High time resolution MRPC for CEPC-ToF

Kai Sun, Yuexin Wang , Jianing Liu , Yi Wang , Manqi Ruan

Outline

1. **Physical requirements of the Particle identification system**
   - PID of CEPC
2. **MRPC Detector and some new Progress of MRPC in THU Group**
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3. **20ps high time resolution MRPC & electronic readout system**
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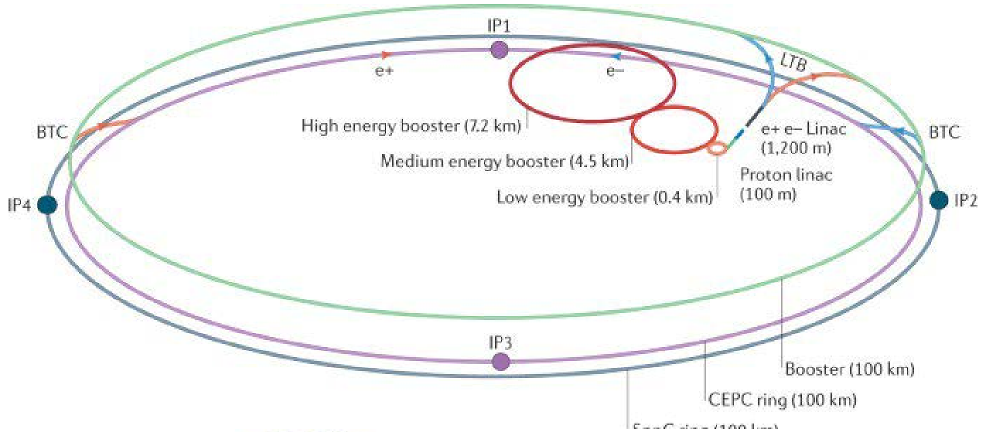
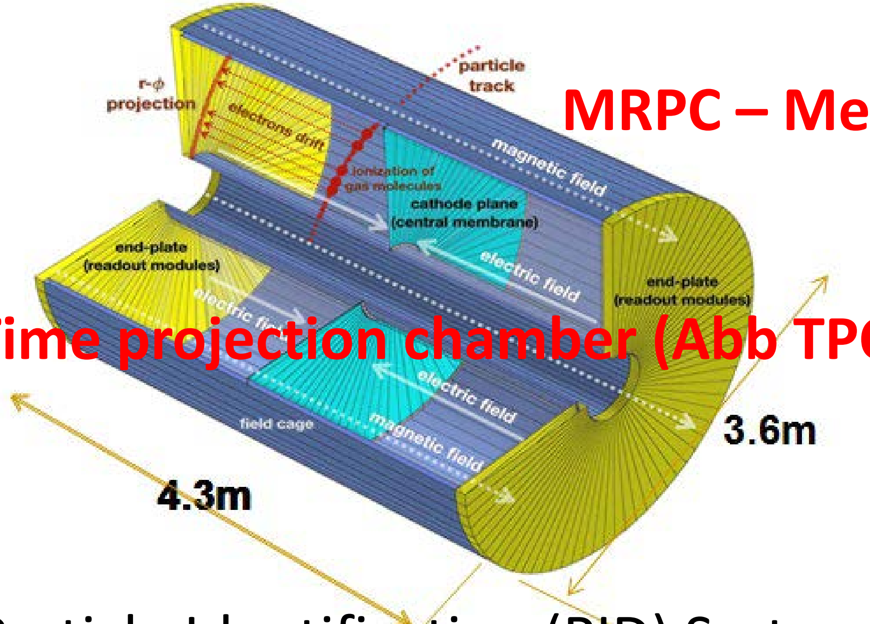
   - CEPC-ToF MRPC Parameters
5. **Summary**

1. Physical requirements of the Particle identification system

PID of CEPC

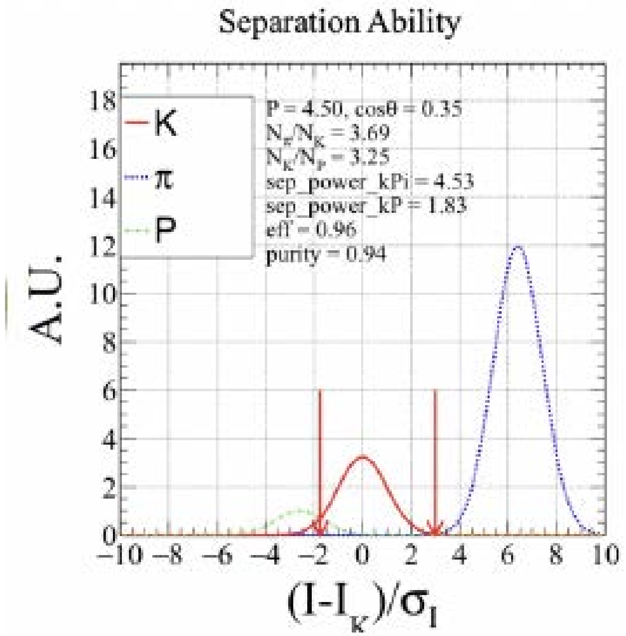




MRPC – Measure ToF

Time projection chamber (Abb TPC)

Particle Identification (PID) System



Geant4 simulation:

If:

TPC energy loss resolution: dE/dx < 2.5%

ToF: <50 ps

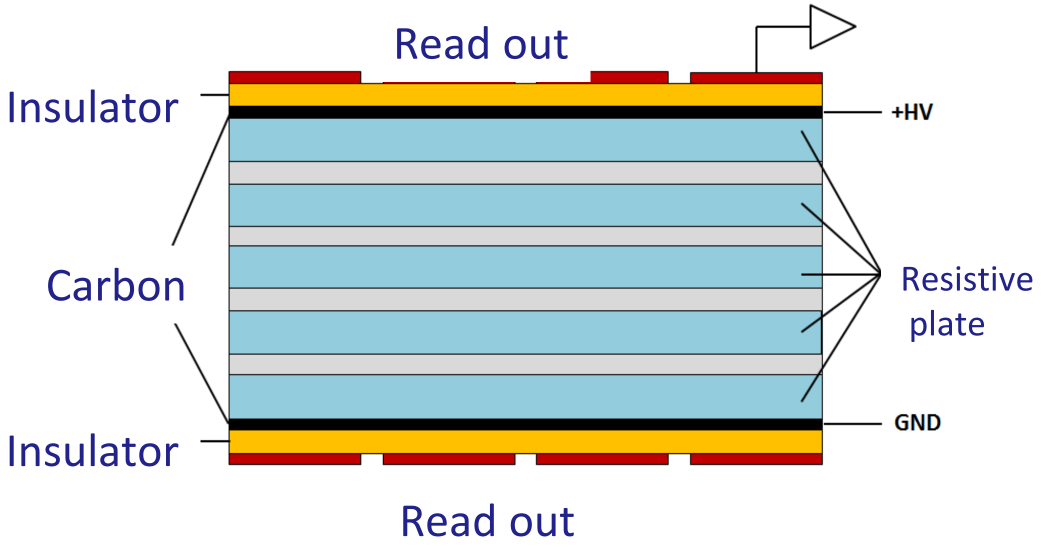
Then:

PID of K/π: > 98%

From Manqi's summary @ 2022 CEPC workshop

2. MRPC Detector and some new Progress of MRPC in THU Group

Multigap Resistive Plate Chamber (MRPC)



- Application in nuclear physics experiments
- Application in industry（Muon tomography)
- Application in medicine（TOF-PET）

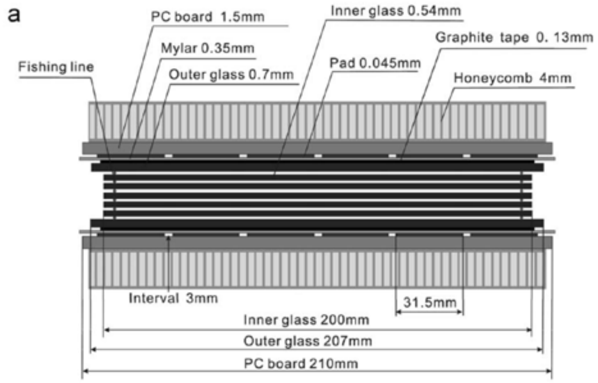
Standard parameters:

- Resistivity of glass: ~10^{12} Ω.cm
- Working gas: 90%Freon+5%iso-butane+5% SF6
- Time resolution <100 ps
- Efficiency >95%
- Charge: a few PC
- Dark current: <100 nA
- Noise ~ 1 Hz/cm2
- Rate < 100 Hz/cm2
- Large area, low cost

MRPC in ToF System

MRPC has been broadly adopted to construct the Time of Flight (TOF) systems in HEP experiments.

