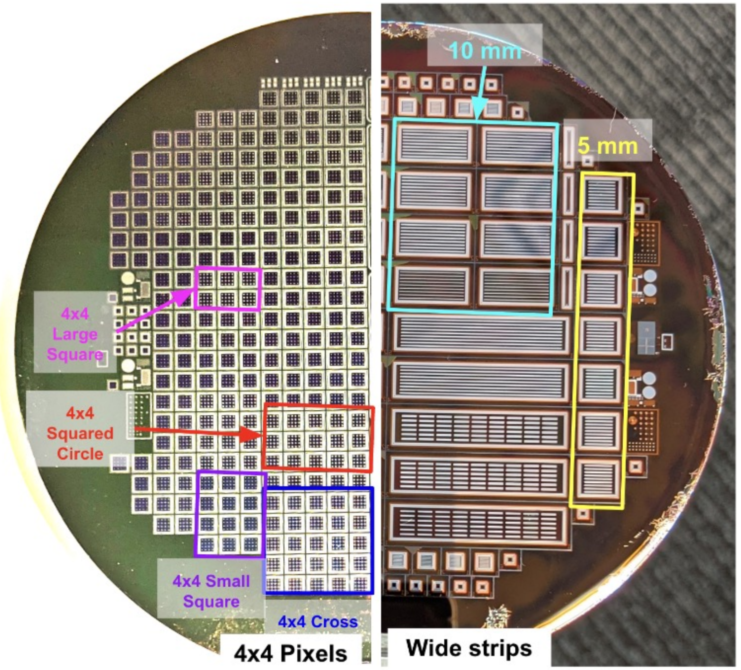
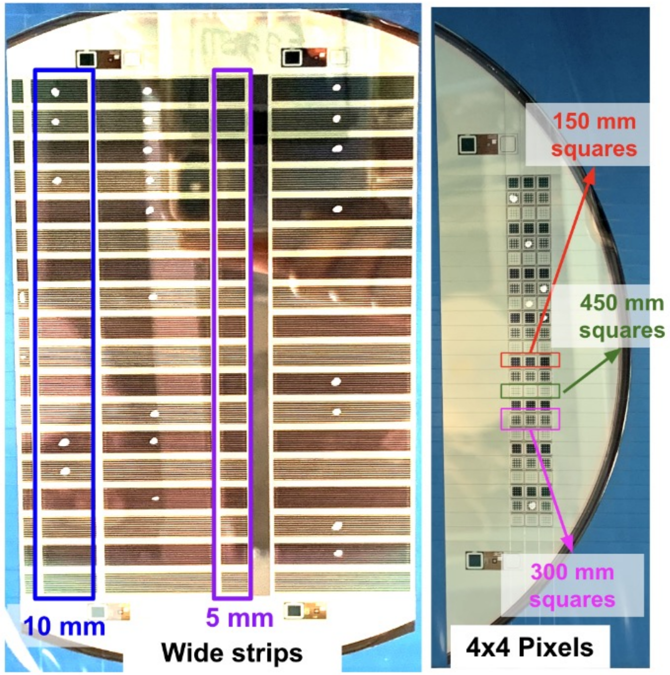
HPK vs BNL AC-LGAD Sensors

ePIC AC-LGAD TOF DSC Weekly Meeting

Shirsendu Nanda

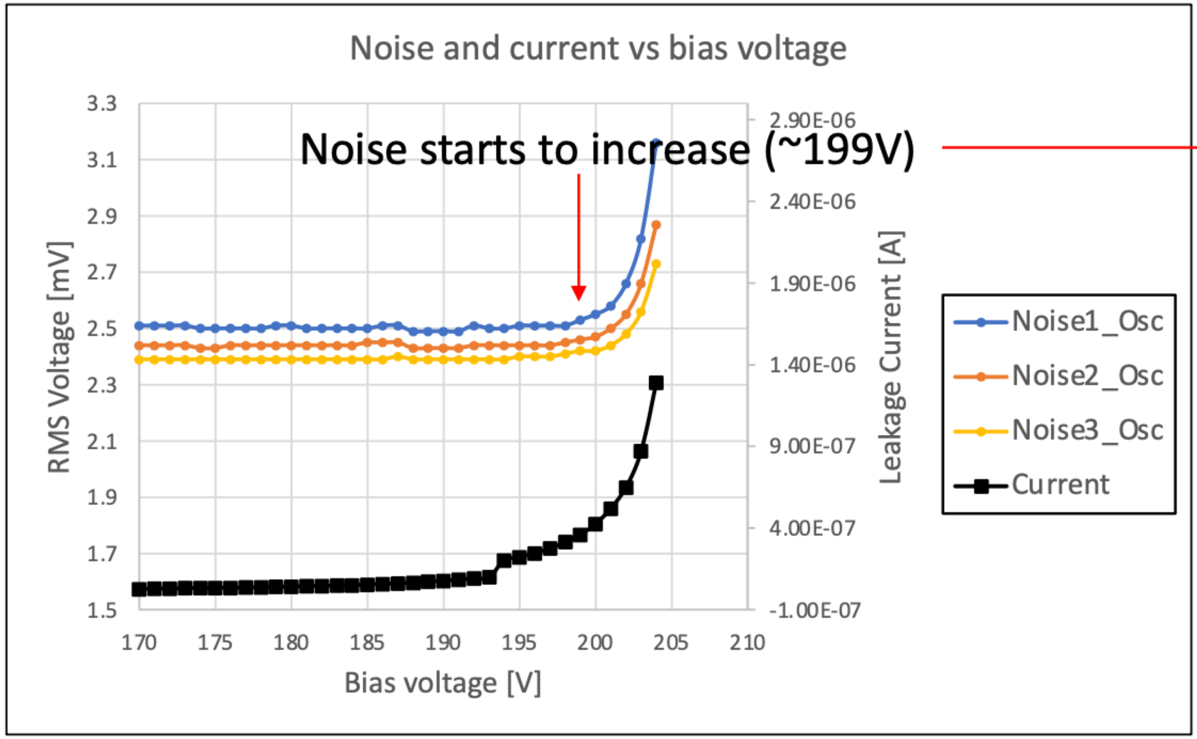


BNL-IO



HPK

Choice of operating voltage:



Sensor is operated at 198V.

