High time resolution design of iTOF-MRPC and Simulation, Track reconstruction of TPC in CEE experiment.

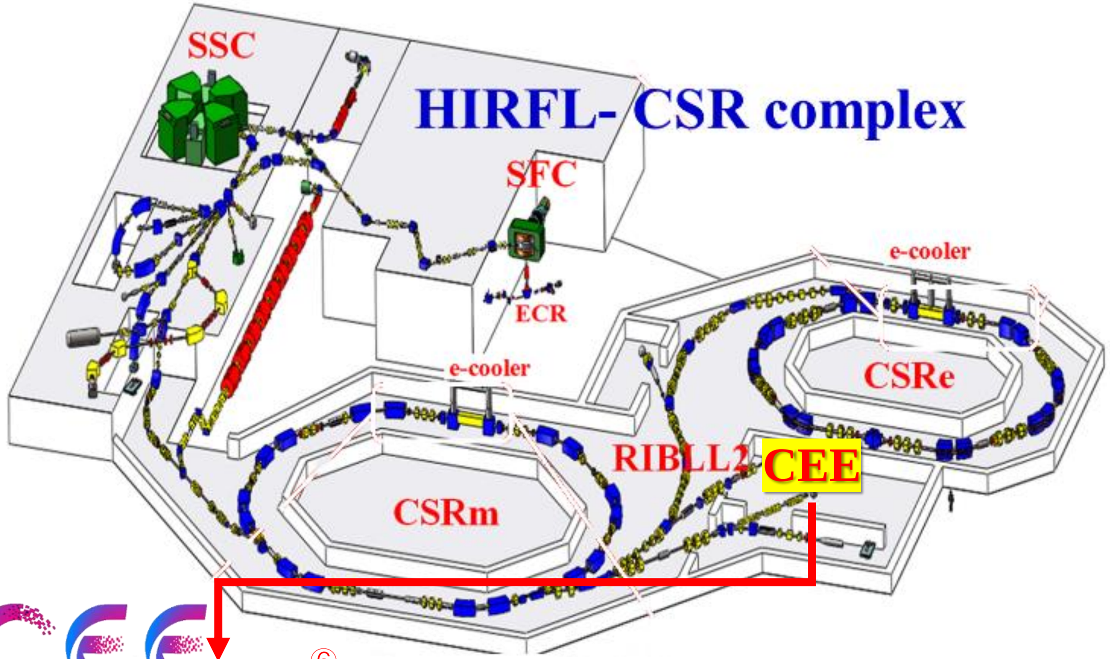
Dongdong Hu (USTC) Dhananjaya Thakur(IMP)

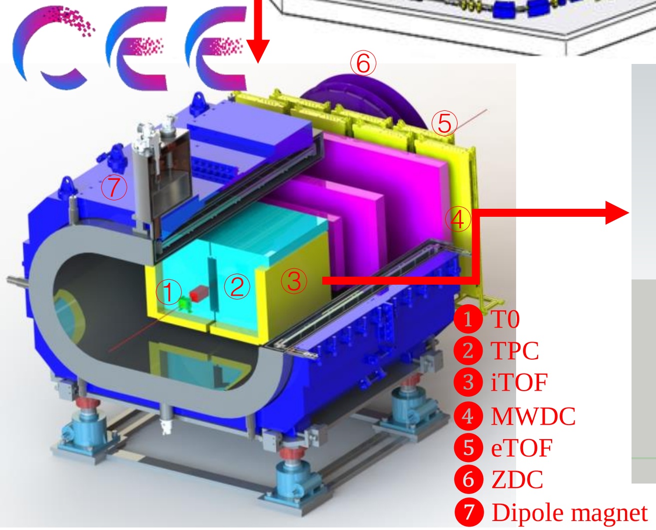
State Key Laboratory of Particle Detection and Electronics
Department of Modern Physics, USTC
Institute of modern physics, Chinese Academy of Sciences

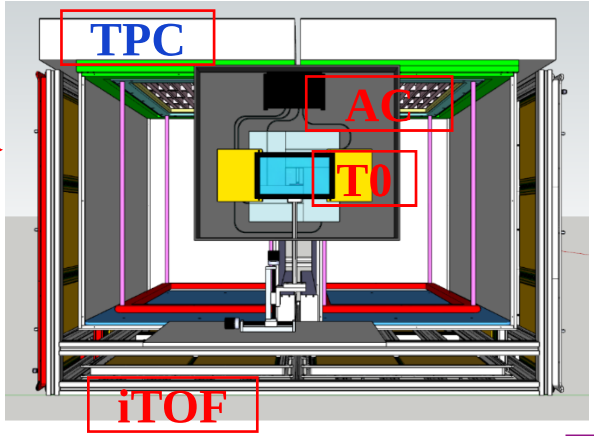
Outline

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

CSR-external Target Experiment







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

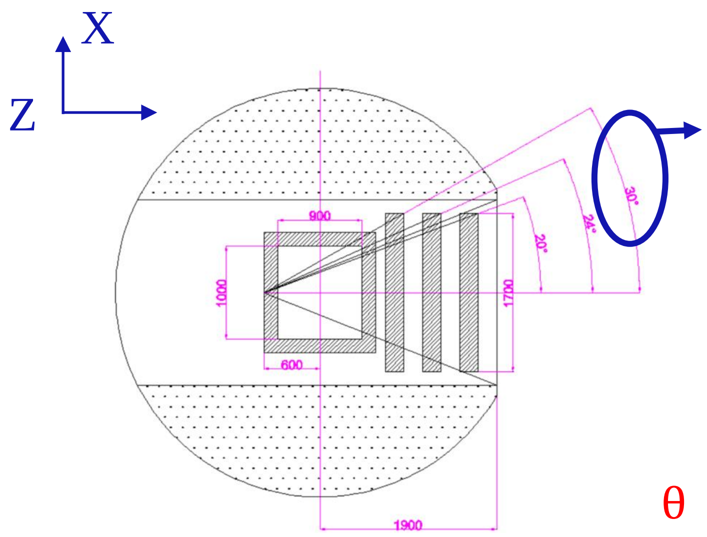
Goals： to study the bulk properties of dense matter and to understand the quantum chromo-dynamic (QCD) phase diagram

Fix target

Intensity ： 10^6 pps (particles per second)
Reactivity ： 1%
Reaction rates ： 10 kHz
luminosity ： $0.3 \cdot 10^{28}\ cm^{-2}s^{-1}$

- ❖ The TPC is the most critical detector in the CEE set-up which provides charged particle track position, momentum, and charge
- ❖ The TOF system is critical for the identification of charged particles in the GeV energy region.

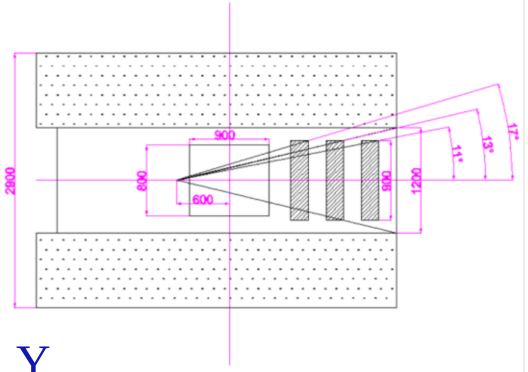
Main task of iTOF and TPC



30^o

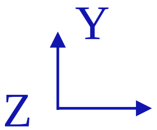
Top View

θ（30^o、 107^o）



Side View

φ（-17^o、 17^o）



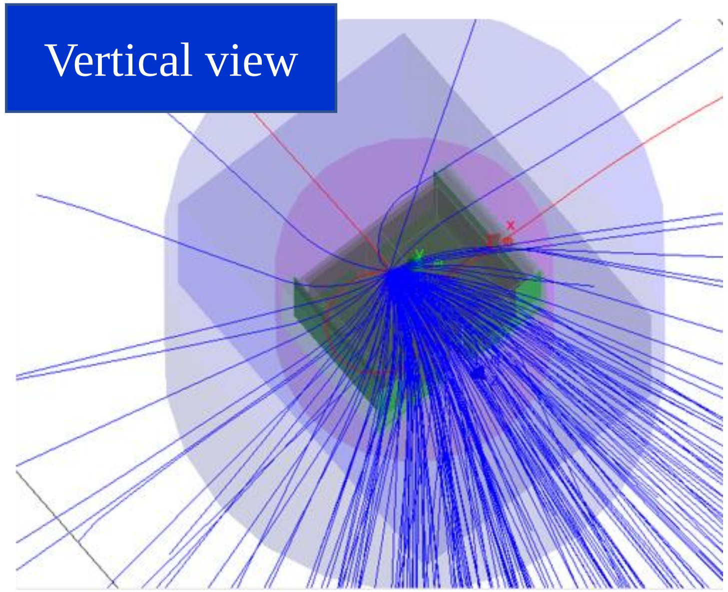
CEE charged particle identification system

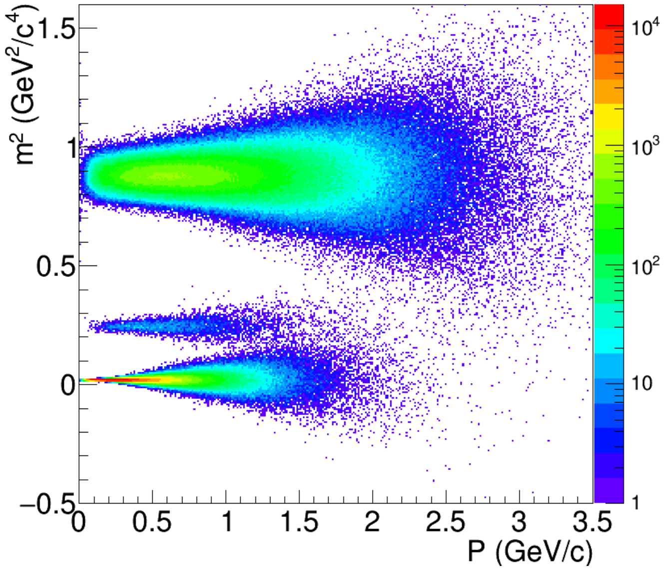
Main task

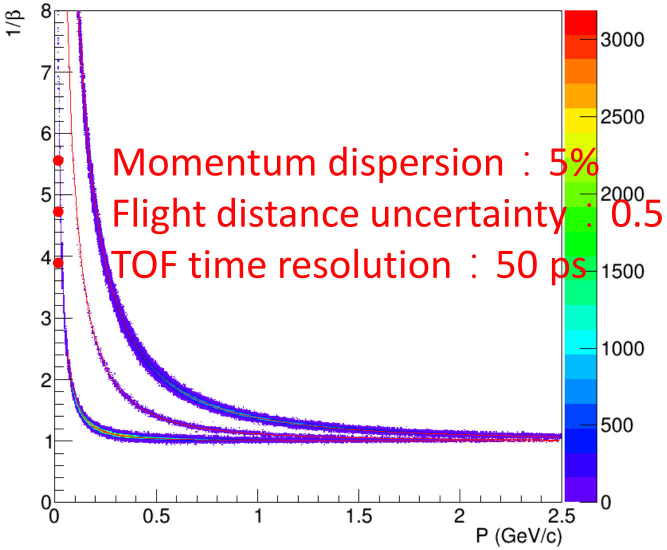
In the middle rapidity, or polar angle region (30° - 107°) in the laboratory frame, the measurement and identification systems for charged particles are iTOF combined with TPC.

