

SD-433: Reconstruction and LDF-fitting procedure

G. Silli, D. Melo, D. Ravignani, M. Roth | November 27, 2020

ITeDA-KIT



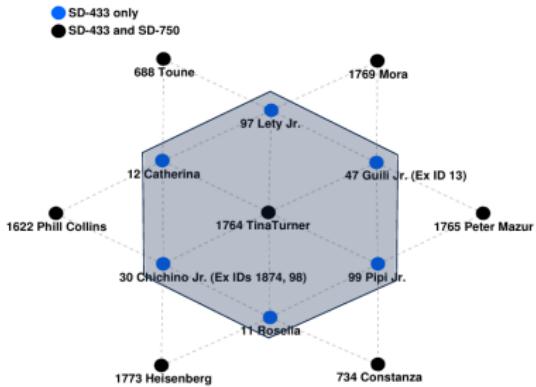
Evolution of the SD-433



■ 2013

The first hexagonal cell has been completed: six additional tanks around the central one, Tina Turner. These seven SD stations constitute the unique elementary cell of the SD433 array.

The whole hexagon became fully operational at mid May 2013.



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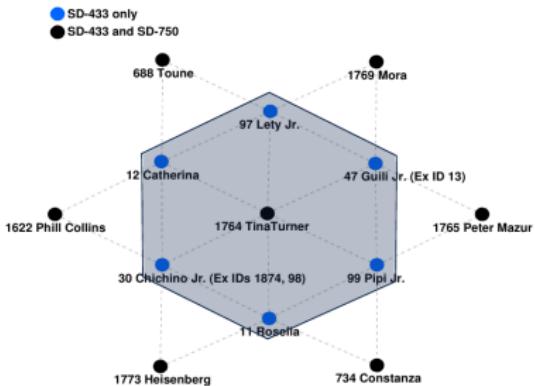


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SD-433 dedicated working group formed



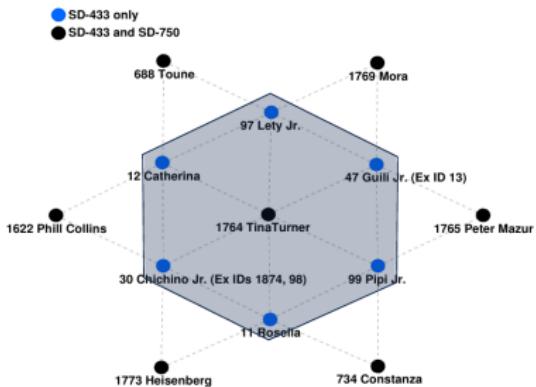
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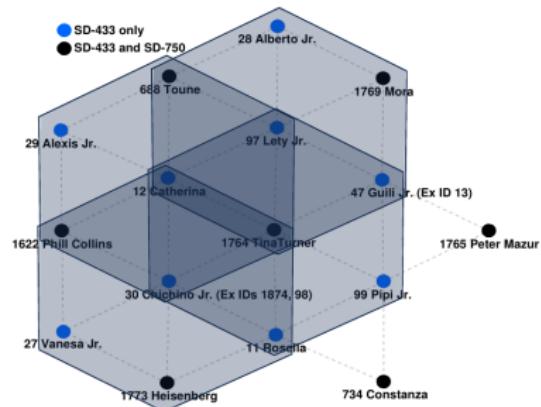
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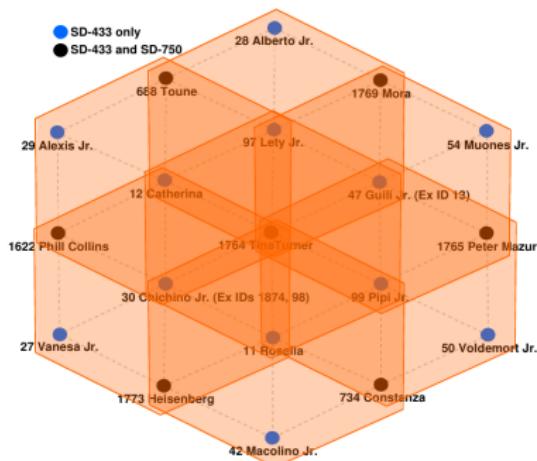
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- 2019
Three more additional WCDs deployed (right). Seven hexagons aperture.
The SD-433 is now completed!



Motivation



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- Photon search programme down to $\sim 10^{16}$ eV :
(southern hemisphere) IceCube at $\sim 10^{15}$ eV and Auger
above $\sim 10^{17.3}$ eV.
Contribute to the multi-messenger studies.
Indirect probe of the CR composition .

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- Extend the Auger surface measurements to lower energies:
extend the energy spectrum to observe the second knee,
where a transition from Galactic to Extra-Galactic CRs may take place.

Second knee:

- Main motive for the construction of the SD-750.
- Reported by Telescope Array, IceTop and Kascade-Grande as a steepening of the spectrum around 10^{17} eV.
- 10^{17} eV is below the energy threshold of the SD-750

Denser array is required!

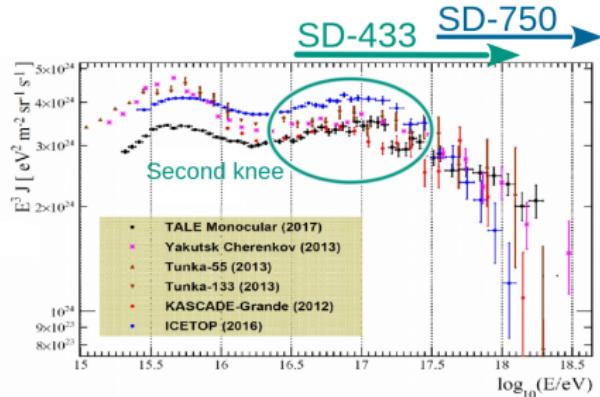
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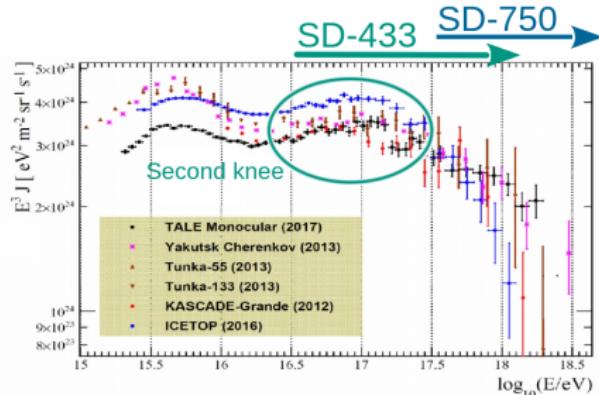
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Denser array is required!

