



LGAD与ALTIROC芯片和LATIC芯片 倒装键合后的时间性能

李莊

Overview

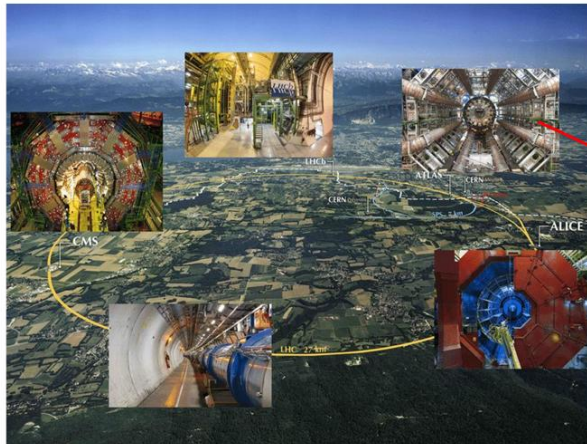
- ▶ 背景介绍
- ▶ LGAD与ALTIROC键合后的时间性能
- ▶ 自研LATIC芯片及其与LGAD键合过程
- ▶ 总结

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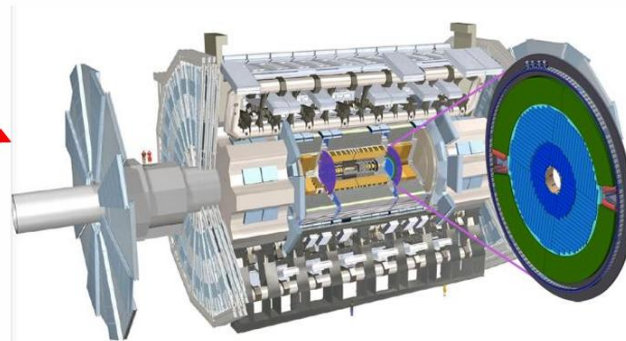
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ATLAS HGTD project

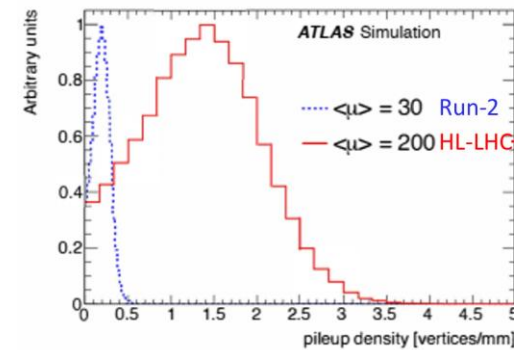
- ▶ LHC亮度升级：提升碰撞频率，能够更加有效地进行粒子物理实验
- ▶ 堆积问题：碰撞频率提升带来大量无效事例，使基于空间信息的重建变得困难
- ▶ 应对方法：引入高精度的时间信息，增强粒子区分能力，使事例重建更准确
- ▶ **HGTD**: High-Granularity Timing Detector
 - ◇ 50 ps ; 1.3 mm × 1.3 mm
- ▶ **LGAD**: Low-Gain Avalanche Detector



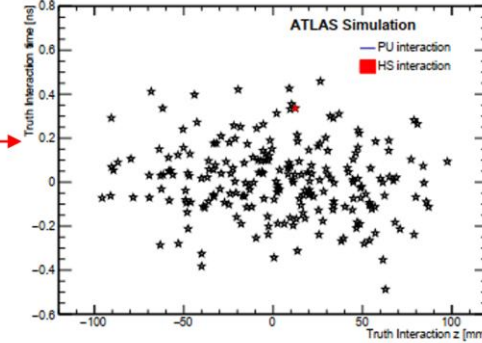
ATLAS Detector in LHC



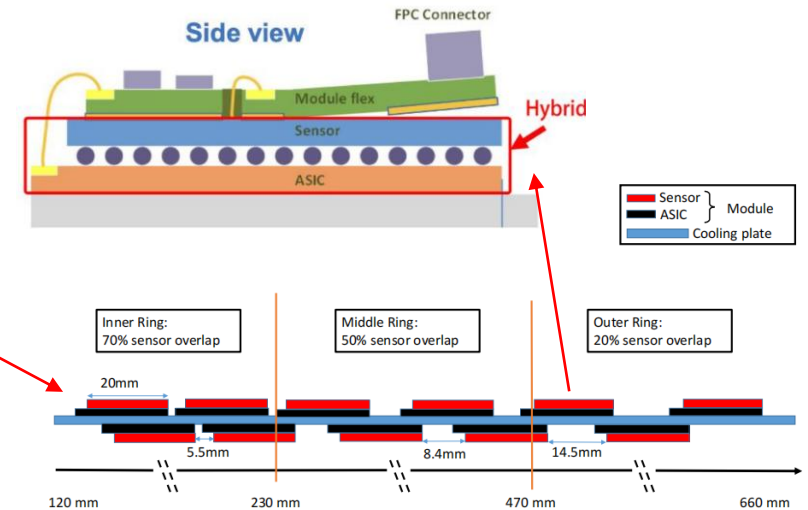
Position of the HGTD within ATLAS



Local pileup vertex densities at generator level



truth interactions in a single bunch crossing in the z-t plane

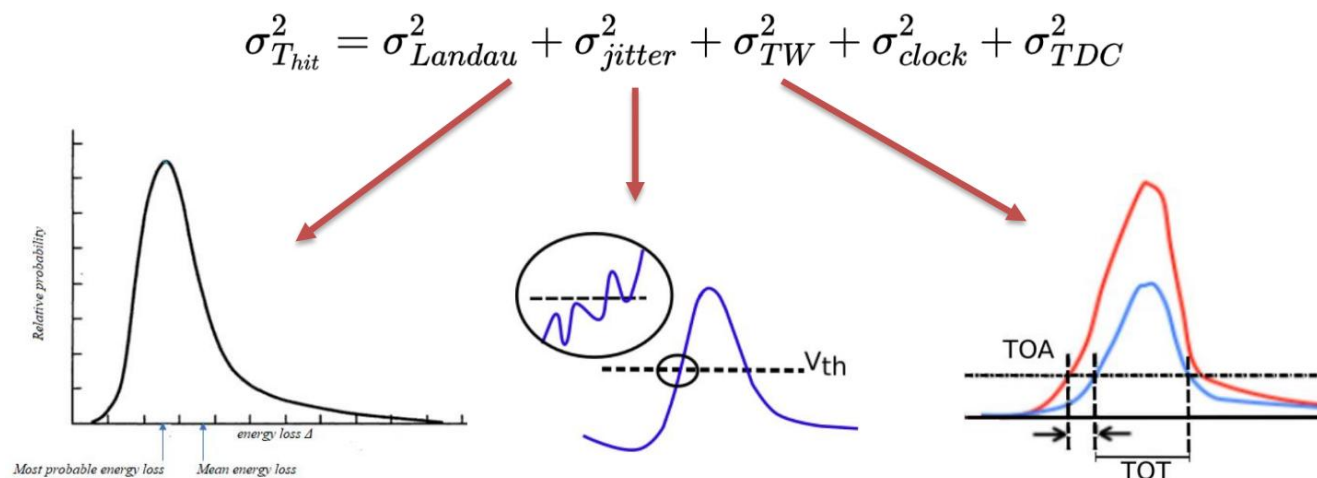


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时间性能：精度的贡献项和测试方法

- ▶ LGAD读出中影响时间性能的因素：



- ▶ 激光测试：

$$\sigma_{T_{hit}}^2 = \cancel{\sigma_{Landau}^2} + \sigma_{jitter}^2 + \cancel{\sigma_{TW}^2} + \sigma_{clock}^2 + \sigma_{TDC}^2$$

