Activity and financial requests - Auger LNGS

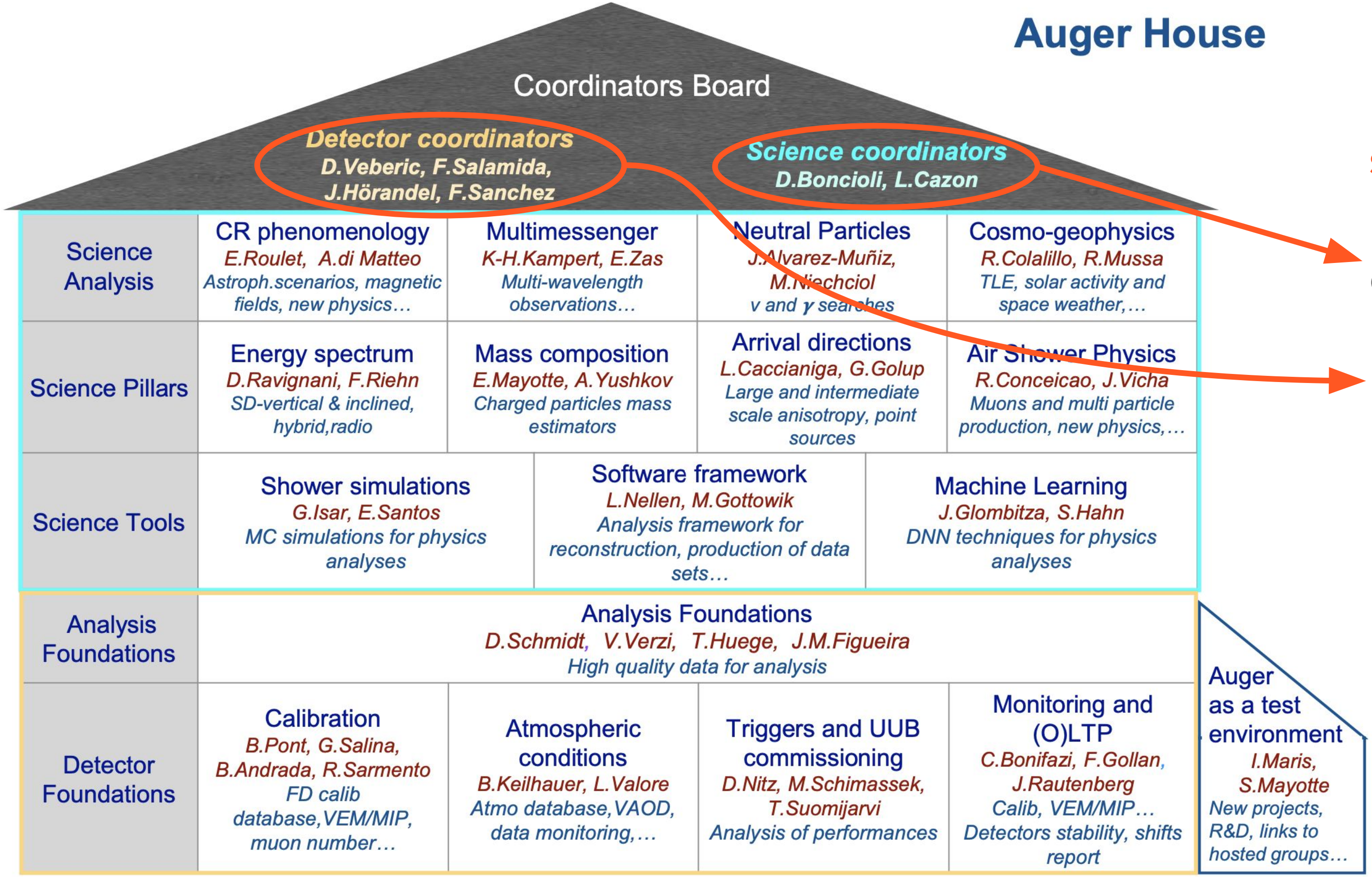
F. Salamida
Università dell'Aquila & INFN LNGS

L'Aquila Auger Group

10.7 FTE in total (8.4 in 2024)

1	Sergio Petrera	0%	GSSI	Prof. Ordinario - **in quiescenza**
2	Vincenzo Rizi	60%	UNIVAQ	Prof. Ordinario
3	Ivan De Mitri	60%	GSSI	Prof. Ordinario
4	Roberto Aloisio	60%	GSSI	Prof. Ordinario
5	Francesco Salamida	80%	UNIVAQ	Prof. Associato - **Responsabile locale**
6	Denise Boncioli	70%	UNIVAQ	Prof.ssa Associata
7	Carmelo Evoli	60%	GSSI	Prof. Associato
8	Felicia Barbato	60%	GSSI	RTD/B
9	Pierpaolo Savina	60%	GSSI	RTD/A
10	Fabio Convenga	100%	UNIVAQ/LNGS	Assegnista
11	Emanuele Avocone	60%	UNIVAQ	Assegnista
12	Camilla Petrucci	100%	UNIVAQ	Dottoranda
13	Alessandro Cermenati	100%	GSSI	Dottorando
14	Luciana Andrade Dourado	100%	GSSI	Dottoranda
15	Igor Vaiman	100%	GSSI	Dottorando

Responsibilities in Auger



Since January 2024

Denise Boncioli - Science Coordinator

Francesco Salamida - Detector Coordinator FD

Publications 07/2023 - 07/2024

1. AugerPrime Surface Detector Electronics - JINST 18 (2023) P10016
2. Testing Hadronic-Model Predictions of Depth of Maximum of Air-Shower Profiles and Ground-Particle Signals using Hybrid Data of the Pierre Auger Observatory - Phys. Rev. D 109, 102001 (2024)
3. Constraints on metastable superheavy dark matter coupled to sterile neutrinos with the Pierre Auger Observatory - Phys. Rev. D 109, L081101 (2024)
4. Ground observations of a space laser for the assessment of its in-orbit performance - Optica 11 (2024) 263-272
5. Constraining models for the origin of ultra-high-energy cosmic rays with a novel combined analysis of arrival directions, spectrum, and composition data measured at the Pierre Auger Observatory - JCAP 01 (2024) 022
6. Radio Measurements of the Depths of Air Shower Maxima at the Pierre Auger Observatory - Phys. Rev. D 109 (2024) 022002 (sibling of a PRL)
7. Demonstrating Agreement between Radio and Fluorescence Measurements of the Depth of Maximum of Extensive Air Showers at the Pierre Auger Observatory - Phys. Rev. Lett. 132 (2024) 021001 (sibling of the PRD)
8. Impact of the Magnetic Horizon on the Interpretation of the Pierre Auger Observatory Spectrum and Composition Data - Accepted in JCAP

