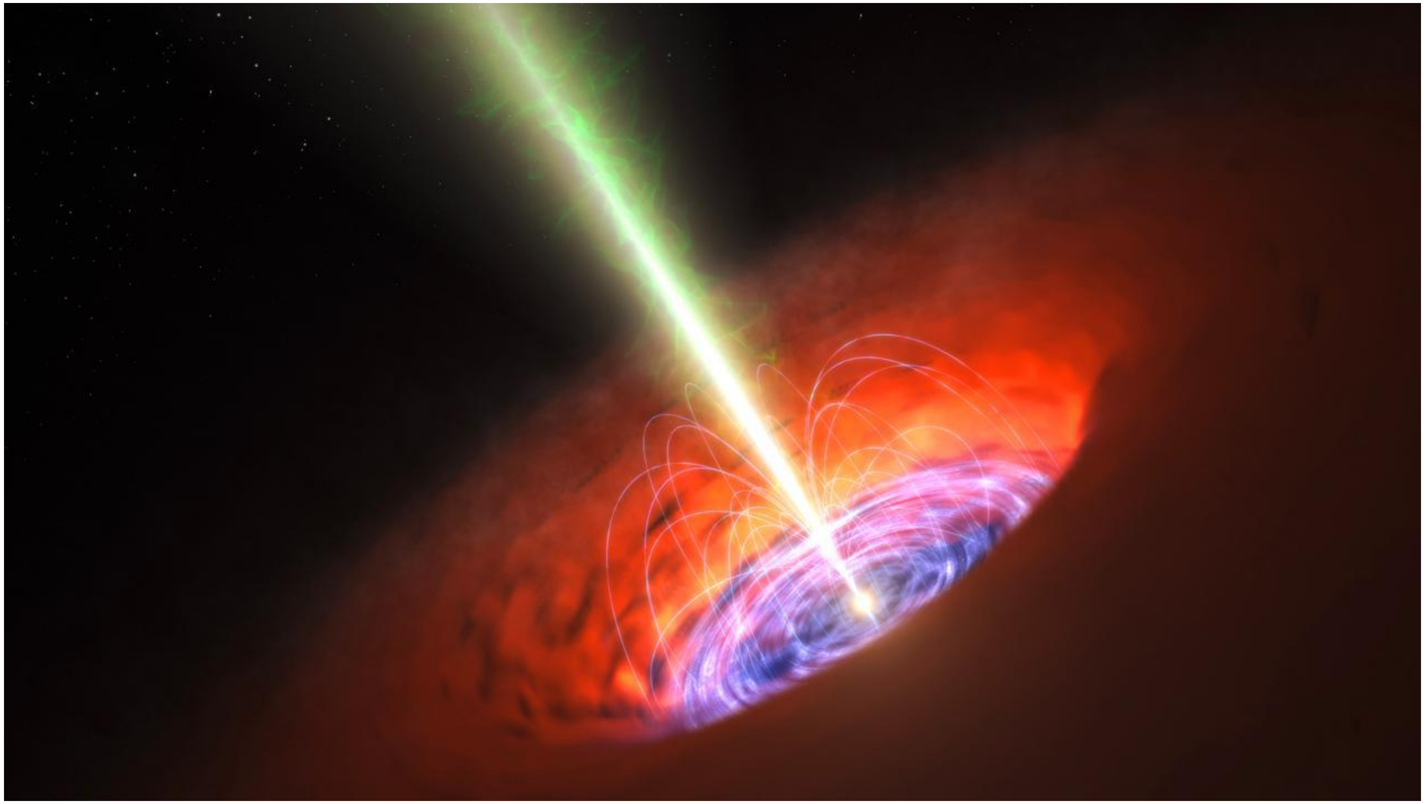
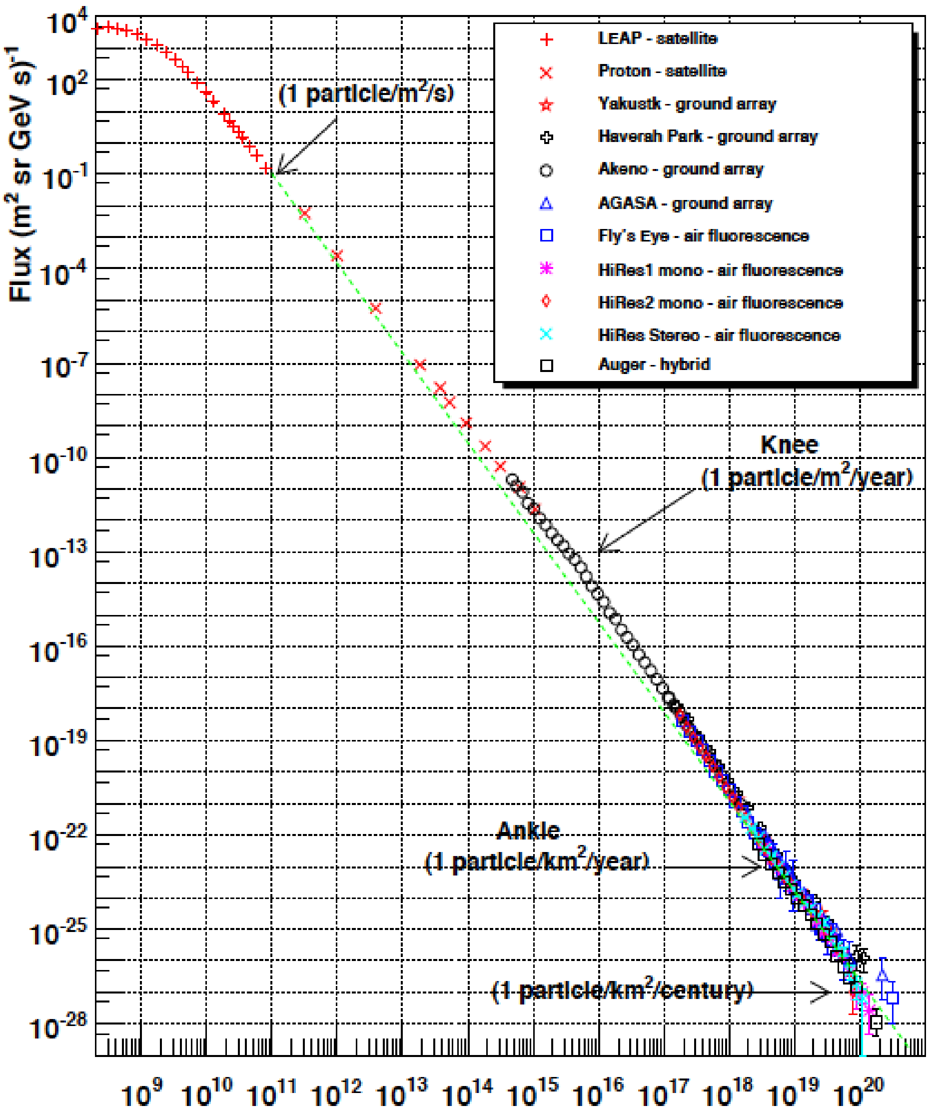
The Extreme Universe:
high energy cosmic rays



Mário Pimenta,
Valencia, May 2018

Charged cosmic rays (p/nucleus)

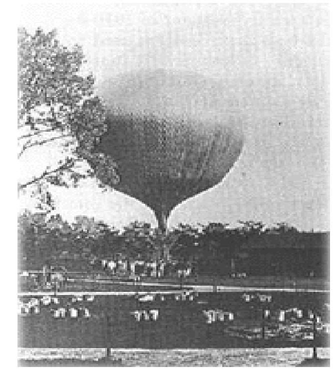
Viktor Hess, 1912



http://www.physics.utah.edu/~whanlon/spectrum.html

LHC

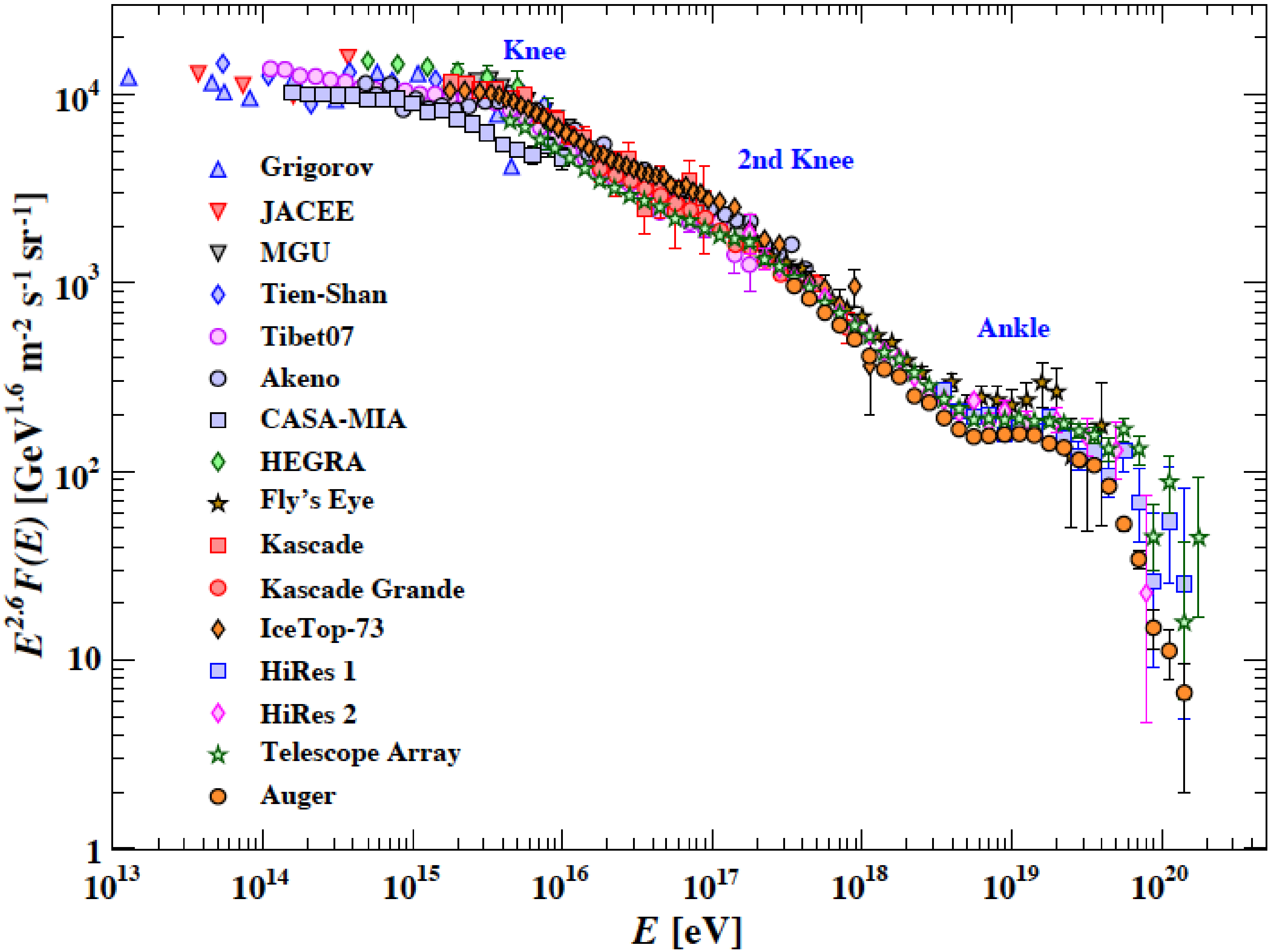
100 TeV



$$\frac{dN}{dE} \propto E^{-\alpha}$$

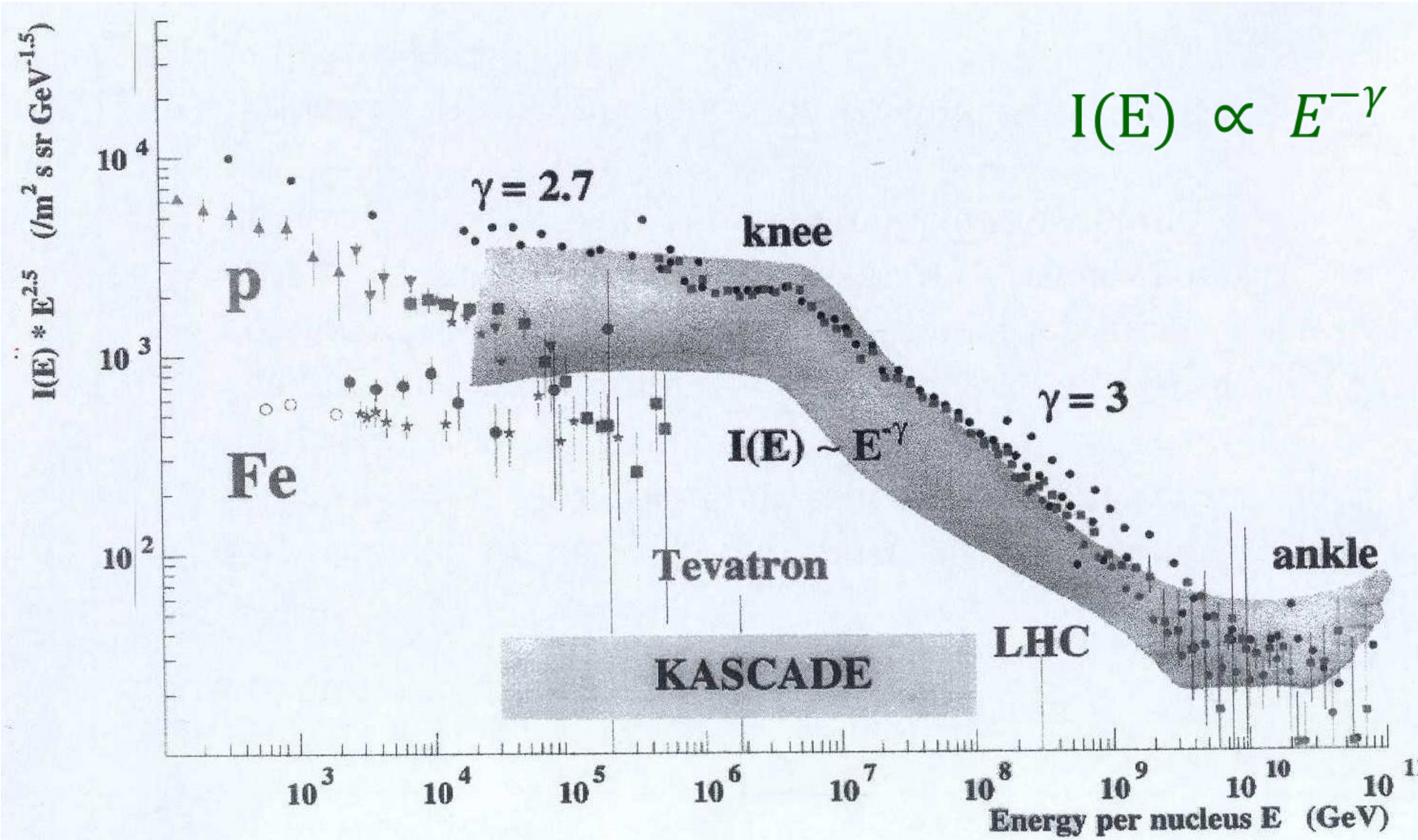
$$\alpha = \begin{cases} 2.7 & E < 10^{16} \\ 3.0 & 10^{16} < E < 10^{18} \\ 2.7? & E > 10^{18} \end{cases}$$

Energy spectrum (E >10^{14} eV)

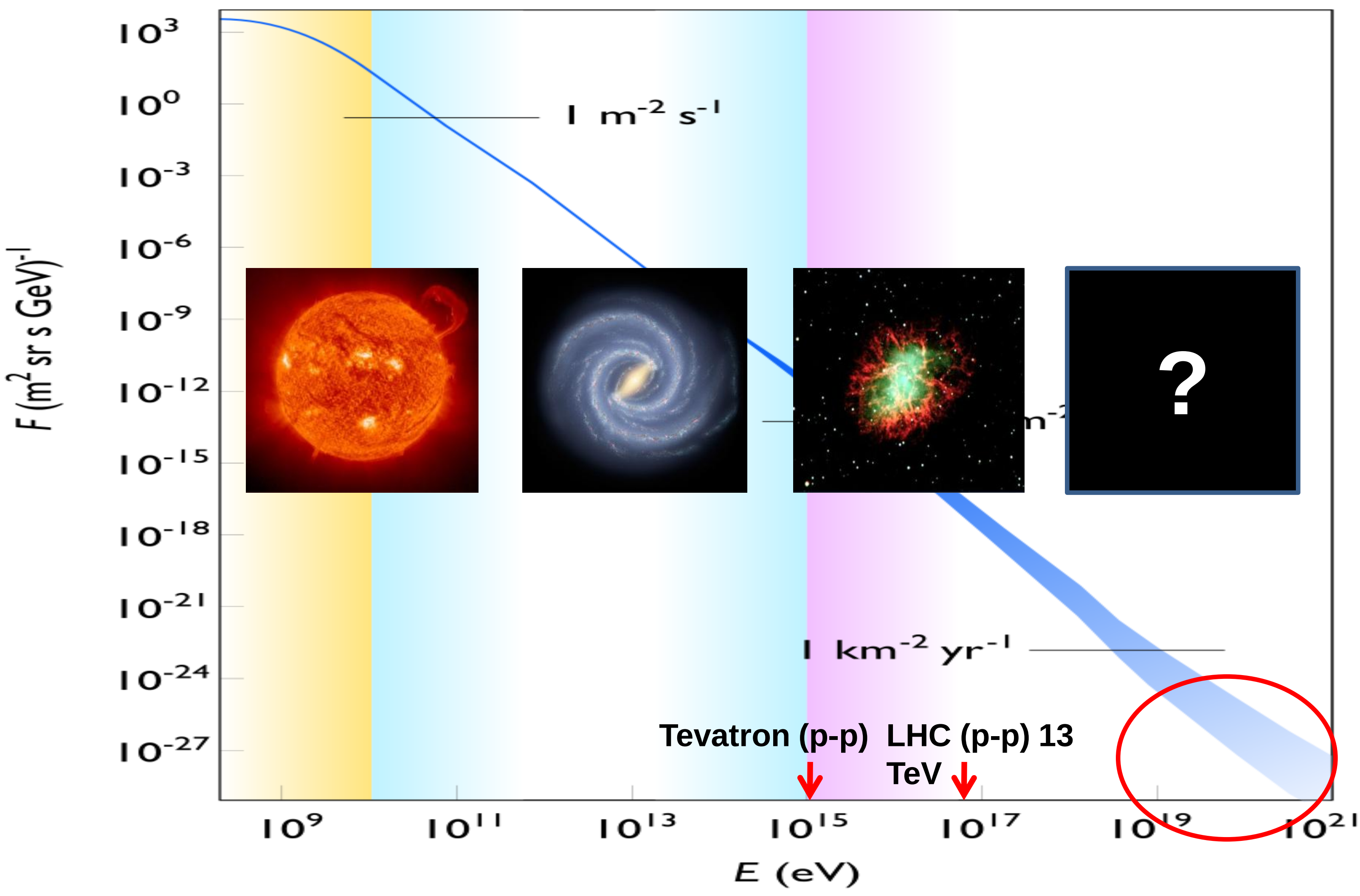


From Beatty, Matthews, and Wakely, “Cosmic Rays", in Review of Particle Physics, 2018

Anthropomorphic representation

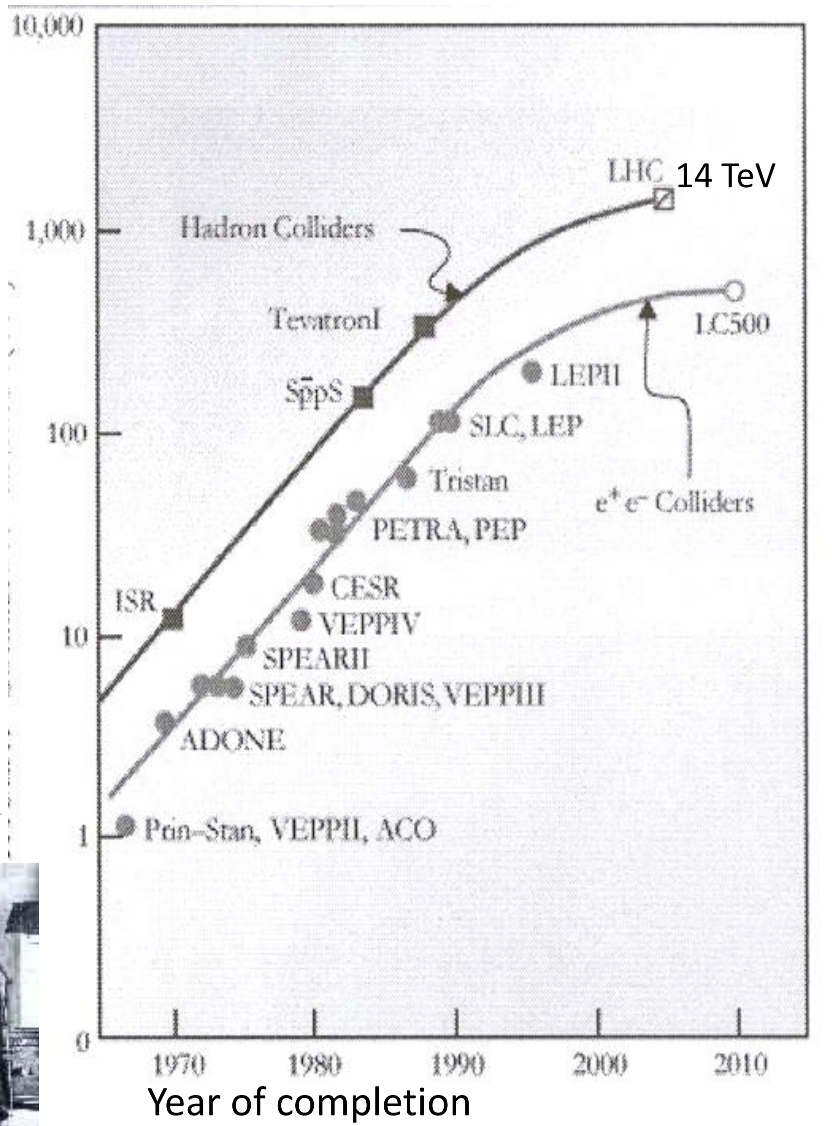


Origin ?



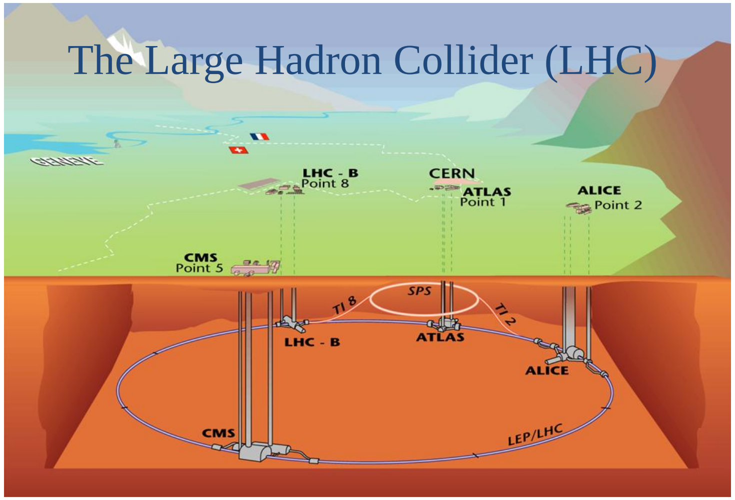
10^3
10^0
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-18}
10^{-21}
10^{-24}
10^{-27}
F (m^2 sr s GeV)$^{-1}$
1 m^{-2} s^{-1}
?
1 km^{-2} yr^{-1}
Tevatron (p-p)
LHC (p-p) 13 TeV
10^9
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
10^{21}
E (eV)

Surpass human-made accelerators !



~ 10 MeV

~1930



R ~10 km, B ~ 10 T

E ∝ BR ~ 10 TeV

High Luminosity

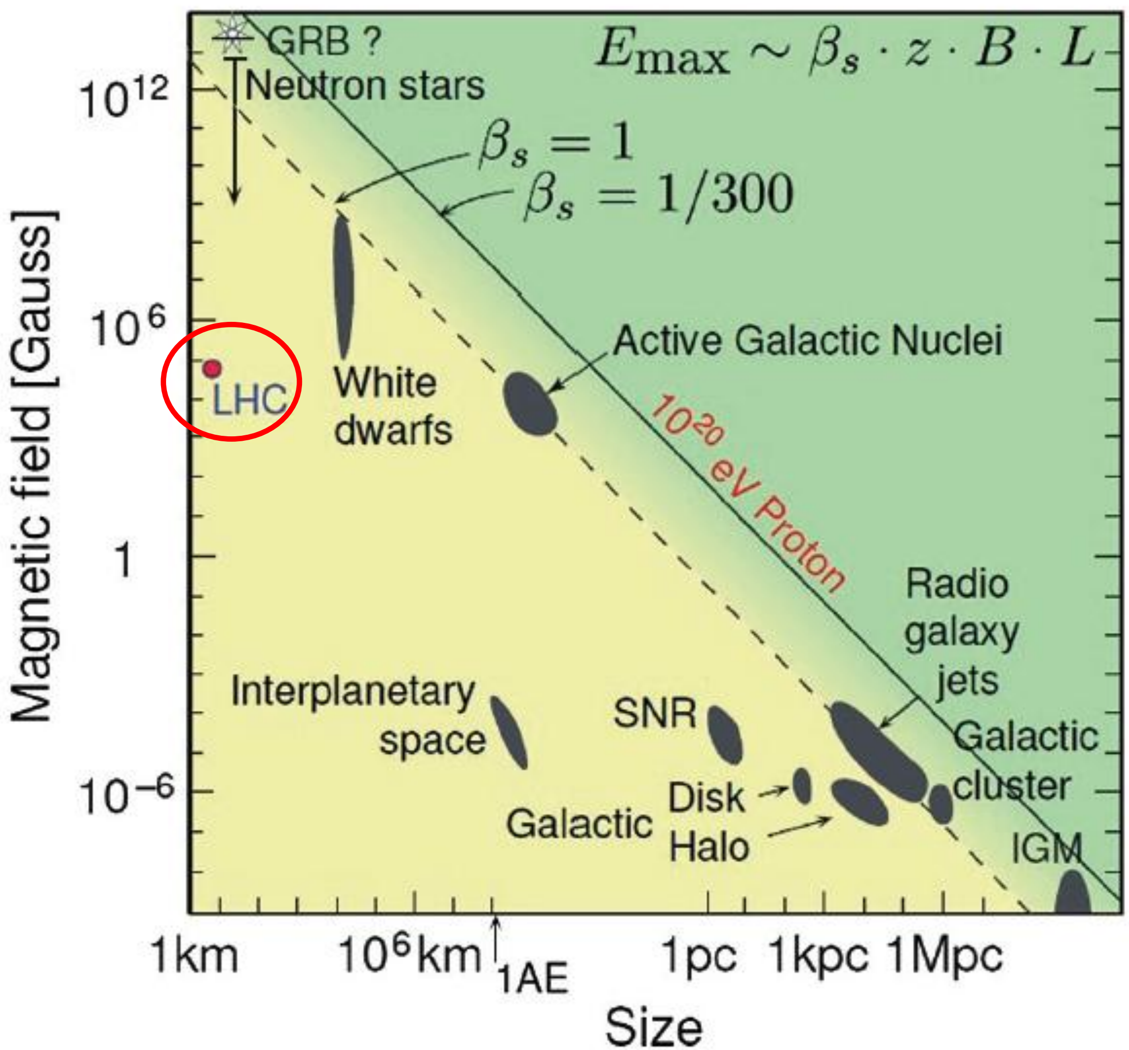
Sophisticated detectors

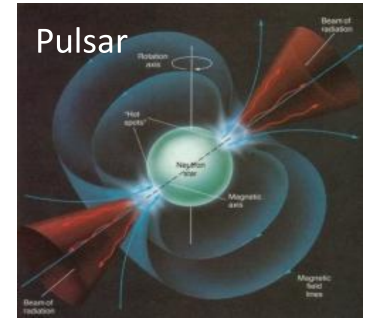
Central region

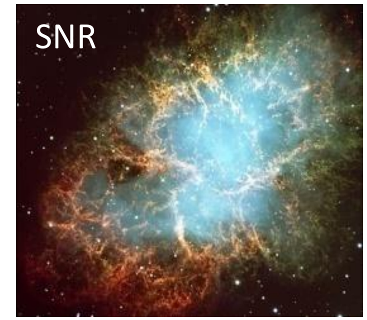
Energy limited

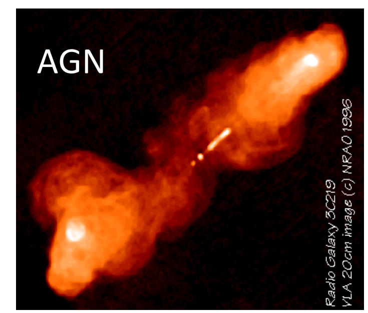
Where can be these accelerators in the Universe?

Hillas plot



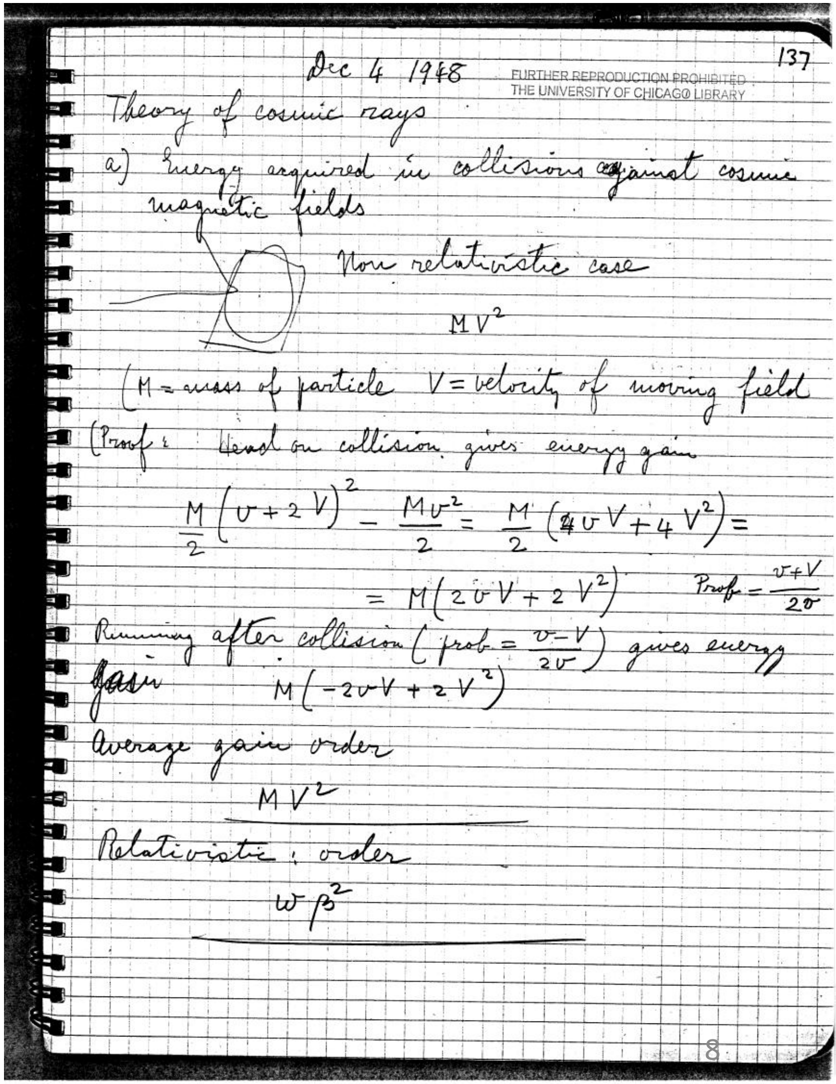






How to generate bottom-up energies much higher than thermal?

Enrico Fermi, Werner Heisenberg and Wolfgang Pauli



137

Dec 4 1948

Theory of cosmic rays

a) Energy acquired in collisions against cosmic magnetic fields

Non relativistic case

MV^2

(M = mass of particle V = velocity of moving field

(Prob: Head on collision gives energy gain

$$\frac{M}{2}(v+2V)^2 - \frac{Mv^2}{2} = \frac{M}{2}(4vV+4V^2) =$$

$$= M(2vV+2V^2) \qquad \text{Prob} = \frac{v+V}{2v}$$

Running after collision (prob $= \frac{v-V}{2v}$) gives energy gain

$$M(-2vV+2V^2)$$

Average gain order

MV^2

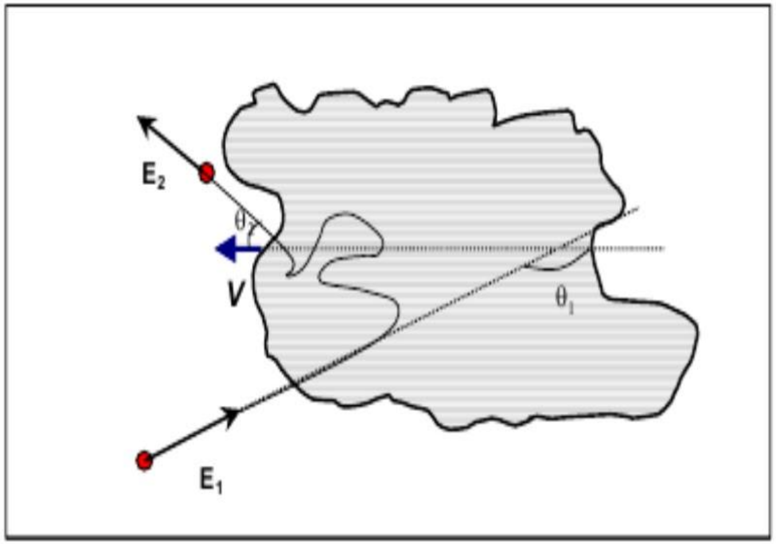
Relativistic: order

$w\beta^2$

Acceleration mechanism

Fermi 2nd order (1949)

particles accelerated in stochastic collisions with massive interstellar clouds (collisions to a moving diffusive wall!)



In the cloud reference frame

$$E_1^* = \gamma\, E_1(1 - \beta \cos\theta_1)$$
$$E_2^* = E_1^*$$

Back to the Lab reference frame

$$E_2 = \gamma\, E_2^* \,(1 + \beta \cos\theta_2^*)$$

Then:

$$\frac{\Delta E}{E} = \frac{1 - \beta\cos\theta_1 + \beta\cos\theta_2^* - \beta^2\cos\theta_1\cos\theta_2^*}{1-\beta^2} - 1$$

But:

$$\langle\cos\theta_2^*\rangle = 0$$

$$\langle\cos\theta_1\rangle = \frac{\int_{-1}^{1}\cos\theta_1 \overbrace{(1-\beta\cos\theta_1)}^{\text{Probability}}\,d\cos\theta_1}{\int_{-1}^{1}(1-\beta\cos\theta_1)\,d\cos\theta_1} = -\frac{\beta}{3}$$

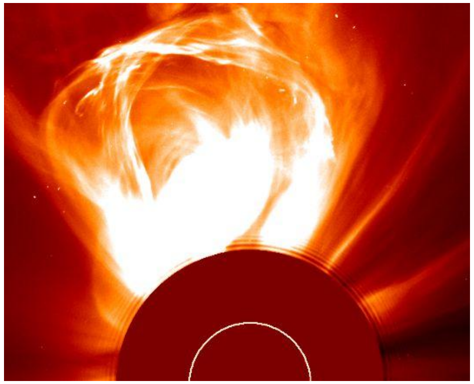
$$\left\langle\frac{\Delta E}{E}\right\rangle \simeq \frac{4}{3}\beta^2$$

$\beta \sim 10^{-4}$!!!

