# SPMT commissioning with small showers data

**Gioacchino Alex Anastasi,**
on behalf of the Torino group

*Online meeting Auger Italia, 06/05/2021*

# *Outline*

- ✦ SPMT on the field
- ✦ Small showers data from stations with pre-production UUBs
- ✦ The SPMT inter-calibration: where are we?
- ✦ SPMT simulation

# *SPMT on the field*

**Small showers acquisition,**
**stream to CDAS and transmission to Lyon**
**running smoothly since the end of November 2020.**

★ **79 SPMTs in the field with the new UUBs**

- ◉ 29 installed in December 2020 (pre-production array)
- ◉ 48 installed in March-April 2021 (pre-production array + EA)
- ◉ **2 used for tests : Trak** (id. 0020) & **Clais** (id. 0022)

★ **03/04/2021** : firmware update (necessary for small showers acquisition)

# SPMT cross-calibration data acquisition

Small showers selection by each station UUB

| | Variables | Size | Freq. |
|---|---|---|---|
| **EVENT info** | GPS time | 32 bit x 2 | **~200/h** (~300/h if a LPMT masked) |
| | event enumerator | 32 bit | |
| | **AREA_PEAK_SATUR x 6** (LPMT1-2-3 - sPMT - SSD LG-HG) | **32 bit x 6** | |
| **MUON info** | GPS sec | 32 bit | ~ 1 / min |
| | LPMT VEM charge x 3 | 16 bit x 3 | |
| | SSD MIP charge | 16 bit | |
| **DAQ info** | GPS sec | 32 bit | ~ 1 / 5 min |
| | LPMTs masked status | 16 bit | |
| | HG/LG ratio x 3 | 16 bit x 3 | |
| | LPMT threshold x 3 | 16 bit x 3 | |
| | online VEM calibration x 3 | 16 bit x 3 | |

Stream data every hour to CDAS

At CDAS level :

➡ small showers data-stream **reading**

➡ **storage** into “monitoring-like” ROOT files

Transfer data to Lyon every day

**Thanks to Ricardo for all the work on this item !**

**~ 7 kB / h**
**(~12 kB / h if a LPMT is masked) from each station**

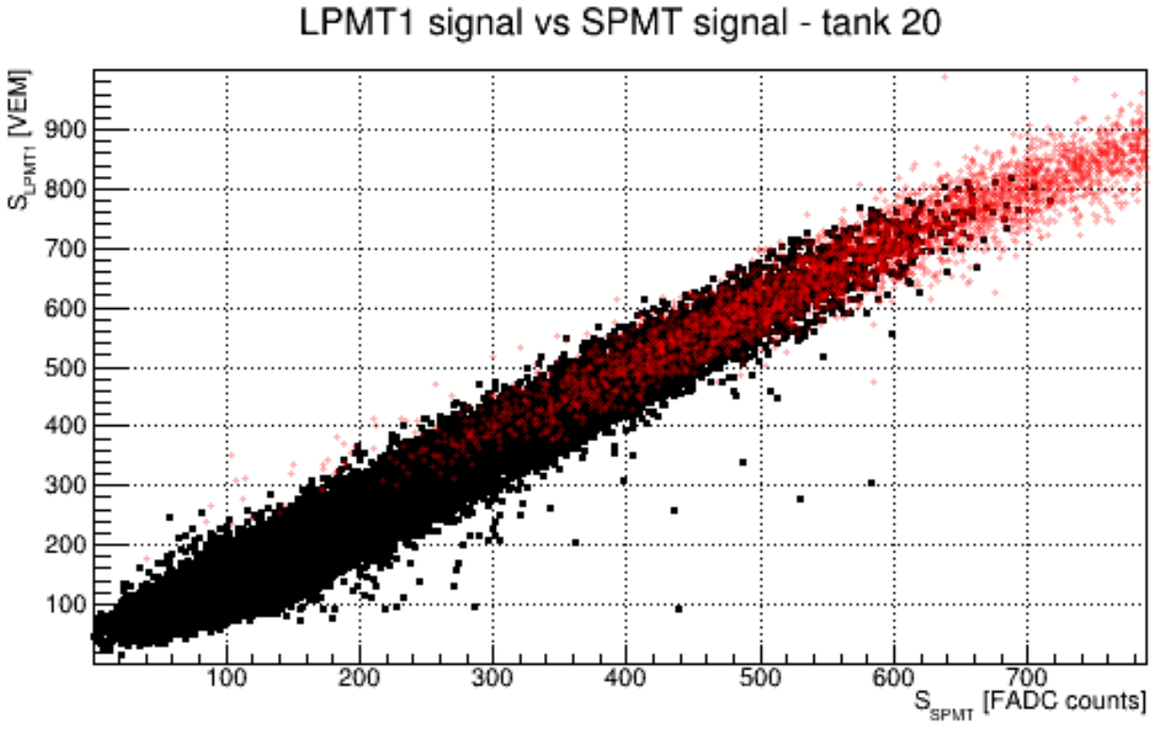
**Small showers selection and stream to CDAS activated** on:

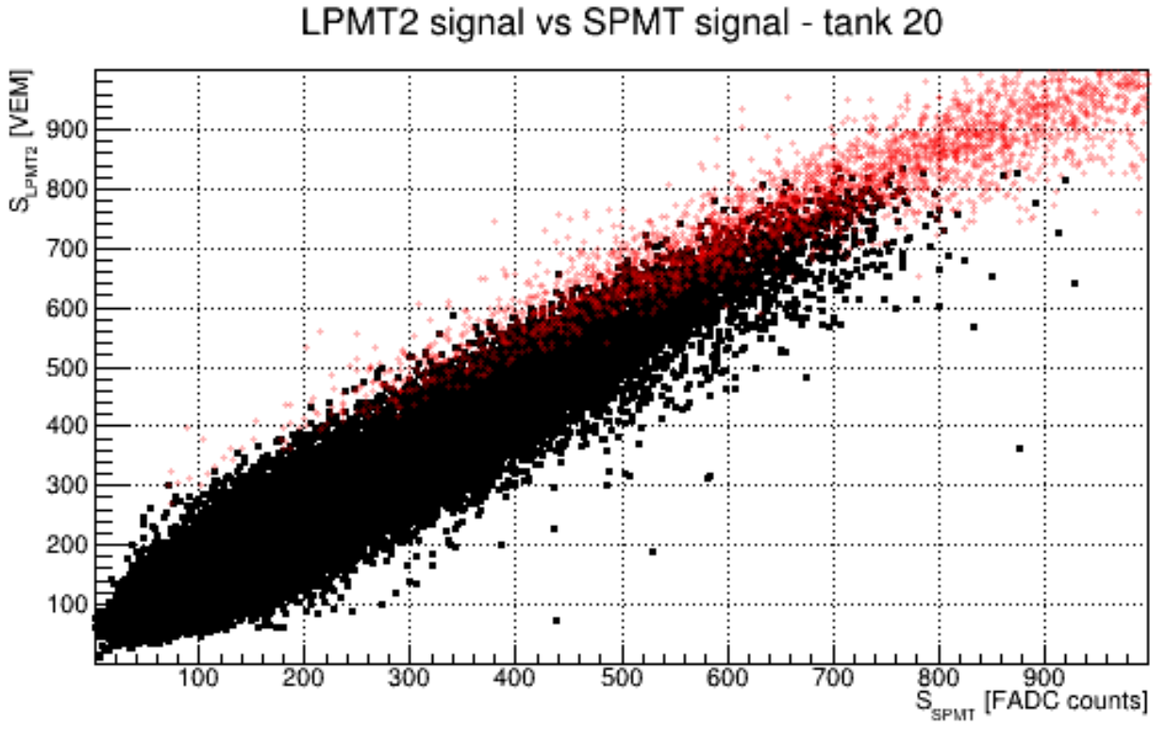
- Trak (2020/Oct/27)
- Clais (2020/Nov/02)
- all other UUB tanks (2020/Nov/05)

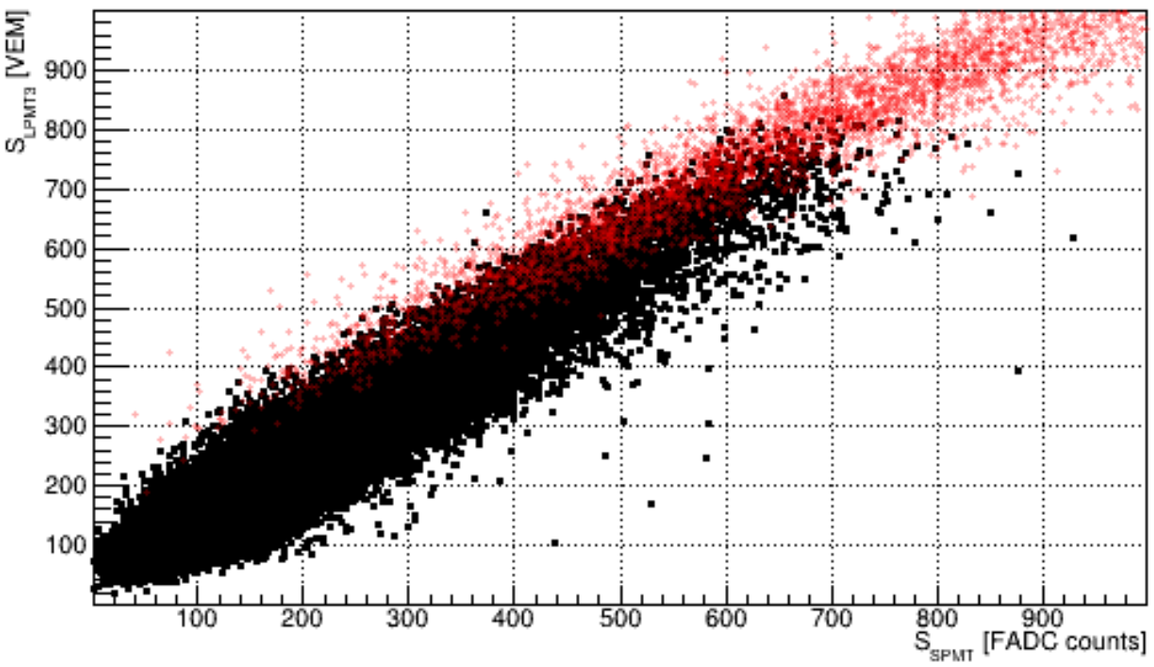
**On 2020/Oct/27, modified version of CDAS started.**

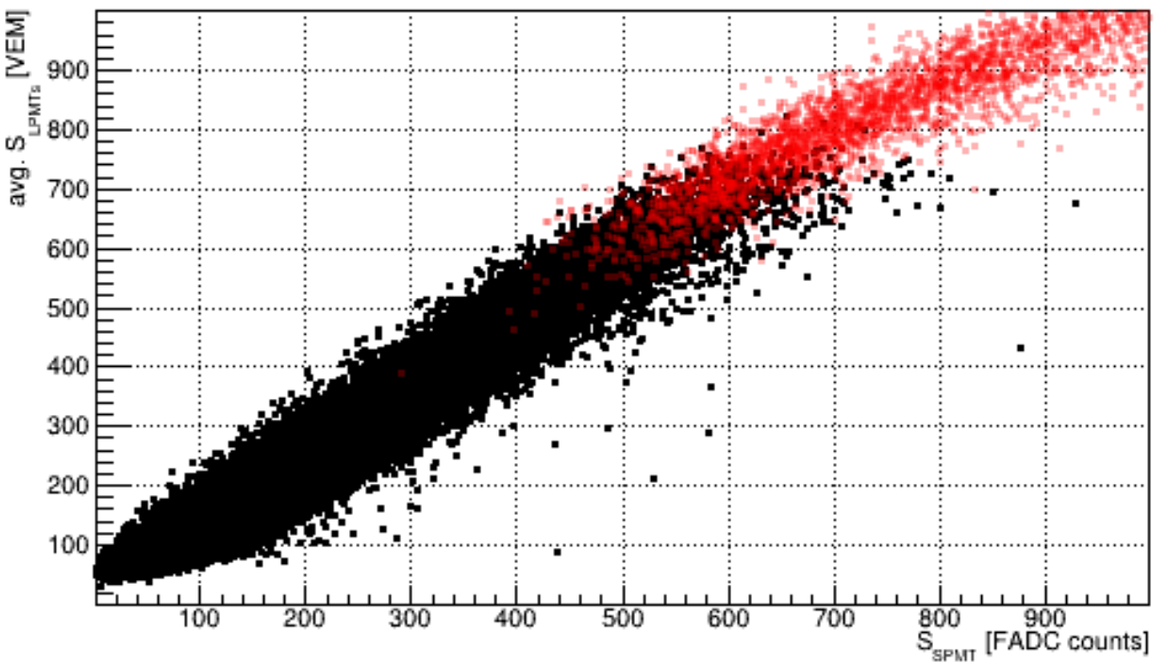
**Stream to Lyon also activated !**

# Scatter plot - Trak (id. 20)



# SPMT cross-calibration

Determination of the calibration **factor β**

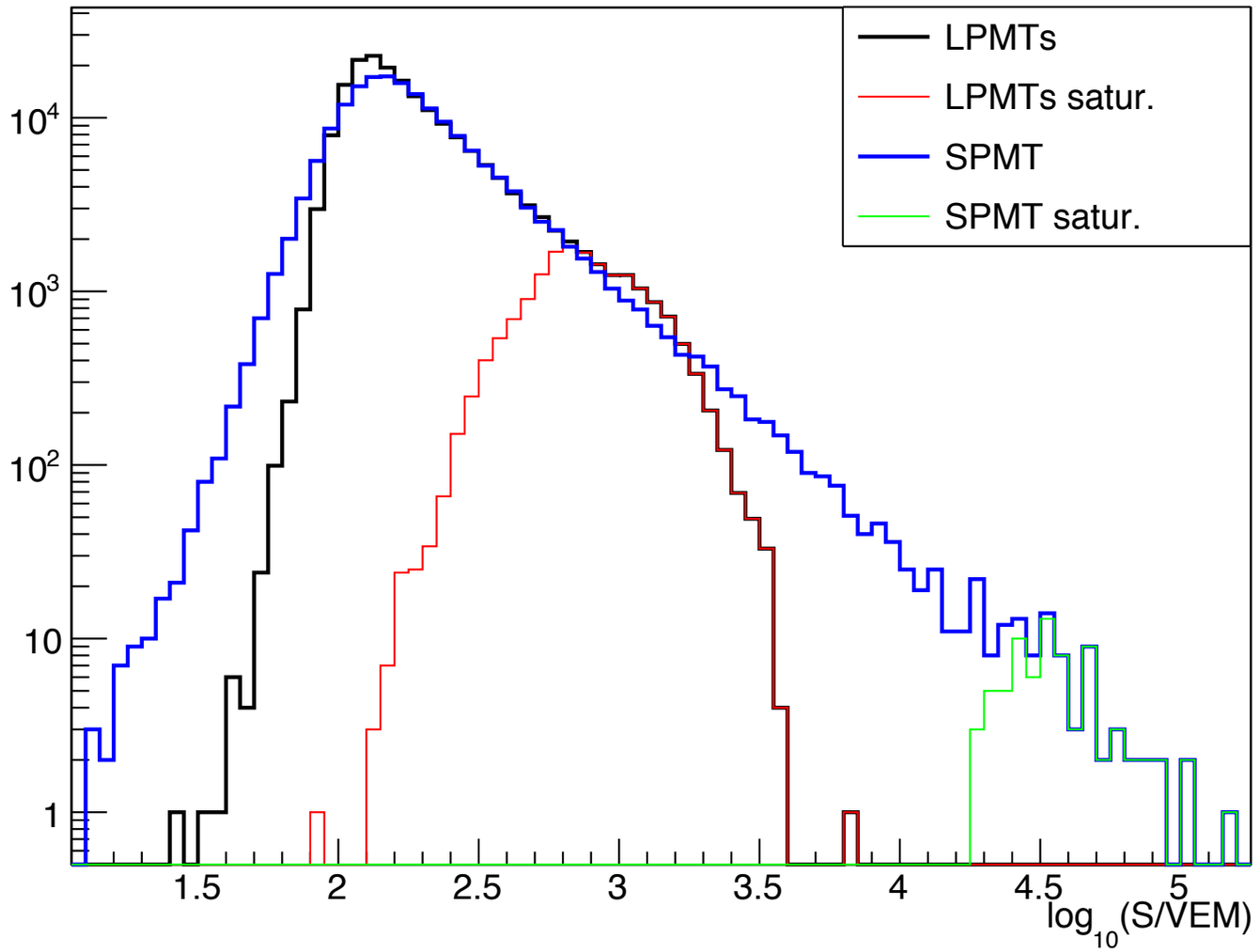
$$S_{LPMT}[VEM] = \beta \; Q_{SPMT}[FADC \; counts]$$

exploiting ***small showers signals*** ( ~200 events/h with the current selection).