(Yesterday reported by Vadim ☺)



The multigap structure brings:

- Narrow gap thus high time resolution
- Necessary gap thickness bring good efficiency

In construction | Proposed

	ALICE	STAR	FOPI	BESIII	BM@N	MPD	CBM	SoLID
Active area per detector (cm)	120 x 13	22 x 8.4	90 x 4.6	0.5x(9.2+14.8)x32.8	35.1 x 16	64 x 30	33 x 27.6	--
Total active area (m^2)	141	50	5	1.33	/	52	120	10
Pad size (cm)	3.7 x 2.5	6.3 x 3.1	90 x 0.3	(9.1~14.1) x 2.4	16 x 1	64 x 1	27 x 1.0	(16~28) x 2.5
Gap × thickness(mm)	10 x 0.25	6 x 0.22	6 x 0.3	12 x 0.22	12 x 0.22	15 x 0.20	10 x 0.25	32 x 0.128
Gas mixtures ($C_2H_2F_4$/ C_4H_{10}/SF_6)	90/5/5	95/5/0	85/5/10	90/5/5	98/0/2	90/5/5	90/5/5	90/5/5
Operating field (kV/cm)	96	107	110	109	114	120	110	150
Efficiency	99.9%	95-97%	97±3%	99%	95%	98%	97%	98%
Time resolution(ps)	40	60	73±5	60	65	40	60	20 ps
Max rate (Hz/cm^2)	50	10	50	50	5k	2k	30k	20k

The MRPC applications are in the trend of the higher **counting rate** and **time precision**.

Low resistive glass developed for high counting rate

- Voltage drop in the gas gap when avalanche happens

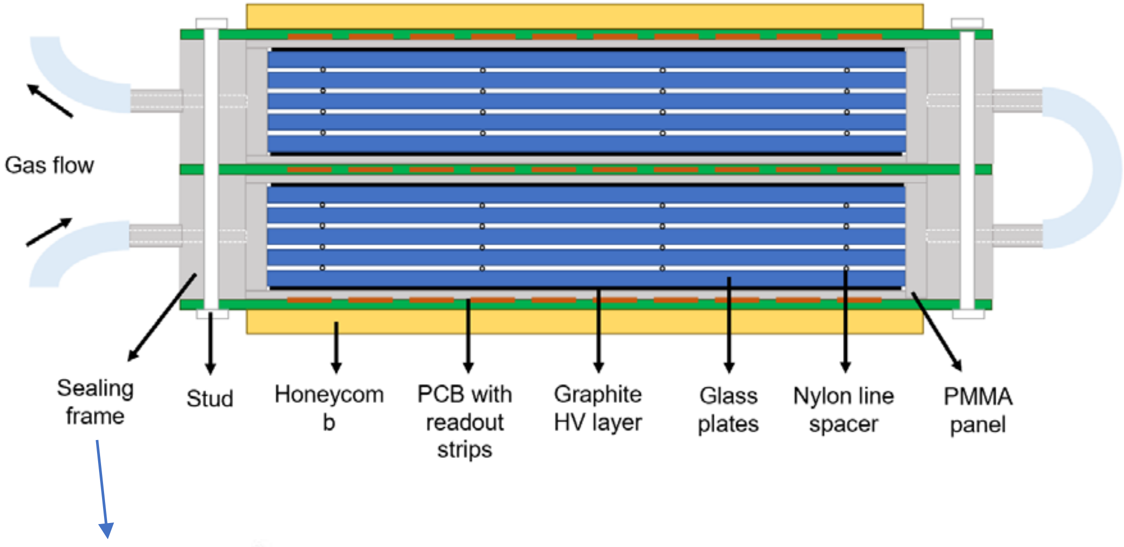
$$\overline{V}_{drop} = V_{ap} - \overline{V}_{gap} = \overline{I}R = \overline{q}\phi\rho d$$

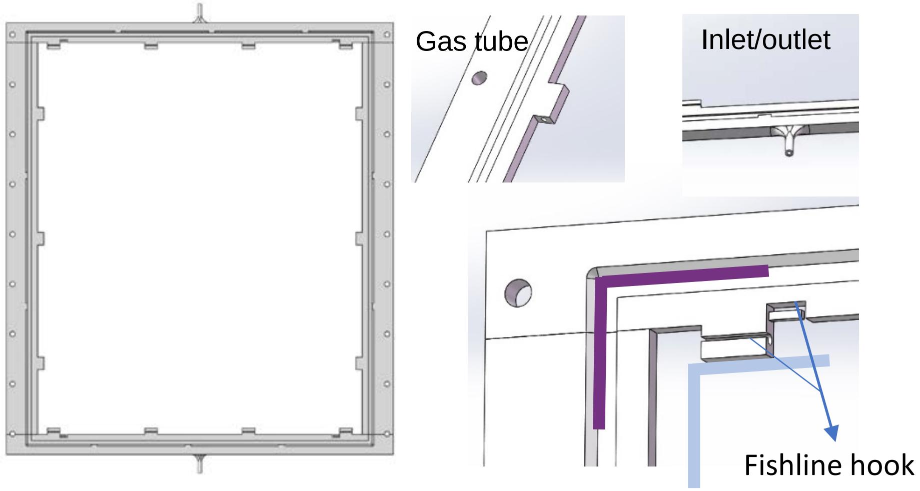
- Voltage drop smaller in one event, the MRPC can have higher efficiency and rate capability
- Low resistive glass can reduce the voltage drop, obtaining a higher counting rate
- Volume resistivity (Ω·cm): 10^{12} (Other glass)-> 10^{10} (Low resistive glass) -> Higher counting rate

Dimension	33 x27.6cm2
Bulk resistivity	~1010Ωcm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20μm
Surface roughness	<10nm
Dielectric constant	7.5 - 9.5
DC measurement	stable up to 1C/cm2

- Has been operated at STAR-eToF and mCBM, Bam test result: 93%, 80 ps ,70 kHz/cm^2

Sealed MRPC

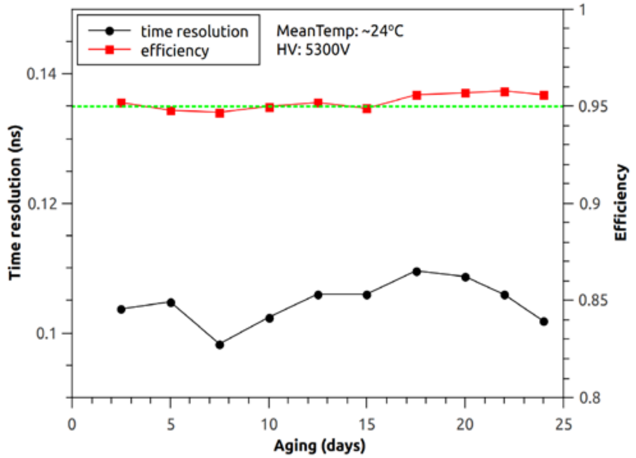




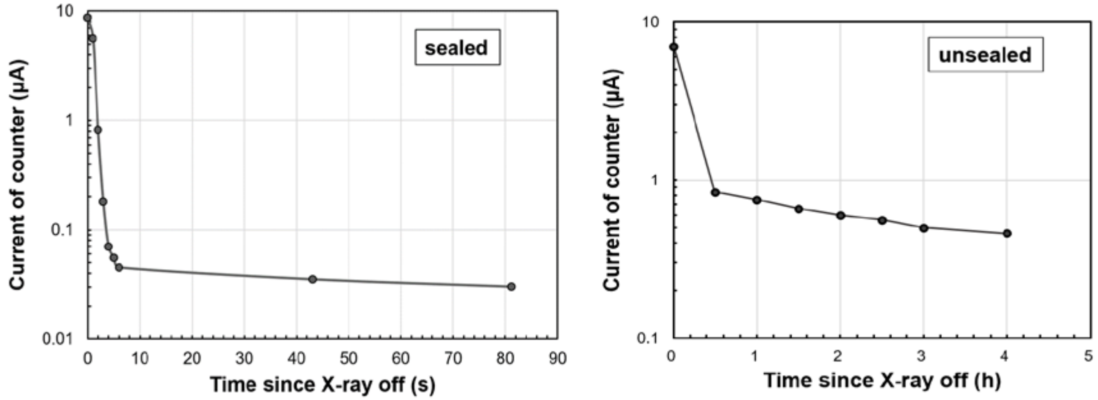
3D printed sealing frame with Good strength, insulation and radiation persistency

- Features :