The publications with a relevant contribution from the L'Aquila group are highlighted

Main LNGS group activities

- Spectrum Measurement with Hybrid Events i.e., Fluorescence Detector + Surface
- Development and Maintenance of the SimProp Code for UHECR Propagation
- Analysis of Spectrum + Composition Measurements in Terms of Astrophysical Scenarios
- High-Energy Neutrinos and photon searches in the Context of Multimessenger Astronomy
- Mass Measurement Analysis
- Study of Limits on Lorentz Invariance Violation with UHECRs
- Limits on Dark Matter
- Properties of UHECR Fluxes Exiting Galaxies
- Outreach activities: Auger Masterclass, Street Science
- Commissioning of the UUB
- Atmospheric Characterization Activities with the Raman Lidar/CLF

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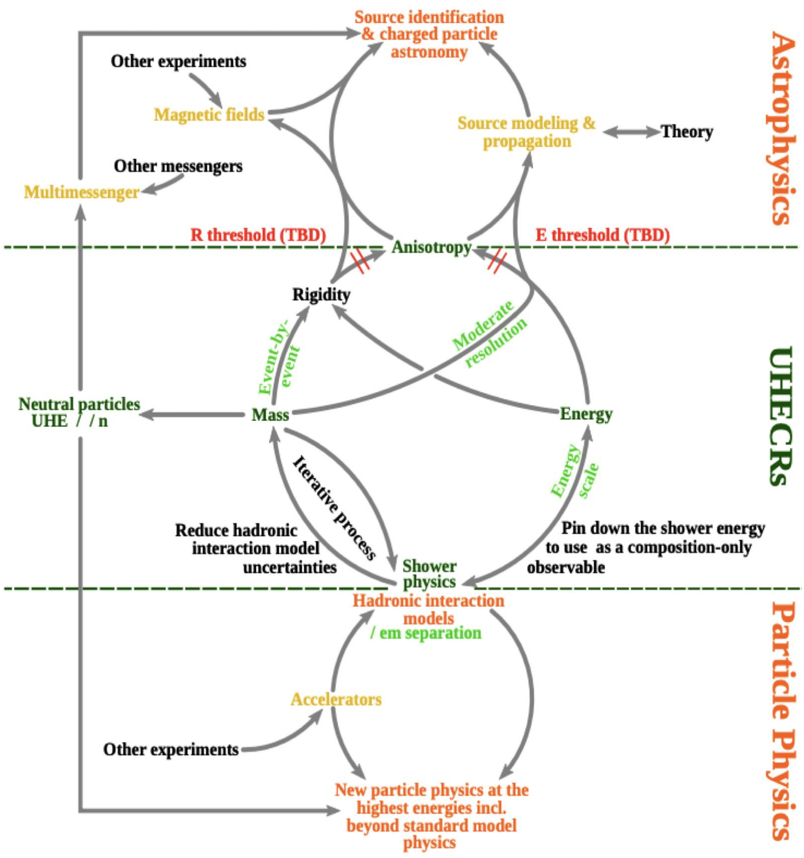
The items that will be discussed in the next slides are highlighted

Neutral particles and Multi-Messenger Physics



- Neutral particles play a crucial role for the current efforts in **multi-messenger astronomy**
- One of the main goals: understanding <u>where and how</u> UHECRs are produced
- Intimate connection between UHE photons and neutrinos and UHECRs
- Can be produced either directly at the sources of UHECRs (**astrophysical**) or during their propagation through the Universe (**cosmogenic**)
- <u>Complementary messengers</u>: photons trace the local Universe up to Mpc scales, while neutrinos can traverse the whole Universe
- Neutral particles can also serve as cosmic probes of fundamental physics and open a window to new physics

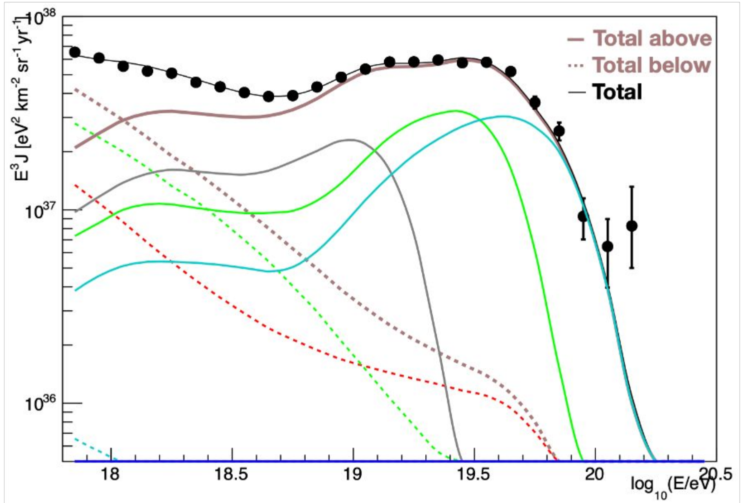
Neutrinos and Multi-Messenger Physics

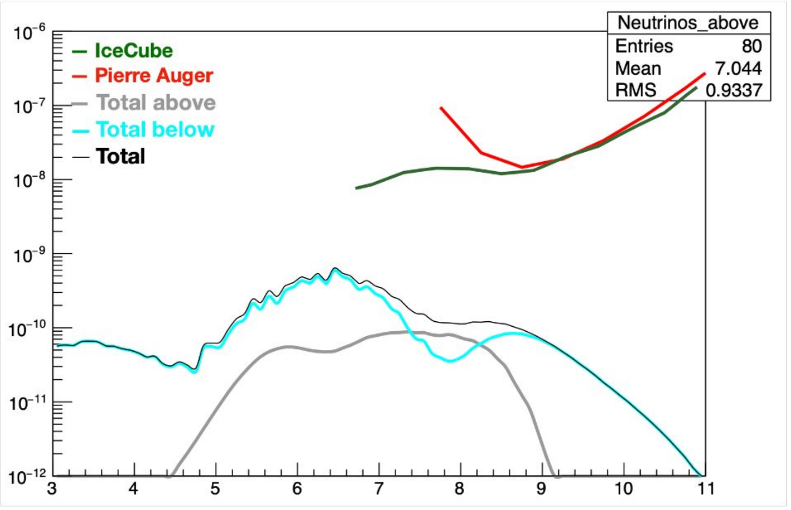
Simultaneous information coming from UHECRs spectrum and associated neutrino fluxes

