中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Timing and spatial performance of IHEP AC-LGADs

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On behalf of IHEP HGTD sensor group

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Outline

- Standard LGAD vs AC-LGAD
- Performance of IHEP Standard LGAD
- Simulation of AC-LGAD design parameters
- Timing and spatial performance of IHEP AC-LGAD
- Summary

Standard LGAD vs AC-LGAD

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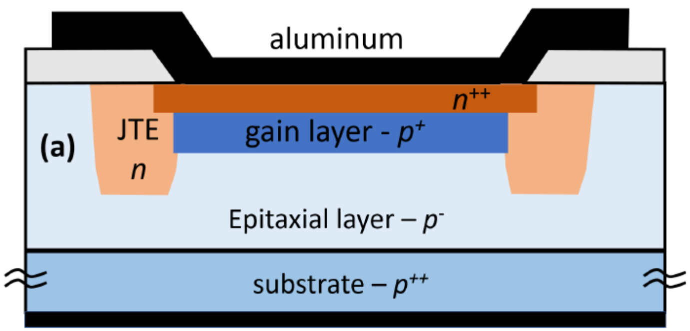
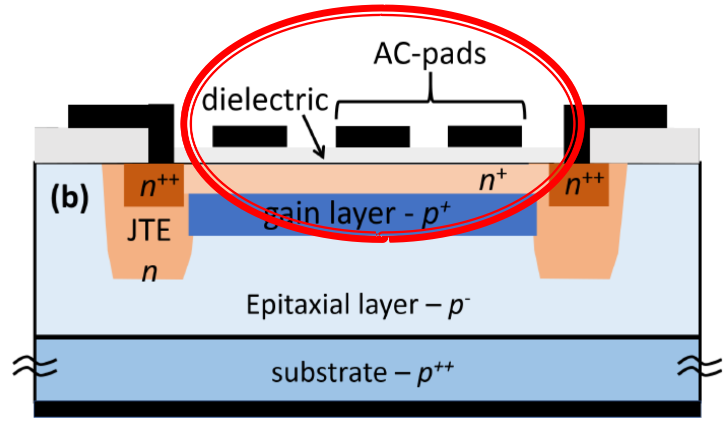
- Low Gain Avalanche Detectors(LGAD) is an avalanche PN diode which work below breakdown voltage(liner mode) and with Gain >10 for effectively charge collection.





Standard-LGAD

- The DC readout electrode
- Time resolution ~ 35ps
- Position resolution: sensor size
- Dead zone: JTE, Pstop, 50~100um

AC-LGAD

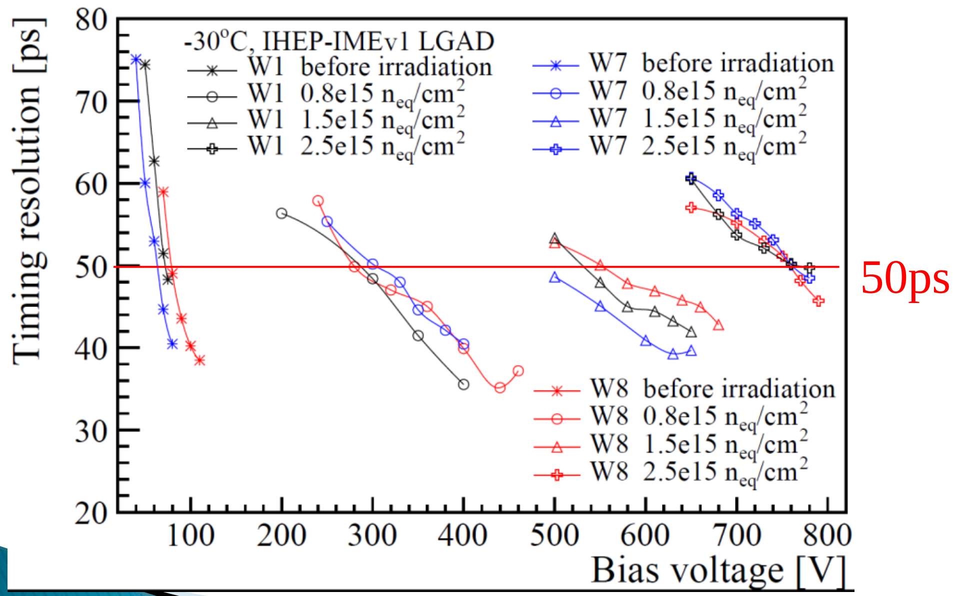
- AC coupled readout electrode
  collected charge from each electrode is related with particle injection position.
- Time resolution ~ 35ps
- Position resolution: 10-50 um
- Dead zone : 0 mm (no dead zone)

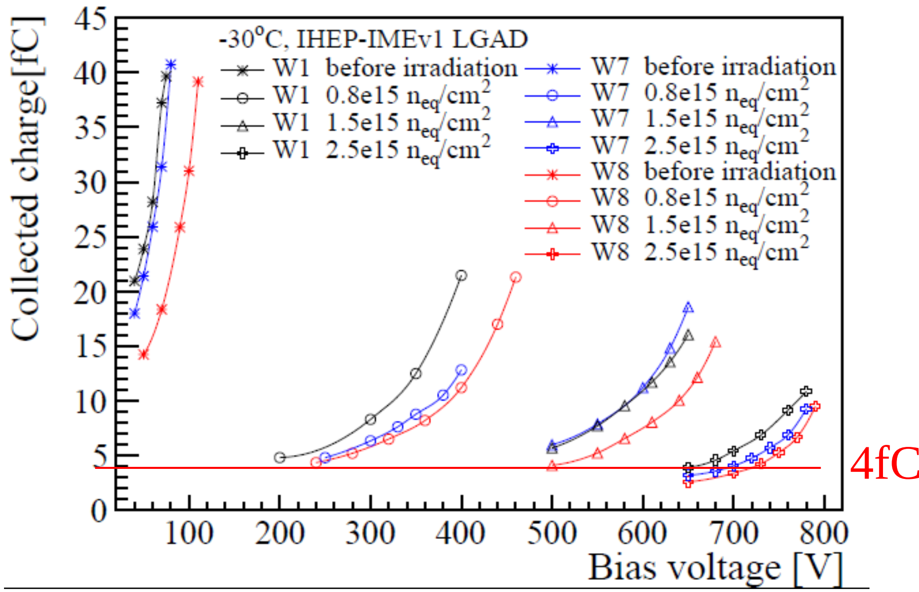
[#] Gabriele D'Amen et al., Electrical and timing performance of AC-LGADs, 37th RD50 Workshop, Zagred, online, 2020.

