Pierre Auger Observatory Open Data and the Auger International Masterclasses

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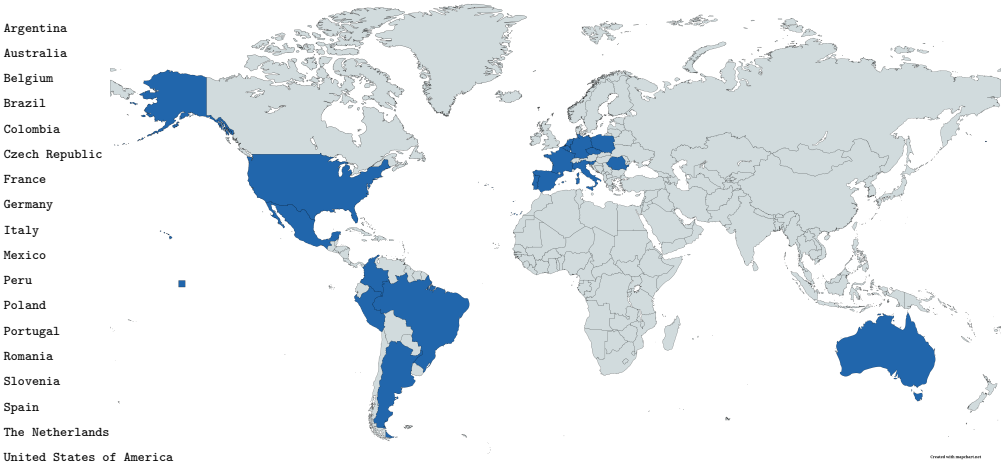
MINISTRY OF EDUCATION, YOUTH AND SPORTS

FZU Institute of Physics of the Czech Academy of Sciences

Pierre Auger Observatory

Pierre Auger Collaboration

About 400 authors from nearly 90 institutes from 18 countries



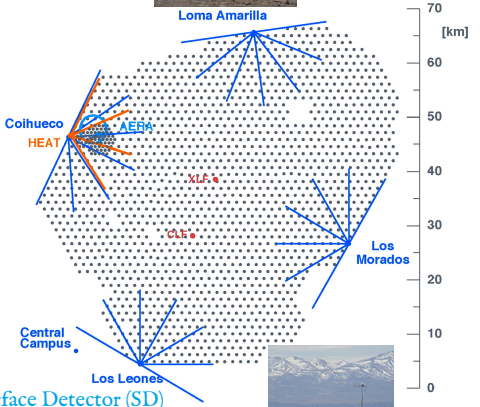
Pierre Auger Observatory

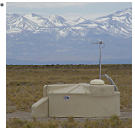
Malargüe, Province of Mendoza, Argentina

$35.2° S, 69.5° W, \sim 1400$ m a.s.l.

Fluorescence Detector (FD)

- 27 Schmidt telescopes
- $\sim$ 15% duty cycle



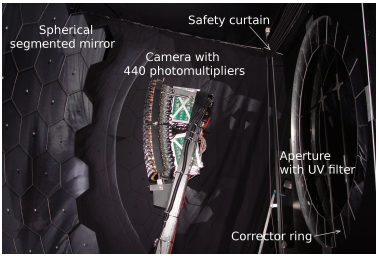


Surface Detector (SD)

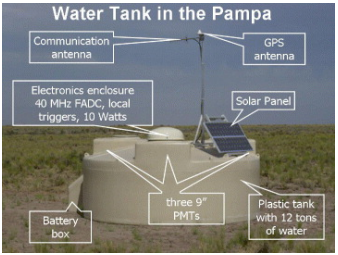
- 3000 km^2
- 1660 water-Cherenkov detectors
- $\sim$ 100% duty cycle

A hybrid detector

Fluorescence Detector



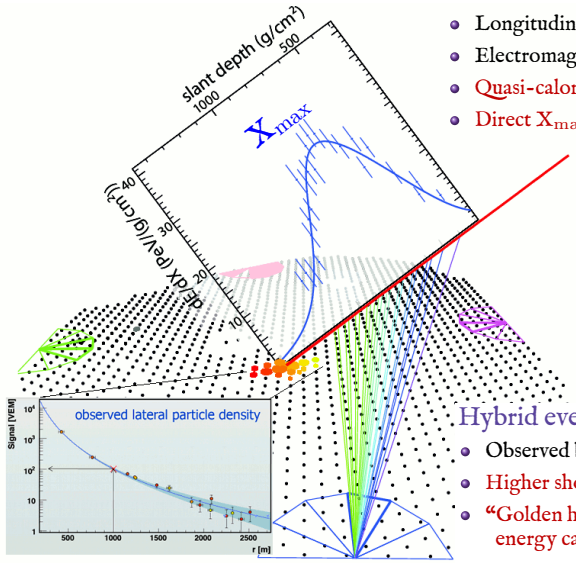
Surface Detector station



A hybrid detector (II)

Fluorescence Detector

- Longitudinal shower profile
- Electromagnetic component
- Quasi-calorimetric energy estimation
- Direct X_{max} measurement



Surface Detector array

- Lateral particle distribution
- Electrons, muons, high-energy photons
- High statistics

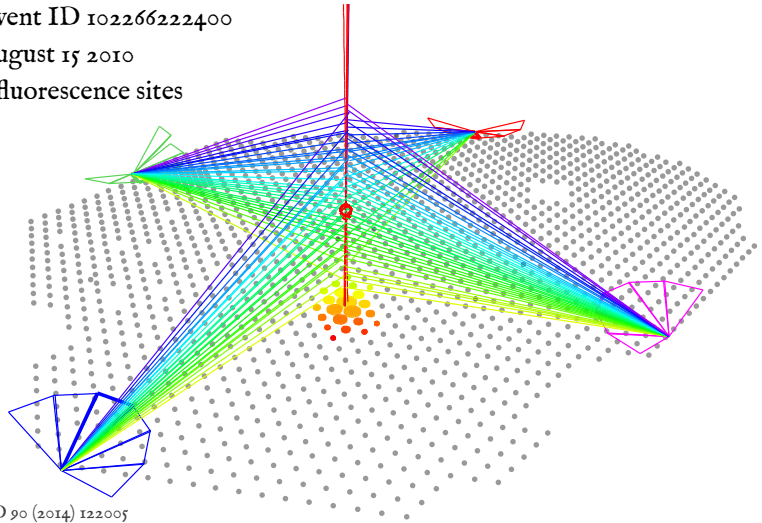
Hybrid events

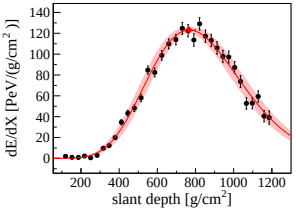
- Observed by both detectors
- Higher shower reconstruction accuracy
- "Golden hybrid" events provide the energy calibration of the SD array

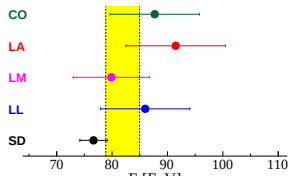
Measurement of the depth of the shower maximum $X_{\max}$

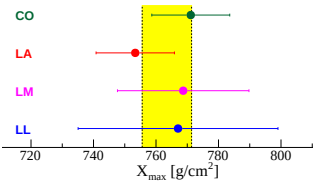
Real Auger Hybrid event:

- Event ID 102266222400
- August 15 2010
- 4 fluorescence sites



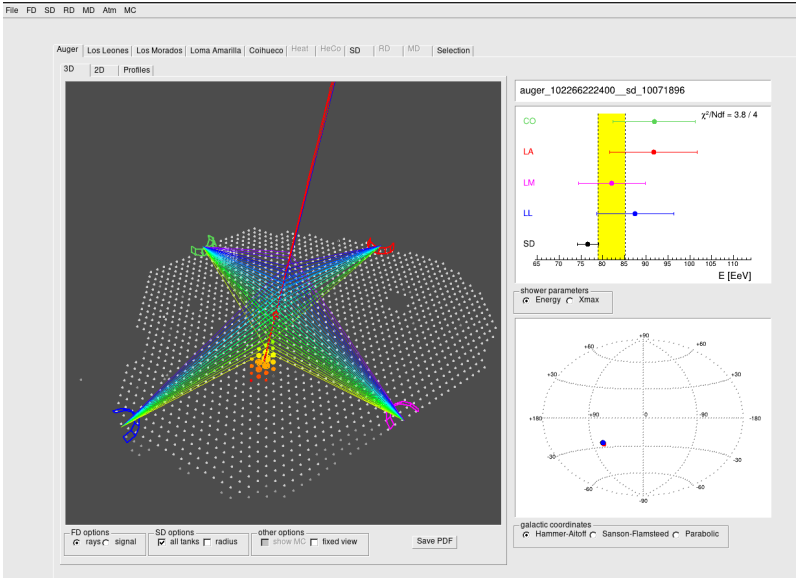






Phys. Rev. D 90 (2014) 122005
Phys. Rev. D 90 (2014) 122006

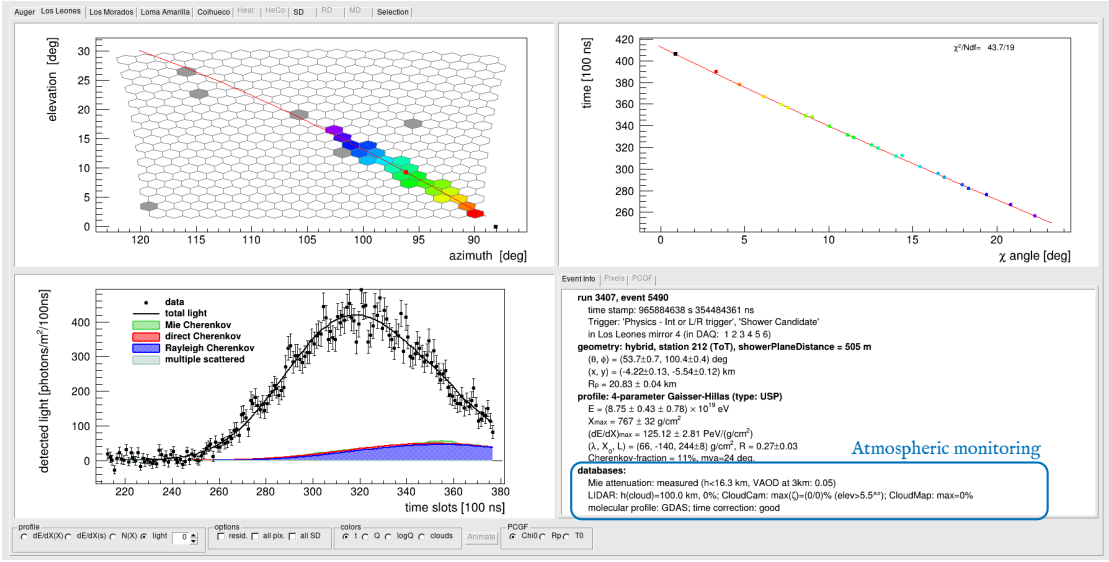
Quadruple event in EventBrowser: 3D view