- ✓ Small polar angle：MWDC + eTOF
- ✓ Large polar angle：TPC + iTOF
- ✓ Start time：T0

Requirements of iTOF







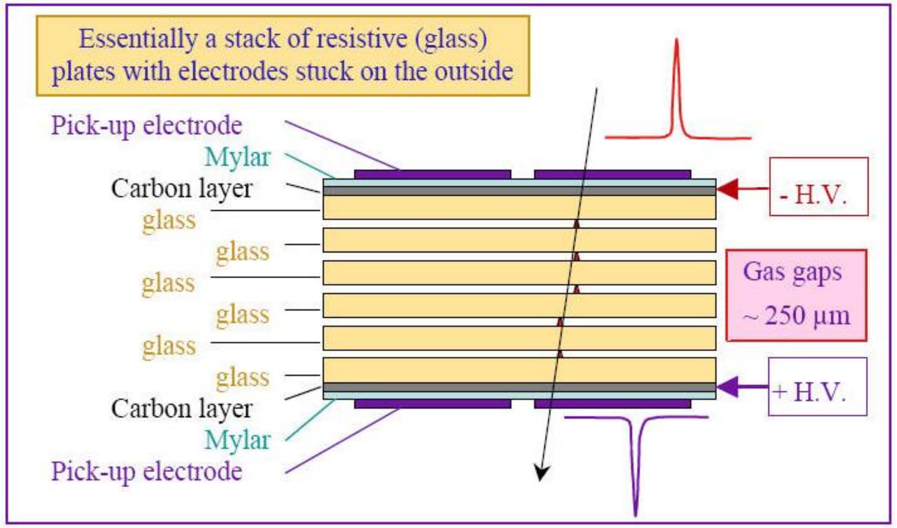
- Geant4
- Generator: UrQMD-3.4
- Beam energy: $E_{\mathrm{kin}} = 1.0$ GeV/u
  particle: Ar-Ar
- Magnetic field: 0.5 T
- Target position: Z = -35 cm
- Collision parameter: b=1~10 fm （1000， 2000…)

Requirements ：

Time resolution:	30-40ps
Occupancy:	10%-15%
Particle flux:	50 $\mathrm{Hz/cm^2}$
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]

- Good 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

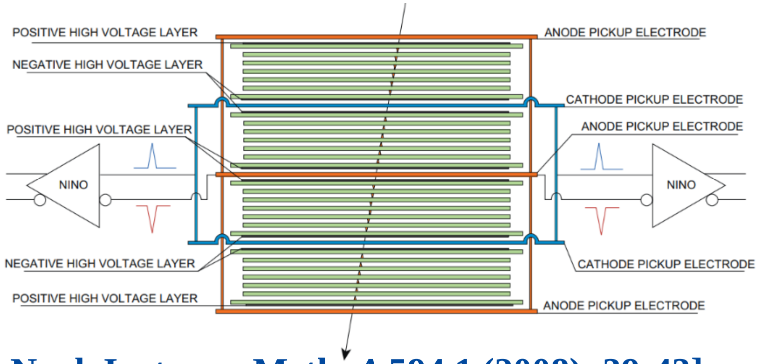
λ : the number of clusters per unit length

$\alpha - \eta$: 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]

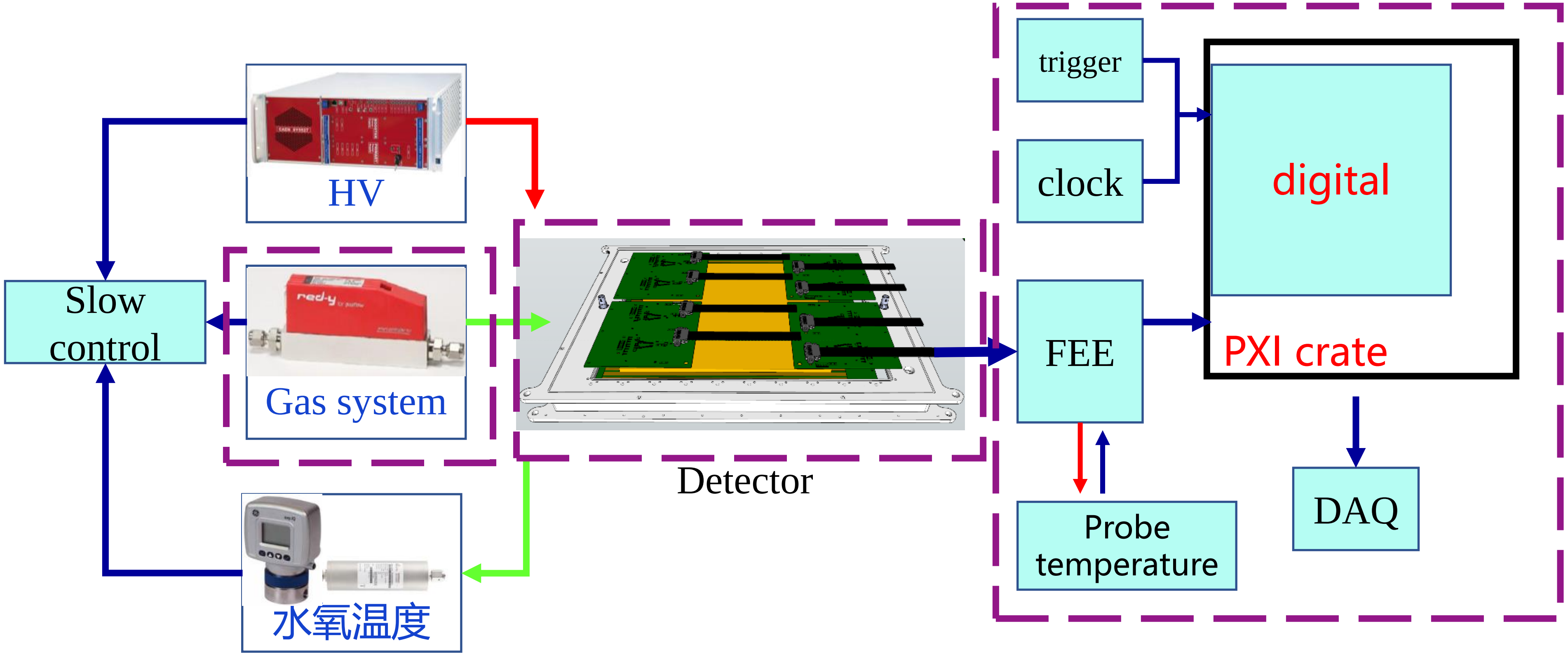
The way to get higher time resolution:

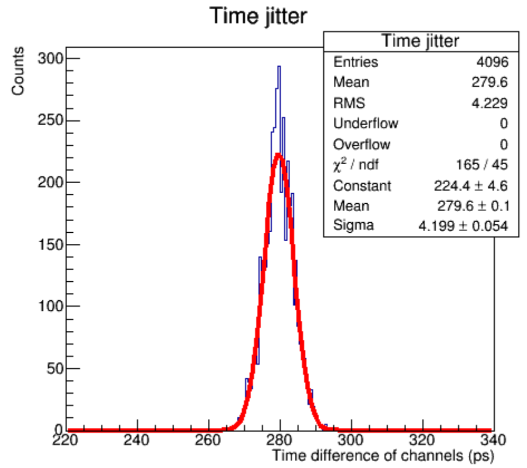
- Reduce gap thickness
- More gaps
- Improve the time resolution of front end electronics(FEE)
- Choose a good working gas

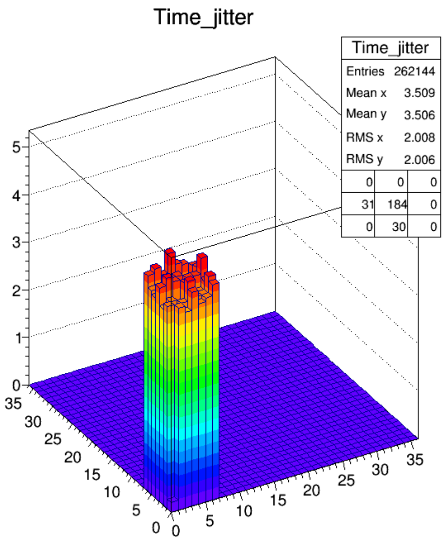
High time resolution MRPC designed by CERN

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

How to improvement the Time resolution





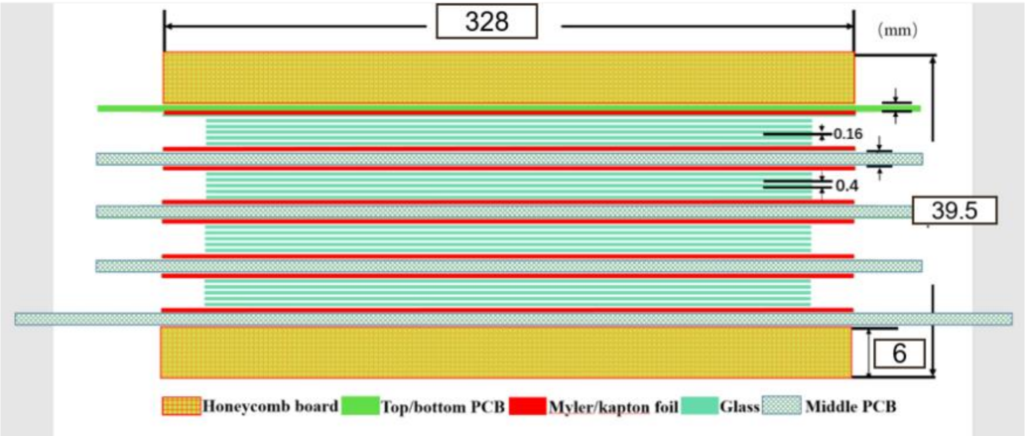


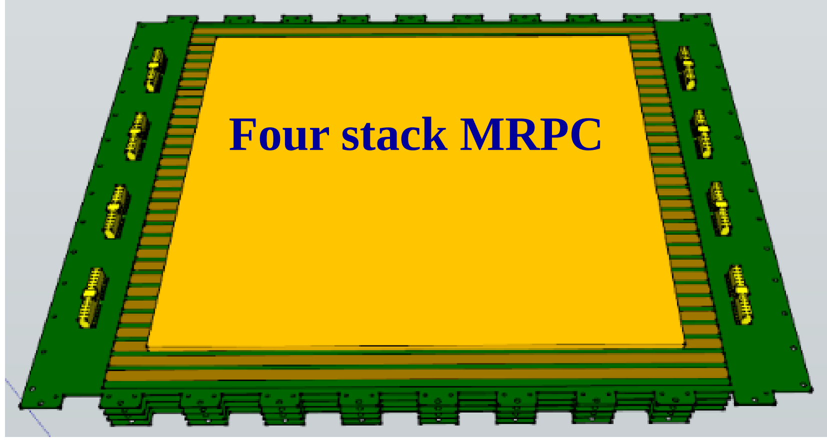
- ☐ Detector
- ☐ Gas system and gas transportation
- ☐ Electronic

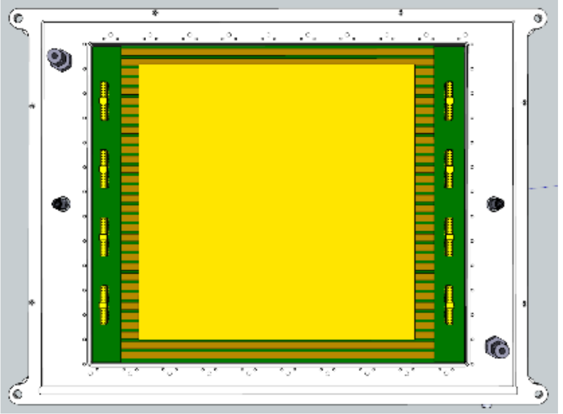
- NINO FEE + FPGA TDC
- Time jitter < 10 ps
- Uniformity ~ 2.4%

