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A very thin MRPC developed for TOF-PET

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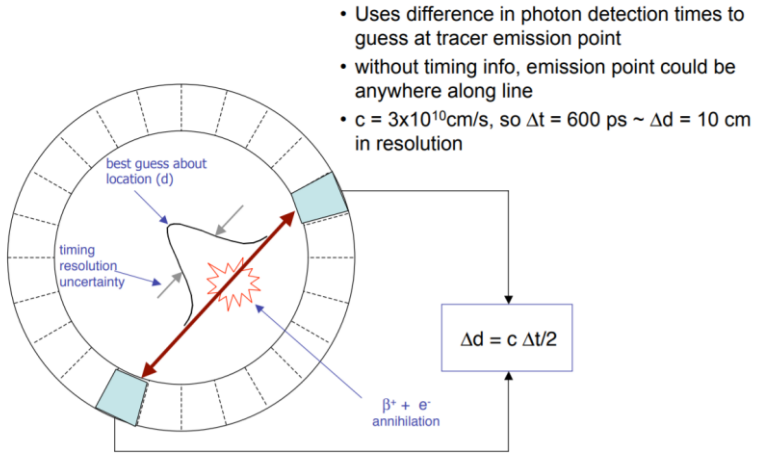
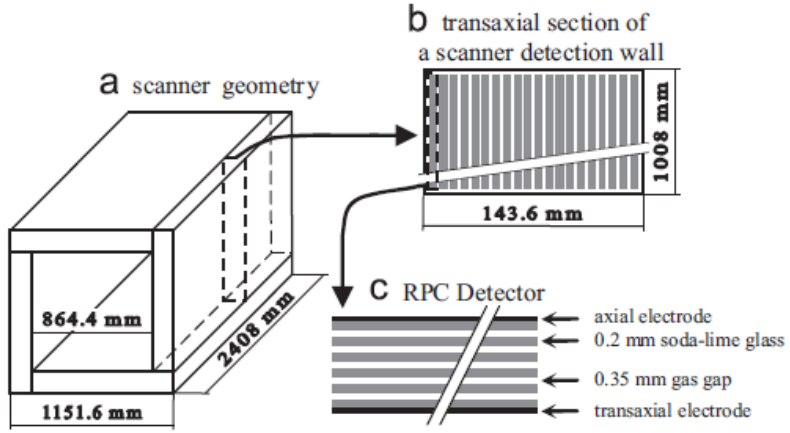
2023-9-27

Research background





[M. Couceiro et al. Portugal 2012]

■ Traditional TOF-PET

Scintillator detector + PMT

- ➢ Time resolution is not high > 50ps
- ➢ Thickness of the scintillator > 3cm
- ➢ Low reception, information is wasted
- ➞ Long detection time, poor accuracy

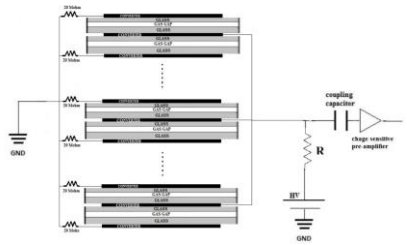
■ MRPC TOF-PET

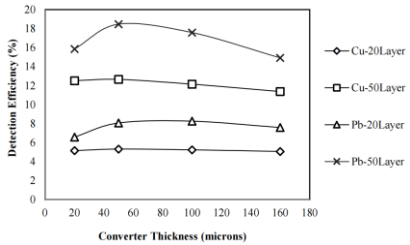
Advantages

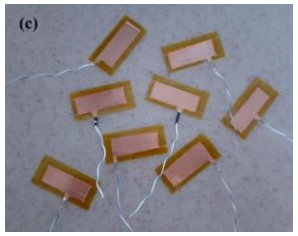
- ➢ Excellent time resolution < 20ps
- ➢ Ultrathin sensitive zone ~ 100μm
- ➢ Large area → whole body PET
- ➞ Make up for the low efficiency for γ

Others' work

- **20 gas gaps double-stack MRPC with Multi-layer Copper Converters**







[S. Razaghi et al. 2021]

- **Monte Carlo simulation study of RPC-based 0.511MeV photon detector**

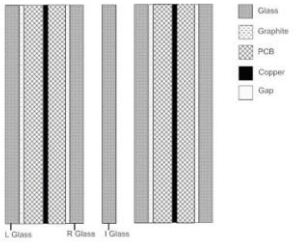
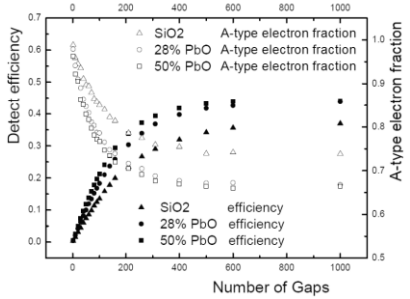
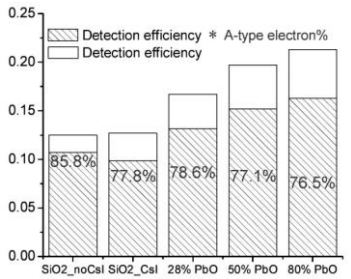


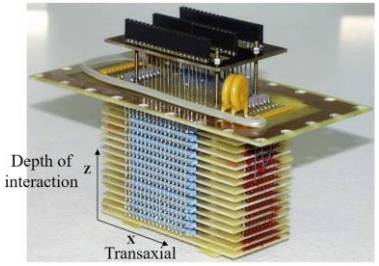
Figure 1. Detector structure of the RPC-based PET unit.

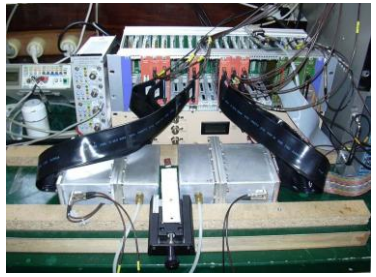


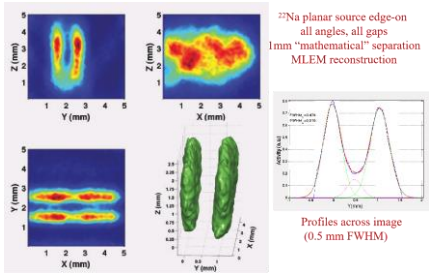


[W. Zhou et al. 2014]

- **RPC-PET for small animals**







[Paulo Martins et al. 2014]

Improve the detection efficiency by increasing the number of converters and gas gaps

➞ low time resolution, poor positioning accuracy, high cost for too many electronic channels