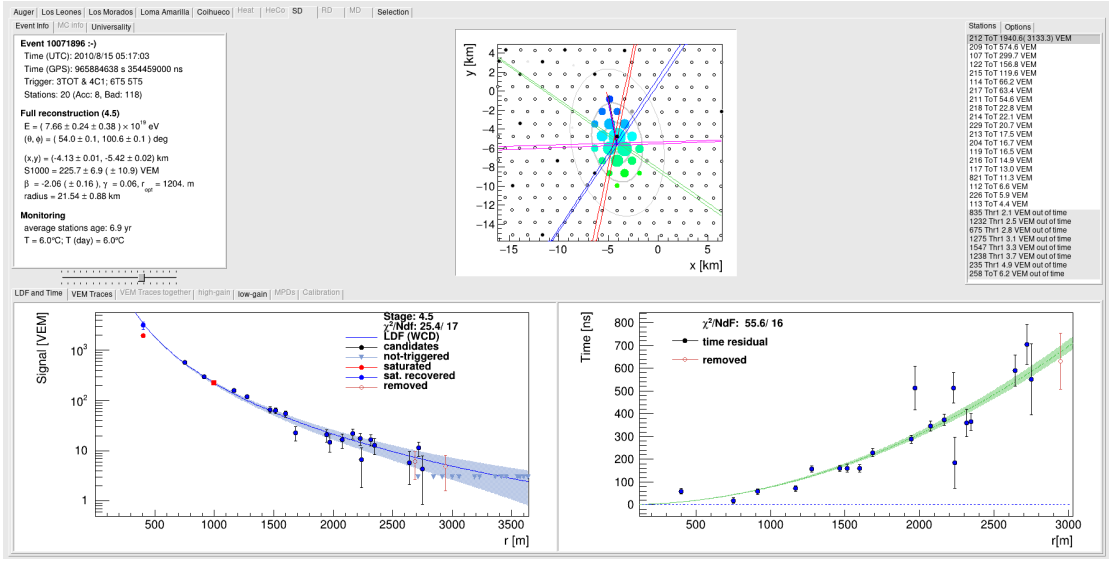
- Menus with more display options
- Tabs for detectors & event selection

⇐ All reconstructed energies & $X_{\max}$

Quadruple event in EventBrowser: Los Leones FD site

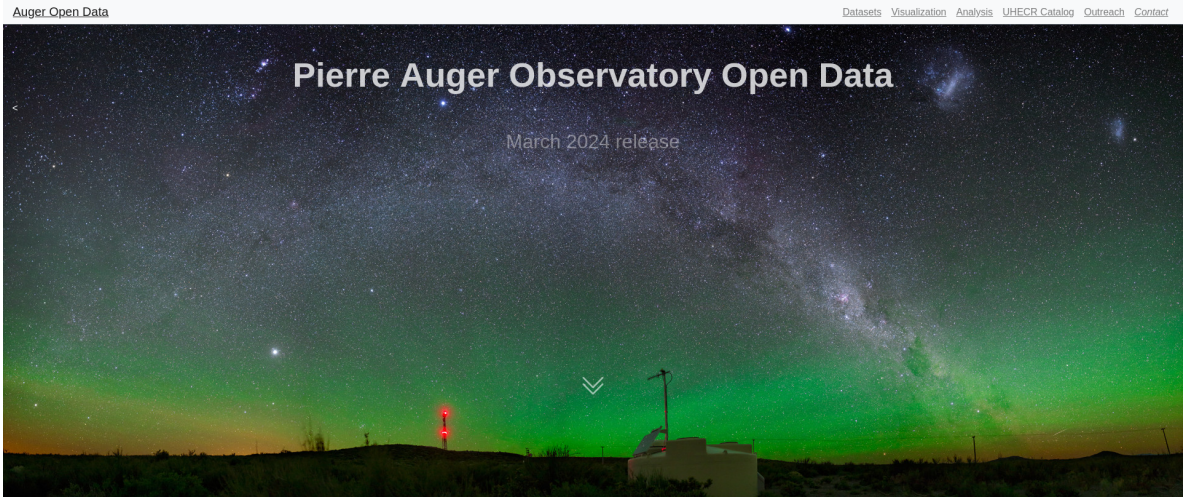


Quadruple event in EventBrowser: SD view



Auger Open Data portal

https://opendata.auger.org/



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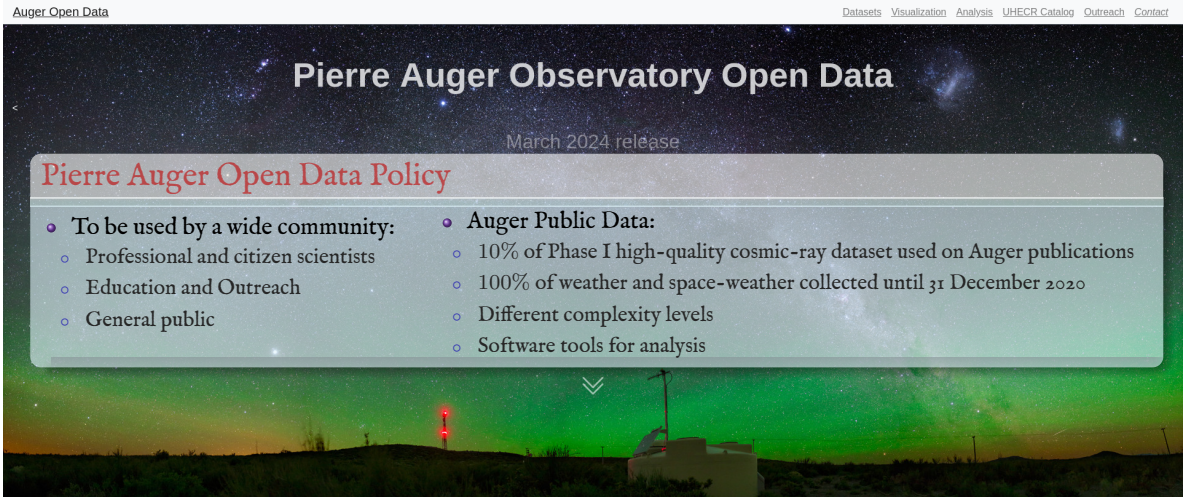

Yearly updates during the whole lifetime of the Pierre Auger Observatory

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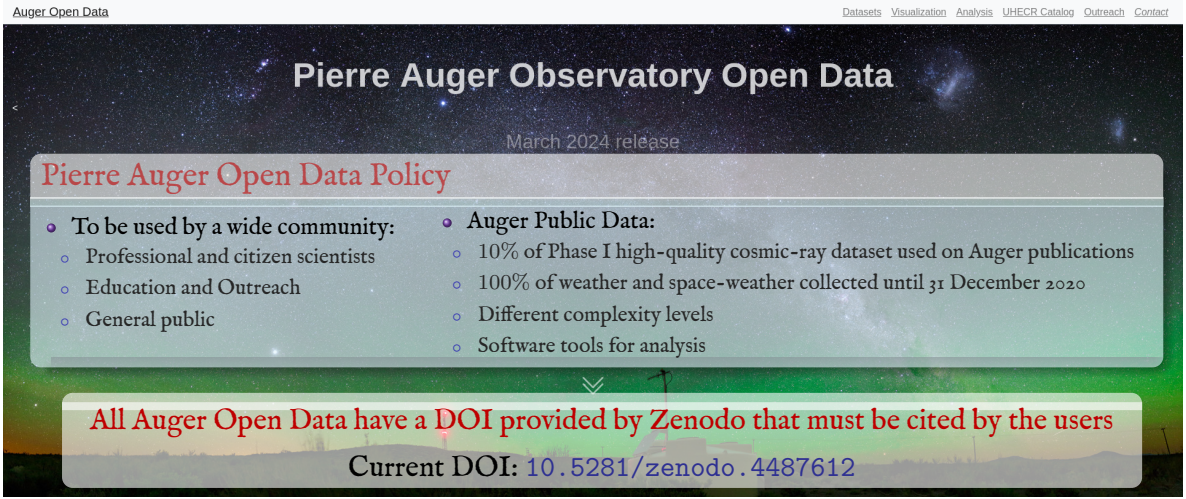
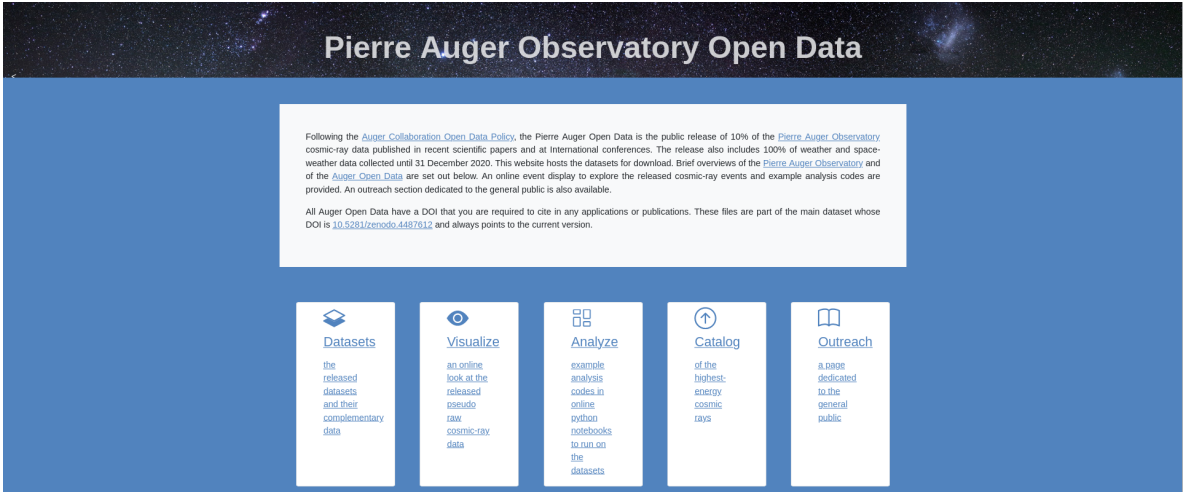