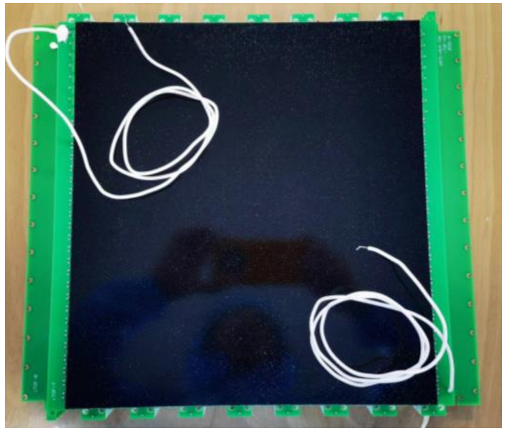
[IEEE Transactions on Nuclear Science 68.8 (2021): 1976-1983]

Prototype of inner TOF



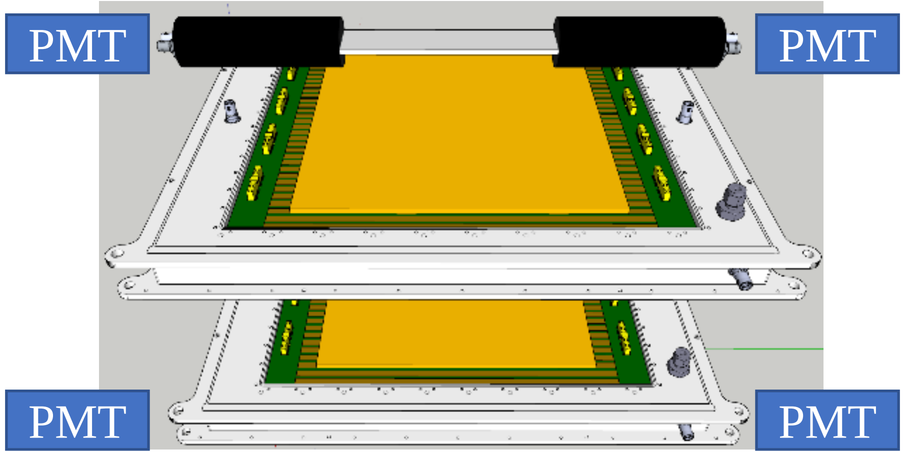


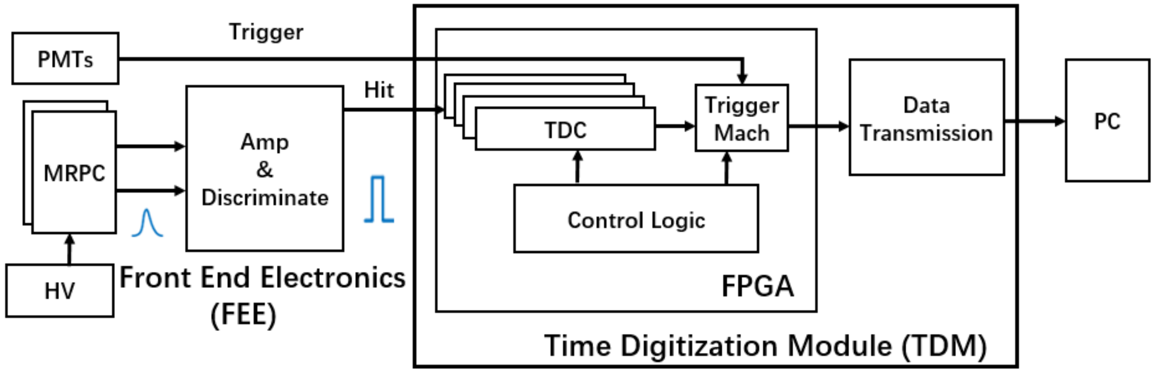




Gap	width	0.160mm
	quantity	4 × 6
Glass thickness		0.55mm
Readout strip		(7mm + 3mm) × 32 Double end readout
Impedance		30Ω

Cosmic Ray Test platform





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

Trigger:
Plastic scintillator + PMT

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

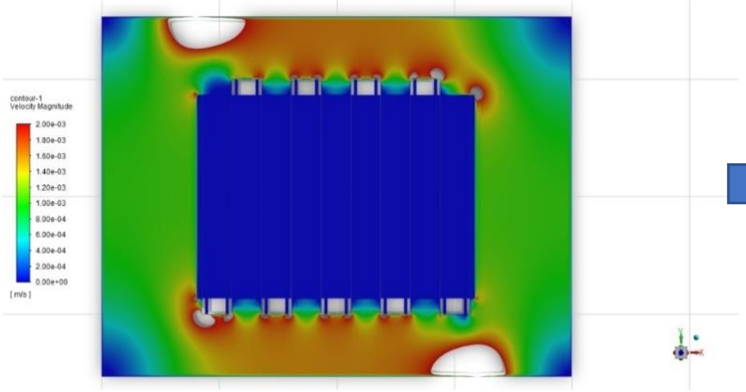
Gas transportation

Hydromechanics simulation: Fluent

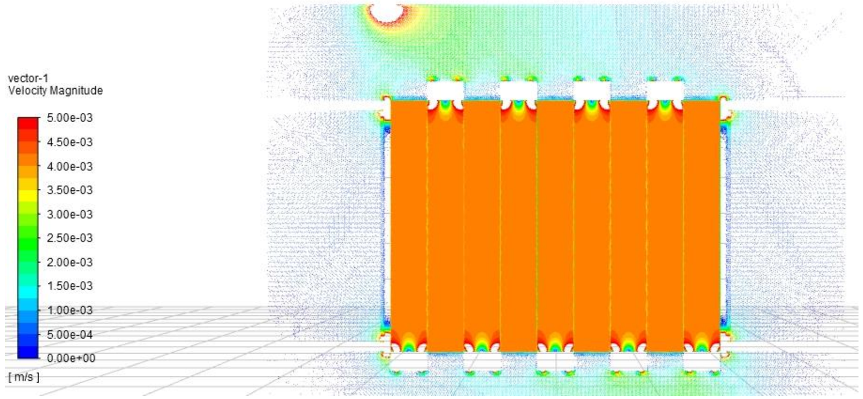
MRPC structure and the blocker: design and optimize

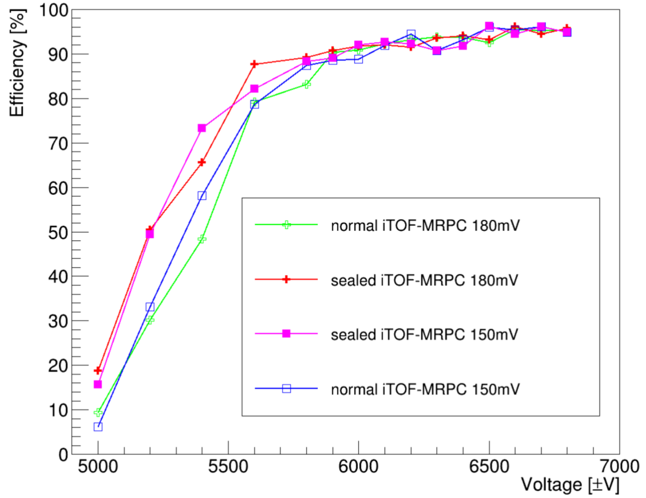
Gas exchange mode: from passive spread to active airflow

original



optimization



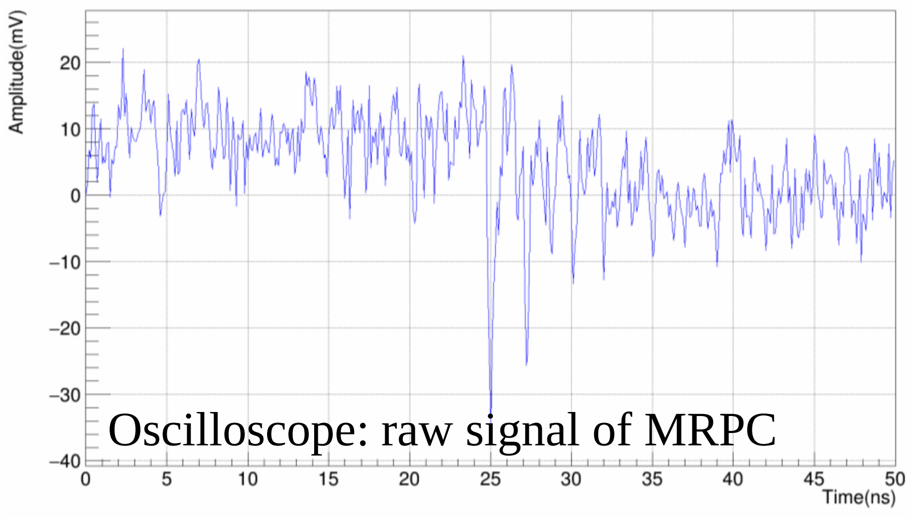


Color represents airflow speed

- Greatly reduce the use of working gases, environmentally friendly
- Slowing aging effect
- Improve the time resolution

Liu, Z., Carnesecchi, F., Williams, M. C. S., Zichichi, A., & Zuyeuski, R. (2019). Timing performance study of Multigap Resistive Plate Chamber with different gap size. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *927*, 396-400.

