UNIVERSITÀ DEGLI STUDI DELL'AQUILA

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

Latest Results from the Pierre Auger Observatory

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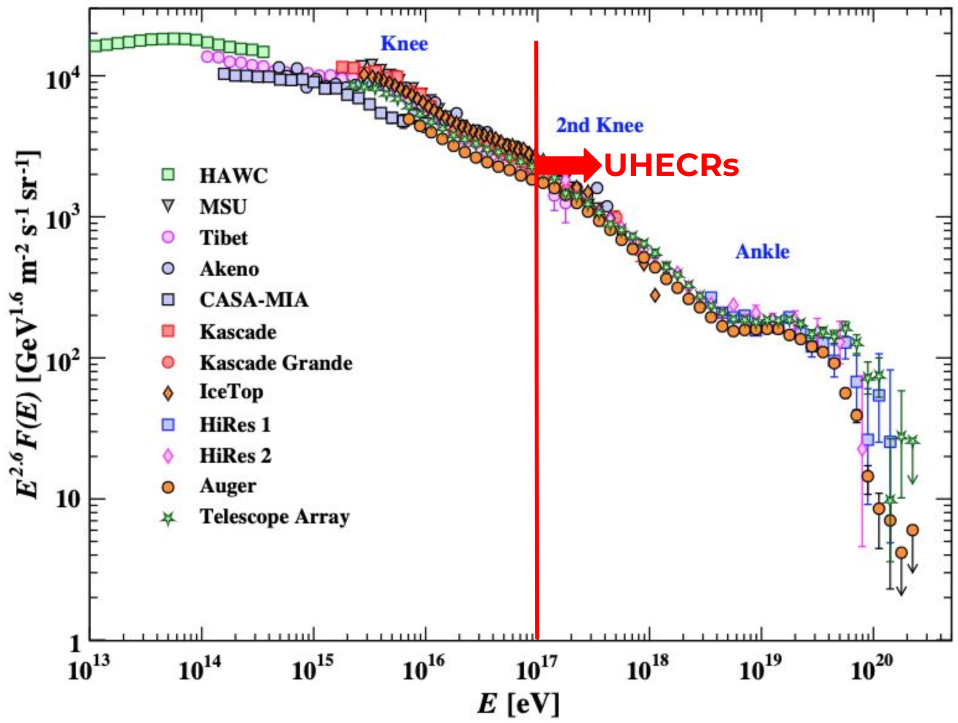
University of L'Aquila and INFN LNGS

International conference PUMA22 - Probing the Universe with Multimessenger Astrophysics
23-30 September 2022, Sestri Levante

The Strange Science Case of the Ultra High Energy Cosmic Rays

Particles with E = 10^{17}-10^{20} eV , $\sqrt{s}$ = 14-450 Tev



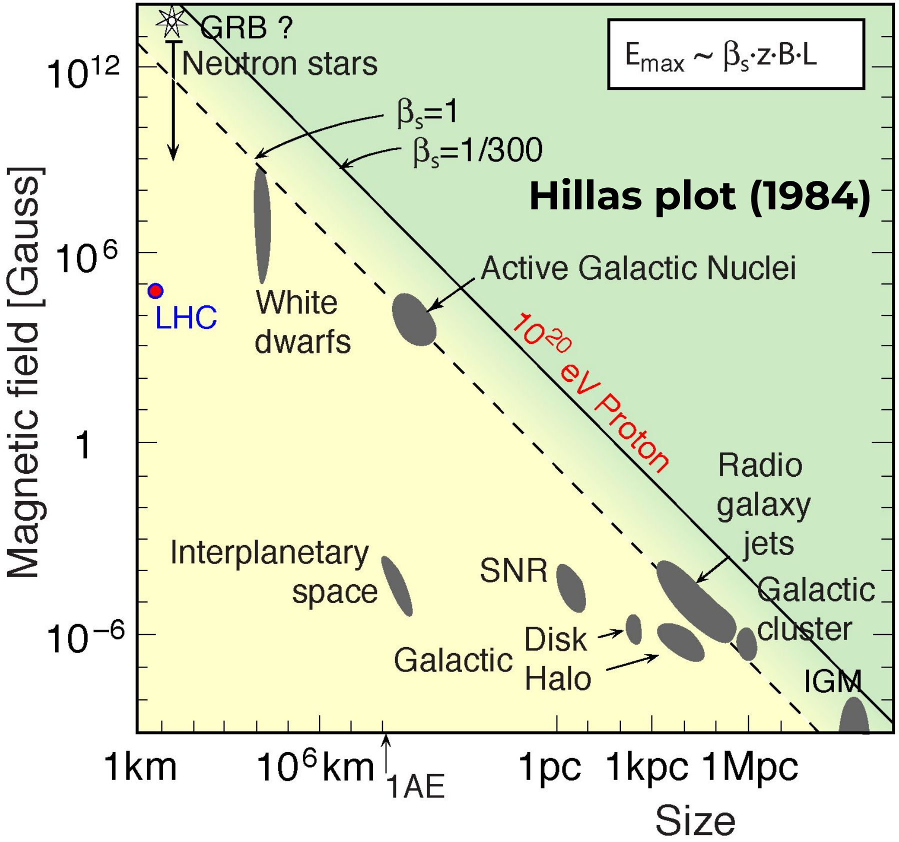
ASTROPHYSICS

- What is the nature and origin of UHECRs?
- What is causing the suppression of the flux at the highest energies?
- Which are the sources? can we perform UHECRs astronomy?
- How are UHECRs accelerated to such extreme energies?

FUNDAMENTAL PHYSICS

- Tests of fundamental interactions and their models in extreme energy regimes
- Constrain or find hints of new phenomena (e.g. Lorentz invariance violation)

How are UHECR produced?



With LHC technology need accelerator of size of Mercury's orbit to reach 10^{20}eV

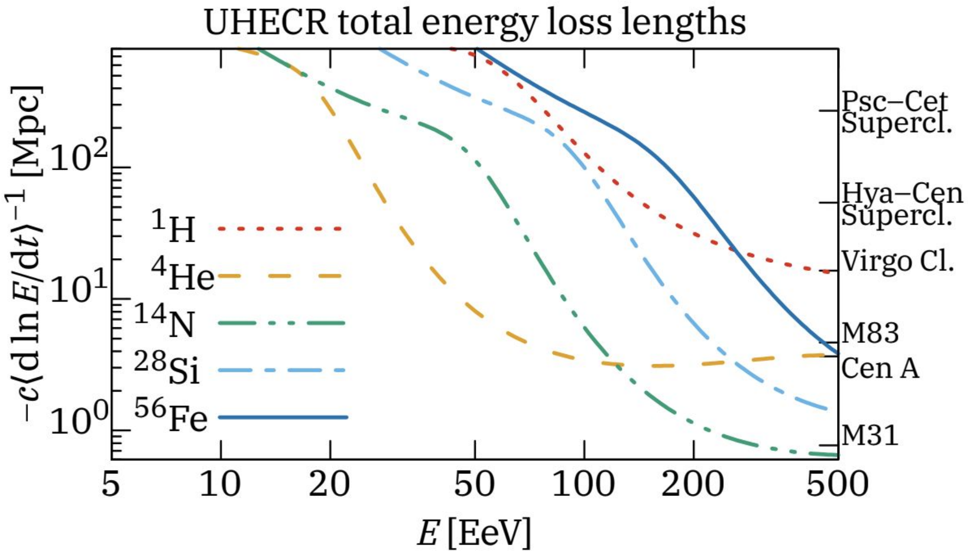
<u>Realistic constraints more severe</u>

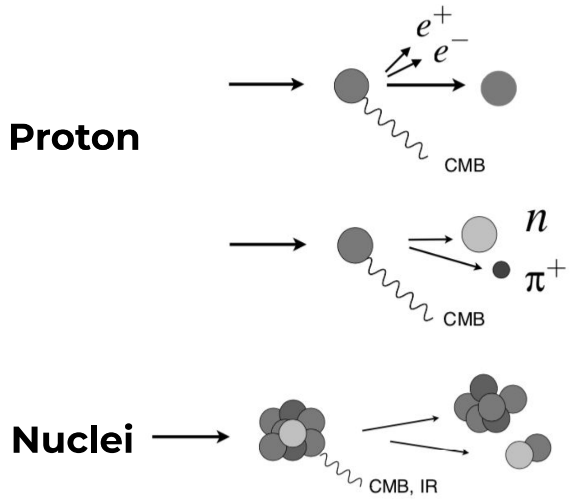
- small acceleration efficiency
- synchrotron & adiabatic losses
- interactions in source region

How they reach Earth?

Processes during extragalactic cosmic ray propagation

- Adiabatic energy losses due to the expansion of the Universe
- Interactions with photon backgrounds:
  - Pair production (Cosmic microwave background)
  - Disintegration (Extragalactic background light)
  - Pion production

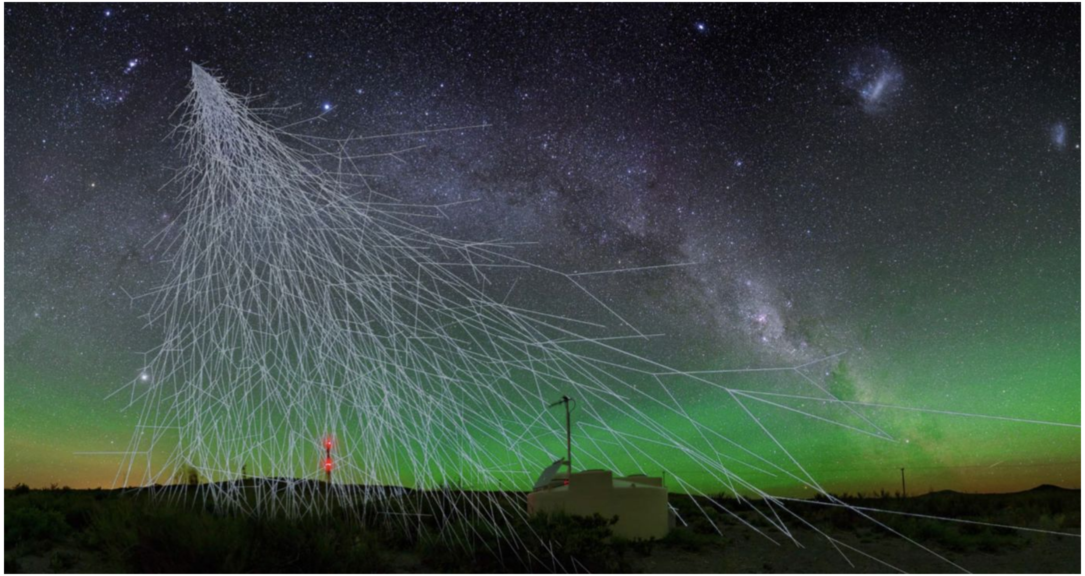


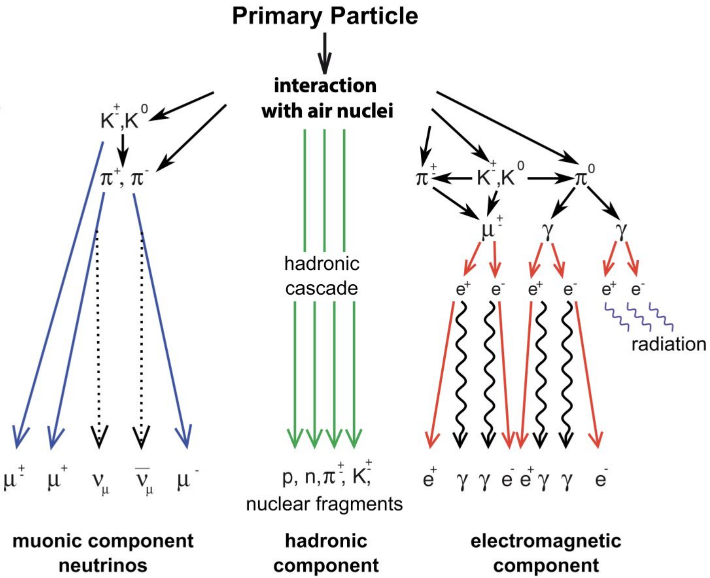


- NO He >50 EeV, CNO > 100 EeV expected
- Extreme-E CRs can only be: local, &/or protons, &/or heavy nuclei
- source or propagation scenario?
  Composition at the highest energies and the detection of cosmogenic neutrino and/or photons is of key importance

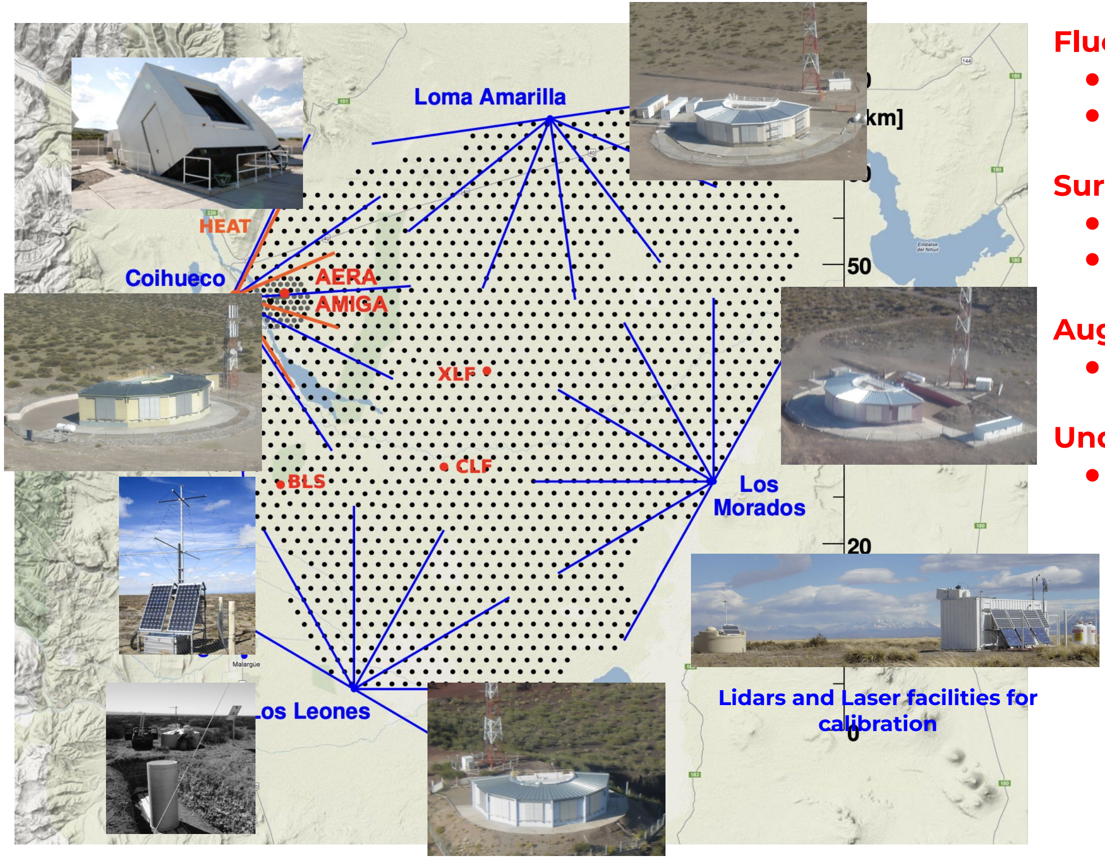
How to measure UHECRs?

- Due to the low flux of UHECRs (1 particle per km^2 yr^{-1} above 10^{19} eV) we need huge instrumented areas for detection
- UHE particles interacting with atmosphere (mainly N and O) initiate a cascade of ionised particles and electromagnetic radiation i.e extensive air shower (EAS)
- 3 components: muonic, hadronic, electromagnetic





The Pierre Auger Observatory



Fluorescence detector (FD)

- 24 telescopes in 4 sites, FoV: 0-30°, E>10^{18} eV
- HEAT (3 telescopes), FoV: 30 - 60°, E>10^{17} eV

Surface detector (SD)

- 1660 stations in 1.5 km grid, 3000 km^2 E > $10^{18.5}$ eV
- 61 stations in 0.75 km grid, 23.5 km^2,E > $10^{17.5}$ eV

Auger Engineering Radio Array (AERA)

- 153 antennas in 17 km2 array

Underground muon detector

- 17 buried scintillators

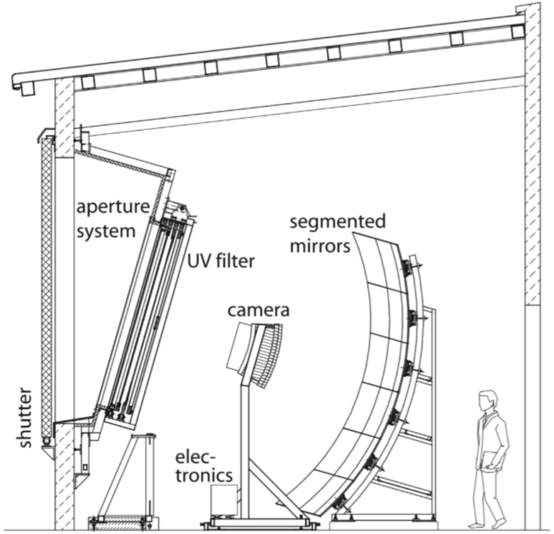
Auger Phase I data taking from 2004 on (from 2008 with the full array):

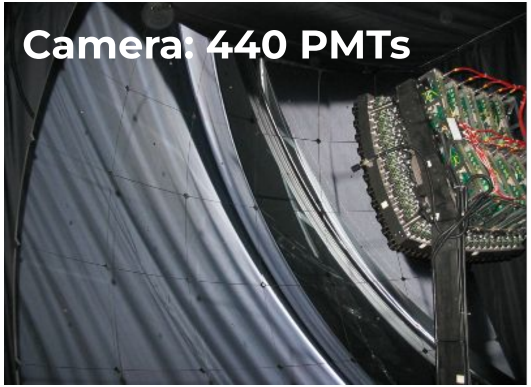
- > 120.000 km^{2}sr yr for anisotropy
- > 90.000 km^{2}sr yr for spectrum

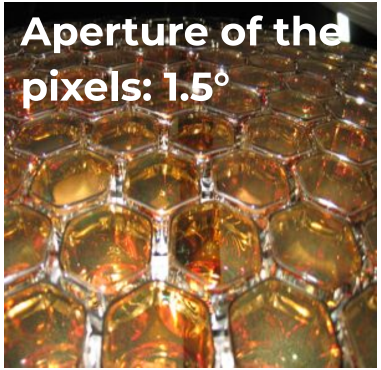
Auger Phase II data taking from 2023 to 2030...

