ToF External Tracking Resolution Requirements

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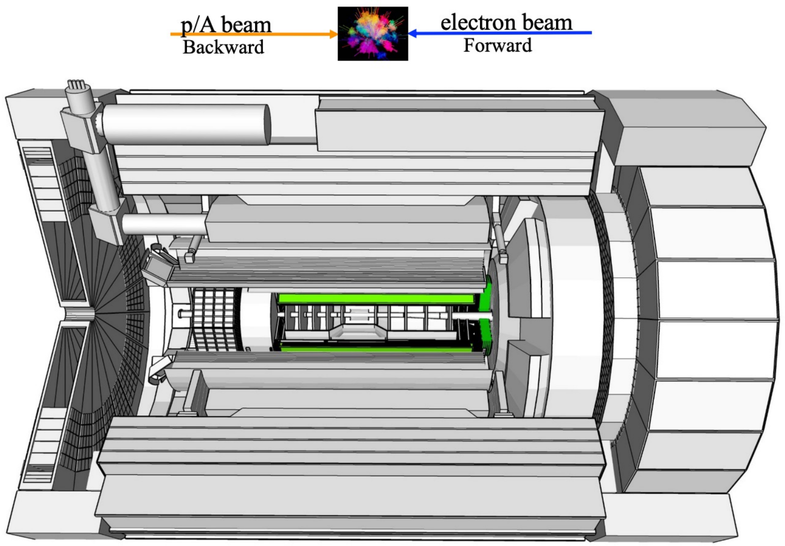
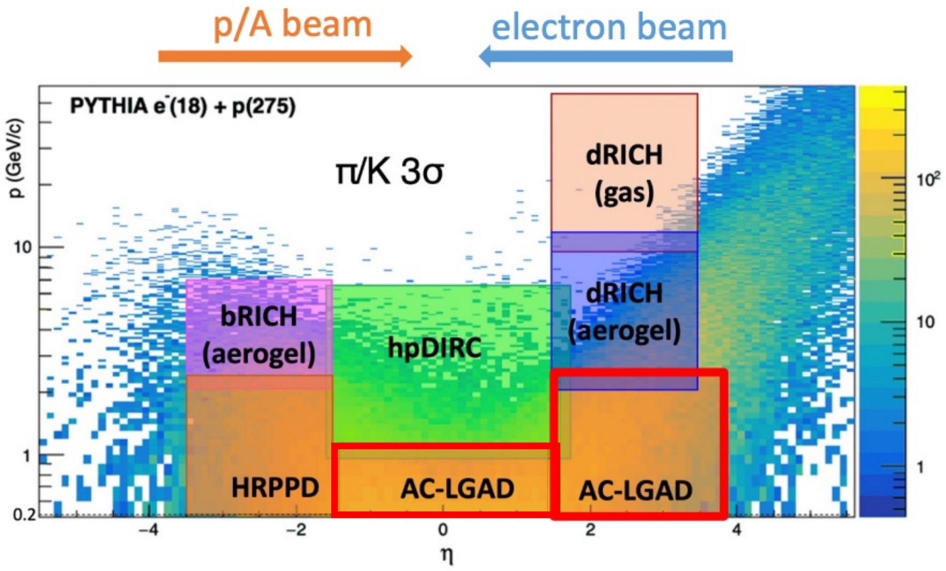
ePIC Collaboration Meeting
Argonne National Laboratory

UNIVERSITY OF ILLINOIS CHICAGO

Specifications of ePIC AC-LGAD ToF detectors in EIC:

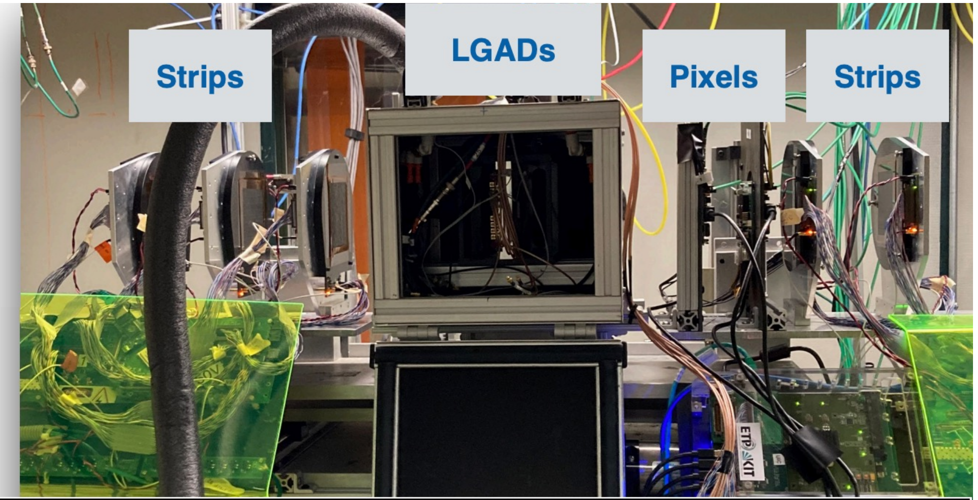


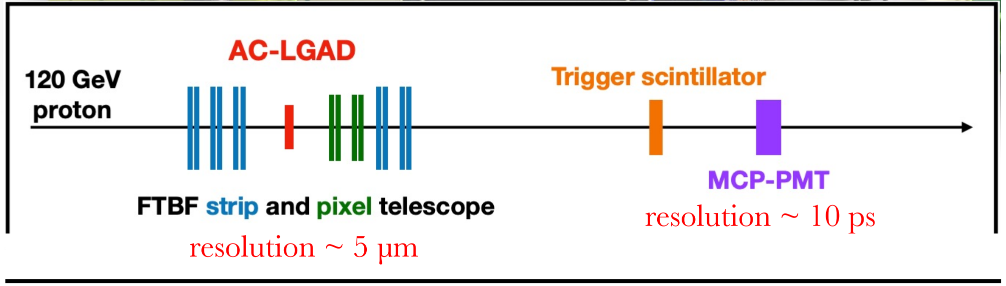


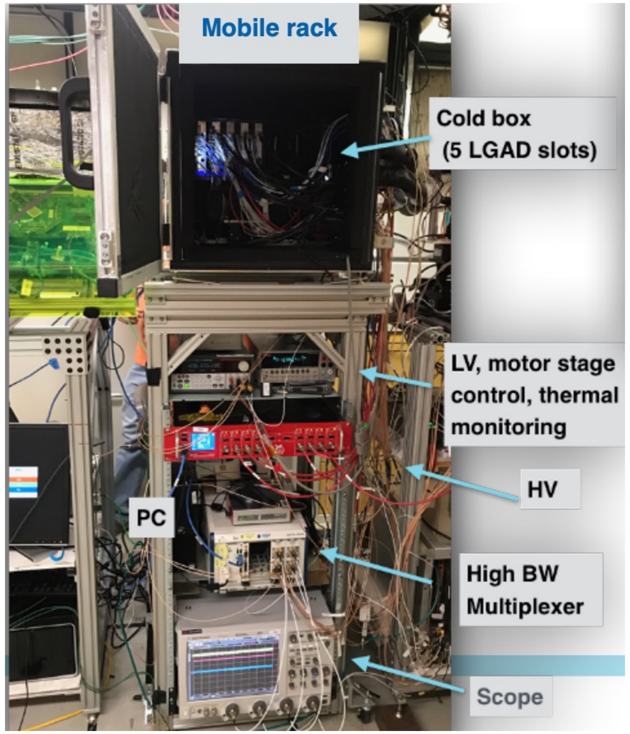
- ToF : PID capabilities below the threshold of Cherenkov PID detectors

	Angular accept.	Channel size (mm^2)	Timing Resolution	Spatial resolution	Material budget
Barrel ToF	$-1.4 < \eta < 1.4$	0.5*10	35 ps	30 μm in φ	0.01 X0
Forward ToF	$1.5 < \eta < 3.5$	0.5*0.5	25 ps	30 μm in x and y	0.05 X0

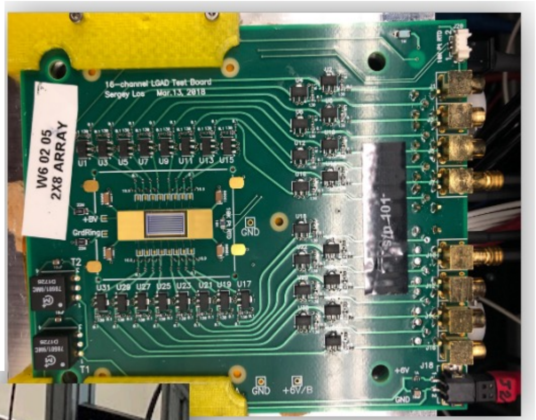
Fermilab test beam setup for AC-LGADs:





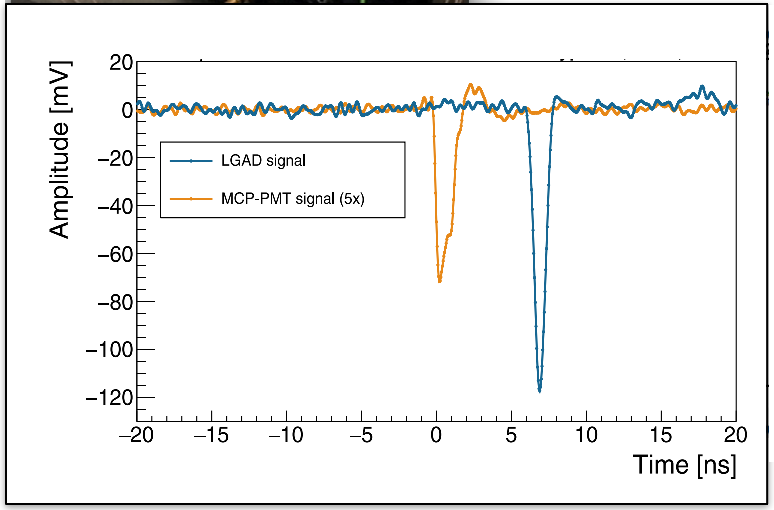


FNAL 16 Ch Board



Record 20k events during 4s spill

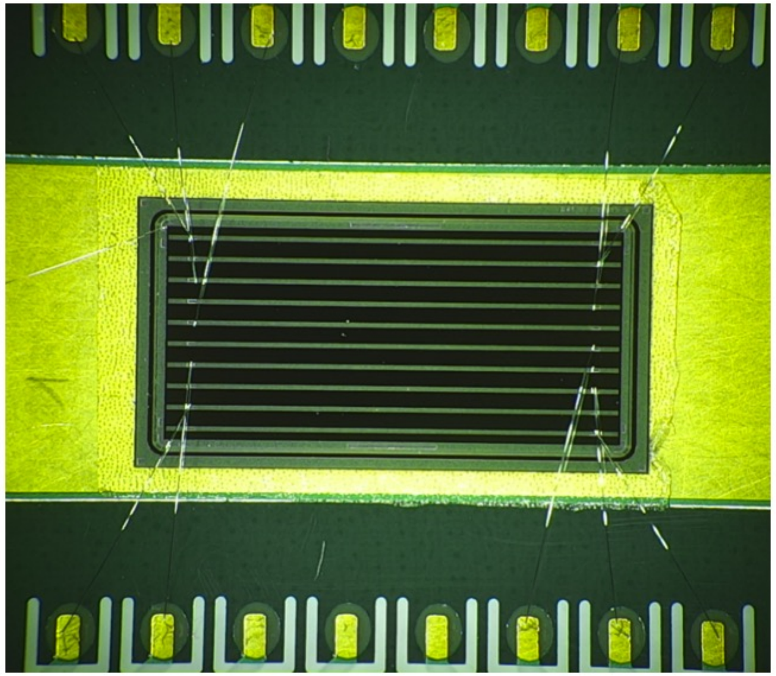
8-channel oscilloscope, 2 GHz, 10 GSa/s



- 120 GeV primary proton beam from main injector
- AC-LGAD and MCP-PMT waveforms were recorded in the oscilloscope
- Stable temperature of 20^0 C maintained inside the cooling block
- Optimal bias is a few volts below the breakdown (stable noise from the channels)
- Sensor alignment based on position of sensor along beamline and rotation around beam

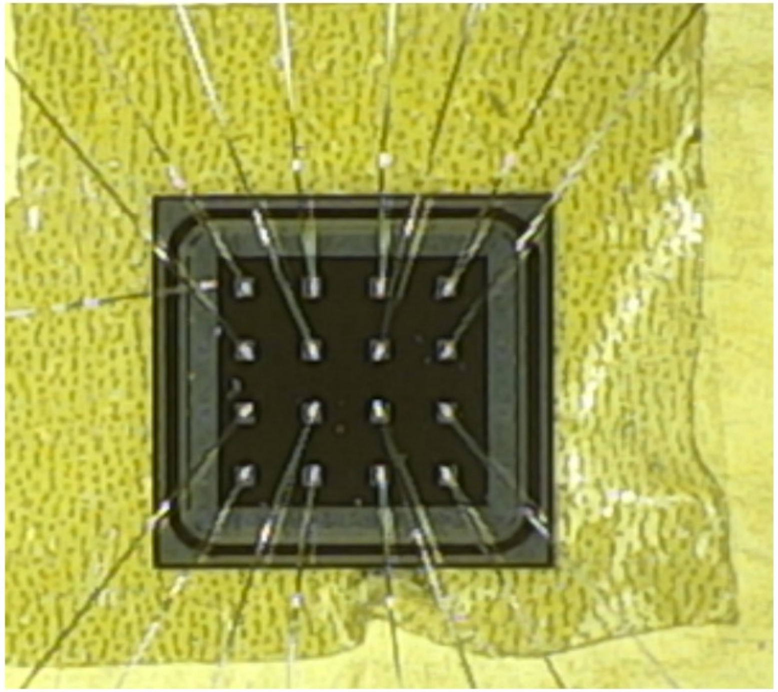
Large area AC-LGAD sensors in test beam campaign 2023:

HPK strip sensor



10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm^2 capacitance

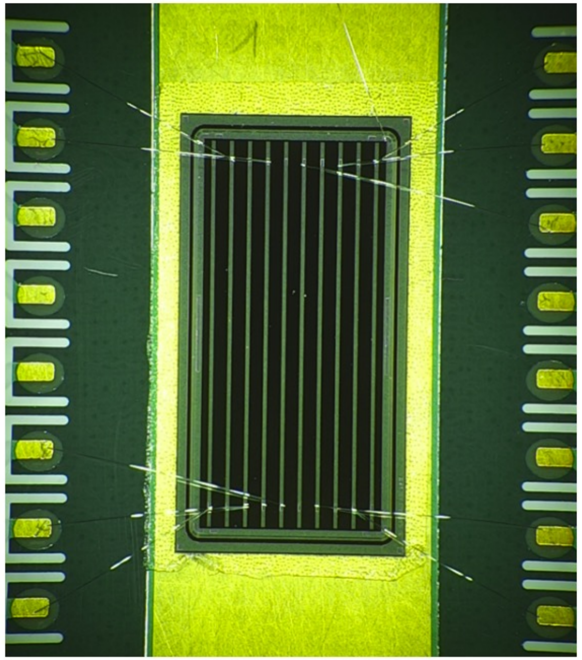
HPK 4 × 4 pixel sensor

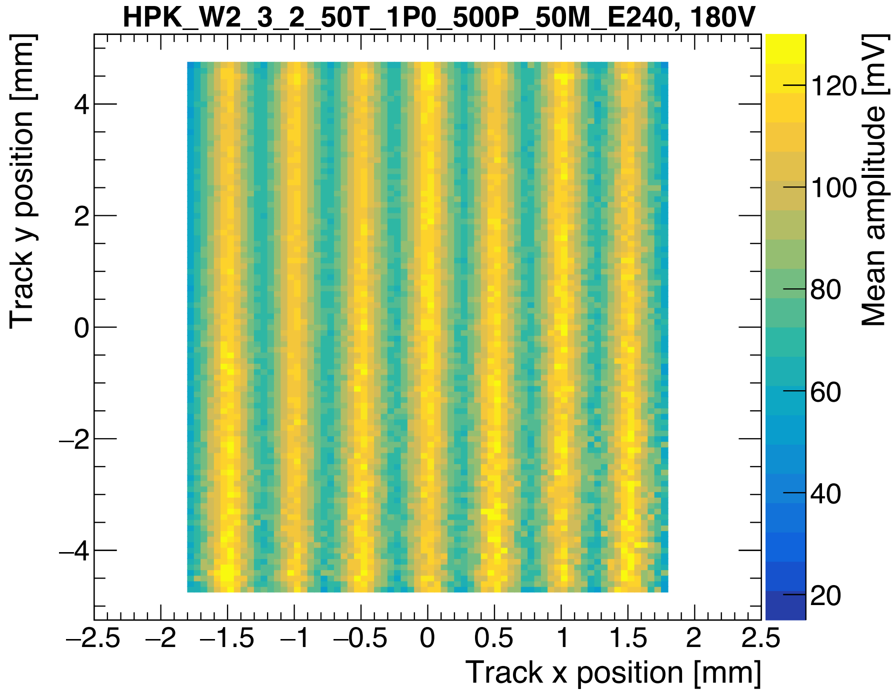


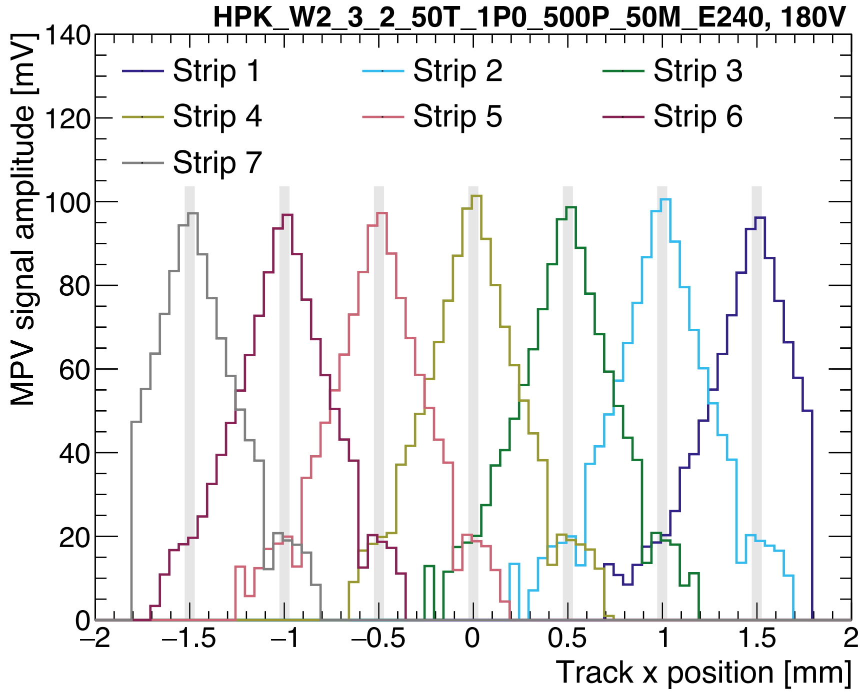
500 × 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm^2 capacitance

Large area AC-LGAD strip sensor :

