



LIP Internship Program'2020



Cosmic Rays in a single day

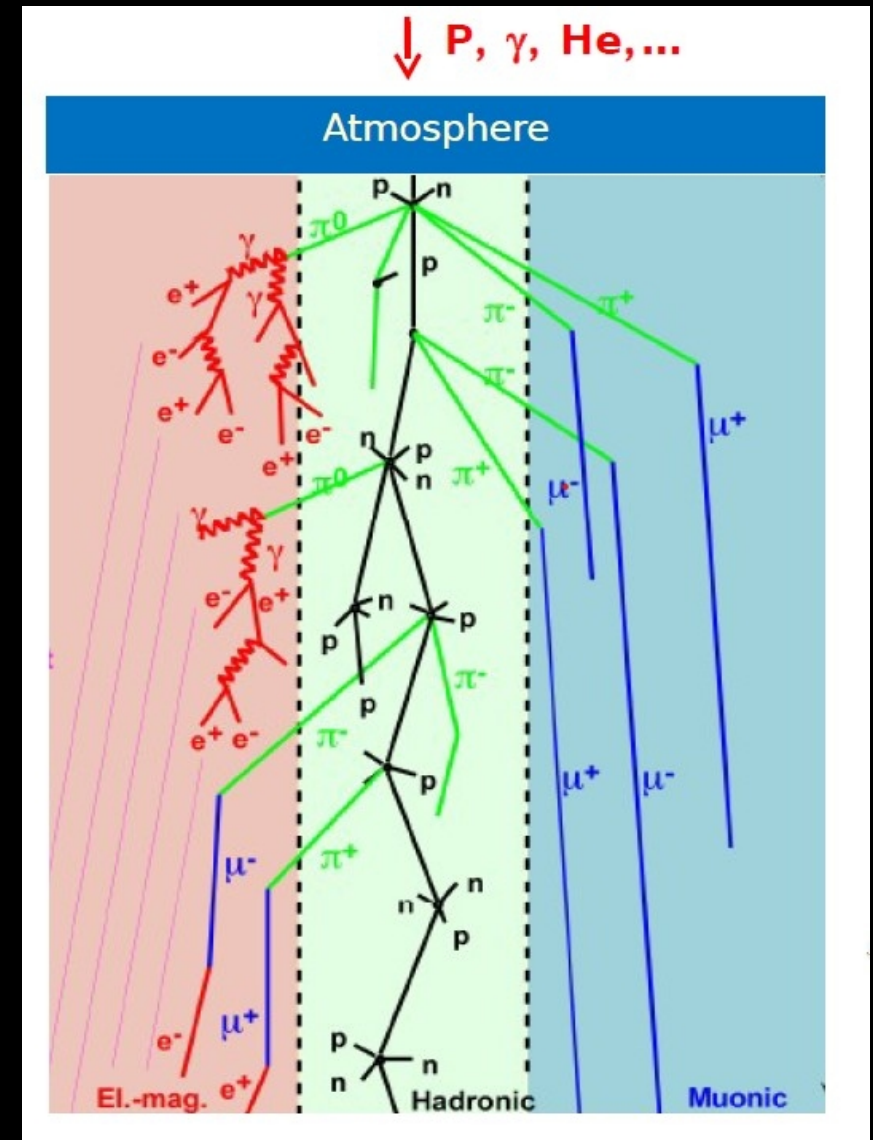
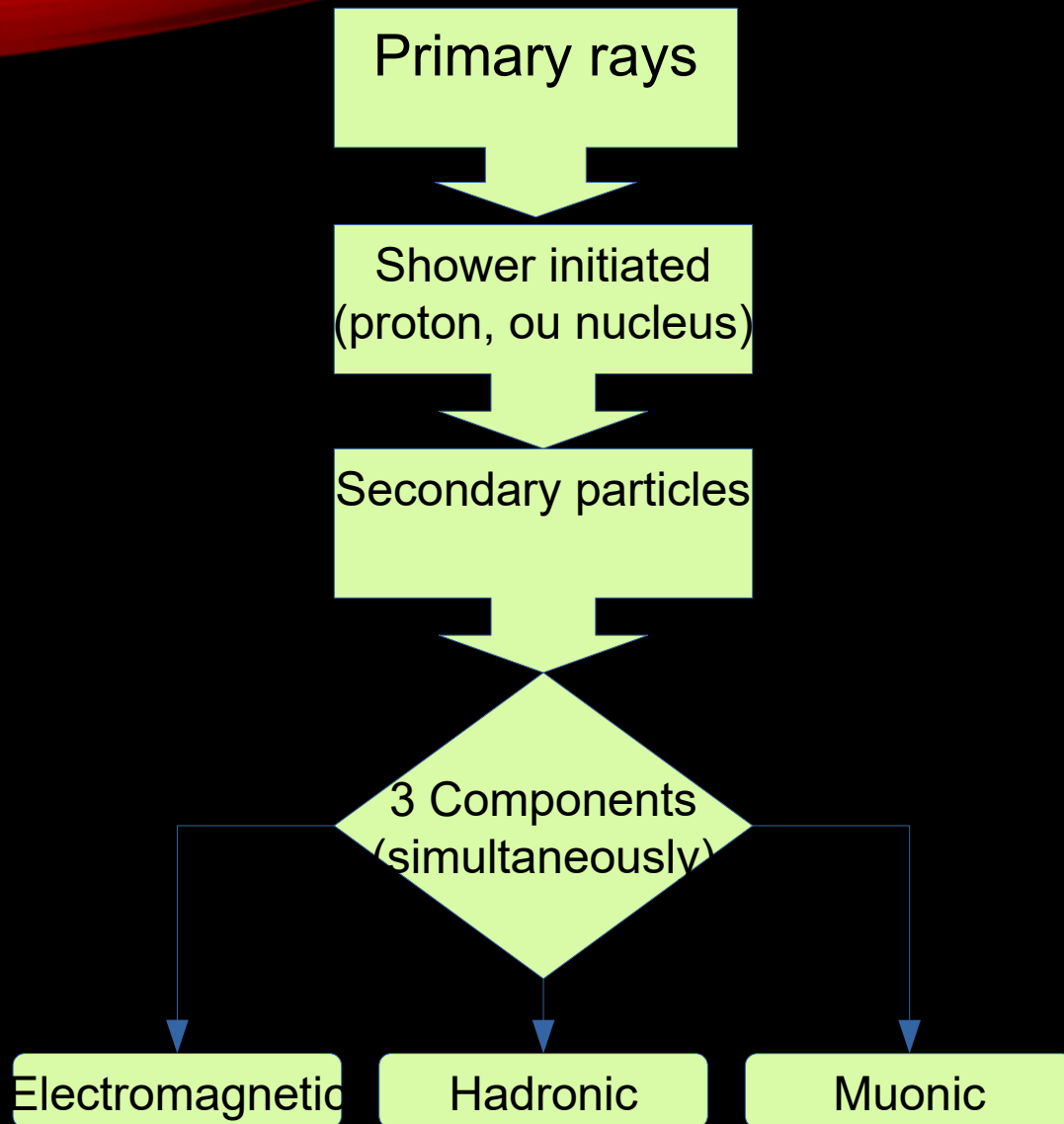
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10 September 2020

Objective

- Provide active investigative activities to know cosmic rays and latest discoveries and to know the work of scientists.
- Explore 10% of data Pierre Auger Observatory in a Masterclasses.
- Outline a program dedicated to secondary school students to explore data in a day.
- Identify the physical concepts and data processing techniques to implement during an investigative cycle.
- Investigative cycle in a “Cosmic Rays in a single day”:
 - Principal question;
 - Previsions;
 - Exploring;
 - Answering the principal question.