★ Small showers are T1 events selected requiring a 2-fold coincidence among the LPMTs signals above a chosen threshold (changing with the individual LPMTs counting rates).

**Spectra comparison** method

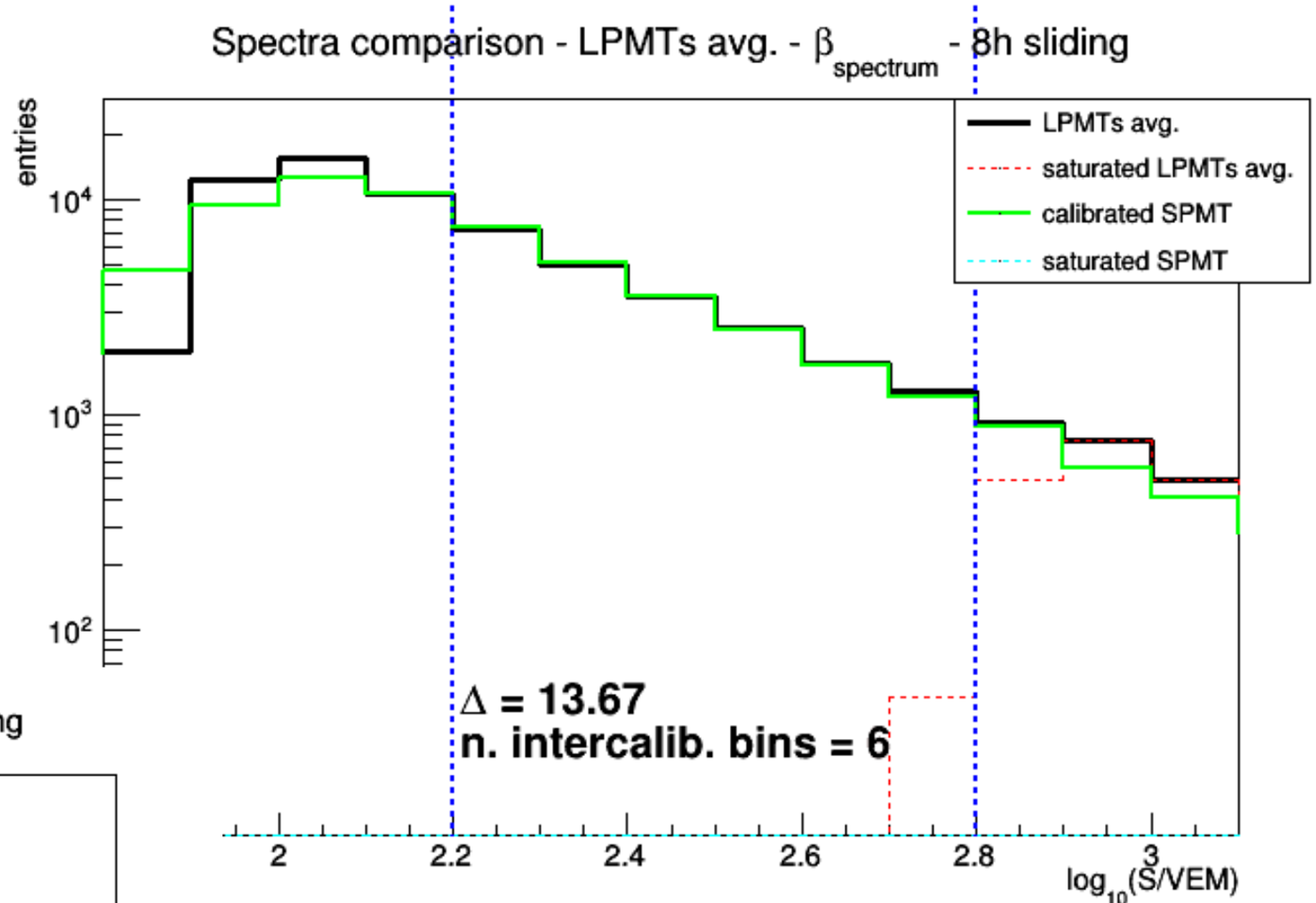
- considered the most reliable in the superposition region (*where <15% of LPMT signals are saturated*).
- effective for measurement of **unsaturated signal up to** (at least) **~20,000 VEM**
- **β** should be **updated every hour** (using sliding intervals of 8 hours) to **follow the temperature.**

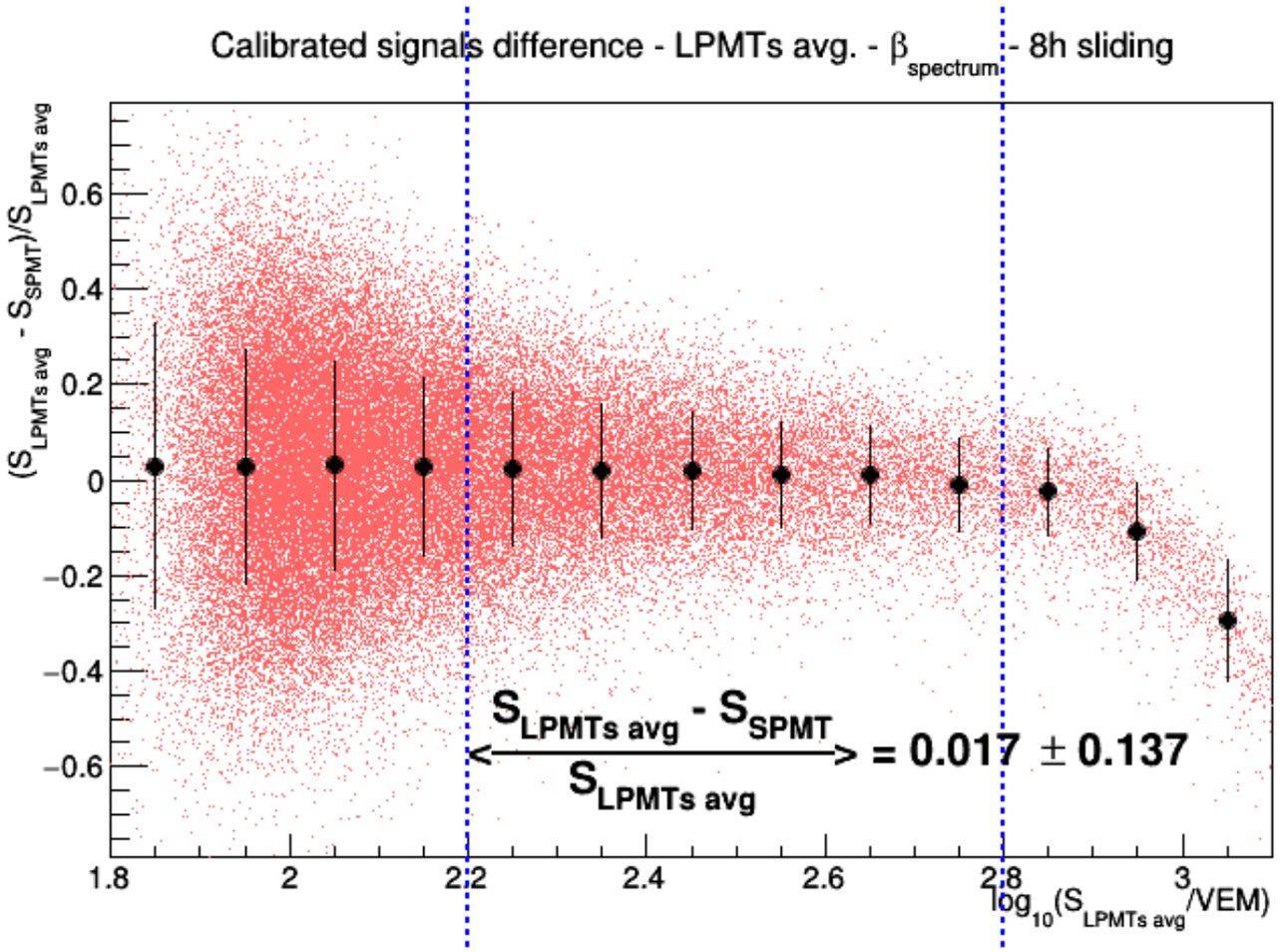


# Checking the calibration result

**Cumulative** spectrum and signal differences with **2 weeks of data**, where each SPMT signals is calibrated using the β closer in time.

**Very good agreement in the inter-calibration region.**

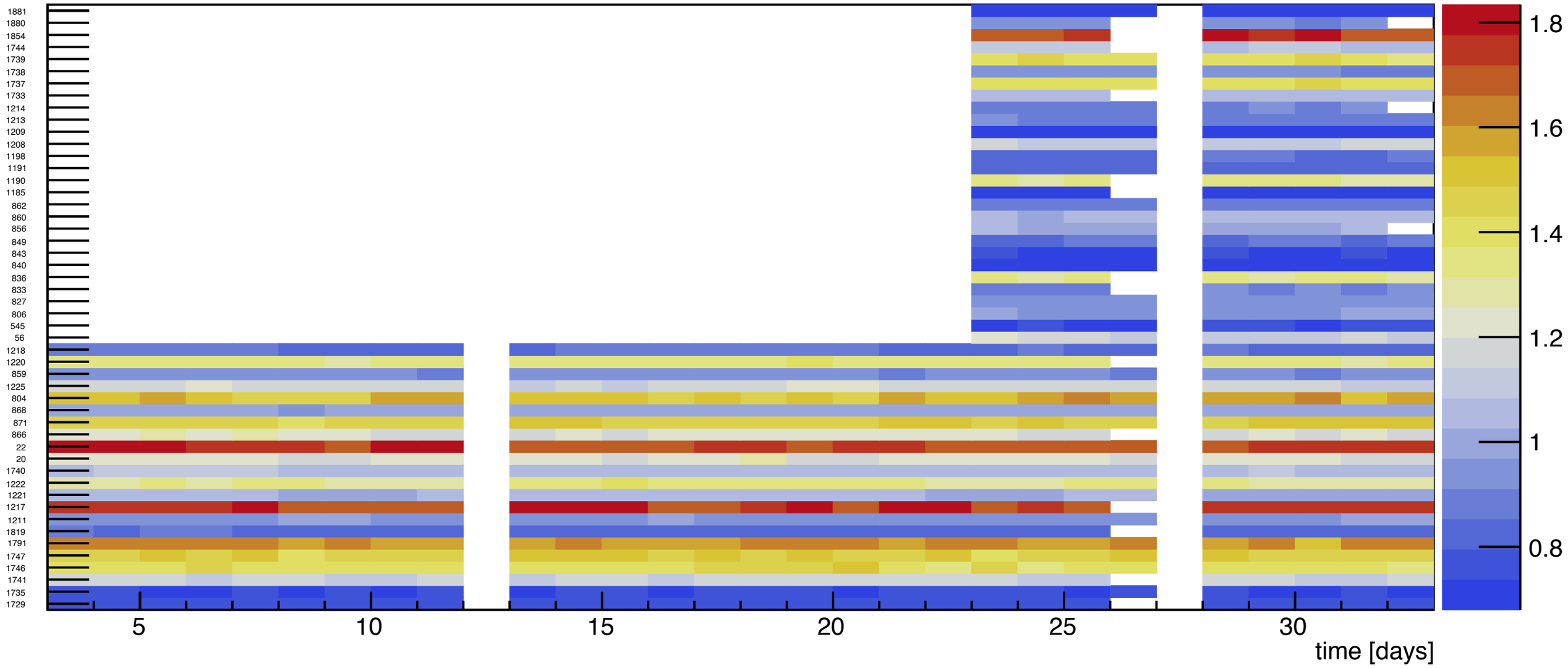



Study of **accuracy** and **resolution** of the technique underway.

Dispersion in the calibrated signal differences anyway lower than 15% in the inter-calibration region.

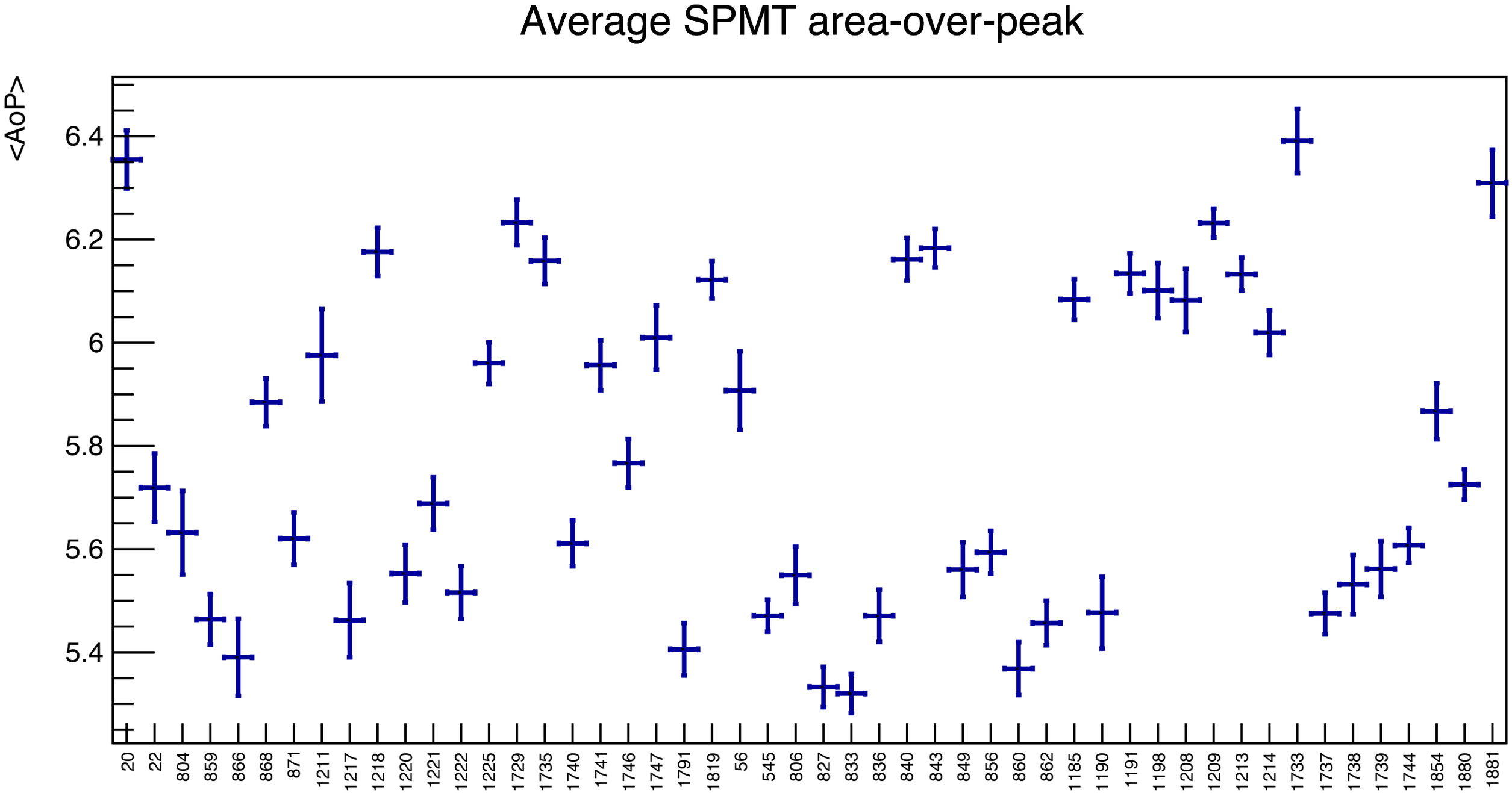
# Average calibration factor




**Inter-calibration factor β in blocks of 24h for 50 selected tanks.**

Spread mainly due to the different SPMT HVs and the different correlation between HV and gain for each photomultiplier.