Performance of IHEP Standard LGAD

- In order to separate collisions in limited space, ATLAS High Granularity Timing Detector (HGTD) project choose thin Low Gain Avalanche Detectors(LGAD) as sensors, which have timing resolution better than 50ps.

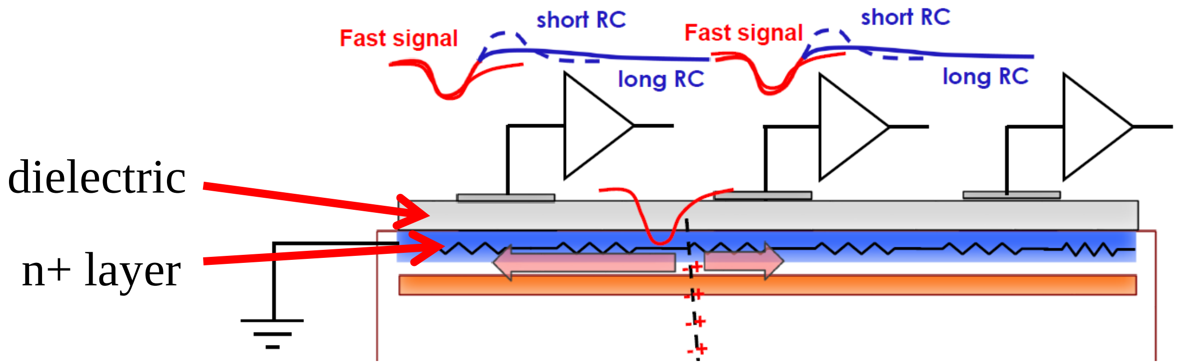
- IHEP LGAD： Time resolution and charge collection results before and after irradiation show that the sensor satisfy the project specification.（collected charge larger than 4fC, time resolution can reach 50ps）





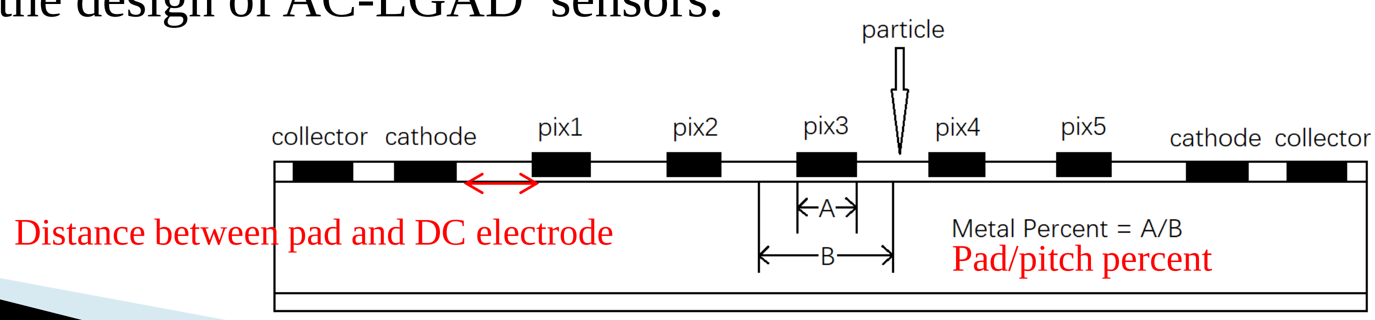
Simulation of AC-LGAD parameters

- As shown in the figure, RC will affect the signal shape(overshot)
  n+ layer with different dose → R
  dielectric material and thickness → C



