
# UHECR2024 Poster Awards

**Daniel Supanitsky**, Instituto de Tecnologia en Deteccion y Astroparticulas

**Yoshiki Tsunesada**, Osaka Metropolitan University

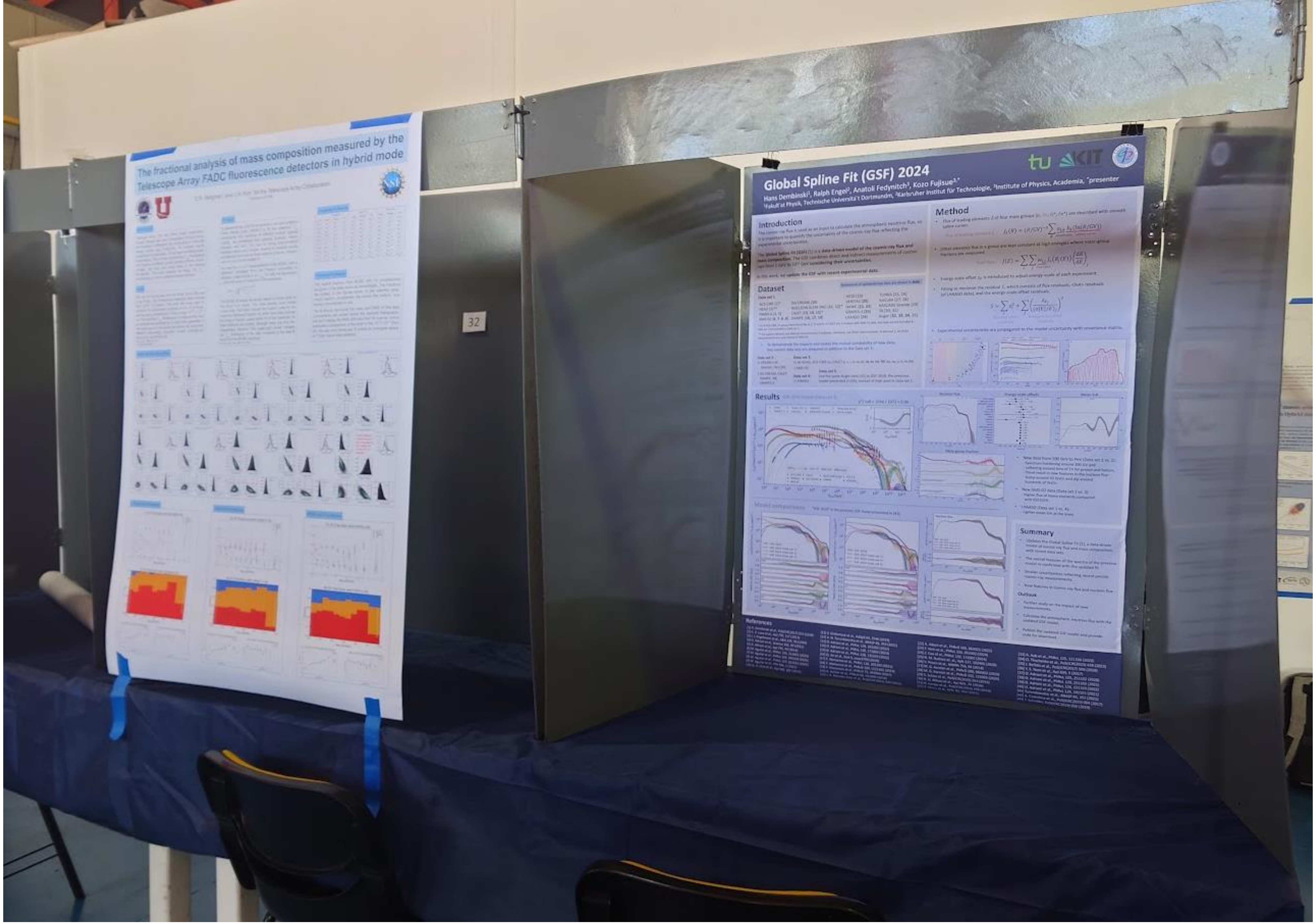
21 Noviembre, 2024

# UHECR2024 Statistics and Poster Awards

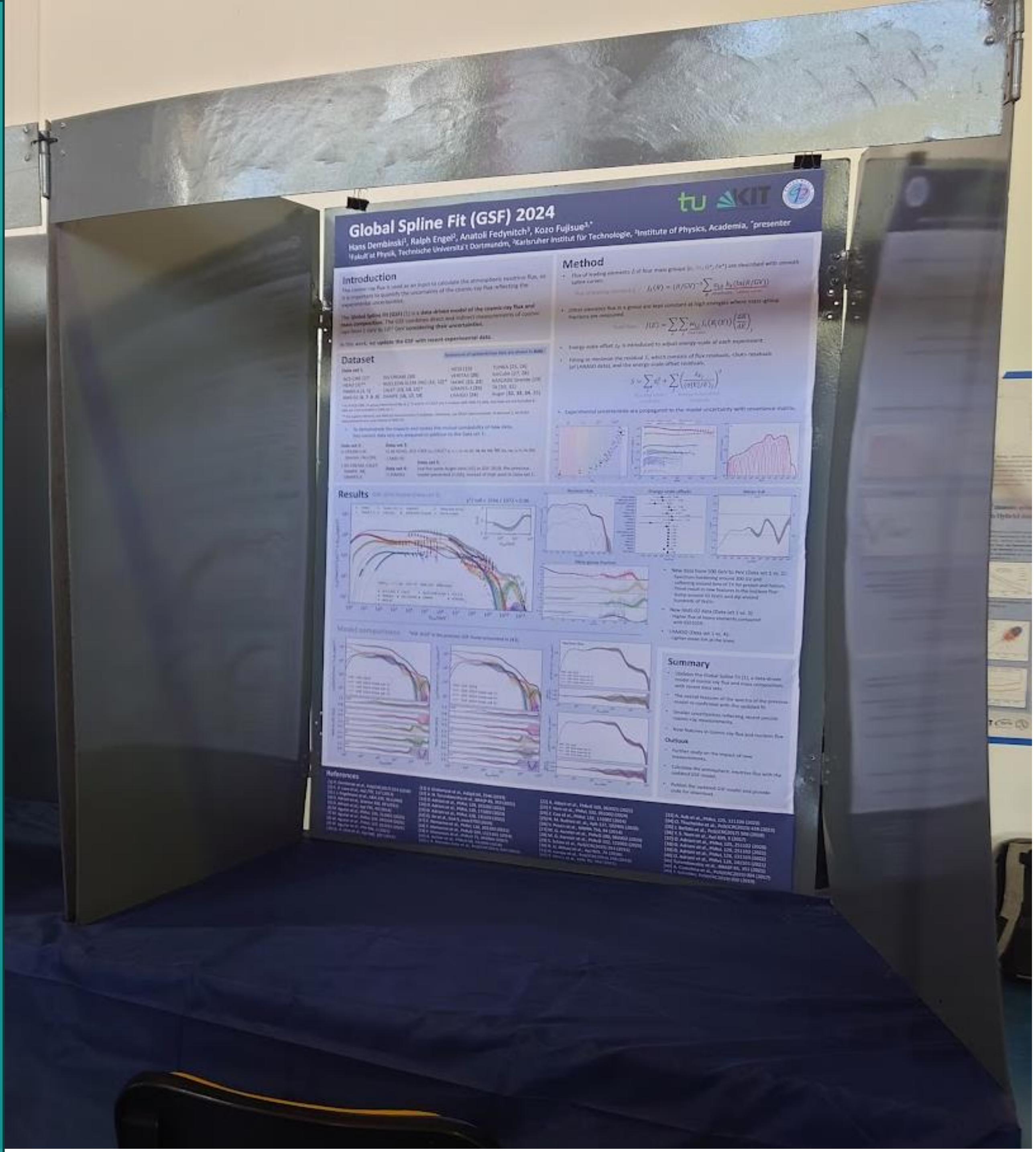
- 8 invited reviewers and 53 oral talks
- 59 poster contributions
- Circular 29 October: *"On the final day of the Symposium, two rapporteurs will summarize all poster contributions, and two posters will receive awards."*
- Rapporteurs assigned:
    - Daniel Supanitsky, Instituto de Tecnologia en Deteccion y Astroparticulas, Argentina
    - Yoshiki Tsunesada, Osaka Metropolitan University, Japan
- We appreciate your cooperation for providing the poster pdfs before the conference begins.

# Poster Rapporteur: Tsunesada

Poster session at the Auger Assembly Building



The fractional analysis of mass composition measured by the Telescope Array FADC fluorescence detectors in hybrid mode
32
Global Spline Fit (GSF) 2024
Hans Dembinski1, Ralph Engel2, Anatoli Fedynitch3, Kozo Fujisue3,*
1Fakultät Physik, Technische Universität Dortmund, 2Karlsruher Institut für Technologie, 3Institute of Physics, Academia, *presenter
Introduction
Method
Dataset
Results
Summary
References


Global Spline Fit (GSF) 2024
Introduction
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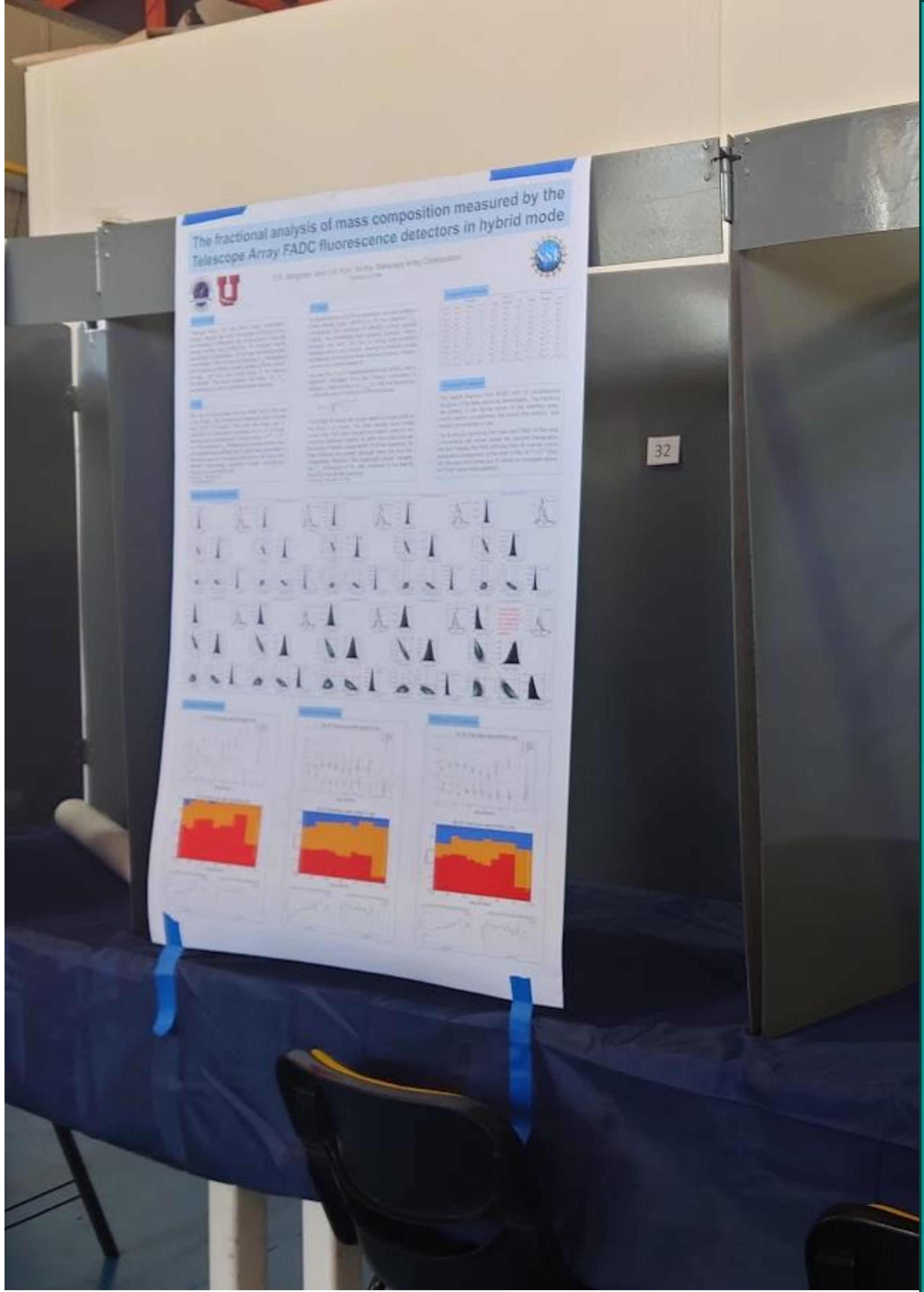
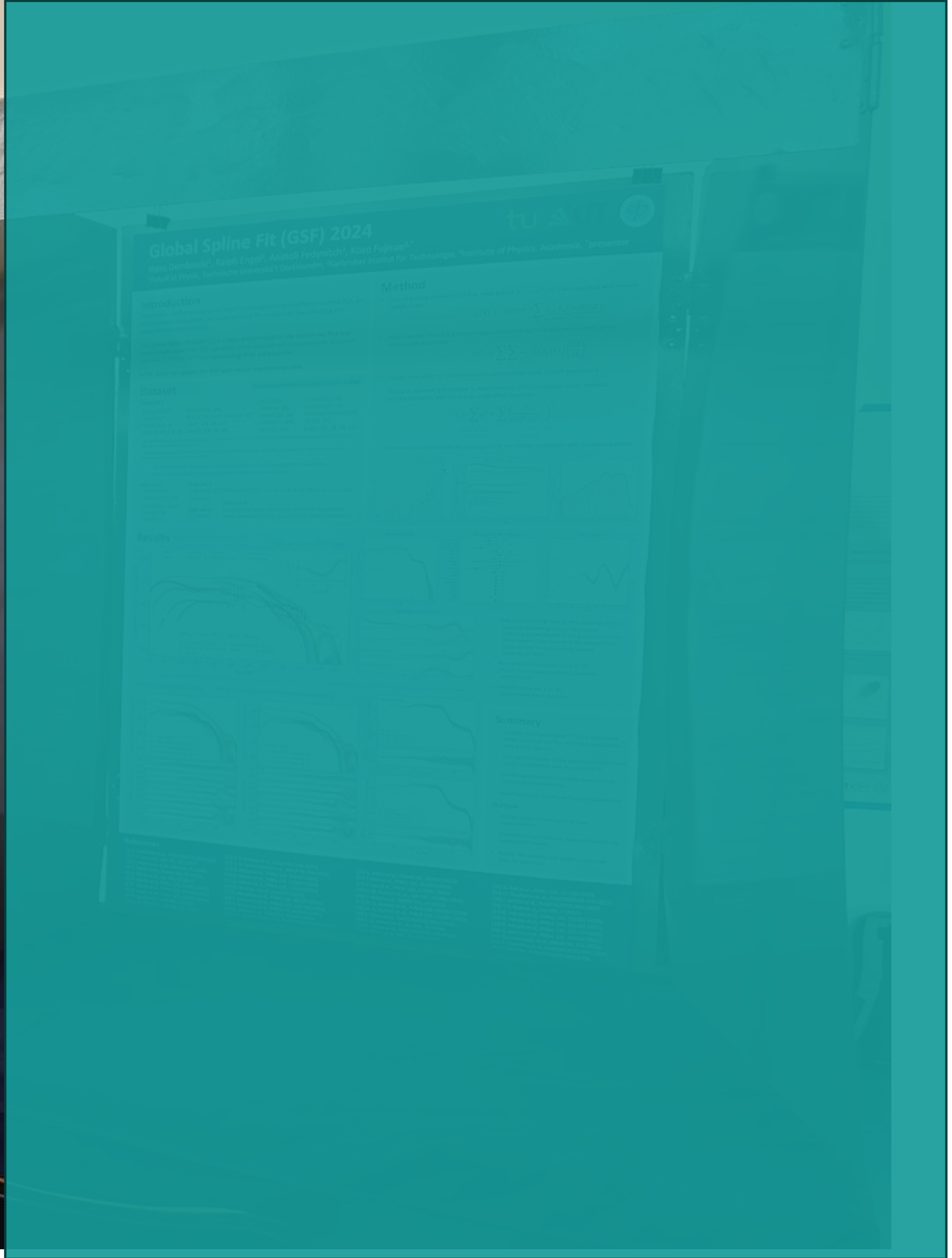
Outlook
References