10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm^2 capacitance



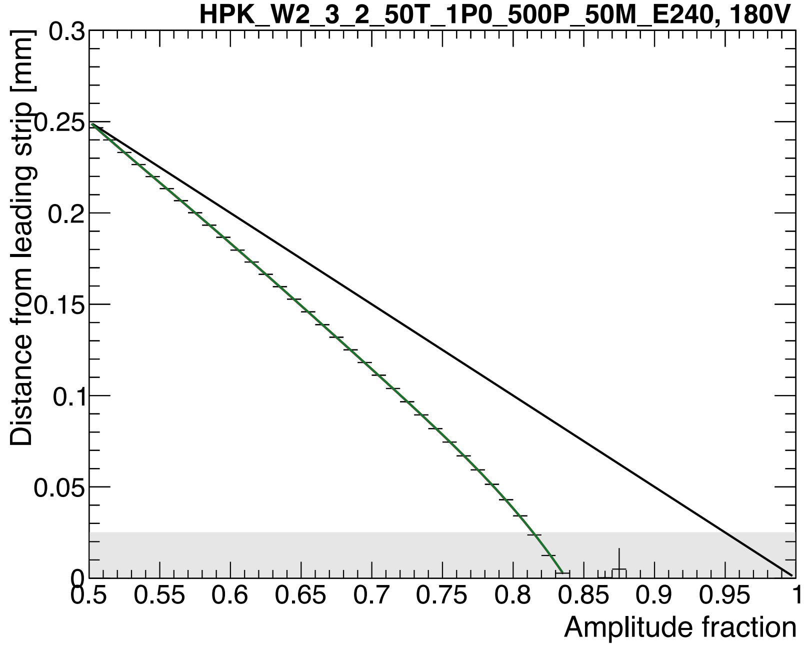




- Signal sharing between strips enables the ‘x’ position (perpendicular to the strip direction) reconstruction
- Unable to perform the ‘y’ position (along the strip direction) reconstruction in strip sensor

Spatial resolution in large area AC-LGAD strip sensor :

10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm² capacitance

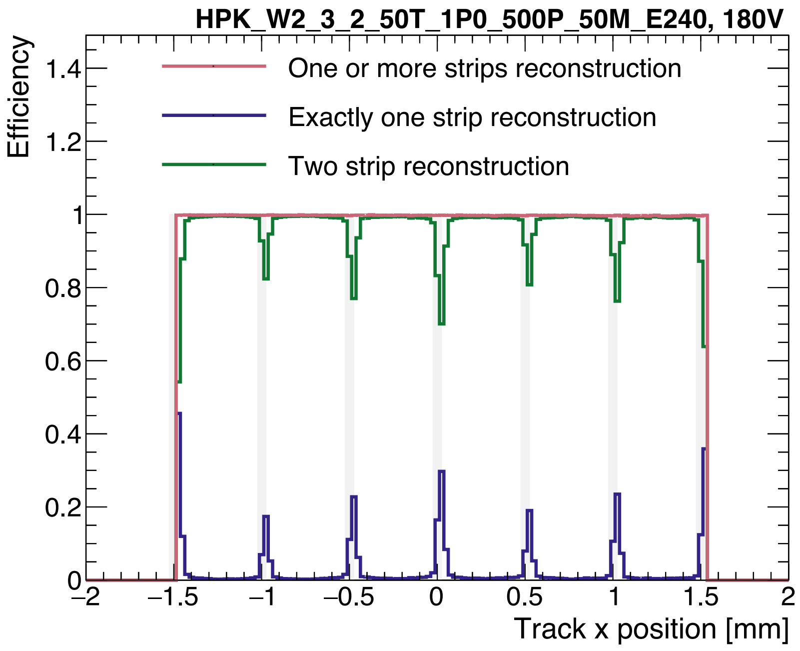


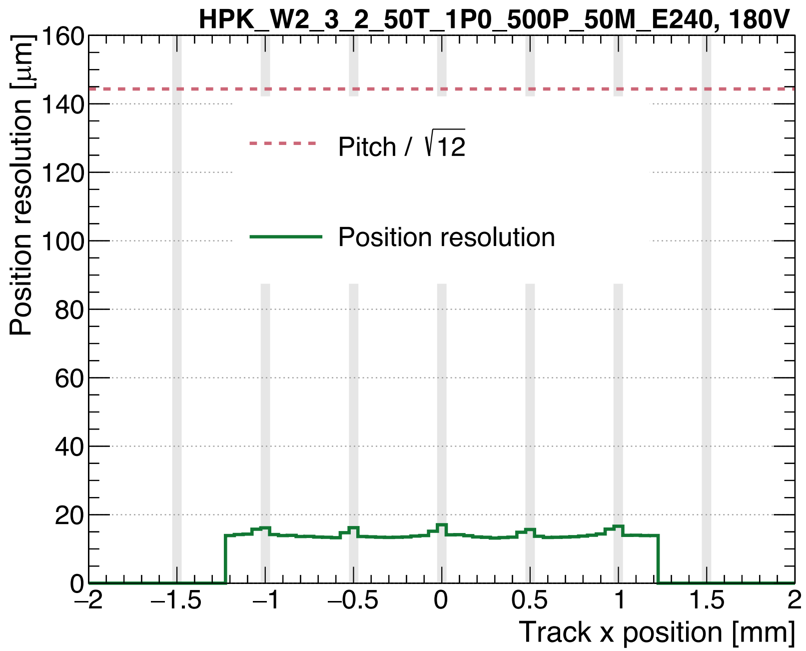
- Amplitude fraction $f = a1 / (a1 + a2)$ where $a1$ and $a2$ are the leading and sub-leading strip amplitudes

- Two-strip reconstruction at gap and one-strip reconstruction on metal

- Efficiency reaches ~100%

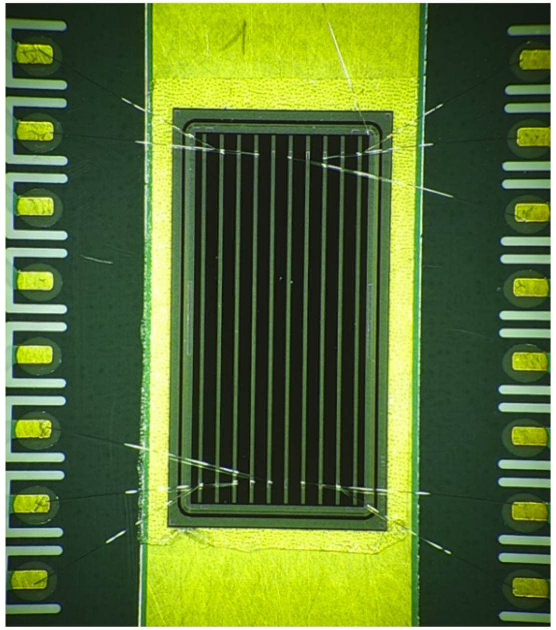
- Position resolution ~ 12 – 15 μm

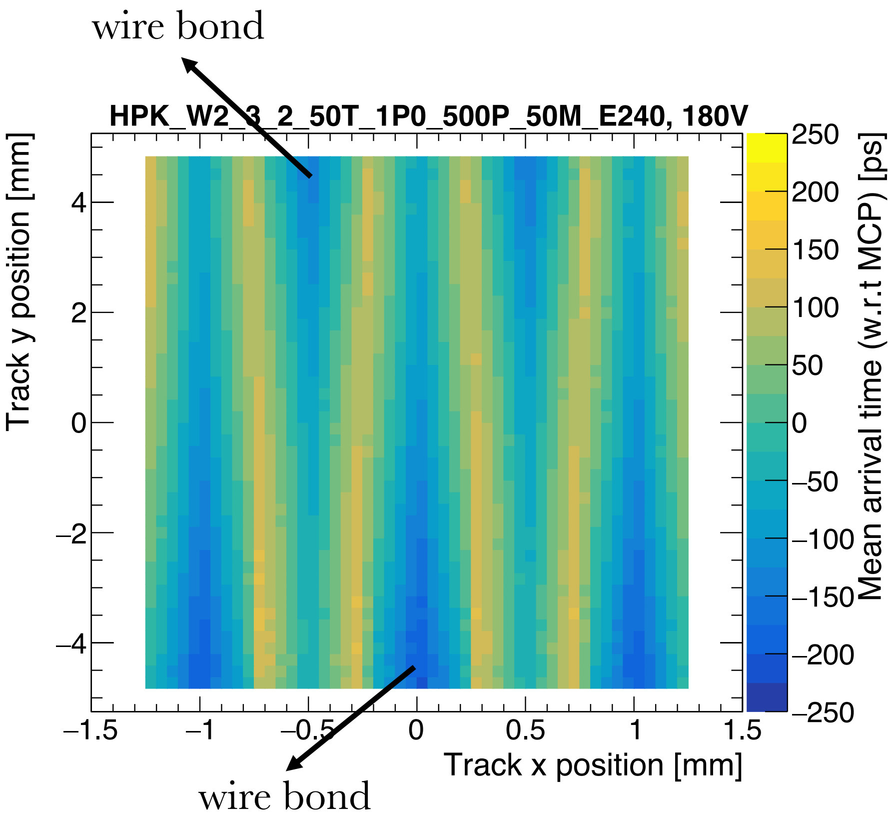


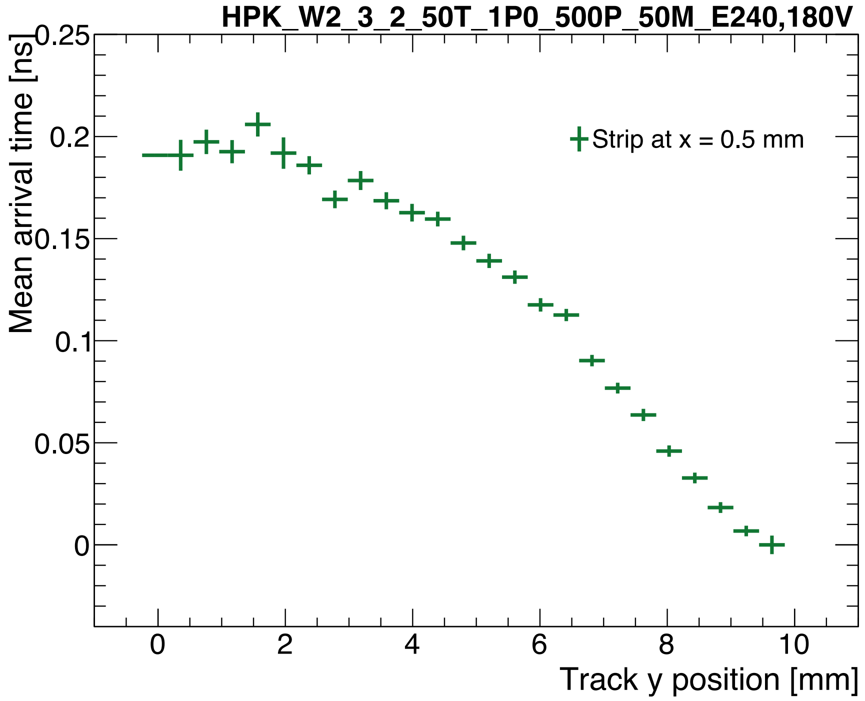


Time delay in large area AC-LGAD strip sensor :

