Istituto Nazionale di Fisica Nucleare
Sezione di Catania

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Sezione di Torino

SPMT commissioning status

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AugerPrime SDEU F2F meeting
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Summary

Total number of SPMT units to be installed : 1510

✓ 1477 already installed

✤ 33 missing (25 in forbidden areas, 8 due to problematic installation)

✓ only 16 SPMTs with hardware issues since beginning of the deployment.

See Antonella's slides at the ORR SDEU session for detailed information.

The SPMT commissioning mainly includes :

- HV setting and cross-calibration
  (for the extension of the WCD signal dynamic range)
- inclusion in the SD reconstruction
- monitoring of
  - SPMTs units (from *SlowControl*)
  - small showers acquisition
  - SPMT cross-calibration

Reference GAP for
SPMT cross-calibration
GAP2022_018

Dynamic range

Automatic setting (see backup for details)

-> SPMT HV to reach S_{max} = 22,500 VEM <-

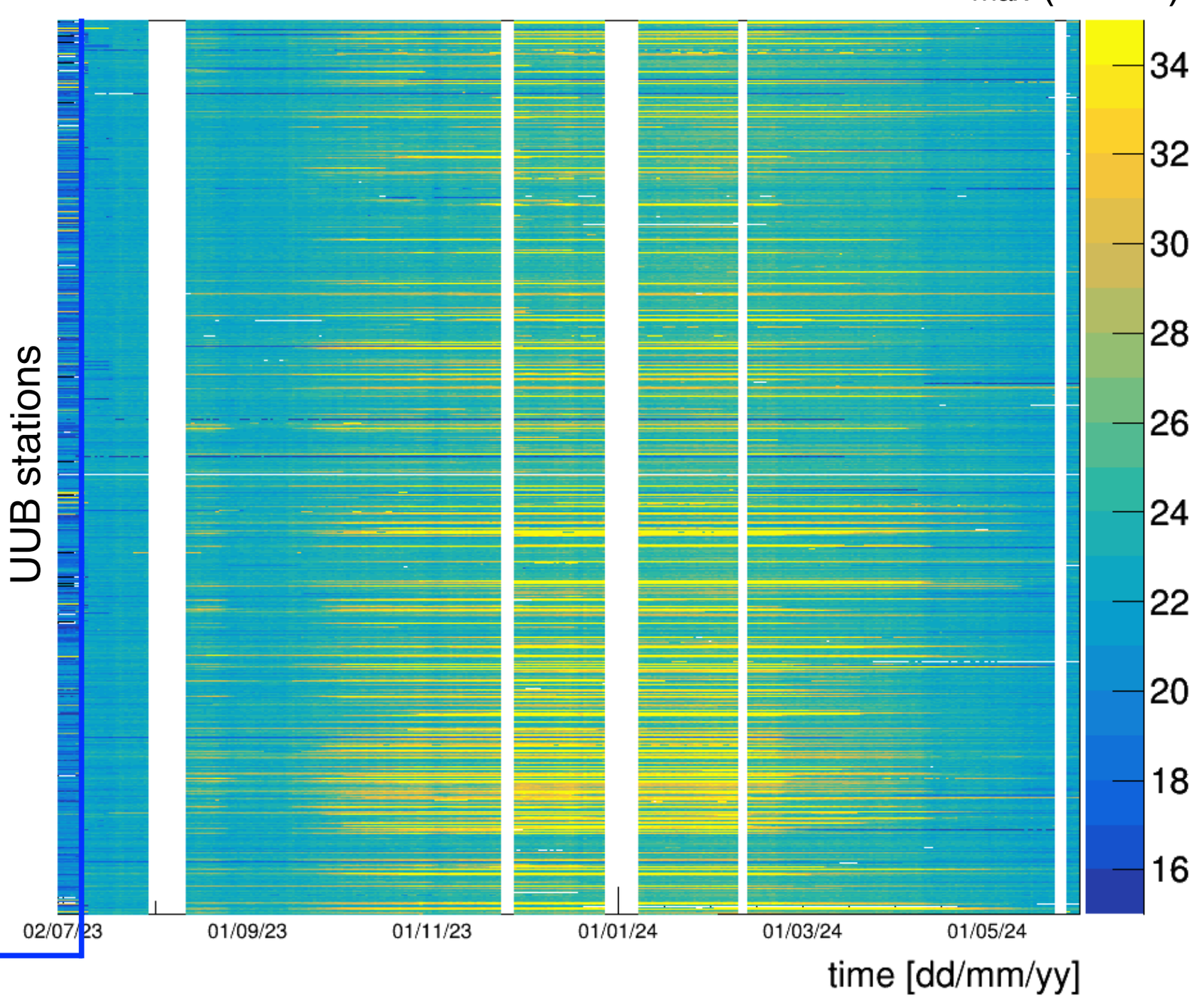
Maximum signal without saturation S_{max} estimated using small showers data

Procedure successful in almost all SPMTs !

~1% failure, due to:

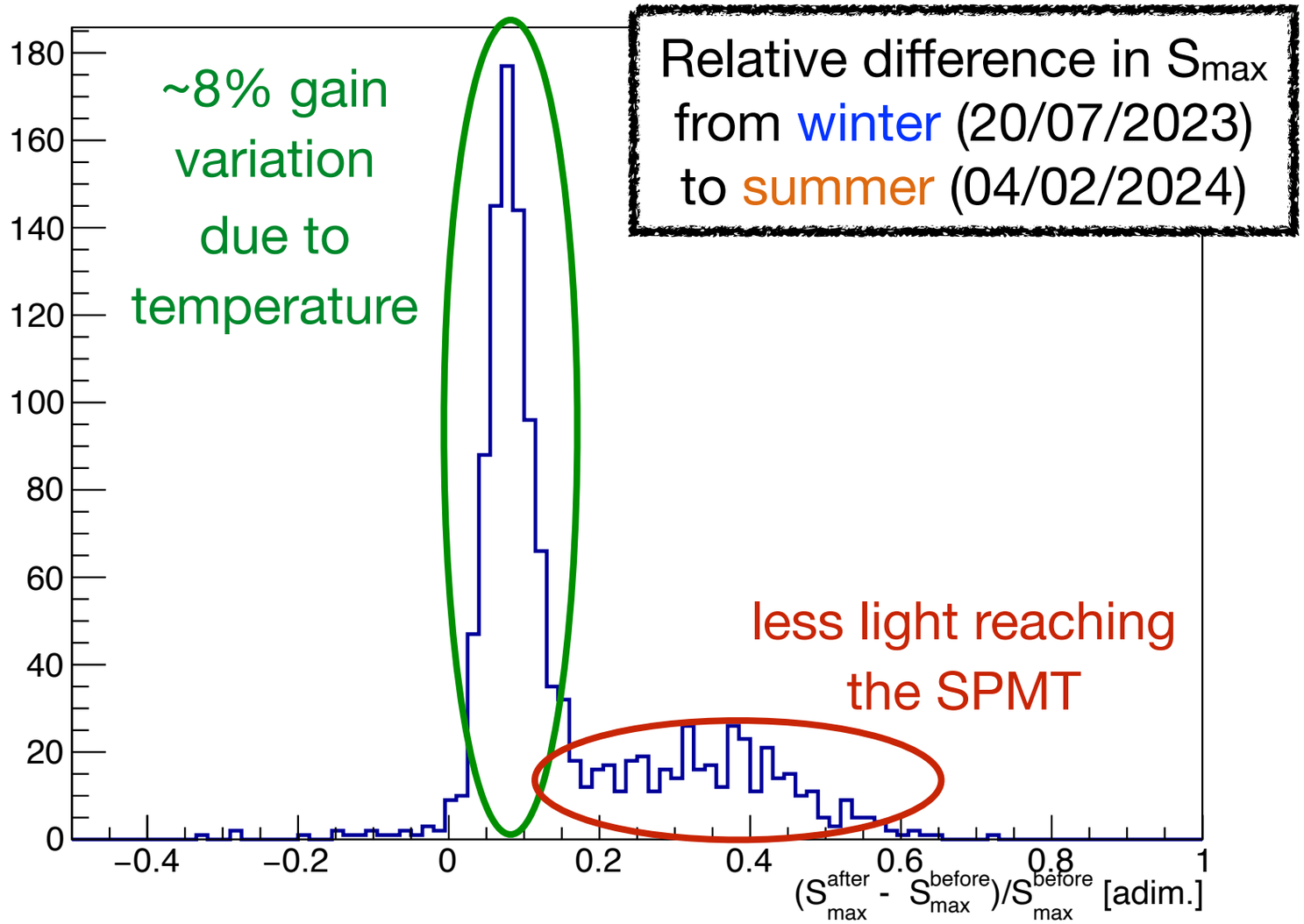
- presence of a non-masked but malfunctioning LPMT
- (rarely) instabilities in the data acquisition

07/07/2023 : UUB-DAQ software update including the automatic HV setting

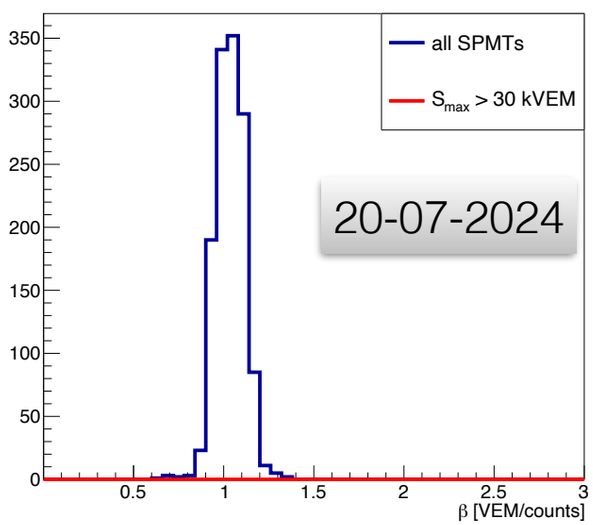


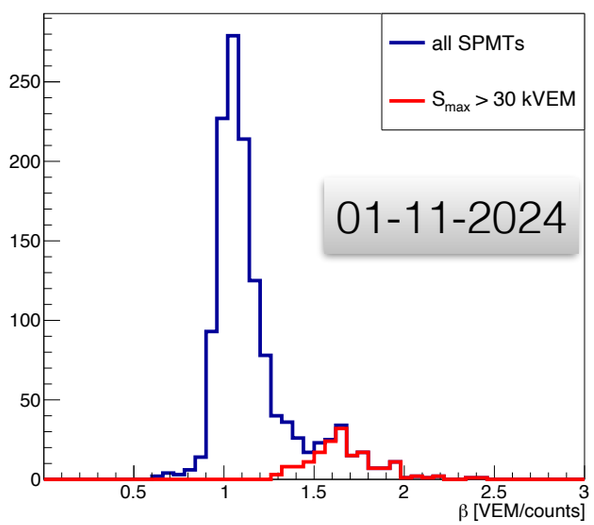
Performance of the cross-calibration

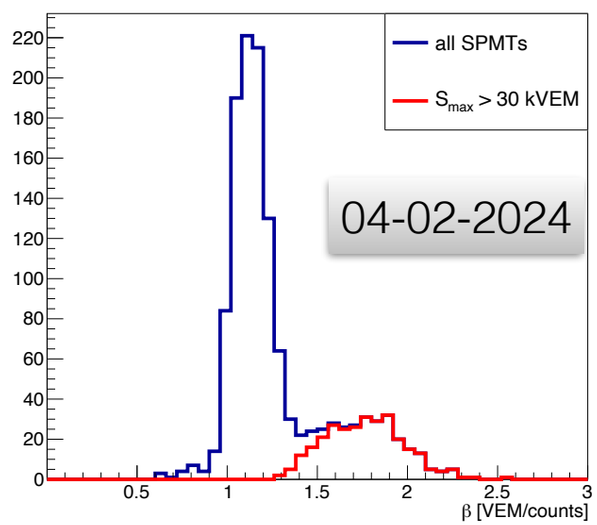
- **SPMTs nicely working in ~80% of station**
  - ✳ variation with temperature (~0.4%/°C) within expectations
- **decrease in measured light for ~20% of SPMTs**
  - ➡ <u>seasonal behavior</u> (see also next slides)

