清華大學
Tsinghua University

为TOF-PET开发的一种非常薄的MRPC

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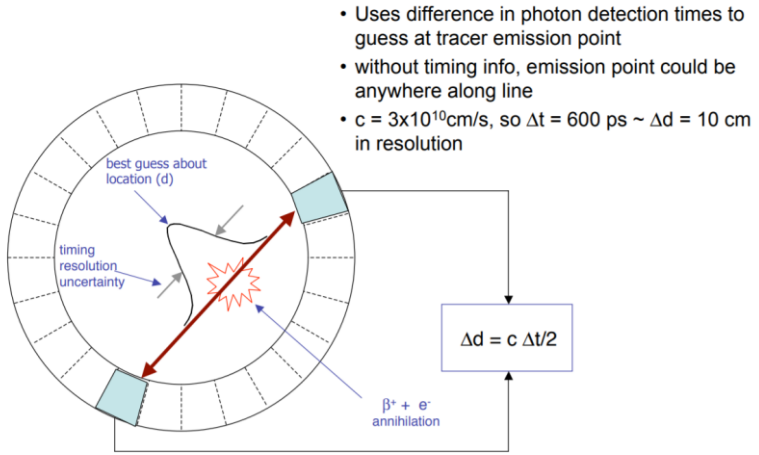
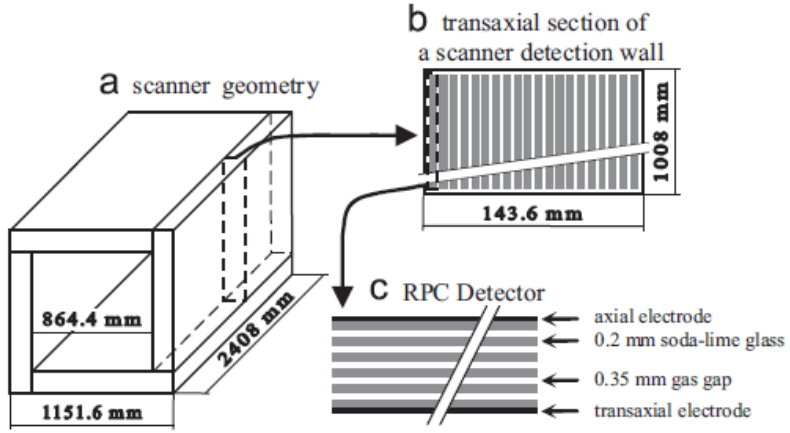
清华大学工程物理系
2023-10-13

研究背景





[M. Couceiro et al. Portugal 2012]

■ 传统 TOF-PET

闪烁体探测器 + PMT

- ➢ 时间分辨不够高 > 50ps
- ➢ 闪烁体本身厚度 > 3cm
- ➢ 接收度小，浪费了很多信息

➞ 检测时间长，精度差

■ MRPC TOF-PET

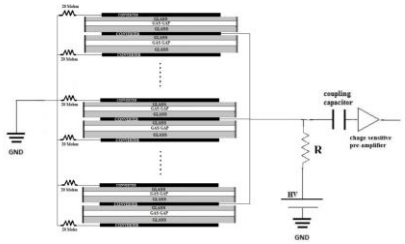
优势

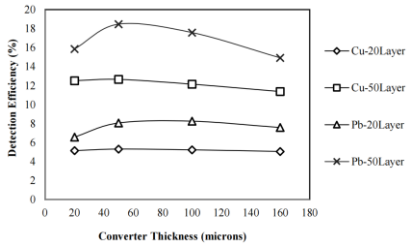
- ➢ 时间分辨率优秀 < 20ps
- ➢ 超薄的灵敏区 ~ 100μm
- ➢ 大面积 → 可做全身PET

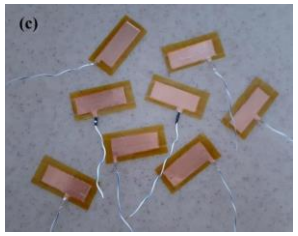
➞ 弥补单层探测器效率低的缺陷

已有研究

- **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**

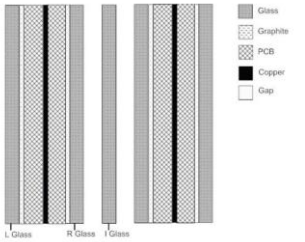
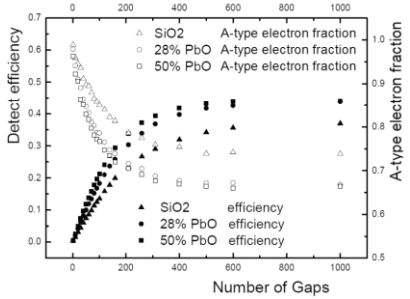
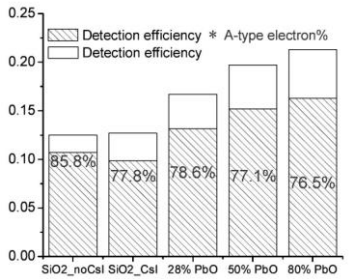


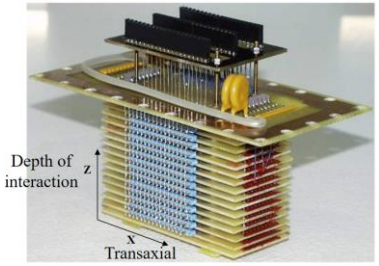
Figure 1. Detector structure of the RPC-based PET unit.

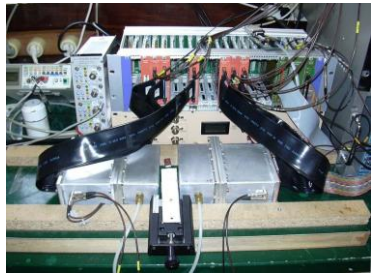


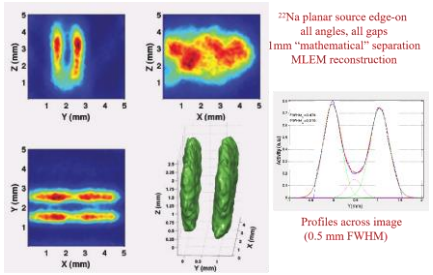


[W. Zhou et al. 2014]

- **RPC-PET for small animals**







[Paulo Martins et al. 2014]