- Leakage current vs. bias voltage, and noise (from all channels) vs. bias voltage
- Find the bias voltage where the noise begins to increase. Sensor is operated at 1-2 volts below that bias voltage.
- At the same time keep a check on the leakage current (sensor not operated at very high current)

Systematic Study of Sensor Performance: Strip

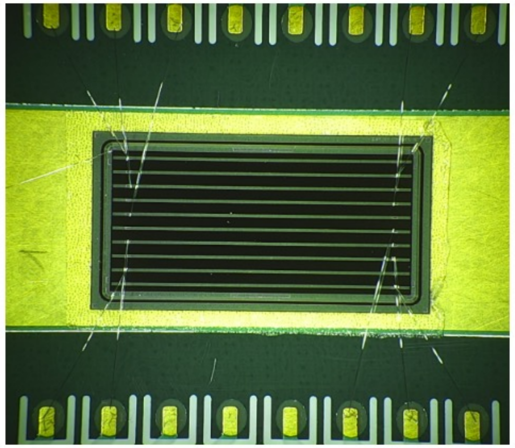
Name	Wafer	Pitch (µm)	Strip length (mm)	Metal width (µm)	Active thickness (µm)	Sheet resistance (Ω/□)	Capacitance (pF/mm^2)	Optimal bias voltage (V)
HPK Wide strip								
SH1	W9				20	1600	600	114
SH2	W4					400	240	204
SH3	W8			50	50		600	200
SH4	W2	500	10			1600	240	180
SH5	W5						600	190
SH6	W9			100	20	1600	600	112
SH7	W8				50	400	600	208
BNL Wide strip								
SB1	WB1			50	50	1400	270	170
SB2	WB1	500	10	100	50	1400	270	160
SB3	WB2			50	50	1400	260	185

