

Light frequency studies per channel in ProtoDUNE-DP

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DPPD meeting, 17-03-2020



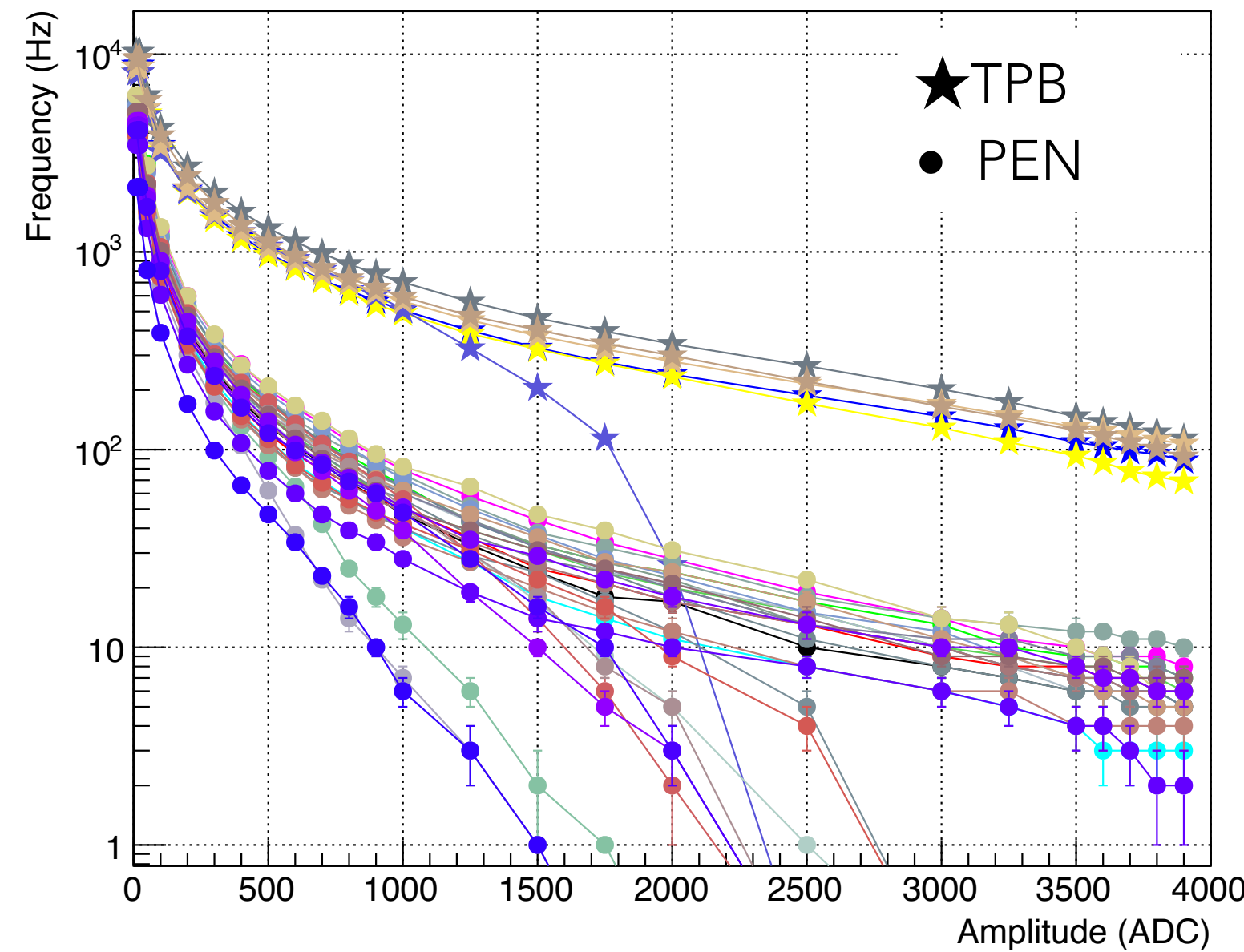
◆ **Some questions / topics:**

1. Are the PMTs working under **high light-frequency conditions**?
2. What **amount of light** do the PMTs usually receive?
3. What ADC channels show **saturation**? When?
4. In which **dynamic range** do the PMTs operate with (the most) **linear response**?
5. **Comparison to 3x1x1m³** detector

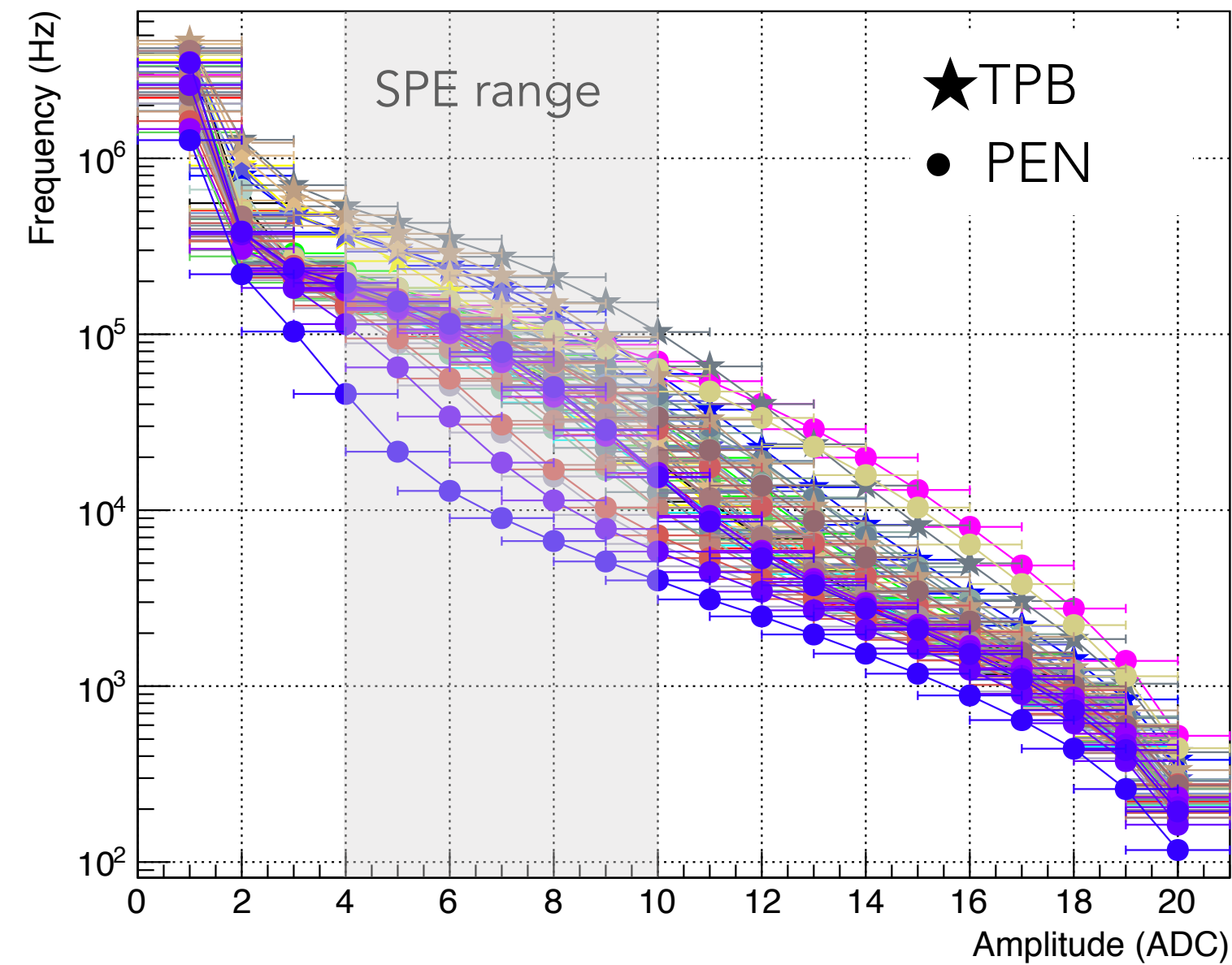
1. Light frequency

PRELIMINARY!

threshold > 21 ADC *



1 ADC > threshold > 21 ADC **



◆ **Reminder:**

- S1: >21ADC (3PE)
- SPE = 7 ± 3 ADC

◆ **S1 rates:**

- TPB: 8.9 ± 0.8 kHz
- PEN: 4.7 ± 0.8 kHz

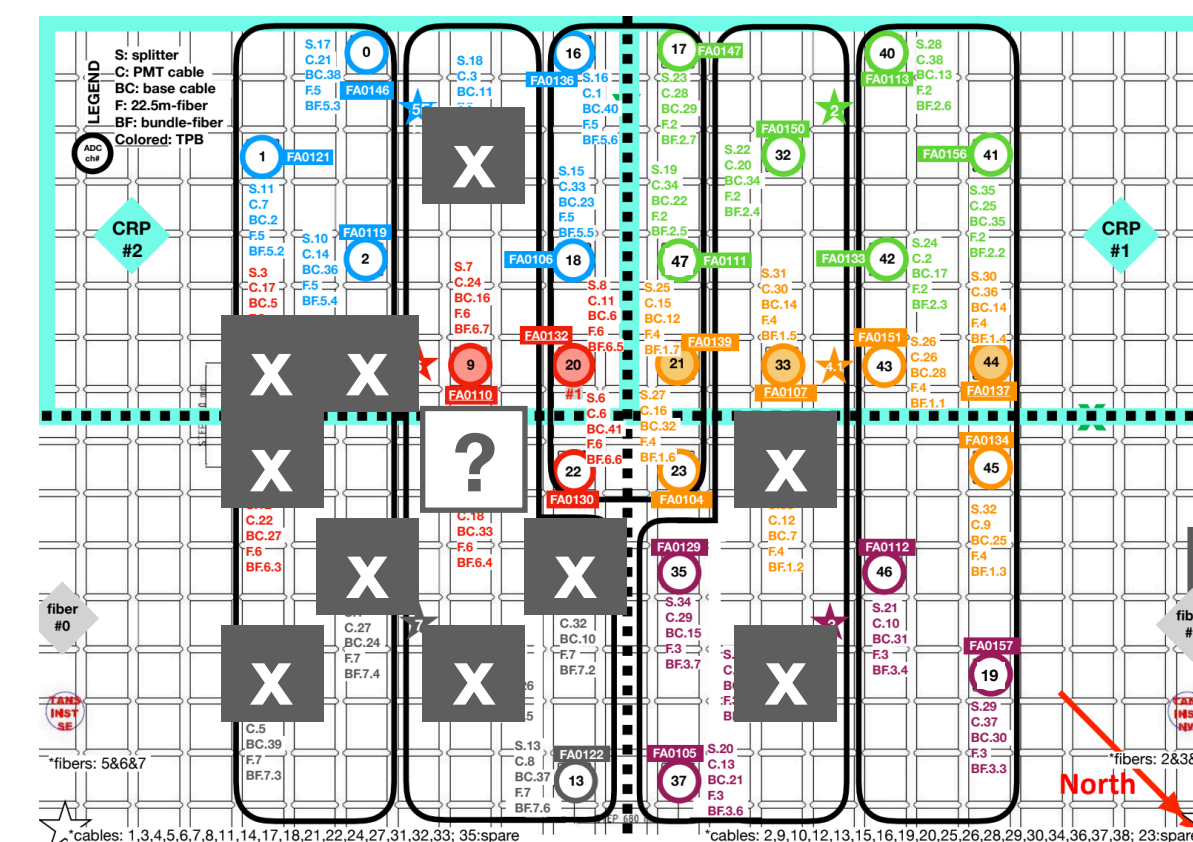
◆ **SPE rates:**

- TPB: 370 ± 50 kHz
- PEN: 150 ± 30 kHz

* A variable window after S1 identification is ignored

** A 150 us window after S1 identification is ignored

- ◆ 10 PMTs (9 PEN + 1 TPB) seem to saturate at amplitudes < 3000 ADC ! We want to understand the reason
- ◆ FA0124 is probably operating at low gain (real saturation?)

