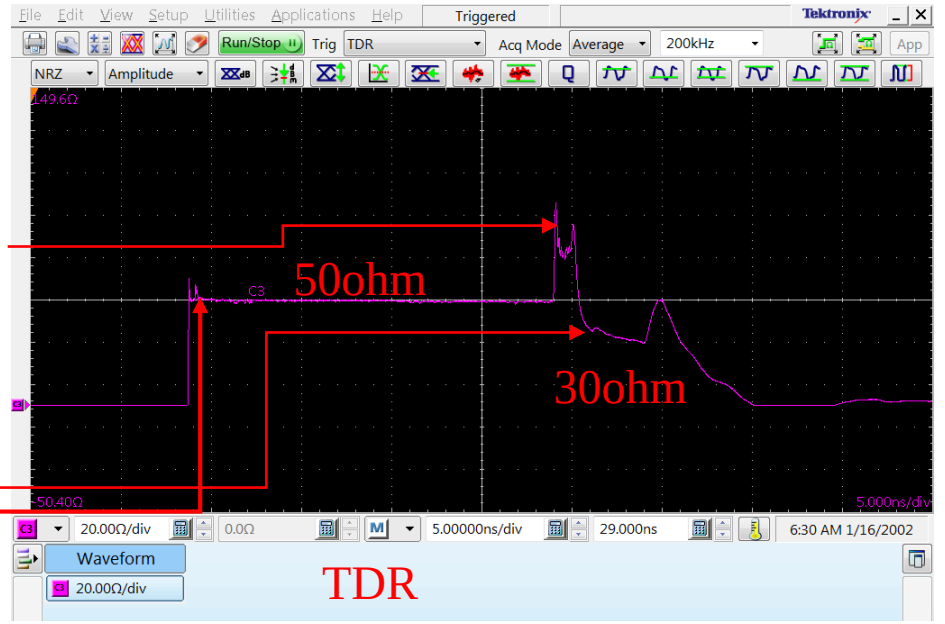
iTOF-MRPC impedance

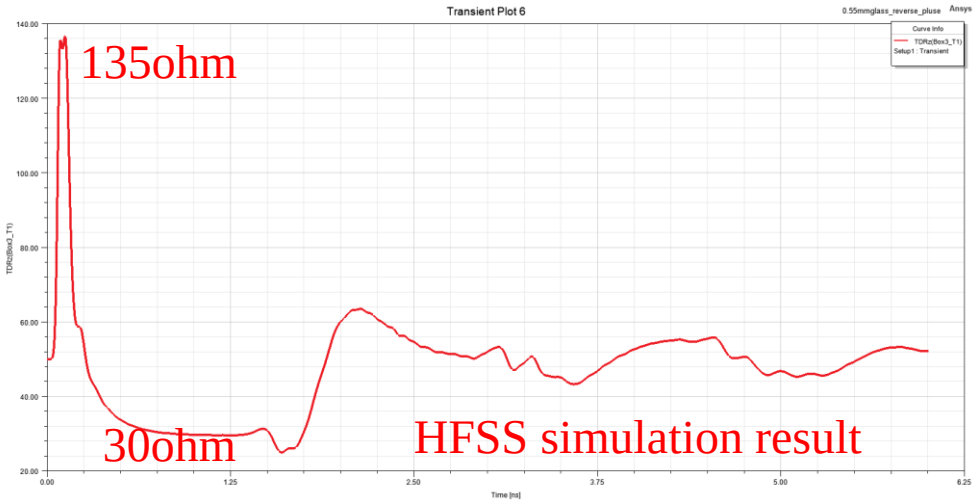


Adaptor and signal pin

Readout strip

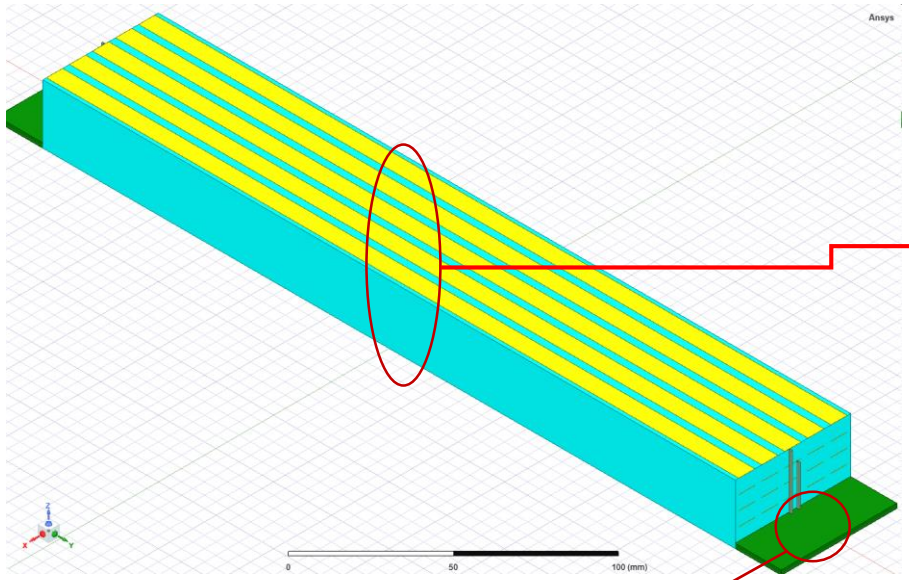
transmission line

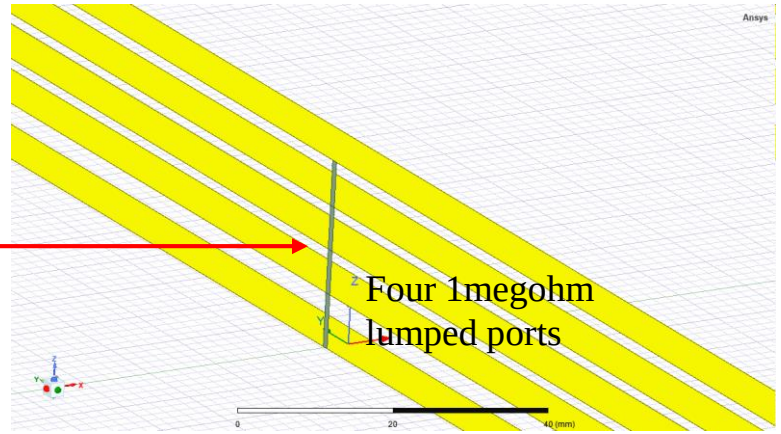


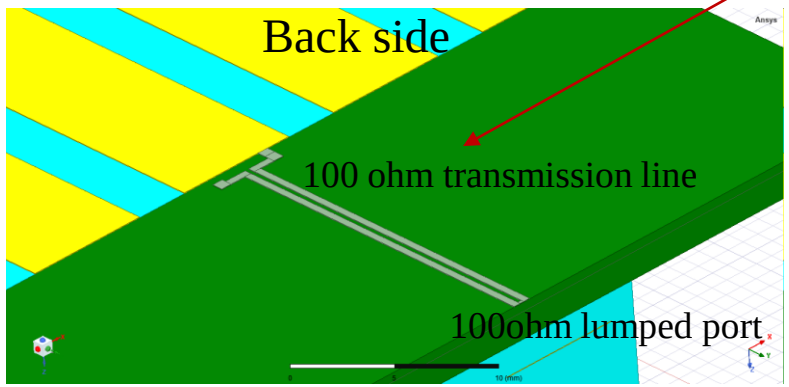


