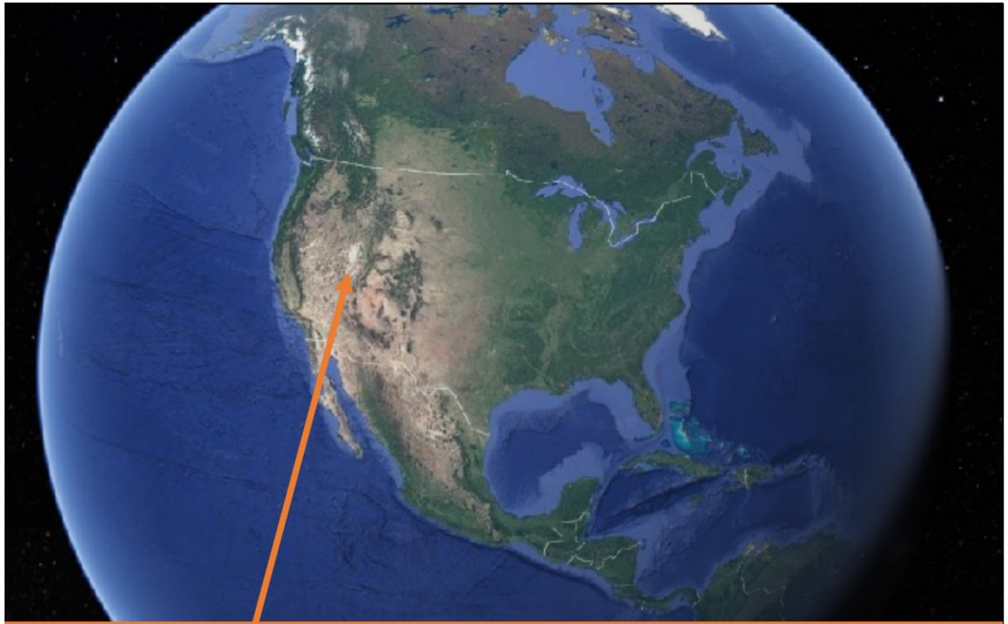
Recent results on ultra-high-energy cosmic rays from the Telescope Array experiment

G.I. Rubtsov (INR RAS)

photo by Oleg Kalashev

Telescope Array observatory

- The largest cosmic ray observatory in the northern hemisphere



Telescope Array

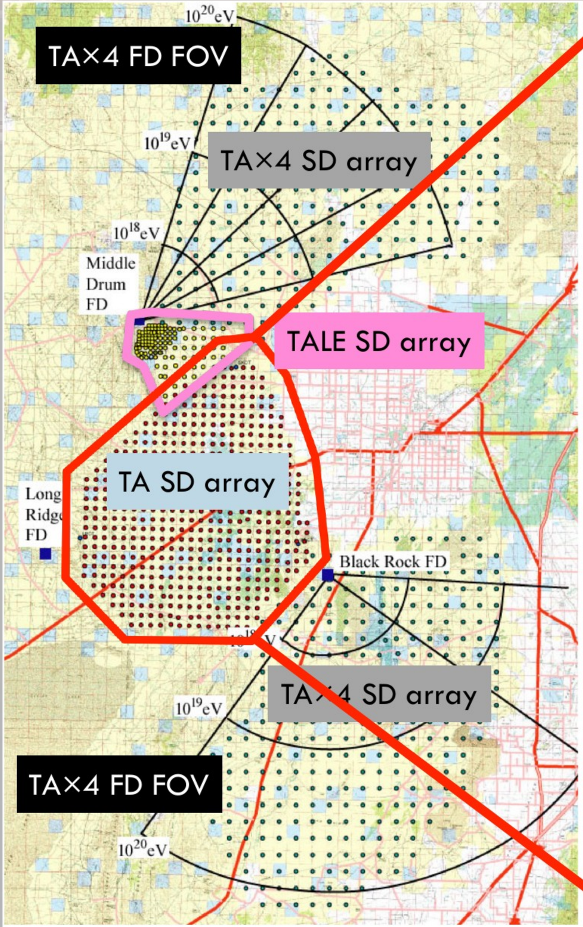
- Delta, Utah, USA. ~1400 m above sea level
- Collaborators from HiRes, AGASA and other institutes

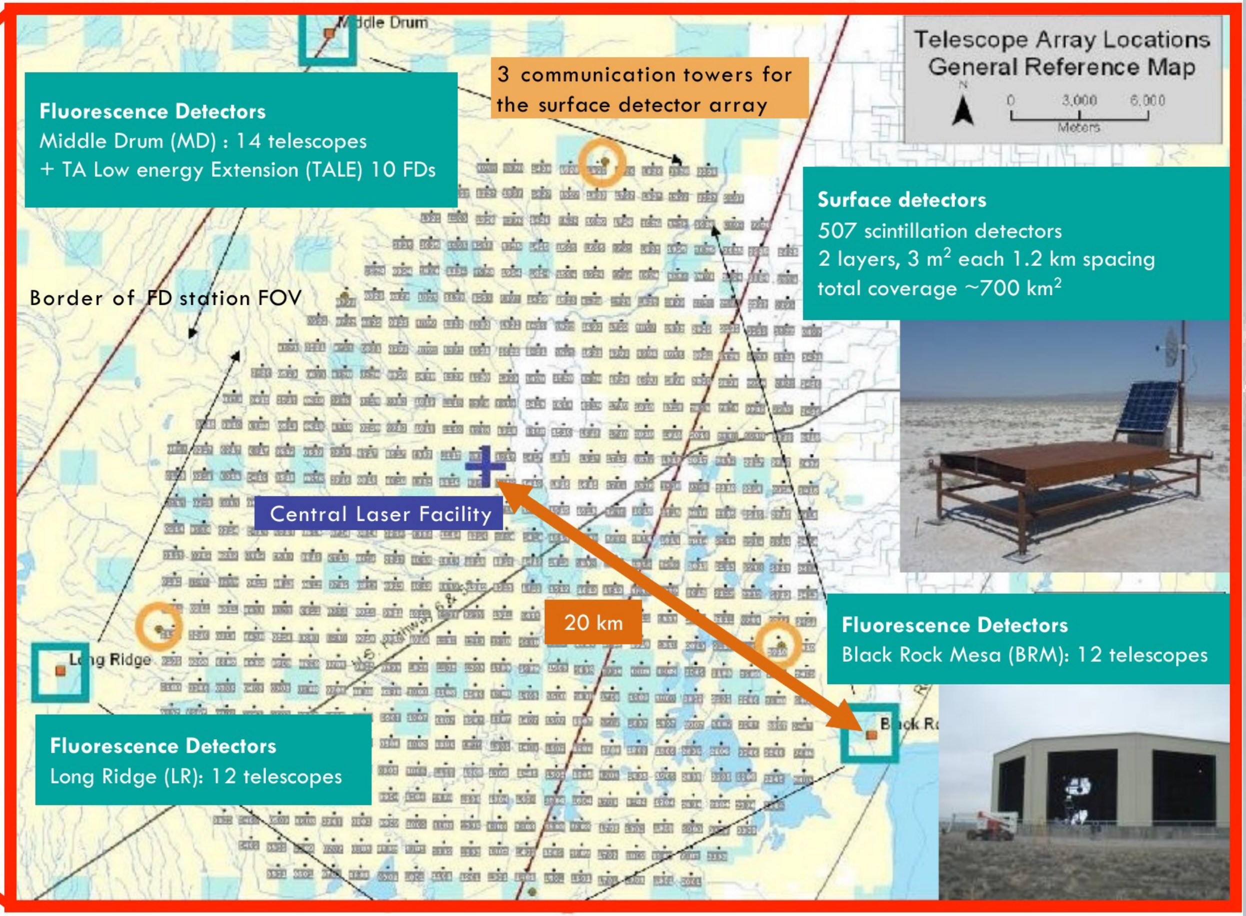
Scientific Goals

- Origin and nature of the ultra-high energy cosmic rays:
  - spectrum, composition, anisotropy
- Physics of high energy hadronic interactions
- Multi-messenger and interdisciplinary studies
  - photons, neutrinos, dark matters
  - thunderstorms, terrestrial gamma-ray flash

