Measurement of the cosmic ray flux near the second knee with the Pierre Auger Observatory

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for the Pierre Auger Observatory

--ICRC2019--
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PIERRE AUGER OBSERVATORY

Overview

First measurement of the second knee by the Pierre Auger Observatory using the 750 m surface array and a Cherenkov[1] analysis

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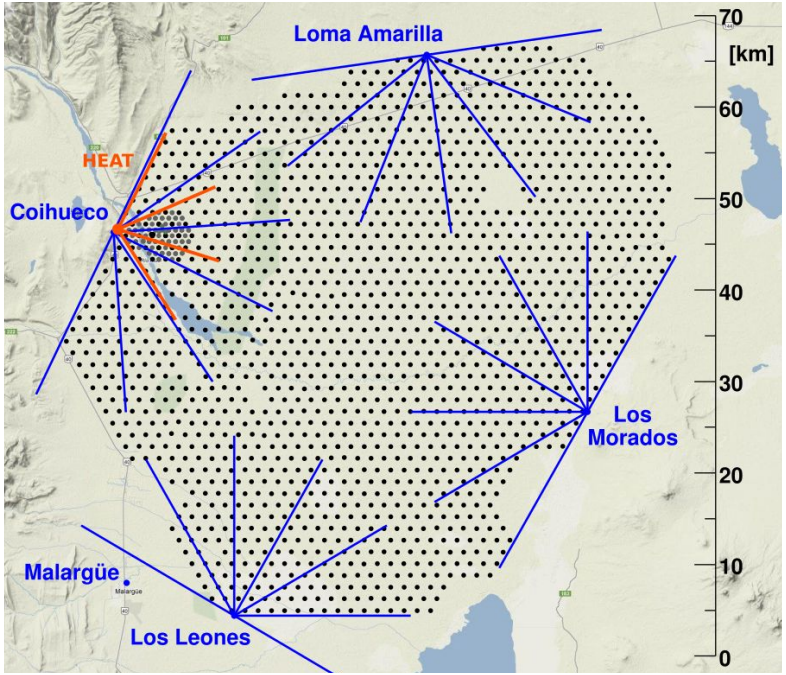
1) Improvements of air shower detection by surface detector (SD)
2) New method to calculate the SD energy resolution directly from data
3) Measurement of the cosmic ray spectrum above $10^{16.5}$ eV
   a) Combination of Cherenkov analysis and the 750m SD
4) Comparison to other measurements near the second knee

[1] V. Novotny, POS(ICRC2019)374, Poster #193

Extending the 750 m Array at Auger



Surface detector (SD) array

- ~1660 Cherenkov Detectors
- Observe secondaries on the ground

Fluorescence detector (FD)

- Observe shower development
- Set the observatory's energy scale[2]

Low energy extensions

- High Elevation Auger Telescope (HEAT)
- 750 m SD array

[2] B. Dawson, POS(ICRC2019)231

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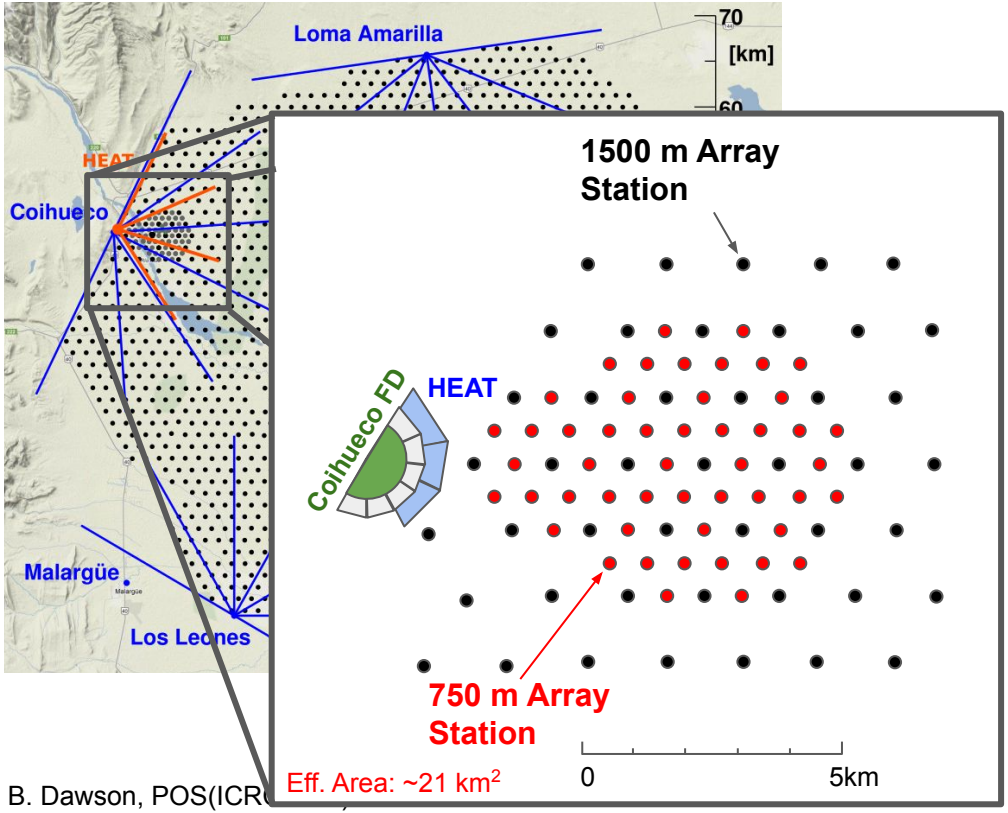