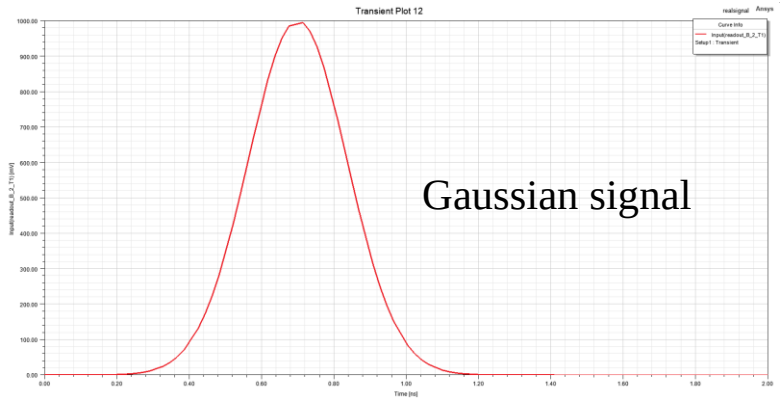
iTOF Impedance model

HFSS simulation









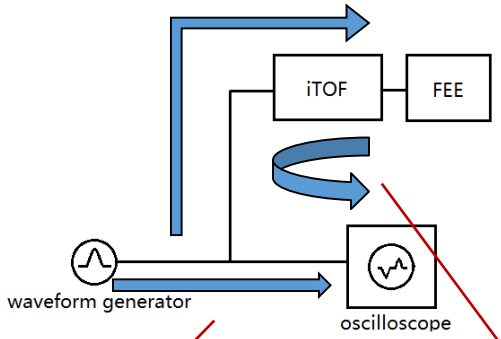
- Use equivalent medium to replace gap, PCB and glass
- 300mm readout strips
- 100ohm transmission line and 100ohm lumped port
- Four 1megohm lumped ports is placed between the readout strips of each stack