Yearly updates during the whole lifetime of the Pierre Auger Observatory

Navigating through the Auger Open Data portal

https://opendata.auger.org/



Auger Open Data portal - Datasets

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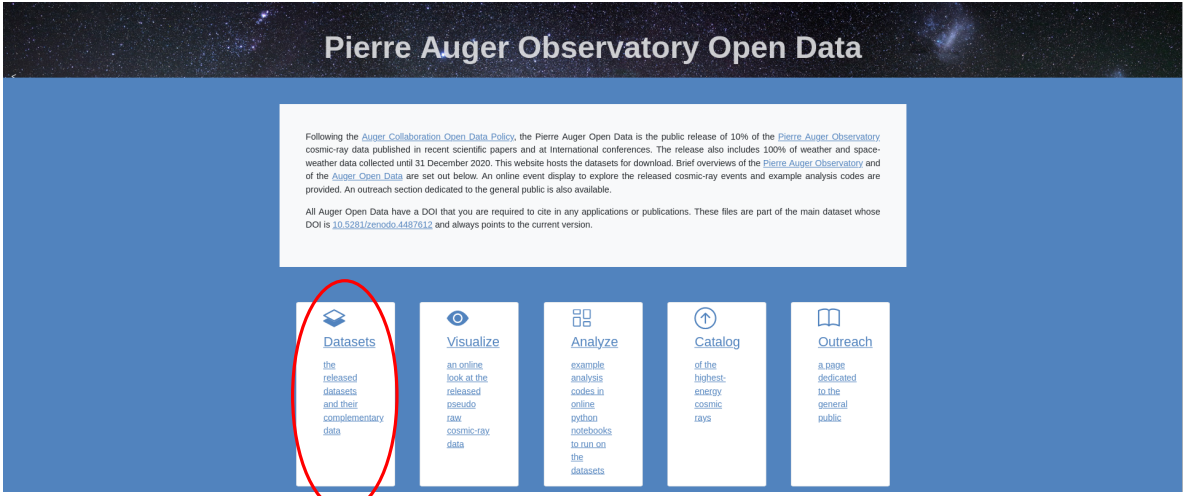

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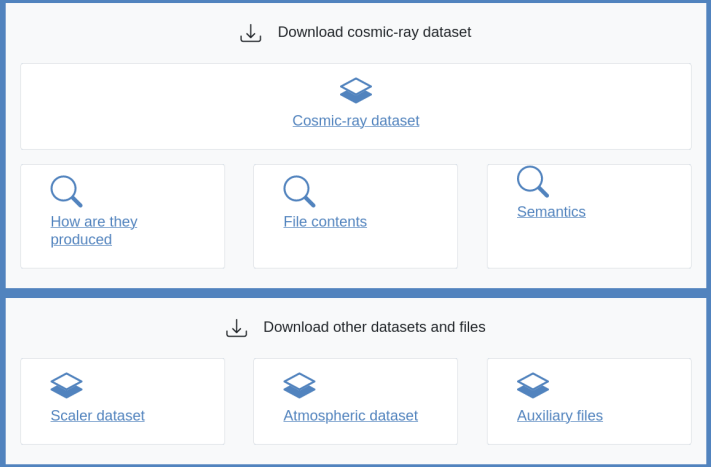

Auger Open Data portal - Datasets

List of releases:

- **Feb 15, 2021: release 1, DOI** 10.5281/zenodo.4487613
  - 10% of vertical (zenith angles $0° - 60°$) SD 1500 m and hybrid (SD 1500 m and FD) well reconstructed events from the dataset used in 2019 ICRC
  - Basic event display, tutorials and physics notebooks following the main Auger results
- Oct 26, 2021: release 1.1, DOI 10.5281/zenodo.5588460
  - 100% of weather and space-weather data collected until 31 December 2020
  - Physics notebooks to analyze weather and space-weather data
  - Outreach page dedicated to general public
- Dec 22, 2022: release 2, DOI 10.5281/zenodo.6867688
  - 10% of SD 1500 m inclined (zenith angles $60° - 80°$) well reconstructed events from the dataset used in ICRC 2019
- Mar 20, 2024: release 3, DOI 10.5281/zenodo.10488964
  - 10% of SD 750 m array (zenith angles $0° - 40°$) well reconstructed events from the dataset used in Eur. Phys. J. C 81, 966 (2021)
  - Catalog of the 100 most energetic events, ApJS, 264, 50 (2023)

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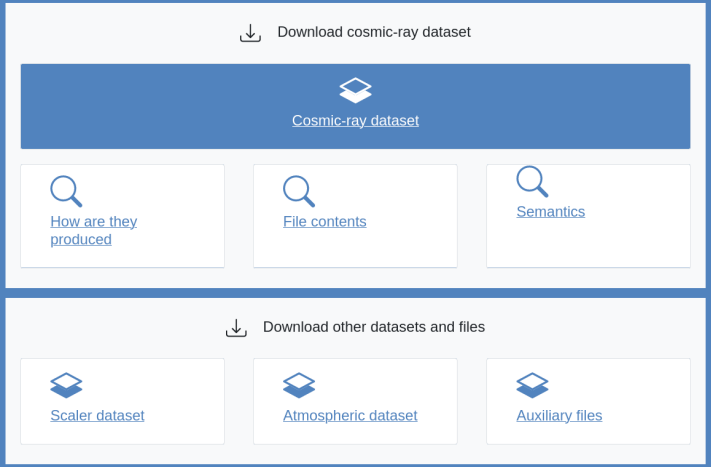
Auger Open Data portal - Cosmic-ray dataset

https://opendata.auger.org/



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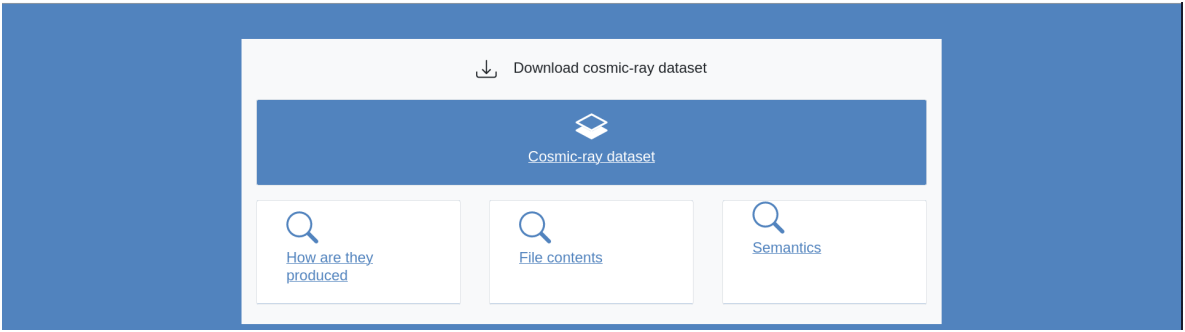

March 2024 release:

- Comprises 81,121 cosmic-ray events, of which:
  - 25, 086 were measured with the SD 1500 m array
  - 54, 481 were measured with the SD 750 m array NEW!
  - 3, 348 are hybrid events
    - 197 were measured with the HEAT-Coihueco telescopes NEW!

Dataset available in two formats:

- Pseudo-raw data
  - JSON file
- High-level data for the reconstructed events
  - CSV file

Auger Open Data portal - Cosmic-ray dataset

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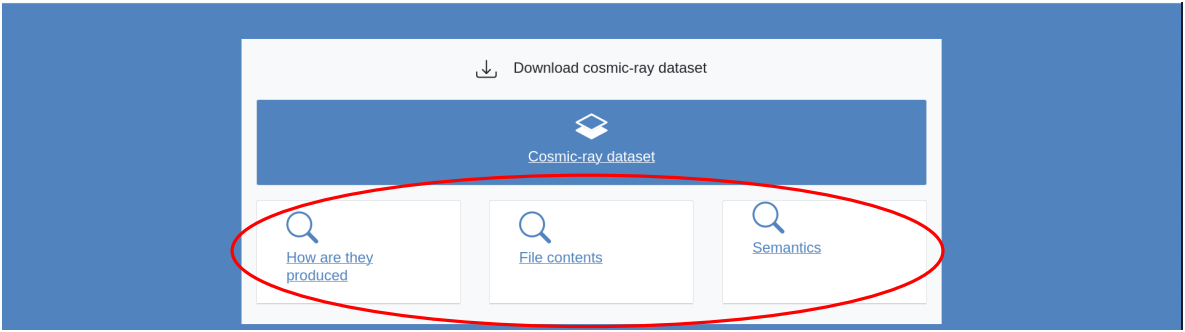
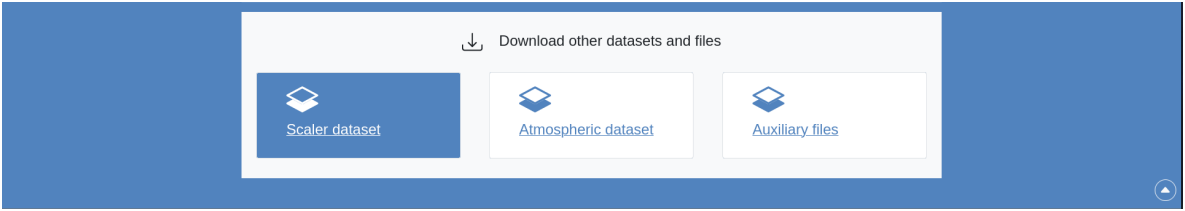


