MRPC R&D towards high rate, high time precision and working more environment friendly

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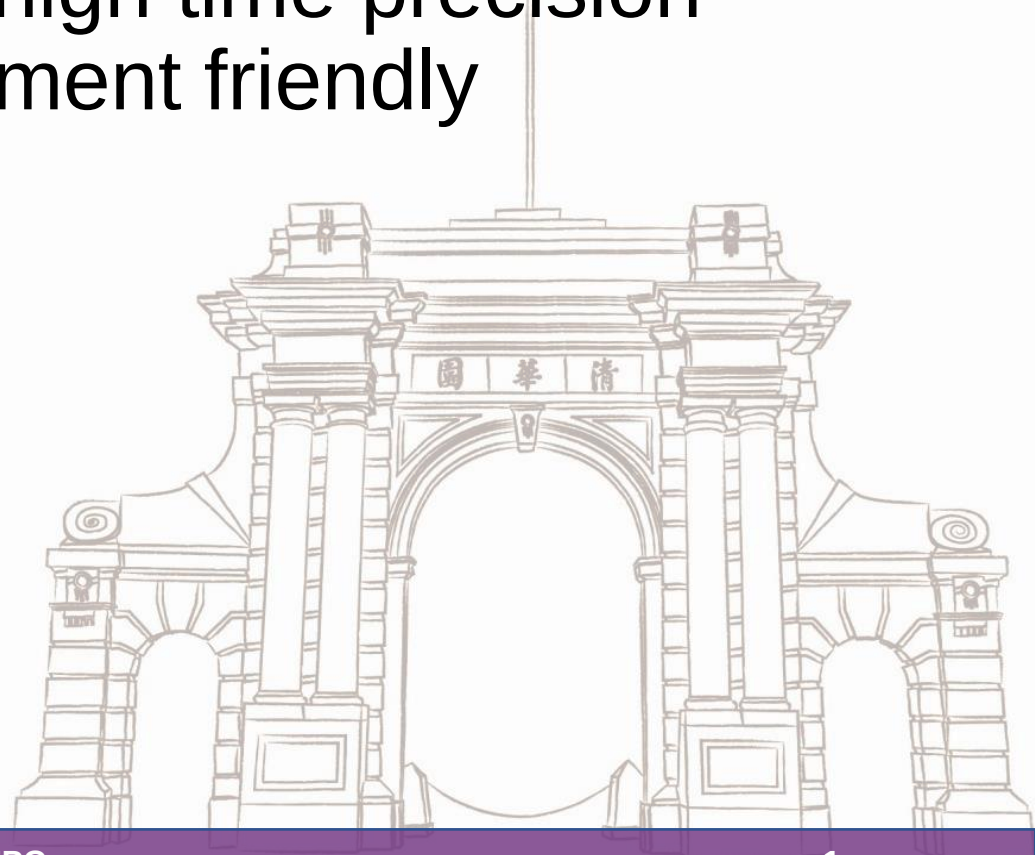
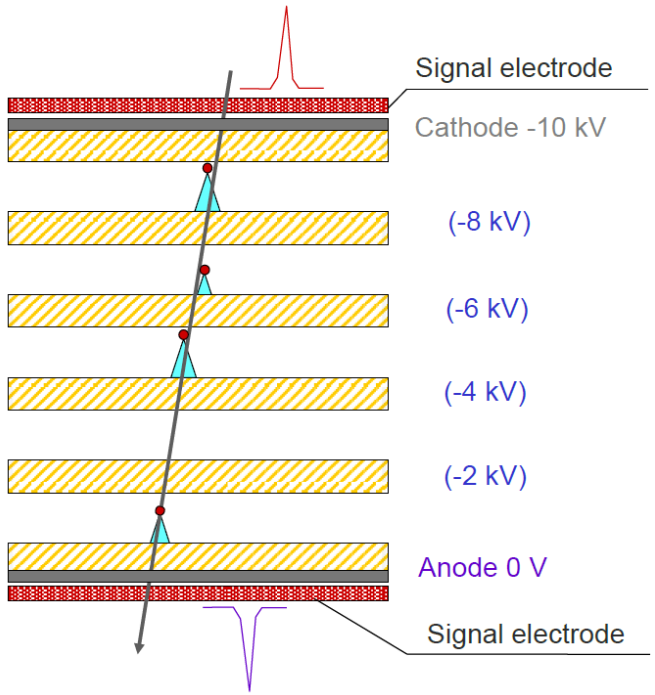


Outline

- Multigap Resistive Plate Chamber (MRPC)
- MRPC at the R&D frontier: rate and time resolution
  - Application: prototype with time precision <20 ps
- The gas related challenges and solutions
  - Application: sealed MRPC for CEE-eTOF
- Summary

Multigap Resistive Plate Chamber

First proposed by E. C. Zeballos



The multigap structure brings:

- Narrow gap thus high time precision
- Necessary gap thickness for good efficiency

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

					In construction	Proposed
	ALICE	STAR	FOPI	BESIII	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	33 x 27.6	--
Total active area (m^2)	141	50	5	1.33	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	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	10 x 0.25	10 x 0.25
Gas mixtures ($C_2H_2F_4$/ C_4H_{10}/SF_6)	90/5/5	95/5/0	85/5/10	90/5/5	90/5/5	90/5/5
Operating field (kV/cm)	96	107	110	109	110	106
Efficiency	99.9%	95-97%	97±3%	99%	97%	98%
Time resolution(ps)	40	60	73±5	60	60	**20 ps**
Max rate (Hz/cm^2)	50	10	50	50	**30k**	**10k**

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

Expanding the MRPC rate capability

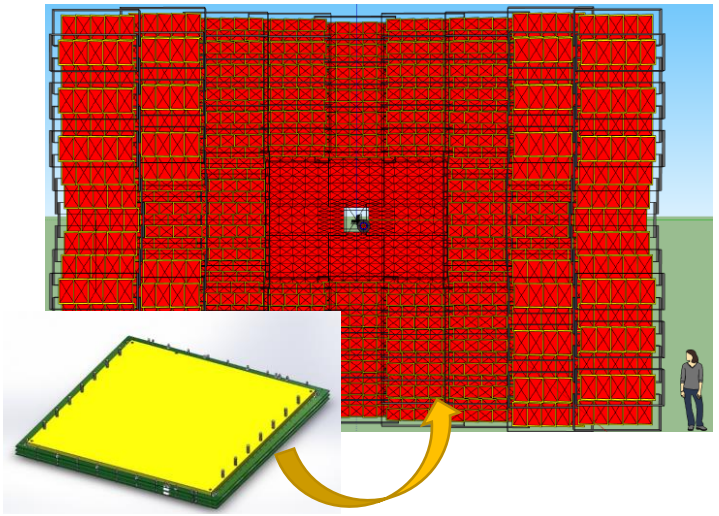
- One must control the voltage drop (efficiency loss) when incident flux goes up.

