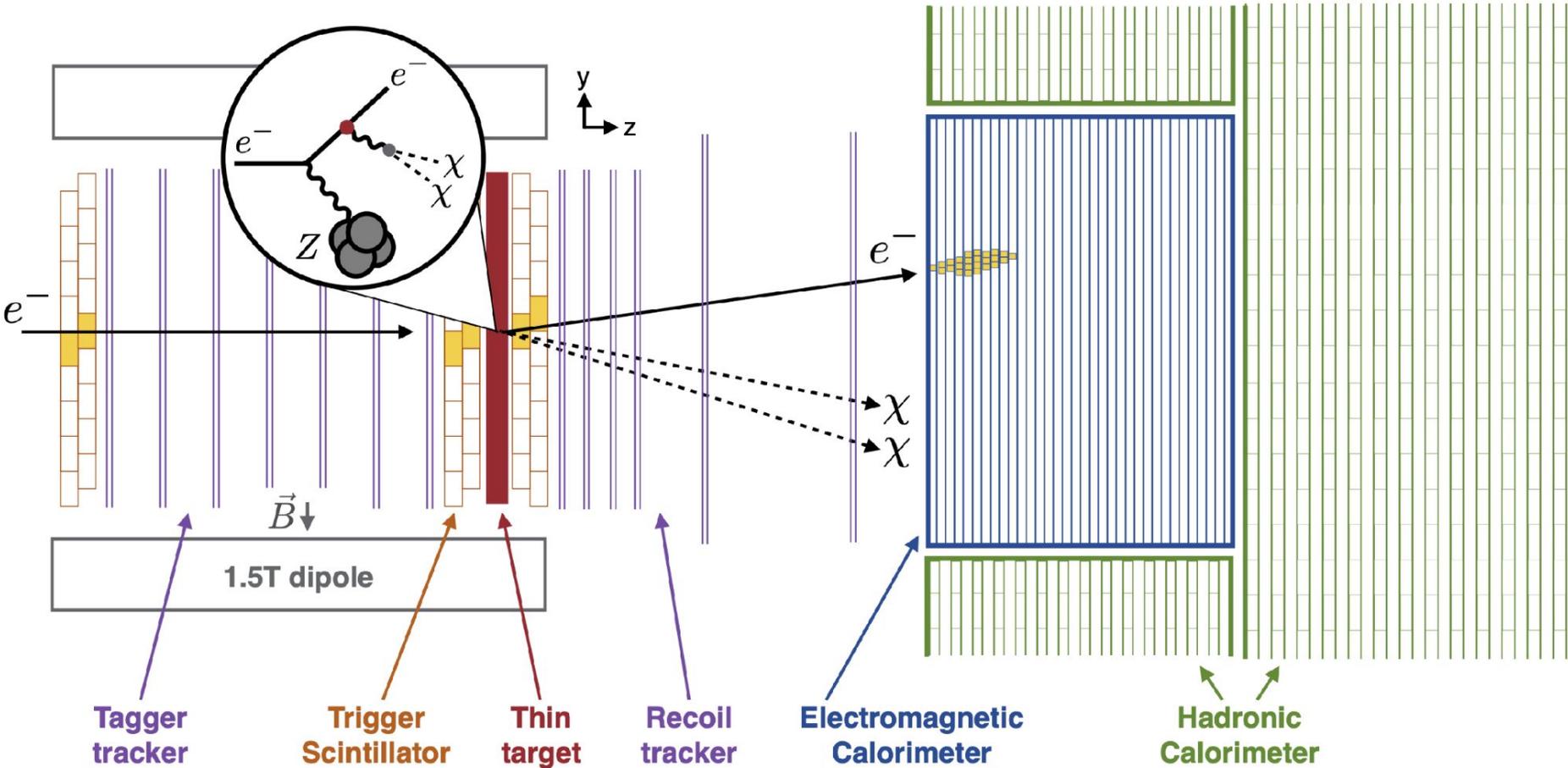




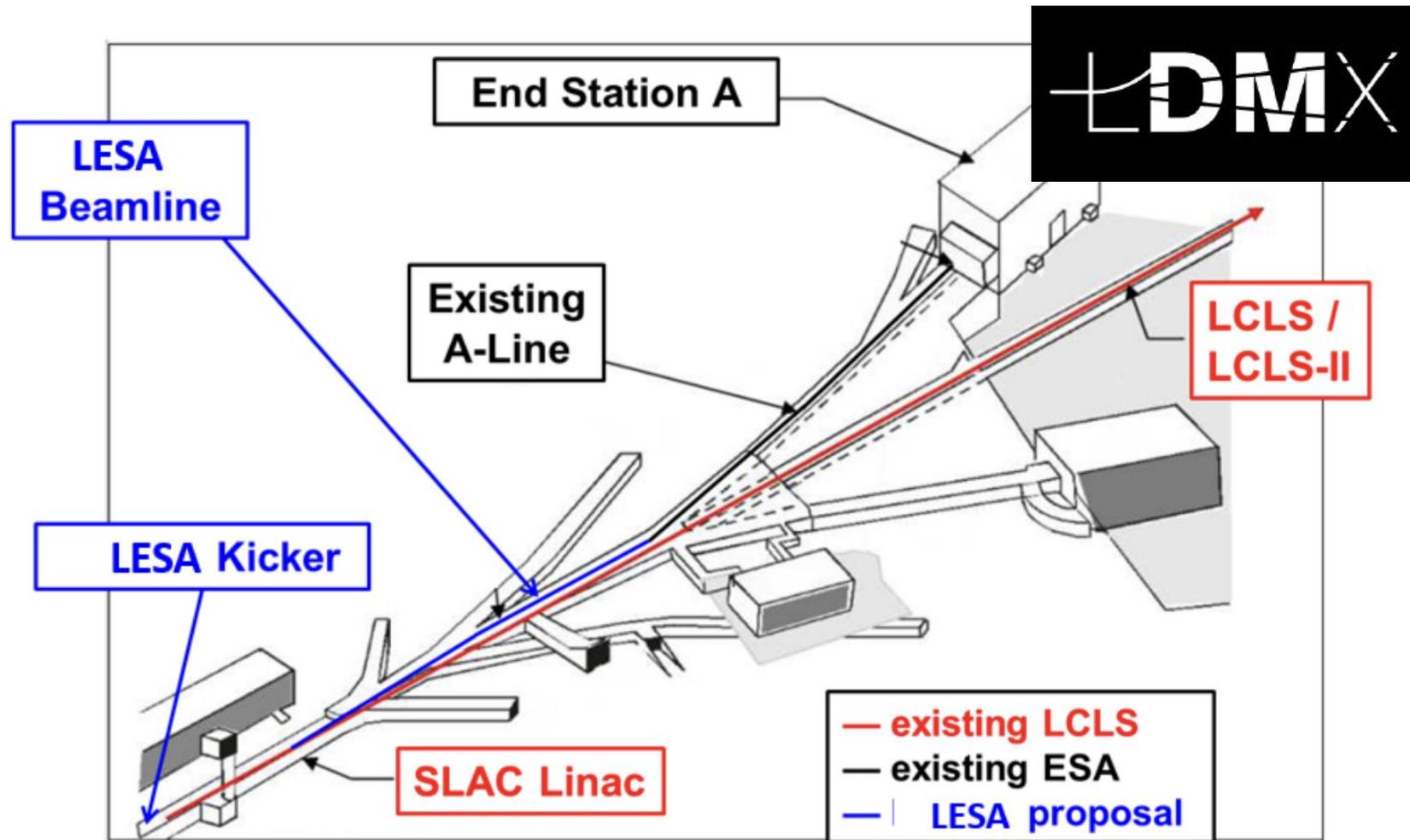
# Experience with LDMX Hodoscope in S30XL beamline

Elizabeth Berzin, Andrew Whitbeck, Ben Reese, Rory O'Dwyer, Jessica Pascadlo, **Lauren Tompkins** and others from LDMX & LESA teams

