Overview of the Auger@TA project and preliminary results from Phase I

Fred Sarazin on behalf of the Auger-TA Working Group on SD cross-calibration ("Auger@TA")

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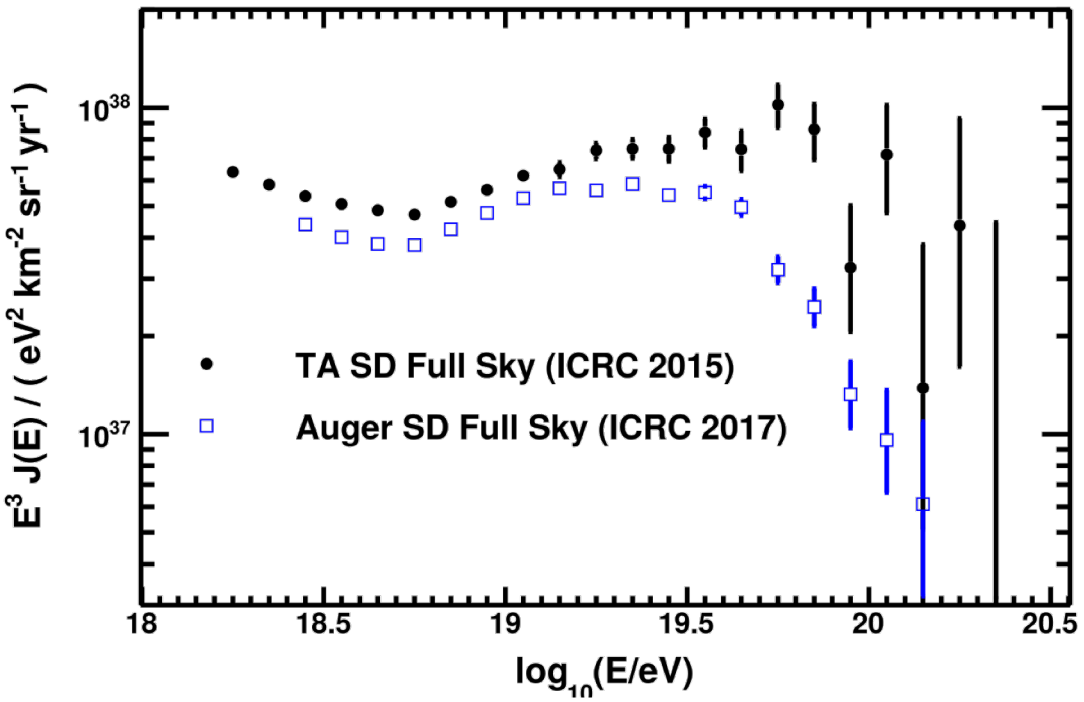
UHECR 2018, Paris (France), Oct 8-12, 2018

Motivation

- Auger and TA spectra can be reconciled around the ankle by scaling the energy by 10.4%. However, disagreement around the flux suppression is apparent.

- What are the sources of the discrepancy?
  - Difference between the northern and southern UHECR skies?
  - Unknown detector and/or reconstruction biases?

- Auger@TA joint experimental effort aims at examining the latter hypothesis through two phases.
  - Phase I: perform station-level comparisons
  - Phase II: perform event-level comparisons



From: D.Ivanov, ICRC 2017, PoS 498
Auger and TA WG on spectrum

AUGER@TA – Phase I

Station-level comparisons of a group of Auger and TA SD stations

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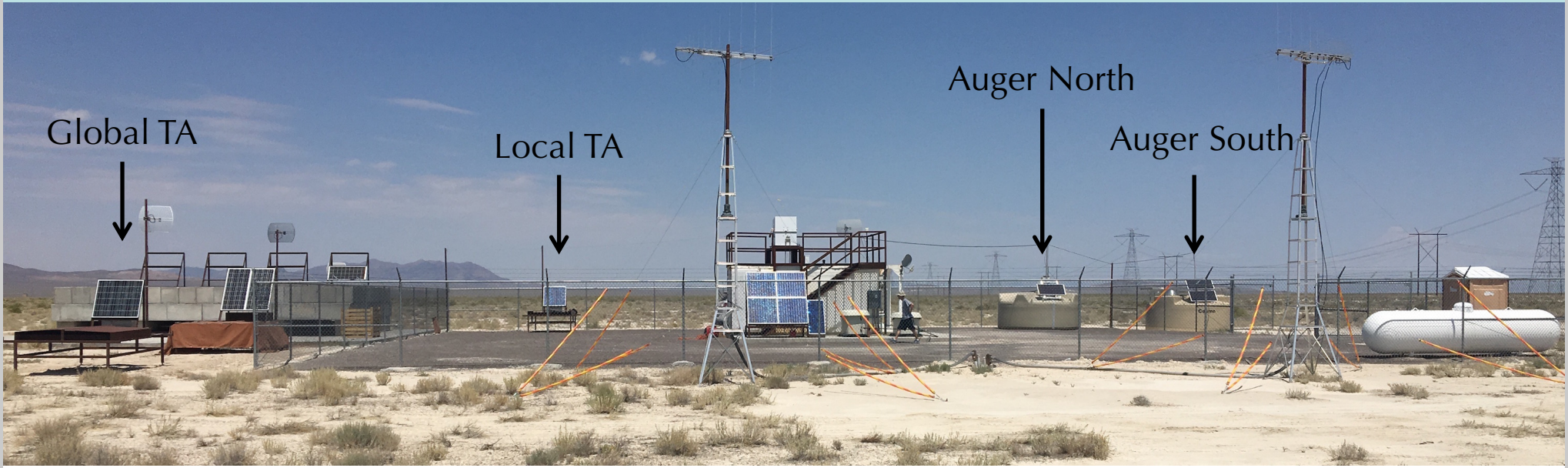
Auger@TA setup at the TA Central Laser Facility (CLF)?



- **Two TA SD stations:**
  - One connected wirelessly to the TA global trigger (but not part of the TA trigger)
  - One connected through cables to the Auger@TA electronics to form a local trigger with the Auger SD stations

- **Two Auger SD stations:**
  - One standard 3-PMT station (also equipped with a mechanical prototype of the Auger Upgrade scintillator detector)
  - One prototype 1-PMT station (aka “Auger North”)

Auger@TA triggers at the TA CLF site

Local TA

L1 timestamps

L2 data (picoscope)

Auger North

Auger South

T2 timestamps

T3 data

Auger@TA electronics

T3 requests

Global TA (DET2421)

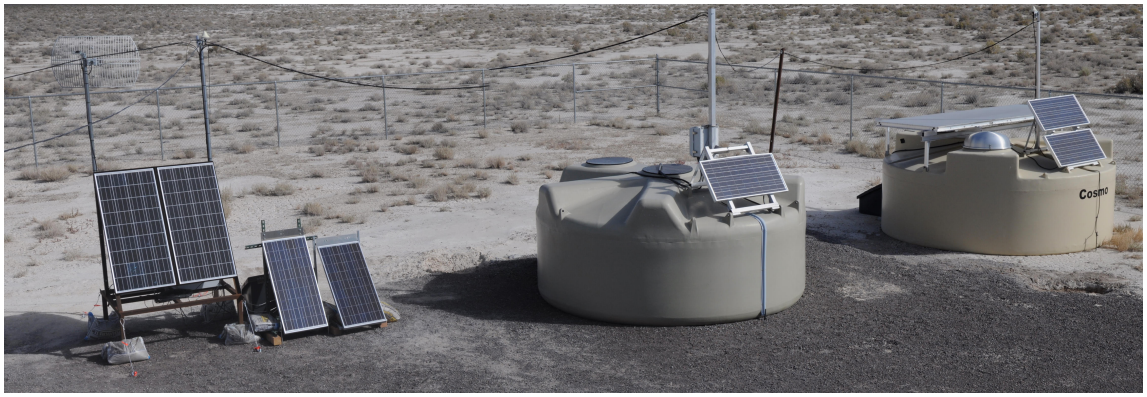
L2 data

L2 requests

To Auger@TA electronics

L1 timestamps from full TA

TA central DAQ



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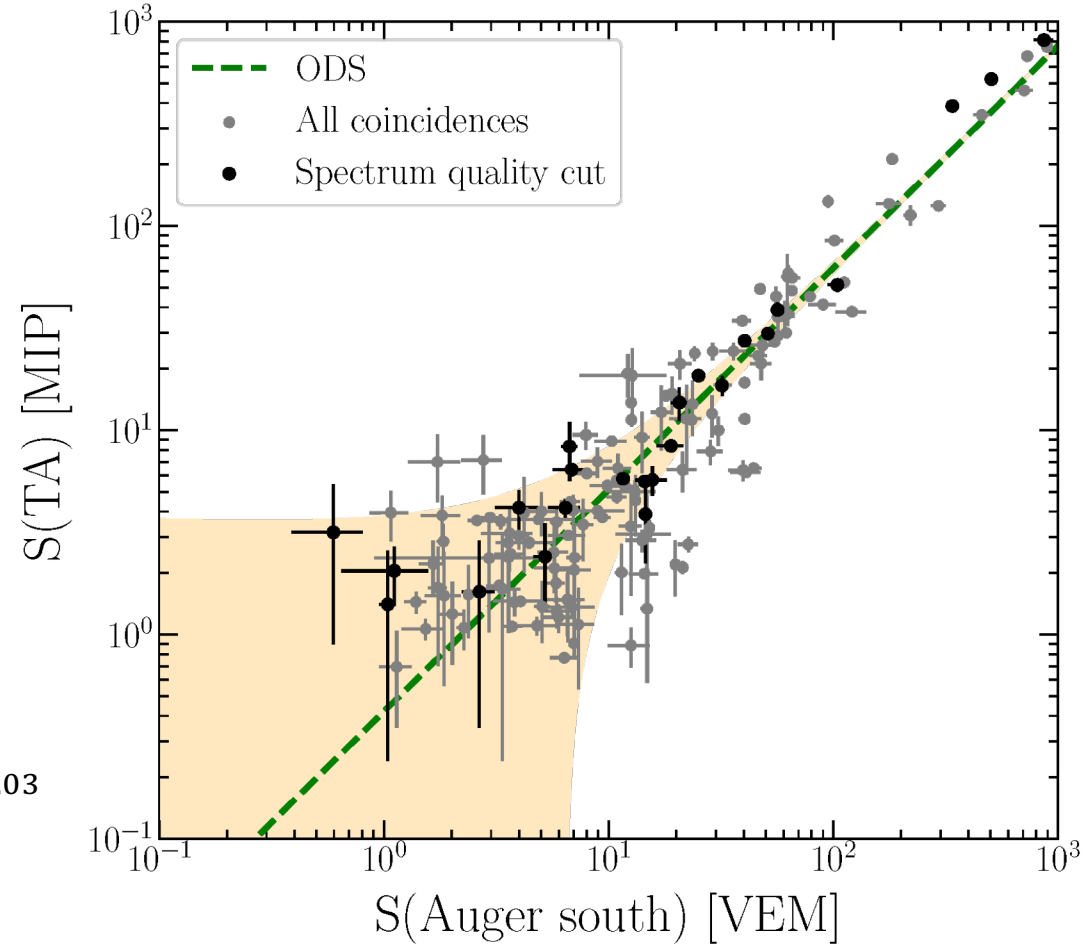
S(TA) [MIP] vs S(Auger) [VEM]