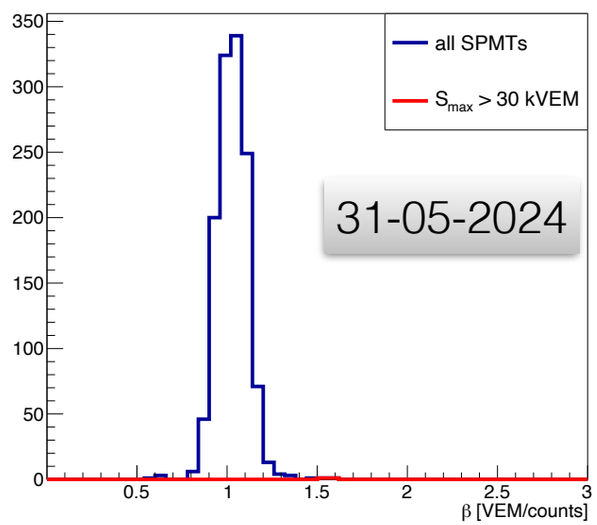


↓ Less light ⟹ larger cross-calibration factor β ↓

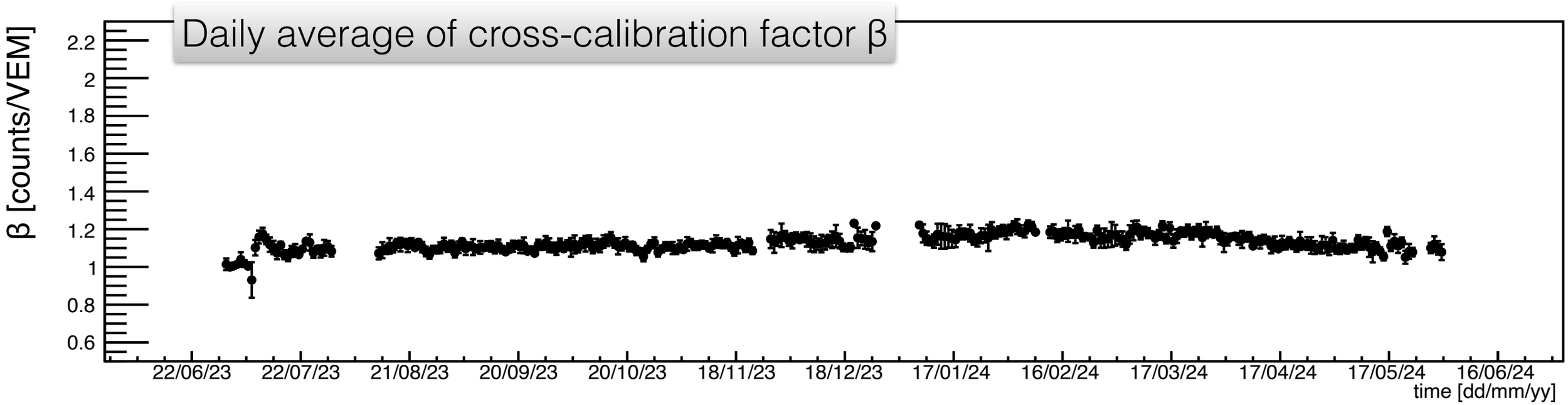




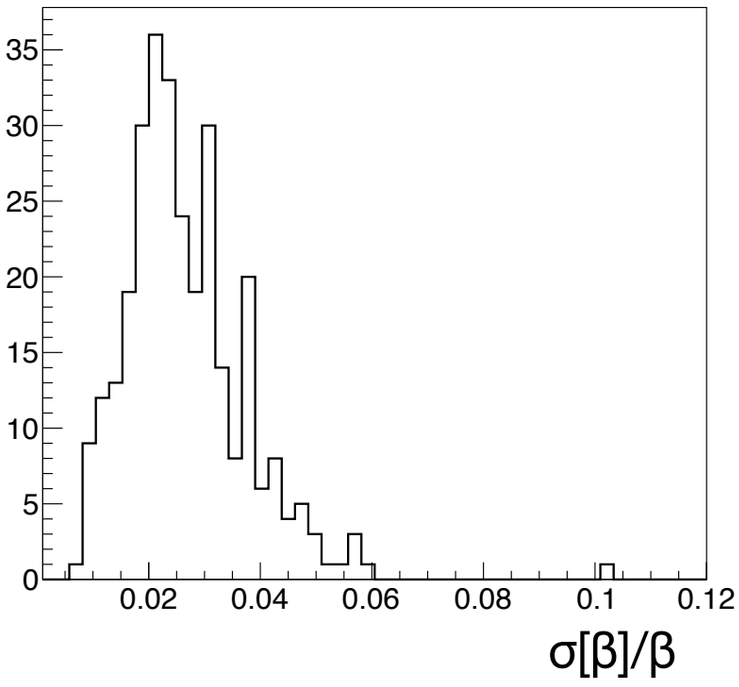




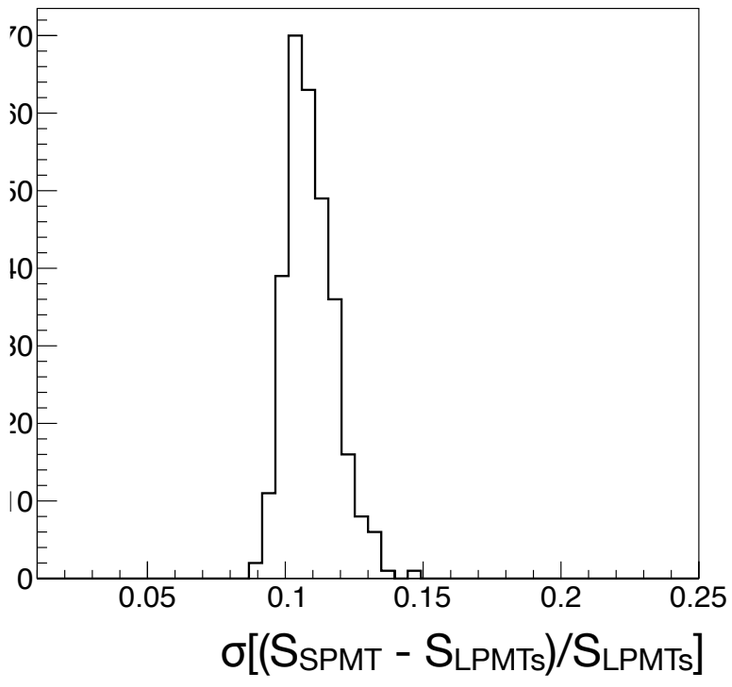
Stable cross-calibration (example LsId 433)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.

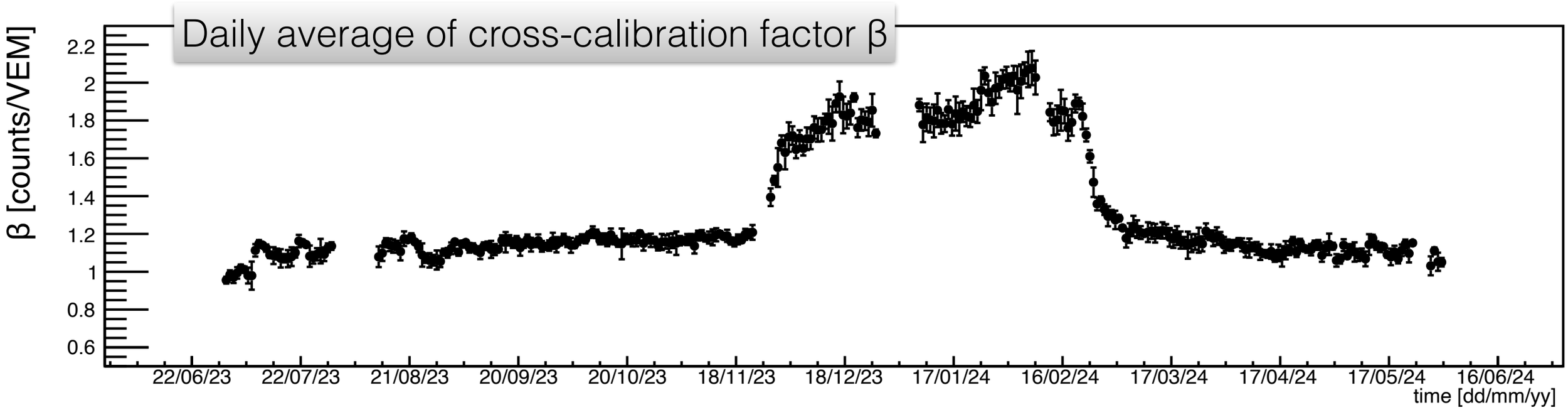


SPMT in a good station

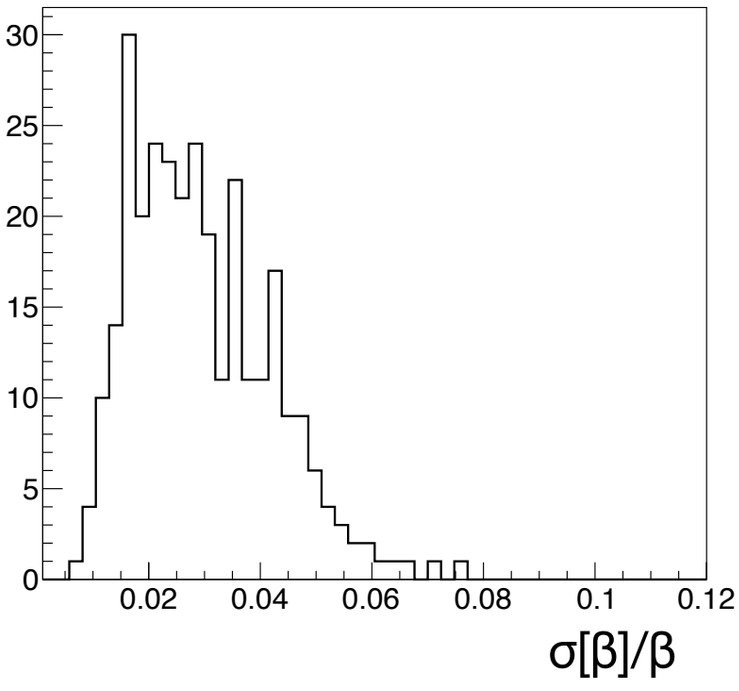
$\sigma[\beta]/\beta < 4\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}]$ ~ 10-12%

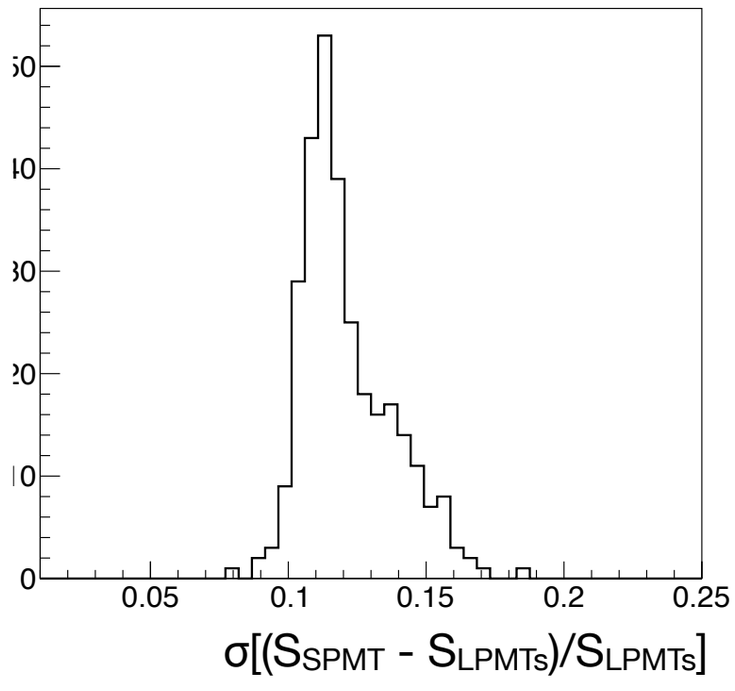
Deficit in the light at the SPMT (example LsId 822)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.



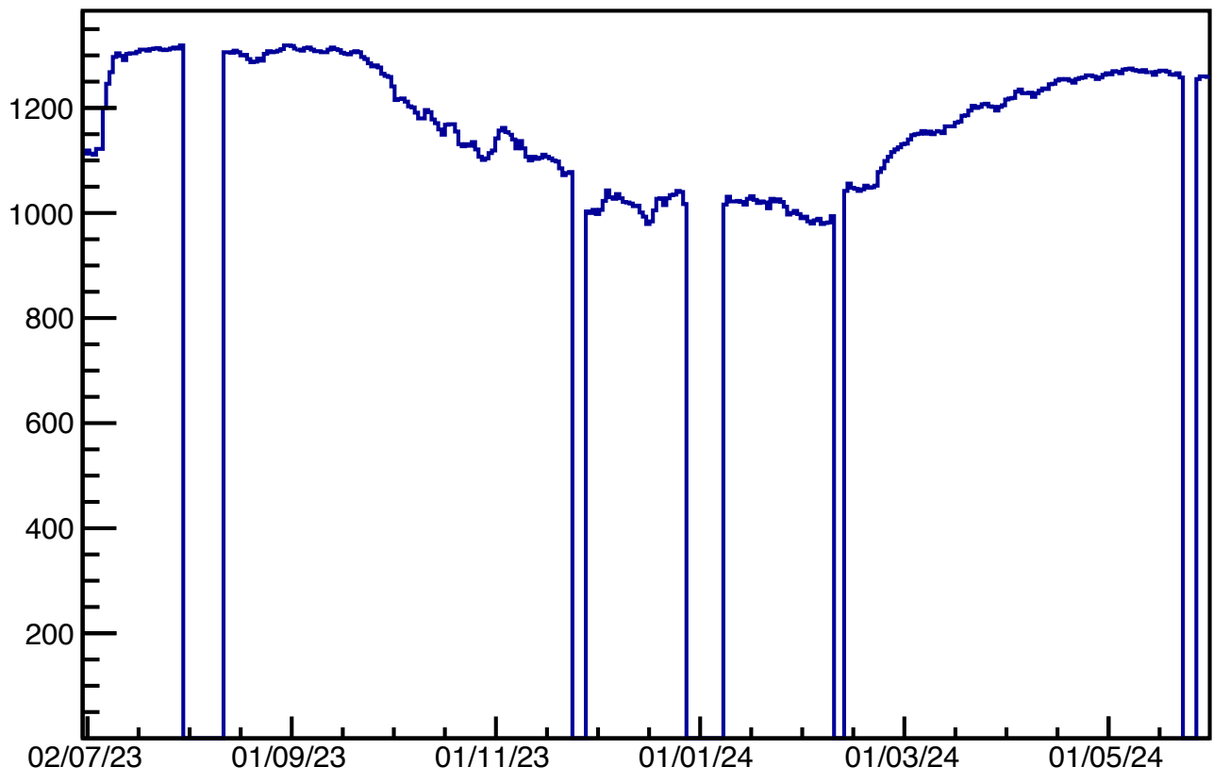
When the light reaching the SPMT reduces…