Acceleration mechanism

Fermi 1st order

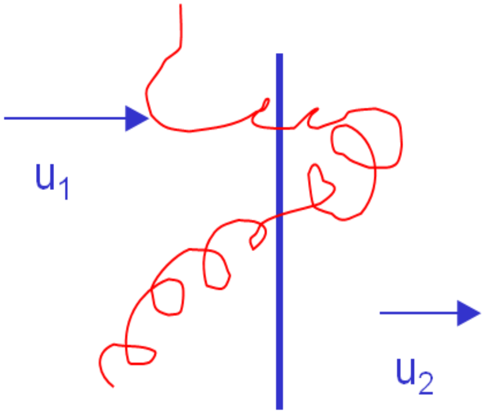
Solar coronal mass ejection 9 Mar 2000



Shock formation :

- Sudden release of Energy (CMEs, SNRs, GRBs,…)
- Supersonic flow hits an obstacle (AGNs jets, pulsar winds, …)

Particles gain energy by consecutive crossings of the shock front!



$$\frac{\Delta E}{E} = \frac{1 - \beta\cos\theta_1 + \beta\cos\theta_2^* - \beta^2\cos\theta_1\cos\theta_2^*}{1-\beta^2} - 1$$

Crossing probability α cos(θ)

Now (plane shock front):

$$\langle\cos\theta_1\rangle = \frac{\int_{-1}^{0}\cos^2\theta_1\, d\cos\theta_1}{\int_{-1}^{0}\cos\theta_1\, d\cos\theta_1} = -\frac{2}{3}$$

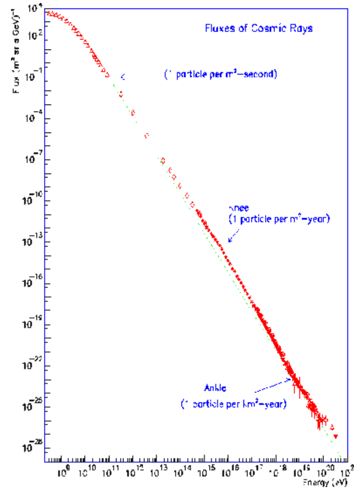
$$\langle\cos\theta_2^*\rangle = \frac{\int_{0}^{1}\cos^2\theta_2^*\, d\cos\theta_2^*}{\int_{0}^{1}\cos\theta_2^*\, d\cos\theta_2^*} = \frac{2}{3}$$

$$\left\langle\frac{\Delta E}{E}\right\rangle \simeq \frac{4}{3}\beta$$

The power law

$$\frac{dN}{dE} \propto E^{-\gamma}$$

$$(N > E) \propto E^{-\gamma+1}$$



In each cycle the particle gains a small fraction of energy ε. After n cycles:

$$E_n = E_0 (1+ \varepsilon)^n$$

Or the number of cycles to attain an energy E is:

$$n = \ln(E/E_0)/\ln(1+\varepsilon)$$

The particle may escape from the shock region with some probability P_i. Then the probability to escape with $E>E_n$ is:

$$P_{E_n} = P_i \sum_{j=n}^{\infty} (1-P_i)^n = (1-P_i)^n$$

and

$$\frac{N}{N_0} = P_{E_n} = \left(\frac{E}{E_0}\right)^{-\alpha}$$

$$\alpha = -\frac{\ln(1-P_i)}{\ln(1+\epsilon)} \cong \frac{P_i}{\epsilon}$$

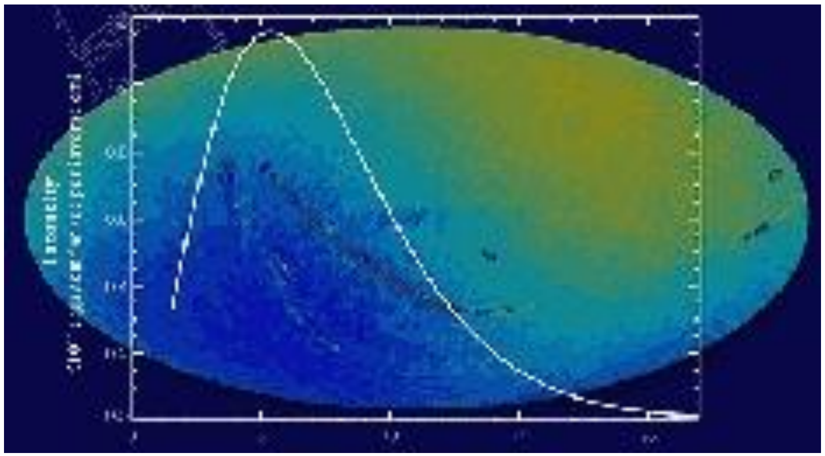
$$\frac{dN}{dE} \propto \left(\frac{E}{E_0}\right)^{-\gamma}$$ γ=α+1

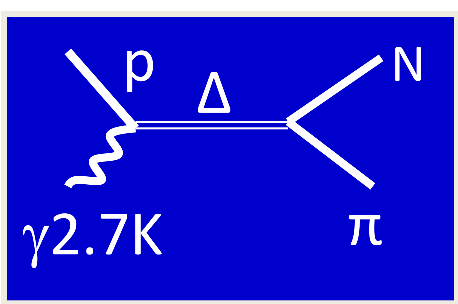
$$\boxed{\left(\frac{dN}{dE}\right)_{Source} \approx E^{-2}}$$

Supersonic shock

$$\boxed{\left(\frac{dN}{dE}\right)_{Earth} \propto \left(\frac{dN}{dE}\right)_{Source} .\tau_{esc}(E) \propto E^{-2.7}}$$

The Greisen-Zatsepin-Kuzmin (GZK) cutoff





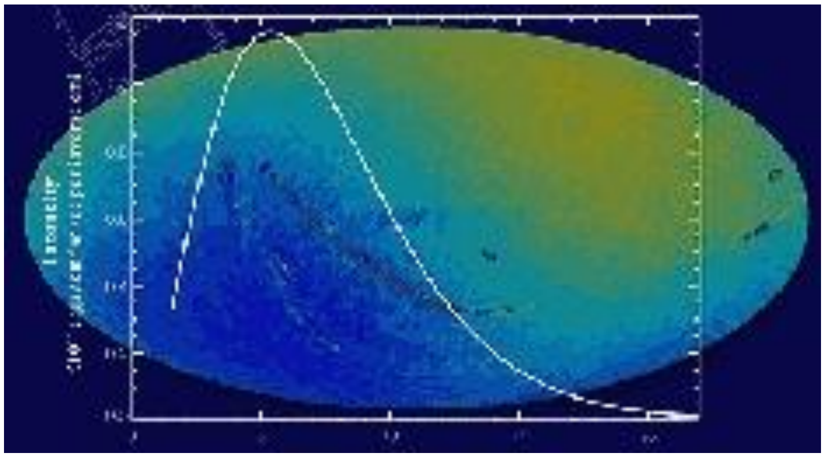
$$E_p \approx 10^{20}\,\mathrm{eV}$$

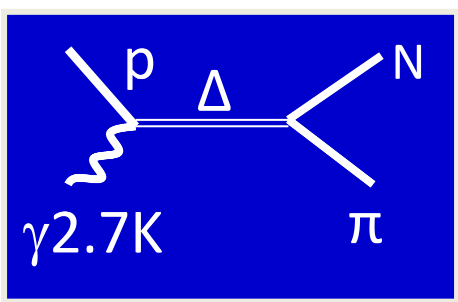
$$\lambda = \frac{1}{\sigma_{p\gamma}\,\rho_{CMB}} \approx 6\ \mathrm{Mpc}$$

$$\pi^0 \longrightarrow \gamma\gamma$$

$$\pi^+ \longrightarrow \mu^+ \nu_\mu \longrightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu$$

The Greisen-Zatsepin-Kuzmin (GZK) cutoff





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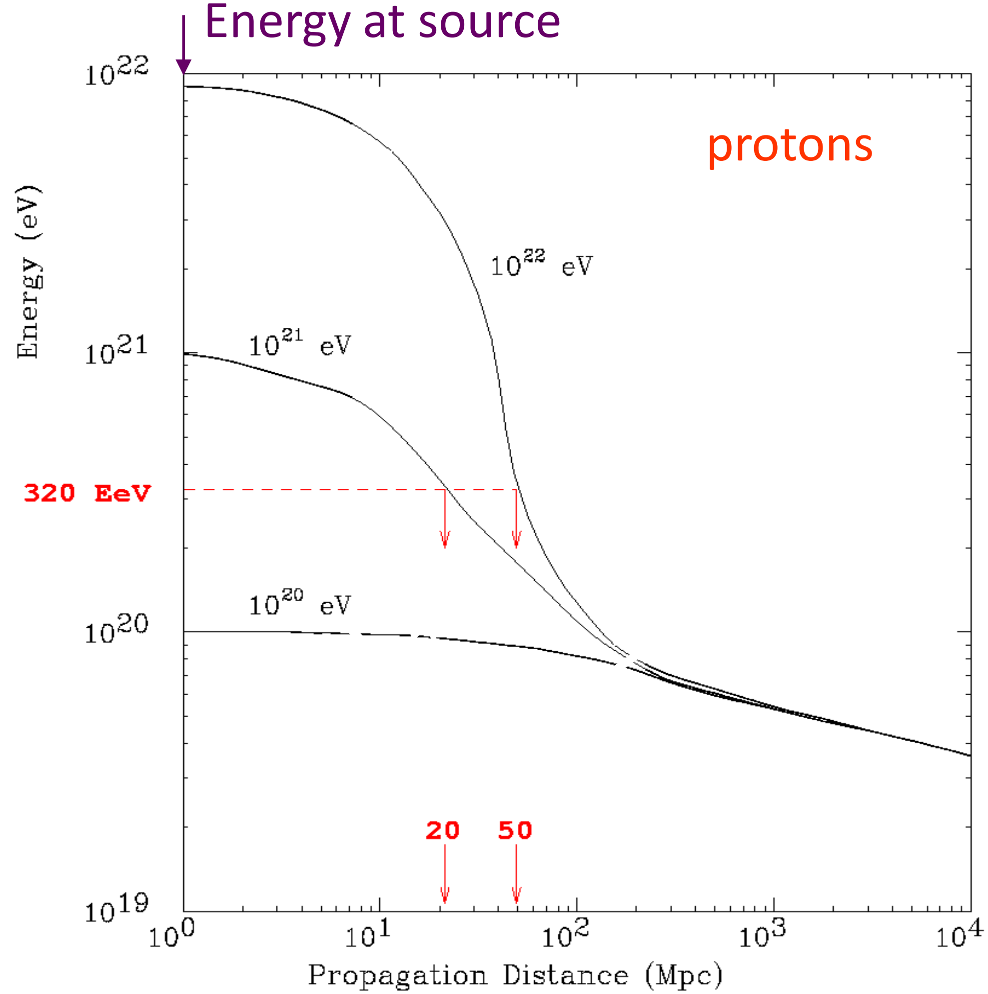
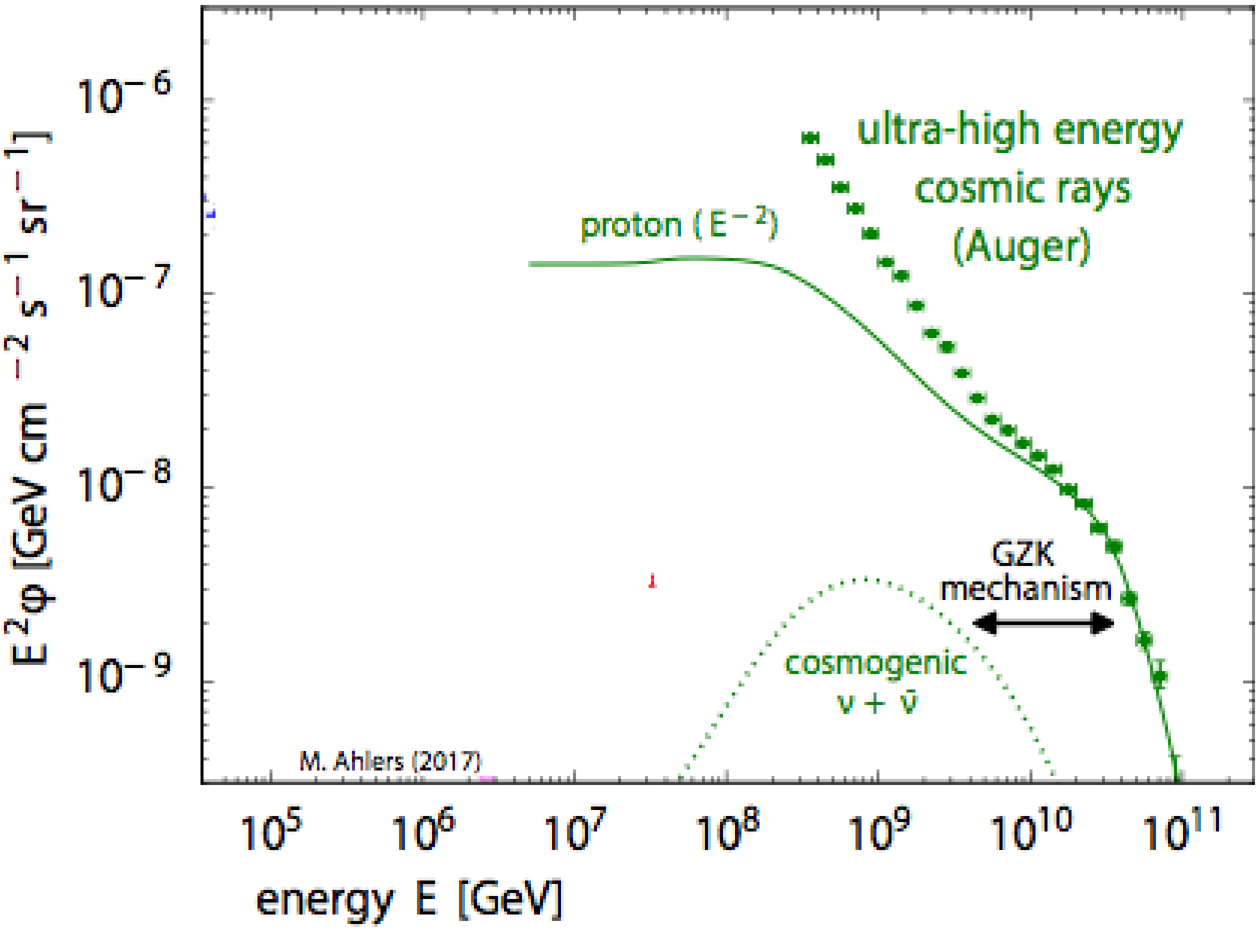


Propagation distance (Mpc)

Predicted (and observed) Spectrum



Particle flux multiplied by E^2

$$E^2 \frac{dN}{dE} = E \frac{dN}{d\ln E}$$

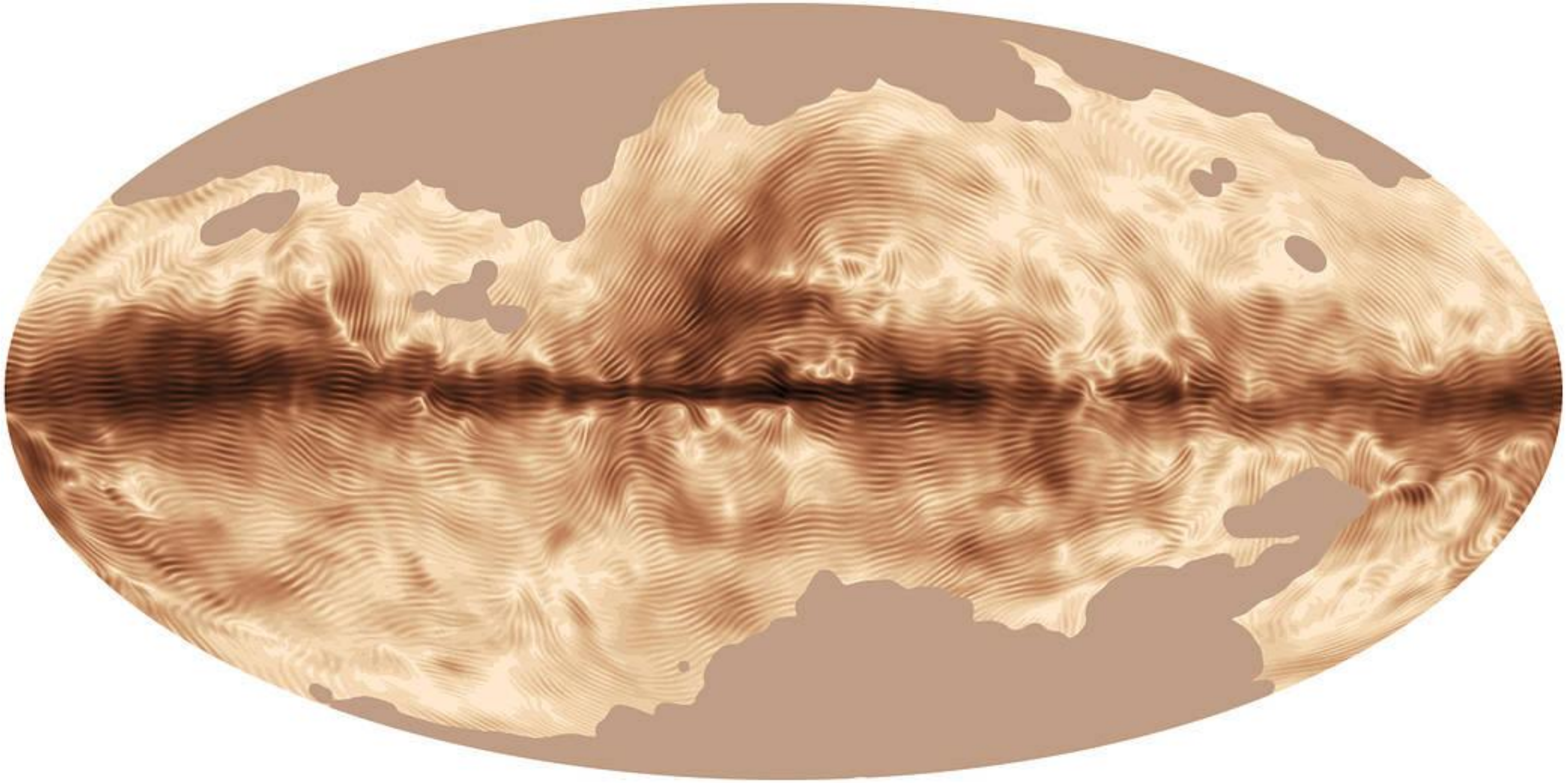
Energy density per decade

$$\rho_{\text{decade}} = \int_{\text{decade}} E \frac{dN}{d\ln E} \, d\ln E$$

No cosmogenic neutrinos observed so far

Milky Way Galactic Magnetic Field

as seen by Planck satellite

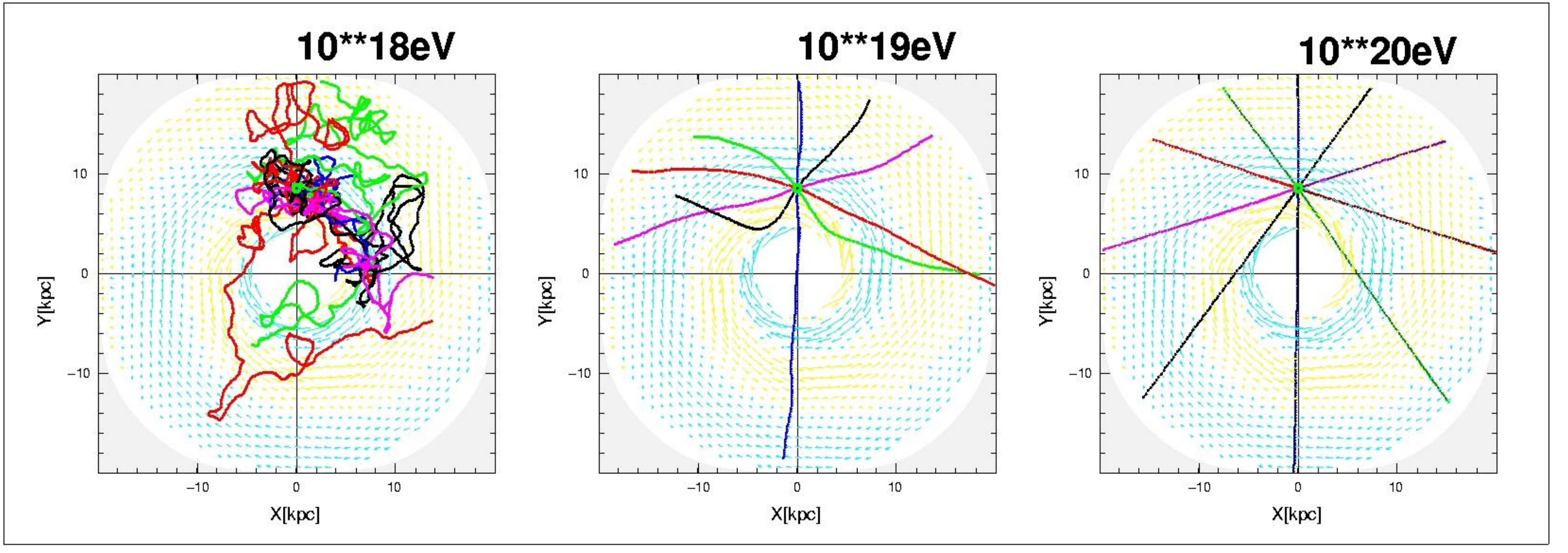


Galactic $B \sim 10^{-6}$ G

Extra-Galactic $B \leq 10^{-9}$ G

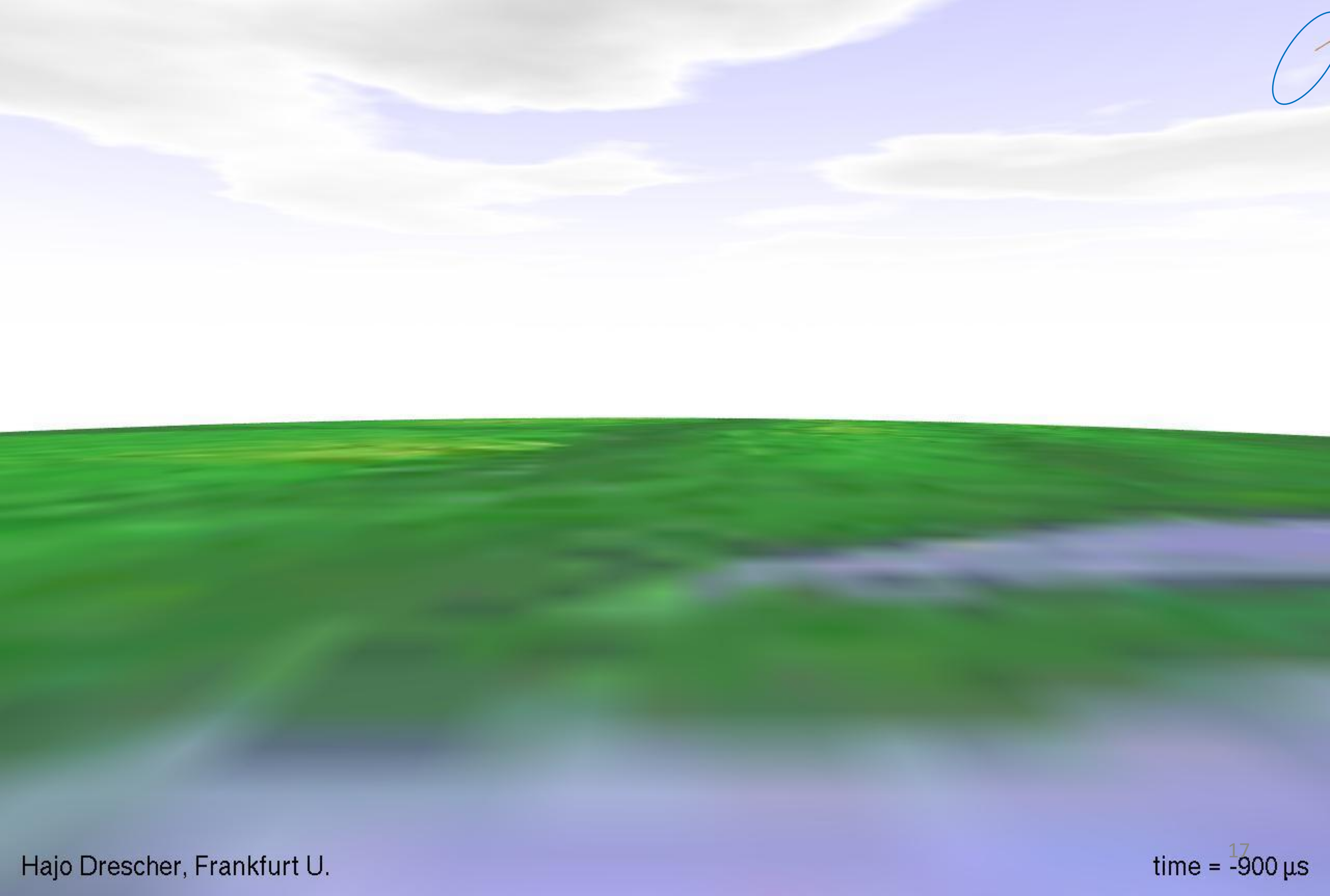
Deflection in the Galactic Magnetic Field (p)

T.Stanev

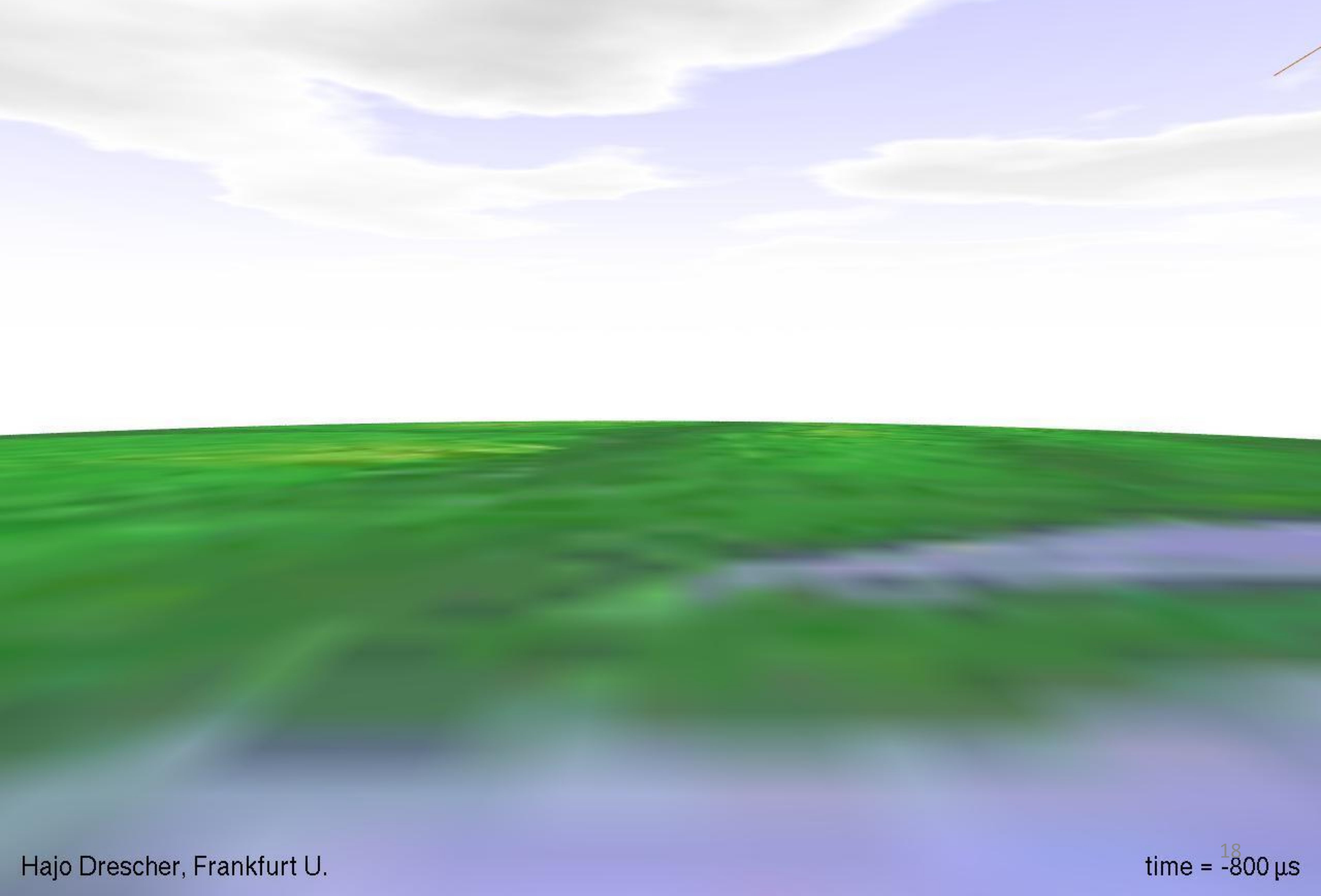


Above 10^{19} : Astronomy !

Entering in the Atmosphere

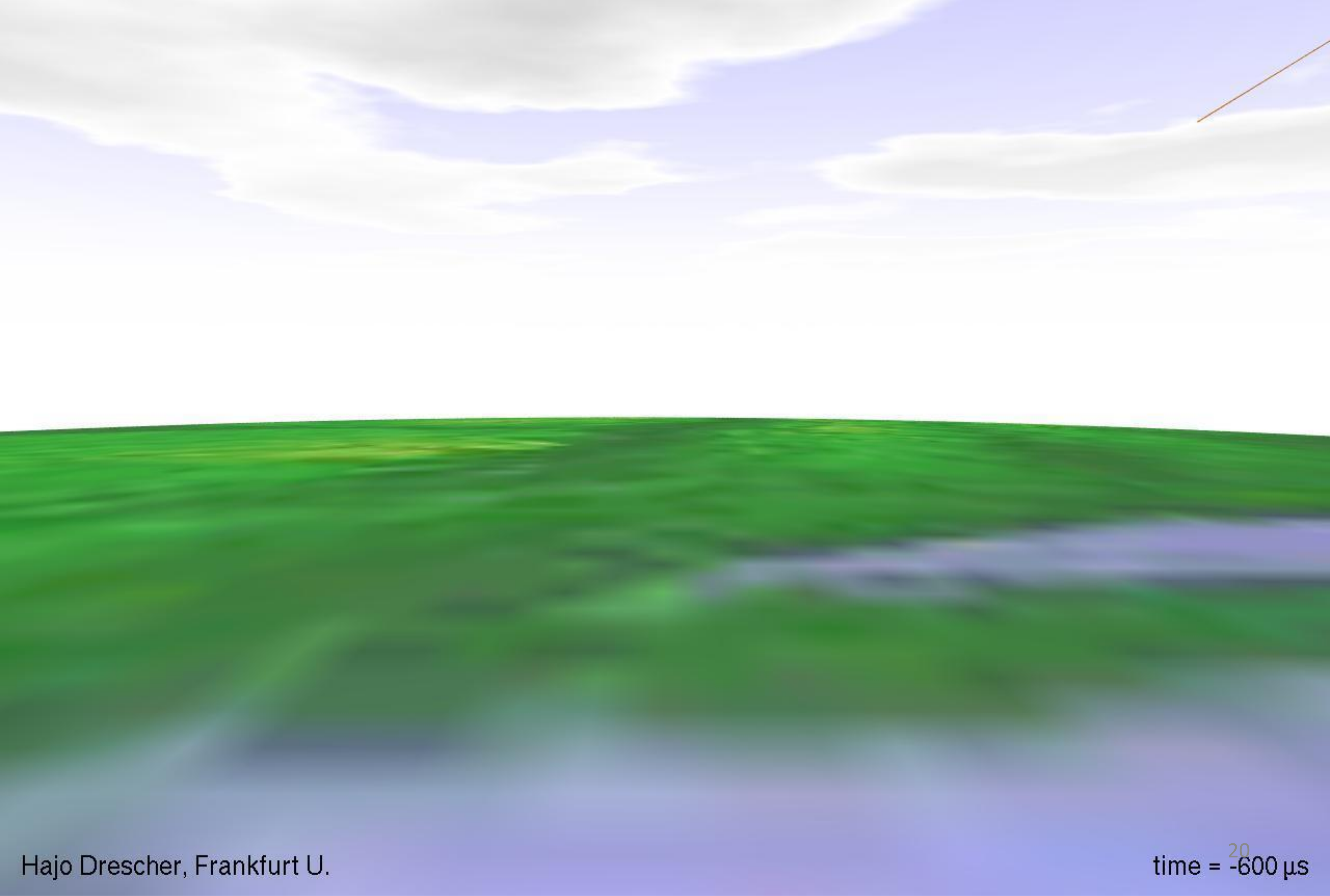


Entering in the Atmosphere



Entering in the Atmosphere

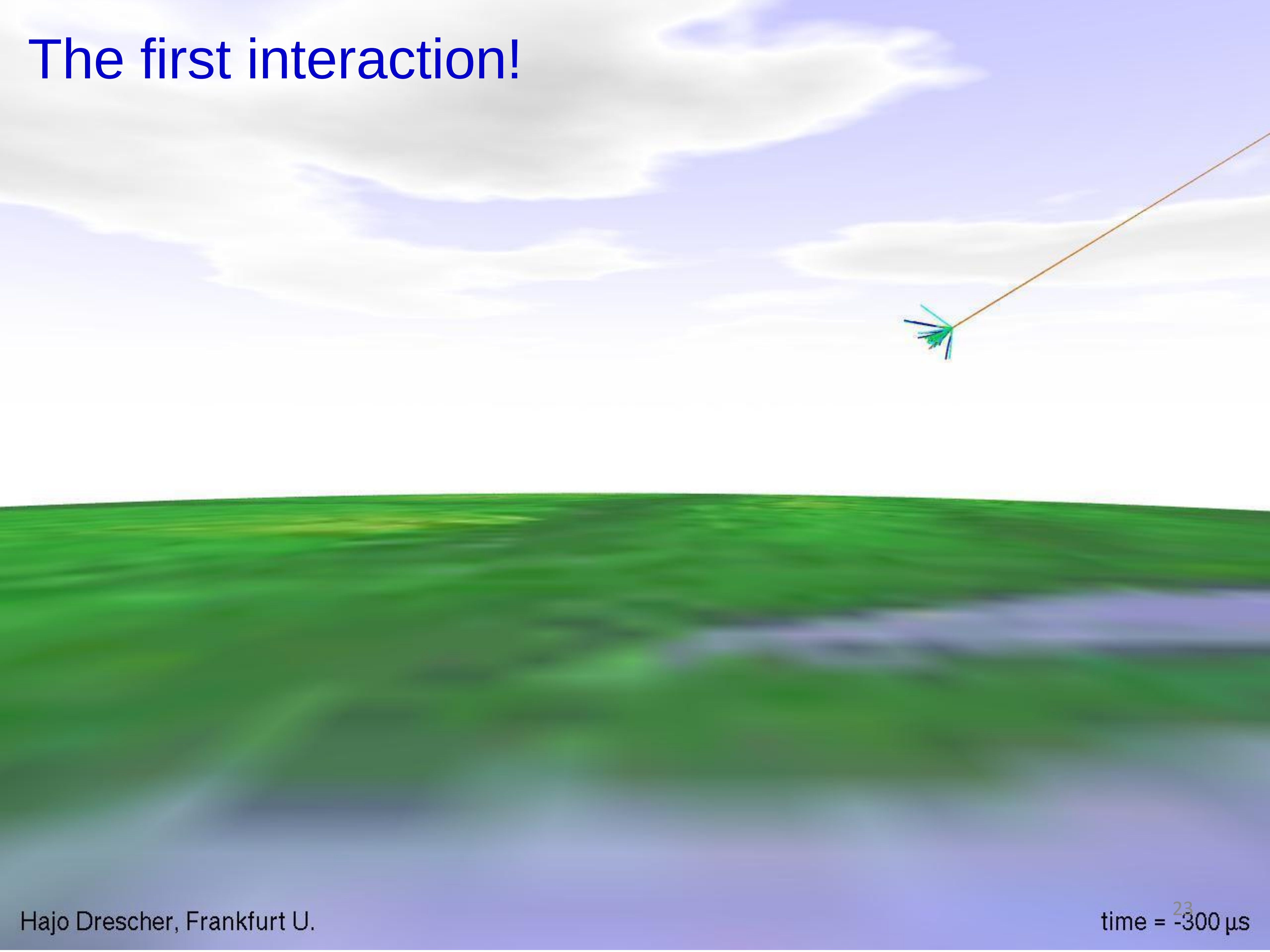
Entering in the Atmosphere



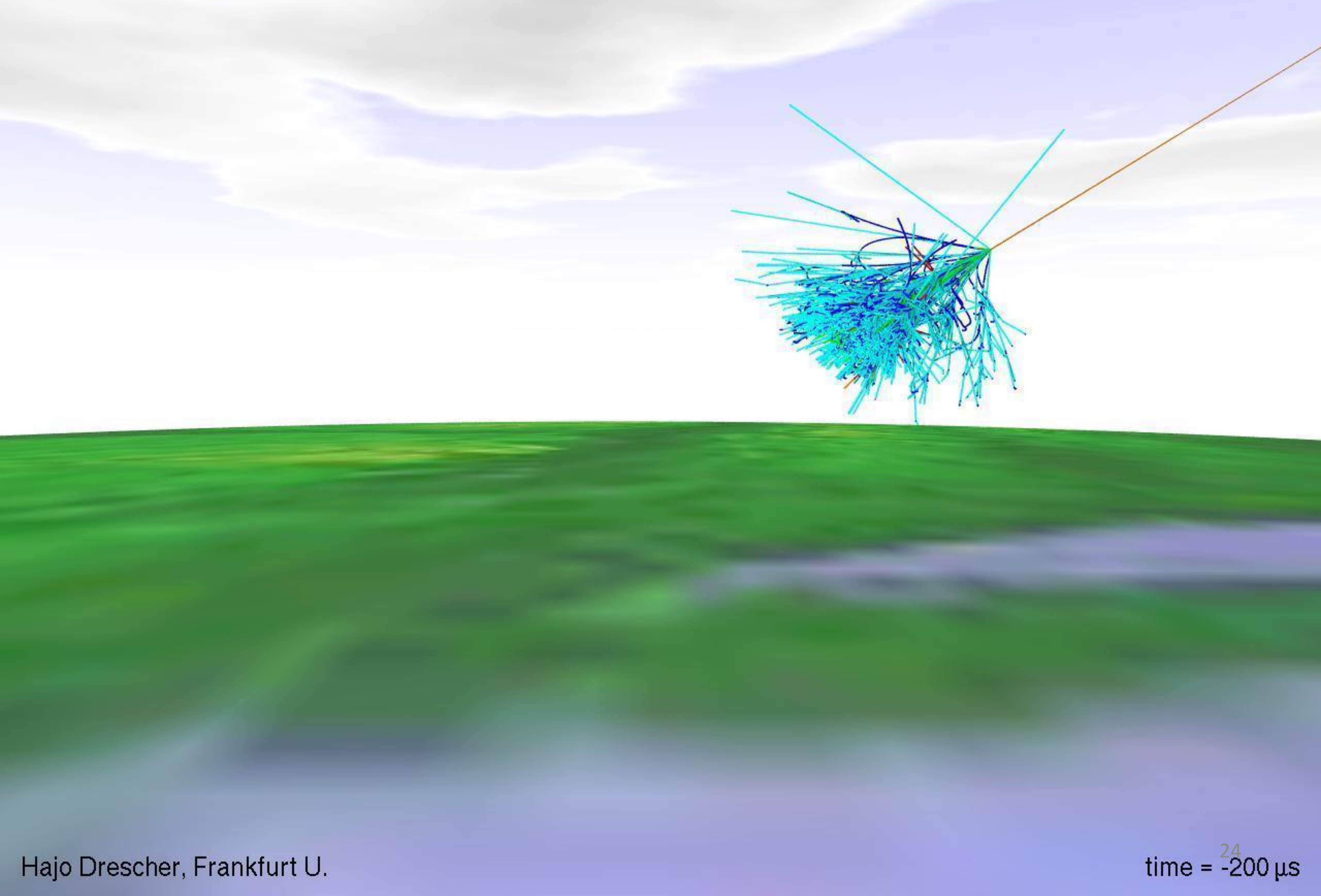
Entering in the Atmosphere

Entering in the Atmosphere

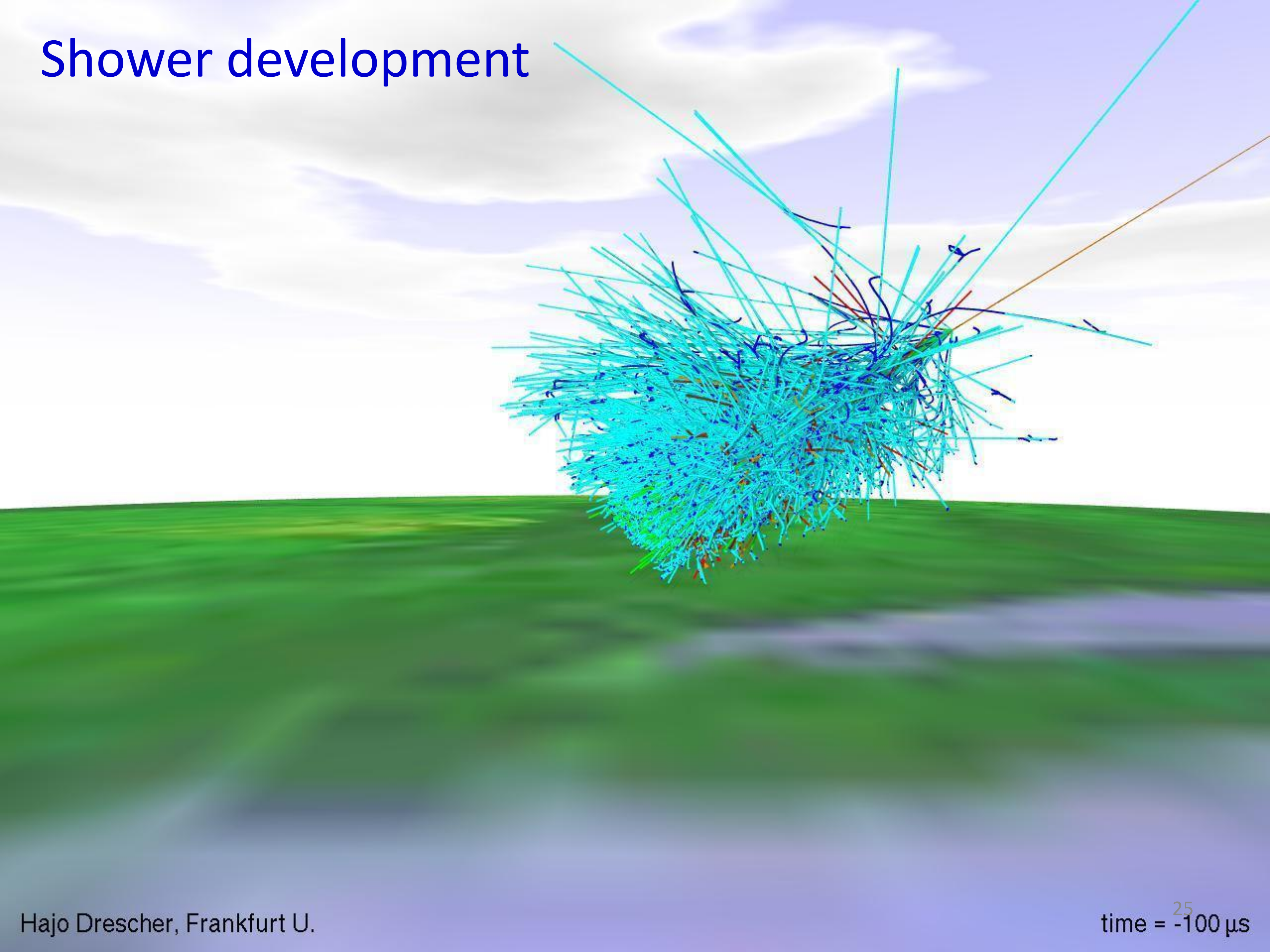
The first interaction!



