

4D tracking detector based on AC-LGAD technology for the future collider experiment



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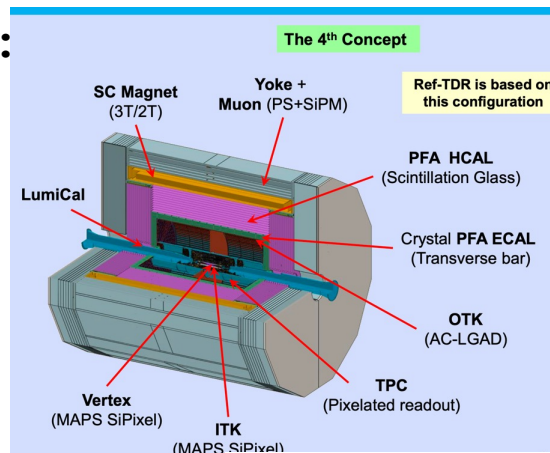
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Motivation

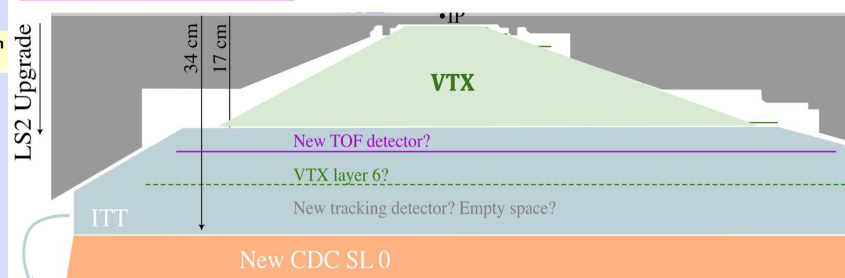
- Time of Flight based on AC/DC-LGAD technology:

- CEPC Out Tracker
- Belle II upgrade, ITT, Time resolution < 50 ps

✓ **Timing detector is complementary to gas detector: 50 ps** could improve the separation ability



If the new CDC scenario was chosen:

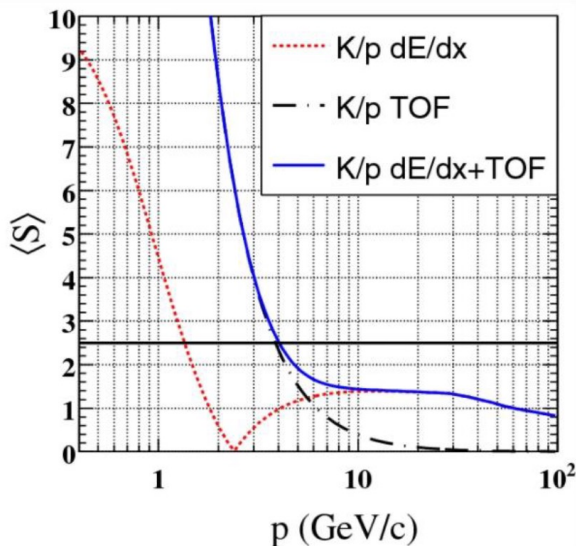
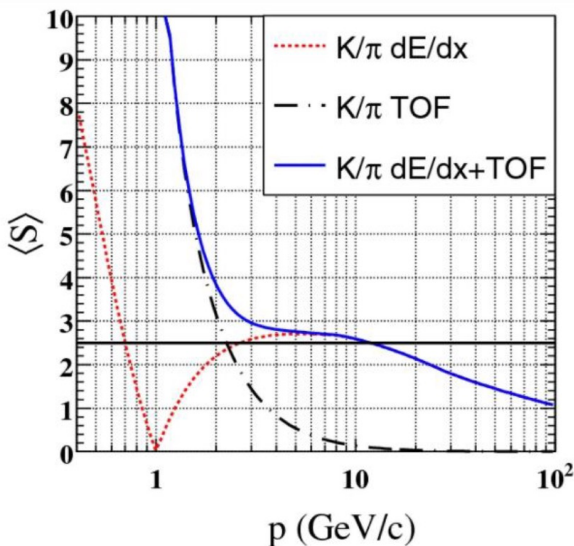


A Gap between VTX and new CDC => leaving tracks in this region uncovered -low pt tracks

Proposal: Add a detector here!
 • Fast timing detector (PID based on TOF) -> ITT region (Inner Timing Tracker)
 => Identify a fast timing, practical solution with acceptable material.
 • Preliminary simulation to understand the performance

