Calibration of the Upgraded Surface Detector Stations of the Pierre Auger Observatory

27 November 2020

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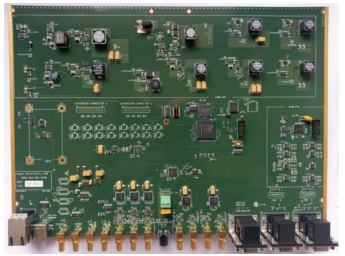
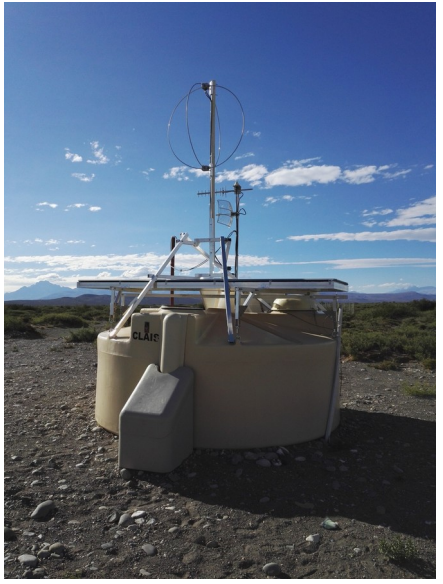
AugerPrime Surface Detector

What is **new** for the Surface Detector stations ?



- Electronics boards HIRSAP 2019
- Small PMT inside water-Cherenkov detectors (WCD)
- Scintillator detectors (SSD):
  - Validation tests and comparisons with simulations HIRSAP 2018
  - Calibration and event data analysis **HIRSAP 2020**
- Radio antennas



SD Data Processing

Why is calibration important ?

PMT traces
PMT histograms
Online estimates
Trigger information

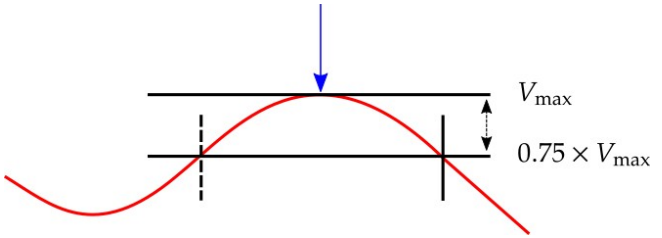
Normalization factors
PMT baselines
PMT signals
WCD total signal
VEM/MIP

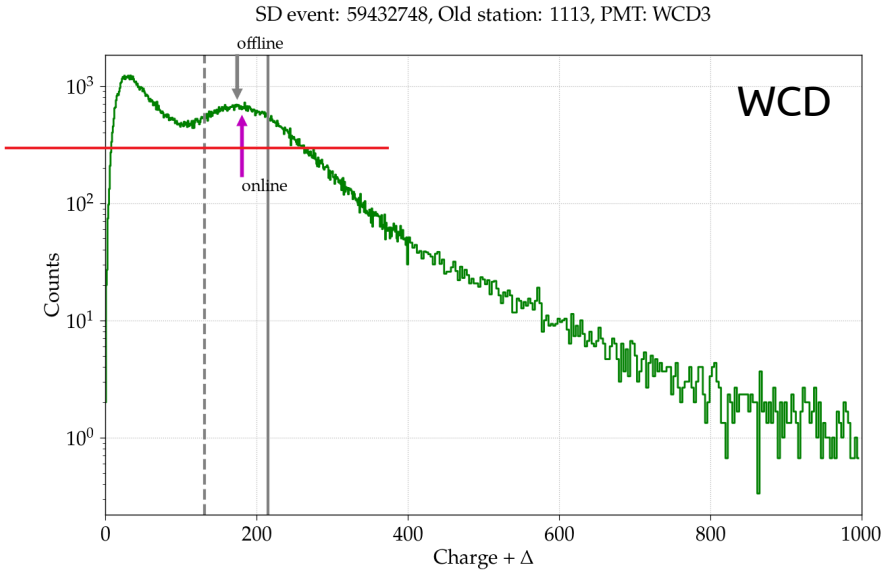
Shower geometry
Lateral distribution
Shower size

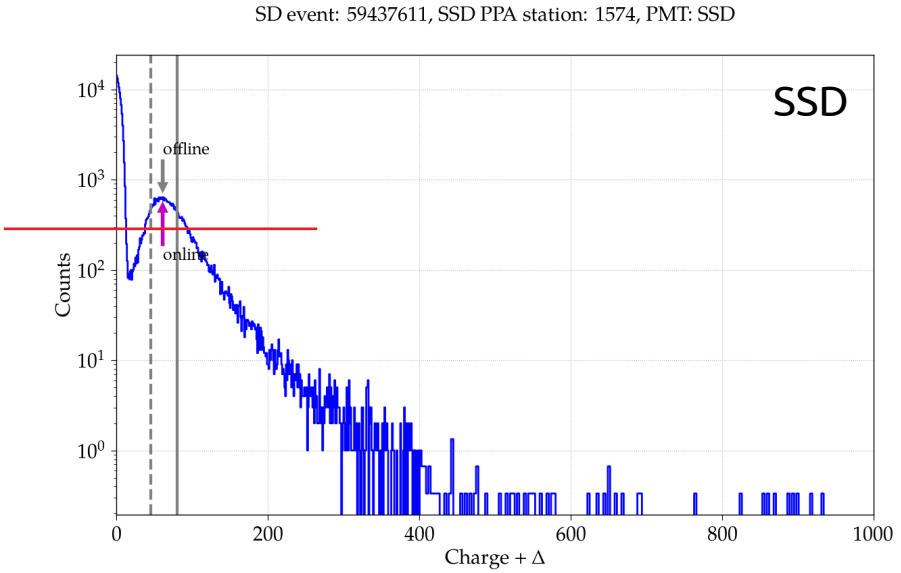
→ Optimization and adaptation of calibration procedure

Current Calibration of WCD and SSD

- Muon hump search by determination of left and right “shoulders” around first maximum
- Check if online value within the shoulder limits
- If fit algorithm fails → online charge value used
- Analytic quadratic fit of bins in-between shoulders