The SD-433 will allow for the first time the measurement the three UHE spectrum features not only by a single observatory but with the same detection technique

Data selection and recovery



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The Missing silent problem:

- CDAS was recording data from T3 triggered stations **only** (2013-2018)
- only T3 triggered stations in the event
- no informations on silent stations (T2 triggered - T2Flag not saved)
- silent stations for the 6T5 condition (20K 6T5 events lost in 5 years)
- 6T5 from SD-750 events (CDAS)
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Two restoring methods:

- **T2Raw-method:** T2raw monitoring file - additional module (T2Restorer) - silent stations are made during the reconstruction process (SdCalibrator)
- **TankLife-method:** TankLife (@ Lyon CC) monitoring files - silent stations included in CDAS files - same format kept. (M.Roncoroni)

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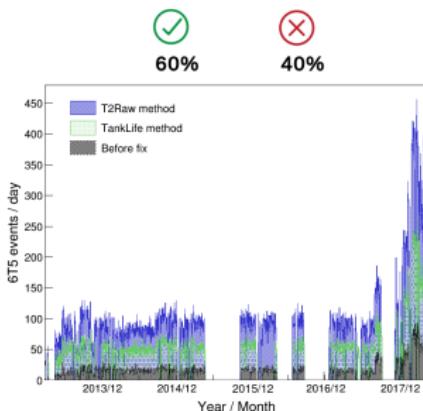
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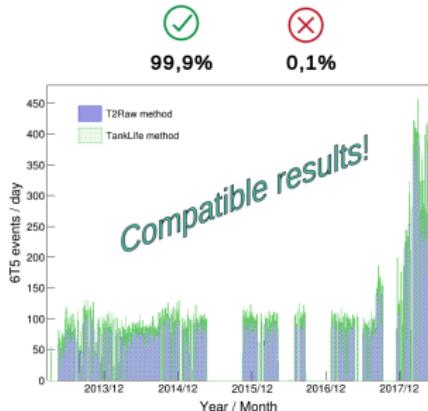
CROSSCHECKS
→
T4 events + EnRec>0

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LDF parametrization



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Event reconstruction settings:

- SD-433 rec. settings (S.Messina et al., GAP 2014-094)
- Using ToTd-MoPS triggers (M.Settimo et al., GAP 2013-114)
- time period: 2013 – 2020 (including missing silents)

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Event-by-event fit:

- the idea is to fit the LDF parameter β , together with S_{250} and core position, for each event independently.
- set β as free parameter (LDFFinder settings)
- global fit using the obtained β_i values is applied
- fit is performed using a β -only NKG-like LDF ($\gamma = 0$)

$$S(r_i) = S_{r_{opt}} \left(\frac{r_i}{r_{opt}} \right)^\beta \left(\frac{r_i + r_{scale}}{r_{opt} + r_{scale}} \right)^\beta$$

β is fitted event wise
for events with enough stations

Event-by-event fit of the LDF

event data

β binned in $\sec\theta$ and $\log(S_{250})$

β parametrization

LDF parametrization



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- No saturated events
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- Zenith angle dependent T4 trigger efficiency (from simulations)
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Additional requirements for a free β fit (Adapted to the SD-433 array spacing by interpolating the values of the Regular and Infill arrays (svn commit: r33162)):

- 2 stations in [125 m, 450 m] with distance ≥ 225 m **OR**
- 3 stations in [125 m, 450 m] with distances ≥ 200 m **OR**
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After these cuts: 36353 selected events

Parametrized β



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- standard slope parametrisation

$$\begin{aligned}\tilde{\beta}(\sec \theta, \log S_{250}) = & \quad a + b \log S_{250} \\ & + (c + d \log S_{250}) \sec \theta \\ & + (e + f \log S_{250}) \sec \theta^2\end{aligned}$$

- binned (✓) & unbinned parametrization (✗)
- χ^2 method to determine the set of beta parameters (a,b,c,d,e,f)
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Value	-1.71	-0.43	-1.83	0.88	1.23	-0.44

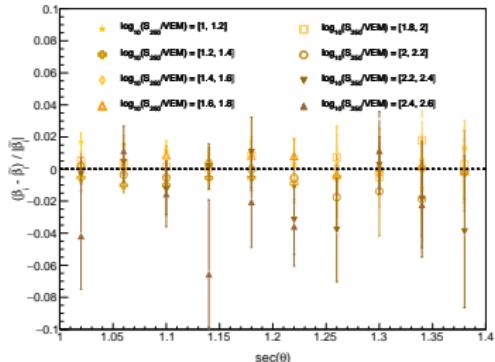
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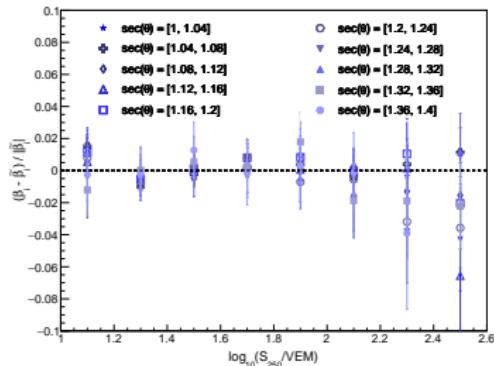
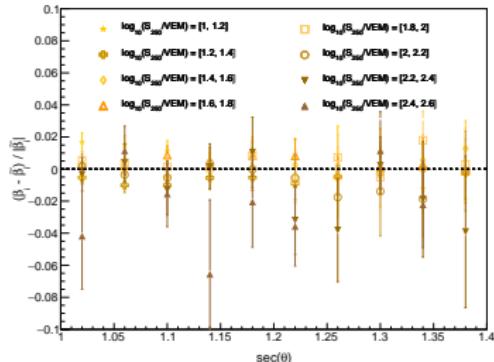
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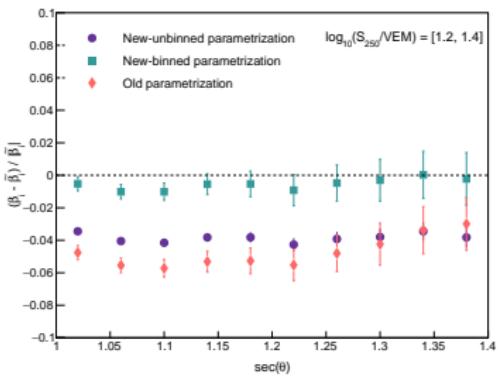