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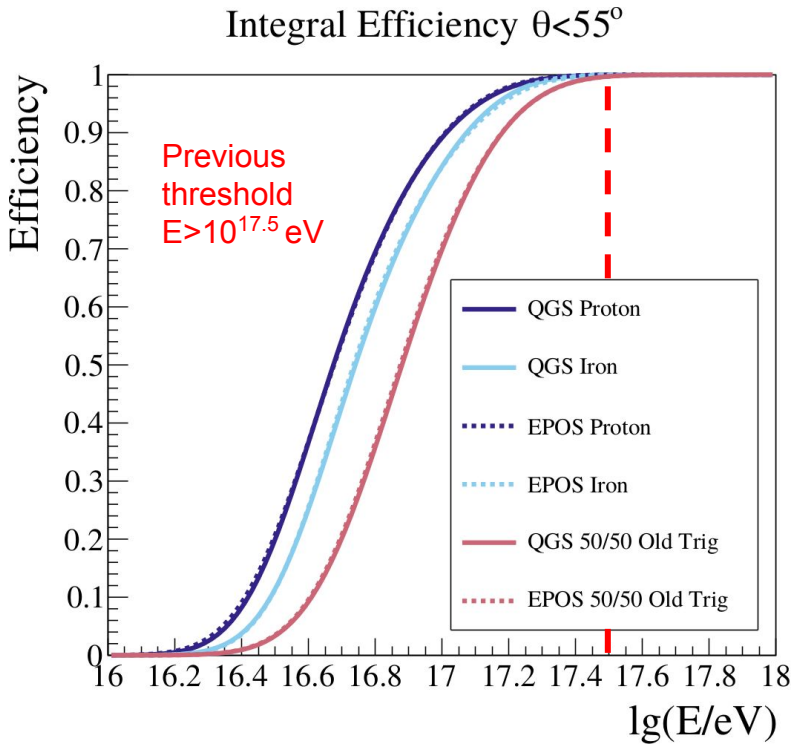
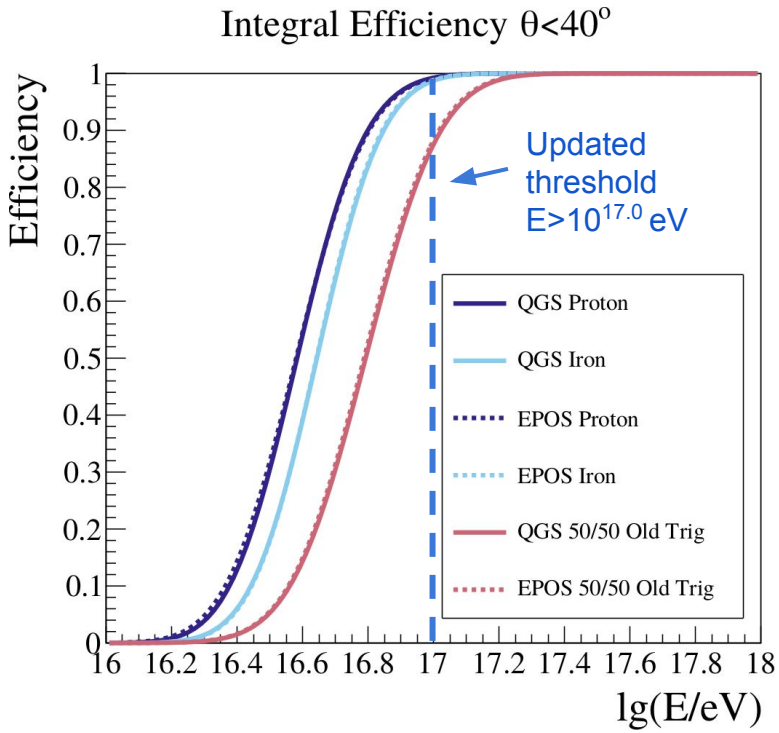
[2] B. Dawson, POS(ICRC

Improvements to Air Shower Detection

- Additional set of particle triggers designed, completed installing at SD stations in 2014
- Increases sensitivity of the array to electromagnetic component of air showers
- Change threshold for >98% trigger eff. from (θ < 55°, E > $10^{17.5}$ eV) to (θ < 40°, E > $10^{17.0}$ eV)





Additionally Detected Events

SD reconstruction[3] philosophy unchanged from previous analyses

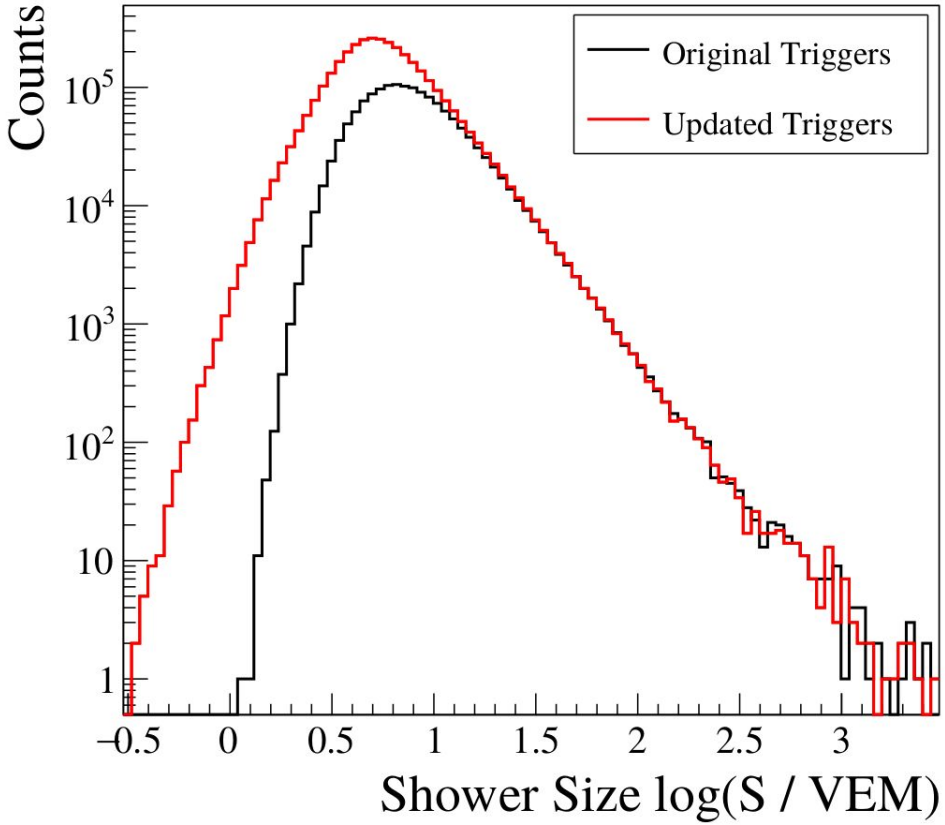
SD produces *energy estimator*, the expected signal @ 450 m, **S(450)**

Data set for spectrum:

Jan. 2014 - Aug 2018

Exposure 105.40 km^2 sr yr

~600k events detected by 750 m

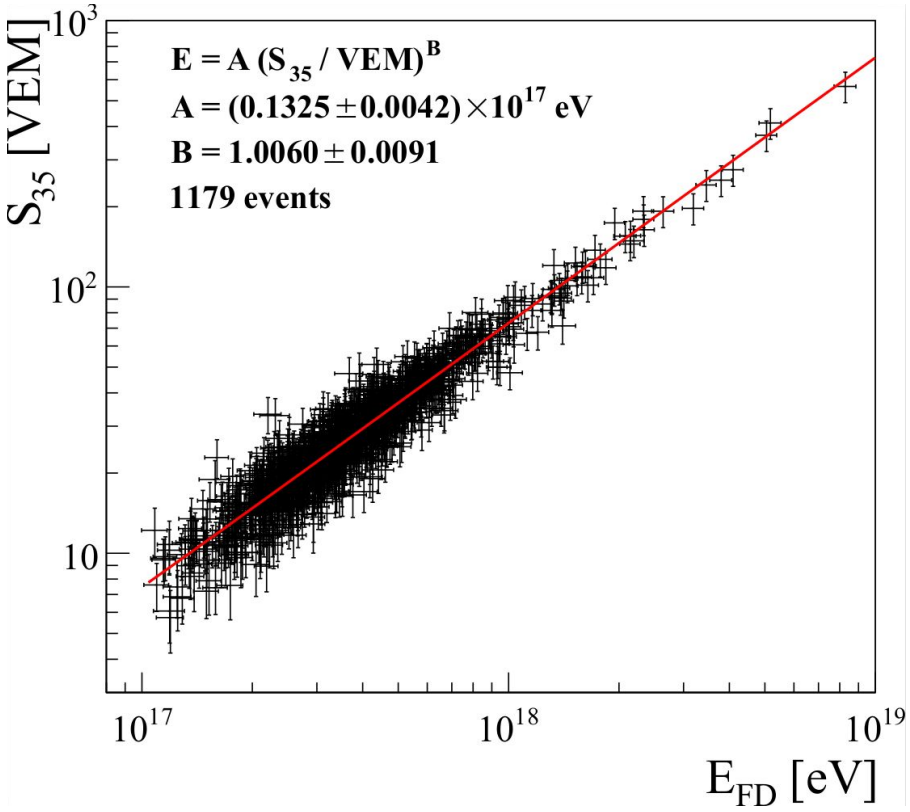


[3] D. Mockler, POS(ICRC2019)353, Poster #188

SD Energy Calibration

Energy calibration performed using events, independently reconstructed by FD and SD

Now also use these events for...