The fractional analysis of mass composition measured by the Telescope Array FADC fluorescence detectors in hybrid mode
32


Global Spline Fit (GSF) 2024

# UHECR2024 Posters: Group 1

- Propagation talks
  - Nuclear transformation at sources or in the extragalactic photon fields
- Shower simulation talks
  - Hadronic interactions
  - Neutrinos showers
  - Radio showers
- Detector talks
  - Muons
  - Infill/add-on detectors
  - Calibration
  - Radio antennas
  - Primary gamma-rays
- Analysis methods
  - Machine learning
  - Inclined shower reconstruction
  - Composition studies
- Atmospheric studies
  - Sky monitoring
  - Magnetic/Electric fields
  - Elves, sprites, TGFs
- Outreaches
- Future detectors

# Propagation talks

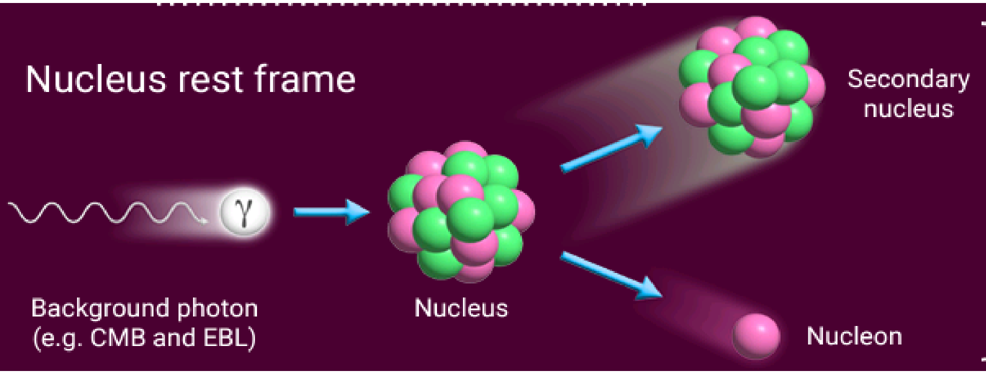
- L. Merejon, Julian Rautenberg: Stochastic description of UHECR interactions (CRPropa)
- L.A. Dourado et al.: Enhanced photodisintegration model in Simprop Sirente

# Enhanced photodisintegration model for cosmic ray nuclei in SimProp Sirente

L. Andrade Dourado[1,3,4], D. Boncioli[2,4], A. di Matteo[4], C. Evoli[1,4], S. Petrera[1,4], F. Salamida[2,4]

## **Photodisintegration** interactions in UHECRs

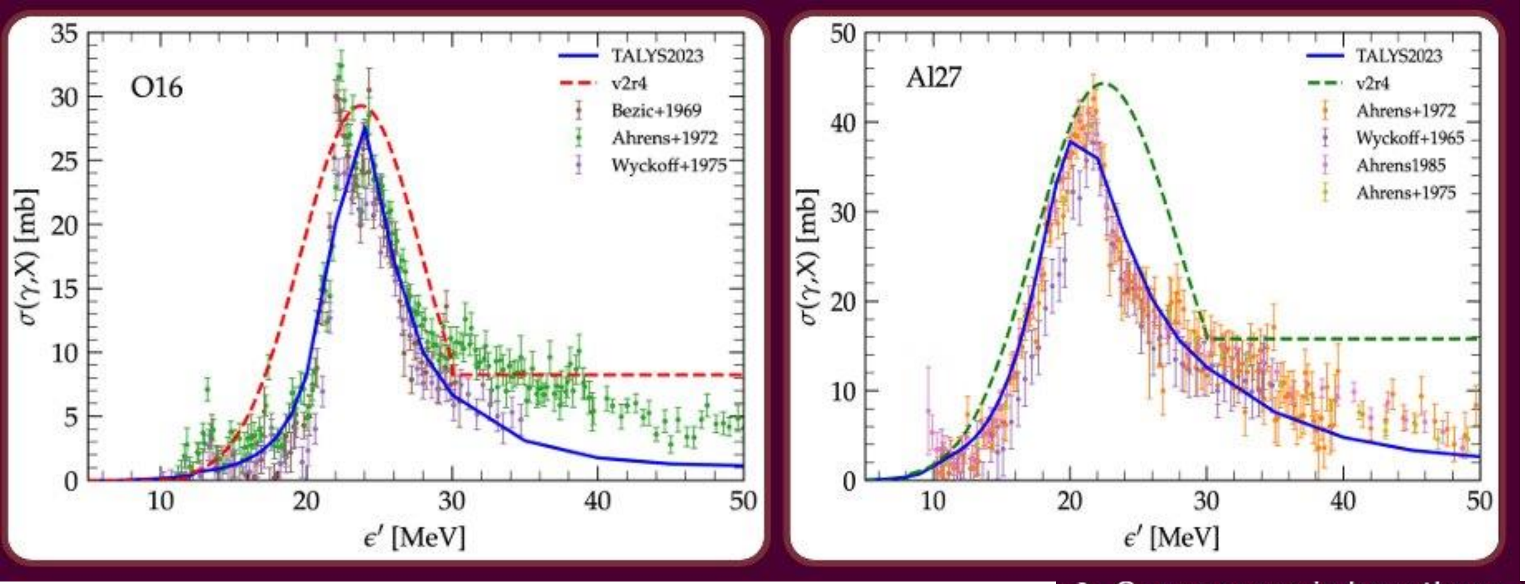
→ In the nucleus rest frame, the energy of the photon is boosted by the nucleus's Lorentz factor, reaching **MeV energies**




Here we illustrate a single nucleon extraction, but there are **several** possible channels, each with a specific probability of occurring

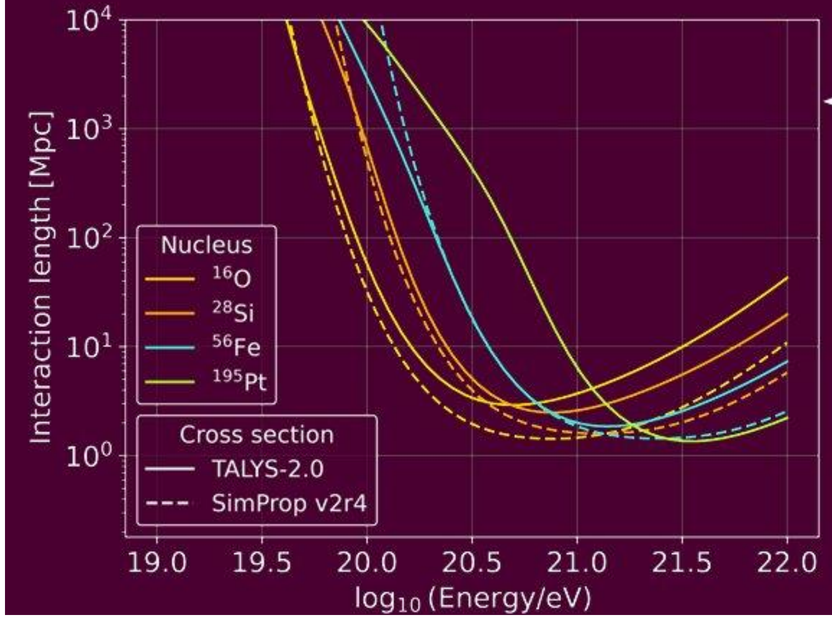
In *SimProp* v2r4, one of the models for the total inelastic cross section combines a **single-nucleon** and **α-particle extraction**, parameterized with channels from TALYS (nuclear interaction software) [3]

We are updating SimProp Sirente with the **latest available cross sections in TALYS**, **testing the approximation of one-nucleon plus alpha-particle emission**, and extending the nuclear network for **ultra-heavy (*A* > 56) UHECRs**




➔ Our concern is how these differences between the models affect the **interaction length** of particles

$$\lambda_A(\Gamma) = cA \left[ \frac{c}{2\Gamma^2} \int_{\epsilon_{\mathrm{th}}}^{\infty} d\epsilon' \epsilon' \sigma_A(\epsilon') \underbrace{\int_{\frac{\epsilon'}{2\Gamma}}^{\infty} d\epsilon \frac{n_\gamma(\epsilon)}{\epsilon^2}} \right]^{-1}$$




The integral of the density of background photons has an analytic solution for CMB

**New cross sections impact up to 40% in the Lorentz factor range of $\Gamma \sim 10^{10}$**

**$^{195}$Platinum: heavier elements expand the horizon for UHECRs**

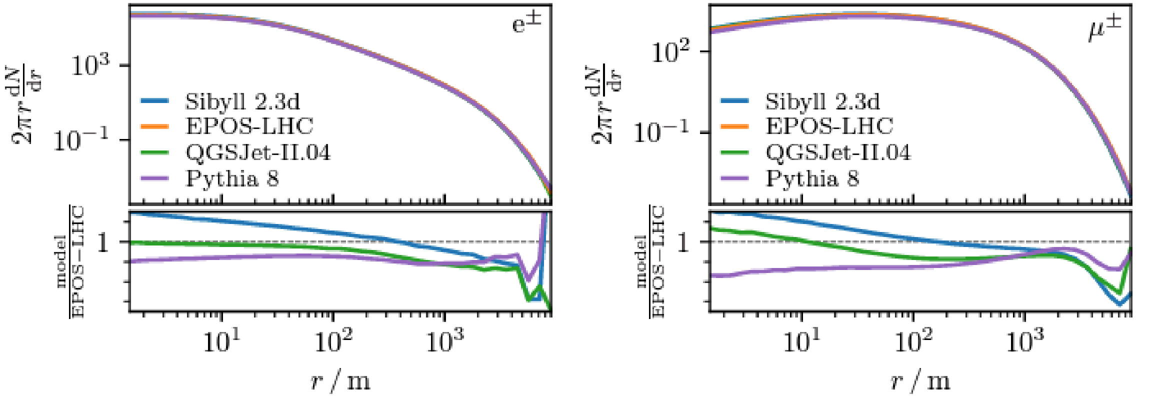
# Shower Simulation Talks

- C. Gaudu: Implementing Phytia 8 into CORSIKA-8
- J. Carasa-Velente: nuSpaceSim: An E2E simulation package for upward-moving showers
- F. Ellwanger: Investigations of CORSIKA thinning level for photon-hadronic separation at UH energies