Cosmic rays



Pierre Auger Observatory

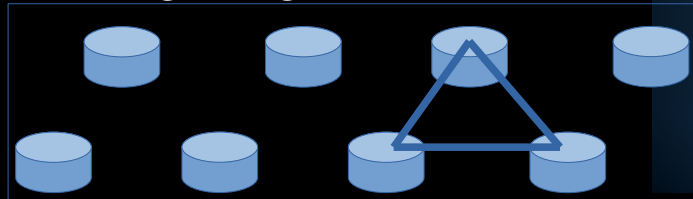
Ultra High Energy Cosmic Ray (UHECR)

Design

- UHECR Study $E \geq 10^{18} \text{ eV}$

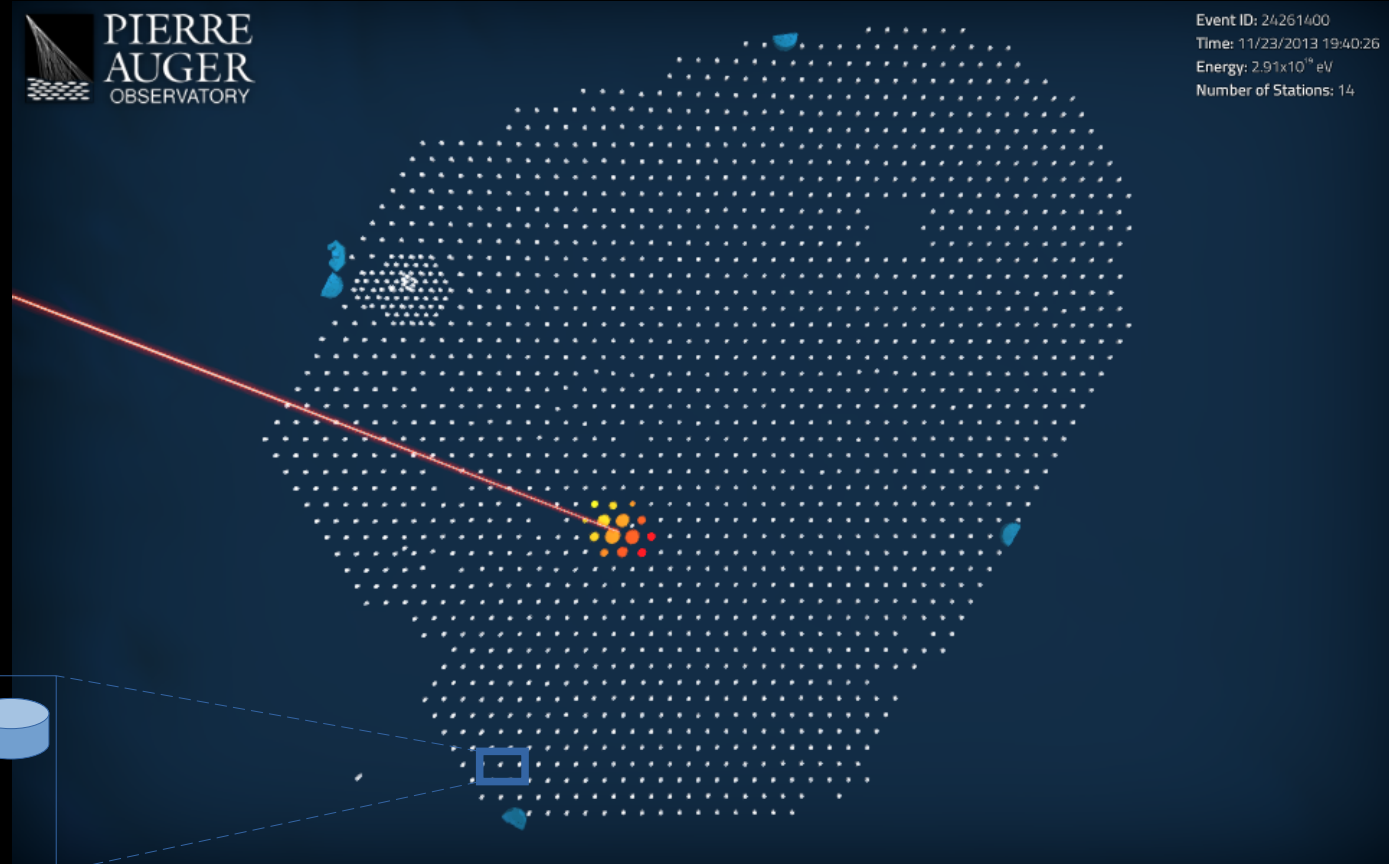
- UHECR detection
· Surface Detector (SD)

A 1500 m triangular grid



- Total Number of SD: 1600

· Fluorescence Detector (FD)
4 fluorescence telescopes



- In Malargüe - Argentina
- Altitude relative to sea level: 1400 m
- Total area of SD: 3000 km^2

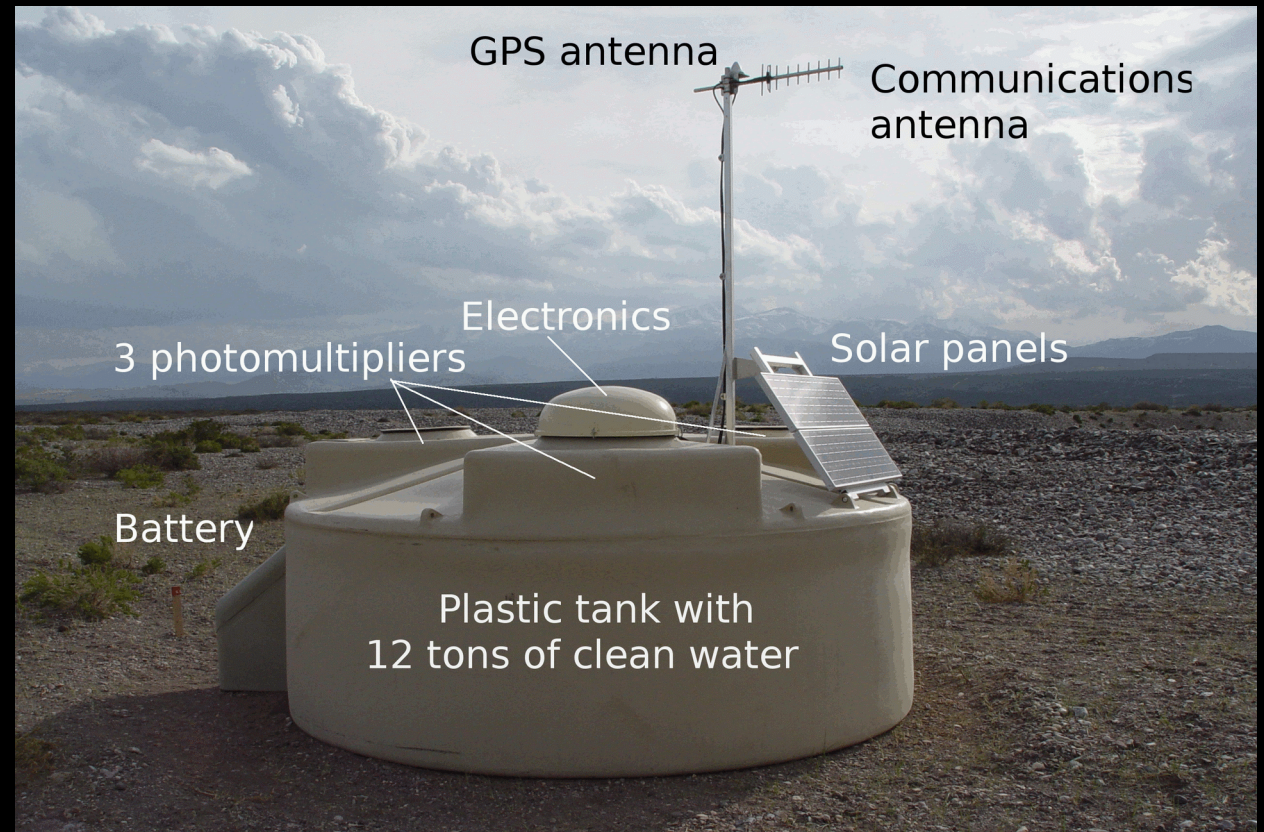
Surface detector

How do we detect cosmic ray showers?