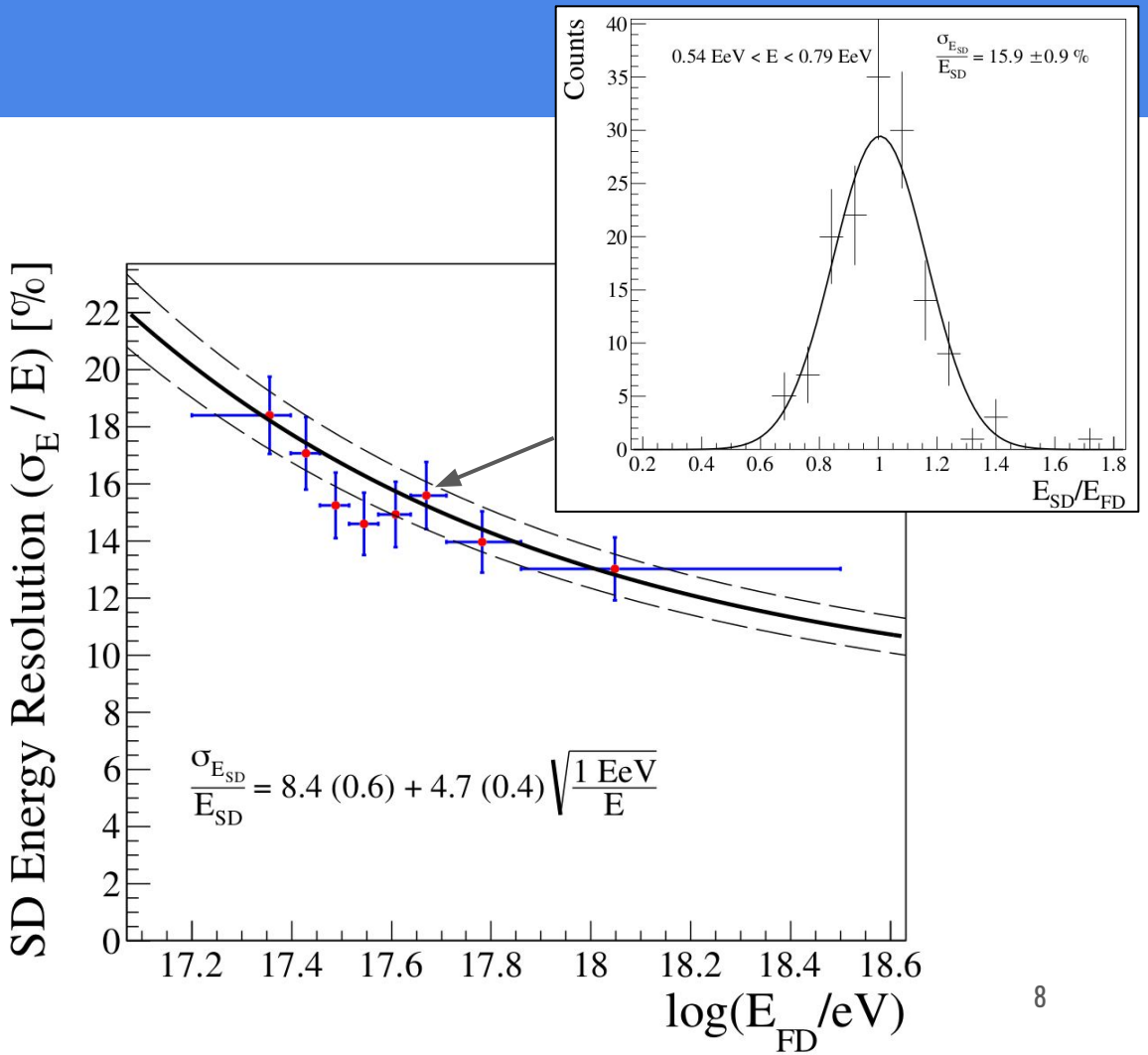


SD Energy Calibration

Energy calibration performed using events, independently reconstructed by FD and SD

Ratio of E_{SD} / E_{FD} used to estimate the SD energy resolution directly from data

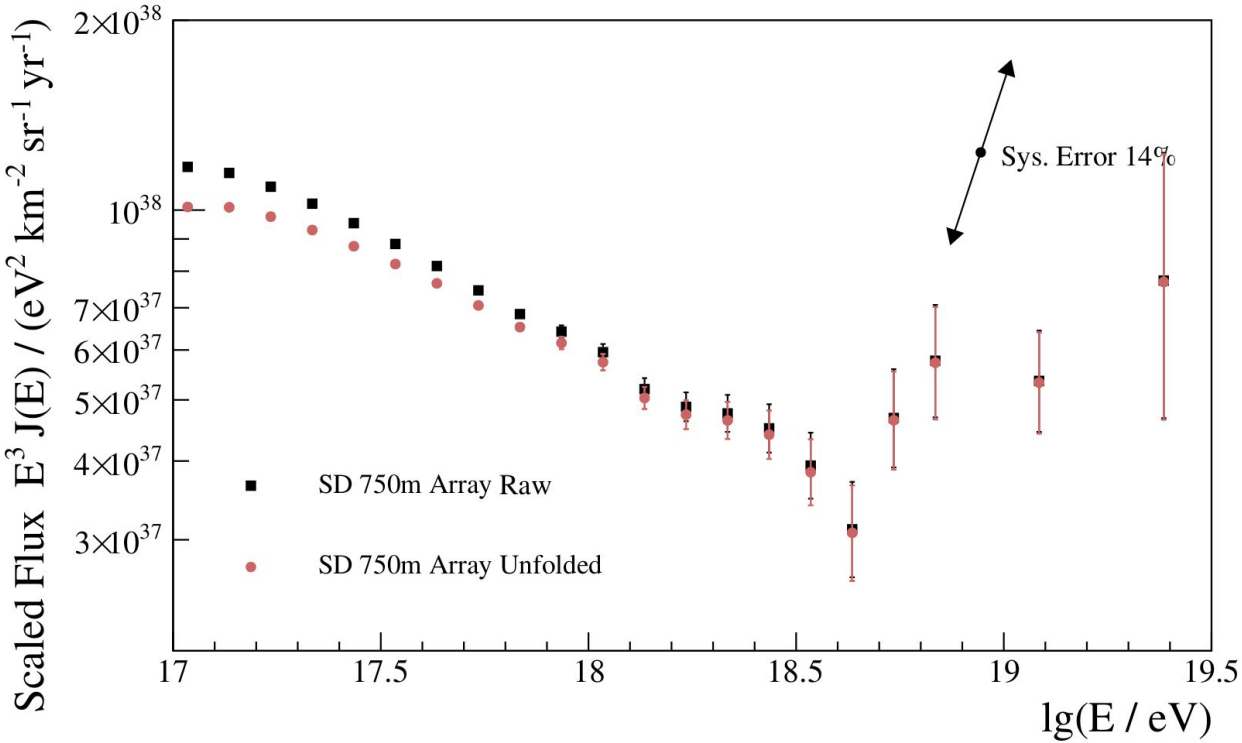
Resolution of the 750 m array is 10 - 25% in the relevant energy range