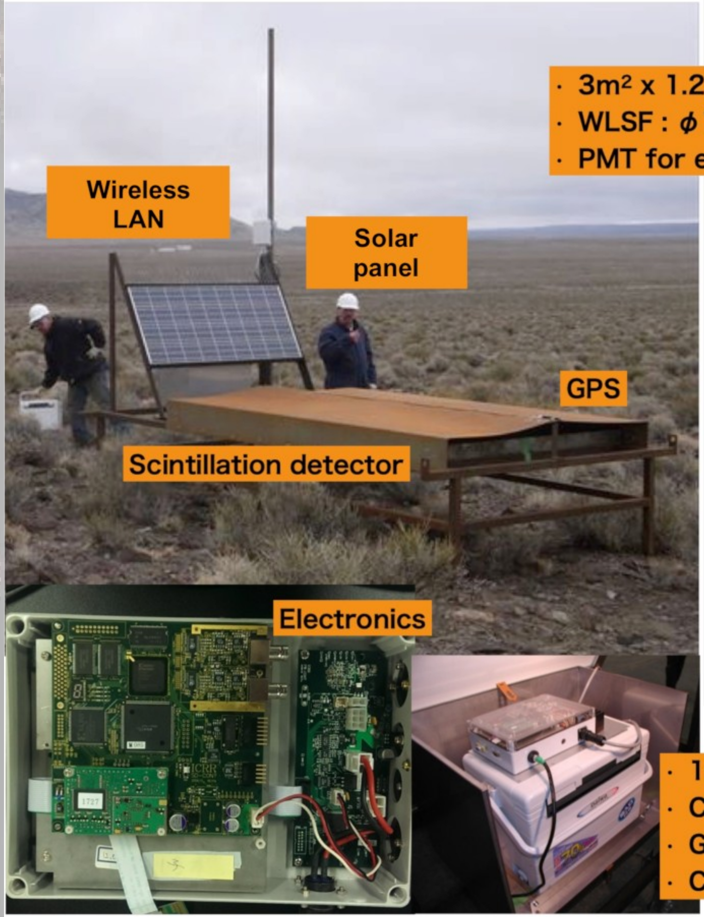
129 members
30 institutes, 9 countries

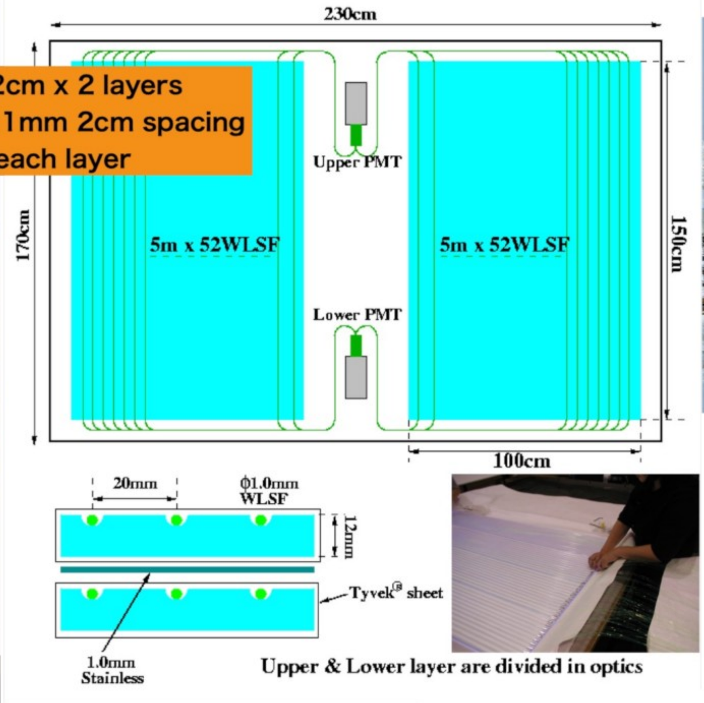
Telescope Array observatory





Surface Detector (SD)



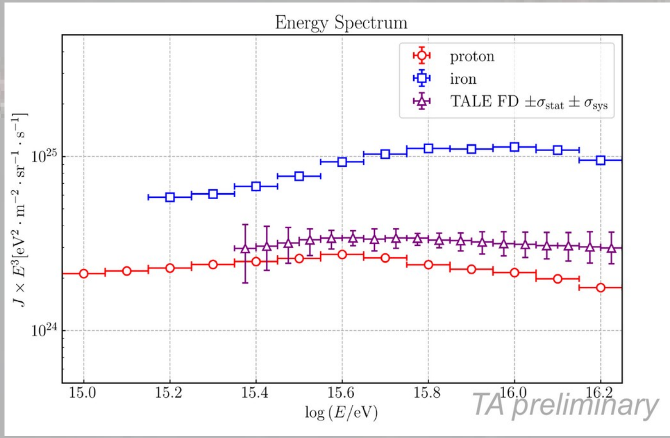


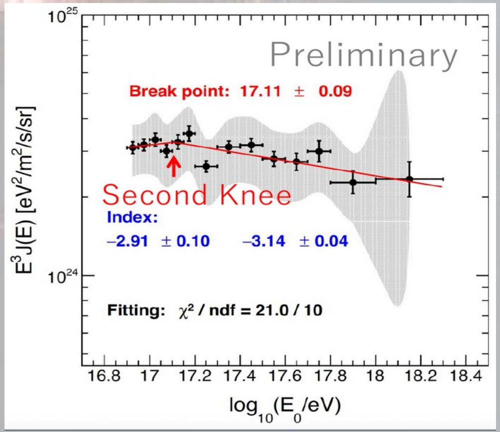
- 507 plastic scintillation stations
- 2 layers, 1.2 cm thick, 3 m^2 area
- 1.2 km square grid spacing covering

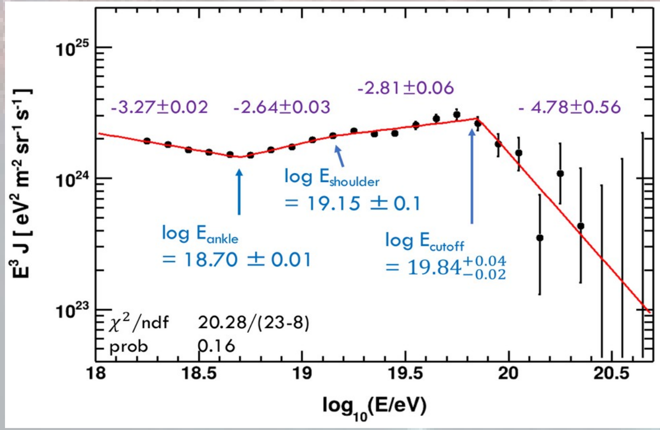
~700 km^2

From 10^{15} eV to more than 10^{20} eV within one observatory

- [Monday, 14:45] Haruto Matsushita, TALE infill SD spectrum @ PeV
- [Monday, 15:00] Hitoshi Oshima, TALE hybrid spectrum above 30 PeV
- [next talk] Jihyun Kim, TA SD spectrum from 1 EeV to N x 100 EeV
- *This talk: TA connection to UHECR sources and Multi-Messenger*

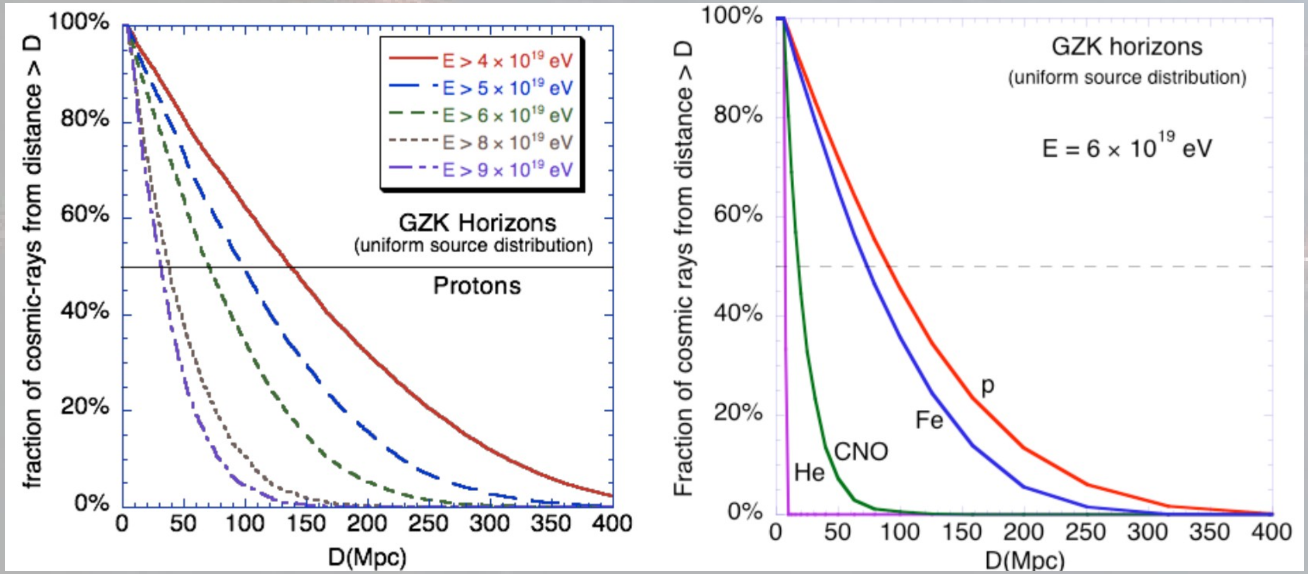






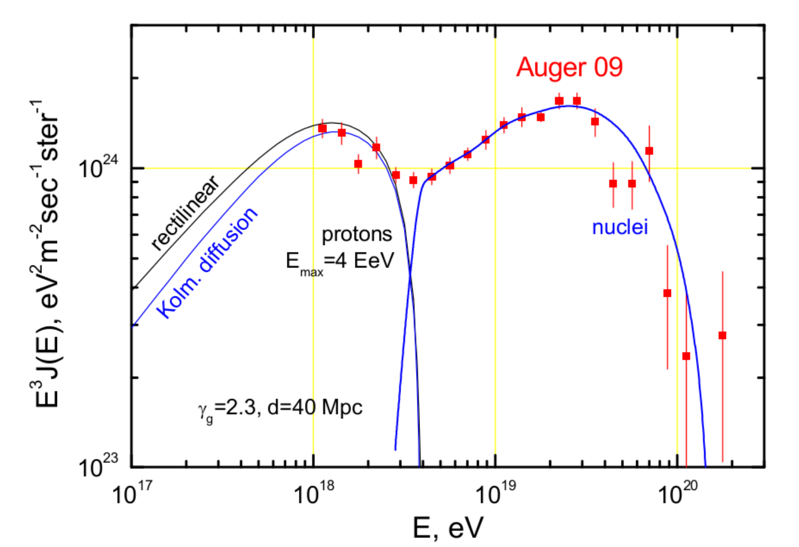
Is charged particle astronomy possible?