MRPC raw signal

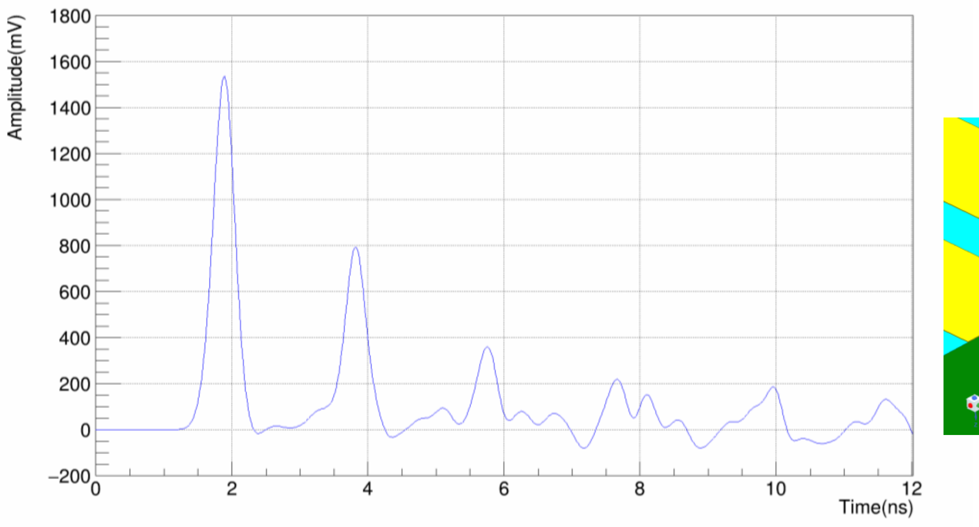


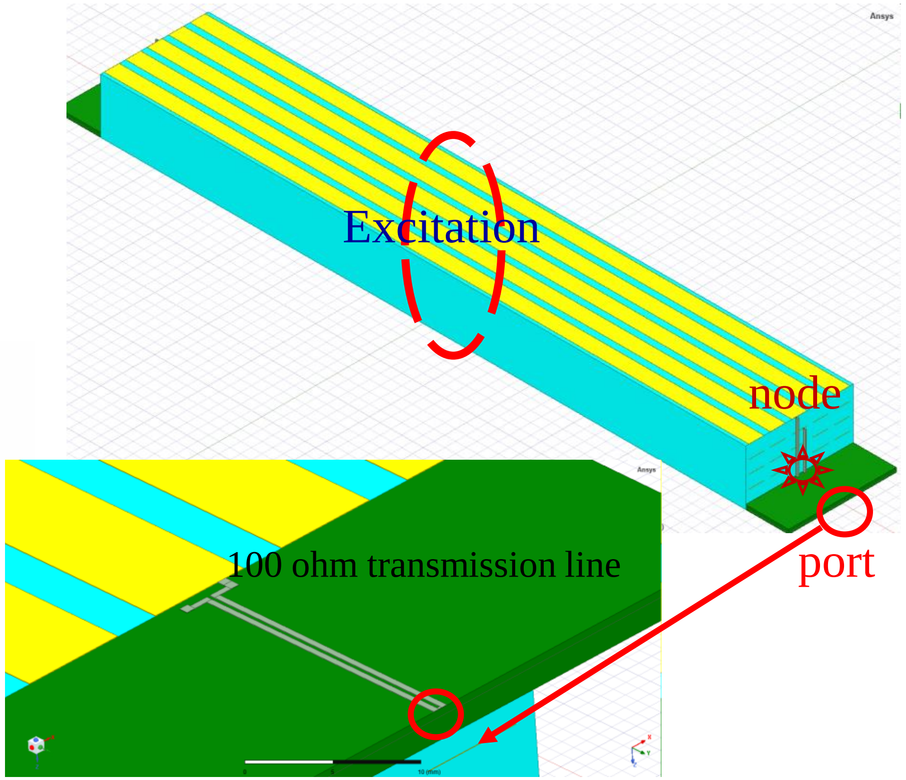
Oscilloscope: raw signal of MRPC

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

Signal rise time: 275ps

Reflection is significant



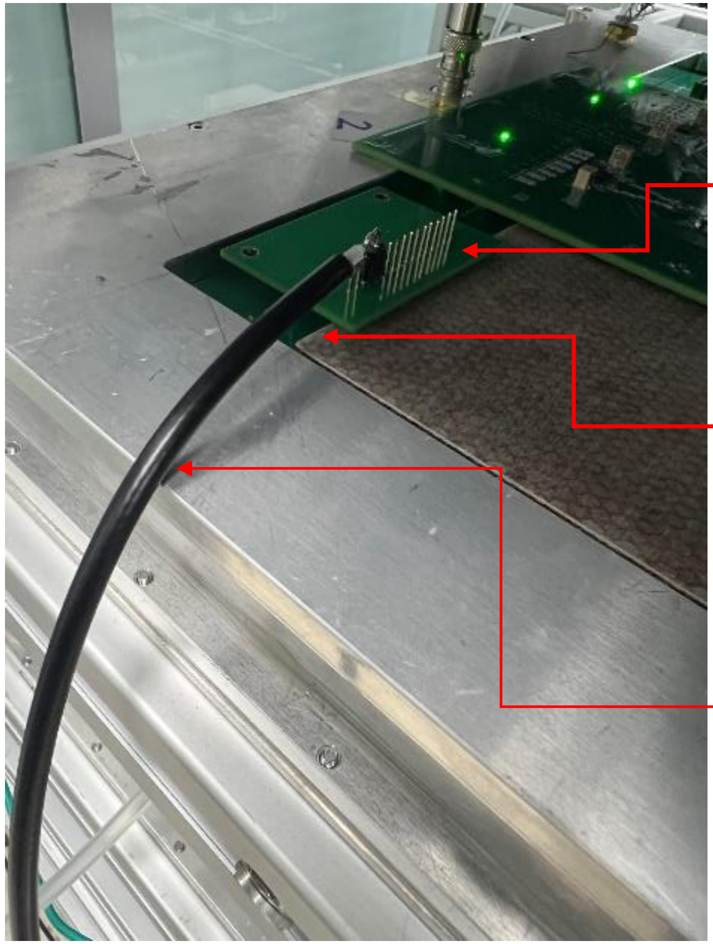


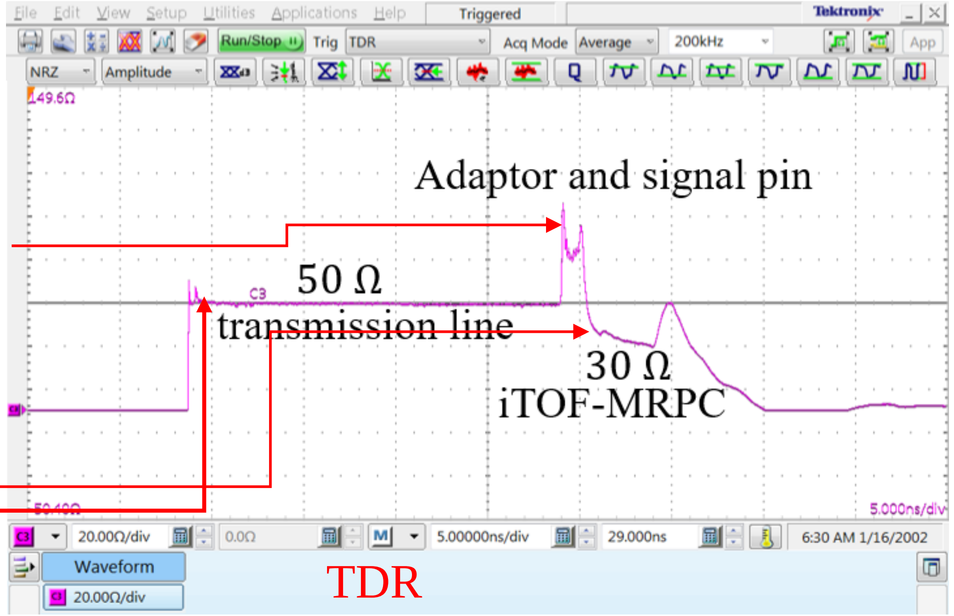
100ohm lumped port

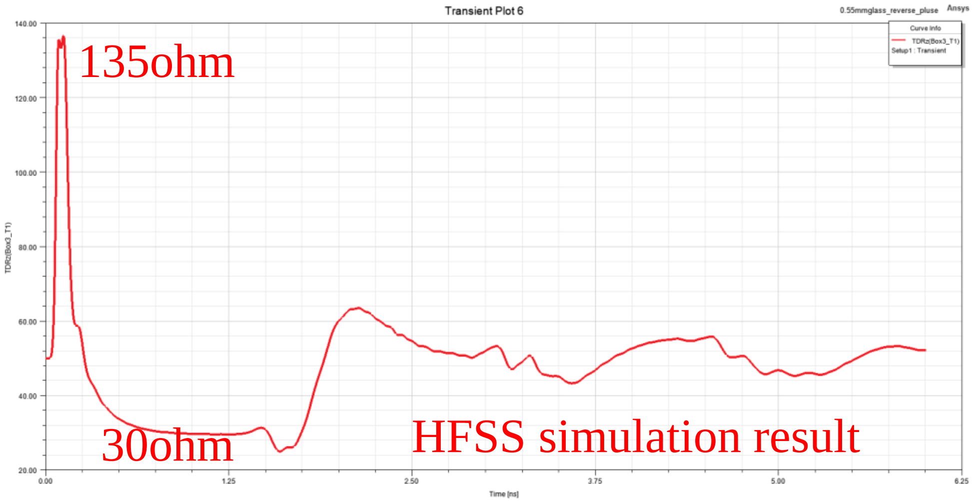
HFSS
Excitation: Gaussian signal
1V amplitude
230ps rise time