Detailed documentation of the available data:

- Details on how data were selected
- Description of the content of files
- Semantics for each data field

Auger Open Data portal - Scaler dataset

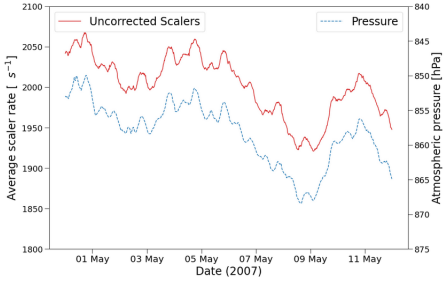
https://opendata.auger.org/



Available since the Oct 26, 2021 release:

- More than 10^{15} events detected between
  March 2005 and December 2020
  - Detection of particles from 10 GeV to $\sim$ TeV cosmic rays

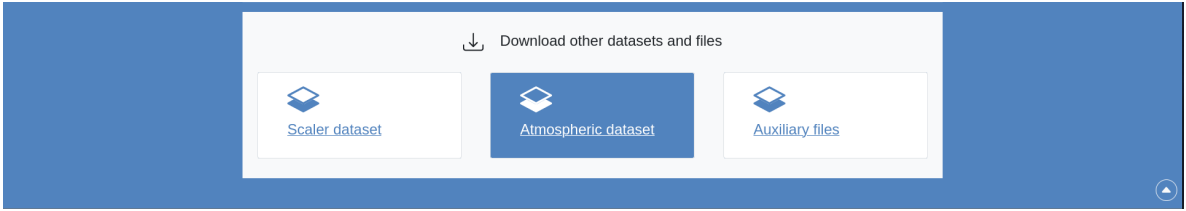
- Studies of terrestrial and extra-terrestrial phenomena
- Transient events
- Forbush decrease
- Solar modulation of the cosmic-ray flux



From the Outreach Jupyter Notebook: "Explore the scaler data"

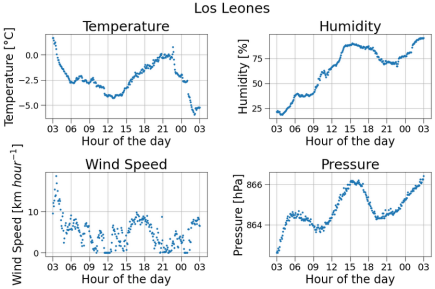
Auger Open Data portal - Atmospheric dataset

https://opendata.auger.org/



Available since the Oct 26, 2021 release:

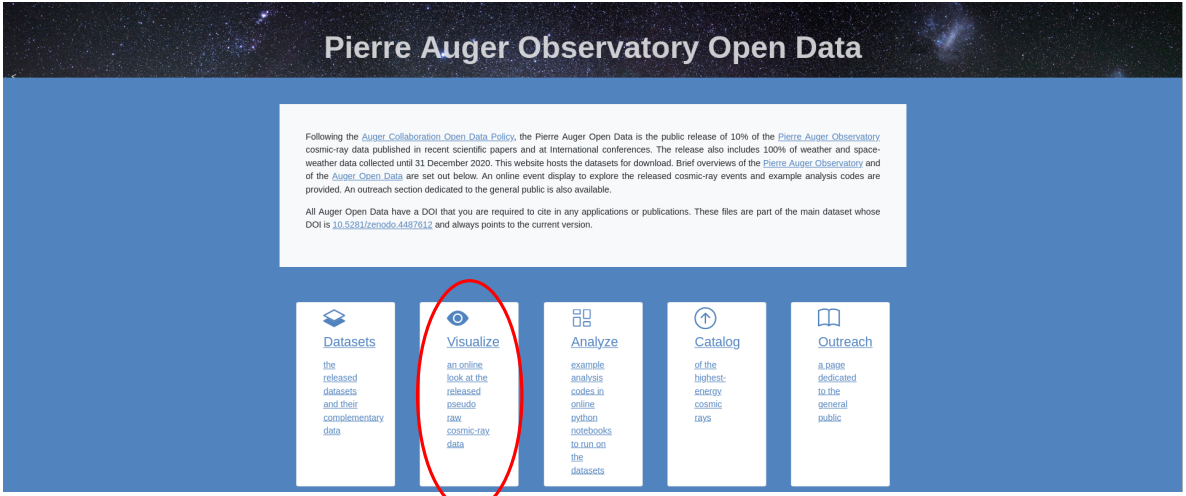
- Weather conditions measured at 5 or 10-minute intervals at 5 different locations
  - Time, temperature, pressure, density, average density, relative humidity, average wind speed
- Relevant for the energy calibration of the SD array



From the Outreach Jupyter Notebook: "Explore weather stations data"

Auger Open Data portal - Visualize

https://opendata.auger.org/



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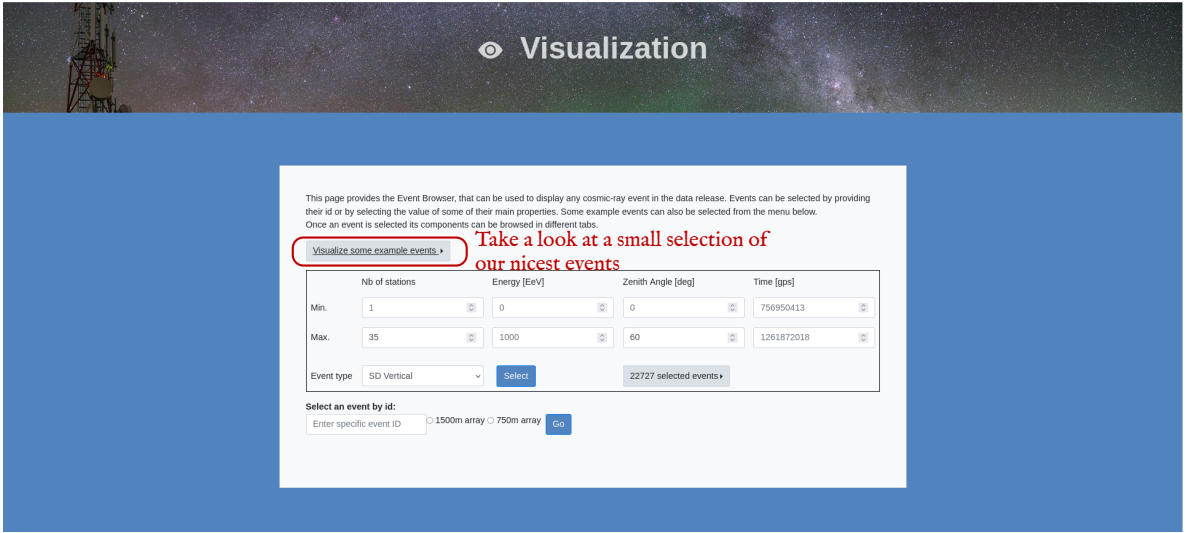

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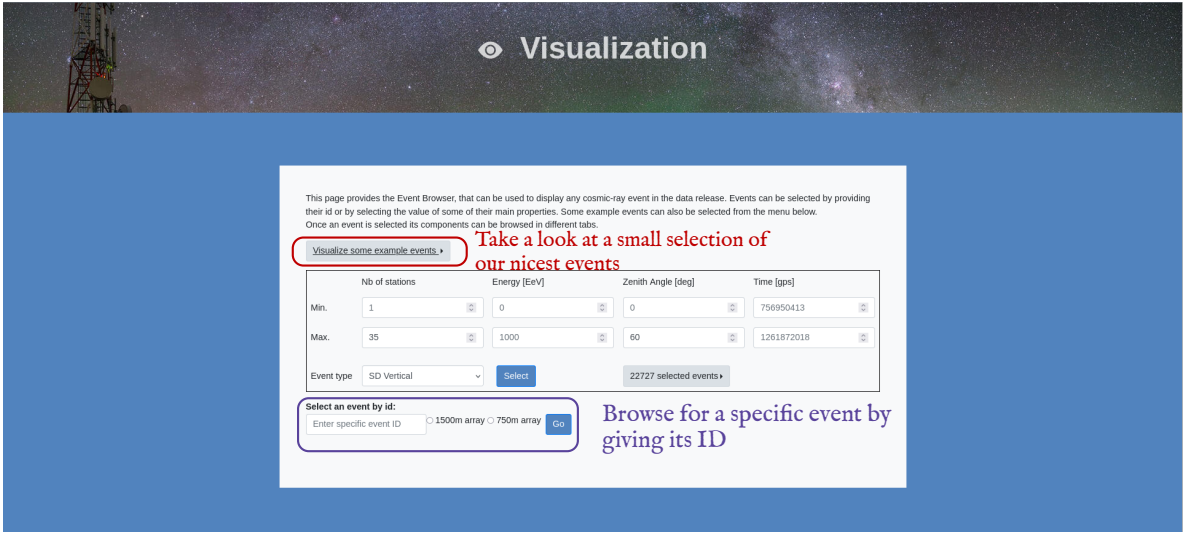