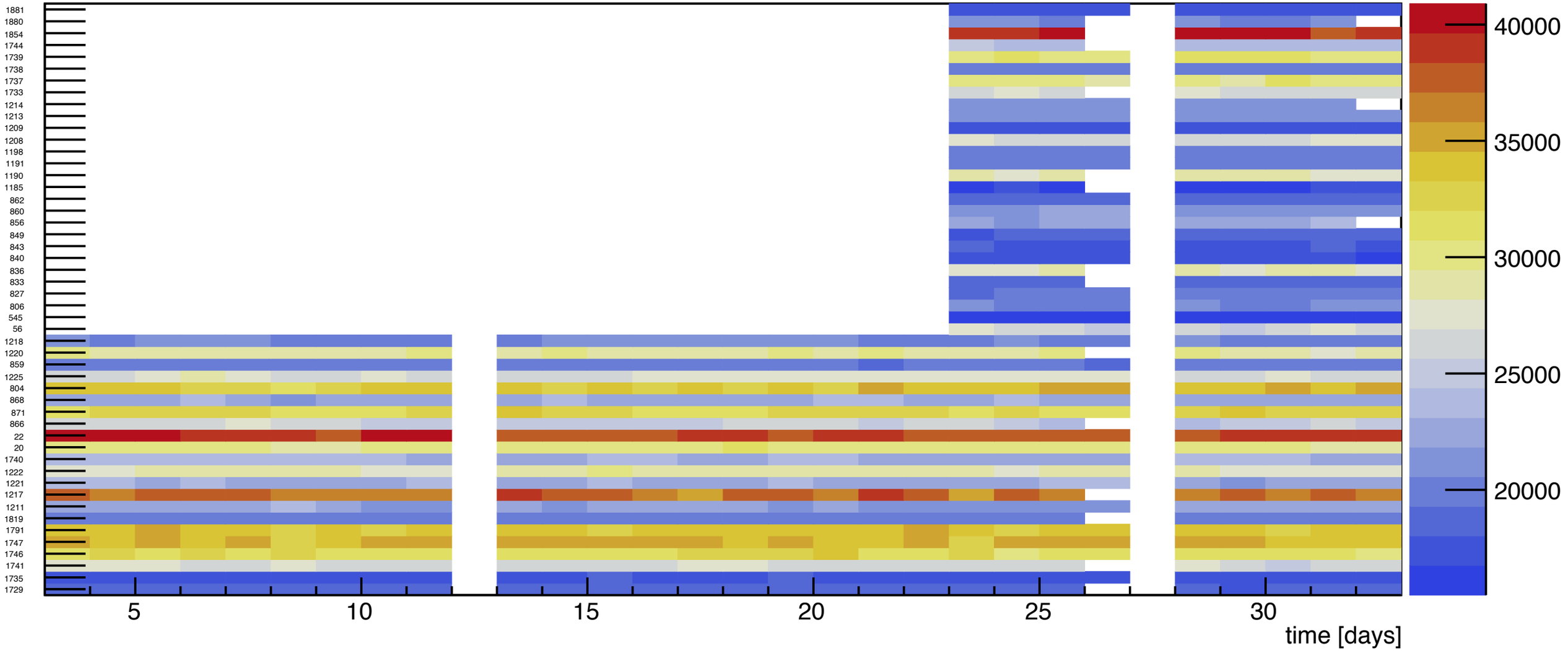
# Area over Peak - SPMT




**Average SPMT area-over-peak for 50 selected tanks.**

Spread mainly due to the different condition of each WCD.

# Signal range extension

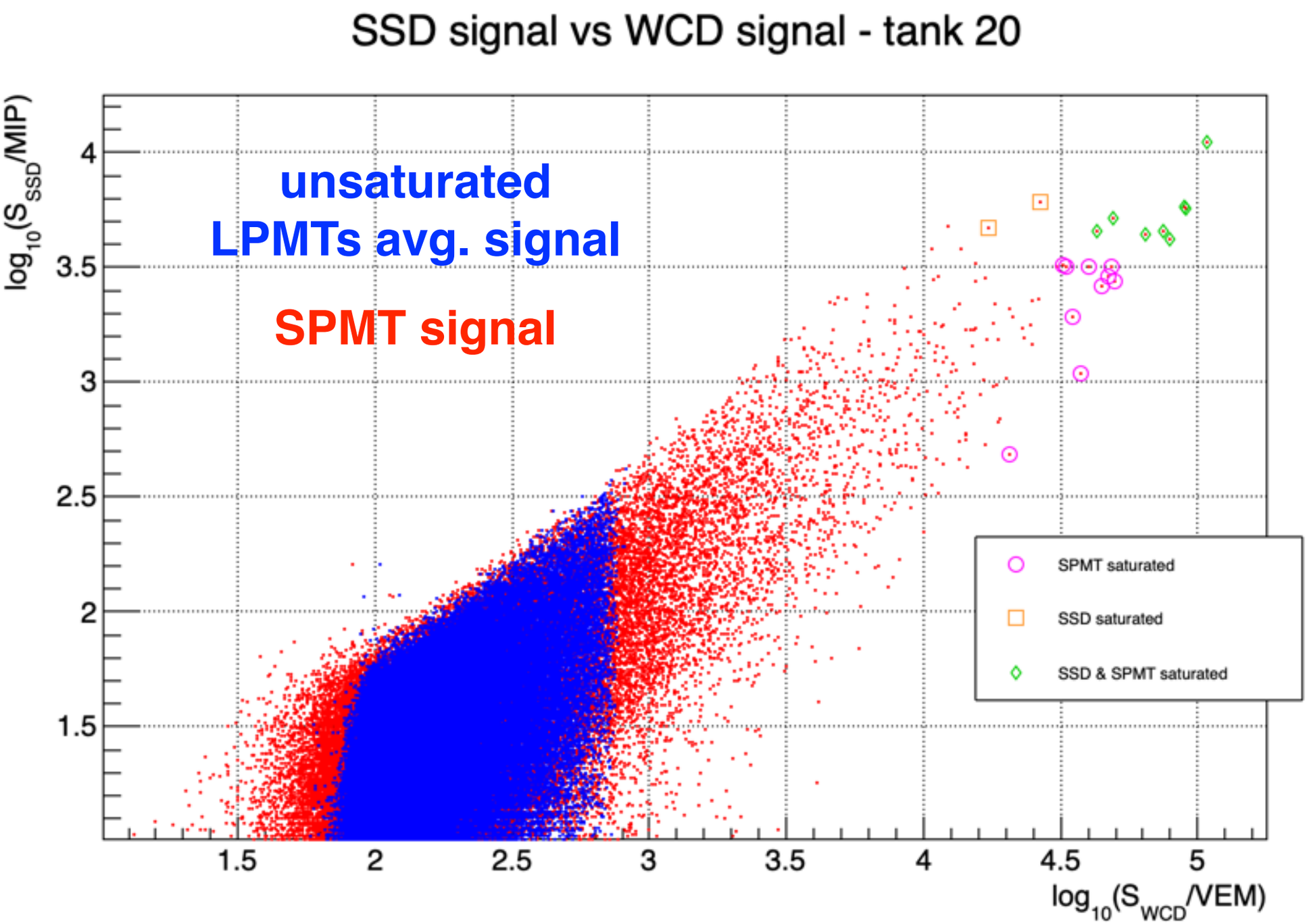



$$< S_{max} > = < AoP > \times peak_{saturation} \times \beta$$

where ***peak*$_{saturation}$ ~ 3900 FADC counts** (β and average AoP from previous slides).

**Only few tanks are below the target value at the moment.**

# SSD signals in small showers




Cumulative scatter plot with 1 month of small showers data.

Signals more spread than in standard events, but correlation clearly present.

# SPMT offline cross-calibration

Data transferred to Lyon every day

**~ 250 MB / day**
**for the entire**
**SD-1500 array**

Calibration procedure
(will be) performed
completely offline
in Lyon

(not interfering with
LocalStation processes)

**Lyon**
Perform SPMT calibration
Storage results into ROOT TTree

**Monitoring**
Use SPMT calibration results
to fill the databases

**SD event production**
Add SPMT calibration results
to the merging (like T2Life, etc.)

**Final quantities in SD events for each tank**

- $\beta_{spectr}$ x 4
- sigma($\beta_{spect}$) x 4
- $\chi^2$ of calibration fit x 4
- quality flag x 4

**average every hour**

- # small showers
- thresholds x 3
- custom VEM x 3 + MIP

**average every 8 hours (sliding)**

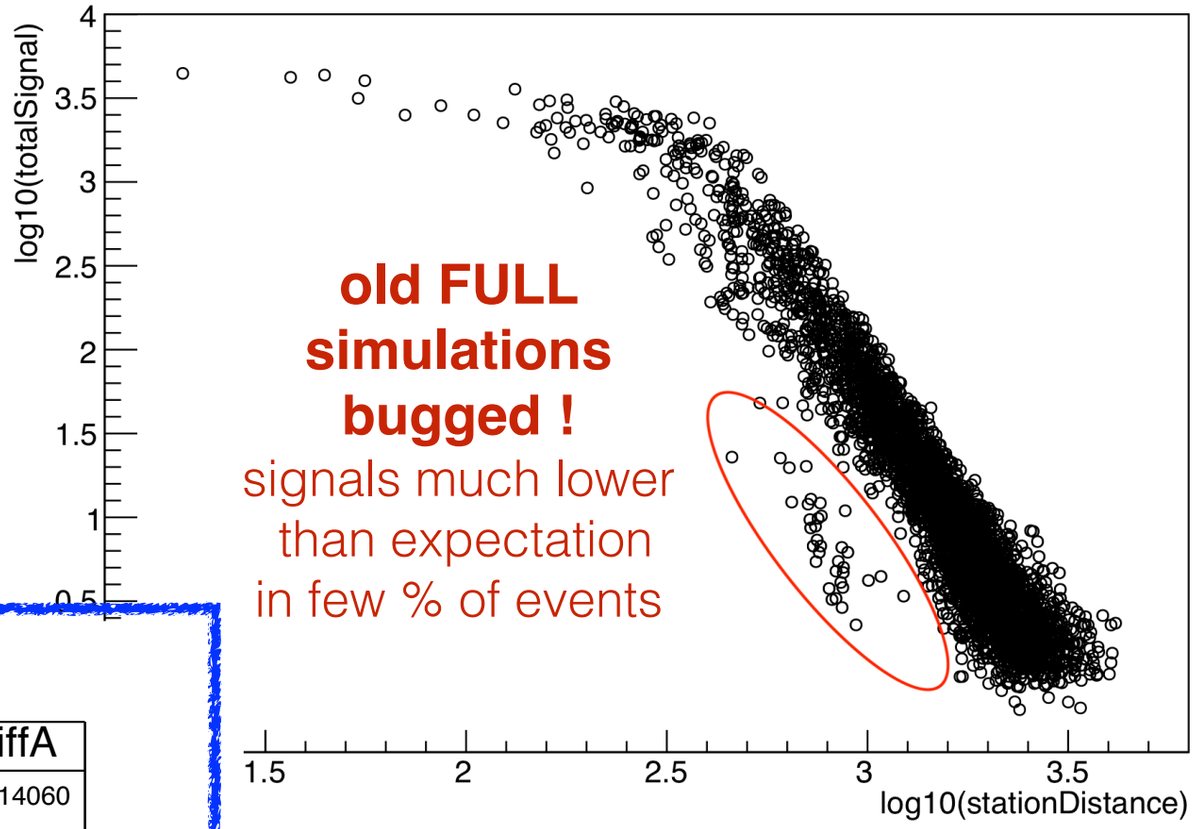
- $\beta_{spectr}$ x 4
- AoP SPMT
- Satur. small shws signals

# *Simulation*

# Recovery of the FULL GEANT4 simulation

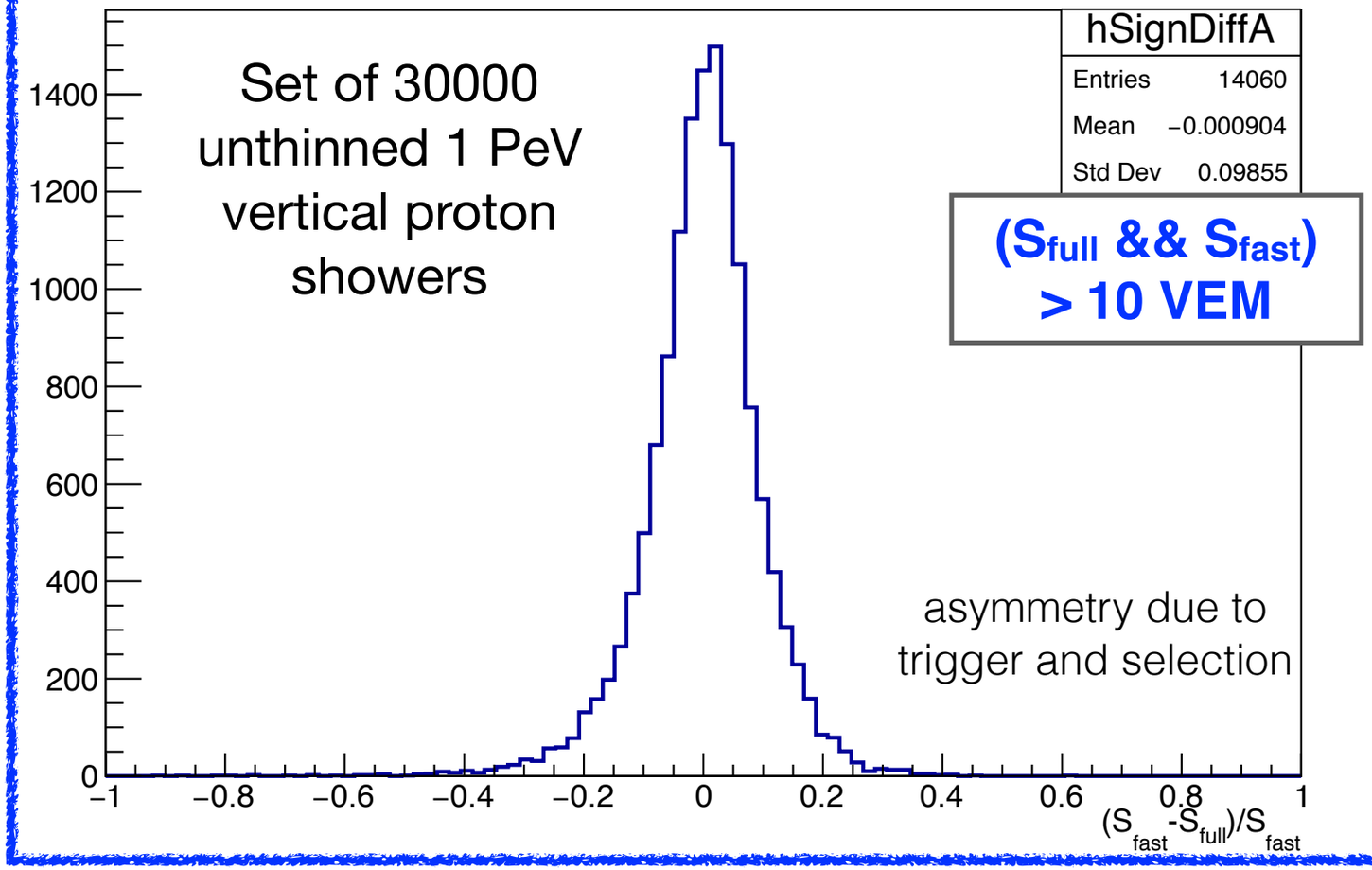
SPMT implemented in the GEANT4 station (AugerPrime WCD + SSD).