- Multiple detectors
- UHECR detector test bench facility

Fluorescence Detectors

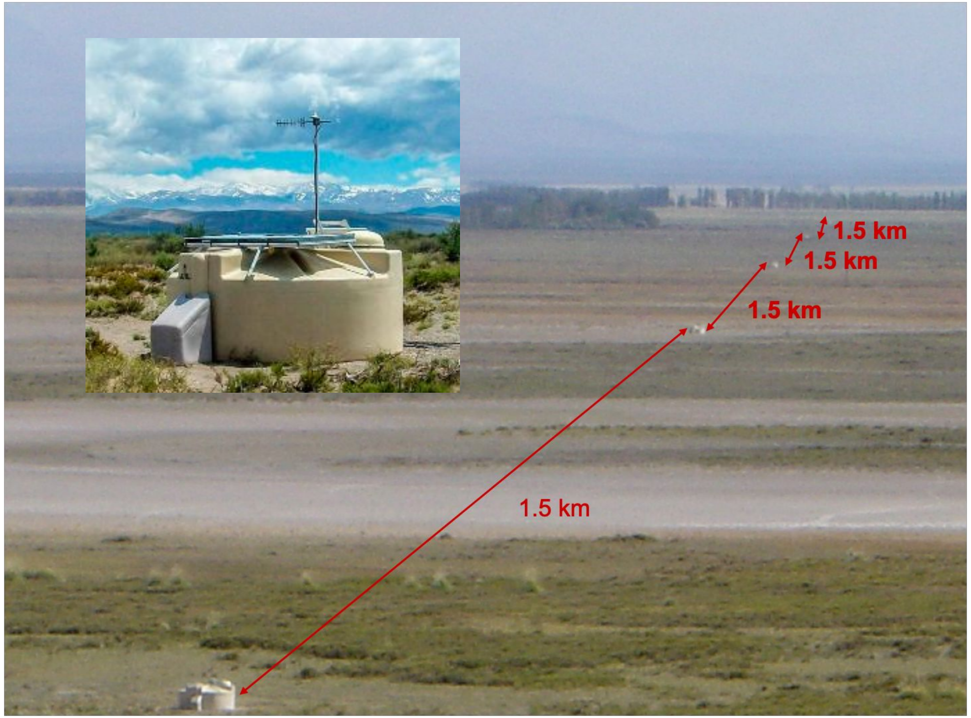


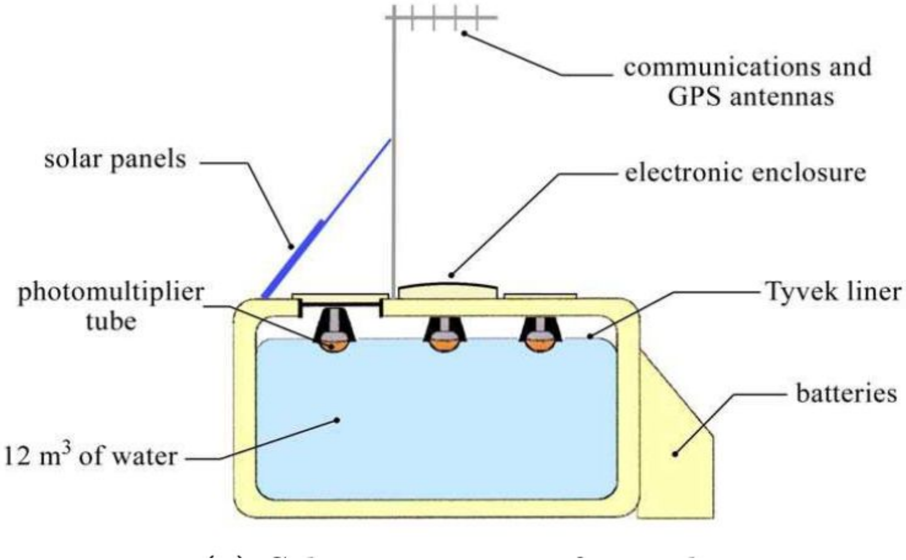




- FD measures the fluorescence light produced by the excitation of nitrogen in the atmosphere by the EAS particles
- 30° fov in elevation and azimuth for each telescope
- ~14% duty cycle (data taking during moonless clear nights)

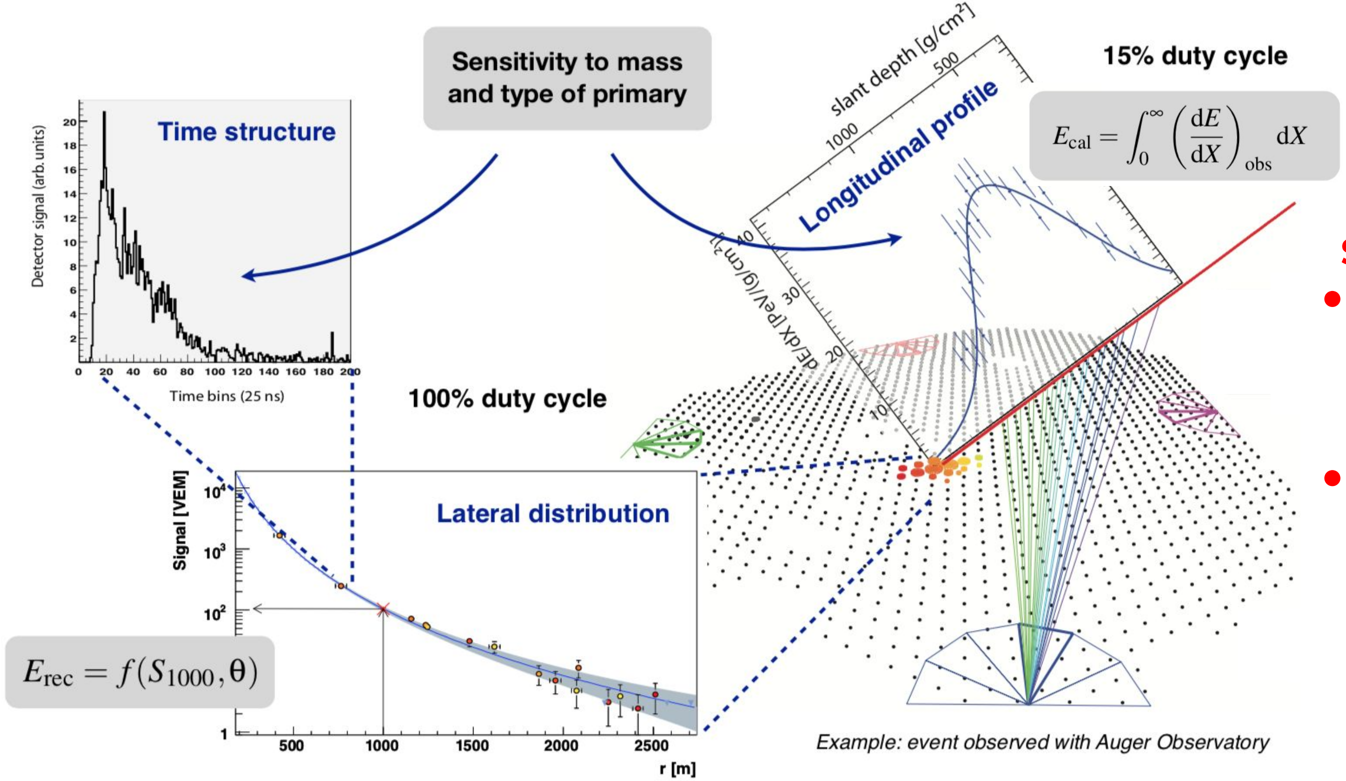
Surface detectors





- SD measure the Cherenkov light produced in water by EAS particles at ground
- ~100% duty cycle

The hybrid concept



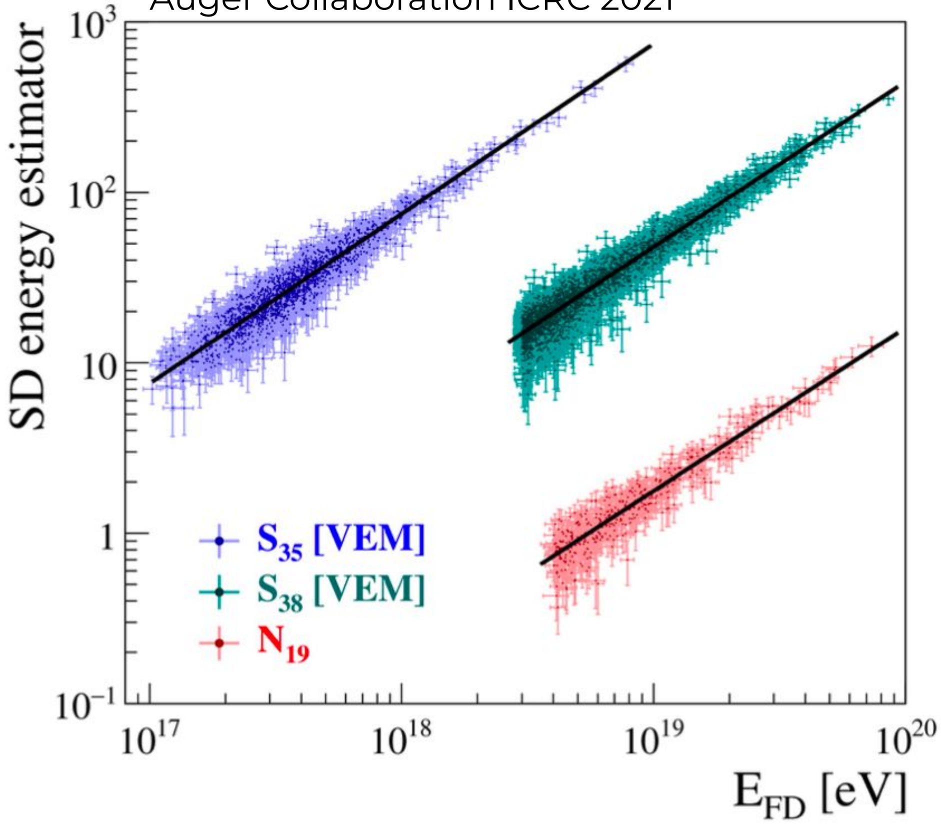
Example: event observed with Auger Observatory

STRATEGY

- Measure the same air showers with 2 independent detectors (golden hybrid events)
- use golden hybrids to calibrate the entire SD data sample

Calibration with FD energy scale

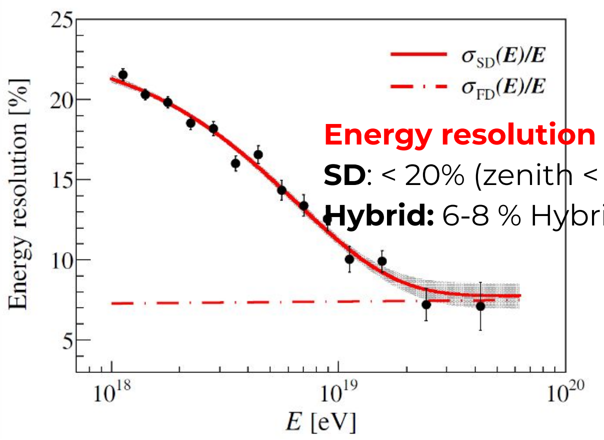
Auger Collaboration ICRC 2021



Energy scale uncertainty

ICRC 2013

Fluorescence yield	3.6%
Atmosphere	3.4% – 6.2%
FD calibration	9.9%
FD profile recon.	6.5% – 5.6%
Invisible energy	3% – 1.5%
Stability of energy scale	5%
TOTAL	14%

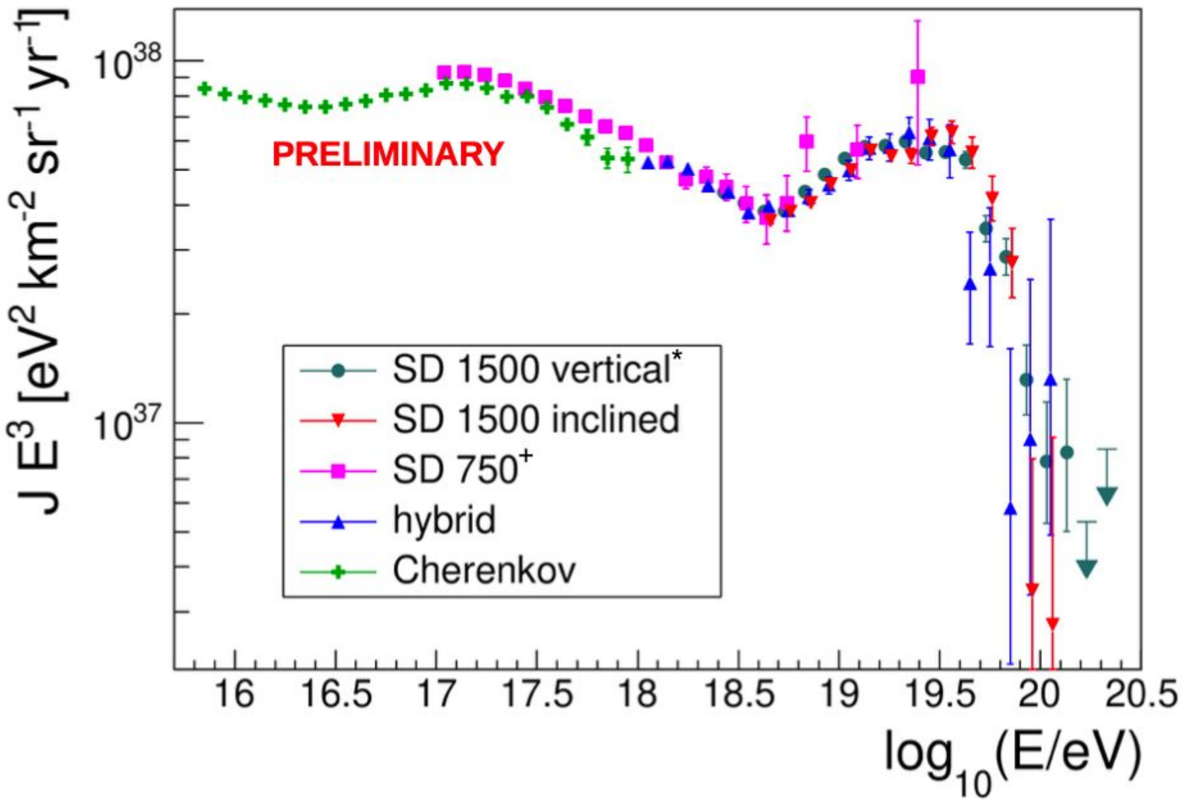


Energy resolution

SD: < 20% (zenith < 60° and E > 2.5 EeV)

Hybrid: 6-8 % Hybrid [ICRC 2019]

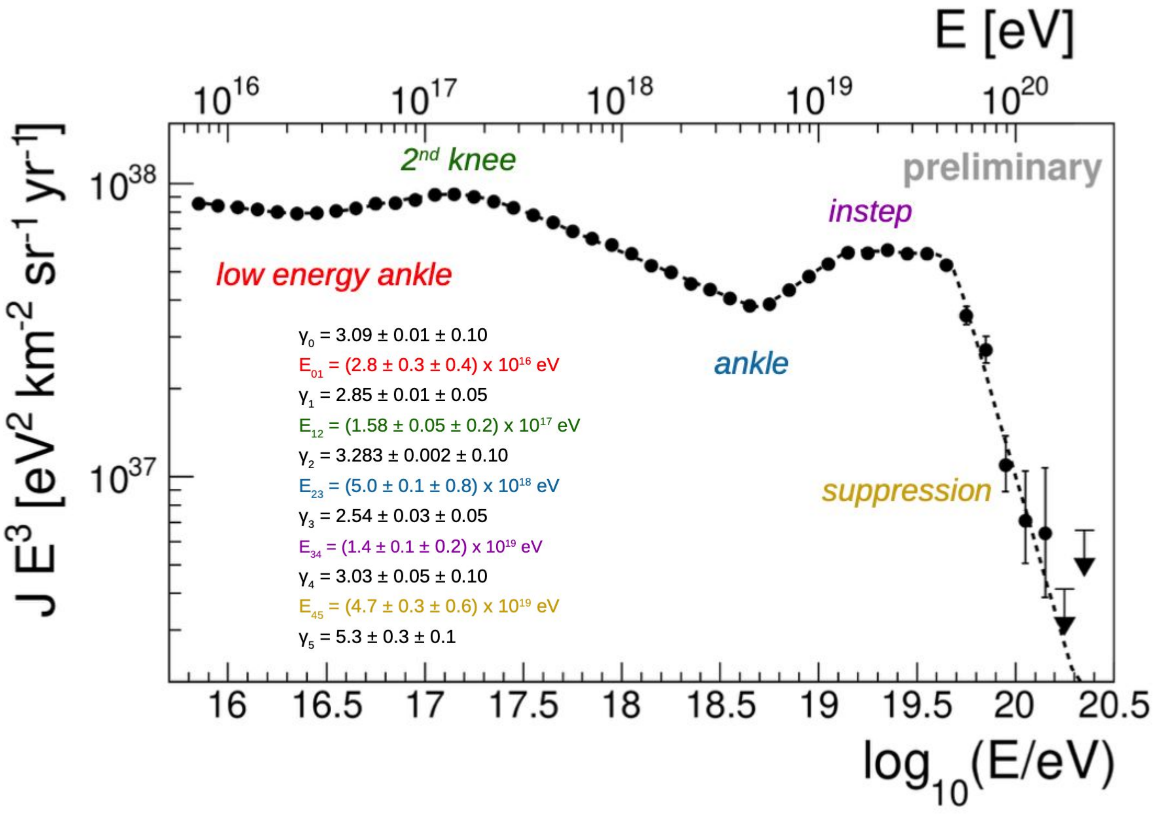
The Auger energy spectrum



SD Data sample:
215030 events 1/1/2004 – 31/8/2018
Exposure: 60400 km^2 sr

- Five measurements
- more than 3 order of magnitudes
- same energy scale
- Fluxes in agreement within systematic uncertainties (1%-7%)

