Self calibration of LEDs in D-Eggs for IceCube-Upgrade

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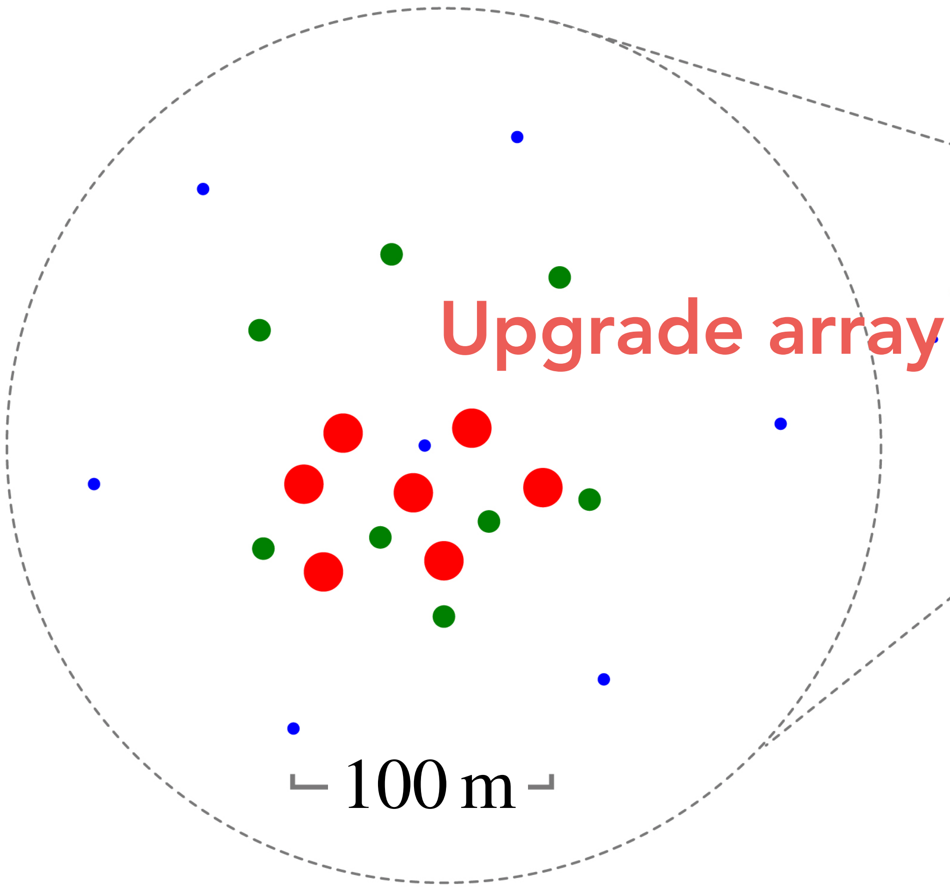
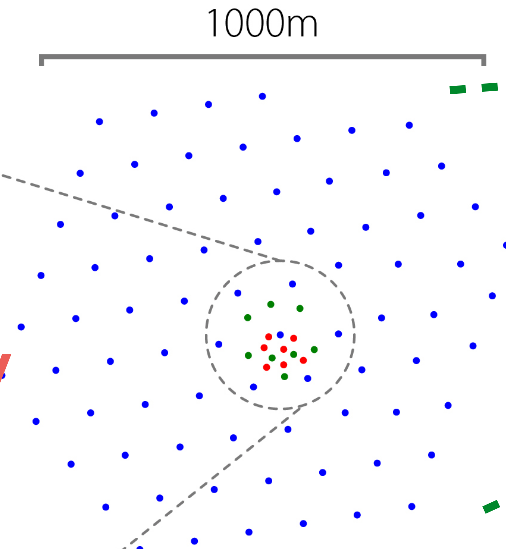
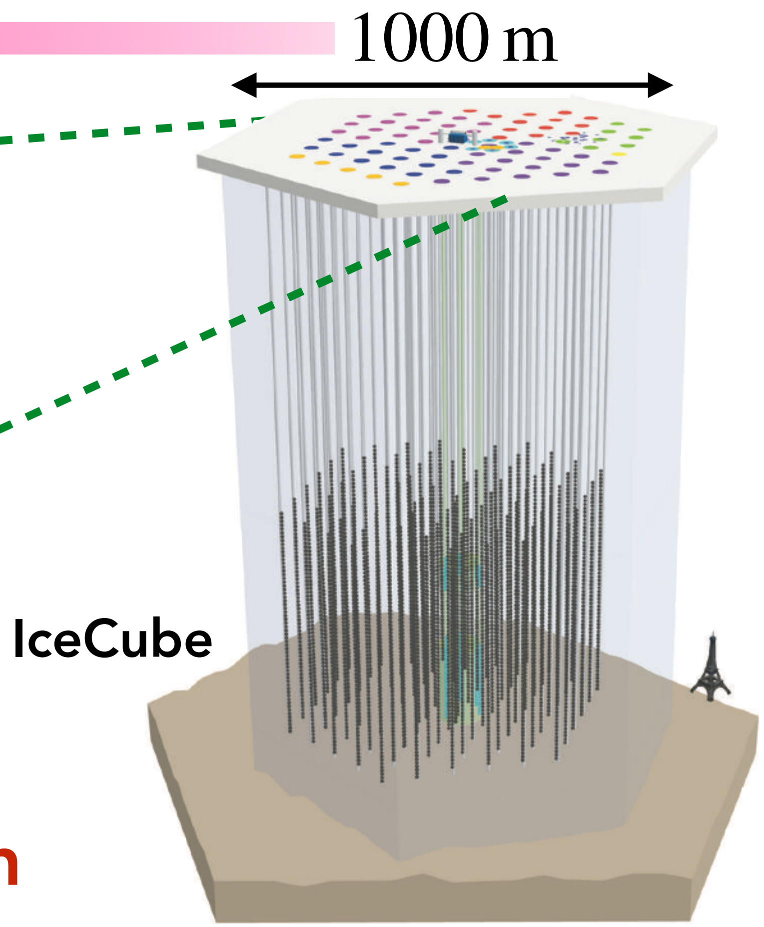
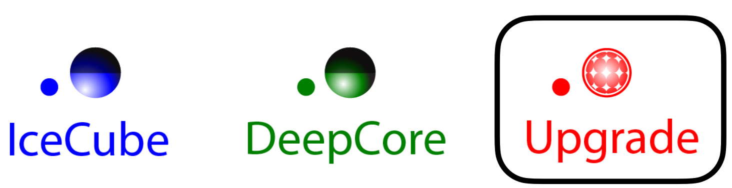
Chiba University

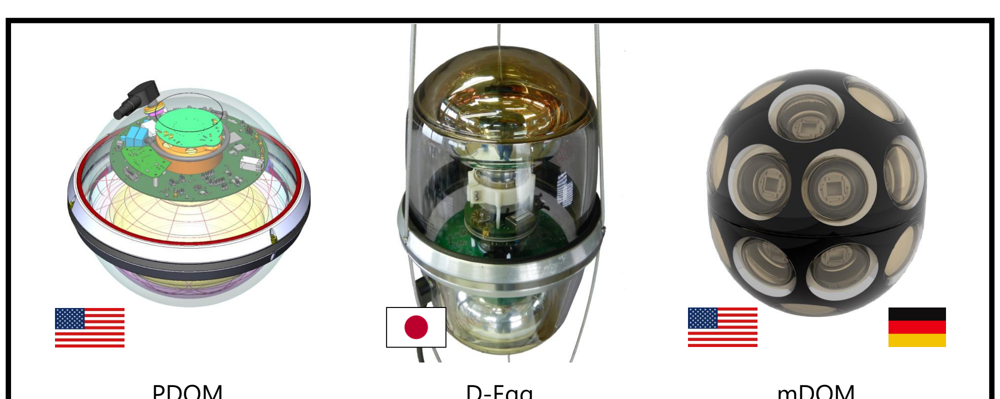
IceCube-Upgrade







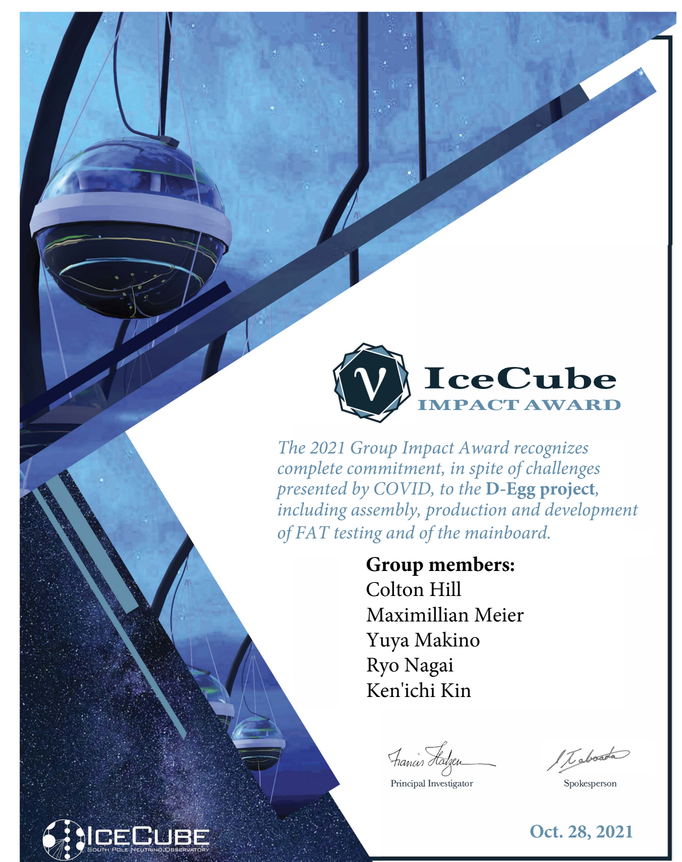




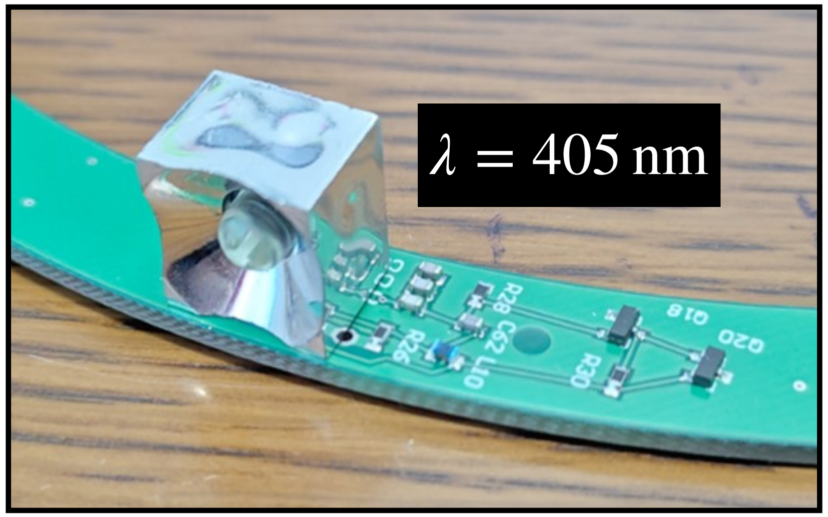
- **2025/26 Construction**
  - Delay due to COVID-19… :(
  - As a first step of **IceCube-Gen2**
- Enhance the sensitivity of GeV-Scale neutrino physics
- Precise calibration of the ice properties
  - Contribute to reduce the uncertainty related to photon propagation in ice