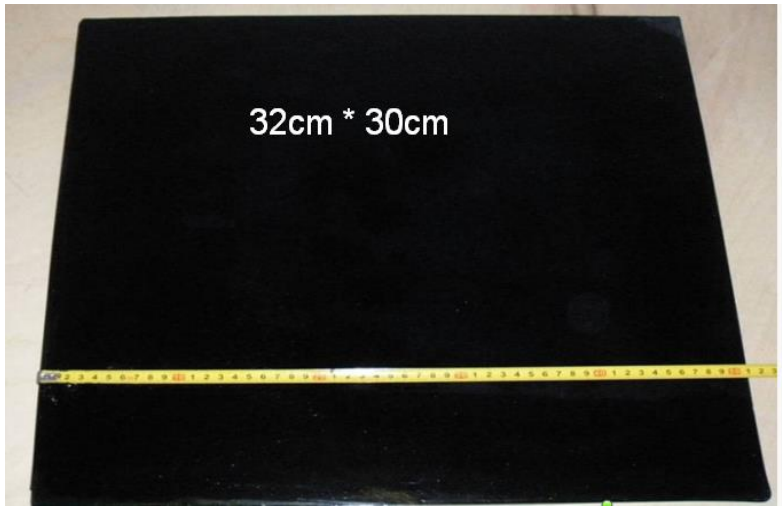
$$V_{gap} = V_{ap} - \bar{V}_{drop}$$

$$\bar{V}_{drop} = \bar{I}R = \bar{q}\Phi\rho d$$

Decrease the resistivity of the electrodes

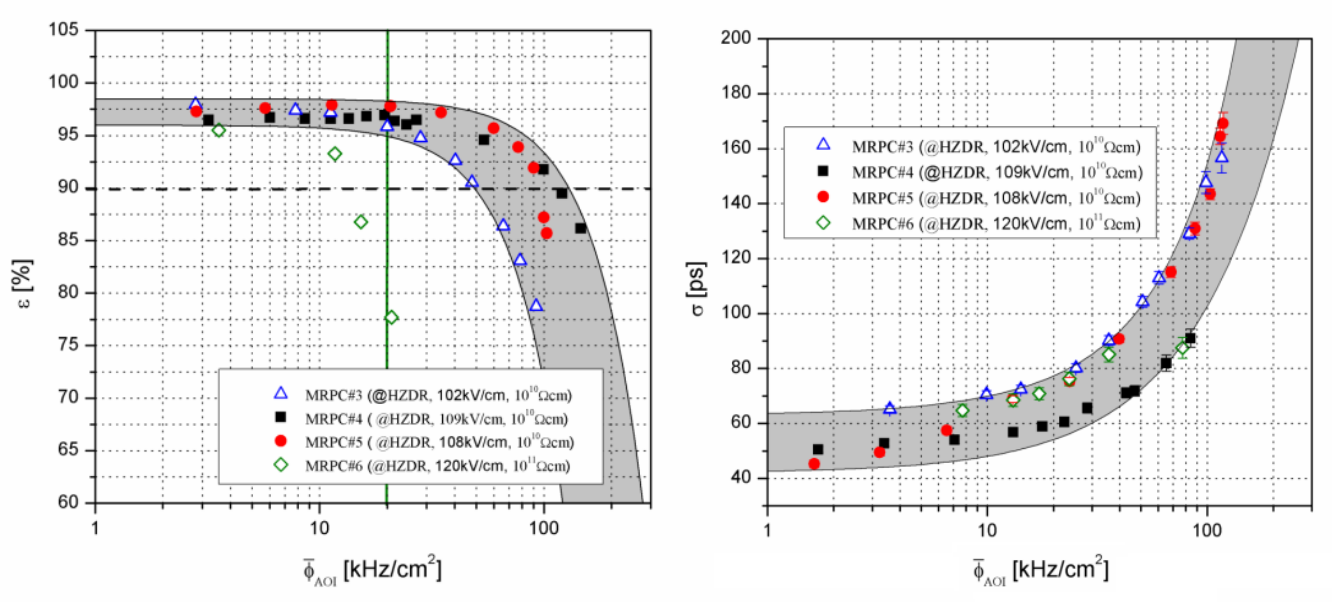
- MRPC2 with low-resistive glass will be applied in CBM-TOF wall, and has been operating at FAIR-Phase 0 programs like STAR-eTOF and mCBM





With the low-resistive glass developed in Tsinghua, resistivity has decreased by 2 orders of magnitude. (common float glass: 10^{12} Ωcm, low-resistive: 10^{10} Ωcm)