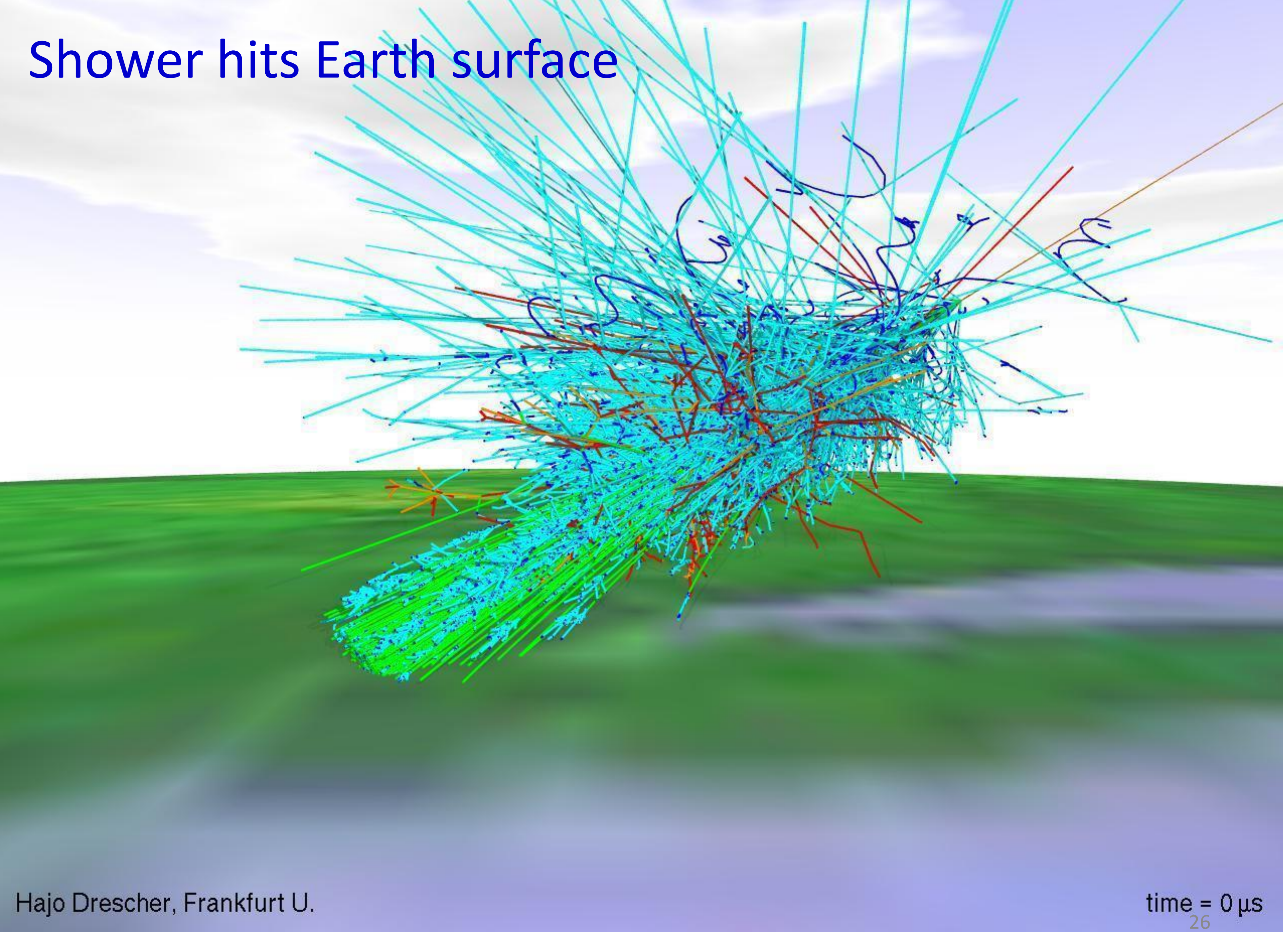
Shower development



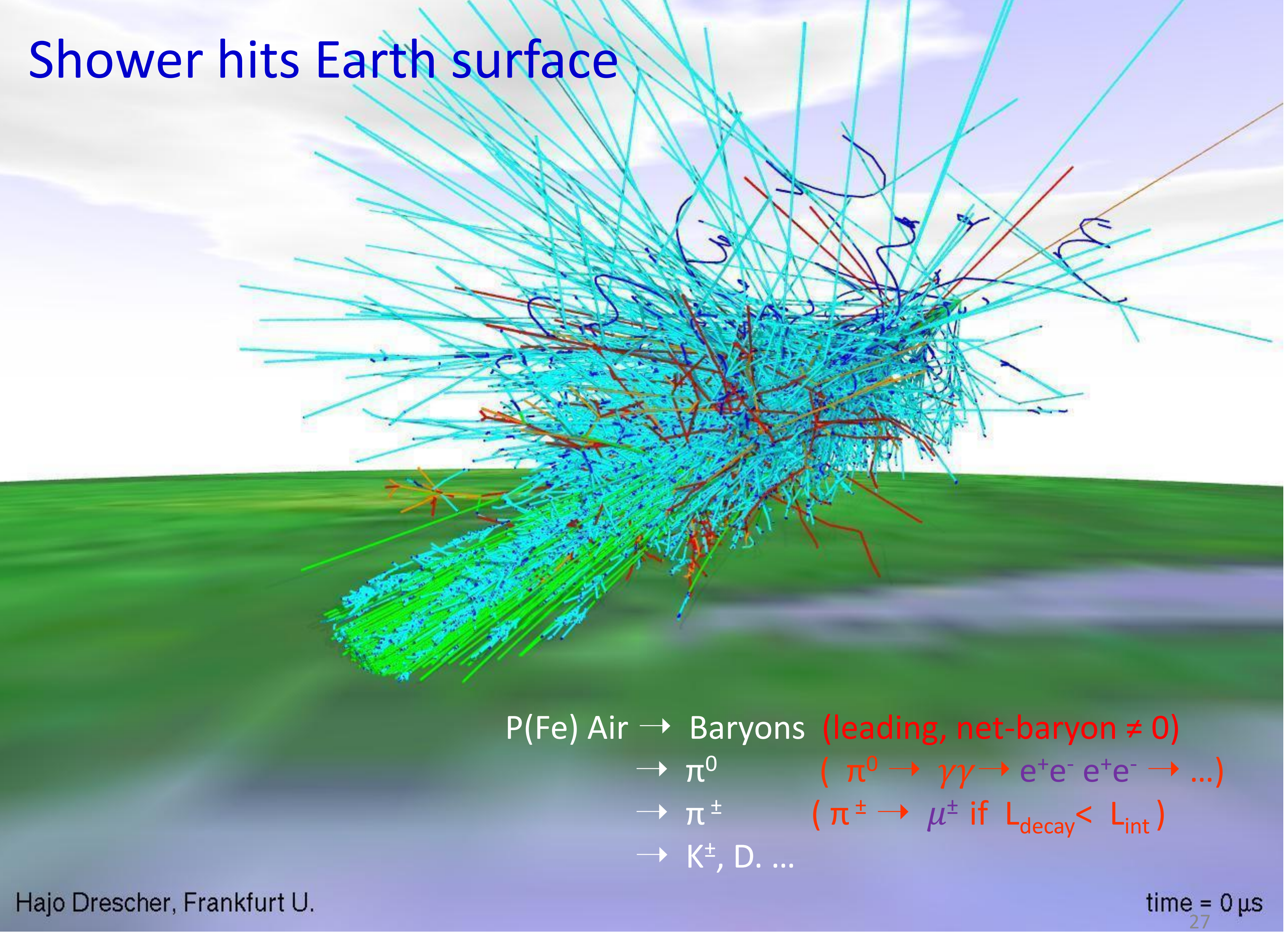
Shower development



Shower hits Earth surface



Shower hits Earth surface



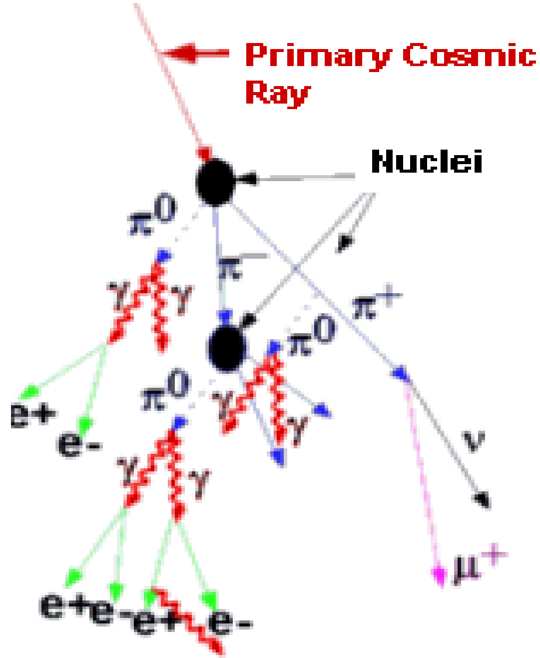
P(Fe) Air $\rightarrow$ Baryons (leading, net-baryon ≠ 0)

$\rightarrow \pi^0$ ($\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^- e^+e^- \rightarrow \ldots$)

$\rightarrow \pi^{\pm}$ ($\pi^{\pm} \rightarrow \mu^{\pm}$ if $L_{decay} < L_{int}$)

$\rightarrow K^{\pm}$, D. ...

Particle interactions



P(Fe) Air $\rightarrow$ Baryons (leading, net-baryon ≠ 0)

$\rightarrow$ π^0 ($\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^- e^+e^- \rightarrow \ldots$)

$\rightarrow$ $\pi^\pm$ ($\pi^\pm \rightarrow \mu^\pm$ if $L_{decay} < L_{int}$)

$\rightarrow$ $K^\pm$, D. ...

e.m. and weak interations

- well known !

hadronic interations

- large uncertainties !
- forward region, small p_t, very high $\sqrt{s}$
- main parameters: σ_{in}, k_{in}, <n>, (fraction π^0, Nb of Baryons, ...)

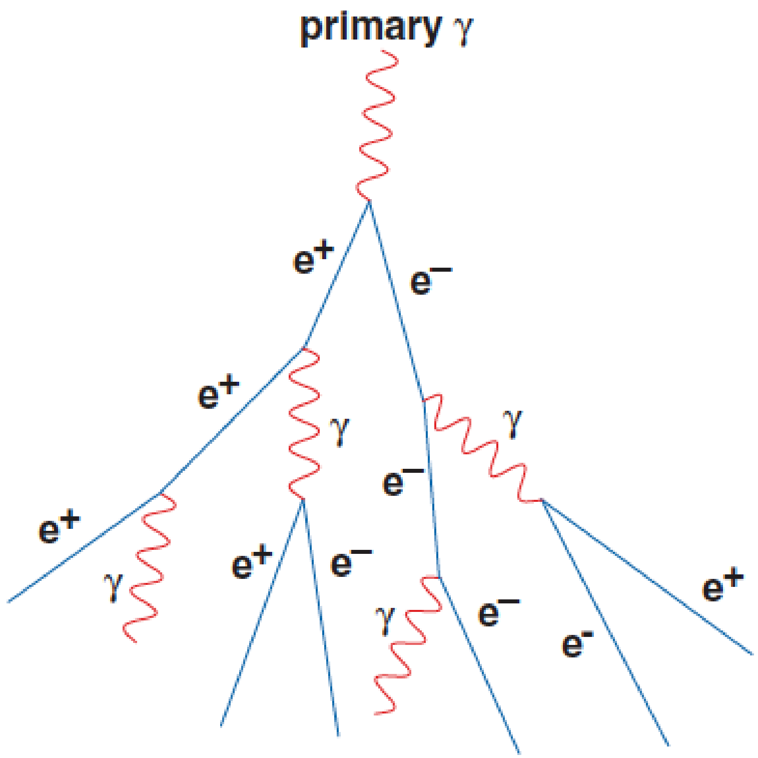
Nuclear fragmentation

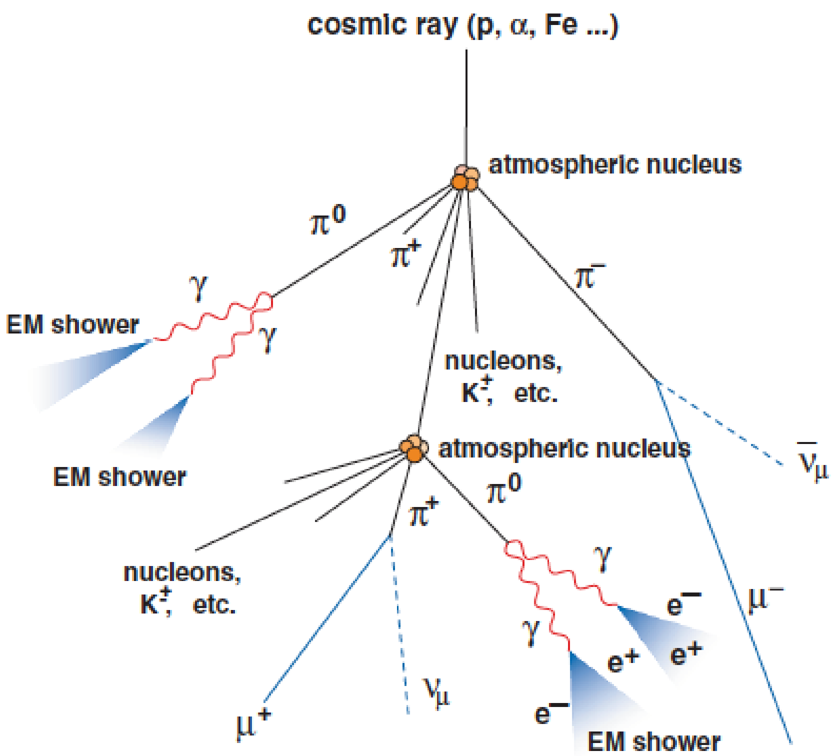
- Nuclei are not just a superposition of nucleons !

Missing Energy

- 5% to 10% ...

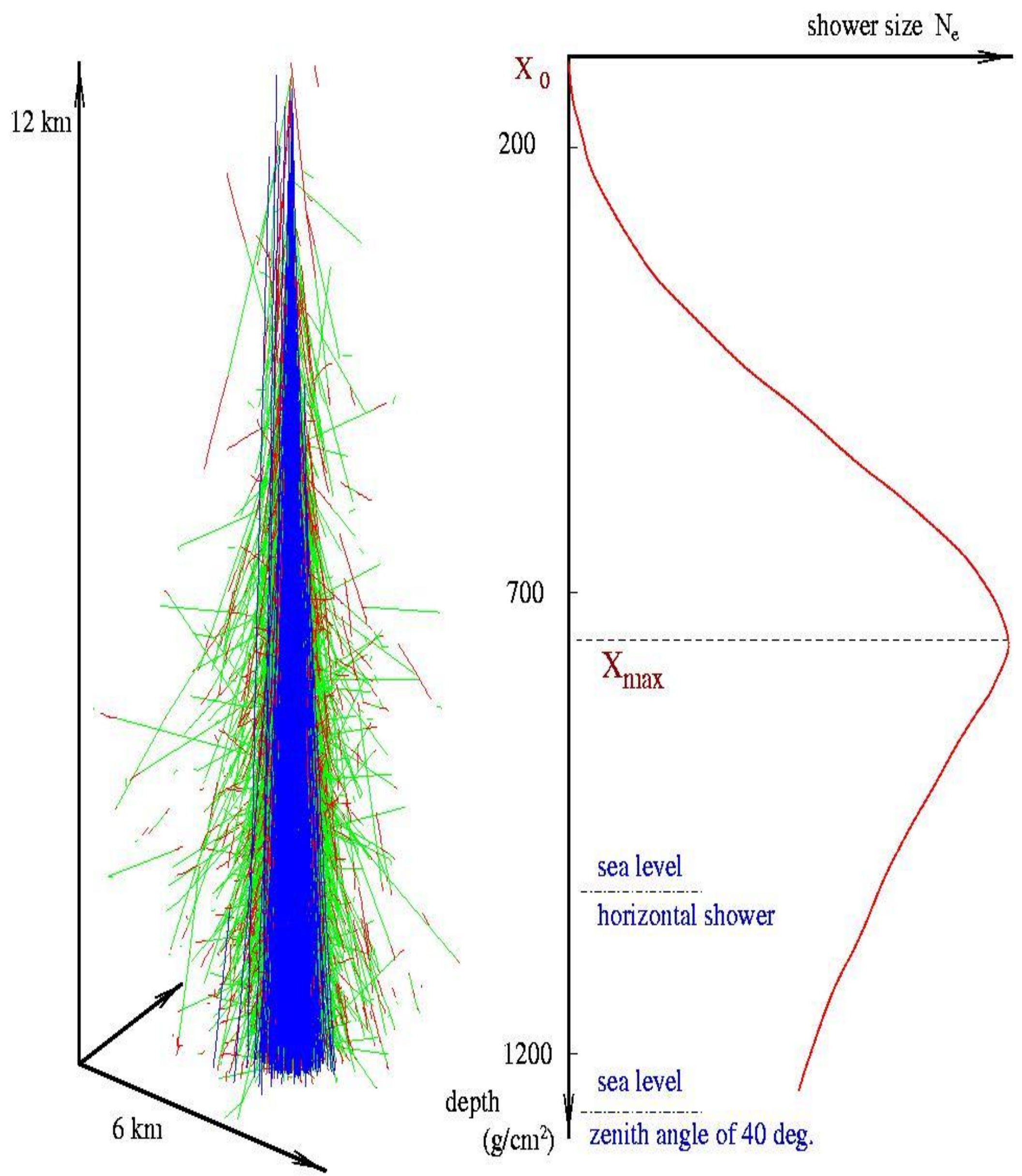
Shower cascades





Extensive Air Showers (EAS)

10^{19} eV

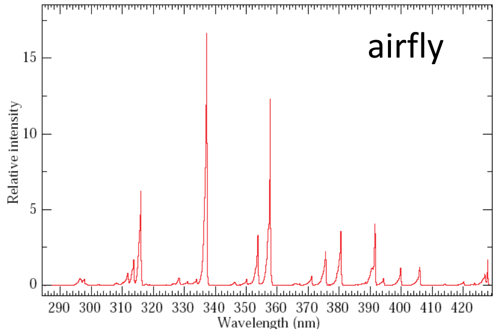


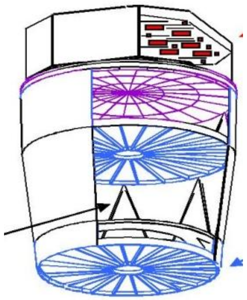
$$X(l) = \int_0^l \rho(x)dx$$

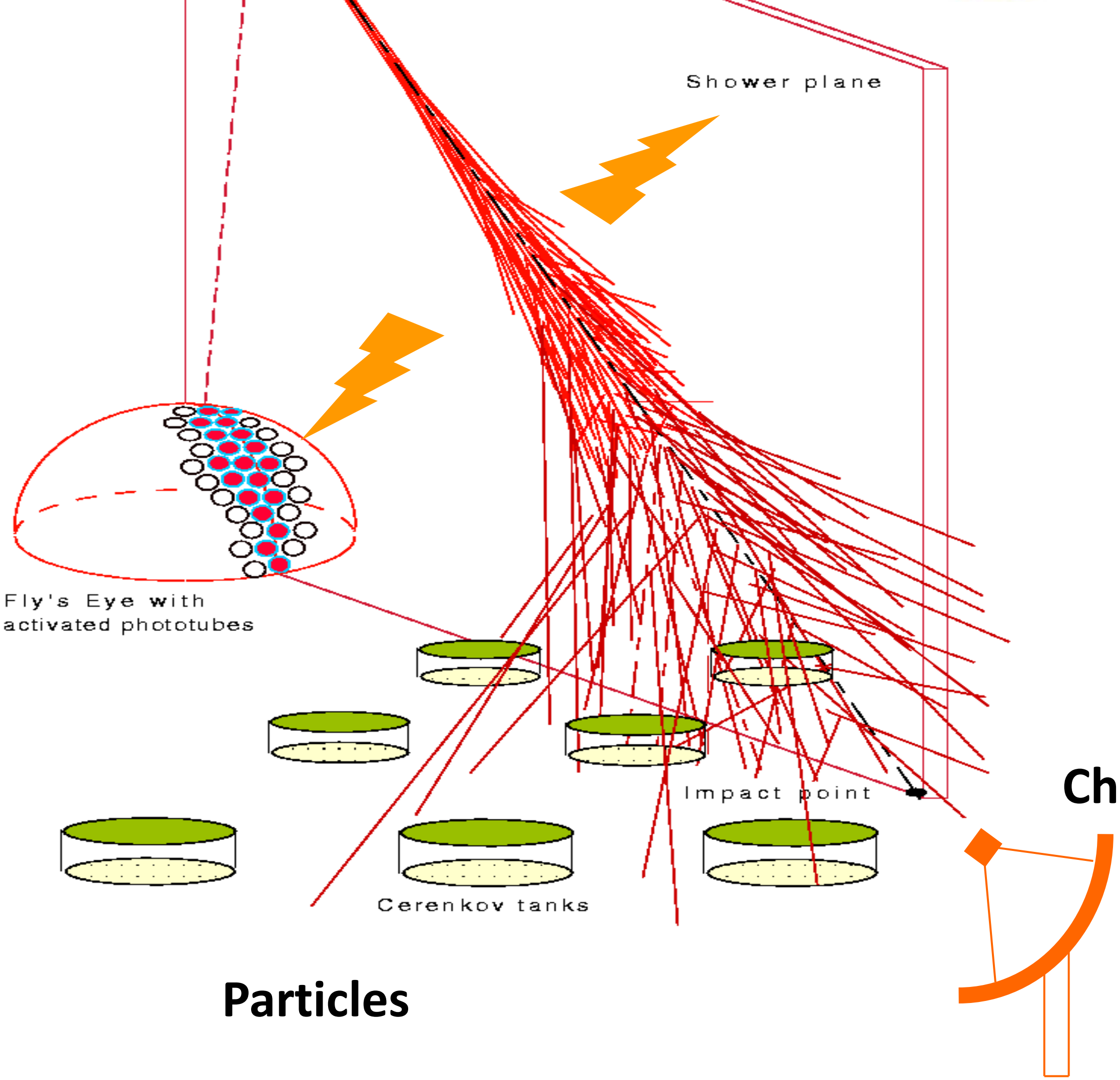
EAS detection

Fluorescence

electrons excite N_2 molecules





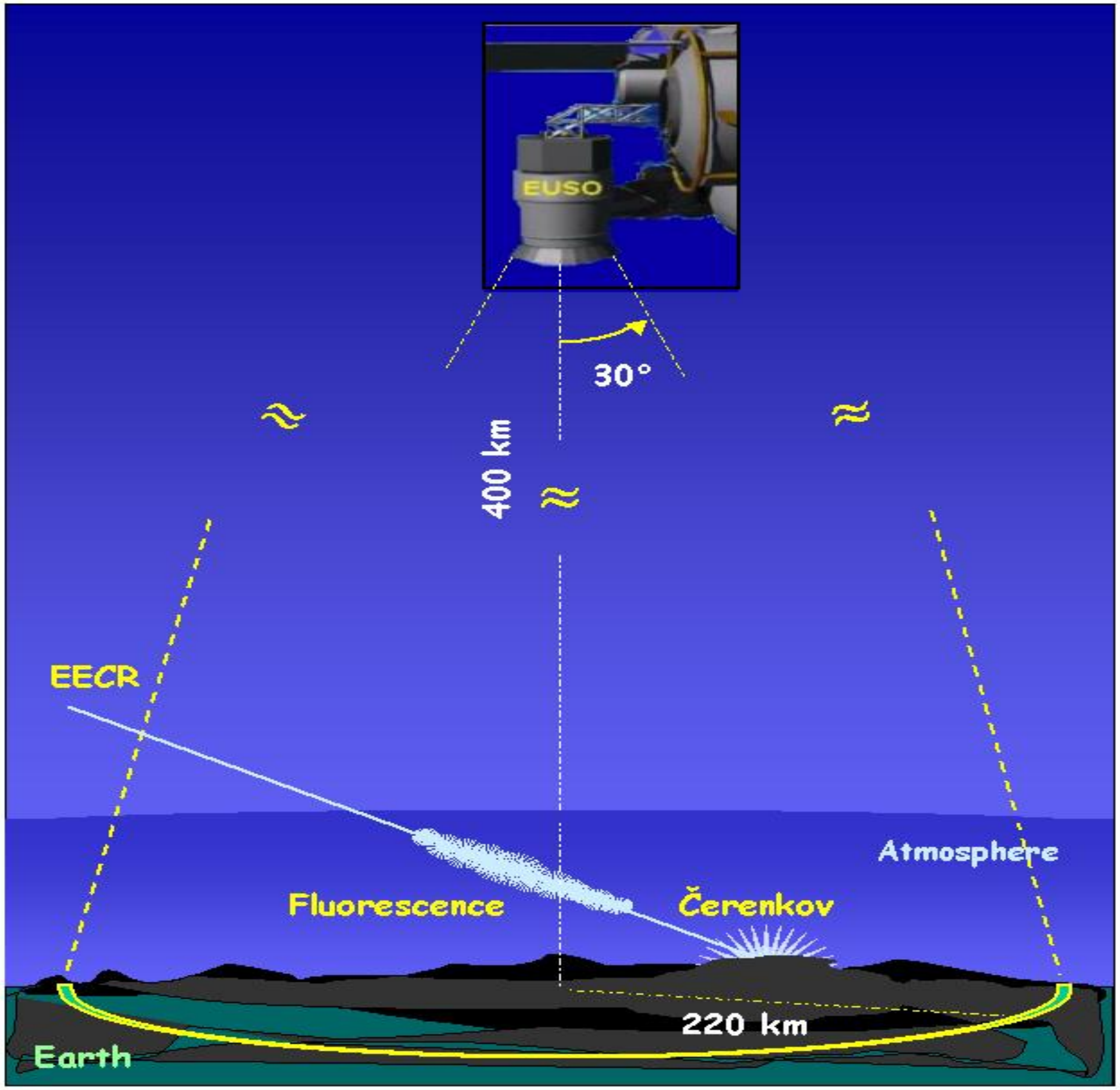


Cherenkov

Particles

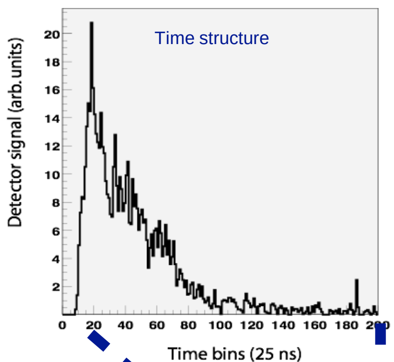
Fluorescence from space

JEM-EUSO

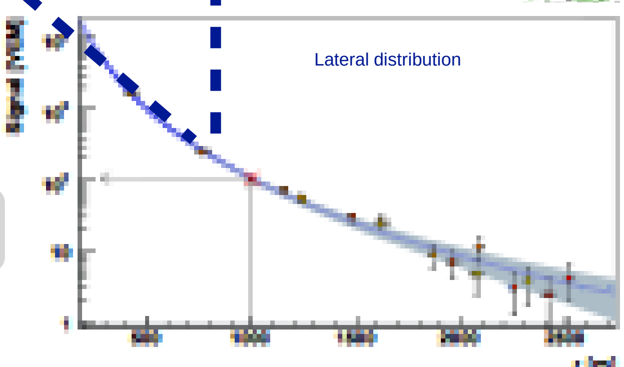


Measurements by an Hybrid detector at Earth

$$E_{\mathrm{cal}} = \int_0^\infty \left(\frac{\mathrm{d}E}{\mathrm{d}X}\right)_{\mathrm{obs}} \mathrm{d}X$$

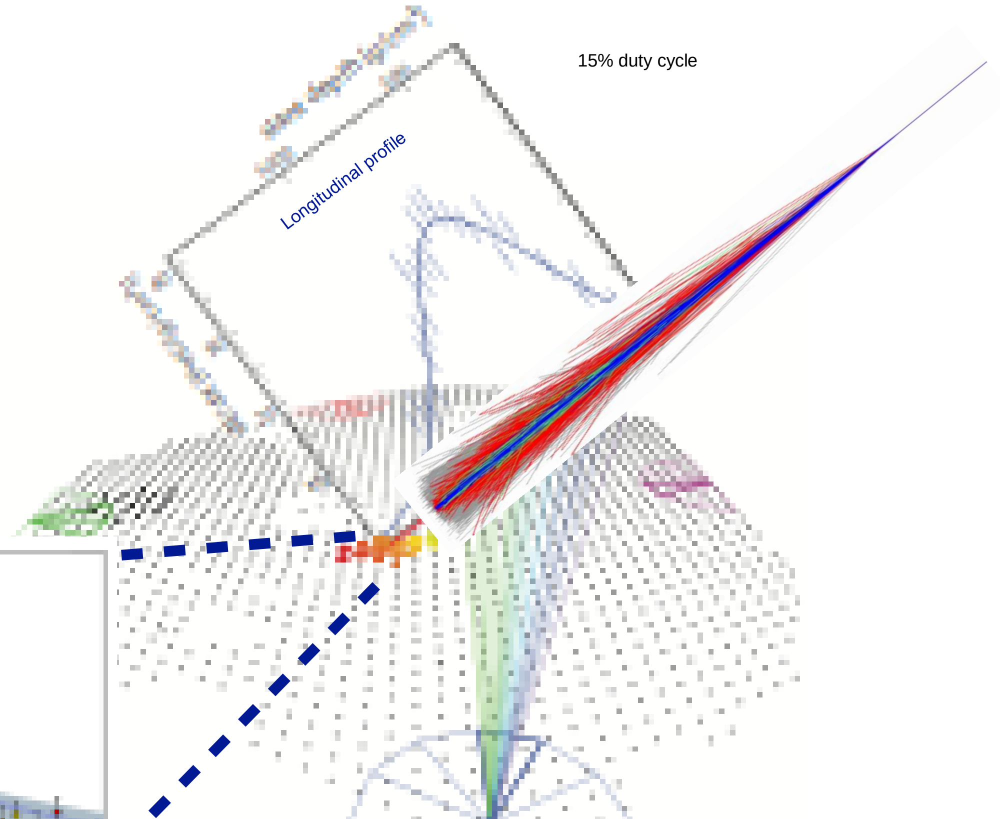


100% duty cycle



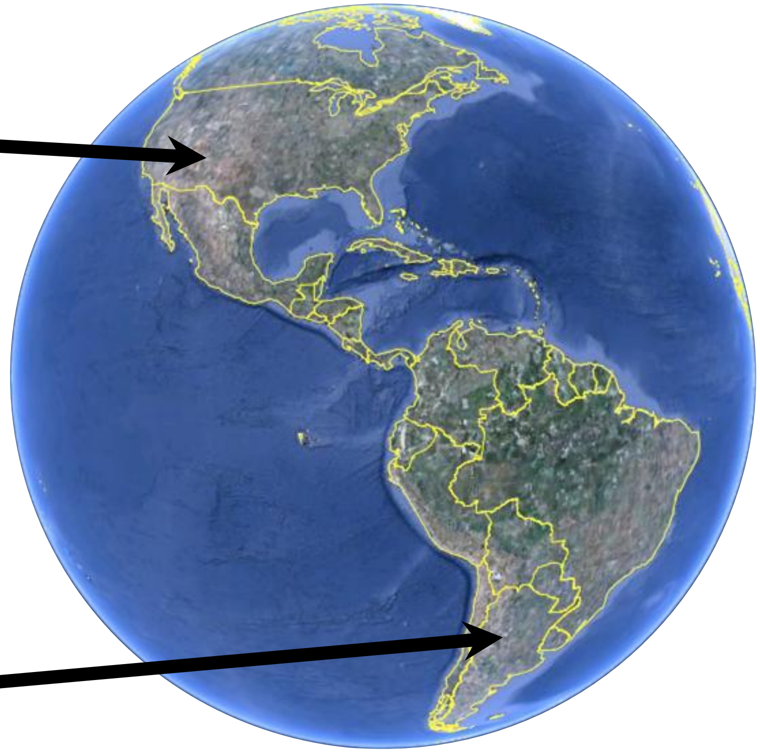
$$E_{\mathrm{rec}} = f(S_{1000}, \theta)$$

15% duty cycle



Example: event observed with Auger Observatory

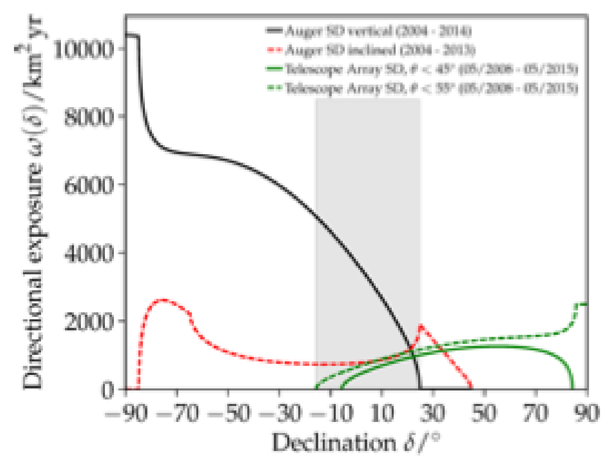
Earth Observatories



Telescope Array (TA)
Delta, UT, USA
507 detector stations, 680 km^2
36 fluorescence telescopes

Pierre Auger Observatory
Province Mendoza, Argentina
1660 detector stations, 3000 km^2
27 fluorescence telescopes

Together full sky coverage



Auger:
- 6.7×10^4 km^2 sr yr (spectrum)
- 9×10^4 km^2 sr yr (anisotropy)

TA:
- 8.1×10^3 km^2 sr yr (spectrum)
- 8.6×10^3 km^2 sr yr (anisotropy)

Telescope Array (TA)

Area ~ 680 km^2

3 fluorescence telescopes

507 double-Layer scintillators

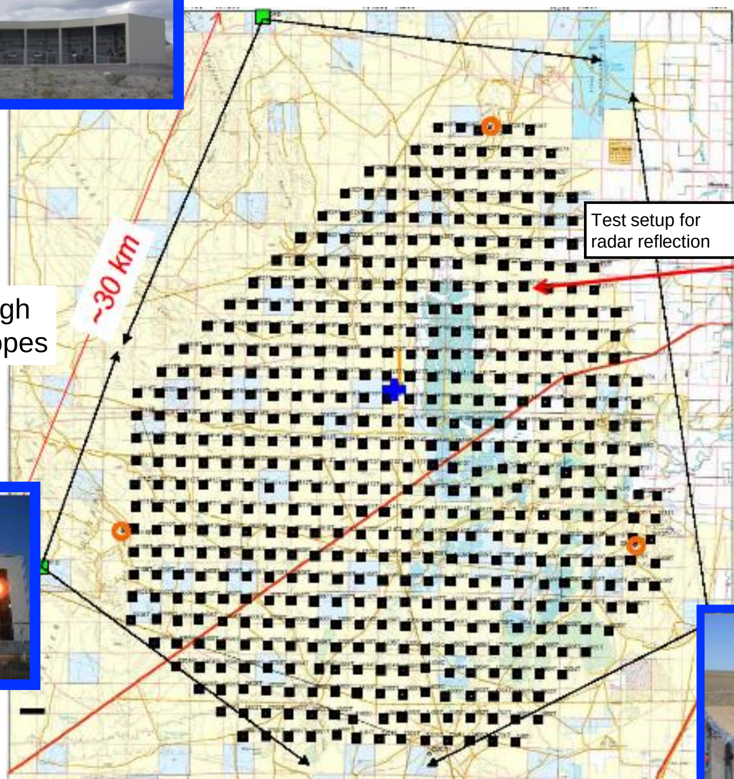
Talk by Abu-Zayyad

Middle Drum: based on HiRes II

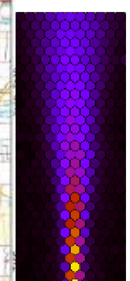
TALE (TA low energy extension)

LIDAR
Laser facility

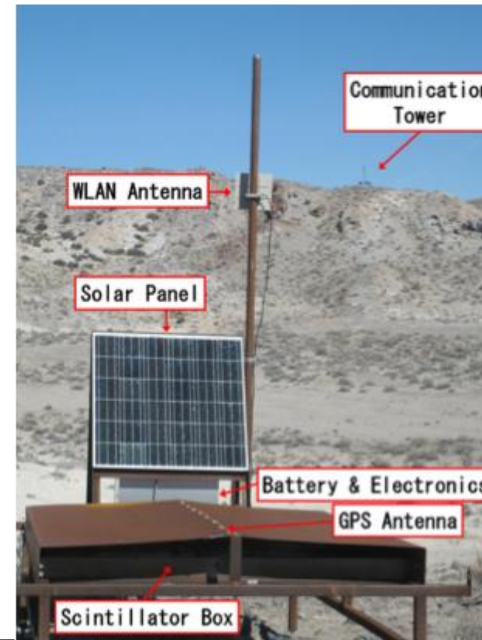
Infill array and high
elevation telescopes