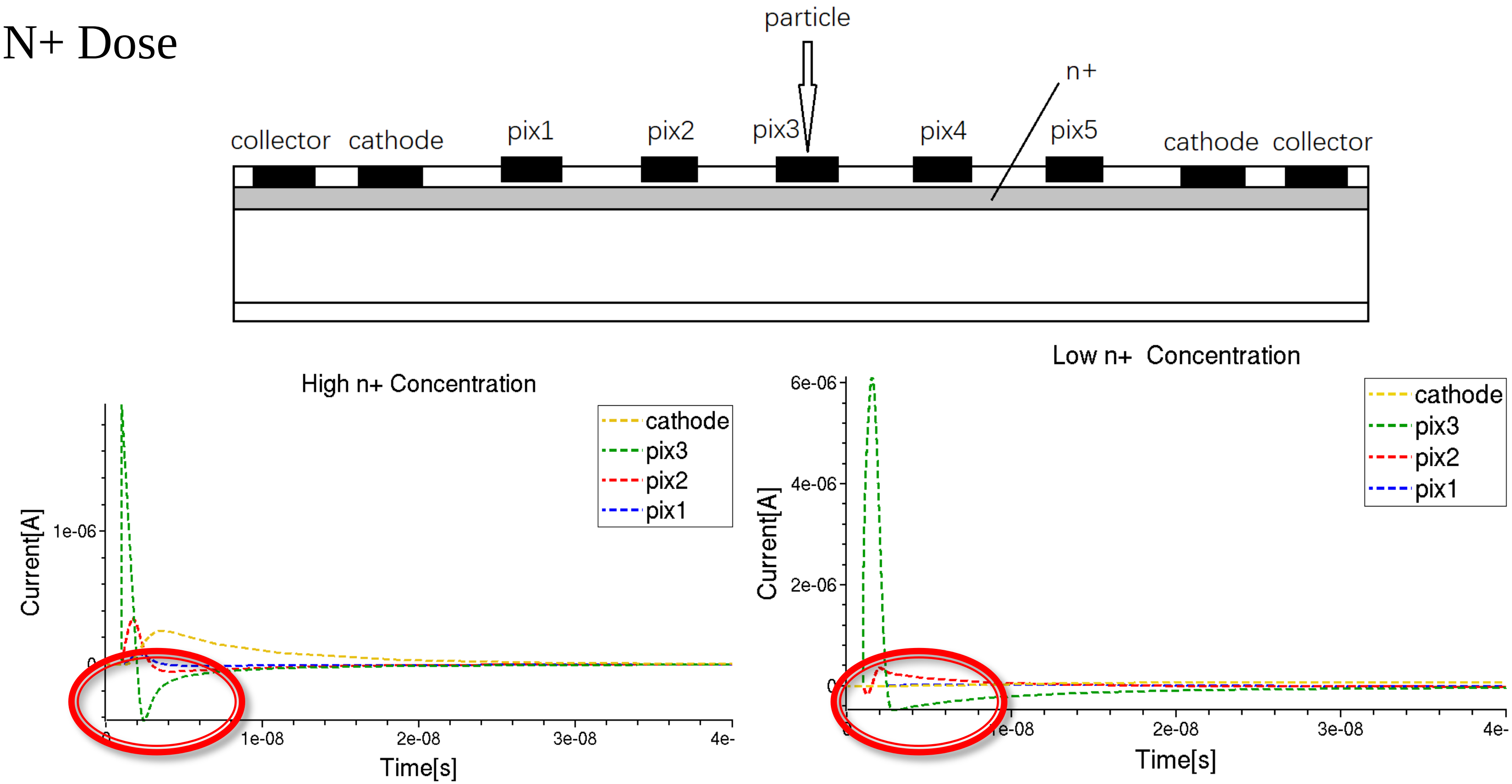
#Nicolo Cartiglia, UFSD group, The 1-um project, 37th RD50 Workshop, Zagred, online, 2020.

- Other parameters different with standard LGAD are pad/pitch percent and distance between pad and DC electrode, which also should be simulated and set during the design of AC-LGAD sensors.



Simulation of AC-LGAD parameters

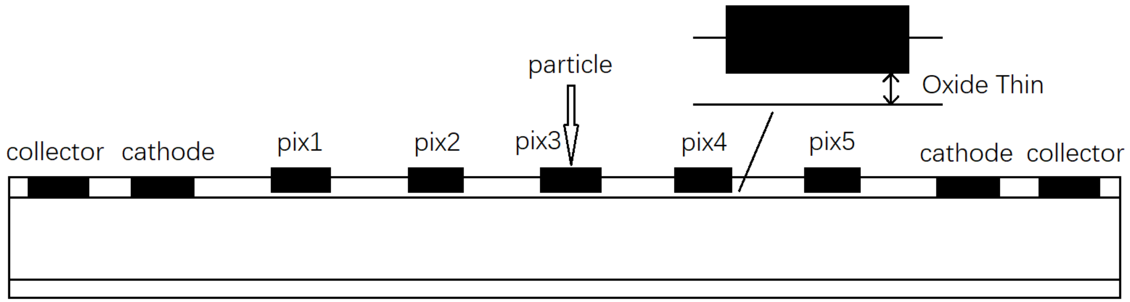
- N+ Dose

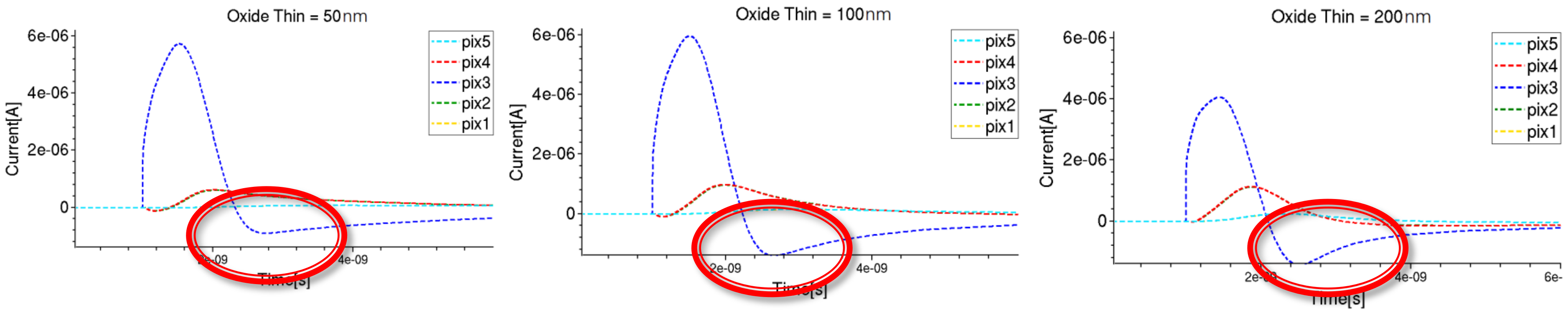


As decreasing the n+ dose, R increases, signal overshot decreases.

Simulation of AC-LGAD parameters

- Oxide thickness





As increasing the oxide thickness, the shape of signal change worse.