**Position, geometry and detector properties checked and updated.**




**old FULL simulations bugged !**
signals much lower than expectation in few % of events

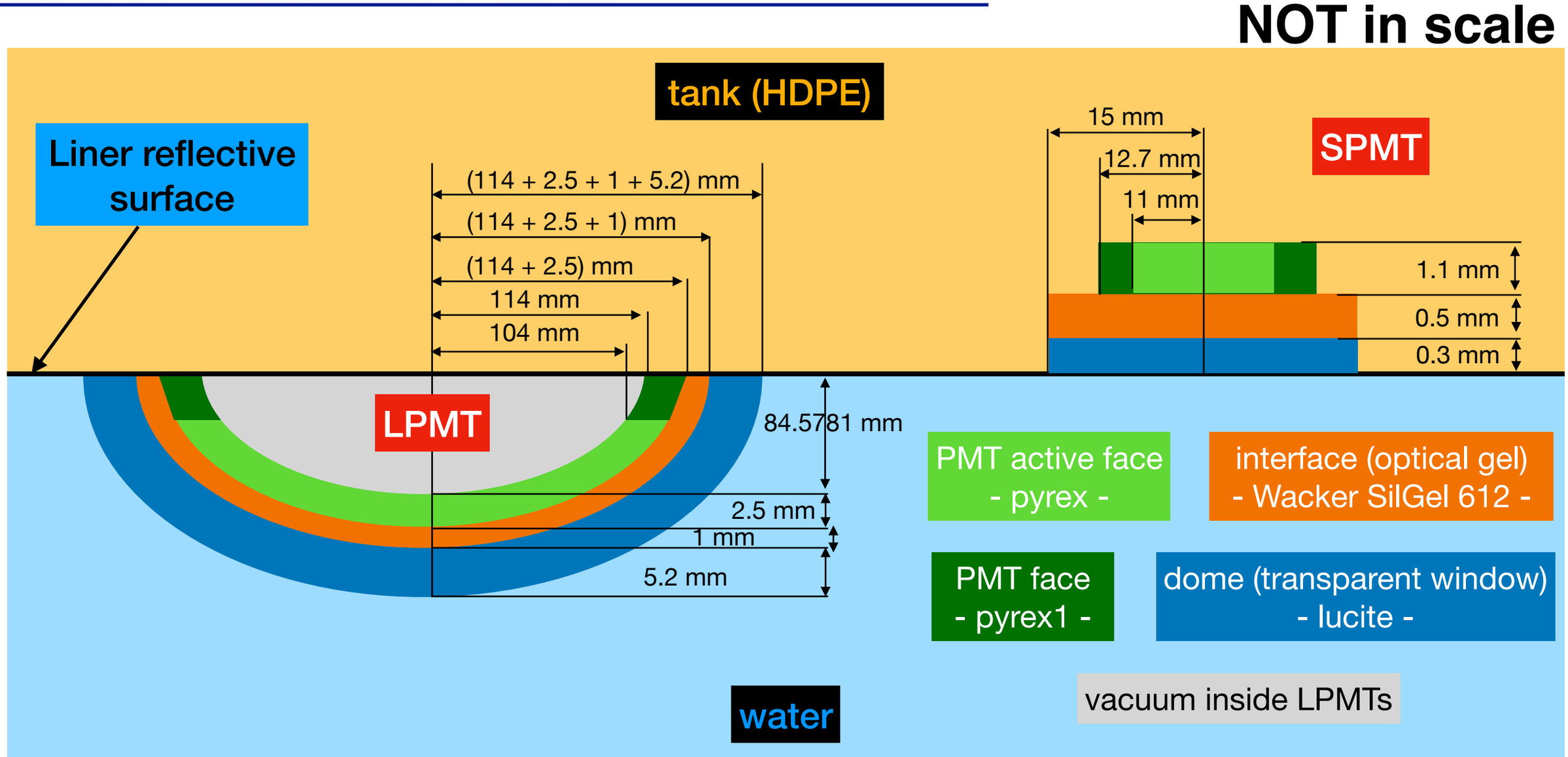
Signal differences LPMTs average




✓ **FULL simulation mode now working and tested**

✓ Final validation with high energy events performed Eric Mayotte and Sonja Schröder.

# GEANT4 station PMTs




Schema of the PMTs simulation as defined in *G4StationConstruction.cc*
The LPMTs are formed by half-ellipsoids (one inside the other) while the SPMT is constituted by cylinders (G4Tubs in GEANT4).

**In the FAST mode, such shapes are hard-coded (only the dimensions of each part can be changed).**

# *Validation of the new FAST mode*

✓ Validated using **integrated signals** from “small showers”

- ~30,000 **unthinned** CORSIKA protons showers, with energy [$10^{13}$,$10^{15}$] eV and zenith [0°,60°]
- core @ tank center using the **CachedDirectInjector**

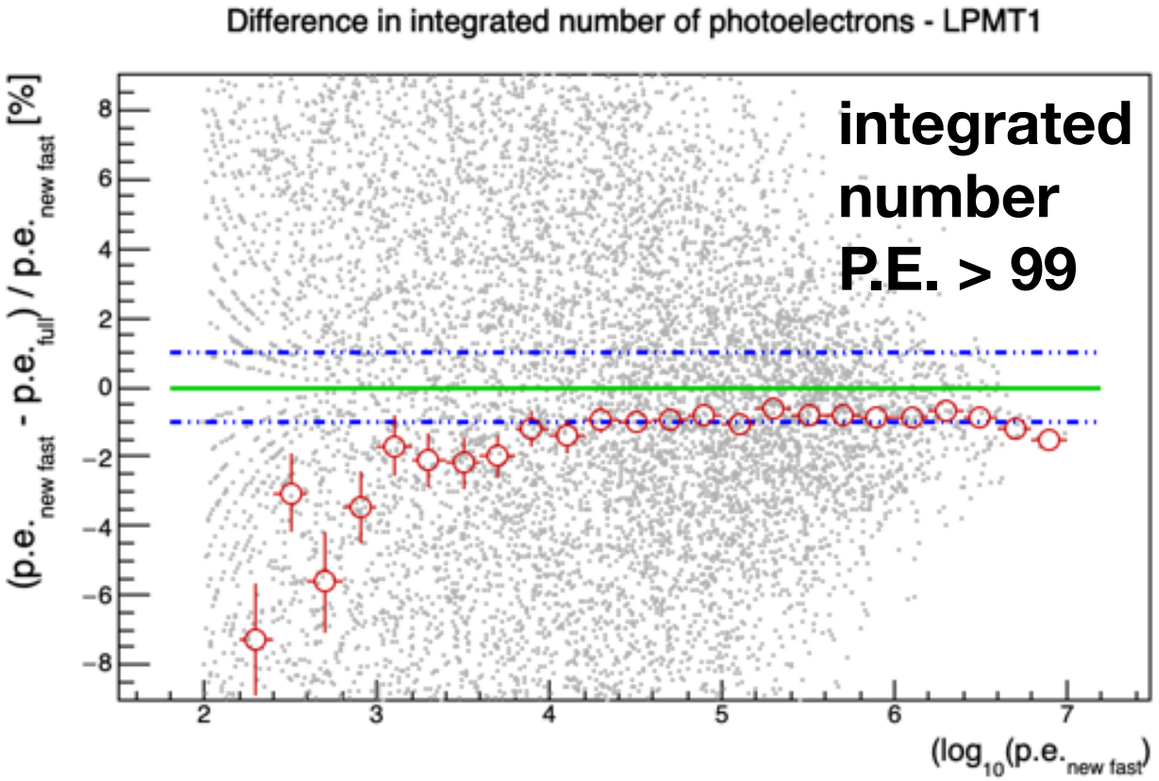
✓ Validated comparing **traces**

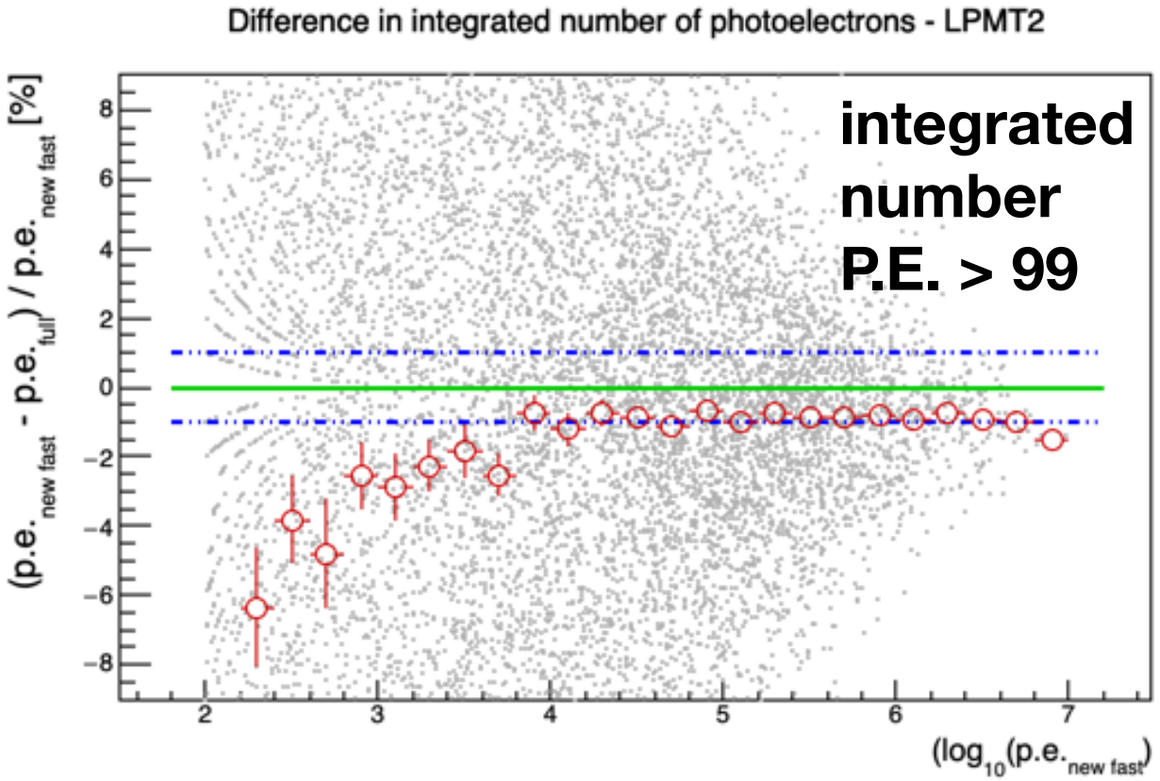
- single 1GeV muon, vertical and inclined (42°, 60°)
- 250 muons, 1 GeV, vertical and inclined (42°, 60°)
- 250 electrons, 250 MeV, vertical and inclined (42°, 60°)

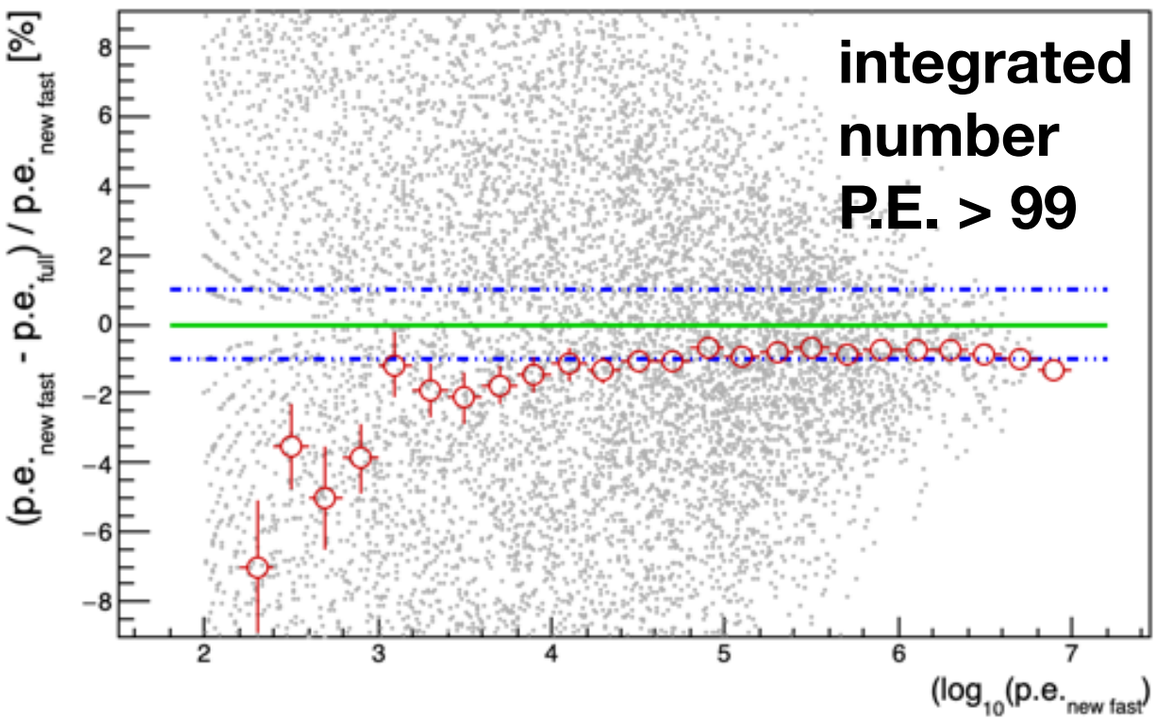
★ Difference between old and new FAST simulations on average negligible.

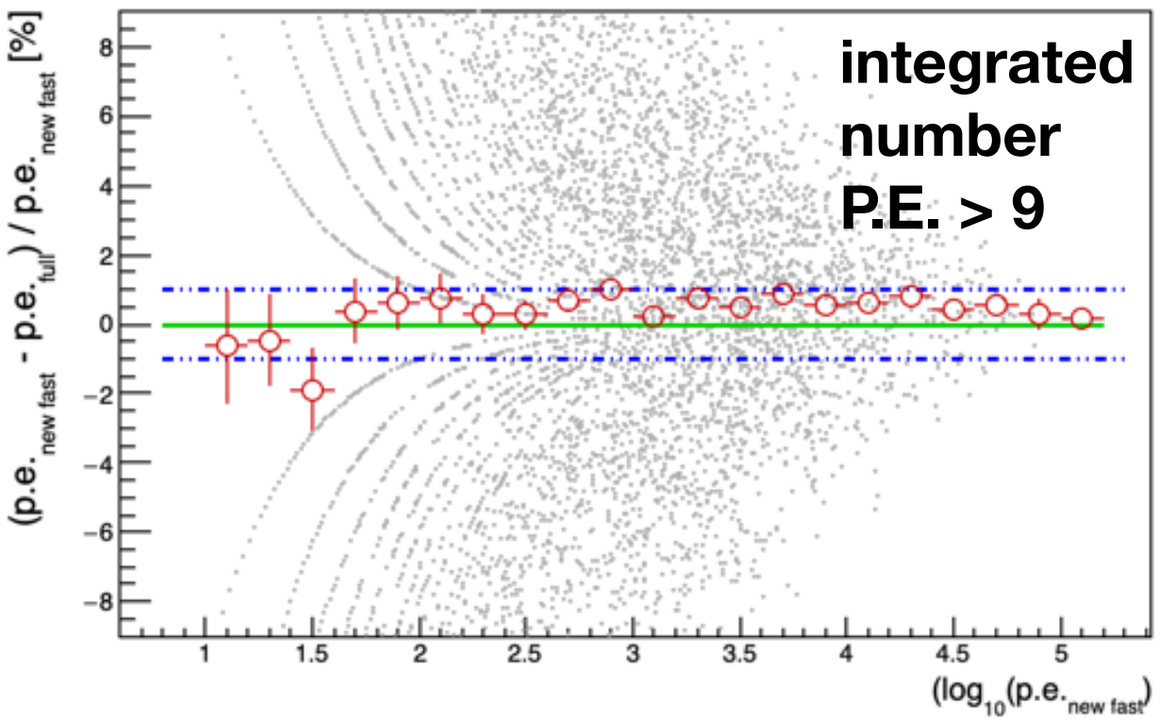
★ Bias between FULL and FAST simulations ~1-2% (**same as the old FAST**).