- Gray data points: signals measured in co-located TA and Auger stations at the TA CLF, when a time coincidence is established with the TA global trigger
- Black data points: additional condition on TA spectrum quality cut (i.e. well reconstructed showers)
- Expected slope consistent with simulations (ICRC 2017, PoS 395)
- Orthogonal Distance Square (ODS) fit:

$$S(TA)_{MIP} = (0.42 \pm 0.05) S(Auger)_{VEM}^{1.09 \pm 0.03}$$



*[Note: Signals **not** corrected for (slight) difference of location between Auger / TA SD stations]*

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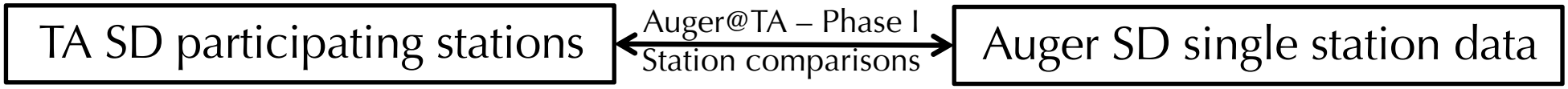
Auger@TA phase I – data analysis global trigger



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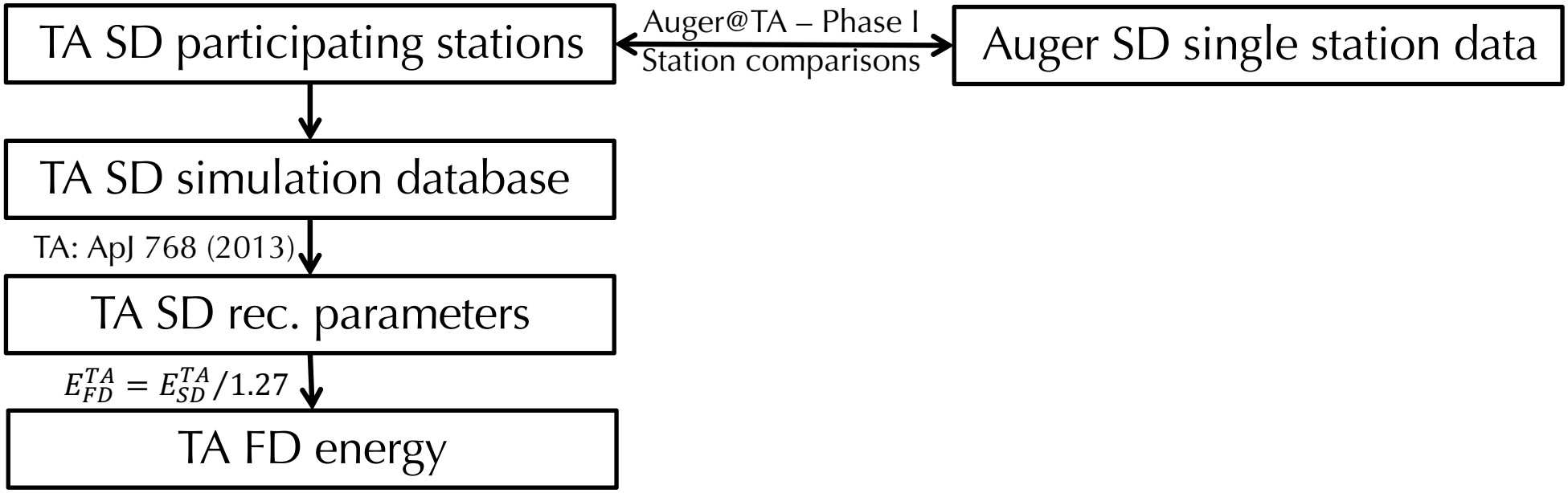

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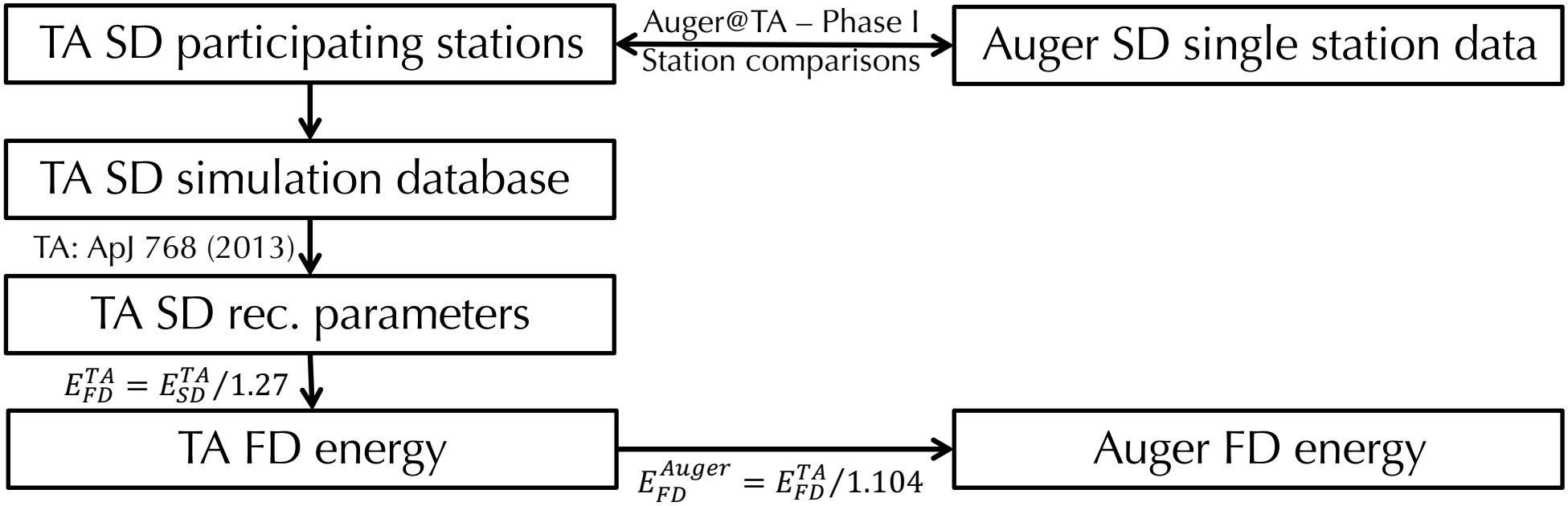

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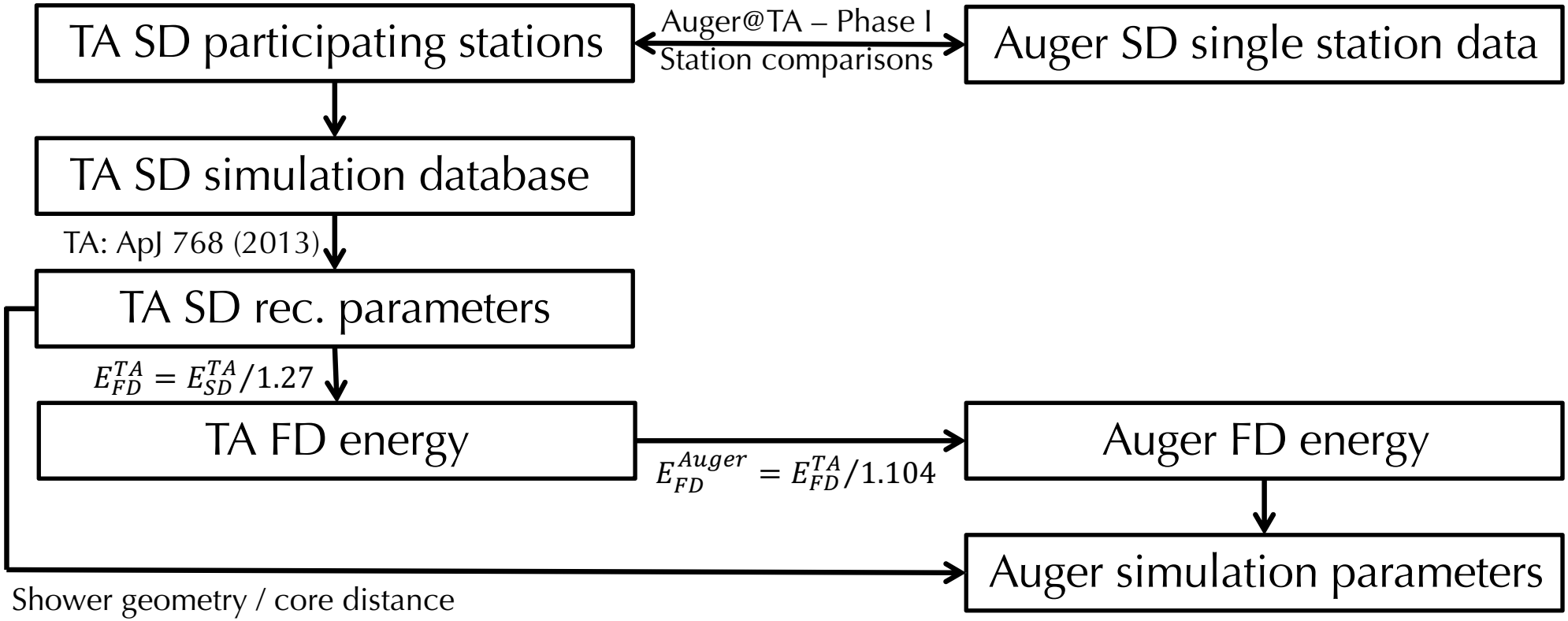