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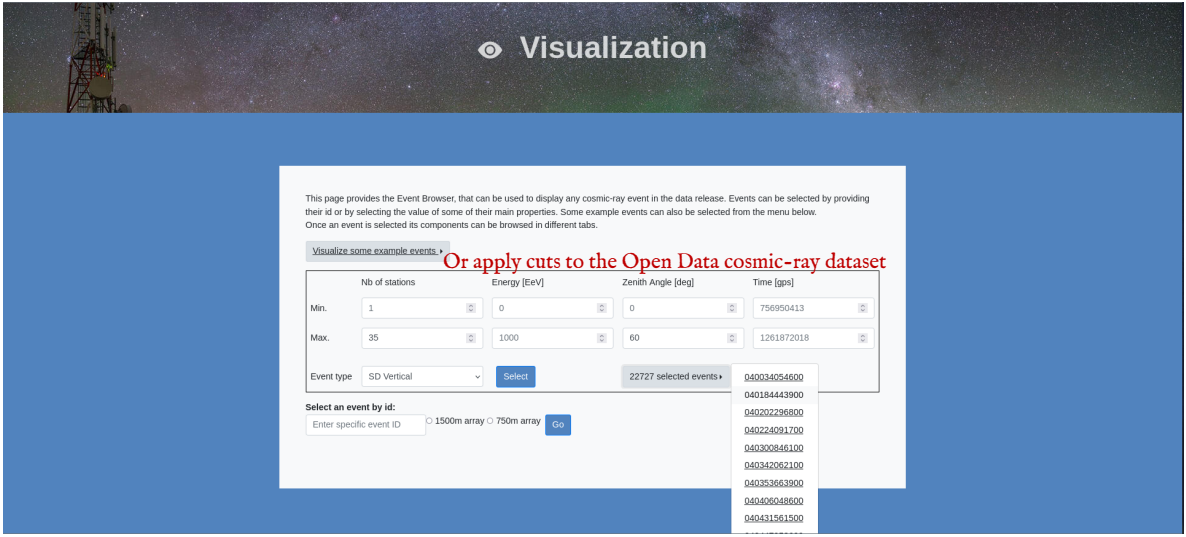


Auger Open Data portal - Visualize

Event 172657447200 | Ground array view | SD traces | SD reconstruction | FD camera view | FD reconstruction | 3D view

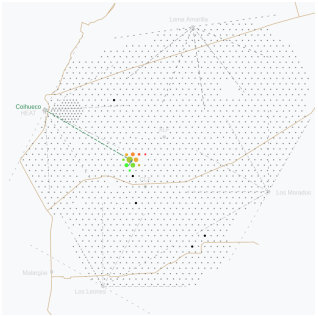
Golden Hybrid event 2

A high energy hybrid seen at a large distance by one FD.

Event 172657447200 is a 16.1 EeV, 35.8 degrees zenith angle hybrid event recorded on Sep 23 2017 08:41:27.

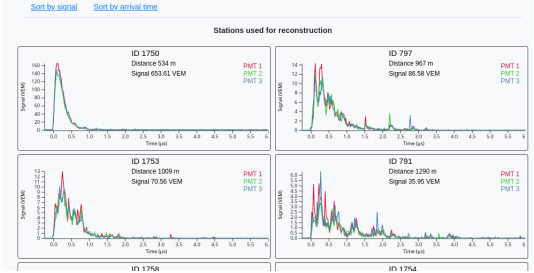
Different views of the event are available by selecting the corresponding tabs.

You can also directly download the JSON data file corresponding to the pseudo-raw data. An example notebook able to process the file is provided.

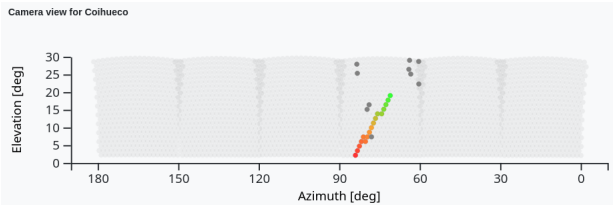


Event detection: "pseudo-raw" data

SD traces:



FD camera view:



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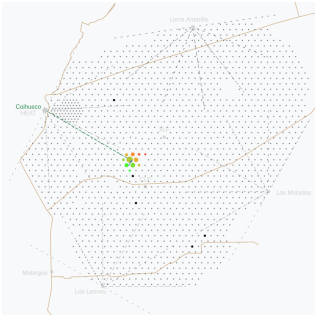
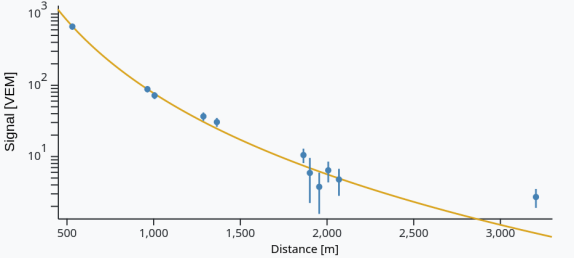
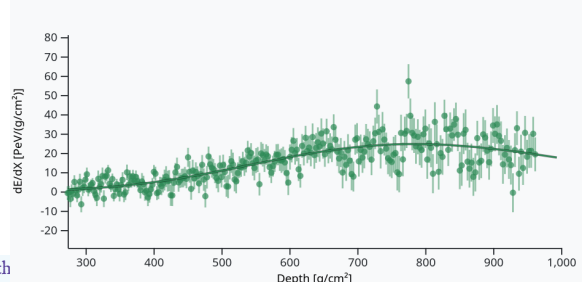


Event reconstruction

SD: Lateral distribution function

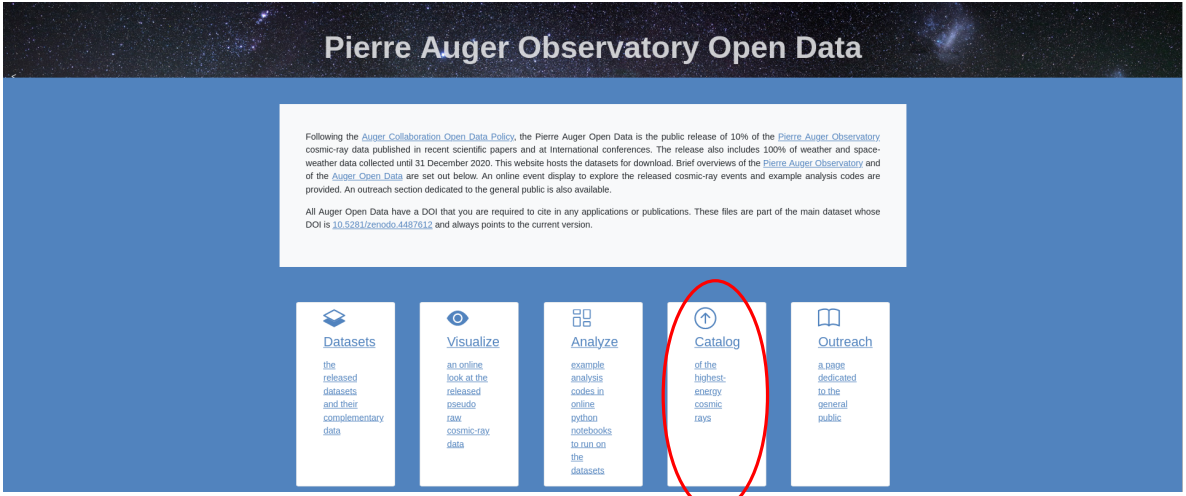


FD:
Profile of deposited energy in atmosphere



Auger Open Data portal - UHECR Catalog

https://opendata.auger.org/



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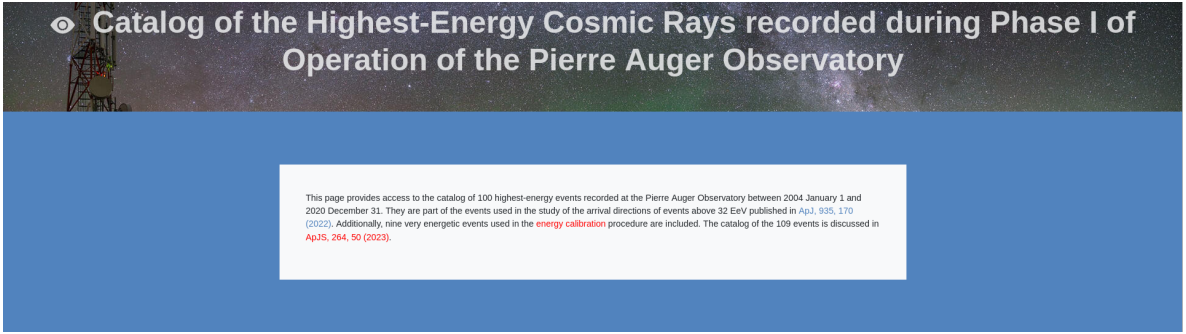
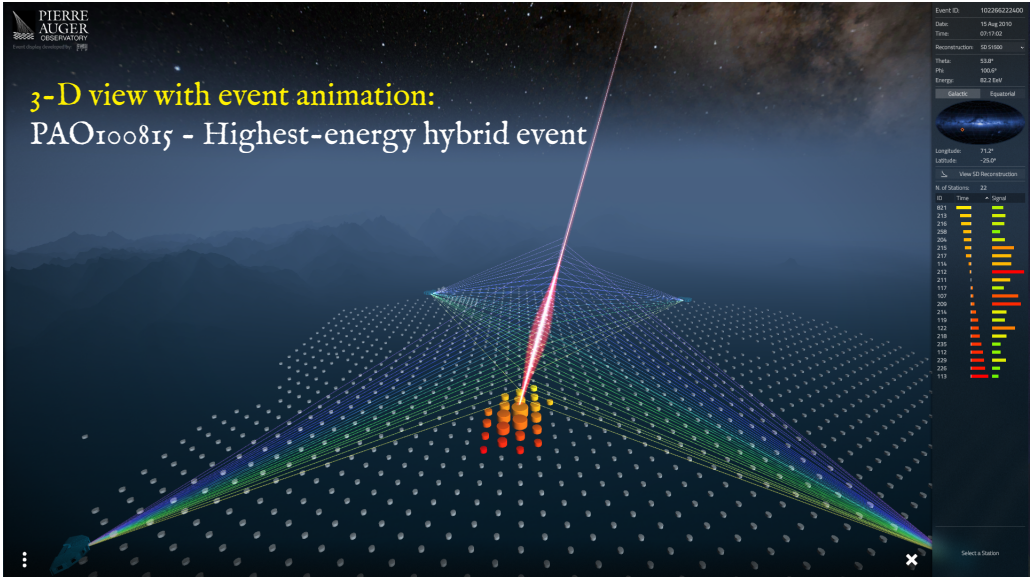