Simulation of AC-LGAD parameters

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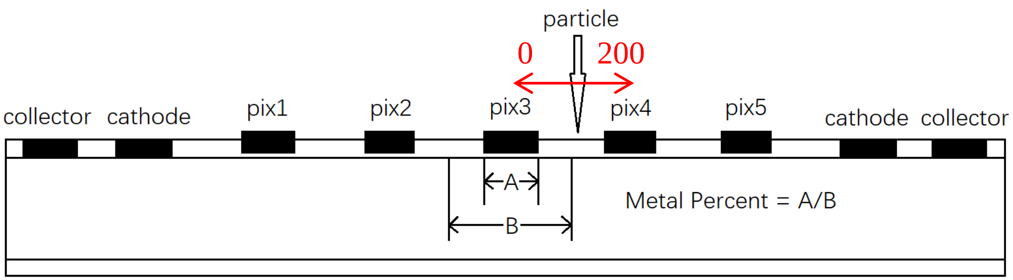
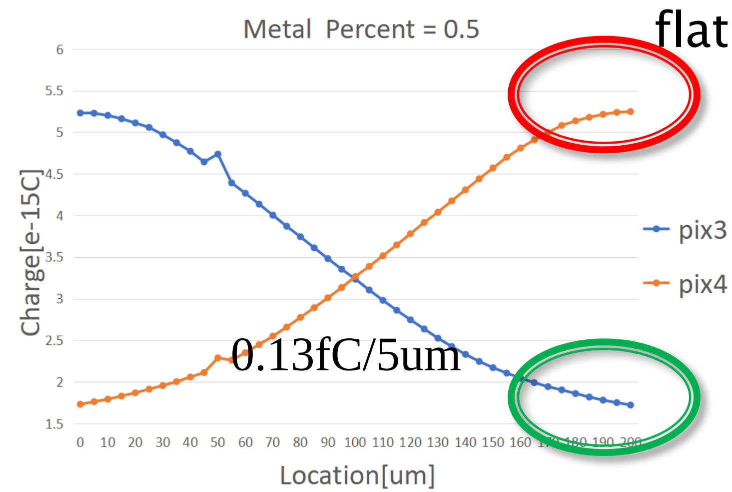
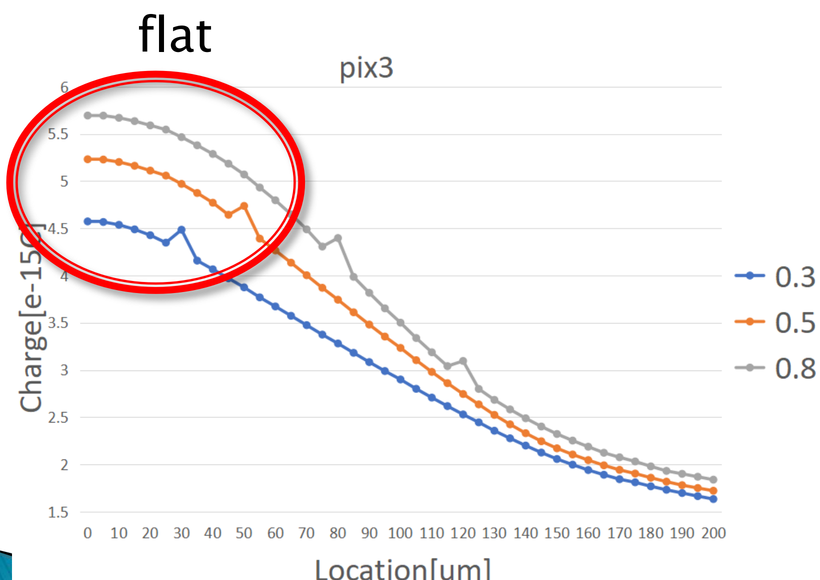
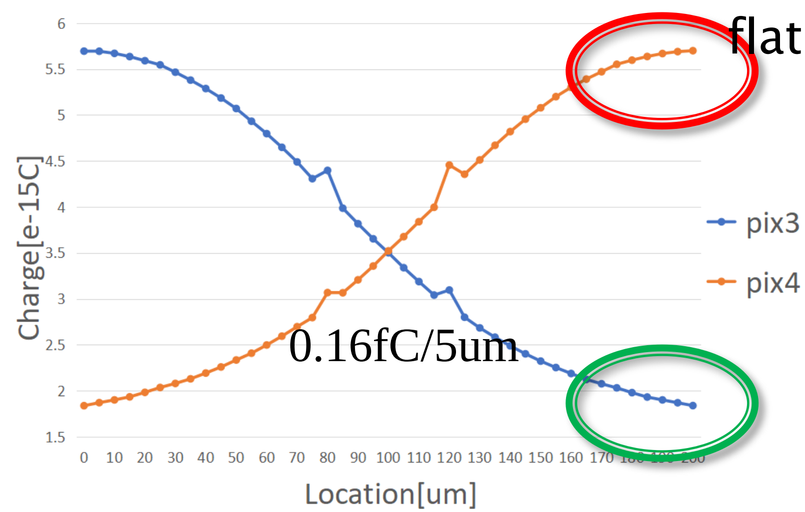
- Pad/pitch percent: A/B