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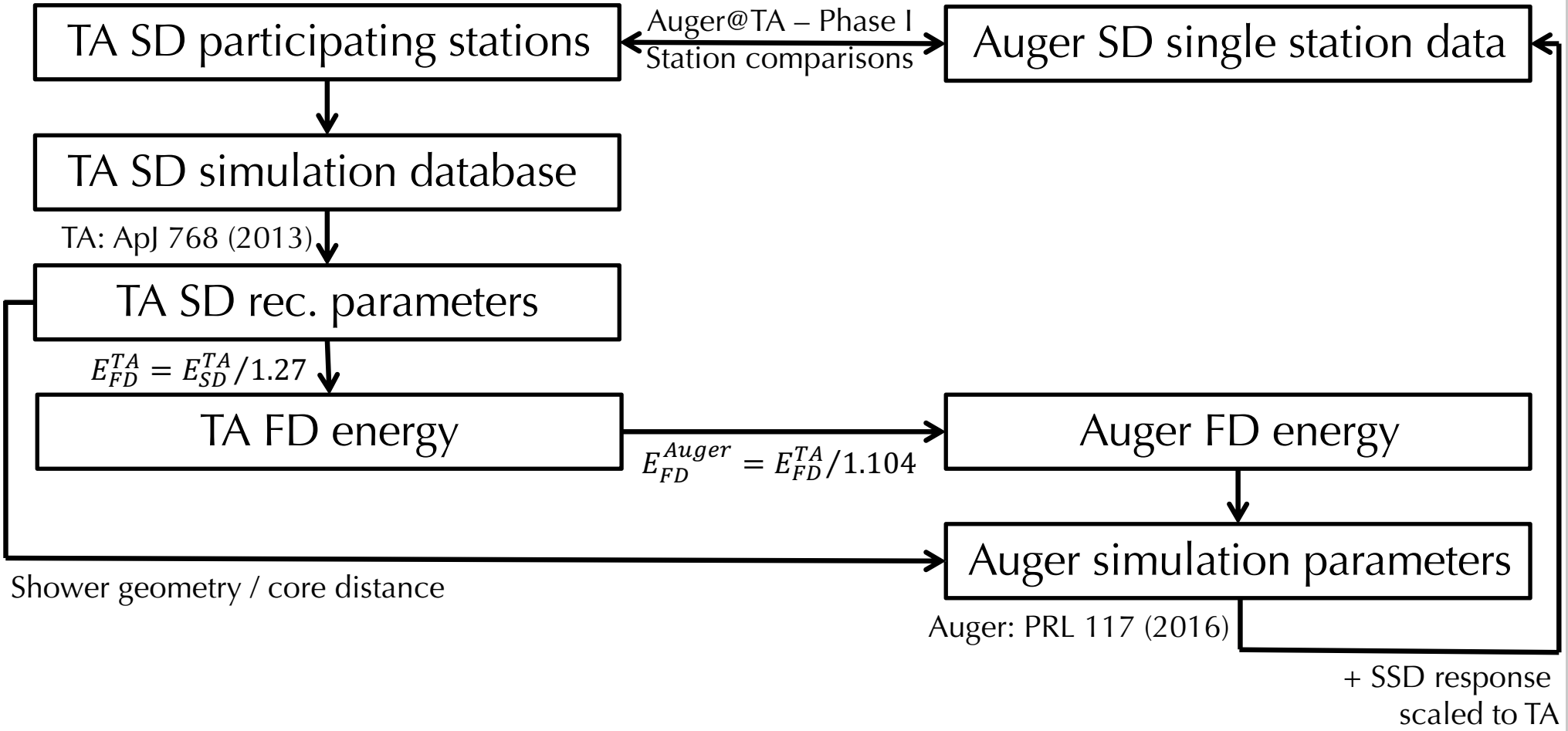
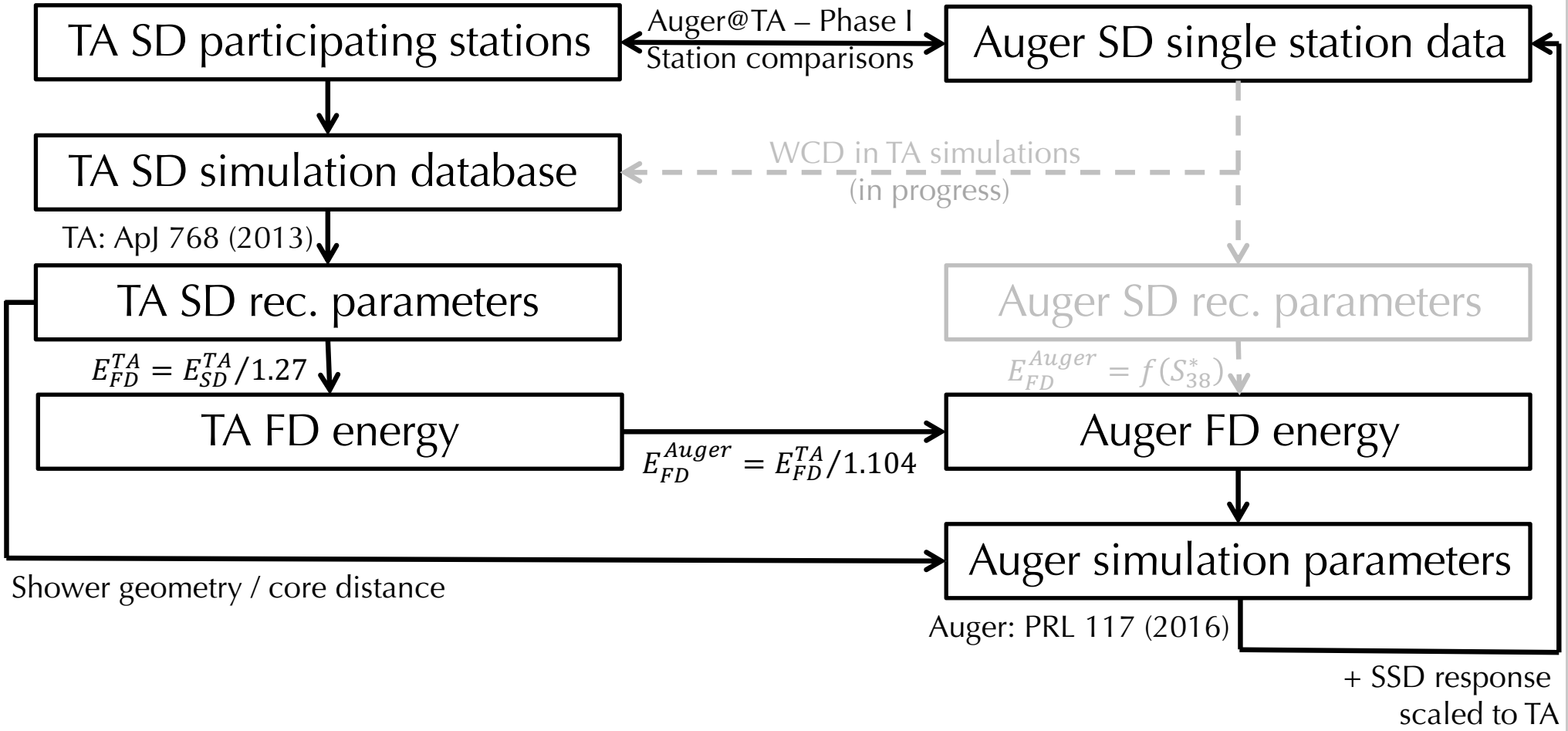


Auger@TA phase I – data analysis global trigger



Shower / signal selection parameters

DATA COLLECTION PARAMETERS:

- TA global L2 trigger list provided to Auger SBC
- T3 request sent to Auger / reads out everything within 100μs of L2 trigger
- Requests for TA data bundled quarterly
- TA data (following quality cut below) are shared, as per MOU agreement, using a tighter ±32μs coincidence if the core distance from CLF ≤ 2 km

TA QUALITY CUT FOR RECONSTRUCTED SHOWERS (ApJ 768 L1 (2013)):

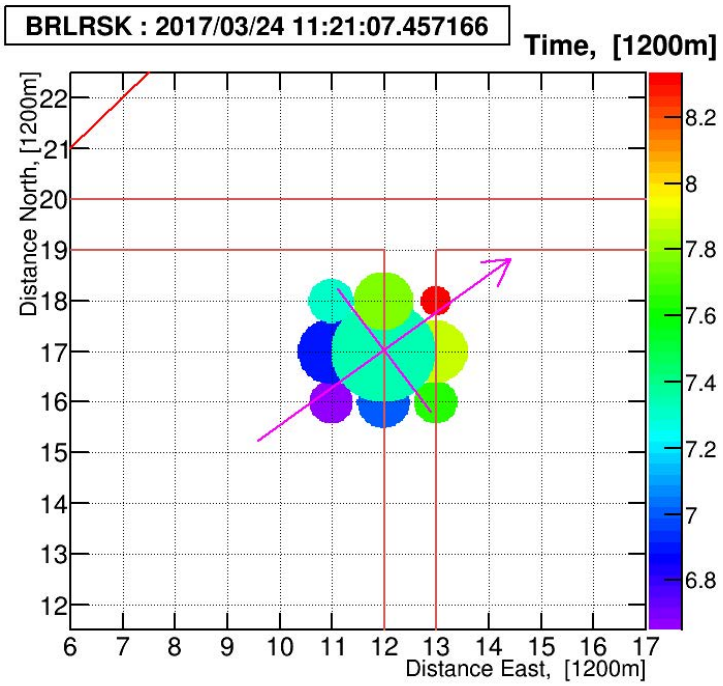
- Number of TA SDs ≥ 5
- Zenith angle ≤ 45°
- Standard deviation of S800 ≤ 0.25
- χ^2 /ndf in geometry and profile ≤ 4.0
- Uncertainty of arrival direction ≤ 5°
- Primary energy ≥ 1 EeV

ADDITIONAL SHOWER / SIGNAL SELECTION PARAMETERS:

- E(TA) > 3. x 10^{18} eV – 80% trigger efficiency TA SD *[NIM A689 (2012) 87]*
- S(TA@CLF) > 5 MIP – Station signal above threshold / prevents accidental coinc.
- S(Auger@CLF) > 3 VEM – Station signal above threshold / prevents accidental coinc.

Step 1 : TA reconstructed data to Auger simulations

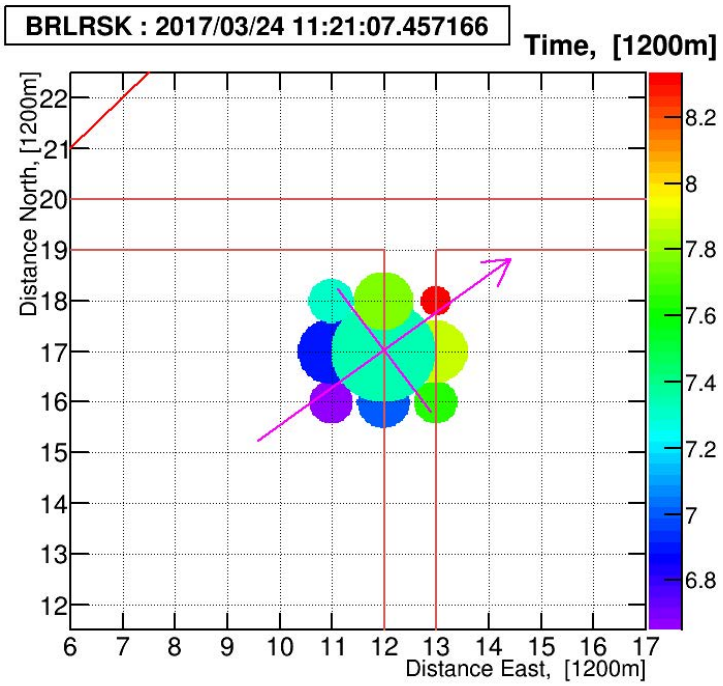
TA reconstructed data



Energy (TA FD): 4.58 EeV
Zenith angle: 38.28º
Azimuth angle: 216.69º
Core distance (global TA station): 825 m
Core distance (Auger station): 811 m

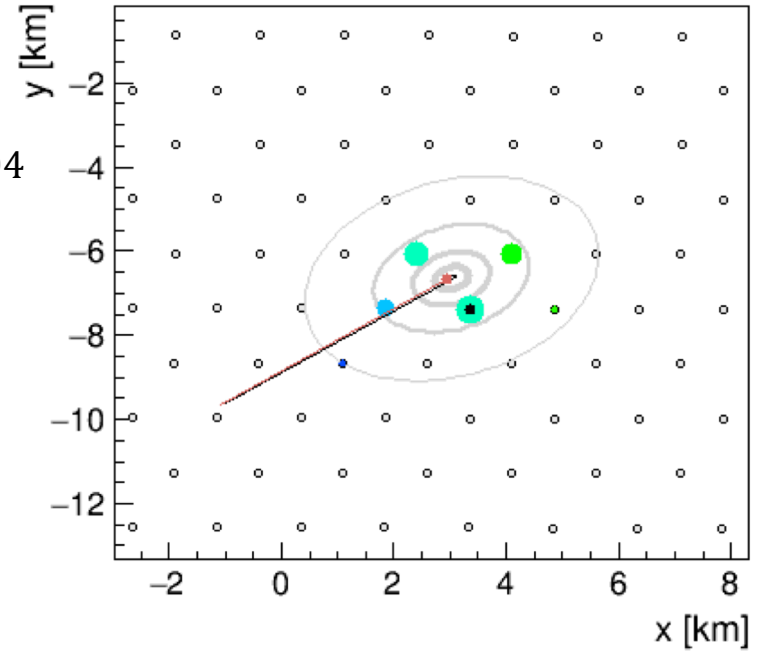
Step 1 : TA reconstructed data to Auger simulations

TA reconstructed data



$E^{FD}_{Auger} = E^{FD}_{TA}/1.104$
(ICRC 2017, 498)

Auger simulations



Energy (TA FD): 4.58 EeV
Zenith angle: 38.28º
Azimuth angle: 216.69º
Core distance (global TA station): 825 m
Core distance (Auger station): 811 m

Energy (Auger FD): 4.15 EeV
Zenith angle: 38.28º
Azimuth angle: 216.69º
Core distance (SSD): 825 m
Core distance (WCD): 811 m

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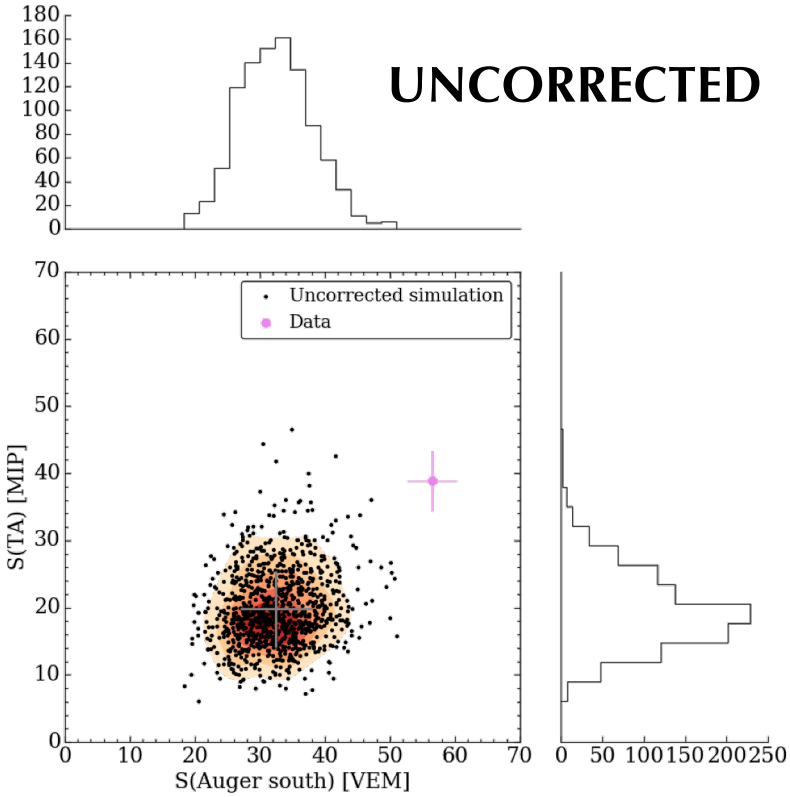
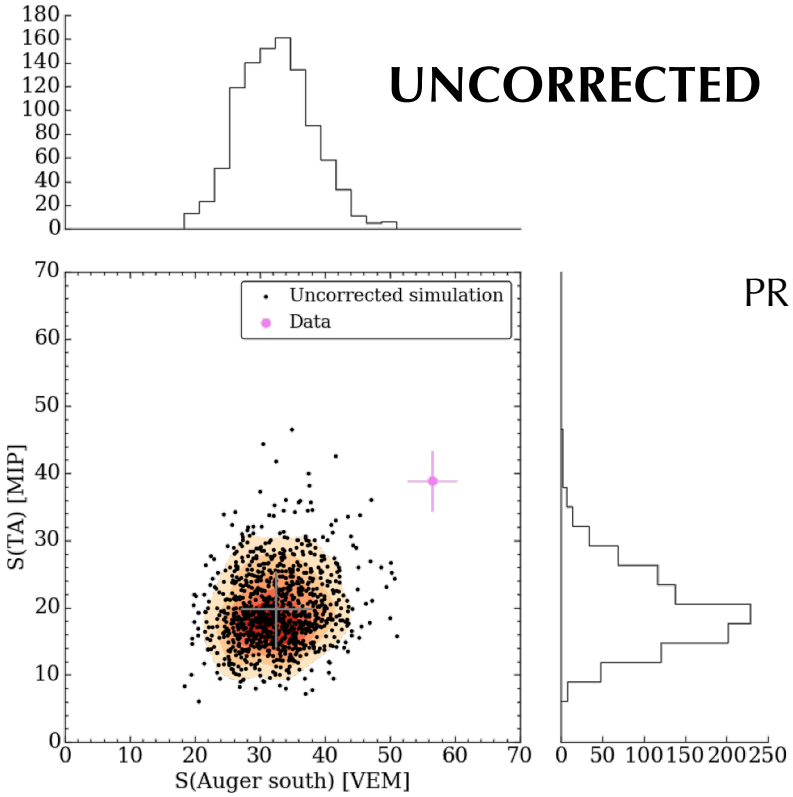
Step 2: Correction for experimental muon excess



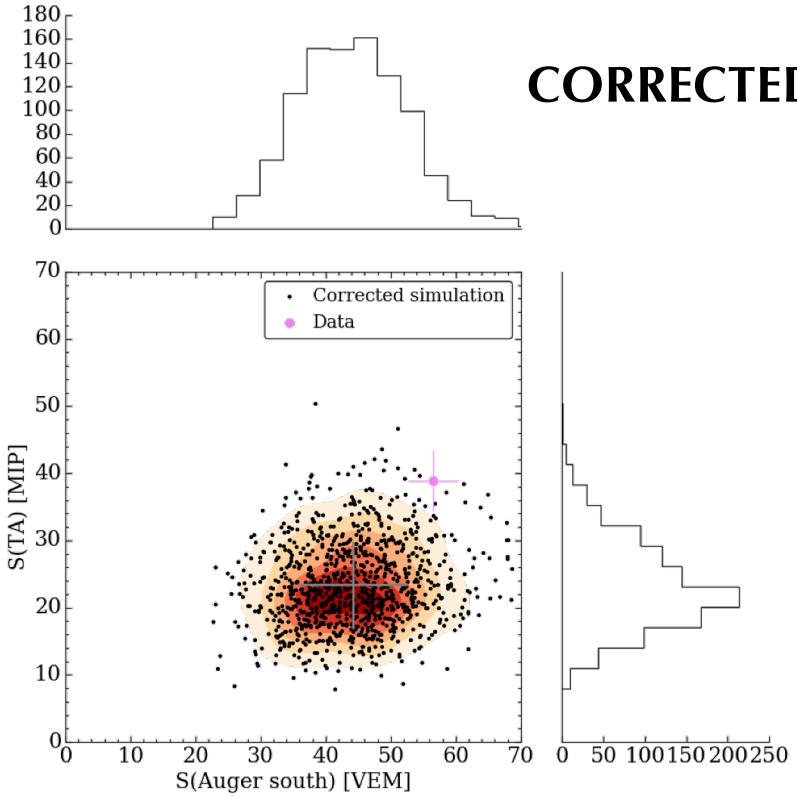
Simulations:

- Hadronic models: QGSJET II.03/04, EPOS-LHC
- Shown here: QGSJET II.04
- S_{WCD}([VEM]) directly from Auger Offline
- S_{TA}([MIP]) scaled from S_{SSD}([MIP]) obtained with Offline

Step 2: Correction for experimental muon excess



PRL 117, 192001 (2016)



Simulations:

- Hadronic models: QGSJET II.03/04, EPOS-LHC
- Shown here: QGSJET II.04
- S_{WCD}([VEM]) directly from Auger Offline
- S_{TA}([MIP]) scaled from S_{SSD}([MIP]) obtained with Offline

Correction:

- S_{em} and S_{μ} corrections, mostly for μ excess
- Correction parameters available only for QGSJET II.04 and EPOS-LHC

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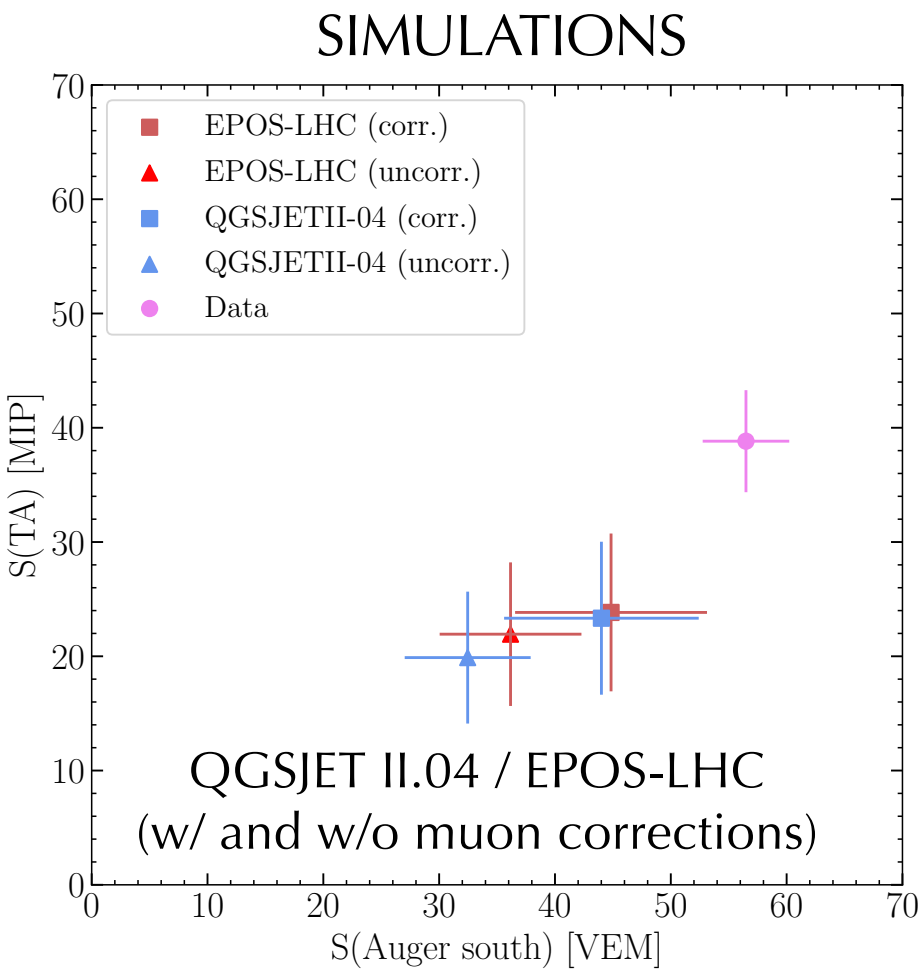
Step 2: Correction for experimental muon excess



