AC-coupled LGAD development by IHEP for future lepton collider

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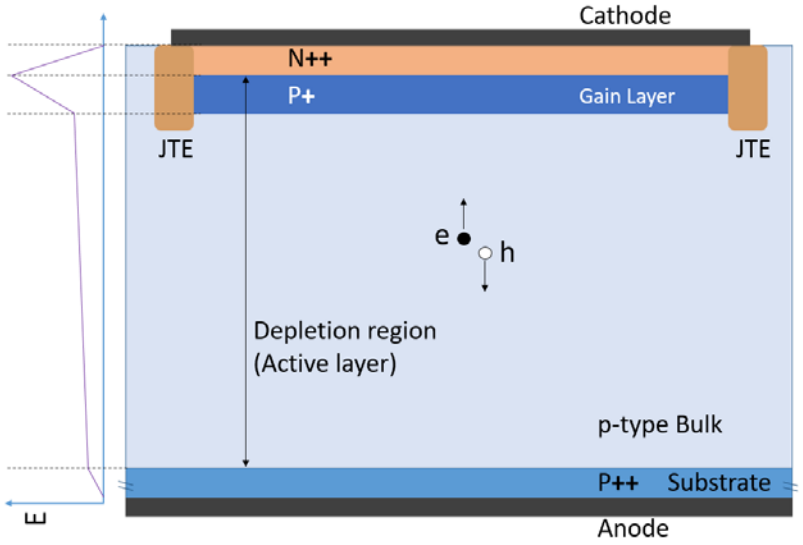
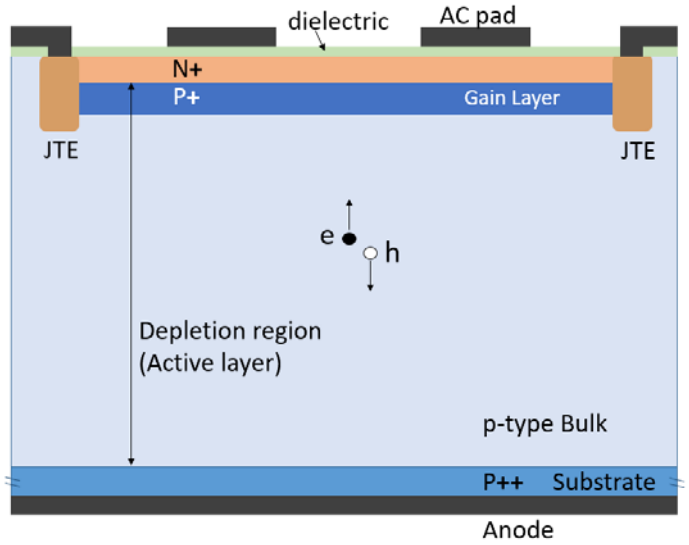
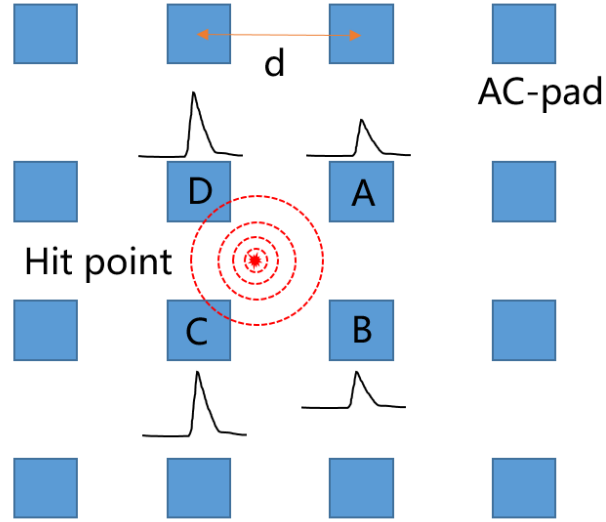
1. Introduction of AC-LGAD



LGAD (Low-Gain Avalanche Diode)



AC-LGAD (AC-coupled LGAD)



AC-pad layout scheme

LGAD

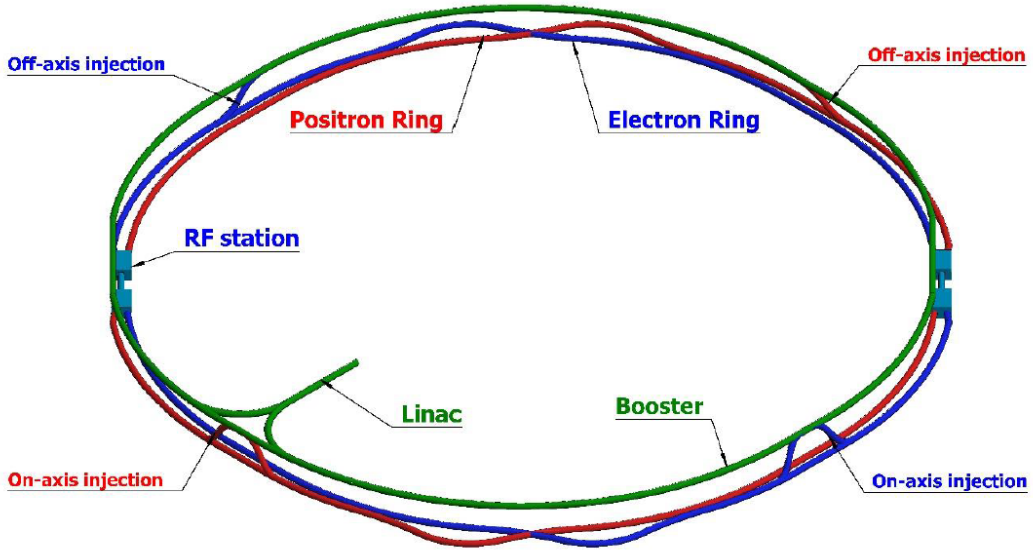
- The read-out pad is connected to N++ layer
- Time resolution ~ 30ps
- Position resolution: sensor size