- ▶ 放射源+示波器测试：

$$\sigma_{T_{hit}}^2 = \sigma_{Landau}^2 + \sigma_{jitter}^2 + \sigma_{TW}^2 + \cancel{\sigma_{clock}^2} + \cancel{\sigma_{TDC}^2}$$

- ▶ 放射源/束流测试(片内TDC)：

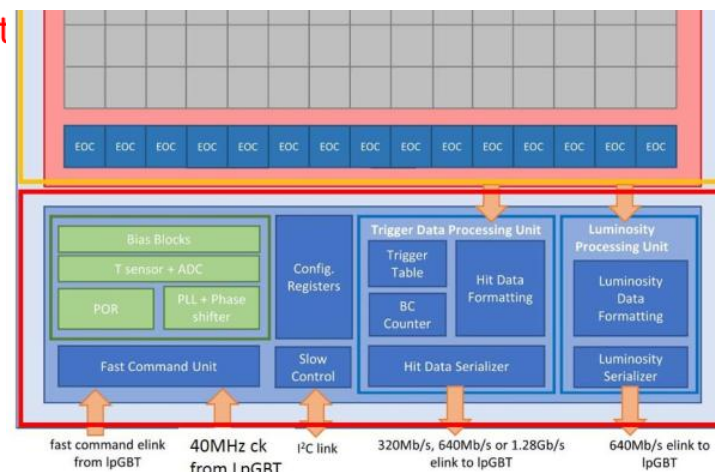
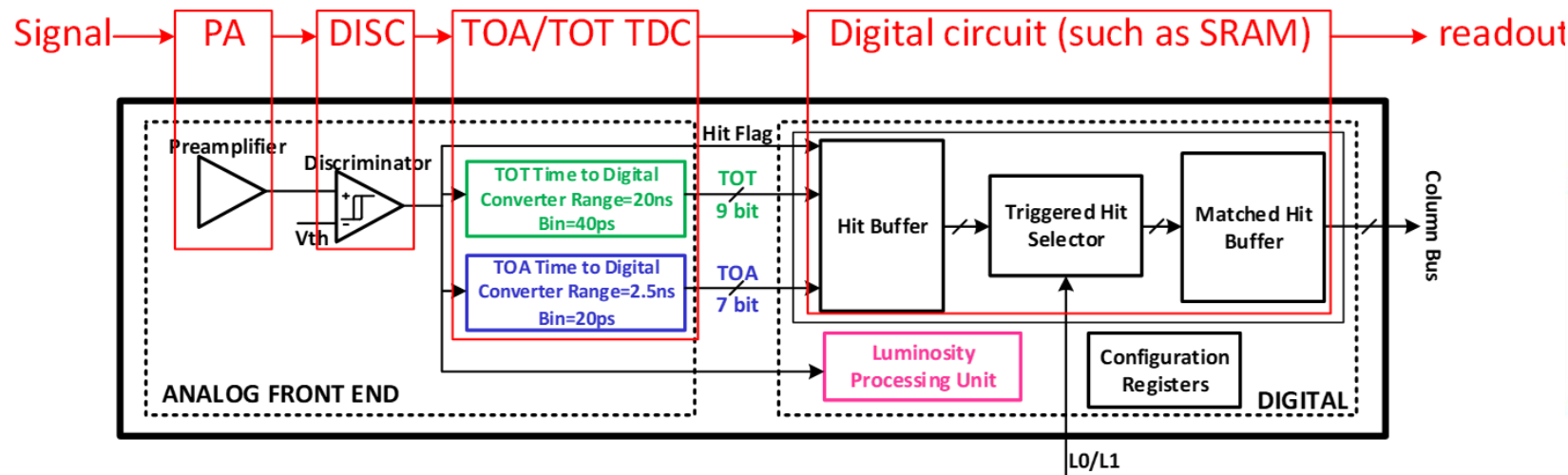
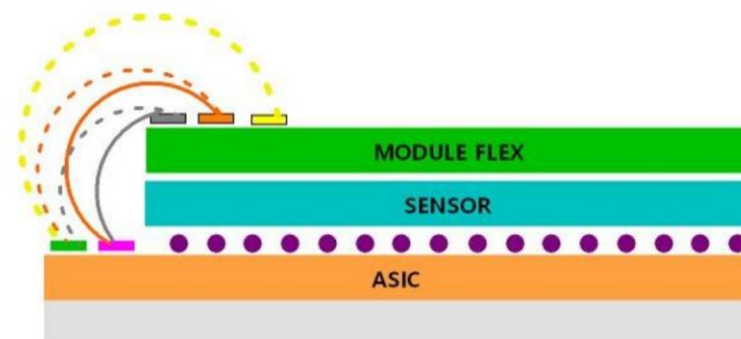
$$\sigma_{T_{hit}}^2 = \sigma_{Landau}^2 + \sigma_{jitter}^2 + \sigma_{TW}^2 + \sigma_{clock}^2 + \sigma_{TDC}^2$$

Hybrid tested

测试板编号	sensor	ALTIROC	Hybridization	已完成的测试
B109	Pre-production IHEP-IME	A	Baseline Hybridization	Laser、testbeam
B110	Pre-production IHEP-IME	A	Baseline Hybridization	β 、testbeam
B117	Pre-production USTC-IME	A	ACP Hybridization	β 、testbeam
B118	Pre-production USTC-IME	A	ACP Hybridization	Laser、testbeam
USTC-B1	Pre-production USTC-IME	3	Baseline Hybridization	Electronic、 β

ALTIROC芯片简介

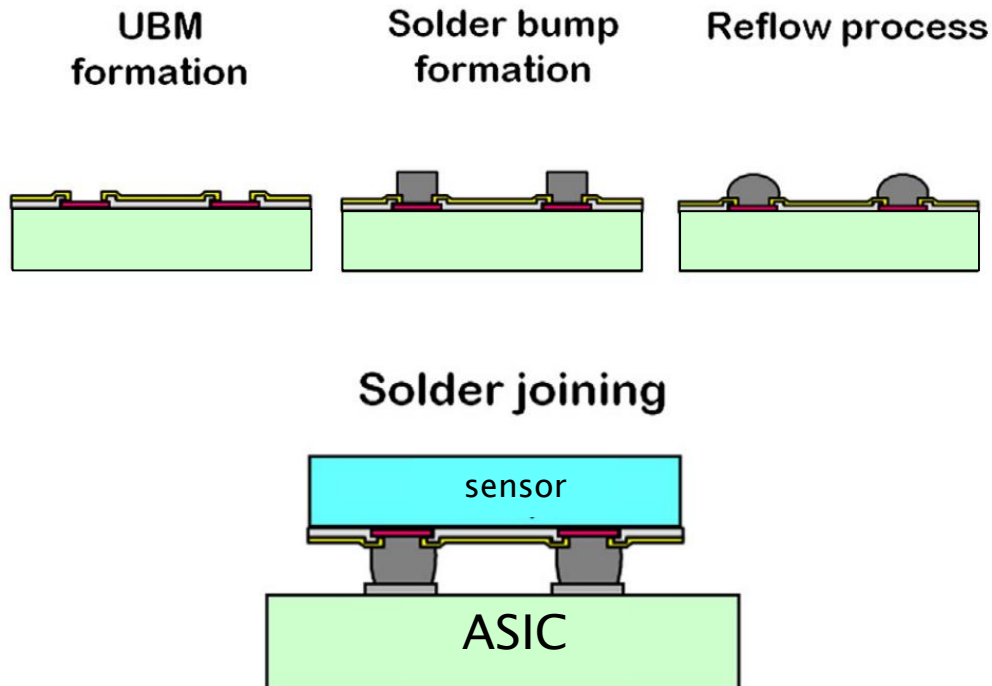
- ALTIROC, ATLAS LGAD Timing Integrated Readout Chip (15×15 通道)
- 功能：对LGAD输出的微弱电流信号完成放大、甄别、到达时间(TOA)和过阈时间(TOT)的测量
- 结构：与LGAD相同通道尺寸的阵列型结构，15×15通道
 - 通道内电路：前放、甄别器、TDC、数字电路
 - 外围电路：偏置、时钟、慢控制、触发和数据处理
- 版本迭代：ALTIROC-3到ALTIROC-A升级
 - 决定时间分辨的前端电路不变
 - 在TDC中用高阈值MOS管减小功耗
 - 去除TDC的TOA busy信号改善TDC非线性，修改一些数字bug
 - 优化pad阵列便于打线