Rate capability verified through beam test: 93%, 80ps@70kHz/cm^2

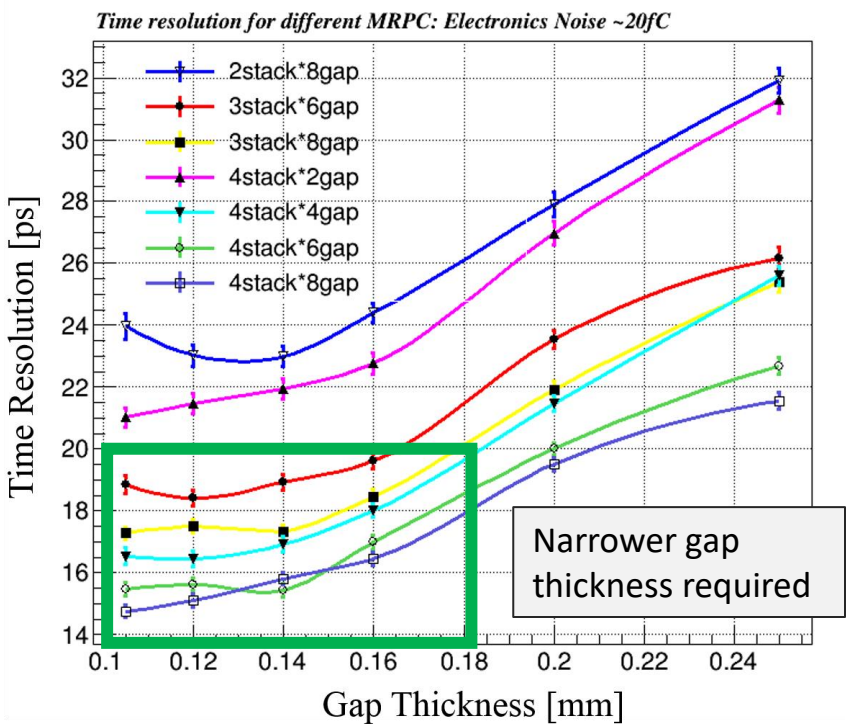


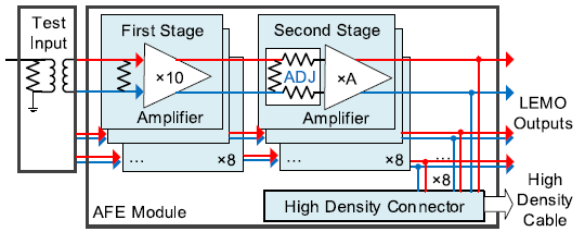
Towards a time precision < 20 ps

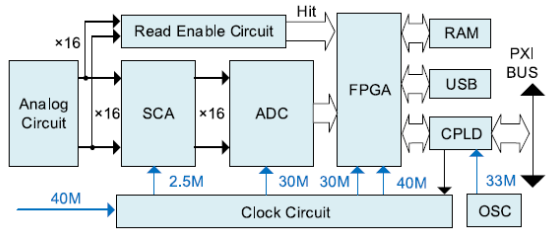
Time over Threshold (ToT) method
– Leading and trailing time

Waveform sampling technology

- G4 simulation indicates proper ways to design the gap thickness and arrange the stacks



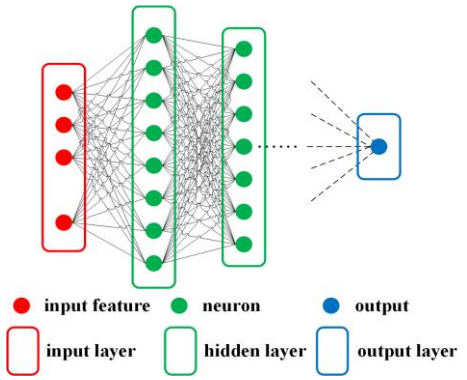




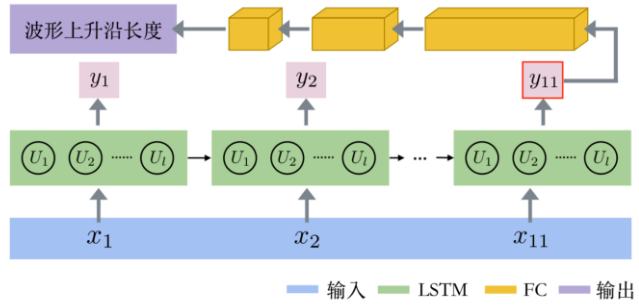
Nucl. Instrum. Meth. A 925 (2019) 53.

σ_t Fast-End Electronics: Bandwidth: 1.4 GHz, Gain: 26-40 dB, Noise (NSD): < 1.5 nV/√Hz $\oplus$ σ_t Waveform Digitization: Sampling freq.: 5 GS/s, Noise ampl.: 0.5 mV $<$ 5 ps

- Waveform provides detailed information of avalanche that allows more calibration methods.



An MLP neuron network for position calibration



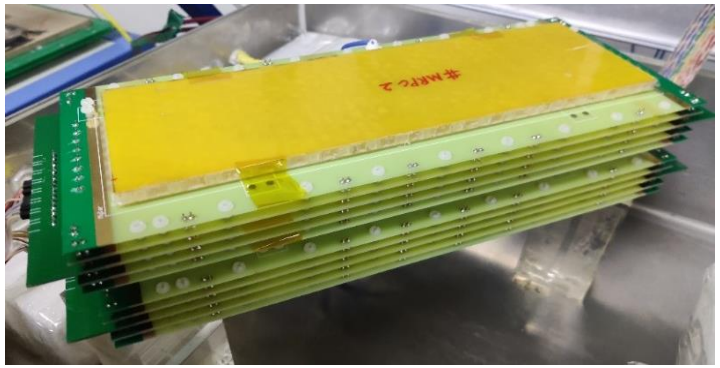
An LSTM model for signal leading edge recognition and time calibration

Besides the 'intrinsic' time resolution of the detector, it is also crucial to develop an **advanced readout technique.**