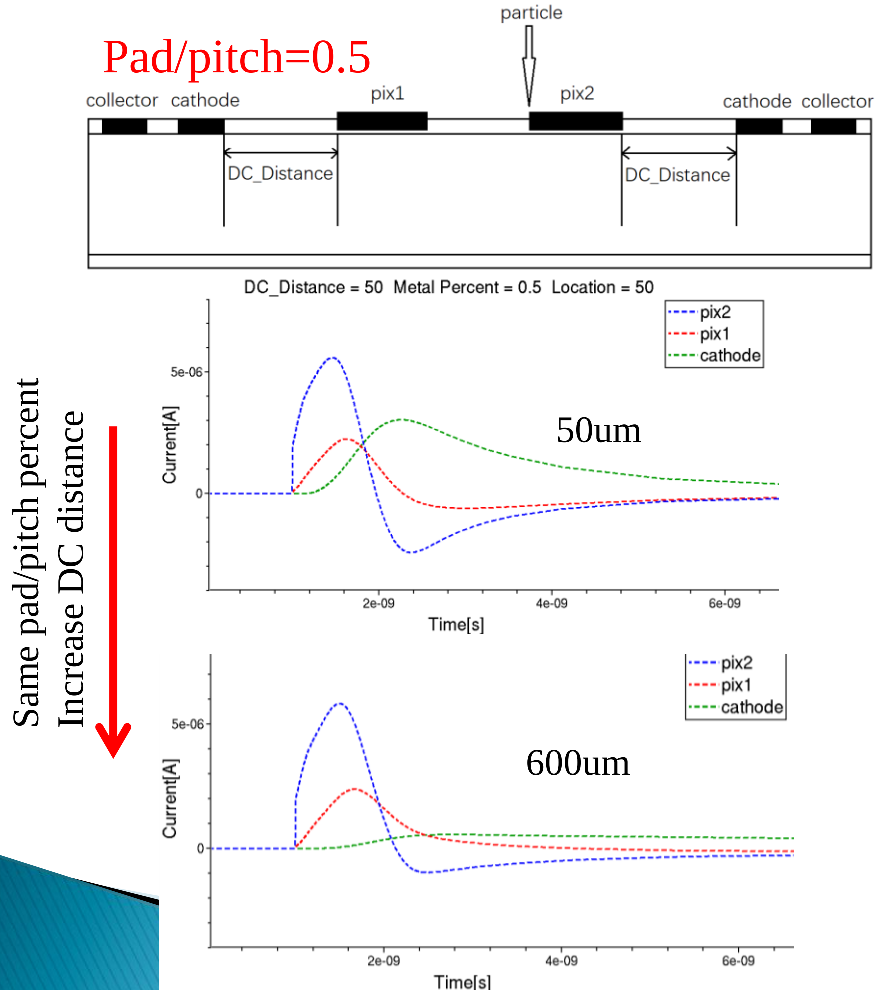


As increasing the pad/pitch percent, the flat part (pad region) increase but we can use pixel nearby to decide the position.

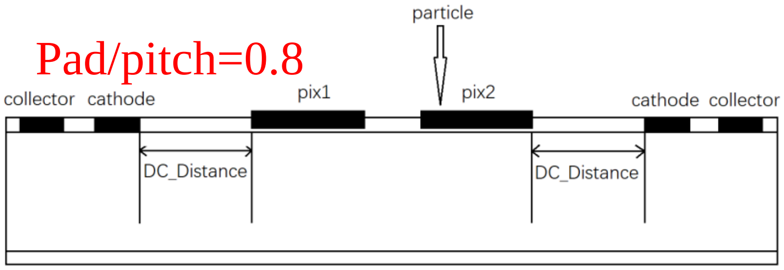
Simulation of AC-LGAD parameters

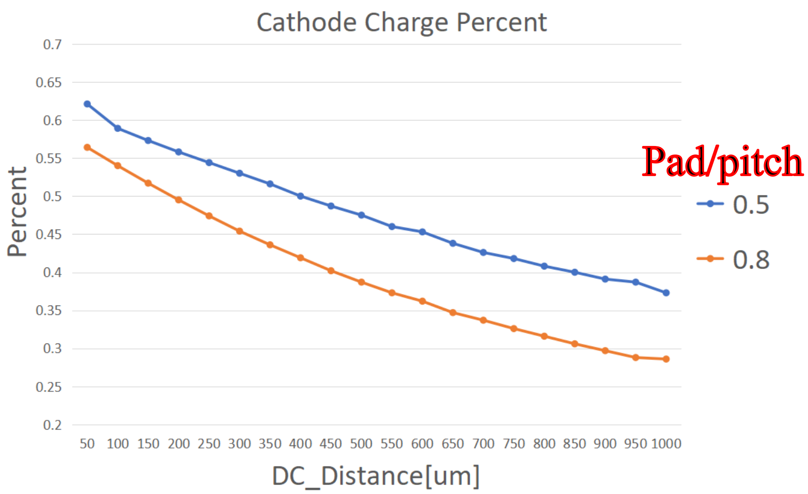
- DC distance will affect collected charge of the pixels nearby
- DC distance for sensors with different pad/pitch percent

Pad/pitch=0.5



Pad/pitch=0.8



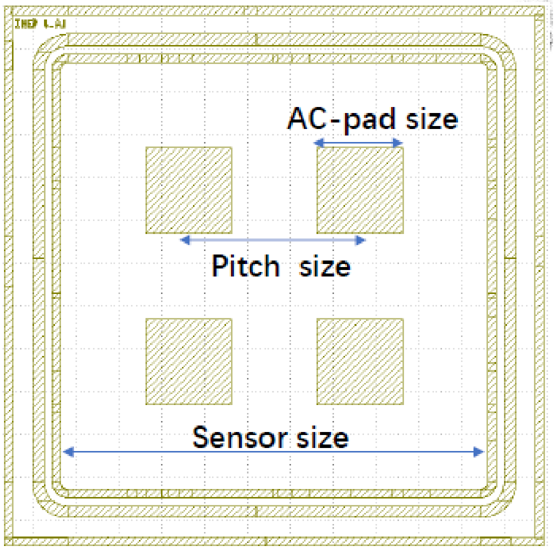


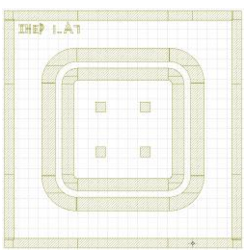
As increasing the distance between DC and pixel, the charge collected by the DC electrode will decrease