Hybrid的两种键合方式

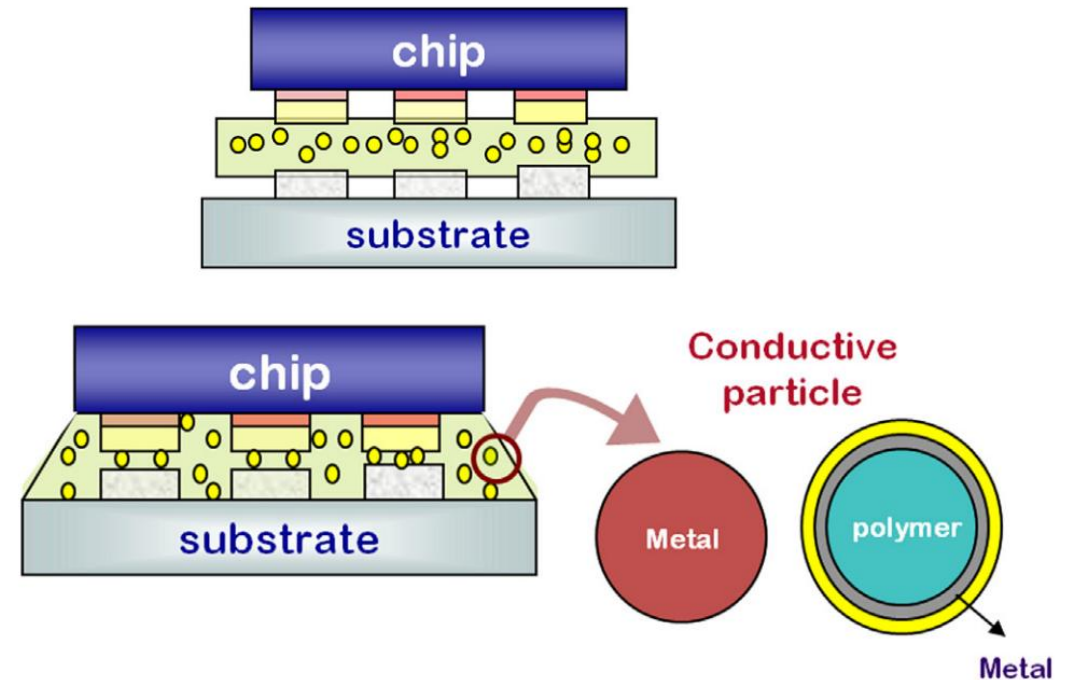
▶ Baseline hybridization

- ◇ Sensor and ASIC UBM
- ◇ Deposited solder bumps (SnAg, 80 μm) on ASIC
- ◇ Align, heat and compress



▶ ACP Hybridization

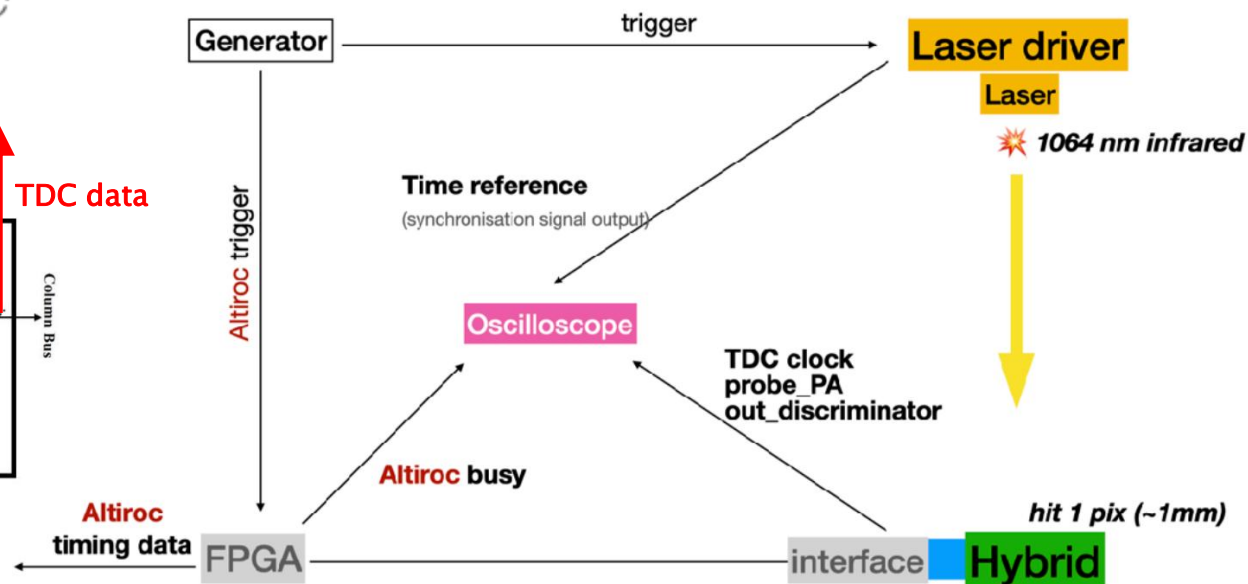
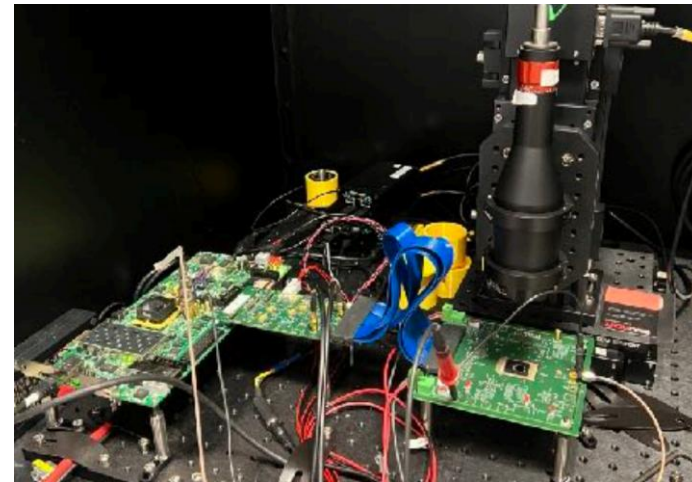
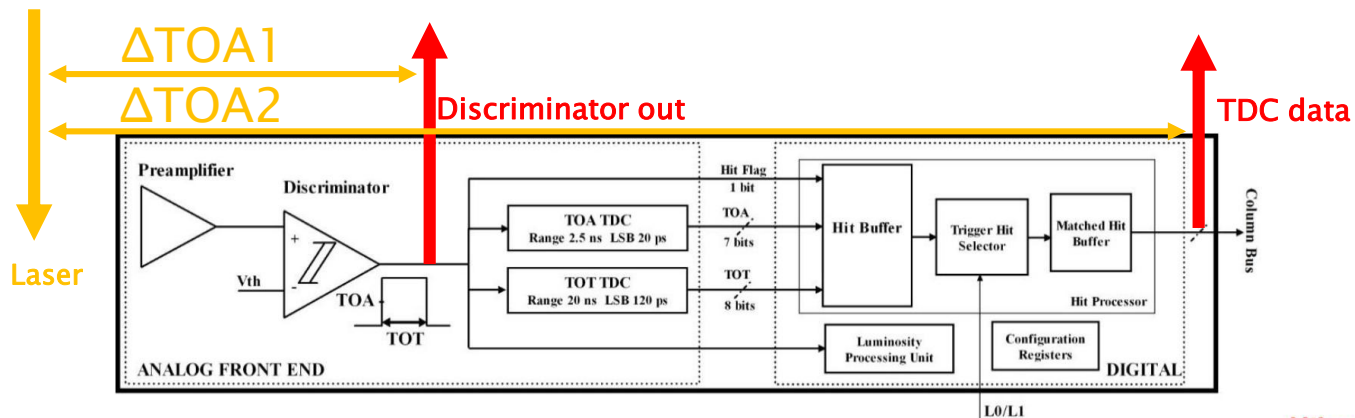
- ◇ (Double) gold stud deposition
- ◇ Anisotropic Conductive Paste (ACP)
- ◇ Non-Conductive Adhesive (NCA)
- ◇ Align and compress