2 EG POPULATIONS: $$\frac{dN}{dE} \propto f_A \left(\frac{E}{10^{18} eV} \right)^{-\gamma} \times f_{cut}(E, Z_A R_{cut}) \times (1+z)^m$$

- Fitted parameters:
  - Primary mass composition $\times 2$ (^{1}H, ^{4}He, ^{14}N, ^{28}Si, and ^{56}Fe)
  - Spectral index γ_{HE}, γ_{LE}
  - Maximal energy $E_{max,HE}$, $E_{max,LE}$

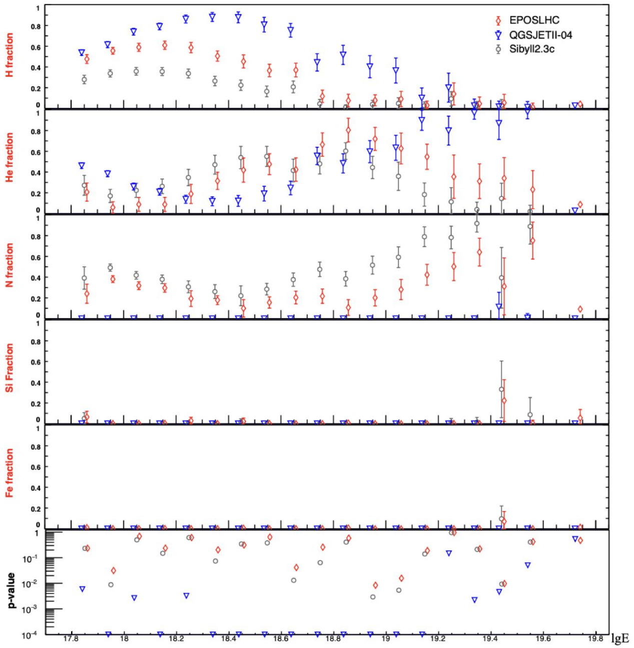
- Scanning over m, z_{max} parameters:
  - $m_{HE,LE} \in [2.0, 5.0]$
  - $z_{max(HE,LE)} \in [1.0, 5.0]$





Mass composition/fractions

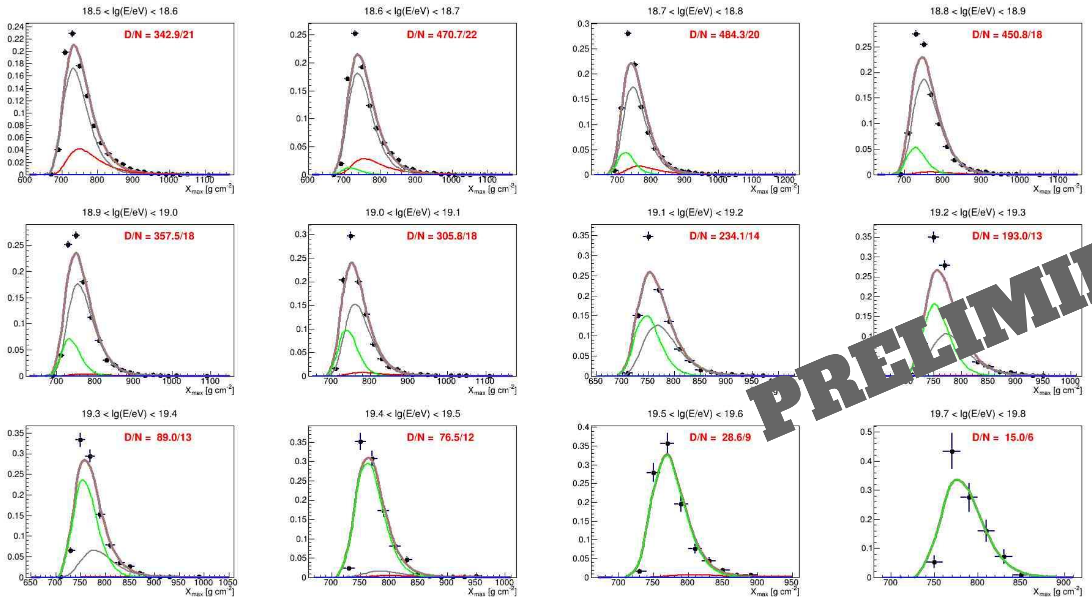
- Cosmogenic neutrinos are more sensitive to the distribution of UHECR sources in redshift than UHECR themselves, due to the UHECR horizon
- Cosmogenic neutrinos are produced in photo-meson productions -> UHECR mass composition influences the expected neutrino flux (as well as the UHECR spectral parameters)

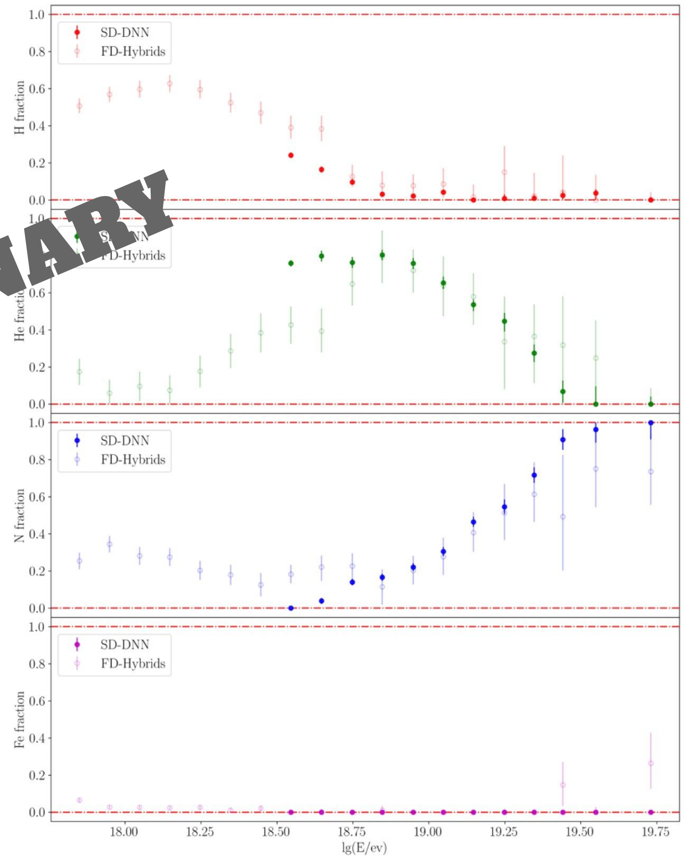


- Determining the UHECR proton fraction at the highest energies is crucial for understanding the detected UHECR mass composition, but also indirectly to better constrain the UHECR characteristics

