CEPC timing detector R & D
--AC-coupled LGAD for 4D tracking

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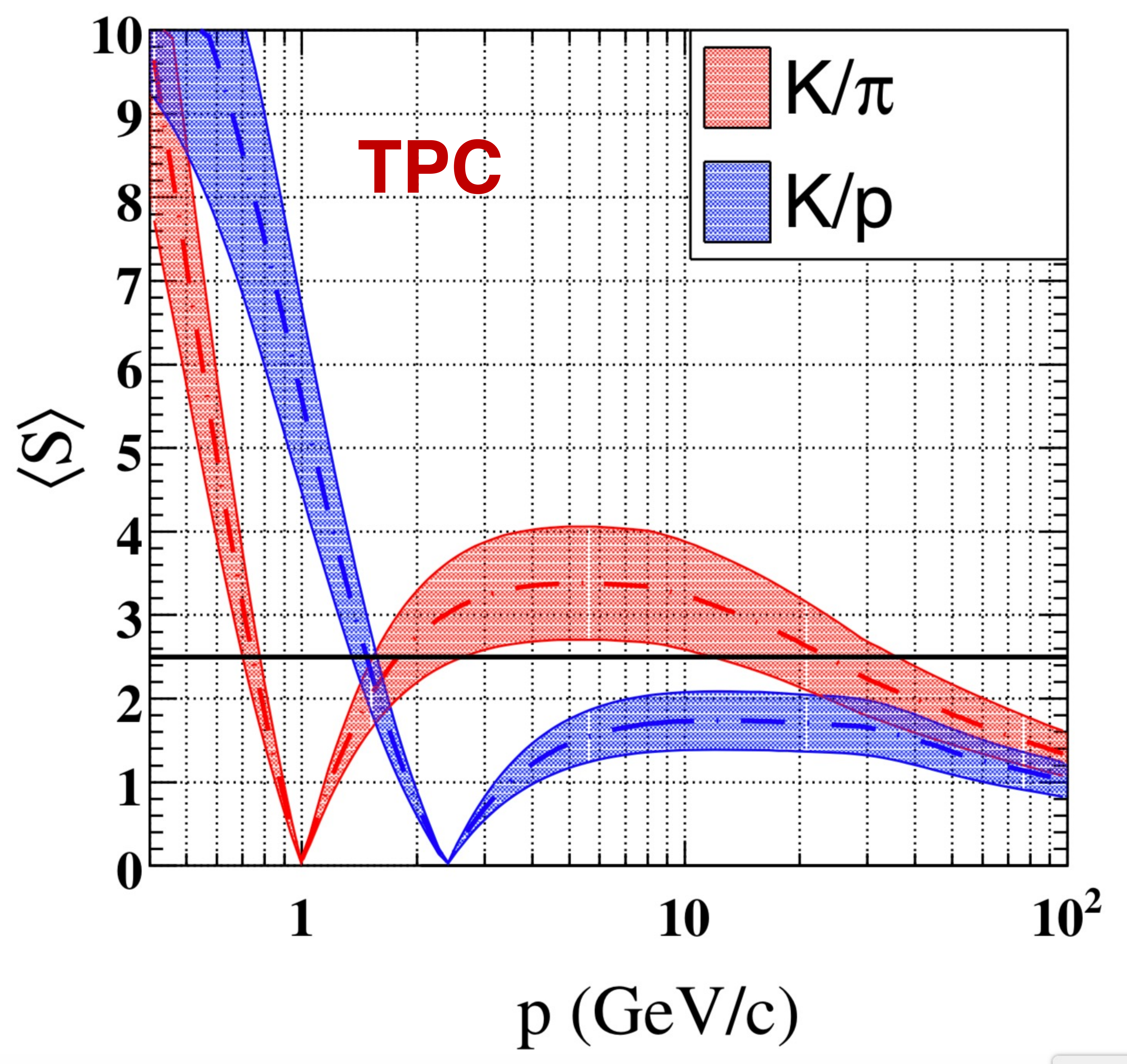
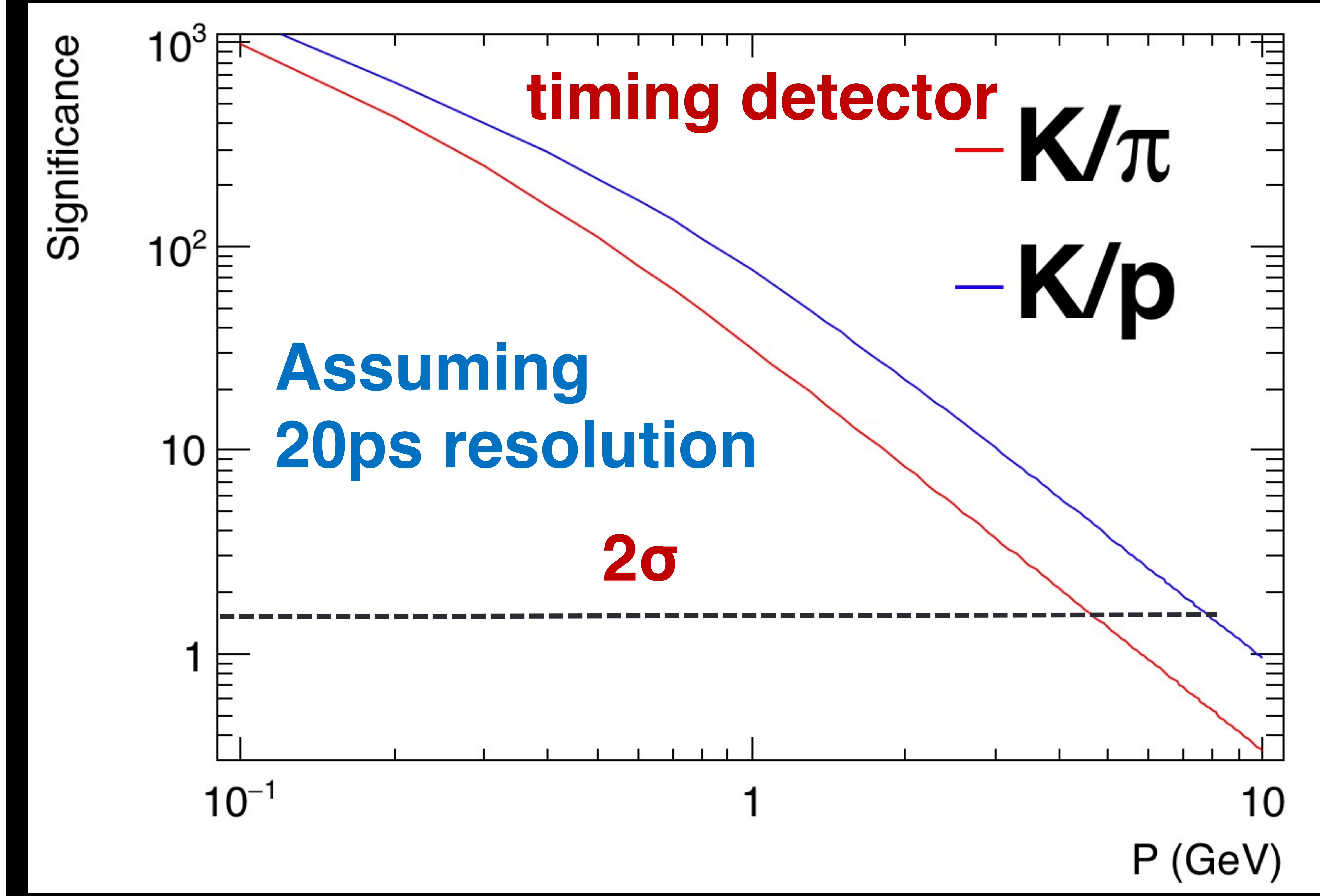
CEPC timing detector : motivation

- **CEPC will produce 10^{12} Z boson at Z pole → Rich flavor physics program**
- **Gas detector is responsible for particle identification in flavor (dE/dx)**
  → Challenge: 0.5-2GeV for K/pi separation, >1.5GeV for K/p separation
- **Timing detector is complementary to gas detector**
  → 0-4GeV for K/pi separation, 0-8GeV for K/p separation

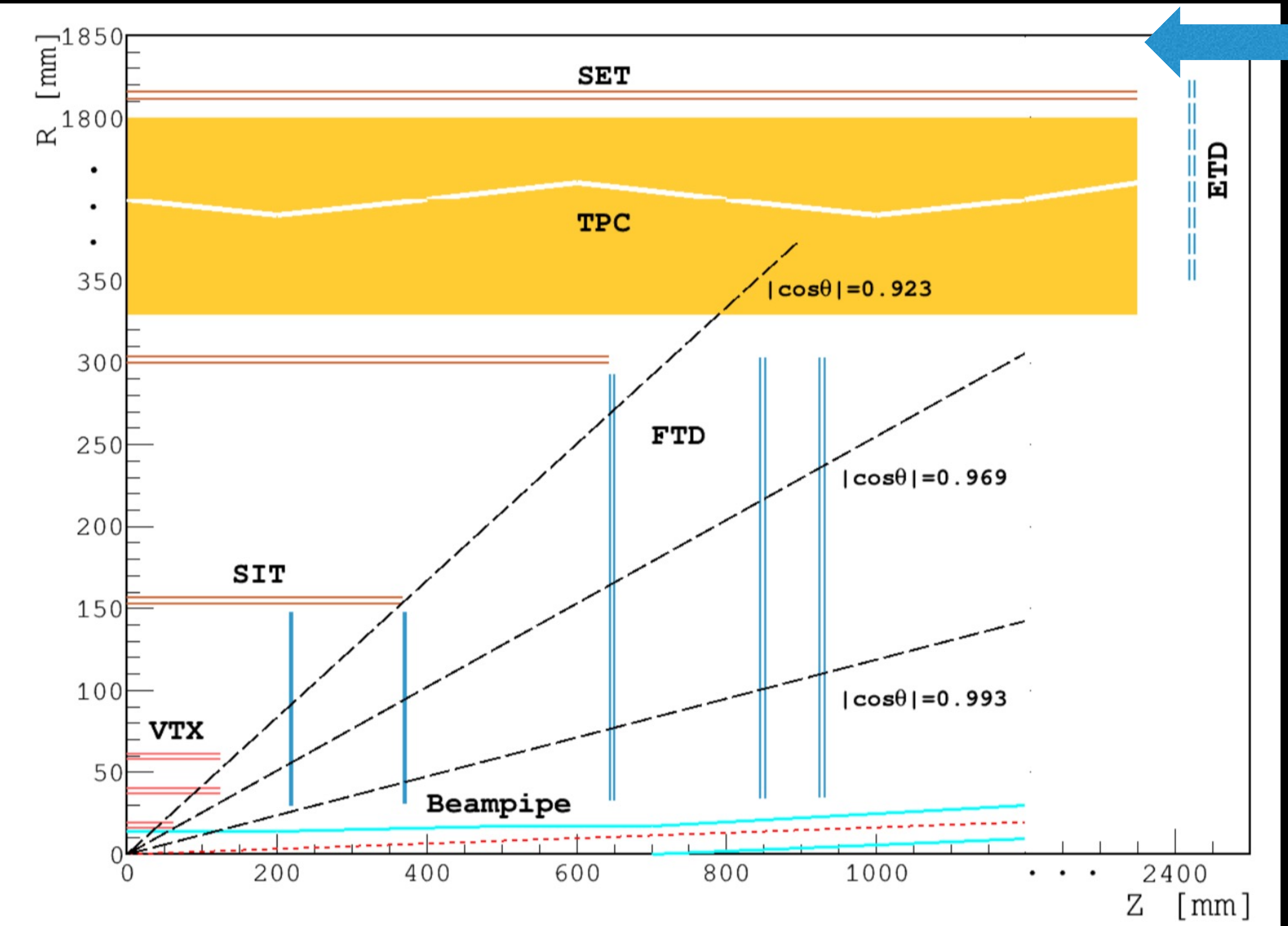




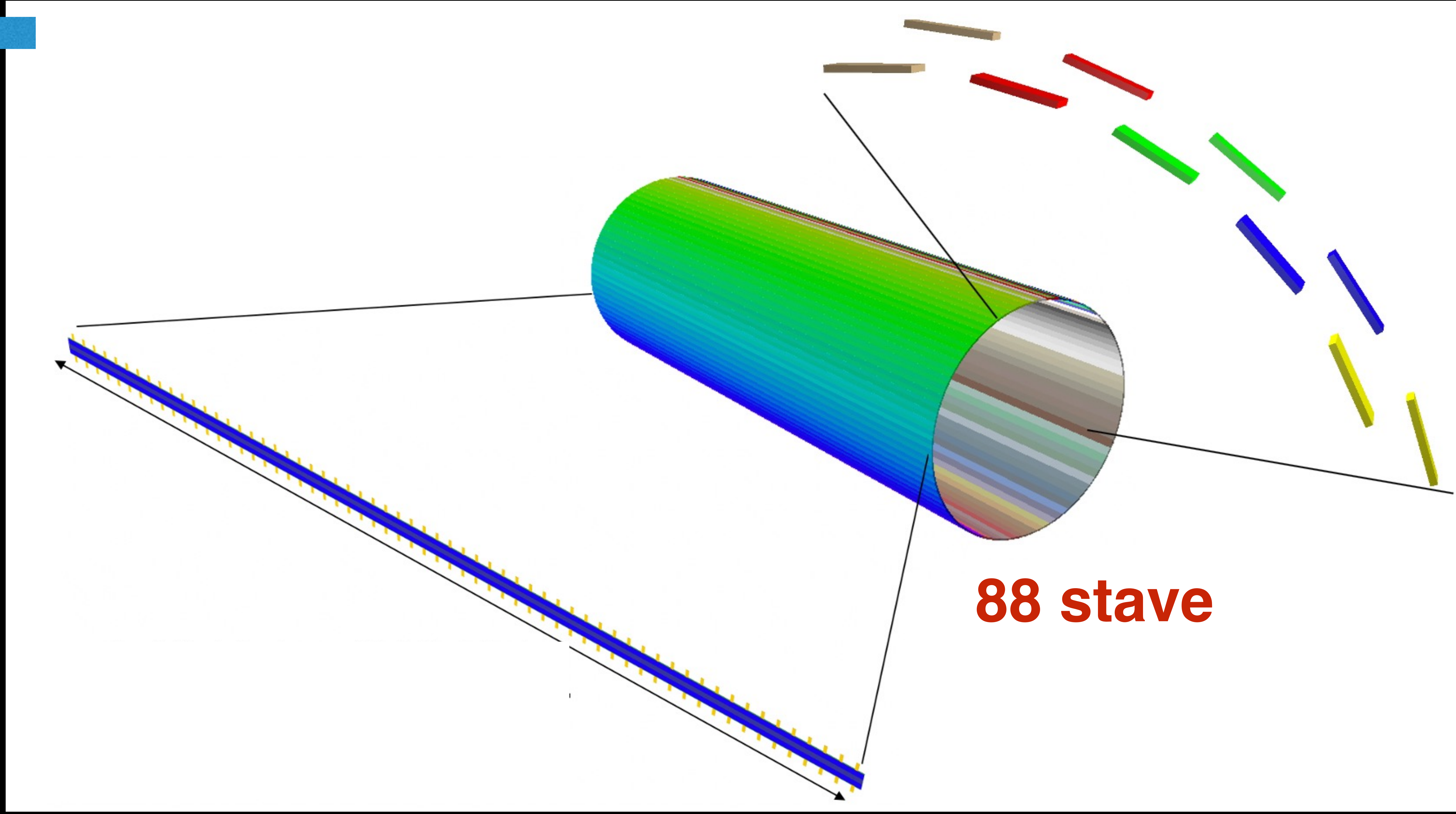
CEPC timing detector : Concept

- **Timing detector: Between tracker and calorimeter**
- **→ TOF Close to outer tracker, Radius ~1.8m**
- **Target time resolution: 50 pico-second(ps)**
- **New proposal: TOF+ outer layer tracker= 4D detector**
- **Target spatial resolution: 7~10 μm**

