

Review of experimental data from Pierre Auger Observatory and Telescope Array

Ioana C. Mariş

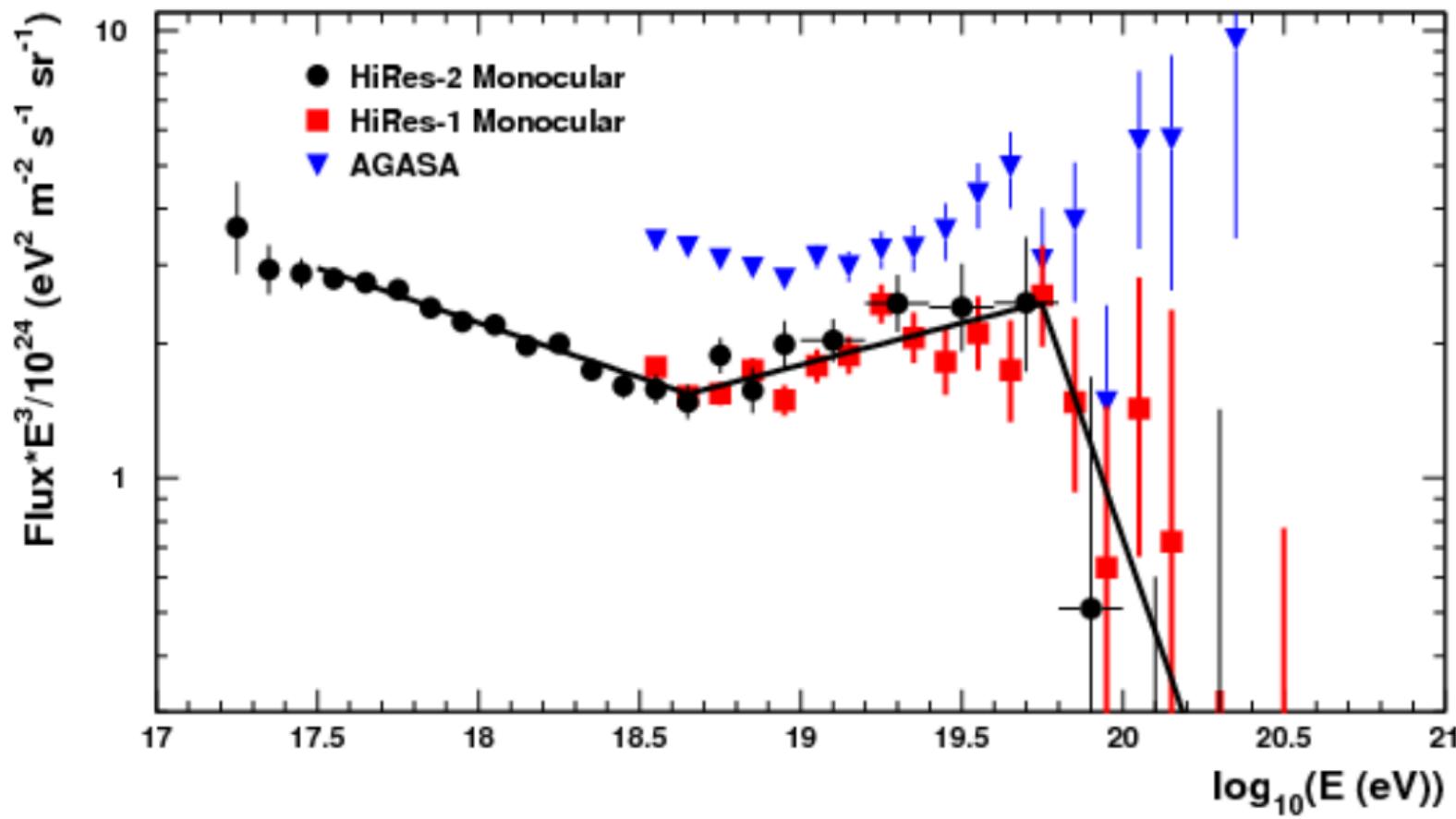
based on the work of both collaborations and the working groups

Université Libre de Bruxelles

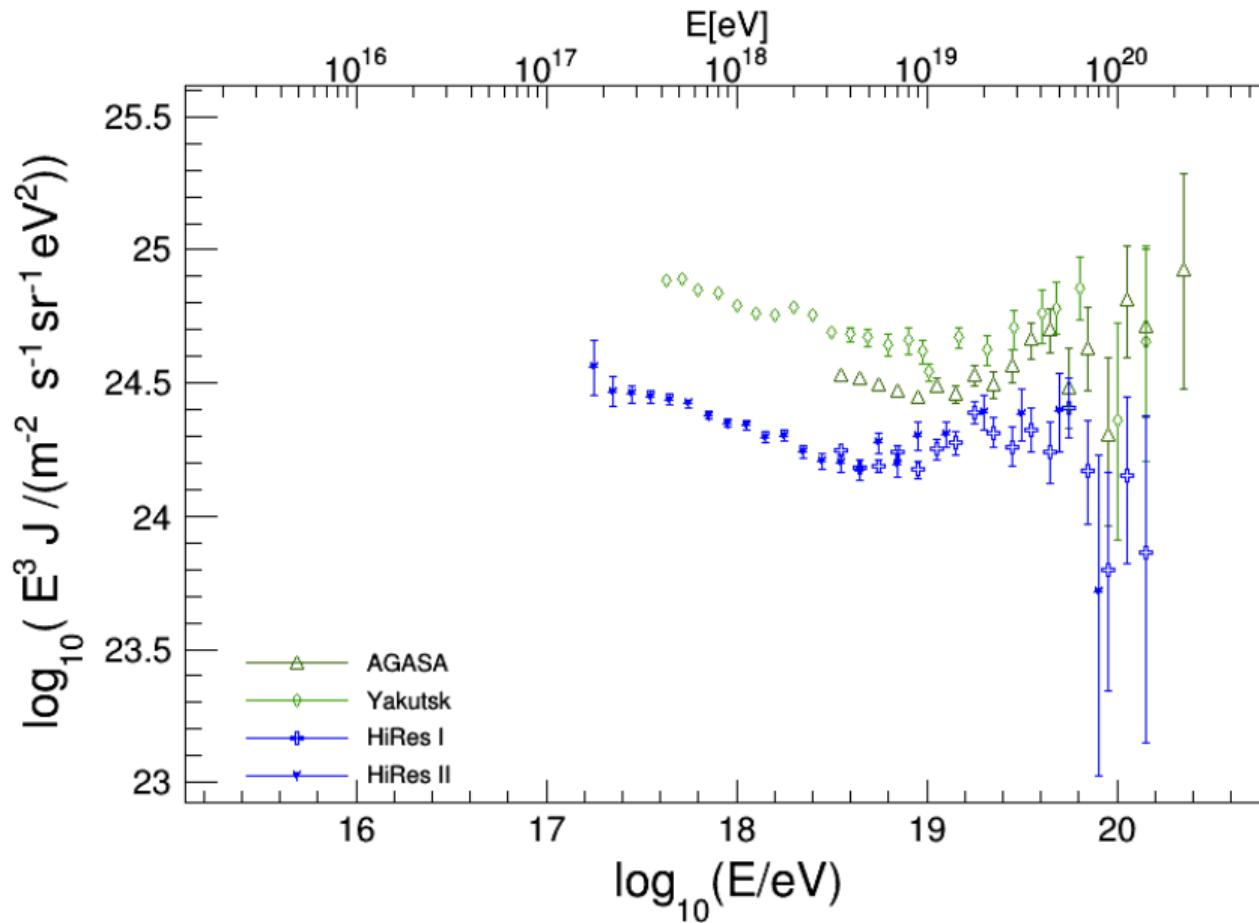
Cosmic Rays and Neutrinos in the Multi-Messenger Era

07 December 2020

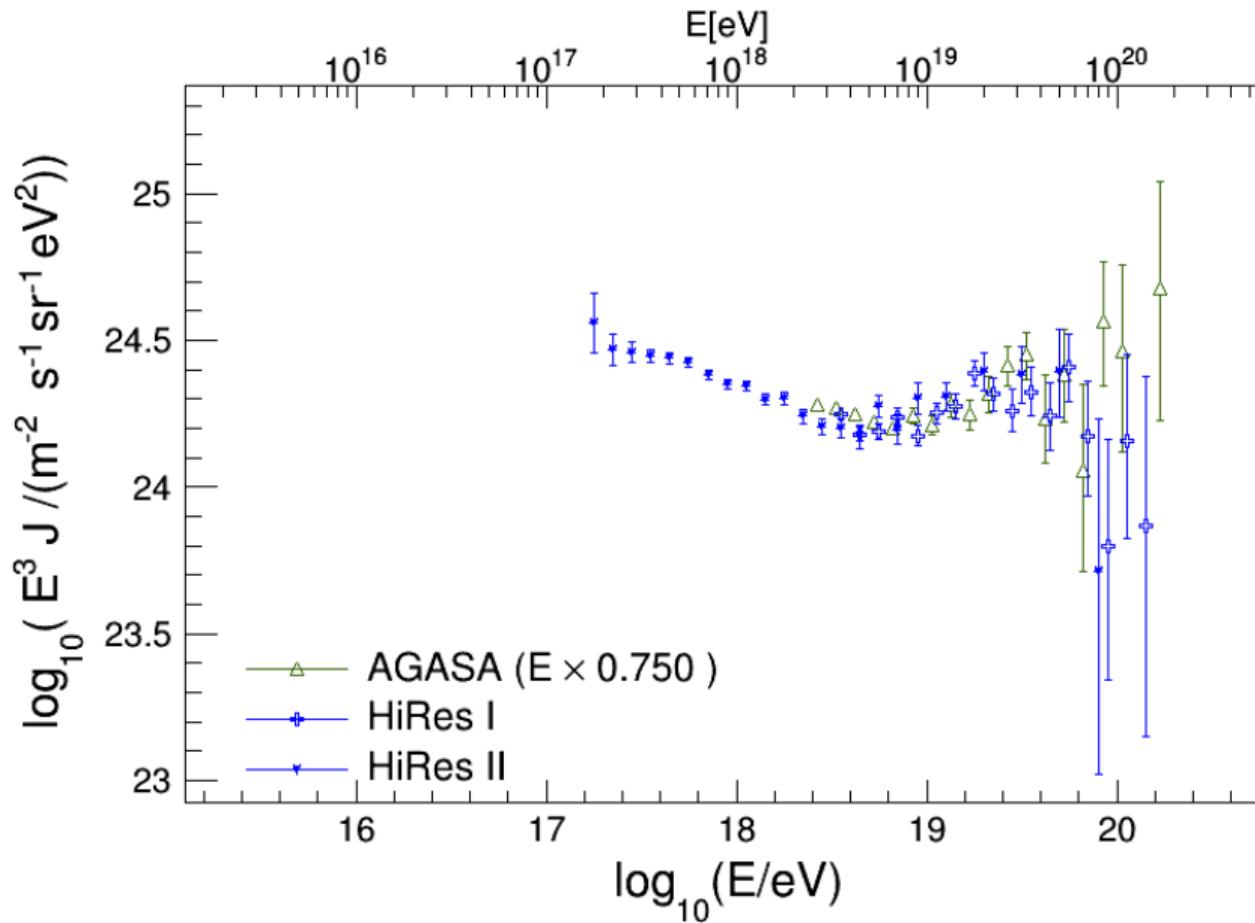
15 years ago: Flux suppression or new physics?



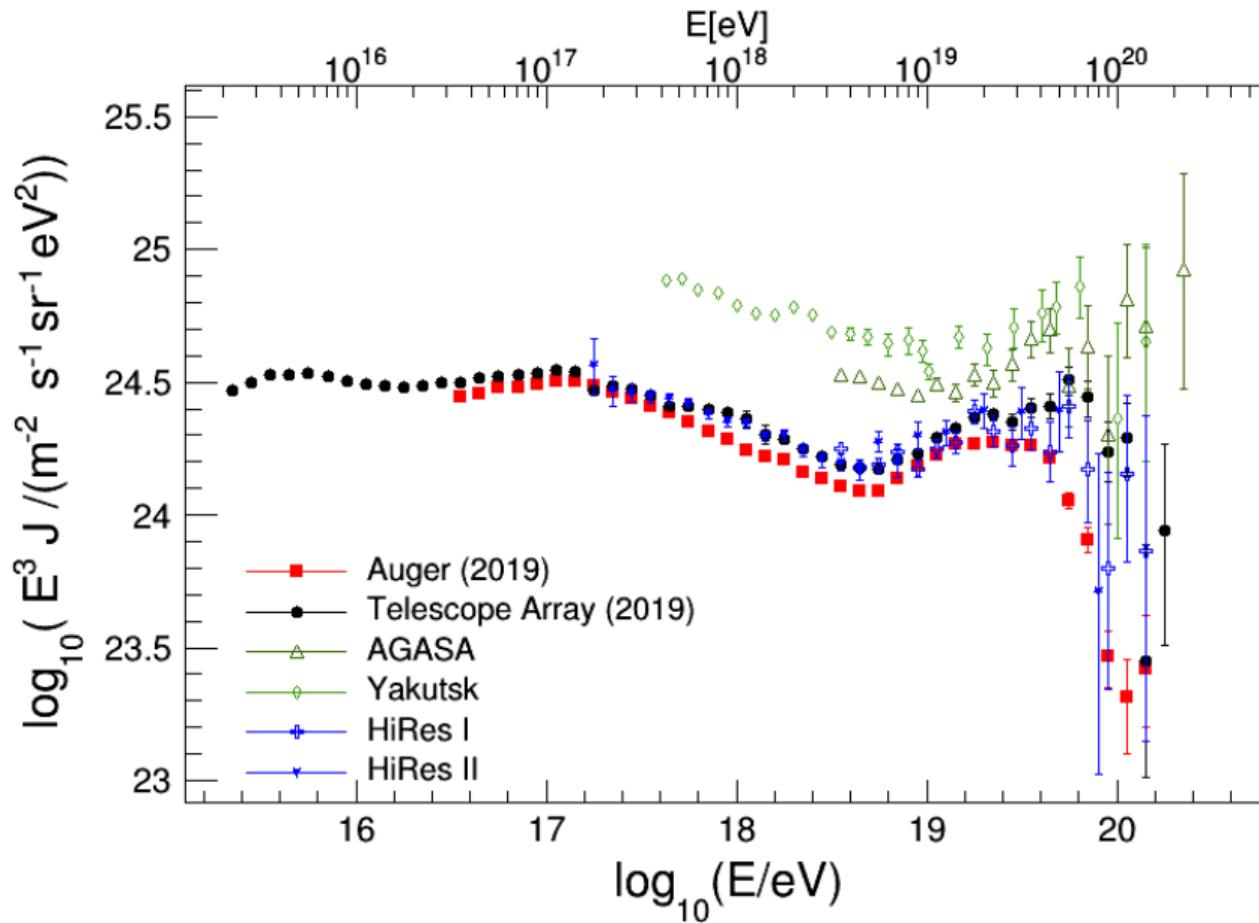
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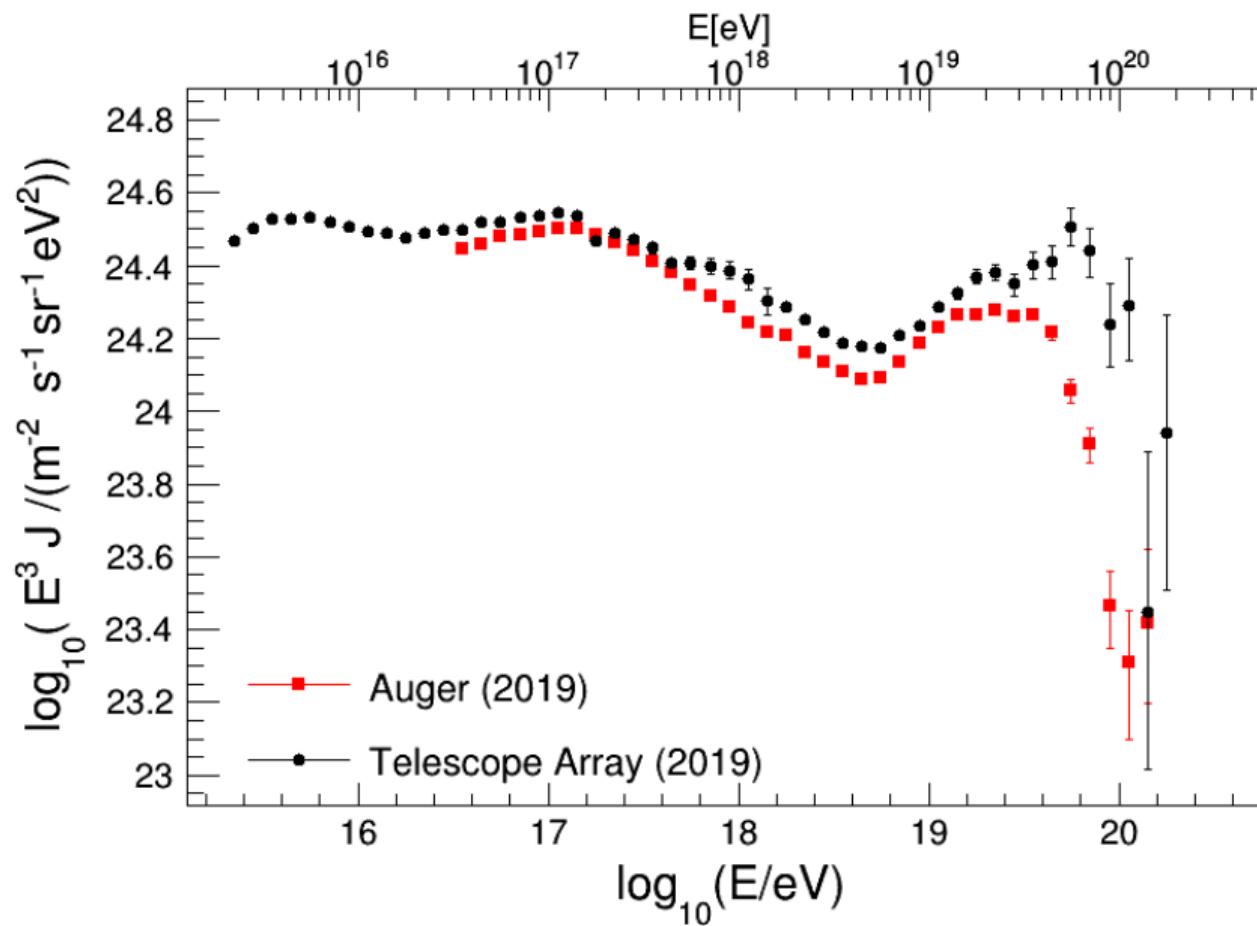
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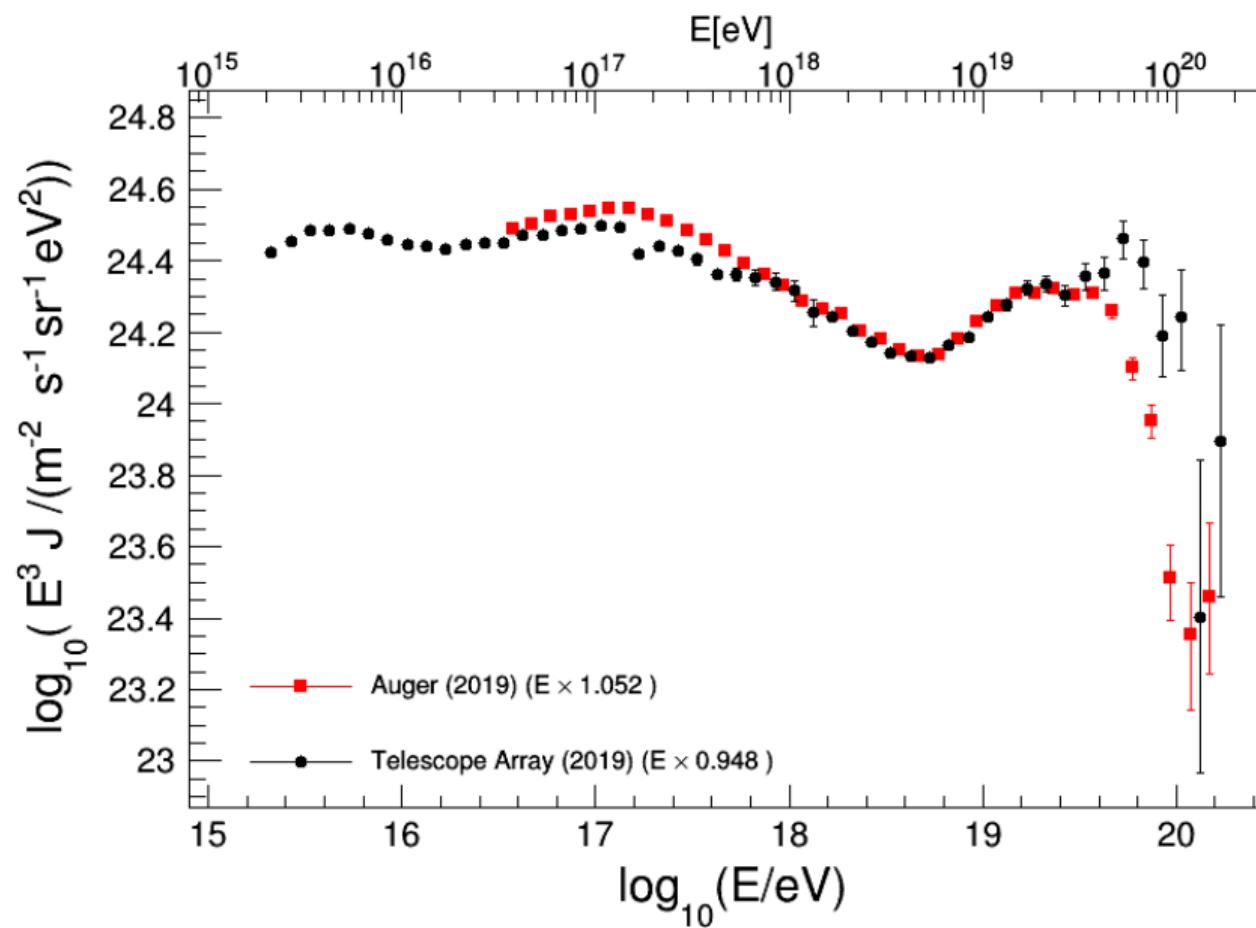
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Today: Towards deep understanding of systematic uncertainties

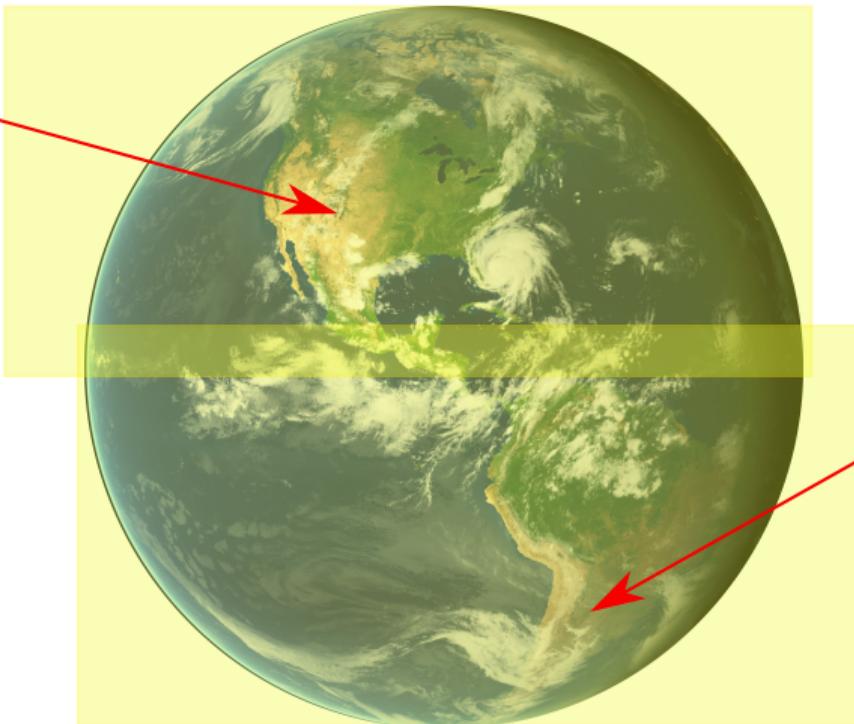


Today: Towards deep understanding of systematic uncertainties



UHECRs with full sky coverage and complementary techniques

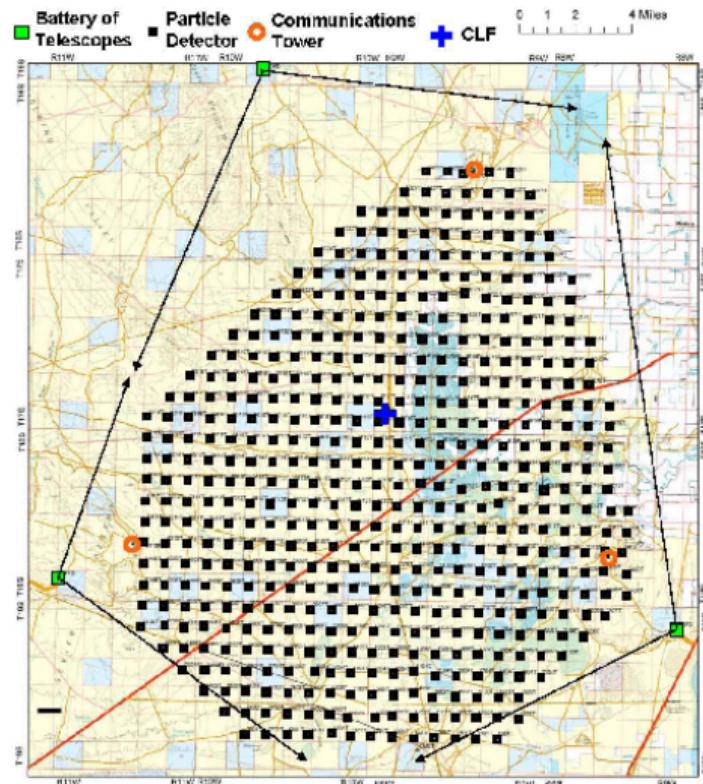
Telescope Array
Delta, Utah, USA



Pierre Auger Observatory
Province of Mendoza,
Argentina

Combining the data from the two largest observatories.