AC-LGAD

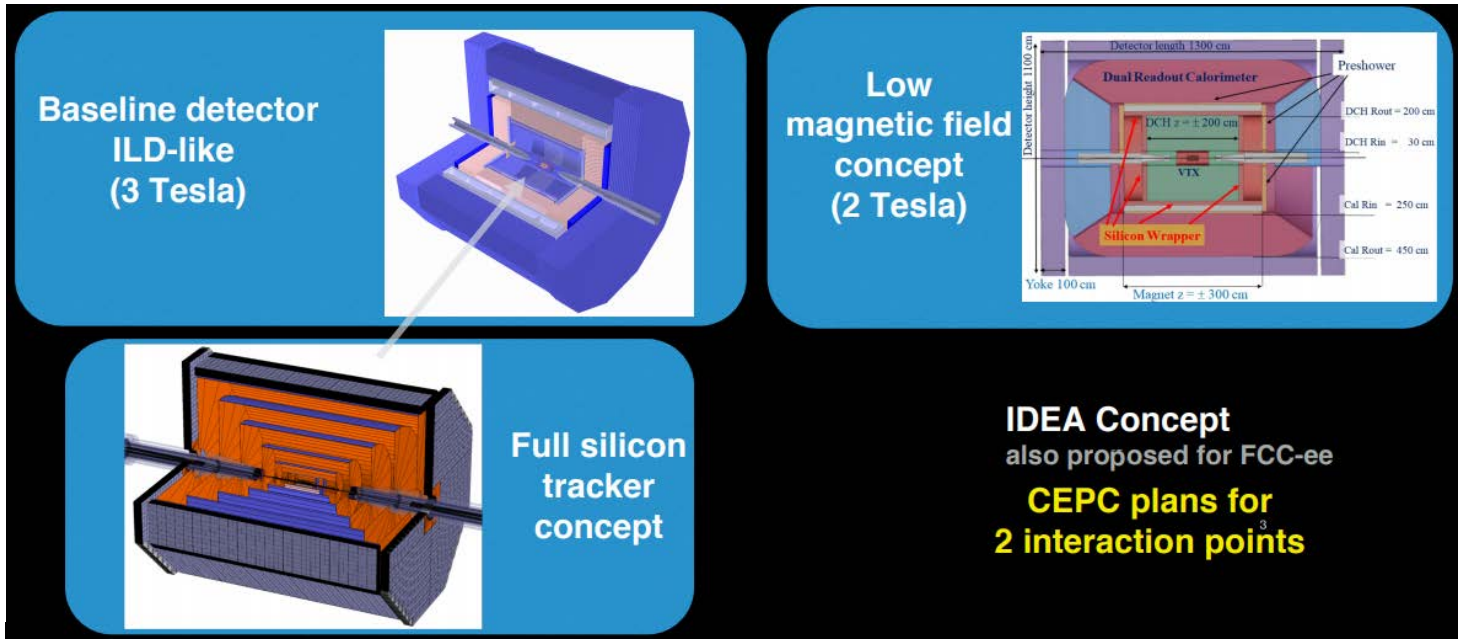
- AC-pads separated from the N+ layer by a thin dielectric (SiO_2)
- Large area, 100% fill factor
- Time resolution ~ 30ps
- Position resolution: 10-50 μm
- **4D detector：position + time**

2. CEPC timing detector : Conceptual design

- AC-LGAD can be used as a 4D tracker for future electron collider experiments
- Fcc-ee/CEPC will produce Tera Z (~10^{12}) Z boson at Z pole -> Rich flavor physics
- High-precision 4D detector is powerful for particle identification (PID)