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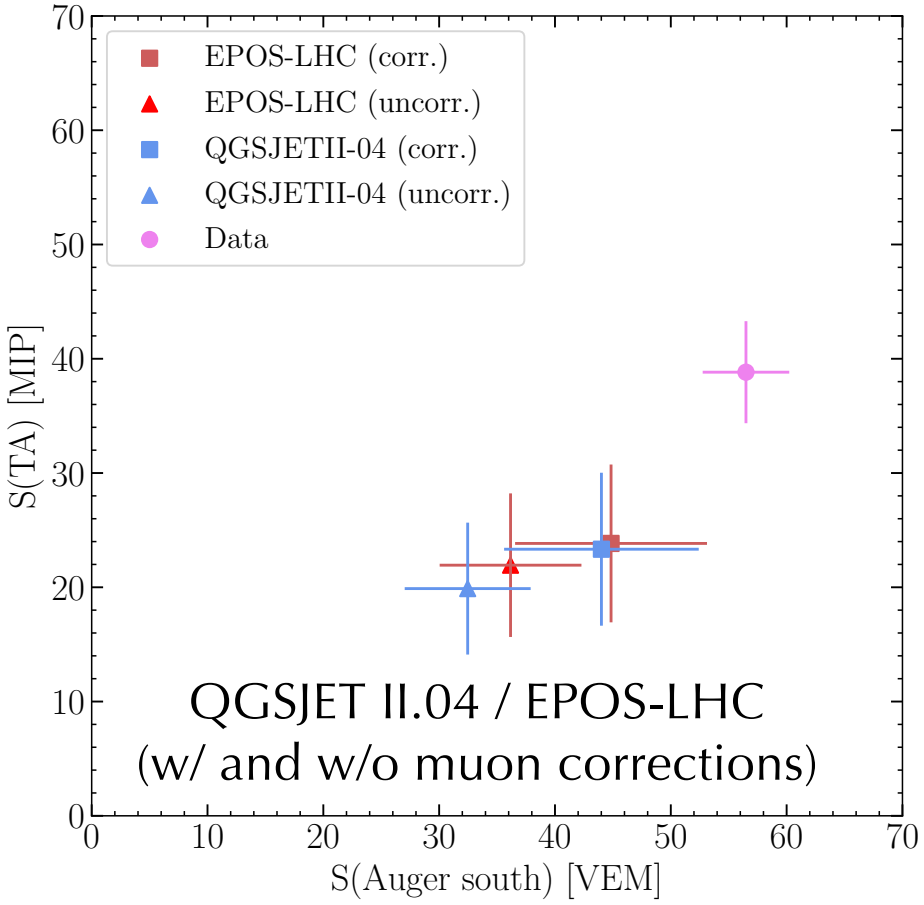
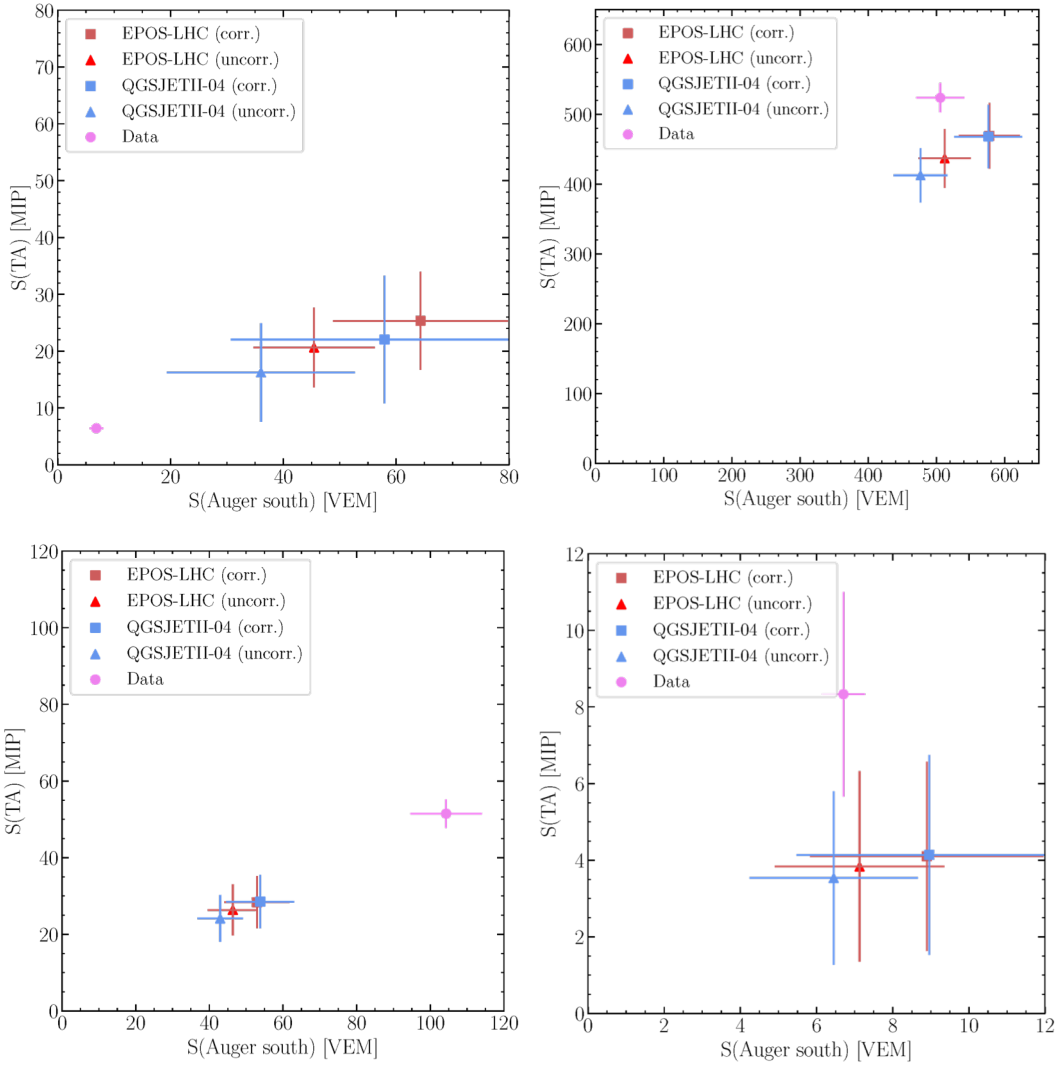
Step 2: Correction for experimental muon excess

SIMULATIONS



Other events:



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Step 3: Mahalanobis distance characterization

$$D_M = \sqrt{(\vec{x}_{data} - \vec{\mu})^T S^{-1} (\vec{x}_{data} - \vec{\mu})}$$

- A metric is needed to estimate the distance between the experimental data point and the predictions from simulation for each event
- **Mahalanobis distance** (introduced in 1936) is the multi-dimensional generalization of the idea of measuring how many standard deviations away a data point P is from the mean of a distribution D.
  - $\vec{x}_{data} = (S_{CLF}(Auger), S_{CLF}(TA))$ and $\vec{\mu} = (S_{SIM}(Auger),\ S_{SIM}(TA))$
  - S is the covariance matrix
- **Note:** in what follows, ΔD_M is not calculated (work in progress)

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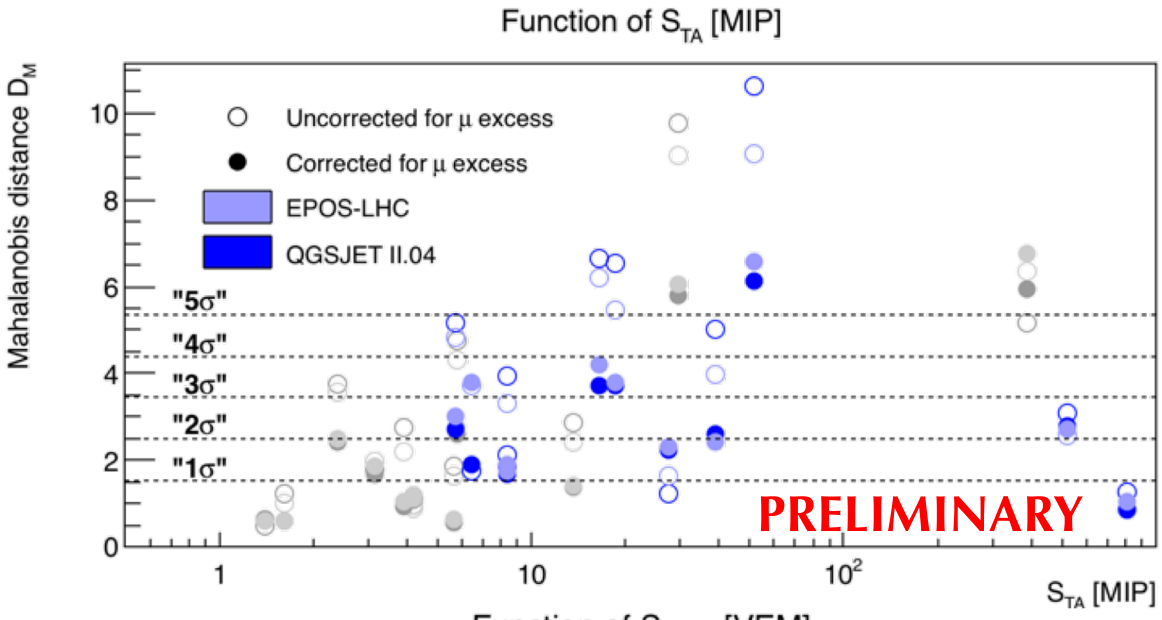
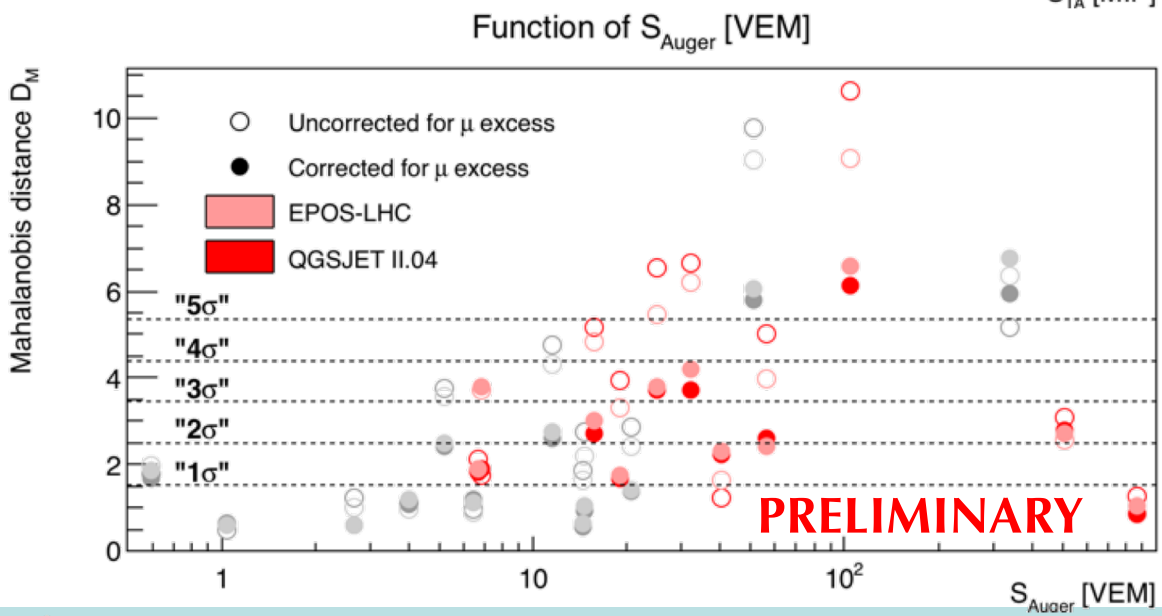
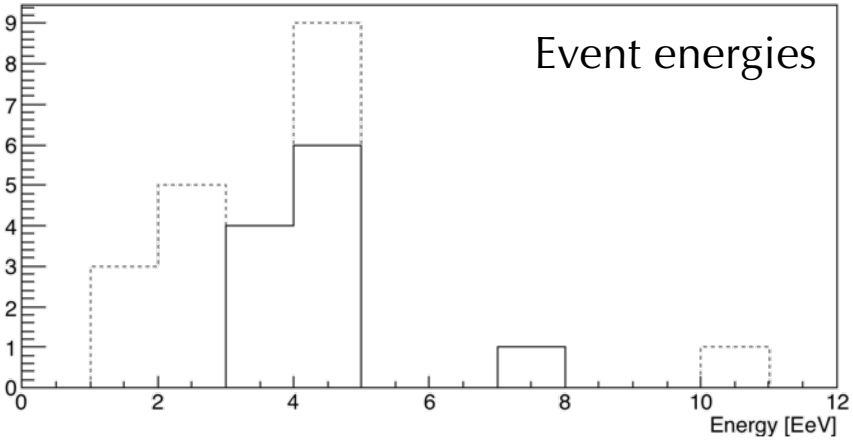
Step 3: Mahalanobis distance characterization – S_{TA} and S_{Auger}





