First Results on HPK Sensors from FNAL Beam Test 2023

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eRD112/LGAD Consortium Meeting

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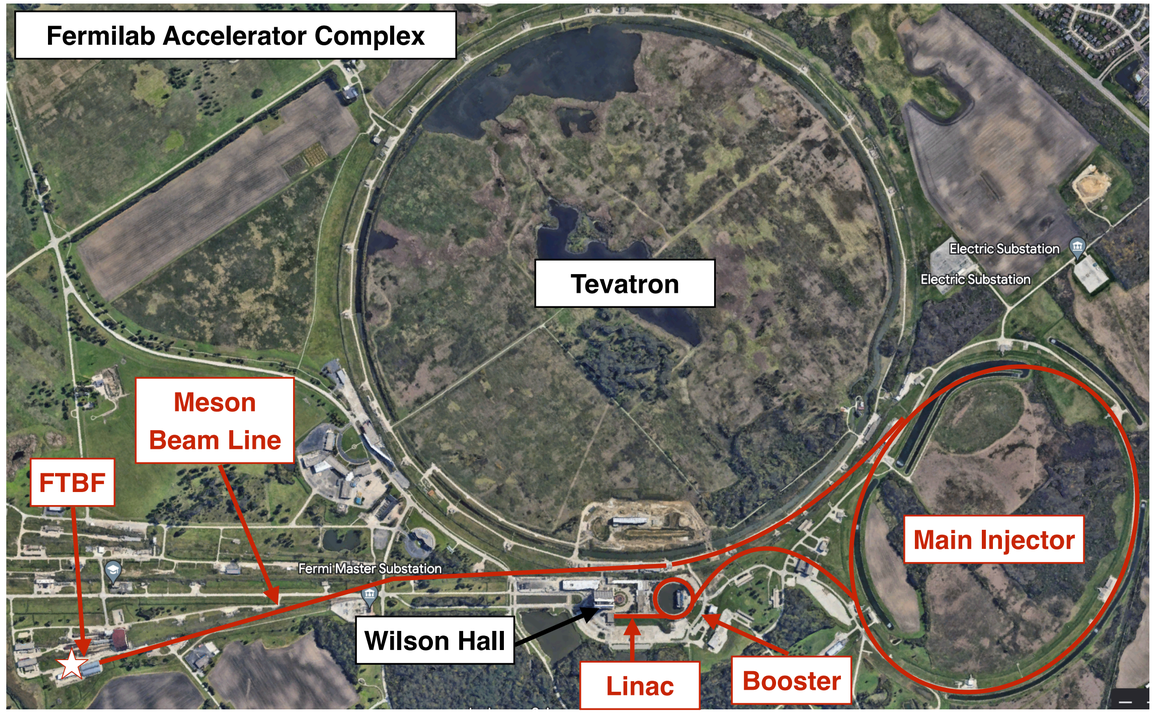
Overview

- Recently concluded an AC-LGAD test beam focused on HPK sensors for EIC
  - Lasted about a month
  - Beam outage extended test beam campaign by ~two weeks

- Collected data for both strips and pixels
  - Used 120 GeV protons from Main Injector
  - Used **FTBF telescope** for track reference
  - Used **Photek MCP-PMT** for time reference