- Determination of heavy masses relevant for understanding of acceleration processes (re-acceleration?) and/or mass composition in acceleration sites

Mass composition/fractions





- the higher statistics of SD w.r.t FD (> factor 10) allow to reach higher energies (~ above 19.5)
- the preliminary results show an overall agreement with FD (Z dependent peak position)

Fundamental Physics: LI Violation in EAS

- Lorentz Invariance (LI) could be considered as a low-energy approximation and it may be deformed approaching the Planck scale (about 15 orders of magnitude larger than the LHC center of mass energy).
- Possible LIV effects can be tested at the extreme energies available in UHECR propagation and shower development
- Following the phenomenological approach of S. R. Coleman and S. L. Glashow D 59, 116008 (1999) :

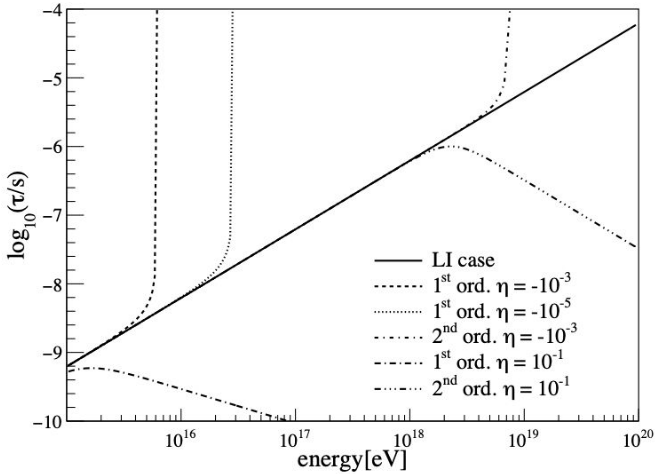
$$E^2 - p^2 = m^2 + \eta^{(n)} \frac{p^{n+2}}{M_{\rm Pl}^n}$$

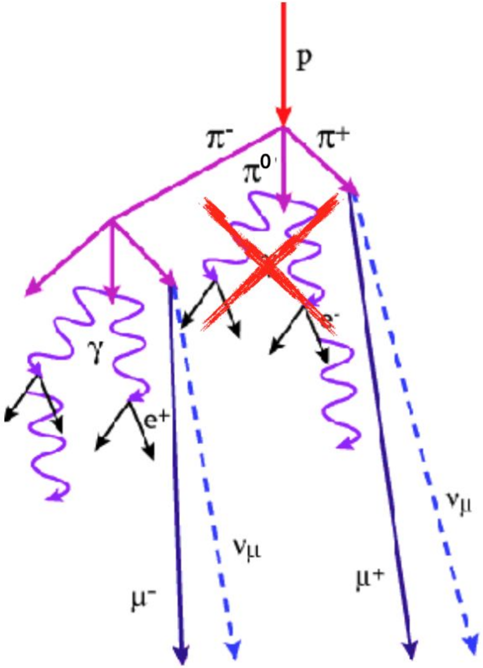
n is the order of the perturbation

$$m_{\rm LIV}^2 = m^2 + \eta^{(n)} \frac{p^{n+2}}{M_{\rm Pl}^n}$$

$$\gamma_{\rm LIV} = E/m_{\rm LIV}$$

for certain LIV scenarios the neutral pion in showers does not decay above a certain energy threshold





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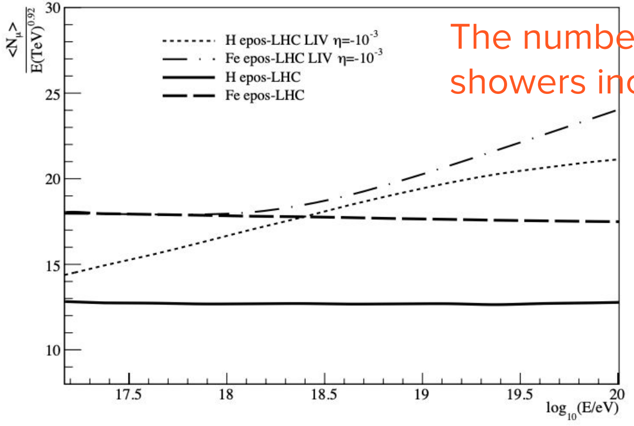
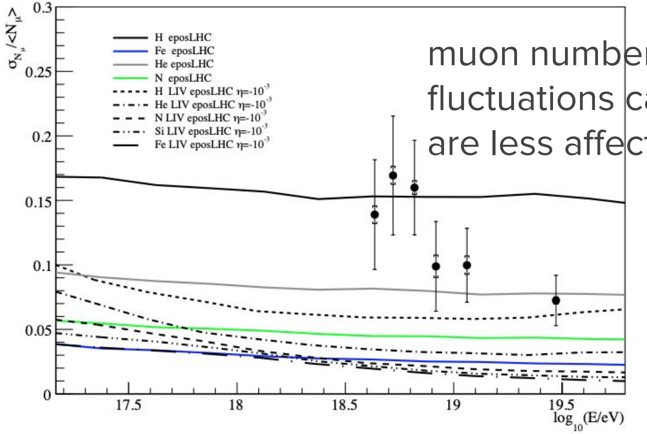
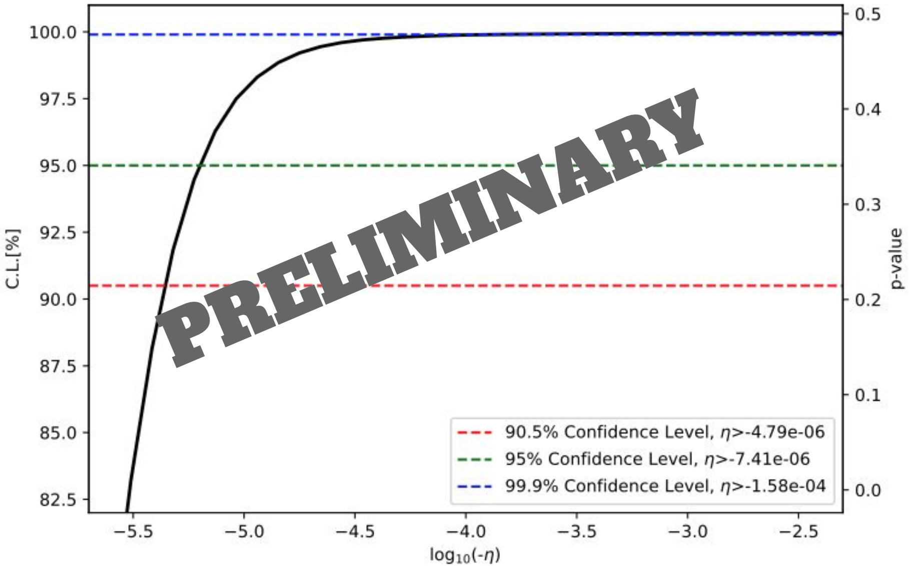