通过增加转换体和气隙的个数来增加探测效率 → 低时间分辨、低定位精度

研究进展

清華大學 Tsinghua University

★ **制作一个4室32气隙，气隙宽度128μm的MRPC原型机**

☑ 对宇宙线的时间分辨 < 20 ps ; 对gamma的时间分辨 < 58 ps

★ **制作一个超薄8气隙，气隙宽度128μm的MRPC原型机**

☑ 灵敏区厚度 < 5 mm

☑ 对宇宙线的时间分辨 < 39 ps ; 对gamma的时间分辨 < 50 ps

★ **建造一个TOF-PET系统**

在^{22}Na源两侧各放置3个8气隙的MRPC探测器进行定位，每个MRPC的电子学单独读出

☐ 定位精度 < 3 mm

★ **制作一个超薄、高探测效率、高时间分辨的RPC原型机**

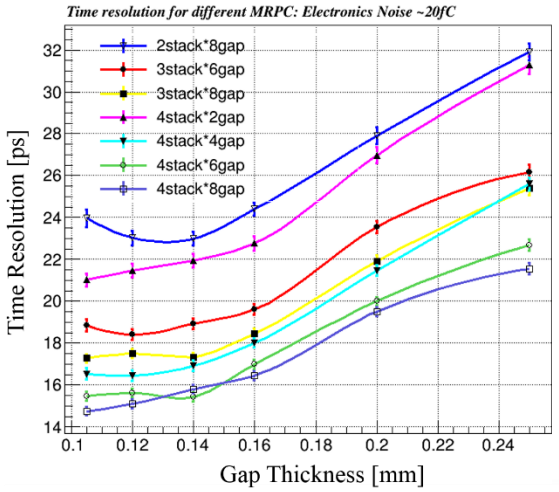
☑ 灵敏区厚度 < 3 mm

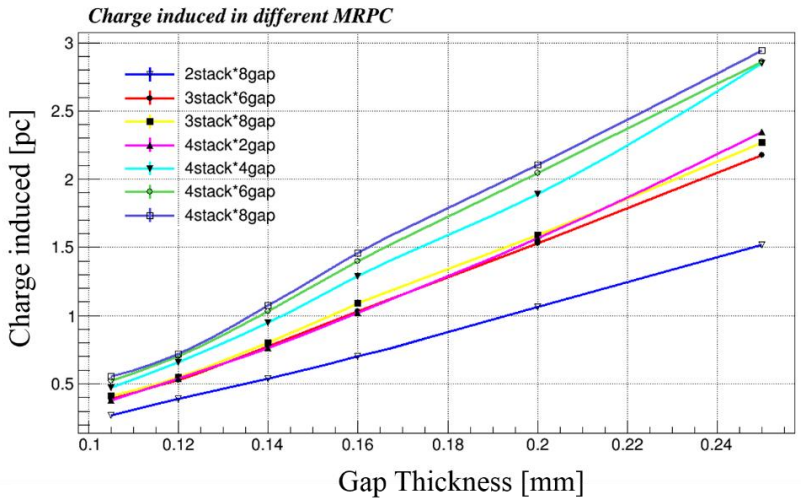
☐ 时间分辨 < 20 ps

☐ 探测效率 > 7%

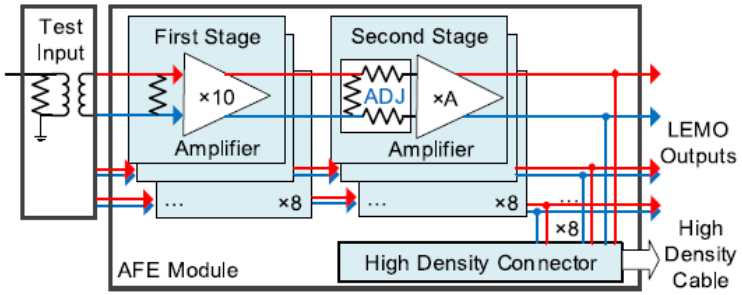
☐ 能量分辨 < 20%

研究进展

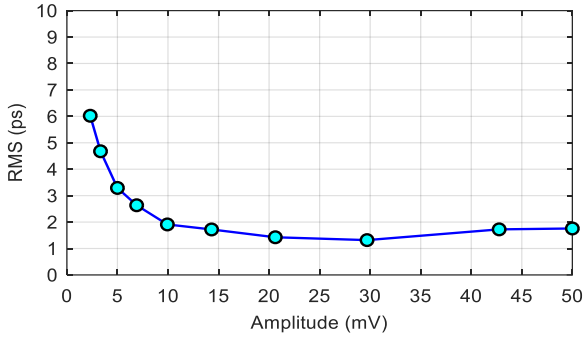




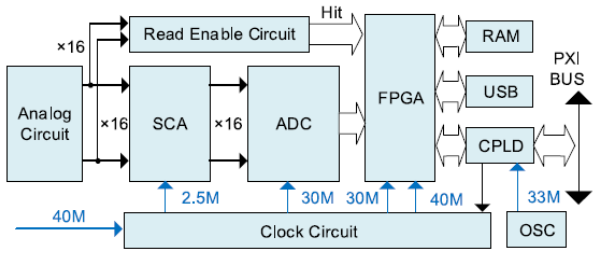
- 气隙厚度低于160 μm，超过3个室，每个室超过4个气隙 ➡ 20 ps
- 气隙厚度越薄，气隙数量越多，并不能显著提高时间分辨能力
- 优化探测器：气隙厚度104 μm增加到128 μm



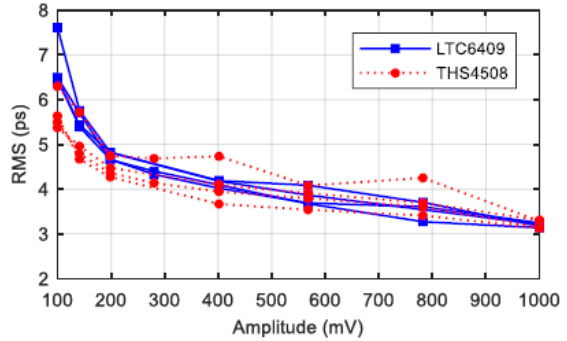
前端电子学模块示意图



- 增益：26 dB ~ 40 dB
- 带宽：1.4 GHz
- 时间分辨能力：< 4 ps



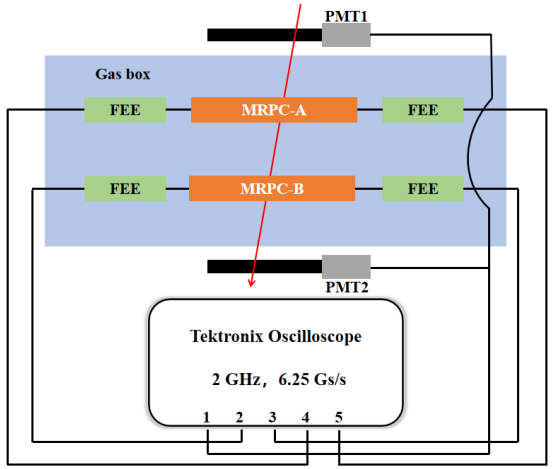
波形数字化模块框图

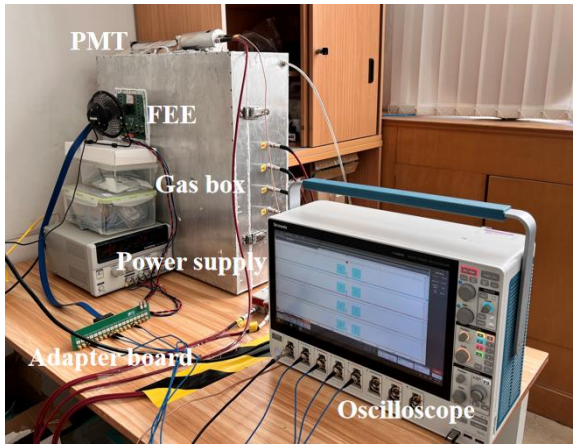


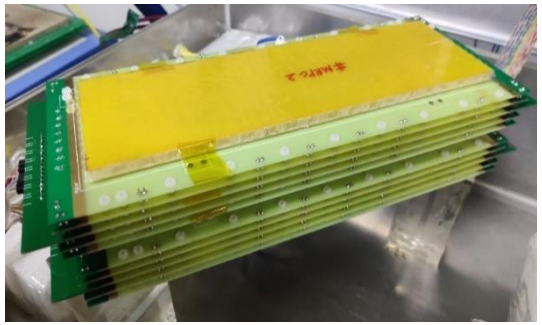
- 开关电容阵列(SCA)：1024个采样电容
- 最大采样频率：5.12 GHz
- 噪声：0.5 mV
- 时间晃动：< 8 ps