$\sigma[\beta]/\beta < 6\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}]$ ~ 13-15%

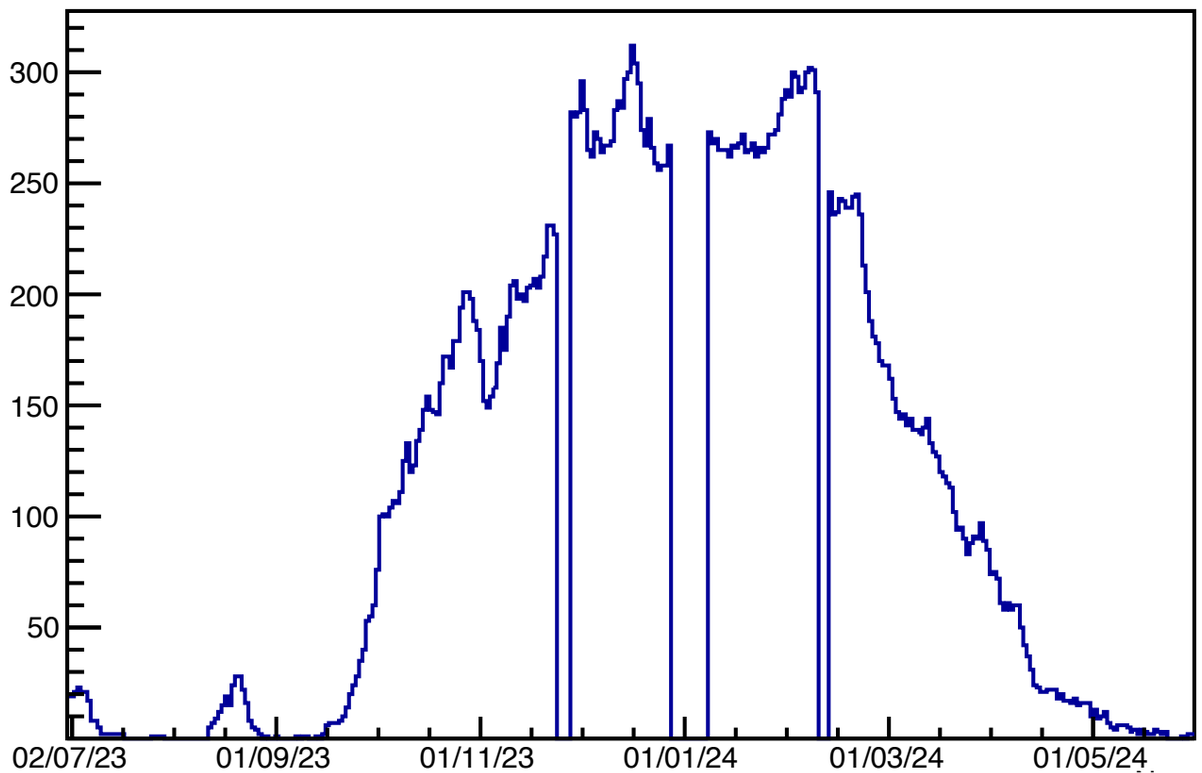
Evolution in time

Number of tanks with $S_{max} \in [15, 30]$ kVEM



Generally good & stable SPMTs

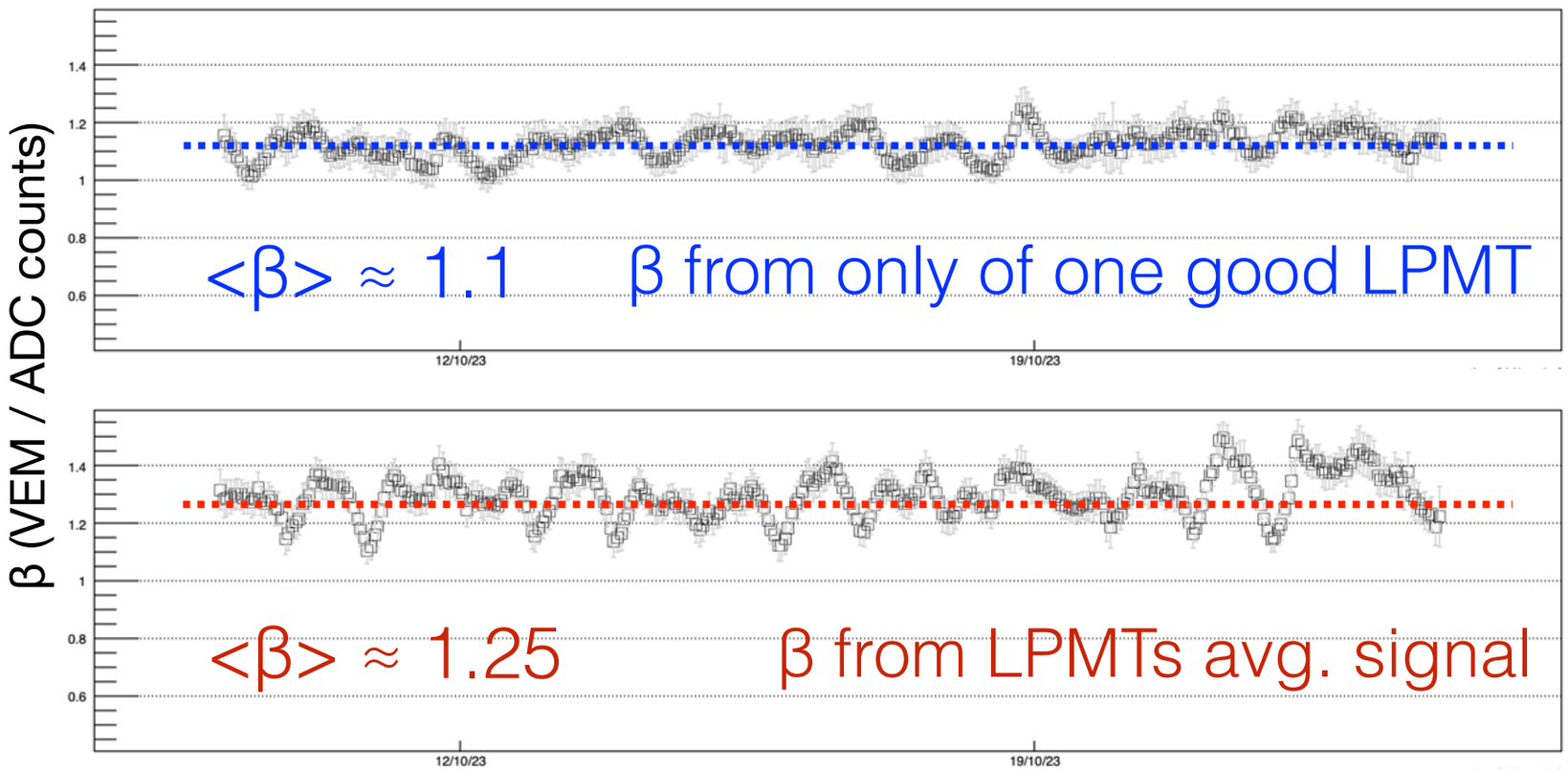
Number of tanks with $S_{max} > 30$ kVEM



Reduction of light at the SPMT

- **Clearly seasonal effect (even if its origin is not fully understood)**
- **Cross-calibration always performed**
  (effect on accuracy of the final calibrated signal to be studied)
- Monitoring of this issue under development

Issues with non-masked but malfunctioning LPMTs

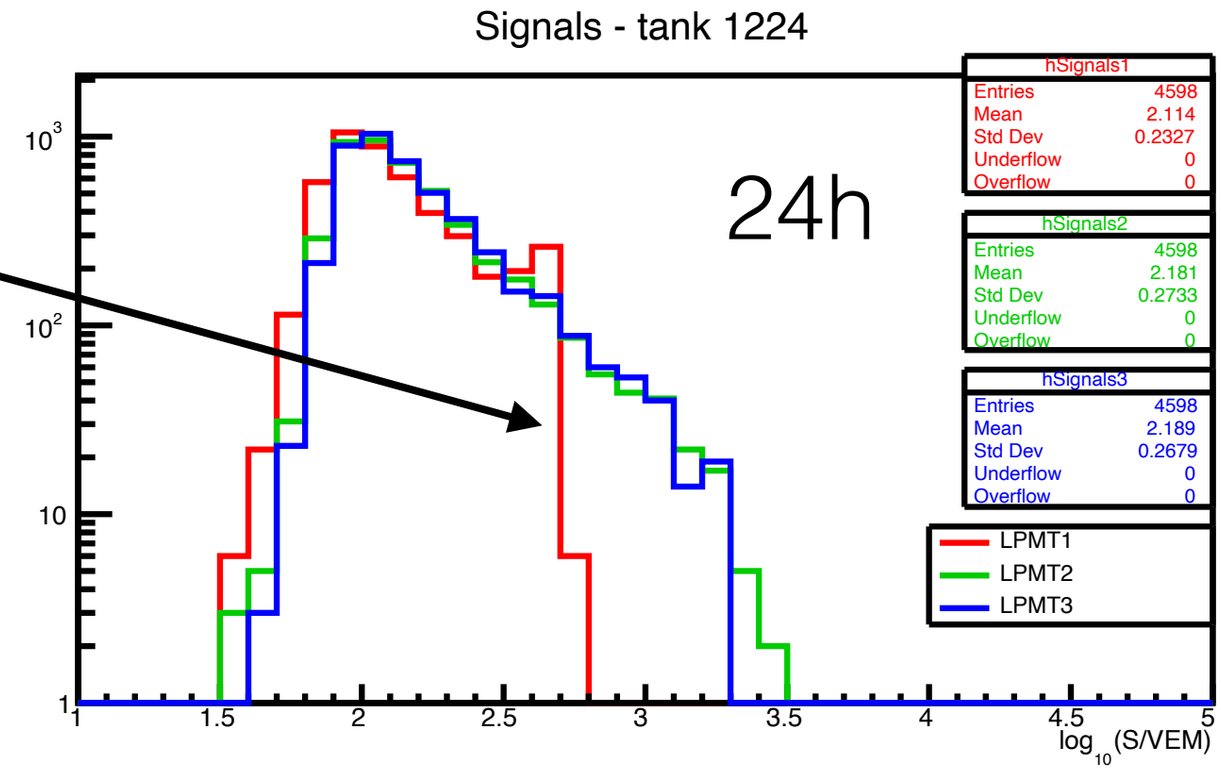


- Non-masked but bad LPMTs spoil the cross-calibration in ~3% of stations (link).

✓ Issue mitigated in the latest Offline tag with additional checks during the SD rec.

➡ To be implemented : selection based on signal spectra from the small shower dataset.

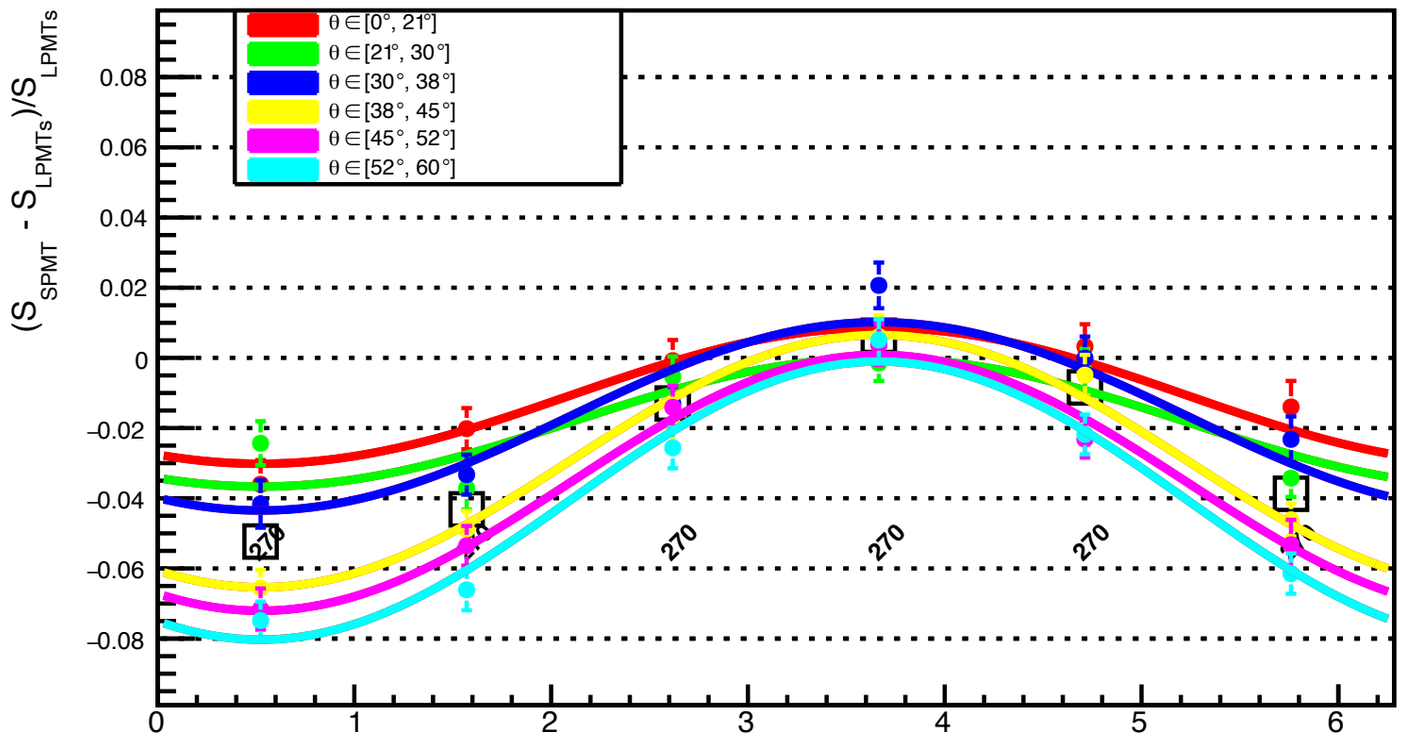
➡ For better performances also the (new) standard quality cuts for UUB LPMTs are needed.