Telescope Array

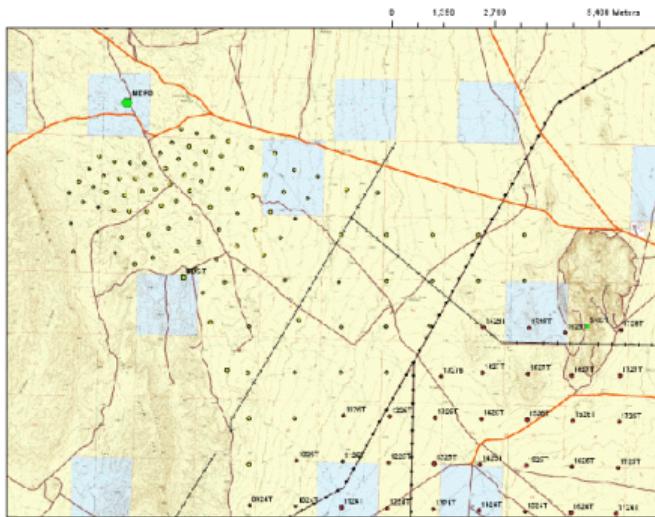


700 km² (507 scintillators, 1200m square grid),
38 telescopes



Surface detectors

Telescope Array



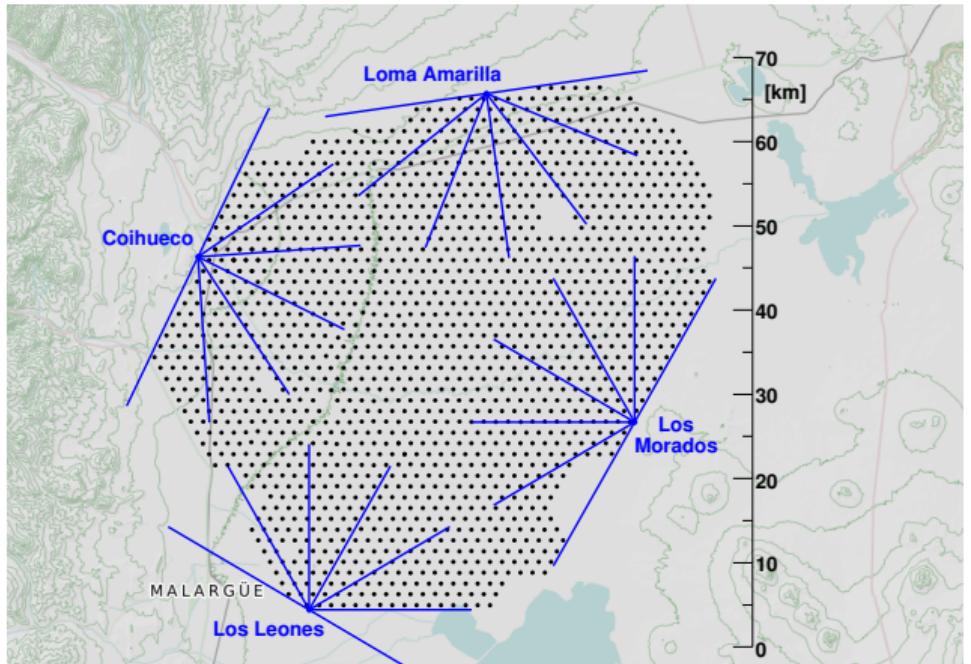
TALE extension (also with another 104 counters)



Surface detectors

Pierre Auger Observatory

Fluorescence Telescopes



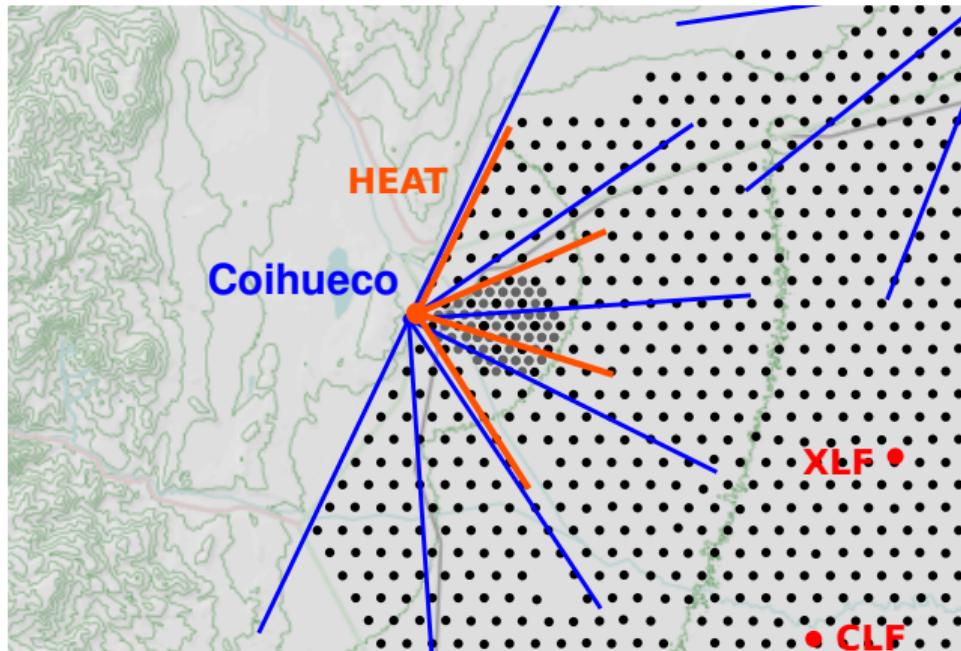
3000 km² (1660 water Cherenkov detectors), 27 telescopes



Surface detectors

Pierre Auger Observatory

Fluorescence Telescopes



Surface detectors

27 km² (750 m spacing), 3 HEAT telescopes
large program for monitoring of the atmosphere

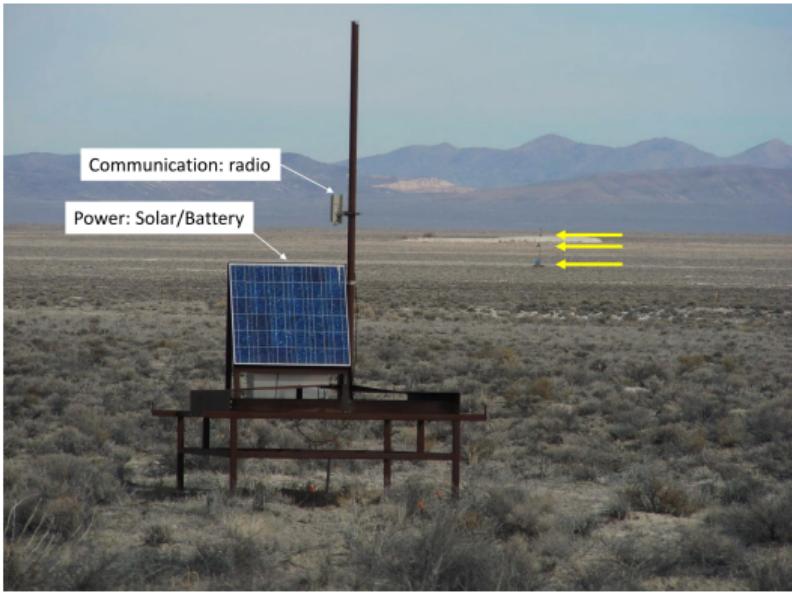
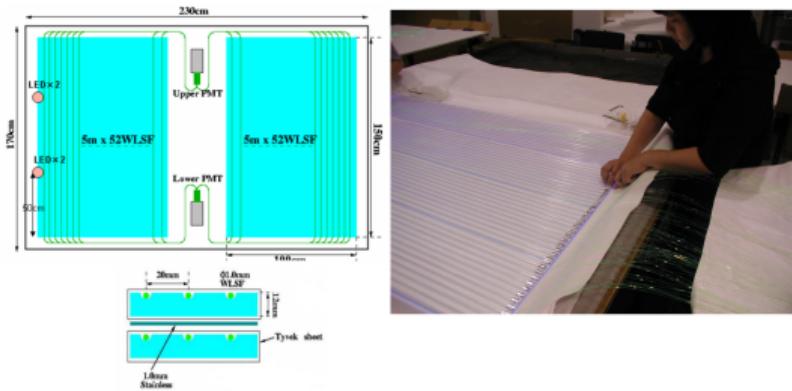
Auger water Cherenkov detectors



- 1660 independent units
- 3 m diameter, 1.2 m height, 12T
- equipped with solar panels, GPS and radio antennas
- 3 PMTs (8 inch)
- 10 bits FADCs, 40MHz
- calibrated each minute with muons

Measurement of the μ^\pm , e^\pm , γ reaching the ground

Telescope Array scintillators



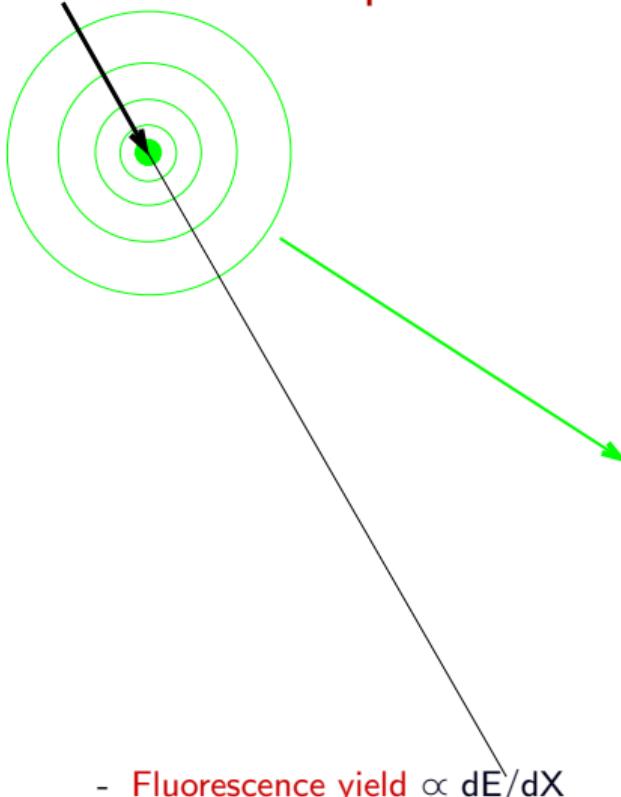
- 507 independent units
- plastic scintillators (AGASA), 3 m^2 surface, 2 layers
- equipped with solar panels, GPS and radio antennas
- 2 PMTs and 12 bits FADCs, 40MHz
- calibrated with muons

Measurement of the ionizing particles reaching the ground



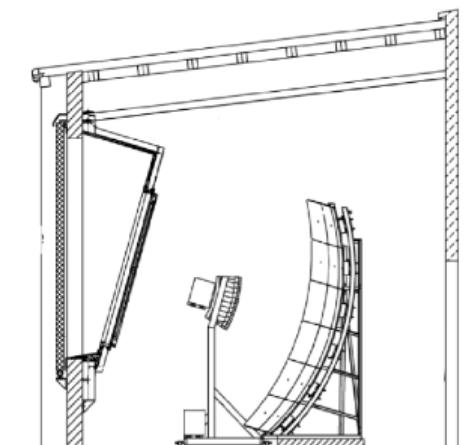
Schmidt optics, 440 (256 for TA) PMTs camera, 10m² (1-6.8 m² for TA)mirror

From measured photons to energy: air showers emissions



- Fluorescence yield $\propto dE/dX$

- Cherenkov yield $\propto N_e$, universality of the energy deposit $dE/dX = \alpha_{\text{eff}}(s) \cdot N_e$

