SPE background measurements in ProtoDUNE-DP

update!

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DPPD meeting, 03-03-2020

Ciemat   DUNE

Motivation & goals

✦ **Background sources/contributions at SPE level:**

- **PMT dark current:** expectation from characterization: *~2 kHz at G=1e7, JINST 13 (2018) T10006*

- **Activity of Ar-39, Ar-42**: expectation? Dedicated simulations are requiered

✦ A very low noise level in waveforms is essential to identify SPE pulses: **pedestal RMS = 0.6 ± 0.1 ADC** ✓

✦ **Goals/tasks:**

- <u>Obtain the average SPE rate measured by the PMTs to understand the low-energy background in the detector that must be taken into account in other studies</u>

- Compare different detector conditions (fields on/off) & PMT gains & trigger modes & …

- Study the SPE rate stability in time

- PEN/TPB comparison

- Separate DC contribution (uncorrelated signals)

- Compare to simulations/estimations: measured vs expected (**urgent! priority right now!**)

✦ **PMT runs: random trigger & CRT trigger (next slide)**

PMT runs of interest

* PMT trigger runs could be used as well

Random trigger	#1625	#2041	#2605	#2606	#2652	#2653	#2680	#2681
Date	Oct18, 2019	Nov26, 2019	Feb11, 2020	Feb11, 2020	Feb17, 2020	Feb17, 2020	Feb24, 2020	Feb24, 2020
Fields	OFF	OFF	Grids, LEMs(*)	Grids, LEMs(*)	Ext. CRP1(**)	Ext. CRP1(**)	OFF	OFF
PMT gains	1e7 (20190912)	1e7 (20190912)	1e7 (20191126)	5e7 (20191126)	1e7 (20191126)	5e7 (20191126)	5e7 (20191126)	1e7 (20191126)
Time window	1 ms	16 us	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms
Sampling (ns)	16	16	16	16	16	16	16	16
#events (subruns)	30k (250)	500k (58)	20k (42)	20k (42)	20k (42)	10k (21)	20k (42)	10k (21)

(*) Grids (**6kV**,3.9kV,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.5kV across; <u>cathode and FFS off</u> (ext.+ampl. CRP1, no drift)

(**) Grids (**6kV**,3.9kV,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.4kV across, <u>cathode: 50 kV, FFS: 4.8 kV</u> (ext.+ampl. CRP1 + drift)

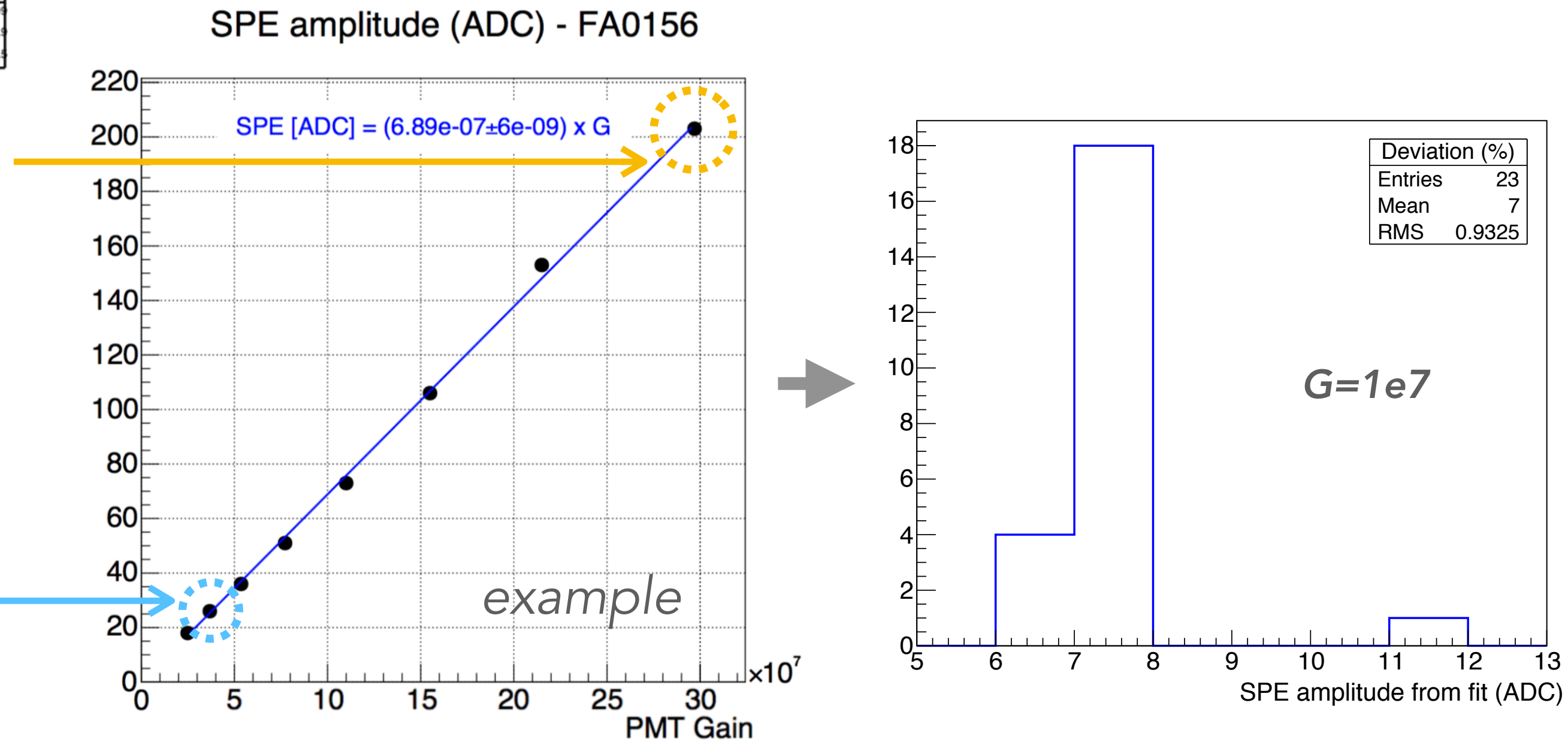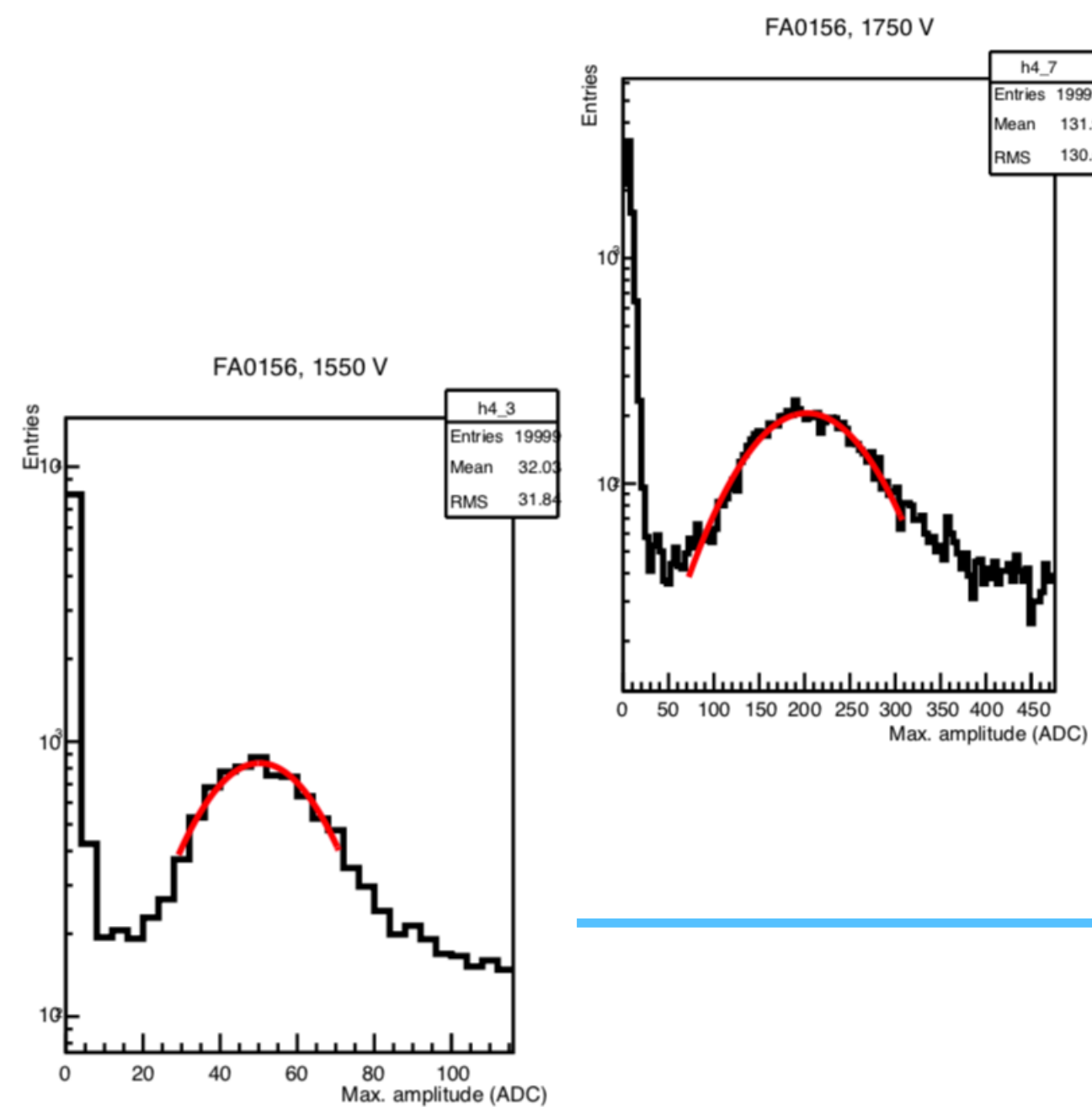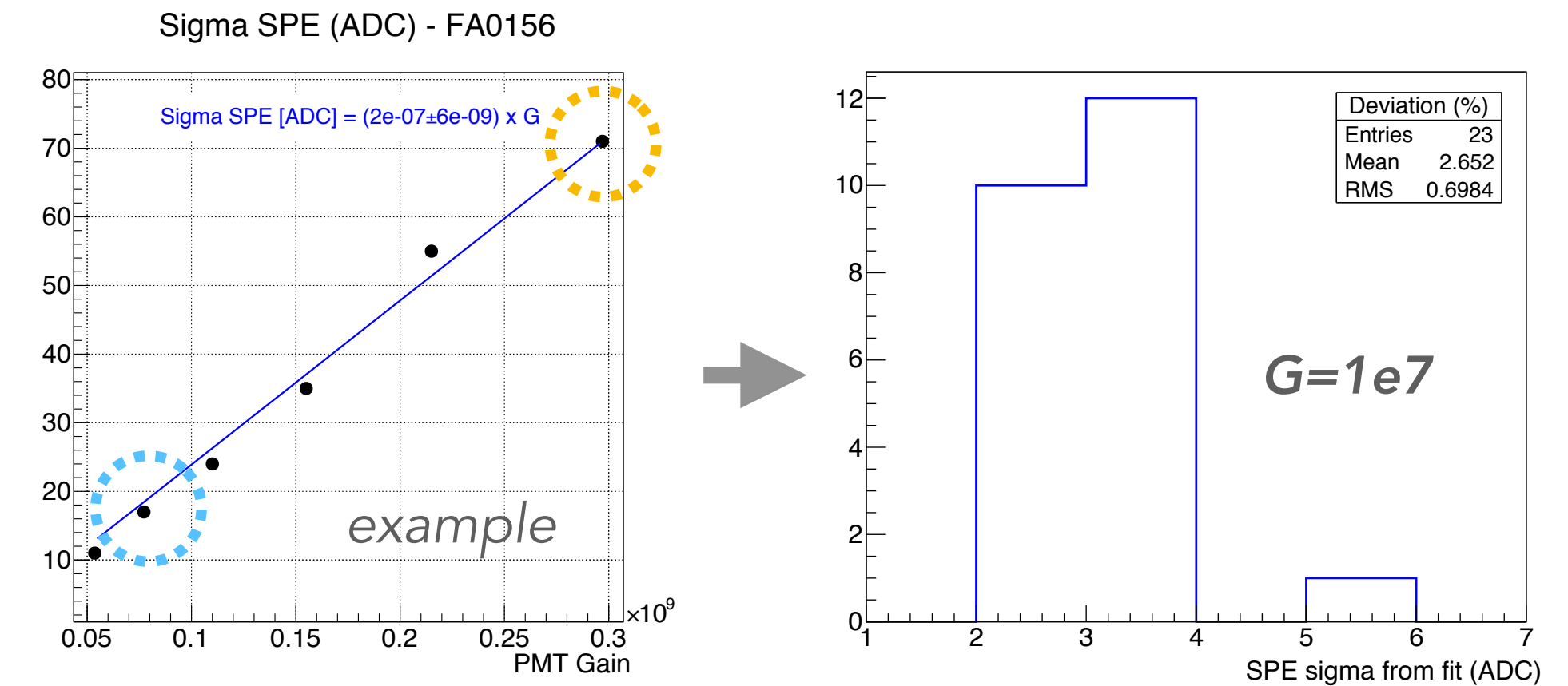| CRT & LCS	#2663	#2664	#2665	#2666	#2667	#2668
Date	Feb20, 2020	Feb20, 2020	Feb20, 2020	Feb20, 2020	Feb20, 2020	Feb20, 2020
Measurement	Gain calibration	CRT trigger	Gain calibration	CRT trigger	Gain calibration	CRT trigger
PMT gains	2e7 (20191126)	2e7 (20191126)	5e7 (20191126)	5e7 (20191126)	1e8 (20191126)	1e8 (20191126)
Time window	2 us	4 ms	2 us	4 ms	2 us	4 ms
Sampling (ns)	16	16	16	16	16	16
#events	20k	900	20k	900	20k	800