Our research route

Tsinghua University

★ **Develop a 4-stack 32-gap MRPC prototype with 128 μm gas gap**

☑ Time resolution for cosmic rays < 20 ps ; for gamma < 58 ps

★ **Make a thin 8-gap MRPC prototype with 128 μm gas gap**

☑ Sensitive area thickness < 5 mm

☑ Time resolution for cosmic rays < 39 ps ; for gamma < 50 ps

★ **Build a TOF PET system**

Place three 8-gap MRPCs on each side of ^{22}Na for positioning

The electronics of each MRPC are read out separately

☐ Positioning accuracy < 3 mm

★ **Create a high efficiency, high time resolution RPC prototype**

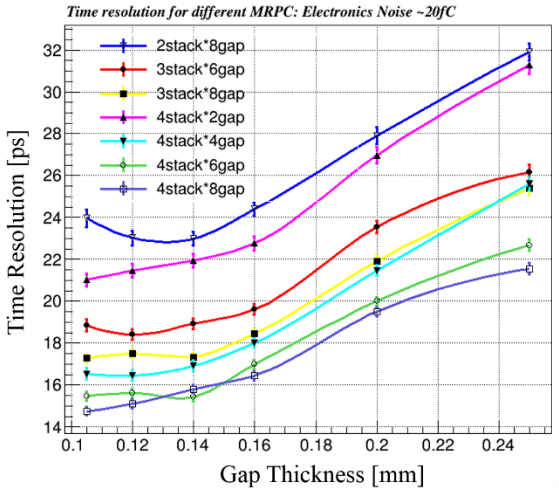
☑ Sensitive area thickness < 3 mm

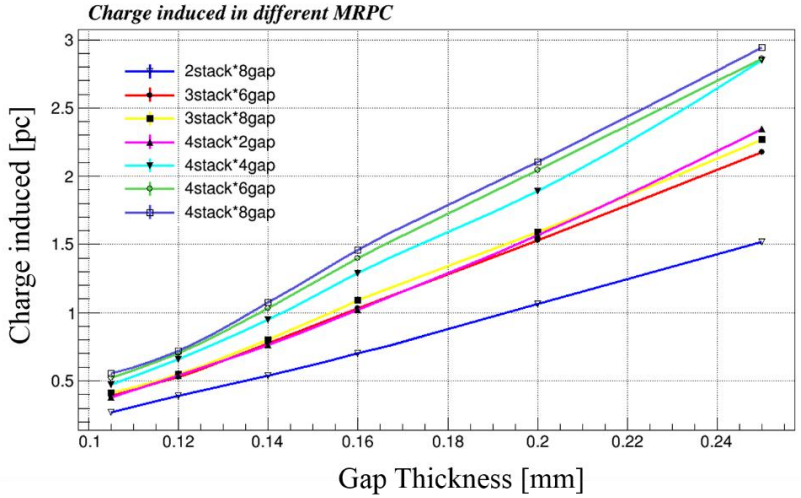
☐ Time resolution < 20 ps

☐ Detection efficiency > 7%

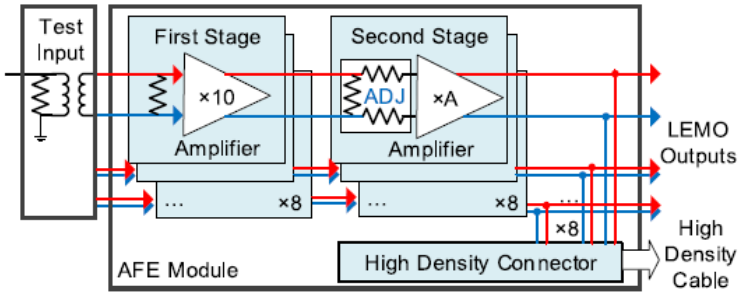
☐ Energy resolution < 20%

Our studies

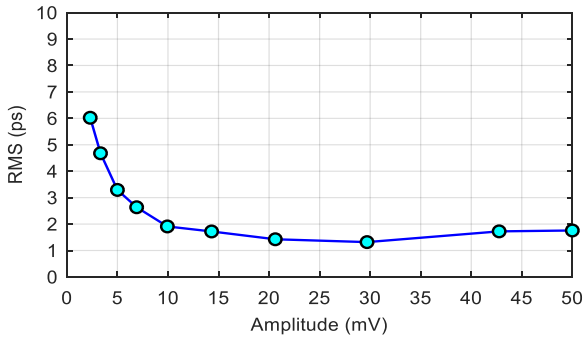




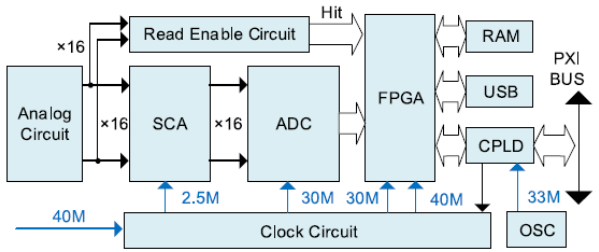
- Gas thickness < 160 μm， numbers of chamber > 3, numbers of gas gap in each chamber > 4 ➞ 20 ps
- The thinner the gas gap thickness or the more the number of gas gaps, can't significantly improve the time precision.
- Optimize MRPC ~ Gas thickness 104 μm ➞ 128 μm



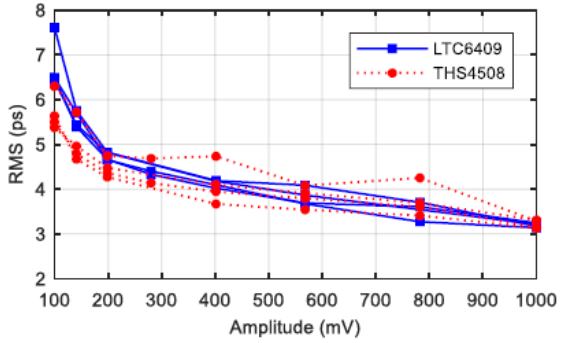
Front-end electronics module



- Gain is 26 dB ~ 40 dB
- Bandwidth is 1.4 GHz
- Time jitter < 4 ps



Waveform digitization module



- Switched Capacitor Array ~1024 sampling capacitors
- Maximum sampling frequency ~ 5.12 GHz
- noise ~ 0.5 mV
- Time jitter < 8 ps

4-stack 32-gap MRPC cosmic ray test

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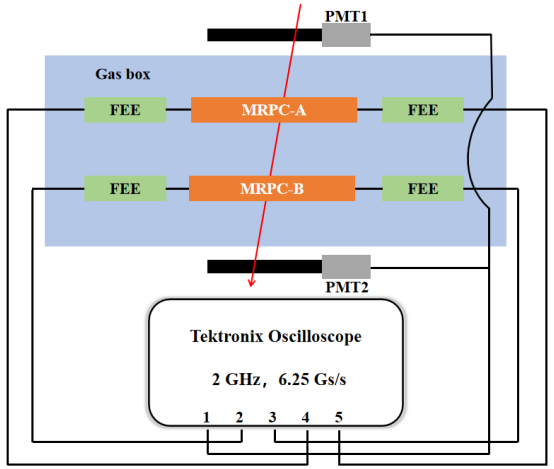
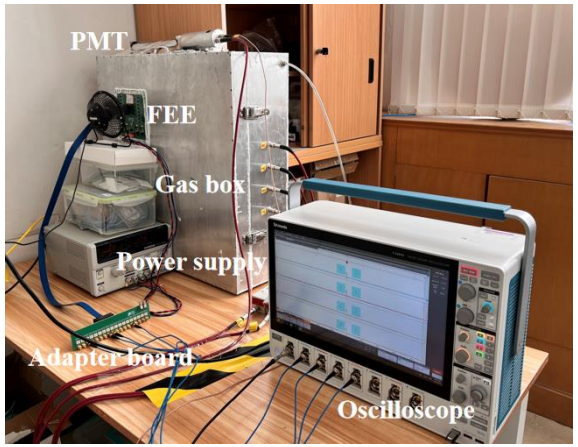
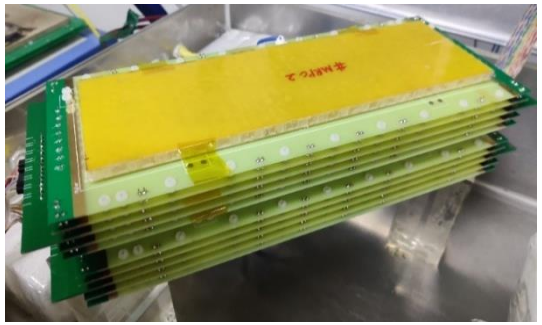
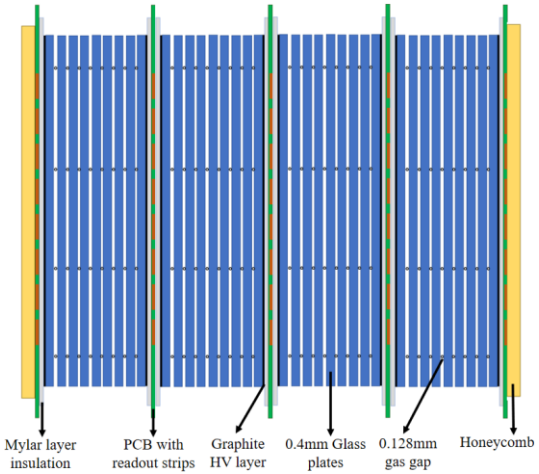
MRPC prototype + Fast amplifier + Waveform digitization module