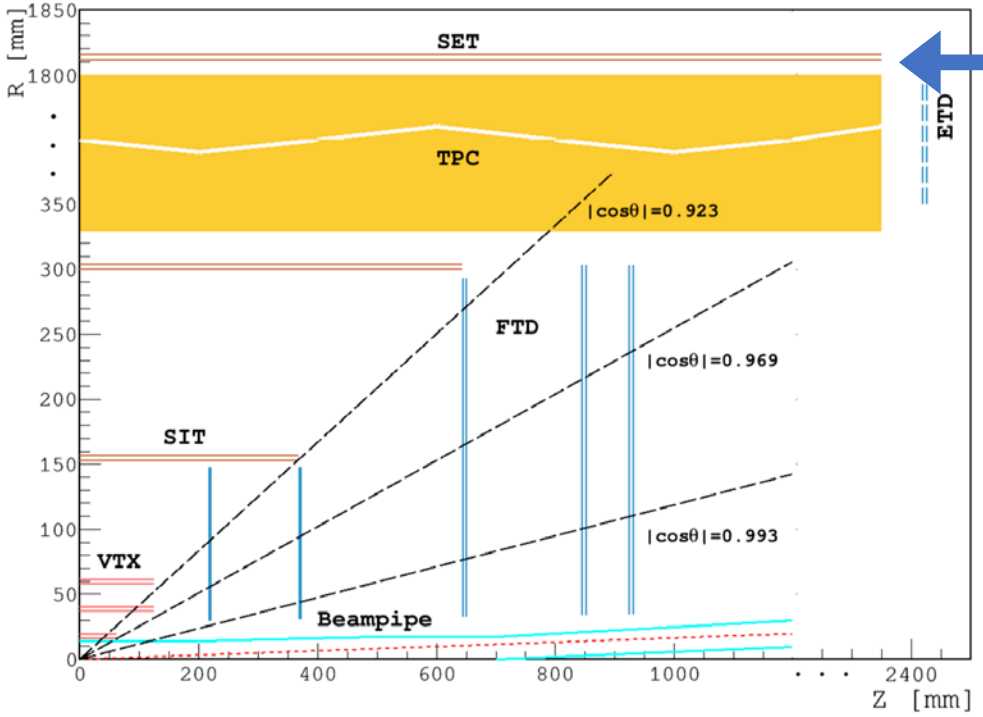


CEPC Layout

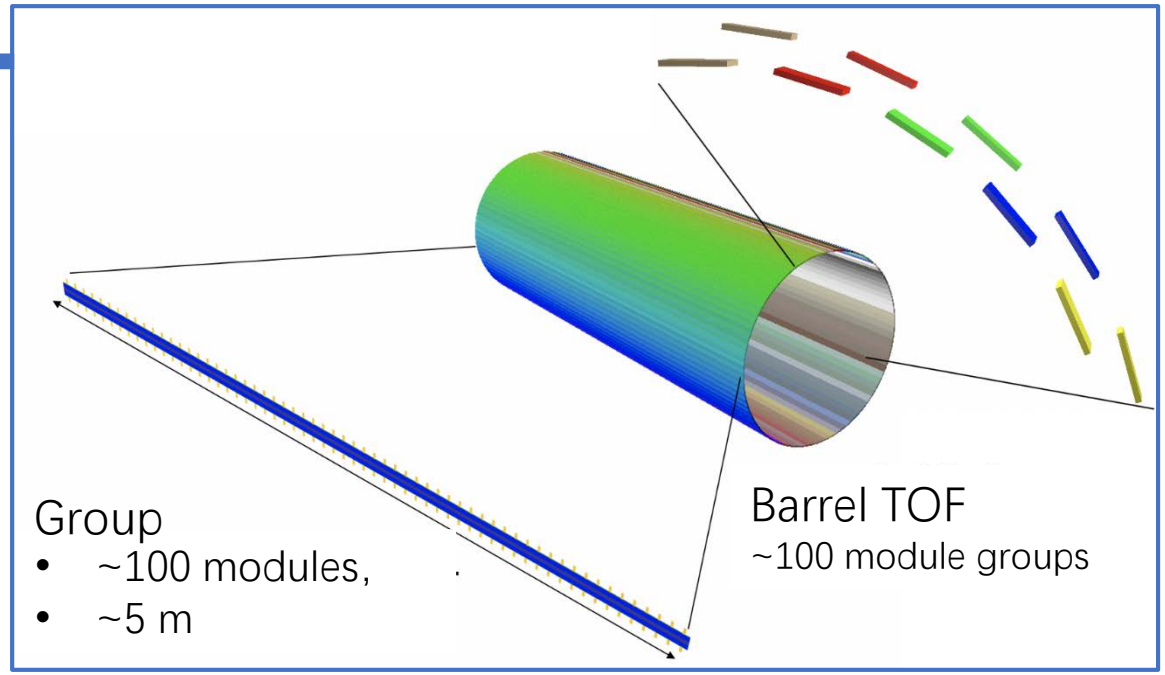


2. CEPC timing detector : Conceptual design

- Timing detector: Between tracker and calorimeter
- Close to (or replace) the SET tracker, Radius ~1.8m
- **Area of detector (Barrel : ~50m^2 , Endcap: ~20m^2)**
- **Target time resolution: 20-30 ps**
- **Large area, low readout density**



Baseline detector concept in CDR

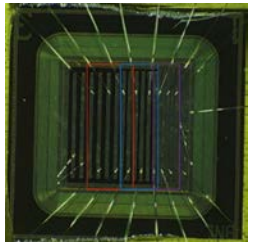


Timing detector in Barrel region

3. AC-LGAD sensors development by IHEP

FBK

BNL

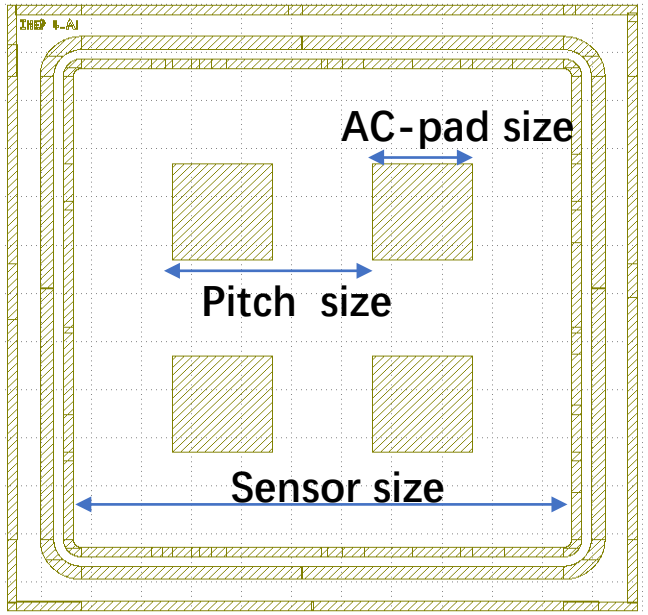


According to the current report, the pitch size of AC-LGAD is 50~500 μm, such as FBK / BNL AC-LGAD

https://indico.cern.ch/event/861104/contributions/4503072/attachments/2306673/3924214/H.%20Sadrozinski.pdf

IHEP designed a **larger pitch** AC-LGAD

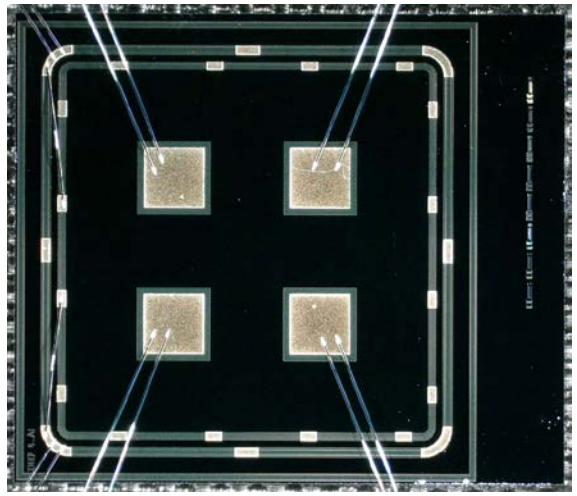
IHEP AC-LGAD
- large area
- Pitch 2000 μm
- low readout density