D-Egg : Main Detector of IC-Upgrade

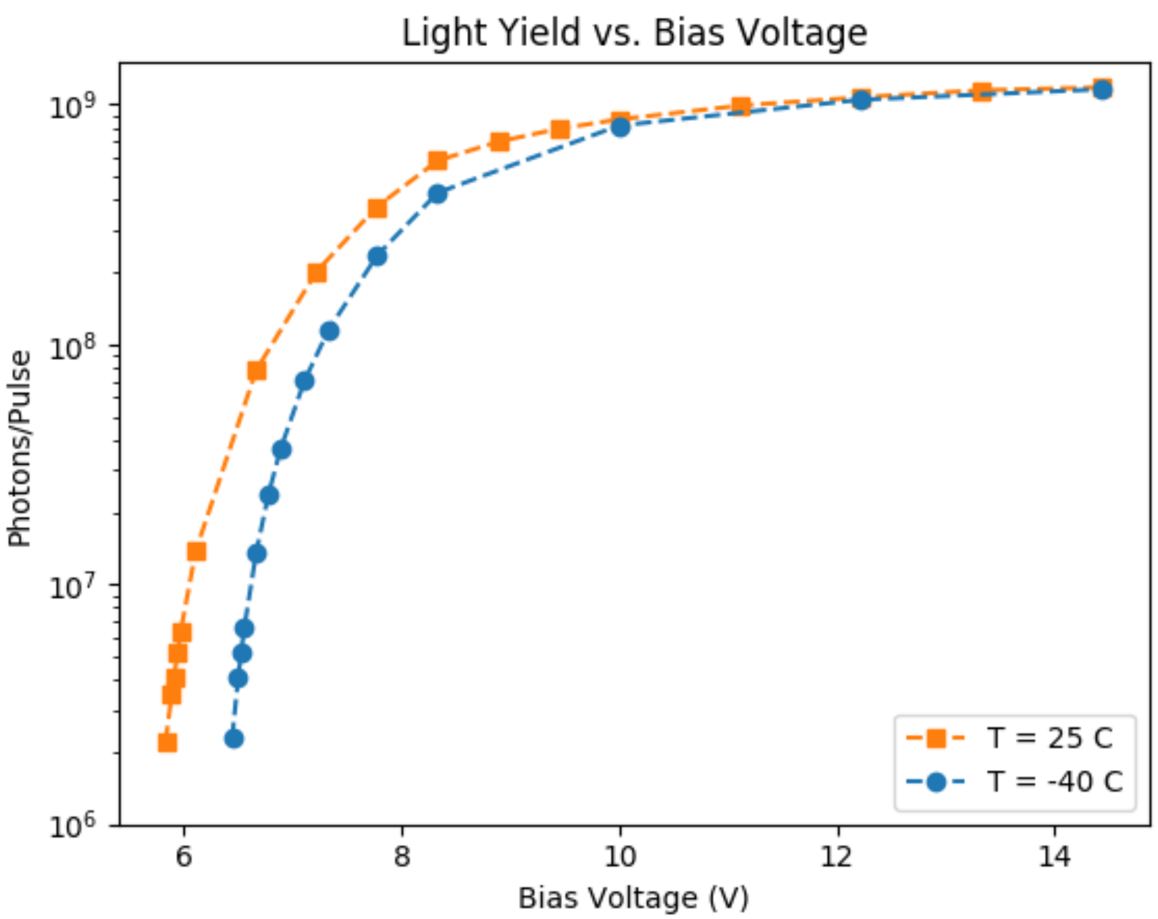
- Developed by **Chiba group**, the production was completed last year (2021)
- 4π detection allows us to improve the detection efficiency
- ~300 D-Eggs will be deployed

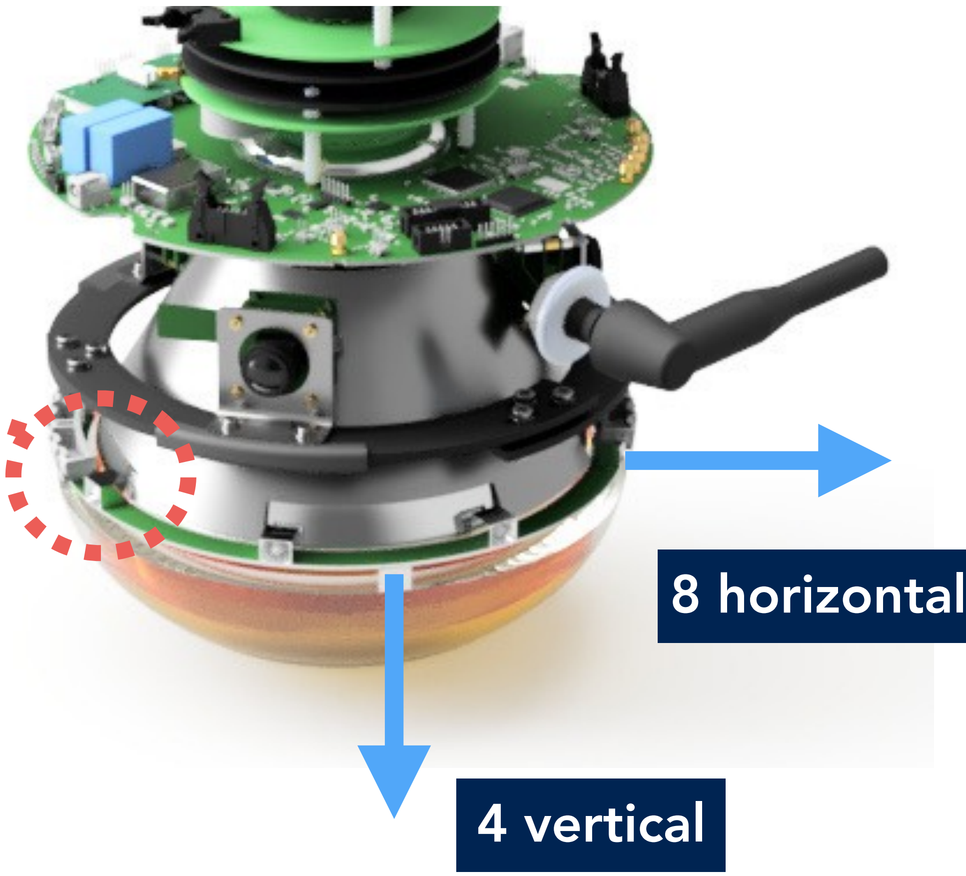


LED Flasher Calibration System



Kapustinsky pulser



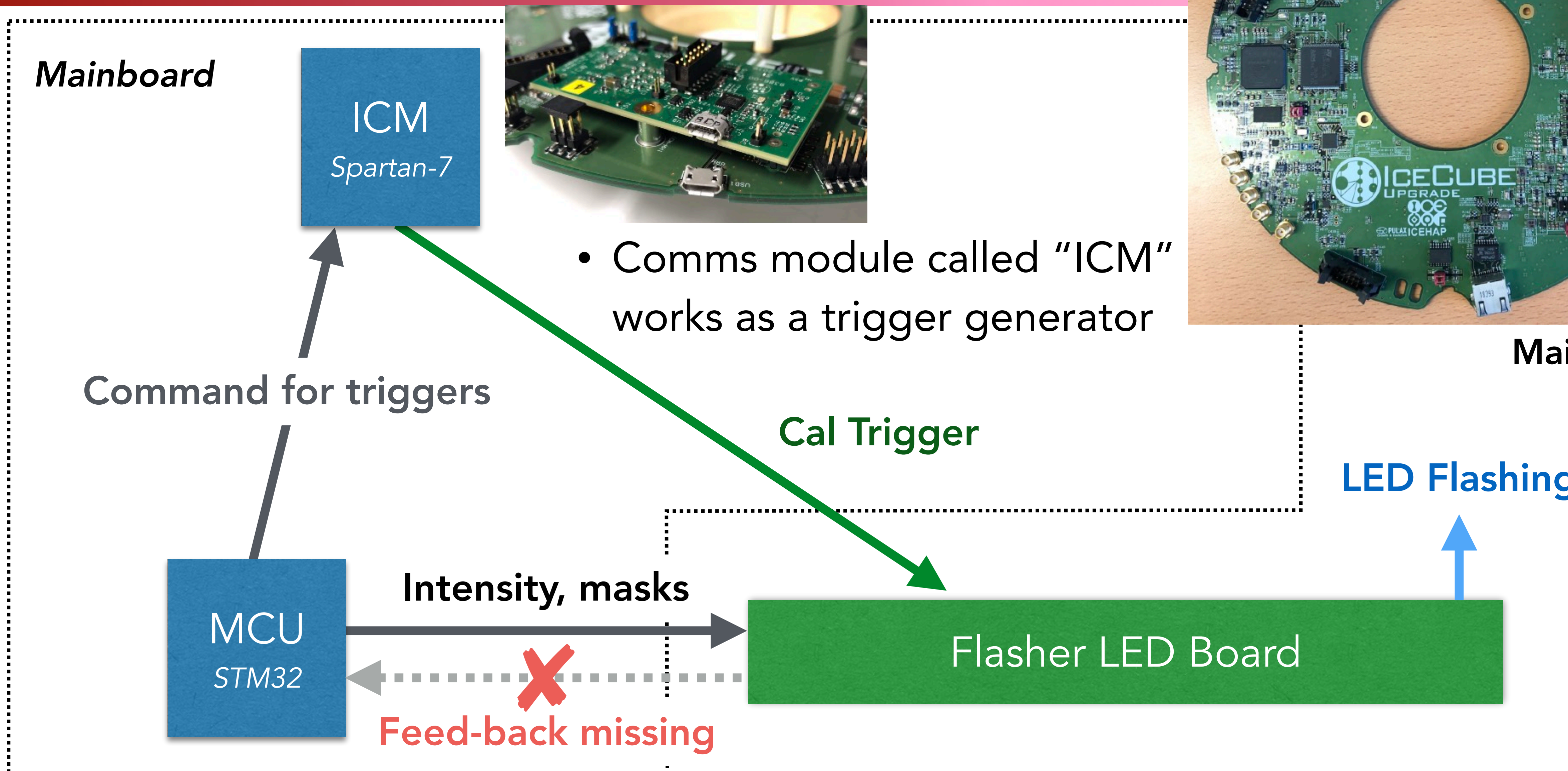


– In Ice –

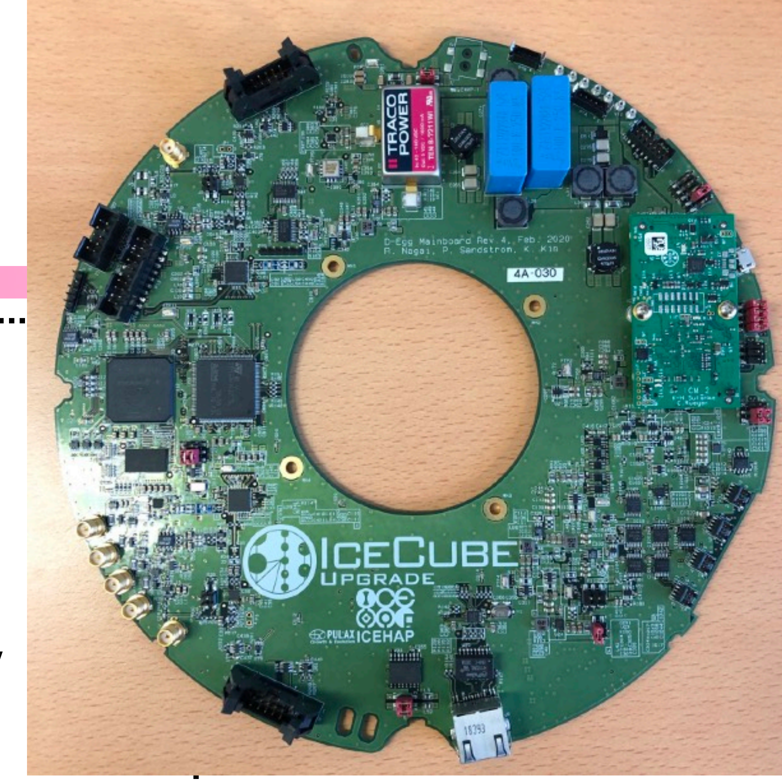
Detect #photons of
next to D-Eggs / DOMs

Measure the ice property

LED Flasher System



- Comms module called "ICM" works as a trigger generator

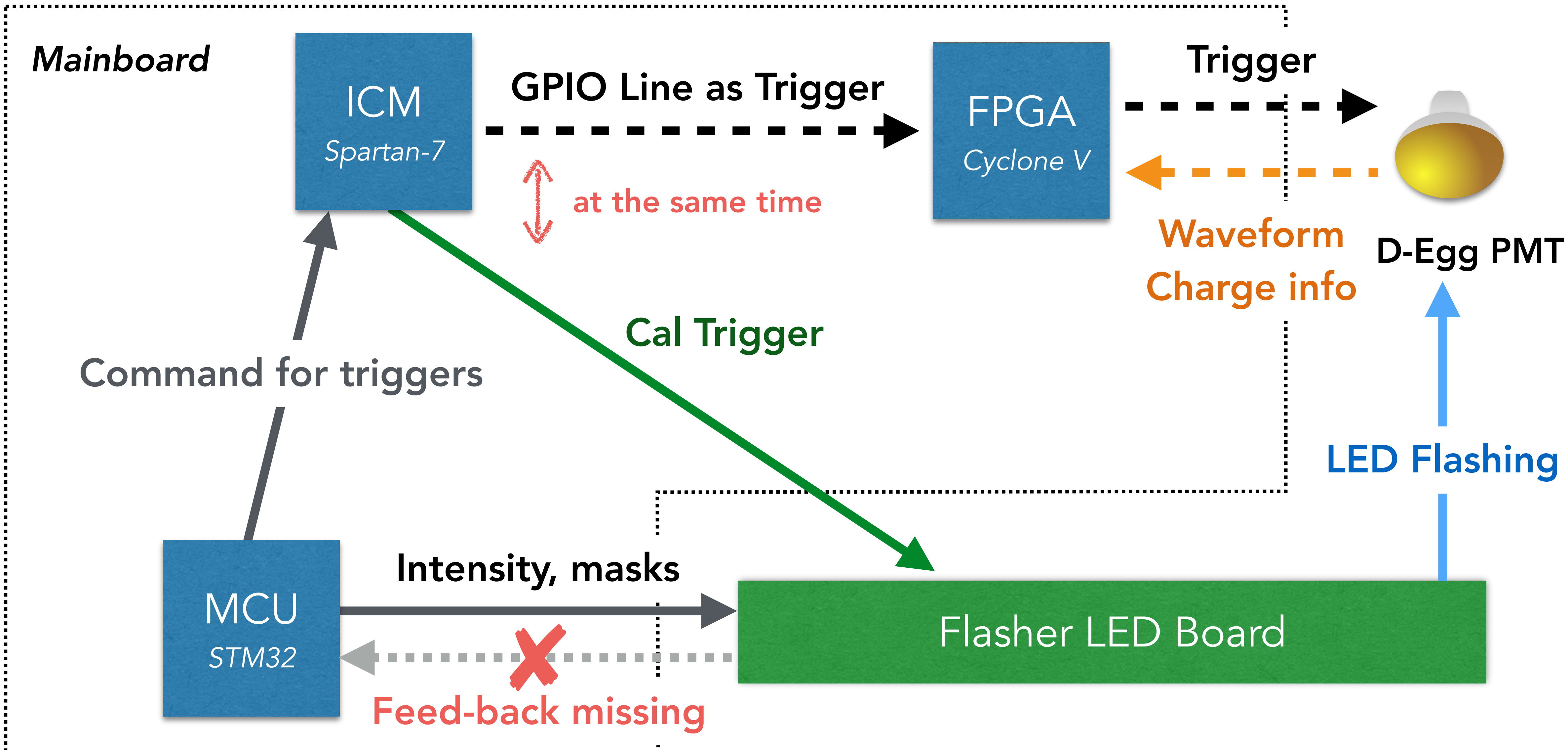


Mainboard

- MCU can control the LED intensity & masks
- ICM FPGA publishes the flashing triggers, but no feed-backs