激光测试

- ▶ 信号源产生两路同步信号，分别触发激光和读出。激光源产生激光和时间参考电信号。
- ▶ $\Delta TOA1$ ：示波器直接测量激光时间参考信号和甄别器信号的时间差。
- ▶ $\Delta TOA2$ ：用片内TDC测激光信号相对时钟的时间差，用示波器测激光时间参考信号相对时钟的时间差，二者作差。

$$\sigma_{T_{hit}}^2 = \cancel{\sigma_{Landau}^2} + \cancel{\sigma_{jitter}^2} + \sigma_{TW}^2 + \sigma_{clock}^2 + \sigma_{TDC}^2$$



激光测试

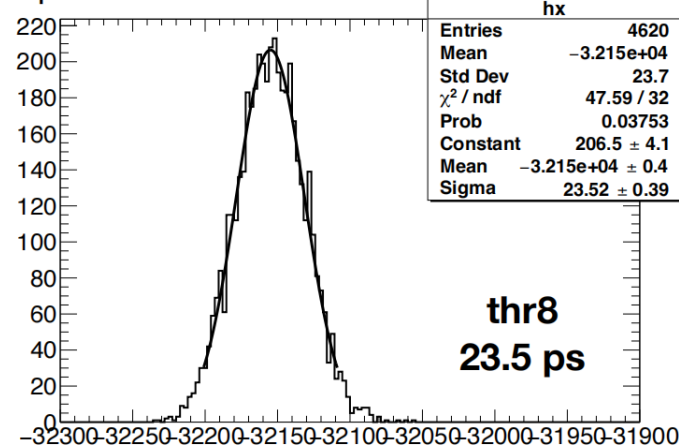
▶ IHEP sensor + baseline键合(1 pixel tested)

- ◇ 信号幅度 ~26mV
- ◇ Disc-Laser 23.5 ps
- ◇ TDC-Laser 26 ps

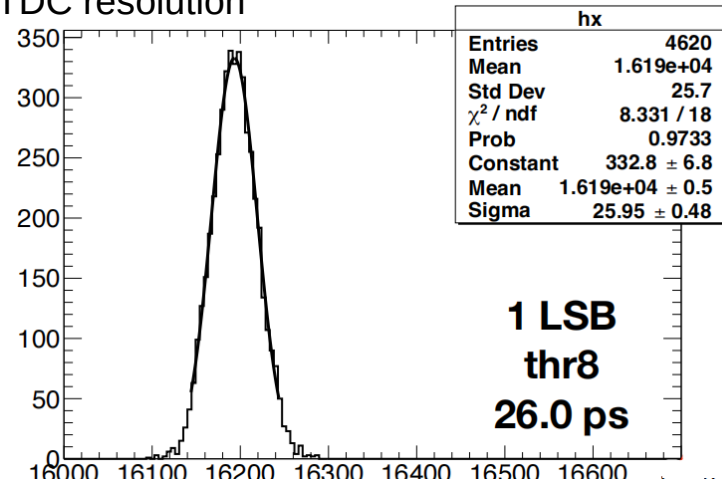
▶ USTC sensor + ACP键合(5 pixels tested)