IHEP AC-LGAD

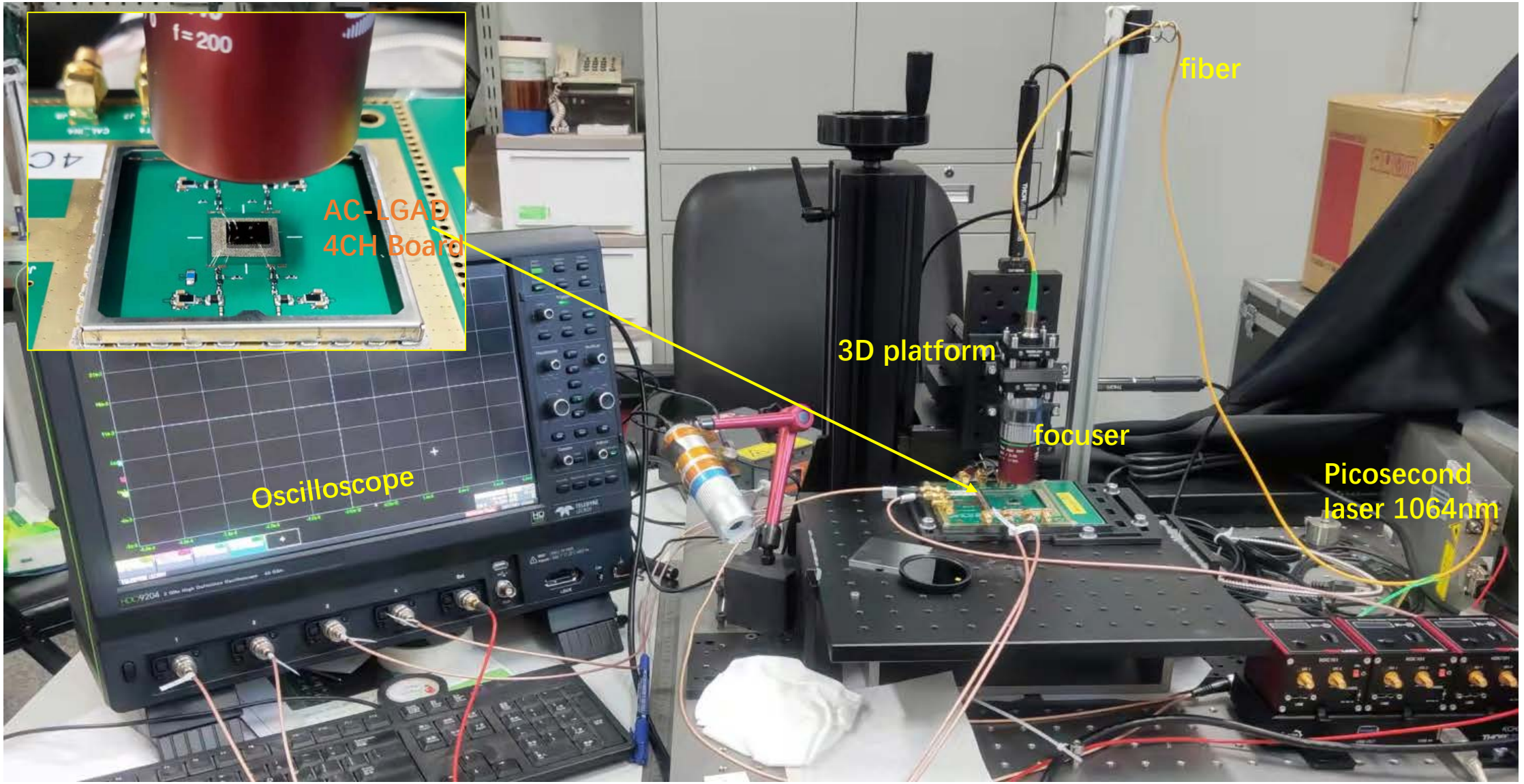
Sensor	N+ dose [unit]	AC-pad size [μm]	Picth size [μm]
W7Q1	10.0	1000	2000
W5Q1	5.0	1000	2000
W5Q2	1.0	1000	2000
W5Q3	0.5	1000	2000
W5Q4	0.2	1000	2000