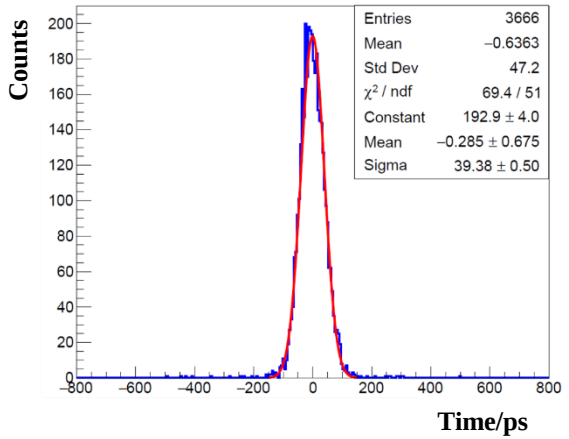




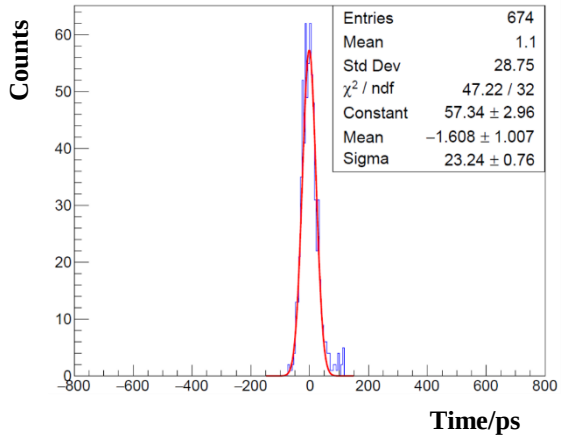




	MRPC prototype
gas gap thickness	128 μm
number of gas gaps	4 chambers × 8 gaps
glass material	**low resistivity glass**
glass thickness	400
readout strips	5 mm in width (2 mm clearance)

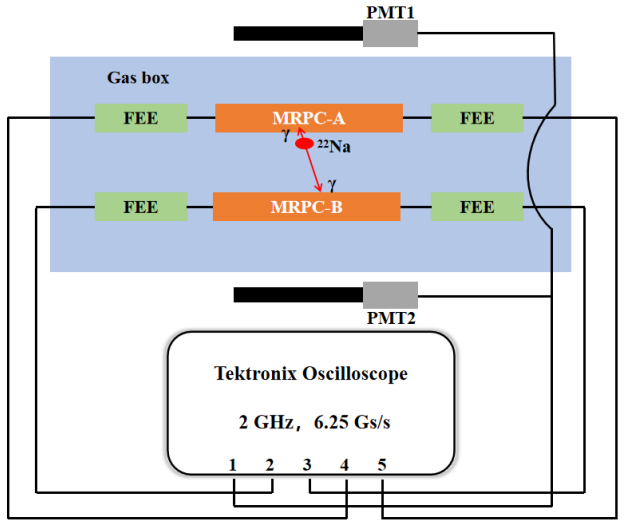


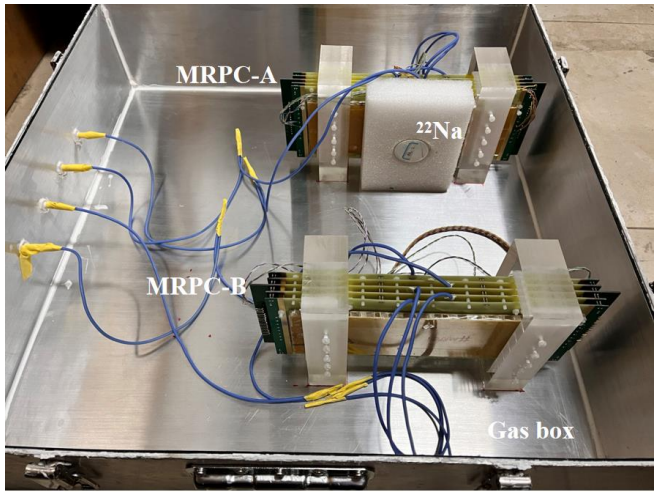
Time resolution ~ 27 ps

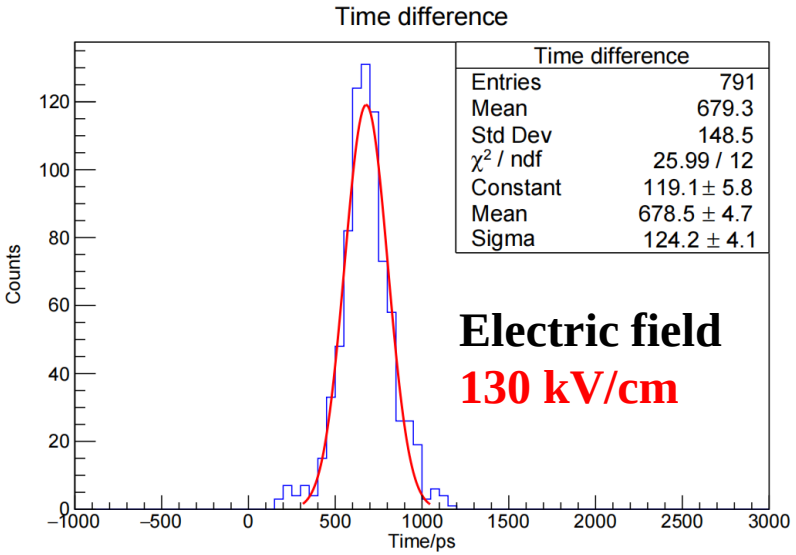


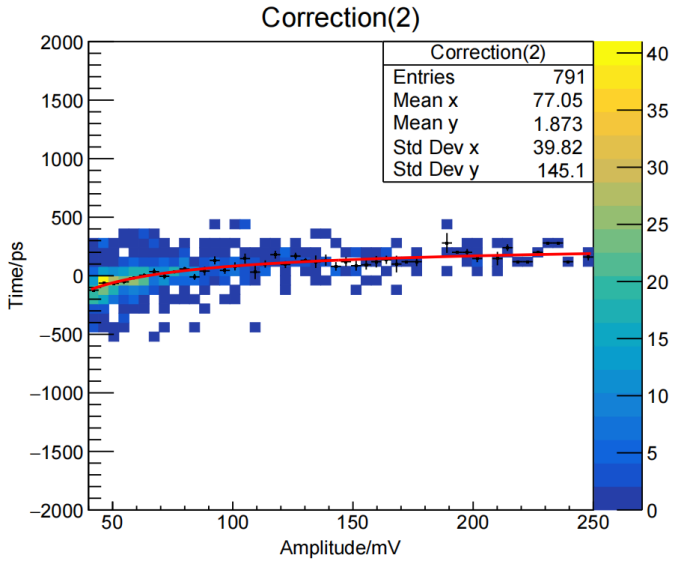
Time resolution after vertical case selection ~ 16.44 ps