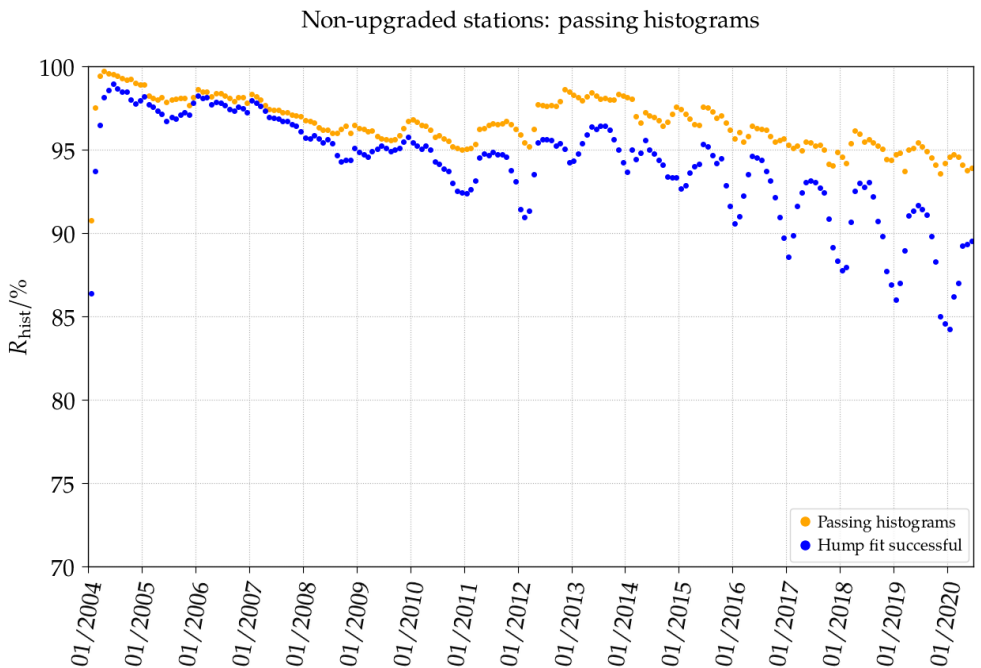


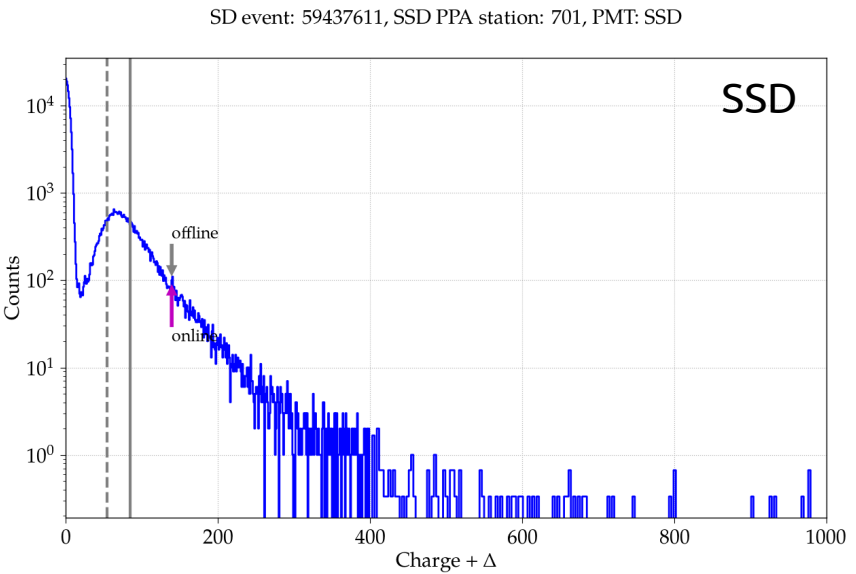




Current Calibration of WCD and SSD

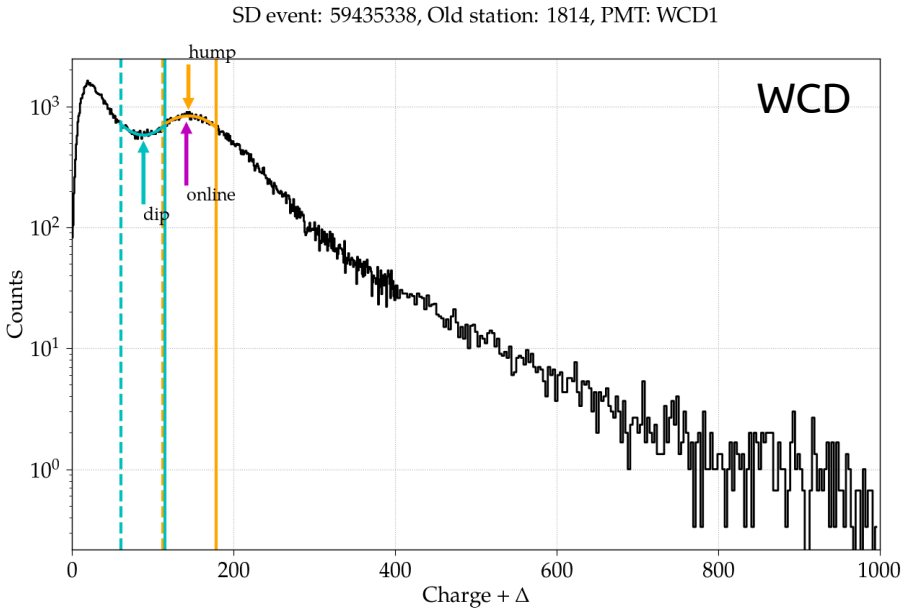
- Limited flexibility due to several fixed variables (e.g., start values, thresholds)
- WCD: Number of successful fits decreases (change of charge histogram shapes)
- SSD: Filler module for online estimates → incorrect charge calibration





New Calibration of WCD and SSD

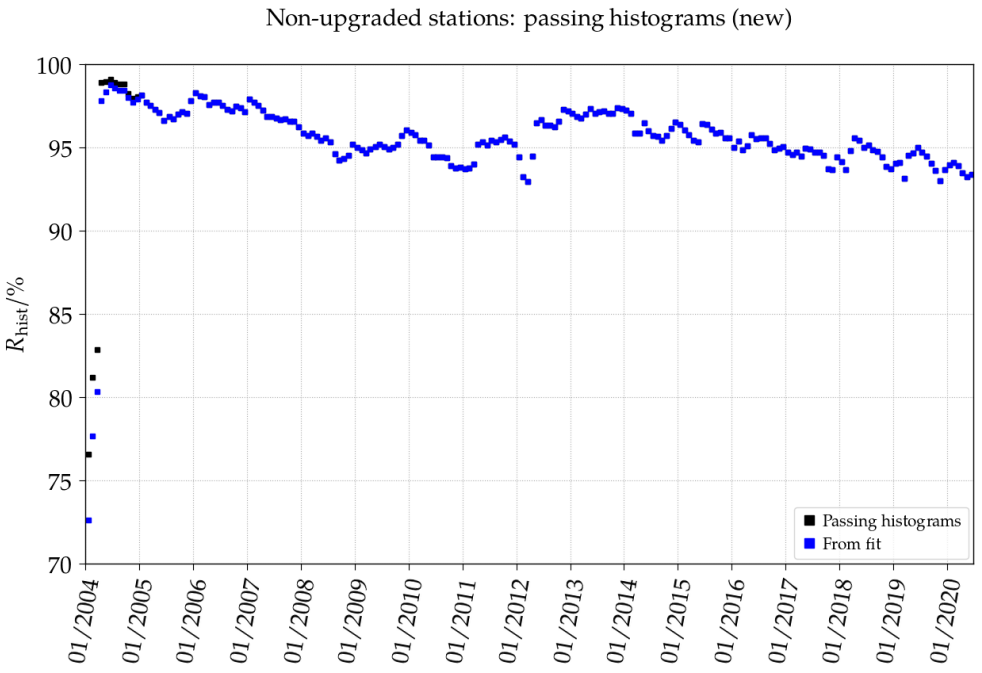
- Search for hump and dip positions (both extremes necessary for successful calibration)
- Calculate 3-bin-density at each bin position: $d_i = \frac{1}{3}\left(\frac{1}{\Delta_{i-1}}N_{i-1} + \frac{1}{\Delta_i}N_i + \frac{1}{\Delta_{i+1}}N_{i+1}\right)$
- Left and right limits around extremes with relative thresholds (10σ, 8σ, 5σ)
- Analytic quadratic fit of bins in-between limits (for dip optional)

