Study of a MAPS Detector Prototype

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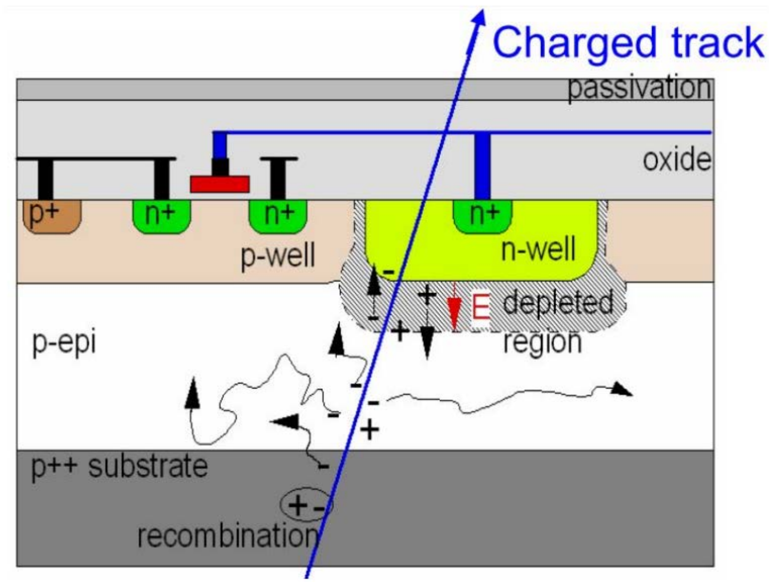
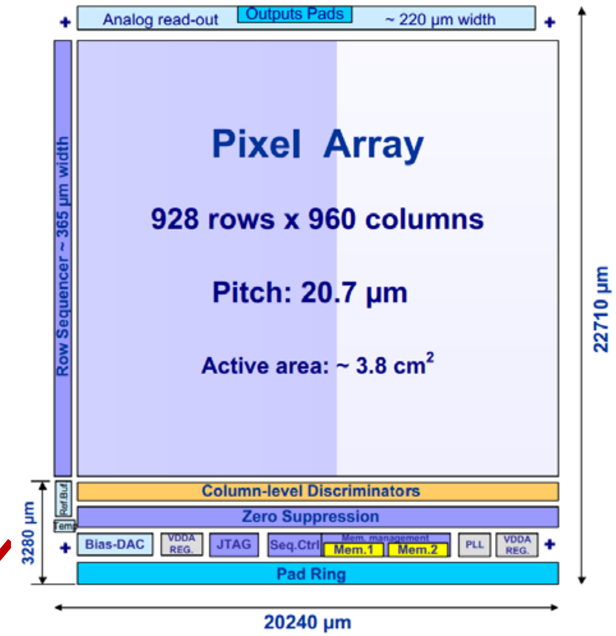
高能物理研究所

MAPS and prototype for MDC Upgrade



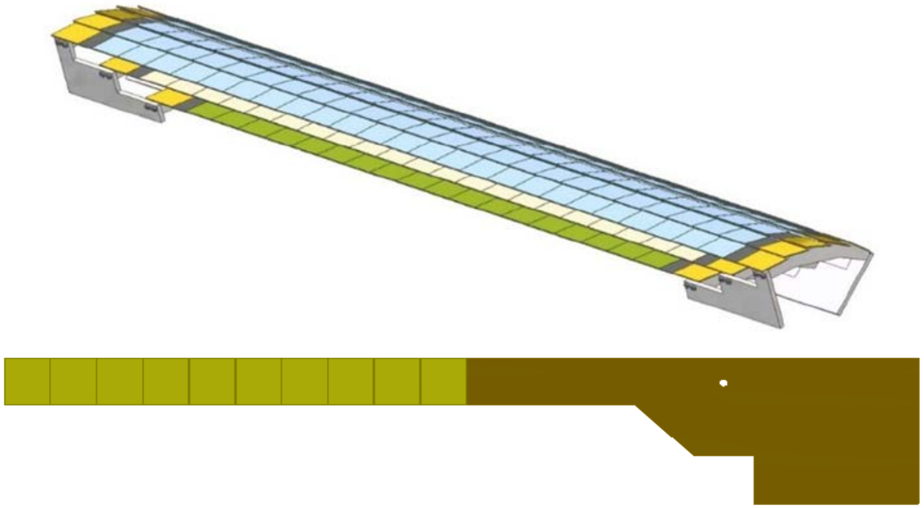


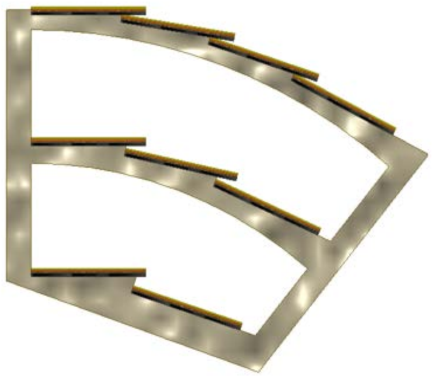
- 高能物理实验对低物质量内径迹室和顶点探测器的需求
- MAPS(Monolithic active pixel sensor)具有低物质量、高空间分辨率等优点
- 法国Strasbourg IPHC
- 应用于STAR vertex detector 及ALICE ITS upgrade 等

MDC内室升级预研采用MIMOSA28

- Density: 20.7µm pixel pitch, ~0.9Mpixels/chip
- Spatial resolution: a few µm
- Rating capability: ~10^6Hz/cm^2
- Material budget: ~50µm thick
- Radiation tolerance: ~1 MRad, 10^{13} n_{eq}/cm^2
- Room temperature operation