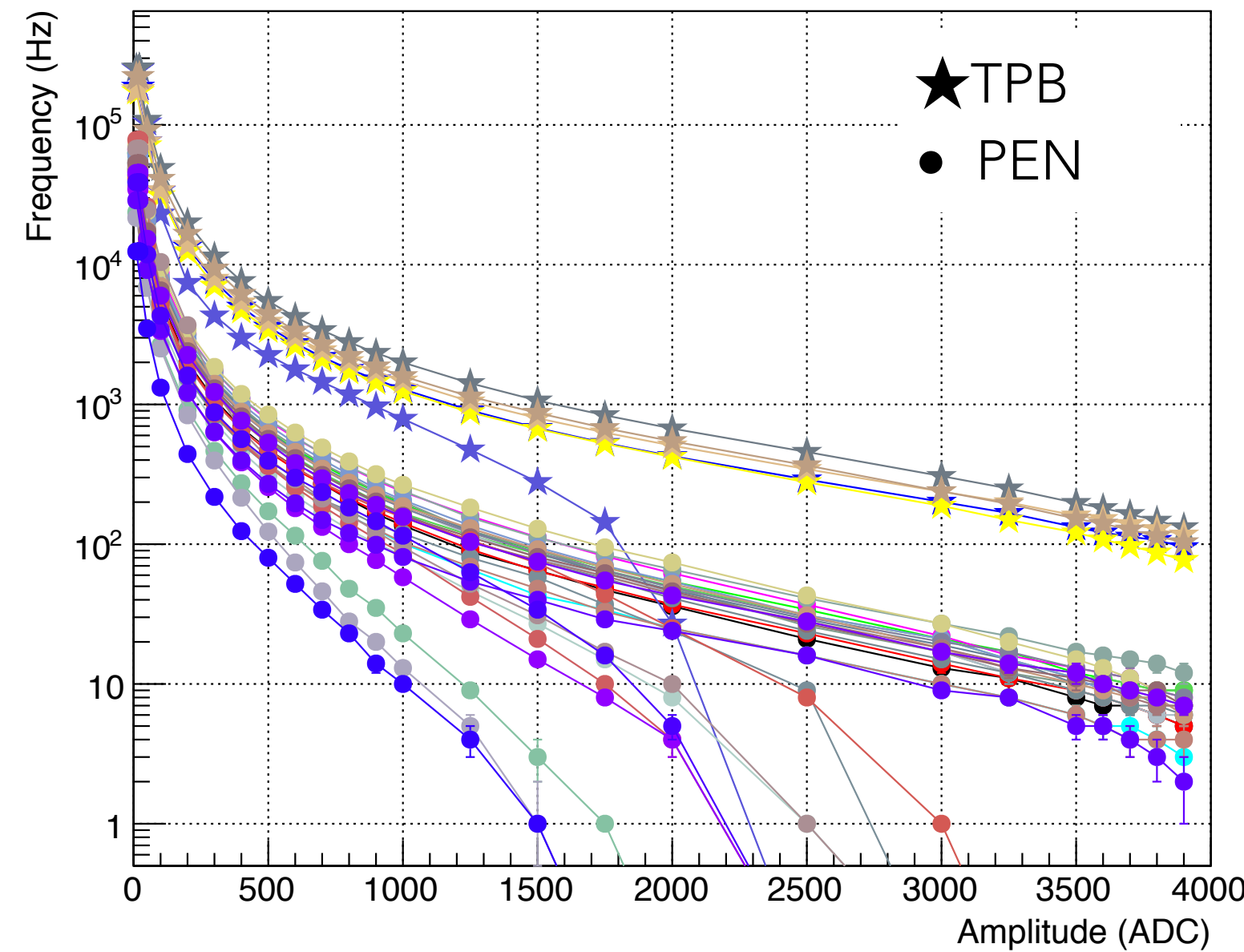


Positions of PMTs with early saturation

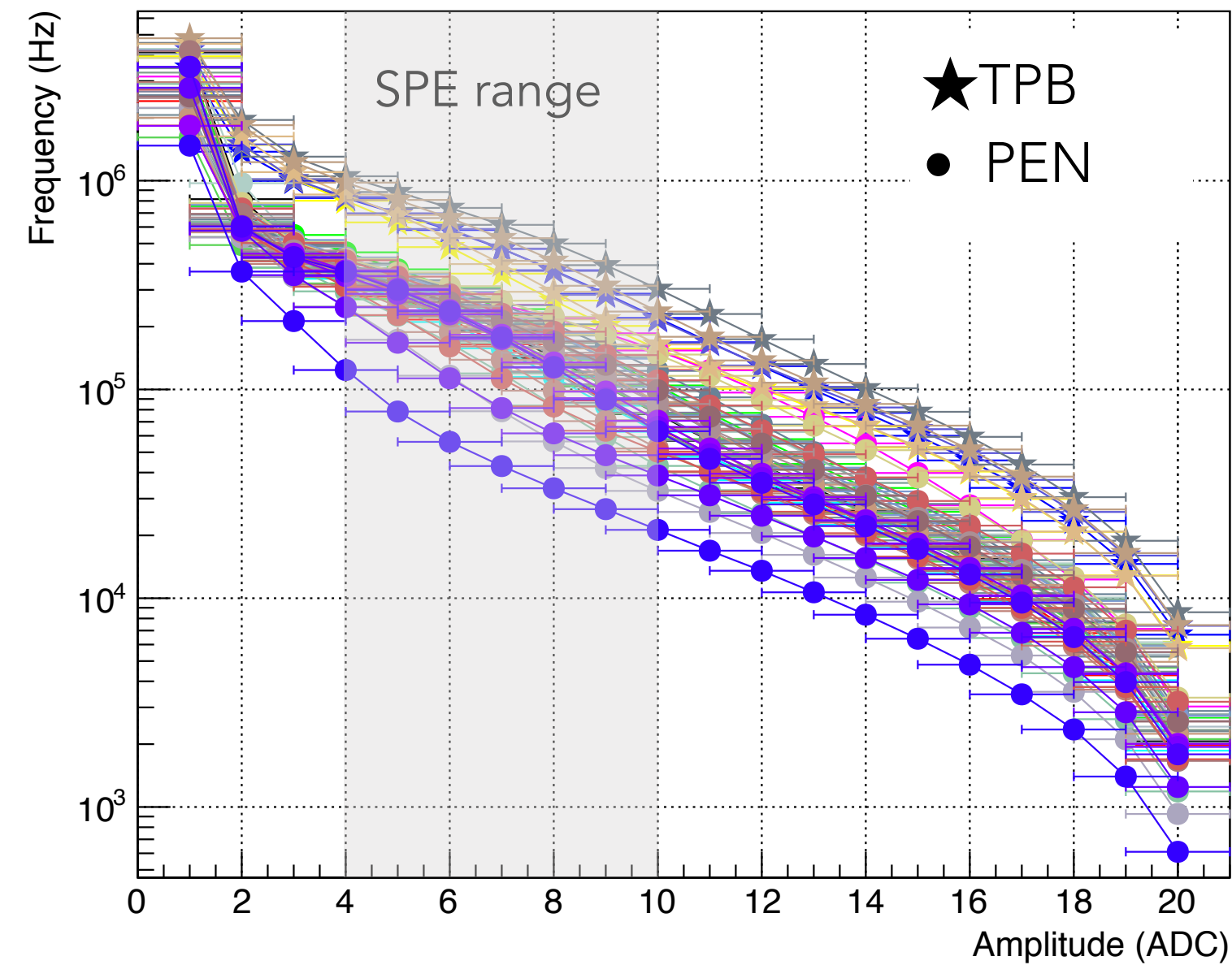
1. Light frequency

PRELIMINARY!

threshold > 21 ADC *



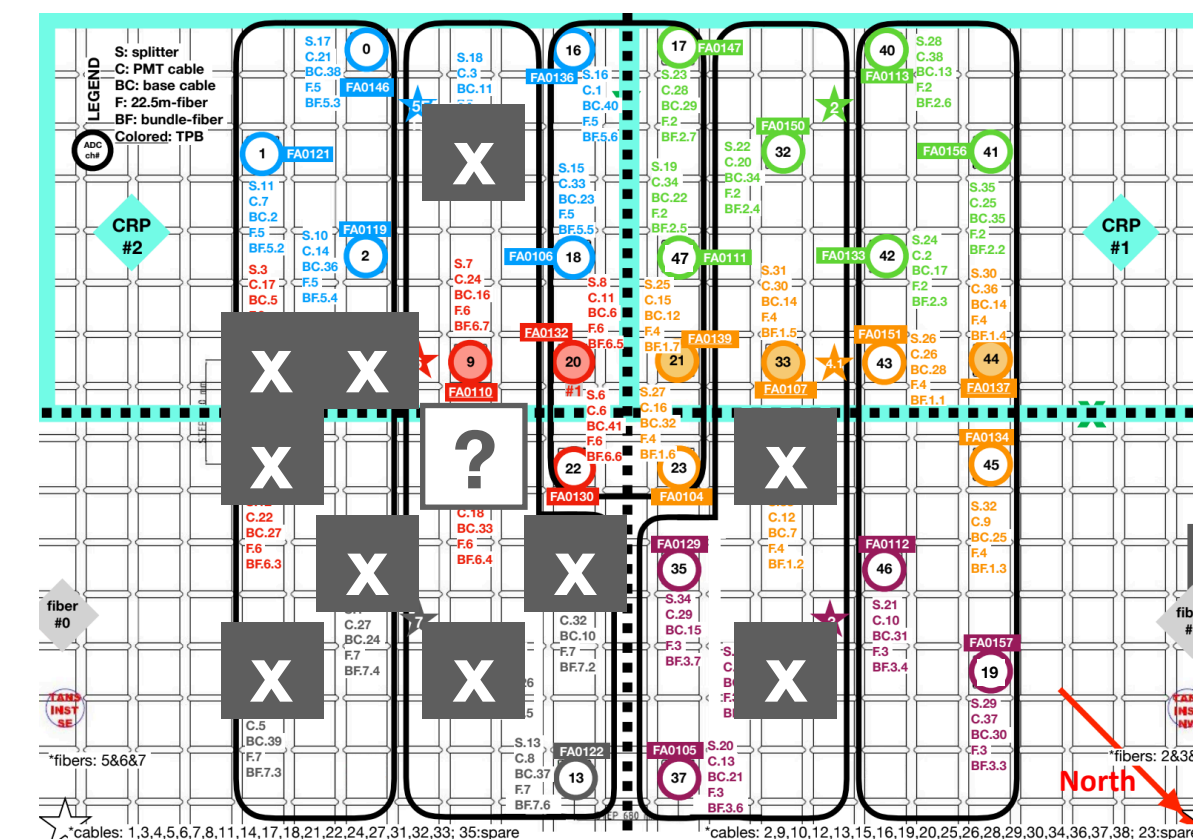
1 ADC > threshold > 21 ADC **



- ◆ **Reminder:**
 - S1: >21ADC (3PE)
 - SPE = 7 ± 3 ADC
- ◆ **Light signals > 21 ADC:**
 - TPB: 210 ± 30 kHz x23
 - PEN: 50 ± 10 kHz x10
- ◆ **4 ADC < light signals < 10 ADC:**
 - TPB: 680 ± 60 kHz x2
 - PEN: 270 ± 50 kHz x2

* ALL the light in the events!
 ** ALL the light in the events!

- ◆ 10 PMTs (9 PEN + 1 TPB) seem to saturate at amplitudes < 3000 ADC ! We want to understand the reason
- ◆ FA0124 is probably operating at low gain (real saturation?)



wrt previous

Positions of PMTs with early saturation

1. Light frequency

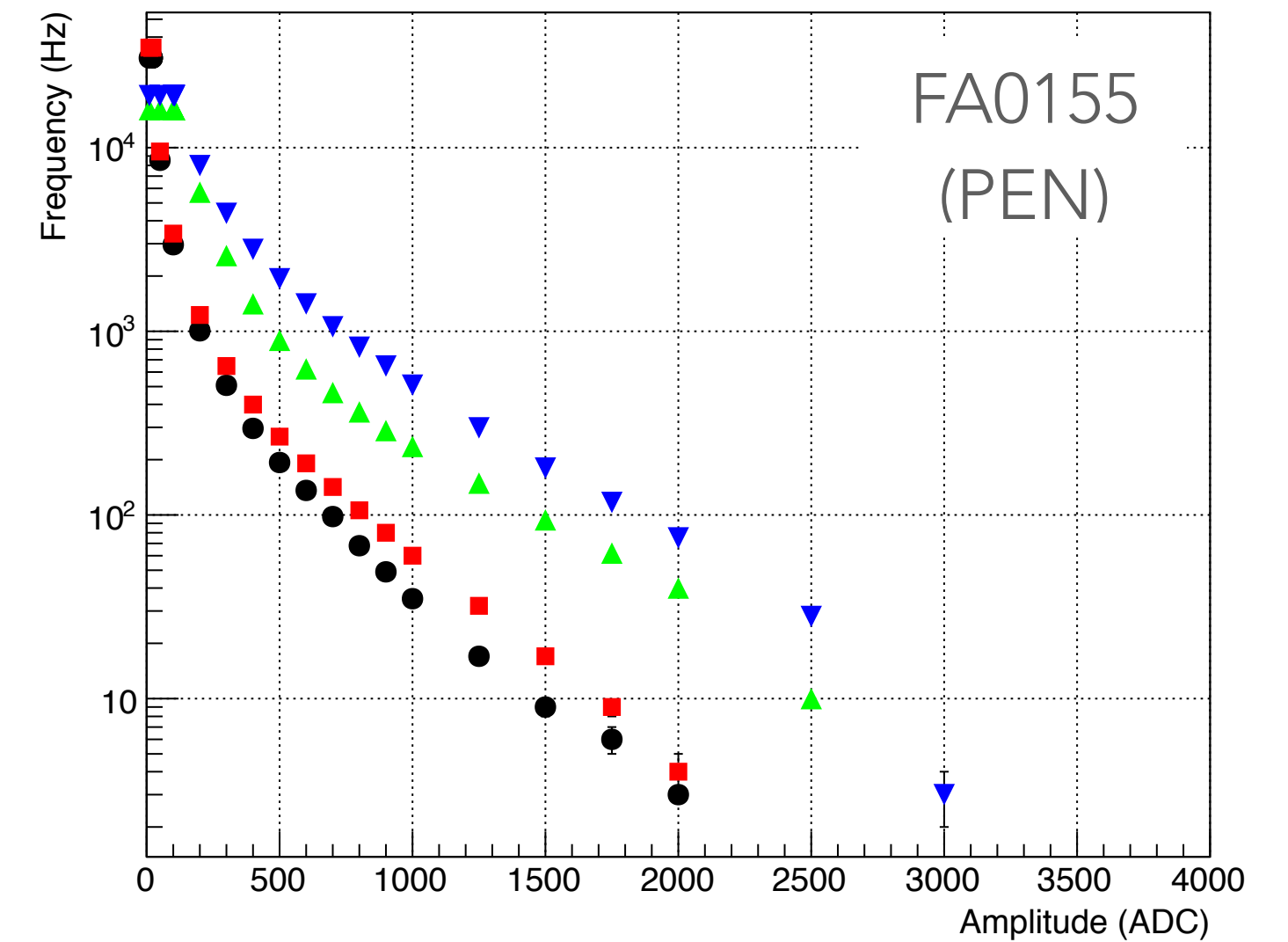
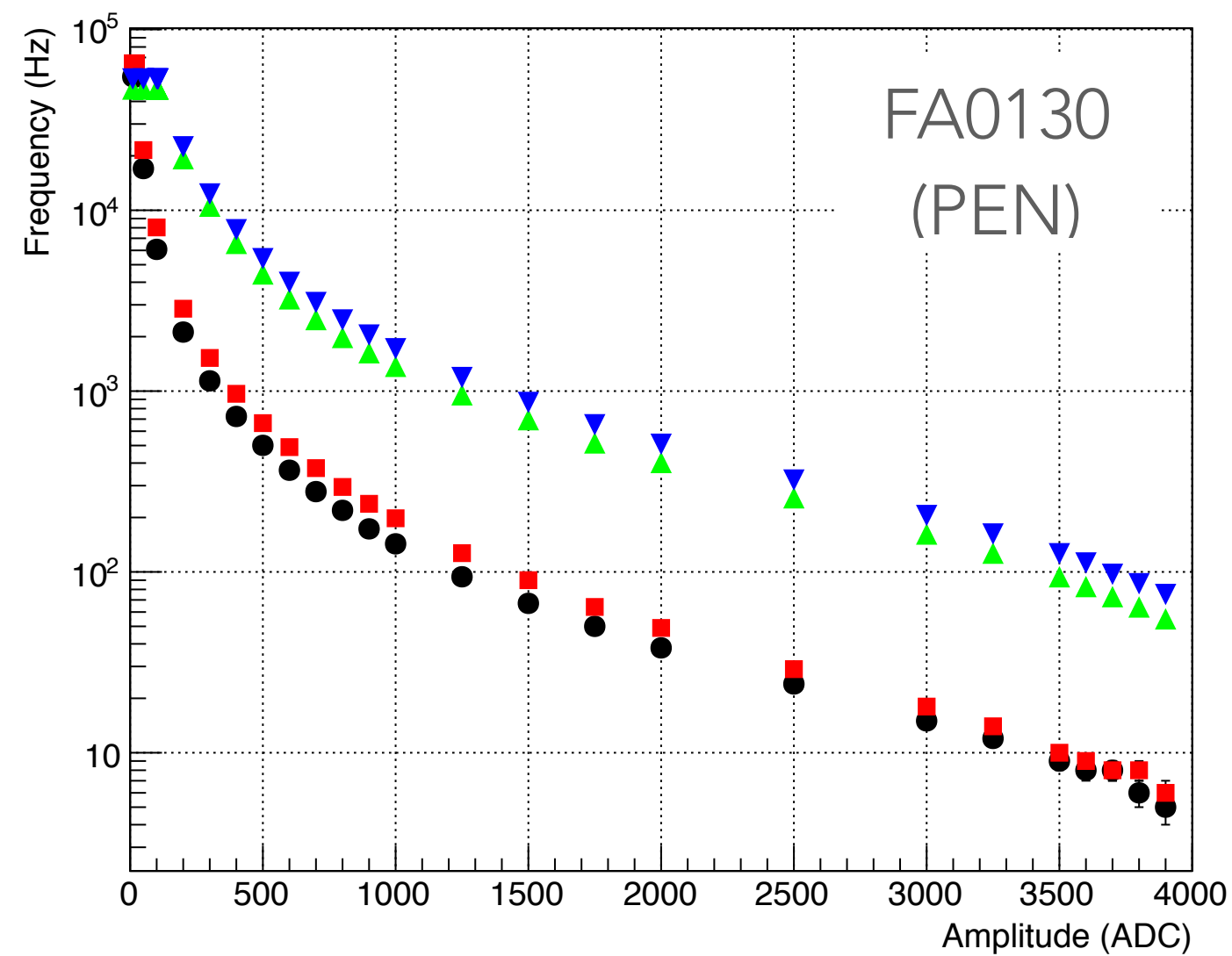
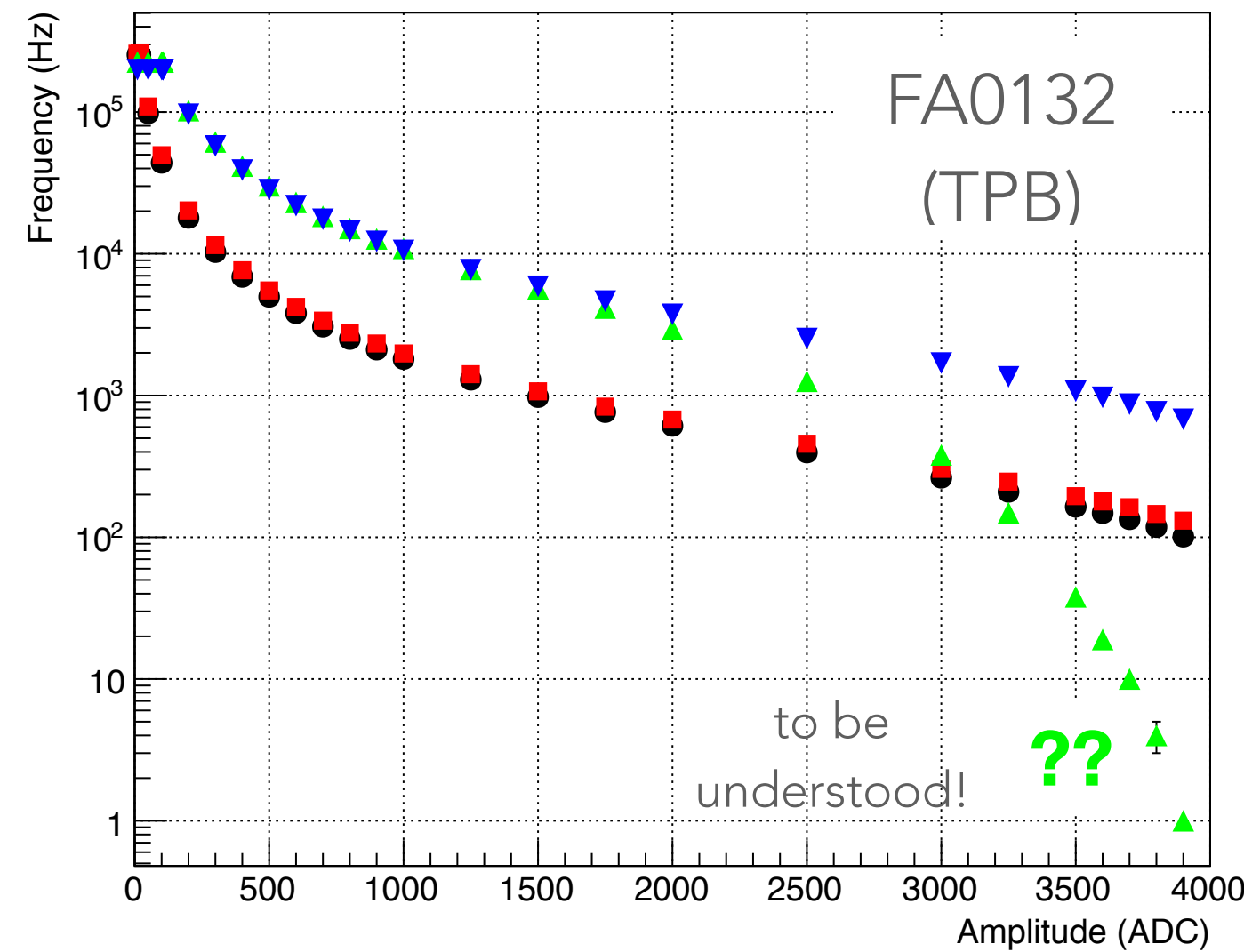
◆ Different field conditions and days:

- Random trigger runs
- Counting all the light signals
- No gain correction is applied



- #2652 (17Feb), $G=1e7$, fields on*
- #2681 (24Feb), $G=1e7$, no fields
- ▲ #2653 (17Feb), $G=5e7$, fields on*
- ▼ #2680 (24Feb), $G=5e7$, no fields

* Cathode 50 kV, FFS 4.8 kV, grid1 **6.0 kV**, grid2 **3.9 kV**, LEMs1 3.1 kV, LEMs2 3.4 kV



1. Light frequency

Run #2783-2808 & #2811-2816

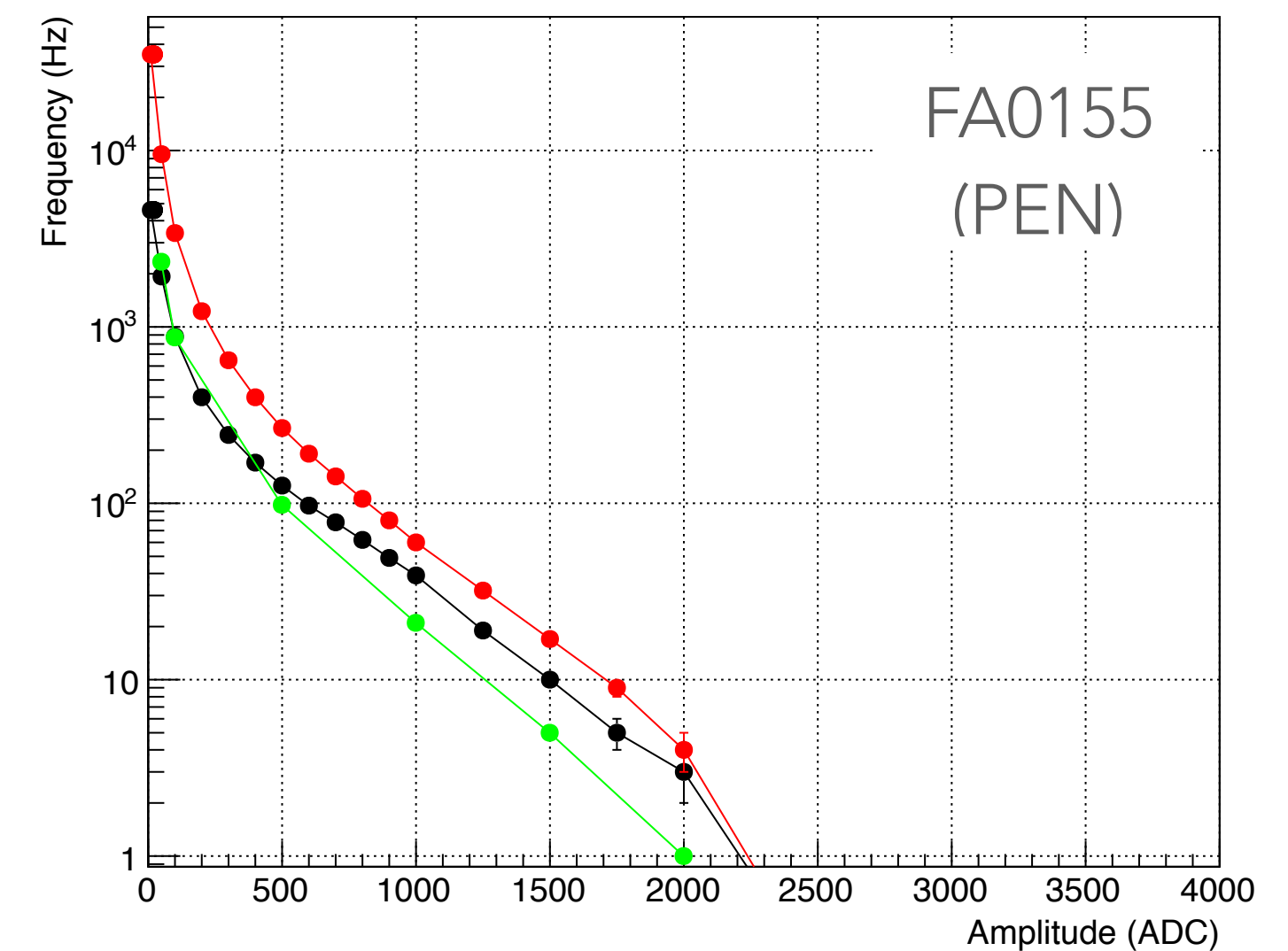
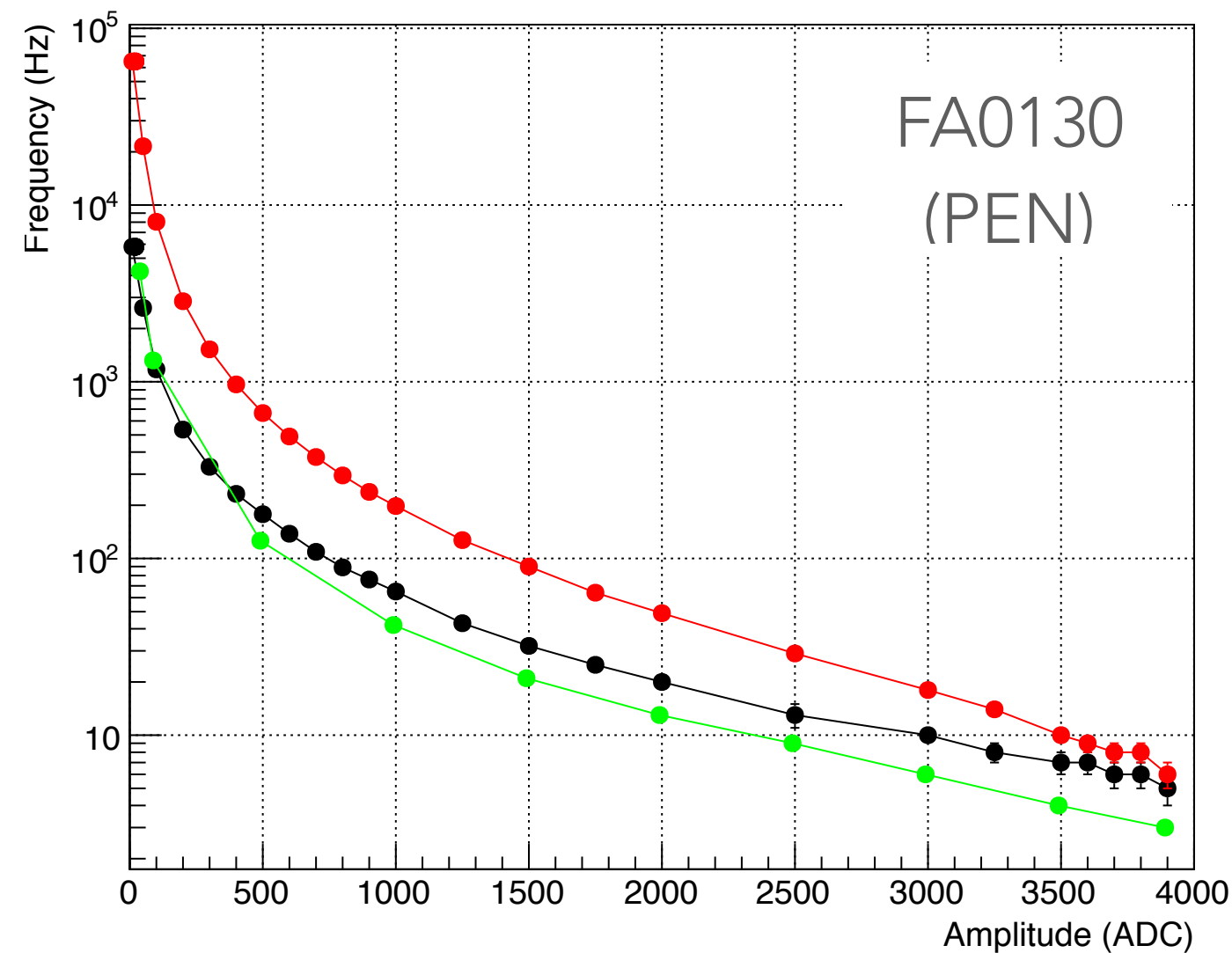
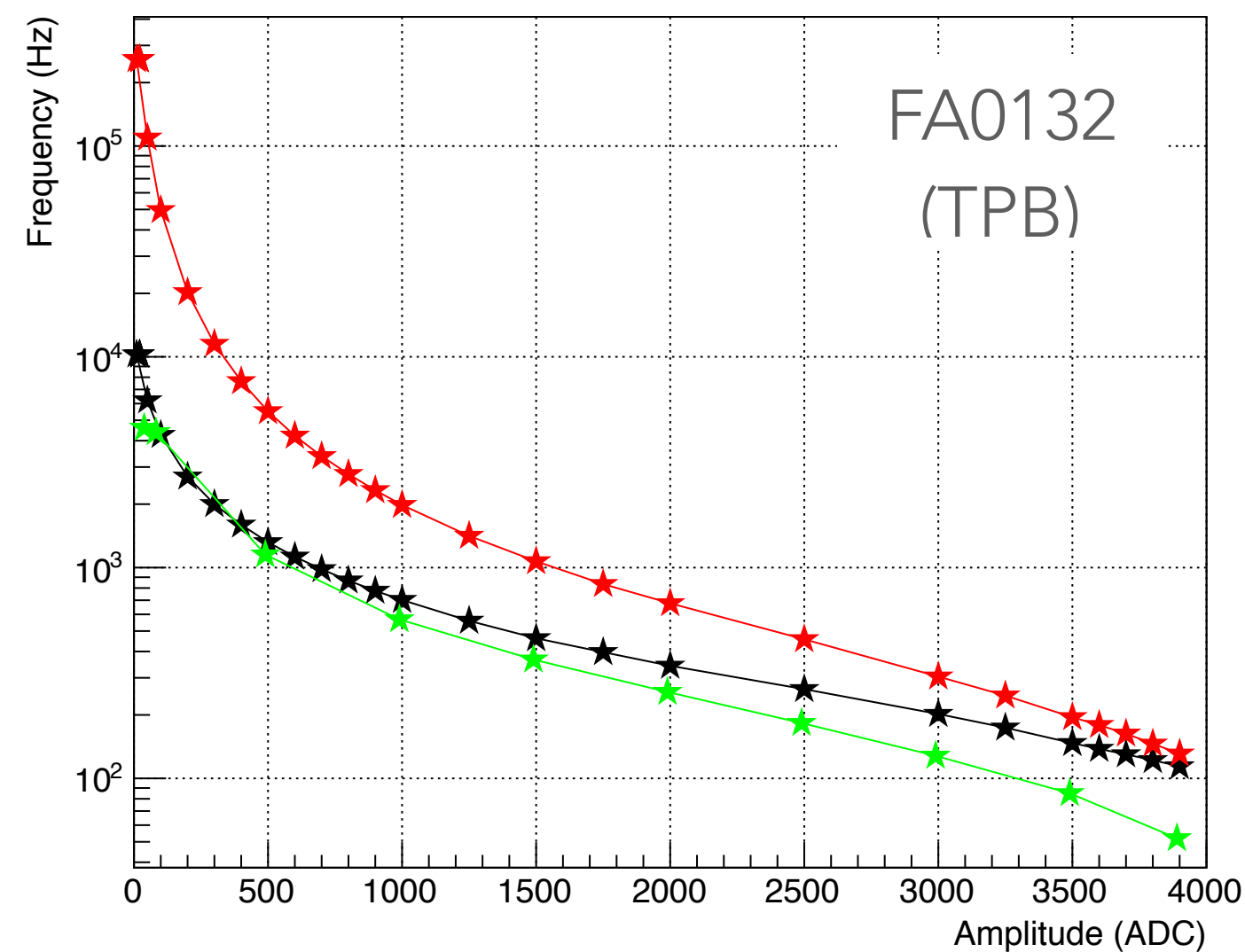
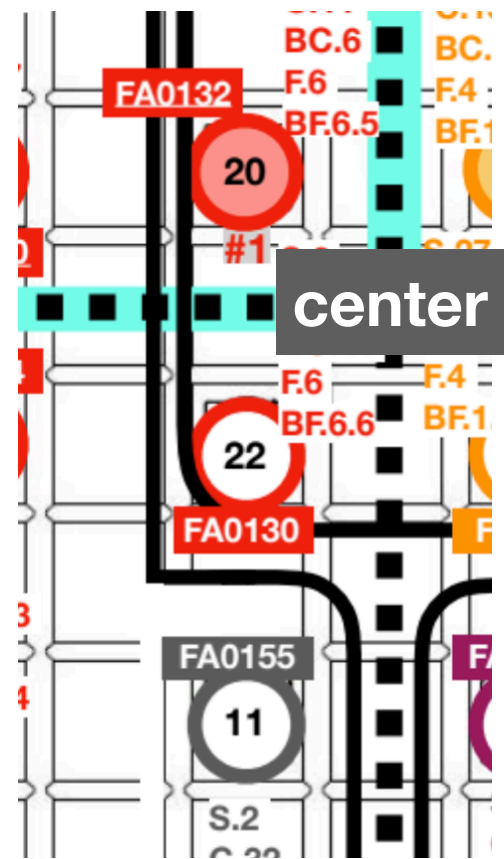
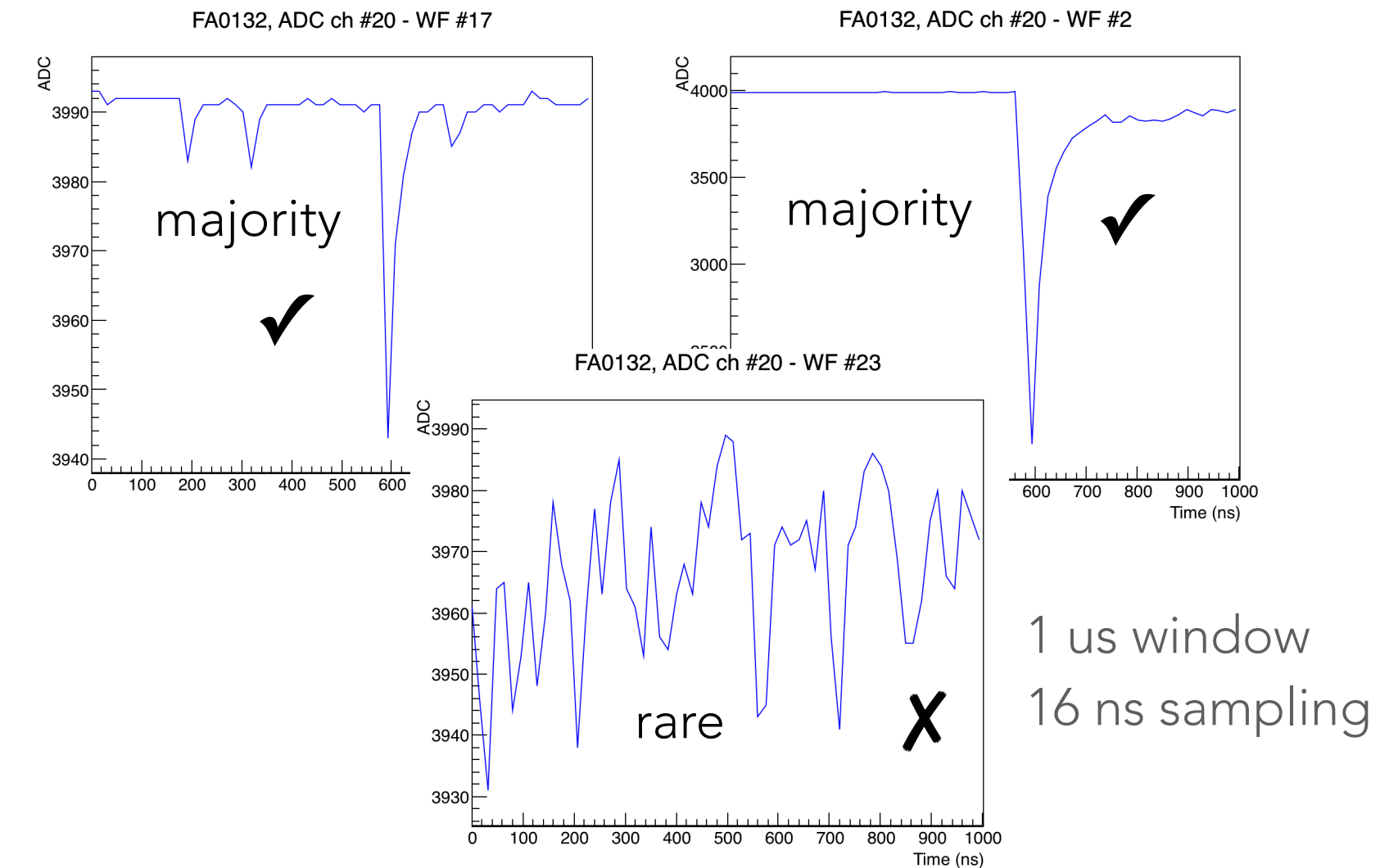
(PMT trigger ch #20, #22, #11, fields on*, 1e7, Mar11-12)