Test setup for
radar reflection



Electron light
source (ELS):
~40 MeV



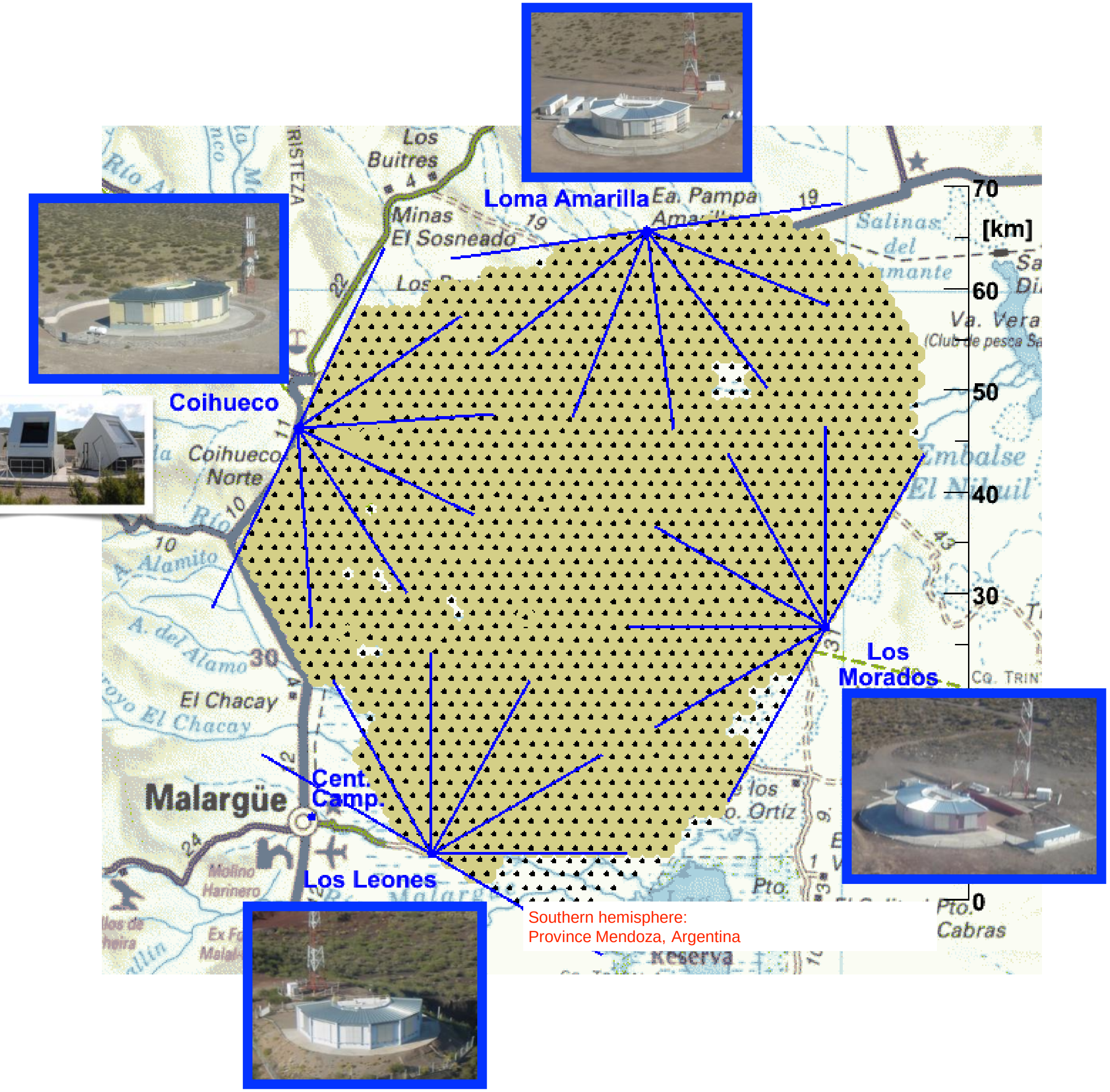
Northern hemisphere: Utah, USA

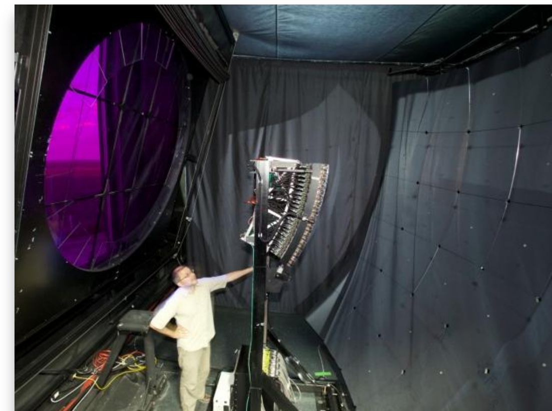
Pierre Auger Observatory

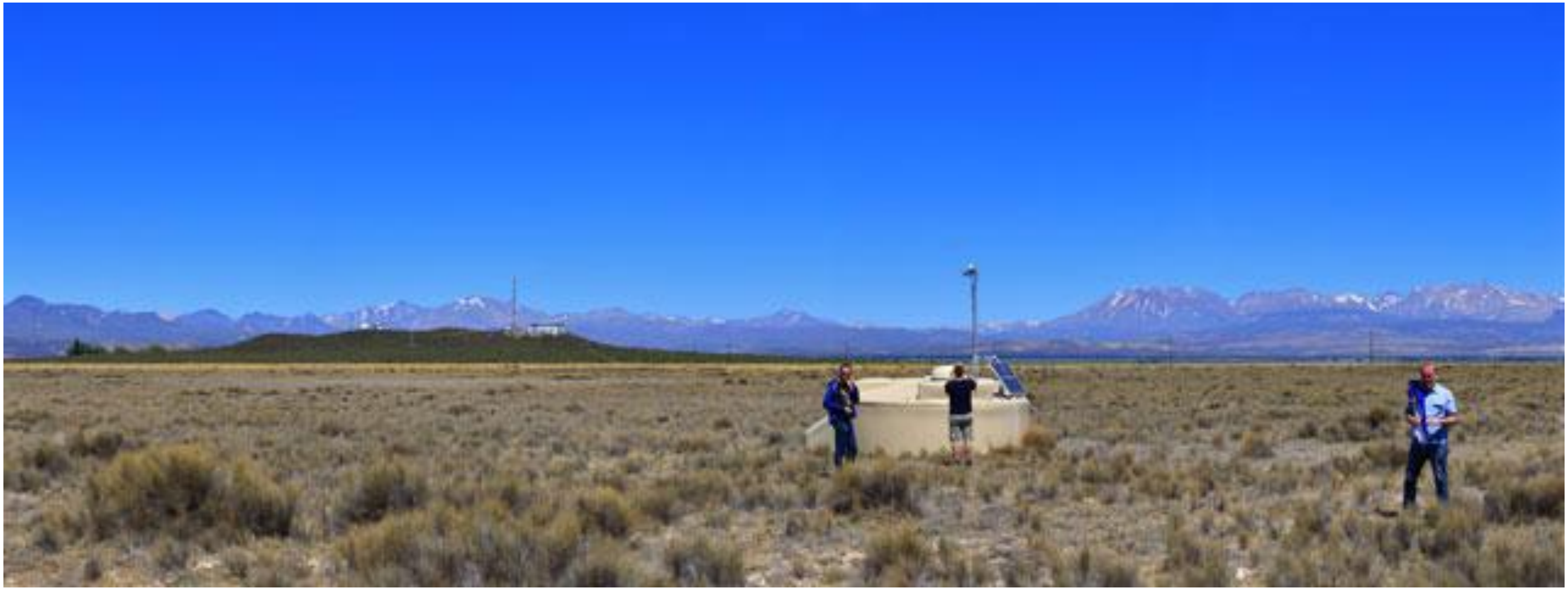
Area ~ 3000 km^2

24+3 fluorescence telescopes

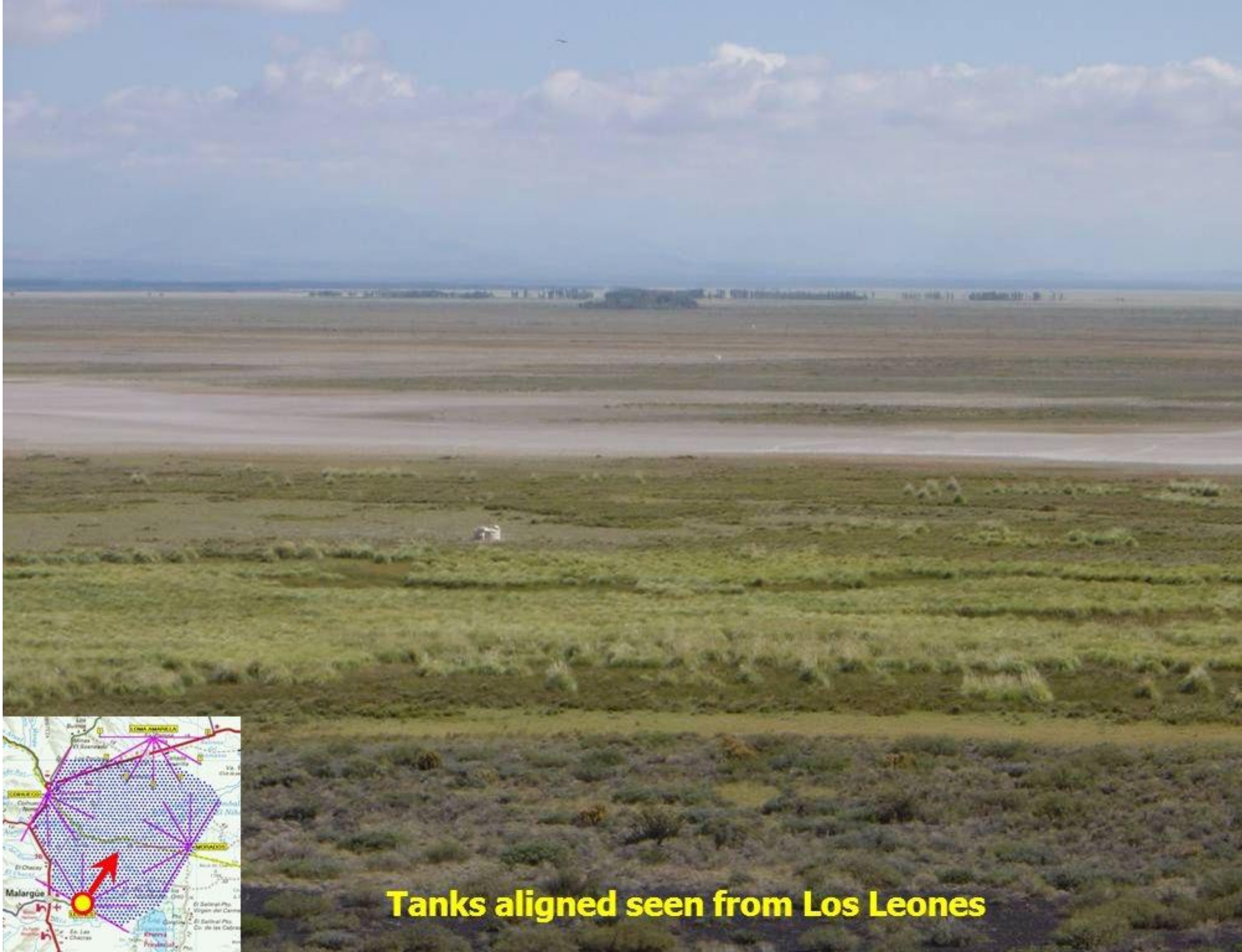
1600 water Cerenkov detectors



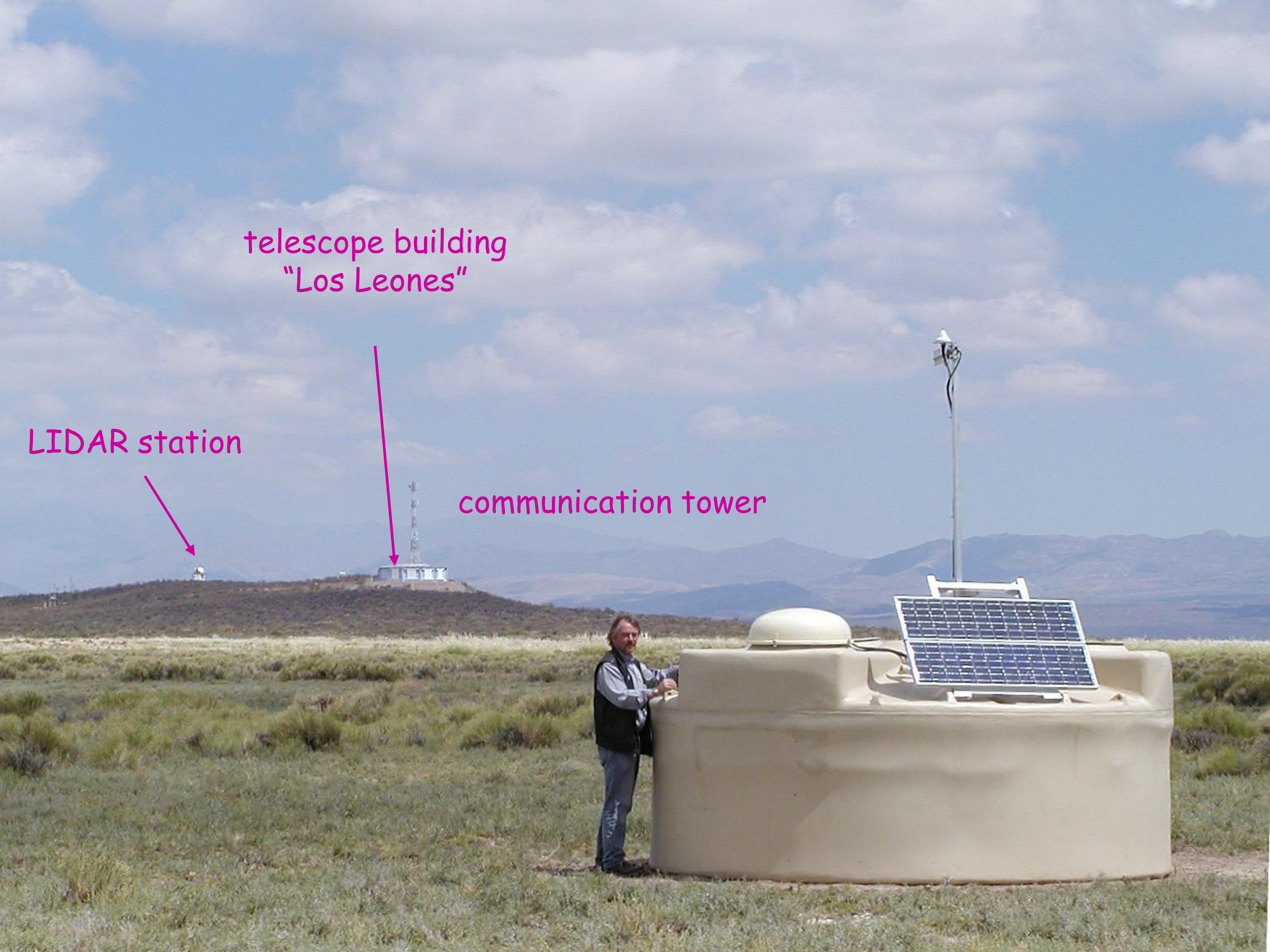


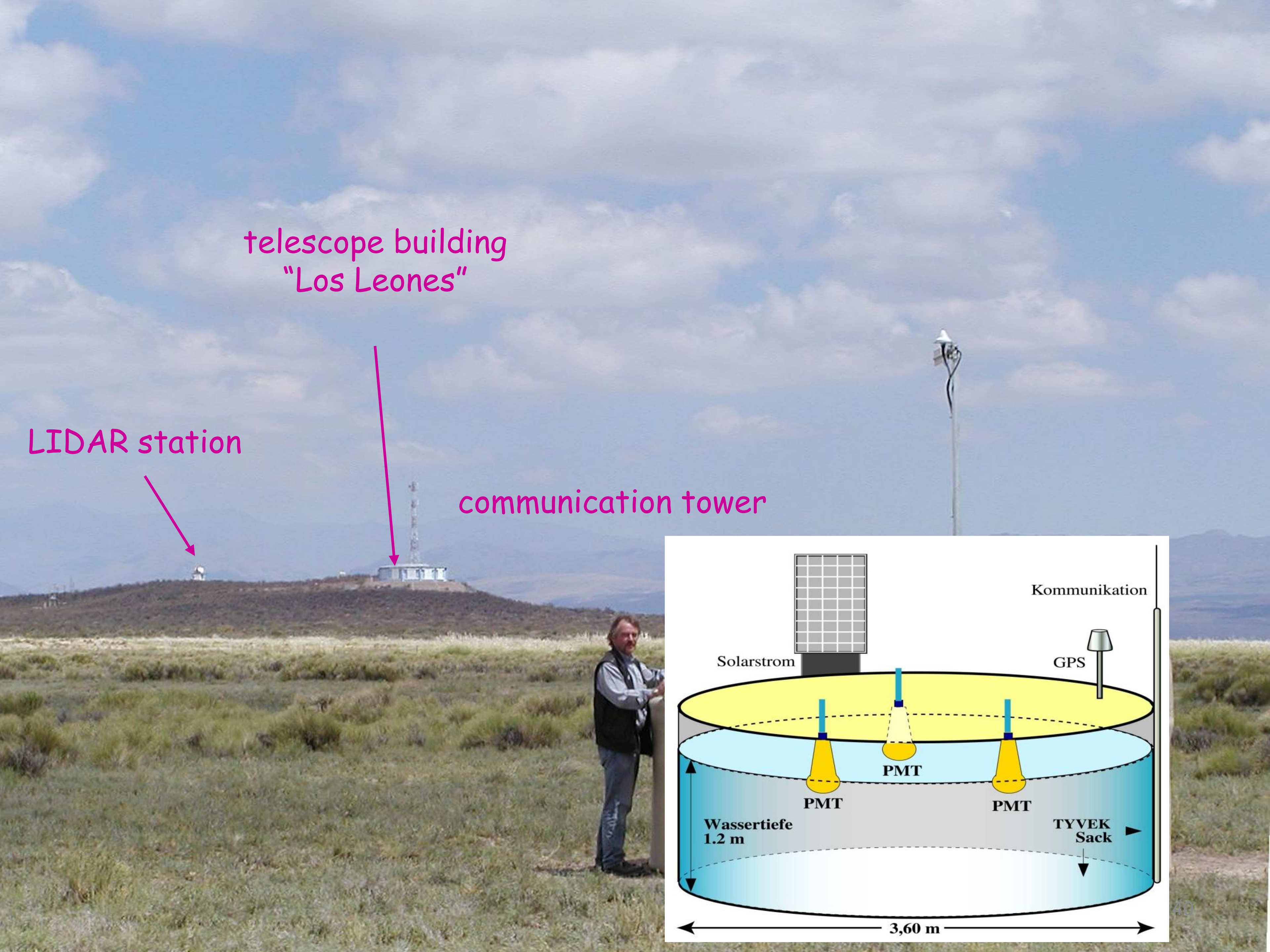



Escuela Nº 4-190
Dr. James W. Cronin
MALARGÜE - MENDOZA



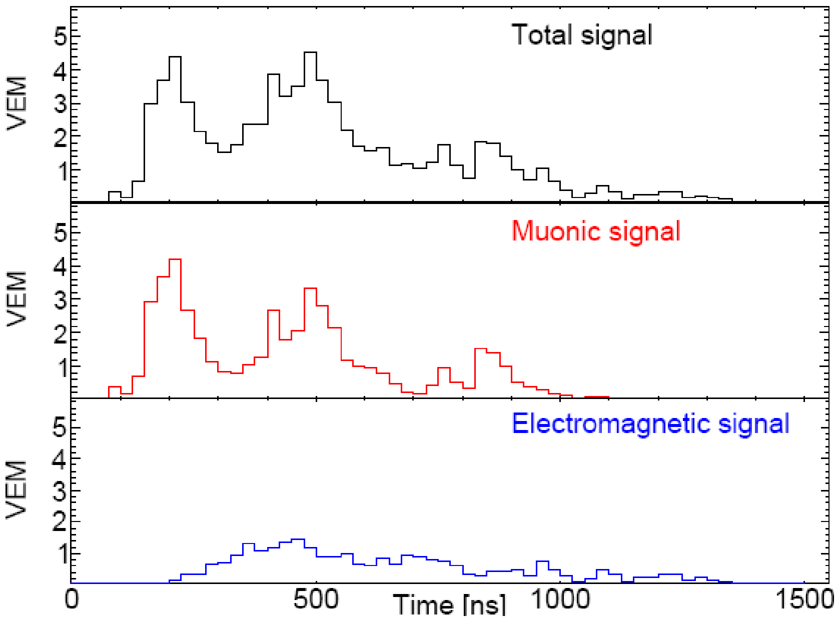
Tanks aligned seen from Los Leones

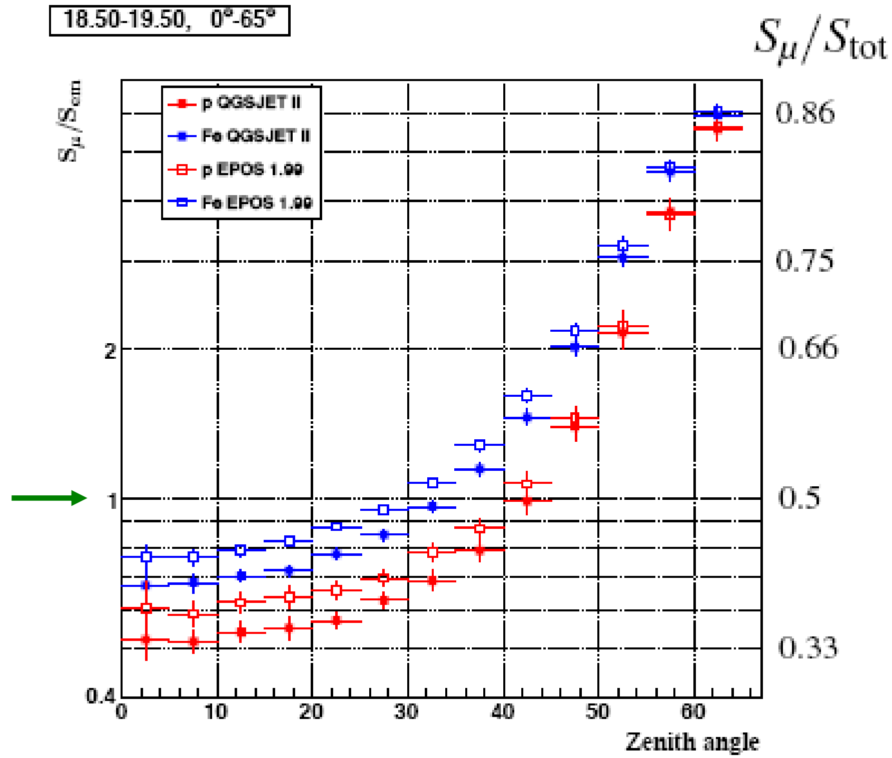

telescope building
“Los Leones”
LIDAR station
communication tower


telescope building
“Los Leones”
LIDAR station
communication tower
Kommunikation
Solarstrom
GPS
PMT
PMT
PMT
Wassertiefe
1.2 m
TYVEK
Sack
3,60 m

E.M. and μ signal in the WCDs

Individual time traces

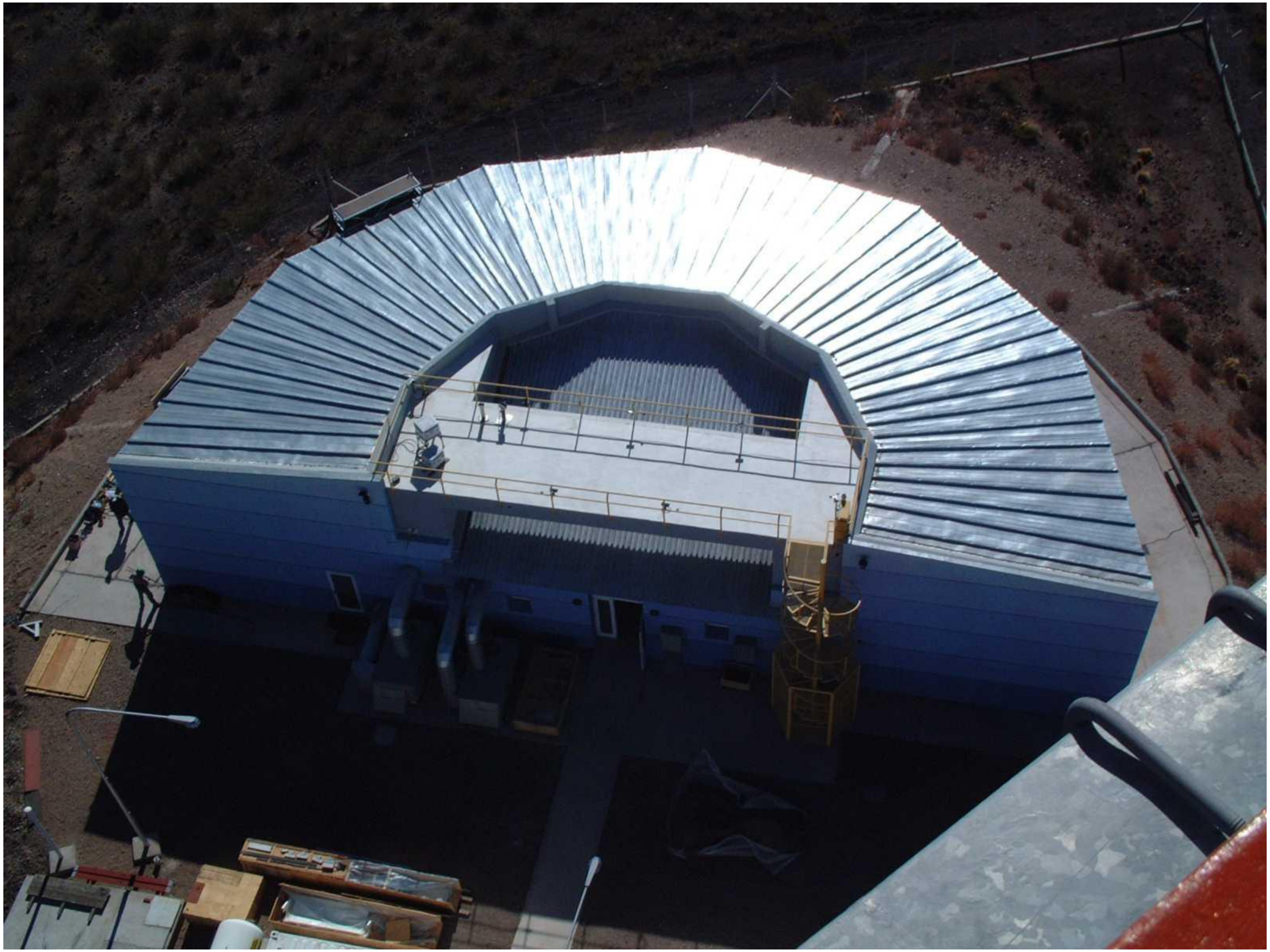




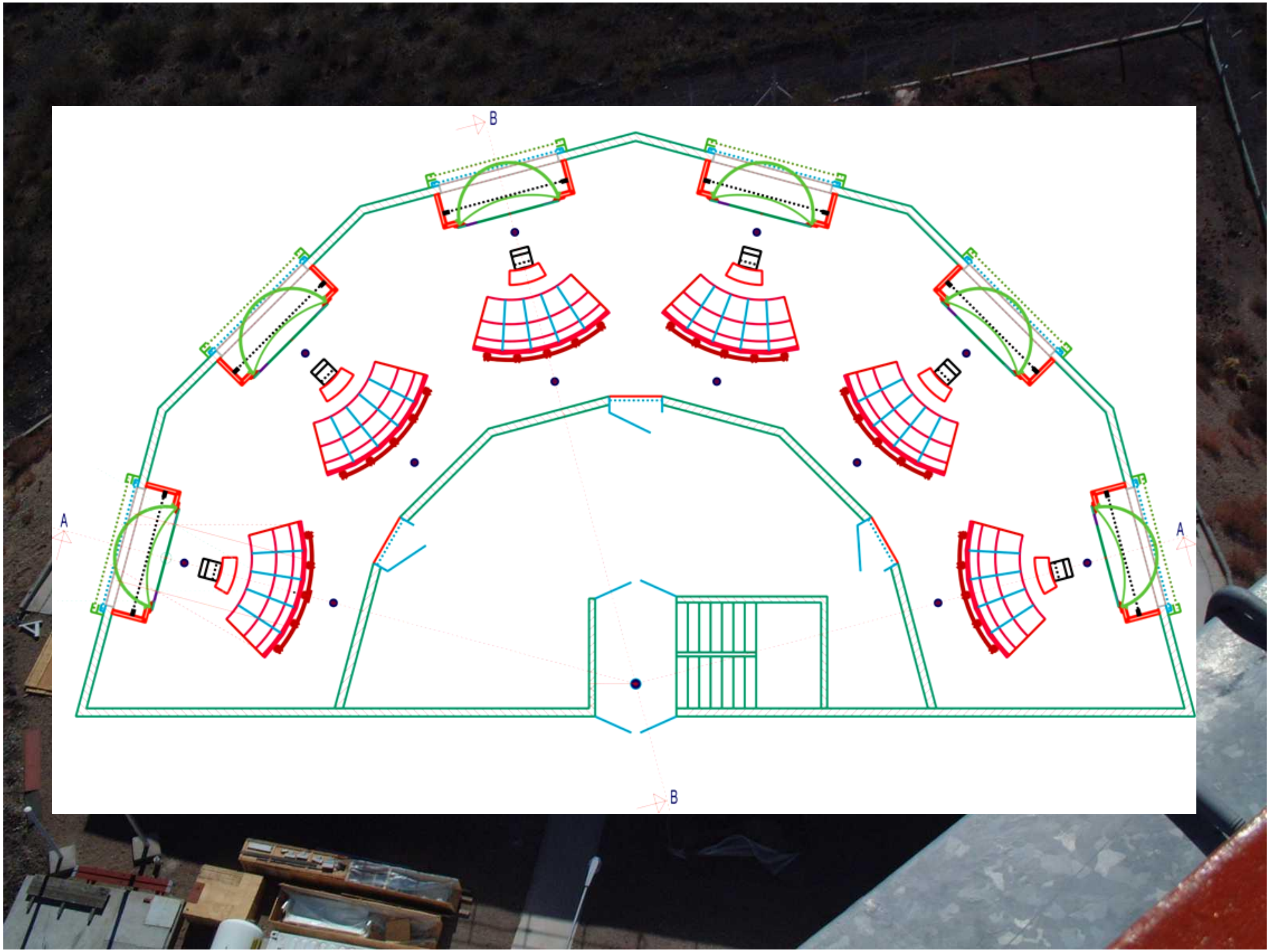
Proton, ϴ =45°, E= 10^{19} eV ,
d= 1000m

$$S_{\rm MC}(E,\theta,X_{\rm max}) \;=\; S_{\rm em}(E,\theta,DG) + N_\mu^{\rm rel} S_\mu^{\rm QGSII,p}(10^{19}\,{\rm eV},\theta,DG)$$

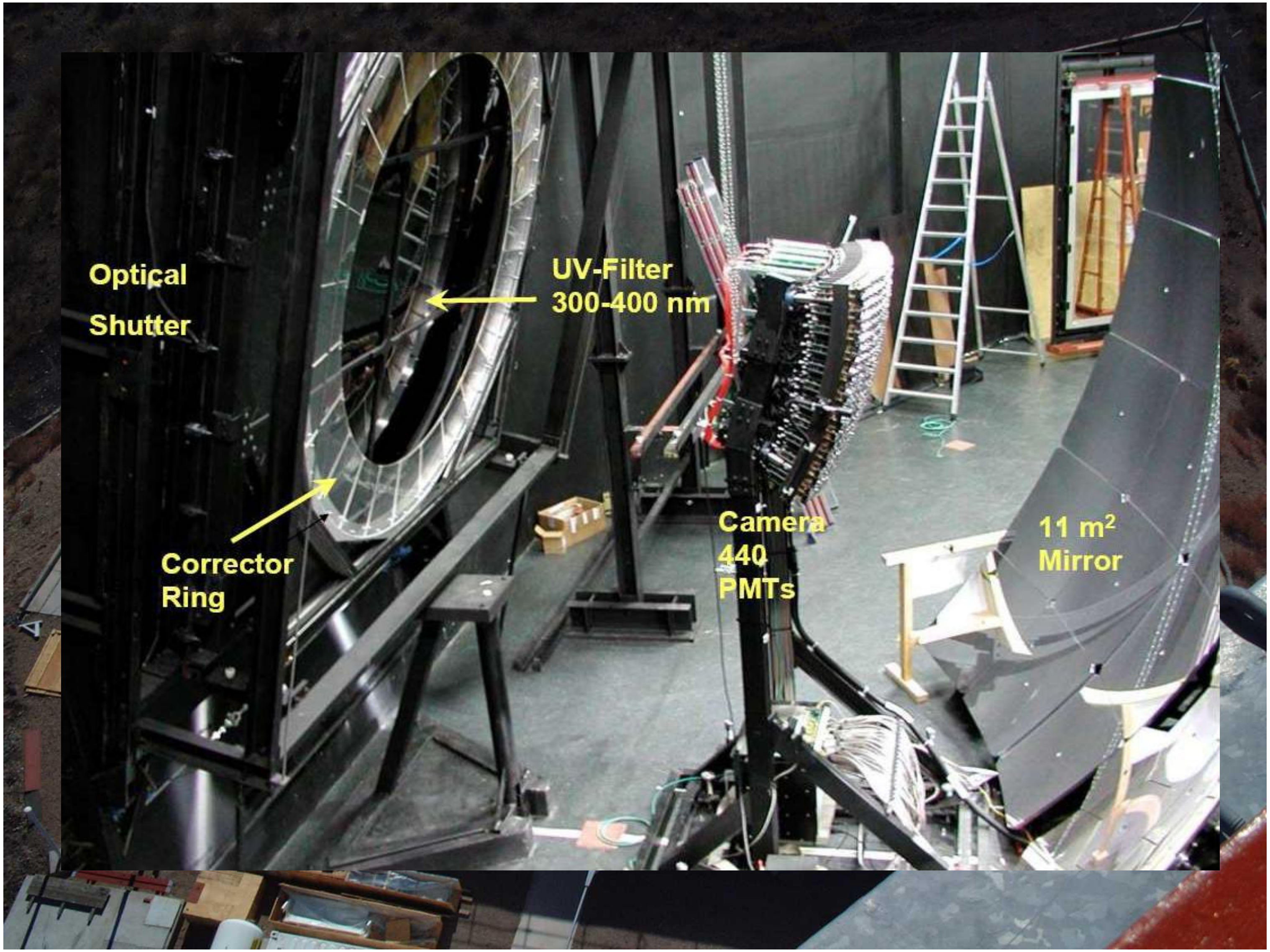
The fluorescence detectors (FD)



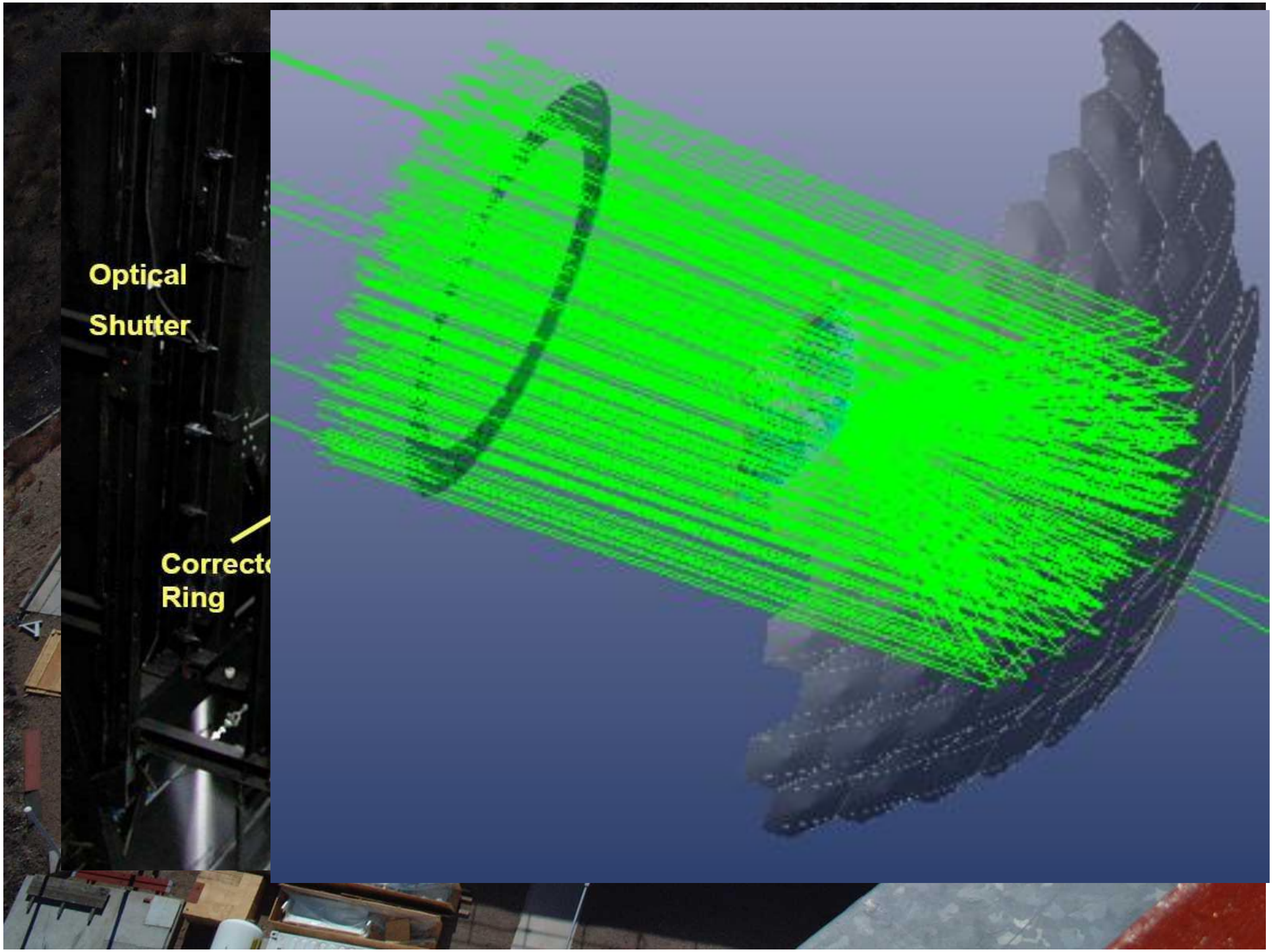
The fluorescence detectors (FD)



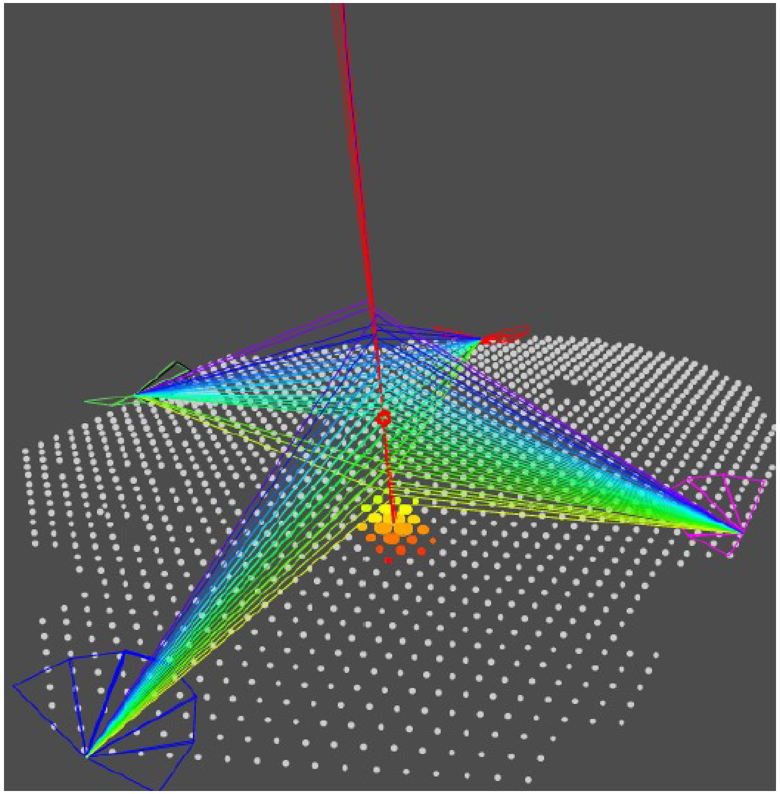
The fluorescence detectors (FD)

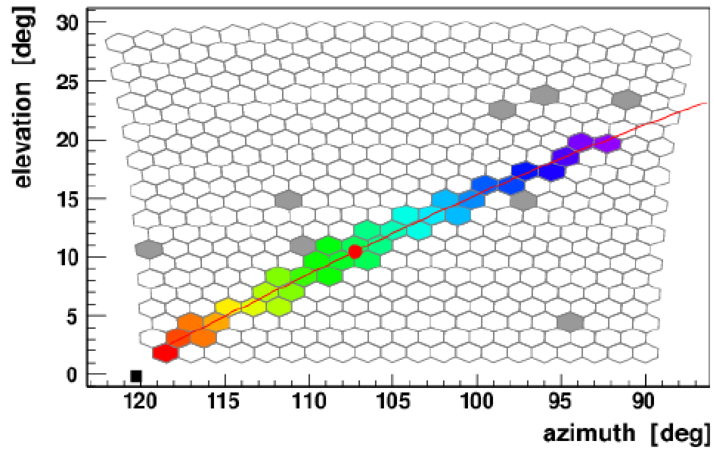


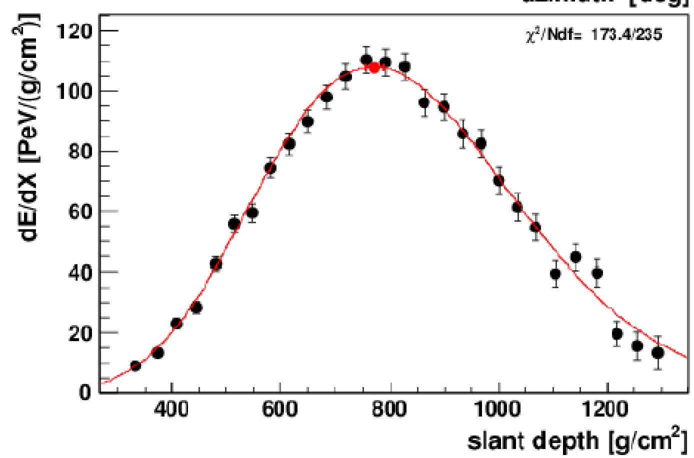
The fluorescence detectors (FD)

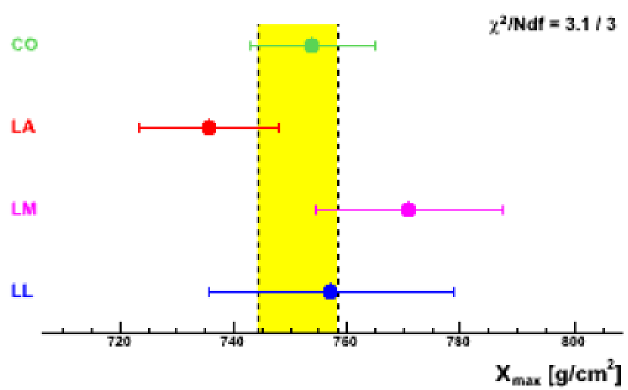


A 4 eyes hybrid event !