HPK 50 um thick

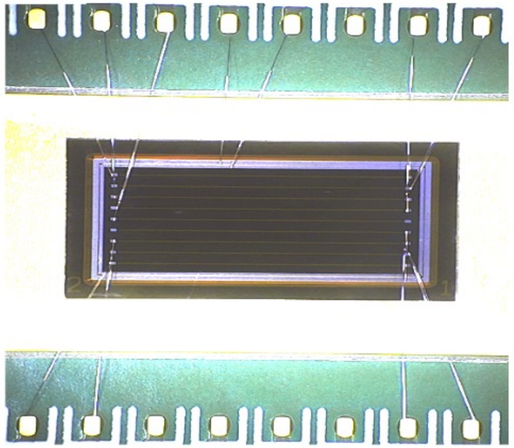
BNL 50 um thick, higher capacitance

BNL 50 um thick, lower capacitance

SH7



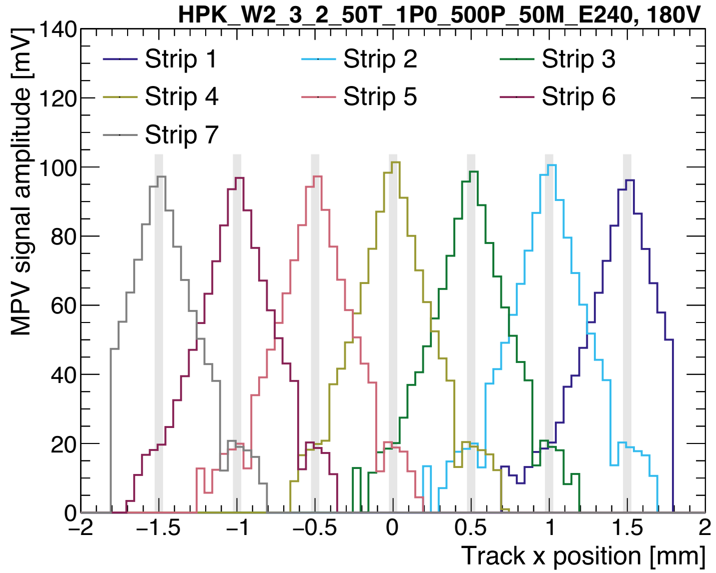
SB1

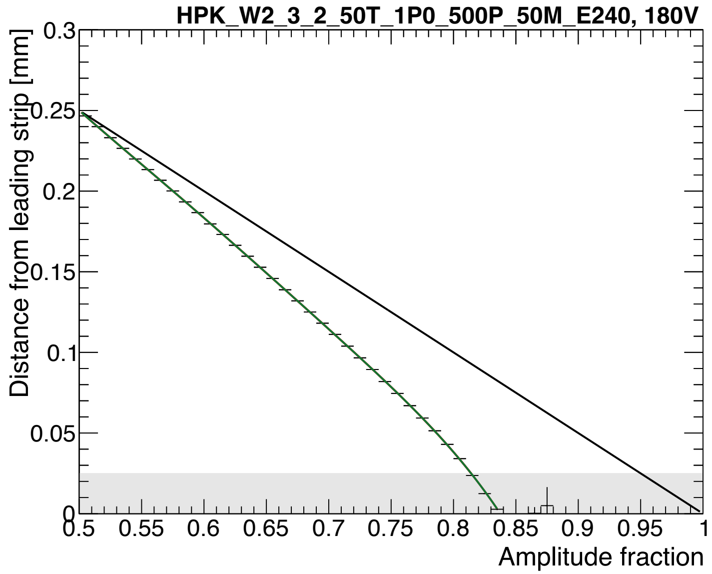


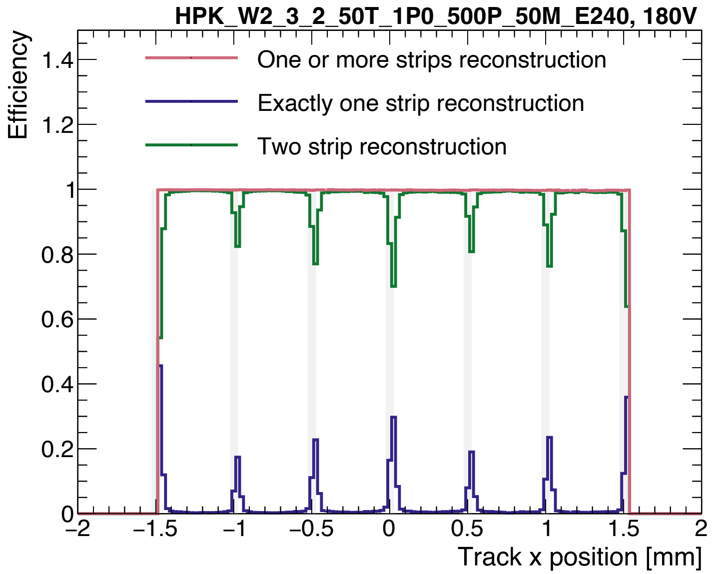
Spatial resolution in AC-LGADs:

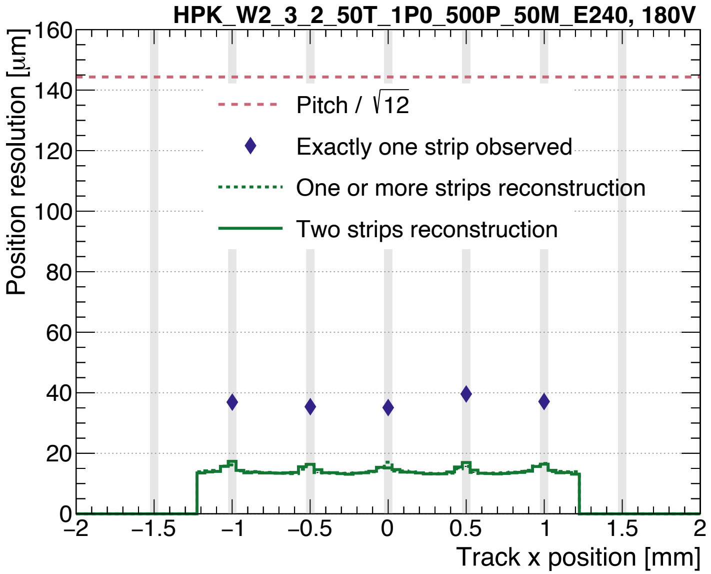
HPK Strip : 10 mm length, 500 μm pitch, 50 μm metal width, 1600 Ω/□ resistivity, and 240 pF/mm² capacitance

- Signal sharing between strips enables the x position reconstruction
- 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







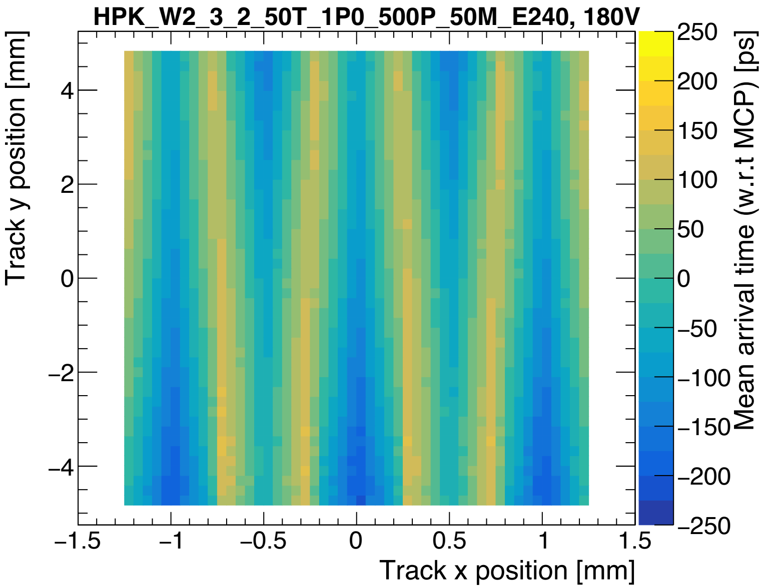


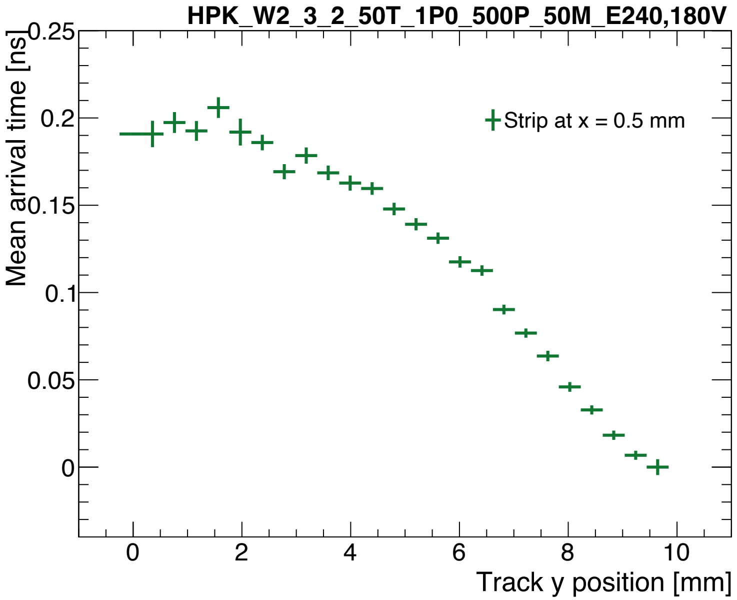
- Efficiency reaches ~100%
- Two-strip resolution ~ 12 – 15 μm
- One-strip resolution ~ 40 μm on metal