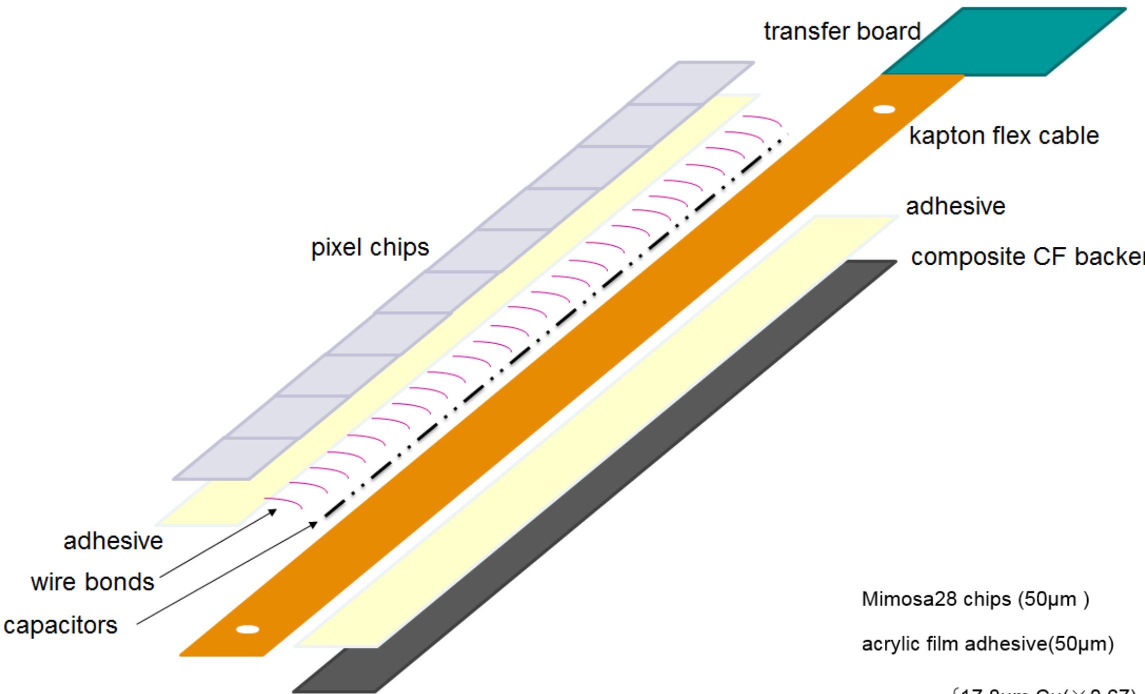
R&D target: a MAPS Prototype



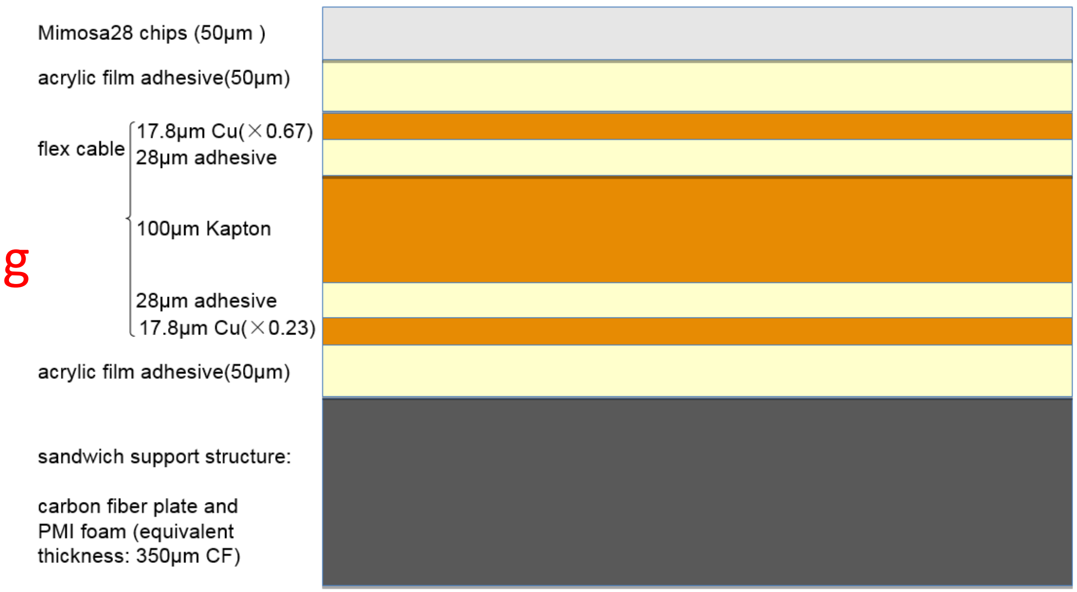


- 探测器模型结构
  - 1/10 Coverage of the inner tracker (~ 720cm^2→180 chips→180M pixels)
  - ϕ direction: 2 , 3 and 4 ladders for the 1st, 2nd and 3rd layer respectively
  - Z direction: 2 sets of ladders each layer
  - 10 Mimosa28 chips with dimension of 2cm×2cm in each ladder
- Chip →ladder →sector → layer →prototype

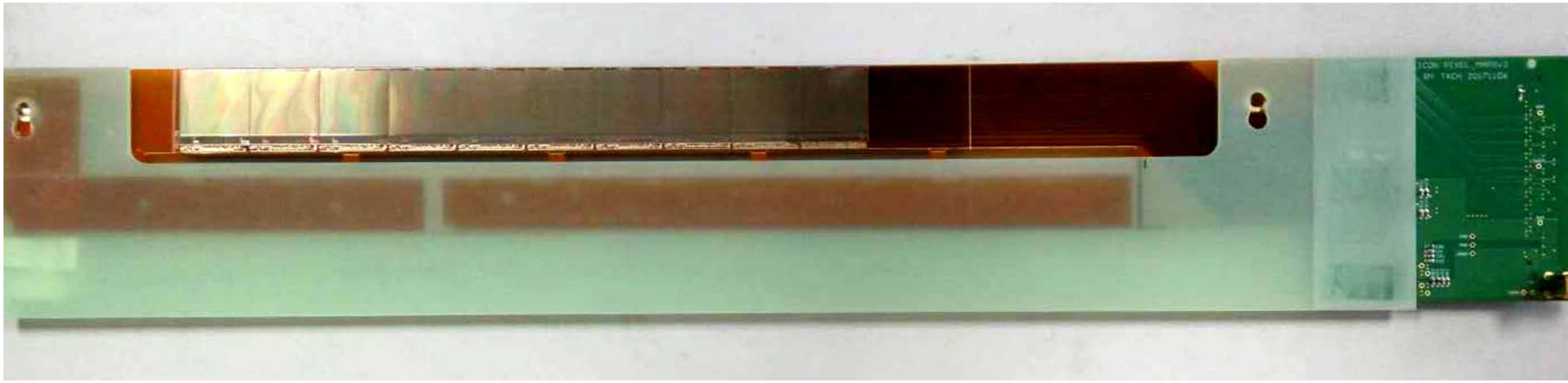
Ladder Design



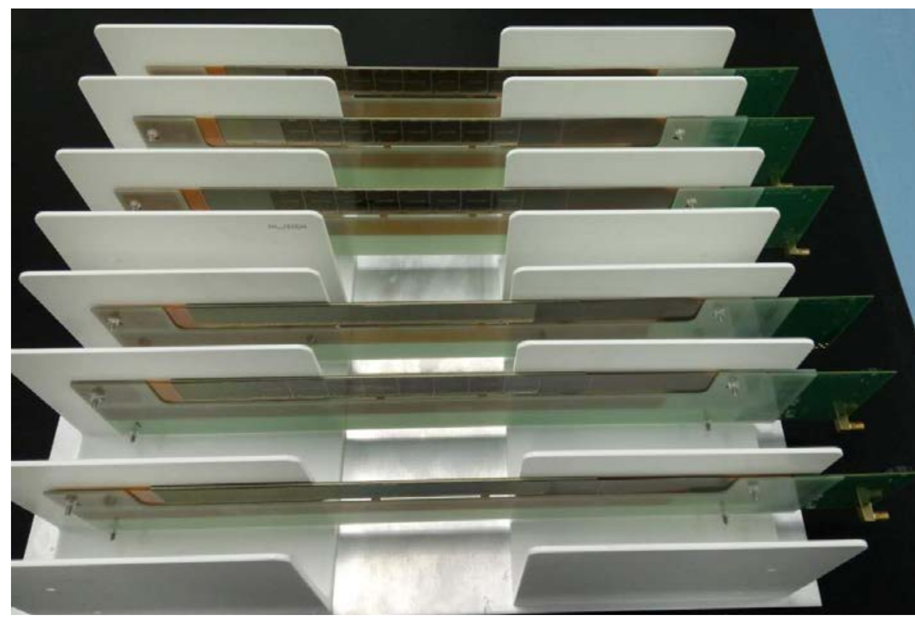
- 探测模块 (Ladder): basic building block of the detector, key issue for the prototype
  - Ten Mimosa28 chips (50µm)
  - Flex cable
  - Carbon fiber mechanical support



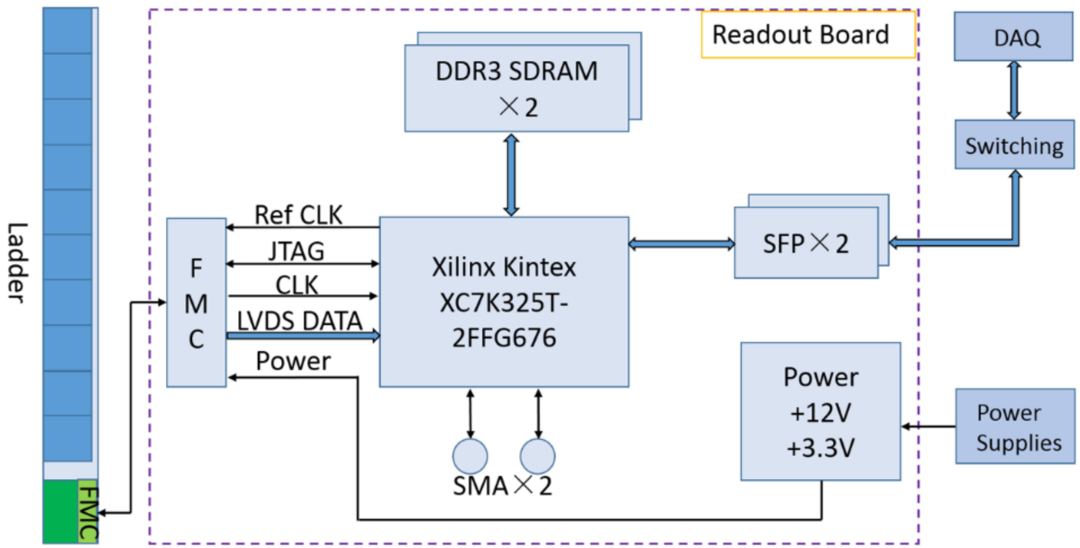
Ladder Assembly



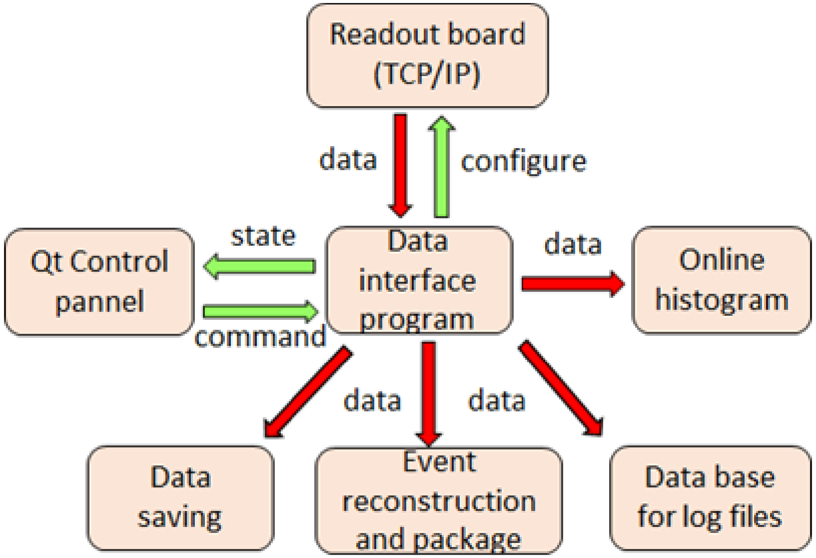
- Ladder assembly was operated at a dedicated jigs to ensure the location accuracy of the chips
- 低物质量、高位置精度探测模块
  - Material budget calculation: 0.37% X_0 /ladder, 0.51% X_0 /layer (ladder + supporter)
  - Chip location accuracy by imaging machine: < 10µm