Energy

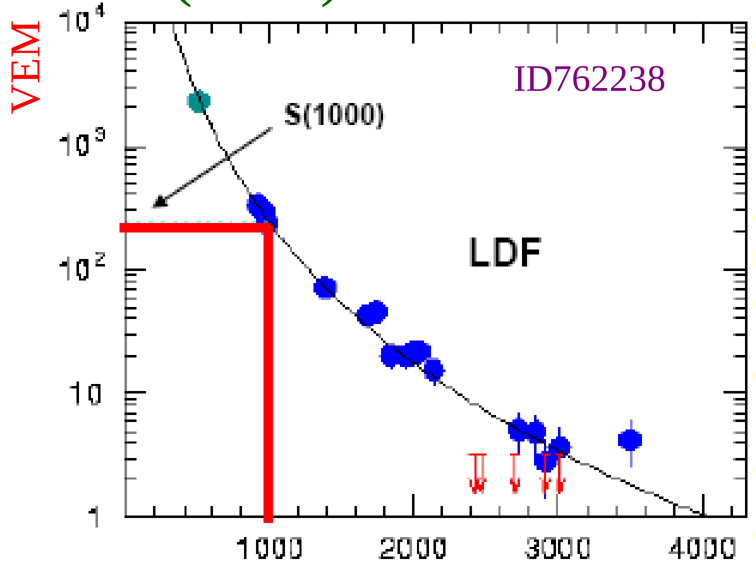
$E = (7.1 \pm 0.2)\ 10^{19}$ eV

Depth of the maximum

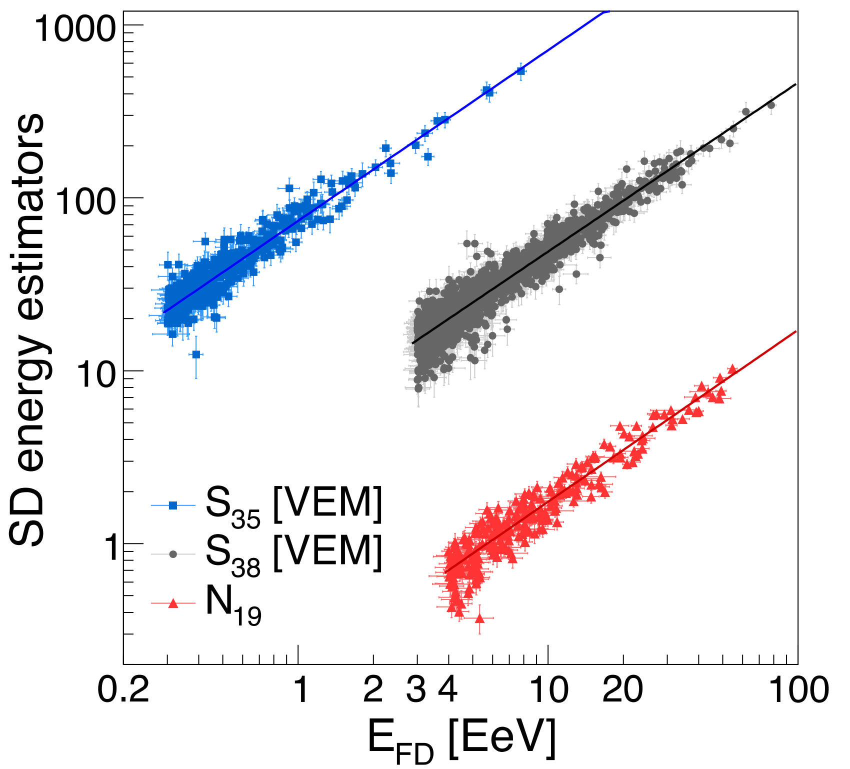
$X_{max} = (752 \pm 7)$ g/cm^2

SD Energy calibration in Auger

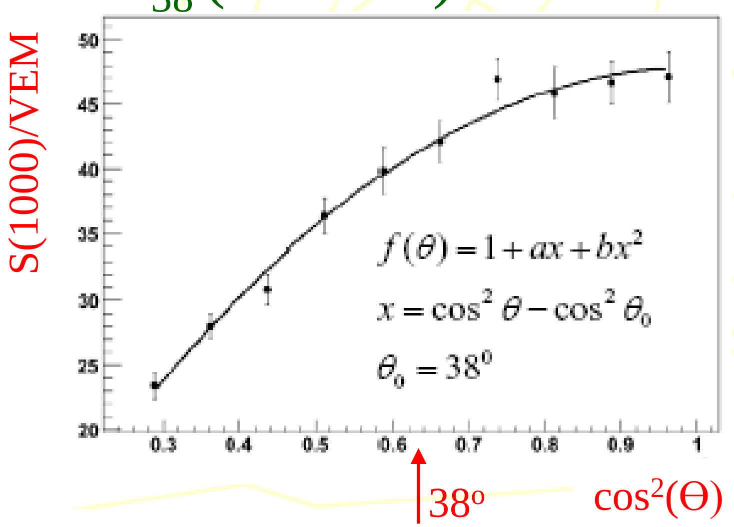
S(1000)



Calibration



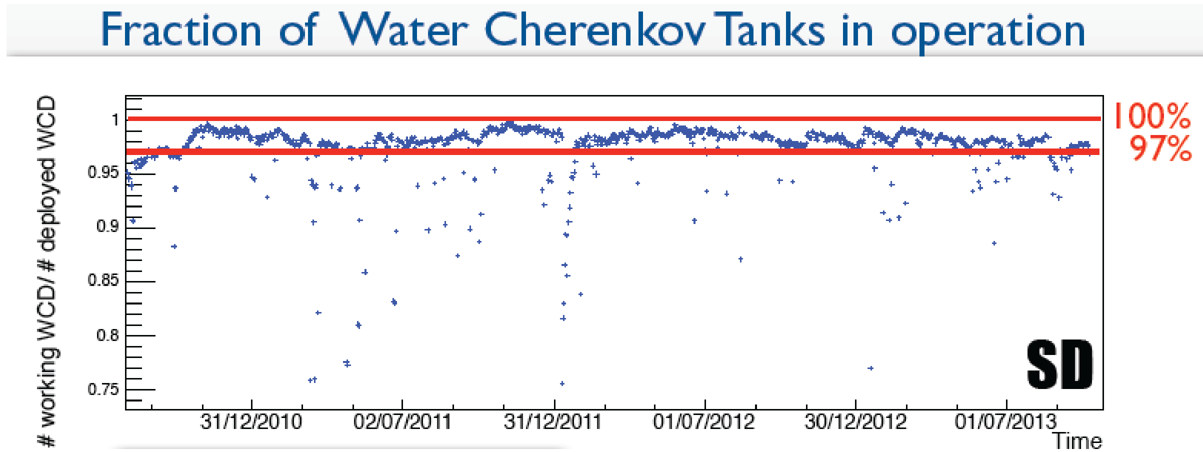
S_{38} (das CIC)



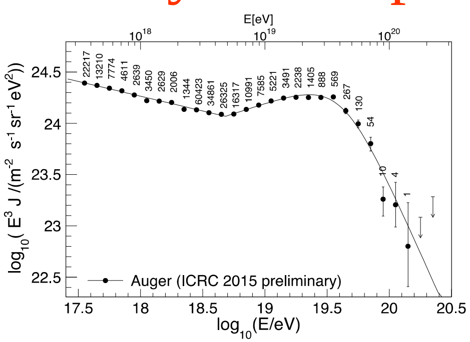
$\sigma_E < 10\%$

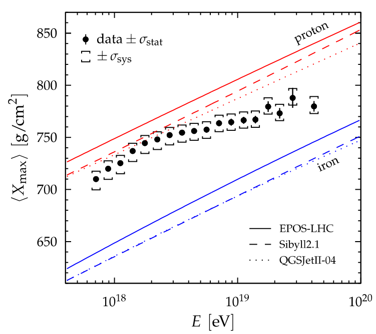
Auger is running smoothly

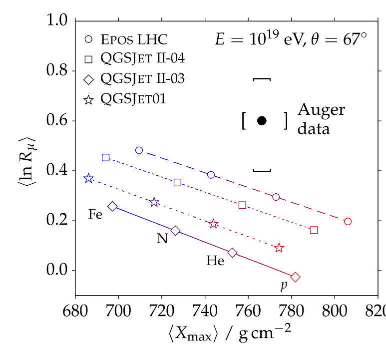
The Swiss clock!

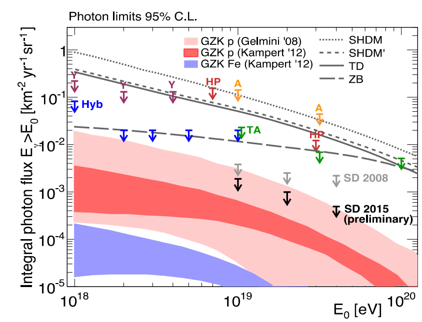


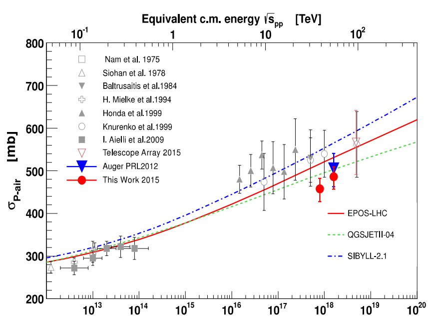
Many and important results !

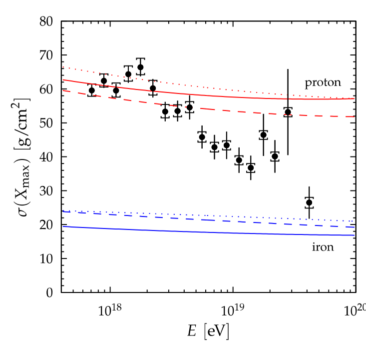


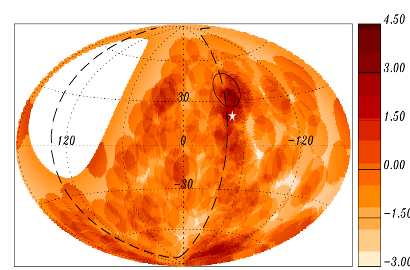


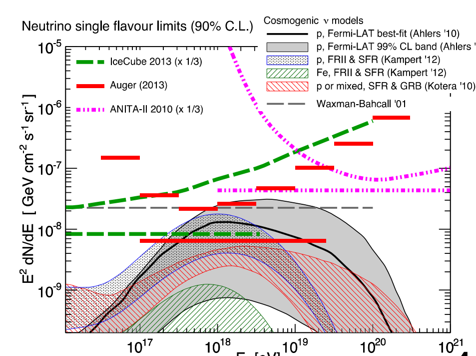




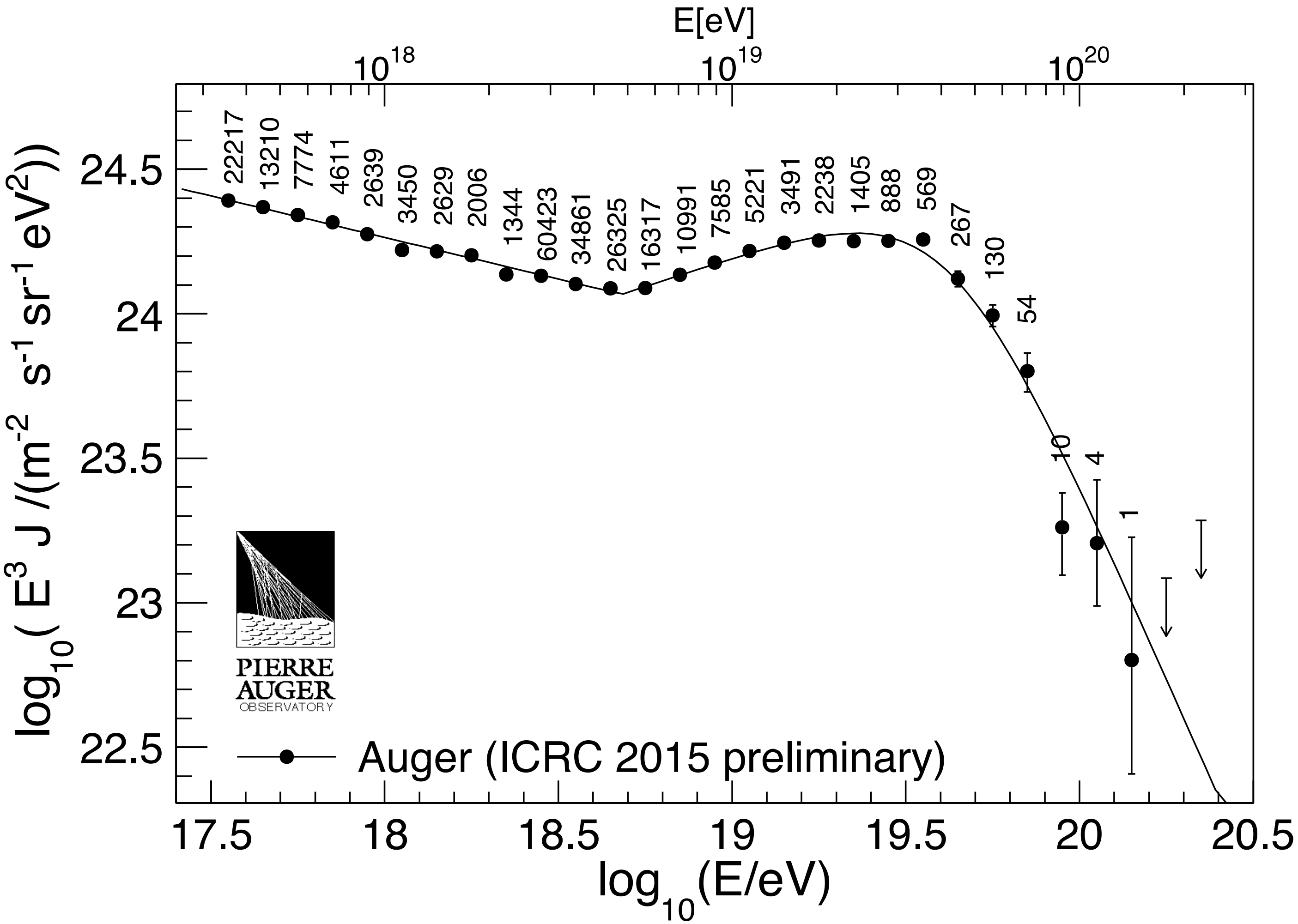


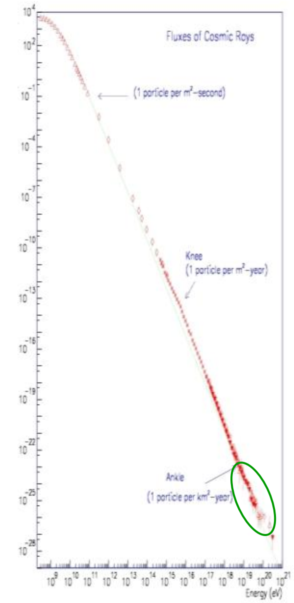






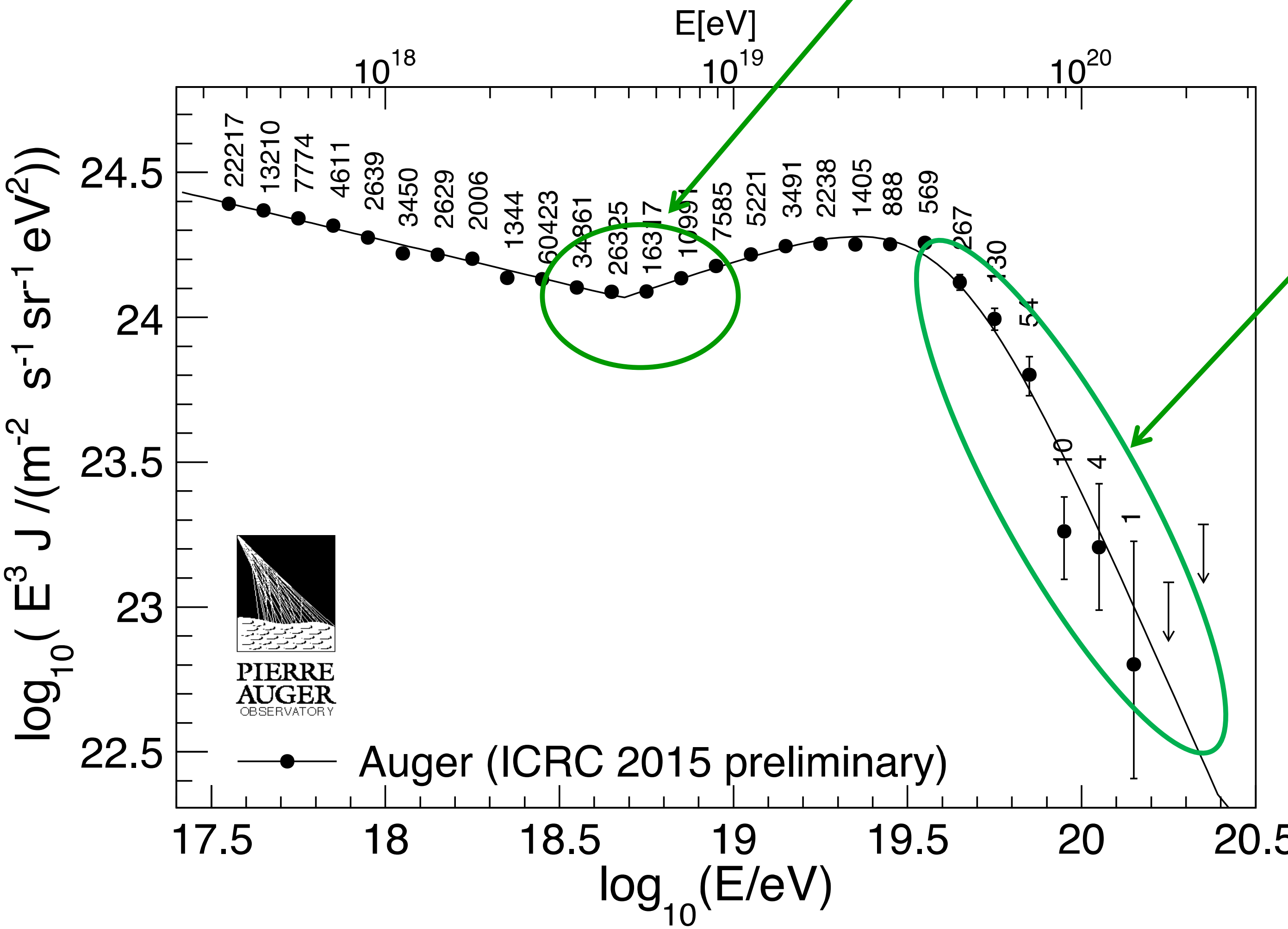
Energy spectrum

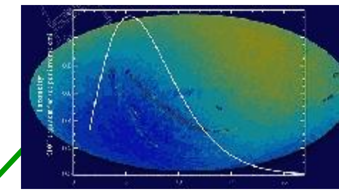


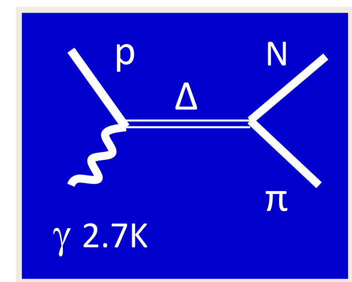


Energy spectrum

Ankle



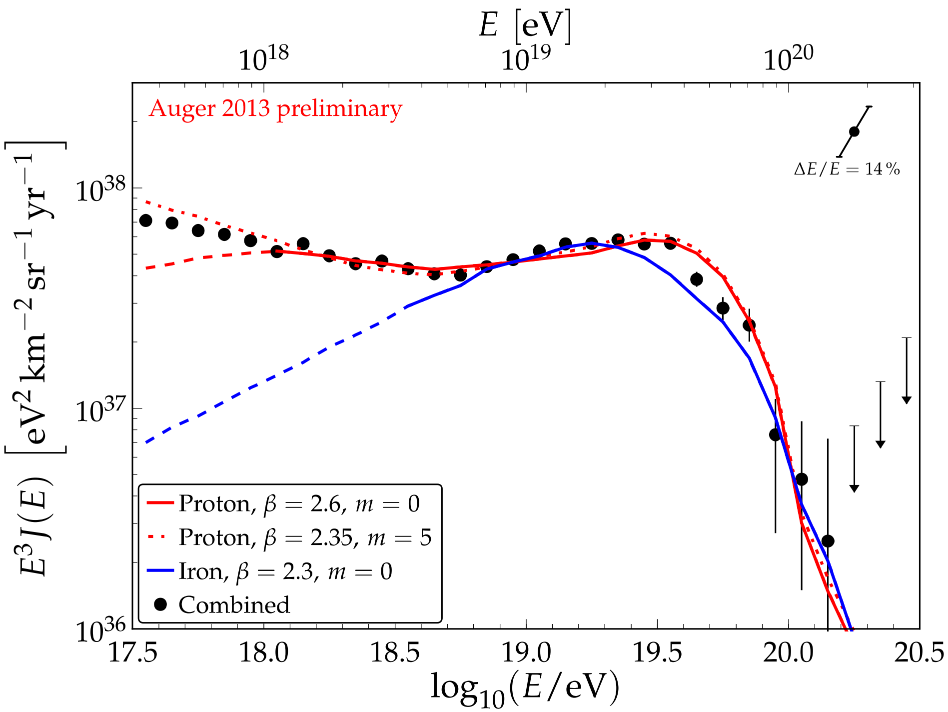


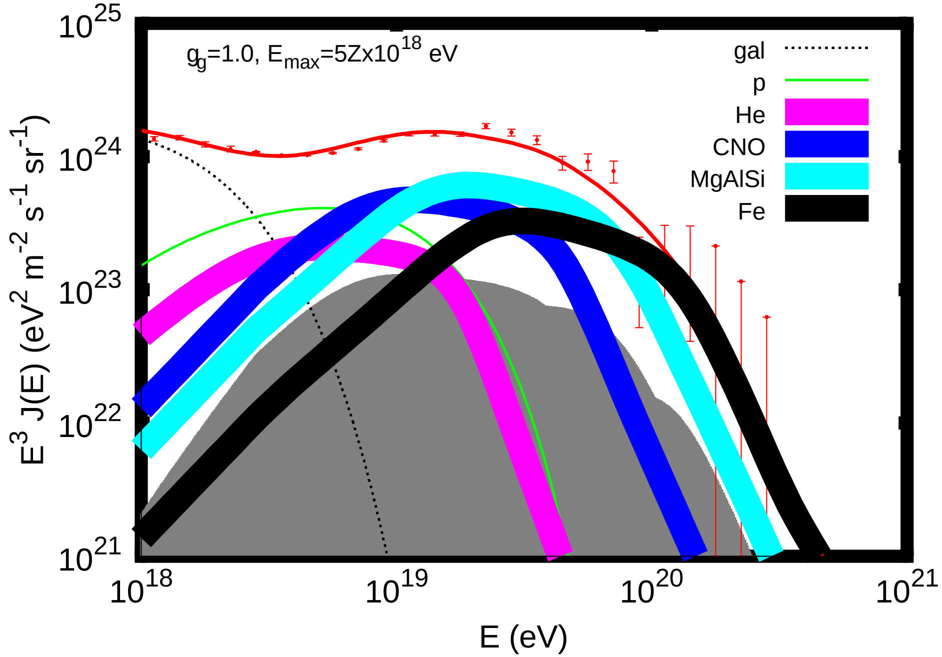


GZK like suppression !!!

GZK or the exhaustion of sources ???

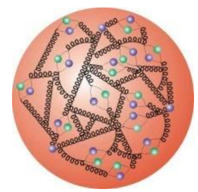
Old Data





Composition is the key to disentangle the two scenarios!

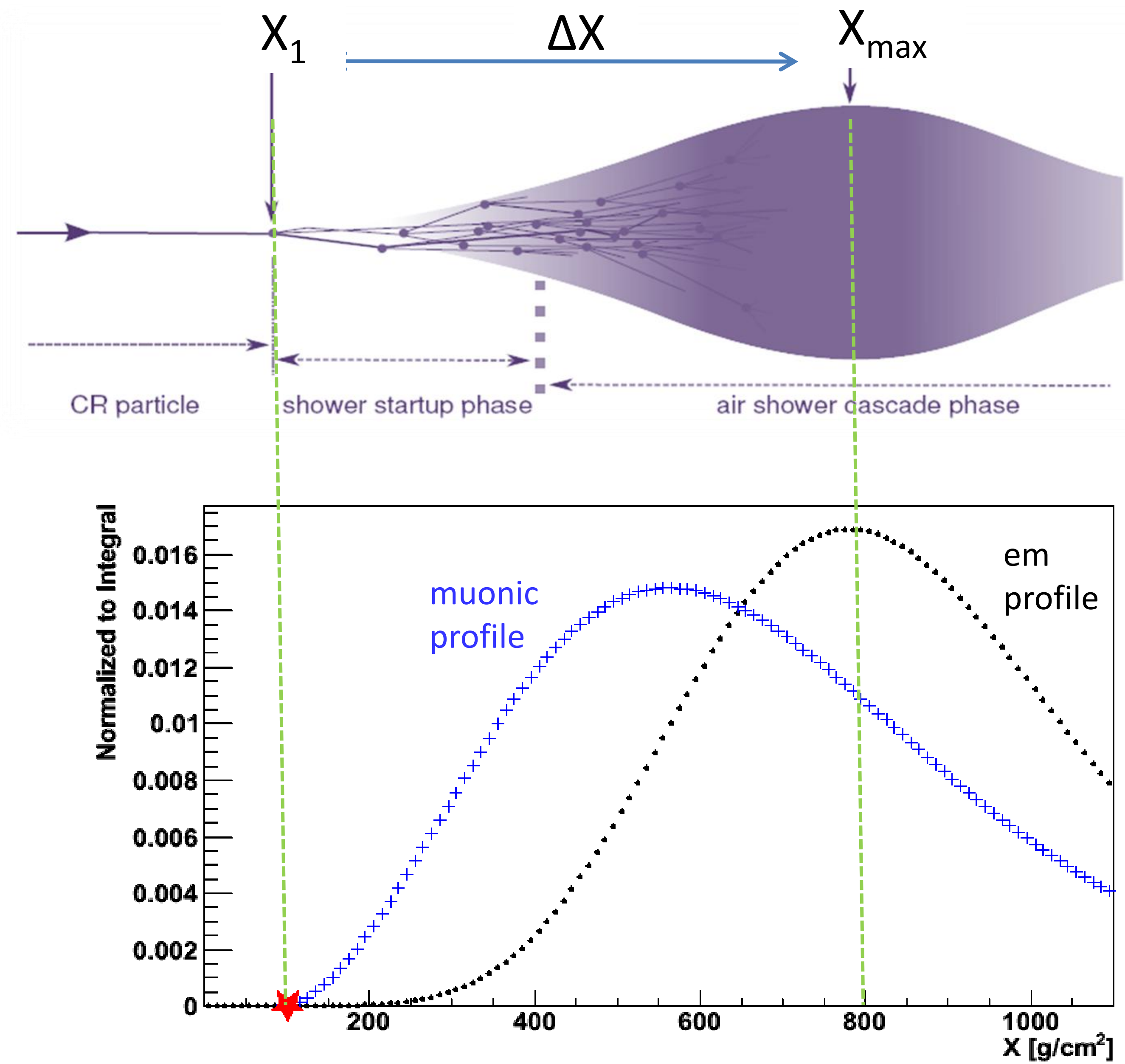
X_{max} and the “beam composition”



Proton

Nuclei (Iron, …)

Shower development



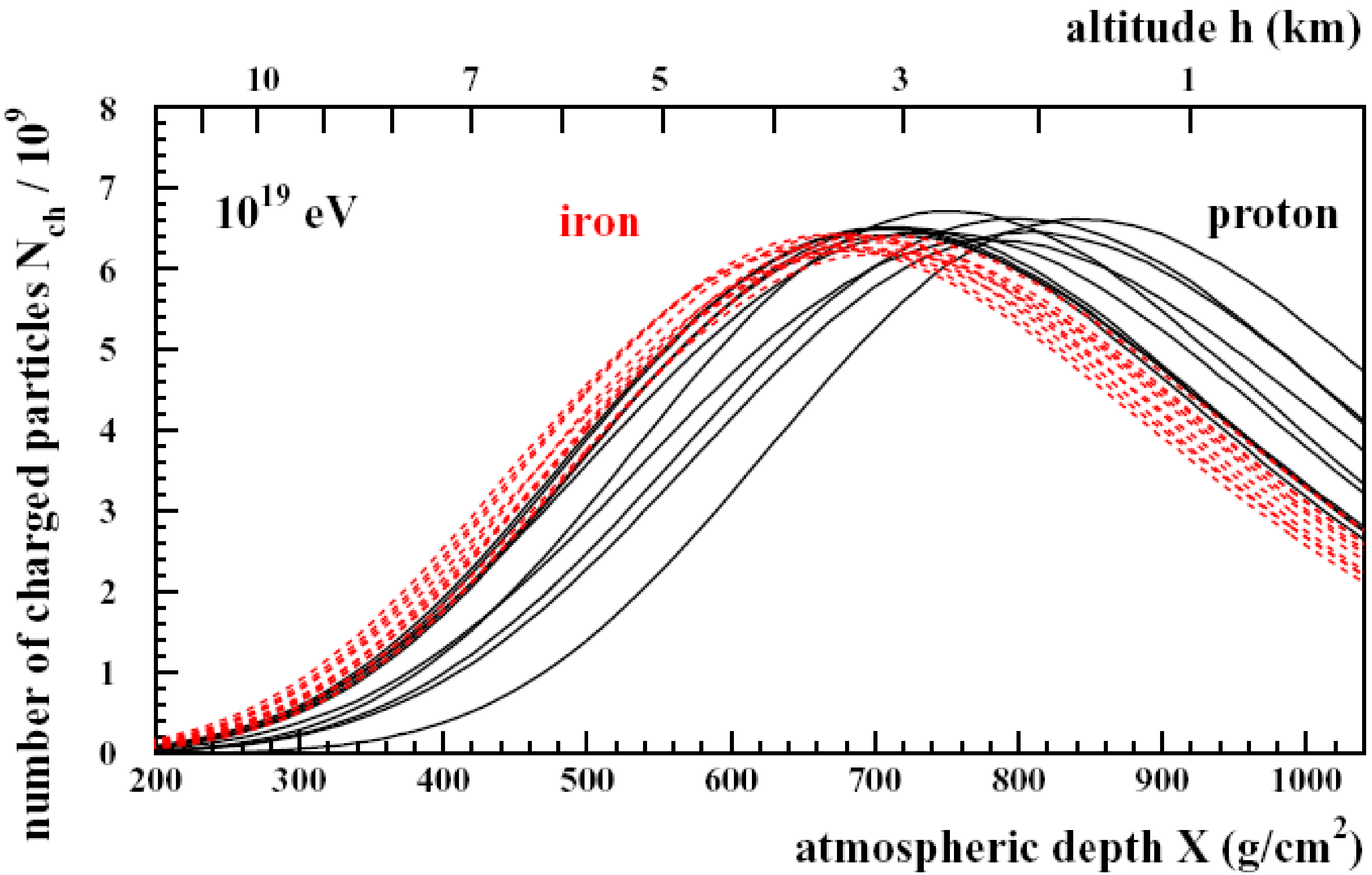
$$X_{max} = X_1 + \Delta X$$

$$E \propto N_e$$

$$\propto \int \frac{dN_e}{dX} dX$$

$$N_\mu \propto \int \frac{dN_\mu}{dX} dX$$

Fe/p longitudinal profiles



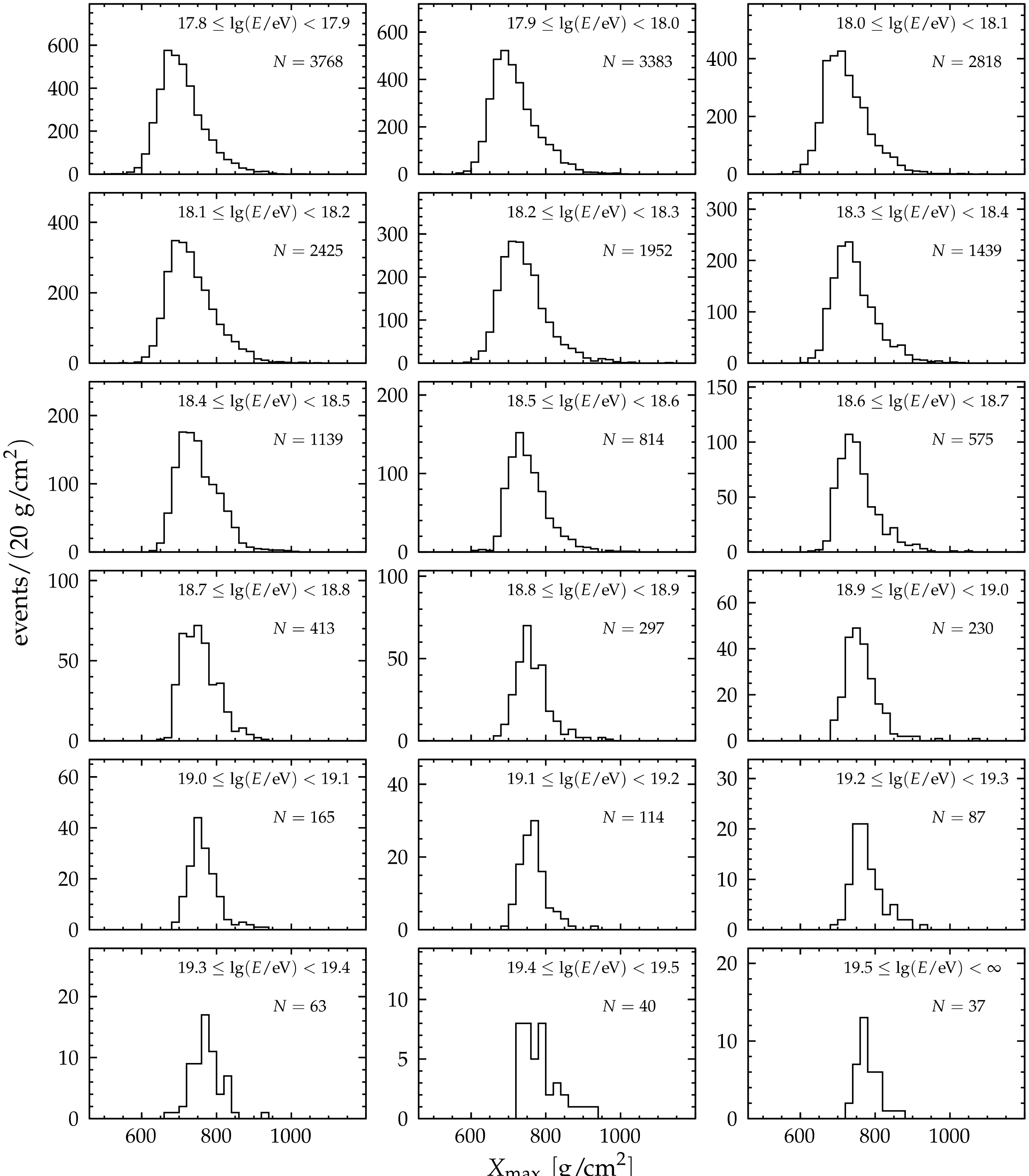
Iron ~ 56 nucl(E/56)

Smaller fluctuactions

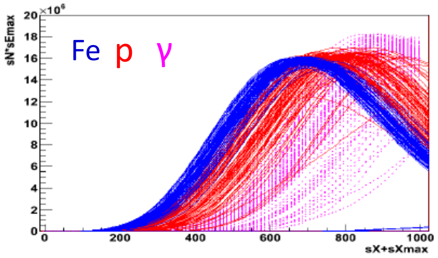
Smaller X_{max}

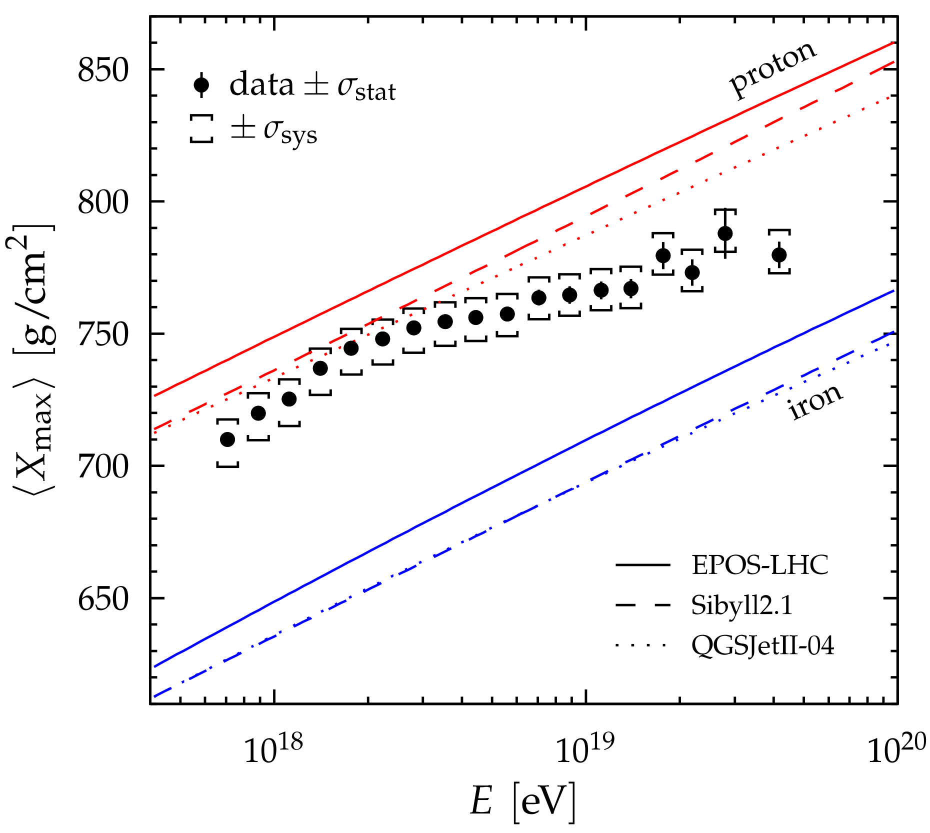
X_{max} distributions

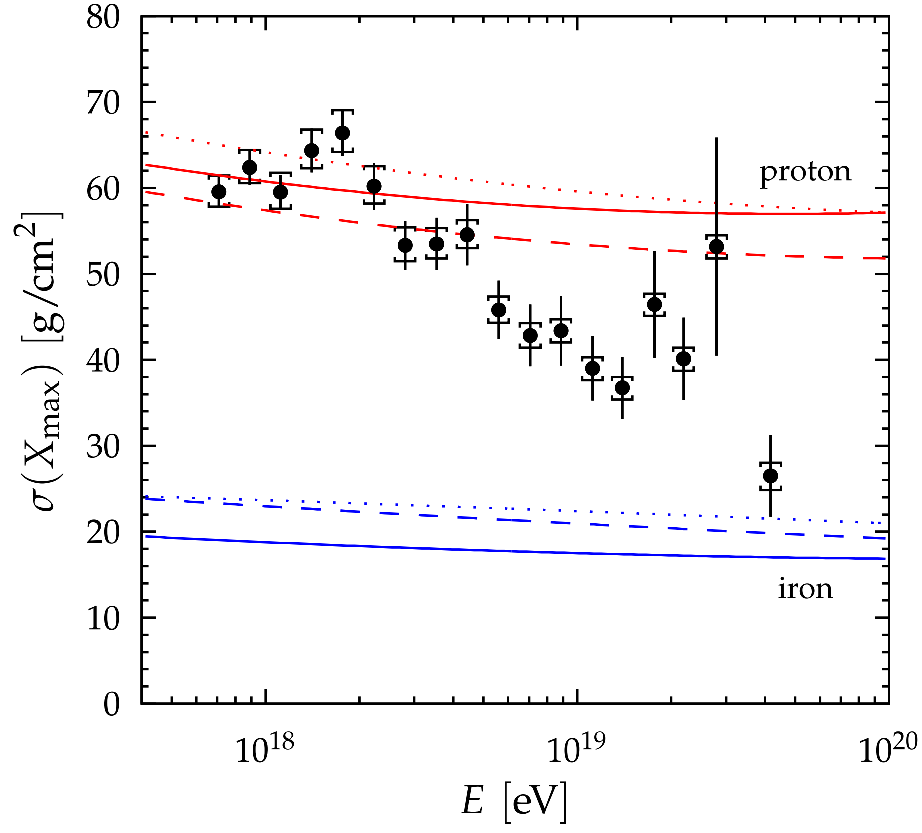
As the energy increases the distributions become narrower !!!



$\langle X_{max} \rangle$ and RMS(X_{max})







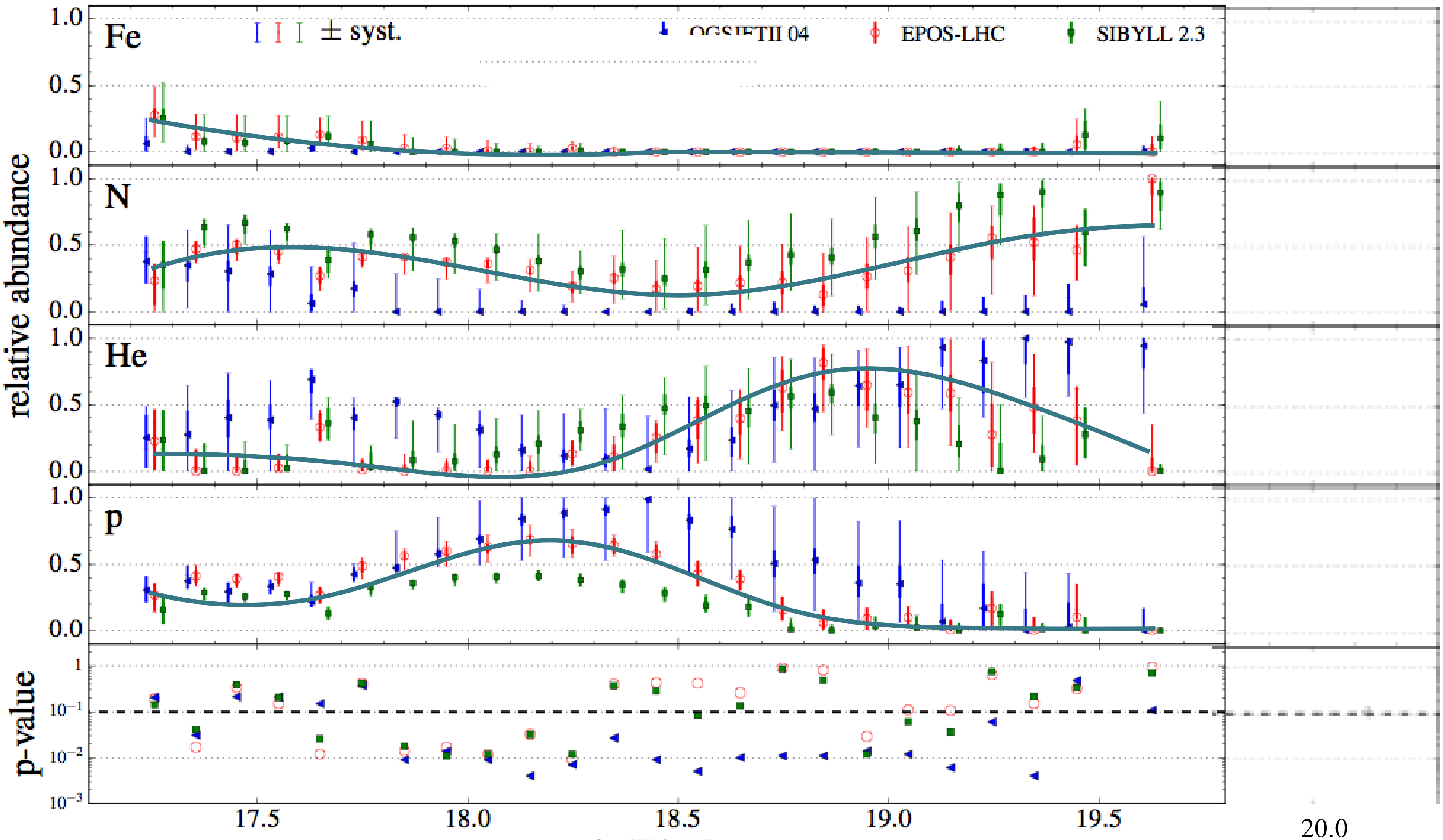
A clear change above 3 10^{18} eV

Beam composition ??? Hadronic interactions???

Mass composition

fluorescence telescope data (15% duty cycle)

Auger, preliminary



Composition could be explained by disintegration of ~ C or Si nuclei, very hard energy spectrum at injection favored (~ E^{-1}) ...

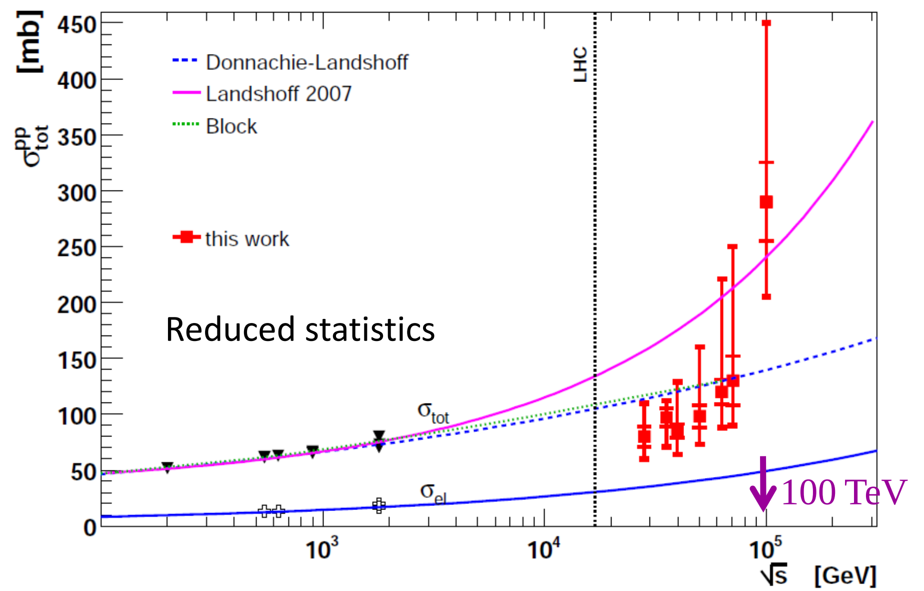
The “Particle Physics” interpretation …

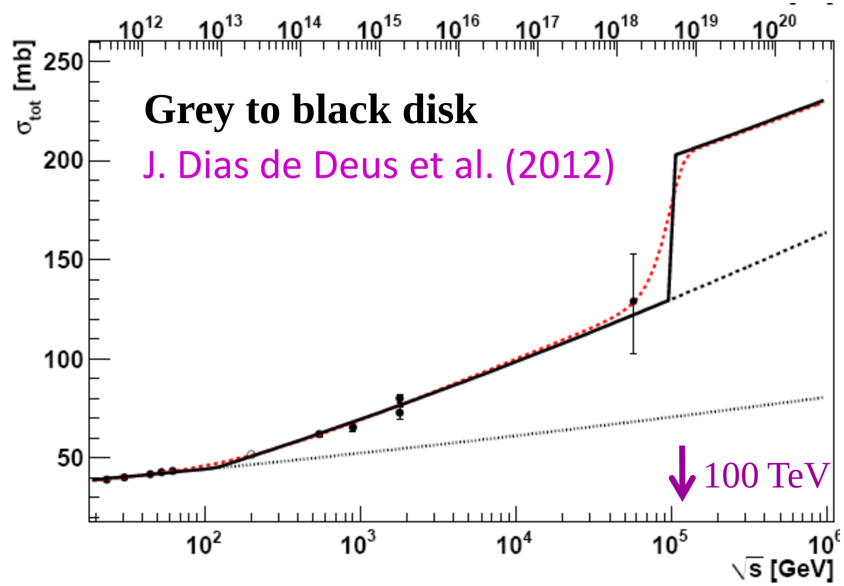
If just proton …

A dramatic increase in the proton-proton cross section

But no violation of the Froissart bound !

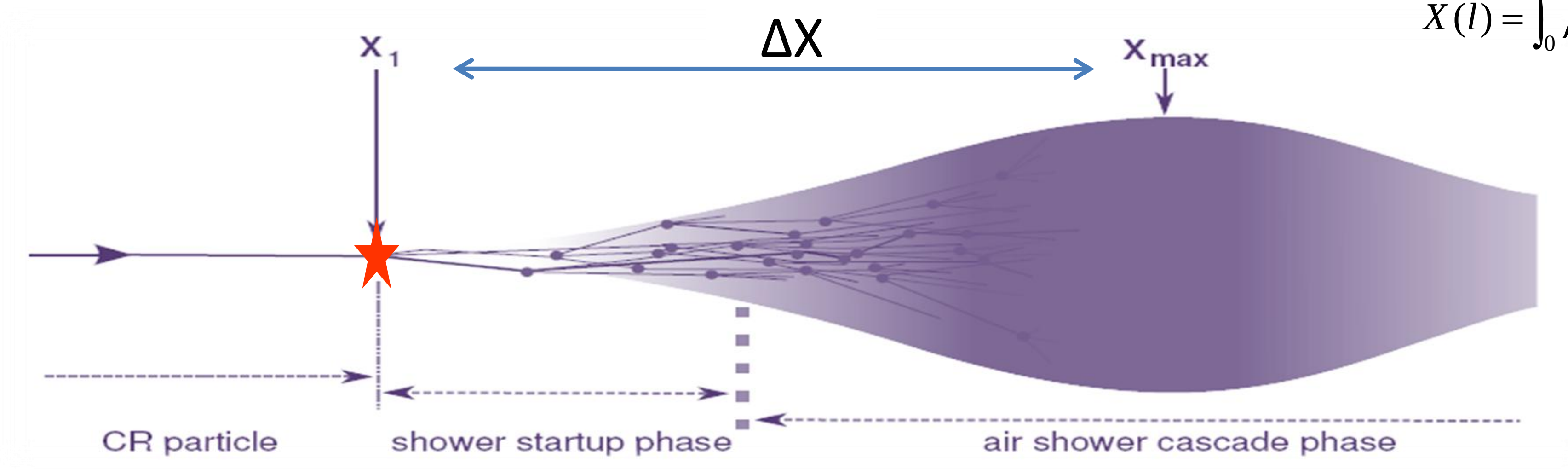
R.Ulrich (2008)



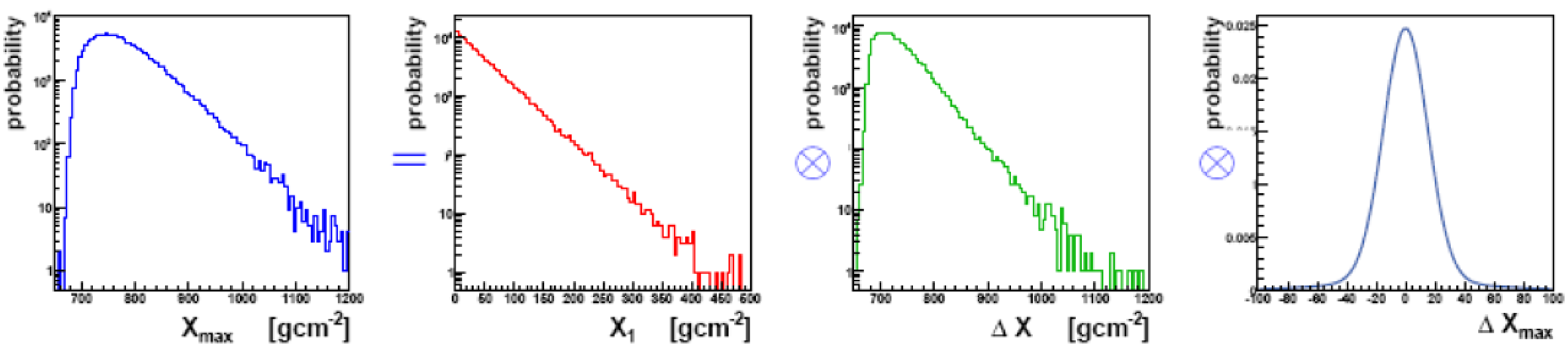


<X_{max} >distribution

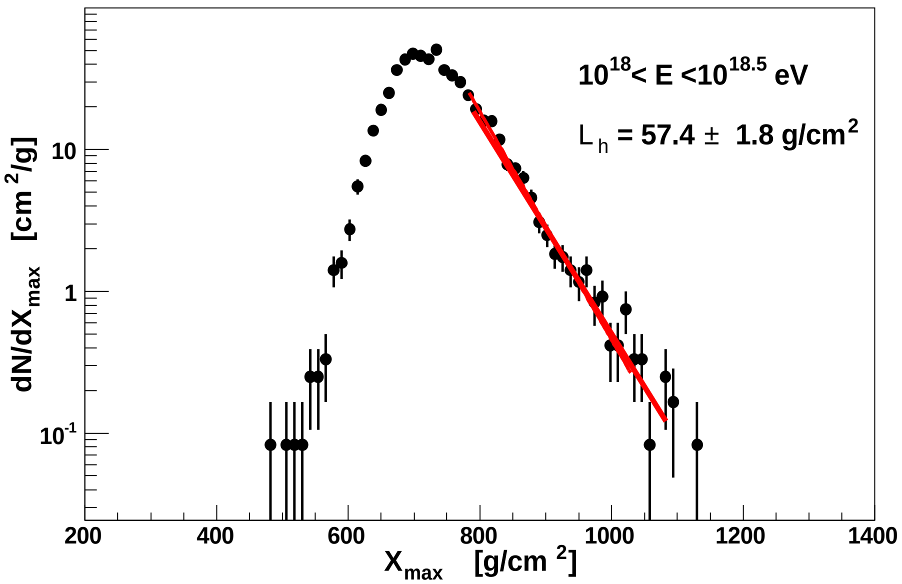
$$X(l) = \int_0^l \rho(x)dx$$

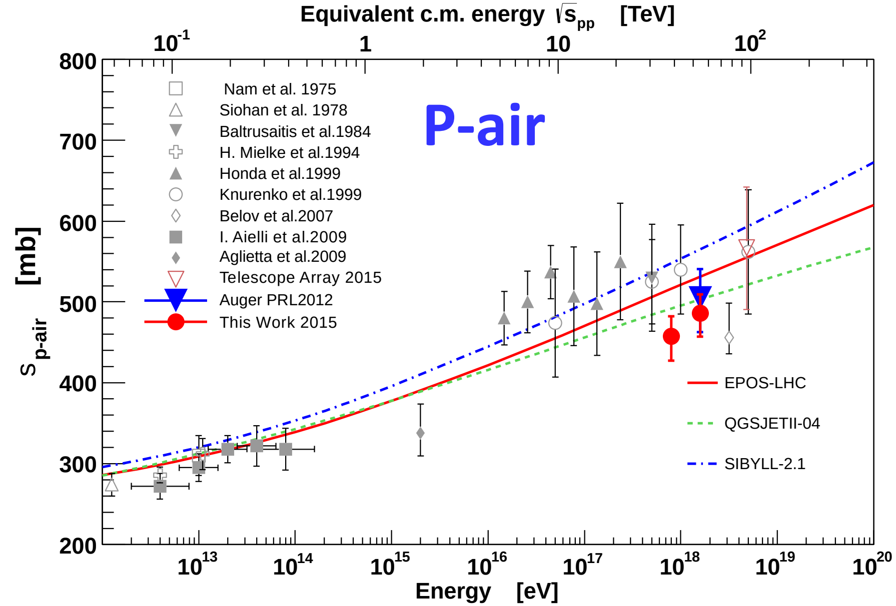


X_1 ΔX Experimental resolution

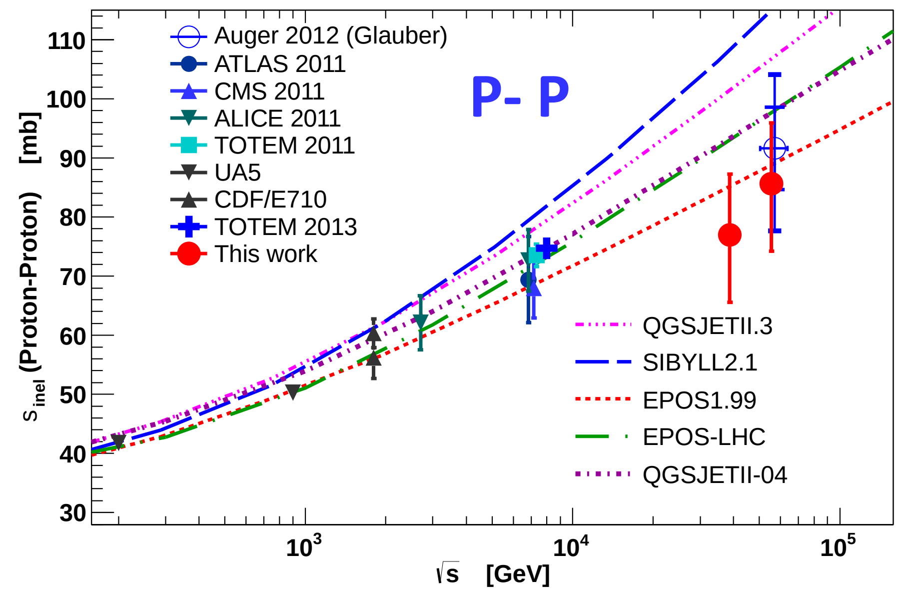


Proton cross-section



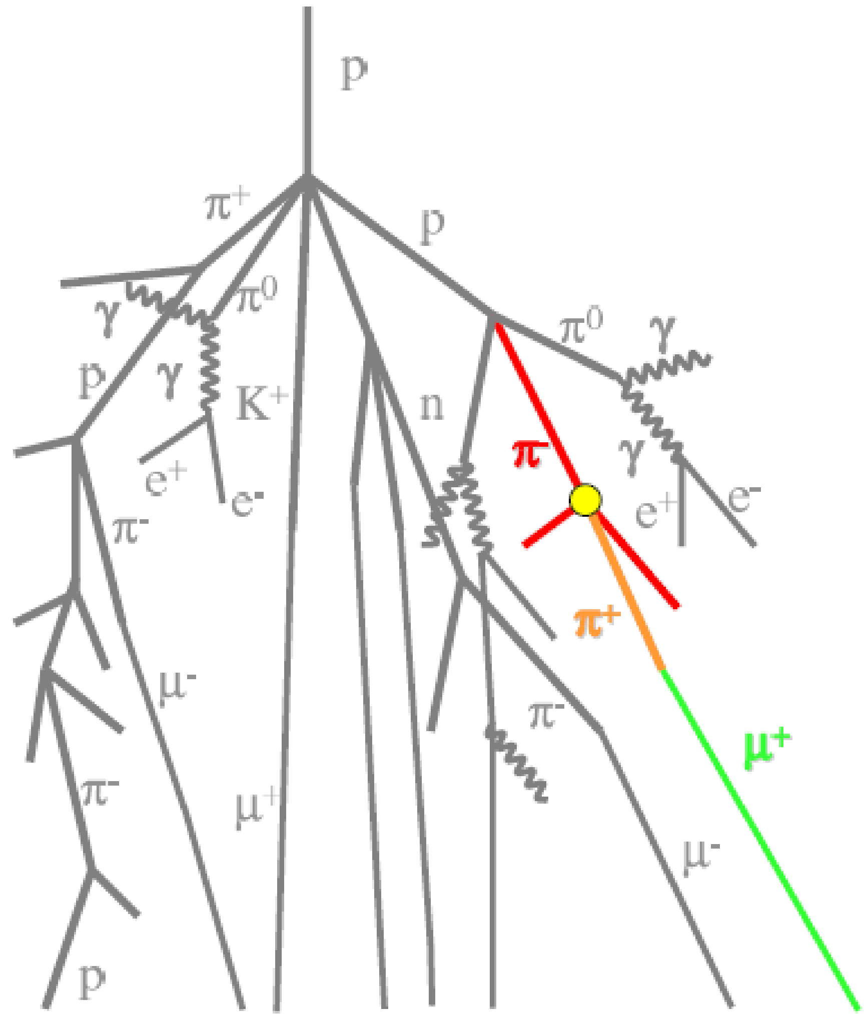


If % p > 20%, % He < 25%



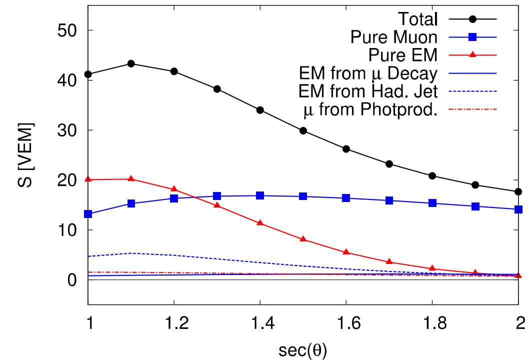
Slightly lower than it was expected at the time by most of the models, but in good agreement with recent LHC data.

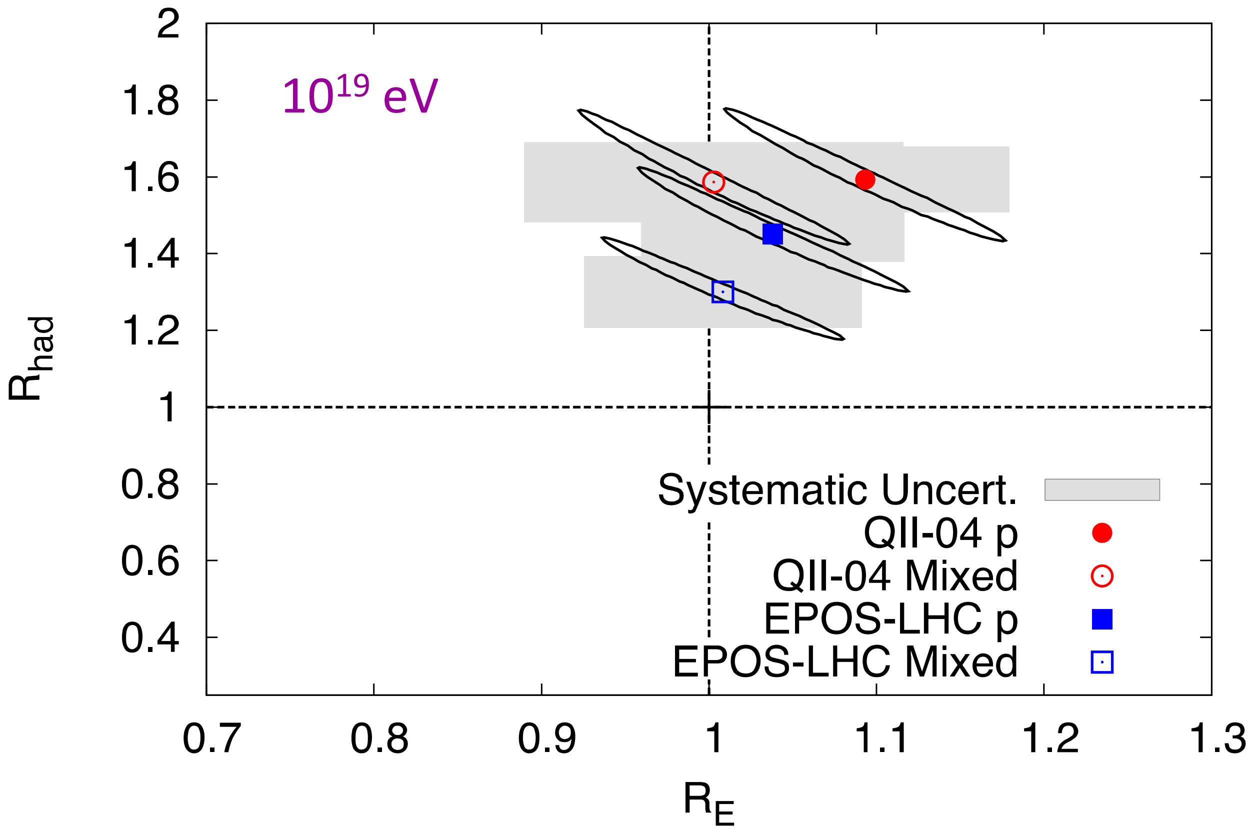
The “number of μ_s



The “number of μs

$$S_{\rm resc}(R_E, R_{\rm had})_{i,j} \equiv R_E\, S_{EM,i,j} + R_{\rm had}\, R_E^{\alpha}\, S_{{\rm had},i,j}$$

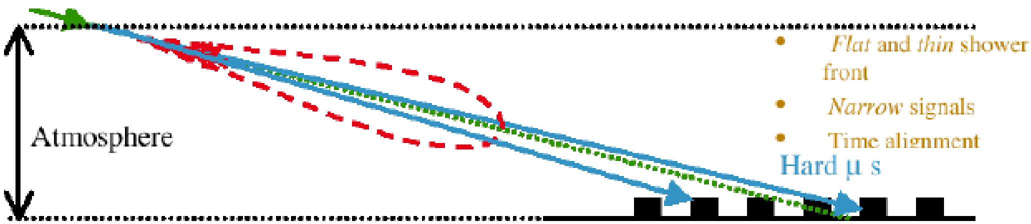


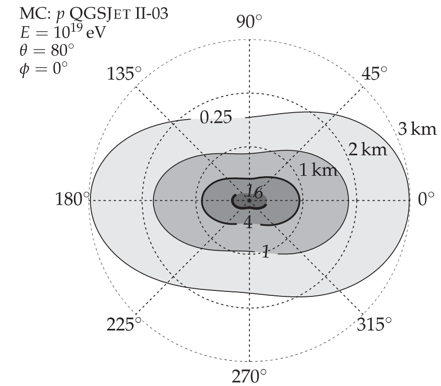


Model	R_E	$R_{\rm had}$
QII-04 p	$1.09 \pm 0.08 \pm 0.09$	$1.59 \pm 0.17 \pm 0.09$
QII-04 Mixed	$1.00 \pm 0.08 \pm 0.11$	$1.61 \pm 0.18 \pm 0.11$
EPOS p	$1.04 \pm 0.08 \pm 0.08$	$1.45 \pm 0.16 \pm 0.08$
EPOS Mixed	$1.00 \pm 0.07 \pm 0.08$	$1.33 \pm 0.13 \pm 0.09$

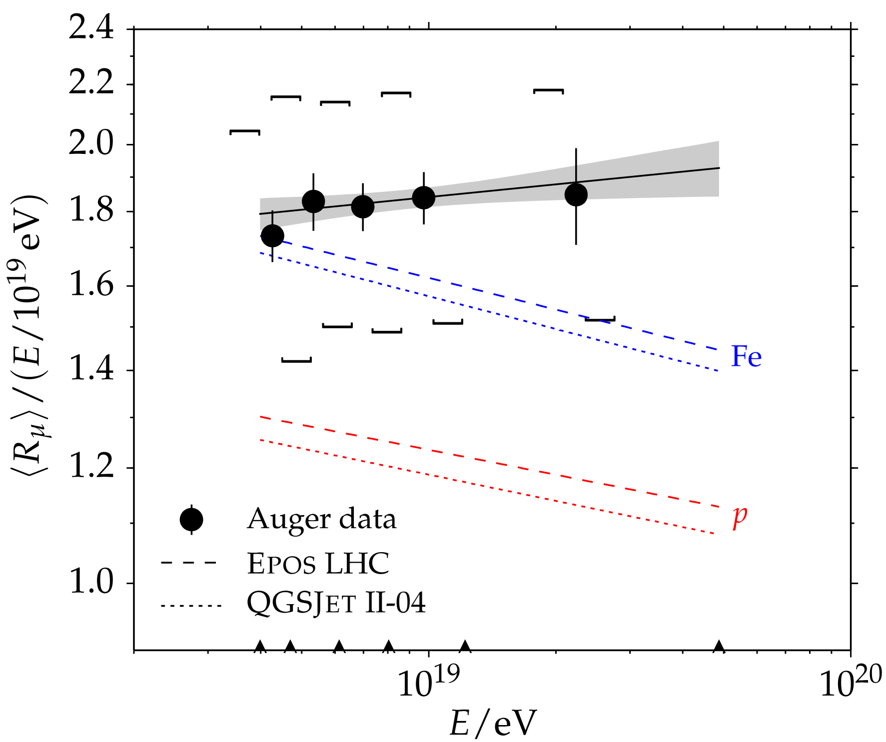
Hadronic signal in data is significantly larger

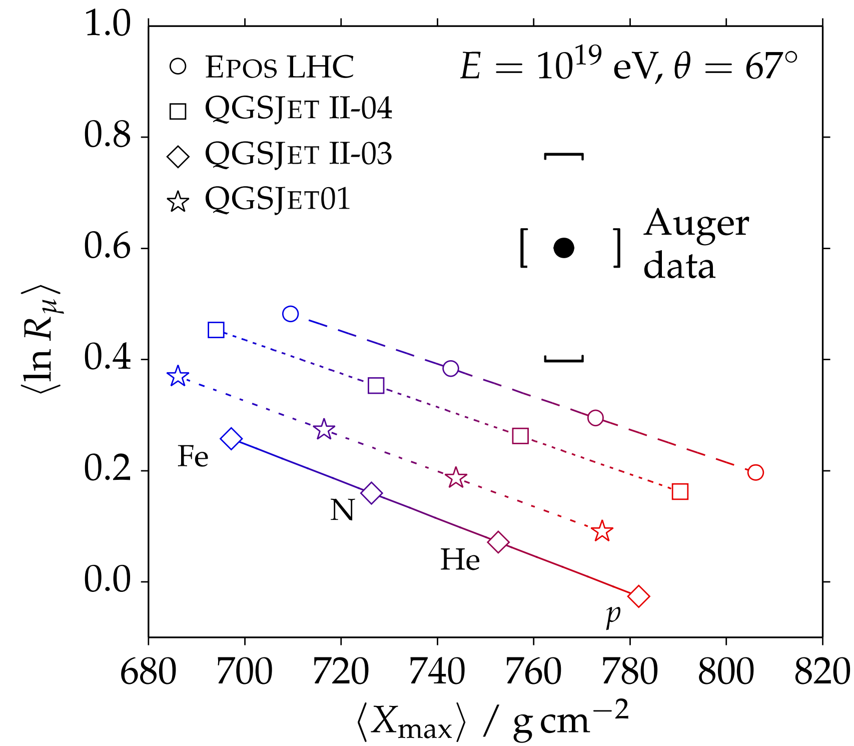
The “number of μs (inclined showers)





$$R_\mu = N_\mu^{true} / N_\mu^{map}(\theta, \phi) = N_{19}^{true}$$

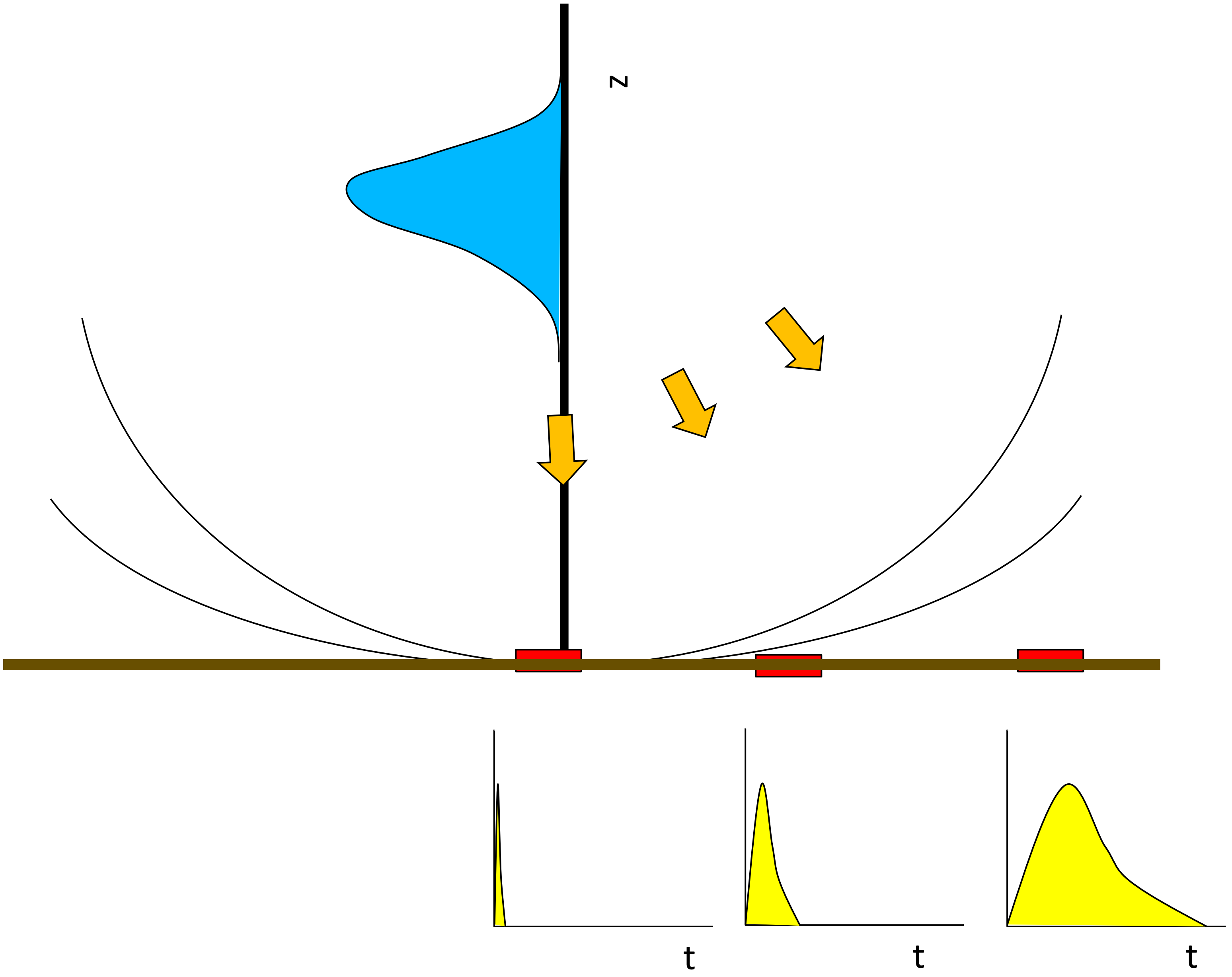




Tension between data and all hadronic interaction models !!!

Muon Production Depth (MPD)

L. Cazon, R.A. Vazquez, A.A. Watson, E. Zas, Astropart.Phys.**21**:71-86 (2004)
L.Cazon, PhD Thesis (USC 2005)



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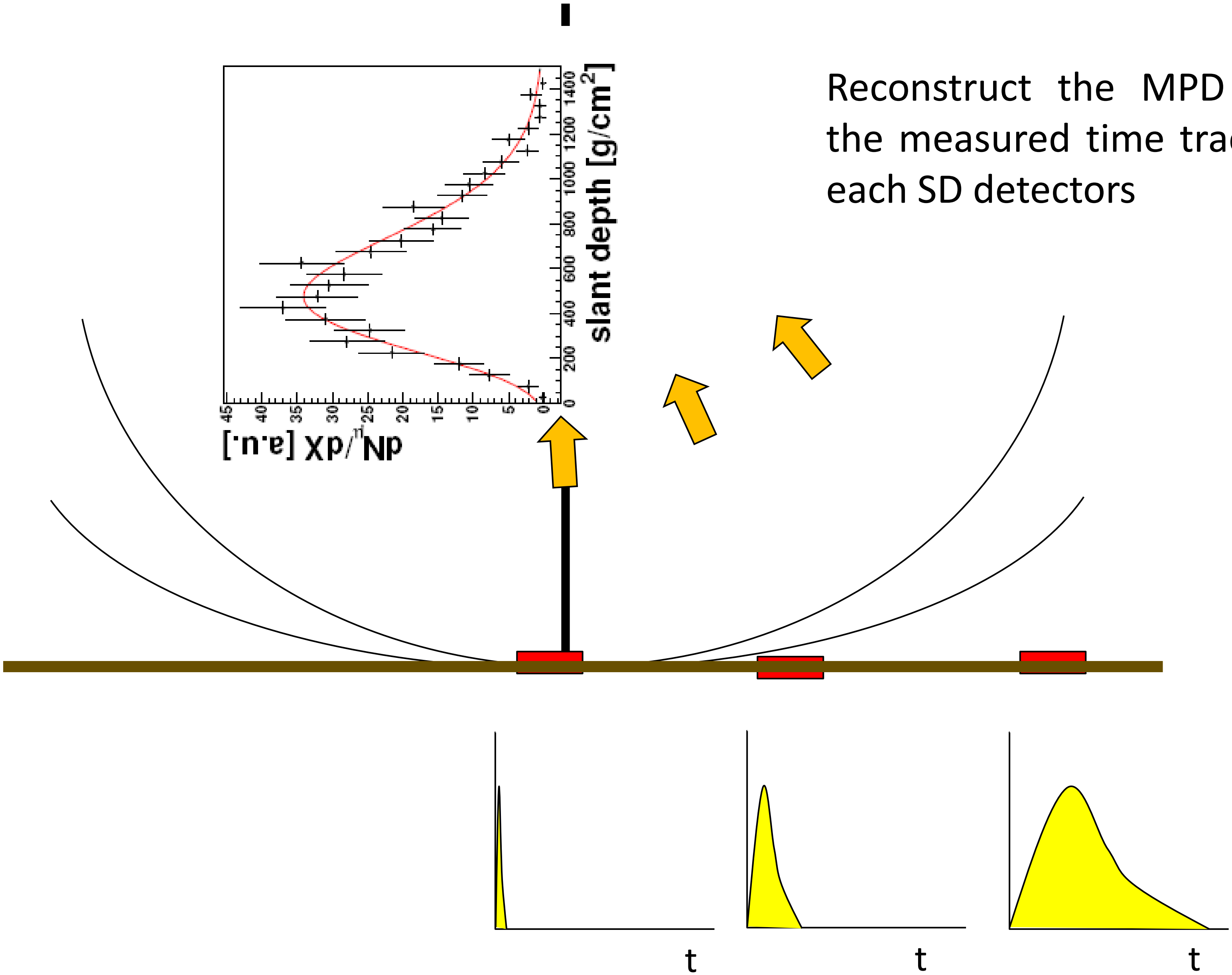
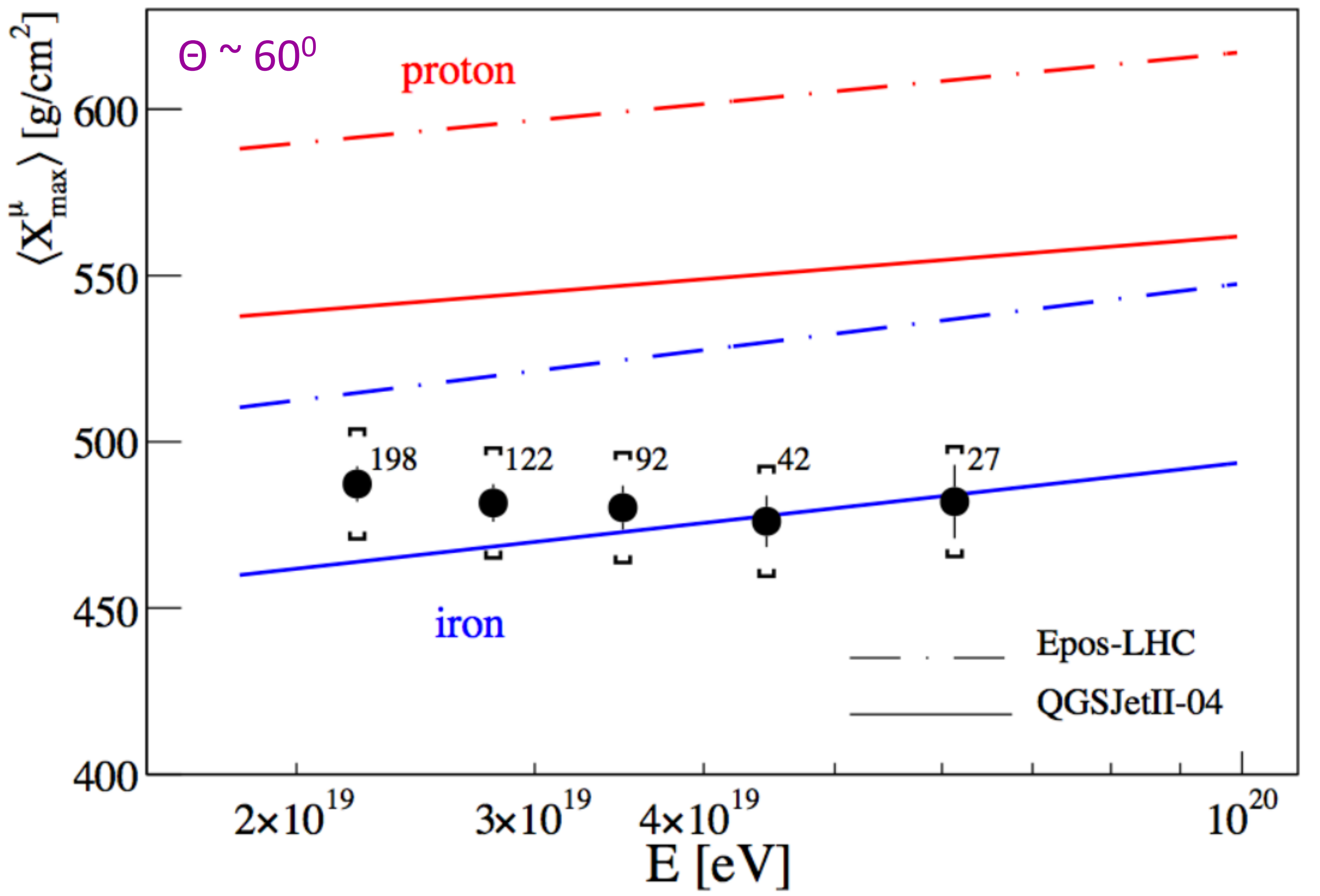
Astropart.Phys.**21**:71-86 (2004)
L.Cazon, PhD Thesis (USC 2005)

Reconstruct the MPD from the measured time traces at each SD detectors

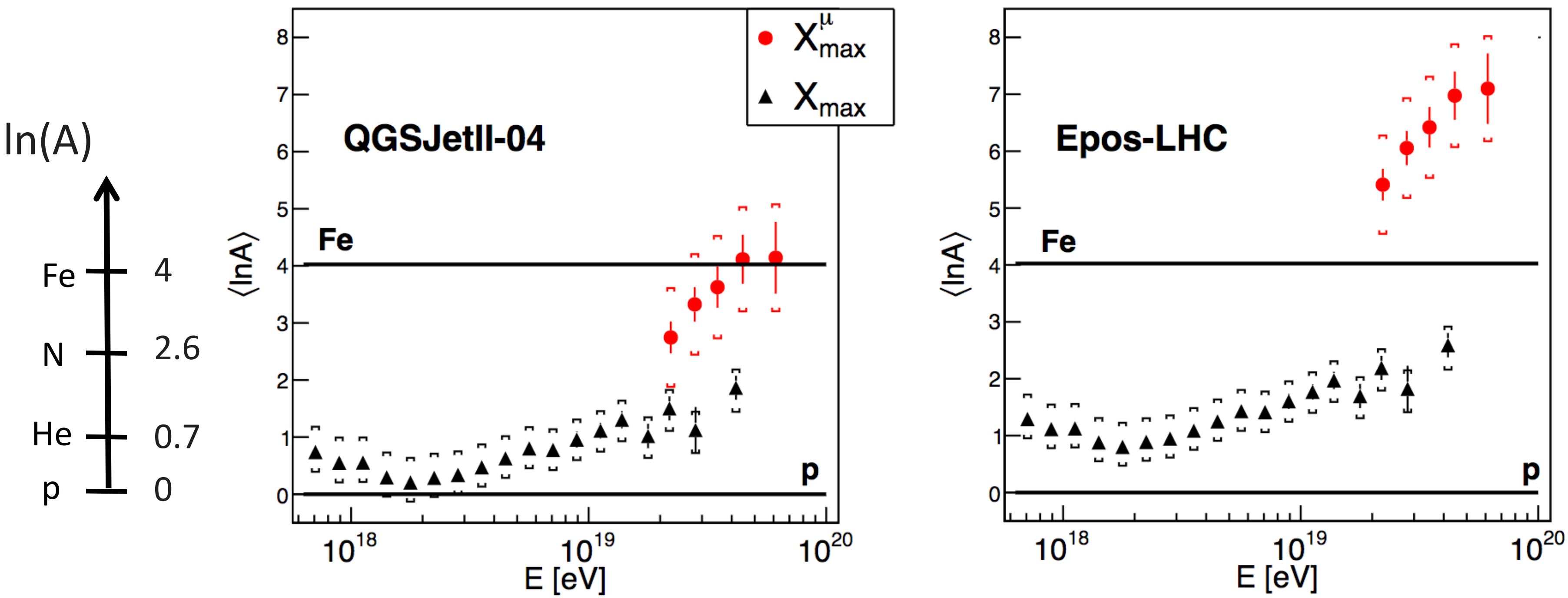


$<X^{\mu}_{max}>$



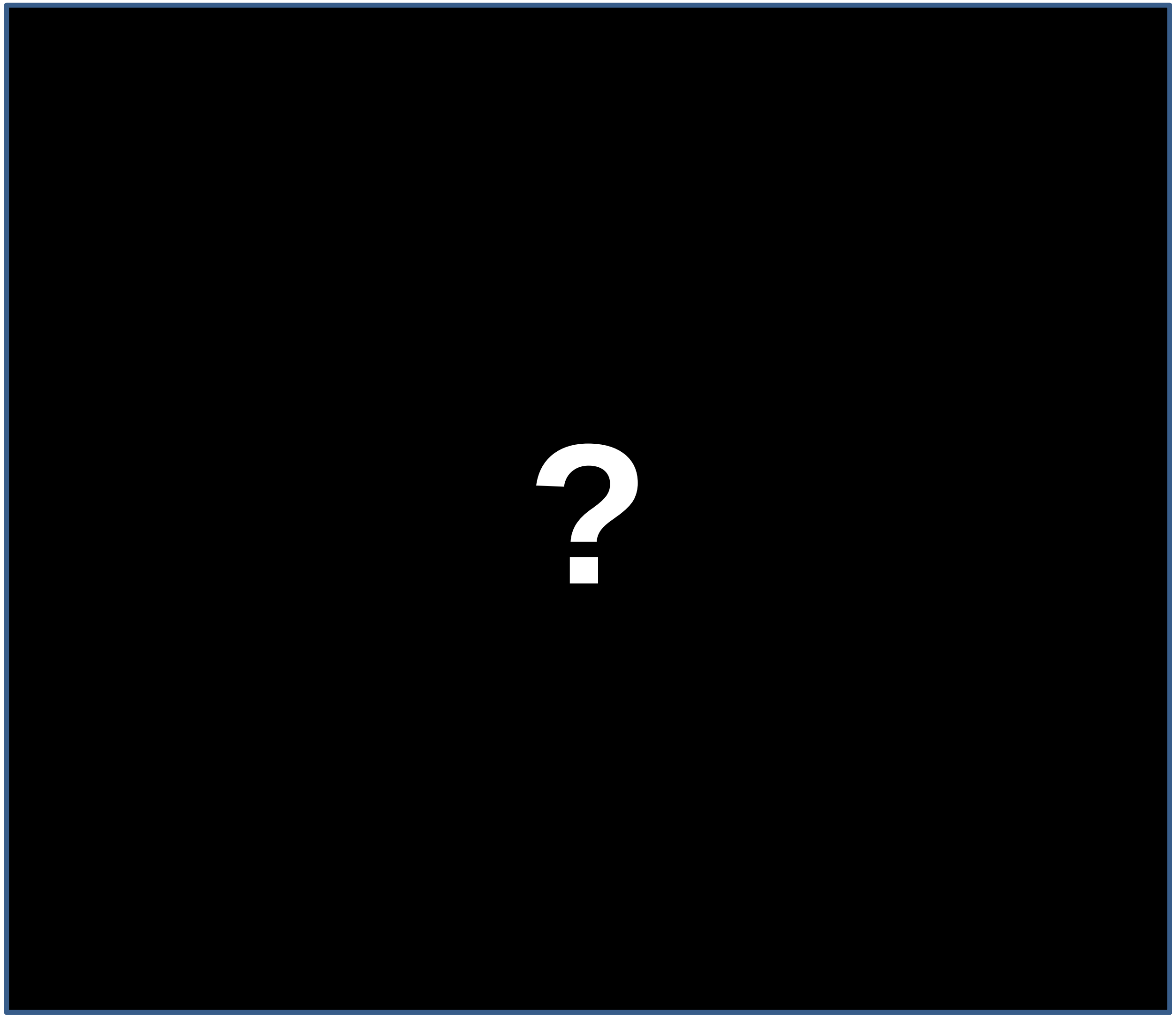
Θ ~ 60⁰
proton
iron
198
122
92
42
27
Epos-LHC
QGSJetII-04
⟨X^μ_max⟩ [g/cm²]
600
550
500
450
400
2×10^19
3×10^19
4×10^19
10^20
E [eV]

<ln A> from X_{max} and X^{μ}_{max}



(X_{max}, X^{μ}_{max}) is sensitive to hadronic development of the shower (rapidity distributions, …)

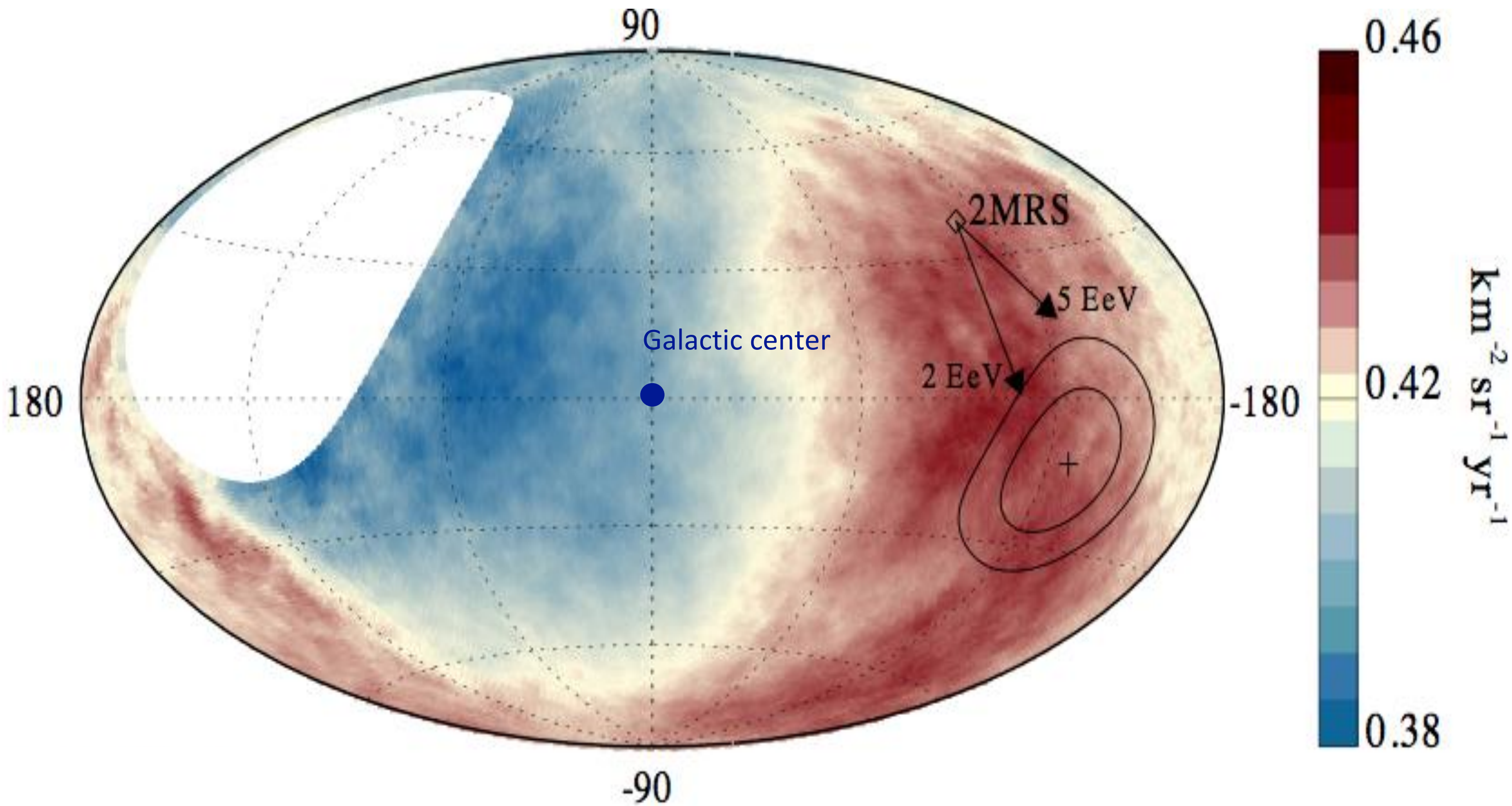
Origin



Extragalactic Origin

$E > 8 \times 10^{18}\,\mathrm{eV}$

Auger - 6.5% dipole at 5.2 sigma

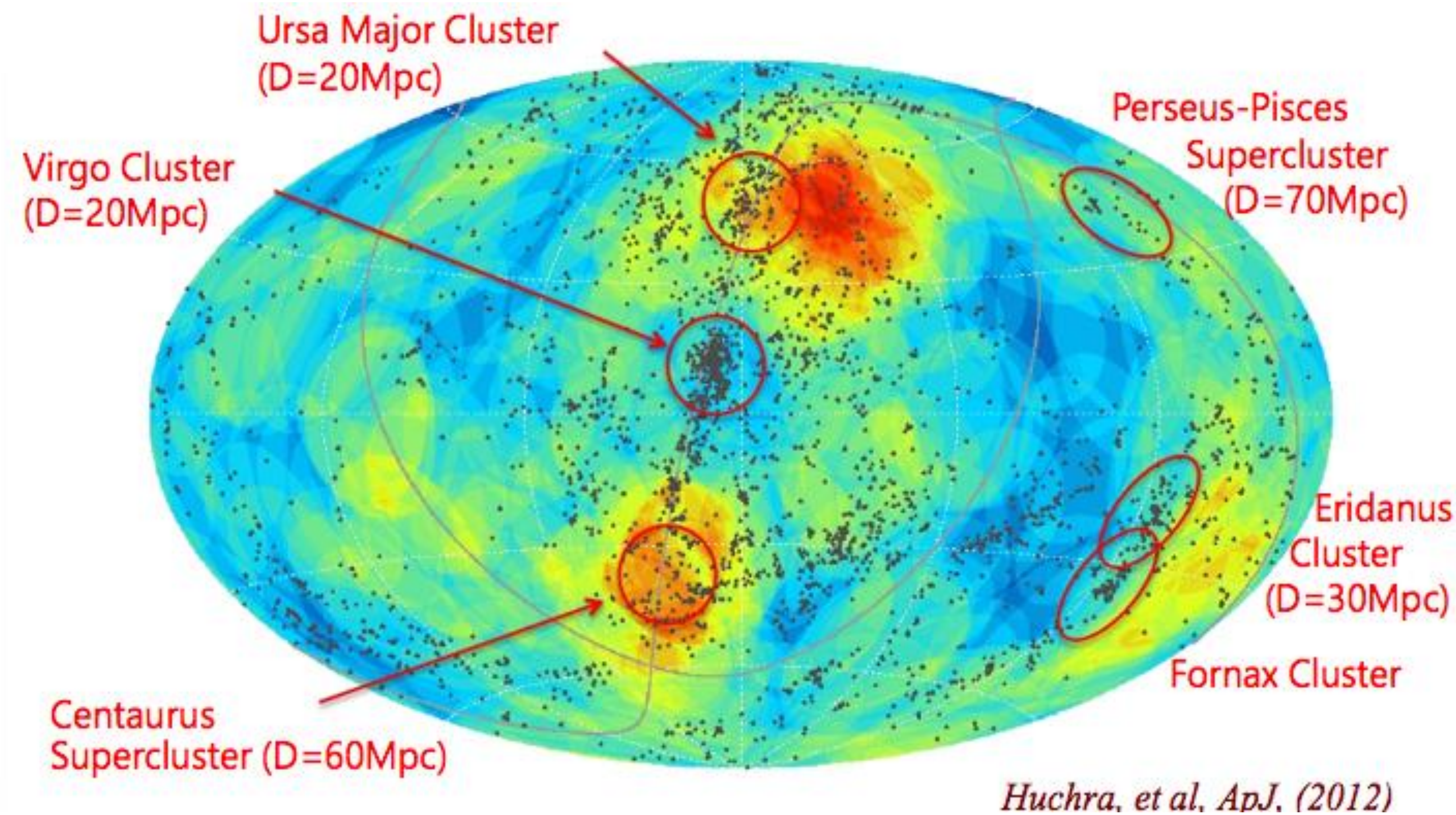


Arrival directions follow mass distribution of near-by galaxies

Hot/Warm spots

$E > 6 \times 10^{19}\,\mathrm{eV}$

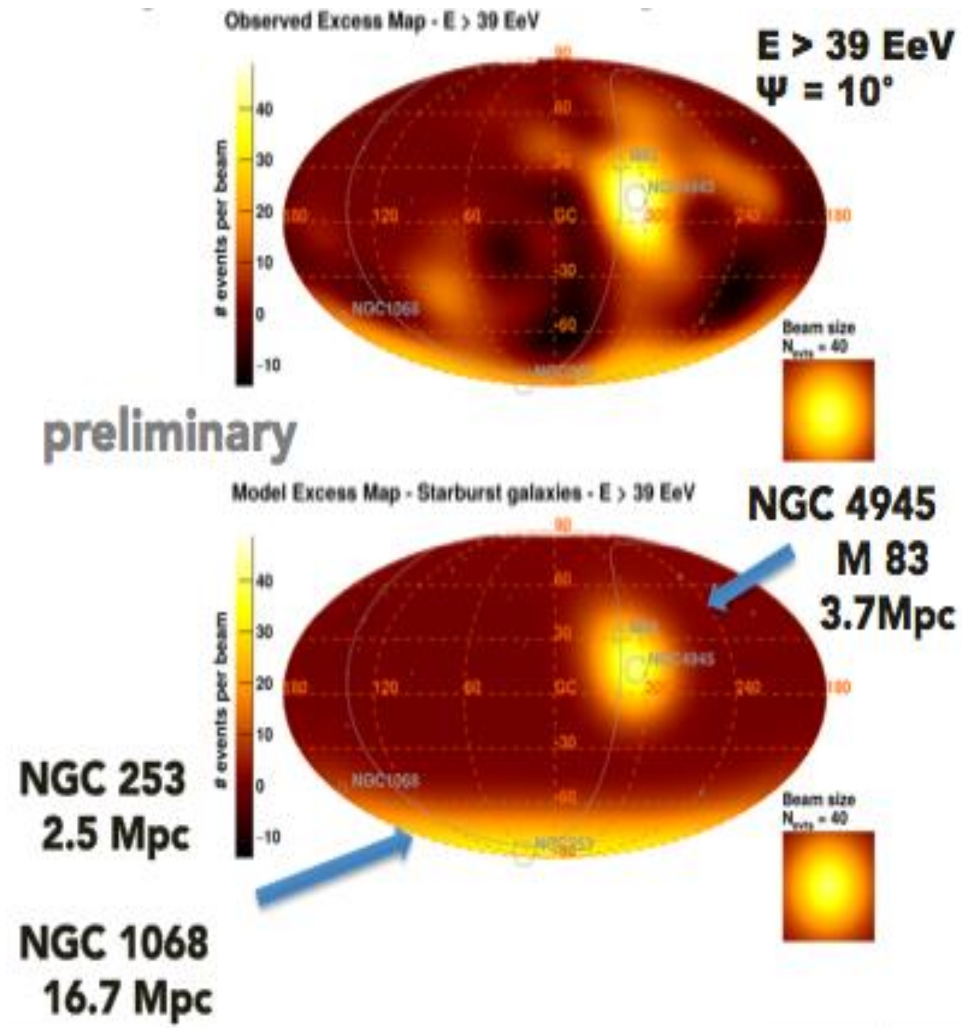
TA and Auger: over-densities ~20° size



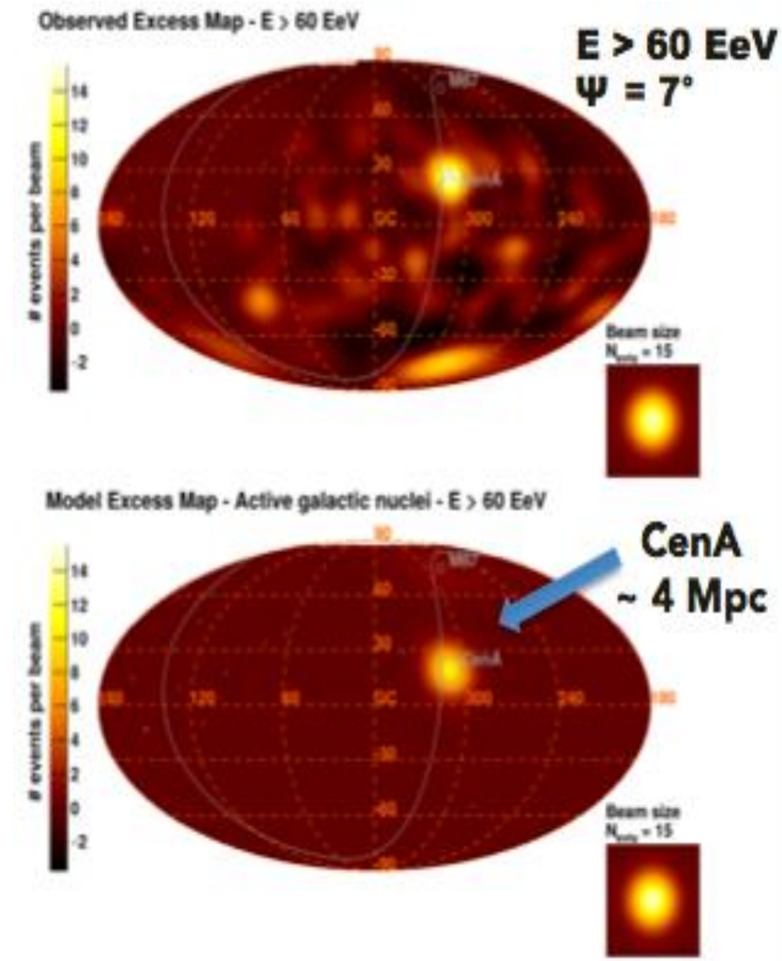
Galaxies with D < 45 Mpc
(2MASS catalog)

Anisotropy – Correlation with catalogs (Auger)

Starburst galaxies

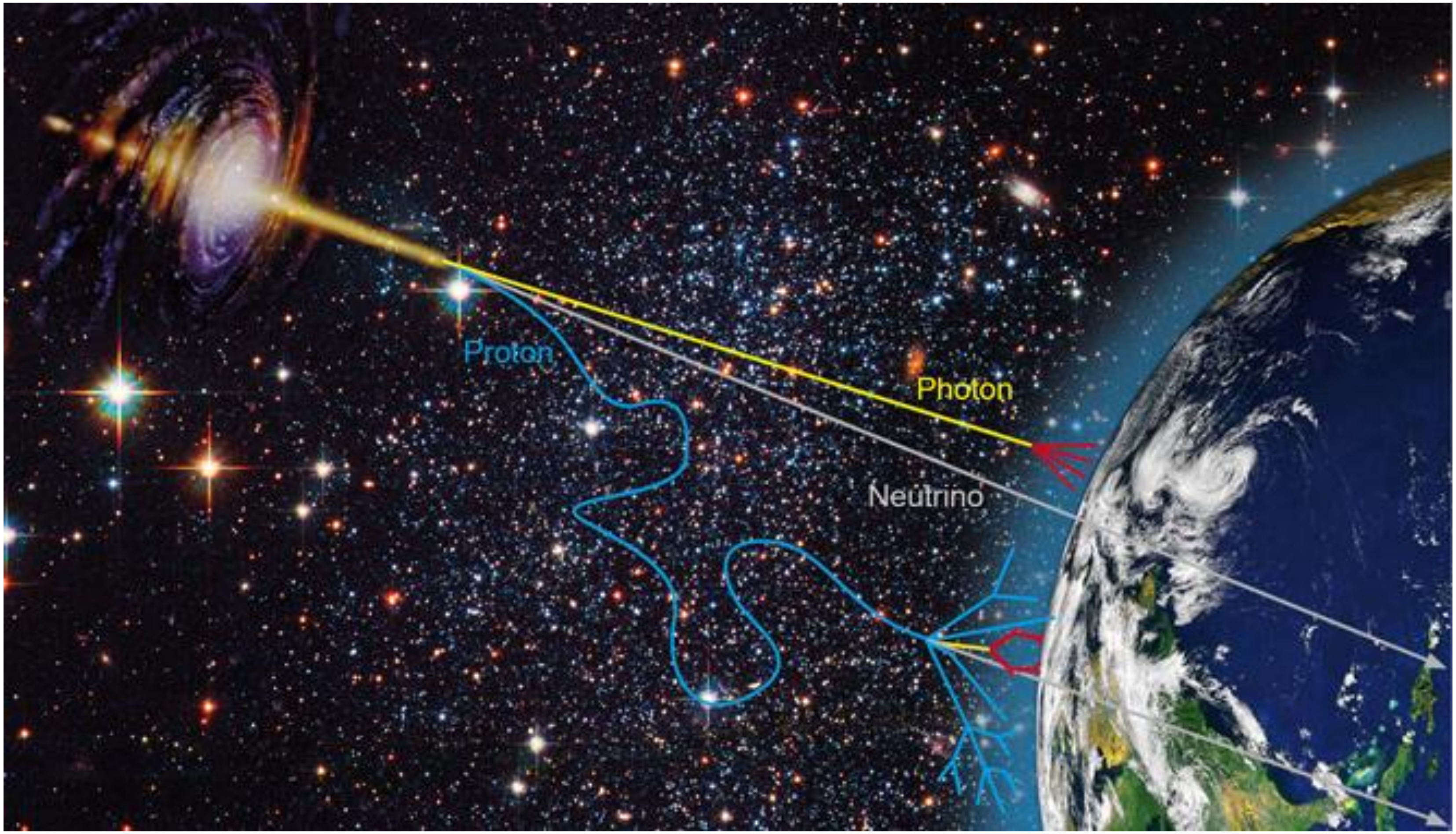


AGNs

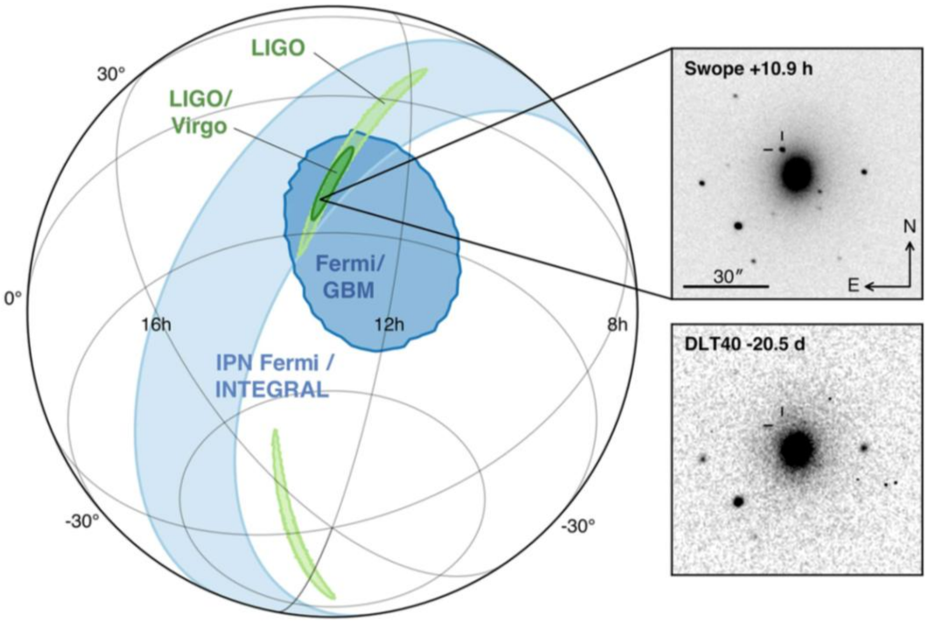


(Giaccari ICRC 2017)

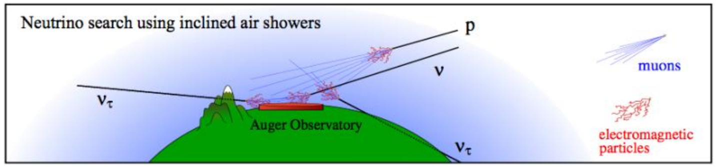
The Multimessager Era

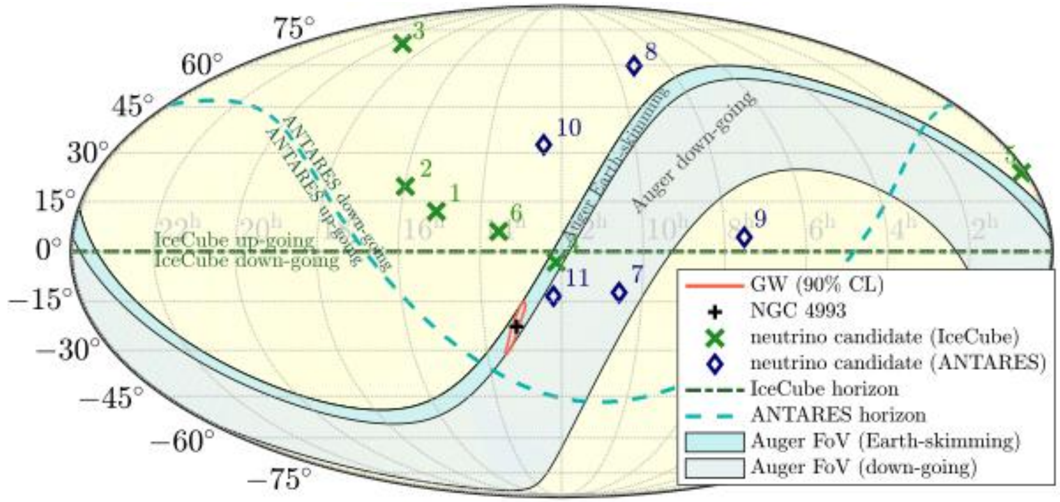


GW170817

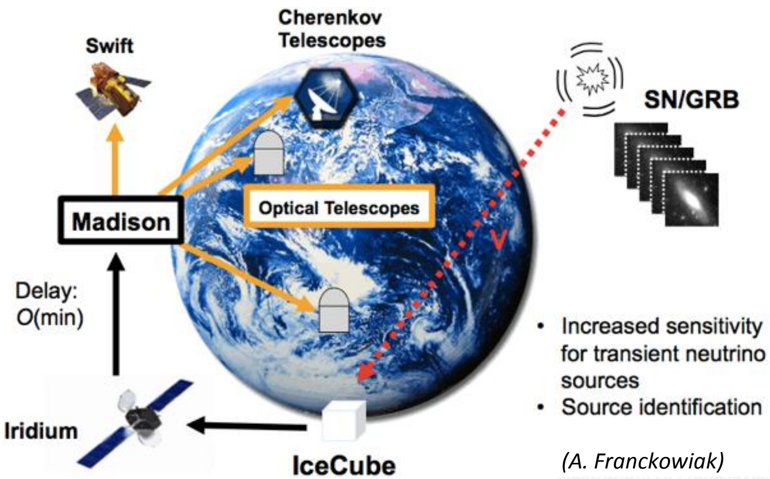


The first multimessenger discovery of a binary neutron star merger





First source of astrophysical neutrinos at high energy?



09.05.18, 13:33

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE: 17/09/23 01:09:26 GMT
FROM: Erik Blaufuss at U. Maryland/IceCube <blaufuss@icecube.umd.edu>

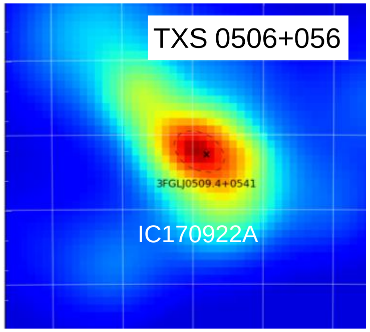
Claudio Kopper (University of Alberta) and Erik Blaufuss (University of Maryland) report on behalf of the IceCube Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability of being of astrophysical origin. The event was identified by the Extremely High Energy (EHE) track event selection. The IceCube detector was in a normal operating state. EHE events typically have a neutrino interaction vertex that is outside the detector, produce a muon that traverses the detector volume, and have a high light level (a proxy for energy).