- ◇ 信号幅度 ~30mV
- ◇ Disc-Laser 16-19 ps
- ◇ TDC-Laser around 25-30 ps

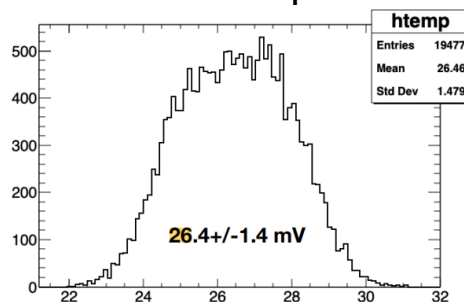
B109 probe discriminator resolution



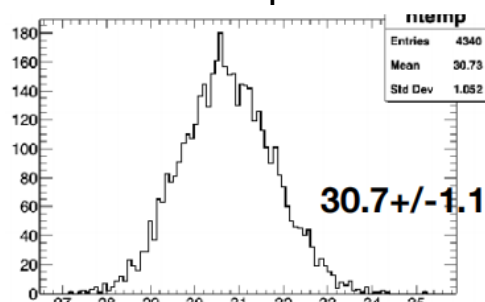
TDC resolution



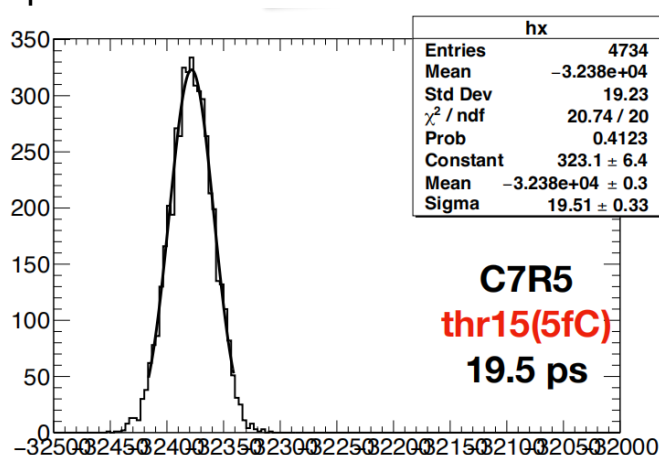
B109 PA amplitude



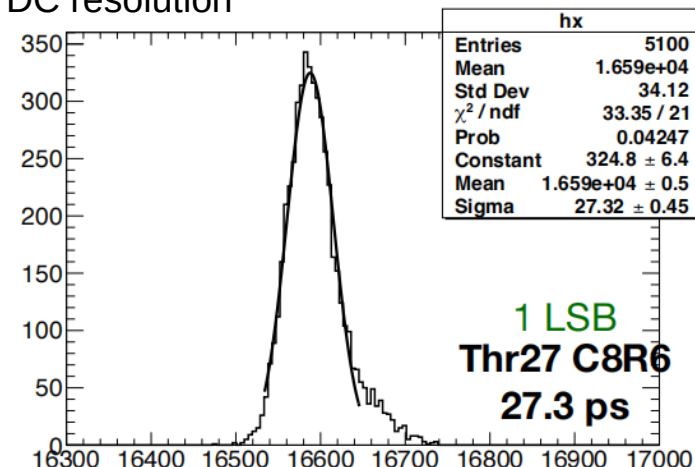
B118 PA amplitude



B118 probe discriminator resolution



TDC resolution

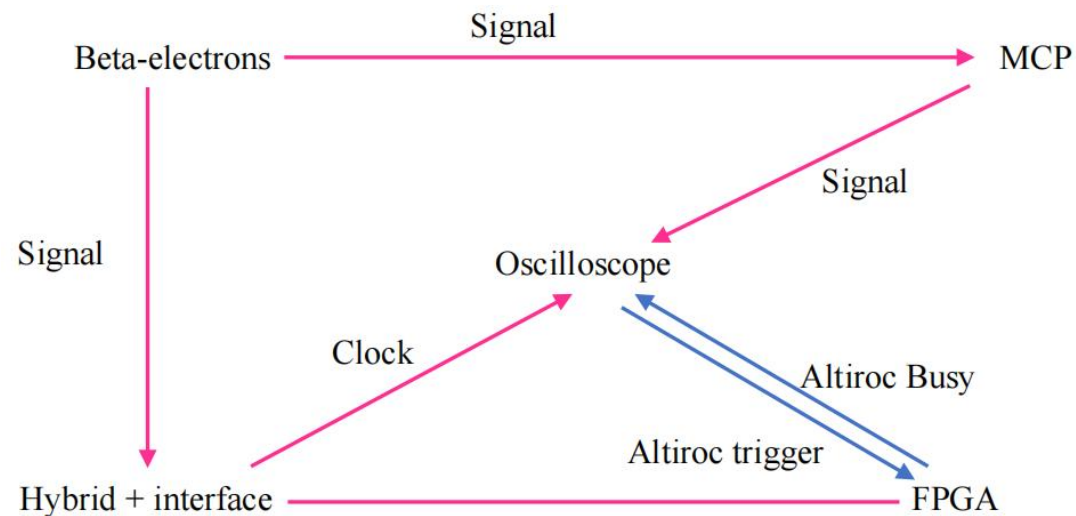
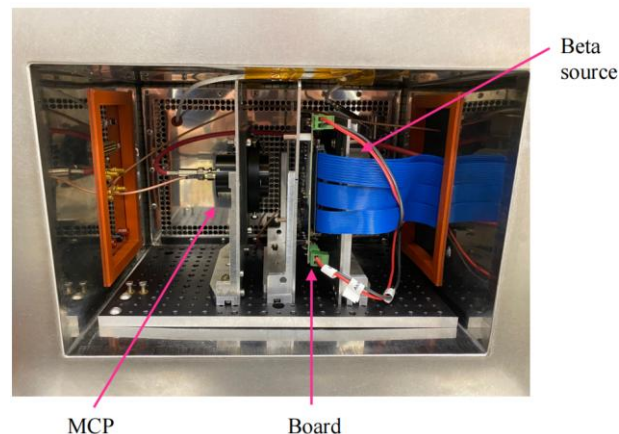


放射源测试

► Testbench in CERN

- ◇ 环境温度: -30°C
- ◇ 放射源: ^{90}Sr
- ◇ $\sigma_{\text{MCP}} \sim 10 \text{ ps}$

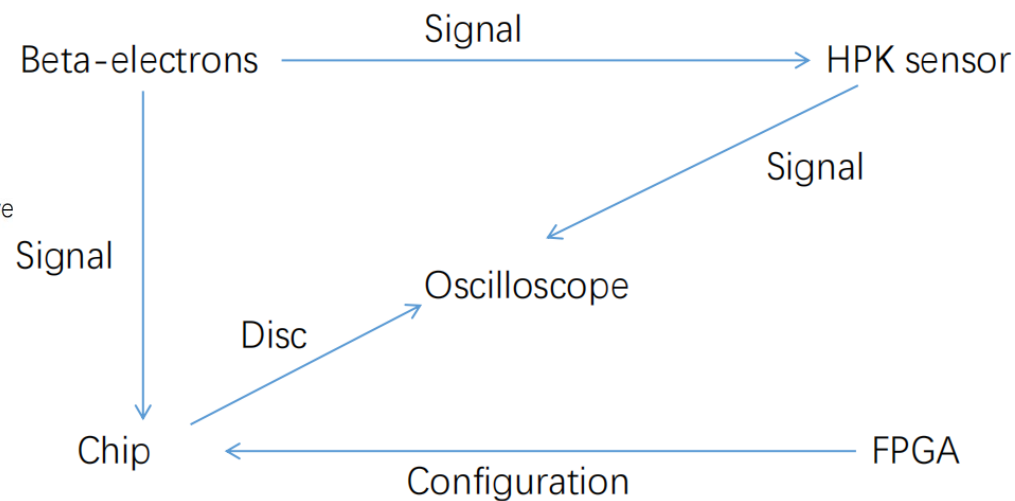
$$\sigma_{T_{\text{hit}}}^2 = \sigma_{\text{Landau}}^2 + \sigma_{\text{jitter}}^2 + \sigma_{\text{TW}}^2 + \sigma_{\text{clock}}^2 + \sigma_{\text{TDC}}^2$$



► Testbench in USTC

- ◇ 环境温度: -30°C
- ◇ 放射源: ^{90}Sr
- ◇ $\sigma_{\text{HPK sensor}} \sim 45 \text{ ps}$

$$\sigma_{T_{\text{hit}}}^2 = \sigma_{\text{Landau}}^2 + \sigma_{\text{jitter}}^2 + \sigma_{\text{TW}}^2 + \cancel{\sigma_{\text{clock}}^2} + \cancel{\sigma_{\text{TDC}}^2}$$