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Presented:

- Distribution $\frac{\beta_i - \bar{\beta}_i}{|\bar{\beta}_i|}$ as a function of $\sec \theta$



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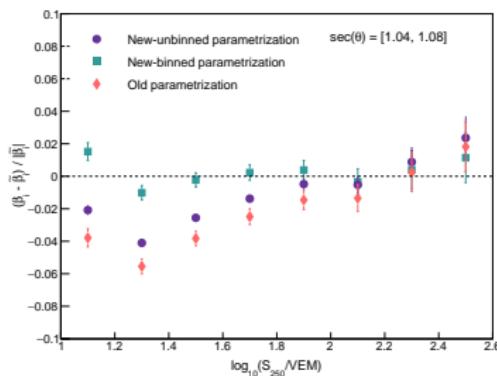
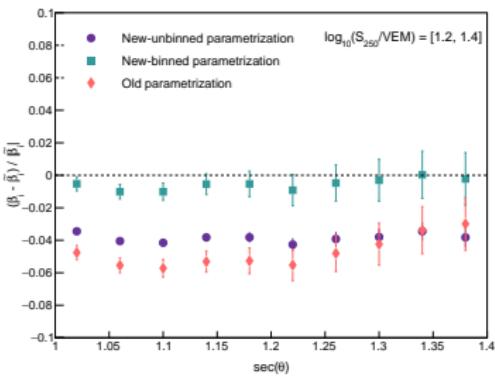


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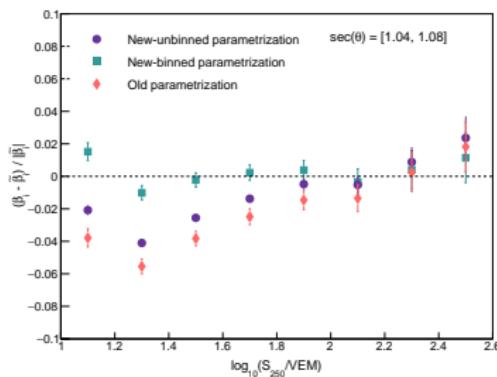
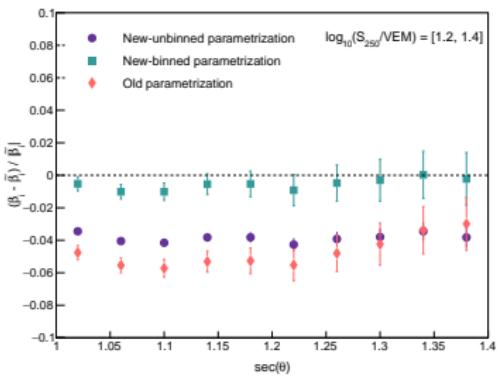


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- Distribution $\frac{\beta_i - \bar{\beta}_i}{|\bar{\beta}_i|}$ as a function of $\sec \theta$ and $\log(S_{250})$
- Old (standard SD-433) vs New parametrizations (binned and unbinned)
- Binned parametrization (10 x 8 intervals respectively)
- show as example: $\sec \theta = [1, 1.4]$ and $\log(S_{250}) = [1, 2.6]$ (backup)



Old & new parametrization



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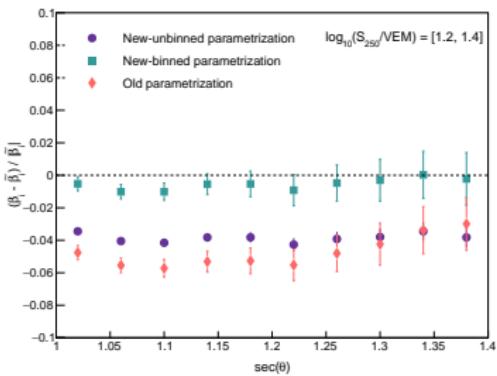


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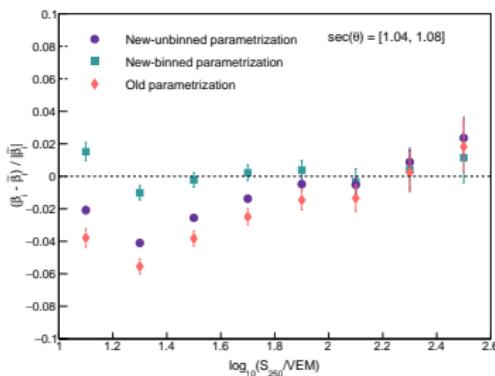
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We chose the binned parametrization !!!



Energy calibration



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- Energy calibration done with data from May 2013 to Feb. 2015 with
 - ~ 200 events
 - S. Messina GAP 2017-044
 - SD-433 against SD-750 Calibration

Energy calibration



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Karlsruhe Institute of Technology

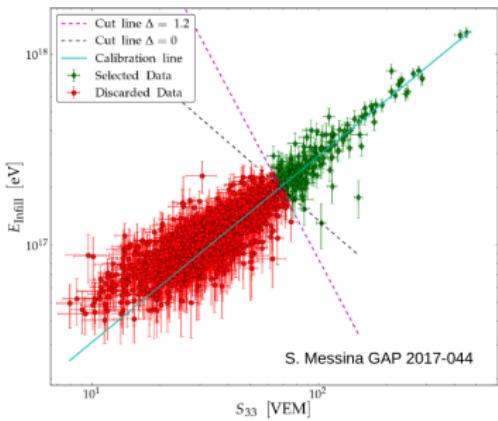
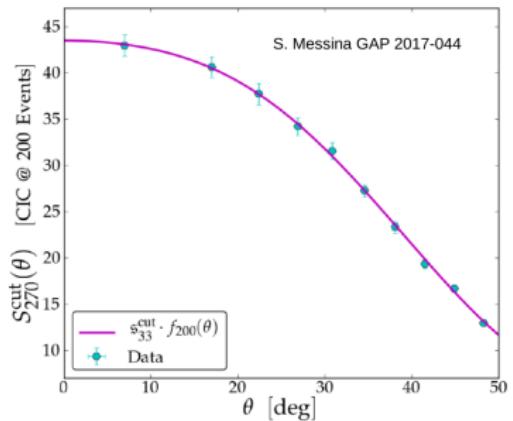
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Options:

- FD: HEAT/Coihueco eyes

Preferred calibration method

Limited duty cycle and low quality events.