- Input a Gaussian signal with 1V amplitude and 230ps rise time

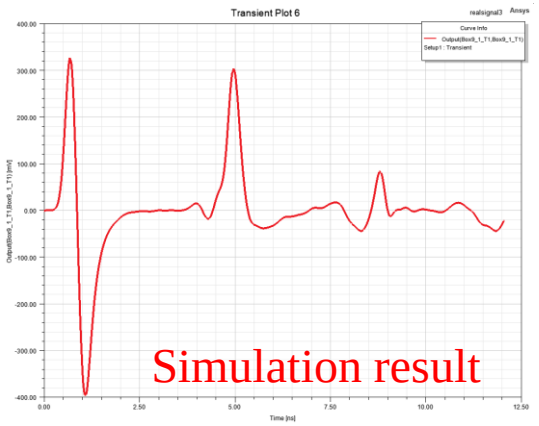
Verification of simulation

T-Junction measures signal reflection

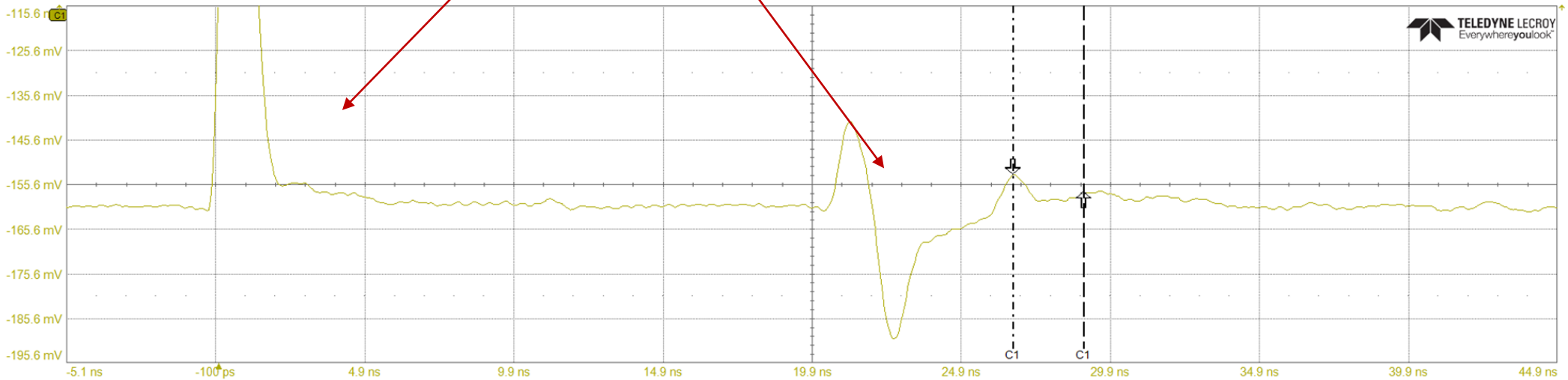
One end of iTOF is connected with waveform generator and the other end is FEE