# LDMX: Search for Light Thermal Relic Dark Matter

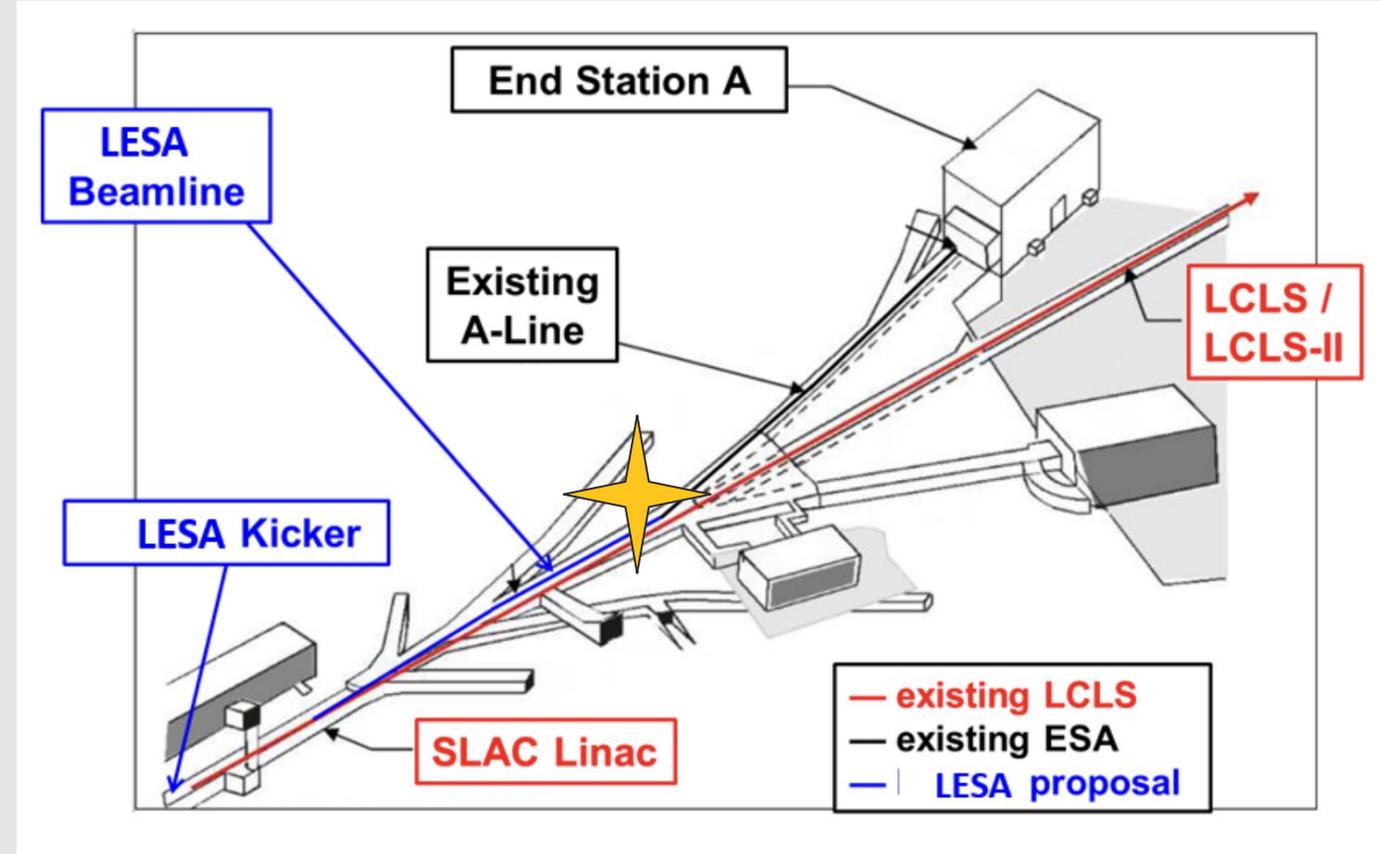


# LDMX: Search for Light Thermal Relic Dark Matter



# LDMX in S30XL

- General goals:
  - LCLS-II dark current is too low for accurate measurement via accelerator tools
  - Wanted to demonstrate the feasibility of measuring dark current with LDMX TS
    - Helps set the scale for laser operations needs
  - Learn to work with accelerator folks
- LDMX Additional Goals:
  - Test timing in with LCLS-II
  - Demonstrate basic readout capability
  - Integrate APx hardware (trigger board)



LDMX Hodoscope Prototype

# TS Prototype in S30XL

- Installed prototype is one module, consisting of 12 PVT bars readout by SiPMs arranged in two layers.
- Readout by digitizer which sent data to FPGA on surface for DAQ
- Installed late February; took data parasitically to LCLS-II operations for about a month.

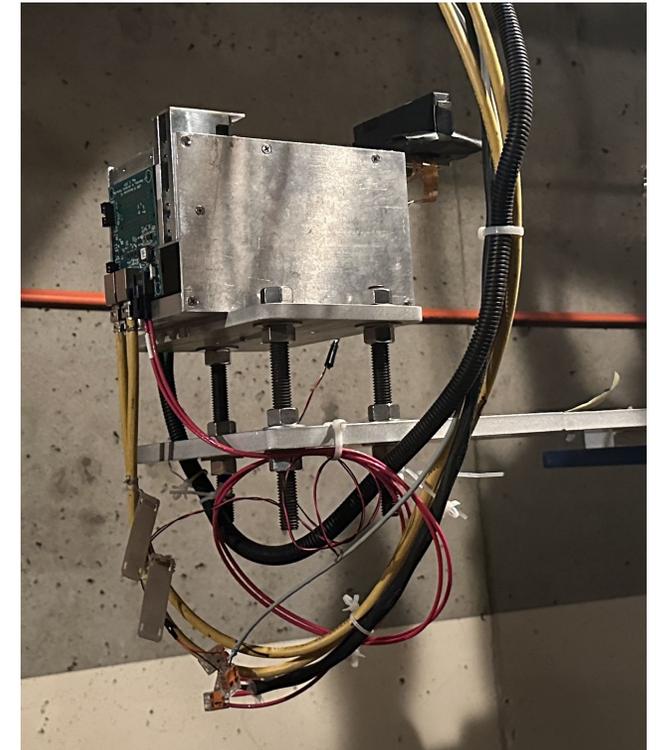
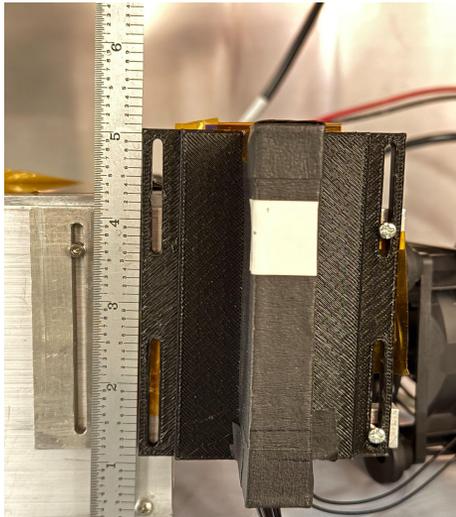
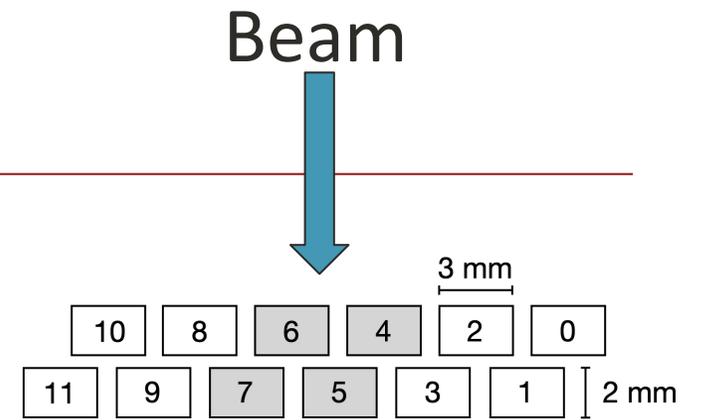
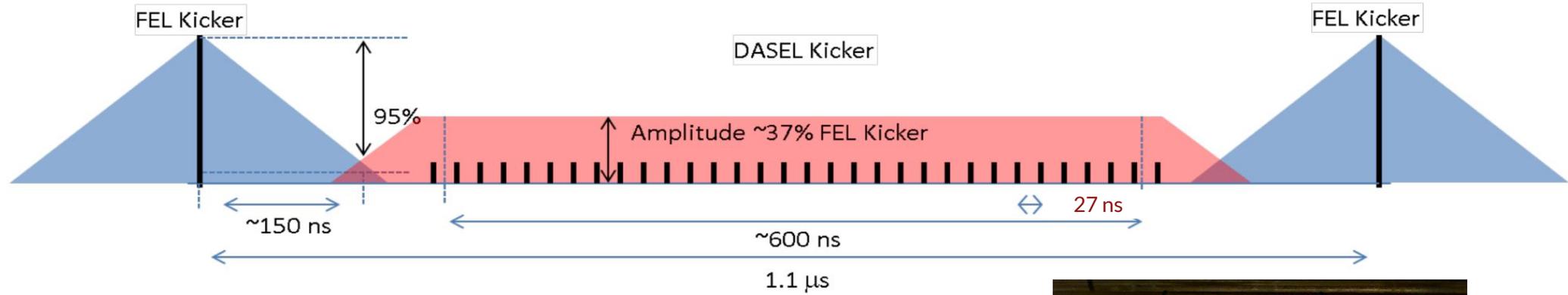


Image Credits: Jessica Pascadlo, L Tompkins

# Beam Structure and Environment



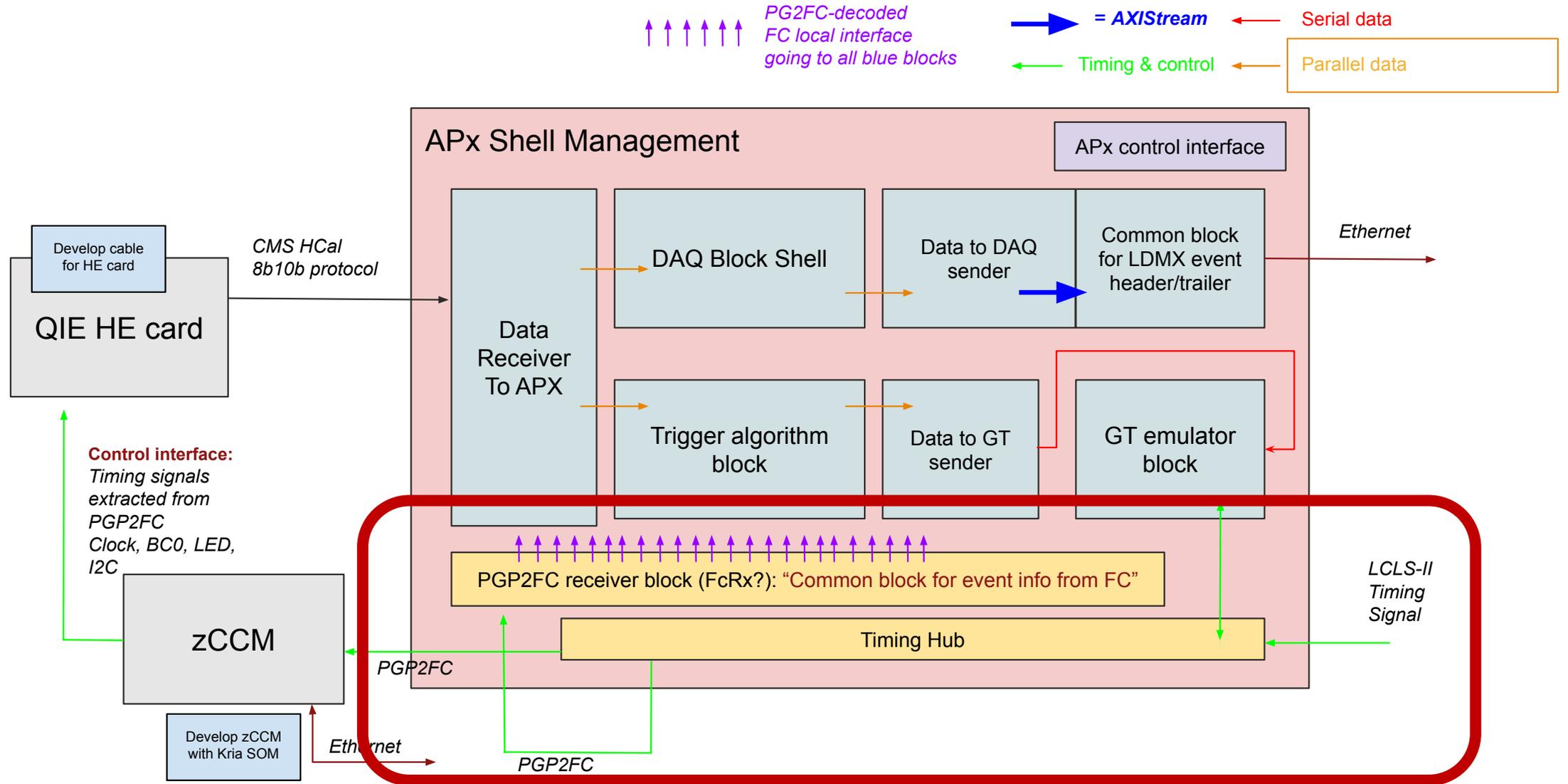
Busy environment! Lots of beamlines  $\rightarrow$  stray radiation  $\rightarrow$  made self-triggering hard

Used LCLS-II timing information to trigger entire kicker window.