10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm² capacitance







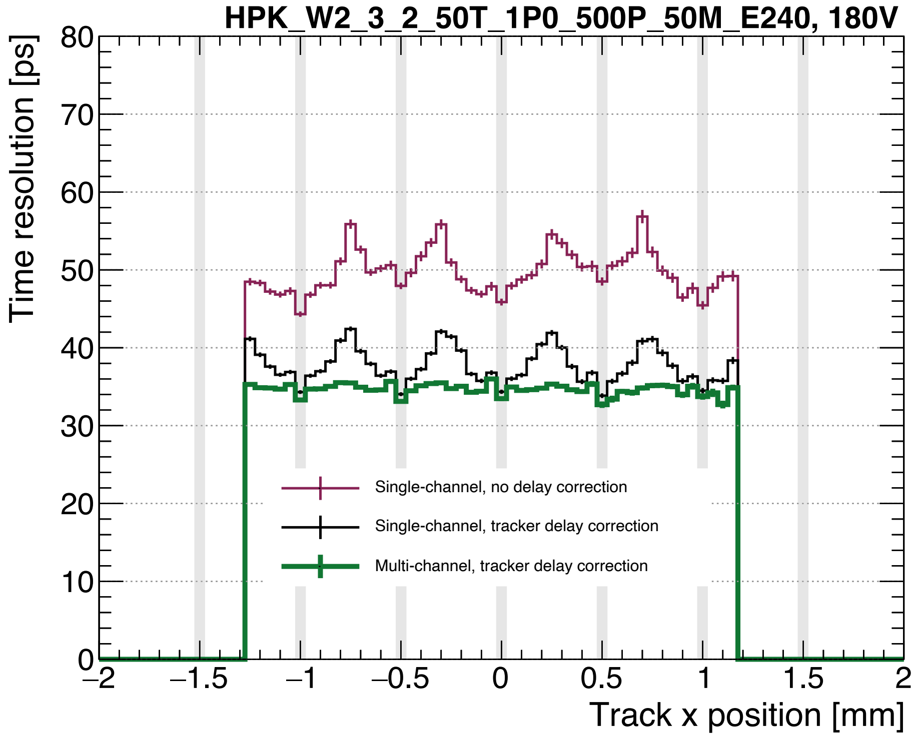
- Due to larger electrodes, distant signals arrival with delays O(100 ps)
- Position-dependent time delay correction is essential
- Delay map use the resolution of 50 μm for x position and 200 μm for y position

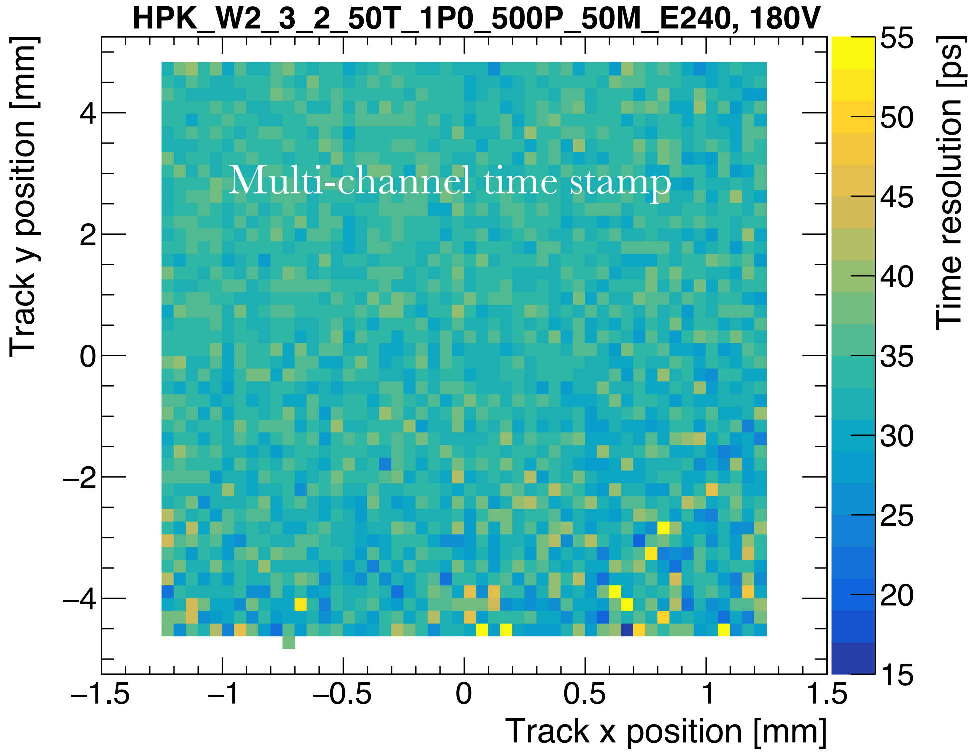
can be achieved by the sensor itself

from external tracker

Time resolution in large area AC-LGAD strip sensor :

10 mm length, 500 µm pitch, 50 µm metal width, 50 µm thickness, 1600 Ω/□ resistivity, and 240 pF/mm² capacitance





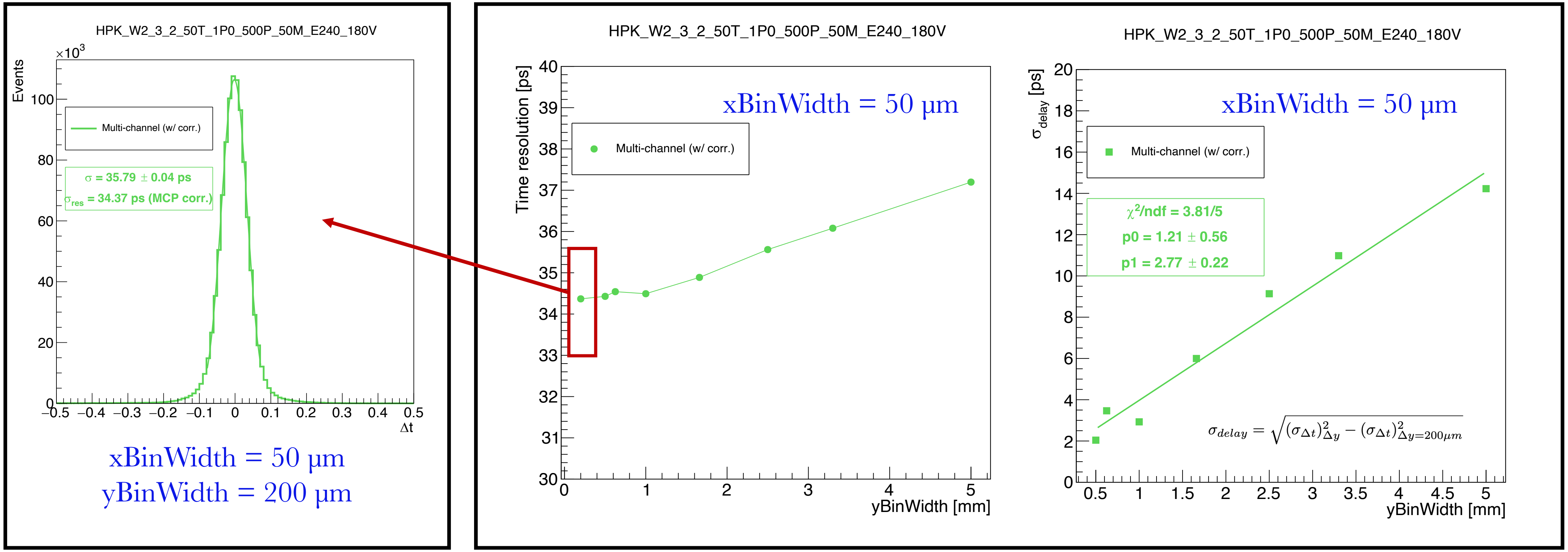
- Without delay correction, the time resolution ~ 45 – 55 ps
- Adding the tracker-based delay corrections improves the resolution to ~ 35 – 42 ps
- Using multi-channel timestamp with delay correction, time resolution ~ 34 ps (almost uniform across surface)

Multi-channel time stamp,

$$t_{\text{reco}} = \frac{a_1^2 t_1 + a_2^2 t_2}{a_1^2 + a_2^2}$$

Impact of delay map resolution on time resolution in large area AC-LGAD strip sensor :