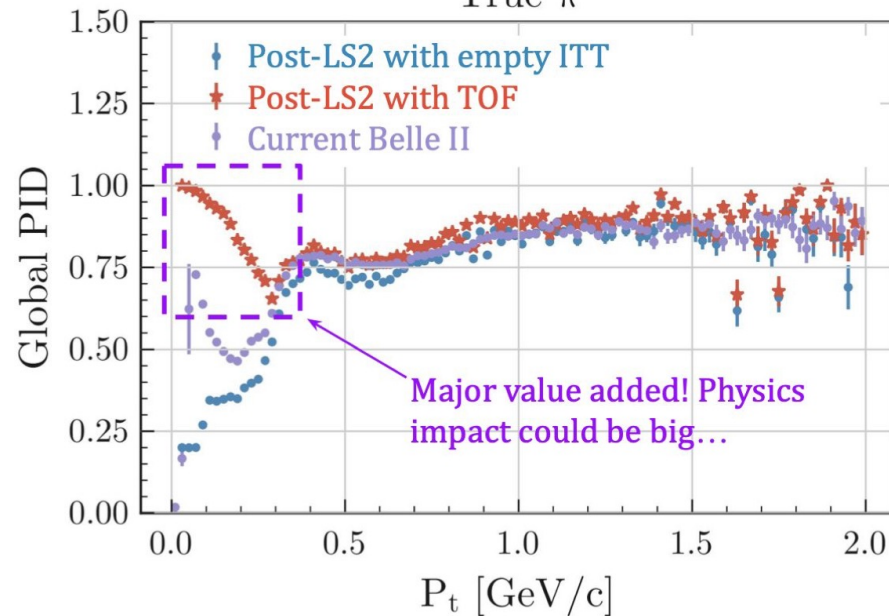
K/ π separation

K/proton separation



CEPC RefTDR, 2025

True π



Belle II upgrade, 2025

How to face the challenges of the Time precision

■ Contribution of the timing precision

$$\sigma_{T_{hit}}^2 = \underbrace{\sigma_{Landau}^2}_{\sim 39 \text{ ps}} + \underbrace{\sigma_{TW}^2 + \sigma_{jitter}^2 + \sigma_{clock}^2 + \sigma_{TDC}^2}_{\sim 25 \text{ ps}} + \dots (\sigma_{t_0}^2)$$

Sensor **Read-out electronics** **Other sources**

~30 ps *~25 ps*

Landau: Fluctuations of energy deposition + charge transport in the sensor

- ✓ Mitigation: thinner the active thickness, saturated drift velocity

Timewalk effect: Signal amplitude affects the Time-of-Arrive(ToA)

- ✓ Could be reduced with CFD method(ToT)