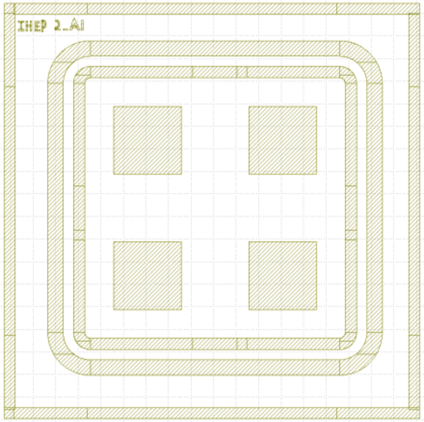
AC-LGAD sensors developed by IHEP

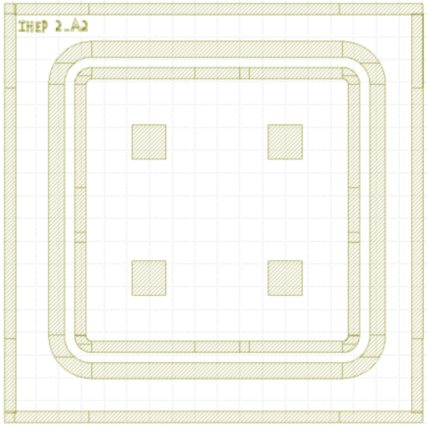
- Sensors with different pad-pitch size

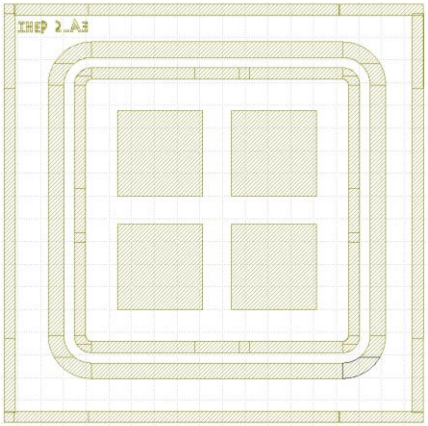
Sensors	Sensor size [µm]	AC-pad size [µm]	Picth size [µm]
1-A7	1000	100	450
2-A2	2000	300	1200
2-A1	2000	600	1200
2-A3	2000	750	1000
4-A1	4000	1000	2000











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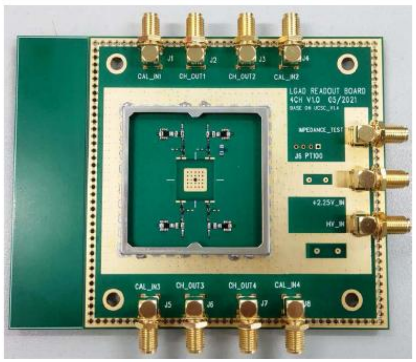
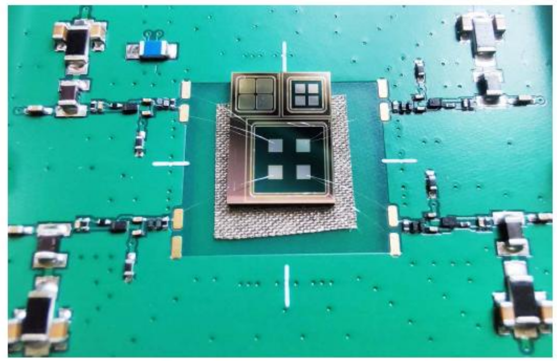
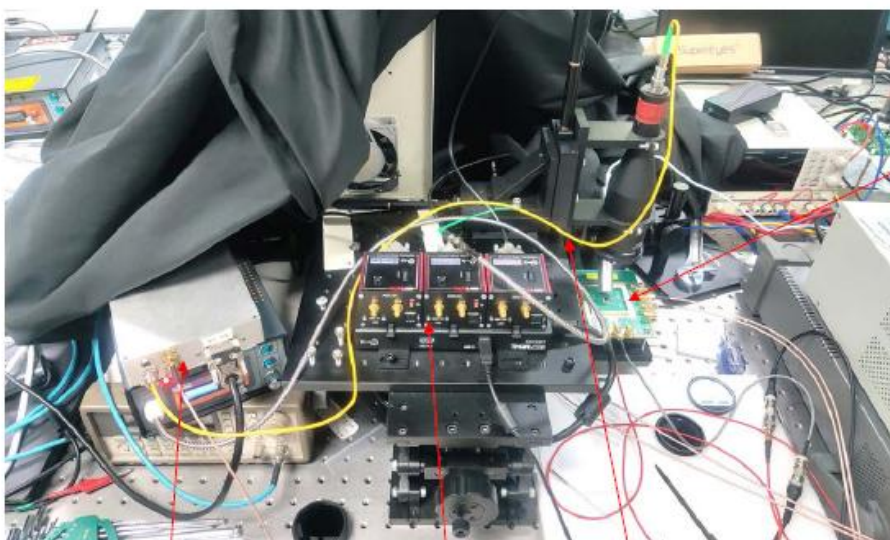
Set up for testing

- 4 channels readout board with fast amplifiers (~2GHz)
- Pico-second laser testing system for AC-LGAD (1064nm)
- 3D X-Y-Z stage platform (precision : ~1um)