- Actively analyzing the data but already have some preliminary results



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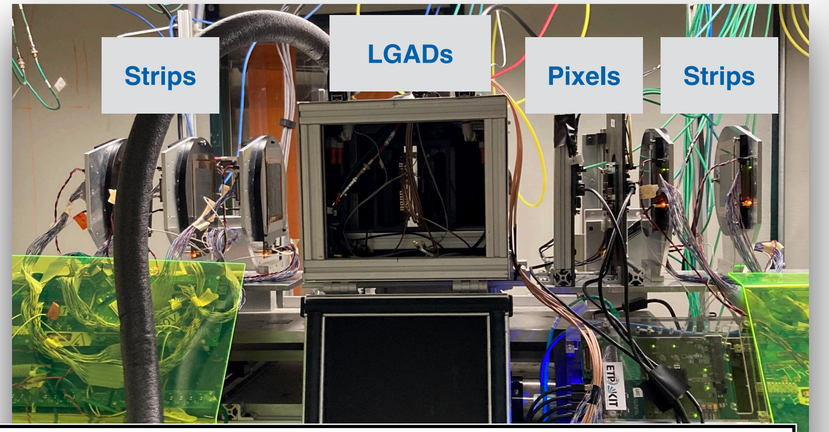
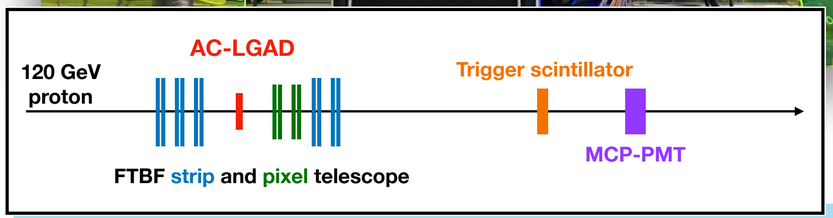
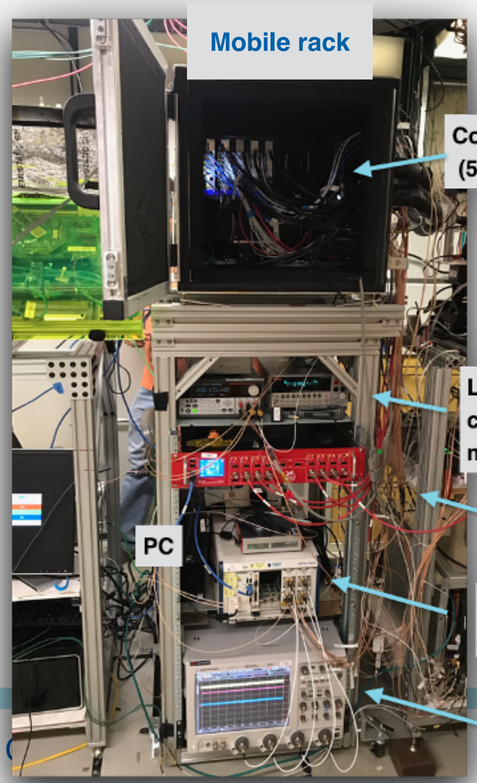
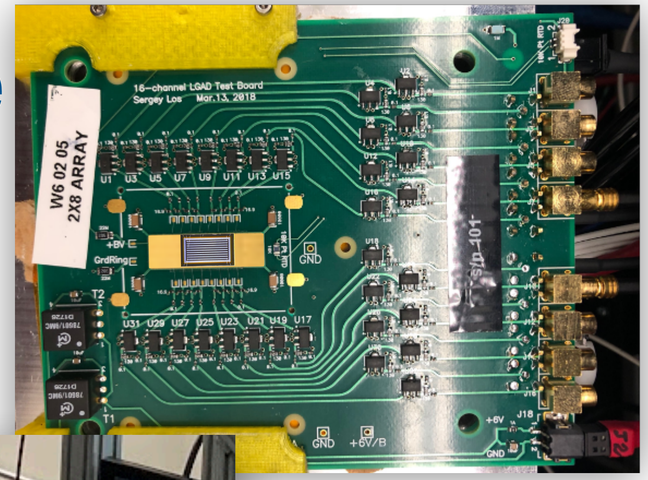
Fermilab 4D-trackers test beam infrastructure

- Permanent setup in FNAL test beam facility (FTBF)
  - Movable: slide in and out of beamline as needed, parasitic use of beam
  - Environmental controls: sensor temperature (-25 C to 20 C), and humidity, monitoring
  - **Time reference with ~ 10 ps resolution (MCP)**
  - DAQ: high bandwidth, high ADC resolution **8-channel scope**
  - Record 20k events during 4 s spill,
  - **Tracker with ~5 µm resolution**
- Developed **readout boards** for the characterization of LGADs
  - Without complex ASIC and DAQ

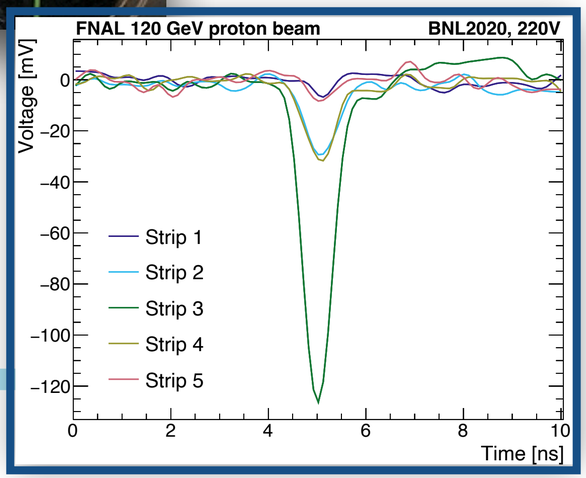








8-channel oscilloscope, 2 GHz, 10 GSa/s



Sensors tested

- Tested samples with various parameters
  - **Resistivity**: C-type and E-type
  - **Coupling capacitance**: 240 and 600
  - **Metal electrode:**
    - For strips 50 and 100 microns width
    - For pixels 150² and 300² microns area
  - **Active thickness**: 20 and 50 microns
  - **Strip pitch:** 80 and 500 microns
  - **Strip length:** 5 and 10 mm