The energy spectrum



2nd knee observed

- different models: more than one Galactic component? (H4a, GST)
- is the 2nd knee the iron one? (rigidity dependent cut-off)

ankle at ~ 5 10^{18} eV confirmed

- dip model
- mixed models: superposition of heavier nuclei

Suppression at ~ 5 10^{19} eV confirmed

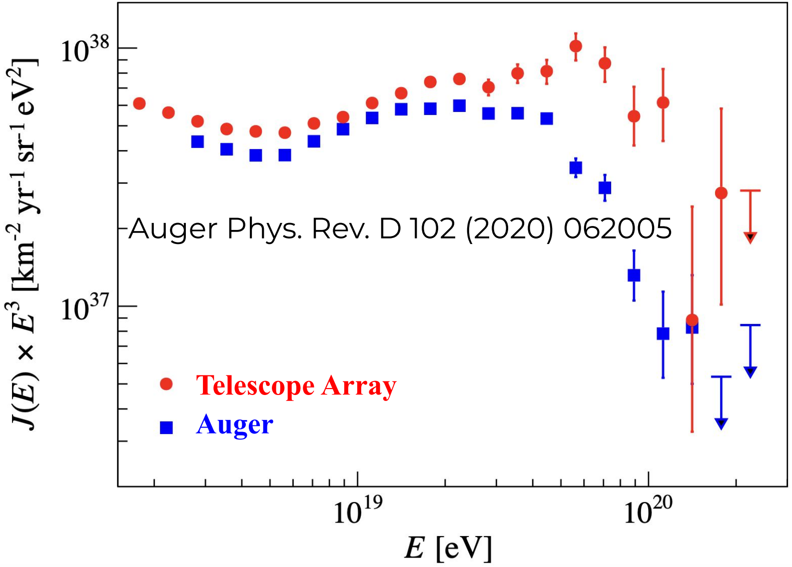
light composition (p + <10% heavier)
- soft injection spectrum (slope ~ 2)
- production of cosmogenic ν

mixed composition
- hard injection spectrum (slope ~ 1)
- cosmogenic ν and γ suppressed

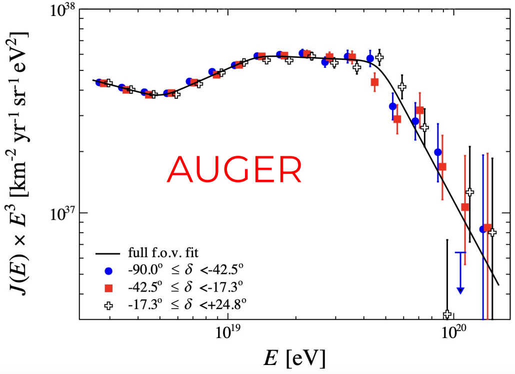
new feature instep at ~ 10^{19} eV identified

hint for low energy ankle at ~ 10^{17} eV

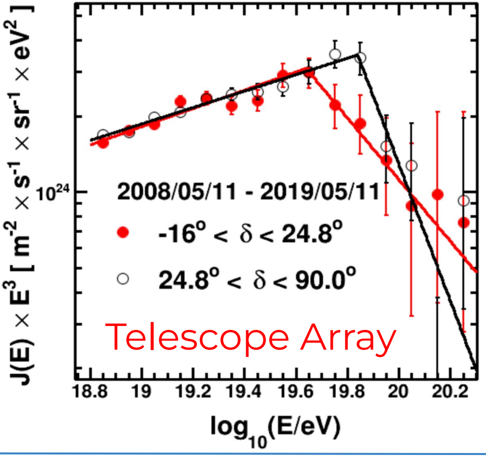
The energy spectrum in Auger and TA



DECLINATION DEPENDENCE



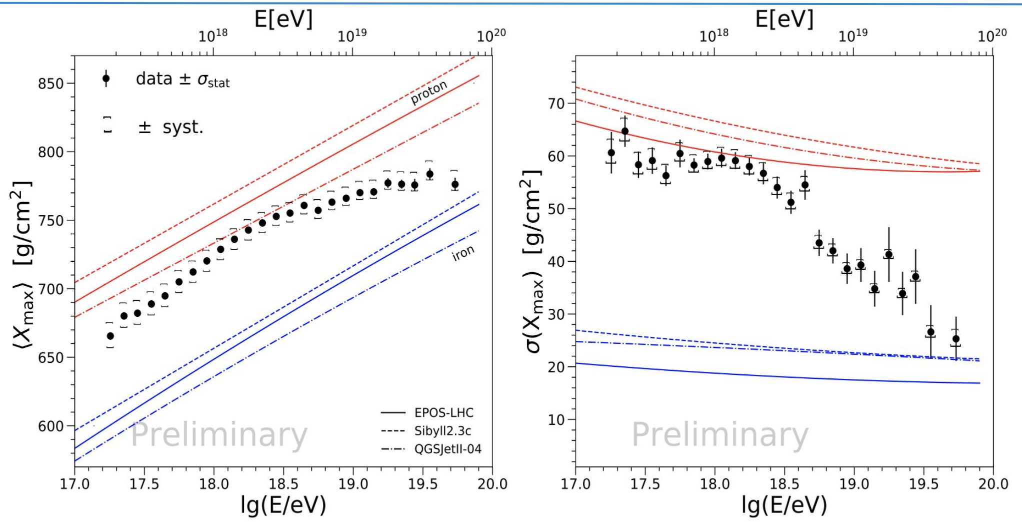
Auger: Only a trend for a slightly larger intensity in the South: consistent with dipole at E > 8 EeV



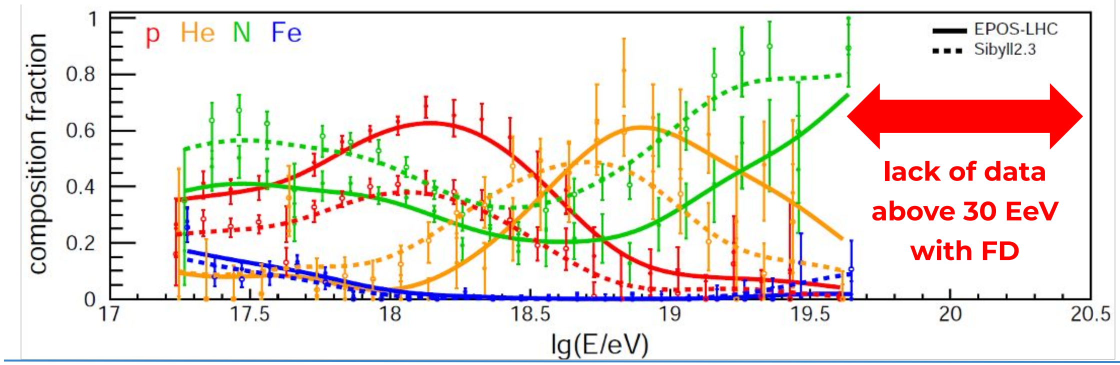
TA: Differences in the suppression energy, with an excess of intensity in the Northernmost sky

- Energy scale: different fluorescence yield and invisible energy models
- σ_{syst} on the two energy scales : **14% for Auger** and **21% for TA**
- **γ**0: is in agreement!
- 2nd knee position: within 1.8σ
- **γ**1: within 2.1σ
- general agreement rescaling the energies by **+5.2% for Auger** and **−5.2% for TA**

Mass composition



- change of slope of X_{max} and decrease of $\sigma(X_{max})$ across the ankle
- X_{max} and $\sigma(X_{max})$ indicate lighter composition up to ~2 EeV, heavier above this energy
- At higher energies, consistent with less mixed composition
- the uncertainties in the models are currently the main source of systematics

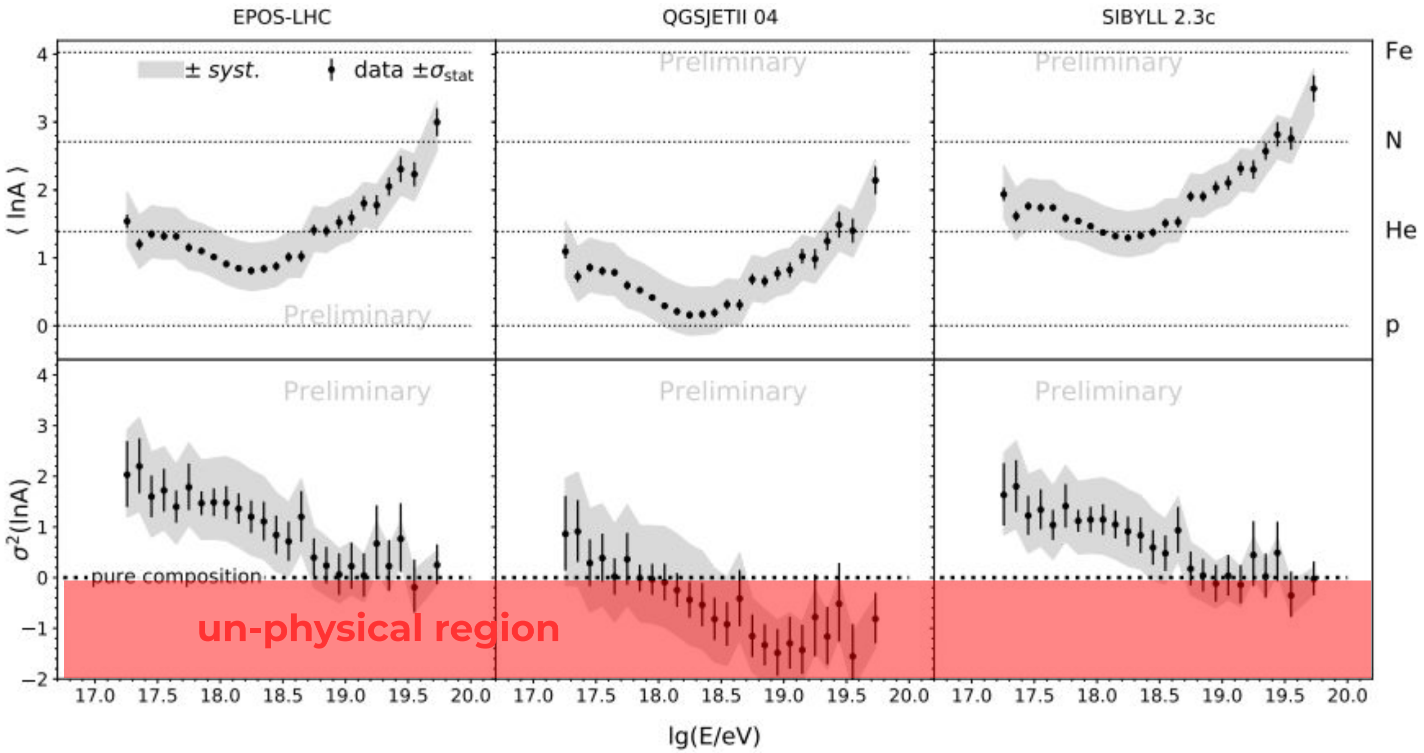


Mass fractions at Earth from fitting 4 mass groups to the measured X_{max} distributions

Front. Astron. Space Sci. 6 (2019) 23

<lnA> and variance

- Model independent trend in <lnA>
- Pure composition excluded below and around the ankle
- QGSJETII04 is in tension with data

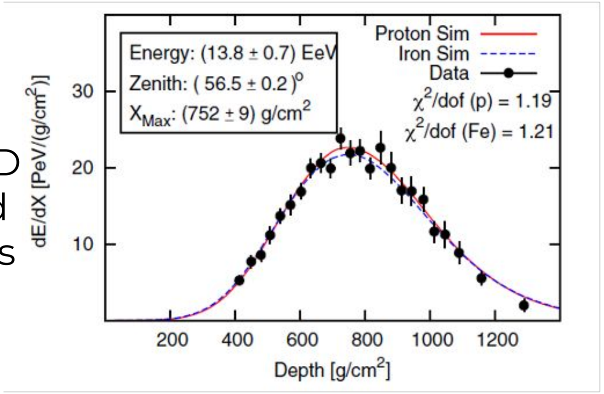


Auger Prime and NN approach will provide additional info on mass composition

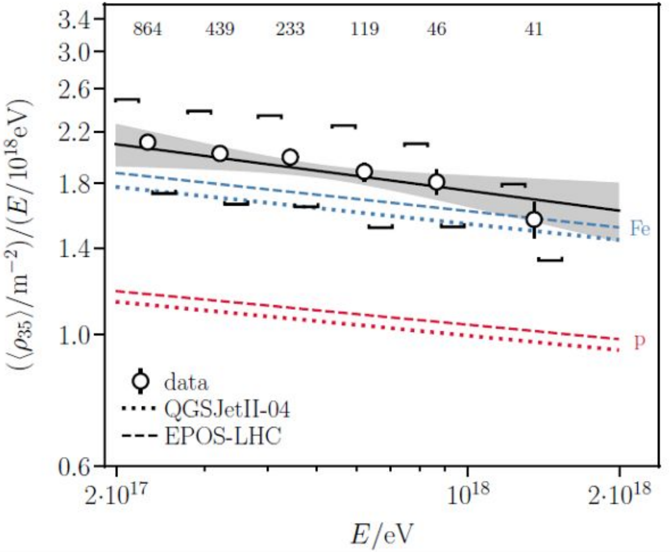
Hadronic interactions models

How well hadronic models reproduce Auger data?

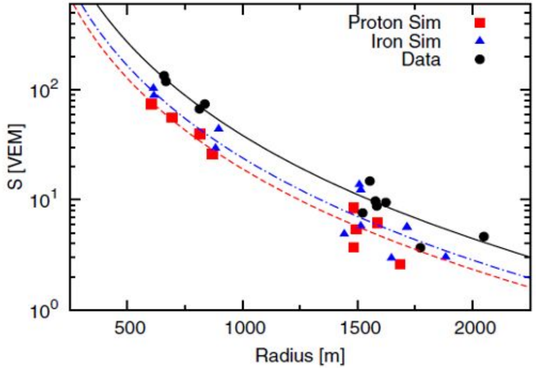
Observed longitudinal profile from FD is reproduced by simulations



Eur. Phys J. C (2020) 80:751: first direct measurement of muon number with UMD at Auger



Measured signal at the ground differ for data and simulations

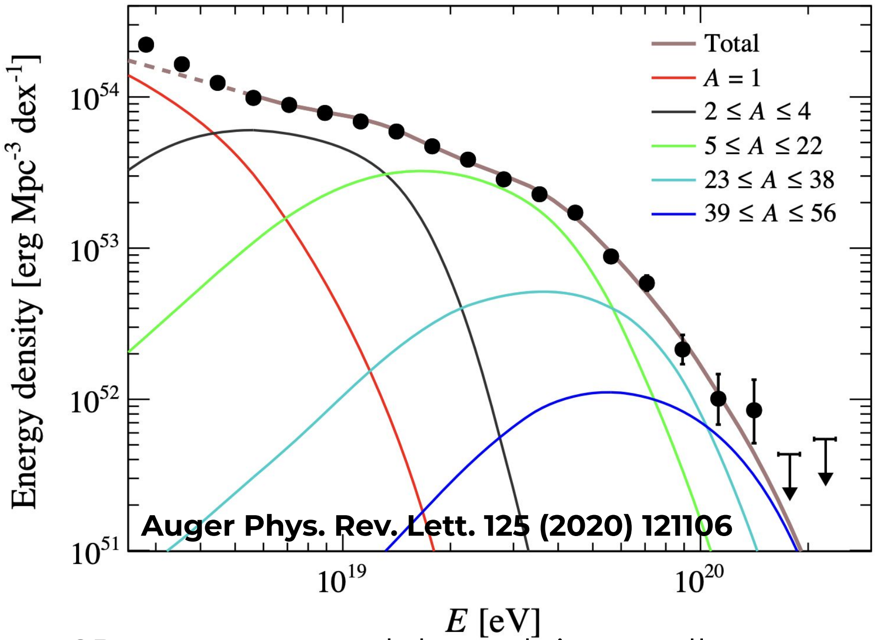


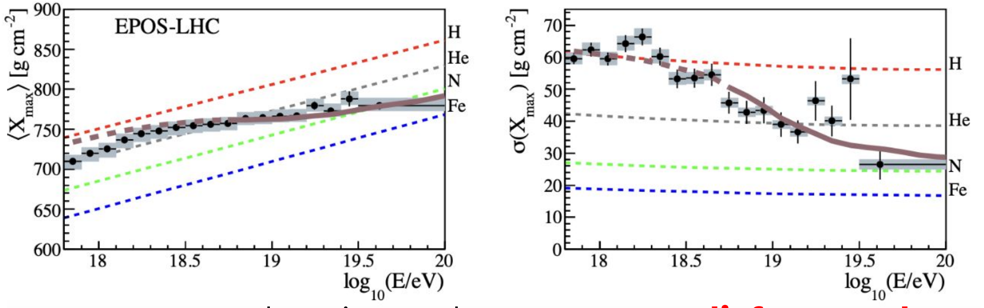
- Evidence of muon excess 1.3< R_{had}<1.6
- Insensitive to energy scale uncertainty R_E~1
- Muon number from models in tension with data
- fluctuations of muons are in agreement Phys. Rev. Lett. 126 (2021) 152002

Astrophysical scenarios

Simultaneous fit of **flux** and **composition** to find source scenarios more compatible with data