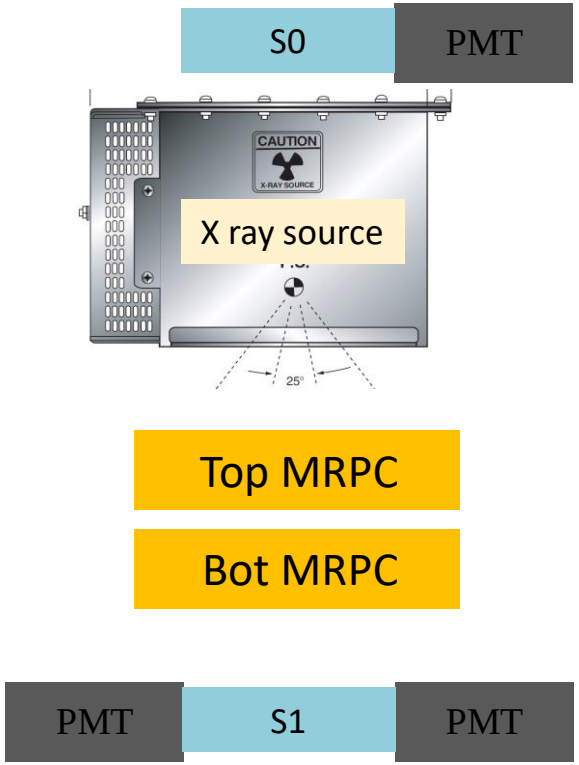
The high-rate high-resolution prototype

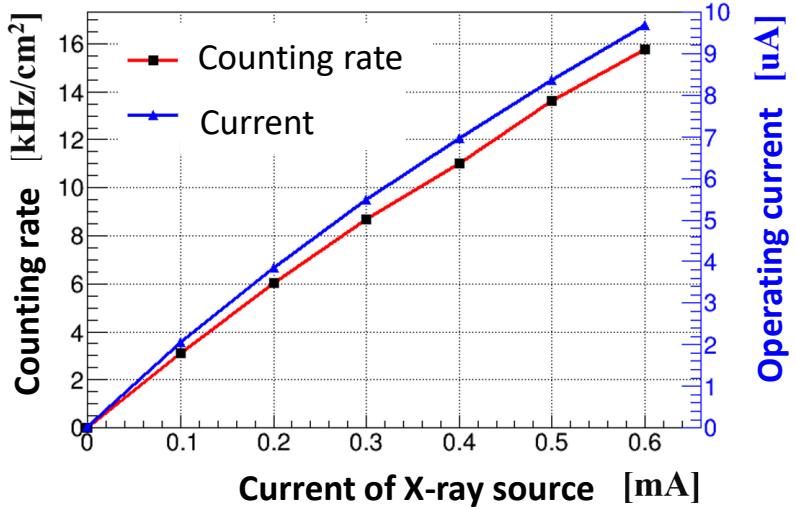
- Two prototypes has been assembled and tested.

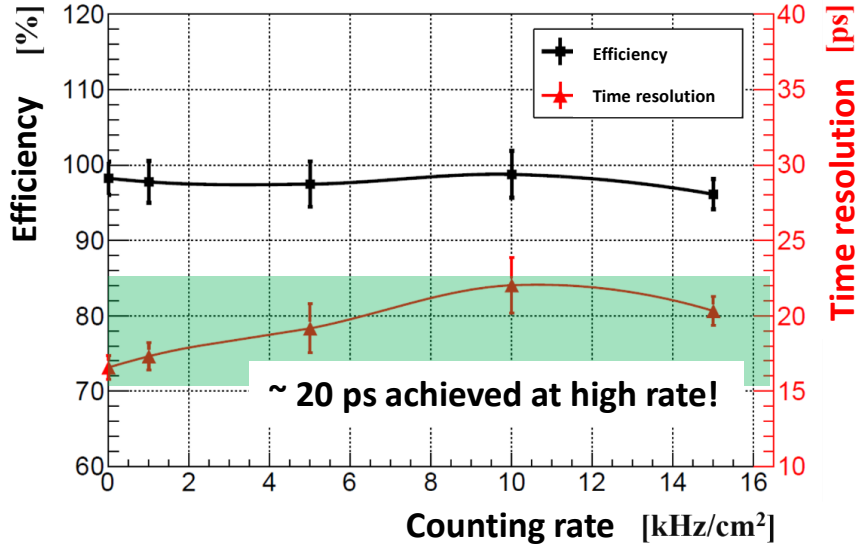
Parameter	Value
Gap thickness (mm)	**0.128**
N of gaps	4 x 8
glass	**Low-resistive**
Glass thickness(mm)	0.4
Strip interval (cm)	**0.5 width + 0.2 gap**



- The high rate test is carried out by discriminating cosmic event in X-ray irradiation.

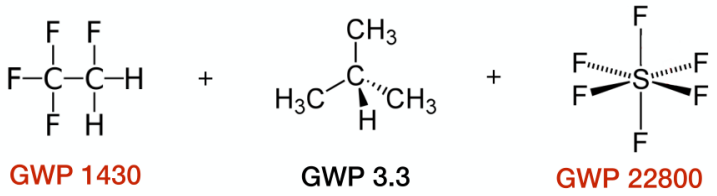




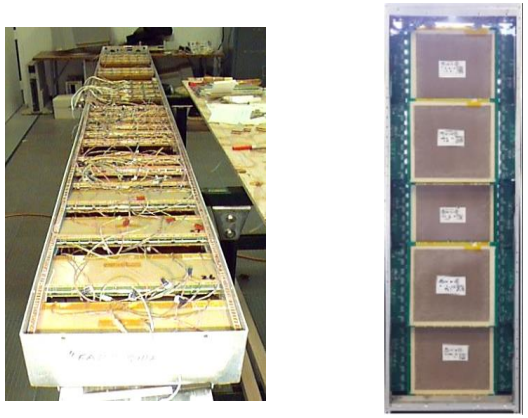


Gas-related challenges of MRPC

- Regulations against greenhouse gases causes uncertainty:
  availability, cost, eco-impact, …

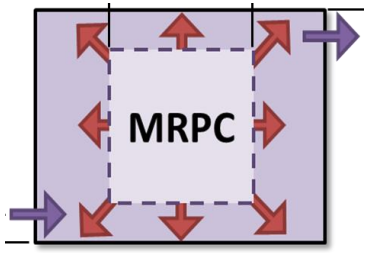


- Application with large area:
  gas flow, cost, leakage, …



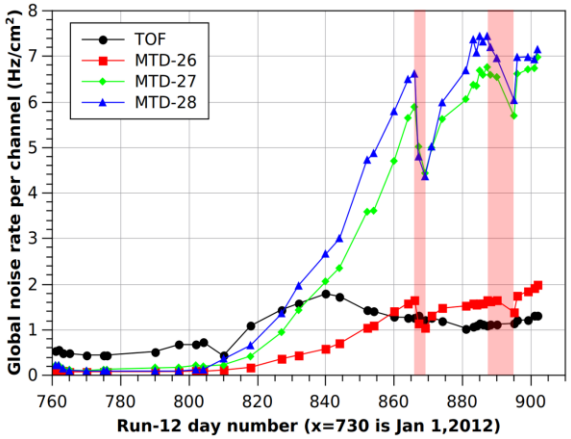
STAR-TOF (left) and CBM-TOF (right) detectors in gas boxes forming a module