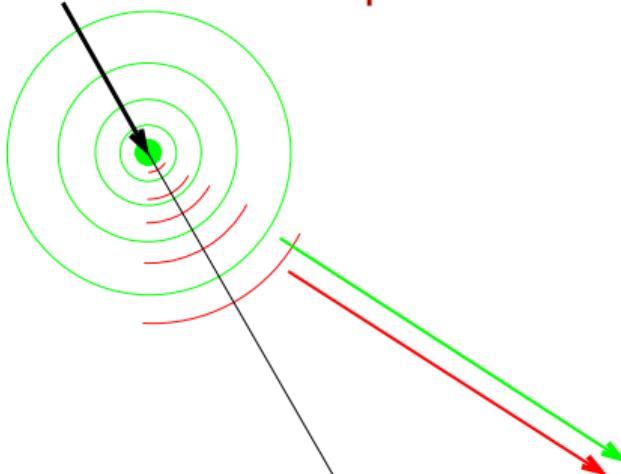


Differences between TA and Auger

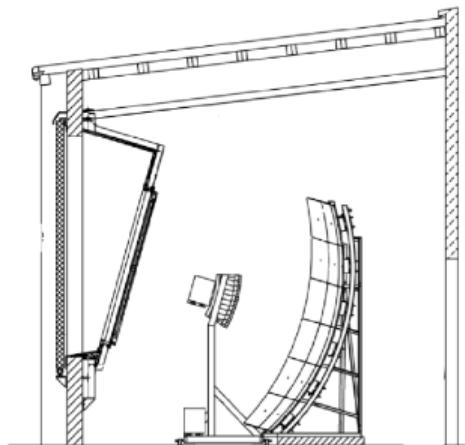
- isotropic fluorescence emission: absolute fluorescence yield assumptions
- forward beamed direct Cherenkov light: lateral distribution
- Rayleigh- and Mie- scattered light: dependent on the aerosols and atmospheric conditions (VAOD)
- Invisible energy correction

adapted from M.Unger

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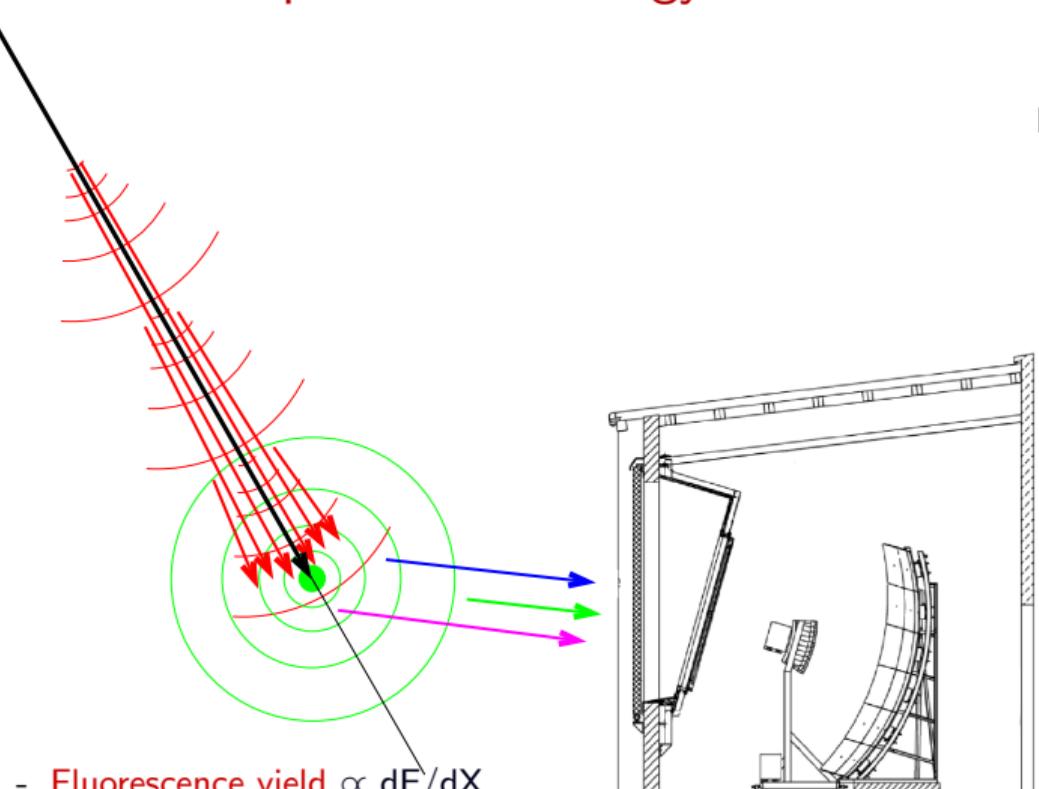


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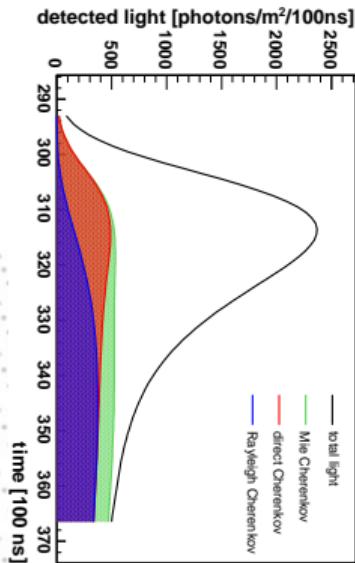
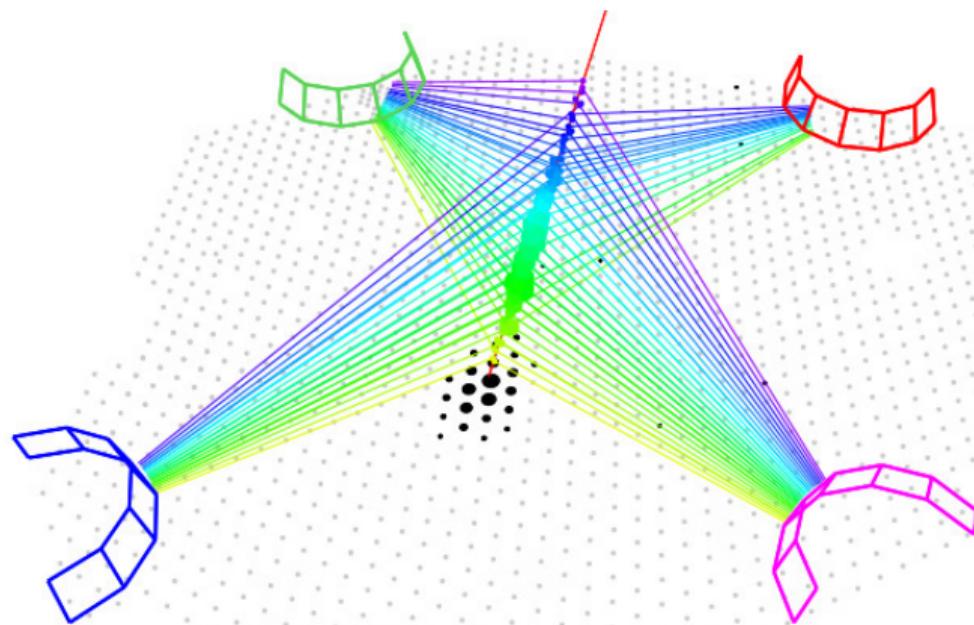
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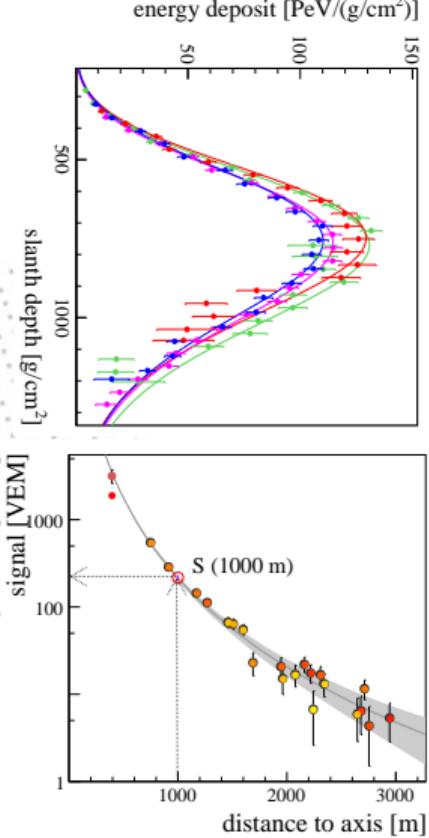
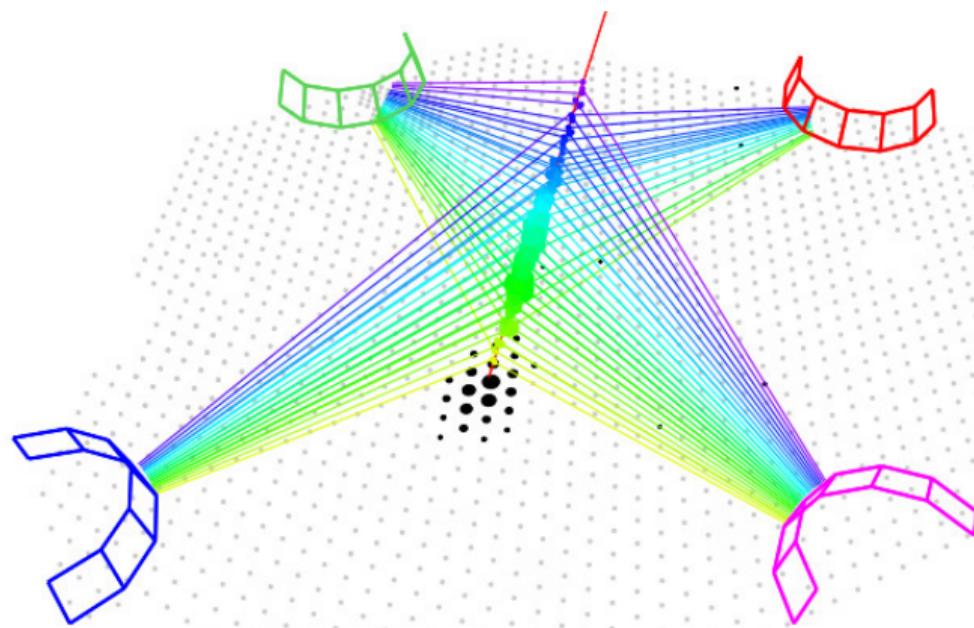
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adapted from M.Unger

Hybrid detector and energy estimation



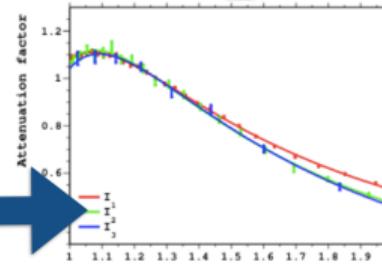
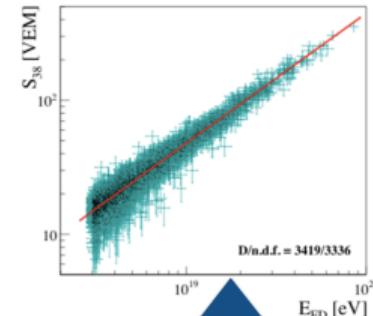
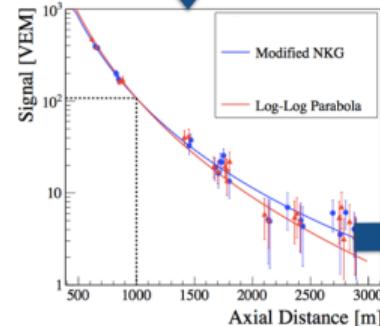
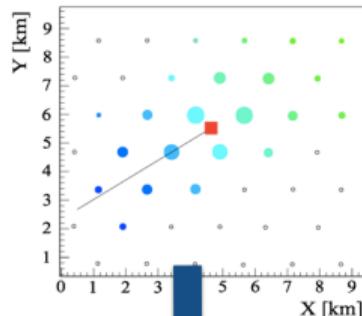
Hybrid detector and energy estimation



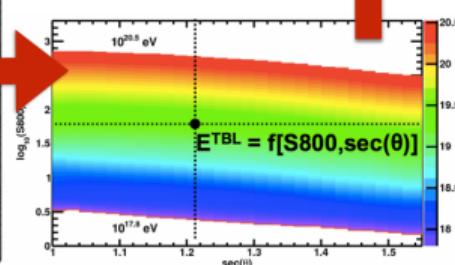
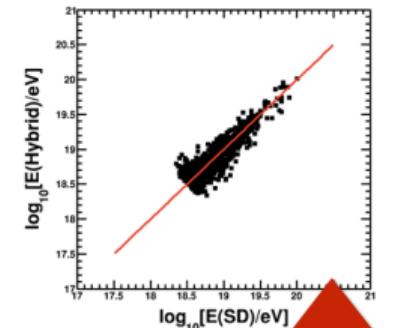
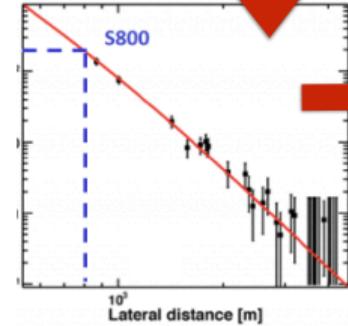
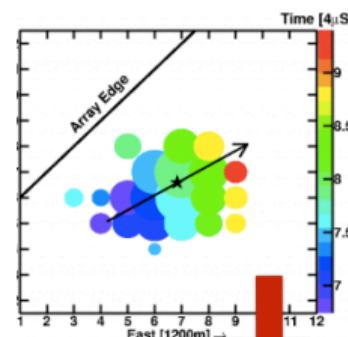
$$E_{FD} = \int dE/dX + \text{invisible energy correction}, E_{SD} = f(\theta, S_{1000})$$