The number of muons in showers increases



muon number relative fluctuations can be used as are less affected by HIM

increasing Violation strength



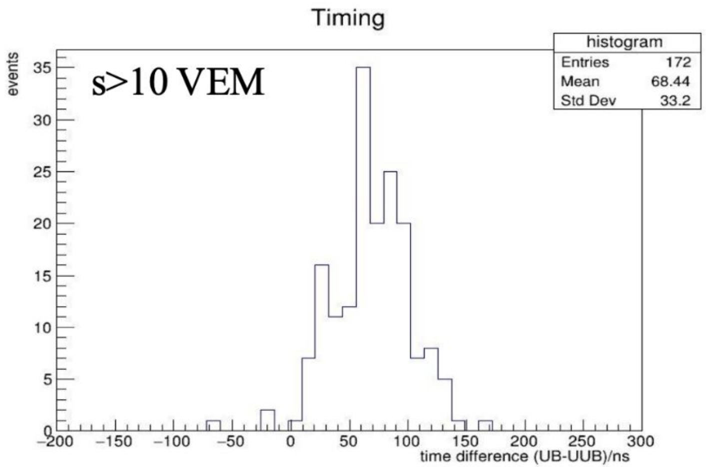
- Very good limits can be established on LIV parameter
- PRL paper in preparation

UUB commissioning: FD-SD time offset

- Between UB and UUB there is a time offset
- Indirect offset measurement
- Direct offset measurement on Jamie
- The value was measured to be

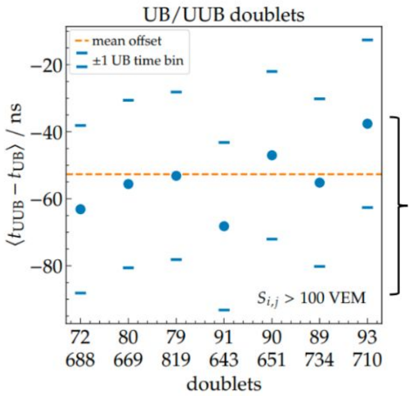
$$\Delta t_{ub-uub}^{start\ time} = 68.4 \pm 2.5ns$$

- Estimating how the presence of some outliers may affect the measurement, despite this is the best we have so far



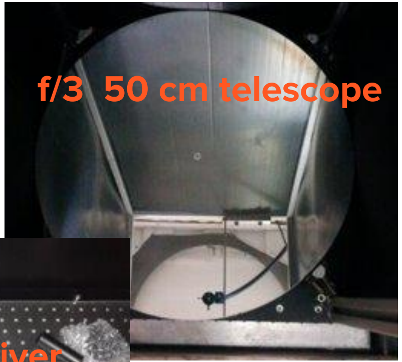
Direct measurements made on a tank equipped with UB and UUB

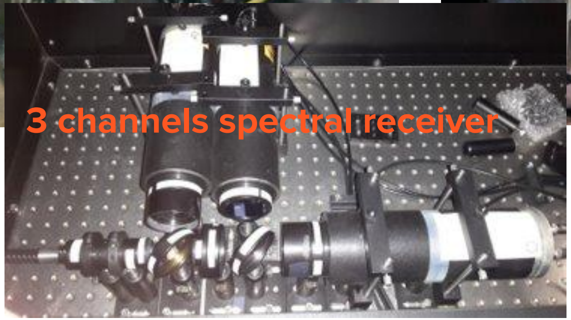
GAP-2023-032



40-70 ns

Atmospheric Monitoring



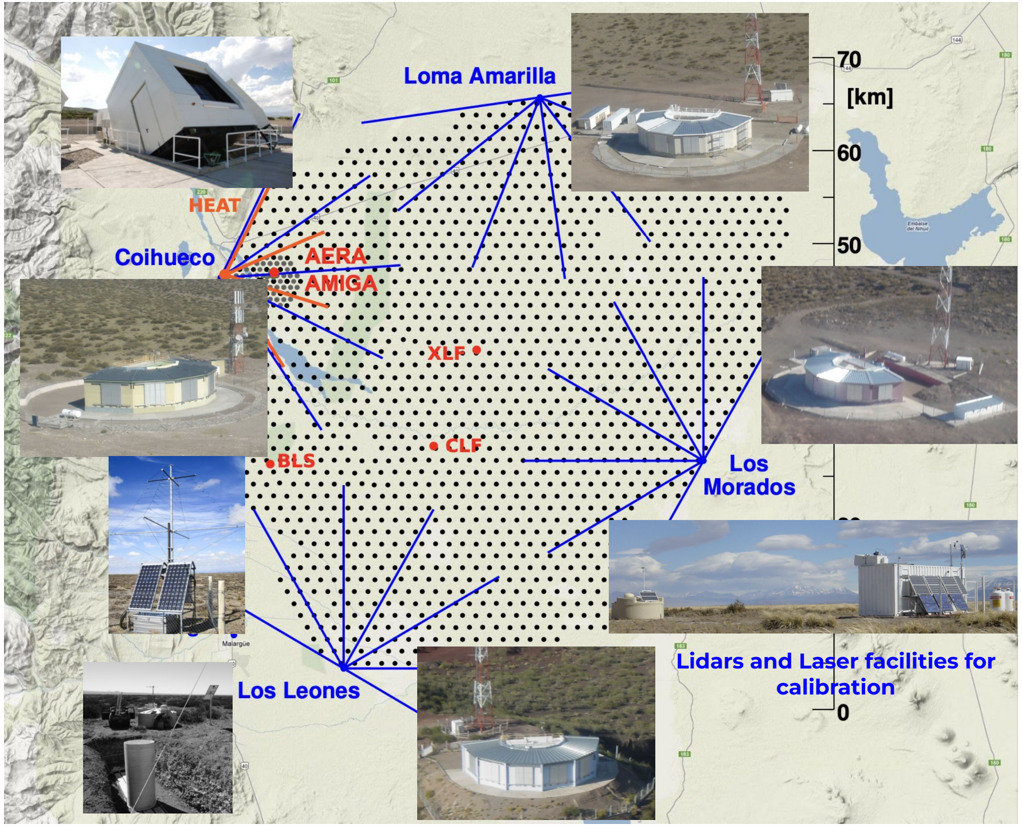


- The Auger Raman Lidar is measuring the aerosol optical properties @355 nm since November 2013;
- Laser and single board computer maintenance @ CLF by V.Rizi in November 2024/ March 2025 work in synergy with the Naples group (see R. Colalillo talk for details)