- Deflection of 60 EeV protons in the GMF is about 2º-6º
- Can we see the nearest source?
- Can we see GZK reaction? cosmogenic photons and neutrinos
  Berezinsky, Zatsepin, Phys. Lett B 28, 423 (1969)



A. Olinto et. al., White paper on UHECR (2009)

Disappointing model?

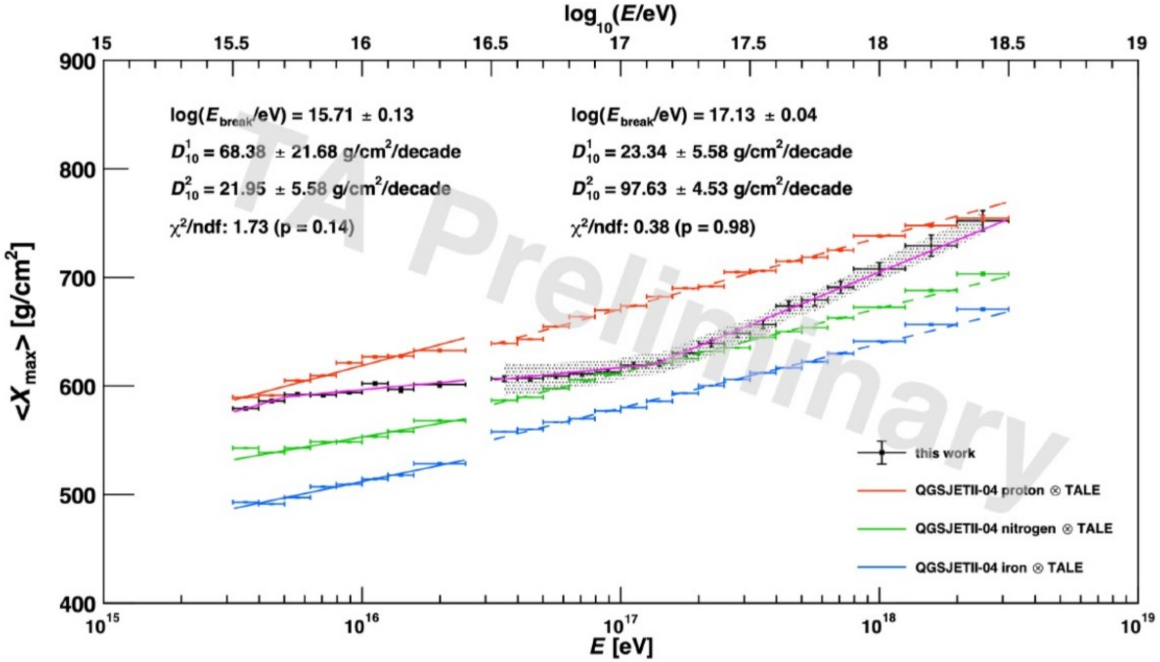


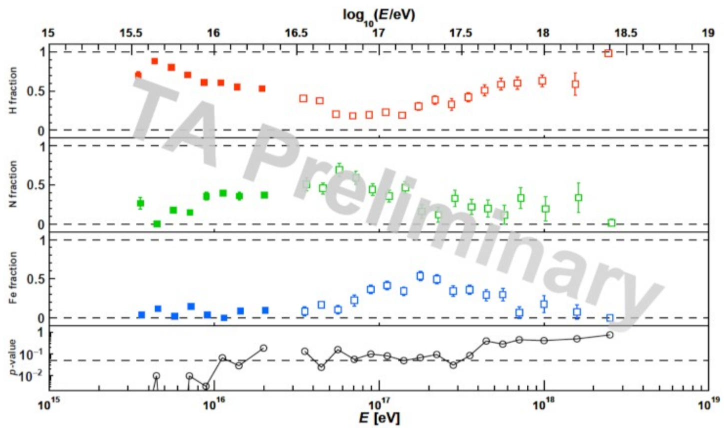
- Arrival directions do not correlate with the sources
- No observable cosmogenic neutrinos
- No cosmogenic photons

  Aloisio, Berezinsky, Gazizov, Astropart. Phys. 34 (2011)

- What positive we expect:
  - Dipolar and quadrupolar anisotropy
  - Astronomy with the highest energy particles
- Primary composition is a key to the source problem

TALE and TALE infill hybrid composition

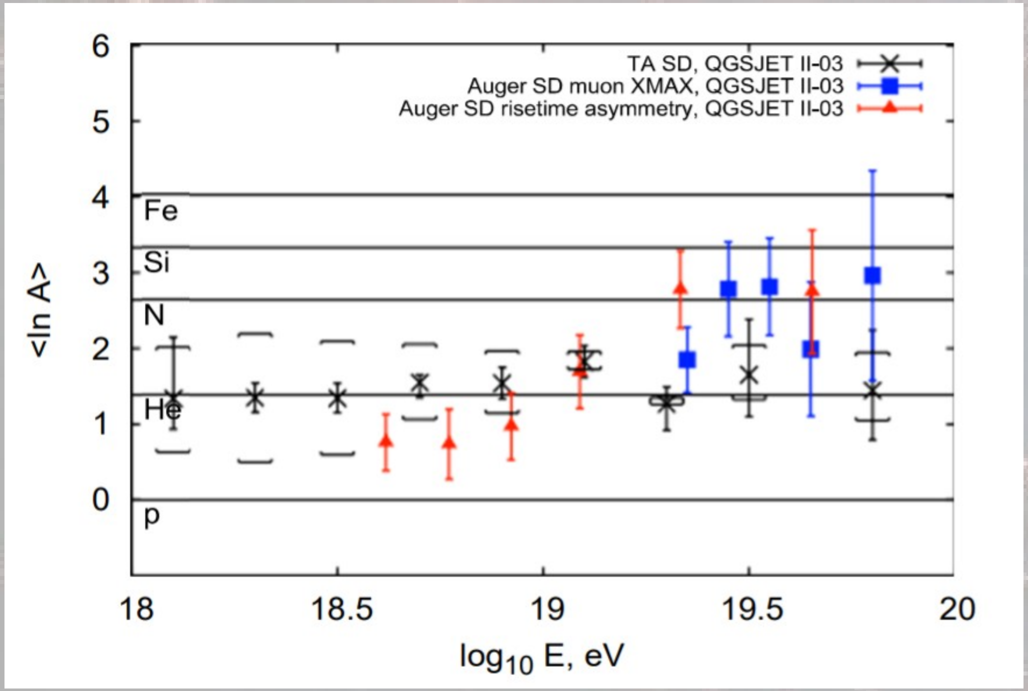


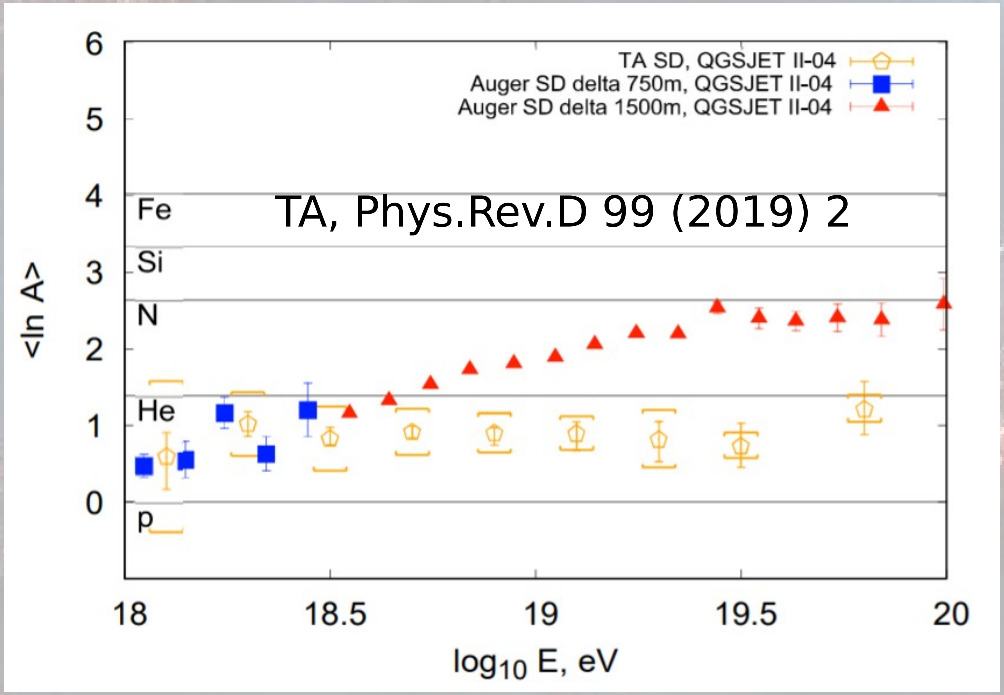


- Breaks in the ⟨X_{max}⟩ coincide with the knee and second knee.
- X_{max} distribution fits show a transition from light to heavy composition, peaking near $10^{17.13}$ eV.