Modulations in zenith and azimuth

★ From simulated showers:

- azimuth modulations due to the non-central SPMT location;
- zenith modulations due to the differences in the PMT geometries.



★ Currently parameterized and corrected in SD rec. **during the LDF fit.**

SPMT corrected signal

$$S_{corrected} = S_{SPMT} \;/\; C(\theta, \phi)$$

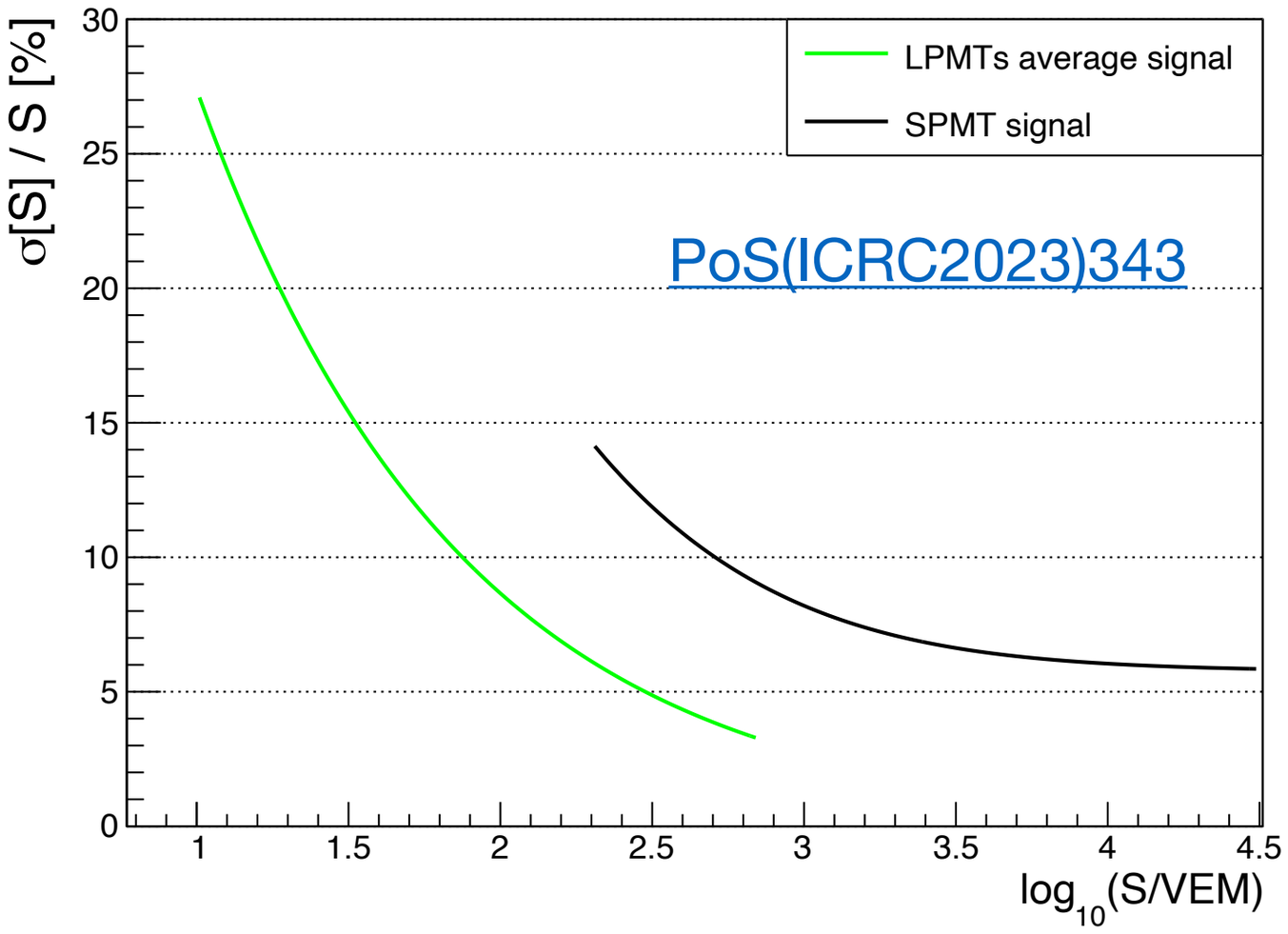
$$C(\theta, \phi) = 1 + Z(\theta) + A(\theta)\cos(\phi - 30^{\circ})$$

$$Z(\theta) = z_1 \sin^2\theta$$

$$A(\theta) = a_1 \sin\theta$$

with z_1 = -0.056 , a_1 = -0.0506

SPMT signal accuracy



Relative SPMT signal accuracy

(GAP2022_018)

$$\frac{\sigma_{S_{SPMT}}}{S_{SPMT}} = \sqrt{a^2 + \frac{b^2}{S_{SPMT}}}$$

- evaluated using 1 month of small showers data from 300 SPMTs:

$$a = (5.8 \pm 1.1)\,\%$$

$$b = (1.8 \pm 0.2)\ \mathrm{VEM}^{1/2}$$

✓ consistent results obtained with simulations of UHE p/Fe-initiated showers in UUB twin stations

SPMT signal (relative) accuracy:

- **~10% @ LPMTs saturation**
- **~6% @ highest signals**

✓ implemented in the Offline

★ Extrapolated maximum bias at highest signals: (2.8 ± 2.0)%

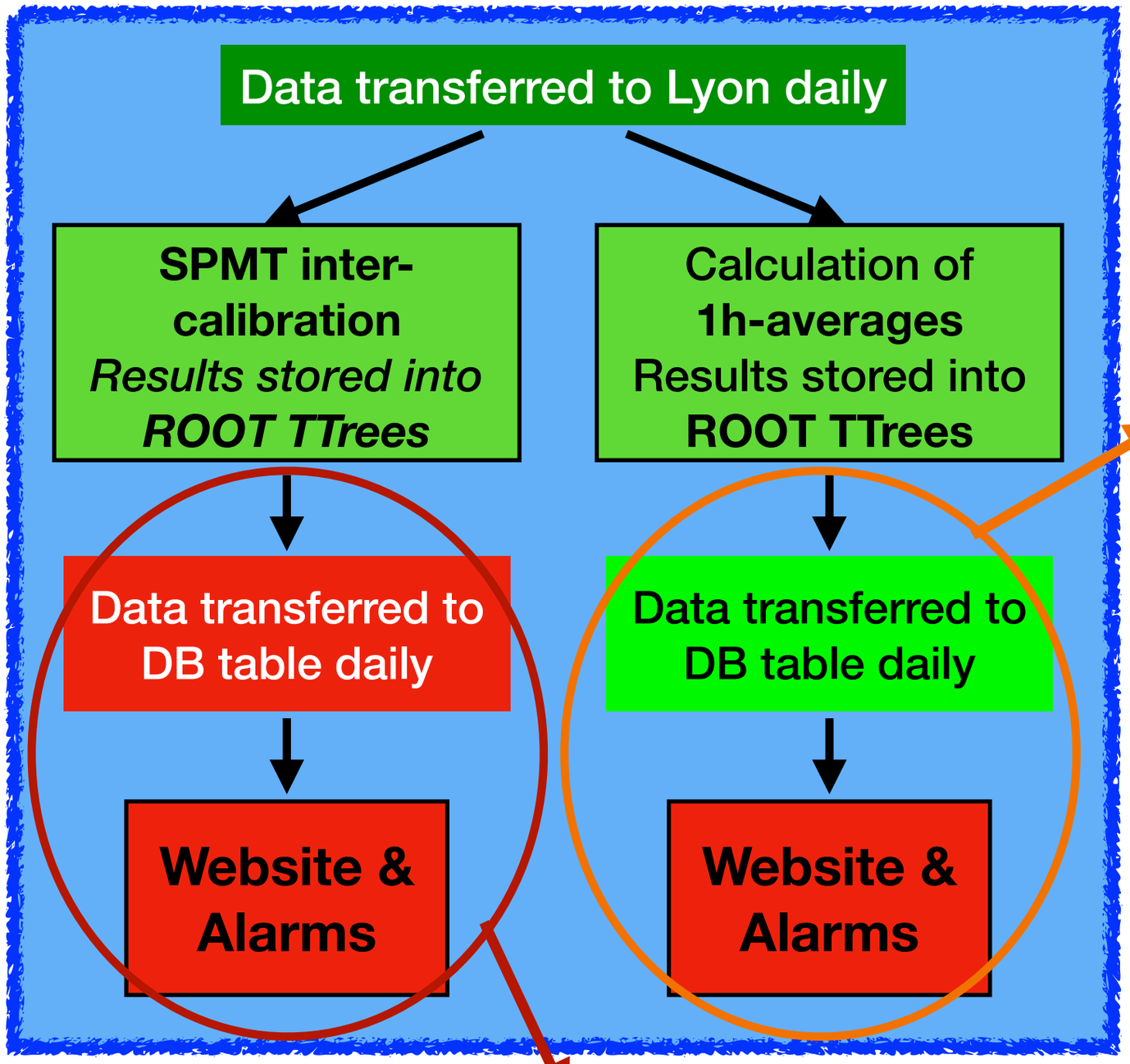
Other Offline & reconstruction infos

- SD event **production v2r4** (which includes the SPMT cross-calibration) available starting from 03/08/2022.
- SPMT included in simulations (see *Offline call 24/04/2023*, download).
- SPMT signal integrated 5 bins (~42 ns) before the LPMTs start bin due to delay > 30 ns of the LPMTs (*see backup for more details*).
- Code for including SPMT signal in the LDF fit already implemented (see *Offline call 28/08/2023*, download) **but currently in the LDFFinder XMLs** `useSPMTSignal = false`.
- In the latest Offline tag, the calibrated and corrected SPMT signal is stored in the standard ADST *PMTRecData*

  `signal_spmt = station.GetPMTTraces(eTotalTrace,4).GetVEMSignal()`

  where `station` is an ADST *SdRecStation* object.

SPMT monitoring



Monitoring of **SPMT inter-calibration & dynamic range extension** performed manually (codes not in public repositories).

Monitoring of small showers acquisition *partially* implemented

➡ codes under ***augermonitoring***

- calculation of 1h-averages
- filling of the MonitSmallShowers table (see also slide in backup)

- **alarms under development**

"*Hardware*" (i.e. SlowControl) monitoring in common with the other components.

➡ alarms missing for all AugerPrime detectors

➡ should add check of SPMT I_{mon}/V_{mon} *ratio*

Conclusions and outlook

In the vast majority of the array, the SPMT is working and extending the signal dynamic range with optimal performances.

