First results of USTC AC-coupled LGAD

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Outline

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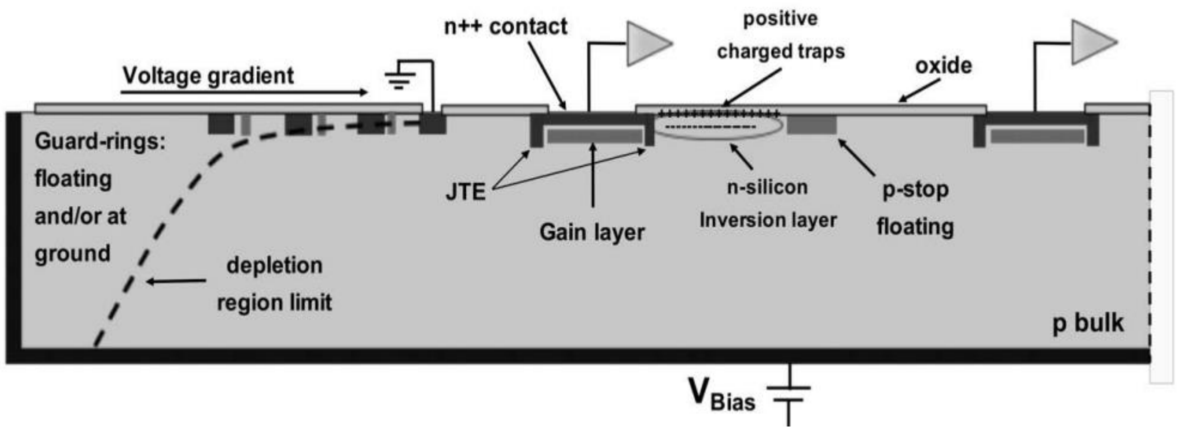
- Production of USTC AC-LGAD
  - Static characterization
  - Signal characterization
- Performance of USTC AC-LGAD
  - Spatial resolution
  - Time resolution
- Future design optimization of AC-LGAD
- Summary

Introduction

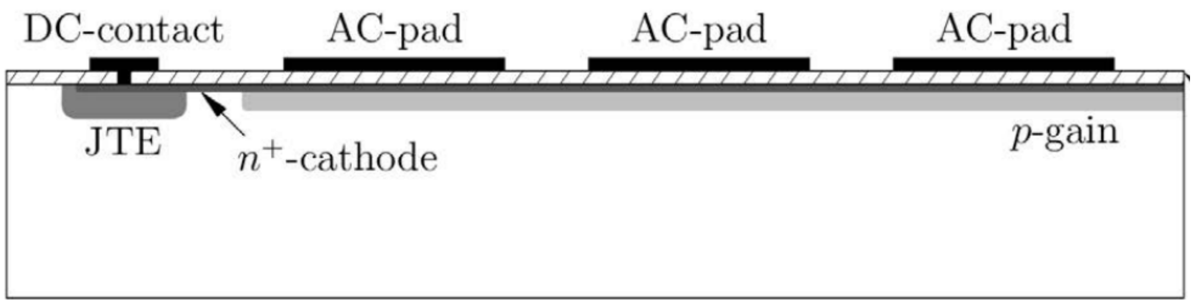
DC-LGAD

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

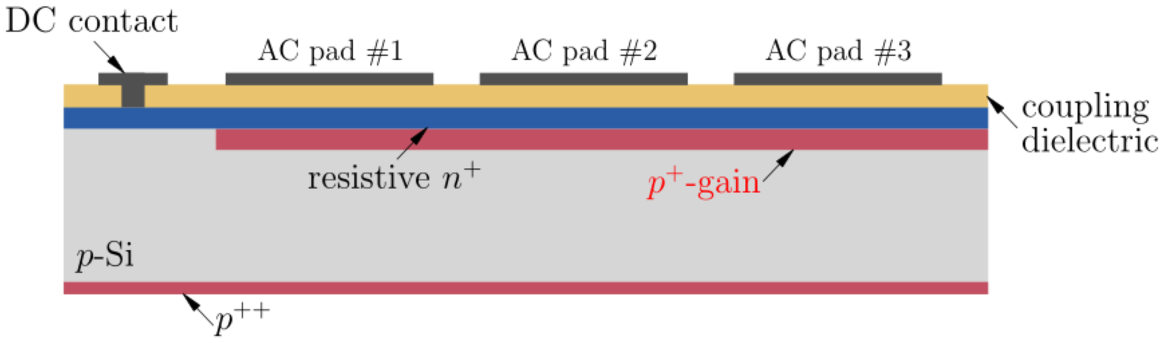
1. based on LGAD, but use AC-coupled readout method
2. advantages
   - good time resolution inherited from DC-LGAD
   - signal is related to particle injection position, possible to get a better spatial resolution
   - no dead areas, a continuous gain implant is used to achieve 100% fill factor



Introduction

Signal formation

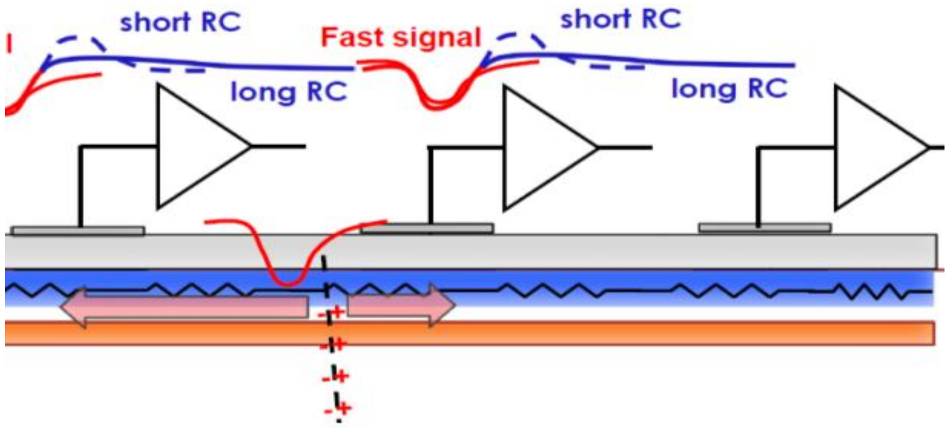
1. When there is particle incidence, the secondary charges drift towards their respective electrodes
2. The multiplied electrons experience a certain sheet resistance in their path towards the DC contact. The signal is capacitively induced on a cluster of AC pads via the coupling dielectric.
3. The signal on AC electrodes discharges to ground. So the signal generated in AC-LGAD is bipolar.



AC-LGAD parameters

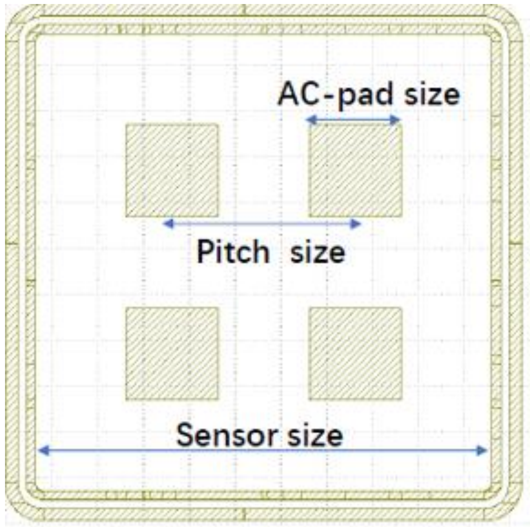
- n+ layer doping concentration → R
- dielectric material and thickness → C
- geometrical configuration(e.g., pad size and pitch size)