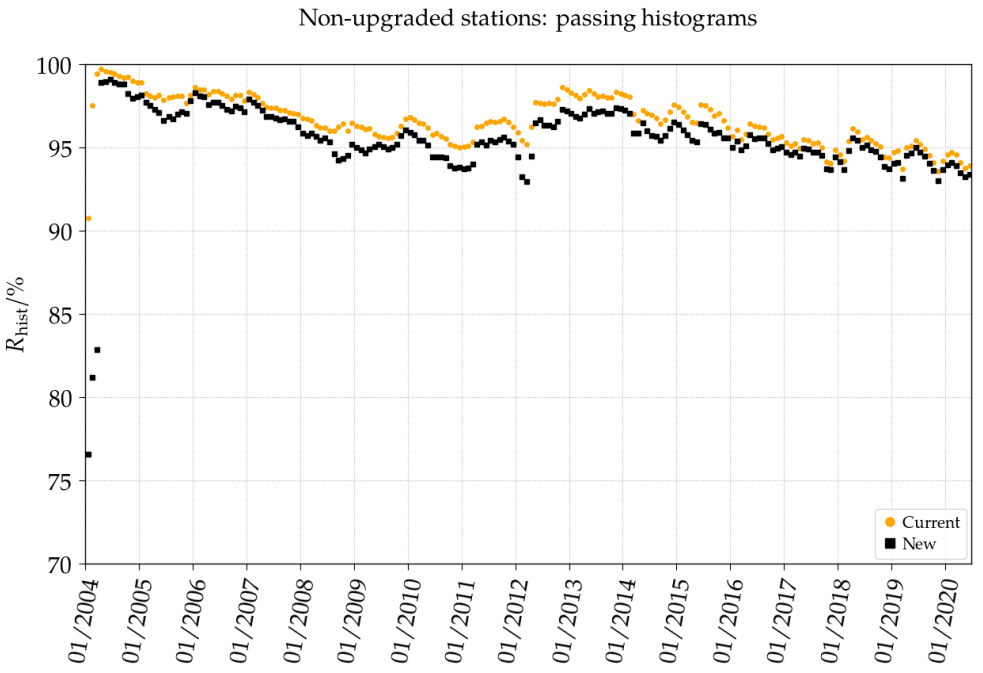


New Calibration of WCD

- New algorithm only successful when hump and dip determined

  → Higher quality, but lower number of passing histograms

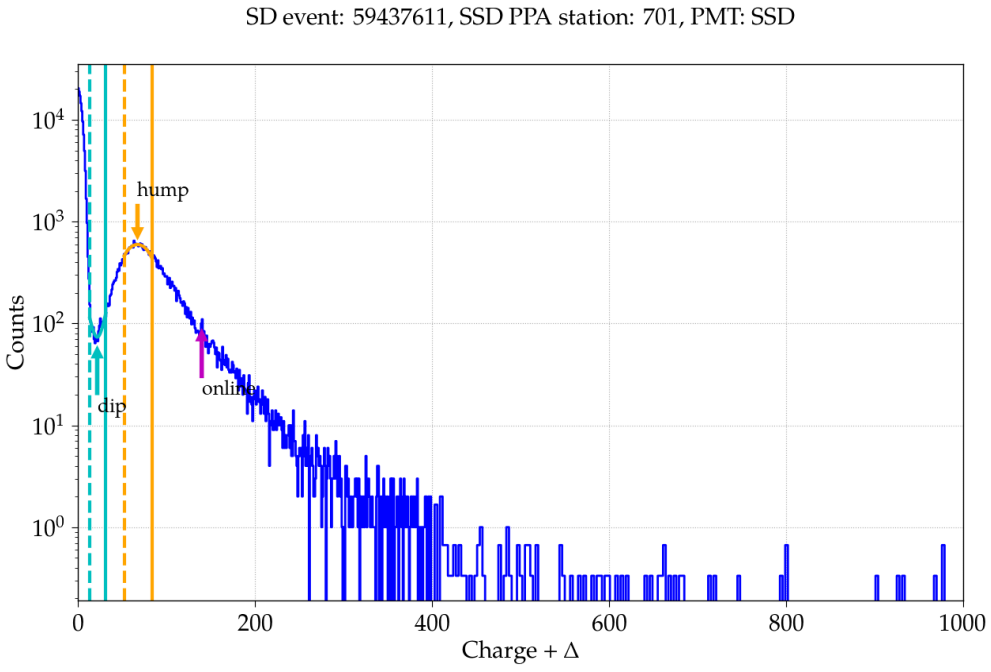


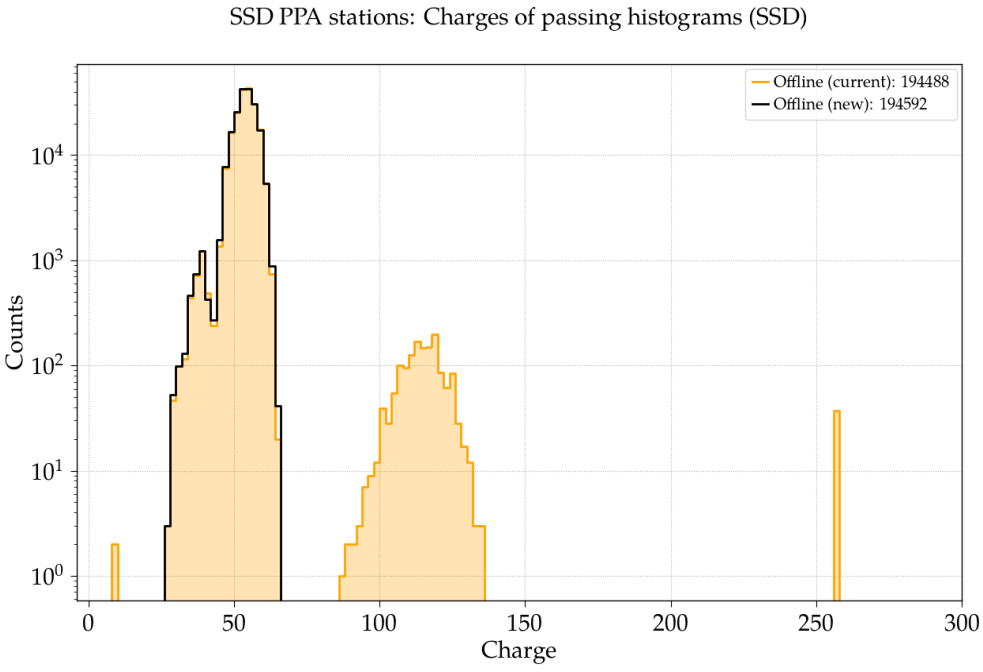


New Calibration of SSD