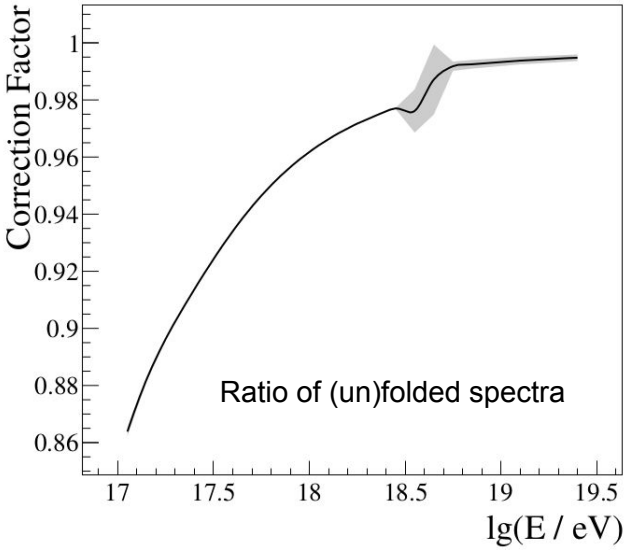


Correction of Detector Effects

Measurement corrected for asymmetric event migration using forward folding

Includes: SD energy resolution, trigger efficiency, bias in energy assignment

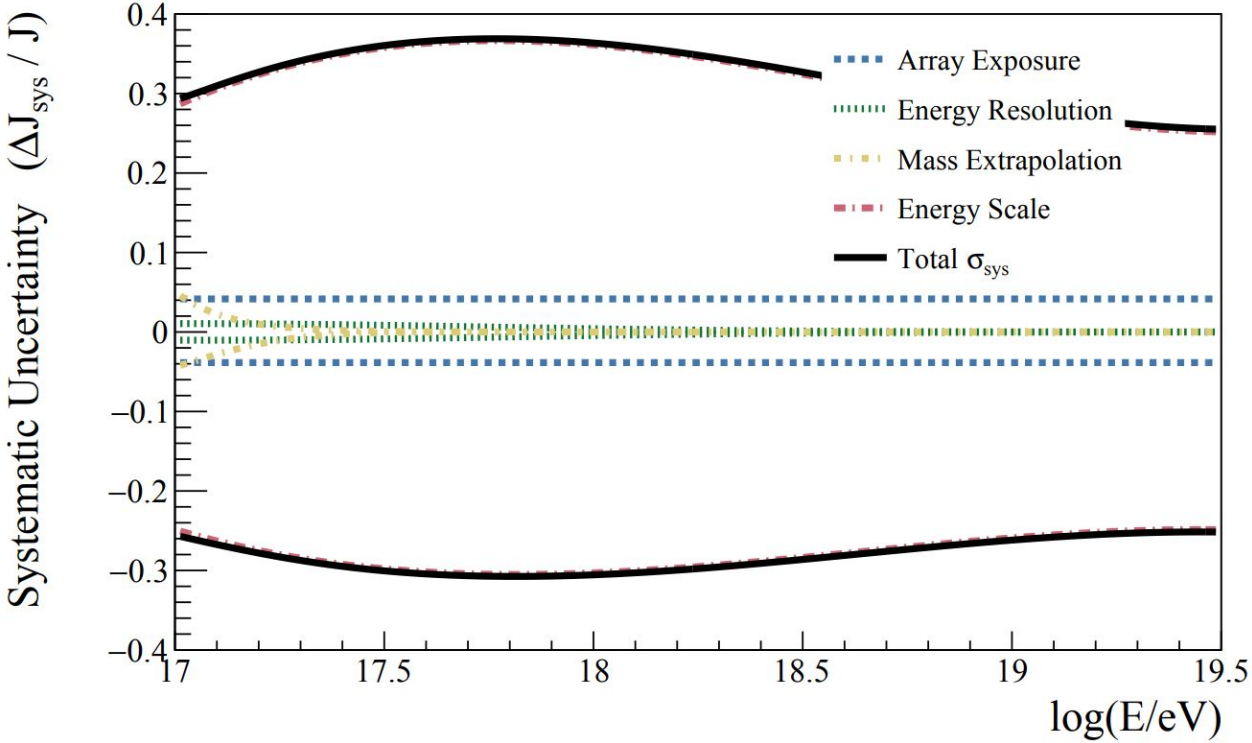




Systematic Flux Uncertainty

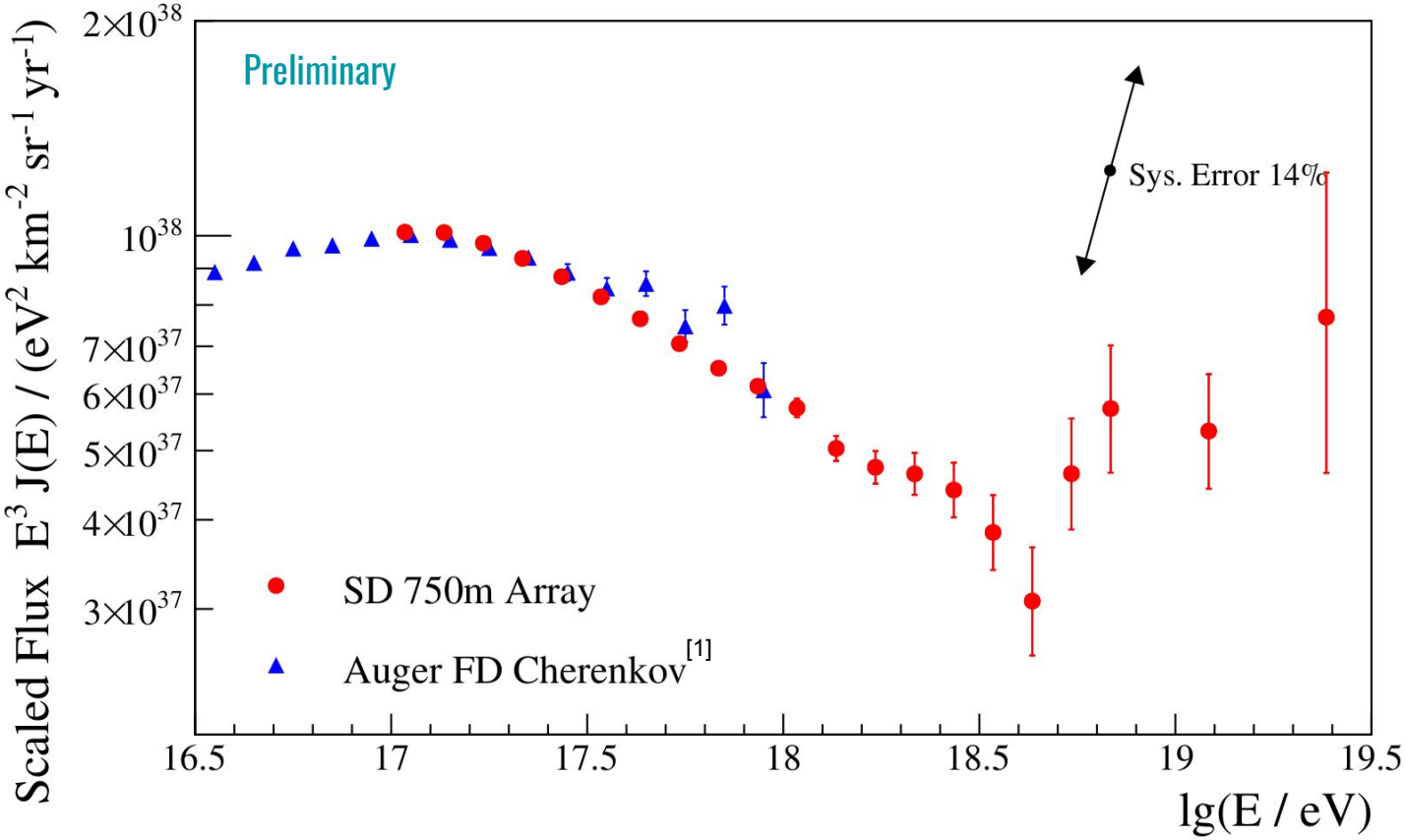
Systematic uncertainty on the flux is dominated by the uncertainty of the 14% energy scale[2]