K. Fujita, PoS(ICRC2025)261
TA Collaboration, Phys.Rev.D 113 (2026) 6, 062003

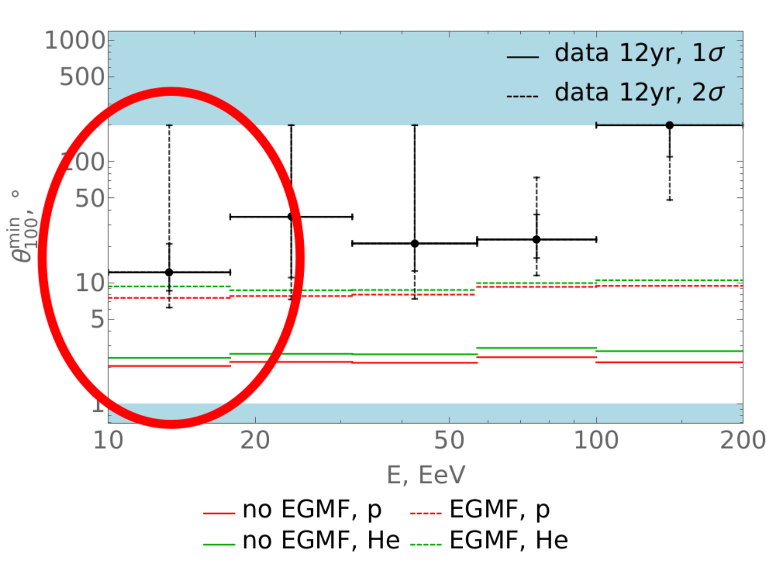
TA SD composition with Machine learning (BDT)

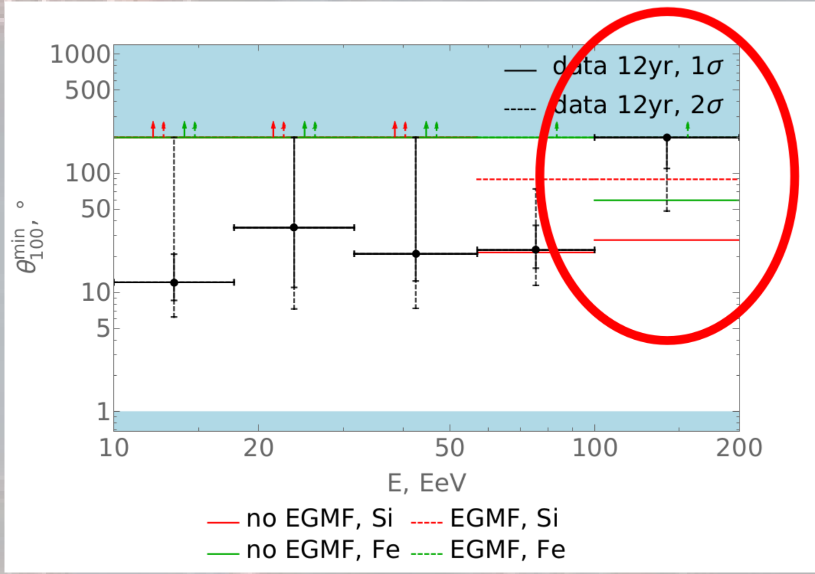




- Composition at the highest energy part (~ 100 EeV) is not known or uncertain

Mass composition from anisotropy of the arrival directions

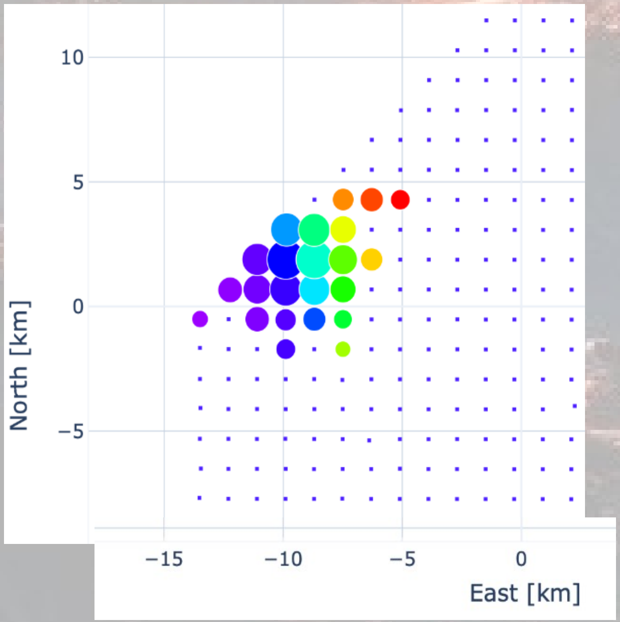


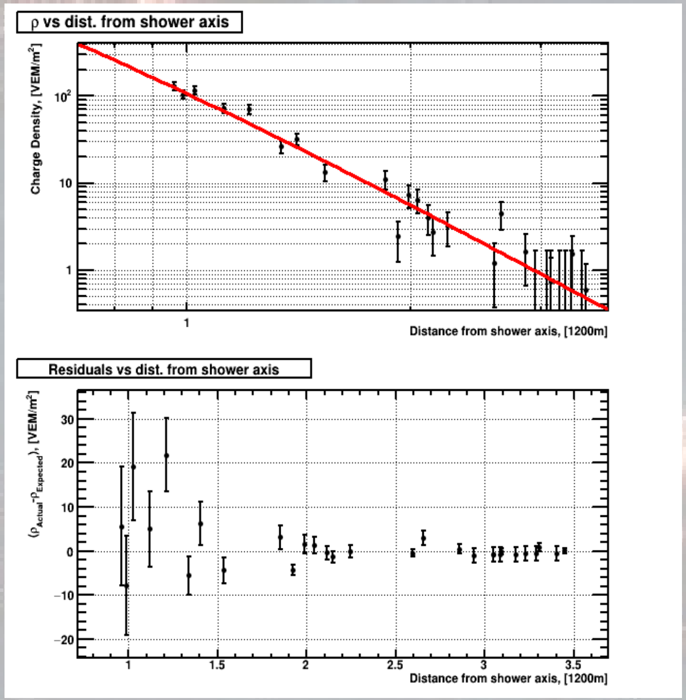


Heavy composition at the highest energies (E>100 EeV)!

Telescope Array Collaboration,
Phys.Rev.D 110 (2024) 2, 022006
Phys.Rev.Lett. 133 (2024) 4, 041001

An extreme Energy Event registered by TA SD

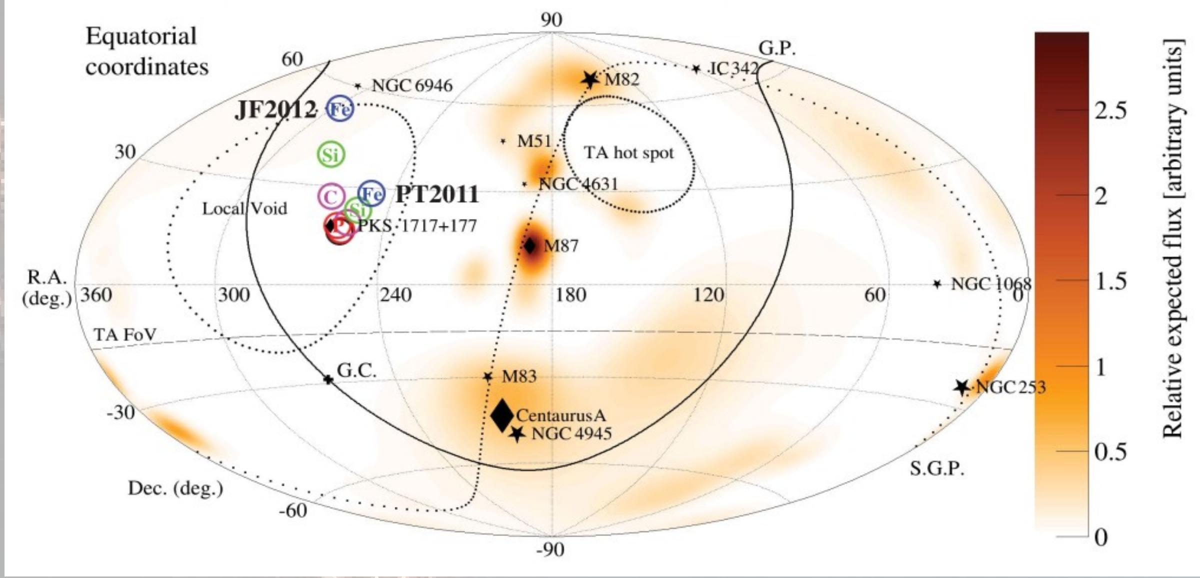




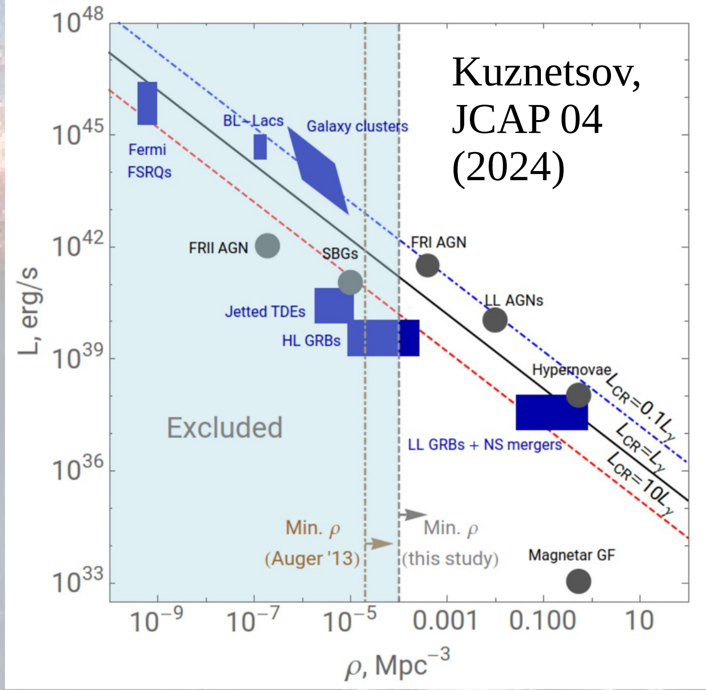
- Observed with TA SD at 10:35:56 on 27 May 2021 (UTC). No FD observation

Science 382, 903–907 (2023).