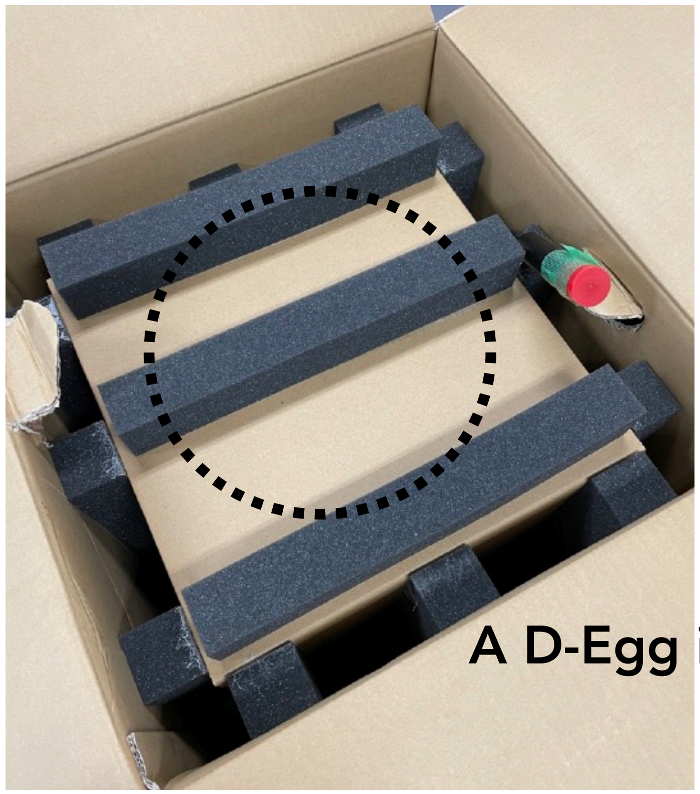
How do we know if it works or not in ice?

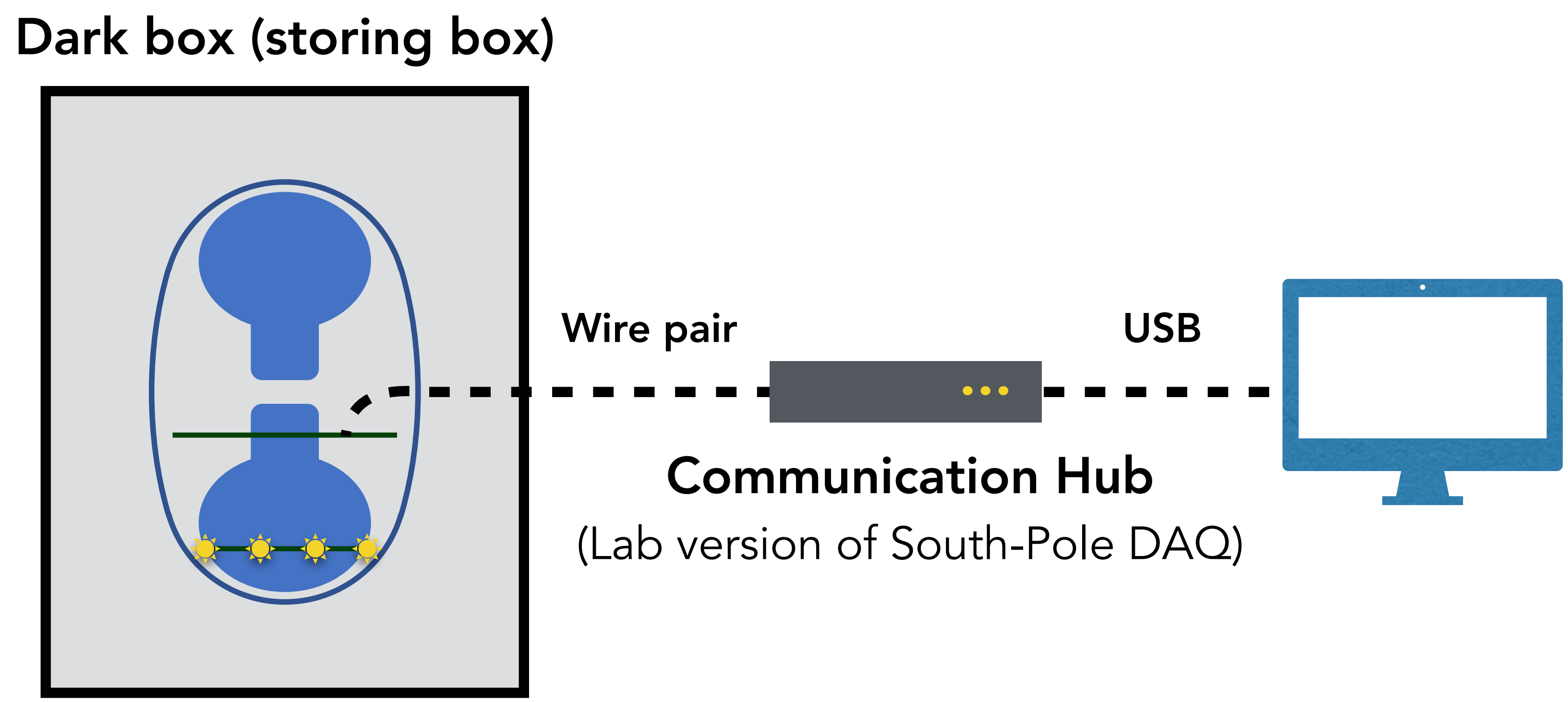
Self Calibration of the LED Flasher!

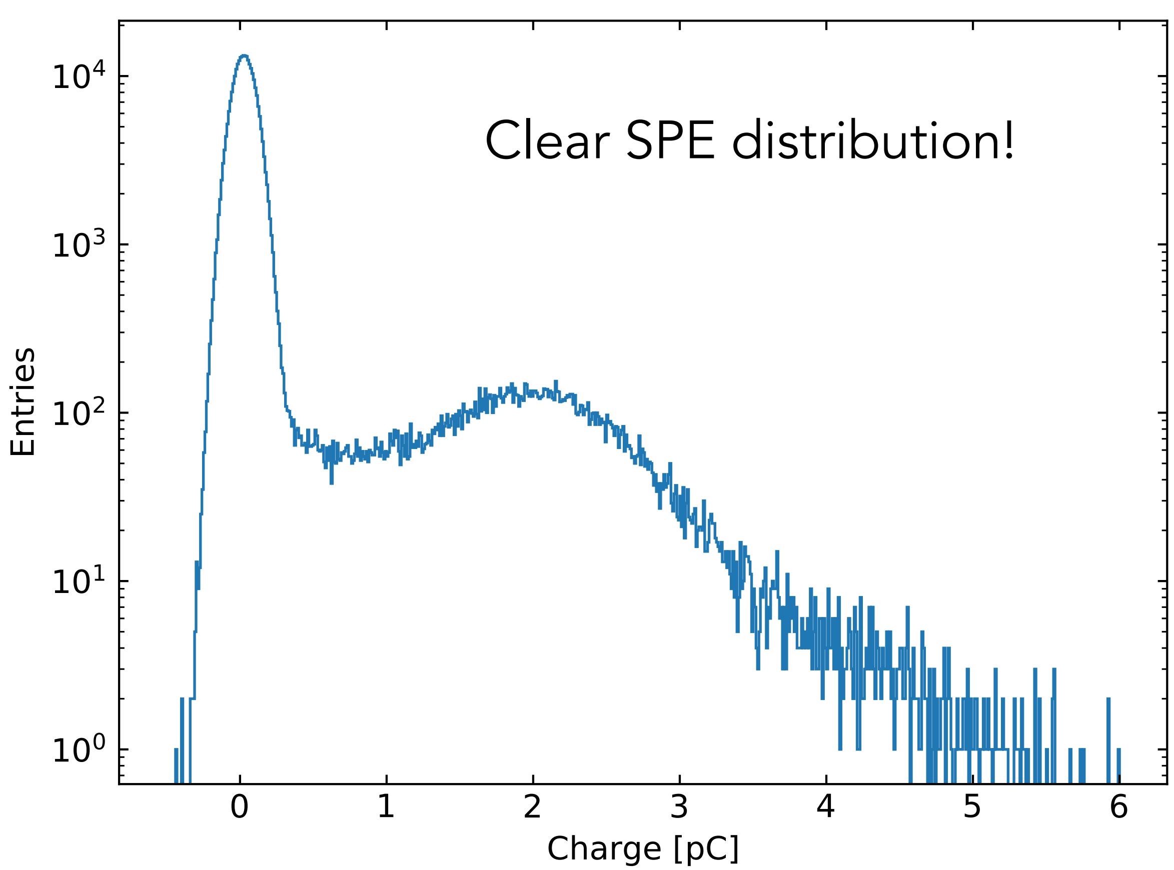


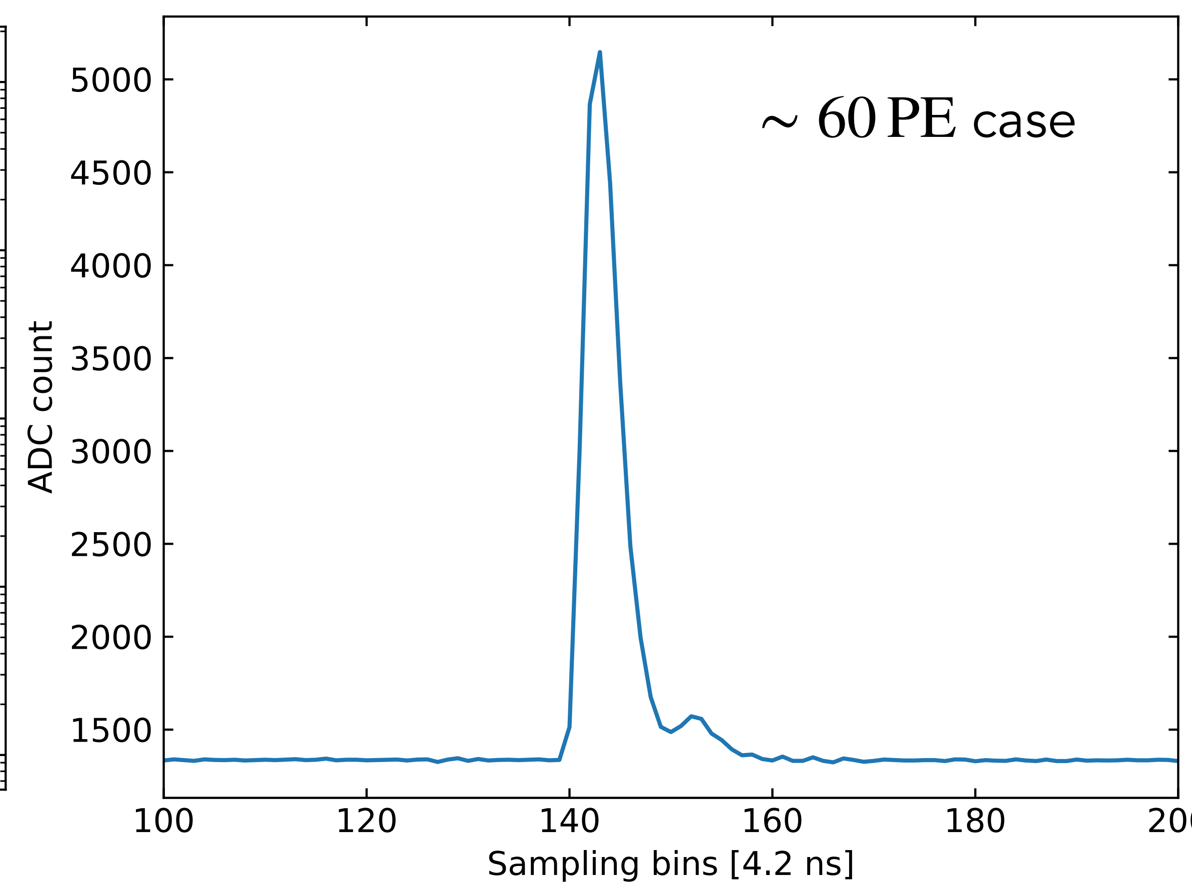
- **I modified firmware** to work ICM ↔ FPGA GPIO as a PMT trigger line
- Can verify LEDs by looking signals from low-gain D-Egg PMT with the synchronized triggers