Kicker limited to 10Hz operation for radiation protection



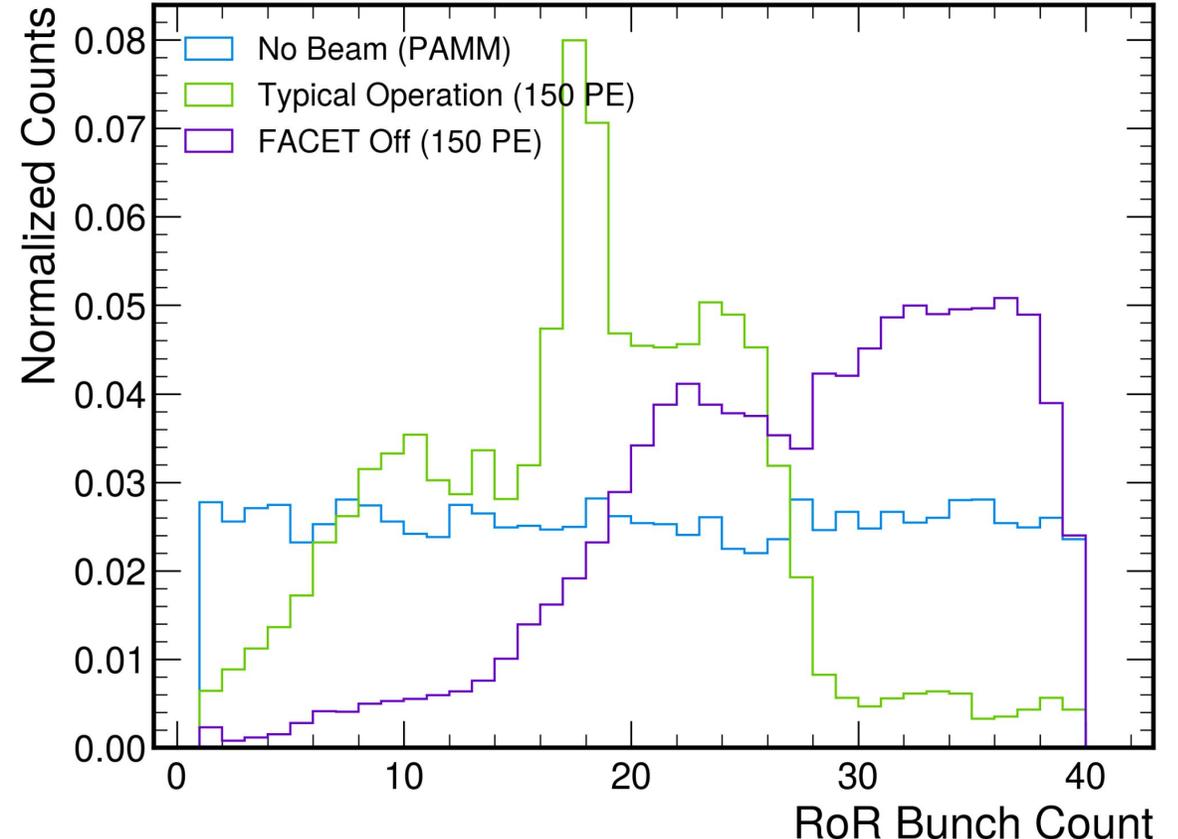
# Triggering and Data Acquisition



# Beam Backgrounds

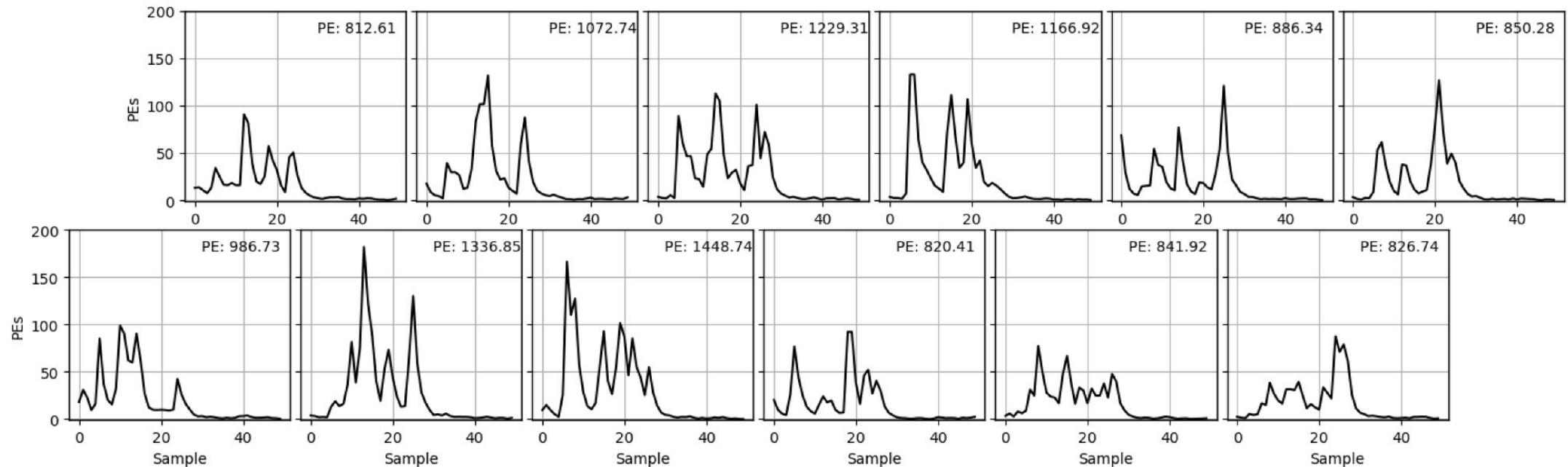
- Unlike ESA, several beamlines in vicinity
- Initial testing with self-trigger, observed a high rate (several kHz) of MIP-like backgrounds, seemingly associated with other nearby beam activity.
  - Backgrounds had clear structure with respect to LCLS-II timing message.
  - Timing profile of backgrounds shifted with changes in beam activity.
  - High rates were observed even without NC and SC lines active.
- Able to reduce self-trigger rate to  $\sim 500$  Hz with alternative TDC-based trigger.

- **Much of this likely specific to location in tunnel.**



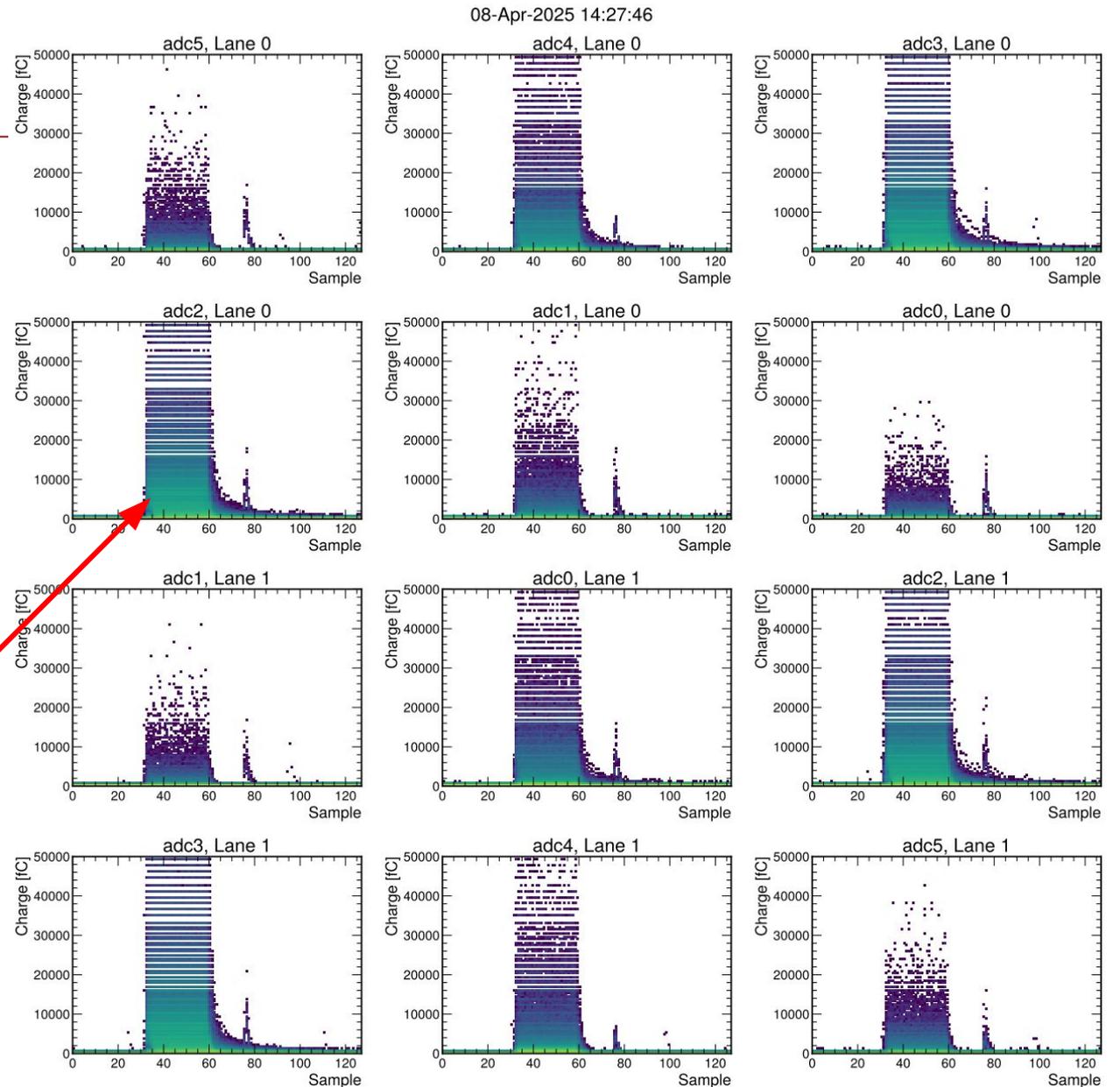
# Beam Background Event Example

- Backgrounds are not localized in space
- Activity spans ~30-40 37 MHz samples.