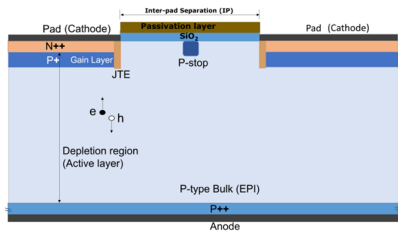
TDC: TDC binning/non-linearity

Clock: Jitter from the clock of the system

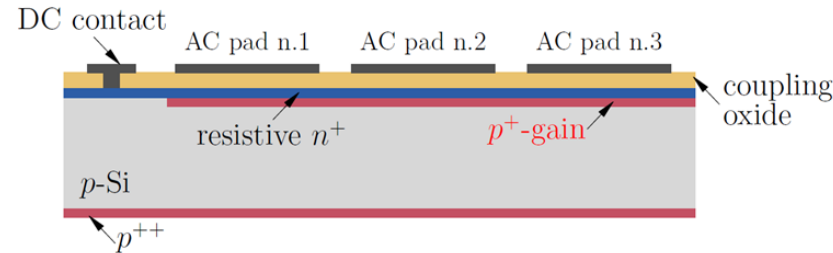
Design and Production of AC-LGAD sensor

- Aim to 4D track: 30 ps – 50 ps, 8 ~ 10 μm
- AC-LGAD: no dead region

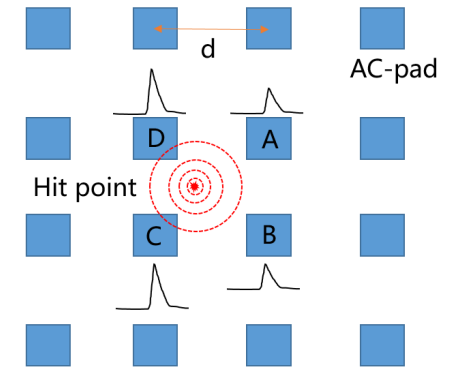
LGAD



AC-LGAD



Signal of AC-LGAD

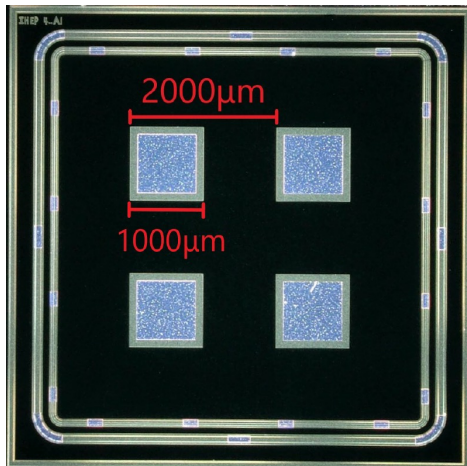


- Metal pads are connected to n++ layer
- Time resolution ~ 30ps
- Position resolution: pixel size/ $\sqrt{12}$
- Radiation hardness: $10^{15} \sim 10^{16} n_{eq}/\text{cm}^2$

- Metal AC-pads are separated
- Time resolution ~ 30ps
- Position resolution: 5~10 μm
- Radiation hardness: $10^{15} \sim 10^{16} n_{eq}/\text{cm}^2$

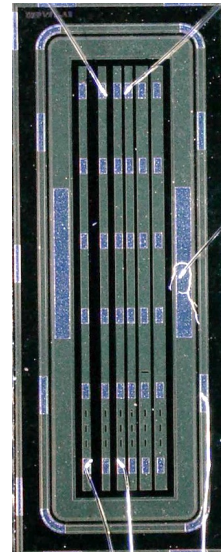
Different designs of AC-LGAD in IHEP

- **Different designs of AC-LGAD in IHEP**
 - EPI thickness 50 μm , sensor thickness 725 μm
 - ✓ **Pixels AC-LGAD:**
 - ✓ **Strip AC-LGAD:**



Pixels AC-LGAD:

- Pitch size 2000 μm
- pad size 1000 μm

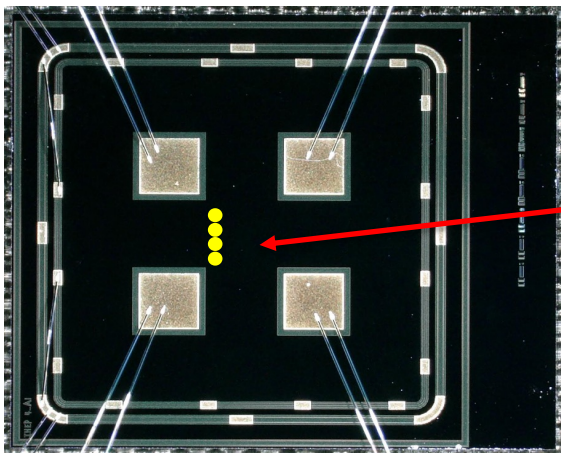
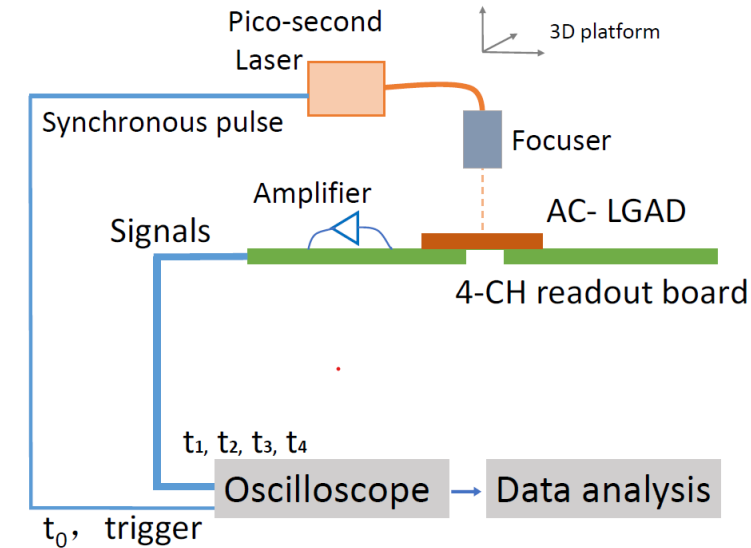


Strips AC-LGAD:

- Strip length 5.6mm, width 100 μm
- Different Pitch size:
 - 150 μm , 200 μm , 250 μm