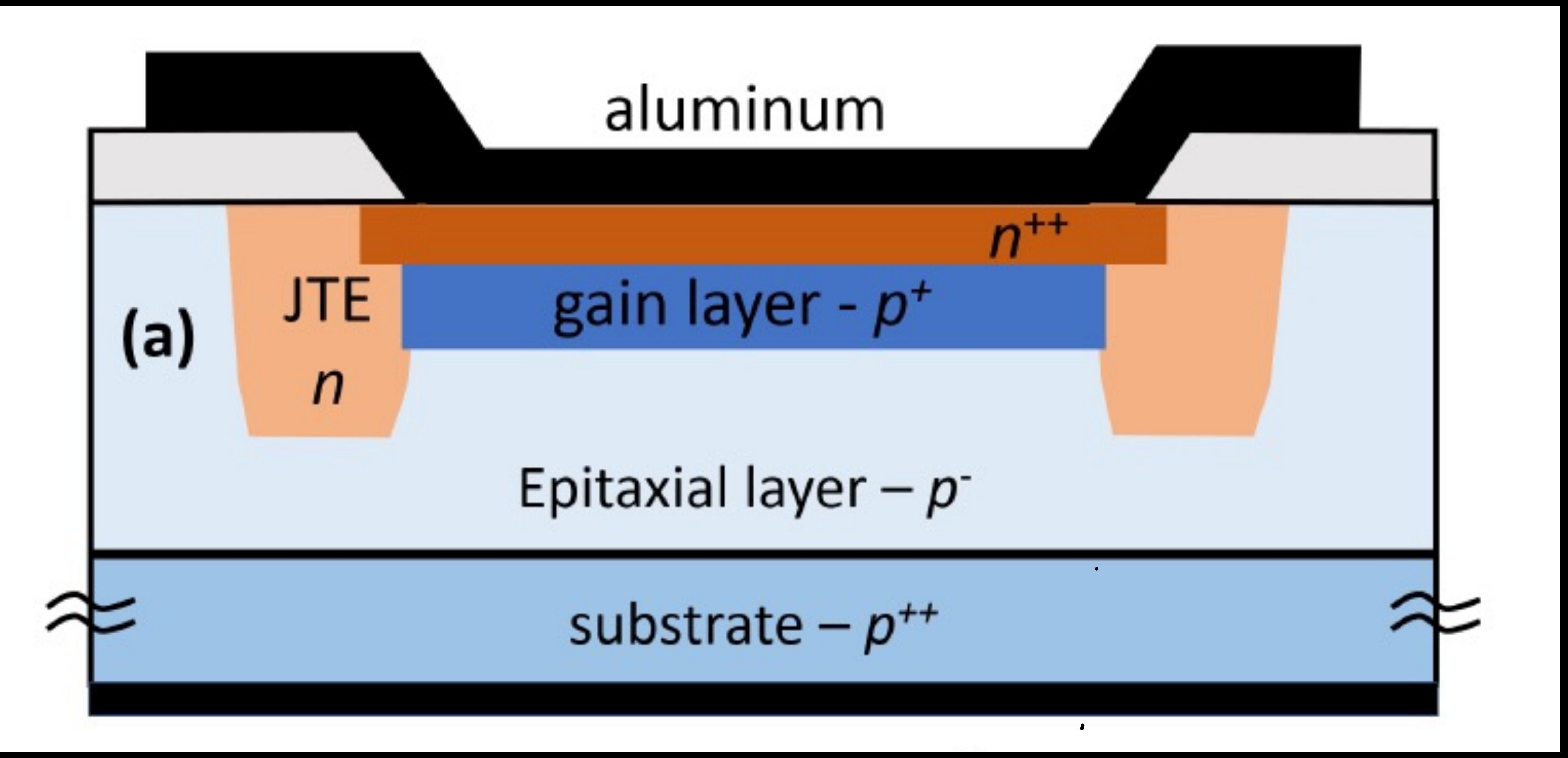
Baseline detector concept in CDR

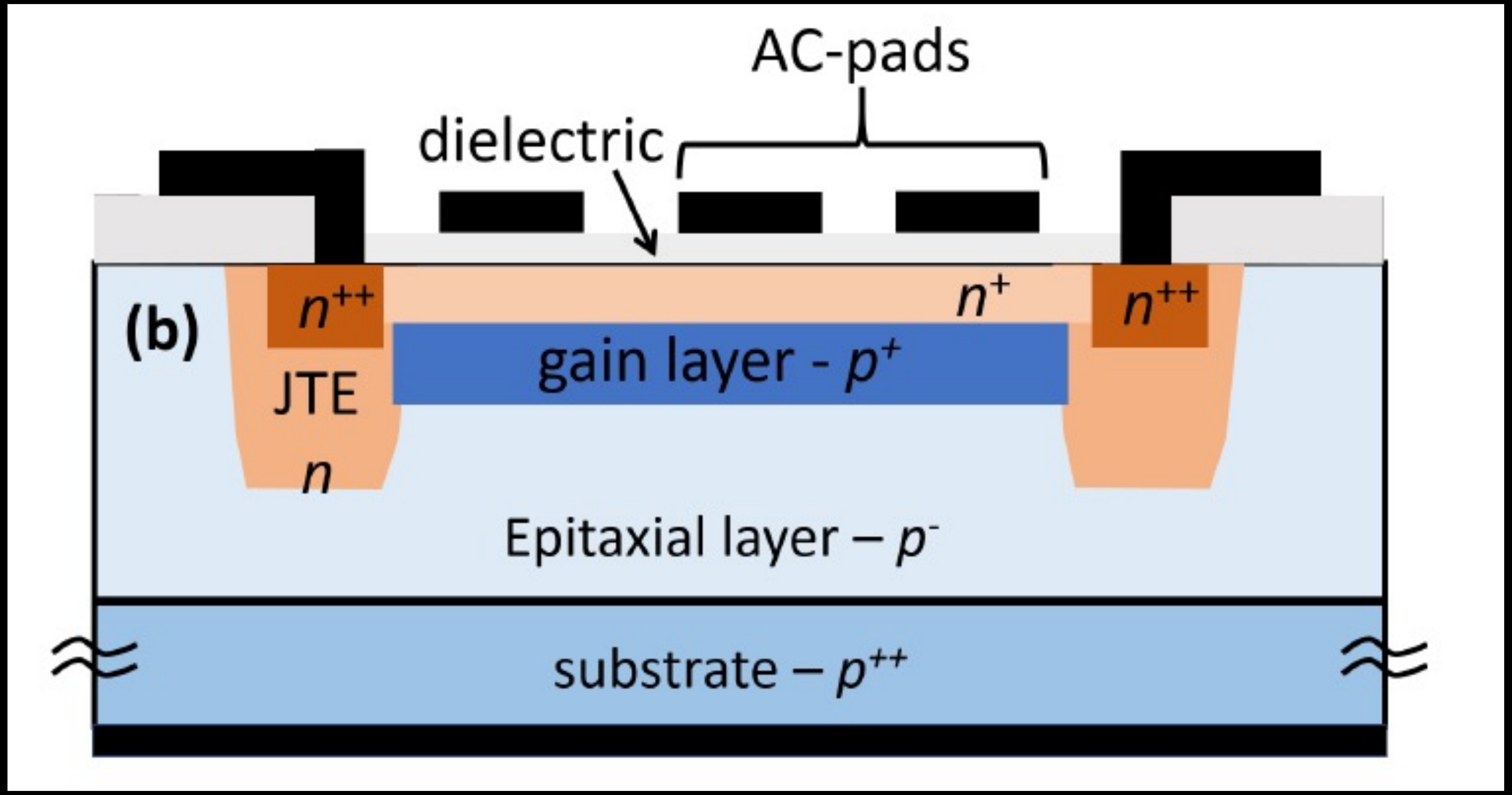


Timing detector in Barrel region



Introduction of Low-Gain Avalanche Detectors (LGAD)





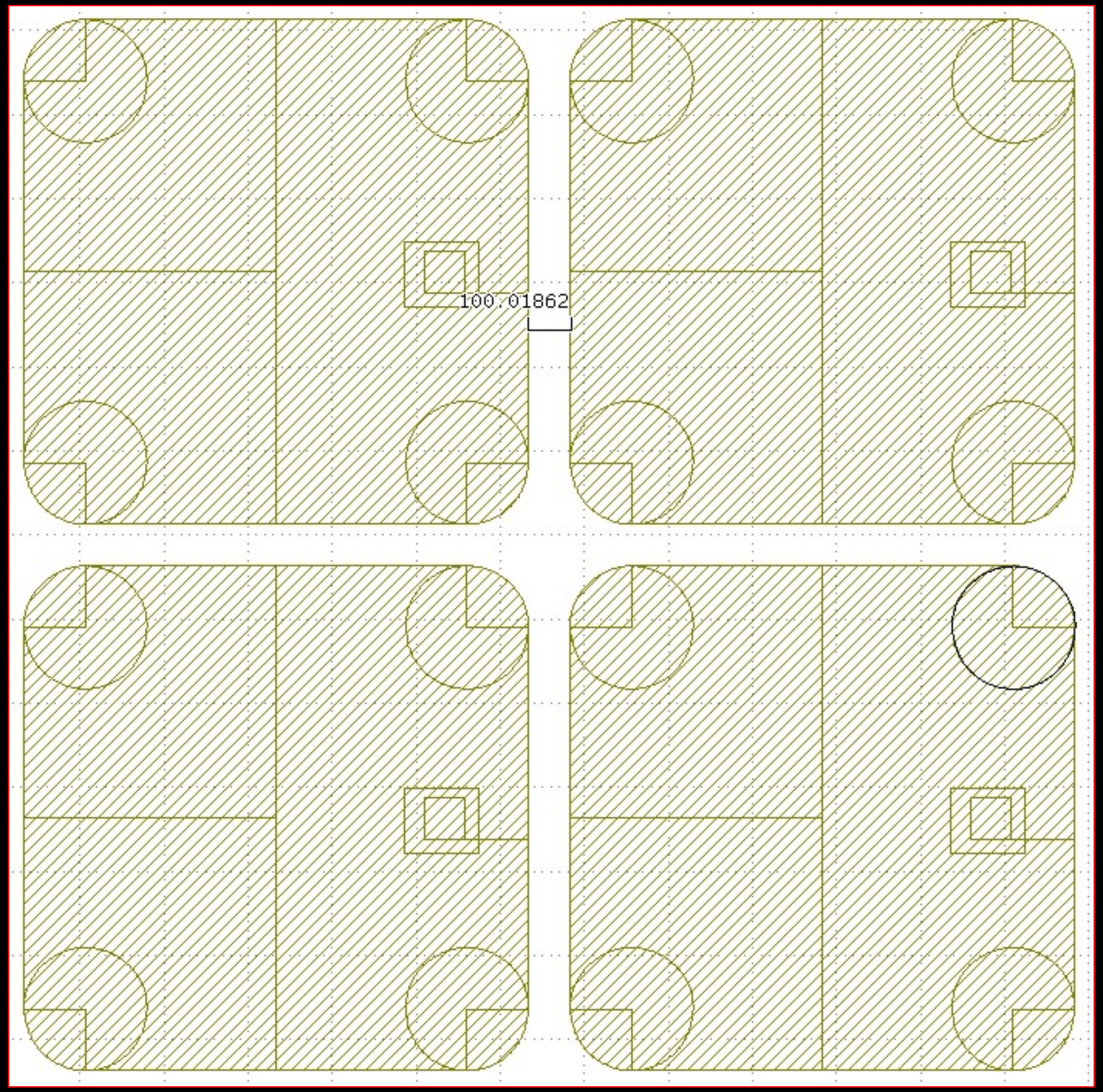
DC-LGAD

- aAplication: **LHC, CEPC TOF**
- The DC readout
- Time resolution ~ **30ps**
- Position resolution: **~1mm**
- Dead zone : **~ 0.1mm**

AC-LGAD

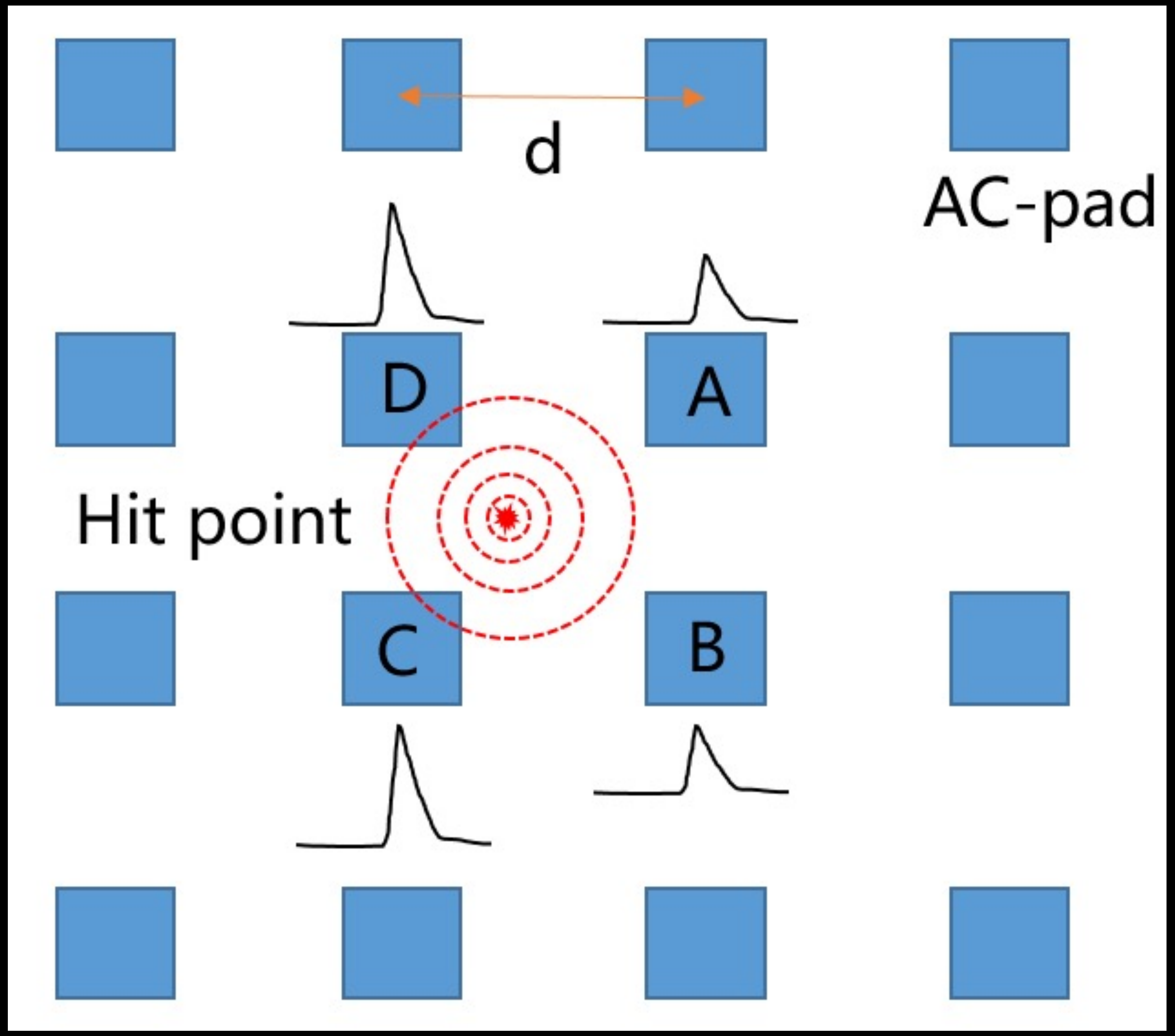
- Application: **CEPC TOF +SET (4D tracker)**
- AC coupled readout
- Time resolution ~ **30ps**
- Position resolution: **10-50 um**
- Dead zone : **0 mm (no dead zone)**