Main parameters Different N+ dose

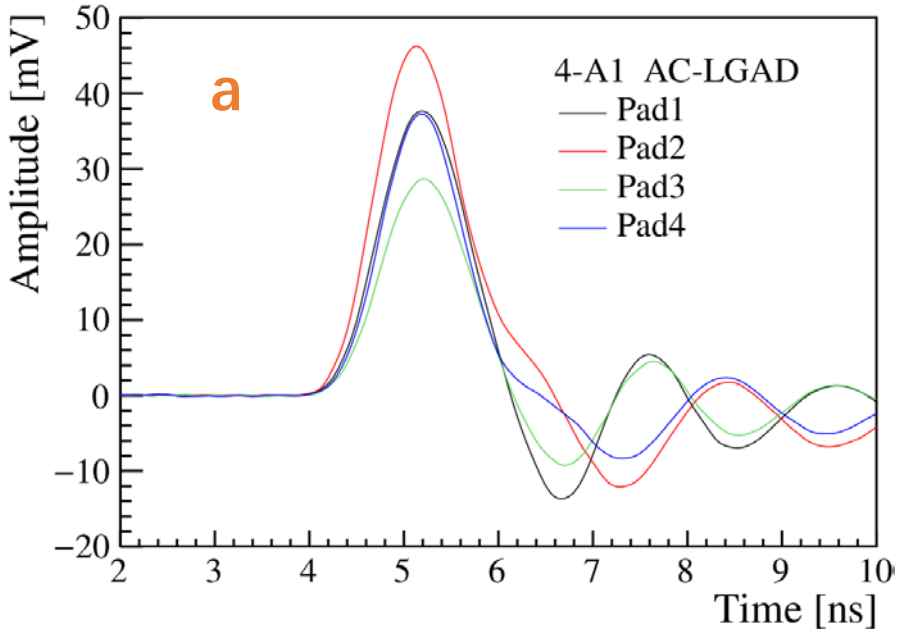


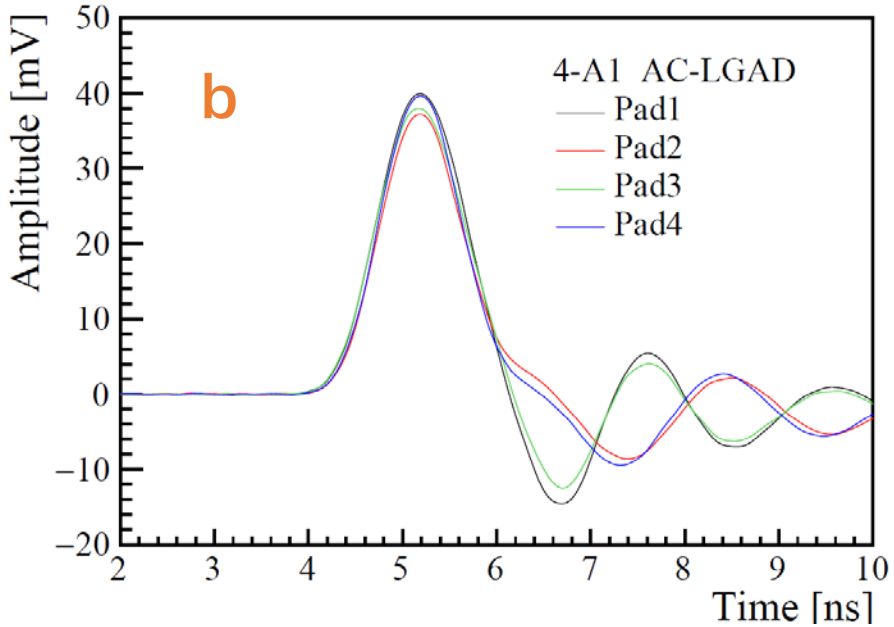
IHEP AC-LGAD

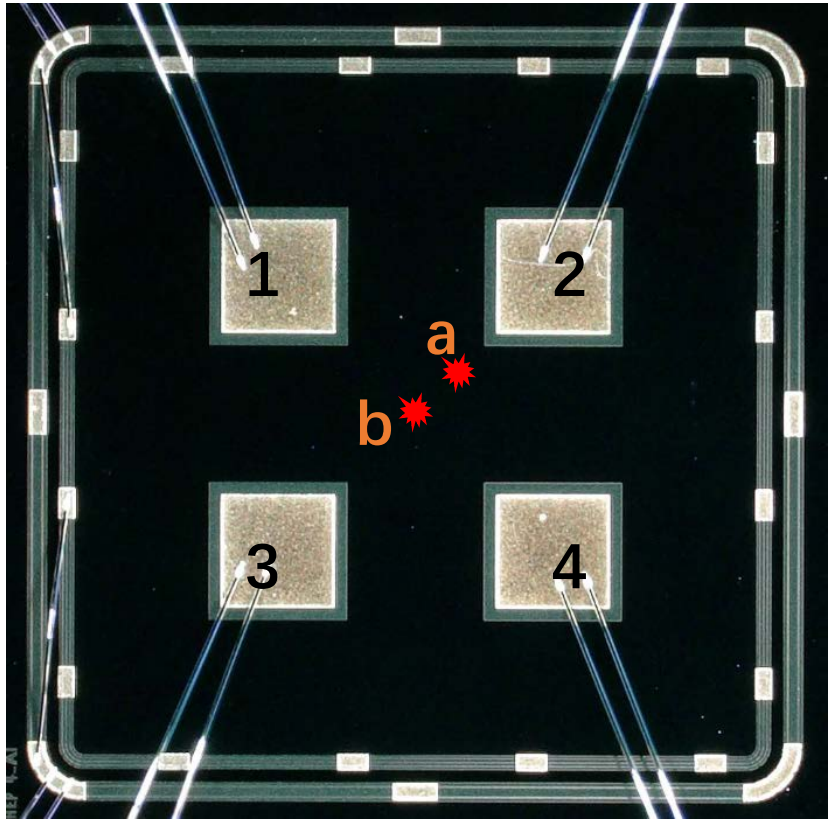
4. Picosecond laser test



5. Signal attenuation



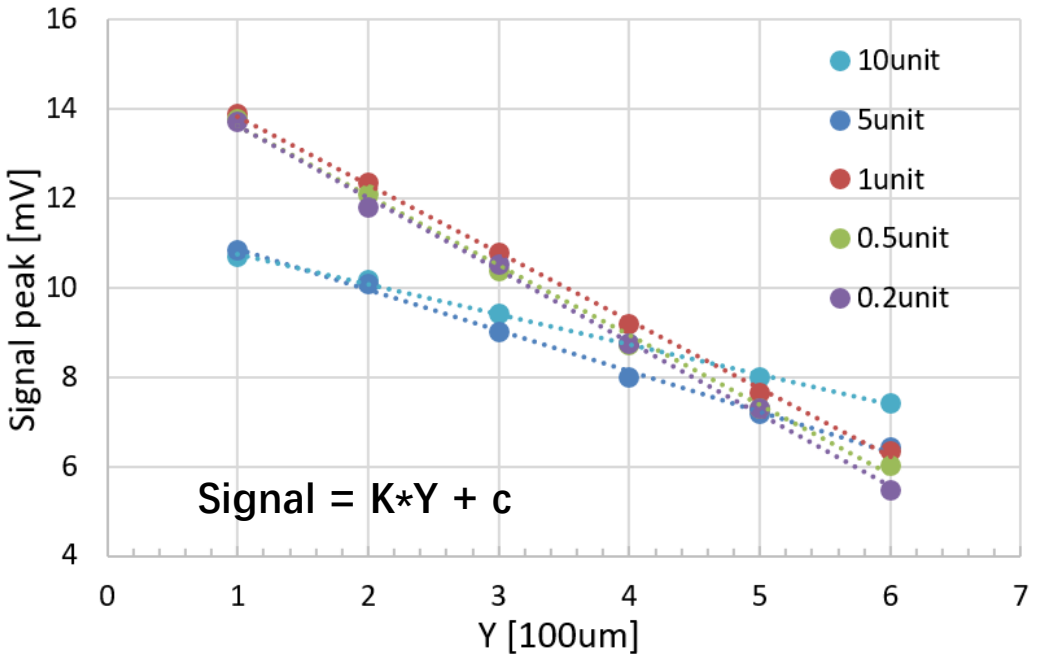


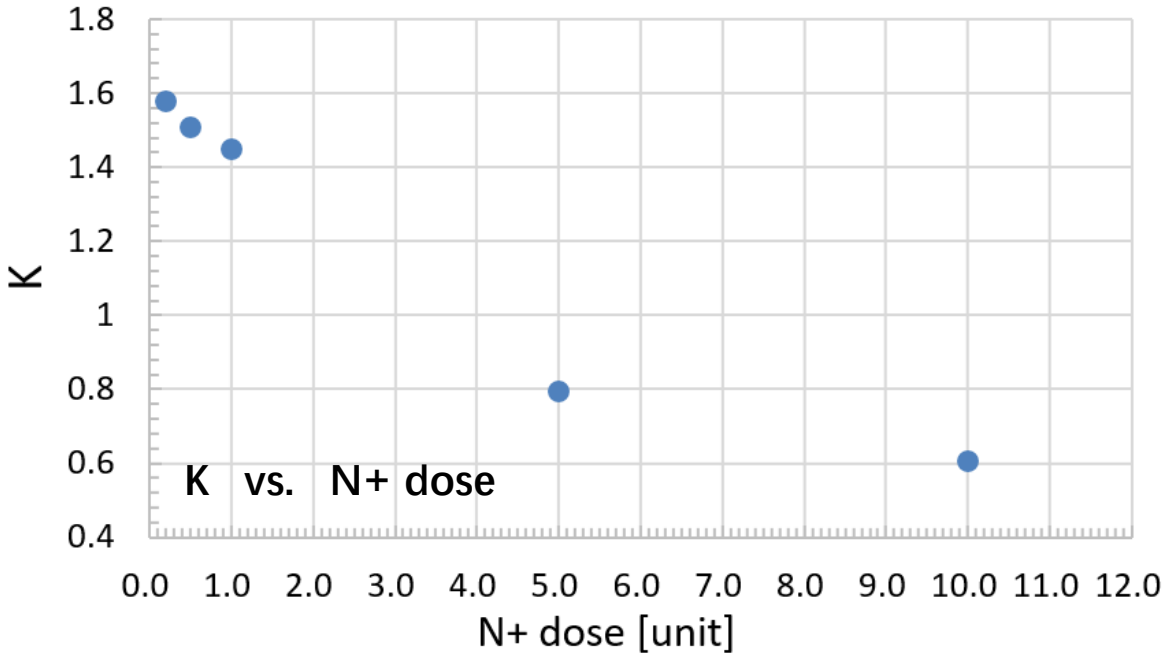


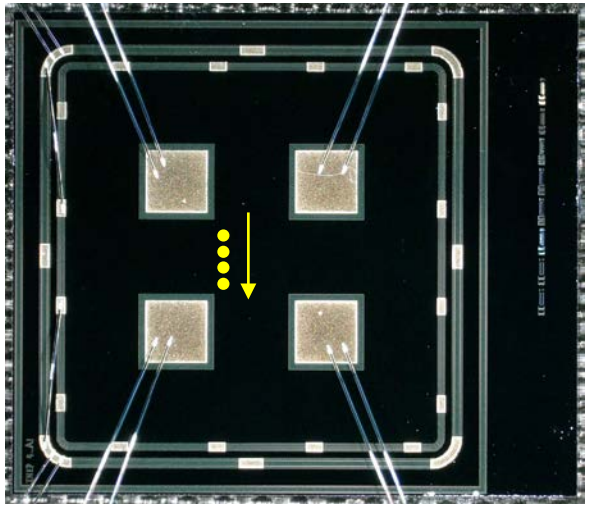
The signal is closely related to the laser hit position

- **Point a**: close to Pad 2 and away from Pad 3, Pad 2 has the largest signal and Pad3 has the smallest signal.