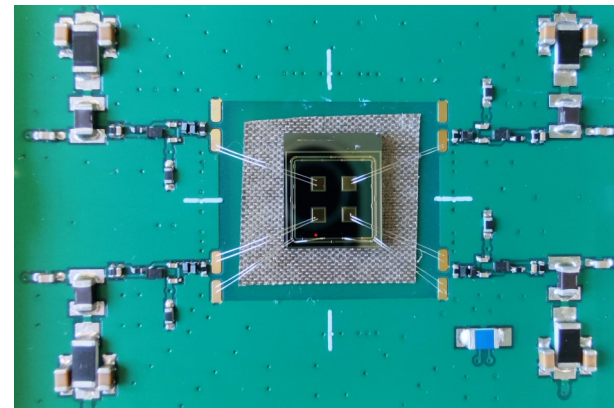
Performance Test Setup of AC-LGAD

- Timing and spatial resolution test of AC-LGAD
- Transient current technique (TCT)
- Picosecond Laser: 1065 nm , spot size $10\ \mu\text{m}$ (3σ), 12 MIPs
- 4 channels readout board designed by IHEP
 - 470 Ω Broadband inverting trans-impedance amplifier
 - Reference of 1 channel board designed by UCSC



Laser spot

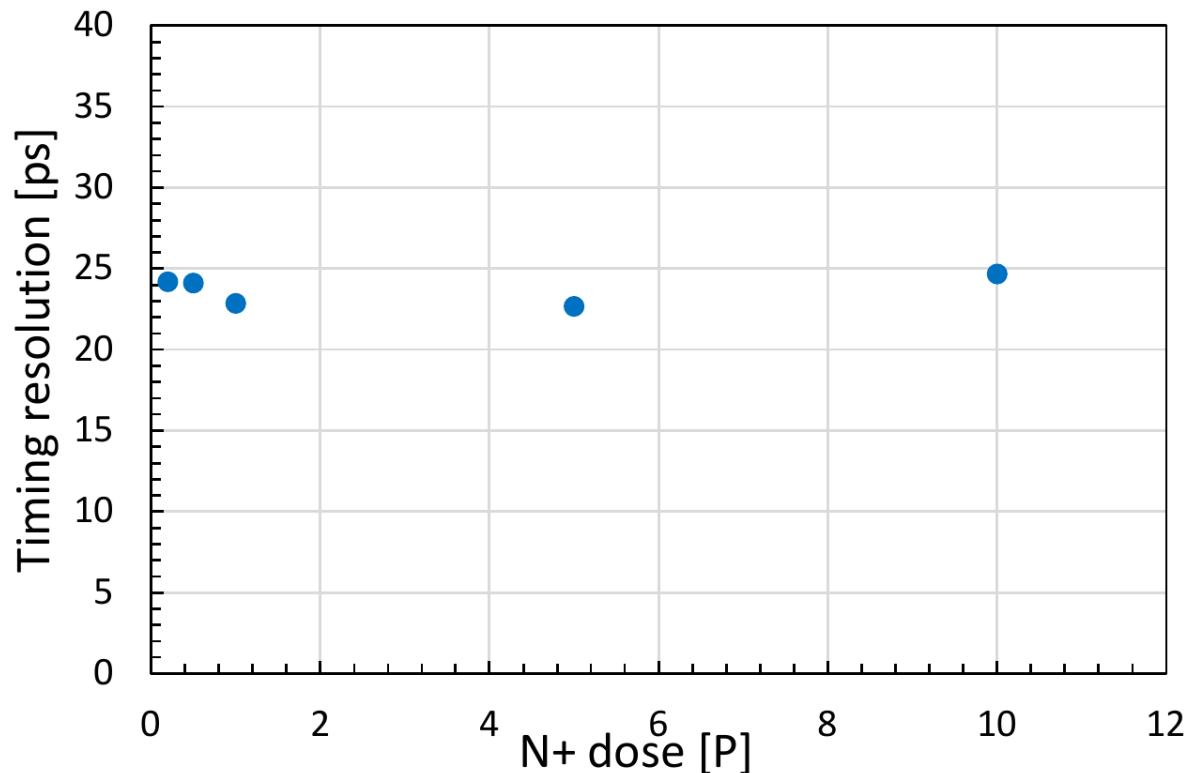
4 channels readout board designed by IHEP