The oscilloscope is connected between the waveform generator and the iTOF using a T-Junction



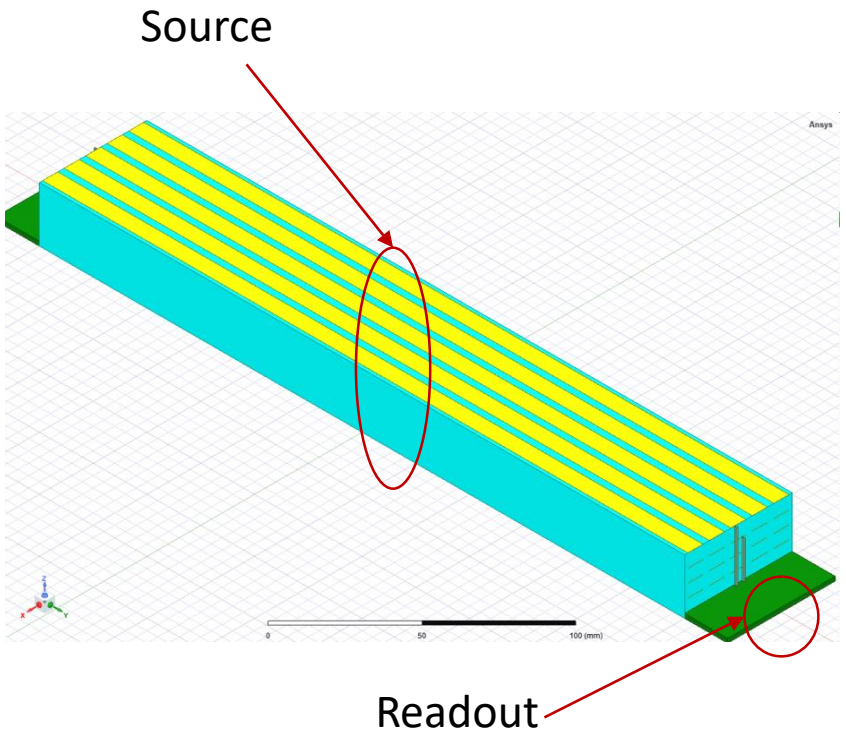


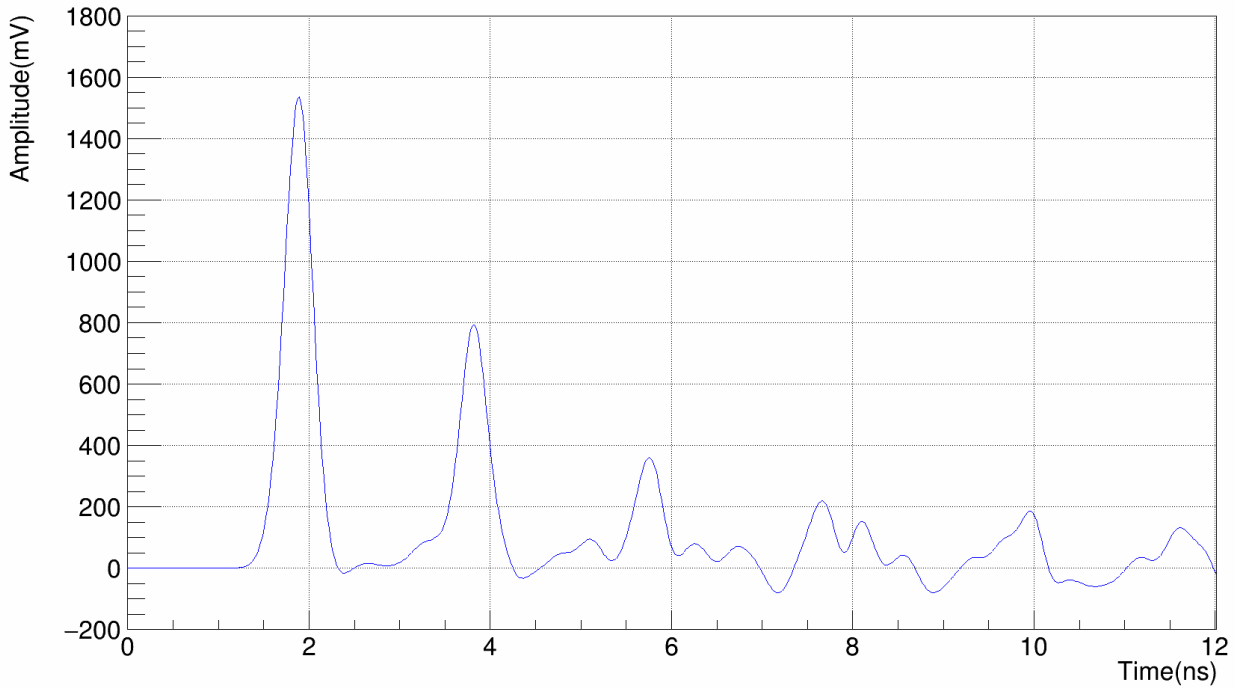
Apply Excitation from one port in the side of iTOF and read the reflected signal