Charged particle travels at a speed above the speed of light in the medium (water), they will emit Cherenkov radiation.

Cherenkov detectors

- Cherenkov radiation
- Photomultiplier (PMT)
- Electrical signal is proportional to the secondary particles energy
- Registered time GPS based timing



The cosmic ray spectrum

Direct detection:

LEAP - satellite $10^8 \text{ eV} - 10^{11} \text{ eV}$

Proton - satellite $10^{11} \text{ eV} - 10^{15} \text{ eV}$

Indirect detection:

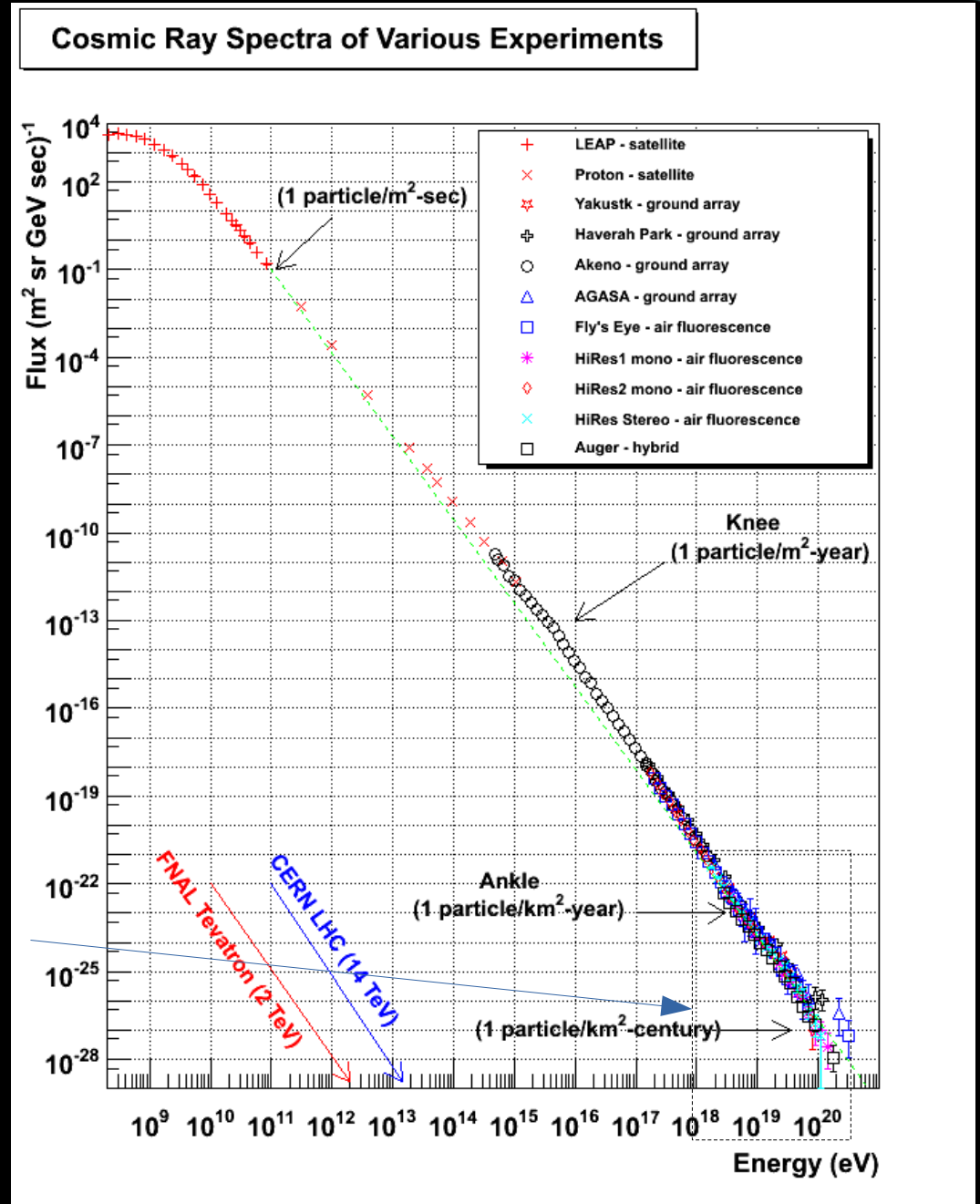
Akeno – ground array $10^{15} \text{ eV} - 10^{17} \text{ eV}$

**Auger – Hibrid
ground array(SD) + air fluorescence(FD)**

The Auger range of energies $10^{18} \text{ eV} - 10^{20} \text{ eV}$

Empirical relation between flux and primary energy particle follows a power law:

$$F(E) \propto E^{-\alpha}$$



Investigative cycle in a “Cosmic Rays in a single day”

Example of the investigative cycle to answer question 1

Principal questions:

question 1: What is the energy spectrum of the primary cosmic rays seen in Auger?

Previsions:

Students' ideas when asked, what they know about the energy spectrum?

How would you organize the number of particles and the energy?

Exploring:

Use real data; VISPA software; work with numbers and units; linear and logarithmic scales; prefixes; solid angle; cartesian; equatorial and galactic coordinates.

Answering the principal question:

In small groups and plenary, discuss the results compatibility between collaboration (100%) and public data (10%).

Exploring

How to do the flux plot?