* Cathode 50 kV, FFS 4.8 kV, grid1 **6.0 kV**, grid2 **6.2 kV**, LEMs1 3.1 kV, LEMs2 3.4 kV

◆ New approach / crosscheck:

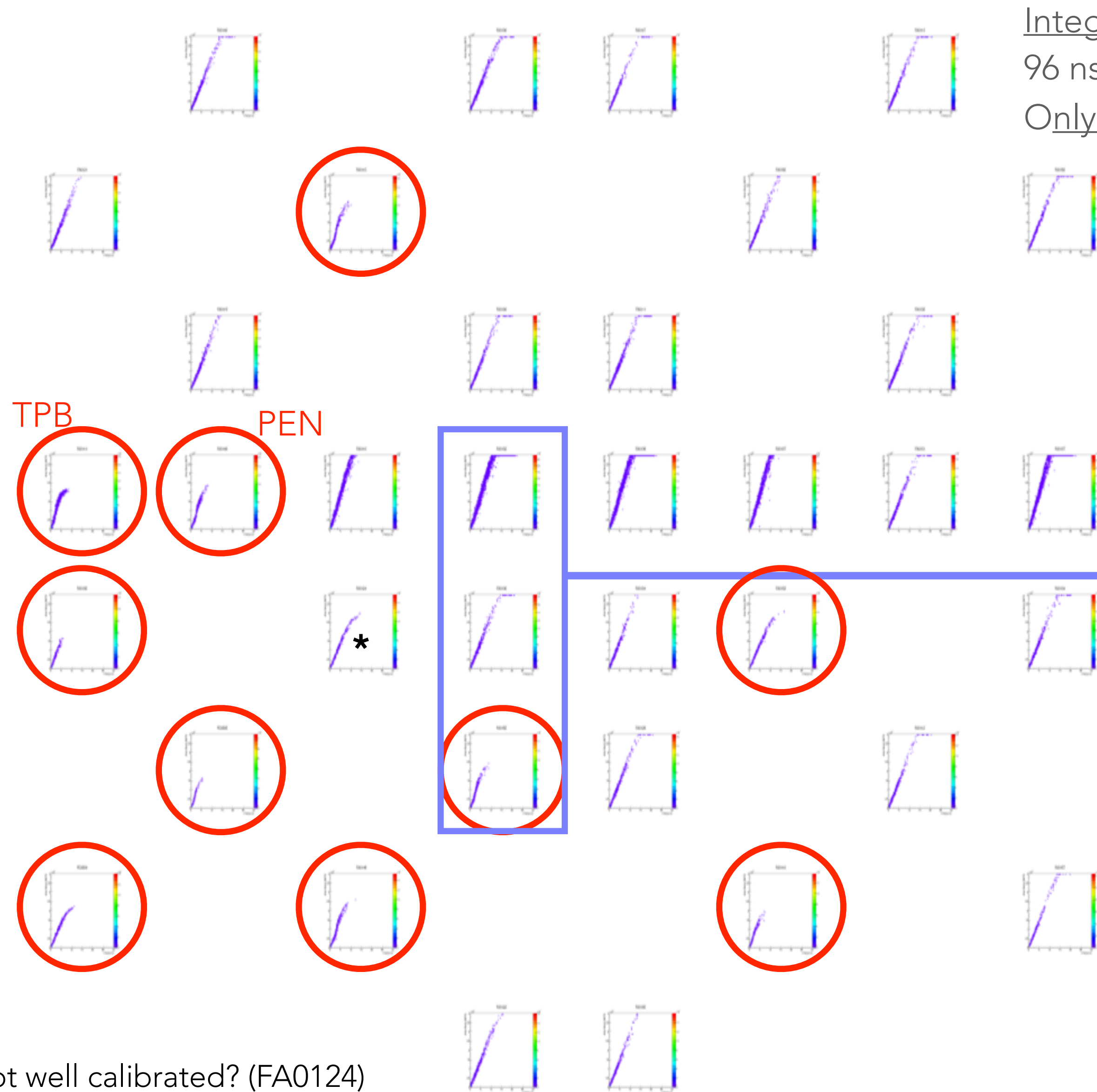
- Measurements doing a threshold scan (PMT trigger)
- More statistics for large amplitudes (smaller errors)
- Rate = #Events / (last_timestamp - first_timestamp)
- Variations can be due to the timestamp precision ($\pm 1s$)
- The WR timestamp ($\pm 0.1s$) could be used instead!

- ★ ● Random trigger #2681 (24Feb), S1 signal counting
- ★ ● Random trigger #2681 (24Feb), all the light signals
- ★ ● **PMT trigger #2783-2816 (11-12Mar), threshold scan (hardware)**

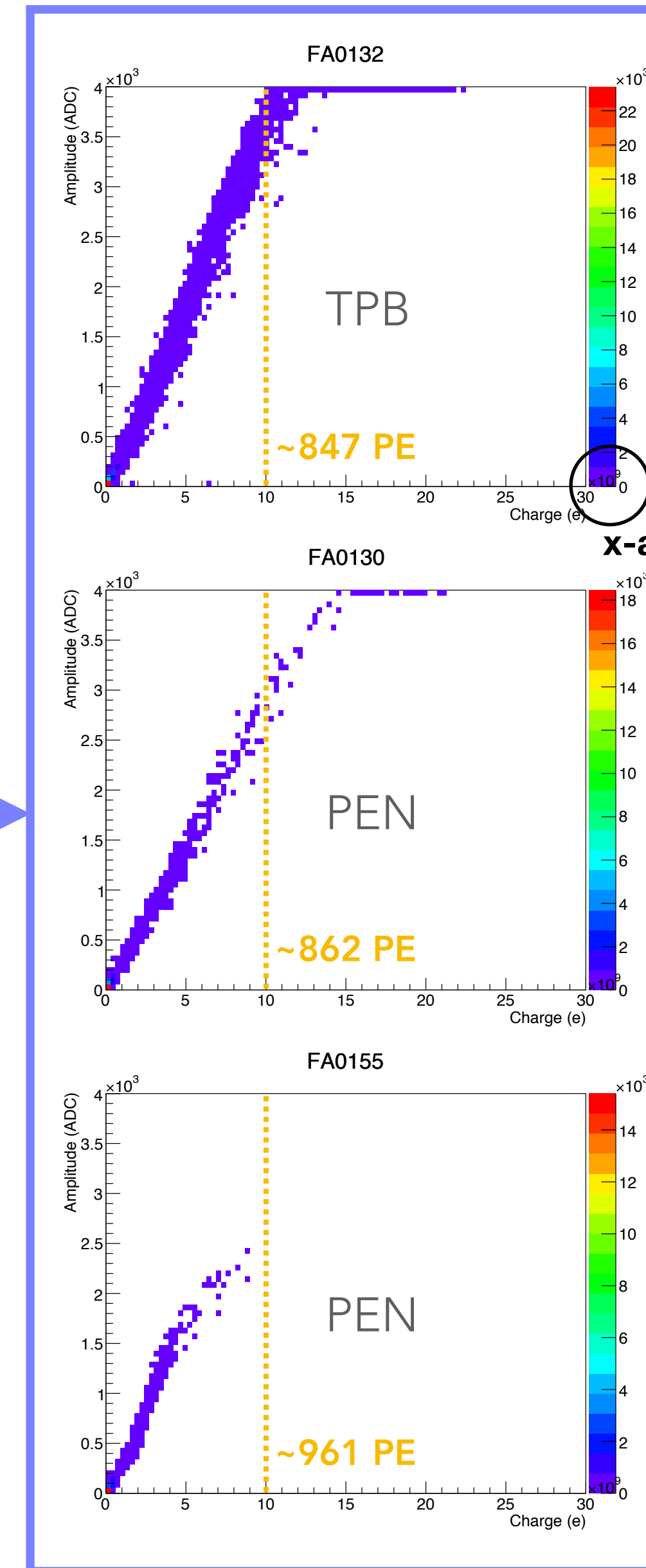


2. Amount of light

Run #2681 (random trigger, no fields, 1e7, 1 ms, 16 ns, Feb24) 7



Integration window:
96 ns (-2,+3)bins
Only S1 signals!



Real PMT gain
(corrected using
the calibration
20200224)

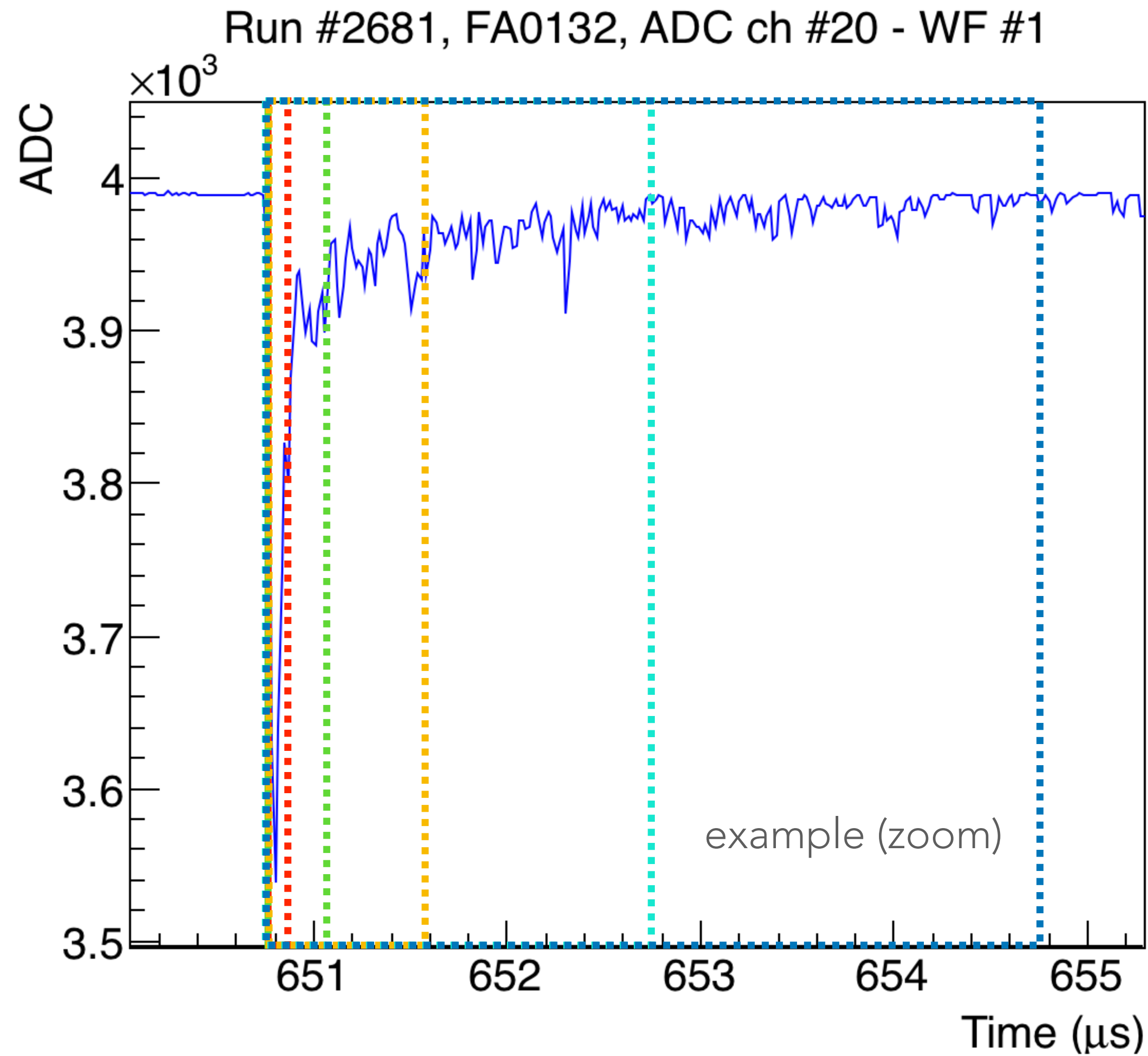
G=1.18e7

G=1.16e7

G=1.04e7

* not well calibrated? (FA0124)

2. Amount of light



Integration windows:

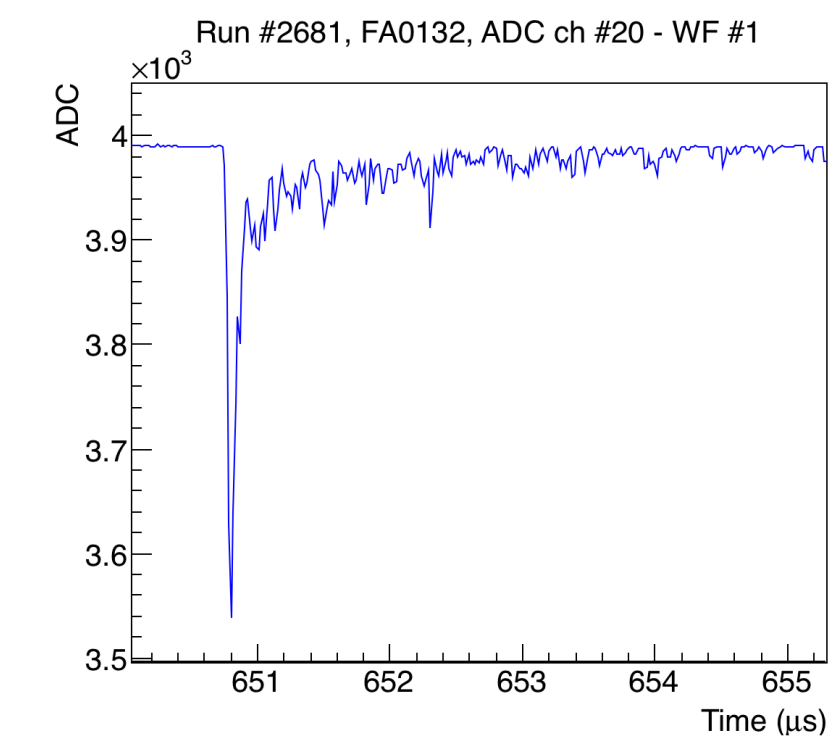
96 ns (-2,+3)bins

320 ns (-2,+17)bins

800 ns (-2,+47)bins

2000 ns (-2,+122)bins

4000 ns (-2,+247)bins



2. Amount of light

integration window →

96 ns (-2,+3)bins

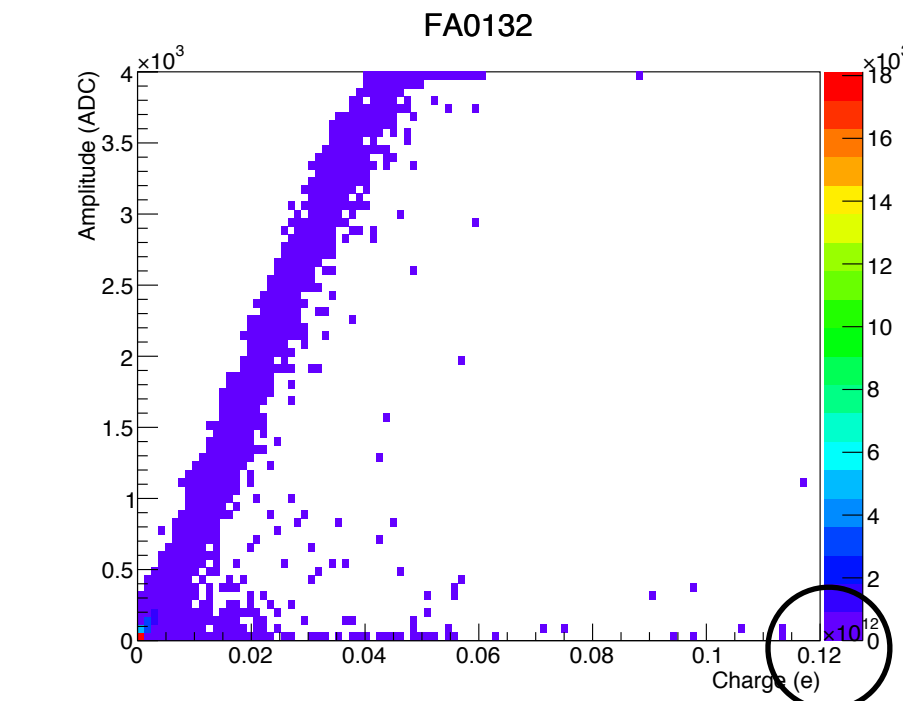
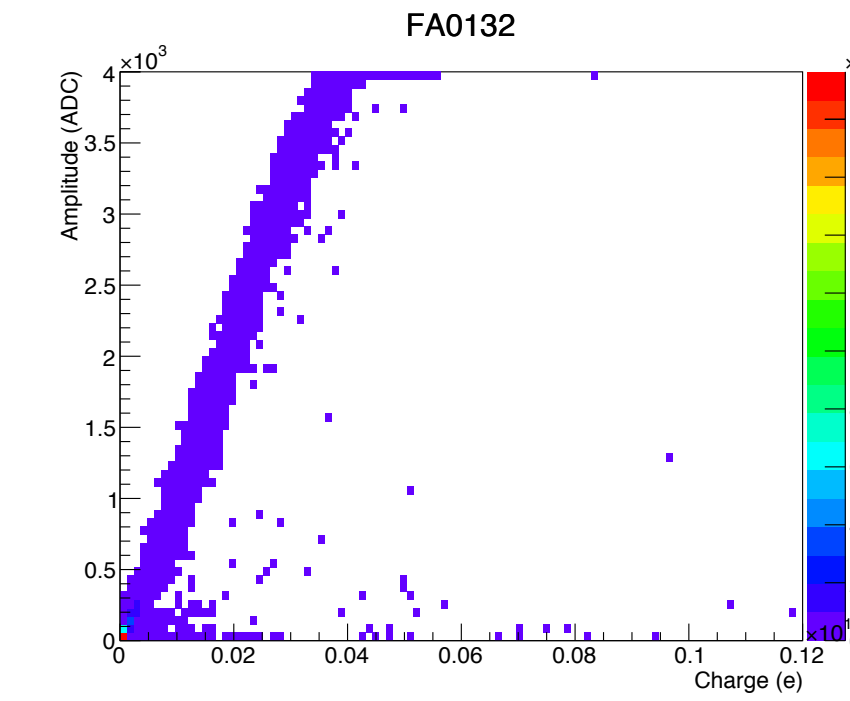
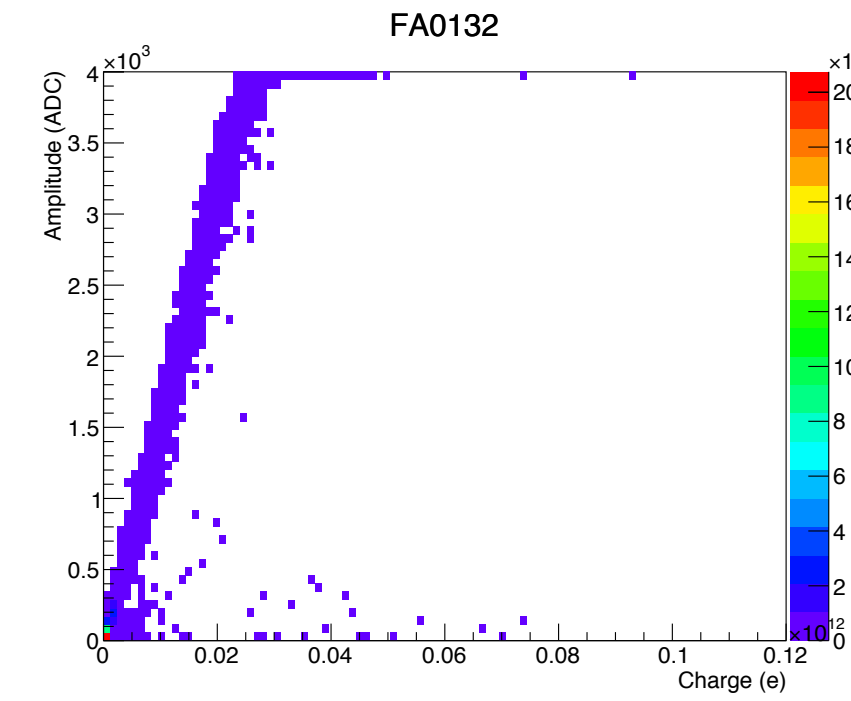
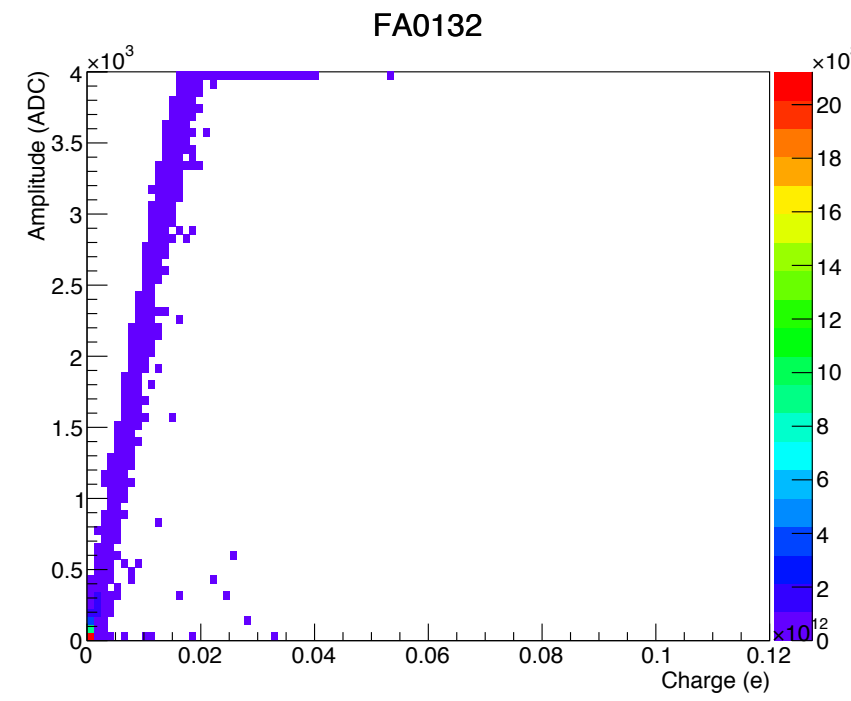
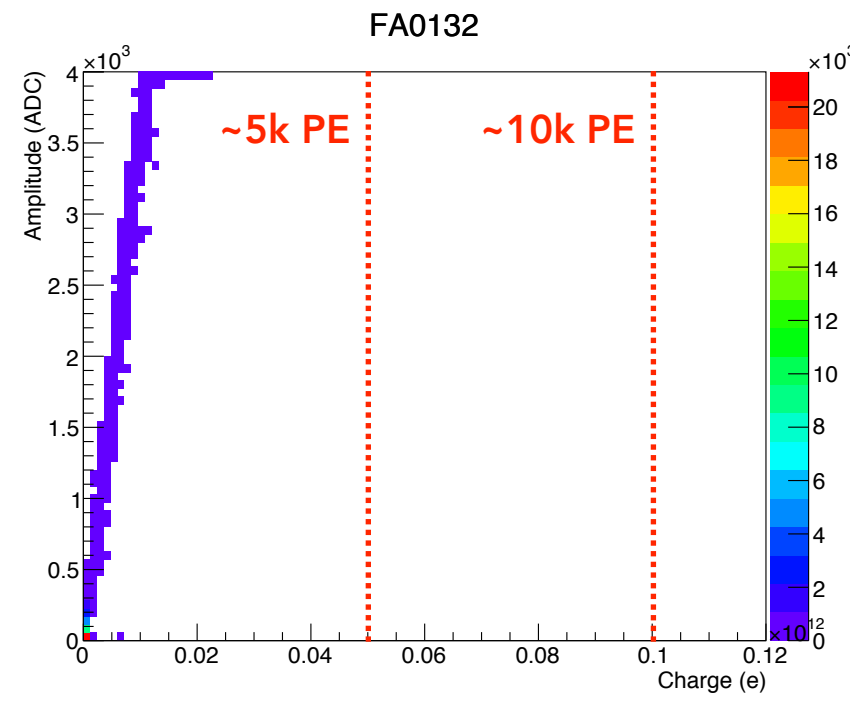
320 ns (-2,+17)bins