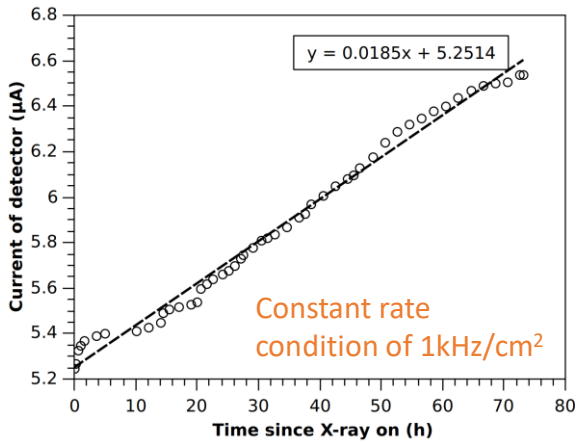
- Gas pollution effect in high rate conditions



Narrow gap of MRPC and large gas volume ---
ionization products exchanged slowly by **diffusion**

…observed in HEP experiments and lab tests.

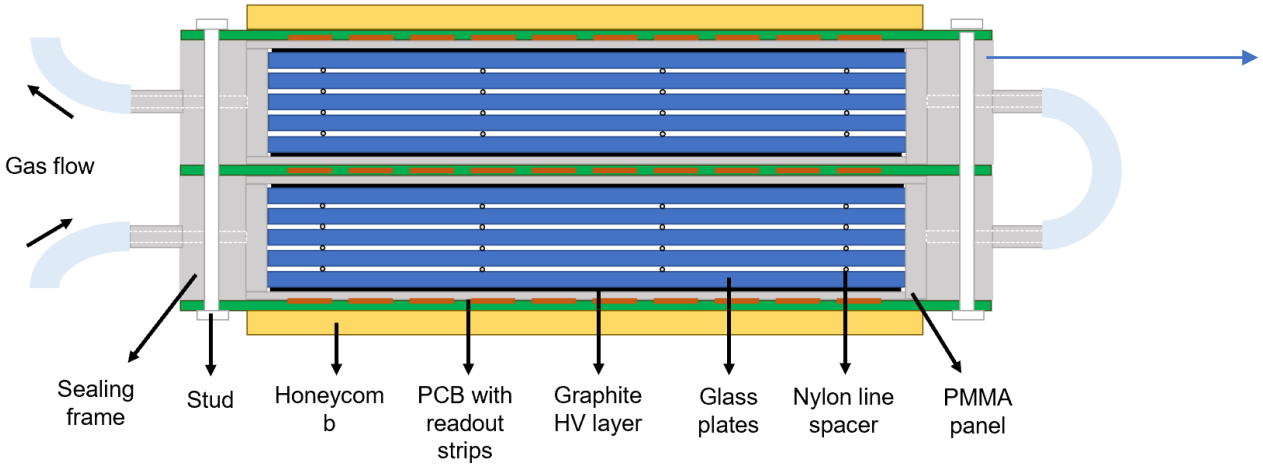


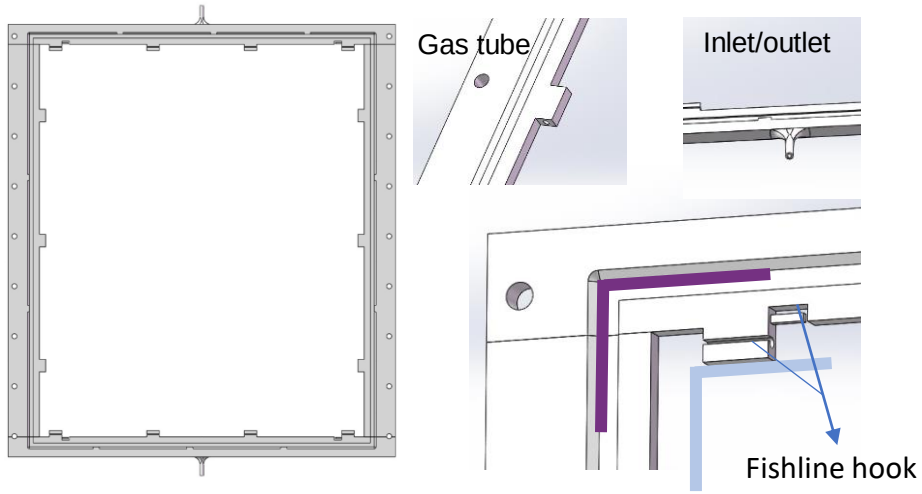


Pollution caused noise and current rise

Motivation: A wise design of the gas volume shall promote the gas exchange and decrease the gas consume.

Sealed MRPC



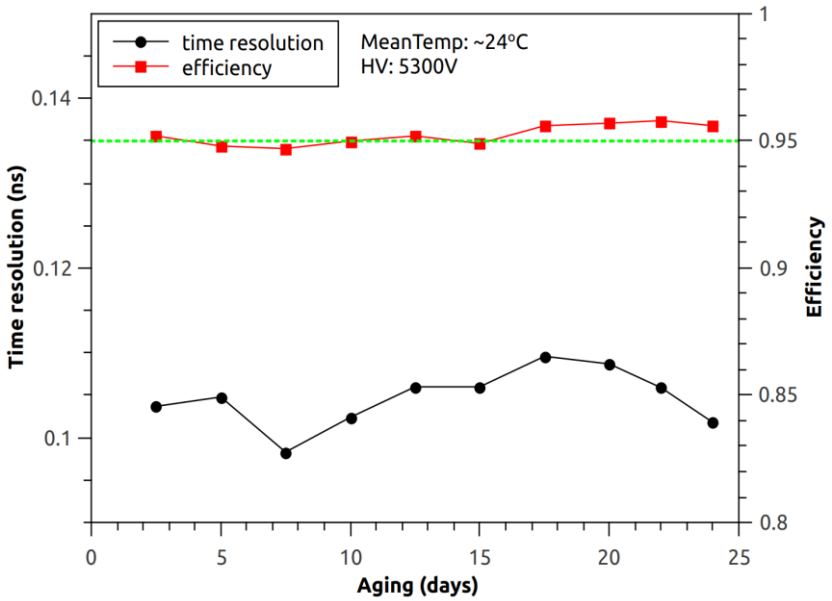


3D printed sealing frame with Good strength, insulation and radiation persistency

- With the lateral side mostly enclosed, the counter itself becomes a gas box. The sealed design brings the features of:

1. **Gas saving**: 20 sccm/m^2 gas flow with common practice

With cosmic ray test of a counter, 1 mL/min flow is examined with stable operation for the tested 24 days!