10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm^2 capacitance

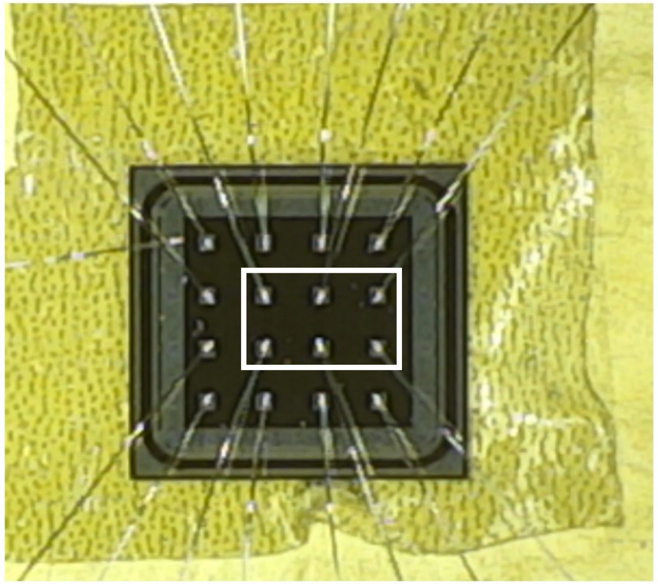


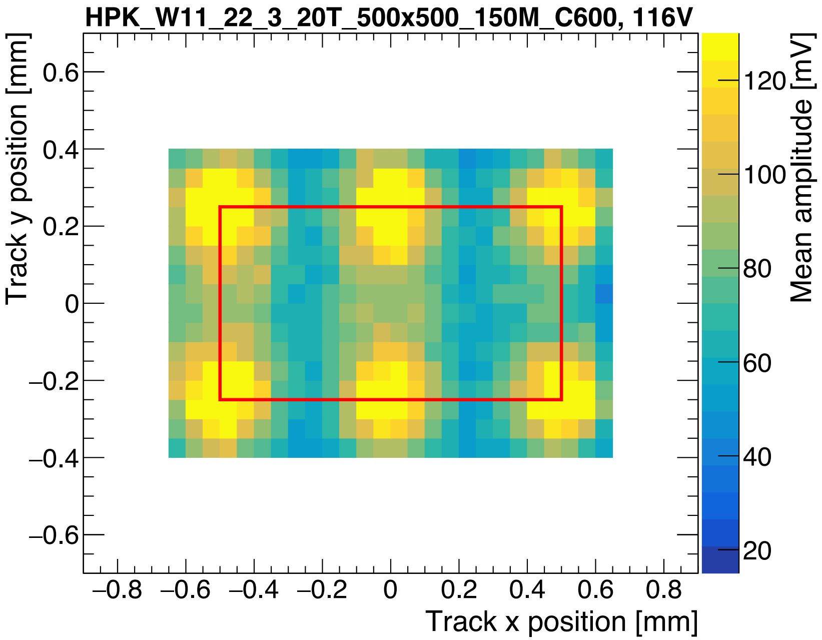
- Delay contribution in the time resolution increases with increasing yBinwidth in delay map along the direction of the strips

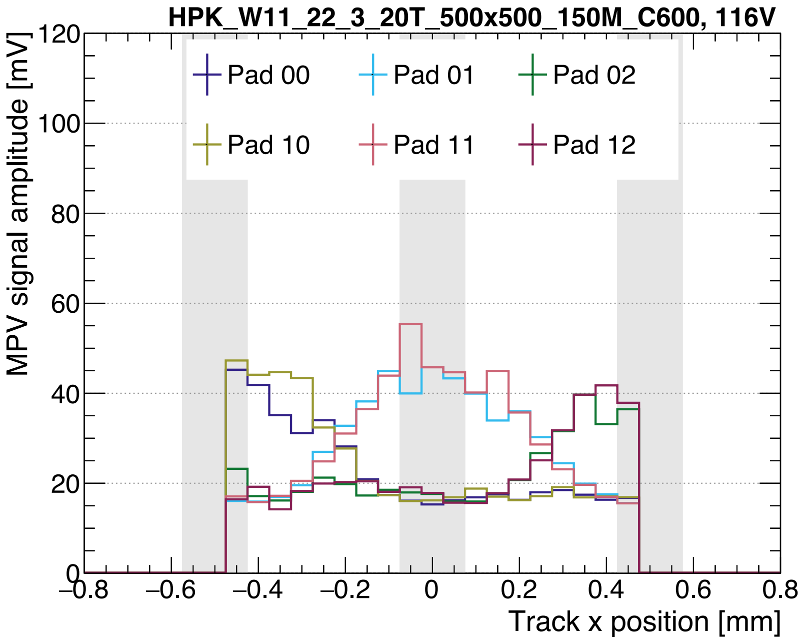
- Negligible change in time resolution until yBinwidth = 1.5 mm, and a change of ~ 2ps at yBinwidth = 5 mm (half of the strip length)

Large area AC-LGAD pixel sensor :

500 × 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm^2 capacitance





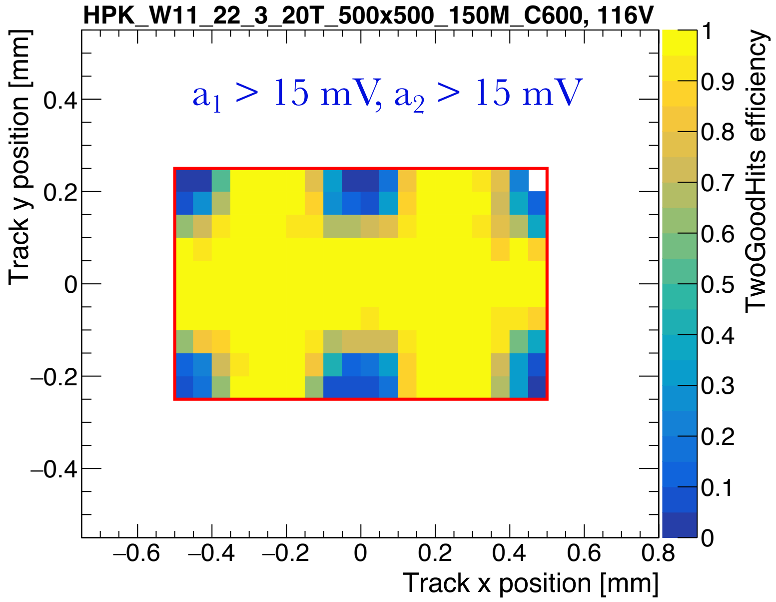


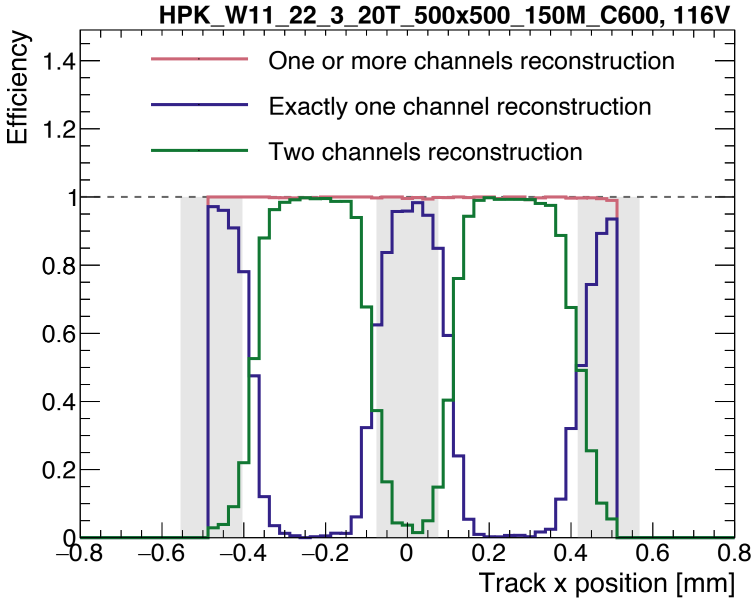
- Signal sharing between pads enables the position reconstruction in both direction (x and y)
- Significantly smaller charge sharing in the metal pad limits the two-channel reconstruction
- Threshold of 15 mV on amplitude for leading and sub-leading channels to qualify for two-channel reconstruction

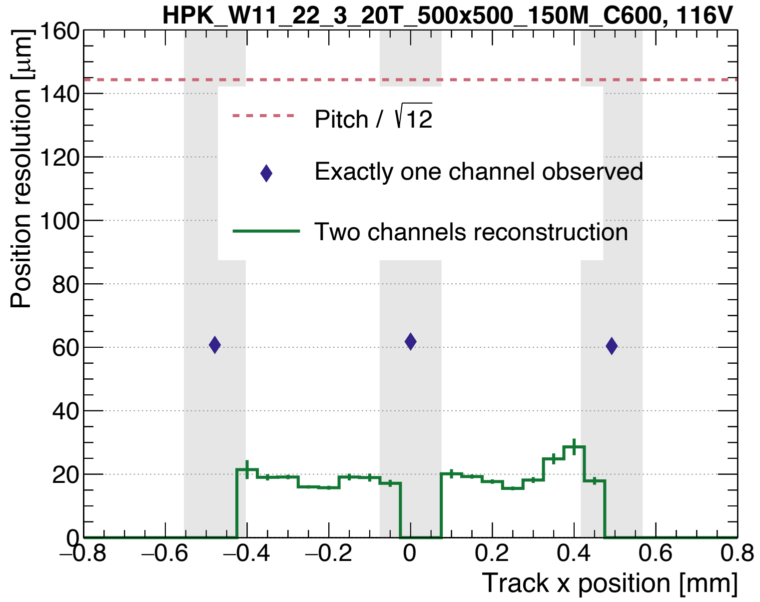
(*) the gray box only represents the location of metal pad; it also contain the gap region between metal pads in same column

Spatial resolution in large area AC-LGAD pixel sensor :