Signal transmission

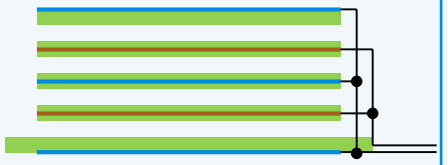
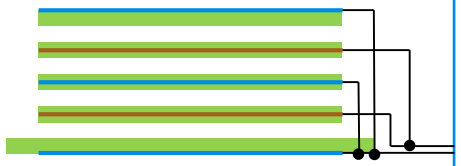
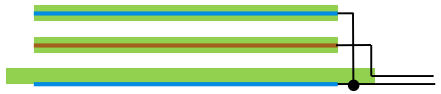
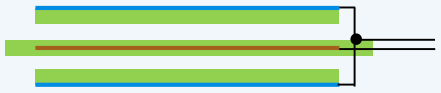
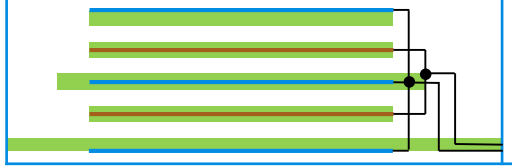
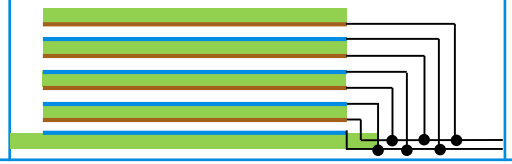
Excitation is applied from the four ports in the middle of the iTOF, and readout from ports on one side of the iTOF





- The reflection is significant
- Rise time from 230ps to 296ps

More MRPC geometry

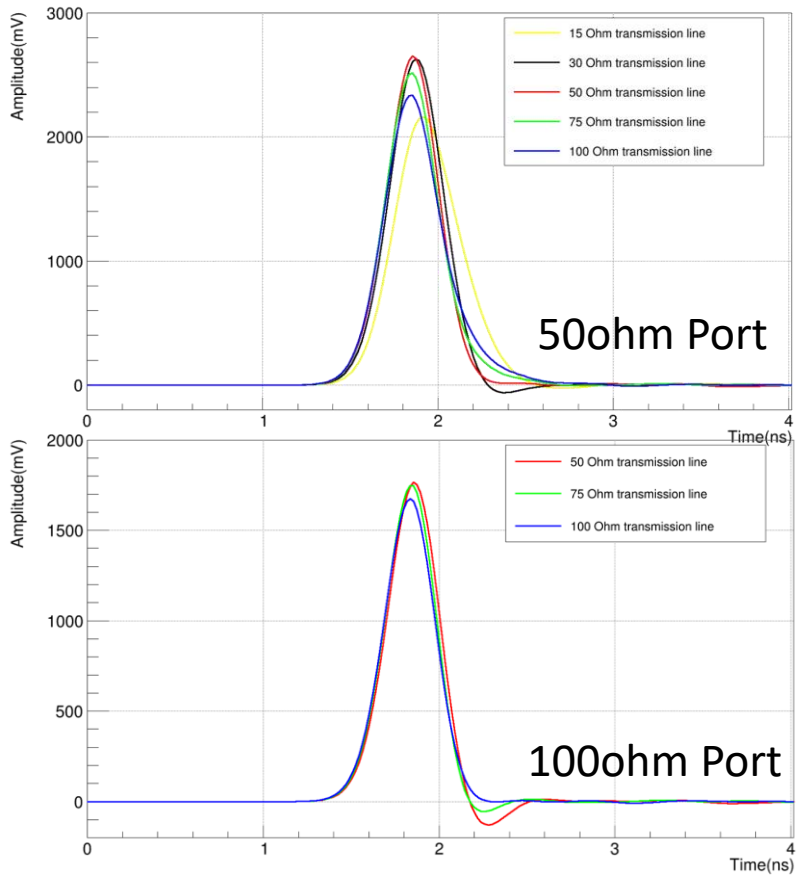
Geometry	First peak amplitude	Second peak amplitude	Rise time	Geometry	First peak amplitude	Second peak amplitude	Rise time
4 stacks, 2 pin, bottom PCB readout 	1.54V	52% of first peak	296ps	1 stacks, 1 pin, bottom PCB readout 	0.91V	11%	261ps
4 stacks, 4 pin, bottom PCB readout 	1.59V	55%	296ps	2 stacks, 2 pin, bottom PCB readout 	1.23V	20%	308ps
4 stacks, 2 pin, middle PCB readout 	1.72V	41%	260ps	2 stacks, 1 pin, middle PCB readout 	1.22V	24%	288ps
4 stacks, 2 pin, middle PCB readout 	1.72V	41%	261ps	4 stacks, 8 pin, bottom PCB readout 	0.59V	90%	277ps