- **Feb 20, 2020**: Grids (**6kV,6.2kV**,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.4kV across; <u>cathode: 50 kV; FFS: 4.8 kV</u> (ext.+ampl. CRP1&2 + drift)

SPE definition

Reminder! (Jan2020 CM)

✦ **SPE amplitude characterization:**

- SPE amplitude extracted from data in LAr (G vs HV runs)
- Average SPE amplitude @ G=1e7: 7 ± 3 ADC
- **S/N > 11 for SPE @ G=1e7** (requirement for DUNE: S/N > 5)

Sigma SPE (ADC) - FA0156

Sigma SPE [ADC] = (2e-07±6e-09) x G

example

G=1e7

SPE amplitude (ADC) - FA0156

SPE [ADC] = (6.89e-07±6e-09) x G

example

G=1e7

SPE identification & counting

✦ **SPE counting algorithm:**
- pedestal = 20 first samples with 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, SPE = 7 ± 3 ADC, S1 > 21 ADC, min_SPE = 4 ADC, max_SPE = 10 ADC
- Example #2: G=5e7, SPE = 35 ± 15 ADC, S1 > 105 ADC, min_SPE = 20 ADC, 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)

(*) Scan on window_no_SPE values in next slide

✦ **Scan on window_no_SPE values:**

- Run #2681: random trigger, 1e7, fields off, 36 PMTs, ~2k events (2 s in total)
- Old ignored window: 16 us
- **New ignored window (optimal): 150 us (minimum rate for 100-150 us)**
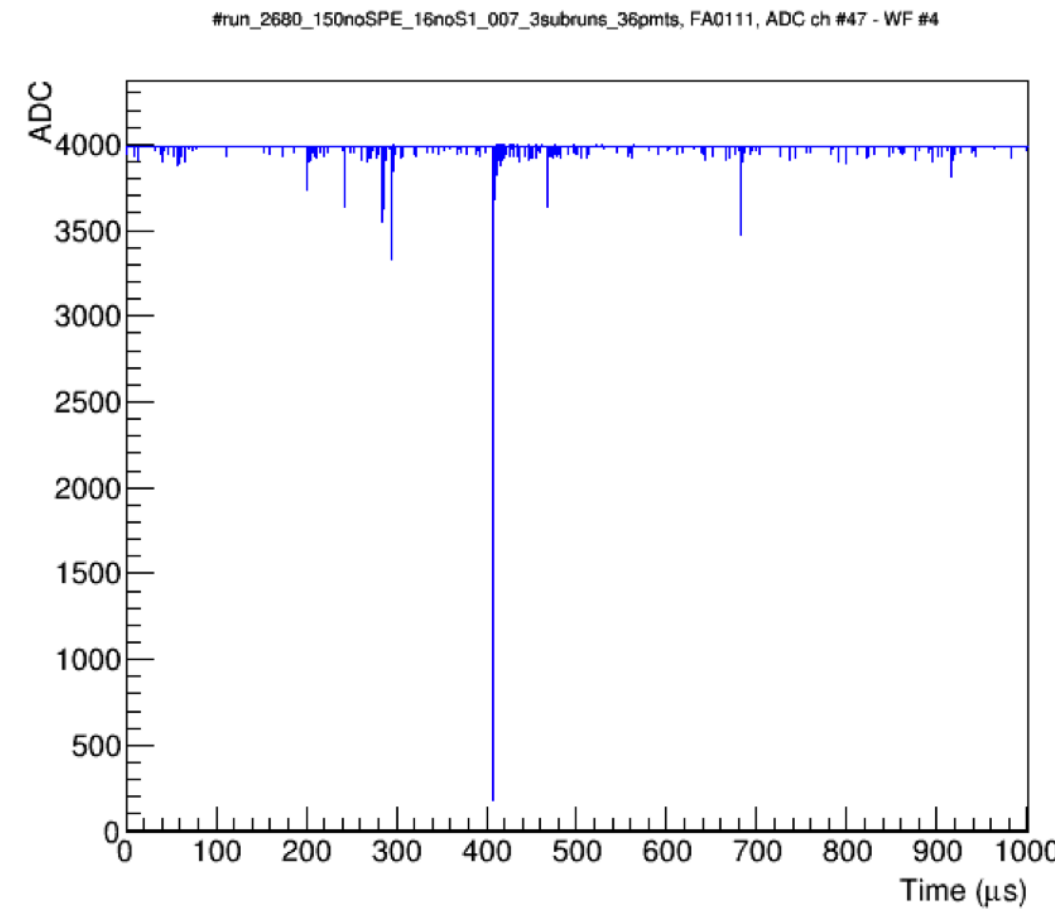- Compromise: less SPE signals from previous S1 but enough statistics
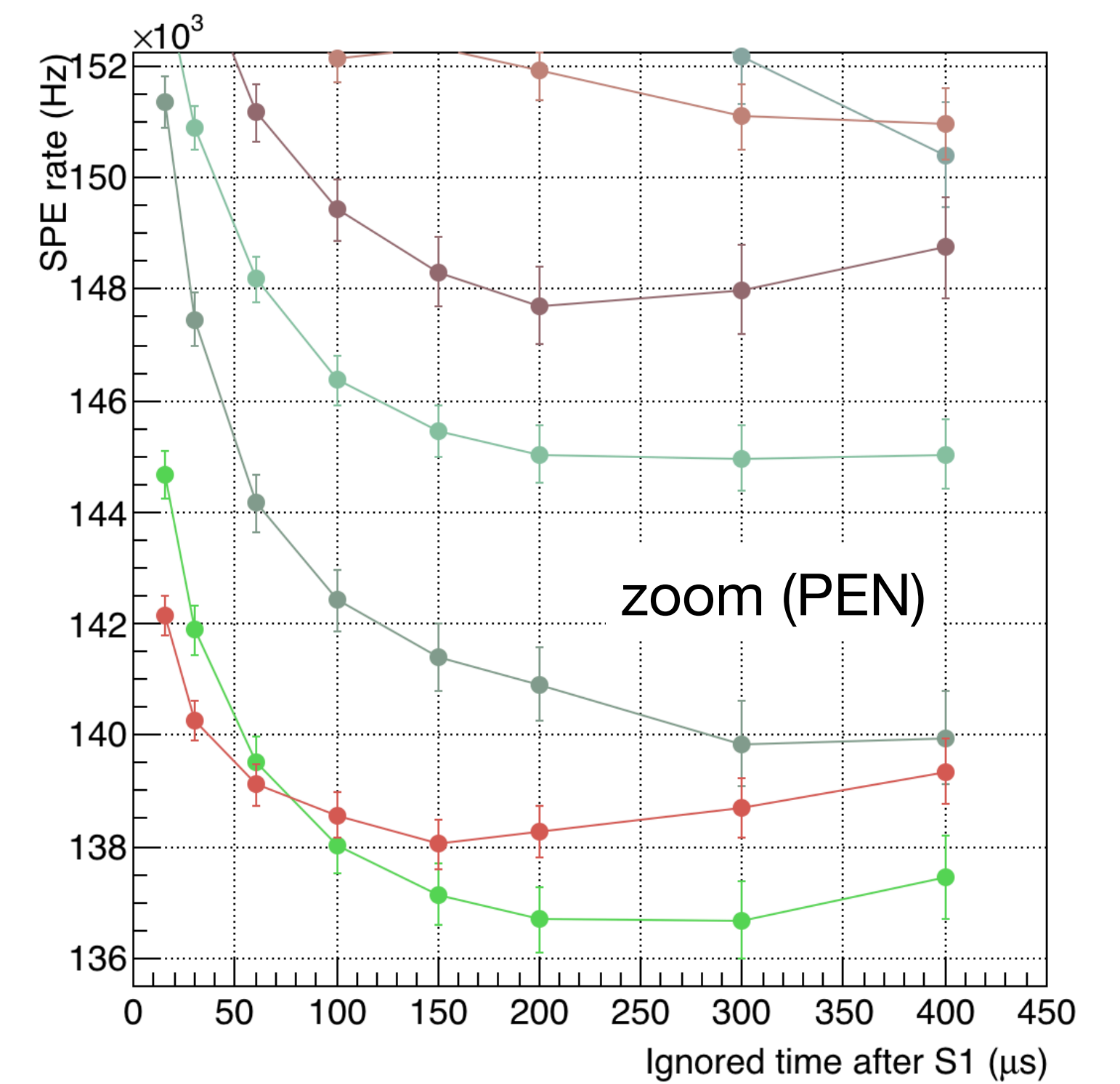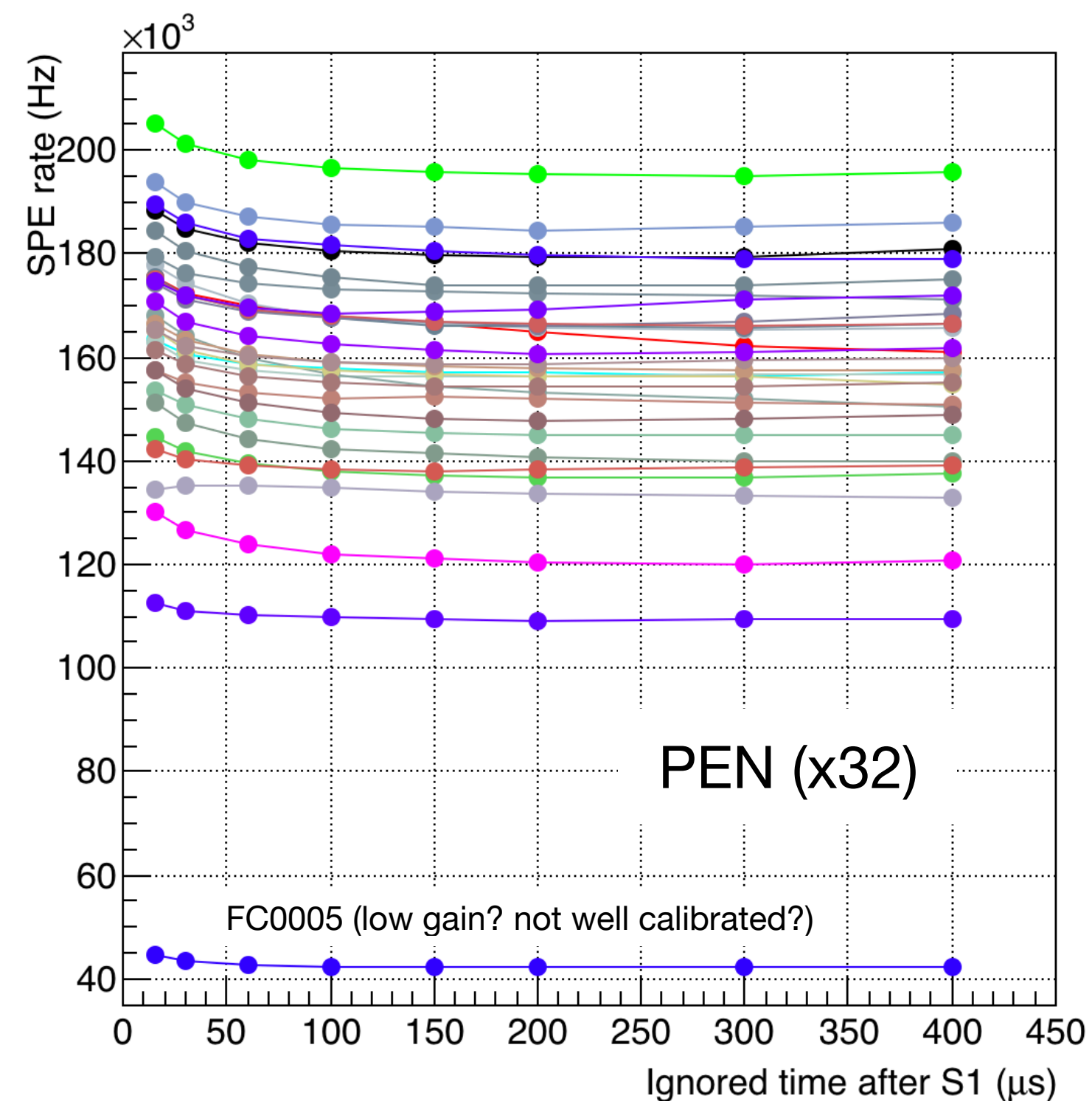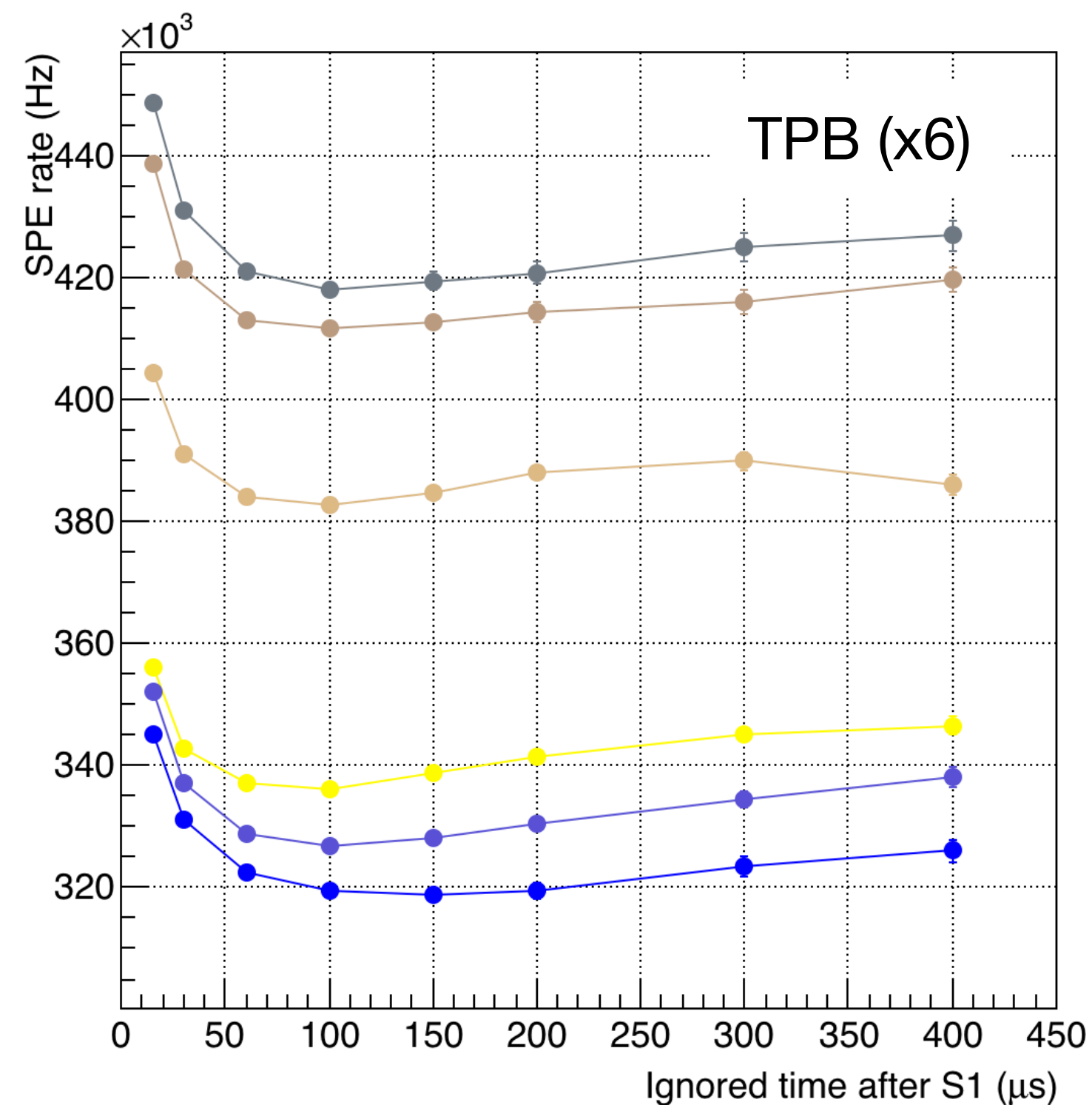
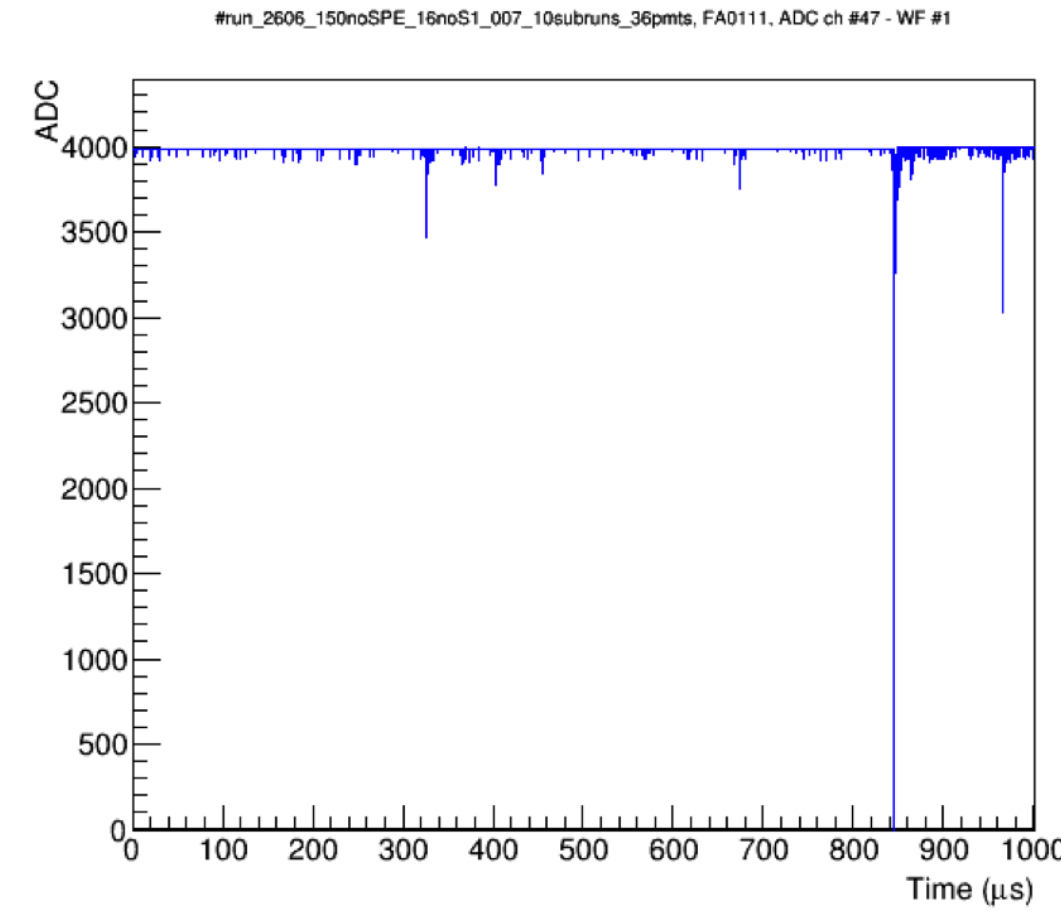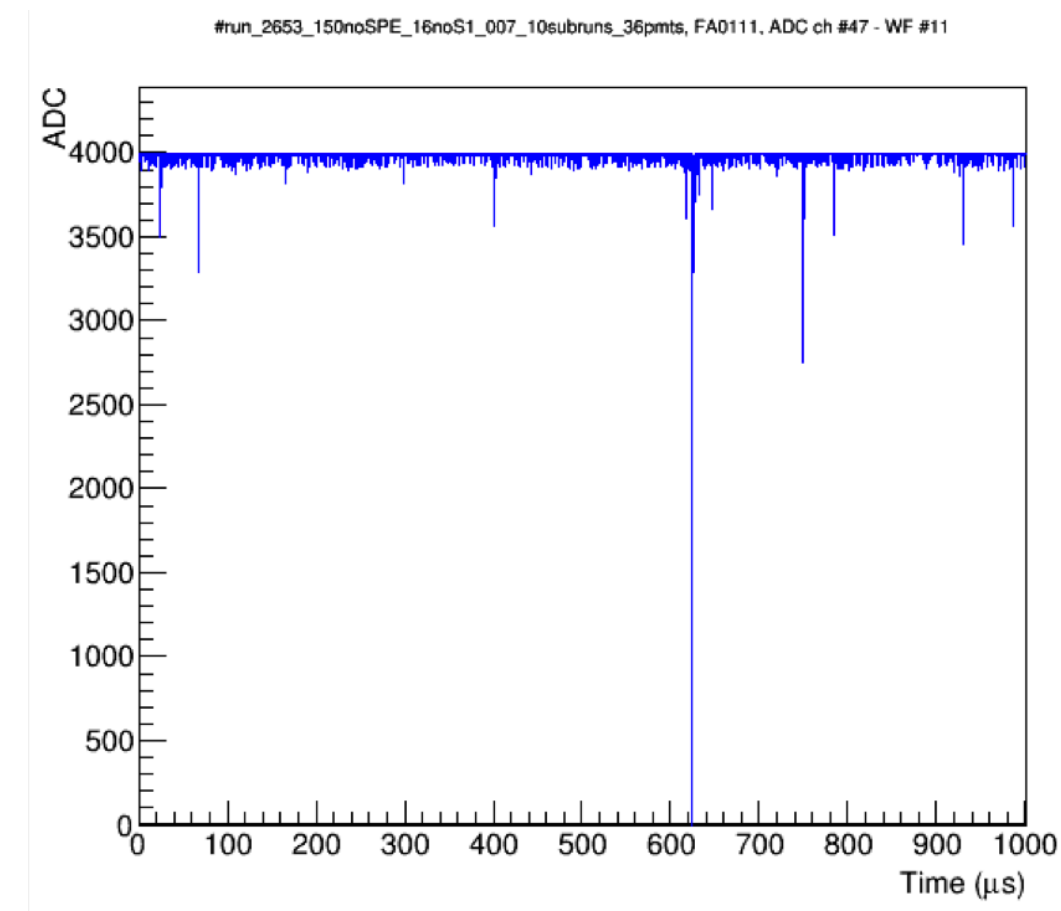# SPE background analysis