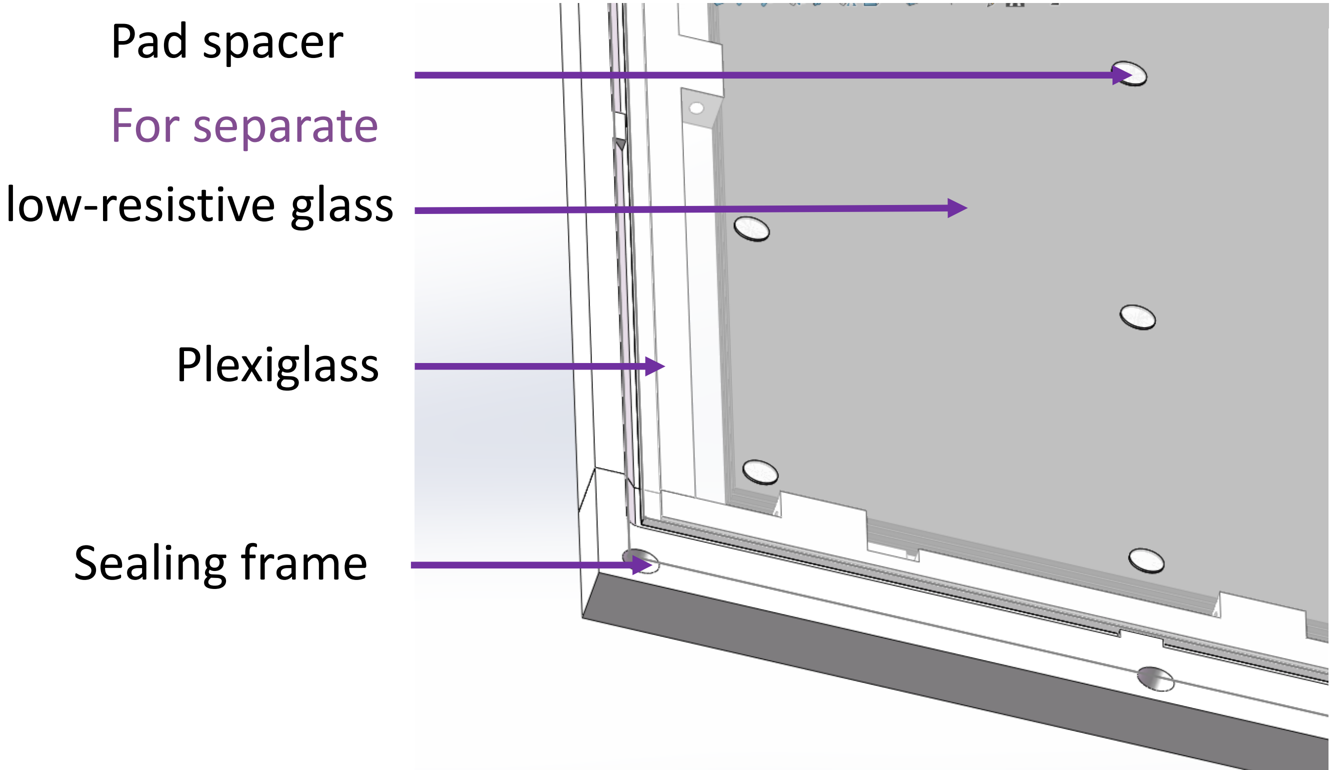
1. **Gas saving :** stable operation under < 10 sccm/m^2 gas flow in cosmic ray test

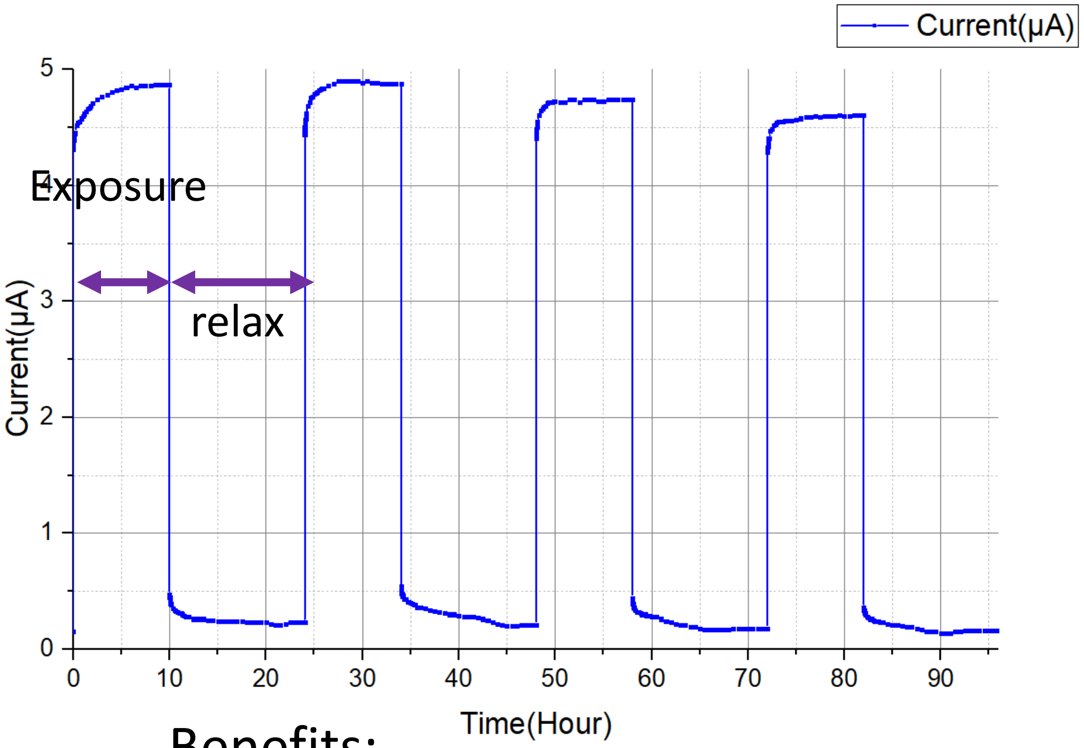


2. **Higher gas exchange efficiency:**
- Decrease the wait time for gas purging in X-ray test
- Excellent current behavior under high rate irradiation



Pad spacer MRPC





Aging test:

- X-ray tube: 45 kV / 0.1 mA
- 4 rounds
- 10 hours of X-ray exposure
- 14 hours of relax
- Irradiation 3 kHz/cm^2

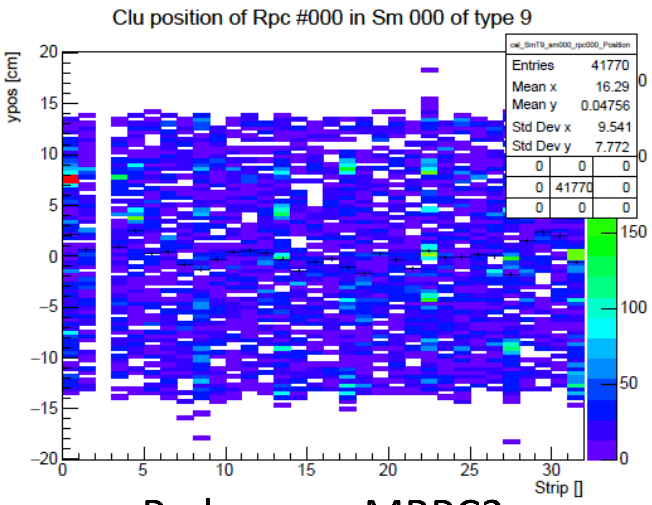
Benefits:

- No obvious aging effect
- Earlier saturation
- Dark current decreases very fast

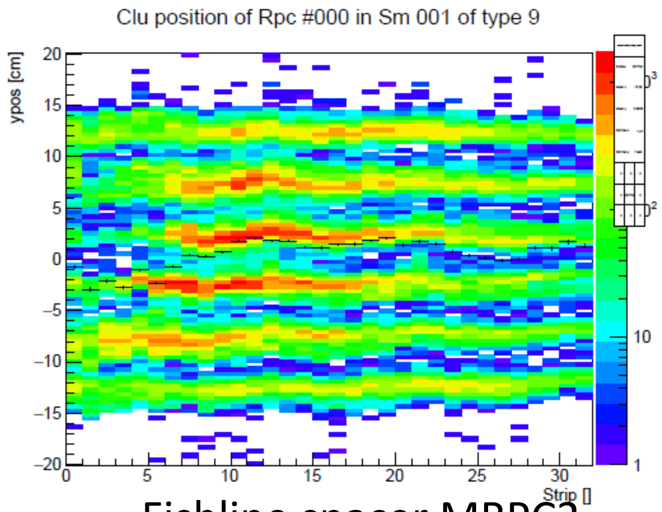
Also

- Bigger effective area

Low resistive glass + Sealed MRPC + Pad Spacer



Pad spacer MRPC2
665 hits/100 time slices



Fishline spacer MRPC2
18646 hits/100 time slices
@Ingo Deppner

- In the cosmic analysis by @Ingo Deppner From CBM, The spacer area can be seen clearly through the hit–position fig. We can see that pad spacer MRPC have less noise at the spacer area.