Coincident events were extremely unlikely to pass the strict quality cuts.

Energy calibration



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- **Cherenkov-dominated events**

PCGF reconstruction (Vladimír Novotný).

Enable to decrease the energy threshold for the spectrum measurement down to $10^{15.5}$ eV. Few events in coincidence.

Energy calibration



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Coincident events were extremely unlikely to pass the strict quality cuts.

- **Cherenkov-dominated events**

PCGF reconstruction (Vladimír Novotný).

Enable to decrease the energy threshold for the spectrum measurement down to $10^{15.5}$ eV. Few events in coincidence.

- **SD-750**

Previous calibration

Infill measurement of the CR energy taken as reference to perform the energy calibration

Energy calibration



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Options:

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	FD	Cherenkov	SD-750
--	----	-----------	--------

time period	2013-2019	2013-2015	2013-2019 ICRC
SD-433	836	60	33822 (6T5)

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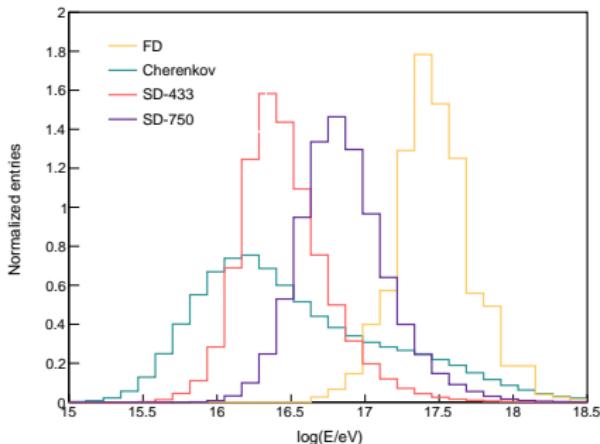
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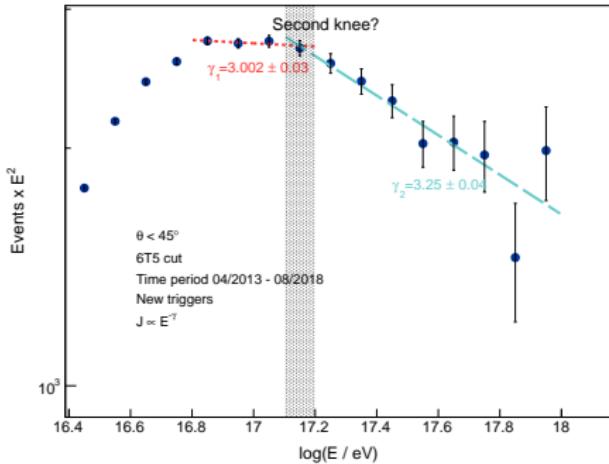
Preliminary histogram



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- used the recovered 6T5
- Old Offline reconstruction (S.Messina)
- clear break at $10^{17.15}$ consistent with the second knee



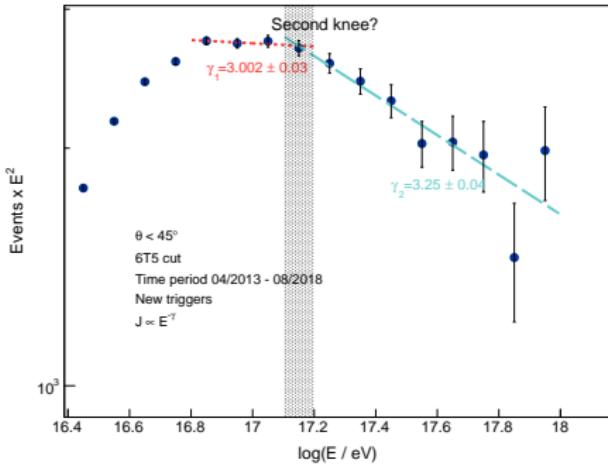
Preliminary histogram



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Preliminary histogram

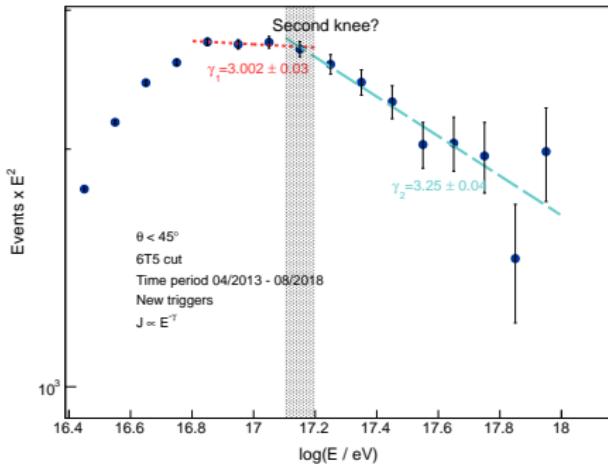


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...results are very encouraging!!!



Conclusions



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Summary:

- Silent stations fully restored
- SD433 Data set available for the collaboration
- LDF slope β parametrized as a function of $\sec \theta$ and S_{250}

Conclusions



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Next step:

- Constant Intensity Cut (CIC)
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Conclusions



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- Constant Intensity Cut (CIC)
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SD433 Group on-going analyses:

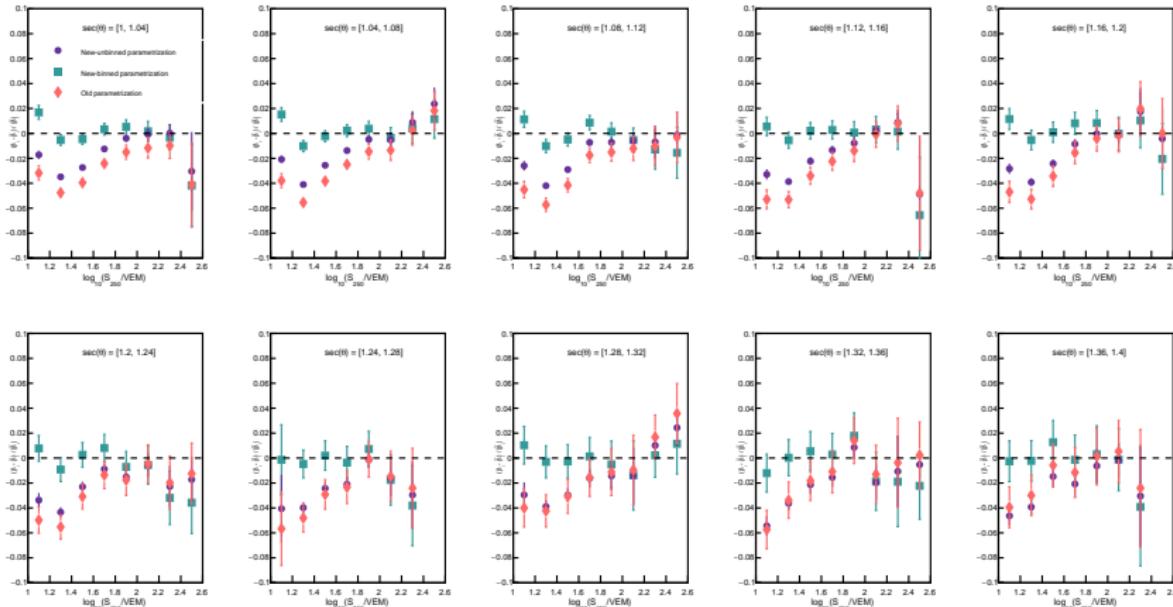
- Data quality checks and alternative bad period method (N.Gonzalez)
NG et al, OCM2, Nov. 2020
- 433-750 trigger efficiency (G.Brichetto)