4-stack 32-gap MRPC gamma test

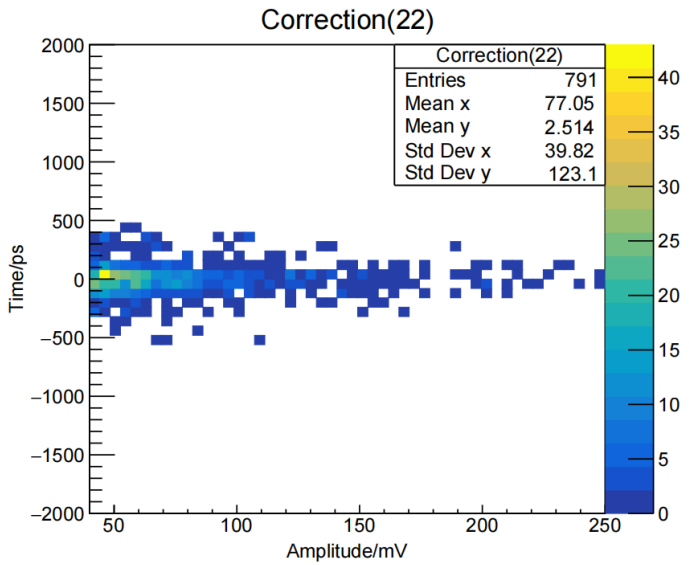




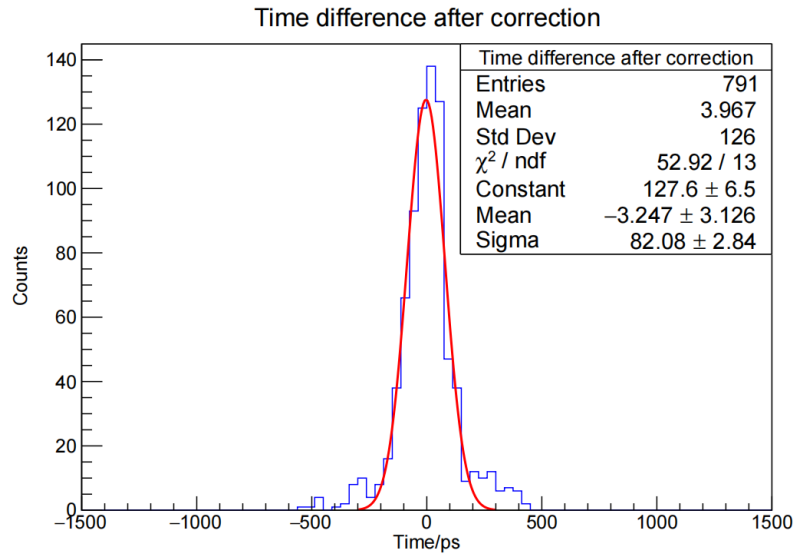




Before time-slewing correction



After time-slewing correction



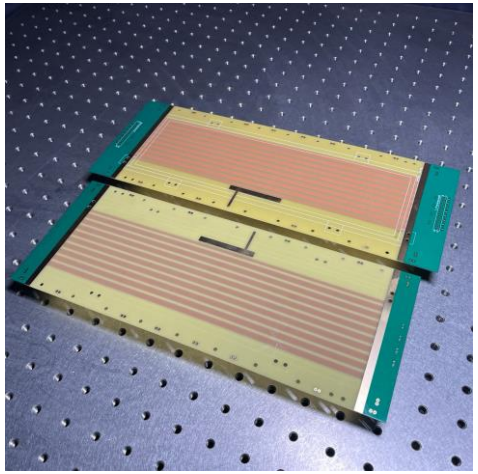
Time resolution ~ 58 ps

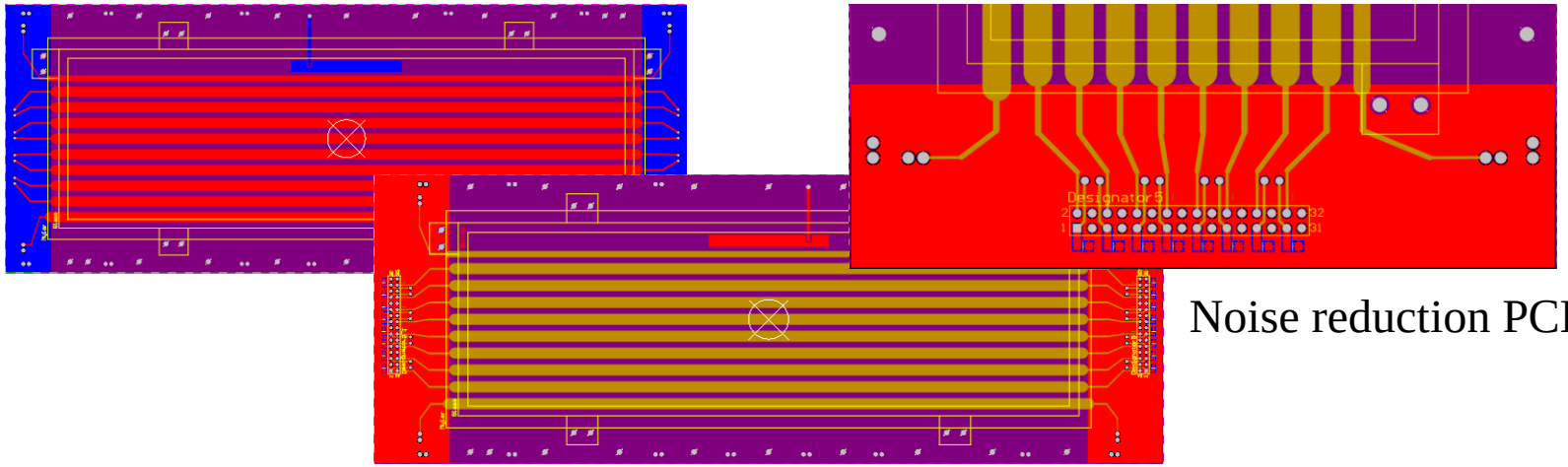
Research of ultra-thin MRPC prototype

Tsinghua University

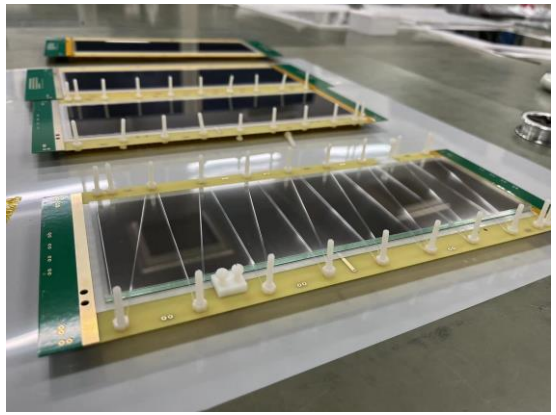
Effect of thickness of MRPC on time resolution

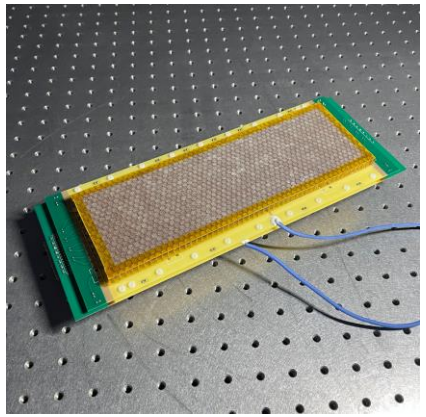
$$\Delta L = t_A + \frac{x_A}{c} - \left(t_B + \frac{x_B}{c}\right) = \Delta t + \frac{x_A}{c} - \frac{x_B}{c} \qquad \sigma_{\Delta L}^2 = \sigma_{\Delta t}^2 + (\frac{1}{c})^2 \sigma_x^2 * 2, \sigma_x = \frac{\text{Thickness of MRPC}}{\sqrt{12}}$$