1 - histogram

2 -Exposure

$$\text{exposure} = S \Omega t$$

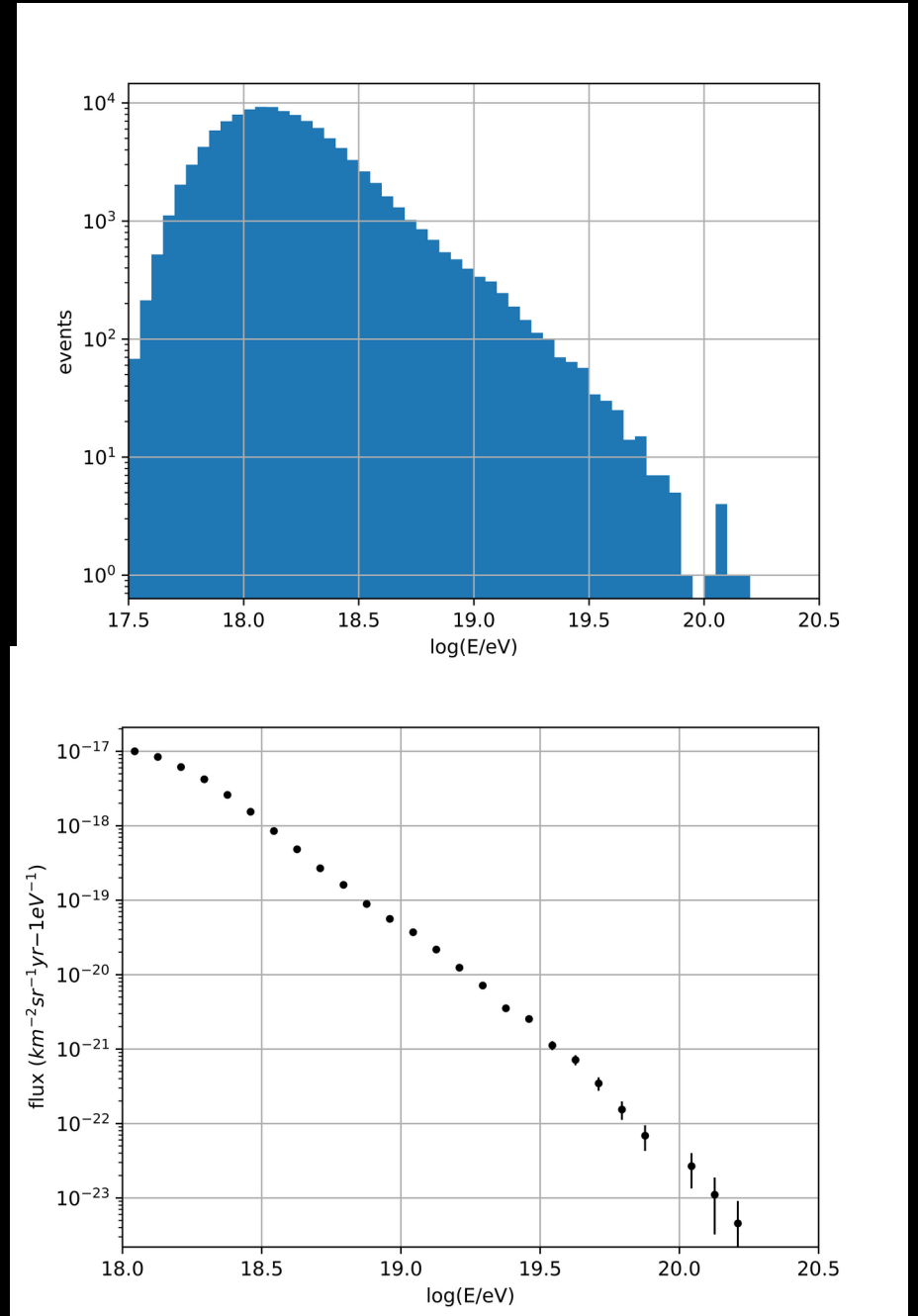
3 -Flux

$$\text{differential flux} = \frac{N}{E S \Omega t}$$

4 - Selection of energies

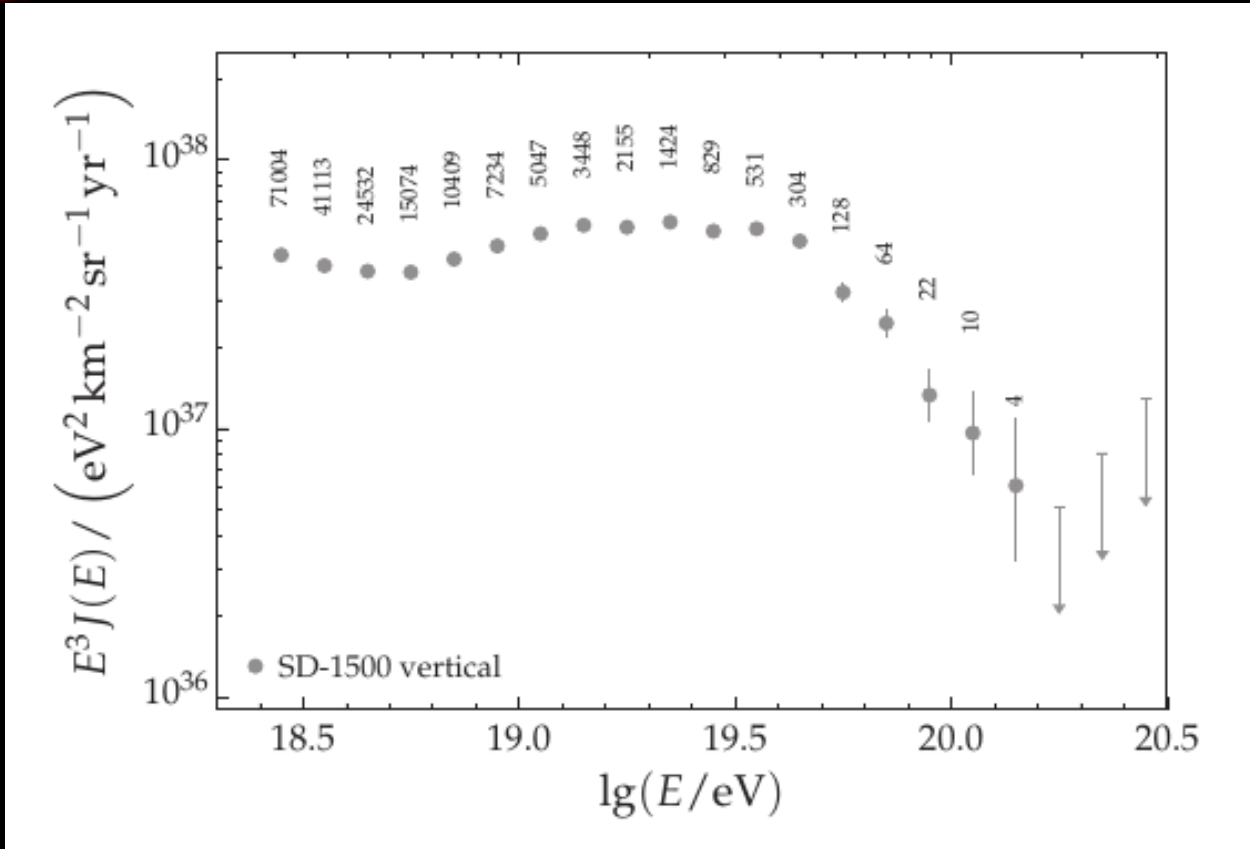
how to compare the energy spectrum with that of the Auger collaboration?

Multiply the differential flow by E^3

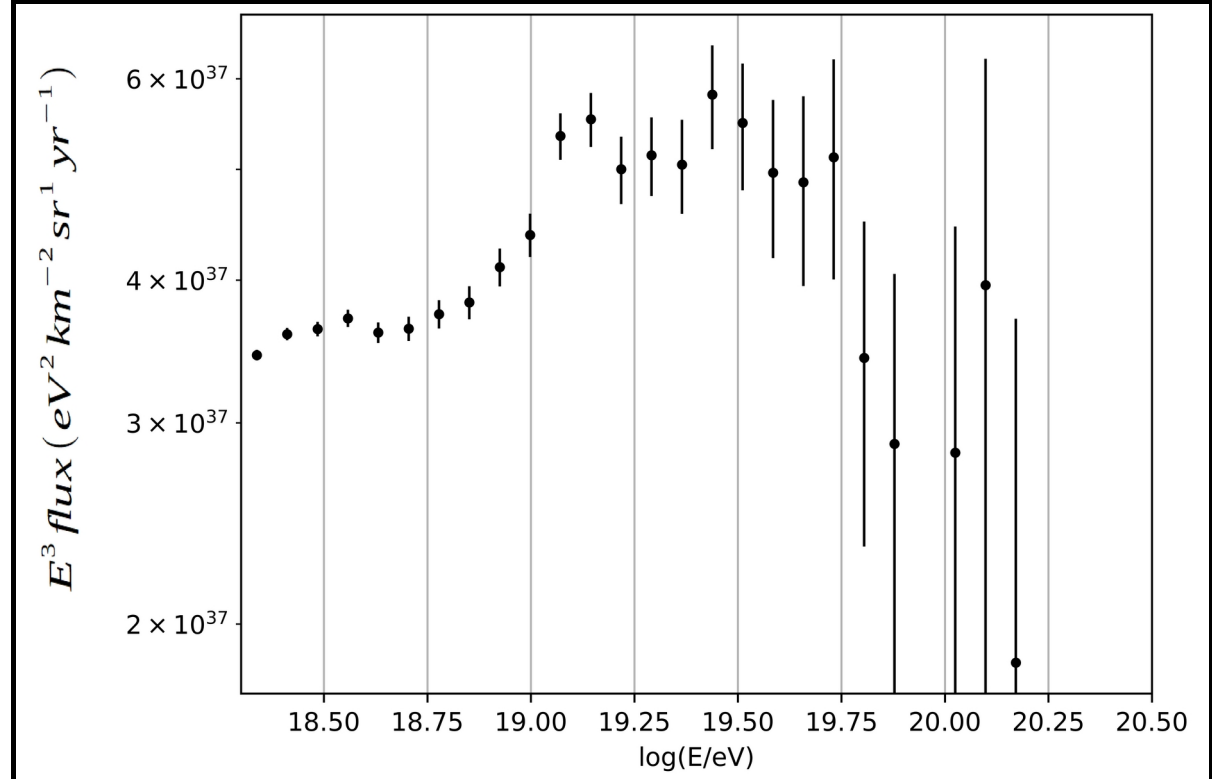


Interpretation of the data and its compatibility and answer to the question 1.