Paper in preparation





- CR are propagated through interstellar medium
- no magnetic fields

- sources accelerating only protons are **disfavoured**
- uniformly distributed sources accelerating nuclei [rigidity dependent] are **favoured**
- indication that "instep" at 10^{19} eV may be due to the **interplay between He and CNO components**
- individual nearby source not favored, spectrum flat in declination
- additional component required below 5 10^{18} eV (possibly a tail from galactic CR)
- energy density in CR above the ankle constraints the luminosity density for extragalactic objects like AGN and SB

Large Scale anisotropy

Auger - Science 315 (2017) 1266

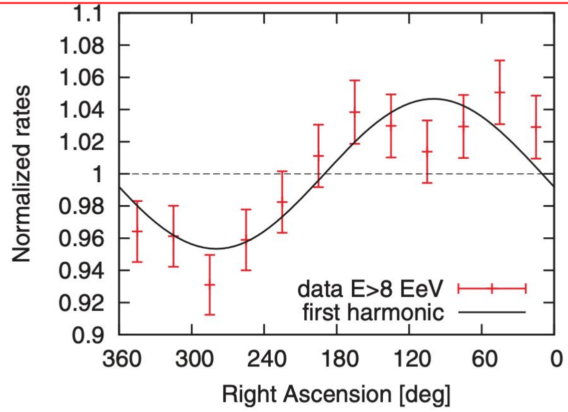
Rayleigh analysis of the first harmonic in right ascension

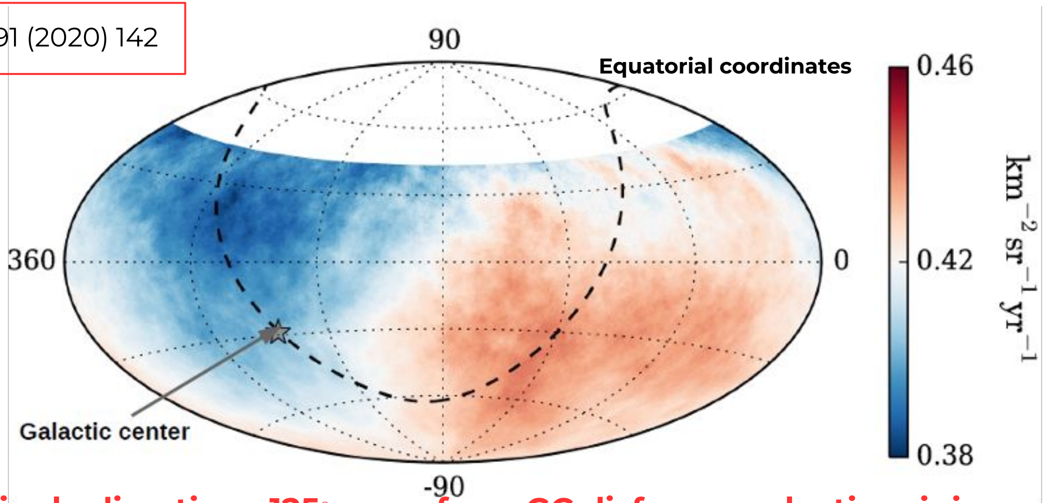
Energy (EeV)	Number of events	Fourier coefficient a_α	Fourier coefficient b_α	Amplitude r_α	Phase φ_α (°)	Probability $P(\geq r_\alpha)$
4 to 8	81,701	0.001 ± 0.005	0.005 ± 0.005	$0.005^{+0.006}_{-0.002}$	80 ± 60	0.60
≥8	32,187	−0.008 ± 0.008	0.046 ± 0.008	$0.047^{+0.008}_{-0.007}$	100 ± 10	2.6×10^{-8}

E > 8 EeV

Exposure = 76800 km^{2}sr y

Modulation at **5.2σ** (**6σ** with 15% more data - Astrophys. J. 891 (2020) 142

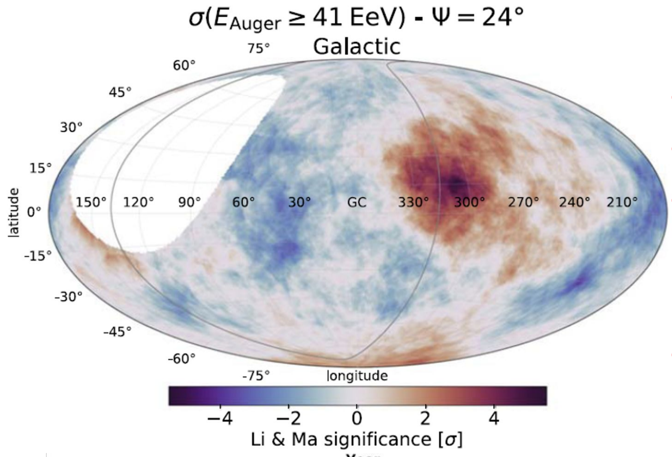


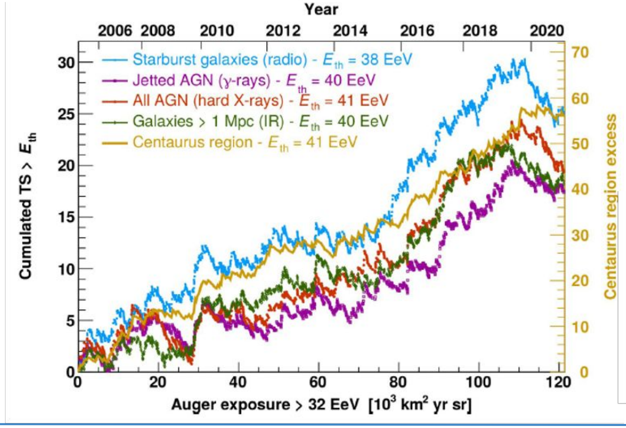


3D dipole amplitude $6.5^{+1.3}_{-0.9}\%$ at (α;δ) = (100°; -24°)

Dipole direction ~125° away from GC disfavors galactic origin

Intermediate Scale anisotropy





Blind search for overdensities

- Energy [32-80] EeV - zenith up to 80°
- 2635 events between 1/1/2004 and 31/12/2020
- Centaurus A region:
  - most significant excess, 2.2 σ p.t., at ψ=24° E>41 EeV
  - direction fixed at Cen A 3.9 σ p.t., at ψ=27° E > 41 EeV
- autocorrelation with (GC, GP, SGP) not significant

Data available at **https://doi.org/10.5281/zenodo.6504276**

Likelihood test for anisotropy with astroph. catalogs

Most significant signal at E_{th} = 38-41 EeV,
ψ =23° - 27°, signal fraction 6-15%

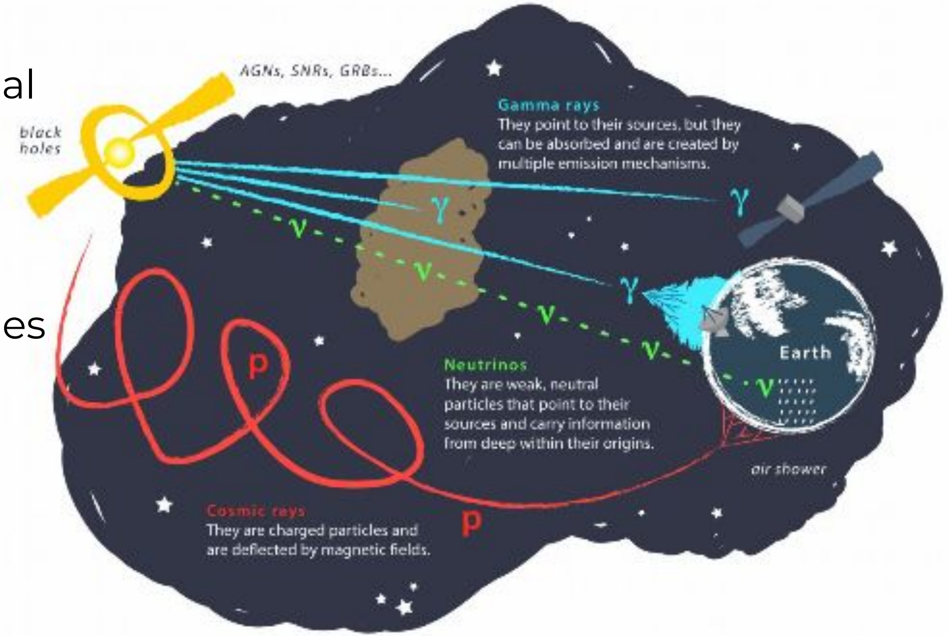
Catalog	E_{th} [EeV]	Ψ [deg]	α [%]	TS	Post-trial p-value
All galaxies (IR)	40	24^{+16}_{-8}	15^{+10}_{-6}	18.2	6.7×10^{-4}
Starbursts (radio)	38	25^{+11}_{-7}	9^{+6}_{-4}	24.8	3.1×10^{-5}
All AGNs (X-rays)	41	27^{+14}_{-9}	8^{+5}_{-4}	19.3	4.0×10^{-4}
Jetted AGNs (γ-rays)	40	23^{+9}_{-8}	6^{+4}_{-3}	17.3	1.0×10^{-3}

4σ for SB
3.1 σ for Jetted AGN

Multi-messenger and Fundamental Physics

Different cosmic messengers provide complementary information about potential sources (see E. De Vito this conference)

- Cosmic rays (nuclei):
  - Accelerated by extreme astrophysical events
  - Deflected by magnetic fields
- **Gamma-rays:**
  - Propagate in straight lines
  - Easily absorbed at ultra-high energies
- **Neutrinos:**
  - Not deflected and not absorbed
  - Low interaction rate i.e difficult to detect

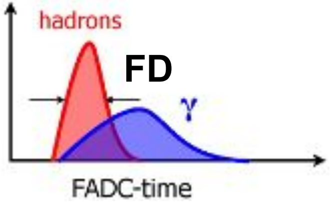


... and Fundamental Physics:
Dark Matter, **LIV**, BSM

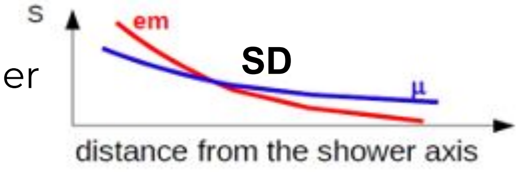
Photon searches

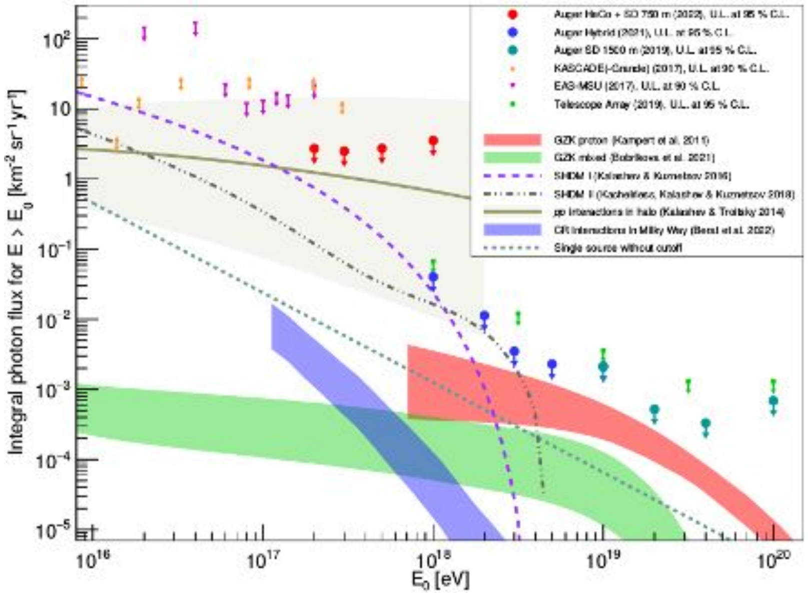
Photon signature:

- deeper Xmax, less muon



- steeper LDF and broader signal





Upper limits on diffuse photon flux

Recently published on Ap. J. 933 (2022)125:
11 candidates > 10 EeV (SD)
22 candidates > 1 EeV (Hybrid)

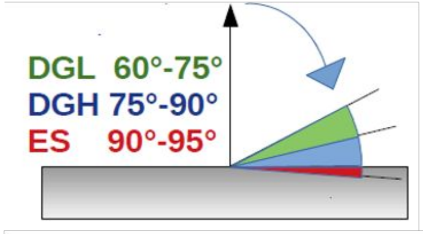
Targeted search **NO Candidates found**

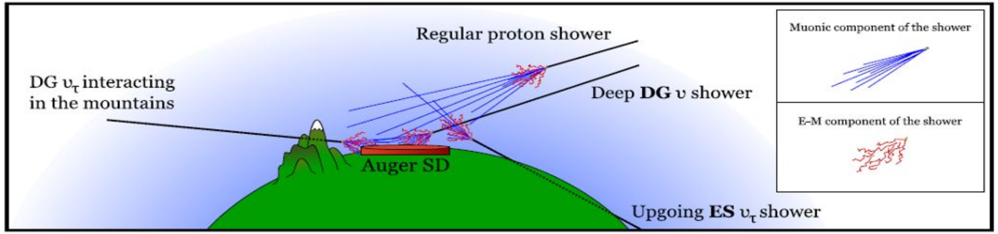
- In coincidence of known sources including **CenA** and the **Galactic Center** [UL extrapolating HESS flux]
- GW follow-up (4 events)

Top-down model disfavored

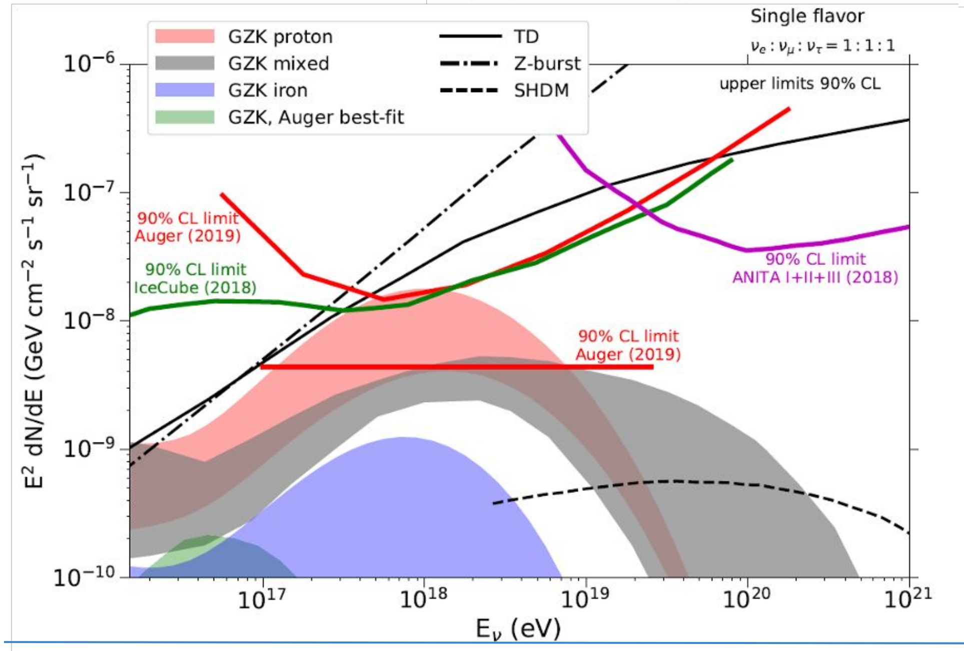
- CR proton dominated scenario disfavoured
- constraining mass and lifetime of dark matter particles
- **Auger Phase II:** additional information for better photon/hadron separation or photon discovery

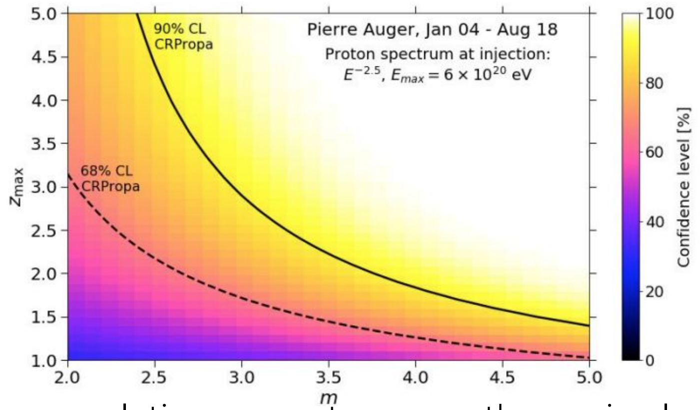
UHE Neutrino searches (SD)





SIGNATURE: inclined "young"showers





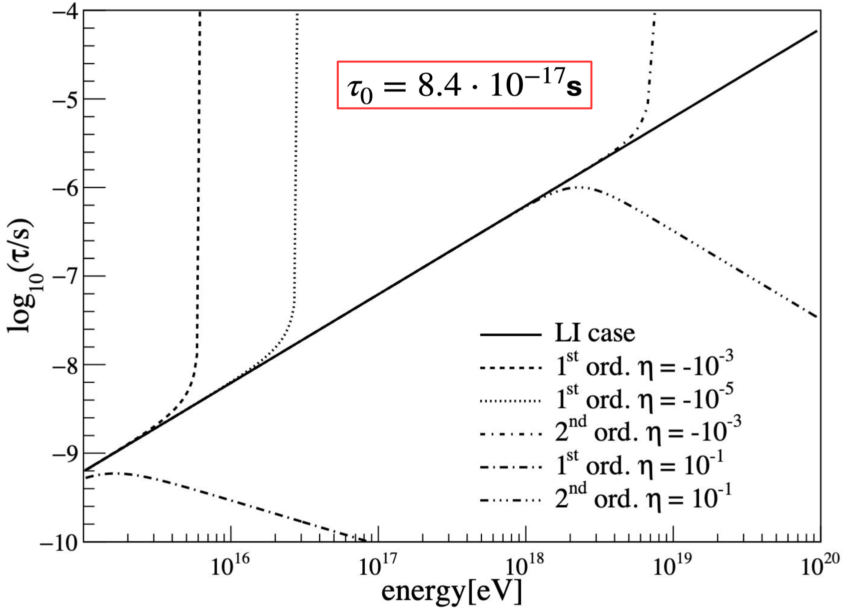
m: source evolution parameter z max : the maximal redshift at which UHECR are accelerated