- **Point b**: the center position is the same as the 4 Pads, and the signal peak is the same.

5. Signal attenuation



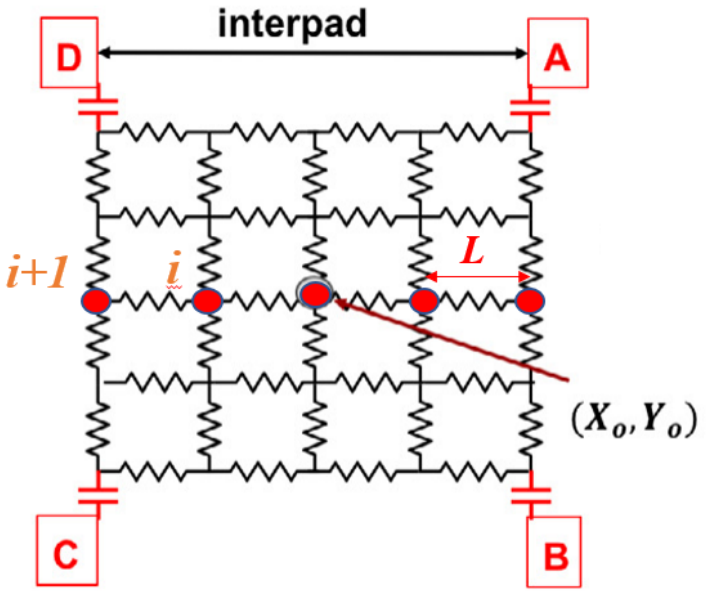




- The signal decreases with distance
- The factor K is obtained by the linear fit
- The K is the sensitivity of the signal to distance

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

6. Position Reconstruction



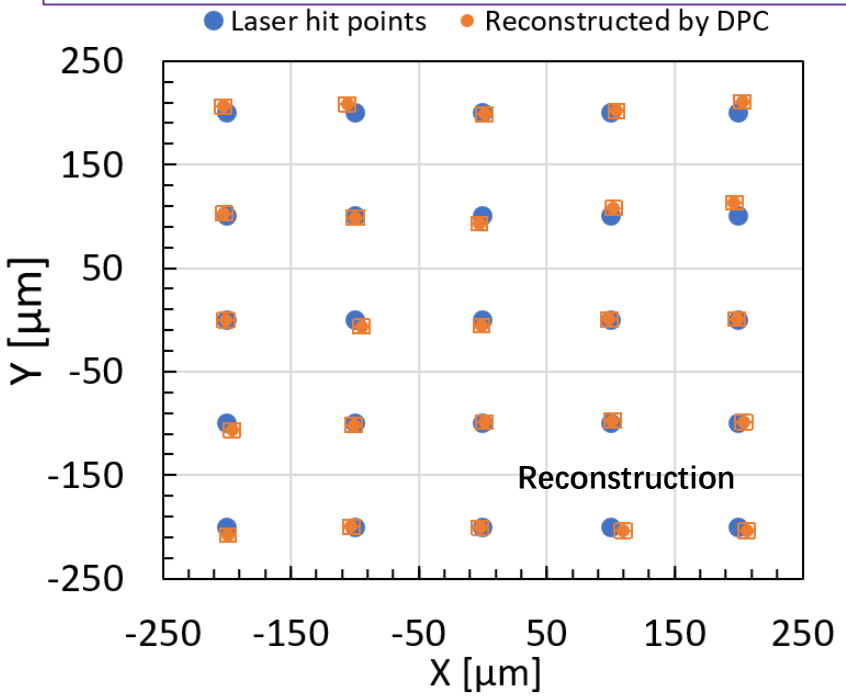
$$X = X_0 + k_x\left(\frac{q_A + q_B - q_C - q_D}{q_A + q_B + q_C + q_D}\right) = X_0 + k_x m$$