Auger spectrum (2017-100%)



Public Data Auger spectrum (10%)



galactic extragalactic extragalactic

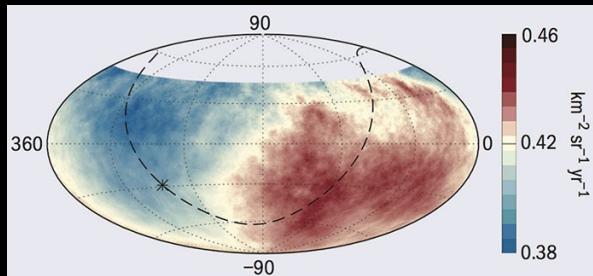
Example of the investigative cycle for the question 2

question 2: Where do the highest energy cosmic rays seen by Auger come from?

Final part: Answering the principal question

Fluxes of particles in equatorial coordinates

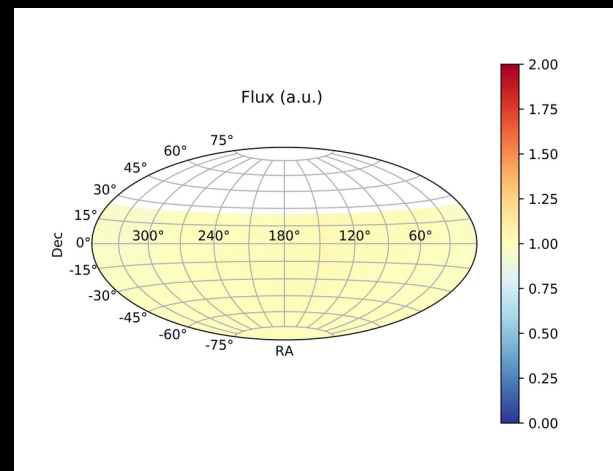
Auger (2017-100%)



$E \geq 8 \text{ EeV}$

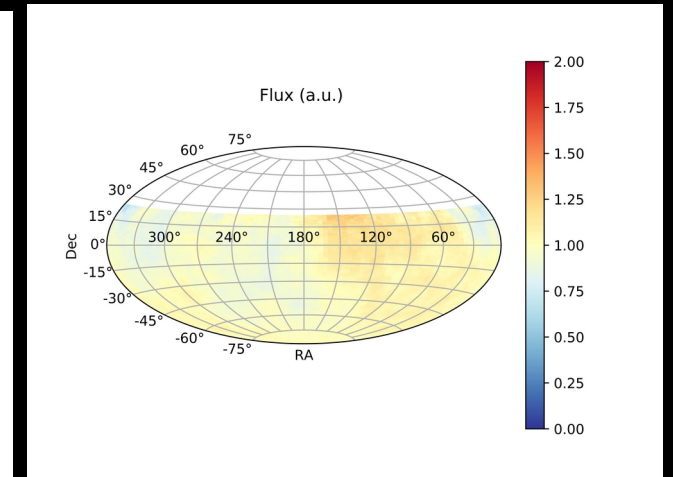
cosmic-ray anisotropy

Public Data Auger(10%)



$E \geq 0.1 \text{ EeV}$

cosmic-ray isotropy



$E \geq 8 \text{ EeV}$

cosmic-ray anisotropy

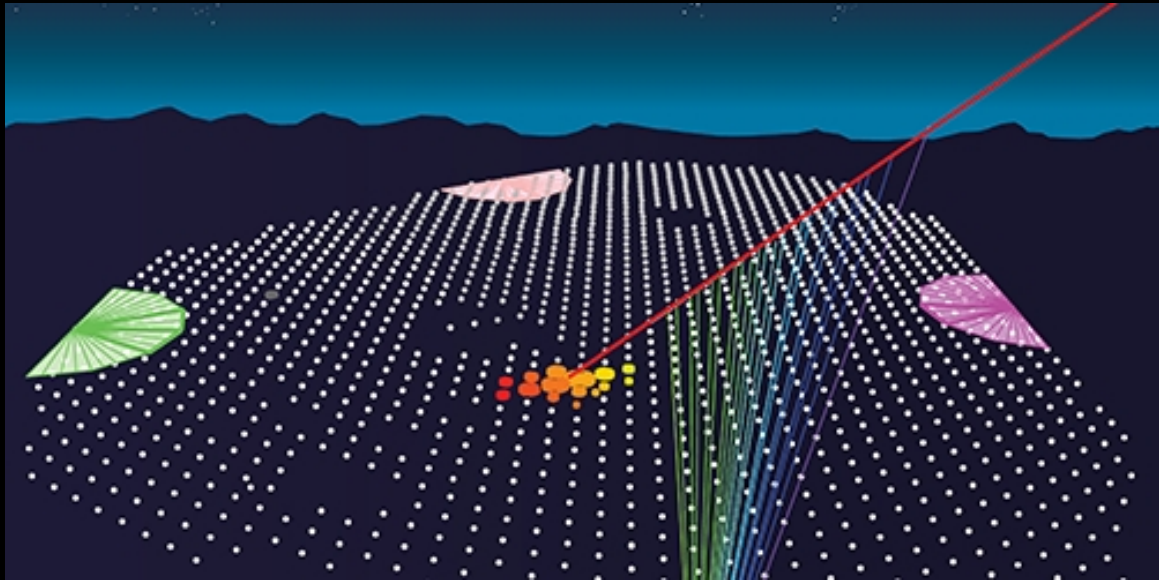
Conclusions

- A day with cosmic rays has all the elements to let young people know what it is to be a scientist in particle physics.
- Allows you to use an active strategy to disseminate scientific processes to students and teachers.
- Allowed to prepare masterclasses “Cosmic Rays in a single day” in Madeira island in November, this year.