node

- The more nodes, the more serious the reflection
- Rise time of middle PCB readout is faster than bottom PCB readout

Signal integrity

To study the signal integrity, we completely absorb the signal from the other side so that only the first peak is left behind, eliminating the interference of the reflected peak.

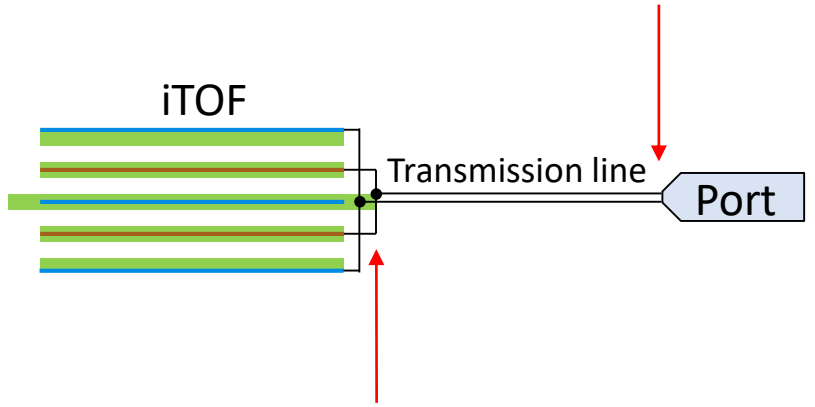


Port	Transmission line	Rise time	Fall time
50ohm	15ohm	276ps	372ps
50ohm	30ohm	267ps	247ps
50ohm	50ohm	264ps	246ps
50ohm	75ohm	261ps	307ps
50ohm	100ohm	263ps	370ps
100ohm	50ohm	264ps	206ps
100ohm	75ohm	259ps	207ps
100ohm	100ohm	259ps	231ps

Rise time does not change much with the transmission line impedance.

