IHEP AC-LGAD的空间与时间分辨率研究

The spatial and time resolution of AC-coupled LGAD developed by IHEP

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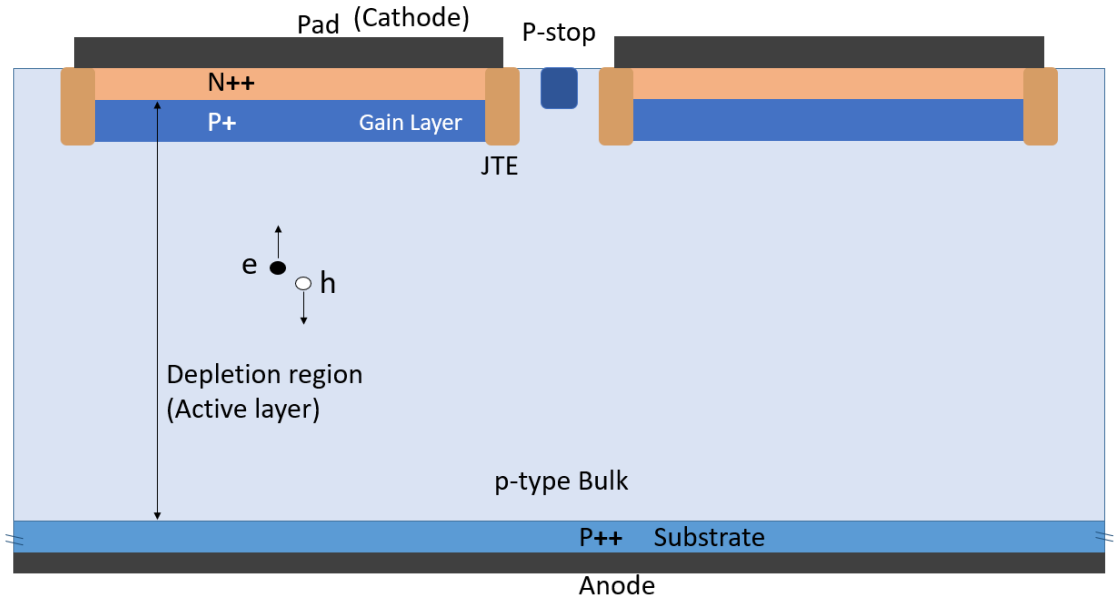
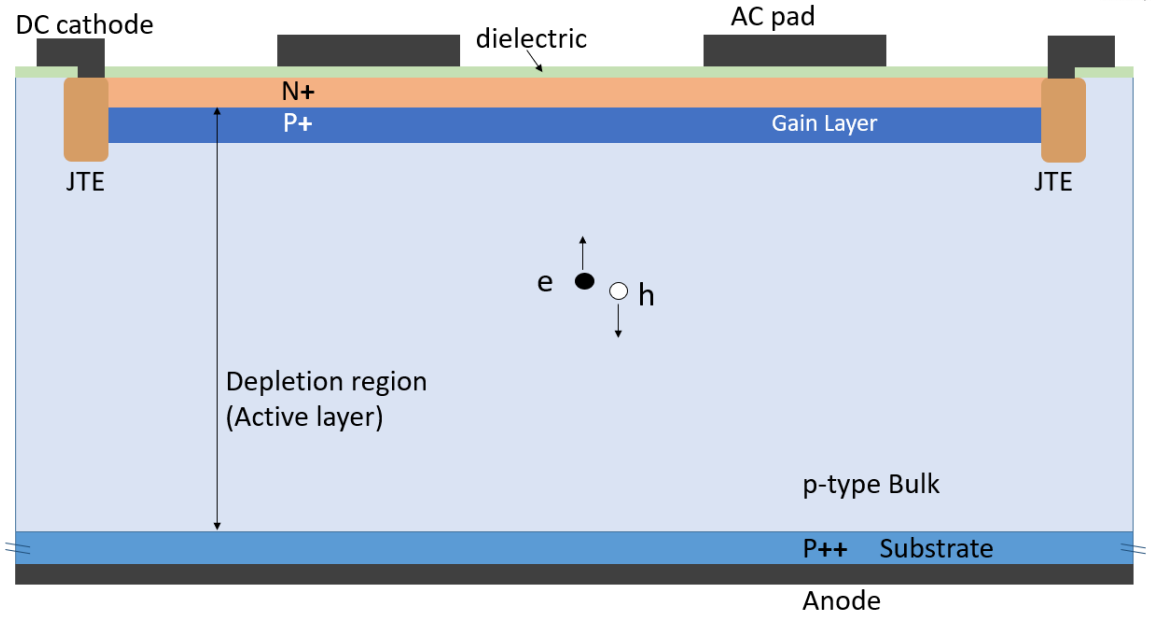
1. AC-LGAD简介



LGAD (Low-Gain Avalanche Diode)

- The metal pads is connected to N++ layer
- **Time resolution ~ 30ps**
- Position resolution: pixel size/$\sqrt{12}$
- Radiation hardness: 10^{15} ~$10^{16}n_{eq}/cm^2$



AC-LGAD (AC-coupled LGAD)

- Metal AC-pads separated from the N+ layer by a thin dielectric (Si_3N_4, SiO_2)
- no dead zone (**100% fill factor**)
- **Time resolution ~ 30ps**
- **Position resolution: 5~10 μm**
- Radiation hardness: 10^{15} ~$10^{16}n_{eq}/cm^2$

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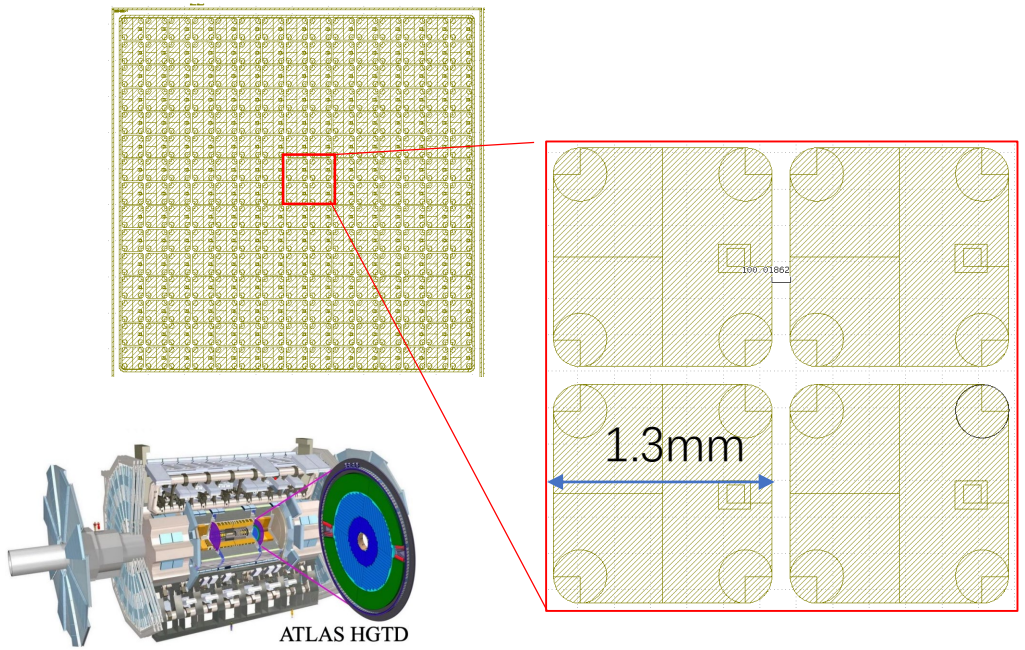
1. AC-LGAD简介

