
# 大面积MRPC高颗粒度高时间精度读出电子学系统设计

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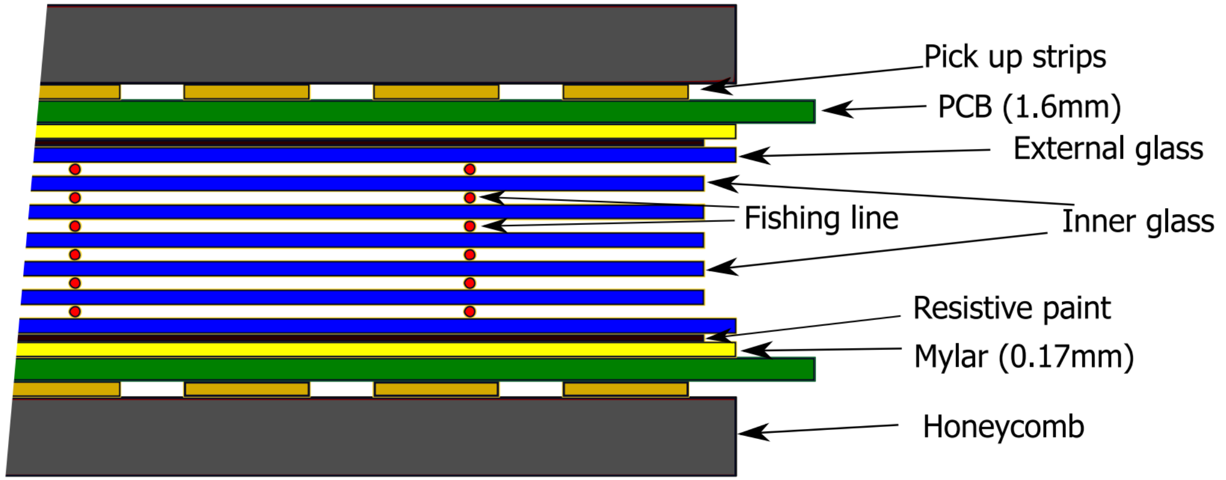
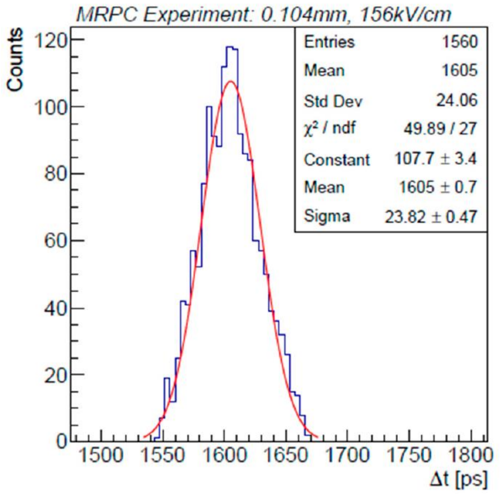
上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

# MRPC 探测器简介

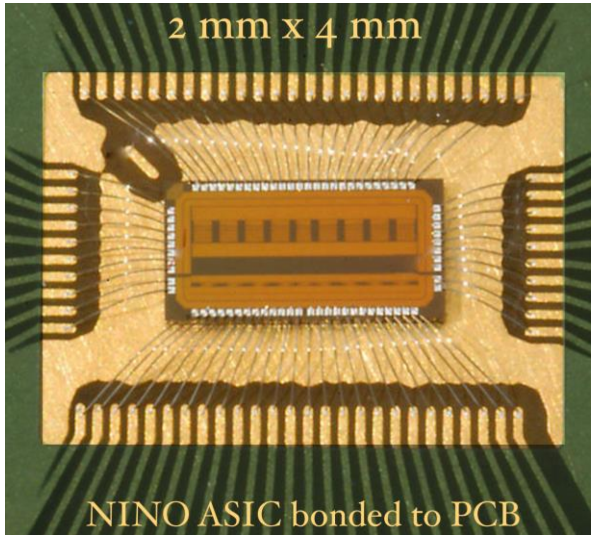
- MRPC: 基于RPC发展而来
  - 多个窄气隙 (100-250 um)
  - 高效率，高时间分辨率
- 性能参数:
  - 极快时间响应: 分辨率 < 50 ps
  - 高探测效率: ＞95%
  - 事例率: float glass ~ 1kHz/cm^2 for, low-resistivity glass ~ 70 kHz/cm^2.
- 应用场景:
  - RHIC-STAR, LHC-ALICE and BES-III 飞行时间探测(TOF)
  - 高时间精度 TOF-PET
  - 宇宙线缪子成像

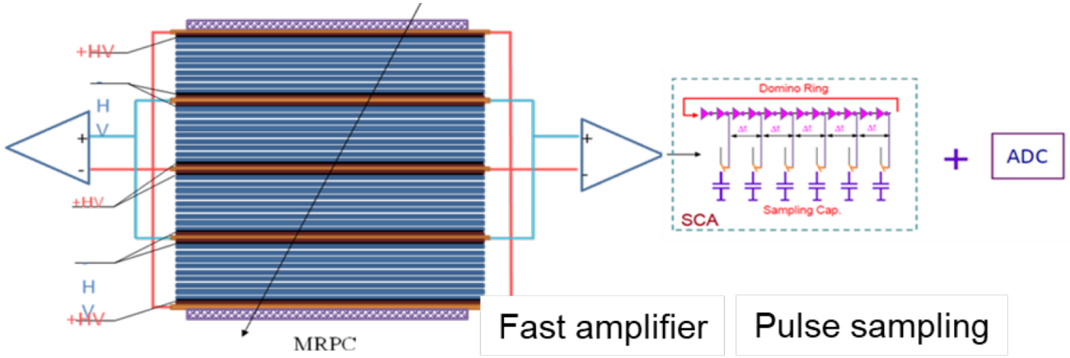


# MRPC 读出电子学方案调研

- 信号读出方案:
  - 双端条状读出
  - 高颗粒度 pad 读出：支持更高事例率读出
- MRPC 读出电子学方案
  - 前端 ASIC + TDC
    - 前端 NINO ASIC : 8 通道前端, ToT 输出
    - 时间测量 HPTDC / FPGA-TDC : time resolution < 25 ps
    - 在 CERN ALICE 和 RHIC STAR 实验中使用
  - 高速波形采样 + 时间重建
    - 波形采样: SCA ASIC
    - 时间重建 : FPGAs/software 机器学习算法
    - 针对高技术率场景 (SoLID, EIC, Muon Tomography)