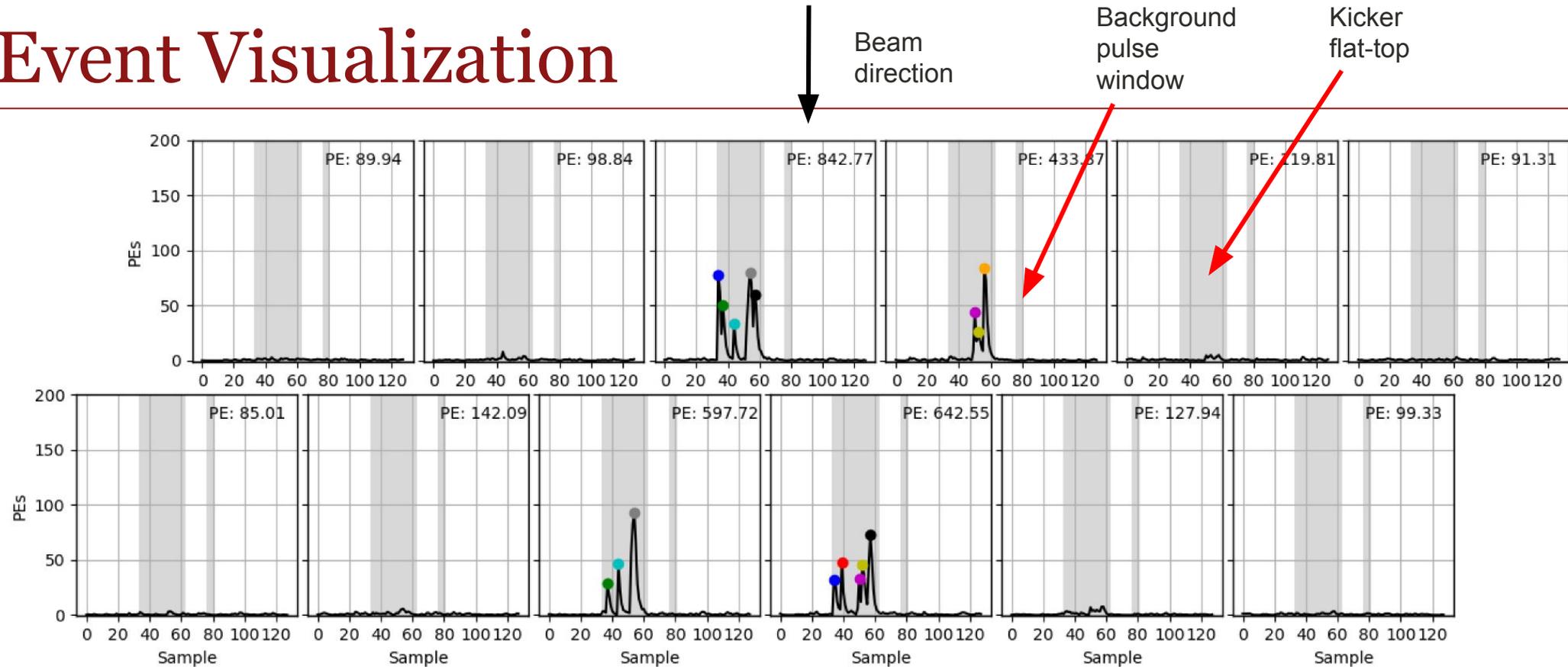


# Event Waveforms

- Data taken with kickers firing, TS triggering on 10 Hz kicker trigger timing signal.
  - Charge is read out in 37 MHz time samples (total window of 128 samples per event).
  - Light yield:  $\sim 16000$  fC/MIP
- Period of  $\sim 800$  ns of activity (samples 33-63), consistent with dark current from the kicker flat top.
- Noise/background assessed with kicker off data – very low



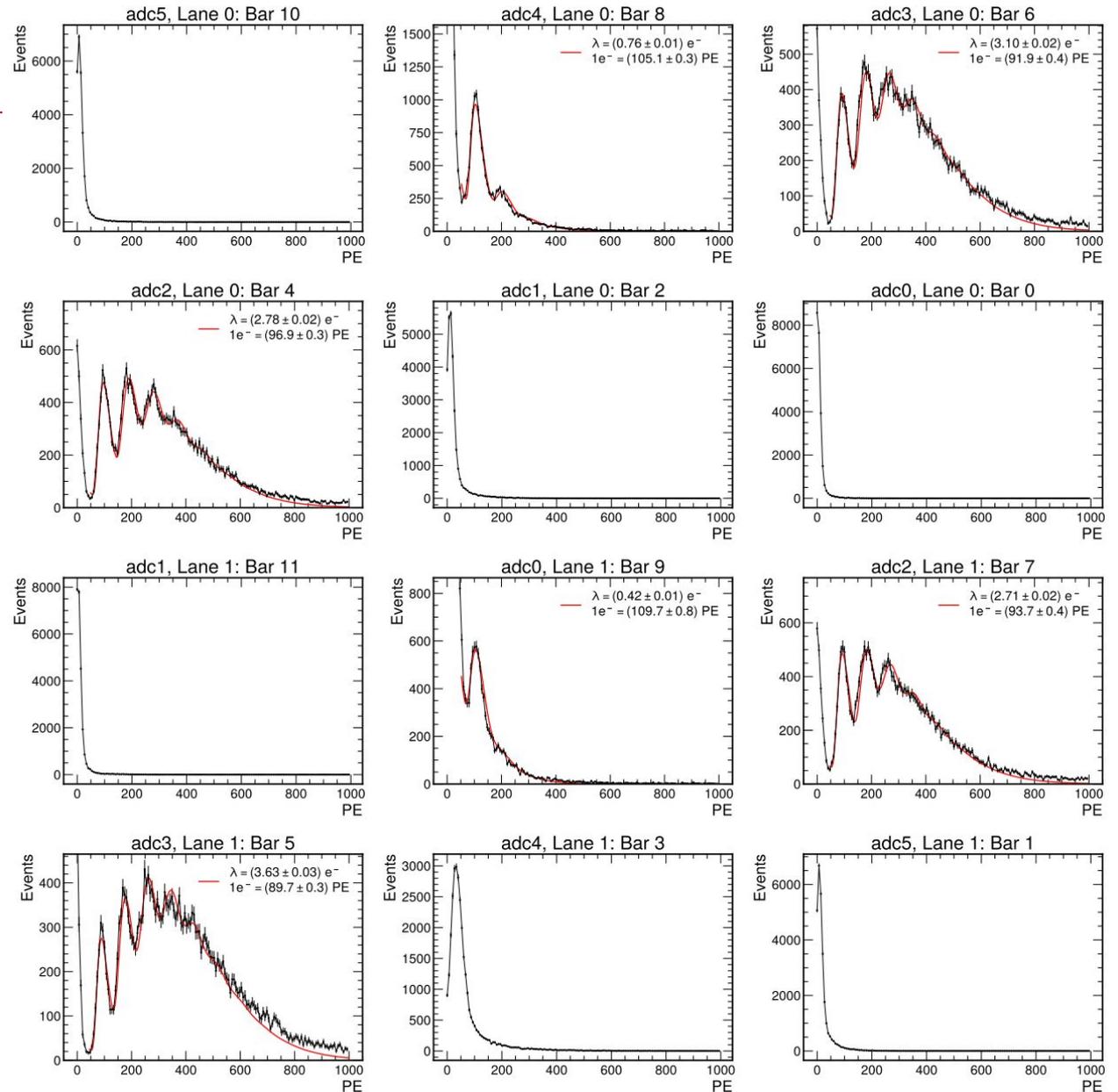
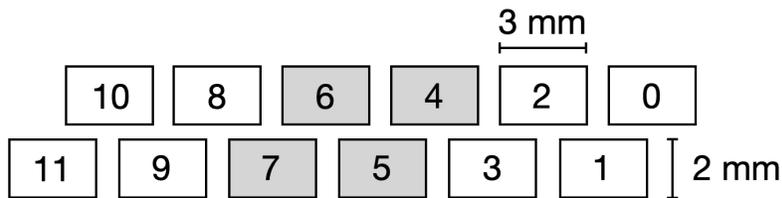
# Event Visualization



- Plot display shows physical arrangement of scintillating bars (not to scale).
  - Colored points: pulses that arrive in the same time sample.
  - In this example: 9 electrons
- Pulses from individual electrons are visible in time-sample window corresponding to kicker flat-top.