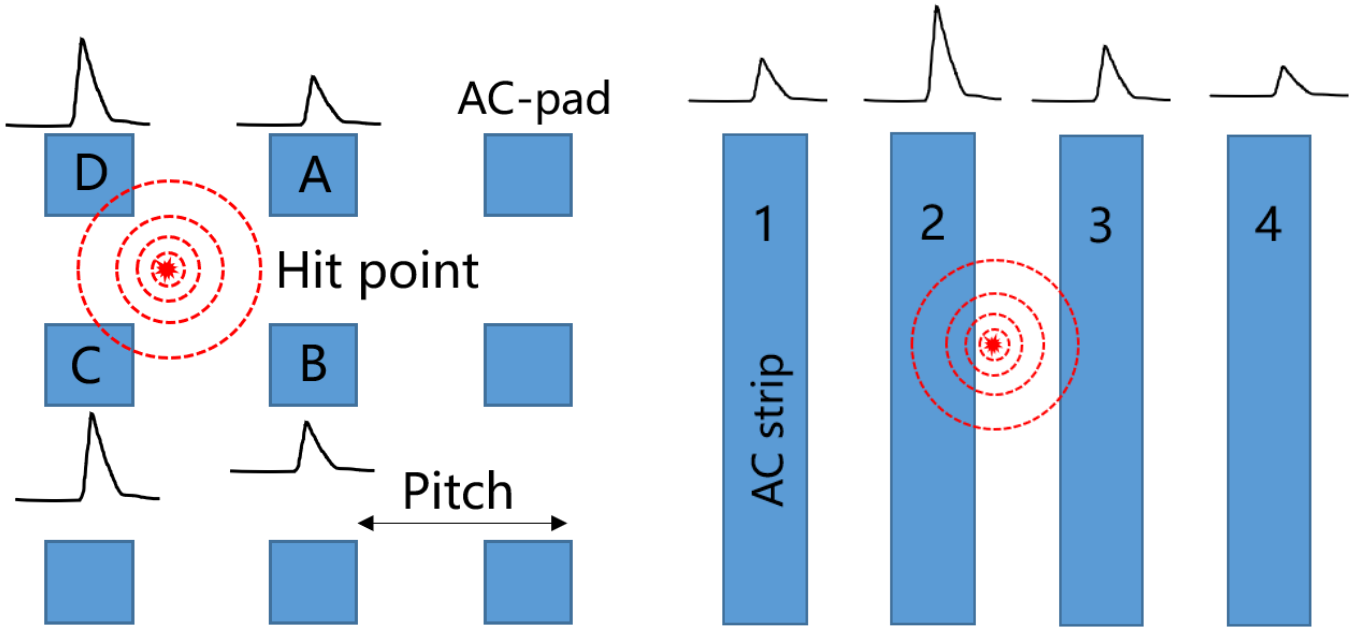
15×15 LGAD for ATLAS HGTD project



- Dead zone : ~0.1mm
- Pixel size: 1.3mm

Smaller Pixel size -> Lower fill factor

AC-LGAD：two layout schemes for AC-pads



Pixels AC-LGAD:
- Position information: **1 layer (x,y)**
- Bump bonding

Strips AC-LGAD:
- Position information: **2 layers for (x,y)**
- Lower readout electronics density, no bump bonding

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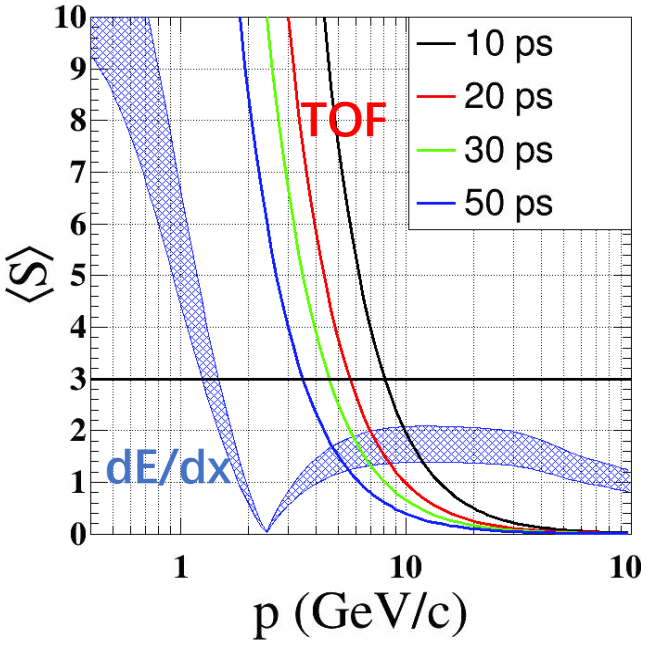
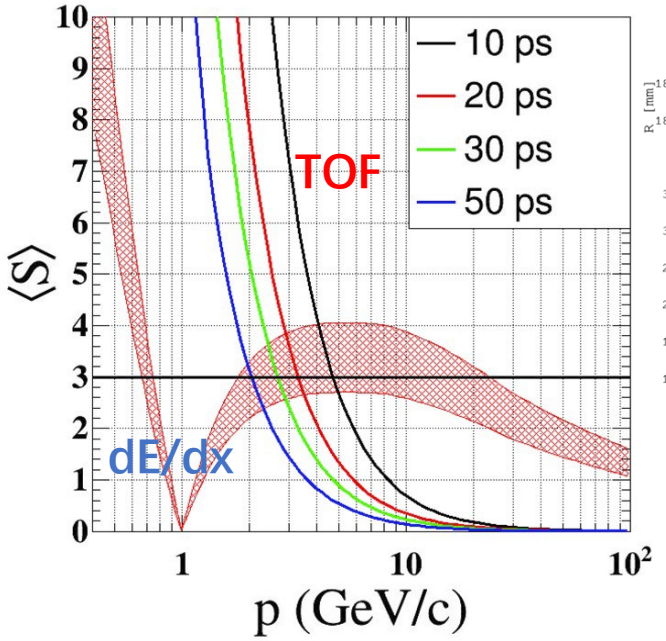
2. AC-LGAD的应用：CEPC 时间探测器

- **CEPC will produce 10^{12} Z boson at Z pole: Rich flavor physics program**
- **Particle separation problems** of Gas detector (dE/dx) for CEPC flavor physics:
  - **0.5-2 GeV for K/pi separation, >1.5 GeV for K/p separation**
- **CEPC International Advisory Committee: one of the key recommendations**
  Precision timing detector should be determined as a matter of urgency (4D tracker)
- **Timing detector is complementary to gas detector:** improves the separation ability
  0 - 4 GeV for K/pi separation, **0 – 8 GeV** for K/p separation
- **Concept design:** Offer the time and spatial information (4D tracker) Close to / replace SET tracker

K/p separation

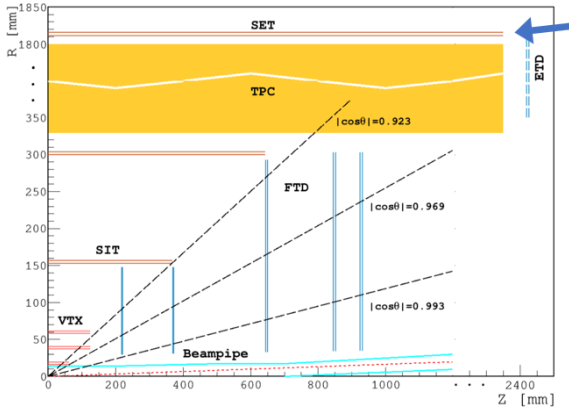


K/pi separation

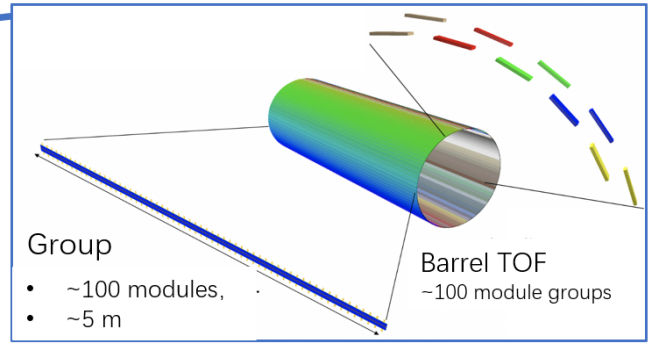


CEPC LGAD timing detector concept designs

Baseline detector concept in CDR



LGAD timing detector in Barrel region



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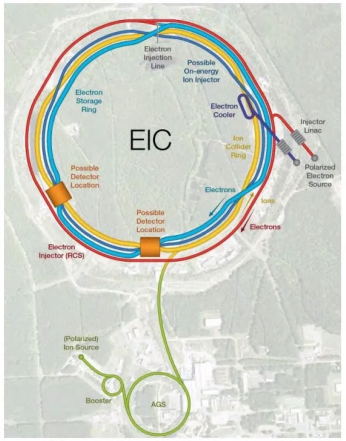
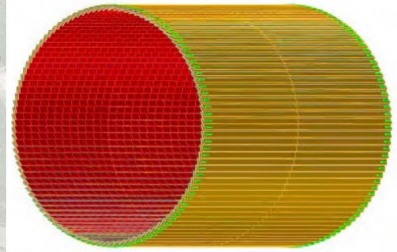
2. AC-LGAD的应用

电子离子对撞机EIC：Timing-tracker

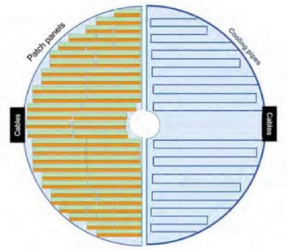


Barrel AC-LGAD detector



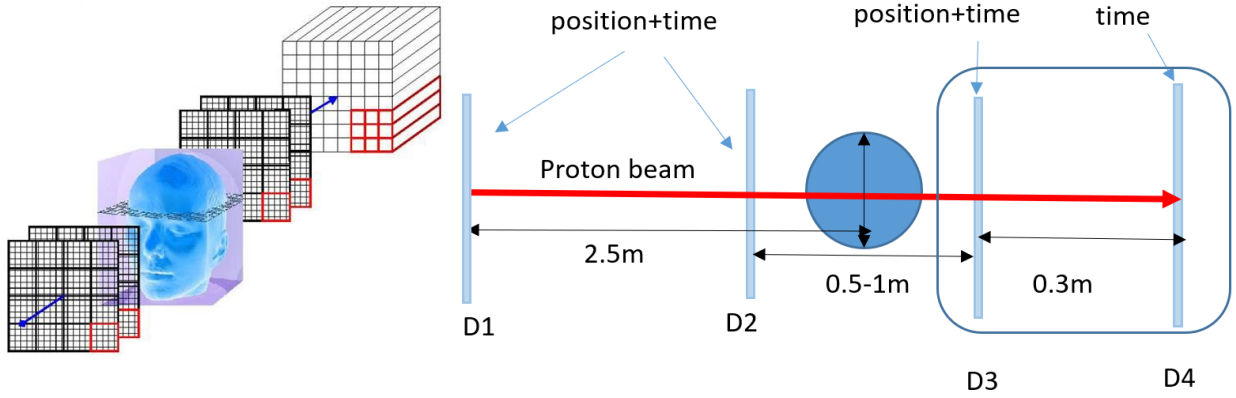
10.9 m^2

Hadron endcap AC-LGAD detector

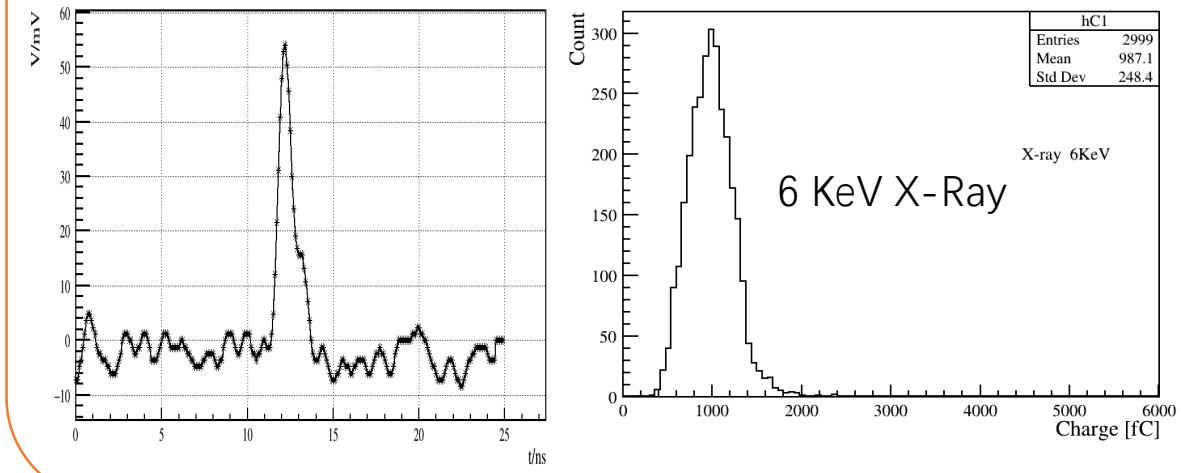


2.22 m^2

核医疗设备如：质子治疗 与 质子CT中的探测器



先进光源中**X射线探测器**



其它应用

- 束流测试平台的束流望远镜
- 激光定位与导航：激光雷达
- 其他粒子物理与核物理实验中径迹与时间探测器
- ……

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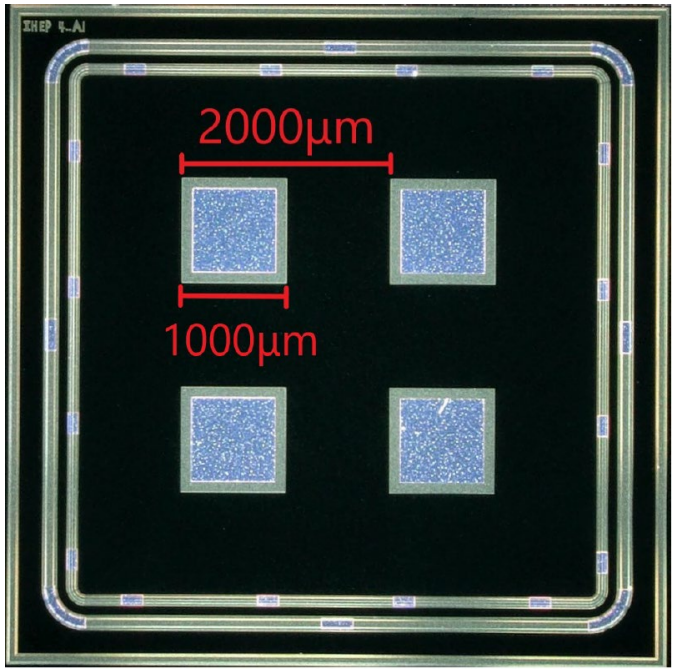
3. 高能所 IHEP AC-LGAD 探测器设计

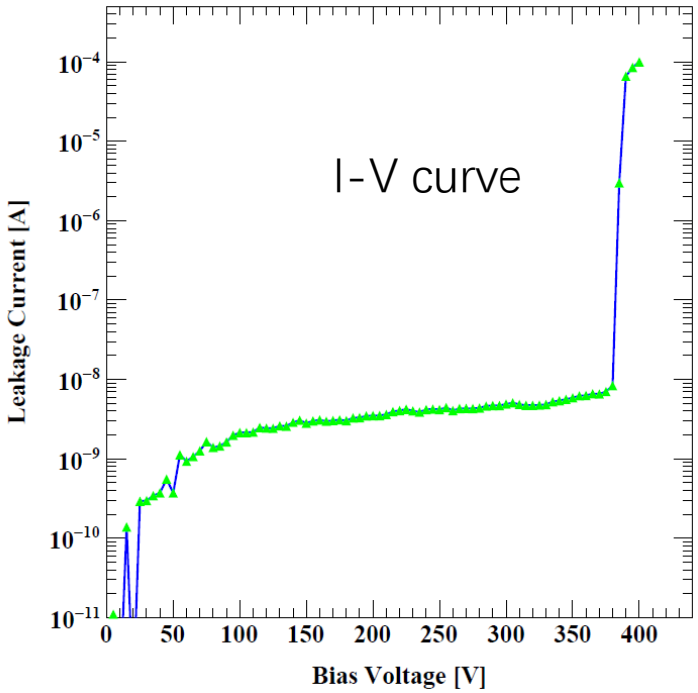
Pixels AC-LGAD：

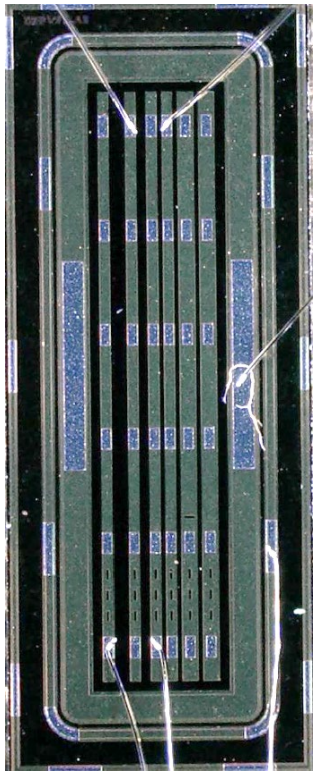
- Position information： 1 layer
- Pitch size 2000um, pad size 1000um
- Different N+ dose：
  - **10P，5P，1P，0.5P，0.2P**

Strips AC-LGAD：

- Position information： 2 layer
- Strip length 5.6mm, width 100um
- Different Pitch size：
  - **150um、200um、250um**







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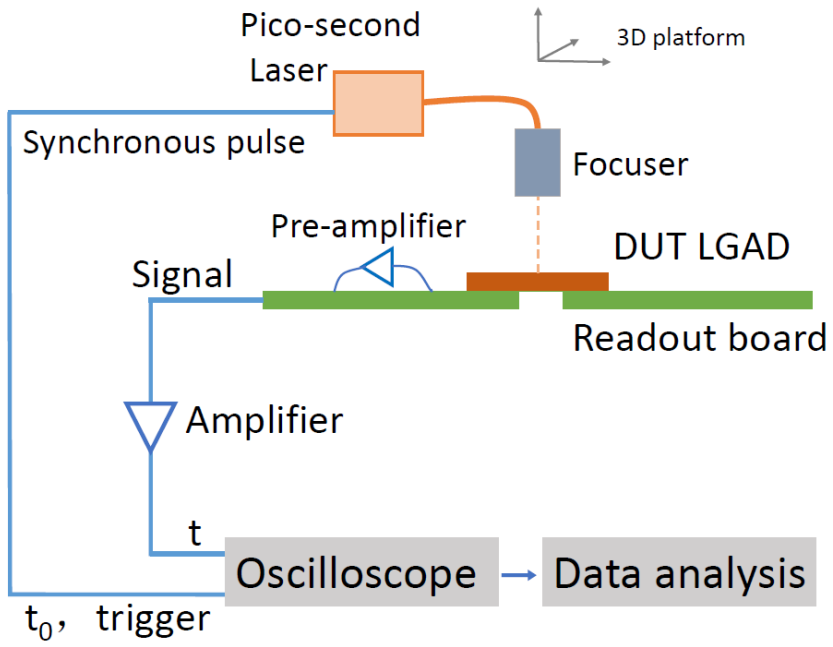
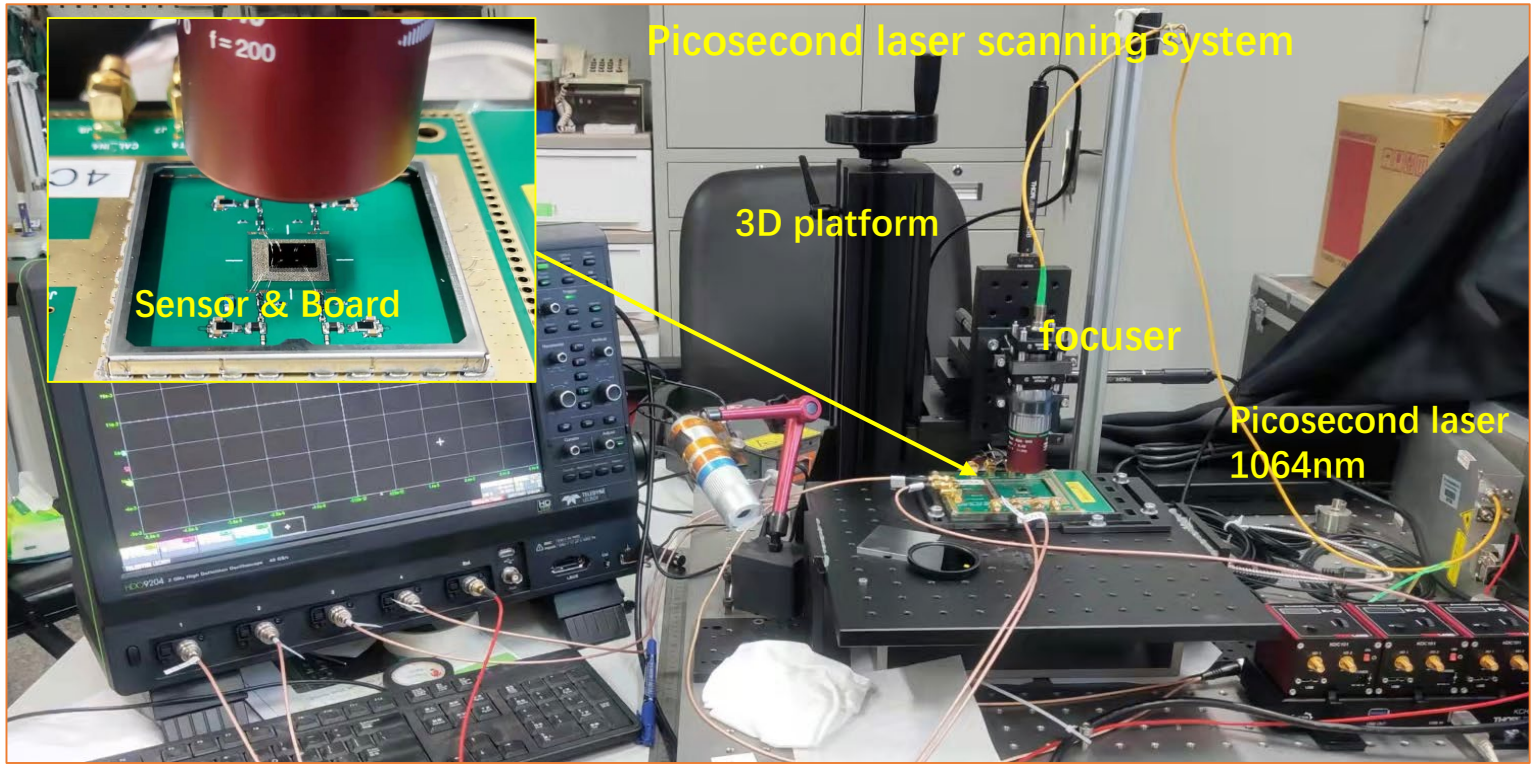
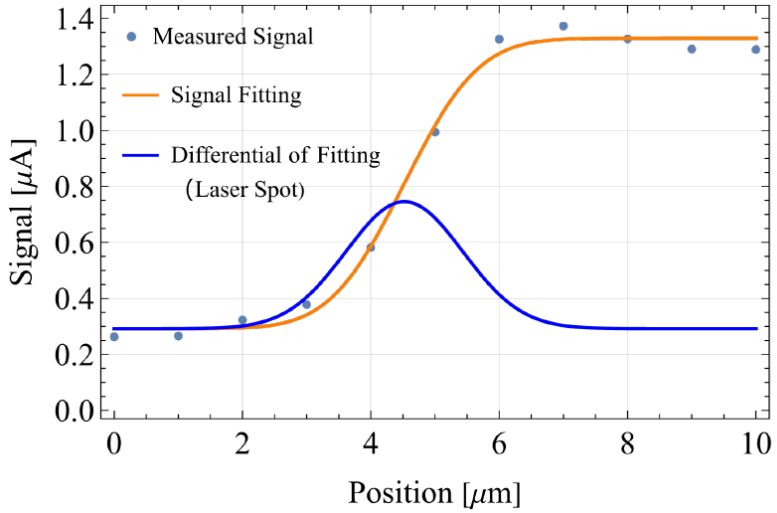
4. 皮秒激光测试：测试系统

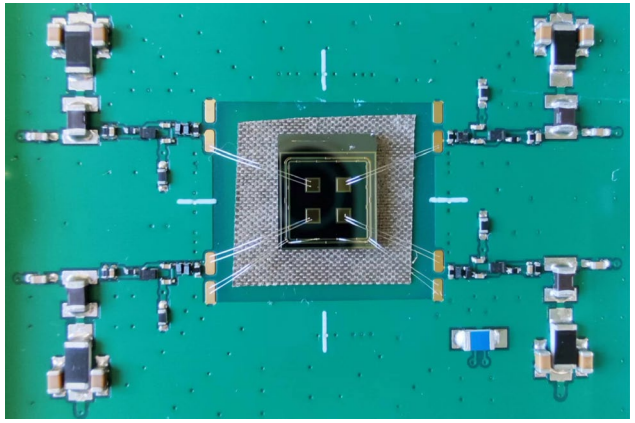






Picosecond laser scanning system

- Displacement accuracy 1 μm
- Automated scanning
- Picosecond laser 1064nm
- Laser pulse energy ~ 1 pJ
- Laser spot size 2~5 μm



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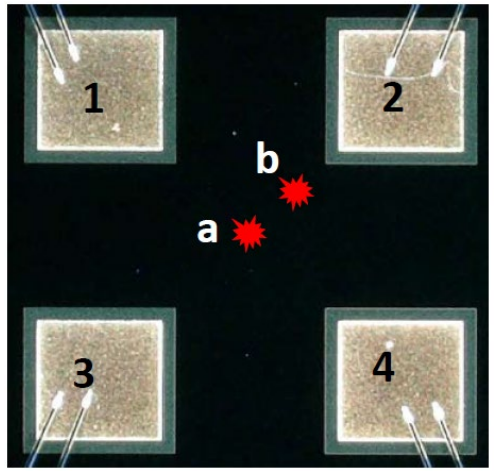
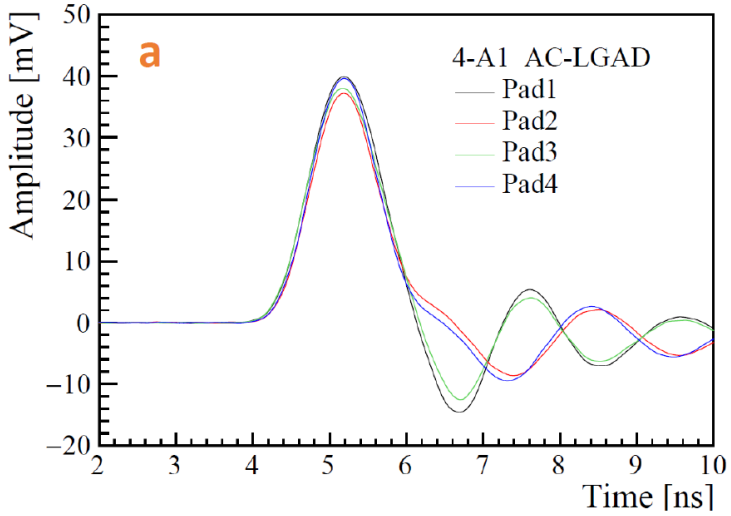
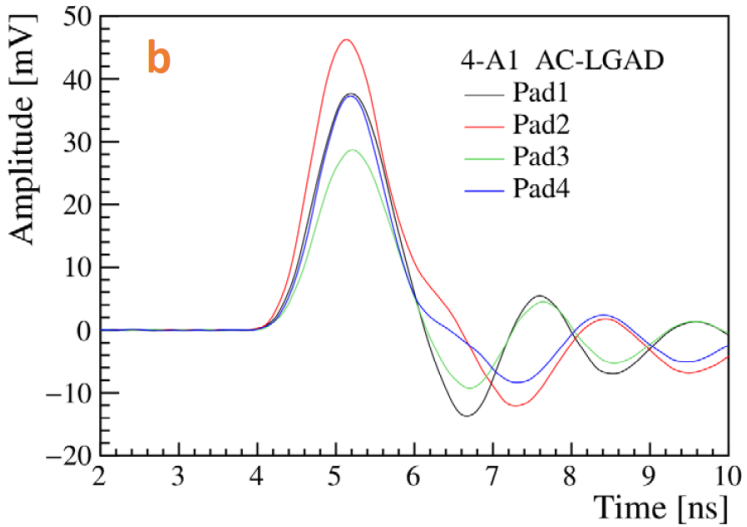
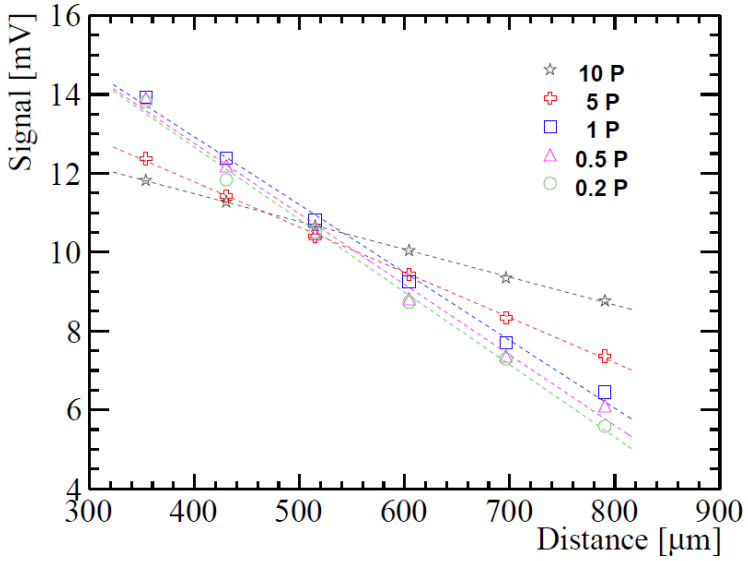
4. 皮秒激光测试：信号特征



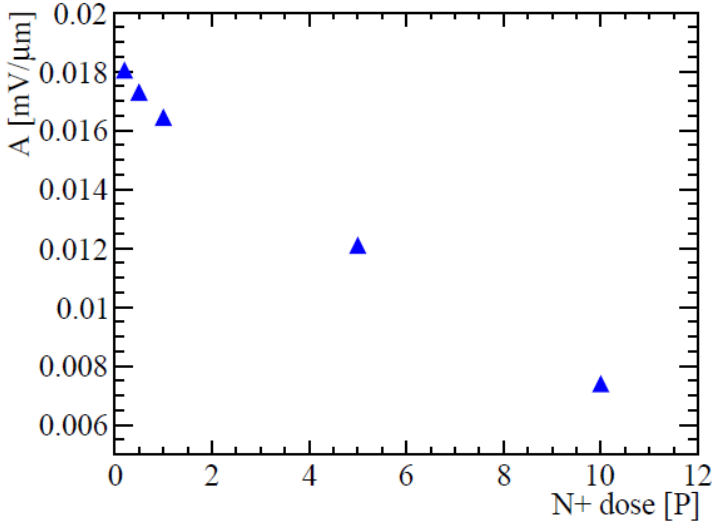




signal amplitude vs. distance



attenuation factor *A*



- The signal decreases with distance
- The factor *A* is obtained by the linear fit

- The *A* decreases with the increase of N+ dose
- Low N + dose means high resistivity

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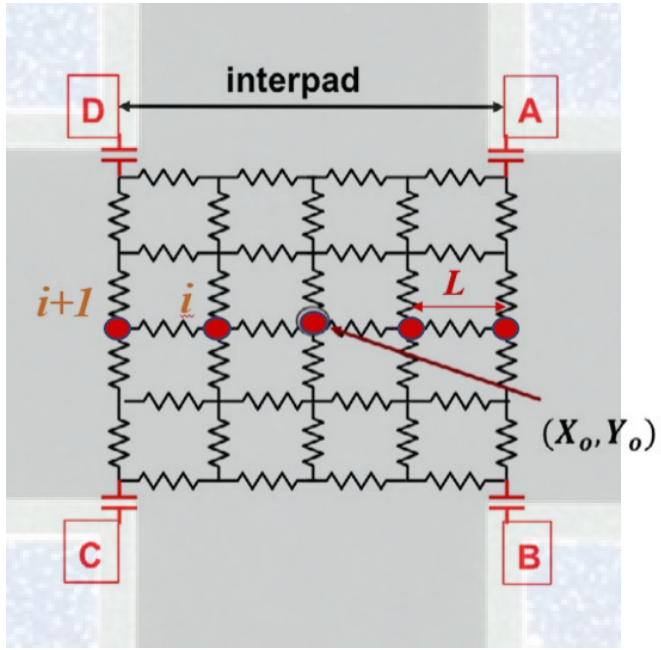
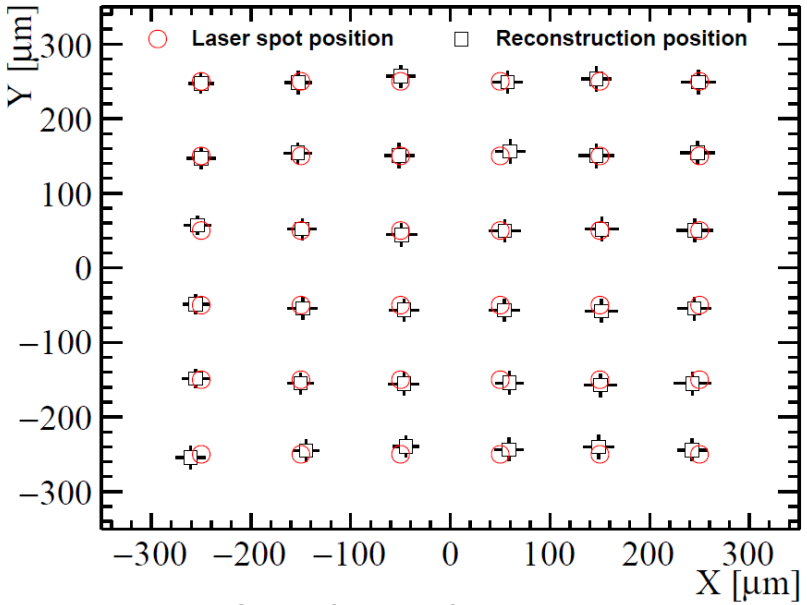
5. 位置信息重建：pixels AC-LGAD

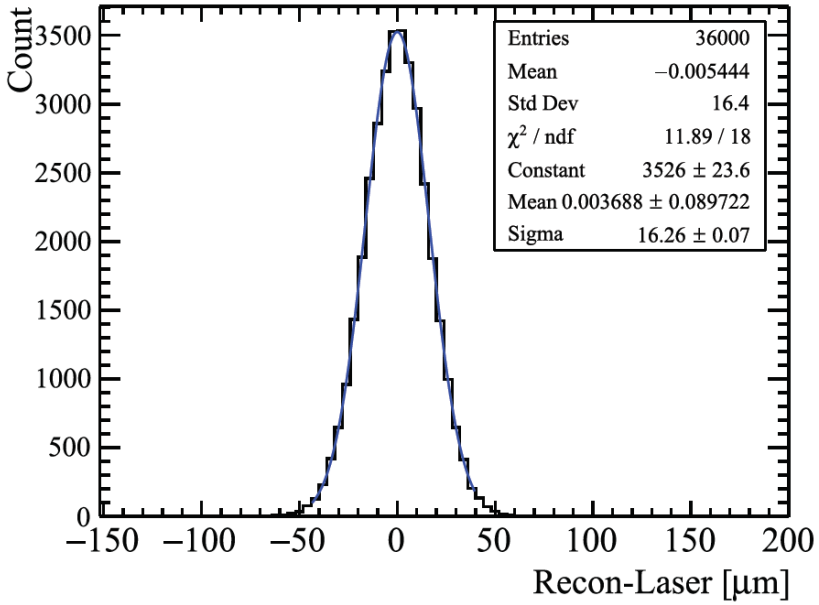


reconstructed 6x6 positions



Good consistency

Spatial resolution：reconstruction - laser



$$X = X_0 + k_x\left(\frac{q_A + q_B - q_C - q_D}{q_A + q_B + q_C + q_D}\right) = X_0 + k_x m$$

$$Y = Y_0 + k_y\left(\frac{q_A + q_D - q_B - q_C}{q_A + q_B + q_C + q_D}\right) = Y_0 + k_y n$$

Correction factor： k_x k_y

$$k_x = L\frac{\sum(m_{i+1} - m_i)}{\sum(m_{i+1} - m_i)^2} \qquad k_y = L\frac{\sum(n_{i+1} - n_i)}{\sum(n_{i+1} - n_i)^2}$$

Discretized Positioning Circuit model (DPC)

Spatial resolution：

- the sigma of the difference between the laser and the reconstructed position

$$\sigma_{spatial} = \sigma_{reconstruction-laser}$$

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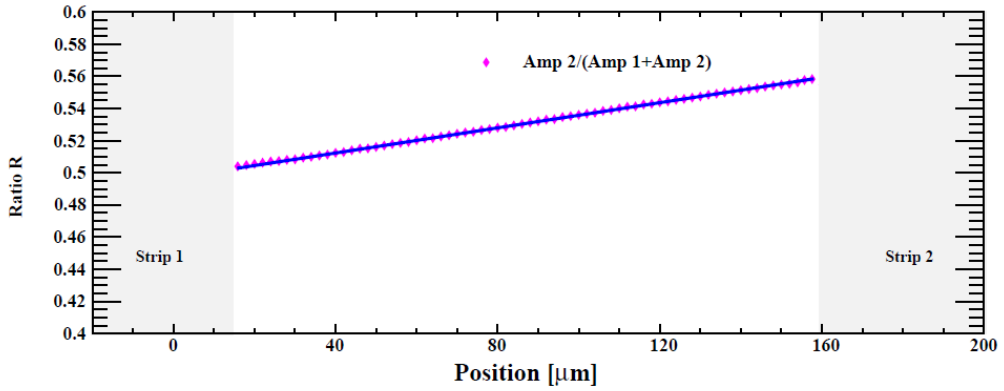
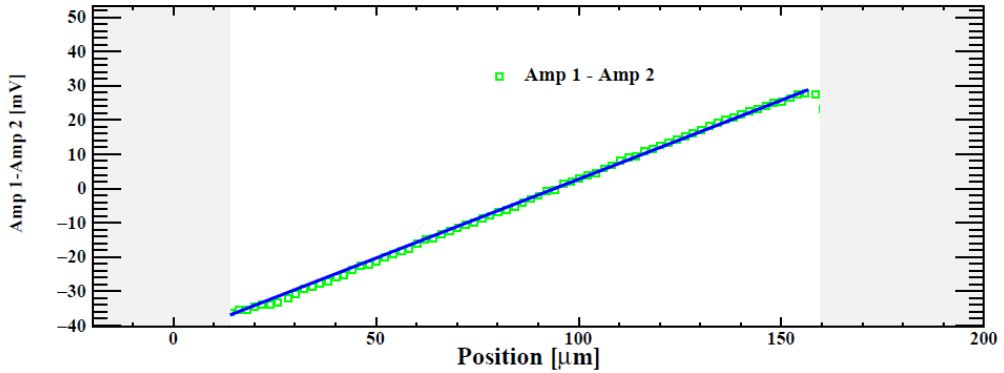
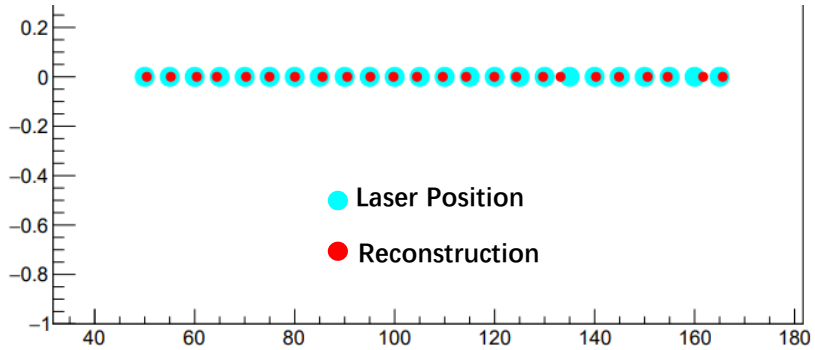
5. 位置信息重建：strips AC-LGAD





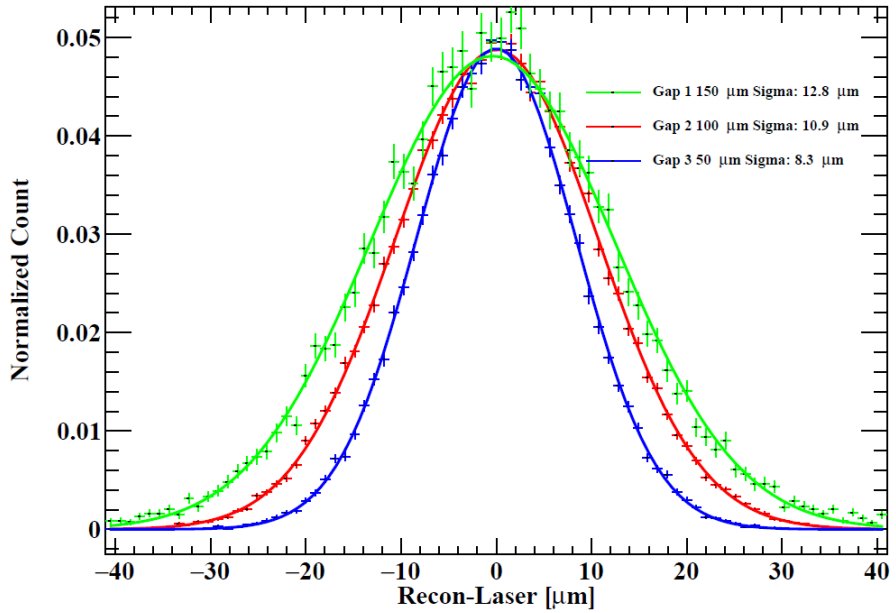


reconstructed positions

reconstructed position

$$R = \frac{Amp_2}{Amp_1 + Amp_2}$$

$$x = \frac{R - c}{k_R}$$



Position reconstruction:

- The fraction of the signal (*R*) changes linearly with the movement of the laser.

- Good consistency between the reconstruction position and the laser position
- The smaller the pitch size, the better the spatial resolution

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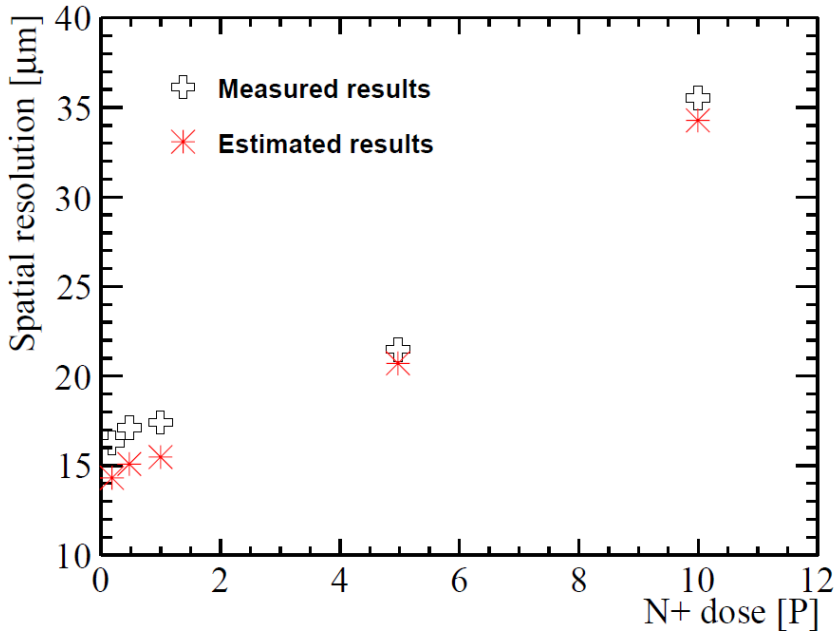
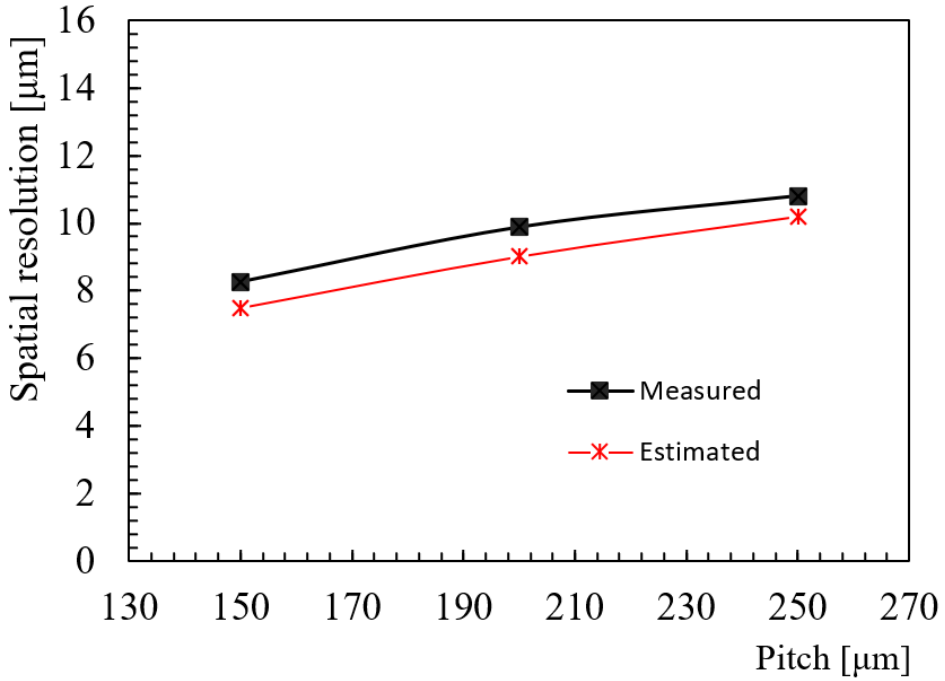
6. N+剂量与单元尺寸对空间分辨率的影响