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

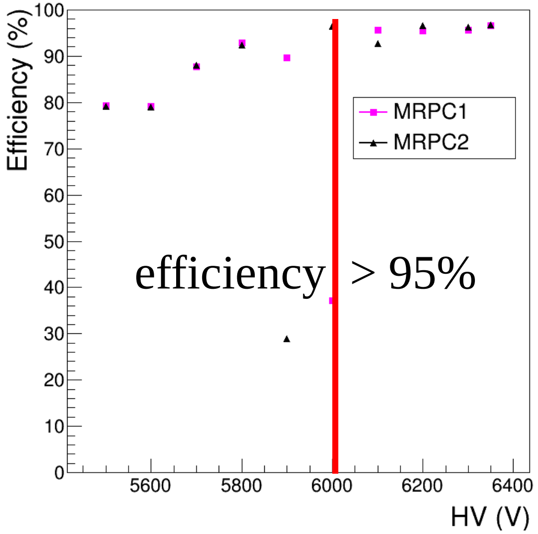
iTOF-MRPC impedance

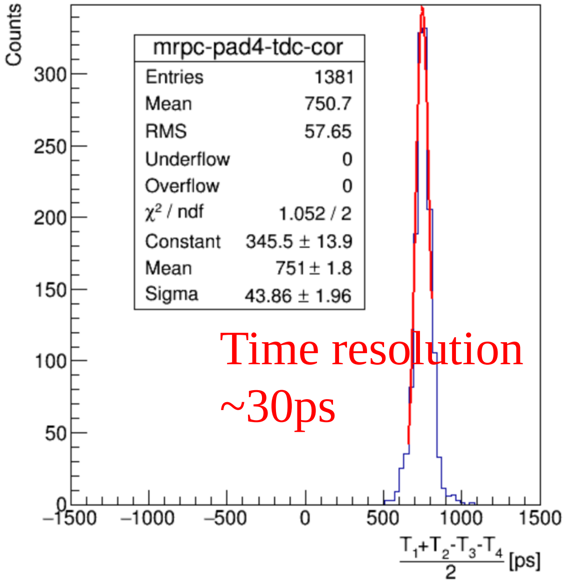




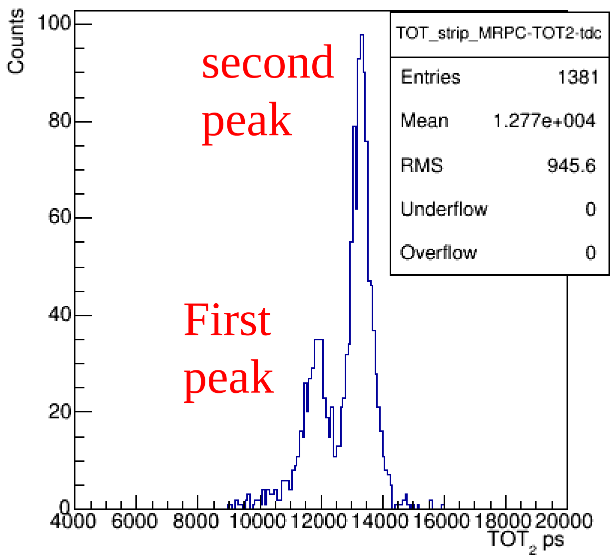


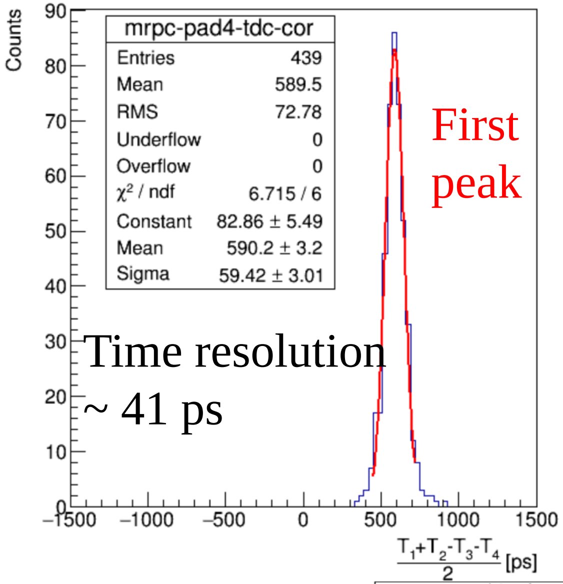
Cosmic ray test results





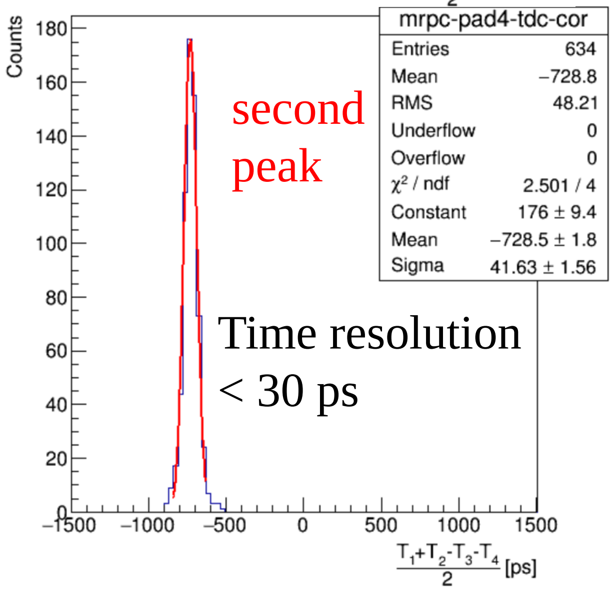
$$\sigma_t = Sigma/\sqrt{2}$$



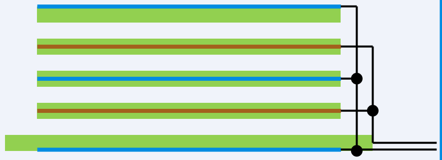
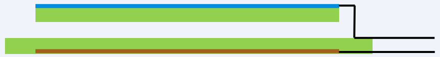
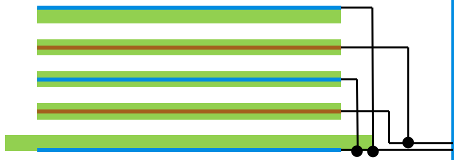
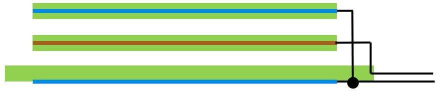
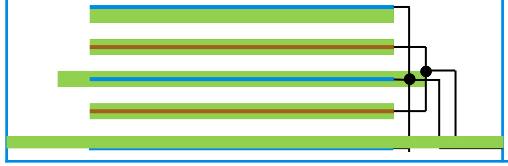
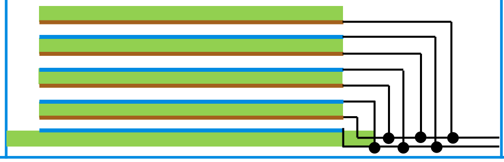


Working electric field:
129 kV/cm

Threshold:
180 mV



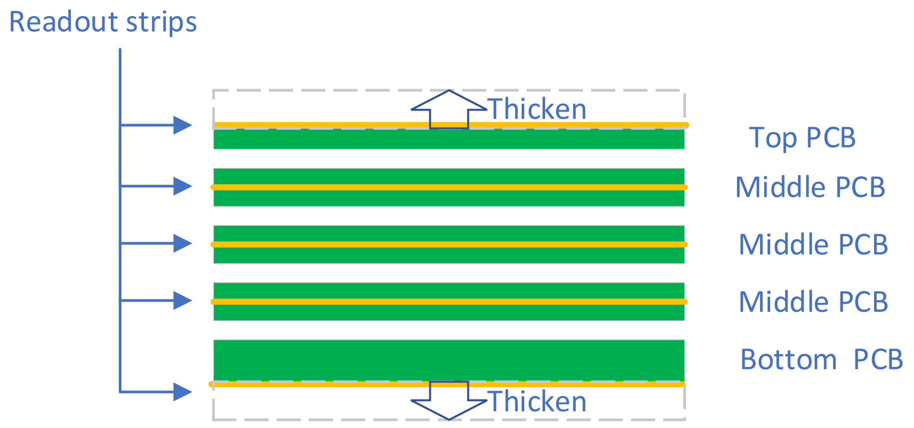
More MRPC geometry

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

- The more nodes, the more serious the reflection
- When the signal pick up from the middle readout PCB, Leading edge of the output signal is steeper than that from bottom PCB readout

Signal velocity and Modal dispersion

PCB	Top PCB	Middle PCB	Bottom PCB
Signal velocity	$1.855 \times 10^8\ m/s$	$1.587\times 10^8\ m/s$	$1.827 \times 10^8\ m/s$

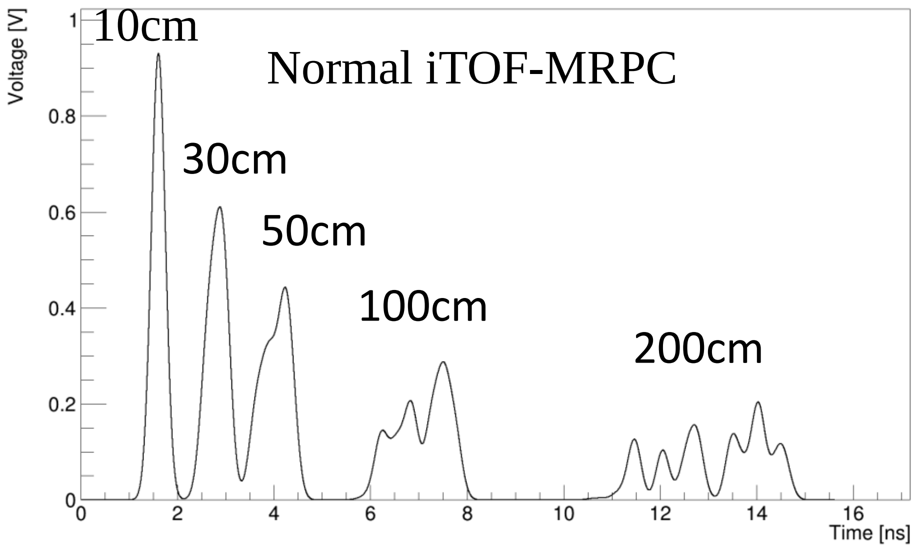


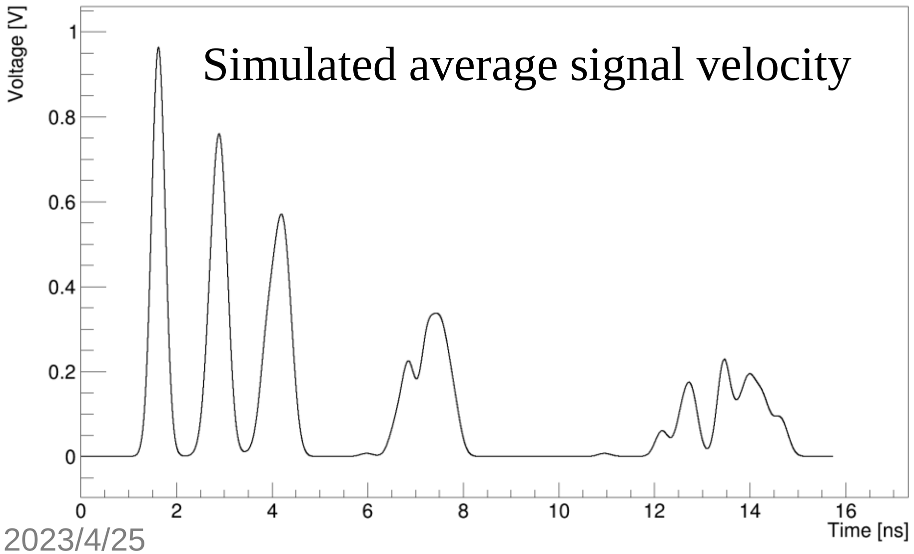
When extracting from the middle PCB, the signal of Bottom PCB has been delayed for about 80ps,which balance the arriving time of signals of each PCB.

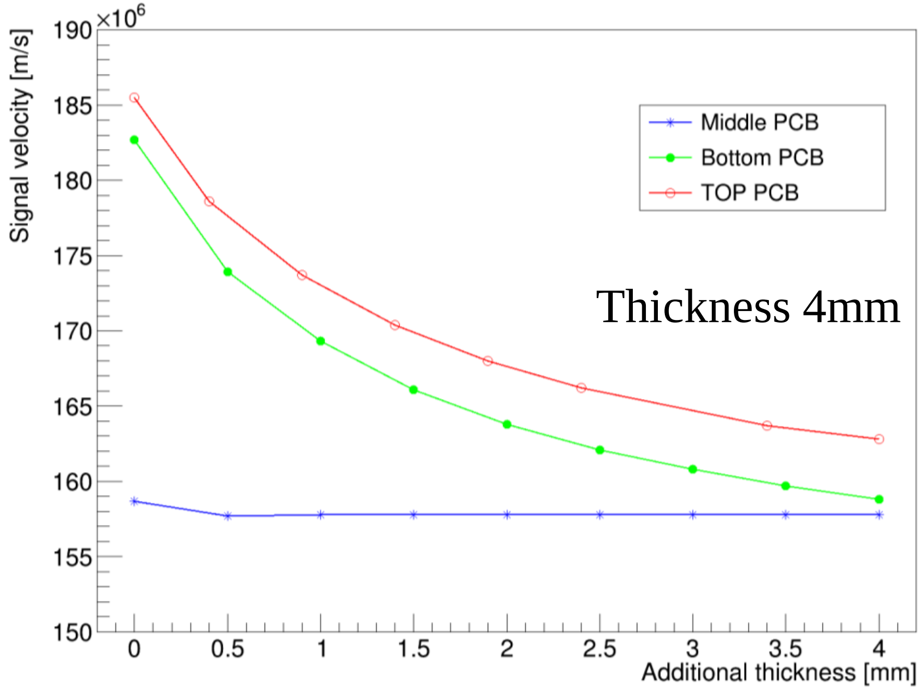
The average signal velocity is the weighted average of the signal velocity of each mode calculated using the multi-conductor transmission line theory. Each mode has a different signal velocity, known as modal dispersion

Signal velocity and Modal dispersion

Length of readout strip:

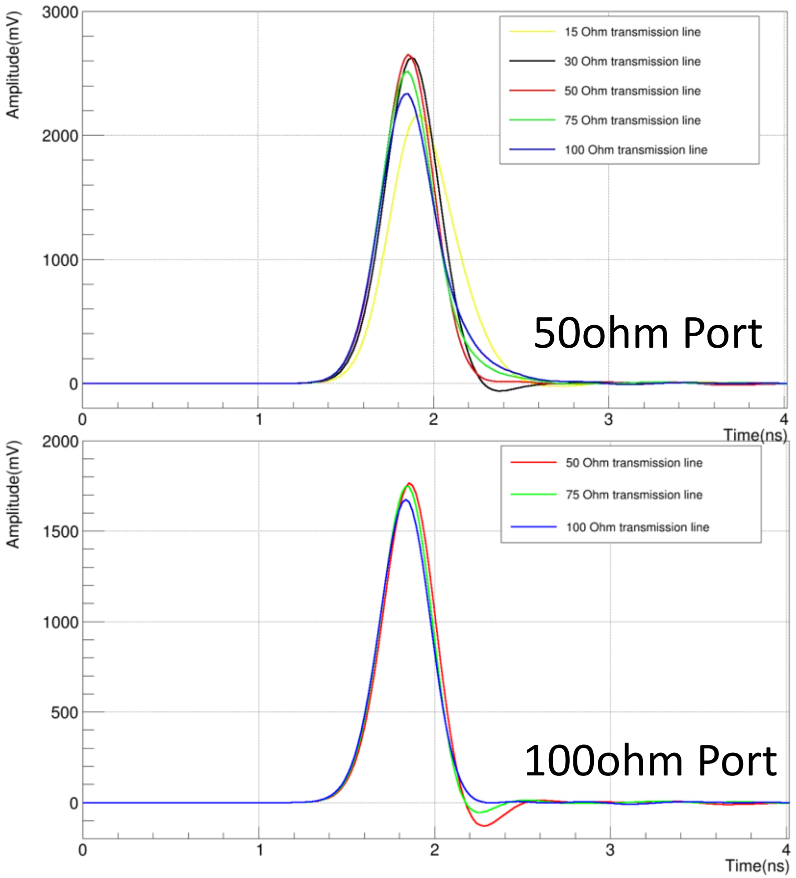






Signal integrity

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.