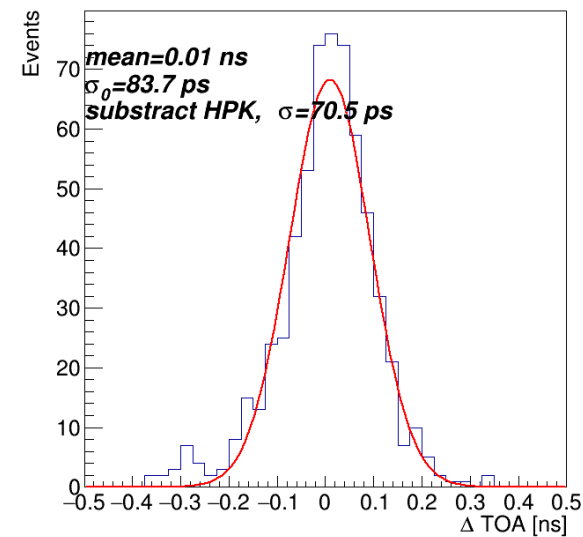
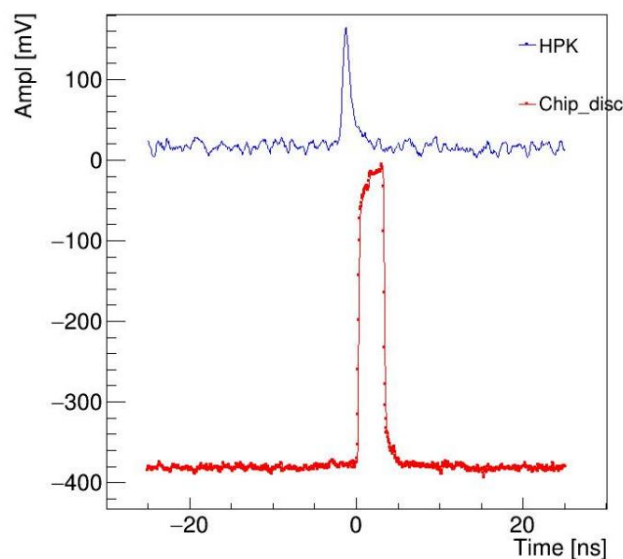
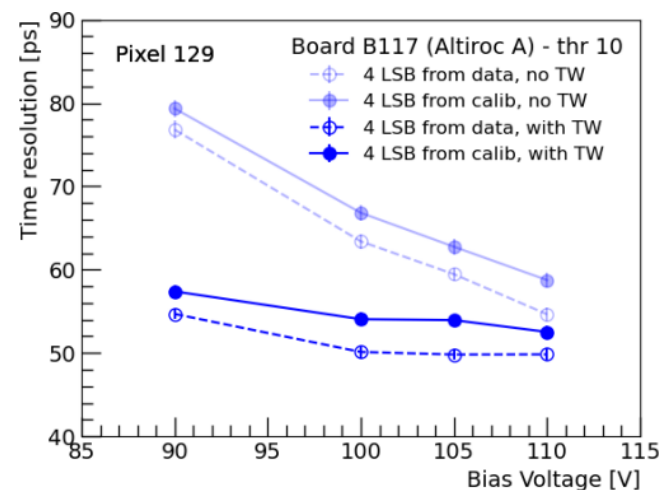
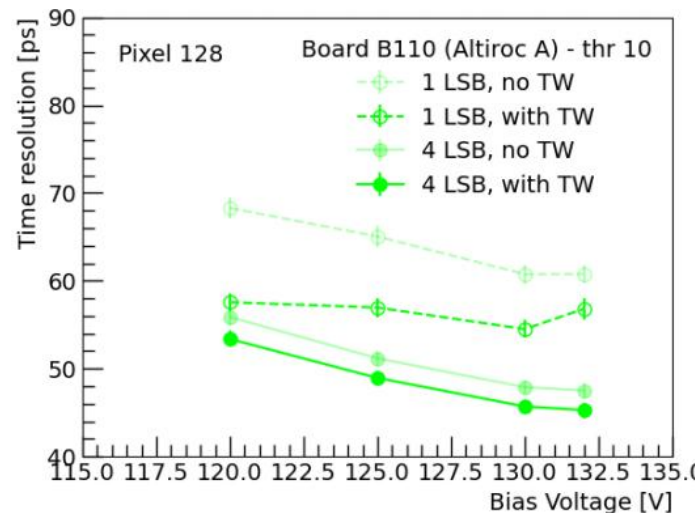
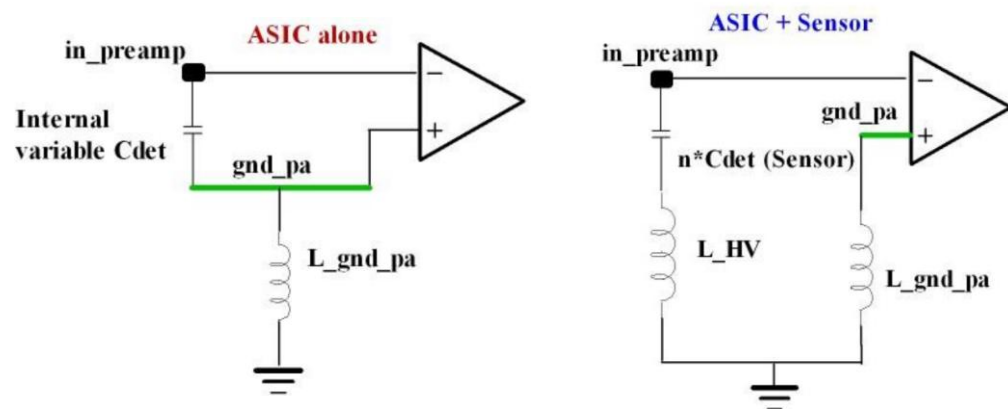
放射源测试

► Test in CERN

- ◇ IHEP sensor + baseline键合
 - Better time resolution at higher voltage (~45 ps)
- ◇ USTC sensor + ACP键合
 - Time resolution ~ 51 ps
- ◇ Better time resolution using LSB calibration and time walk calibration.

► Test in USTC

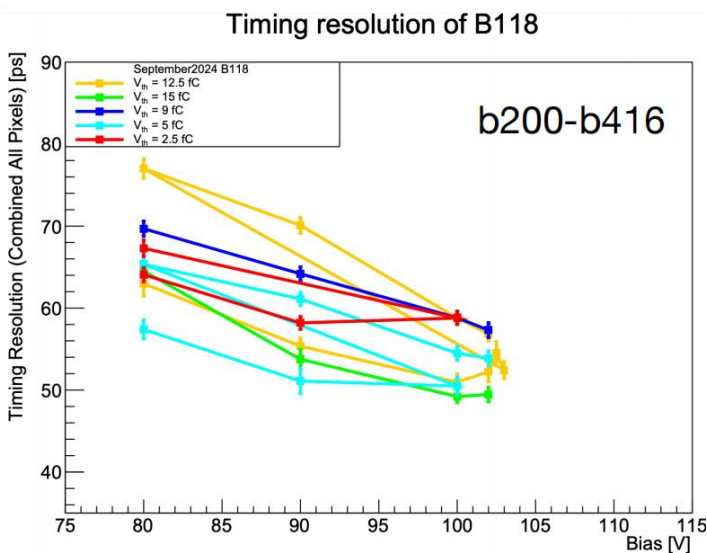
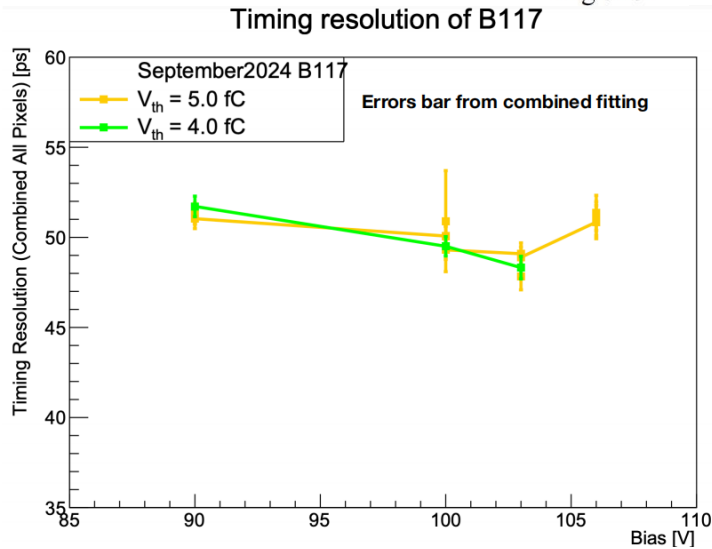
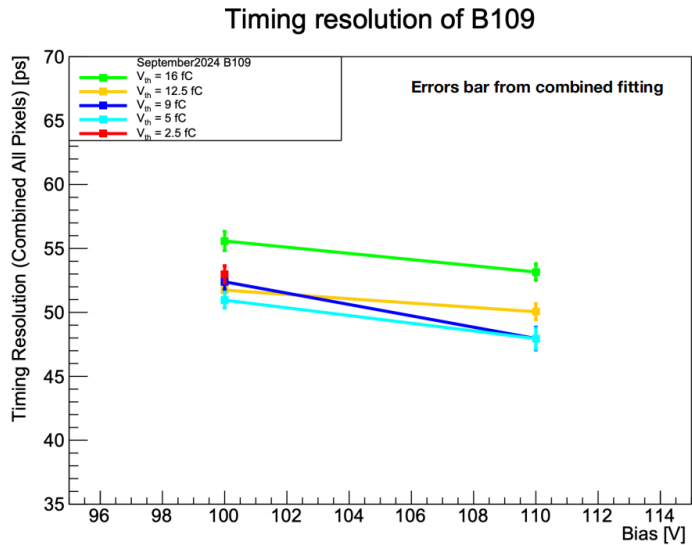
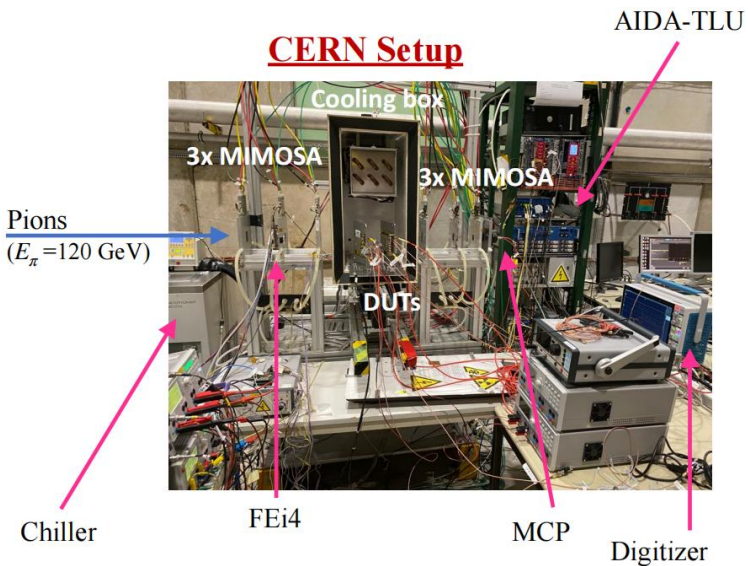
- ◇ USTC sensor + baseline键合
 - TW and subtract HPK: 70.5 ps
 - Reason for bad resolution: HV decouple