March 2024 release:

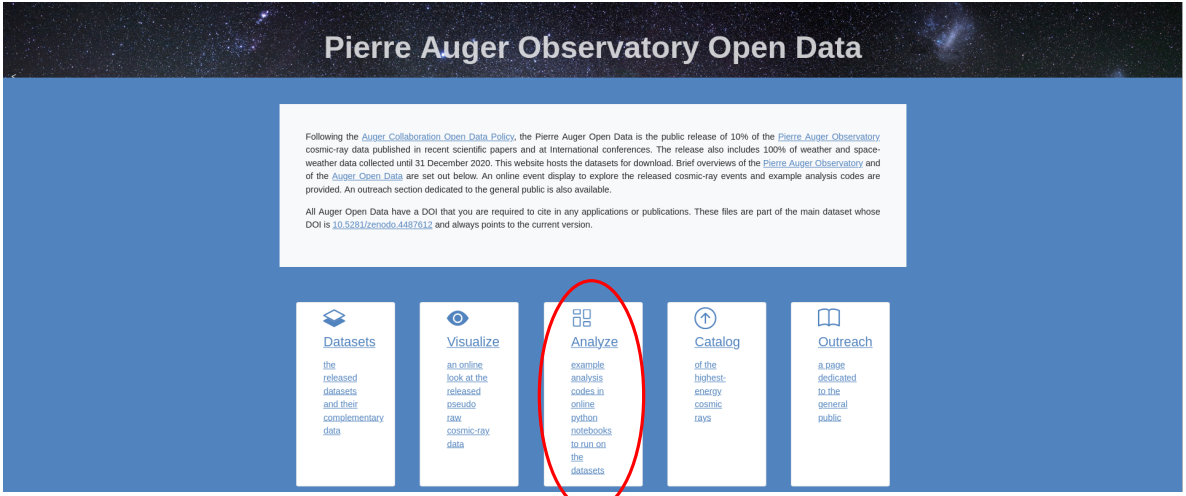
- Catalog of the 100 highest-energy events detected with the Auger Phase I data, published in ApJS, 264, 50 (2023)
  - Data taken during January 1, 2004 and December 31, 2020
  - Dataset comprises a fraction of the events used in the study of the arrival directions of events above 32 EeV published in ApJ, 935, 170 (2022)
- Also available are 9 very energetic Golden-hybrid events used in the calibration of the SD array

Auger Open Data portal - UHECR Catalog



Auger Open Data portal - Analyze

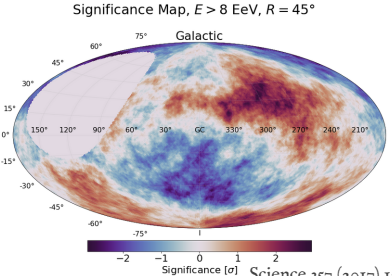
https://opendata.auger.org/



Auger Open Data portal - Analyze

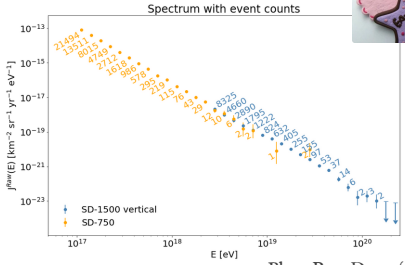
Jupyter Notebooks containing code snippets of our analyses

The UHECR sky



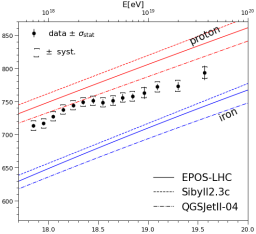
Science 357 (2017) 1266

The energy spectrum



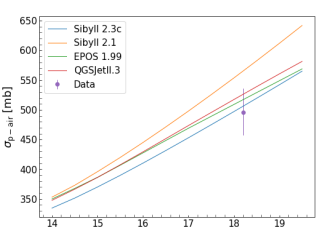
Phys. Rev. D 102 (2020) 062005

The depth of $\langle X_{max} \rangle$



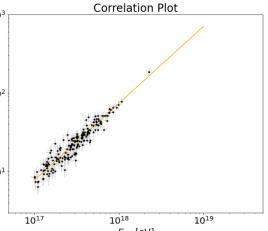
Phys. Rev. D 90 (2014) 122005

p-air cross-section



Phys. Rev.L. 109 (2012) 0622002

Energy calibration

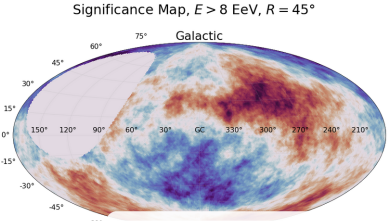


Phys. Rev. D 102 (2020) 062005

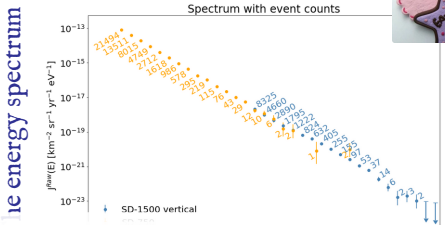
Auger Open Data portal - Analyze

Jupyter Notebooks containing code snippets of our analyses

The UHECR sky

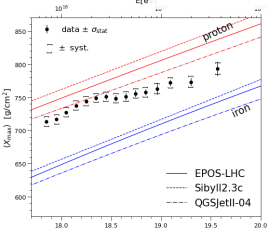


e energy spectrum



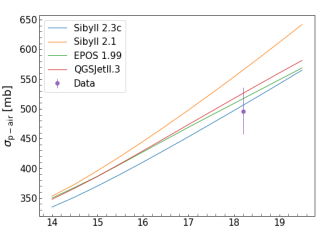
- Notebooks can be run in Kaggle or downloaded to run locally
- Easy to modify for new features in the proposed analyses

The depth of $\langle X_{\max} \rangle$



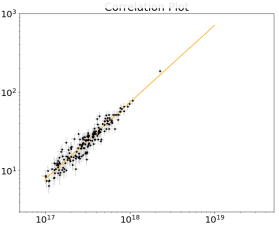
Phys. Rev. D 90 (2014) 122005

p-air cross-sectio



Phys. Rev.L. 109 (2012) 0622002

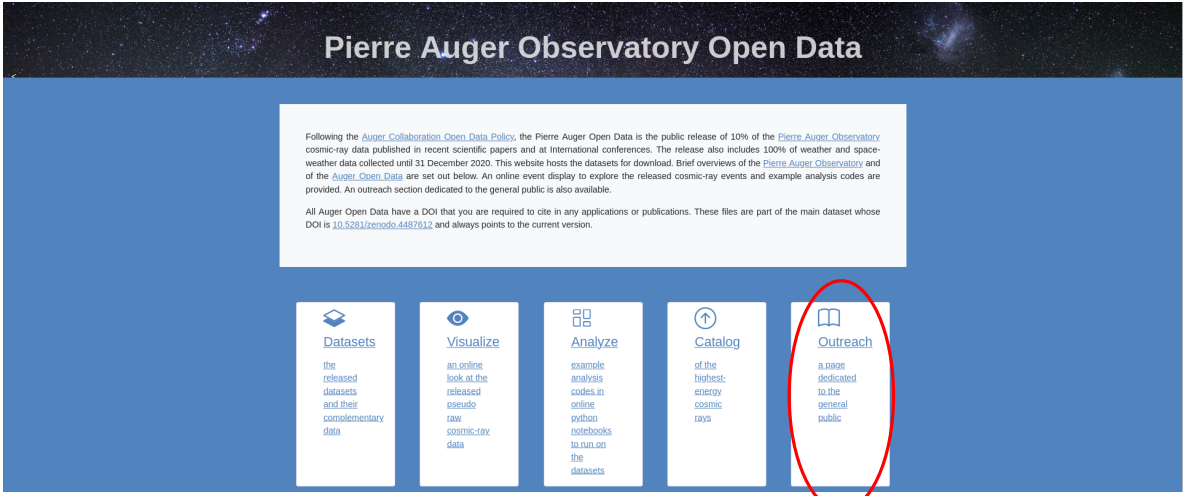
Energy calibratio



Phys. Rev. D 102 (2020) 062005

Auger Open Data portal - Outreach

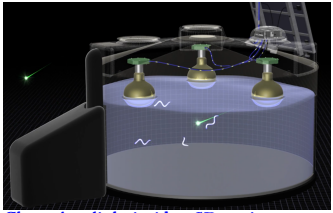
https://opendata.auger.org/



Auger Open Data portal - Outreach

Introduction to cosmic rays, videos, documentation for citizen scientists

Air shower animation

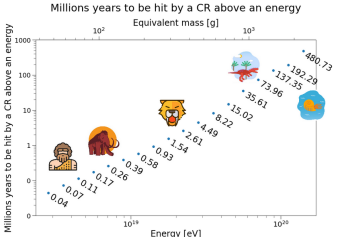


Cherenkov light inside a SD station

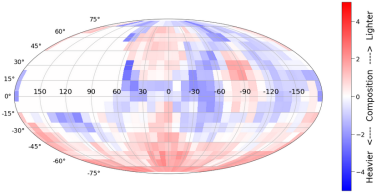
Fluorescence light inside a telescope

Jupyter Notebooks containing simplified analysis code and tutorials on how read the data files from all datasets