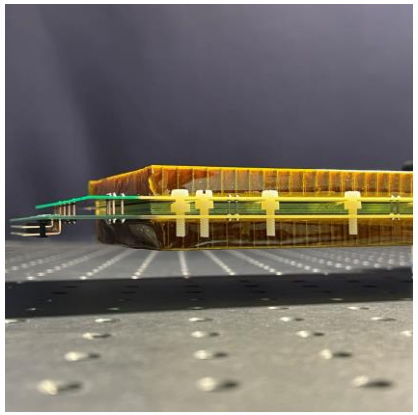




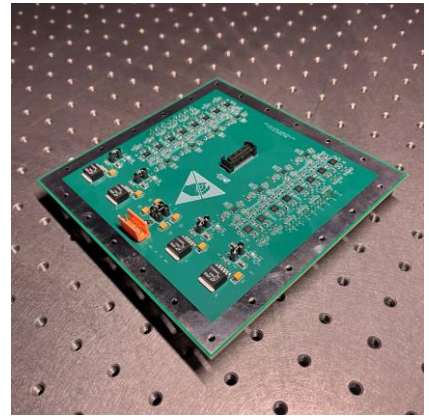
Noise reduction PCB





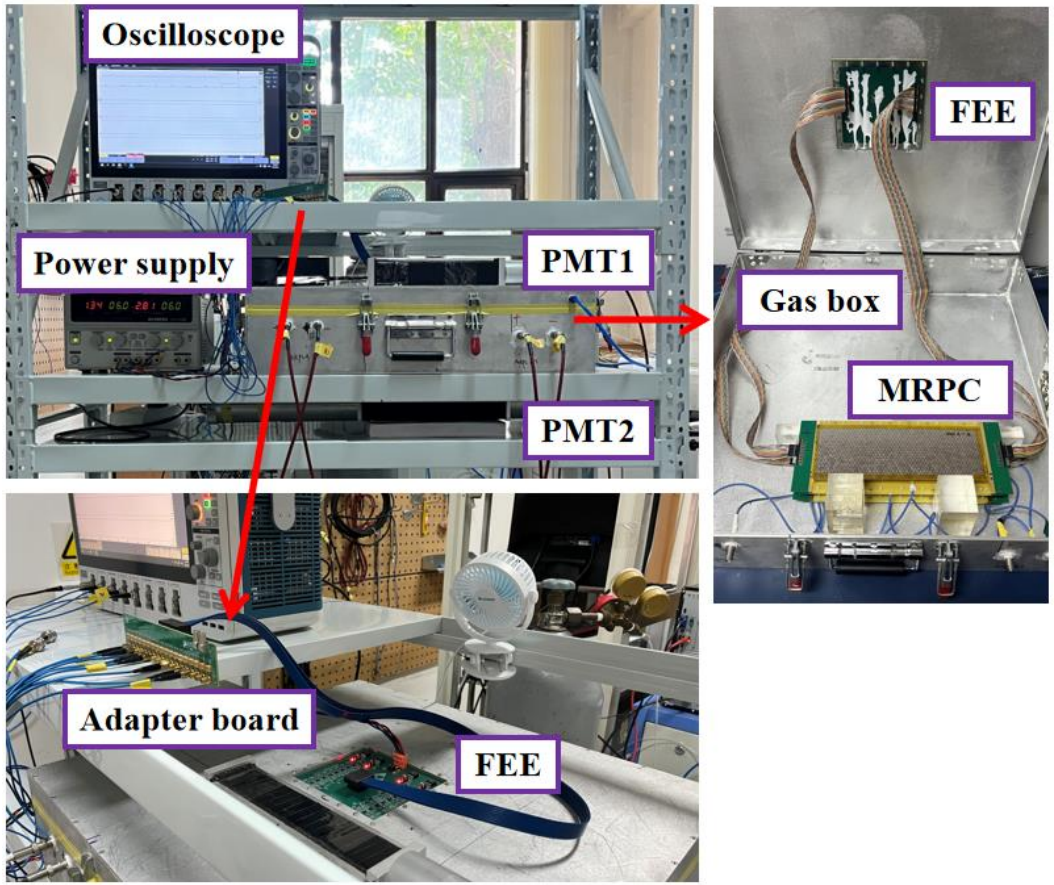


Production of ultra-thin MRPC

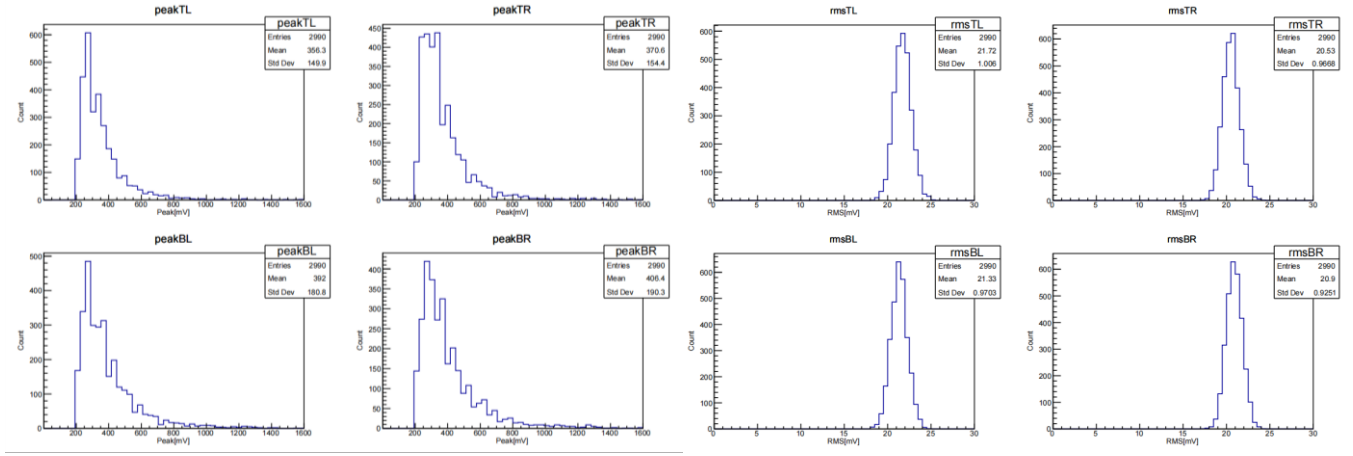


Front-end electronics

Ultra-thin 8-gap MRPC cosmic ray test

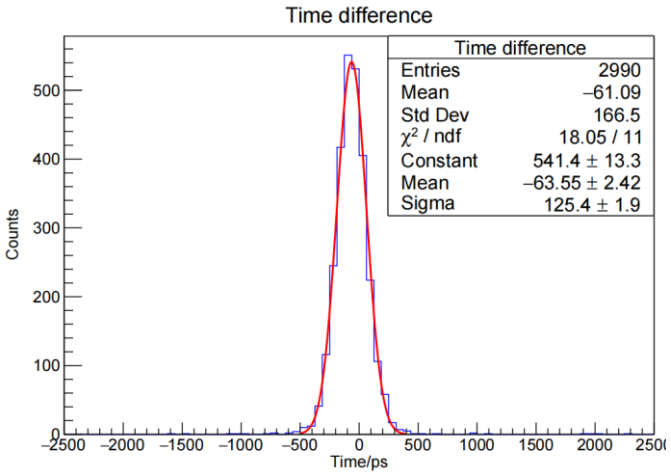


Experimental system

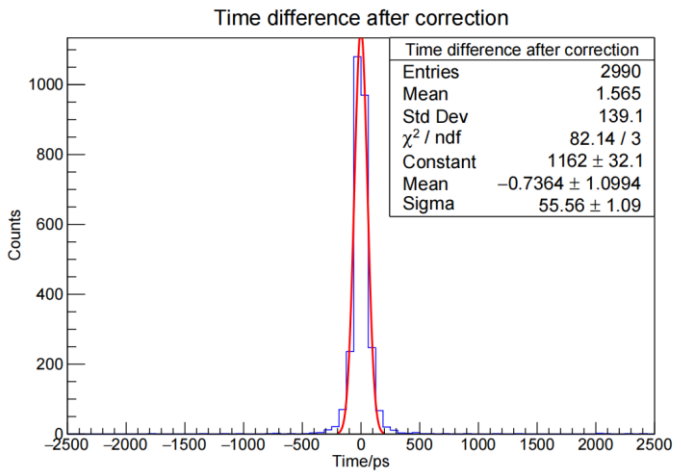