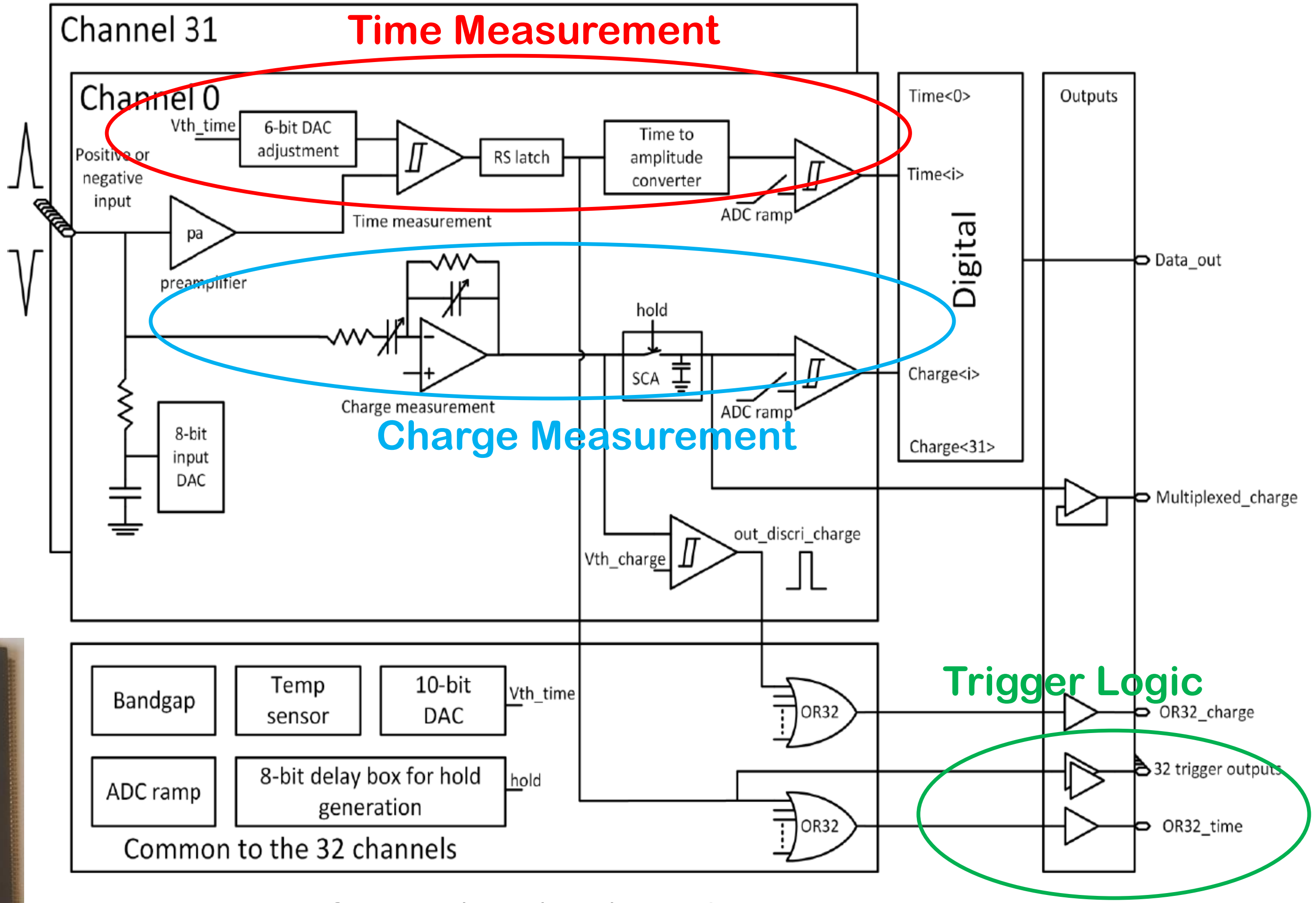
# 本研究读出电子学方案

- 读出要求
  - 主要挑战：高颗粒度，高事例率，高时间分辨率
  - MRPC 尺寸大： 100×100 cm.
  - 读出通道数多：2×2 cm 读出pad, 约 2500 读出通道.
  - 支持大于 20kHz 事例率, 时间分辨率好于 100 ps

- 前端电子学方案
  - FE 板：多通道 ASIC 读出，FPGA 控制和接收数据.
  - ASIC 选择 — PETIROC2B
    - 32-ch 模拟输入，内部集成前放和比较器
    - 支持时间和电荷数字读出，时间测量精度 ~40ps
    - 支持最高事例率~40 kHz
- DAQ 和时钟同步
  - SFP 数据汇板汇总传输数据
  - 时钟同步板发送同步时钟

# Petiroc 介绍

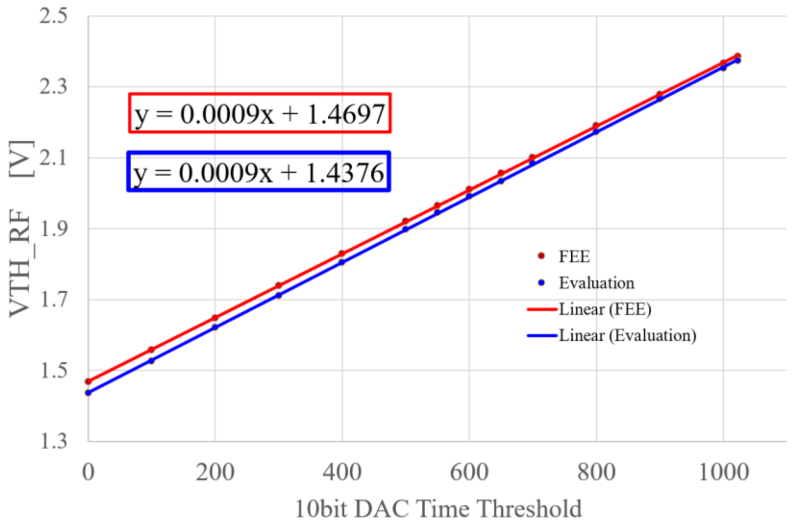
- 模拟输入：32-ch
- 可 32 通道 TOT 输出
- 内部集成电荷和时间数字化
- 支持 80Mbps 串行数字输出
- TDC 时间测量精度约 40ps
- 32 通道前端放大器
  - 时间测量：固定增益 40 倍前端放大
  - 电荷测量：成形电路
- 功耗：6mW/ch