Energy conversion for the surface detector

Auger: S1000 → CIC → E_{FD}



Telescope Array: S800 → E_{MC} → E_{FD}



adapted from O.Deligny

Energy spectrum this talk

Arrival directions Peter Tinyakov

Mass composition Michael Unger

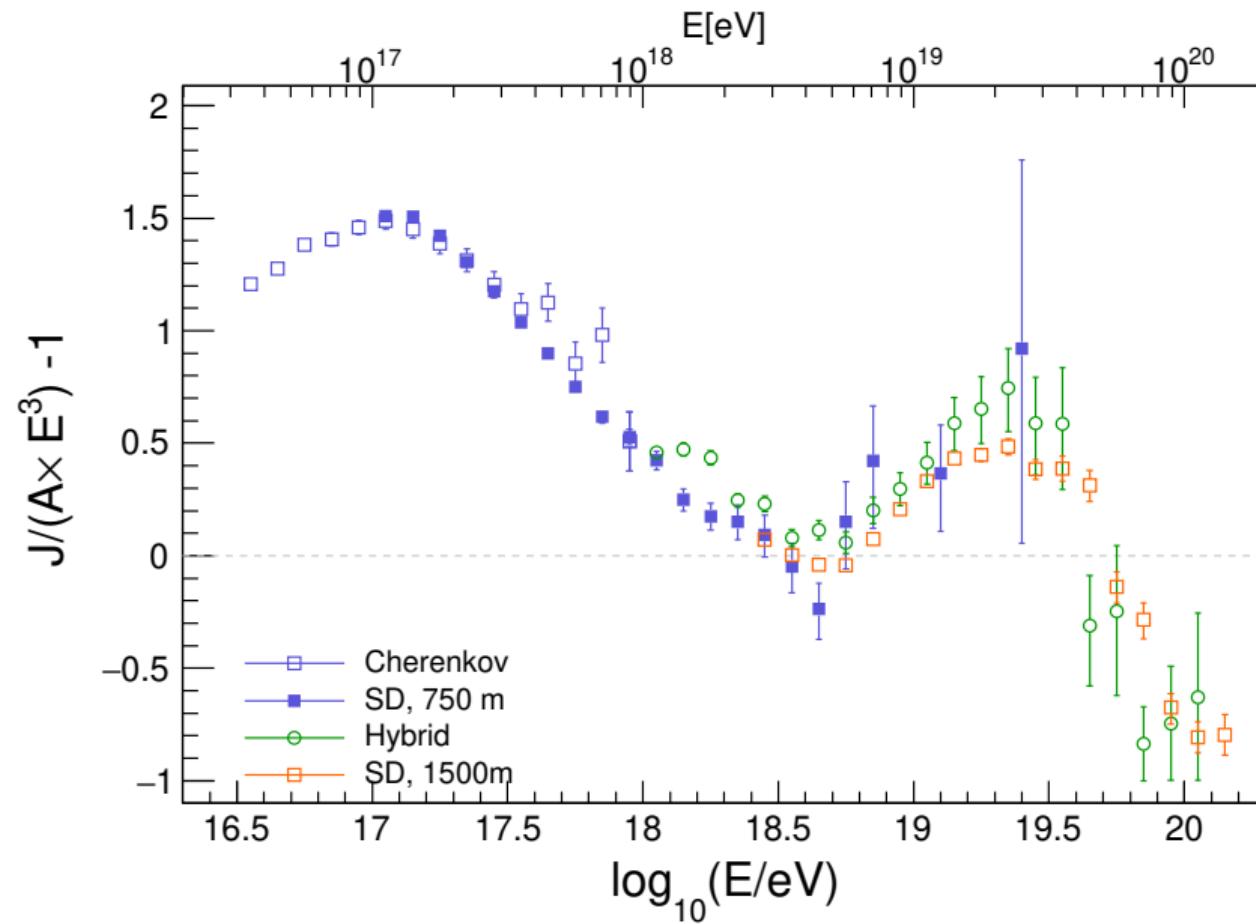
Photons and neutrinos this talk

Muon number Michael Unger

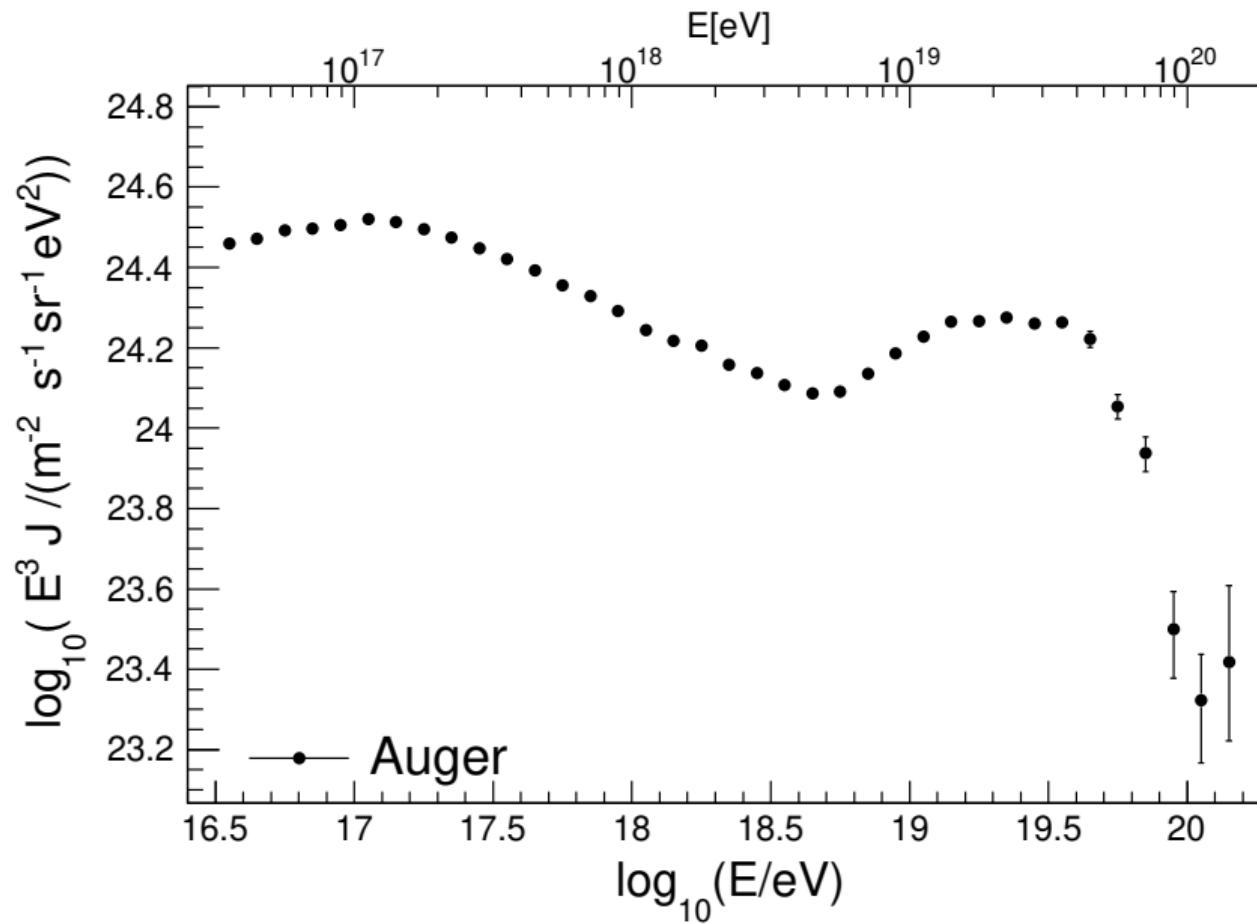
p-p cross-section Michael Unger

Not included: monopoles limits, radio measurements, elves, ...

Energy spectrum

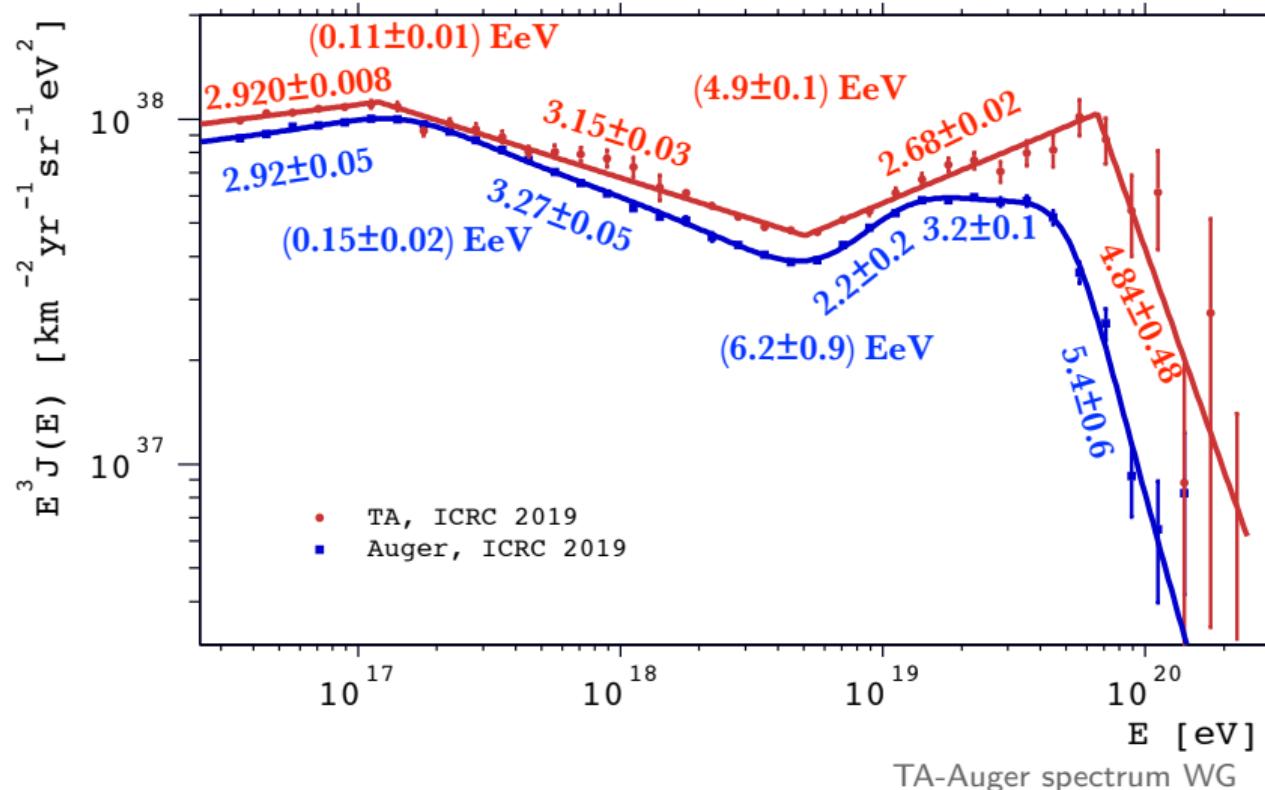


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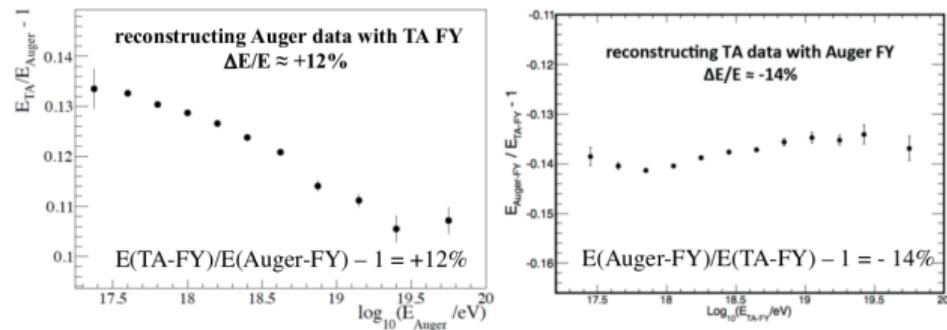
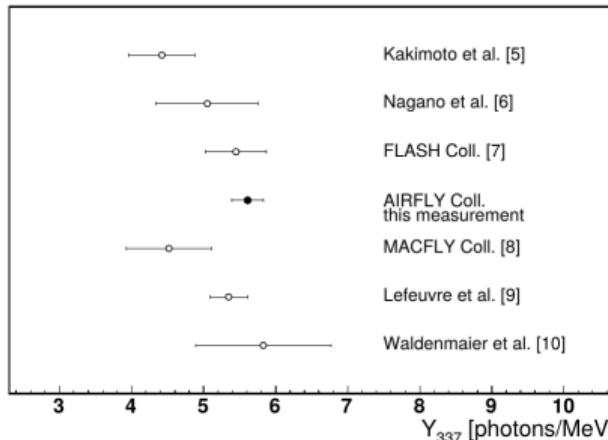