束流测试

- Set-up:
 - CERN SPS with 120 GeV pion beam
 - Temperature stable at -30 °C
 - $\sigma_{\text{MCP}} \sim 10$ ps
- 测试结果:
 - 两种sensor和键合方式都可以实现优于50ps的性能，像素之间具有良好的均匀性。

Board	Best timing [ps]	Bias [V]@Best timing	threshold [fC] @Best timing	Probe MPV [mV] @Best timing
B109	45.88	110	5-9	35
B117	47.91	103	4-5	25
B118	47.63	100	5 or 15	29



小结

- 根据测试结果，对时间精度的各项贡献估计如下：

Factor	Contribution	Comments
1- ASIC jitter	18 $\pm$ 2 ps	Qinj 20 fC
2- Clocks jitter	14 $\pm$ 1 ps	No seen during testbeam
3- TW contribution	25 $\pm$ 10 ps	TW correction works well, less efficient when were are close to the breakdown Voltage as less TW to be corrected
4- Sensor's Landau fluctuation	30 $\pm$ 5 ps	
5- TOA TDC Non Linearity	22 $\pm$ 5 ps	Possible contribution of digital noise
TOTAL	50.3 $\pm$ 12 ps	

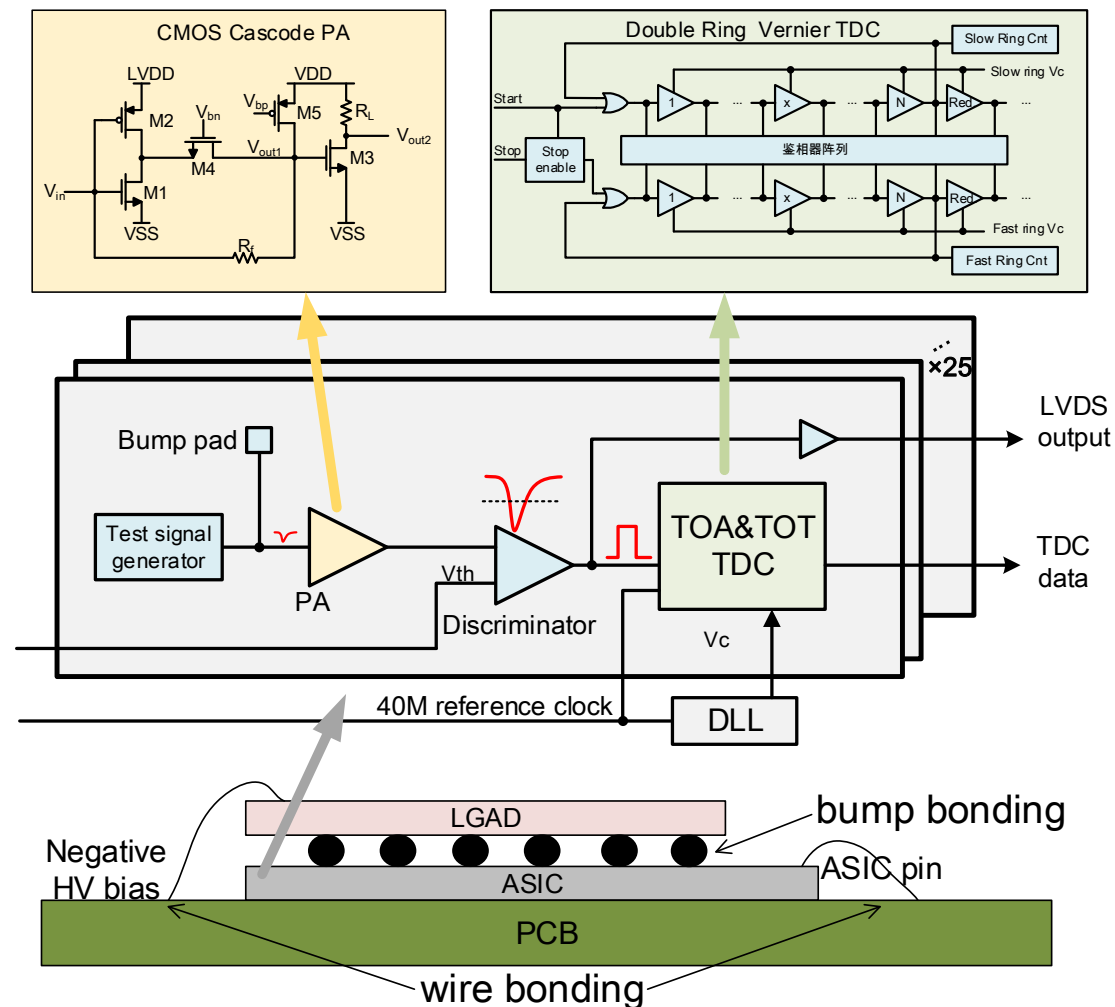
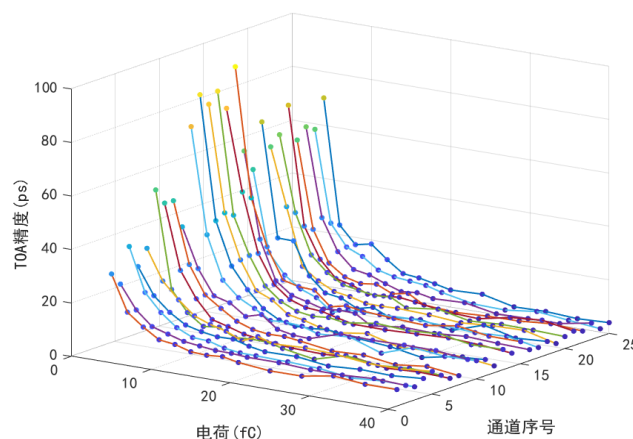
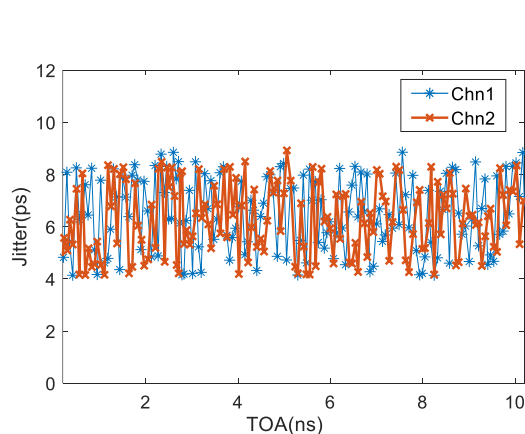
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LATIC: LGAD Amplification and Timing IC