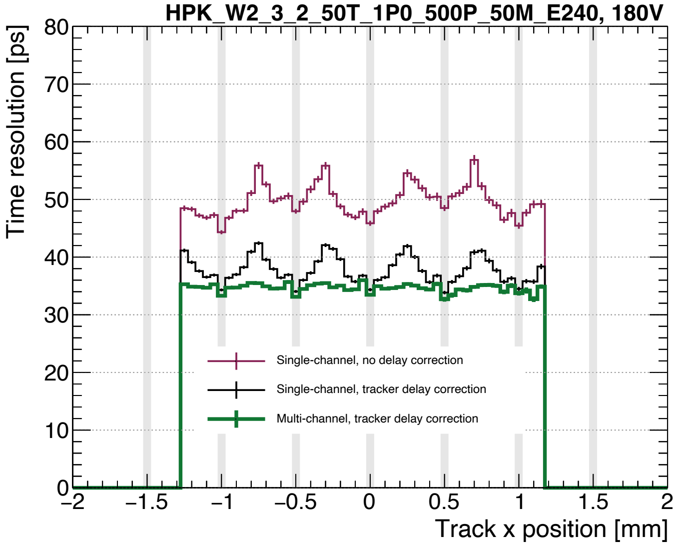
Time resolution in AC-LGADs:

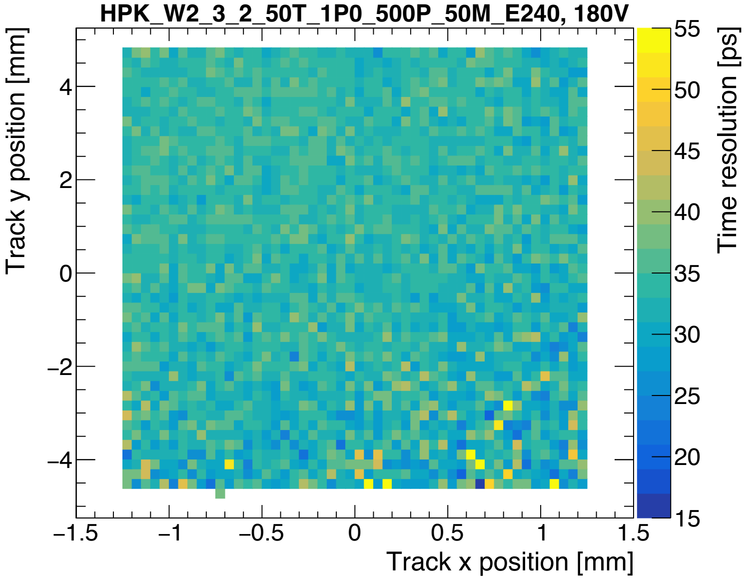
HPK Strip : 10 mm length, 500 µm pitch, 50 µm metal width, 1600 Ω/□ resistivity, and 240 pF/mm^2 capacitance

- Due to larger electrodes, distant signals arrival with delays O(100 ps)
- Position-dependent time delay correction is essential, using the external tracker
- Delay map use the resolution of 50 µm for x position and 200 µm for y position
- Multi-channel time stamp, $t_{reco} = \frac{a_1^2 t_1 + a_2^2 t_2}{a_1^2 + a_2^2}$





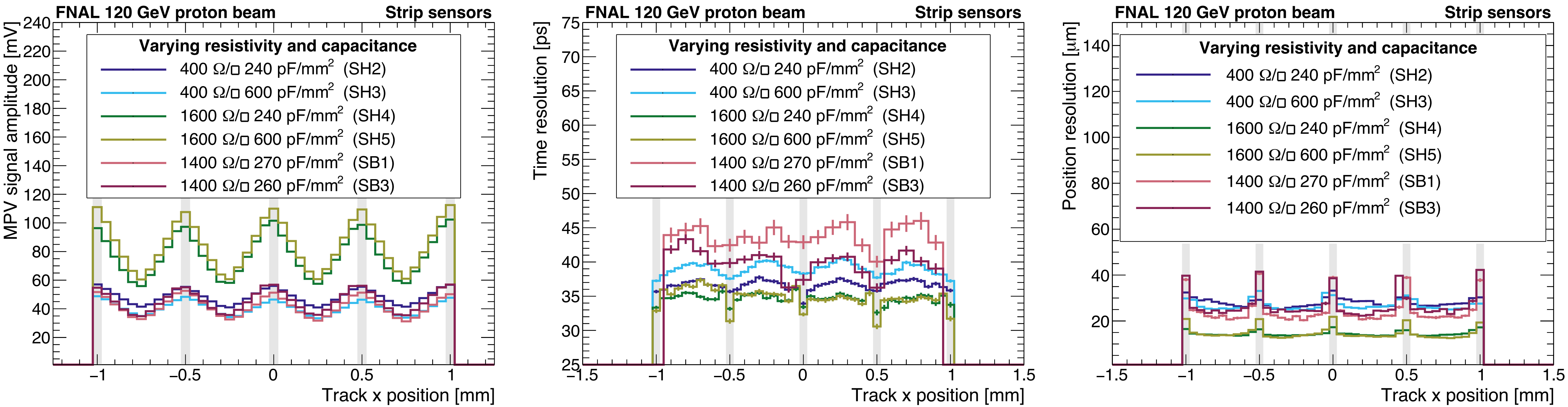




- Without delay correction, the time resolution ~ 45 – 55 ps
- Adding the tracker-based delay corrections improves the resolution to ~ 35 – 42 ps
- Using multi-channel timestamp with delay correction, time resolution ~ 34 ps