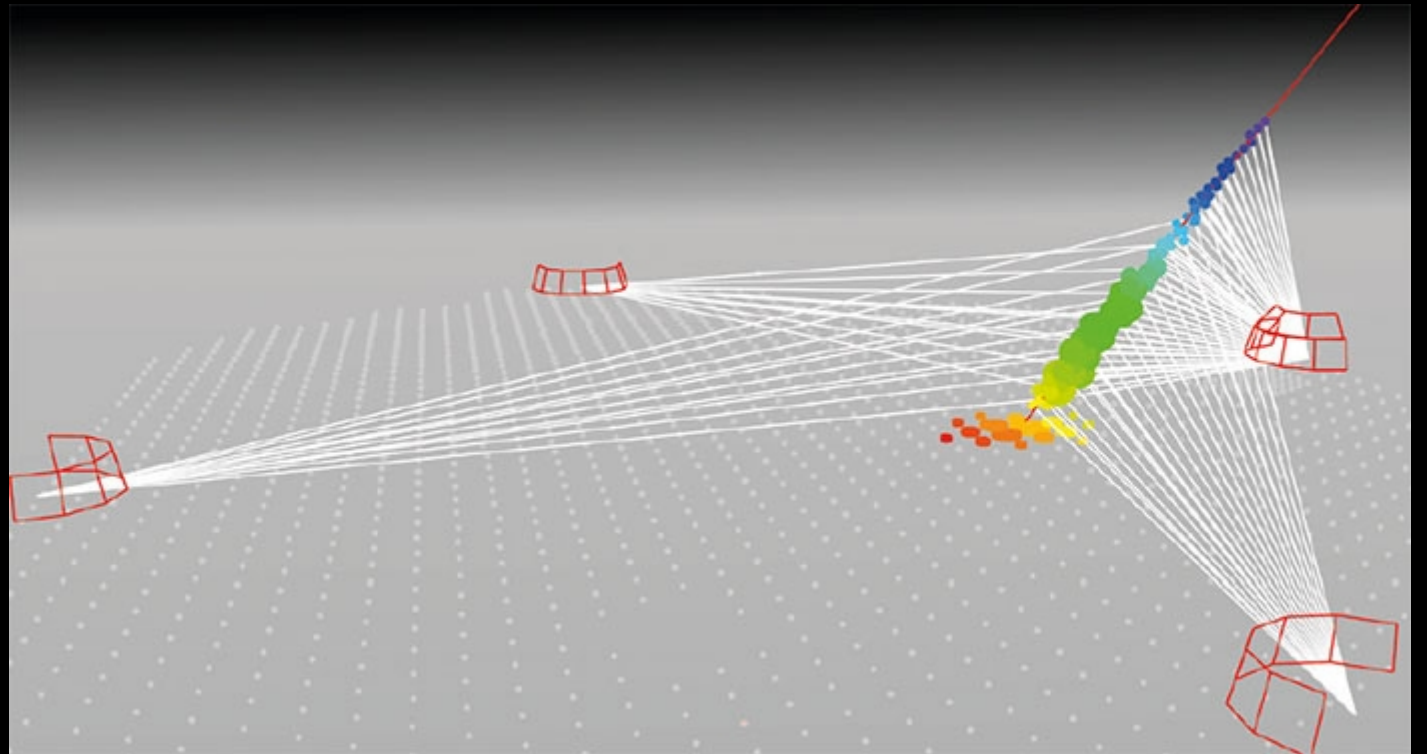
MIGUEL

SYSTEM



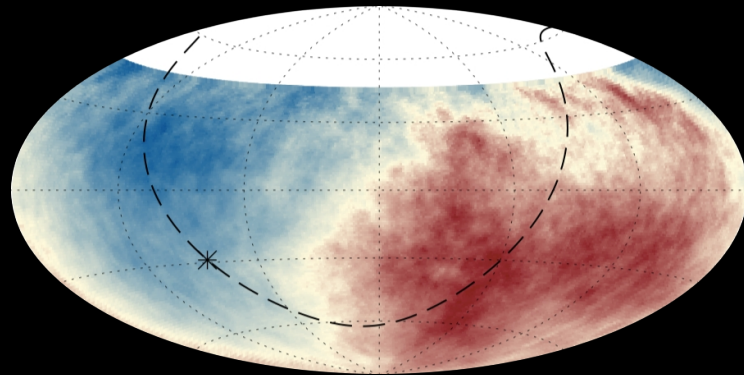
FLUORESCENCE DETECTOR

The Auger Observatory's fluorescence detectors are much more sensitive than the human eye and can "see" distant air showers develop



TOOLS

Is developed at the RWTH Aachen University in Germany and is used for teaching data analysis



Auger Spectrum 2017

```
1 ##### Introductory Block #####
2
3 #imports
4 import numpy as np
5 import pylab
6 from scipy.optimize import curve_fit
7 import matplotlib.pyplot as plt
8 import json
9 import math
10 from scipy import ararray as ar,exp, sqrt, diag
11
12
13 #"/home/AugerMCTest/HiguelDT/2010_Dados"
14
15 ##### Block 1 #####
16 # Reading one file and print the main physical quantities and paramet
17
18 * with open('100086876100', 'r') as myfile: # read file
19
20 data=myfile.read()
21 obj = json.loads(data)
22
23 print("event identification (Id):" + str(obj['id']))
24 print("Number eyes: " + str(obj['NofEyes']))
25 print("Eyes data: " + str(obj['Eyes']))
26
27
28
29
30 for x in obj['Eyes']:
31     aux1-x['atmDepthProf']
32     aux2-x['energyDepositProfErr']
33
34     print("number and eye name: " + str(x['Eye']) + " " + str(x['eyeName']))
35     print ("CalEnergy +- error CalEnergy = (" + str(x['CalEnergy']) + " +- " + str(x['CalEnergyErr'])
36     print ("TotalEnergy +- error TotalEnergy = (" + str(x['TotalEnergy']) + " +- " + str(x['TotalEnergyErr'])
37     print ("dEdXmax +- error dEdXmax = (" + str(x['dEdXmax']) + " +- " + str(x['dEdXmaxError']) + ") ;
38     print ("Xmax +- error Xmax = (" + str(x['Xmax']) + " +- " + str(x['XmaxErr']) + ") gcm-2)
39     print ("Uspl +- error Uspl = (" + str(x['Uspl']) + " +- " + str(x['UsplError']) + ") gcm-2)
40     print ("Uspr +- error Uspr = (" + str(x['Uspr']) + " +- " + str(x['UsprError']) + ")
41     print ("theta +- error theta = (" + str(x['theta']) + " +- " + str(x['thetaErr']) + ") deg)
42     print ("phi +- error phi = (" + str(x['phi']) + " +- " + str(x['phiErr']) + ") deg)
43     print (" Maximum distance = " + str(x['DistXmax']) + " m")
44     print (" Maximum height = " + str(x['HeightXmax']) + " m")
45
46
47 ##### Block 2 #####
48 # Energy deposit (dEdX) as a function of atmospheric depth X
49 # To see only scatterplot, comment the "plt.plot(X, Gauss(X, "popt"), '-',label='fit')"
50 # Definition non-normalized Gaussian-functions: dE/dX = dEdXmax*exp(-(X-Xmax)**2)/(2*Uspl**2)
51
52 pylab.figure()
53
54 #estimate of the reading of the experimental points of:
55 #notation usual:
56
```

OUTPUT:

event identification (Id):100086876100
Number eyes: 1
Eyes data: [{"CalEnergyErr": 0.112127, "pixelCharge": [972.011, 746.799, 1028.36, 1013.39, 1011.99, 829.909, 860.493, 712.585, 717.122, 566.25, 583.6
number and eye name: 4 Cuihuco
CalEnergy +- error CalEnergy = (1.43977 +- 0.112127) EeV
TotalEnergy +- error TotalEnergy = (1.68974 +- 0.133169) EeV
dEdXmax +- error dEdXmax = (2.47951 +- 0.124705) PeV/gcm-2
Xmax +- error Xmax = (718.738 +- 35.6475) gcm-2
Uspl +- error Uspl = (230.376 +- 10.8862) gcm-2
Uspr +- error Uspr = (0.256229 +- 0.0601265)
theta +- error theta = (54.5935 +- 0.706958) deg
phi +- error phi = (230.509 +- 0.875895) deg
Maximum distance = 18872.5 m
Maximum height = 7344.54 m
New p0=[dEdXmax/PeV/gcm-2, Xmax/gcm-2, Uspl/gcm-2] =
p0: [-2.44587013 748.9800455 230.96371345]
delta p0 [0.18128286 20.77496247 24.52032433]
Xminimum = 372.344 Xmaximum = 1172.4