Introduction of AC-LGAD (2)



DC-LGAD

- CEPC application: **TOF**
- Cross-talk: no
- Dead zone : **~0.1mm**



AC-LGAD

- CEPC application: **TOF +SET (4D tracker)**
- Cross-talk: can be adjusted
- Dead zone : **0 mm (no dead zone)**

AC-LGAD prototype for CEPC

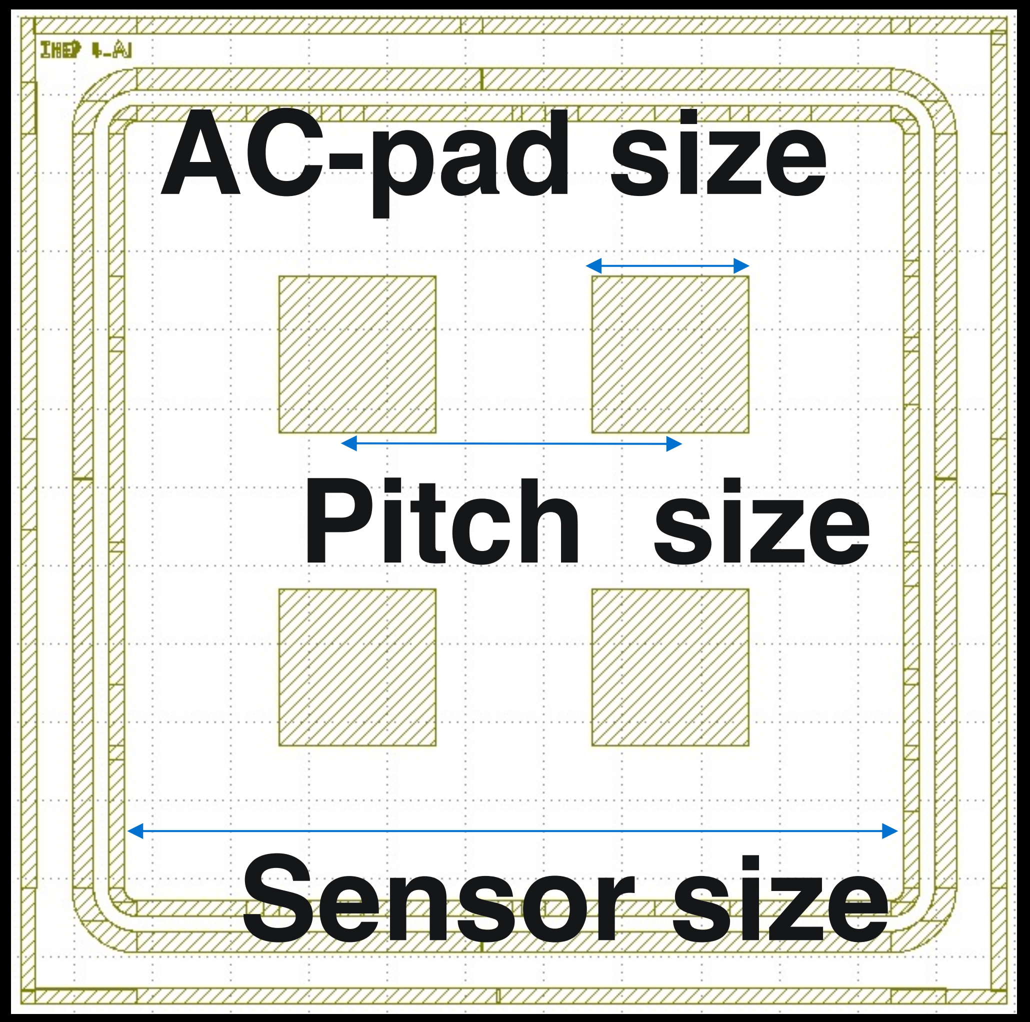
- **AC-LGAD first proposed by INFN in RD50, and first fabricated by FBK.**
- **First AC-LGAD prototype in China by IHEP-IME in 2021.**

➢ **Try different sensor geometry and doping**

➢ **Choose this large pitch geometry → save readout channels**

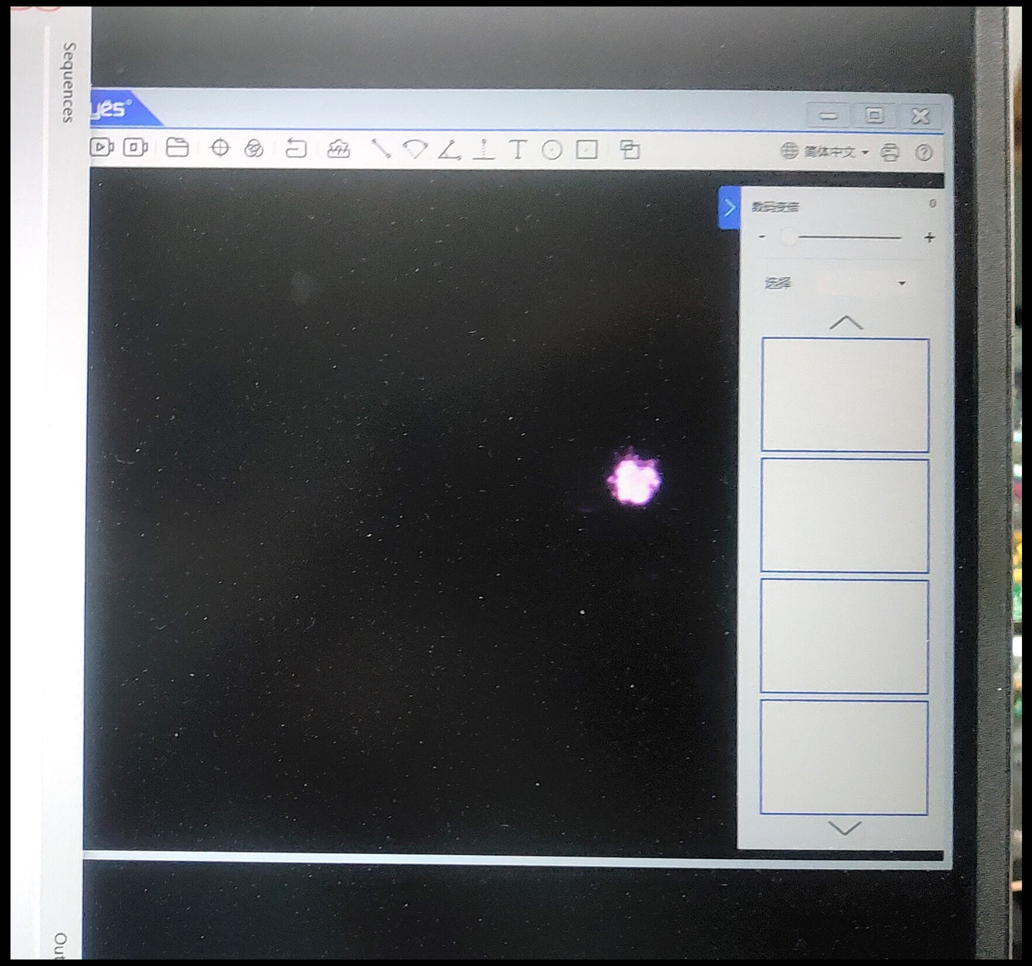
Sensors	N+ dose [unit]	Sensor size [µm]	AC-pad size [µm]	Picth size [µm]
W7Q1	10	1000	1000	2000
W5Q1	5	2000	1000	2000
W5Q2	1	2000	1000	2000
W5Q3	0.5	2000	1000	2000
W5Q4	0.2	4000	1000	2000

4-A1

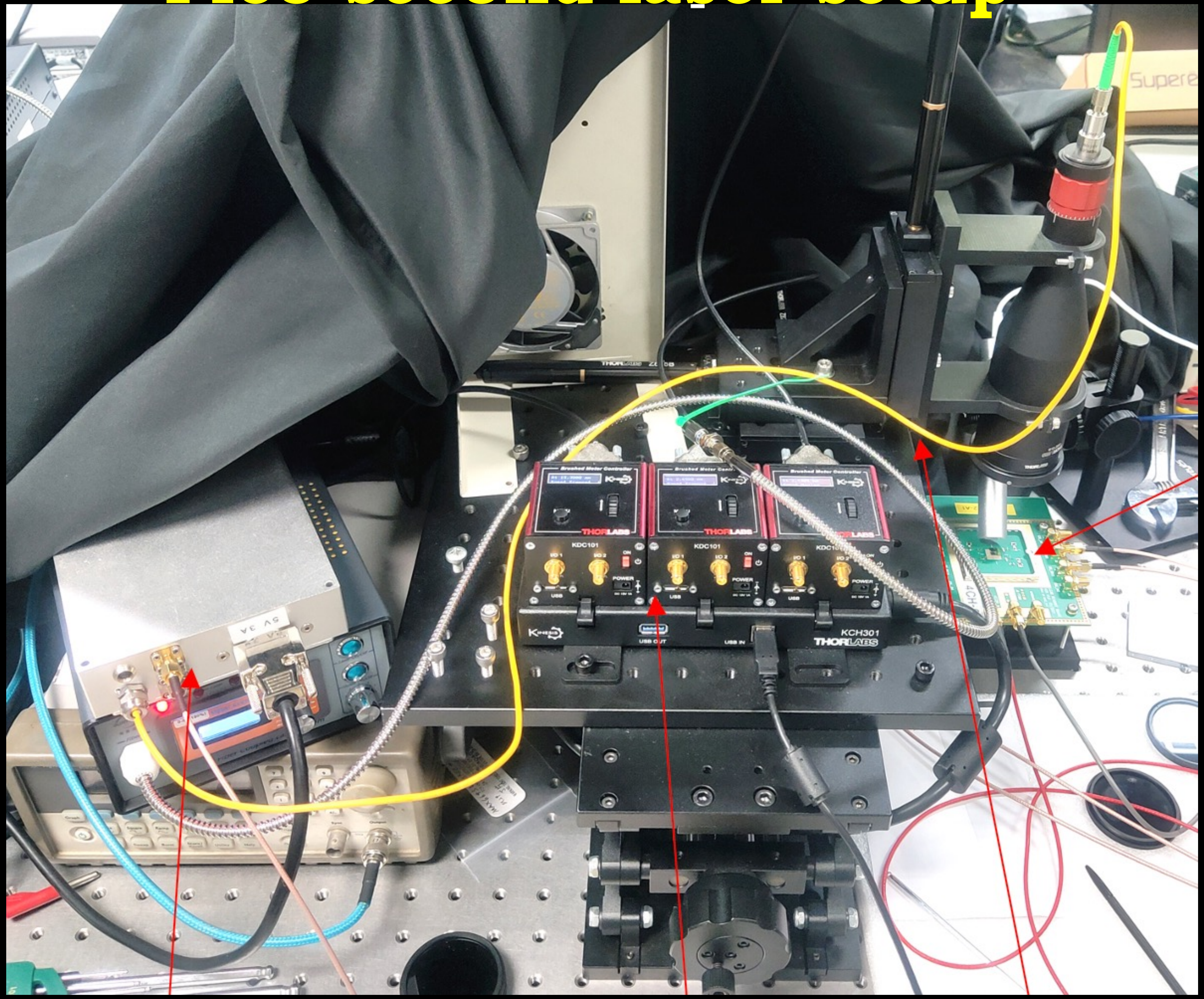


Laser testing for AC-LGAD

- Pico-second laser testing for AC-LGAD
- 4 channels readout board with fast amplifiers (~2GHz)
- 3D X-Y-Z stage platform (precision : ~1um)