Sealed MRPC

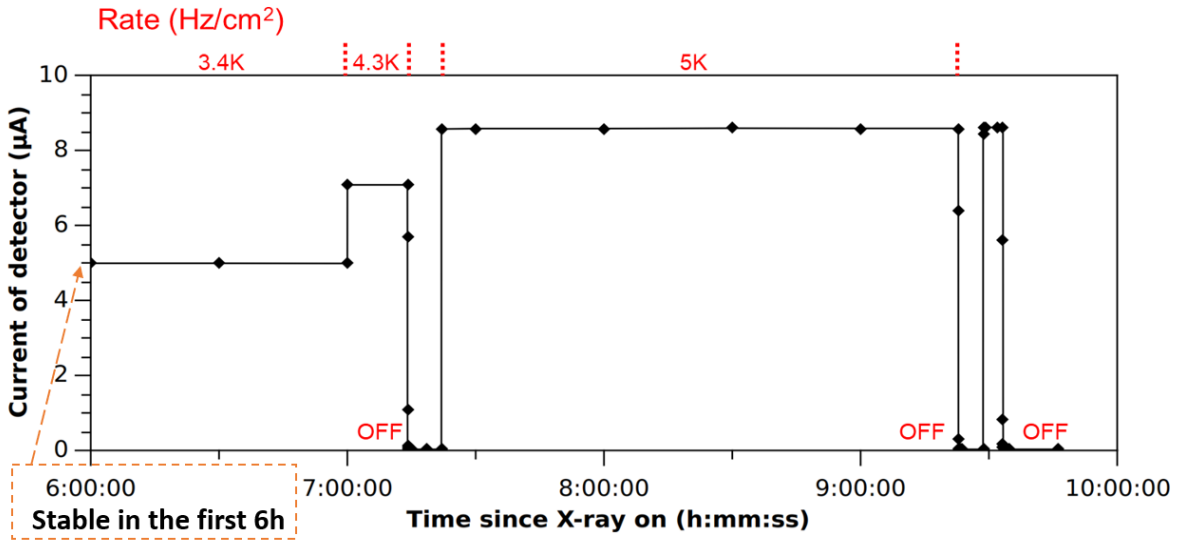
2. **Promoted gas exchange**

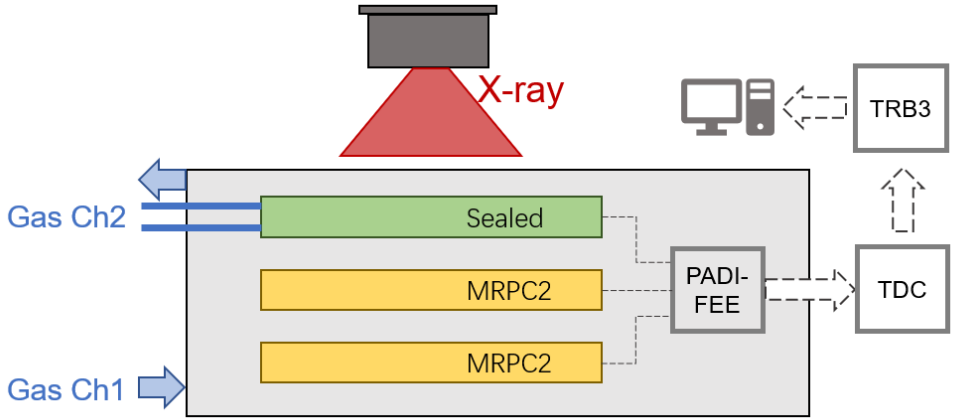
Decrease the wait time of gas purging:

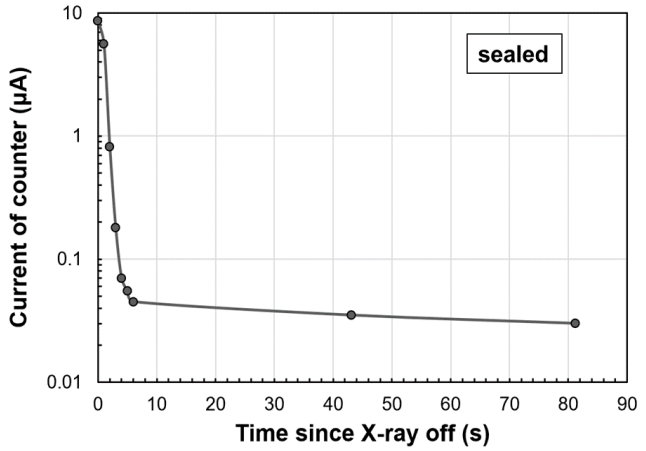
- Reach the working HV in 2h since flowing the gas

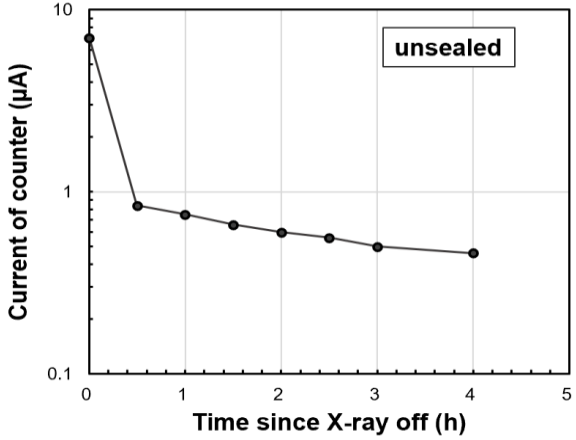
Excellent current behavior under high rate irradiation:

- Stable current with constant rate condition.
- Fast decay of dark current since when X-ray is off