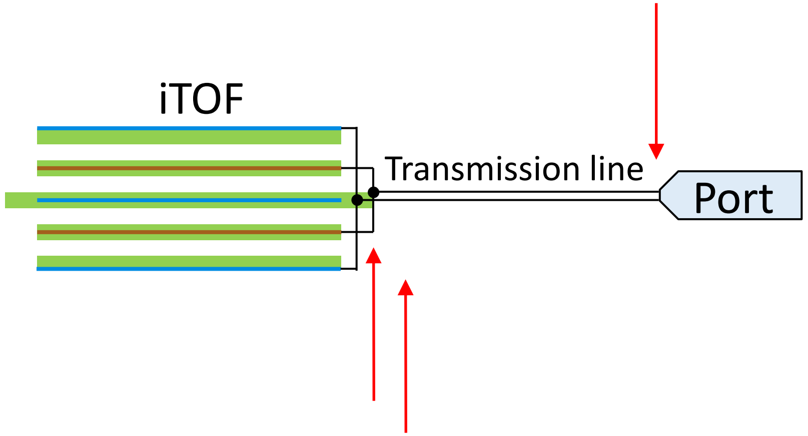


Port	Transmission line	leading	trailing
50ohm	15ohm	276ps	372ps
50ohm	30ohm	267ps	247ps
50ohm	50ohm	264ps	246ps
50ohm	75ohm	261ps	307ps
50ohm	100ohm	263ps	370ps
100ohm	50ohm	264ps	206ps
100ohm	75ohm	259ps	207ps
100ohm	100ohm	259ps	231ps

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

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

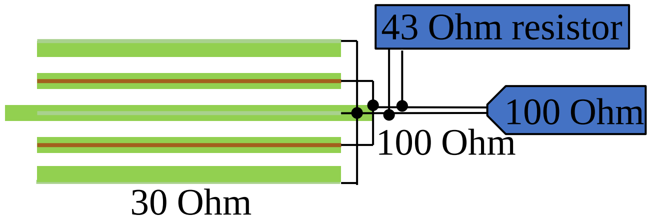
$Z_{transmission\ line} < Z_{port} \longrightarrow$ overshoot occur

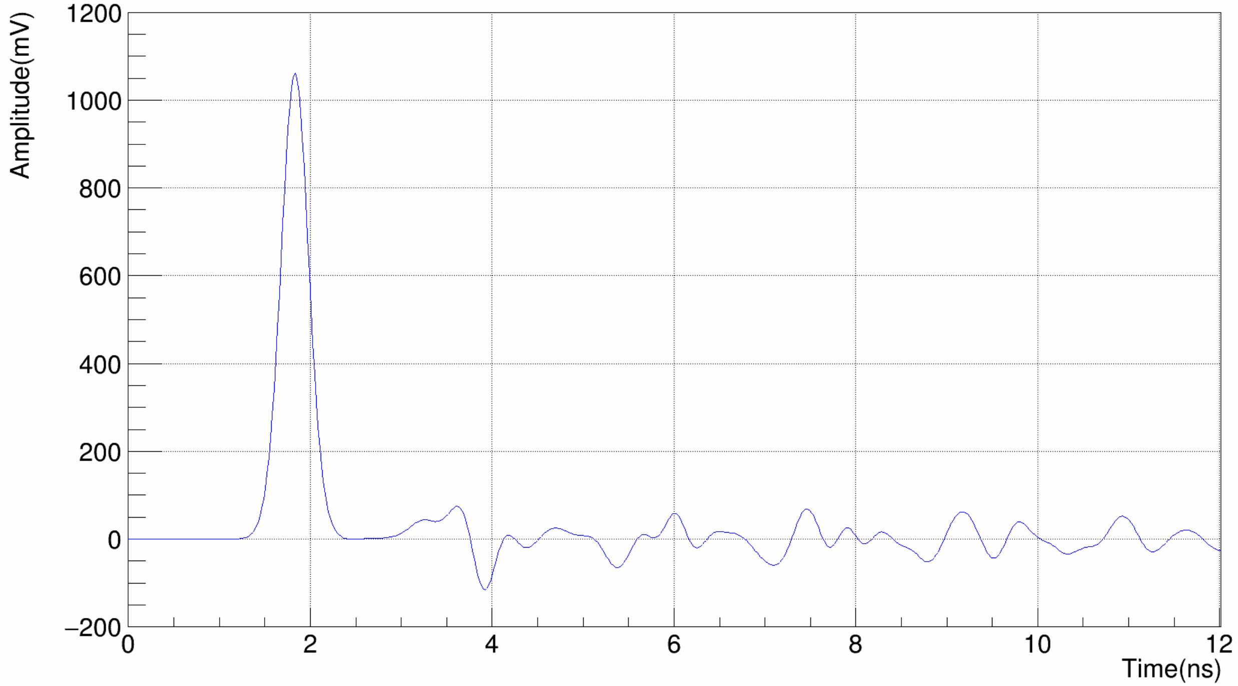


$Z_{transmission\ line} \neq Z_{iTOF} \longrightarrow$ amplitude of the first peak reduced

Impedance matching

If the output port is connected in parallel with a 43 ohm resistor, it can be completely impedance matched



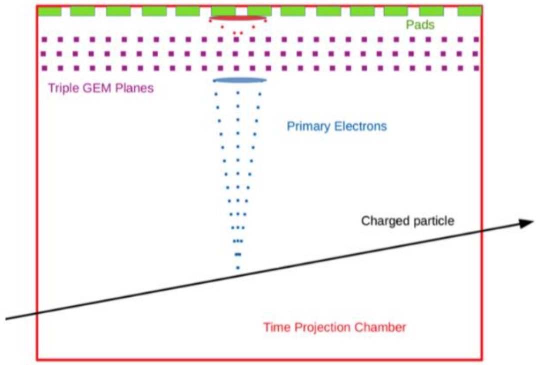


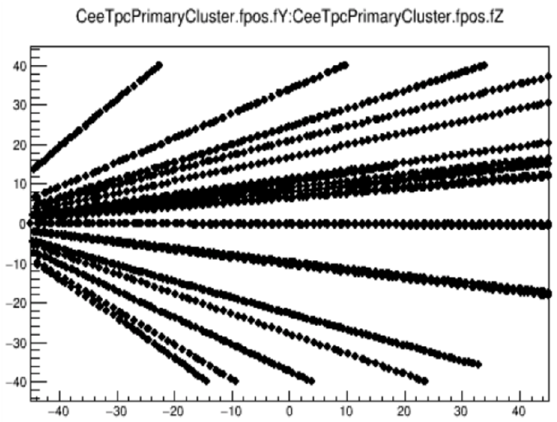
First peak	1.72 V ⟶ 1.07 V
Reflection	41% ⟶ 7%
Rise time	261 ps ⟶ 266 ps
Fall time	236 ps ⟶ 262 ps

Reflection is significantly reduced.

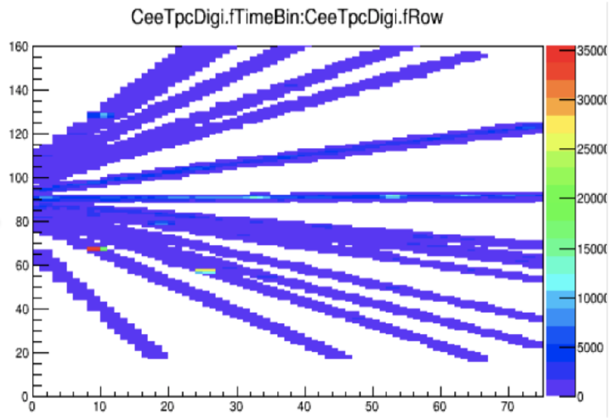
TPC Simulation and cluster reconstruction

➢ Simulation and digitization:





primary ionization distribution

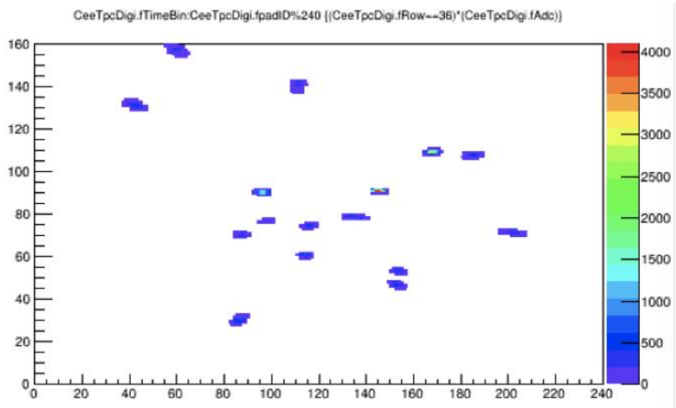


simulated TPC read-out digis

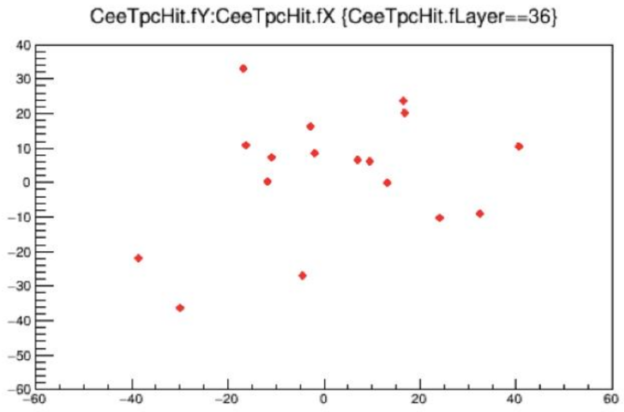
- position of ionization electrons

➢ For each pad, convolute the time for electrons arrive with electronics (SAMPA chip) response function

➢ Cluster reconstruction:



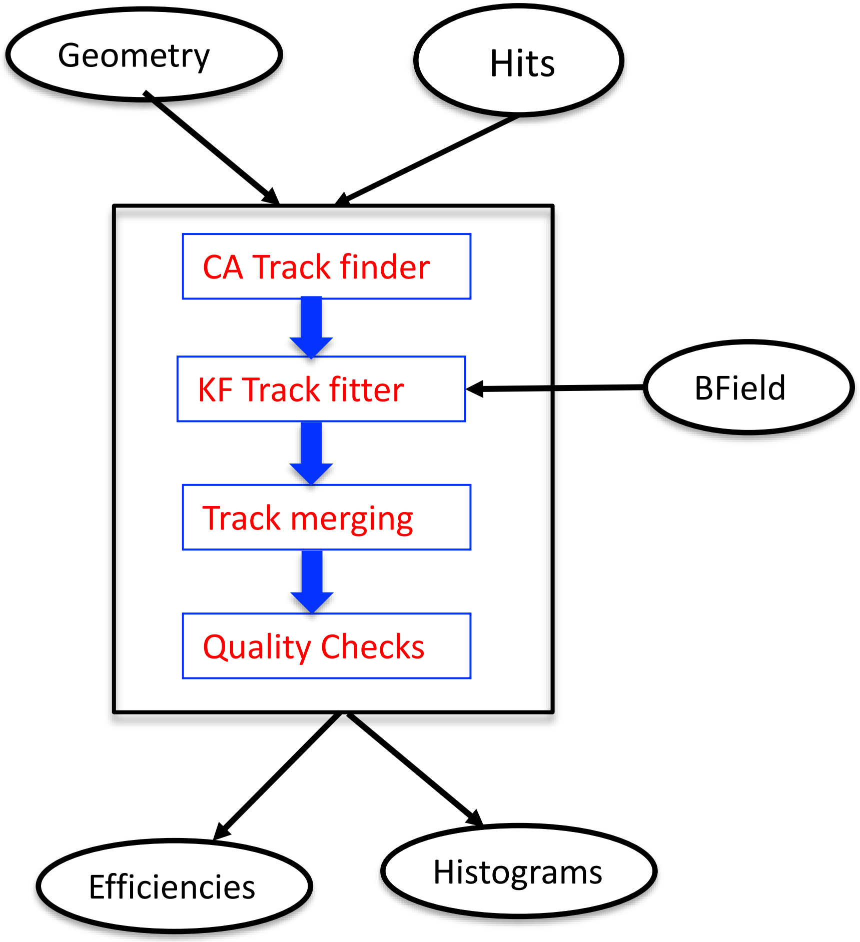
simulated TPC read-out digis



reconstructed TPC hits

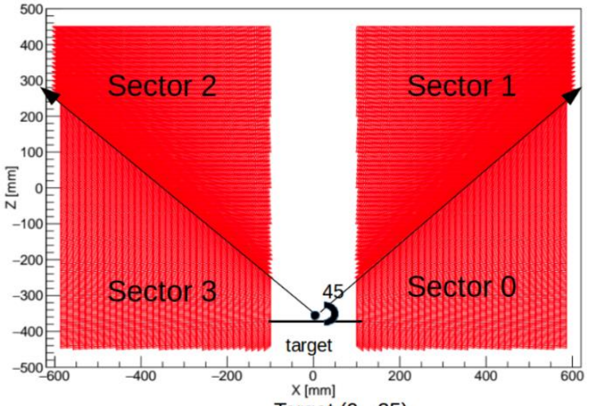
The poster: L04
Simulation, Digitalization and Track reconstruction in Time Projection Chamber of Future CSR-External target Experiment at HIRFL