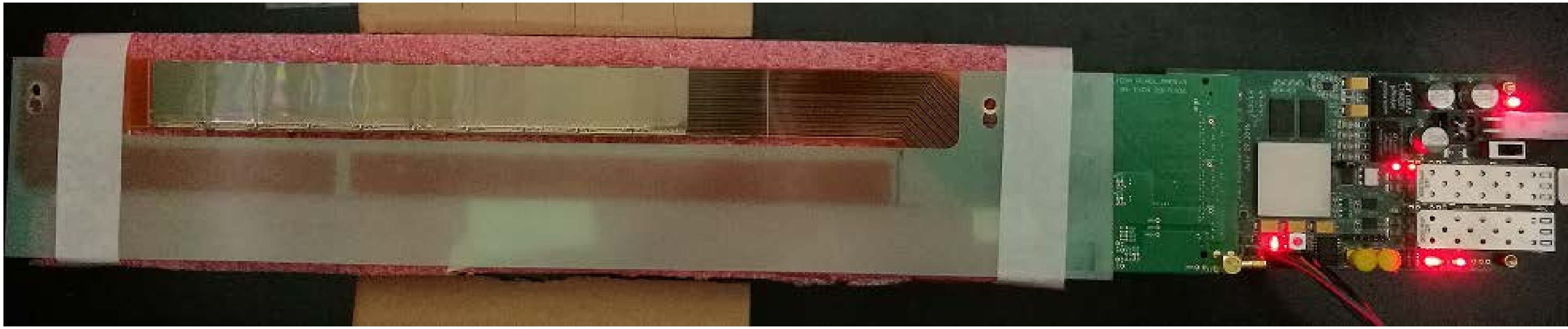
Readout Electronics and DAQ



- Distributed system
- Ladder → FCB → Readout Board → Switching → PC
- SiTCP : high-speed and highly reliable data transmission
- Readout speed: 30~40MB/s/ladder



Ladder Test



阶段一

硬板PBC，芯片的引脚与功能测试

阶段二

柔性PCB设计、单芯片测试

阶段三

柔性PCB改进设计、双芯片测试

阶段四

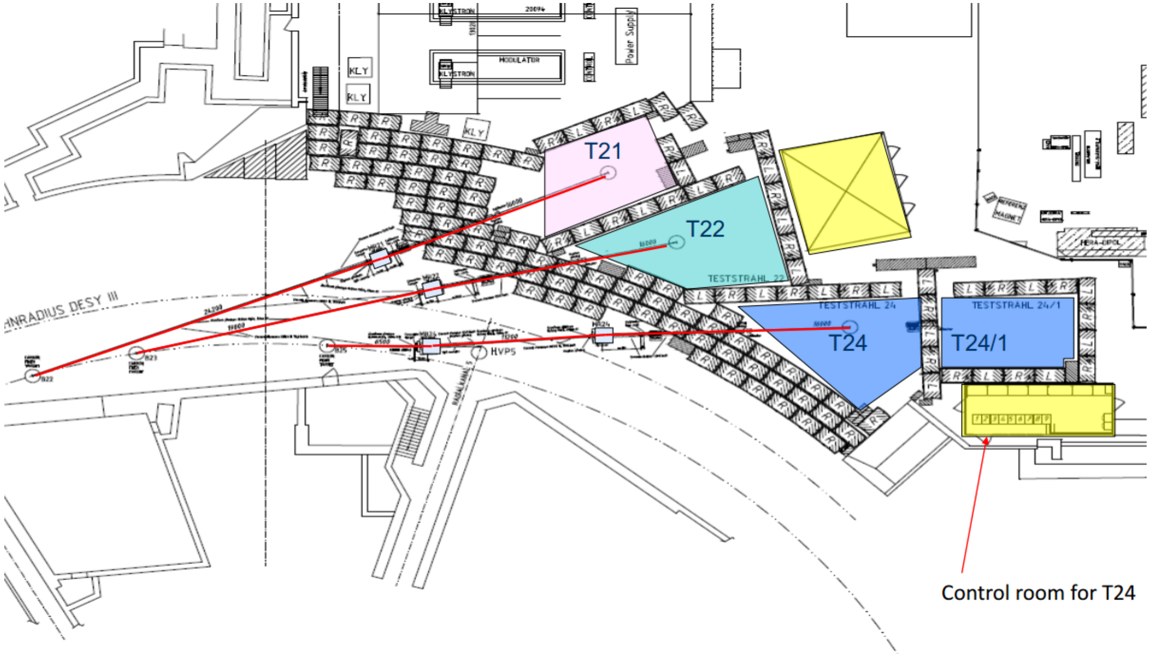
柔性PCB改进设计、满芯片（十个）测试

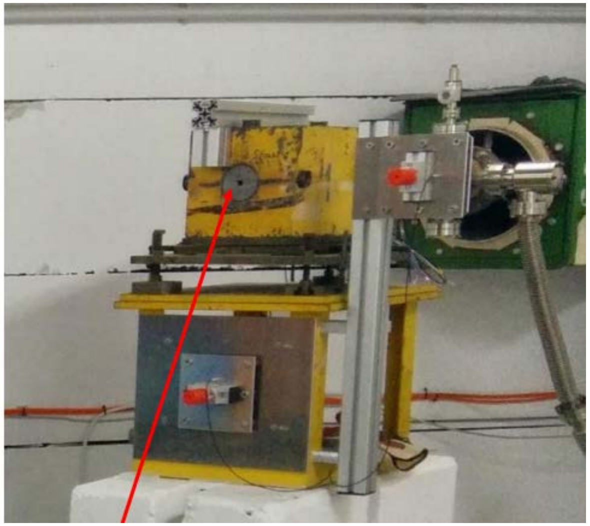
阶段五

System Beam test

- 硬板PCB→柔性PCB
- 单片芯片测试→双片芯片测试 →完整ladder的测试
- Ladder 批量研制→ladder系统放射源测试→ladder系统束流测试

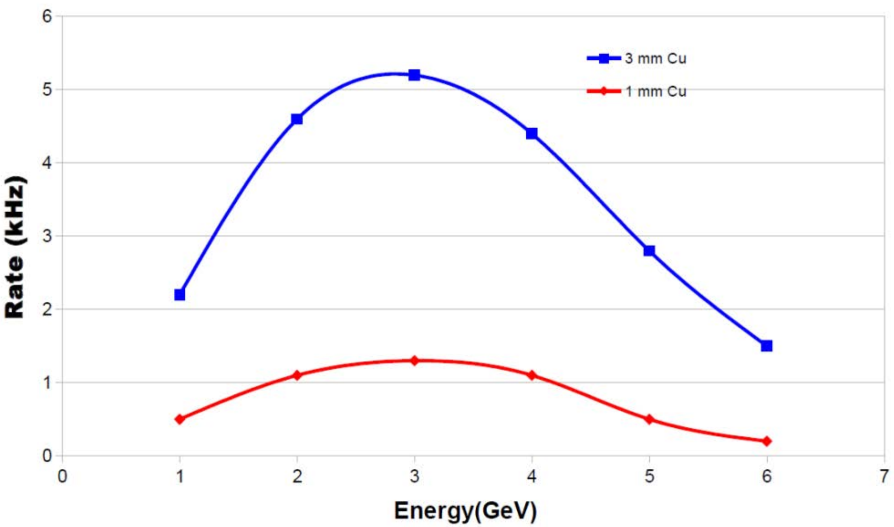
Test Beam in DESY





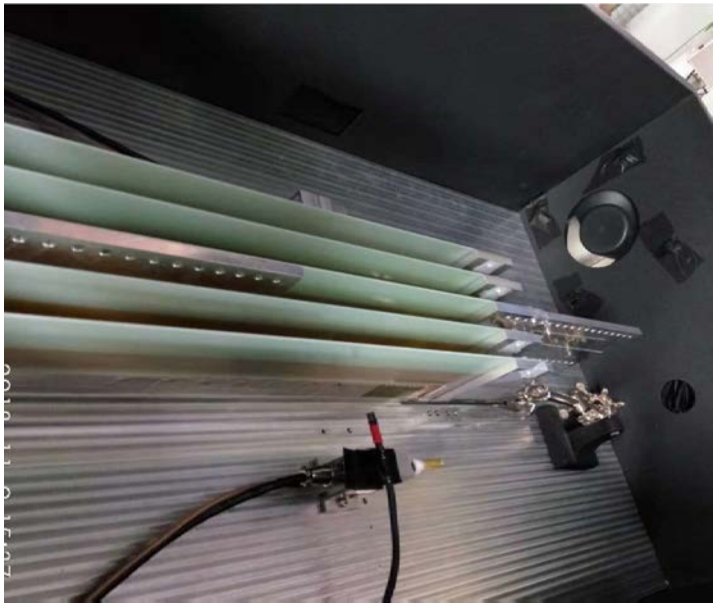
lead collimator

- November 5-11, 2018
- T24 testbeam
- Electron beam
- The intensity is dependent of the energy and the target selected
- Beam size defined by lead collimator