Work still needed to

- ➡ finalize the small showers' acquisition monitoring
- ➡ implement a monitoring of the cross-calibration procedure
- ➡ study the SPMT signal in the SD reconstruction, including:
  - switching from saturated LPMTs to SPMT (currently implemented as discussed here)
  - biases with respect to the current LDF parametrization
  - accuracy in the core determination
  - effect on S1000 —> energy
  - …

Final note : small showers can be used also for monitoring & commissioning of LPMTs (and SSD) given their rate of ~200 evts/h

Backup

Small showers acquisition

Small showers selection in each Local Station

Stream data every hour to CDAS

@ CDAS
(i) decompress small showers data-stream
(ii) storage into “monitoring-like” ROOT files

Data transfer to Lyon every day

@ Lyon (cca-in2p3)
Small showers analysis and β calculation

Calibration :
add β in SD data during merging

Monitoring :
add values (daily) to new DB table

Small showers stored by CDAS-DAQ in one *spmt_yyyy_mm_dd.root* file per day with data from ~00:00 to ~23:59 of dd/mm/yyyy **from the whole array (< 300 MB/day).**

Small shower = T1 event selected as (n-1)-fold coincidence among unmasked LPMTs (tuning individual thresholds)

	Variables	Freq.
EVENT info	GPS time	**~ 200/h** (~ 400/h with a masked LPMT)
	event enumerator	
	AREA_PEAK_SATUR x 6 (LPMT1-2-3 / sPMT / SSD LG-HG)	
MUON info	GPS sec	~ 1 / min
	LPMT VEM charge x 3 (from histograms, custom process)	
	SSD MIP charge	
DAQ info	GPS sec	~ 1 / 5 min
	LPMTs masked status	
	HG/LG ratio x 3	
	LPMT threshold x 3	
	online VEM (peak) x 3	

Codes in the SDEU/UUB/daq and CDAS-DAQ repositories

SPMT HV setting

GOAL : set the HV allowing to measure signals <u>without saturation</u> at least up to 20,000 VEM

Saturation determined by the FADC dynamic range

$$\text{d.r.} = 4095 \text{ - baseline} \sim 3845 \text{ FADC counts}$$

In first approximation $Q_{max} = AoP_{ref} \times d.r.$

Thus, for the SPMT signal $S_{max} = AoP_{ref} \times d.r. \times \beta$

where AoP_{ref} is the signal width and β the calibration factor

Procedure performed on-tank using small showers :

- β = harmonic mean of the $S_{\text{LPMTs avg.}}$ / Q_{SPMT} signal ratio
- $AoP_{ref} = \langle AoP \rangle_{small\ showers}$

  (conservative choice : width of signal in standard events larger than in small showers)

✓ **Automatic procedure activated during July 2023**

<u>code maintained</u> in the `SDE/UUB/daq` gitlab repository

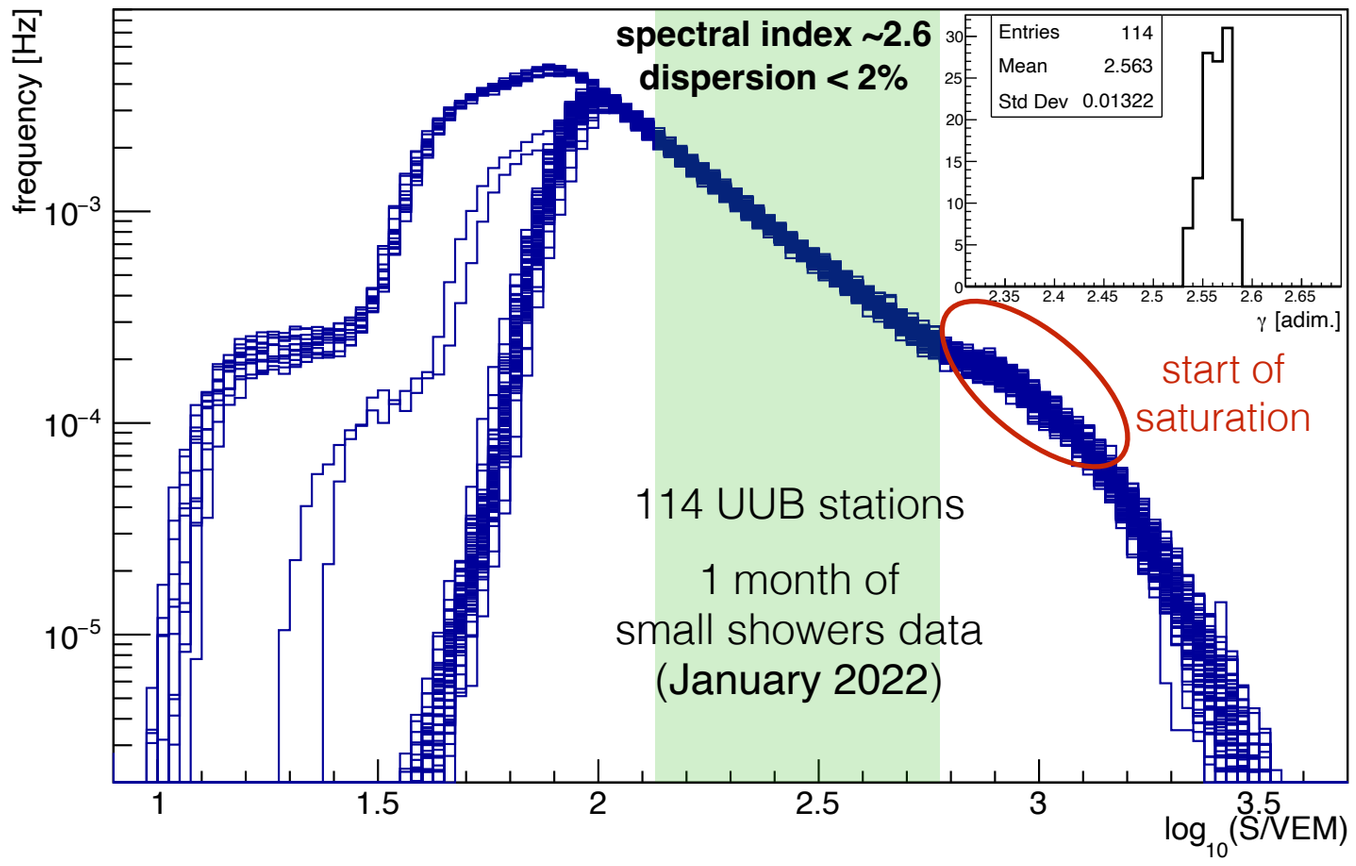
SPMT calibration : spectra comparison method

small showers selection
equal across the array

equal
CR flux

signal spectra in VEM
independent of station

exploit signal spectra as
absolute reference for the SPMT



Find the inter-calibration factor β, defined as

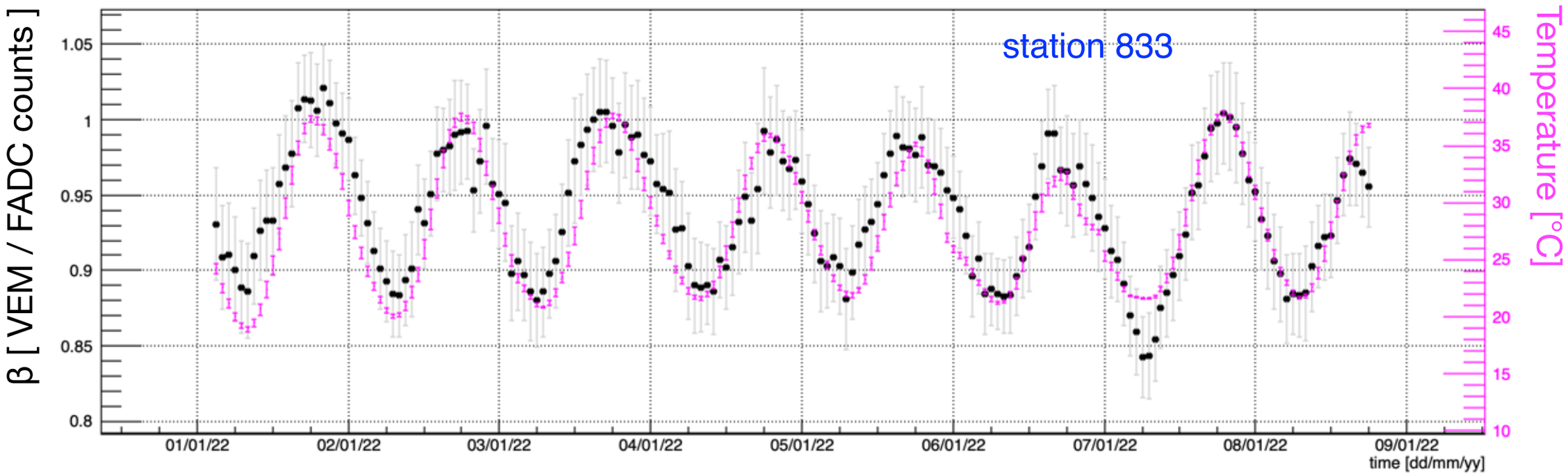
$$S_{SPMT}\ [VEM] = \beta\ Q_{SPMT}\ [FADC\ counts]$$

which minimizes the distance Δ between the LPMTs and SPMT signal spectra in a region of superposition where few LPMT signals are saturated, with

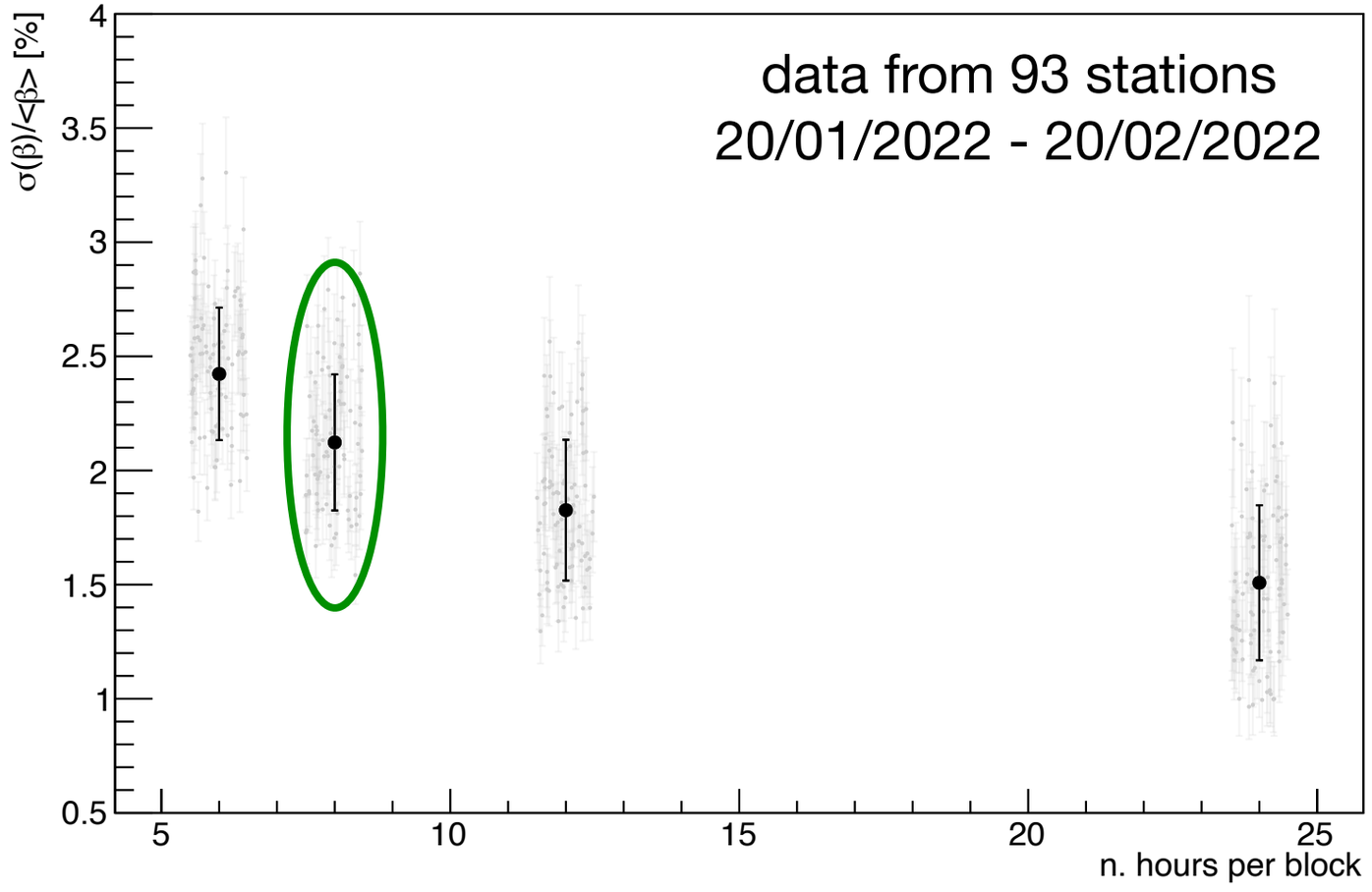
$$\Delta = \sum_{i=1}^{N_{bins}} \frac{(c_i^{LPMT} - c_i^{SPMT})^2}{c_i^{LPMT} + c_i^{SPMT}}$$

Details of the procedure in GAP2022_018 (*link*)

Inter calibration precision



- ✓ β is updated every hour using **sliding intervals** of k hours to **follow the temperature variations**
- ✓ **k = 8 h** **trade-off** between **precision (~2.2%)** and correlation with temperature.