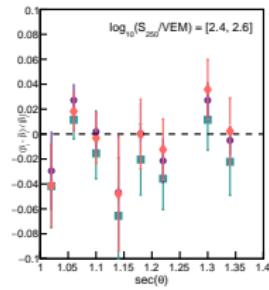
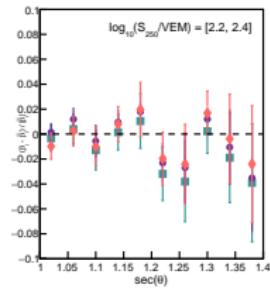
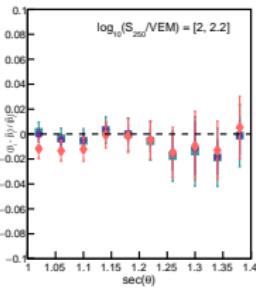
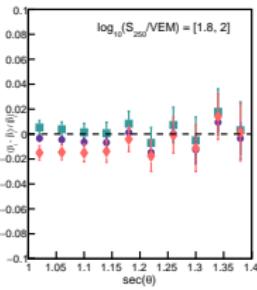
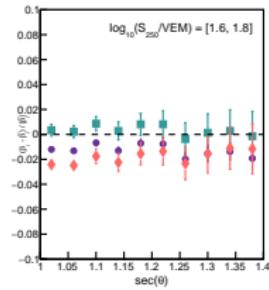
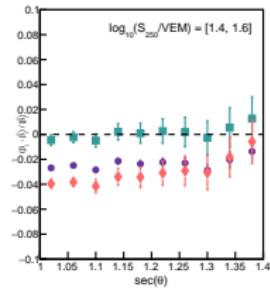
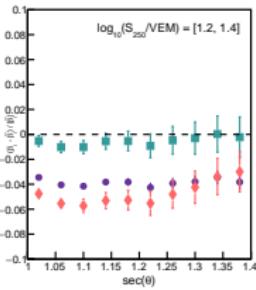
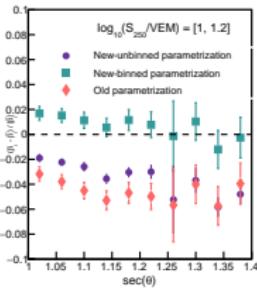
thank you!