Spatial resolution Vs. N+ dose



Spatial resolution Vs. pitch size



Resolution estimation:

$$\sigma_{spatial} \approx \frac{N}{A}$$

A: signal attenuation factor

N: noise RMS (sensor + electronics)

- N+ dose 10 P⟶0.2 P, spatial resolution 36 -> 16 μm.
- **Lower N + dose** has higher resistivity and larger attenuation factor, ->**better spatial resolution**.
- Pitch size 250um ⟶ 150um, spatial resolution 11 -> 8 μm.
- **Smaller pitch sizes** result in faster signal attenuation and larger attenuation factor, ->**better spatial resolution**

Spatial resolution can also be evaluated according to signal attenuation factor and noise level.

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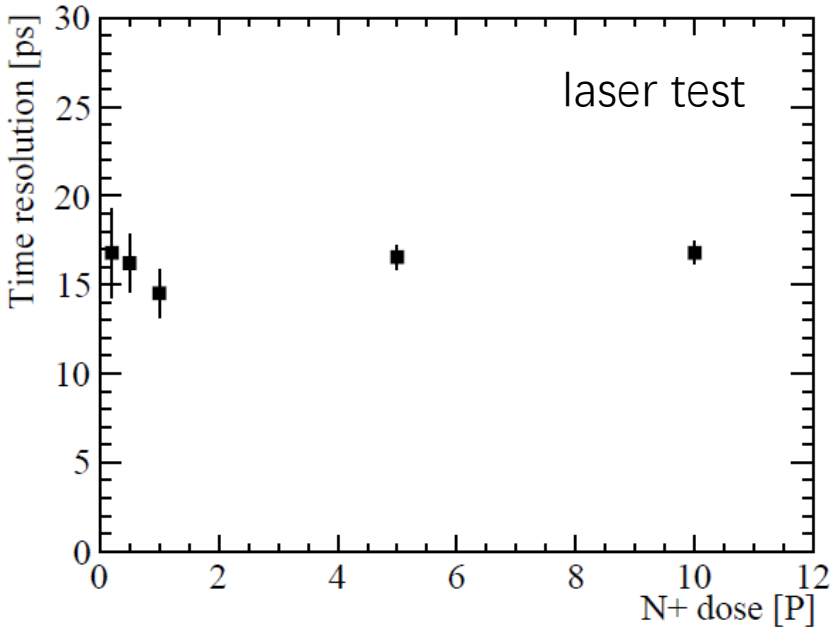
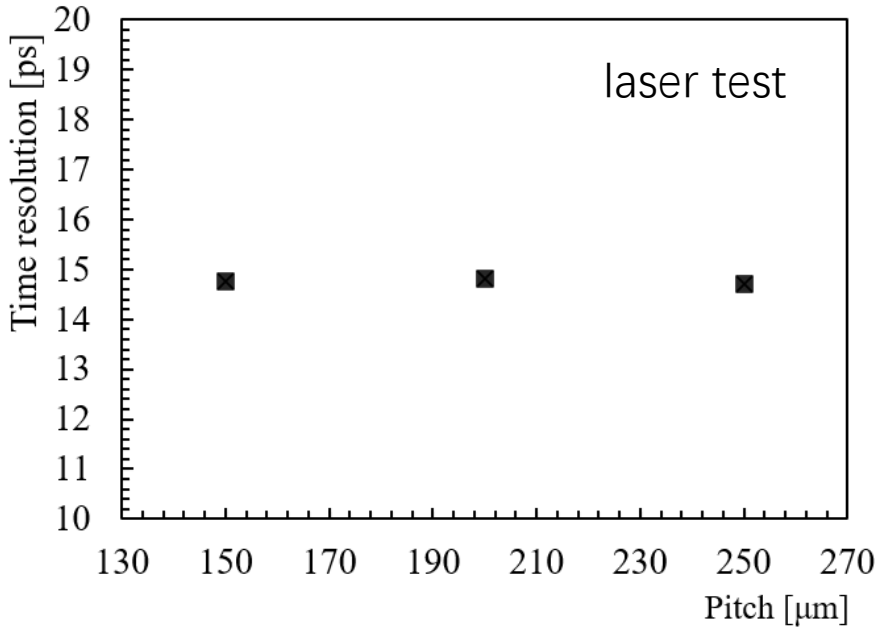
7. 时间分辨率

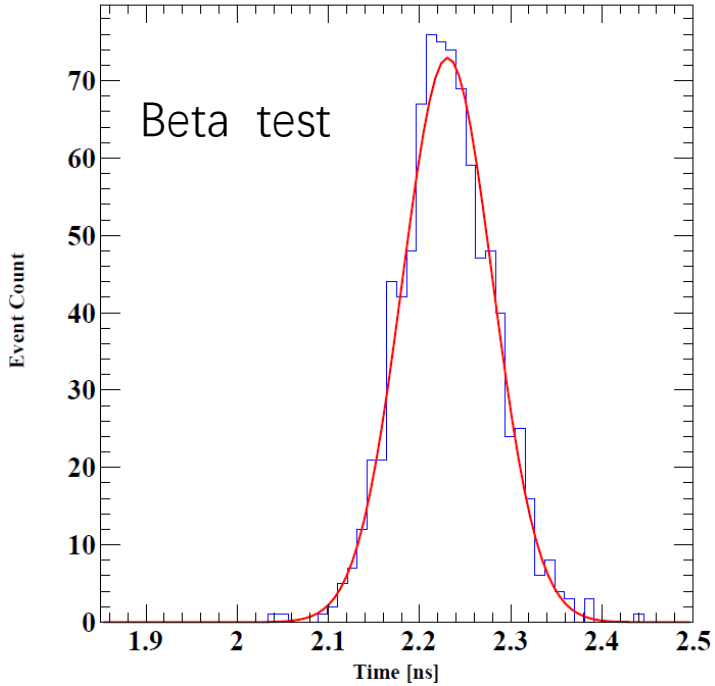
Time resolution Vs. N+ dose



Time resolution Vs. pitch size



Time resolution
tested by beta source



- 在0.2-10.0P的注入剂量范围内，时间分辨率无明显变化。
- Strips AC-LGAD的pitch 150um-250um 范围内，时间分辨率也未表现明显变化。
- 激光测试得到的时间分辨率仅包含jitter项，未包含Landau项。
- 根据beta源（电子）测试AC-LGAD的时间分辨率为 37.5ps。

Sigma Δt = 47.1 ps
Sigma AC-strip： 37.5 ps

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{Landau}^2 + \sigma_{Jitter}^2$$

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8. 总结

- AC-LGAD is a new 4D detector （position + time）
- IHEP has designed pixels and strips AC-LGAD sensors
- **The best spatial resolution of strips AC-LGAD ~8μm**
- **The best spatial resolution of pixels AC-LGAD ~16μm**
- **Low N+ dose and small pitch size have better spatial resolution**
- **The signal attenuation factor and noise level are the main parameters for estimating the spatial resolution**

The next plan of IHEP AC-LGAD

- Test beam
- Optimize n+ p+ layers and AC-electrodes
- Advanced algorithms for the reconstruction
- Ultra Low Noise Electronics
- ASIC and monolithic integration
- ……

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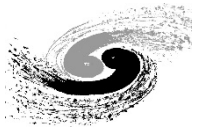

Thanks