- This type of MRPC will go through a beam test this year in the mCBM experiment.
- These new Technologies can be used in CEPC-ToF MRPC

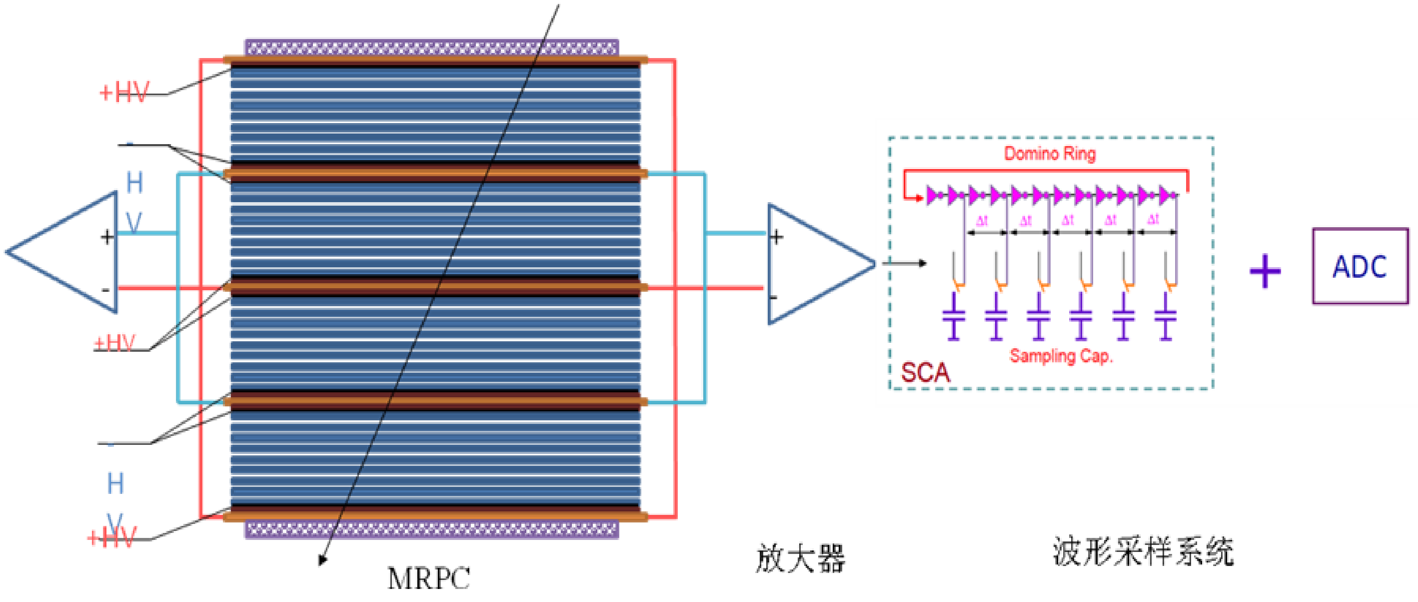
Benefits

- High counting rate (70 kHz/cm^2)
- Environment-friendly (10 $sccm/m^2$)
- No obvious aging effect
- Good current behavior
- Good noise behavior

sccm: Standard Cubic Centimeter per Minute

3. 20ps high time resolution MRPC & electronic readout system

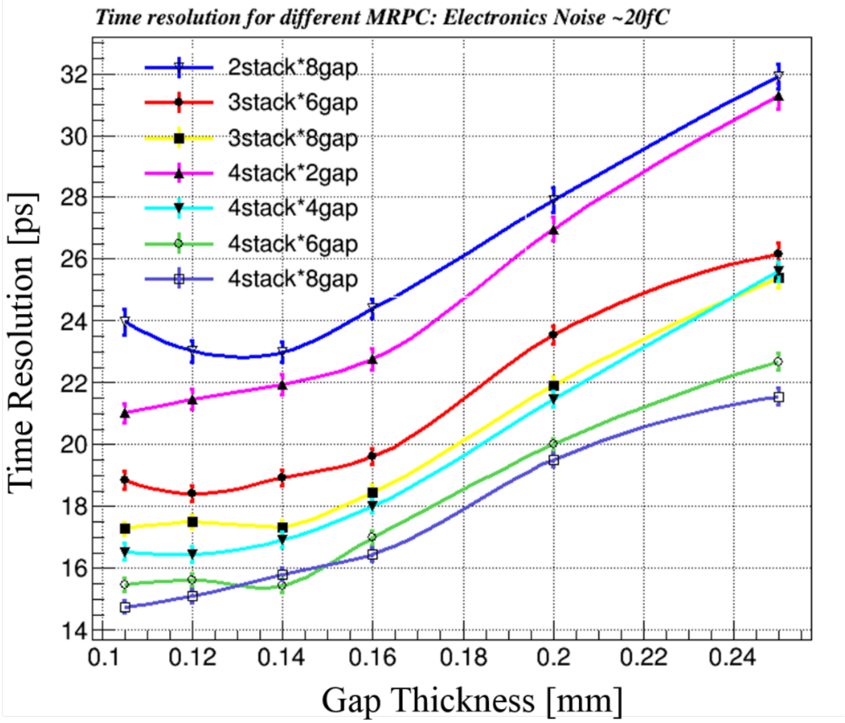
20ps MRPC developed for SoLID-ToF system



$$\sigma_{TOF} = \sqrt{\sigma_{MRPC} + \sigma_{electronics}}$$

- σTOF <20 ps，
- Intrinsic resolution of narrow gaps MRPC is around 15 ps
- Time jitter of readout electronics <13~15 ps。

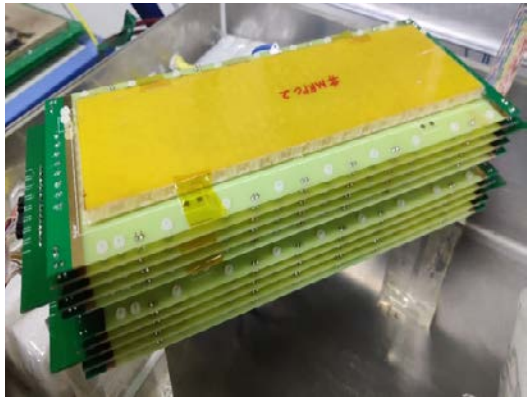
- Simulation indicates proper ways to design the gap thickness and arrange the stacks.



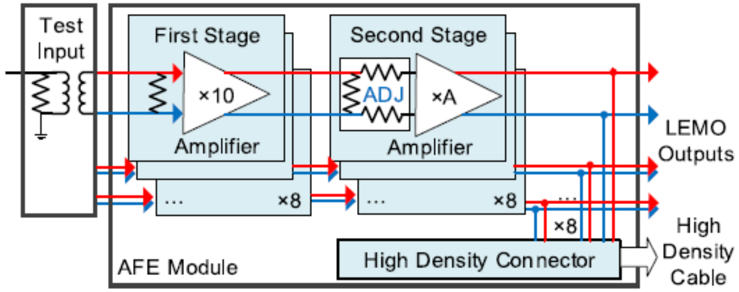
σ_{MRPC} < 20 ps, if:

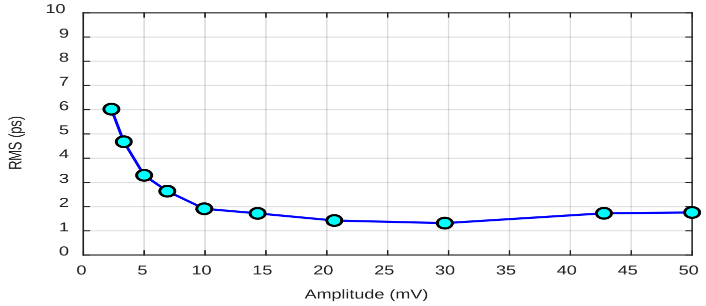
- the gas gap: < 0.18 mm
- gap number: > 3 stack*6 gap = 18

Electronic Readout System for SOLID-ToF

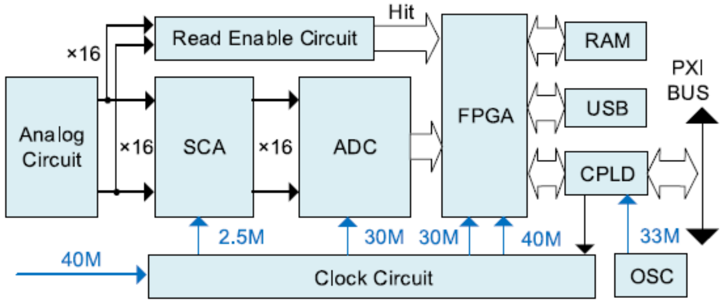


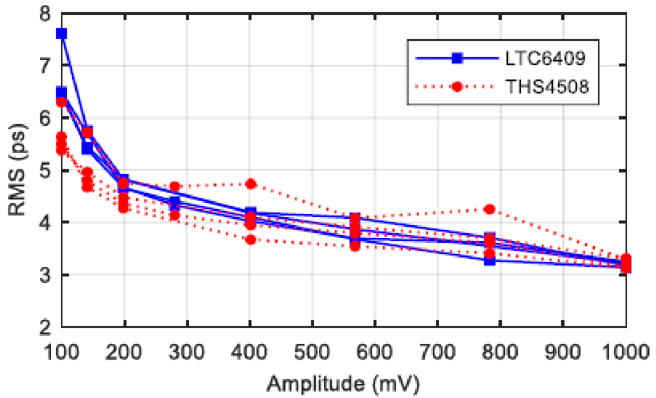
	MRPC prototype
gas gap thickness	128 μm
number of gas gaps	4 chambers × 8 gaps
glass material	**low resistivity glass**
glass thickness	400
readout strips	5 mm in width (2 mm clearance)





