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TA/Auger Spectrum Working Group Effort

1. UHECR 2010, Nagoya, Japan. Formed a working group aimed to compare and cross check the spectrum results.

2. UHECR 2012, Geneva, CERN. Auger and TA successfully cross-checked their methods for the first time.

3. UHECR 2014, Springdale, UT, USA. Detailed discussion of the energy scale systematic uncertainties. First discussions on searching for spectrum declination dependence.

4. UHECR 2016, Kyoto, Japan. Auger and TA spectra compared in the same region of sky (aka “common declination band”) for the first time.

5. ICRC 2017, Busan, Korea: A more systematic comparison of Auger and TA spectra in the common declination band using better methods and a discussion of relevant systematic uncertainties.
TA and Auger Surface Detectors

Pierre Auger: 3000 km²

Telescope Array: 700 km²

(not drawn to scale)
Surface Detector Event

Auger: S1000 -> event energy

TA: S800 -> event energy
Energy Scale

\[ E = A (S_{38})^B \]

- Calibrate SD energy scale to that of fluorescence detectors (FD) using hybrid events => energy scale systematic uncertainty is that of the FD.

- Auger: Apply constant intensity cut method to get \( S_{38} \) from \( S1000 \), then calibrate \( S_{38} \) to FD

- TA: Initial energy estimate from \( (S800, \text{zenith angle}) \) using Monte Carlo then calibrate energy scale to FD
Auger and TA Surface Detector Spectra

- Ankle at \( \sim 3 \text{ EeV} \), cutoff at \( \sim 40 \) to \( 60 \text{ EeV} \)
- \( \sim 10\% \) energy scale difference around ankle region
- Large discrepancy in shape at \( E > \sim 10^{19.4} \text{ eV} \)
  - Systematic uncertainties, reconstruction biases?
  - Anisotropies?
Energy Scale Difference

- Different fluorescence yield and missing energy correction models used
- 10% energy scale shift well within stated 14% (Auger) and 21% (TA) energy scale systematic uncertainties
- Energy dependence of this shift smaller than 5%
Rescale Auger and TA energies

- Constant rescaling factor of 5.2%
- From fitting ratio of fluxes Auger/TA into a unity in the ankle region
- Auger energies raised by 5.2%
- TA energies lowered by 5.2%
- Agree in the ankle region $10^{18.4} \text{ eV} < E < 10^{19.4} \text{ eV}$ after rescaling
- Difference above $10^{19.4} \text{ eV}$ persists after locking energy scales of experiments
Auger-TA Common Declination Band Spectrum Analysis

- Restrict $\delta$ to [-15°, 24.8°] range
- Excludes TA hot spot
- Independence of exposure on declination (aka “1/$\omega$ method”):

$$J_{1/\omega}(E) = \frac{1}{\Delta\Omega\Delta E} \sum_{i=1}^{N} \frac{1}{\omega(\delta_i)}$$

(UHECR 2016 proceedings)
Entire Sky Spectra

- $E^3 J(E) / (\text{eV}^2 \text{ km}^2 \text{ sr}^{-1} \text{ yr}^{-1})$

- TA SD, Full Sky (E rescaled by -5.2%)
- Auger SD, Full Sky (E rescaled by +5.2%)

$log_{10}(E/\text{eV})$ vs. $E^3 J(E)$
Common Declination Band

Better agreement between TA and Auger in the common declination band
• Second break points are roughly in agreement in the common declination band
• Smaller but significant difference remains in the common declination band
Declination Dependence in TA

- 3.9σ effect in TA using broken power law fit
- Auger sees no significant declination dependence
Check of the TA SD Energy Reconstruction Bias Using FD

- TA SD energies compared to TA FD using hybrid events
- ~4% uncertainty on the slope. More details: see D. Ivanov, PoS(ICRC2017)496
- No significant energy reconstruction bias found
Summary

- Pierre Auger and Telescope Array surface detector spectra in good agreement in the ankle region after a 10% energy scale shift
- No declination dependence seen in Auger spectrum
- $3.9\sigma$ declination dependence in TA using broken power law fit
  - Not caused by biases in the energy determination or exposure
- Better agreement between TA and Auger in the common declination band
  - Second break points occur in the same place