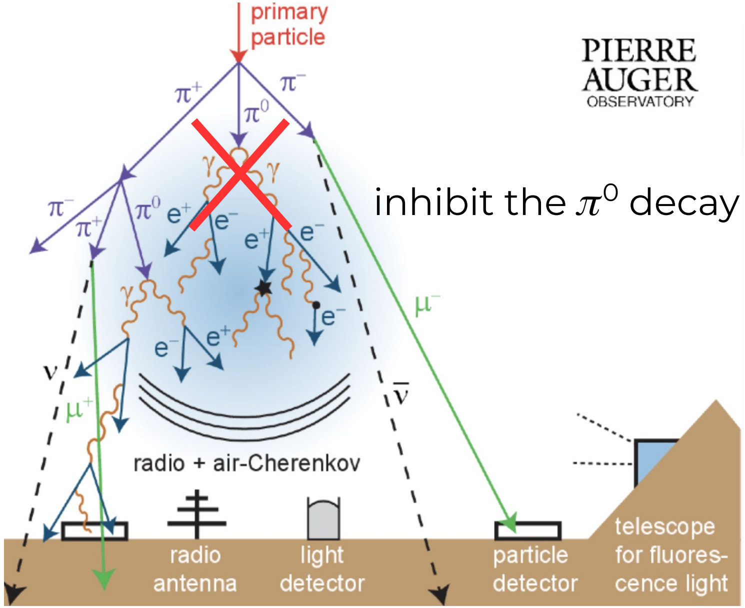
Exclusion of a significant region of parameter space (z_{max}, m) from non observation of ν assuming sources of CR accelerating only protons

Limits on the LIV with air showers

Lorentz Invariance Violation effects can be studied using a **modified dispersion relation** (Coleman, Glashow)

$$E^2 - p^2 = m^2 + \sum_{n=0}^{N} \eta^{(n)} \frac{p^{n+2}}{M_{Pl}^n} \Rightarrow m_{\rm LIV}^2 = m^2 + \eta^{(n)} \frac{p^{n+2}}{M_{\rm Pl}^n} \Rightarrow \gamma_{\rm LIV} = \frac{E}{m_{\rm LIV}} \Rightarrow \boxed{\tau = \gamma_{\rm LIV}\tau_0}$$

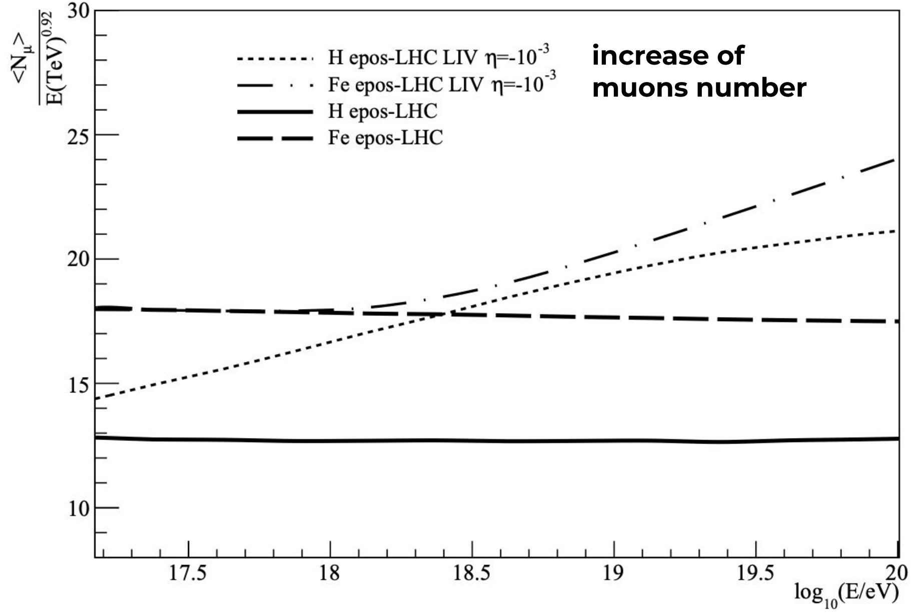


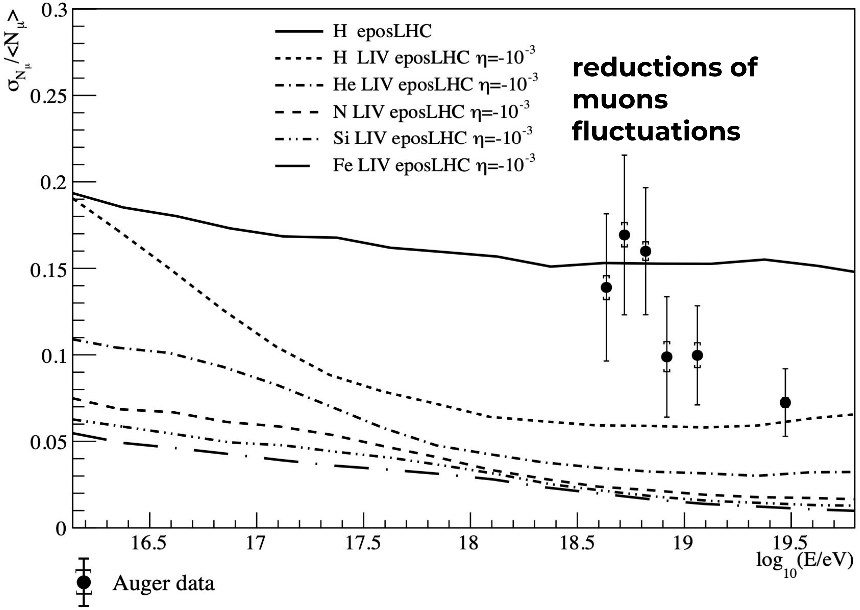


inhibit the π^0 decay

Limits on the LIV

- From MC muons are very sensitive to LIV
- Using the muon fluctuations measurement at the Pierre Auger Observatory



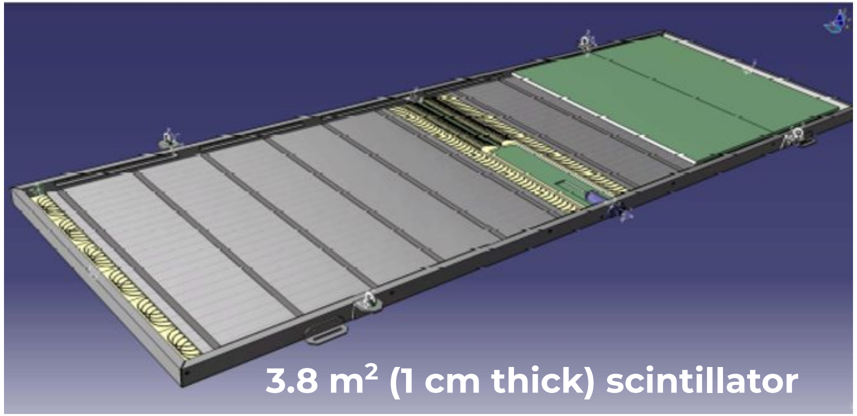


new bound for $\eta^{(1)}$ is $[-5.95 \cdot 10^{-6}, 10^{-1}]$ at 90.5% of CL

Auger Prime upgrade

SCIENCE CASE

- Origin of the flux suppression, GZK vs. maximum energy scenario
- Search for a flux contribution of protons up to the highest energies at a level of ~ 10%
- Study of extensive air showers and hadronic physics $\sqrt{s}$=70 TeV



UPGRADE PLAN

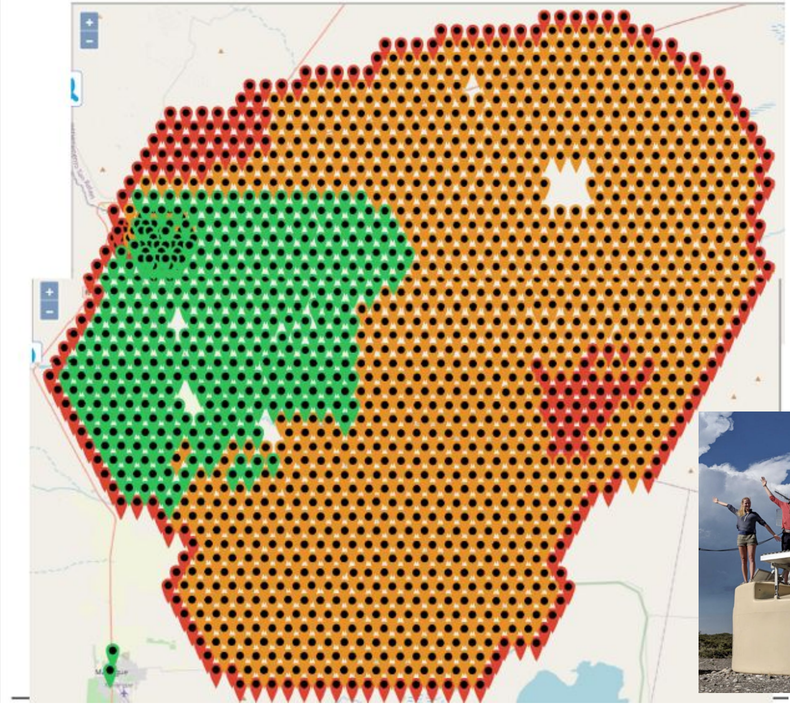
- Scintillators **SSD**
- Upgraded and faster electronics **UUB** (40 MHz - 120 MHz)
- Extension of dynamic range with small **sPMT**
- Underground buried **UMD** detectors
- Radio antennas **RD**

Auger Prime status

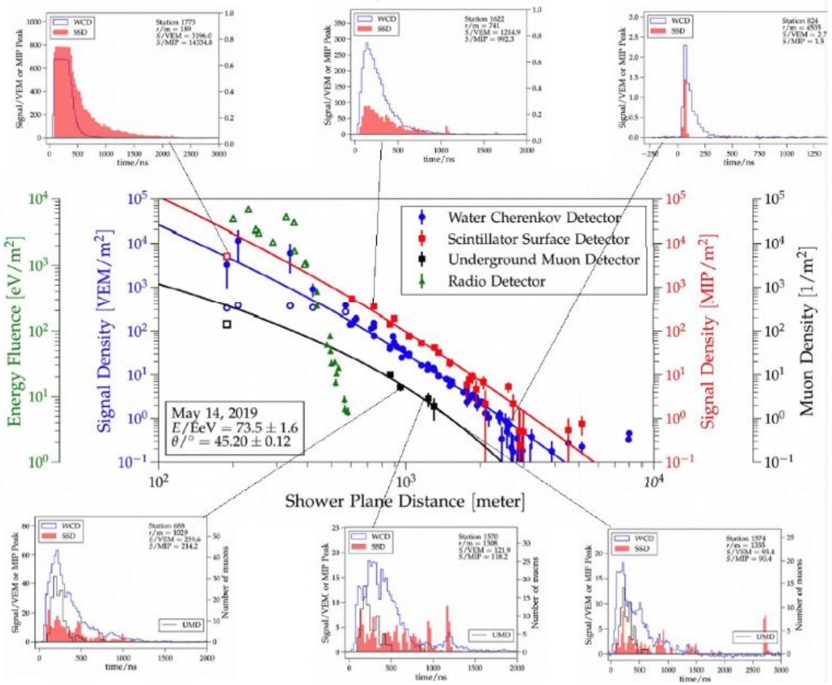
1436 SSD stations **deployed**

25% of the array equipped with UUB and SSD-PMT and sPMT

Installation completed with UUBs in early 2023

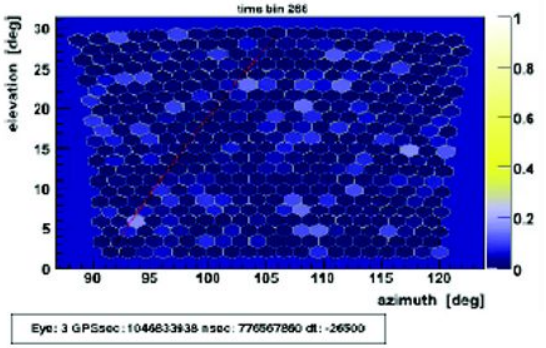


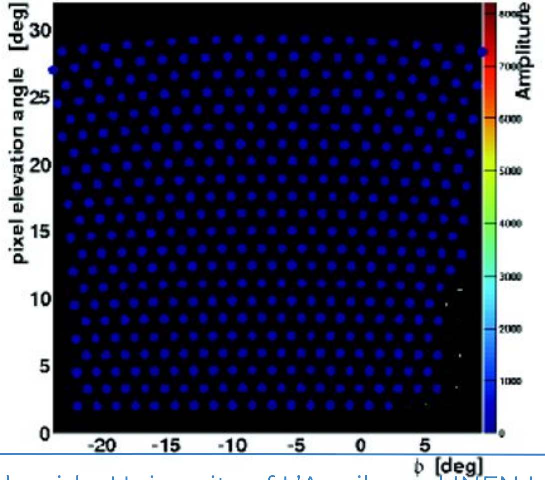
Super Hybrid event



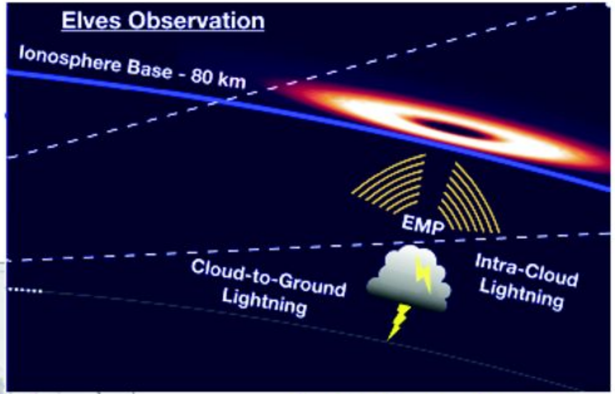
Auger as a laboratory for Earth phenomena

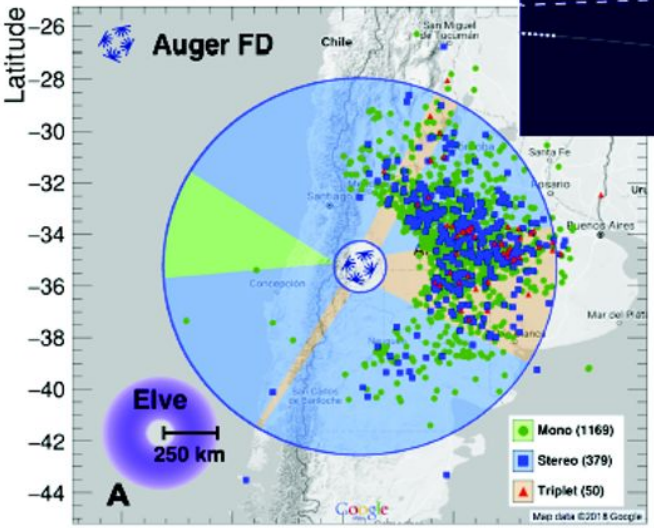
Observation of Elves with FD





Published on "Earth and Space Science" 7 (2020) e2019EA000582





1600 elves observed

Short article to appear in EOS News

High-level publications of correlation with super bolts in preparation

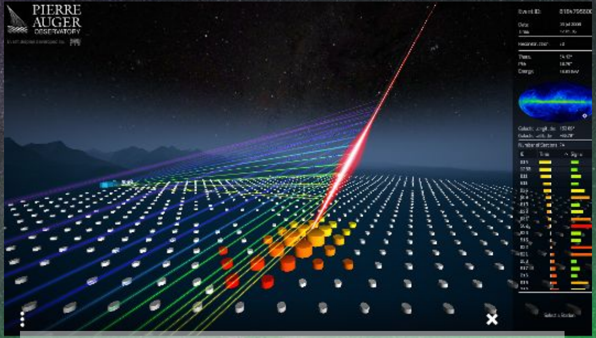
Auger Open Data

Pierre Auger Observatory Open Data

February 2021 release

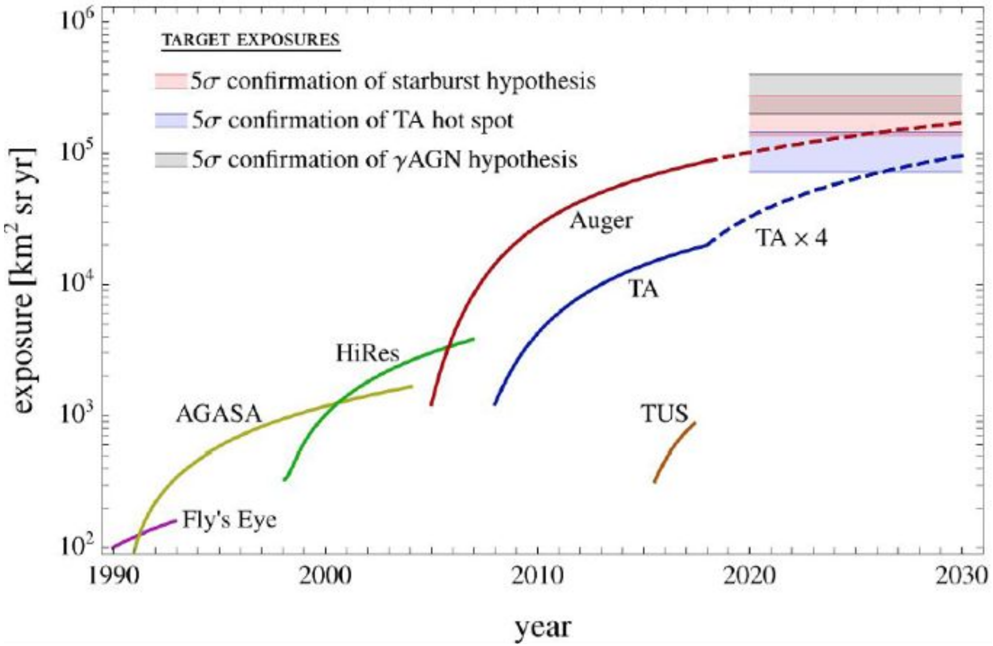
https://opendata.auger.org
doi 10.5281/zenodo.4487613

- 10% cosmic ray data
- 100% atmospheric data
- Close to raw data and higher level reconstruction
- Surface and Fluorescence Detectors
- JSON and summary CSV files
- Python code for data analysis



Event visualization example

Conclusion



OPEN QUESTIONS

1. **What is the origin of flux suppression?**
   - fundamental constraints on sources and their properties
2. **is there a fraction of protons above ~5 10^{19}eV?**
   - feasibility of charged particle astronomy
   - proof for future experiments
3. **can we disentangle composition and hadronic interaction systematics ?**
   - constraints on hadronic multiparticle production from EAS
   - constraints on new physics beyond the reach of LHC
   - new measurements at accelerators

FUTURE STEPS

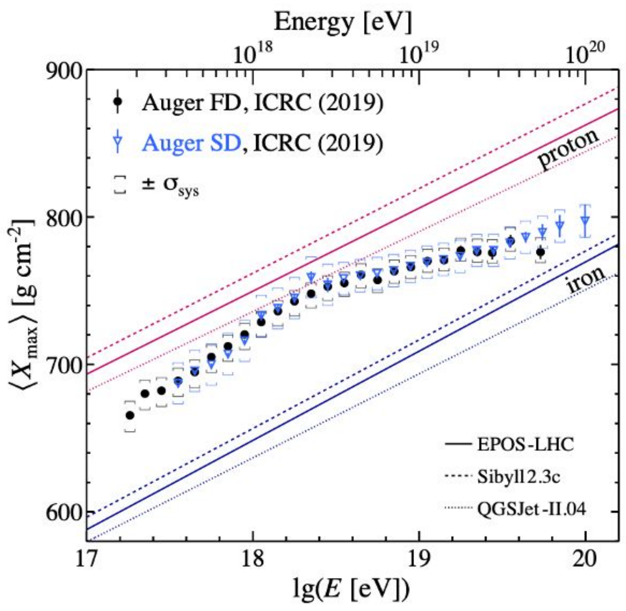
- Increase in statistics at UHE
- Composition sensitivity at and above the suppression region (E>4 10^{19} eV)
- More data on neutrinos (and photons)
- More information on hadronic interactions

Thanks for listening!