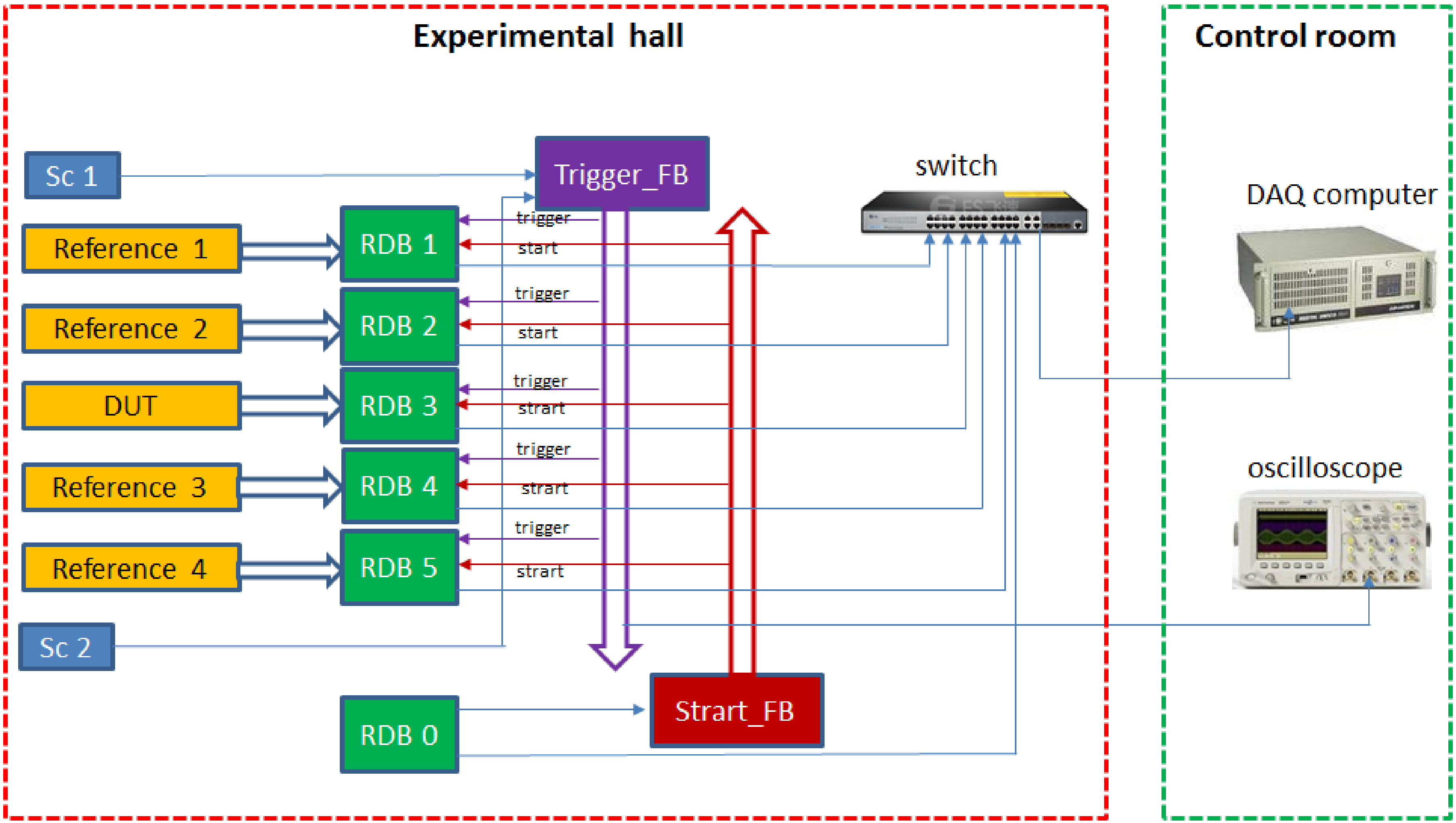


Test Beam in DESY

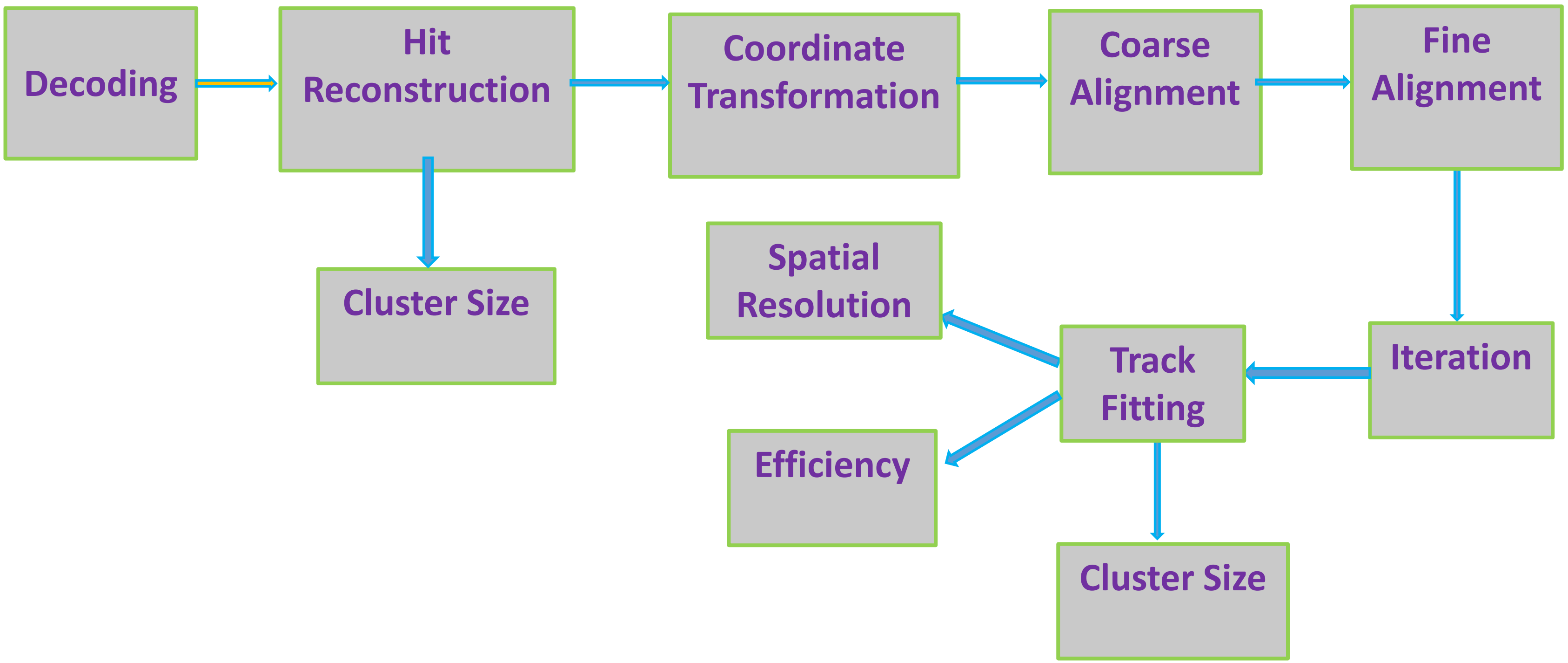
- Energy Scan
- Ladder scan
- Threshold scan
- Gap between the neighboring chips
- Material budget test
- Target scattering test
- Cooling air flow



System Setup

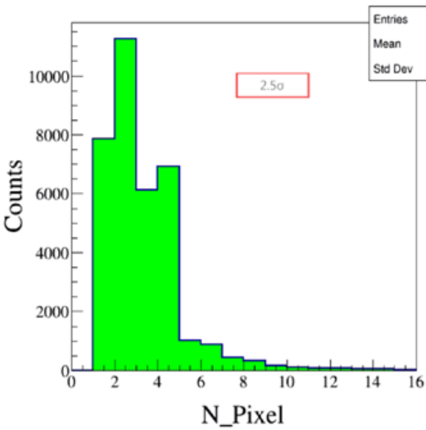


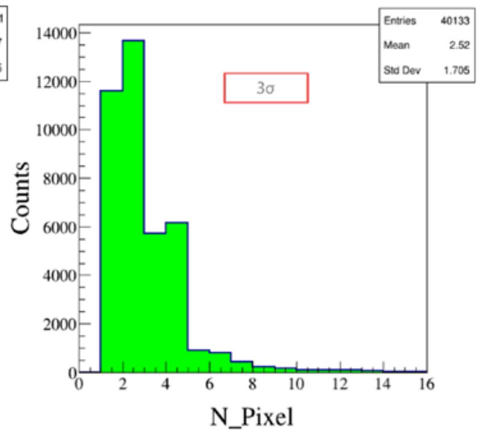
Analysis Software Framework

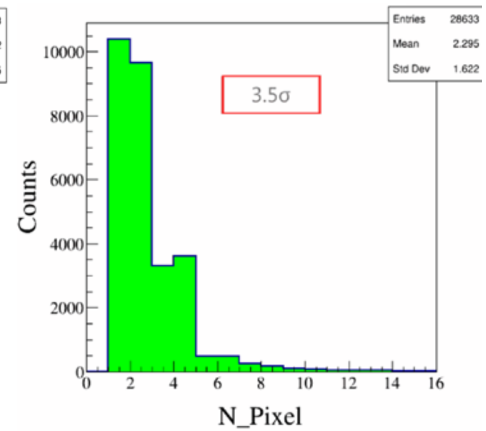


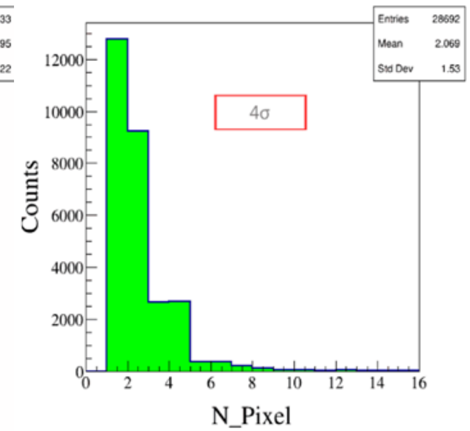
- Hit reconstruction : cluster size, digital signal, no seed
- Alignment: high precision
- Tracking

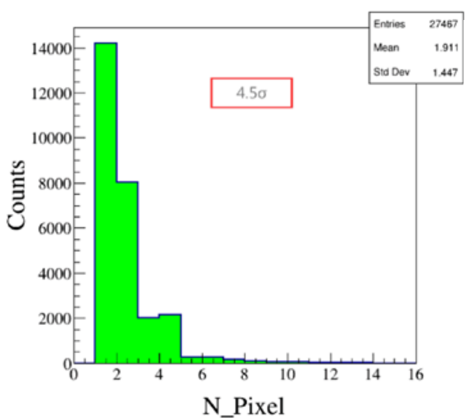
Cluster Size Analysis

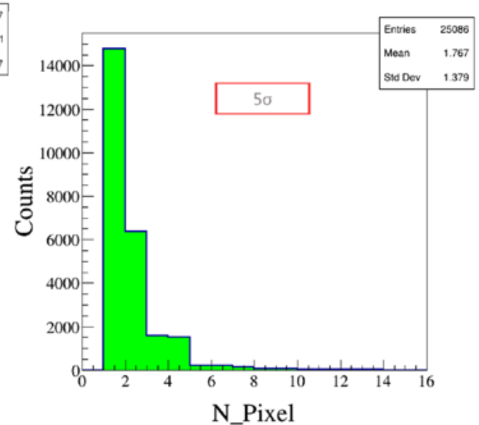


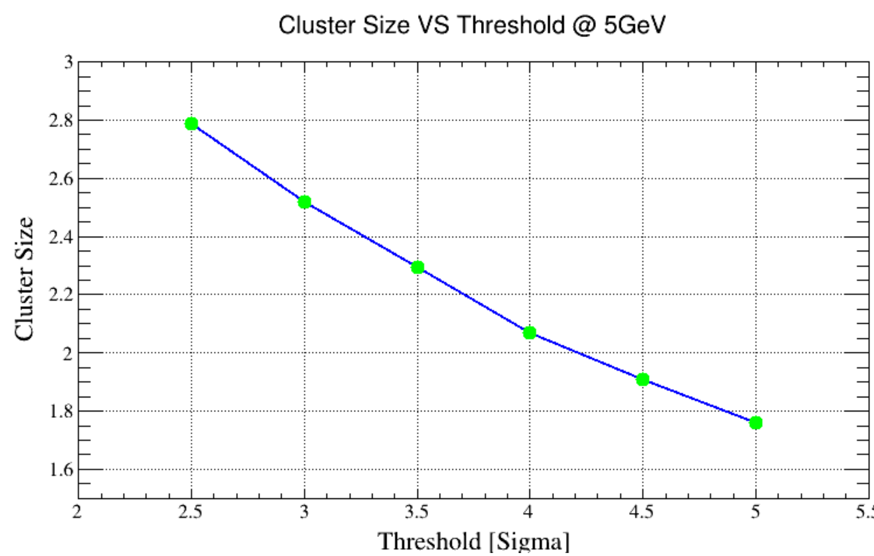






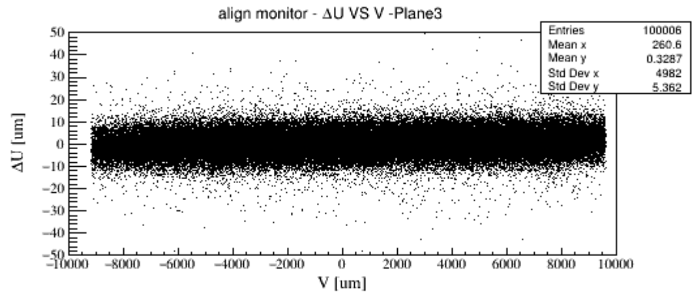


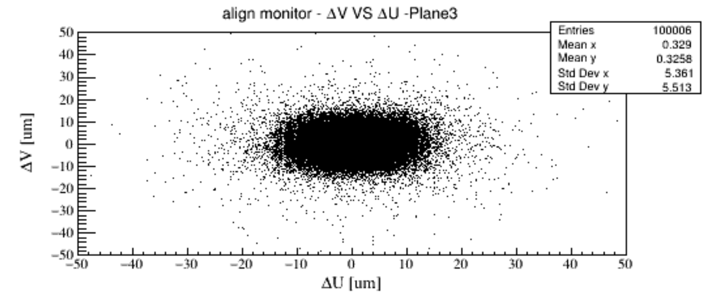


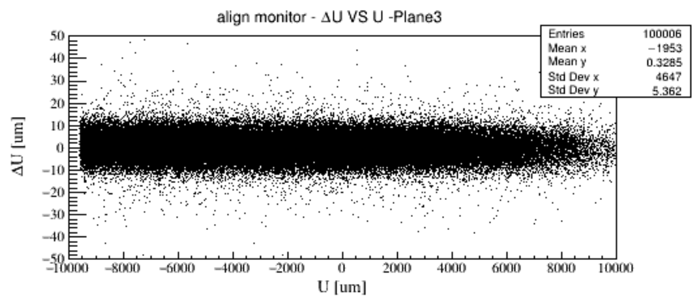


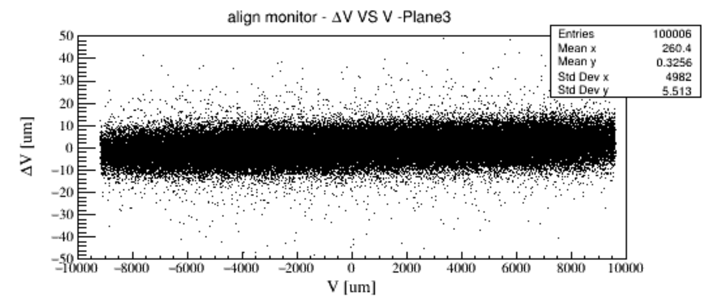
- Charge collection by thermal diffusion
- Charges sharing: one hit can lead to several fired pixels, be benefit to spatial resolution
- Reconstruction algorithm