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

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

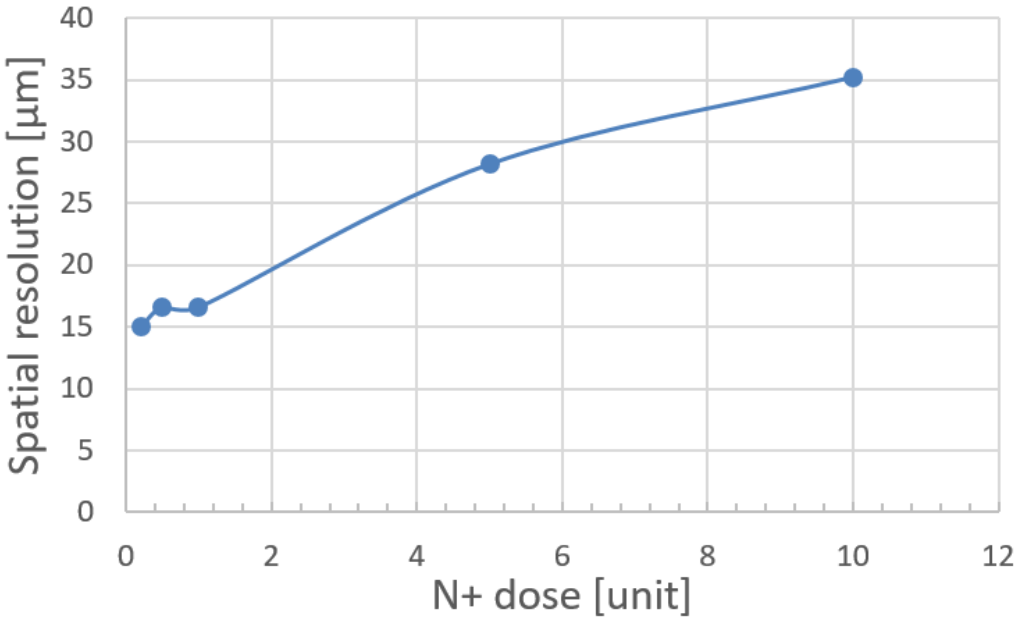
$$\sigma_{spatial} = \sigma_{reconstruction-laser}$$

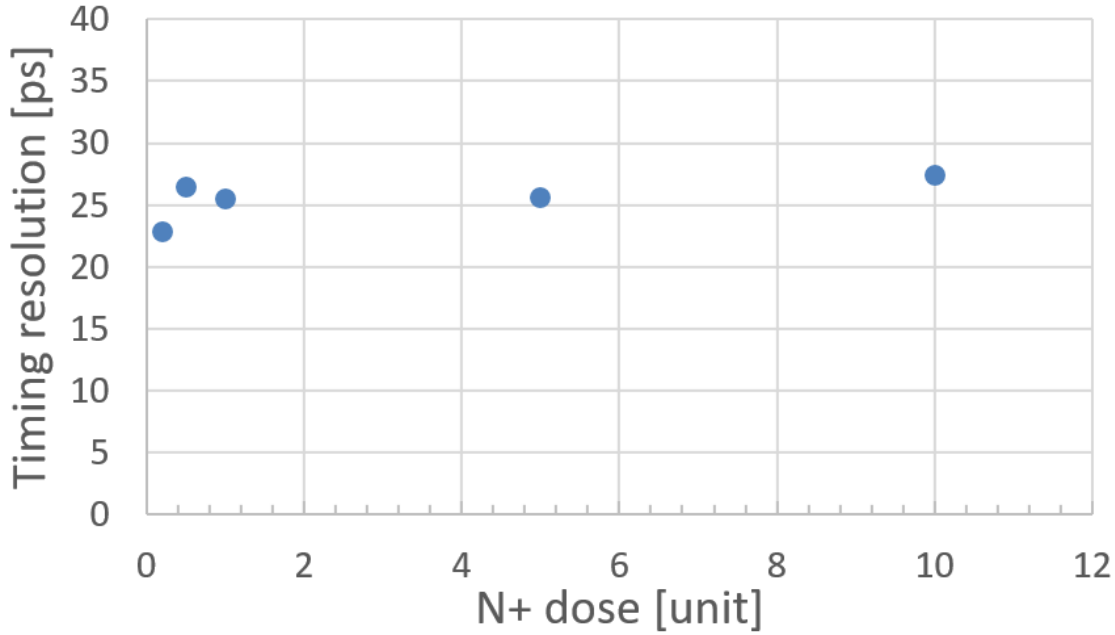
Timing resolution：

- the sigma of the average of arrived times （4 channels）

$$\sigma_t = \sigma_{(t1+t2+t3+t4)/4}$$

6. Spatial resolution & Timing resolution





Spatial resolution

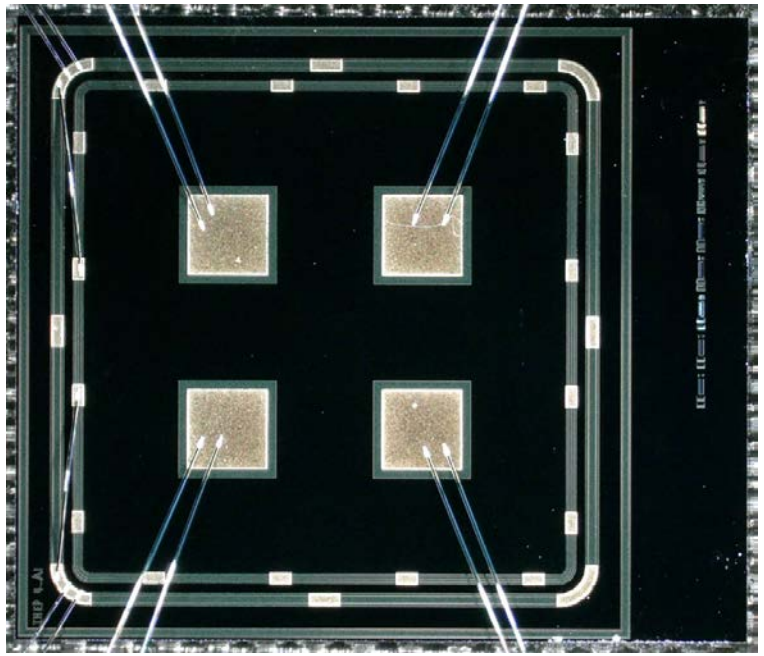
- N+ dose 10 unit⟶0.2 unit, the spatial resolution from 28 to 15 μm.
- Lower N + dose has higher resistivity, better spatial resolution.