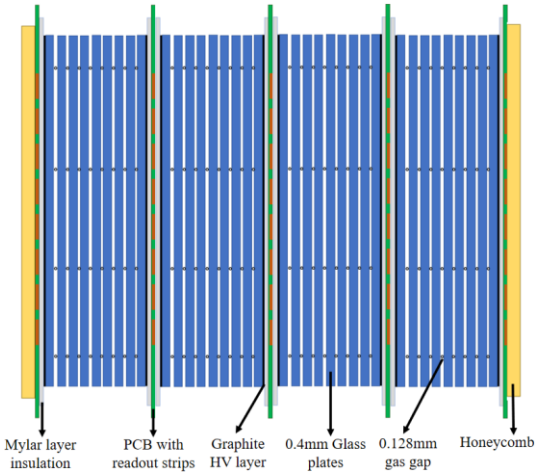
4室32气隙MRPC宇宙线测试

MRPC原型机 + 快速放大器 + 快速采样系统

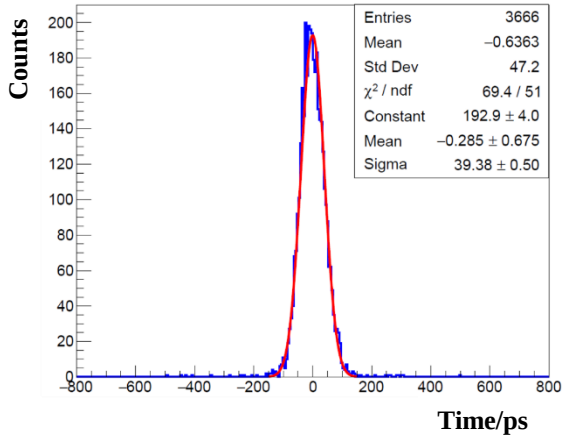




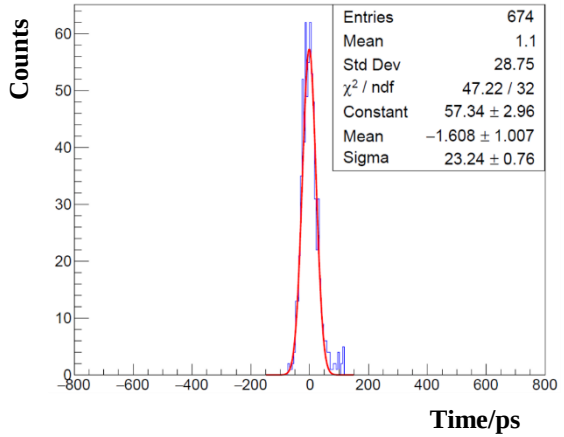




	MRPC prototype
gas gap thickness	128 μm
number of gas gaps	4 chambers × 8 gaps
glass material	**low resistivity glass**
glass thickness	400
readout strips	5 mm in width (2 mm clearance)

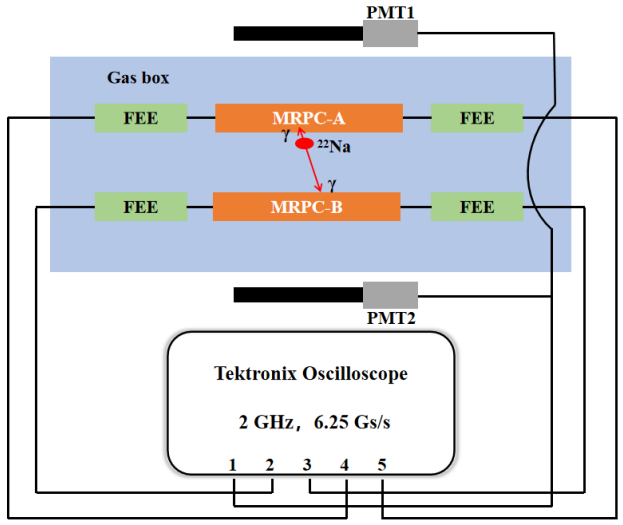


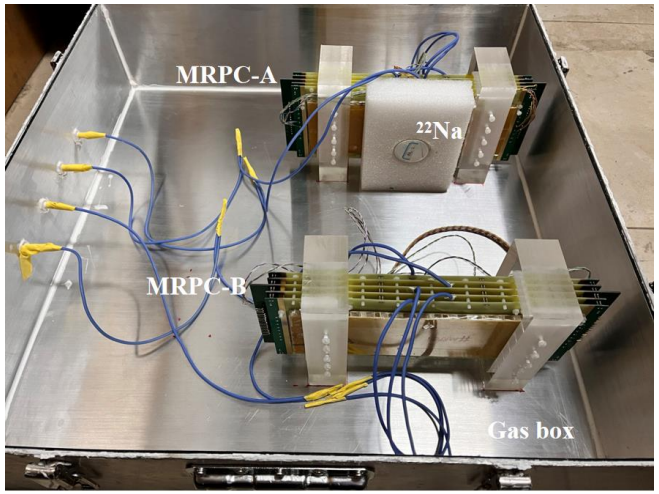
时间分辨：27 ps

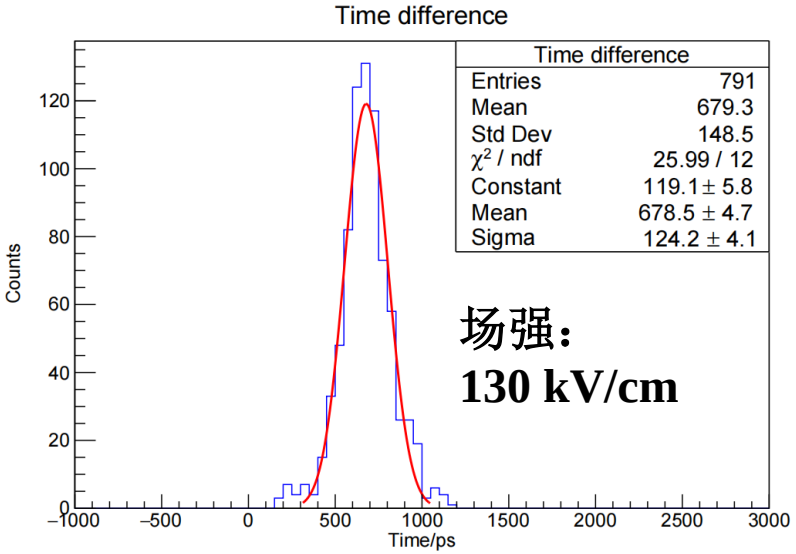


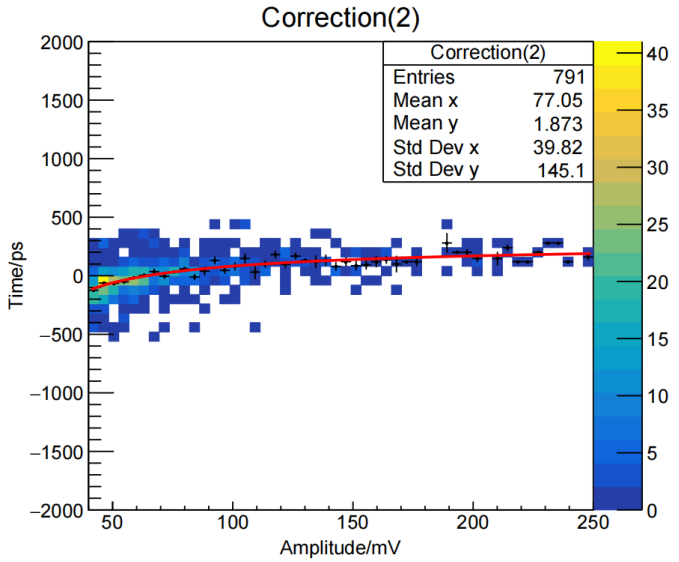
垂直事例挑选后的时间分辨率：16.44 ps

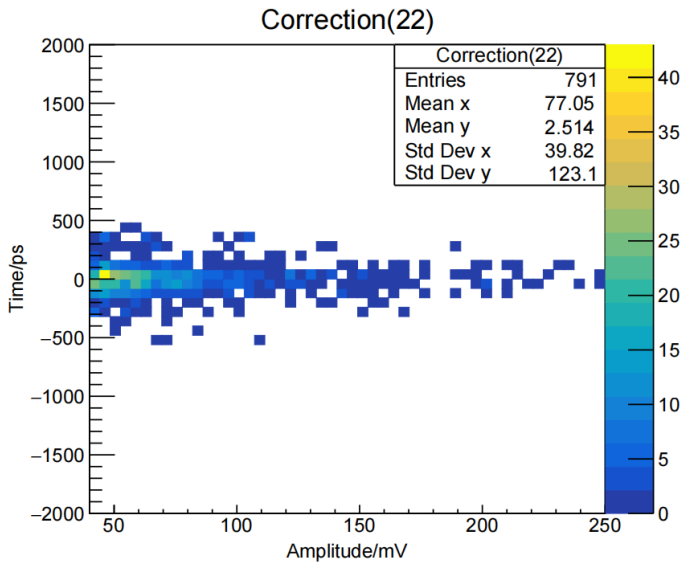
4室32气隙MRPCgamma测试

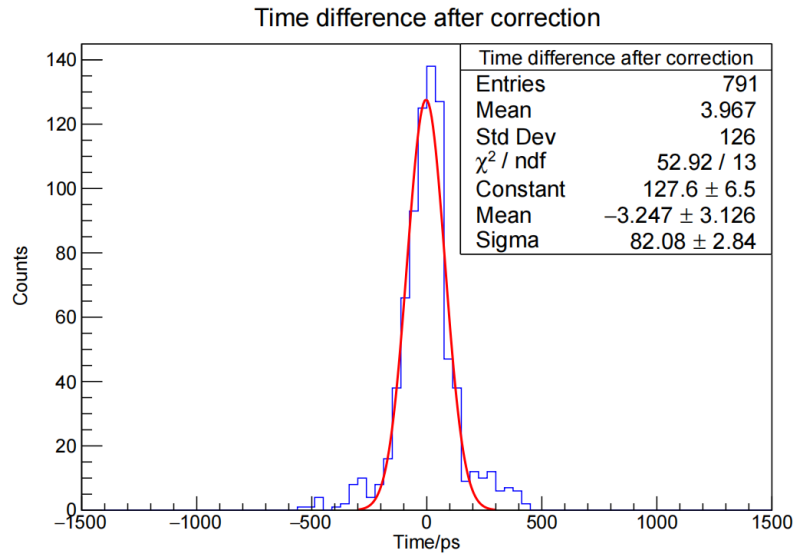












时幅矫正前

时幅矫正后

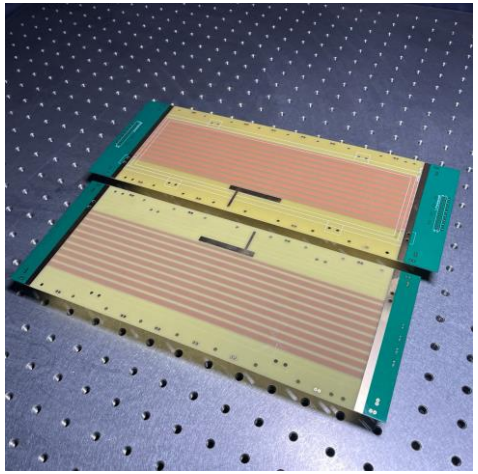
时间分辨：58 ps

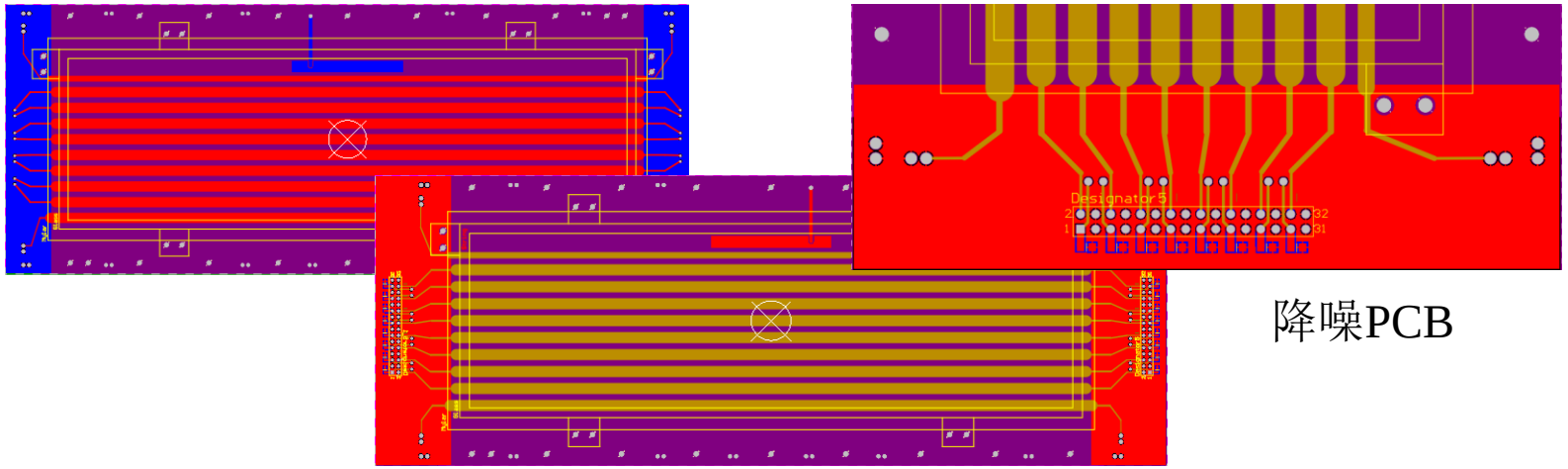
超薄、高时间分辨MRPC样机的研发

清華大學 Tsinghua University

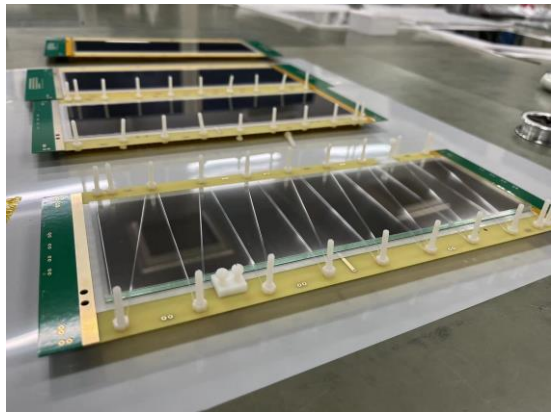
■ 探测器厚度对时间分辨的影响

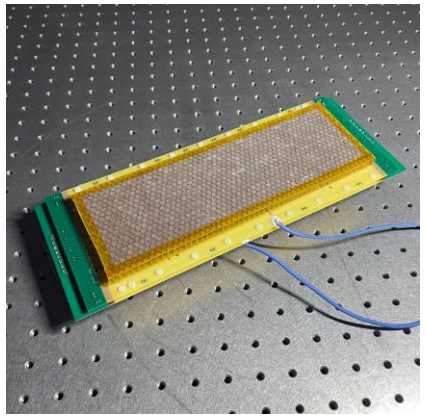
$$\Delta L = t_A + \frac{x_A}{c} - \left(t_B + \frac{x_B}{c}\right) = \Delta t + \frac{x_A}{c} - \frac{x_B}{c} \qquad \sigma_{\Delta L}^2 = \sigma_{\Delta t}^2 + (\frac{1}{c})^2\sigma_x^2 * 2, \sigma_x = \frac{\text{Thickness of MRPC}}{\sqrt{12}}$$



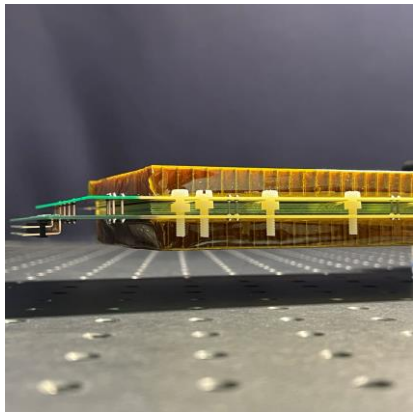


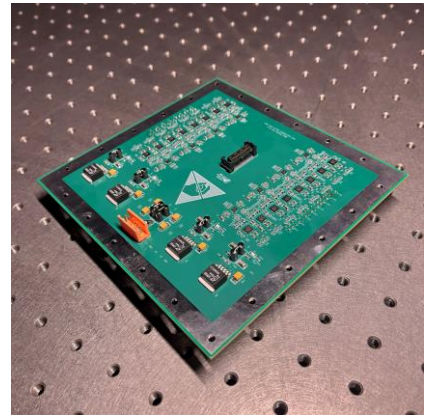
降噪PCB





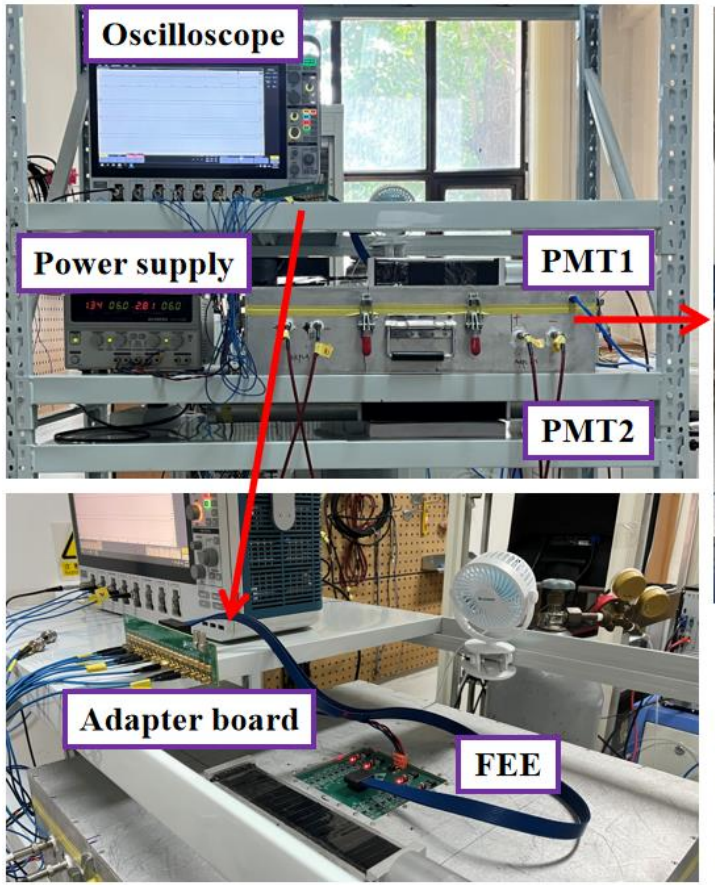
超薄MRPC样机的生产

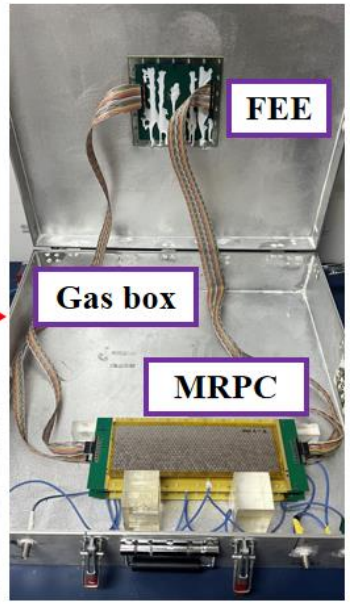




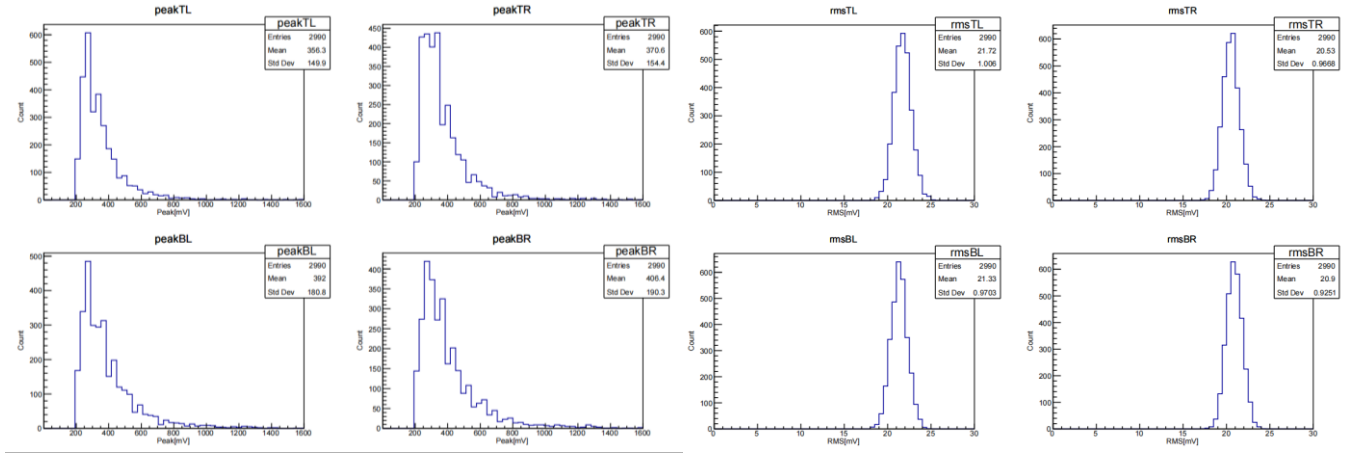
前放电子学

单室8气隙MRPC宇宙线测试



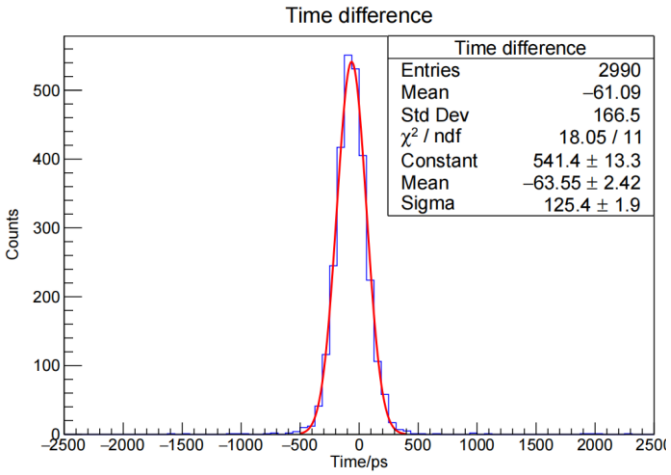


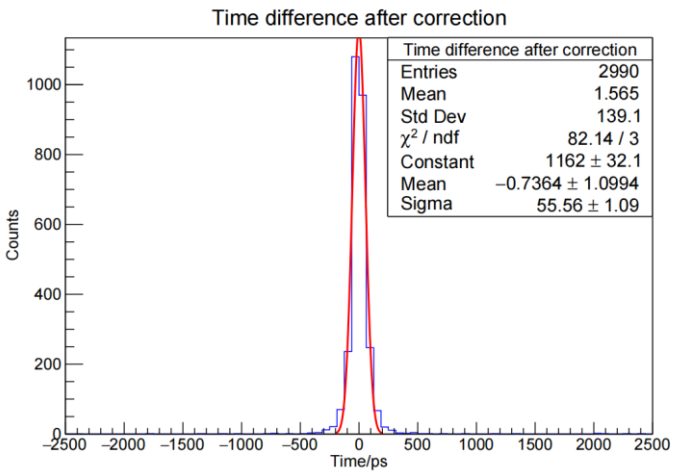
实验系统搭建



adc ~ 370mV

rms ~ 20mV

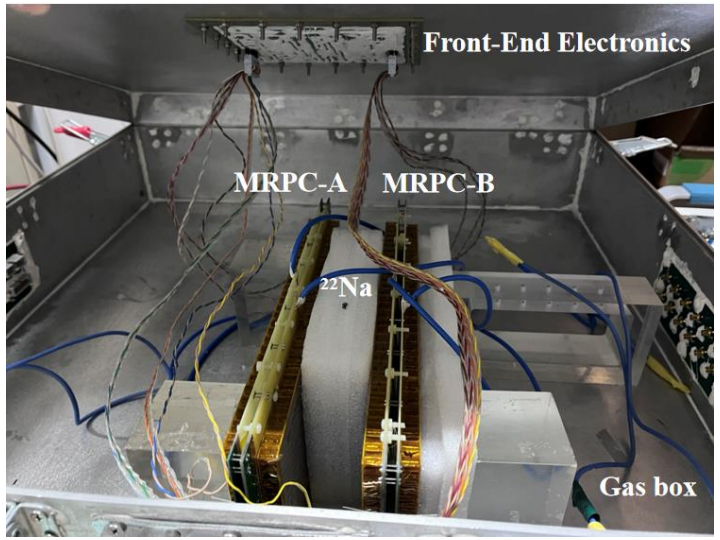


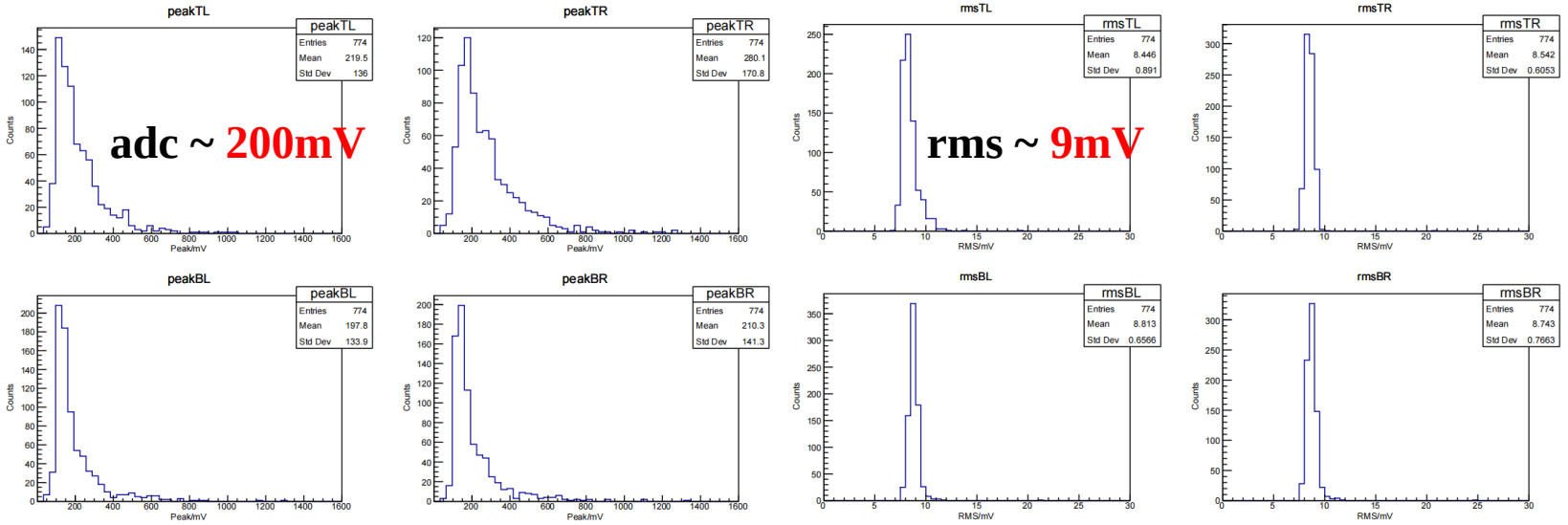


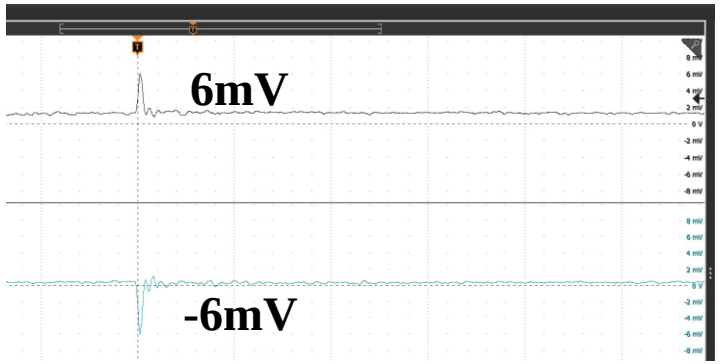
10倍基线噪声，阈值200mV

时间分辨：$55.56/\sqrt{2}$ ~ 39 ps

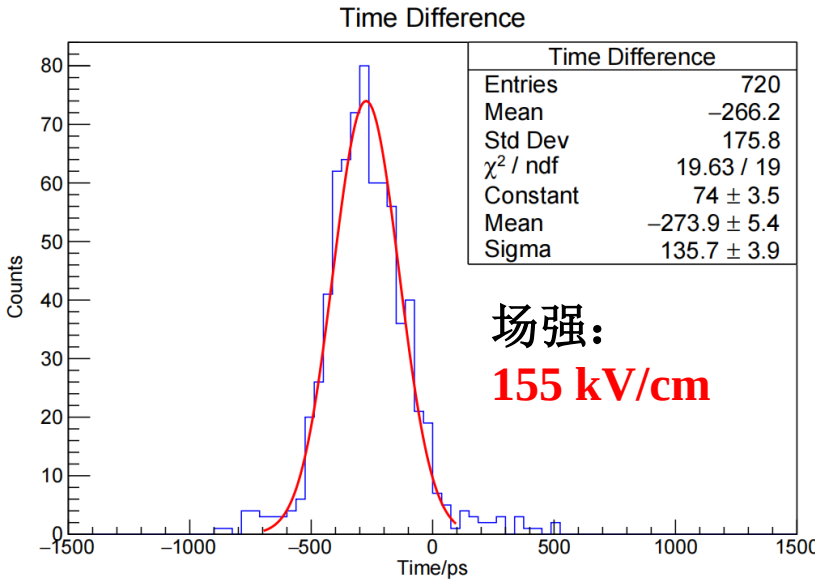
单室8气隙MRPCgamma测试



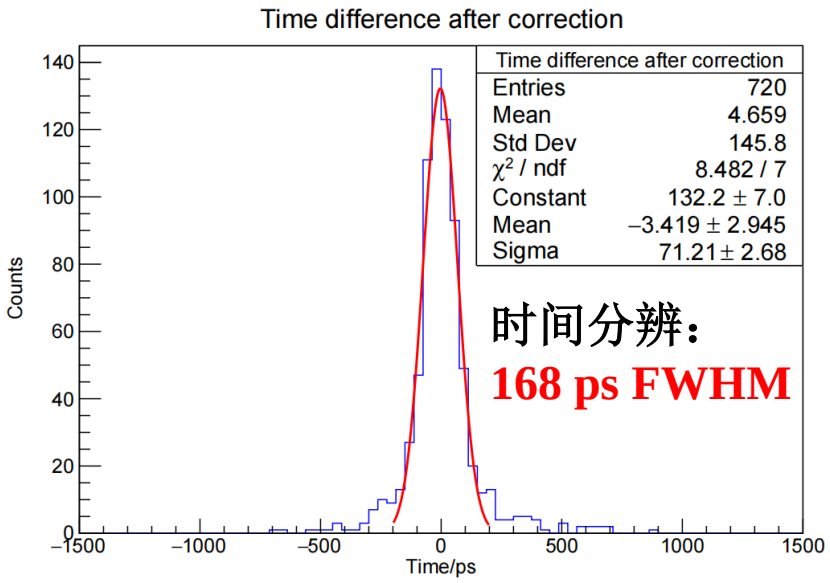




一对原始差分信号



场强：
155 kV/cm



时间分辨：
168 ps FWHM

单光子时间精度：71.2/√2 ~ 50 ps

新型RPC原型

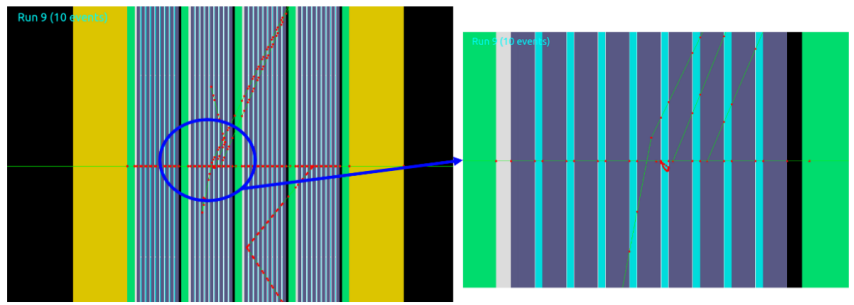
超薄、高时间分辨、高探测效率 RPC-PET

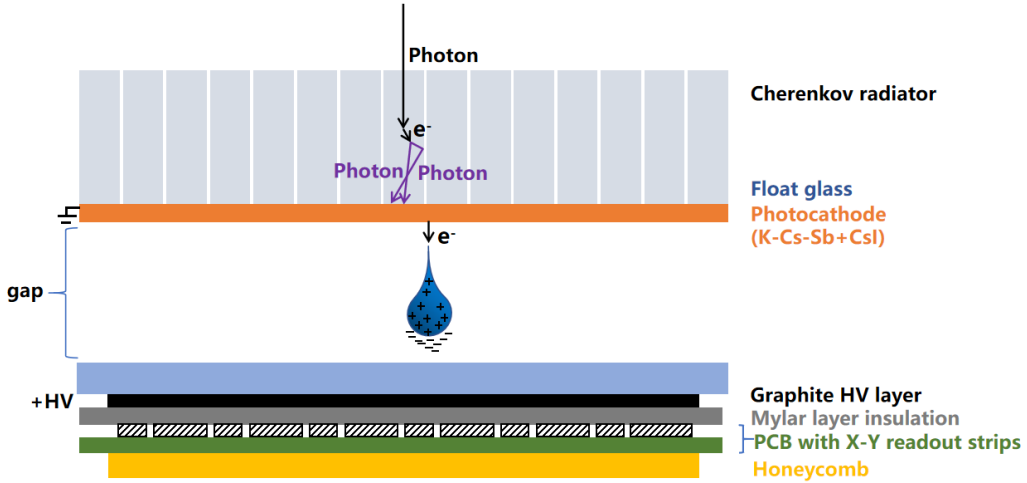
- **模拟得到传统 MRPC （气隙宽度128μm）对0.511MeV伽马光子：**

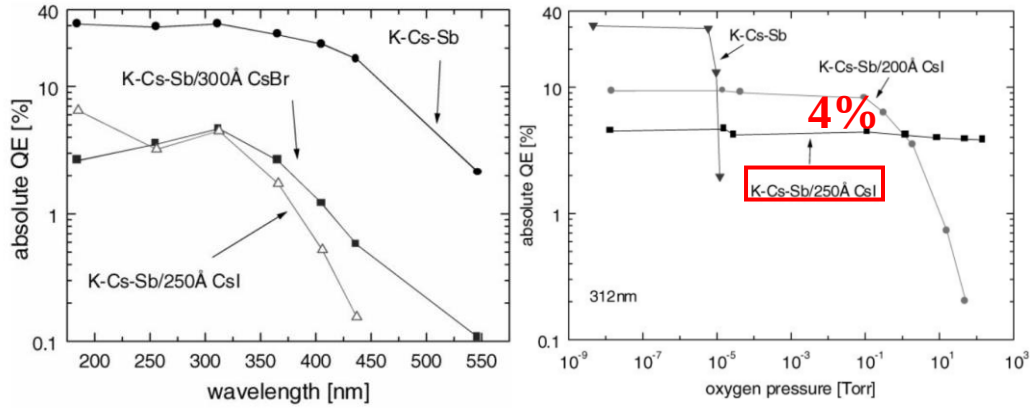
  1气隙探测效率约为0.2%

  1室8气隙探测效率约为1.5%

  4室32气隙探测效率约为6.3%







[A. Breskin et al. Israel 2000]

- **性能指标：**

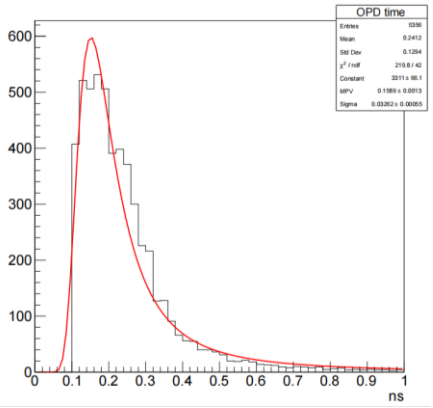
  时间分辨：<20ps　　探测效率：6.4%

  灵敏区厚度：<3mm　　能量分辨率：优于20%

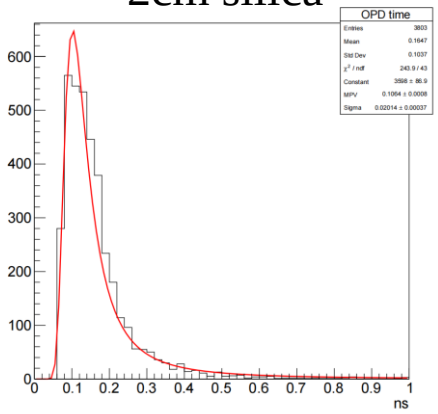
新型RPC原型

- 切伦科夫辐射体(silica)中光程差的计算

3cm silica

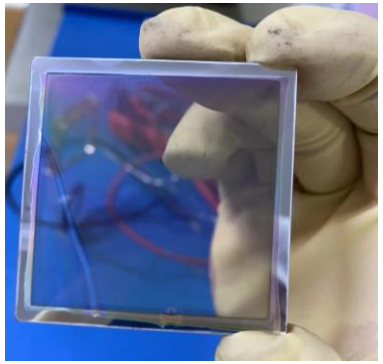


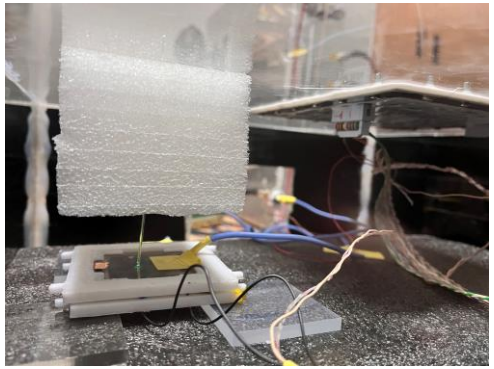
2cm silica

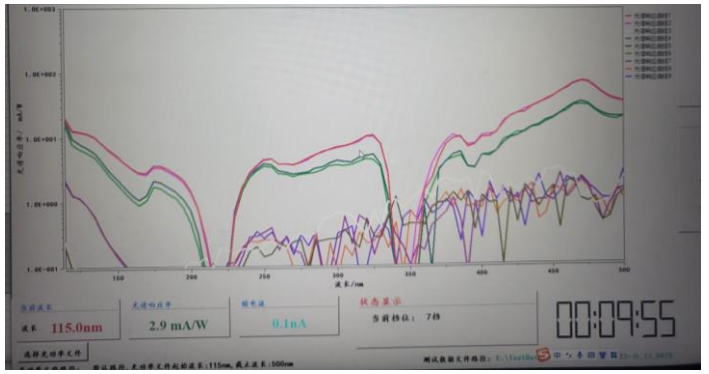


Thickness of silica	Time in silica(average)	Time in silica σ	Detection efficiency
7cm	491ps	70ps	16%
5cm	372ps	52ps	13%
3cm	241ps	32ps	8.7%
2cm	**164ps**	**20ps**	**6.4%**
1cm	80ps	8ps	3.2%

- 新型RPC的制作





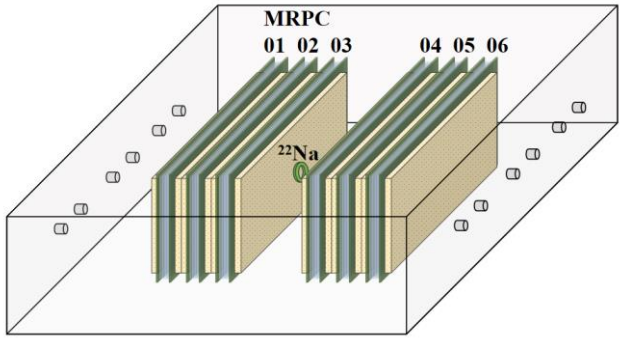


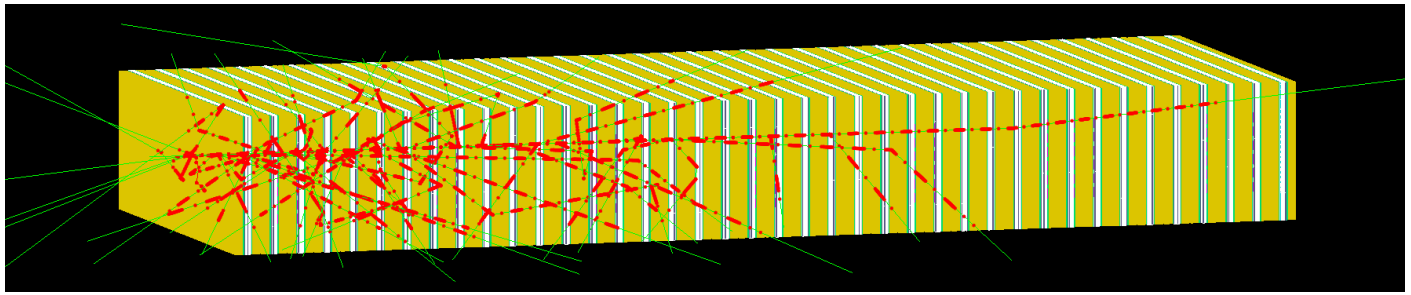
K-Cs-Sb+CsI　　电场强度 ~ 180 kV/cm，暗电流 ~ 0.04 μA、0.03 μA

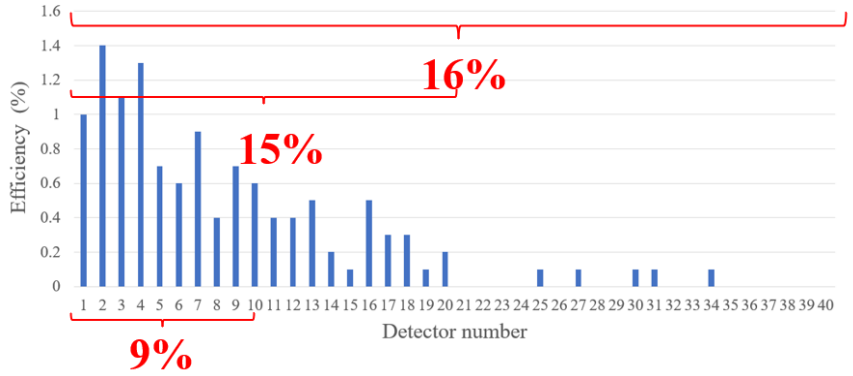
研究计划

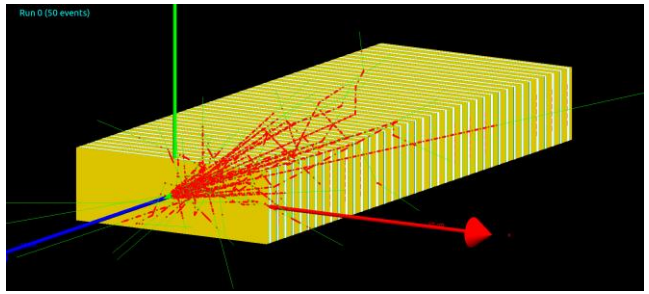
清華大學 Tsinghua University

- 在^{22}Na源两侧各放置3个8气隙的MRPC探测器进行定位









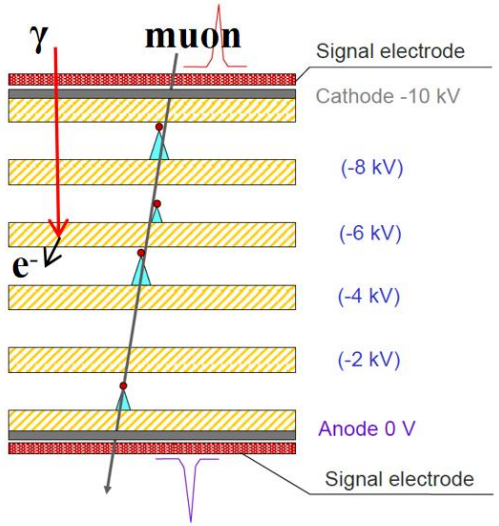
- 发展高时间分辨、高探测效率 RPC-PET

  研发更合适的切伦科夫光→电子转换体，改善镀膜工艺

总结

清華大學 Tsinghua University

- **完成4室32气隙的MRPC原型机的研发和测试**
  - 对宇宙线的时间分辨：20 ps
  - 对0.511MeV gamma 的时间分辨：58 ps
  - MRPC探测器的厚度影响对gamma的时间分辨
- **完成超薄8气隙MRPC原型机的研发和测试**
  - 对宇宙线的时间分辨： 39 ps
  - 对0.511MeV gamma 的时间分辨：50 ps
  - 不同粒子与MRPC探测器的不同作用方式影响时间分辨
- **提出一种超薄、高时间分辨、高探测效率 RPC**
  - 使用转换体来提高探测效率 → 效果有限
  - 通过增加气隙的个数来提高探测效率 → 定位精度变差
  - 采用切伦科夫辐射体和复合光阴极 → 提高单气隙的探测效率到6.4%



Thanks For Your Attention!

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