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon), more sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

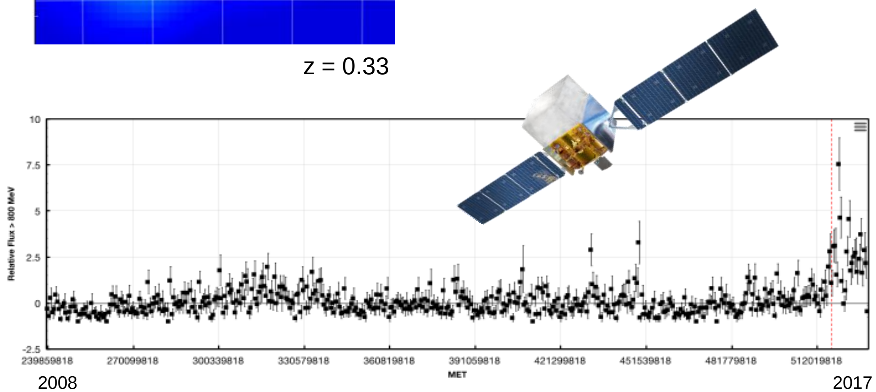
Date: 22 Sep, 2017
Time: 20:54:30.43 UTC
RA: 77.43 deg (-0.80 deg/+1.30 deg 90% PSF containment) J2000
Dec: 5.72 deg (-0.40 deg/+0.70 deg 90% PSF containment) J2000

We encourage follow-up by ground and space-based instruments to help identify a possible astrophysical source for the candidate neutrino.



z = 0.33

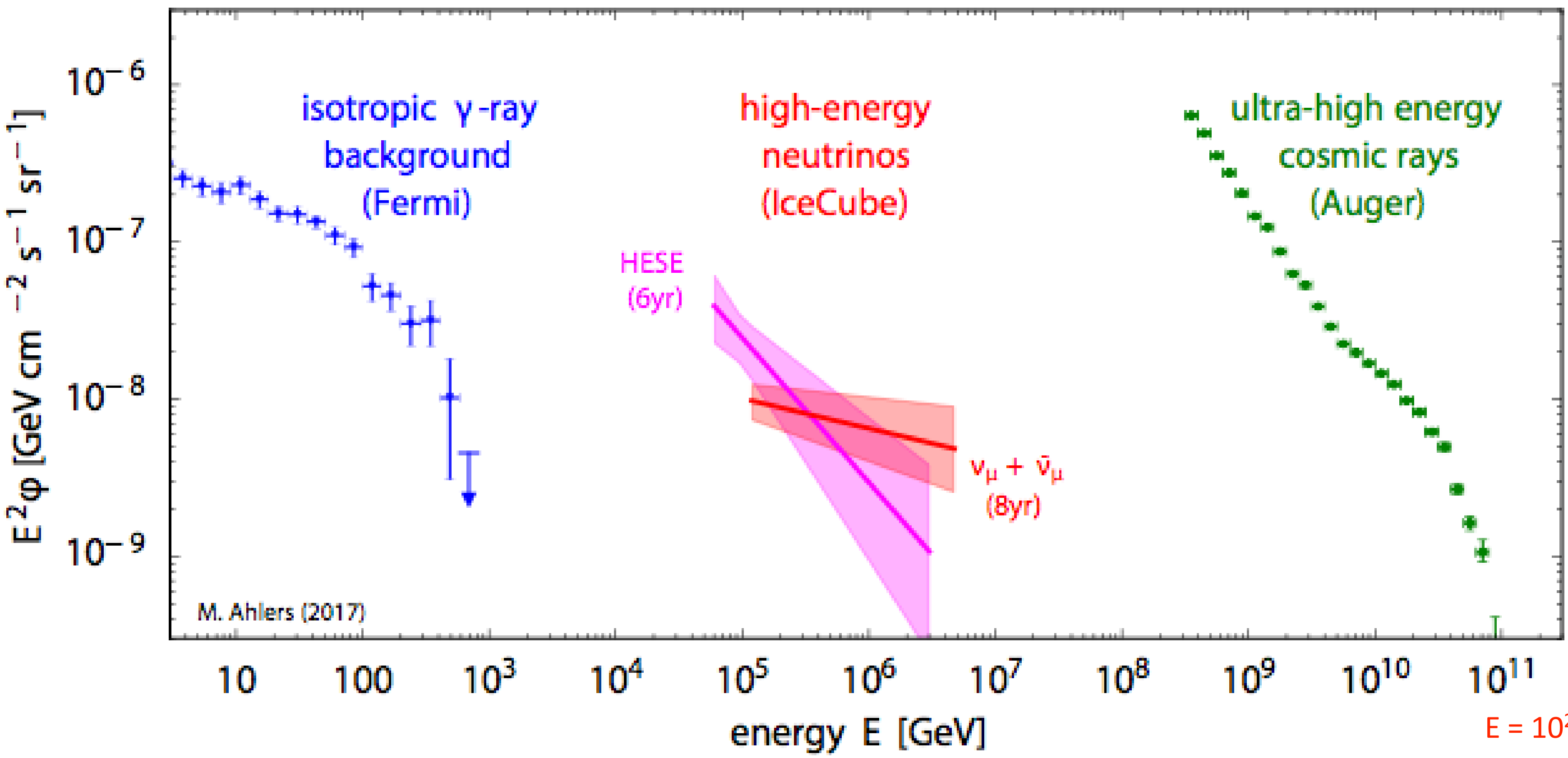
MAGIC: flare E > 100 GeV



FERMI: flare (found 6 days later)

IceCube 1709922A, publications in preparation

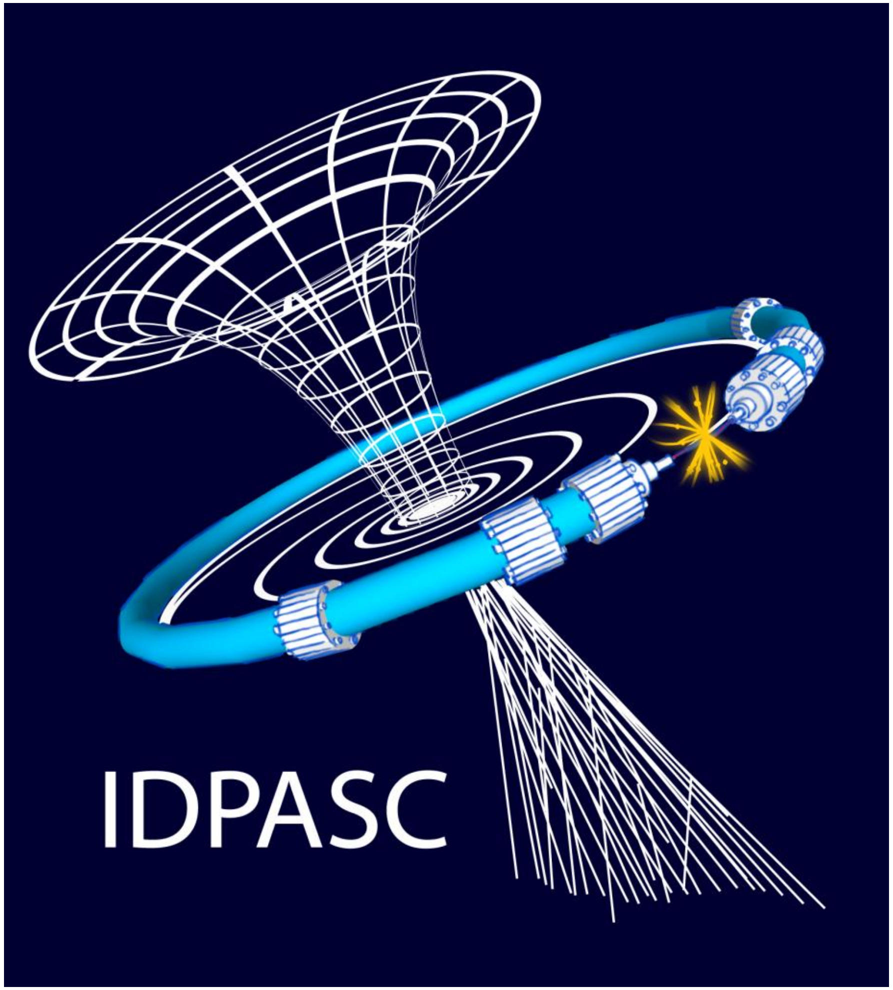
The Universe at the highest energies !



E = 10^{20} eV

Energy density per decade similar in all three messenger particles

The Universe remains to be discovered !

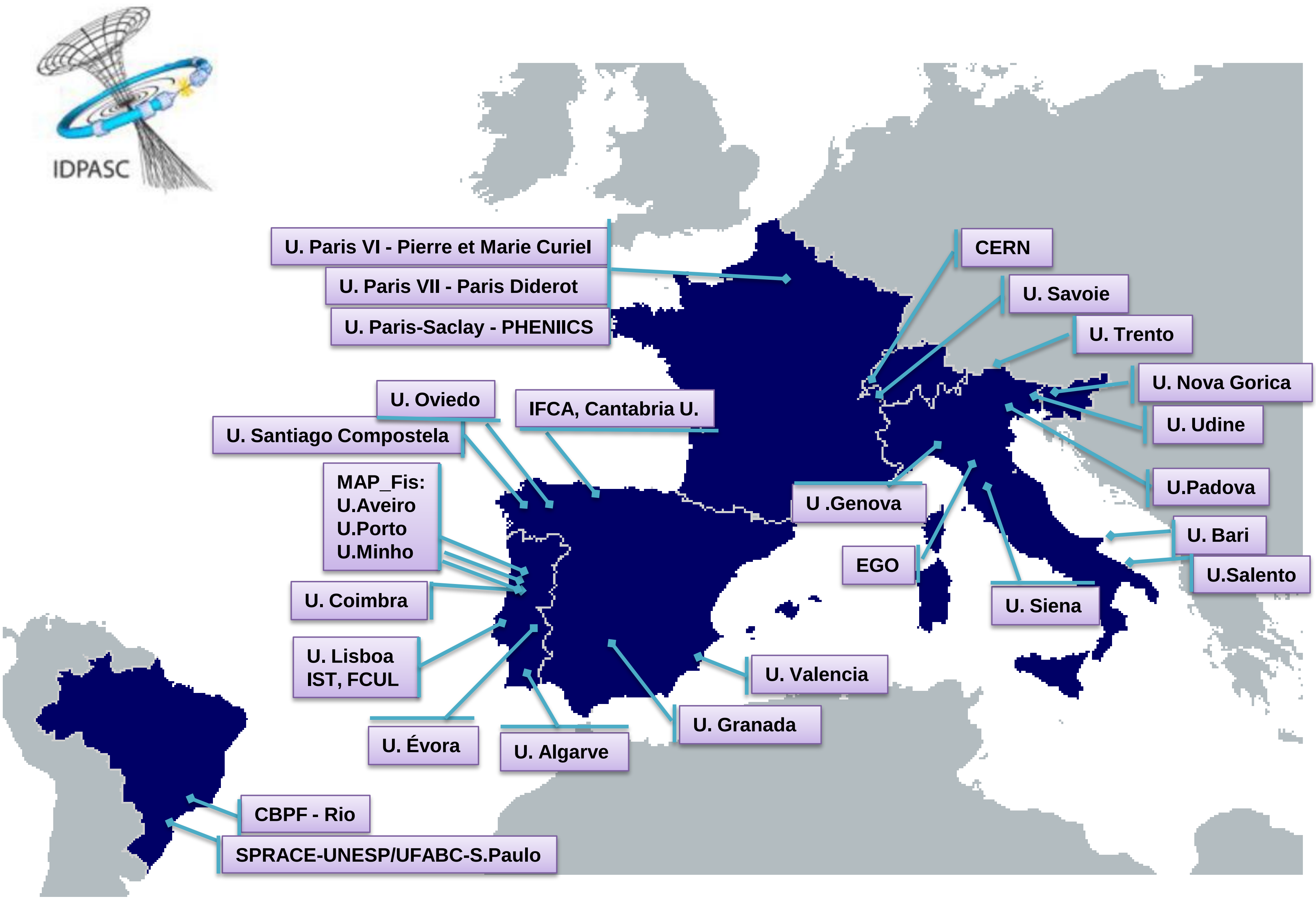


International Doctorate Network in Particle Physics, Astrophysics and Cosmology

LIP

TÉCNICO LISBOA

Mário Pimenta
May 2018



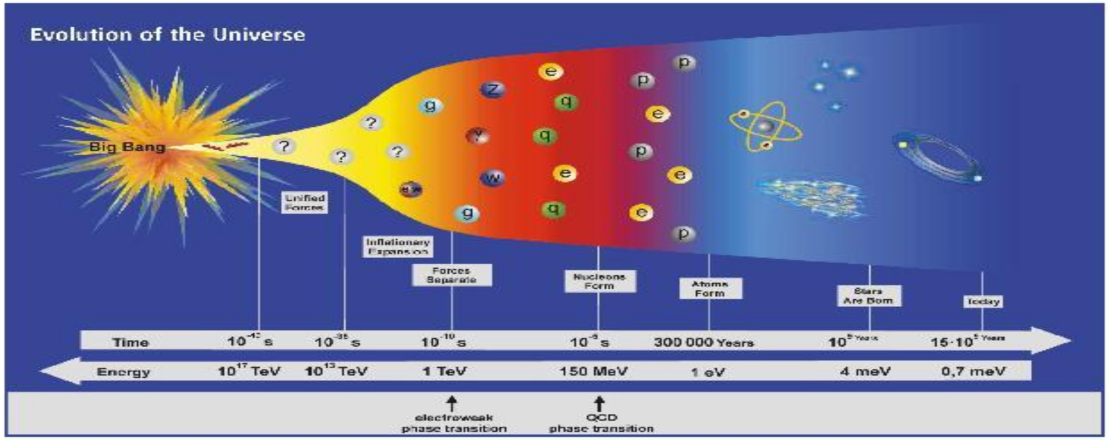
IDPASC
U. Paris VI - Pierre et Marie Curiel
U. Paris VII - Paris Diderot
U. Paris-Saclay - PHENIICS
CERN
U. Savoie
U. Trento
U. Nova Gorica
U. Udine
U. Oviedo
IFCA, Cantabria U.
U. Santiago Compostela
MAP_Fis:
U.Aveiro
U.Porto
U.Minho
U.Padova
U .Genova
U. Bari
EGO
U.Salento
U. Coimbra
U. Siena
U. Lisboa
IST, FCUL
U. Valencia
U. Granada
U. Évora
U. Algarve
CBPF - Rio
SPRACE-UNESP/UFABC-S.Paulo

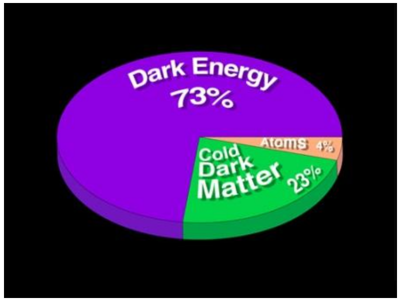
Particle Physics:

"Matter" and Interactions

Astronomy/ astrophysics:

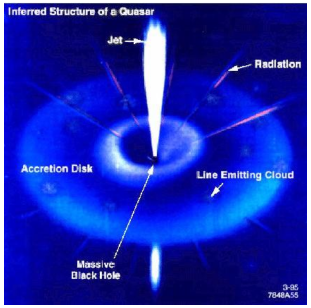
"Objects" in the sky



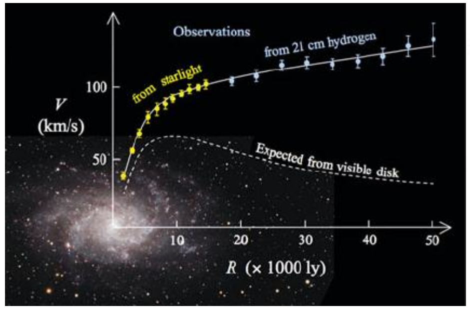


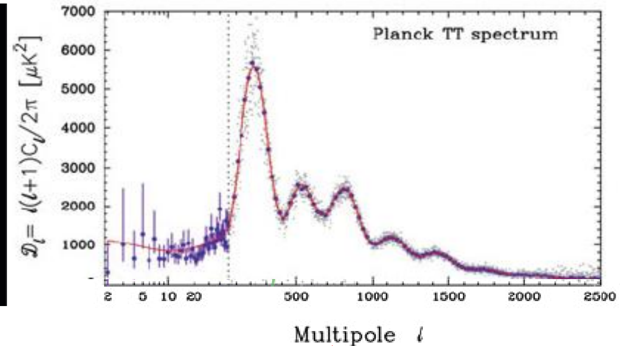
Cosmology:

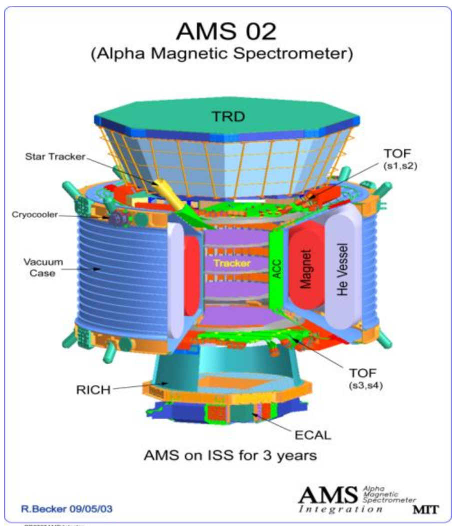
Origin and evolution of the Universe

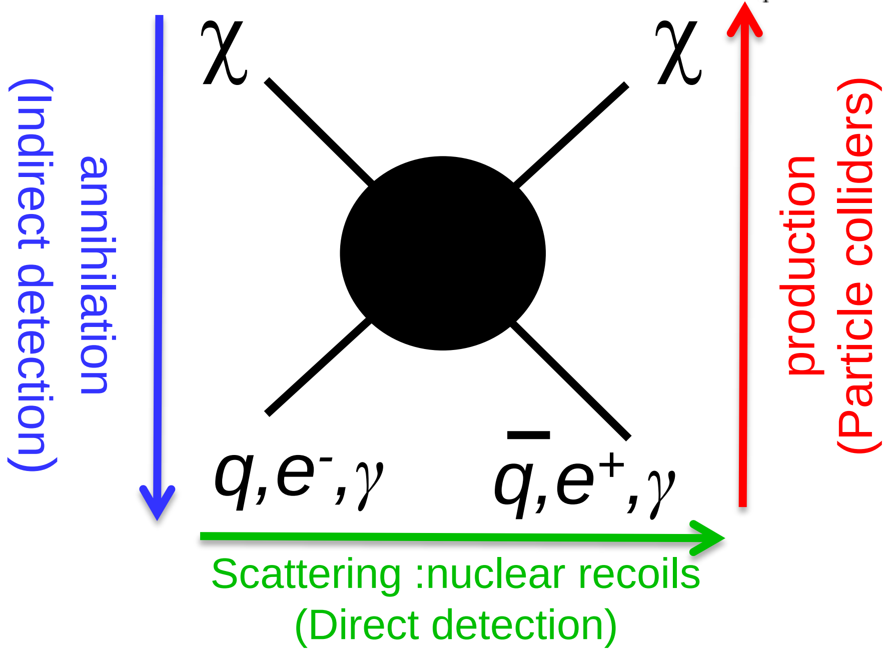


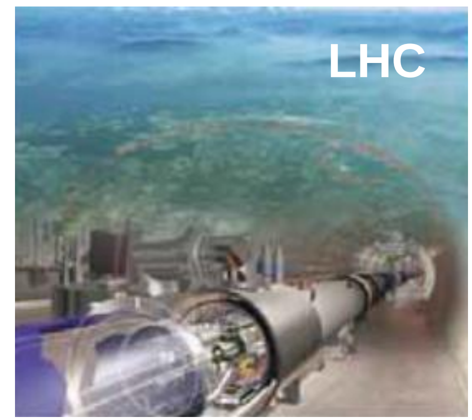
Dark matter


Observations
from 21 cm hydrogen
from starlight
Expected from visible disk
V (km/s)
100
50
10 20 30 40 50
R (× 1000 ly)


Planck TT spectrum
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
7000
6000
5000
4000
3000
2000
1000
2 5 10 20 500 1000 1500 2000 2500
Multipole ℓ

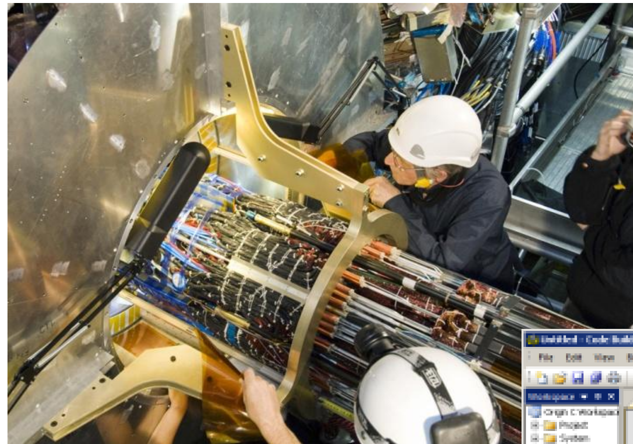

AMS 02
(Alpha Magnetic Spectrometer)
TRD
Star Tracker
TOF (s1,s2)
Cryocooler
Vacuum Case
Tracker
ACC
Magnet
He Vessel
TOF (s3,s4)
RICH
ECAL
AMS on ISS for 3 years
R.Becker 09/05/03
AMS Integration
MIT


annihilation
(Indirect detection)
χ
χ
q, e^-, γ
$\bar{q}, e^+, \gamma$
production
(Particle colliders)
Scattering :nuclear recoils
(Direct detection)

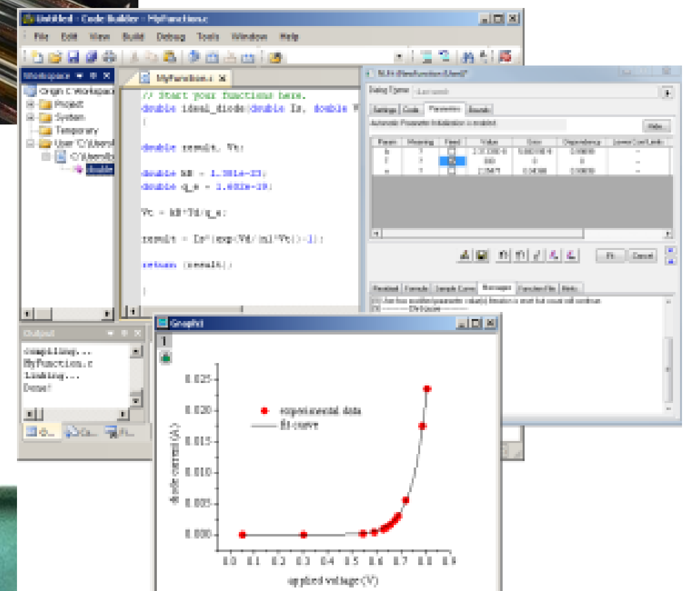

LHC

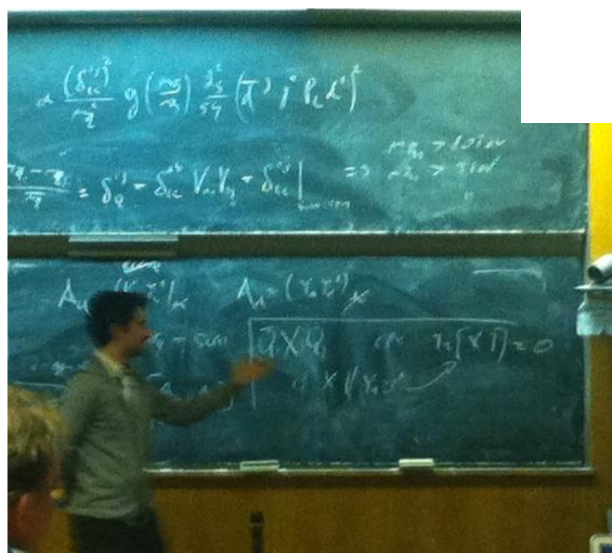

LUX

Not really a super Man/Woman ...



BUT !!!





Student profiles

Several scientific profiles have to co-exist!
from the experimental physics students interested in the development of new detectors or data acquisition and readout systems to the theoretical physics student interested in the development of string theories.

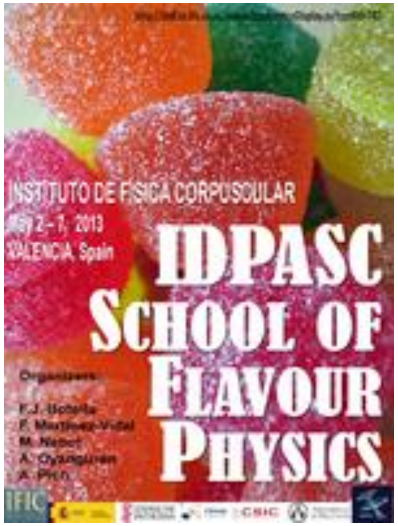
to all students a minimum common scientific background should be provided.

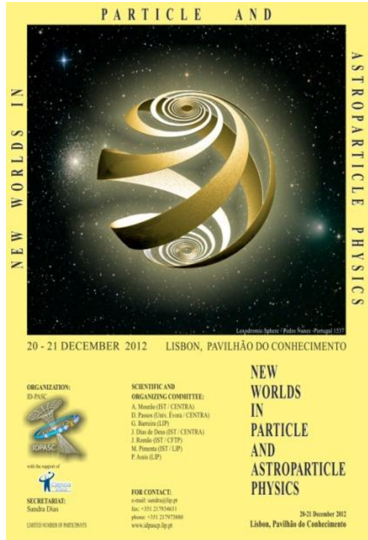
This common background will favour the future mobility and employment of the students either in scientific research projects and institutions or in the society at large.

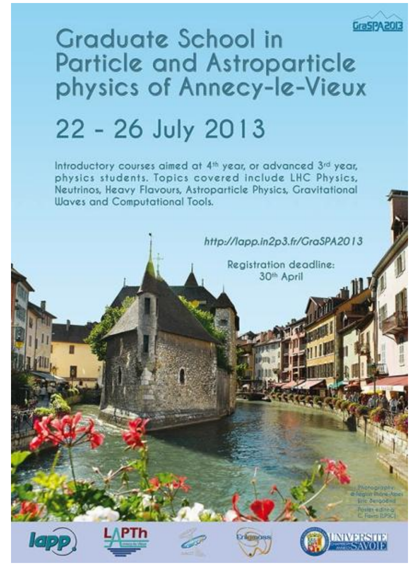
Activities

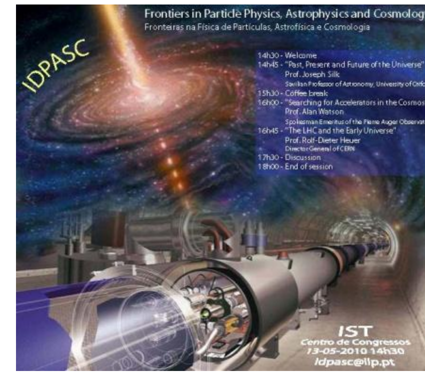
- Schools and Workshops
  - ✓A general IDPASC school every year
    (2 weeks: mornings lectures/afternoon exercises/exam at the end)
  - ✓ Thematic schools
- Courses
  - ✓Specific courses via video-conference
- Public sessions
  - ✓General public (in particular last years high school students and teachers)
- Doctoral Scholarships (IDPASC-Portugal)
  - ✓2010/2011/2012 – 20 grants
  - ✓2014/2017 – 20 grants

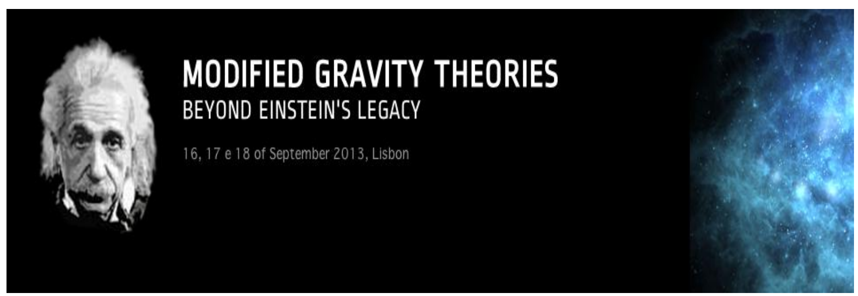
IDPASC Posters ...

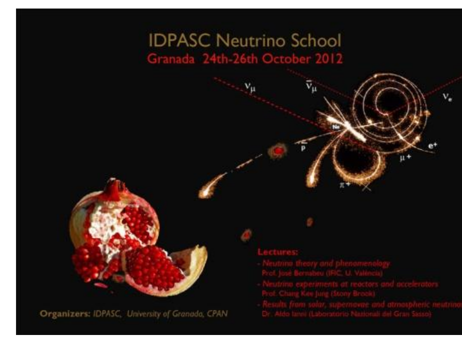


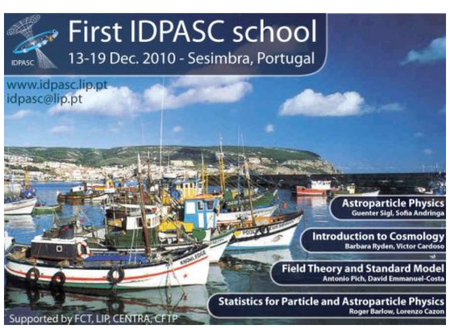


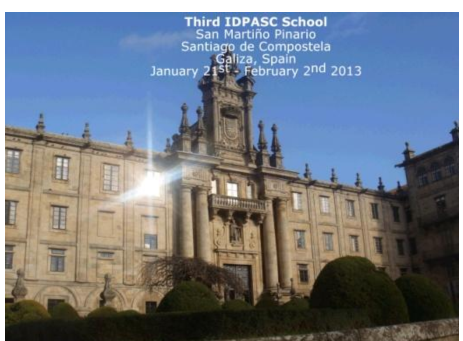


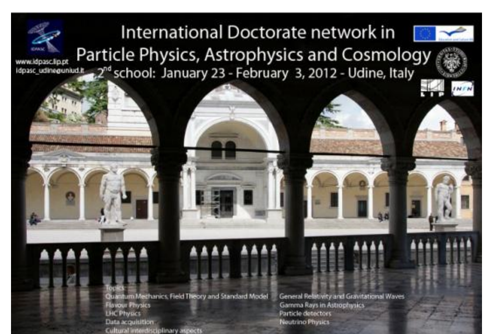


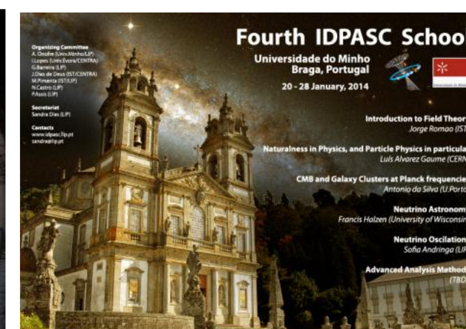






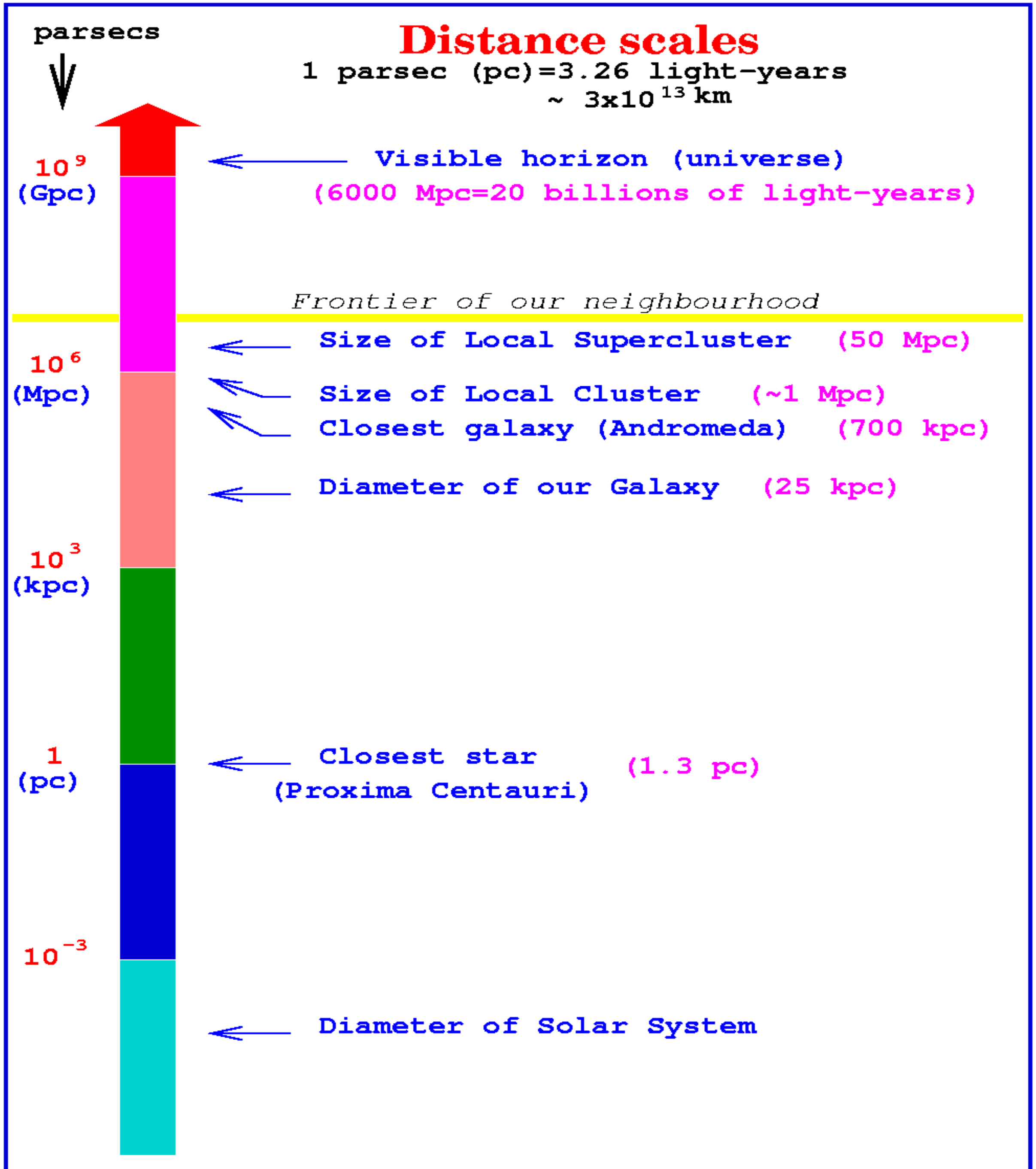






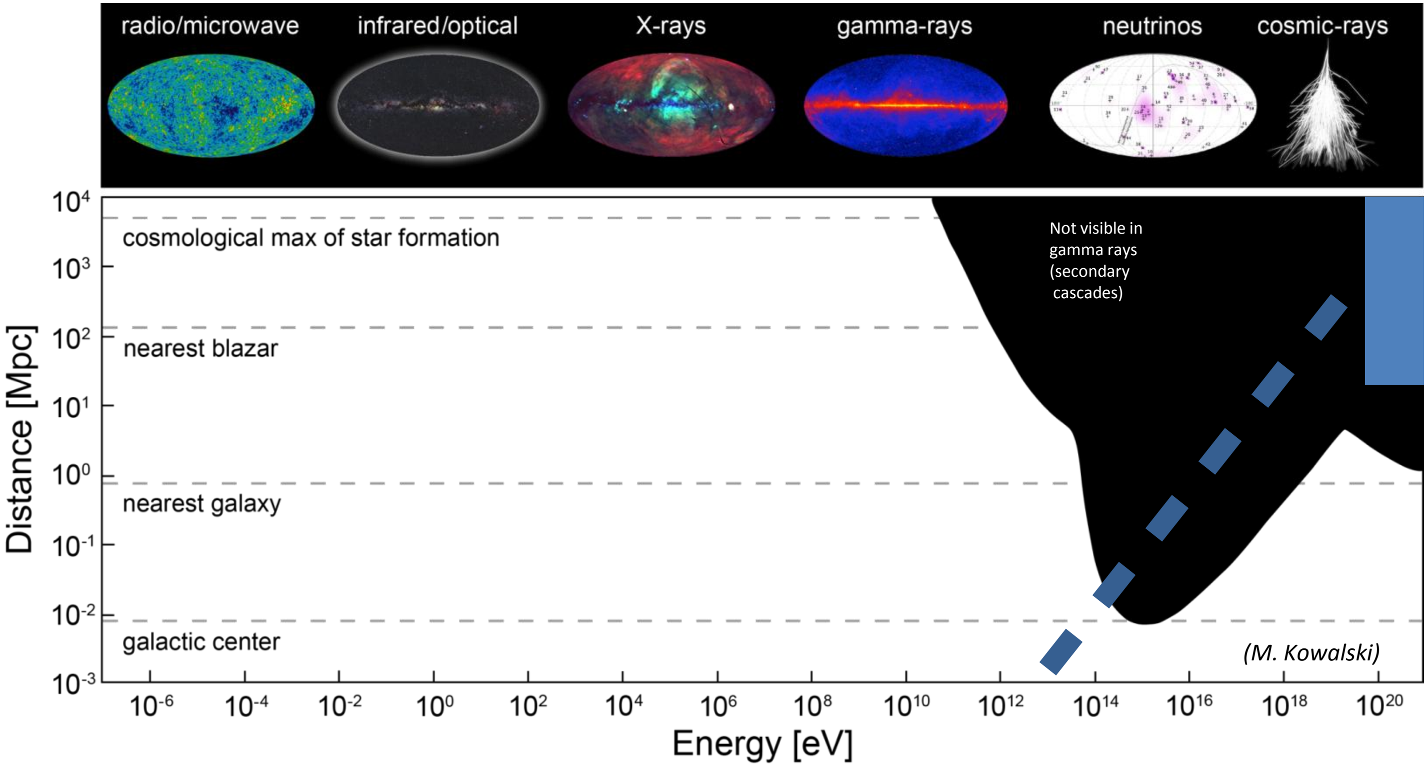
IDPASC

www.idpasc.lip.pt



parsecs
Distance scales
1 parsec (pc)=3.26 light-years
~ 3x10^13 km
10^9
(Gpc)
Visible horizon (universe)
(6000 Mpc=20 billions of light-years)
Frontier of our neighbourhood
Size of Local Supercluster (50 Mpc)
10^6
(Mpc)
Size of Local Cluster (~1 Mpc)
Closest galaxy (Andromeda) (700 kpc)
Diameter of our Galaxy (25 kpc)
10^3
(kpc)
1
(pc)
Closest star
(Proxima Centauri)
(1.3 pc)
10^-3
Diameter of Solar System

Propagation distances of different messenger particles



Not visible in
in cosmic rays
(energy loss effects)

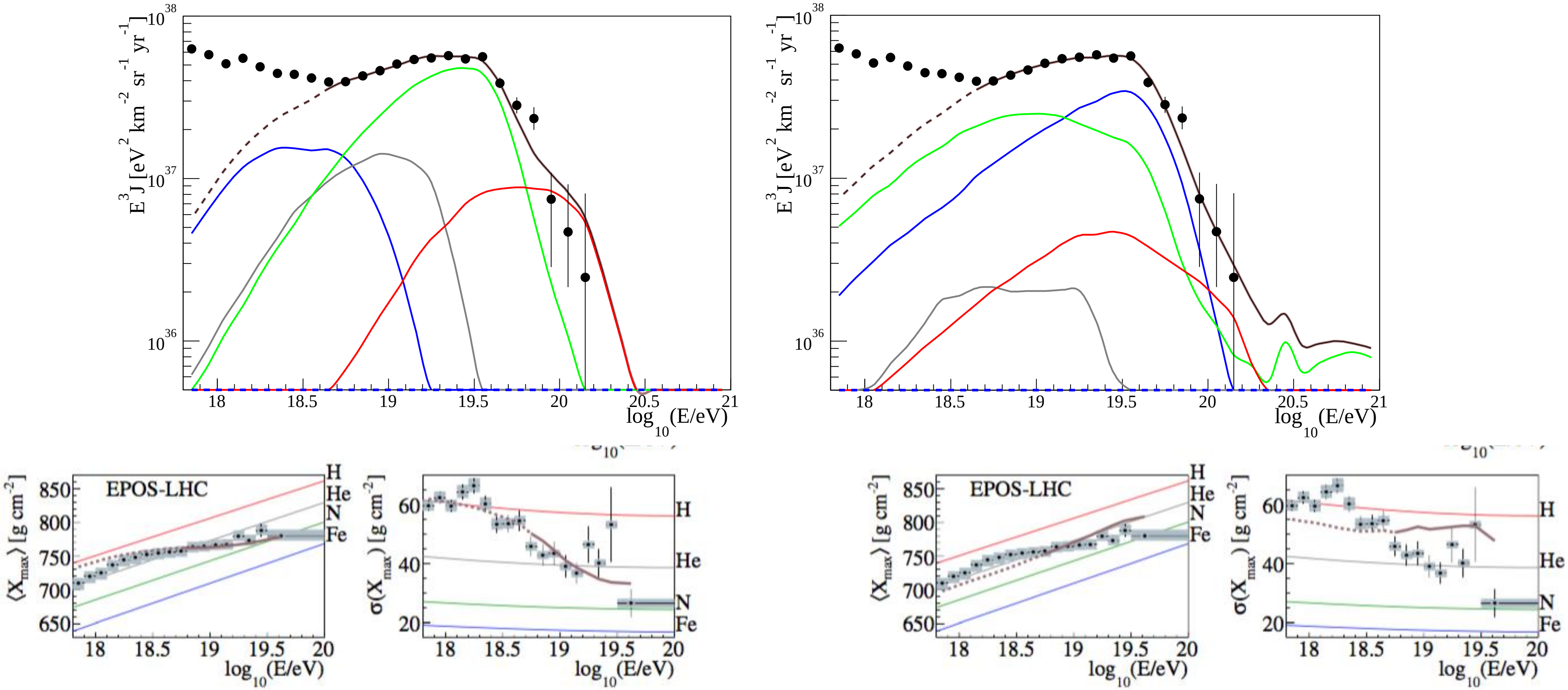
Cosmological evolution
of sources important

Magnetic horizon for cosmic rays
(diffusion time exceeds lifetime of Galaxy / Universe)

Combined fits

Protons (blue)
Helium (gray)
Nitrogen (green)
Iron (red)

A. di Matteo for the Pierre Auger Coll., Proc 34th ICRC (2015)



A Fit (spectrum, <X_{max}>, RMS(X_{max})) is always possible but it requires a very unusual metallicity of the sources!