500 ✕ 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm² capacitance



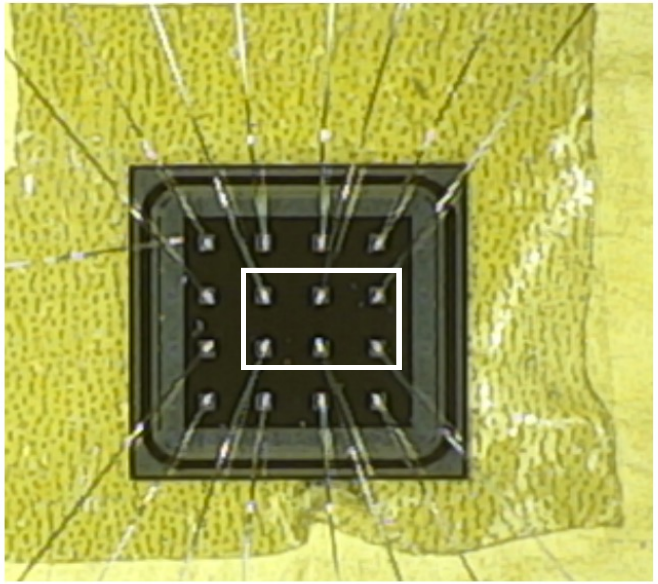


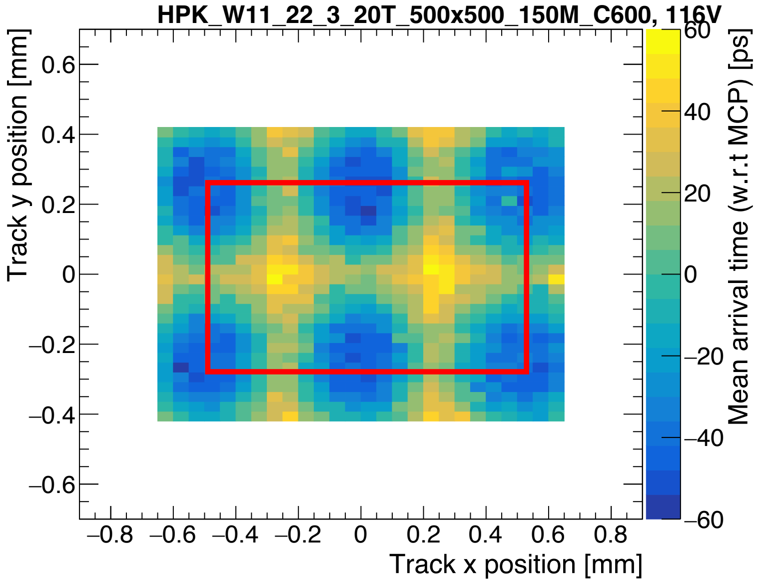


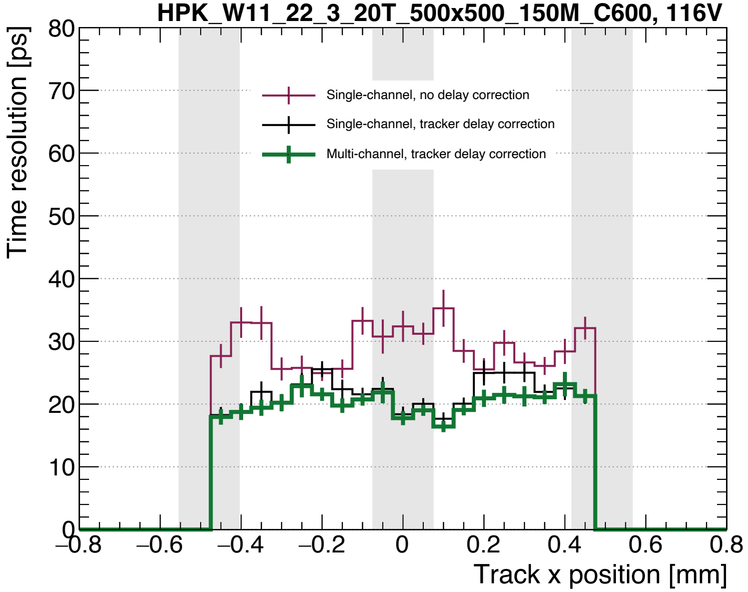
- For each event, the amplitude from two channels in column has been added to enhance the charge sharing in gap regions
- Two-channel efficiency ~ 1 in mid gap region and suffers in and near metal pad region
- Two-channel position resolution ~ 20 μm
- Position resolution in metal pads (~ 60 μm) can be improved by further reducing the metal pad width

Time resolution in large area AC-LGAD pixel sensor :

500 × 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm² capacitance







- Delay map use the resolution of 50 μm for x position and 50 μm for y position
- Without delay correction, the time resolution ~ 30 ps
- Adding the tracker-based delay corrections improves the resolution to ~ 20 ps
- Using multi-channel timestamp with delay correction, time resolution ~ 20 ps

can be achieved by the sensor itself

Summary :

- In strip sensor,
  - x resolution (perpendicular to the strip direction - ϕ direction in lab frame) of delay map for correction be achieved by the sensor itself
  - For y resolution (along the strip direction - z direction in lab frame) of delay map, need to rely on external tracker with a reasonable resolution
    - negligible change in time resolution until yBinwidth = 1.5 mm, and an increase of ~ 2.5 ps from 34.5 to 37 ps with yBinwidth = 5 mm
- In pixel sensor (metal width of 150 μm),
  - x and y resolution (along x and y direction in lab frame) of delay map for correction be achieved by the sensor itself

Extra slides:

AC-LGAD team:

Fermilab: Christopher Madrid, Irene Dutta, Artur Apresyan, Sergey Los, Cristián Peña, Si Xie

BNL: Wei Chen, Gabriele Giacomini, Alessandro Tricoli, Gabriele D’Amen, Enrico Rossi

LBNL: Ryan Heller, Zhenyu Ye

Caltech: Si Xie

Universidad Técnica Federico Santa María: Claudio San Martín, William K. Brooks, Matías Barría

University of Illinois at Chicago: Shirsendu Nanda, Danush Shekar, Zhenyu Ye

The University of Iowa: Ohannes Kamer Köseyan

Yerevan Physics Institute: Aram Hayrapetyan

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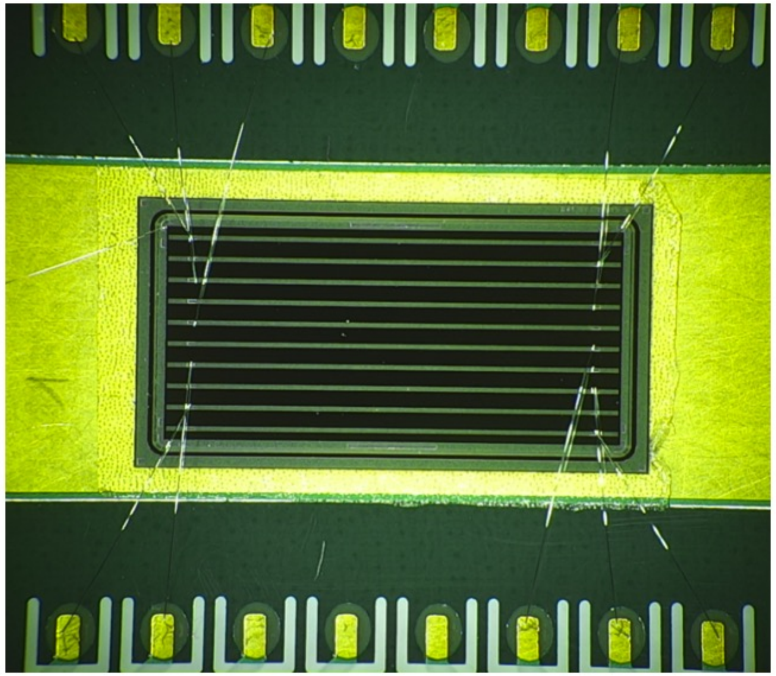
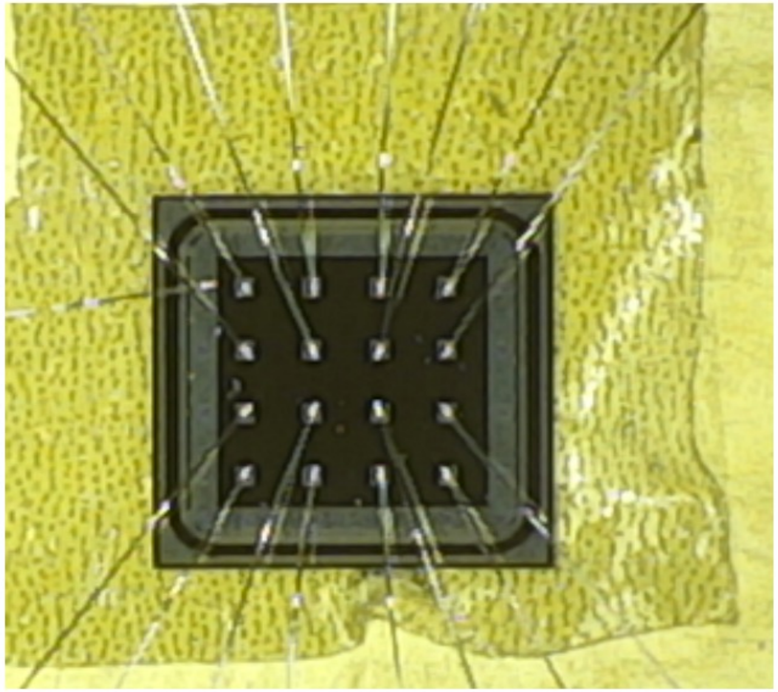
Large area AC-LGAD sensors in test beam campaign 2023:

HPK strip sensor



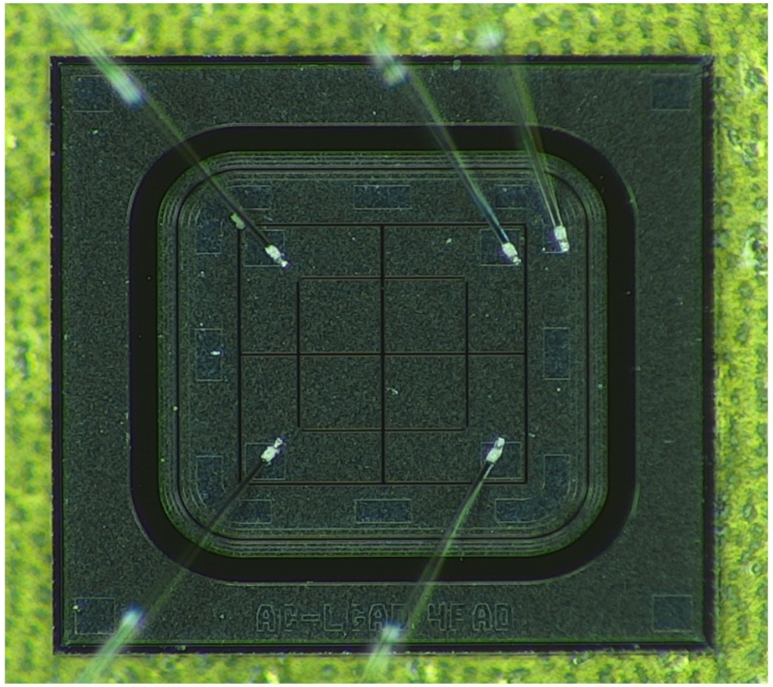
10 mm length, 500 μm pitch, 50 μm metal width, 50 μm thickness, 1600 Ω/□ resistivity, and 240 pF/mm^2 capacitance

HPK 4 ╳ 4 pixel sensor



500 ╳ 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm^2 capacitance

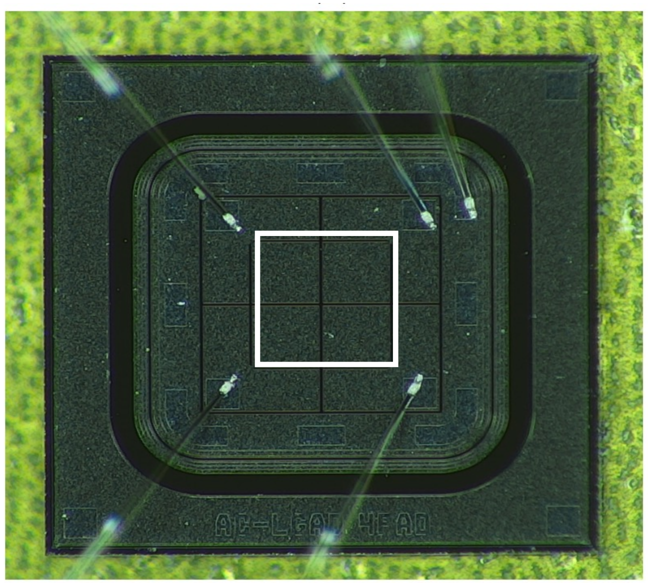
HPK 2 ╳ 2 pixel sensor

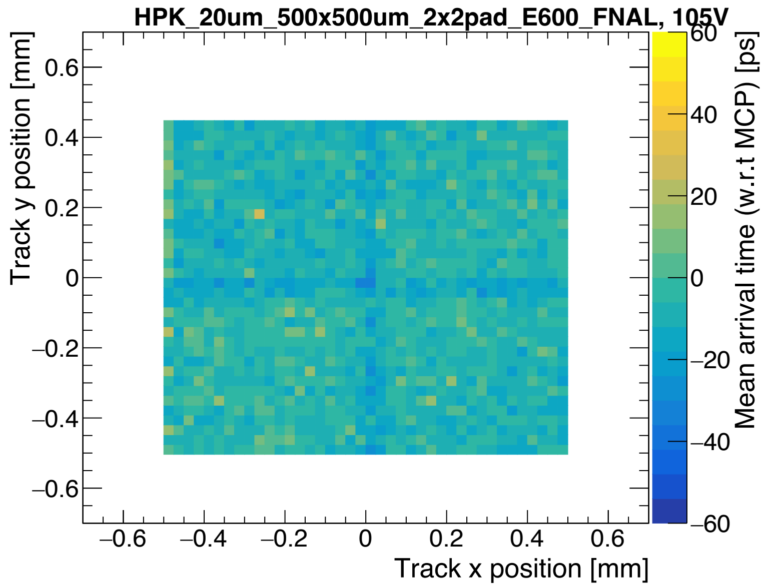


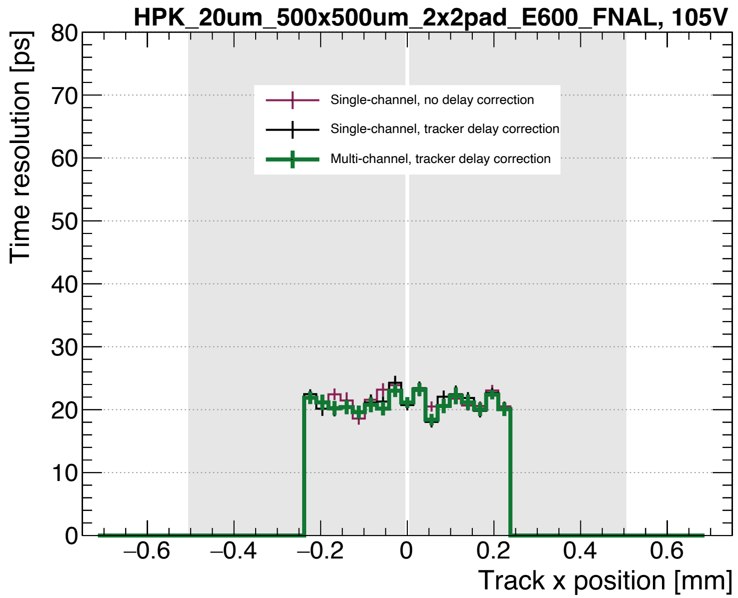
500 ╳ 500 μm pitch, 20 μm thickness, 450 μm metal width, 1600 Ω/□ resistivity, and 600 pF/mm^2 capacitance

Time resolution in large area AC-LGAD (2 x 2) pixel sensor :

500 × 500 μm pitch, 20 μm thickness, **450 μm metal width,** 1600 Ω/□ resistivity, and 600 pF/mm² capacitance

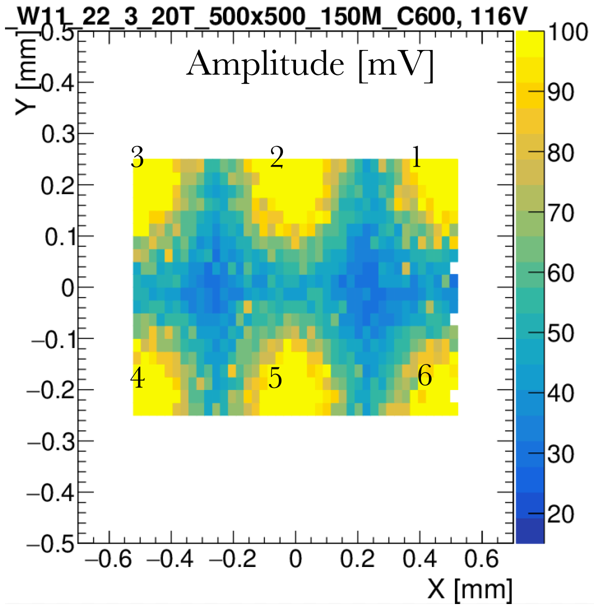


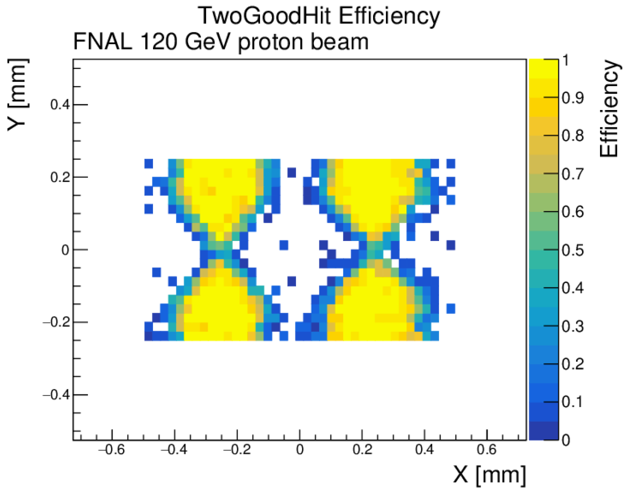


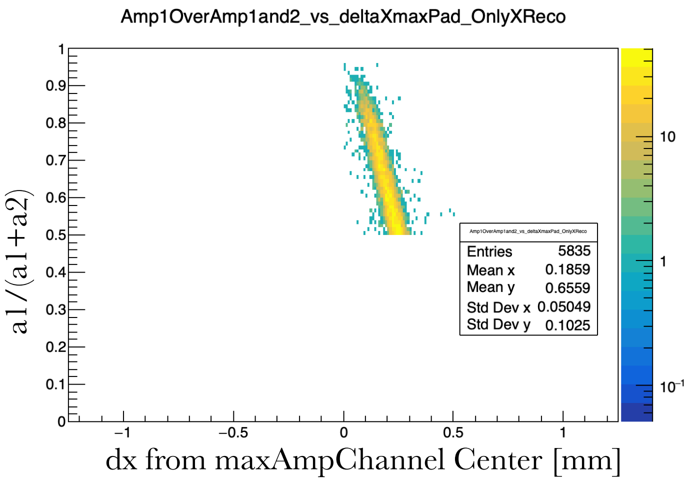


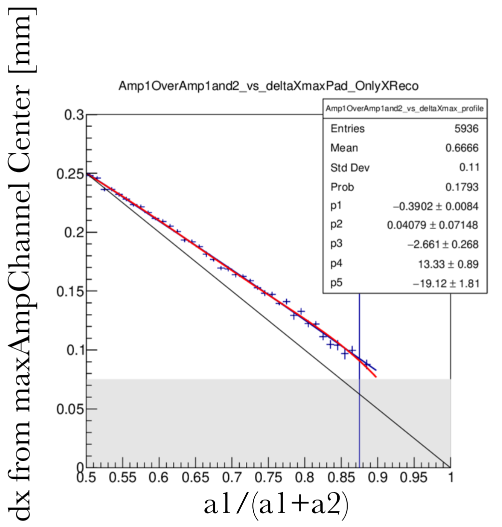
- Mean arrival time for the signal is significantly small O(10 ps)
- Delay map use the resolution of 50 μm for x position and 50 μm for y position
- No significant improvement using the delay map correction
- Time resolution ~ 20 ps (almost uniform across surface)