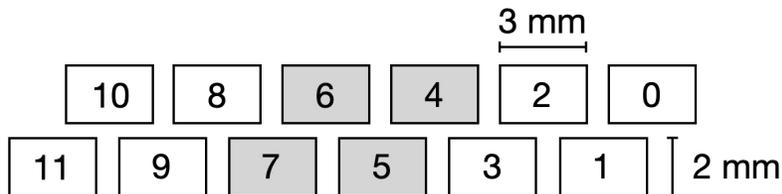
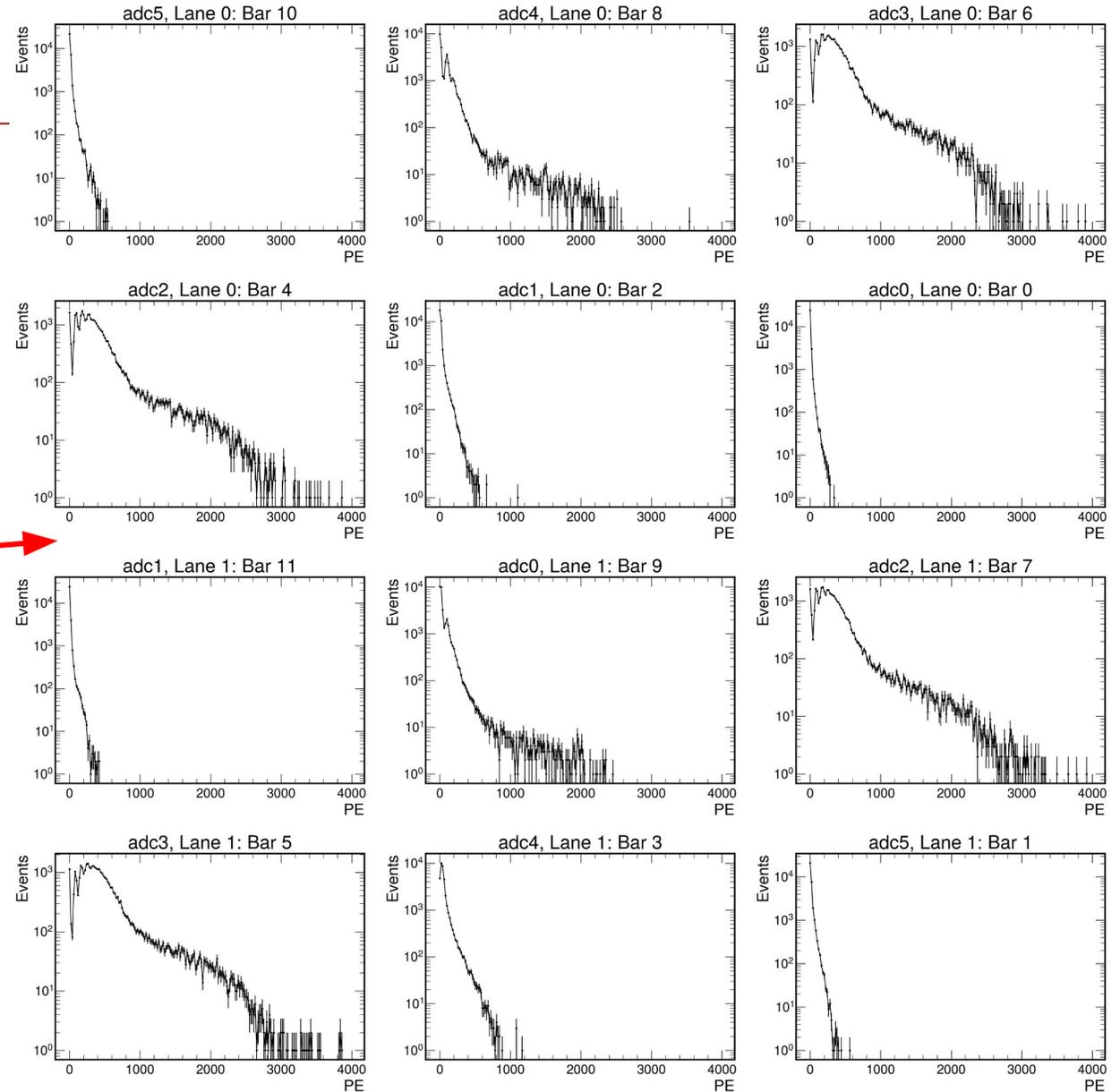
# Measured Charge

- Plots show total charge integrated over full kicker flat-top window.
- Distributions are fit to Poisson-distributed sum of Landau peaks (red line).
- Initial dark current estimate:
  - $\sim 7 e^-$  per kicker window:  $\sim 1.6 \text{ pA}$



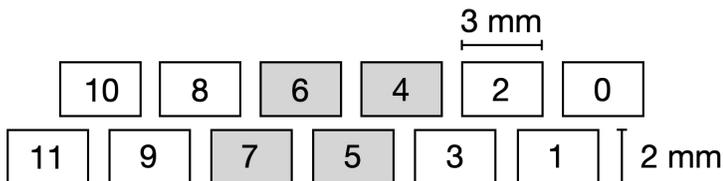
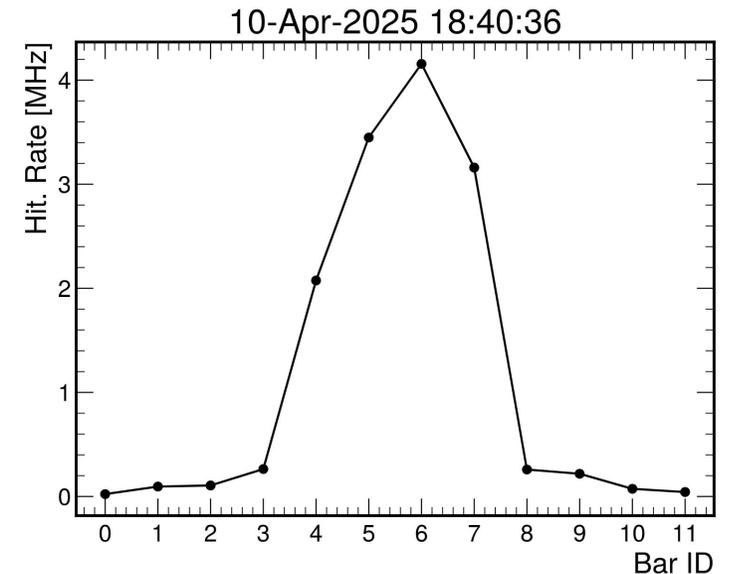
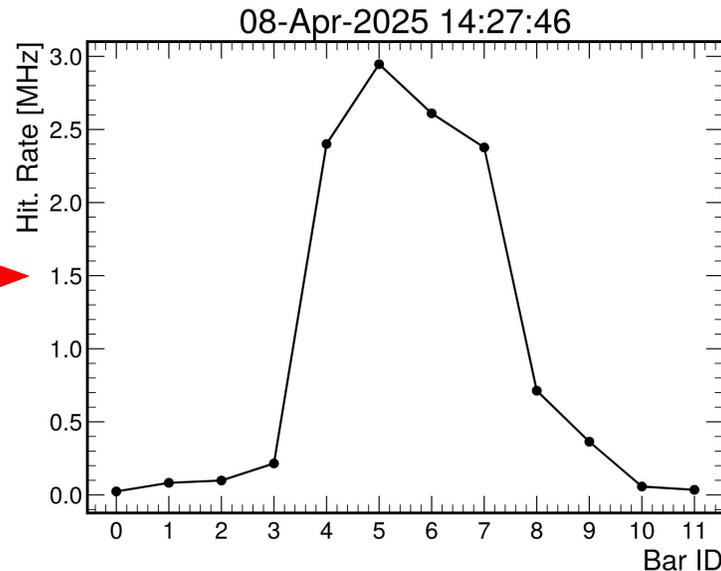
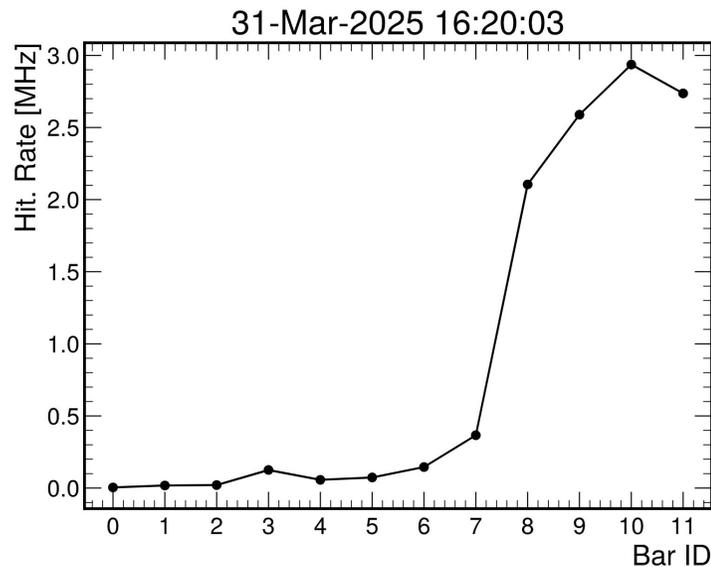
# Measured Charge

- We occasionally see events with an abnormally large number of electrons ( $\sim 10$ ) in a single 37 MHz sample.
  - $\sim 2\%$  of pulses have height  $> 500$  PE (at least 5-6 electrons).
- Charge distributions show an additional feature at  $\sim 2000$  PEs.
- These high charge events appear uniform in time.



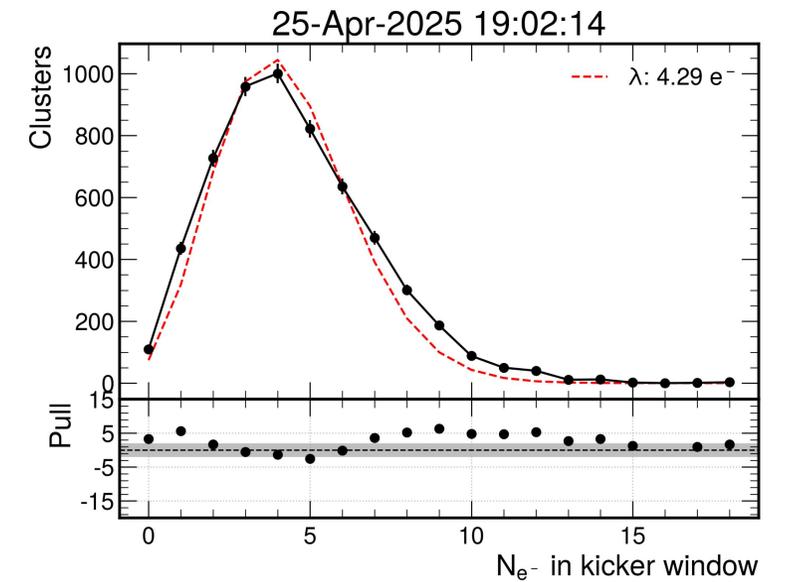
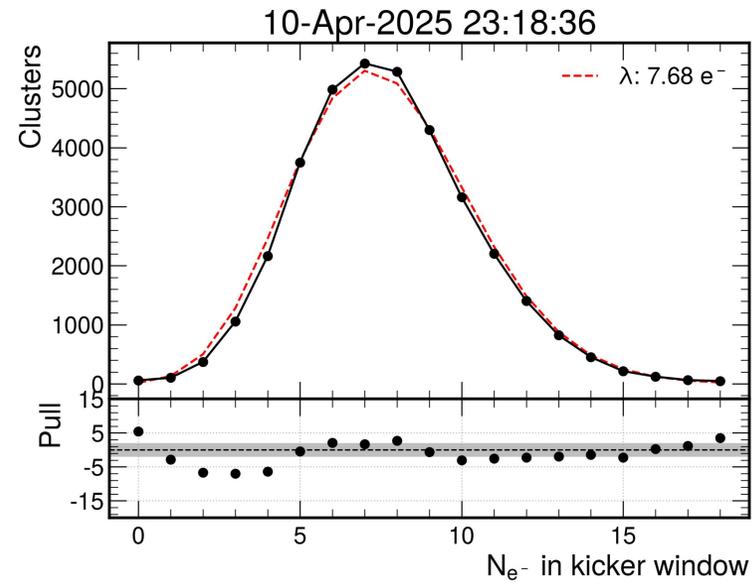
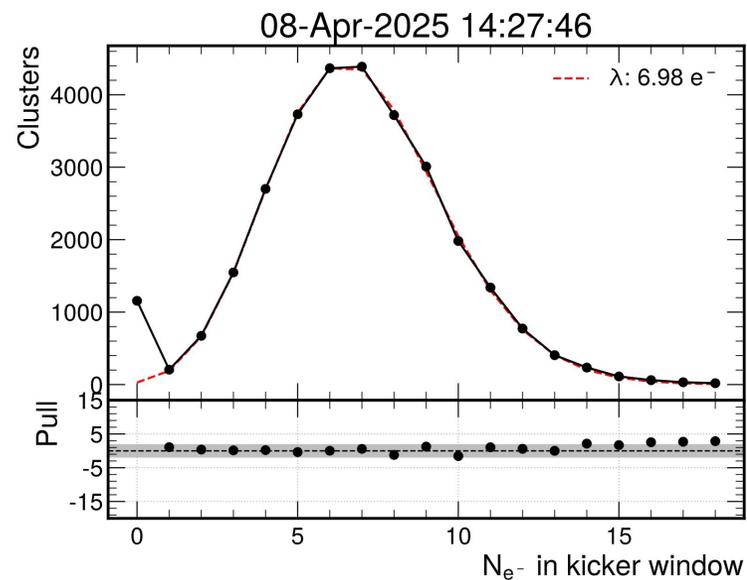
# Beam Profile/Steering

- First measurements of dark current showed that beam spot was slightly misaligned.
- We were able to steer the beam to the center of the TS using Jessica's live monitoring tools.
- Total steering range was  $\sim 1$  cm in x,  $< 1$  cm in y.
- Slight changes in shape of beam spot observed over run period.



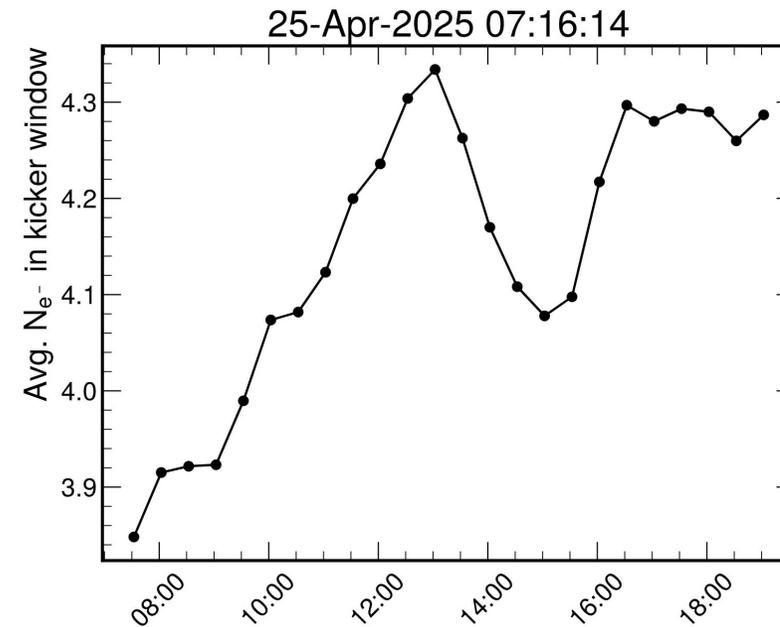
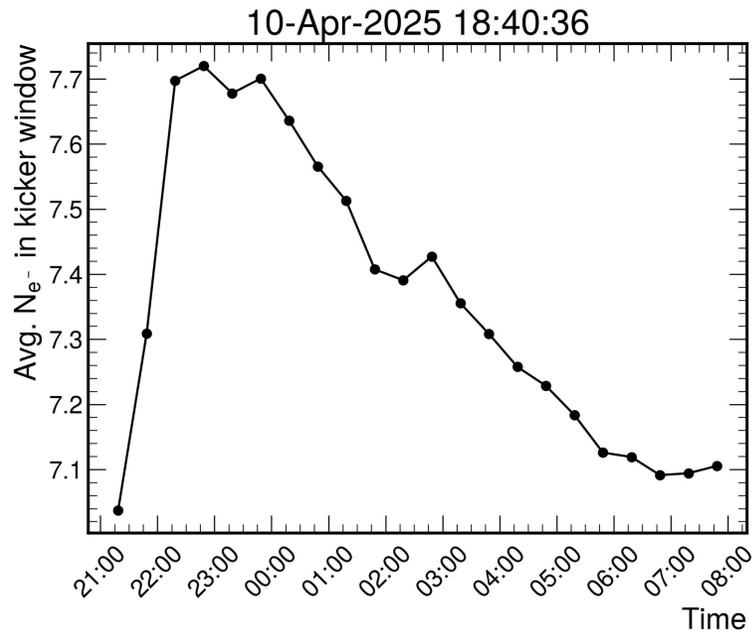
# Electron Counting

- Number of electrons in kicker window closely follows Poisson distribution.
  - Deviations from Poisson distribution potentially due to slightly changing dark current rate over time, and pulse finding effects from narrowing beam spot.
- Disagreement at  $N_e = 0$  due to times when kicker operation was interrupted.



# Dark Current Stability

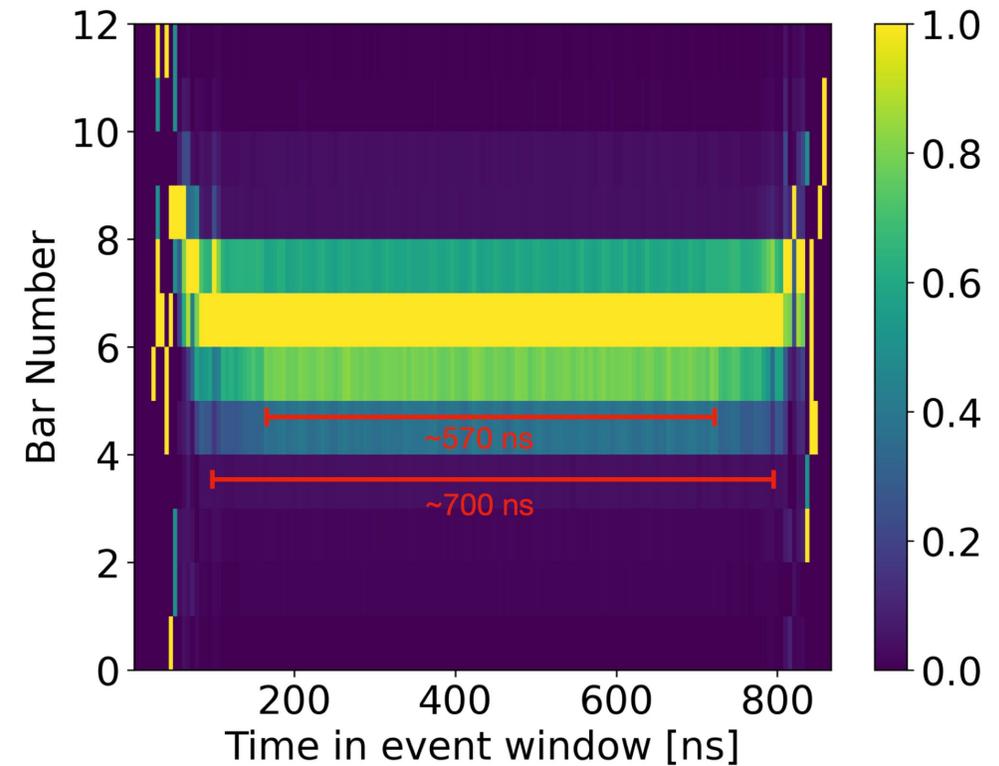
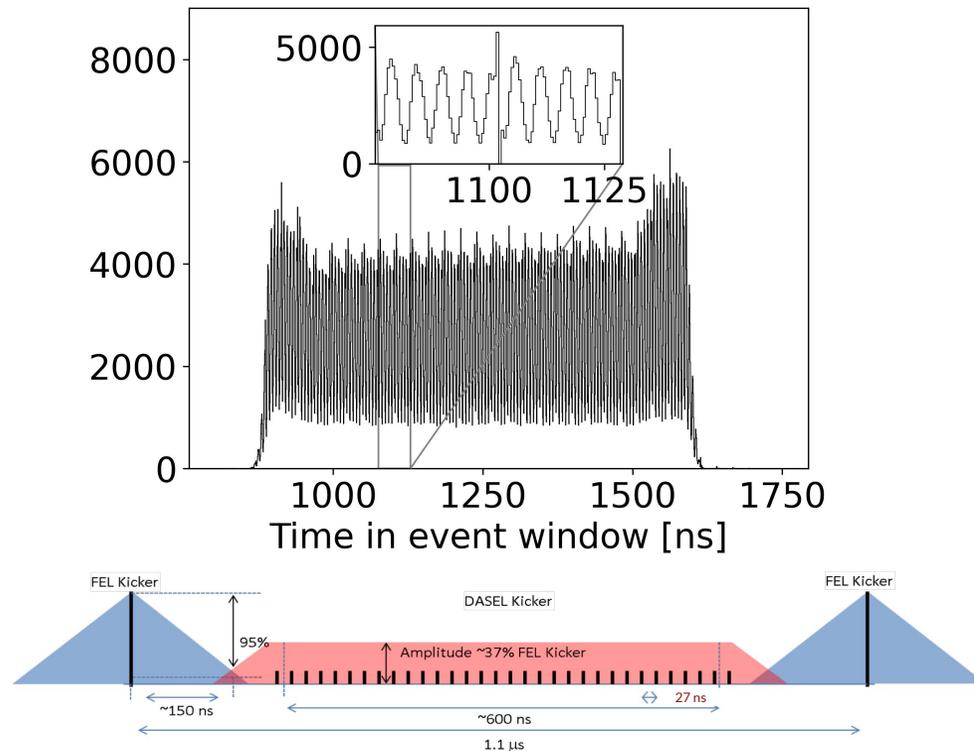
- Apart from interruptions to the kicker, dark current is largely stable within continuous run periods.
- Larger changes were observed before/after multi-day interruptions (PAMMs, etc.)
- Initial measurements of dark current were  $\sim 7$  e- per kicker window, but later measurements suggested  $\sim 4$  e-.



Time

# Kicker Pulse Spatial and Temporal Shape

- 186 MHz timing structure is visible in electron arrival times using TDC information ( $\sim 0.5$  ns resolution).
- Beam profile sweeps across the detector during kicker pulse rise and fall times, and stabilizes for a 570 ns flattop, in agreement with expectations.