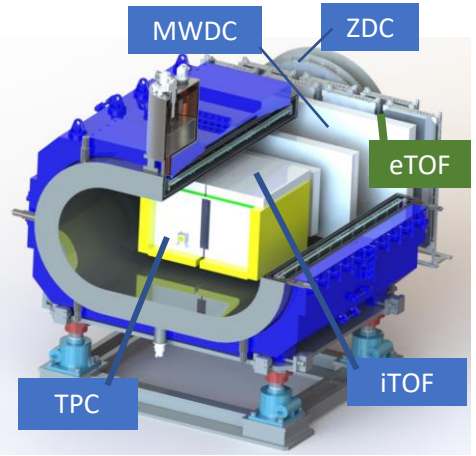


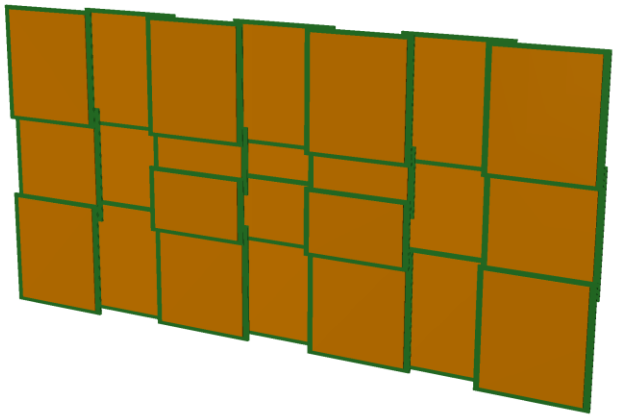


Sealed MRPC for CEE-eTOF

☐ CSR External-target Experiment at IMP, Lanzhou.

In construction for full operation by 2024.

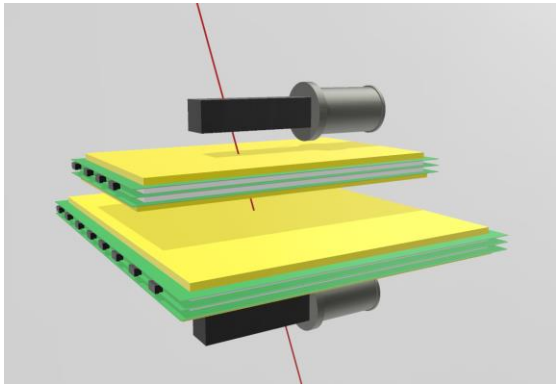




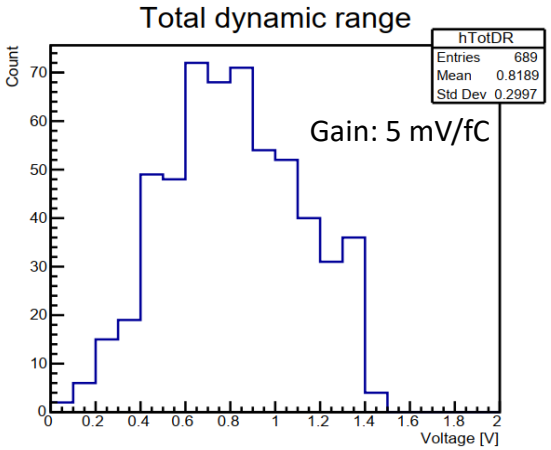
eTOF subsystem consists of 24 sealed MRPCs

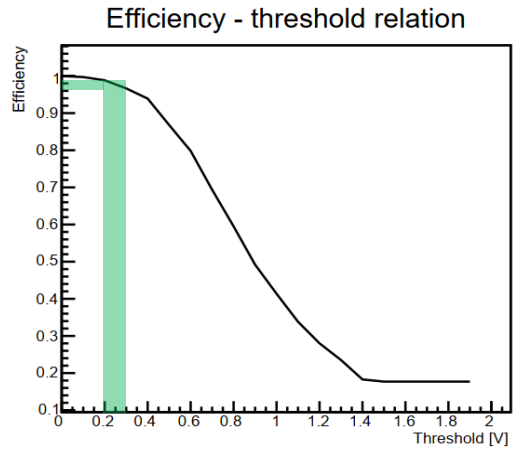
N of strips	32	16
N of gaps	2× 5	
Gap thickness(mm)	0.25	
N of counters	18	6
Active area(mm^2)	480×560	480×280
Strip interval(cm)	1.5+0.2	1.5+0.2
Strip length(cm)	48	

☐ Cosmic test stand has been set up for the prototypes.

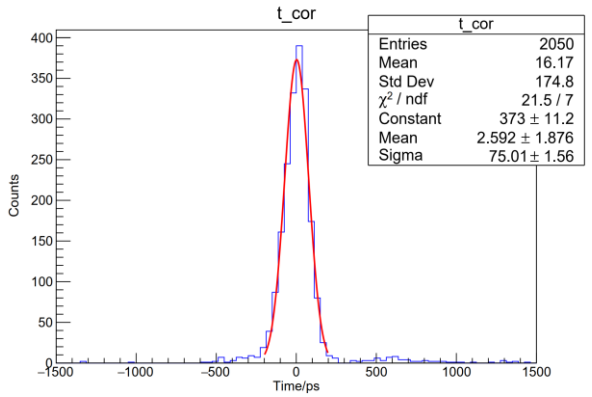


At the working point of 6900V, with a proper 250 mV threshold the **efficiency can reach >97%**

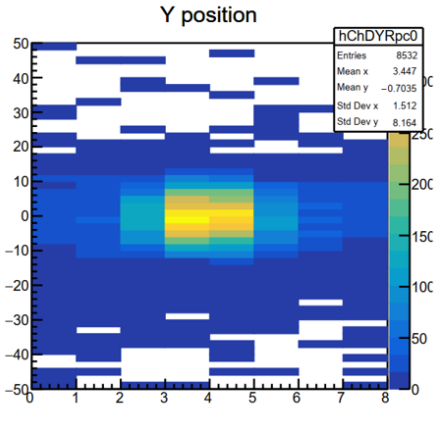




After correction the time resolution reaches 75/√2=**53 ps** for single counter

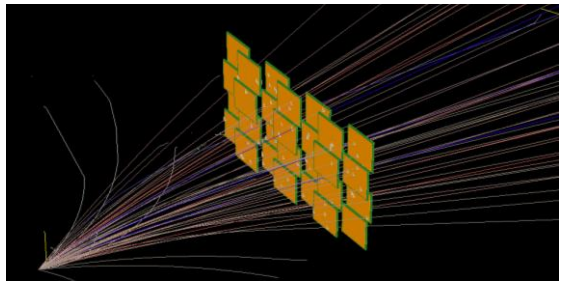


Reconstructed position obtained.

