Preliminary Test Beam Results on 2nd BNL Production

Christopher Madrid
eRD112/LGAD Consortium Meeting
February 22, 2023

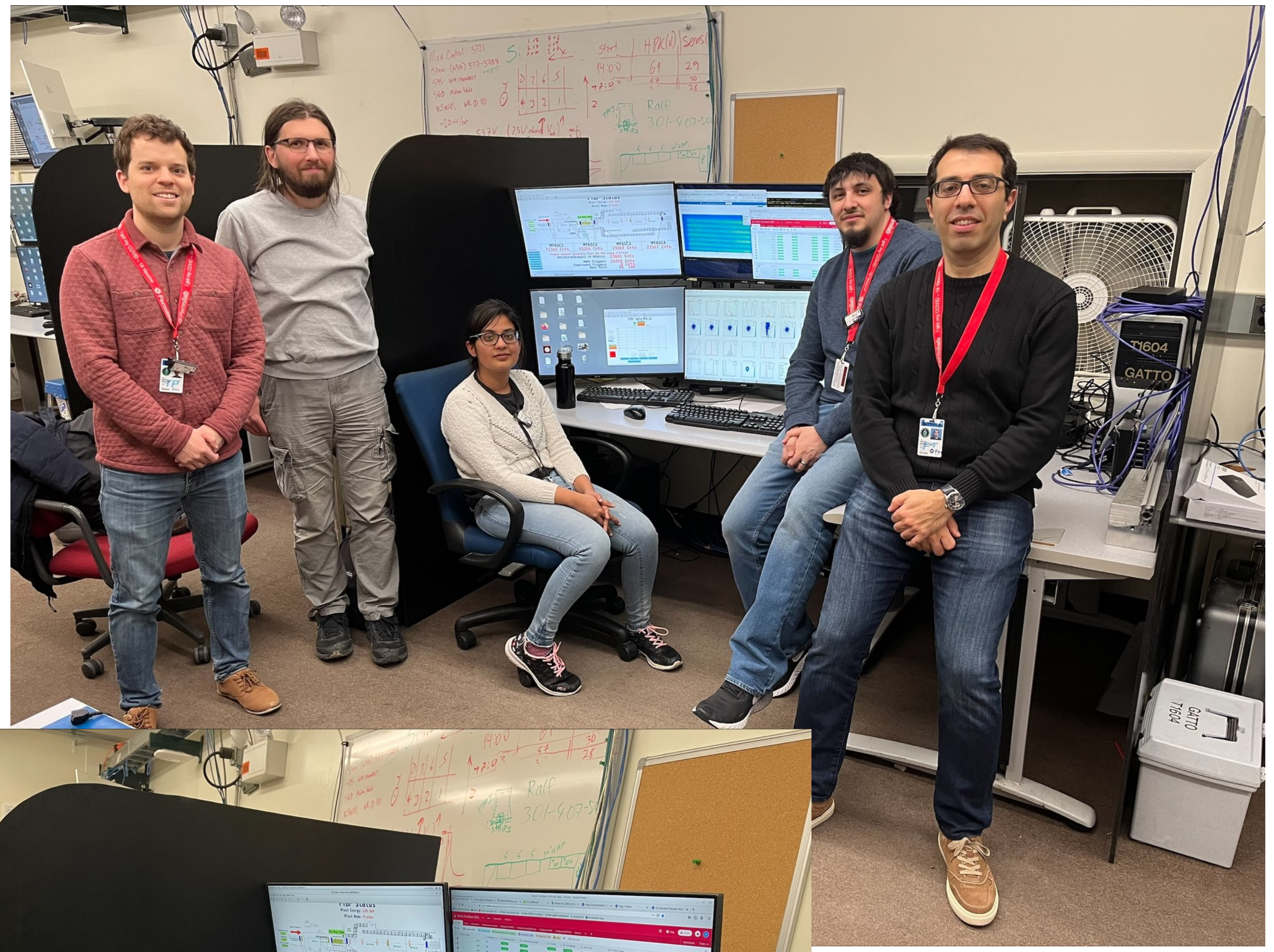
Introduction

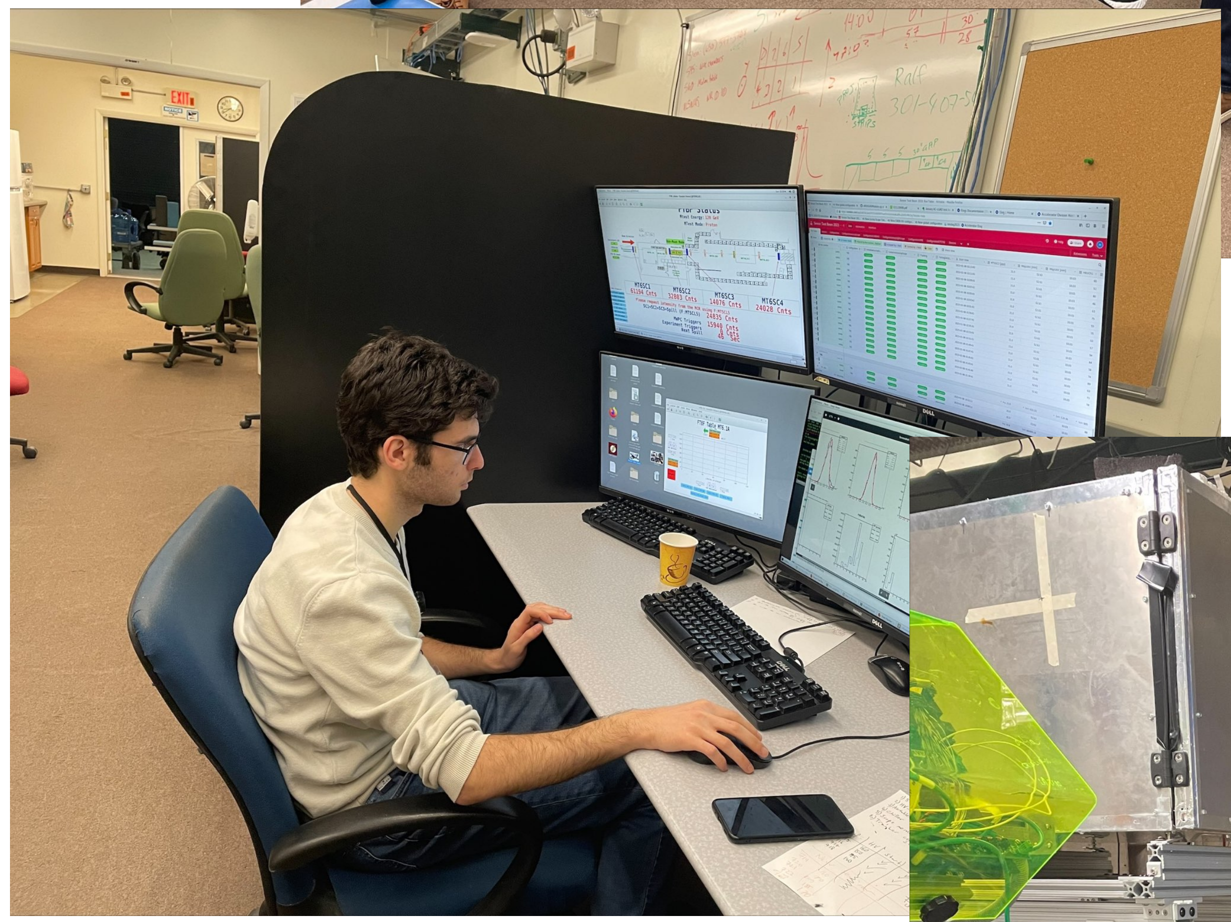
- **Studying AC-LGAD sensors with 500 µm pitch at the FNAL beam test facility**

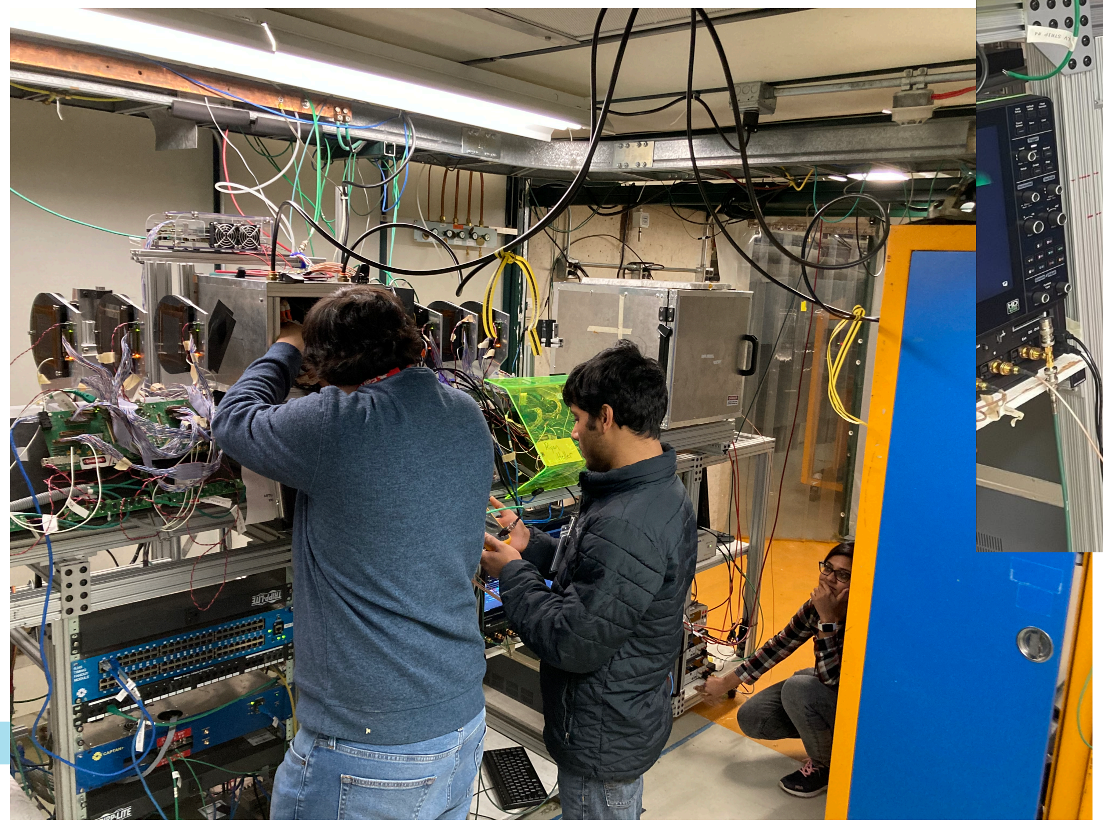
- Performed a **beam test in March 2022** focusing on first batch of long strip BNL sensors
  - Previous test beam presentation to eRD112 (link)
  - Paper detailing 2022 beam test results (arxiv.2211.09698)

- **Recently concluded another beam test on second batch of long strip BNL sensors and new HPK 500x500 µm² pixels**
  - January 4-10th, 2023

- January 2023 beam test measurement goals
  - **Confirm previous performance with uniform gain sensors**
  - **Measure performance with 50 µm width metal electrodes**
  - **Study impact of 50 µm vs. 20 µm active thickness for 1cm length BNL sensors**
  - **Study thickness variation for HPK pixels**