Fast amplifier
Bandwidth=1.4GHz



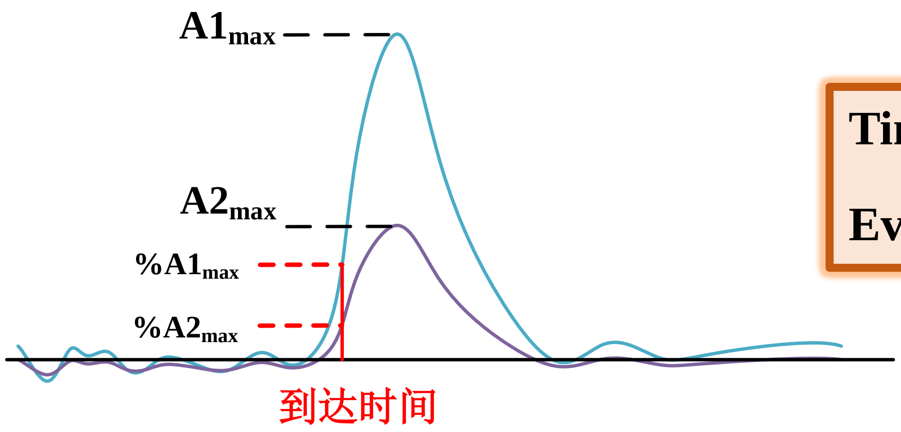


Waveform sampling
Based on DRS4
Sampling freq=5 GS/s

Electronic from Zhao Lei Group from USTC

Cosmic Test Results

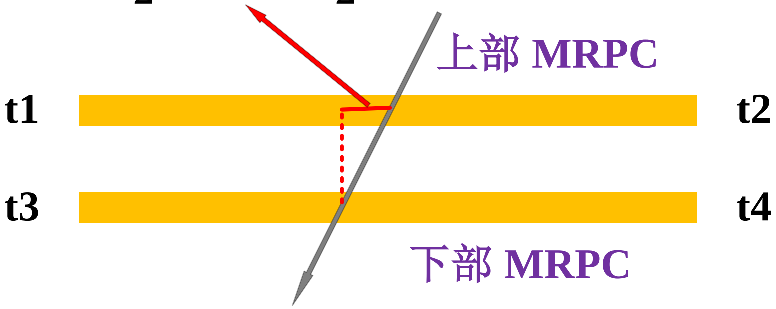
MRPC + fast amplifier + DRS4



Timing： **CFD**

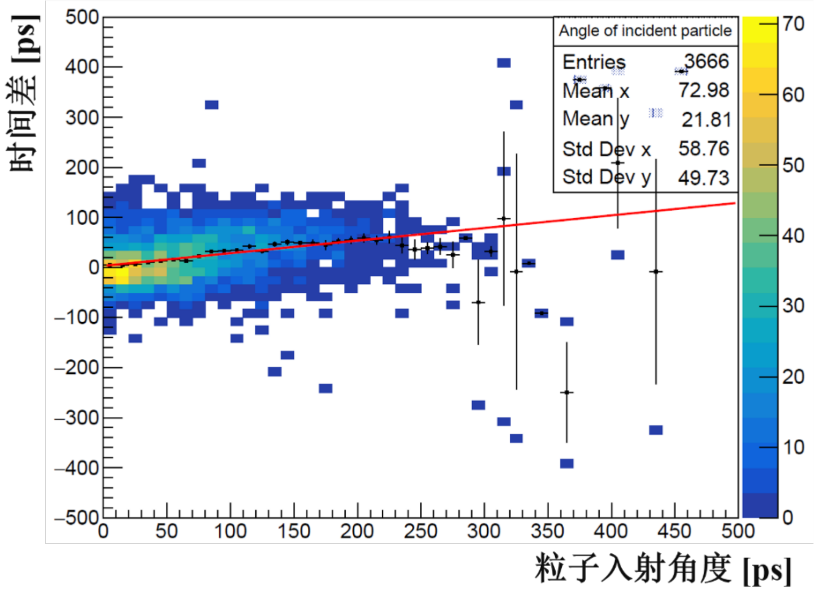
Event choose： **Vertical cosmic ray**

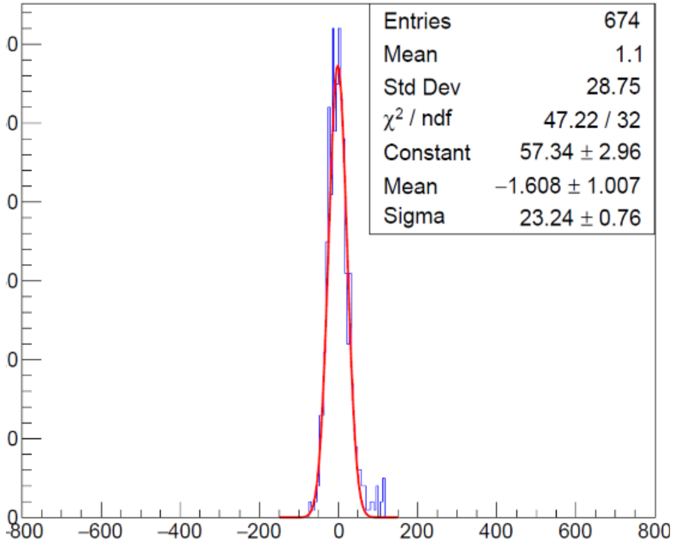
$$cut = [\frac{(t1-t2)}{2} - \frac{t3-t4}{2}] < 3\sigma_{\Delta t}$$



$$\Delta t = (t1+t2)/2 - (t3+t4)/2$$

$$\sigma_{MRPC} = \sigma_{\Delta t}/\sqrt{2}$$



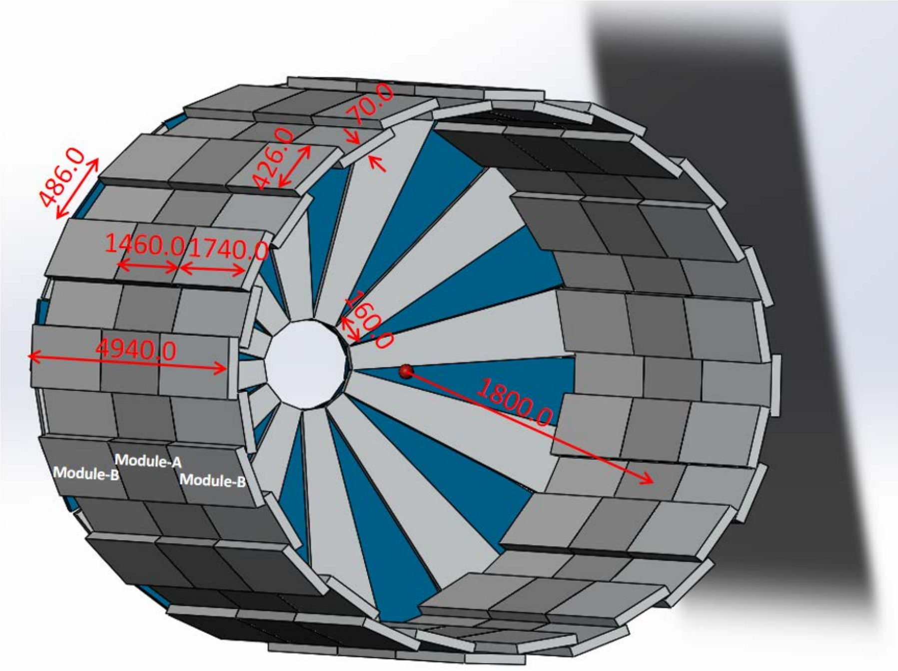


- Total time resolution

$$\sigma = \frac{23.24\text{ps}}{\sqrt{2}} = 16.43\text{ps}$$

4. Overall structure and the parameter of CEPC-ToF MRPC

CEPC-ToF Overall Structure



Parameters:

- Time Resolution: <35ps
- PID of π/k: 2.5GeV @3σ
- Total Area: ~77m^2
- Number of electronic channels: 37632
- Power Consumption: 17mW/channel
- Energy Loss: $0.1X_0$