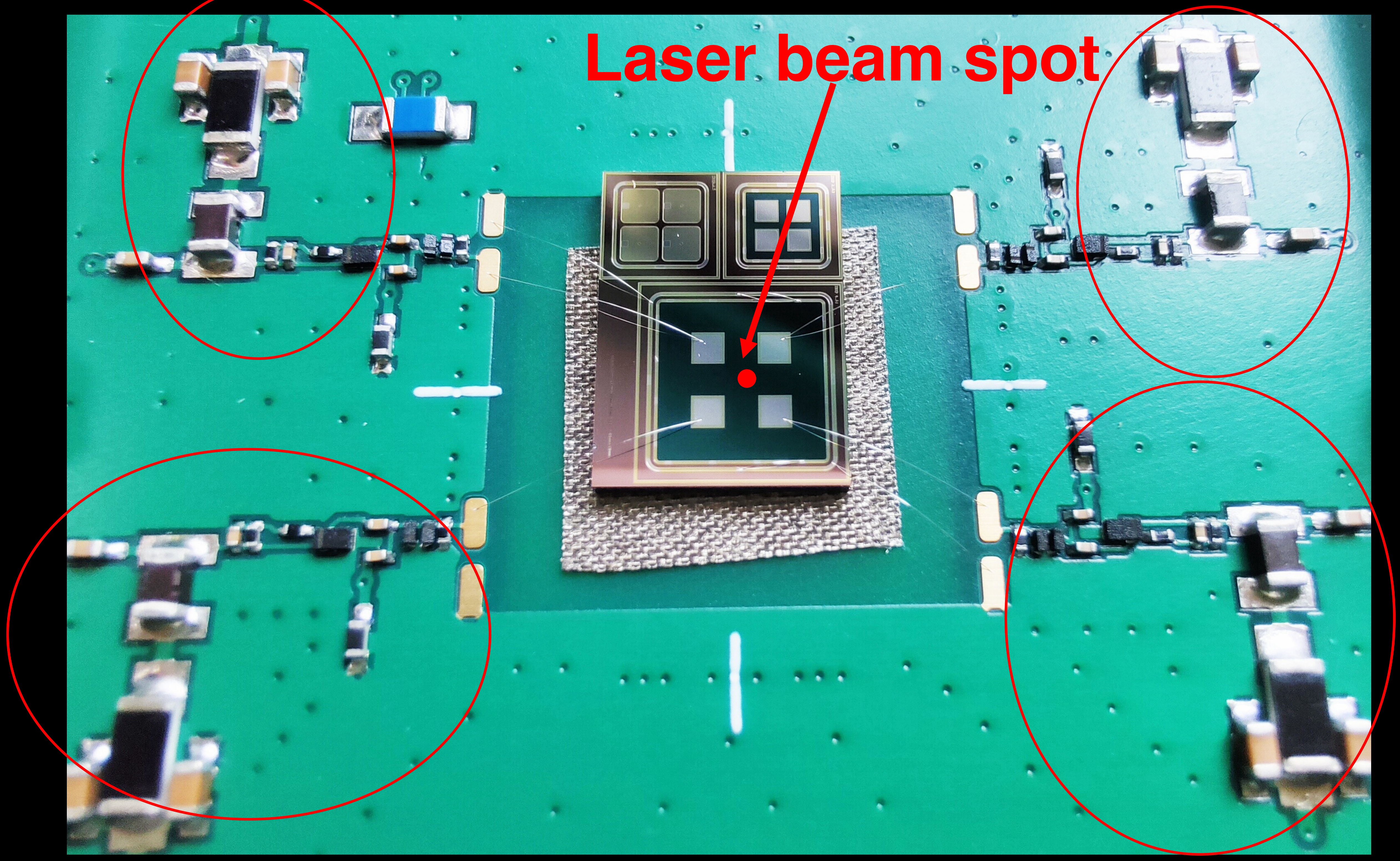


Pico-second laser setup



X-Y-Z platform

4 channels fast readout board



Laser testing for AC-LGAD

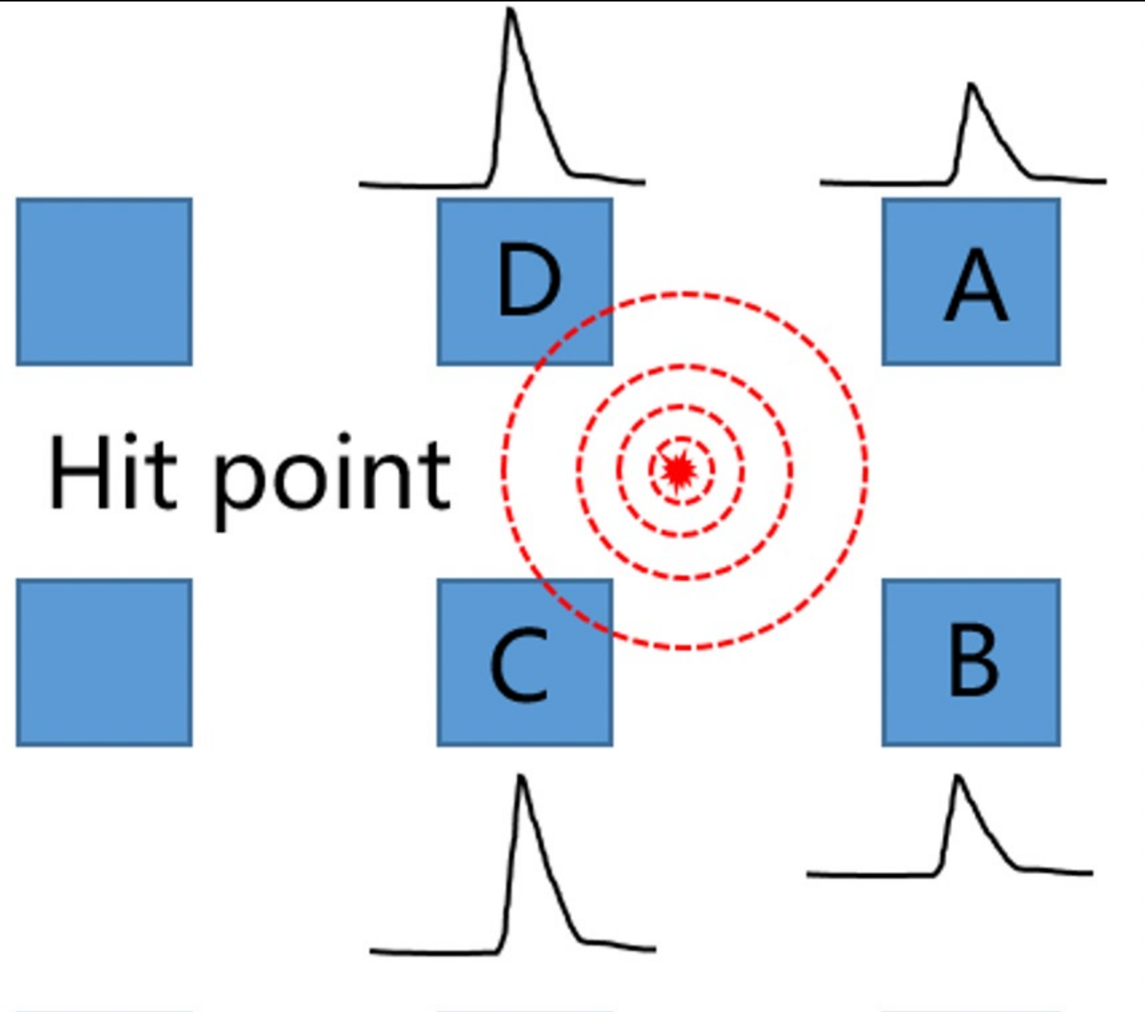
- **Pico-second laser testing for AC-LGAD**
- **4 channels readout board with fast amplifiers (~2GHz)**
- 3D X-Y-Z stage platform (precision : ~1um)
- the ballistic deficit of the signal is smaller in large AC pads

Laser shooting in the middle
4 channels has similar signal amplitude

Laser shooting in the upper right
Upper right channel has larger amplitude

Laser testing for AC-LGAD： Readout and spatial reconstruction

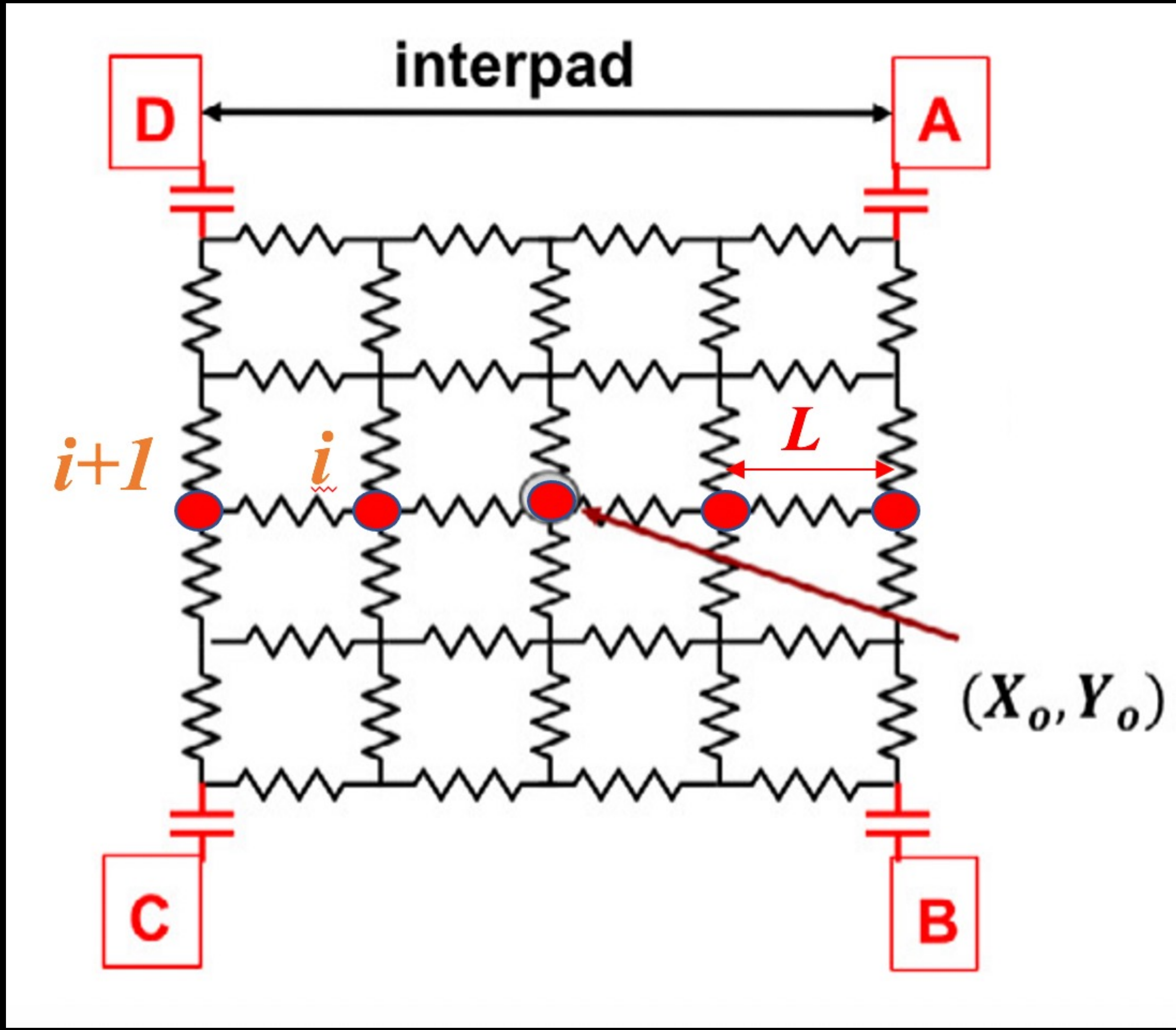
- **Position reconstruction by Discretized Positioning Circuit model (DPC)**
- **Input is 4 channels signal amplitude**



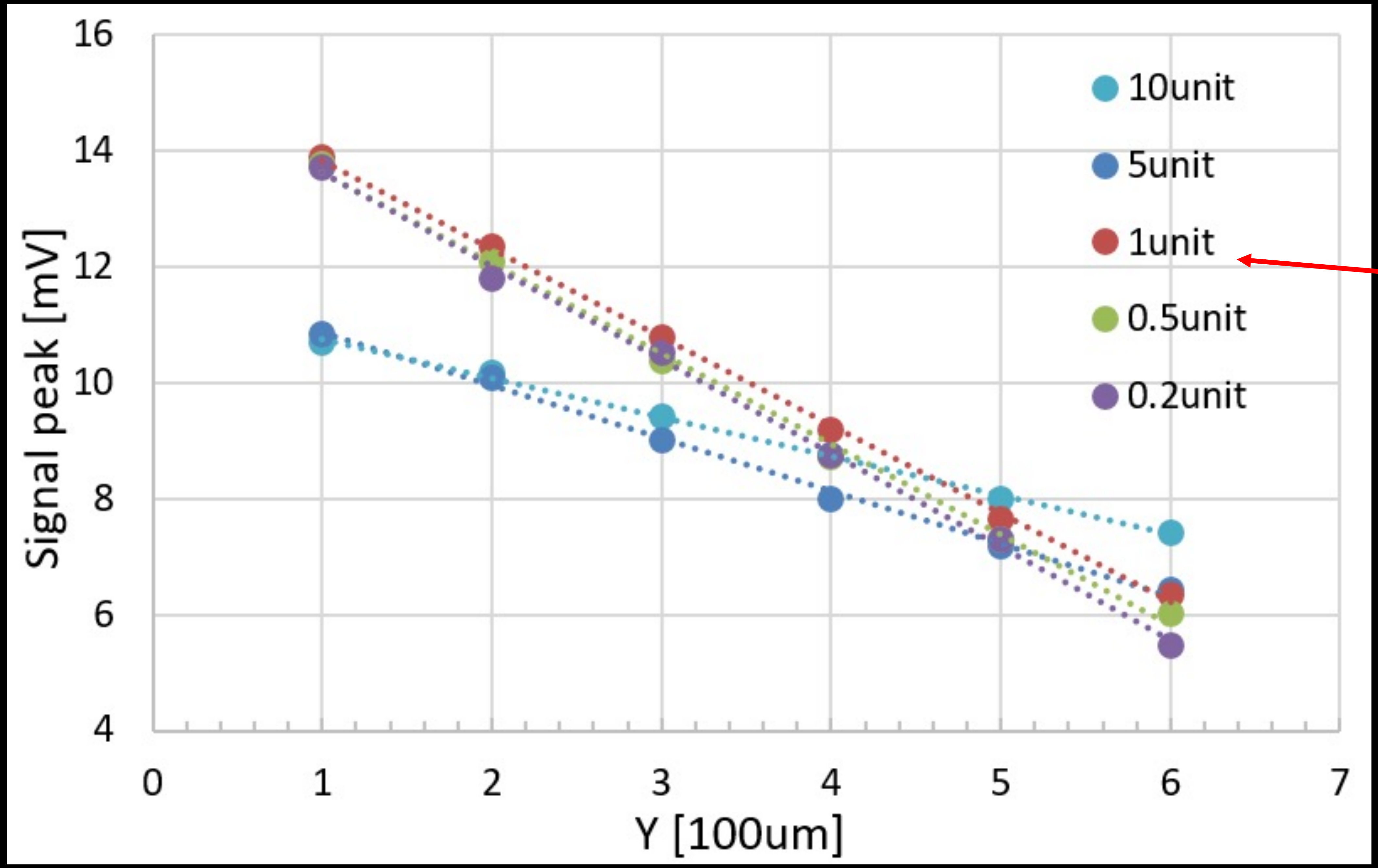
$$X = X_0 + k_x\left(\frac{q_A + q_B - q_C - q_D}{q_A + q_B + q_C + q_D}\right) = X_0 + k_x m$$