Richieste Finanziarie 2025

Capitolo	Descrizione	Parziali (k€)		Rimuovi	Modifica	Totale (k€)	
		Richieste	SJ			Richieste	SJ
consumo	manutenzione ordinaria Lidar Raman e CLF e contributo per single board computer spare	3.00	0.00			3	0
missioni	n.1 meeting annuale con i Referees CSN2-INFN per il responsabile locale	1.00	0.00			63	0
	n.2 turni di presa dati FD (Rivelatore di Fluorescenza) presso l'Osservatorio Pierre Auger (1 turno/persona: 4 keuro)	8.00	0.00				
	Partecipazione al Meeting di Collaborazione Internazionale (Marzo 2025) per 5 persone (3 keuro/persona/meeting)	15.00	0.00				
	Partecipazione al Meeting di Collaborazione Internazionale (Novembre 2025) per 5 persone (3 keuro/persona/meeting)	15.00	0.00				
	n.2 turni tecnici (in concomitanza con il meeting di collaborazione di Marzo e di Novembre, 4 keurox 2 = 8 keuro) per responsabilita' manutenzione Lidar Raman/CLF	8.00	0.00				
	n.2 trasferte (n.1 in situ 3 keuro e n.2 in Europa 1.5 keuro x 2) di coordinamento scientifico dell'osservatorio per responsabilita "Science coordinator" di Auger	6.00	0.00				
	n.2 turni tecnici (in concomitanza con il meeting di collaborazione di Marzo e di Novembre, 4 keuro x 2 = 8 keuro) per responsabilita di coordinamento del Detector dei Fluorescenza.	8.00	0.00				
	2 missioni per 1 fisici (2K * 4) al CNAF per le operazioni di trasferimento dell'Auger data center da Lyon al CNAF	2.00	0.00				
trasporti	Trasporti sul sito per partecipazione meeting Novembre 2025	1.00	0.00			5.5	0
	Trasporti sul sito per partecipazione meeting Marzo 2025	1.00	0.00				
	Trasporti sul sito sperimentale per turno FD	1.50	0.00				
	Trasporto sul sito per turni tecnici di manutenzione Lidar Raman ed FD	2.00	0.00				
Totale						71.5	0

The Pierre Auger Observatory



Southern hemisphere: Malargue, Province Mendoza, Argentina

Surface detector (SD)

- 1600 stations in 1.5 km grid, 3000 km^2 E > $10^{18.5}$ eV
- 61 stations in 750 m grid, 23.5 km^2, E > $10^{17.5}$ eV
- 19 stations in 433 m grid, E > 6 10^{16} eV

Fluorescence detector (FD)

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

Auger Engineering Radio Array (AERA)

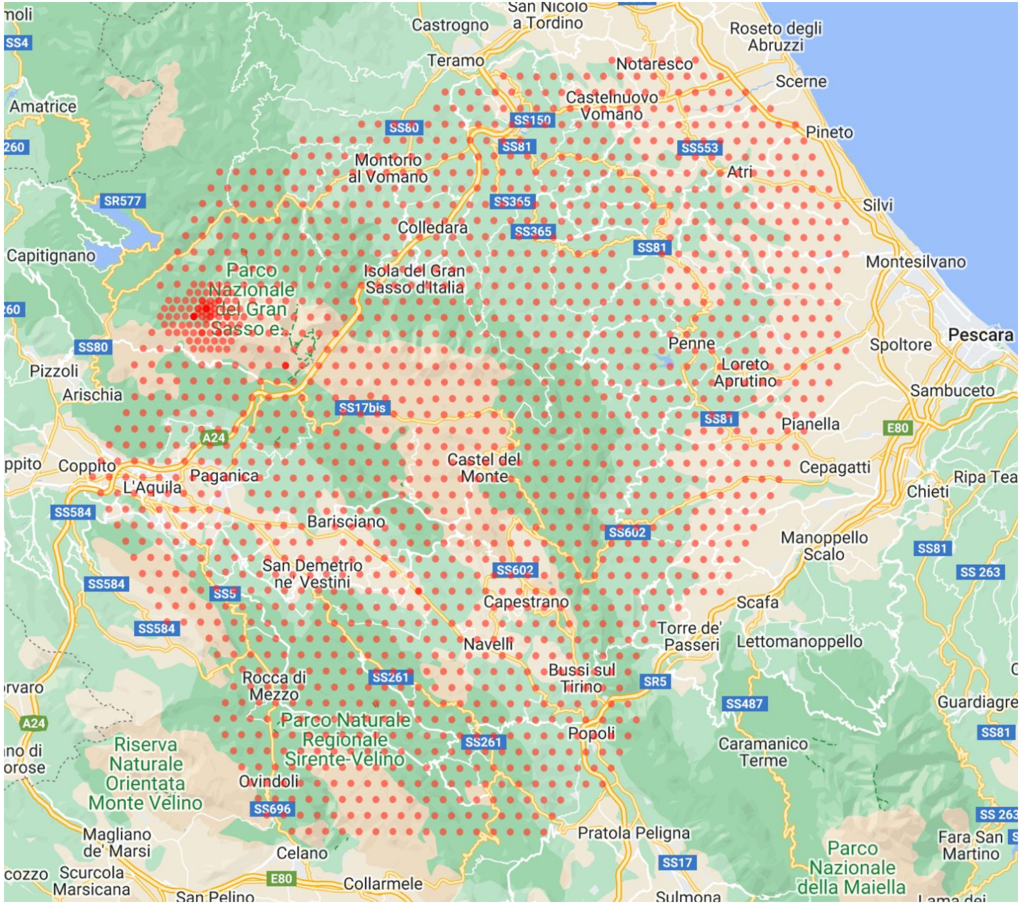
- 153 antennas in 17 km^2 array, E> 4 10^{18}eV