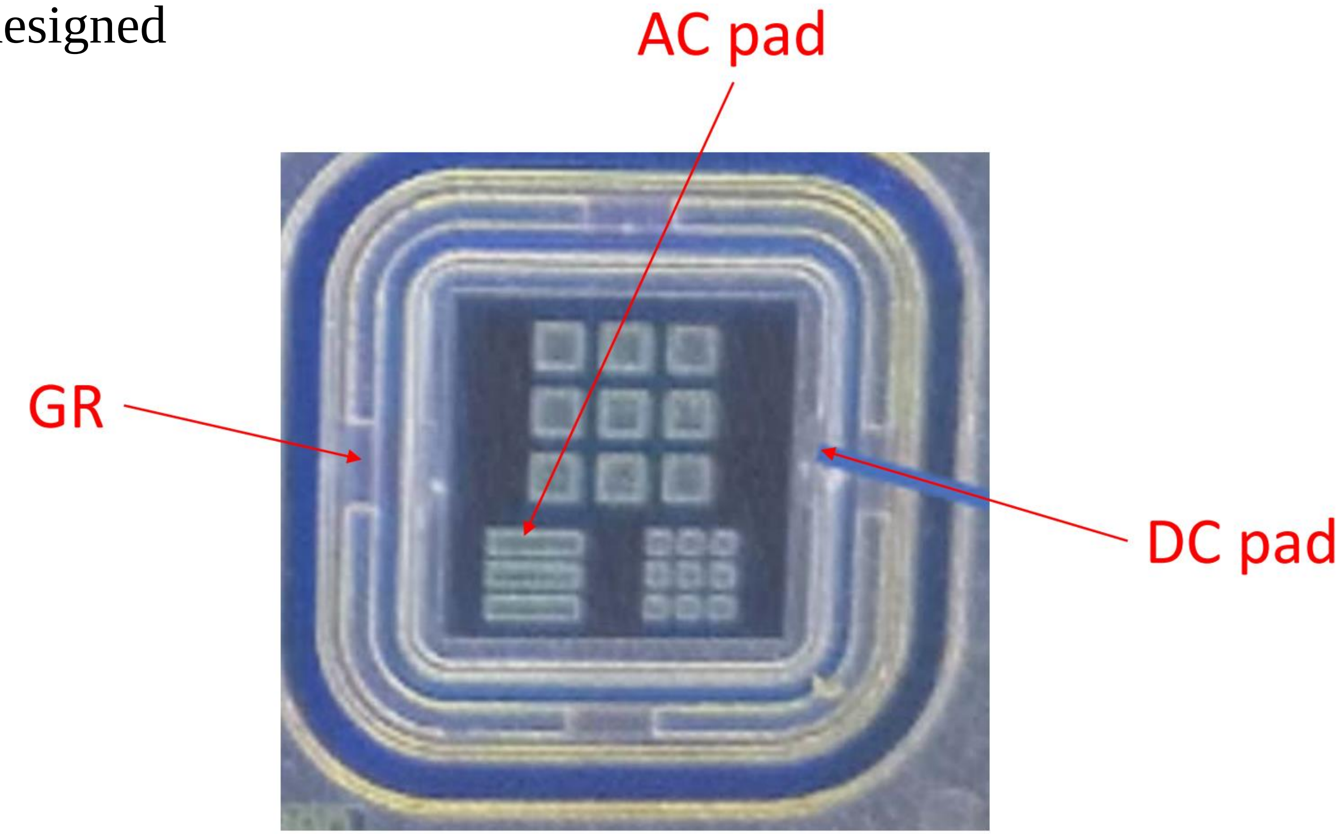
These parameters should be considered and set during the design of AC-LGAD sensors.



NRFC-USTC AC-LGAD

- Two wafers with different n+ dose were designed and fabricated
- Wafer with different n+ dose
  - W5 high n+ dose
  - W6 low n+ dose
- Sensor size : 1300*1300*50 μm
- Sensor with different pad-pitch size
  - Large pad size/pitch: 100/150 μm
  - Small pad (Strip) size/pitch: 50/75 μm

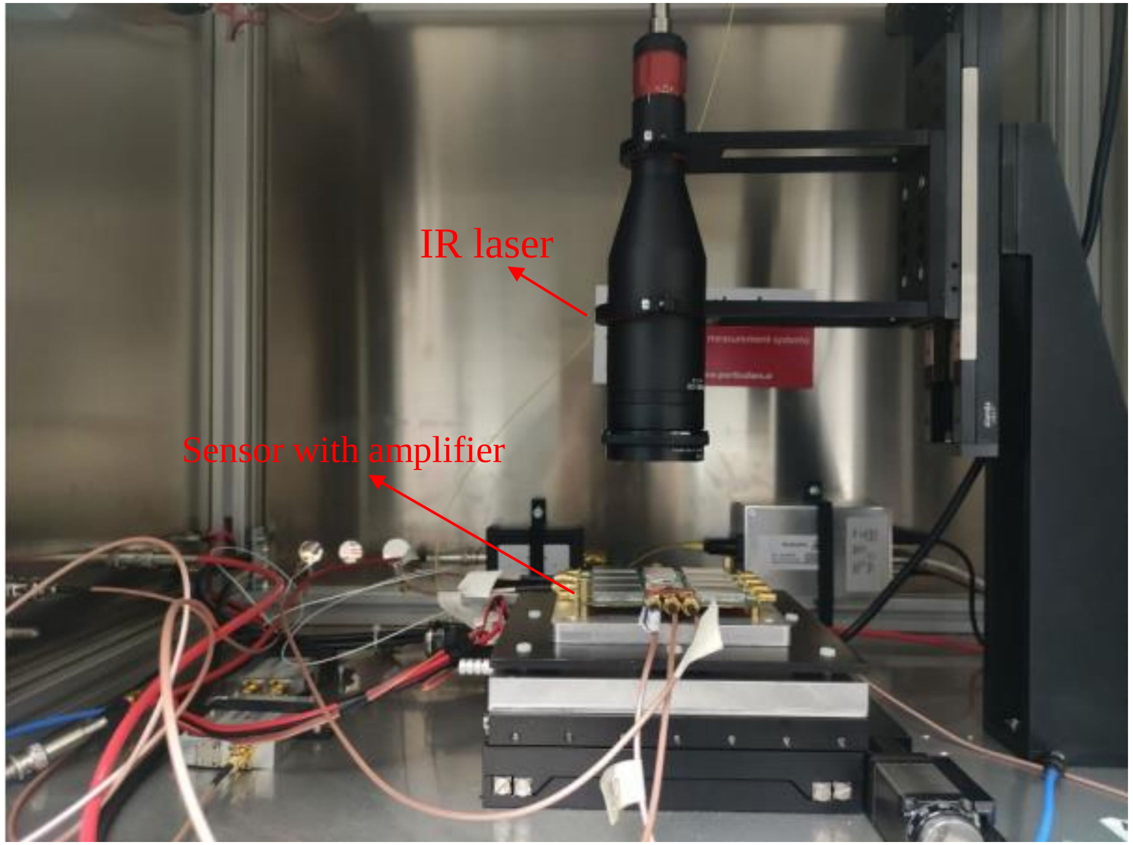




Signal response

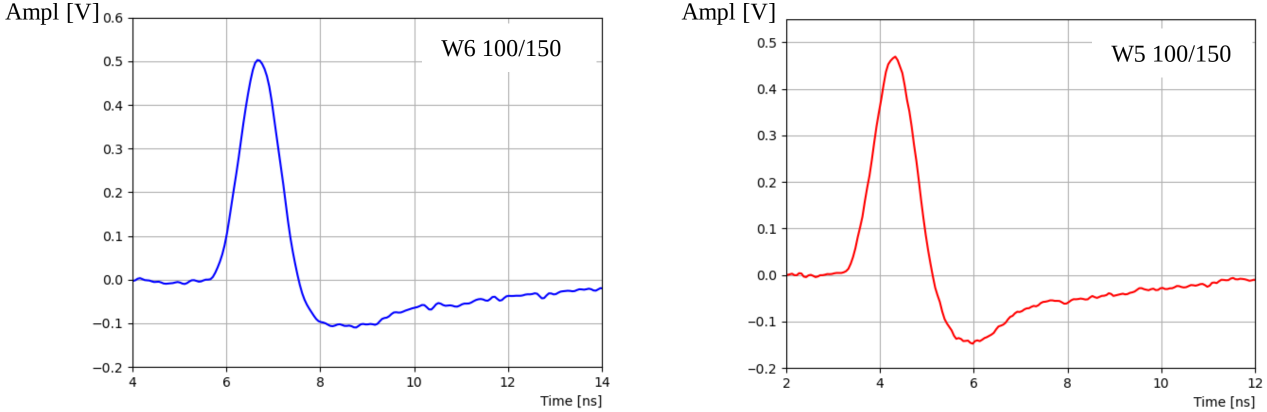
To stimulate the production of secondary charges and readout an AC signal from detectors, we set up the IR laser of the Transient Current Technique (TCT) at USTC.