# New FAST vs FULL

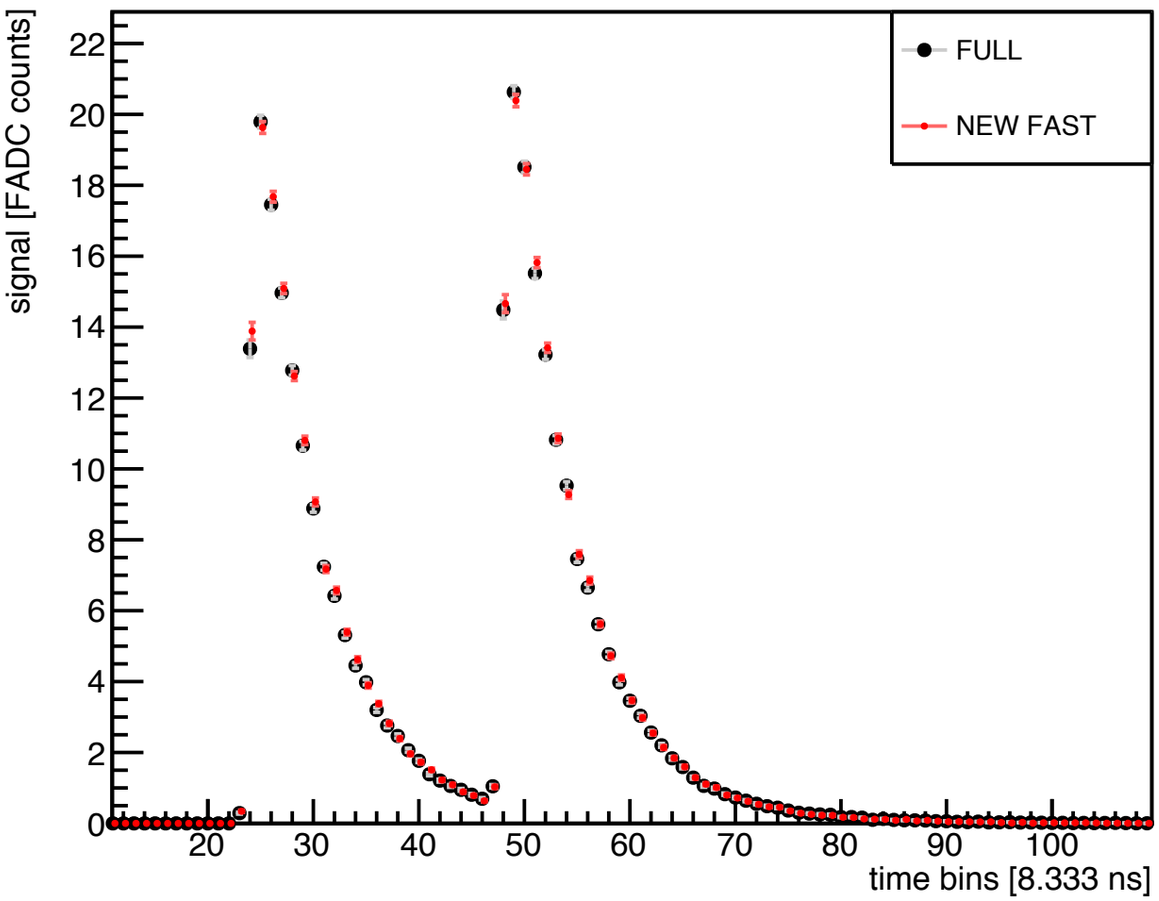


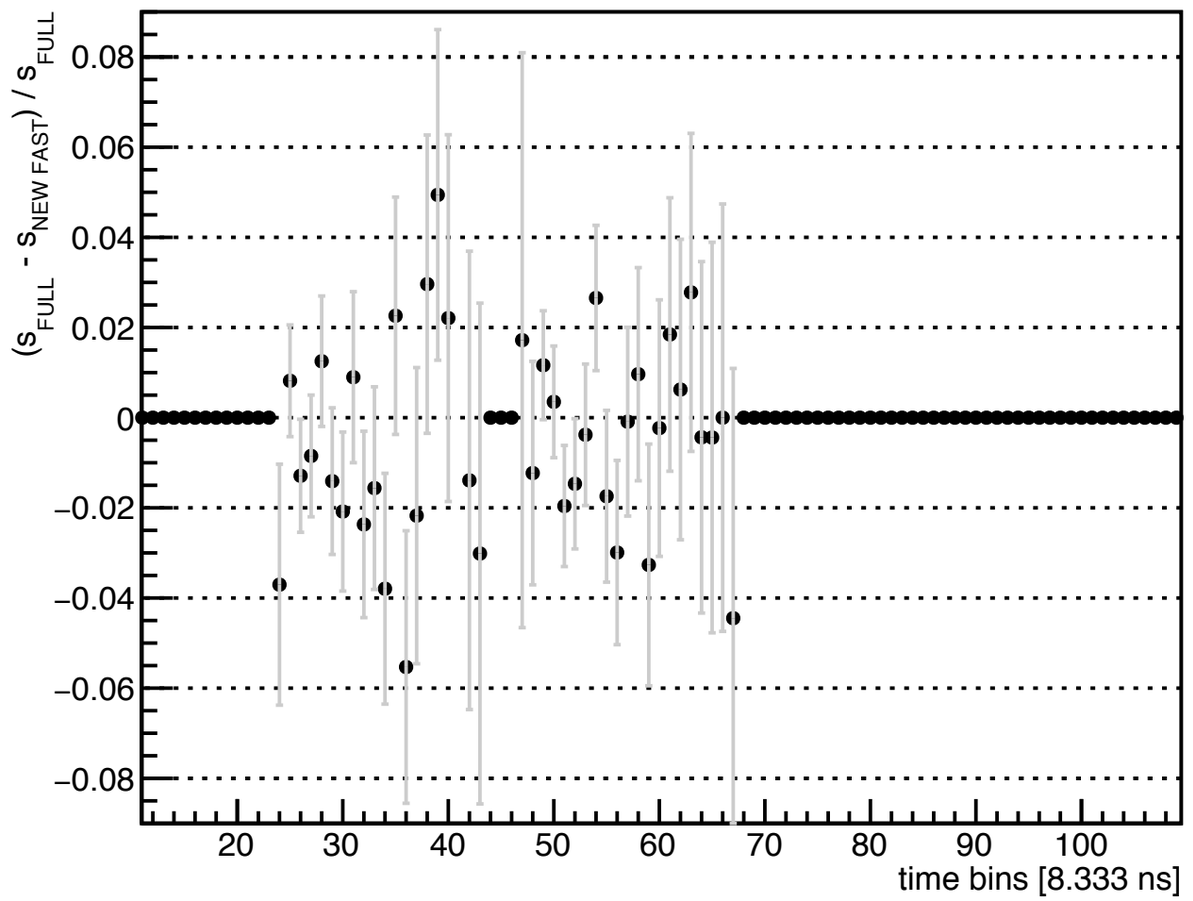



# 250 muons traces - SPMT




The SPMT signal is naturally much smaller, so with larger fluctuations.

The trace is well reproduced by the updated FAST mode, **without bin-to-bin biases** larger than 1-2% (on average) w.r.t. the FULL simulations.

# *Conclusions*

- ➡ Small showers acquired and transferred to Lyon *(since 03/04/2021 with correct firmware)* from **79 tanks with pre-production UUBs**.

- ➡ SPMT inter-calibration procedure under validation.
  - Next step : inclusion of the SPMT inter-calibration factor in the standard SD data production.

- ➡ FAST simulation with the inclusion of the SPMT **implemented.**

Thanks for your attention !

# *Backup*

# SPMT To-Do(s)

★ SPMT DAQ
Automatic HV setting procedure to be finalized and tested.

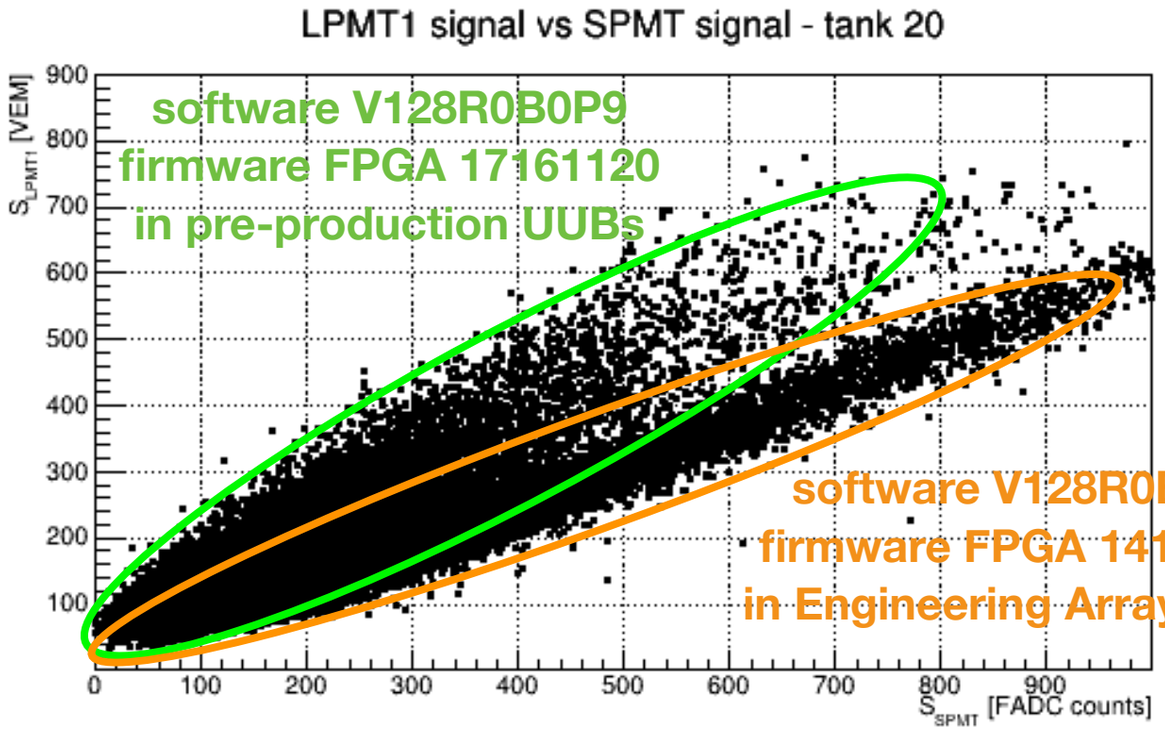
★ SPMT (inter-)Calibration

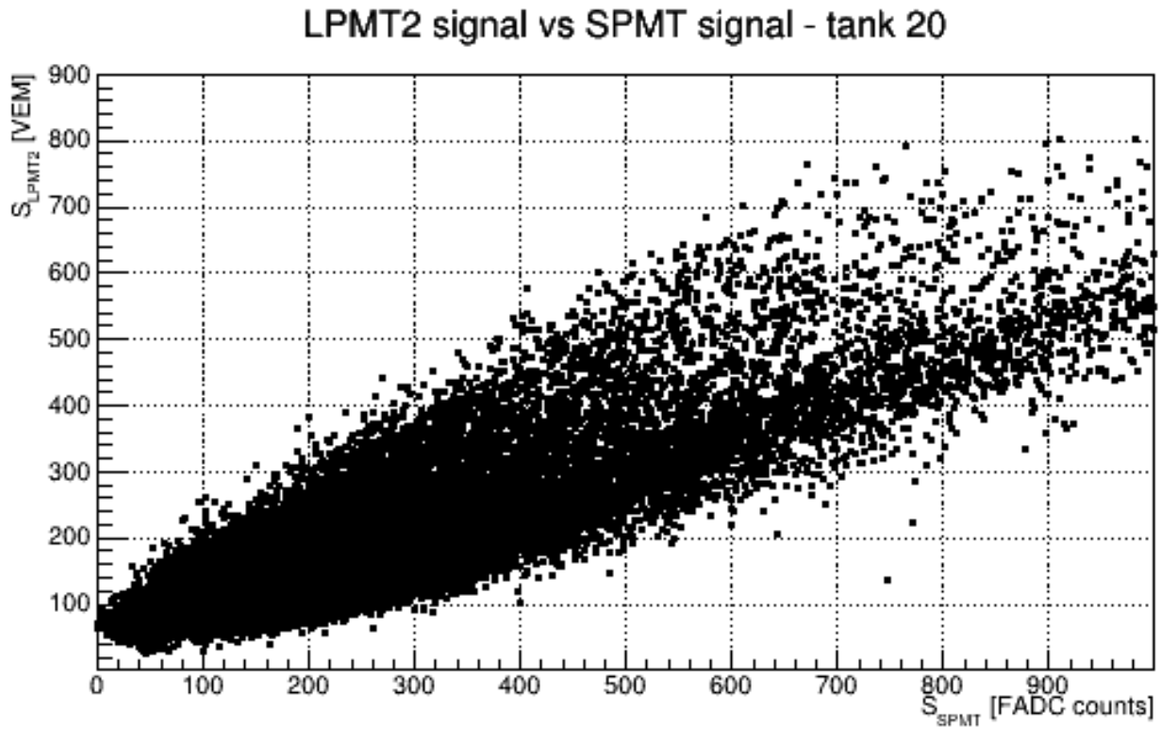
- calibration procedure in Lyon must be automatized;
- addition of the inter-calibration factor (and related quantities) during the merging procedure of the SD events;
- *CDASToOfflineConverter* to be consequently updated.

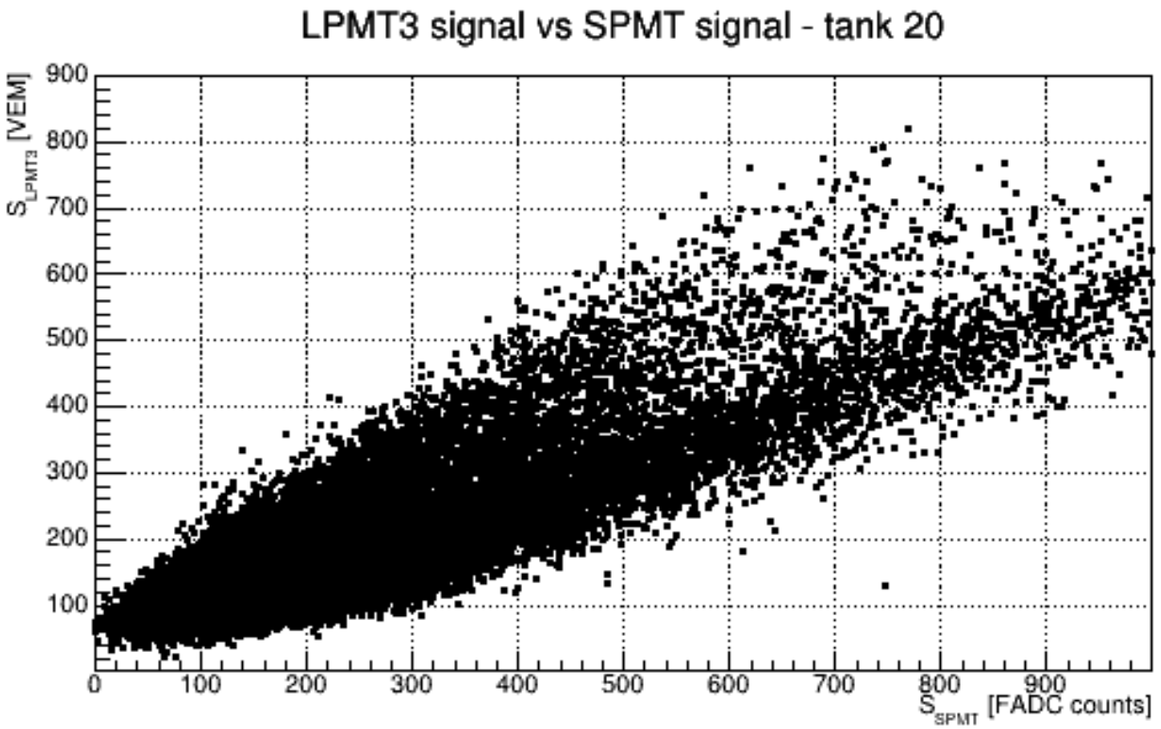
★ WCD LDF

- update of the *SdCalibratorOG* for the SPMT signal integration;
- inclusion the SPMT signals in the WCD *LDFFinder* when the LPMTs signal is saturated.