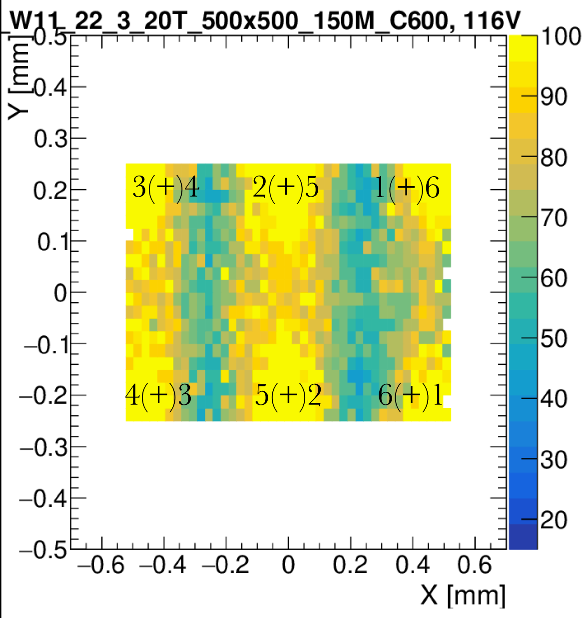
x position reconstruction in pixel sensor:

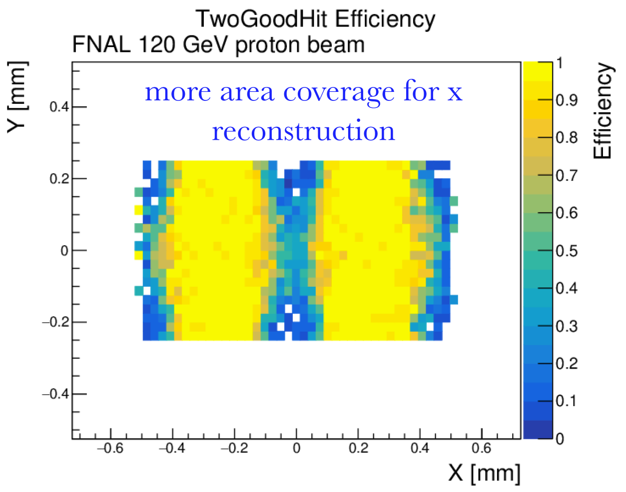


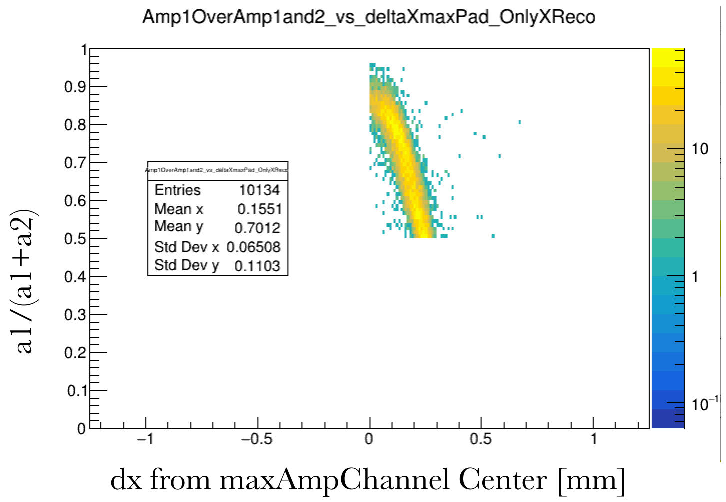


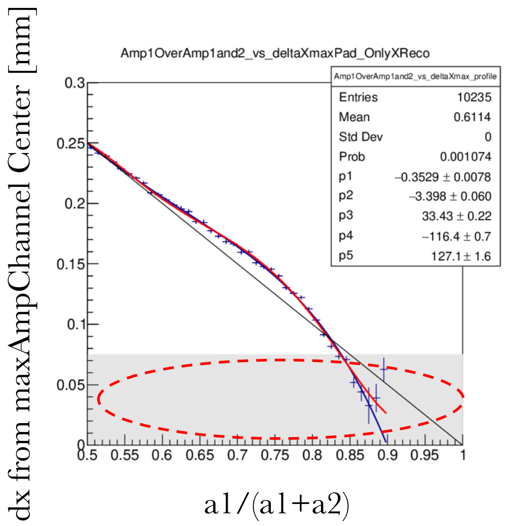






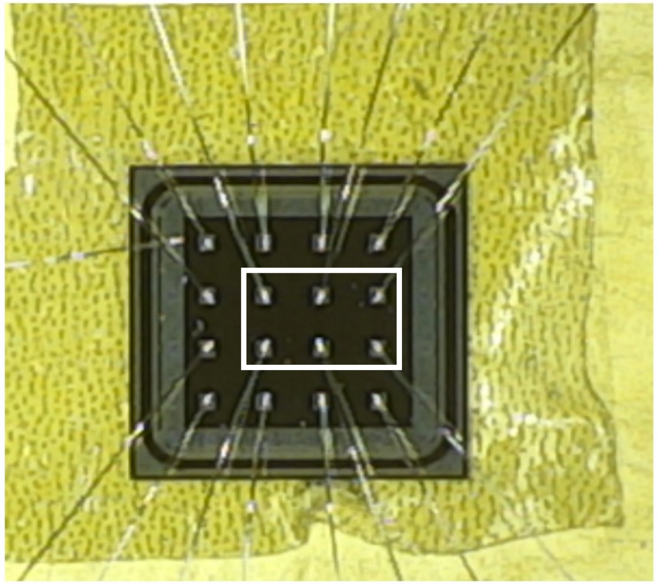


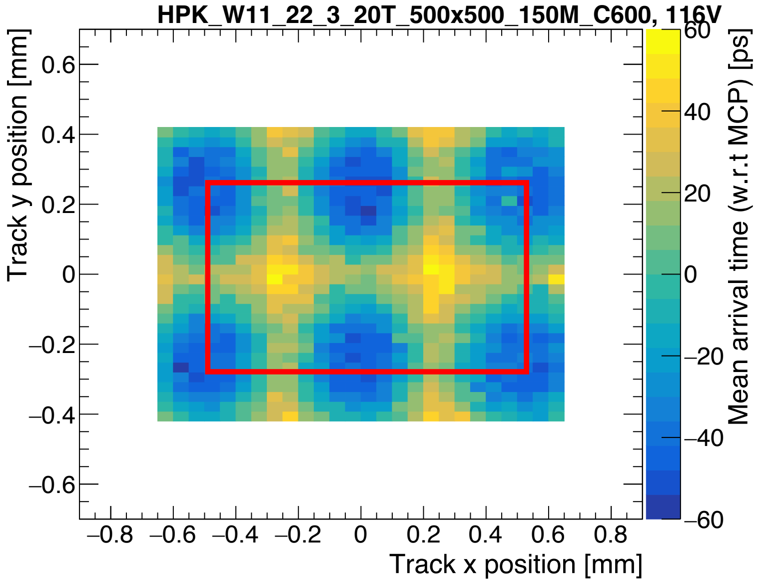


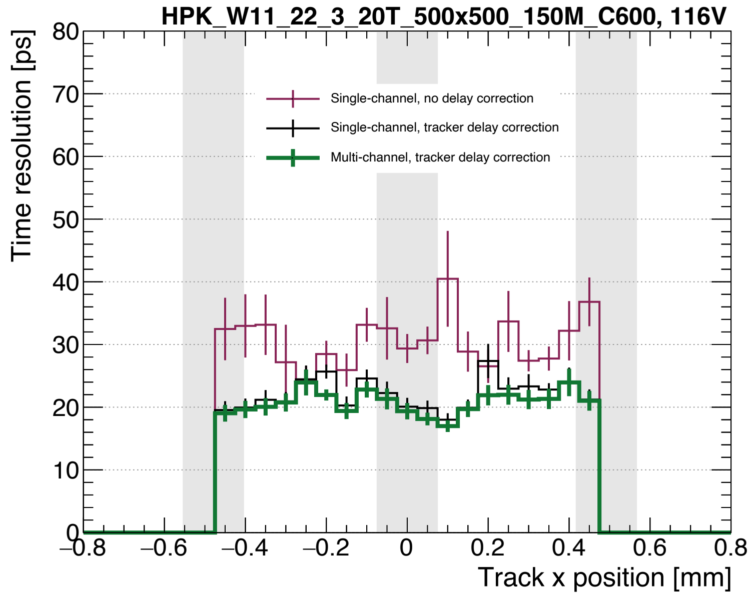


Time resolution in large area AC-LGAD pixel sensor :

500 × 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm² capacitance







- Delay map use the resolution of 50 μm for x position and 50 μm for y position
- Without delay correction, the time resolution ~ 30 ps
- Adding the tracker-based delay corrections improves the resolution to ~ 20 ps
- Using multi-channel timestamp with delay correction, time resolution ~ 20 ps

can be achieved by the sensor itself