- No check for online estimate in-between hump limits

  → Incorrect filler module estimate not used

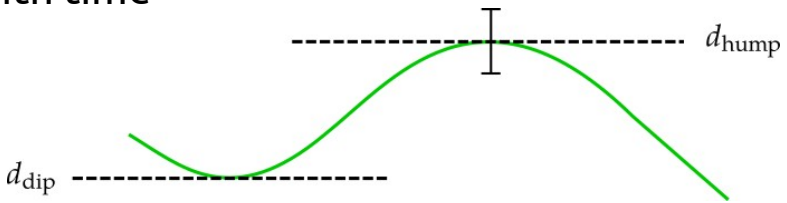


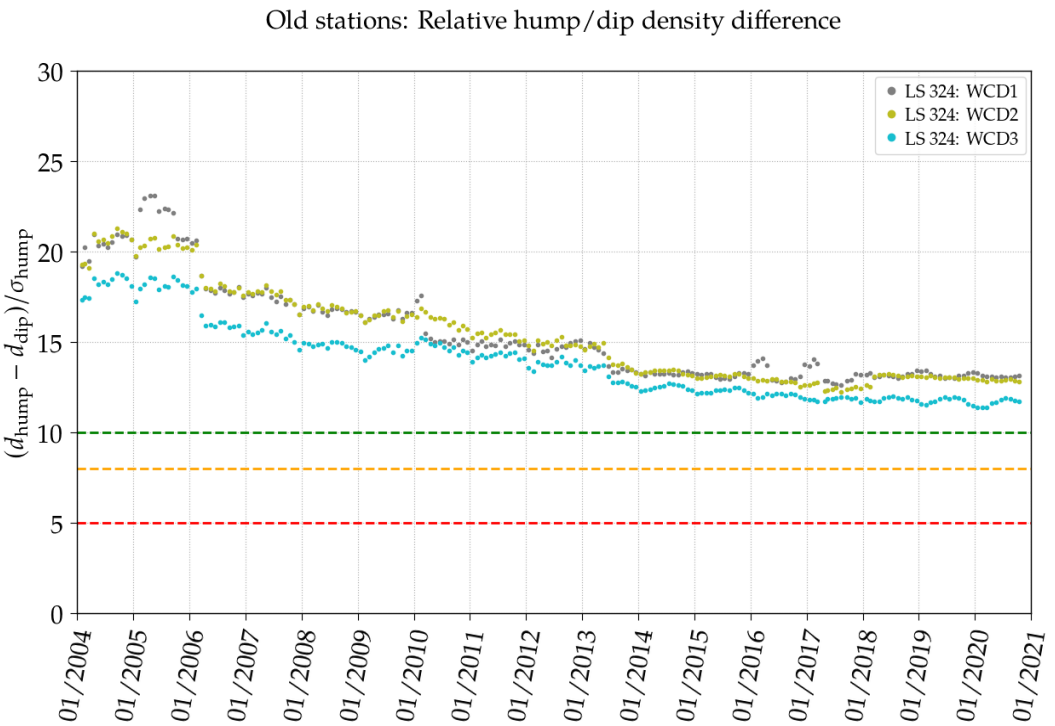


Long-term Performance

- Calibration depends on shape of histograms which changes with time
- Prediction of future performance