*from Petiroc datasheet v2.5a

# 第 1 版前端原型验证

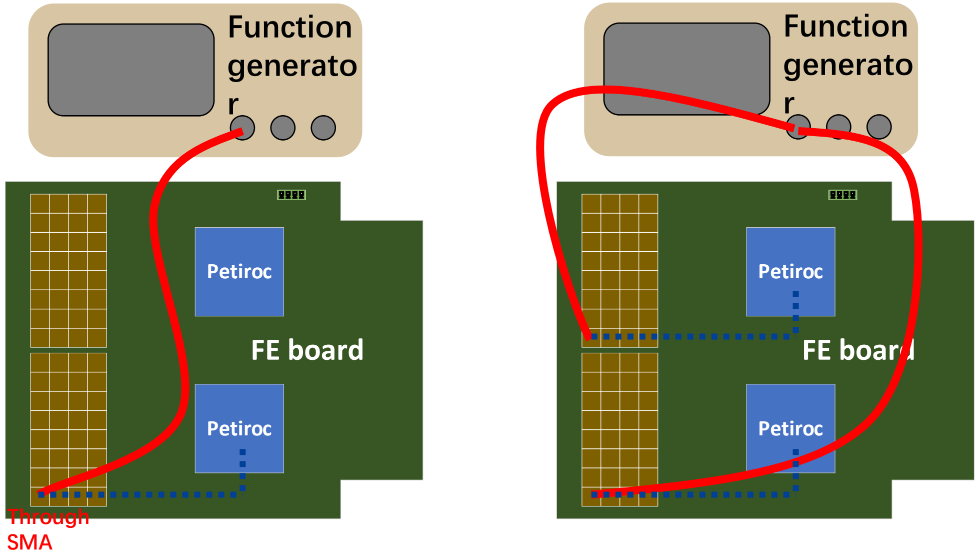
- 4 颗 PETIROC , 共 128 ch
  - 背面 PCB 沉金 pad 收集感应电荷
  - PCB 使用盲埋孔工艺（避让感应 pad）
- 验证了ASIC 配置和信号注入读出功能
- PETIROC 输入敏感，有些串扰问题

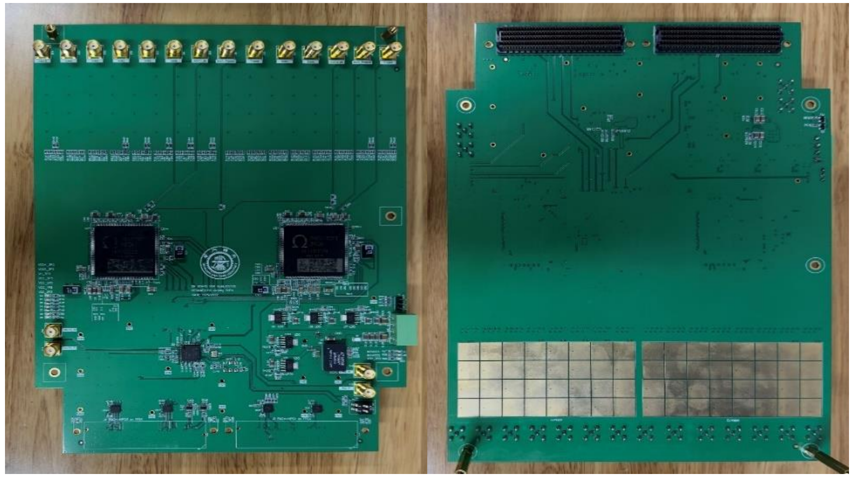


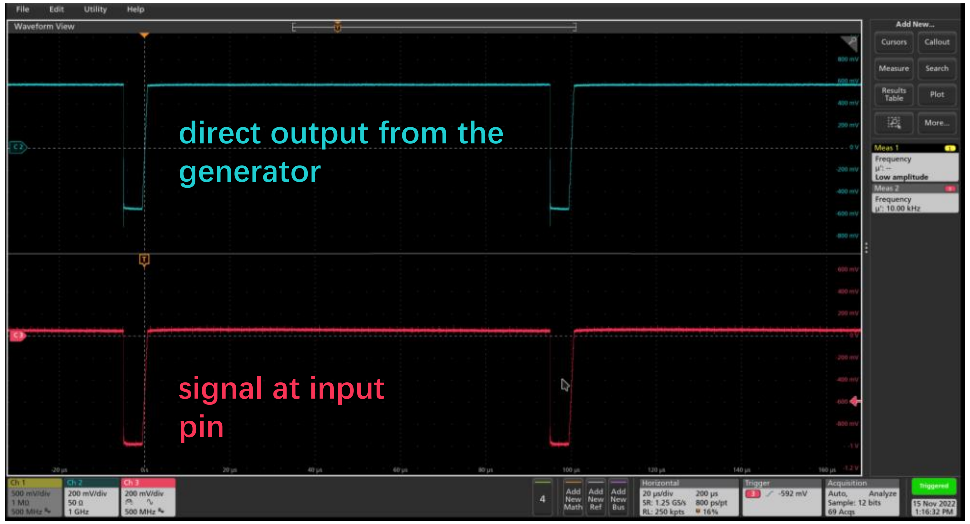

```
==========================10 bit step===========================
Ch0 : 64 Coarsetime: 1100011101, Decode: 100001011 ==> Counter: 267, Hit: 1
Ch1 : 65 Coarsetime: 1000010110, Decode: 111110010 ==> Counter: 498, Hit: 0
Ch2 : 66 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch3 : 67 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch4 : 68 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch5 : 69 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch6 : 70 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch7 : 71 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch8 : 72 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch9 : 73 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch10: 74 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch11: 75 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch12: 76 Coarsetime: 1111100010, Decode: 101011110 ==> Counter: 350, Hit: 0
Ch13: 77 Coarsetime: 1001011110, Decode: 111001010 ==> Counter: 458, Hit: 0
Ch14: 78 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch15: 79 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch16: 80 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch17: 81 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch18: 82 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch19: 83 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch20: 84 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch21: 85 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch22: 86 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch23: 87 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch24: 88 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch25: 89 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch26: 90 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch27: 91 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch28: 92 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch29: 93 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch30: 94 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
Ch31: 95 Coarsetime: 1100010101, Decode: 100001100 ==> Counter: 268, Hit: 1
```