Fantastic Four 1961

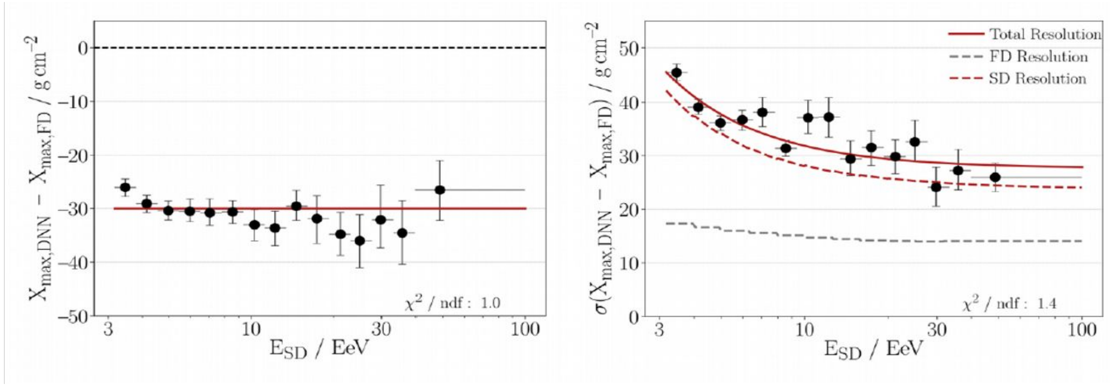
Backup slides

Mass composition (prospects)



Neural network approach tested with hybrid events

Promising in view of the additional info provided by the upgraded SD detector



SD can extend the measurement of <Xmax> (worse resolution)

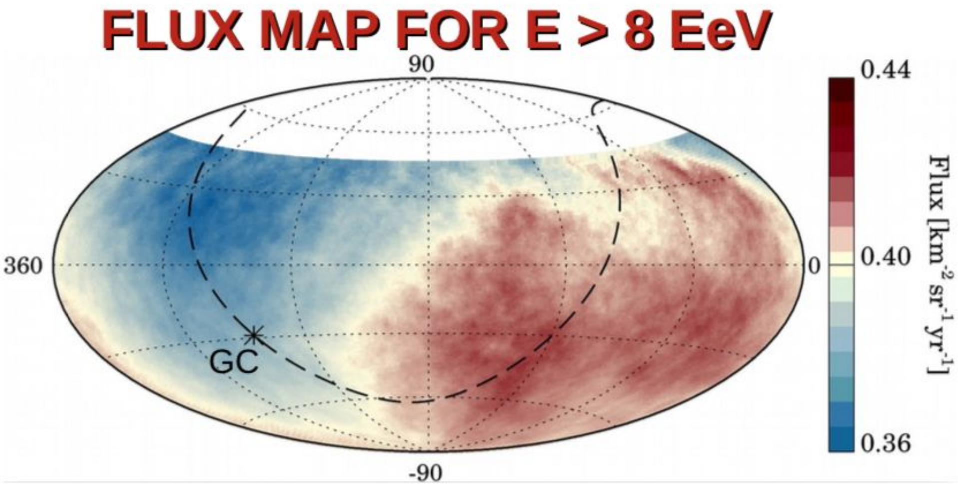
Large scale anisotropy

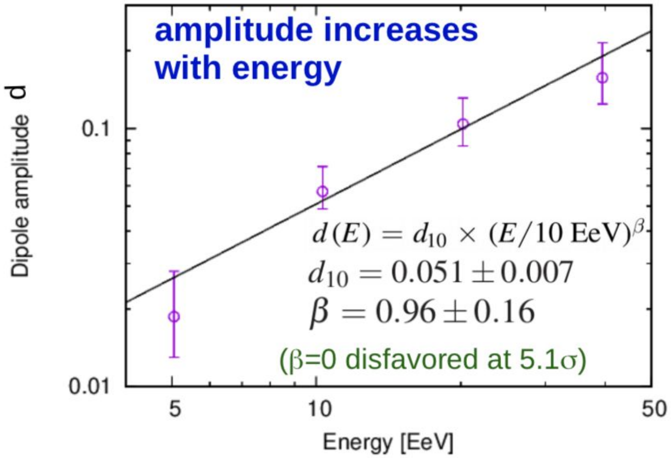
Weighted Fourier Analysis to obtain modulation in right ascension and azimuth

Auger data: Exposure >92000 km^2 sr yr

OBSERVATION (>5σ): 3D dipole above 8 EeV at (α,δ)=(98^0,-25^0): $(6.6\,^{+1.2}_{-0.8})$ %, 125^0 away from GC

the UHECRs are extra-galactic above 8 EeV, while predominantly Galactic below few EeV





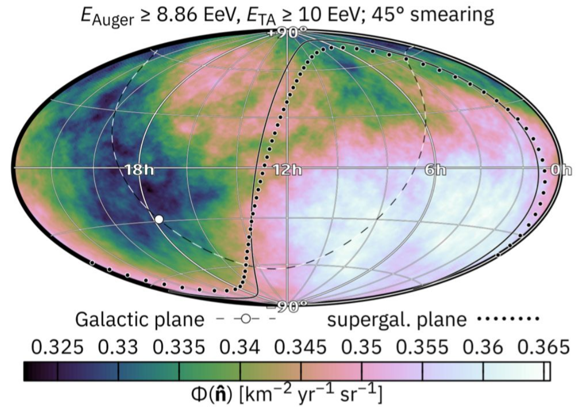
Full sky coverage with Auger + TA

Large Scale Anisotropy

Energy threshold
- 8.86 EeV for Auger
- 10 EeV for Telescope Array

Events
- ~31000 events

- Agreement with Auger alone, smaller uncertainty
- Hint for a quadrupole moment



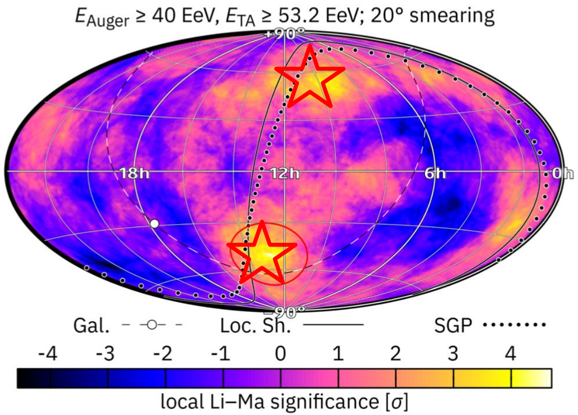
Intermediate Scale Anisotropy (<30^0)

Energy threshold
- 40 EeV for Auger
- 53.2 EeV for Telescope Array

Events
- 969 events

Blind search

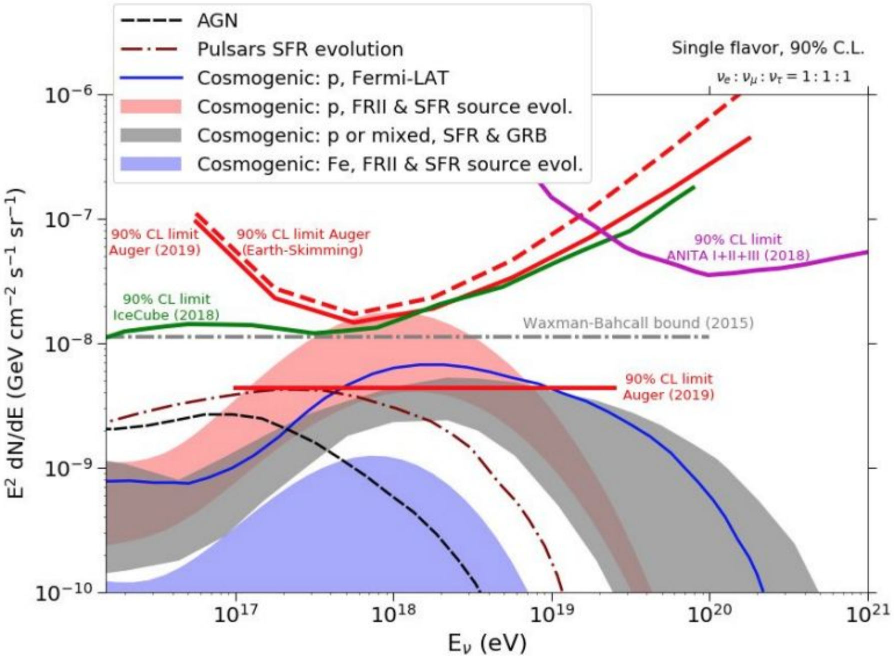
20^0 radius around ($\boldsymbol{\alpha}$=12^h50^m, $\boldsymbol{\delta}$= - 50^0), 2.6σ post-trial
15^0 radius around ($\boldsymbol{\alpha}$= 9^h30^m, $\boldsymbol{\delta}$= +54^0), 1.5σ post-trial



Cosmogenic neutrinos

Expected events:
Red band: 1.4 - 5.9
Gray band: 0.8 - 2.0
Blue band (top): 0.4

$$p + \gamma \rightarrow n + \pi^+$$
$$\rightarrow \mu^+ + \nu_\mu$$
$$\rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$



Maximum sensitivity around EeV k(90% CL) < 4.4. 10^{-9} GeV cm^{-2} s^{-1} sr^{-1}

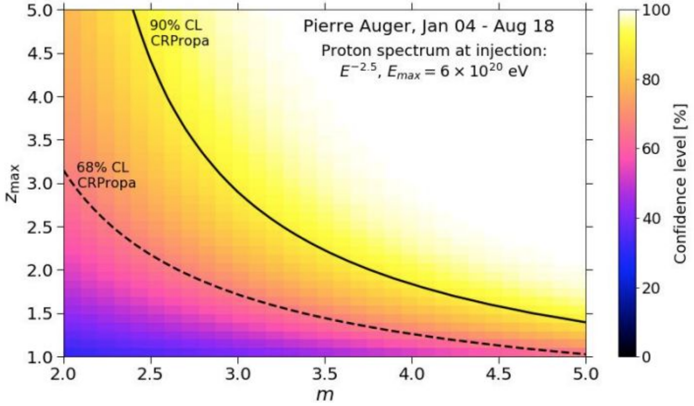
CONSTRAIN ON PROTON MODELS

UHECR source evolution models parameterized as :

$$\Psi(z) \propto (1+z)^m$$

m: source evolution parameter z max : the maximal redshift at which UHECR are accelerated

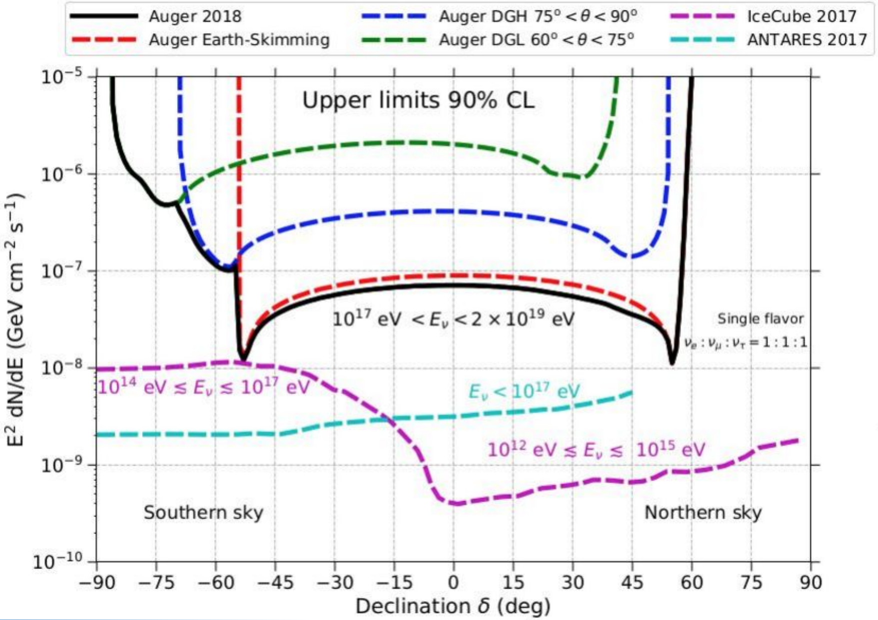
Exclusion of a significant region of parameter space (z_{max}, m) from non observation of ν



UHE neutrinos: point like sources

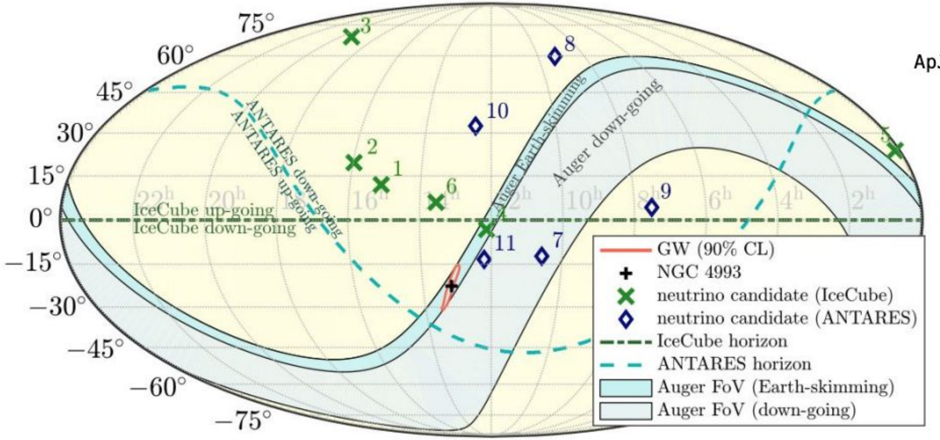
Steady sources

- Good sensitivity at EeV energies in a broad range in declination
- Energy range complementary to IceCube and Antares



Transient sources (e.g GW)

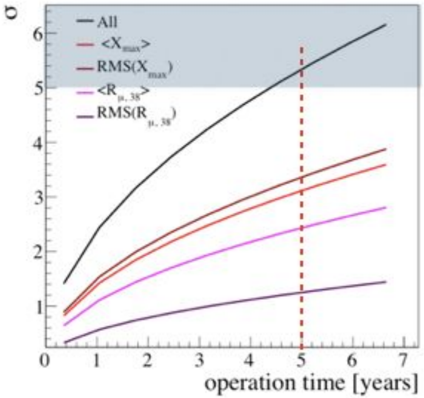
- ANTARES, Icecube & Auger searched for in coincidence with GW170817 from TeV to EeV
- Very good Auger sensitivity because source was in the FoV of Earth Skimming at the moment of merger
- Sensitive to neutrino luminosities below 5x10^{46}erg/s for certain periods during 1-day follow-up searches

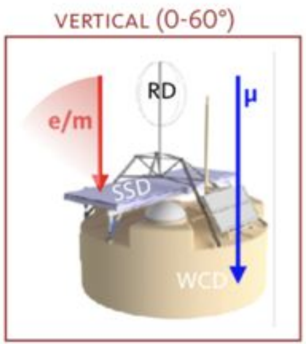


ApJ,

The future of UHECR: Auger Prime detectors

VERTICAL SHOWERS



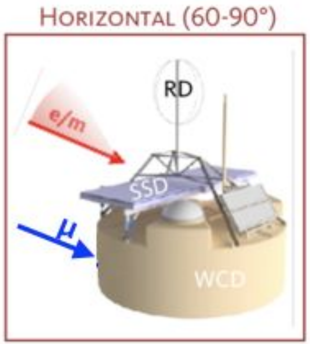


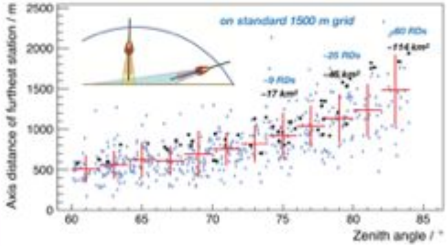
Significance of distinguishing two different realisations of "maximum rigidity model" :