- Set up for testing
- 3D X-Y-Z stage platform
    - Position resolution: <1μm
- Laser
    - Wavelength: 1064 nm
    - Focusing with the lens group
    - Beam spot: <10um@1064nm
- DUT
    - Sensor: NRFC W5/W6 AC-LGAD
    - USTC 9-channel amplifier
- Trigger: Laser sync pulse
- Oscilloscope
    - Sampling rate: 20 Gs/s
    - Bandwidth: 1 GHz



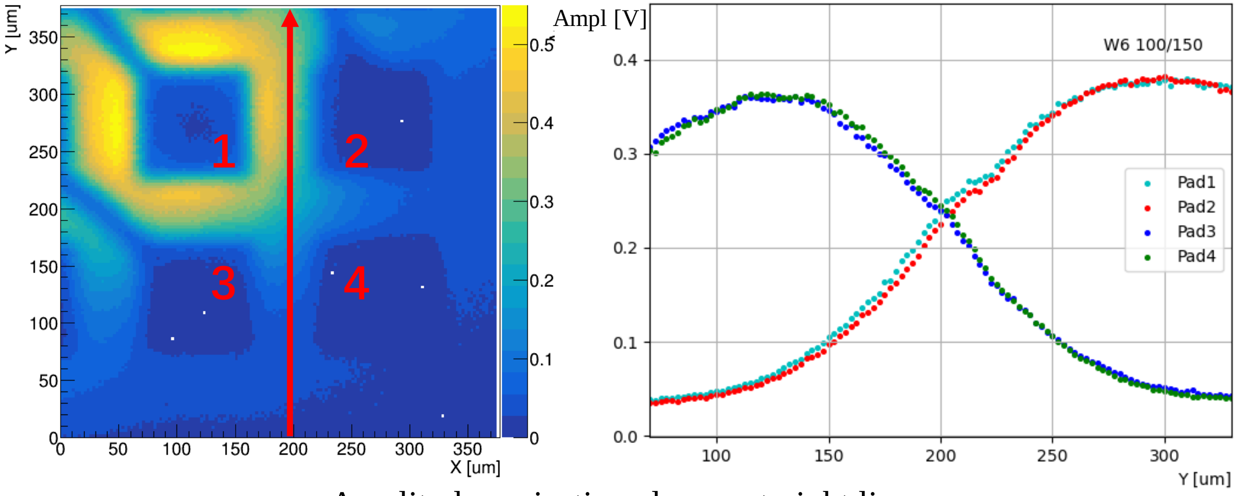
Signal characterization

- Signals acquired with the TCT



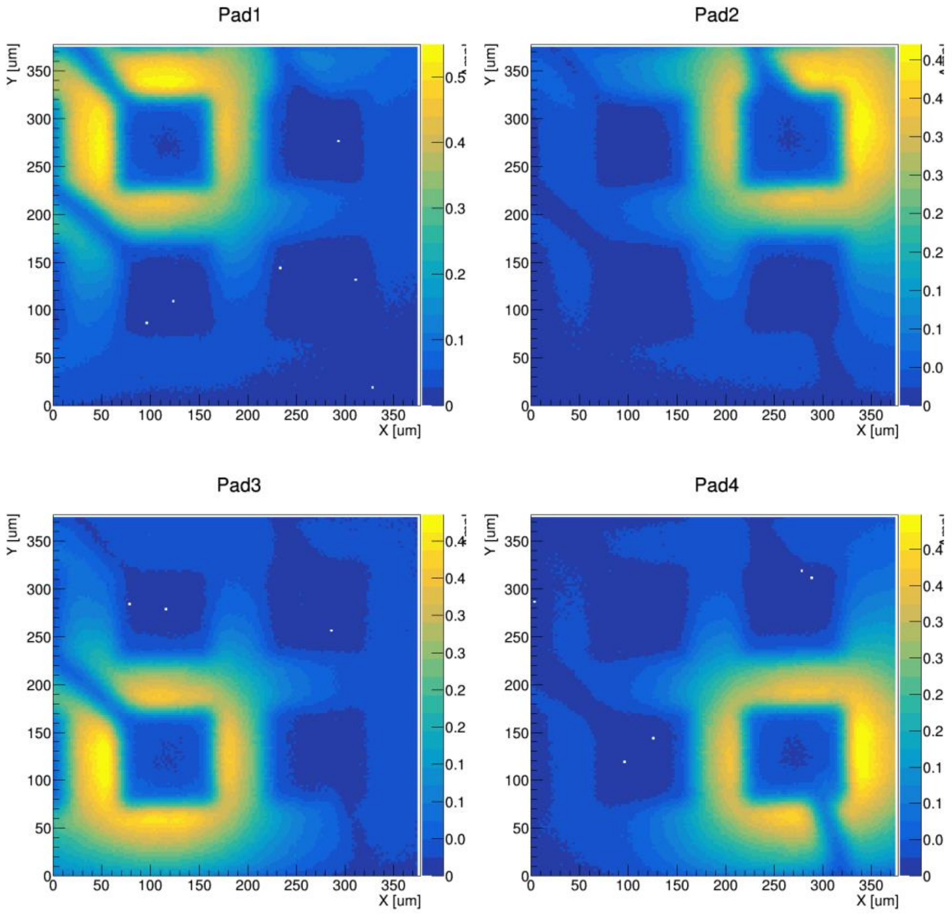
Waveforms acquired from W5 and W6

- 1D profile



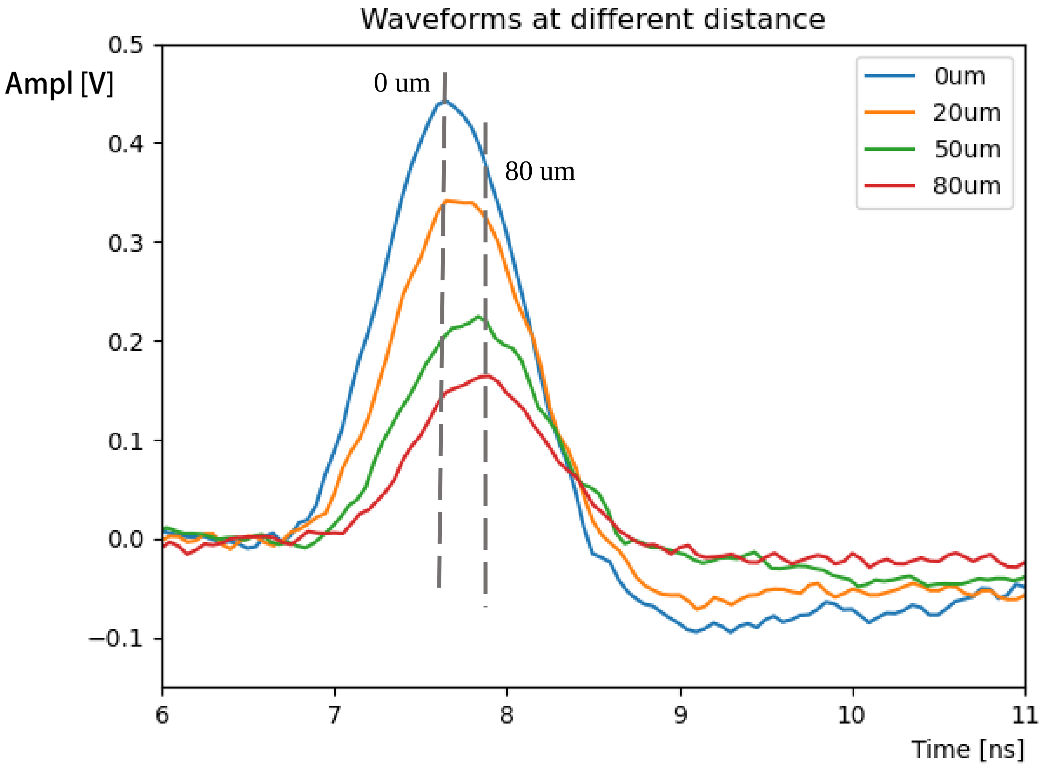
Amplitude projection along a straight line

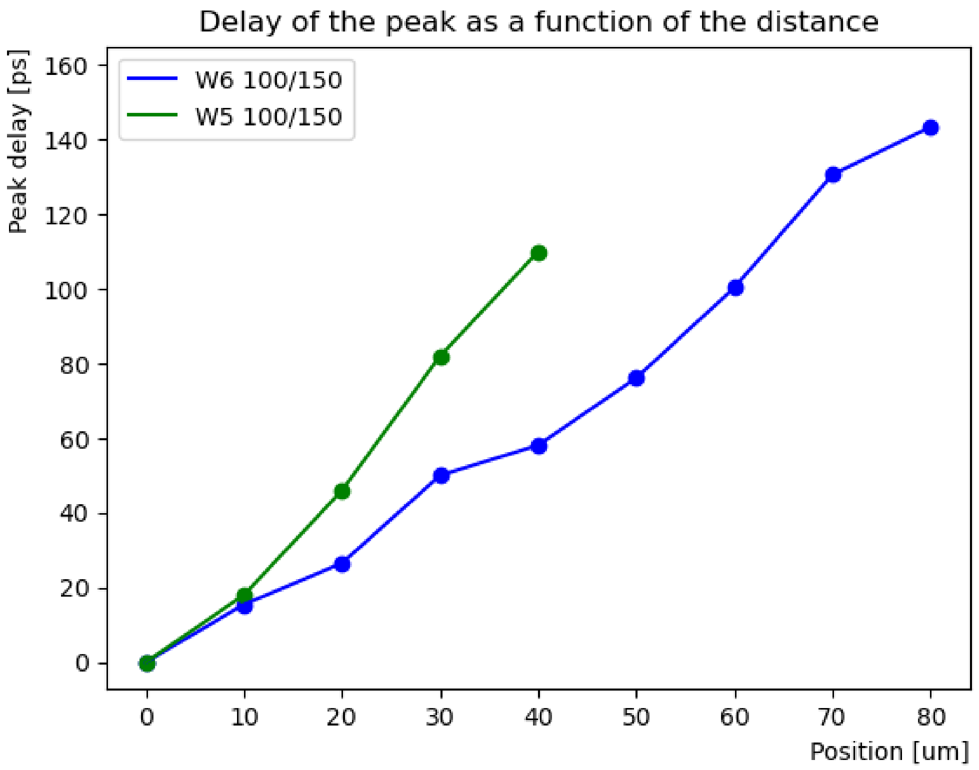
- 2D scan for W6 100/150 pads
  - XY: laser incidence position
  - Z: signal peak amplitude