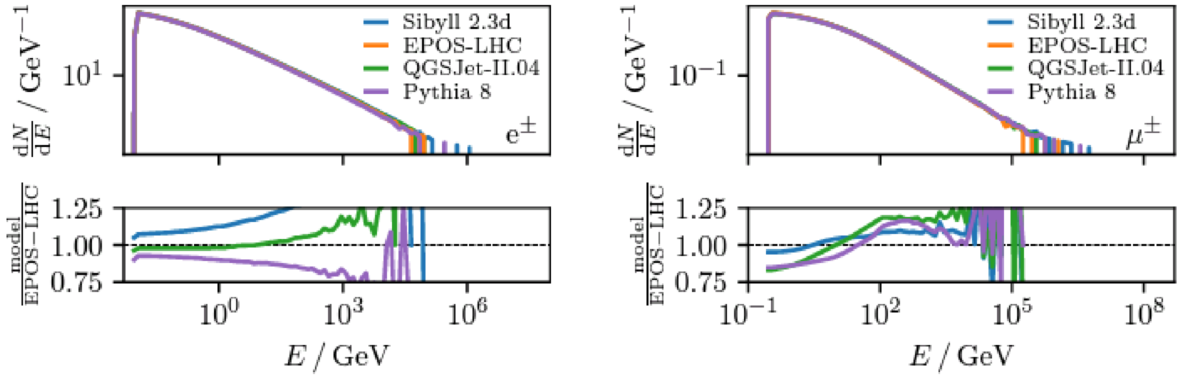
# Implementing Pythia 8 for EAS Studies: Another Piece to the Muon Puzzle

Chloé Gaudu, Bergische Universität Wuppertal, Germany

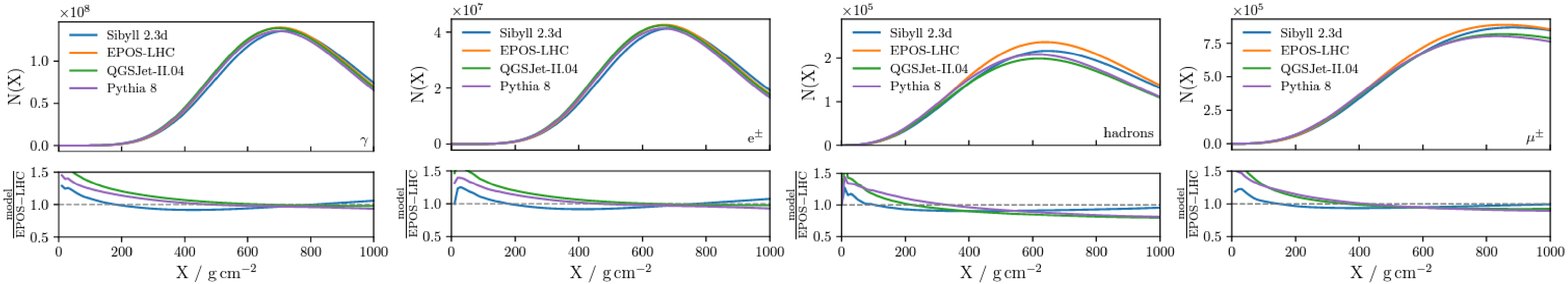
## Lateral profile*




## Energy spectrum*




## Longitudinal profile*



# Auger Muon Talks

- M.P. Shahvar, NN identification of highly inclined muons in WCD
- M. Gottowik: Muons in inclined showers with AERA and WCD
- M. Scornavacche: Effect of knock-on electrons in UMD
- J. de Jesus: Improved calibration methods for UMD
- J. de Jesus: Data-driven method for corner-clipping effect in UMD

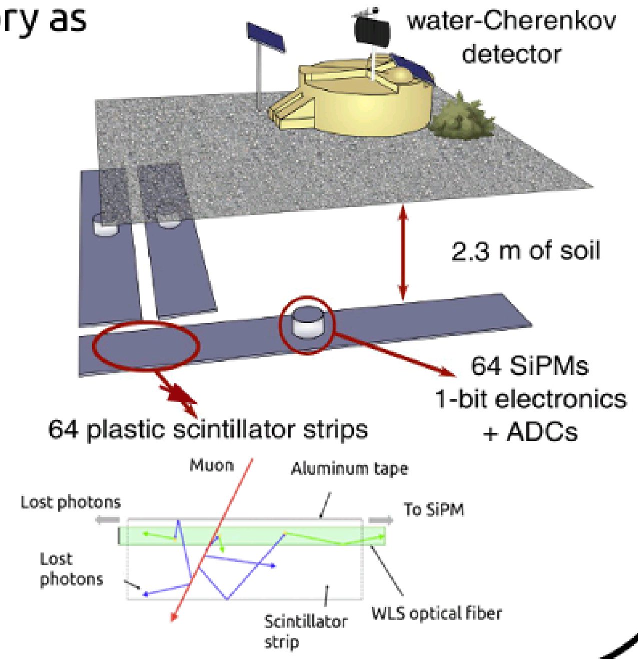
# Data-driven method to quantify and correct the corner-clipping effect in segmented muon counters


J. de Jesús[a,b], J.M. Figueira[a], F. Sanchez[a], D. Veberič[b]

a) Instituto de Tecnología en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina
b) Karlsruhe Institute of Technology (KIT). Institute for Astroparticle Physics (IAP), Karlsruhe, Germany

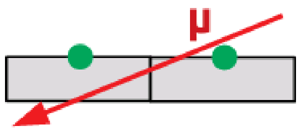

## Underground Muon Detector (UMD) [1]

- Use UMD of the Pierre Auger Observatory as an example
- Array of muon detectors buried in the vicinity of water-Cherenkov detectors
- Each detector comprises 3 modules of 10 m² of plastic scintillator
- Each module is segmented into **64 independent strips**
- Muon signal → a bar is triggered if signal is above threshold for ≥ 12.5 ns

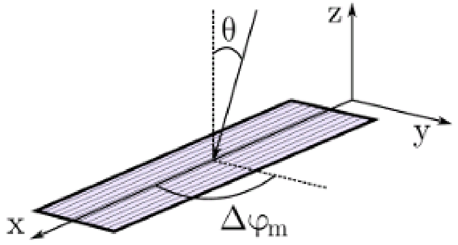



## Corner-clipping muons

- An inclined μ may trigger two neighboring strips




- Effect dependent on the zenith and the azimuth of the muon w.r.t. the module



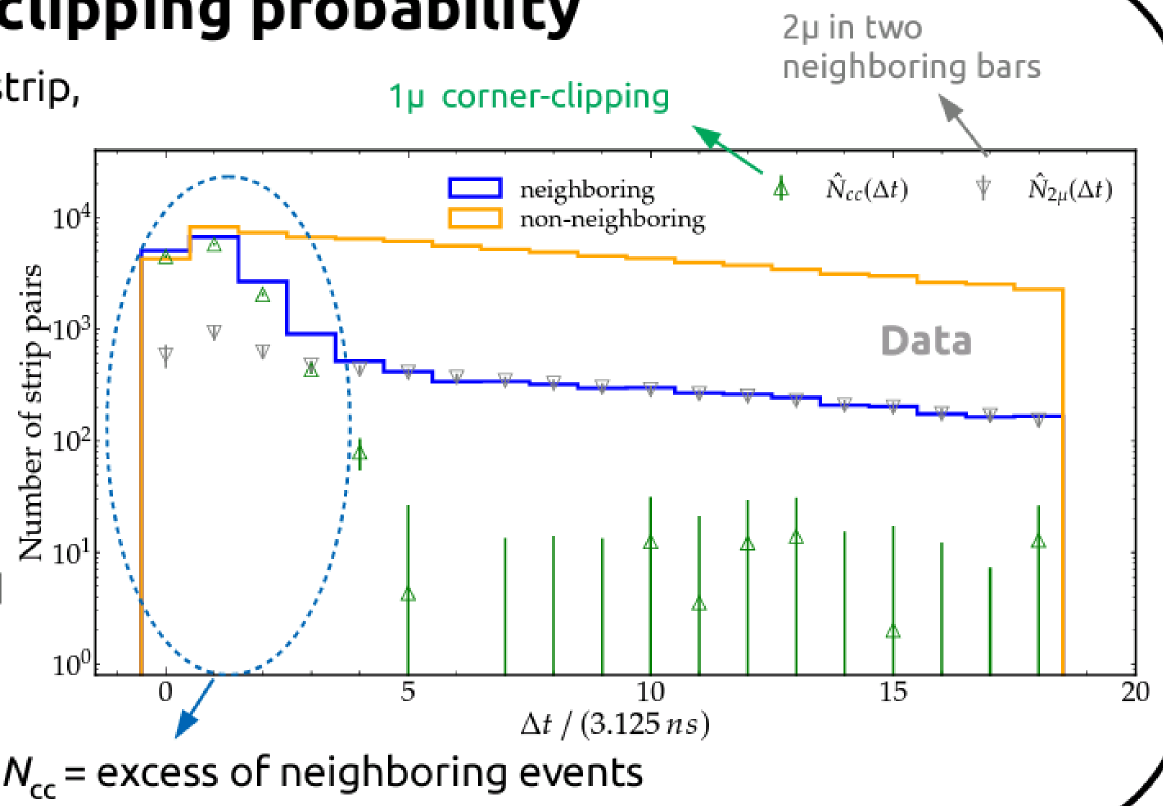

- Source of **bias**, leading to overcounting
- Previously accounted for with simulations

# Single-muon corner-clipping probability

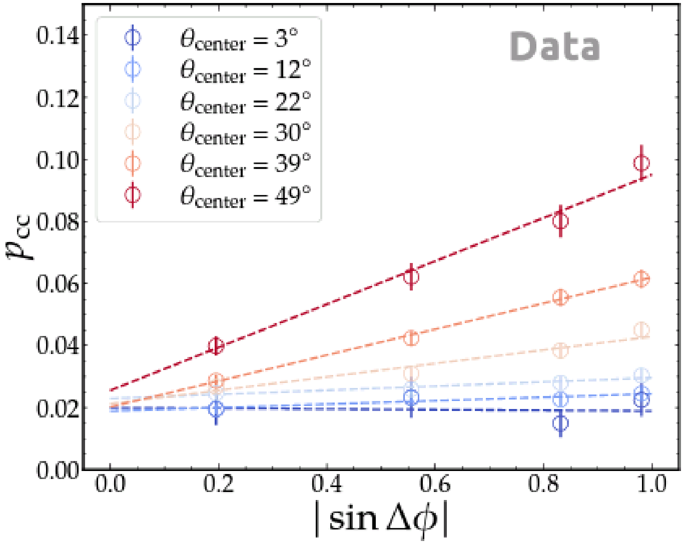
- When a single muon is injected into a module it can activate one strip, $N_{1strip}$, or two neighboring strips, $N_{cc}$ (corner-clipping)
- Single-muon corner-clipping probability:

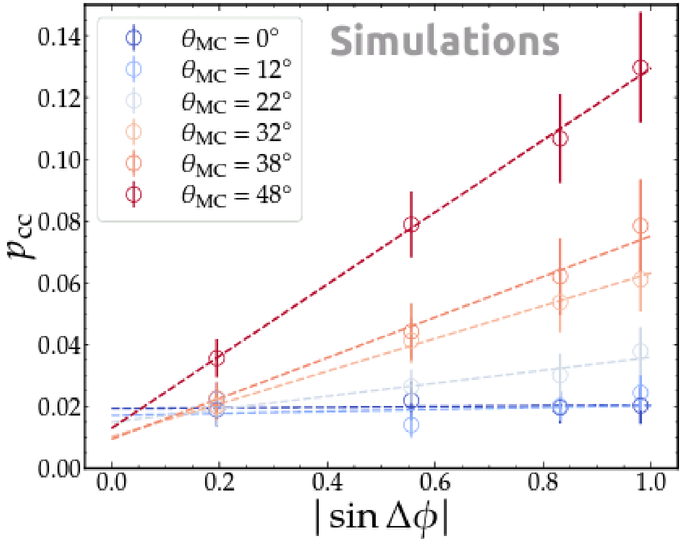
$$p_{cc}(\theta, \Delta\phi) = \frac{N_{cc}(\theta, \Delta\phi)}{N_{1\mu}(\theta, \Delta\phi)} \cong \frac{N_{cc}(\theta, \Delta\phi)}{N_{cc}(\theta, \Delta\phi) + N_{1strip}(\theta, \Delta\phi)}$$

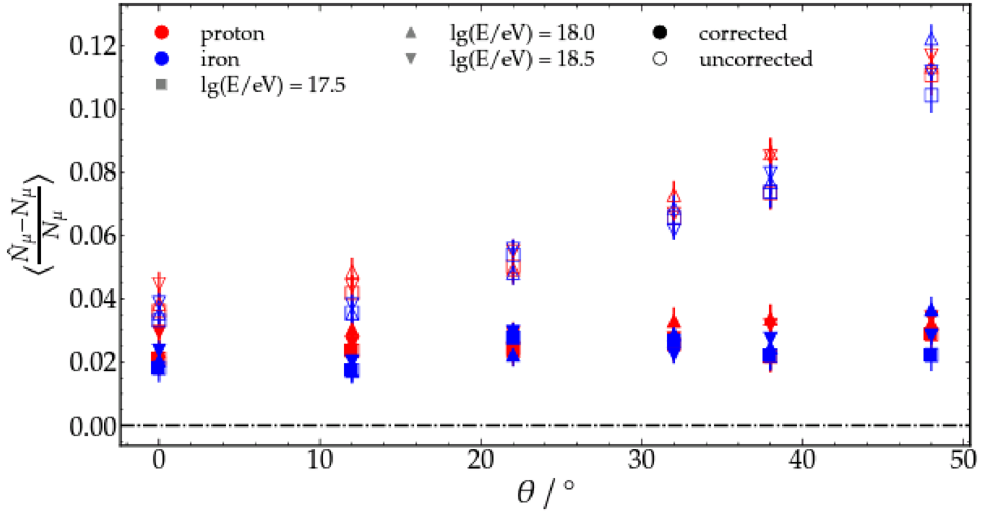
- Use **timing with modules with only 2 strips activated** → $\Delta t$ = difference between start times of the 2 strips
- $N_{cc}$ obtained by quantifying **excess of events with Δt < 5** in the neighboring histogram → difference between the neighboring and non-neighboring distributions attributed to corner-clipping muons
- $p_{CC}(\theta, \Delta\varphi)$ can be **obtained from data and be used to correct for overcounting**