Delay of LPMTs w.r.t. SPMTs

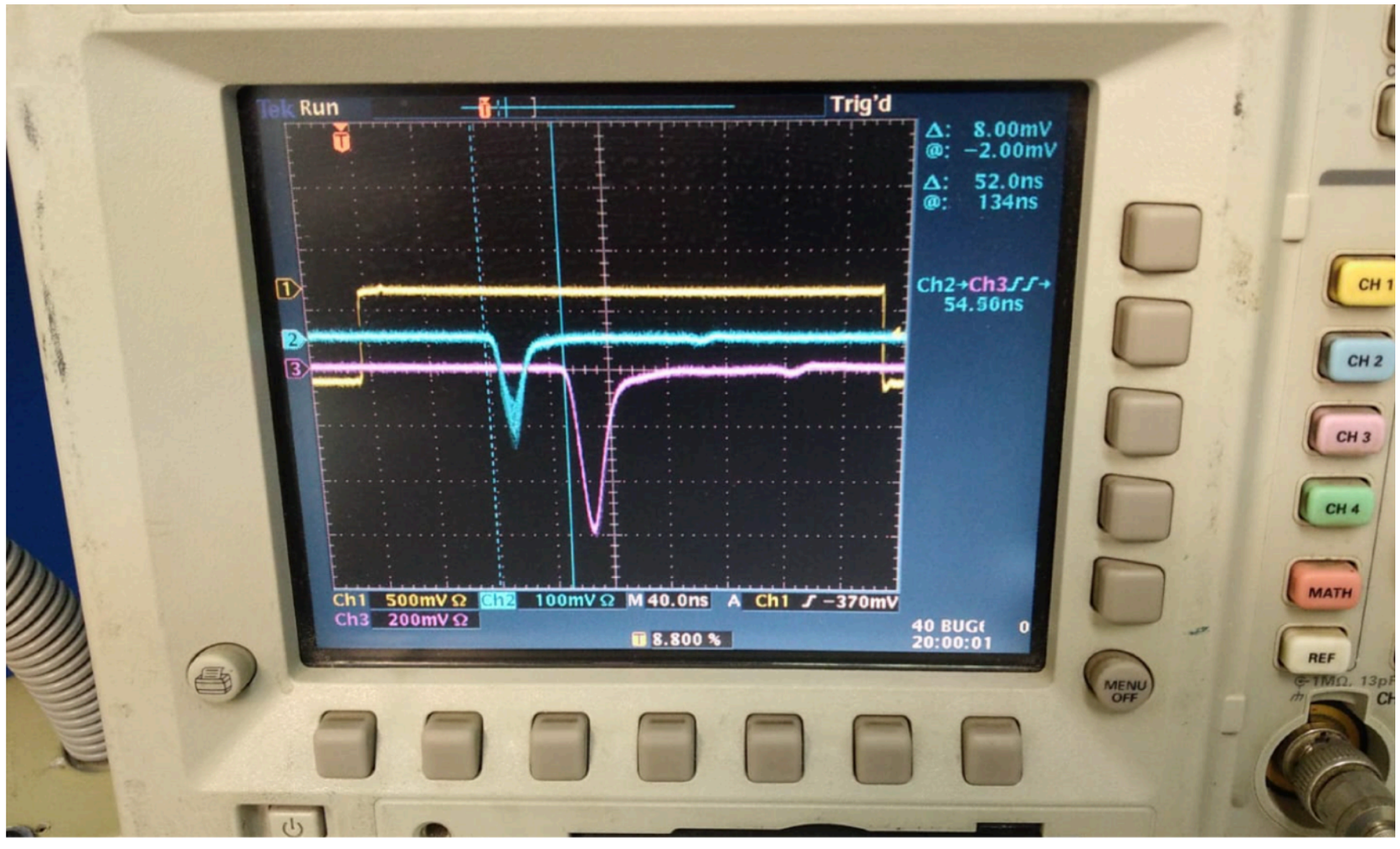
- Difference in the cable lengths:
  l_SPMT = 2.45 m , l_LPMT = 3.6 m **——> 5-6 ns**

- Purely due to photomultipliers (first dynode etc) measured for a couple of LPMT and SPMT in SDeCo (***thanks Juan Pablo!***)
  ——> 28-30 ns

blue = SPMT

pink = LPMT

yellow = trigger



Cross-calibration in CDAS-user & Offline

- ✦ SPMT cross-calibration added in the *IoSdCalibSPMT* class starting from **CDAS-user v6r4** (that is the version used in the latest ape releases).
- ✦ reproduced in the Offline class *SmallPMTCalibData*

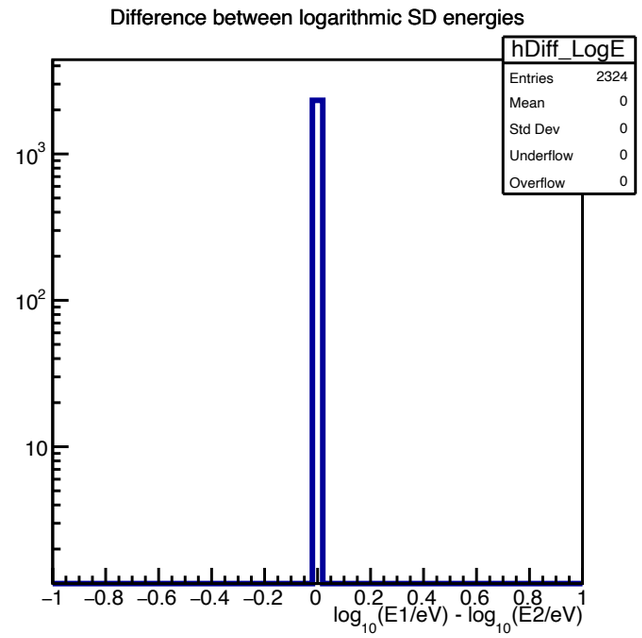
name	definition
station ID, startTime, endTime	LS ID, start & end of the (8h) interval in GPS seconds
uptime	excluding empty intervals longer than *dt* =180 s *dt* based on small showers rate of ~0.055 Hz
event_ratio	% of small showers with $S_{LPMTs\ avg.} > S_{min}$ and $Q_{SPMT} > 10$ FADC counts
β & $\delta(\beta)$ x 4	LPMTs avg. result + one value for each LPMT

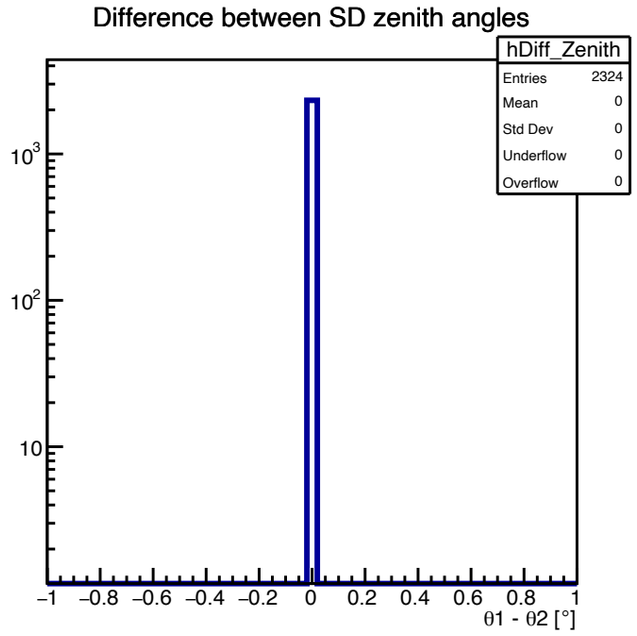
When the cross-calibration is not available, the SPMT signal is not used in the SD reconstruction.

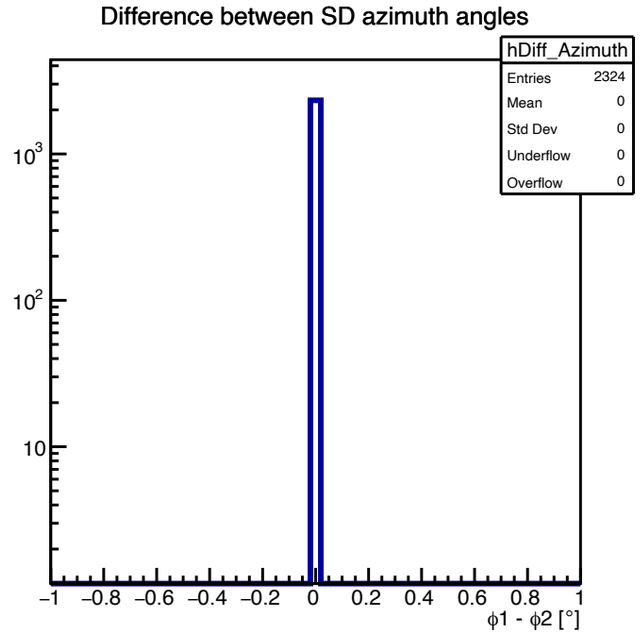
Thus no “SPMT bad periods” are needed at the moment.

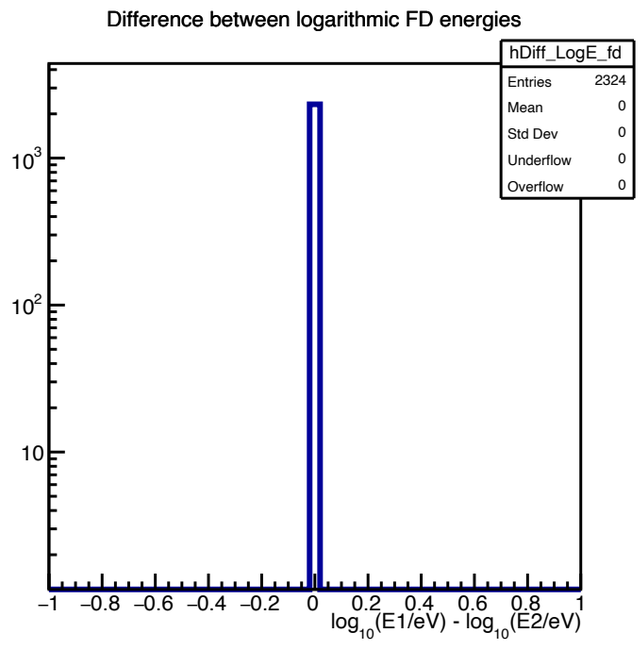
SD event production v2r4

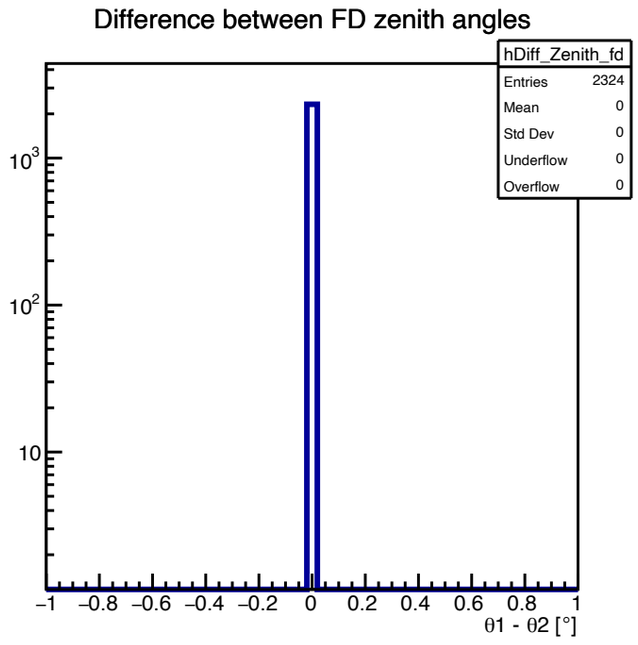
- New production v2r4 verified to give exactly the same results of Prod v2r0 (see presentation at CDAS call on 19/04/2023, slides download).

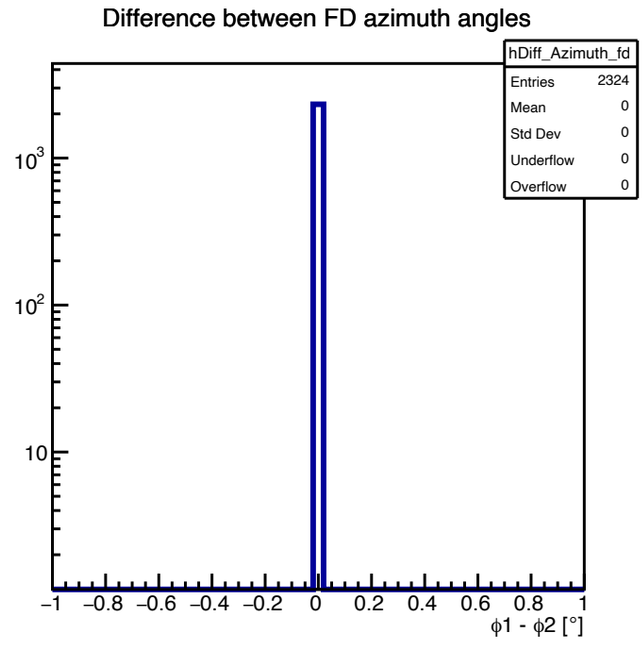












← Differences between reconstruction of Prod-v2r0 and Prod-v2r4 events ←

SPMT codes

- ➡ Small showers acquisition
  - ➡ Local station DAQ: SDEU/UUB/daq
  - ➡ CDAS-DAQ: Apps/SPMT
  - ➡ *example code to read small showers files: spmt_example*