adc ~ 370mV

rms ~ 20mV



threshold ~ 200mV



Time resolution $55.56/\sqrt{2}$ ~ 39 ps

Ultra-thin 8-gap MRPC gamma test

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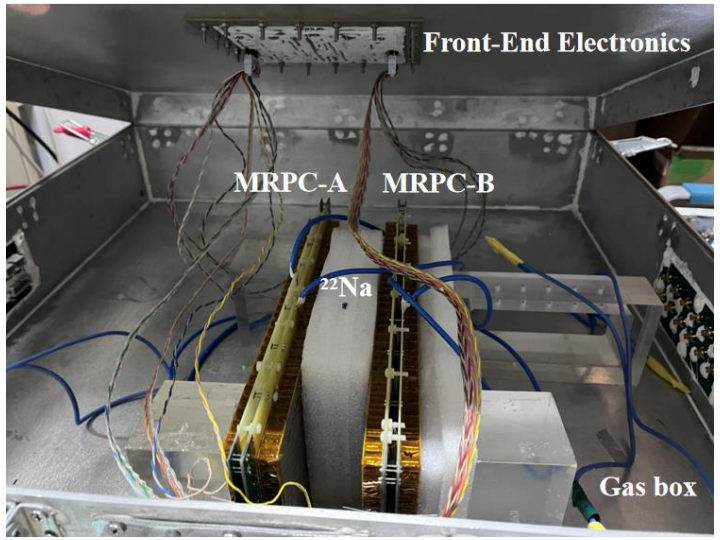
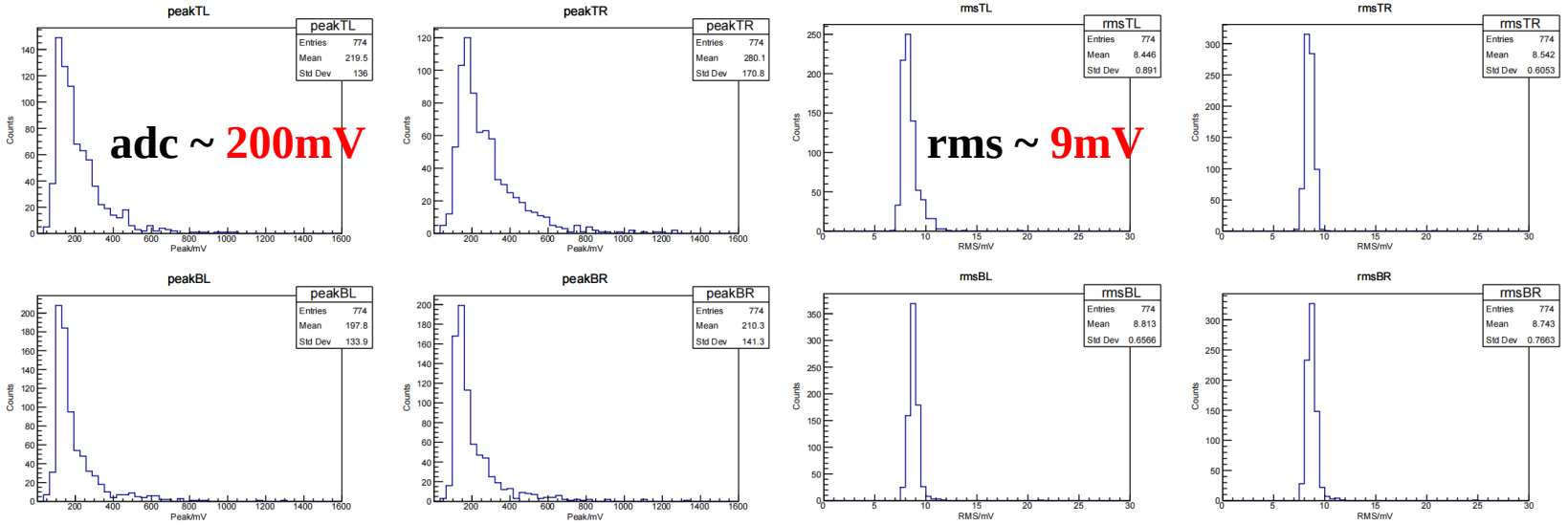
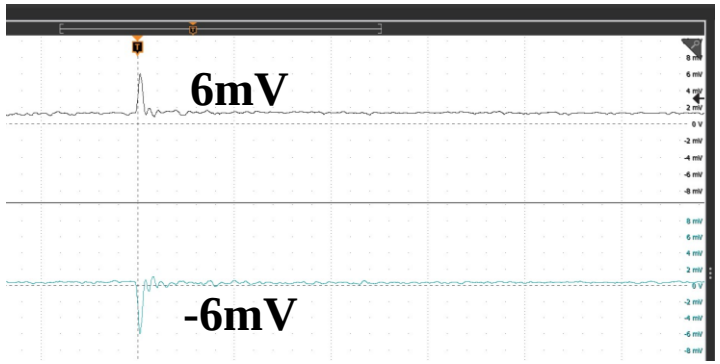
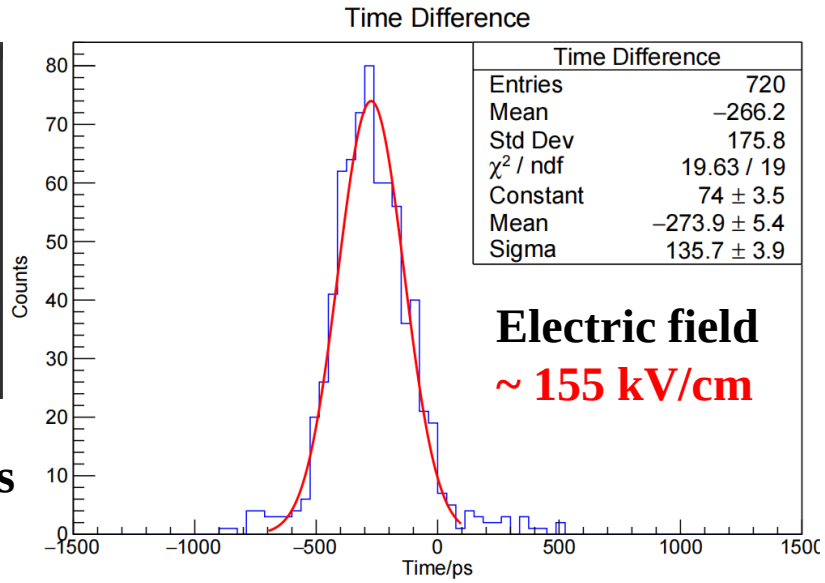
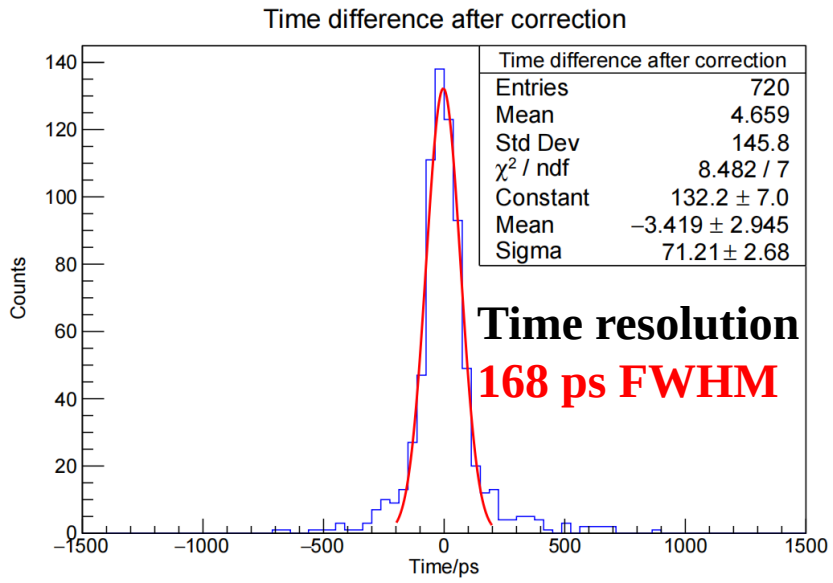