Backup: β as a function of $\log(S_{opt})$



Backup: β as a function of $\sec(\theta)$



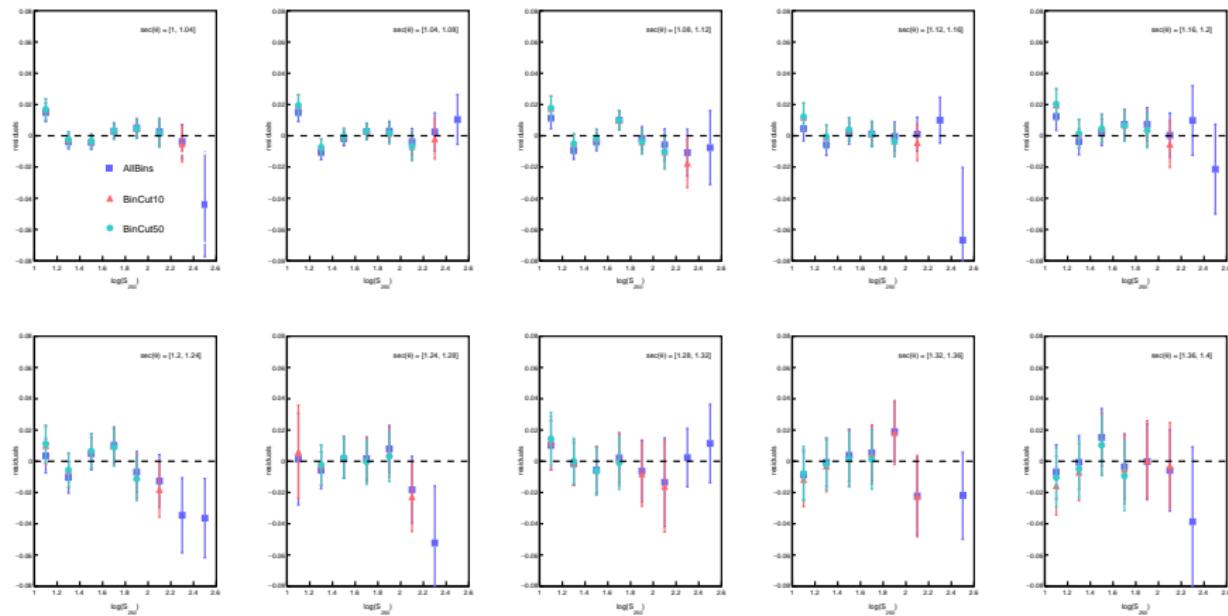
TProfile parameters: bin cut applied



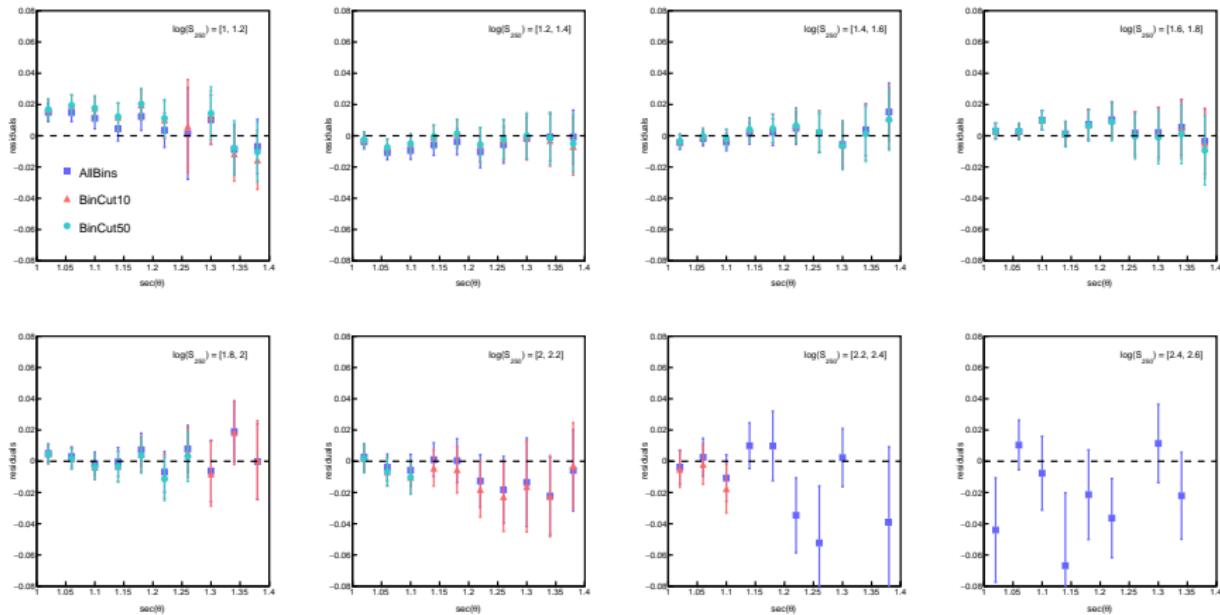
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TProfile parameters: bin cut applied



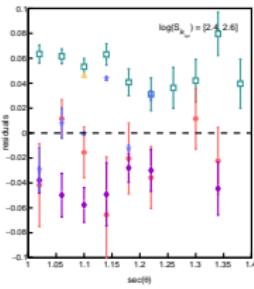
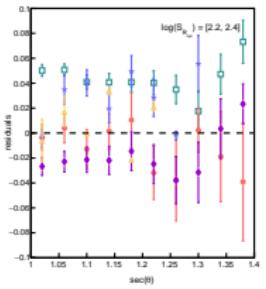
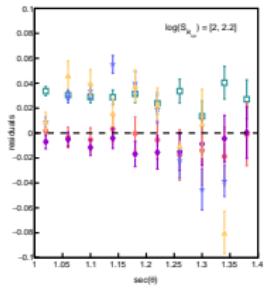
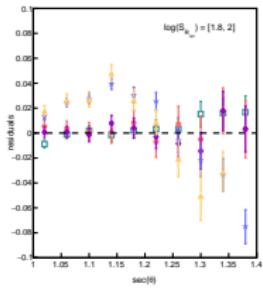
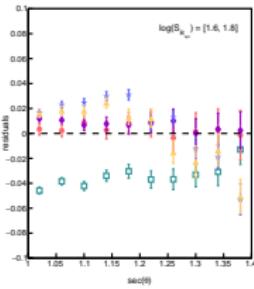
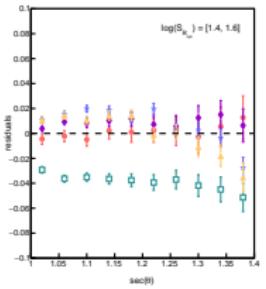
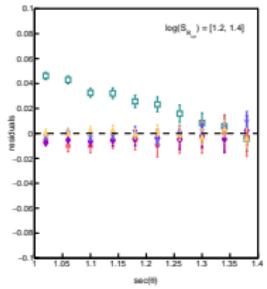
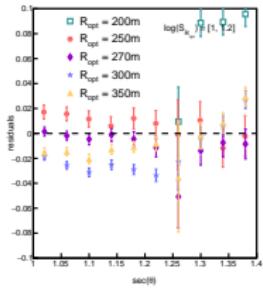
Residuals: R_{opt}



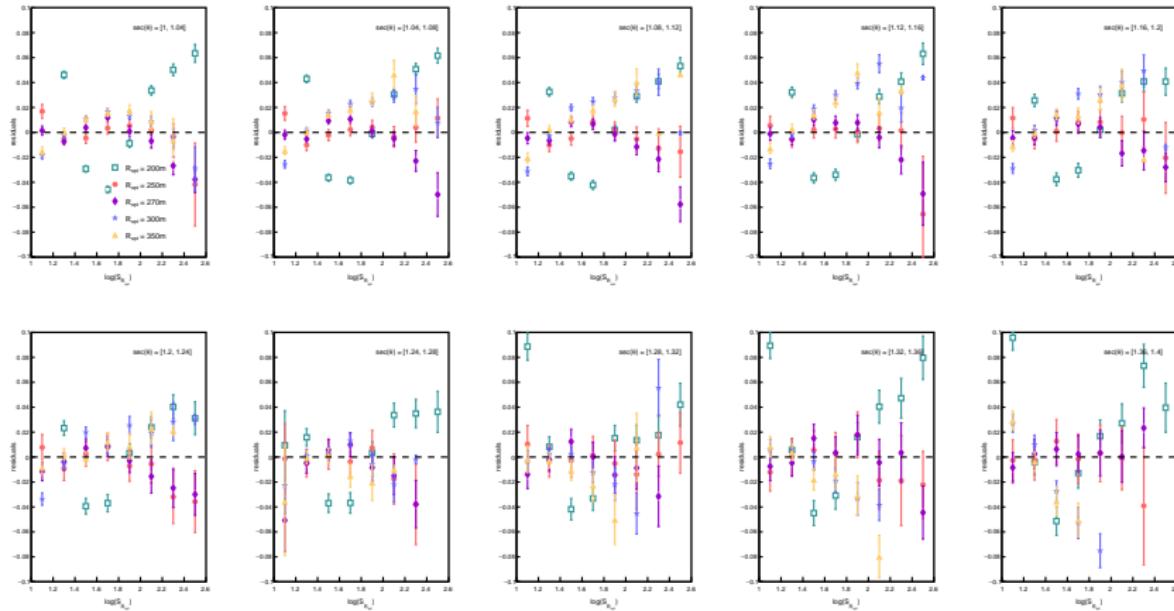
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Residuals: R_{opt}



Before



```
[INFO] Modules/SdReconstruction/Risetime1000LLL/Risetime1000LLL.cc:483: FitEventRiseTime: Passed Cut: station 98, distance 0.366109 km, risetime 71.1206 ns
[INFO] Modules/SdReconstruction/Risetime1000LLL/Risetime1000LLL.cc:483: FitEventRiseTime: Passed Cut: station 99, distance 0.321474 km, risetime 82.9982 ns
[INFO] Modules/SdReconstruction/Risetime1000LLL/Risetime1000LLL.cc:490: FitEventRiseTime: Passed Cut: station 97, distance 0.740777 km, risetime 54.7319 ns
[INFO] Modules/SdReconstruction/Risetime1000LLL/Risetime1000LLL.cc:407: Run: The Risetime at 1 km is 111.305 +- 22.487 ns
[INFO] Modules/SdReconstruction/DLECorrectionGg/DLECorrection.cc:231: Run: DLECorrection::Run()
[INFO] Modules/SdReconstruction/DLECorrectionGg/DLECorrection.cc:147: CorrectDLE: DLECorrection::CorrectDLE()

station id in crown range (t5posteriorEventSelector) 1764
station id close to the core (t5posteriorEventSelector) 1764
station id close to the core (t5posteriorEventSelector) 11
station id in crown range (t5posteriorEventSelector) 98
station id close to the core (t5posteriorEventSelector) 98
station id in crown range (t5posteriorEventSelector) 99
station id close to the core (t5posteriorEventSelector) 99
[INFO] SdEventPosteriorSelector.cc:219: Run: T5Posterior = 0
[INFO] SdEventPosteriorSelector.cc:234: Run: tTrigger 0 -> 0
[INFO] Modules/General/RecDataWriterNG/RecDataWriter.cc:249: Run: .
[WARN] Modules/General/RecDataWriterNG/Detector2ADST.cc:338: FillDetector: Could not locate requested data in the database, Did not find requested data for:
Component name : overall_quality
Component property: property
Detector time = 2016-01-01T12:49:39.923804000Z (UTC), 11356877945:9:2380e+008 (GPS)
[INFO] Modules/General/RecDataWriterNG/Offline2ADST.cc:526: FillDetectorGeometryIncremental: Updating SD stations
[INFO] Framework/Detector/Detector.cc:189: Update: to time 2016-01-01T12:52:08.825619000Z (UTC), 1135687945:8.25619e+008 (GPS)
[INFO] EventIO/CdAS/CDAS0fflineEventConverter.cc:227: ConvertIoSdTEvent: auger_160010313000_sd_36168008
CDAS0fflineConverter Branch---Station id + 11
CDAS0fflineConverter Error = 0
CDAS0fflineConverter rsIt->T2L1fe1
CDAS0fflineConverter Branch---Station id + 98
CDAS0fflineConverter Error = 0
CDAS0fflineConverter rsIt->T2L1fe1
CDAS0fflineConverter Branch---Station id + 1764
CDAS0fflineConverter Error = 0
CDAS0fflineConverter rsIt->T2L1fe1
CDAS0fflineConverter Branch---Station id + 99
CDAS0fflineConverter Error = 0
CDAS0fflineConverter rsIt->T2L1fe1
[INFO] Modules/General/EventFileReaderOG/EventFileReader.cc:287: Run: Event id = 'auger_160010313000_sd_36168008'
[INFO] Modules/SdReconstruction/SdPMTQualityCheckerKg/SdPMTQualityChecker.cc:78: Run: Applying PMT quality flags according to information in raw event ...
[INFO] Modules/SdReconstruction/SdPMTQualityCheckerKg/SdPMTQualityChecker.cc:164: PMTChecks: Flagging whole PMT 1 of station 1764 as bad (reason: vemPeak out of allowed range). Flagging whole PMT 2 of station 1764 as bad (reason: vemPeak out of allowed range).

[INFO] Modules/SdReconstruction/SdStationPositionCorrection0G/SdStationPositionCorrection.cc:241: Run: Station offsets: (11: 0ns) (98: 0ns) (1764: -1.33668e-09ns) (99: 0ns)
0168008----- 11----- 2
0168008----- 98----- 2
0168008----- 1764----- 2
0168008----- 99----- 2
[INFO] SdEventSelector.cc:1145: BottomUpSelection: Seed theta = 41.8842, phi = -25.1009 deg (site)
station id in crown range 11
station id in crown range 98
station id in crown range 99
[INFO] SdEventSelector.cc:864: IsEventT5: Only 3 (out of 6) functioning neighbors for max-signal station 1764 found (candidates: 3, silent: 0, rejected: 0).
eventTime 2016-01-01T12:52:08.825619000Z (UTC), 1135687945:8.25619e+008 (GPS)
[INFO] SdEventSelector.cc:612: Run: T4 = 4C1; T5 = 0; Bad period id=1117
[INFO] SdEventSelector.cc:623: Run: T4 = 4C1; T5 = 0; Bad period id=1117
[INFO] Modules/SdReconstruction/SdPlaneFit0G/SdPlaneFit.cc:221: Run:
# candidate stations = 4
parycenter = (11364.2, 54336.9, 1324.4) [m] (site)
pary time = -10862.3 [ns] (to event time)
local/site zenith angle diff. = 8.500142 [deg]
```