4 channels PCB board



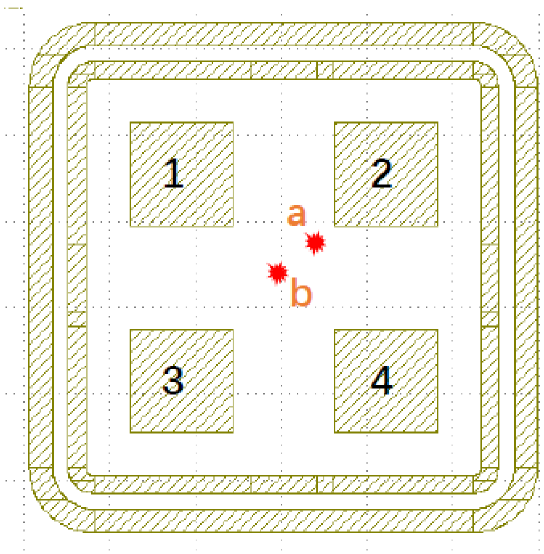
Test board with sensor

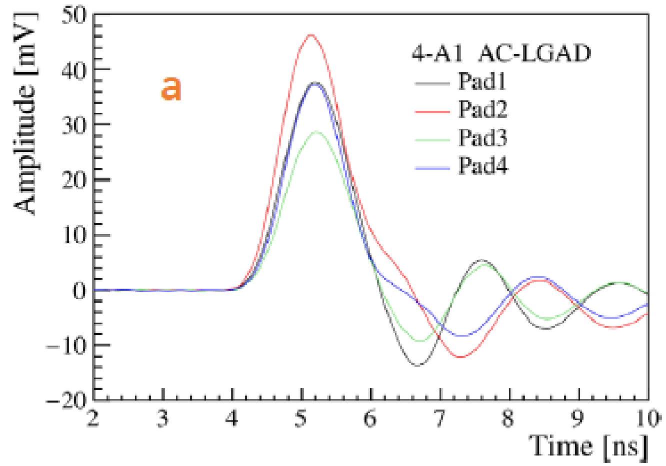
Pico-second laser

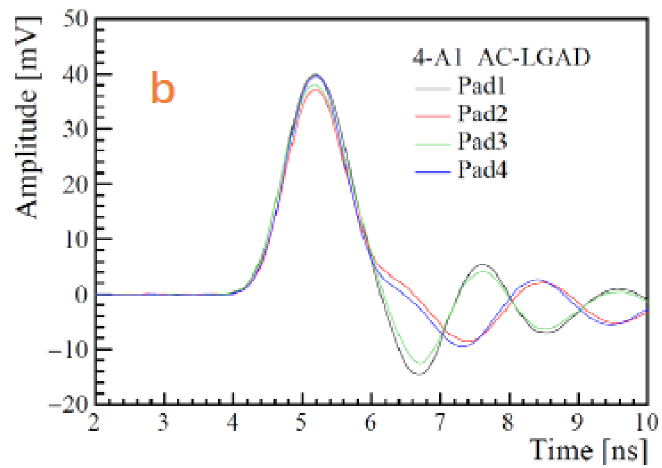
X-Y-Z platform

Spatial performance of IHEP AC-LGAD

- Position injection and signals





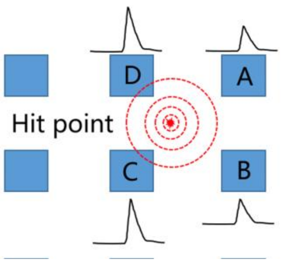


The coupled signal or collected charge from the 4 pixels is closely related to the position of the laser injection.

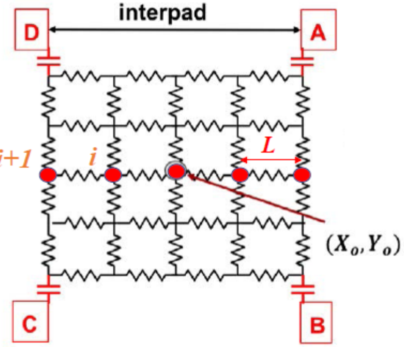
Spatial performance of IHEP AC-LGAD

- DPC method

Position reconstruction by Discretized Positioning Circuit model (DPC) #



Discretized Positioning Circuit model (DPC)

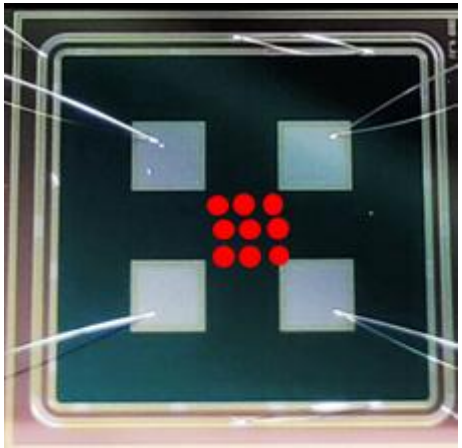


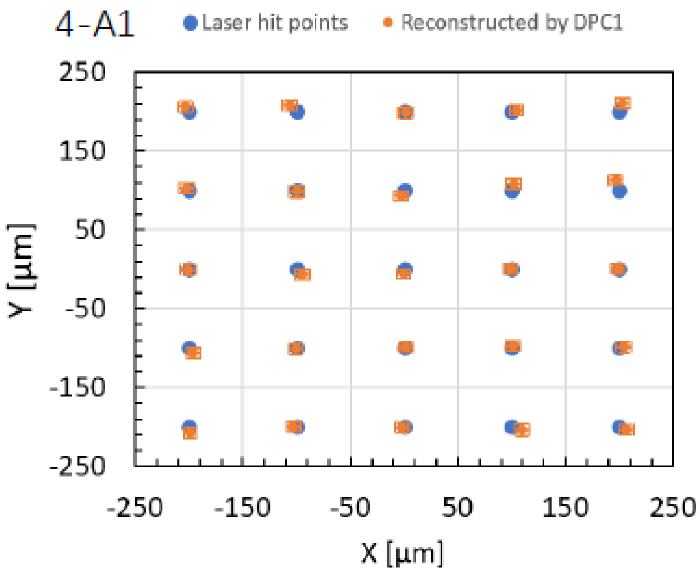
$$X = X_0 + k_x\left(\frac{q_A + q_B - q_C - q_D}{q_A + q_B + q_C + q_D}\right) = X_0 + k_x m$$