Test Setup

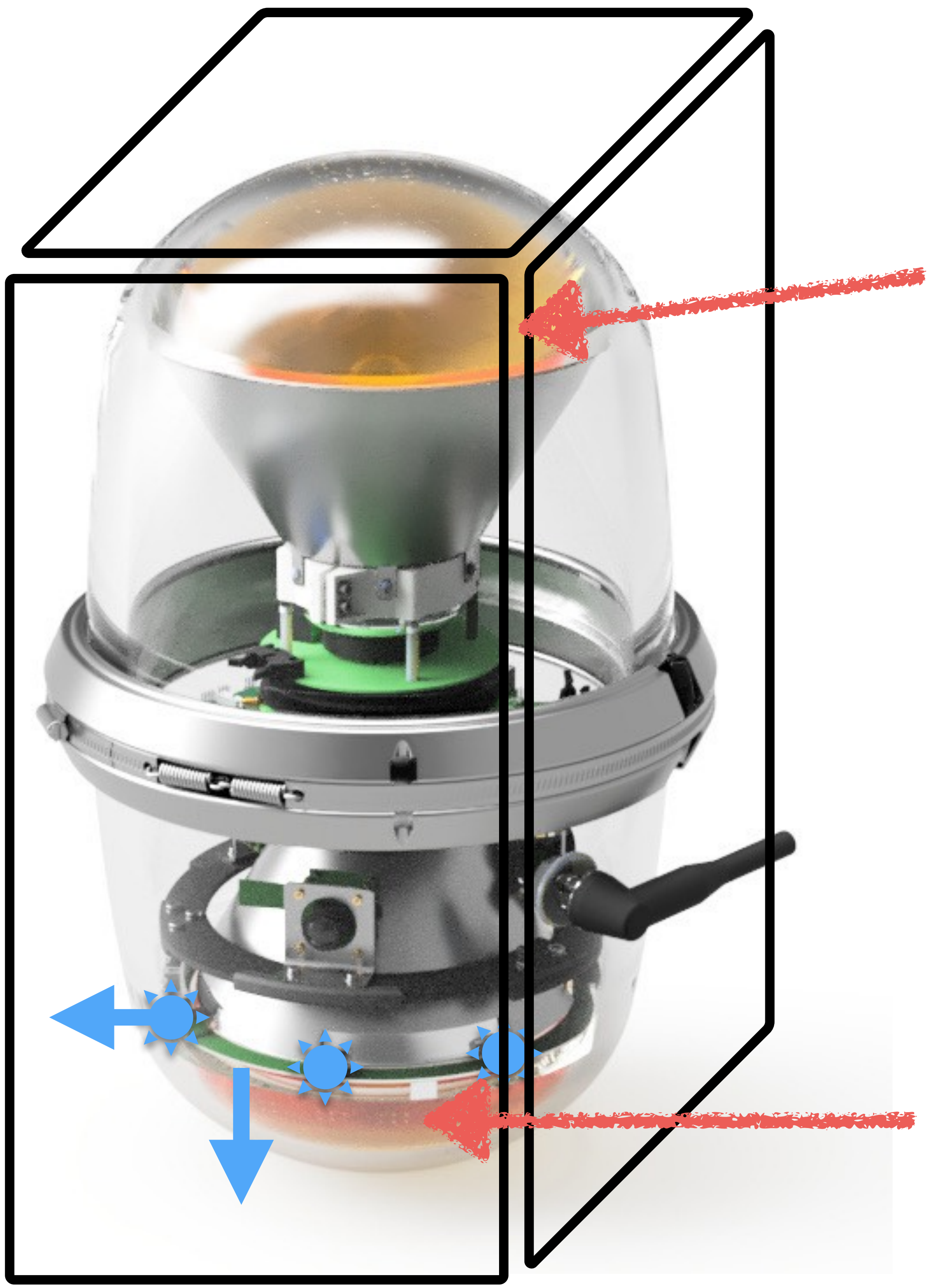

A D-Egg inside

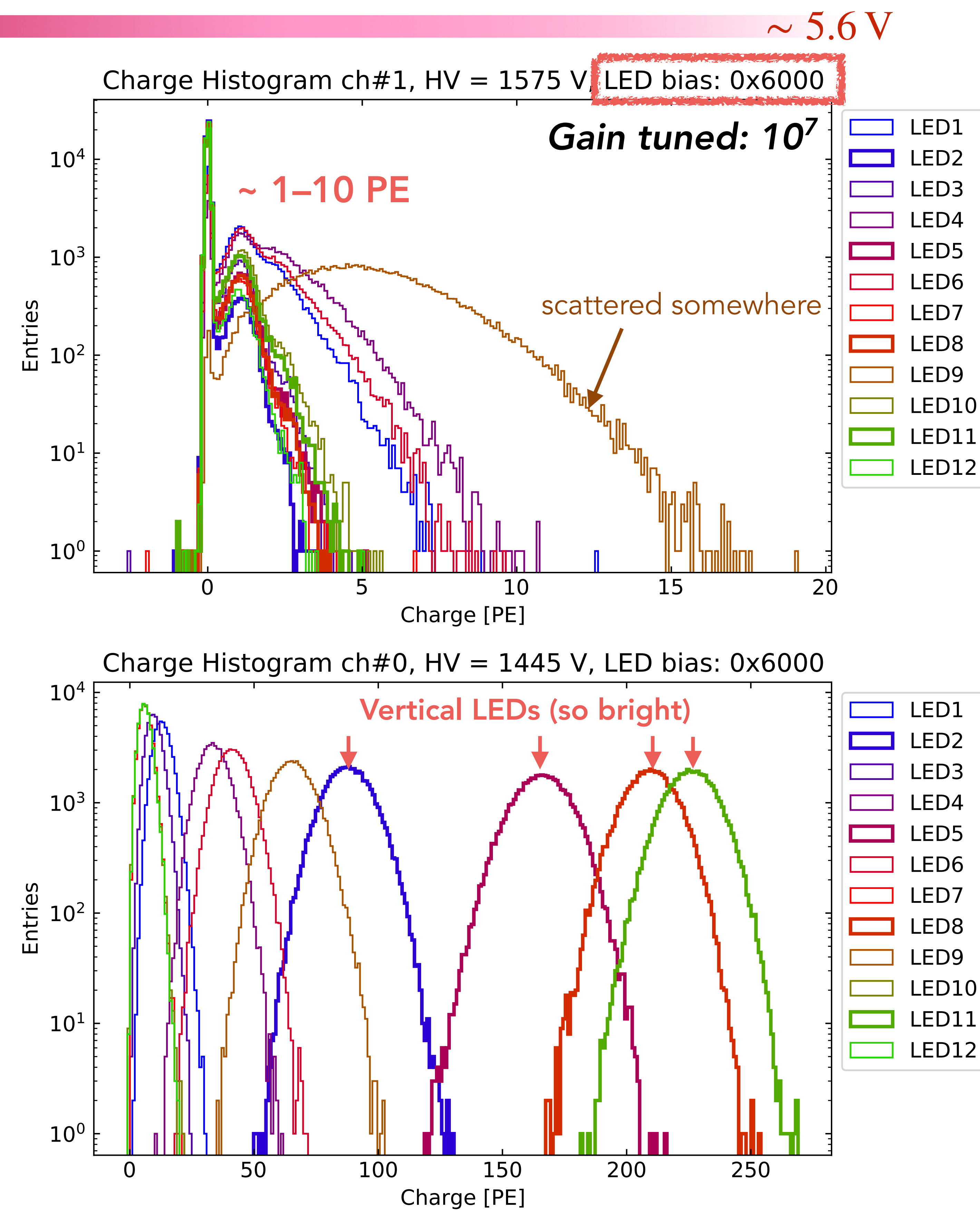

Dark box (storing box)
Wire pair
USB
Communication Hub
(Lab version of South-Pole DAQ)


Clear SPE distribution!
Entries
Charge [pC]
10^4
10^3
10^2
10^1
10^0
0
1
2
3
4
5
6

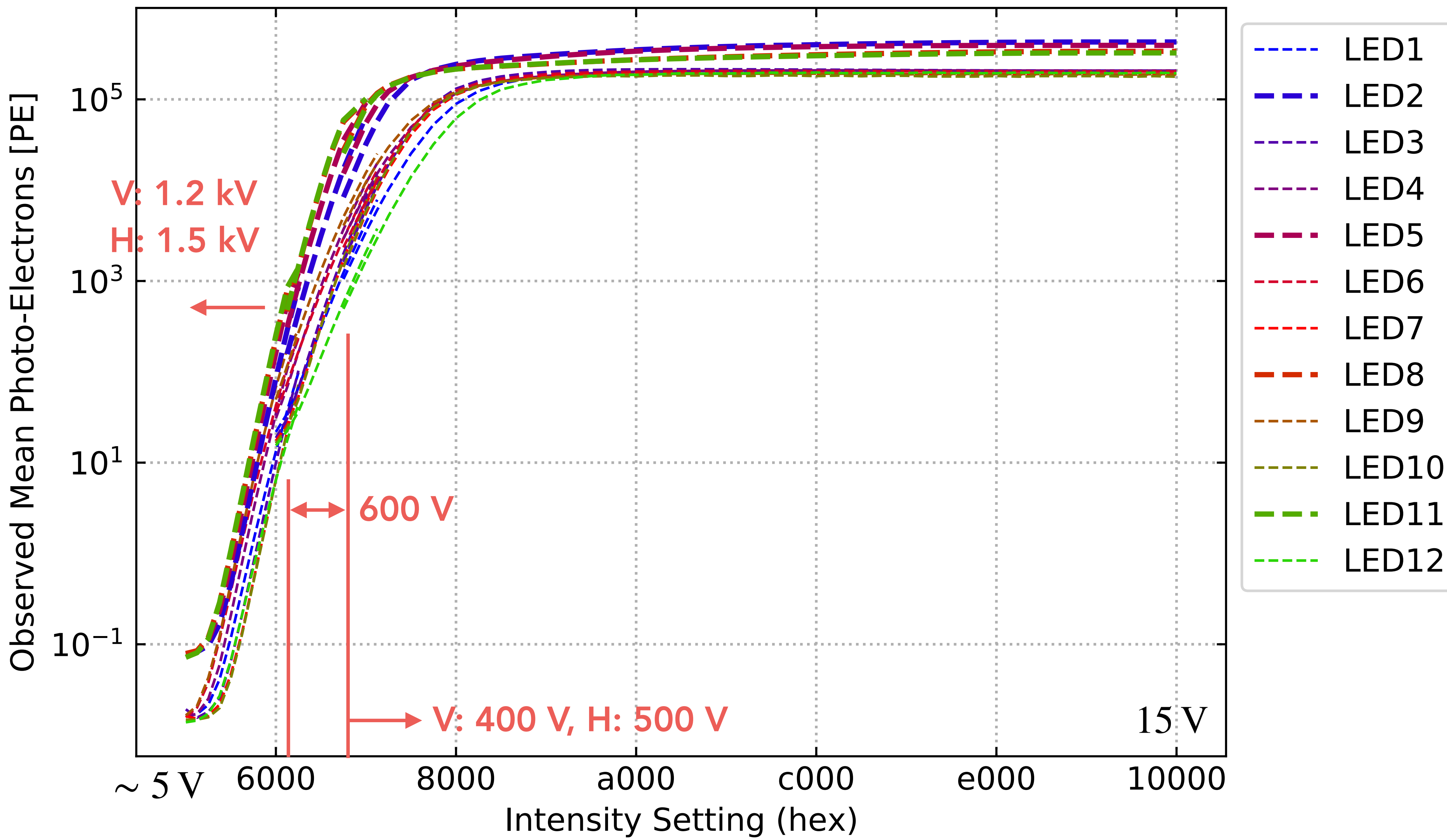

~ 60 PE case
ADC count
Sampling bins [4.2 ns]
5000
4500
4000
3500
3000
2500
2000
1500
100
120
140
160
180
200