- as it predicts, i.e. no protons at UHE
- adding 10% protons

>5σ in 5 years of operations

HORIZONTAL SHOWERS

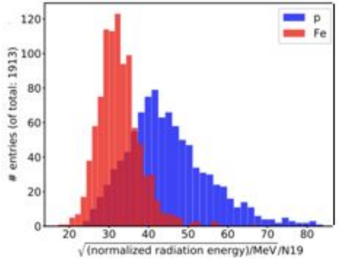


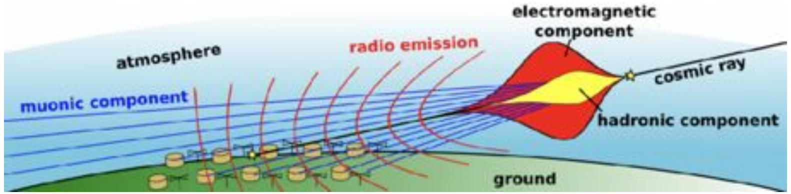


RADIO Hybrid:

E_{rad} from radio

muons from WCD



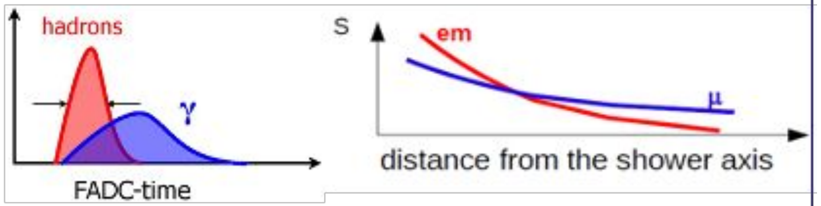


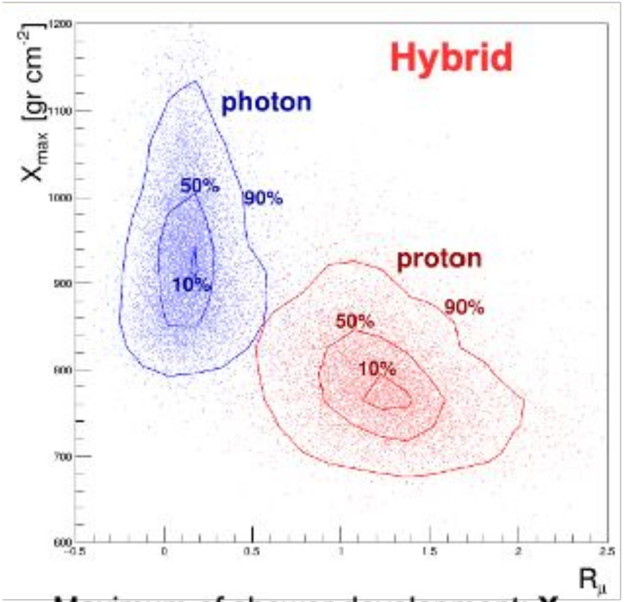
Hybrid and SD photon search

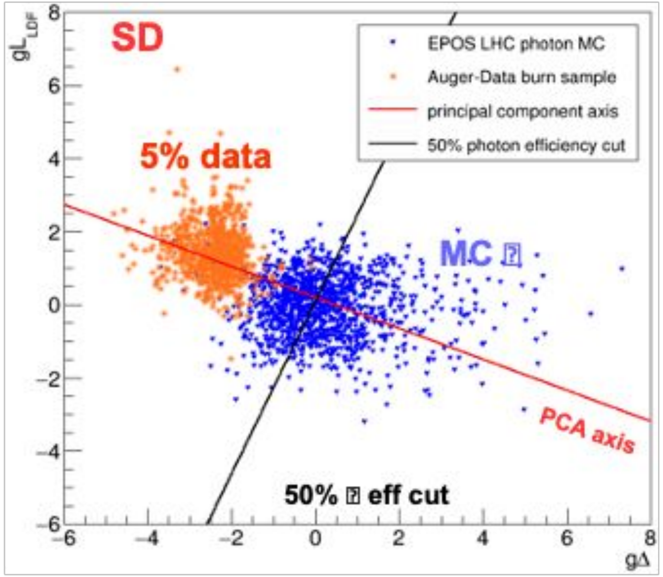
Photon signature

deeper Xmax, less muons

steeper LDF and broader signal





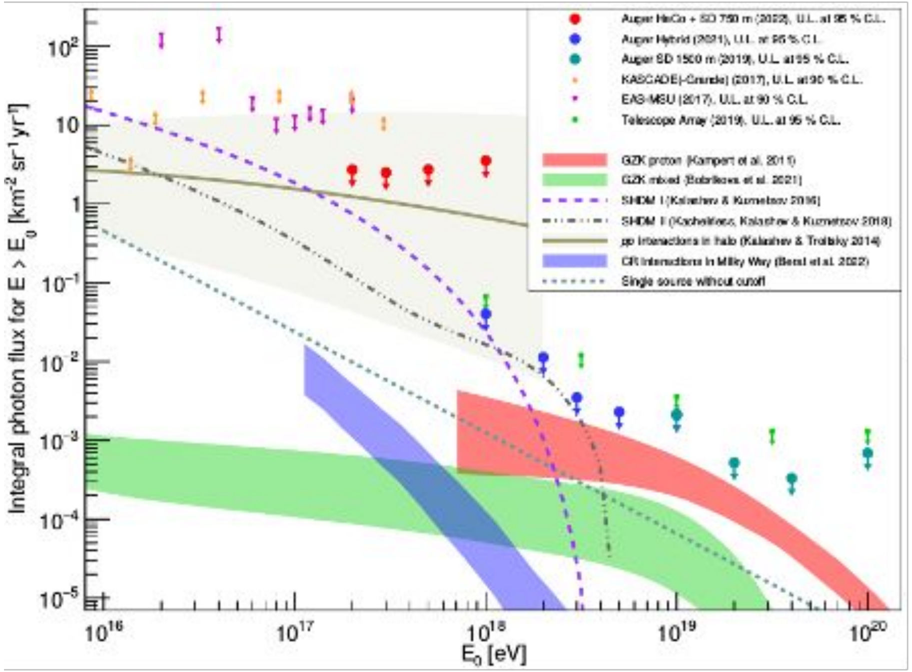


Maximum of shower development: $\mathbf{X_{max}}$
Muon content of the shower (universality): R_{μ}

Deviation from data <LDF>: $\mathbf{gL_{LDF}}$
rise-time rel. event-wise quantity: $\mathbf{g_{\Delta}}$

Upper limits on diffuse photon flux

Ap. J. 933 (2022)125



Strictest limits at E> 0.2 EeV

11 candidates > 10 EeV (SD)

22 candidates > 1 EeV (Hybrid)

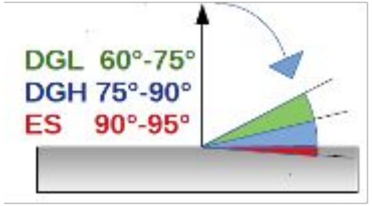
Targeted search
In coincidence of known sources including CenA and the Galactic Center [UL extrapolating HESS flux]

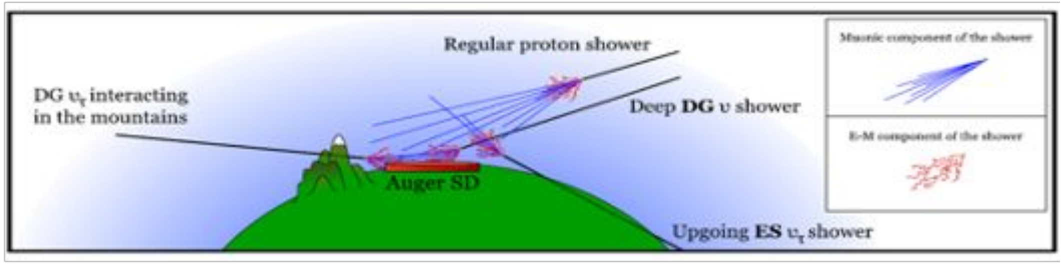
GW follow-up (4 events)

NO Candidates found

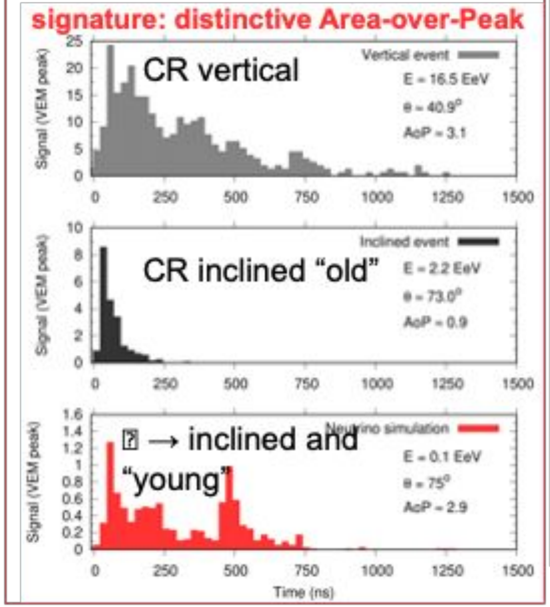
- **Top-down model disfavored**
- CR proton dominated scenario (also the most pessimistic cases) disfavoured
- constraining mass and lifetime of dark matter particles → **see R. Aloisio at this Conf.**
- Auger Phase II: additional information for better photon/hadron separation or photon discovery

UHE neutrinos with the SD

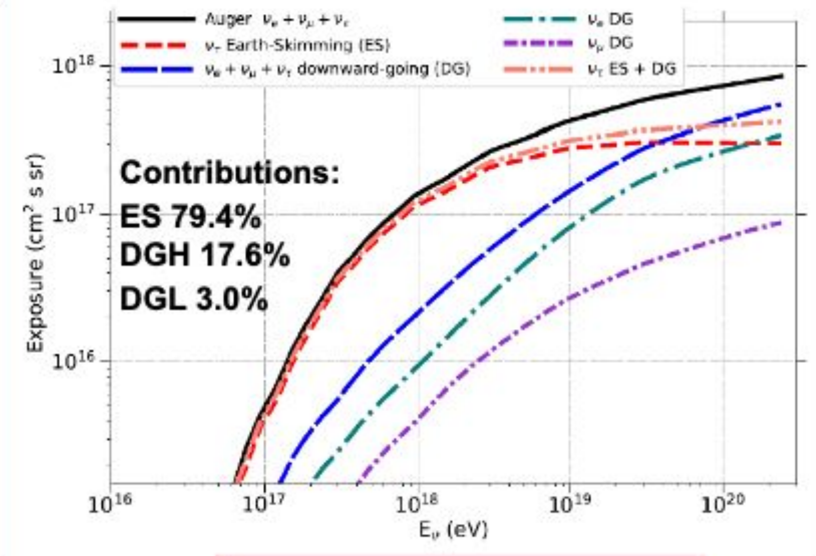




typical signal shapes



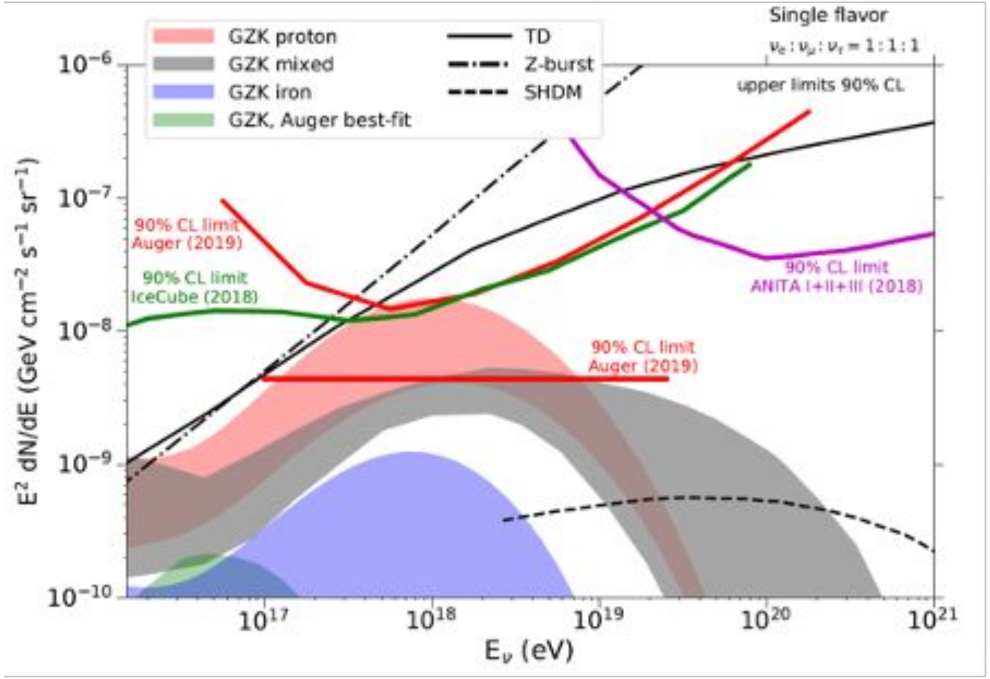
Sensitivity to different channels



ν_τ ES sensitivity dominant

Upper limits on the diffuse neutrino flux

Pierre Auger Coll., JCAP 10 (2019) 022



Identification criteria applied "blindly" to the search data set

Point-like sources

also in coincidence with observations by other experiments

For example TXS 0506+056

Coincidence with GW

For example GW170817

GW follow-up (62 events, stack analysis)

NO Candidates found

NO Candidates found

Maximum sensitivity ~ **1 EeV**

Upper limits set assuming dN/dE = k E^{-2}

→ k∼ 4.4 x 10^{-9} GeV cm^{-2} s^{-1} sr^{-1} [0.1 – 25] EeV

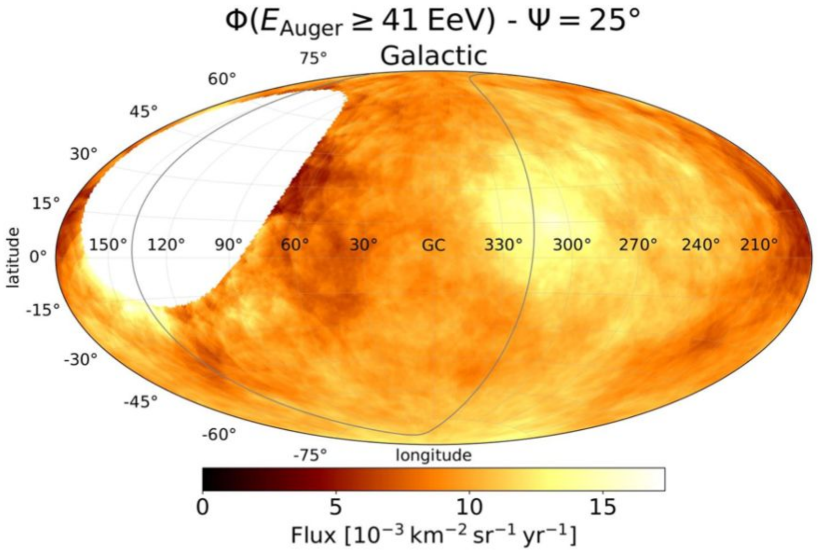
Blind search

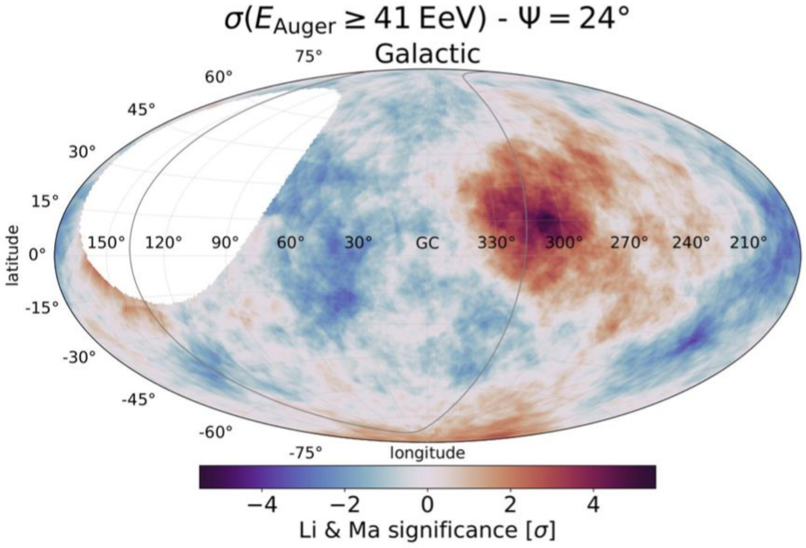
Search with little to no *a priori*: most prominent overdensity in the whole observable sky

Parameter space is scanned in

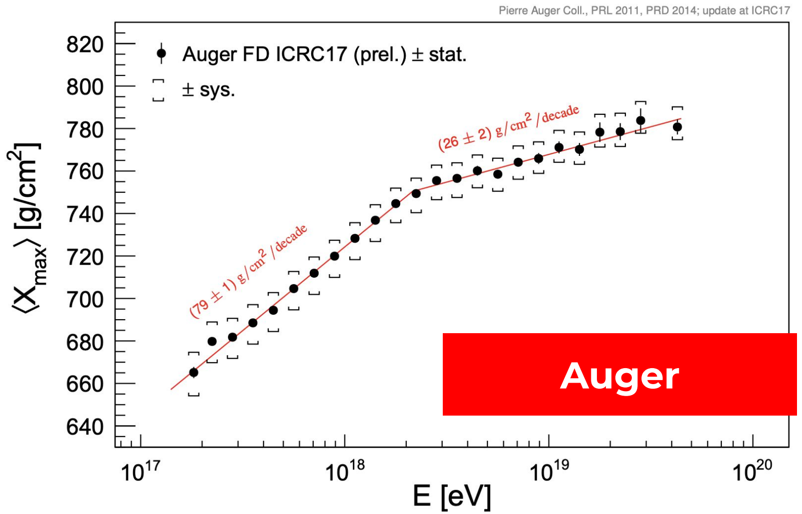
- Direction (R.A., Dec)
- Threshold energy 32 EeV ≤ Eth ≤ 80 EeV
- Top-Hat angular scale 1° ≤ ψ ≤ 30°

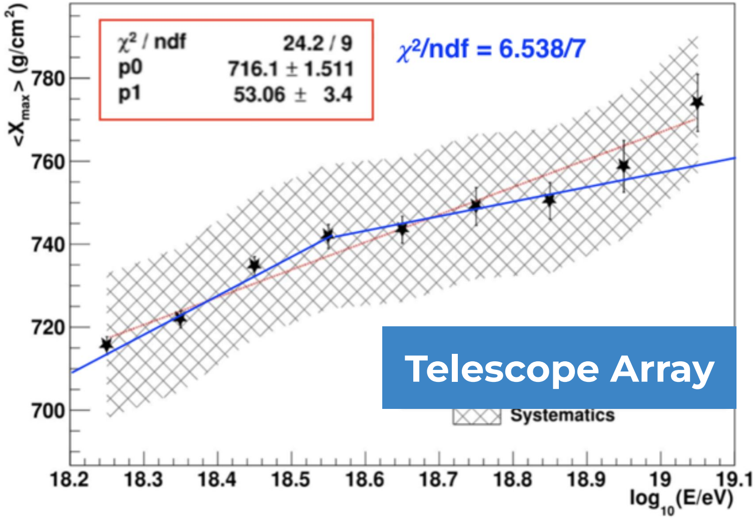
Largest significance post-trial **2.2σ**
found at (RA, dec)=(196.3°, -46.6°) or (l, b)=(305.4°, 16.2°)
Nobs = 156 vs Nexp=98 at Eth 41 EeV and Ψ=24°





Tension on composition between Auger and TA?