Restriction of analysis to energy range with >98% trigger efficiency ⇒ < 5% uncertainty related to composition below FD measurements



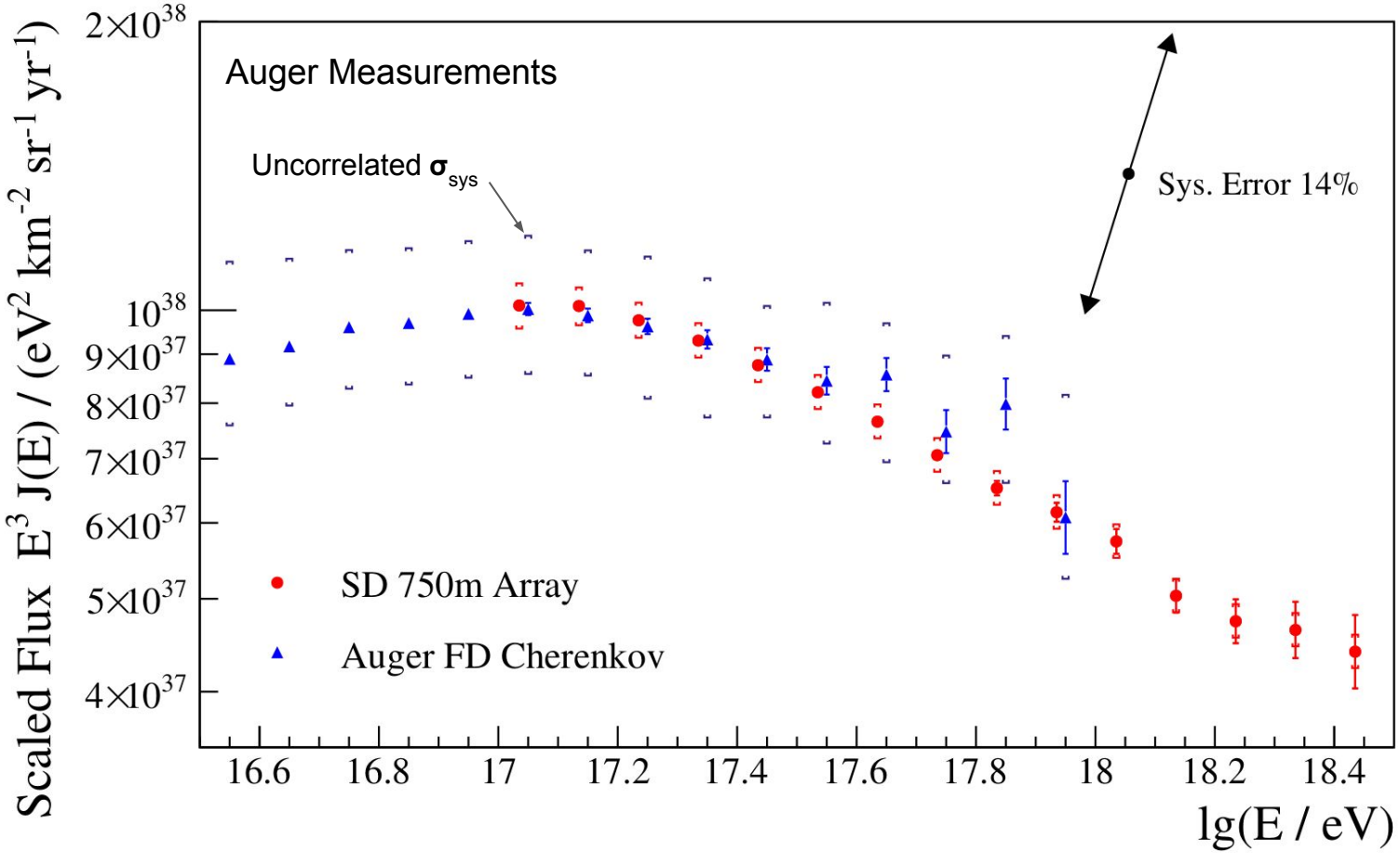
[2] B. Dawson, POS(ICRC2019)231

The Energy Spectrum Measured by Auger



[1] V. Novotny, POS(ICRC2019)374, Poster #193

Spectrum Near the Second Knee



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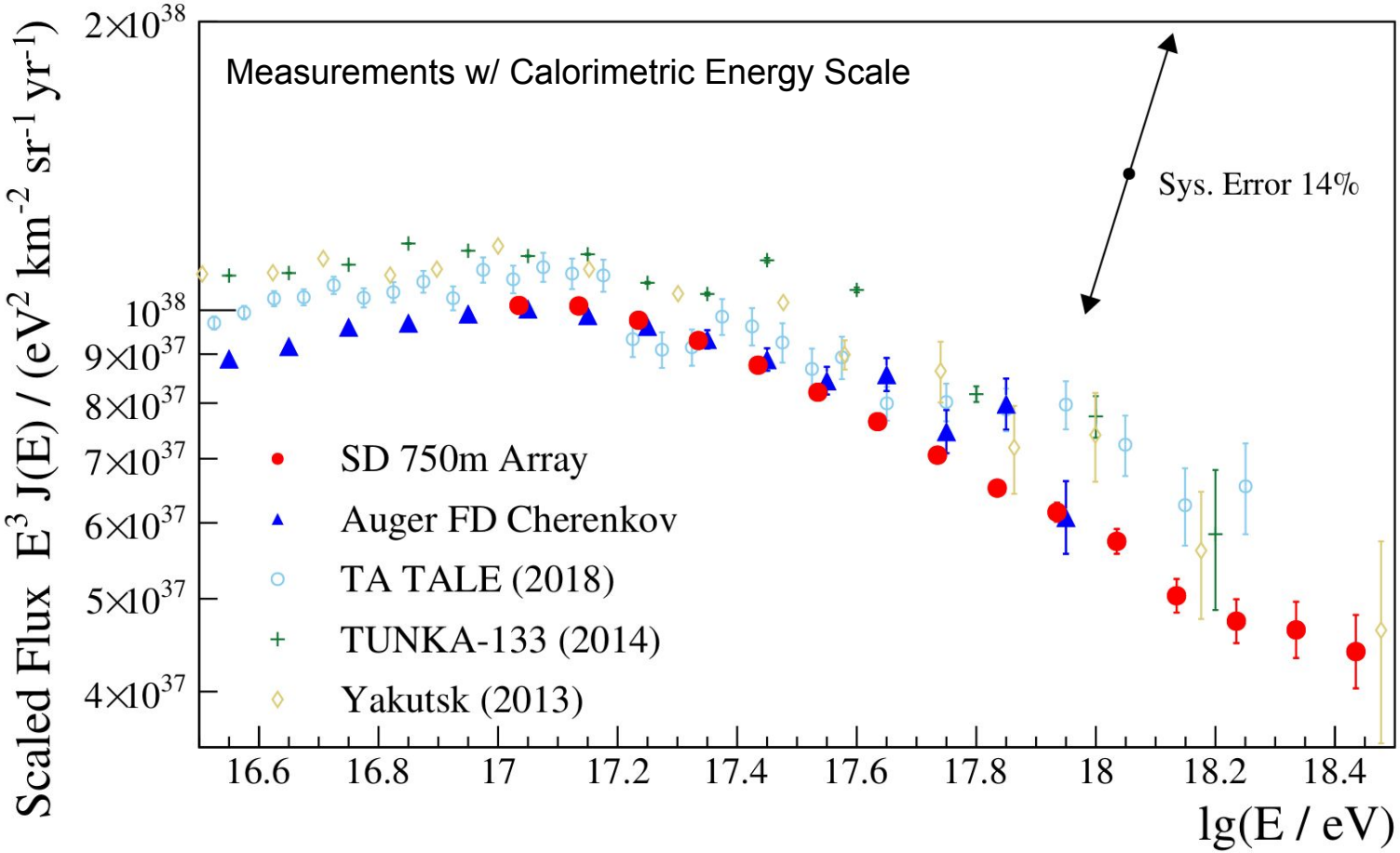