- E = **244 ± 29(stat.) ± 51(syst.) EeV**, zenith angle $\theta = 38.6°$

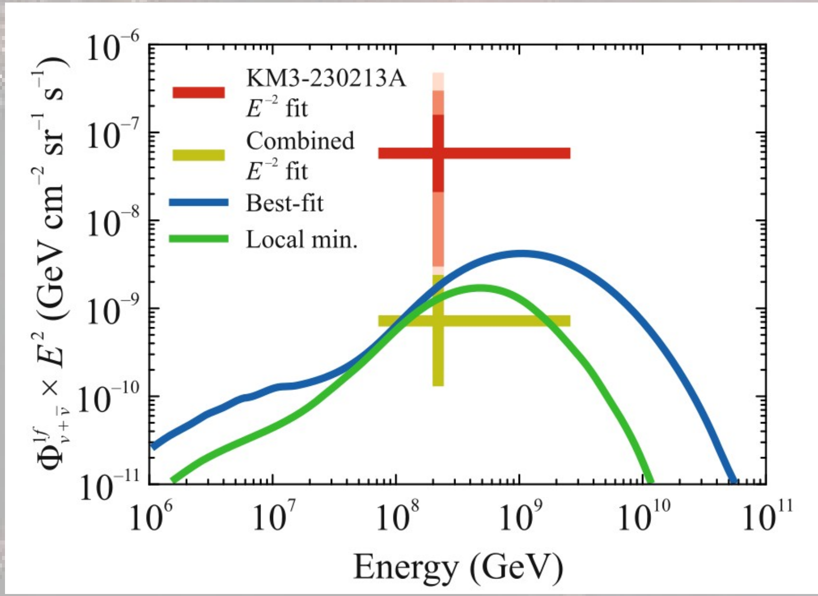


TA, Science 382, 903–907 (2023)

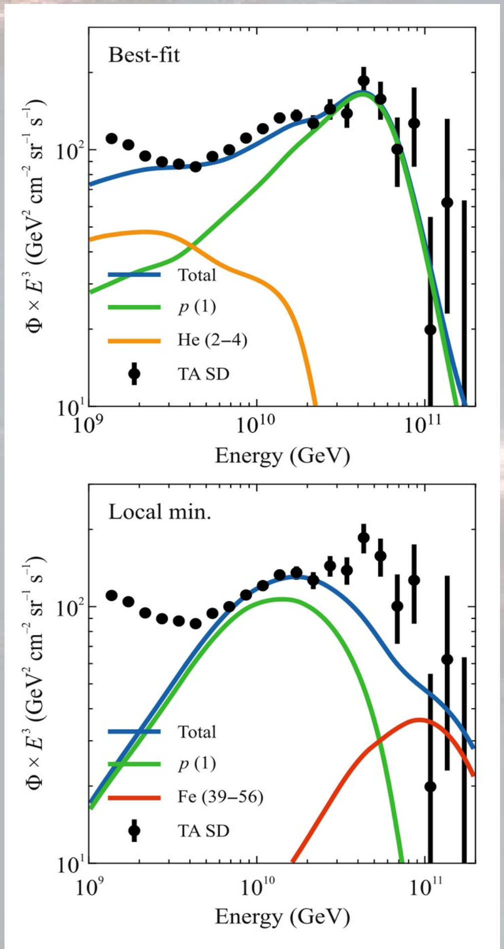


- $E = 2.44\text{x}10^{20}$ eV
- Event is coming from cosmic void
- Not a gamma-ray
- Primary particle should be a **heavy nuclei**
- The source is closer than 5 Mpc
- Constraint on the number density of sources

KM3-230213A UHE event as a cosmogenic neutrino



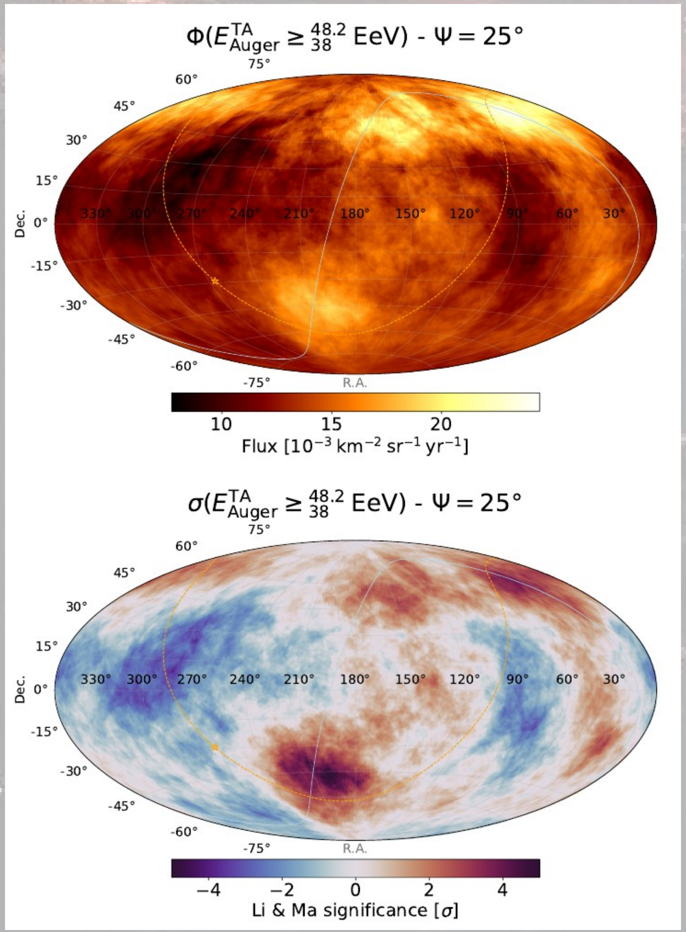
Kuznetsov et al, JETP Lett. 123 (2026) 5



TA spectrum and composition fit
Bergman,
PoS (ICRC2021)

- TA composition leads to natural explanation of KM3-230213A UHE event as a cosmogenic neutrino

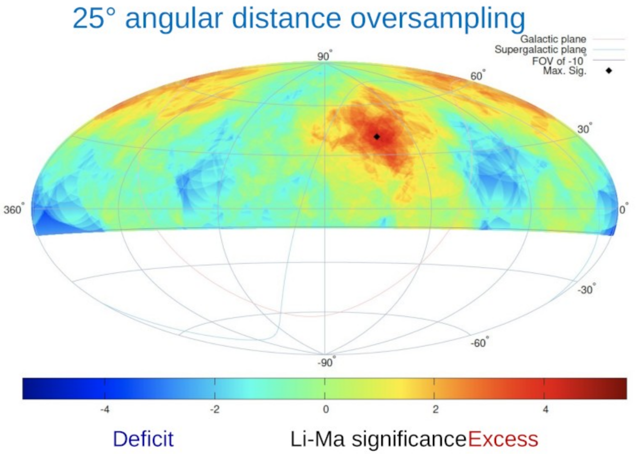
Observed UHECR sky



- Joint Auger + TA data
- Flux excess is observed in Centaurus A are at South (Auger) and Ursa Major constellation and Perseus-Pisces Supercluster regions at North (TA)
- No individual sources are observed

A. Gálvez Ureña, ICRC 2025

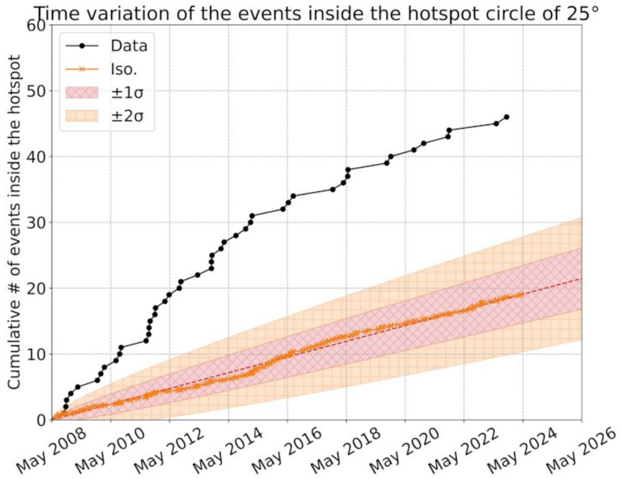
Telescope Array hot spot (16 yrs)



- 16-year TA SD data, E > 5.710^{19} eV
- 228 events (16-year TA SD data)
- Max local sig.: **4.9σ** at (144.0°, 40.5°)

  N_{obs}: 46 events
  N_{bg}: 19.1 events
  ~141% excess
- Post-trial probability:

  2.9



Growth of the Hotspot

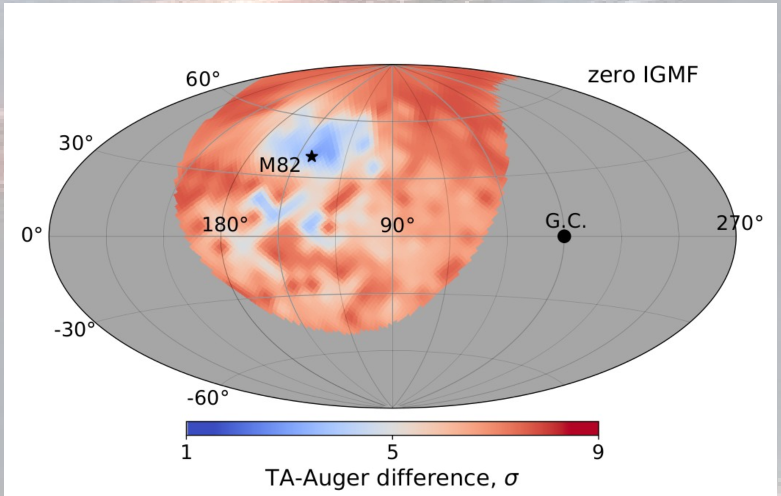
- Black dots: cumulative # of events falling inside the hotspot circle of 25° from (144.0°, 40.5°)
- Orange X's: cumulative # of isotropic background expectation

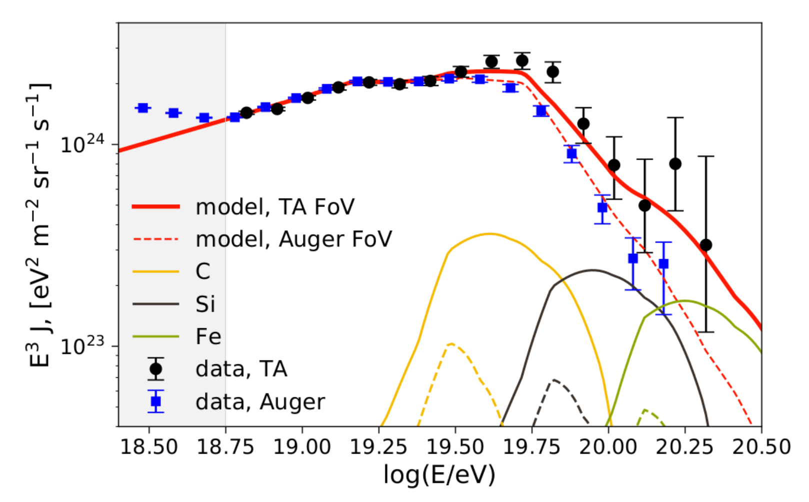
J. Kim, ICRC'2025

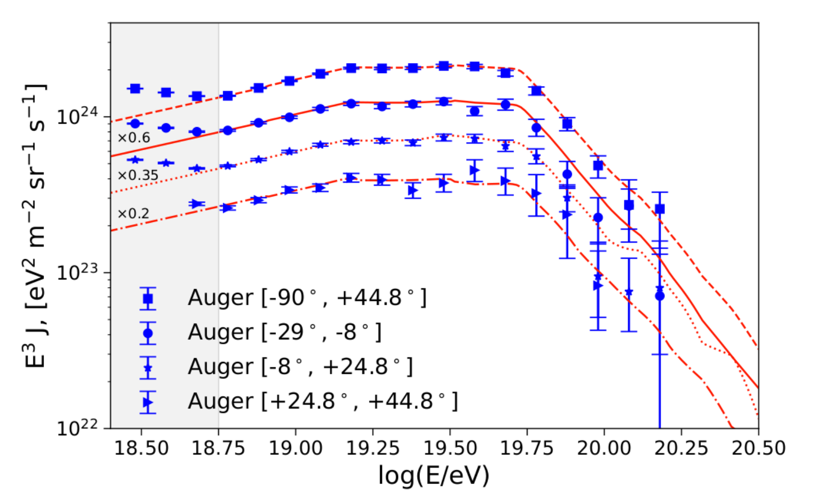
Hotspot interpretation as a bright nearby source

- Natural explanation for TA and Auger spectra difference

Korochkin, Tinyakov, Semikoz, arXiv:2511.09406





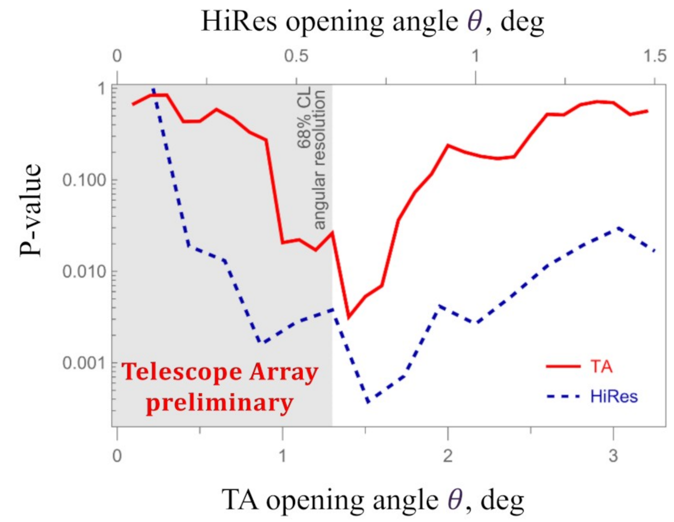


TA: BL Lac correlations

- HiRes has reported correlation of cosmic rays with E>10 EeV with BL Lac type objects (catalog of 156 objects with mag<18)

D. Gorbunov et al., JETP letters, 2004

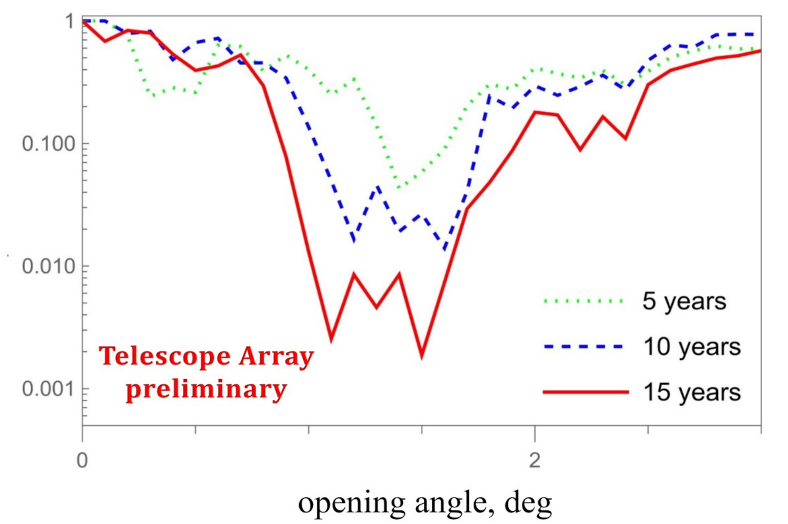
- The correlation is tested with the 15 years of TA SD data
- Post-trial probability p=0.04 (2.1σ)



The results are consistent, but signal for TA is weaker.

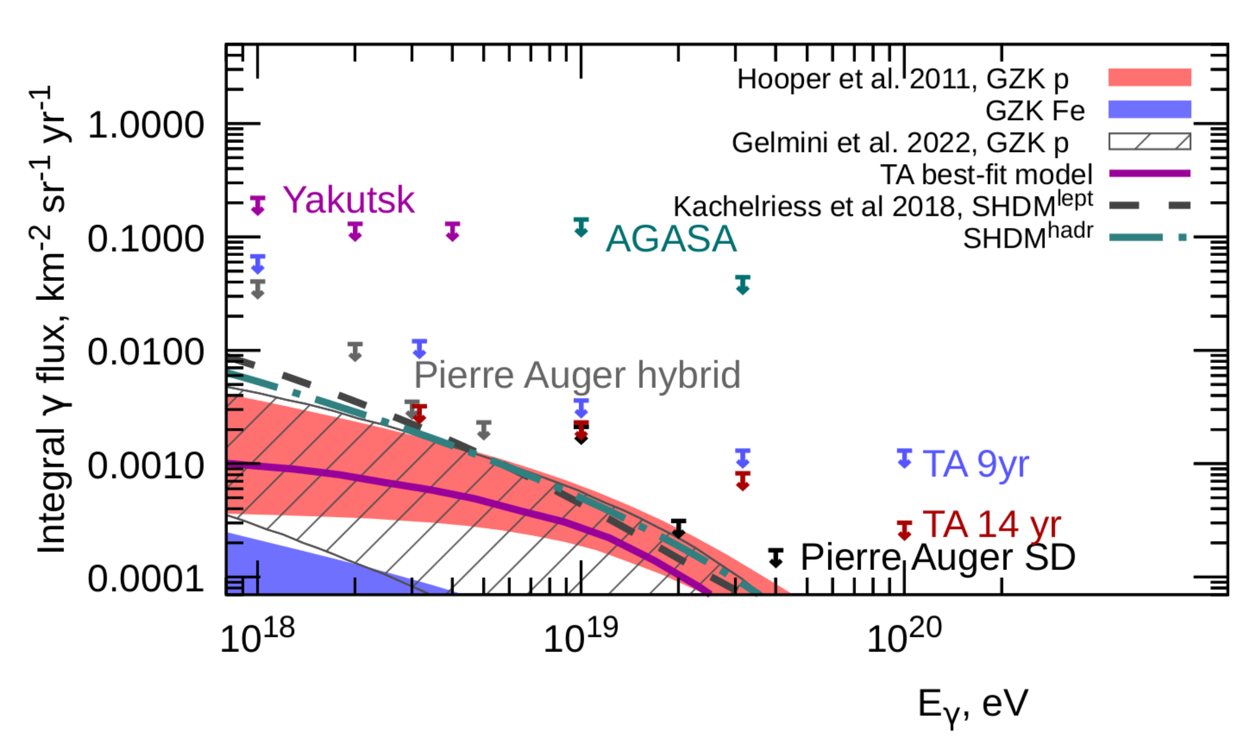
Fraction of excess events from BLLs in the data set:

Data set	fraction, %	68% CL	95% CL
HiRes stereo	3.0	±1.2	$^{+2.7}_{-2.0}$
TA SD	0.66	±0.25	$^{+0.50}_{-0.47}$

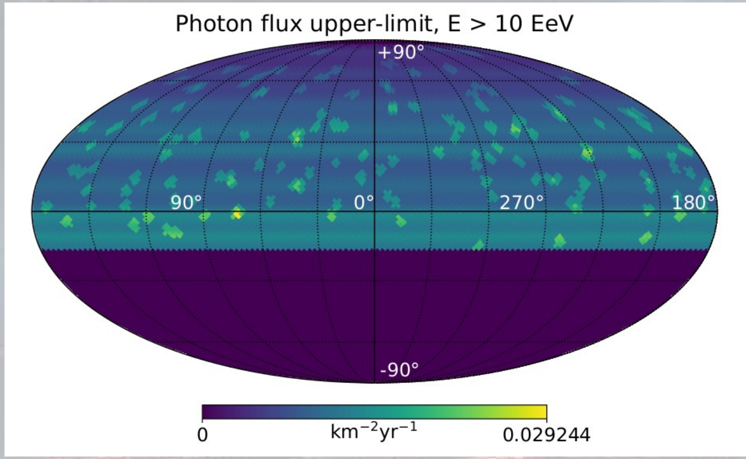


M. Kudenko, PoS(ICRC2025)311

Search for primary photons

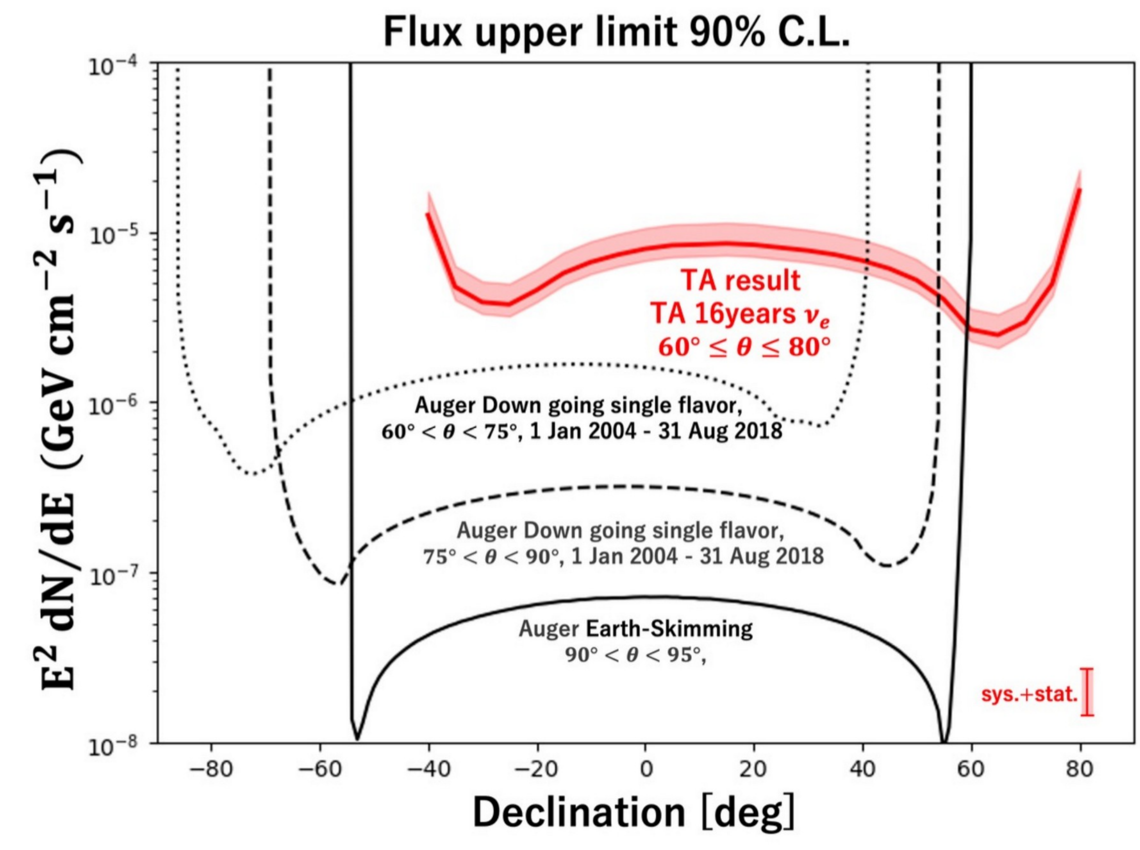


Telescope Array Collaboration, JCAP 06 (2026) 052



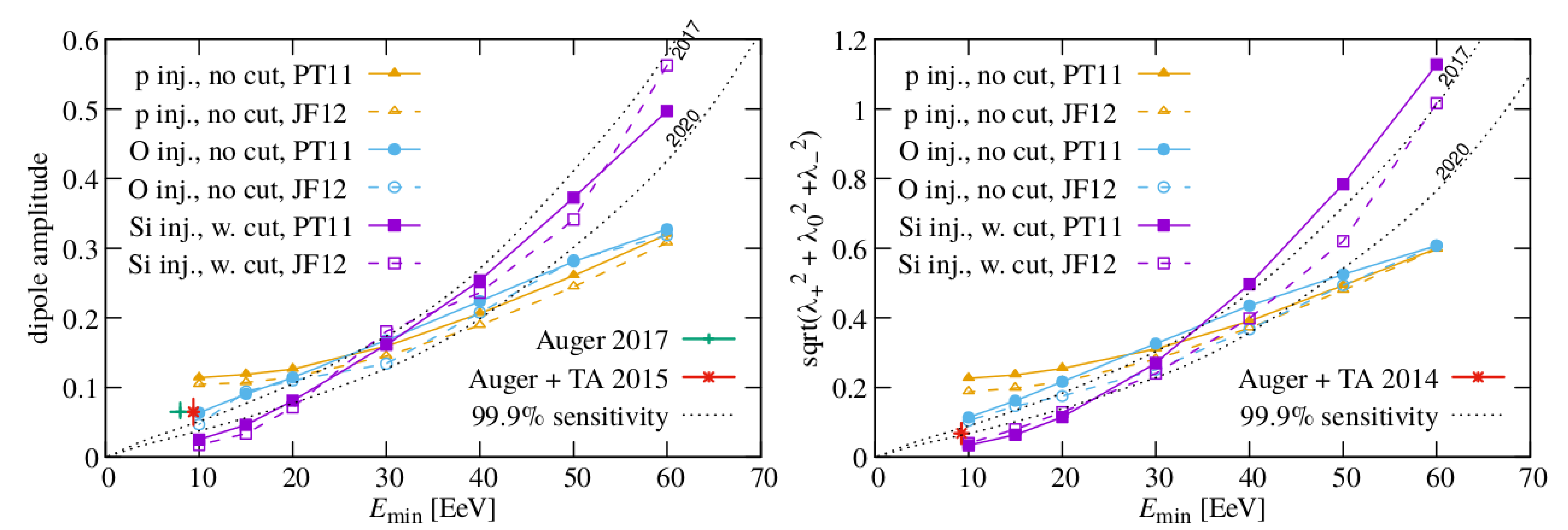
Telescope Array Collaboration, MNRAS 492 (2020) 3

Search for primary neutrino



- Upper limits on UHE neutrinos are obtained with 16 years of TA SD data.
- Inclined shower events : 60°< θ <80°
- No neutrino event was observed ($N_{\rm exp}$ = 2.44).