# Application of the method to data and simulations




- ✔ Data and simulations show similar behavior
- Corrected muon estimator:

$$\hat{N}_\mu = \frac{-64 \ln(1 - k/64)}{1 + p_{cc}(\theta, \Delta\phi)}$$

$k$ → number of triggered bars

- ✔ After correction, bias is flat with θ and below 3%

# Radio Antenna Talks

- M. Gottowik: Muons in inclined showers with AERA and WCD
- S. Verpoest et al.: A new antenna array at Auger 433m array
- S. Strahns et al.: Electric field reconstruction in radio detectors with Information Field Theory
- B. de Errico: GRAND@Auger
- J. Horandel: Radio detectors at Auger: Status, performance, and plans

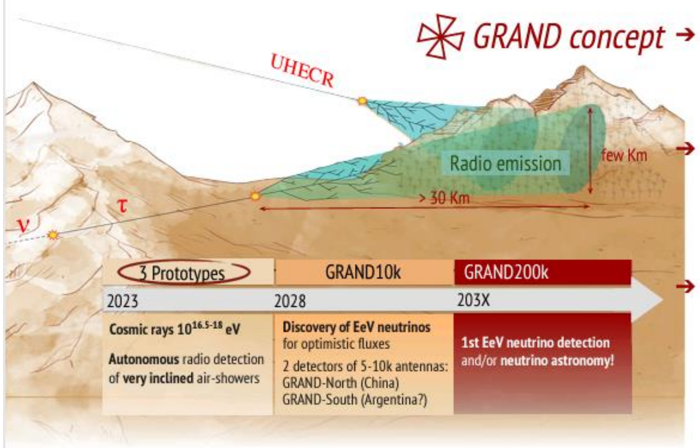
# GRAND@Auger: status and first results

Beatriz de Errico[1] for the GRAND Collaboration

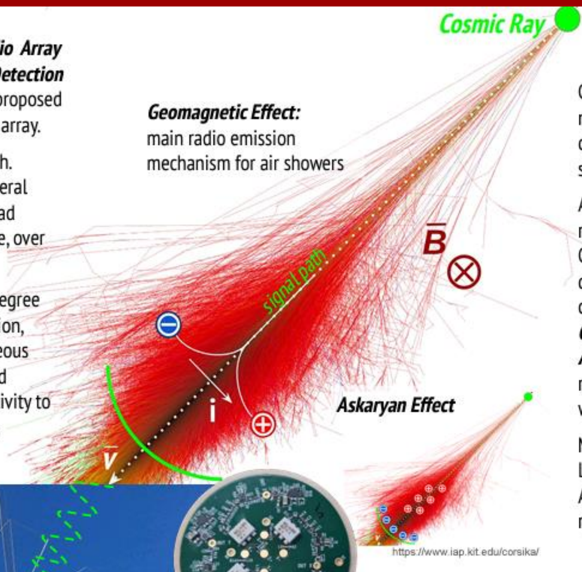
[1]Physics Institute, Federal University of Rio de Janeiro, UFRJ

beatrizspe@pos.if.ufrj.br

## GRAND concept




- The ***Giant Radio Array for Neutrino Detection*** (GRAND) is a proposed sparse antenna array.
- Staged approach. Final stage: several sub-arrays spread across the globe, over 200,000 Km$^2$.
- Expected sub-degree angular resolution, wide instantaneous field of view and excellent sensitivity to neutrino fluxes.




## Radio emission

Cosmic rays, gamma rays and neutrinos can induce particle cascades in the atmosphere, called air showers.

Air showers emit electromagnetic radiation from ***30-200 MHz***. Correspond to transient pulses with duration <~ 100 ns. Radio emission can be modeled by two mechanisms: ***Geomagnetic Effect*** and the ***Askaryan Effect***. Within coherence region, the amplitude scales linearly with particle energy.

Mature detection technique (LOPES, LOFAR, CODALEMA, AERA, TREND). Antennas are cheap, scalable and robust; allowing ~100% duty cycle.

## GRAND@Auger

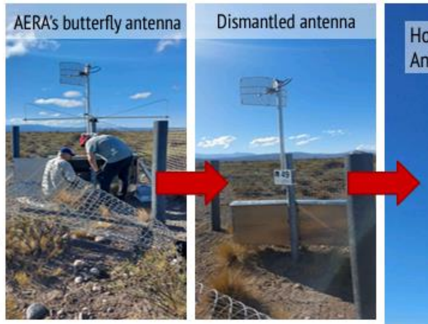
GRAND's three prototype arrays:

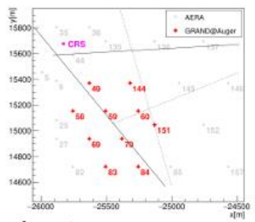
- GRANDProto300 in China
- GRAND@Nançay in France
- ***GRAND@Auger in Argentina***

GRAND@Auger came to be as an agreement between the ***GRAND*** and ***Pierre Auger*** Collaborations. 10 repurposed AERA stations as GRAND's Horizon Antennas. Deployment was completed in August 2023.

***Goals:***

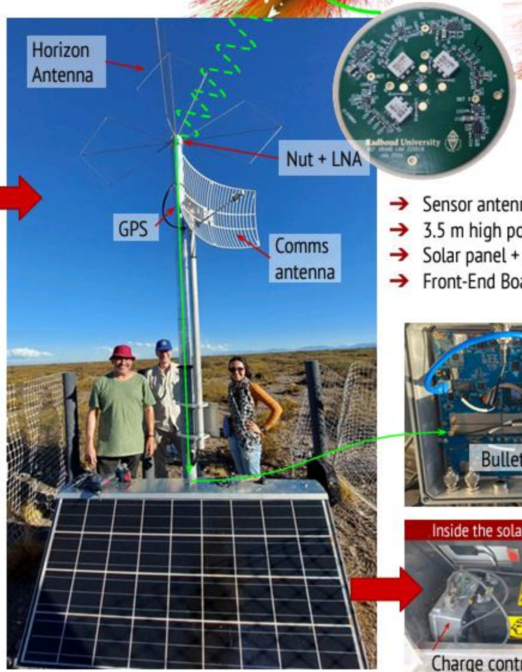
- Validate GRAND's detection concept;
- Search for air showers events in time coincidence with Auger SD's events;
- Validate GRAND's reconstruction performance;



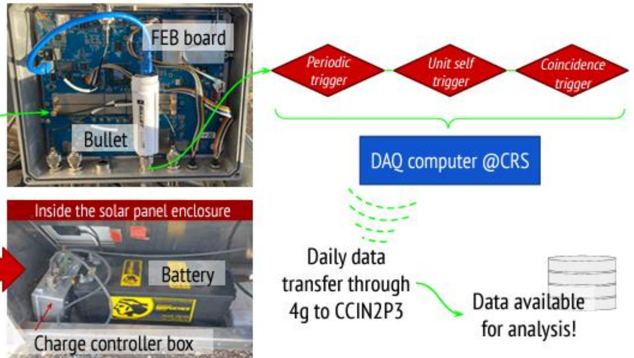

***Array layout:***

- 0.5 Km$^2$ with 250 m spacing;
- Expected order 30 air shower events/day between $10^{16.5}$ to $10^{18.5}$ eV;




## Setup specifications

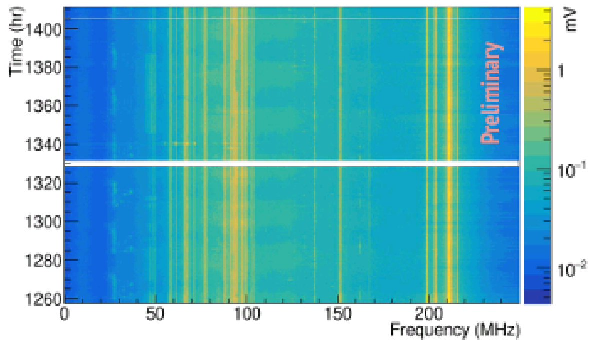
- Sensor antenna with 3 polarizations;
- 3.5 m high pole;
- Solar panel + charge controller + battery;
- Front-End Board inside Faraday cage;
- 30-200 MHz filtering;
- 500 MSPS ADC;
- Flexible filtering and triggering;
- Wireless data transfer;



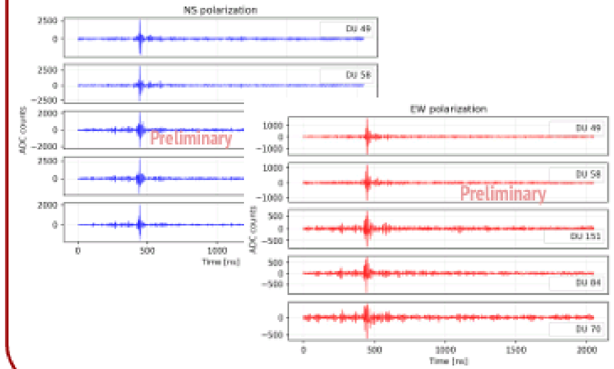
# First results & analyses

## 1. Data through 2023 & 2024

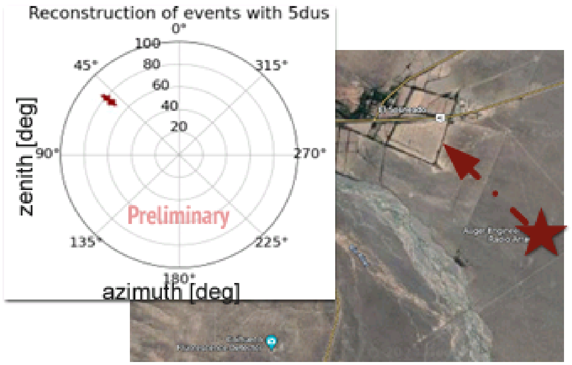
- 10 Detector Units (DUs) operational;
- Commissioning and debugging of hardware and software;
- Stable data taking with functional hibernation settings;



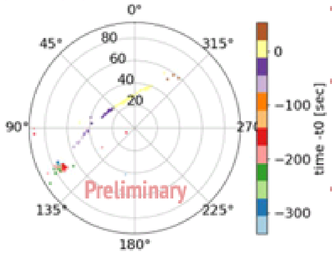

- Online self-trigger tests and optimization;
- Self-triggered events with at least 3 DUs in coincidence;
- Trigger rate ~ 100 Hz;




## 2. Arrival Direction Reconstructions



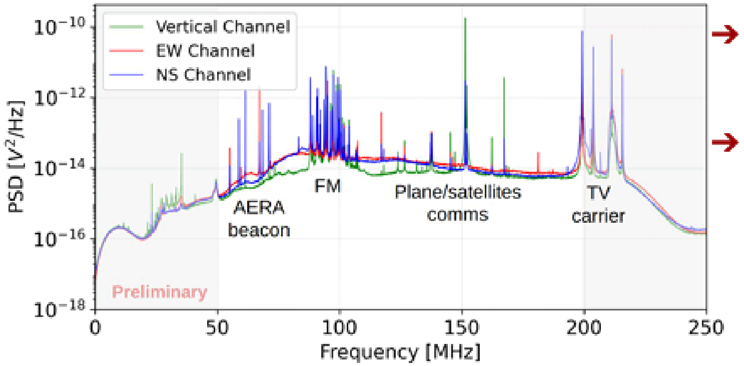

- 14 online self-triggered coincidence events reconstructed;
- Three independent analyses: analytic PWF, Minuit PWF/SWF and TREND SWF;
- Pointed towards two nearby villages;



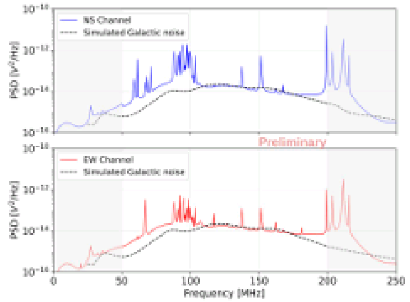

Flight TAM8133, Santiago to São Paulo

- Several plane tracks identified
- Timestamps in correspondence to actual flight times
- Further analyses on transient detection rate and timing precision
- Aimed calibration with AERA beacon

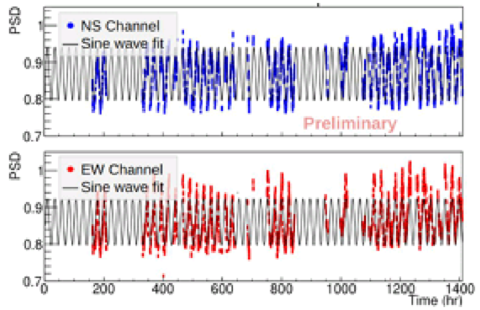
## 3. Background Studies

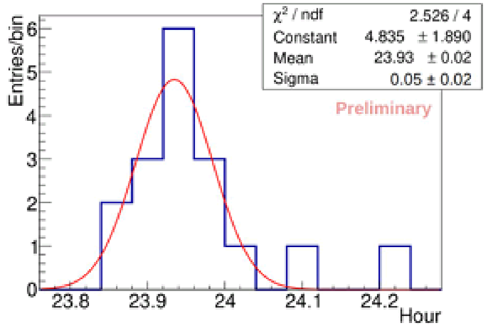



- Local environmental background characterization;
- Narrowband transient noise sources identified through arrival direction reconstruction & known local sources;




- ***On-going analysis*** for Galactic Background (GB) searches;
- Antenna calibration potential
- Preliminary comparisons of ***GB + RF chain simulations vs. measured PSD*** indicate agreement;




- Sine wave fit over data from **March and April 2024, 120 to 200 MHz** range;
- Galaxy's expected period: 23h56min = 23.934hrs

*Averaged results over all 10 DUs for NS and EW polarizations:*

- ***Mean period = 23.93 ± 0.02 h***
- Std of period = 0.05 ± 0.02 h
- $\chi^2$/ndf = 2.5/4

FAPERJ CAPES UFRJ

A special thank you to the ***Pierre Auger Collaboration*** for all the provided support and to the ***Pierre Auger Observatory local staff***, specially ***Juan Pablo Gongorra***, for the availability, the extensive help and the warm welcome.