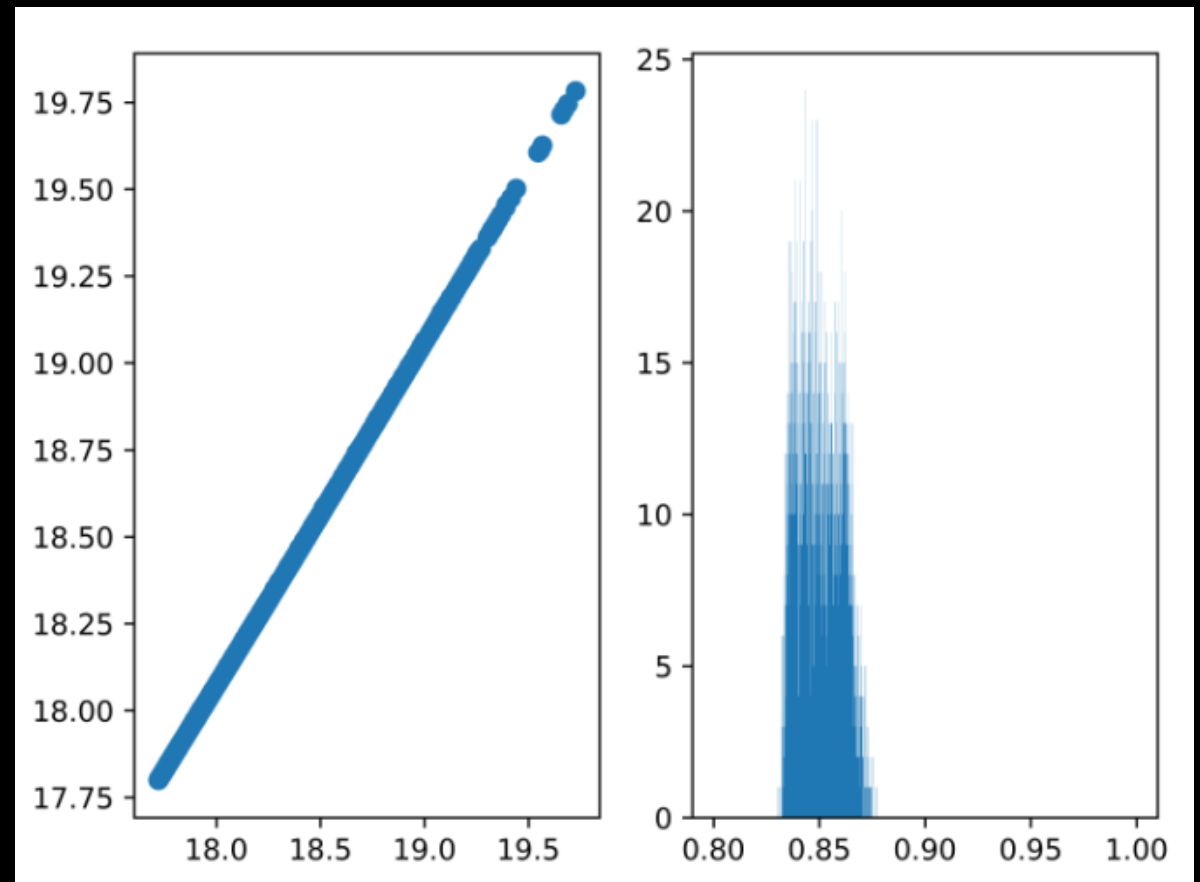
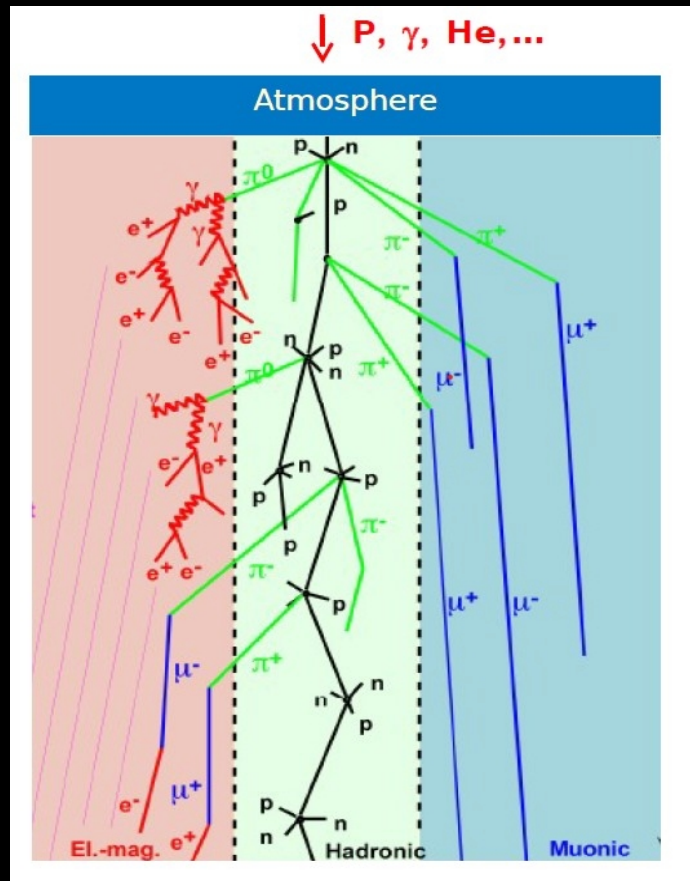
runtime: 4.49 s

/home/AugerMCTest/JorgeDT

integral_100086876100 fit_dEdX_as_a_func compatibility_10131 fit_exercise3.png fit_dEdX_as_a_func fit_dEdX_as_a_func fit_dEdX_as_a_func fit_dEdX_as_a_func
dEdX_as_a_func X_max_logE_selati LogEdXmax_D LogEdXmax_H LogEdXmax_th CorrectionFactor_2 TotalEnergy_four_ey scatter_fit.png
scatter.png four_eyes_four_plot four_eyes_four_plot

The Visual Physics Analysis (VISPA)