Check intensity of each LED



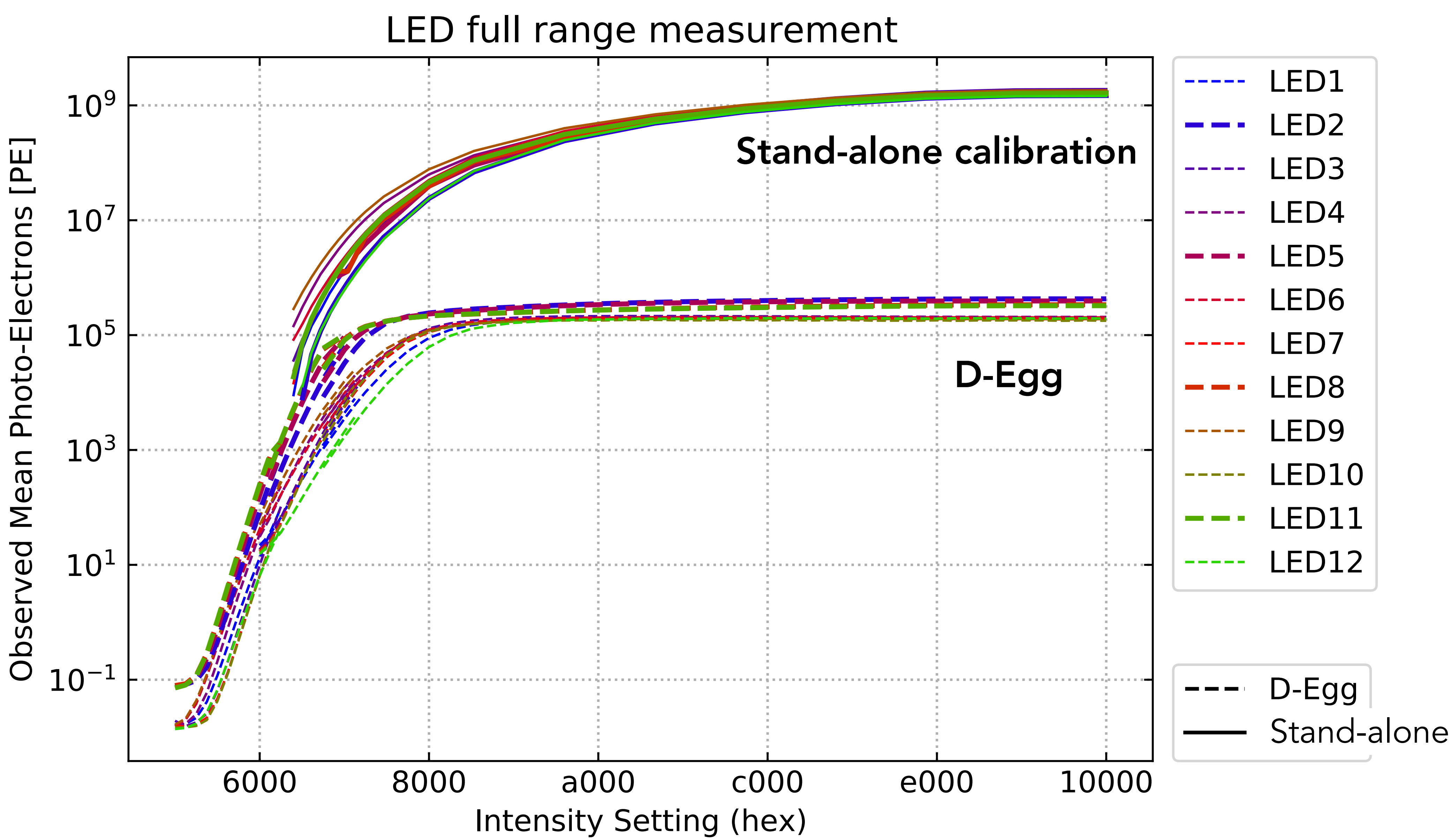


Bias Voltage Scan



- To cover such wide range, have to divide into 3 regions with different PMT gains
- Could see the luminosity trend, but seems saturated at the high intensity regions

Comparison to stand-alone calibration



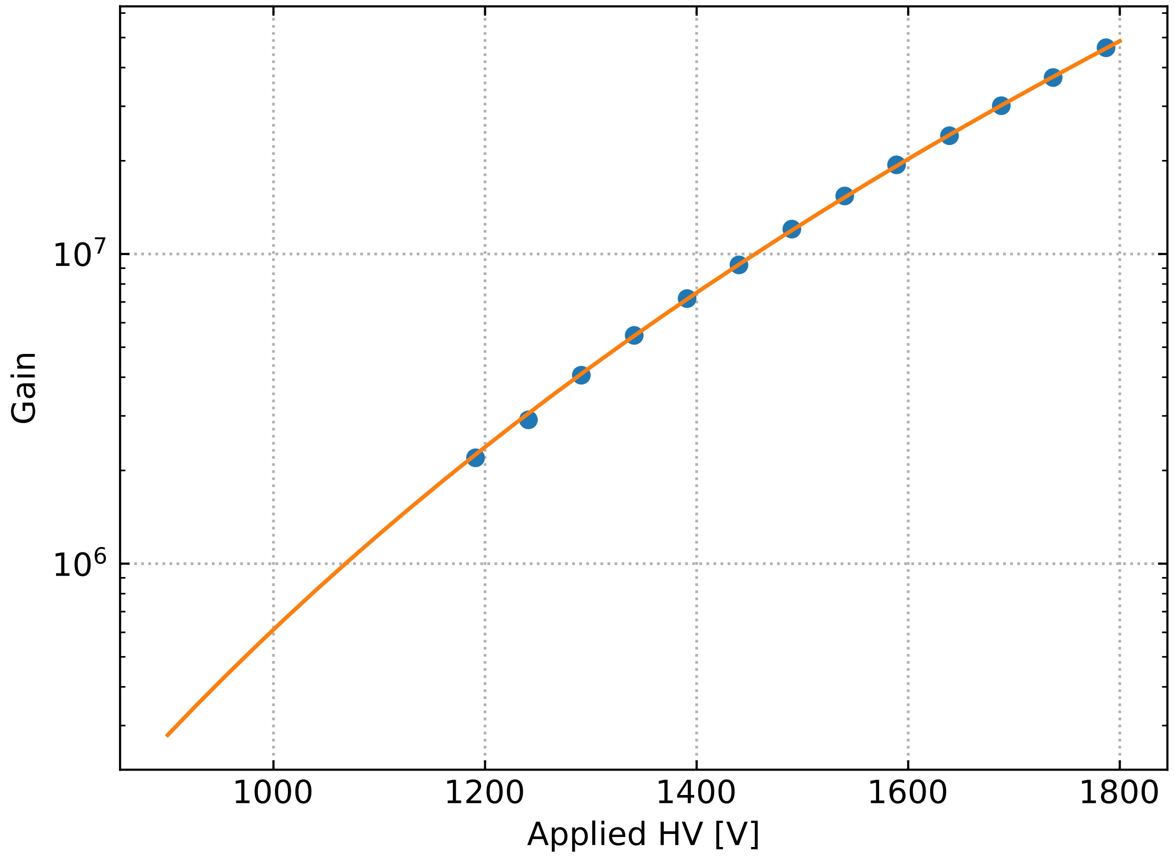
- Could not reach the maximum range (10^9 PE) by this work
- Difficult to know the absolute luminosities from the data, but we can see the relative ones precisely in short time

Summary

- Chiba group developed the new detector "D-Egg" for the IceCube-Upgrade
- Recently, we developed the self calibration system by improving our firmware
- Now it's possible to detect LED signals with synchronized triggers
- Measurement of the absolute luminosity seems difficult (have to consider the location, direction, and so on…)
- At least, we can know the relative luminosity for each LED
- The calibration will be included into the tests before shipping to South-Pole, see the detector-to-detector variation

Back up

Gain calibration



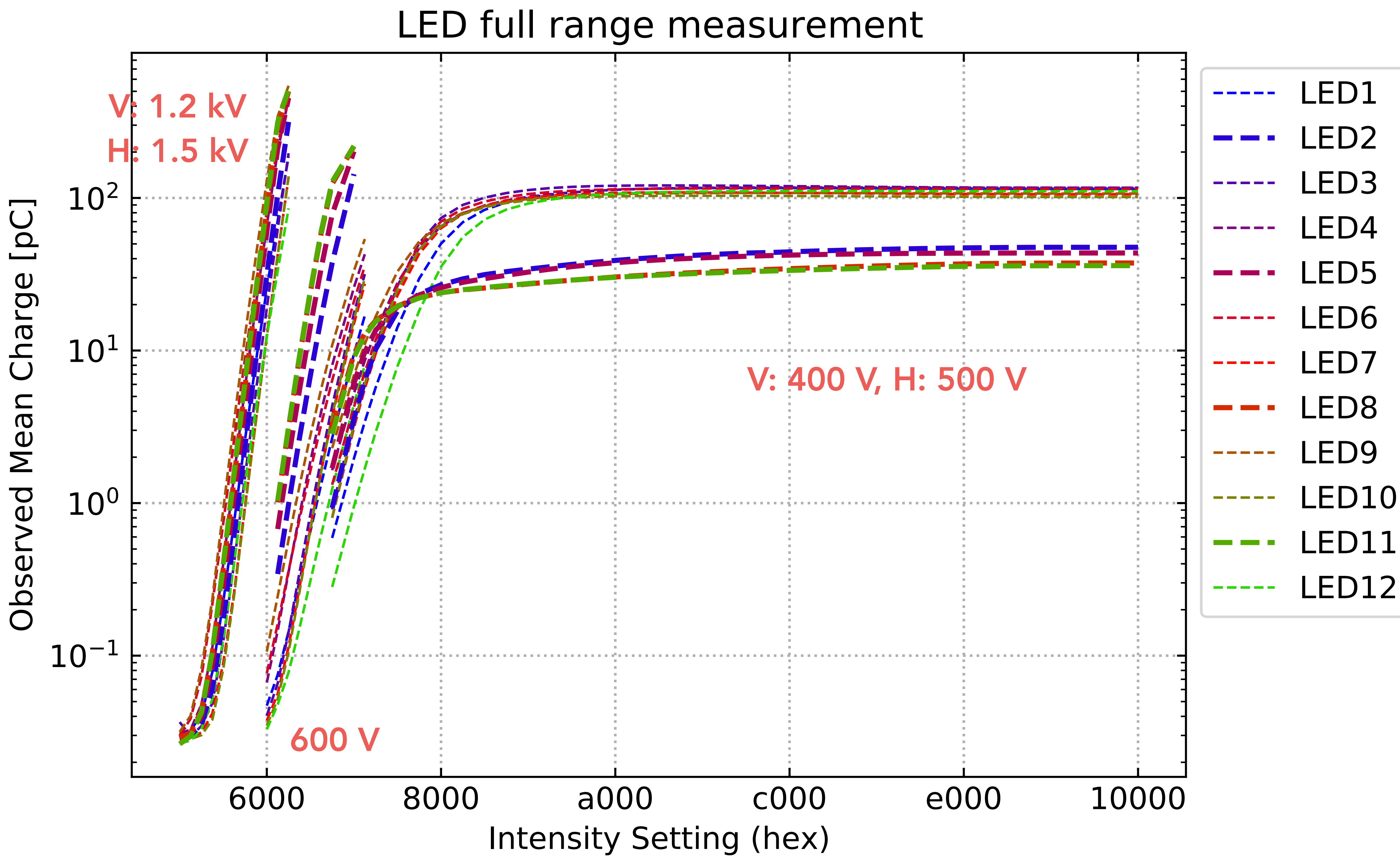
$$g = A \cdot (V\,[\mathrm{kV}])^B$$

$$A = 6.127 \times 10^5$$

$$B = 7.445$$

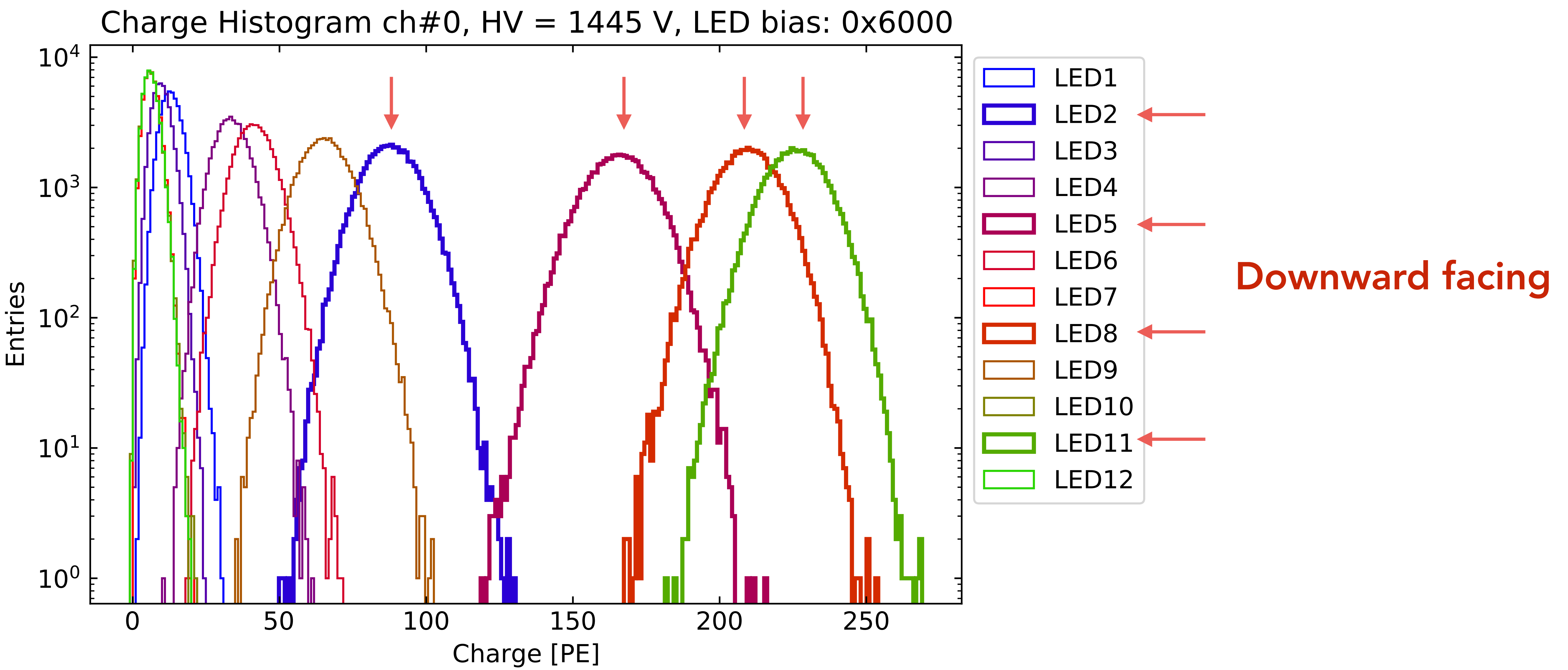
- LED1 with 0x5800 bias, charge-stamp
- Fit them and each gain is evaluated from the parameters A and B