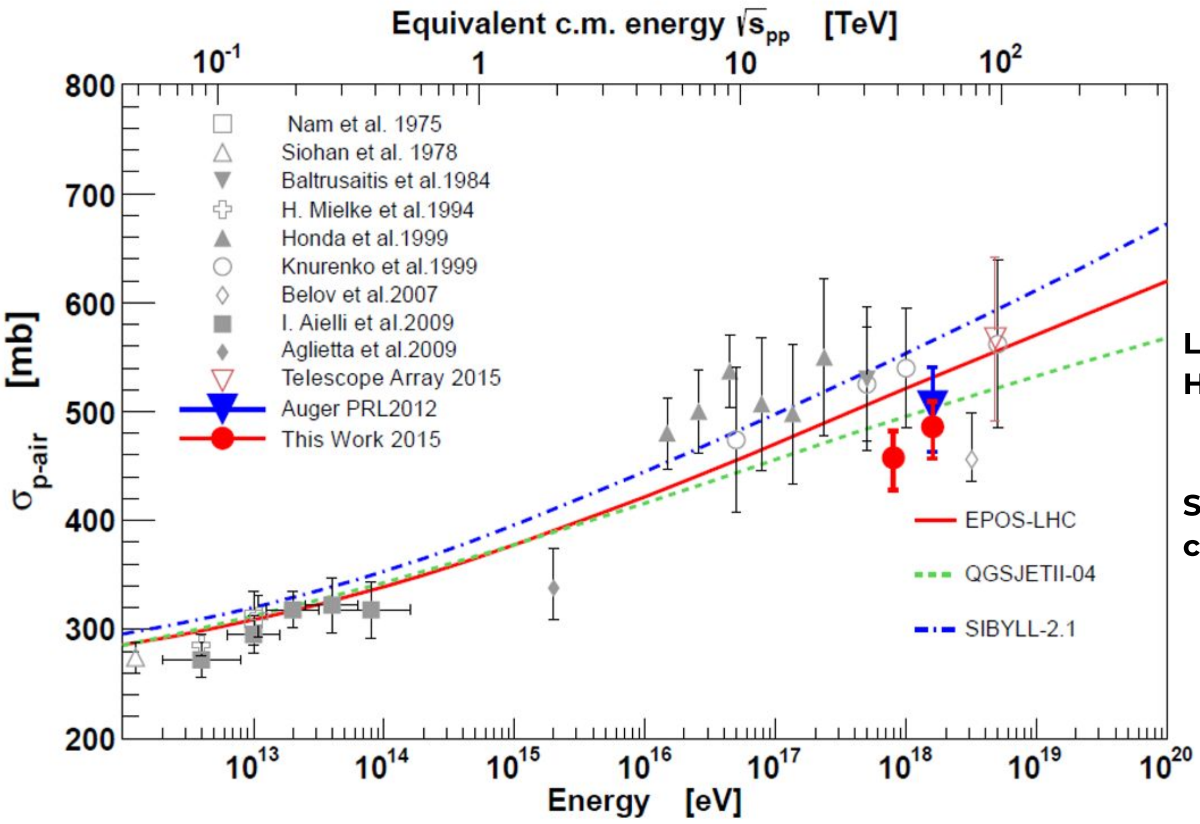
- X_{max} res. ~25 to ~15 g cm^{-2} (from $10^{17.8}$ eV to $>10^{19.7}$ eV)
- Systematic uncertainty on $X_{max} \leq 10$ g cm^{-2}

- X_{max} res. 17.2 g cm^{-2} (from $10^{18.2}$ eV to 10^{19} eV)
- Systematic uncertainty on X_{max} ~ 17 g cm^{-2}

Auger data show trend towards heavier composition above $10^{18.4}$ eV

- TA data have less statistical separation power and larger systematics
- TA data compatible with mix of 4 elements with 75% (p+He) below $10^{19.1}$ eV
- direct comparison is difficult (AUGER unbiased measurement, TA biased by detector acceptance)
- CAVEAT: TA analysis with QGSJetII-04 only [excluded by Auger σ(Xmax) measurement]

p-air cross section



Lower energy [457±18(stat)+19/-25(syst)] mb
Higher energy [486±16(stat)+19/-25(syst)] mb

Sys uncertainty: method, models, helium contamination

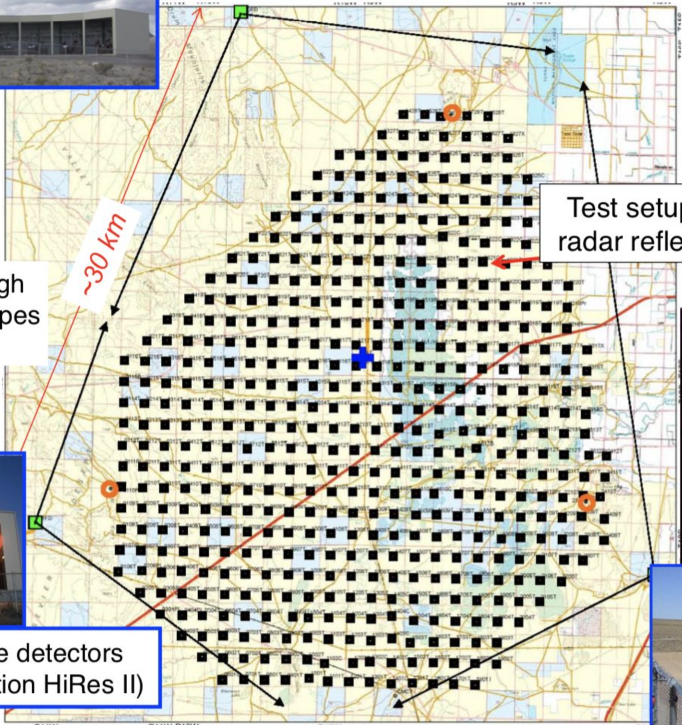
Telescope Array (TA)

Middle Drum: based on HiRes II

TALE (TA low energy extension)

LIDAR
Laser facility

Infill array and high
elevation telescopes

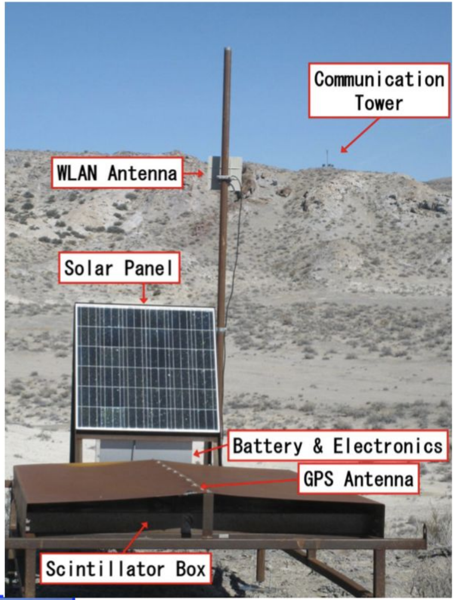


Test setup for
radar reflection

Detector Upgrade in progress , see next slides

3 fluorescence detectors
(2 new, one station HiRes II)

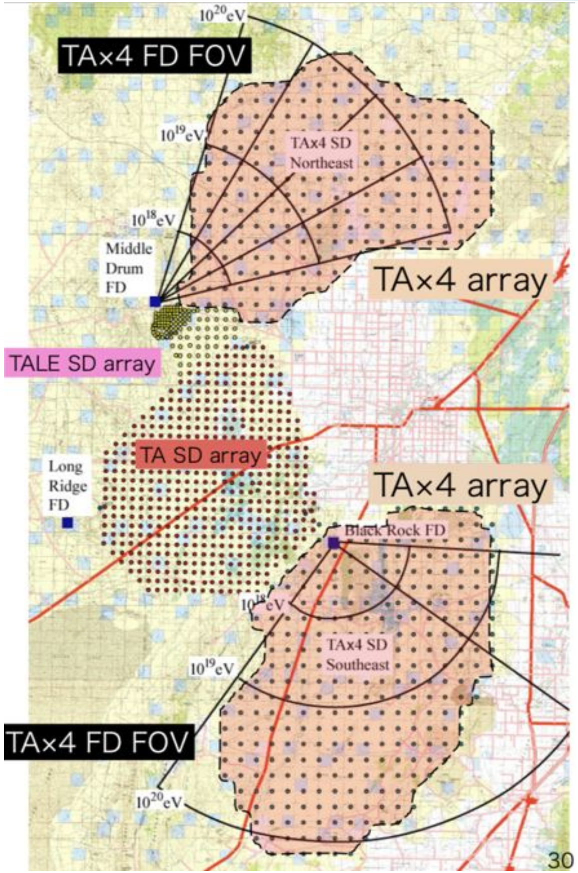
Electron light
source (ELS):
~40 MeV



507 surface detectors:
double-layer scintillators
(grid of 1.2 km, 680 km^2)

Northern hemisphere: Utah, USA

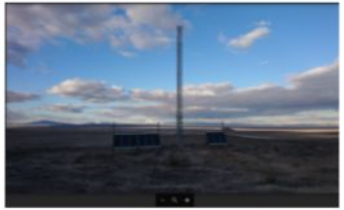
The future of UHECR: TA x 4



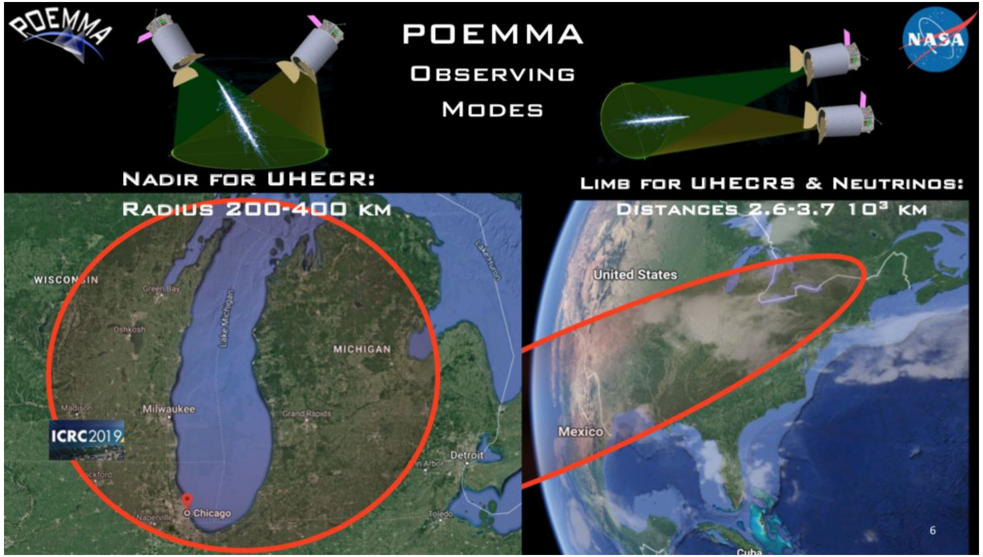
AIM: increase the coverage up to ~3000 km^2 to increment the statistics at UHE

- **SD array:** increased by 500 stations with 2 km spacing
- **FD telescopes:** increased by 4 FD in the Northern site, 8 in the Southern site

Feb. 19 - Mar. 12, 2019:
- 257 SDs
- 6 communication towers

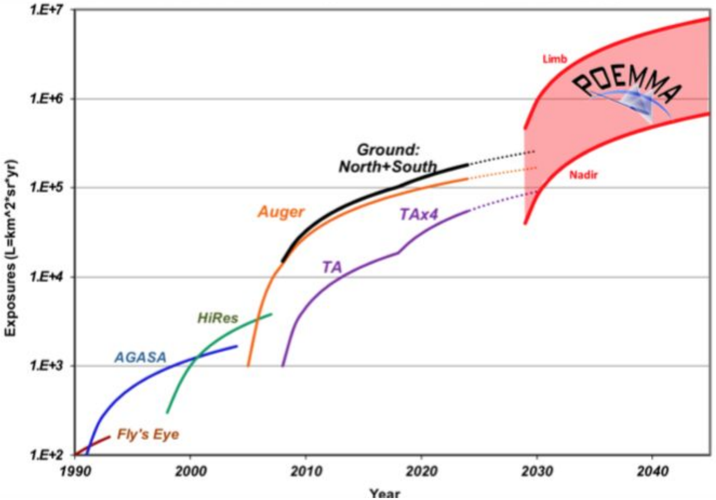


The future of UHECR: POEMMA



Probe **O**f **E**xtreme **M**ulti-**M**essenger **A**strophysics

- 2 satellites flying in loose formation
- 4 m wide FoV (45°) Schmidt mirrors
- fast (1μs) UV camera for fluorescence observation + ultrafast (10 ns) optical camera for Cherenkov obs.



GOAL: observation of UHE cosmic particles with E ≳ 10^{19} eV to study their origin

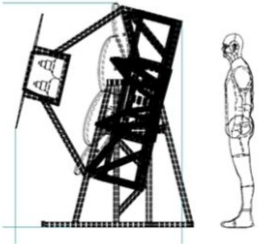
- huge gain in exposure (~10^5 km^2 sr yr) for both charged CRs and neutrinos
- full sky coverage of the celestial sphere
- sensitivity to neutrinos > 2 x 10^{19} eV from FD of ν-induced EAS
- follow-up of transients

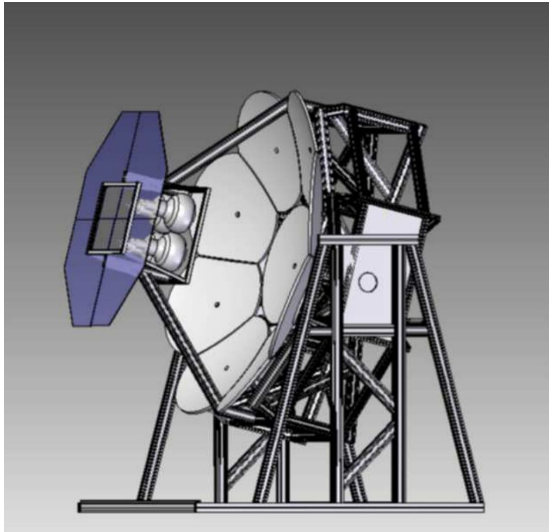
The future of UHECR: FAST

Fluorescence detector **A**rray of **S**ingle-pixel **T**elescopes

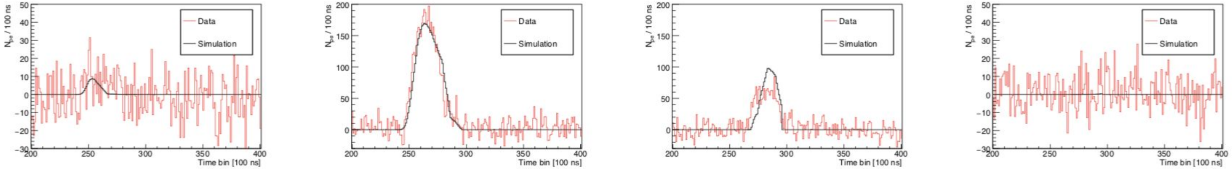
Reference: T. Fujii et al., Astropart.Phys. *74* (2016) 64-72

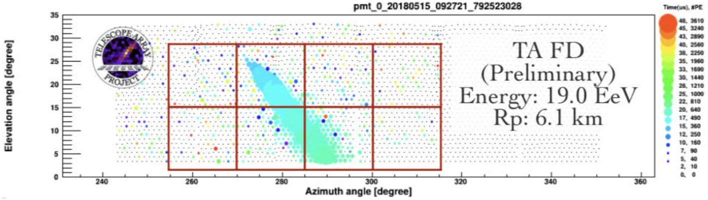
- UHECR and neutral particles **E > $10^{19.5}$ eV**
- mass discrimination on event by event basis
- huge target volume with lower cost w.r.t current FDs
- Deploy on a triangle grid with 20 km spacing, like “Surface Detector Array”





- Smaller optics and single or a few pixels 1 m^2 aperture, 15°×15° FoV
- Low-cost and simplified telescope
- installed for X-calibration and trigger at **Auger** and **TA**





FAST top-down reconstruction (Preliminary)

Zenith	Azimuth	Core(X)	Core(Y)	Xmax	Energy
59.8 deg	-96.7 deg	7.9 km	-9.0 km	842 g/cm²	17.3 EeV

E = 1.73 x 10^{19}