Barrel region:

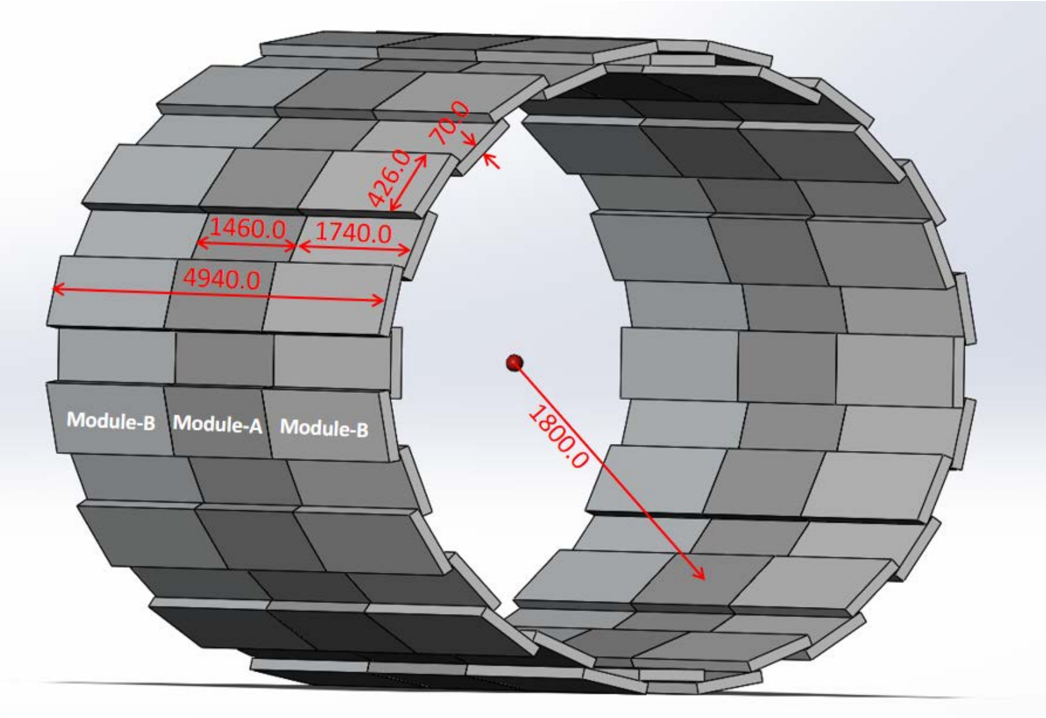
Two layers of towers overlap along the circumferential direction, with 16 towers per layer. Each tower contains one Module-A and two Module-B,

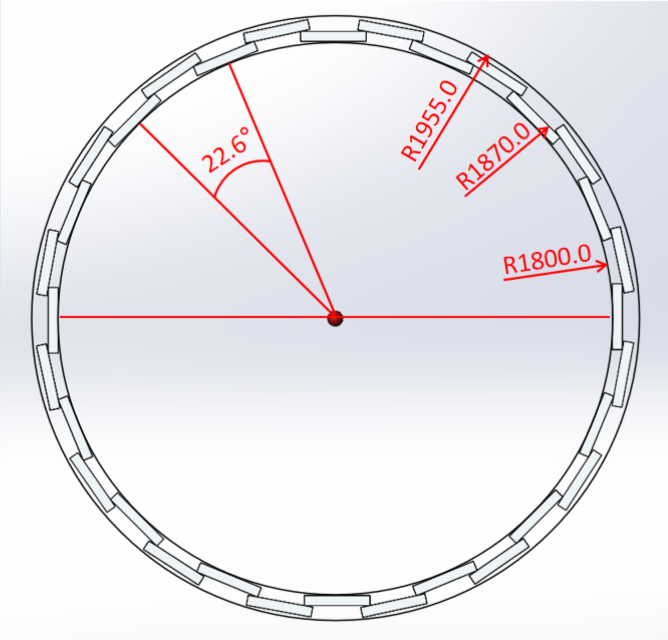
There are two overlapping readout strips between two neighboring MRPCs in Module-A and Module-B, with a width of 10+2.5 mm

Endcap region:

24 modules at one endcap, which overlap in two layers. Each module has five MRPC detectors, with 1-2 overlapping readout strips between two neighboring MRPCs. Each detector has 24 readout strips, which are 10+3.5 mm wide.

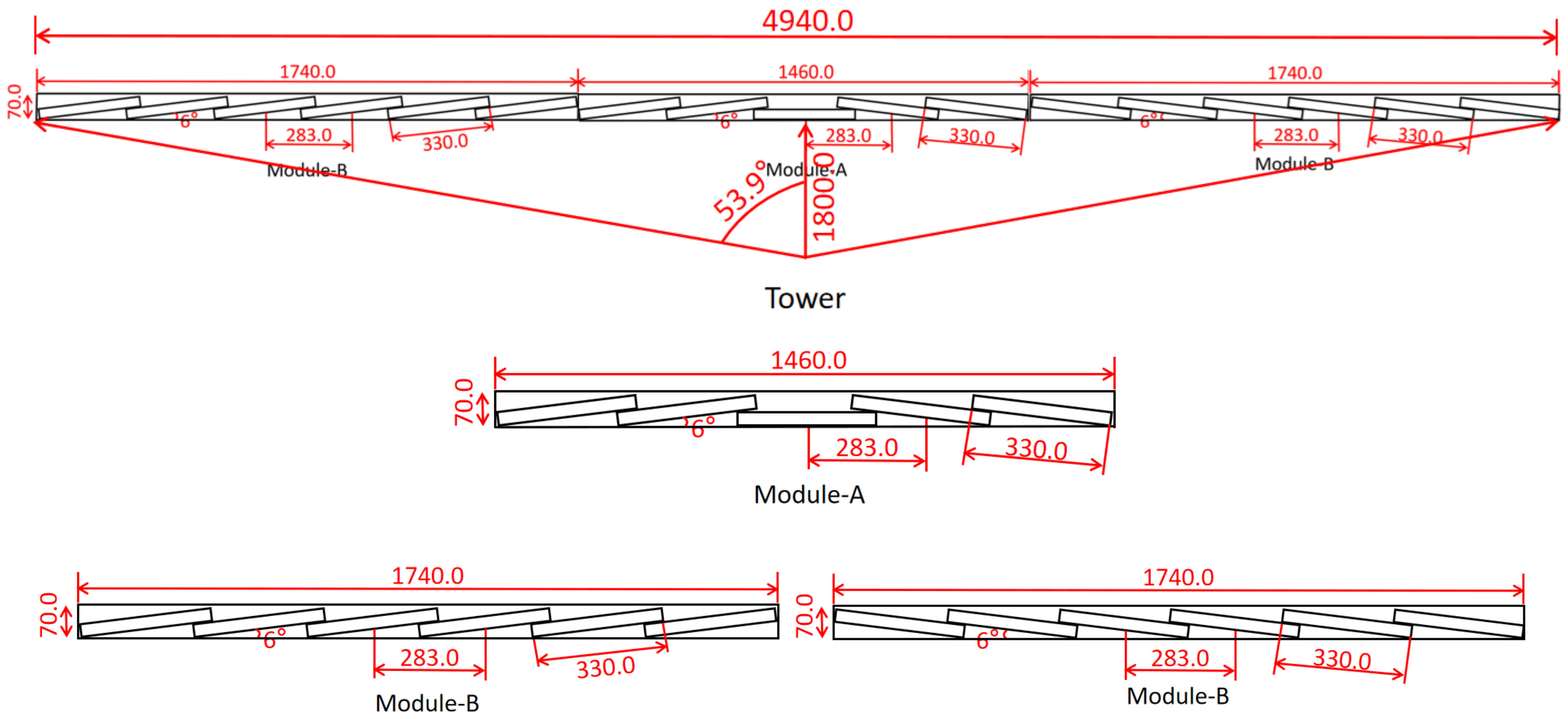
CEPC-ToF Overall Structure





Main sizes of the barrel region

CEPC-ToF Overall Structure



Arrangement of MRPCs inside the box along the beam direction

- One Tower contains Three Models: one Model A, and two Model B, We ensure full coverage of the effective area