After



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```
Component name : overall_quality
Component property: property
Detector time = 2016-01-01T12:49:39.923884000Z (UTC), 1135687796.9.23804e+08 (GPS)
[INFO] Modules/General/RecDataWriterNG/Offline2DST.cc:526: FillDetectorGeometryIncremental: Updating SD stations
[INFO] Framework/Detector/Detector.cc:189: Update: to time 2016-01-01T12:52:08.825619000Z (UTC), 11356877945.8.25619e+08 (GPS)
[INFO] EventIO/CDAS/CDASToOfflineEventConverter.cc:227: ConvertIoSdToEvent: auger_160010313000_sd_36168008
[INFO] CDASToOfflineConverter Branch---Station id = 11
CDASToOfflineConverter Error = 0
CDASToOfflineConverter rsIt->t2L1f1
CDASToOfflineConverter Branch---Station id = 98
CDASToOfflineConverter Error = 0
CDASToOfflineConverter rsIt->t2L1f1
CDASToOfflineConverter Branch---Station id = 1764
CDASToOfflineConverter Error = 0
CDASToOfflineConverter rsIt->t2L1f1
CDASToOfflineConverter Branch---Station id = 99
CDASToOfflineConverter Error = 0
CDASToOfflineConverter rsIt->t2L1f1
[INFO] Modules/General/EventFileReaderOG/EventFileReader.cc:287: Run: Event id = auger_160010313000_sd_36168008
[INFO] T2Restorer.cc:37: Run: Restoring T2 Life using monitoring file t2raw
File opened. T2file from t2raw file
11356877945.....sId 11.....t2Flag 1
11356877945.....sId 12.....t2Flag 1
making station id 13.....t2Flag 1
11356877945.....sId 47.....t2Flag 0
11356877945.....sId 97.....t2Flag 1
making station id 97
11356877945.....sId 98.....t2Flag 1
11356877945.....sId 99.....t2Flag 1
11356877945.....sId 1764.....t2Flag 1
11356877945.....sId 30.....t2Flag 0
11356877945.....sId 734.....t2Flag 1
making station id 734
11356877945.....sId 1622.....t2Flag 1
making station id 1622
11356877945.....sId 688.....t2Flag 1
making station id 688 If station is not in the event > MakeStation
11356877945.....sId 27.....t2Flag 0
11356877945.....sId 28.....t2Flag 0
11356877945.....sId 29.....t2Flag 0
11356877945.....sId 1769.....t2Flag 1
making station id 1769
11356877945.....sId 1765.....t2Flag 1
making station id 1765
11356877945.....sId 1773.....t2Flag 1
making station id 1773
File closed.
[INFO] Modules/SdReconstruction/SdPMTQualityCheckerKG/SdPMTQualityChecker.cc:78: Run: Applying PMT quality flags according to information in raw event ...
[INFO] Modules/SdReconstruction/SdPMTQualityCheckerKG/SdPMTQualityChecker.cc:164: PMTChecks: Flagging whole PMT 1 of station 1764 as bad (reason: vemPeak out of allowed range).
Flagging whole PMT 2 of station 1764 as bad (reason: vemPeak out of allowed range).

New silent station!! continue;12
New silent station!! continue;13
New silent station!! continue;97
New silent station!! continue;734
New silent station!! continue;1622
New silent station!! continue;688
New silent station!! continue;1769

In the SdCalibrator module
to avoid new silent station rejection

// loop on stations
int nErrorZero = 0;
for (SEvent::StationIterator sit = sEvent.StationsBegin();
     sit != sEvent.StationsEnd(); ++sit) {
    if (sit->isSilent()){
        cout << "New silent station!! continue;" << sit->GetId() << endl;
        continue;
    }
```

```

[INFO] Modules/SdReconstruction/SdStationPositionCorrection0G/SdStationPositionCorrection.cc:241: Run: Station offsets: (11: 0ns) (98: 0ns) (1764: -1.33668e-09ns) (99: 0ns)
36168008..... 11 ..... 2
36168008..... 98 ..... 2
36168008..... 1764 ..... 2
36168008..... 99 ..... 2
36168008..... 12 ..... 2
36168008..... 13 ..... 2
36168008..... 97 ..... 2
36168008..... 734 ..... 2
36168008..... 1622 ..... 2
36168008..... 1769 ..... 2
36168008..... 1765 ..... 2
36168008..... 1773 ..... 2
[INFO] SdEventSelector.cc:1145: BottomUpSelection: Seed theta = 41.8842, phi = -25.1009 deg (site)
station id in crown range 11
station id in crown range 98
station id in crown range 99
station id in crown range 12
station id in crown range 13
station id in crown range 97
eventTime 2016-01-01T12:52:08.825619000Z (UTC) 1135687945.025619e+08 (GPS)
[INFO] SdEventSelector.cc:612: Run: T4 = 4C1; TS = 1; Bad period id=1117
[INFO] SdEventSelector.cc:623: Run: T4 = 4C1; TS = 1; Bad period id=1117
[INFO] Modules/SdReconstruction/SdPlaneFit0G/SdPlaneFit.cc:221: Run:
# candidate stations = 4
barycenter = (11364.2, 54336.9, 1324.4) [m] (site)
bary time = -10862.3 [ns] (to event time)
local/site zenith angle diff. = 0.500142 [deg]
Stage 1.1: linear plane fit
axis = (0.613534, -0.293597, 0.73306) (bary)
ct0 = 0.0291267 [m]
Stage 1.2: 3d plane fit
axis = (0.619322, -0.290585, 0.729384) (bary)
theta = 43.1652 +/- 0.928552 [deg] (bary)
phi = -25.1359 +/- 1.40362 [deg]
ct0 = -0.0756438 [m]
time chi2 = 0.984709 / 1
time residual = -0.00264774 +/- 0.572919
axis diff = 0.429116 [deg] (to stage 1.1)
[INFO] Modules/SdReconstruction/LDFFinder0G/LDFFinder.cc:393: Run:
# candidate stations = 4 (0 saturated) 9 silent
using barycenter as initial core
barycenter = (11364.2, 54336.9, 1324.4) [m] (site)
bary time = -10862.3 [ns] (to event time)
axis = (0.626255, -0.285125, 0.730745) (site)
= (0.619322, -0.290585, 0.729384) (bary)

```

```

eventTime 2016-01-01T12:52:08.825619000Z (UTC) 1135687945.025619e+08 (GPS)
[INFO] SdEventSelector.cc:612: Run: T4 = 4C1; TS = 0; Bad period id=1117
[INFO] SdEventSelector.cc:623: Run: T4 = 4C1; TS = 0; Bad period id=1117
# candidate stations = 4
barycenter = (11364.2, 54336.9, 1324.4) [m] (site)
bary time = -10862.3 [ns] (to event time)
local/site zenith angle diff. = 0.500142 [deg]
Stage 1.1: linear plane fit
axis = (0.613534, -0.293597, 0.73306) (bary)
ct0 = 0.0291267 [m]
Stage 1.2: 3d plane fit
axis = (0.619322, -0.290585, 0.729384) (bary)
theta = 43.1652 +/- 0.928552 [deg] (bary)
phi = -25.1359 +/- 1.40362 [deg]
ct0 = -0.0756438 [m]
time chi2 = 0.984709 / 1
time residual = -0.00264774 +/- 0.572919
axis diff = 0.429116 [deg] (to stage 1.1)
[INFO] Modules/SdReconstruction/LDFFinder0G/LDFFinder.cc:393: Run:
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```