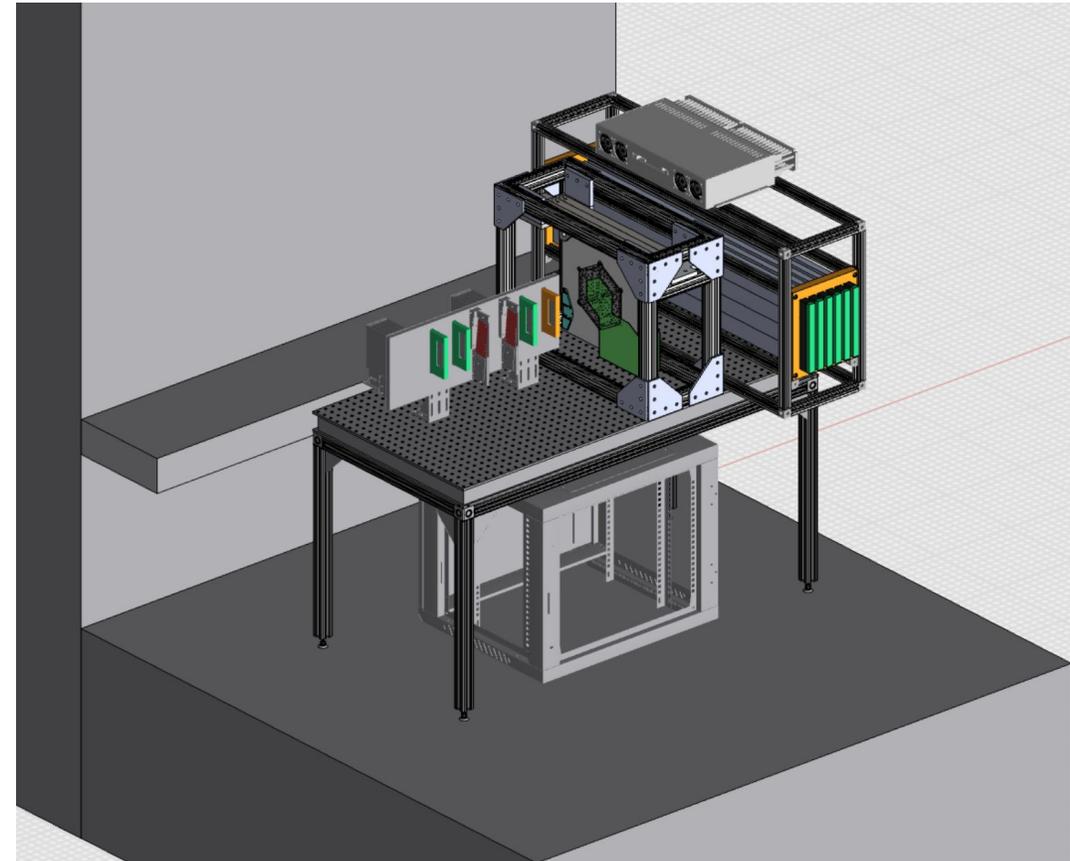
# Lessons Learned & Future Plans

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- Was a learning experience for all involved!
- Once everything was correctly enabled the system was robust and dark current was relatively stable
- Note: cathode changes can have big changes to dark current – no guarantee what it will look like after the long shutdown

## Future plans:

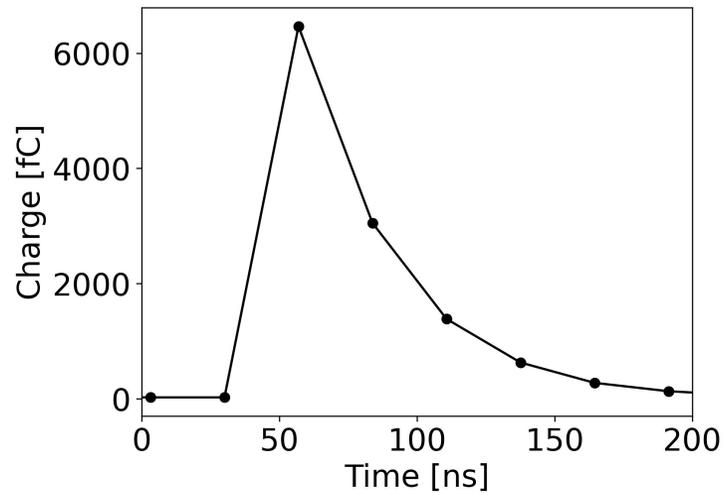
- Working on draft of NIM paper on these results (almost ready for submission!)
- LDMX is planning “slice” test in ESA alcove in December.



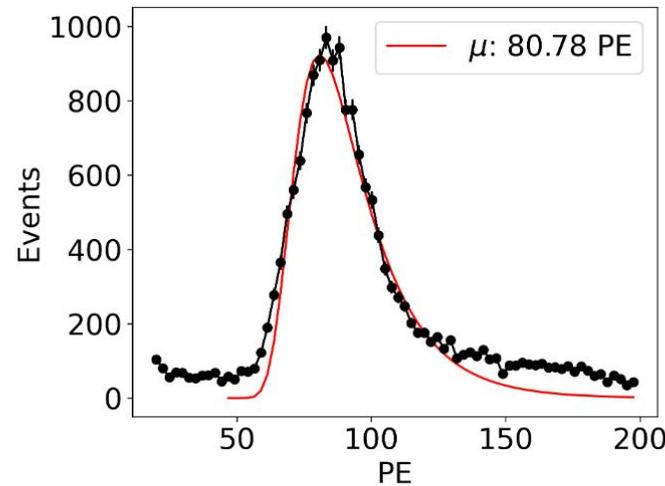
# Backup

# Detector Response

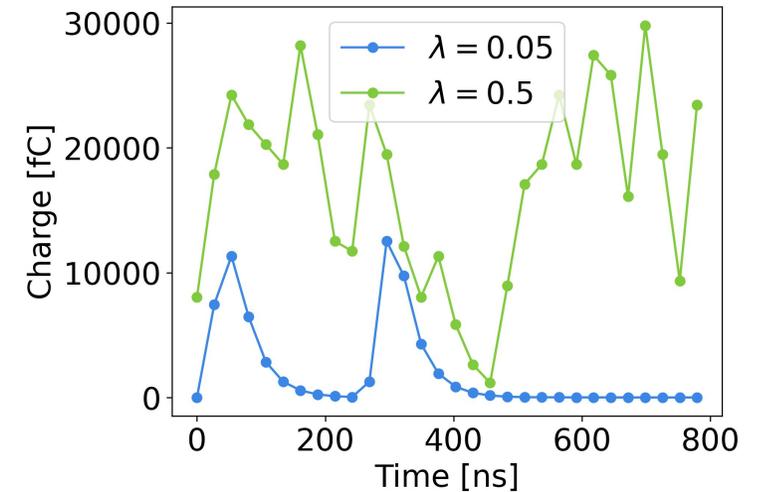
- Scintillation light is detected by SiPMs located at the end of each TS bar—output is a current pulse proportional to amount of scintillation light.
  - SiPM gain:  $1.2e6 e^- / PE$



- Readout electronics integrate the current pulse in intervals of  $\sim 27$  ns, producing a charge pulse with fall time of  $\sim 30$  ns.



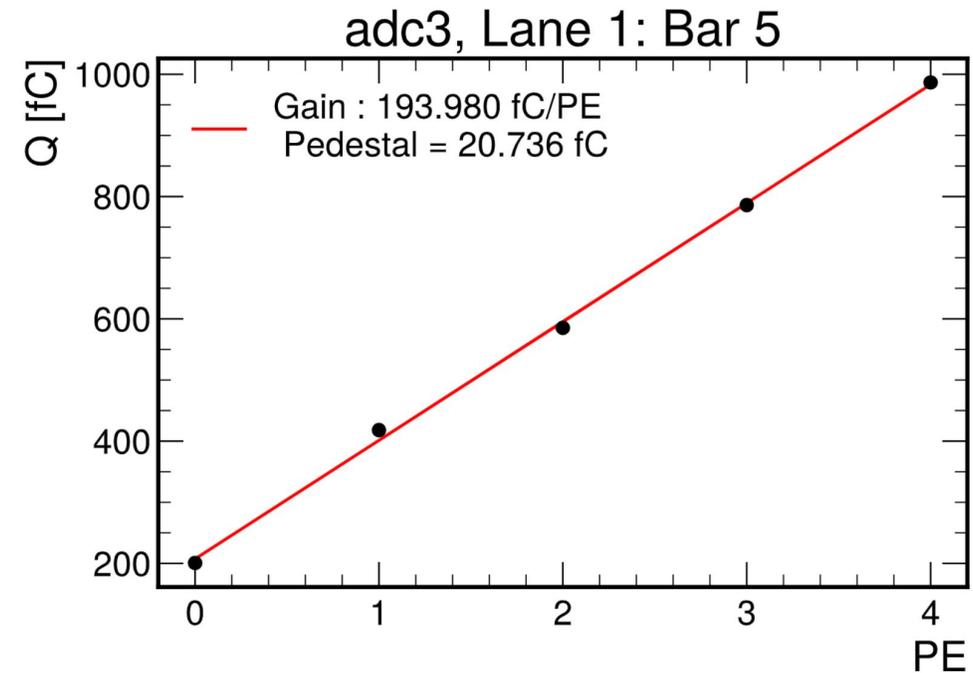
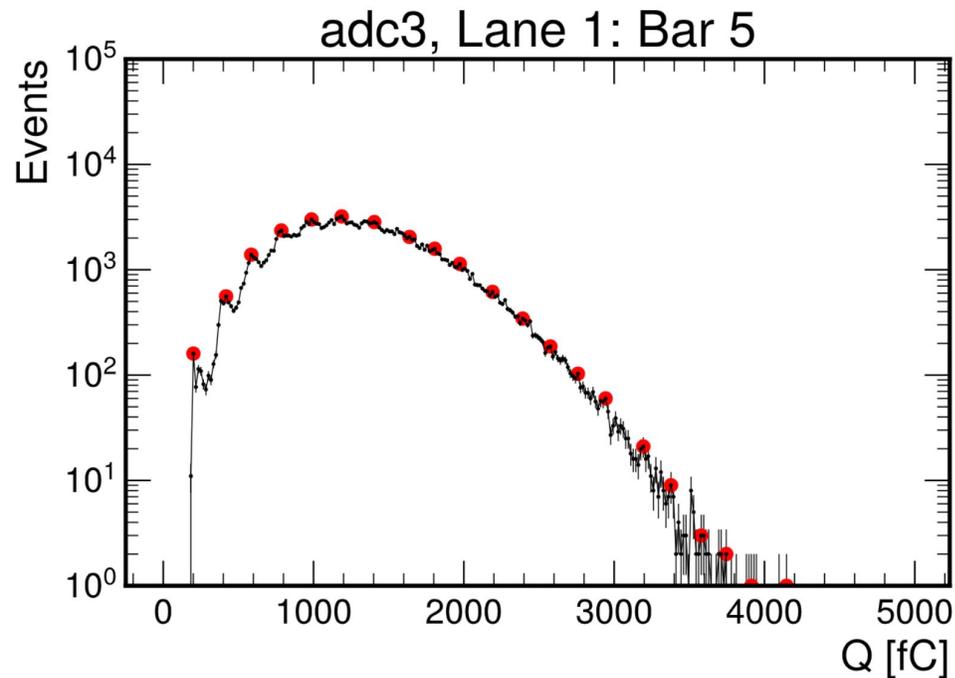
- Distribution of charge for a single electron is peaked at  $\sim 80$  PEs.



- From dark current, we expect a Poisson-distributed number of electrons to arrive in each 5.4 ns bunch (186 MHz).

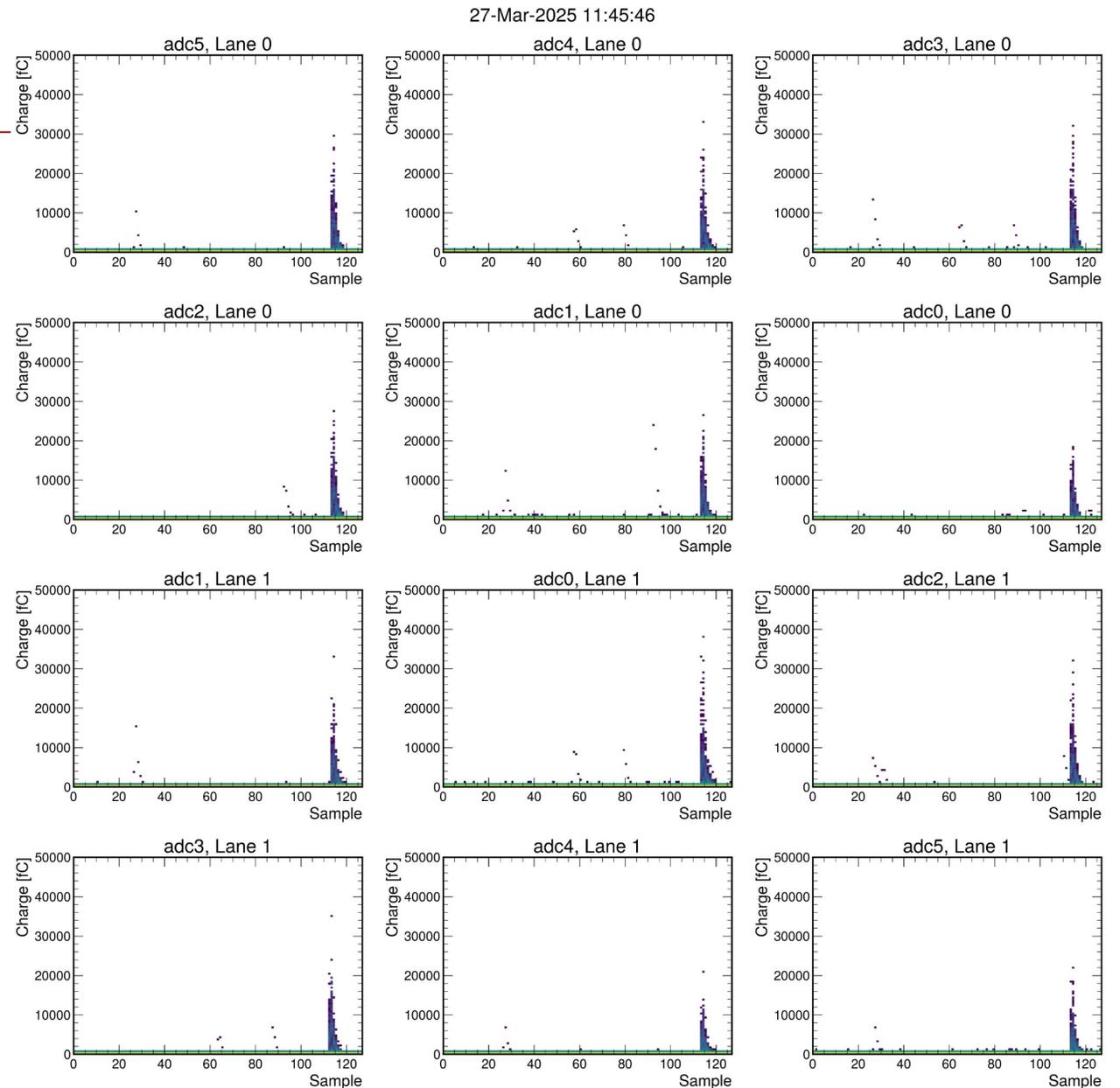
# SiPM Calibration/Performance

- Single PE resolution affected by light leak, but still able to measure gain for most runs.
  - Noise distribution remains well-separated from MIP signal.
- No significant change in gains (or light yield) observed over full run duration.



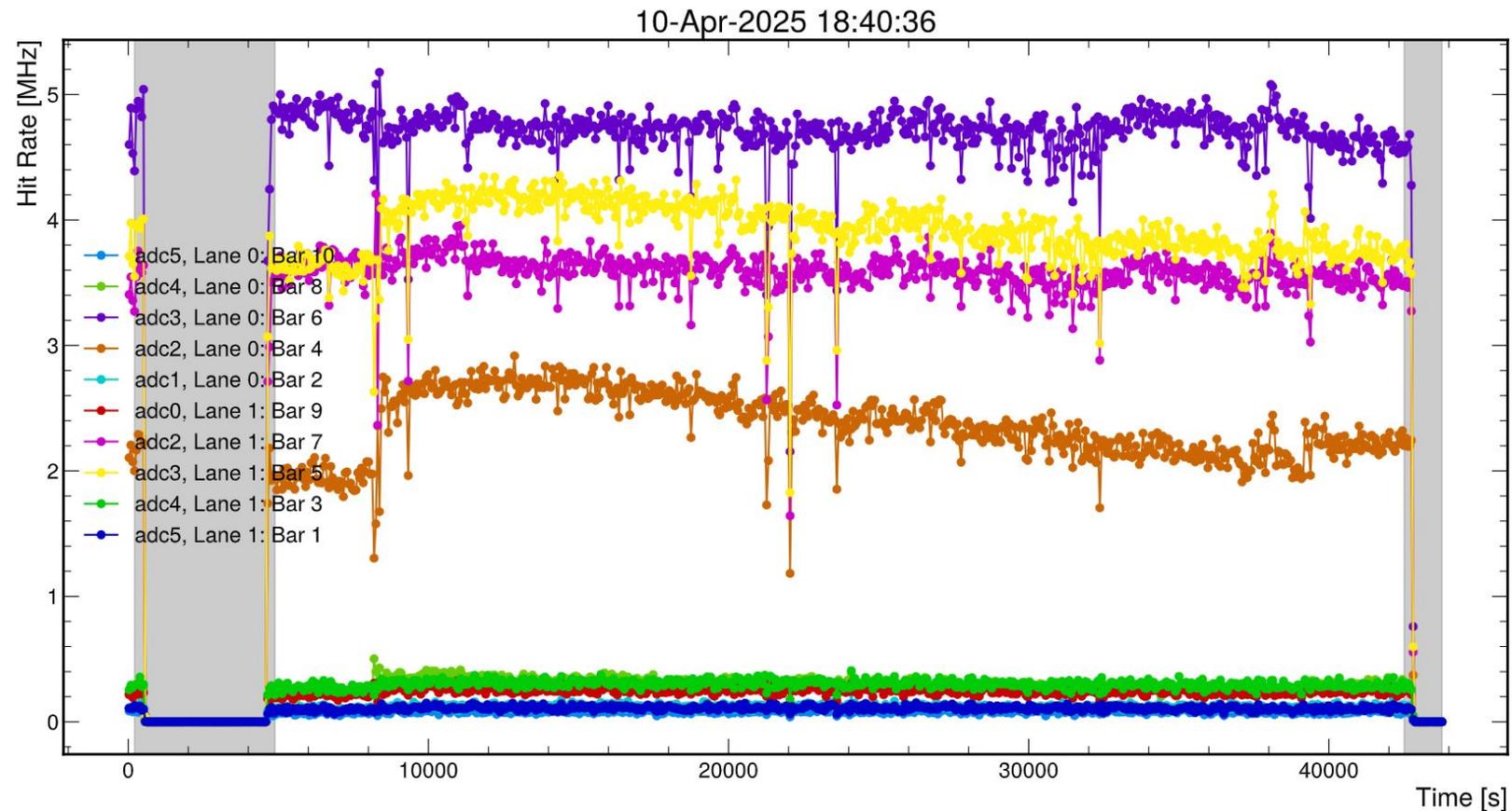
# Noise Characterization

- Plot represents ~1 hour of running, with kicker disabled, triggering on 10 Hz kicker timing signal.
- Very few MIP-like pulses (< 3 per channel) present in kicker window.
- Beam backgrounds are not an issue when readout is timed in with kicker timing signal.
- Single background pulse present at a fixed sample (110).
  - Likely product of upstream kickers, which fire at multiples of 10 Hz.



# Dark Current Stability

- Apart from interruptions to the kicker, dark current is largely stable within continuous run periods.
- Larger changes were observed before/after multi-day interruptions (PAMMs, etc.)
- Initial measurements of dark current were  $\sim 7$  e- per kicker window, but later measurements suggested  $\sim 4$  e-.



# TDC Resolution

- TDCs decrease by  $\sim 1-2$  ns with increasing pulse amplitude (higher amplitude pulses have faster rise time, due to variable QIE input impedance).
- TDC spread decreases with amplitude.
- Observed spread in TDCs corresponding to an individual 5 ns bunch is in agreement with MC generated with ldmx-sw:
  - Simulated 186 MHz bunches with  $\mu = 0.05$  per bunch (3.83 GeV electrons)
  - Implemented rough scaling of pulse rise time with pulse amplitude.
  - Beam spot: 7 mm x 7 mm
  - TDC threshold: 340  $\mu\text{A}$