Test Beam Results on Strip Sensors (BNL vs HPK):

50 um thick, 50 um metal width and 500 um pitch



Summary

- **HPK (SH2, SH3, SH4, SH5):**
  - Higher n+ resistivity = less charge sharing = higher signal amplitude = less jitter = better timing resolution
  - Higher AC-coupling capacitance = less charge sharing = higher signal amplitude
- **HPK vs BNL (SB1, SB3)**
  - Amplitude and resolution of BNL sensors similar like lower resistivity (C-type) HPK sensors
  - Signal amplitude, timing and position resolutions of HPK sensors are much better than BNL-IO sensors

Systematic Study of Sensor Performance: Pixel

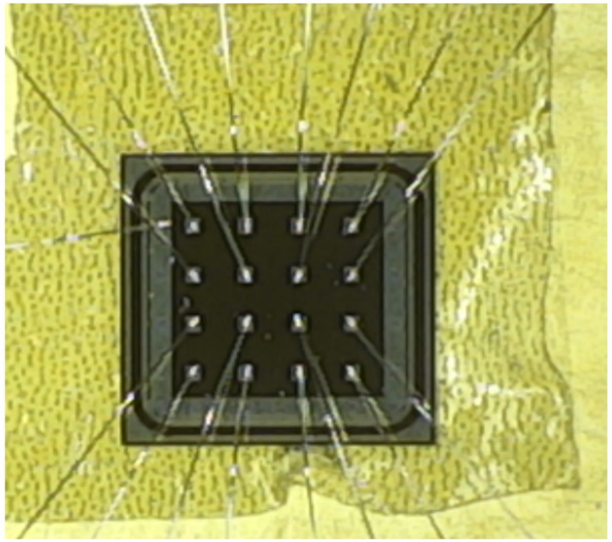
Name	Wafer	Pitch [µm]	Metal width [µm]	Active thickness [µm]	Sheet resistance [Ω/□]	Capacitance [pF/mm^2]	Optimal bias voltage [V]
HPK 2 x 2 Square pixel							
PH1	WP1	510	500	20	1600	600	105
PH2	WP2			30	1600	600	140
PH3	WP3			50	1600	600	190
HPK 4 x 4 Square pixel							
PH4	W11	500	150	20	400	600	116
PH6	W8			50	400	600	200
PH7	W5				1600	600	185
PH8	W9		300	20	1600	600	112
BNL 4 x 4 Square pixel							
PB1	WP4	500	100	20	1400		76
PB2	WP4		200	20	1400	695	80
BNL 4 x 4 Squared Circle pixel							
PB3	WP4	500	110(*)	20	1400	695	85
BNL 4 x 4 Cross pixel							
PB4	WP4	500	400×25(**)	20	1400	695	80
BNL 4 x 4 Square pixel							
PB5	WP5	500	100	30	1400	385	115
PB6	WP5		200	30	1400	385	115
BNL 4 x 4 Squared Circle pixel							
PB7	WP5	500	110(*)	30	1400	385	110
BNL 4 x 4 Cross pixel							
PB8	WP5	500	400×25(**)	30	1400	385	115

HPK 20 um thick square (PH4)

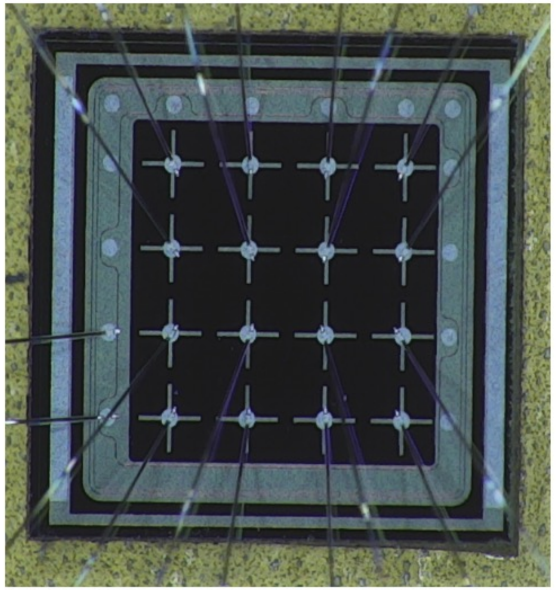
BNL 20 um thick
- Small Square (PB1)
- Large Square (PB2)
- Squared circle (PB3)
- Cross (PB4)

BNL 30 um thick
- Small Square (PB5)
- Large Square (PB6)
- Squared circle (PB7)
- Cross (PB8)