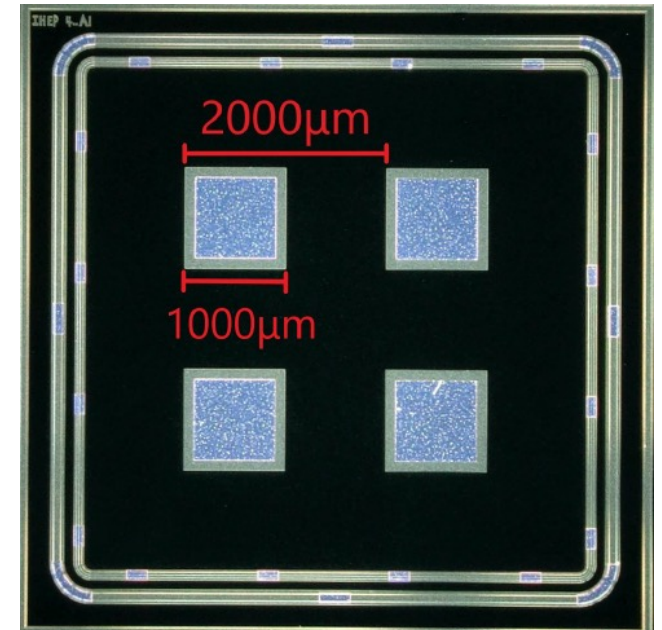
Timing resolution of pixel AC-LGAD

- Timing resolution of AC-LGAD with different N+ dose
 - 22~25 ps (Laser results)
 - N+ very slightly affects the time performance

Timing resolution of AC-LGAD with different N+ dose



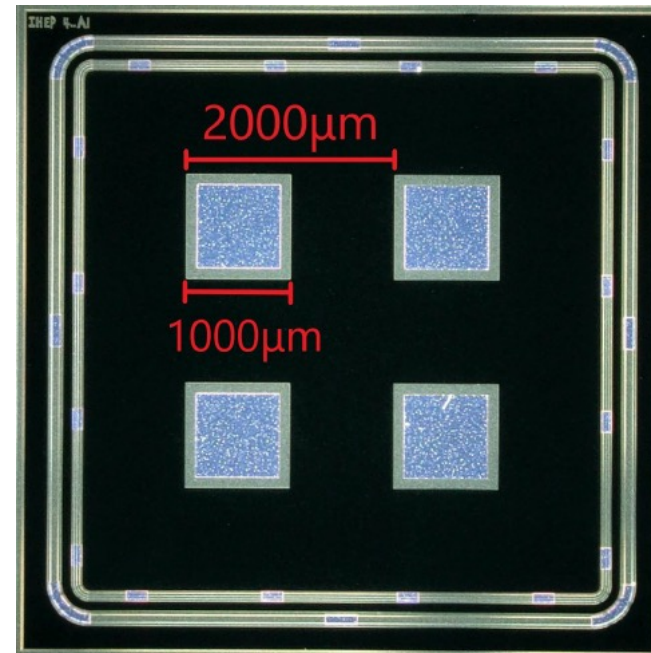
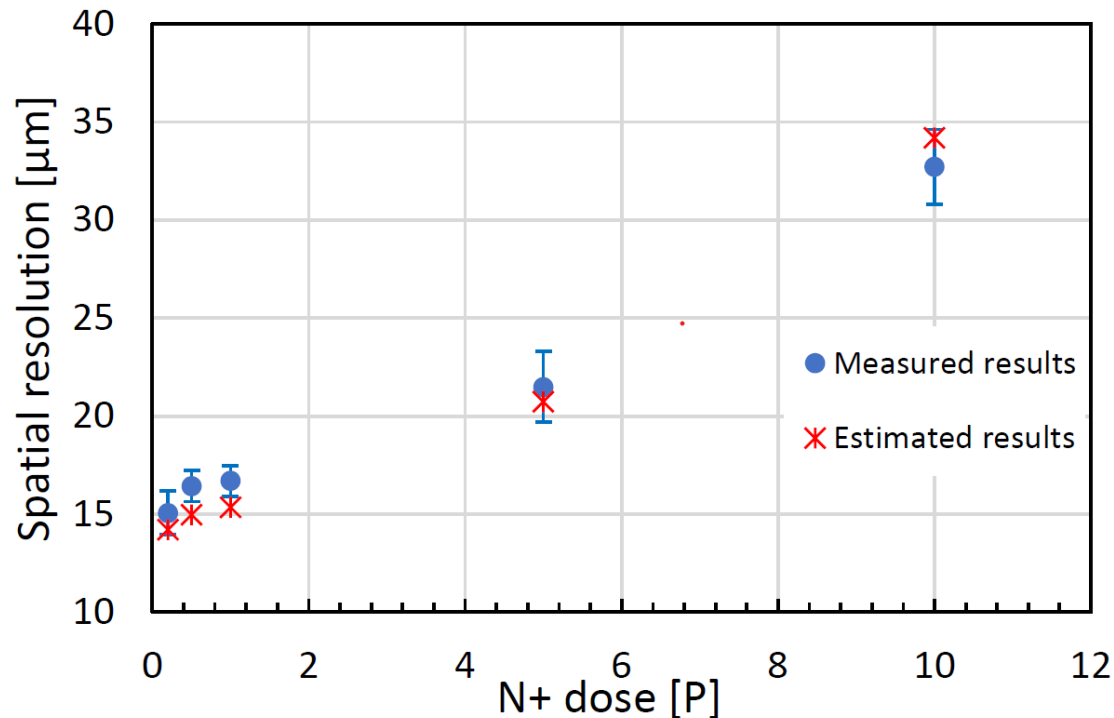
Tested AC-LGAD