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

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

- hit position vs Reconstructed position



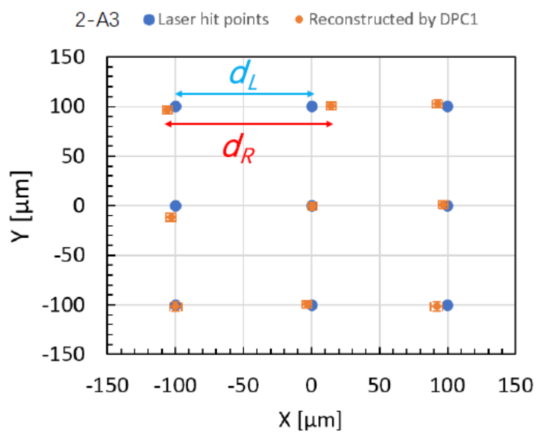


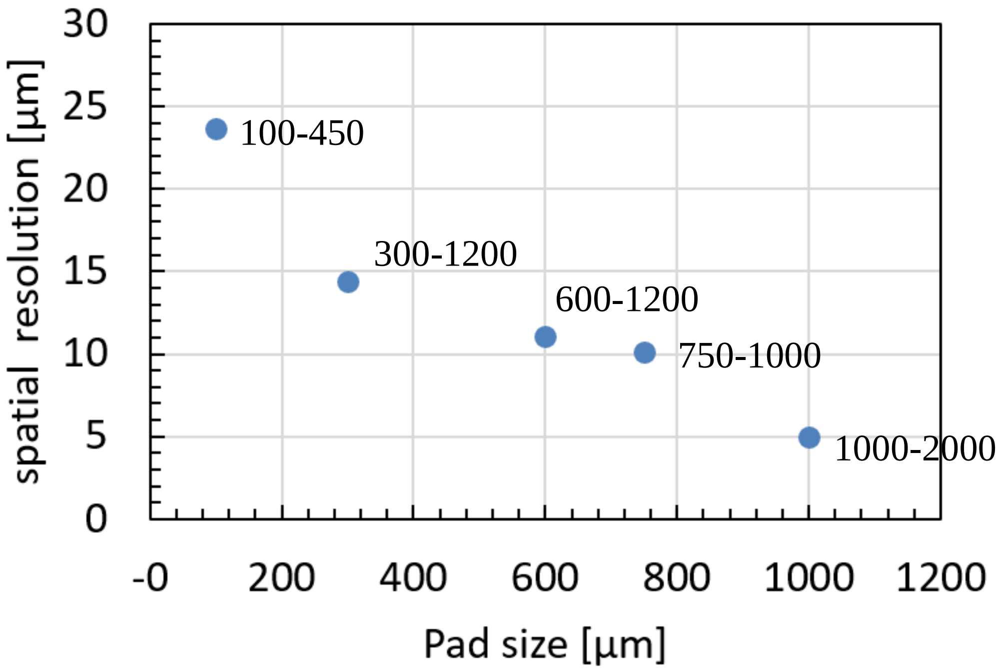
M. Tornago, et al. Nuclear Inst. and Methods in Physics Research, A 1003 (2021) 165319

Spatial performance of IHEP AC-LGAD

- **Spatial resolution：**

The standard deviation of the displacement difference between the laser and the reconstruction (d_L-d_R)

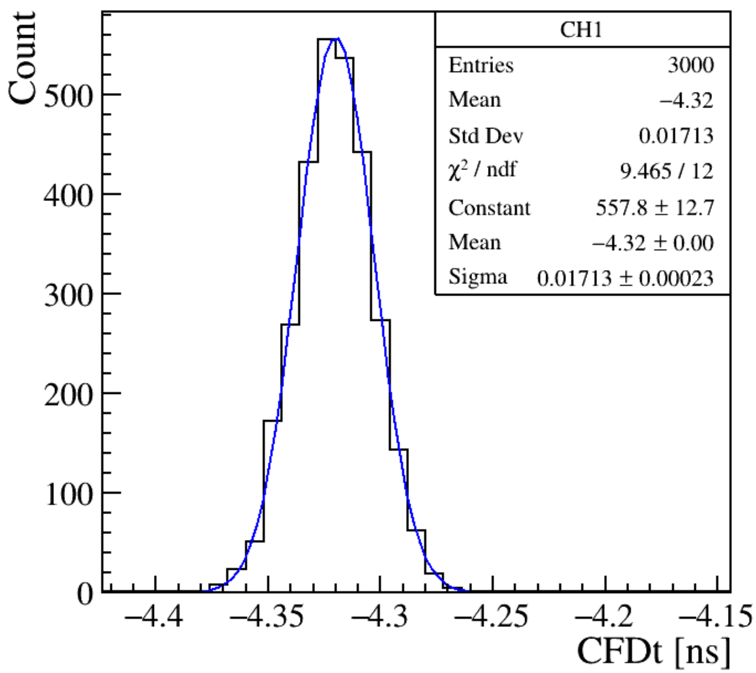




It seems that as increasing the pad size or pad/pitch percent, better spatial resolution will be got.

Timing performance of IHEP AC-LGAD

- The timing resolution is about 15-17 ps (Laser testing)
- Almost no difference for different size of the pads



Sensors	Pad-pitch (μm)	Timing resolution (ps)
1-A7	100-450	15
2-A2	300-1200	16
2-A1	600-1200	17
2-A3	750-1000	17
4-A1	1000-2000	17

From laser test results, the pad size may not affect the time resolution of the AC-LGAD.

Beta testing will be done next.

Summary

- AC-LGAD is a 4D detector (position and time).
- Parameters including n+ dose, oxide thickness, pad/pitch percent, and DC distance will affect the performance of AC-LGAD sensors. Simulation were done about these.
- First IHEP AC-LGAD sensors were fabricated.
- Use pico-second laser for testing and reconstructed the injection position by DPC model
- The best spatial resolution is ~5μm, Timing resolution is ~17ps (Laser test results)
- Sensors with different n+ dose and oxide thickness will be tested next.