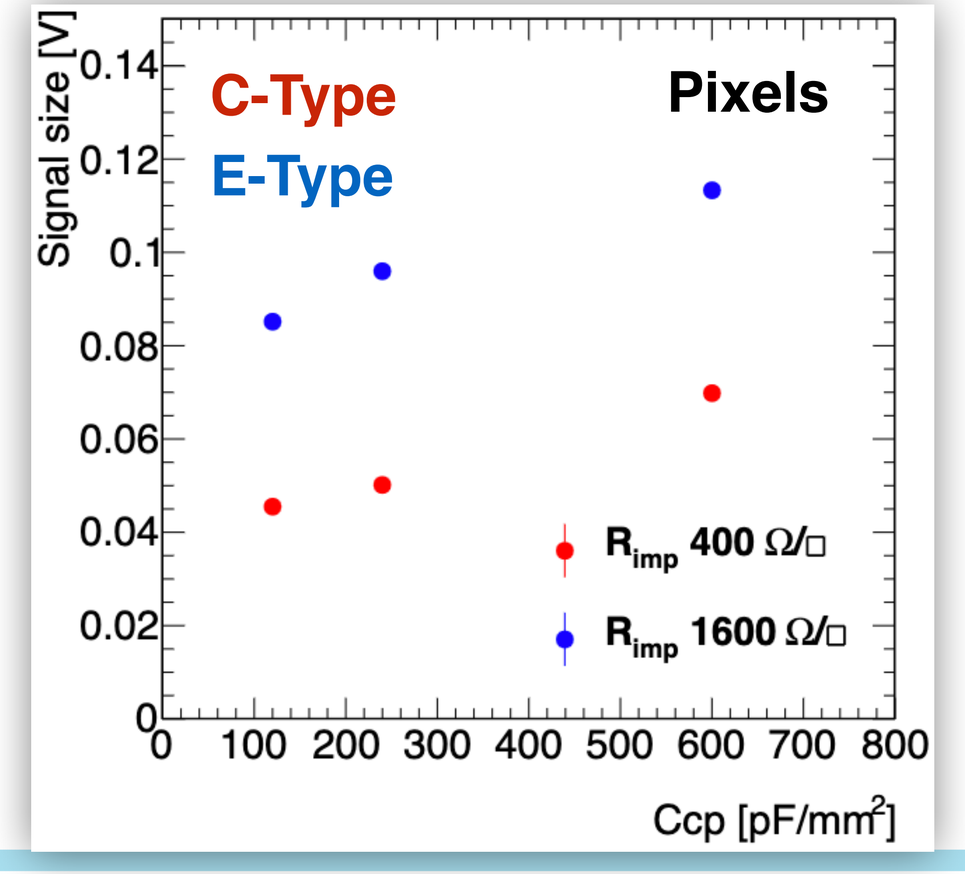
	Wafer_Thickness_Length_Pitch_Metal_Res./CCP
Strips	HPK_W8_50T_1P0_500P_100M_C600
	HPK_W8_50T_1P0_500P_50M_C600
	HPK_W4_50T_1P0_500P_50M_C240
	HPK_W5_50T_1P0_500P_50M_E600
	HPK_W9_20T_1P0_500P_50M_E600
	HPK_W2_50T_1P0_500P_50M_E240
	HPK_W9_20T_1P0_500P_100M_E600
	HPK_W9_20T_0P5_500P_50M_E600
Pixels	HPK_W5_50T_500x500_150M_E600
	HPK_W8_50T_500x500_150M_C600
	HPK_W9_20T_500x500_150M_E600
	HPK_W11_20T_500x500_150M_C600
	HPK_W9_20T_500x500_300M_E600
Small Pitch Strips	HPK_50T_1P0_80P_60M_E240
	HPK_20T_1P0_80P_60M_E240

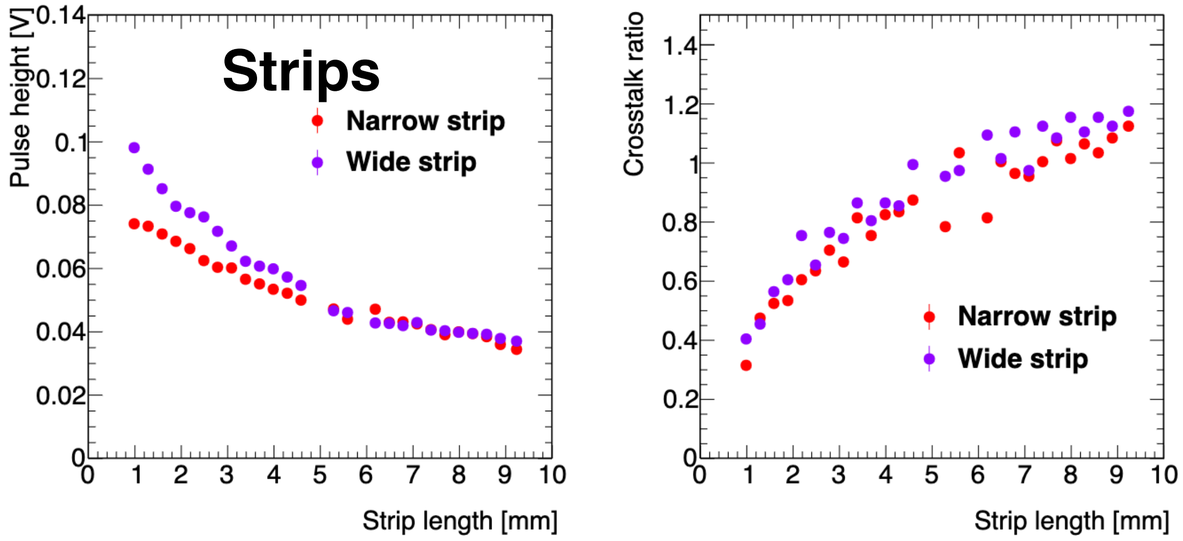
What to expect?