# Calibration Talks

- M. Scornavacche: Effect of knock-on electrons in UMD
- J. de Jesus: Improved calibration methods for UMD
- J. de Jesus: Data-driven method for corner-clipping effect in UMD
- P. Phillip: Calibration of AugerPrime SDs
- T. Tomida et al.: Calibration of TA-FD with "Opto-copter" and CLF

# Calibration of the TA Fluorescence Detectors and Systematic Uncertainties in UHECR Analysis

(1) SHINSHU UNIVERSITY (2) OECU 大阪電気通信大学 (3) (4) ICRR (5) KU (6) UTAH

Takayuki Tomida[1], Daiki Sato[1], Kota Mizuno[1], Aoi Matsuzawa[1], Yuichiro Tameda[2], Katsuya Yamazaki[3], Keitaro Fujita[4], Daisuke Ikeda[5], John Matthews[6] and for the Telescope Array collaboration

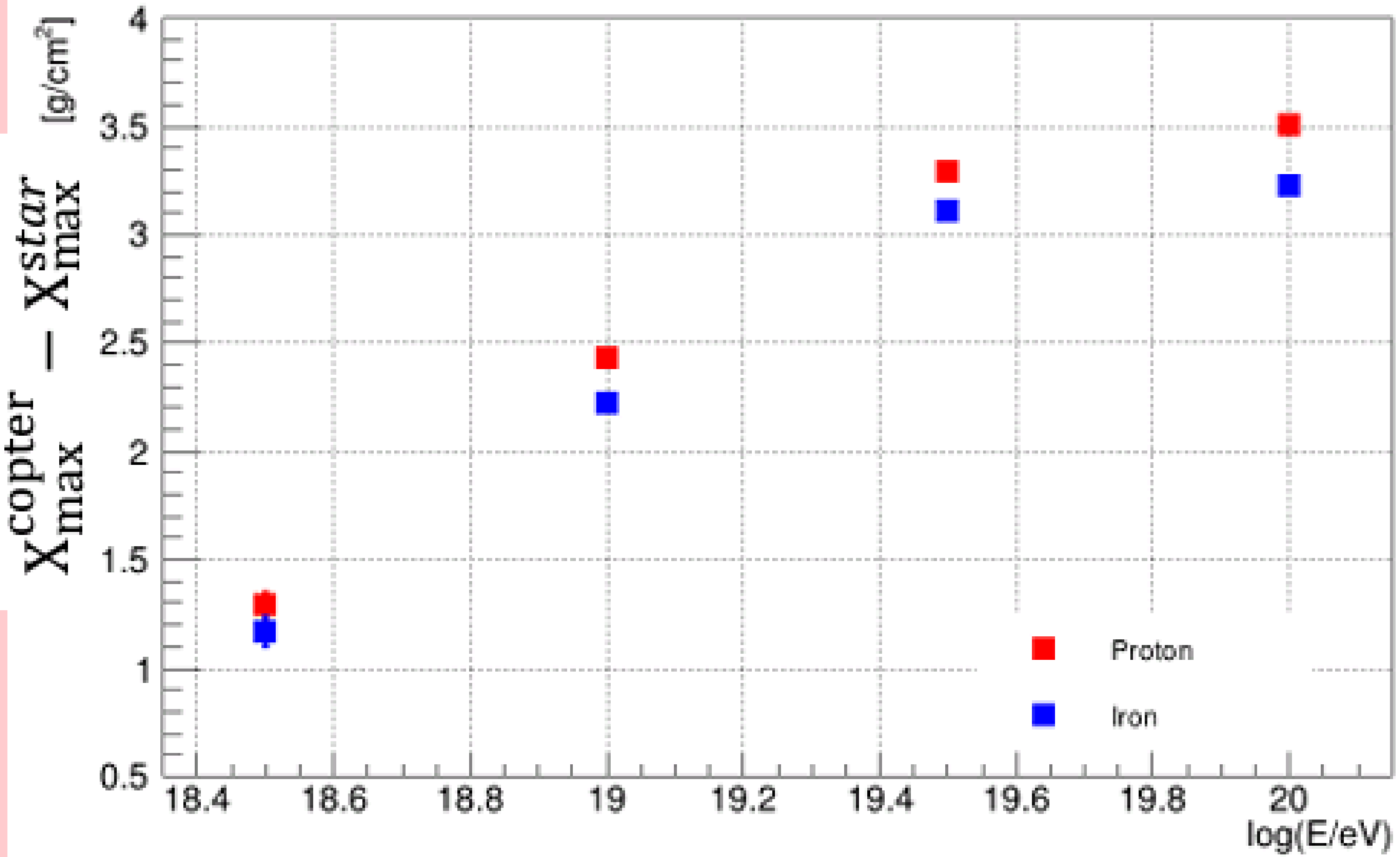
Contact : tomida@cs.shinshu-u.ac.jp

Opt-copter

- UV light source and RTK-GPS on a drone for TA-FD pointing direction calibration
- RTK-GPS: 10-cm positioning accurary, 0.02 degrees pointing accurary
- Update the PMT pointing directions instead of star-tracking methods

| | FD00 | FD01 | FD02 | FD03 | FD04 | FD05 | FD06 | FD07 | FD08 | FD09 | FD10 | FD11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ΔAzimuth [deg.] | 0.05 | 0.00 | 0.04 | 0.04 | 0.04 | 0.02 | 0.01 | -0.04 | 0.01 | -0.05 | -0.02 | 0.01 |
| ΔElevation [deg.] | 0.11 | -0.04 | 0.02 | -0.03 | -0.04 | -0.12 | -0.05 | -0.14 | -0.12 | -0.19 | -0.14 | -0.15 |

**Table 1. The results of FD pointing analysis at BRM station (2018)**



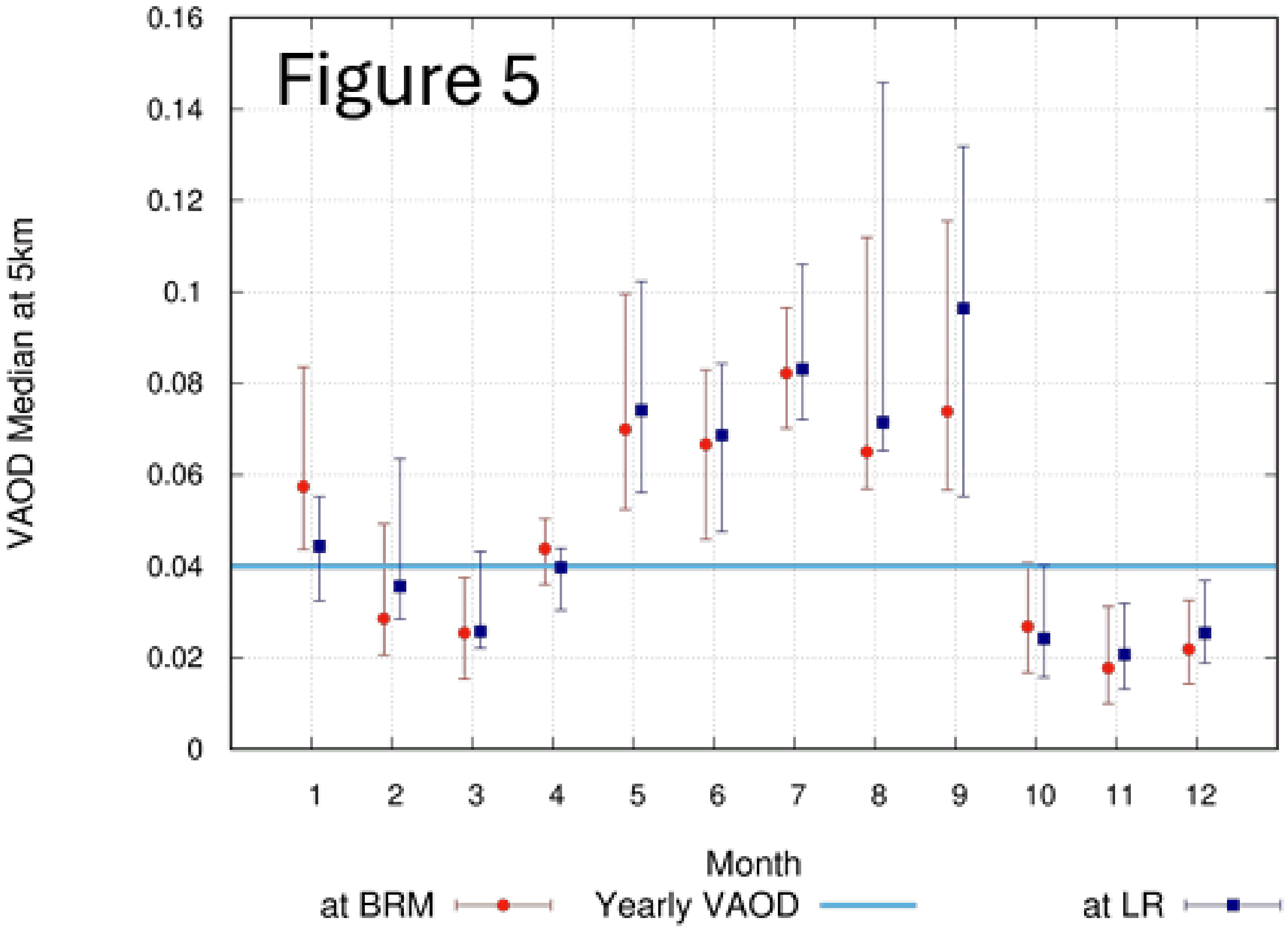


Figure 5
VAOD Median at 5km
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
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6
7
8
9
10
11
12
Month
at BRM
Yearly VAOD
at LR

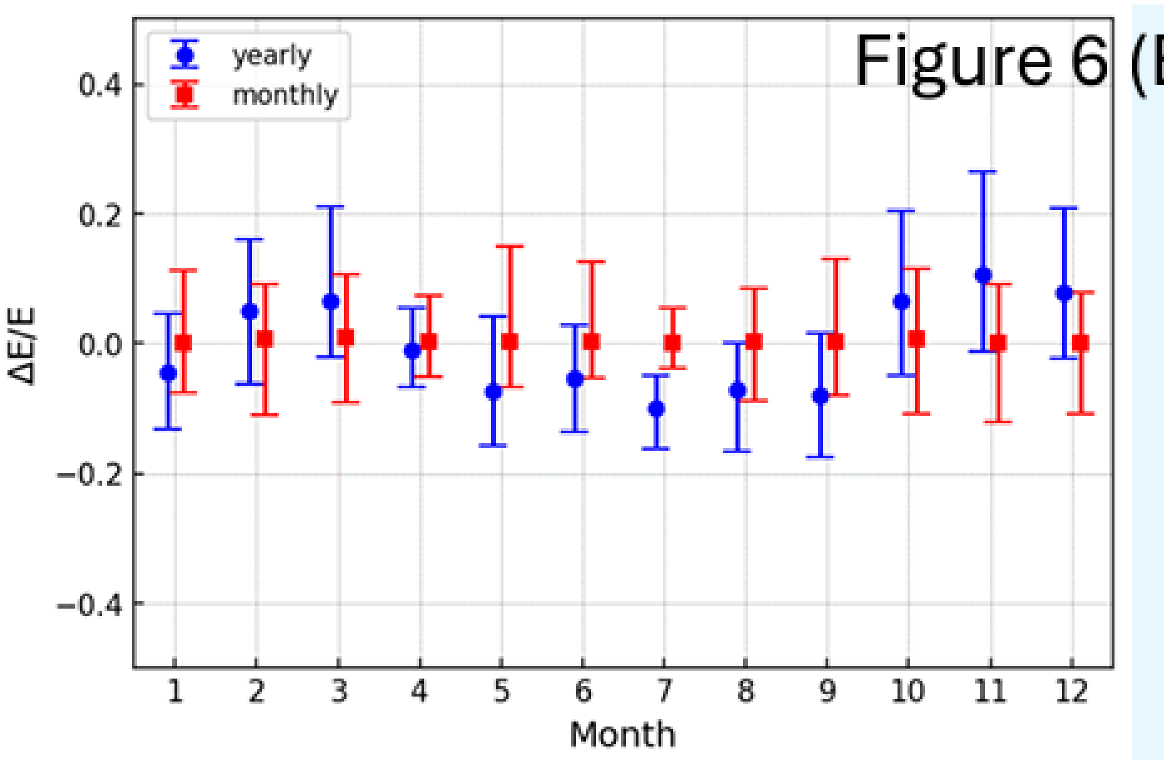



Figure 6 (E
yearly
monthly
ΔE/E
0.4
0.2
0.0
−0.2
−0.4
1
2
3
4
5
6
7
8
9
10
11
12
Month

# Analysis Technique Talks

- M.P. Shahvar, NN identification of highly inclined muons in WCD
- V. Varma: Evaluating the Composition Purity using Xmax and muon density
- E. Rodriguez: NN for photon search with AugerPrime
- C. Koyama: Inclined shower reconstruction with TAx4 SD
- S. Hahn: Machine-learning analysis for Auger
- S. Strahns et al.: Electric field reconstruction in radio detectors with Information Field Theory
- E. Santos: Core software of Auger

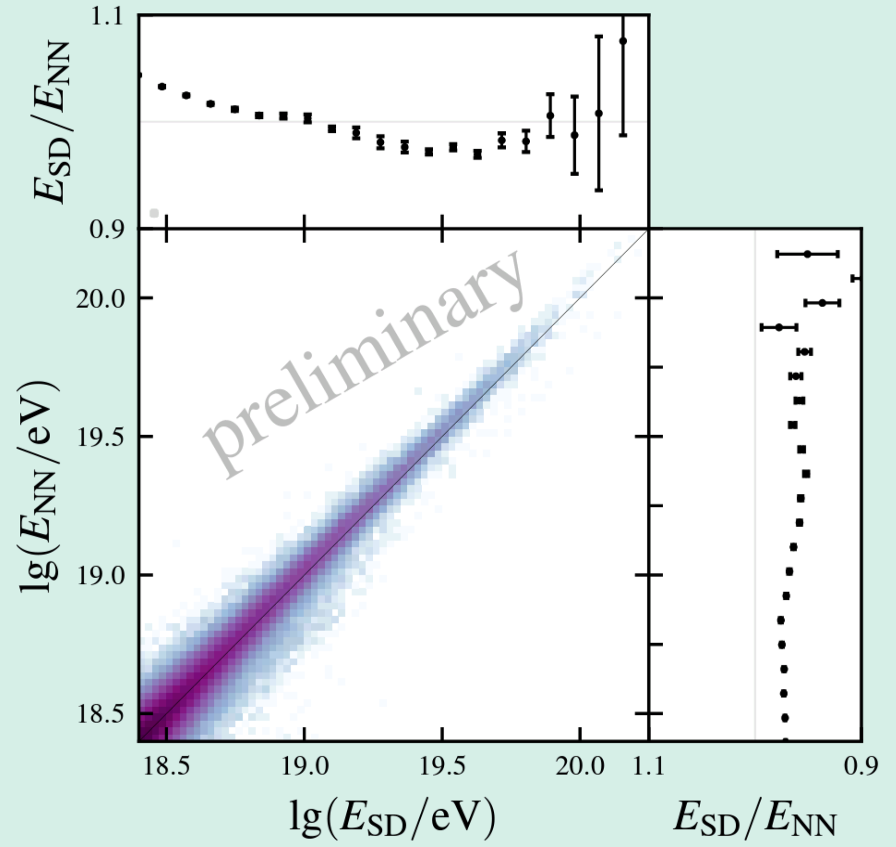
# Machine learning-based analyses using surface detector data of the Pierre Auger Observatory

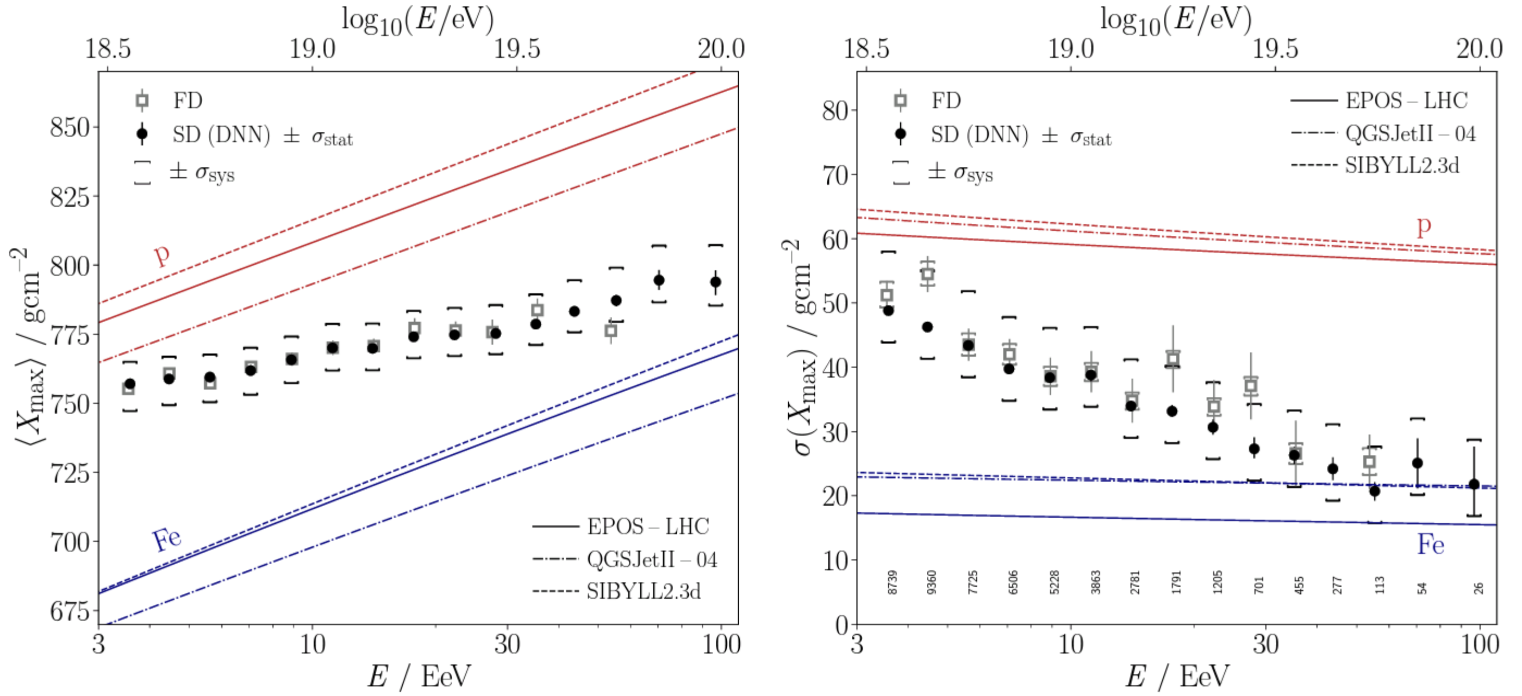
*Steffen Traugott Hahn** for the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

## Shortend abstract

To analyze the complex spatio-temporal data from air shower footprints detected by the Pierre Auger Observatory, machine learning-based algorithms are used to complement traditional methods. These algorithms help extract mass-sensitive observables, such as the number of secondary muons and the (atmospheric) depth of the shower maximum, from the surface detectors, improving the precision of UHECR mass estimates with an uptime of nearly 100%. The machine learning-based analyses perform exceptionally well in simulations and show, after calibration, excellent results when applied to measurements.



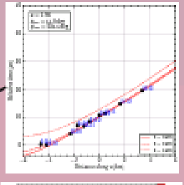
# Analysis of Inclined Air Shower Events Observed by the TA×4 SD

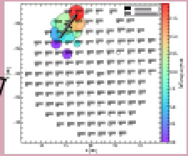
CHISATO KOYAMA for the Telescope Array Collaboration
*Institute for Cosmic Ray Research, The University of Tokyo, 5-1-5 Kashiwa-no-Ha Kashiwa, Chiba, Japan*

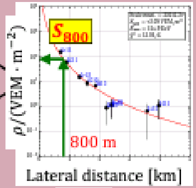
## Extension of the reconstruction method

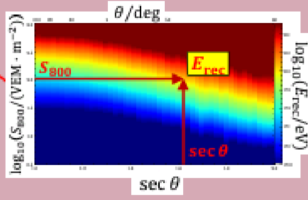
### Event reconstruction process

Information from each SD
↓
**Timing Fit** (Pre-fit)
Obtain the initial value for the Geometry Fit
↓
**Geometry Fit**
Determine $\theta$, $\phi$ & core position
↓
**LDF** (Lateral Distribution Function) **Fit**
Calculate $S_{800}$ from the LDF
↓
**Combined Fit** (Re-fit)
Geometry + LDF (GLDF) Fit
↓
**Energy Estimation**
Estimate $E$ from $S_{800}$ & $\theta$
↓
Reconstructed parameters

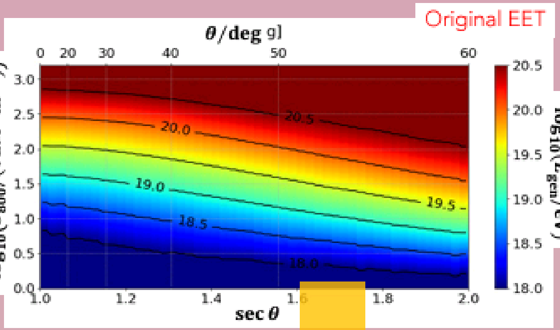


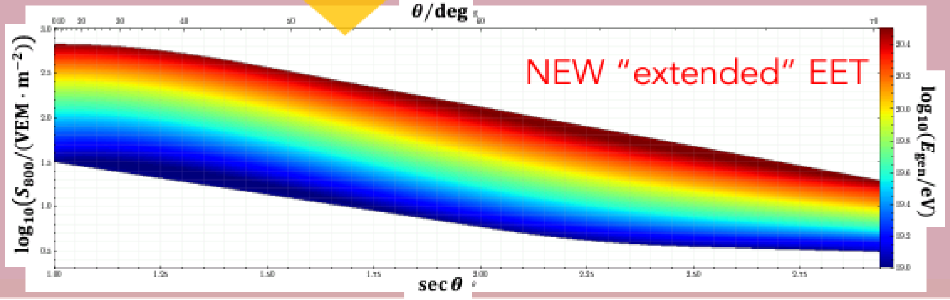





It was necessary to extend the **energy estimation table** (EET) used to the large zenith angle region for reconstructing inclined events. Using an enhanced method, we extended the EET generated from the MC simulation to $\theta = 70°$




### MC simulation dataset

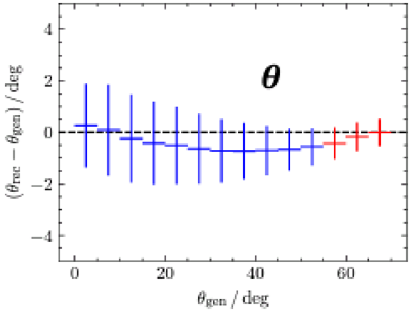
- pure proton, QGSJETII-04
- $10^{17.5}$ eV $\leq E_{gen} \leq 10^{20.5}$ eV
- $0° \leq \theta_{gen} \leq 70°$

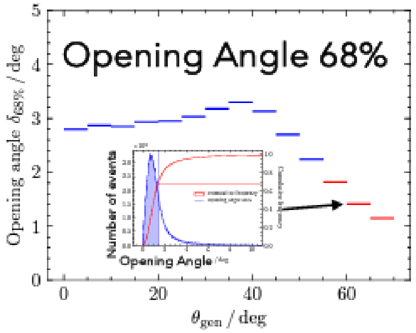
### Selection criteria

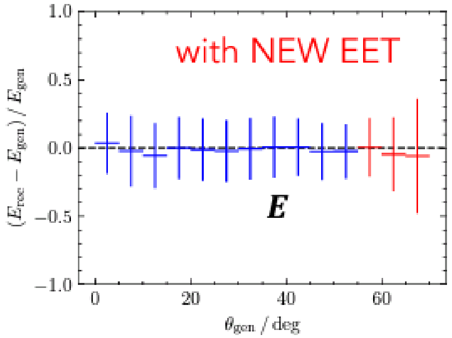
- $N_{SD} \geq 5$
- reduced $\chi^2 \leq 4$
- $\sigma_{S800} / S_{800} \leq 0.5$
- $\sigma_{\text{point direc.}} \leq 6°$
- $D_{border} \geq 400$ m

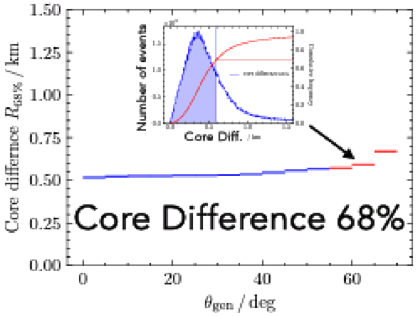
### Evaluation of reconstruction accuracies

Reconstruction accuracies of each parameter are evaluated for each zenith angle (Below are ex. of $10^{20.1}$ eV).




**No significant bias** in the large zenith angle region

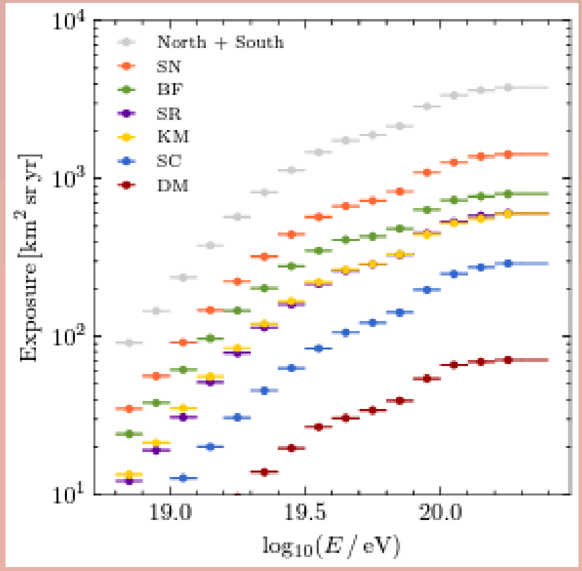
# Measurement of energy spectra

## Cosmic Ray Flux

$$J_i = \frac{\sum_{\text{s.a.}} \frac{(N^{\text{Data}}_{\text{rec}})_i}{\Delta E_i}}{\sum_{\text{s.a.}} \left[ \frac{(N^{\text{MC}}_{\text{rec}}(E_{\text{rec}}))_i}{(N^{\text{MC}}_{\text{gen}}(E_{\text{gen}}))_i} A_{\text{gen}}\Omega_{\text{gen}}\, T \right]}$$

Effective exposure considering bin to bin migration (TA 11yr spectra was assumed)

| | TA × 4 North array | | | TA × 4 South array | | |
|---|---|---|---|---|---|---|
| Sub-array | KM | DM | SN | BF | SR | SC |
| Array area [km²] | ~120 | ~40 | ~230 | ~150 | ~140 | ~110 |
| # of days $T$ [days] | 1120 | 1102 | 1120 | 1093 | 1120 | 1120 |




Exposure values were smaller in the highest energy bin t
energy bins (Because the highest energy of the EET was
extrapolated values are used assuming flat exposure.

Comparison on the numbers of events of observed data $N^{\text{Data}}_{\text{rec}}$ with $E \geq 10^{18.8}$ eV

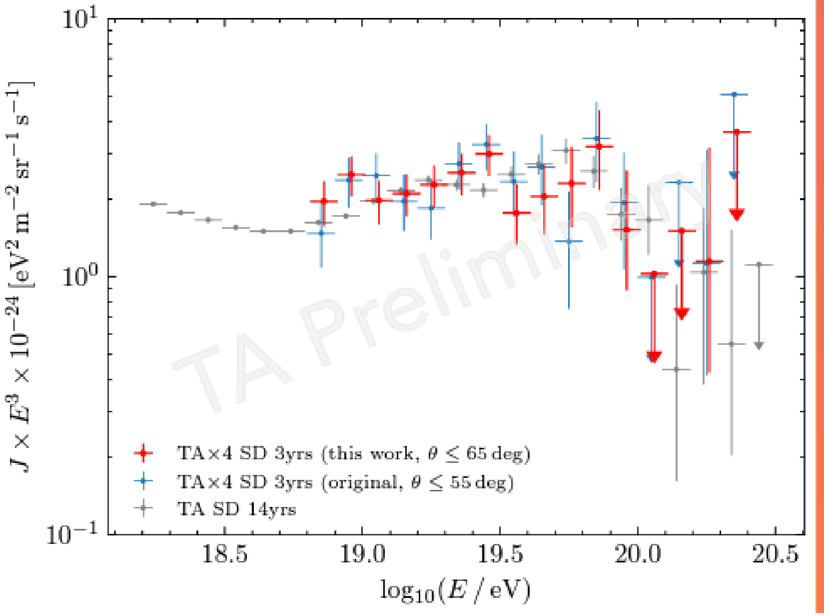
TA × 4 SD original analysis
(Criteria : $\theta \leq 55°$)
$N^{\text{Data}}_{\text{rec}} = 186$

This work
(Criteria : $\theta \leq 65°$)
$N^{\text{Data}}_{\text{rec}} = 259$

1.4 × increase in statistics **

** This is larger than expected increase from expansion of aperture associated with extension of the zenith angle (By extension from $\theta = 55°$ to 65°, aperture expands ~1.2 × larger).
This is because events in low-energy region where reconstruction efficiency is not 100% are more likely to be reconstructed in the large zenith angle region.

than in the lower
s too low), so that




Good agreements with previous analysis

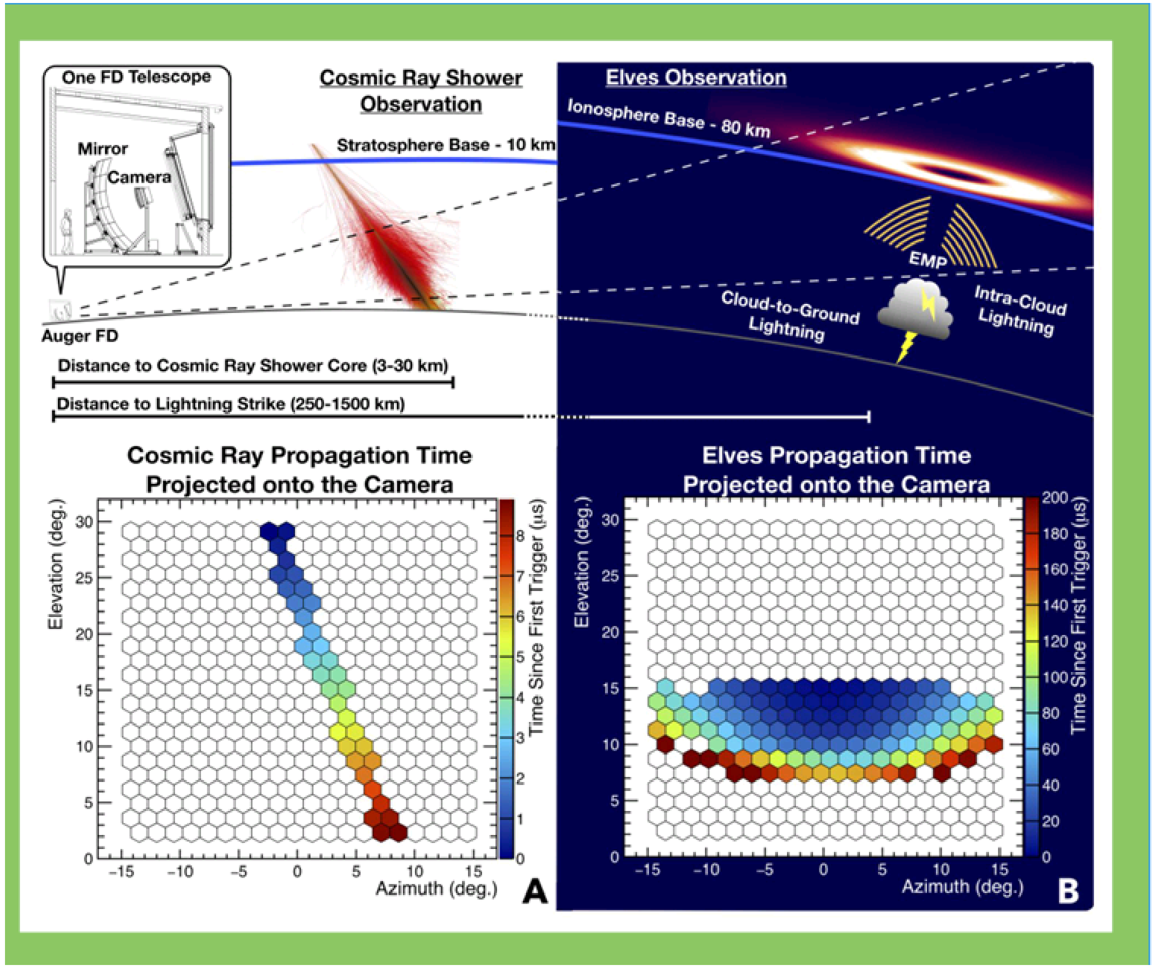
# Atmospheric Studies

- L. Valore and M. Busken: Upgrade of atmospheric monitoring system of Auger
- R. Mussa: Results and prospects in atmospheric electricity and solar activity studies in Auger

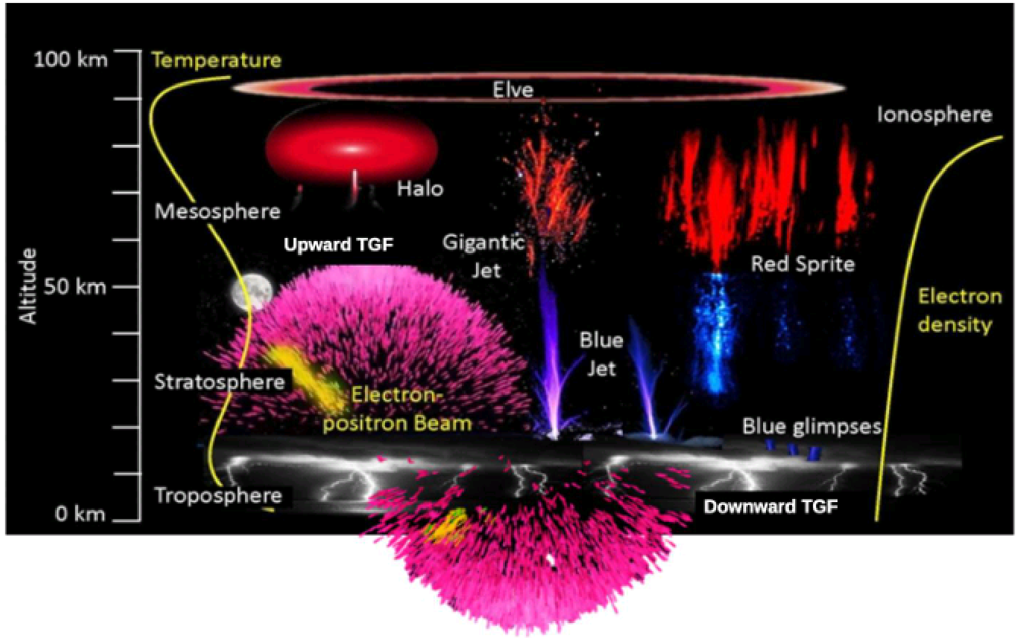
JHECR 2024

# Results and prospects in atmospheric electricity studies and solar physics at the Pierre Auger Observatory

Roberto Mussa for the Pierre Auger Collaboration
INFN, Sezione di Torino, mussa@to.infn.it




## Types of Transient Luminous Events (TLE)




**Thunderstorms are the most energetic natural particle accelerators on Earth.** Very bright events are produced in coincidence with lightning and the Pierre Auger Observatory proved to be a unique instrument to study these phenomena.

# New Detectors

- A. Elsenhans et al: ANDESPix: A digital SiPM for ANDES muon detectors
- T. Sako: ALPACA and ALPAQUITA
- L. Lavitola: MultiPMT detectors for SWGO
- B. Flaggs and I. Maris: Layered WCD for next generation arrays
- B. Errico: GRAND@Auger
- Y. Kawachi: TALE-infill array

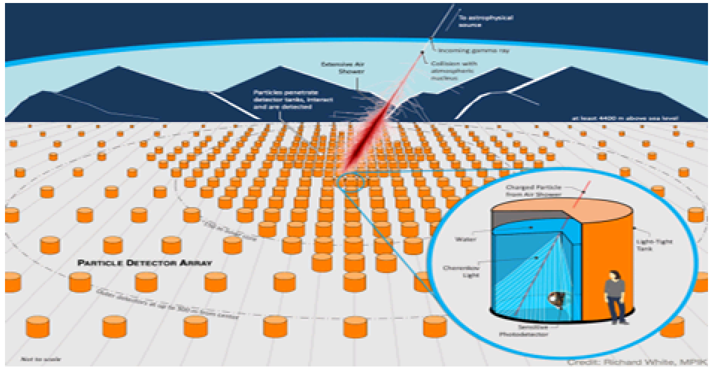
# A proposal for a multiPMT detector in the Southern hemisphere wide field of view gamma-ray observatory (SWGO)

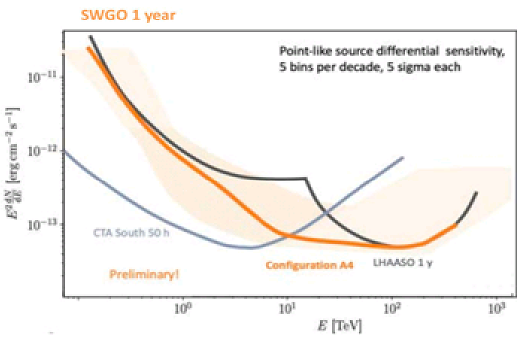
L. Lavitola on behalf of SWGO - INFN Napoli

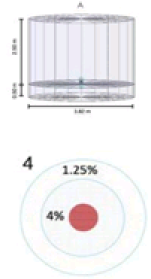
The Southern Wide-field Gamma-ray Observatory

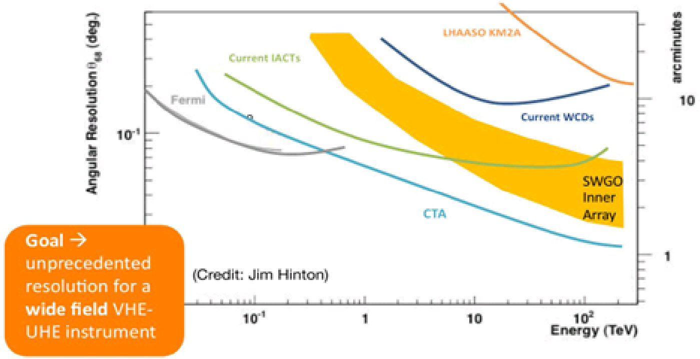
**UHECR 2024**
Malargue, November 17-21 2024

SWGO will be a new ground-based gamma-ray observatory in the southern hemisphere. It will be based on water Cherenkov detectors andi t is proposed to complement existing Northern instruments like HAWC, Tibet-ASg, and LHAASO. The selected site is Pampa la Bola in Chile, at 4770 m, in the Atacama Astronomical Park, featuring a high fill-factor core detector with enhanced sensitivity and a low-density outer Array. This observatory will cover energies from 100s of GeV to PeV, offering near 100% duty cycle and wide field of view. This includes mapping large-scale gamma-ray emissions, accessing the Galactic Centre, and supporting transient and multi-messenger astronomy, with significant potential for cosmic-ray studies and anisotropy detection.