Spatial resolution of pixel AC-LGAD

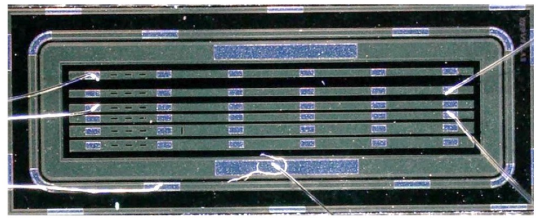
Spatial resolution vs N+ dose

- 10 P \rightarrow 0.2 P, spatial resolution \uparrow 15 μm (minimum)
- Estimated laser point positions fit the measured well
- **Better than the FBK design** even with 2 times larger pitch



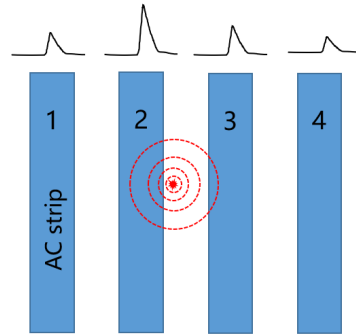
Performance of strip AC-LGAD: Spatial Resolution

7.40 mm (strip length: 5.65 mm)



2.85 mm

Laser point:
2 μ m pitch

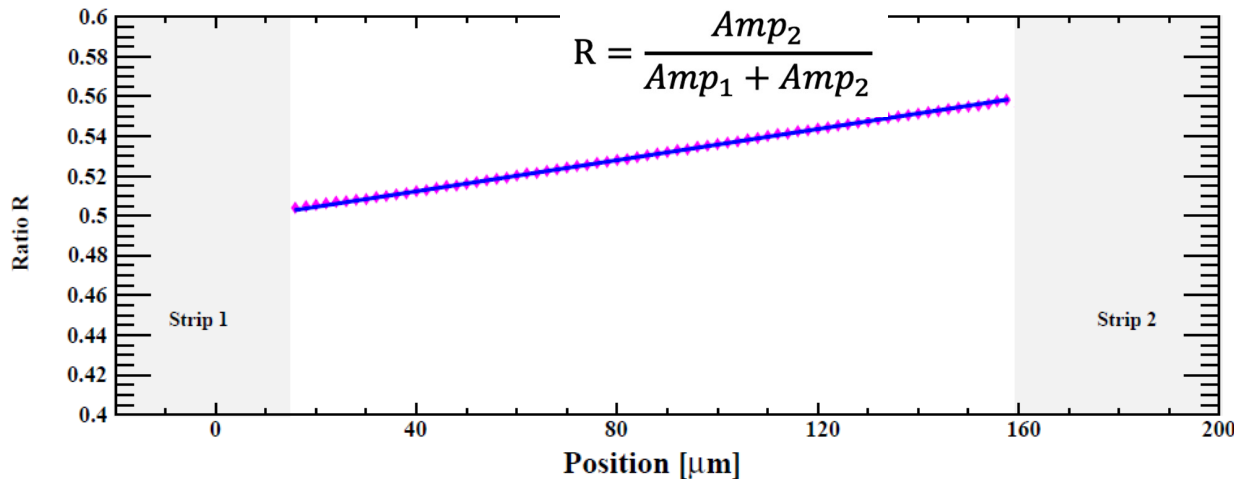


Spatial resolution :

8.3 μ m (150 μ m pitch)