  → reaching limits of new calibration

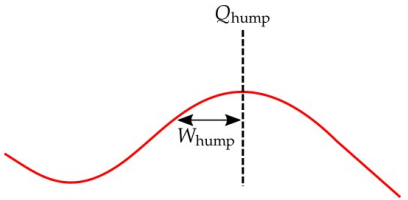


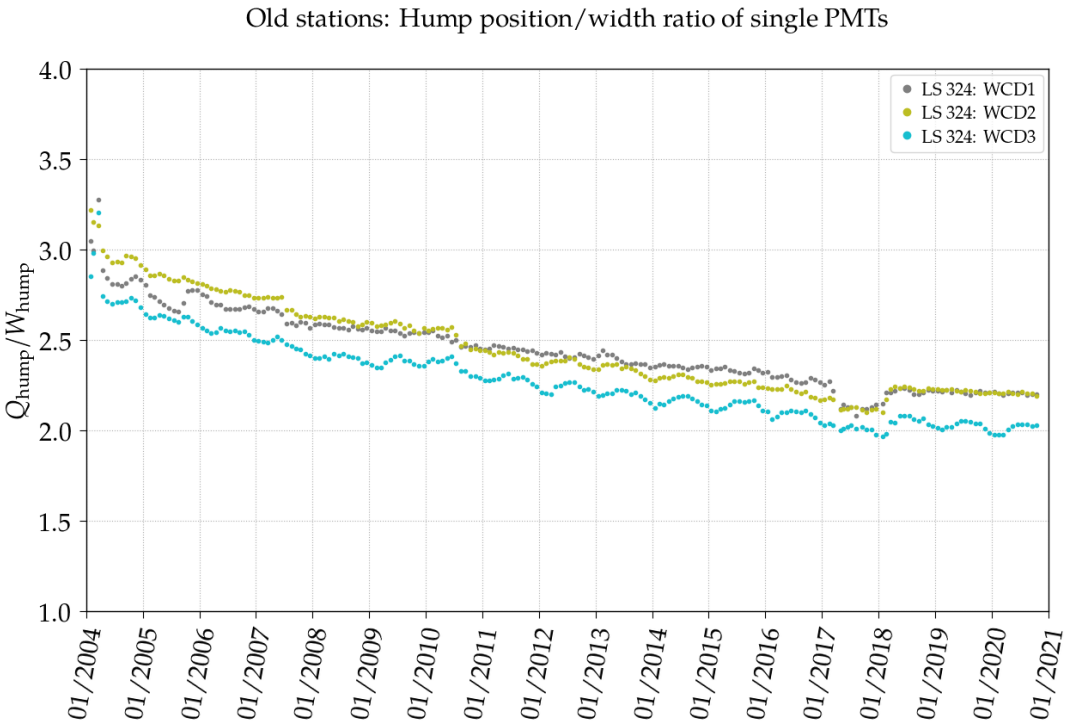


Long-term Performance

- Ratio of hump position (charge) and hump width

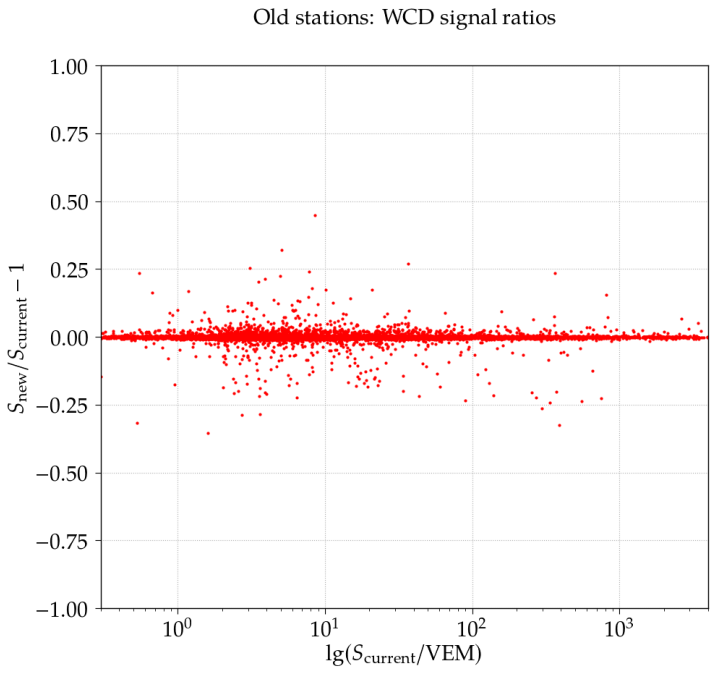
  → Light yield estimate: $N_{\text{eff}} \approx \left(\frac{Q_{\text{hump}}}{W_{\text{hump}}} \right)^2$

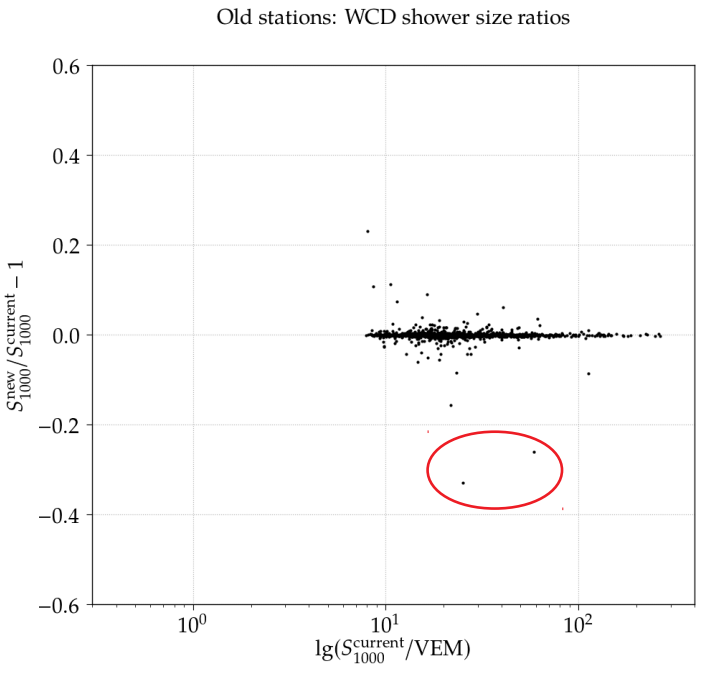




Air Shower Reconstruction

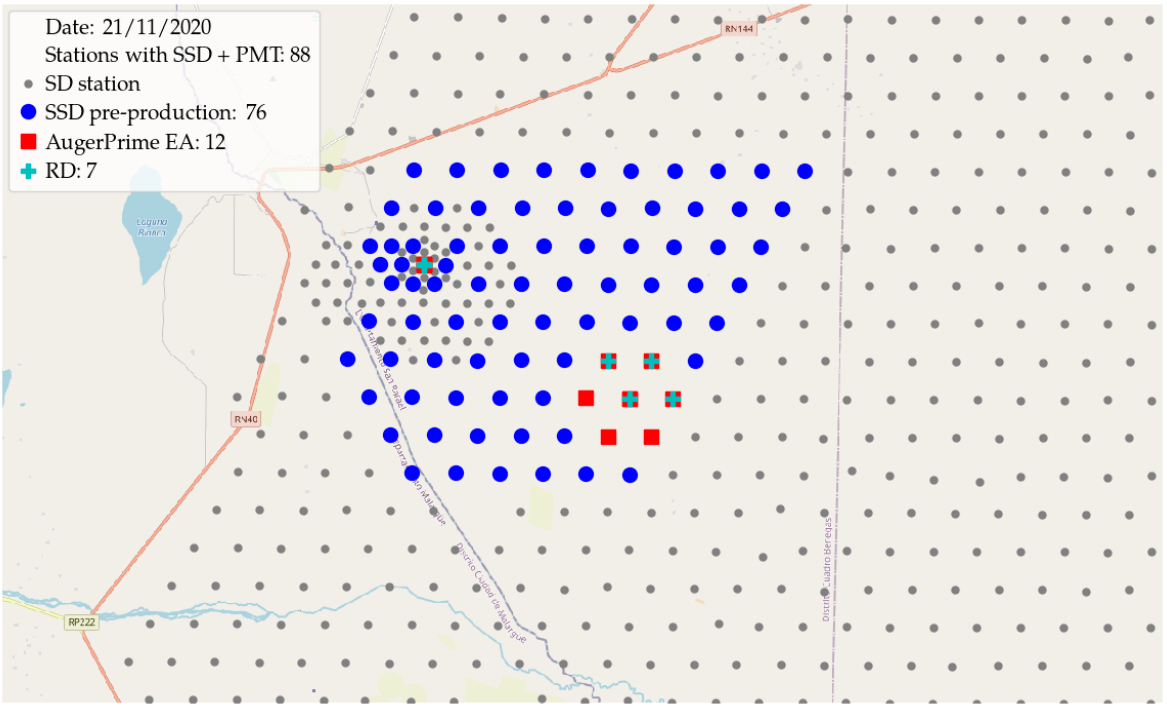
- Comparison: current to new calibration algorithm
- Rejection of PMTs possible → rejection of stations possible → stations in events can differ