CEPC-ToF Overall Structure

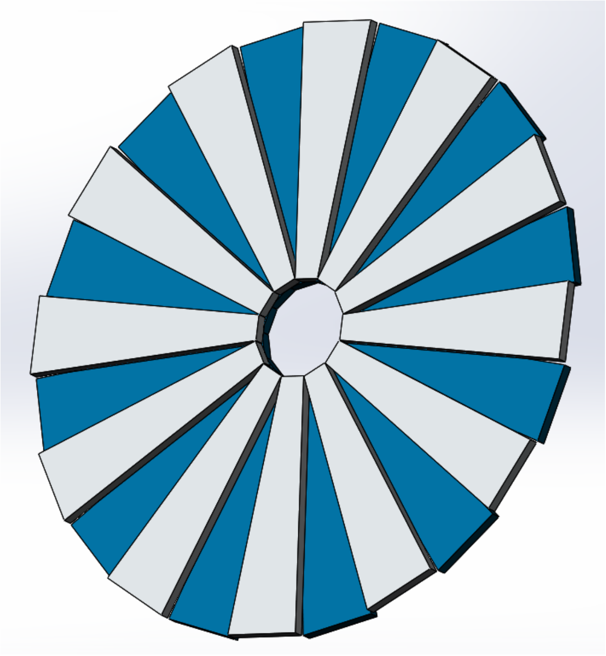
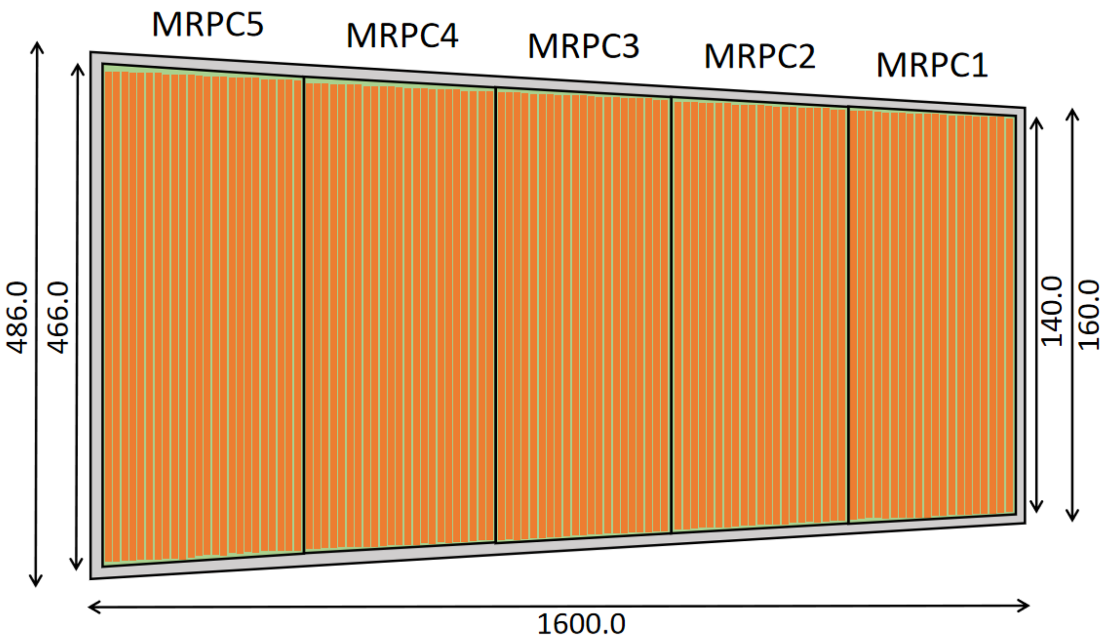


Diagram of the End-cap



Arrangement of MRPCs inside the box in the End-cap

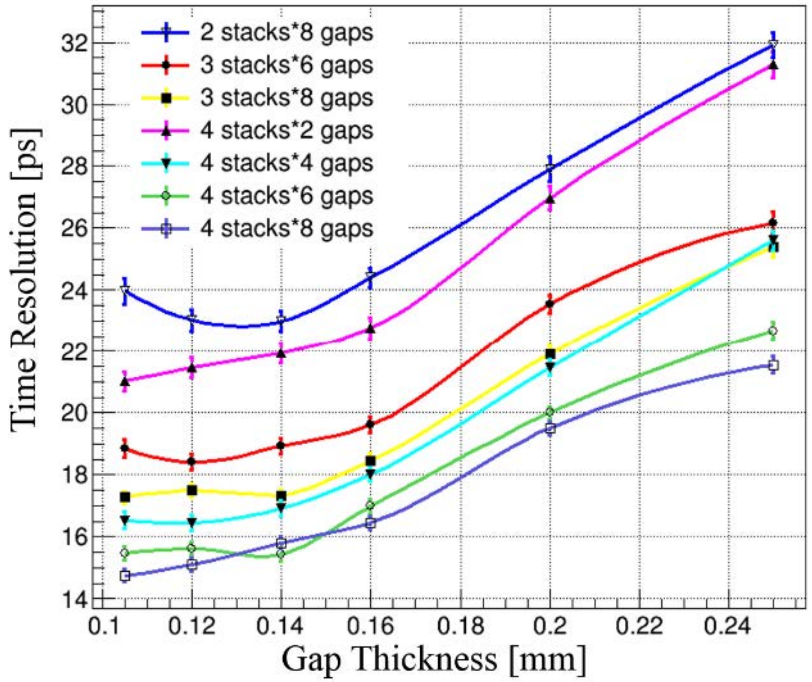
Electronic Readout Parameter for CEPC-ToF System

		Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
Barrel	$MRPC_B$	1	24	0.11	3	48
	Module-A	5	120	0.55	15	240
	Module-B	6	144	0.66	18	288
	Barrel Tower	17	408	1.87	51	816
	$Total_B$	544	13056	59.84	1632	26112
End-cap	$MRPC_E$	1	24	0.07	3	48
	Module-C	5	120	0.35	15	240
	$Total_E$	240	5760	16.80	720	11520
Total		784	18816	76.64	2352	37632

*A barrel tower contains one Module-A and two Module-B.

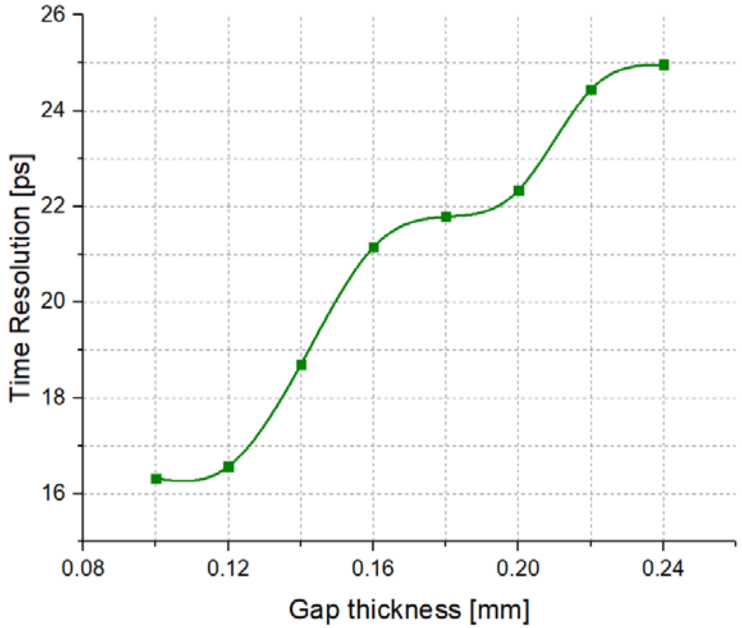
Total electronic channels: 37632

CEPC-ToF MRPC Simulation



Time resolution of MRPCs

with different structure parameters



Time resolution of MRPCs

with different gap thickness

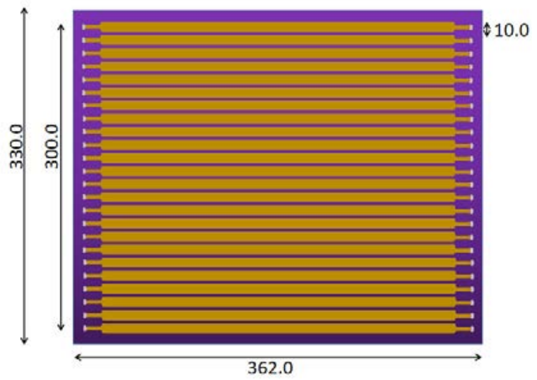
- 4 stacks; 6 gas gaps in each stack; gap thickness 0.14 mm fit the requirement.
- Time resolution of MRPC better than 20 ps in simulation.

