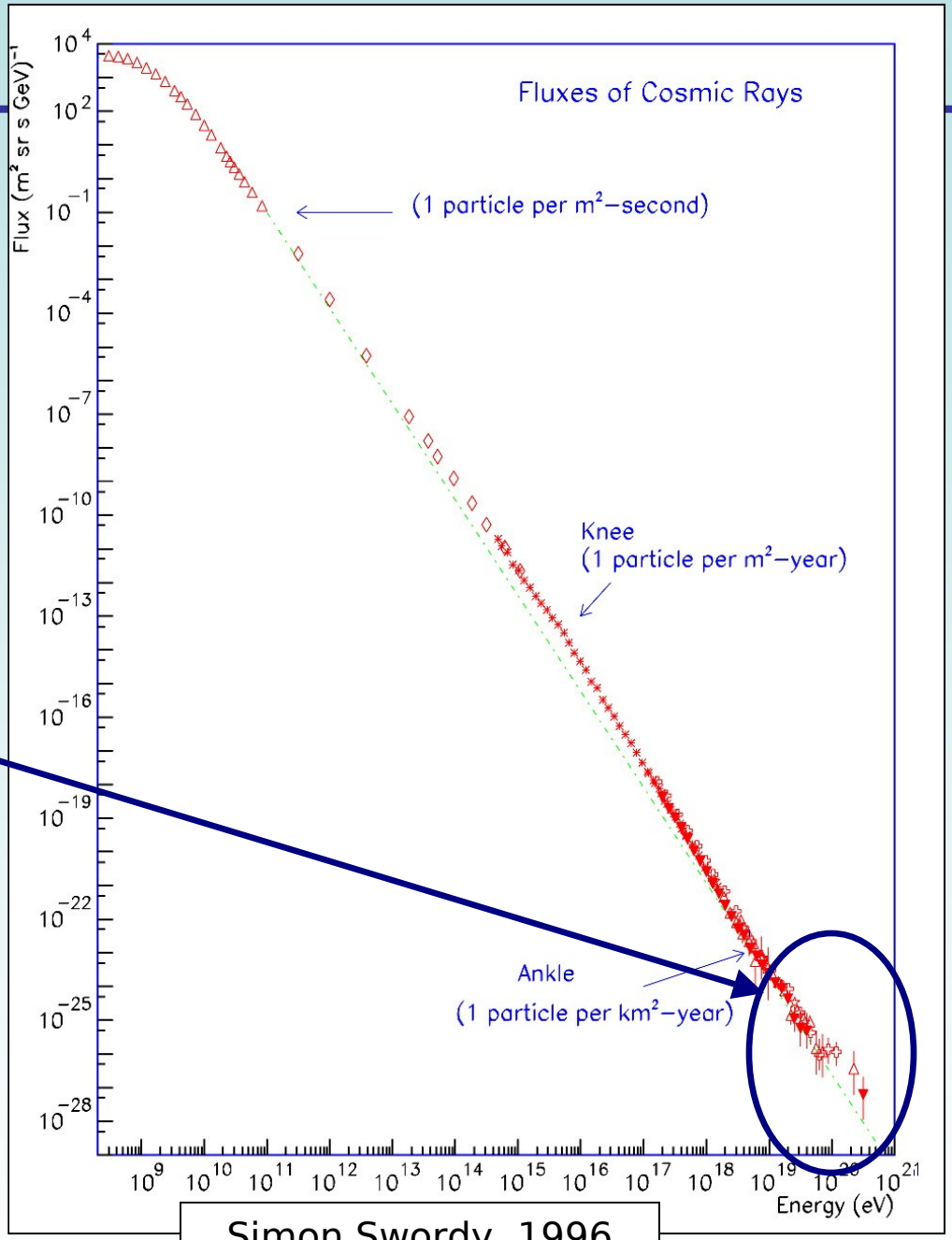
Observatoř Pierra Augera: gigantický detektor kosmického záření

Michael Prouza
Fyzikální ústav AV ČR

What are ultra-high energy cosmic rays (UHECRs)?

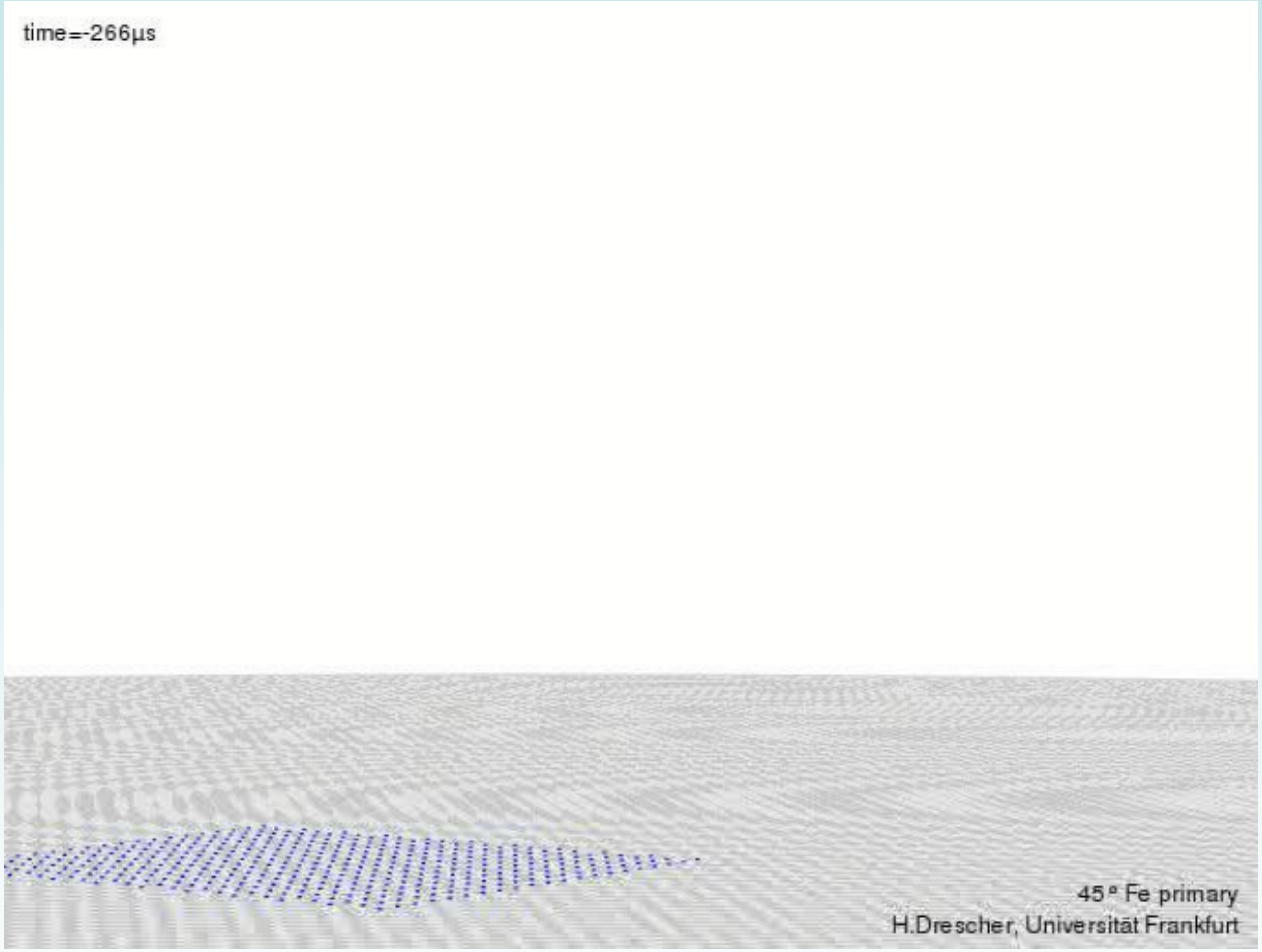
UHECRs are particles with energy above "ankle", say, above 3×10^{18} eV.



Simon Swordy, 1996

The most energetic event:
Detector Fly's Eye, Utah, USA, October 15th 1991
3×10^{20} eV ≈ 50 J

Cosmic ray showers



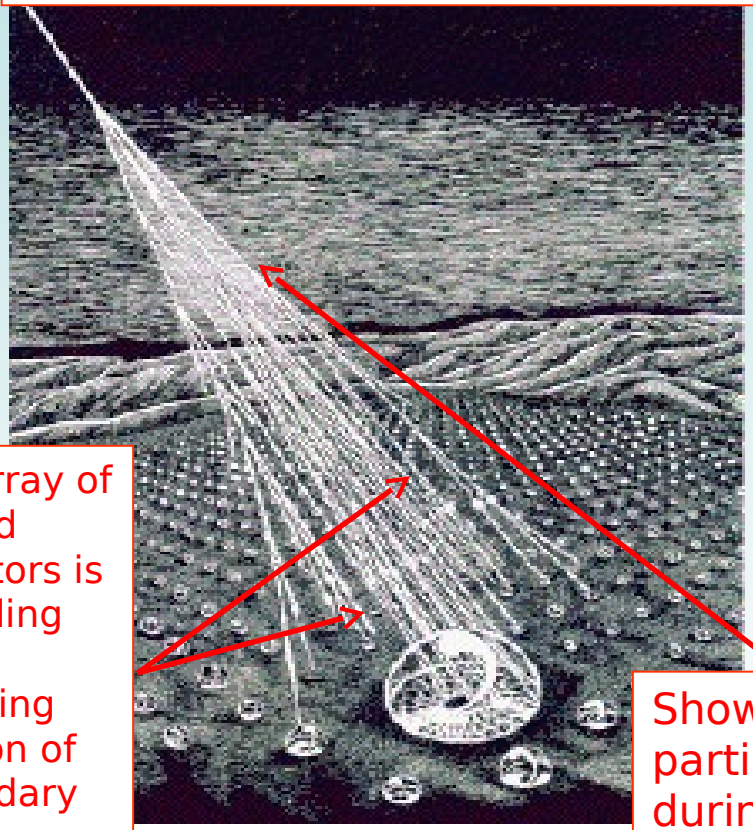
- Primary particle interacts with atmosphere
- Number of secondary particles is created
- Secondaries interact again, and again, ...
- Typical shower 10^{20} eV: 10^{10} particles at ground
- Animation color code:

blue: electrons/positrons
cyan: photons
orange: protons
red: neutrons
gray: mesons
green: muons
(10^{-6} thinning)

H.-J. Drescher, Frankfurt University

How to detect UHECRs?

Primary particle coming from space (proton or light nucleus) hits the atmosphere of the Earth



The array of ground detectors is recording and sampling fraction of secondary particles.

Shower of secondary particles originates during collissions with molecules in the atmosphere.

- The number of secondary particles is proportional to energy of primary particle
- Relative time of detection of individual secondary particles carries information about incident direction of primary particle
- Types of detectors: ground arrays and fluorescence telescopes

Detectors of cosmic rays with ultra-high energies

7 different detectors were in operation during 40 years of measurements and achieved detection of approximately ~ 200 particles with energies over 4.10^{19} eV and only ~ 20 particles with energies over 10^{20} eV.

Surface detectors:

- Volcano Ranch, USA (1959 – 1963)
- SUGAR, Australia (1968 – 1979)
- Haverah Park, UK (1968 – 1987)
- Yakutsk, Russia (1970 – today)
- AGASA, Japan (1990 – 2004)

Fluorescence detectors:

- Fly's Eye, USA (1981 – 1992)
- HiRes, USA (1998 – 2006)
- Telescope Array (2008 – today)

HiRes Experiment (Dugway, Utah)

HiRes-I
21 mirrors
1 ring, full azimuth, 3°-17° elevation
Sample & Hold DAQ System

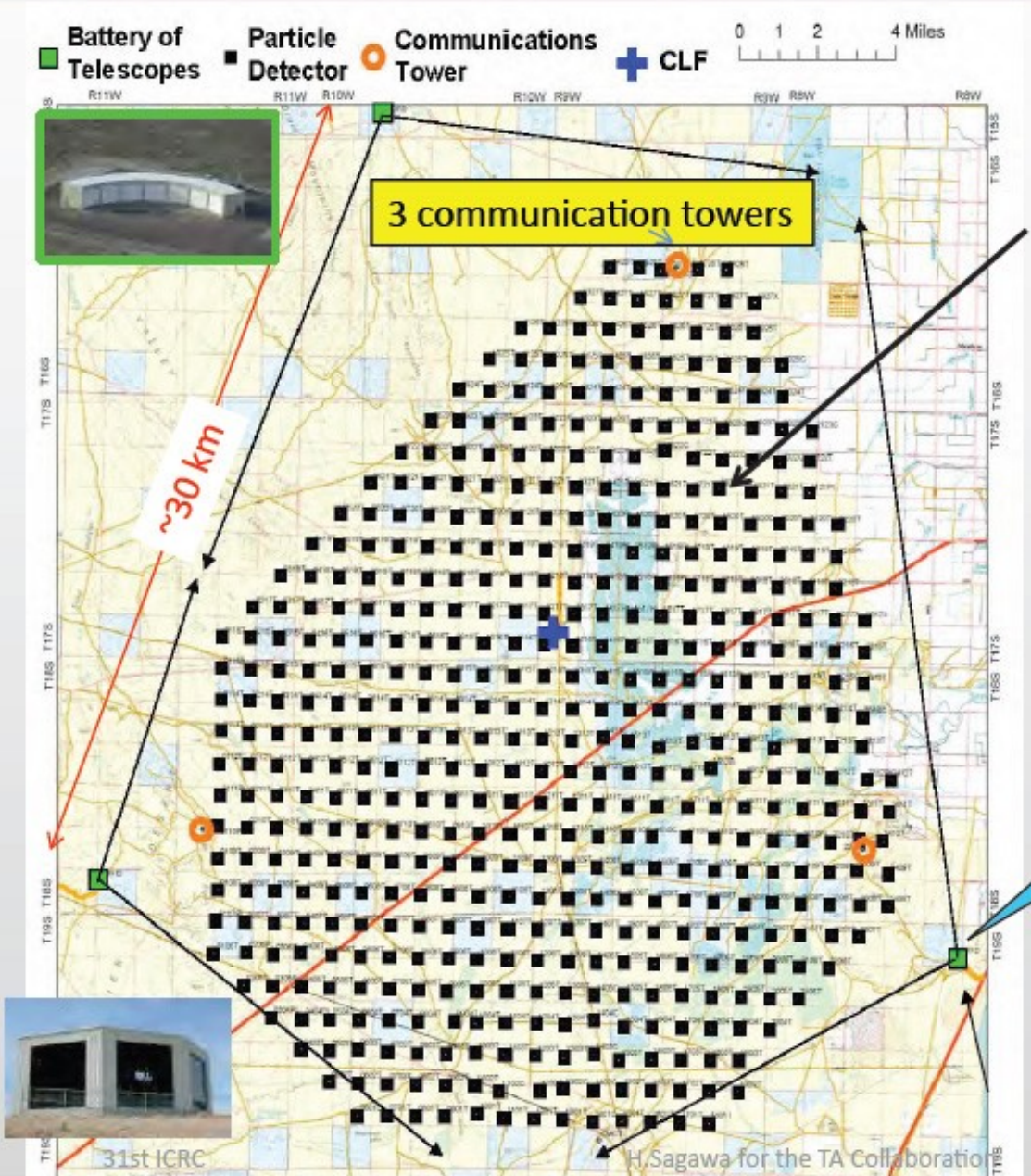
HiRes-II
42 mirrors
2 rings, full azimuth, 3°-31° elevation
FADC DAQ System
Took data: Dec. 1999-April 2006