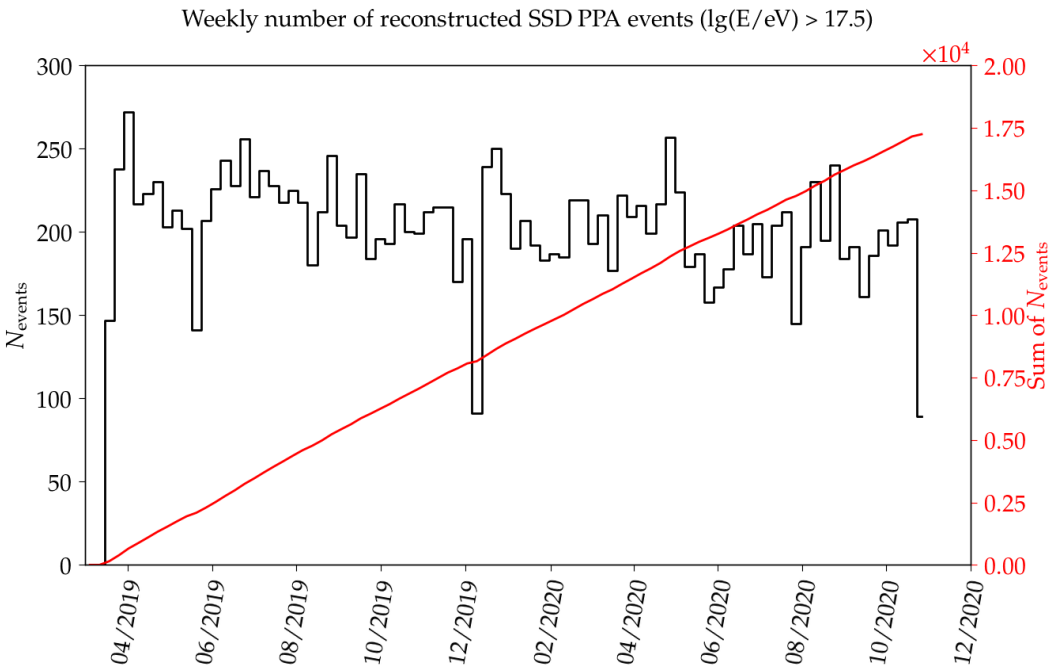
SSD Pre-production Array

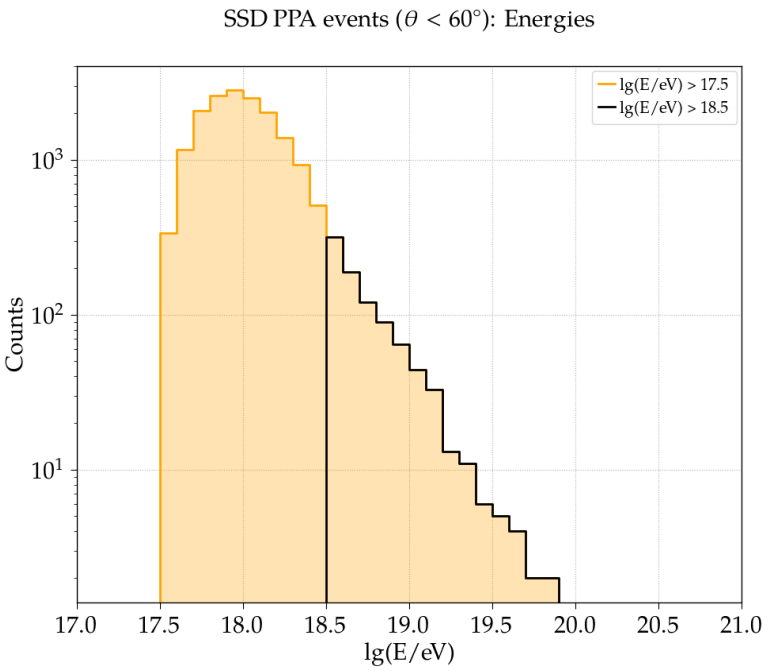
- Data acquisition since March 2019
- SSD PMT connected to non-upgraded electronics (one WCD PMT disconnected)



SSD Pre-production Array

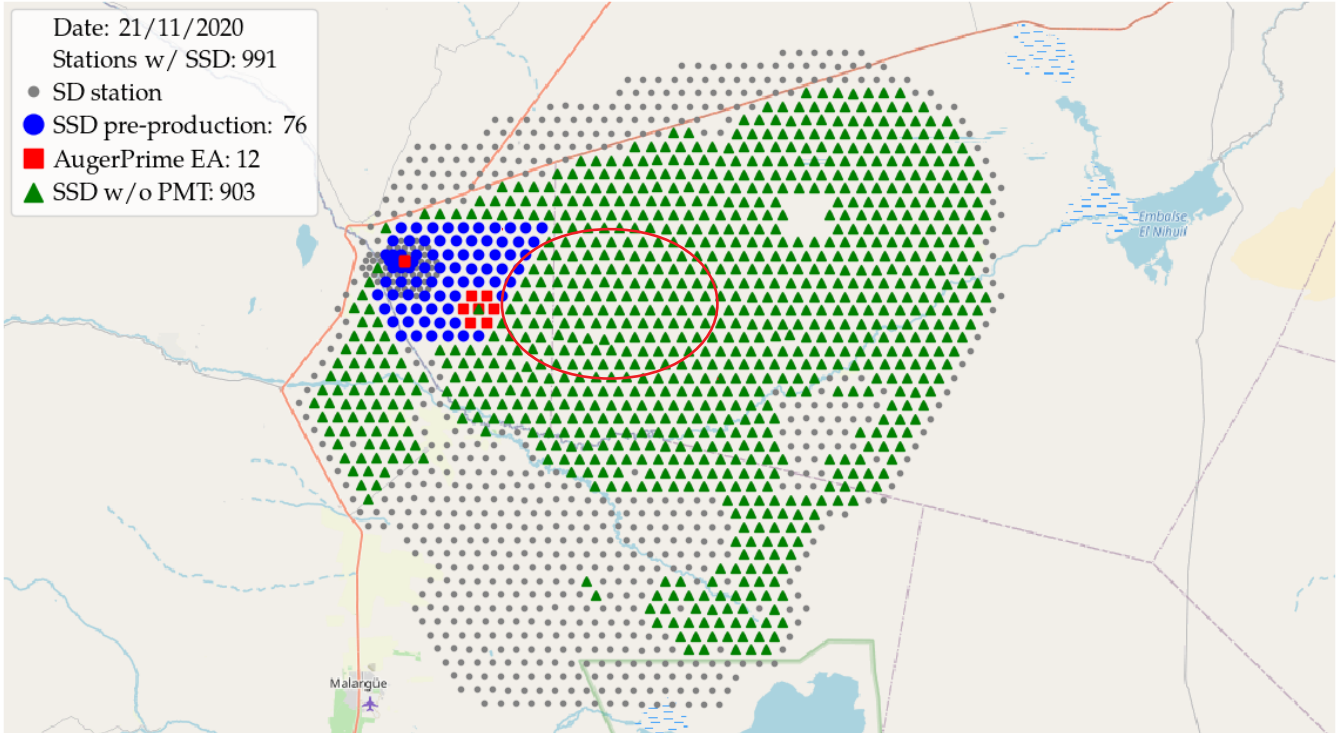
- Data up to November 2020
- Events with zenith angle θ < 60°





Look into the Future

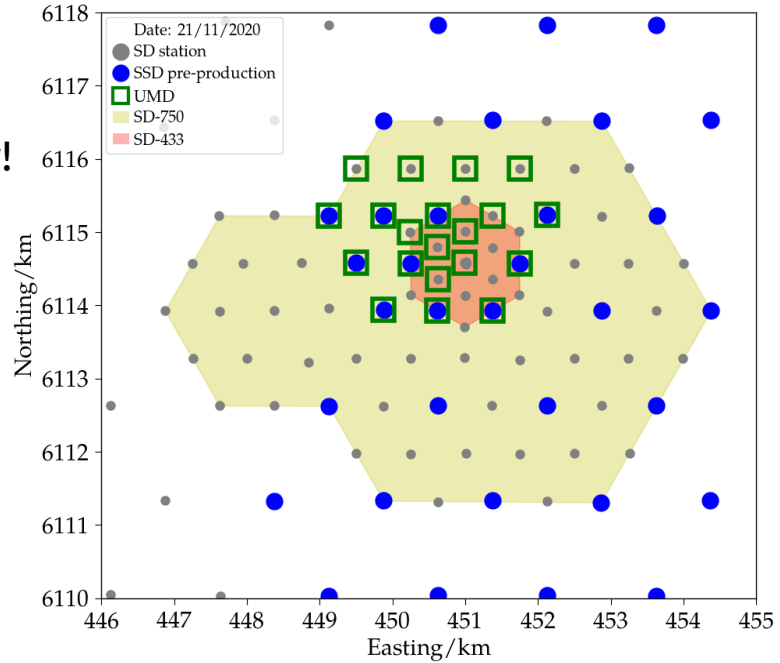
- Production of **1518** SSDs completed
- Ongoing deployment of AugerPrime components
- Very near future: UUB pre-production array (start with 31 new electronics boards)