- New paper from beta source measurements: https://arxiv.org/abs/2305.12355
- Higher the resistivity and coupling capacitance → higher the signal (at a cost of signal sharing)
- Longer the strips → Smaller signals

Table II. Physical parameters of the produced sensor types; Strip and Pixel. The overall size, electrode pitch, electrode width, and the numbers of electrodes in column and row directions are summarized. "Cut Strip" contains strips of different lengths (200µm ~ 8890µm) in one sensor.

Sensor type	Strip	Cut Strip	Pixel		
overall dimension (mm)	11.2 × 2.7		2.4 × 2.4		
electrode pitch (µm)	80		100×100	150×150	200×200
electrode dimension (µm)	40, 45, 60, 70 ×9880	40, 60 ×200~8890	90 ×90	140 ×140	190 ×190
#column×#row	16×1		10×10	6×6	5×5





(a) Pulse height.

(b) Crosstalk ratio.

Fig. 5. The pulse height (left) and crosstalk (right) of dedicated strip sensors with different strip lengths which is measured by ^{90}Sr. Narrow and wide strips are with electrodes of 40 µm and 60 µm widths, respectively. The cross-talk ratio is defined as pulse height of leading divided by the sum of neighboring strips.

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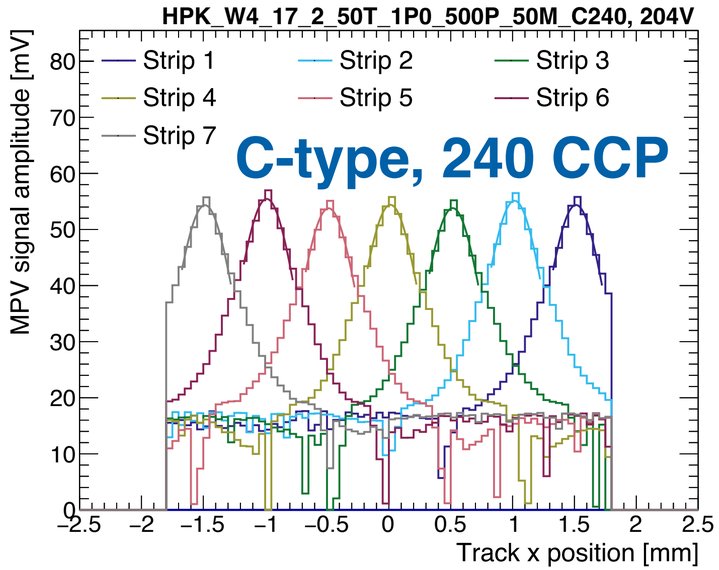
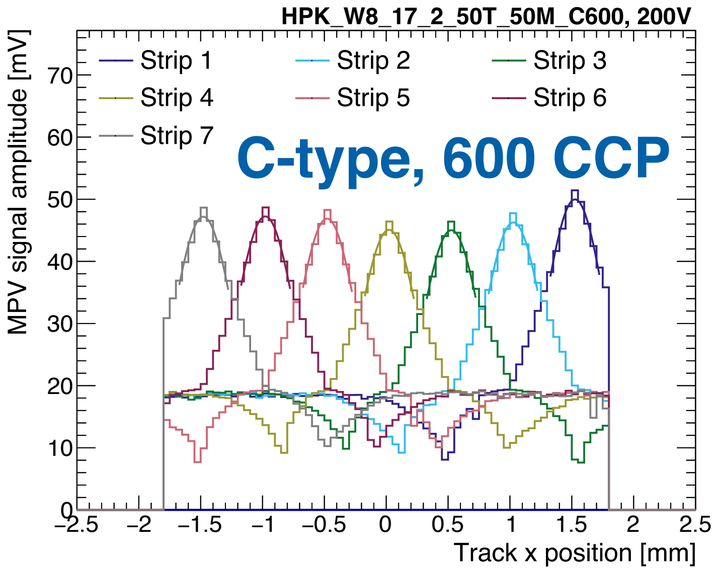
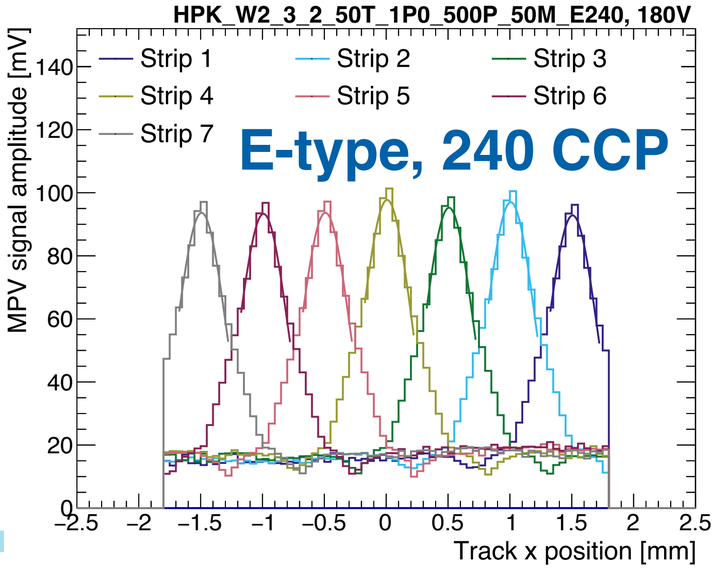
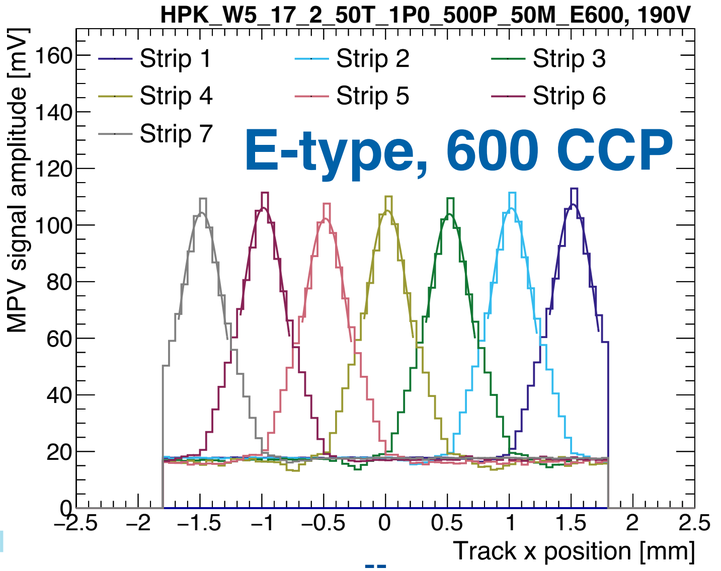
Resistivity and Capacitance