Both:
5.1 m^2 mirrors, 16x16 PMTs

HR I+II data taking:
June 1997-April 2006

Telescope Array (Utah)

Fully Operational since March 2008



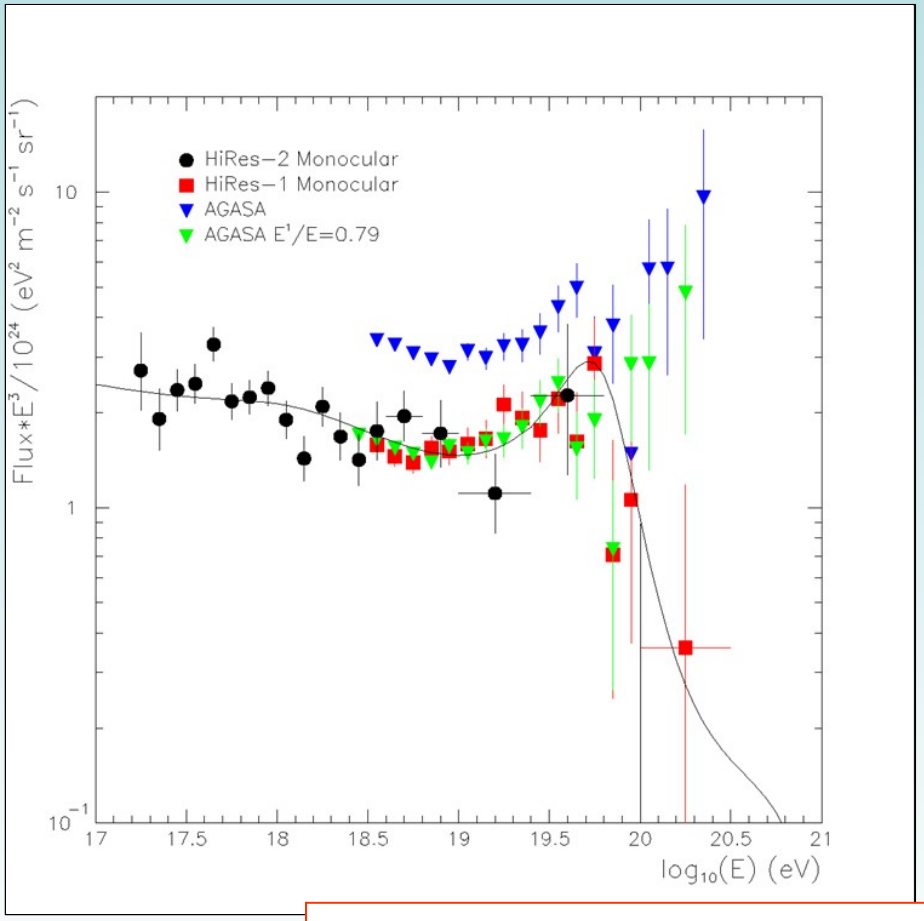
507 Plastic Scintillator Detectors cover ~700 km^2 (1.2km spacing)

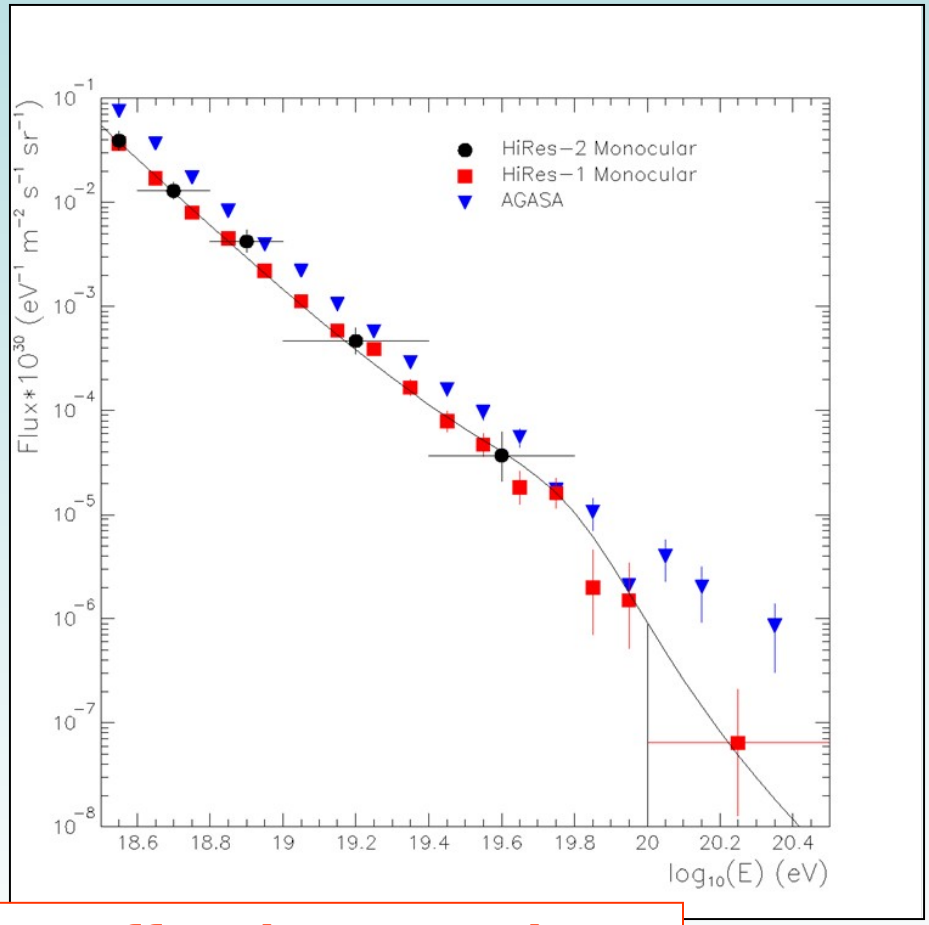
3 Fluorescence Telescope Stations overlook the array.

Utah, USA
39.3 ° N, 112.9 ° W
alt. 1400 m

K.-H. Kampert, EPS-HEP

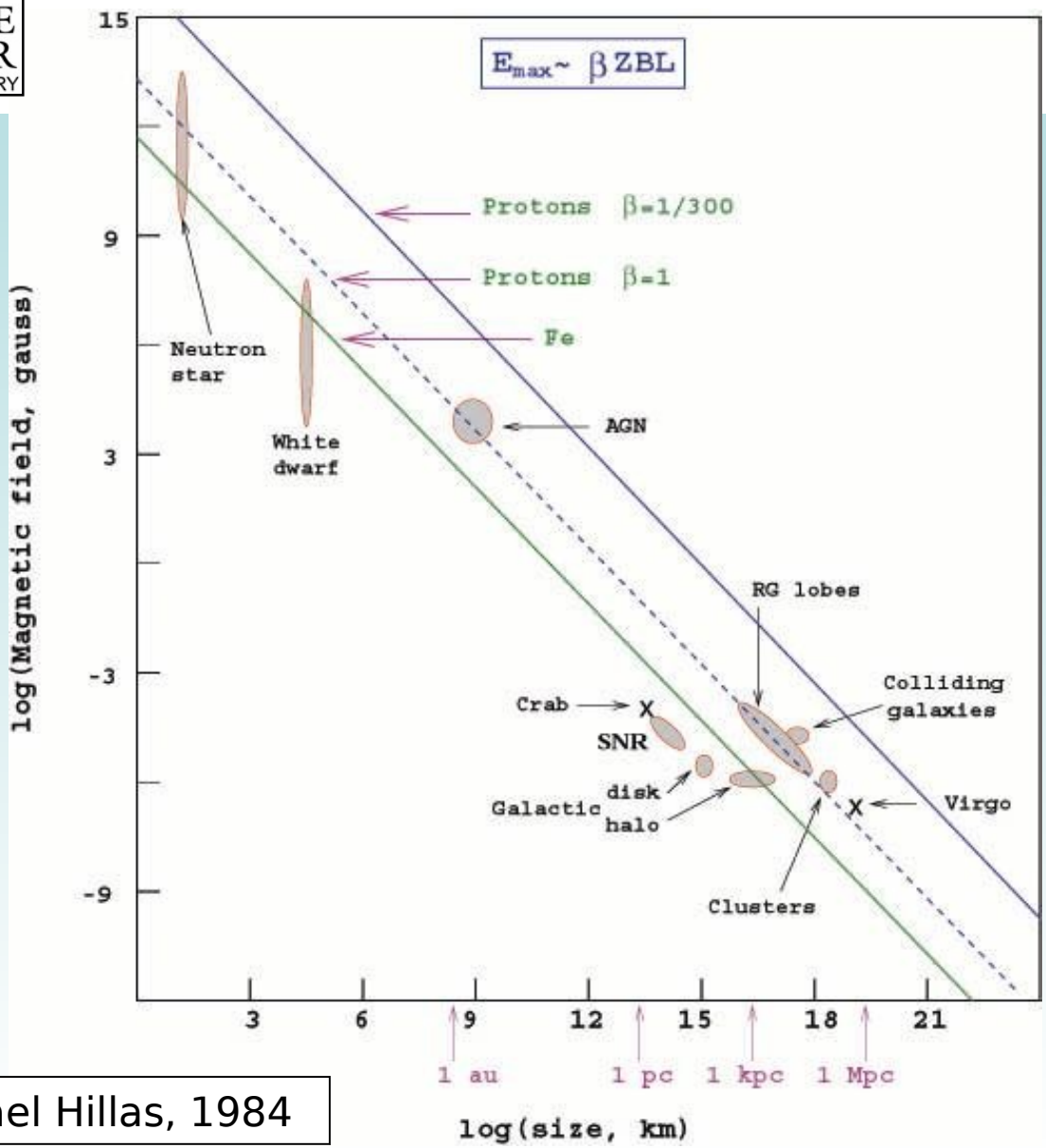
GZK or not to GZK: HiRes vs. AGASA





Is there really GZK-cutoff? Where are the sources?

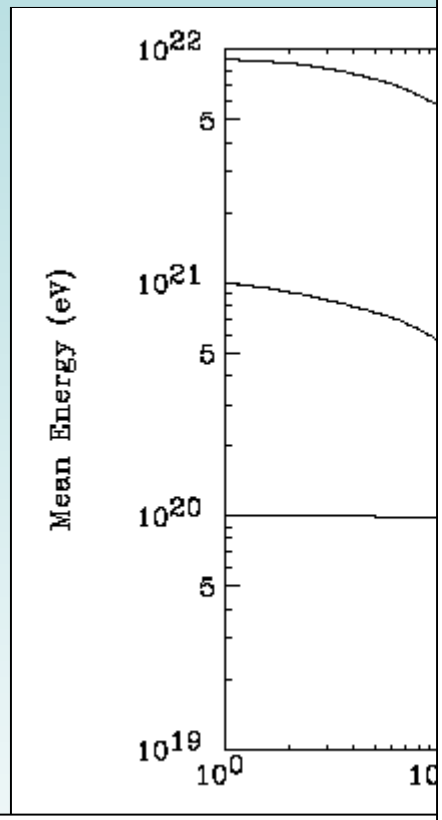
Sites of origin of UHECRs



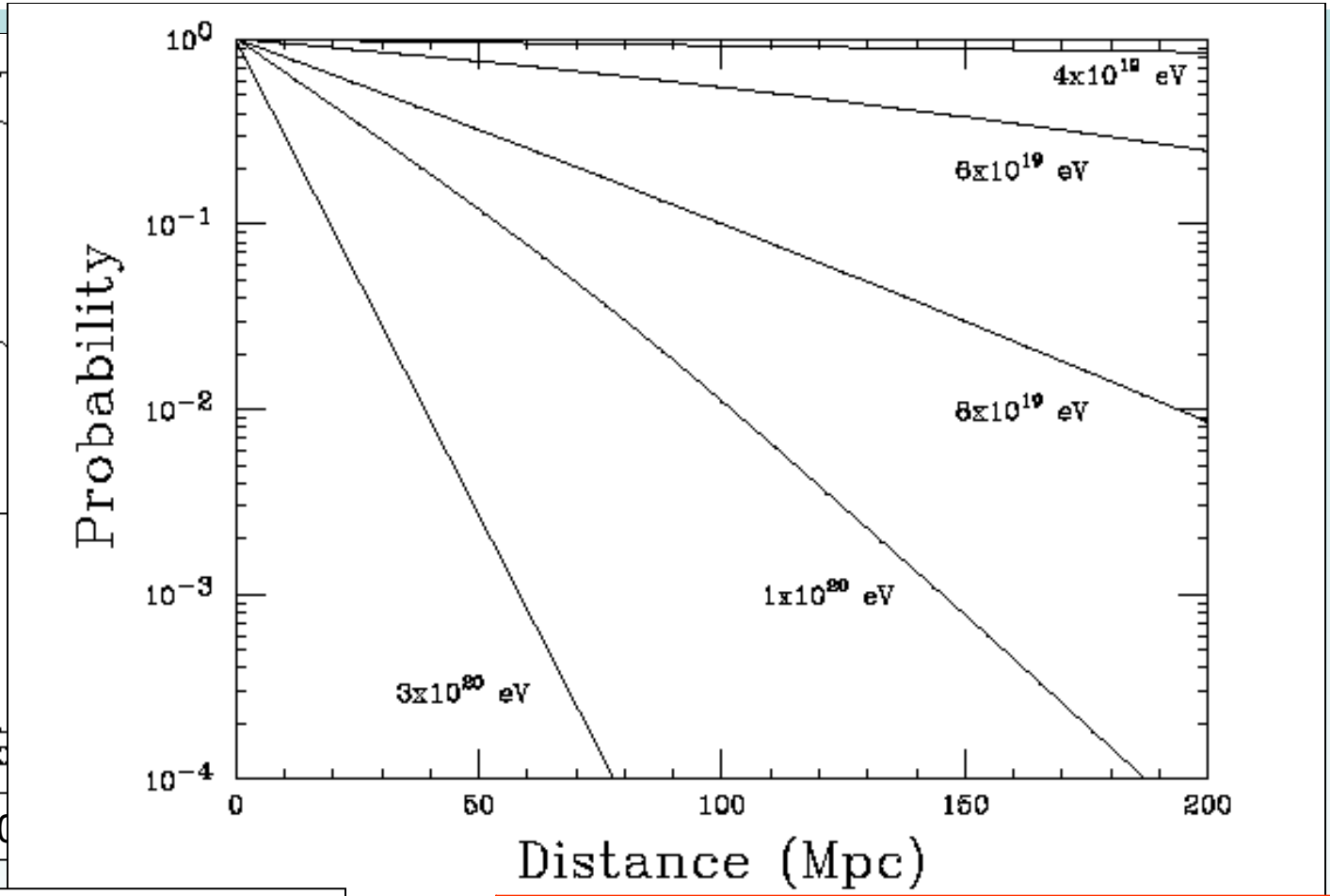
Michael Hillas, 1984

- Fermi acceleration in magnetic fields.
- We need magnetic fields extremely strong OR filling extremely large regions to accelerate particles above 10^{20} eV.
- And still, all parameters have to be finely tuned.