Underground muon detector

- 19(61) stations in 433(750)m array $10^{16.5}$<E< 10^{19} eV

Auger Phase I data taking from 2004 on (from 2008 with the full array) to 2021
AugerPrime commissioning phase 2022-2023
Auger Phase II data taking from 2024 to 2035

The Pierre Auger Observatory



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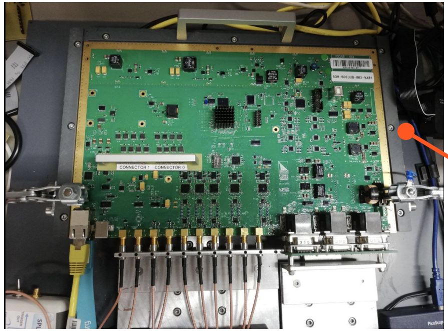
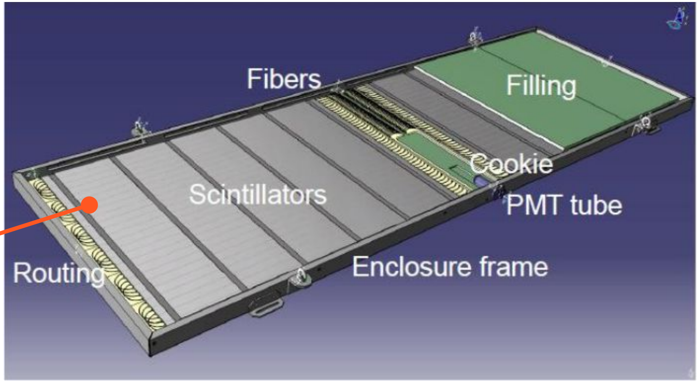
Auger Prime detectors

New electronics (UUB) and Scintillators(SSD)





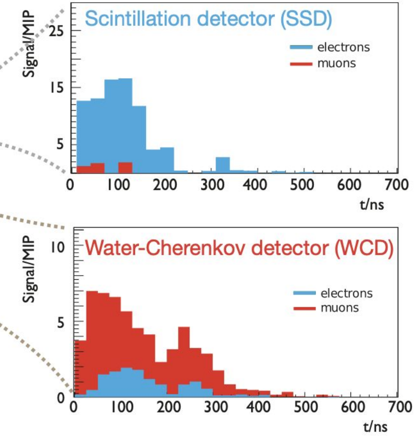
High dynamic range PMTs

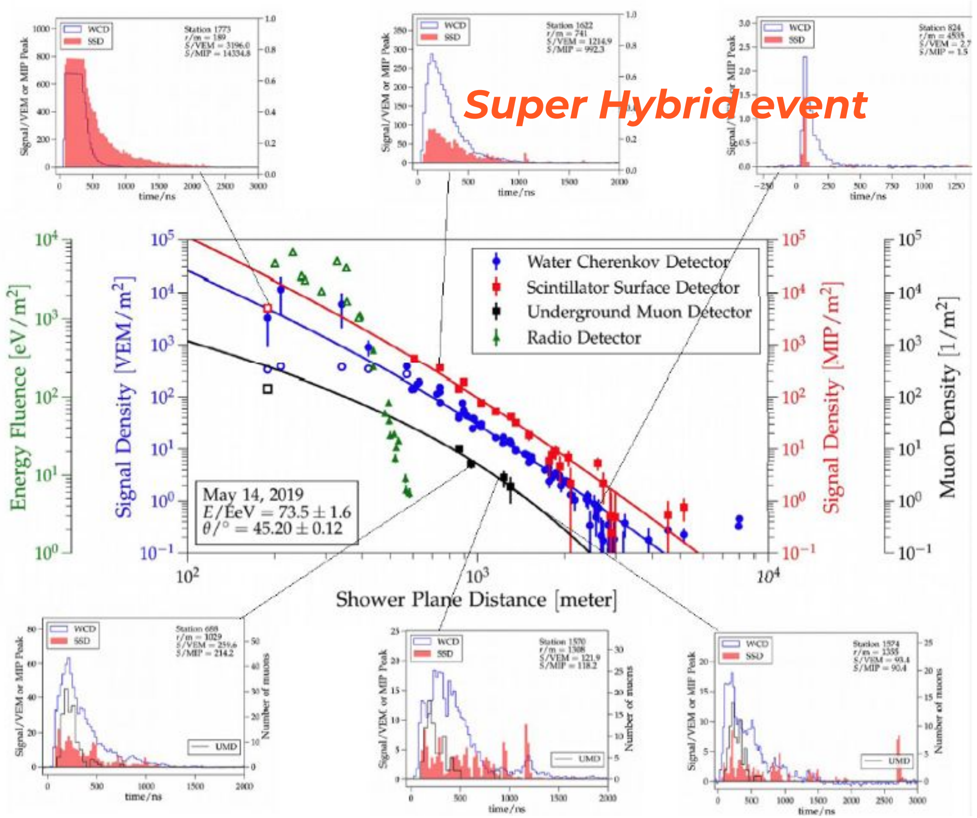
Radio Upgrade

Underground Muon Detector (UMD)