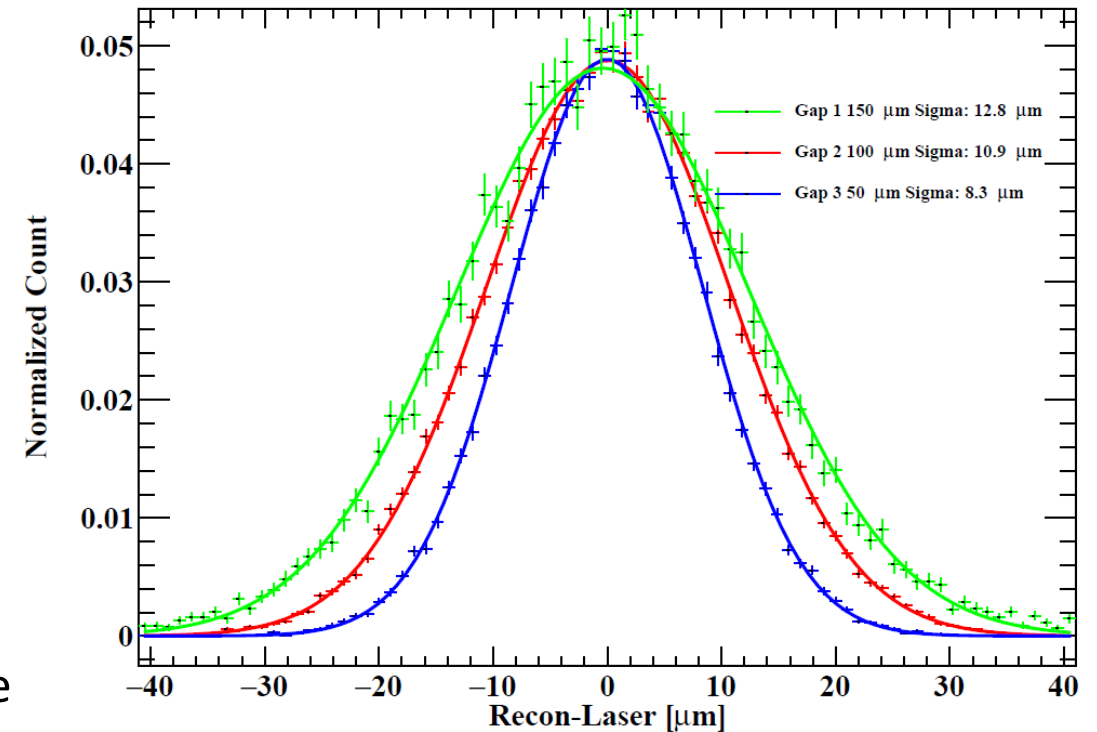
10.9 μ m (200 μ m pitch)

12.8 μ m (250 μ m pitch)

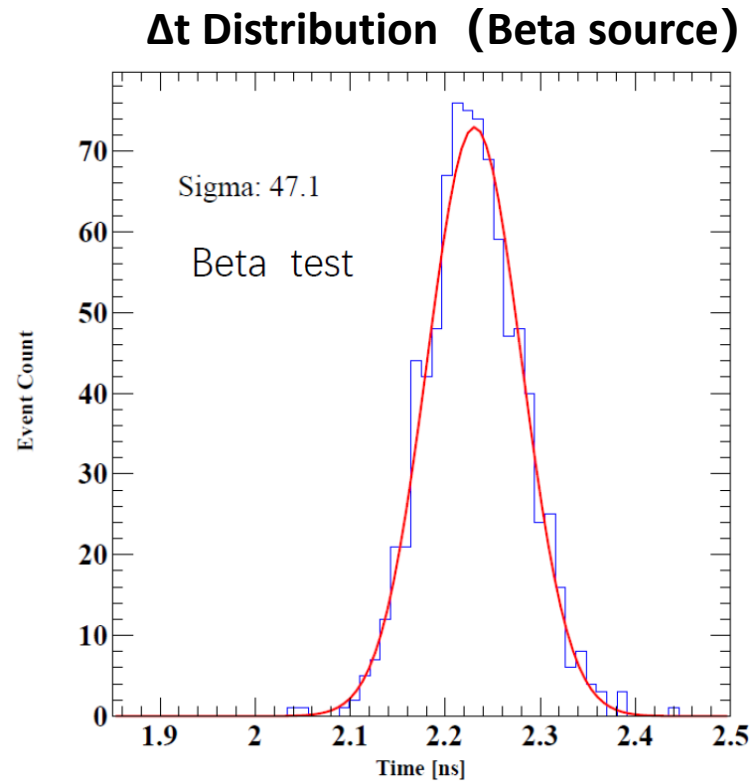
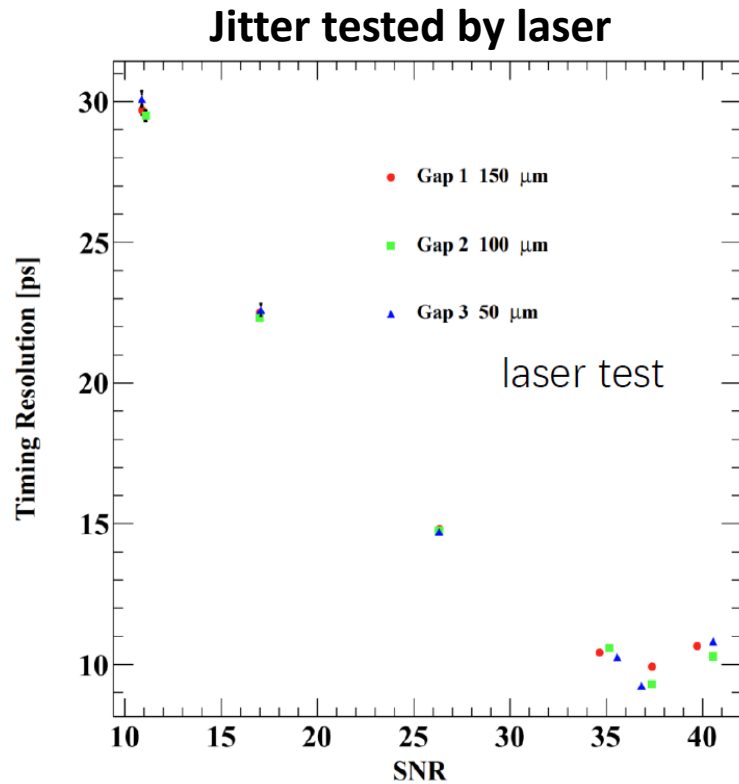