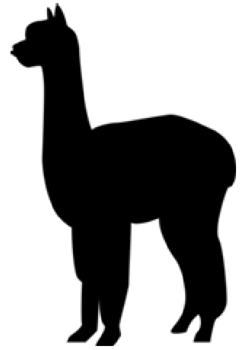


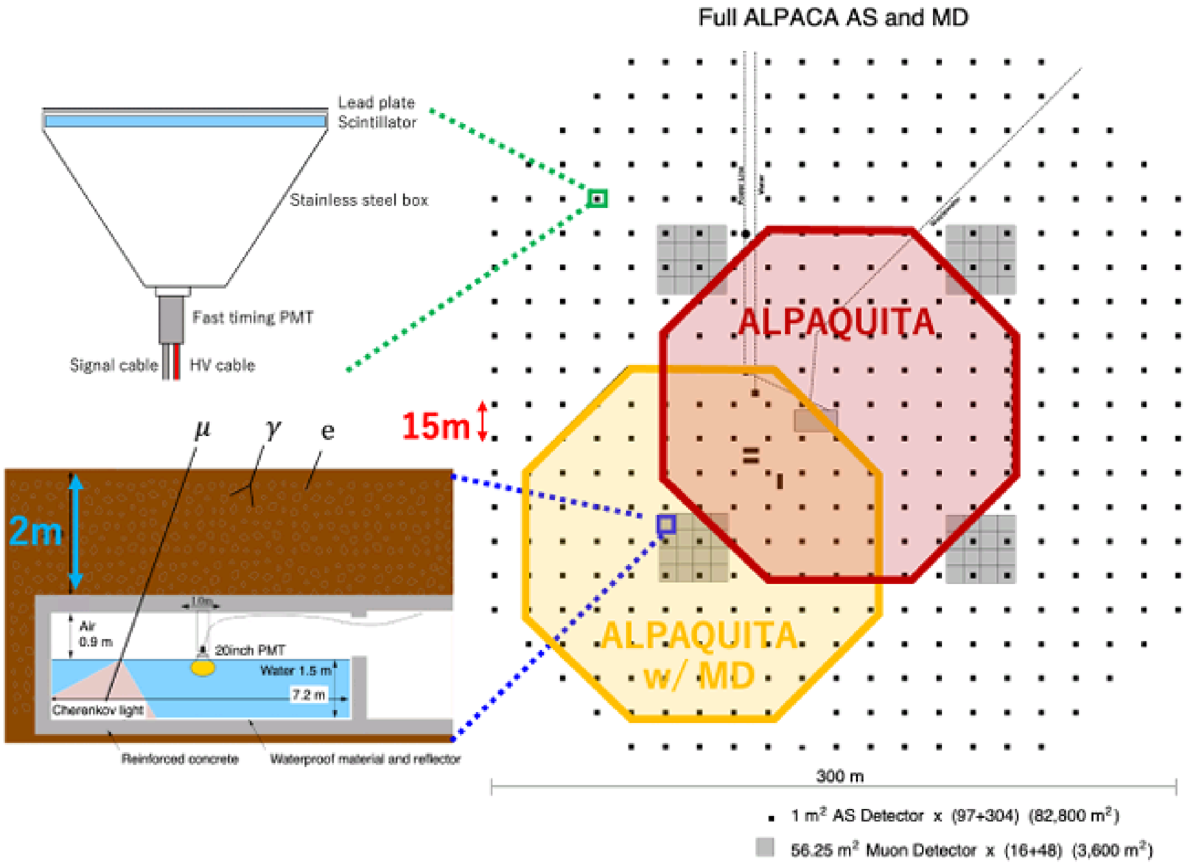



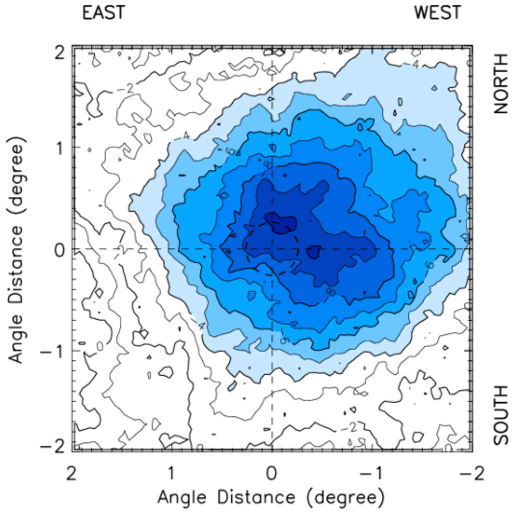



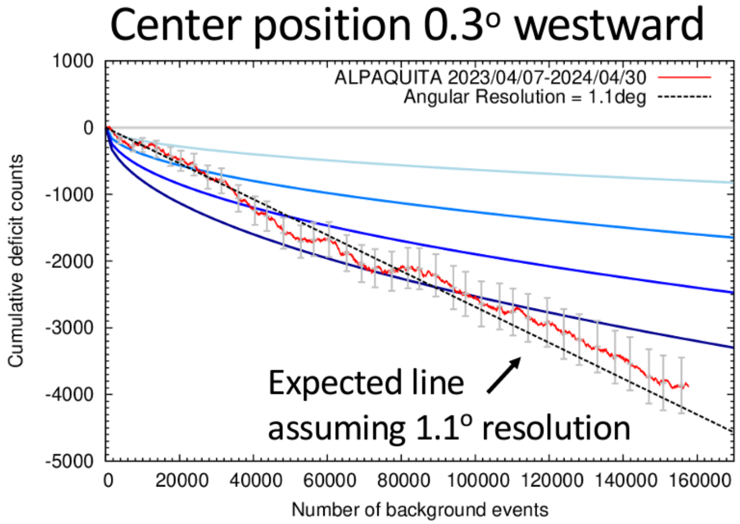
# ***ALPACA*** *project to observe sub-PeV gamma-ray sky in the southern hemisphere*



T. Sako[A], M. Anzorena[A], E. de la Fuente[C], K. Fujita[A], R. Garcia[A], K. Goto[D], Y. Hayashi[E], K. Hibino[F], N. Hotta[G], G. Imaizumi[A], A. Jimenez-Meza[C], Y. Katayose[H], C. Kato[I], S. Kato[A], T. Kawashima[A], K. Kawata[A], T. Koi[J], H. Kojima[K], T. Makishima[H], Y. Masuda[I], S. Matsuhashi[H], M. Matsumoto[I], R. Mayta[B], P. Miranda[B], A. Mizuno[A], K. Munakata[I], Y. Nakamura[A], M. Nishizawa[L], Y. Noguchi[H], S. Ogio[A], M. Ohnishi[A], S. Okukawa[H], A. Oshima[D,J], M. Raljevic[B], H. Rivera[B], T. Saito[M], T. K. Sako[N], T. Shibasaki[O], S. Shibata[K], A. Shiomi[O], M. Subieta[B], F. Sugimoto[A], N. Tajima[P], W. Takano[F], M. Takita[A], Y. Tameda[Q], K. Tanaka[R], R. Ticona[B], I. Toledano-Juarez[C], H. Tsuchiya[S], Y. Tsunesada[T,U], S. Udo[F], R. Usui[H], G. Yamagishi[H], K. Yamazaki[J], Y. Yokoe[A] et al. (The ALPACA Collaboration)



# Outreaches

- B. Garcia: Communicating astroparticle physics with the public
- V. Scherini: The Pierre Auger public data

7th International Symposium on Ultra High Energy Cosmic Rays 2024 - Malargüe, Mendoza, Argentina

# The Pierre Auger Observatory Open Data

V.Scherini* for the Pierre Auger Collaboration
*Università del Salento and INFN Lecce, Italy
Observatorio Pierre Auger, Av. San Martìn Norte 304, 5613 Malargüe, Mendoza, Argentina

## The Open Data Portal

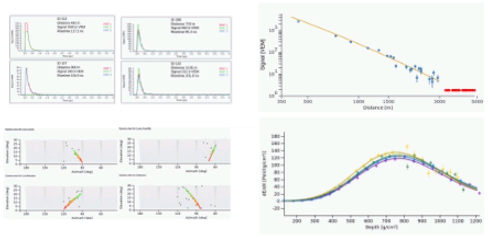
### Datasets

- 10% **cosmic ray dataset:**

~ 81000 events collected by the surface detector (SD) in the time period 2004-2018 used in 2019 ICRC in Madison, USA
  - SD1500 m array events above full efficiency threshold, zenith angle < 80° → 80% coverage of the
  - SD750 m events above 0.1 EeV, zenith angle < 40°

~ 3300 hybrid events, collected simultaneously with the fluorescence detector (FD), and selected according to specific analyses

**JSON files** containing **calibrated data** for each event: surface detector stations with their photo-multiplier traces
**CSV files** containing **high-level info** with reconstructed parameters



**Reconstruction of the highest energy hybrid event in the released UHECR catalog: surface detector (top) and fluorescence detector data and reconstruction (bottom)**

- 100% **atmospheric data**: local condition parameters as pressure, temperature, humidity, and wind speed measured at the Auger site by weather stations and monitoring devices
- 100% **scaler mode data**: rates acquired by surface detector stations in low threshold particle counter mode, for space-weather studies

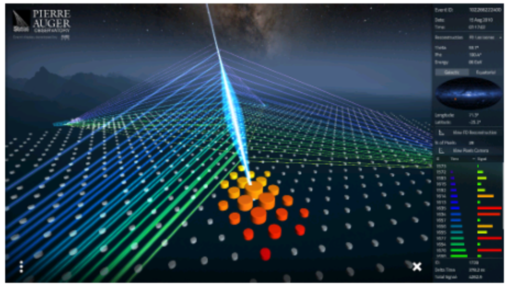

**Zenodo DOI: https://doi.org/10.5281/zenodo.4487612**

### Visualization

A **user-friendly interface** for selecting and browsing each of the public events by specifying an event ID or a range of reconstructed variables, such as the energy or the zenith angle is available. The browser contains an **immersive 3D animation** from the arrival direction of the cosmic rays to the detection of the created extensive air-shower with the instruments of the Observatory.

### UHECR Catalog

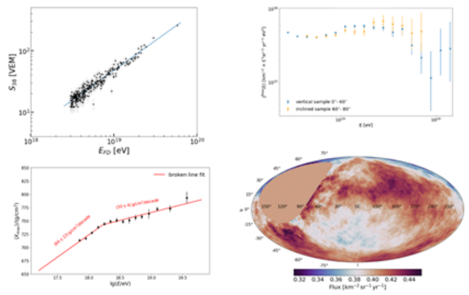
The events published in the catalog of the **100 highest-energy cosmic-ray events** [5] (76 EeV < E < 166 EeV) collected during Phase I of the data taking (between 2004 and 2021), along with the **9 highest-energy hybrid events** used for their calibration, are available for **inspection and download**.
For these events, additional features can be viewed: not only the footprint at ground can be displayed, but also that on the shower plane, and besides the lateral distribution of the shower particles, the user can also see the time delays of the signals with respect to a plane shower front.



**The highest energy hybrid event in the UHECR catalog: the reconstructed zenith angle is 54°, the energy 82 EeV. It triggered 22 SD stations and all FDs**

### Analysis

The Open Data can be analyzed using the provided **Python Jupyter Notebooks**. Tutorial examples are provided in the Portal introducing the Python programming language and its use with the Open Data. More advanced analysis codes are simplified reimplementation of parts of analyses published by the Collaboration. All the Notebooks can be downloaded or run online in a web browser via Kaggle (https://kaggle.org) platform.



**Graphical ouput of the analysis notebooks: energy calibration and spectrum (top), mass composition and arrival directions (bottom)**

### Outreach

The Outreach section, aimed at a **wider audience** and translated into several languages, is providing a unique opportunity to share the excitement of cosmic-ray physics with **students, teachers and citizen scientists** in the general public.
Built in the same spirit as the research part, with the same data, but in a **simplified format**, it is providing **exemplary tutorial and analysis tools** to understand and manipulate the released data..
An invitation to people to **explore data** and use them for their own inquiry by developing original education and outreach activities.

# My Conclusions and Message

- So many significant achievements reported,
- Deserve greater attention and recognition,
- Essential to the successs of this conference.