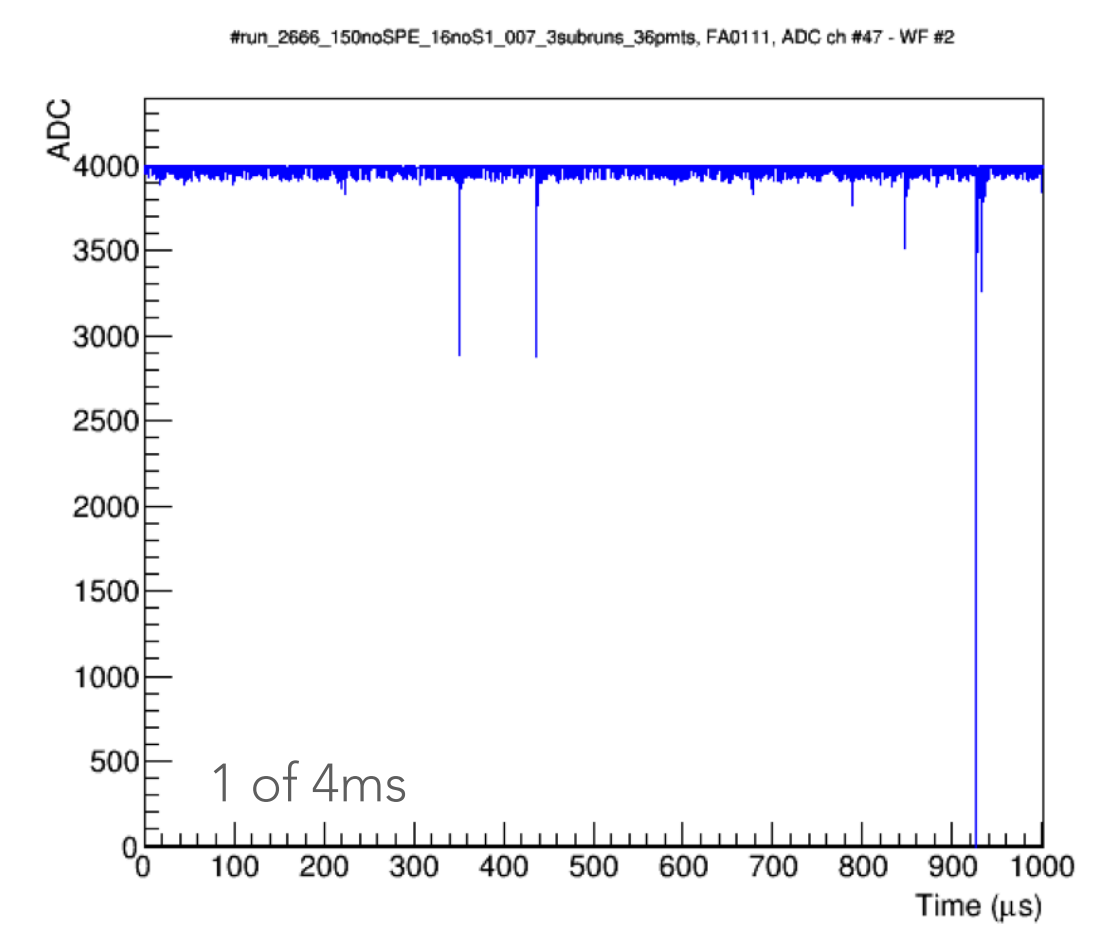**Random trigger runs**

PMT gains: 5e7

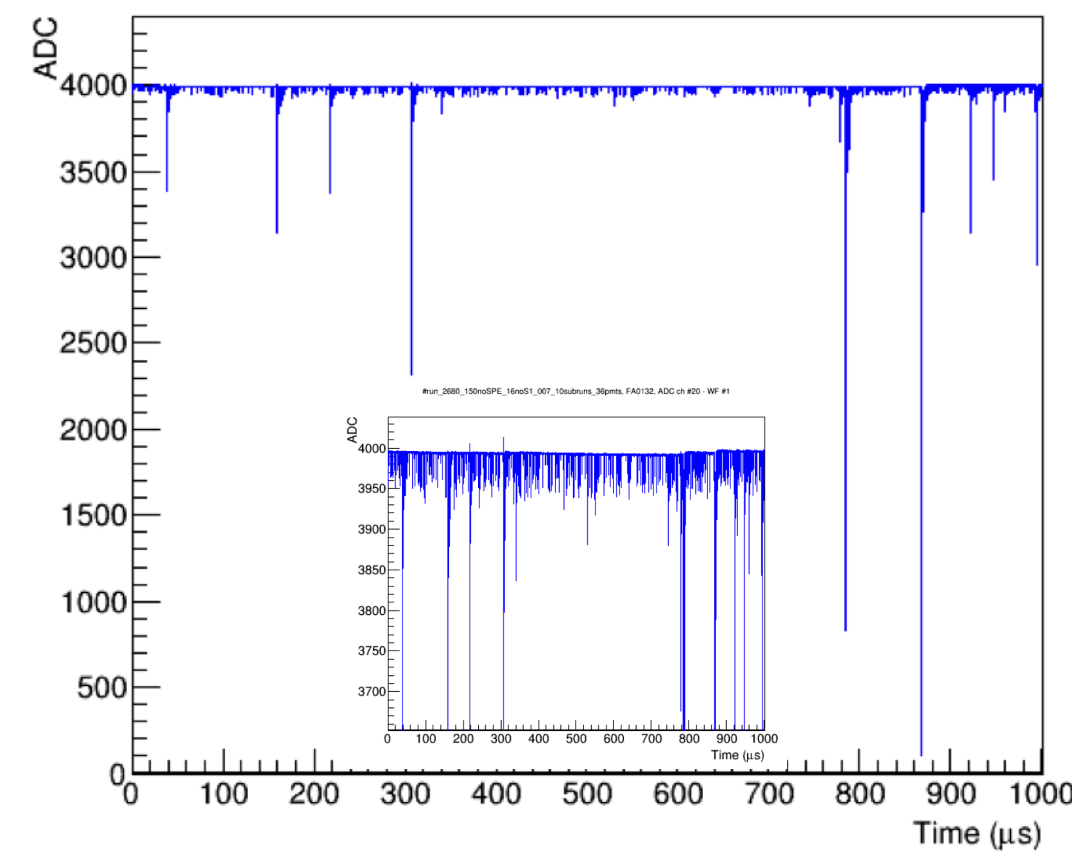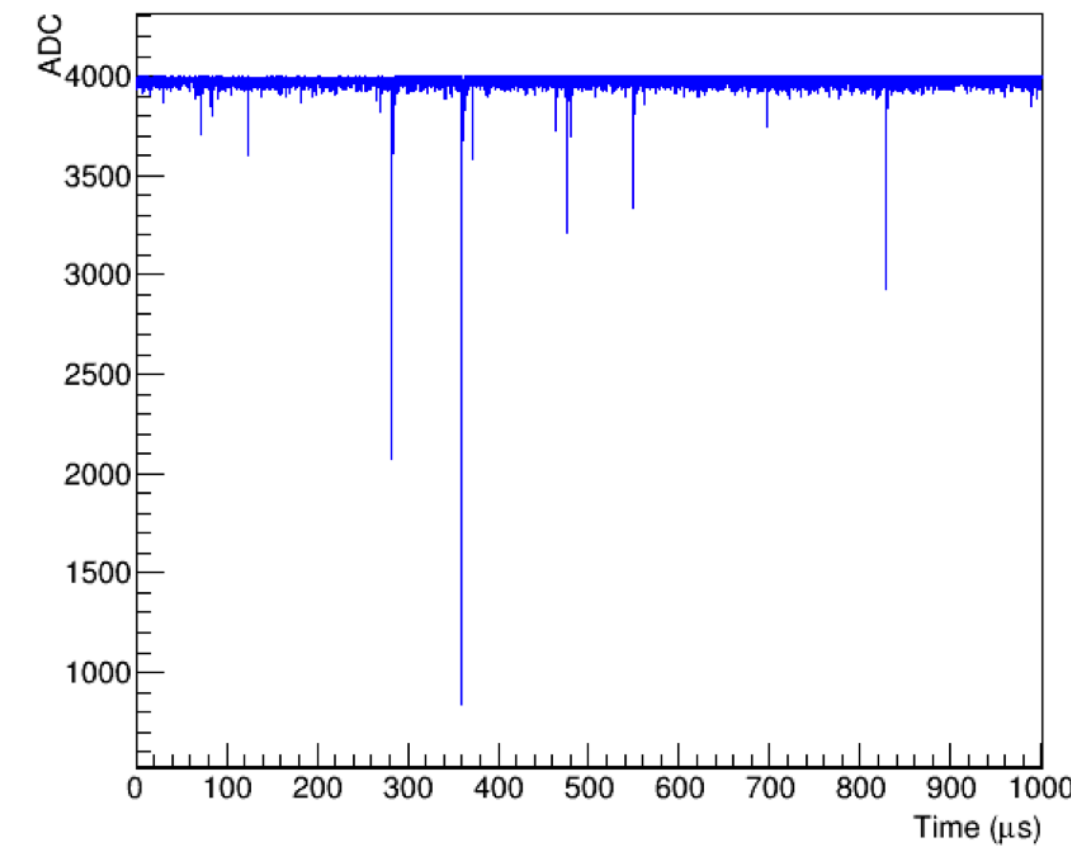| No fields (#2680) | Grids&LEMs (#2606) | Ext. CRP1 (#2653) | Ext. CRPs1&2 (#2666) |

PEN PMT (FA0111)

TPB PMT (FA0132)

Random trigger runs   PMT gains: 5e7

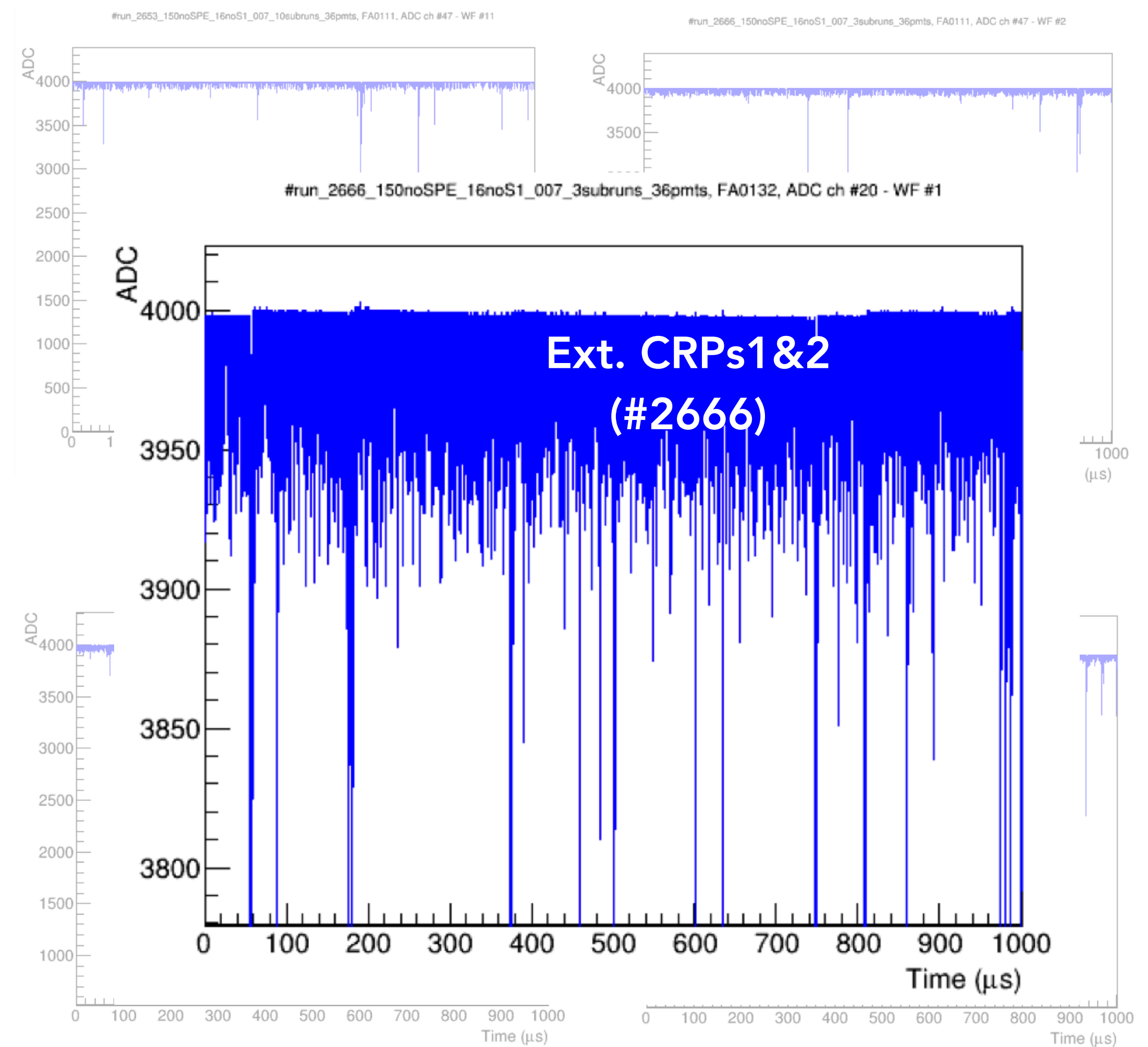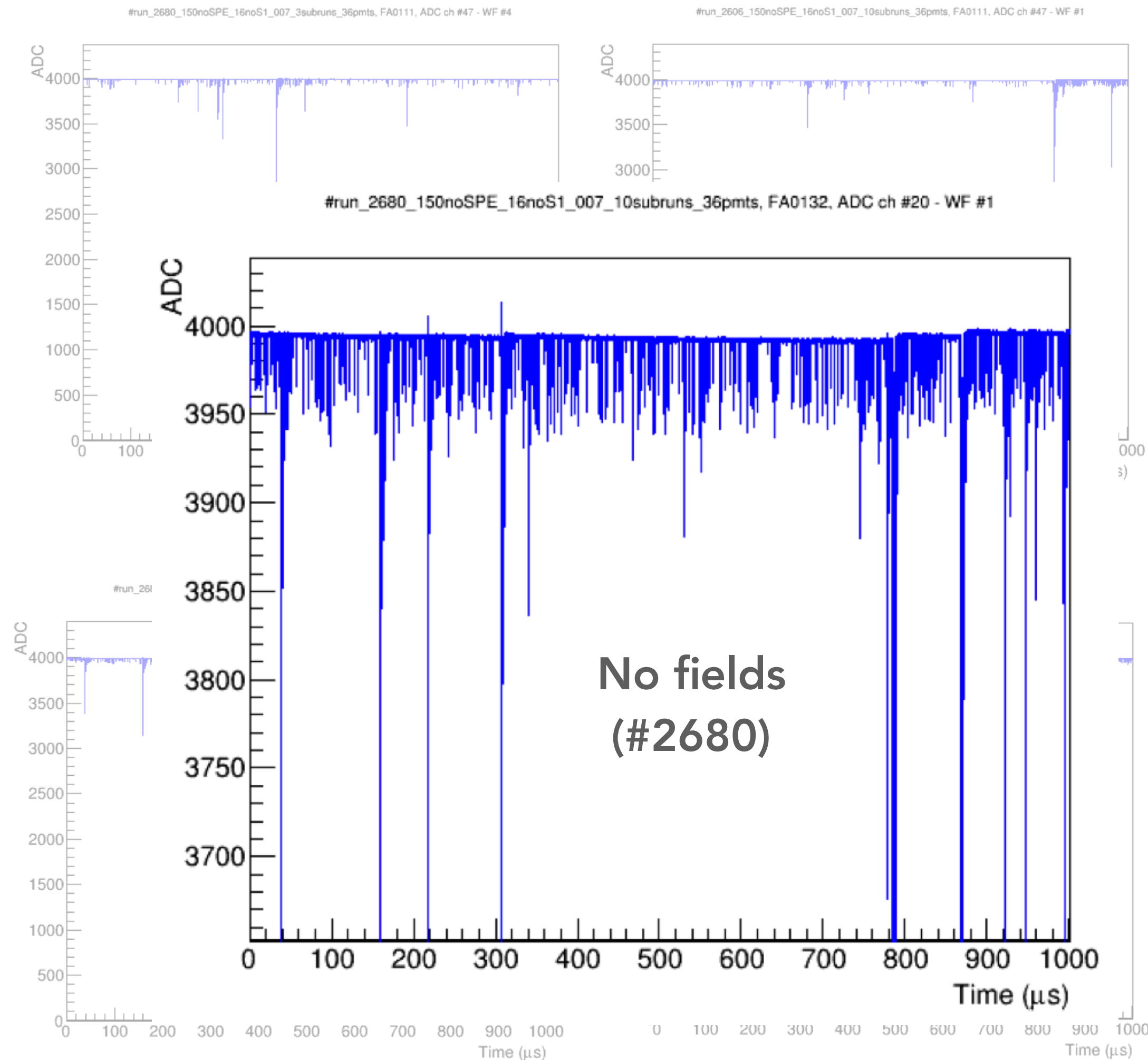No fields (#2680)   Grids&LEMs (#2606)   Ext. CRP1 (#2653)   Ext. CRPs1&2 (#2666)

**PEN PMT
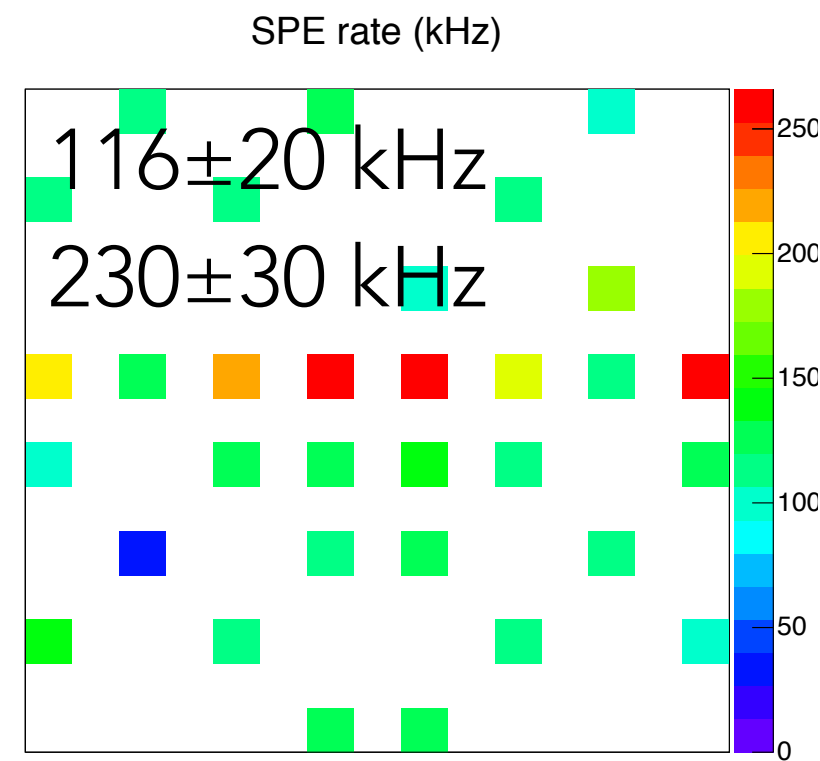(FA0111)**

**TPB PMT
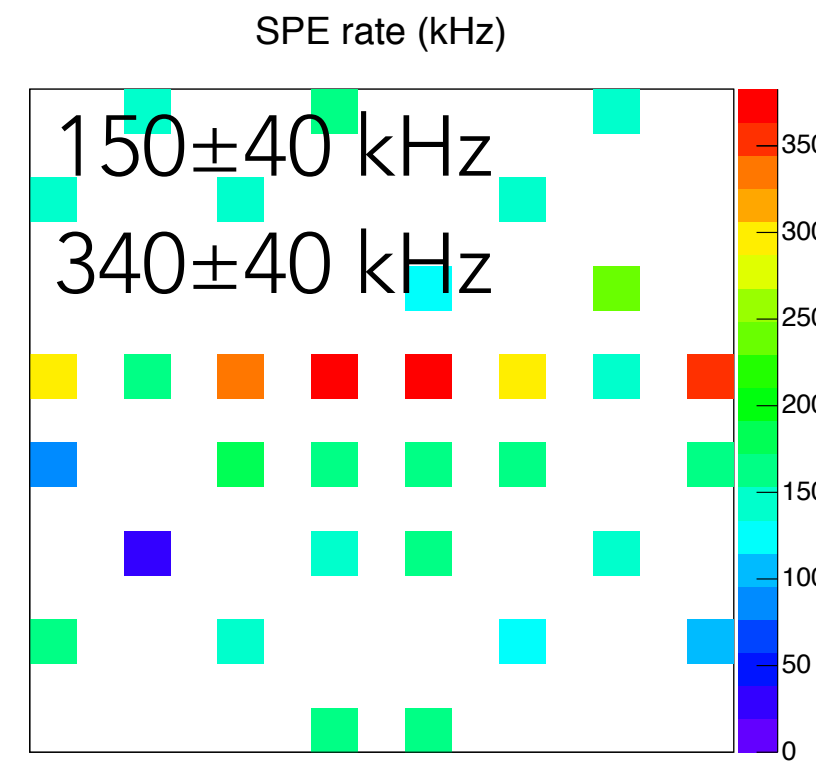(FA0132)**

`Random trigger runs` `PRELIMINARY!`

✦ **#1625 (18Oct, no fields)**
- G = 1e7 (20190912)
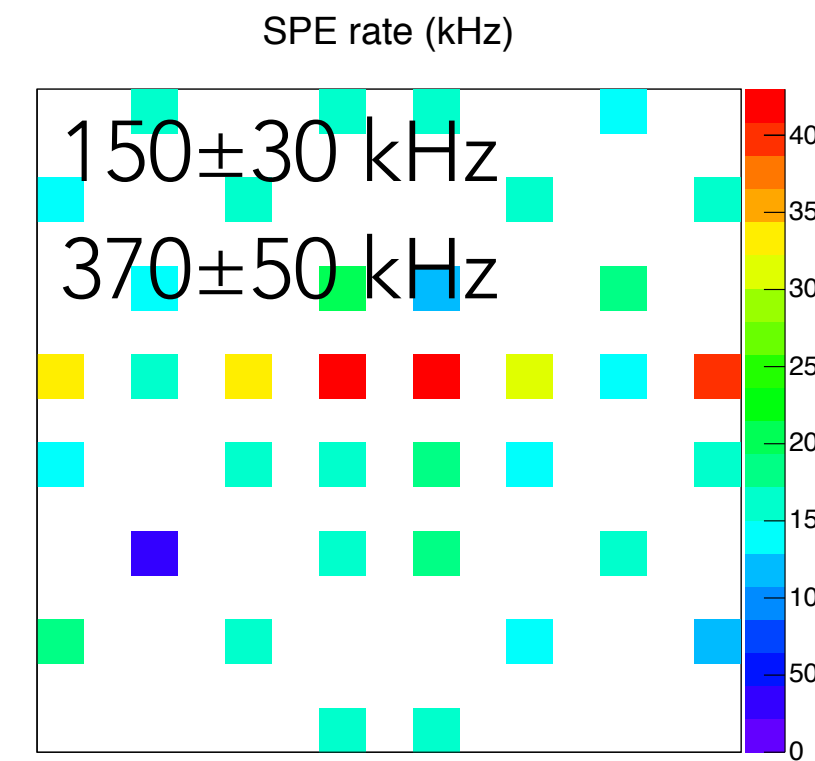- Time: 4.6 s (40 files)

✦ **#2041 (26Nov, no fields)**
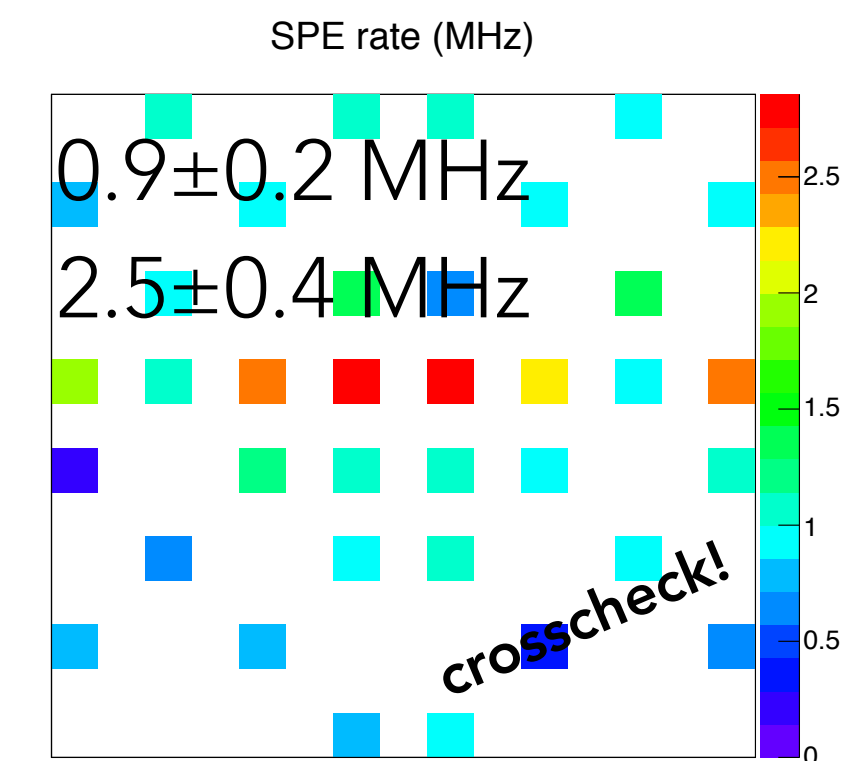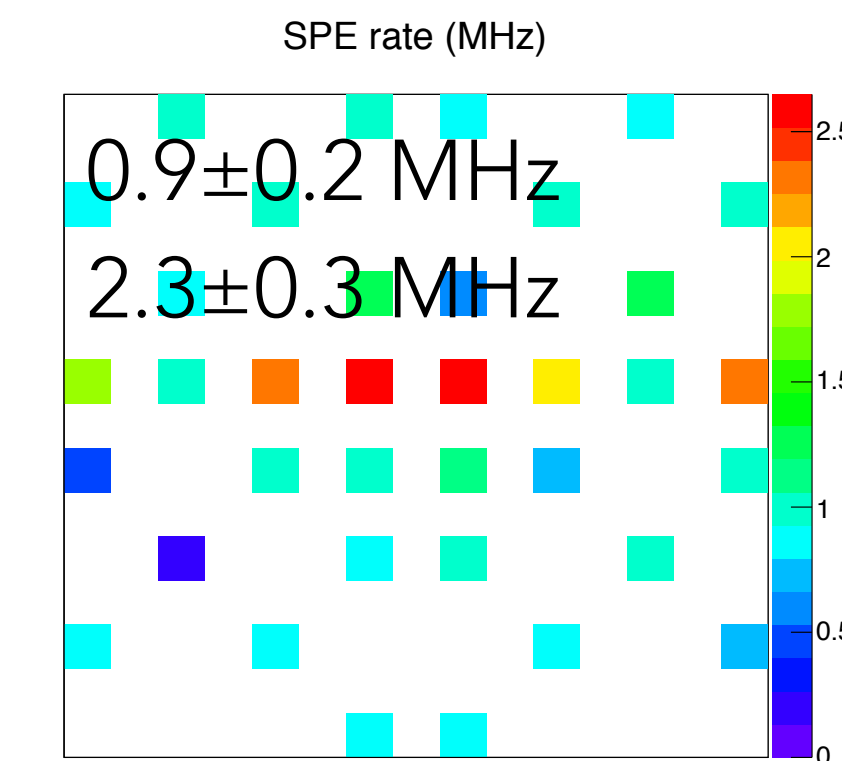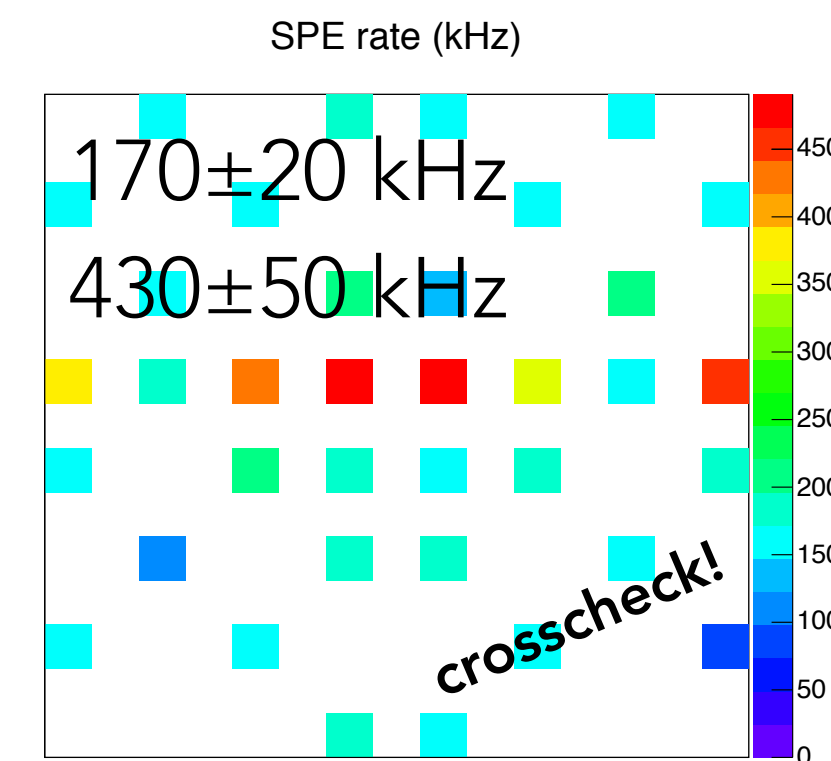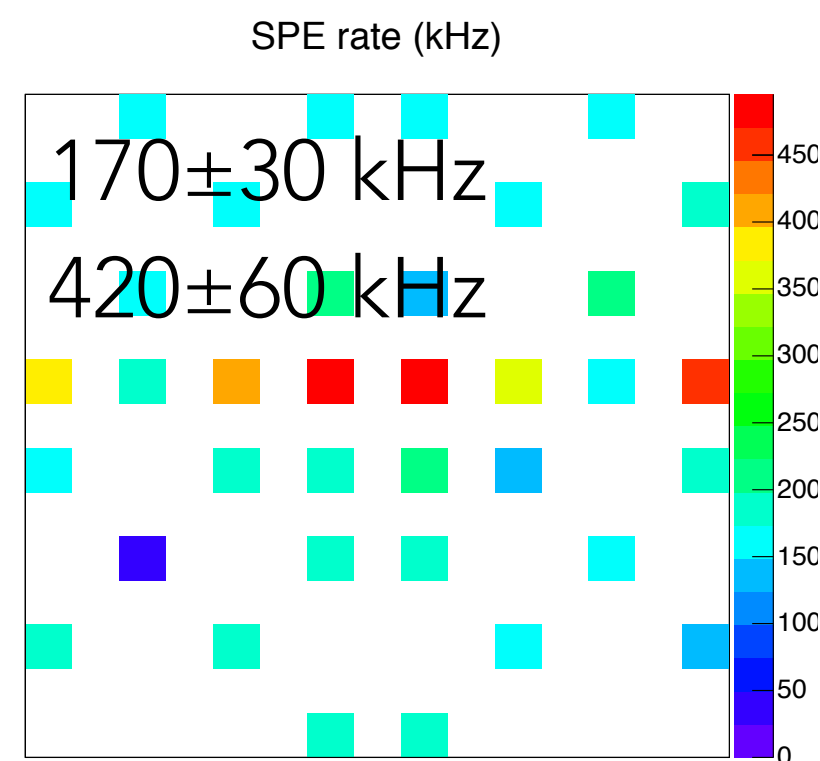- G = 1e7 (20190912)
- Time: 5.5 s (40 files, 16us)

✦ **#2681 (24Feb, no fields)**
- G = 1e7 (20191126)
- Time: 5.2 s (10 files)

✦ **#2680 (24Feb, no fields)**
- G = **5e7** (20191126)
- Time: 4.8 s (10 files)

SPE rate (kHz)

116±20 kHz
230±30 kHz

SPE rate (kHz)

150±40 kHz
340±40 kHz

SPE rate (kHz)

150±30 kHz
370±50 kHz

~

SPE rate (kHz)

160±20 kHz
380±40 kHz

crosscheck!

SPE rate (kHz)

170±30 kHz
420±60 kHz

~

SPE rate (kHz)

170±20 kHz
430±50 kHz

crosscheck!

SPE rate (MHz)

0.9±0.2 MHz
2.3±0.3 MHz

~

SPE rate (MHz)

0.9±0.2 MHz
2.5±0.4 MHz

crosscheck!
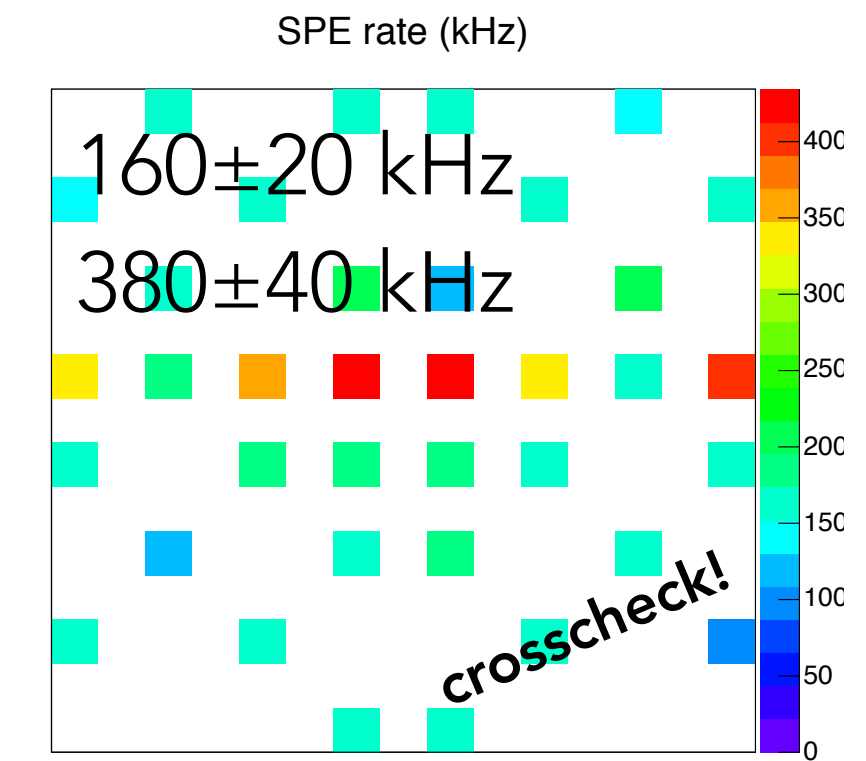
✦ **#2605 (11Feb, grids&LEMs)**
- G = 1e7 (20191126)
- Time: 4.8 s (10 files)

✦ **#2606 (11Feb, grids&LEMs)**
- G = **5e7** (20191126)
- Time: 4.8 s (10 files)

✦ **#2652 (17Feb, extr. CRP1)**
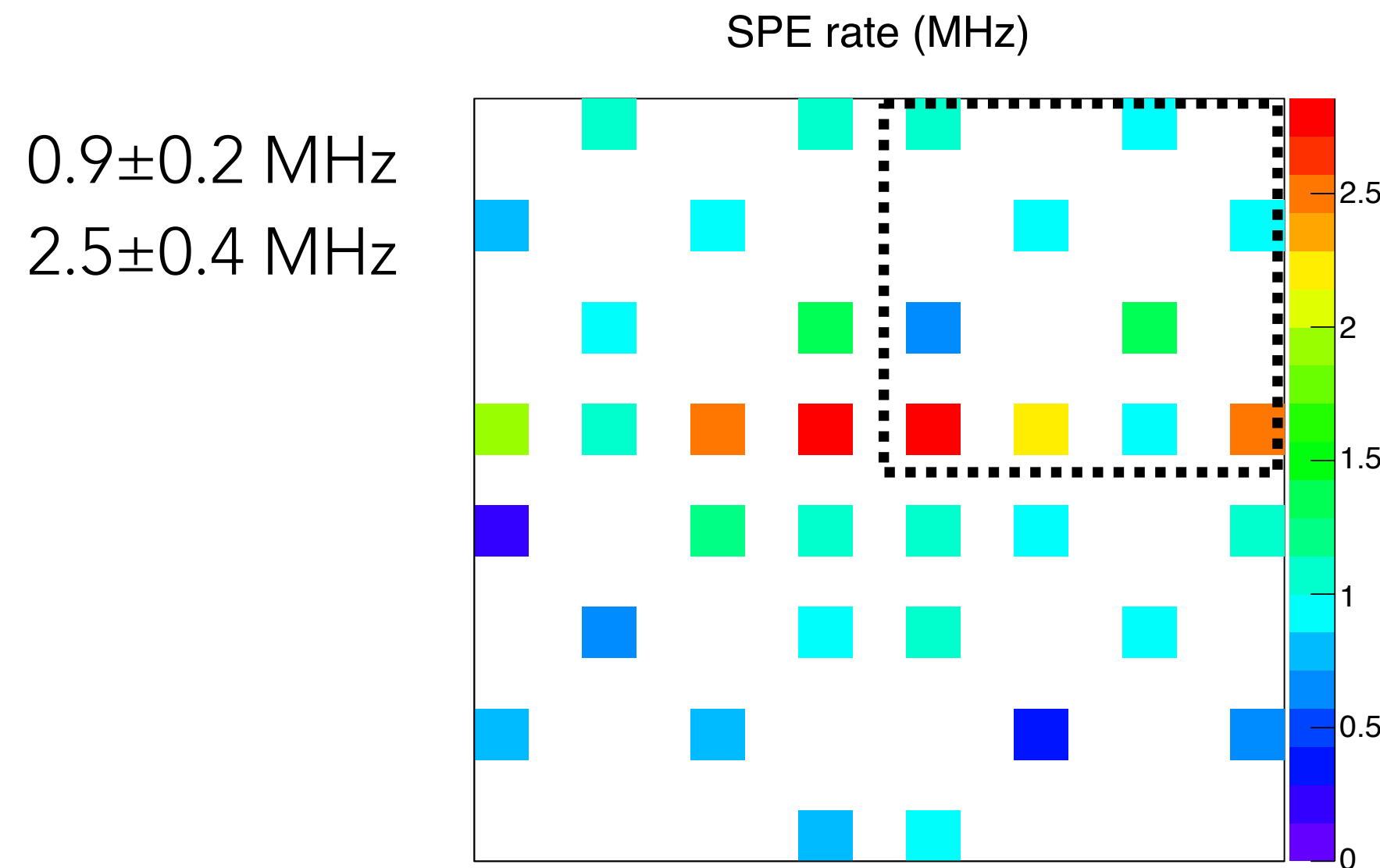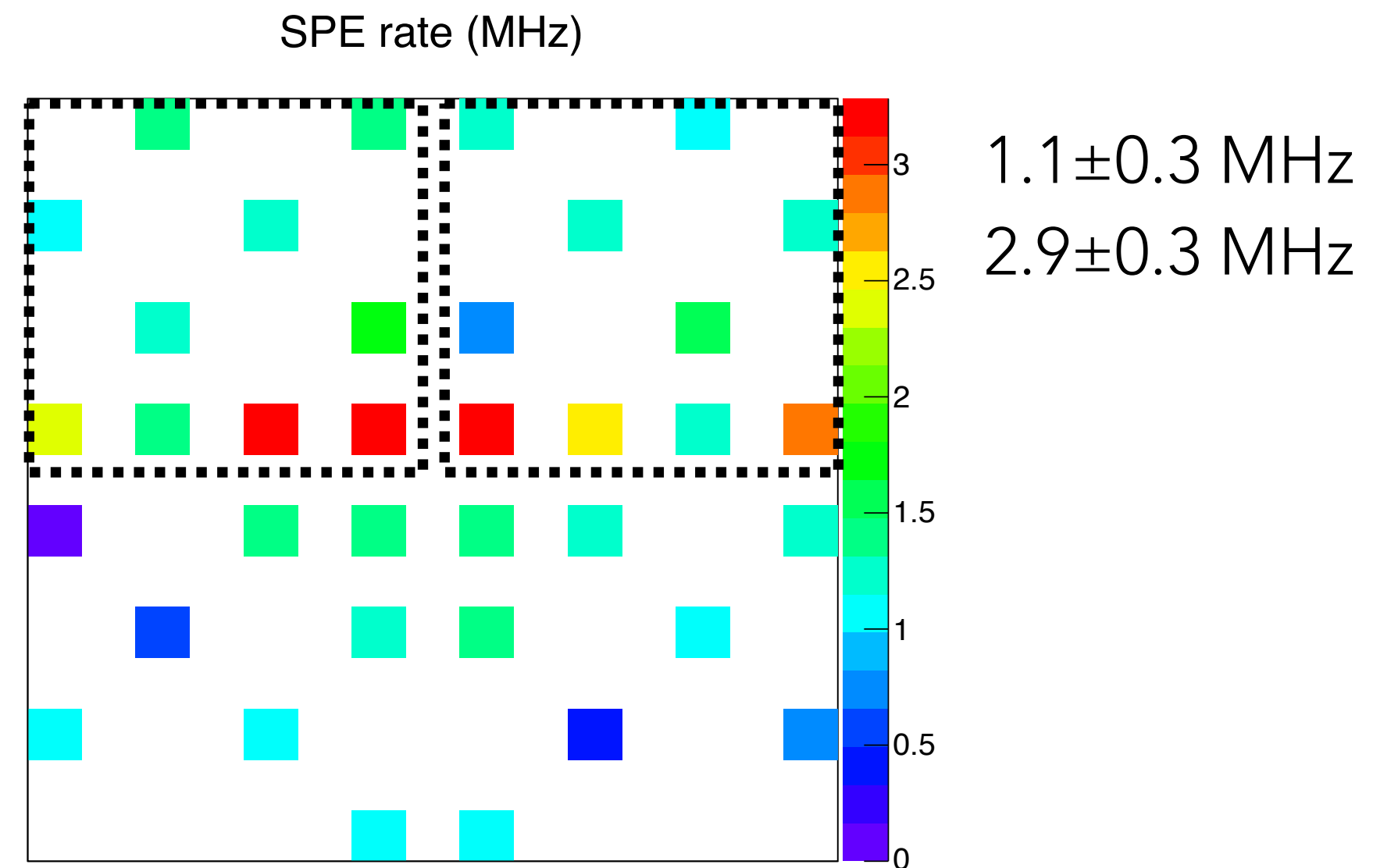- G = 1e7 (20191126)
- Time: 4.8 s (10 files)

✦ **#2653 (17Feb, extr. CRP1)**
- G = **5e7** (20191126)
- Time: 4.8 s (10 files)

SPE background analysis

Random vs CRT trigger **PRELIMINARY!**

SPE rate (MHz)   SPE rate (MHz)

0.9±0.2 MHz   1.1±0.3 MHz

2.5±0.4 MHz   2.9±0.3 MHz

✦ **#2653 (17Feb, ext.+amp. CRP1)**
  - Randon trigger
  - G = **5e7** (20191126)
  - Time: 4.8 s (10 files)

✦ **#2666 (20Feb, ext.+amp. CRPs1&2)**
  - CRT trigger
  - G = **5e7** (20191126)
  - Time: 1.9 s (3files)

✦The **rate increases ~20%** when both CRPs have extraction and amplification wrt only one CRP

✦The difference is not due to the trigger mode! Next comparisons will be done with same trigger
  (no runs available when this analysis was done…)

SPE background analysis

✦**SPE rate vs time under different field conditions:**

- Dots: random trigger; Stars: CRT trigger
- PMT gains: 1e7, 5e7
- Values in the plot: average+-RMS

PEN (x32)

TPB (x6)
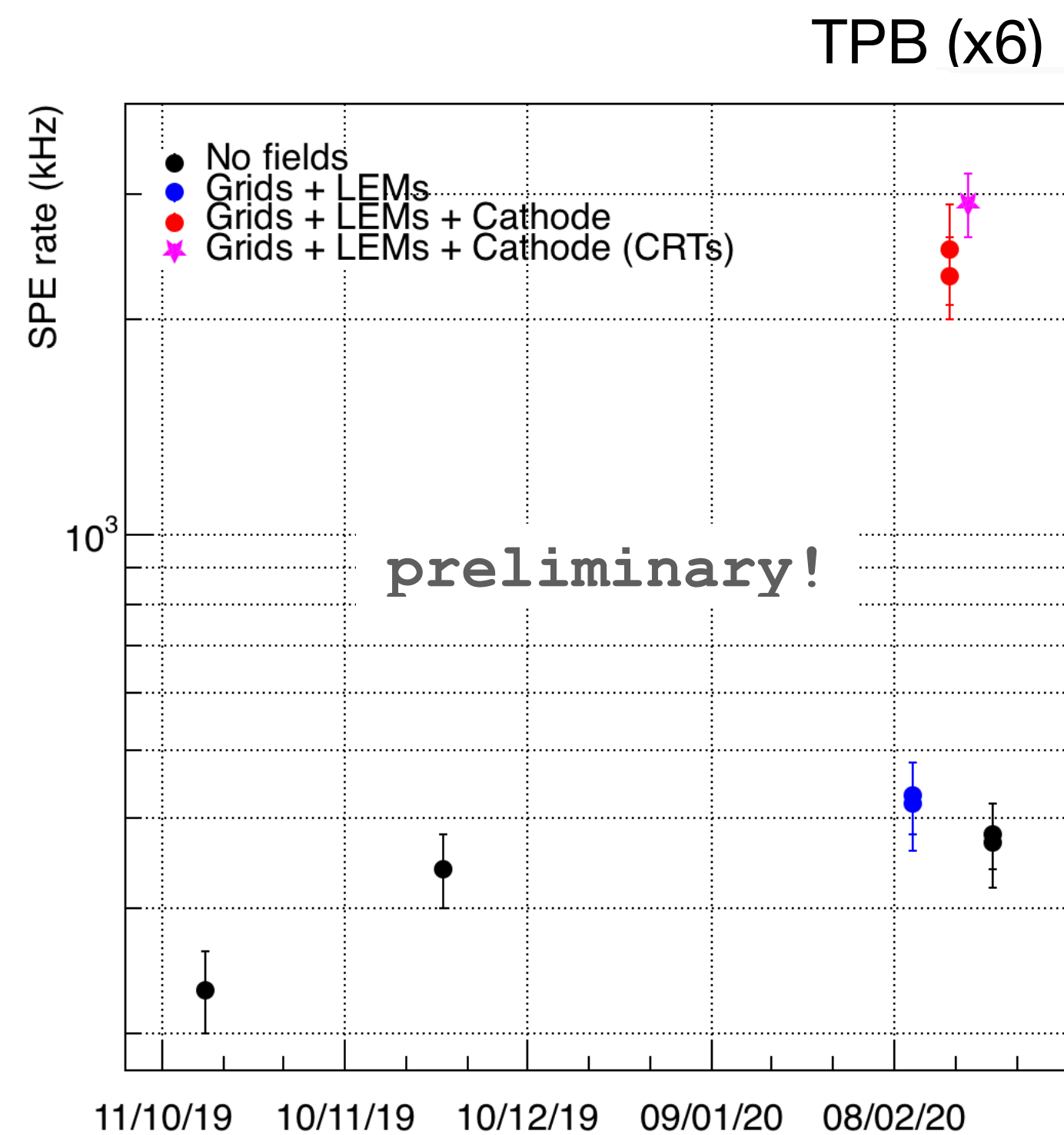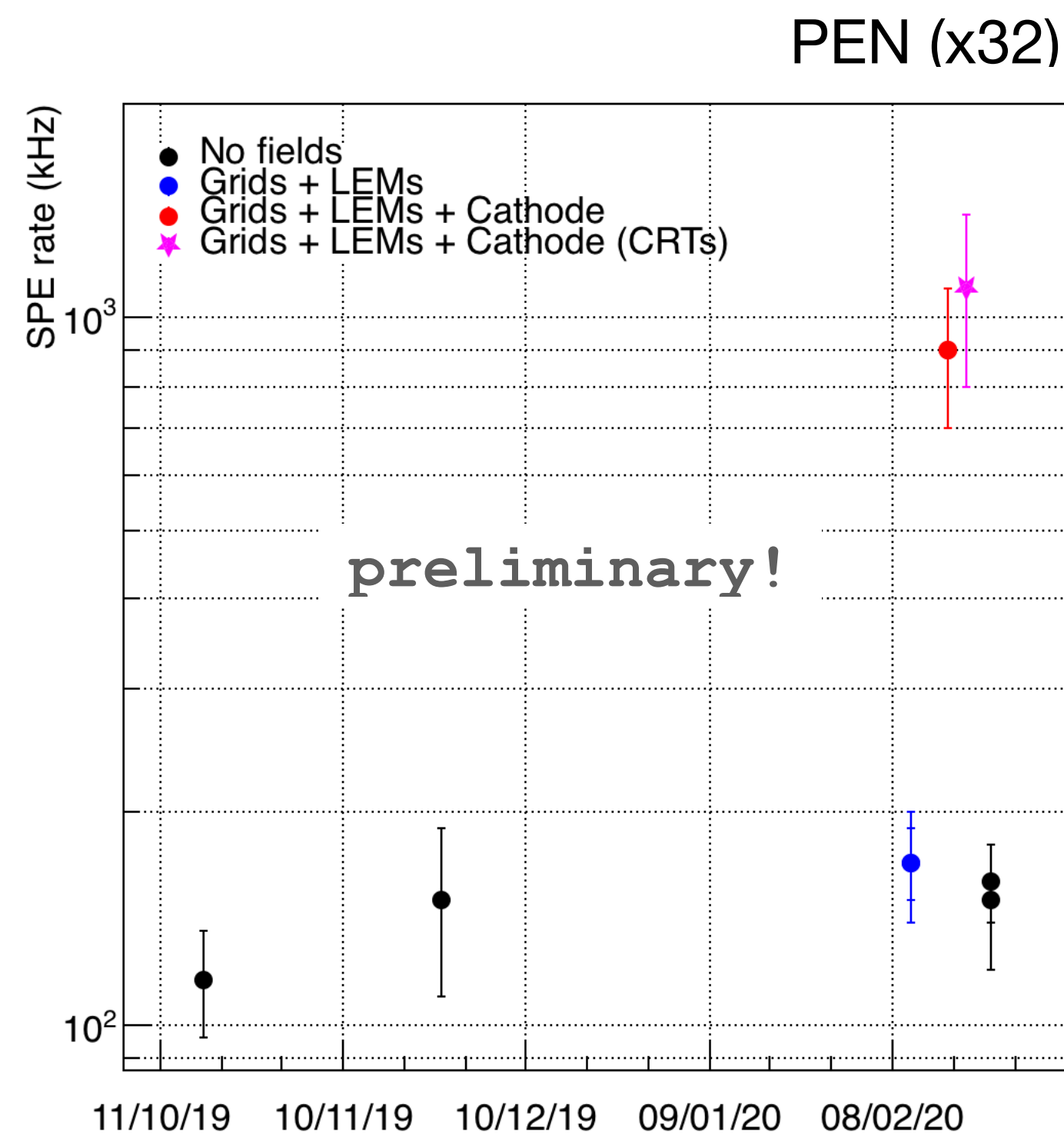
(*) Fields off
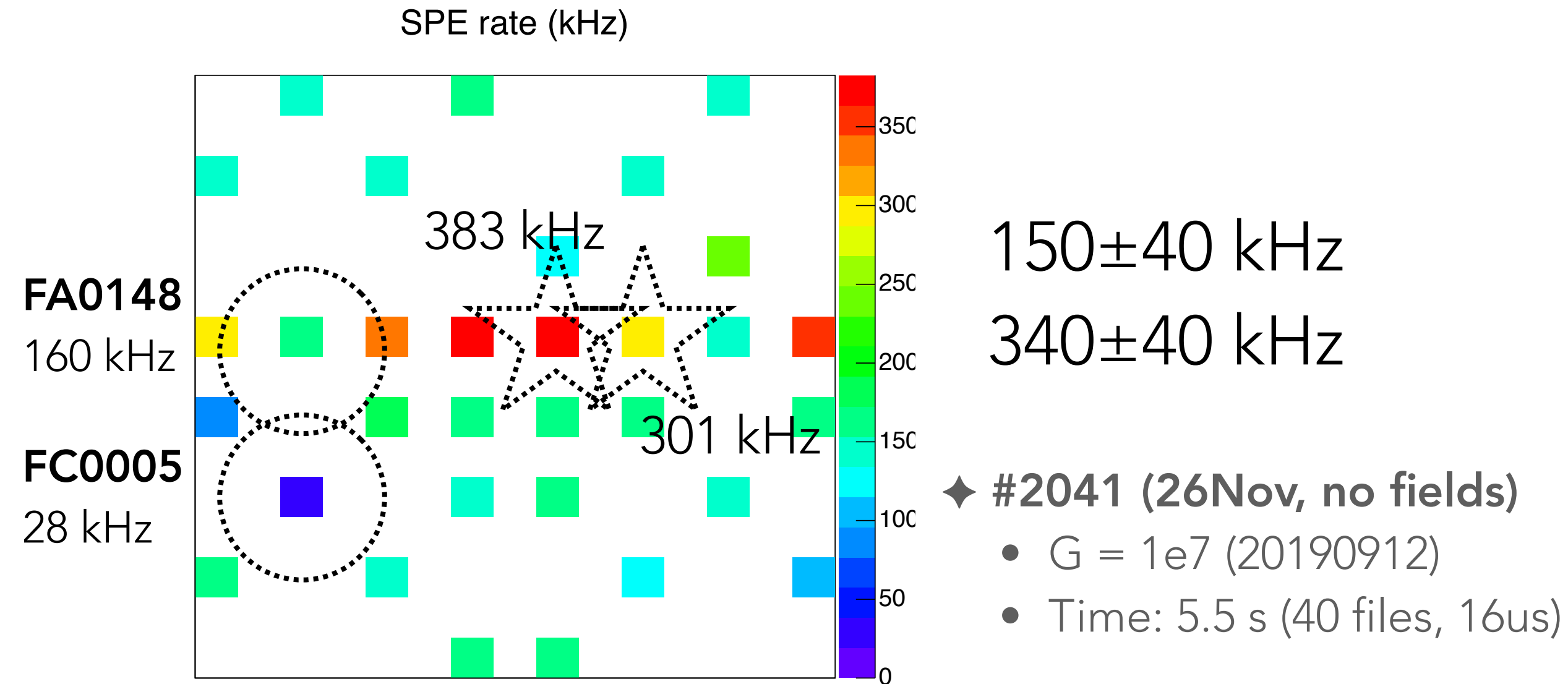
(**) Grids (**6kV**,3.9kV,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.5kV across; cathode and FFS off

(***) Grids (**6kV**,3.9kV,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.4kV across, cathode: 50 kV, FFS: 4.8 kV; only CRP1 extraction

(***) Grids (**6kV,6.2kV**,3.6kV,3.6kV); LEMs CRP1: 3.1kV across; LEMs CRP2: 3.4kV across, cathode: 50 kV, FFS: 4.8 kV; extraction in both CRPs

SPE background analysis

✦ **Comments / new approach:**

• The variations observed among PMTs are larger than expected (~25% for PEN, ~15% for TPB)

• The SPE definition (and hence the rate) is strongly dependent on the PMT gain

• We can determine the <u>SPE amplitude for each PMT using a calibration taken right before the run</u> and see if the rate distribution becomes more uniform (**this analysis is ongoing!**)

SPE rate (kHz)

383 kHz

FA0148
160 kHz

301 kHz

FC0005
28 kHz

150±40 kHz
340±40 kHz

✦ **#2041 (26Nov, no fields)**
• G = 1e7 (20190912)
• Time: 5.5 s (40 files, 16us)

Summary and next steps

✦ Different analyses on the low-energy background in ProtoDUNE-DP are being carried out.

✦ The impact of several conditions/factors has been studied: PMT gain, SPE and S1 definitions, detector conditions, trigger mode…

✦ **Next steps:**

- Look for uncorrelated SPE signals to extract the dark current contribution

- Include gain correction when it is possible (particular SPE amplitude for each PMT)

- Check whether the low-energy background results from data are compatible with simulations