A pair of original differential signals





rms time accuracy per photon $71.2/\sqrt{2} \sim 50$ ps

A new RPC

Tsinghua University

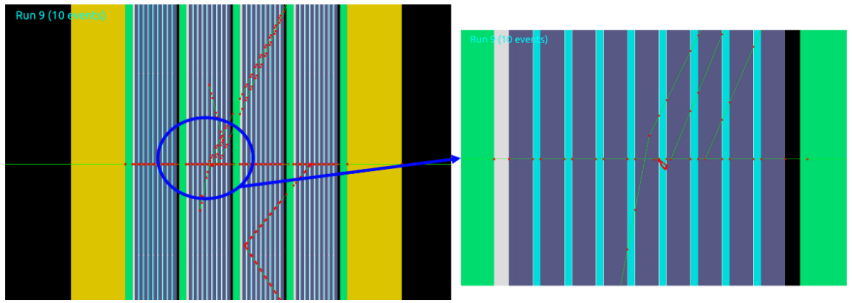
Ultra-thin, high efficiency, high time resolution RPC

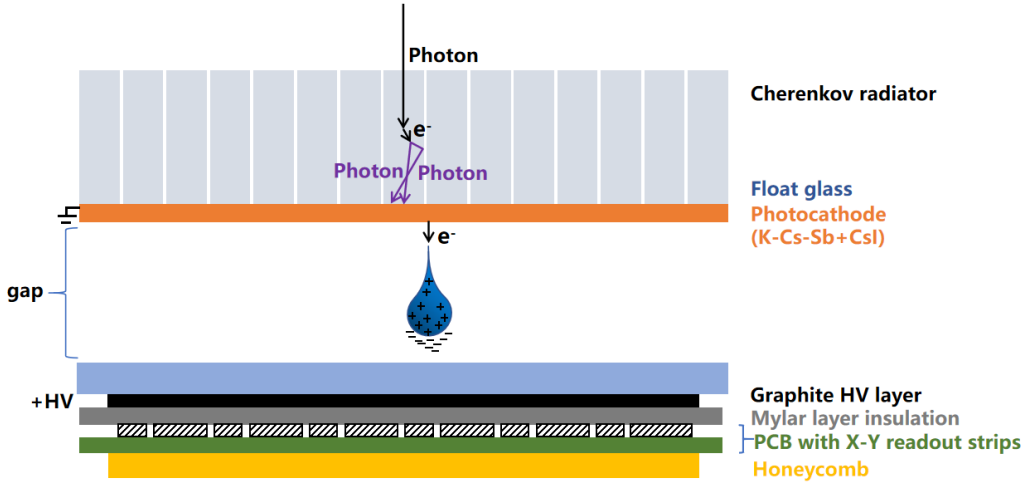
- **Detection efficiency for γ (128 μm gas gap)**

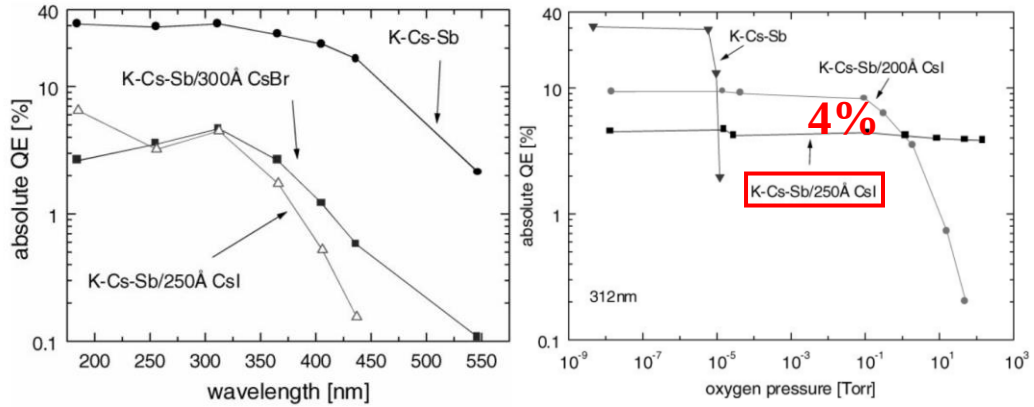
  1-chamber 1-gap ~ 0.2%

  1-chamber 8-gap ~ 1.5%

  4-chamber 32-gap ~ 6.3%







[A. Breskin et al. Israel 2000]

- **Performance indicators**

  time resolution < 20 ps，detection efficiency ~ 6.4%

  sensitive area thickness < 3 mm，energy resolution < 20%

A new RPC

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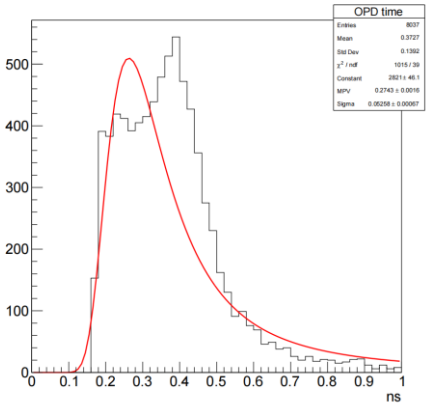
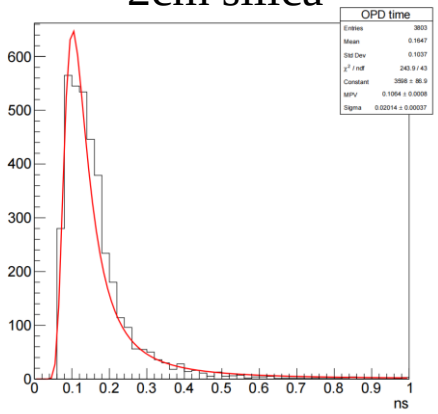
- **Calculation of optical path difference in Cerenkov radiator (silica)**

