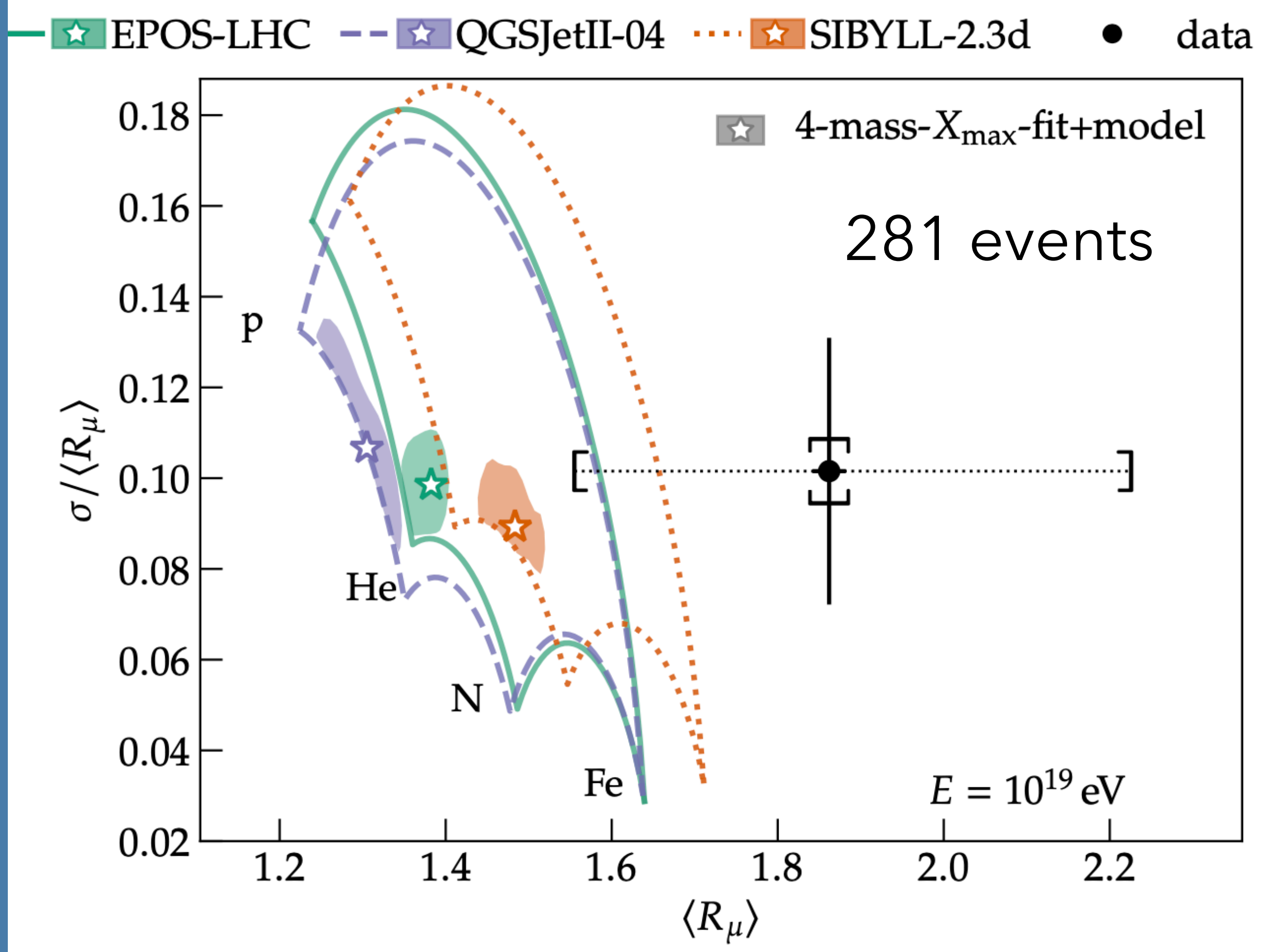
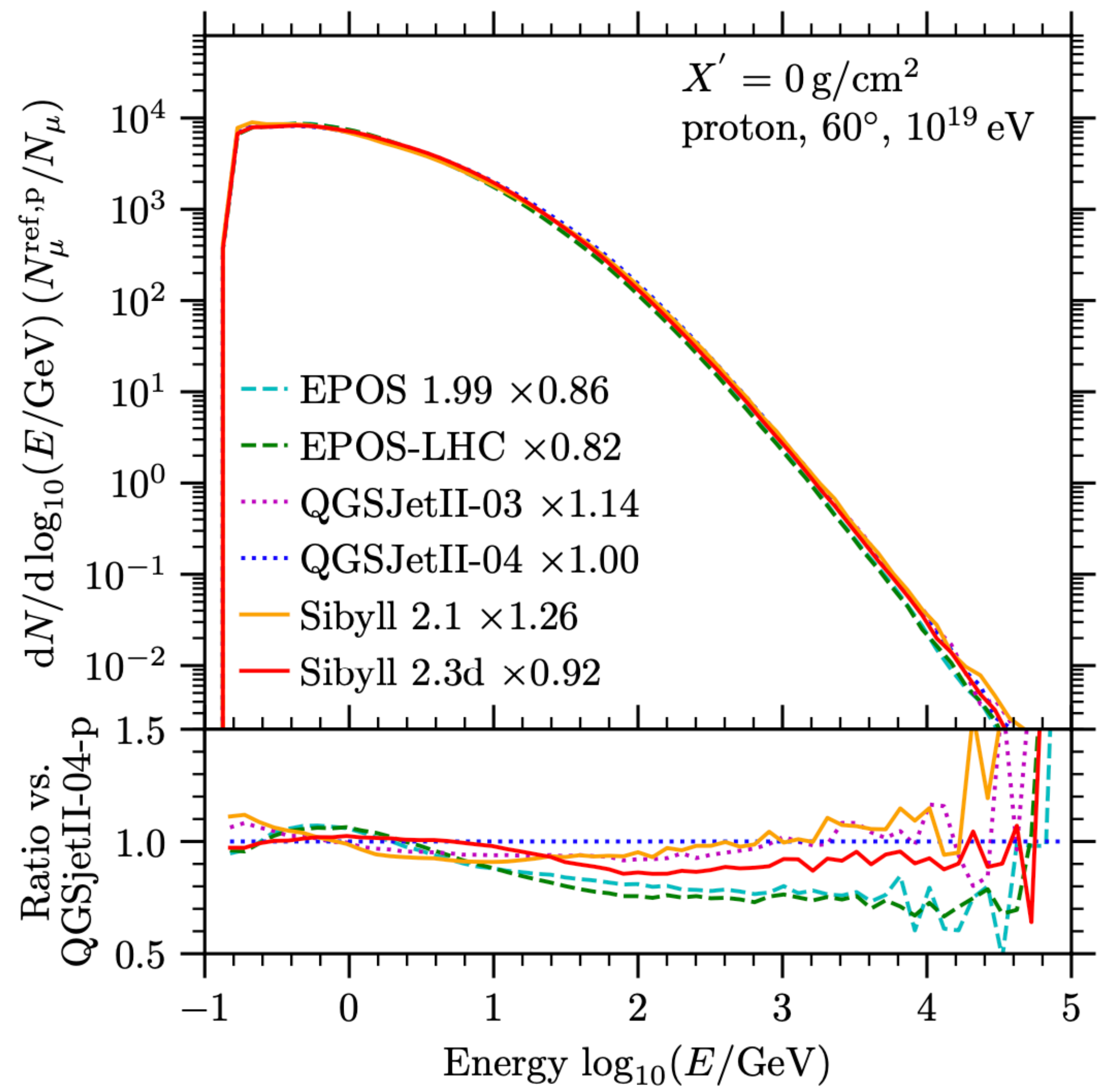
Auger-LIP group

Shower Physics and Data analysis

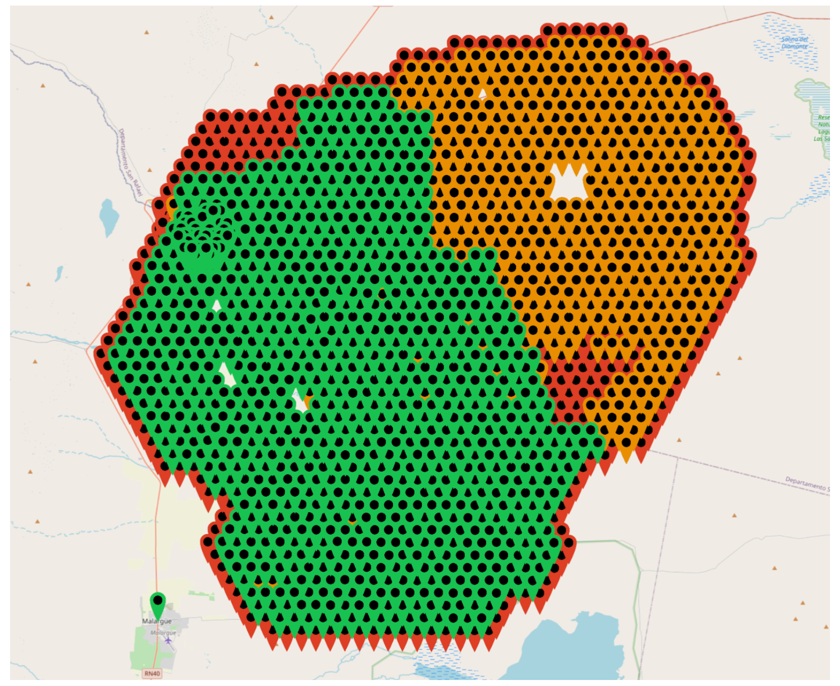


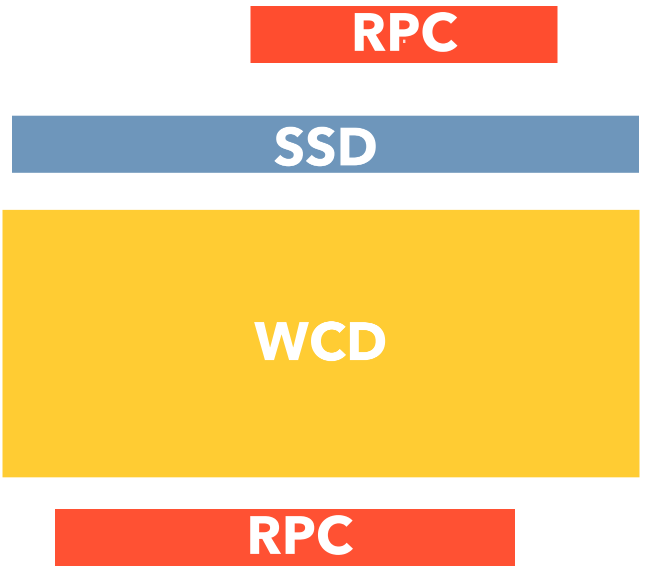
PhysRevLett.126.152002

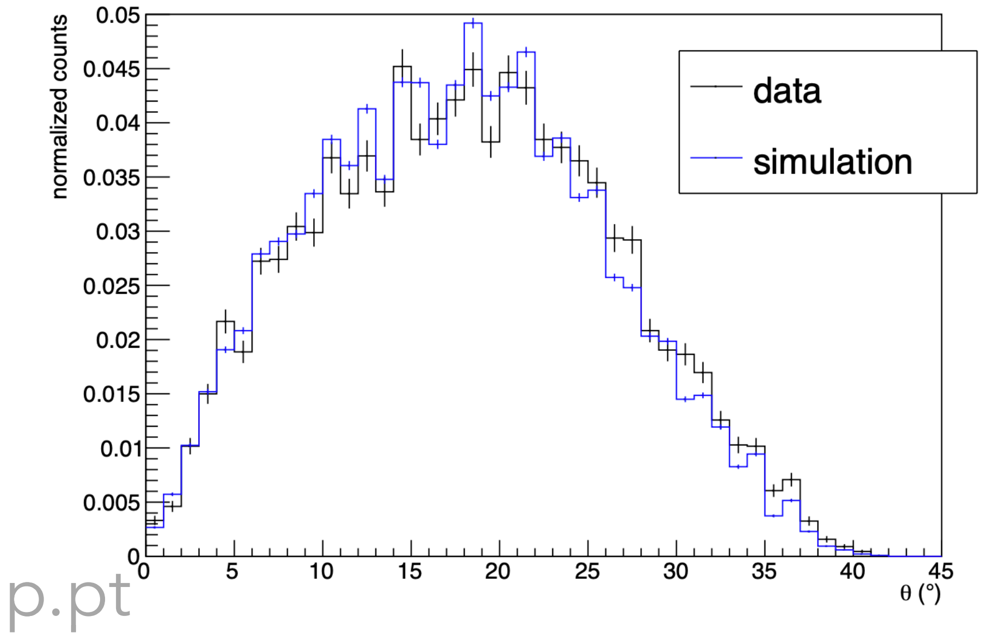


JCAP03 (2023) 022

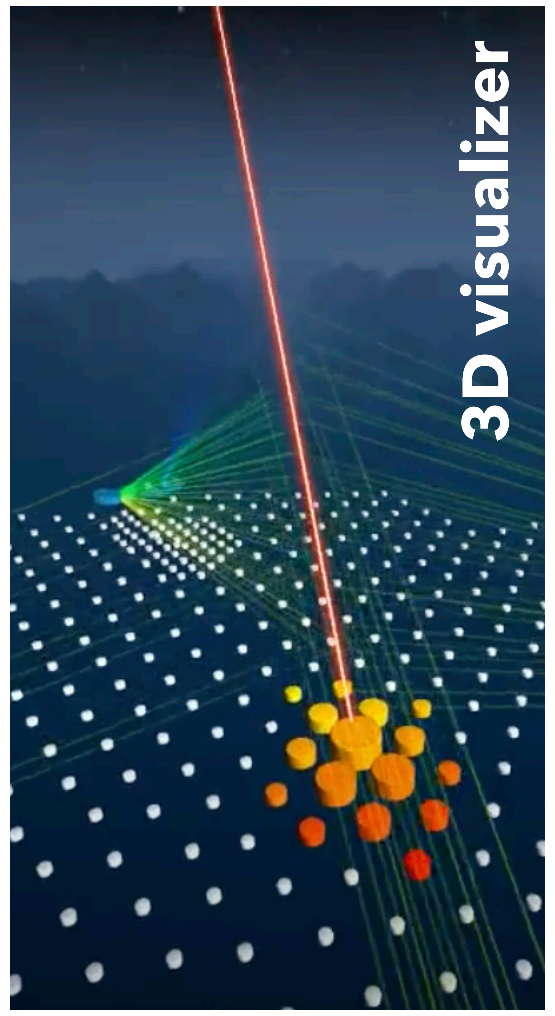
Calibration activities







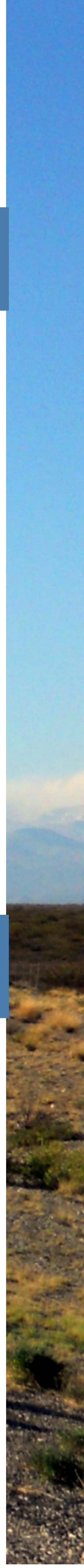
Outreach



3 Auger Masterclass events!
12 institutions, 5 countries
~550 students

ruben@lip.pt

SWOT Analysis



Strength

- The LIP team is relatively large, both in the number of members and competences.
- **FCT has a long-term commitment to the Portuguese participation in the Pierre Auger Observatory**, which hopefully can be extended beyond 2030. This assures the payment of the contribution foreseen in the MoU.

Weakness

- The team has a small number of MSc and PhD students, leading to a lack of workforce, particularly in task 2 (EAS phenomenology).
- The group's **funding level is low for the number of team members**. Resources are limited, thus, missions for meetings and fieldwork in Argentina must be wisely chosen.

Opportunities

- The group has a **strong competence** in extensive air shower phenomenology, simulation, and calibrations using RPC hodoscopes. This places the group in a **privileged position for the required collaboration activities** upon entering the new phase.
- **Visibility within the universities is increasing**, which is an opportunity to attract new students. Lecturing in the Master in Physics program at IST and participating in thematic schools is increasing the awareness of this field.

Threats

- The **funding** of the group has been **renewed every two years through the Fund CERN application**. The current funding assures the group's operation until the end of 2023.