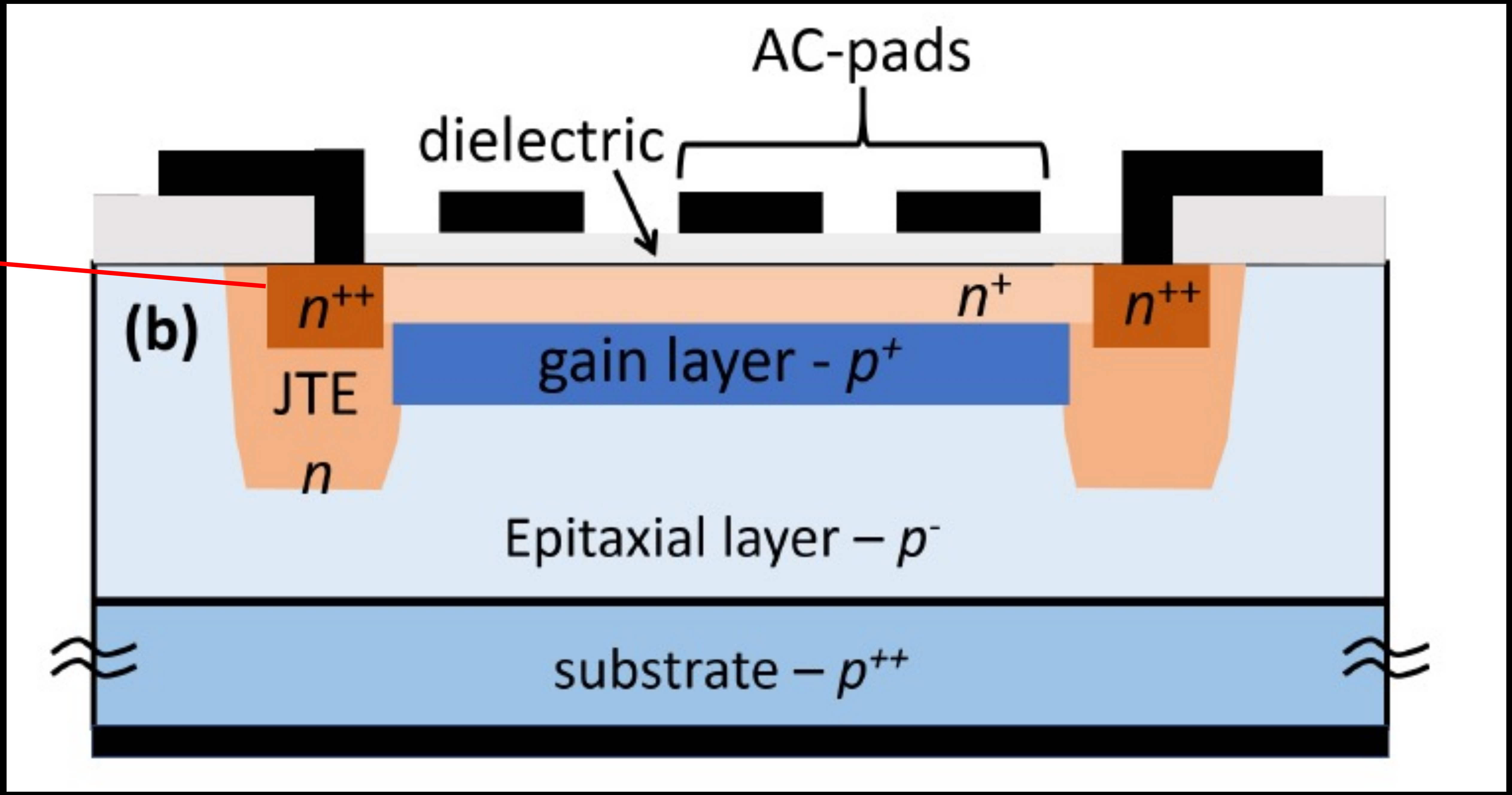
$$Y = Y_0 + k_y\left(\frac{q_A + q_D - q_B - q_C}{q_A + q_B + q_C + q_D}\right) = Y_0 + k_y n$$

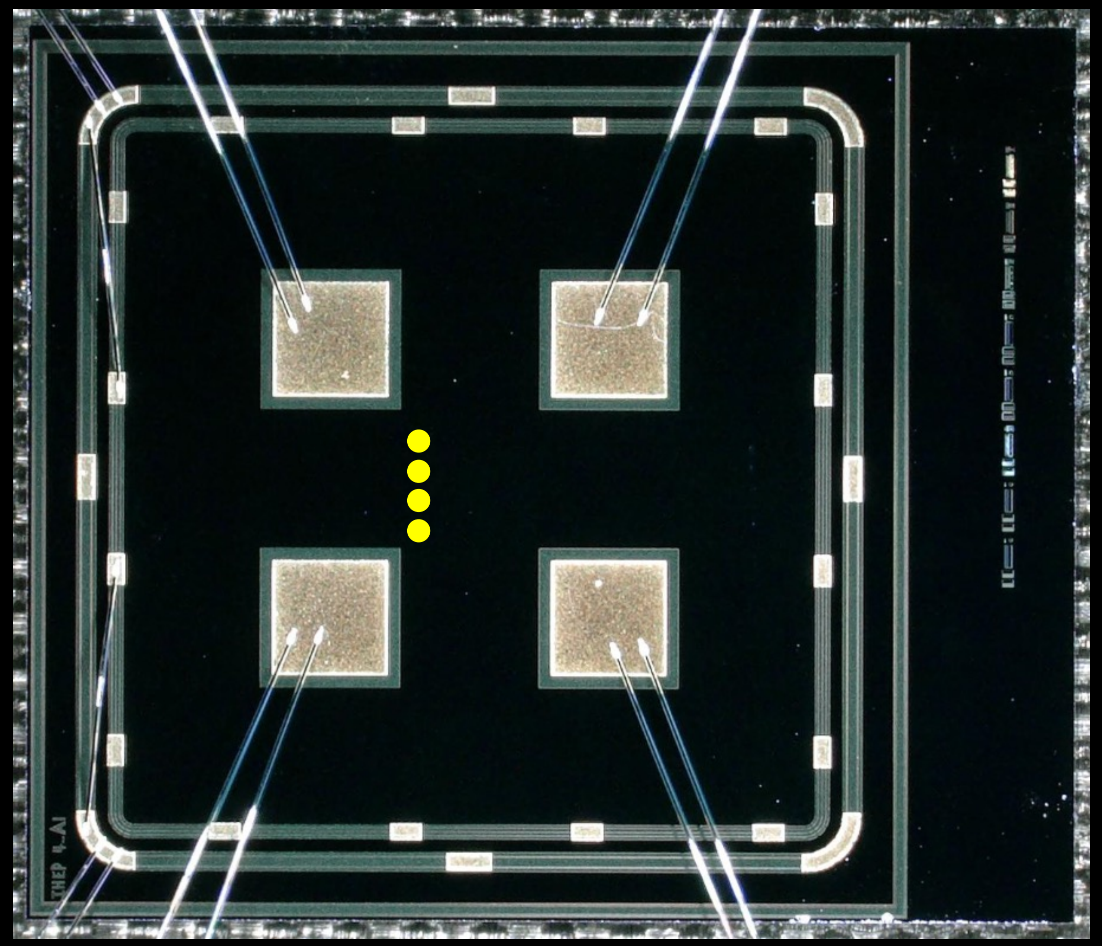
$$k_x = L\frac{\sum(m_{i+1} - m_i)}{\sum(m_{i+1} - m_i)^2} \qquad k_y = L\frac{\sum(n_{i+1} - n_i)}{\sum(n_{i+1} - n_i)^2}$$



Signal attenuation Vs N+ layer doping

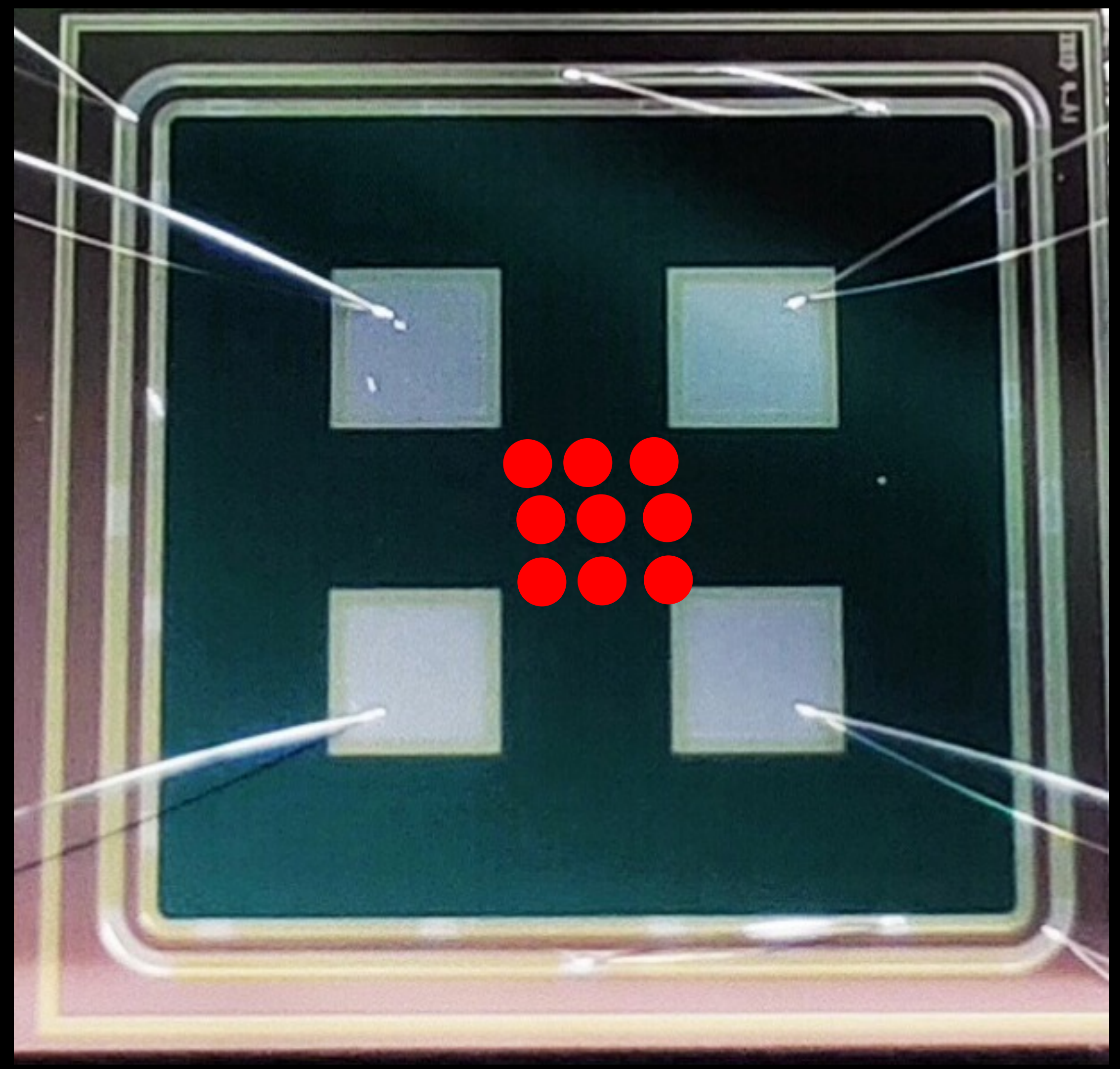






- **Spatial resolution depends on the resistance of n+ layer**
  - Higher Signal attenuation , better spatial resolution
  - Try 5 different n+ doping in one engineering run
  - Lower n+ doping, higher resistance

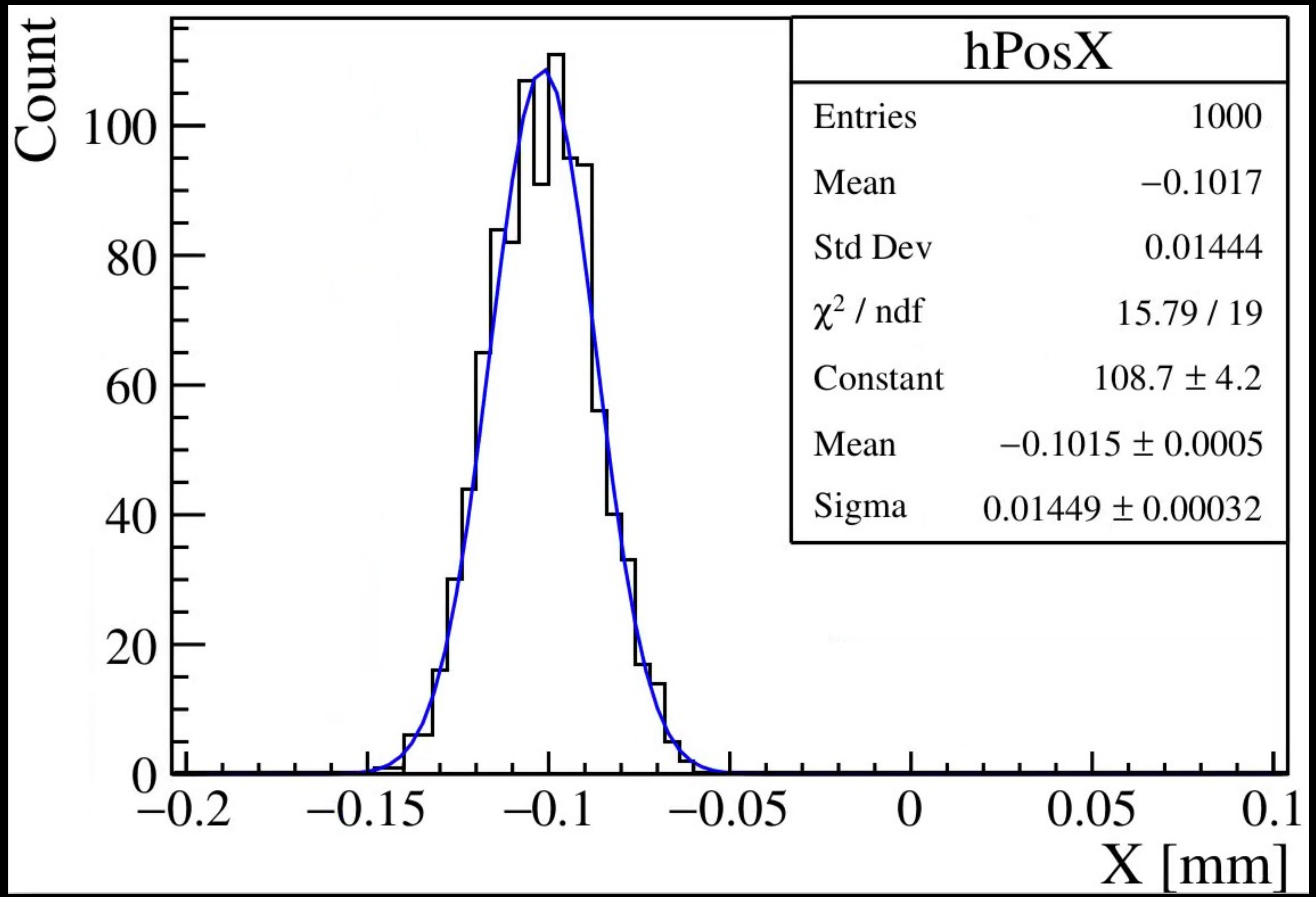
Laser testing for AC-LGAD: spatial resolution