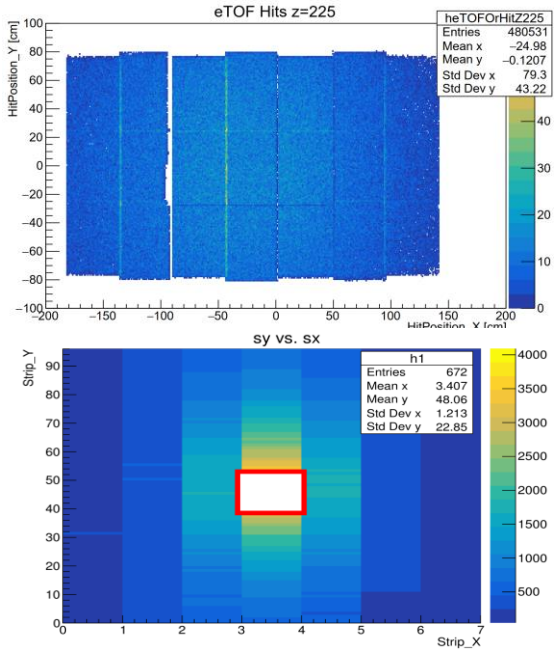


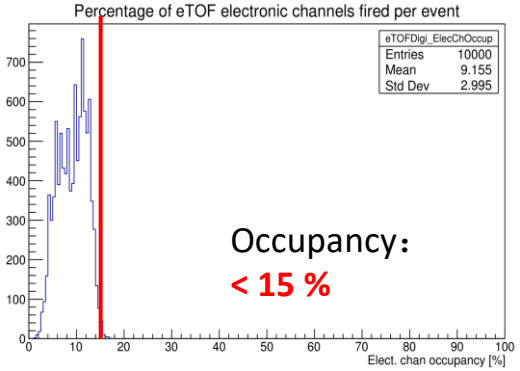
Status of CEE-eTOF

Simulation and analysis of the subsystem were carried out with CeeRoot – a FairRoot based framework.

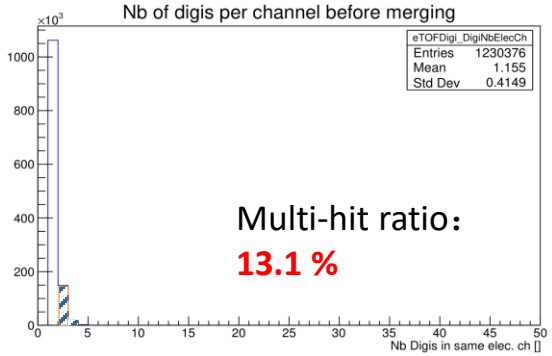


Current design validated.

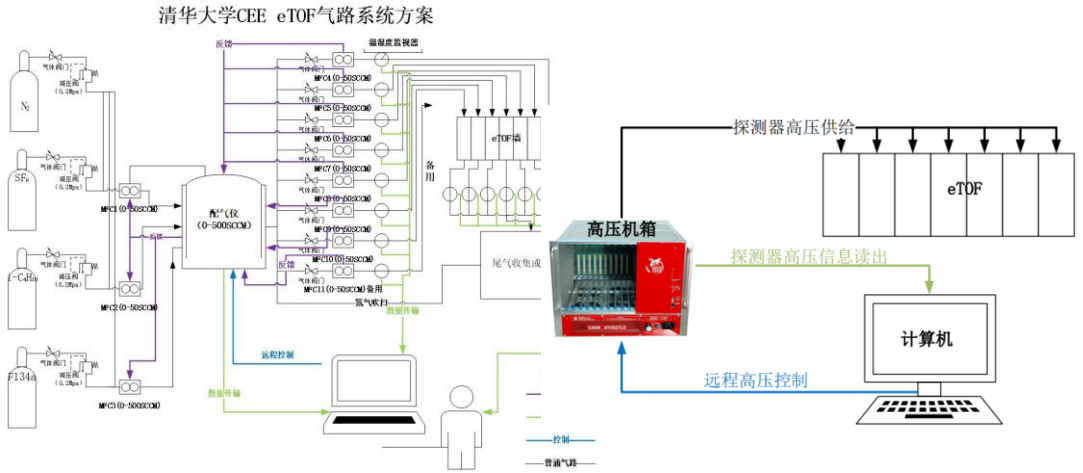




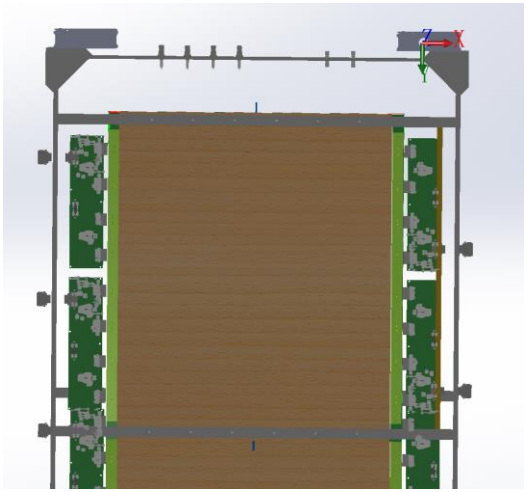
Occupancy：
< 15 %



Multi-hit ratio：
13.1 %



Gas and HV power systems



Installation design and modular stability test

20 mL/min flow for 1 m^2 MRPC realized in practice.

Summary

- Future HEP experiments calls for MRPCs with high rate capability and excellent time resolution.
- Low-resistive electrodes help expand the rate capability.
- Narrow gap width and advanced readout chain help improve the timing performance.
- Prototype has been examined its 96% efficiency and 20 ps resolution at 20 kHz/cm^2 rate condition.
- MRPC faces gas related challenges which motivates an enhanced gas exchange.
- Sealed MRPC with low gas volume has been validated and will be applied to construct CEE eTOF.

Thank you !