THE PIERRE AUGER OBSERVATORY RECENT RESULTS

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CBPF — RIO DE JANEIRO

SÃO PAULO SCHOOL ADVANCED SCIENCE ON HIGH ENERGY AND PLASMA ASTROPHYSICS IN THE CTA ERA

HISTORY CHALCATAYA

1947 Discovery of the pion, emulsions chambers exposed in the Pic di Midi, Pirinées

1947 Cesare Lattes take emulsion chambers to Chacaltaya, Bolivia

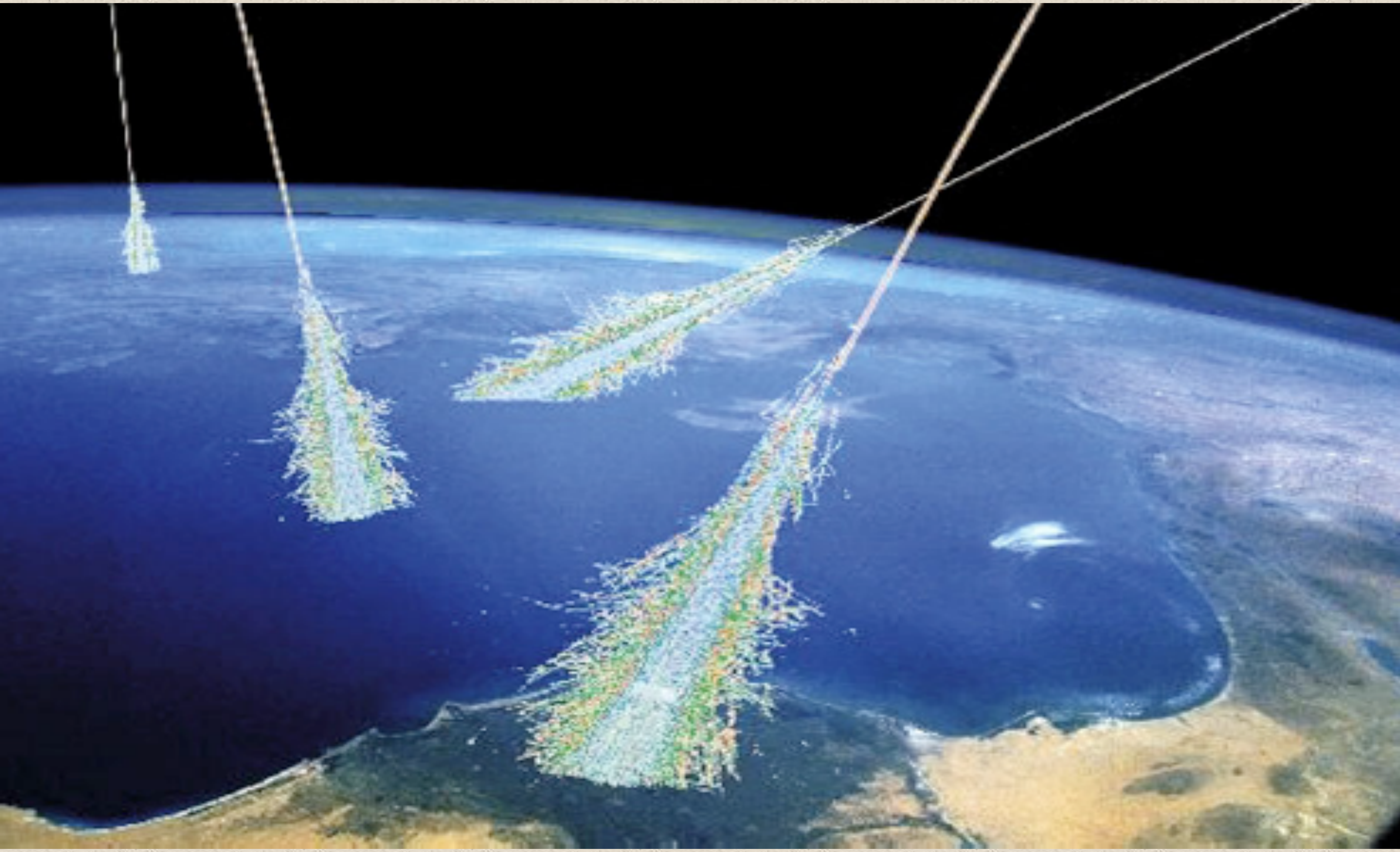
First international Laboratory

Later, in the 60’s Brazil-Japan Collaboration

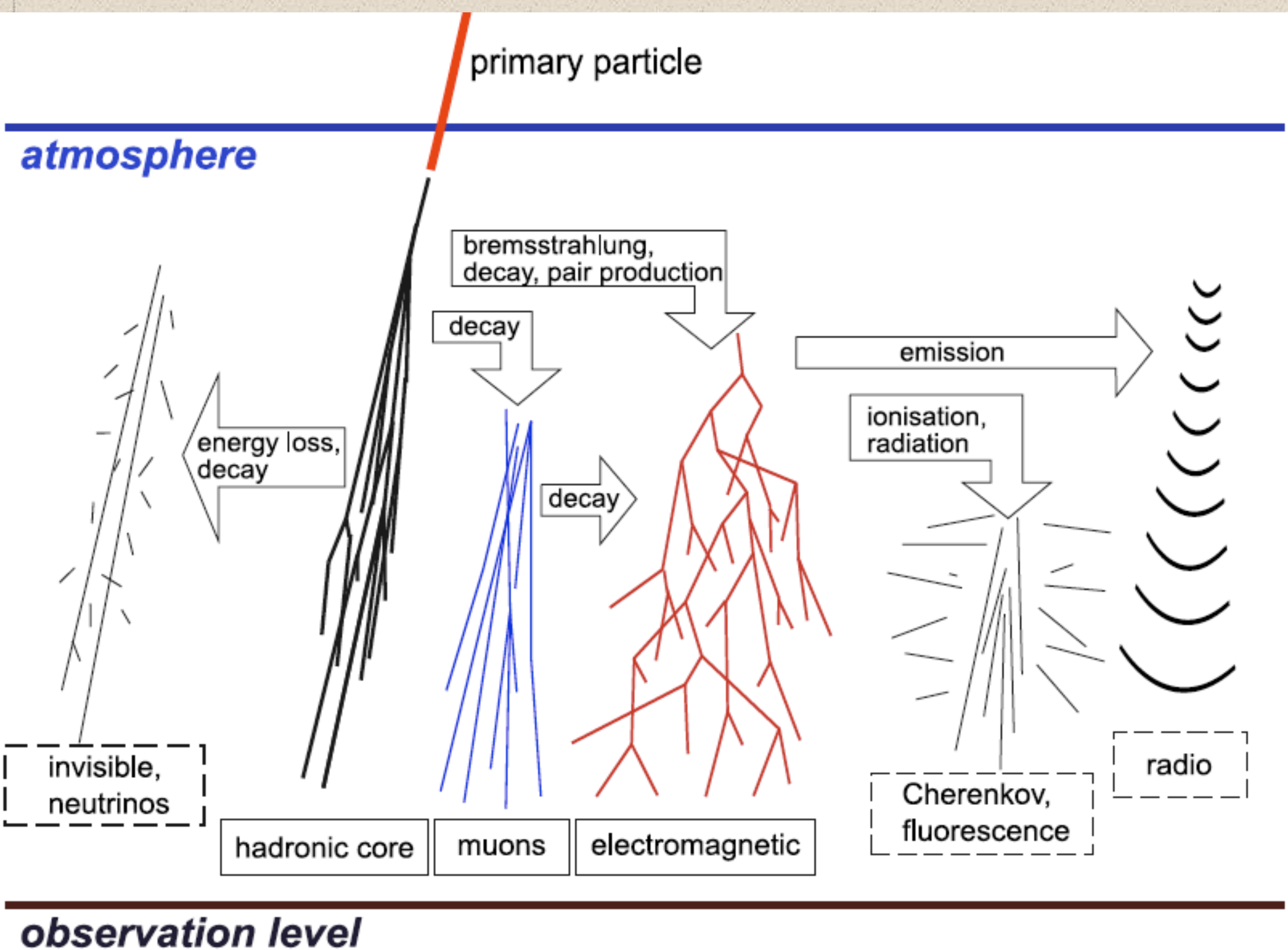
"Death road is over rated :) Chacaltaya is the real deal with LUNA TOURS"

THE PIERRE AUGER OBSERVATORY

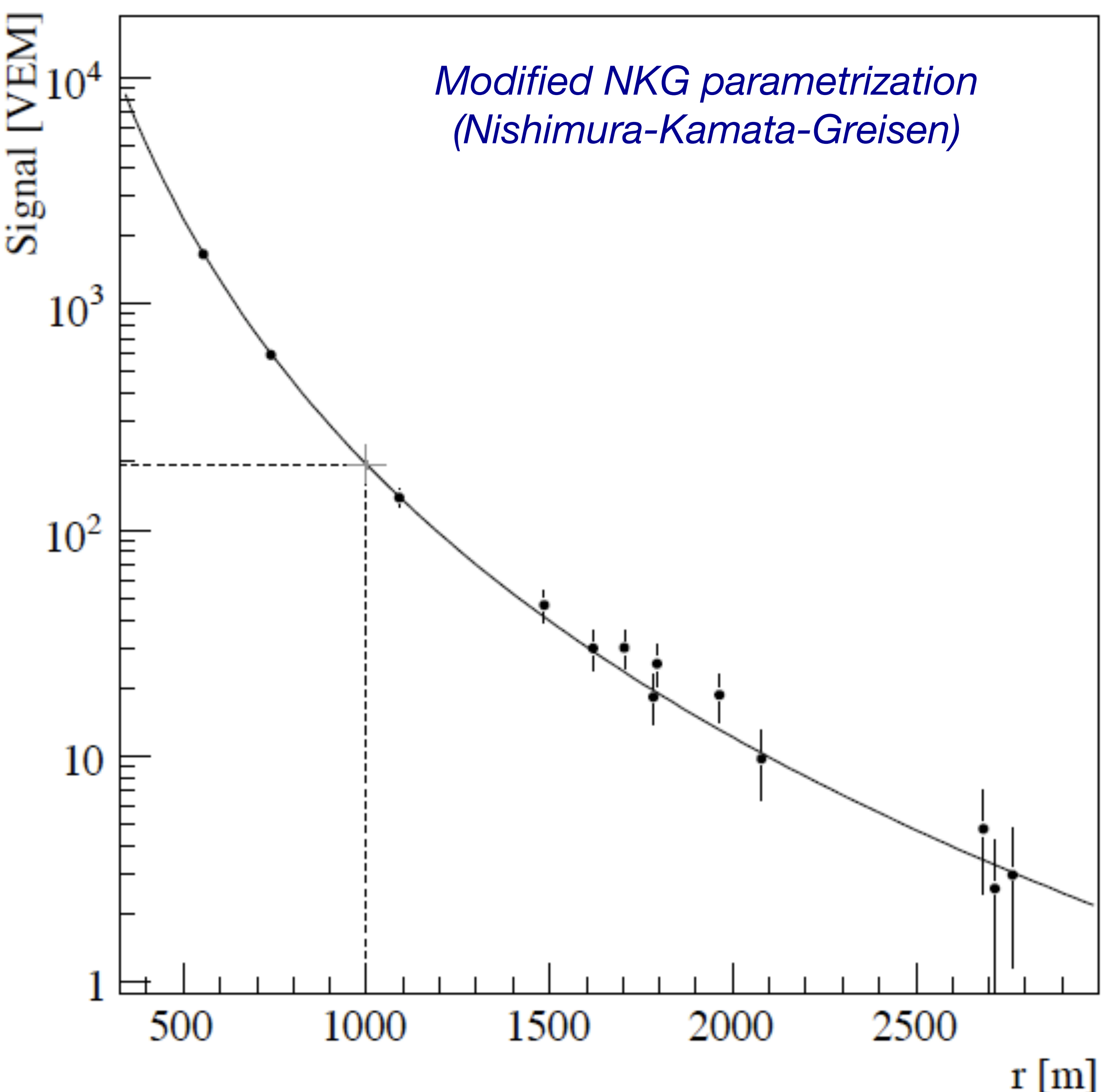
HISTORY OF THE AUGER COLLABORATION

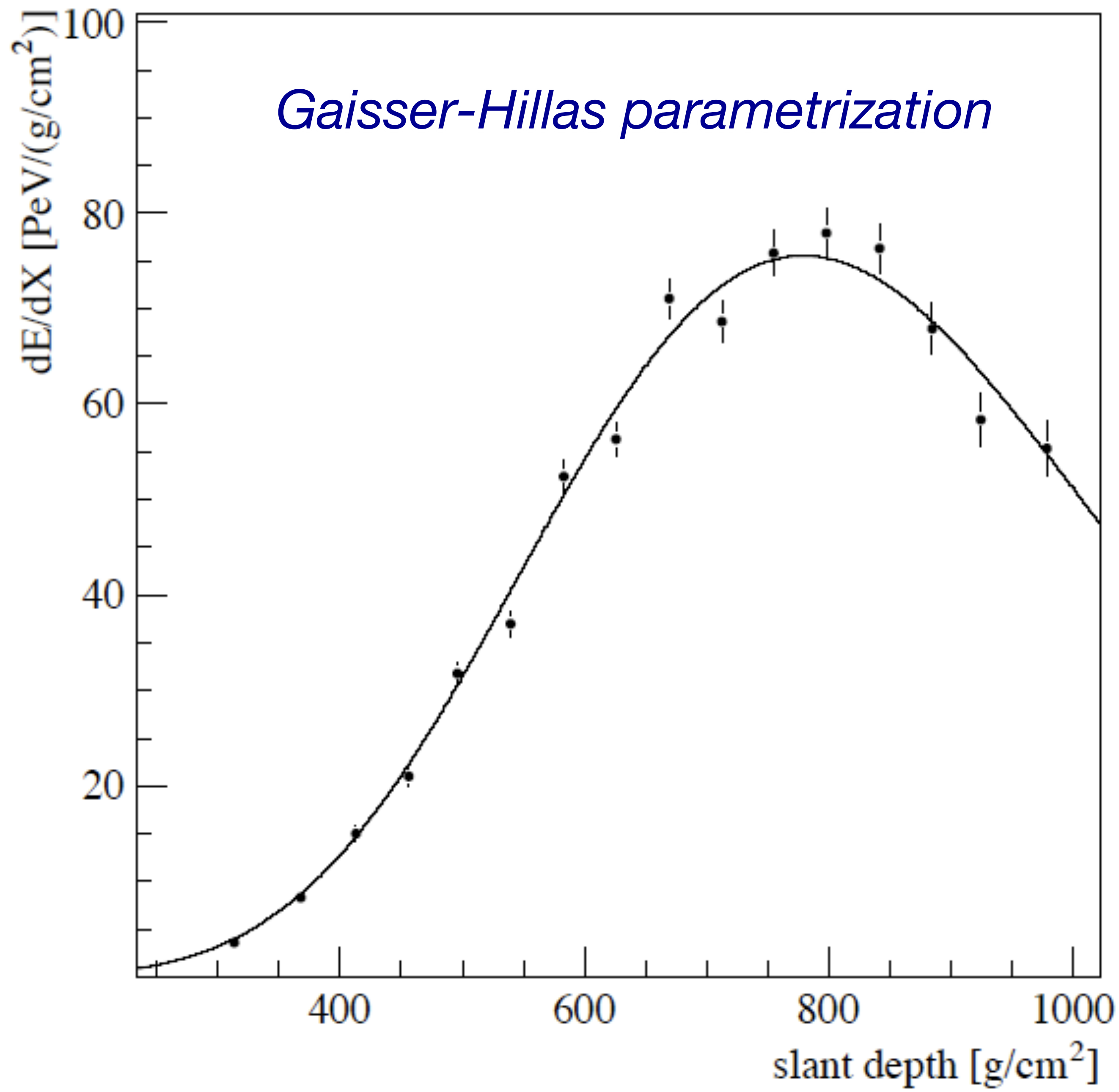


AIR SHOWER


primary particle
atmosphere
bremsstrahlung,
decay, pair production
decay
emission
ionisation,
radiation
energy loss,
decay
decay
invisible,
neutrinos
hadronic core
muons
electromagnetic
Cherenkov,
fluorescence
radio
observation level

AIR SHOWER



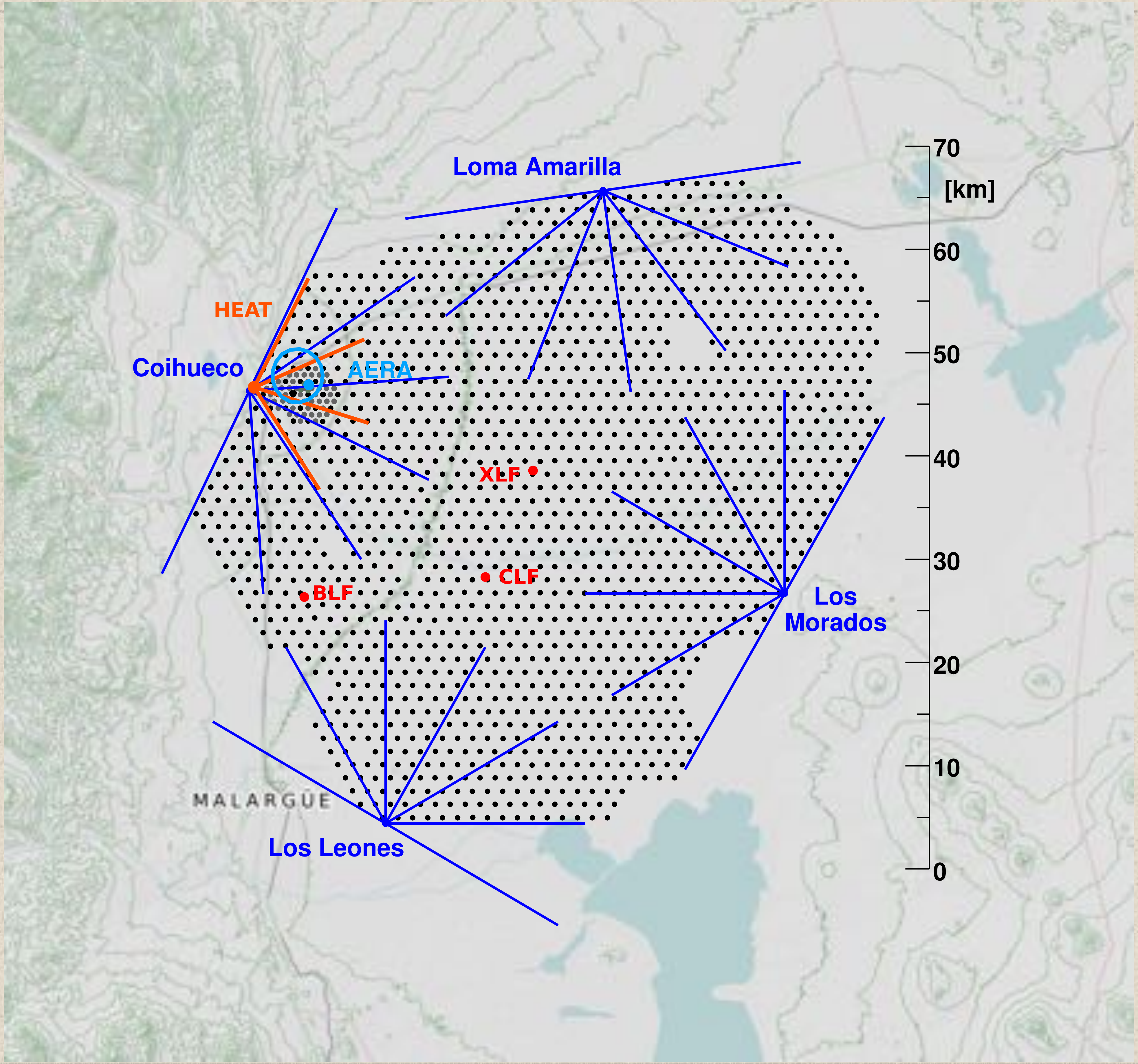


$$S(r) = S_0 \left(\frac{r}{r_s}\right) \left(1 + \frac{r}{r_s}\right)^{-\beta}$$

$$\beta = 3.3 - 0.9 \sec\theta$$

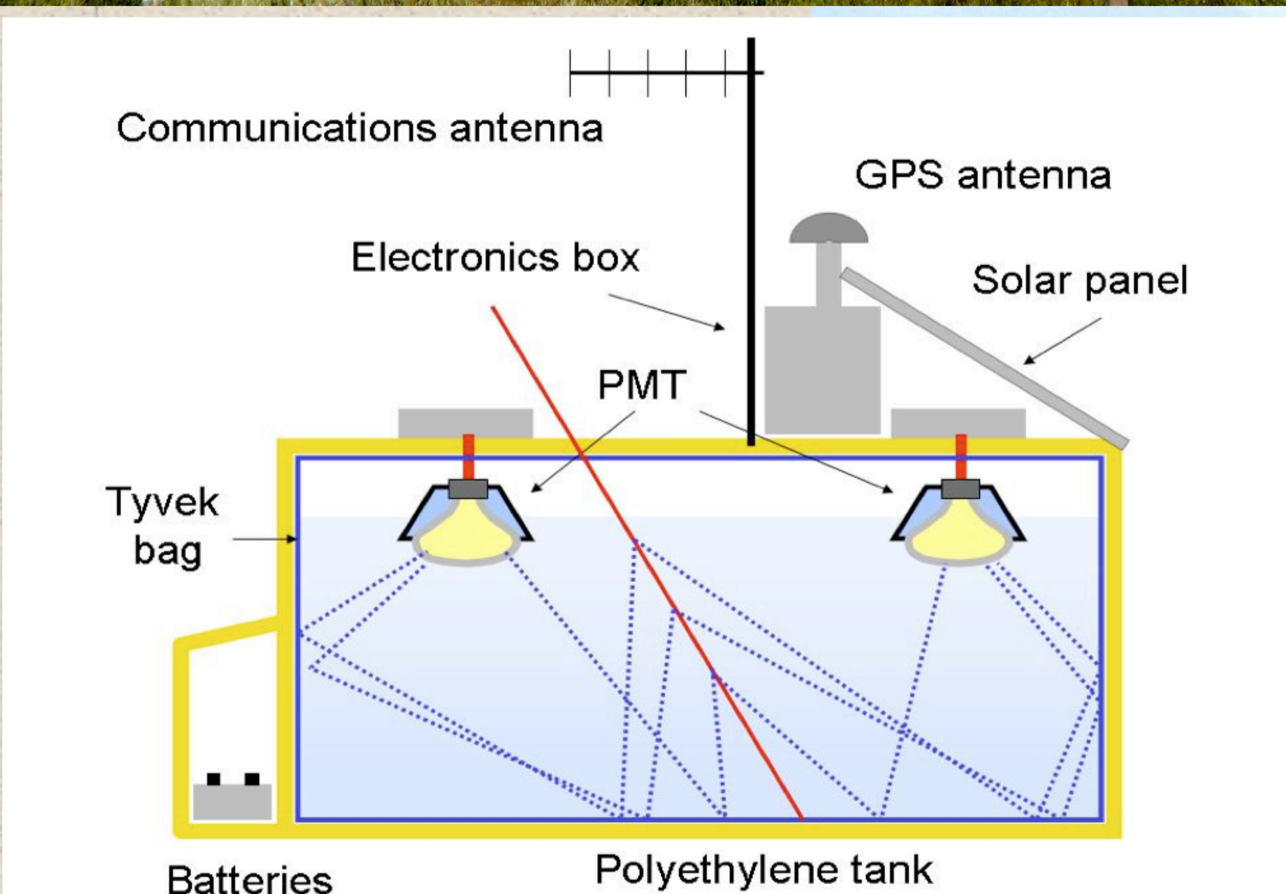
$$N(X) = N_{max} \cdot \left(\frac{X - X_0}{X_{max} - X_0}\right)^{(X - X_0)/\lambda} e^{(X_{max} - X)/\lambda}$$

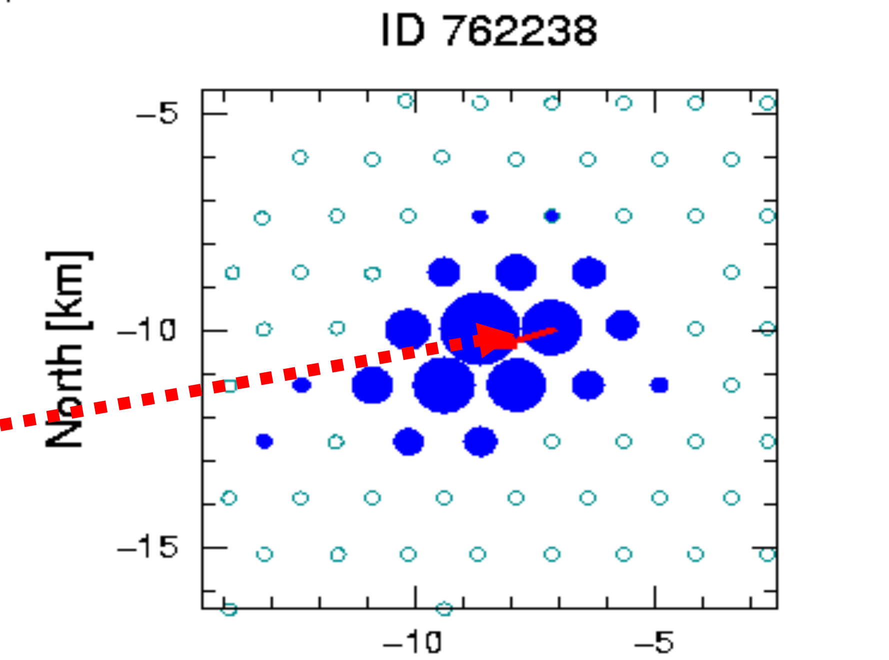
MENDOZA
Villa Nueva
Godoy Cruz
Las Heras
Maipú
Chapanay
Luján de Cuyo
Costa de Araujo
Lavalle
Arroyito
Desaguadero
Potrerillos
Cachueta
Polvaredas
Punta de Vacas
Puente del Inca
Portillo
Agrelo
Ugarteche
Junín
Medrano
Sta. Rosa
Las Catitas
La Dormida
Alto Pencoso
La Paz
Maquinista Levet
Mosmota
San José
Tupungato
Dique El Carrizal
Zapata
Tunuyán
1124
Loma Negra Gde.
Vista Flores
La Consulta
San Carlos
Chilecito
Pareditas
R.E. Ñacuñán
Ñacuñán
Gmte. Salas
Travesía de Tunuyán
MENDOZA
Peñas
A. Villanueva
Sta. Elena
Fuerte San Rafael
Guadales
Diamante
San Rafael
Monte Comán
25 de Mayo
Las Paredes
Salto Rosas
Real del Padre
Rincón del Atuel
Va. Atuel
Pampa del Diamante
Las Malvinas
Gral. Alvear
Bowen
Soitué
El Nihuil
Carmensa
El Sosneado
Los Molles
Malargüe
1752
Co. Peceño
3810
Co. Nevado
Punta del Agua
Co. Toscoso
Fortín Malal-Hue
2685
Co. Tronquimalal
Ea. Arroyo Hondo
Vol. Overo
5189
Co. Sosneado
2354
Pozo de las Animas
Dique Agua del Toro
SANTIAGO
PUENTE ALTO
S. BERNARDO
MAIPU
TALAGANTE
S. José de Maipo
Buin
Paine
MELIPILLA
METROPOLITANA
REGIÓN
COLINA
Lampa
Tiltil
La Parva
Farellones
Nev. El Plomo
6050
LOS ANDES
Co. Juncal
P.Prov. Vol. Tupungato
6570
Co. Tupungato
Co. Tupungatito
5682
Vol. San José
5856
M.N. El Morado
Vol. Maipú
5323
S. Fco. de Mostazal
Sewell
Graneros
CACHAPOAL
RANCAGUA
Coya
Requinoa
Rengo
Co. Yeso
4008
Peumo
Marchihue
SAN FERNANDO
Chimbarongo
COLCHAGUA
4300
Vol. Tinguiririca
Termas del Flaco
Las Leñas
Rio Malo
Po. del Planchón
Vol. Peteroa
4090
4049
CURICÓ
Molina
Teno
Lontué
Hualañé
TALCA
S. Clemente
3830
Vol. Descabezado
Colbún
Armerillo
Las Garzas
S. Javier
Maule
Nirivilo
Curepto
Va. Prat
Gualleco
Putú
Licantén
Iloca
Vichuquén
R.N. Lag. de Torca
Lolol
Paredones
Peralillo
Sta. Cruz
CARDENAL CARO
PICHILEMU
de Lobos
La Estrella
Litueche
Navidad
Rapel
2281
S. Pedro
Bucalemu
SAN ANTONIO
Sto. Domingo
Cartagena
El Tabo
El Quisco
Algarrobo
Curacaví
Casablanca
VALPARAÍSO
Viña del Mar
Quilpue
Limache
Concón
QUILLOTA
Quintero
La Calera
Horcón
Zapallar
Nogales
Llay-Llay
SAN FELIPE
Putaendo
LOS ANDES
R. Blanco
6960
3452
2232
Emb. Peñuelas
Curaumilla
Pampa de la Va
RN-7
RN-40
RN-143

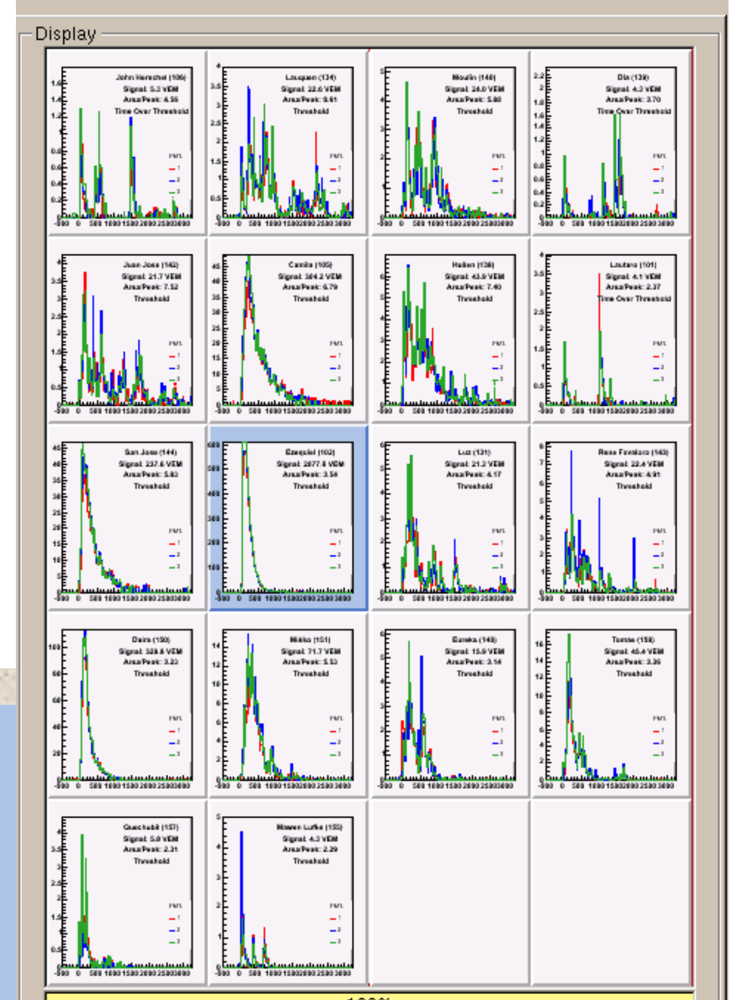


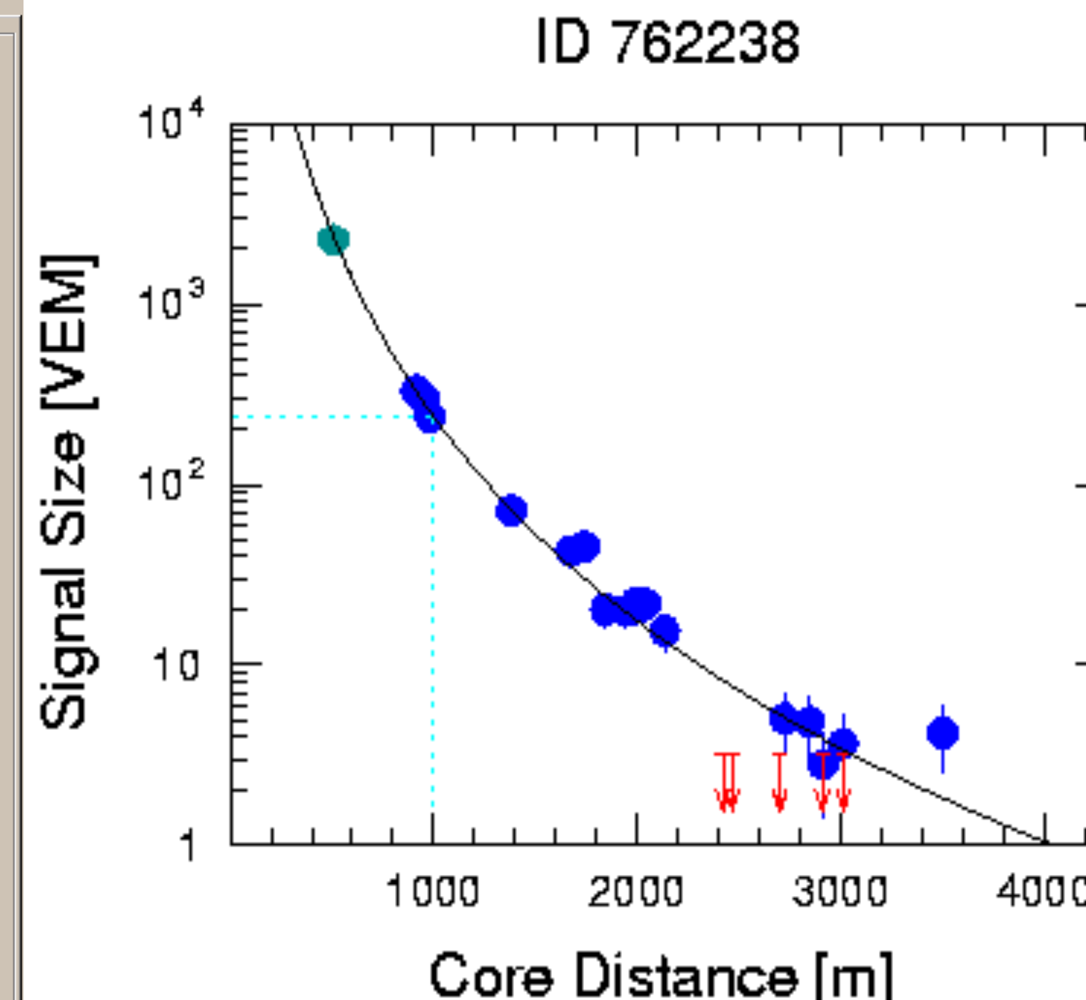
Loma Amarilla
70
[km]
60
50
40
30
20
10
0
HEAT
Coihueco
AERA
XLF
CLF
BLF
Los
Morados
MALARGÜE
Los Leones

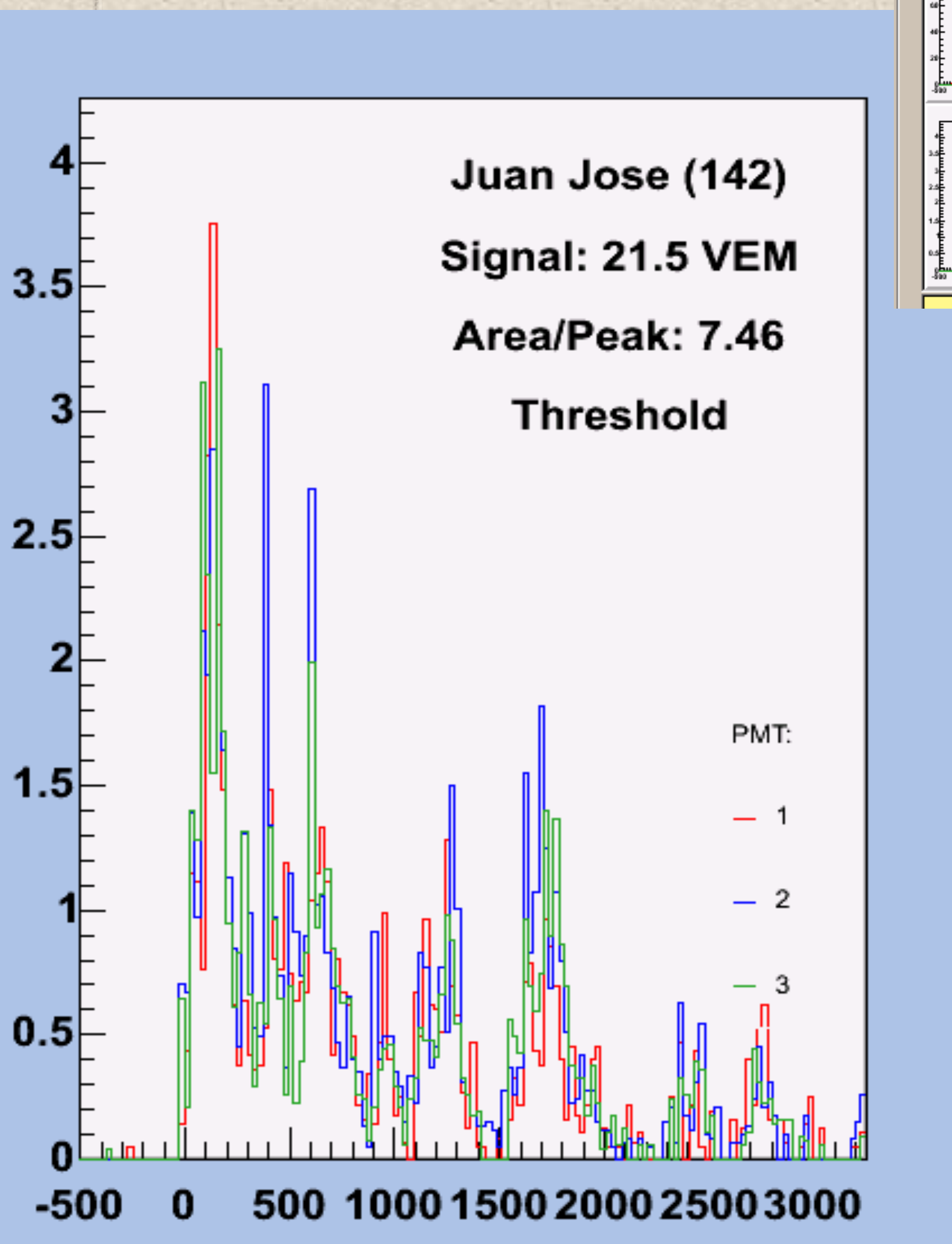

First Auger Tank (2003)
Priscilla

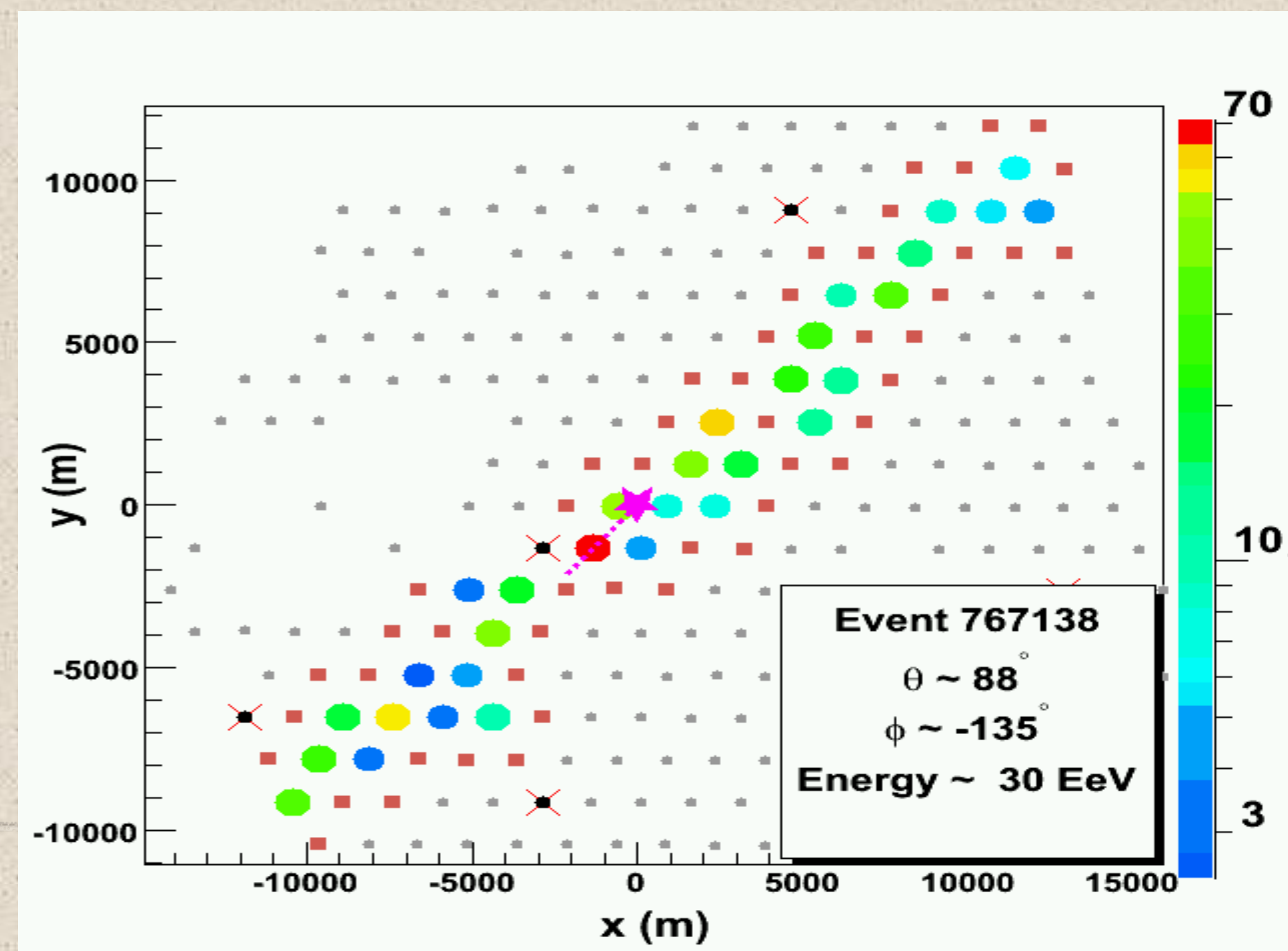

Communications antenna
GPS antenna
Electronics box
Solar panel
PMT
Tyvek bag
Batteries
Polyethylene tank


ID 762238
North [km]
−5
−10
−15
−10
−5

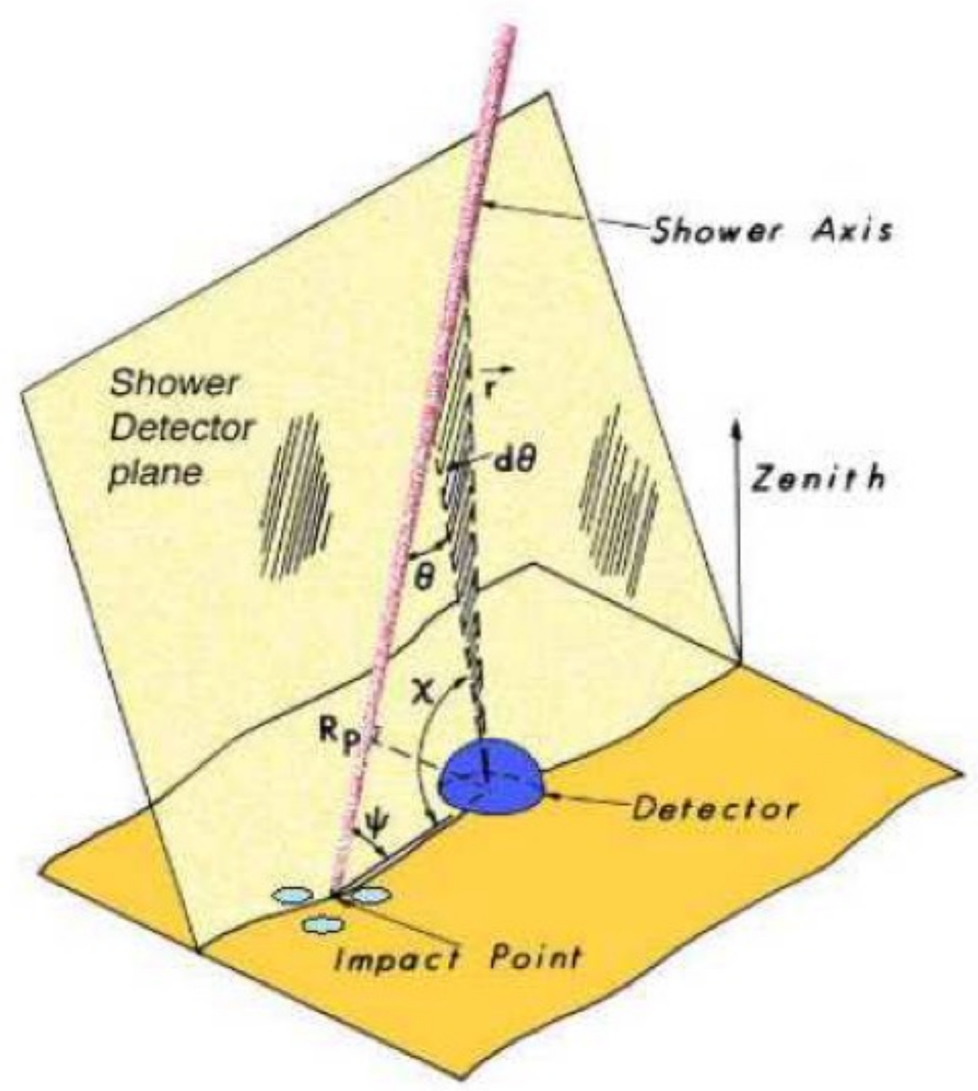

Display

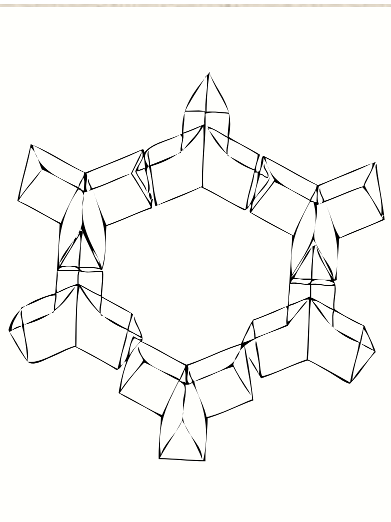

ID 762238
Signal Size [VEM]
10^4
10^3
10^2
10
1
1000
2000
3000
4000
Core Distance [m]


Juan Jose (142)
Signal: 21.5 VEM
Area/Peak: 7.46
Threshold
PMT:
1
2
3
4
3.5
3
2.5
2
1.5
1
0.5
0
-500
0
500
1000
1500
2000
2500
3000

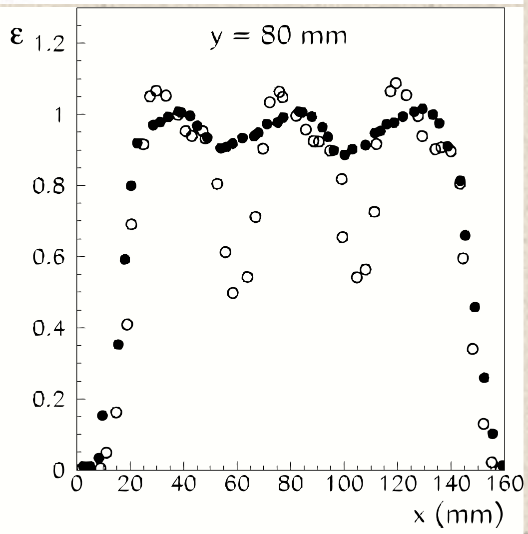

Event 767138
θ ~ 88°
ϕ ~ -135°
Energy ~ 30 EeV
70
10
3
y (m)
10000
5000
0
-5000
-10000
x (m)
-10000
-5000
0
5000
10000
15000

FLUORESCENCE DETECTOR

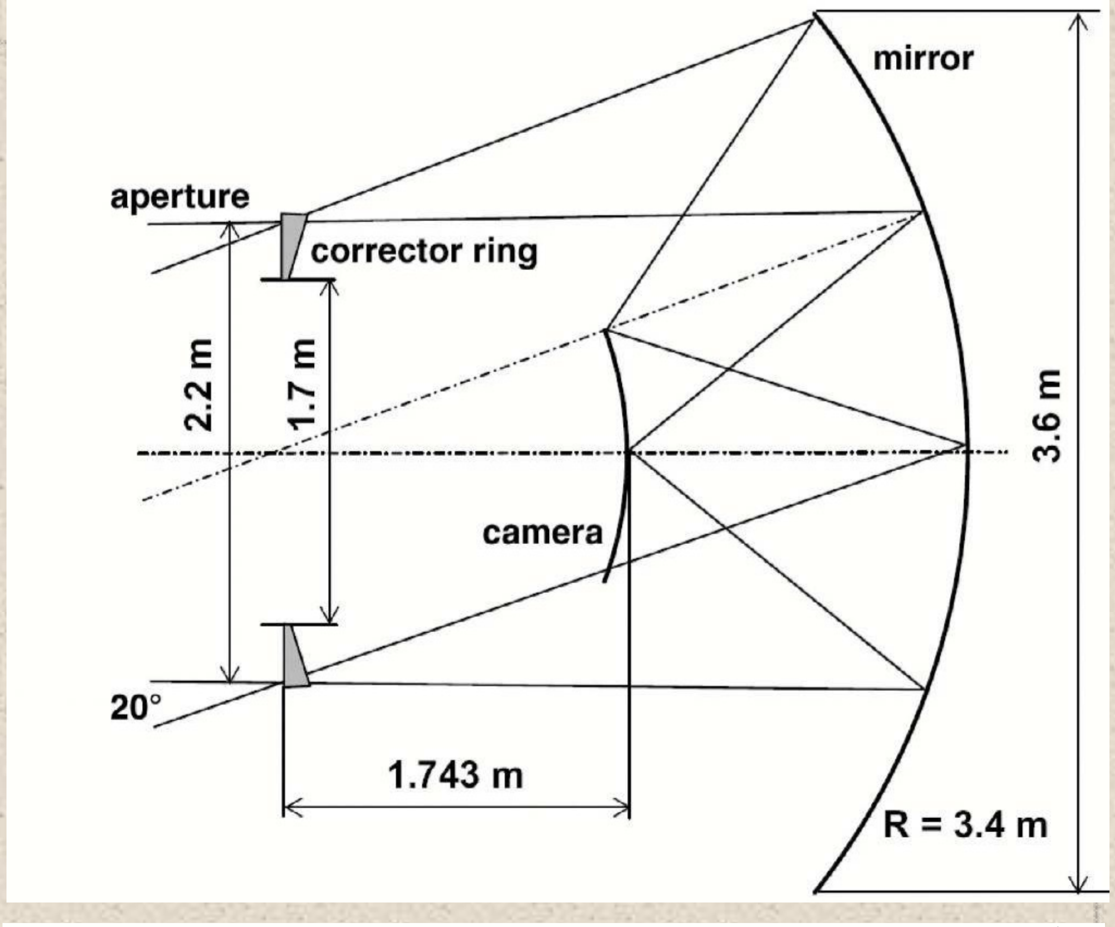


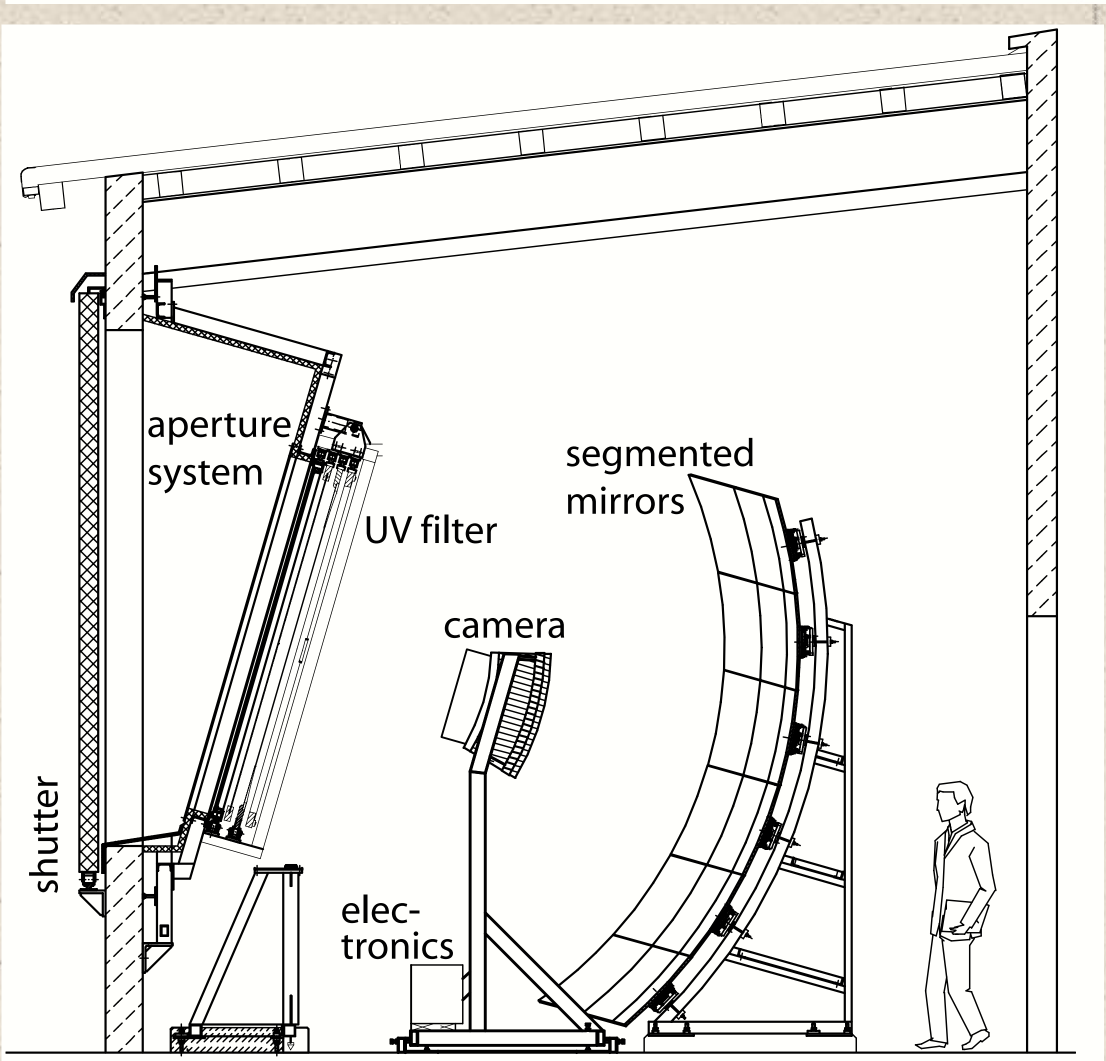


a)

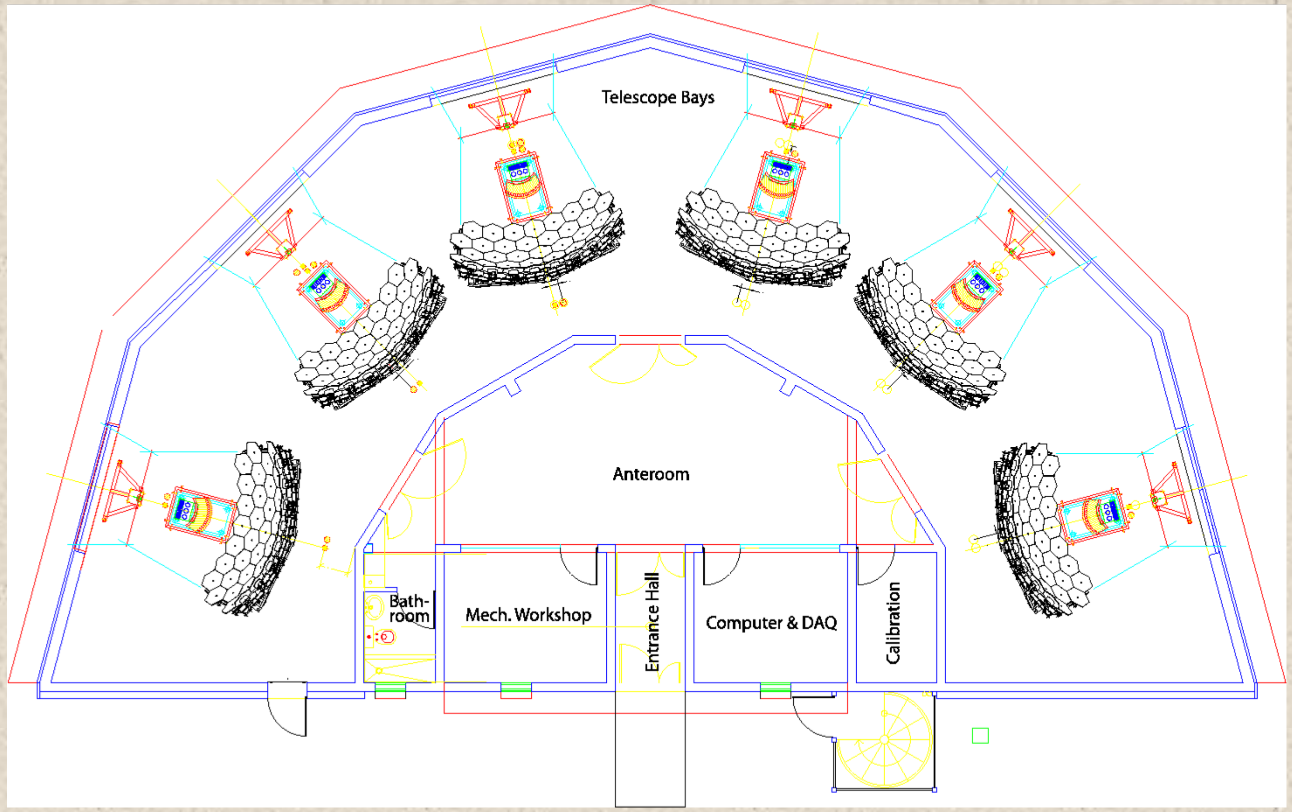


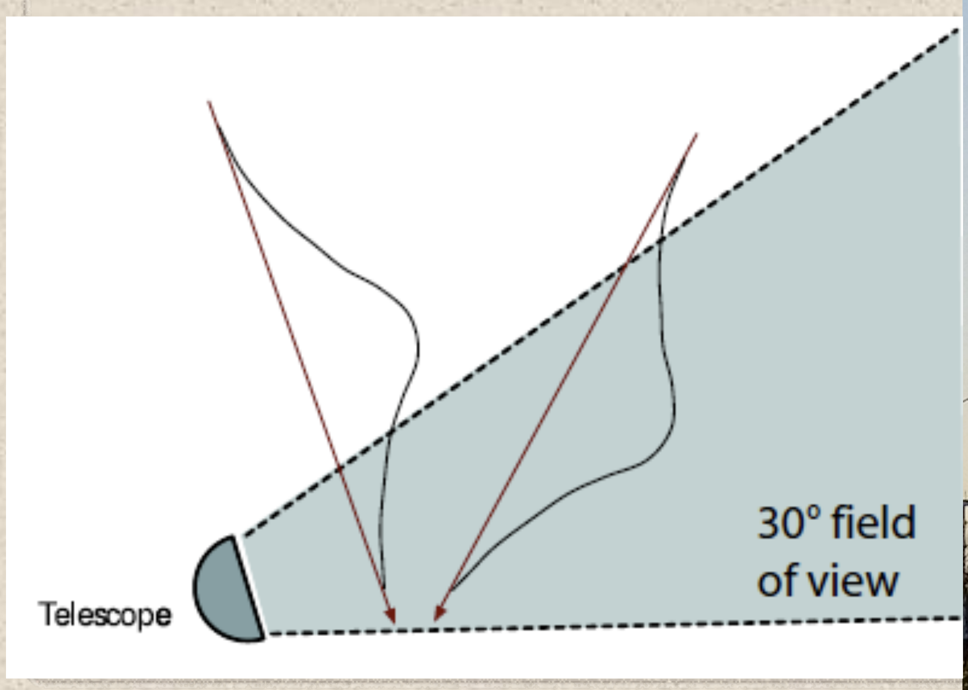
b)

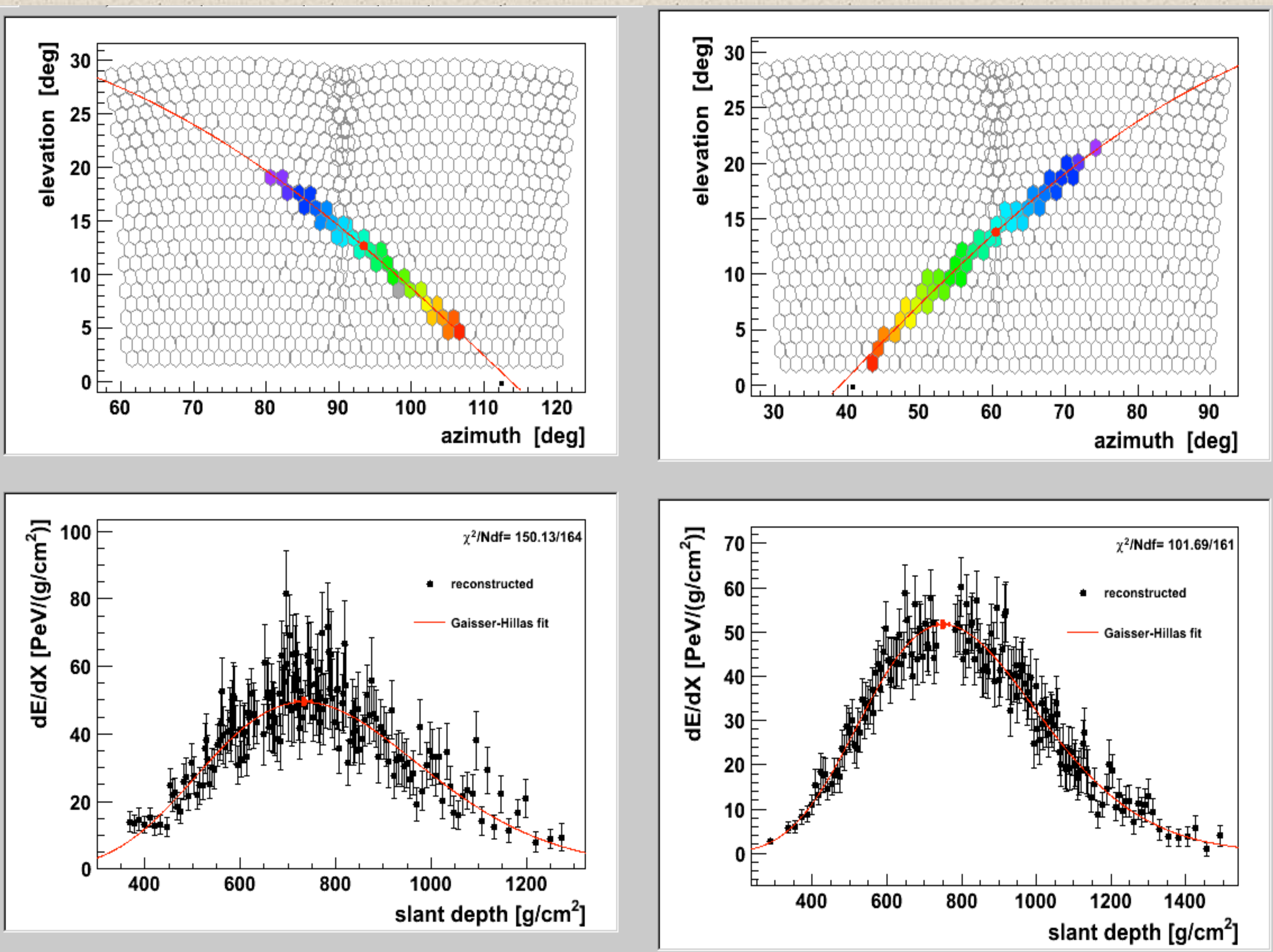




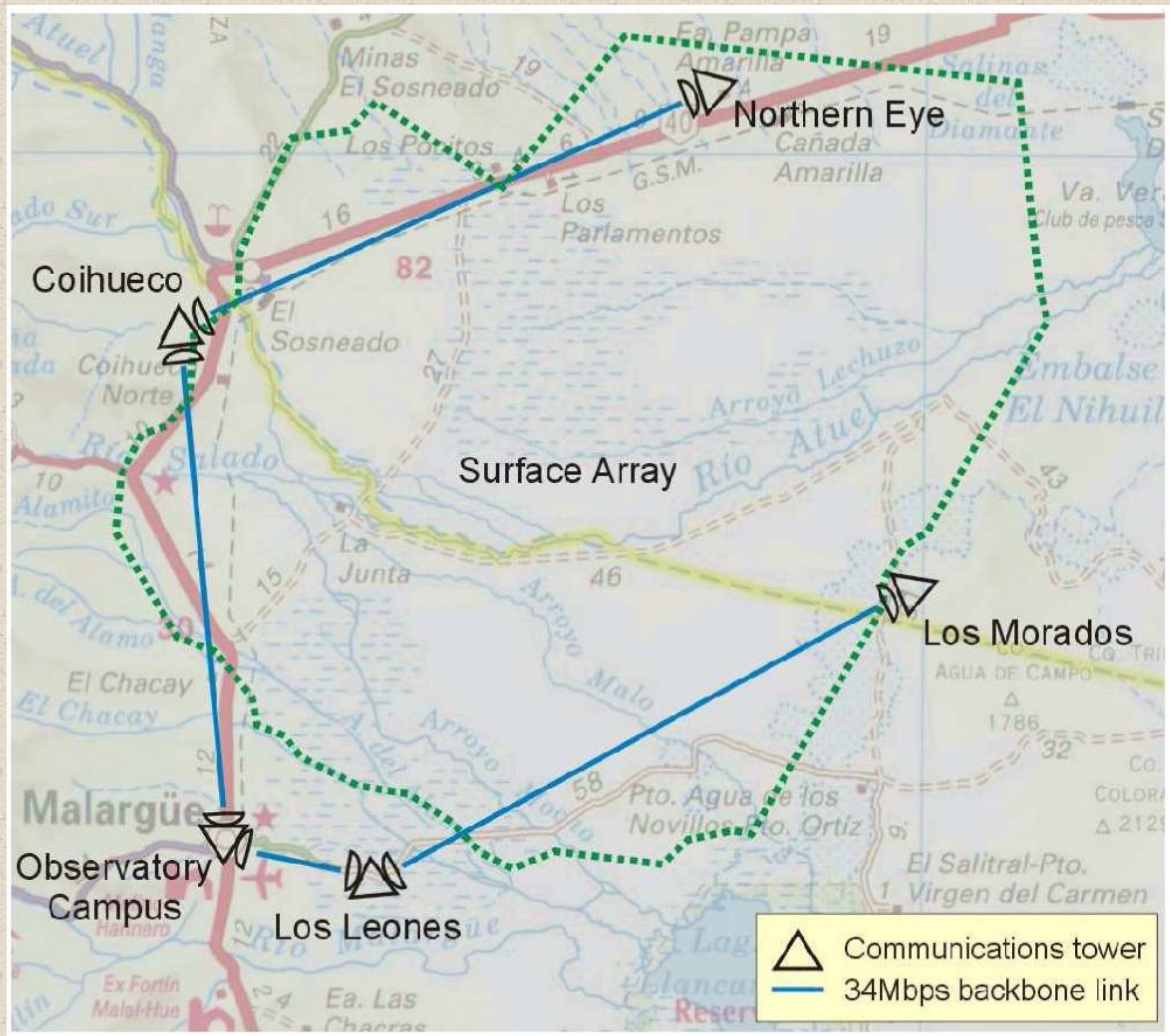
FLUORESCENCE DETECTOR






elevation [deg]
azimuth [deg]
elevation [deg]
azimuth [deg]
dE/dX [PeV/(g/cm²)]
χ²/Ndf= 150.13/164
reconstructed
Gaisser-Hillas fit
slant depth [g/cm²]
dE/dX [PeV/(g/cm²)]
χ²/Ndf= 101.69/161
reconstructed
Gaisser-Hillas fit
slant depth [g/cm²]

COMMUNICATION SCHEME



LIFE IS COMPLICATED

PHYSICS

THE SPECTRUM and COMPOSITION

SPECTRUM

What is it in a power law? $\mathcal{N}(E) = \mathcal{N}_0 \left(\frac{E}{E_0}\right)^{-\gamma}$

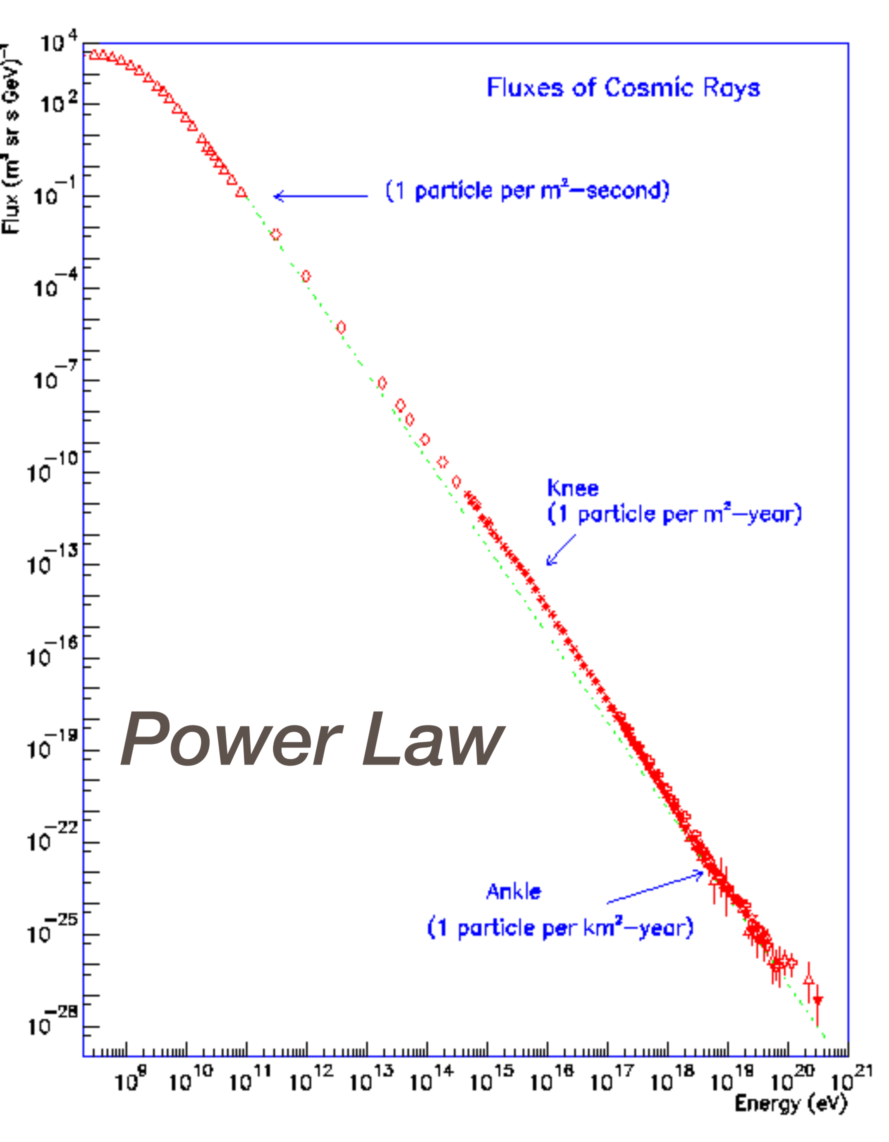
Kick and escape!

KICK: variable E, gets a small kick starting at E_0. After m steps: $E_m = (1+\xi)^m \, E_0 \;\; \text{for} \;\; \xi > 0$

ESCAPE: the total number of elements with property E decreases at each step $N_m = \mathcal{P}^m \, N_0$.

Rephrase the probability to stay in the same state:

$$\begin{aligned} \mathcal{P} &= 1 - \mathcal{P}_{esc} \\ N_m &= (1-\mathcal{P}_{esc})^m \, N_0 \end{aligned}$$



Re-write:

$$\begin{aligned} m \, \ln(1+\xi) &= \ln(\frac{E_m}{E_0}) \\ m \, \ln(1-\mathcal{P}_{esc}) &= \ln(\frac{N_m}{N_0}) \\ \ln(\frac{N_m}{N_0}) &= \frac{\ln(1-\mathcal{P}_{esc})}{\ln(1+\xi)} \, \ln(\frac{E_m}{E_0}) \end{aligned}$$

Put it in infinitesimal form:

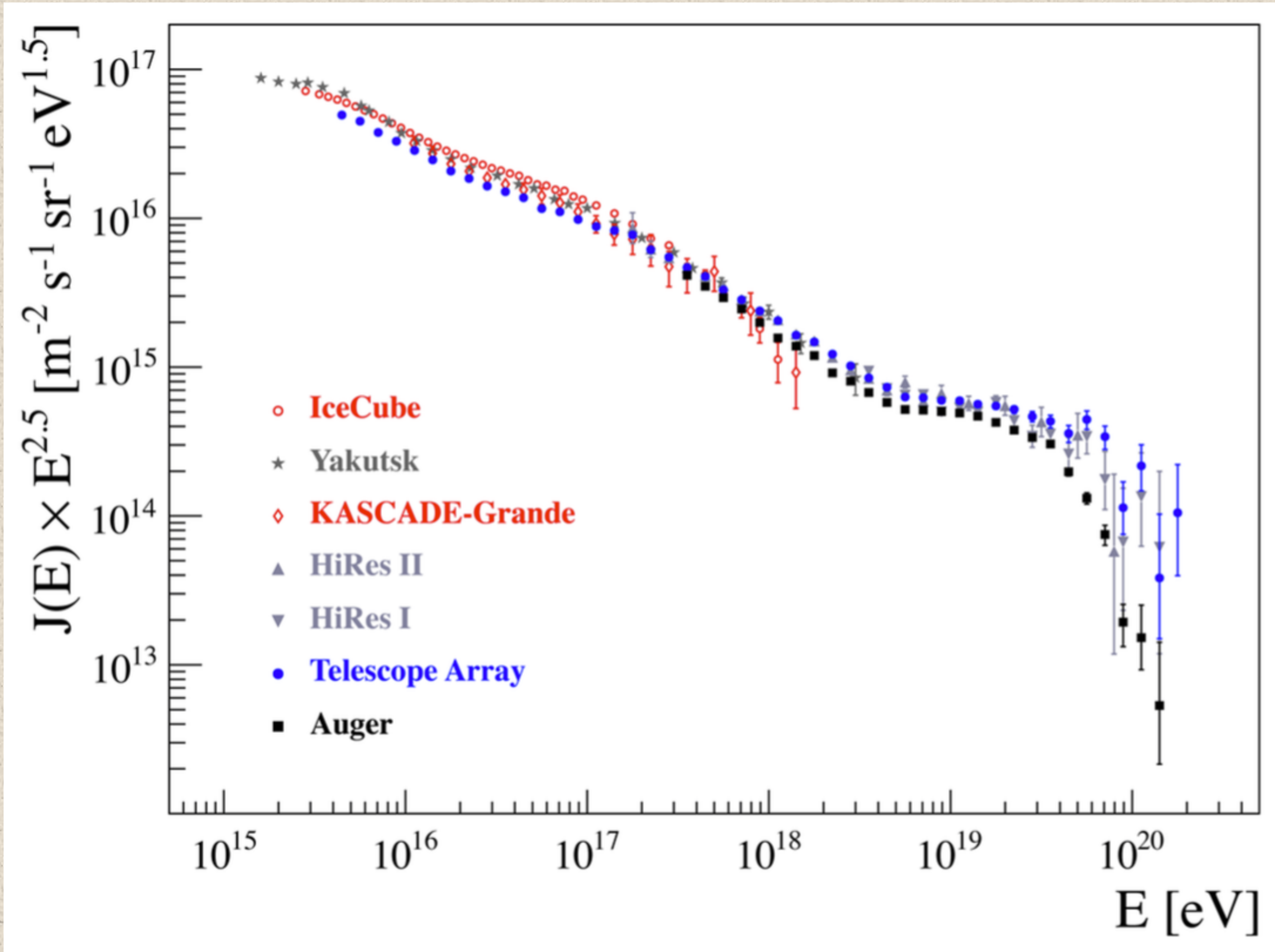
$$\ln(1+\frac{dN}{N}) = -\gamma \ln(1+\frac{dE}{E})$$

$$\gamma = -\frac{\ln(1+\mathcal{P}_{esc})}{\ln(1-\xi)} \simeq \frac{\mathcal{P}_{esc}}{\xi}$$

and voilà

$$\frac{dN}{N} = -\gamma \, \frac{dE}{E}$$

RESULTS: COSMIC RAY SPECTRUM

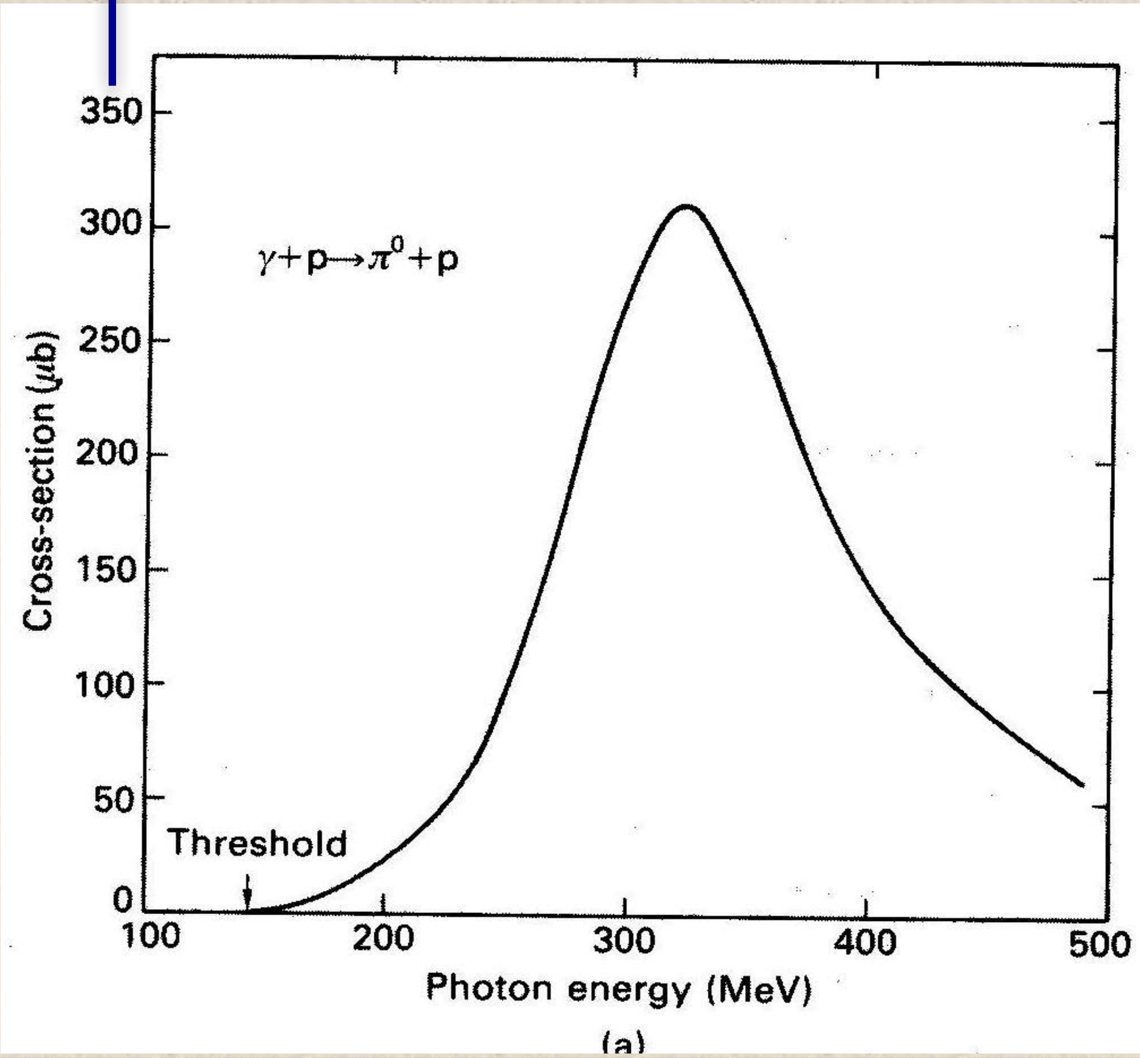


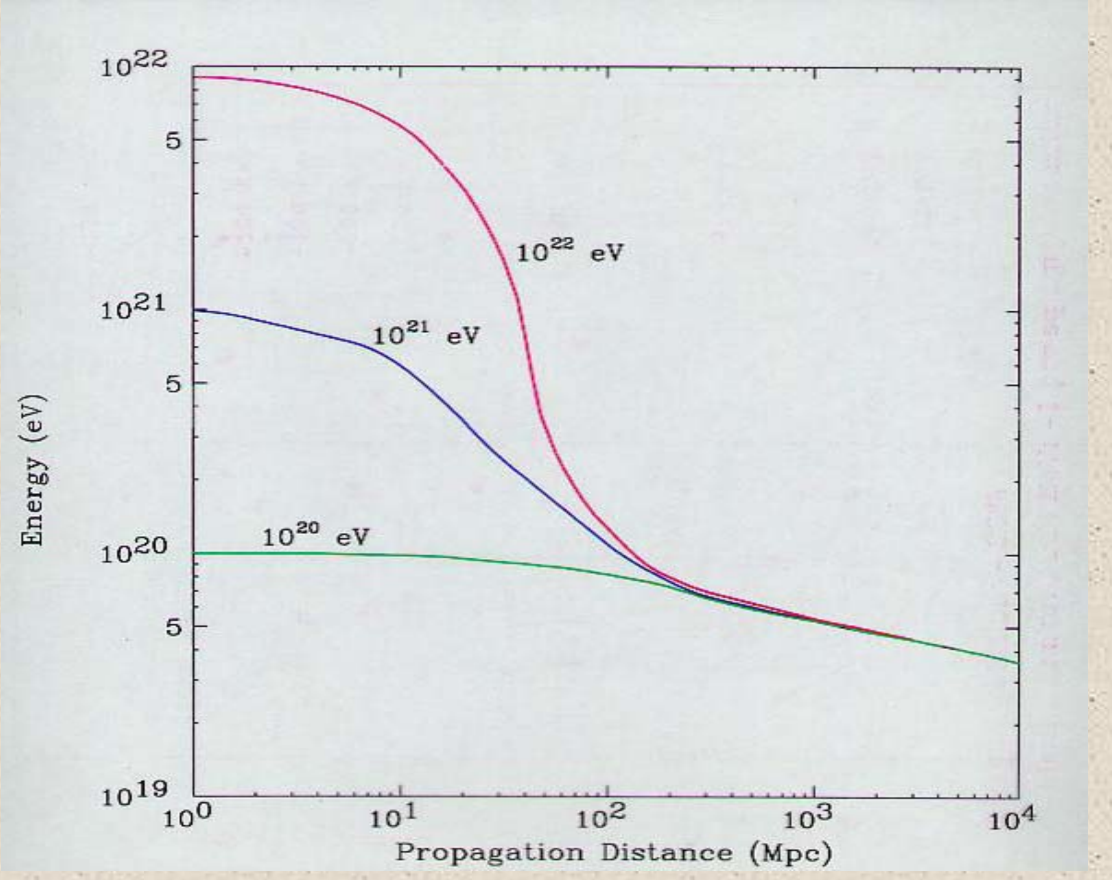
THE GZK CUTOFF

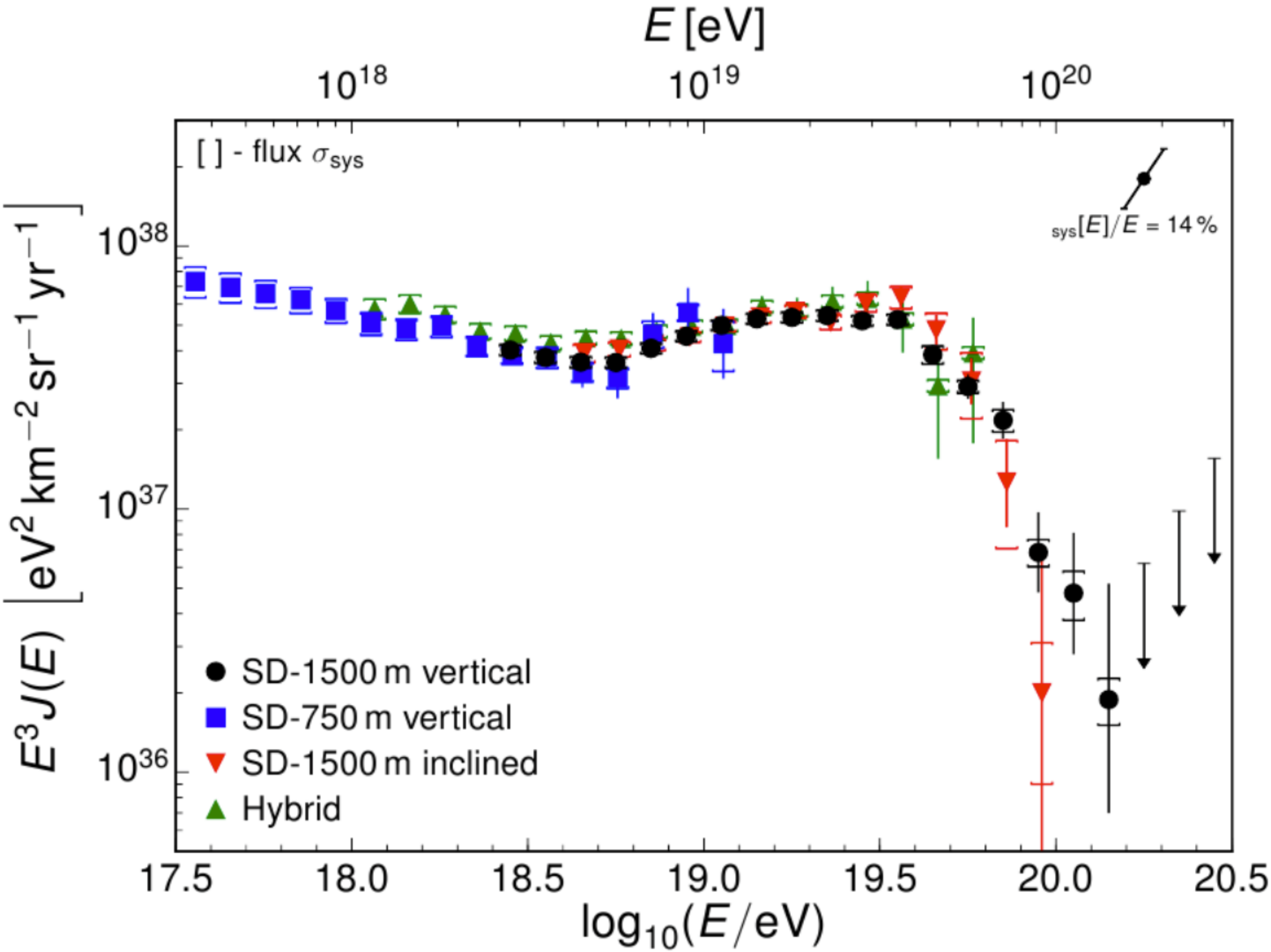
UHECR

$$\gamma + p \rightarrow \Delta^{+}(1236) \rightarrow \begin{cases} p + \pi^{0} \\ n + \pi^{+} \end{cases}$$

Cosmic Radiation Background (2.728 K → 300 GHz)

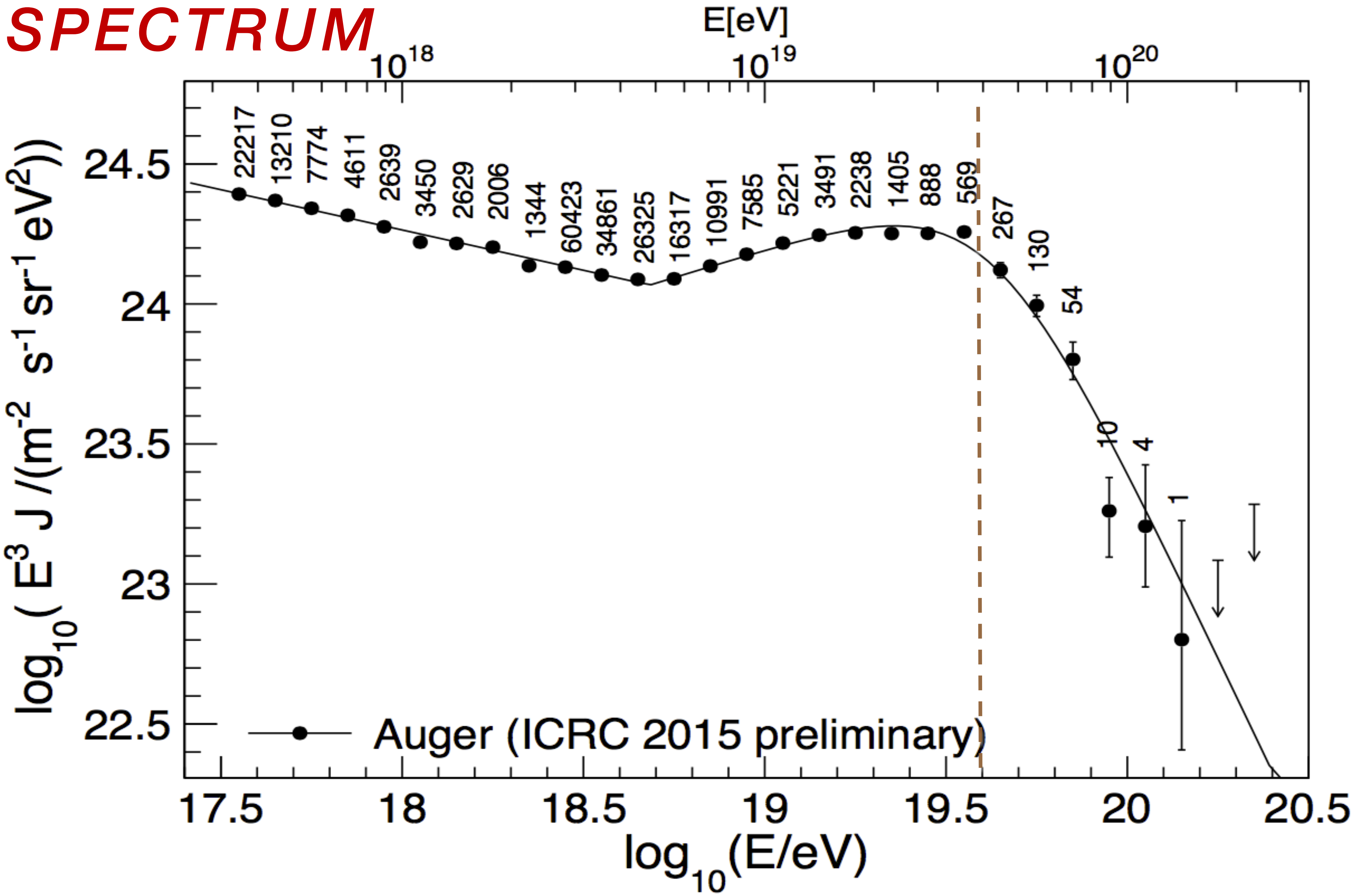






E [eV]
10^18
10^19
10^20
[ ] - flux σsys
sys[E]/E = 14 %
10^38
10^37
10^36
E^3 J(E) [eV^2 km^-2 sr^-1 yr^-1]
SD-1500 m vertical
SD-750 m vertical
SD-1500 m inclined
Hybrid
17.5
18.0
18.5
19.0
19.5
20.0
20.5
log10(E/eV)

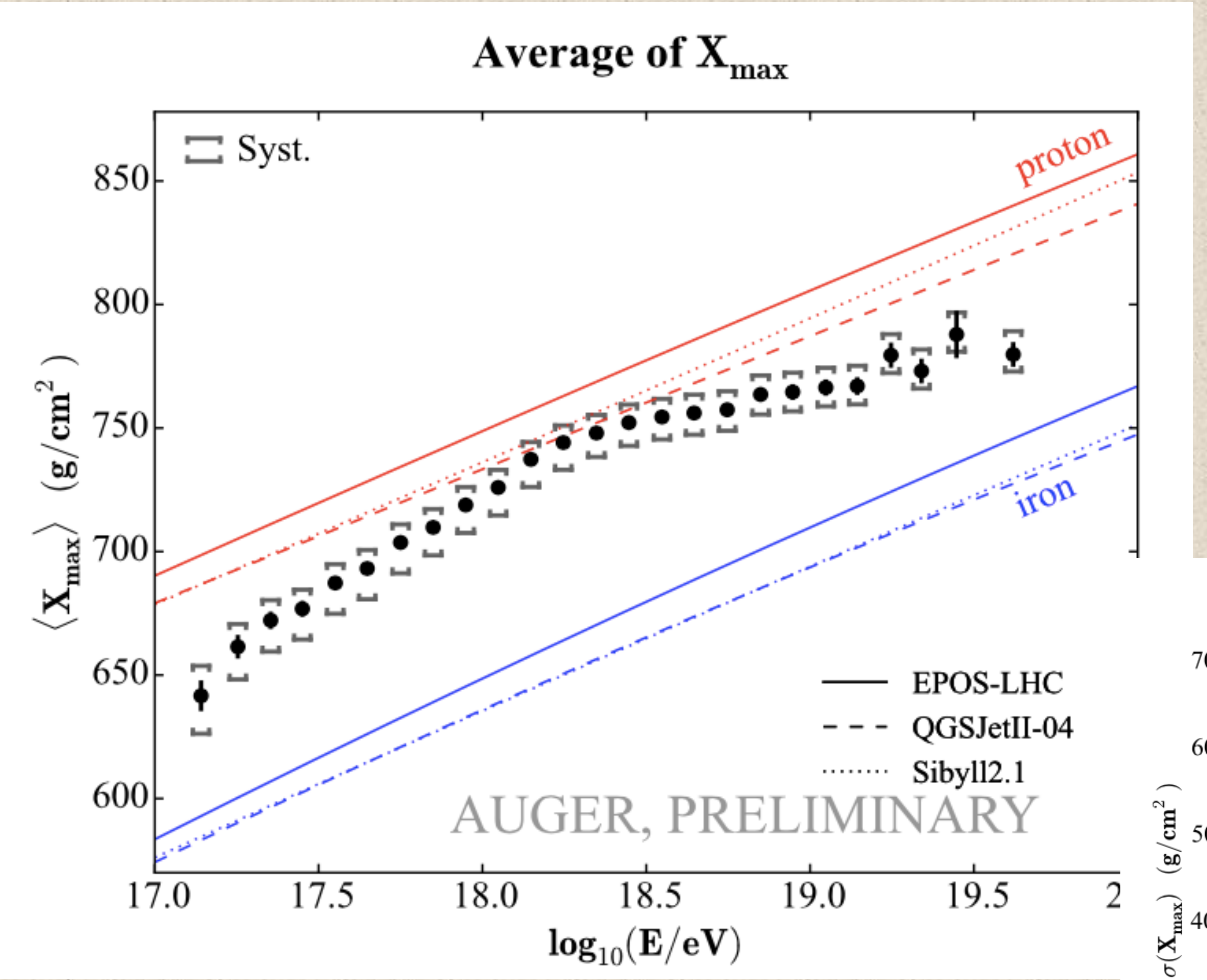
SPECTRUM

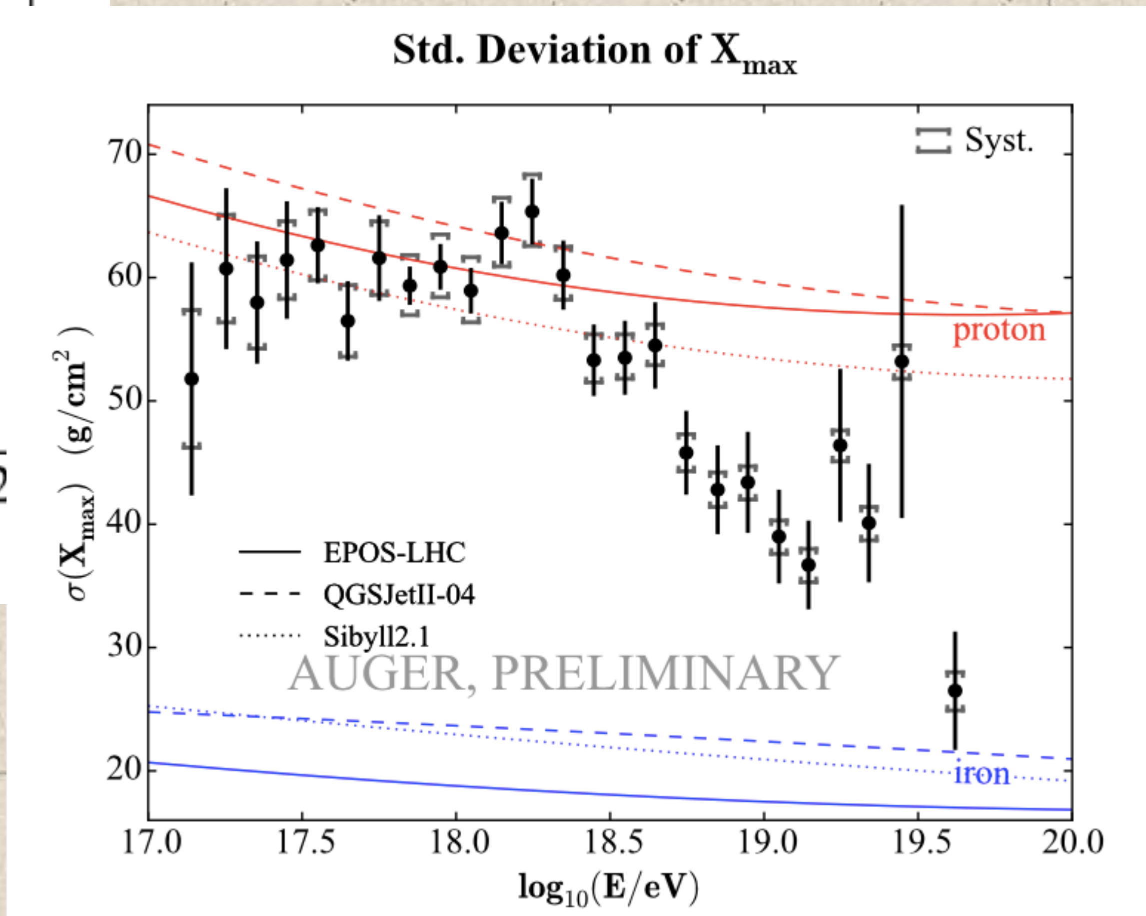


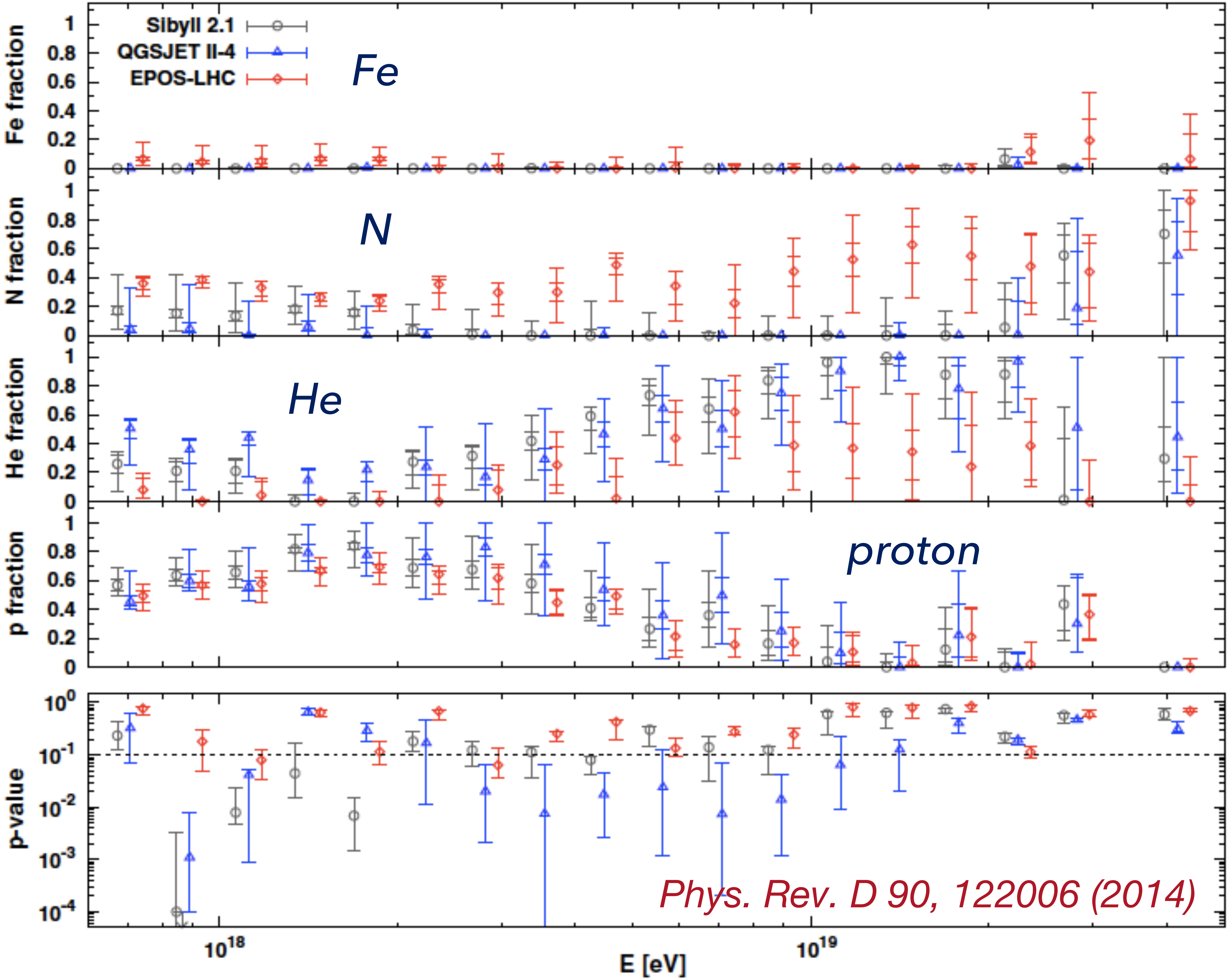
$$J(E) = J_0 \left(\frac{E}{E_{\rm ankle}}\right)^{-\gamma_2} \left[1+\left(\frac{E_{\rm ankle}}{E_{\rm s}}\right)^{\Delta\gamma}\right] \left[1+\left(\frac{E}{E_{\rm s}}\right)^{\Delta\gamma}\right]^{-1}.$$

J_0 [$\mathrm{eV^{-1}km^{-2}sr^{-1}yr^{-1}}$]	$E_{\rm ankle}$ [EeV]	$E_{\rm s}$ [EeV]	γ_1	γ_2	$\Delta\gamma$
$(3.30 \pm 0.15 \pm 0.20) \times 10^{-19}$	$4.82 \pm 0.07 \pm 0.8$	$42.09 \pm 1.7 \pm 7.61$	$3.29 \pm 0.02 \pm 0.05$	$2.60 \pm 0.02 \pm 0.1$	$3.14 \pm 0.2 \pm 0.4$

Mass composition






Sibyll 2.1
QGSJET II-4
EPOS-LHC
Fe
N
He
proton
Fe fraction
N fraction
He fraction
p fraction
p-value
E [eV]
Phys. Rev. D 90, 122006 (2014)

What do spectrum and composition data tell us?

GZK cutoff? There are many way to fit the spectrum!

JCAP 04 (2017) 038

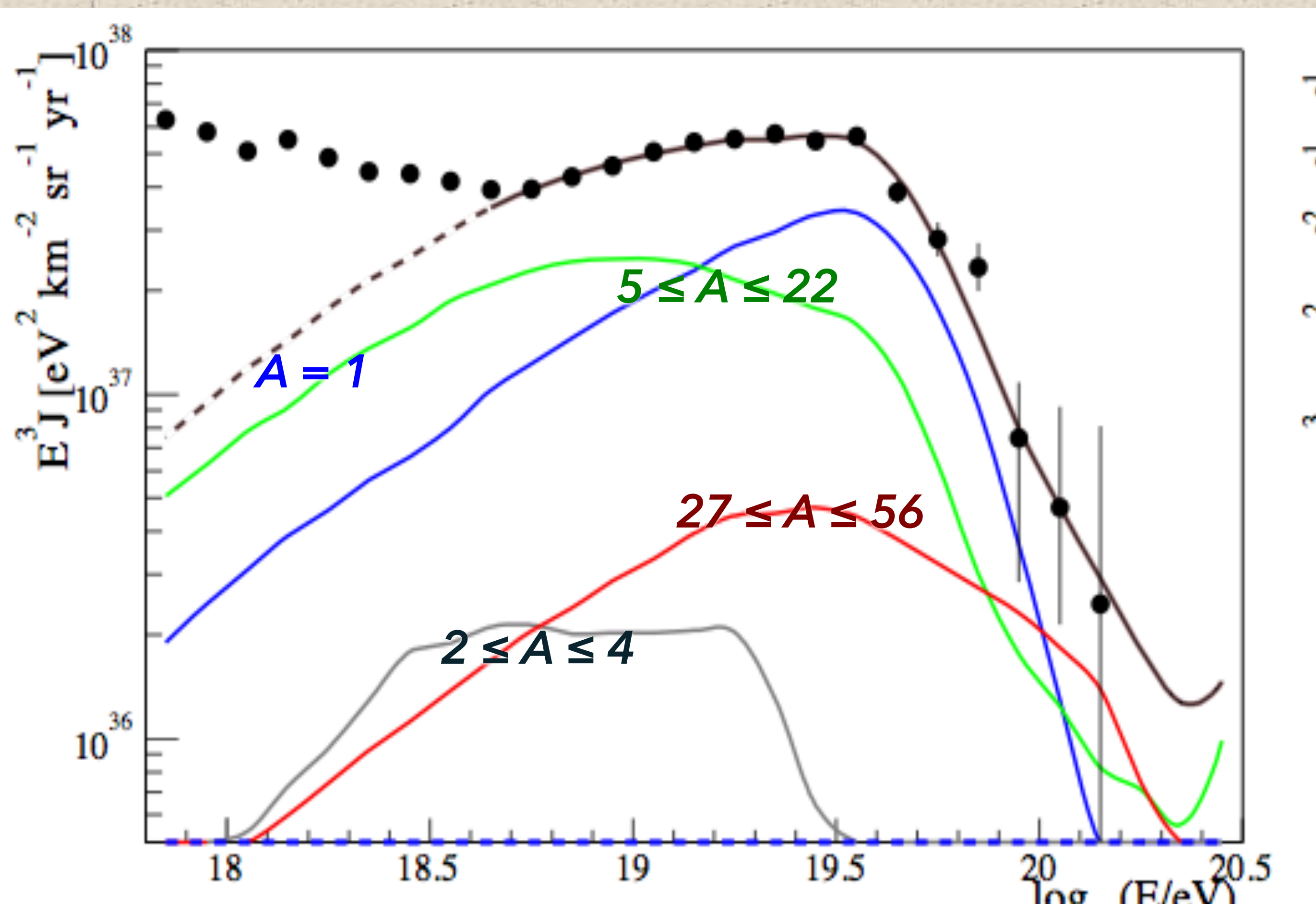
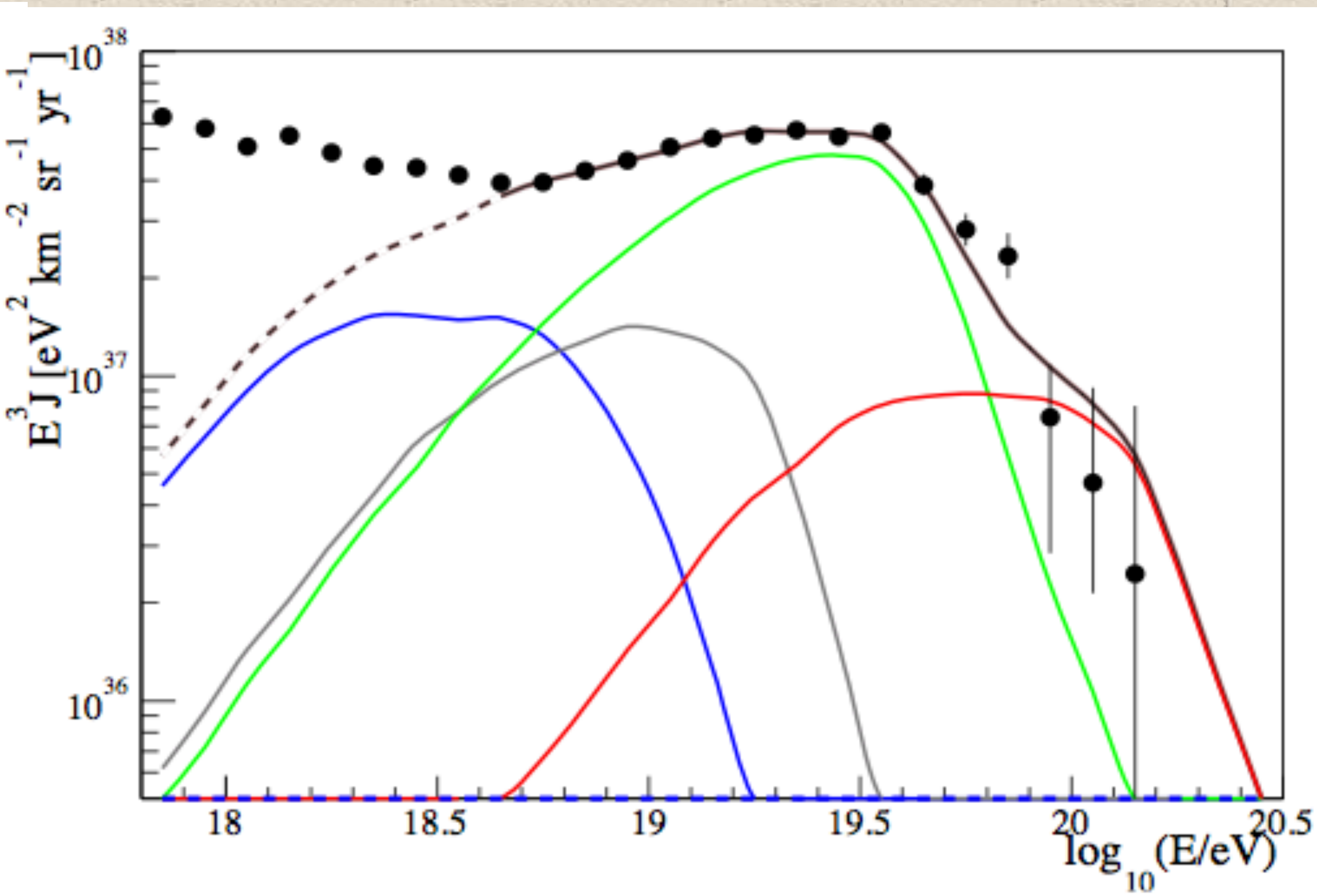


Photo-disintegration scenario

$A + \gamma_{CMB/IBR} \rightarrow (A - 1) + N$

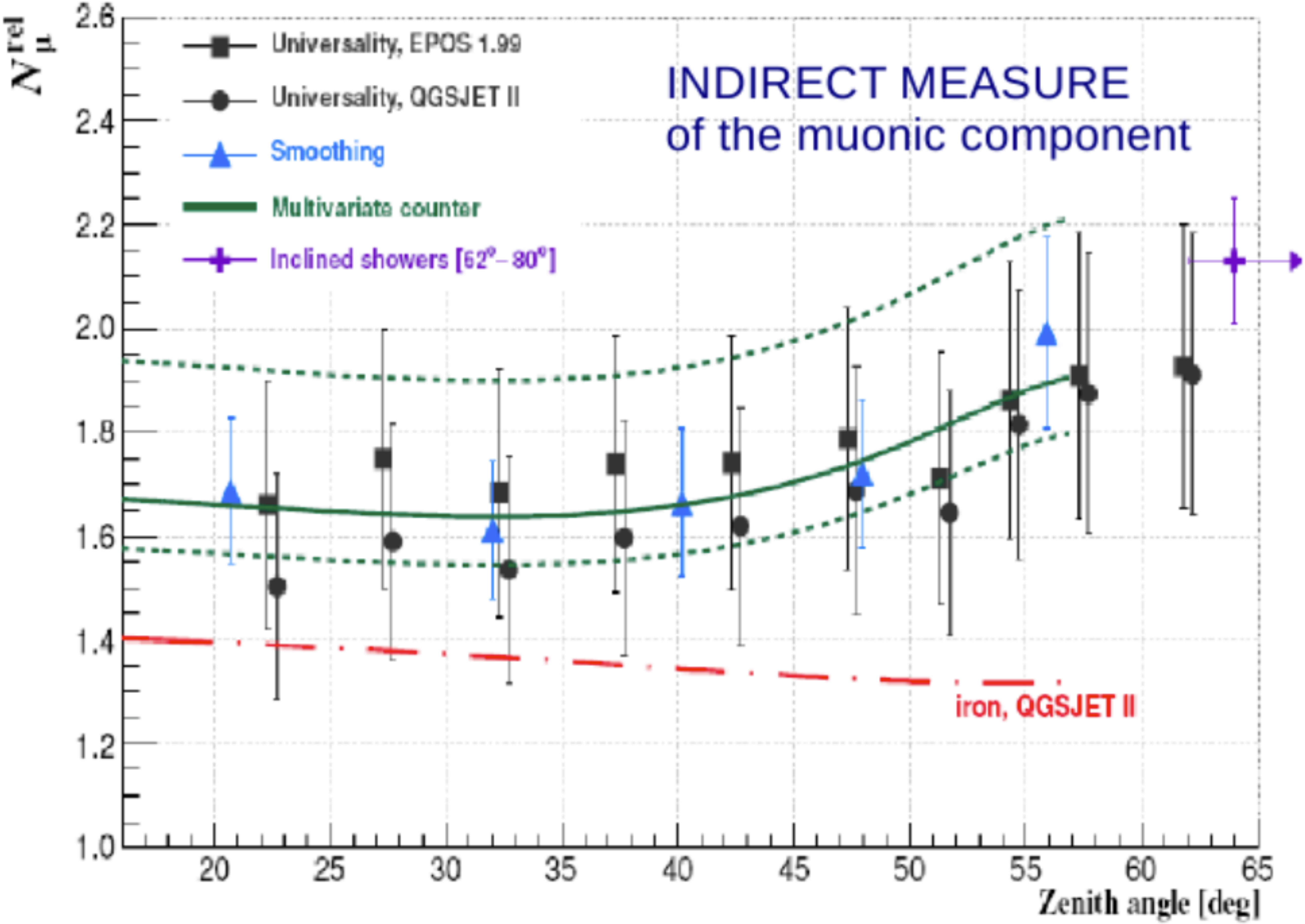


Maximum rigidity scenario

$E_{MAX}^{Z} = Z \times E_{MAX}^{p}$

Origin of the suppression unresolved !!!

Need to discriminate among different scenarios

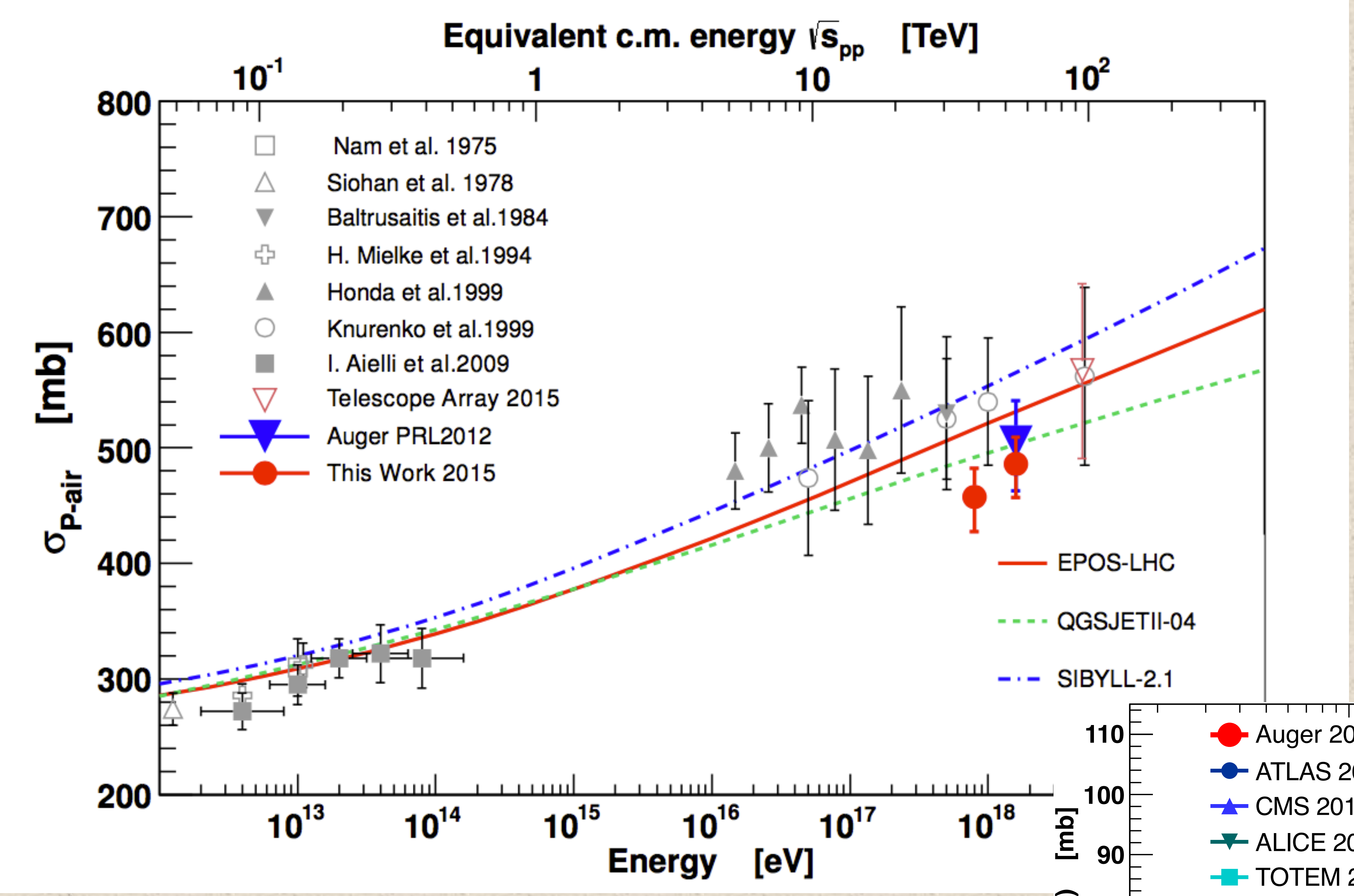


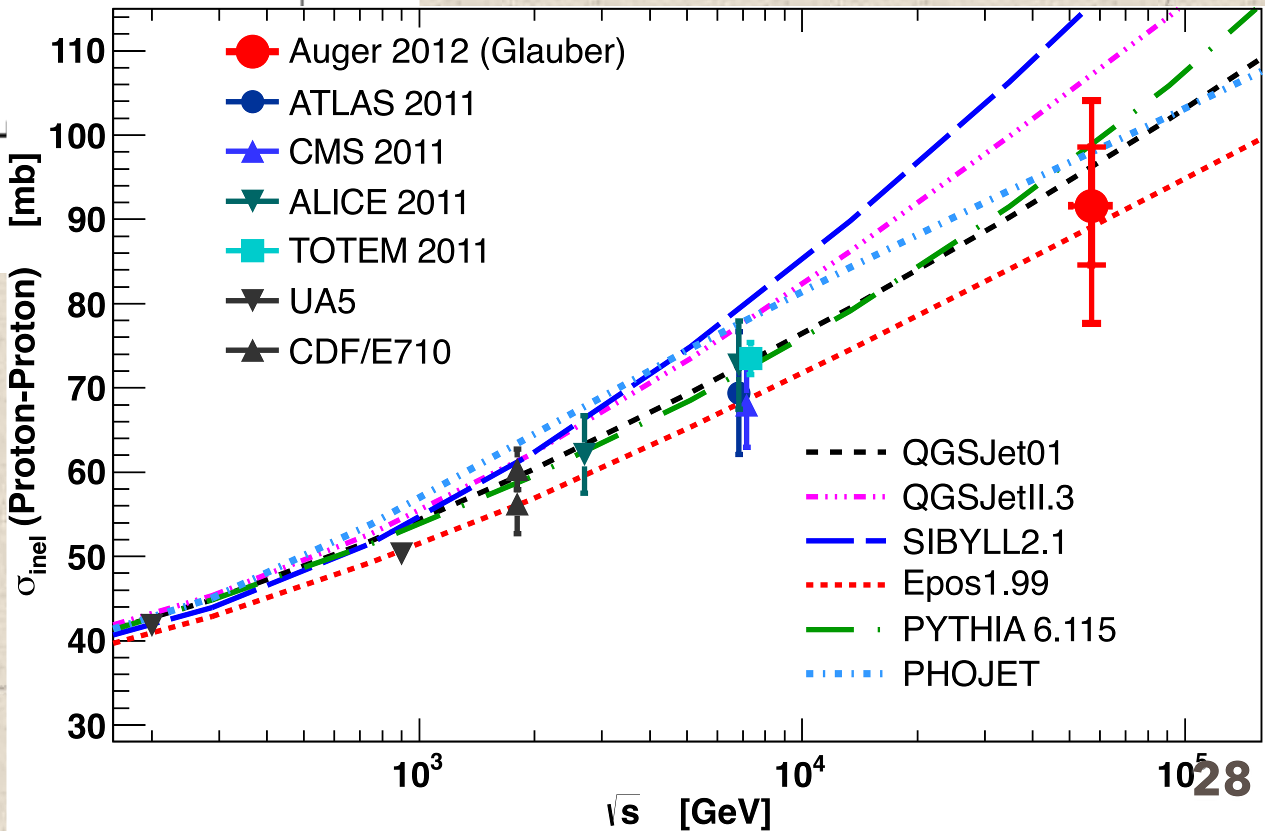
N_μ^{rel}
Universality, EPOS 1.99
Universality, QGSJET II
Smoothing
Multivariate counter
Inclined showers [62°–80°]
INDIRECT MEASURE
of the muonic component
iron, QGSJET II
Zenith angle [deg]
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
20
25
30
35
40
45
50
55
60
65

PHYSICS

THE CROSS SECTION

RESULTS: CROSS SECTION

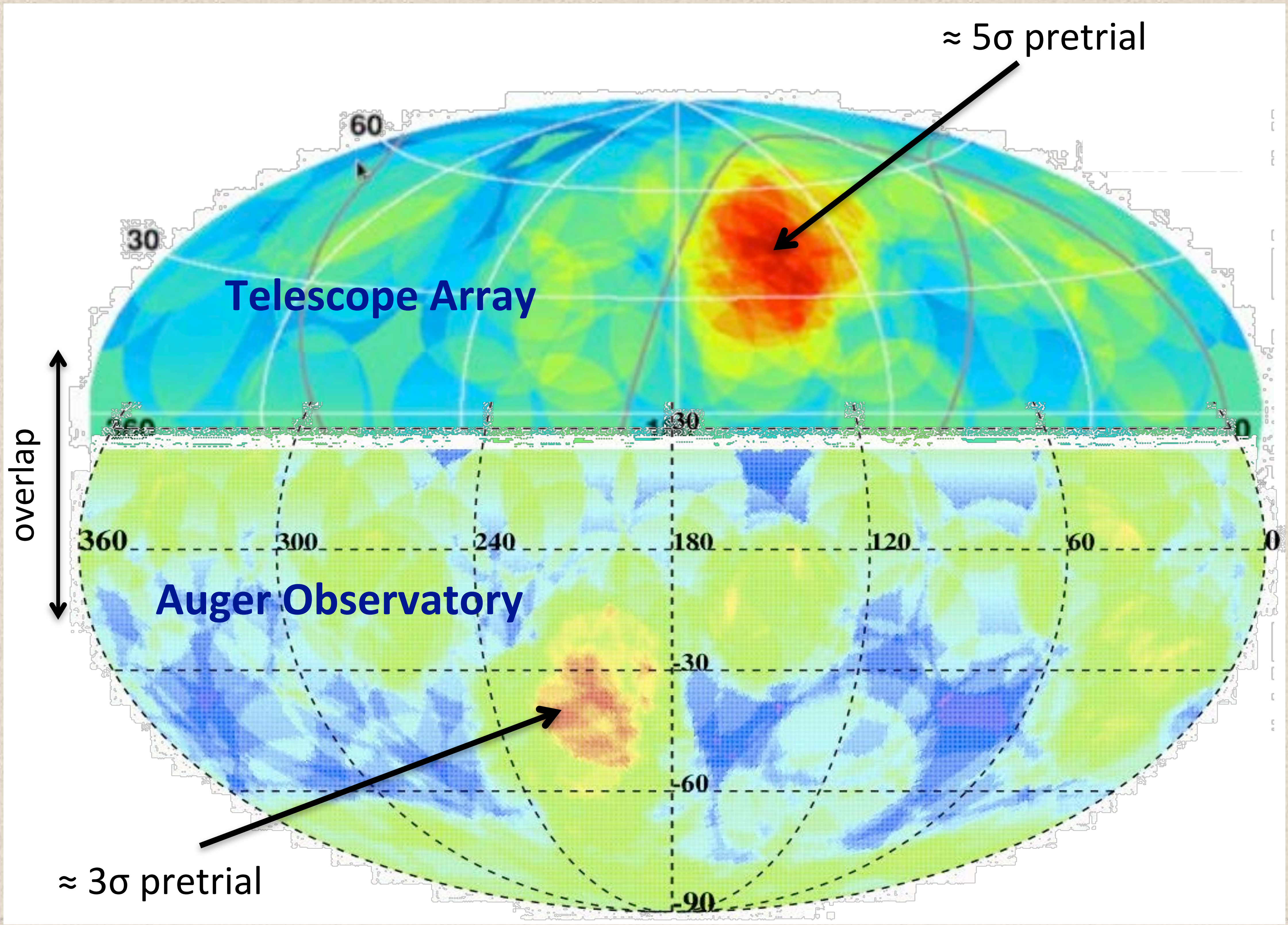




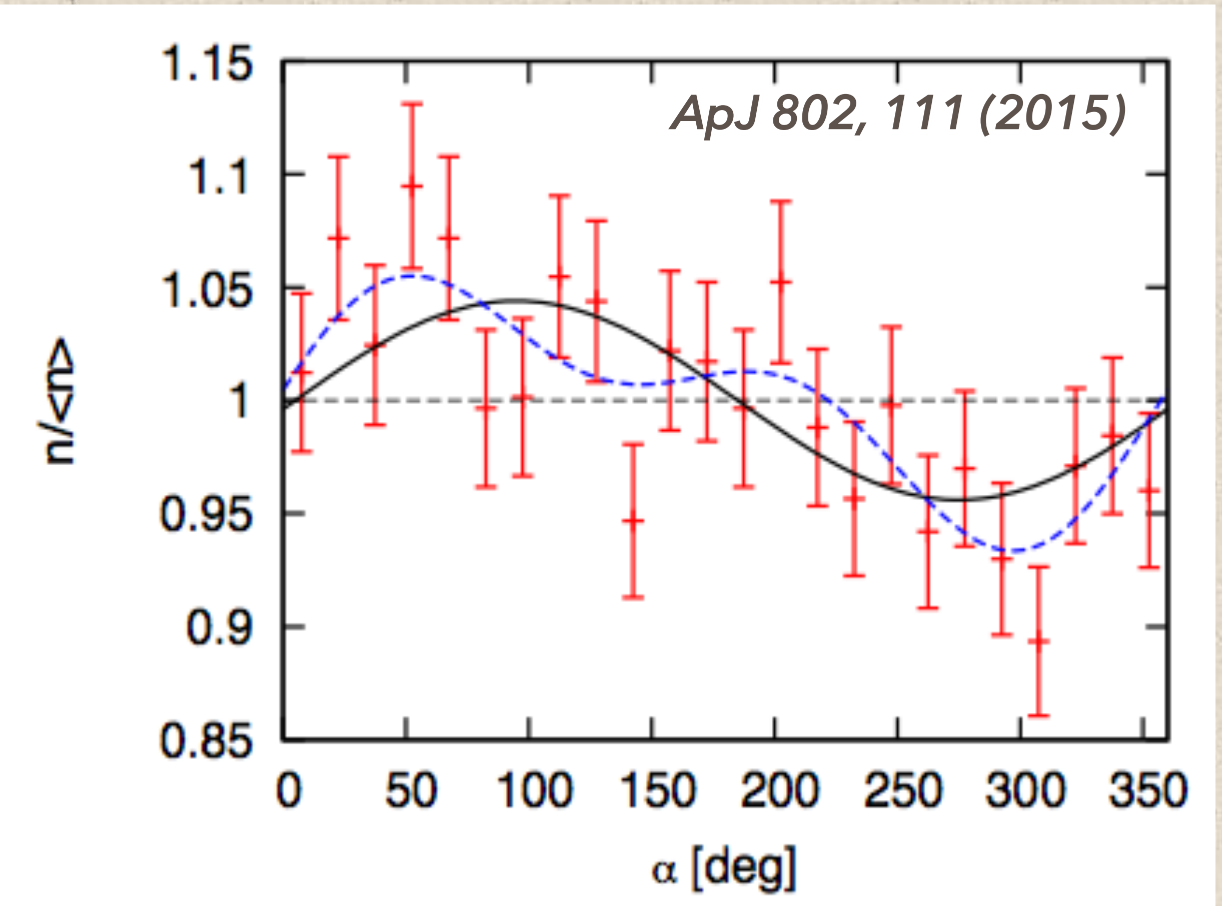
PHYSICS

THE ANISOTROPIES

RESULTS: ANISOTROPY (ABOVE 8EeV)



Arrival direction on the celestial sphere

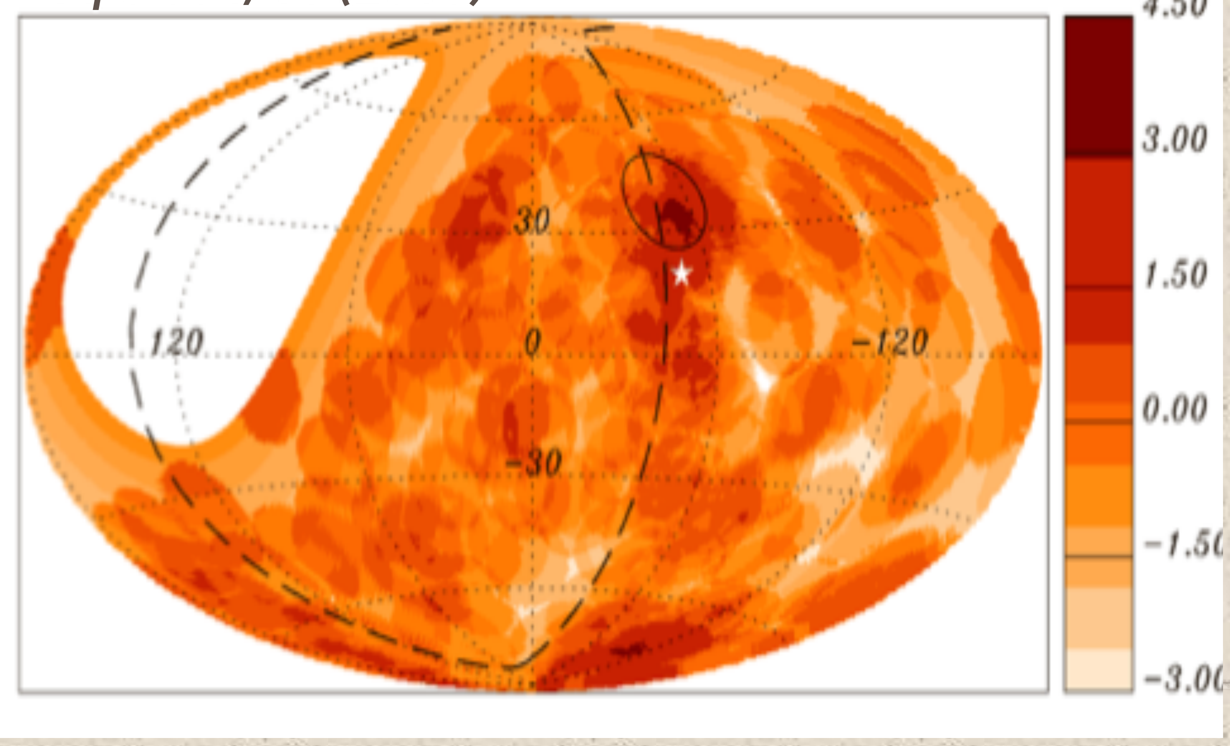


Large scale anisotropy (just below the suppression)

departure from isotropy at ~5.5σ (updated results, to be published)

above 8×10^{18} eV with a (4 ± 1)% amplitude in the first harmonic in RA

ApJ 804, 15 (2015)



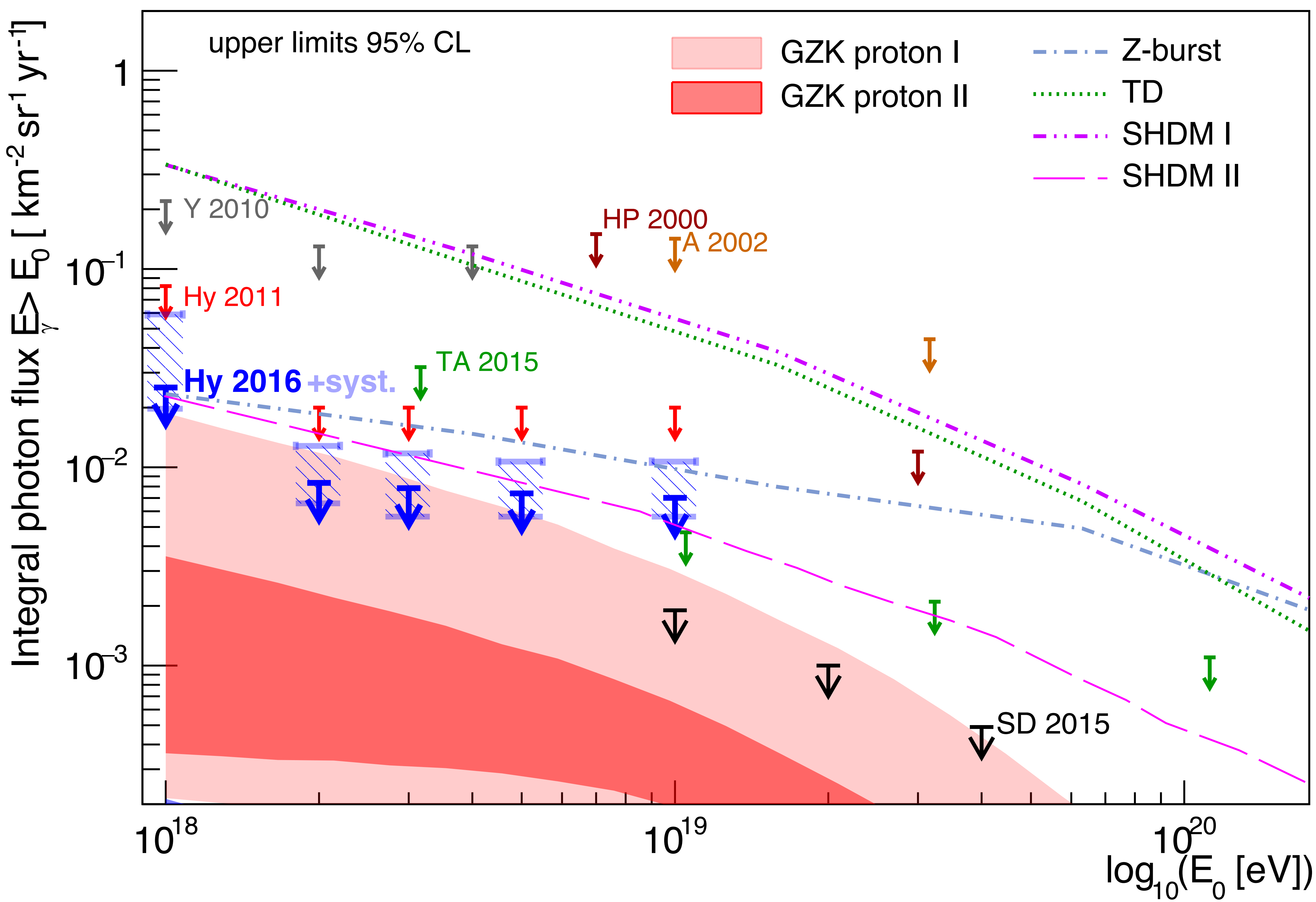
Small scale anisotropy (in the suppression region)

~4.3 σ for E > 54×10^{19} eV EeV and θ = 18° post-trial probability 68%

PHYSICS

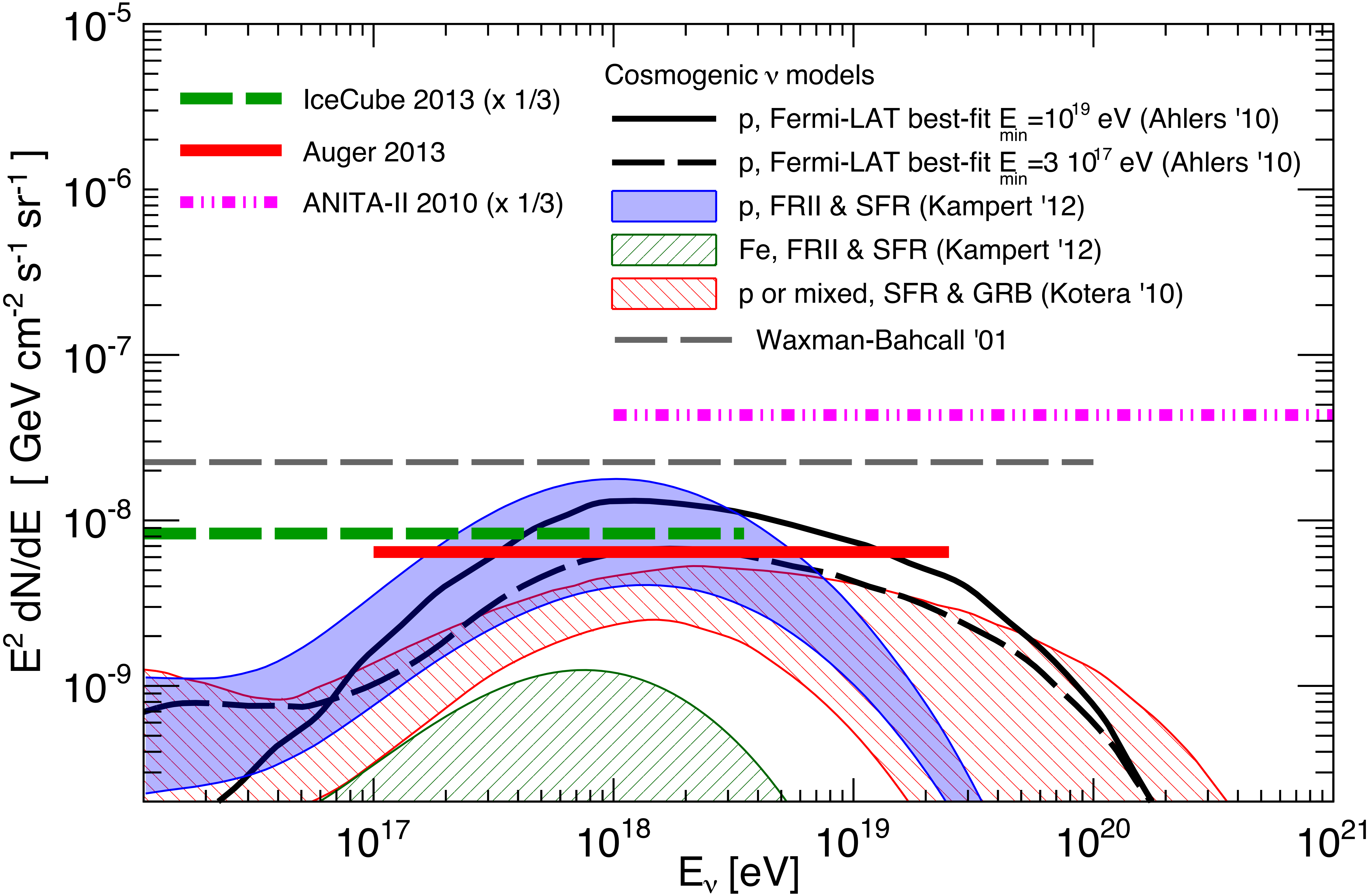
THE LIMITS

RESULTS: PHOTONS



RESULTS: *NEUTRINOS*

Single flavour, 90% C.L.



THE PIERRE AUGER OBSERVATORY

The Pierre Auger Observatory Upgrade

AugerPrime - arXiv:1604.03637

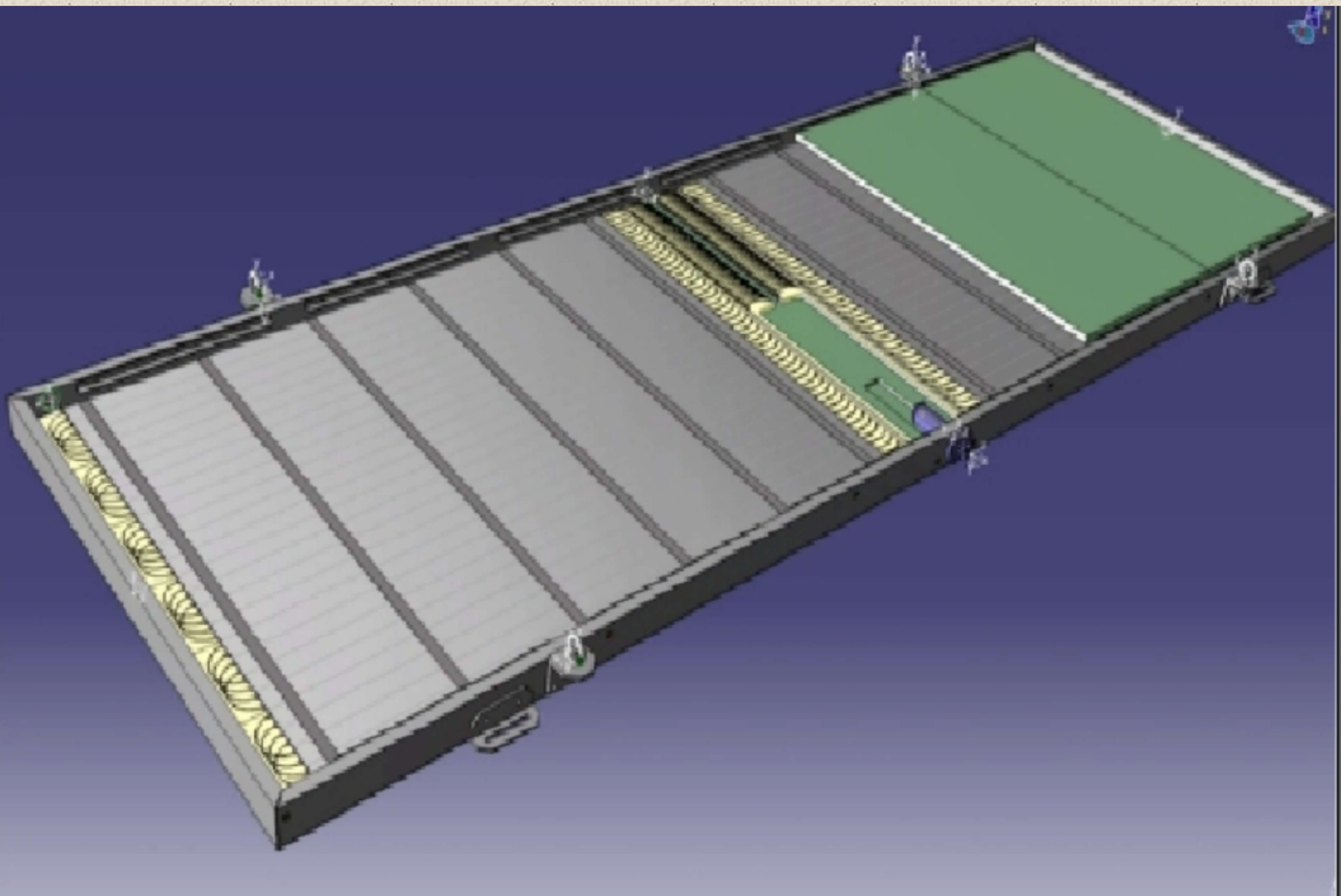
Motivations

- Investigate mass composition in the suppression region on an event-by-event basis
- Reach the sensitivity to detect a small contribution (~10%) of protons in the suppression region
- Study hadronic interactions at center-of-mass energies above 100 TeV

Planned upgrades

- Surface Scintillator Detectors (SSD) above the existing Water-Cherenkov-Detectors (WCD)
- New electronics for faster sampling of both WCD and SSD signals (better timing accuracy, increased dynamic range)
- Underground Muon Detectors in the SD area of 25 km^2 (“infill area”)
- Extend Fluorescence Detector duty cycle from ≈ 15% to ≈ 20%

from Roberta Colalillo



from Roberta Colalillo

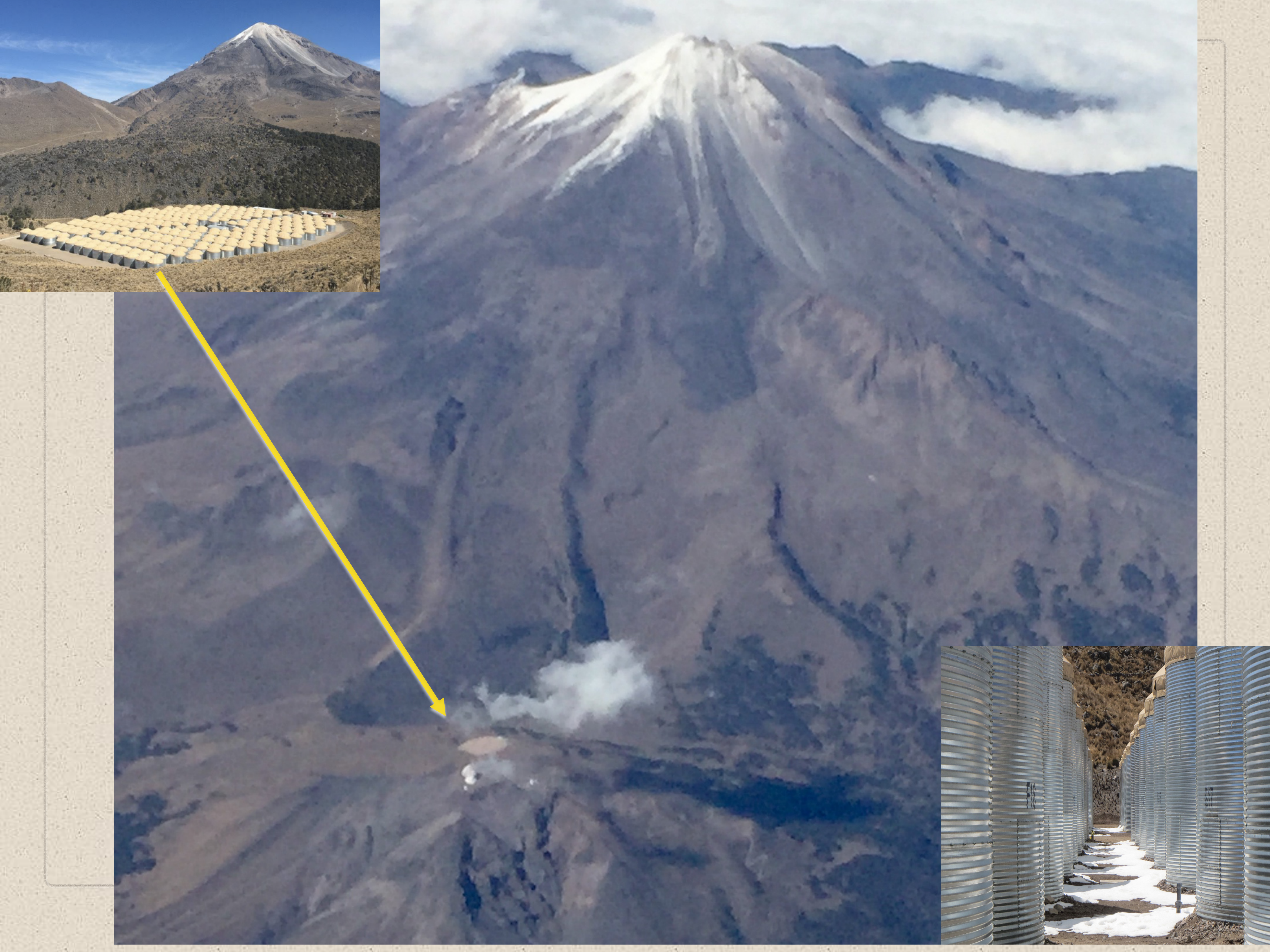
FUTURE EXPERIMENTS

LATTES

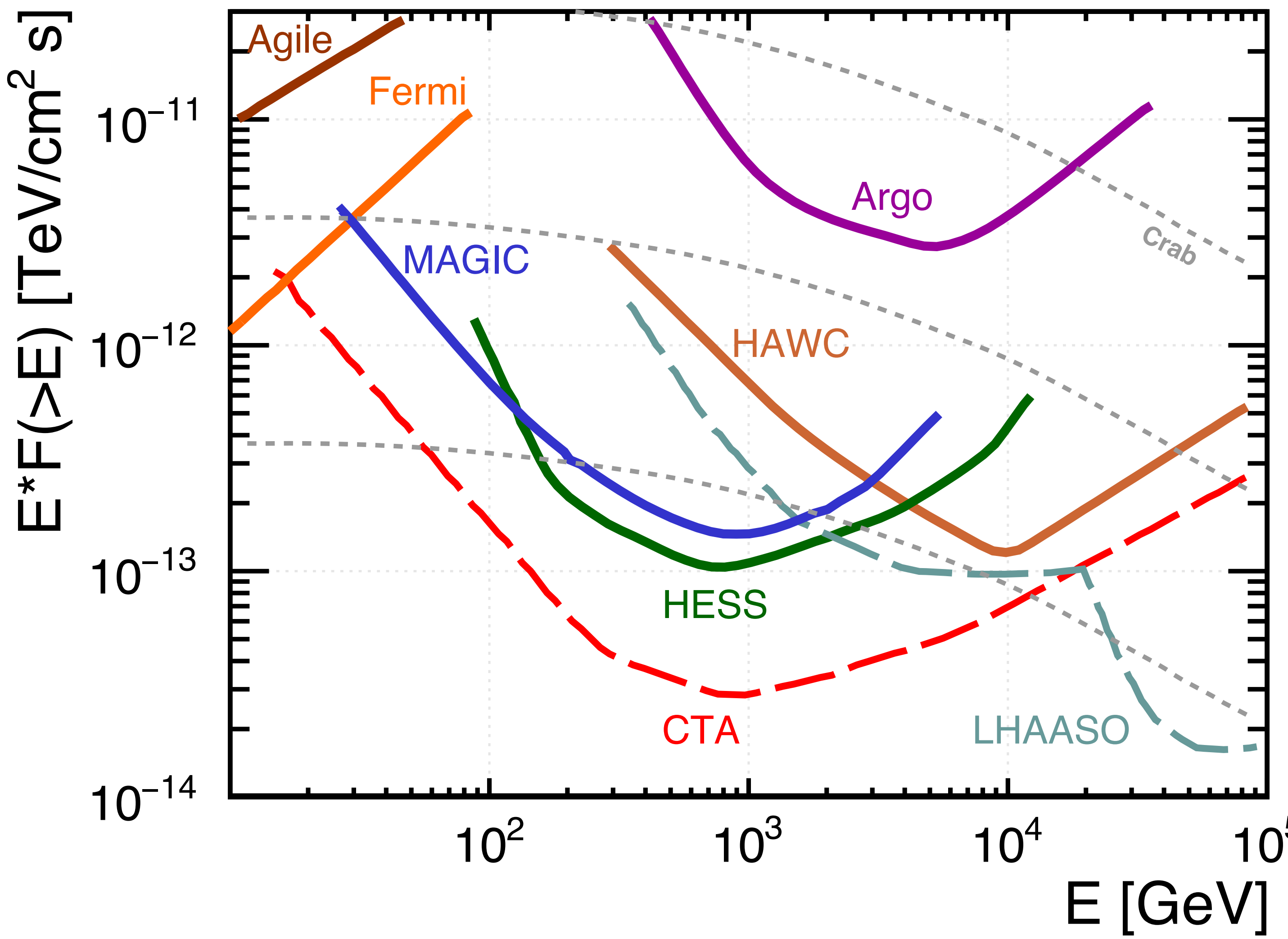
LARGE ARRAY TELESCOPES FOR TRACKING ENERGETIC SOURCES

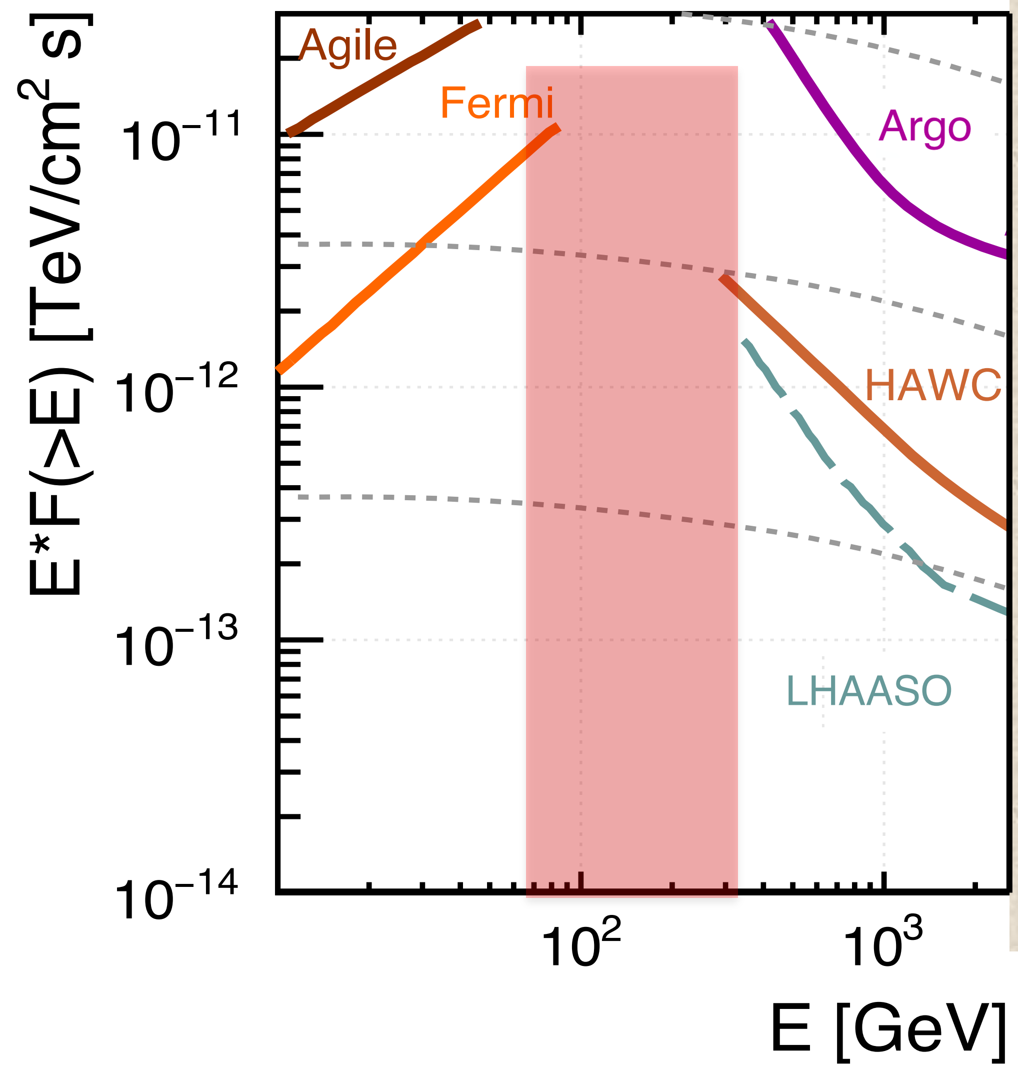
HAWC (Northern Hemisphere)

- ***Altitude 4.100 m.a.s.l.***
- ***20.000 m^2 covered with 300 W.C. Tanks***
- ***200 ton water + 4 Photomultipliers***



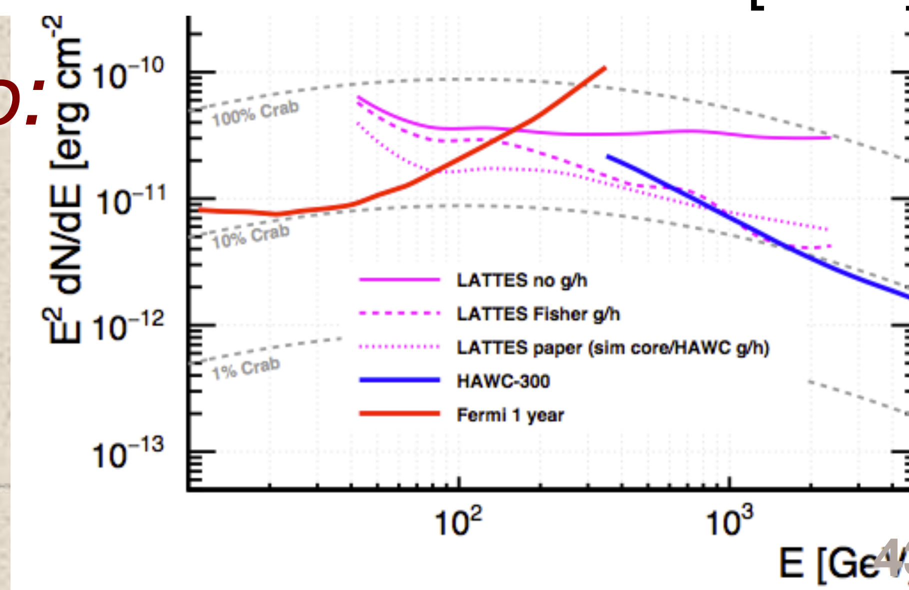
Why LATTES: Present situation





There are no large field of view experiment to:

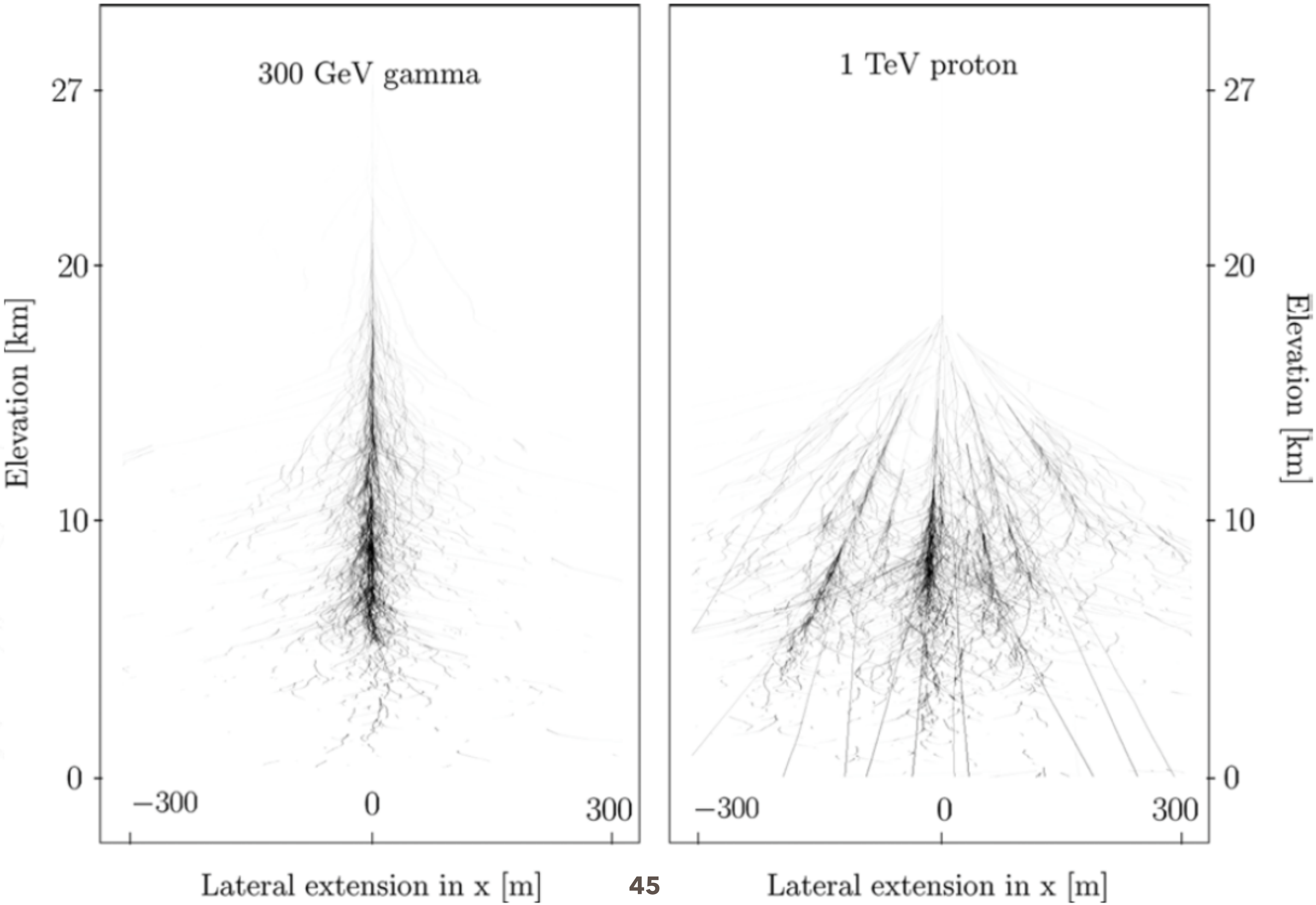
- *Monitor the Center of the Galaxy*
- *Exploit the 100 GeV range*



LATTES OBJECTIVES

- Build a gamma ray detector operating 24/7, field of view of $\pi\ rad^2$
- Low energy sensitivity ~ 100 GeV
- Altitude above 5.000m
- South America (interesting objets)
- Physics:
  - Fast Monitoring: Seendipituos flare hunting+trigger of other observatories
  - Slow Monitoring: Long baseline on several TeV sources
  - General Astrophysics: high energy TeV tail+ sinergy with IACT+wide-FOV observation
  - Fundamental Physics: exotic physics, the unknown

TOPOLOGY OF GAMMAS AND PROTONS



LATTES BASE DESIGN

- *Exposition area of the order of 20.000 m^2*

  (mix of scientific arguments e realism about funding!)

- *Dense coverage of the area*
- *Detetors simple e robust. Low mantainance costs*
- *Good temporal resolution*
- Good hadronic background rejection
- *Good angular resolution*
- Scalable

BASE DESIGN – CONCEPTUAL DESIGN

CESAR

__C__alorimeter __El__ectromagnetic for __S__tudying __AiR__ gammas

Two lines of development for radiador: water or ~~glass~~

Measure the shower energy with good resolution

MARTA

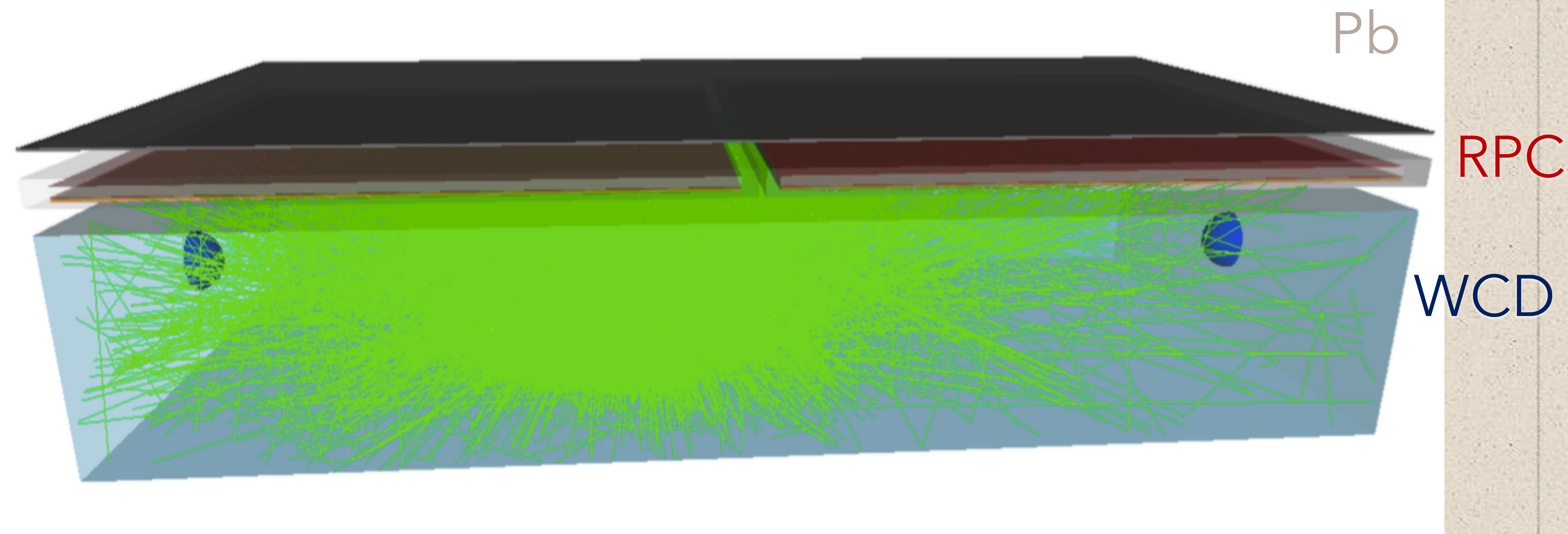
__M__uon __A__rray __R__pcs for __T__agging __A__irshowers

Particle counter based on RPC technology

(RPC -- Resistive Plate Chamber)

Temporal resolution ~ 1 ns

LATTES Station



- *Thin slab of lead (Pb)*
  - *5.6 mm (one radiation lenght)*
- *Resistive Plate Chambers (RPC)*
  - *2 RPC per station*
  - *Each RPC with 4X4 reading pads*
- *Water Cherenkov Detector (WCD)*
  - *2 PMT (diameter 15 cm)*
  - *Dimension: 1.5 m X 3 m X 0.5 m*

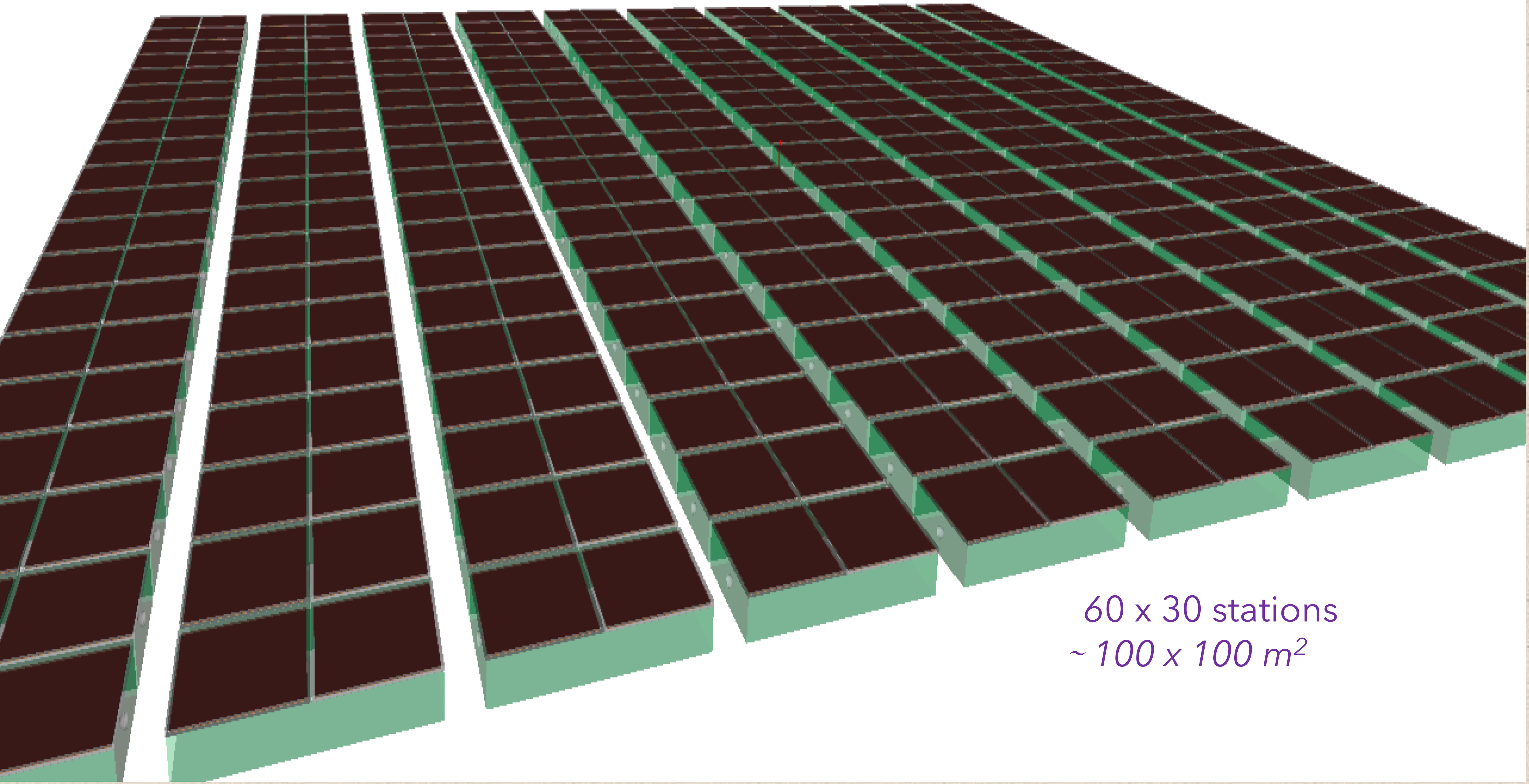
LATTES Layout

Conversor: 5.6 mm Pb

Pattern and timing: RPCs

Calorimeter and

μ identification: WCD

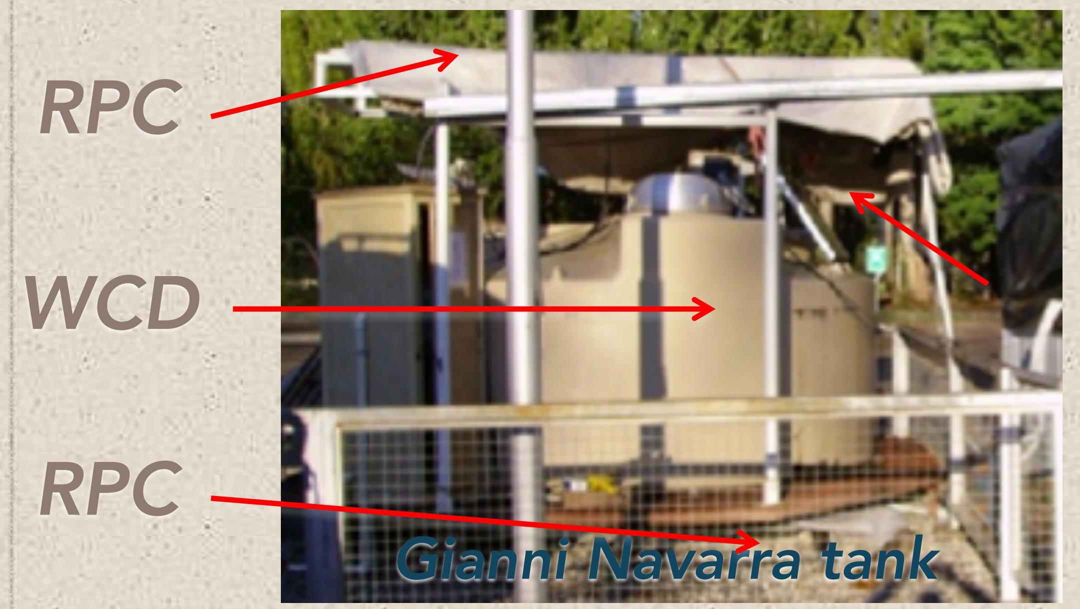


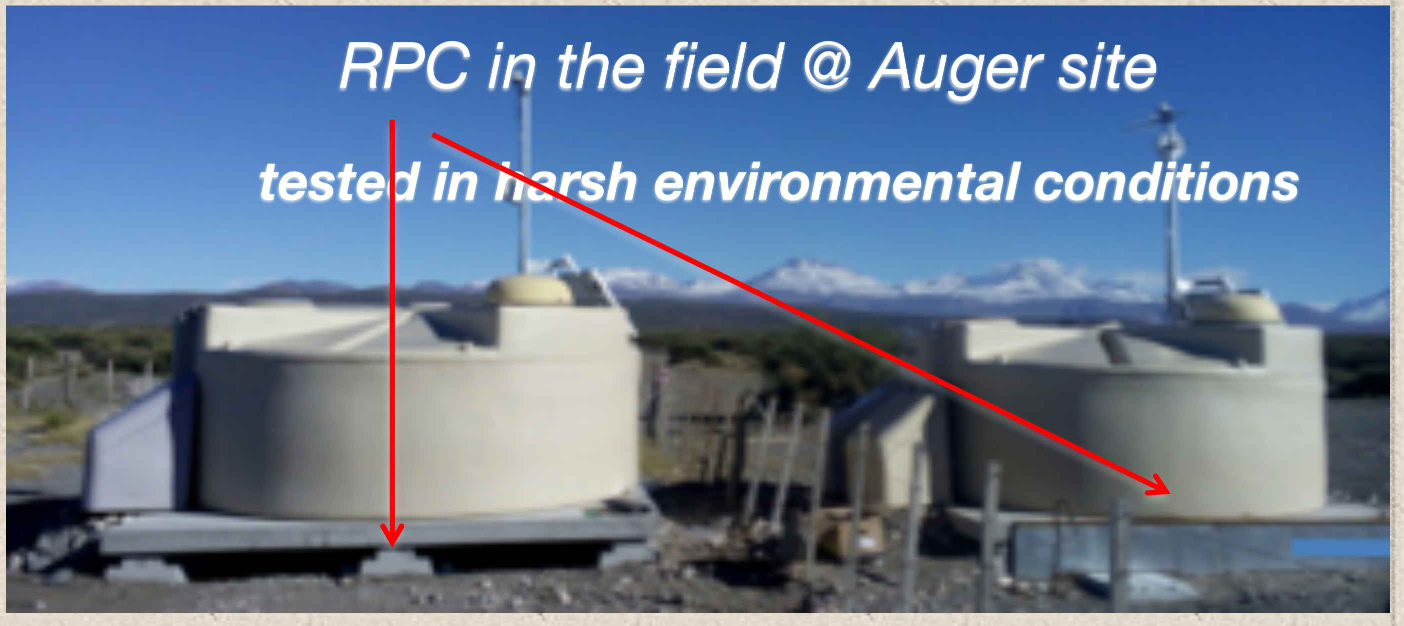
60 x 30 stations

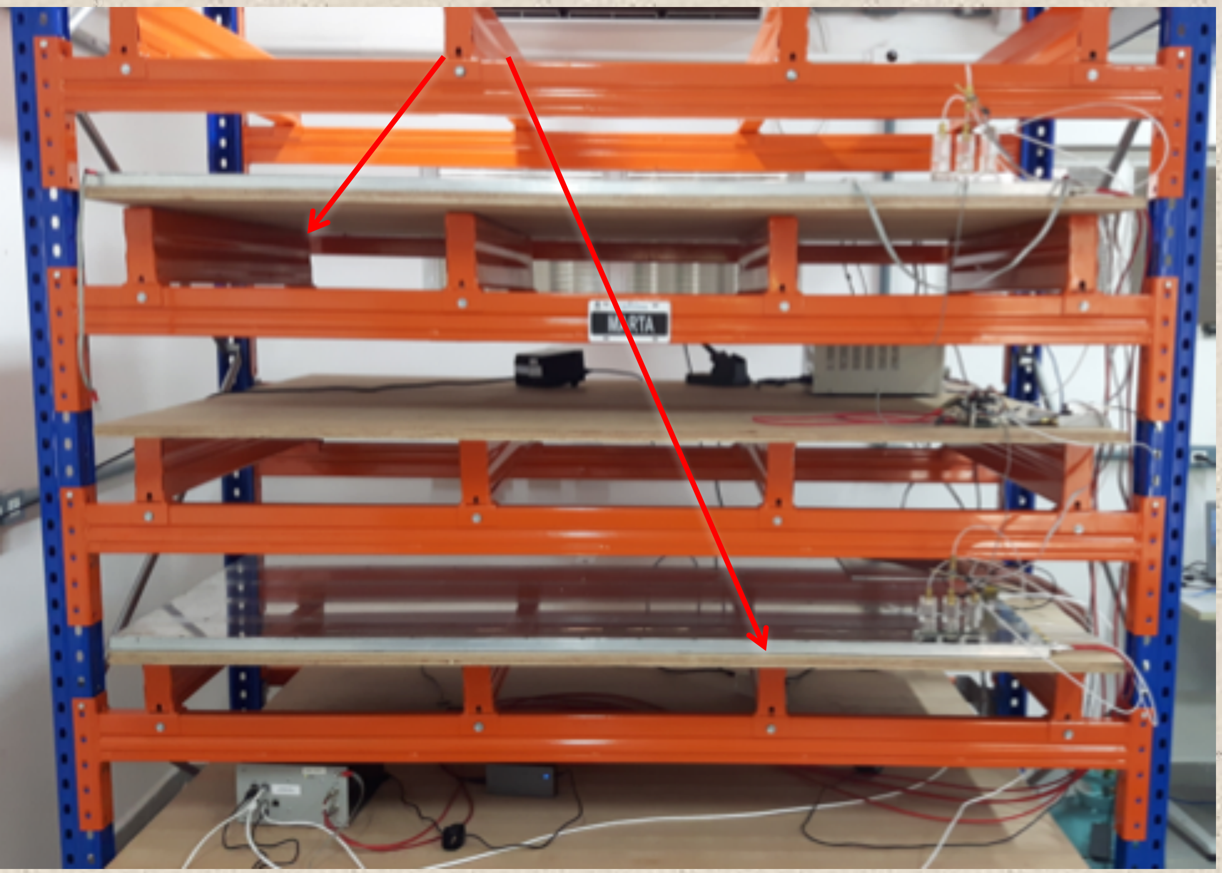
~ $100 \times 100\ m^2$

Ongoing developments and test on RPCs

Same RPCs of the MARTA project (Muon Array with RPCs for Tagging Air showers) used for studying WCD response of the Pierre Auger Observatory



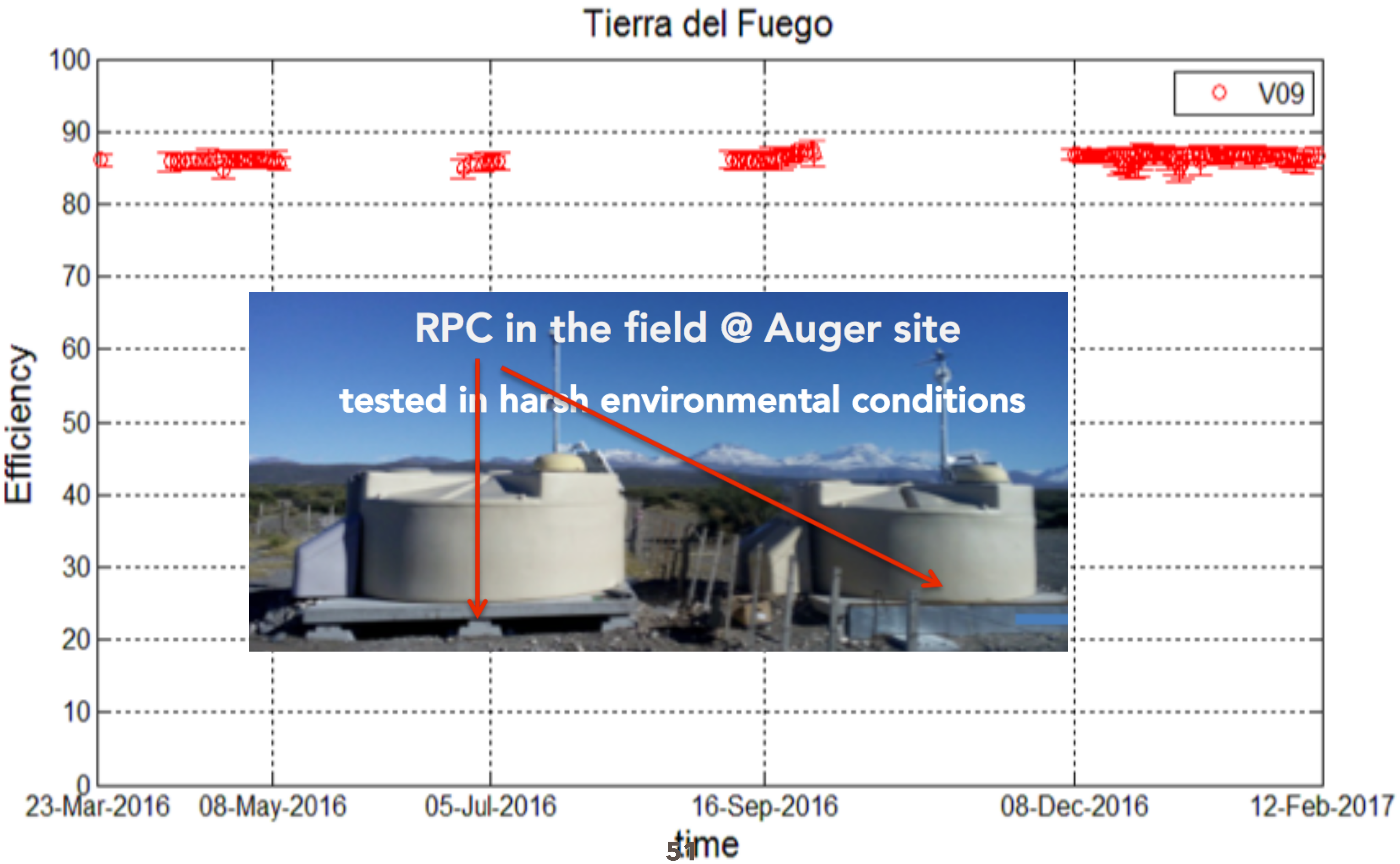




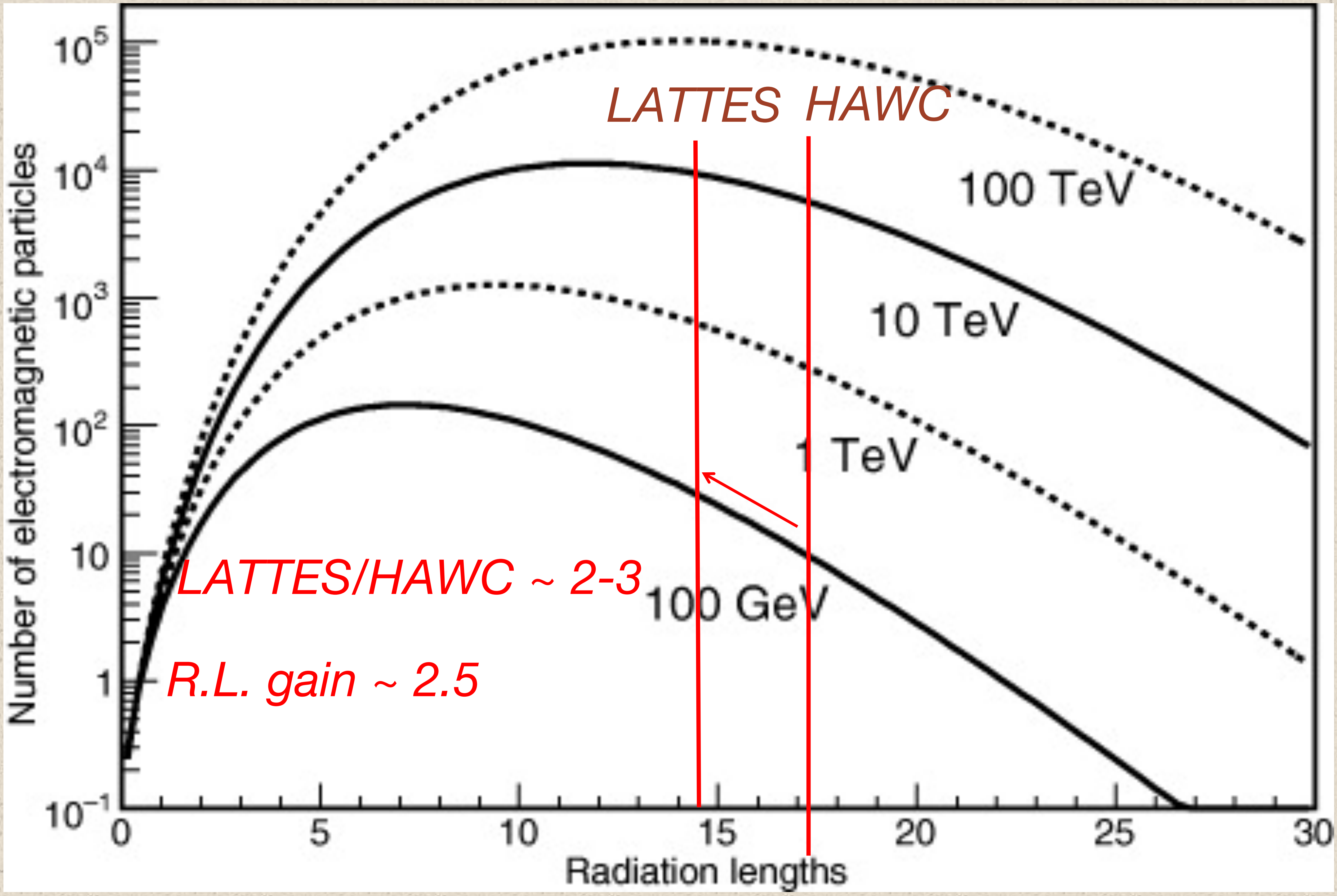
CBPF RPC telescope

- *characterize RPC telescope operation*
- *comparison with a dedicated MC simulation*
- *synergy between two experiments/techniques*
- *RPC used for absolute calibration of SSD*

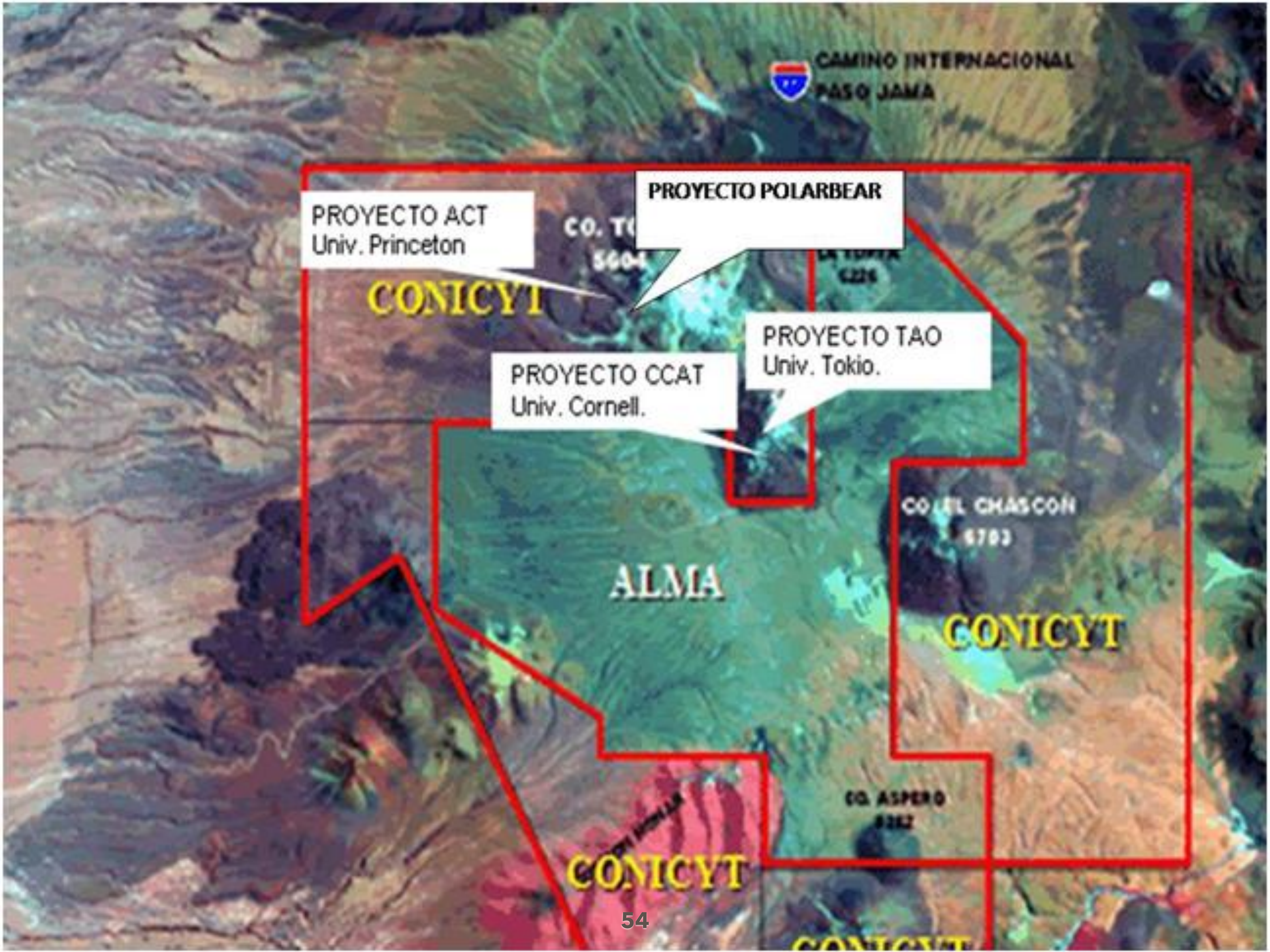
Why RPC's?
MARTA performance on hostile environment



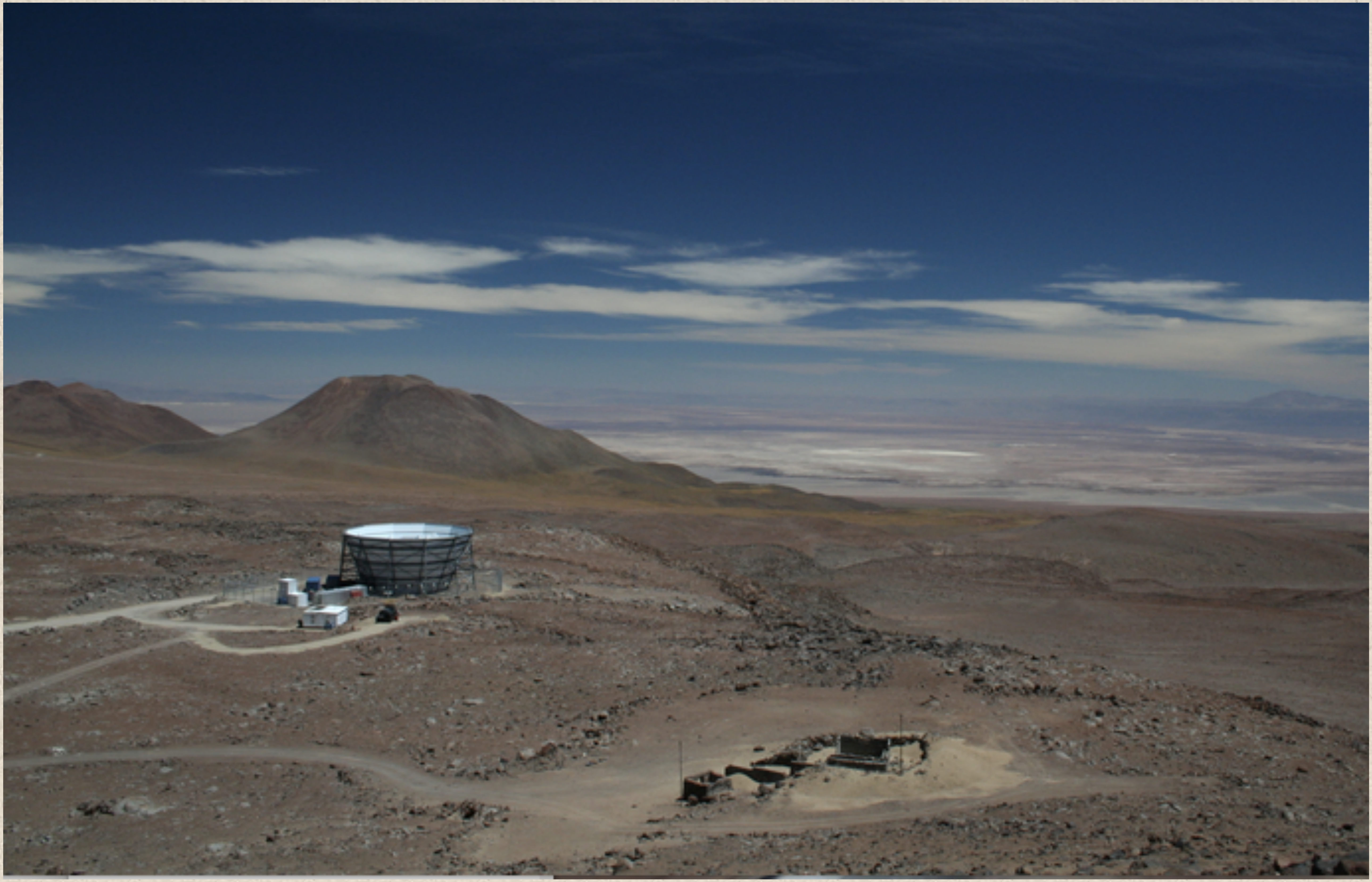
LATTES (Altitude?)



Site for LATTES

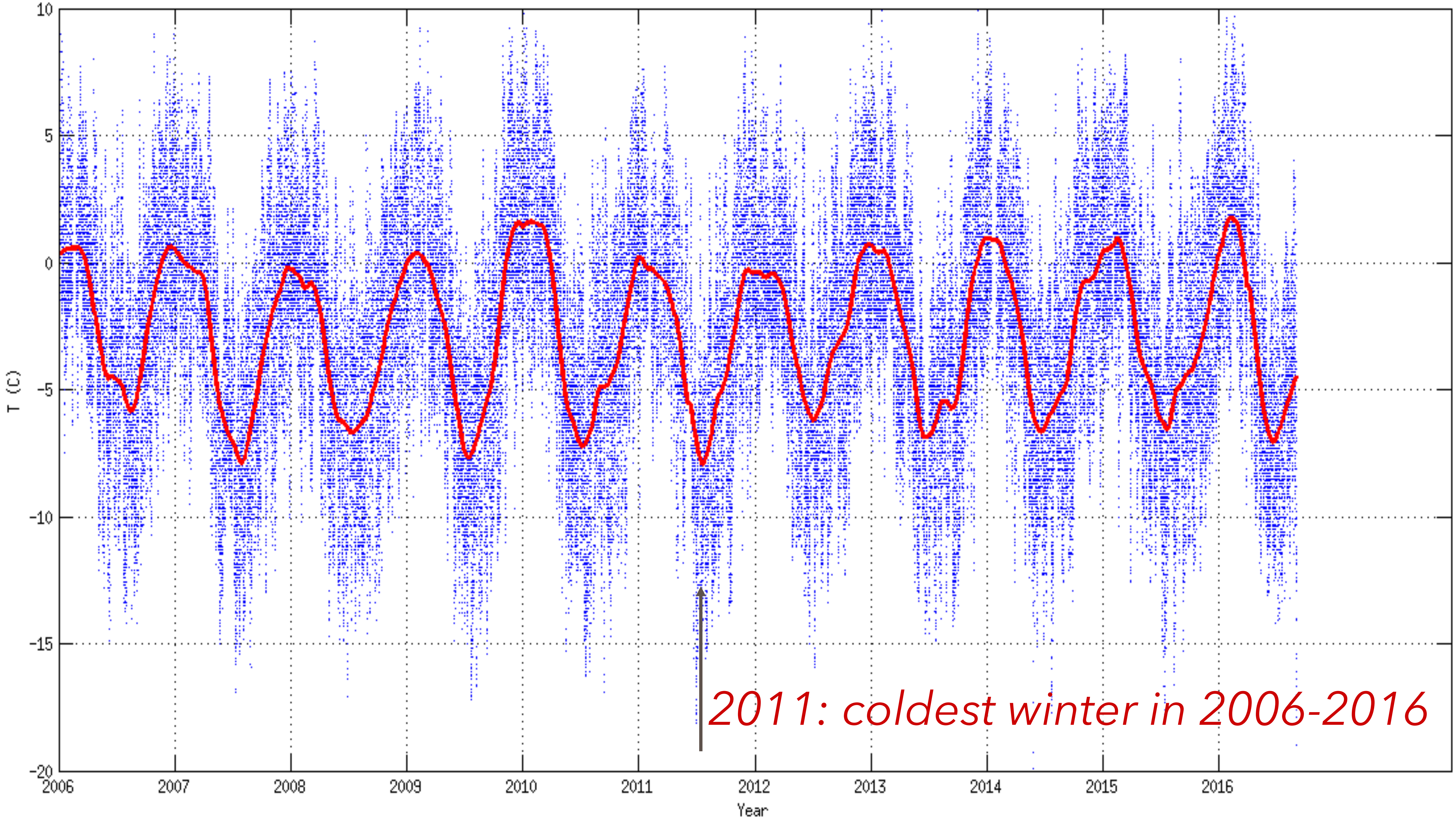

CAMINO INTERNACIONAL
PASO JAMA
PROYECTO POLARBEAR
PROYECTO ACT
Univ. Princeton
CONICYT
PROYECTO TAO
Univ. Tokio.
PROYECTO CCAT
Univ. Cornell.
CO. EL CHASCON
ALMA
CONICYT
CONICYT

Site for LATTES



MODELING – ATMOSPHERE

Data from the ALMA site



Alternative Site for LATTES: San Antonio de los Cobres AR

Site

San Antonio de los Cobres
San
LATTES
5000 m
Banelco Macro
Matienzo
Av. Brígido Zab
Av. Gral. Manuel Belgrano
Hotel de las Nubes
Restaurant Los Patitos
40
YPF
51
Av. la vicuñita
Ayacucho
Sarmiento
Banco Macro
40
Padre Marcenaro Boutell
Av. Brígido Zabaleta
Resto Bar El Malevo
Sumaq Samay

CONCLUSION

AUGER

- *Is a mature experiment, stable and collecting large amount of data*
- *Bound to take data at least until 2025*
- *Preparing the upgrade to improve the resolution on the mass composition*
- *Keep tuned, important results on the verge of being announced*

LATTES

- *Is a large field of view (FOV) γ ray experiment in SA*
- *Complementary to CTA*
- *Next generation of hybrid gamma ray experiments*
- *Good sensitivity to low energy (100 GeV)*
- *Tool to alert on variable sources and transients*