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

Time delay



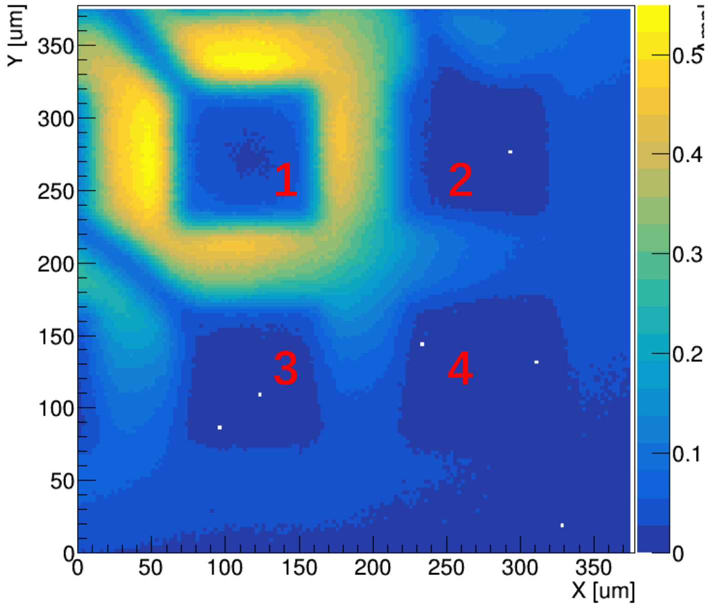


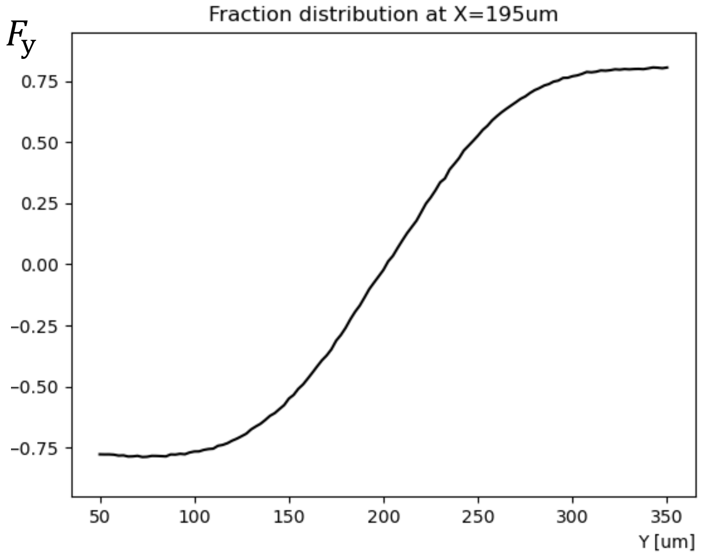
- Since the n+ layer is resistive, there is a delay in the arrival time of the signal which is function of the distance between the hit point and the surrounding pads.
- Slope : W5 = 2.547ps/μm W6 = 1.922 ps/μm
- Since the high n+ doping concentration leading to low mobility, the time delay in W5 is more obvious.
- The delay of peak would degrade the final time resolution, so it is necessary to extract the peak delay versus position curve and apply a proper distance-dependent offset.

Position reconstruction

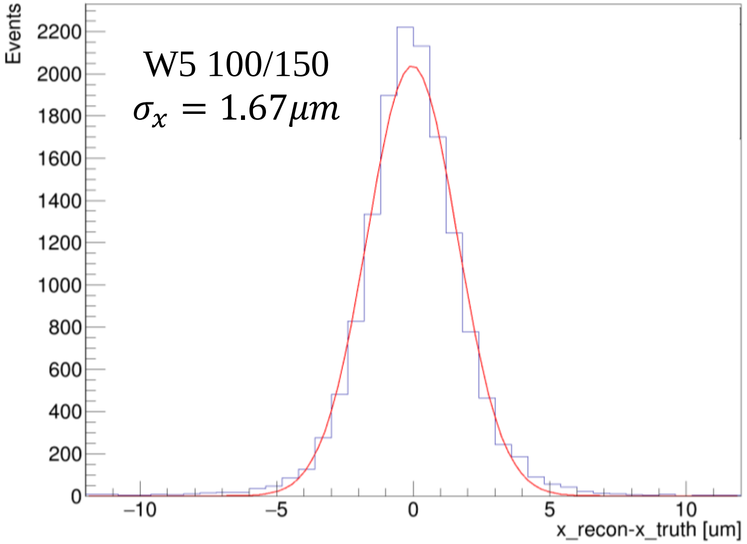
Amplitude-weighted reconstruction method

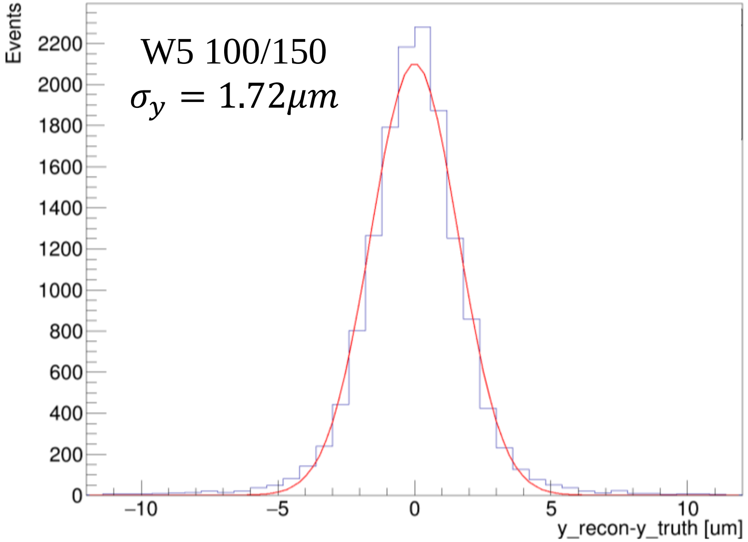
1. Select reconstruction region
   - ➢ Because the electrode will block the laser, the electrode areas need to be removed
   - ➢ Four pads all have signal
2. For each scan point, average the waveform and record the peak amplitude as $\boldsymbol{A_i}$
3. Define $F_x = \frac{A_1+A_3-A_2-A_4}{A_1+A_2+A_3+A_4}$ $F_y = \frac{A_1+A_2-A_3-A_4}{A_1+A_2+A_3+A_4}$
4. Calculate the fraction at different positions and fit with polynomial
5. Apply the polynomial function to reconstruct incident position
6. Calculate the displacement difference between the laser and the reconstruction and fit a Gaussian function to get the spatial resolution



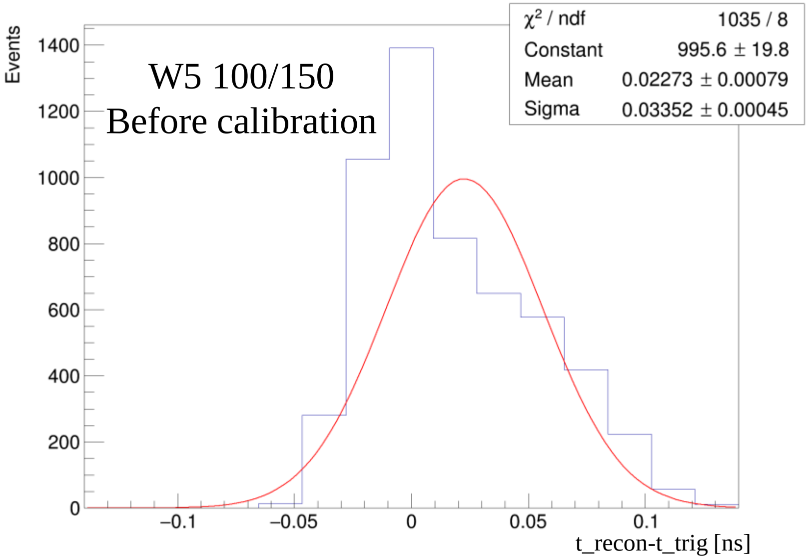


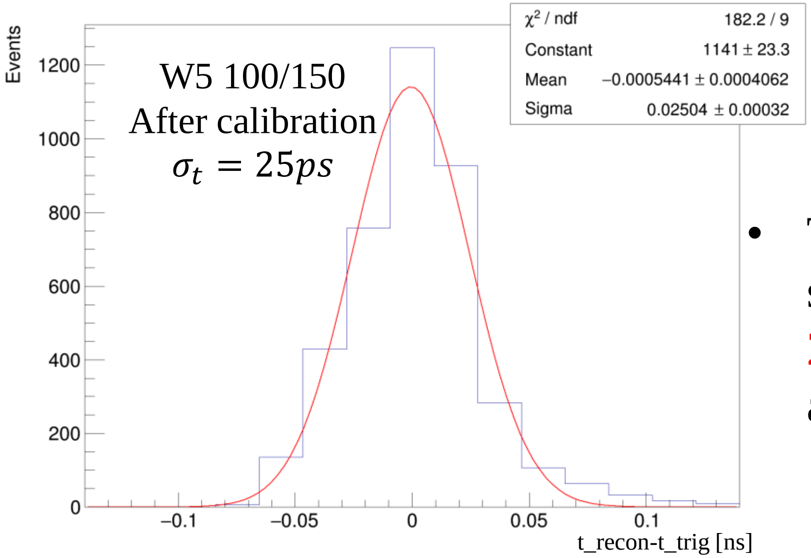
Performance





	$\sigma_x[\mu m]$	$\sigma_y[\mu m]$	$\sigma_t[ps]$
W5 100/150	1.67	1.72	25.0
W6 100/150	1.65	1.60	23.6





- The result shows that in the area where signal sharing works, a spatial resolution of 2 μm and a time resolution of 25ps can be achieved.

Design optimization of AC-LGAD

Motivation

As seen in the previous, signal sharing is related to the AC-LGAD design and depends upon the electrodes. In order to obtain a detector with better performance, a simulation tool for optimizing design is necessary

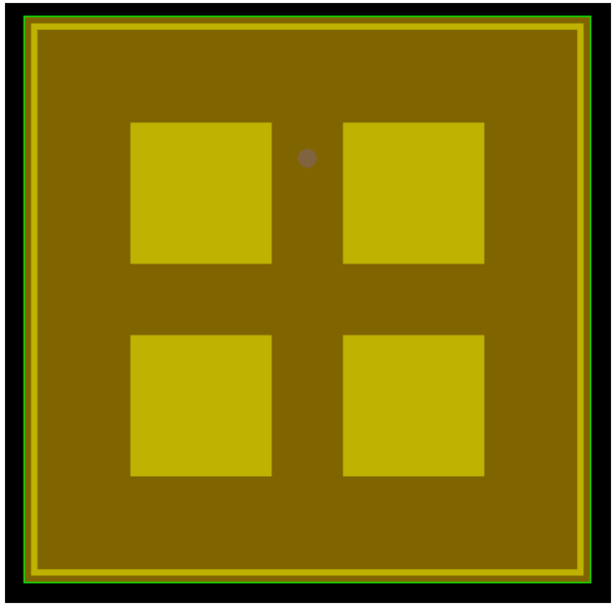
Layer Name	Type	Number	Material	Thickness	Conductivity	Permittivity
Electrode	Signal	1	cu	2.0	5.8E7	–
SiO2	Dielectric	–	sio2	0.5	–	3.7
nplus	Signal	2	nplus	2.0	1.84E6	–
psi	Dielectric	–	psi	2.0	–	9.2
Bottom	Signal	3	cu	2.0	5.8E7	–

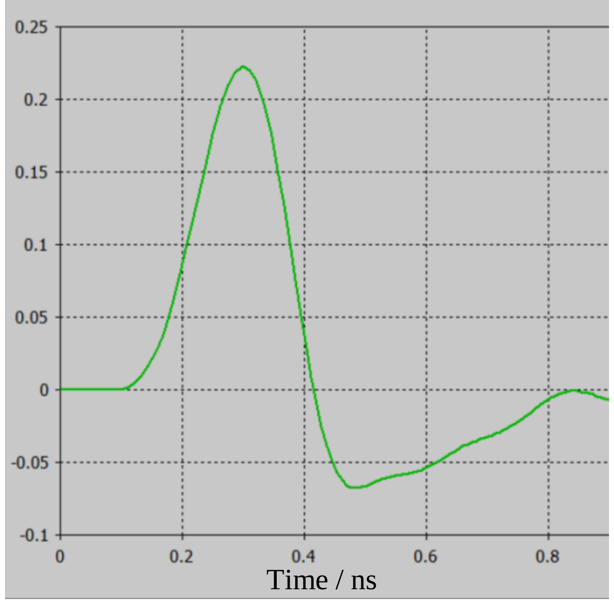
Layer stackup

Simulation

Based on a resistance network, simulate the generation of AC induction signals

1. Set materials permittivity and conductivity to simulate sensor
2. Construct electrode structure to simulate AC electrode
3. Input excitation to obtain induction signal



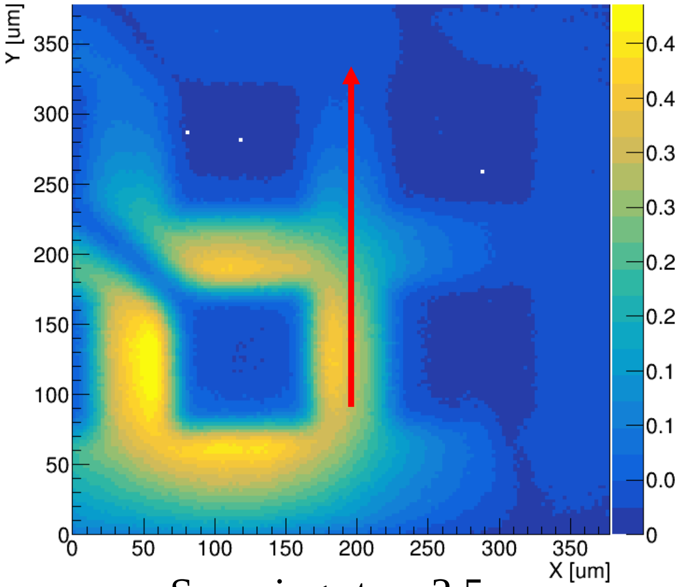


Electrode and signal in simulation

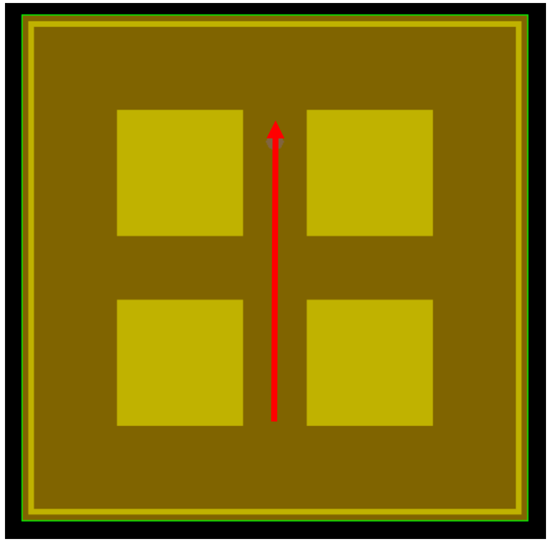
Comparison between simulation and experiment

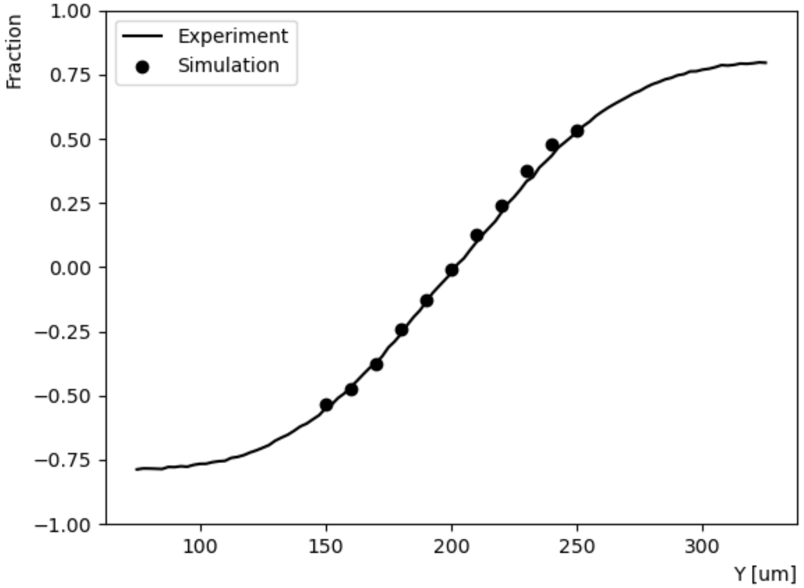
W6 pad 100/150 um

- Define $\boldsymbol{F} = \frac{A_1+A_2-A_3-A_4}{A_1+A_2+A_3+A_4}$
- A_i is the peak amplitude on the pad i
- F is the fraction defined in the y-direction position reconstruction



Scanning step: 2.5μm


Simulation step: 10μm

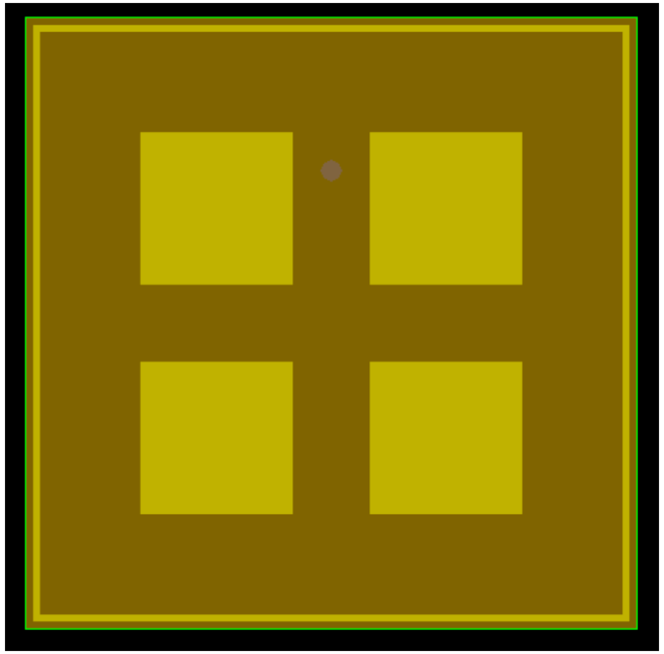


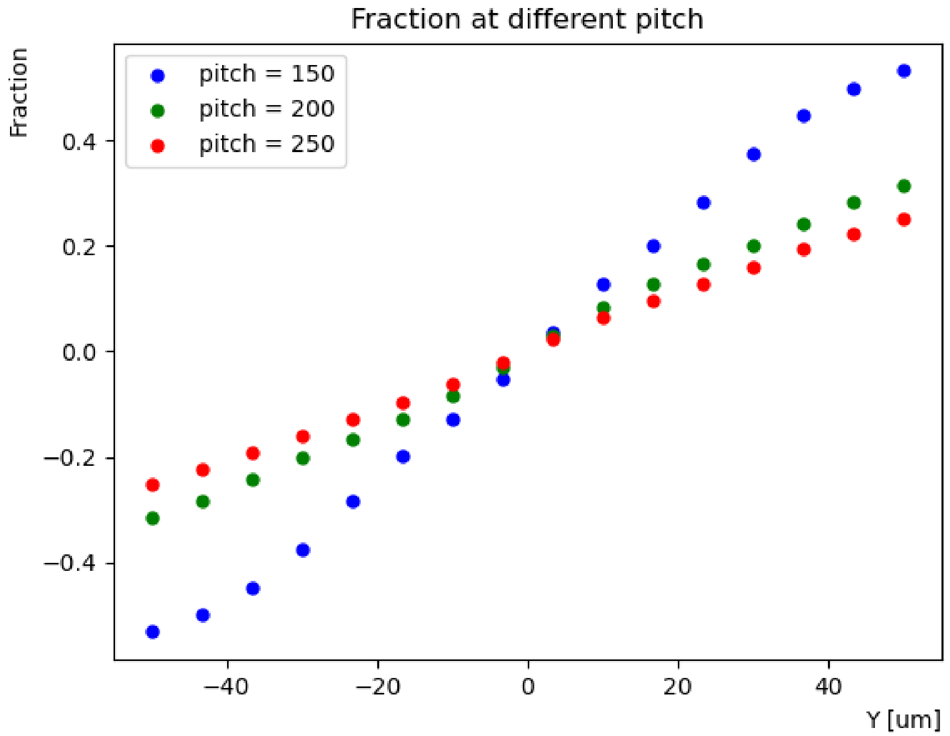
Fraction comparison at X = 195μm

The experiment and simulation are consistent in terms of signal sharing.

Optimization: Pitch size

- Simulation set up: different pitch sizes (150, 200, 250 μm)
- Using $\boldsymbol{F} = \frac{A_1+A_2-A_3-A_4}{A_1+A_2+A_3+A_4}$ to study the changing trends of resolution in different pitch size.
- Since $\boldsymbol{F}$ reflects the position information, the more sensitive $\boldsymbol{F}$ is to position, the better the resolution.





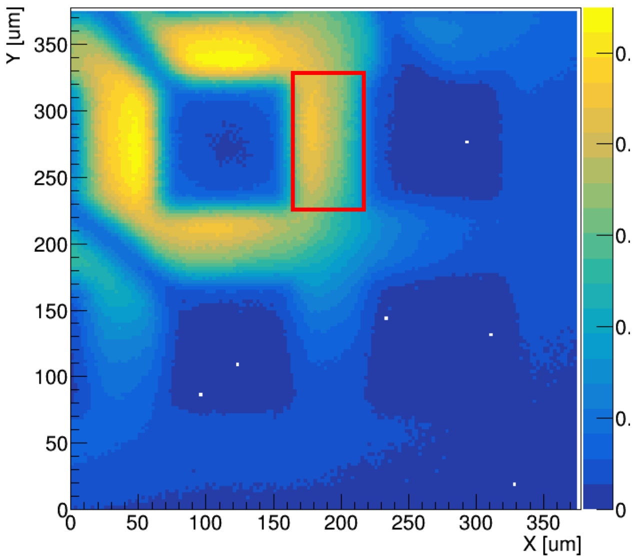
Conclusions:

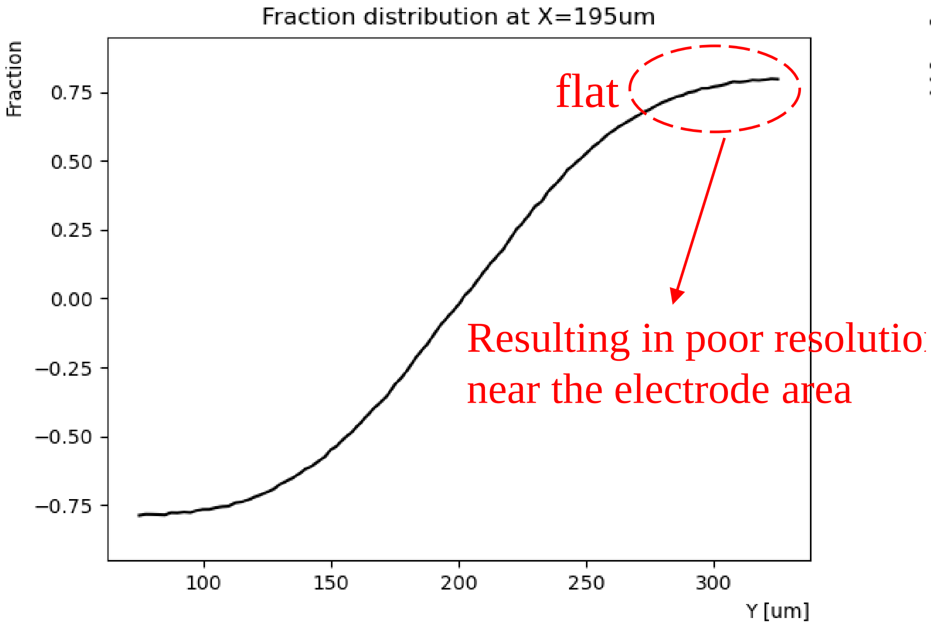
1. As decerasing pitch size, the slope increases, which means better resolution.
2. the relative electrode area increases, which means an increase in areas where signal sharing is not active.