Raw observed charge



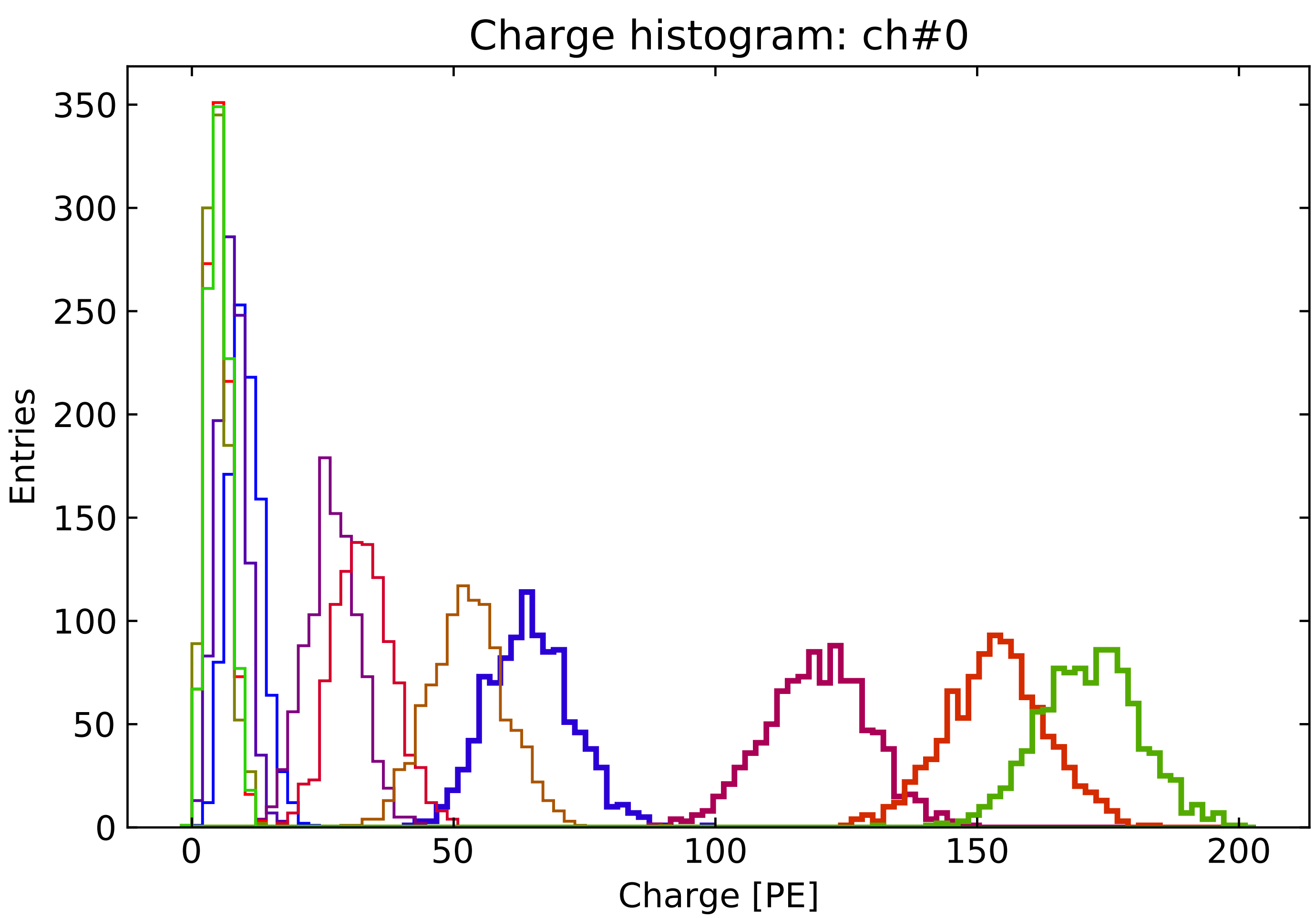
- [-10, +15] window, need to check waveform

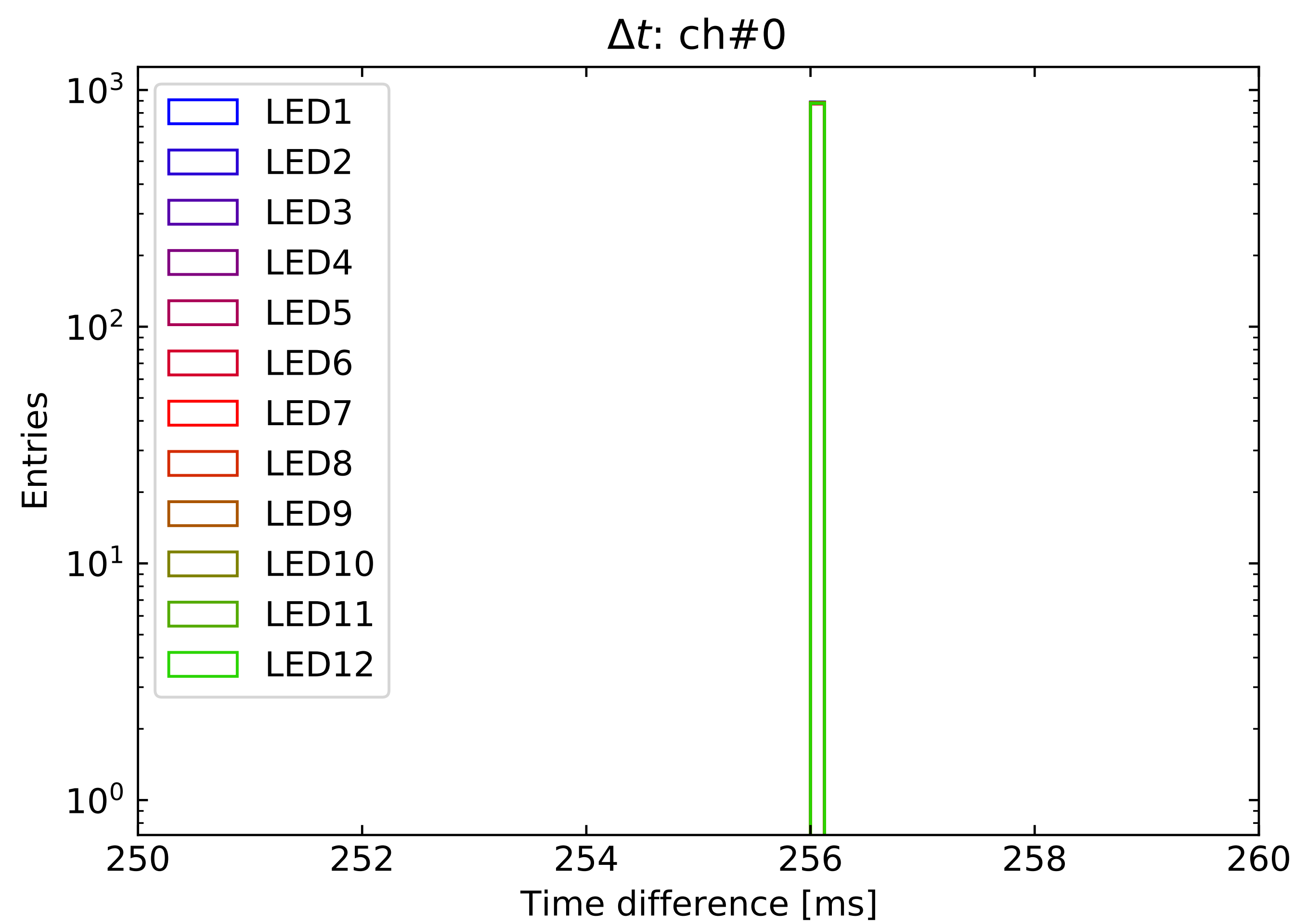
LED variation



- Can see clear difference among the LEDs
- Charge stamp makes possible to scan them by LED intensity settings in short time (~10 sec each)

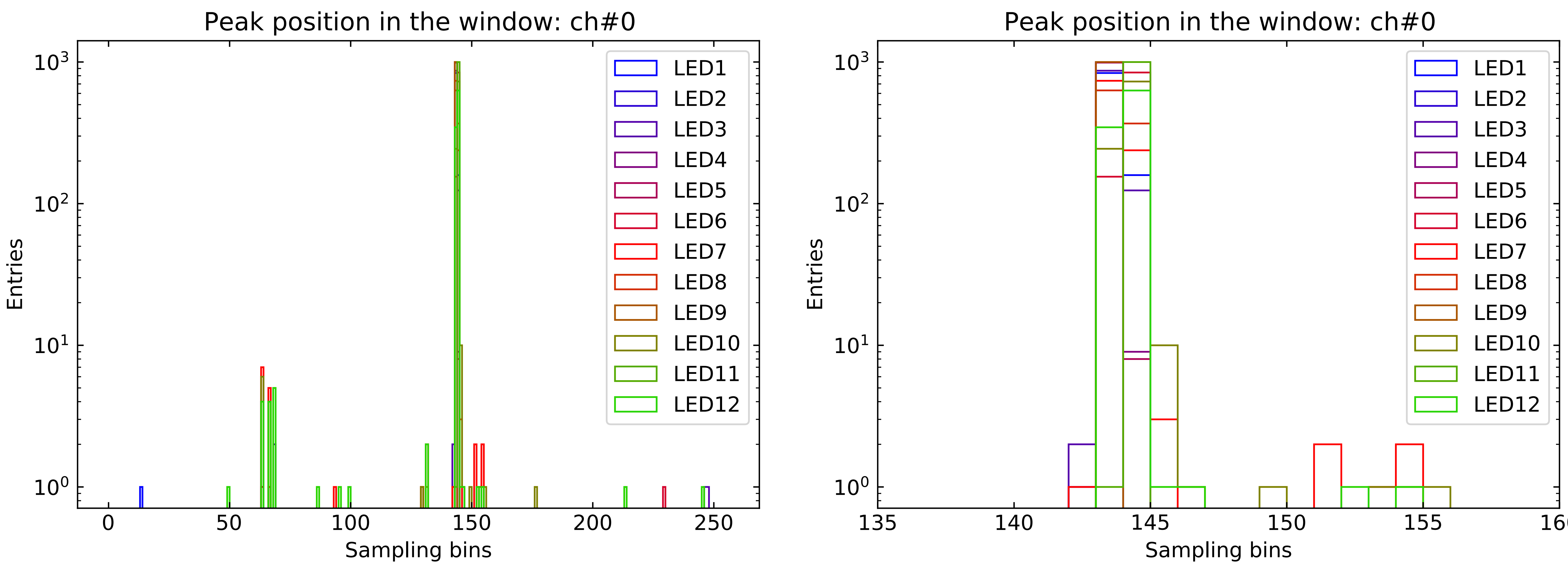
LED variation (waveform stream)