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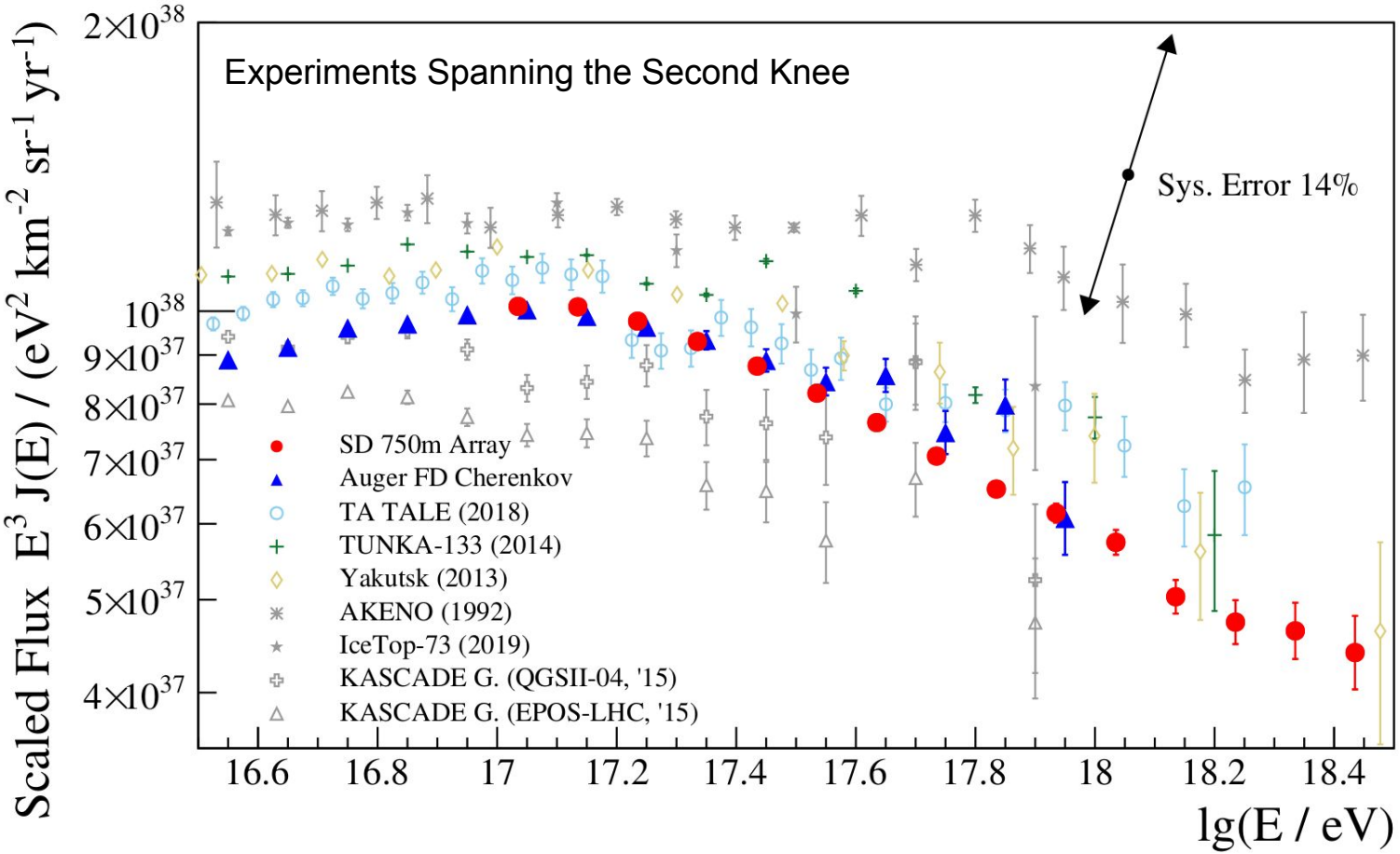
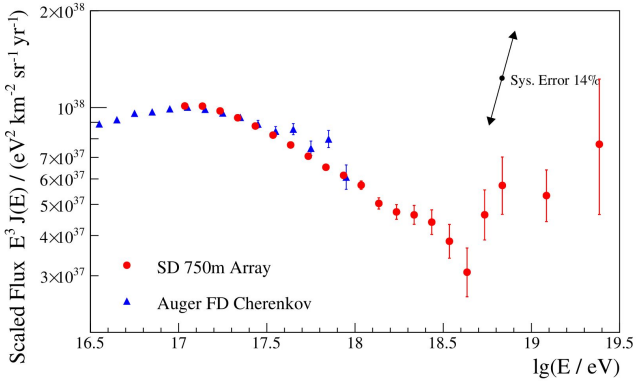


Summary

Update to the particle triggers in SD stations allows for observation of showers at lower energies than previously possible



High statistics measurement of energies above 100 PeV by the SD

- Based on data-driven analyses of detector properties
- Almost MC-independent result