Future optimization

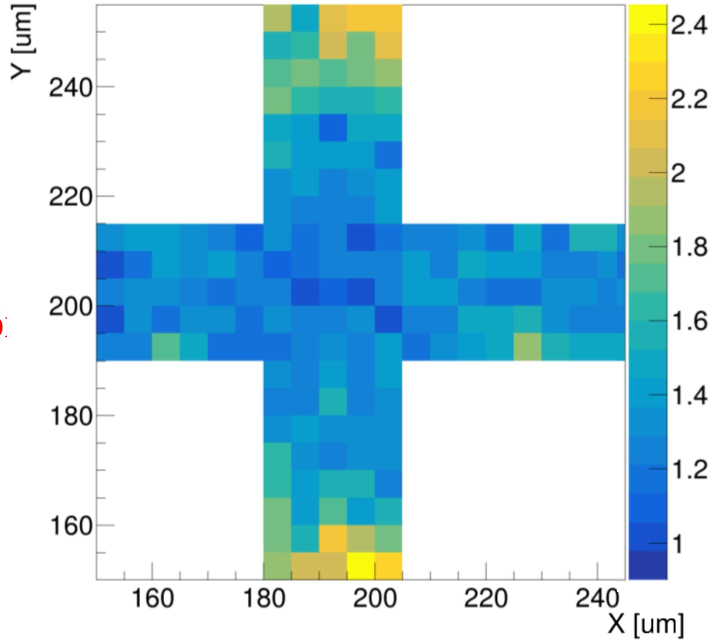
- Shortcomings of pad electrode

1. The metal areas where signal sharing is not active are large.
2. Since the sensitivity of amplitude to position is not uniform, the resolution is not uniform.





σ_y map



- Next we will optimize the electrode structure based on simulation.

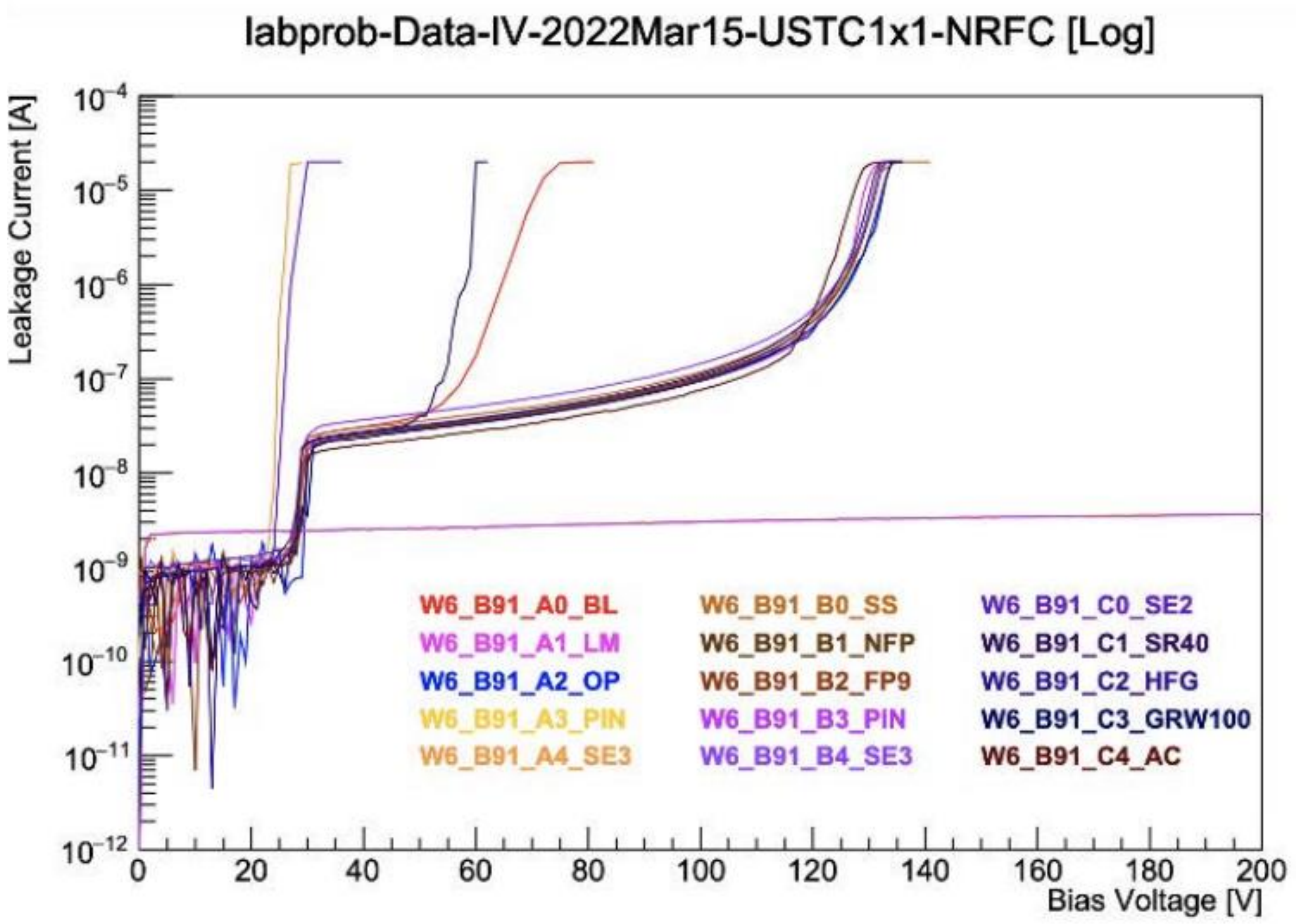
Summary

- AC-LGAD is a innovative detector for 4D-tracking based on AC-coupled readout.
- The first batch of USTC AC-LGADs were designed and produced. The response of signal was measured and described.
- Measurements at the TCT revealed a good 4-D tracking ability. For 100/150μm pitch size, best spatial resolution is ~1.6μm, time resolution is 23.6ps.
- The simulation and experiment are in good agreement. Next we will optimize the electrode structure based on simulation.

Thanks for you attention!

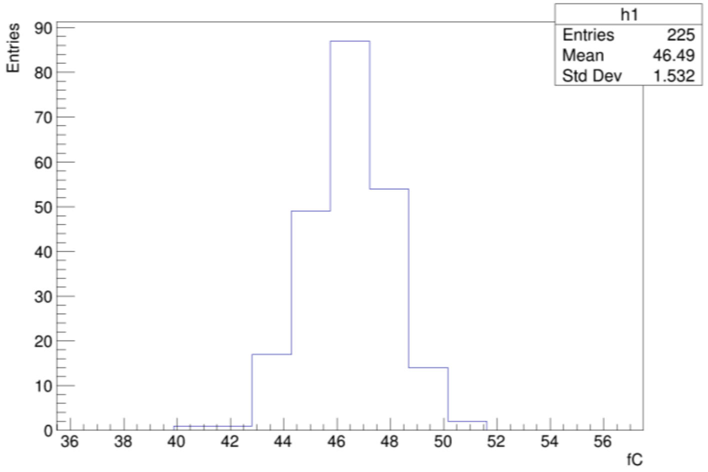
Back up

IV measurement of W6 AC

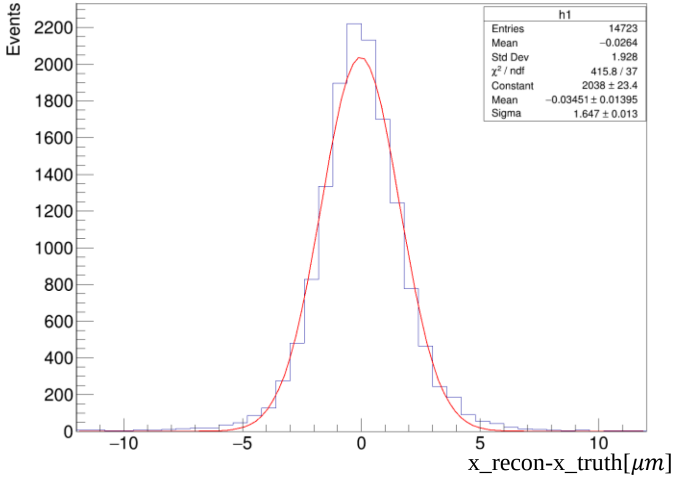


Performance of USTC AC-LGAD

charge collection of W6@130V

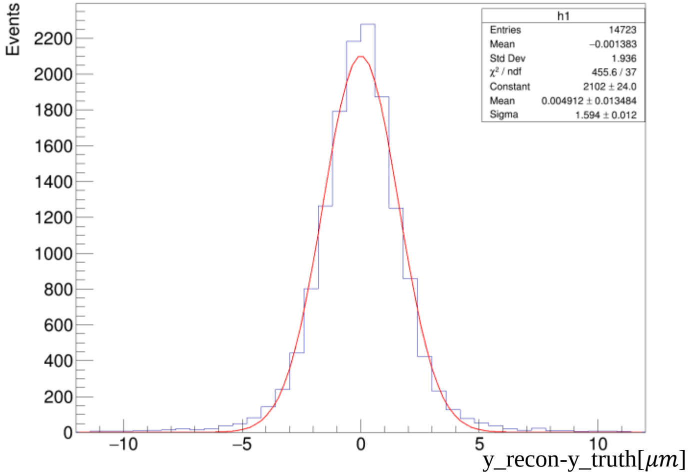


spatial resolution of W6@130V



$\sigma_x = 1.65\mu m$

spatial resolution of W6@130V

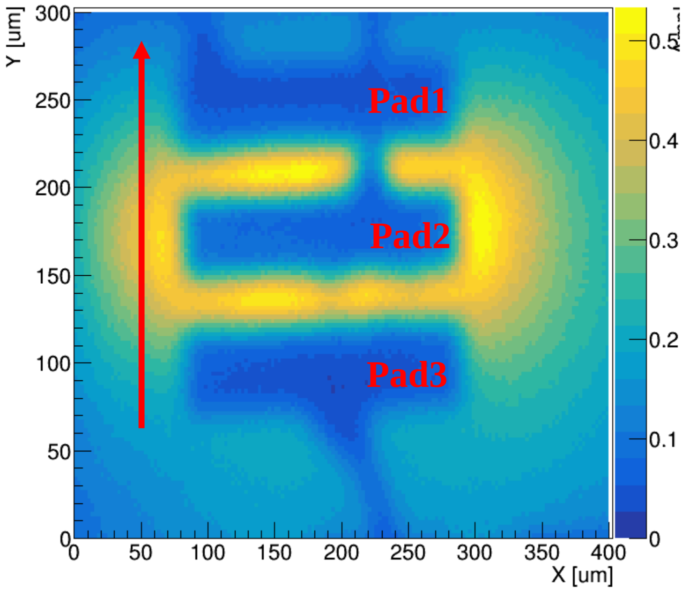


$\sigma_y = 1.59\mu m$

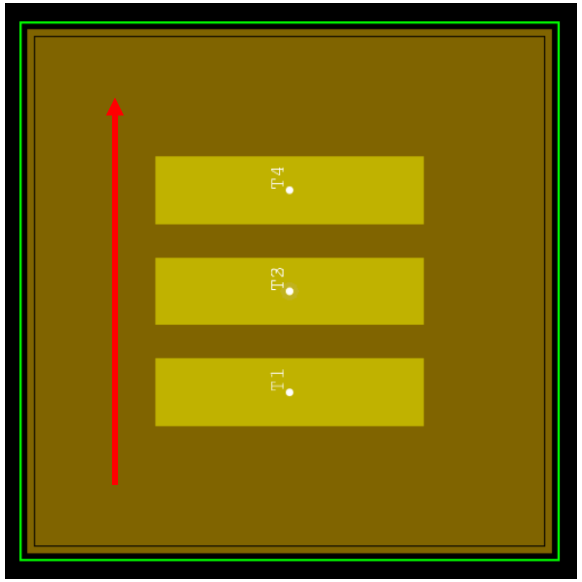
Comparison between simulation and experiment

W6 strip 50/75 um

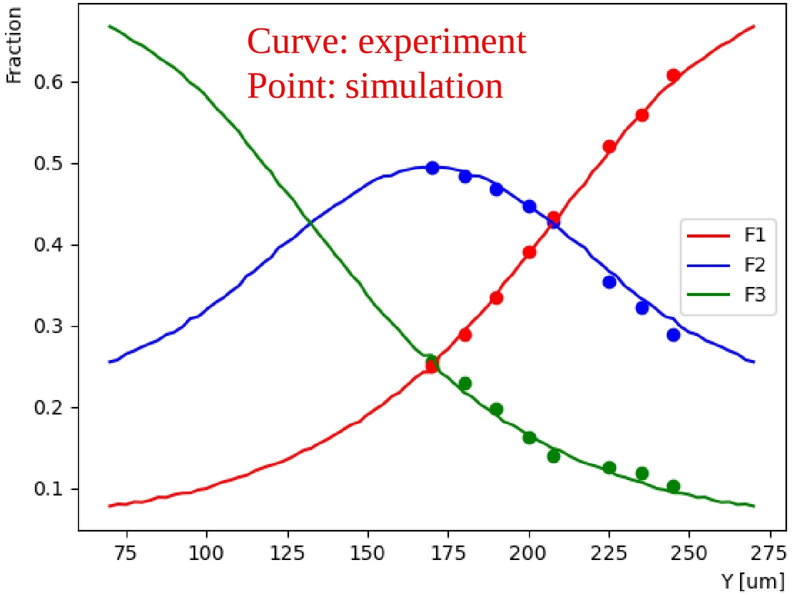
- Define $\boldsymbol{F_i} = \frac{\boldsymbol{A_i}}{\sum_i^n \boldsymbol{A_i}}$
- A_i is the peak amplitude on the pad i
- F_i is the fraction of the total signal amplitude seen on the pad i



Scanning step: 2.5um

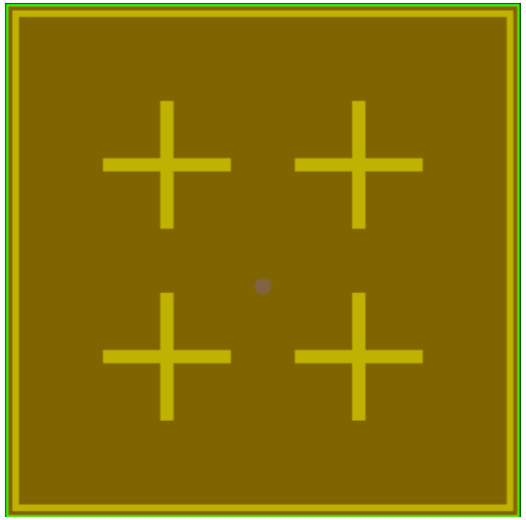


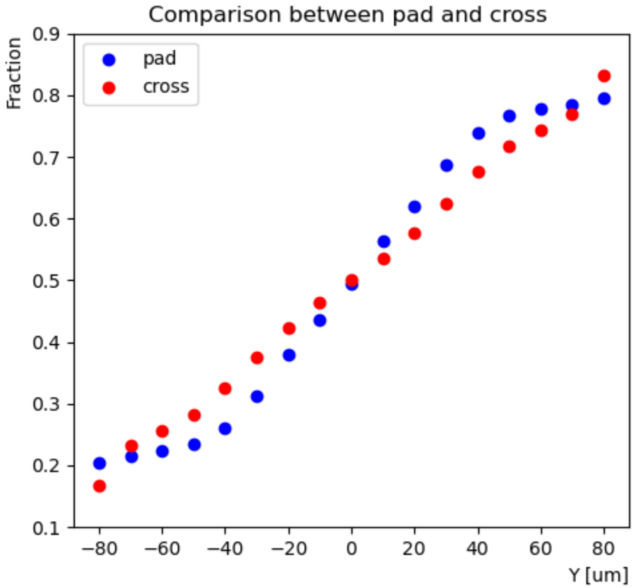
Simulation step: 10um

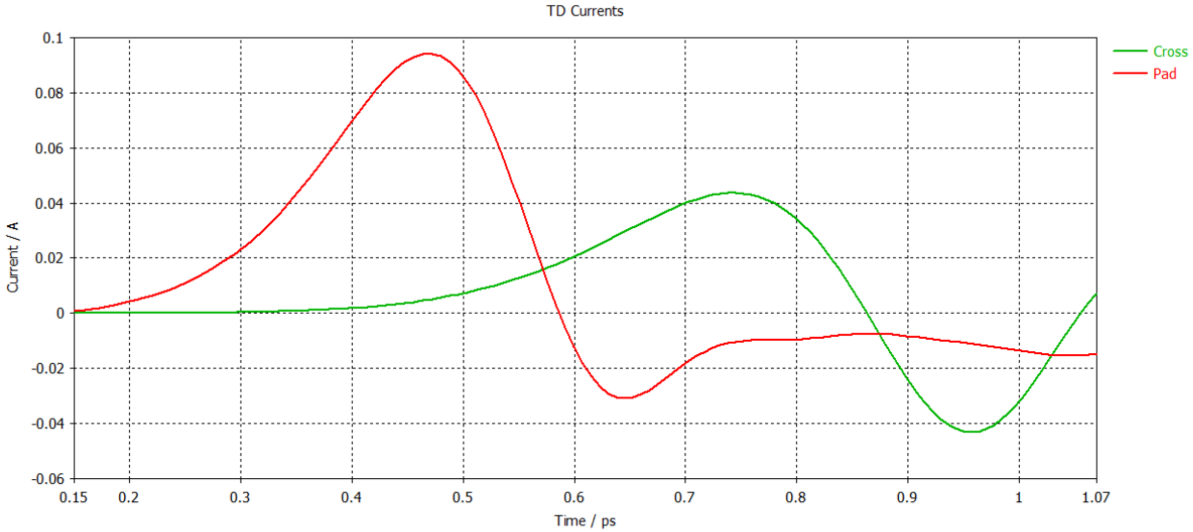


Fraction comparison at X = 50um

Optimization: Cross electrode







- By using cross electrodes, the relative electrode area decreases and the resolution becomes uniform
- But at the same time, the signal peak amplitude is smaller at the same pitch size.