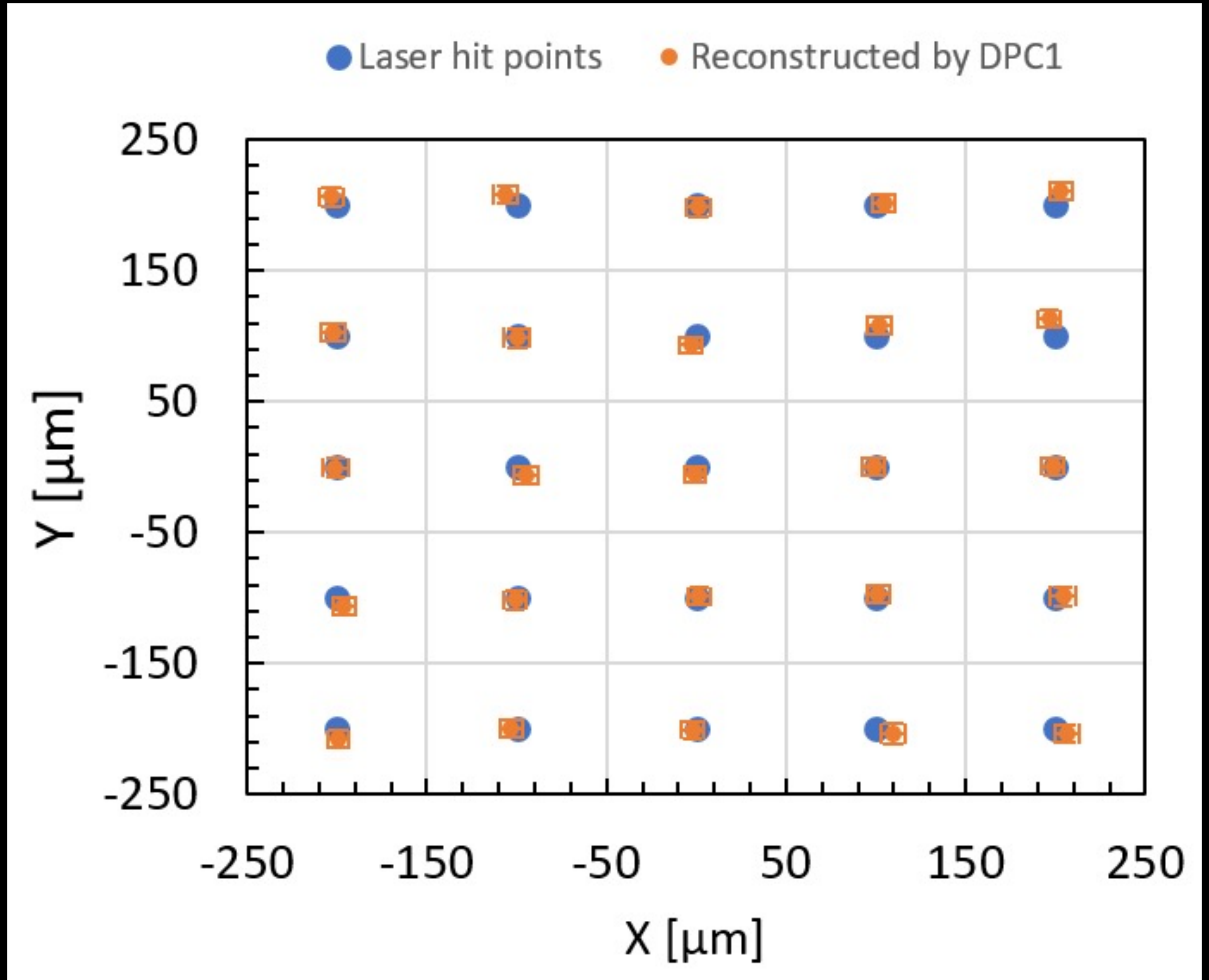
- **Resolution extracted from residual difference from hit position and reconstructed position**
- **The resolution can reach 15μm (2000μm pitch)**

Sensor size	AC-pad size]	Picth size
4000μm	1000μm	2000μm

Spatial resolution

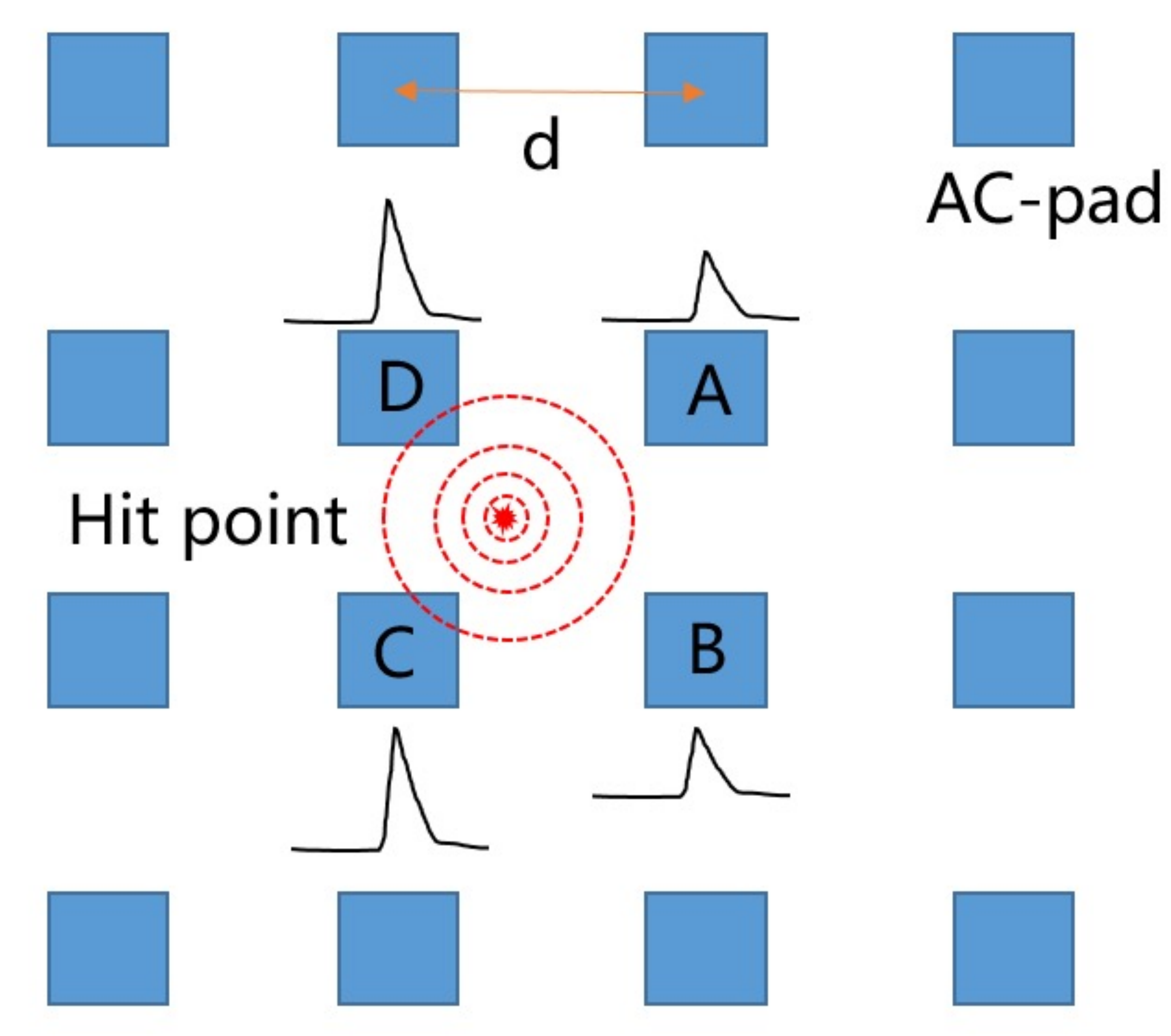


hit position vs Reconstructed position

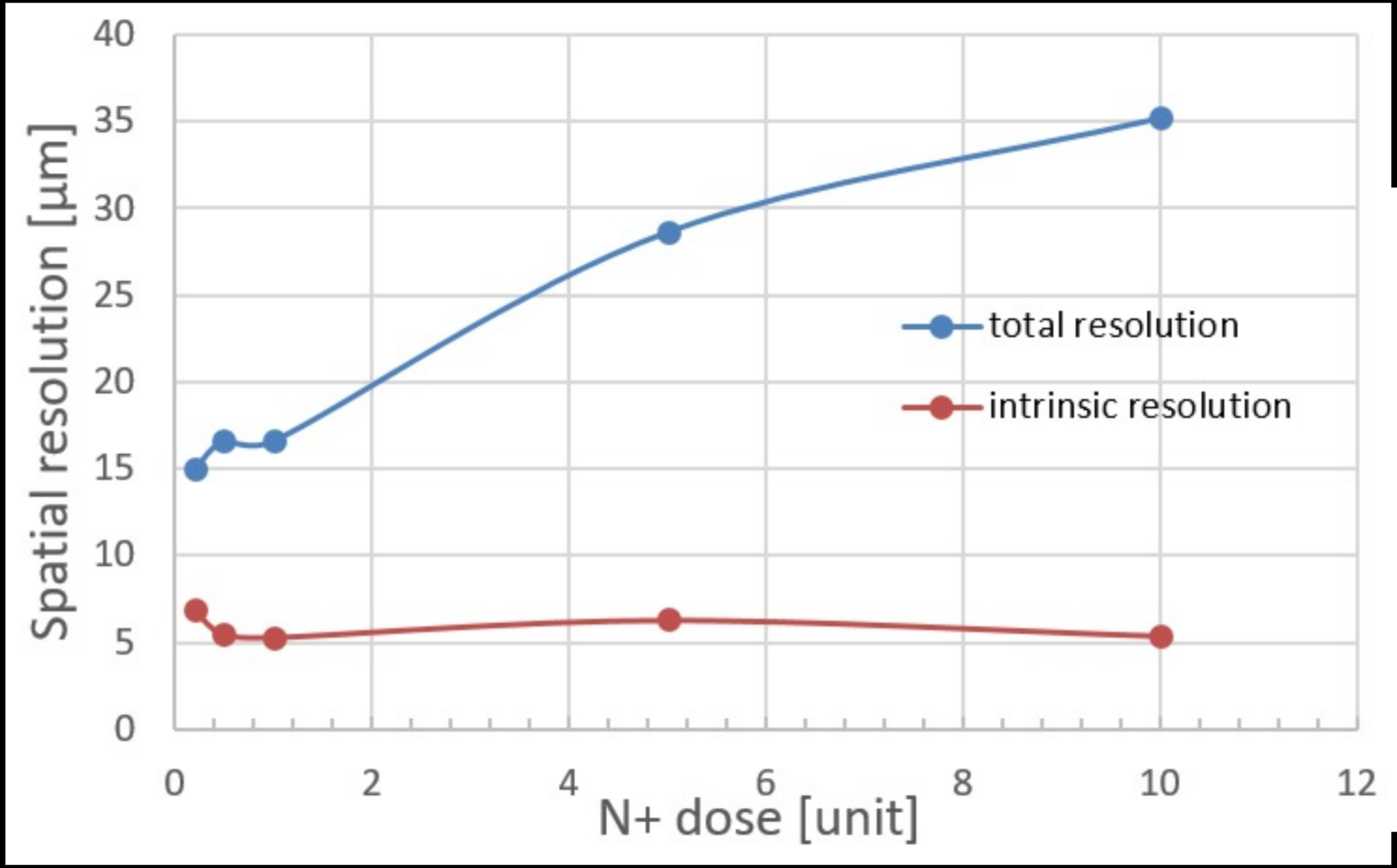


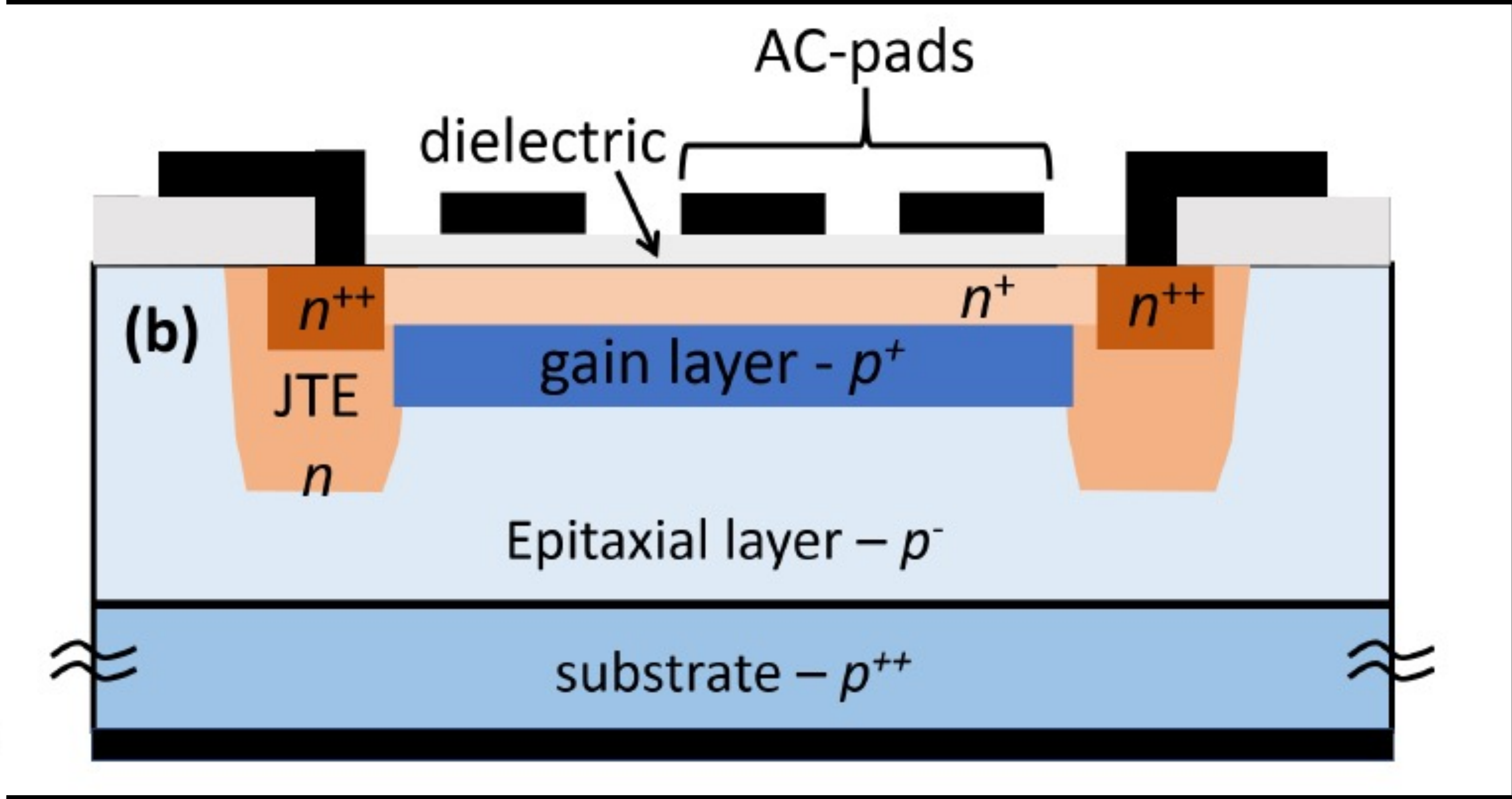
Laser testing for AC-LGAD: spatial resolution

- Lower n+ layer doping, better spatial resolution
- The best resolution can reach 15μm (2000μm pitch)
- Has potential to improve to 5μm in future (improving S/N)