PH4



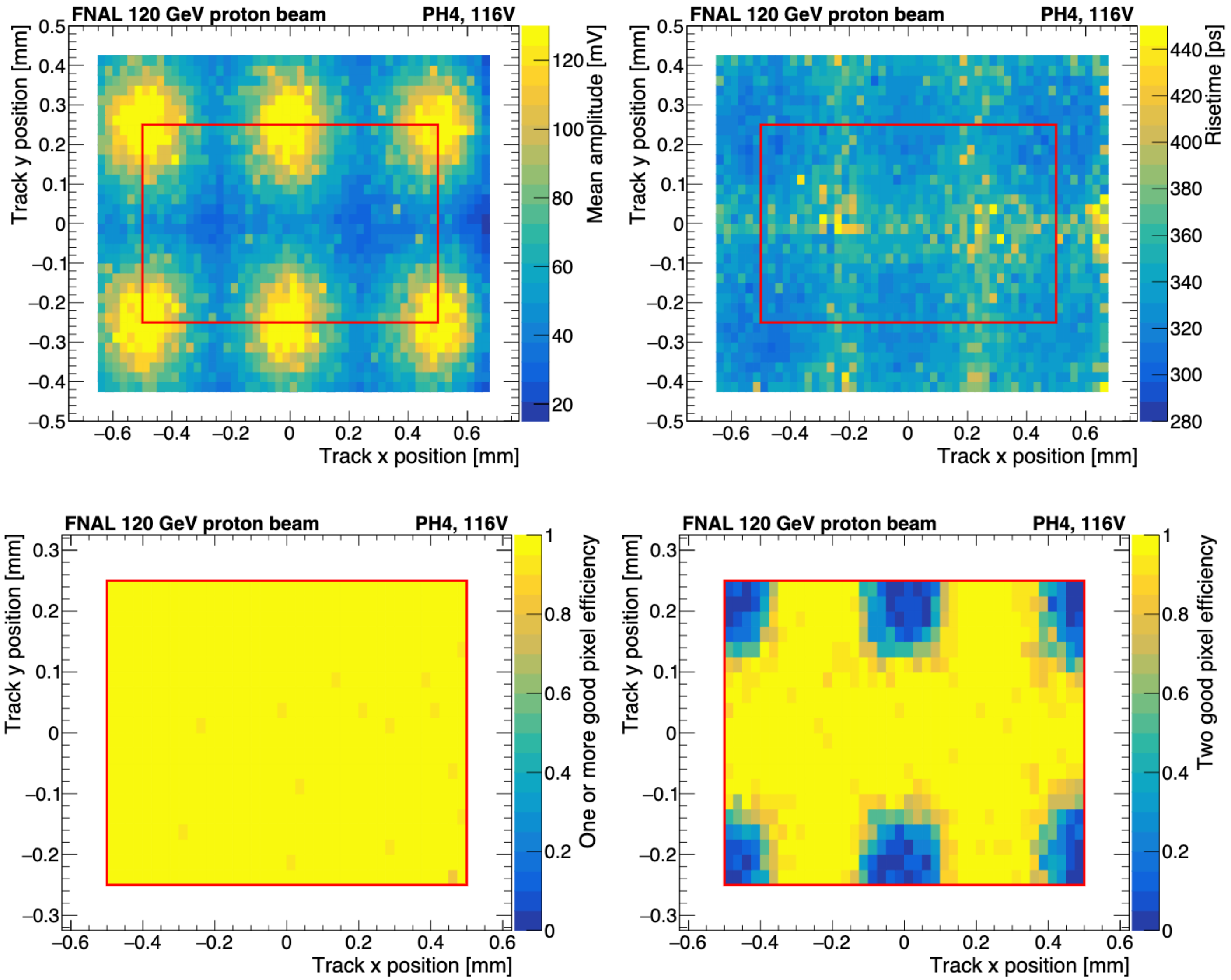
PB4



(*) diameter of the circular metal pad
(**)sensor pads form a cross shape with two metal strips that are 400 µm long and 25 µm wide

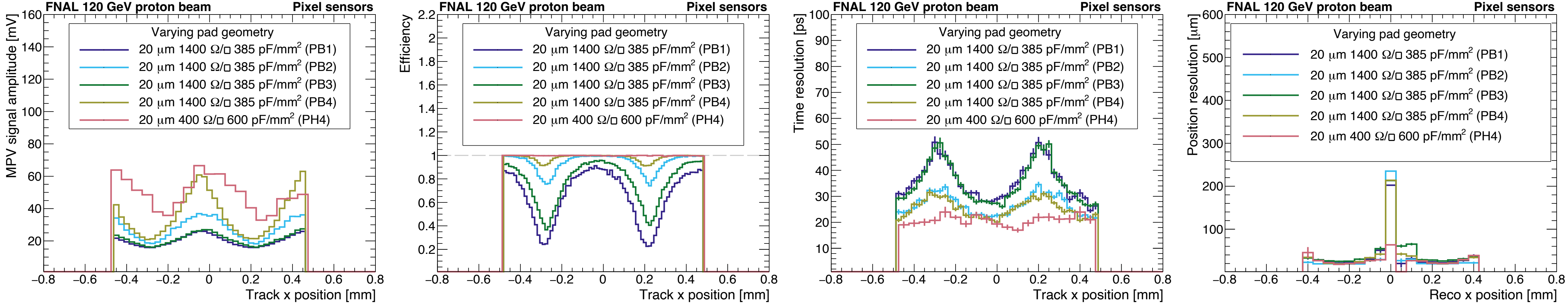
AC-LGAD pixel sensors:

HPK Pixel : 500 x 500 μm pitch, 20 μm thickness, 150 μm metal width, 400 Ω/□ resistivity, and 600 pF/mm² capacitance



- Larger signal size in metal pads compared to gap region
- Faster signals in metal pads and relatively slower in gap region
- 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 gap region and suffers in metal region

Test Beam Results on Pixel Sensors (BNL vs HPK):
20 um thick, 500 X 500 um pitch with different metal width