$Z_{transmission\ line} > Z_{port}$ ⟶ back edge slow down

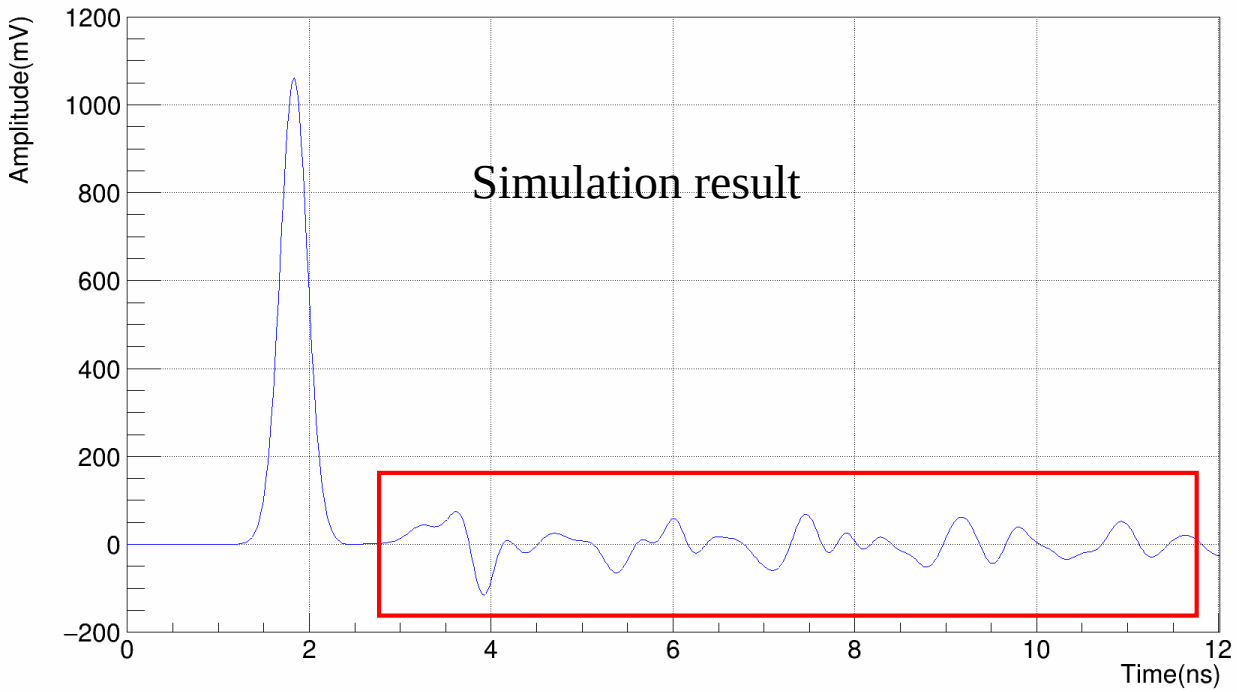
$Z_{transmission\ line} < Z_{port}$ ⟶ overshoot occur

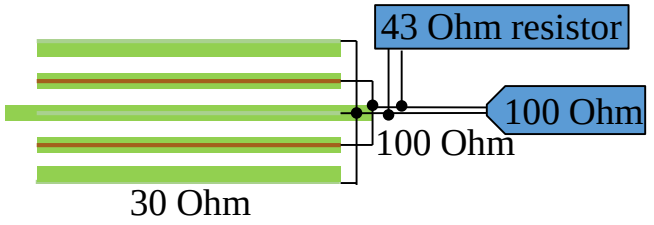


$Z_{transmission\ line} \neq Z_{iTOF}$ ⟶ amplitude of the first peak reduced

Impedance matching

A 43 Ohm resistor was used in parallel with a 100 Ohm transmission line to match the 30 Ohm iTOF.





First peak	1.72 V ⟶ 1.07 V
Reflection	41% ⟶ 7%
Rise time	261 ps ⟶ 266 ps
Fall time	236 ps ⟶ 262 ps

Reflection is significantly reduced.

Conclusion

HFSS simulation

- The magnitude of the reflection is closely related to the number of nodes, while the impedance of the signal pin is less relevant.
- Drawing the signal out from the middle PCB allows the signal amplitude larger and rise faster
- The impedance of the transmission line is consistent with that of iTOF can enhance the first peak of signal, and reduce reflection.
- The impedance of the transmission line is consistent with that of FEE allows the trailing edge of the signal more complete

Summary

- Research and design iTOF prototype, test by cosmic ray
- A time resolution of 30ps is obtained by using NINO FEE+FPGA TDC
- Problem remain: Signal reflection is severe, which makes data analysis difficult
- Simulations are performed to identify the key factors affecting reflection, and there is a possibility of further improvement in time resolution.

Future work

- Further simulation
- The iTOF-MRPC structure and signal extraction method will be adjusted to reduce signal reflection and improve time resolution.

Thank you!