Combined with new Cherenkov spectrum, able to see the second knee

In total, measurement spans three decades in energy

- Clearly see several distinct features[4] in the spectrum

[4] V. Verzi, POS(ICRC2019)450

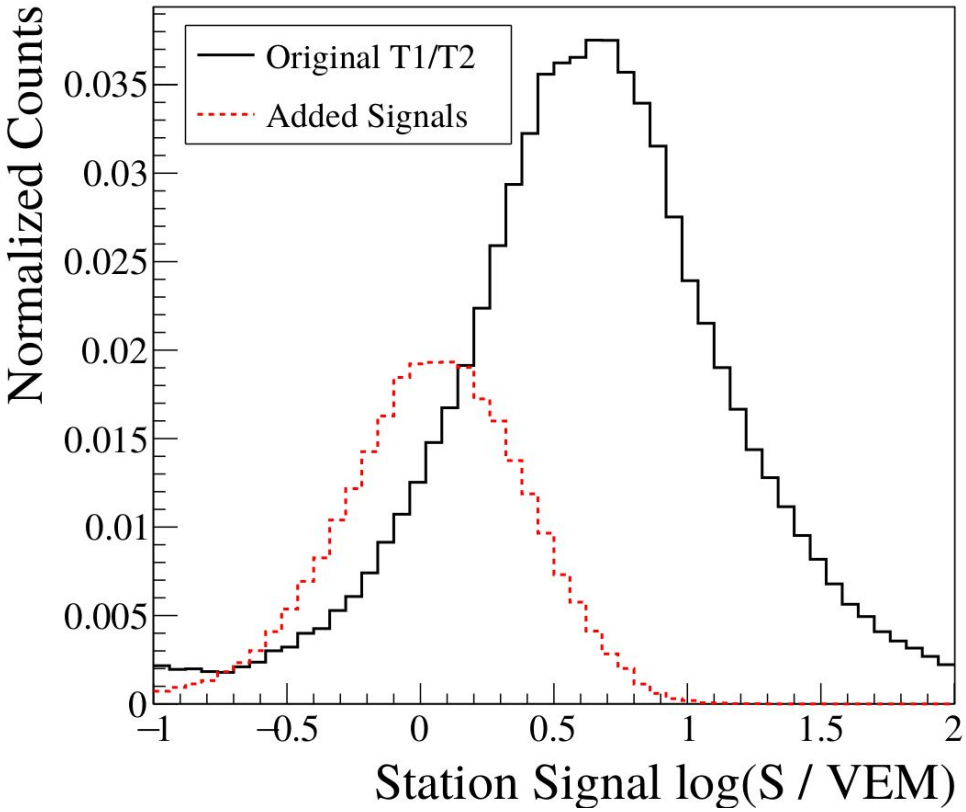
Thank You

Distribution of Individual Station Signals

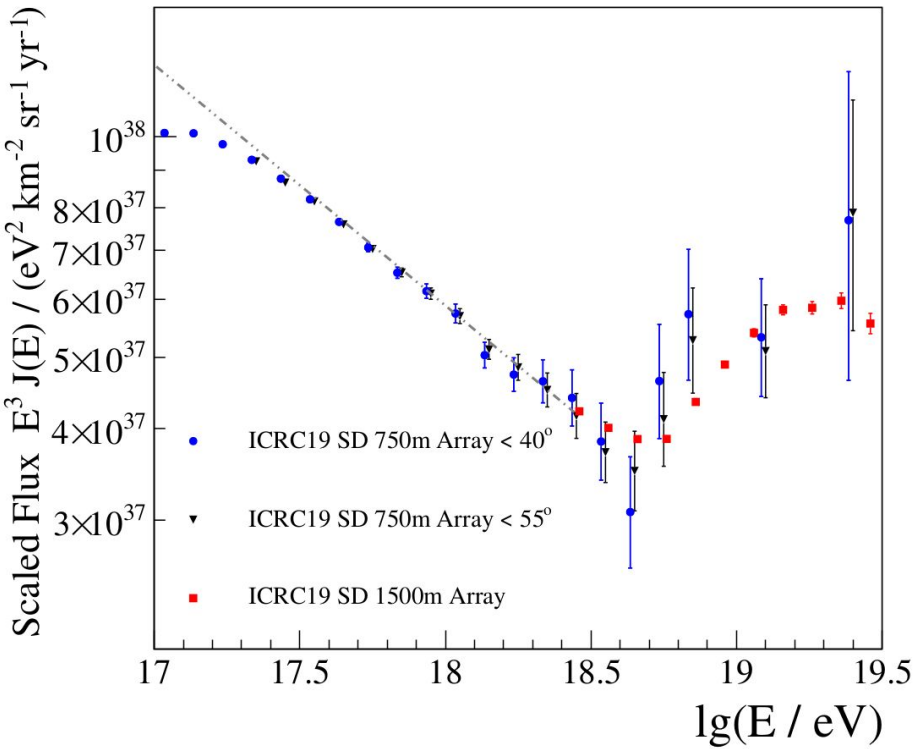
Black distribution shows measured signal sizes using the original particle triggers

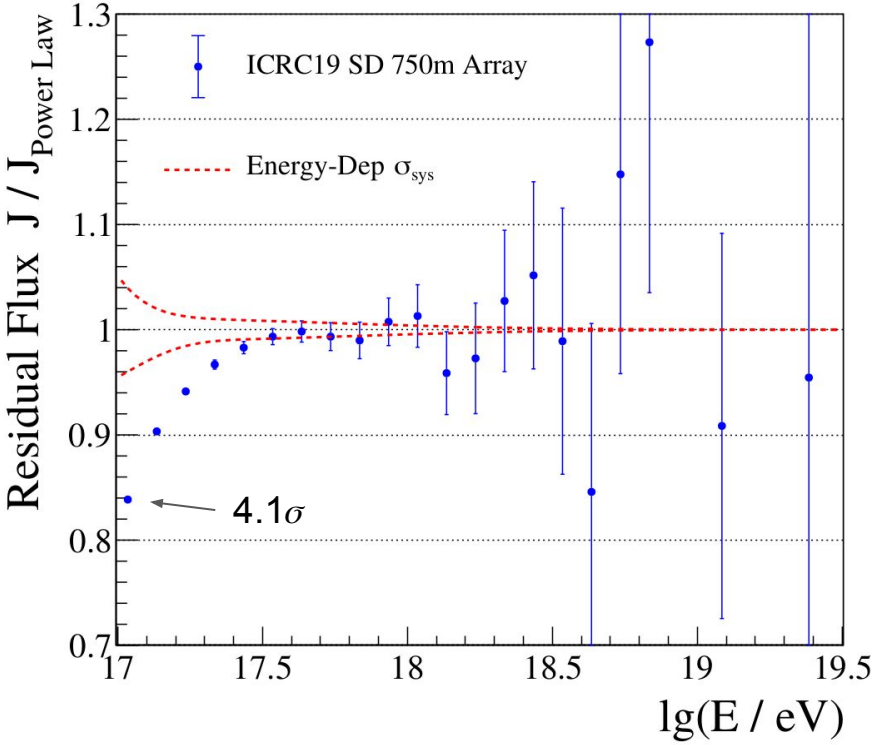
Red distribution is the signal sizes only now observable via the new trigger algorithms