Timing resolution

- The timing resolution ~ 25 ps, and the best is 0.2 unit ~23 ps.
- The N+ dose has little effect on timing resolution

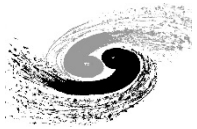
7. Summary

- AC-LGAD is a new 4D tracker (position + time)
- IHEP designed a **large-area AC-LGAD** and studied the **effect of N+ dose**
- Lower N + dose has a better **spatial resolution**, and the best is **15μm**.
- The N+ dose has a little effect on **timing resolution**, and the best is **23 ps**.



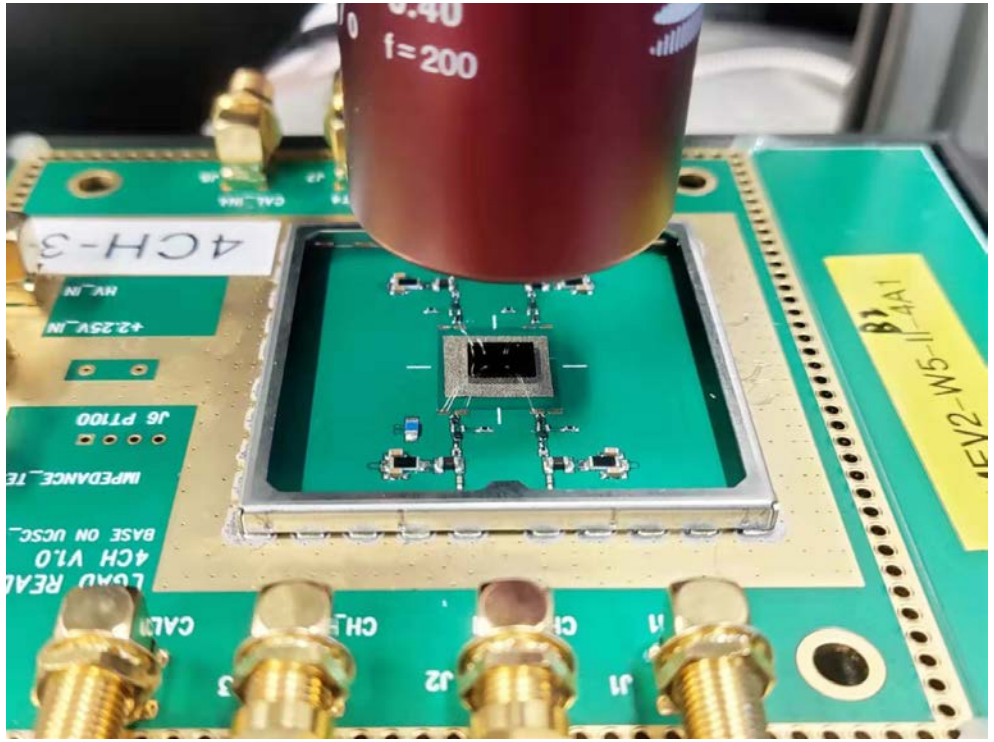
Next plan

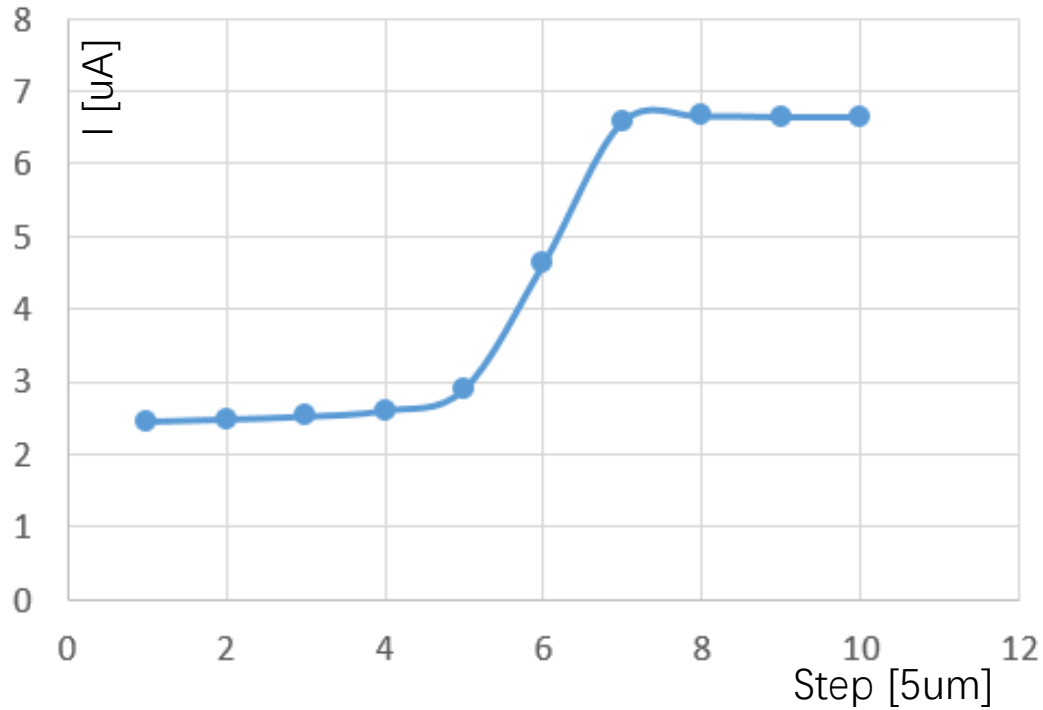
- Beta test
- Next version design



Thanks

Laser Setup





focusing on the sensor is ~15 um