AugerPrime Status

Complementary detectors to discriminate em. and muonic components



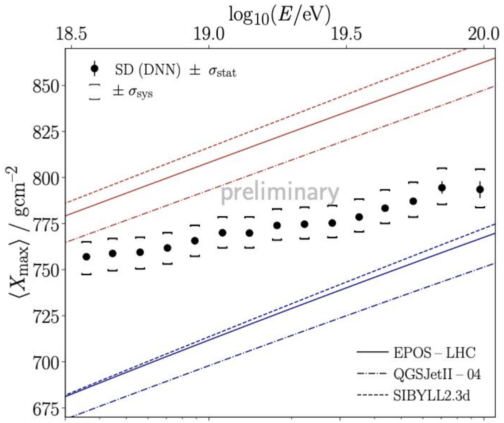


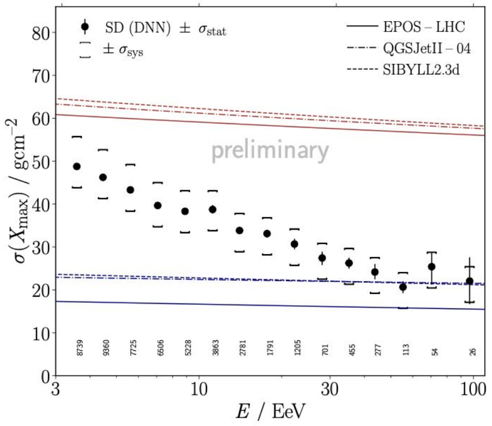
Status of Upgrade

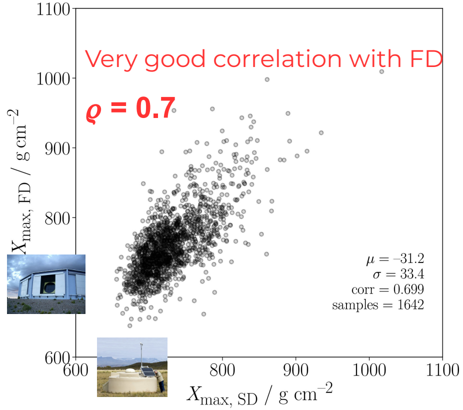
- Scintillators: 1450 installed
- Muon detectors: 38 installed
- Radio: 904 (411) installed

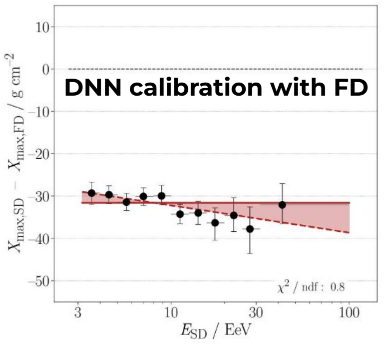
X_{max} from SD using DNN

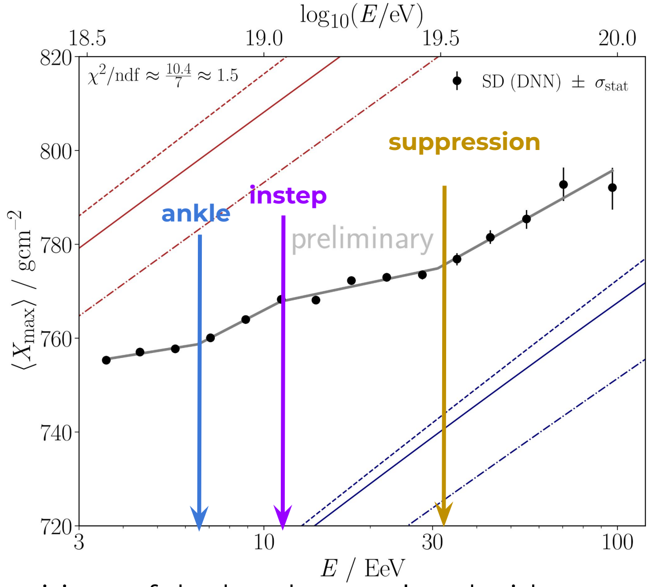
- About **50000** SD events above 3 x 10^{18} eV (factor ~10 more then FD)
- Arrival times and traces fed to CNN + RNN networks









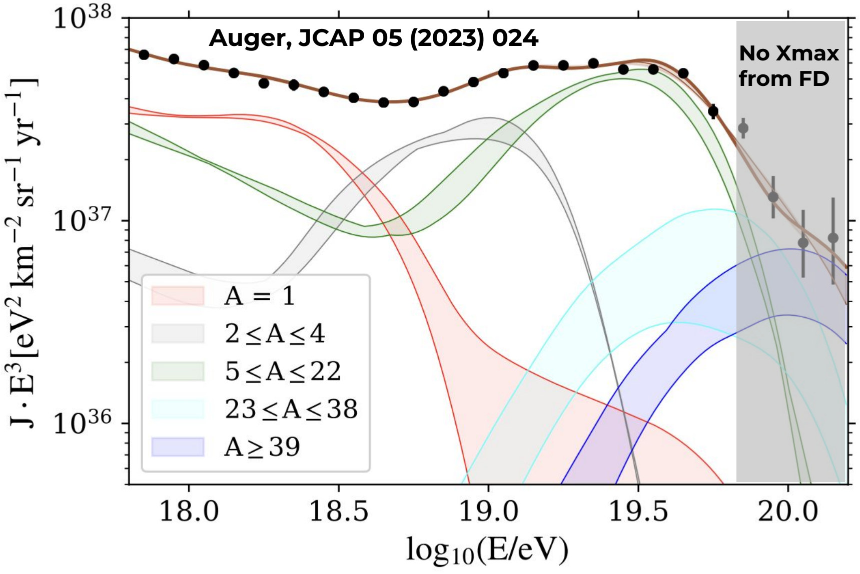


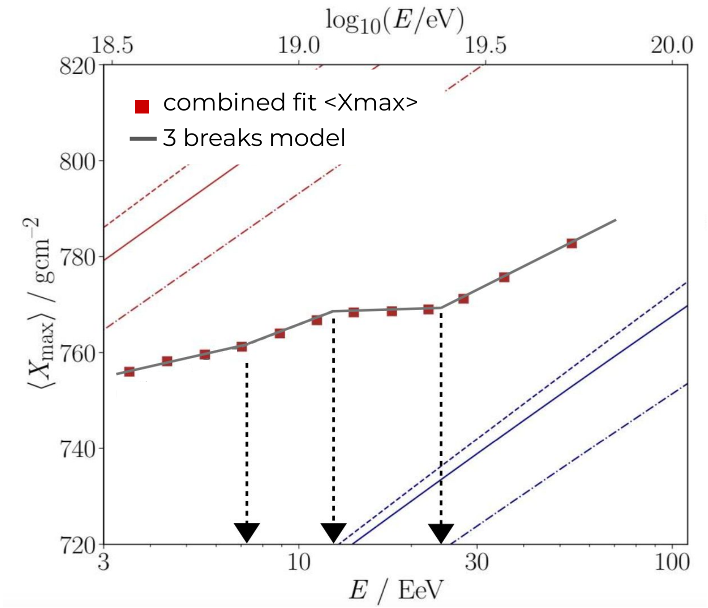
- positions of the breaks correlated with spectrum features
- confirmation that mass composition is lighter and mixed at lower energies, getting heavier and more pure as the energy increase

Astrophysical scenarios and mass composition

SCENARIO: identical source populations uniformly distributed

- proton-only accelerating sources **disfavoured**, nuclei-only accelerating sources **favoured**
- rigidity dependent scenario **favoured** with hard spectral indexes





Prediction from combined fit reproduce the breaks as seen in the DNN analysis