800 ns (-2,+47)bins

2000 ns (-2,+122)bins

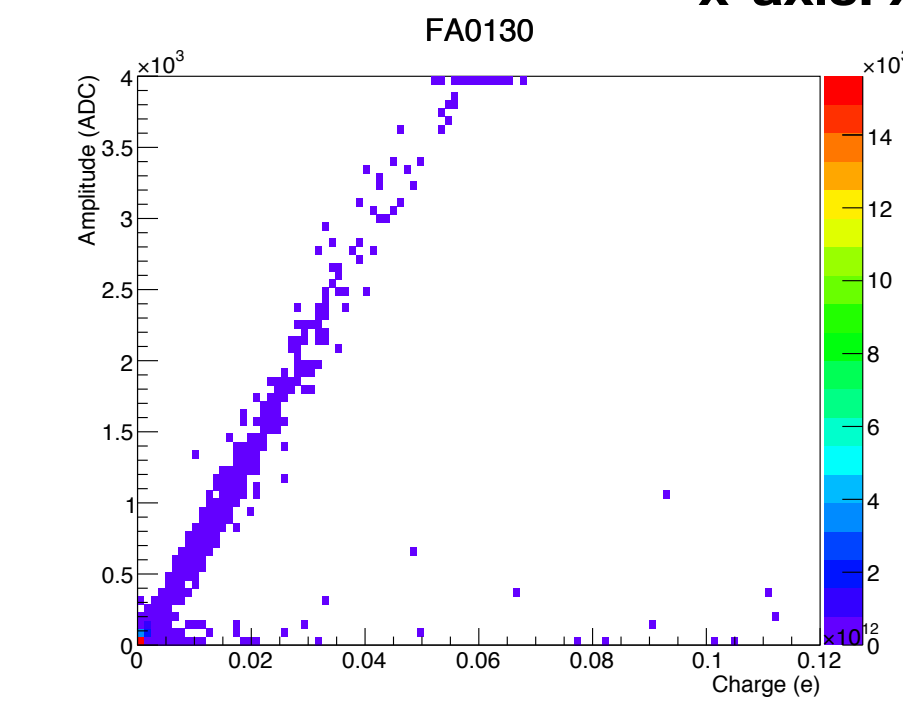
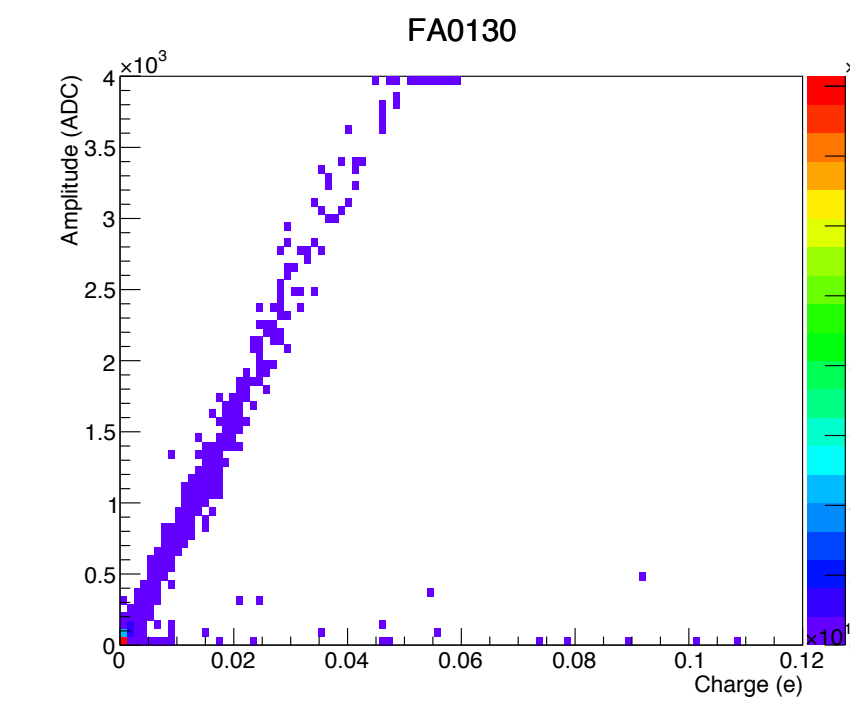
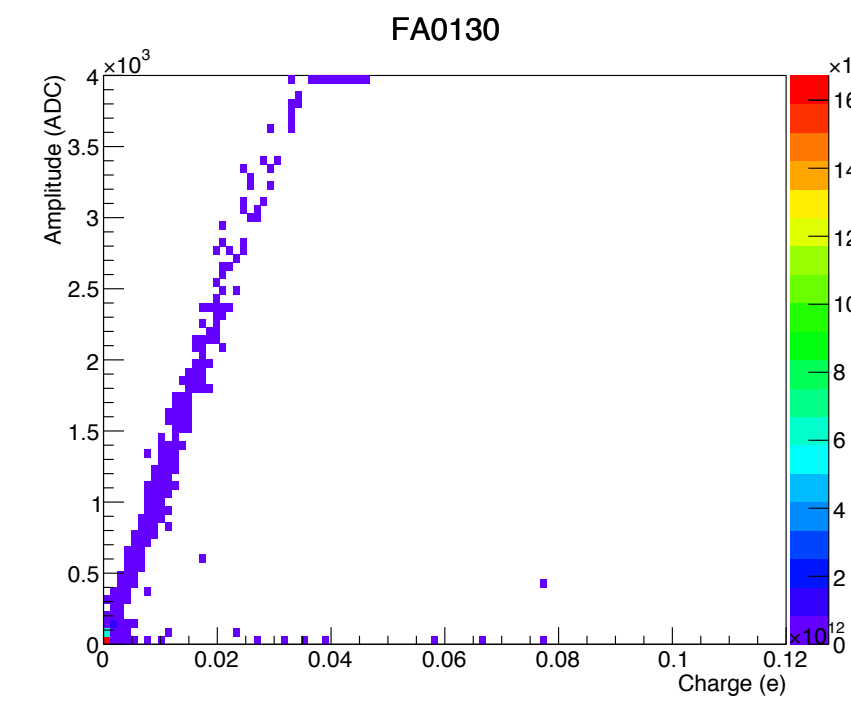
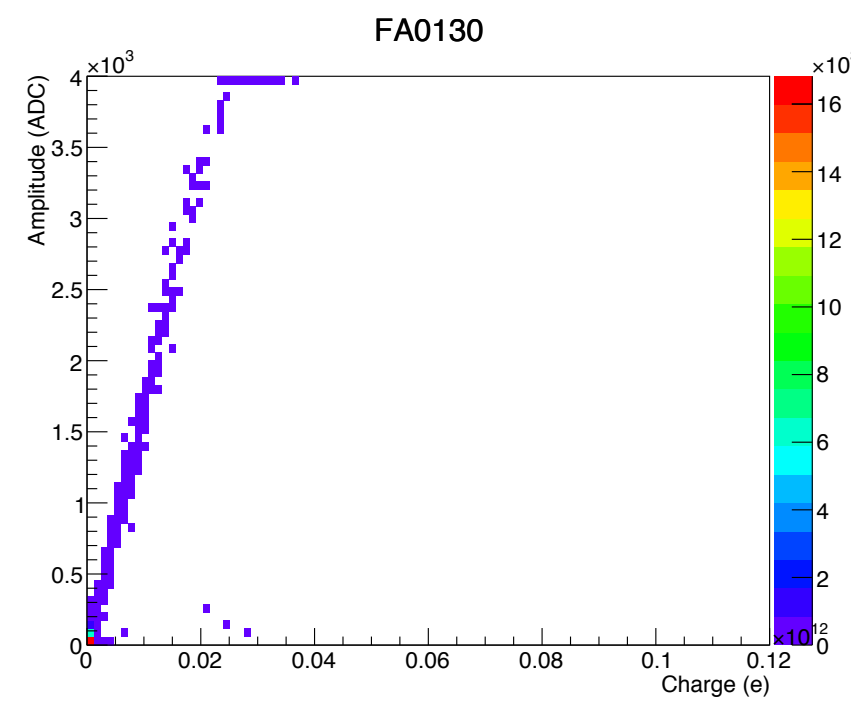
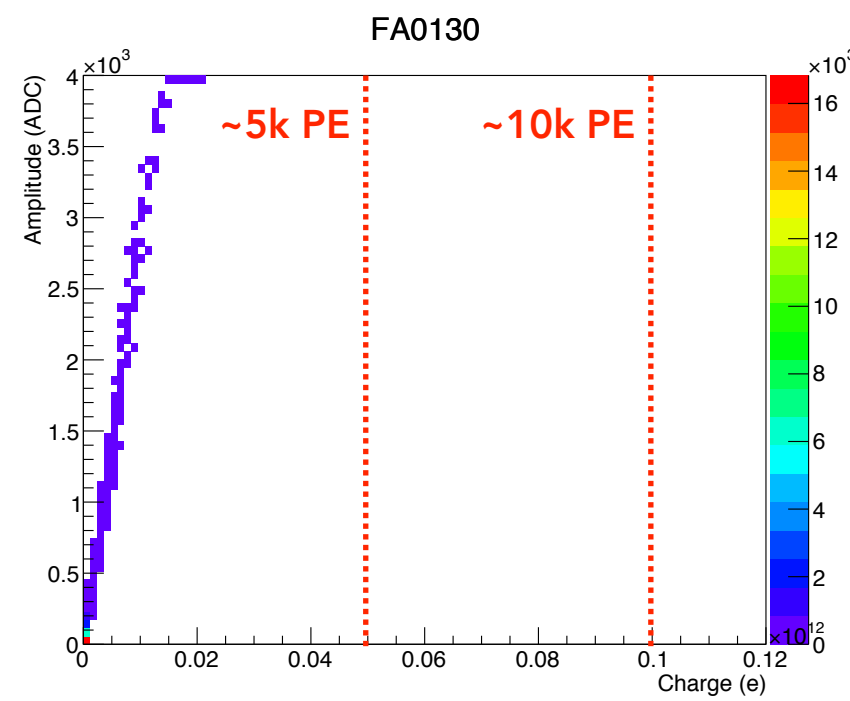
4000 ns (-2,+247)bins

TPB

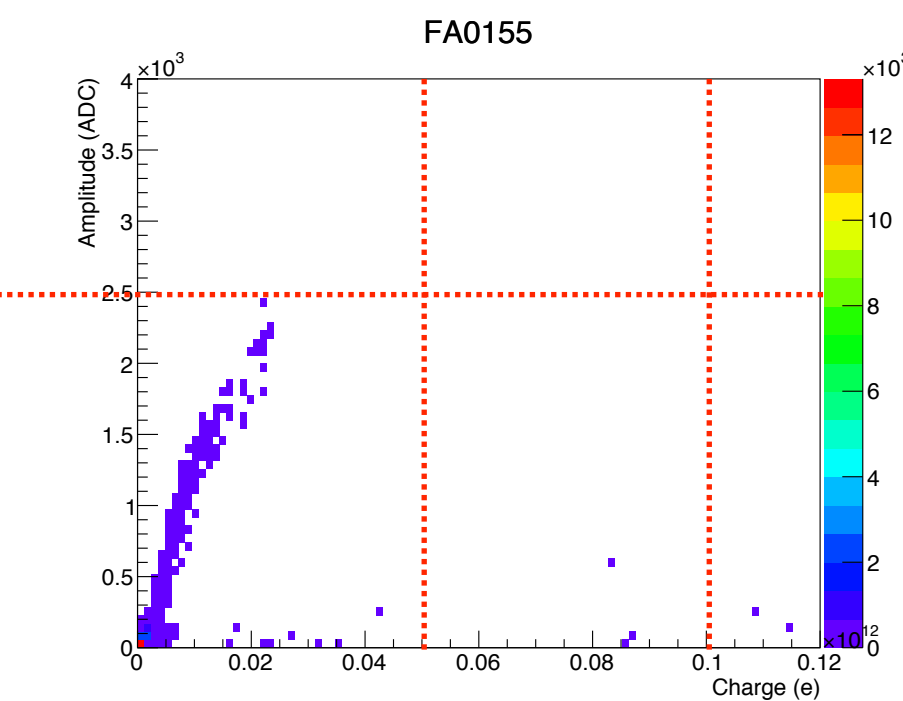
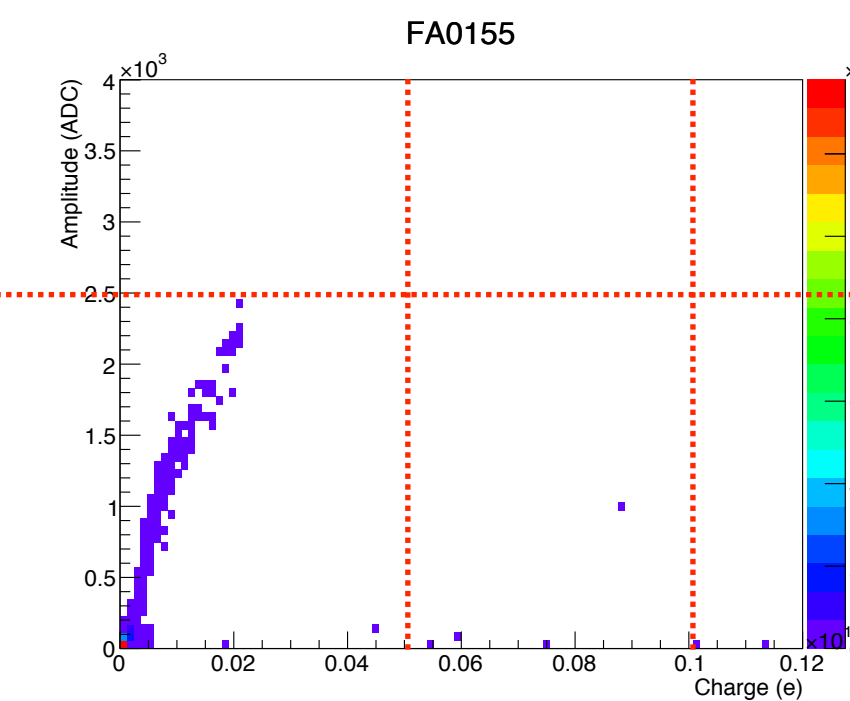
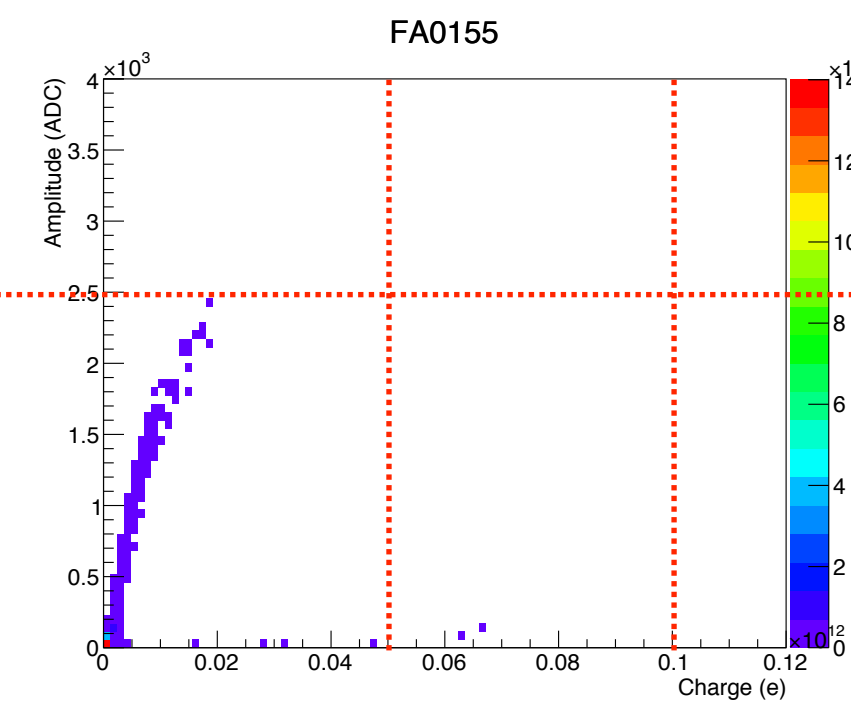
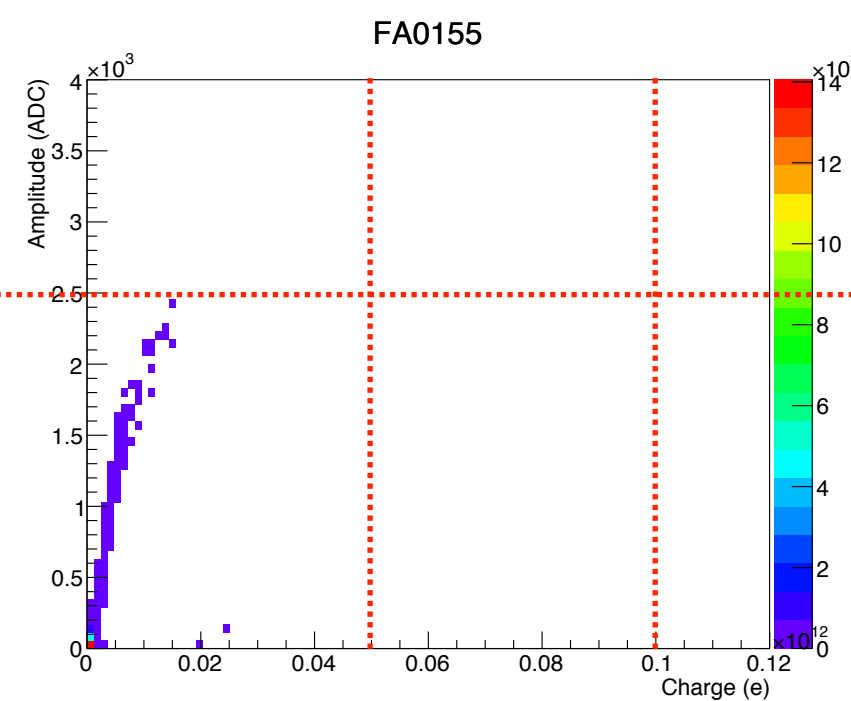
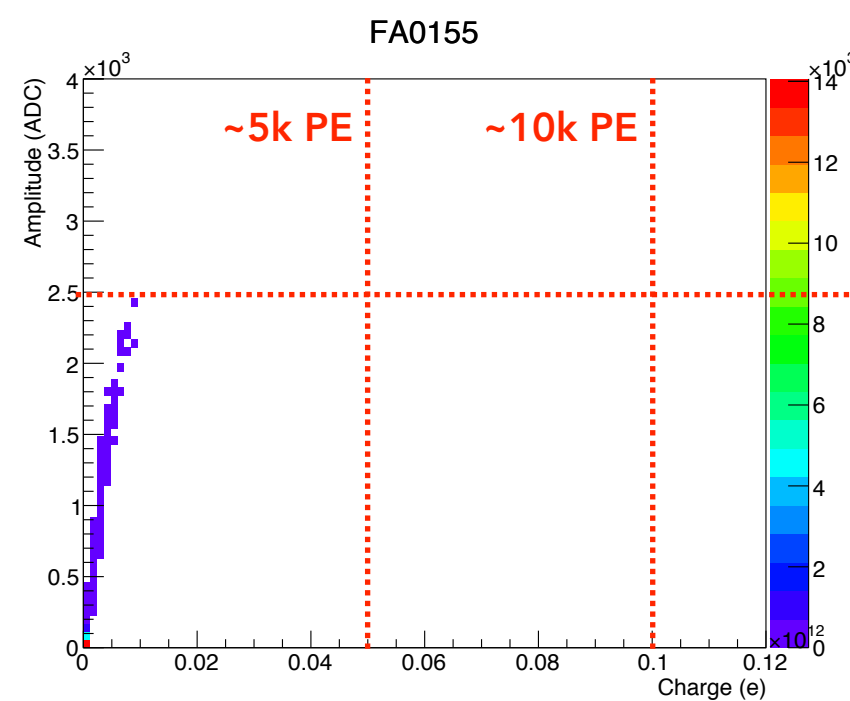