# Test of software and firmware 03/02/21-16/02/21




Clear differences between the software/ firmare installed in the pre-production UUBs and the version in the EA tanks:

-) increased signal dispersion;

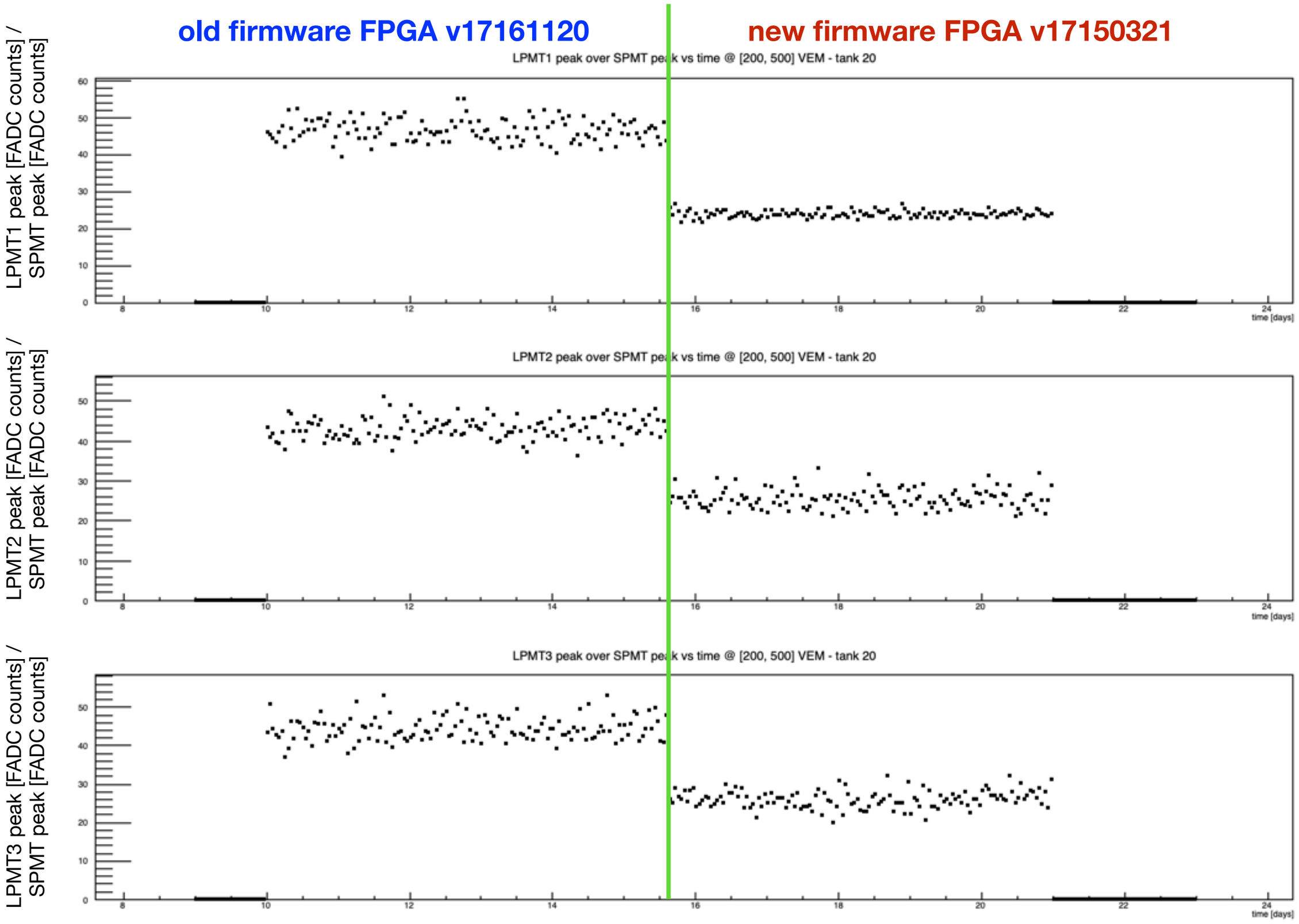
-) (apparently) increased SPMT gain.

**HV values are constant for all the LPMTs and the SPMT in the entire period.**

# $S_{peak}$(LPMTs)/$S_{peak}$(SPMT) vs time - Trak

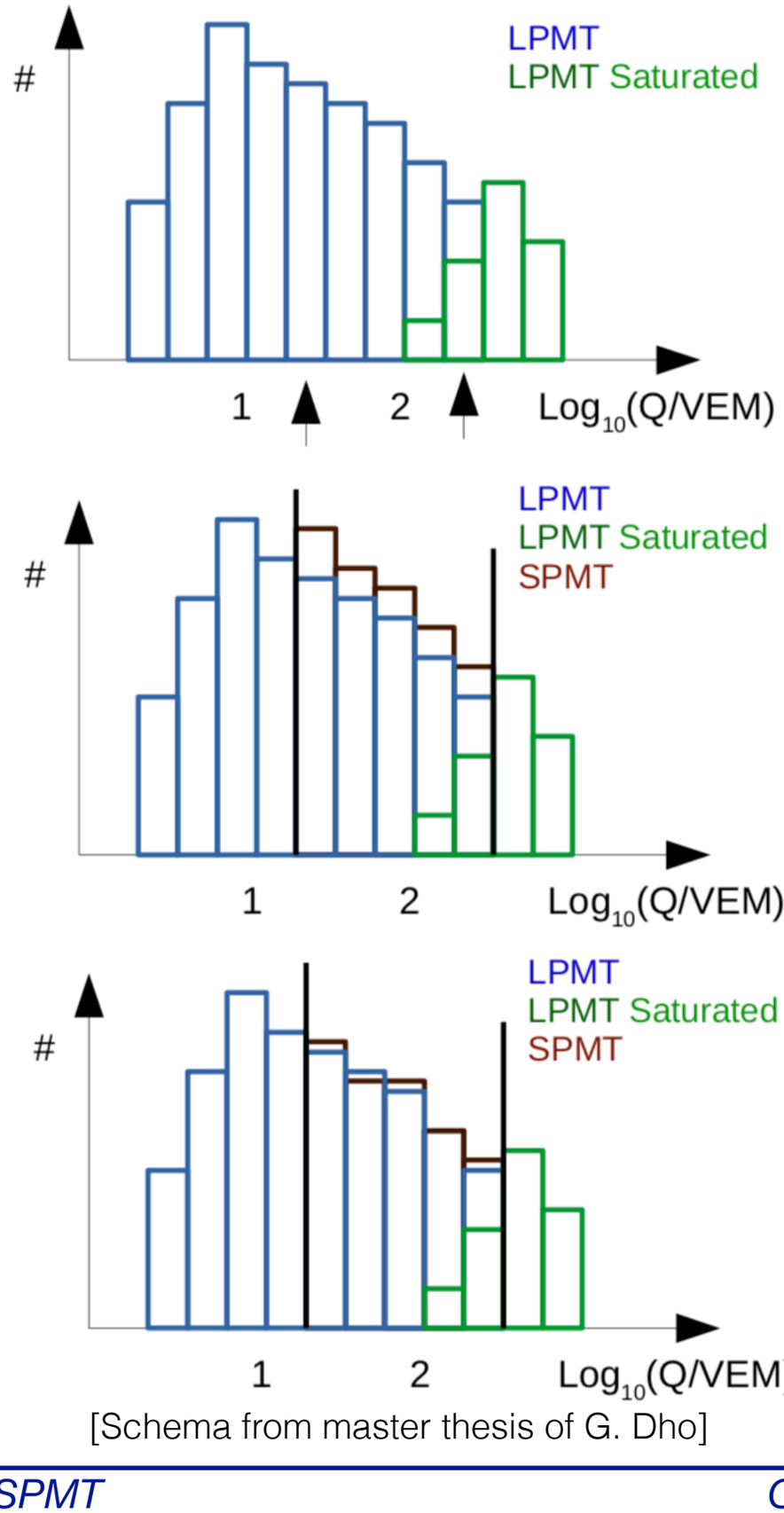
**old firmware FPGA v17161120**

**new firmware FPGA v17150321**




**time = 0 ==> midnight between 28/02/21 and 01/03/21**

# sPMT cross-calibration - spectra comparison method




[Schema from master thesis of G. Dho]

1. The histograms (with defined binwidth) of LPMT signals in VEM are filled.
2. A confidence region from the second bin after the maximum (~150 VEM) to the bin with 15% of saturated events is defined.
3. SPMT histogram is filled using an initial β factor. Only the events ending up in the chosen region are considered.
4. A distance *Q* between the histograms is defined and minimized to find the best β
   A. Dichotomic procedure to define an approximate region around the minimum.
   B. Evaluation of average Q in small regions of β (smoothing the behavior of Q vs β)
   C. Cubic fit of Q as a function of β

**The resulting spectra of SPMT and LPMT are overlapping by definition.**

# Small showers physics

*Expected flux*

Low energy showers with E < few PeV

$$N(>E) \sim 2 \times 10^4 \ (E/GeV)^{-1.7}$$

$$A = \pi^2 \sin^2(\theta_{max}) \ r^2$$

$$Rate(>E) \sim N \times A$$

| | rate with r = 10 m & $\theta_{max}$ = 65° |
|---|---|
| E > $10^{13}$ eV | 2.44 Hz |
| E > $10^{14}$ eV | 0.049 Hz |
| E > $10^{15}$ eV | 0.00097 Hz |

| $\log_{10}$ E | rate [Hz] @ th = 400 counts |
|---|---|
| 12.0 - 12.5 | 0.0030 |
| 12.5 - 13.0 | 0.0061 |
| 13.0 - 13.5 | 0.0084 |
| 13.5 - 14.0 | 0.0107 |
| 14.0 - 14.5 | 0.0102 |
| 14.5 - 15.0 | 0.0080 |
| 15.0 - 15.5 | 0.0046 |
| Total | 0.0510 |

Small showers selection :

T1 events **selected** independently in each WCD as 2-fold coincidence of LPMTs with $S_{peak} \gtrsim 450$ FADC counts.

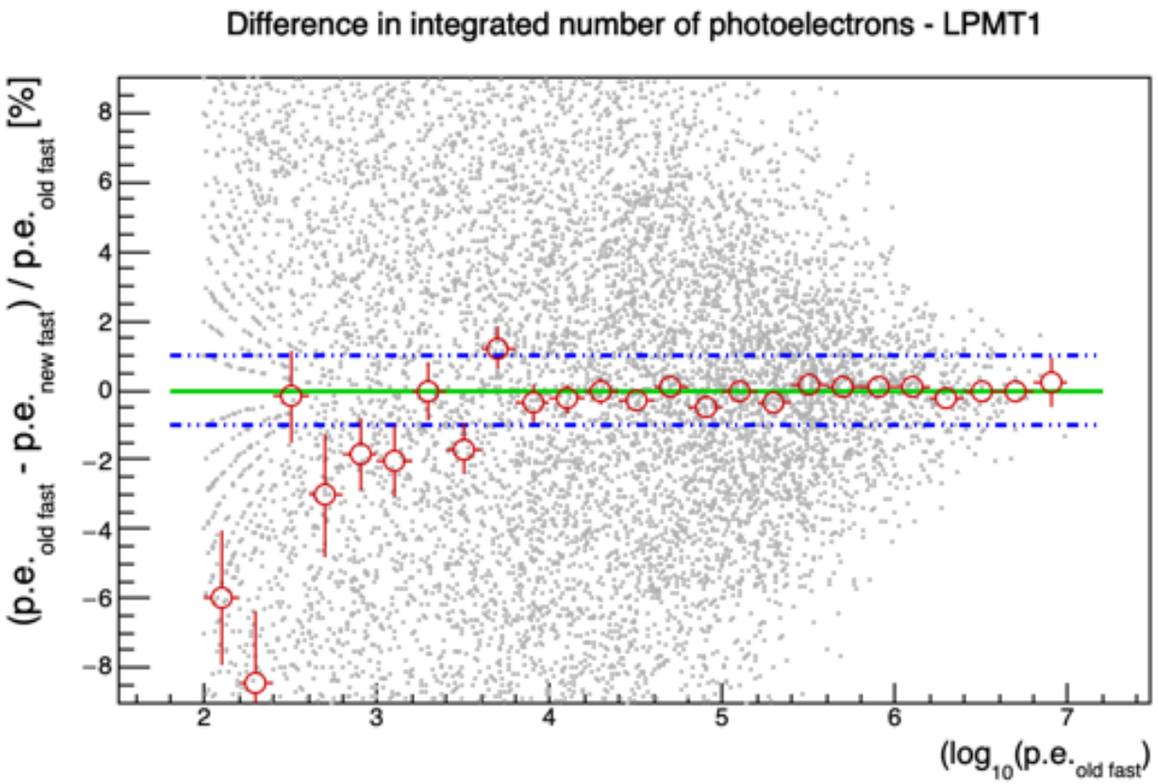
**Small showers measured rate :**

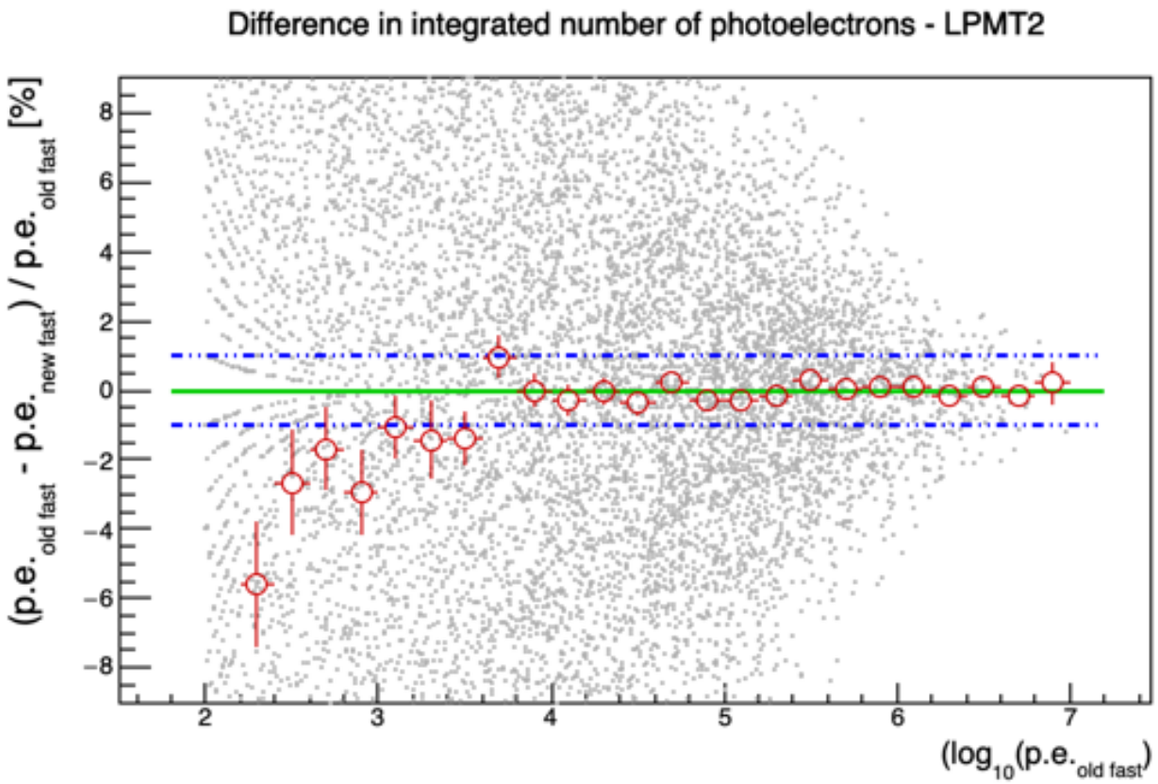
**~0.055 Hz** ( i.e. ~200 evts/h)

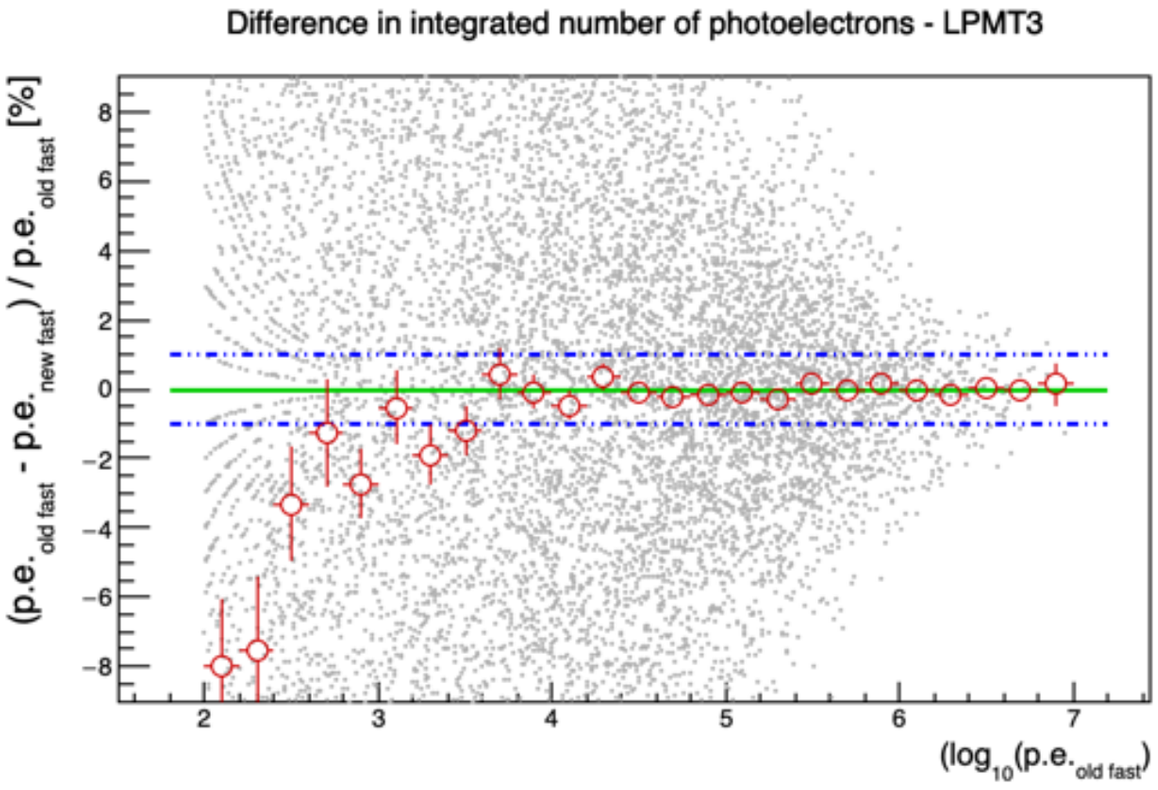
On the left table:

Simulation of low energy **untinned** showers **CORSIKA ver.77100** (using EPOS-LHC and URQMD 1.3cr) and **Offline trunk rev. 33838**

# Old FAST vs new FAST

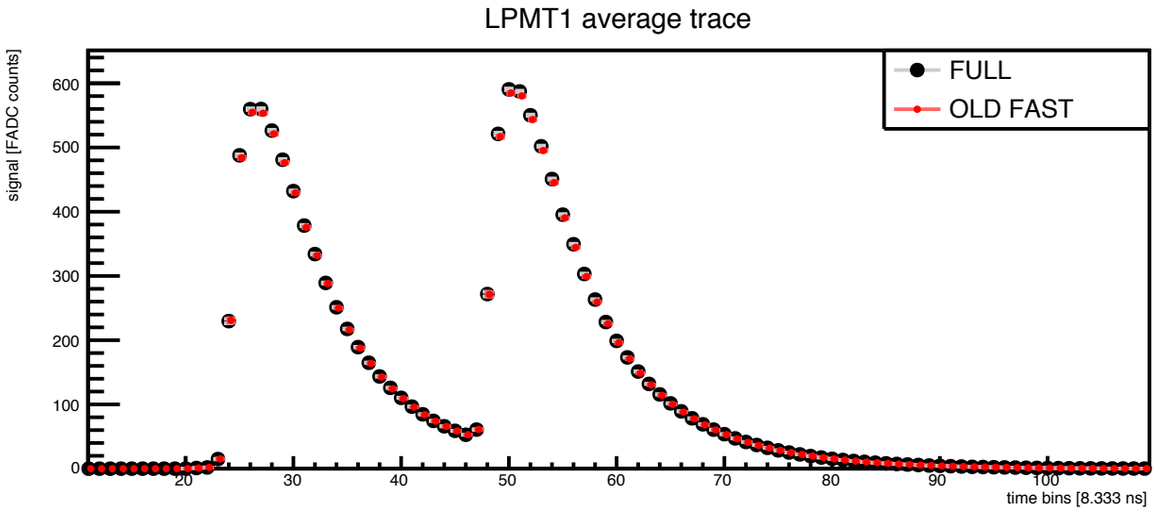


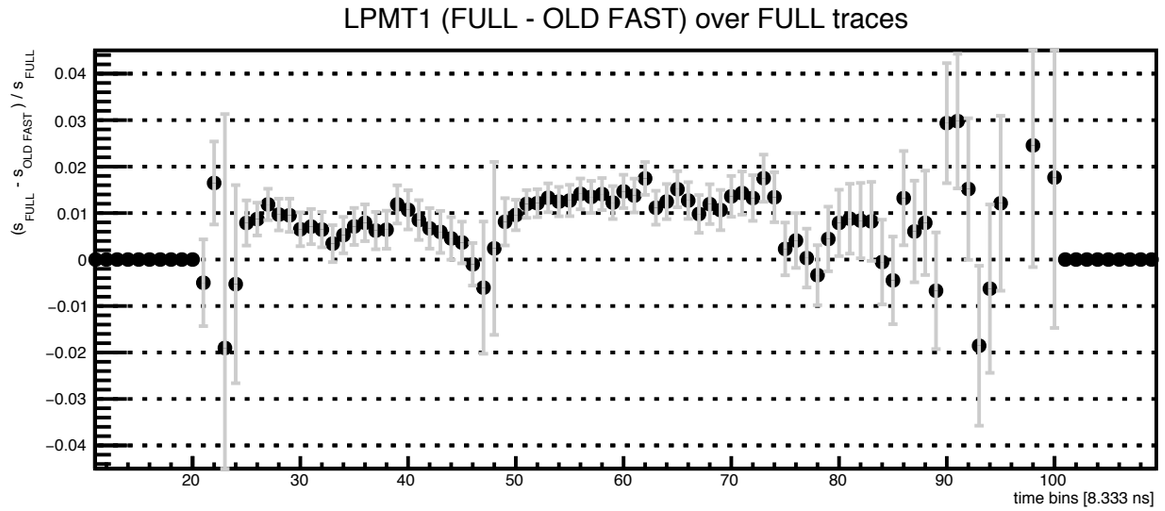



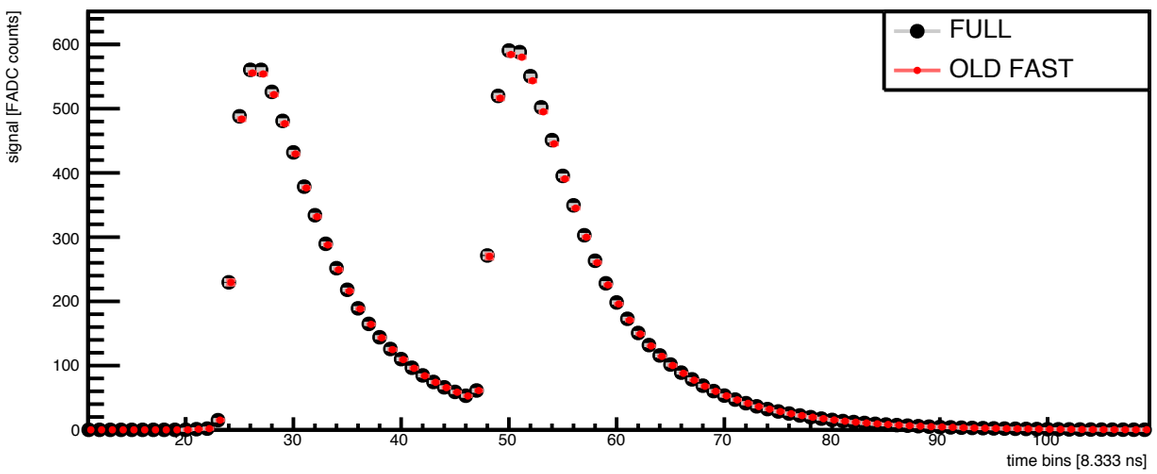



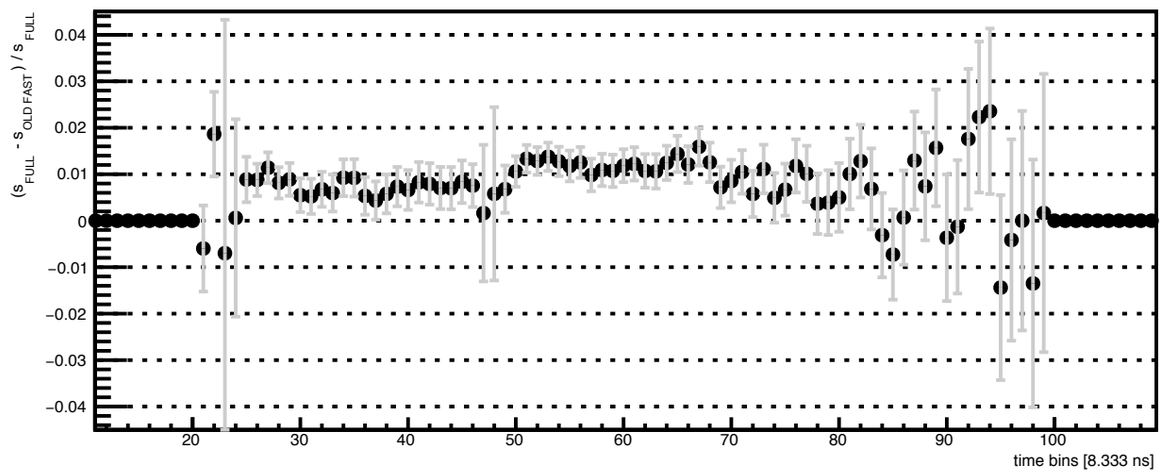

- ✓ Bias between old and new FAST mode becomes on average negligible for large enough signals.