5cm silica

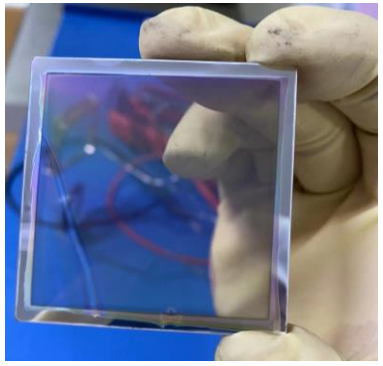


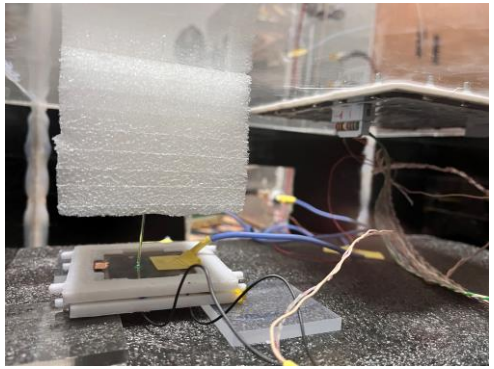
2cm silica

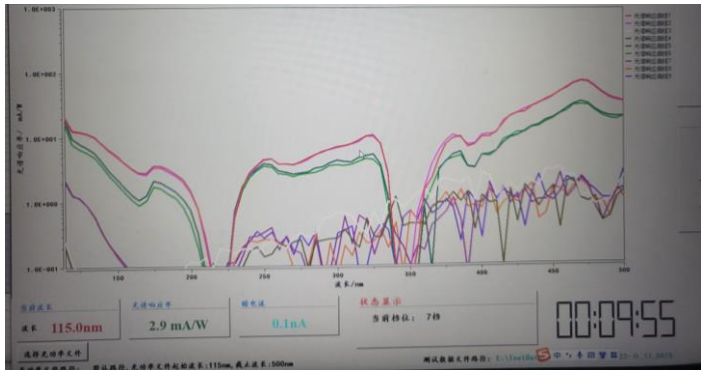


Thickness of silica	Time in silica(average)	Time in silica σ	Detection efficiency
7cm	491ps	70ps	16%
5cm	372ps	52ps	13%
3cm	241ps	32ps	8.7%
2cm	**164ps**	**20ps**	**6.4%**
1cm	80ps	8ps	3.2%

- **Fabrication of the new RPC**



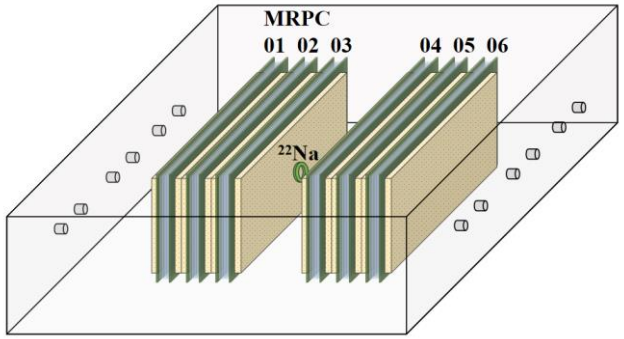


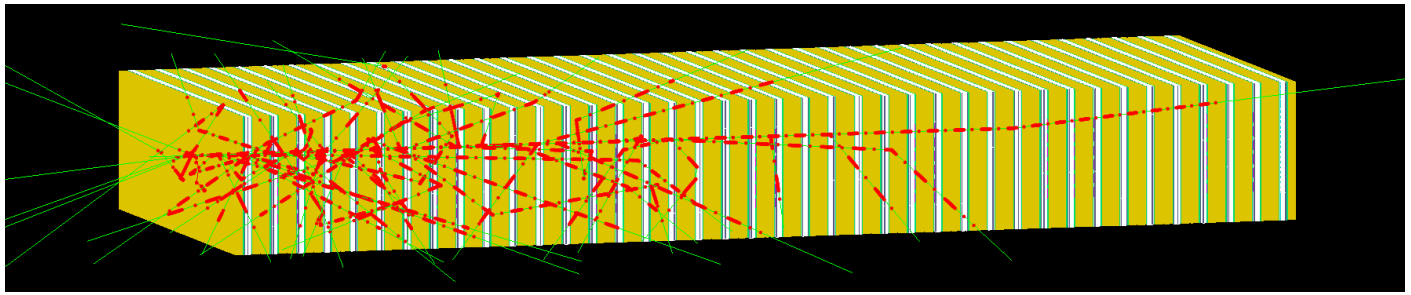


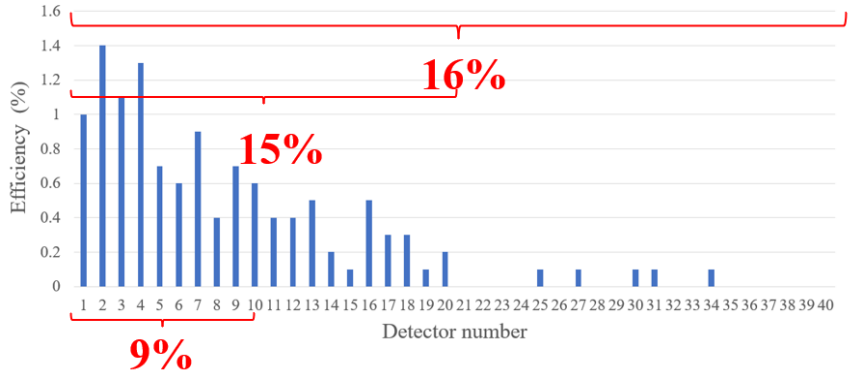
K-Cs-Sb+CsI　　Electric field ~ 180 kV/cm，dark current ~ 0.04 μA、0.03 μA

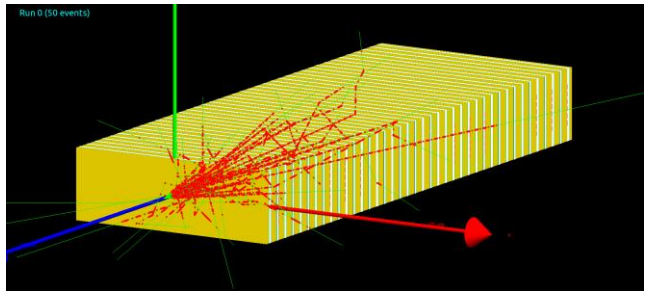
Research plan

- **Three 8-gap MRPC are placed on each side of ^{22}Na for positioning**







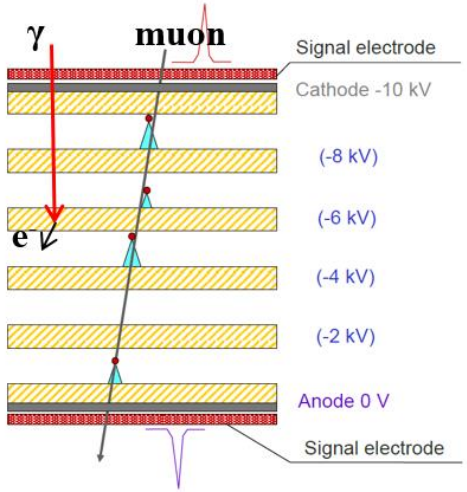


- **Develop the high efficiency, high time resolution RPC prototype**

  Consider a more appropriate Cerenkov photon-to-electron conversion.
  Improve the coating process.

Conclusion

- **A 4-chamber 32-gap MRPC prototype has been constructed and tested**
  - time resolution for cosmic rays ~ 20 ps
  - time resolution for 0.511MeV gamma ~ 58 ps
  - the thickness of MRPC affects the time resolution for gamma



- **An ultra-thin 8-gap MRPC prototype has been developed**
  - time resolution for cosmic rays ~ 39 ps
  - time resolution for 0.511MeV gamma ~ 50 ps
  - the different ways that different particles act with MRPC affect the time resolution
- **An ultra-thin, high efficiency, high time resolution RPC was proposed**
  - use converters to improve detection efficiency ➞ limited improvement
  - increase the number of gas gaps ➞ poor positioning accuracy
  - use Cerenkov radiator + composite photocathode ➞ 6.4% efficiency for one gap

Thanks For Your Attention!

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