x-axis: $\times 10^{12}$

PEN



PEN #1



2. Amount of light

Run #2681 (random trigger, no fields, 1e7, 1 ms, 16 ns, Feb24) 10

integration window →

96 ns (-2,+3)bins

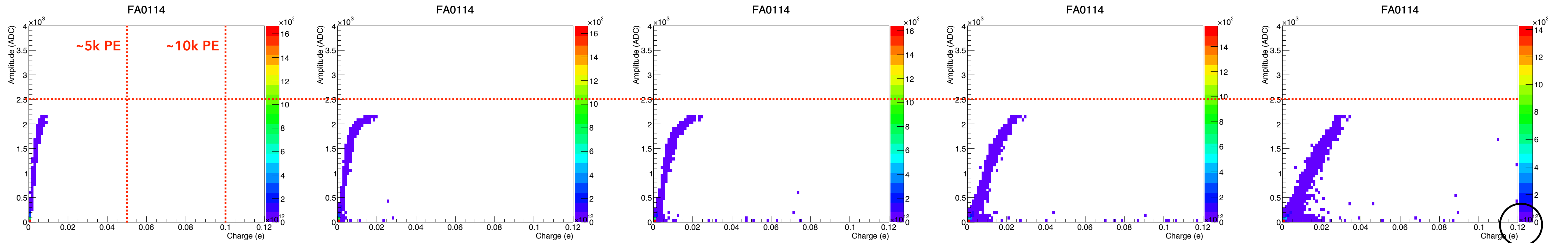
320 ns (-2,+17)bins

800 ns (-2,+47)bins

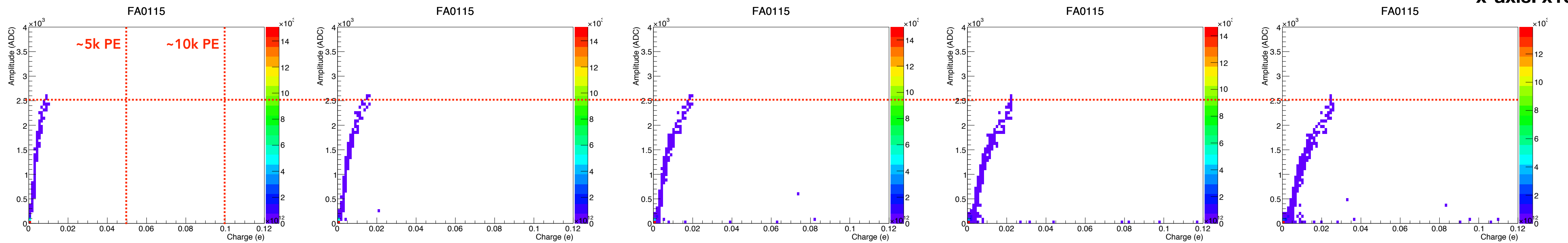
2000 ns (-2,+122)bins

4000 ns (-2,+247)bins

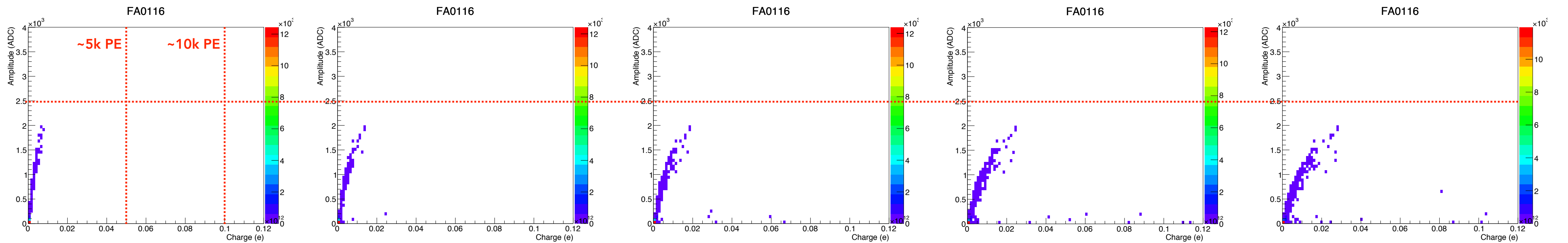
TPB! #2



PEN #3



PEN #4



2. Amount of light

Run #2681 (random trigger, no fields, 1e7, 1 ms, 16 ns, Feb24) 11

integration window →

96 ns (-2,+3)bins

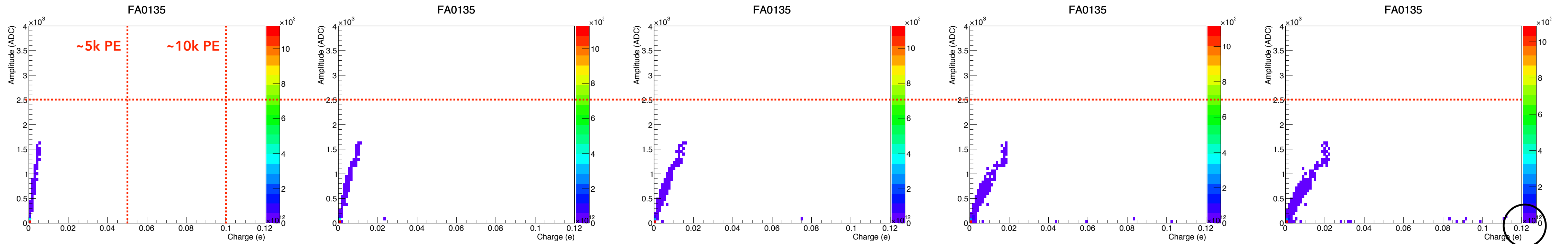
320 ns (-2,+17)bins

800 ns (-2,+47)bins

2000 ns (-2,+122)bins

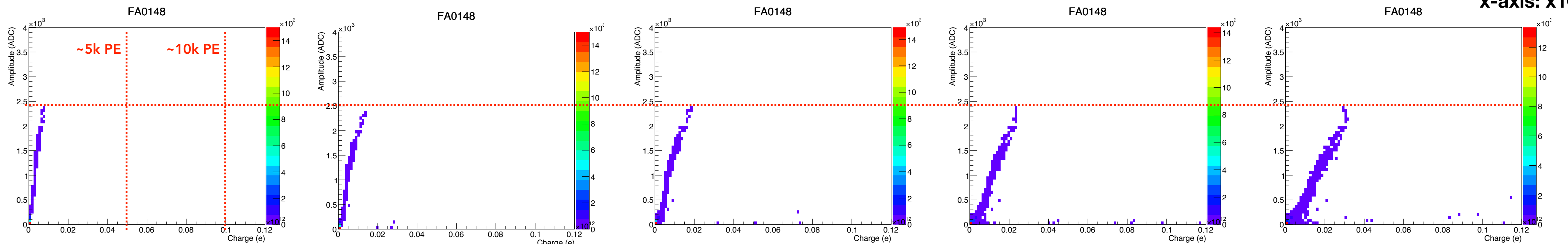
4000 ns (-2,+247)bins

PEN #5

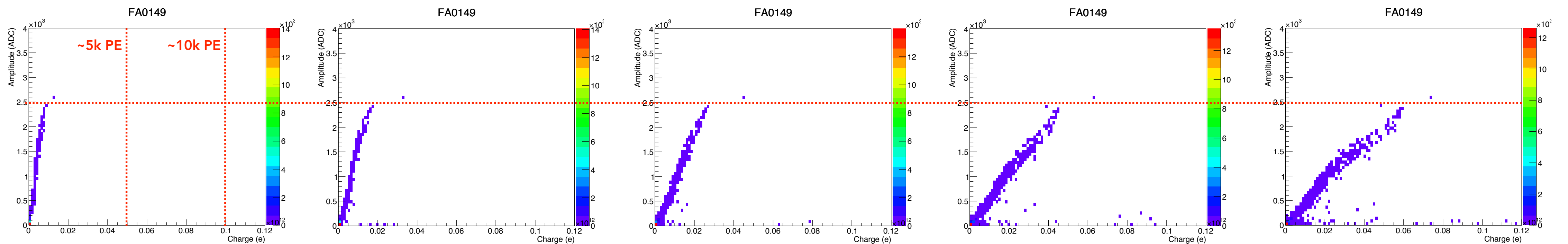


x-axis: x10¹²

PEN #6



PEN #7



2. Amount of light

integration window →

96 ns (-2,+3)bins

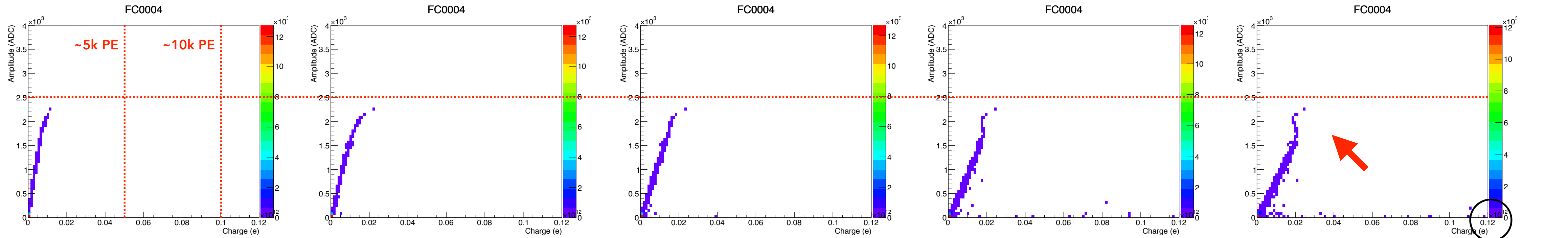
320 ns (-2,+17)bins

800 ns (-2,+47)bins

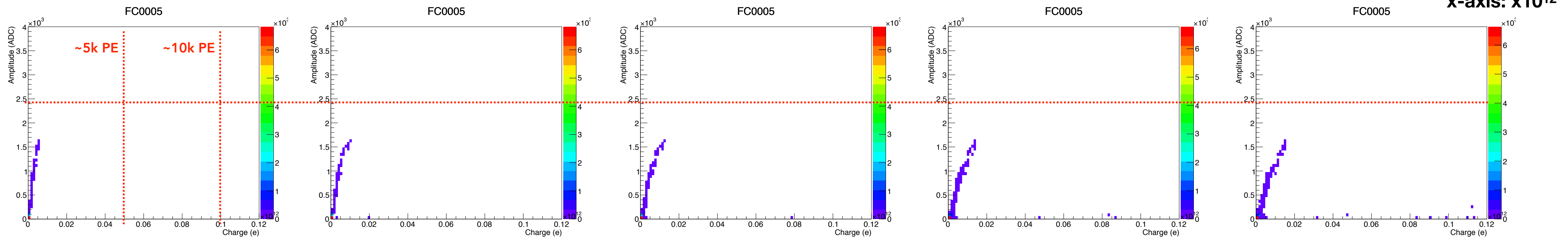
2000 ns (-2,+122)bins

4000 ns (-2,+247)bins

PEN #8



PEN #9



PEN #10 (FA0153) missing + FA0124??

* **To-do:** plot Q_{96ns} vs $(Q_{4000ns} - Q_{2000ns})$ → fast component charge vs slow component charge

3. ADC saturation + 4. (most) linear range

PRELIMINARY!

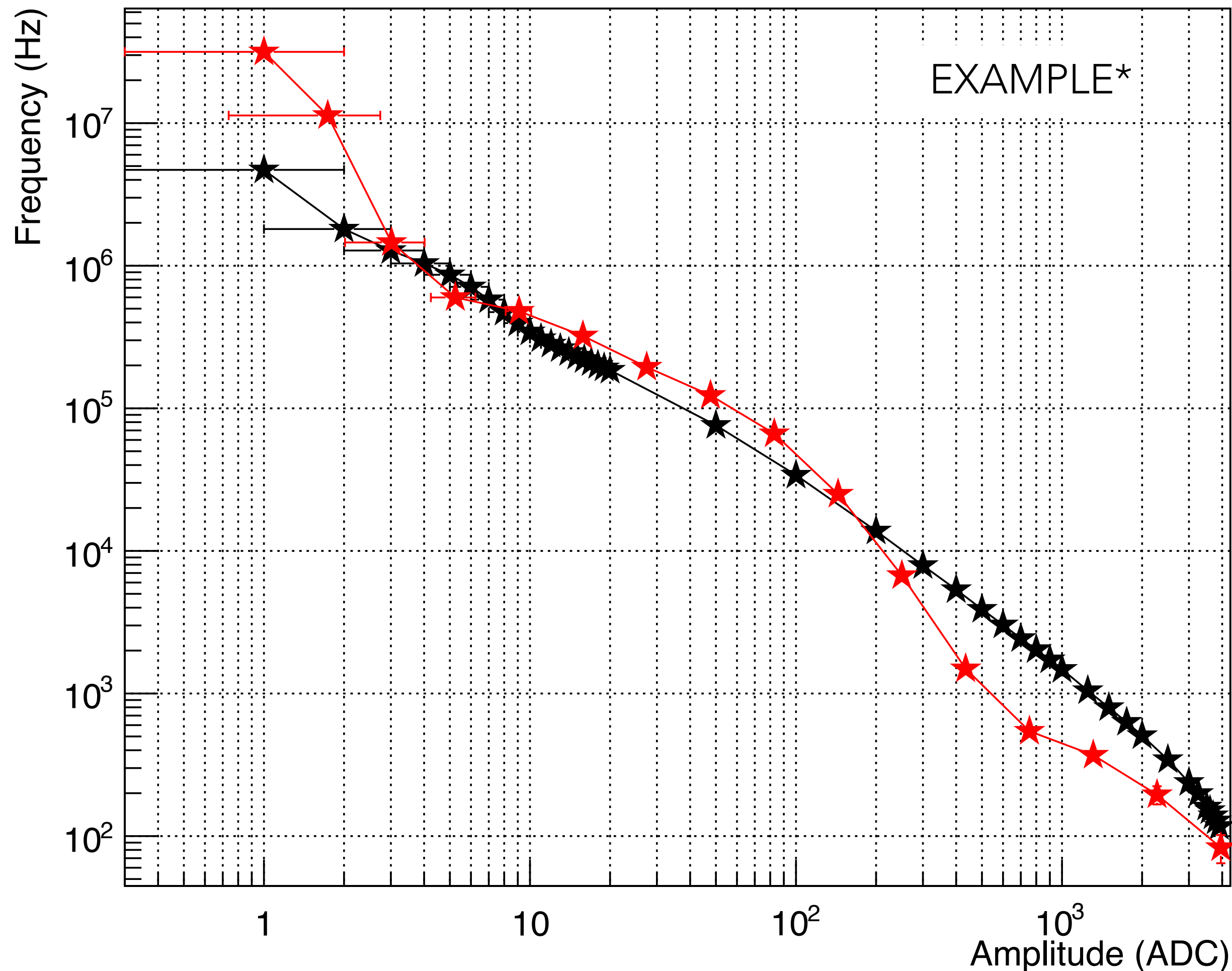
SN	Saturation	~Max. amplitude at 1e7 (ADC)	Max. light (PE)	Saturation frequency (Hz)*	SN	Saturation	~Max. amplitude at 1e7 (ADC)	Max. light (PE)	Saturation frequency (Hz)*
FA0104	standard	4096	to be characterized!	5	FA0139	standard	4096	to be characterized!	103
FA0105	standard	4096		5	FA0146	standard	4096		6
FA0106	standard	4096		9	FA0147	standard	4096		4
FA0107	standard	4096		95	FA0150	standard	4096		7
FA0110	standard	4096		77	FA0151	standard	4096		7
FA0111	standard	4096		8	FA0156	standard	4096		7
FA0112	standard	4096		3	FA0157	standard	4096		2
FA0113	standard	4096		9	FA0124	early?	3000?		—
FA0119	standard	4096		12	FA0114	early	2200		—
FA0121	standard	4096		7	FA0115	early	2600		—
FA0122	standard	4096		6	FA0116	early	2000		—
FA0129	standard	4096		6	FA0135	early	1700		—
FA0130	standard	4096		6	FA0148	early	2400		—
FA0132	standard	4096		132	FA0149	early	2600		—
FA0133	standard	4096		7	FA0153	early	3100		—
FA0134	standard	4096	8	FA0155	early	2500	—		
FA0136	standard	4096	7	FC0004	early	2300	—		
FA0137	standard	4096	117	FC0005	early	1700	—		