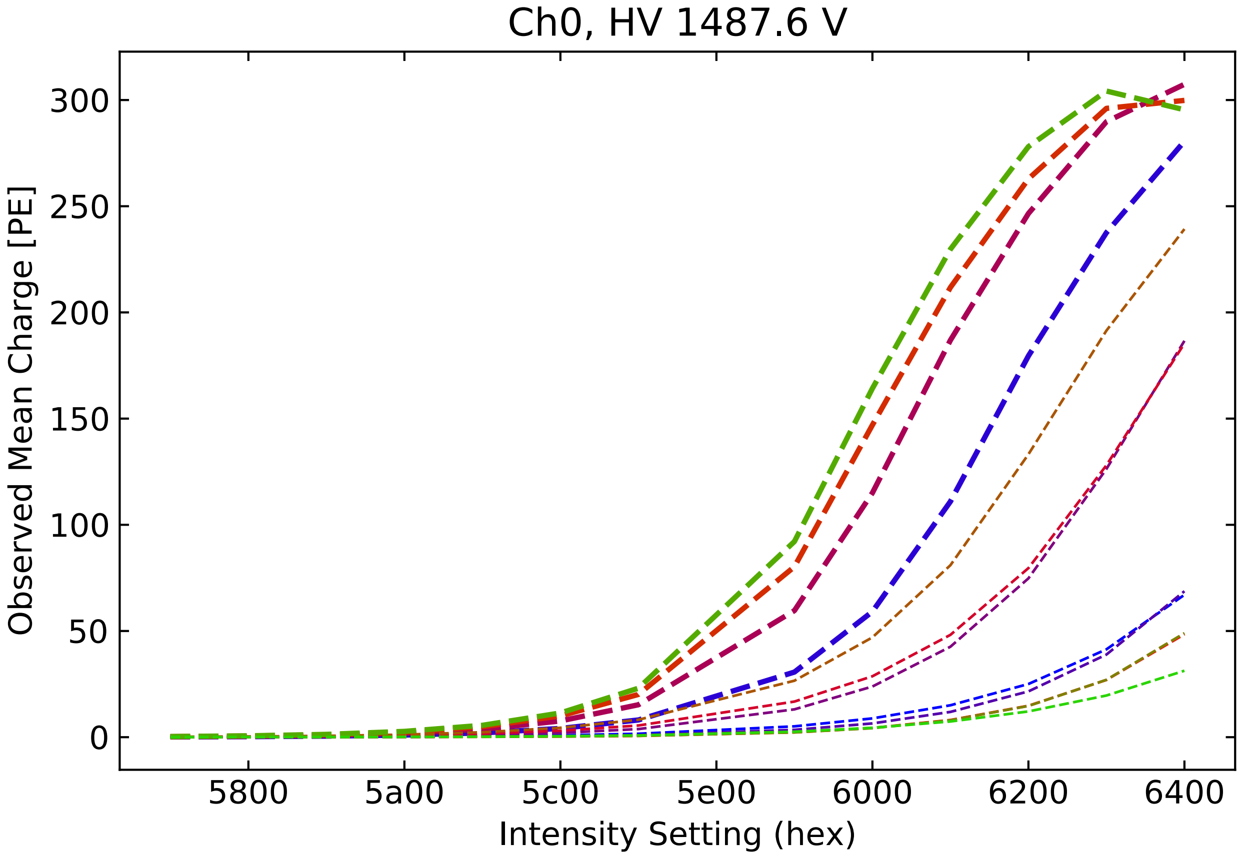
- Though takes much time, we also use the waveform stream, we can know the signal shape and timing information
- All waveforms are triggered by the periodical Cal Trig shown in the right figure

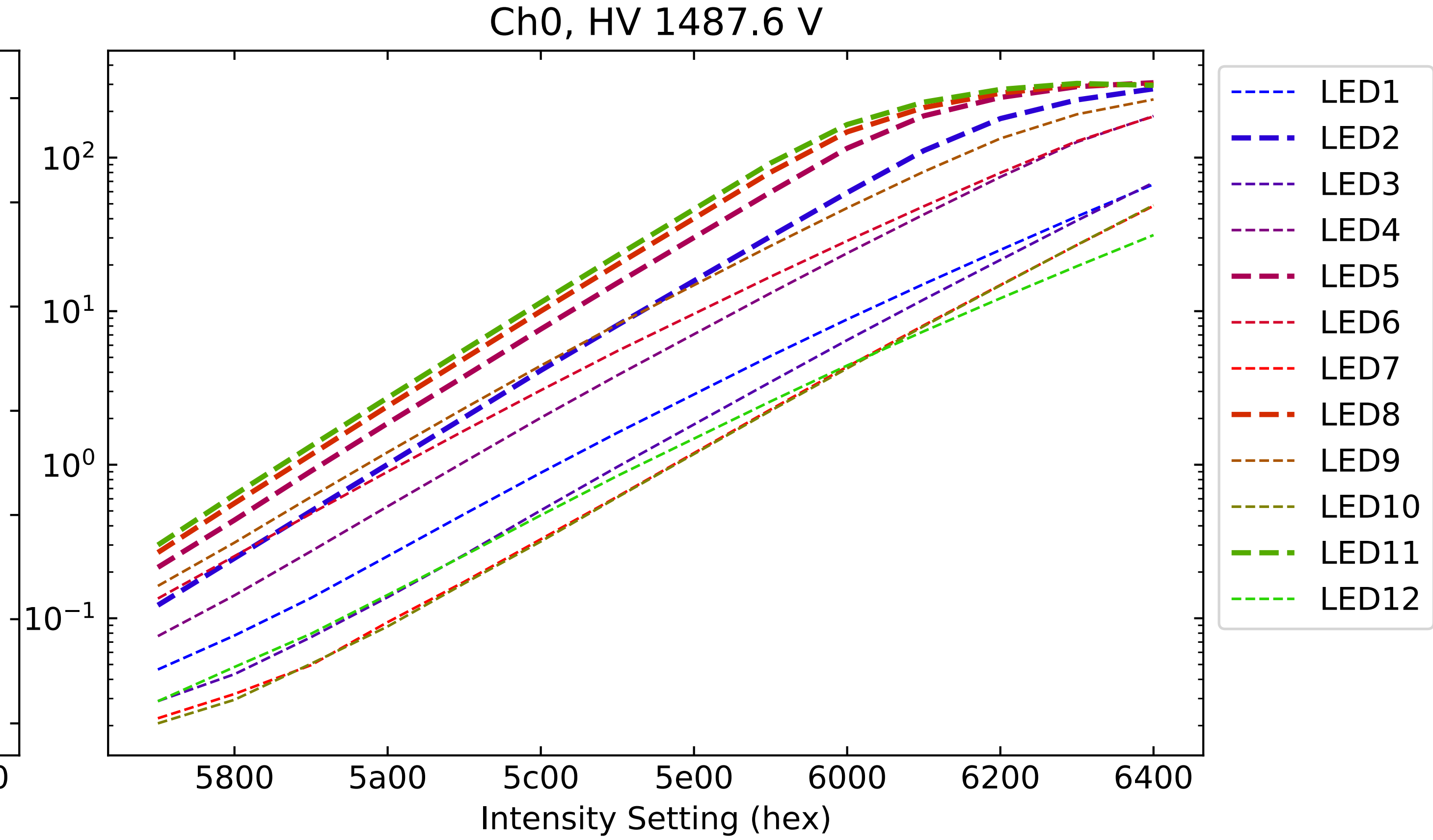
LED variation (timing)



- Peak timing in the waveform sampling window
- Width of 2 or 3 sampling-bin is observed for all LEDs (no difference)

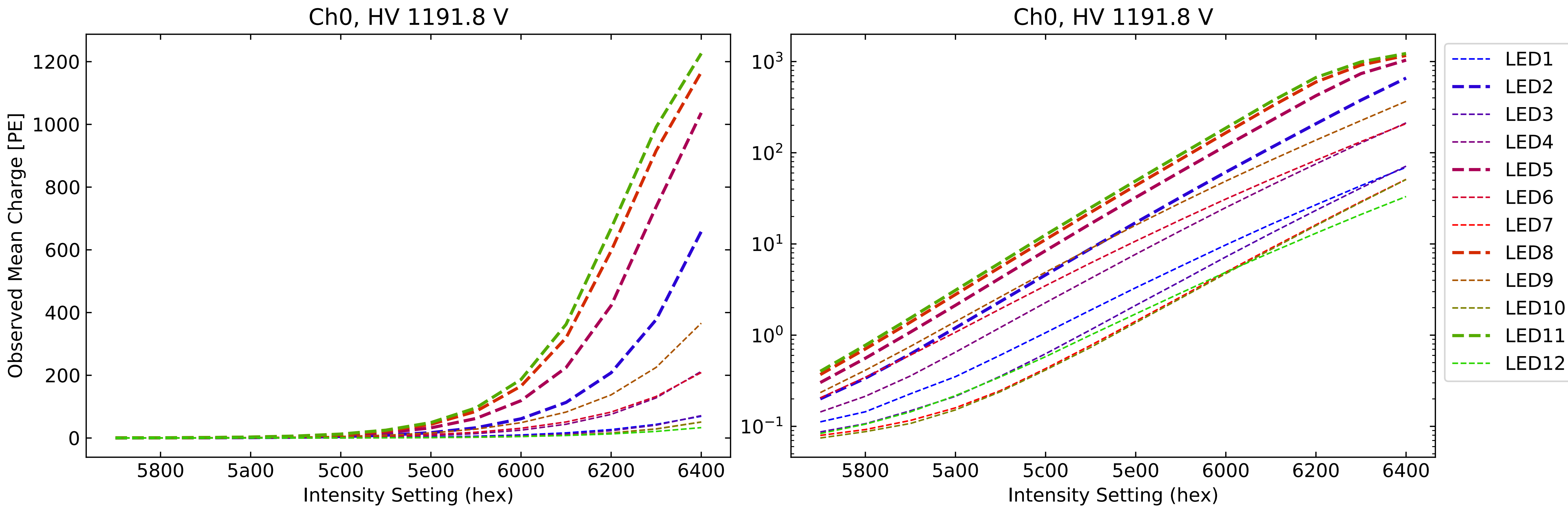
Scanned result





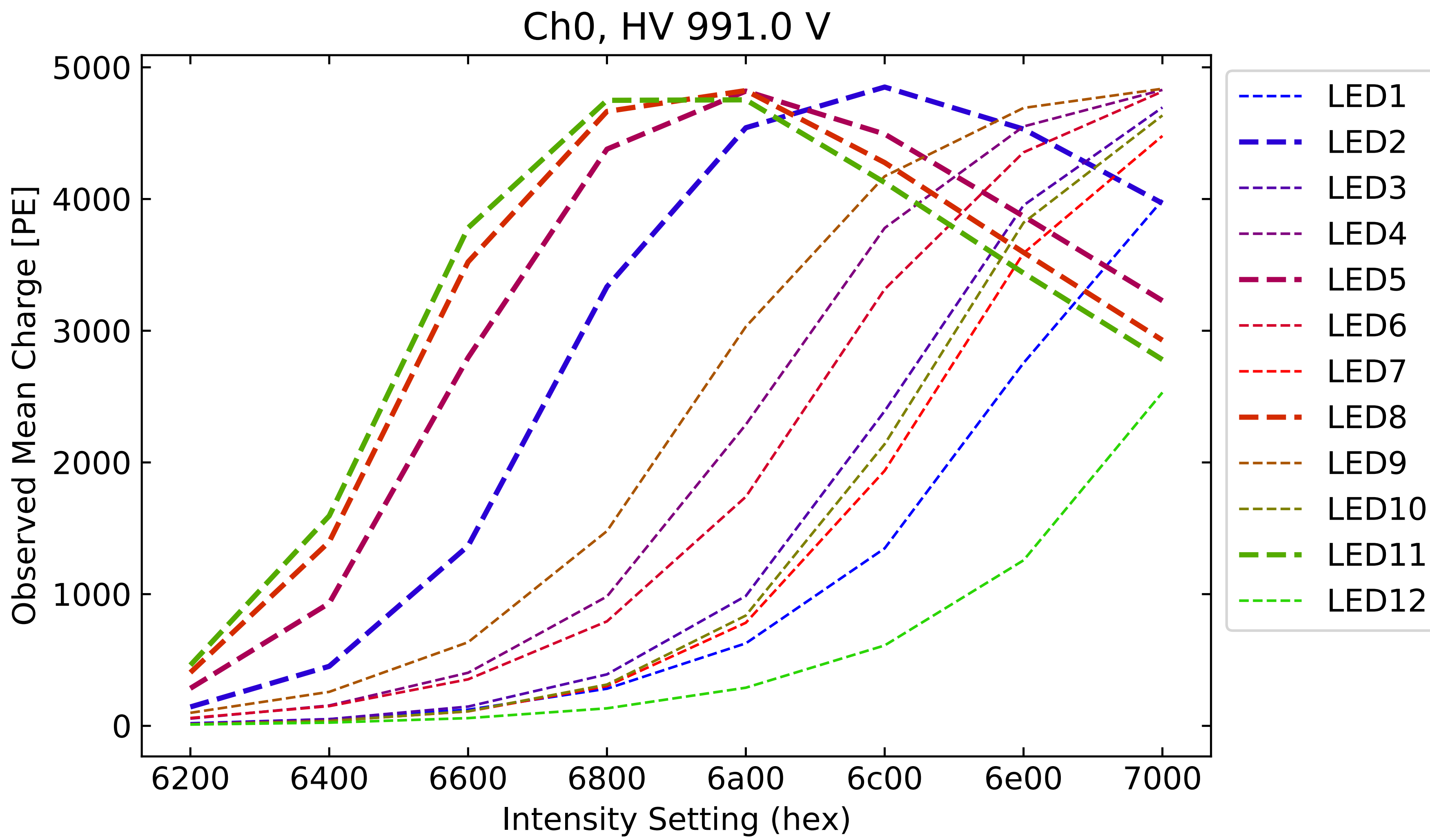
- gain~1.3, charge-stamp scan
  - 50k events each, 0x200 interval, took only 30 min for the scan
- Mean is calculated by simple numpy.mean, so accurate for small values
  - should be Poisson, and difficult to separate from electronics noise
- Looks saturated in higher region