Look into the Future

- Challenge: Calibration algorithm that suits different types of electronics and PMTs
- Modified algorithm more flexible with higher number of successful fits
- Very near future: Adaptations to UUB PPA data

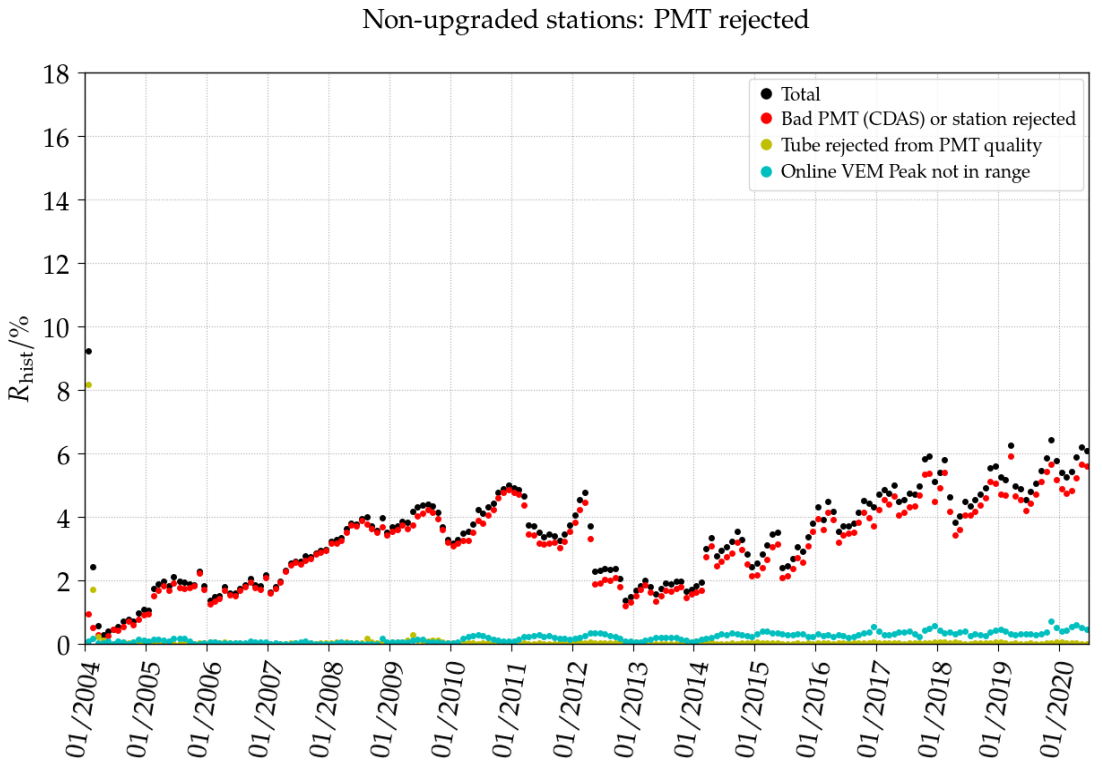
The glorious multi-hybrid detection and data analysis starts now!



Thank You!

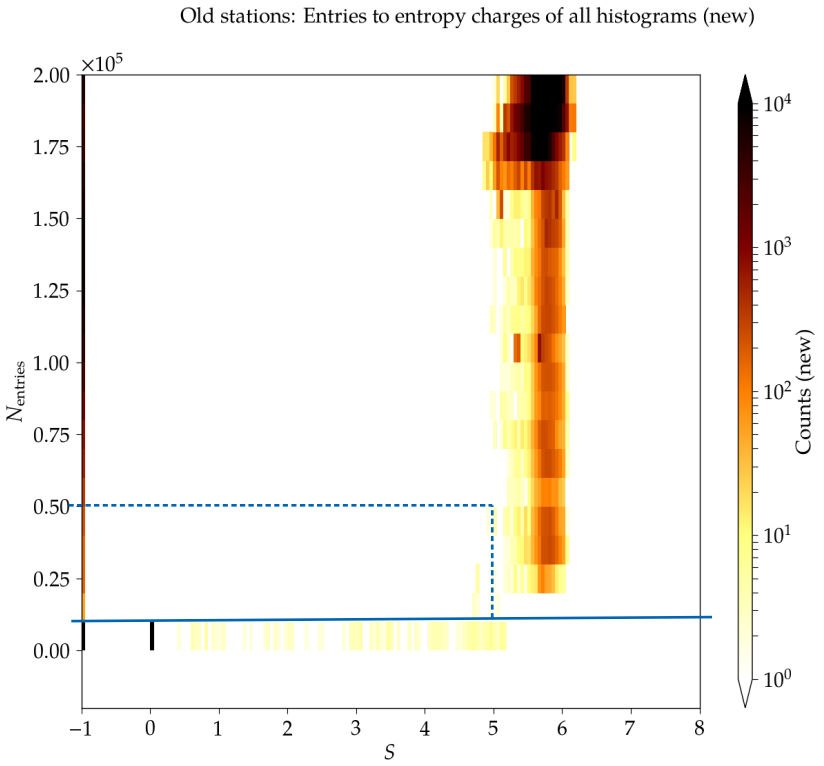
Rejected PMTs

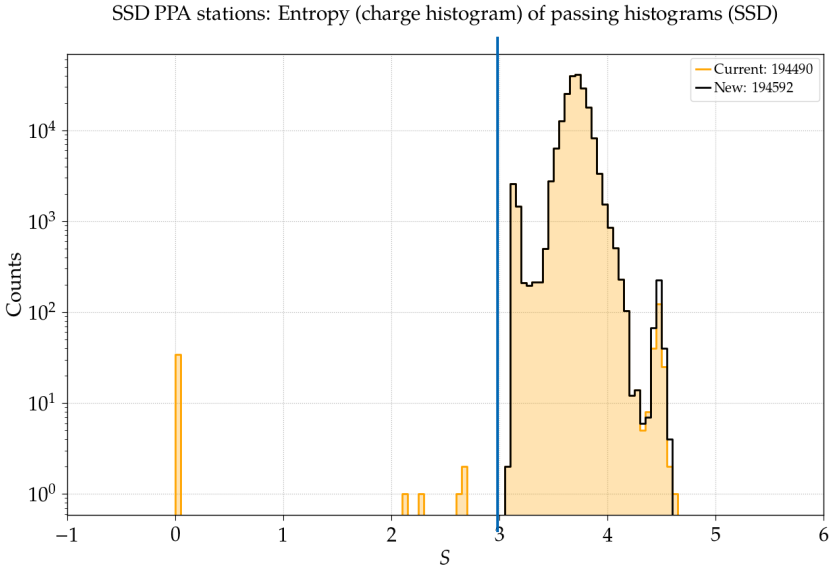
- PMTs rejected by CDAS or during event merging (quality flags from monitoring)
- Additional rejection by certain online values (only available for UB WCD PMTs)