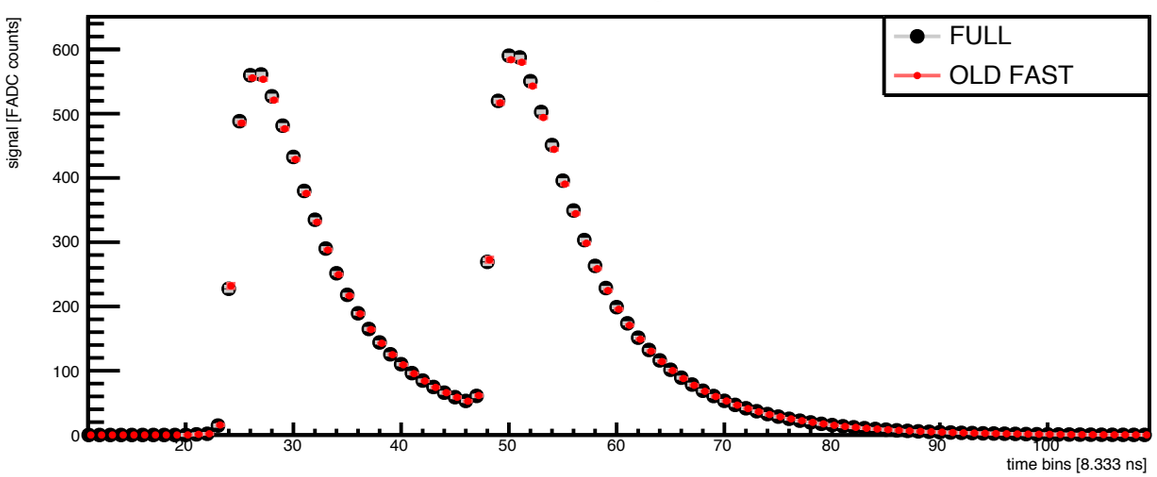
# 250 muons traces - FULL vs OLD FAST

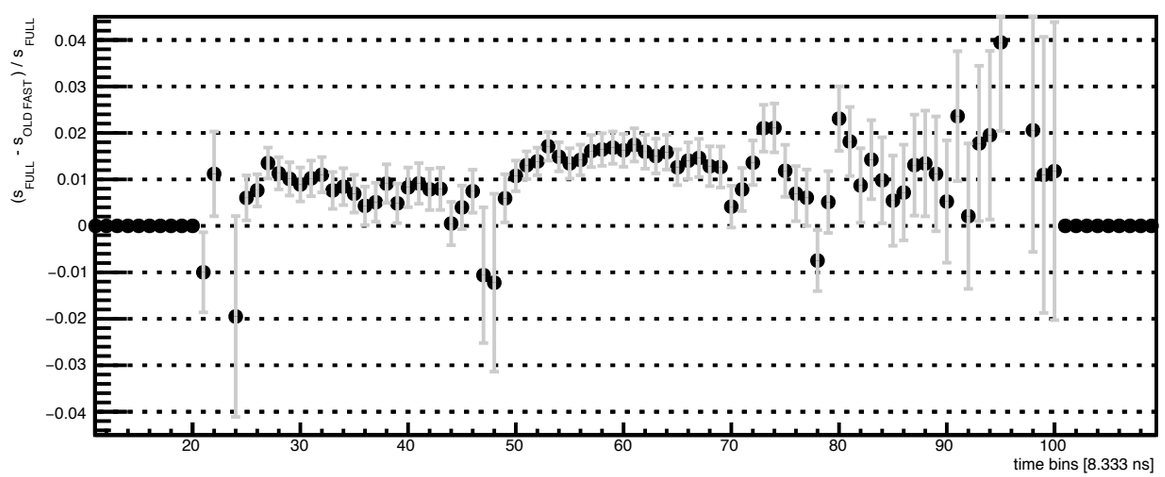


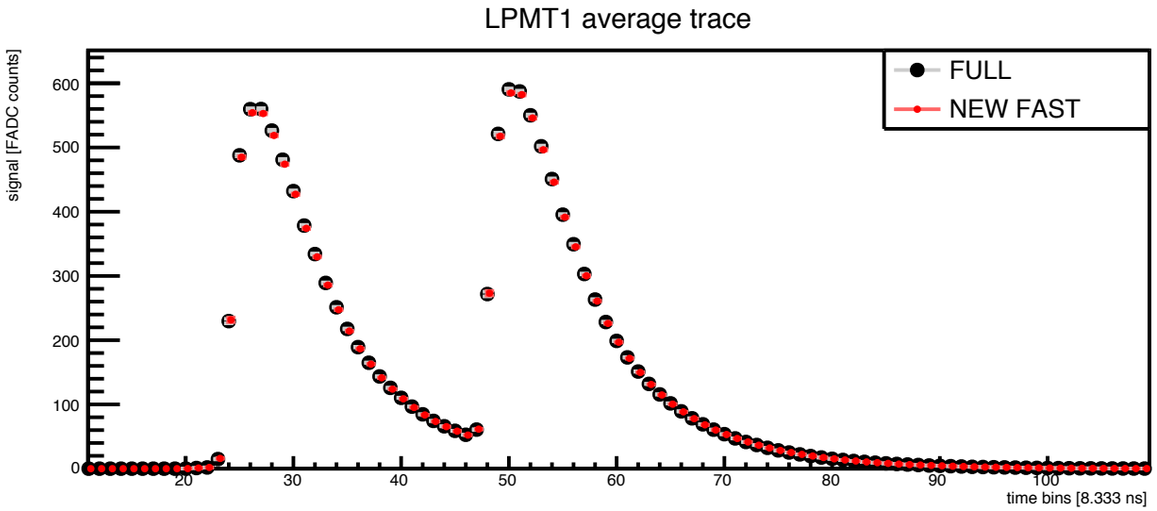



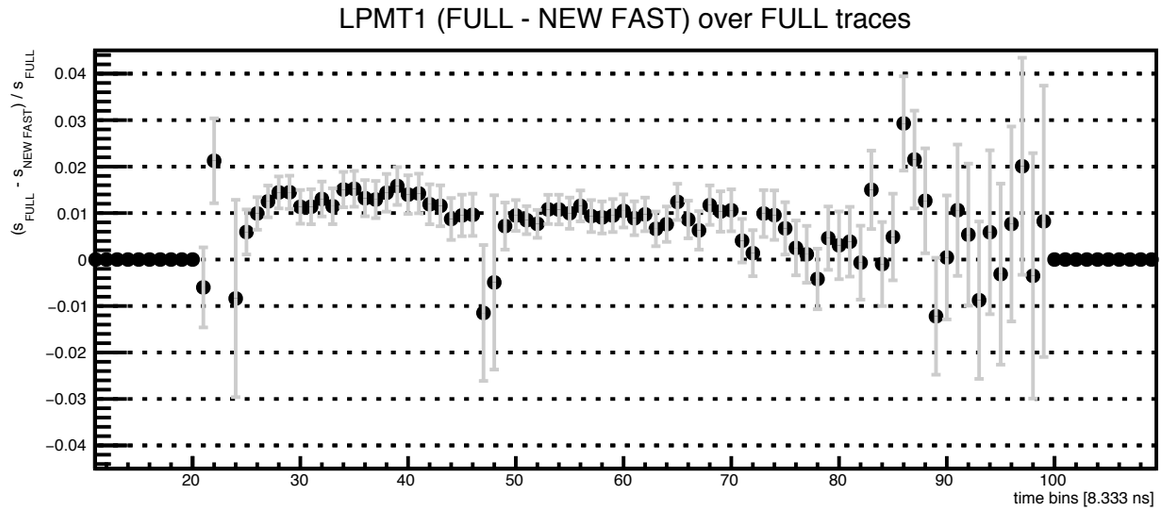



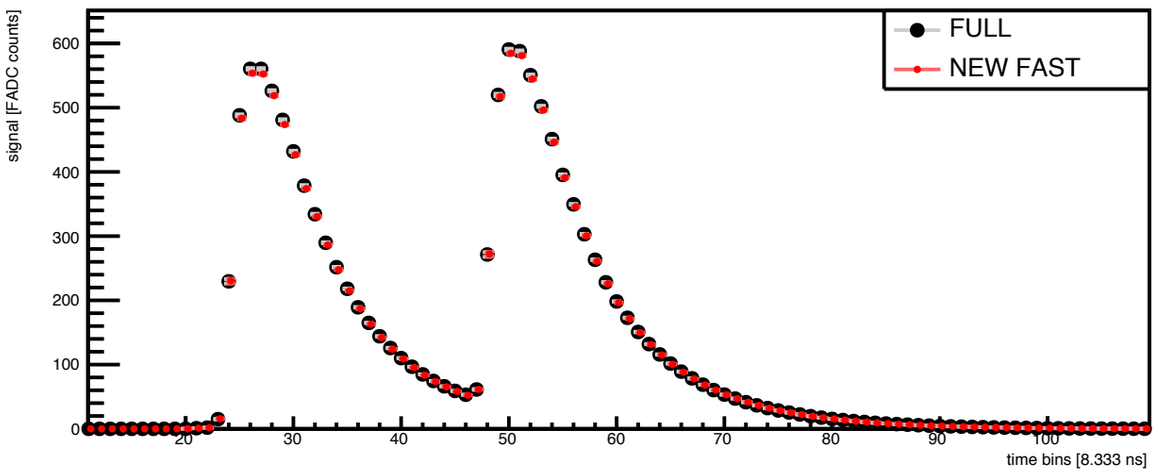



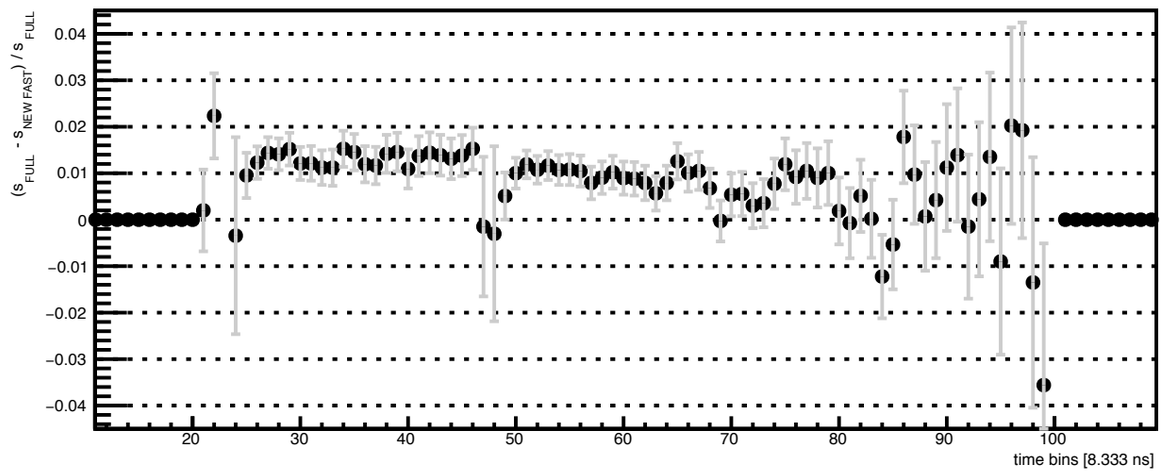



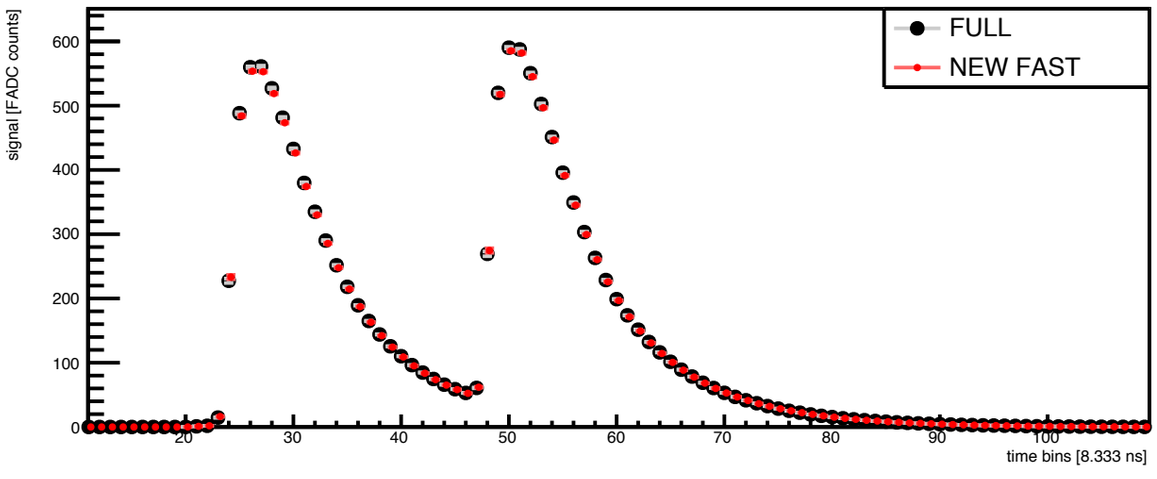
# 250 muons traces - FULL vs NEW FAST

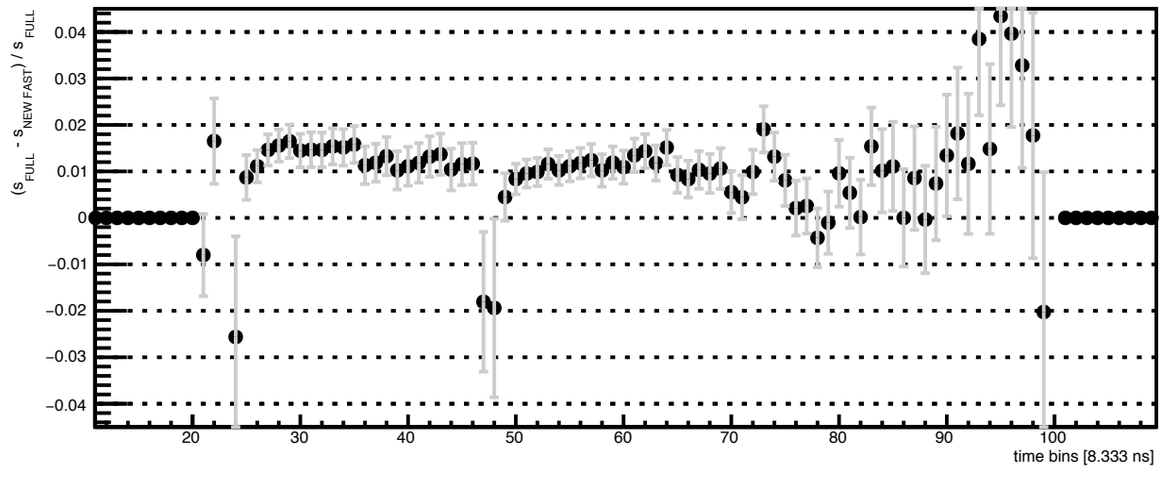


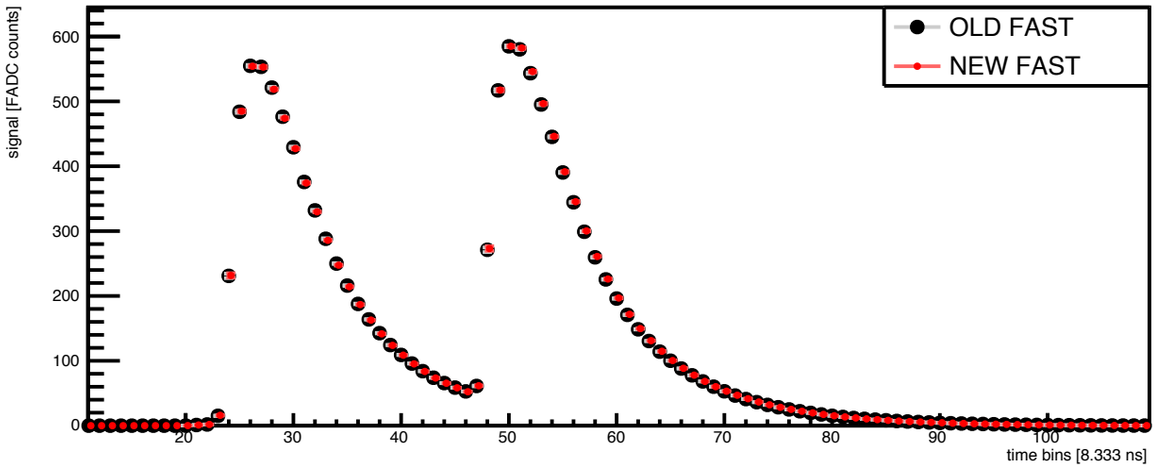



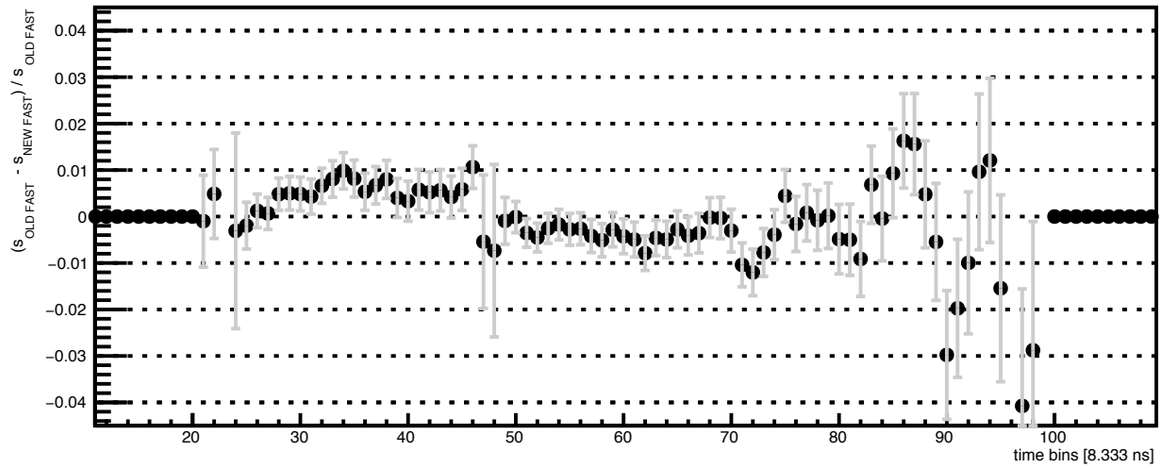



# 250 muons traces - OLD FAST vs NEW FAST

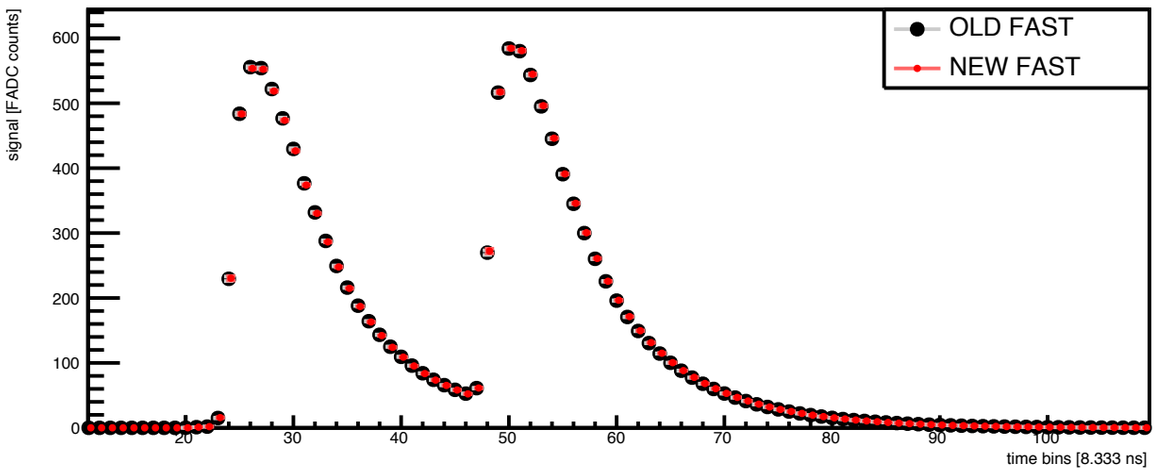
LPMT1 average trace



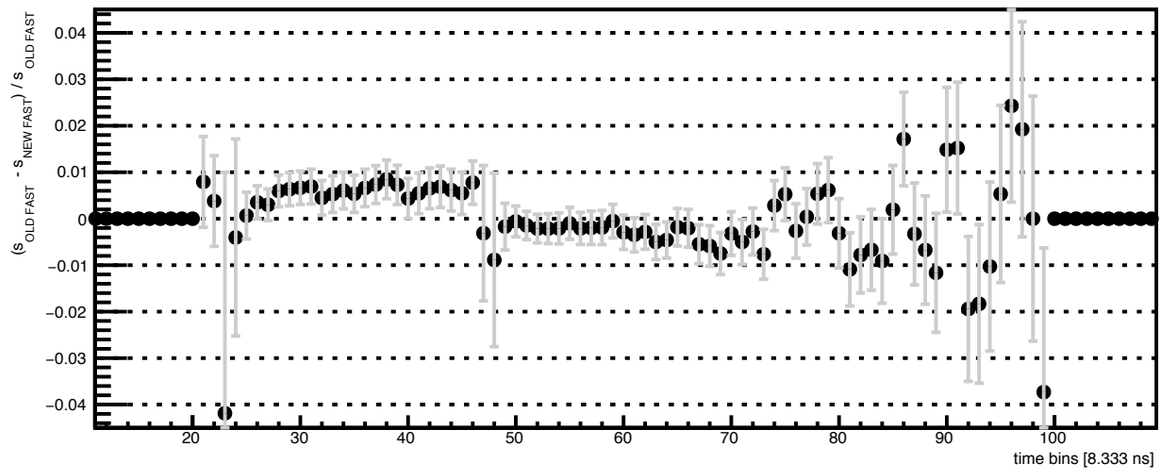

LPMT1 (OLD FAST - NEW FAST) over OLD FAST traces



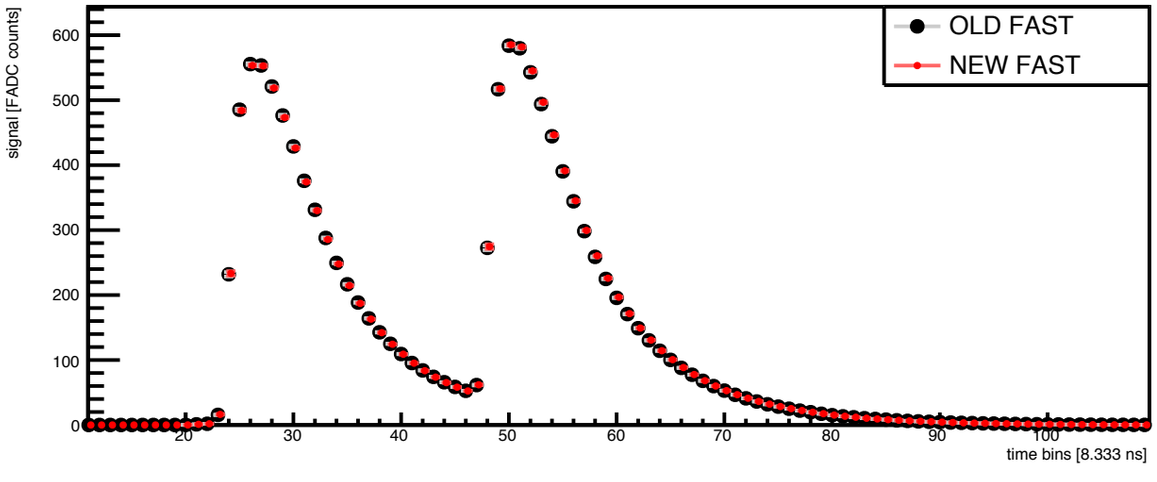

LPMT2 average trace




LPMT2 (OLD FAST - NEW FAST) over OLD FAST traces




LPMT3 average trace




LPMT3 (OLD FAST - NEW FAST) over OLD FAST traces