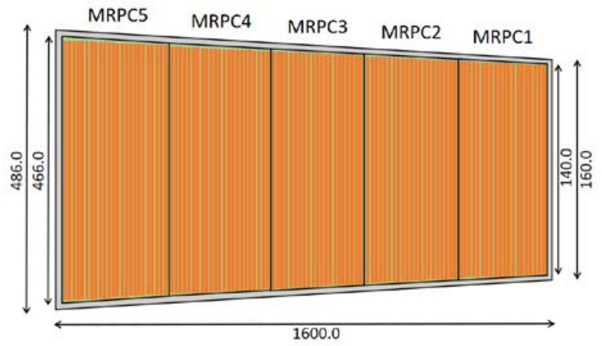
CEPC-ToF MRPC Parameters

- 4 stacks; 6 gas gaps in each stack; gap thickness 0.14 mm; detector thickness 3.02cm

Name of component	Dimensions (mm)	Quantity
Honeycomb	300×362×6	2
PCB	330×366×0.8	5
Mylar	300×362×0.25	8
Float glass	300×362×0.3	28
Gas gap	0.140	24
Readout strip	362×(10+2.5)	24

Name of component	Dimensions (mm)	Quantity
Honeycomb	324×(462~136)×6	2
PCB	354×(466~140)×0.8	5
Mylar	324×(462~136)×0.25	8
Float glass	324×(462~136)×0.3	28
Gas gap	0.140	24
Readout strip	(466~140)×(10+3.5)	24





Energy Loss

Material	Energy Loss $\Delta E/E_0$ (%)
2 plates of Honeycomb	0.09
5 PC boards	2.23
8 Mylars	0.72
28 MRPC glass plates	6.94
Total	9.98

For 1.5GeV electron, the material is ~$0.1X^0$

Paper Published

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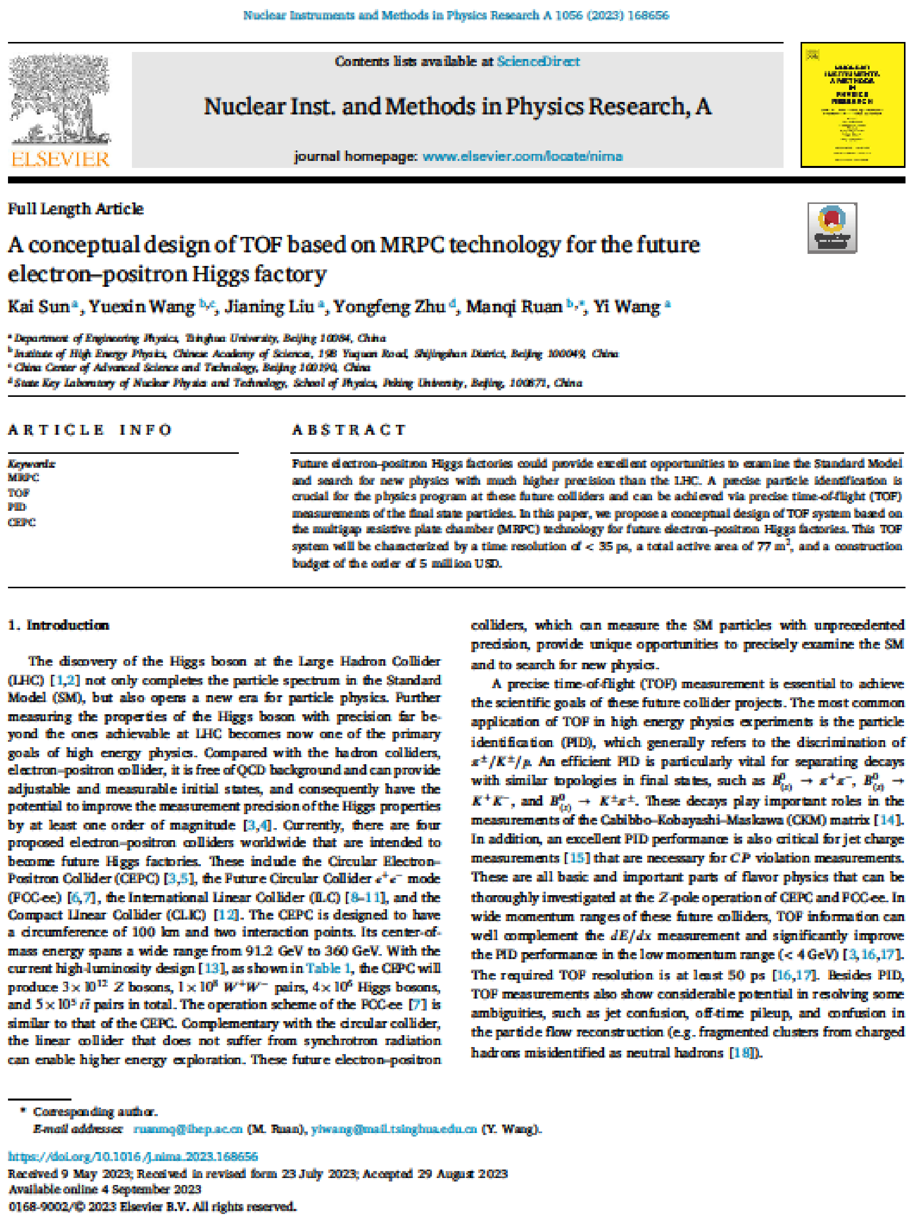
@Cooperated with Ruan Manqi Group form ihep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Full Length Article

A conceptual design of TOF based on MRPC technology for the future electron–positron Higgs factory

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ABSTRACT

Future electron–positron Higgs factories could provide excellent opportunities to examine the Standard Model and search for new physics with much higher precision than the LHC. A precise particle identification is crucial for the physics program at these future colliders and can be achieved via precise time-of-flight (TOF) measurements of the final state particles. In this paper, we propose a conceptual design of TOF system based on the multigap resistive plate chamber (MRPC) technology for future electron–positron Higgs factories. This TOF system will be characterized by a time resolution of < 35 ps, a total active area of 77 m^2, and a construction budget of the order of 5 million USD.

1. Introduction

The discovery of the Higgs boson at the Large Hadron Collider (LHC) [1,2] not only completes the particle spectrum in the Standard Model (SM), but also opens a new era for particle physics. Further measuring the properties of the Higgs boson with precision far beyond the ones achievable at LHC becomes now one of the primary goals of high energy physics. Compared with the hadron colliders, electron–positron collider, it is free of QCD background and can provide adjustable and measurable initial states, and consequently have the potential to improve the measurement precision of the Higgs properties by at least one order of magnitude [3,4]. Currently, there are four proposed electron–positron colliders worldwide that are intended to become future Higgs factories. These include the Circular Electron–Positron Collider (CEPC) [3,5], the Future Circular Collider e^+e^- mode (FCC-ee) [6,7], the International Linear Collider (ILC) [8–11], and the Compact Linear Collider (CLIC) [12]. The CEPC is designed to have a circumference of 100 km and two interaction points. Its center-of-mass energy spans a wide range from 91.2 GeV to 360 GeV. With the current high-luminosity design [13], as shown in Table 1, the CEPC will produce 3×10^{12} Z bosons, 1×10^8 W^+W^- pairs, 4×10^6 Higgs bosons, and 5×10^5 $t\bar{t}$ pairs in total. The operation scheme of the FCC-ee [7] is similar to that of the CEPC. Complementary with the circular collider, the linear collider that does not suffer from synchrotron radiation can enable higher energy exploration. These future electron–positron colliders, which can measure the SM particles with unprecedented precision, provide unique opportunities to precisely examine the SM and to search for new physics.

A precise time-of-flight (TOF) measurement is essential to achieve the scientific goals of these future collider projects. The most common application of TOF in high energy physics experiments is the particle identification (PID), which generally refers to the discrimination of $\pi^\pm/K^\pm/p$. An efficient PID is particularly vital for separating decays with similar topologies in final states, such as $B^0_{(s)} \to \pi^+\pi^-$, $B^0_{(s)} \to K^+K^-$, and $B^0_{(s)} \to K^\pm\pi^\pm$. These decays play important roles in the measurements of the Cabibbo–Kobayashi–Maskawa (CKM) matrix [14]. In addition, an excellent PID performance is also critical for jet charge measurements [15] that are necessary for CP violation measurements. These are all basic and important parts of flavor physics that can be thoroughly investigated at the Z-pole operation of CEPC and FCC-ee. In wide momentum ranges of these future colliders, TOF information can well complement the dE/dx measurement and significantly improve the PID performance in the low momentum range (< 4 GeV) [3,16,17]. The required TOF resolution is at least 50 ps [16,17]. Besides PID, TOF measurements also show considerable potential in resolving some ambiguities, such as jet confusion, off-time pileup, and confusion in the particle flow reconstruction (e.g. fragmented clusters from charged hadrons misidentified as neutral hadrons [18]).

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5. Summary

Summary

- **MRPC Detector is a good choice for ToF system in HEP experiments:**
  - ➢ High time resolution.
  - ➢ High efficiency.
- **New Progress on MRPC:**
  - ➢ Low resistive glass.
  - ➢ Sealed MRPC.
  - ➢ Pad spacer.
- **High time resolution MRPC:**
  - ➢ 4 stacks, 8 gas gaps, 128μm gap thickness
  - ➢ Total time resolution better than 20 ps
- **CEPC-ToF overall structure:**
  - ➢ Barrel region.
  - ➢ Endcap region.
  - ➢ MRPC parameters.

Thank you!

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