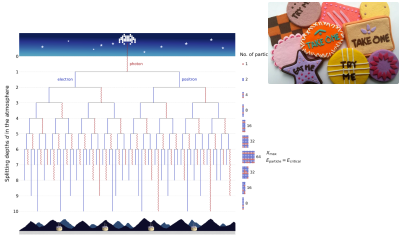
A few examples:



Explore the SD data



Explore the hybrid data

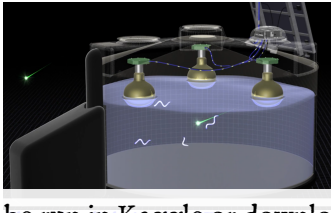


Explore the shower development

Auger Open Data portal - Outreach

Introduction to cosmic rays, videos, documentation for citizen scientists

Air shower animation



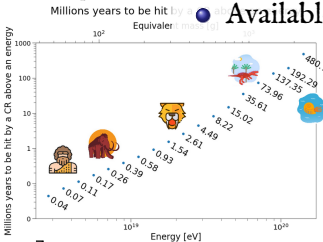
elescope

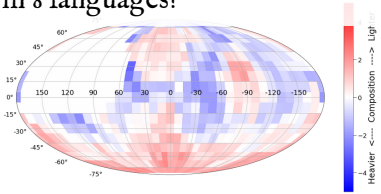
Jupyter Notebook

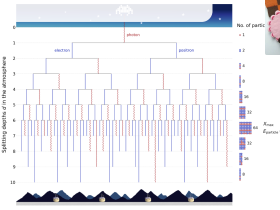
- Notebooks can be run in Kaggle or downloaded to run locally
- Easy to modify for new features in the proposed analyses
- Available in 8 languages!

datasets

A few examples:







Explore the SD data

Explore the hybrid data

Explore the shower development


Welcome to the
PIERRE AUGER
OBSERVATORY
Masterclasses

International Masterclasses

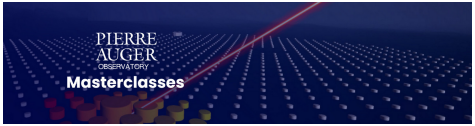
"Be a scientist for one day with the hands on particle physics"

- Yearly activity typically held from February - March
  - More than 13,000 high-school students from
    - 60 countries
    - 225 universities and research centers
- Morning lectures about particle physics and experiments
- Measurements with real data from particle physics experiments
- International video conference with scientists

http://physicsmasterclasses.org

Auger Masterclasses

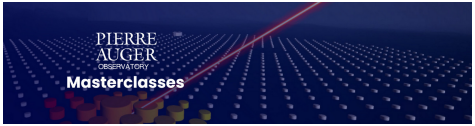
Successful debut in 2023



https://augermasterclasses.lip.pt

- Experimental activity for high-school students on astroparticle physics
- Analyze Auger public data using a friendly interface
  - Based on the tools available in the Auger Open Data portal
- Reach students worldwide by benefiting from the IPPOG contact network for the International Masterclasses Program

Auger Masterclasses - Concept



https://augermasterclasses.lip.pt

What is the origin of ultra-high-energy cosmic rays?

Students are challenged to look for answers to this question by analyzing data of the Pierre Auger Observatory. The measurement includes:

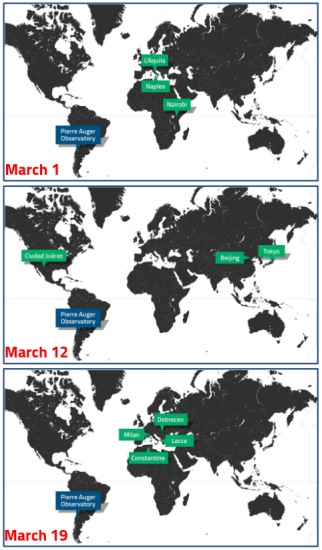
- Visualization of events using an interactive display of the observatory
- Separation of surface-detector stations with signal from those with background
- Visual reconstruction of the arrival direction of the primary cosmic ray
- Fitting the data to determine the energy of the primary cosmic ray
- Application of criteria to select events which point to the source
- Interpretation of sky maps in different coordinate systems

Auger Masterclasses - Two very successful editions

2023 Edition

- 534 students
- 3 Masterclasses events
- 5 countries from 2 continents
  - 12 institutions
    - of which 2 are non-Auger institutions

Auger Masterclasses - Two very successful editions

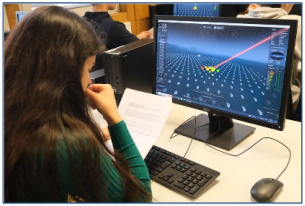


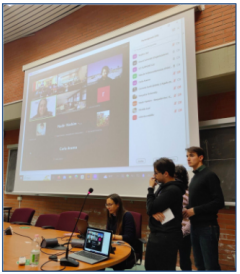
2024 Edition

- 550 students
- 5 Masterclasses events
- 10 countries from 4 continents
  - 16 institutions
    - of which 6 are non-Auger institutions

Auger Masterclasses - Two very successful editions

Some photos from the 2024 edition





Auger Masterclasses - Day Schedule

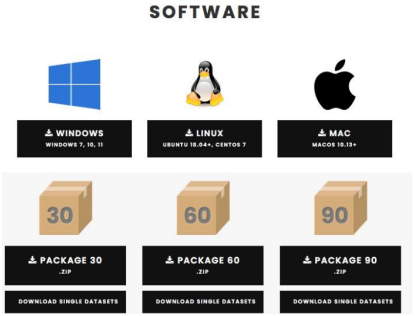
The Masterclass suggested timetable:

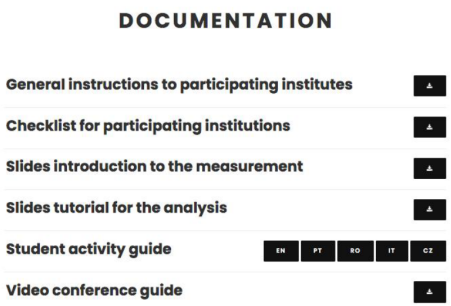
(Check the participating Institutions table to check your timezone)

10:00 – 10:15	Registration and welcome
10:15 – 10:30	Introduction
10:30 – 11:45	Particle and astroparticle physics
11:45 – 12:15	Coffee break
12:15 – 13:00	Experiments in astroparticle physics
13:00 – 14:00	Lunch
14:00 – 16:00	Data analysis
16:00 – 17:00	Video conference with the Pierre Auger Observatory*
17:00 – 17:15	Farewell

Auger Masterclasses - Documentation and Materials

- Preparatory meetings with participating institutions
- Complete list of available resources for the preparation of the activity

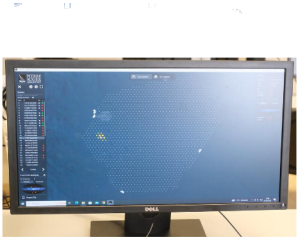


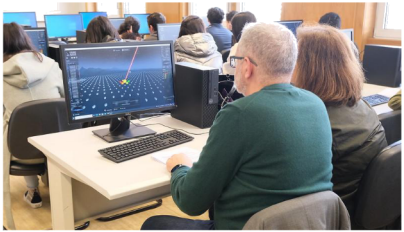


https://augermasterclasses.lip.pt/downloads

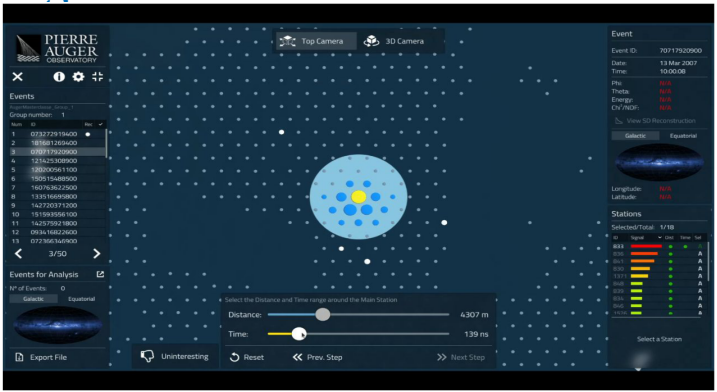
Auger Masterclasses - Morning activities

Auger Masterclasses - Hands-on activity



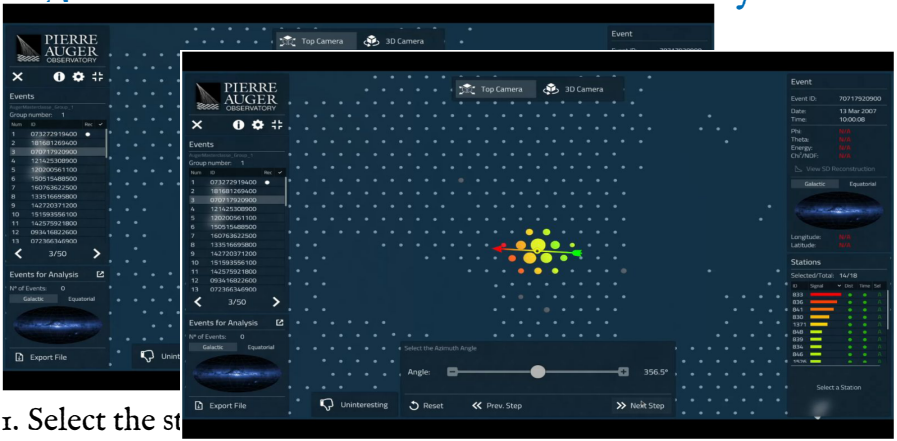


Auger Masterclasses - Hands-on activity



1. Select the stations belonging to the event

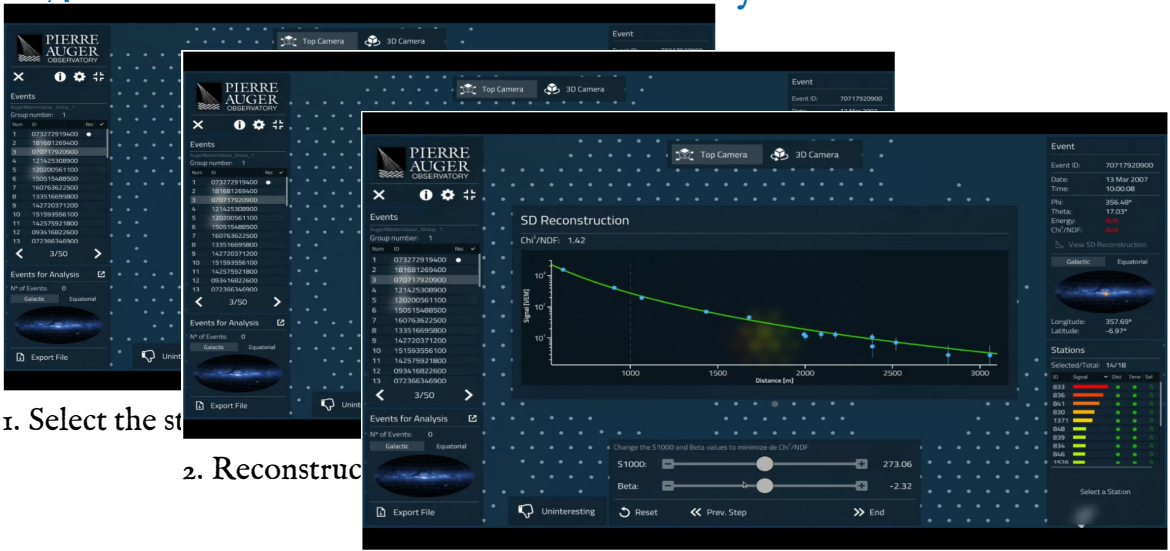
Auger Masterclasses - Hands-on activity



1. Select the st

2. Reconstruct the shower axis

Auger Masterclasses - Hands-on activity

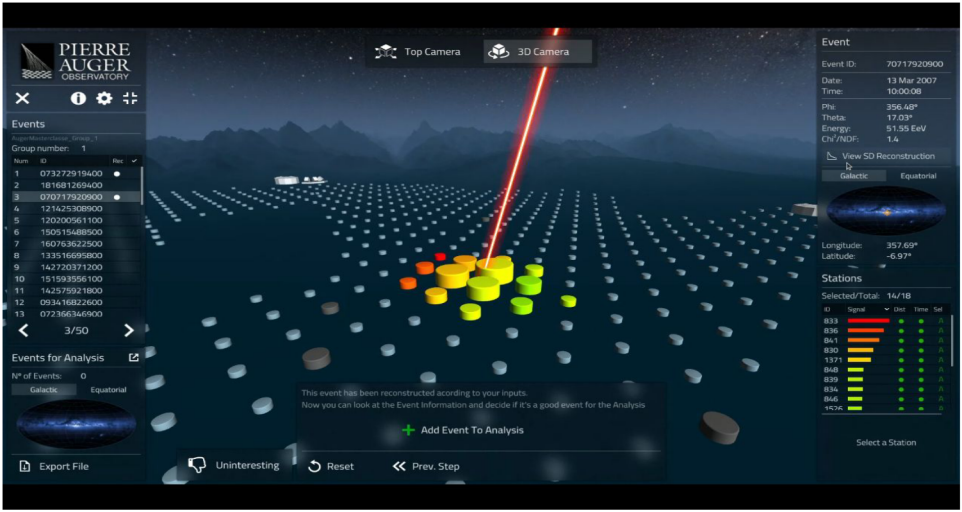


1. Select the st

2. Reconstruc

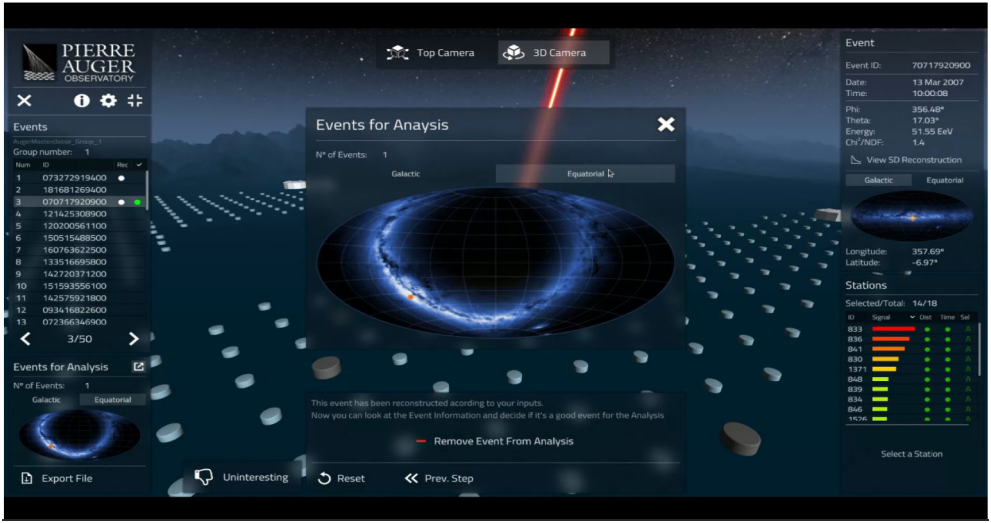
3. Adjust the LDF and estimate the energy of the event

Auger Masterclasses - Hands-on activity



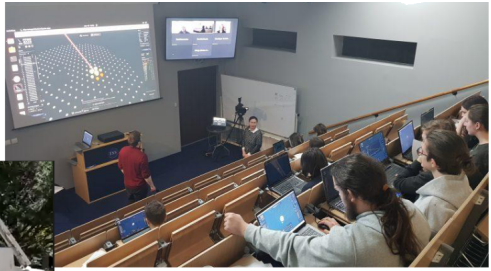
4. An animation appears if all the previous steps were successful

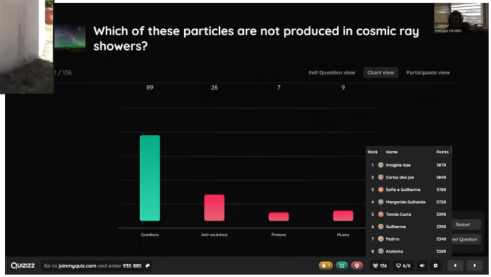
Auger Masterclasses - Hands-on activity



Example of successfully reconstructed event with arrival direction in Equatorial Coordinates

Auger Masterclasses - Video conference and final quiz

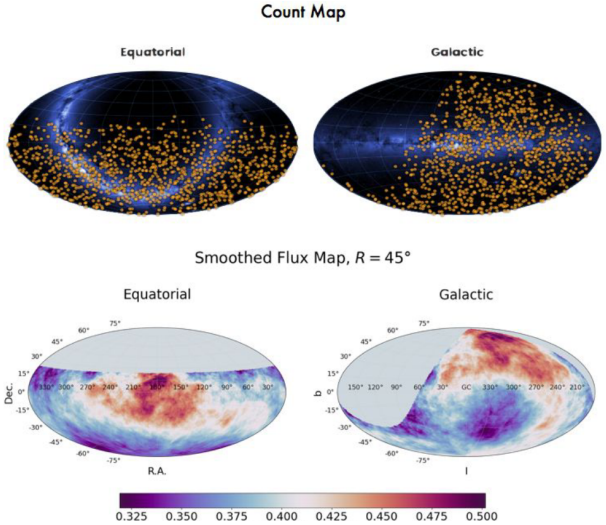




Auger Masterclasses - Results

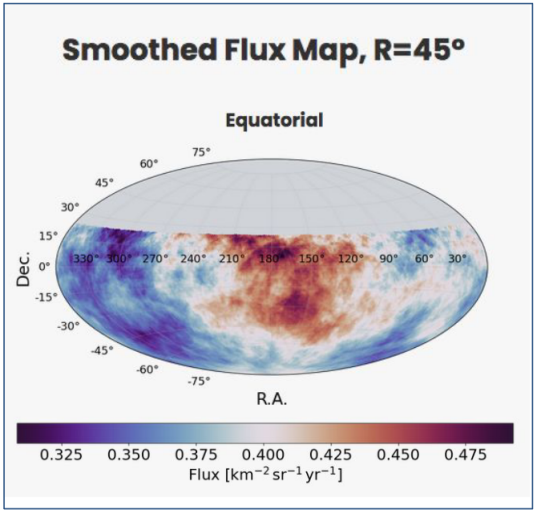
Combined results from one institution at the Masterclasses 2023:

- 1130 reconstructed events
- Dipole patters surges from the combined results even though having low statistical significance

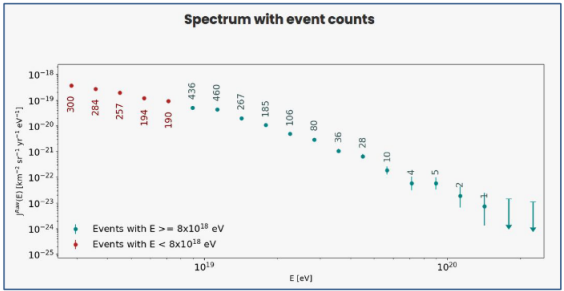


Auger Masterclasses - Results

Results from the Masterclasses 2024:



The spectrum analysis was added!



Available online:
https://augermasterclasses.lip.pt/activities

Conclusions and Outlook

- The Auger Open Data portal is the culmination of a long and demanding commitment to make data public
  - A gateway and a first step for data preservation
  - Public data distributed in several formats allowing its usage for:
    - the scientific community as part of the multi-messenger effort at different levels
    - outreach and educational activities
- Yearly updates, new and larger datasets during the lifetime of the Collaboration

- Auger International Masterclasses integrated in 2023 in the IPPOG network program
  - Two successful editions held in 2023 and 2024
    - Rapid dissemination of the Auger Masterclasses in 2024, reaching 10 countries in 4 continents
  - Strong synergy with the Auger Open portal
- Further editions planned for the forthcoming years
  - New analyses foreseen exploiting the materials available in the Auger Open portal


Thank you very much
for your attention!