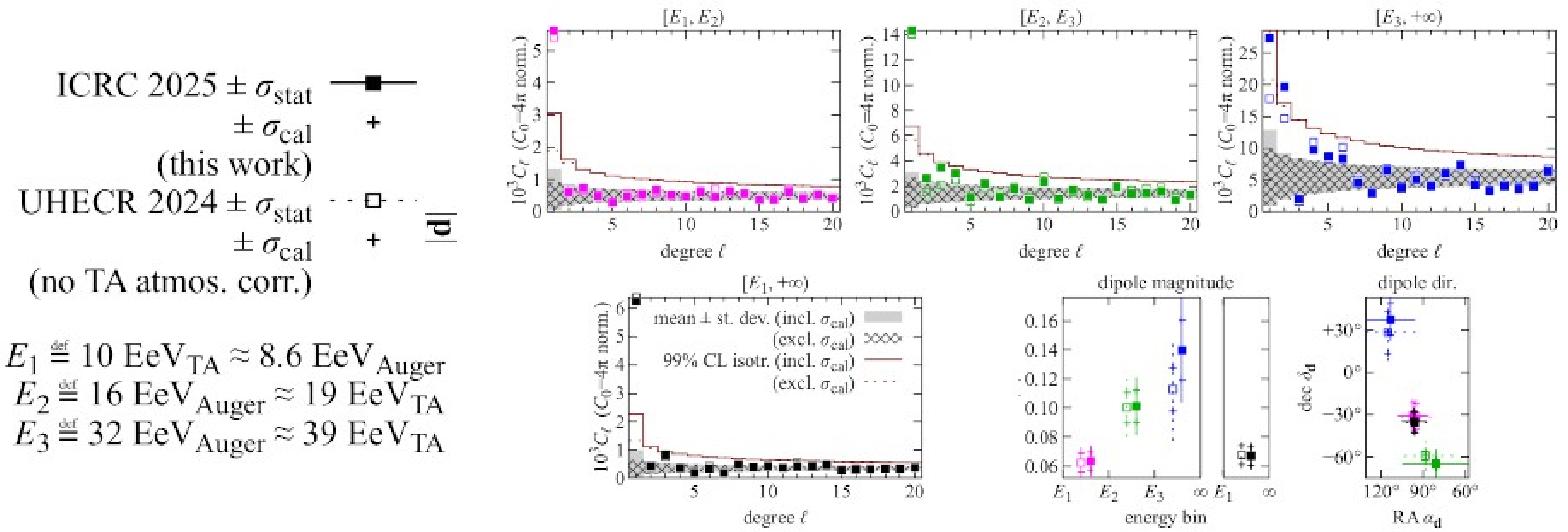
Search for dipole and quadrupole



di Matteo, Tinyakov, MNRAS 476 (2018) 715

- If the source distribution tracks the overall matter distribution, the dipole and quadrupole anisotropy should be observable

TA+Auger: Dipole and quadrupole



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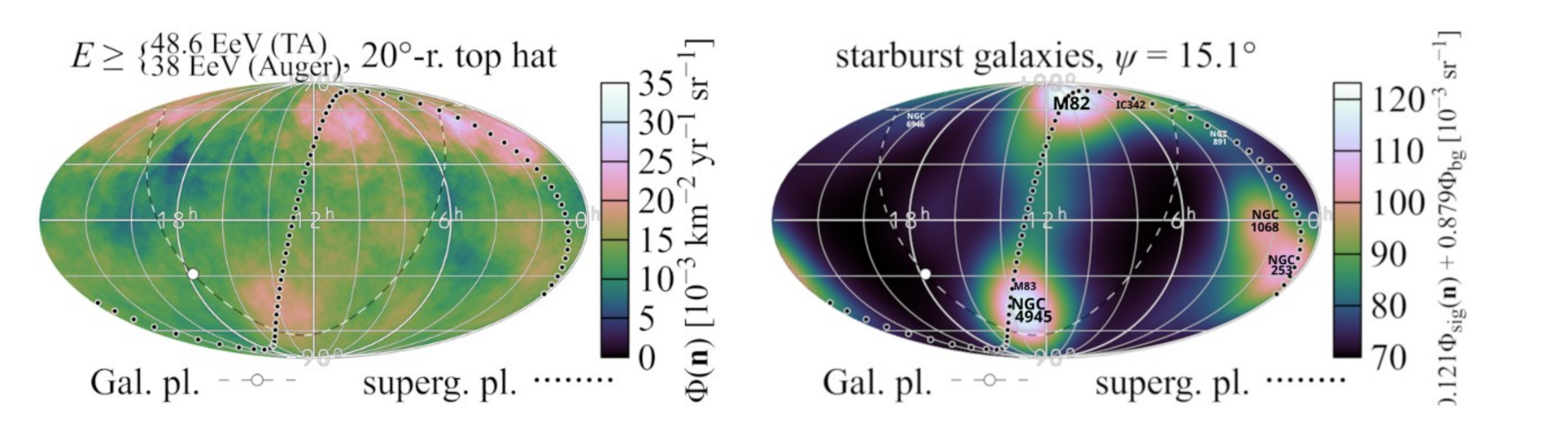
TA-Auger: correlations with starburst galaxies



	E_{min}	TS	$f/\%$	$\Theta/°$	post-trial
All galaxies	$37\,\text{EeV}_{\text{Auger}} \approx 47\,\text{EeV}_{\text{TA}}$	19.3	$13.1^{+4.7}_{-3.6}$	$15.5^{+6.1}_{-3.6}$	3.4σ
Starburst galaxies	$38\,\text{EeV}_{\text{Auger}} \approx 48\,\text{EeV}_{\text{TA}}$	27.3	$10.6^{+56.6}_{-3.2}$	$17.6^{+26.6}_{-4.1}$	4.2σ
All AGNs	$38\,\text{EeV}_{\text{Auger}} \approx 48\,\text{EeV}_{\text{TA}}$	17.6	$4.8^{+1.6}_{-1.4}$	$15.4^{+3.5}_{-2.8}$	3.3σ
Jetted AGNs	$37\,\text{EeV}_{\text{Auger}} \approx 47\,\text{EeV}_{\text{TA}}$	22.9	$8.8^{-2.6}_{-2.3}$	$17.4^{+3.4}_{-2.8}$	3.8σ

A. Gálvez Ureña, ICRC 2025

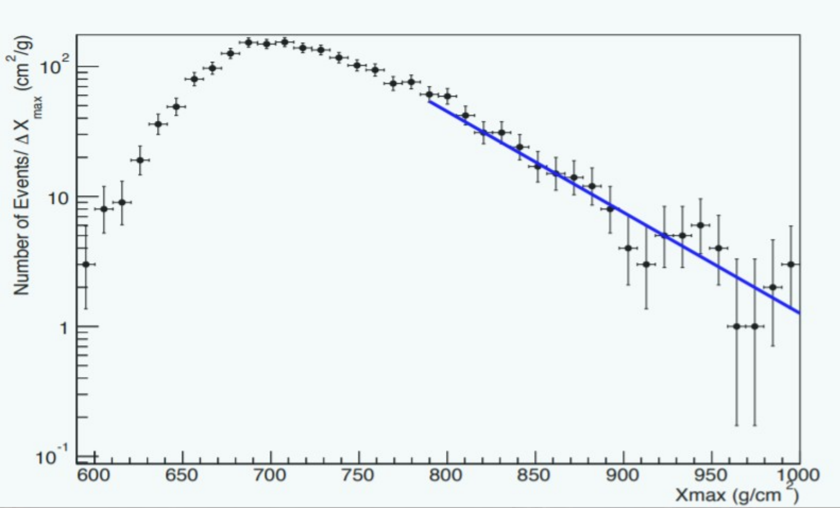
Conclusions

- The Telescope Array provides valuable insights into the origin of UHECRs
- The charged particle astronomy is feasible at the highest energies, the primary mass composition is a key
- KM3-230213A may naturally be interpreted as a cosmogenic neutrino event
- The 244 EeV TA event most likely originated from a nearby source
- The TA hotspot may indicate a bright nearby source
- An enhanced exposure of TAx4 is crucial for revealing new Multi-Messenger connections

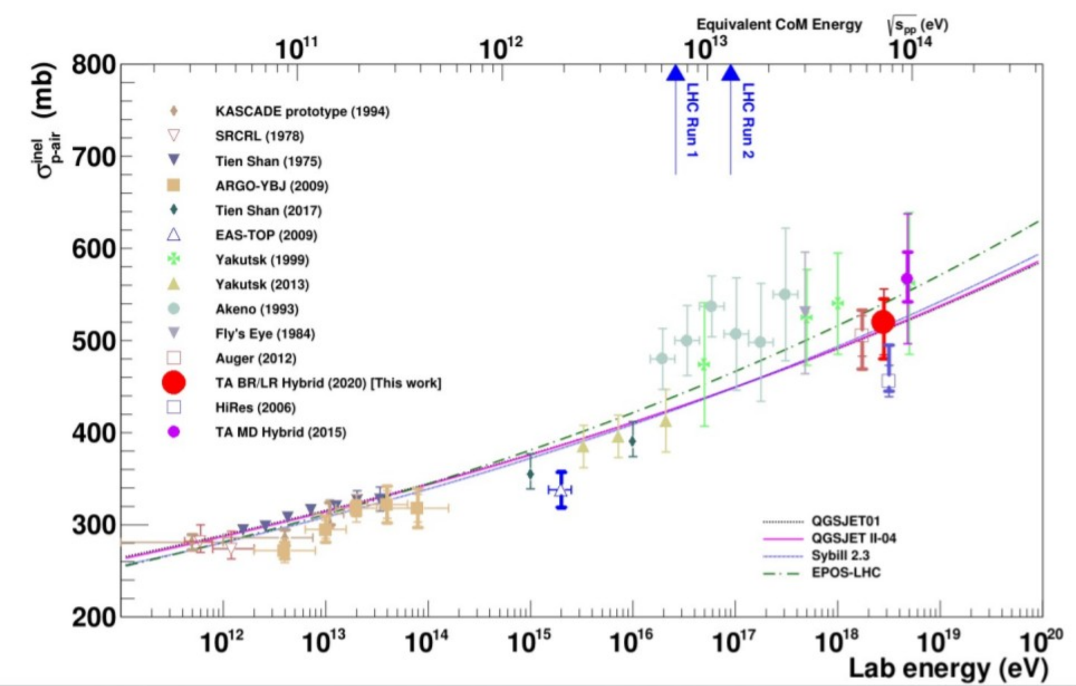
Thank you!

This work is supported in the framework of the State project ``Science'' by the Ministry of Science and Higher Education of the Russian Federation under the contract 075-15-2024-541.

TA proton-air cross-section



Measuring XMAX attenuation length in hybrid mode.



TA Collaboration, Phys. Rev. D 102 (2020) 062004