GZK suppression



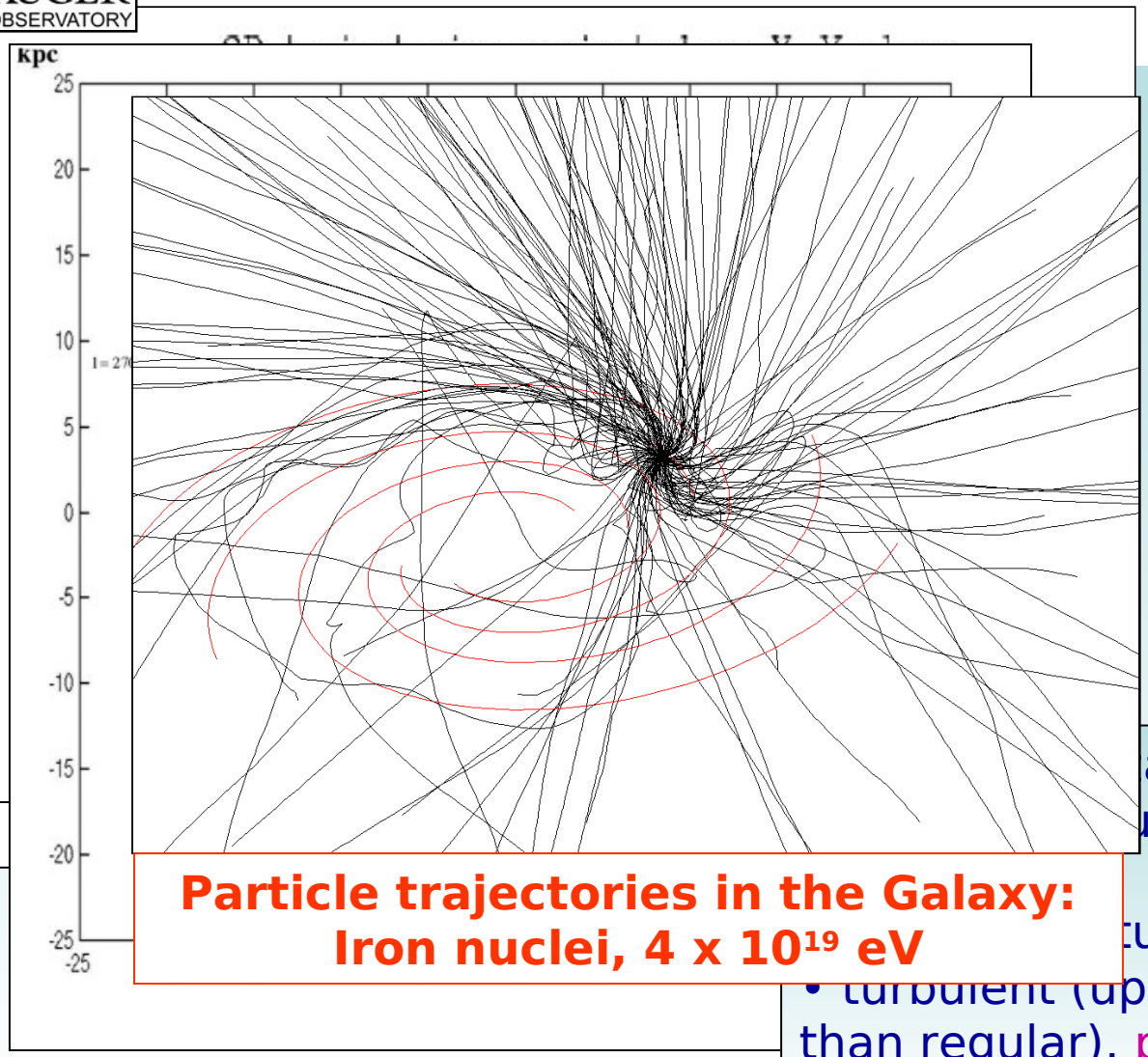
James W. Cronin, 2000



Paul Sommers, 2003

Sources of particles with E > 10^{20} eV have to be within “GZK-sphere” (100 Mpc)

Influence of magnetic fields



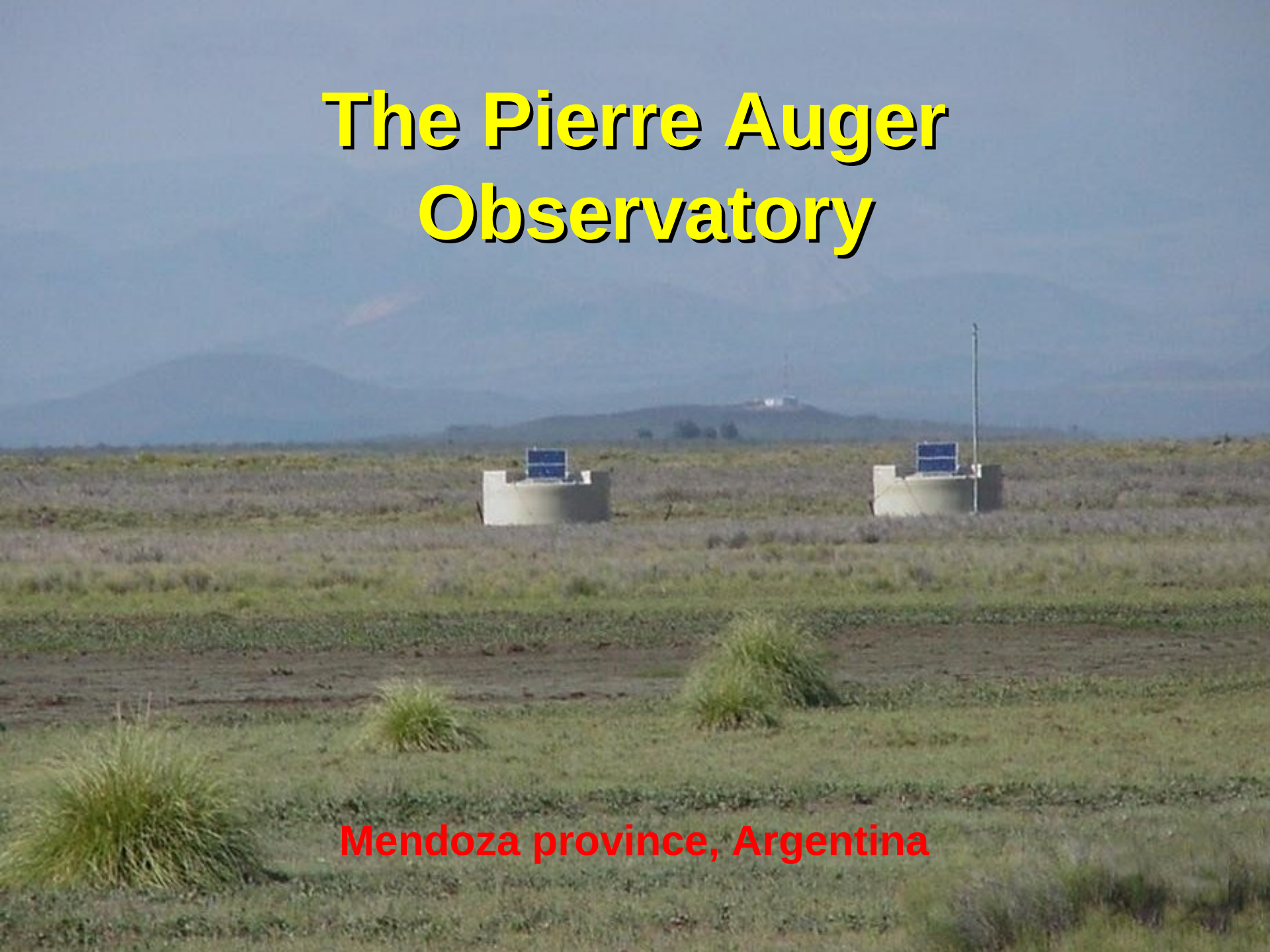
Particle trajectories in the Galaxy: Iron nuclei, 4 x 10^{19} eV

- Above 10^{19} eV - not curved trajectories ? - "Cosmic ray astronomy" ?
- Not so sure...
- Extragalactic magnetic fields could be very important, especially if UHECRs are mainly iron nuclei.
- And what about Galactic magnetic field?

ation, ..., Faraday
urements → field strength

ture surely spiral
- turbulent (up to 3x higher intensity than regular), poloidal and toroidal components exist

The Pierre Auger Observatory



Mendoza province, Argentina

The Pierre Auger Observatory

More than 250 PhD scientists from more than 60 institutions from 15 (+2) countries.

Participating countries:
Argentina, Australia, Bolivia*, Brazil, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Poland, Portugal, Slovenia, Spain, United Kingdom, USA and Vietnam*

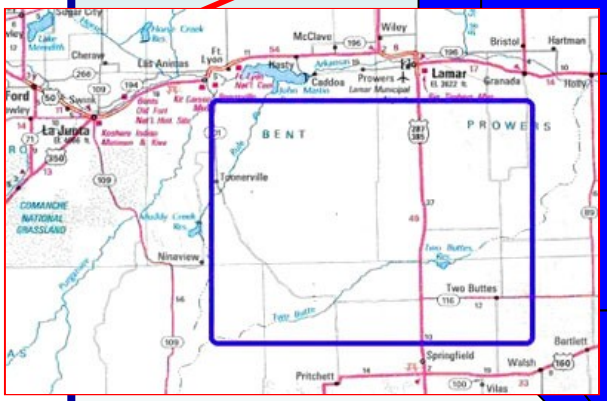
*** - associated countries**

Participating countries are in cyan.

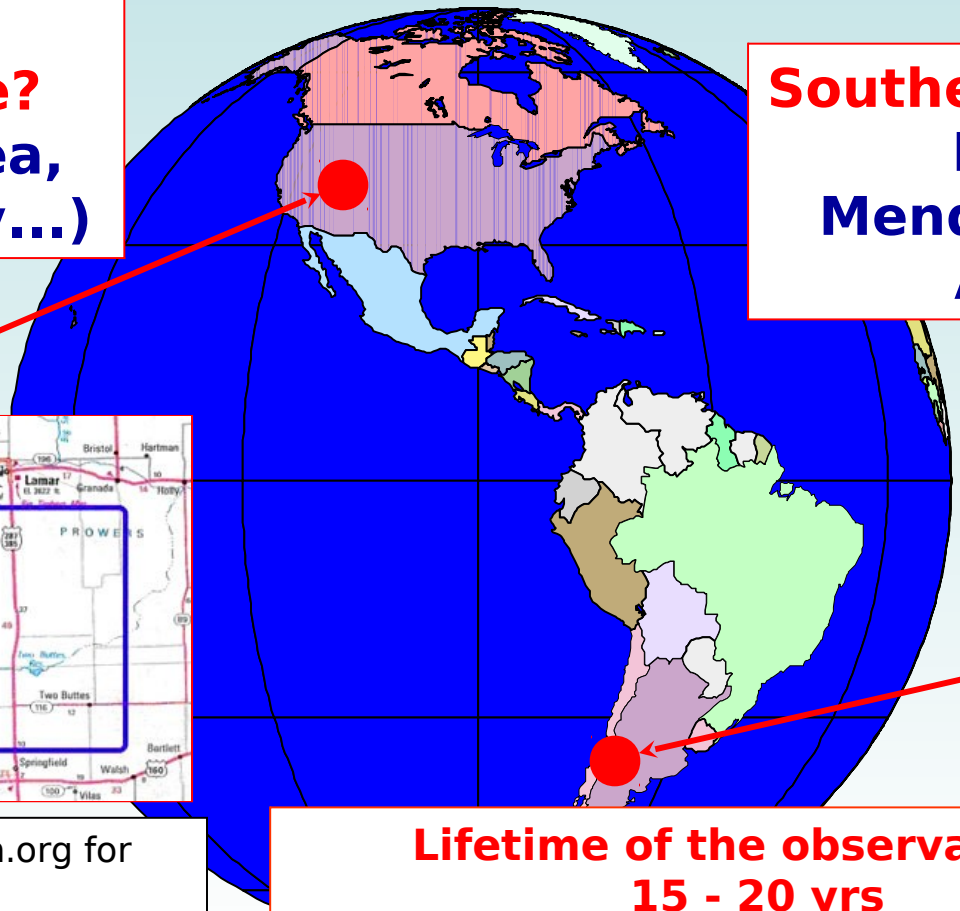
Pierre Auger Observatory

The construction of the southern site in Argentina is completed.

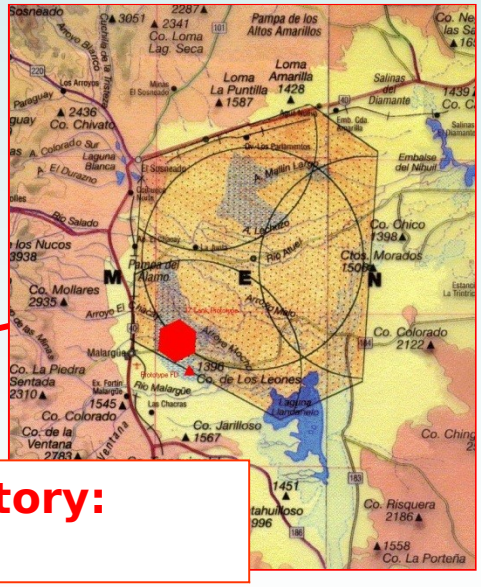
Northern hemisphere? (Original idea, but not likely…)



See www.augernorth.org for details



Southern hemisphere: Malargüe, Mendoza province, Argentina

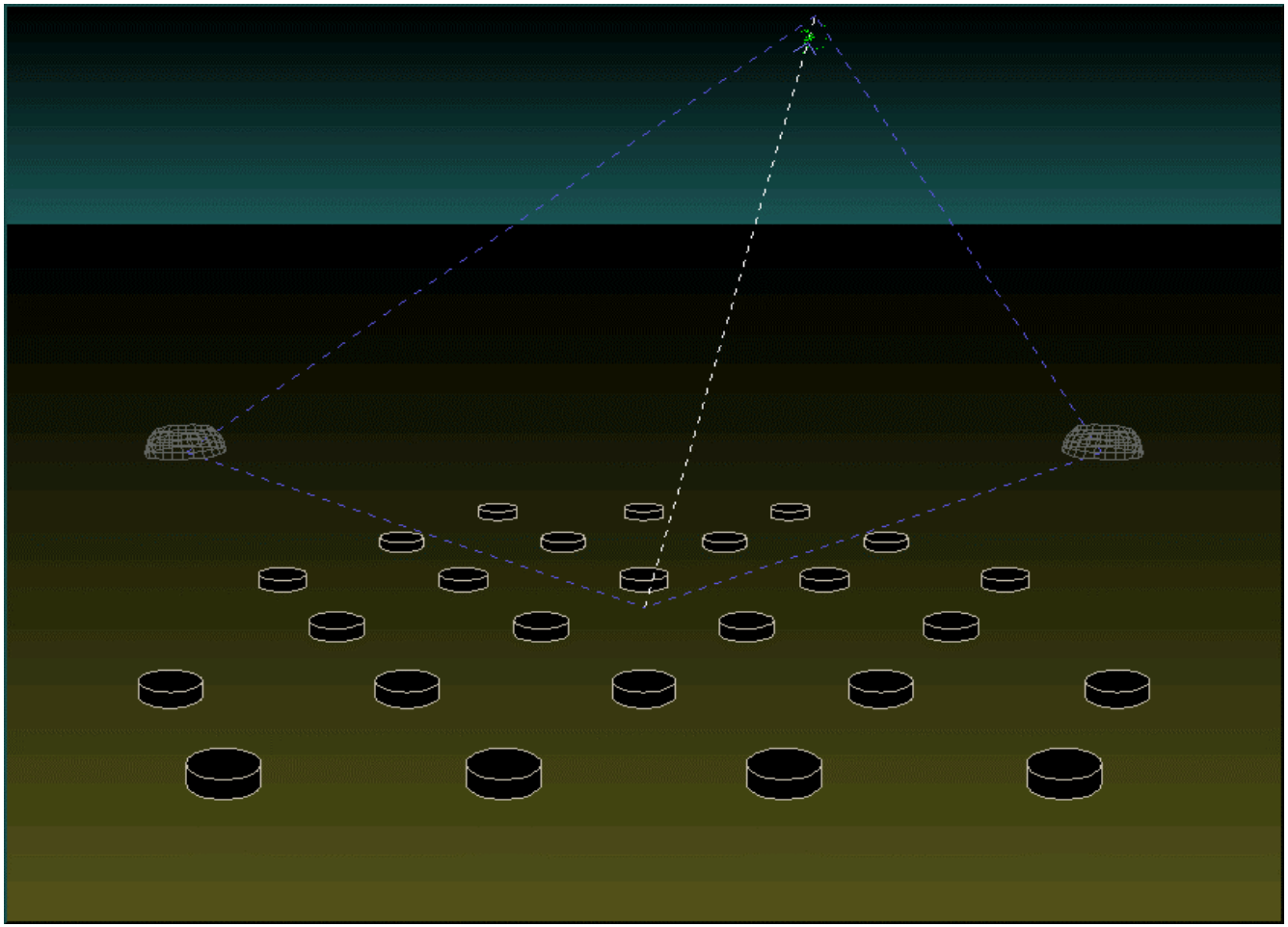


Lifetime of the observatory: 15 - 20 yrs

The Pierre Auger Observatory = hybrid detector of cosmic rays

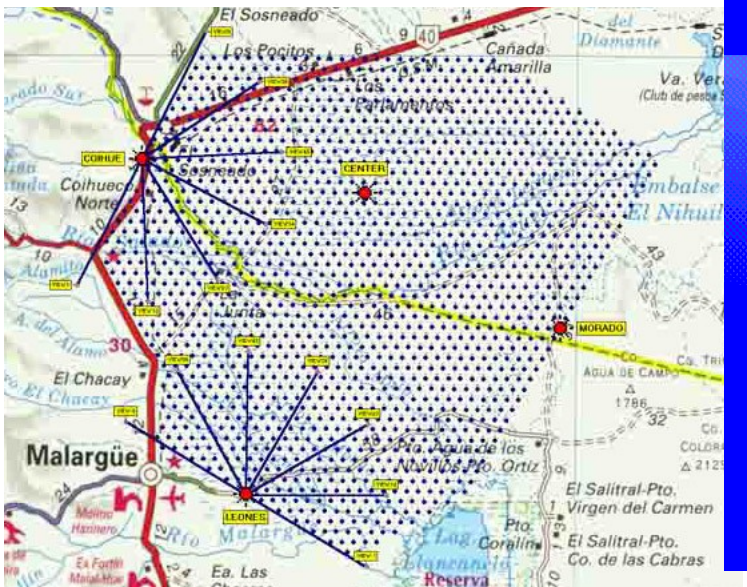
- The array of surface Cherenkovov detectors will be accompanied with system of fluorescence telescopes, which will observe faint UV/visible light during clear nights. This fluorescence light origins as by-product during the interactions of shower particles with the atmosphere.

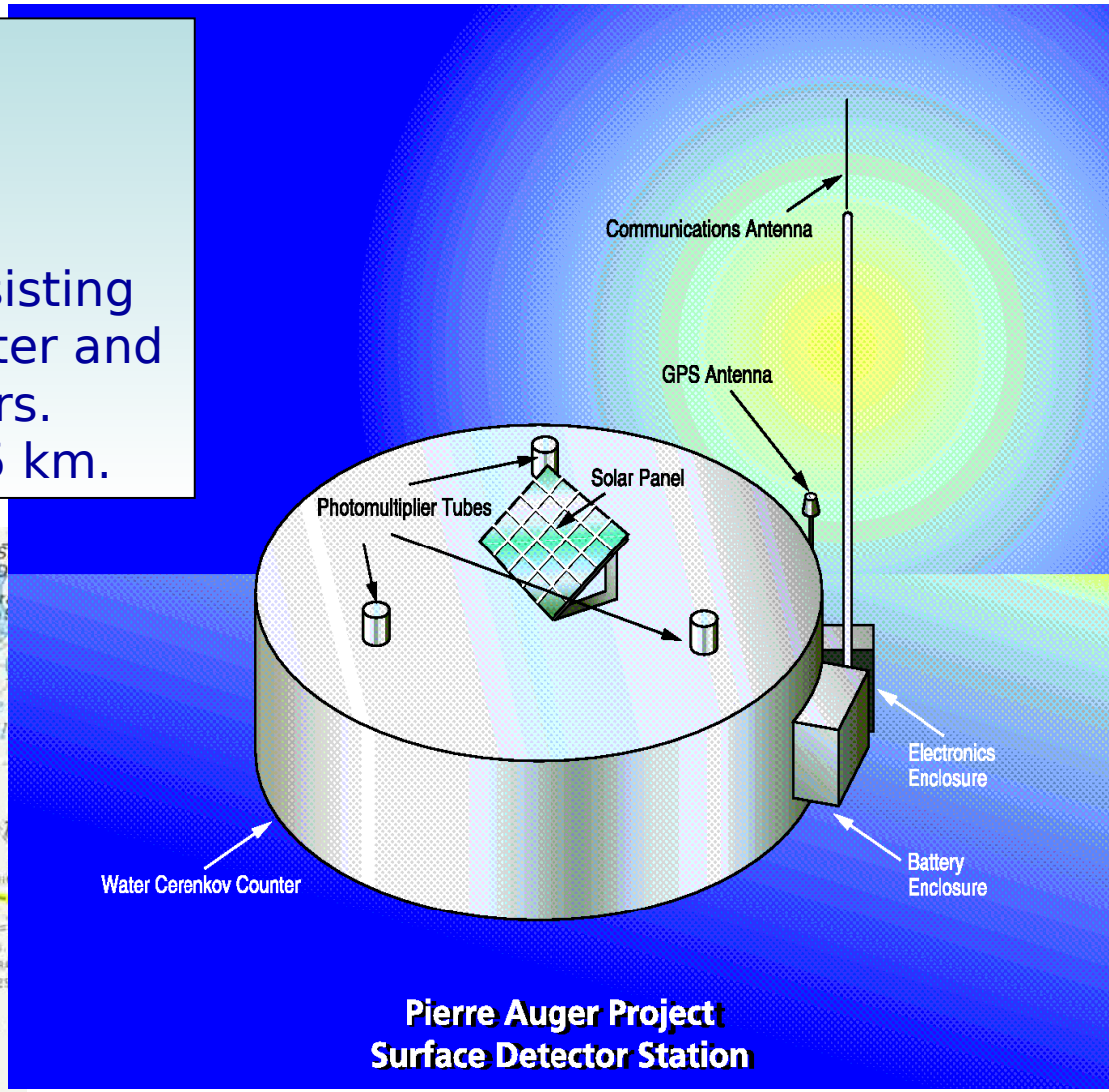
Scheme of hybrid detector function



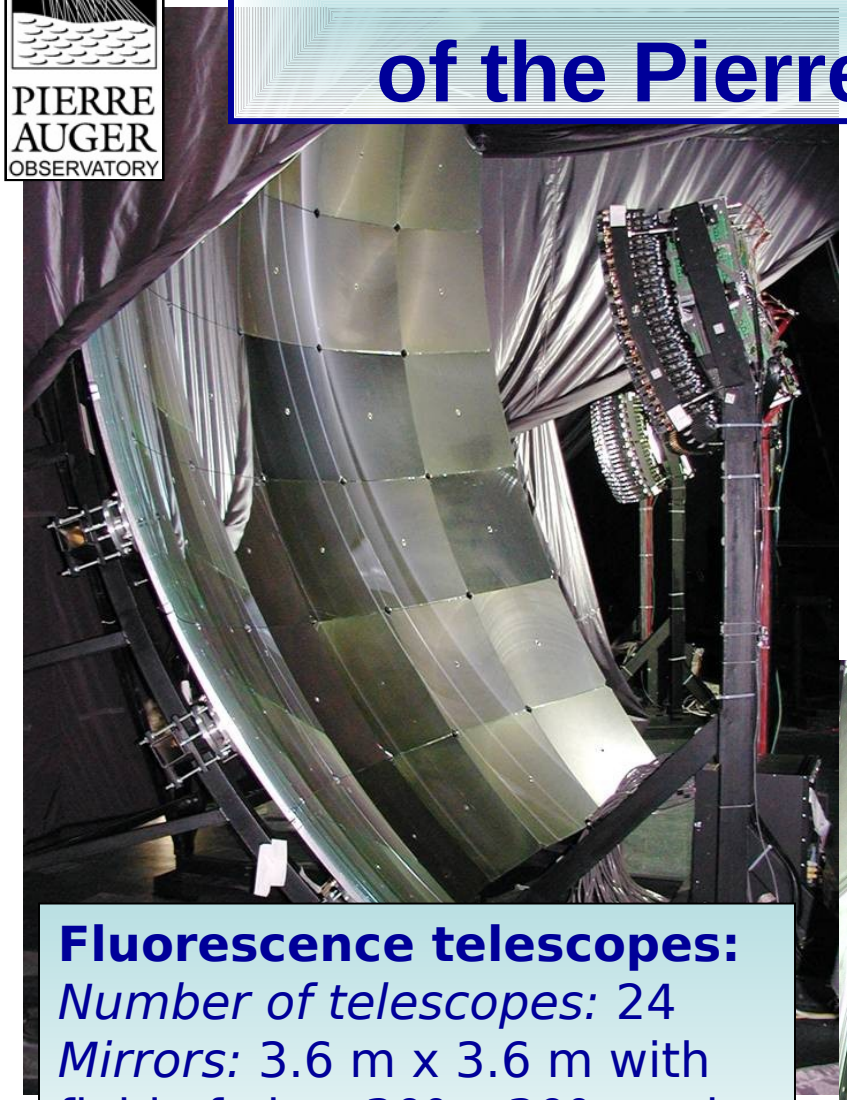
Ground detectors of the Pierre Auger Observatory

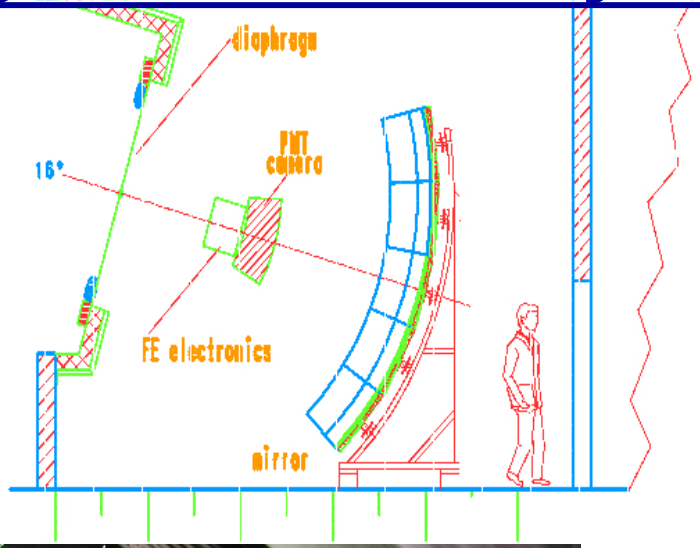
Ground detectors:
Covered surface: 3000 km^2
Number of detectors: 1600
Type of detector: Detector of Cherenkov radiation, each consisting of 12 000 litres of ultrapure water and equipped with 3 photomultipliers.
Spacing between detectors: 1.5 km.

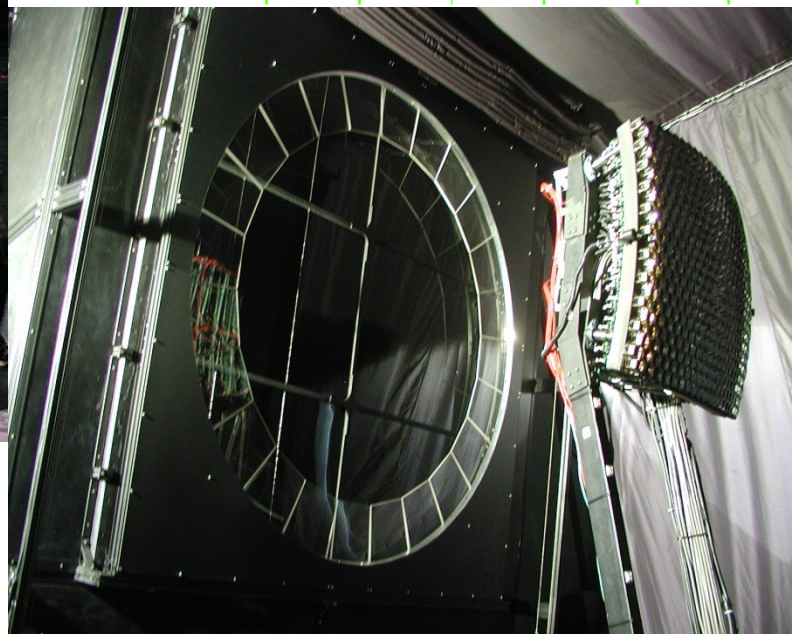




Fluorescence detectors of the Pierre Auger Observatory

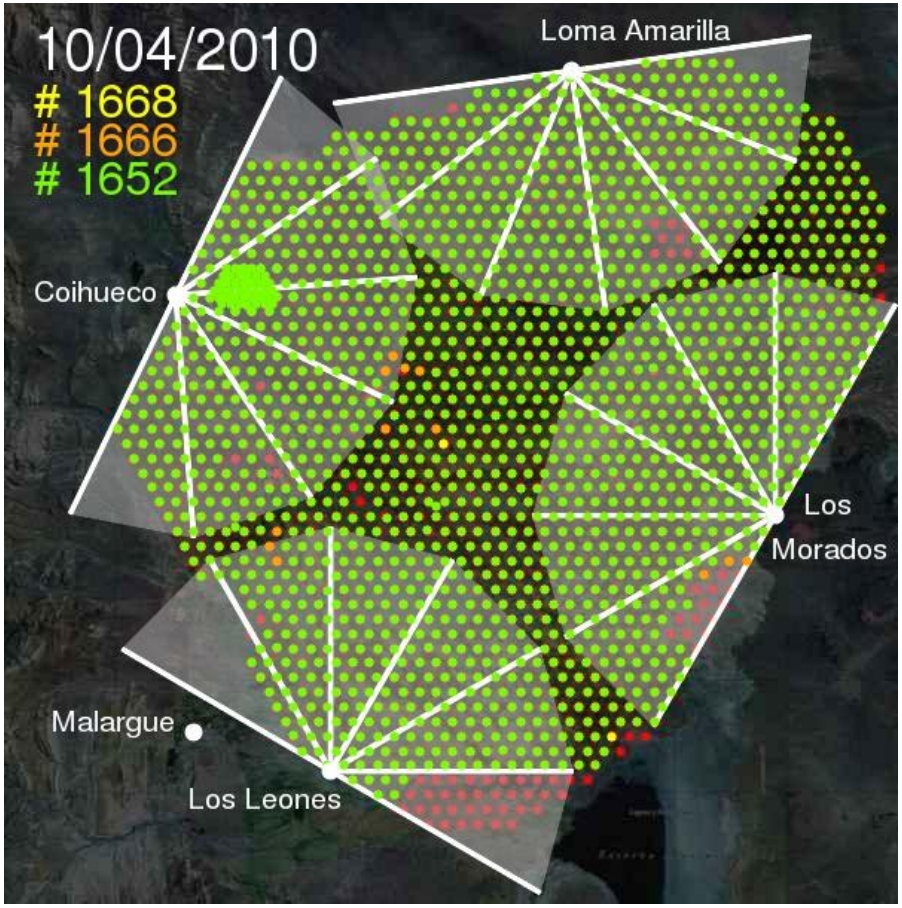


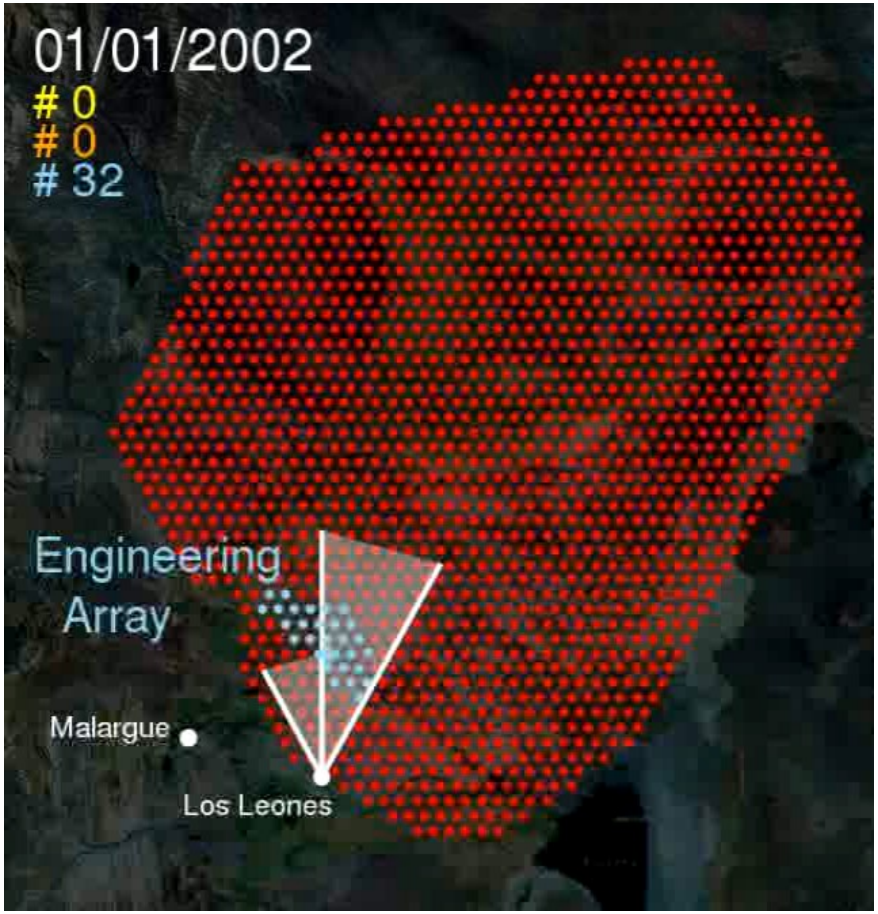




Fluorescence telescopes:
Number of telescopes: 24
Mirrors: 3.6 m x 3.6 m with field of view 30º x 30º, each telescope is equipped with 440 photomultipliers.

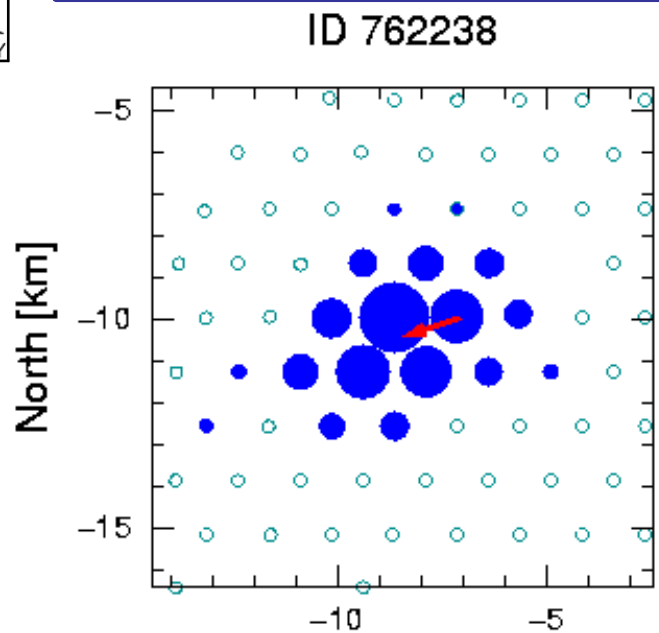
Evolution of the hybrid detector

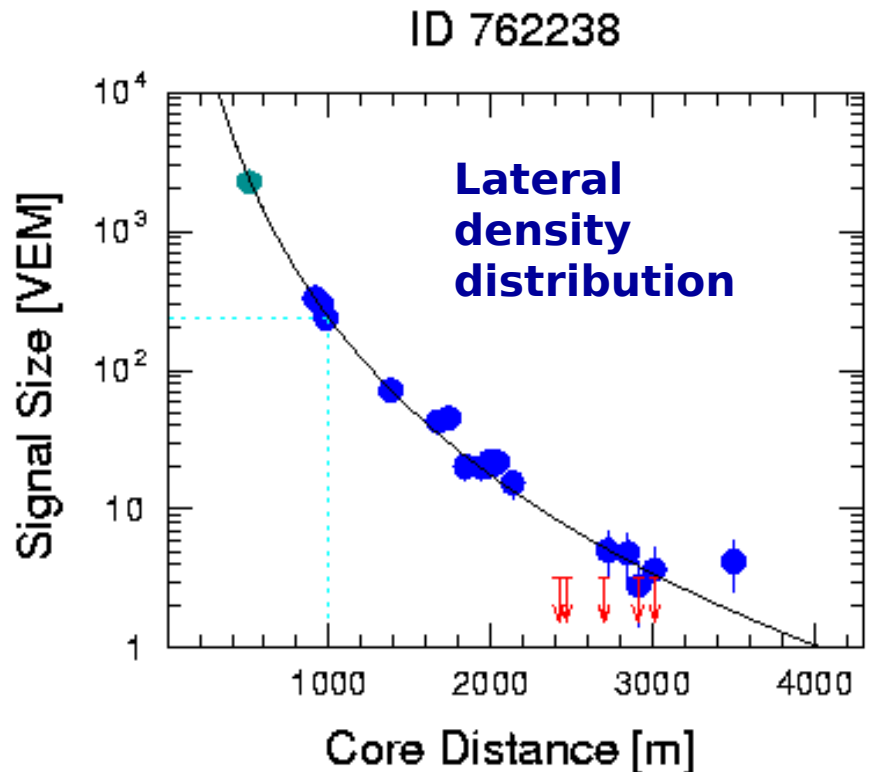


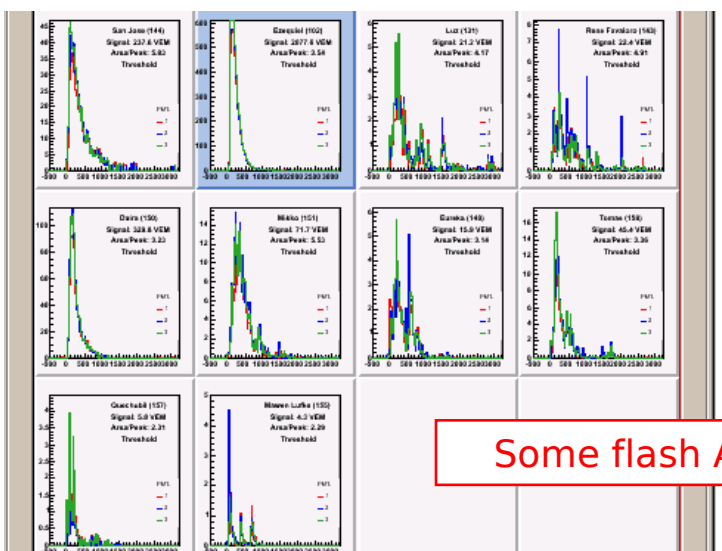


Production of scientific data since late 2003.

Example Surface Array Event
(Θ~ 48º, ~ 70 EeV)

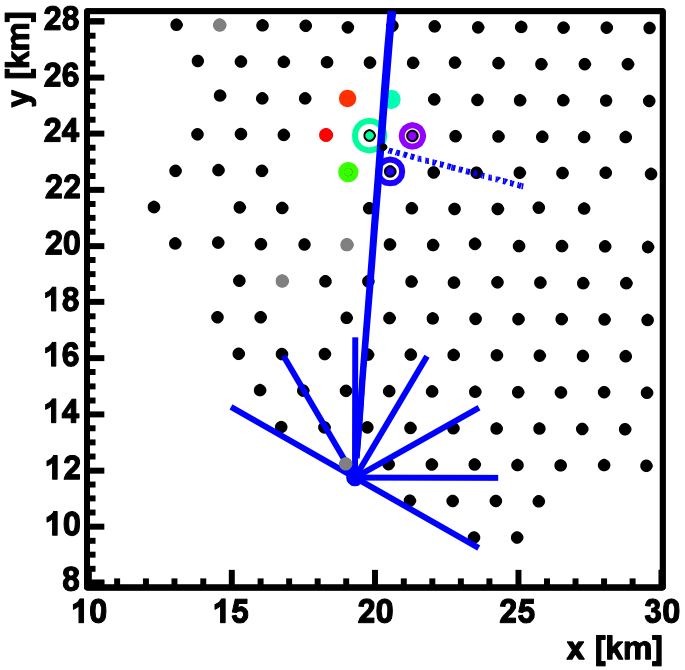


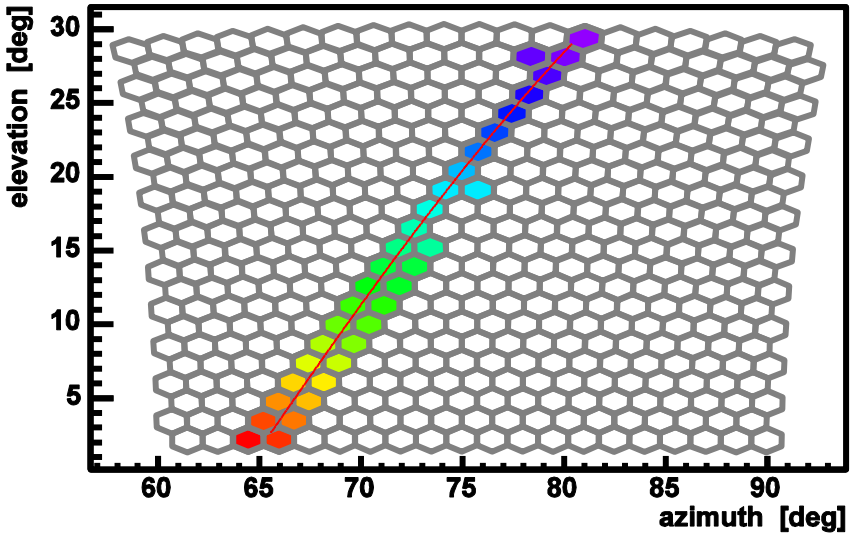


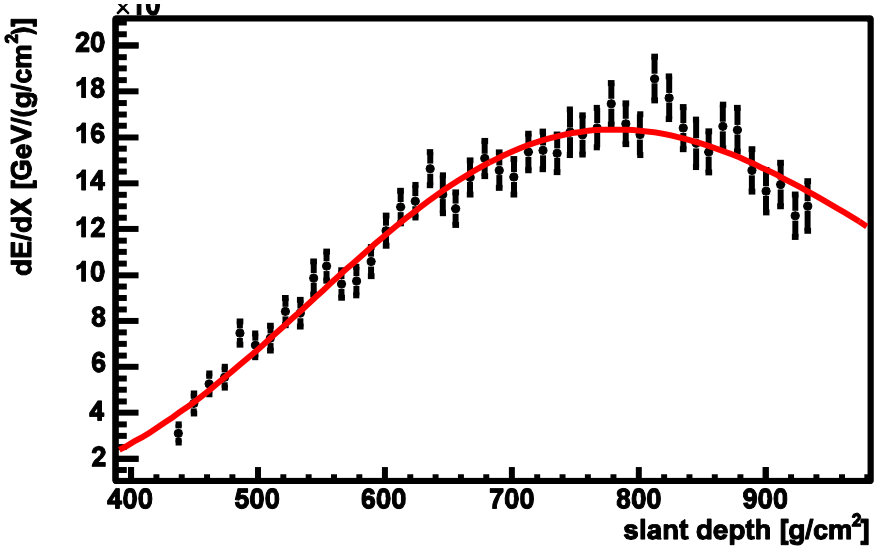


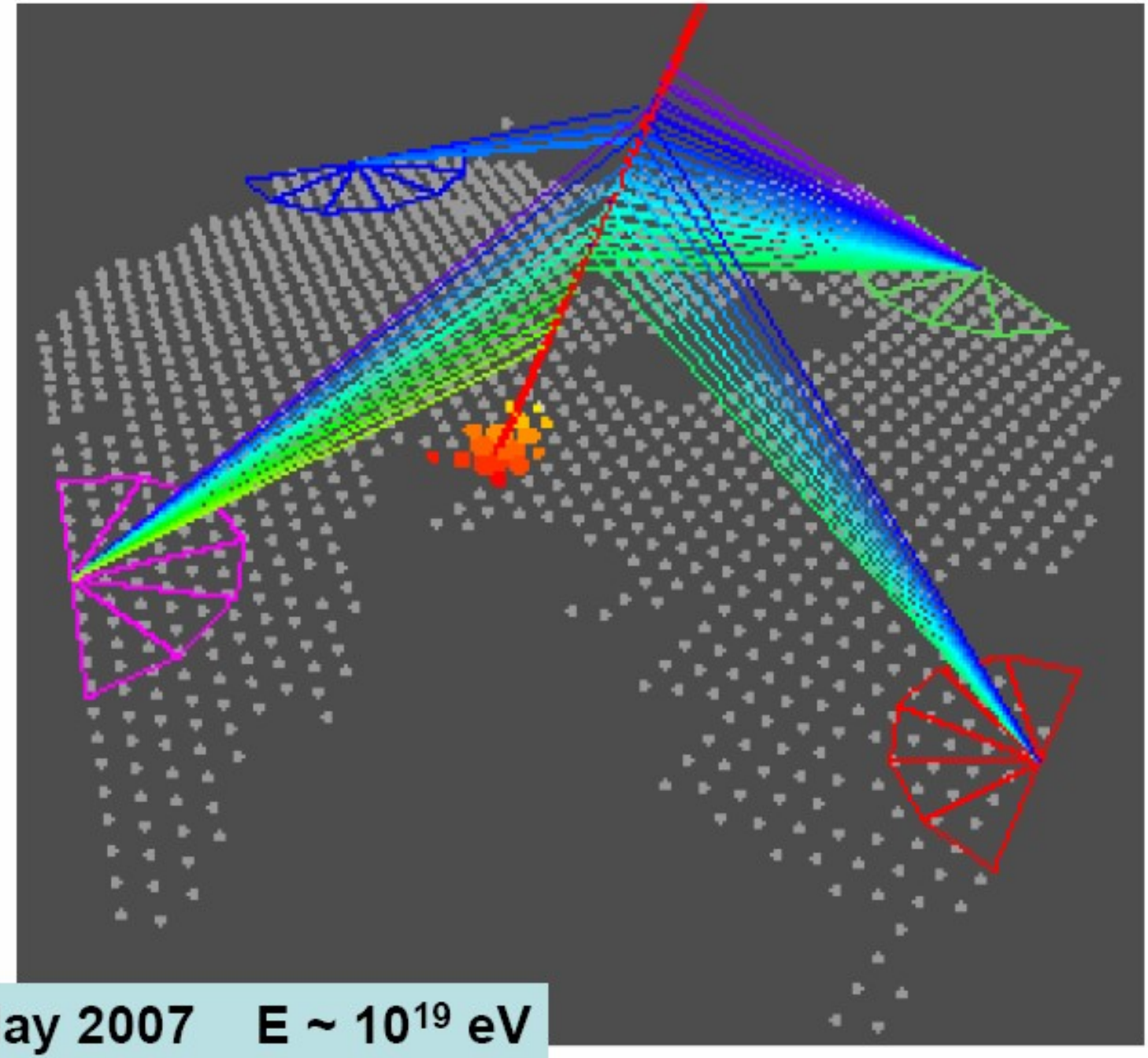
Some flash ADC traces

Example Hybrid Event
(Θ~ 30º, ~ 8 EeV)



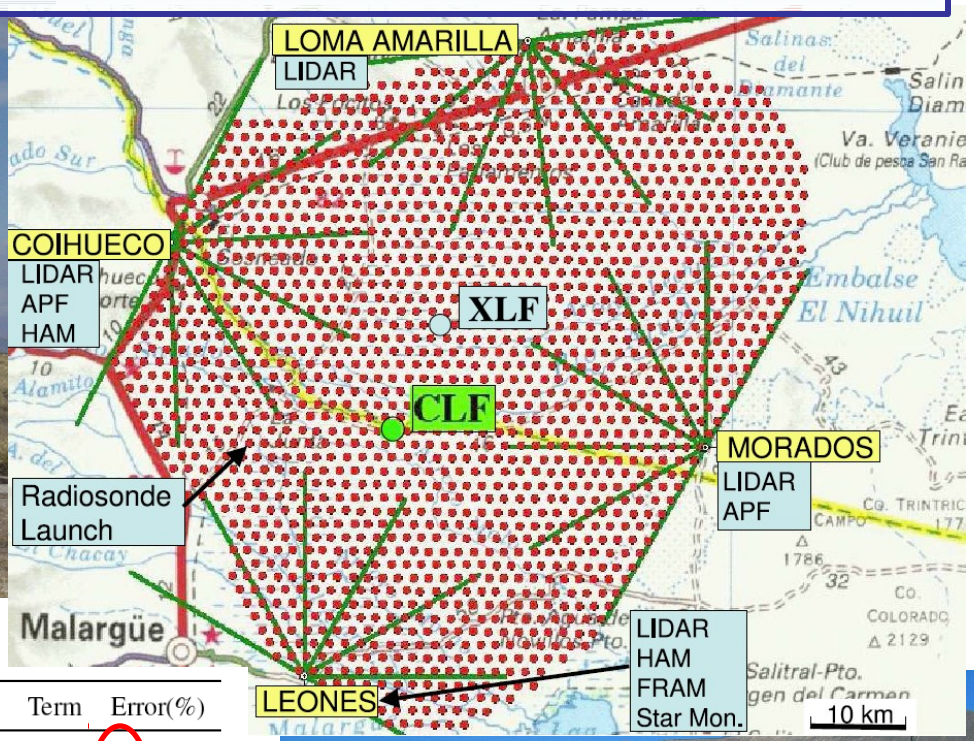






20 May 2007 E ~ 10^{19} eV

Energy estimation, atmospheric monitoring

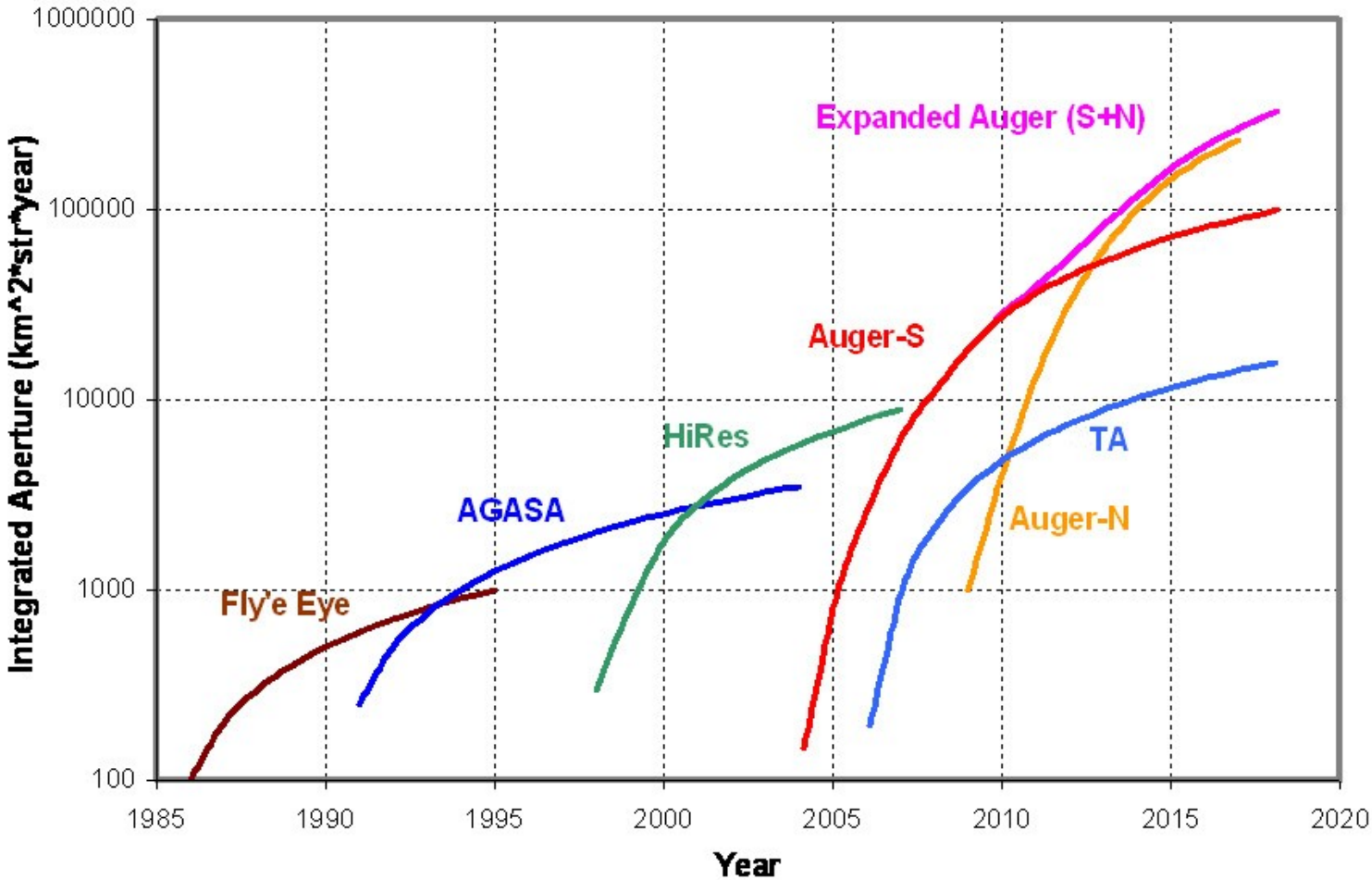


Term	Error(%)	Term	Error(%)
Light collection	5	Atmosphere (aerosols)	10
Detector photometric calibration	12	Atmosphere (clouds)	5
Geometric reconstruction	2	Atmosphere (density profile)	2
Correction for Missing Energy	3	Fluorescence yield	15
	Quadrature Sum = 23		

Current estimates of systematic errors of the FD energy measurement

LIDAR

Comparison of integrated aperture



Currently (Nov 2013) ~ 20 x AGASA

Auger Observatory results

Auger Energy Spectrum

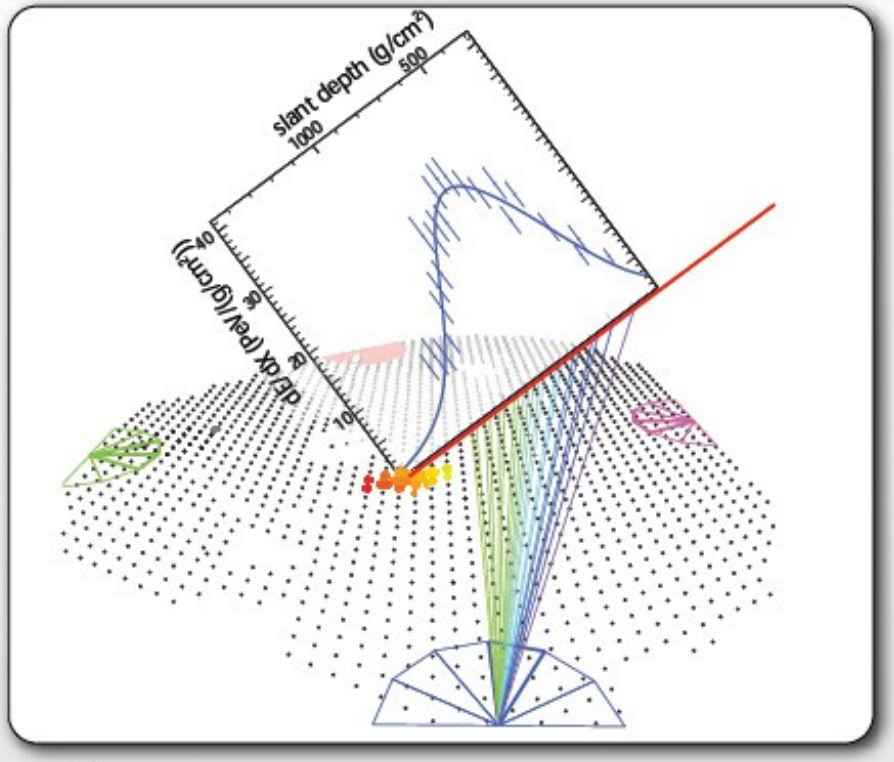
- No spectrum from SD only!