Acknowledgements

fct Fundação para a Ciência e a Tecnologia

Lisb@20²⁰

COMPETE 2020
PROGRAMA OPERACIONAL COMPETITIVIDADE E INTERNACIONALIZAÇÃO

REPÚBLICA PORTUGUESA

PORTUGAL 2020

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

LIP

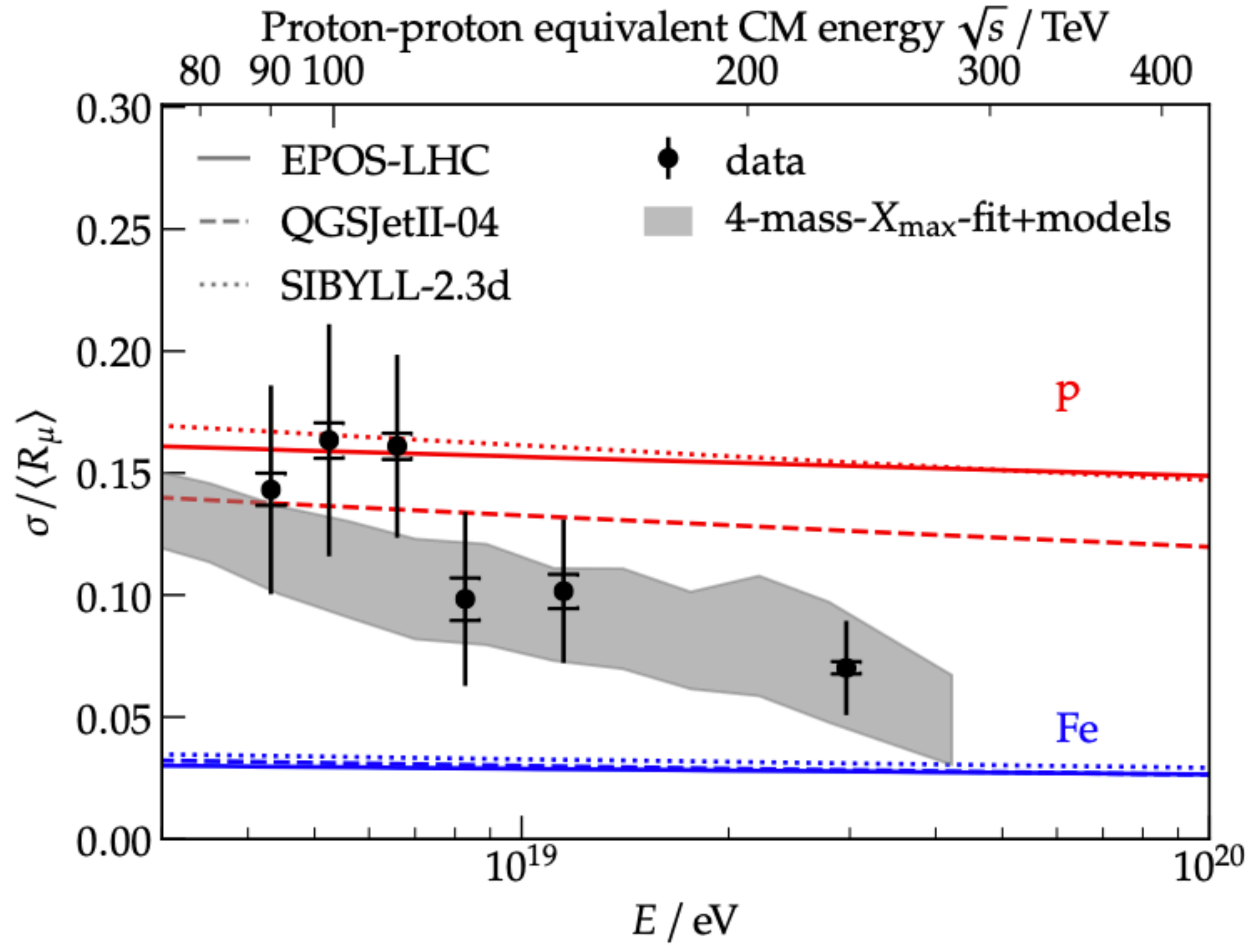
TÉCNICO LISBOA

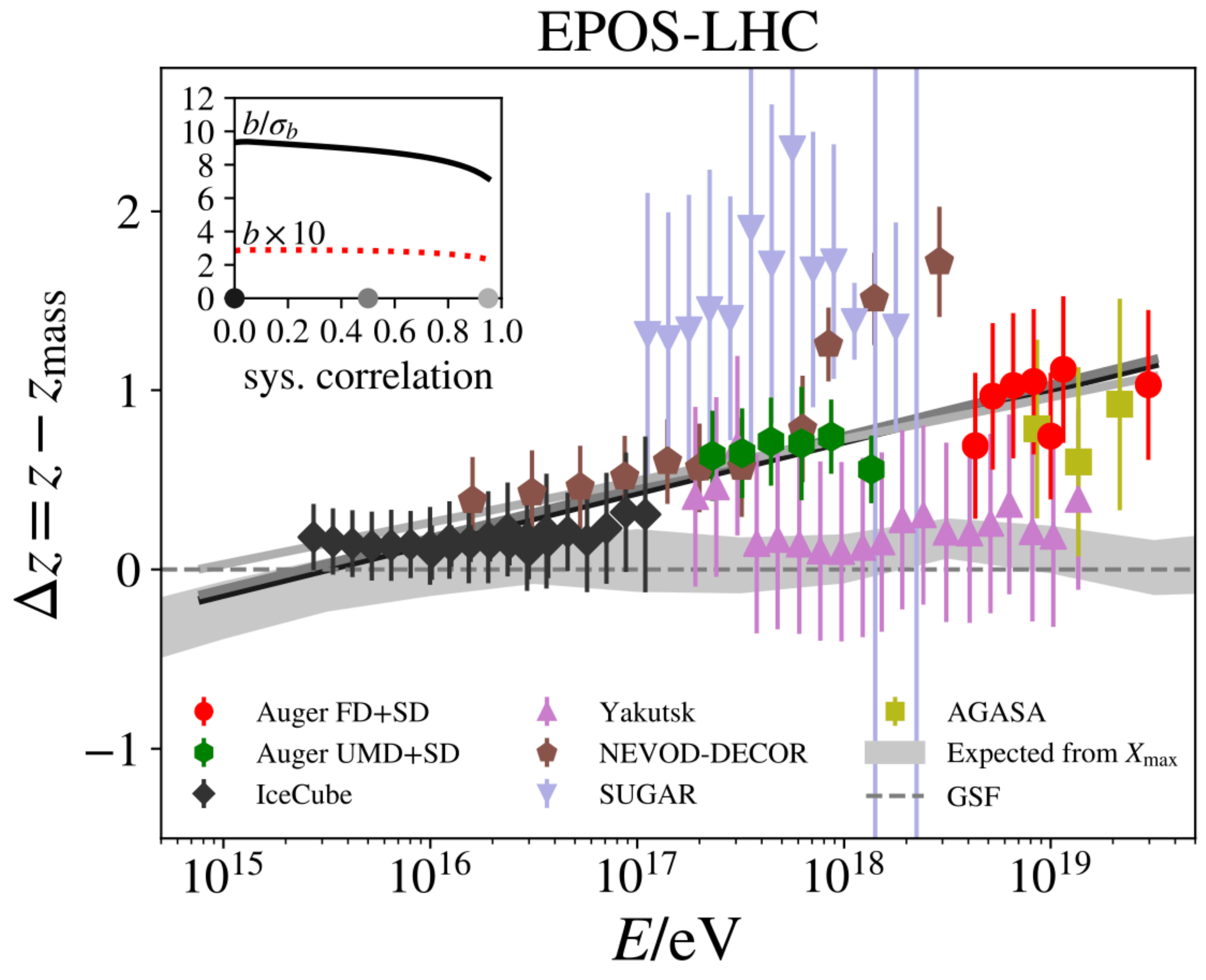
Backup Slides

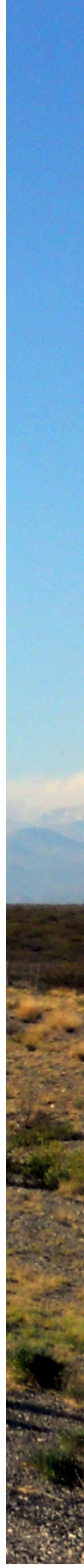
EAS muon puzzle

Pierre Auger coll., Phys.Rev.Lett. 126 (2021) 15, 152002

- There's no easy way to explain the apparent excess of muons in data
- SD calibration well understood and allowed to investigate the relative muon fluctuations
  - Whose agreement with model predictions suggest that the problem might be connected to lower energy hadronic interactions
- Confirmed by the combination of the data of 9 cosmic ray experiments (WHISP)

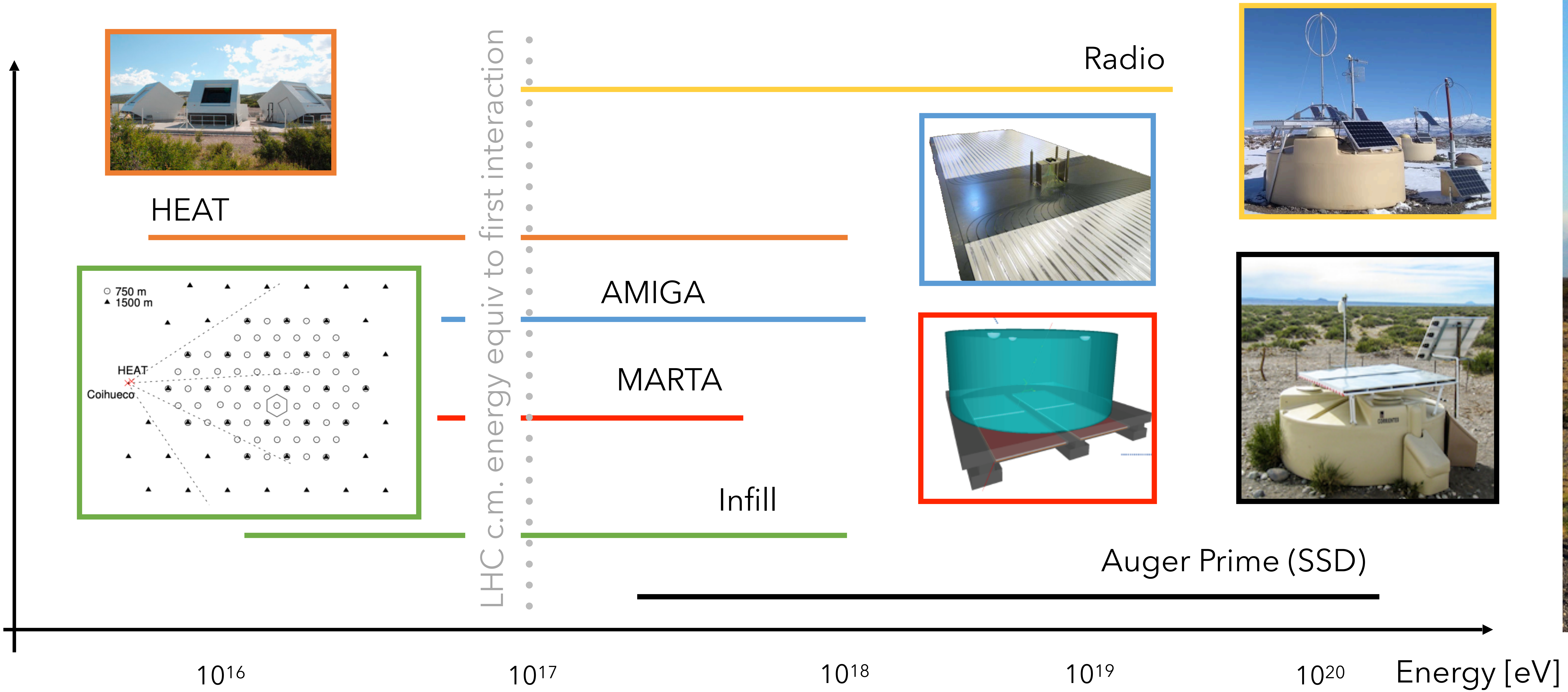




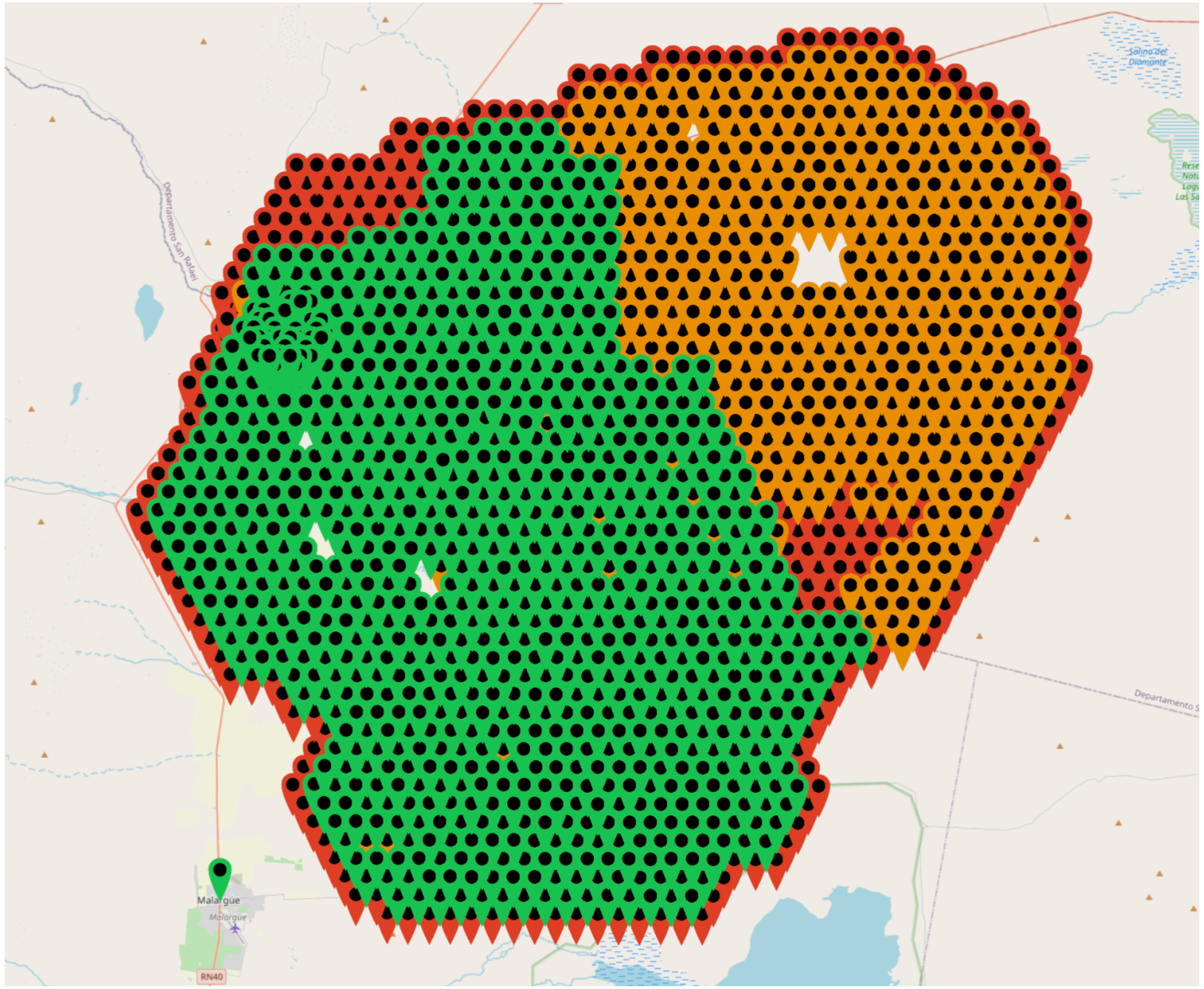


Multi-hybrid shower events

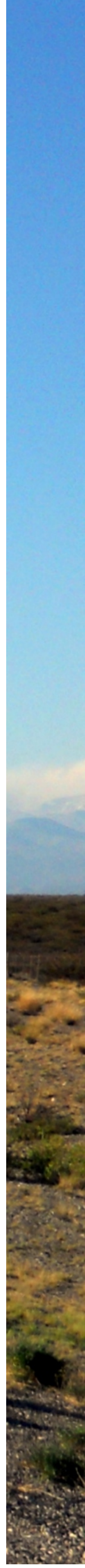
(A plethora of measurements to fully understand the shower)



Auger Prime (SSD + WCD)

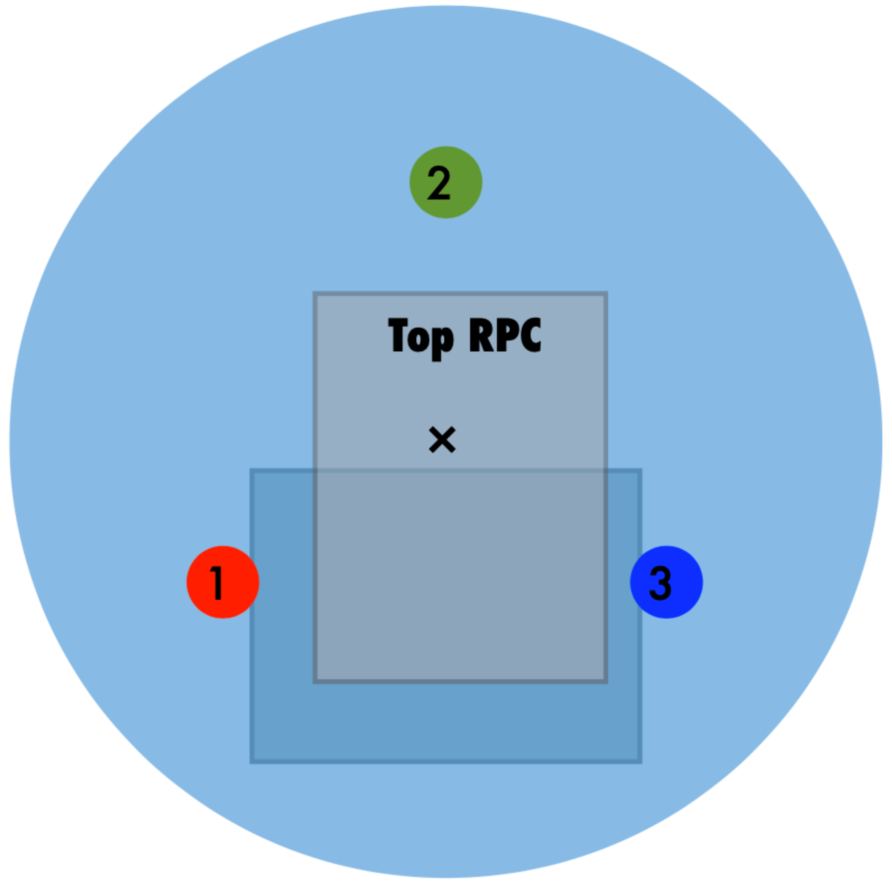


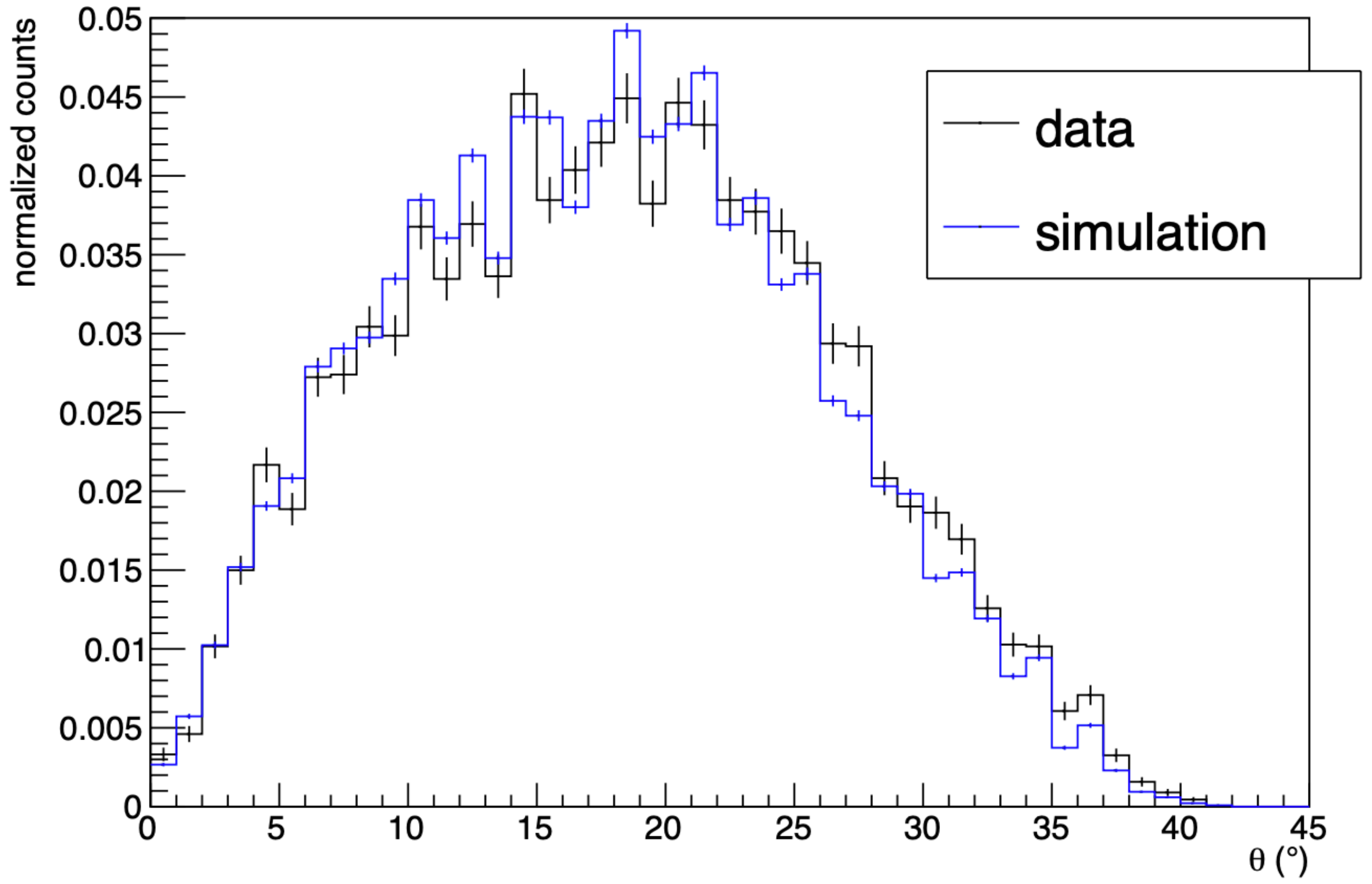
- Upgrade should be completed at the beginning of next year
- Crucial assess the calibration of the scintillator (SSD) and the WCD



