Use of small photomultiplier tube to extend dynamic range of Pierre Auger Observatory surface detector

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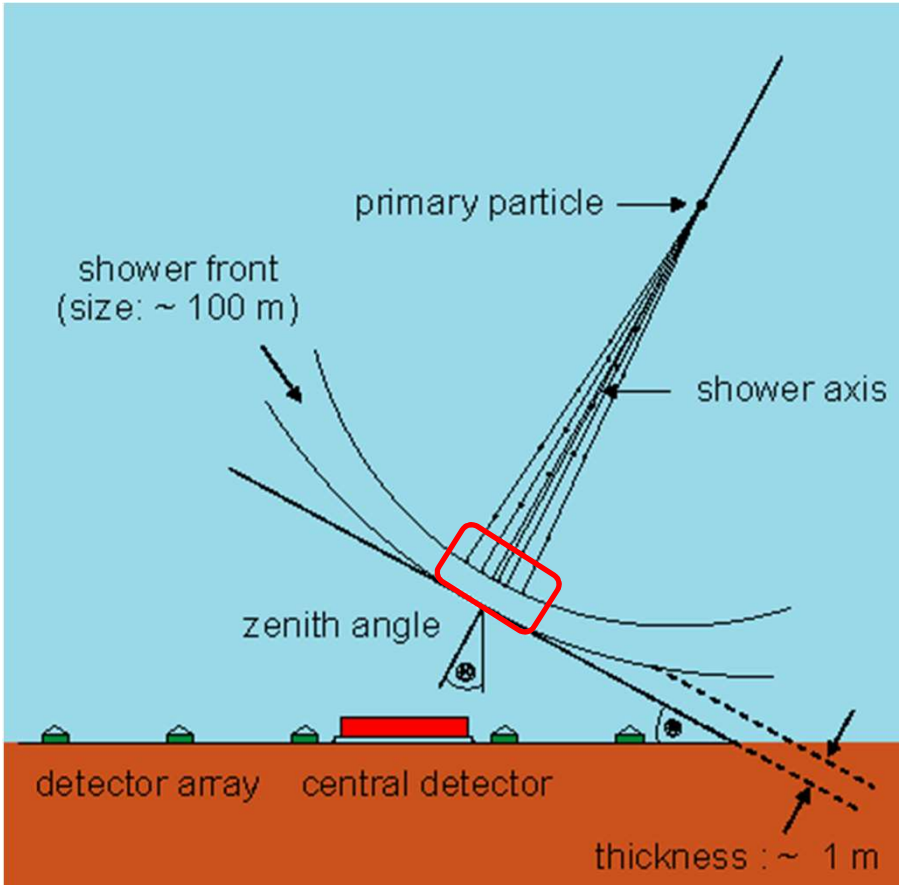
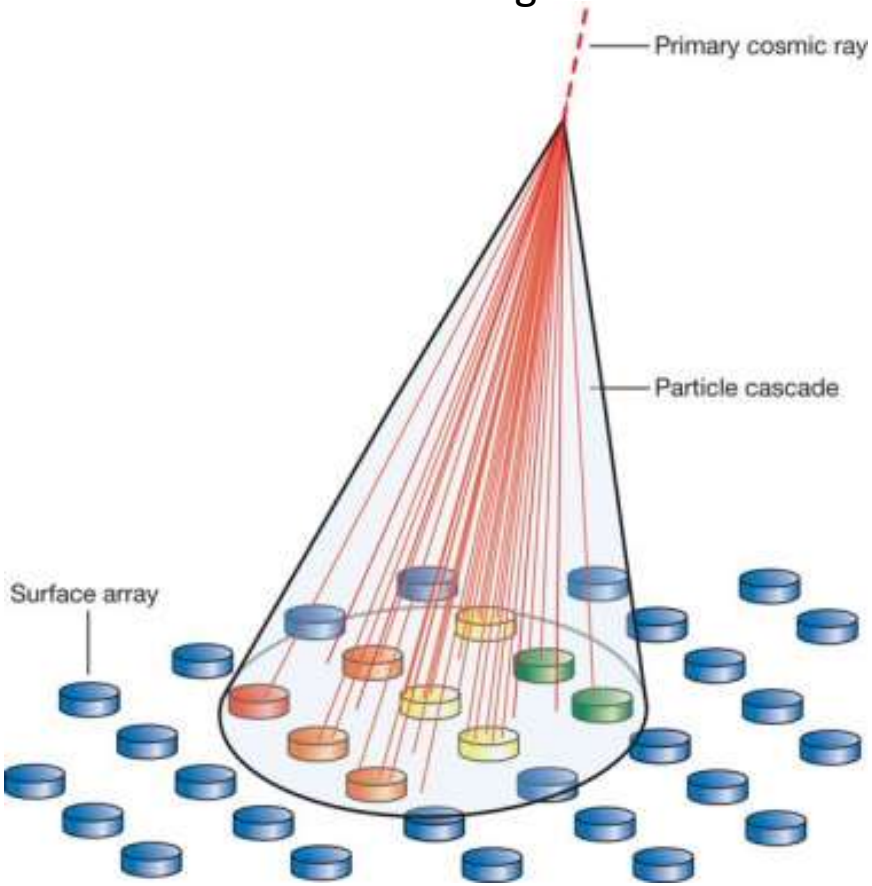
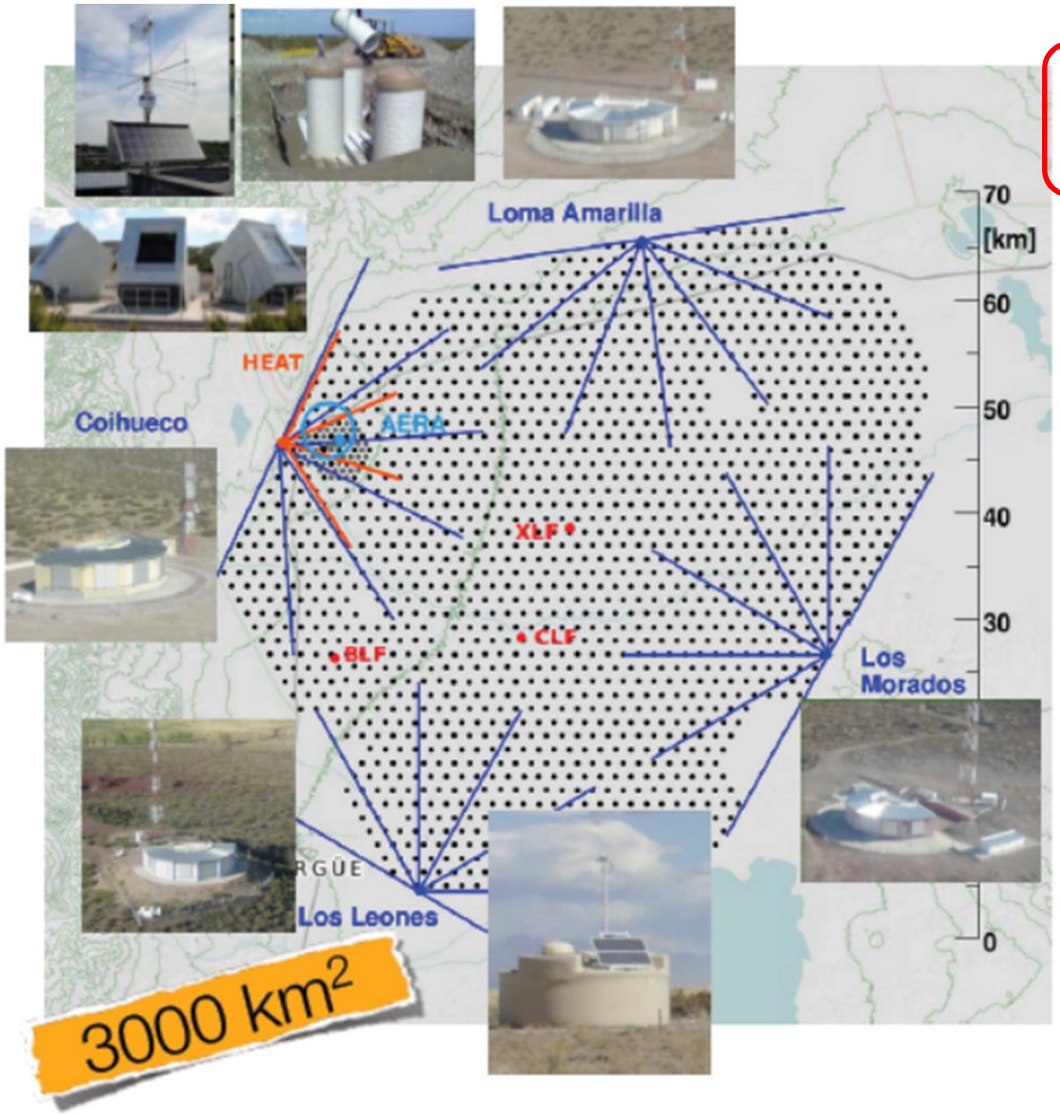
Chuveiro Atmosférico Extenso

Detecção indireta de raios cósmicos de altíssimas energias.





Observatório Pierre Auger

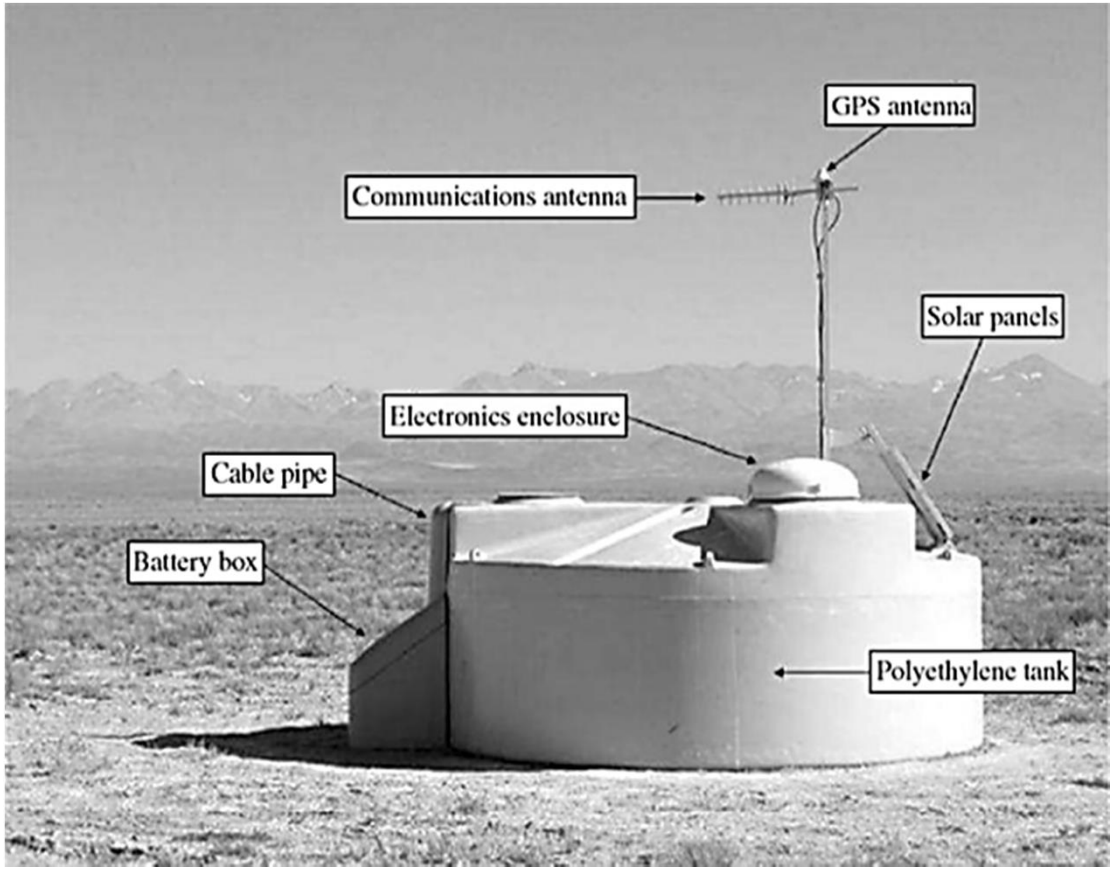


- Water-Cherenkov tanks
  - 1660 in a 1.5 km standard grid
  - 71 in 0.75 km infill grid (~30 km^2)
- Fluorescence Telescopes
  - 24 in 4 buildings overlooking SD
  - 3 in 1 building overlooking the Infill
- Underground Muon detectors
  - engineering array phase - 61 aside the Infill stations
- AERA radio antennas
  - 153 graded 17 km^2
- atmospheric monitoring stations

by A. Castellina

Water Cherenkov Detector (WCD)

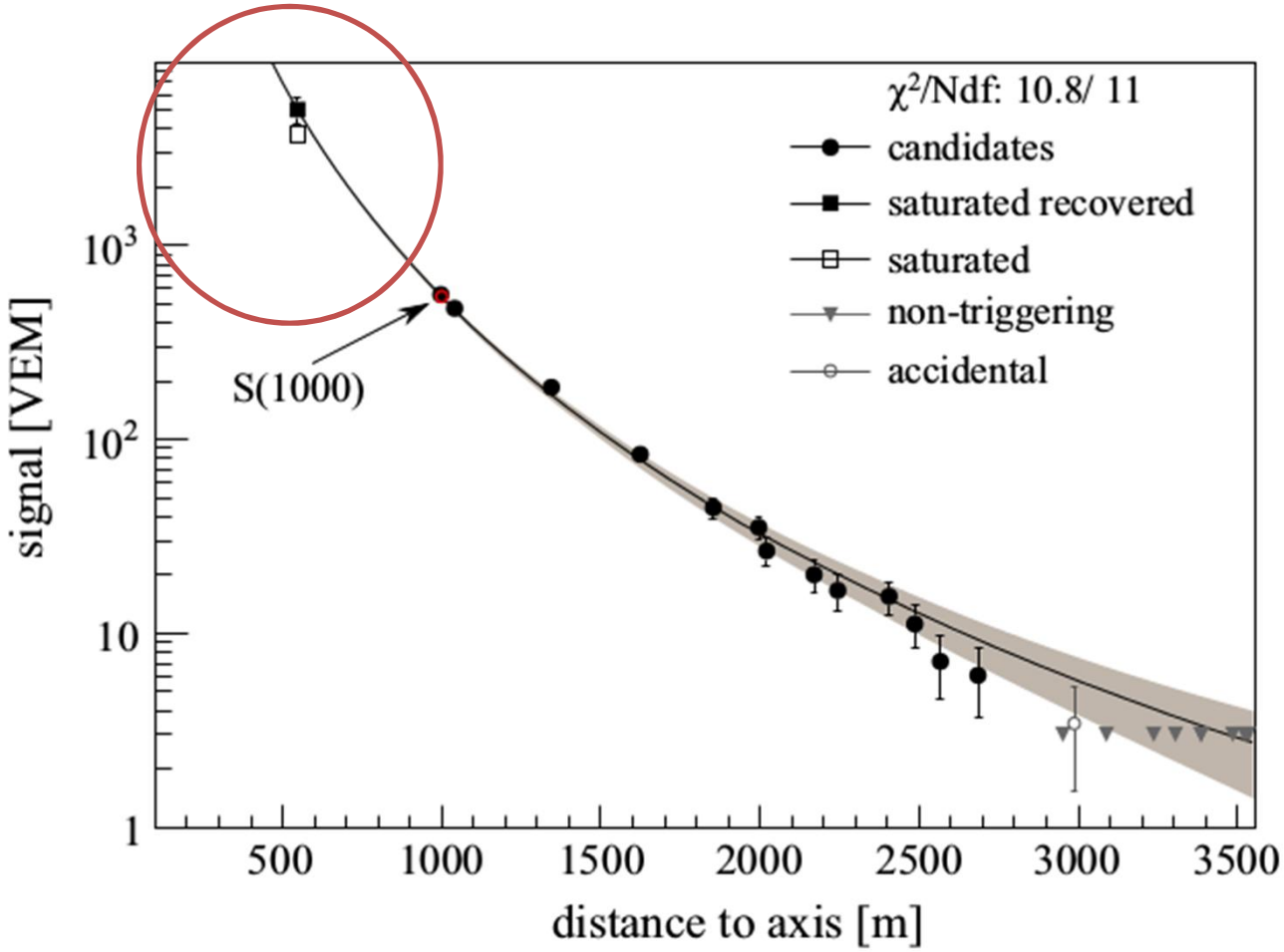
- Liner filled with 12000 l of ultra-pure water.
- 3 photomultiplier tubes on top of liner.
- Electronics to digitize signal, process possible events and communication.
- Power provided by solar panel attached to two 12 V batteries.



Saturação do sinal do WCD

E > 3x10^19 eV

more than 30% events with saturation



Upgrade do Observatório Pierre Auger

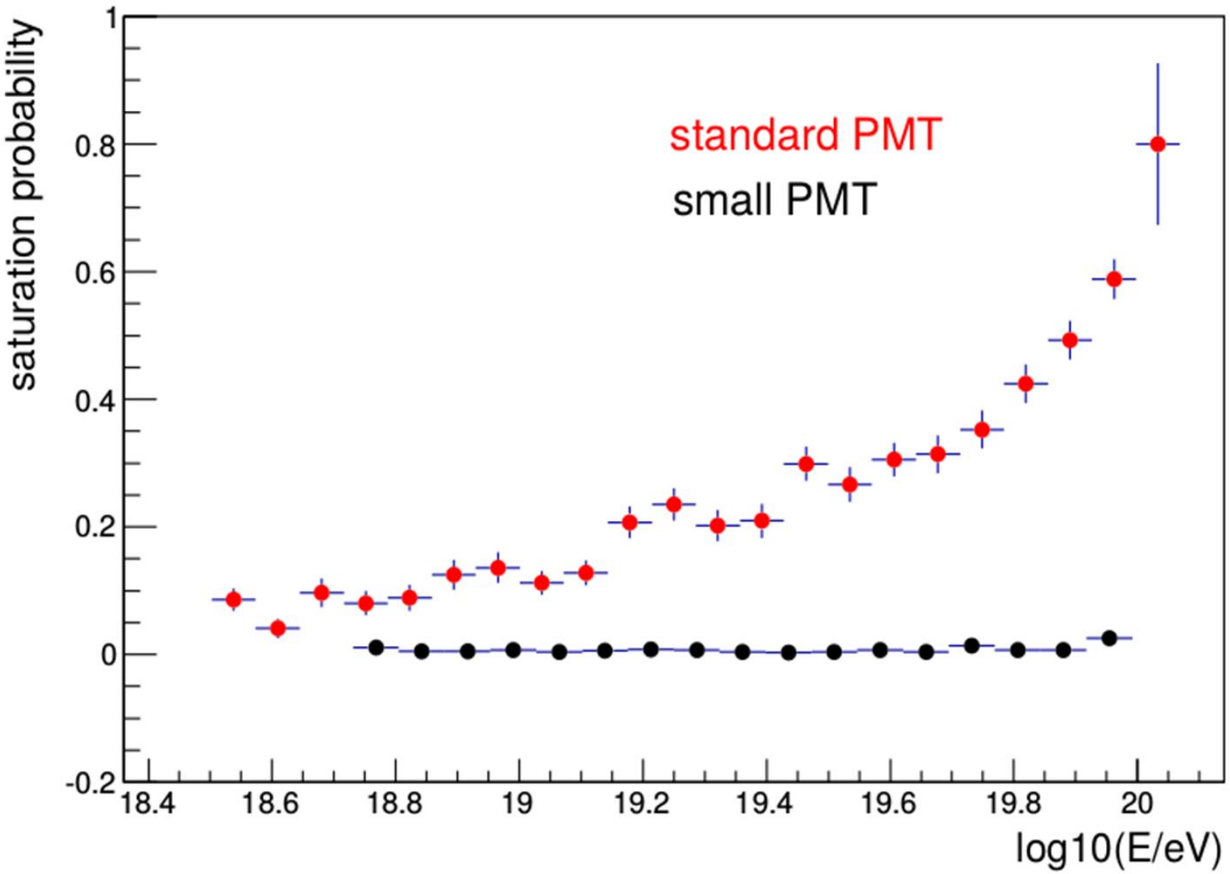
AugerPrime

- Cintiladores
- Small PMT
- Nova eletrônica (120 MHz)

Objetivos do upgrade:

- Melhorar a determinação da composição química
- Origem da supressão do espectro de energia: GZK ou Emax da fonte?
- Fração de prótons com UHE: astronomia de partícula?
- Modelos de interação hadrônica: nova física?

Resultados esperados – Monte Carlo

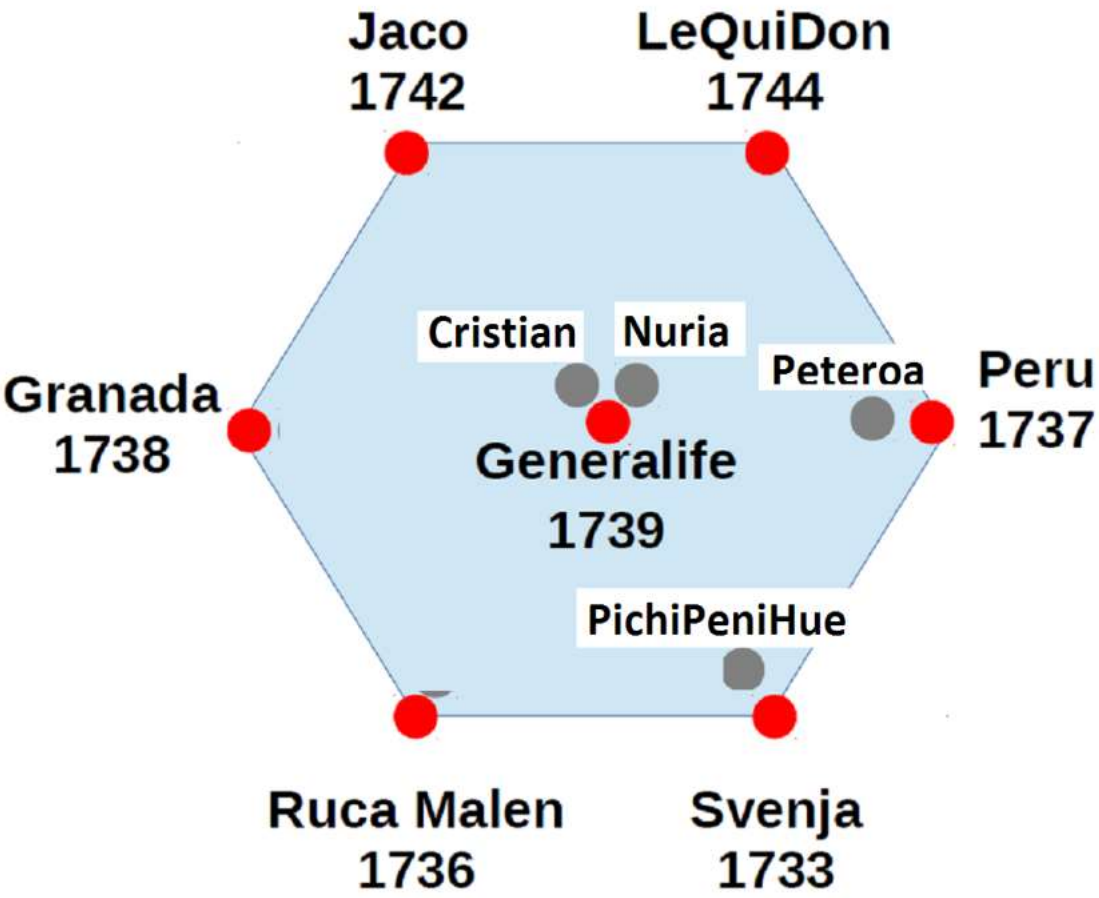


Less than 2% of events are expected to saturate with sPMT.

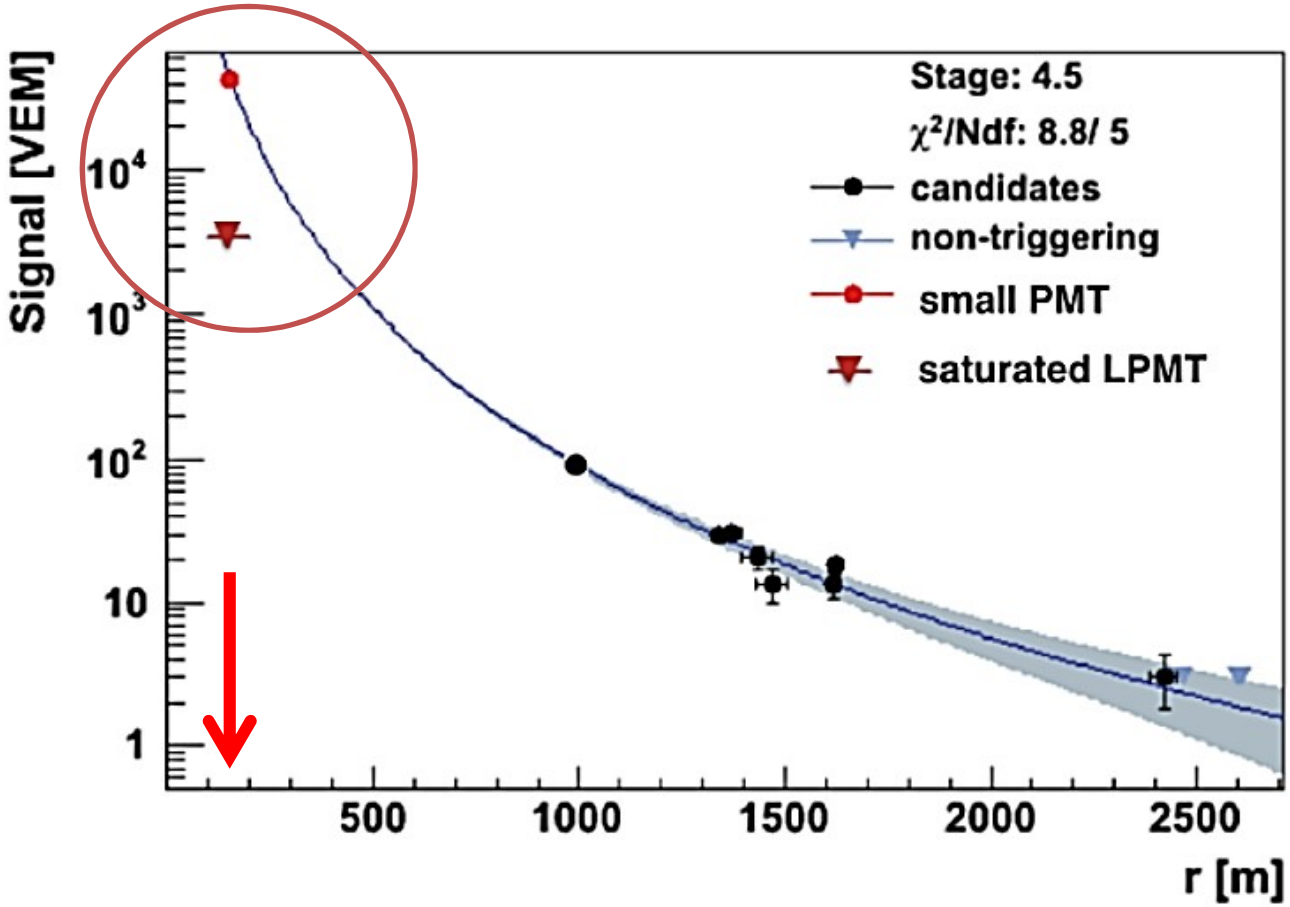
arXiv:1604.03637v1 [astro-ph.IM] 13 Apr 2016

Engineering array - Small PMTs

10 estações



Evento do engineering array

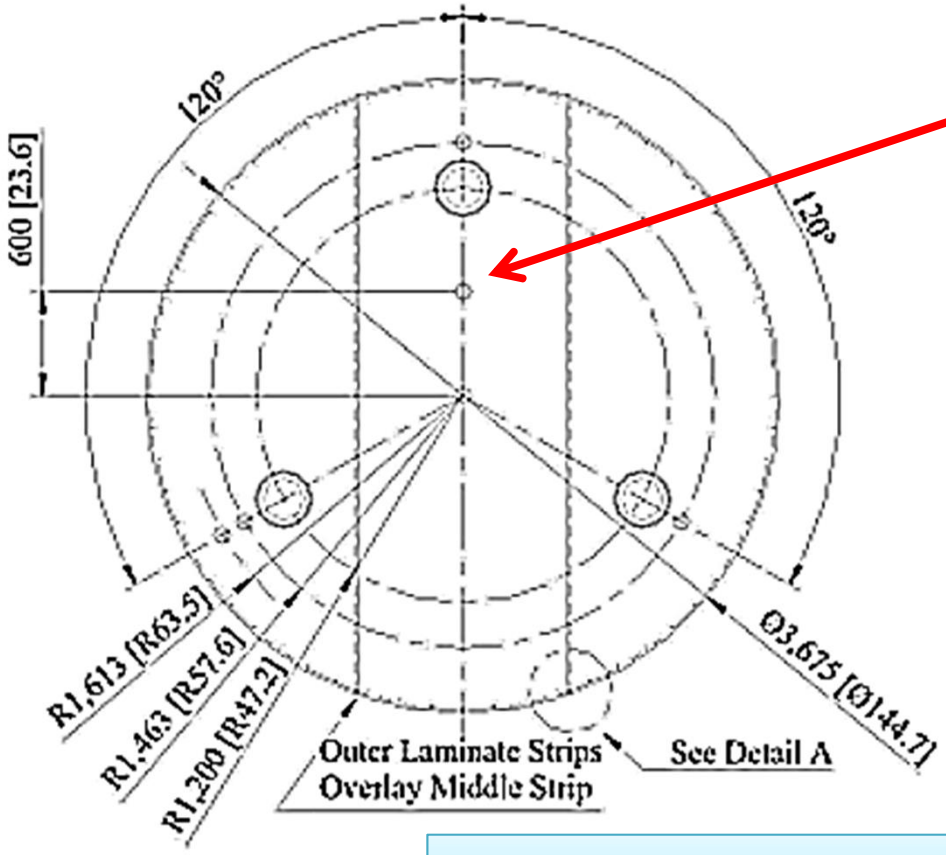


Engineering array sPMT

- Thee sPMT models:
  - Hamamatsu R8619
  - Hamamatsu R6094
  - ET 9107FLB

Station	Model
56	R8619
59	R8619
60	R6094
62	9107FLB
1733	R8619
1736	R8619
1737	9107FLB
1738	R6094
1742	R8619
1744	R8619

Engineering array



- SPMT installed in spear LED window with 30 mm diameter, placed 60 cm off centre.

Model	Diameter (mm)
R8619	25
R6094	28
9107FLB	29

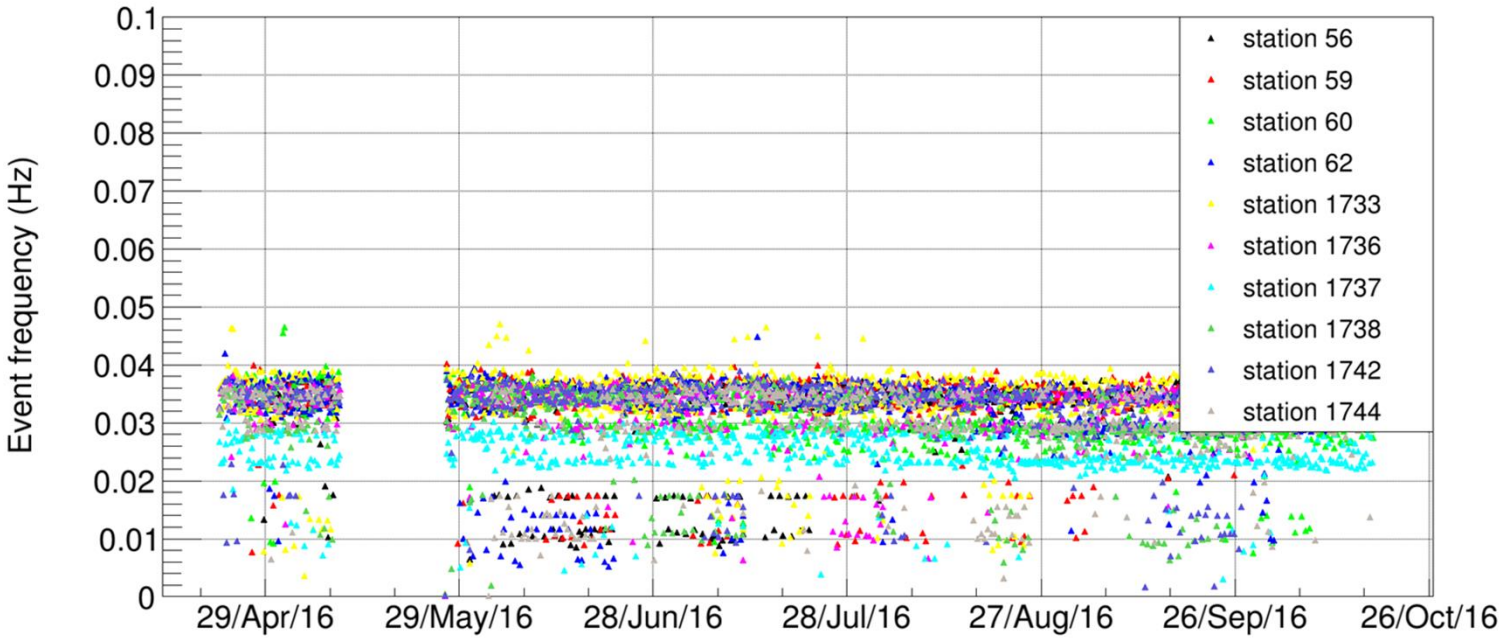
Trigger: signal amplitude higher than 120 ADC chs. in both LPMTs; sPMT signal digitilized with LPMT1 ADC.

Data sets

1. Events recorded by stations PMTs from 21st April to 17th October 2016.
2. Monitoring data:
   - information about behavior of station components
     - PMTs power supply, current, temperature, VEM calibration
   - collected every 6 minutes.

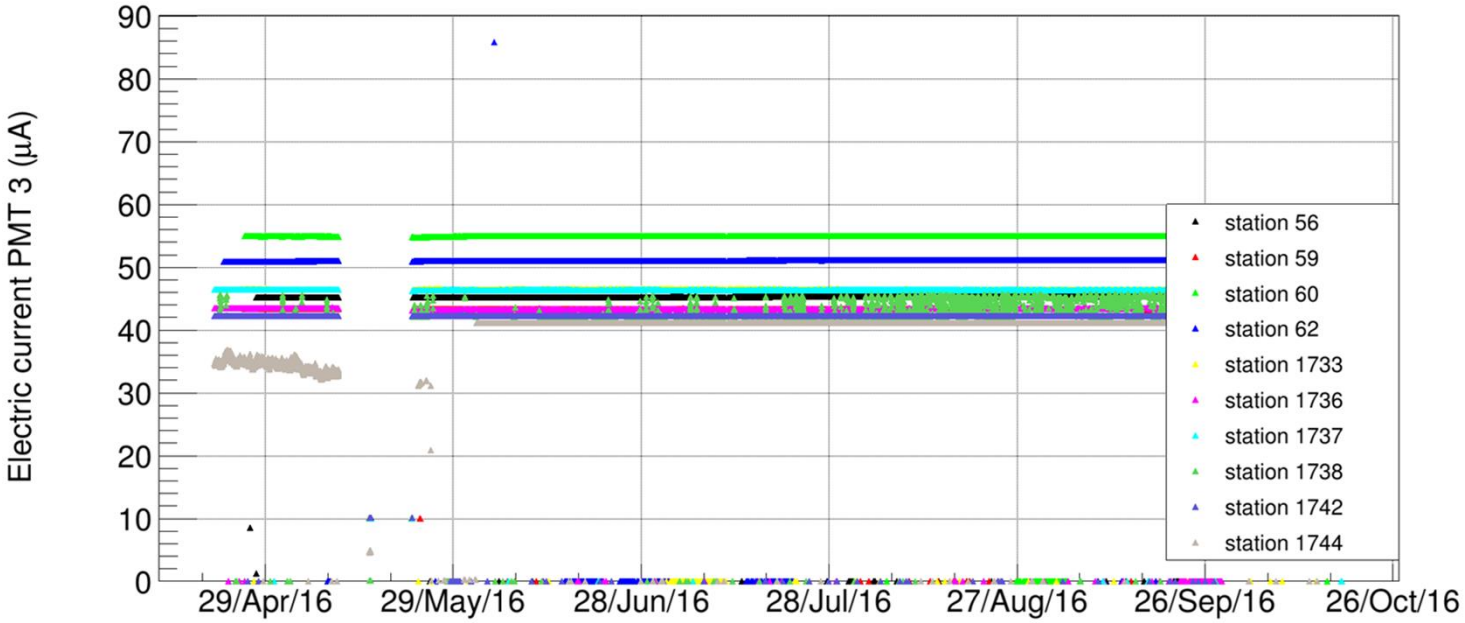
- Two data sets were synchronized.

Event frequency



- Station malfunction may impact frequency of events.
- Gap in acquisition: SD general shutdown due to weather.
- Constant frequency with some fluctuations.

Data validation

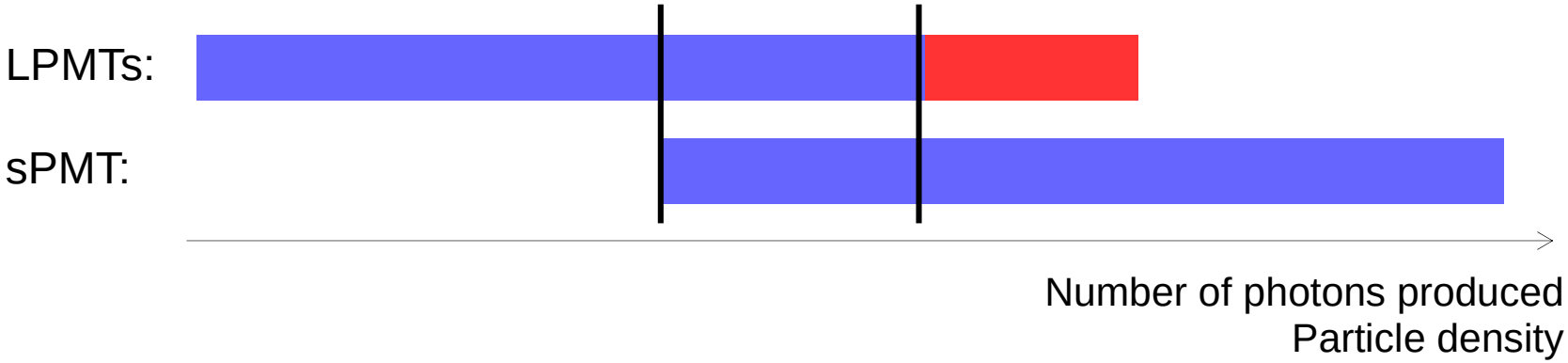


- Most time constant – stable working.
- Sometimes it varies – instability.
- Data of interest: collected under stable condition.
- Cuts were created – select only data of interest.

Data validation

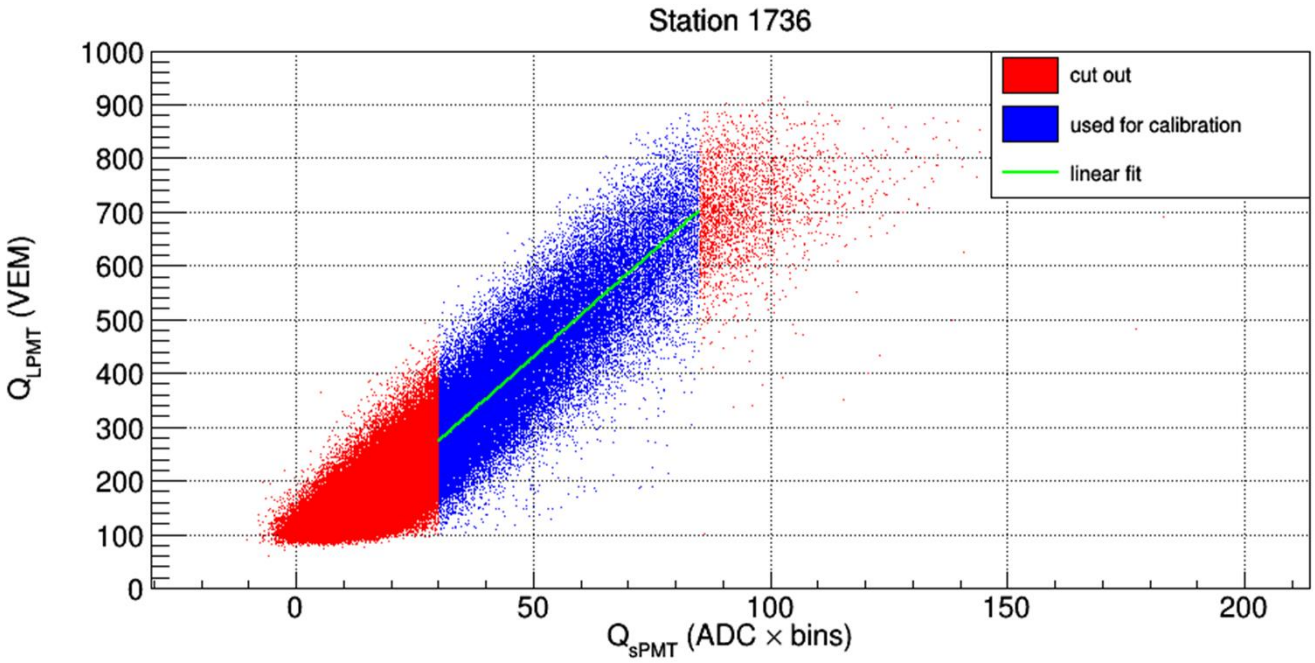
		Cuts	
	Monitoring parameter	**Lower limit**	**Upper limit**
Power supply tension	3.3 V power supply	3.31 V	3.36 V
	-3.3 V power supply	-3.41 V	-3.33 V
	5 V power supply	5.08 V	5.17 V
	12 V power supply	11.85 V	12.1 V
PMTs electric current	sPMT current	13.5 µA	17.0 µA
	LPMT 2 current	37.0 µA	45.0 µA
	LPMT 3 current	40.0 µA	56.0 µA
LPMTs temperatures	LPMT 2 temperature	-7.0 °C	35.0 °C
	LPMT 3 temperature	-10.0 °C	40.0 °C
LPMTs VEM calibration	LPMT 2 VEM calibration	90 ADC ch.	170 ADC ch.
	LPMT 3 VEM calibration	100 ADC ch.	162 ADC ch.

Small PMT calibration



- SPMTs can not detect 1VEM – LPMT calibration method can not be used.
- Events in superposition region – use LPMT VEM calibration to find correspondent sPMTs signals in VEM unit.

Linear fit with vertical cuts



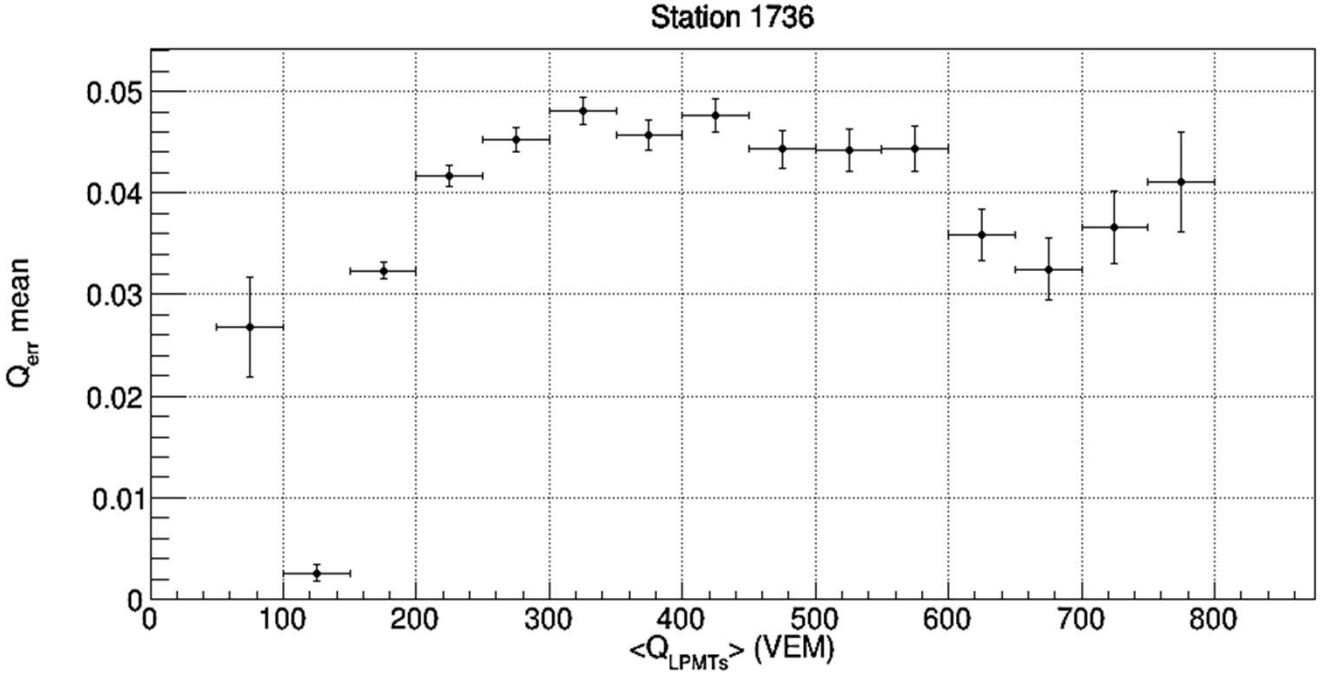
- Linear fit was applied:

$$Q_{<LPMTs>}(\mathrm{VEM}) = p_0 + p_1 Q_{sPMT}(\mathrm{ADC} \times \mathrm{bins})$$

Calibration precision

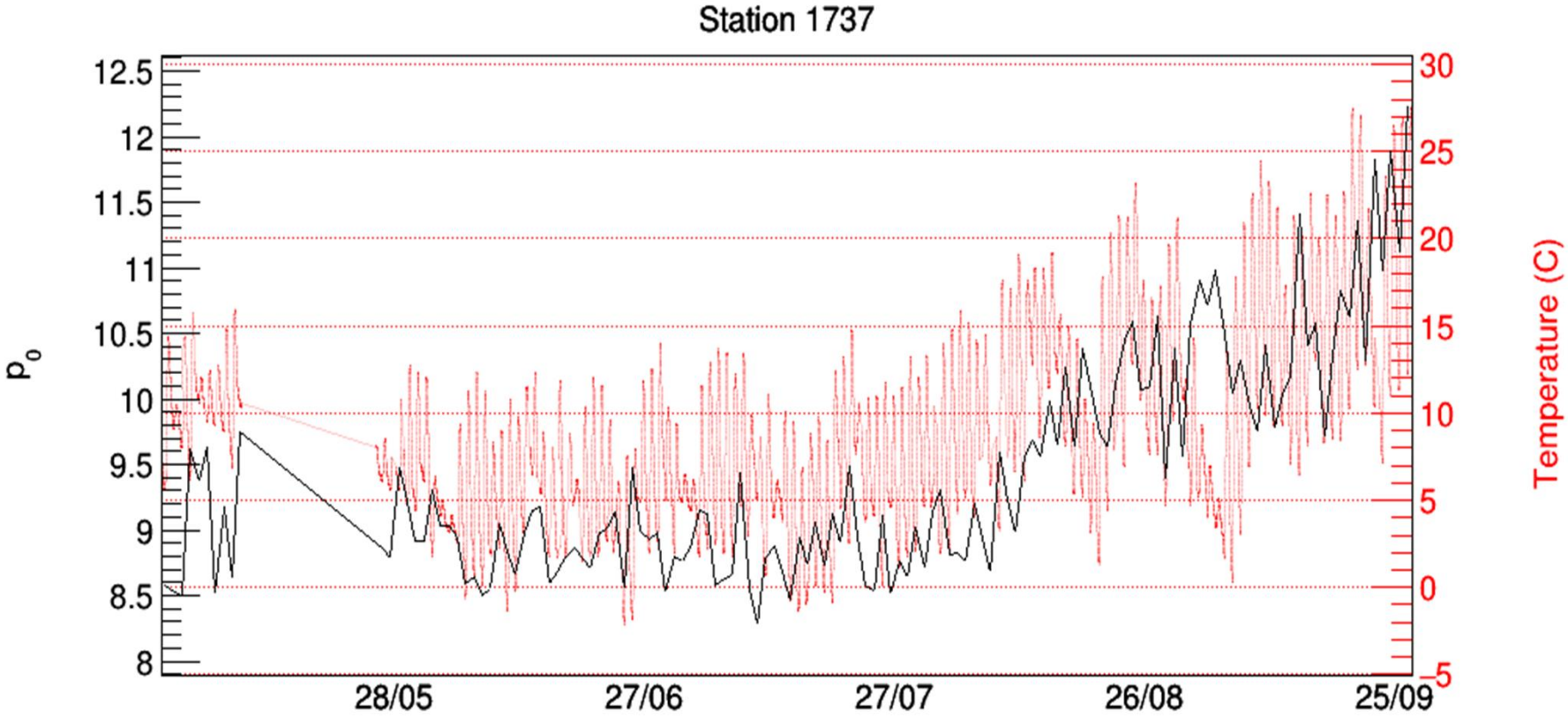
From calibration

$$Q_{err} = \frac{Q_{<LPMTs>}(\mathrm{VEM}) - Q_{sPMT}(\mathrm{VEM})}{Q_{<LPMTs>}(\mathrm{VEM})}$$



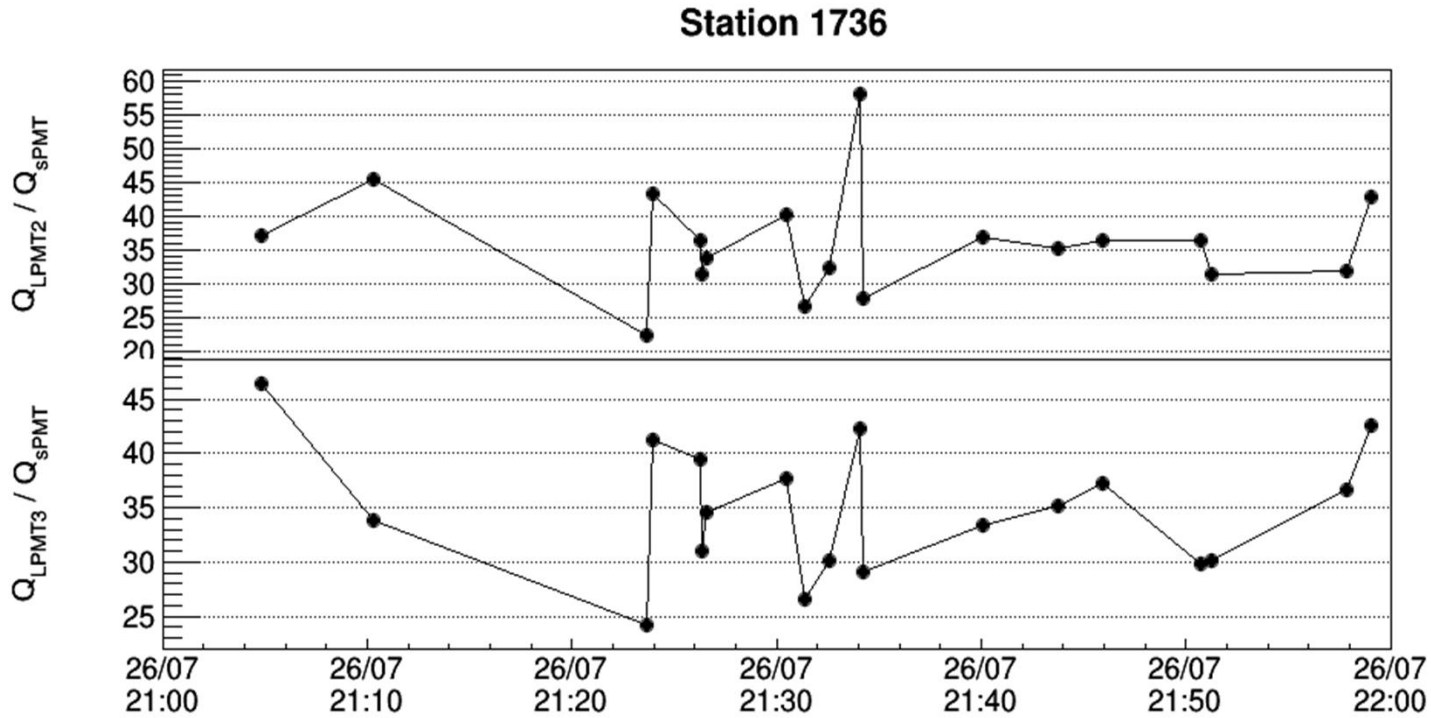
- Calibration error mean is within 5% for station 1736.
- Other stations have similar results with calibration error being always within 10%.

Temperature dependence

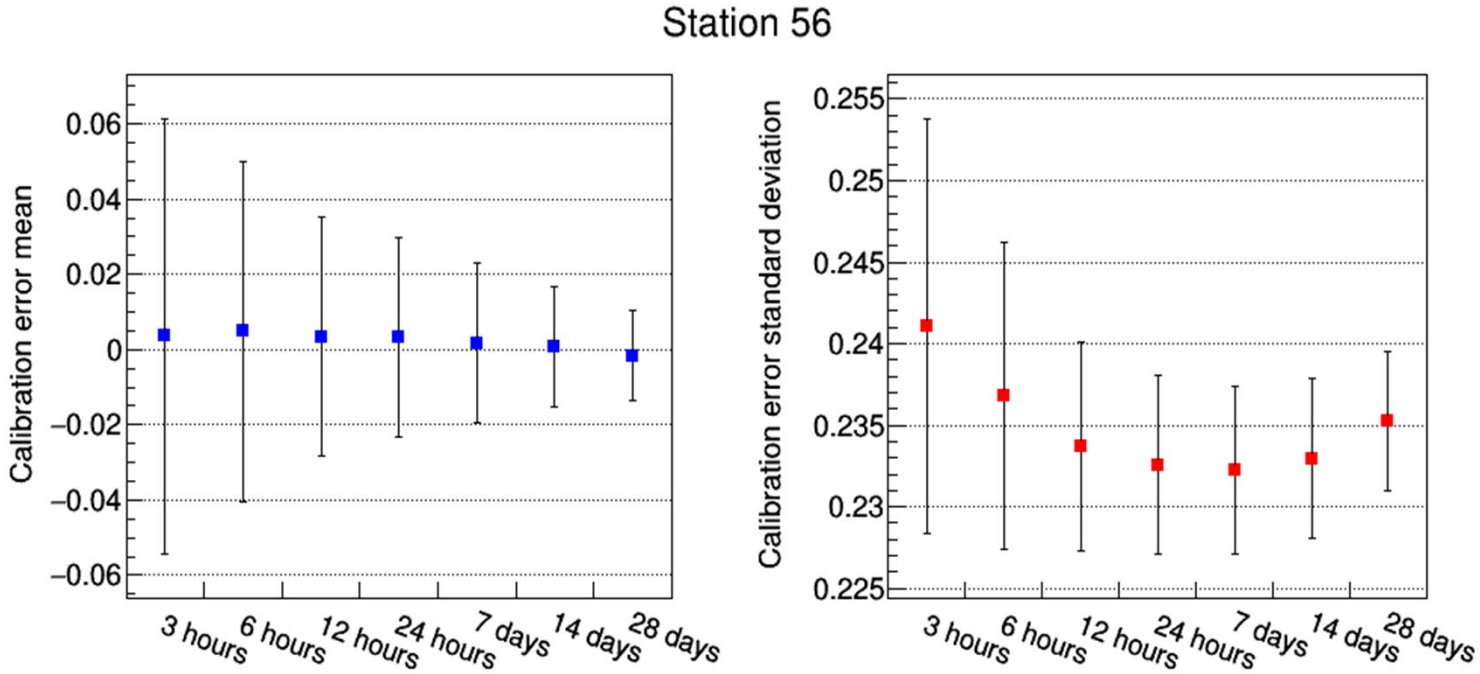


Short time temperature variation

- Short time variation on PMTs charge ratio can not be due to temperature variations.

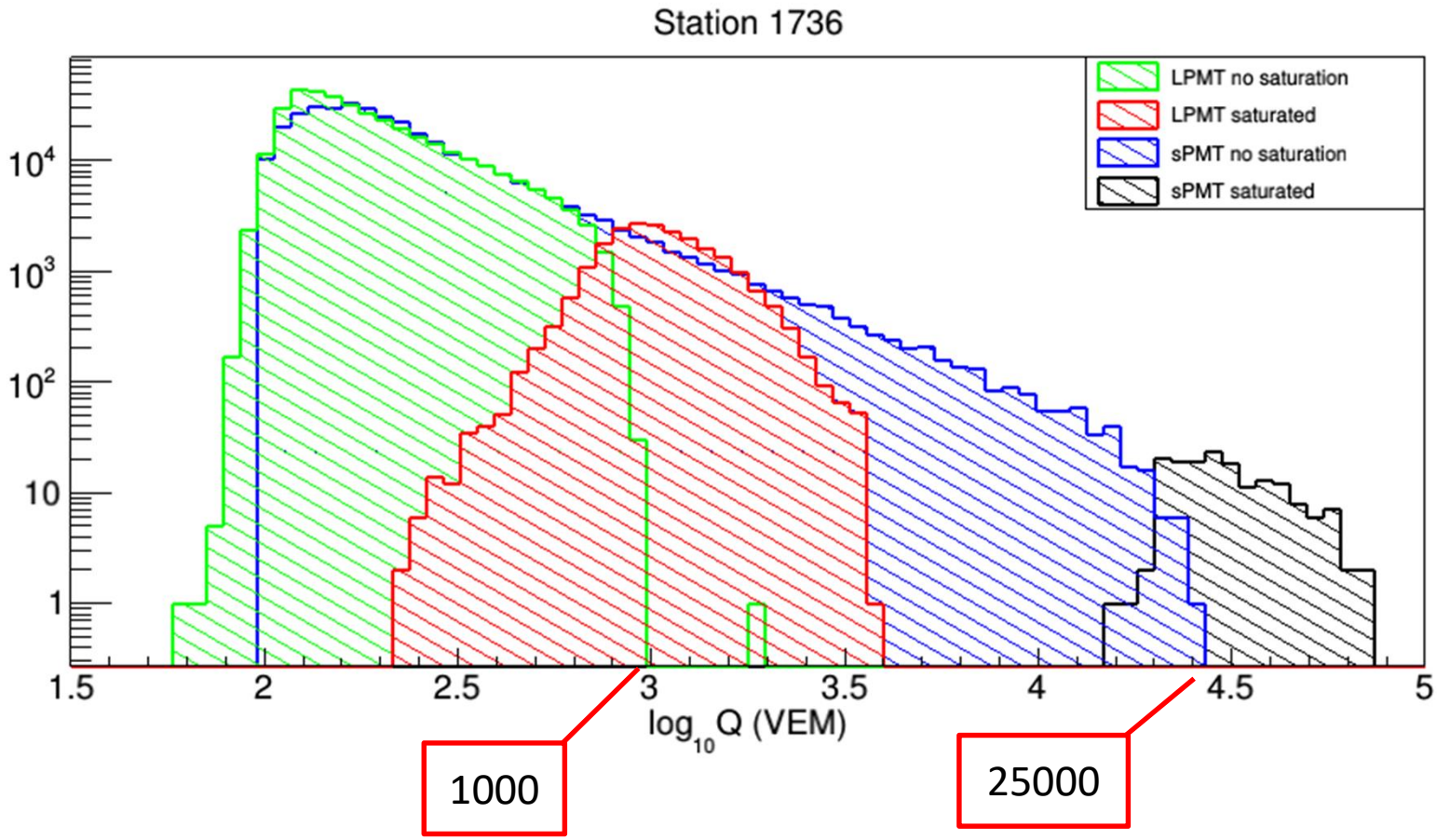


Calibration interval



- Best interval: 24h
  - One of smallest calibration error std. deviation.
  - Calibration error mean close to zero.

Dynamic range extension



Conclusions

- Implementation of sPMT in EA stations extended their dynamic range by a factor of about 25 times, allowing measure the particle density near the shower core (about hundred meters)
- sPMTs are robust to the field environment, performing quite stably.
- Calibration of the sPMTs with respect to the LPMTs is possible.
- There is a dependence on sPMT calibration with temperature.
- Source of calibration error is probably due to stations electronic noise and precision.
- Preferred interval to perform calibration is every 24h.

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