RECONSTRUCTION OF ENERGY



ENERGY DEPOSIT (DEDX) AS A FUNCTION OF ATMOSPHERIC DEPTH X

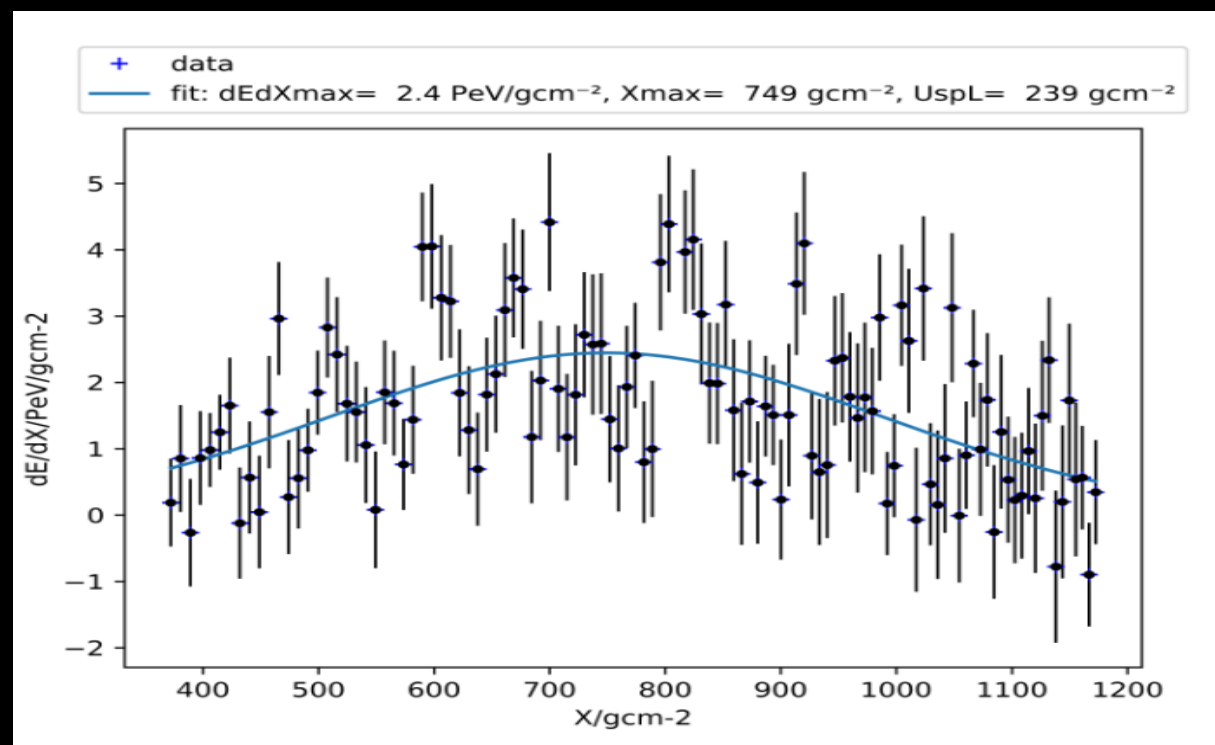
→ Gaussian area

```
#notation usual:
dEdXmax = 2.          # dEdXmax <=> amplitude <=> 1/(sigma x sqrt(2pi))
Xmax = 200.          # Xmax <=> mu <=> average
Uspl = 50.           # Uspl <=> sigma <=> std

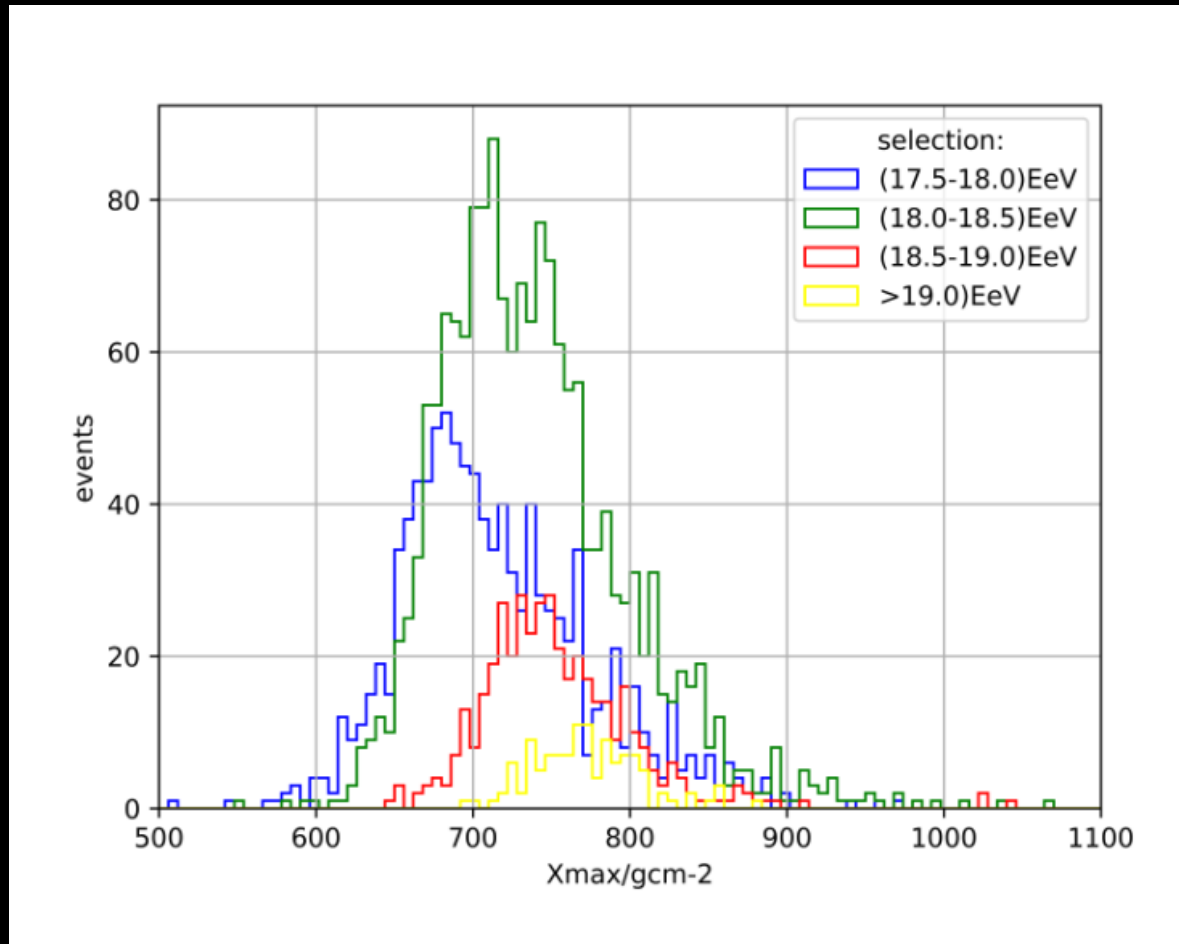
X = aux1
dEdX = aux2
DeltadEdX = aux2error
pylab.errorbar(X, dEdX, yerr=DeltadEdX, fmt='or', capsiz=0, ms=3, elinewidth=1, ecolor='k', mew=1, mec='k', mfc='k')

def Gauss(X, dEdXmax, Xmax, Uspl):
    return dEdXmax*exp(-(X - Xmax)**2 / (2 * Uspl**2))          # The sum of the squared residuals of Gauss(X, *popt) - dEdX is minimized.

popt, pcov = curve_fit(Gauss, X, dEdX, p0=[dEdXmax, Xmax, Uspl])
standardDeviation = sqrt(diag(pcov))                          #standard deviation
```



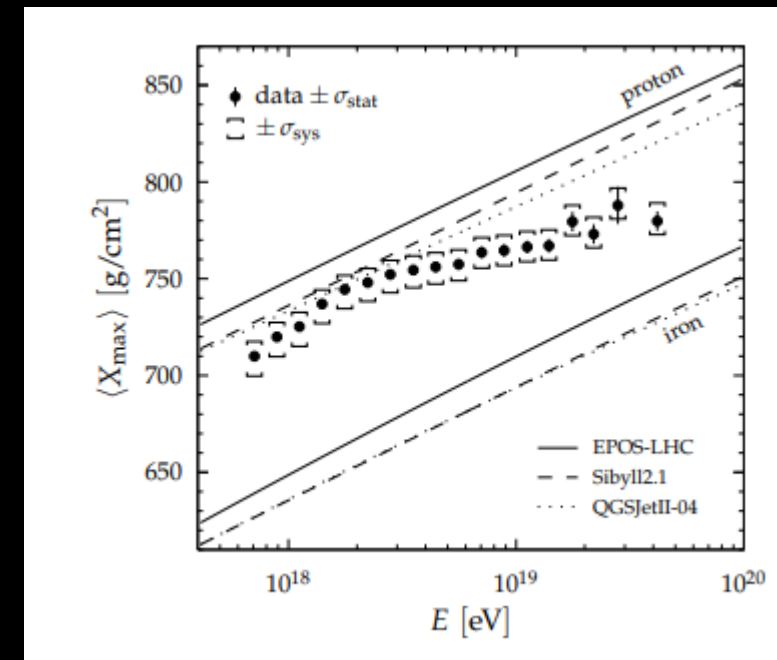
MAX XMAX IN A COSMIC RAY



Origins:

Blue, Green \rightarrow Galactic, max at 18,75

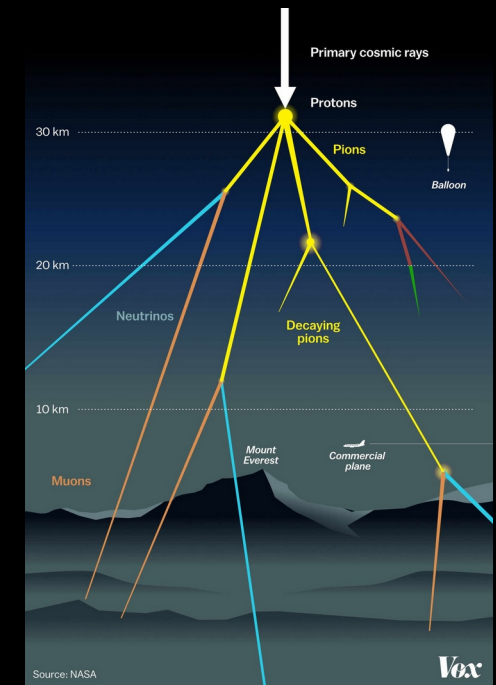
Red, Yellow \rightarrow Extra Galactic, start at ± 19



MY EXPERIENCE

- Vispa and Python
- Physics
- How the data is gathered

```
31 def
32     self.file = None
33     self.fingerprints = set()
34     self.logdupes = True
35     self.debug = debug
36     self.logger = logging.getLogger(__name__)
37     if path:
38         self.file = open(os.path.join(path, "requests.txt"),
39                         "a")
40         self.file.seek(0)
41         self.fingerprints.update(a.request() for a in self.requests)
42
43 @classmethod
44 def from_settings(cls, settings):
45     debug = settings.getbool("DEBUG_REQUESTS")
46     return cls(job_dir(settings), debug)
47
48 def request_seen(self, request):
49     fp = self.request_fingerprint(request)
50     if fp in self.fingerprints:
51         return True
52     self.fingerprints.add(fp)
53     if self.file:
54         self.file.write(fp + os.linesep)
55
56 def request_fingerprint(self, request):
57     return request_fingerprint(request)
```





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Thanks!

Questions that came up?

Jorge Gouveia & Miguel Pereira