- Grey points: de-selected showers – E<3x10^{18}eV (less than 80% TA SD trigger efficiency) or S_TA<5MIP or S_Auger<3VEM
- Muon excess correction generally improves Mahalanobis distance
- Better agreement between QGSJET II.04 and EPOS-LHC after muon excess correction (hadronic model specific tuned parameters in PRL 117, 192001)



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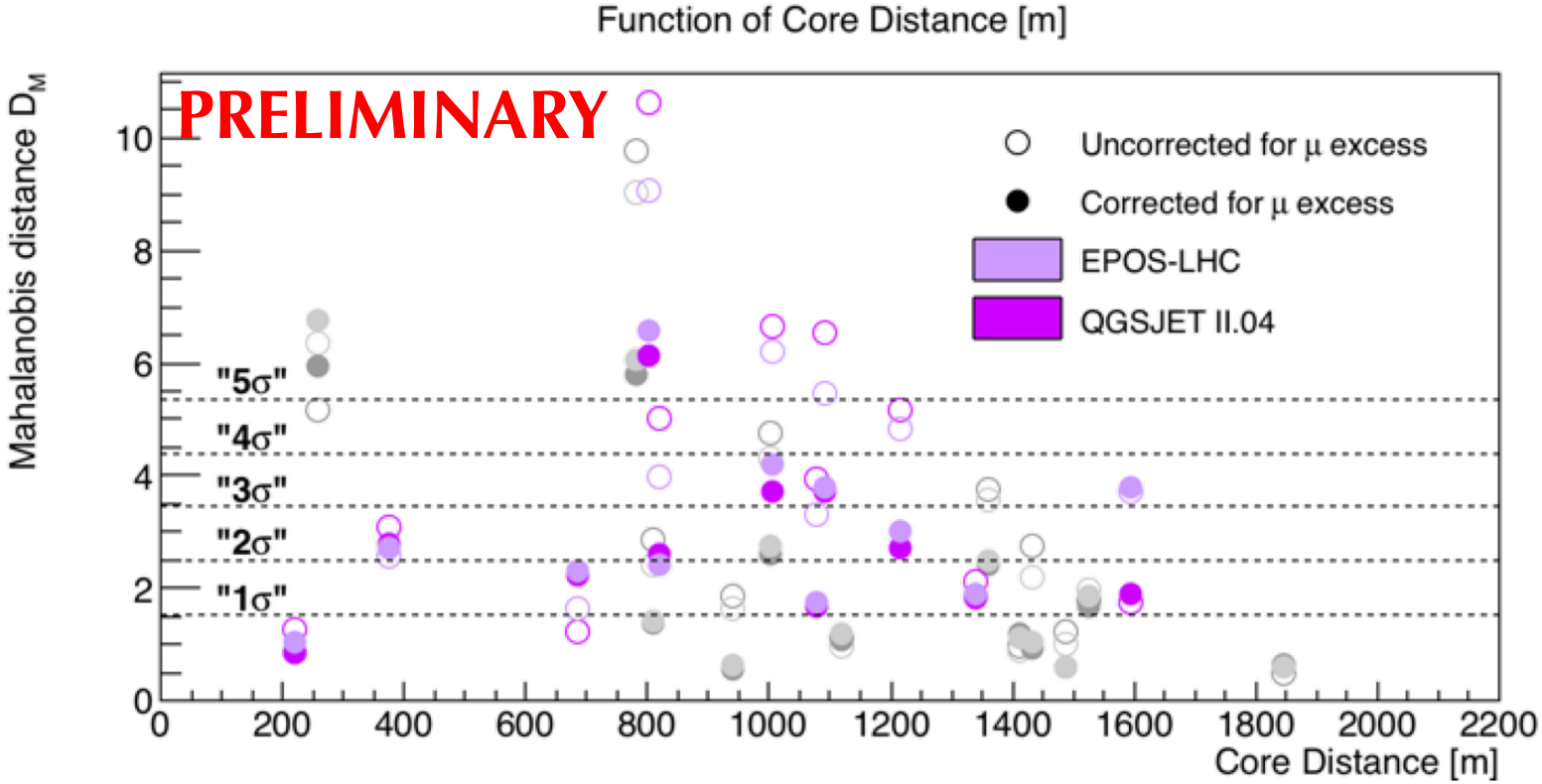
Step 3: Mahalanobis distance characterization – Core distance

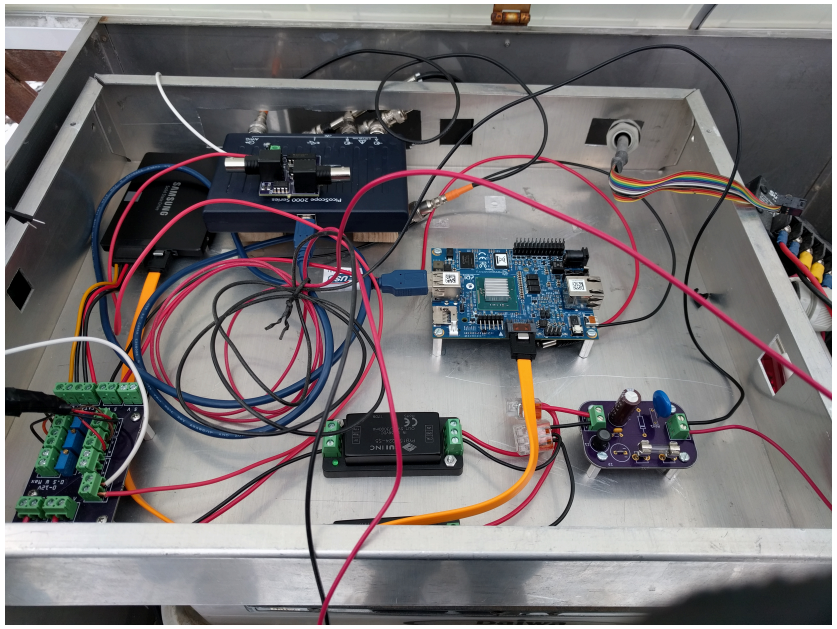


- Larger corrections observed for intermediate core distances
- Low energy showers!
  - Large core distances → Uncertainties dominated by Poisson statistics
  - Small core distances → Signals are EM dominated / relatively small corrections
- **More data needed… data collection still in progress.**

Auger@TA phase I – future plans

DATA COLLECTION

- Continue data collection using TA global trigger for "high energy" showers
- Collect (indirectly) the waveforms from the local TA station
  - Improve external AN – AS triggering scheme to select higher quality "low-energy" showers
  - Try to extract S[MIP] of the local TA station to get more S(TA) vs S(Auger) correlations



DATA ANALYSIS AND SIMULATION

- Add Lateral Distribution Function (LDF) information to Auger@TA MOU agreement
- Include WCD in TA simulations, compute Mahalanobis distance using TA simulation chain
- Additional study with TA scintillator detectors under concrete blocks at CLF?

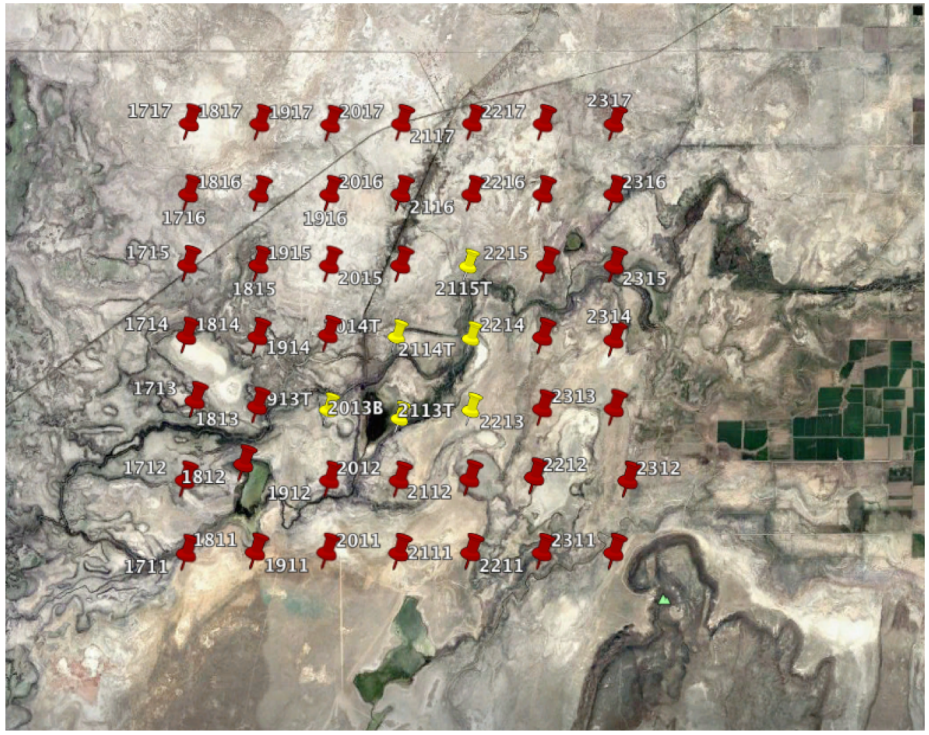
AUGER@TA – Phase II

Deployment and operation of an independent Auger micro-array

[See also poster by C. Covault]

Phase II: deployment and operation of an AN micro-array

- Planned location of the Auger micro-array inside TA [yellow pins]
  - Independent trigger
  - Independent reconstruction
  - ″Hybrid″ Auger–TA reconstruction
  - …



- Auger North SD stations ready to deployed at the TA CRC
- Communication system being tested at CWRU
- Array simulation under way at Mines