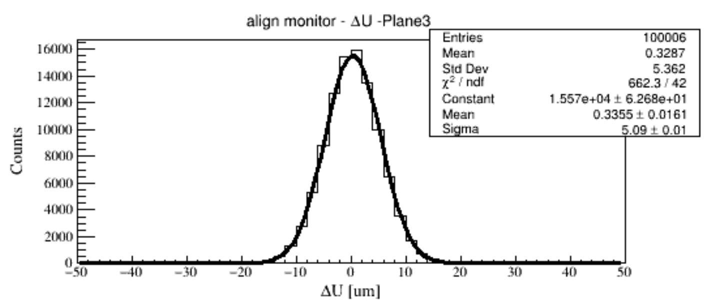
Alignment Results

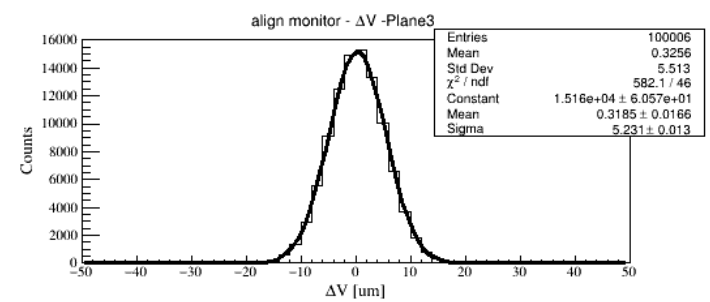


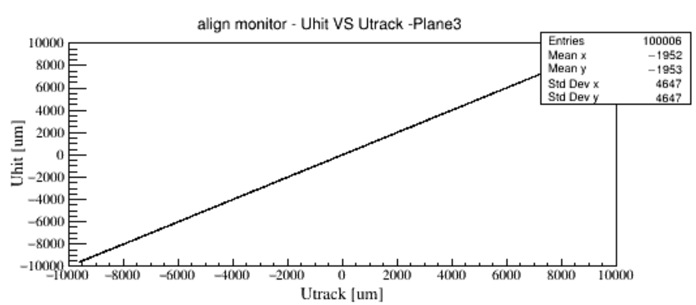


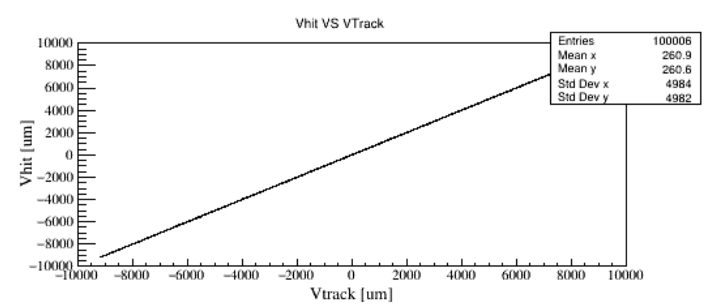




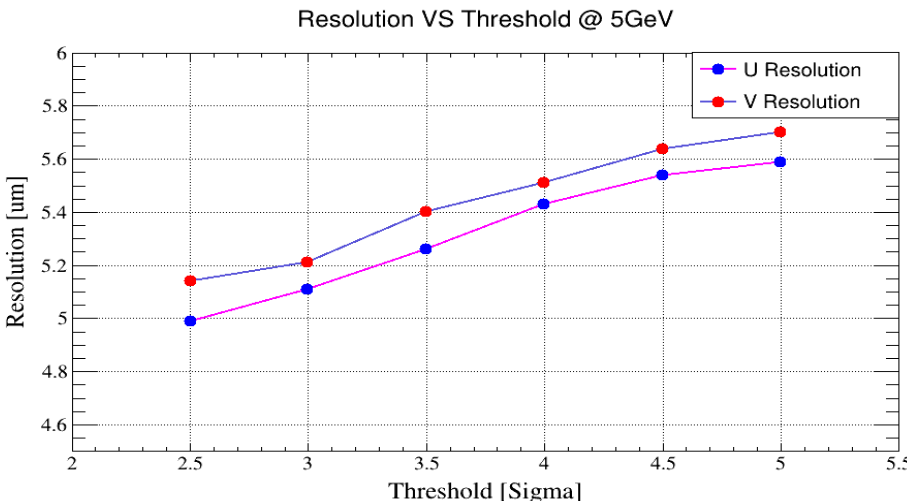




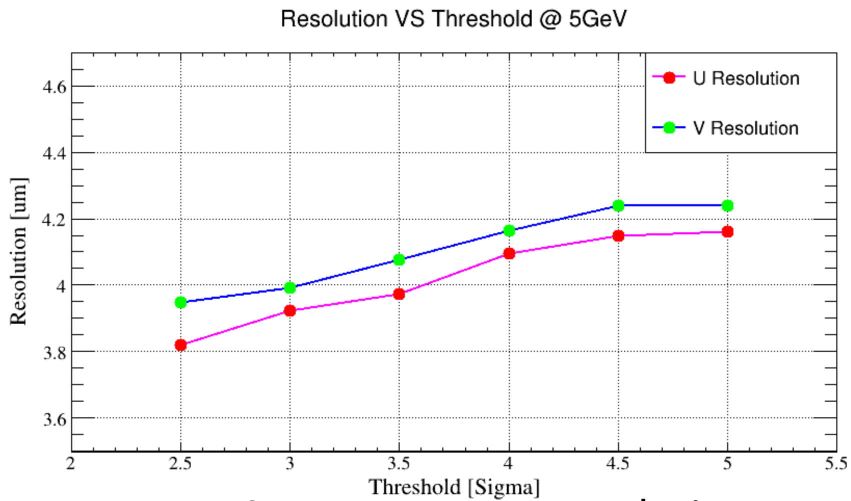




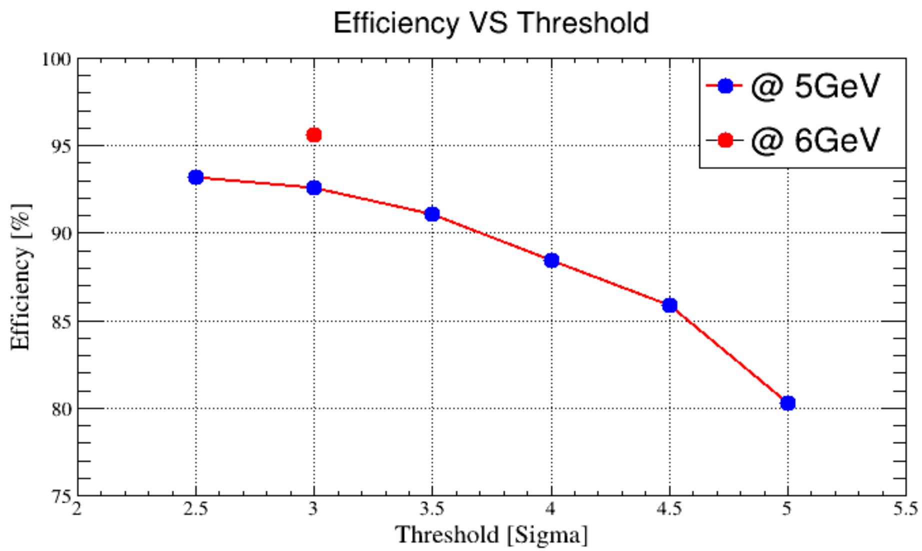
Spatial Resolution and Efficiency



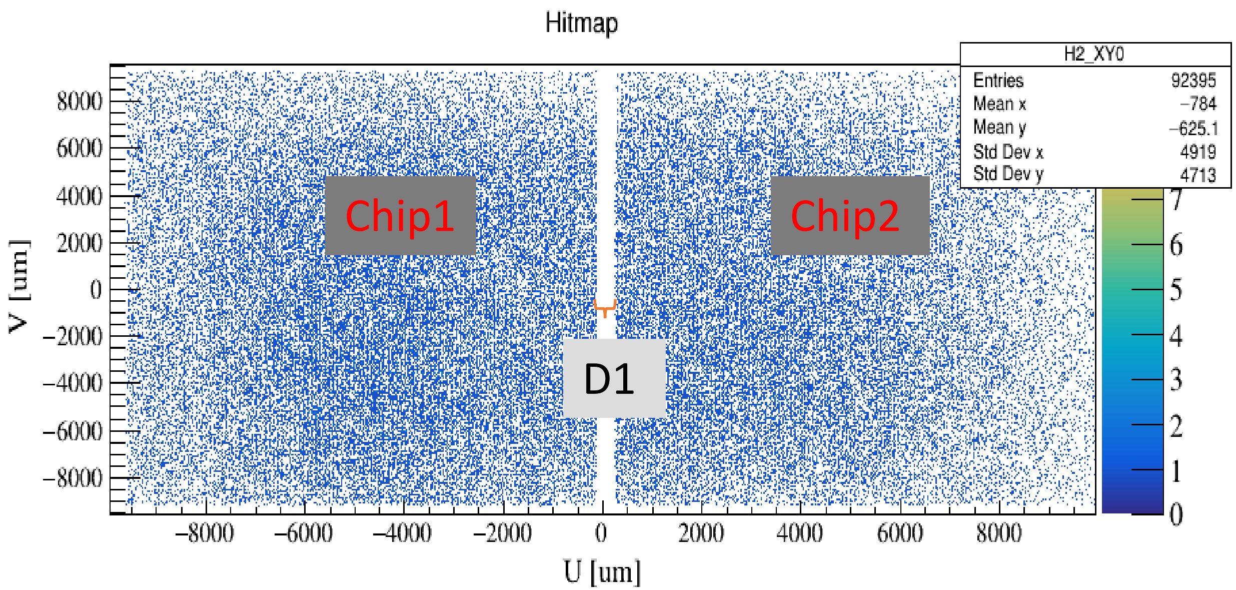
DUT resolution

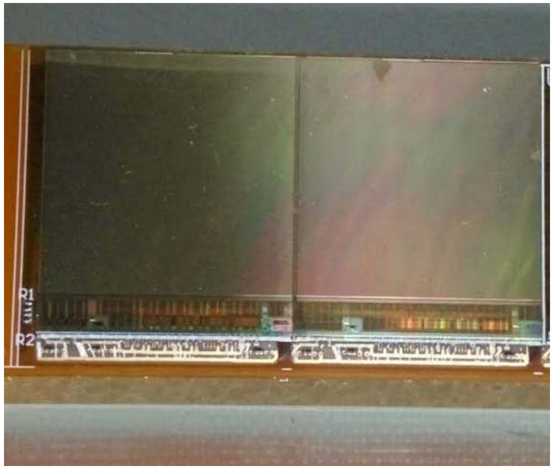


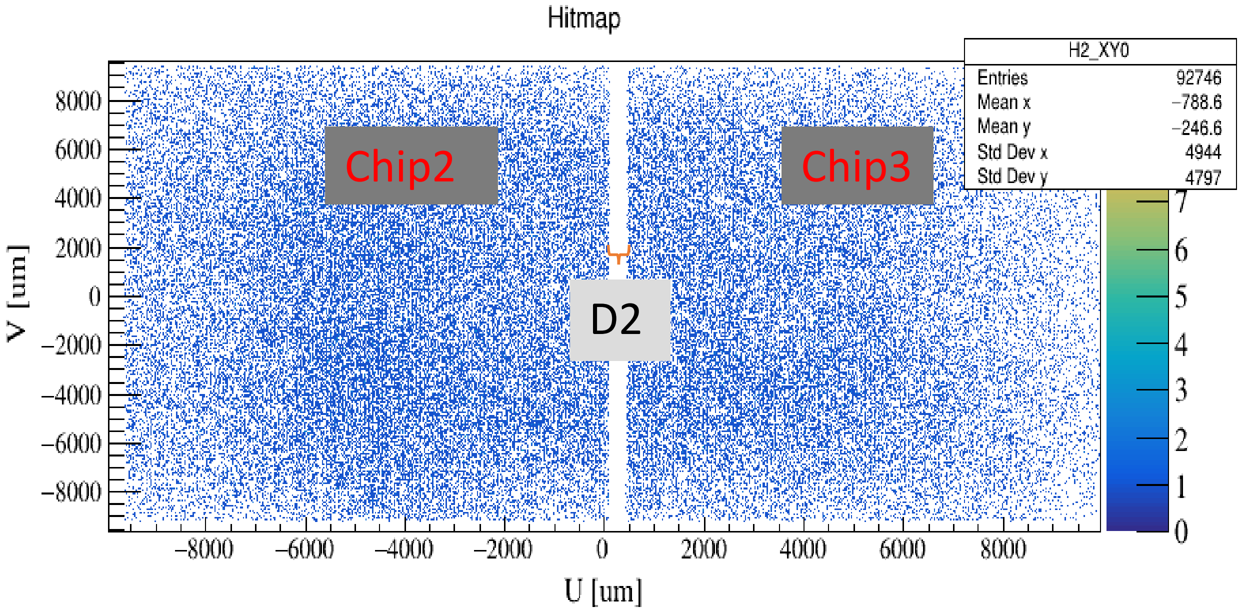
System average resolution



Gap between two chips





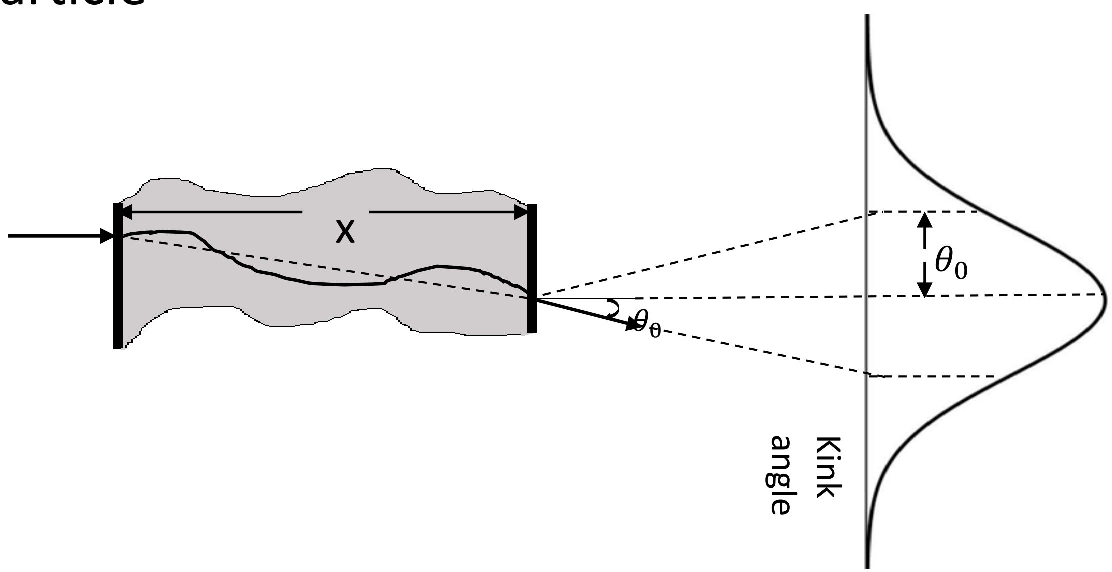


- D1≈D2 ≈ 340μm
- Average gap between neighboring chips is 340 μm