- Relation between particle density parameter S(1000) and FD energy using selected hybrid events

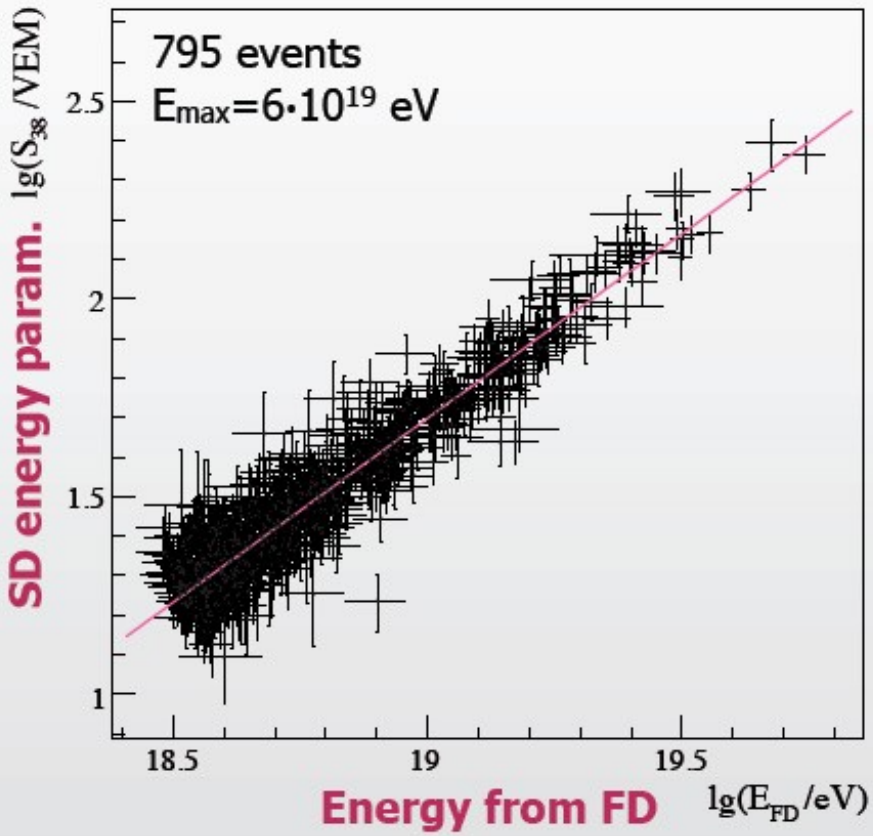
- Aperture from SD

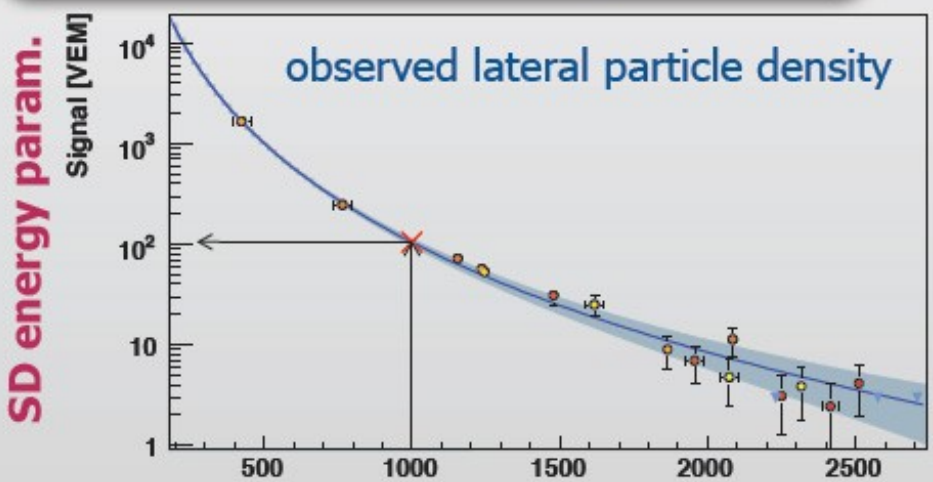
- Combining advantages of FD technique (calorimetric measurement of energy) and of SD technique (well defined aperture; 100 % duty cycle)

Ground Array calibrated by Fluorescence Obs.



Auger @ ICRC09

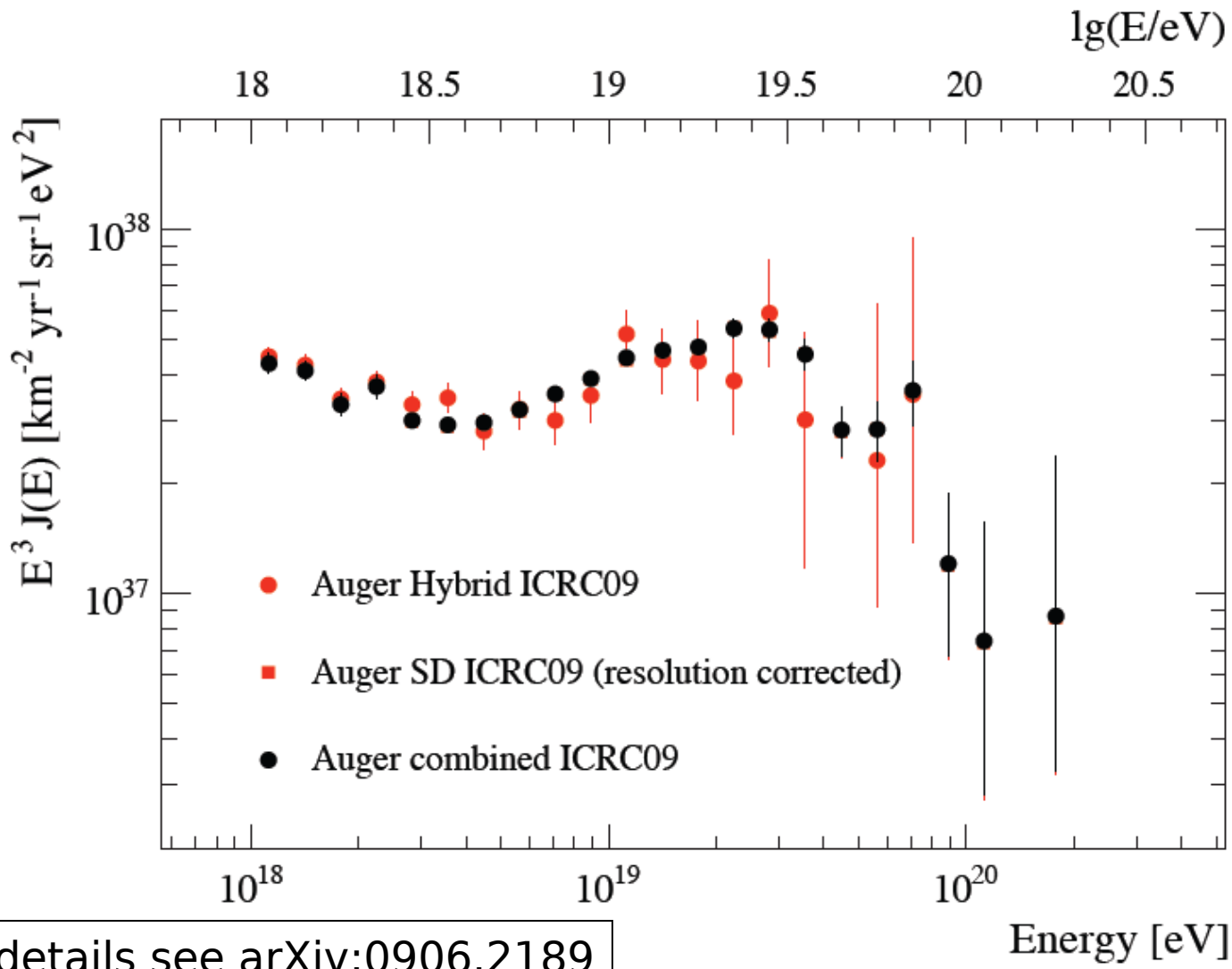




Applied by Auger and Telescope Array

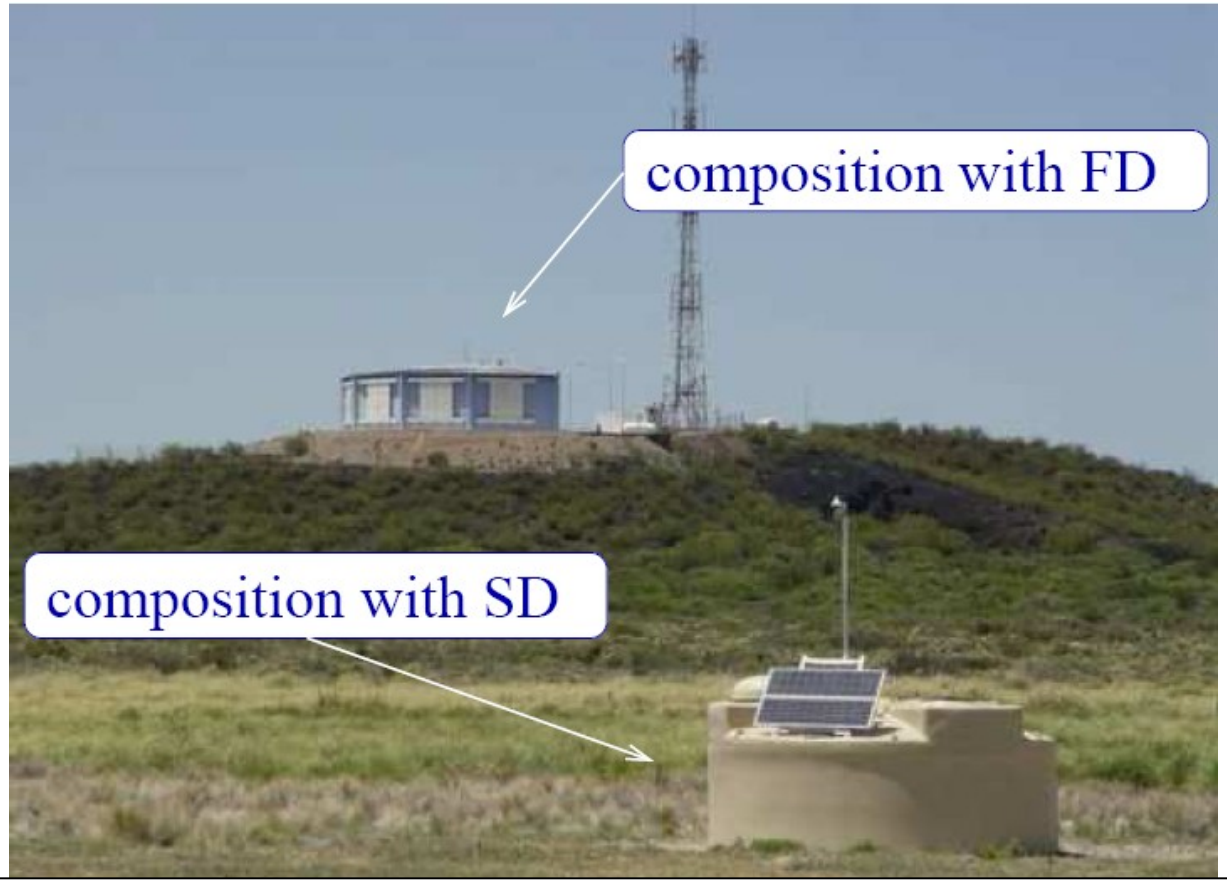
K.-H. Kampert, EPS-HEP

Auger Energy Spectrum



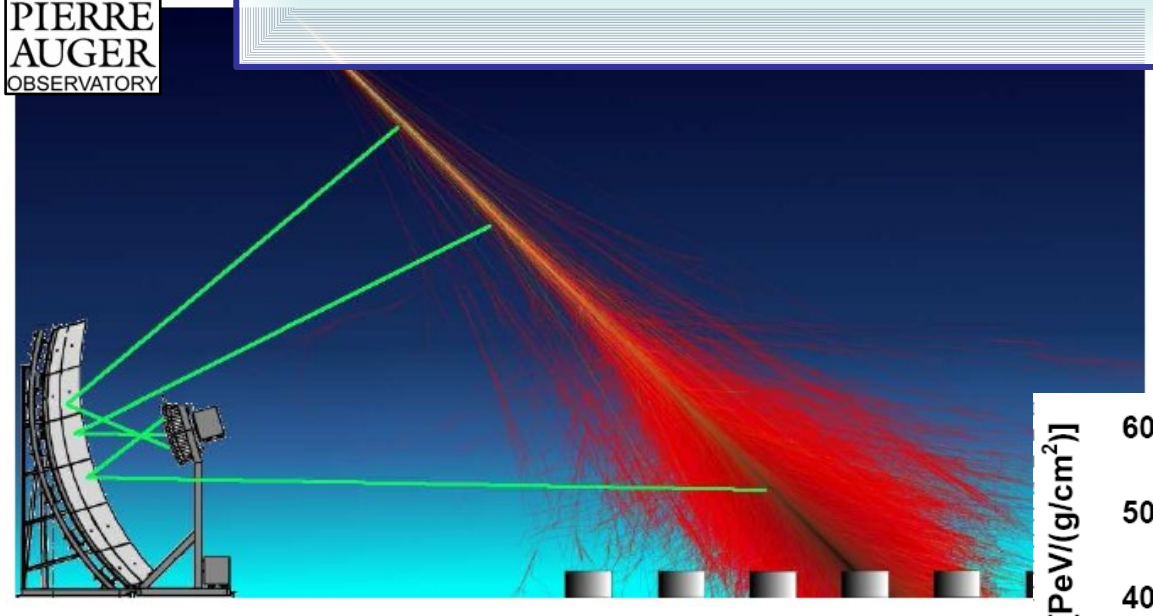
For more details see arXiv:0906.2189

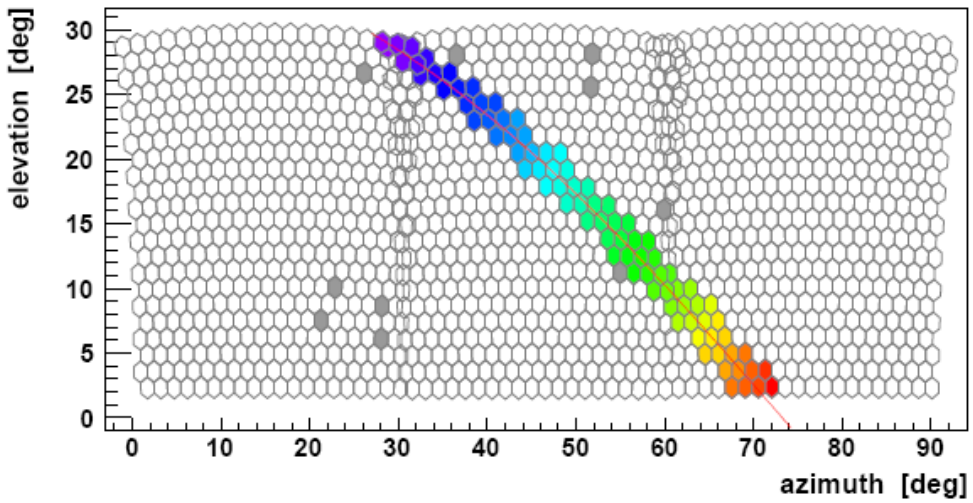
Mass Composition

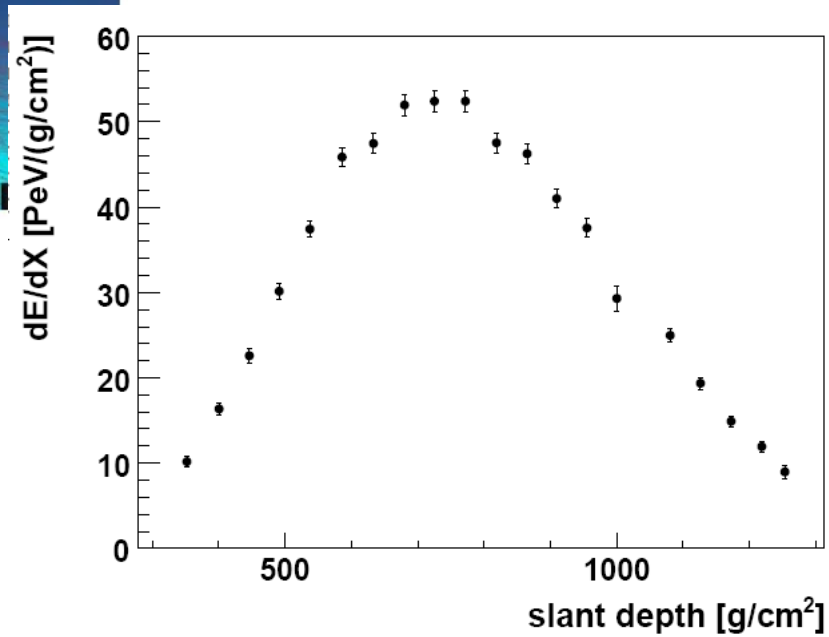


For more details see arXiv:0906.2319
Or talk by Michael Unger: http://web.phys.ntnu.no/~mika/unger2.pdf