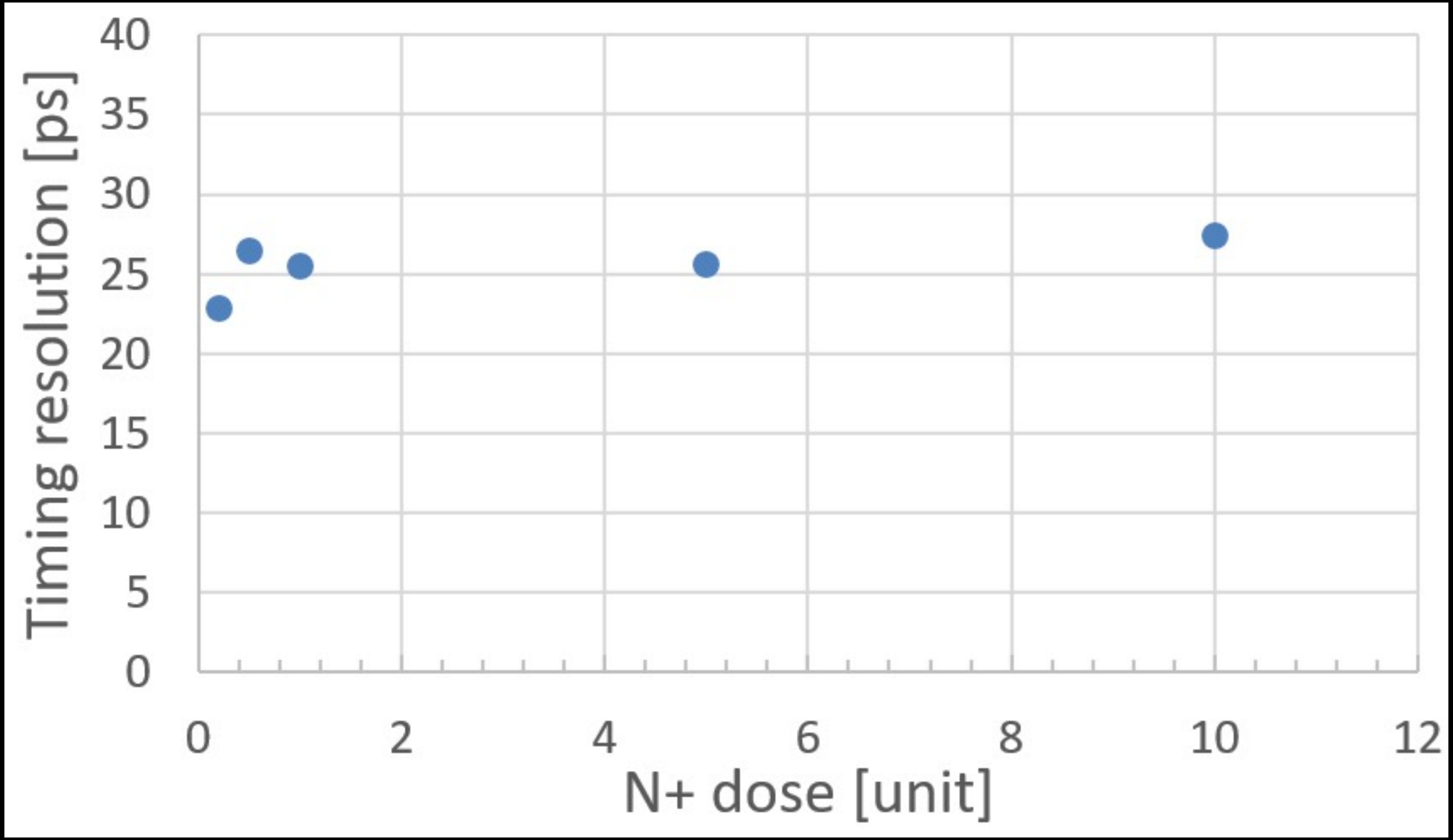
Spatial resolution VS n+ dose





Laser testing for AC-LGAD: timing resolution

- The timing resolution is about 20~30 ps
- The N+ dose and different size of the pads has little impact on timing resolution



Summary

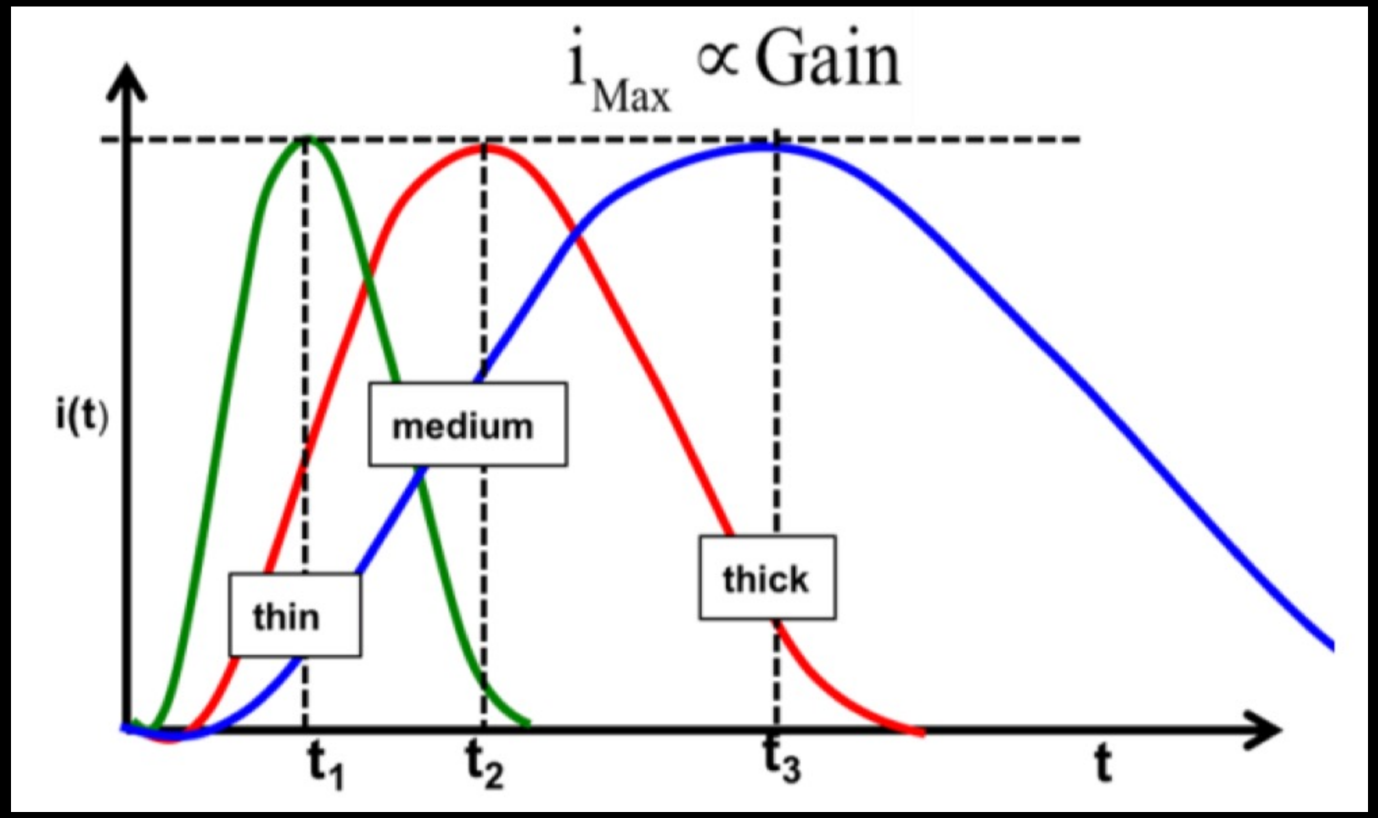
- AC-LGAD is a new 4D detector （position + time）
- First AC-LGAD prototype by IHEP is successful
- Picosecond laser test and reconstructed by DPC model
- The spatial resolution in laser test ~15μm (2000μm pitch)
- Potential to reach to 5μm resolution in future
- Timing resolution 20~30 ps

Low-Gain-Avalanche-detector

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

Landau Noise term:

- Signal fluctuation due to non-uniform charge deposition
- Minimized by reducing thickness of the sensor (50um)

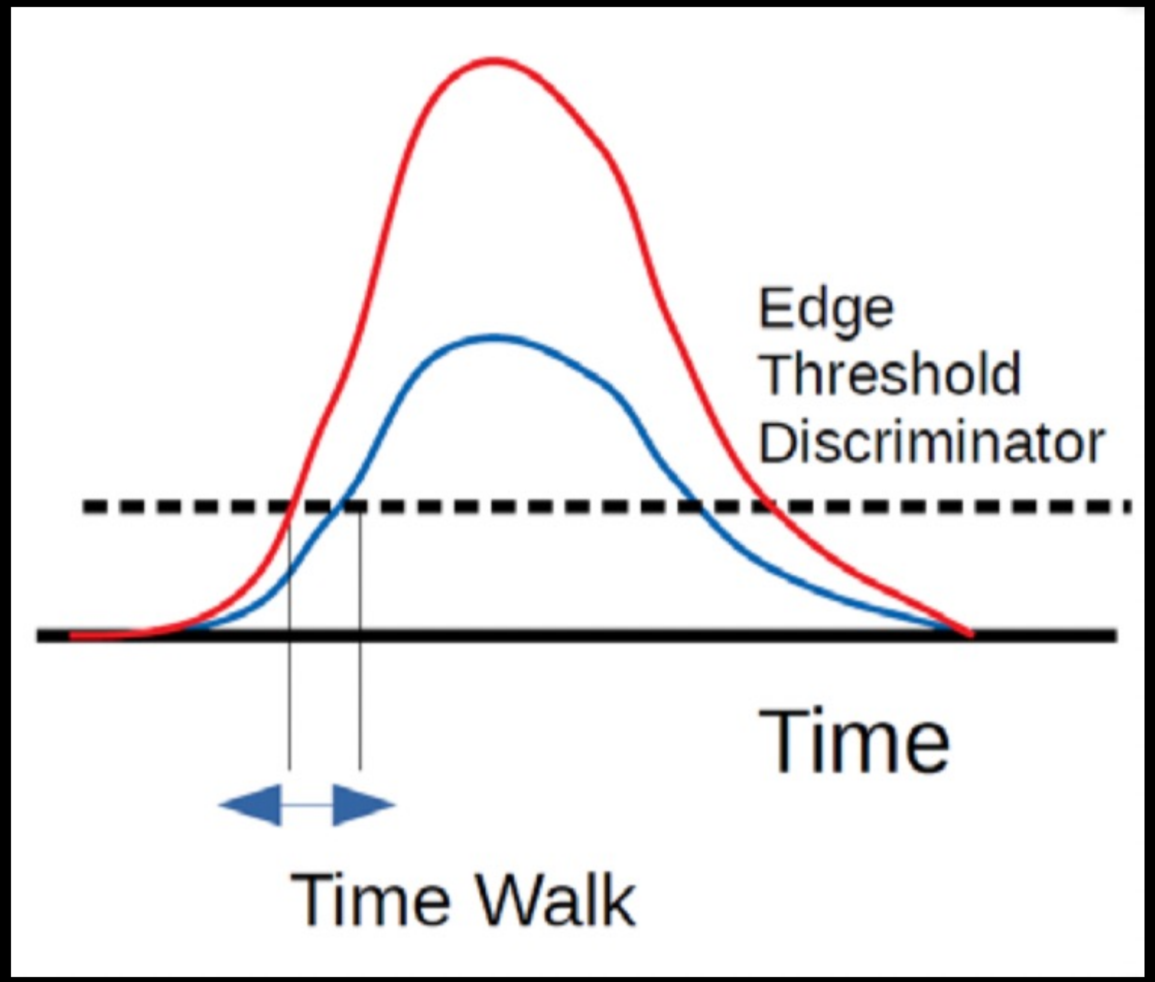


Jitter

$$\sigma_{jitter}^2 = \left(\frac{t_{rise}}{S/N}\right)^2$$

- Need gain to increase S/N
- Need thin detector to decrease t_{rise}

fixed threshold



Time walk

$$\sigma_{timewalk}^2 = \left(\left[\frac{V_{thr}}{S/t_{rise}}\right]_{\mathrm{RMS}}\right)^2$$

- corrected using the amplitude estimate with the time over threshold (TOT).

[1] G. Pellegrini et al., NIM A765 (2014) 12
[2] H.-W. Sadrozinski et al., arXiv: 1704.08666
[3] F. Cenna et al, NIM A796 (2015) 149-153

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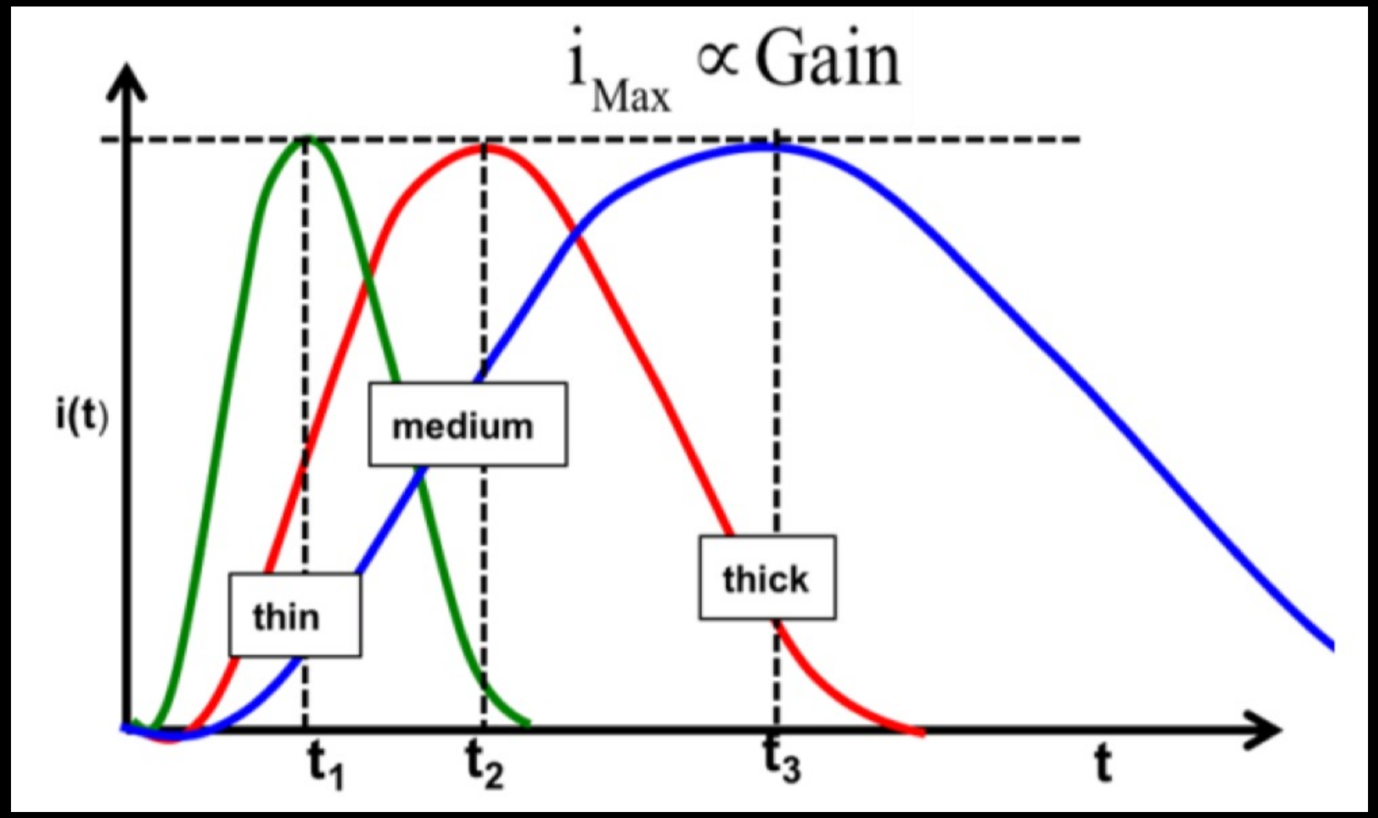