Spectral features

Detailed studies
needed to
understand the
differences



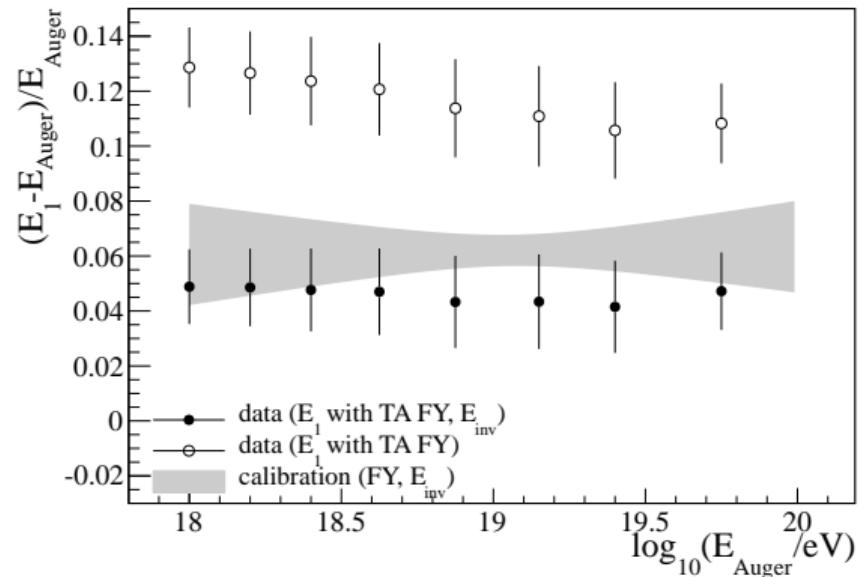
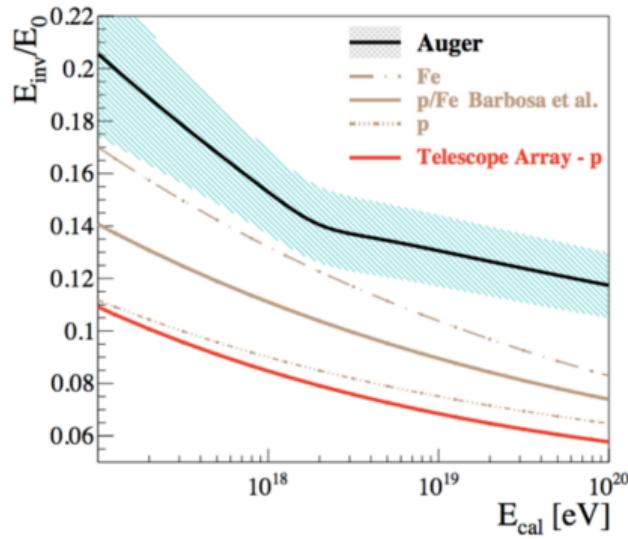
Fluorescence yield and invisible energy



	$E(TA-FY)/E(Auger-FY) - 1$	$E(Auger-FY)/E(TA-FY) - 1$
Auger	+12%	-11%
TA	+16%	-14%

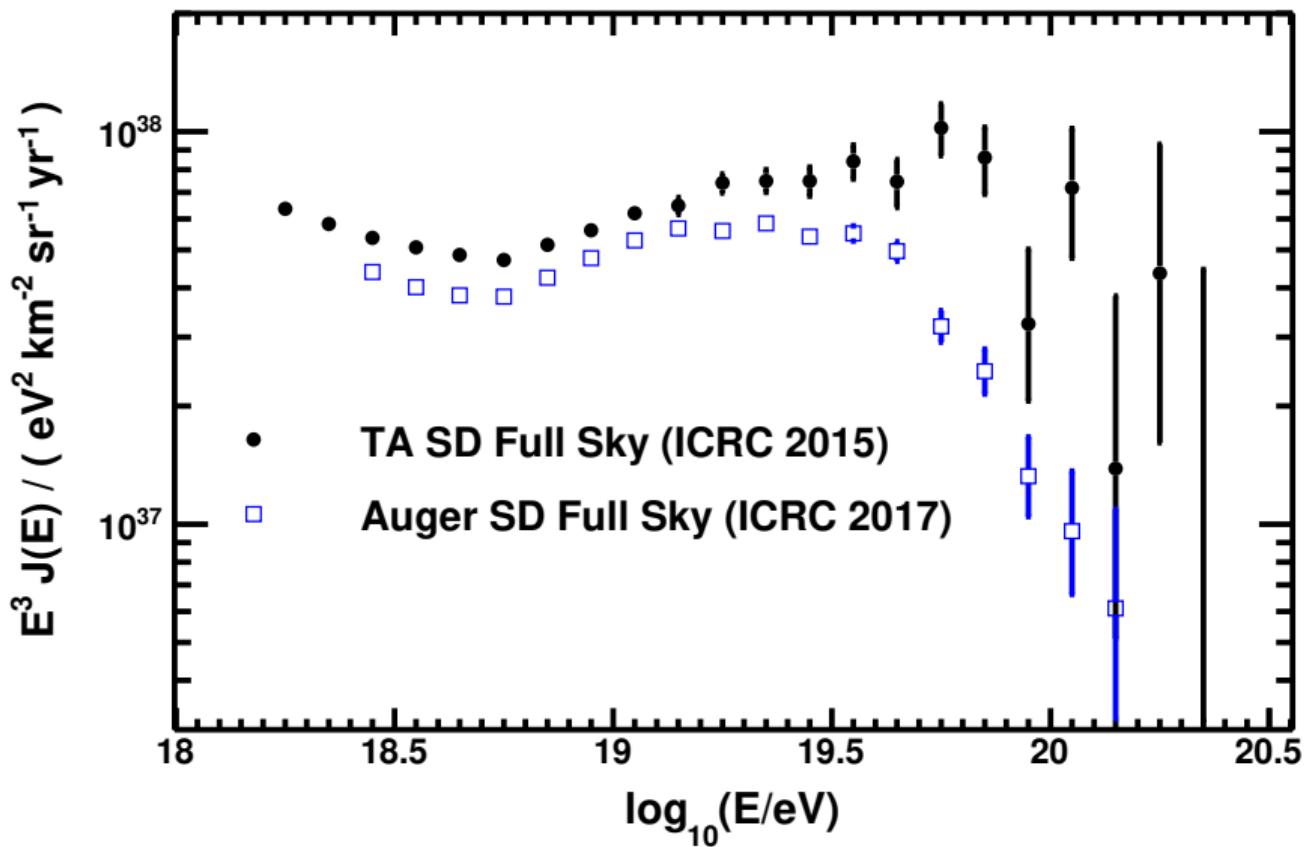
- Auger: AIRFLY (spectrum, absolute intensity, (p,T,h) dependency)
- TA: spectrum- FLASH, absolute intensity- Kakimoto, (p,T)- Kakimoto
- Total energy systematic budget: 14% Auger, 18% Telescope Array

Fluorescence yield and invisible energy

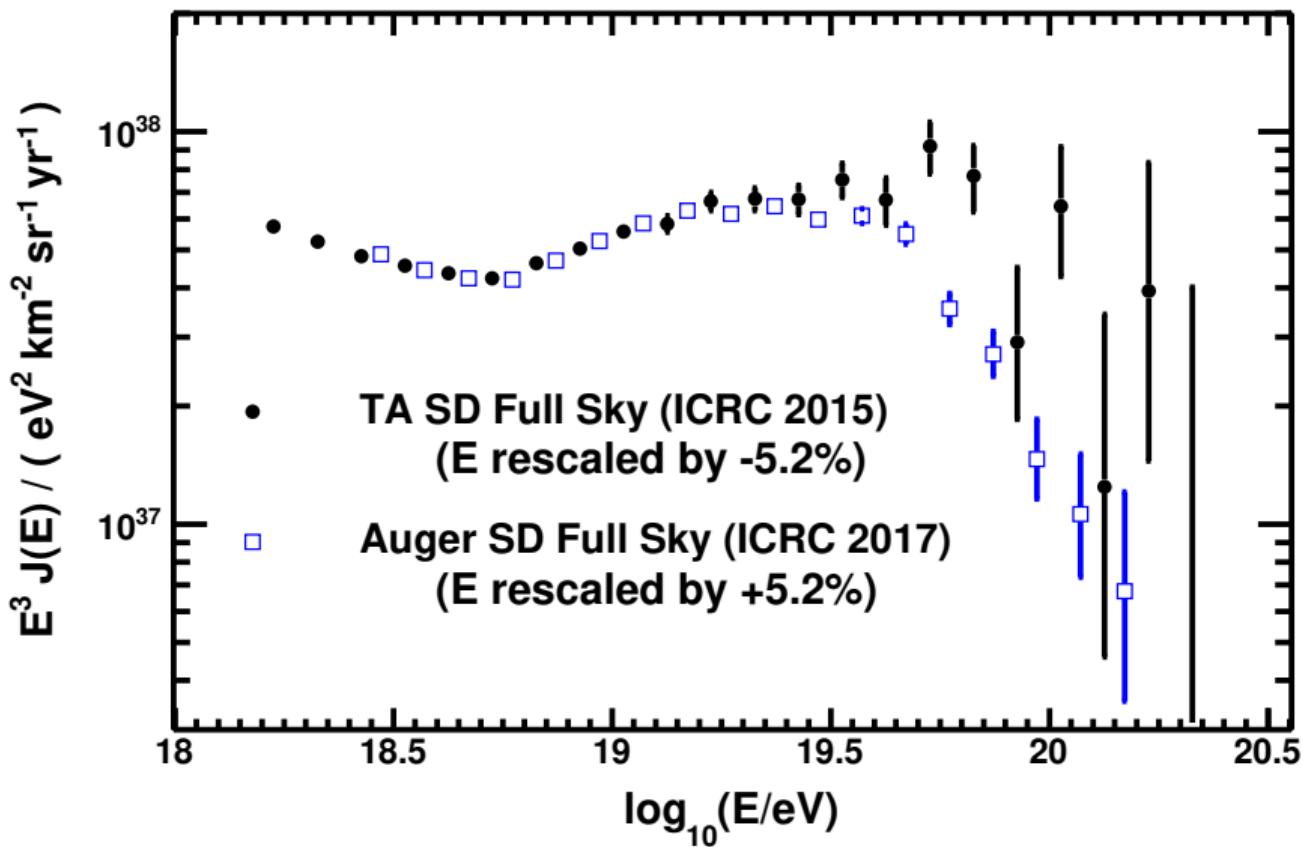


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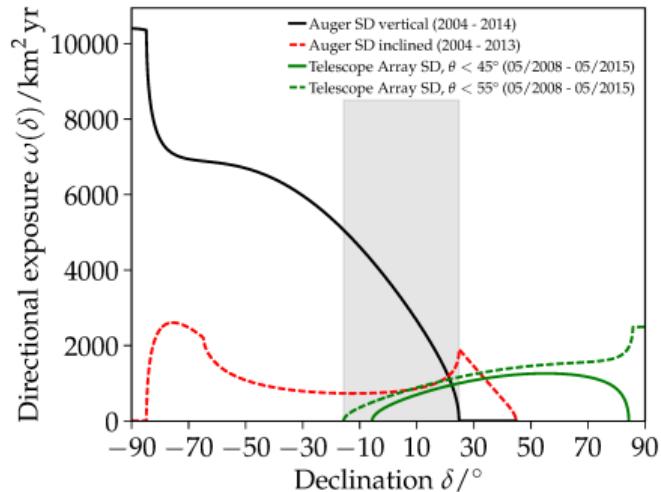
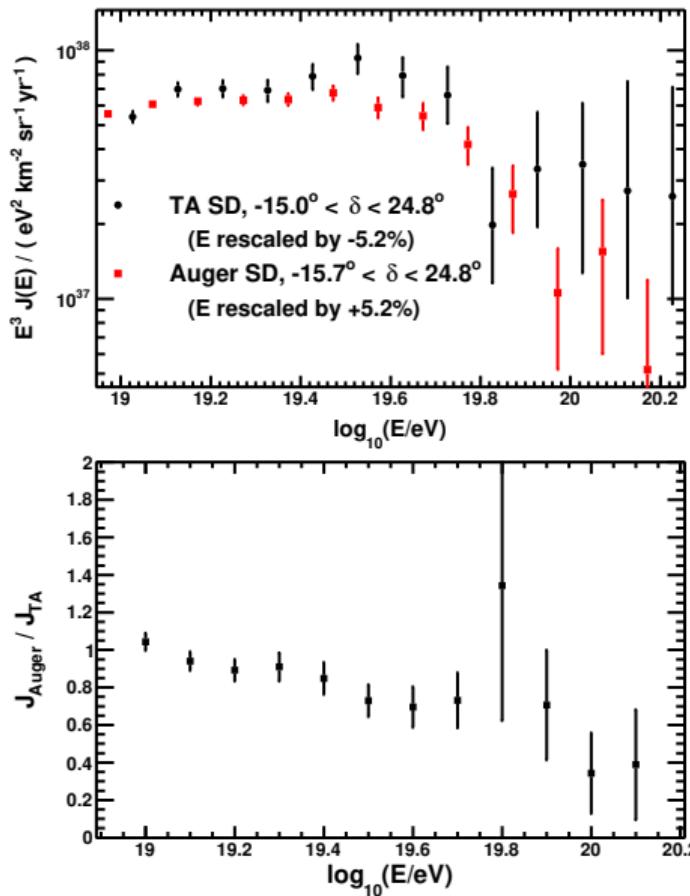
Comparison with Telescope Array