- From pixel beta source results:
  - Expect C-type signals of 50 - 70 mV
  - Observe ~50 mV under metal
  - Expect E-type signals of 90 - 110 mV
  - Observe ~100 mV under metal
- We reproduce beta source results for pixels under strip metal
- Signal drops by 30% or 40% in the gaps for C-type and E-type
- Coupling capacitance does not dominate signal size or sharing
  - Will continue investigating

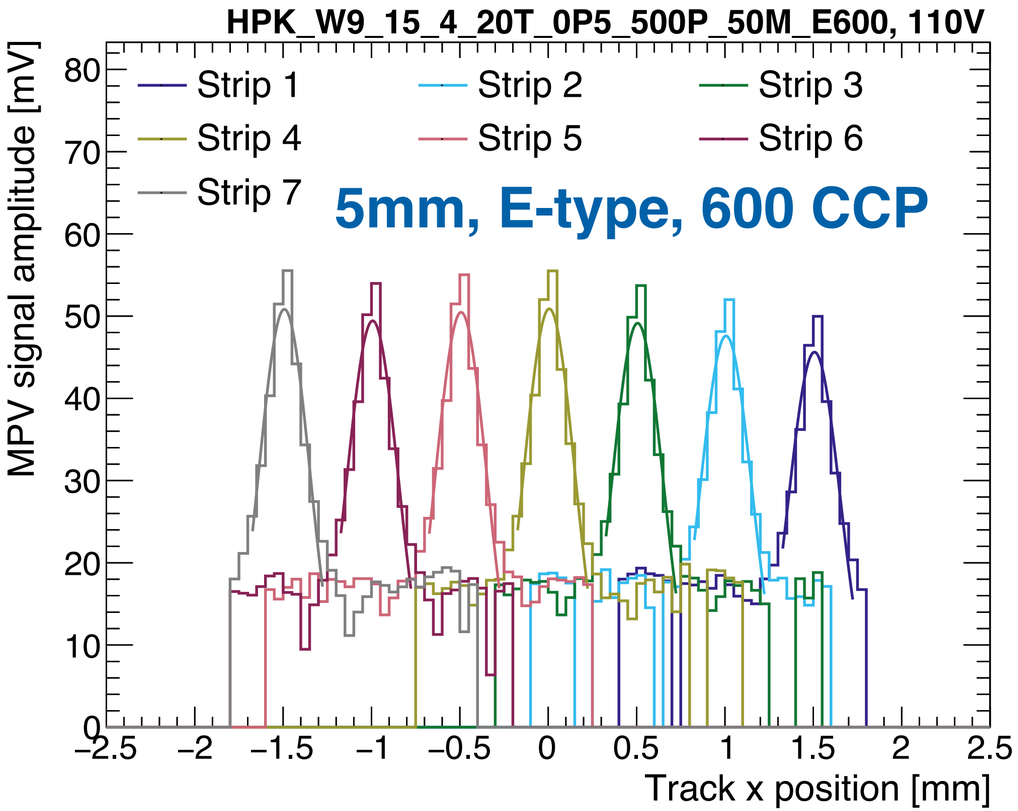


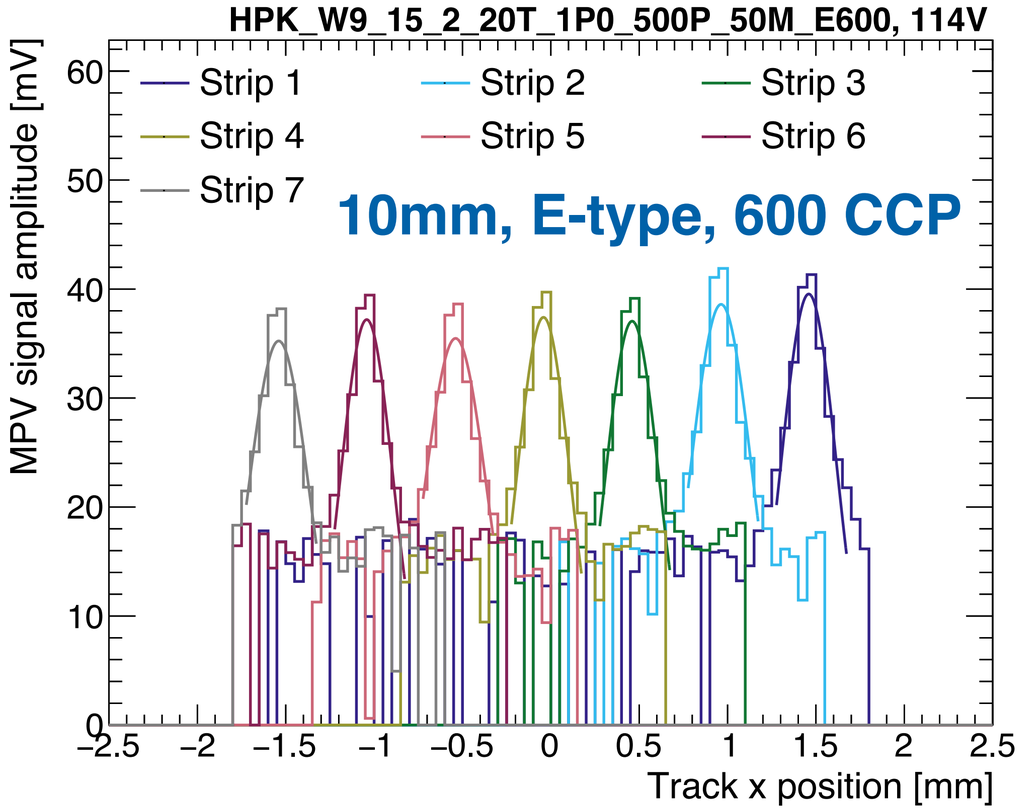






Length Difference

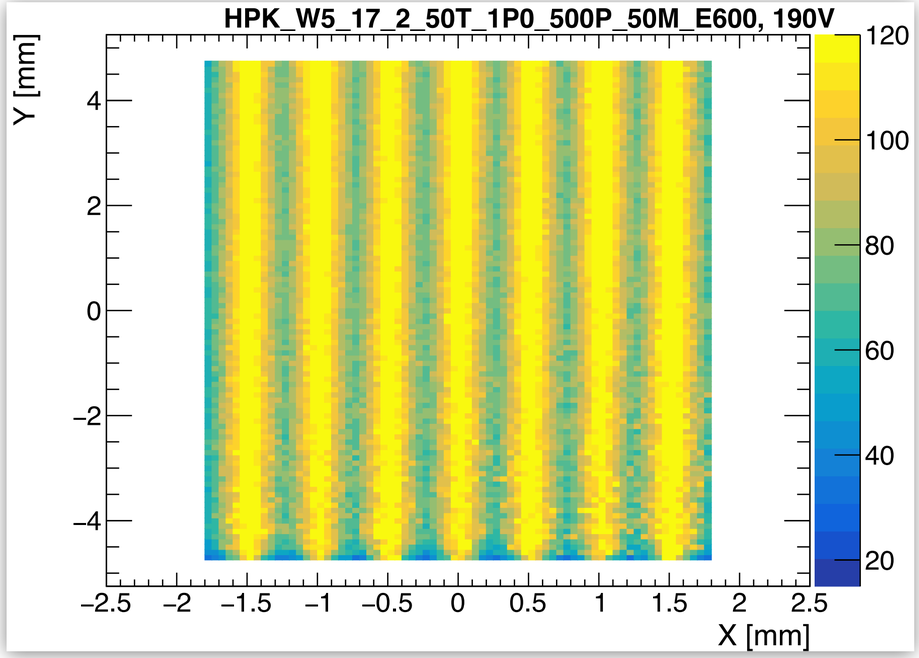




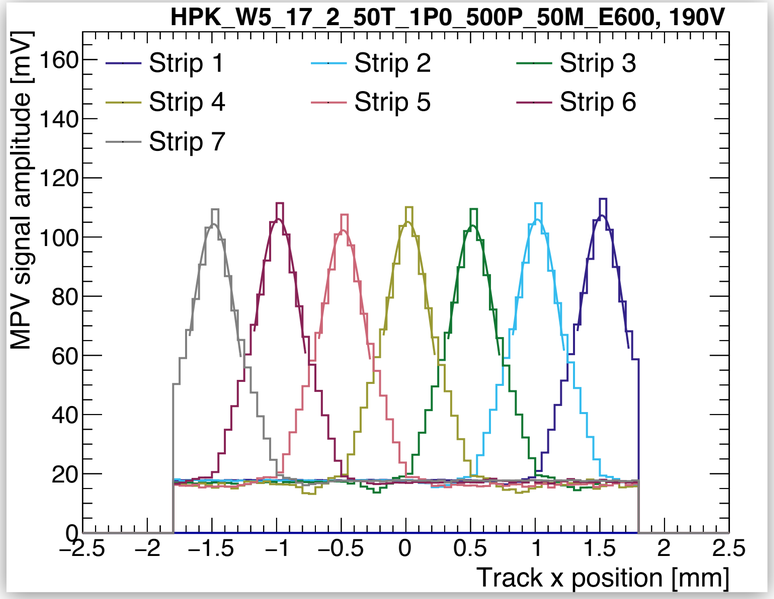