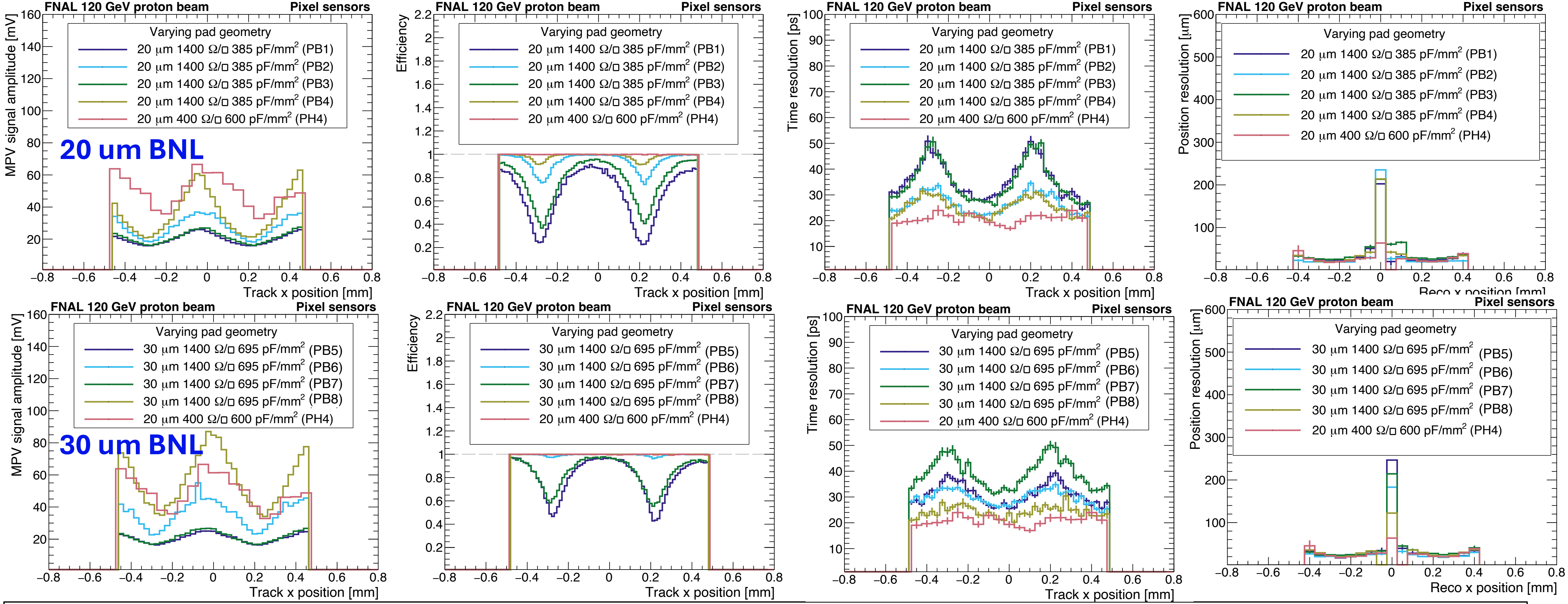
Summary

- **BNL 20 um (PB1, PB2, PB3, PB4)**
  - PB1 and PB3 have significantly smaller signal size
  - BNL pixel sensors with smaller signal size not able to achieve 100% efficiency across the surface
  - Poor timing resolution in the gap region and poor position resolution on metal pad

- **HPK 20 um (PH4) vs BNL 20 um (PB1, PB2, PB3, PB4)**
  - Signal amplitude, efficiency, timing and position resolutions of HPK sensors are much better than BNL-IO sensors

PB1: Small square **PB2:** Large square **PB3:** Squared circle **PB4:** Cross

Test Beam Results on Pixel Sensors (BNL vs HPK)

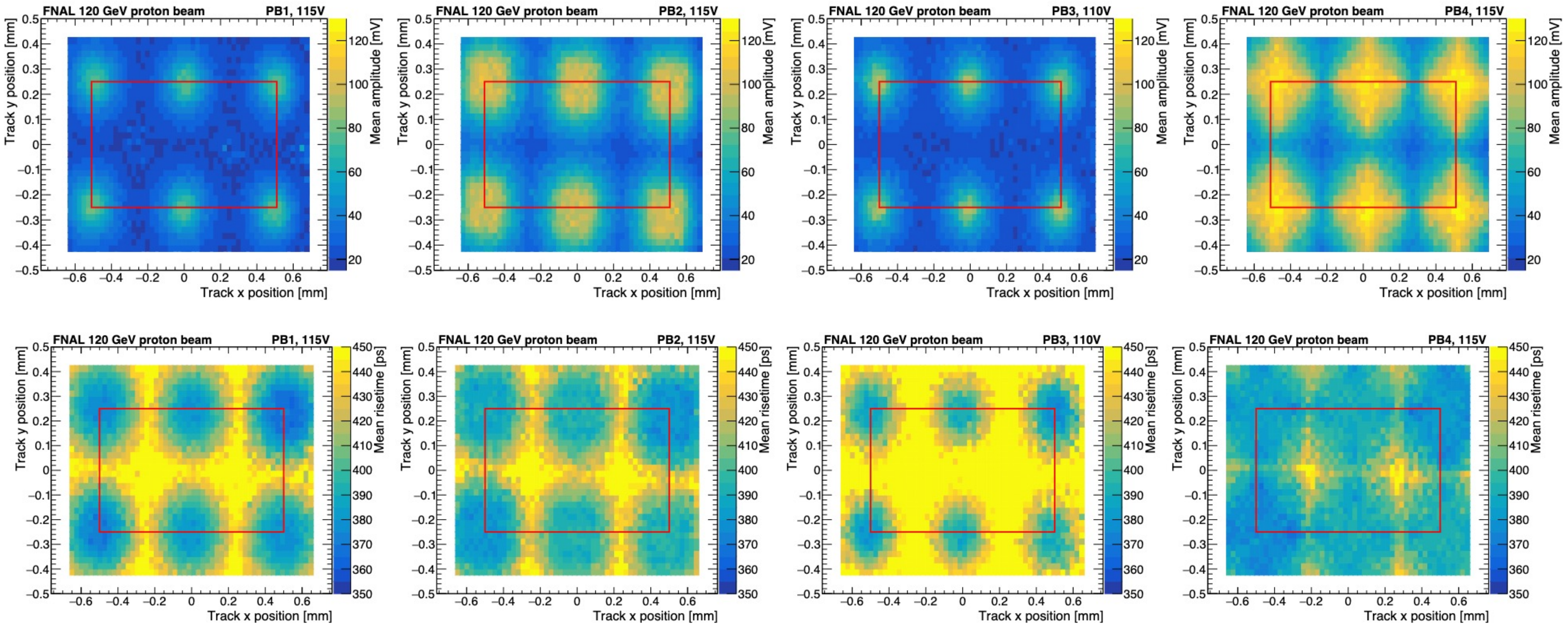


- **HPK 20 um (PH4) vs BNL 20 um (PB1, PB2, PB3, PB4)**
  - Signal amplitude, efficiency, timing and position resolutions of HPK sensors are much better than BNL-IO sensors
- **HPK 20 um (PH4) vs BNL 30 um (PB5, PB6, PB7, PB8)**
  - Efficiency, timing and position resolutions of HPK sensors are better than BNL-IO sensors
  - Cross sensor (PB8) performance is similar like PH4
    - Slightly worse timing resolution due to larger Landau term in PB8
    - PB8 position resolution (140um) at the metal worse than PH4 (60um). Unclear if this can be improved

Extra slides

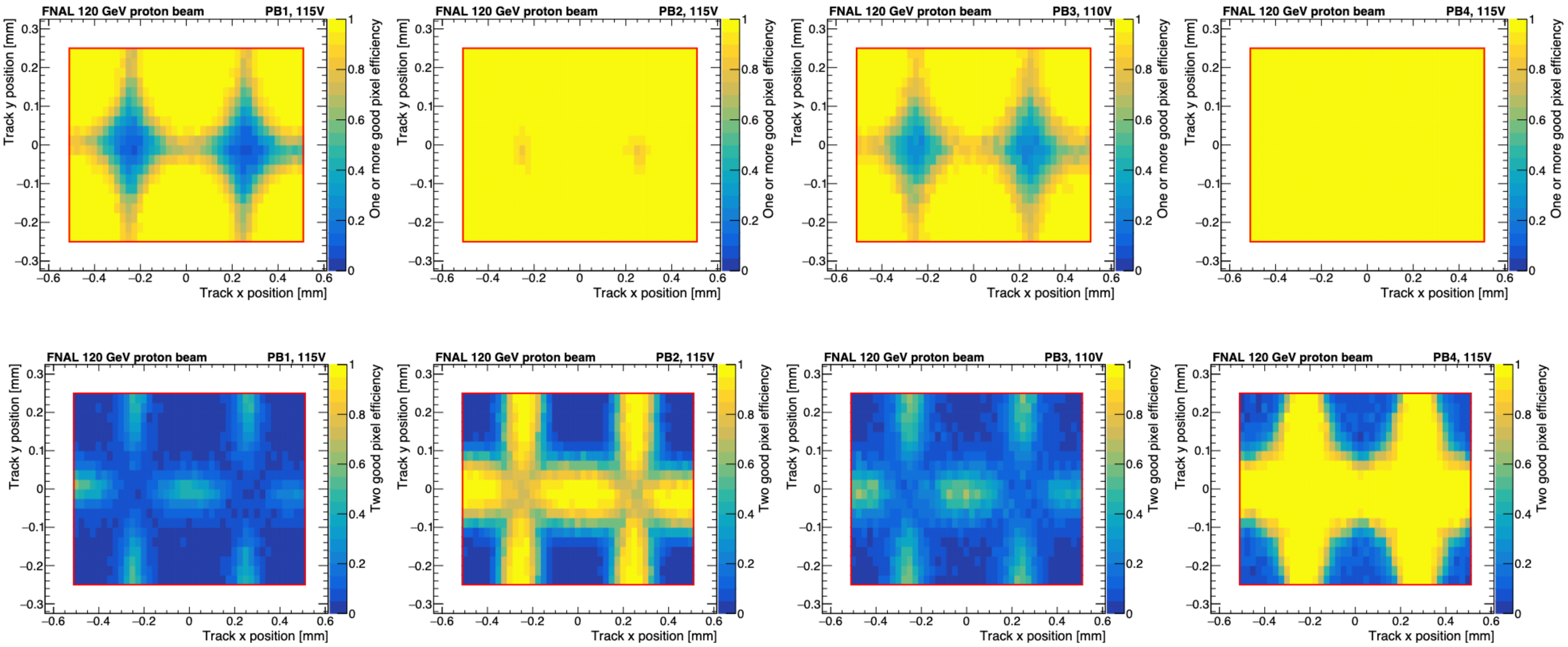
BNL Pixel Sensors (500 x 500 um pitch): 30 um thick

small squares | **large squares** | **squared circles** | **crosses**



BNL Pixel Sensors (500 x 500 um pitch): 30 um thick

small squares | large squares | squared circles | crosses



BNL and HPK Pixel Sensors (500 x 500 um pitch): Two-column Efficiency