Back to the calibration with the RPC hodoscope

- RPC hodoscope installed in the Gianni Navarra tank was reconfigured to include one of the Auger Prime detectors

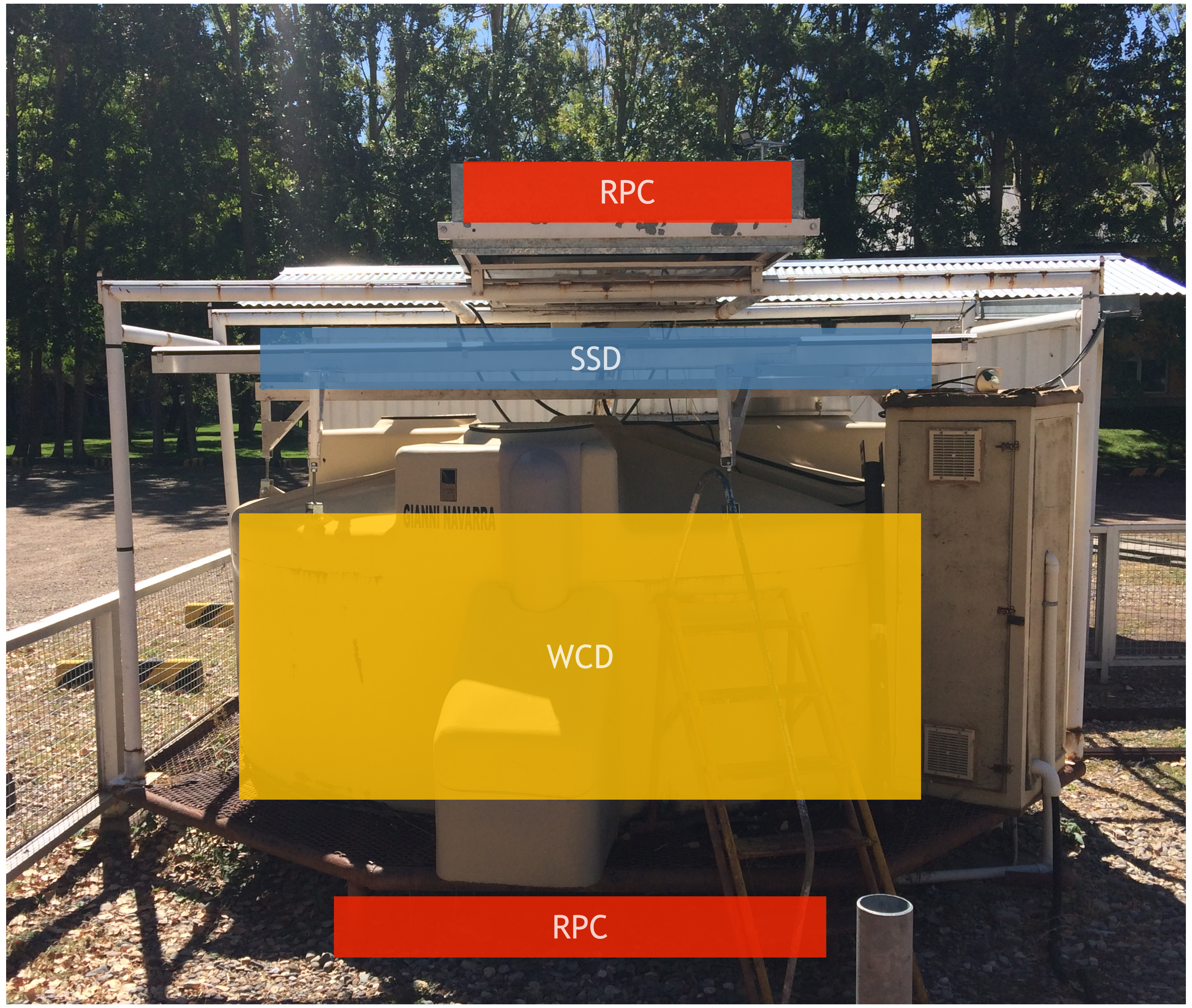


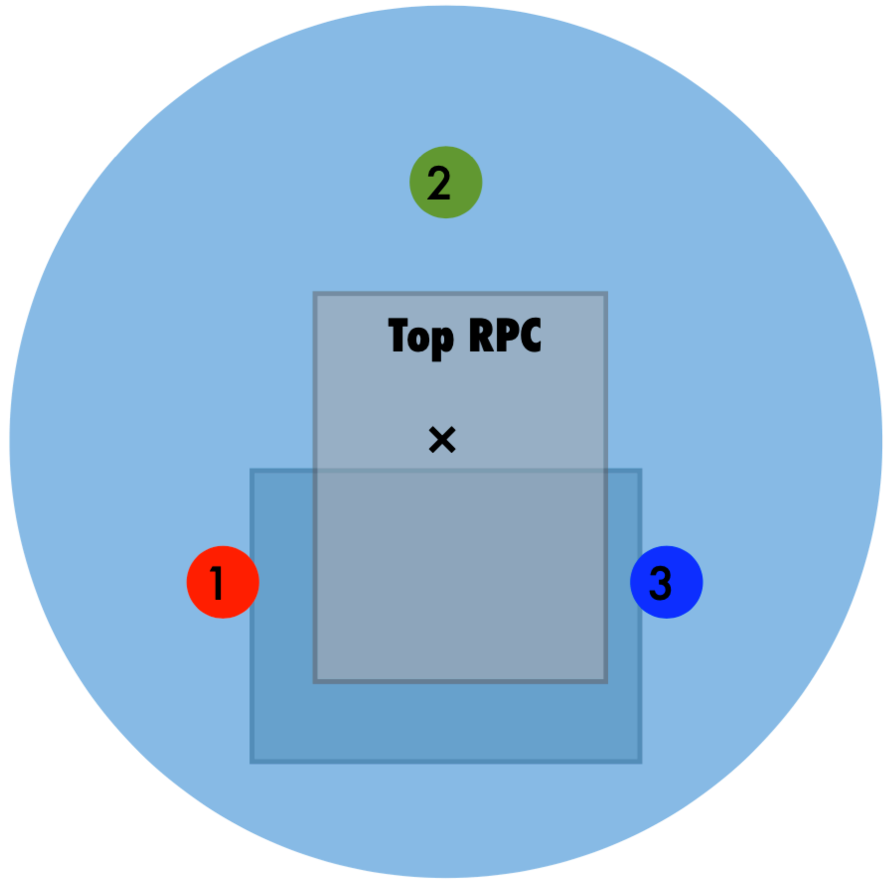


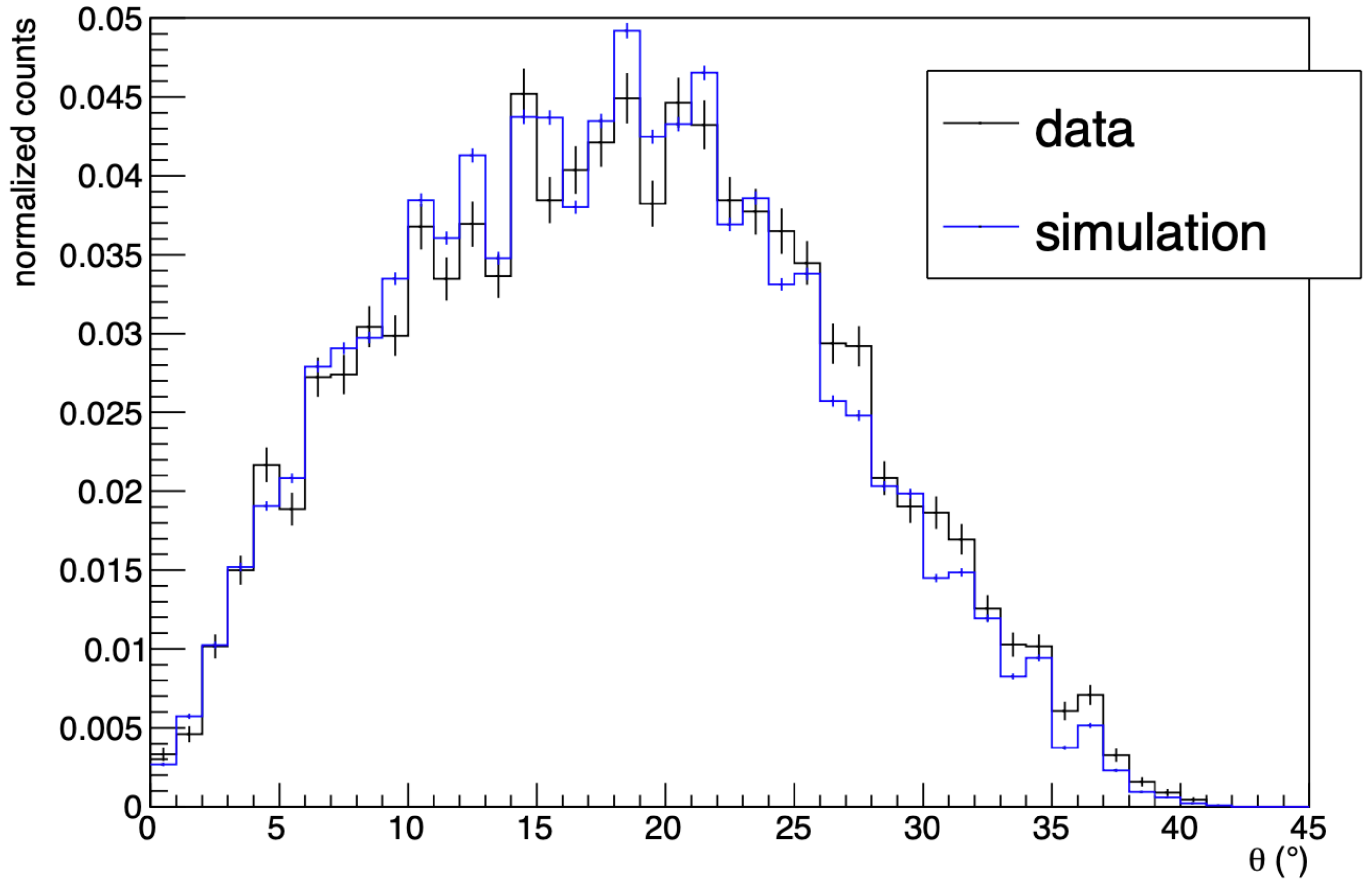
- The data acquisition system was also upgraded to cope with the new electronics board of the WCD and have a more robust/faster acquisition system

Back to the calibration with the RPC hodoscope

- ✧ RPC hodoscope installed in the Gianni Navarra tank was reconfigured to include one of the Auger Prime detectors







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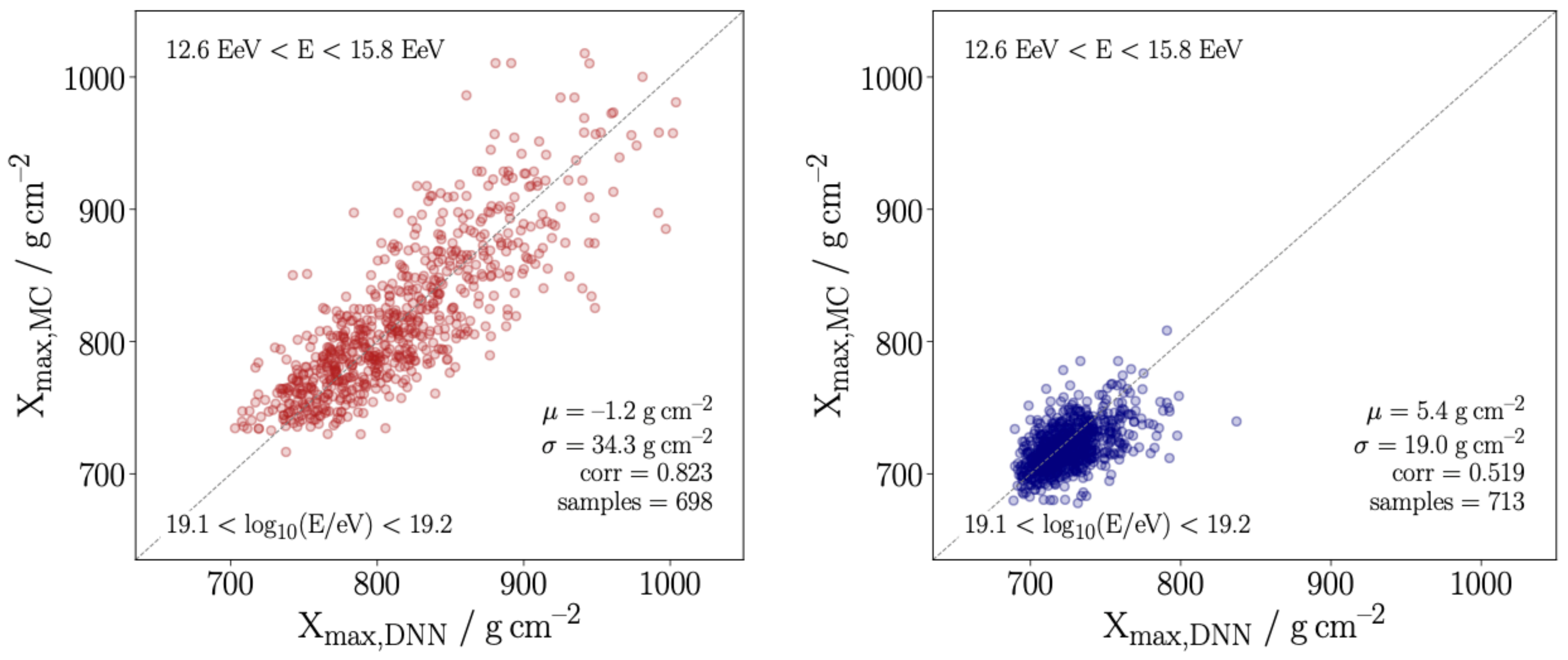
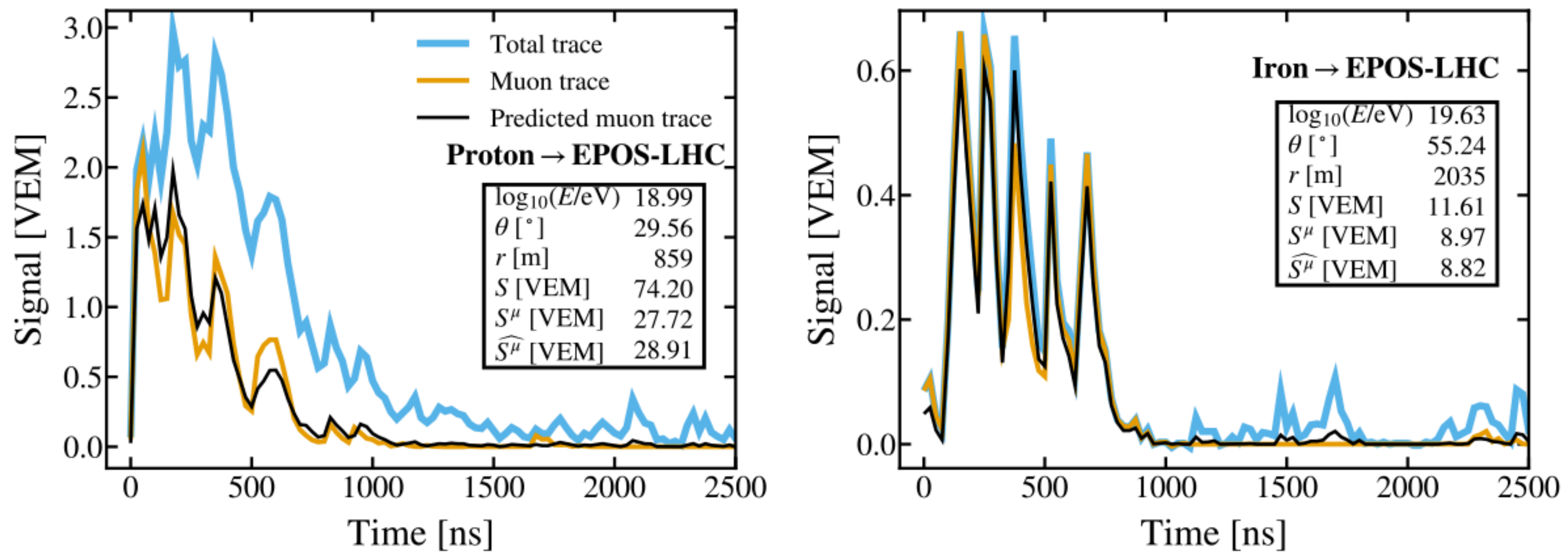
The dawn of Machine Learning @ Auger