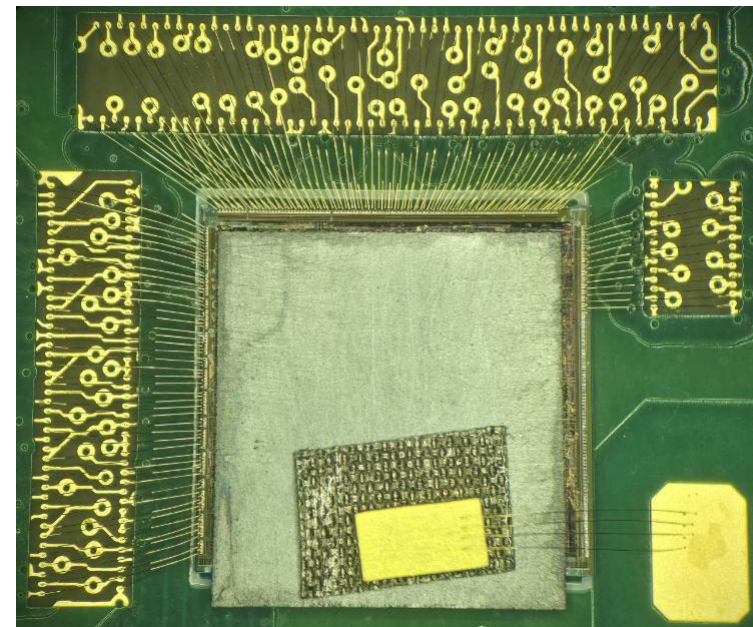
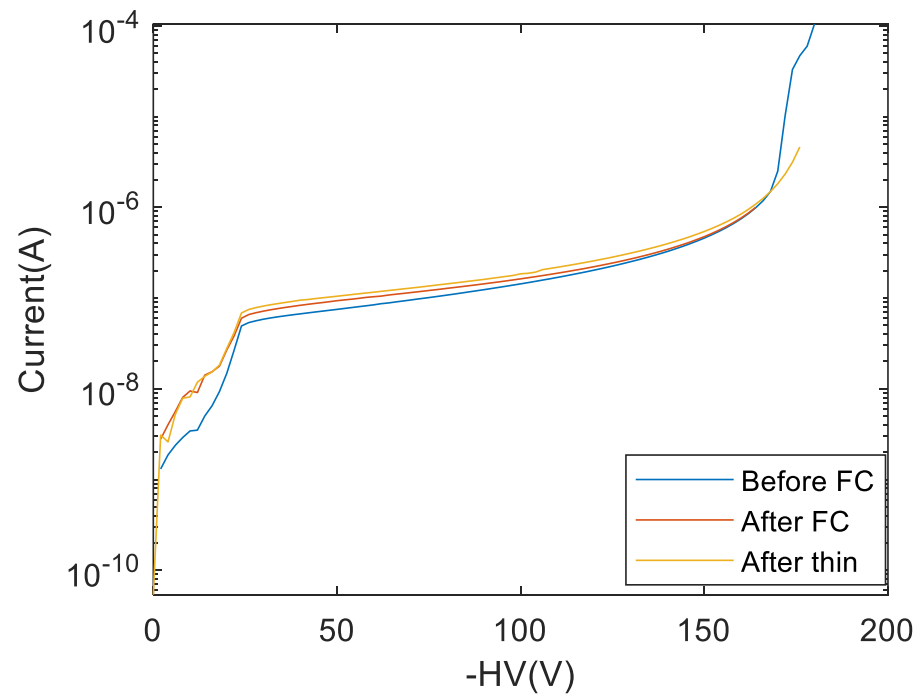
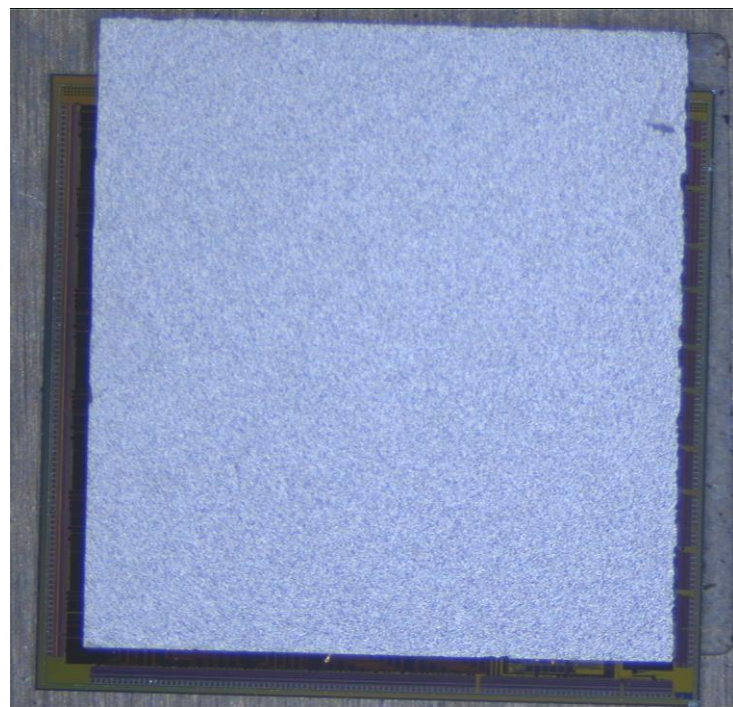
自研LGAD读出原型芯片

- ◇ 5×5通道
- ◇ TDC时间精度: 10 ps
- ◇ 电子学时间精度: 20 ps @10 fC



ACP键合

▶ ASIC植球→ACP与NCA点胶→对齐→加压键合→sensor减薄→PCB打线→测试



总结和展望

- ▶ 通过多家合作单位的一系列测试，研究了 HGTD的预量产LGAD与ALTIROC键合后的时间性能：
 - ◇ USTC和IHEP设计的sensor均能达到HGTD对时间精度的要求。
 - ◇ 除了倒装焊键合方式，基于ACP的键合方式也表现出了同等的时间性能，具有可行性。
- ▶ 介绍了USTC自研的LGAD读出芯片以及键合过程
 - ◇ USTC IME sensor与LATIC已完成键合，IV曲线正常，键合后的功能和性能待验证。
- ▶ Acknowledgement : The speaker acknowledges the contributions to the comprehensive tests by many members of CERN/IFAE/IHEP/IJClab/JSI/USTC ... groups