Scanned result (low gain case)



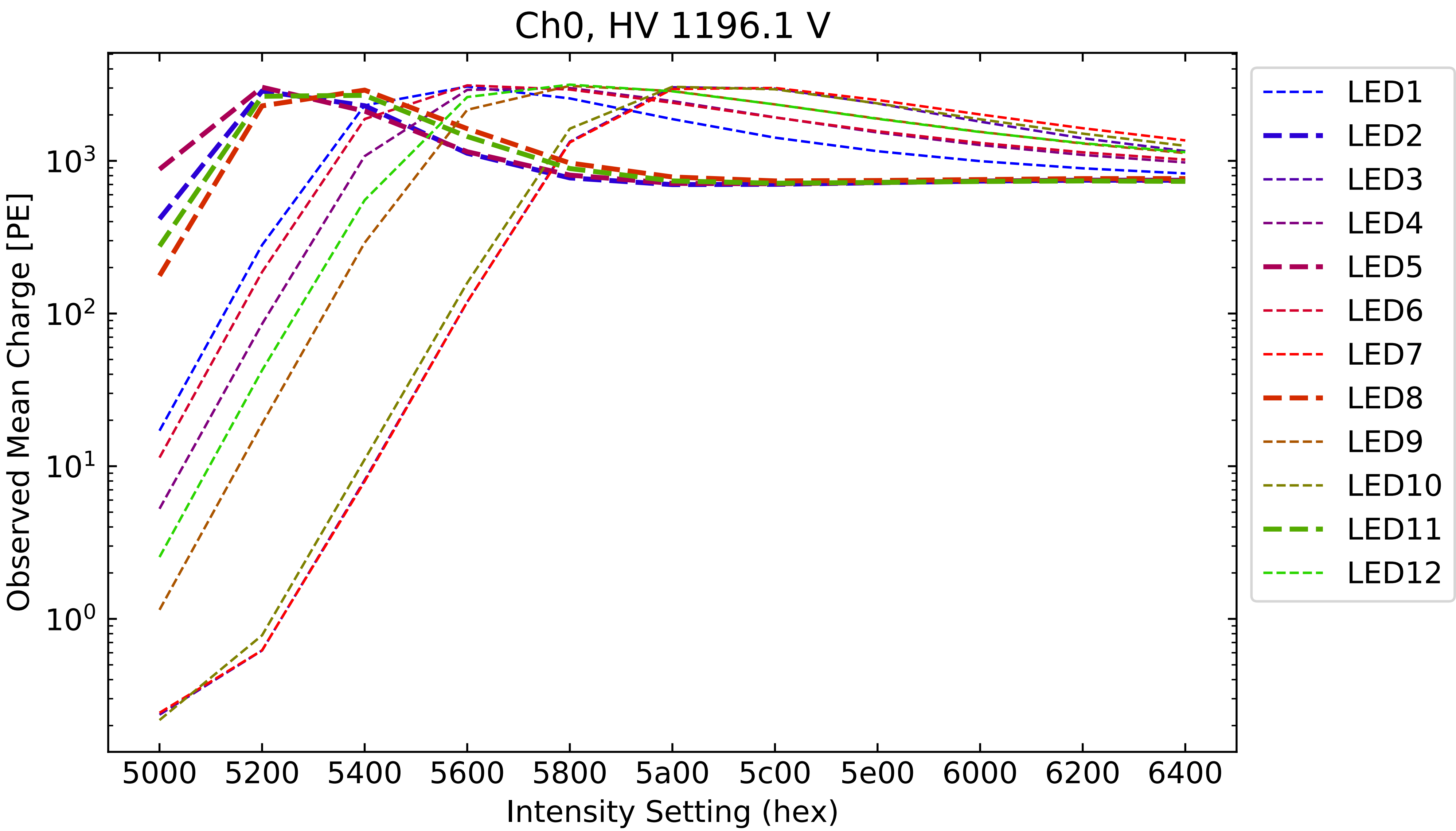
- Lower PE region (PE < 1) is not reliable
- For the full range scan, need to control the PMT gain — LED is so bright, the PMT gain should start from very low gain

Very low gain result (Example, not enough)



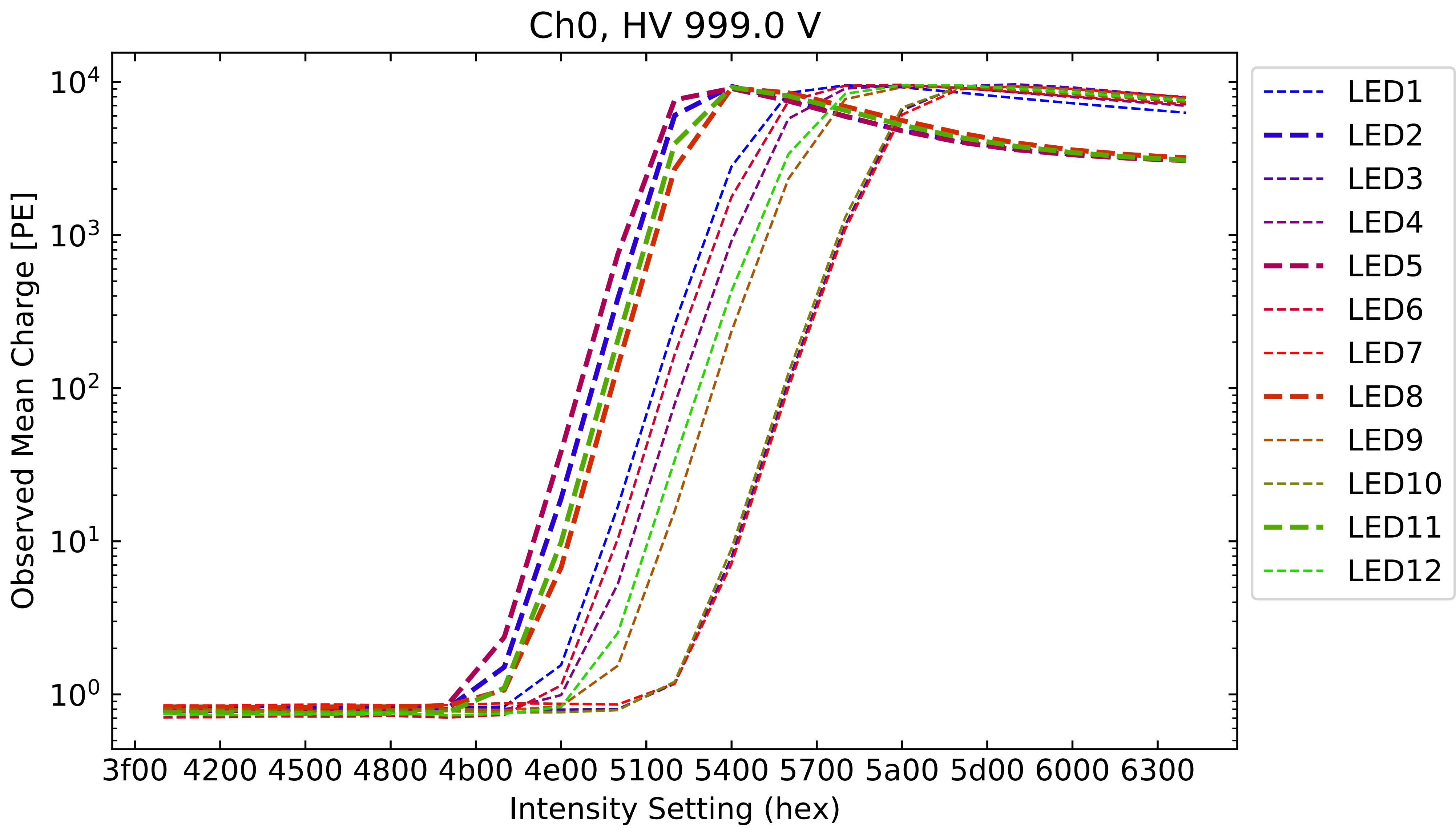
- Can reach some higher intensities, but not all
- Divide horizontal / vertical LEDs and full-range scanning with very low gain (~500 V)

Another sample: D-Egg2020-1-008



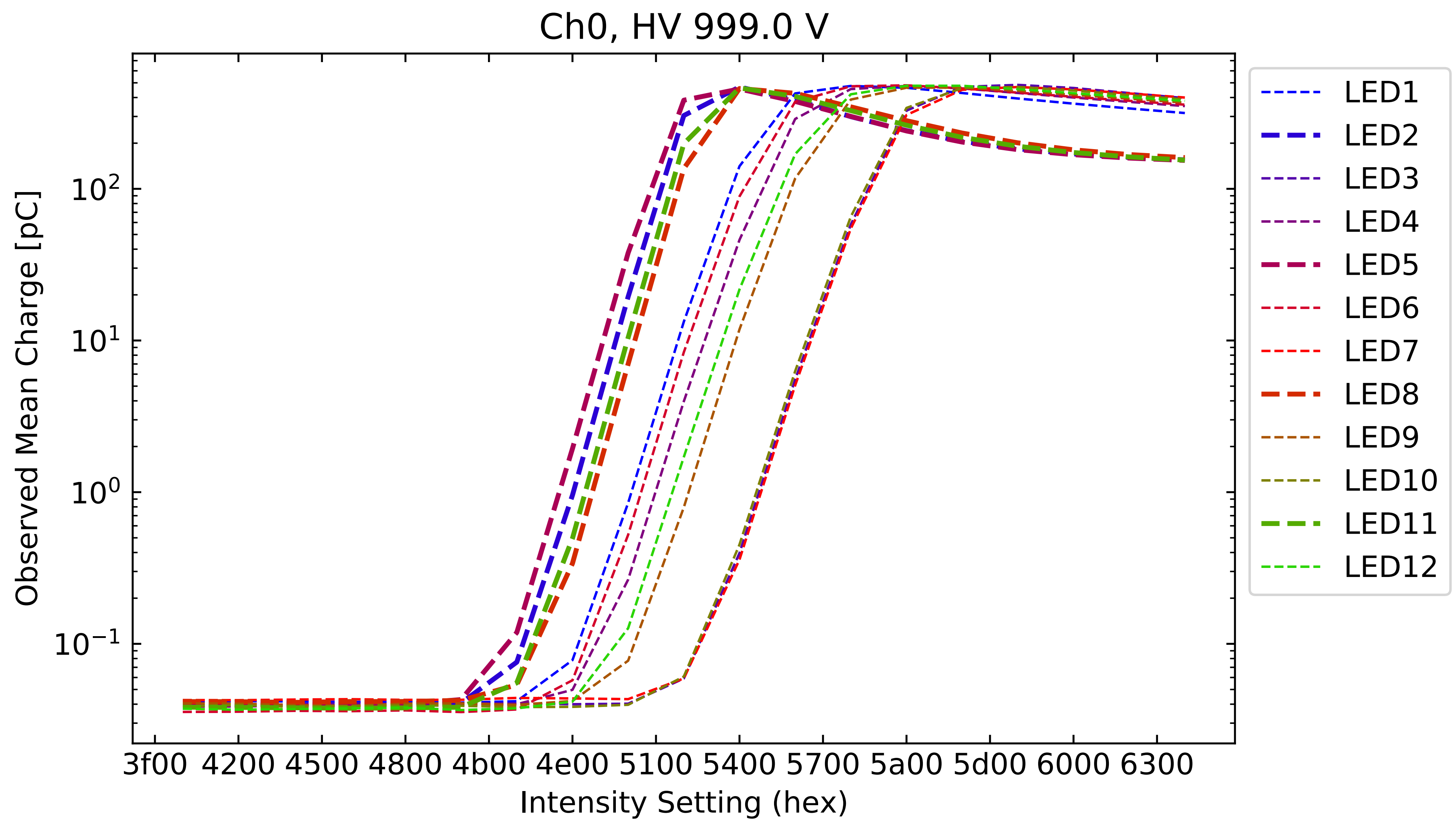
- Mainboard: 4.1-007
- LED brightness is much different from previous…
  → Need further study

Another sample: D-Egg2020-1-008



- Mainboard: 4.1-007
- Tried full range with lower gain. Still observed saturation region

Another sample: D-Egg2020-1-008



- Mainboard: 4.1-007
- Tried full range with lower gain. Still observed saturation region