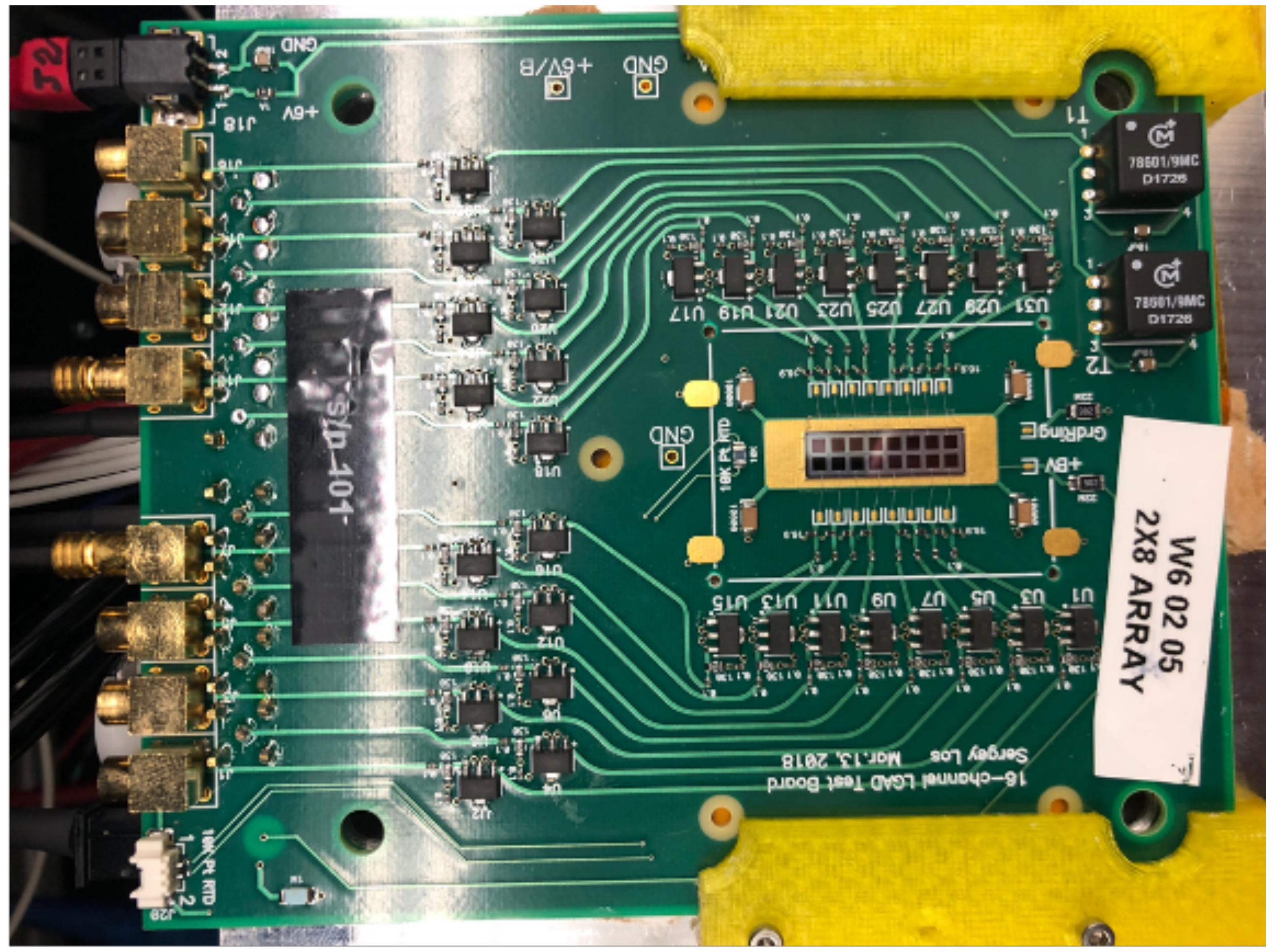


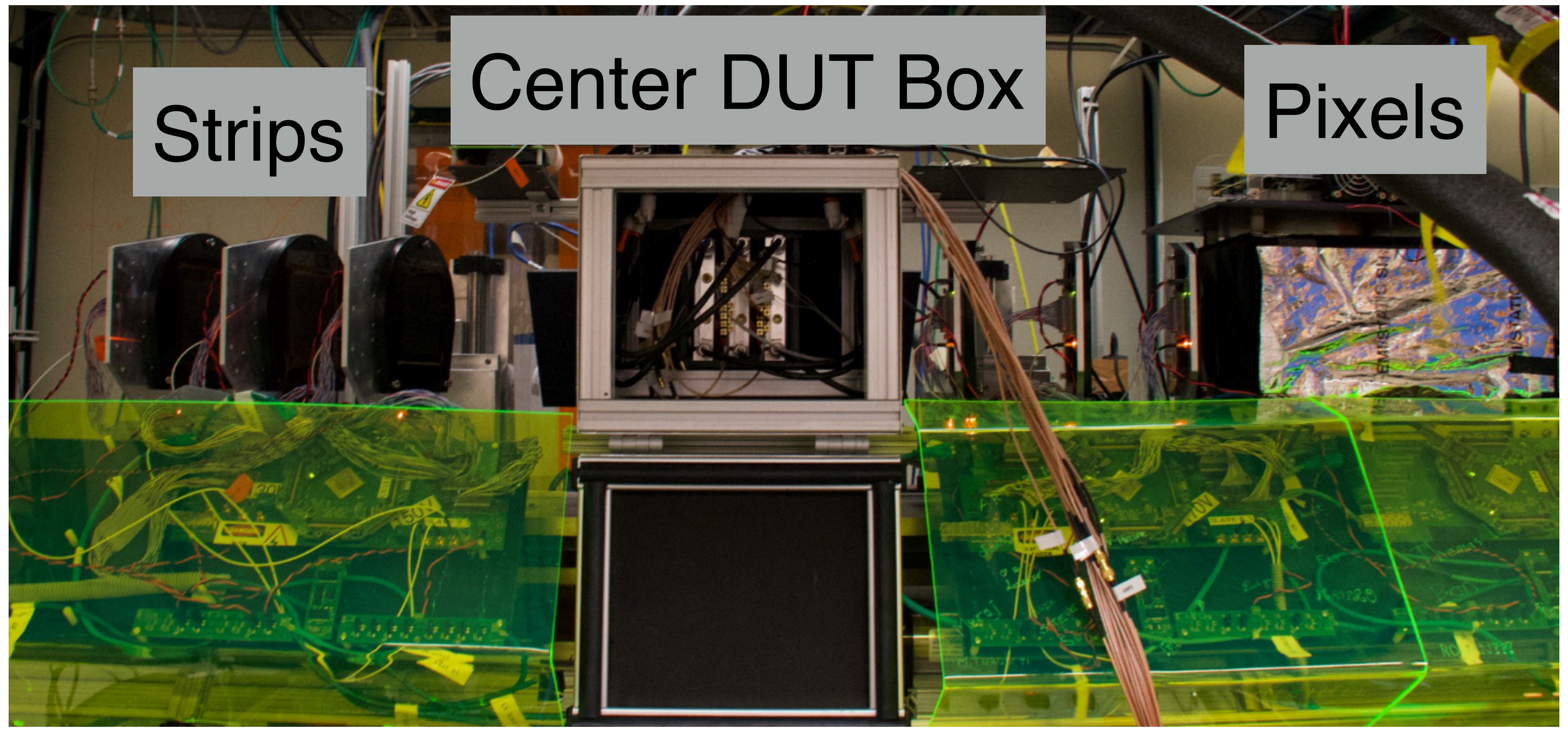


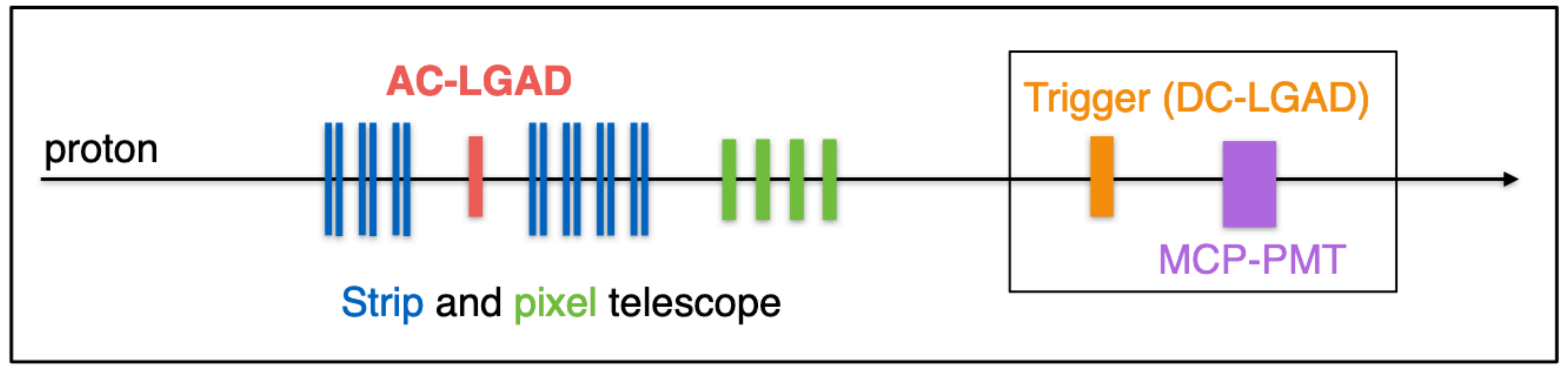


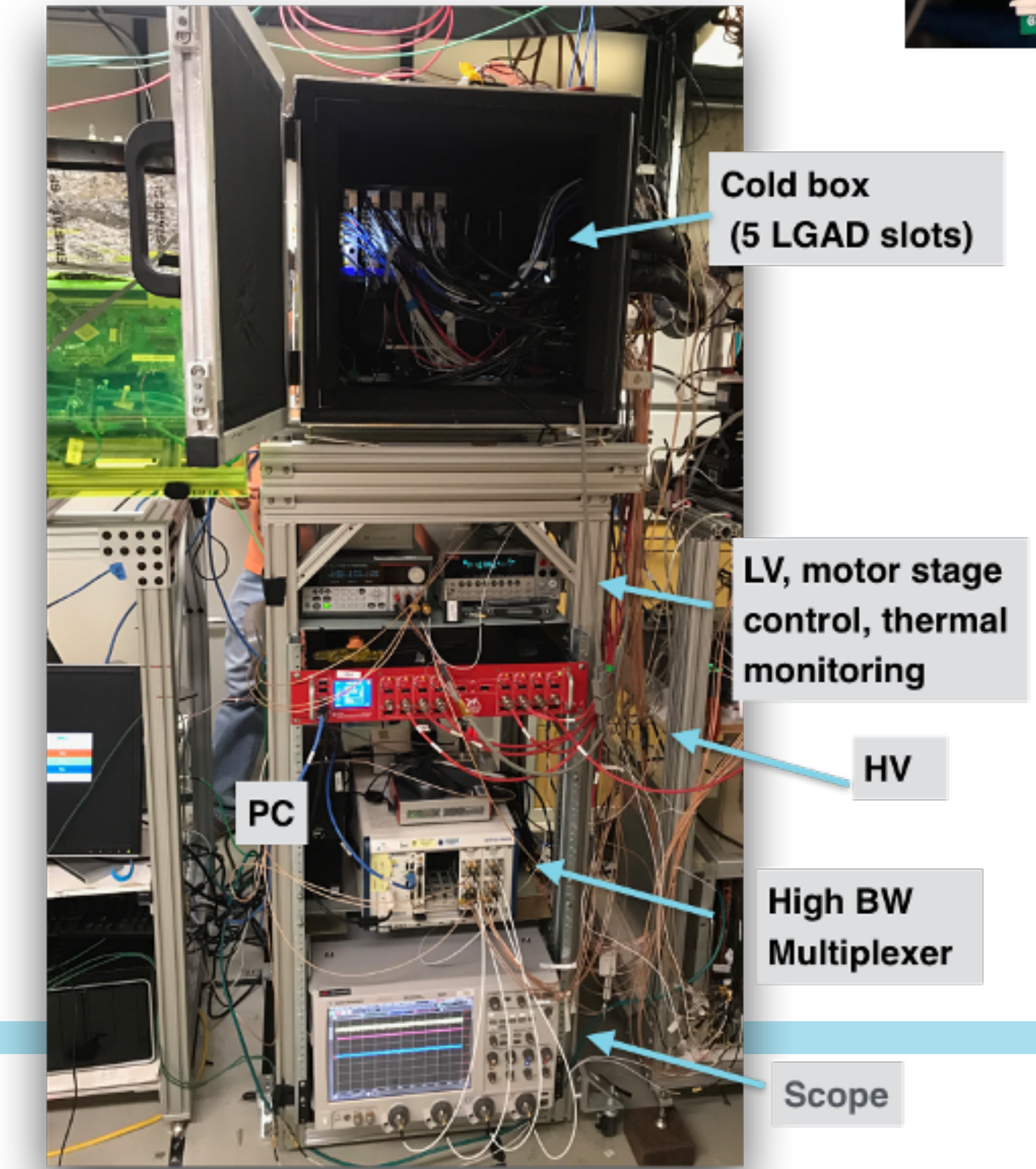
Fermilab 4D-trackers test beam infrastructure

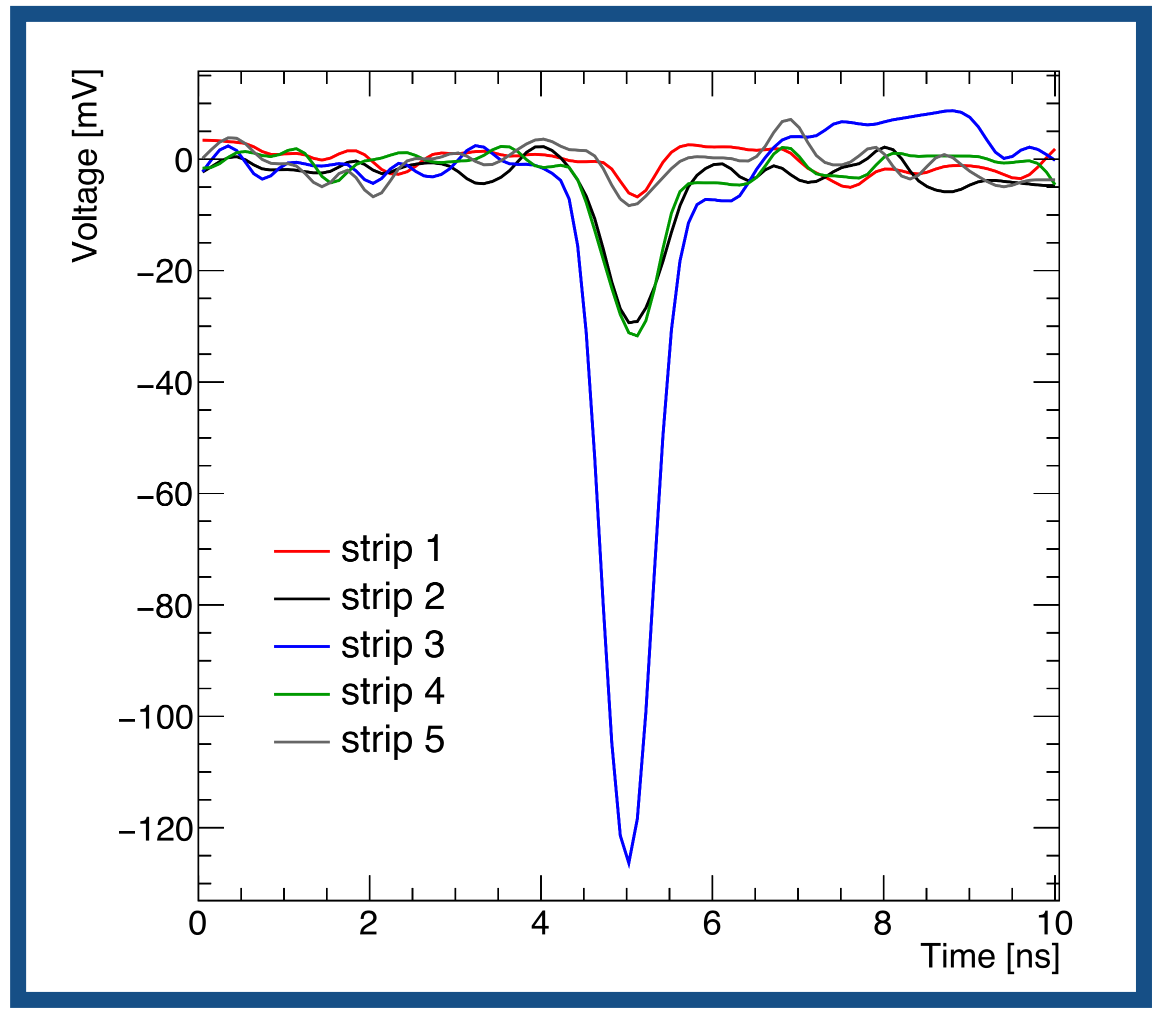
- Permanent setup in FNAL test beam facility (FTBF)
  - Movable: slide in and out of beamline as needed, parasitic use of beam
  - Environmental controls: sensor temperature (-25 C to 20 C), and humidity, monitoring
  - Remote control (stages, HV, LV), logging & reconstruction; σT ~ 10 ps time reference (MCP)
  - Cold operation of up to 10 prototypes at the same time
  - DAQ: high bandwidth, high ADC resolution scope 8-channel scope
  - Record 100k events per minute, tracker with ~5 µm resolution
- Developed readout boards for the characterization of LGADs
  - Without complicated ASIC and DAQ



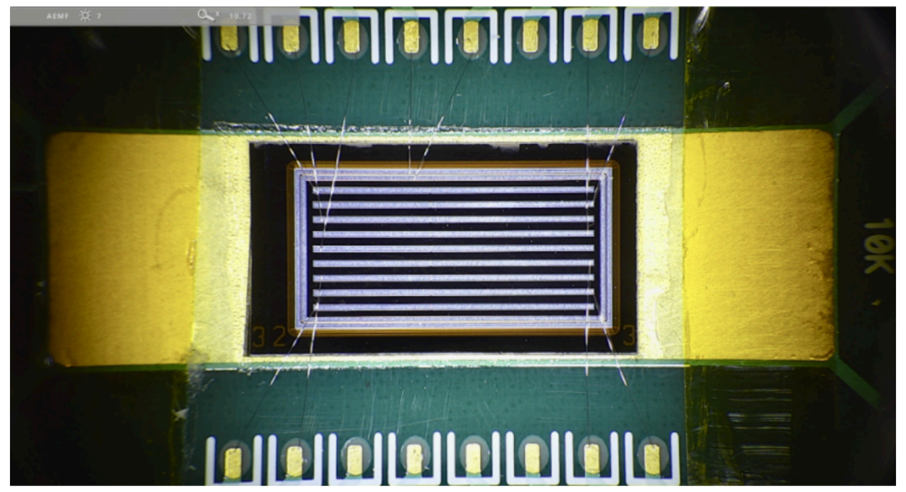




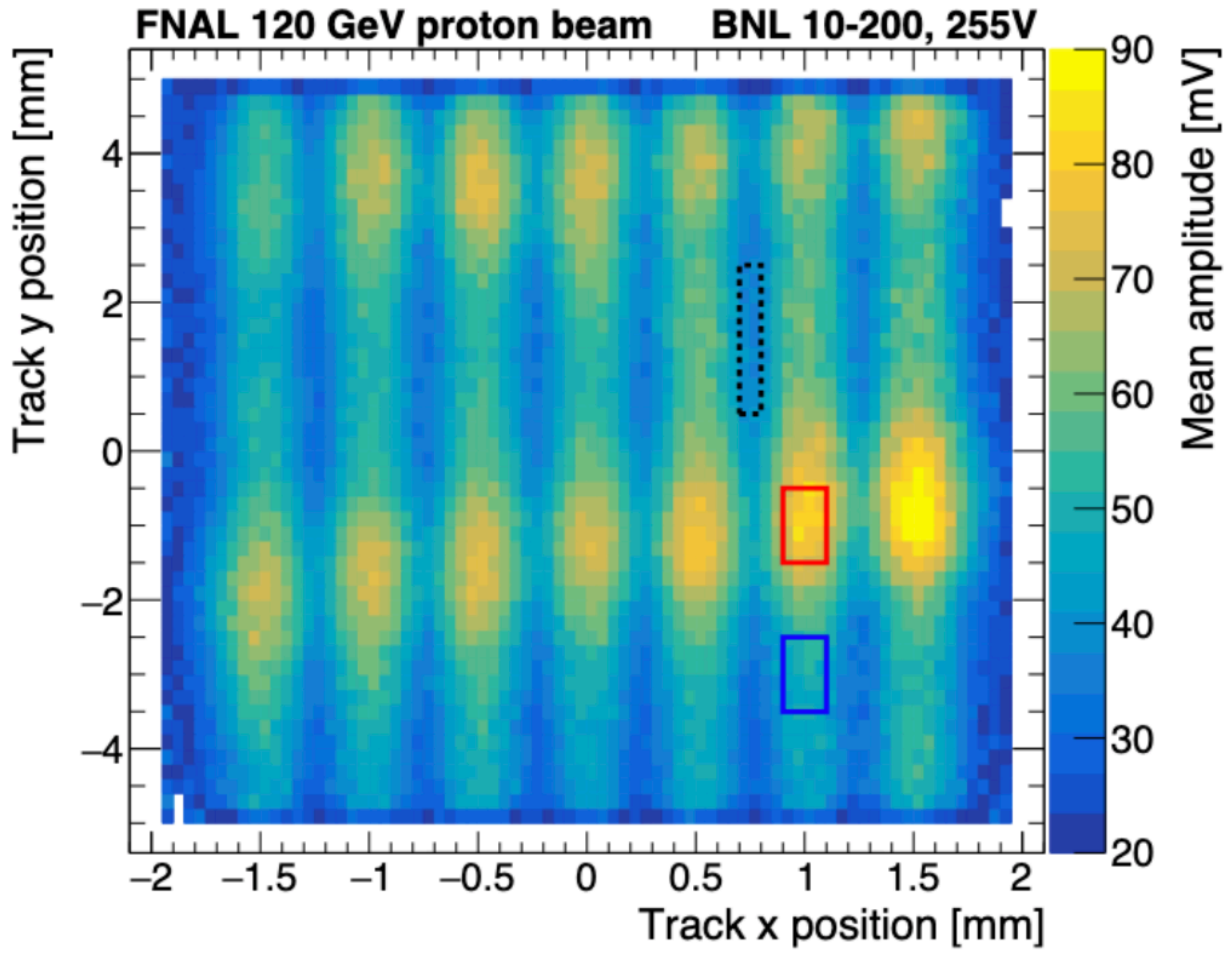


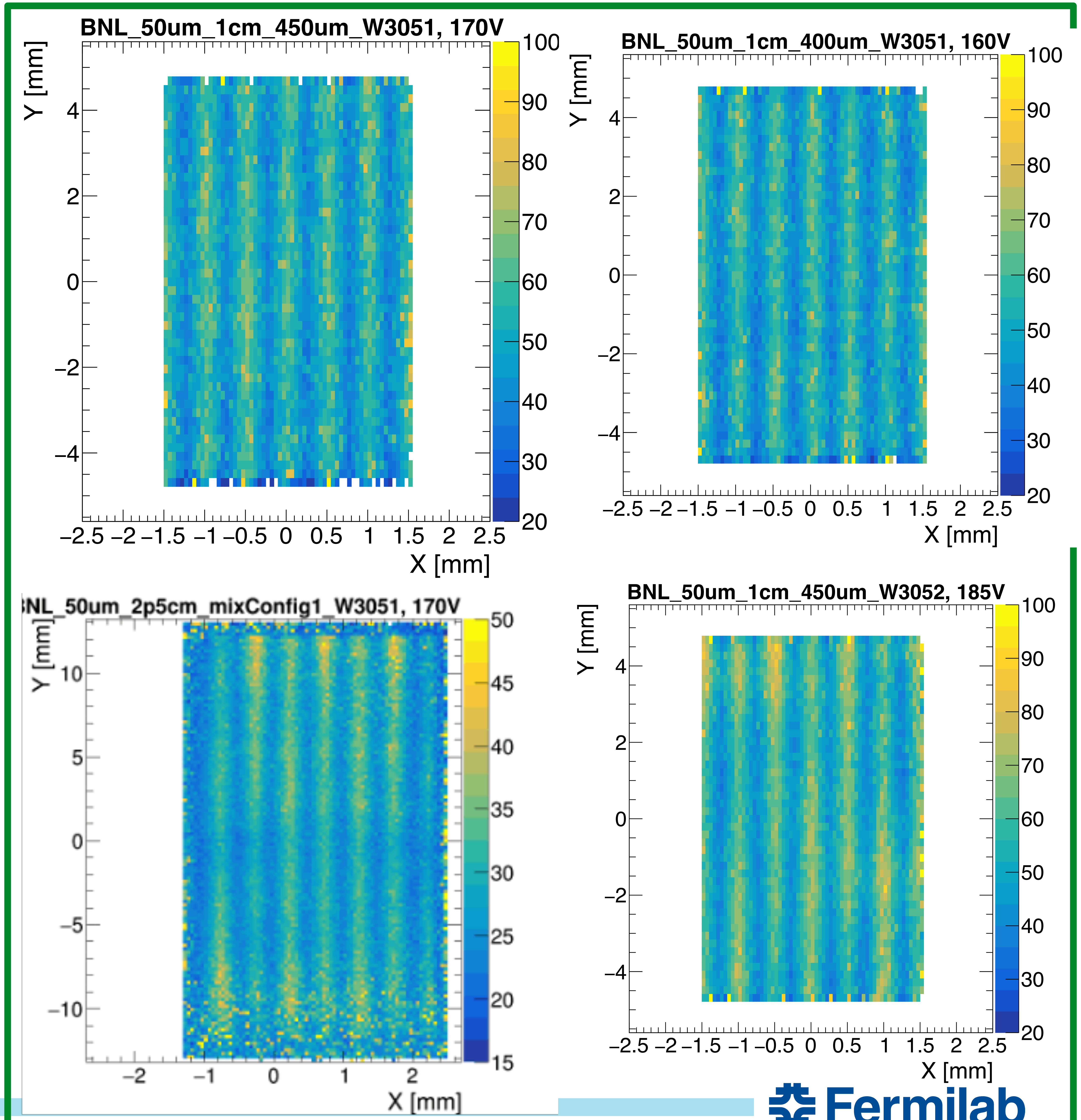


Check gain uniformity



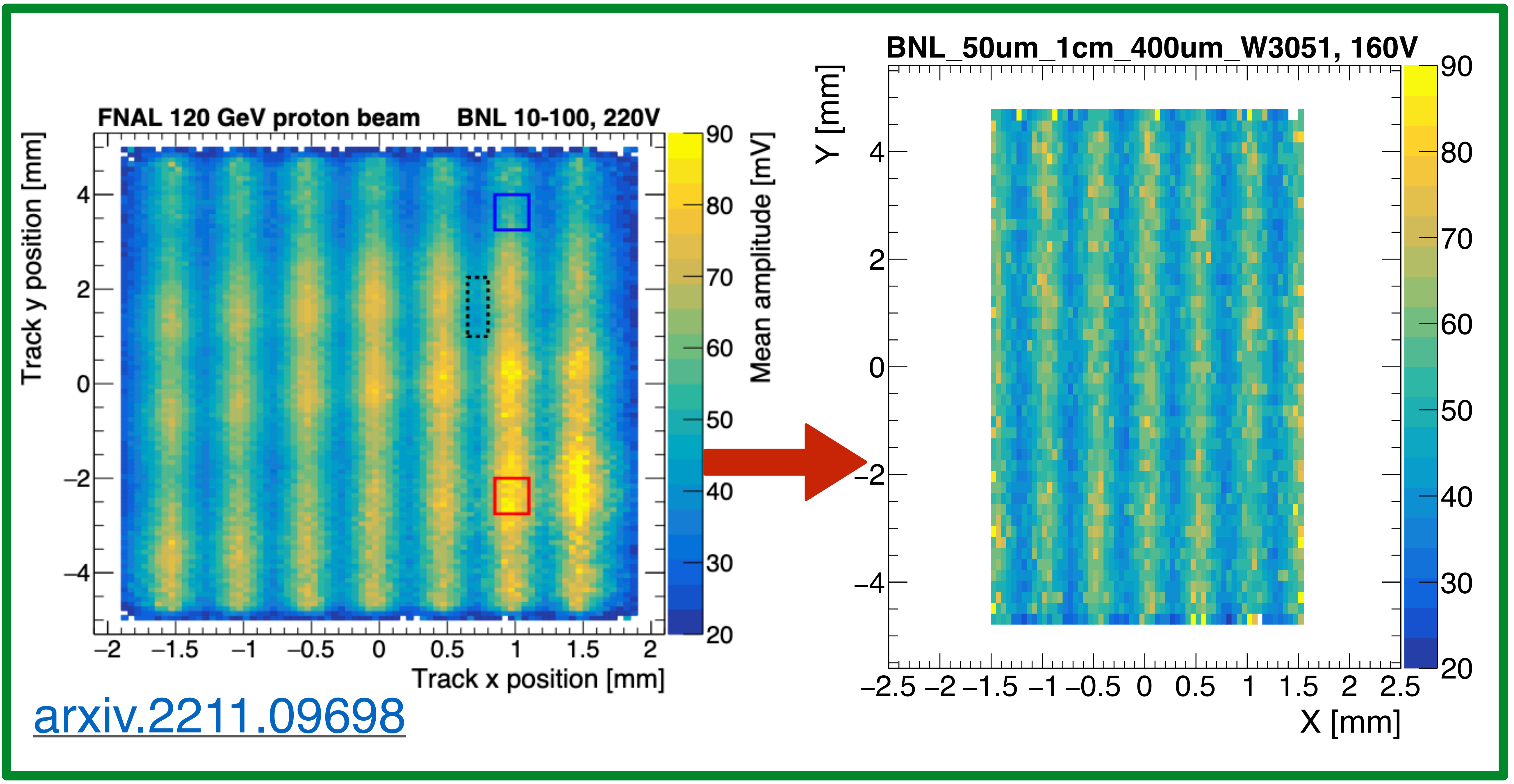
arxiv.2211.09698

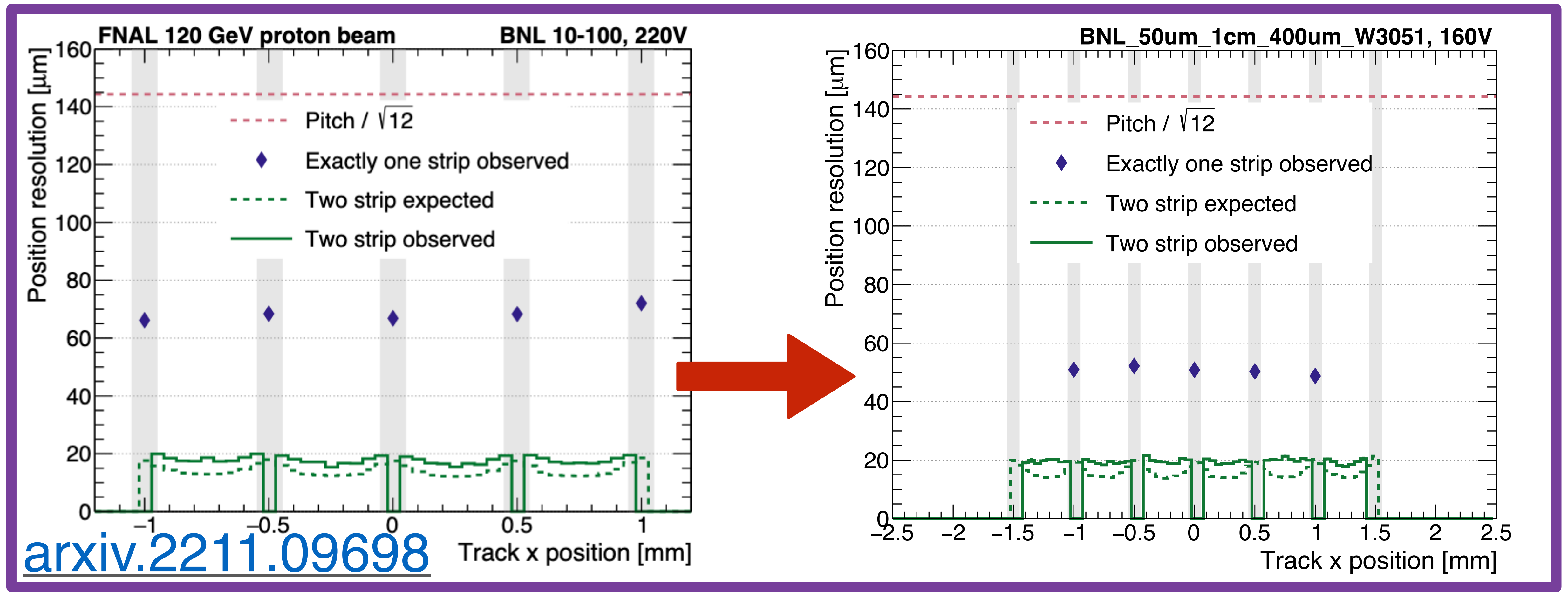


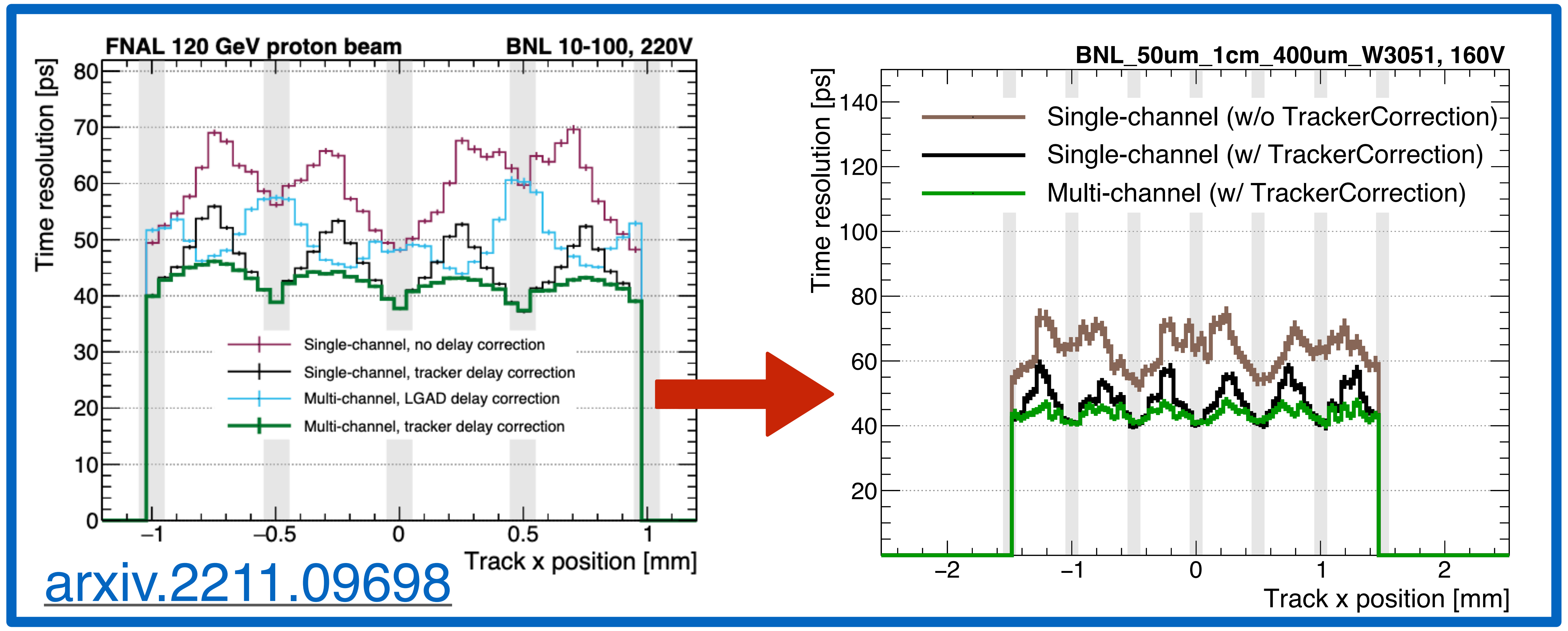


- Greatly improved gain uniformity from **first** BNL large sensor batch compared to **second**
- Operating voltage lower for new batch of sensors

Reproduce previous results

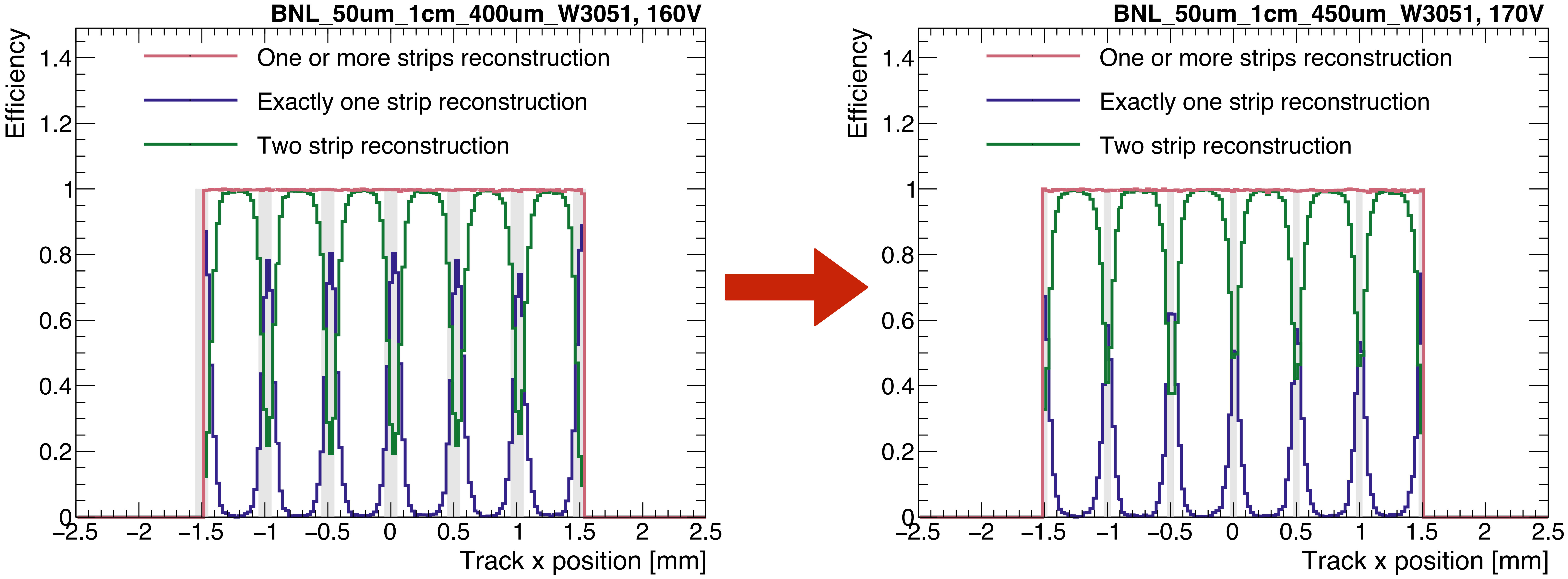






- Signal **amplitude** has decreased for new production
- Similar, **time** and **position** resolutions
- Should be able to build on previous measurements to understand new sensor thickness

Comparing 400 vs. 450 µm metal electrode size



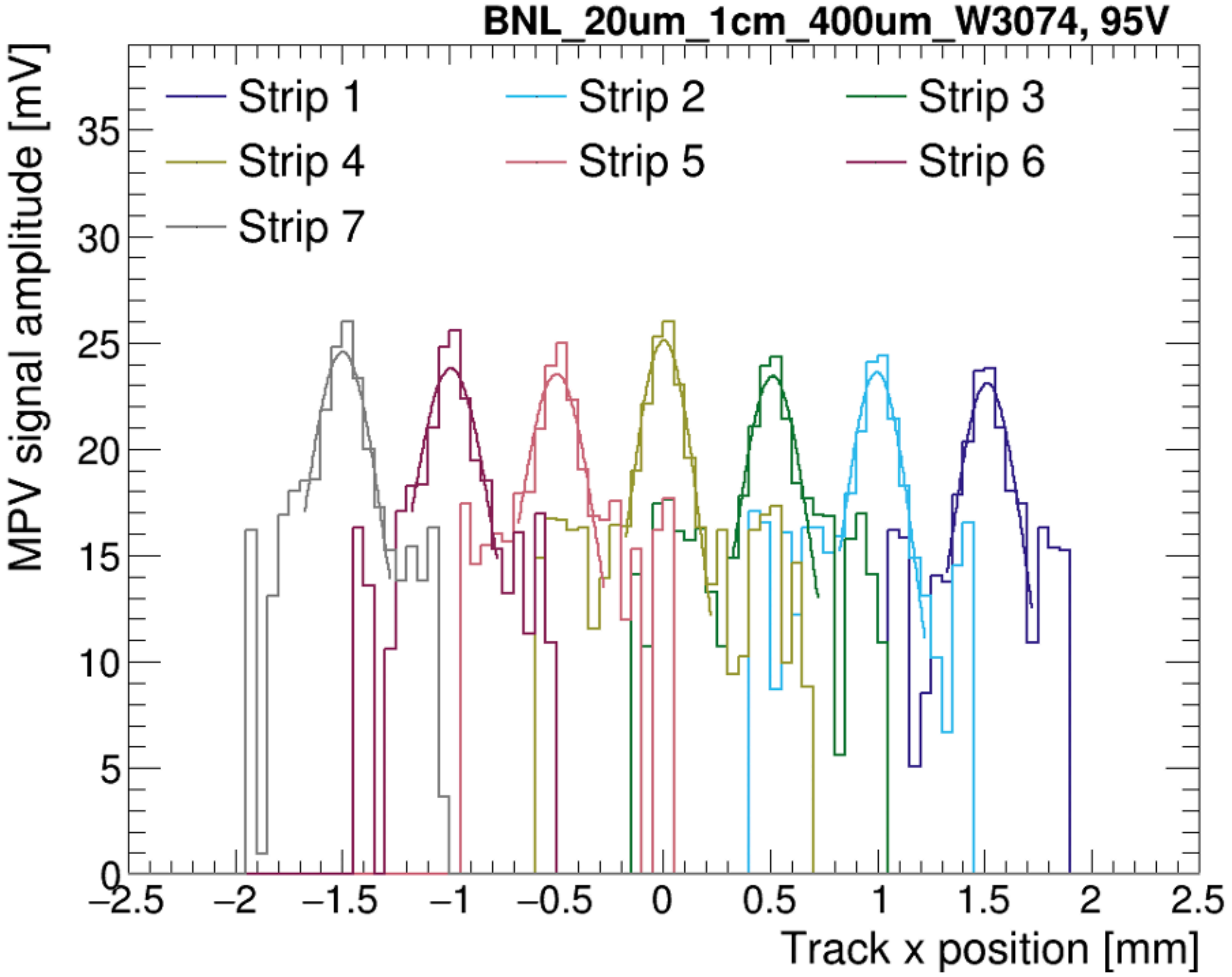
- For 1 cm length sensors conjectured that smaller metal would improve 2 strip efficiency and smooth overall position resolution
- Observe similar signal amplitude, time and position resolution
  - However, did not reach same operating voltage
- **Small improvement to 2 strip efficiency 81% vs. 87%**
- Still studying differences but overall very similar

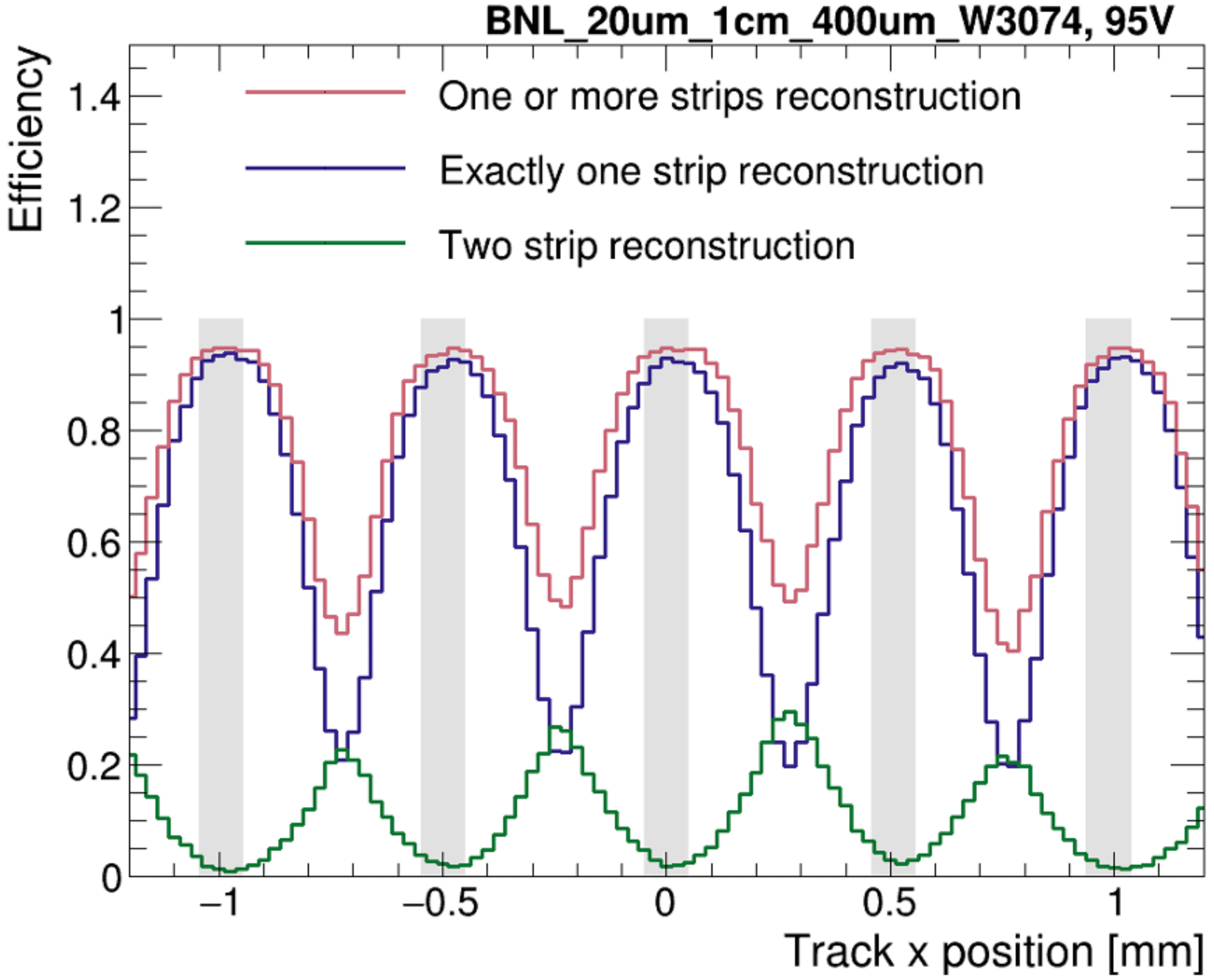
Studying 20 μm thick sensors

- At what point are you signal to noise limited vs. Landau limited for the time resolution when varying sensor thickness?
  - If Landau limited on time resolution can try thinner sensors
  - Expect ~2/5 smaller signals for 20 μm compared to 50 μm sensors (60 mV → 24 mV)

- **Results for best performing BNL 1cm length 20 μm**
  - Observe ~25 mV signals for direct metal hits
    - ~65 mV signals for 50 μm version
  - Do not see usable signals in the gaps
  - **Sensor is not fully efficient at 15 mV threshold**

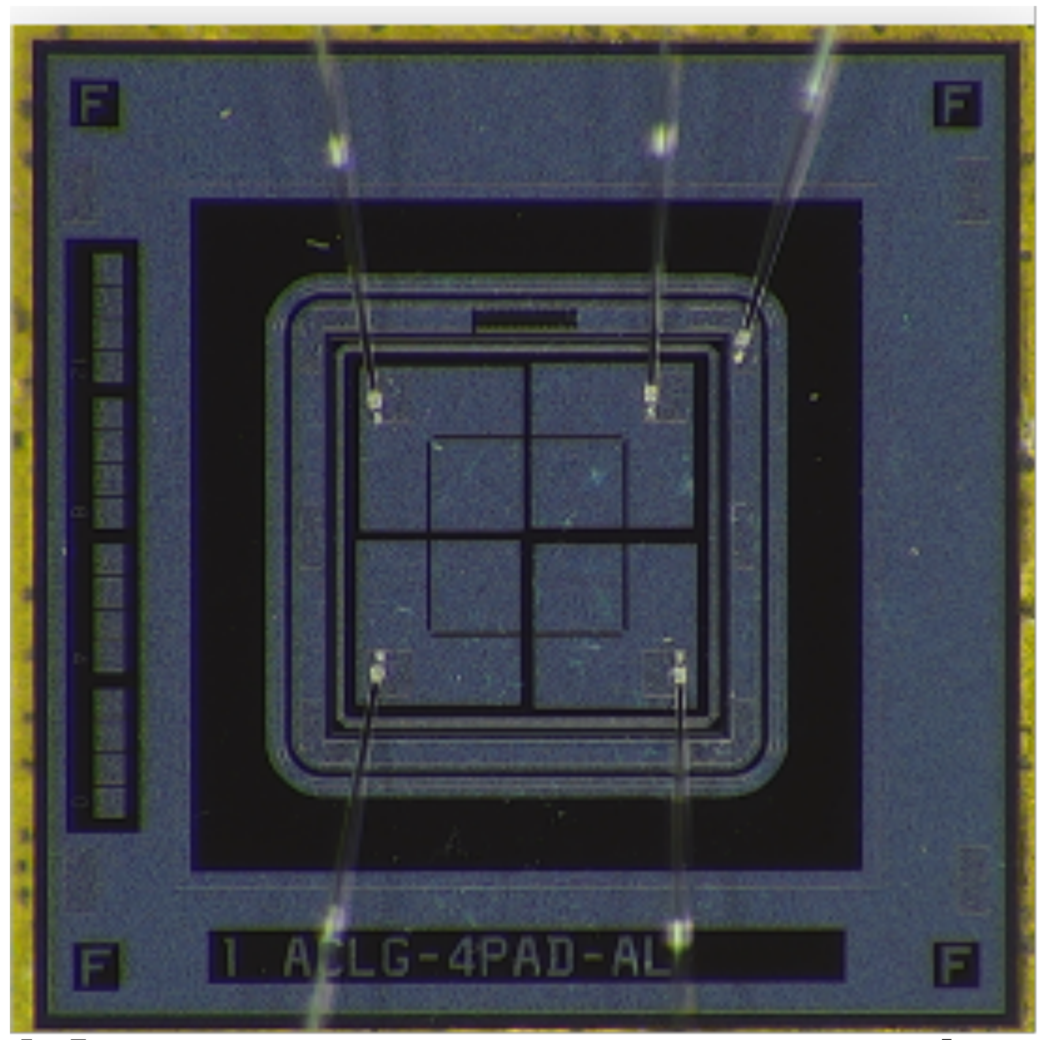
- Worth studying 30-40 μm thick BNL sensors in the future?



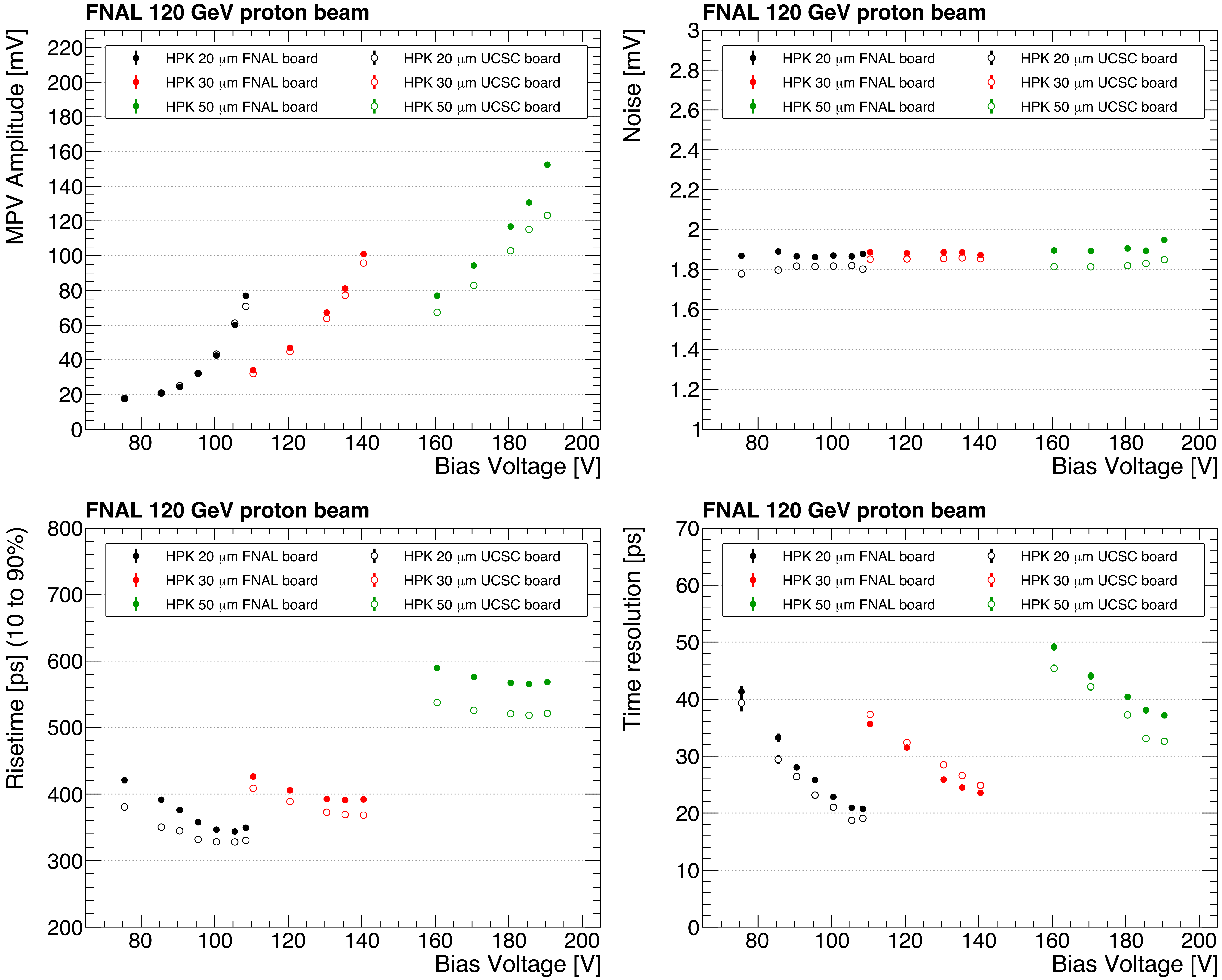


HPK sensor thickness variations

- **Results for HPK sensors that are 20, 30, and 50 µm thick**
- 500x500 µm² channel size
- Observe great timing performance
  - ~20 ps for 20 µm thick sensor
  - ~25 ps for 30 µm thick sensor

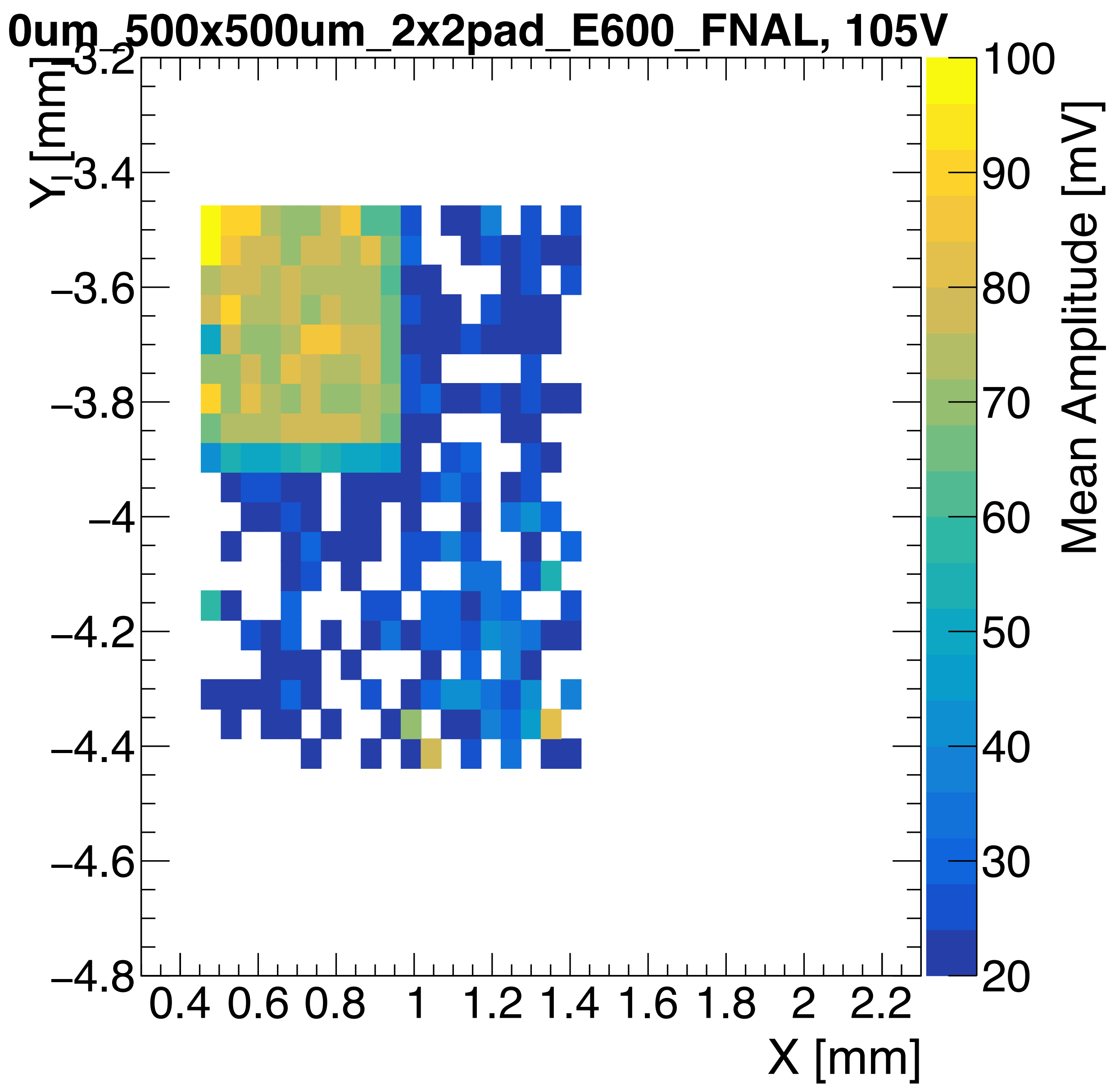


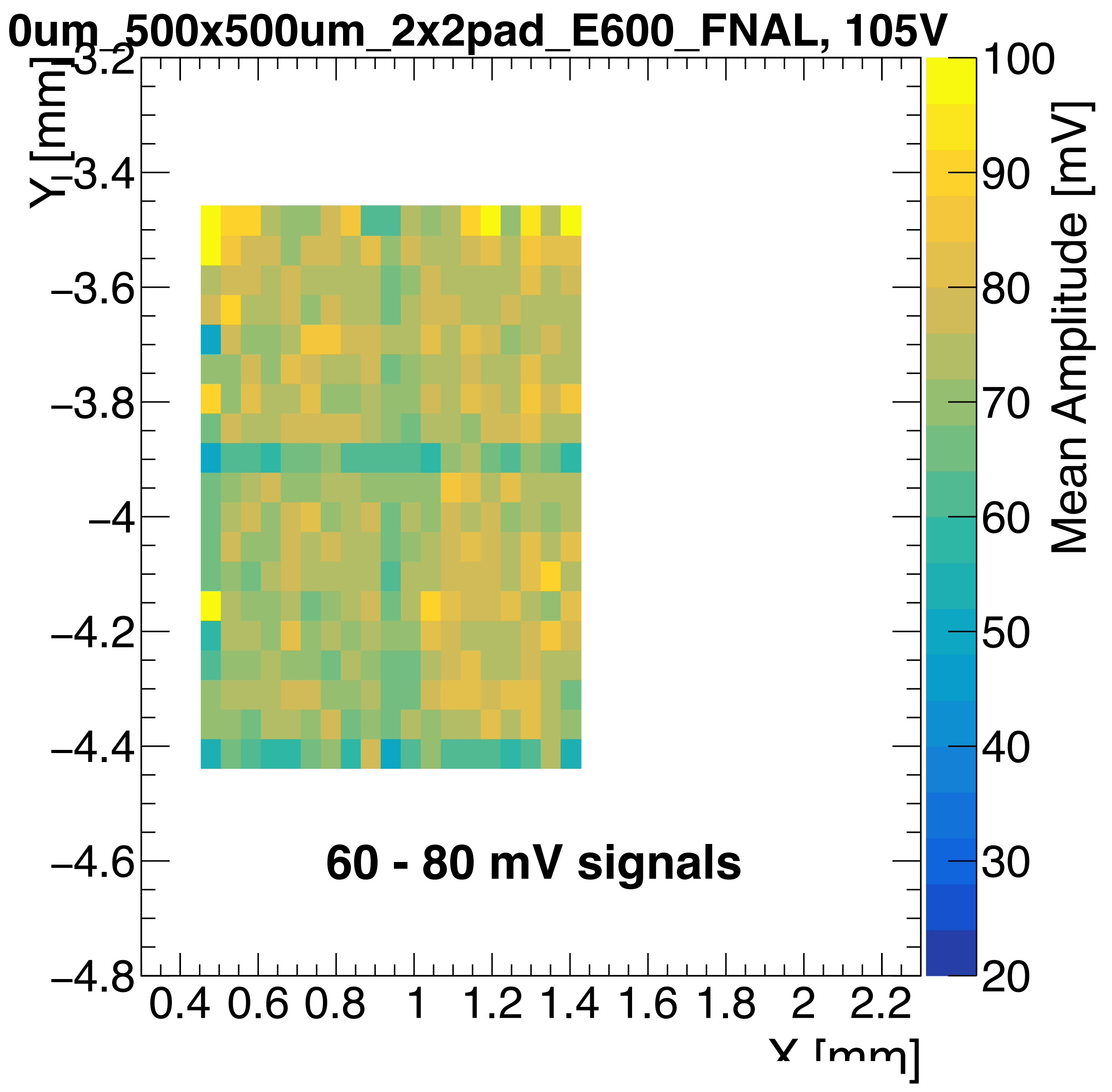
HPK 2x2, 500 µm pad size

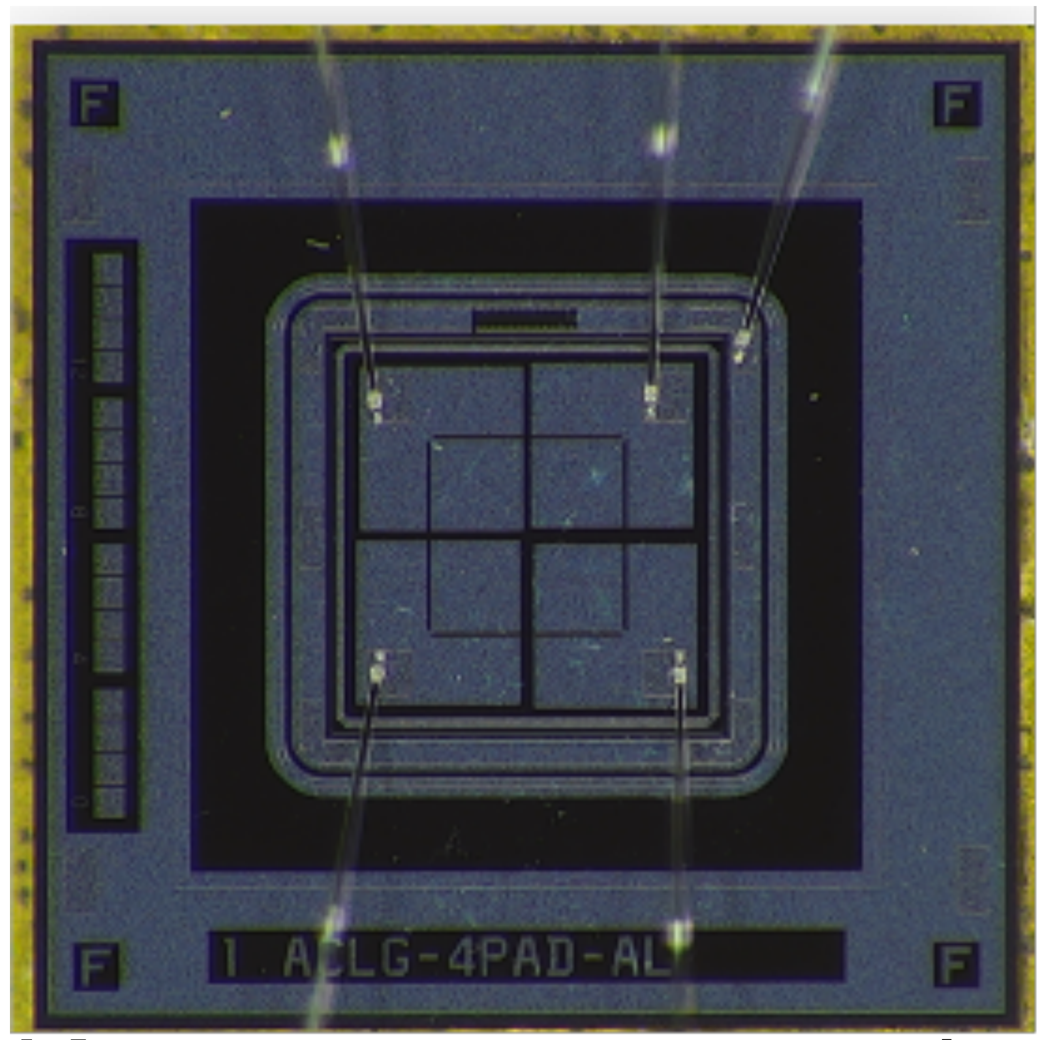


HPK 20 micron results

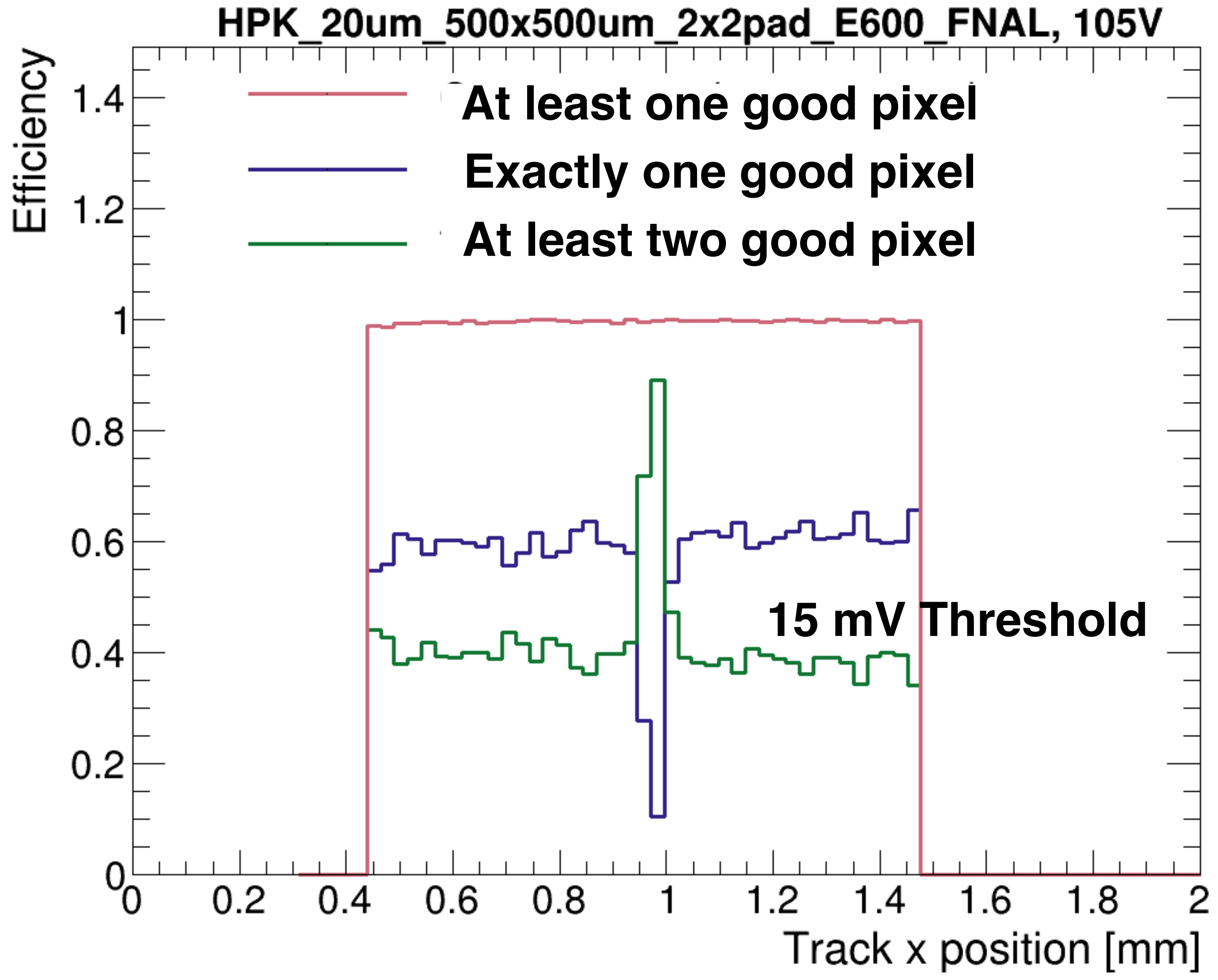
- **Can not use signal sharing for position reconstruction**
- Do not have 2 pixel efficiency outside of the small non-metallized gaps
- Almost fully metallized
- Optimized for timing performance
  - Higher resistivity

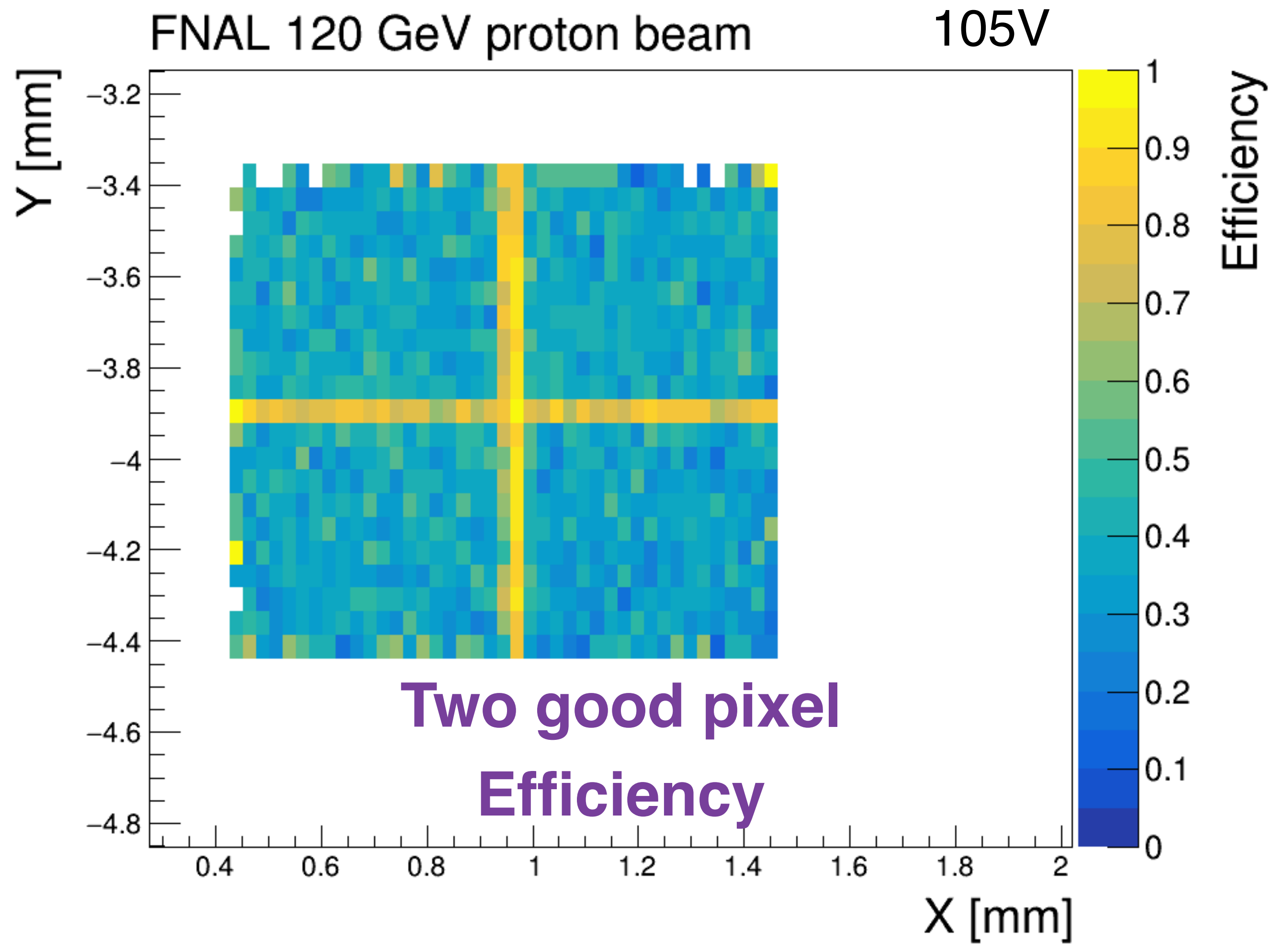






HPK 2x2, 500 μm pad size

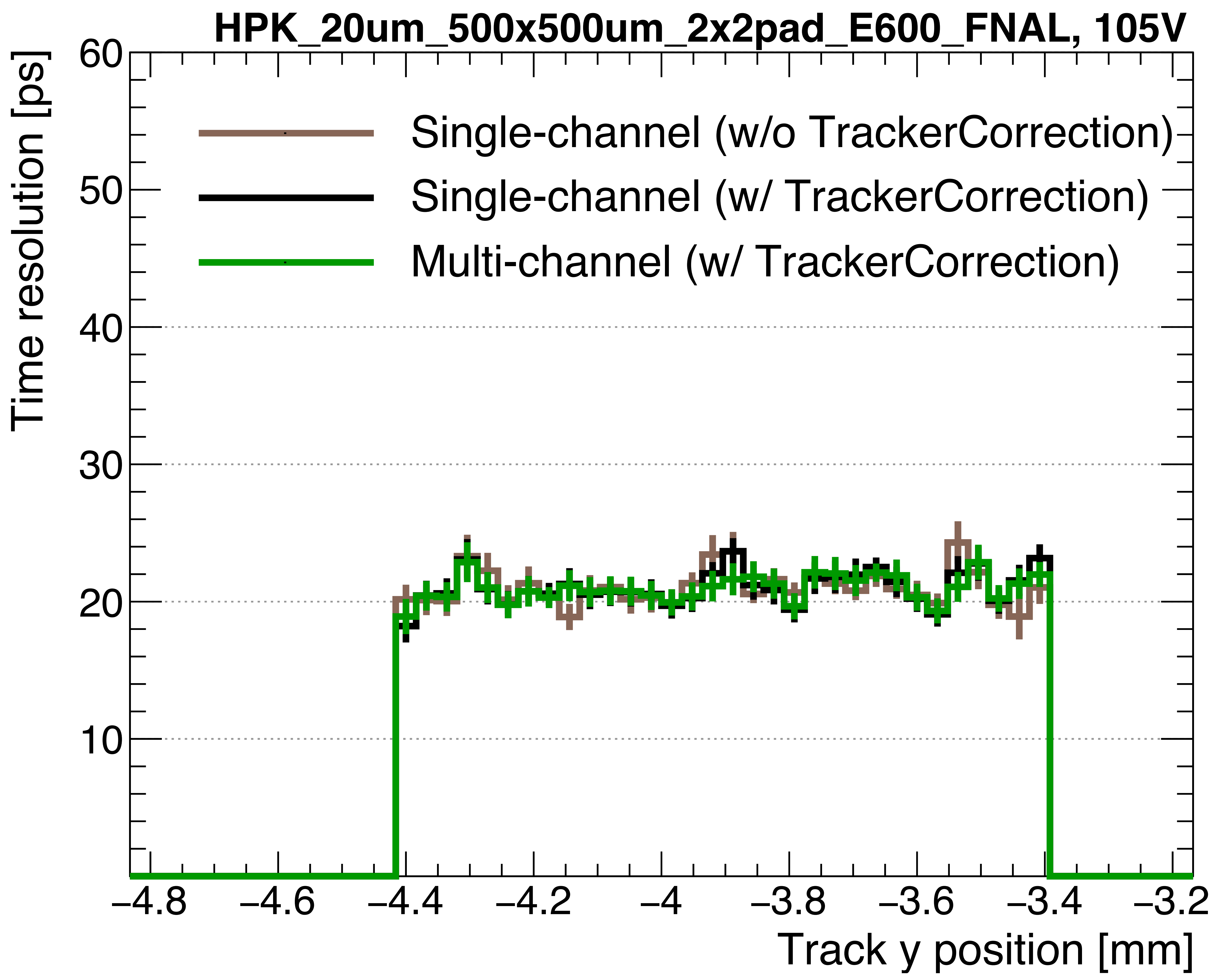


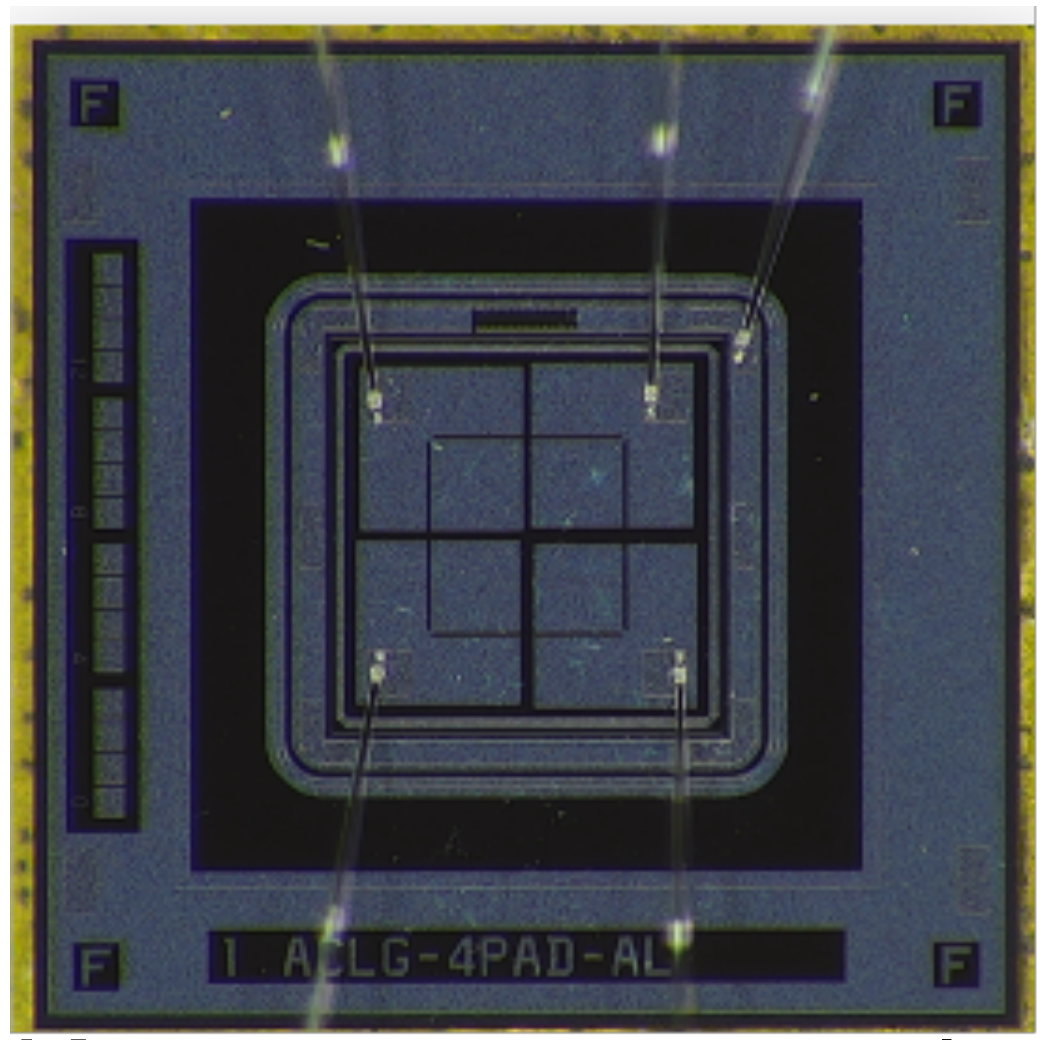


Fermilab

HPK 20 micron results

- Enough signal sharing to cover gap fully
  - Not enough for position reconstruction
- **Observe uniform time resolution across full sensor area**





HPK 2x2, 500 μm pad size

Fermilab

Preliminary Conclusion

- **New batch of BNL sensors have greatly improved gain uniformity**
- Observe similar performance to previous batch for the 50 µm thick sensors
- Small improvement to two strip efficiency observed when decreasing metal electrode size from 100 to 50 µm
- BNL 20 µm thick sensors have small signal size
  - Adapt design, e.g. deeper gain layer, larger metal electrode, tune resistivity,…
  - Worth considering 30-40 µm thick sensors?
- **HPK 20 and 30 µm sensors reach below 25 ps time resolution**
  - Signal sharing not useful for position reconstruction
  - **Fully efficient and have uniform time resolution**
- **Shown preliminary results and will continue analyzing the data**

Backup

Sensors Tested

- 8 BNL sensors
  - 1 cm size, 50/100 µm width metal electrodes
  - 20 µm vs 50 µm
  - 2 wafer types

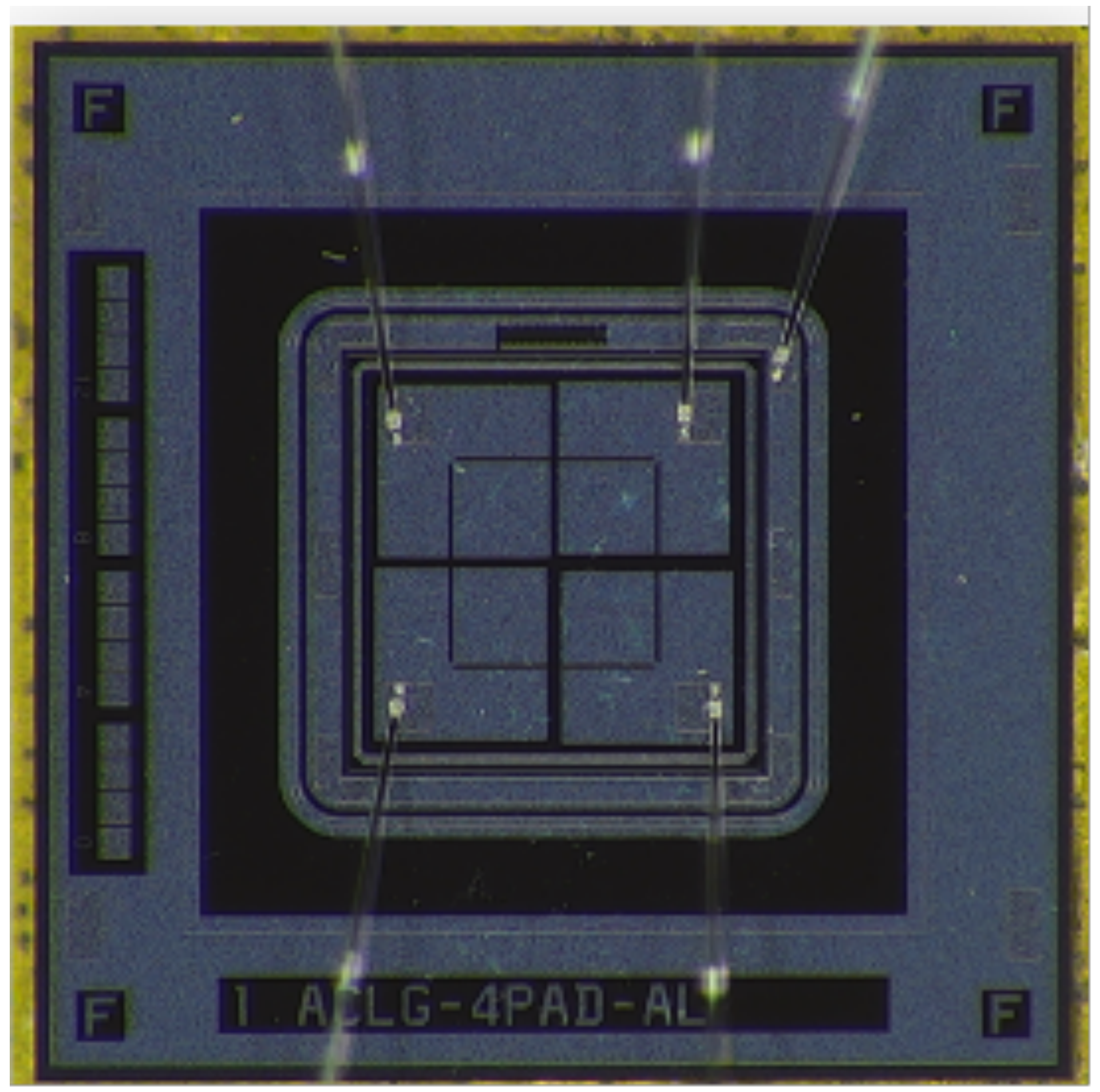
- 6 HPK 500x500µm pad E600, 2x2 sensors
  - 20 µm (2 copies), 30 µm (2 copies) and 50 µm (2 copies) thickness
  - Copies of the same sensor tested on FNAL and UCSC boards

Thickness	Production	Channel Size	Gap	Wafer number
20 micron	BNL Strips	500 µm x 1.0 cm	400 µm	W3074
		500 µm x 1.0 cm	400 µm	W3075
		500 µm x 1.0 cm	450 µm	W3074
		500 µm x 1.0 cm	450 µm	W3075
	HPK Pixels	500x500 µm²	20-50 µm	-
30 micron	HPK Pixels	500x500 µm²	20-50 µm	-
50 micron	BNL Strips	500 µm x 1.0 cm	400 µm	W3051
		500 µm x 1.0 cm	450 µm	W3051
		500 µm x 1.0 cm	450 µm	W3052
		500 µm x 2.5 cm	400/450 µm mix	W3051
	HPK Pixels	500x500 µm²	20-50 µm	-

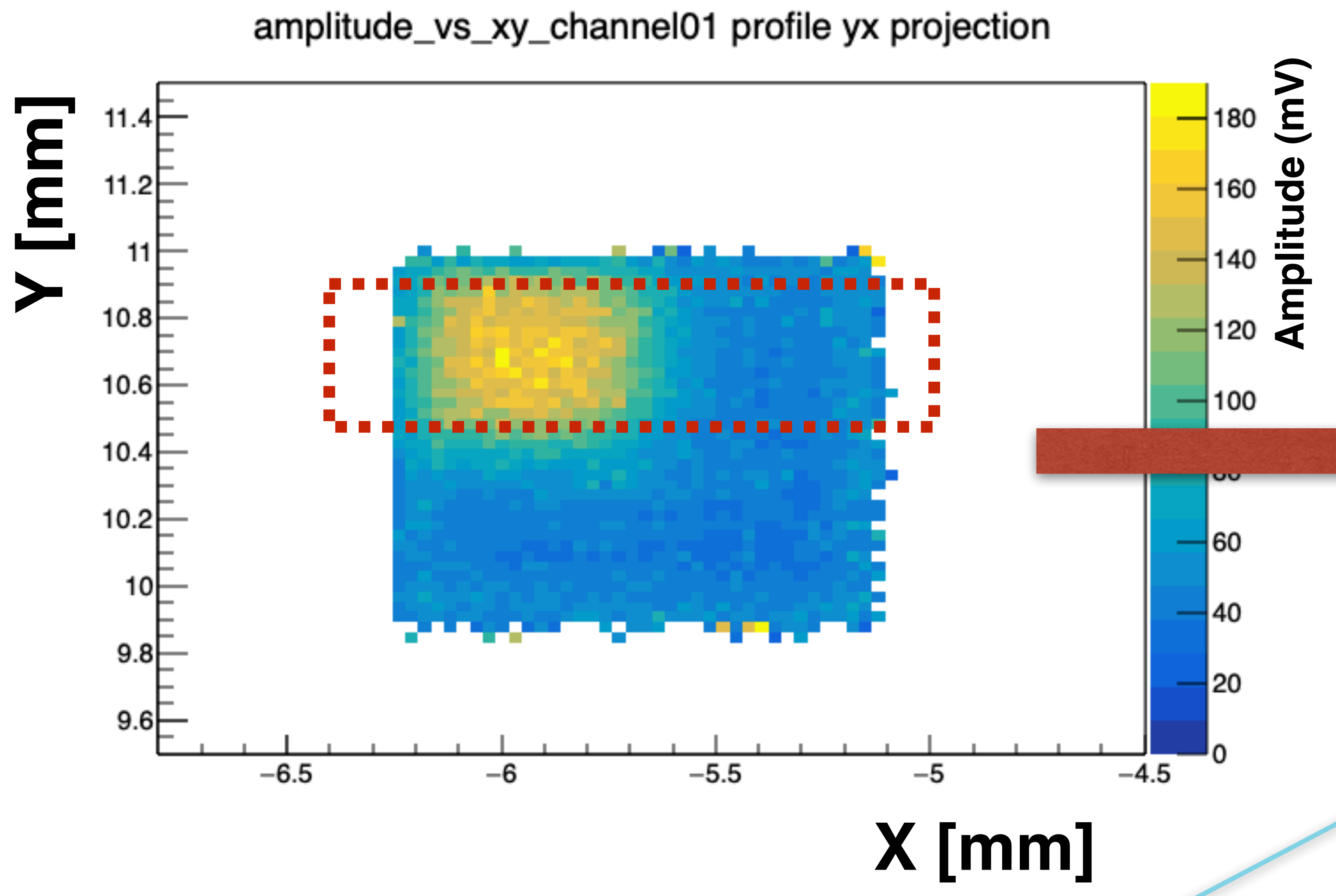
Test beam 2021 results: HPK Pixels

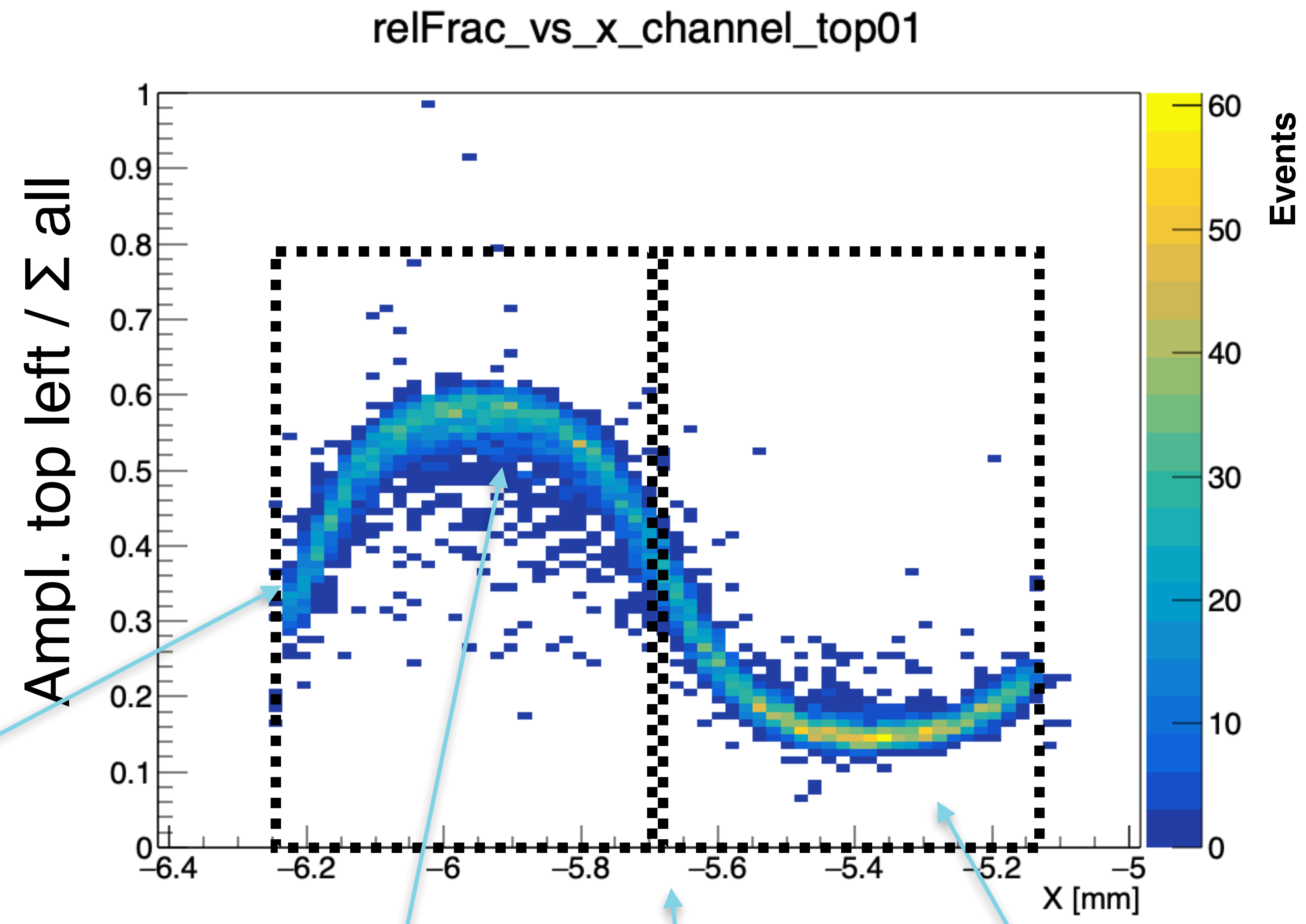
- We have sensors from KEK and U. of Tsukuba that are fabricated at HPK
- Here we have a 2x2 pad sensor with 500 µm size pads
- **The overall performance we observe is great:**
  - 100% efficient, primary signal size are large (~128 mV), and signal sharing extends well into neighboring channel
- **Show effects of signal sharing in 2 dimensions by looking at the signal size for hits to the top left pad**

arxiv:2201.07772



HPK 2x2, 500 µm pad size





Decreased coupling near pad edge

Signal fraction flat at center

300 micron linear region!

Constant distant coupling.

Fermilab