- Take into account the row sequencer on the chip, chip location accuracy is better than 10μm

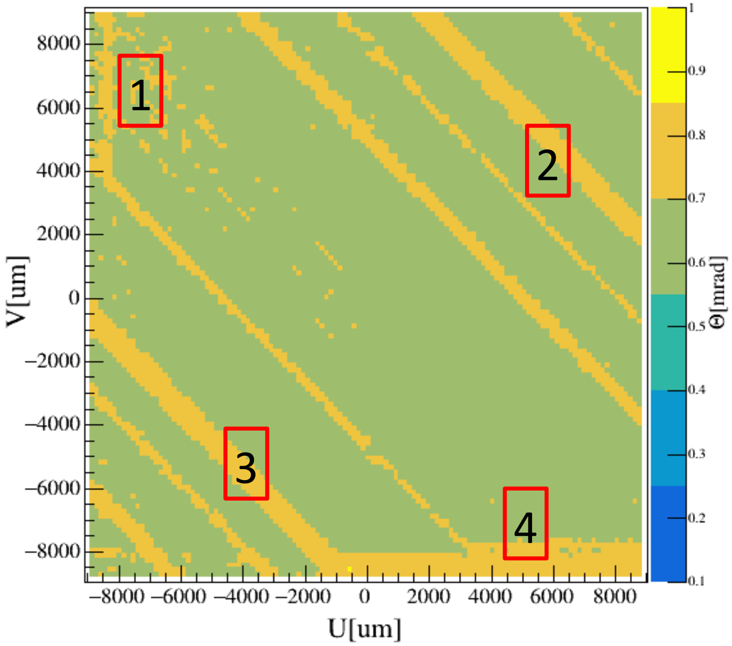
Multiple Scattering

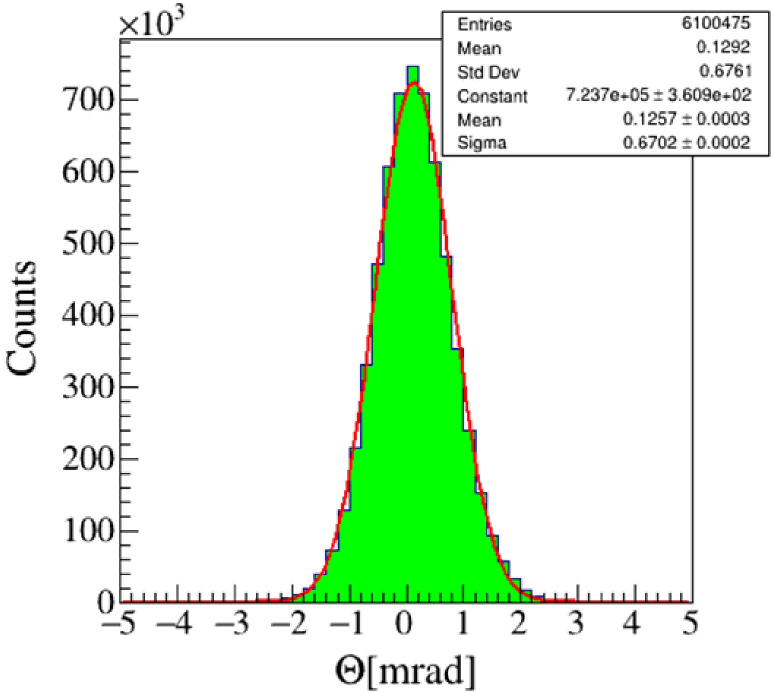
- High-energy particles undergo **multiple coulomb scattering** when passing through the material;
- Kink angle depends on **material budget (x/X0);**
- The **width of the gaussian-like center** is well predicted by the Highland formula;
- Highland formula: $\theta_0 = \frac{13.6MeV}{\beta cp} Z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right)$

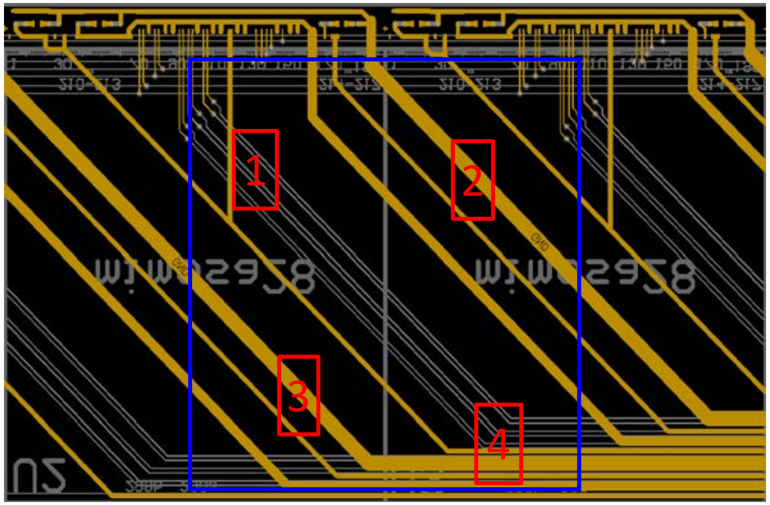
θ_0= RMS of scattering angle
z = charge of incident particle
x = material thickness
X_0 = radiation length