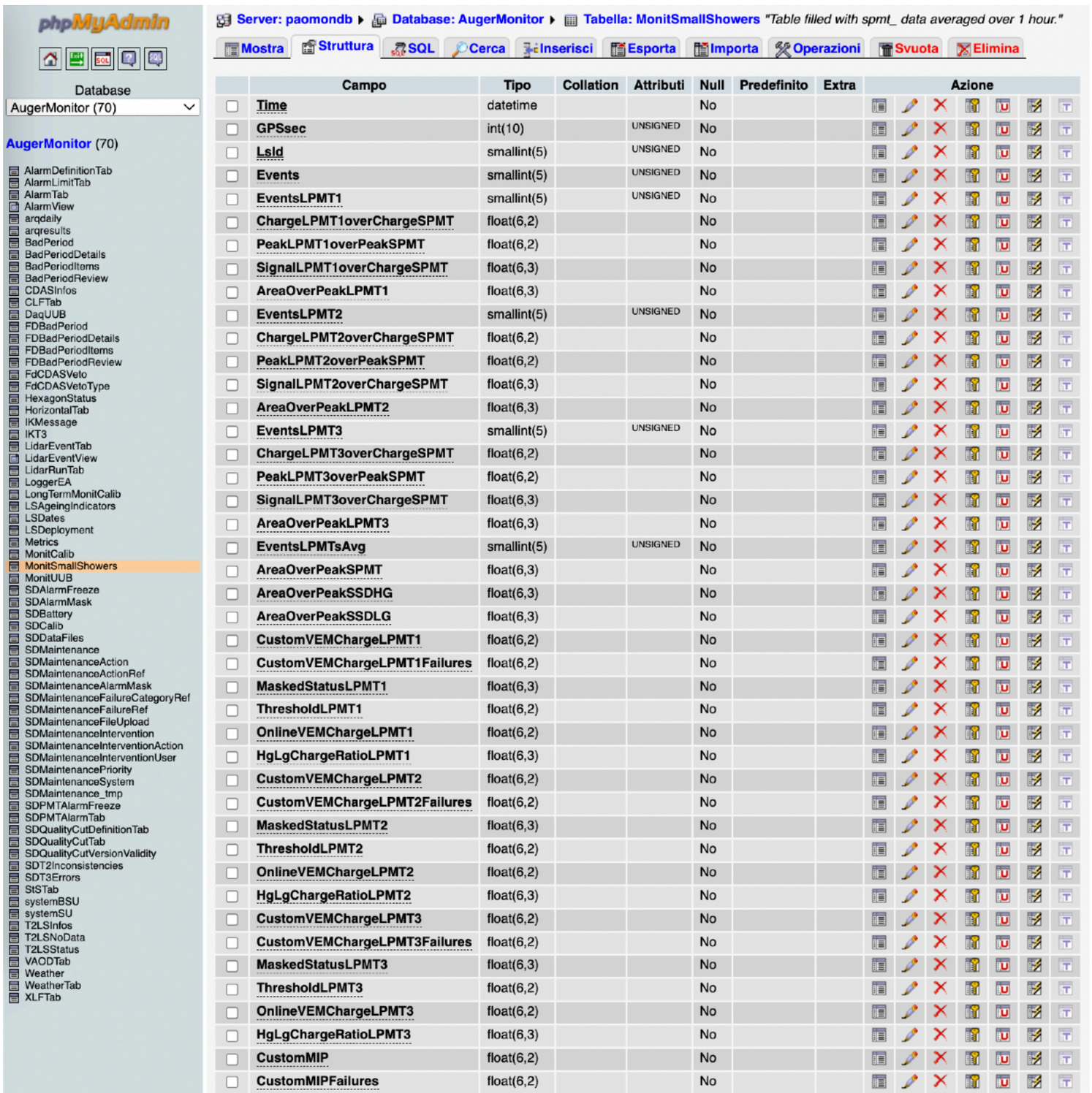
- ➡ SPMT HV setting

- ➡ Small showers acquisition monitoring (running in Lyon)
  - calculation of 1h-averages
  - filling of the MonitSmallShowers table

- ➡ SPMT inter-calibration (running in Lyon)

- ➡ SPMT inter-calibration inclusion in the SD files production (running in Lyon)
  - *IoSdCalibSPMT* class in IoSdData.h & IoSdData.cc
  - SdExtraData.cc & SdExtraData.h

Small showers acquisition monitoring



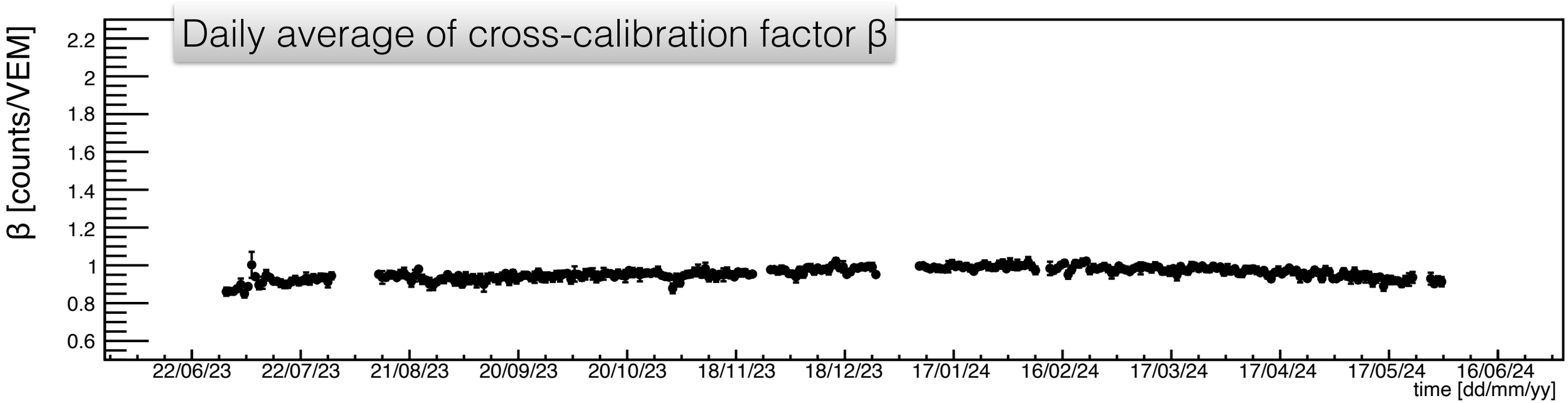
43 variables - 24 entries per day per UUB tank

MonitSmallShowers table added to the _AugerMonitor_ database

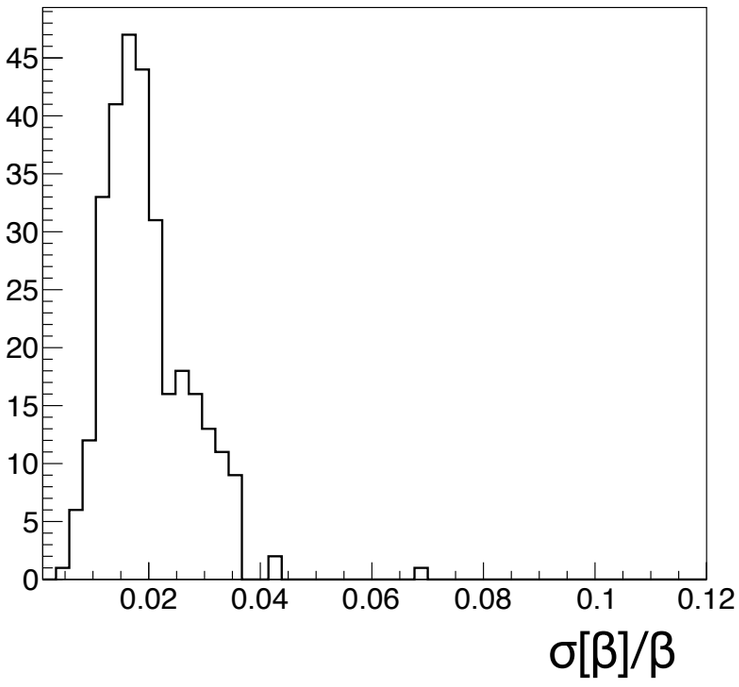
Daily and separately for each tank with a SPMT, one should check :

- presence of acquired data (i.e. number of entries in the table);
- number of small showers (`Events`);
- **then, separately for each LPMT :**
  - masked status (`MaskedStatusLPMT1-2-3`);
  - percentage of failed VEM calibrations using the custom algorithm (`CustomVEMChargeLPMT1-2-3Failures`);
  - number of events above 200 VEM (`EventsLPMT1-2-3`);
  - LPMT signal over SPMT charge ratio (`SignalLPMT1-2-3overChargeSPMT`).

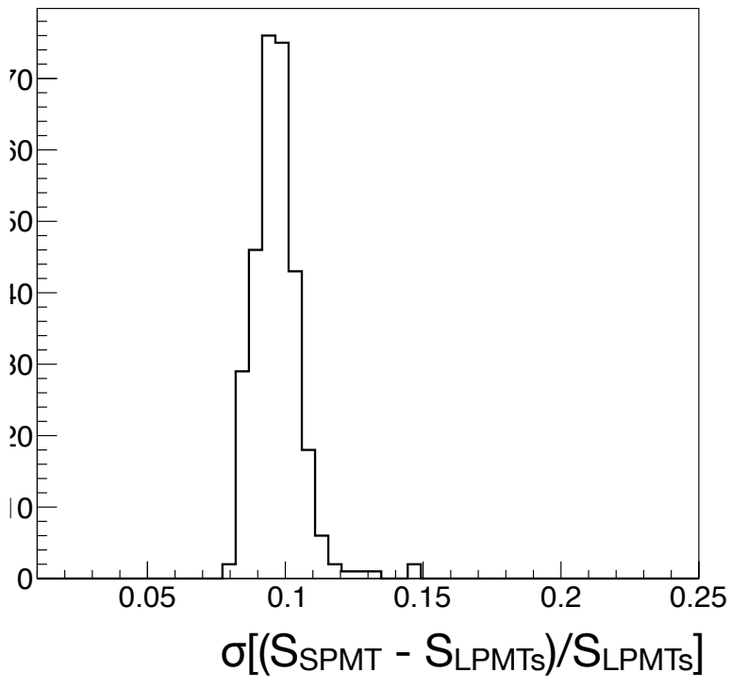
Stable cross-calibration (example LsId 20)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.

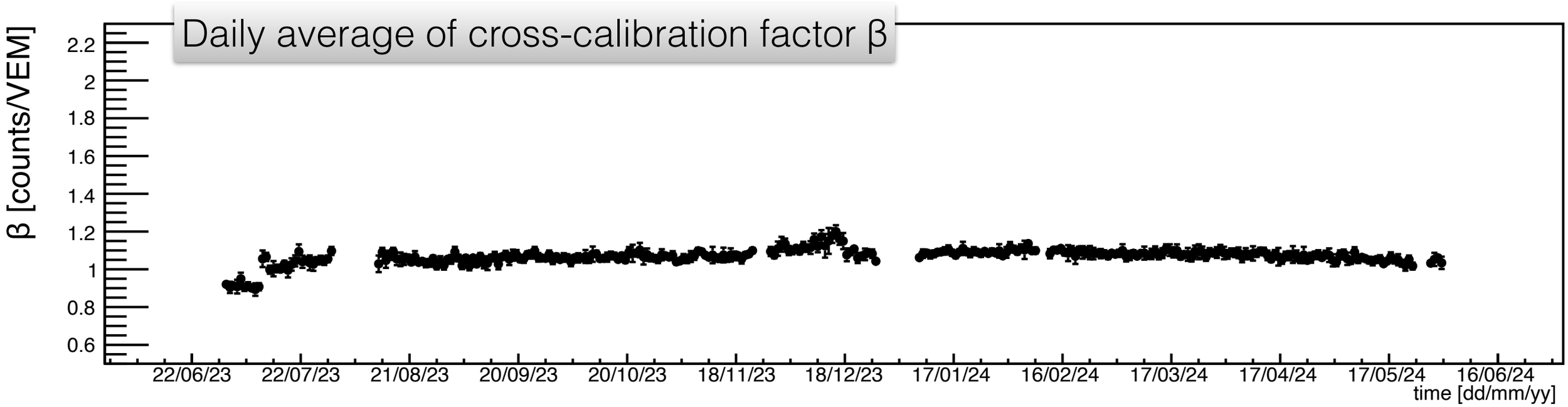


SPMT in a good station

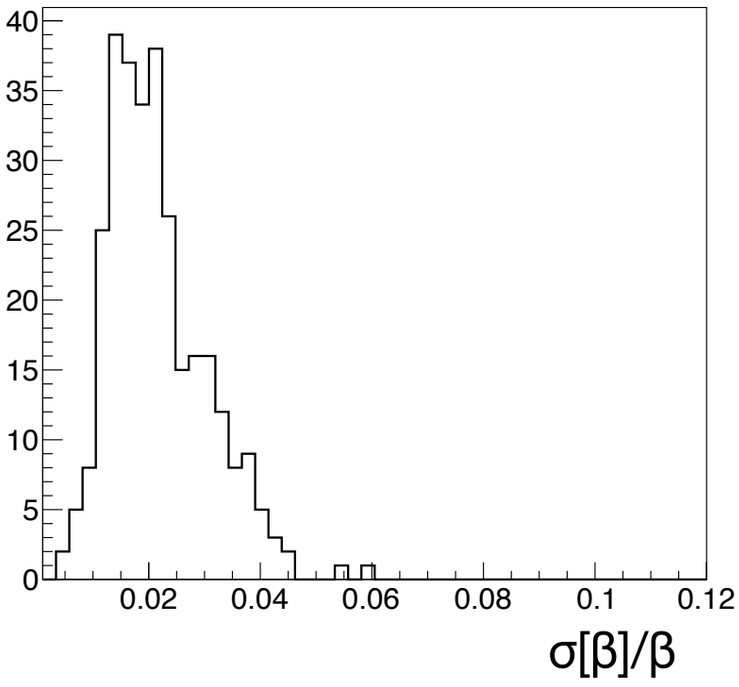
$\sigma[\beta]/\beta < 4\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}] \sim 10\text{-}12\%$

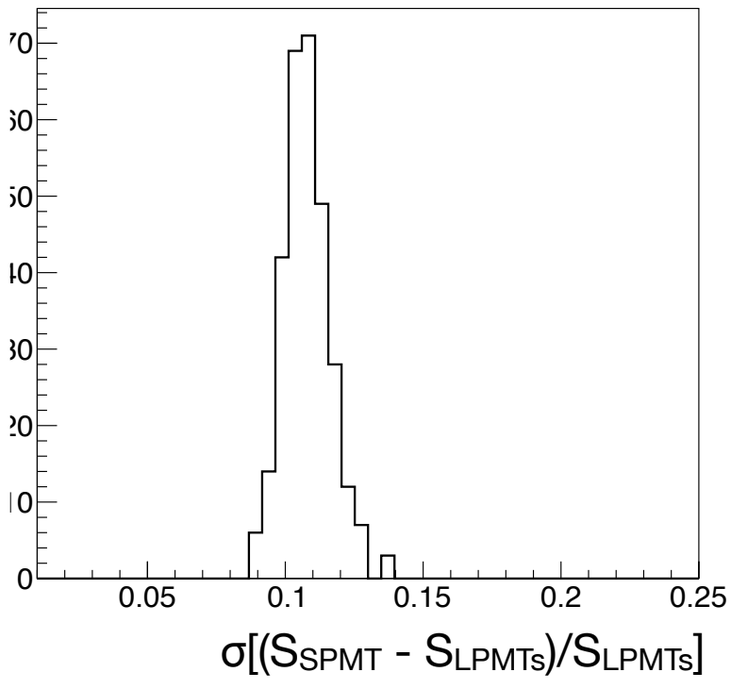
Stable cross-calibration (example LsId 27)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.