TPC Tracking

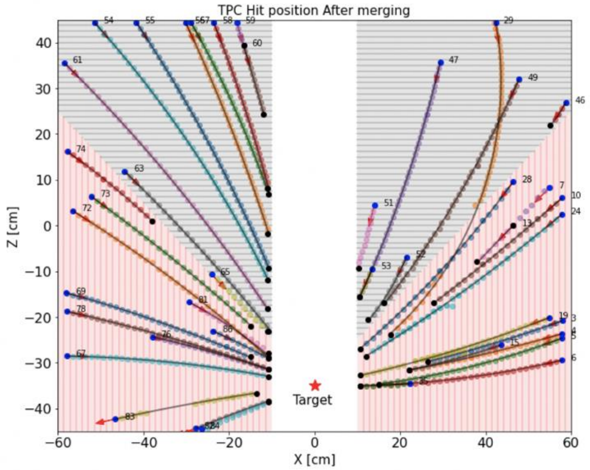


Official Repository: https://gitee.com/CEESM/CeeRoot

CEEROOT



Target (0, -35)



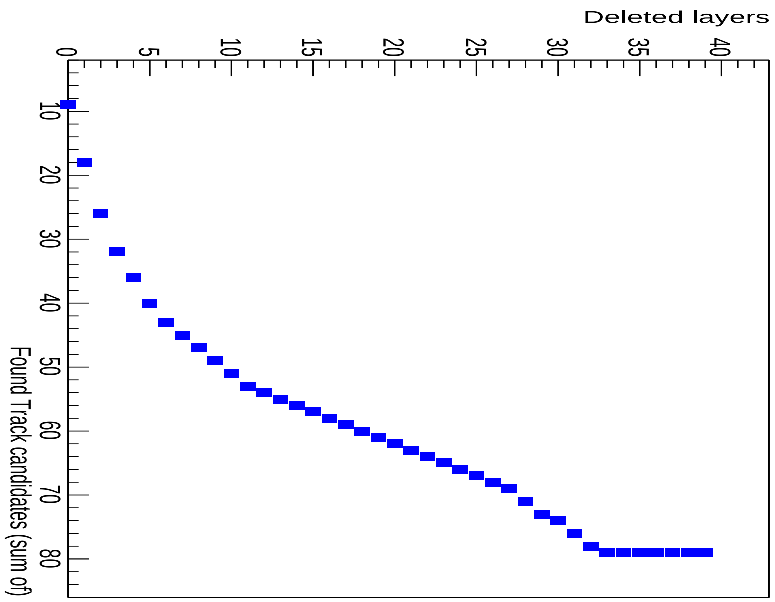
- Apply CA to find track candidate for each sector
  - Apply CA to reconstruct hit triplet/multiplets
  - Connect neighboring triplet to track
- Fit the track candidates by Genfit using Kalman fitter
- Merge the tracks
  - Merge the short tracks to long track in each sector
  - Merge the long tracks crossed the sectors
  - Refit the merged tracks and remove the duplicated tracks

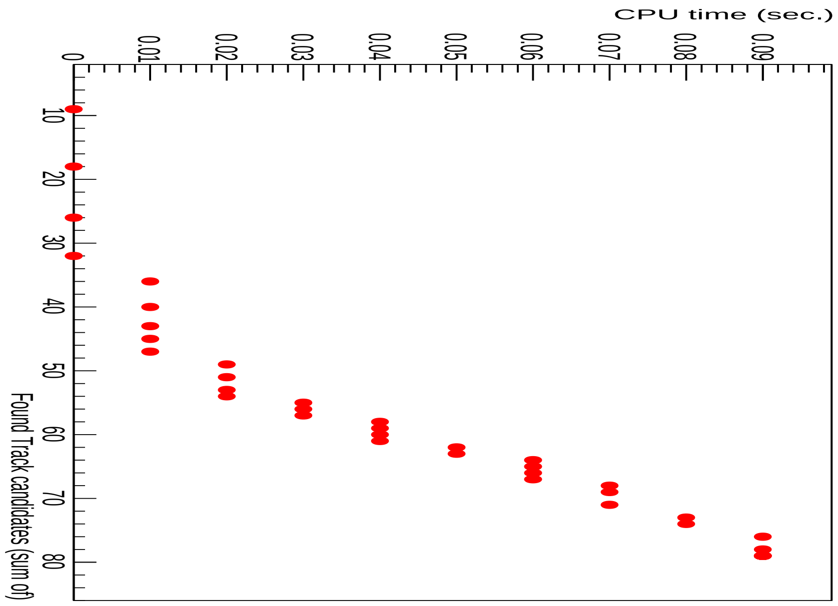
Summary

- Improved the time resolution of MRPC
- Study the signal integrity of iTOF, reduce reflection and leading edge of the signal becomes steeper at the same time.
- Study the gas transportation model of MRPC.
- Simulation, digitization, and Hit Reconstruction is presented for the TPC.
- The single track (π^+) tracking performance:
  - ✓ CPU time 16 sec. for 100 multiplicity
  - ✓ when the Efficiency ~ 92 %, fakes~ 20%
- Momentum resolution is below ~3.5

Thank you

Tracking performance





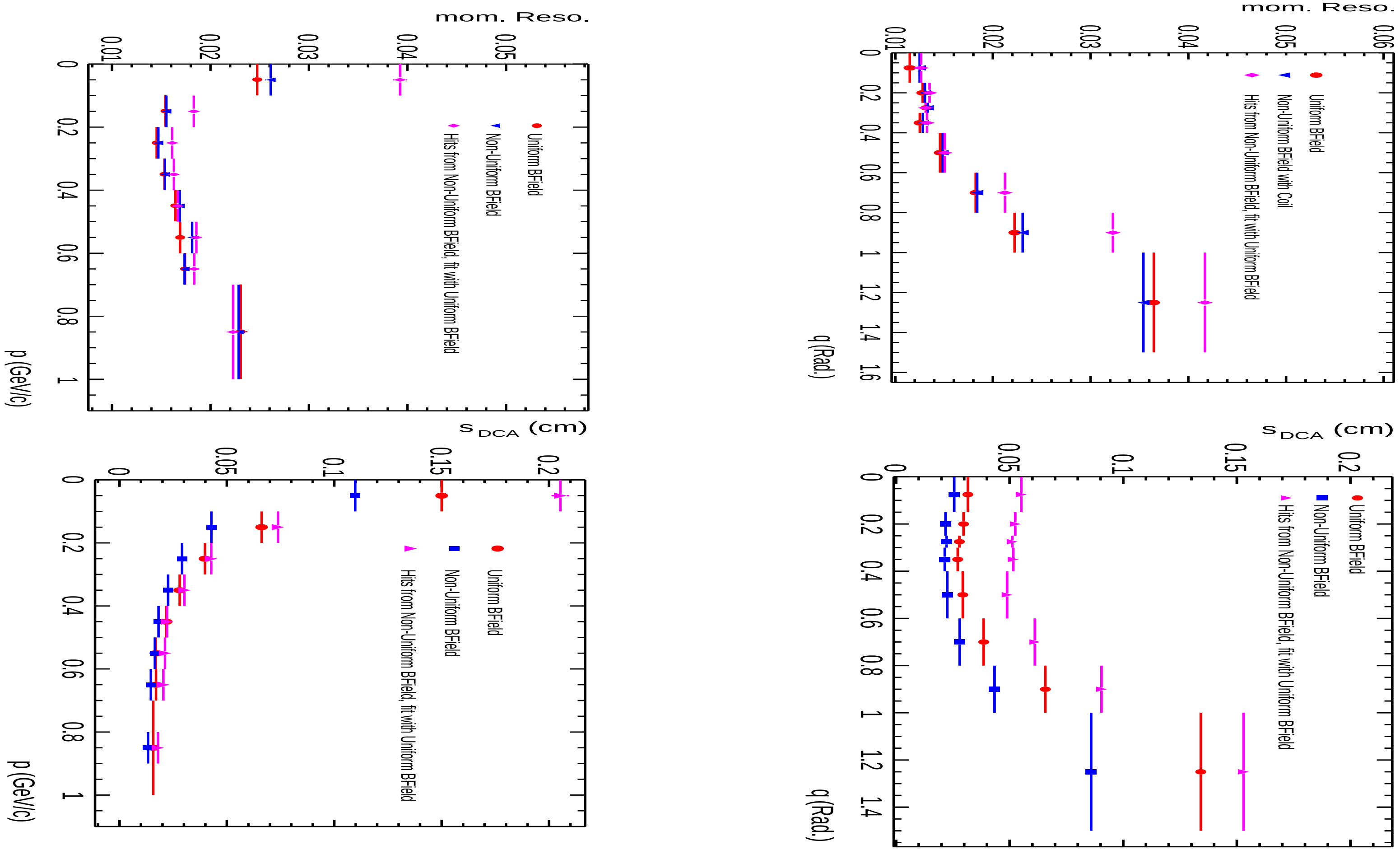
- CPU time for 1 event, 70 tracks using 4 sectors is 5.9 sec. for CA and 3.4 sec for KF.
- Fake rate ~ 20 %, when the Efficiency ~ 92 % (with loose cuts)

Single core CPU is used

```
Model name:          Intel(R) Xeon(R) Gold 6330 CPU @ 2.00GHz
Stepping:            6
CPU MHz:             800.000
CPU max MHz:         3100.0000
CPU min MHz:         800.0000
```

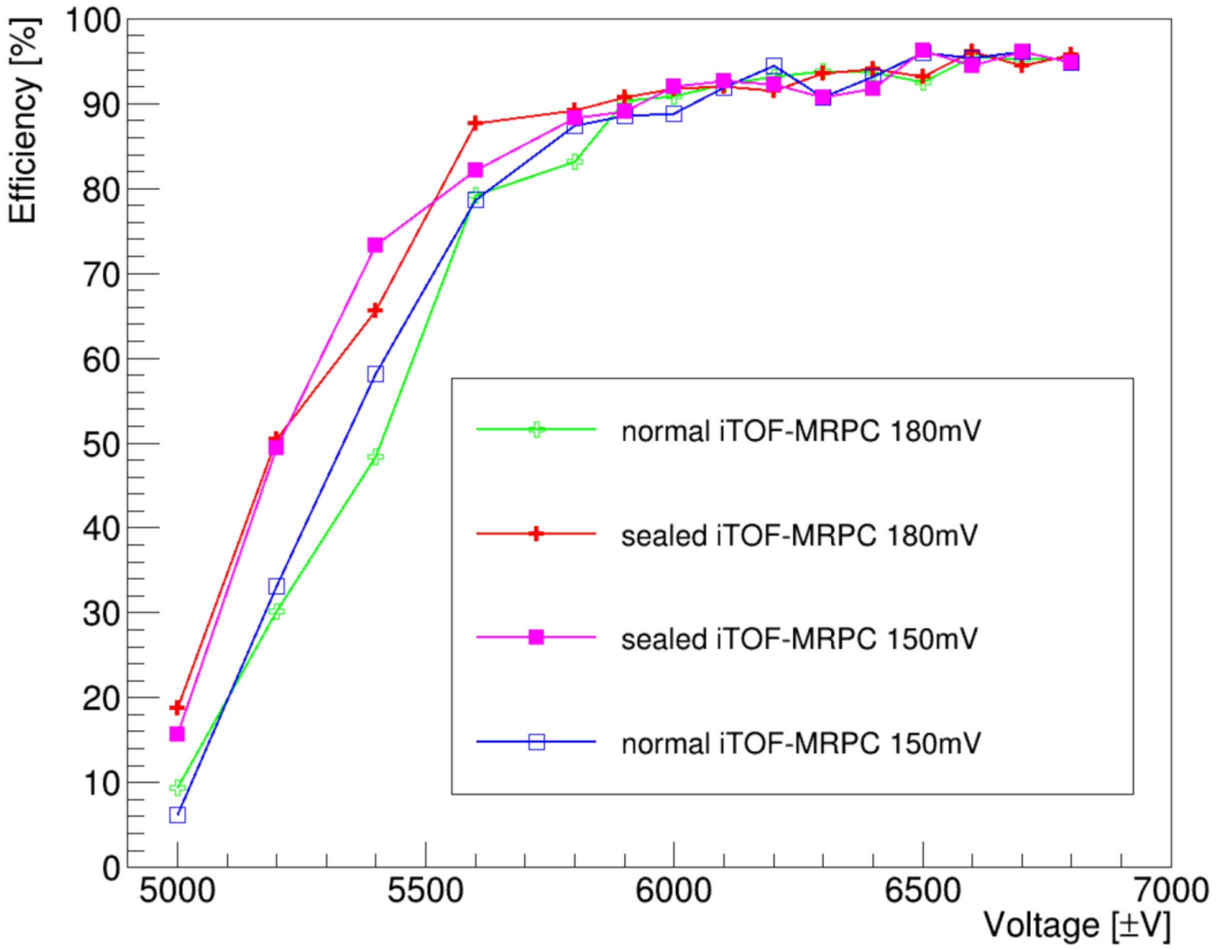
Multiplicity	Triplets (CA+KF)	Multiplets (CA+KF)
70	112.83 sec.	9.2 sec.
100	172 sec.	16.4 sec.

Momentum resolution and DCA

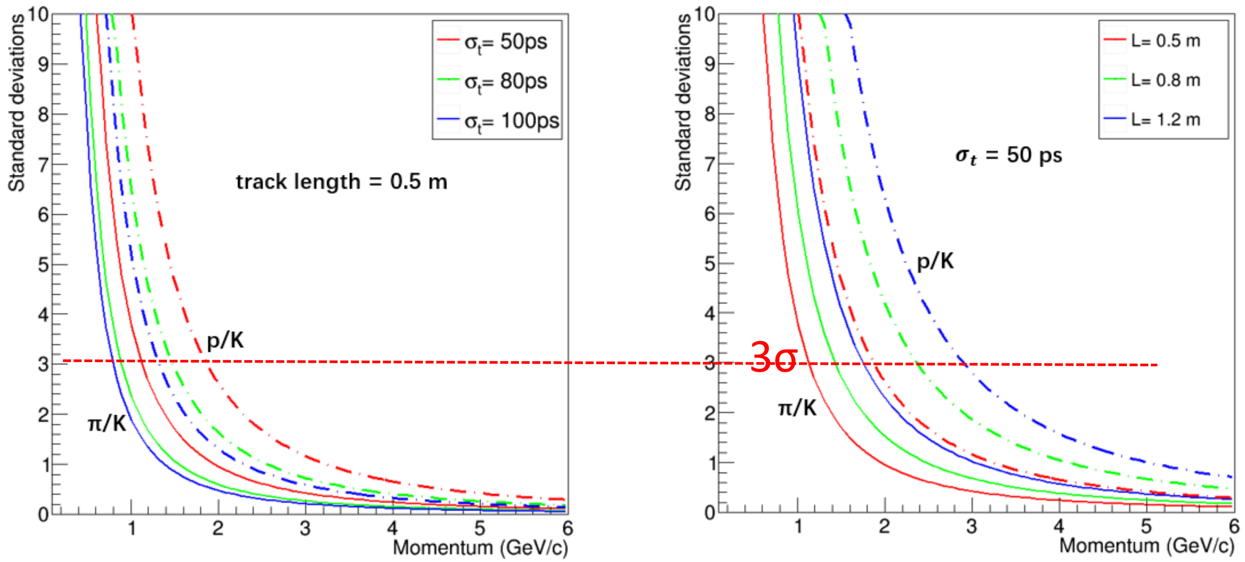


- Momentum resolution is below ~3.5%.
- DCA is below ~ 1.5 mm

backup

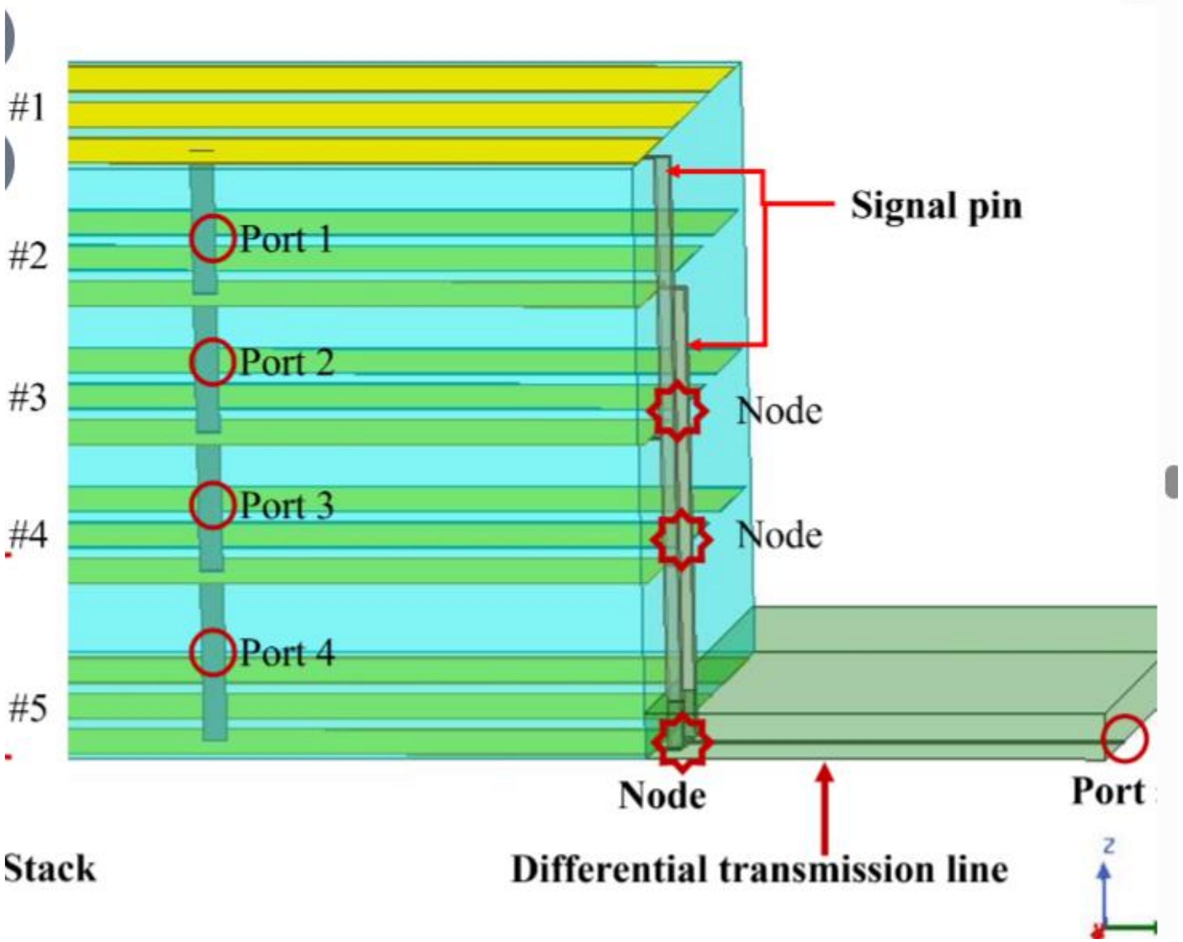


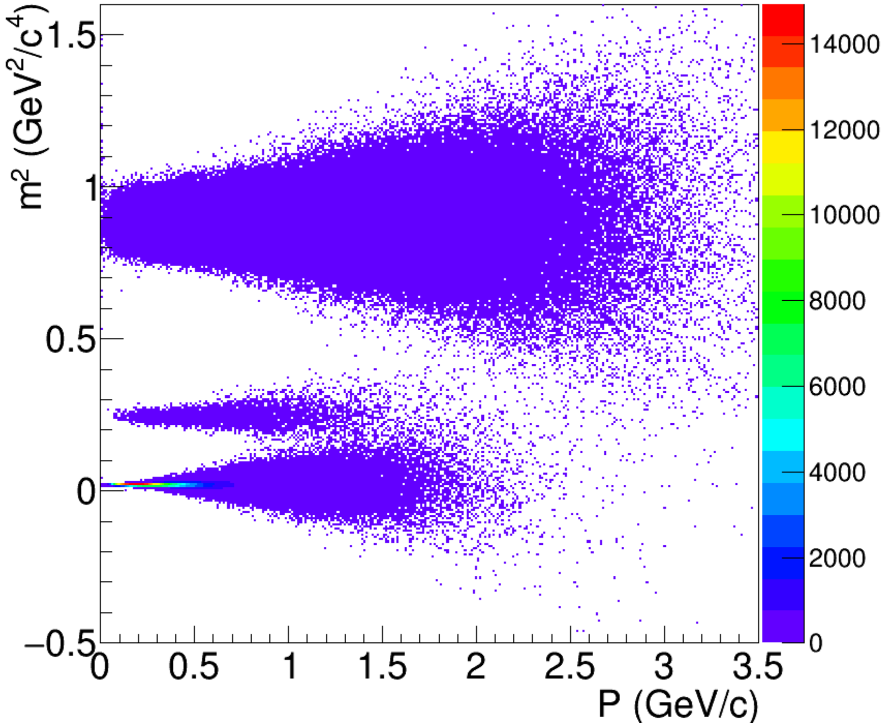
Efficiency [%]
Voltage [±V]
normal iTOF-MRPC 180mV
sealed iTOF-MRPC 180mV
sealed iTOF-MRPC 150mV
normal iTOF-MRPC 150mV



Standard deviations
Momentum (GeV/c)
σt= 50ps
σt= 80ps
σt= 100ps
track length = 0.5 m
p/K
π/K
3σ
L= 0.5 m
L= 0.8 m
L= 1.2 m
σt = 50 ps

model


#1
#2
#3
#4
#5
Port 1
Port 2
Port 3
Port 4
Signal pin
Node
Node
Node
Differential transmission line
Port
Stack
z


m^2 (GeV^2/c^4)
P (GeV/c)
1.5
1
0.5
0
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
14000
12000
10000
8000
6000
4000
2000
0