Material budget







$$\theta_0 = \frac{13.6MeV}{\beta cp} Z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right)$$

θ_0=0.0006702 rad

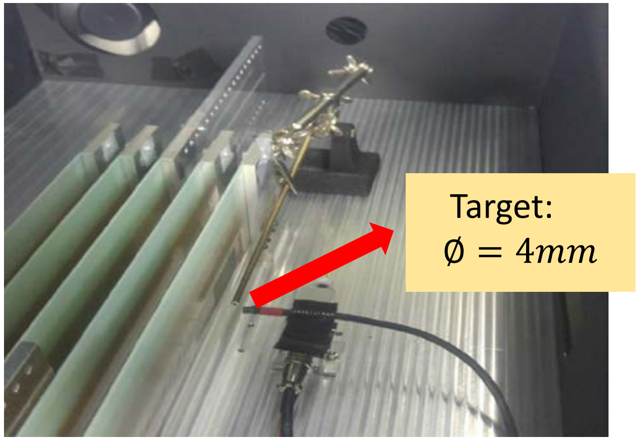
P =1GeV

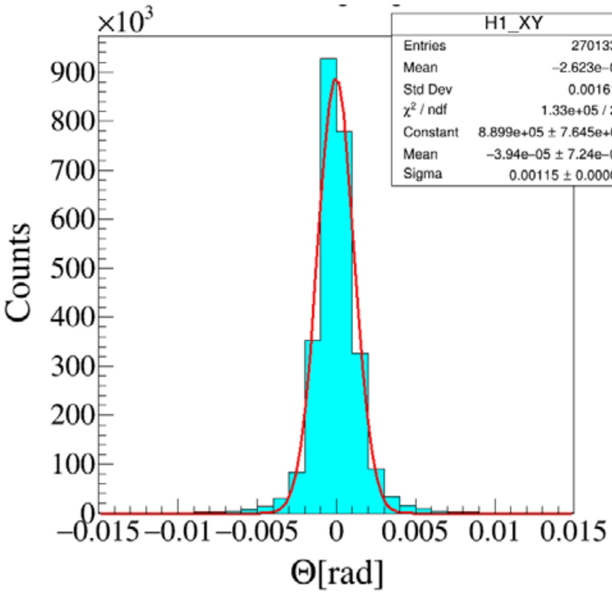
$$\frac{x}{X_0} = 0.39\%$$

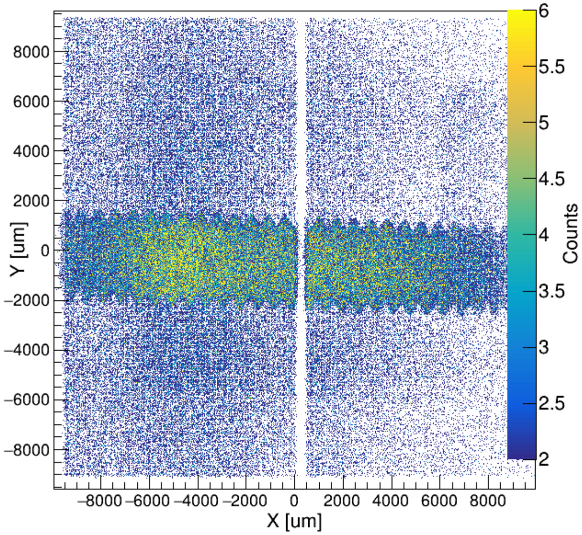
- Be consistent with the calculation result

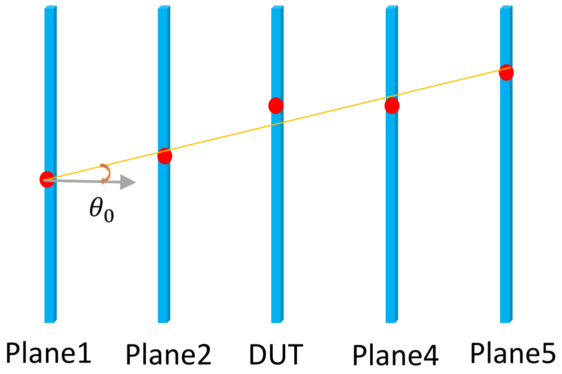
Target Test

- **Goal :Getting the target image according to multiple scattering.**
  - Target in front of plane 1.
  - Target:$\emptyset$=$4mm$.
  - Target:$thickness$=1mm





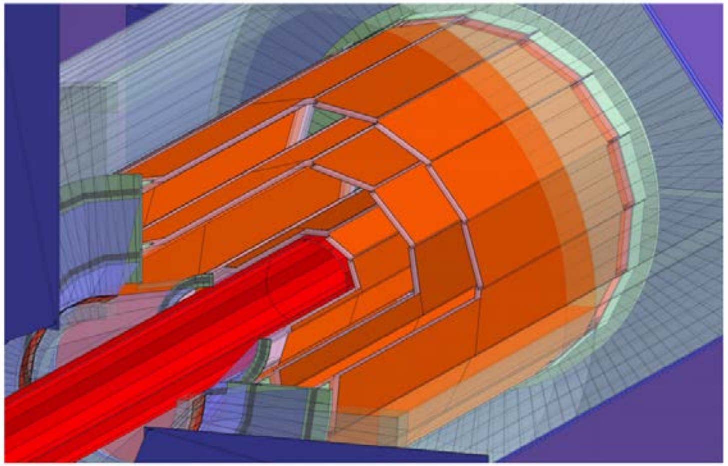


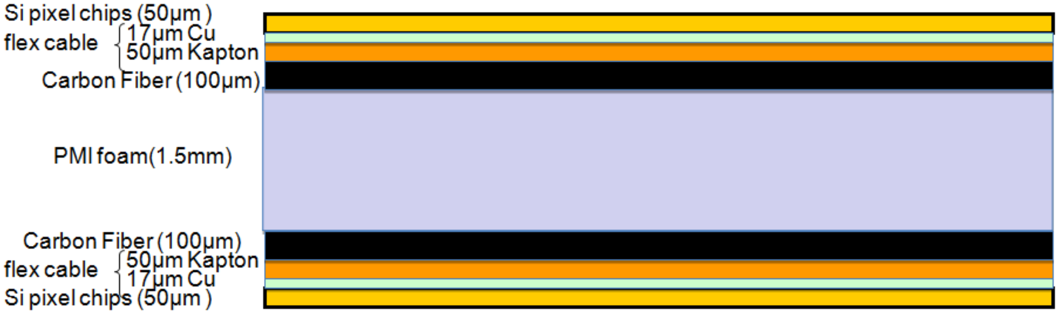


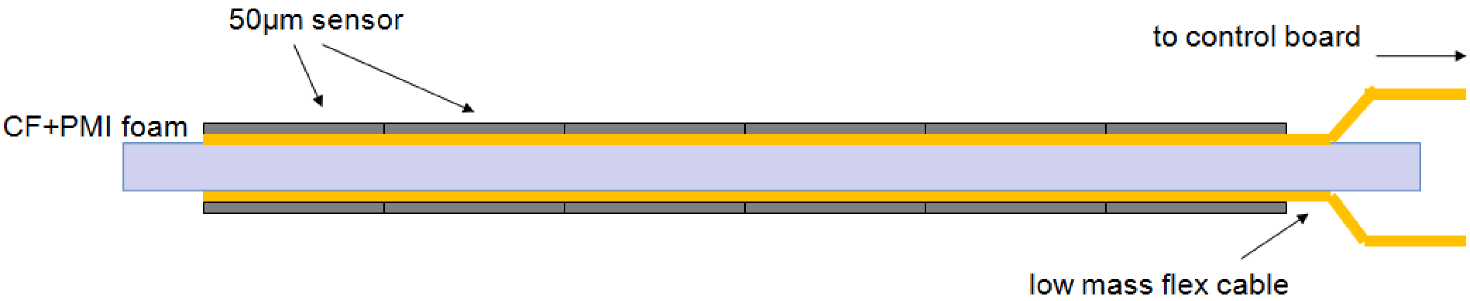
The target's material is copper and $\frac{x}{X_0}|_{\text{theoretical}}$=21.97% X_0

θ_0=0.00115 rad, P =5GeV ➡ $\frac{x}{X_0}$ =20.259%

Double-sided ladder







- Single-sided ladder→ Double sided ladder (CEPC vertex 预研)
- Dummy ladder → functional ladder

Acknowledgement

- Marc Winter, Jerome Baudot, Christine Hu-guo, Mathieu Goffe, Auguste Besson, member of PICSEL group, from IPHC in Strasbourg, France

- DESY (Deutsches Elektronen Synchrotron)

Summary

- The Mass production and performance test of the pixel detector ladders have been finished
- A detector prototype system was set up and tested at T24 beam line in the DESY
- Good performance have been obtained: spatial resolution: 5 μm, efficiency : 96%, high location accuracy of the chips: 10μm, low material budget: 0.39% X_0
- Gain the ability and experience on the key technology and method in the construction of silicon pixel detector for the future high energy physics experiment

Thanks for your attention !