Comparison with Telescope Array

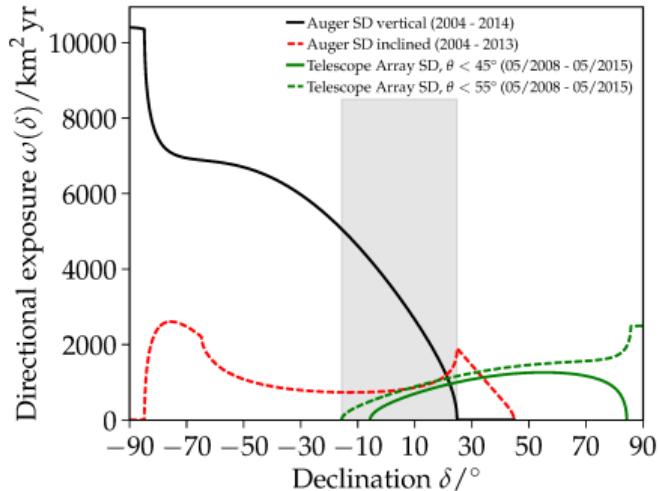
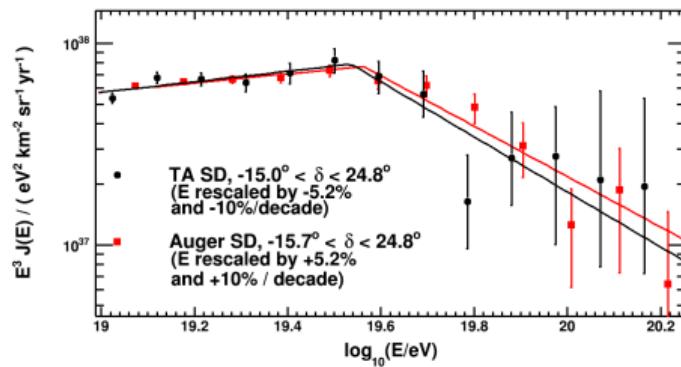
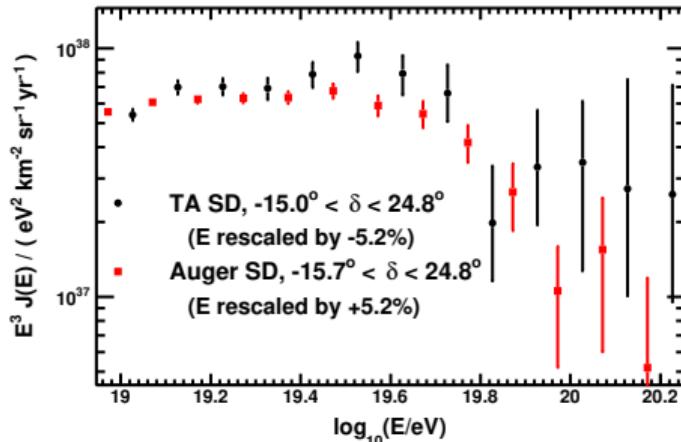


Looking at the same part of the sky



- slightly better agreement, but an energy dependent difference still present
- 10% per decade energy systematic uncertainty not understood

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Energy dependent systematics

TA

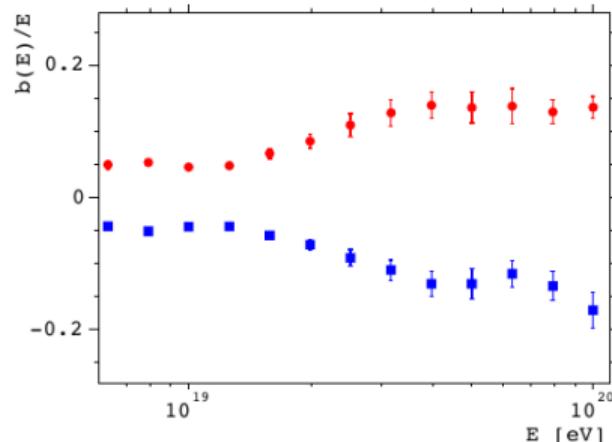
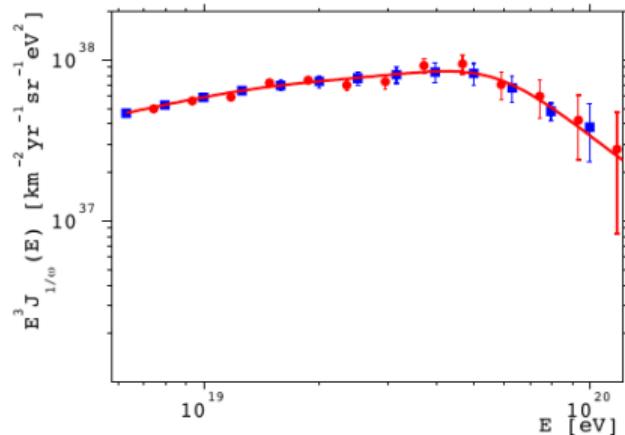
Source of nonlinearity	Amount (% per decade)
FD Invisible energy	$1\% \pm 1\%$
FD Fluorescence yield	$-1\% \pm 1\%$
FD Aerosols	$1.7\% \pm 1\%$
SD and FD comparison	$-2\% \pm 9\%$
Net	$-0.3\% \pm 9\%$

Source of nonlinearity	Amount (% per decade)
Aerosols	$\pm 1\%$
Calibration	$\pm 1\%$
SD and FD comparison	$\pm 2\%$
Constant Intensity Cut	$\pm 2\%$
Net	$\pm 3\%$

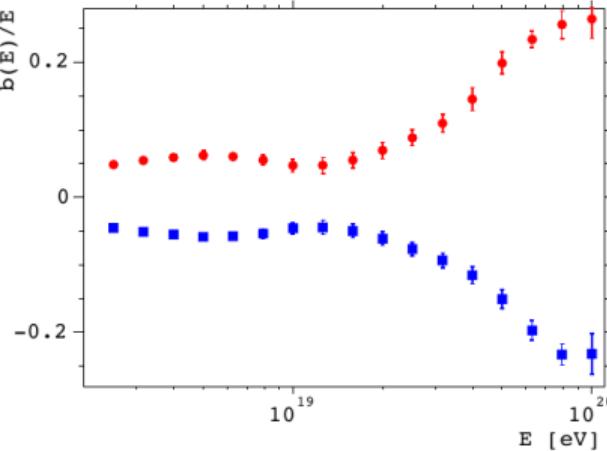
Auger

The known systematic uncertainties cannot account for a 10% /decade shift

Quantifying better the non-linearities in the common and full sky spectras



Full sky



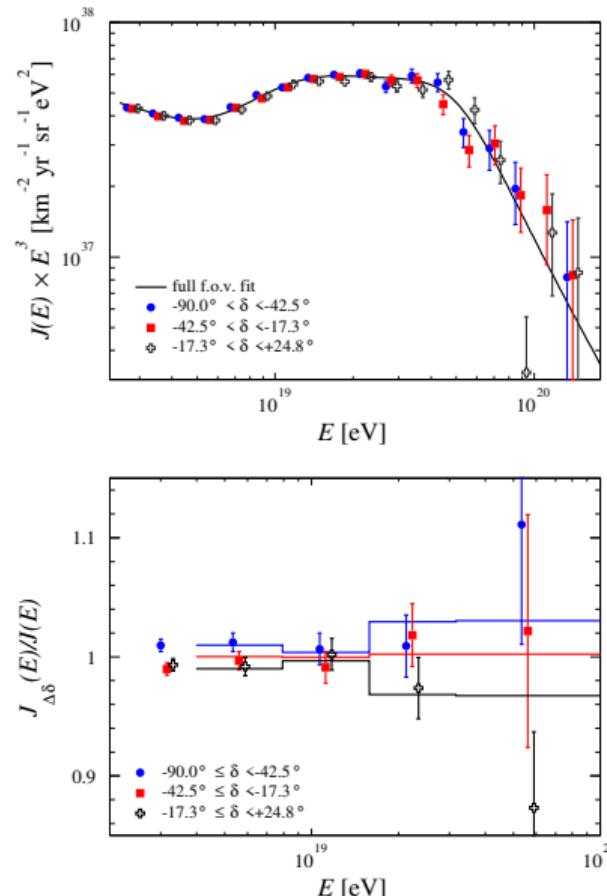
Needed energy shift for scaling Auger to TA

Needed energy shift for scaling TA to Auger

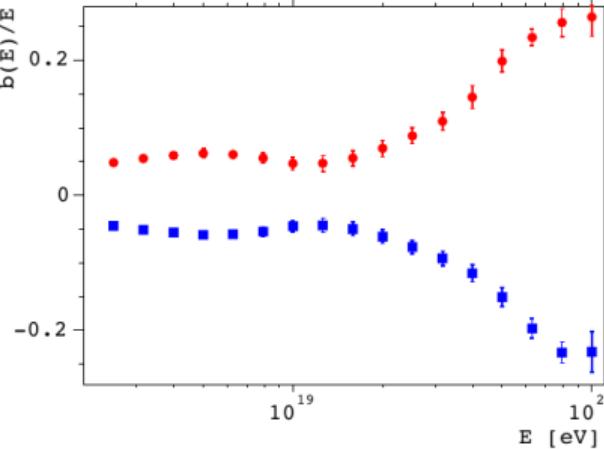
Better agreement in the common declination band