Total observed signals is the sum of the two

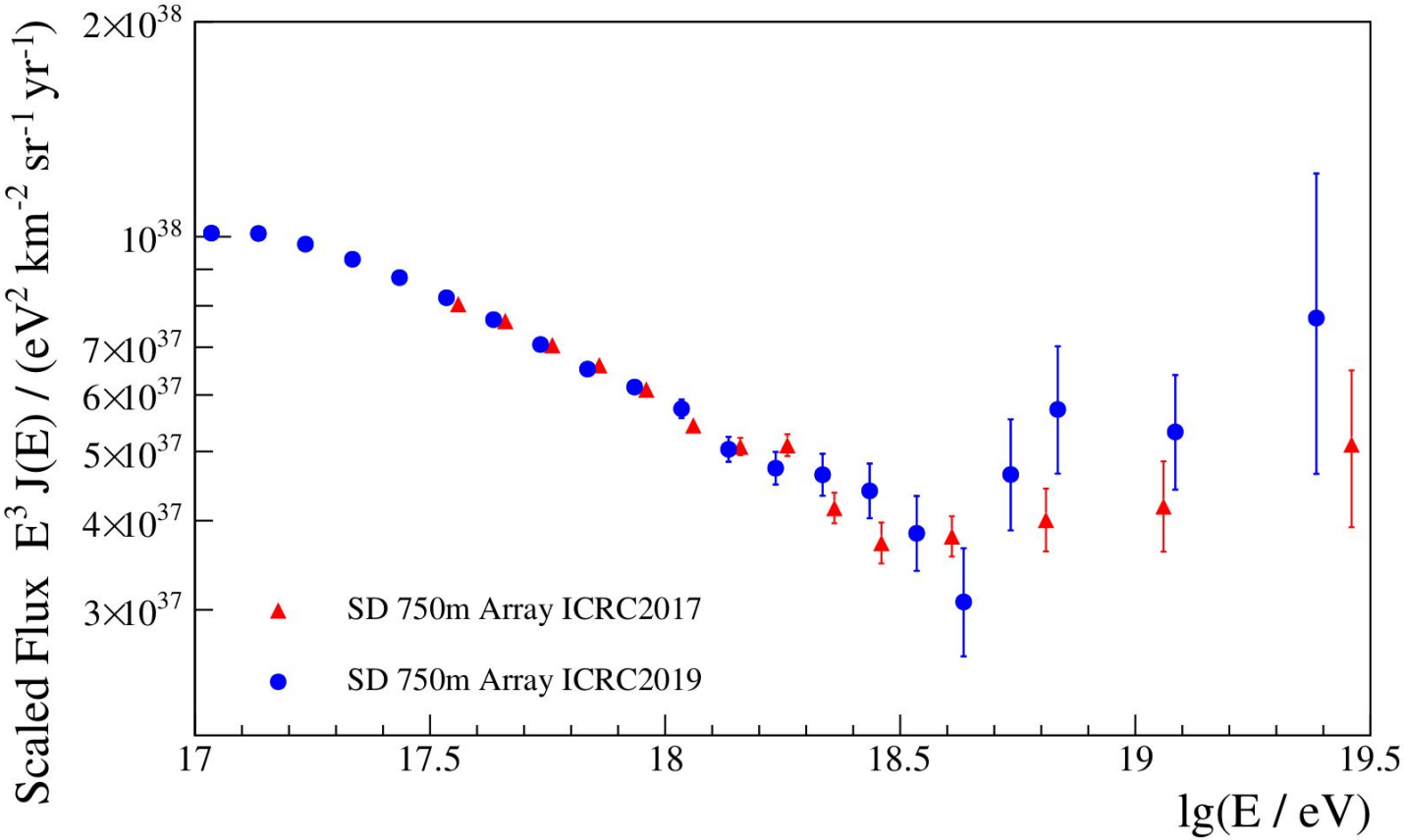


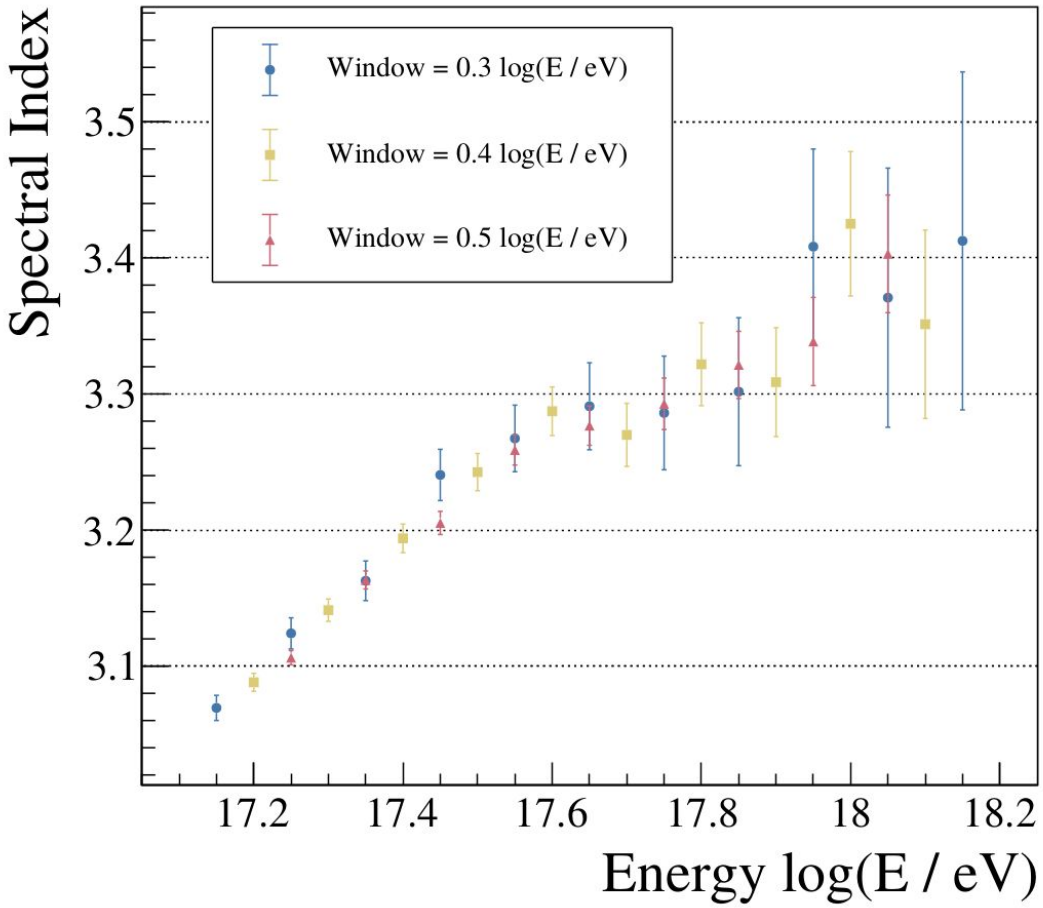
750m Array Near the Second Knee





Comparison to Last ICRC




Spectral Index
3.5
3.4
3.3
3.2
3.1
Window = 0.3 log(E / eV)
Window = 0.4 log(E / eV)
Window = 0.5 log(E / eV)
17.2
17.4
17.6
17.8
18
18.2
Energy log(E / eV)