* Values from run #2681 (1e7, random trigger, no fields)

orange: TPB PMTs

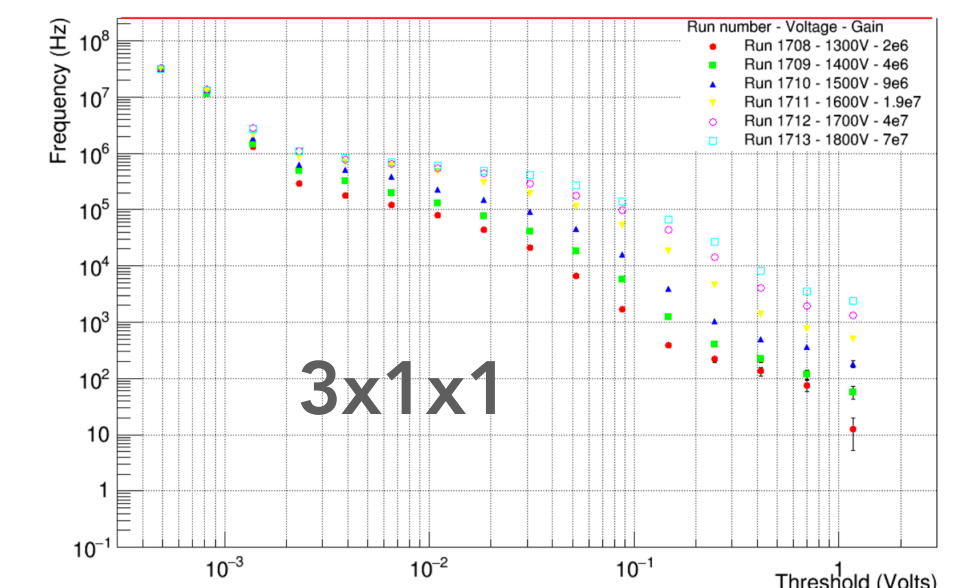
5. Comparison to 3x1x1m³

- ★ **6x6x6 data:** run #2681 (Feb2020), all the light signals, FA0137 (ch#44), TPB, **G=9.26E6**
- ★ **3x1x1 data:** run #1710 (Oct2017), all the light signals, channel #0, TPB coating, **G=9E6** —> J. Soto analysis



- ◆ **The ADC saturation rate is similar: ~100 Hz** for signals >3900 ADC
- ◆ The light frequency wrt 3x1x1 for:
 - **small signals is similar:** ~200 kHz for 10-20ADC-signals
 - **large signals is higher:** ~1000 Hz vs 200 Hz for 1000-2000ADC-signals
 - **noise signals is lower:** ~3 MHz vs 20 MHz for 1-2ADC-signals

* More data (other PMTs & gains) available for other comparisons



-
- ◆ The PMTs ($G=1e7$) usually receive signal rates of **hundreds of kHz (>1 MHz for TPB, >300 kHz for PEN)** in a wide light range (**from a few PE to thousands of PE**)
 - ◆ As expected, **the field conditions do not affect the frequency** of the light signals that can be considered as **S1 signals (>3PE)** although we know the fields contribute to the SPE level rate (tested at different gains)
 - ◆ **The threshold scan (*hardware*) results are in agreement** with the ones from random trigger runs analysis
 - ◆ The PMTs that show particular saturations **should not be included in some analyses** because they could affect the result —> to be discussed
 - ◆ It is important to **understand why some PMTs saturate** and some PMTs don't: they are operating in the same conditions and located close to each other —> characterize in more detail?
 - ◆ Does the maximum amplitude (ADC) for the early-saturating PMTs depend on the **PMT gain**? To be check
 - ◆ We need to define the **PMT dynamic range** for the most linear response possible

Thanks

◆ SPE counting algorithm:

- pedestal = 20 first samples with $\text{ped_RMS} < 3$ ADC
- amplitude = pedestal - ADC_value
- SPE signal if (**min_SPE < amplitude < max_SPE**)
- If a S1 signal is found (**amplitude > 3 average SPE amplitude**), a **window_no_SPE(*)** afterwards is ignored for the SPE counting!
- **SPE_rate = #SPE / effective_time**
- **effective_time = (time_window x #events) - ignored_time**
- **ignored_time <= #S1 x (window_no_SPE)** (< in case S1 is close to the event window end)
- Example #1: for $G=1e7$, $\text{SPE} = 7 \pm 3$ ADC, $\text{S1} > 21$ ADC, $\text{min_SPE} = 4$ ADC, $\text{max_SPE} = 10$ ADC
- Example #2: $G=5e7$, $\text{SPE} = 35 \pm 15$ ADC, $\text{S1} > 105$ ADC, $\text{min_SPE} = 20$ ADC, $\text{max_SPE} = 50$ ADC

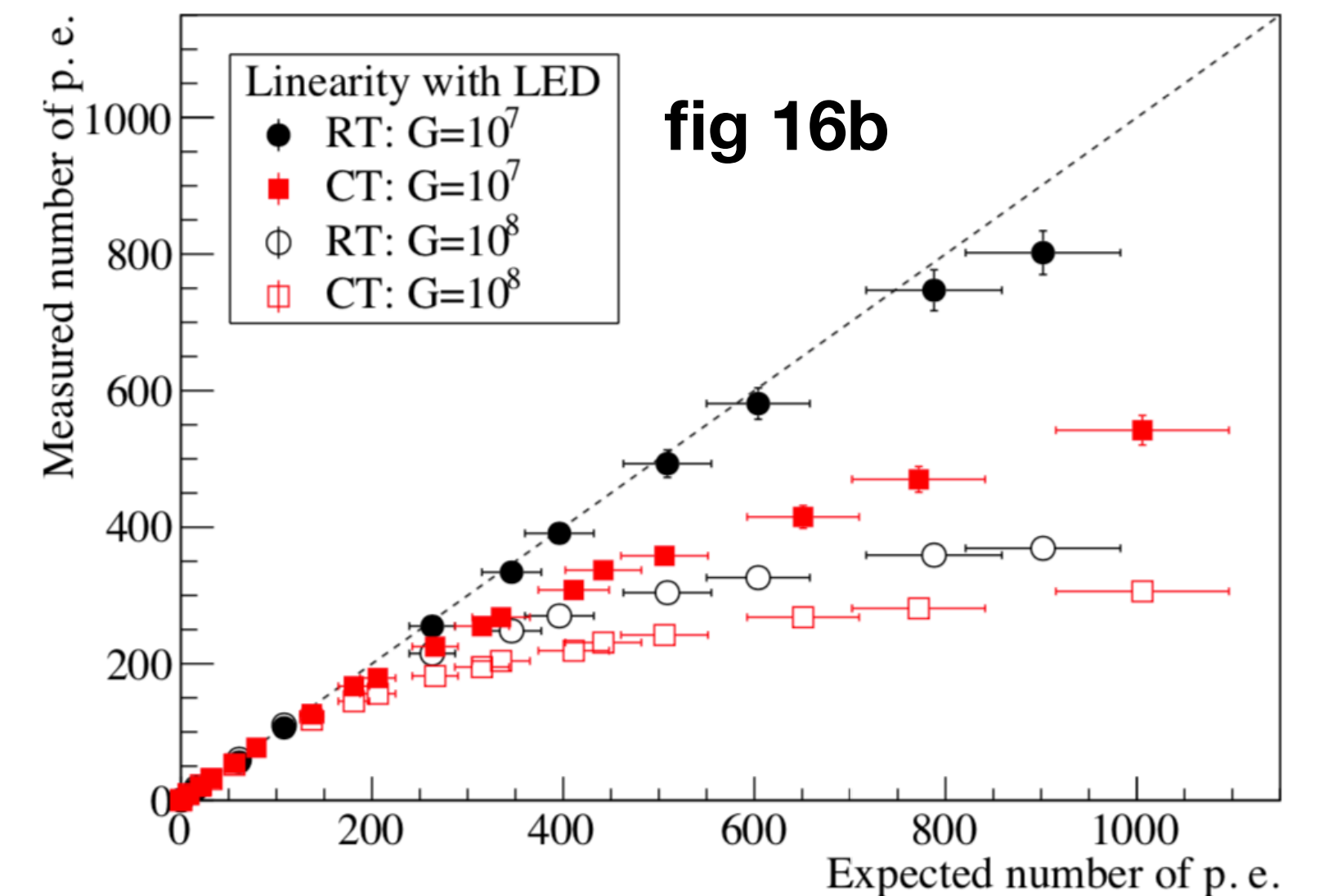
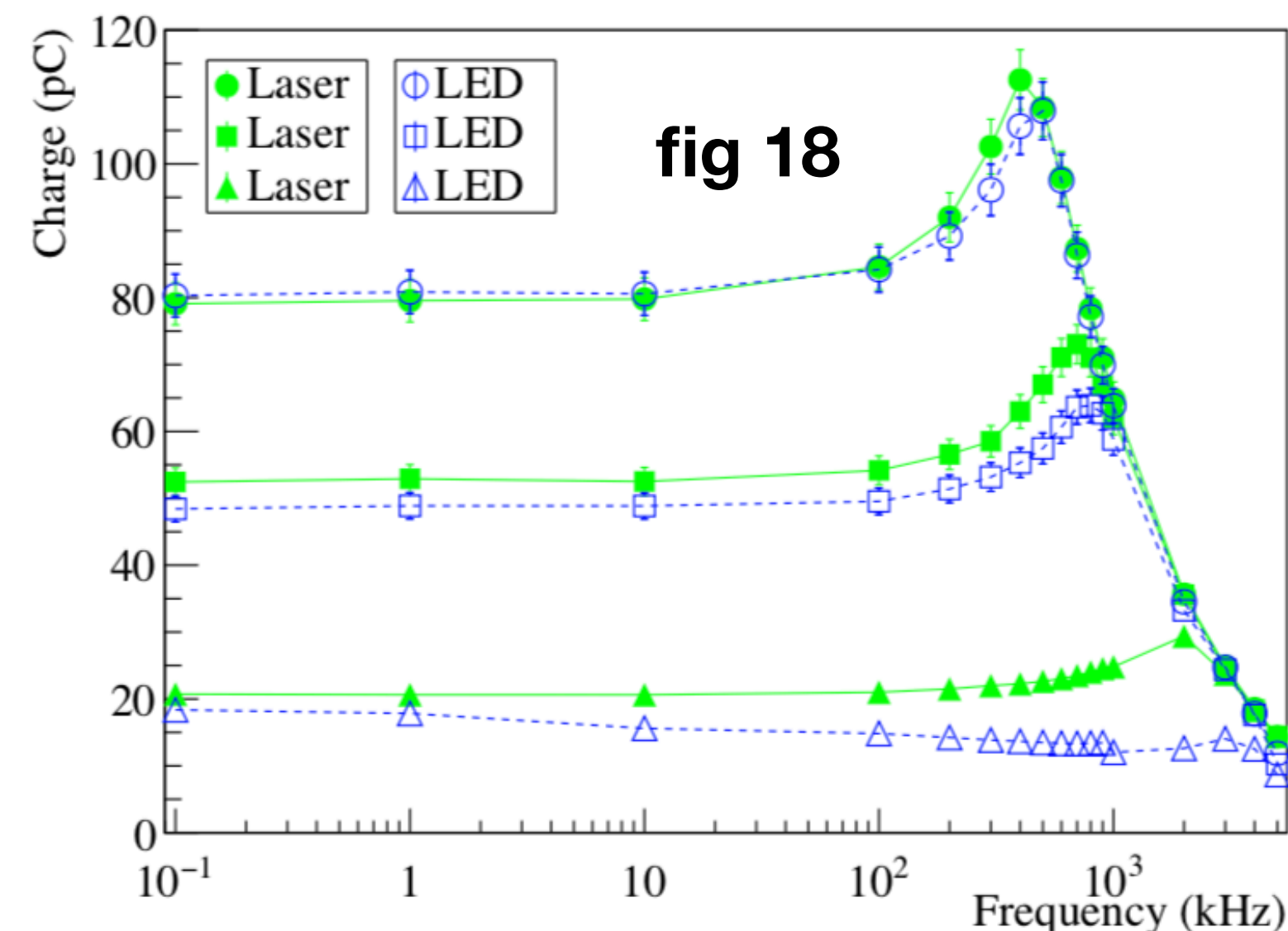
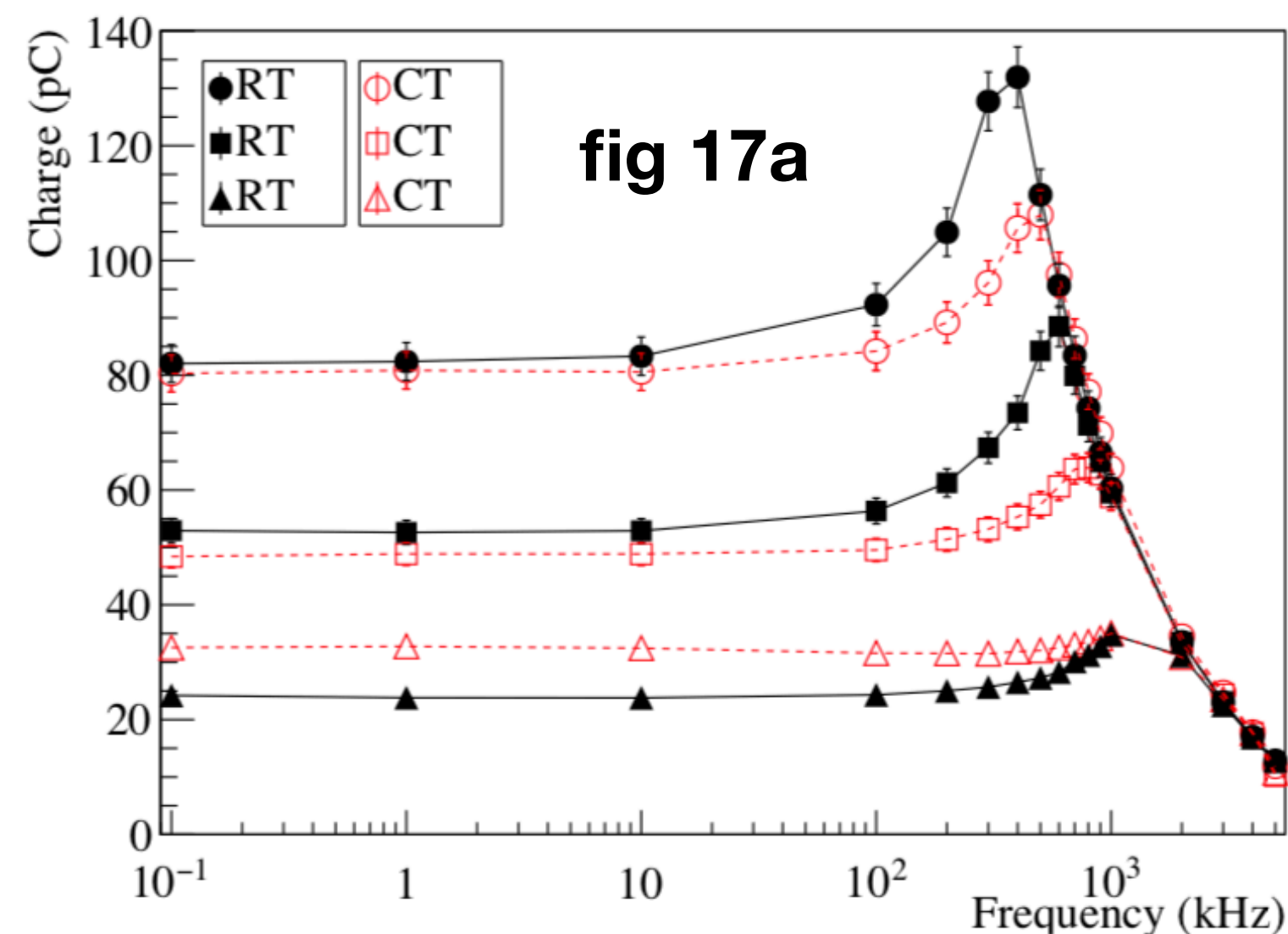
◆ Improvements in the S1 identification algorithm as well! Basically, if a S1 signal is found, a *variable window* afterwards is ignored for the S1 search! (up to **max_window_no_S1**)

- *variable window (us)* = **0.07** (us/ADC) x S1 amplitude (ADC)

(*) Optimal value: 150 us

Cryogenic R5912-20Mod photomultiplier tube characterization for the ProtoDUNE dual phase detector

D. Belver et al 2018 JINST 13 T10006



Comments:

- Linear response is expected up to ~ 200 PE at CT, $G=1e7$ (low frequency)
- Linear response is expected up to ~ 100 kHz at CT, $G=1e7$ for 50 PE (80 pC)