Constant factor of about 10% up to 10 EeV
switching to 20% at 100 EeV

Quantifying better the non-linearities in the common and full sky spectras



Full sky



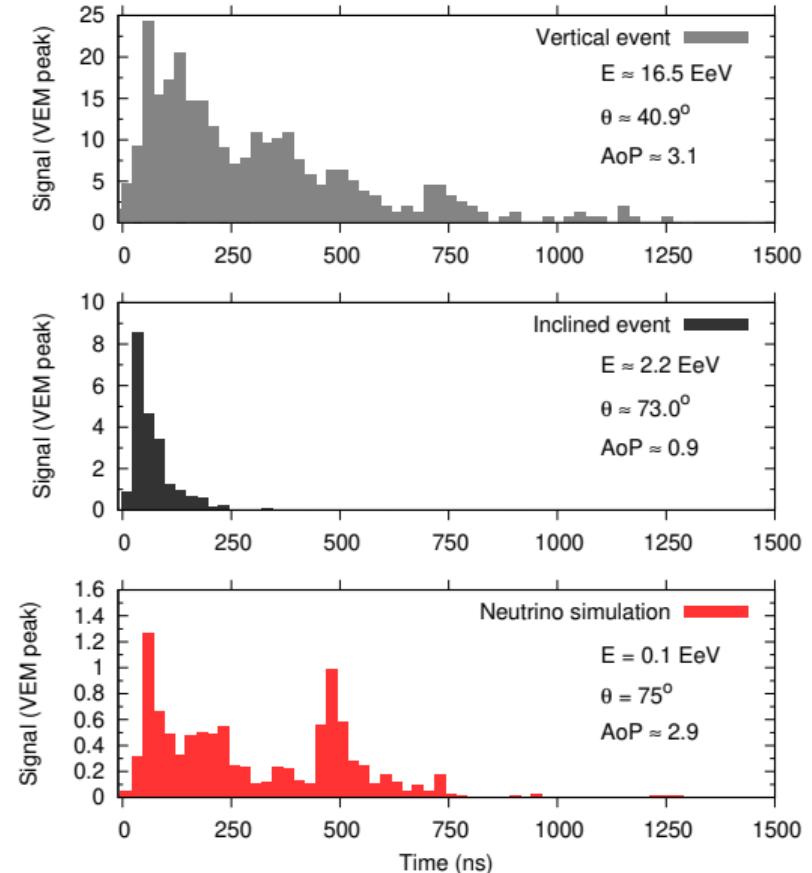
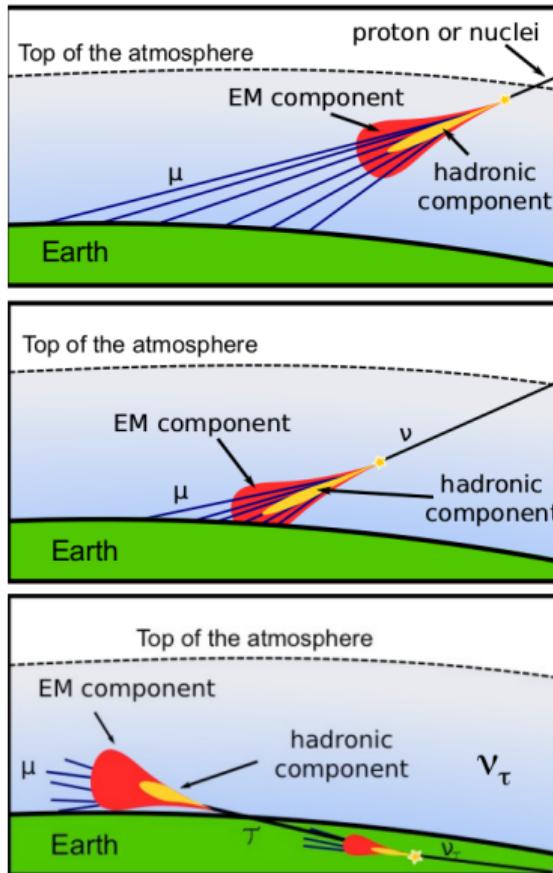
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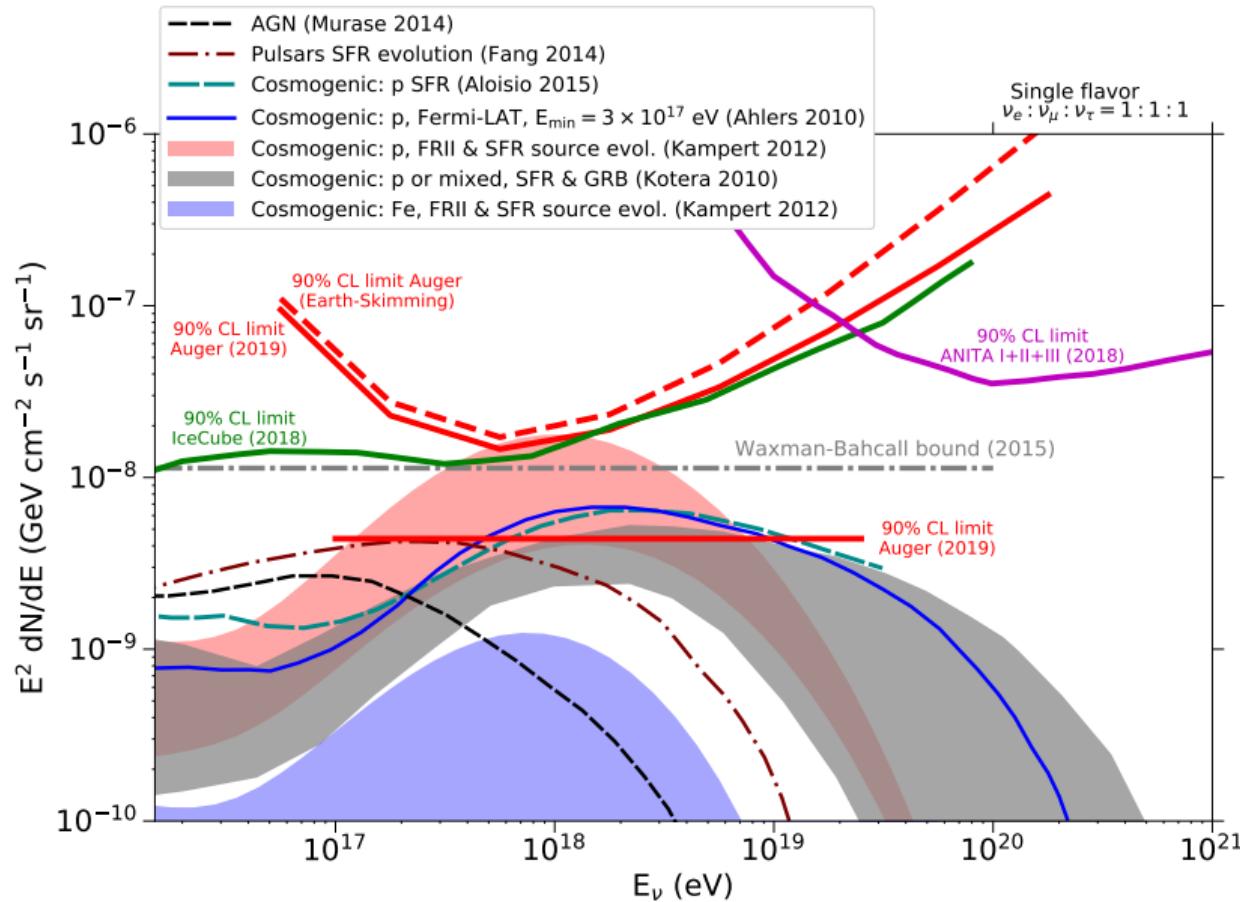
Auger: just the expected difference from large scale
anisotropy

How to detect neutrinos?

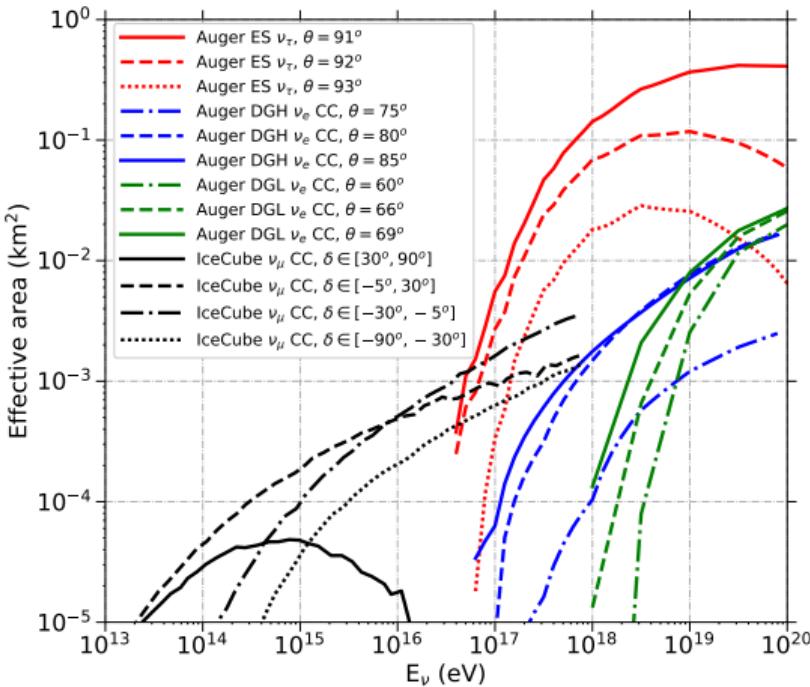
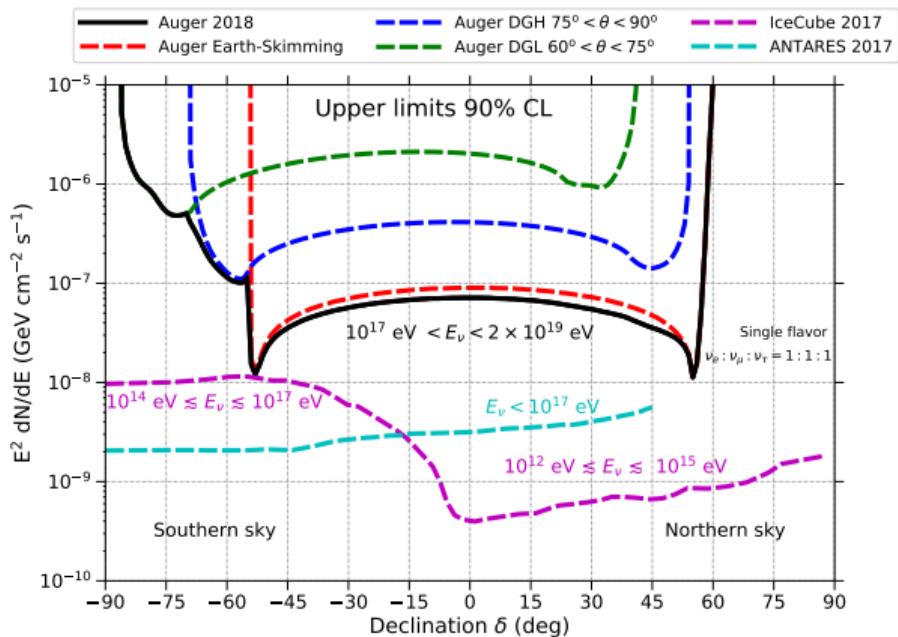


⇒ Inclined air-showers with large e.m. component (young)

Neutrino limits



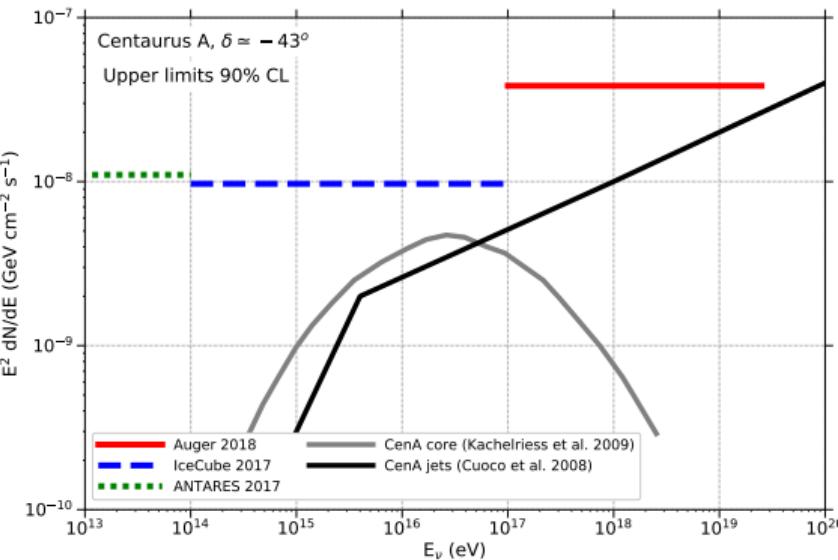
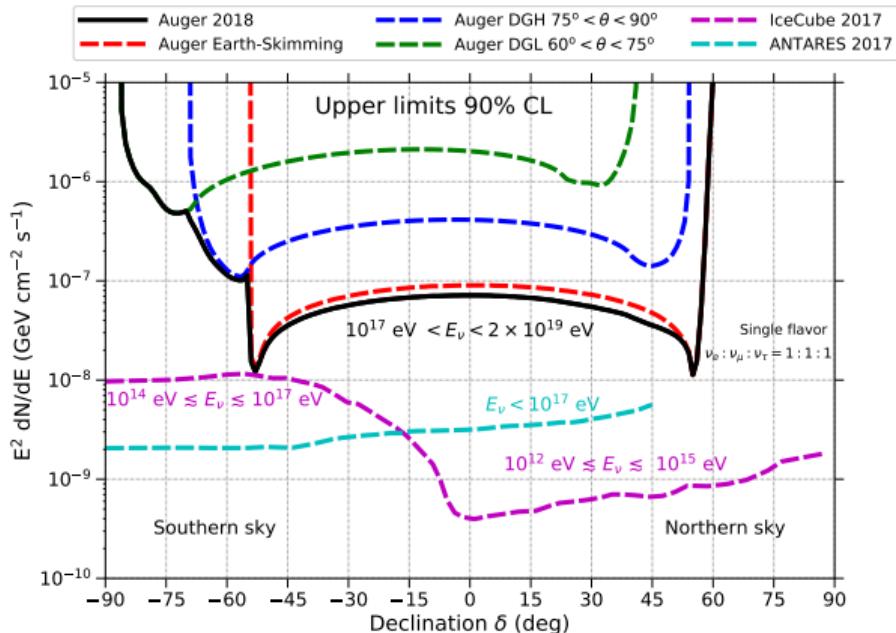
Limits on point-like neutrino sources



No neutrinos identified (data period January 2004 to 31 August 2018)

Unmatched sensitivity to potential sources of EeV neutrinos in the Northern terrestrial hemisphere

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Summary

Continuous collaboration between the Telescope Array and Auger (working groups)

Energy scale and energy spectrum

- For the second knee a very good agreement (to be combined also with other experiments)
- Matching of the ankle by a 5.2% shift in energy
- Nonlinearity of about 10%/decade above 10 EeV not identified
- Future studies needed: Auger@TA, AugerPrime, TA \times 4

Sensitivity also to neutral particles: the ultra high energy neutrinos and photon