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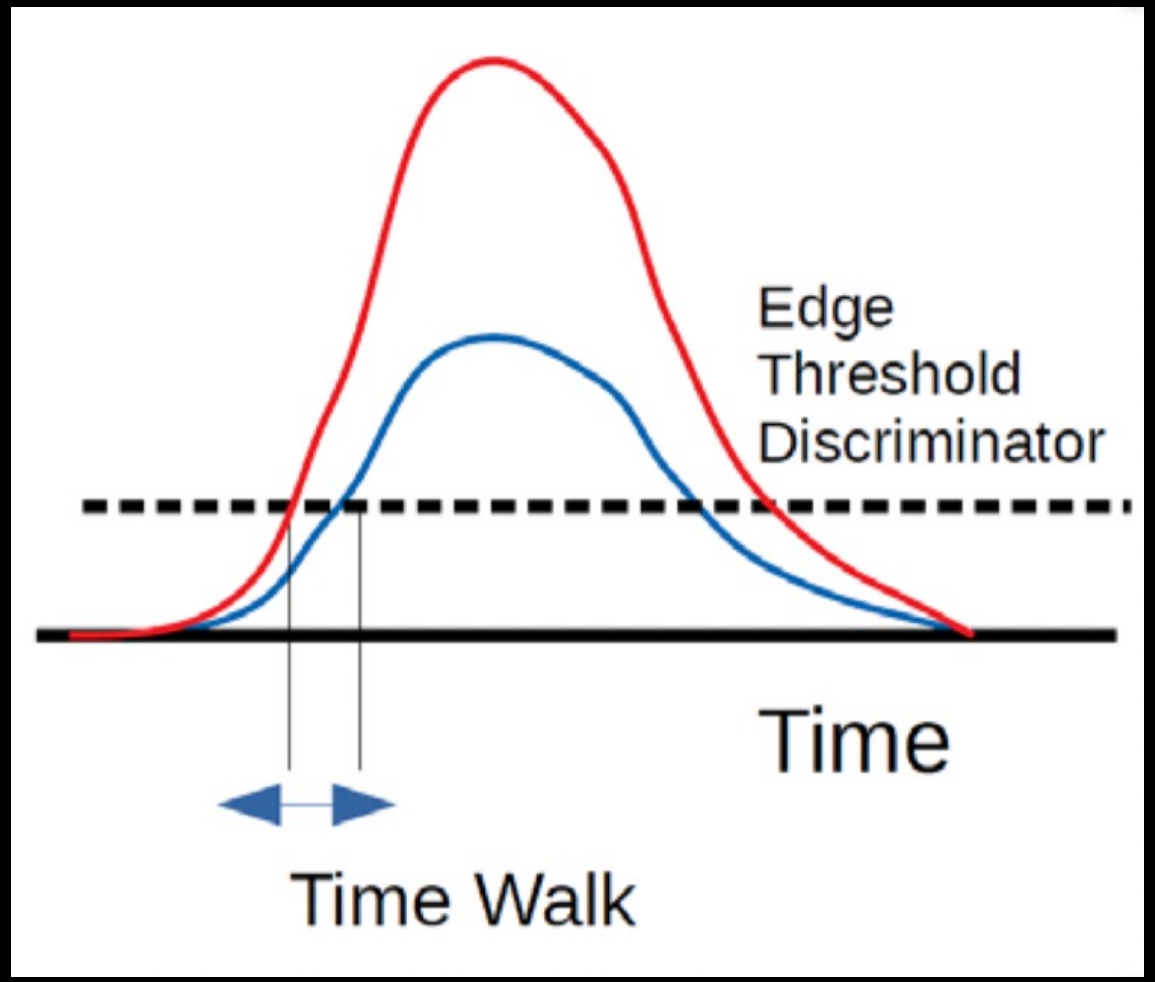

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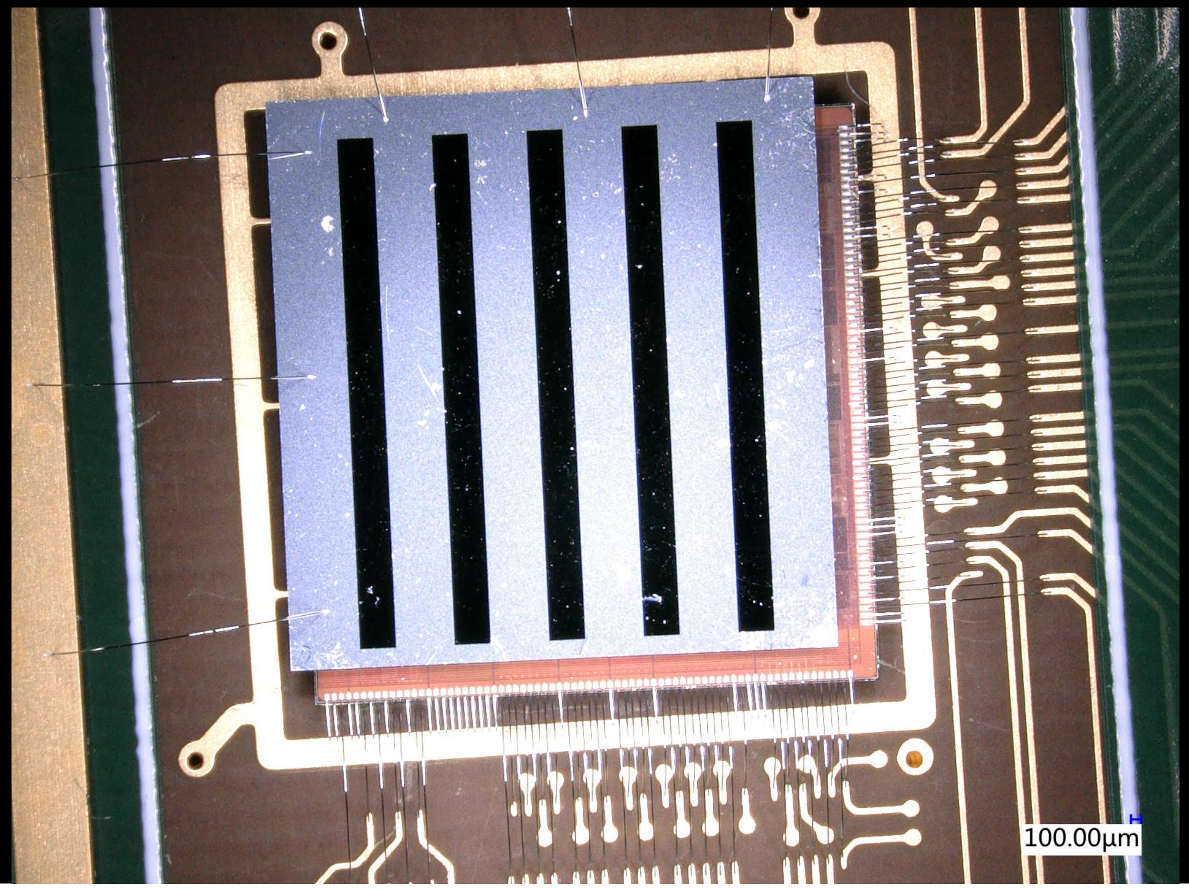
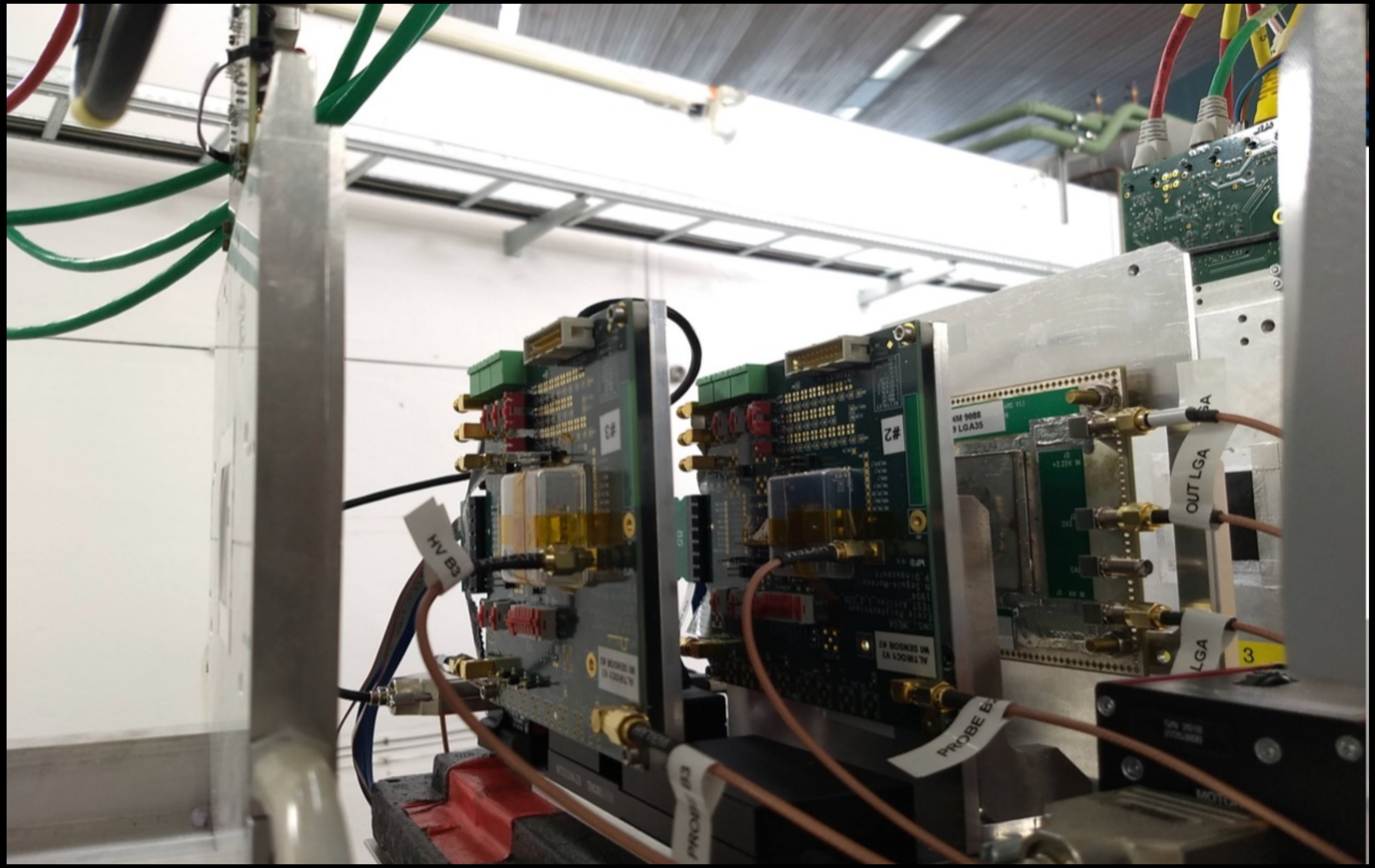
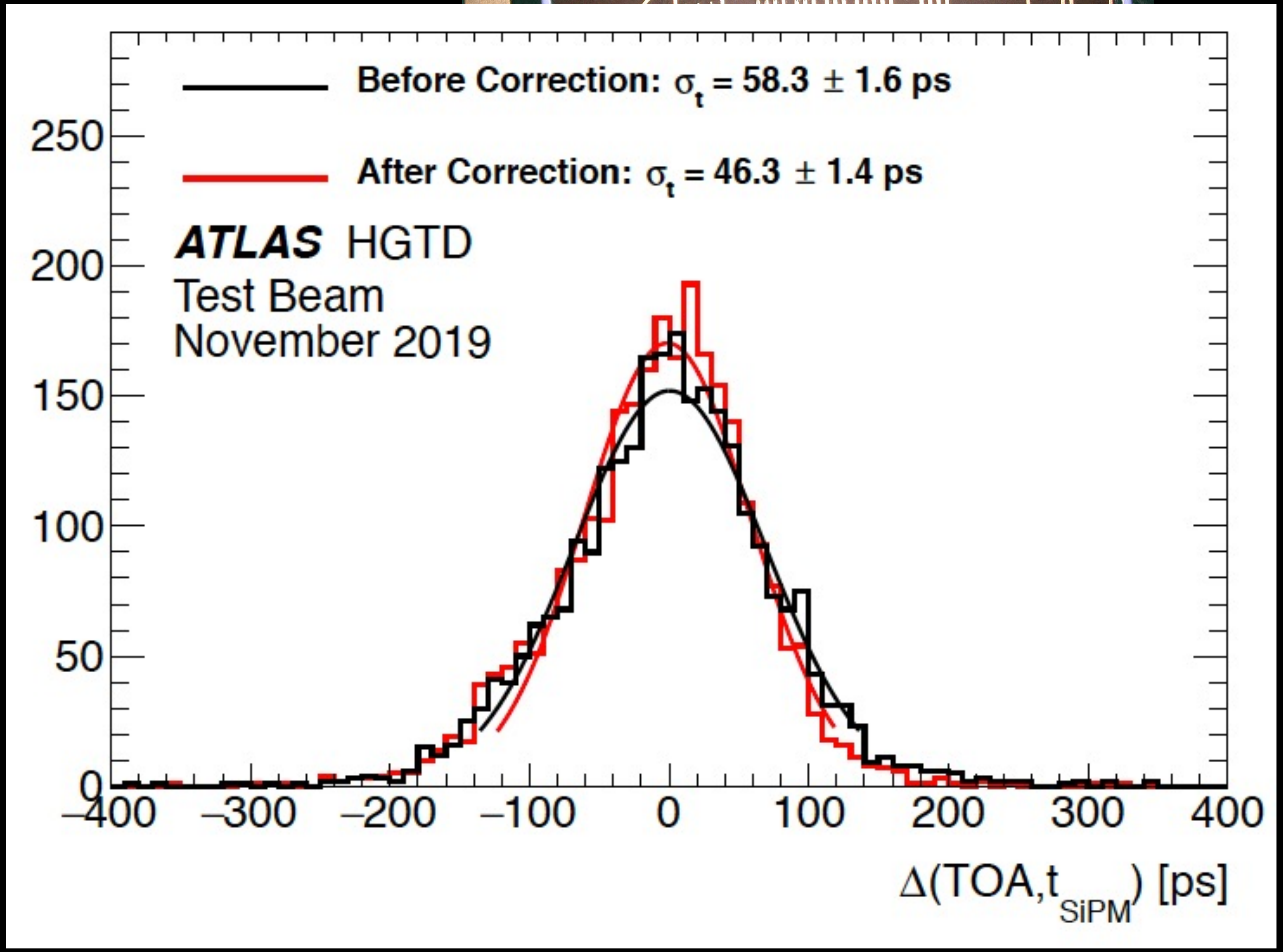
Outlook: Testbeam with ATLAS HGTD module

- ➢**Time resolution: 45ps**
- ➢**Position resolution: ~1mm**
- ➢**Area : 6.5mm*6.5mm --> (2cm*4cm)**







CEPC timing detector : Concept

- **Each module size : ~5cm * 15cm**
- **Further optimization is on going**