Calibration of WCD and SSD

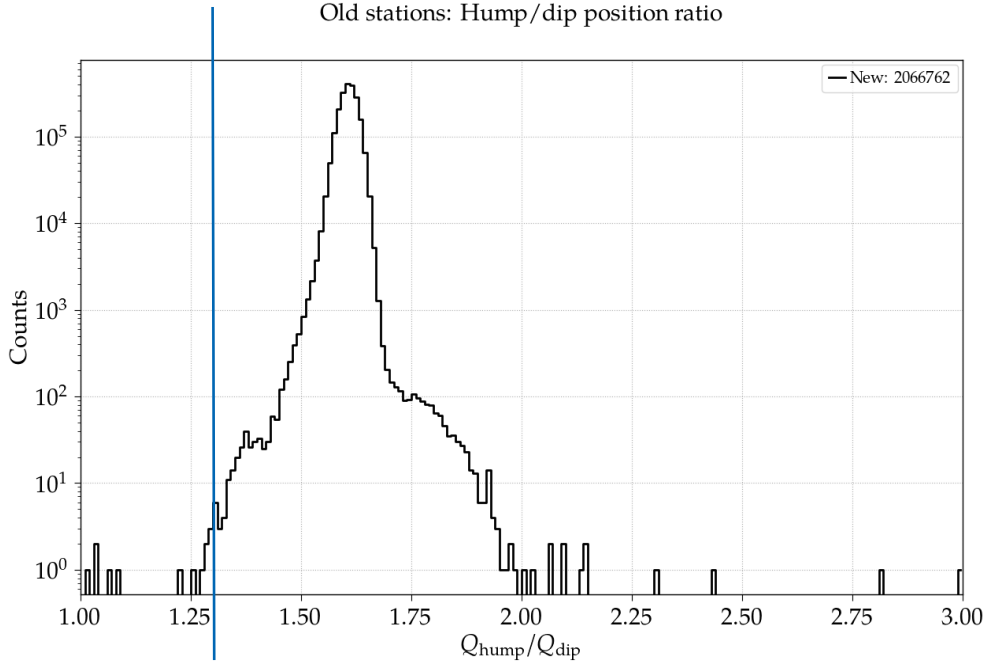
- Pre-selection: Rejection of anomalous histograms before fit procedure
- Check of total number of entries and histogram entropy





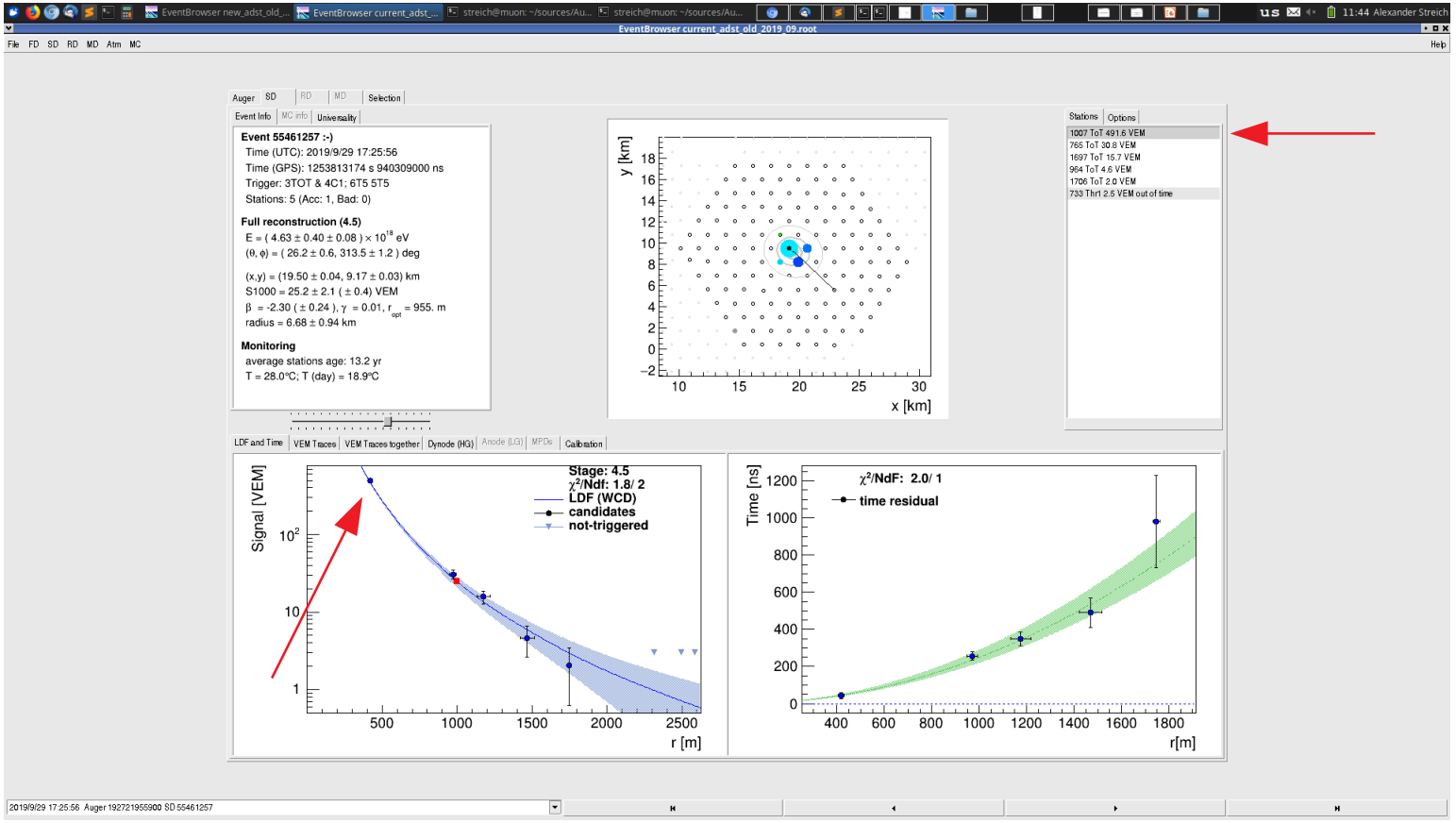
Calibration of WCD and SSD

- Post-selection: Quality check of fit results
- Requirement of minimum hump/dip charge ratio → rejection of fits of fluctuations



Air Shower Reconstruction

- Current calibration algorithm:



Air Shower Reconstruction

- New calibration algorithm: