



Status of USTC 2nd batch AC-LGAD sensor

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On behalf of USTC silicon detector group

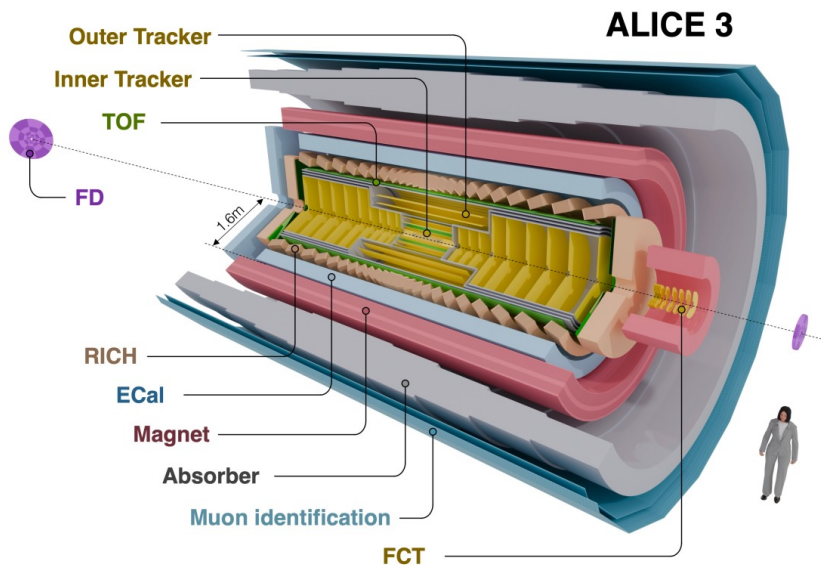
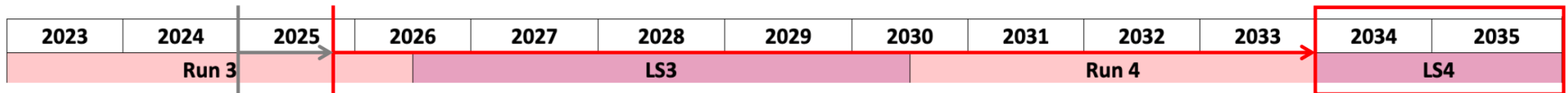
CLHCP 2025.10.30

Outline

- Introduction
- Production timeline
- Design of 2nd AC-LGAD sensor
- Performance of 2nd AC-LGAD sensor
- Summary

Alice3 TOF

- ALICE3 is a brand new heavy ion detector for the next generation of the LHC. The purpose is to gain a deeper understanding of quark matter
- All silicon track detector + **silicon-based TOF detector**
- Project objective: Develop an **AC-LGAD** suitable for ALICE3 TOF

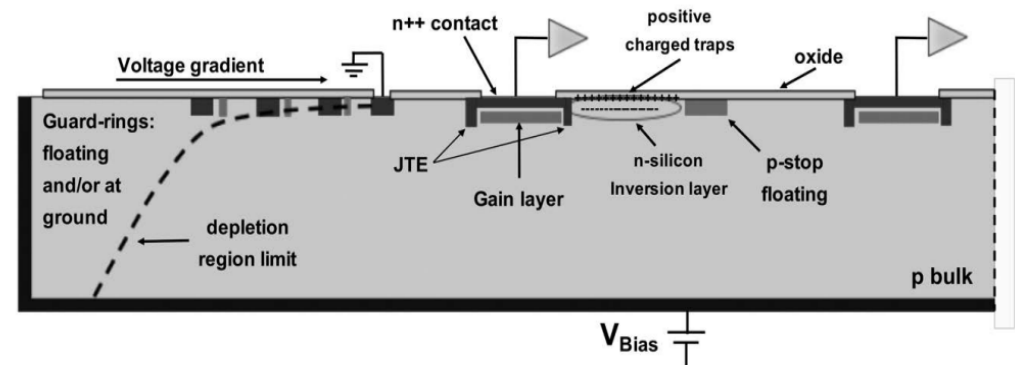


	Inner TOF	Outer TOF	Forward TOF disks
Radius (m)	0.19	0.85	0.15 to 1.0
z range (m)	-0.62 to 0.62	-3.50 to 3.50	± 3.70
Area (m ²)	1.5	37	6
Acceptance	$ \eta < 1.9$	$ \eta < 2$	$2 < \eta < 4$
Granularity (mm ²)	1 × 1	5 × 5	1 × 1 to 5 × 5
Hit rate (kHz/cm ²)	200	15	280
Material thickness (%X ₀)	1 to 3	1 to 3	1 to 3
Power density (mW/cm ²)	50	50	50
Time resolution (ps)	20	20	20

AC-LGAD introduction

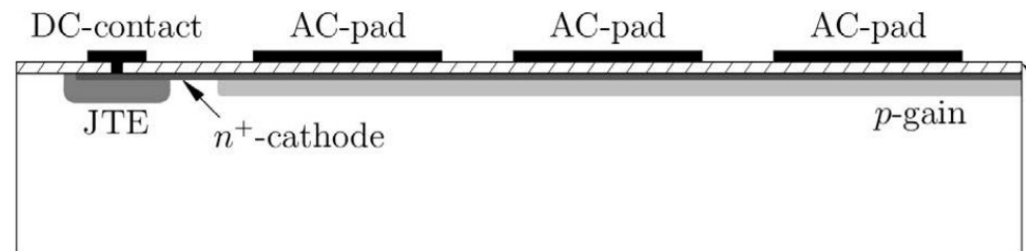
DC-LGAD

1. use DC-coupled readout method, has a thin doped gain layer
2. advantages:
 - amplified signal->good time resolution ~ 35ps
3. disadvantages:
 - dead areas: JTE, P-stop
 - spatial resolution restricted by sensor size



AC-LGAD

1. based on LGAD, but use AC-coupled readout method
2. advantages
 - **good time resolution** inherited from DC-LGAD
 - signal is related to particle injection position, possible to get **a better spatial resolution**
 - no dead areas, a continuous gain implant is used to achieve **100% fill factor**

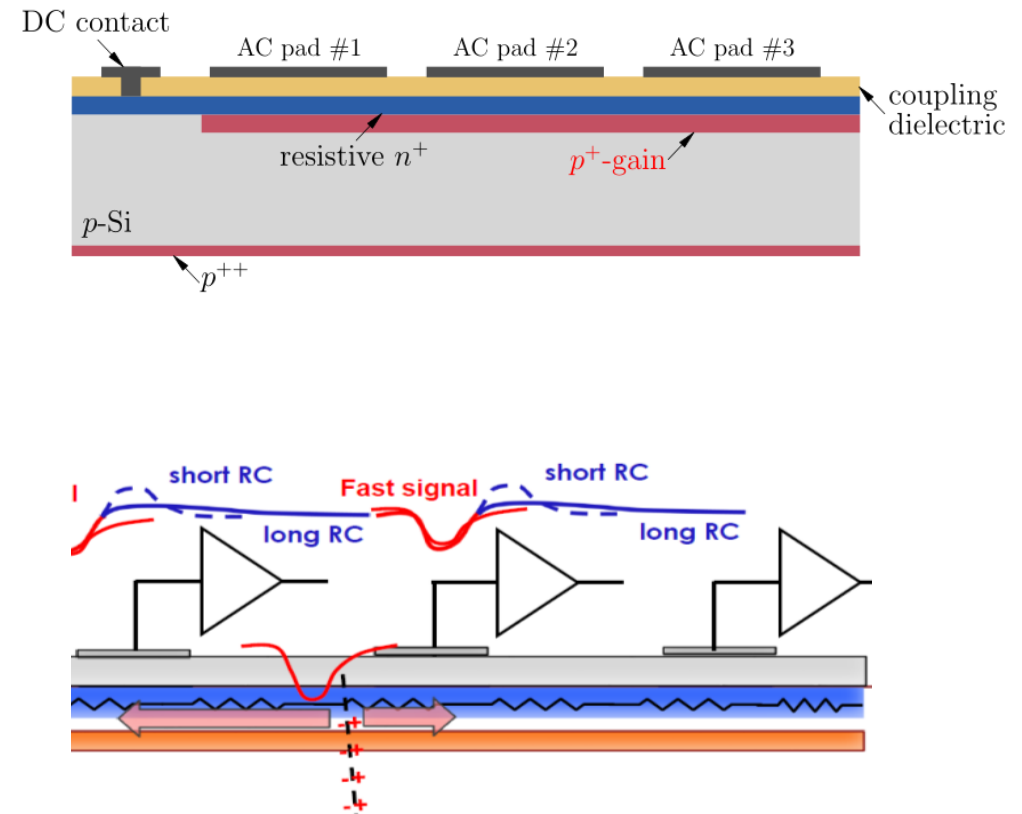


AC-LGAD introduction

➤ Signal formation

1. When there is particle incidence, the secondary charges drift towards their respective electrodes
2. The **secondary electrons** experience a certain sheet resistance in their path towards the DC contact.
3. The **secondary holes** drift towards the p^{++} layer and this process **induces signal** on a cluster of AC pads via the coupling dielectric. The signal on AC electrodes discharges to ground. So the signal generated in AC-LGAD is **bipolar**.

➤ The fast induced signal can be used to reconstruct particle information

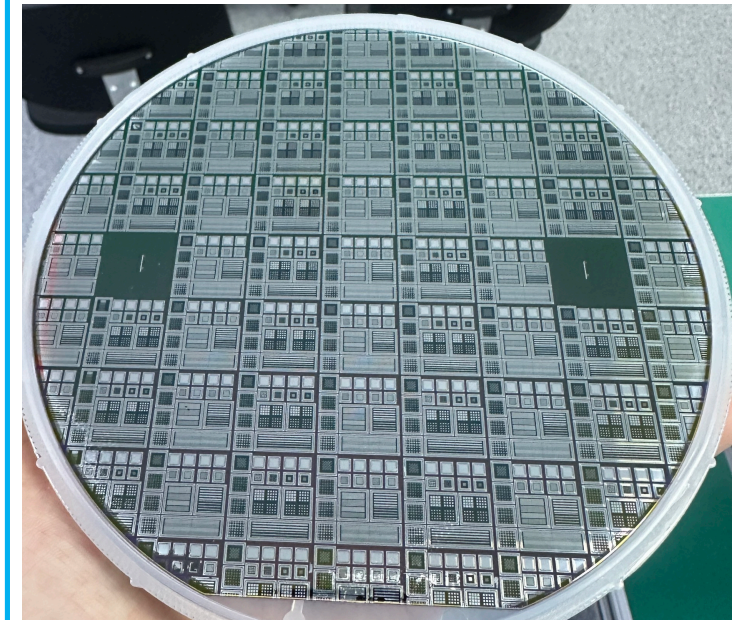
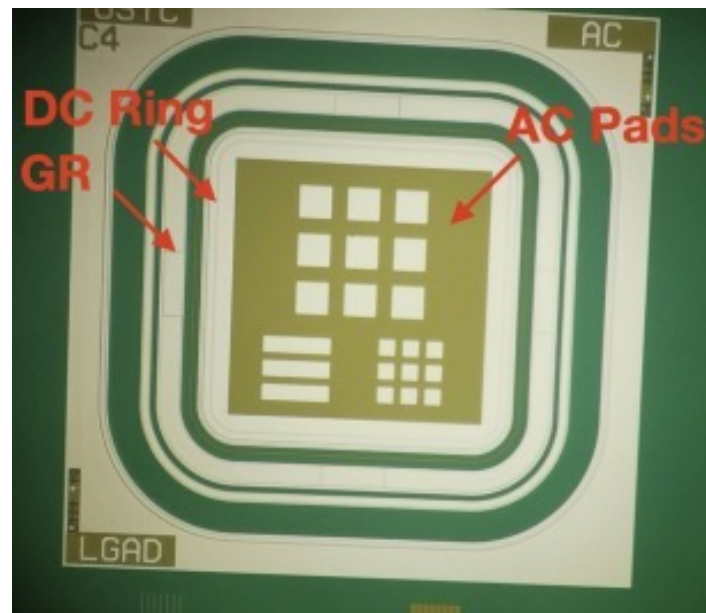


Timeline of USTC AC-LGAD production

- [The first batch of sensor](#) fabricated in 2021 and validated the feasibility of fabrication at USTC center for Micro- and Nanoscale research fabrication (NRFC).
- The preparation for the second batch of AC-LGAD sensor production began in 2024 and completed in July 2025.



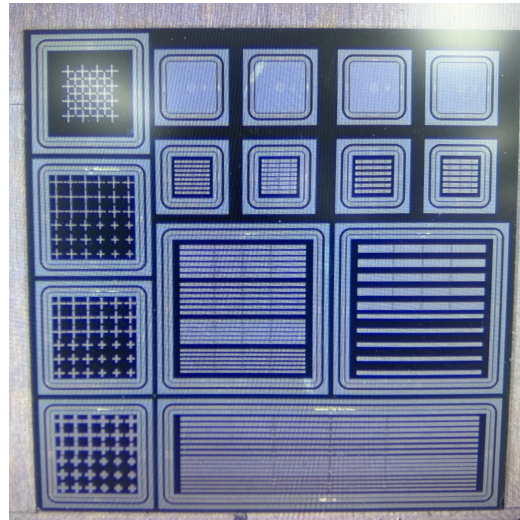
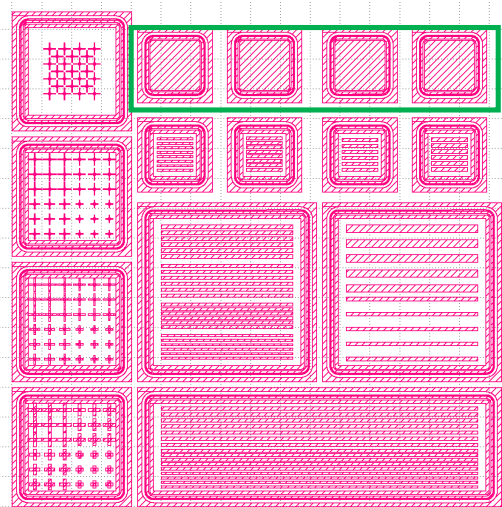
1st batch



2nd batch

AC-LGAD design on 2nd batch

- Sensor thickness
 - 50 μm $\rightarrow$ 35 μm
 - Short drift distance of charge carriers (electrons/holes), faster collection time, and better time resolution
- Doping concentration
 - N+ dose $\rightarrow$ signal sharing
 - P-well dose $\rightarrow$ gain
- Electrode layout



wafer #	n-plus dose	p-gain dose	substrate
1	A	low	35um
2	B	low	35um
3	A	middle	35um
4	B	middle	35um
5	A	high	35um
6	B	high	35um

Strip (1,5,10 mm length)	Pitch	Metal width
	150	70/100
	200	100/125
	500	125/250

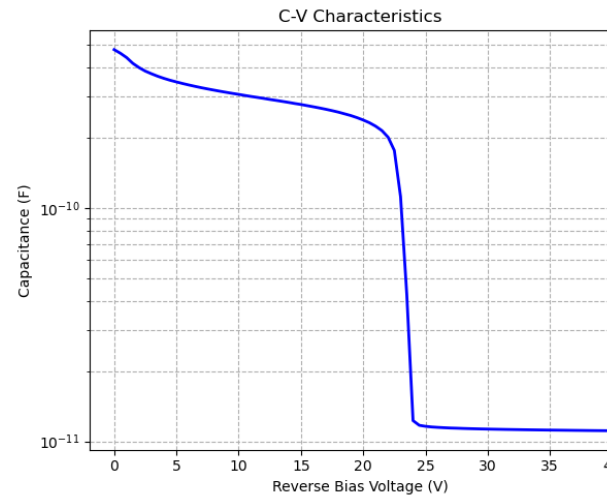
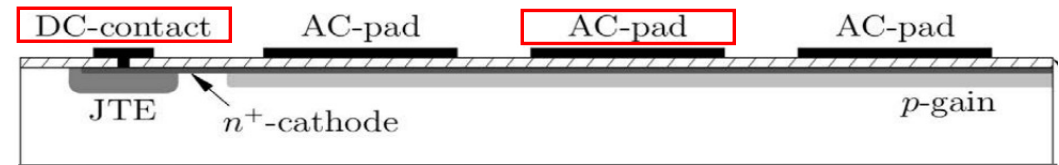
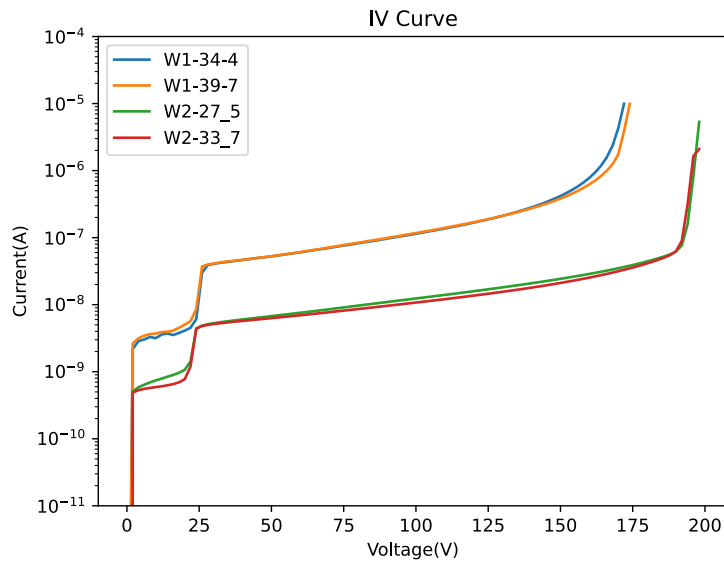
Pixel	Pitch	Metal width
	150	75/100
	300	100/200
	500	200/300/400

Cross	Pitch	Width	Metal length
	500	25	250/350/400/460
	500	50	250/350/400/460
	500	100	250/350/400/460

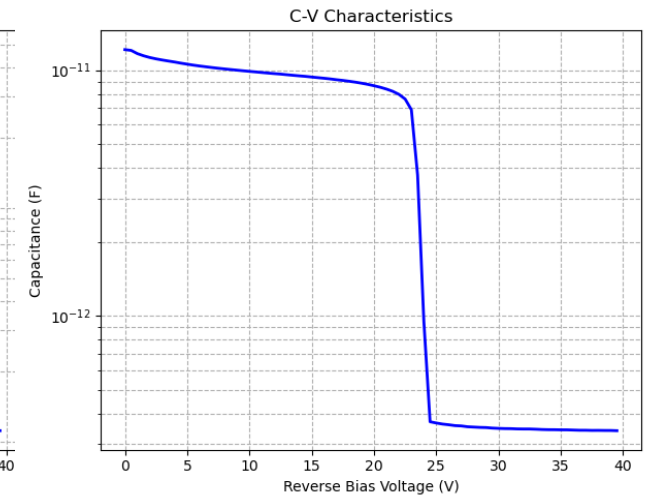
- Production has been completed and preliminary performance tests have been performed on the sensors from W1 and W2.

Static characteristics

- The IV of sensors on the same wafer shows **consistency**. The difference in IV curves between W1 and W2 is caused by the difference in n^+ layer implantation concentration.
- The DC-contact capacitance represents the capacitance of the entire gain region.
- AC electrodes have smaller capacitance, which means the signal has a **faster rise time**.



DC-contact capacitance

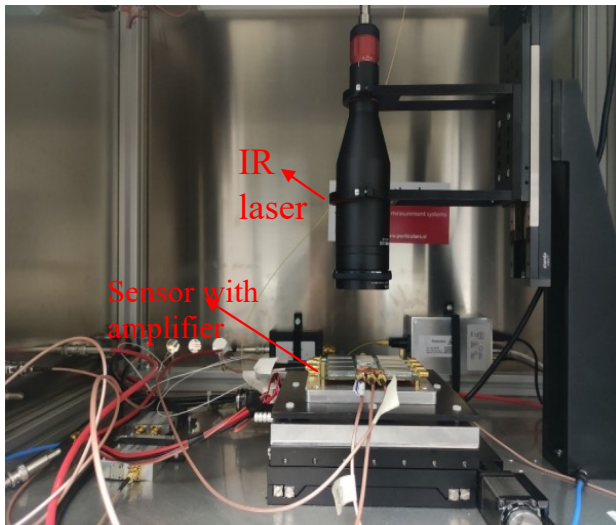


Pixel capacitance

Type	Electrode area(μm^2)	Depletion capacitance(pF)
Strip	70*1200	1.47
Strip	125*1200	2.10
Pixel	100*100	0.20
Pixel	200*200	0.34

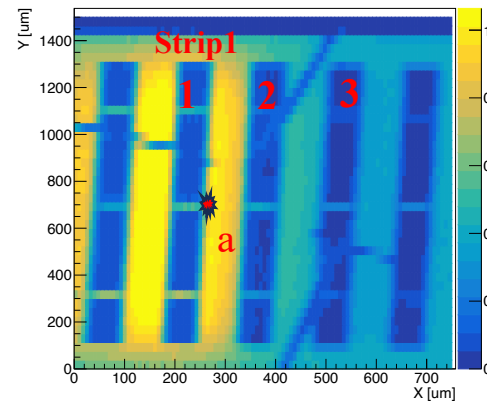
Signal response to infrared lasers

- To stimulate the production of AC signal from detectors, the IR laser of the Transient Current Technique (TCT) was set up.

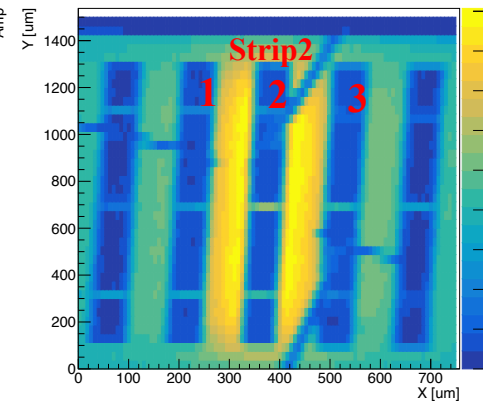
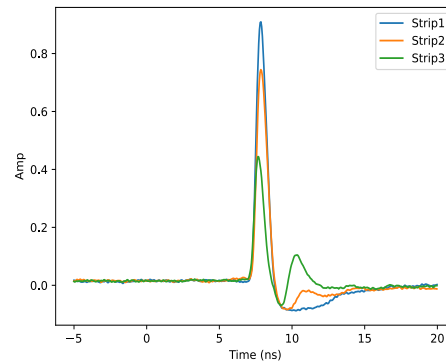


➤ 2D scan for W2 70/150 strip

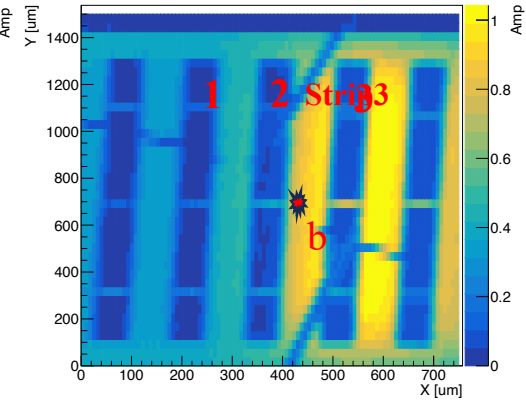
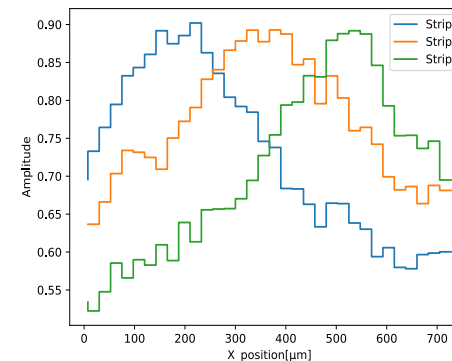
- XY: laser incidence position
- Z: signal peak amplitude



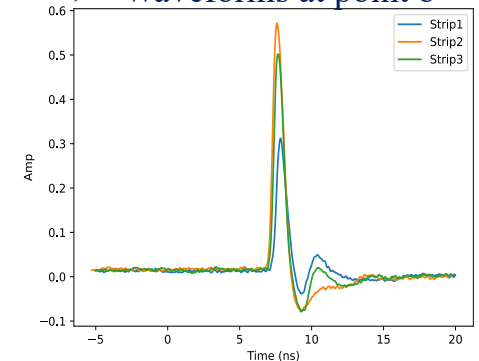
➤ Waveforms at point a



➤ 1D profile



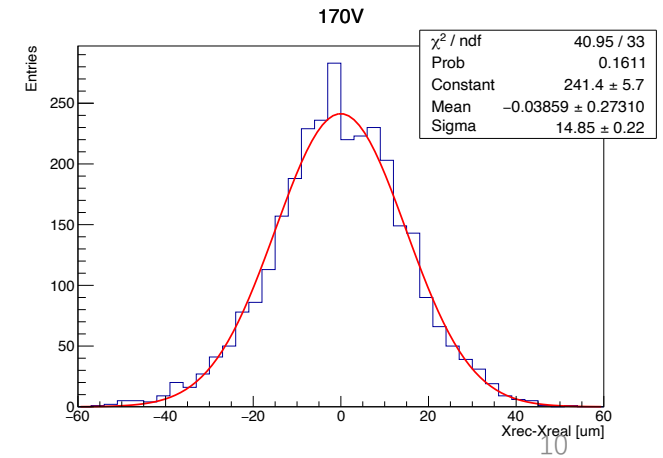
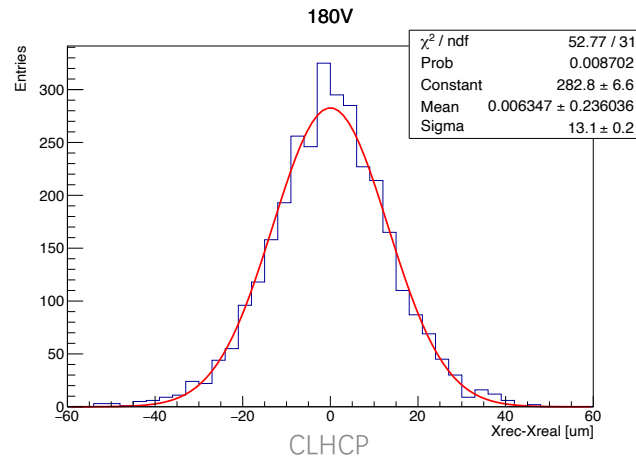
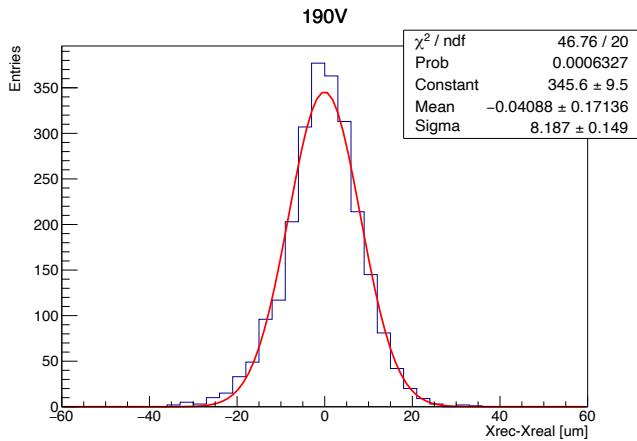
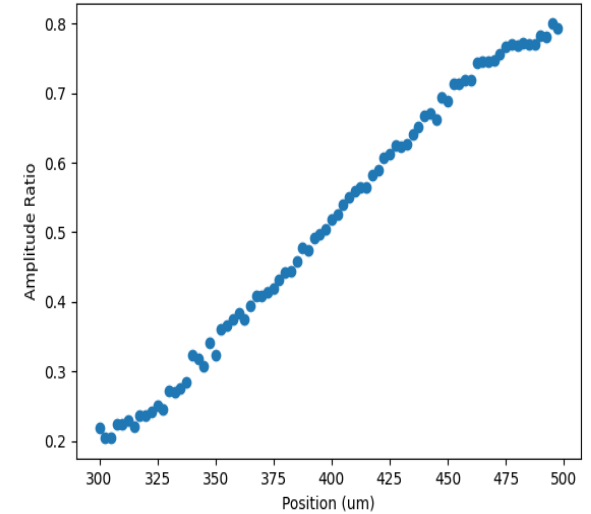
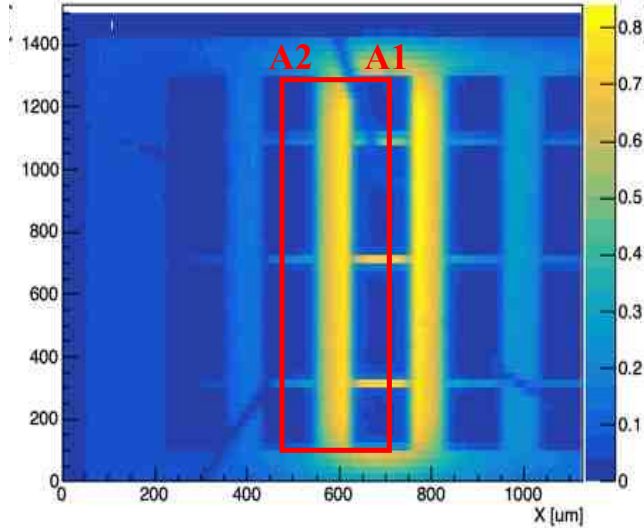
➤ Waveforms at point b



- As shown in the figures, the coupled signal is closely related to the position of the laser injection.

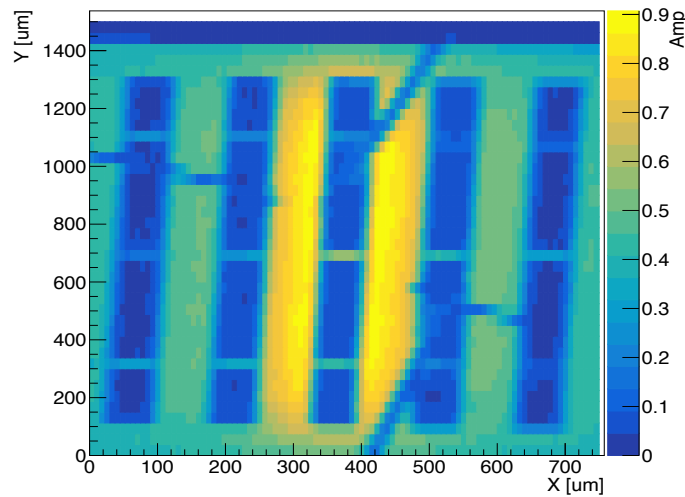
Spatial resolution with infra-red laser

- DUT:
 - USTC-V2 AC-LGAD W1-D1-P8
 - Electrode 125/200 μm
 - Bias voltage: 170/180/190 V
 - Room temperature
- Amplitude ratio method for reconstruction
 - $Ratio = \frac{A_1}{A_1 + A_2}$
 - Scanned region: btw centers of strip 1, 2
 - Straight line to relate Ratio and Position
 - $\sigma_x = 8.2\mu\text{m}$ for 200 μm pitch strip @190V

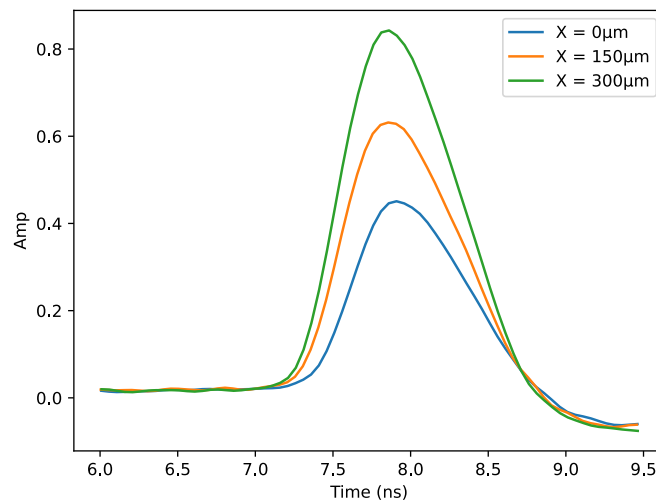


Time-delay

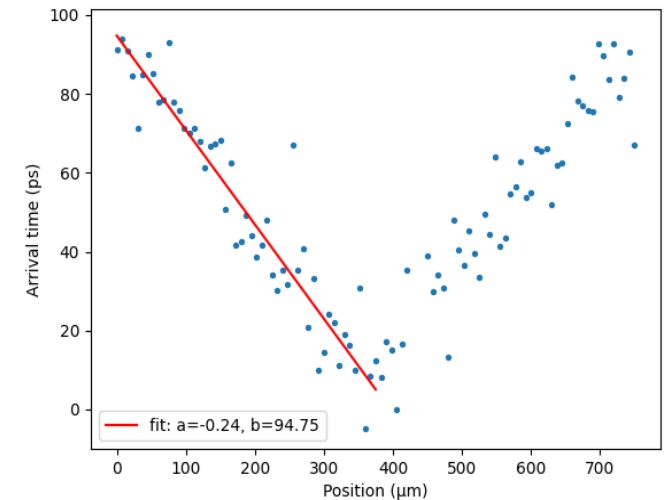
- Not only the signal amplitude, but also the signal arrival time is related to the incident position
- The farther the incident position is from the electrode, the later the signal arrives
- For W2, laser test shows that the time-delay constant is 0.24 ps/ μm



2D scan map for middle strip



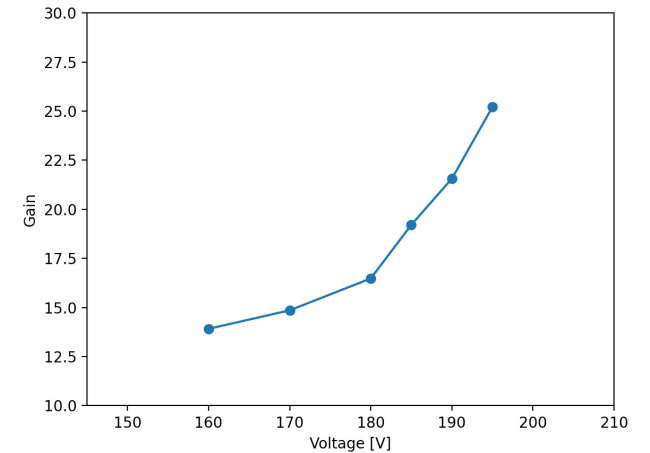
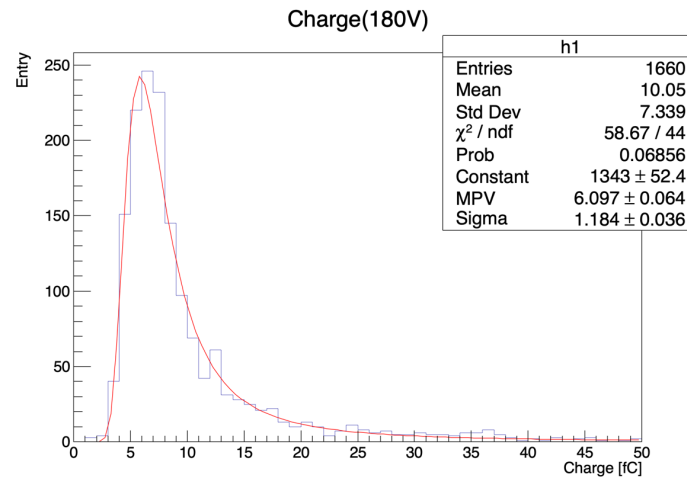
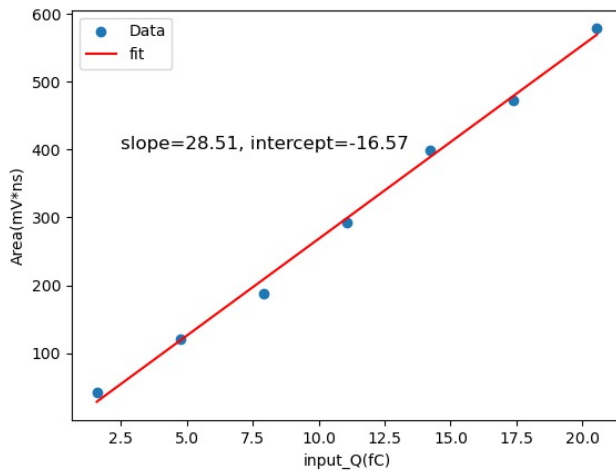
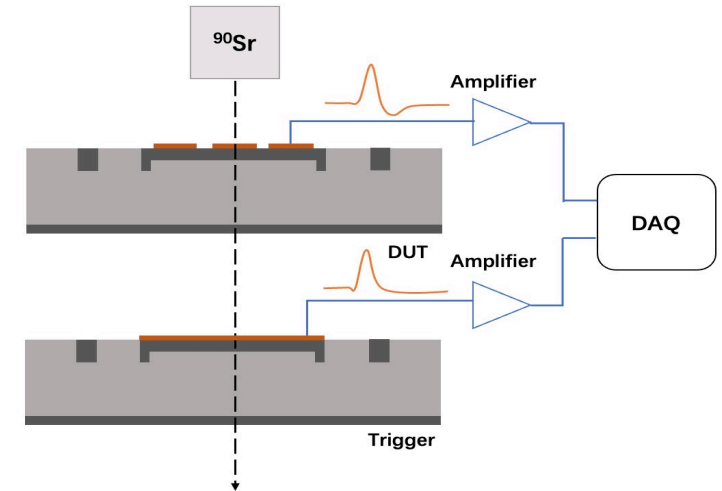
Average waveforms along the x direction



Relationship between T_{CFD} and position

Gain from Sr-90 electrons

- DUT: W2-D32-P5, DC-ring signal
- USTC amplifier board, calibration coefficient is 28.51 mV*ns/fC
- Threshold: 70 mV
- Temperature: 20 deg C
- E_{loss} without gain estimated for 35 $\mu\text{m} \sim 8.34\text{KeV} \sim 0.37\text{ fC}$



Time resolution with Sr-90 at 20 deg C

Reference:

- 20 deg 165V 42.29 ps

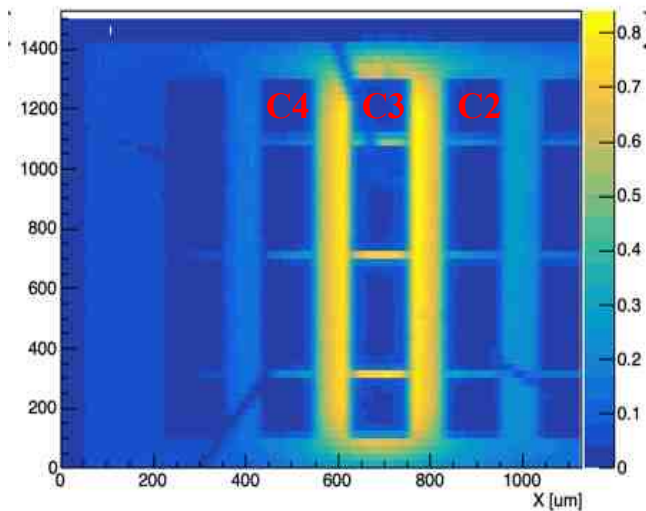
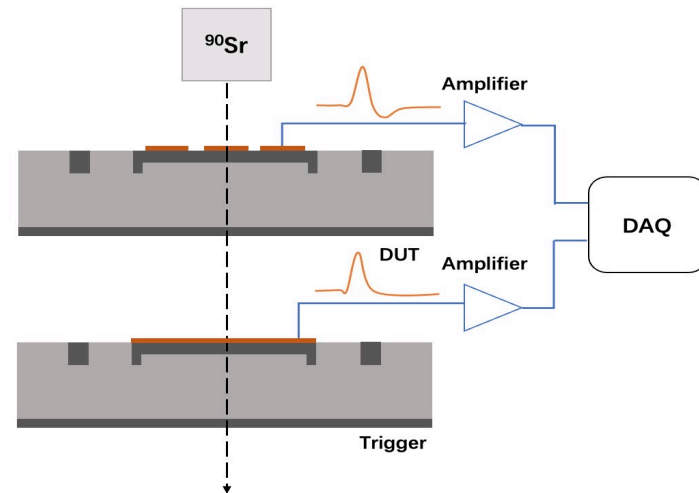
DUT:

- USTCV2 AC-LGAD W2-D32-P5
- Electrode 70/150 μm
- Bias voltage: 205V@20 deg C
- C2,C3(middle strip),C4

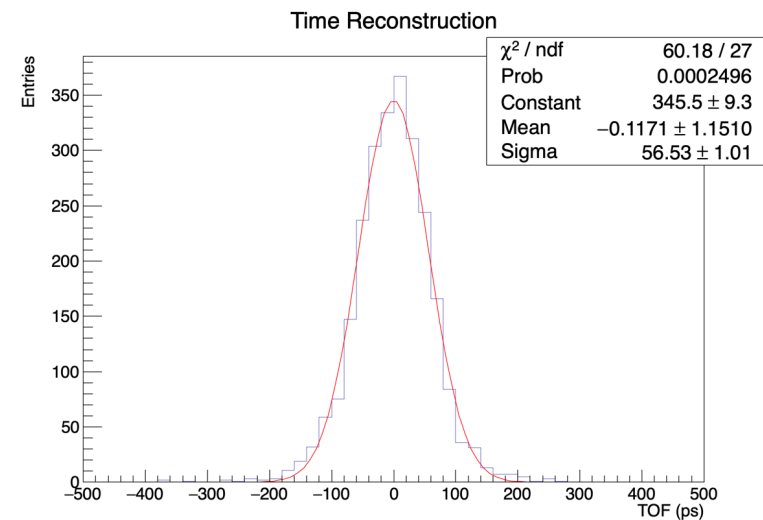
Arrival time

- C3 for time reconstruction
- $A3 > A4$ and $A3 > A2$. Select incidence near the middle electrode

Time resolution: 36.35ps

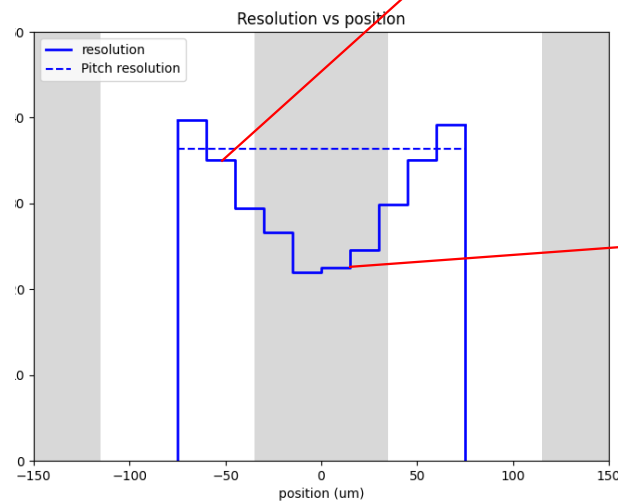
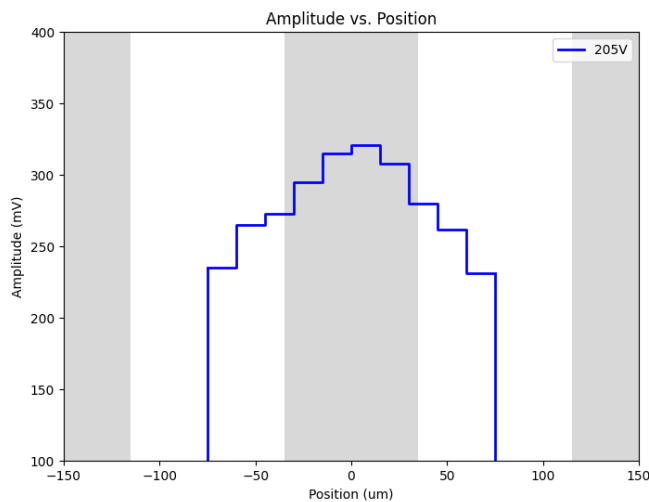


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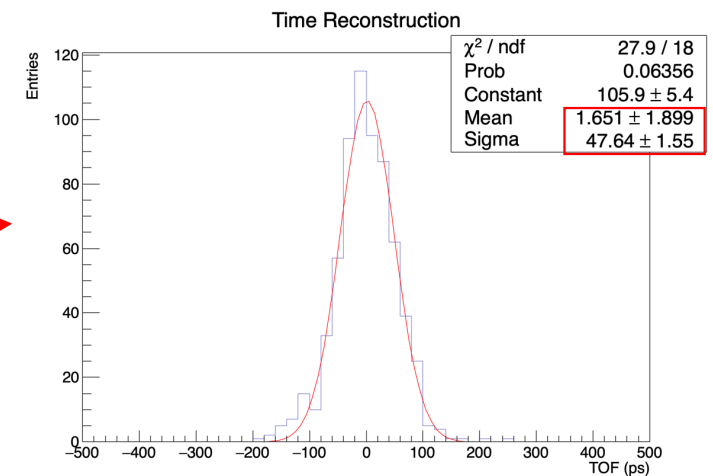
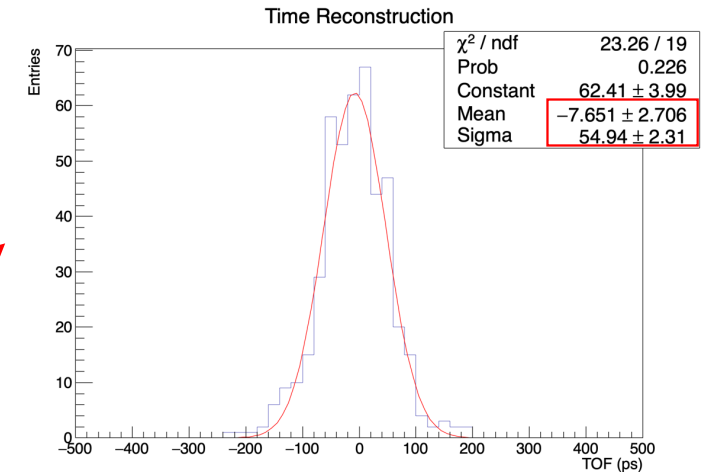


Position dependence-time resolution

- DUT:
 - USTCV2 AC-LGAD W2-D32-P5 205V@20 deg C
 - Sr-90 test
- Using the ratio of amplitudes to divide a pitch into multiple bins
- For AC-LGAD, the time resolution and position are related
 - Signal sharing: Amp vs Position
 - Time delay: Mean (T_{TOF}) vs Position
- The closer to the center of the electrode, the better the time resolution, preferably up to **21.9 ps**

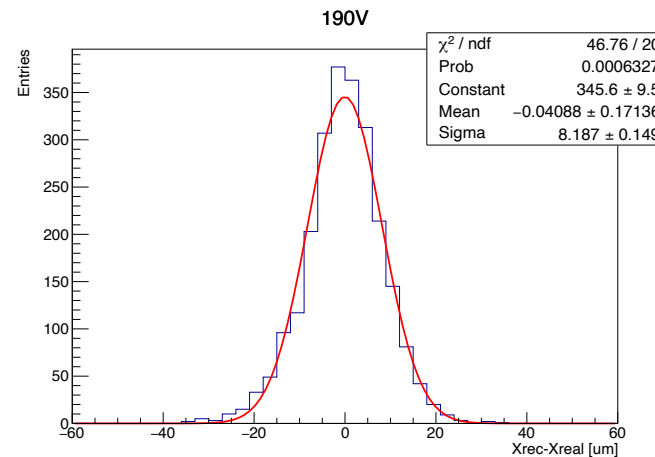
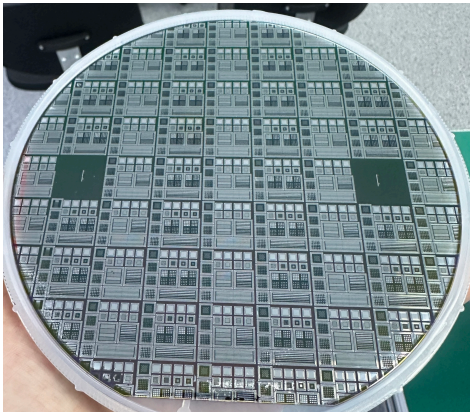


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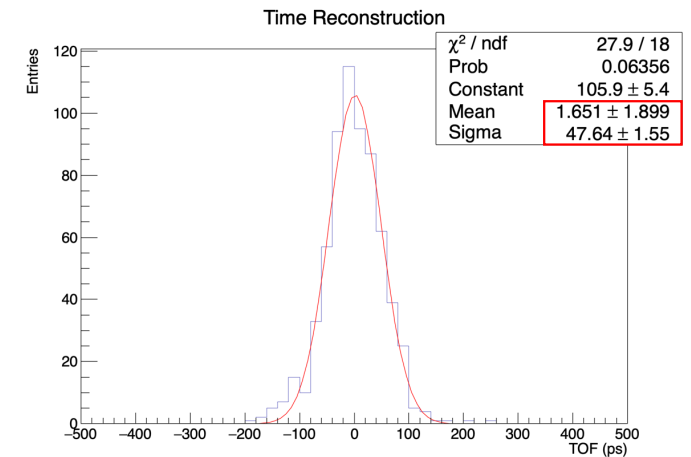


Summary

- The second batch optimized the **sensitive thickness, doping concentration, and electrode design**, and completed production
- The IV and CV test on the probe station showed good consistency, reflecting the consistency during production.
- Preliminary research has been performed on the performance of this batch sensor. More systematic testing will be performed in the future to figure out the impact of different concentration and electrodes on performance.
 - A 200 μm -pitch strip matrix with 125 μm pad side, has concurrently shown $\sigma_x=8.2 \mu\text{m}$.
 - For 70/150 μm strip sensor, The average time resolution within the entire pitch is **36.35 ps**. For events located directly below the electrode, the time resolution can reach **21.9 ps**.



CLHCP



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Thanks for your attention!