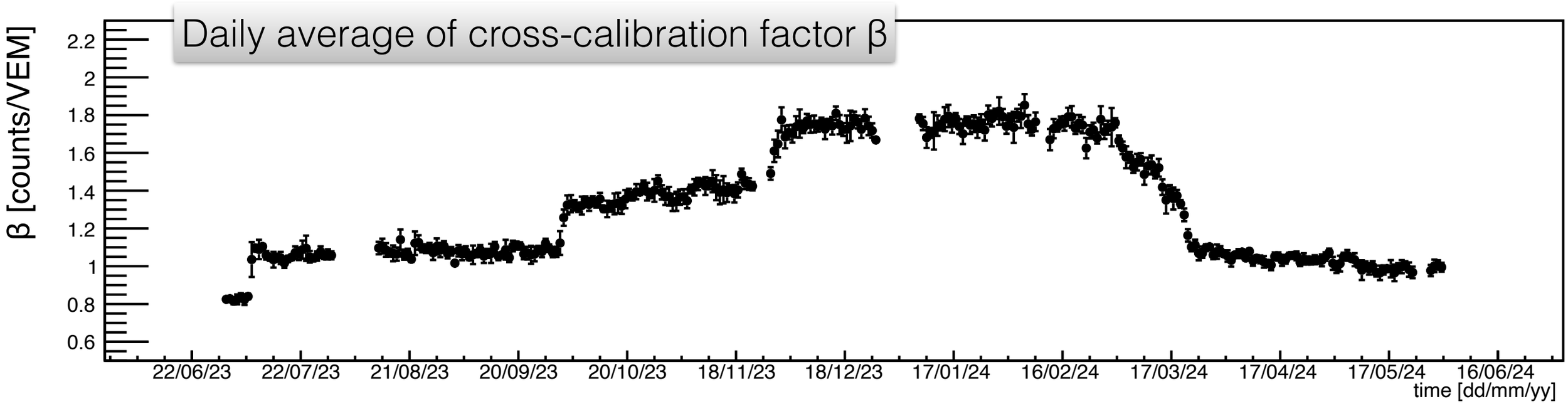


SPMT in a good station

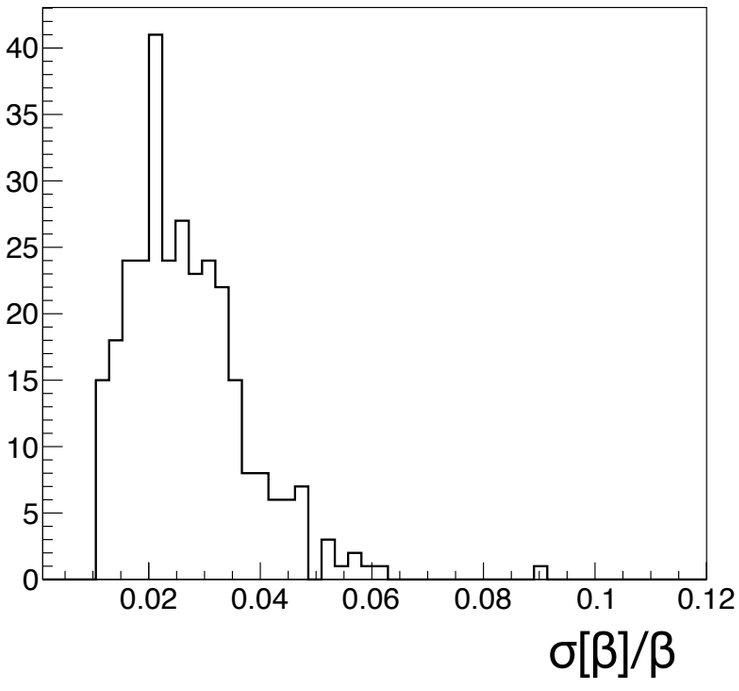
$\sigma[\beta]/\beta < 4\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}] \sim 10\text{-}12\%$

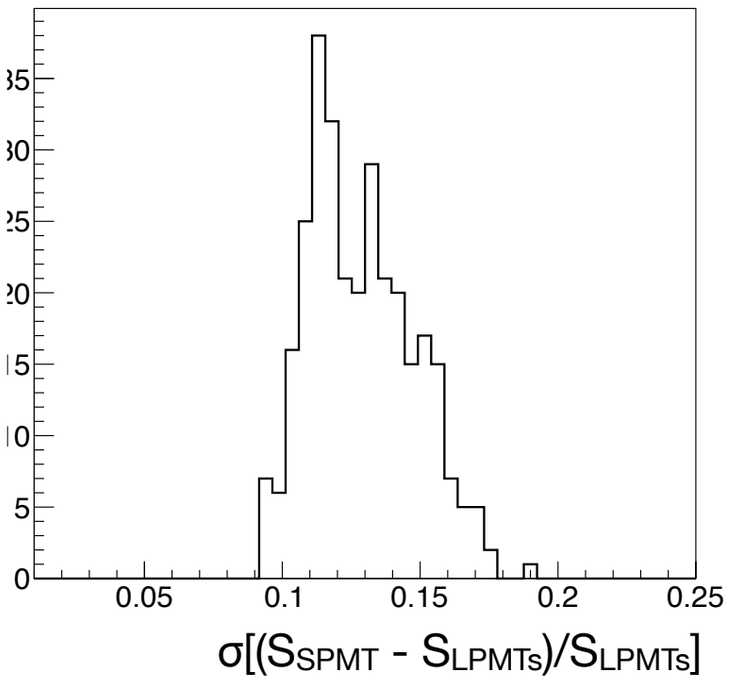
Deficit in the light at the SPMT (example LsId 700)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.

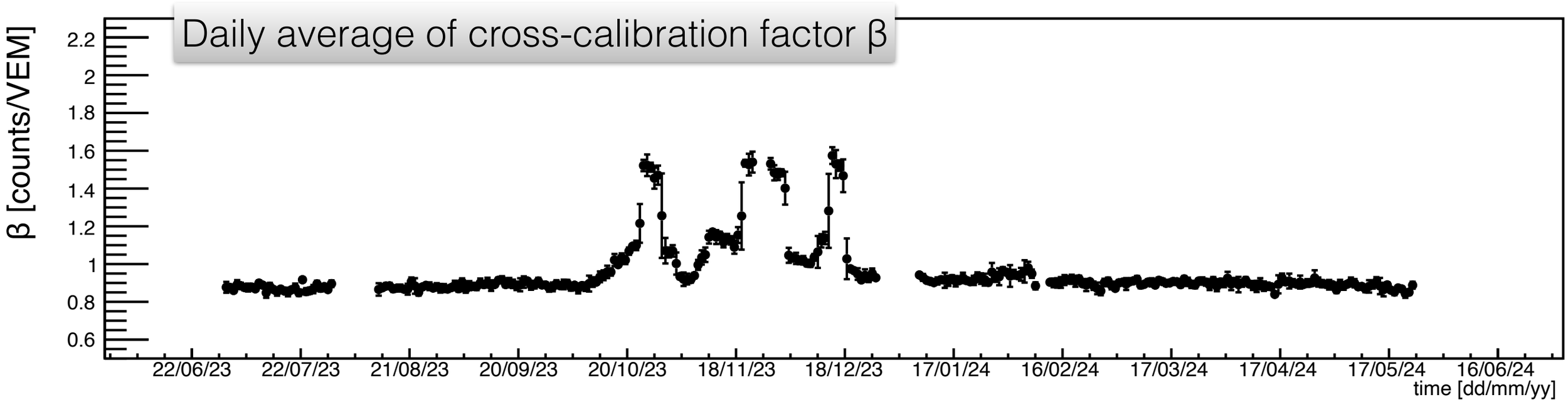


When the light reaching the SPMT reduces…

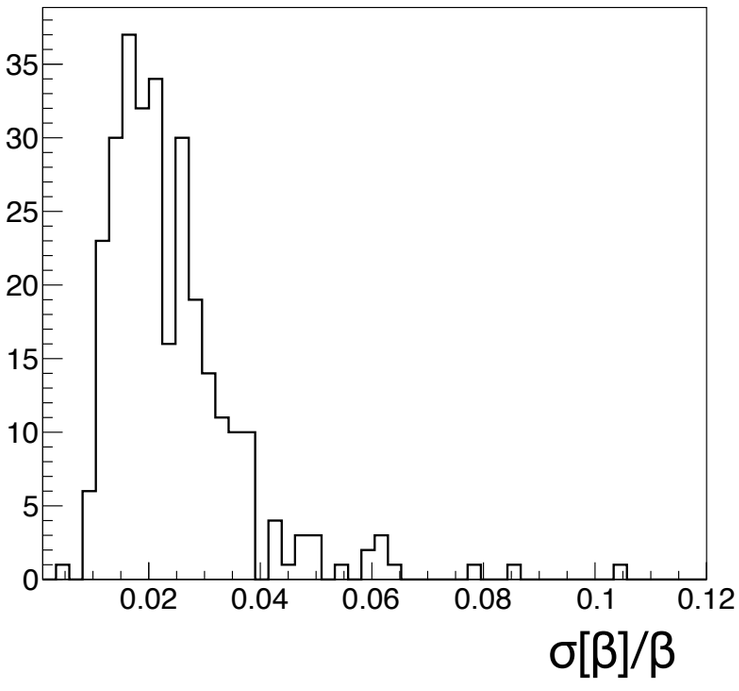
$\sigma[\beta]/\beta < 6\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}] \sim 13\text{-}15\%$

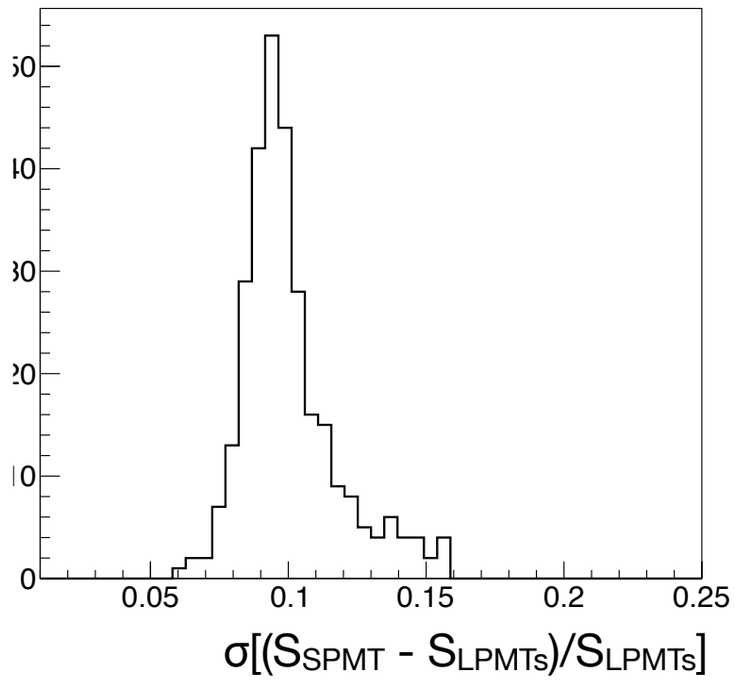
Deficit in the light at the SPMT (example LsId 760)



Daily relative dispersion of β



Daily relative dispersion of SPMT signal w.r.t. LPMTs avg.



When the light reaching the SPMT reduces…

$\sigma[\beta]/\beta < 6\%$

$\sigma[(S_{SPMT} - S_{LPMTs})/S_{LPMTs}] \sim 13\text{-}15\%$