# 第 2 版前端原型验证

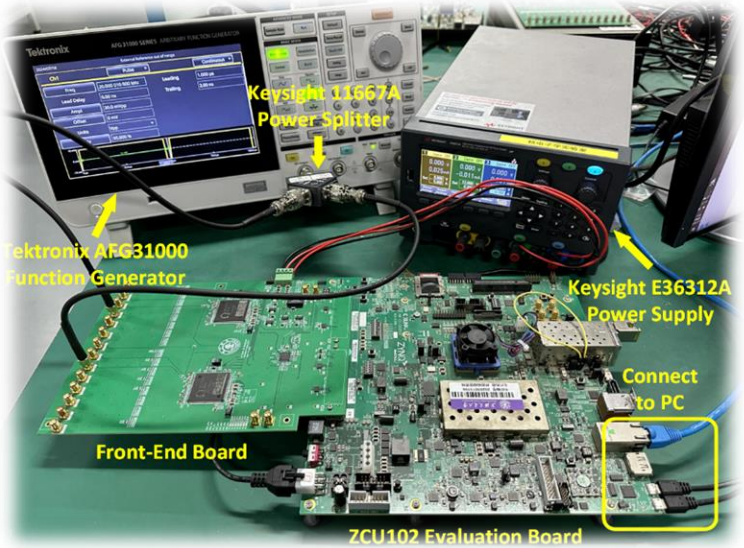
- 包含 2 颗 PETIROC
- 串扰问题得到解决
- 可通过外部注入测试时间测量精度