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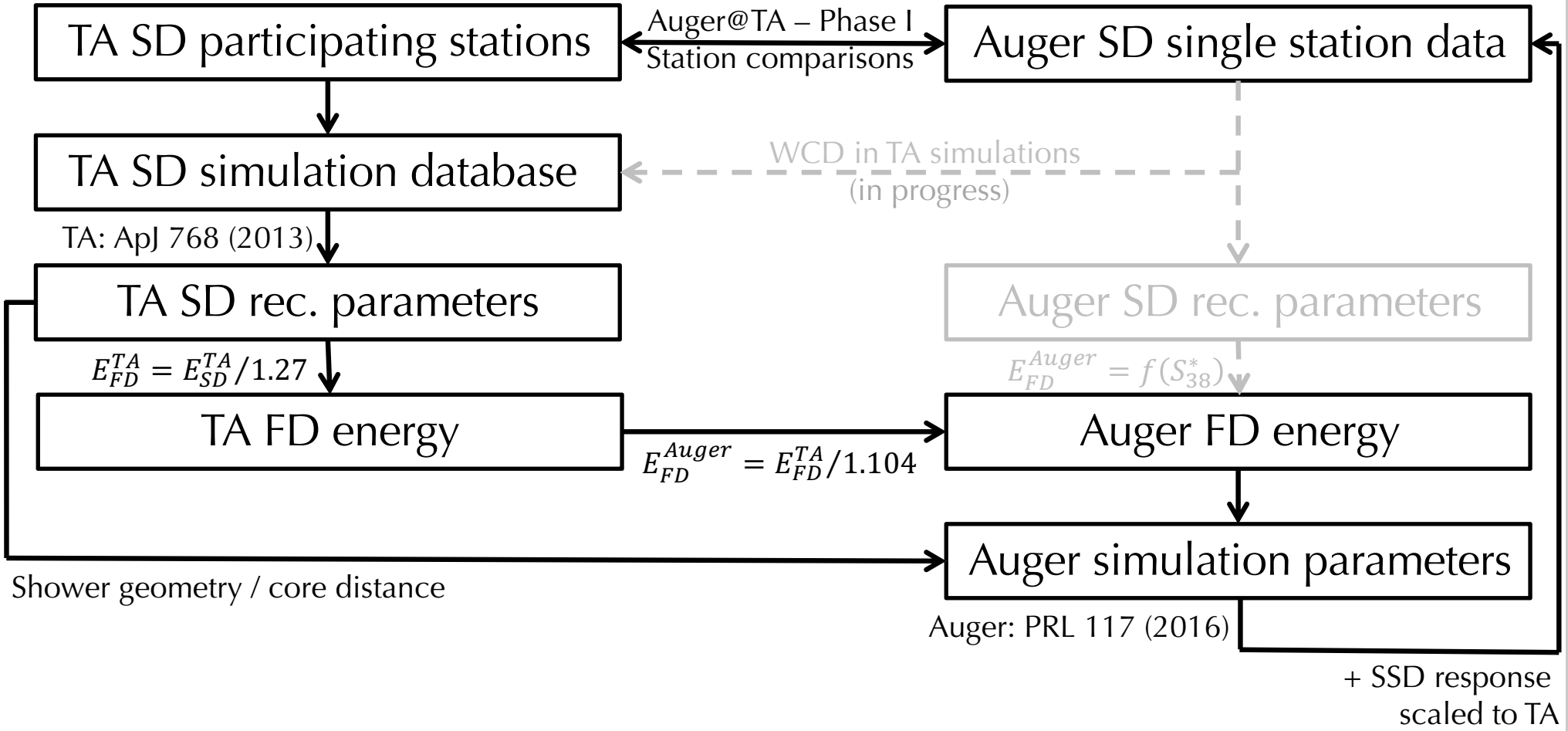
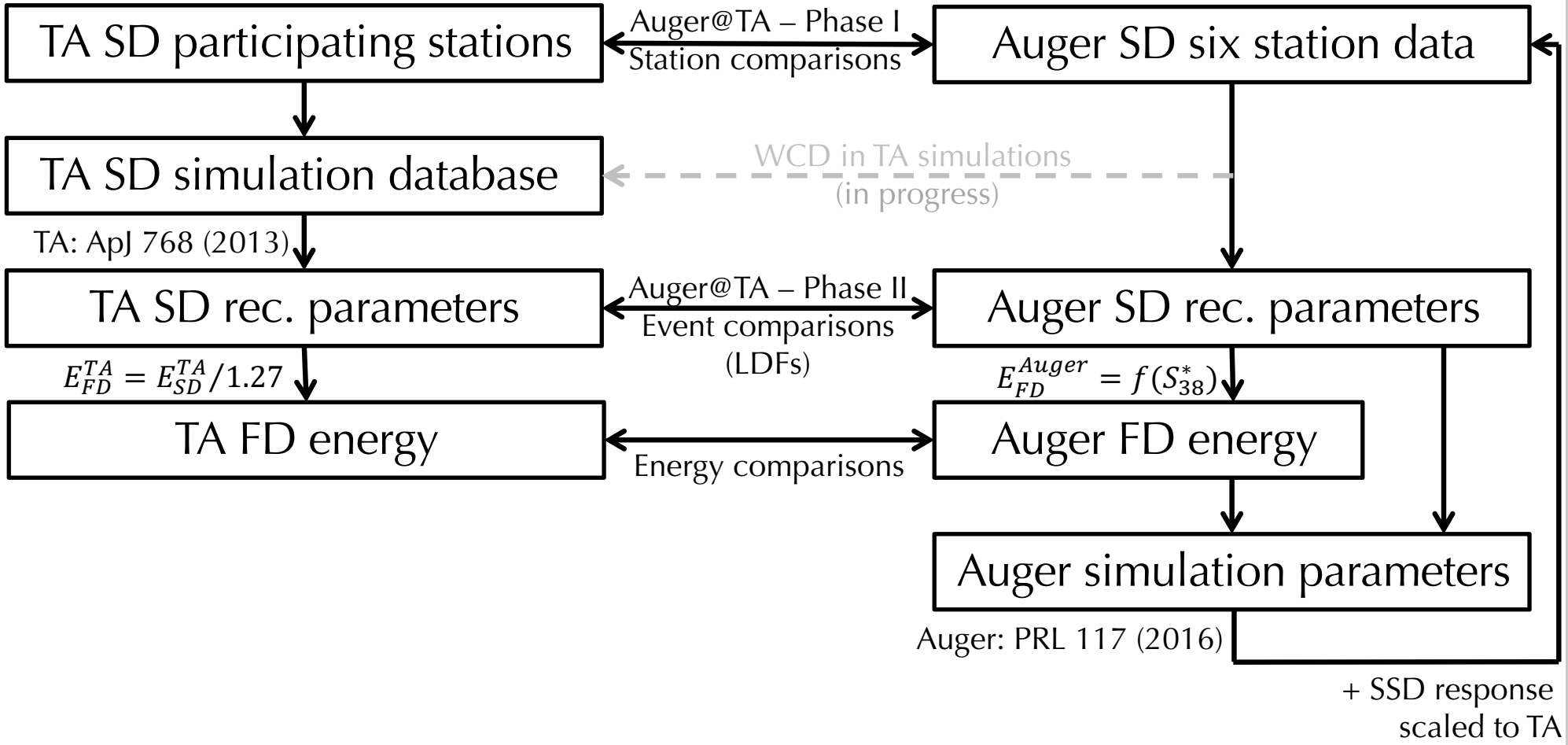
Auger@TA phase I – data analysis global trigger



Auger@TA phase II – planned data analysis



S_{38}^{*}: estimator adapted to TA SD spacing [S(800)]

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Auger@TA phase II – near-term plans

Also see C. Covault poster at this meeting

DEPLOYMENT:

- Deployment (of TA x 4) will start February 2019
- Two Auger North stations deployed using a flat bed truck / water delivered with tanker
- Off-the-shelf communication system between WCDs and Black Mesa tower
- Communication test on-going at CWRU / debugging in the field prior to second deployment
- Full deployment and operation will depend on funding

DATA COLLECTION:

- Two stations = T3 requests = data from EAS, but no independent Auger reconstruction
- Auger – TA co-located detectors = more station-level comparisons

SD cross-calibration (Auger@TA) Working Group members

AUGER

Mines
- Jeff Johnsen (PhD)
- Fred Sarazin
- Orlen Wolf

Case Western (CWRU)
- Corbin Covault
- Ryan Lorek (PhD)
- Sean Quinn (now UCLA)
- Robert Sobin

KIT
- David Schmidt (PhD)

Auger
- Ricardo Sato

TELESCOPE ARRAY

ICRR / Tokyo
- Hiroyuki Sagawa
- Nonaka Toshiyuki
- Toshihiro Fujii (also Auger)
- Takashi Sako
- Ryuji Takeishi

New members welcome!

THE END

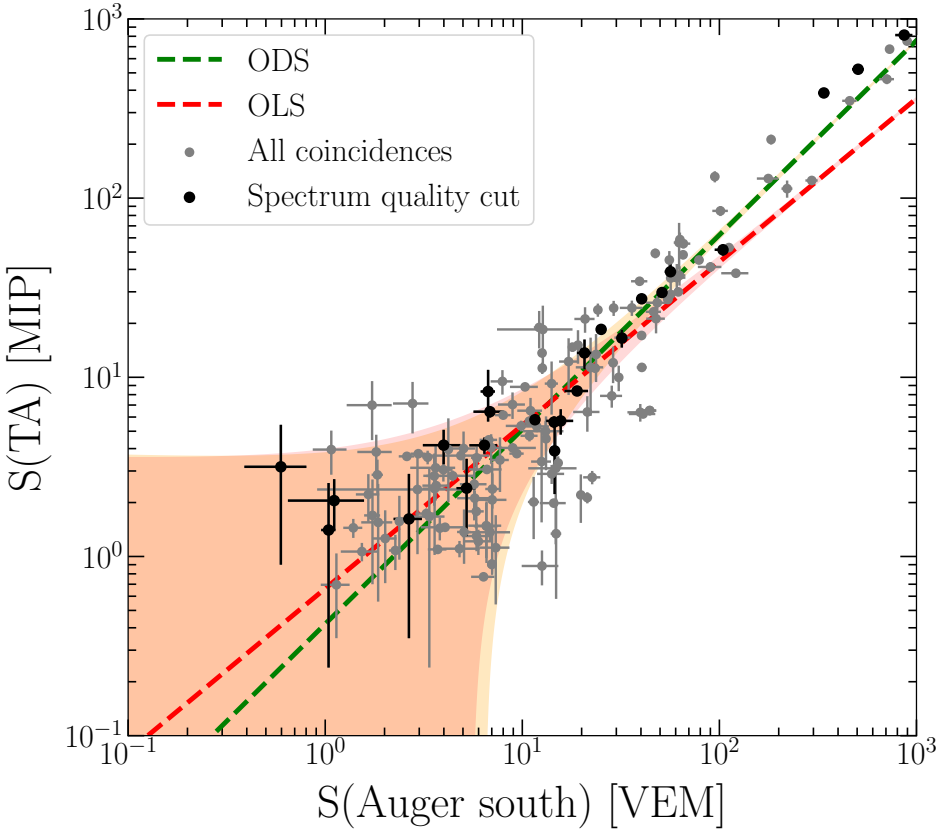
S(TA) [MIP] vs S(Auger) [VEM] – including OLS

- Gray data points: signals measured in co-located TA and Auger stations at the TA CLF, when a time coincidence is established with the TA global trigger
- Black data points: additional condition on TA spectrum quality cut (i.e. well reconstructed showers)
- Expected slope consistent with simulations (ICRC 2017, PoS 395)
- Orthogonal Distance Square (ODS) fit:

$$S(TA)_{MIP} = (0.42 \pm 0.05) S(Auger)_{VEM}^{1.09 \pm 0.03}$$

- Ordinary Least Square (OLS) fit:

$$S(TA)_{MIP} = (0.66 \pm 0.06) S(Auger)_{VEM}^{0.91 \pm 0.03}$$



*[Note: Signals **not** corrected for (slight) difference of location between Auger / TA SD stations]*