Pierre Auger coll., JINST 16 (2021) 07, P07019

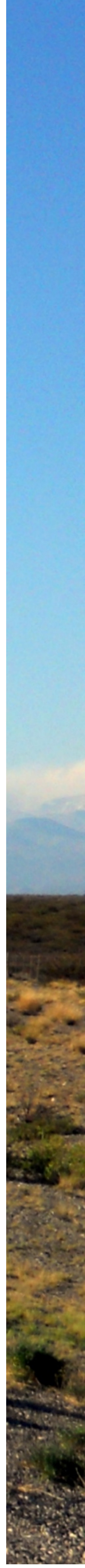


Extraction of Xmax from the SD ground signal

Pierre Auger coll., JINST 16 (2021) 07, P07016

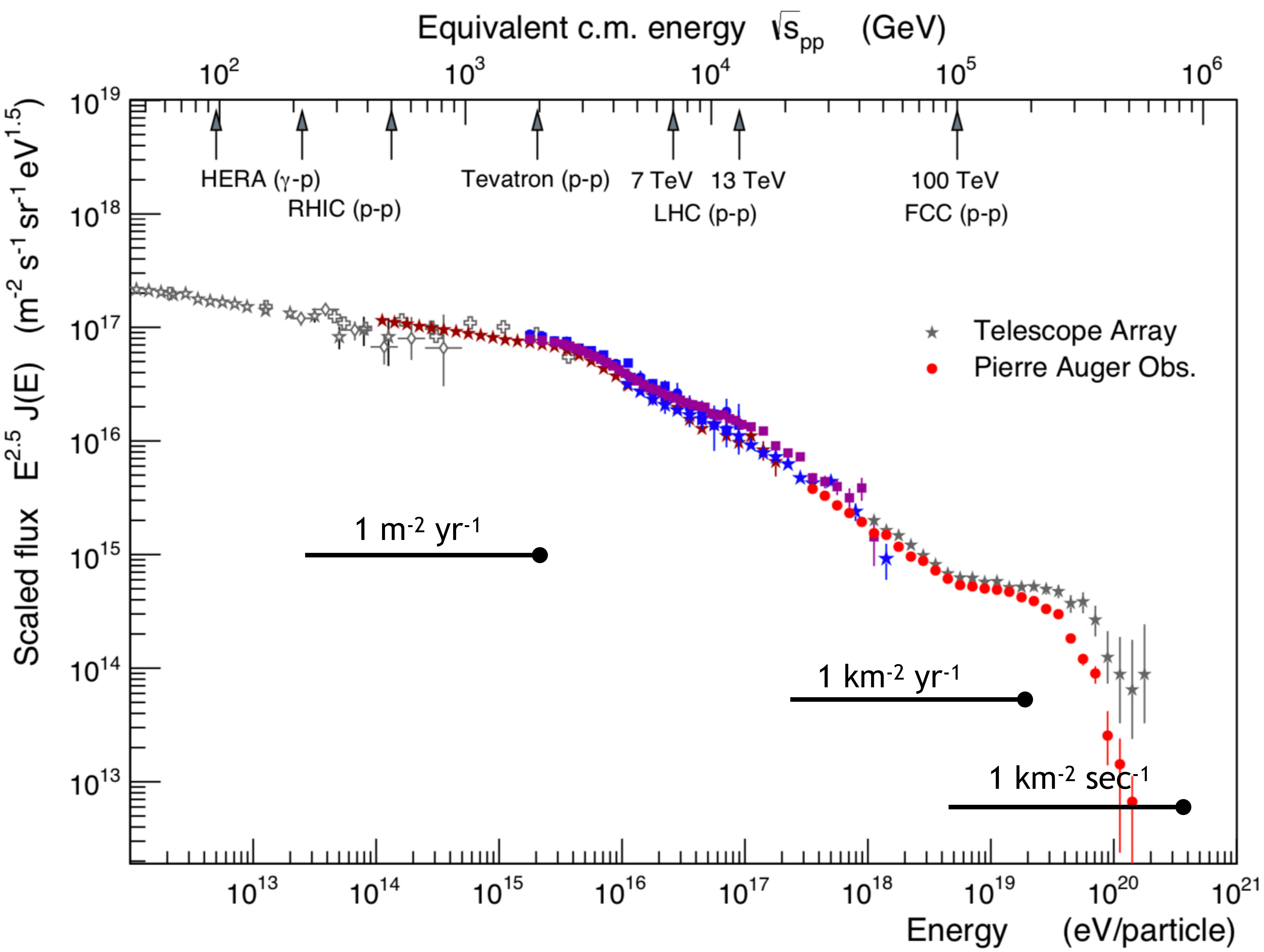


Extraction of Nmu from the WCD signal for vertical showers

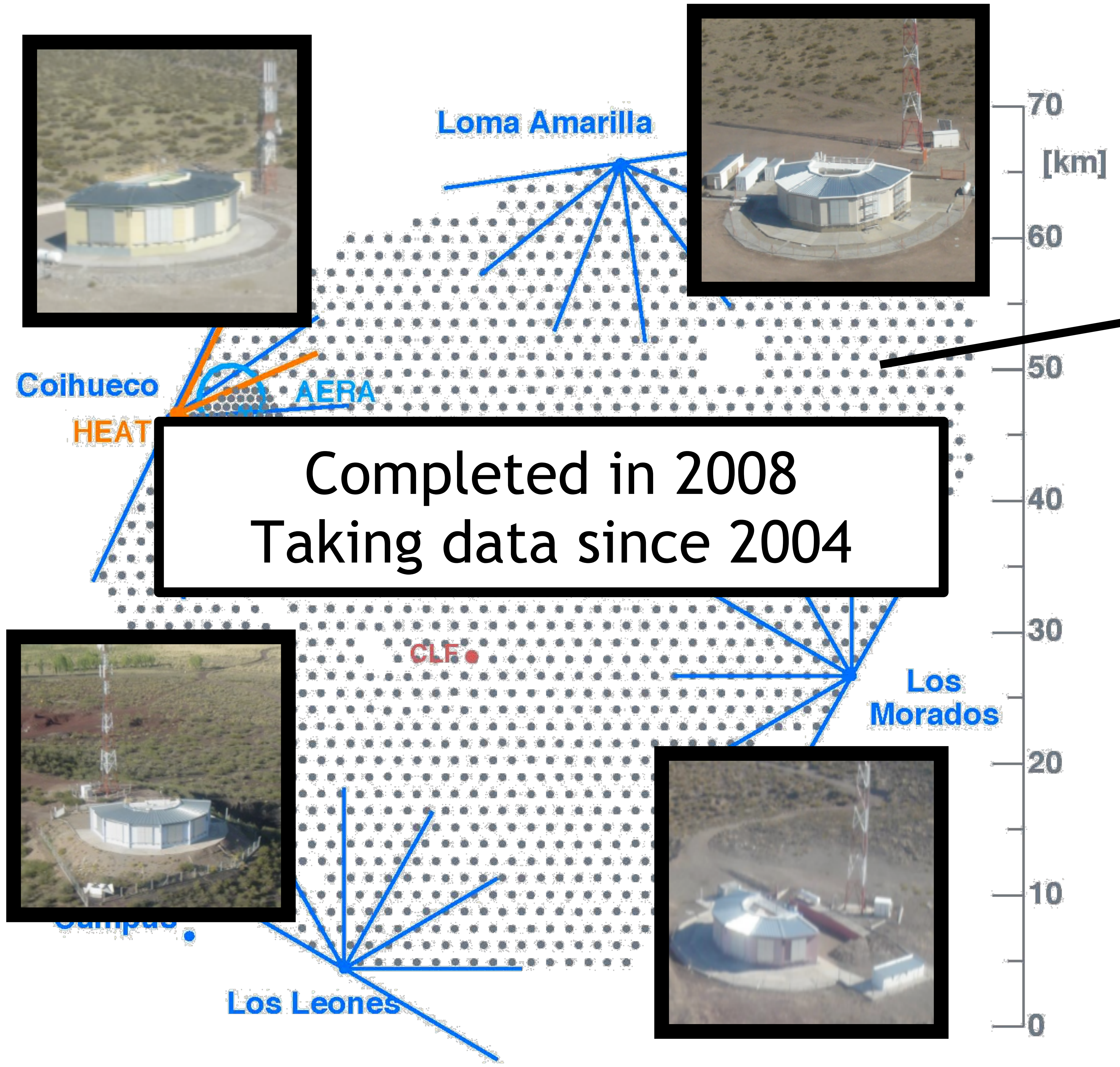


- Both method have good resolutions comparable to those achieved with hybrid events
- Algorithms highly dependent of simulations and might be picking up unknown less controlled shower characteristics
- It is vital to create strategies to achieve self consistent solutions ⇒ RPC hodoscope

Ultra High Energy Cosmic Rays



Pierre Auger Observatory



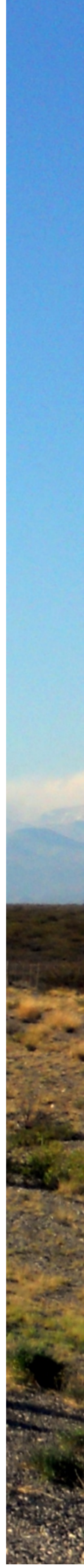
Completed in 2008
Taking data since 2004

~ 60 km

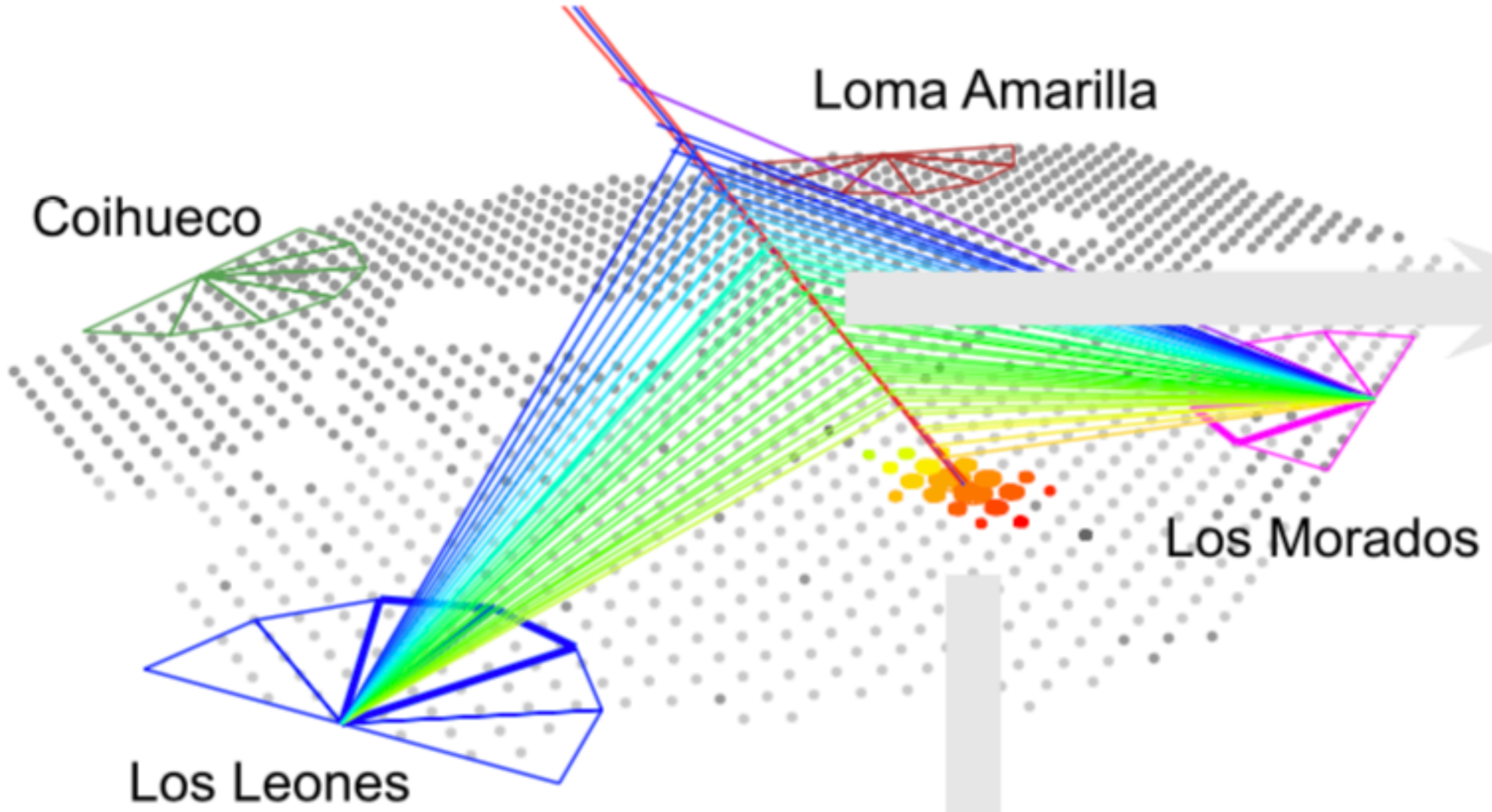
- ~ 1600 Surface detectors (SD)
- In a 1.5 km hexagonal grid
- 3000 km²

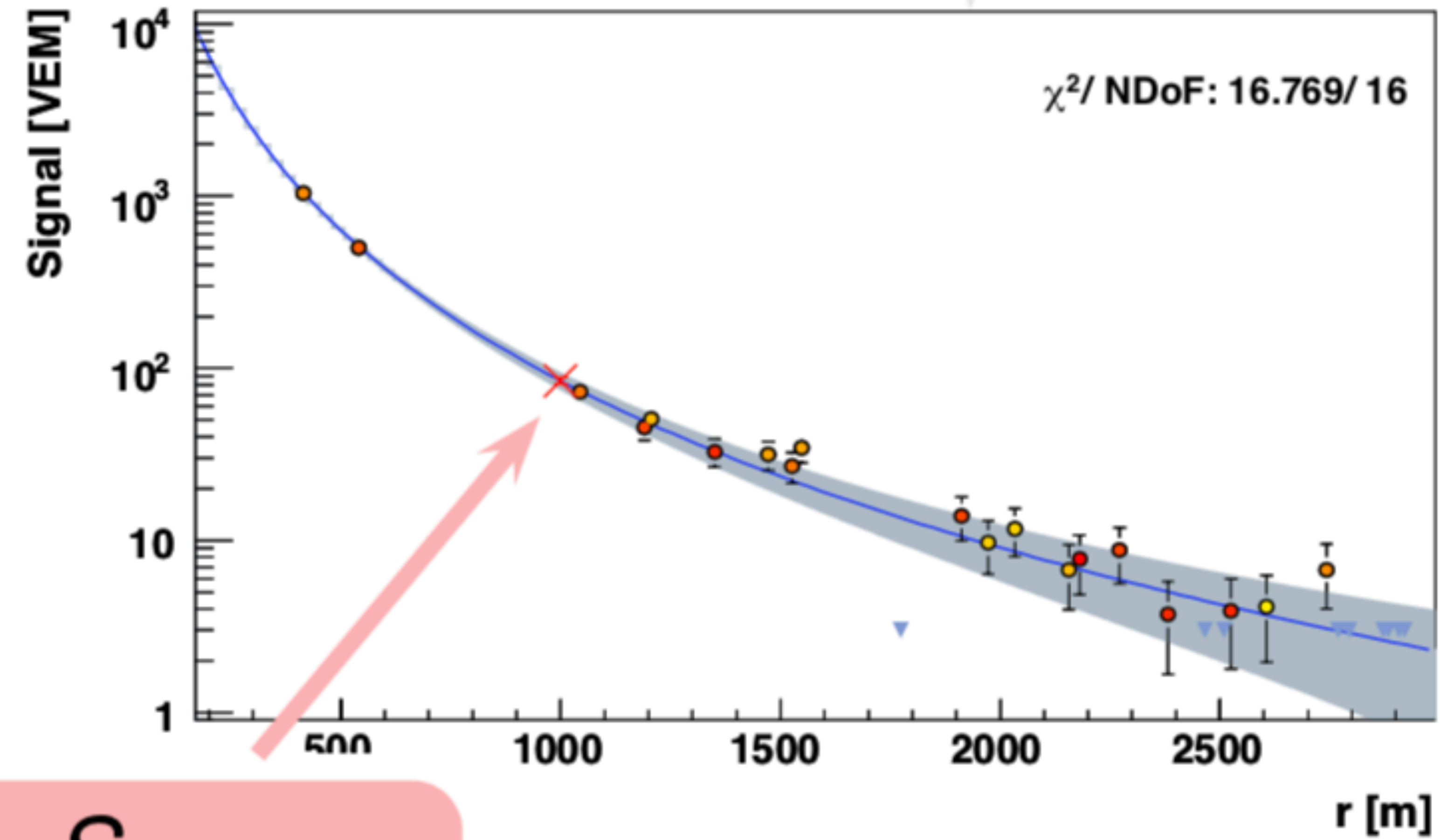
- 4 Fluorescence Detectors (FD)
- 6 x 4 + 3 Fluorescence Telescopes

Built to detect and study the extremely rare UHECR



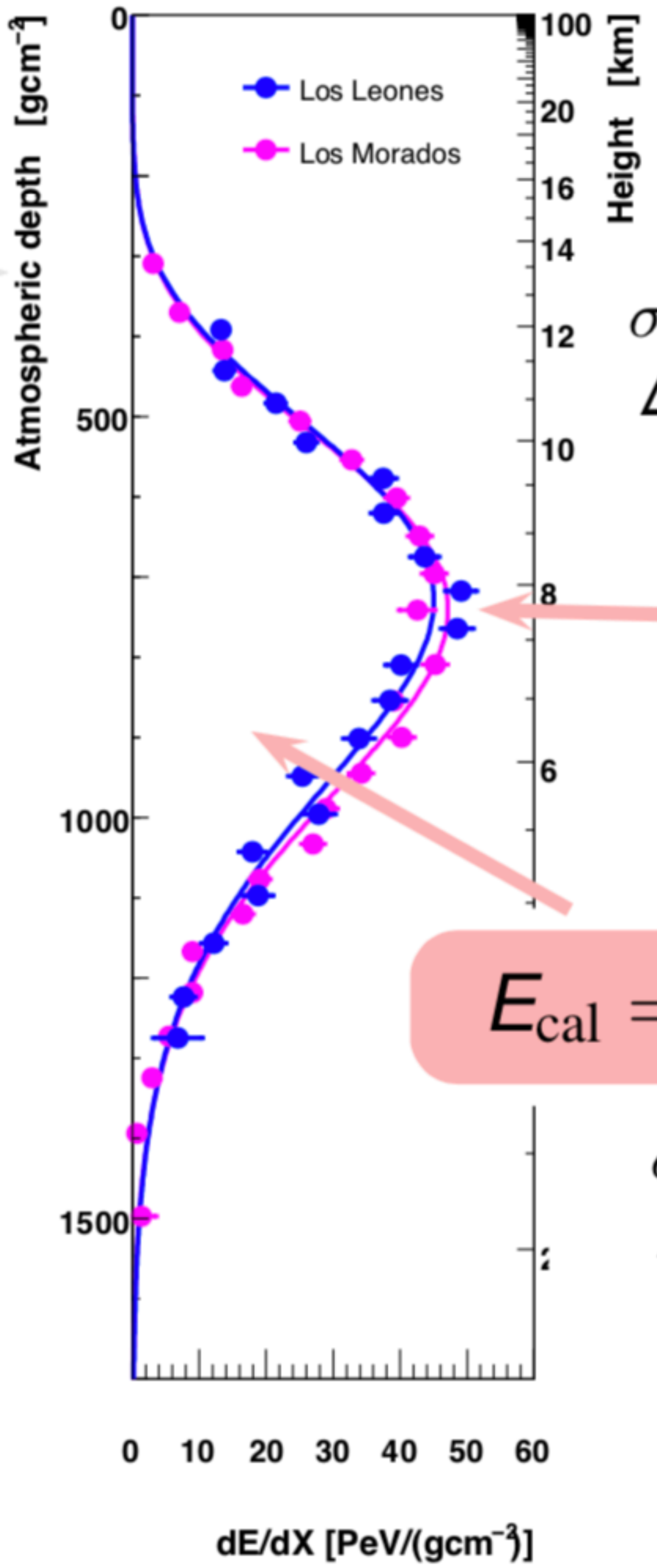
Hybrid Technique (FD + SD)





S_{1000}

$E_{\mathrm{surface}} = f(S_{1000},\, \theta)$



$\sigma_{X_{\mathrm{max}}} \leq 20\,\mathrm{g/cm^2}$
$\Delta_{\mathrm{sys}} \leq 10\,\mathrm{g/cm^2}$

X_{max}

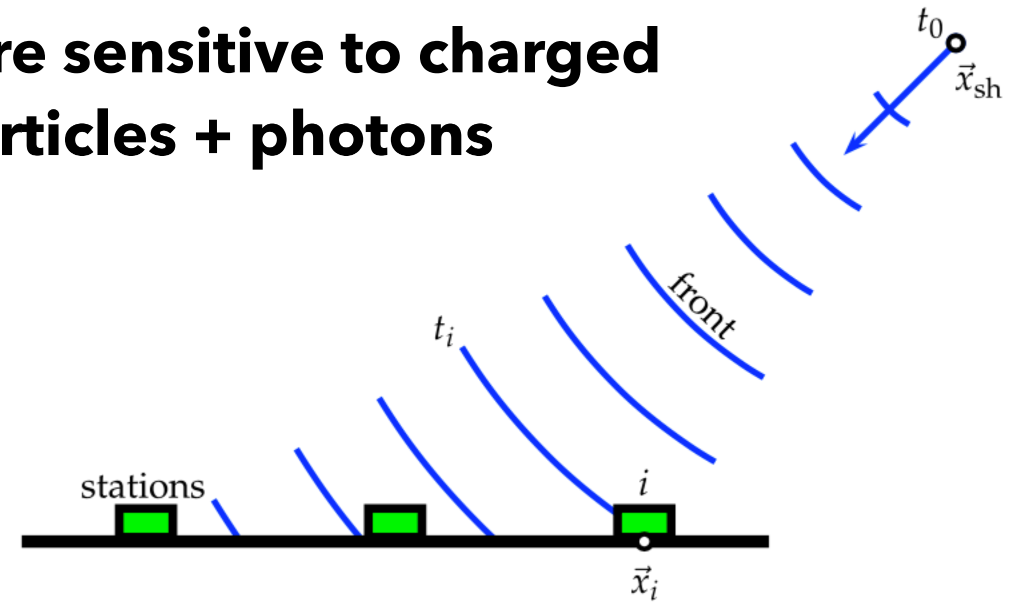
$E_{\mathrm{cal}} = \int \frac{\mathrm{d}E}{\mathrm{d}X}\,\mathrm{d}X$

$\sigma_E/E \sim 8\,\%$
$\Delta_{\mathrm{sys}} \approx 15\,\%$

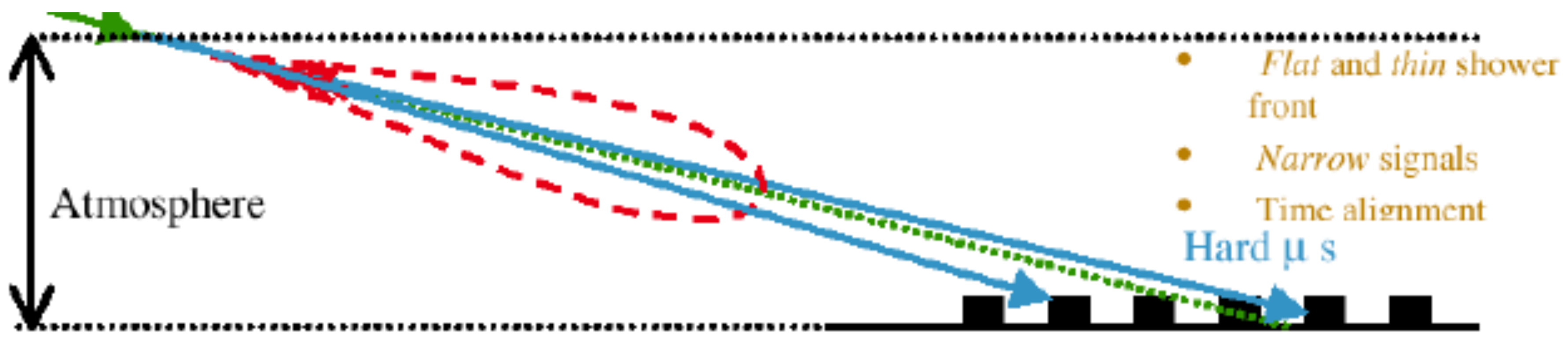
Exploration of inclined showers

- Muons → Assess Hadronic interaction models
- Data selection
  - Zenith angles [62° ; 80°]
  - E > 4 x 10^{18} eV

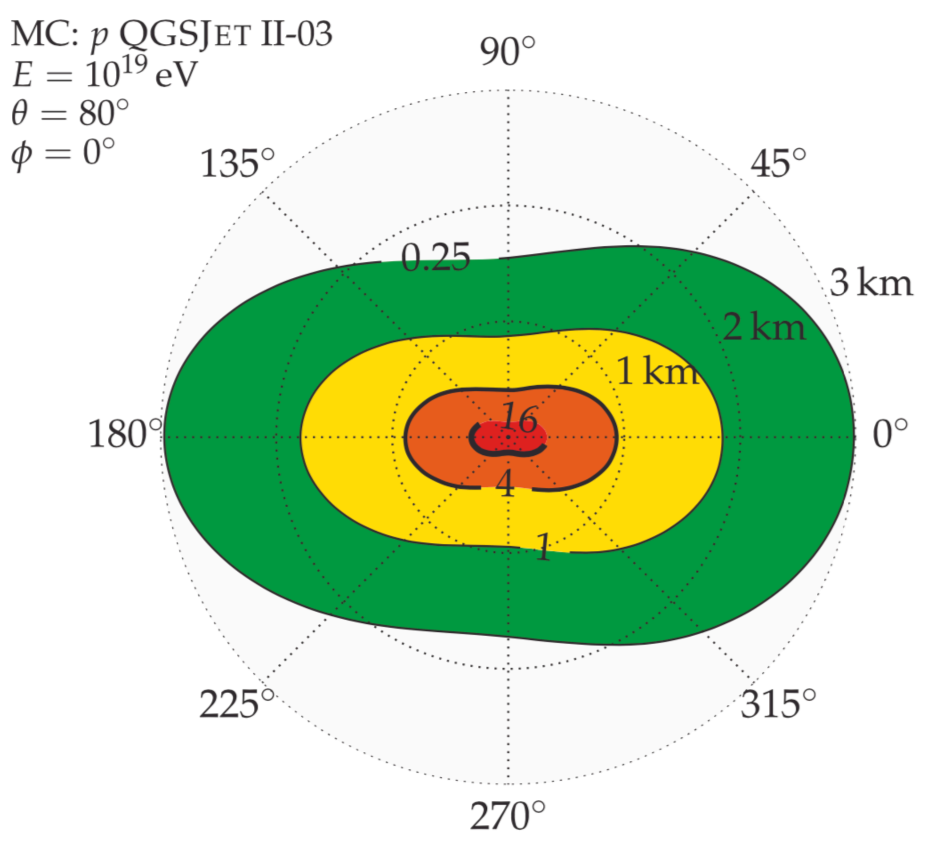
WCDs are sensitive to charged particles + photons

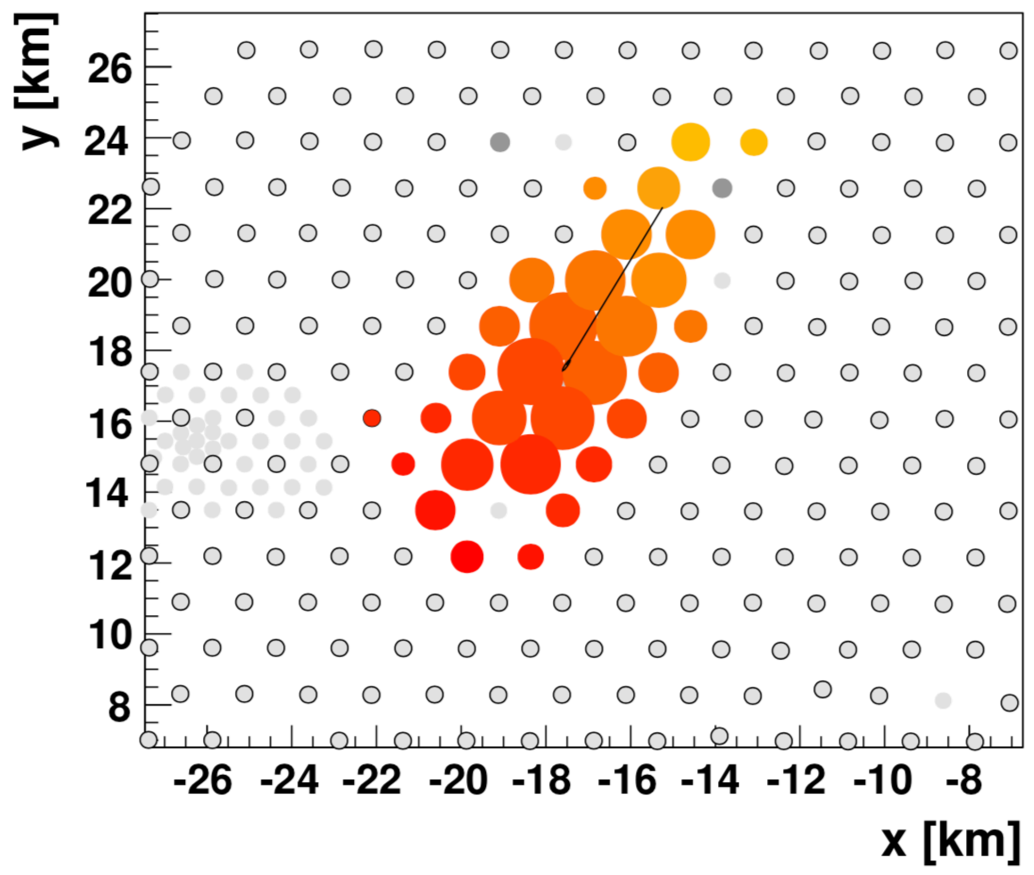


- Inclined shower → Muons



- Energy given by the Fluorescence Detector
- 281 hybrid events

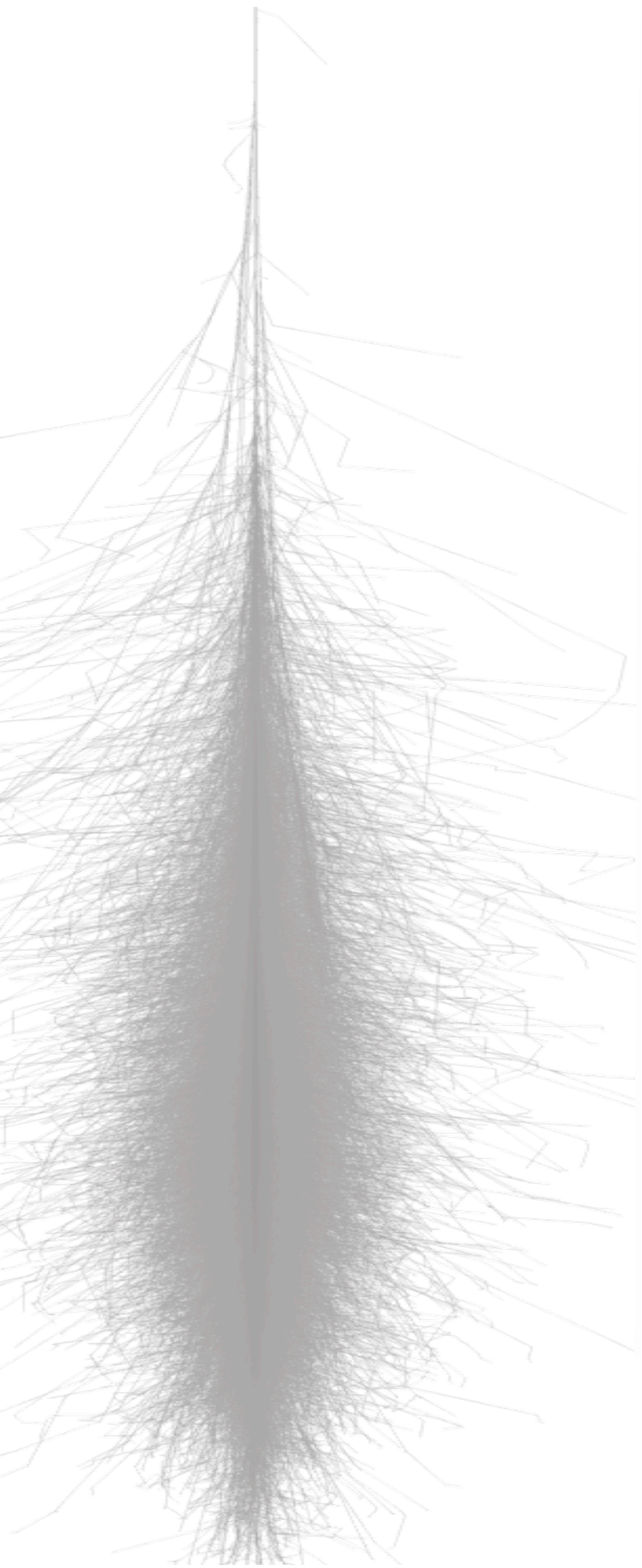




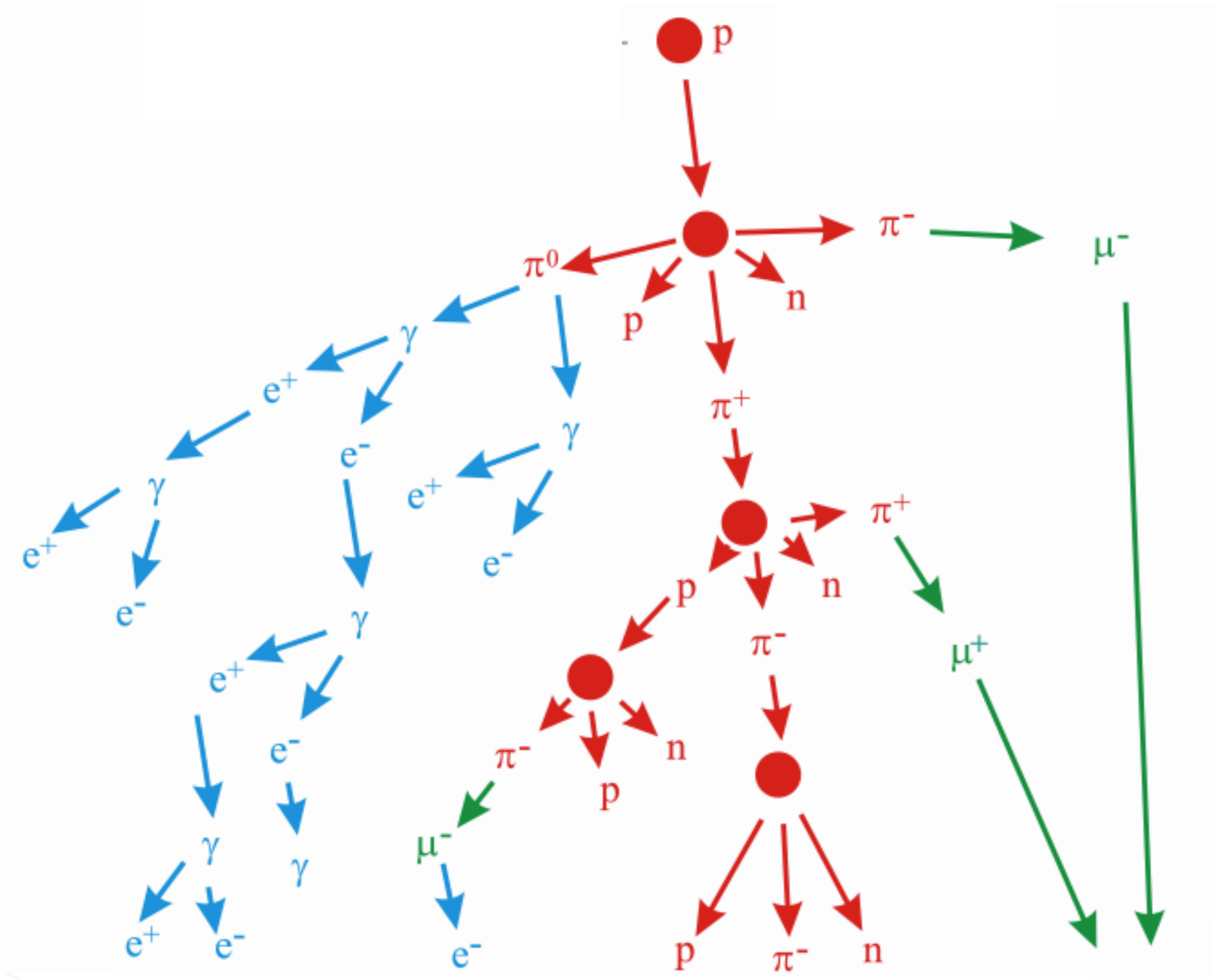
$$\rho_\mu(\text{data}) = N_{19} \cdot \rho_\mu(\text{QGSJETII03},\ p, E = 10^{19}\ eV,\ \theta)$$

$$\boxed{R_\mu = \frac{N_\mu^{data}}{N_{\mu,19}^{MC}}}$$

Extensive Air Showers



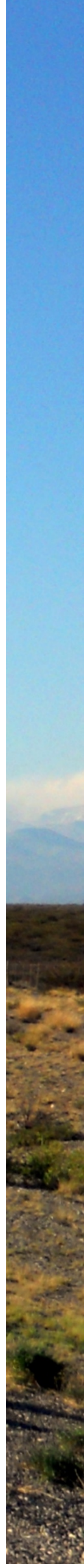
Monte Carlo EAS simulation [CORSIKA]



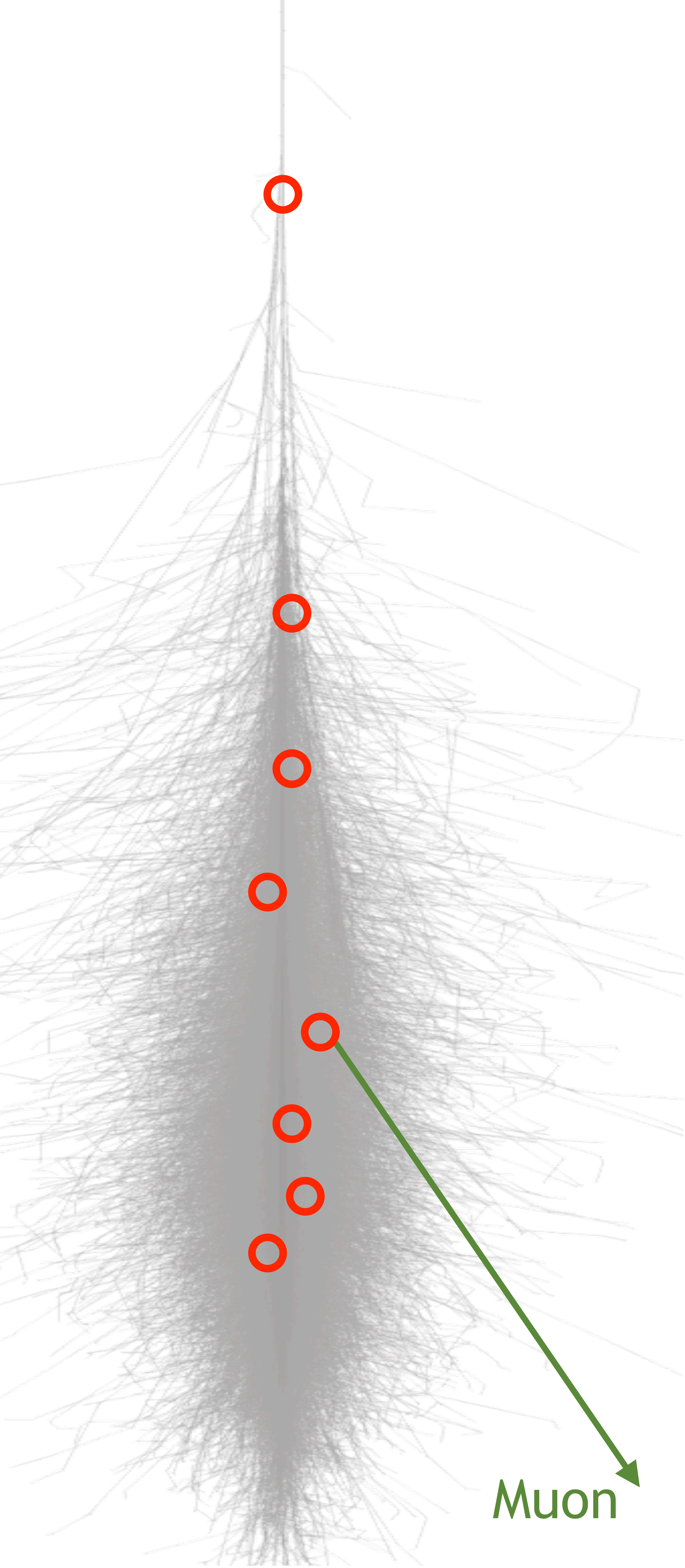
Electromagnetic component

Hadronic component

Muonic component

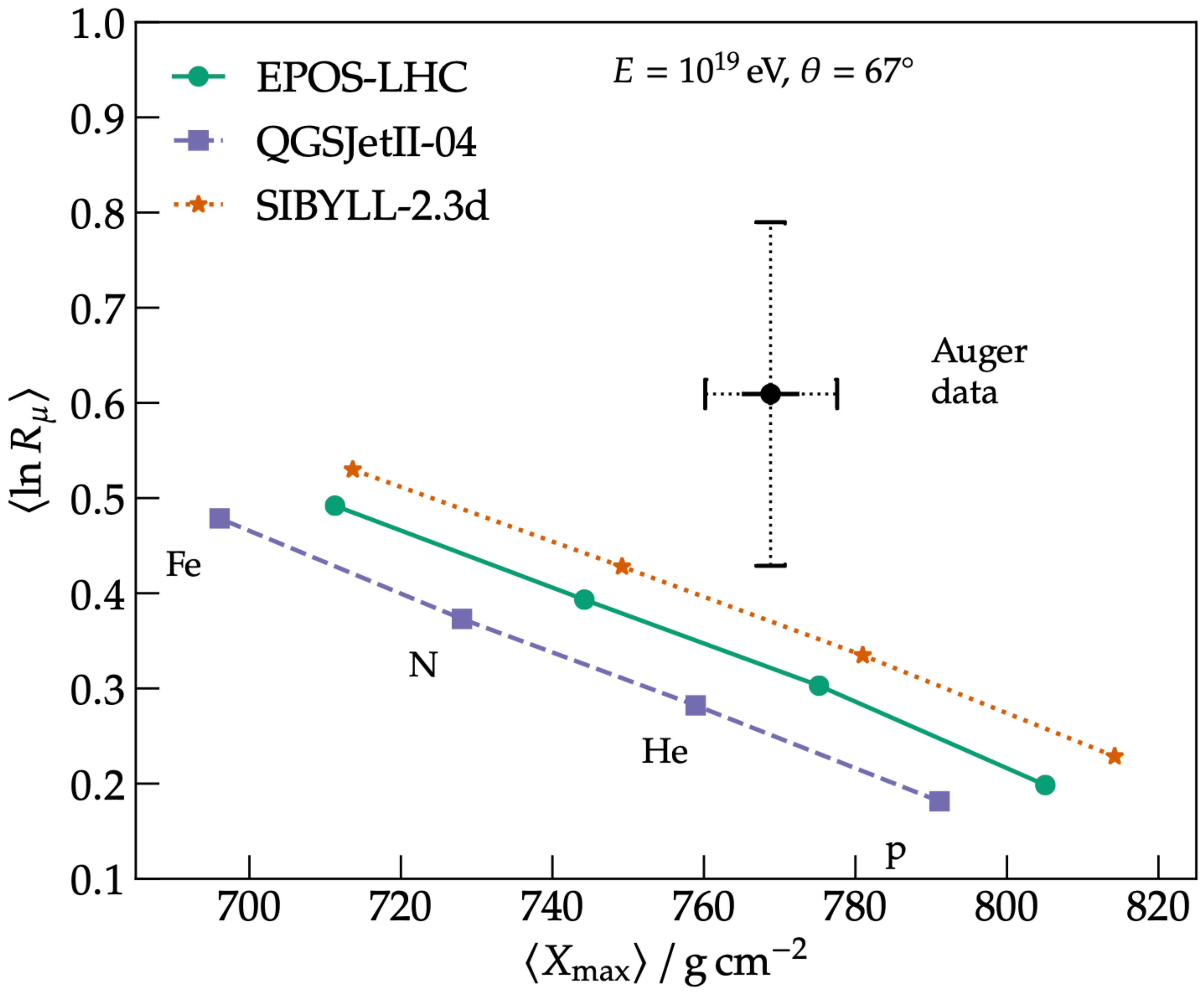


Shower description



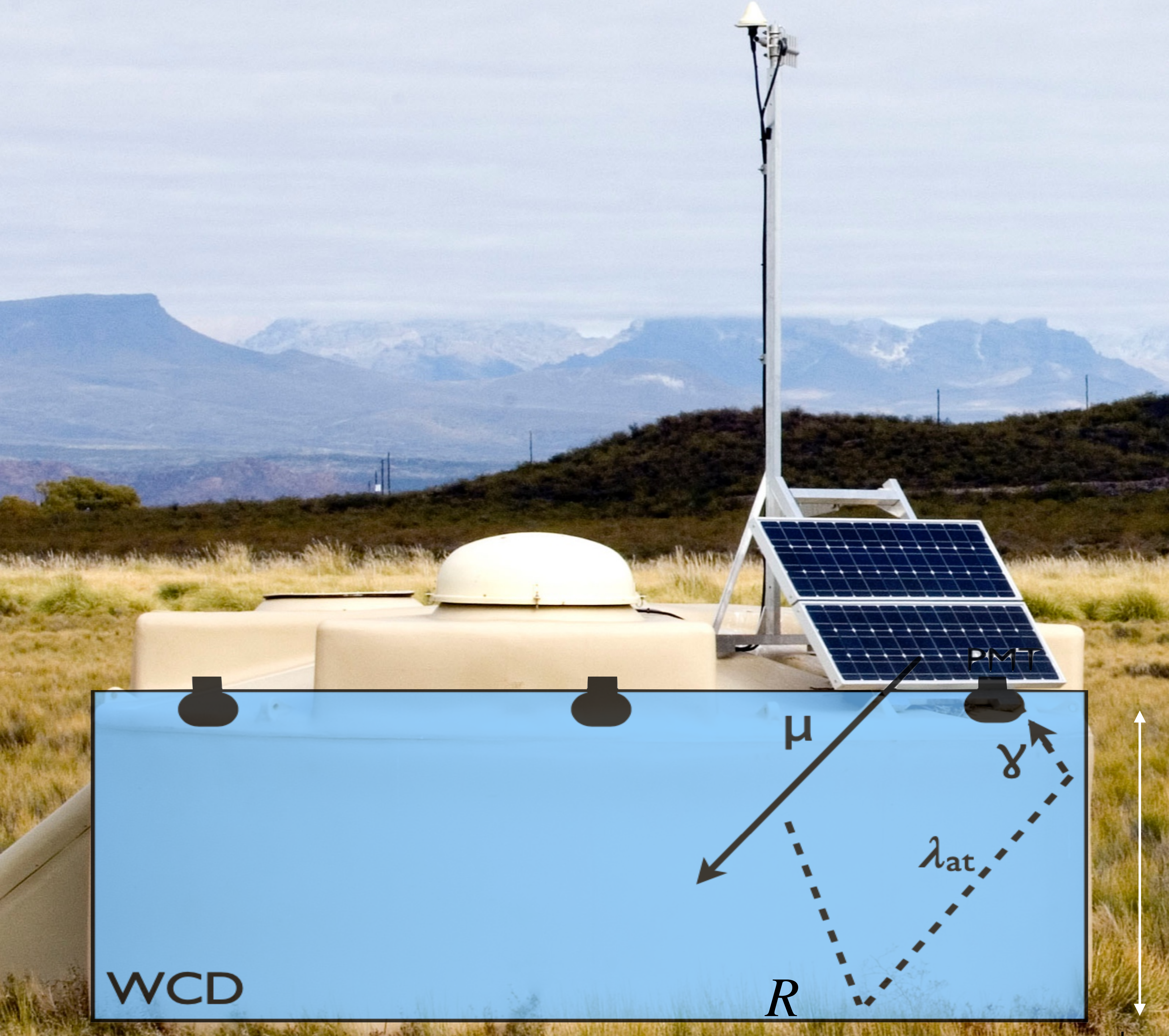
Pierre Auger coll., Phys.Rev.Lett. 126 (2021) 15, 152002

Surface Detector



Fluorescence Detector

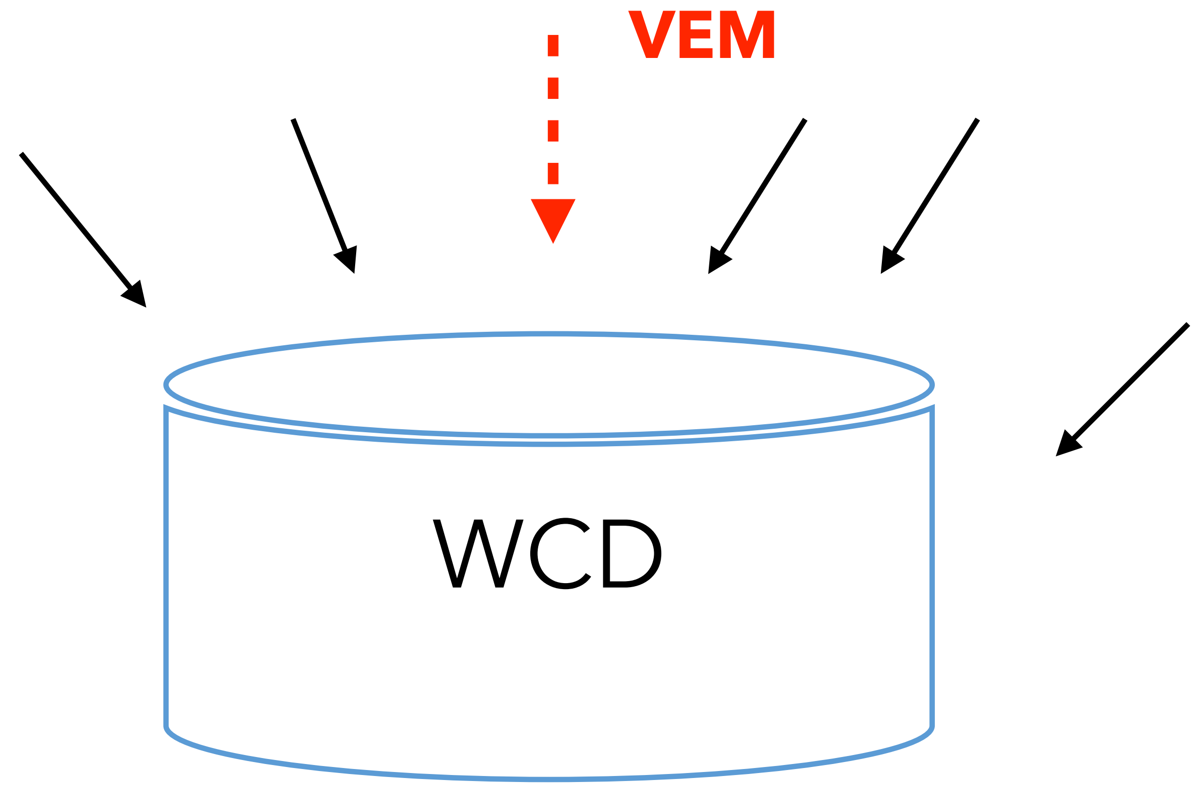
Combination of different measurements **reveals tension between data and all hadronic interaction models**

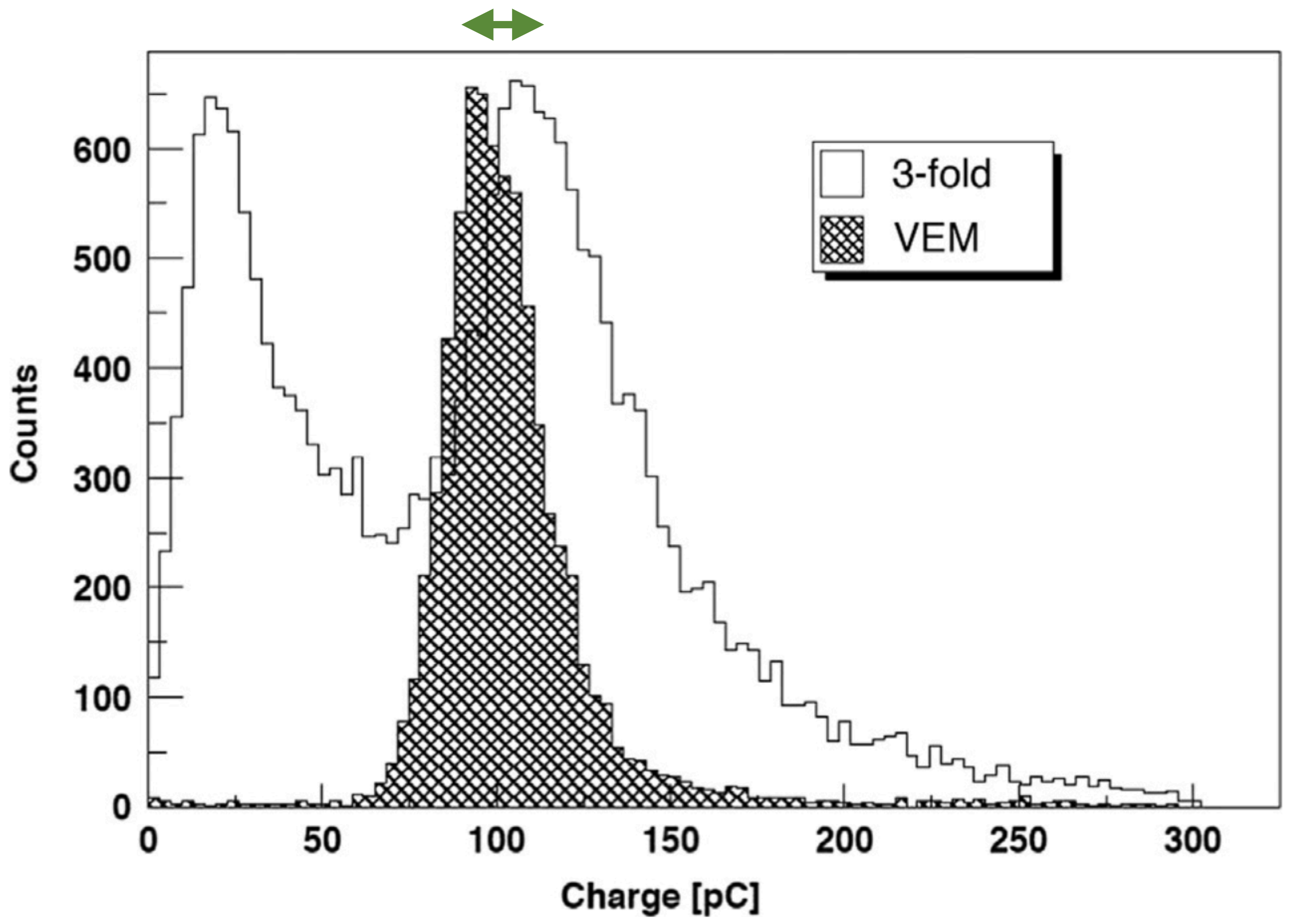


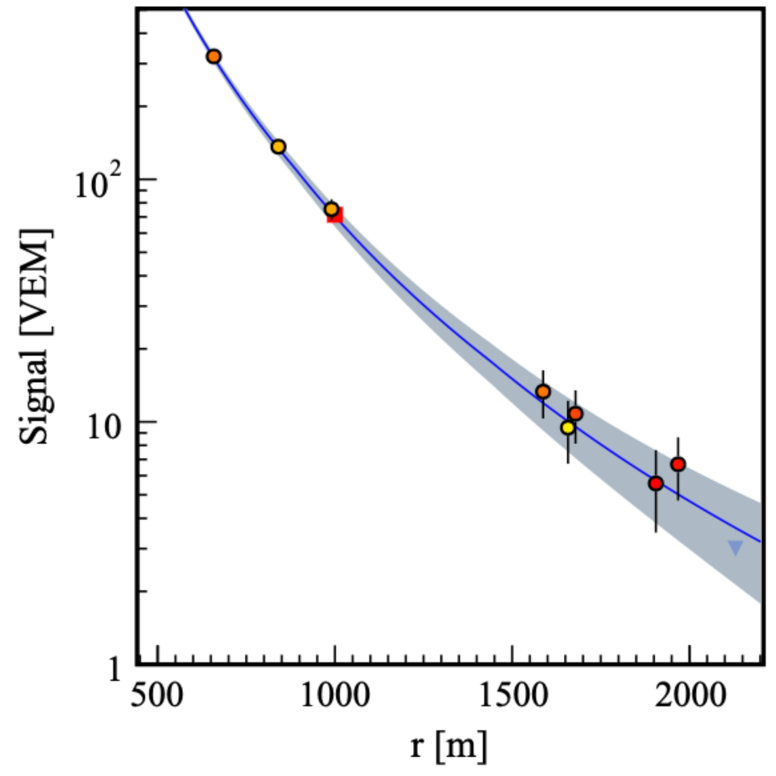
- **Light generation:** Cherenkov yield
- **Light propagation:** attenuation length in water, λ_{at}
- **Light reflection:** Tyvek reflectivity, R
- **Light collection:** PMT geometry, QE
- **Other effects:** water-air transition, ice formation, water level…

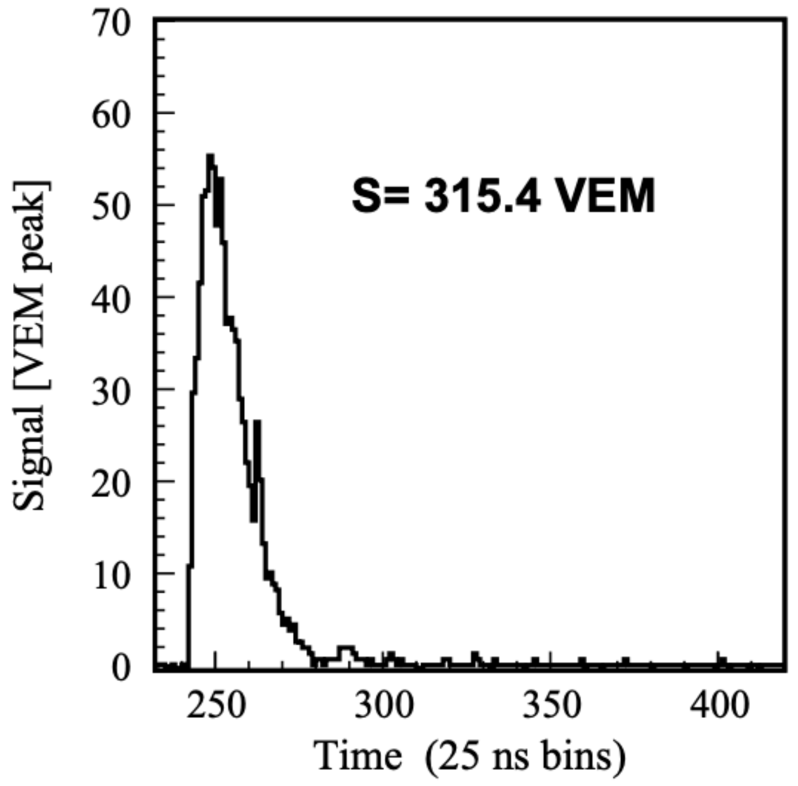
SD calibration (VEM)

Pierre Auger Coll., NIM A 798 (2015) 172

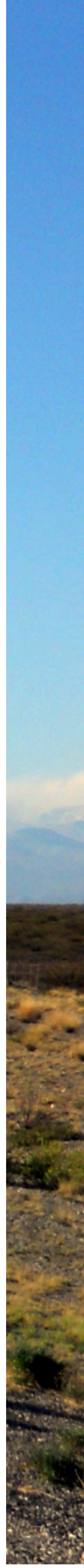








- Use omni-directional atmospheric muons to obtain reference Vertical Equivalent Muon (VEM)



SD calibration (VEM)

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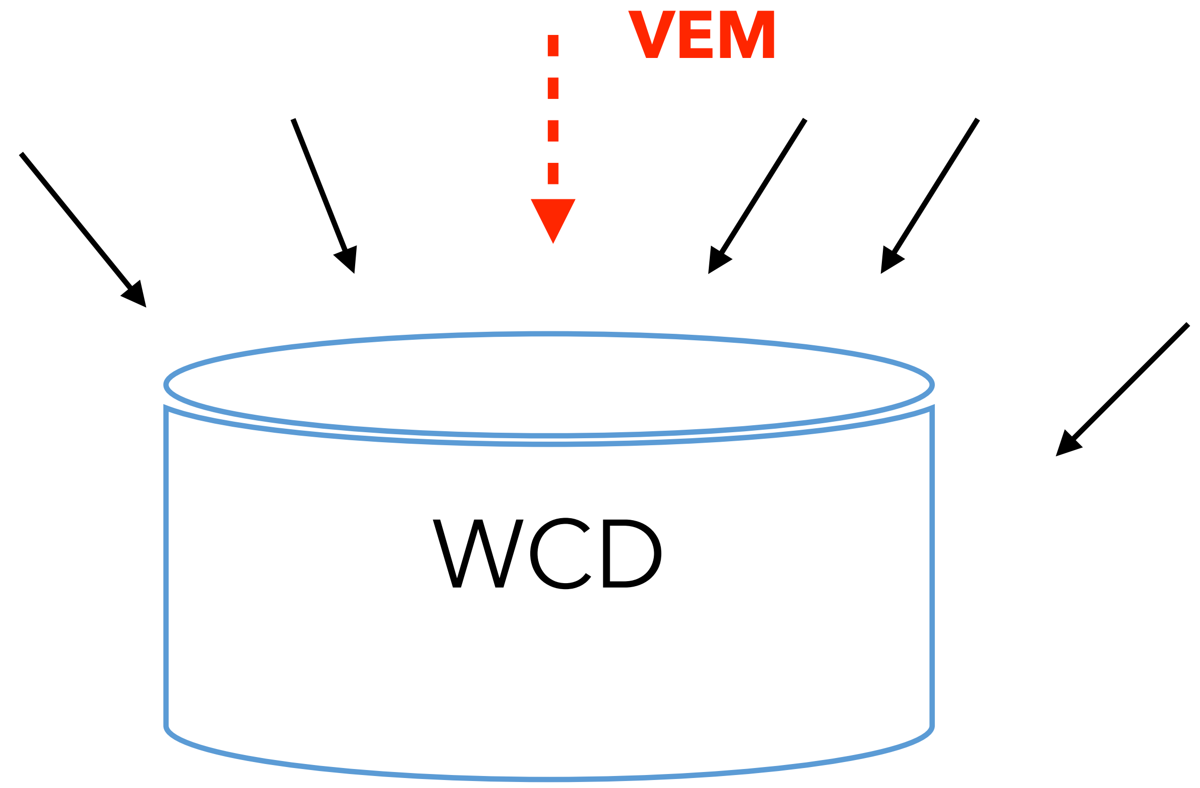
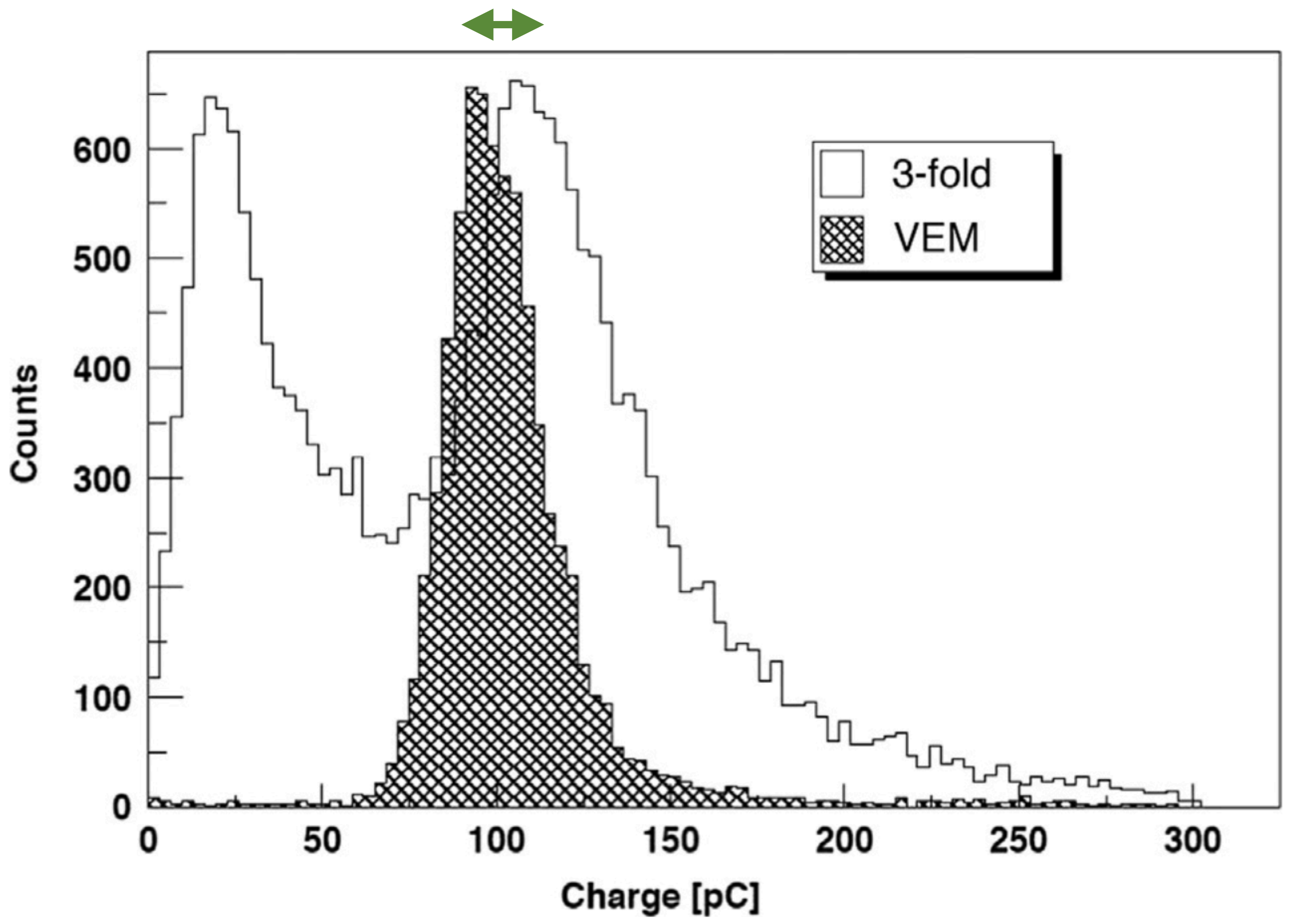
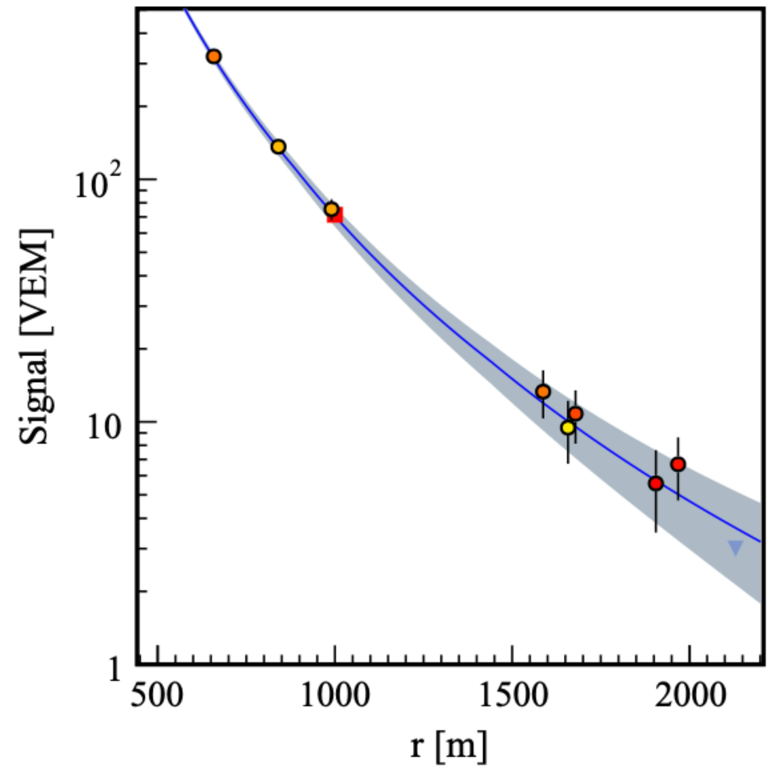
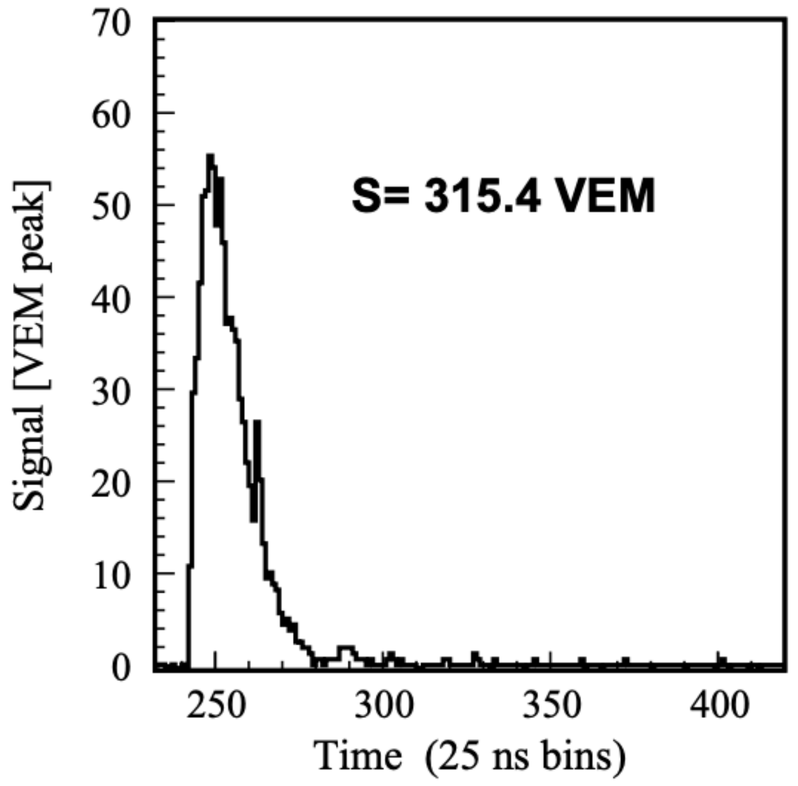
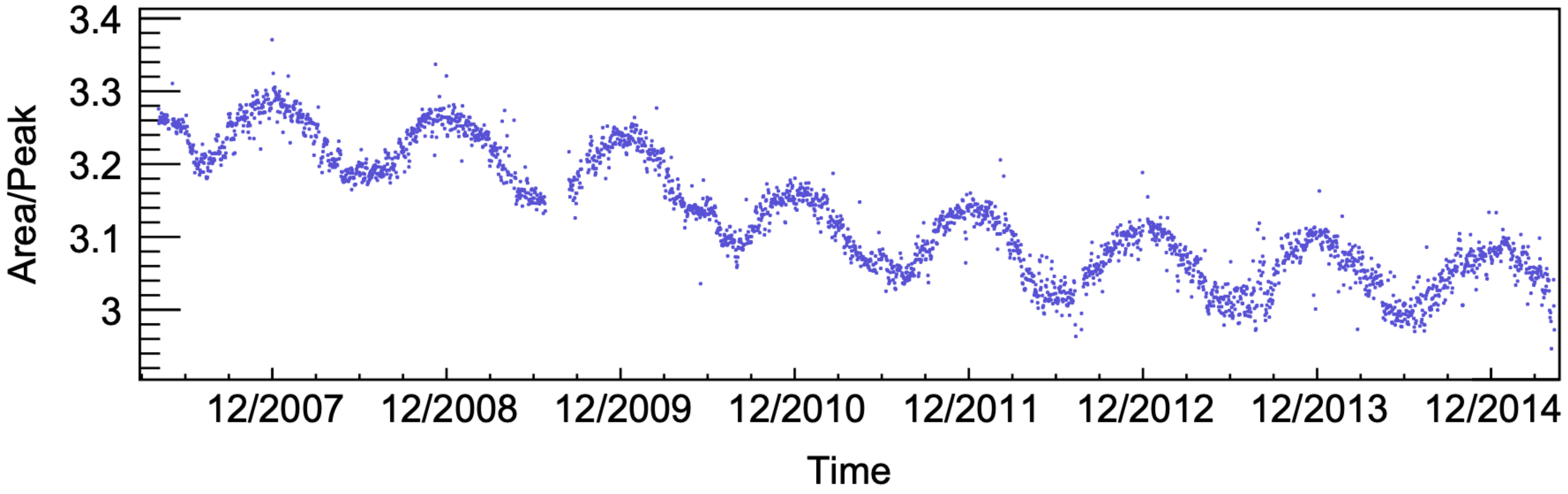


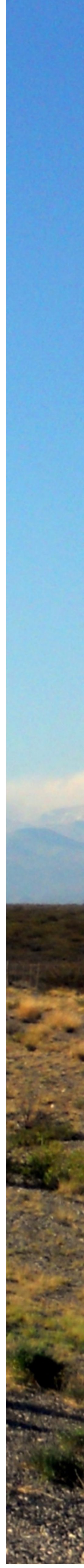






- ✧ Use omni-directional atmospheric muons to obtain reference Vertical Equivalent Muon (VEM)
- ✧ **There are signs that the WCD stations are ageing**
- ✧ Before 2020 it was thought that the systematic uncertainties of the surface detector station alone amounted to $\approx 12\,\%$

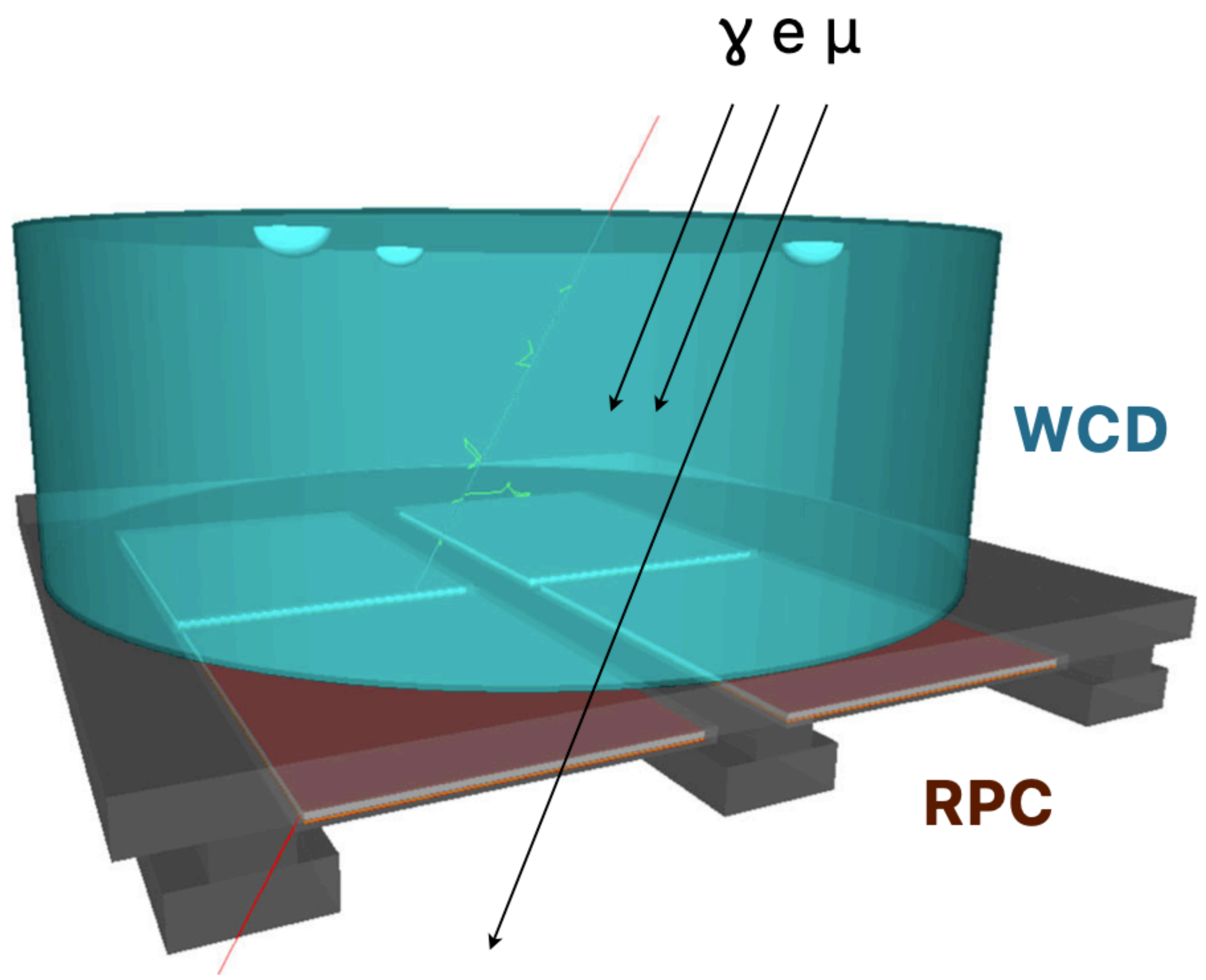


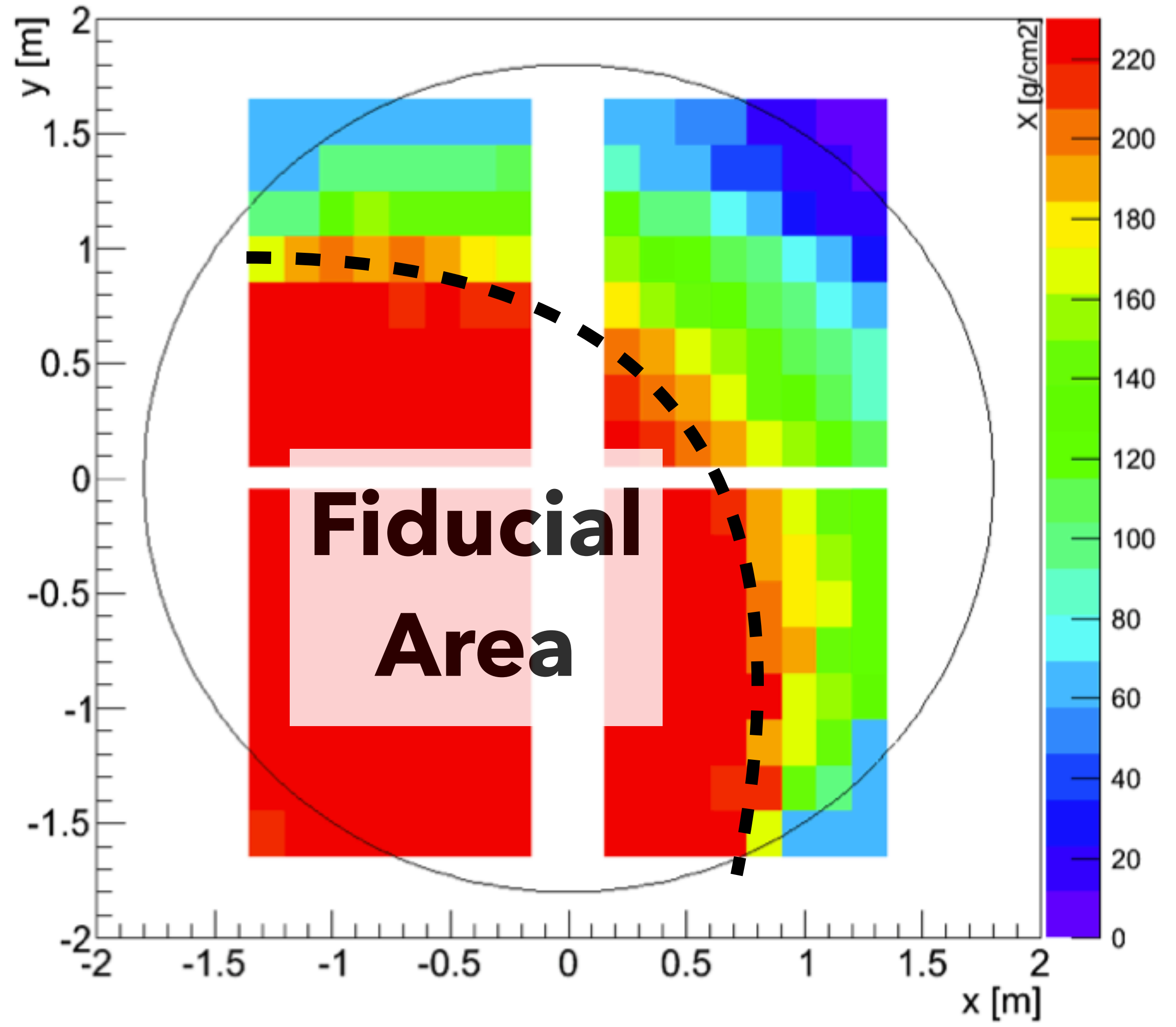


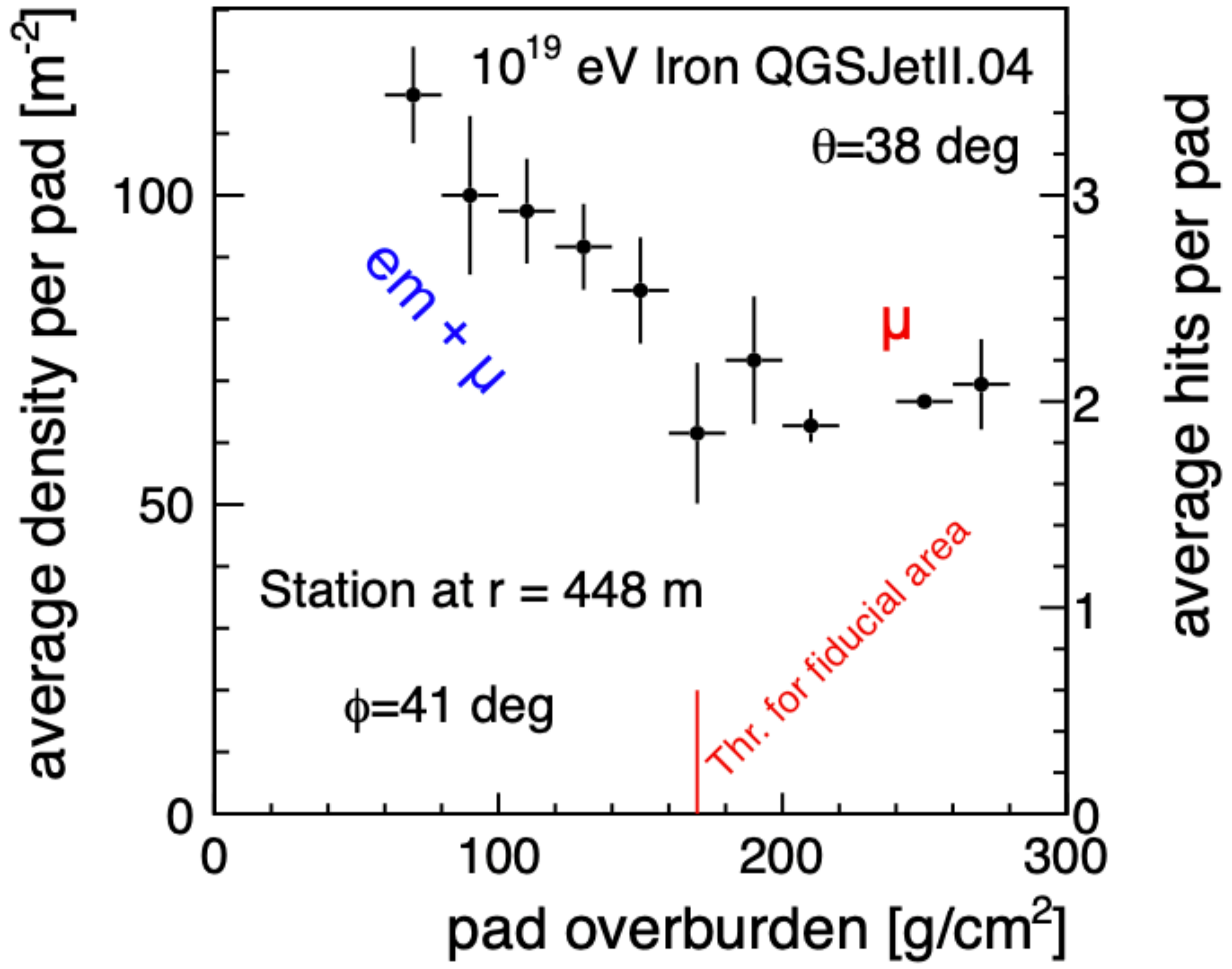
MARTA - Muon Array with RPCs for Tagging Air showers

P. Abreu et al, Eur.Phys.J.C 78 (2018) 4, 333

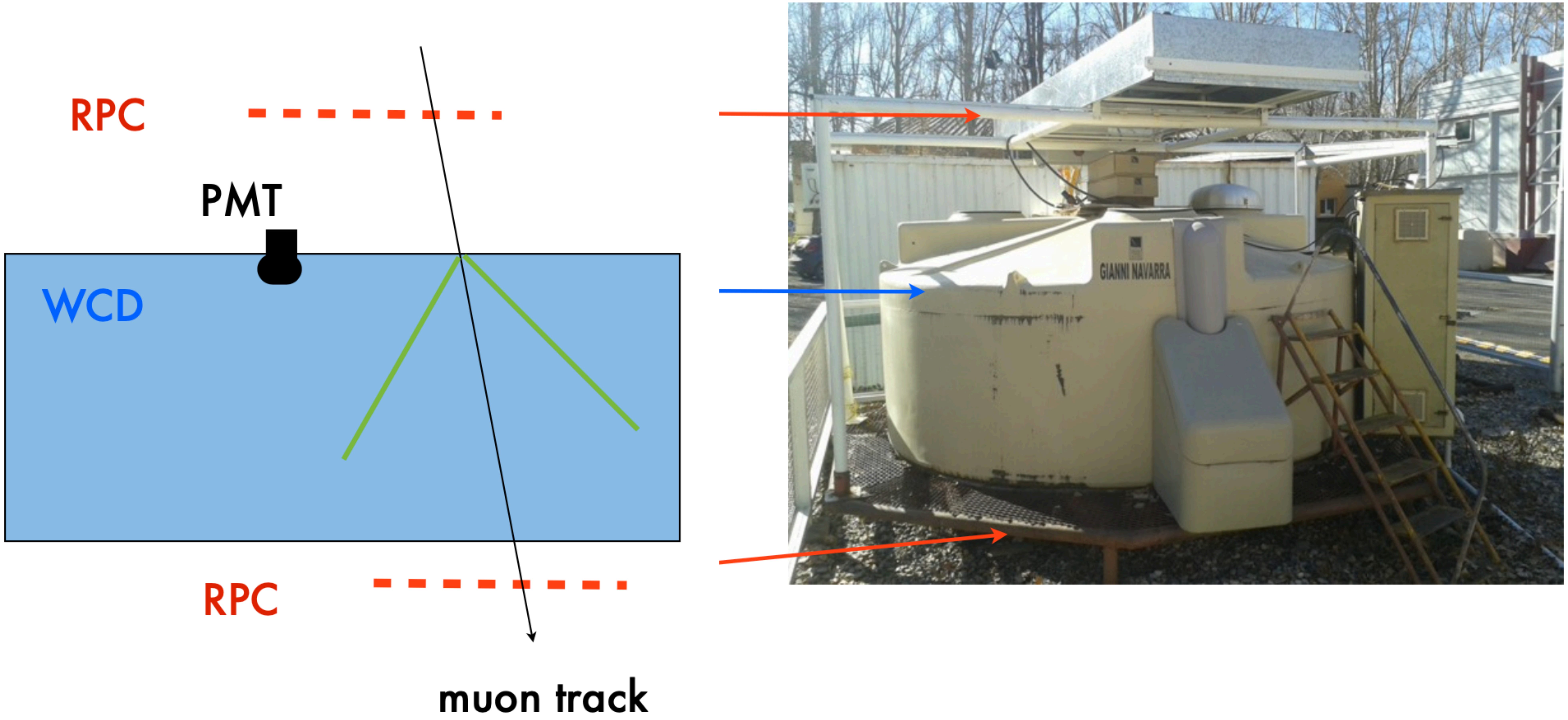
- Combine a water Cherenkov Detector with Resistive Plate Chambers to directly detect the shower muon component
  - Take advantage of the fast timing and segmentation of the RPC





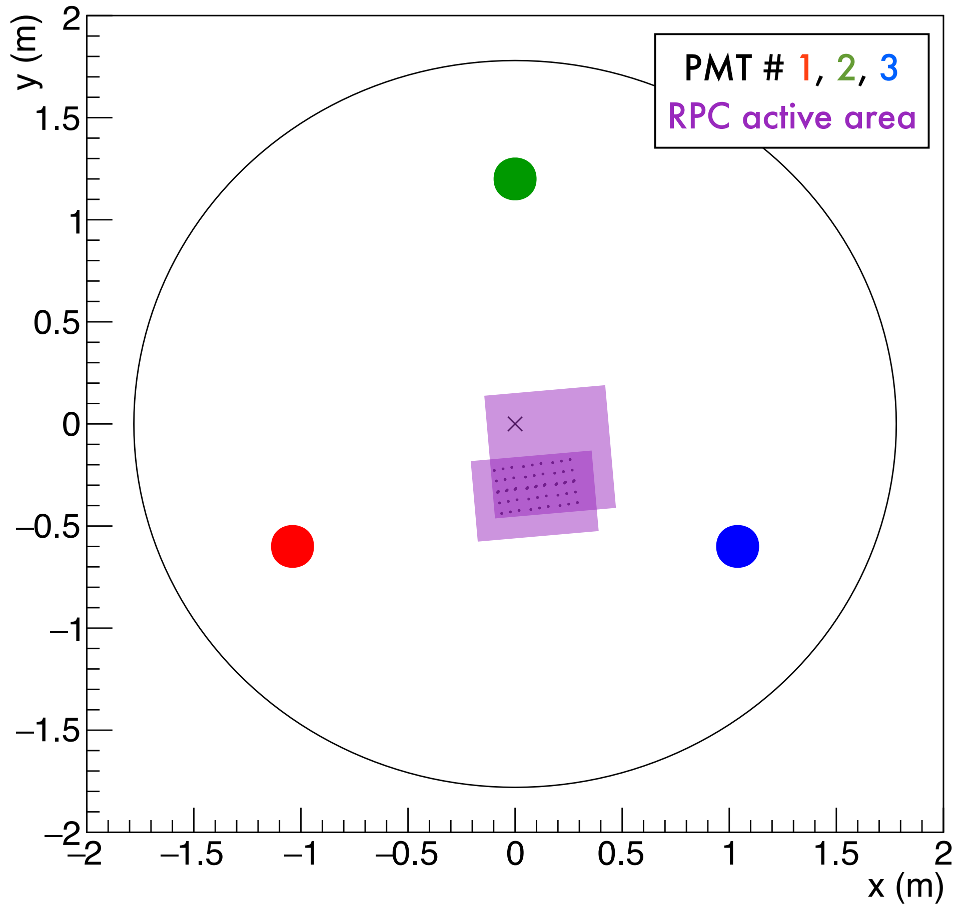


The RPC hodoscope at the Auger test WCD

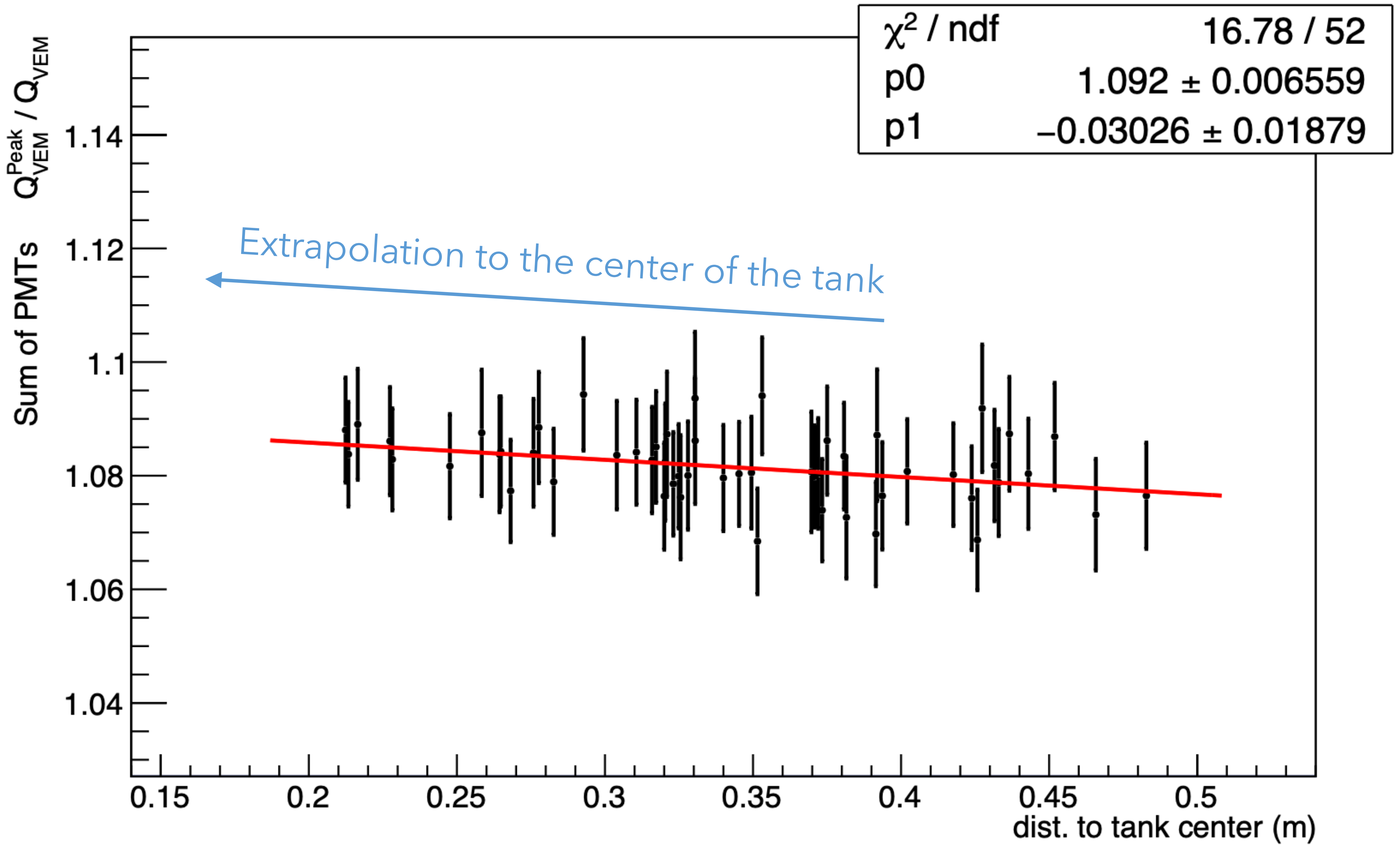


- ✧ Resistive Plate Chambers (RPC): position-sensitive detectors
- ✧ Trigger on atmospheric muons and study the WCD response for selected trajectories

Results: VEM calibration

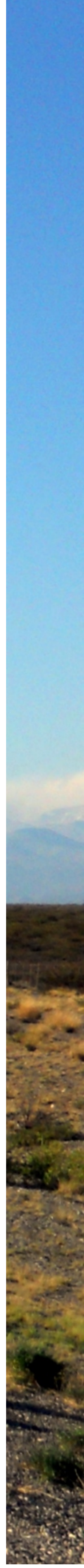


- ✧ Shower *size* in Auger is given in **VEM unit**
  - ✧ The reference is the light detected by the PMTs given the passage a vertical centred muon
  - ✧ The ratio omnidirectional/vertical remains the same for a station with more than **10 years** of operation, i.e., no ageing effects on the calibration



Conversion factor	PMT average	PMT sum
Q^{peak}_{VEM}/Q_{VEM}	1.00 ± 0.02	1.09 ± 0.01
I^{peak}_{VEM}/I_{VEM}	0.92 ± 0.03	

Pierre Auger coll., JINST 15 (2020) 09, P09002



Results: inclined muons

Pierre Auger coll., JINST 15 (2020) 09, P09002

- ✧ WCD signal response for atmospheric muons with inclinations of $\theta \in [20°; 50°]$
- ✧ Simulation able to describe data at the percent level