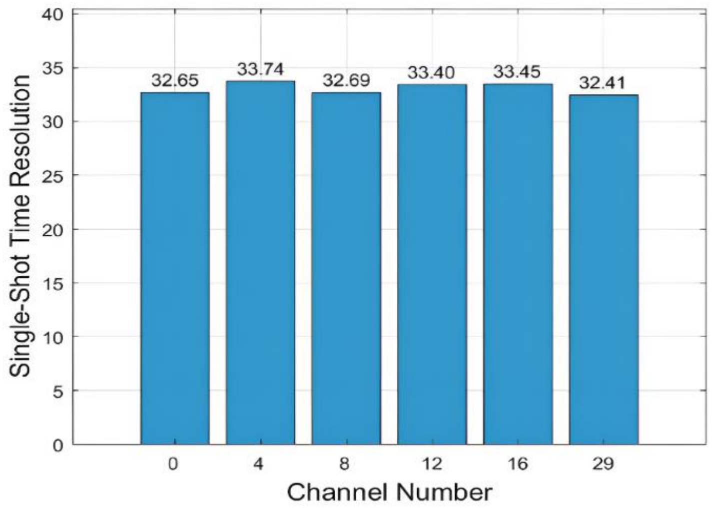


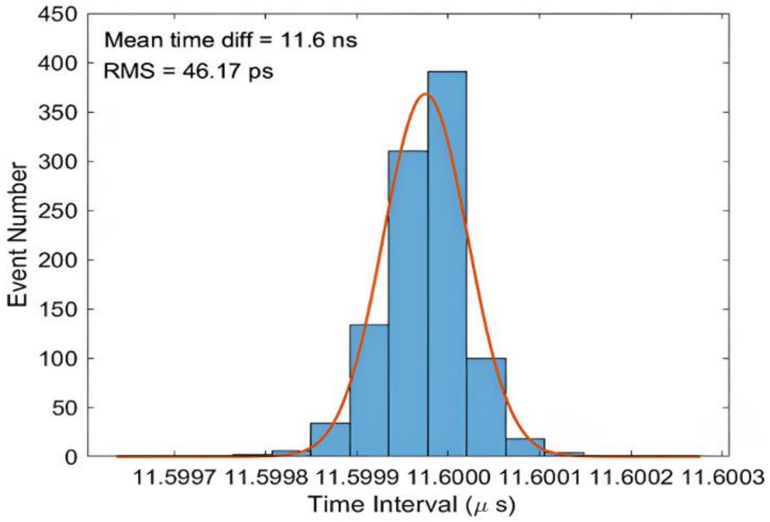


# PETIROC 时间测量精度测试




Time resolution across different channels： $\sigma$=33.06±0.54 ps

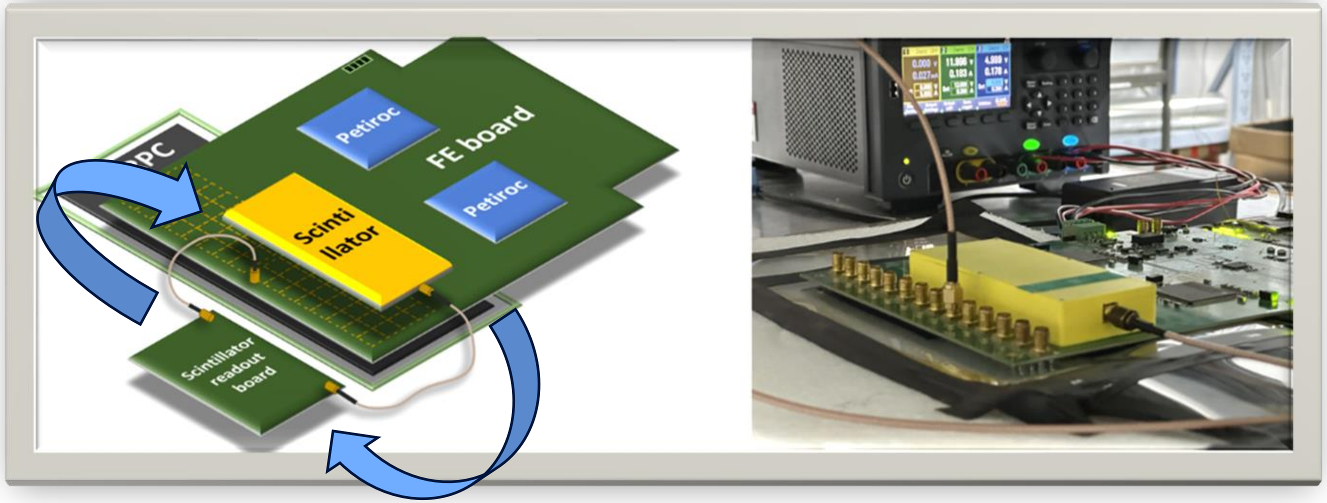


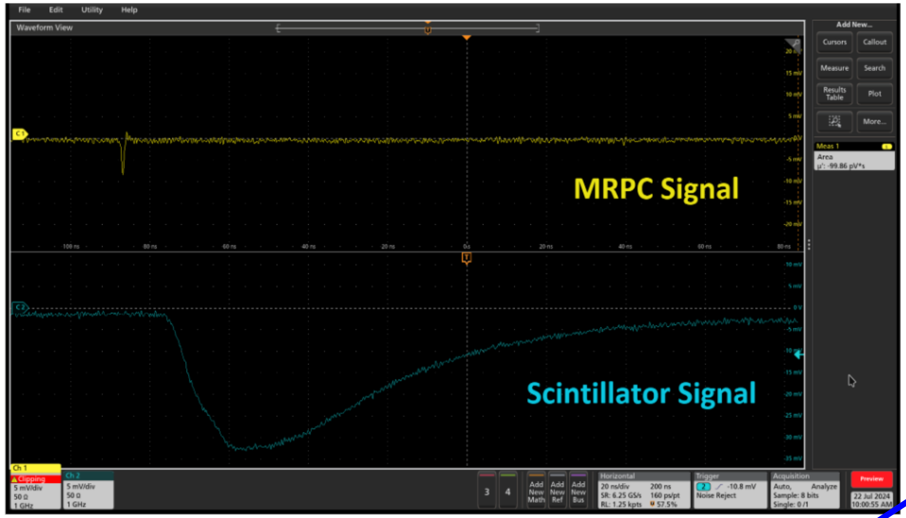

Time resolution in multi-ch：
$\sigma = 43.37 \pm 2.08$ ps

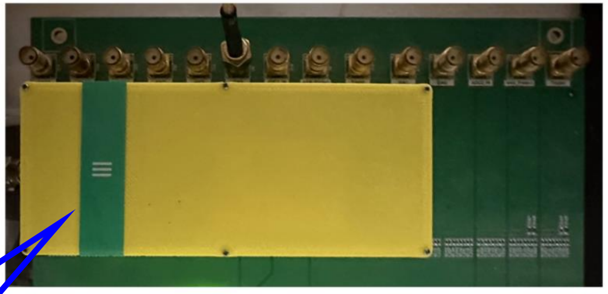
- 注入信号给同一颗芯片的不同通道：
  - 计算两个相邻触发的时间差
- 注入信号给两颗芯片的不同通道：
  - 计算不同芯片两个相邻触发间的时间差

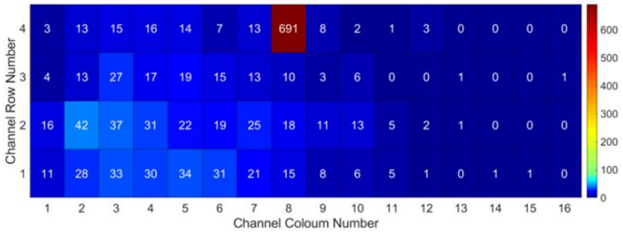
# MRPC 宇宙线联调测试

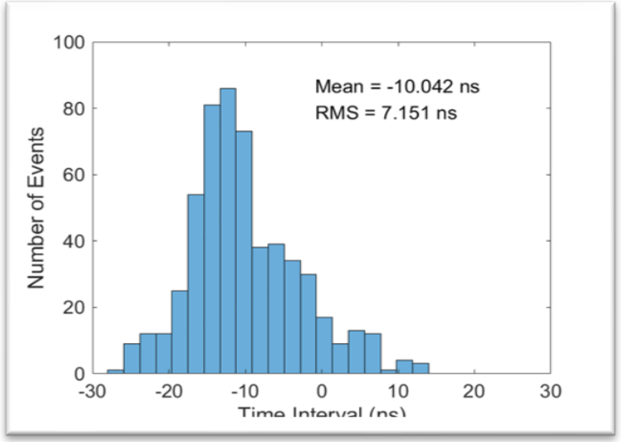
- 闪烁体信号注入 PETIROC
- 闪烁体信号做触发
- 测试闪烁体信号和MRPC信号时间差





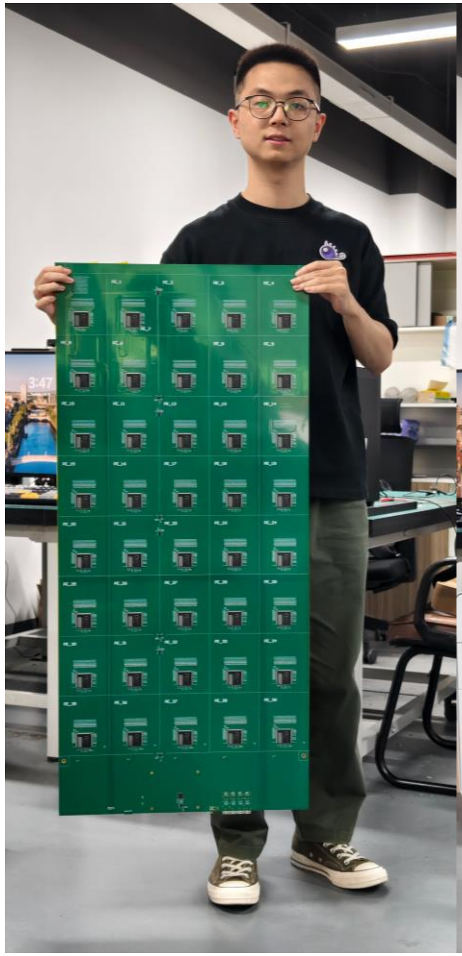




Time differences between MRPC and scintillator signals

背面金属 pad

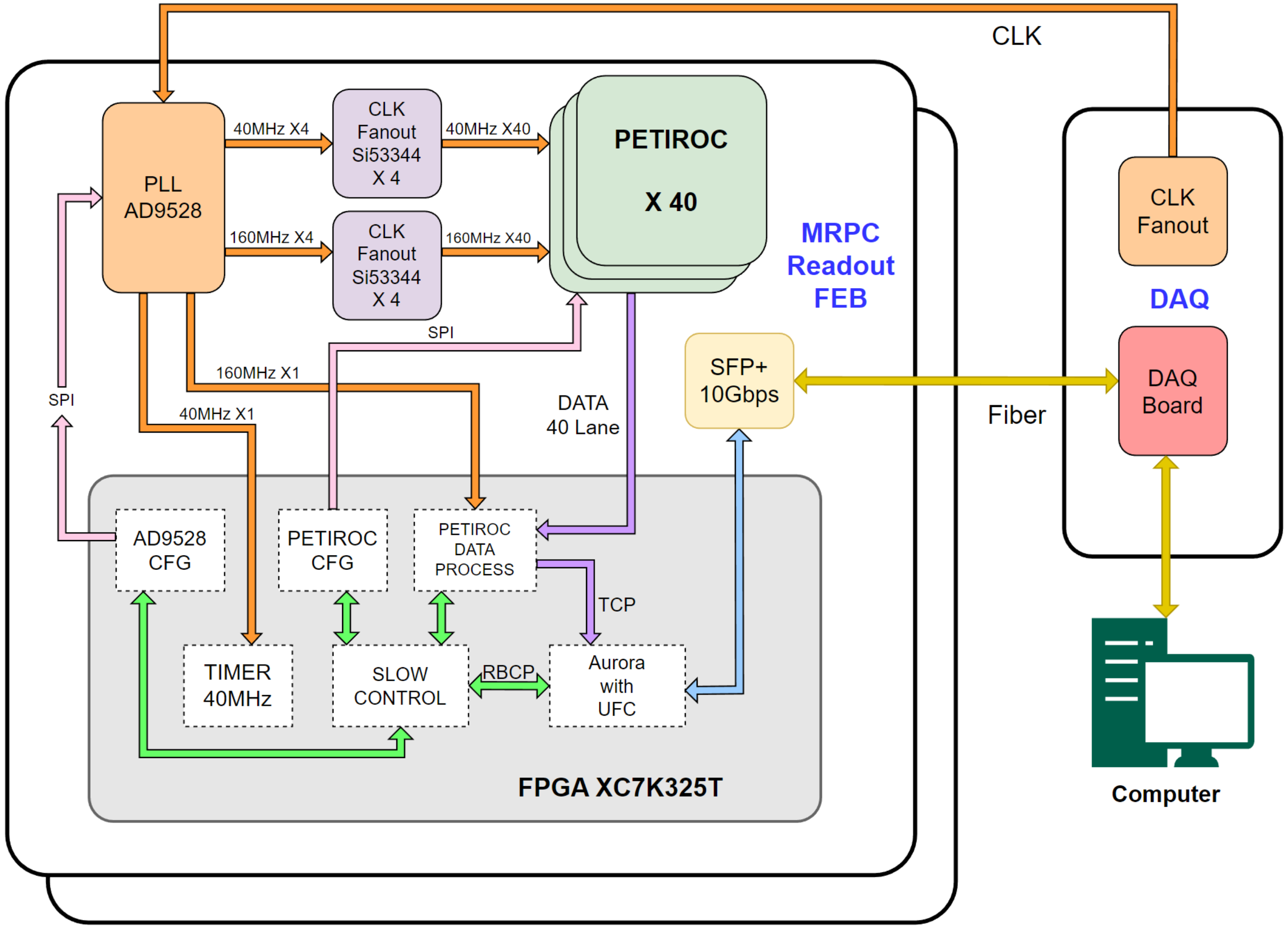
# MRPC 大面积前端读出板设计

- **前端读出电子学板**
  - 两块前端板, 每片 40 颗 PETIROC
  - 尺寸: 110cm x 50cm, pad: 2cm x 2cm
  - 48 x 25 个 pad 感应 MRPC 信号
  - PETIROC 由法国 Imad Laktineh (Lyon) 提供
  - 自主设计 FPGA(7K325T) 核心板接收和处理数据

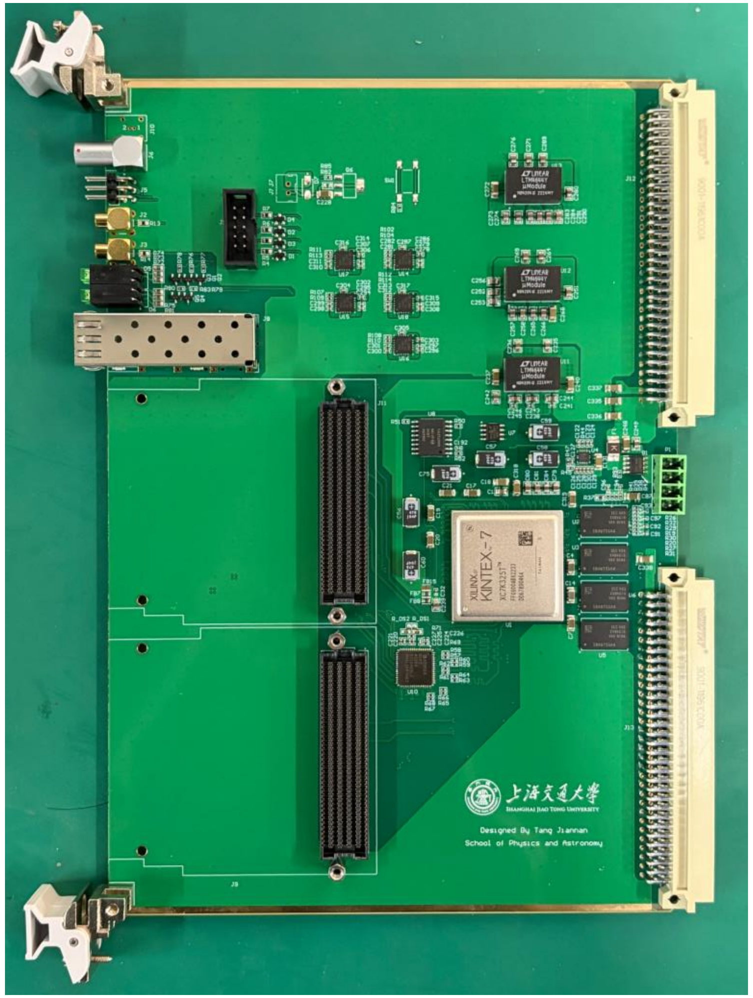



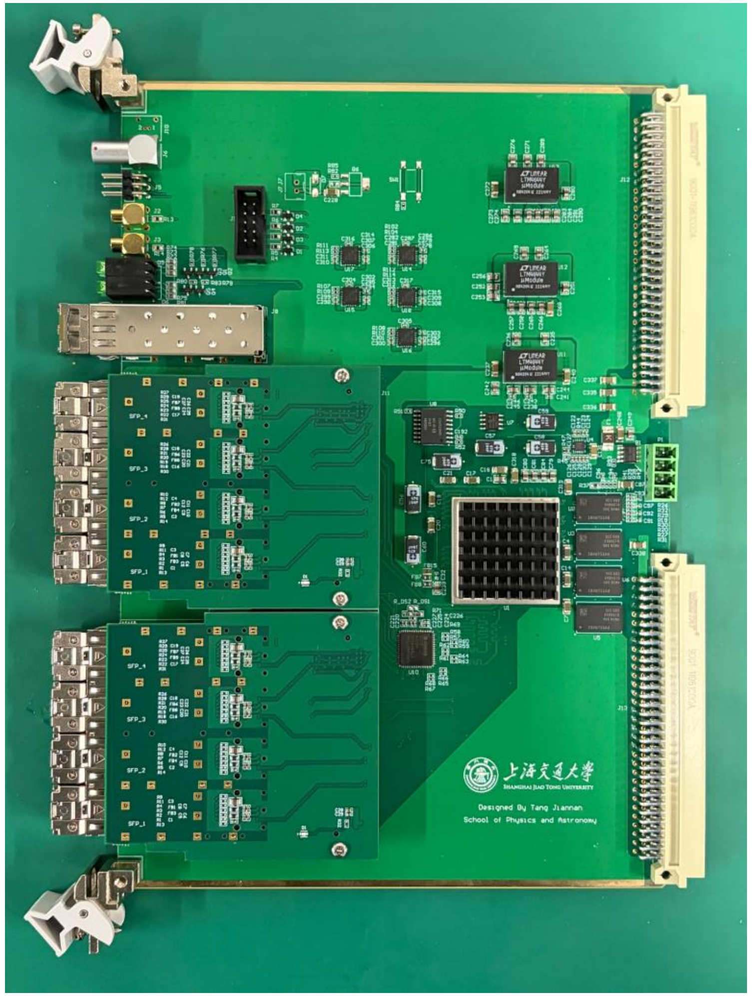
# 读出电子学系统设计

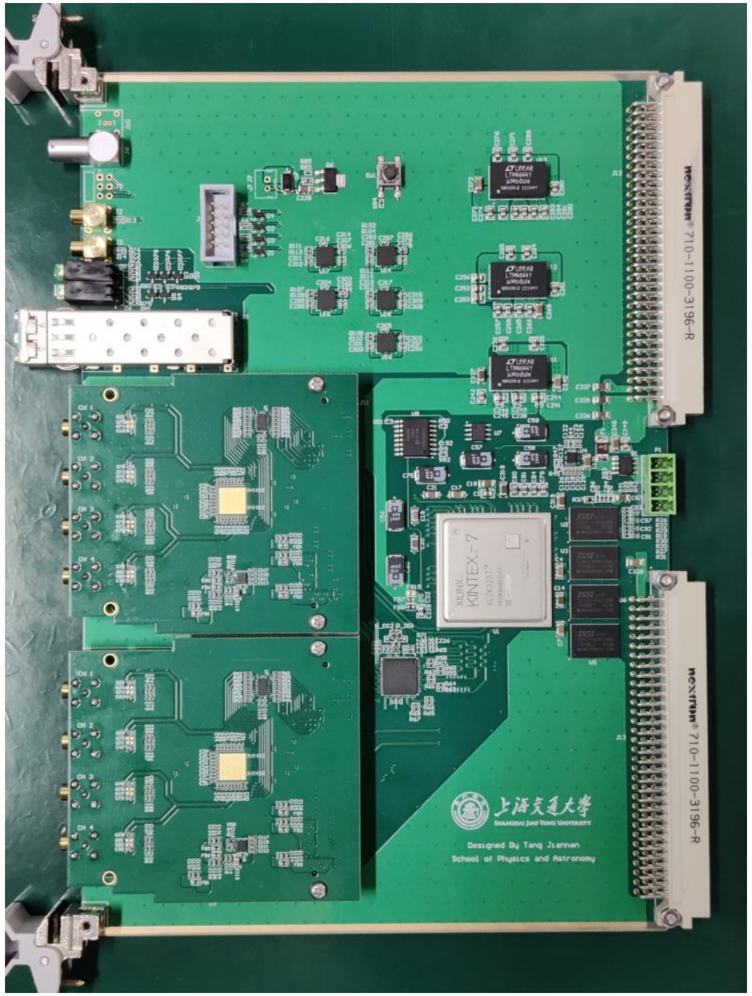
- DAQ：汇总前端板数据，分发慢控
  - 万兆 SiTCP 与电脑通信
  - 基于 Aurora UFC 的分布式慢控
- 前端板：2 片，读出 MRPC 信号
  - FPGA 汇总和处理 PETIROC 数据，控制 FEB
  - 两块 FEB 80 颗 PETIROC 时钟同步
  - 10G SFP+ 传输数据

# 模块化 DAQ 系统

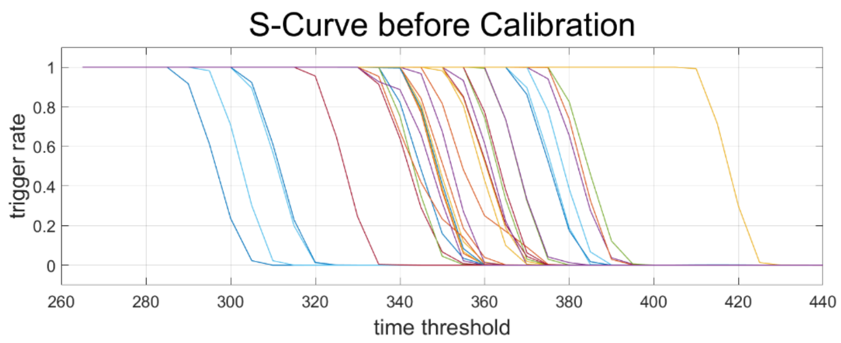


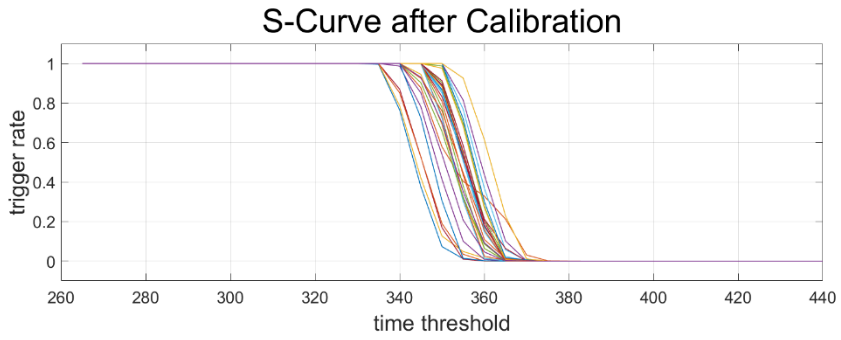


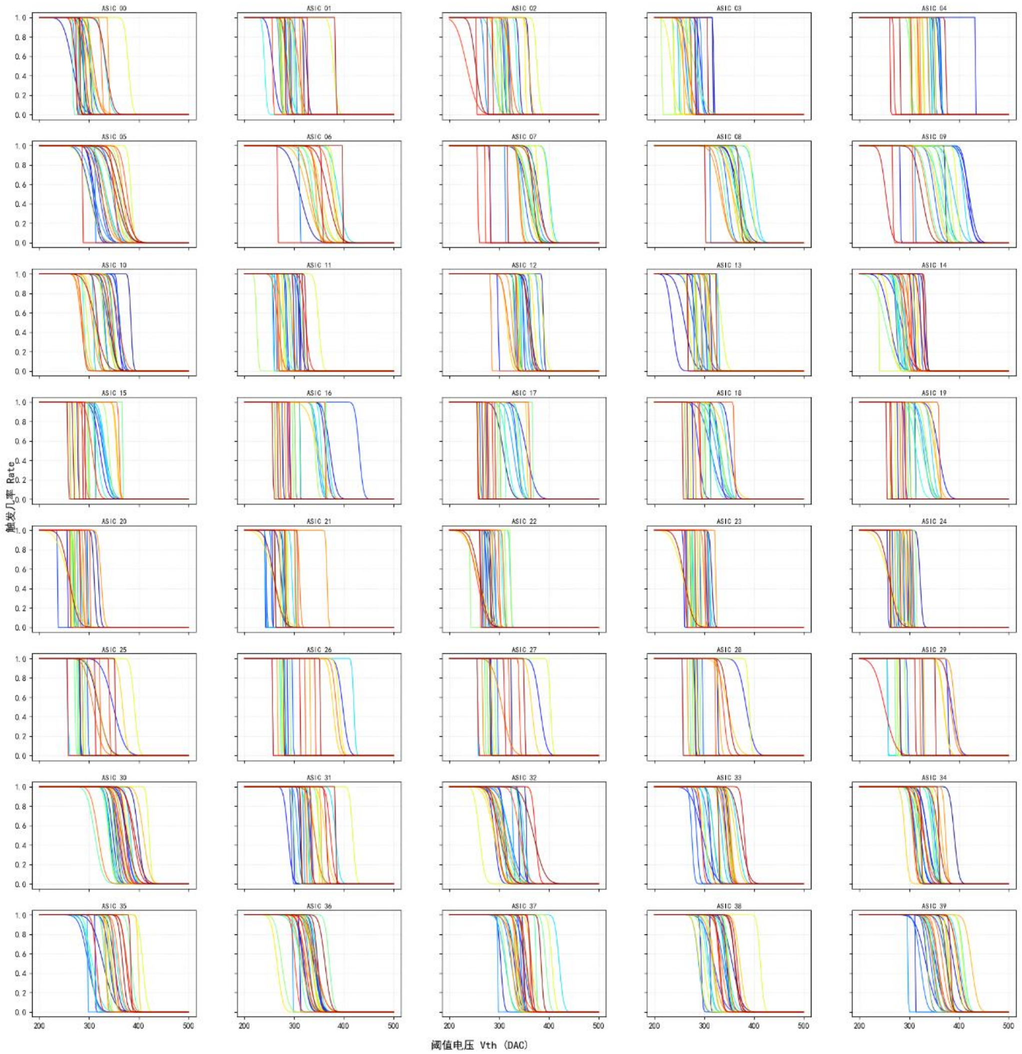


# 前端板刻度测试

- 编写自动扫描 S 曲线程序
- 避免串扰，逐行逐通道刻度
- 正在与 MRPC 联调测试



# 总结

- MRPC 相对于传统 RPC 对读出电子学时间测量性能提出了更高要求
- 采用更高颗粒度的 pad 读出方式，支持更高事例率
- PETIROC2B 因其多通道、高时间分辨率等特点被我们采用读出 MRPC 信号
- 对 PETIROC2B 进行了详细的技术验证和测试
- 设计了 2 块包含 40 颗 PETIROC2B 芯片、尺寸 110cm*50cm 的前端读出板，结合自主设计的 DAQ 系统，组成了一整套可读出 1m*1m 大面积 MRPC 的电子学样机
- 刻度了前端电子学的 PETIROC 芯片 S 曲线，正在与 MRPC 联调测试

# Thank you for your attention

# backup： ASIC 调研

## Mainstream MRPC Readout ASICs

| ASIC Name | Channels / Chip | Architecture Type | Built-in TDC/ADC | Max Event Rate | Key Strengths & Best Use Cases |
|---|---|---|---|---|---|
| NINO (CERN) | 8 | Analog Frontend | No | High | Extreme time resolution 10 ps. Benchmark for Strip TOF. |
| PADI (GSI) | 8 | Analog Frontend | No | 1MHz | Ultra-high rate capability for high-luminosity colliders (CBM). |
| Petiroc 2B (OMEGA) | 32 | Integrated SOC | Yes | 40kHz | Selected Scheme. Ultra-low power 6 mW/ch, high density |
| TOFPET 2 (PETsys) | 64 | Integrated SOC | Yes | 480 kHz | Maximum channel density, dual-threshold triggering. |
| SAMPIC (CEA/CNRS) | 16 | Waveform – based TDC | Yes | Medium | 8.5 - 10 GSPS. Best for AI-driven Muon Tomography. |

## Mapping of the OMEGA ASIC Family

| ASIC Name | Channels | Primary Focus | Built-in TDC / ADC | Target Sensor | Key Comparison vs. Petiroc 2B |
|---|---|---|---|---|---|
| Petiroc 2B | 32 | Time and Charge SOC | Yes / Yes | SiPM / Fast MRPC | Baseline Scheme. Balanced high-density, picosecond timing, and low power. |
| Citiroc 1A | 32 | High-Precision Charge | No / Yes | SiPM / MPPC | Lacks built-in TDC. Only outputs fast trigger for external digitization. |
| Triroc | 64 / 32 | Multi-Modal Imaging | Yes / Yes | SiPM / Bipolar Systems | Higher density, wider charge dynamic range, supports bipolar inputs. |
| Spiroc 2E | 36 | Calorimetry (ILC) | No / Yes | SiPM / Calorimeter | Large analog memory (16 depths), but time resolution is too slow (ns-level). |