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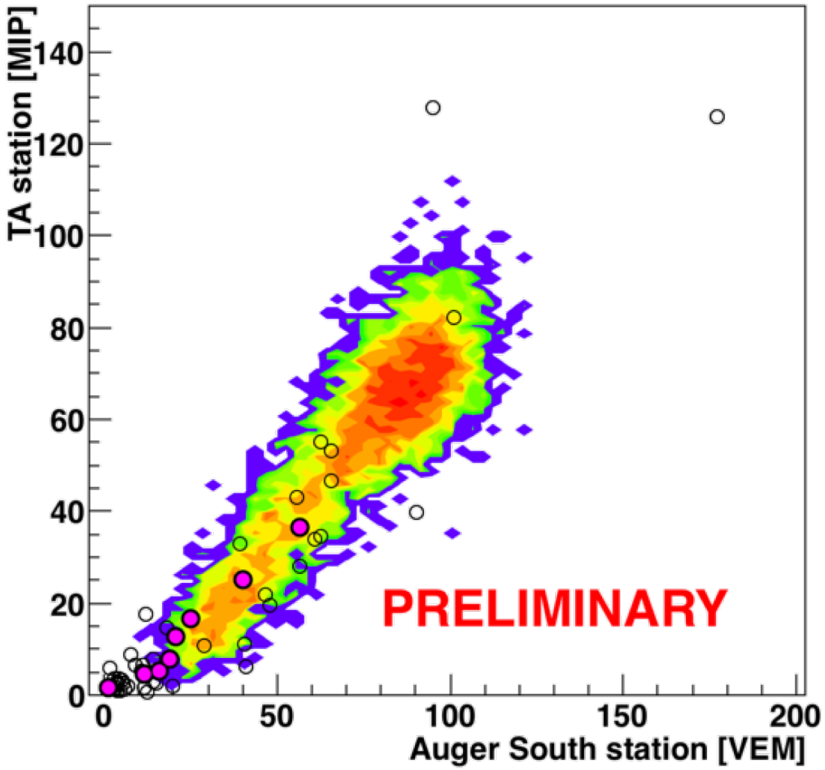
Auger@TA – S(TA) vs S(Auger) correlation

DATA:
- Open circle (all data, ICRC 2017)
- Fill circle (TA reconstructed showers, ICRC 2017)

WCD+SSD Auger simulations:
- Energy: E = 3.98 EeV
- Zenith angle: θ = {0,12,25,36,45,53}°
- Core distance: r = 600 m

SSD (4m²) to TA (3m²):
- Scaling: 0.75



From: S.Quinn et al., ICRC 2017, PoS 395
Auger@TA

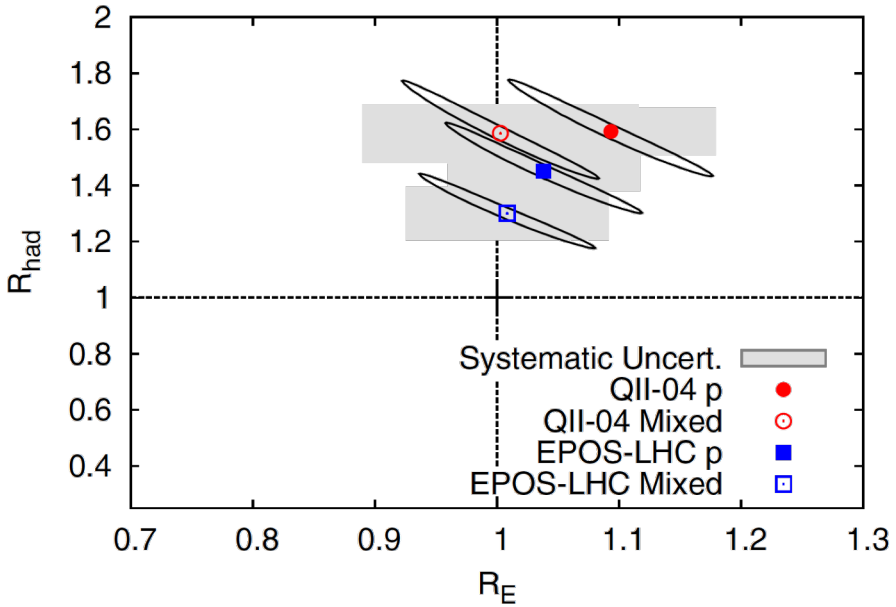
SIMULATION RE-NORMALIZATION:

$$S_{resc}(R_E, R_{had})_{i,j} \equiv R_E S_{EM,i,j} + R_{had} R_E^{\alpha} S_{had,i,j}$$

Assuming protons (α≈0.9):

Model	R_E	R_{had}
QGSJET II.04	1.09±0.08±0.09	1.59±0.17±0.09
EPOS-LHC	1.04±0.08±0.08	1.45±0.16±0.08

Energy range: 6-16 EeV



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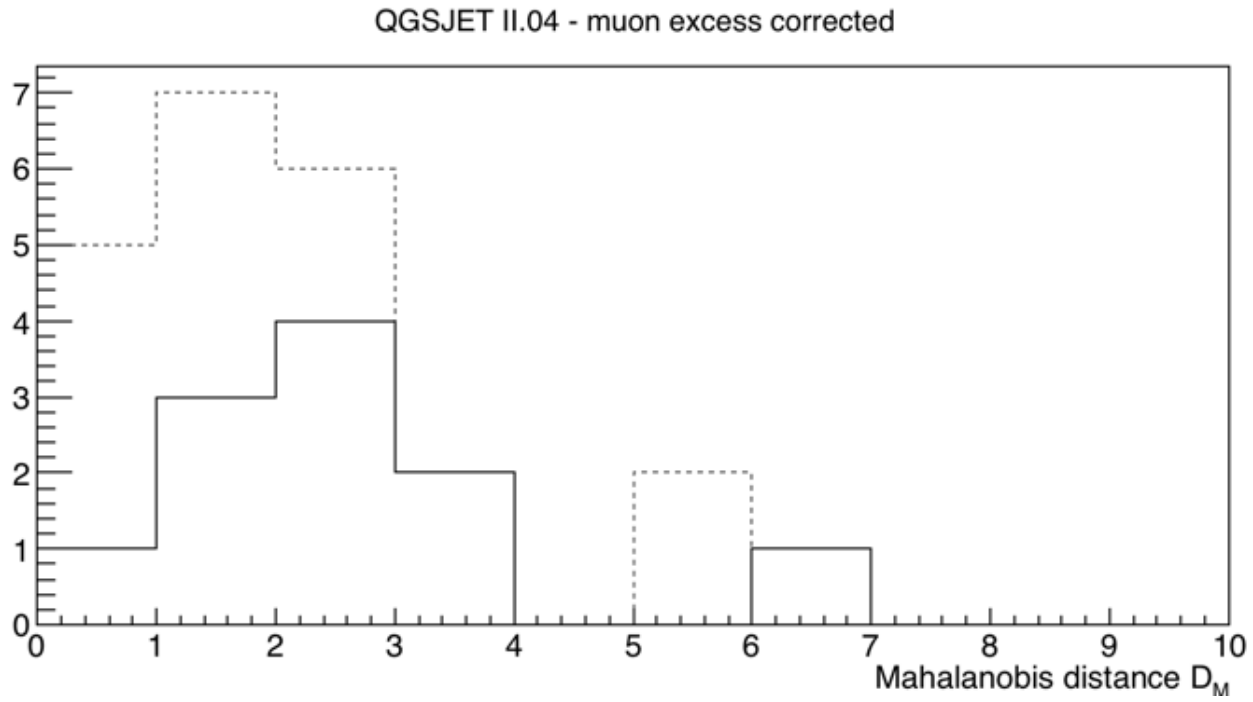
Distribution of Mahalanobis distances (QGSJET II.04 – muon corrected)



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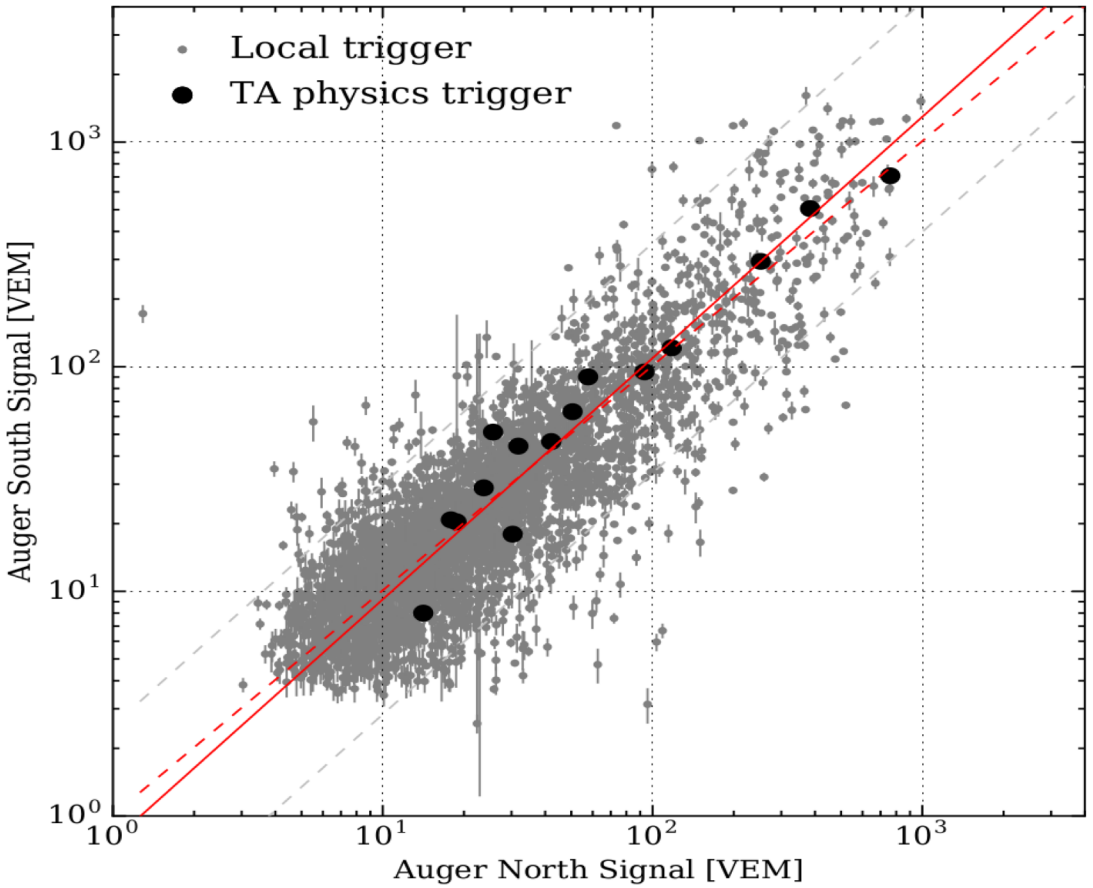
Auger North vs Auger South response



- We don't have (yet) a mean to assess reconstruction parameters using our local trigger b/c we are not able to collect the TA station waveforms, hence we are not able to tighten the correlation of the grey data points
- Correlation with TA global trigger – low statistics.

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