- For the 20 micron thick sensor we observe a ~30% drop in signal size under the metal for 5 vs. 10 mm long strips
- Should expect ~25% drop based on beta source measurements

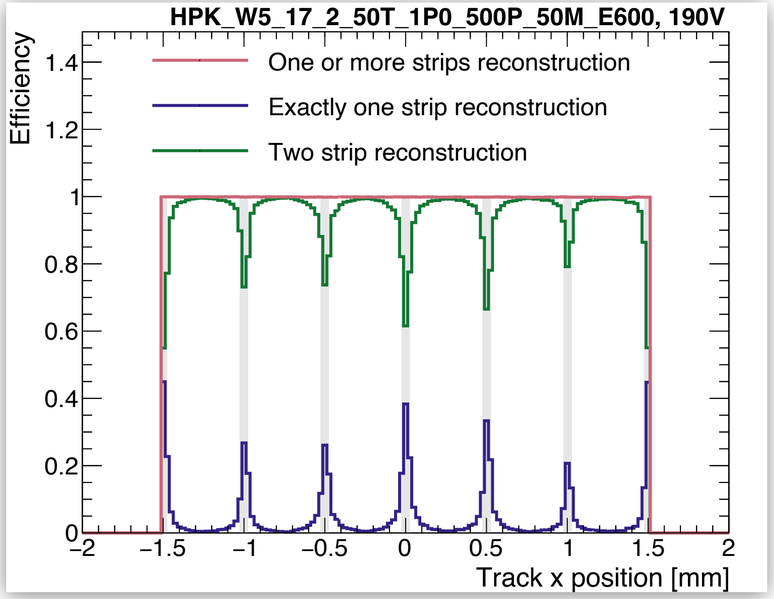
High resistivity 50 micron thick results

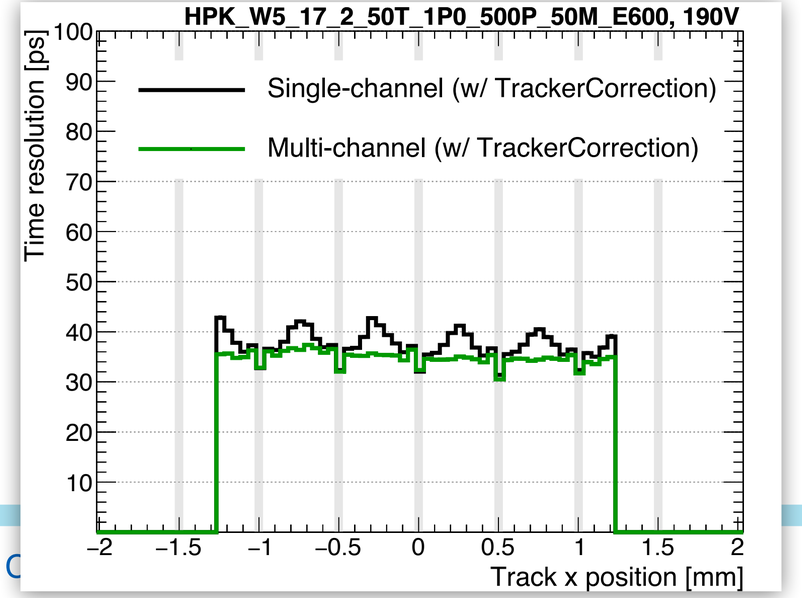
- **Sensor name:**
  - **HPK_W5_50T_1P0_500P_50M_E600**