Position reconstruction:

The fraction of the signal (R) changes linearly with the move the laser.



Performance of AC-LGAD: Time Resolution



Timing resolution of Trigger

$$\Delta T = T_{trigger} - \frac{\sum_i a_i^2 T_i}{\sum_i a_i^2}$$

Weighted timing resolution of three strip electrodes

Sigma $\Delta t = 47.1$ ps

AC-LGAD strip : 37.5 ps

- No significant change in timing resolution was observed for different pitches
- Saturation was observed: ~ 10 ps.
- **37.5 ps timing resolution**, via Beta source test.

Conclusion

- For future collider experiment, the requirement of 4D tracking could benefit the physics definitely
- AC-LGAD is one potential 4D tracking detector candidate
- Prototype of the Pixel AC-LGAD and strip AC-LGAD at IHEP showed very promising results
 - Pixel AC-LGAD: ~ 25 ps (laser), ~ 16 μm (laser) (2000um pitch)
 - Strip AC-LGAD: ~ 37 ps (Beta), ~ 8.3 μm (150 μm pitch,laser)

**Thank you for your
attention!**



-
- **Back up**



AC-LGAD: Spatial Resolution

- **Spatial resolution Vs. Pitch size**
 - ✓ Pitch size 250um → 150um
 - ✓ Spatial resolution 11 → 8 μm (Strip).
- **Smaller pitch sizes → better spatial resolution**

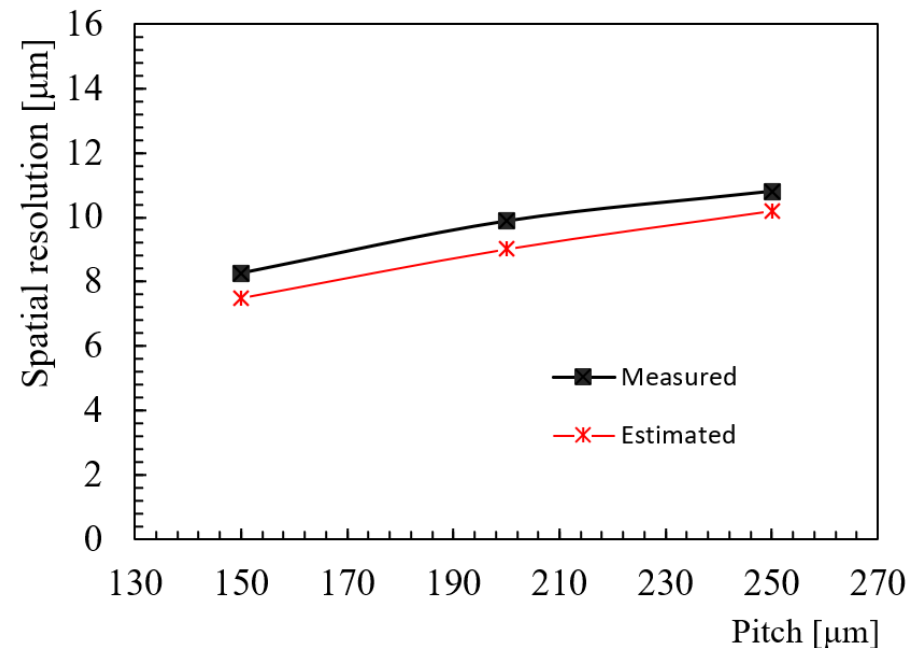
Resolution estimation:

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

A: signal attenuation factor

N: noise RMS (sensor + electronics)

Spatial resolution Vs. pitch size



Ref-TDR is based on this configuration