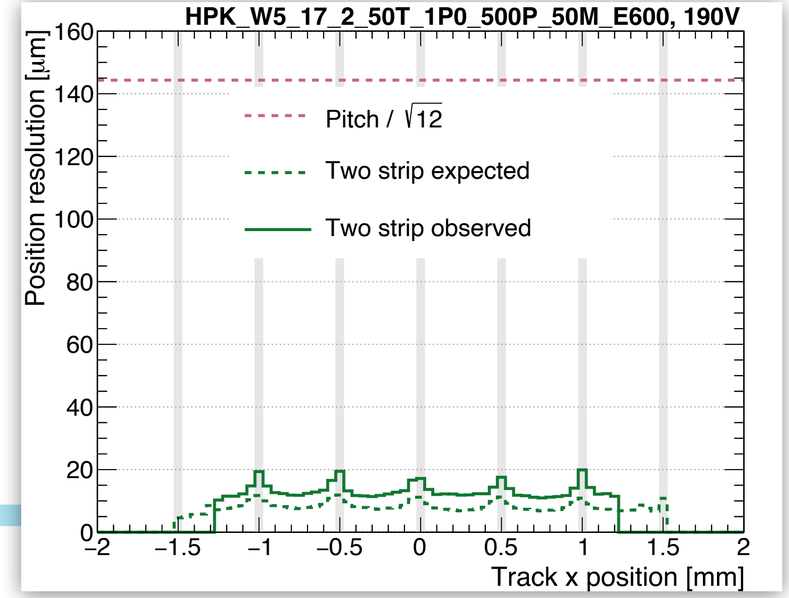


- **Uniform amplitude 60 to 110 mV (gap/metal)**
- **Almost uniform 2-strip cluster eff.**
- **~35 ps and ~15 micron resolution**







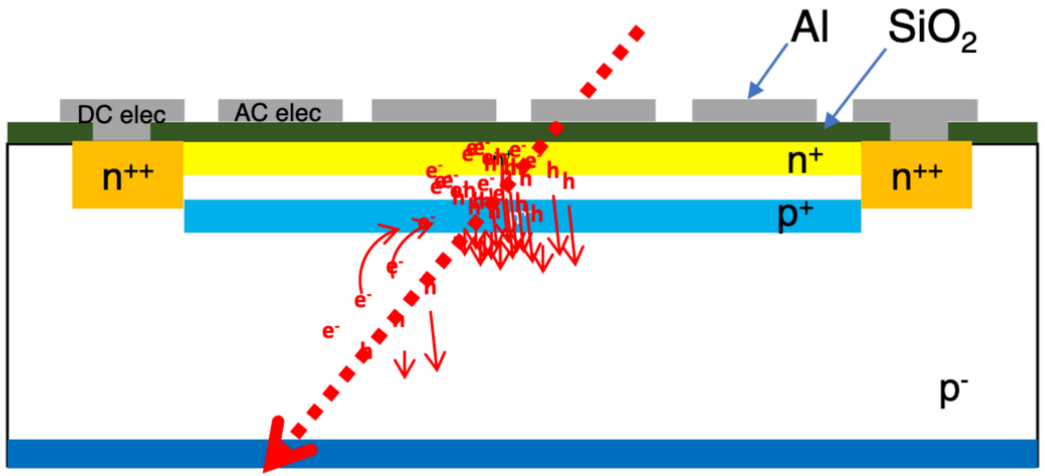


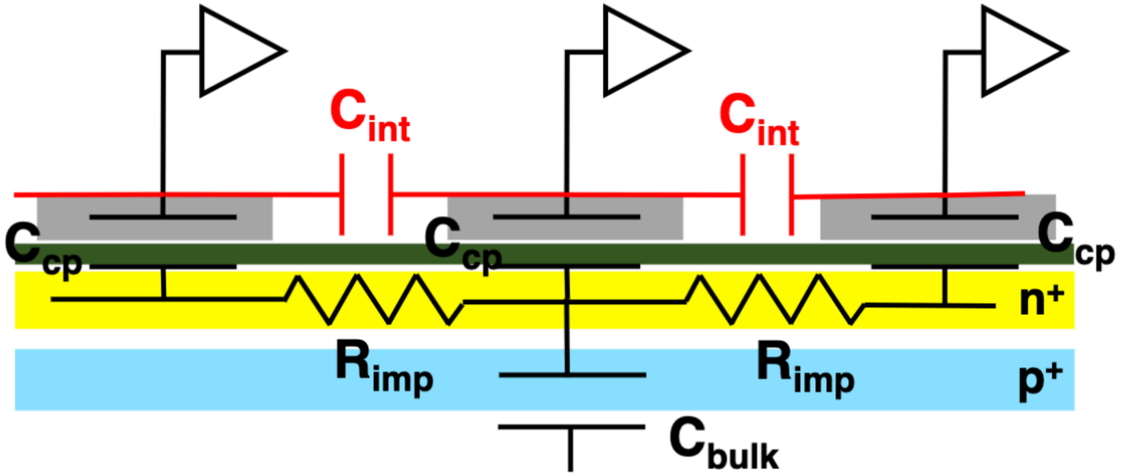
Next steps

- Continue analyzing strip data
  - Plenty more results and conclusions left to be drawn
- Will begin looking at Pixel data this week
- Contribute results to FY23/FY24 proposal
- Write a summary paper for all AC-LGAD results from this year
  - BNL and HPK results
- Draw conclusions for next sensor production

Backup

AC-LGADs Diagrams





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Available HPK Long Strip Sensors

Pitch	Resistivity	Thickness	Length	Metal	Cap.
500 µm	~~E-Type~~	20 µm	5 mm	50 µm	240 pF/mm²
			10 mm		
	C-Type	50 µm	20 mm	100 µm	600 pF/mm²
			25 mm		
80 µm	E-Type	20 µm	10 mm	40 µm	240 pF/mm²
	~~C-Type~~	50 µm	25 mm	60 µm	600 pF/mm²