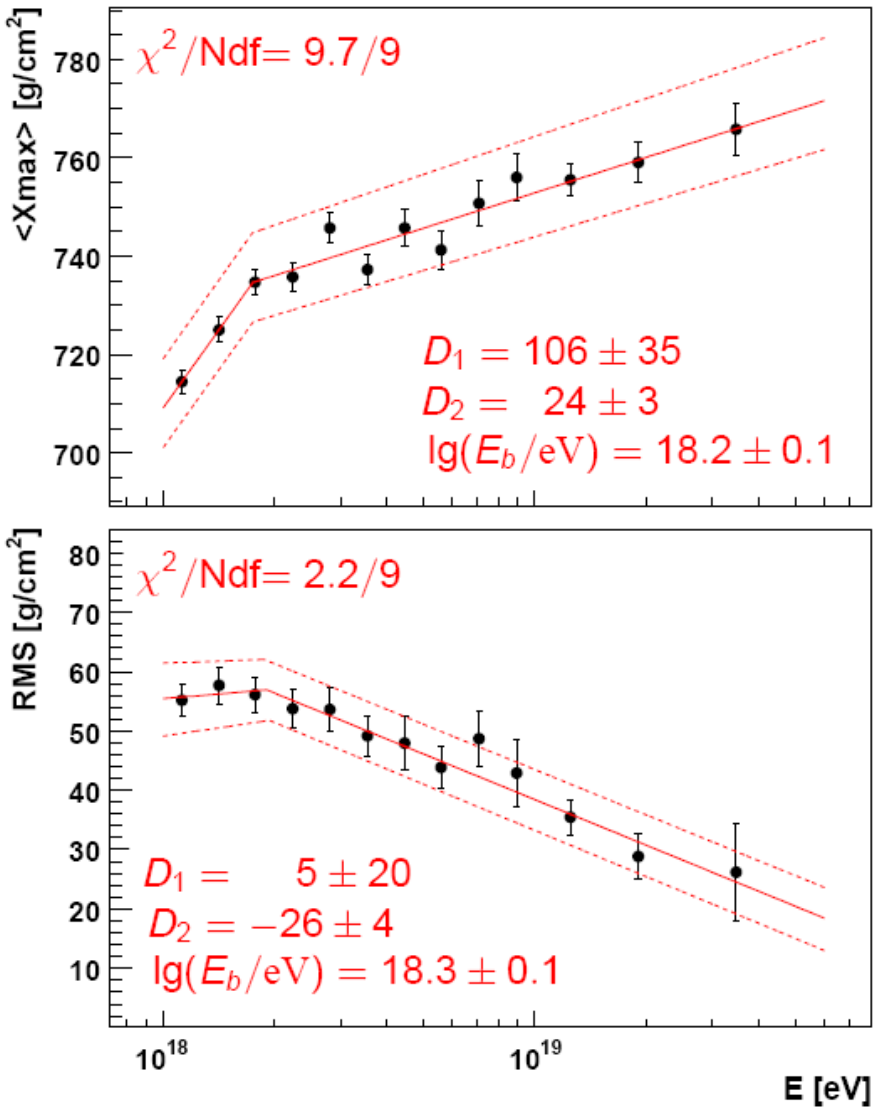
Shower Profile

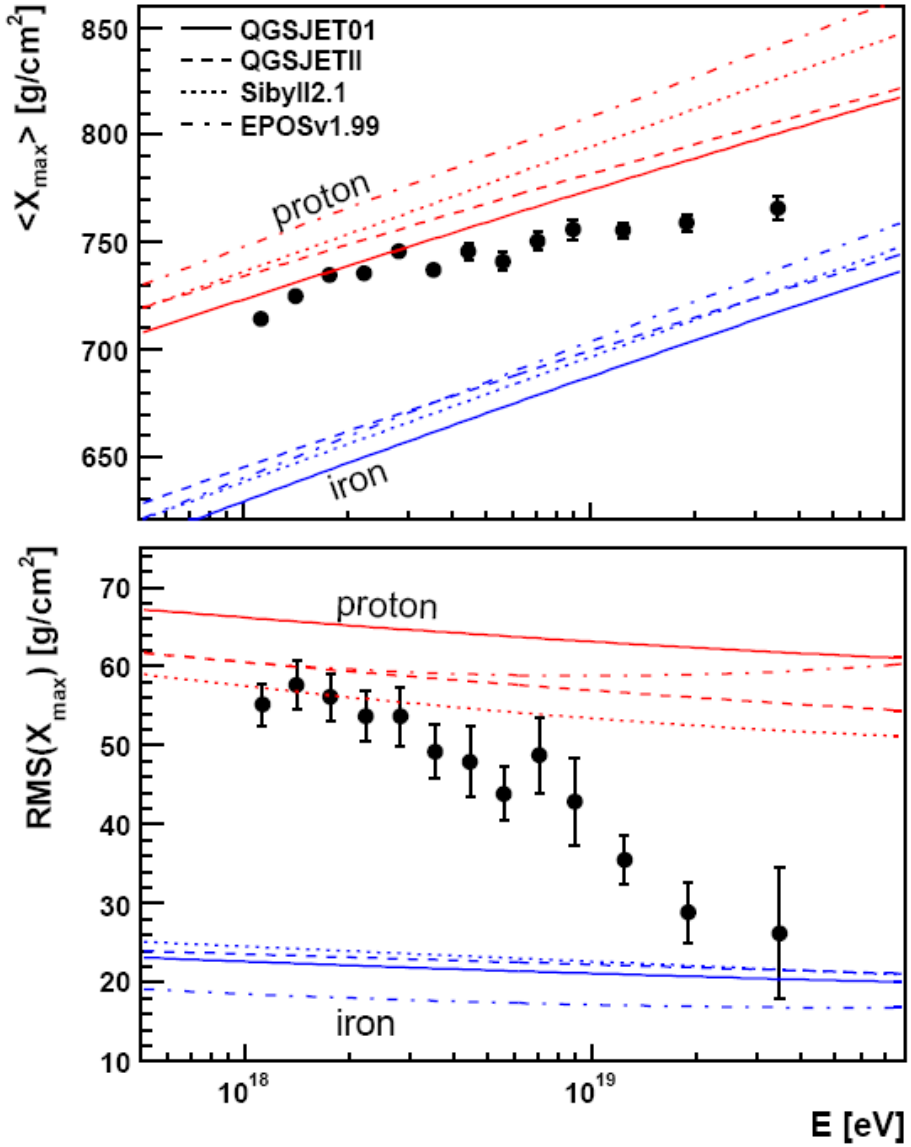




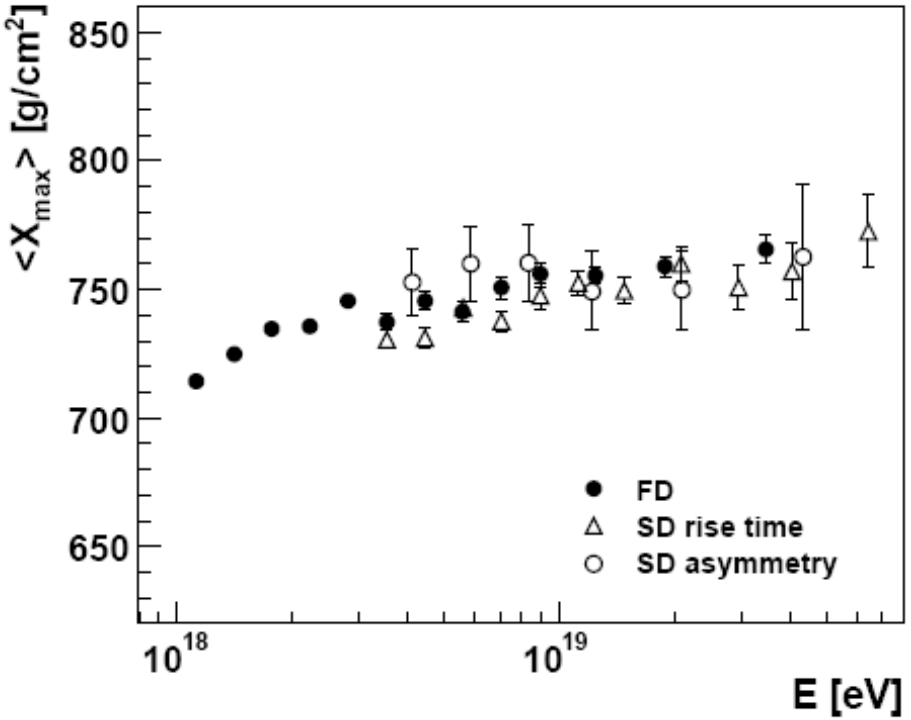


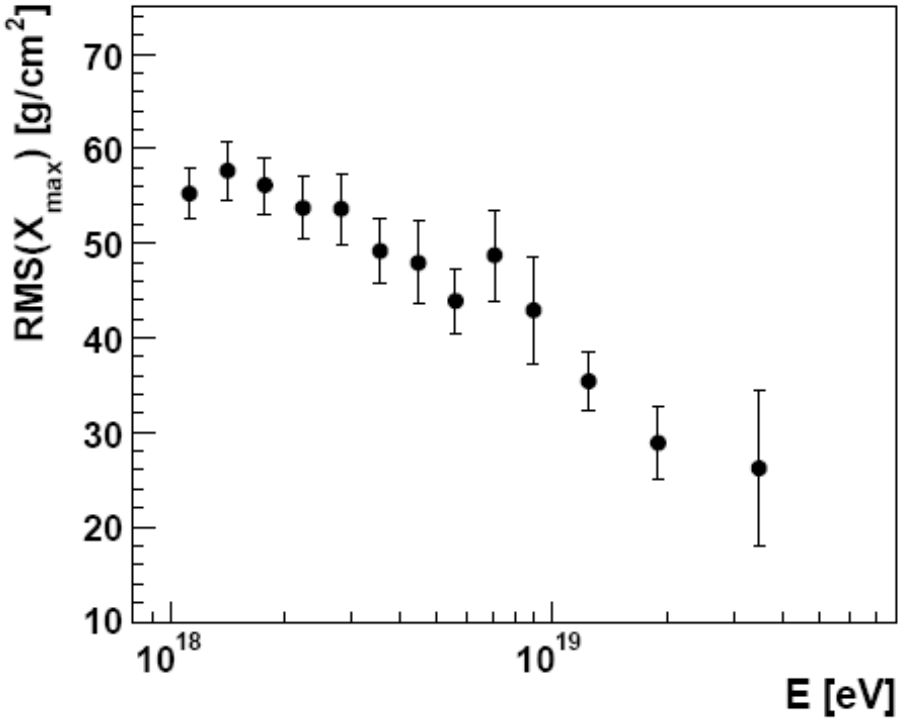
FD mass composition results





Mass composition summary

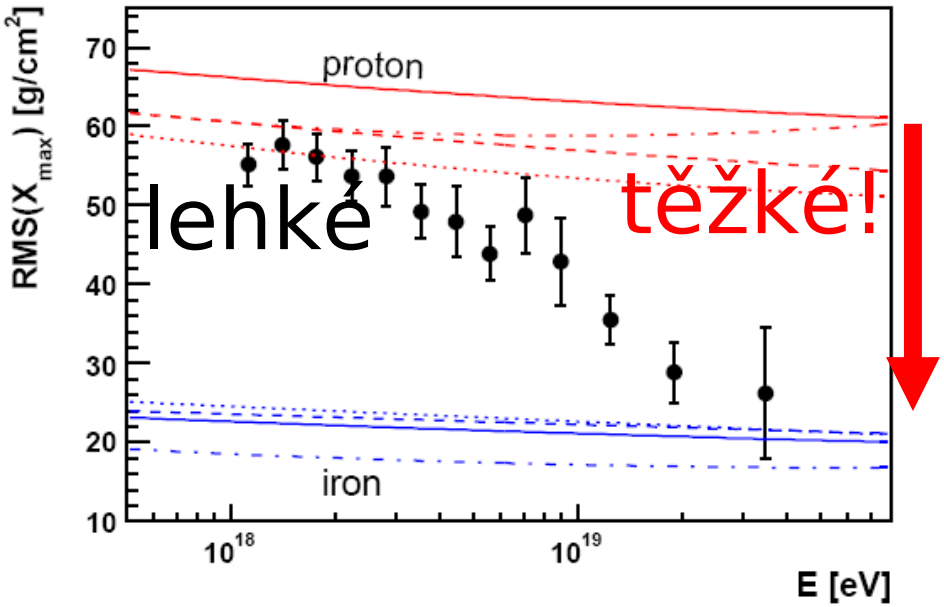


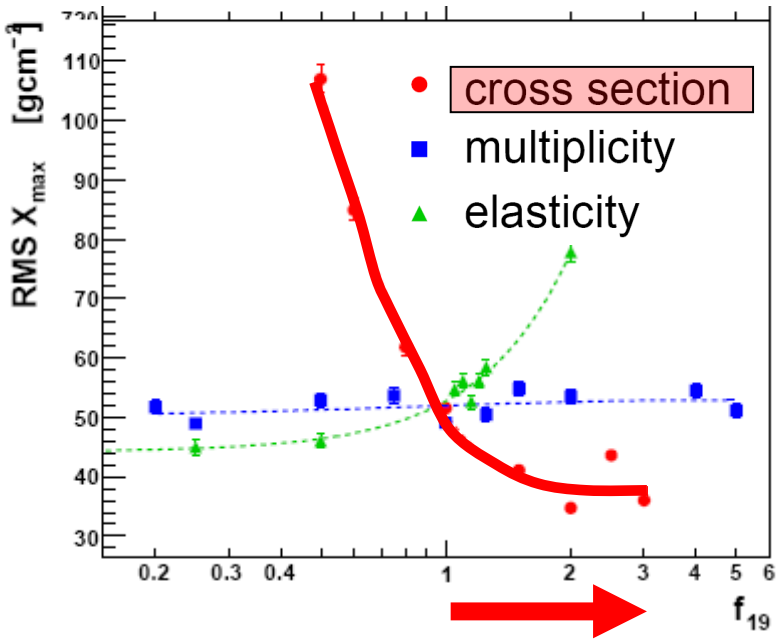


- Elongation rate flattens at high energy
- Fluctuations decrease with energy
- Two options (both can be simultaneously true):
  1.) Cosmic rays heavier at high energy
  2.) Hadronic models at UHE energy need modification

J. Řídký a P. Trávníček

Hadronové složení





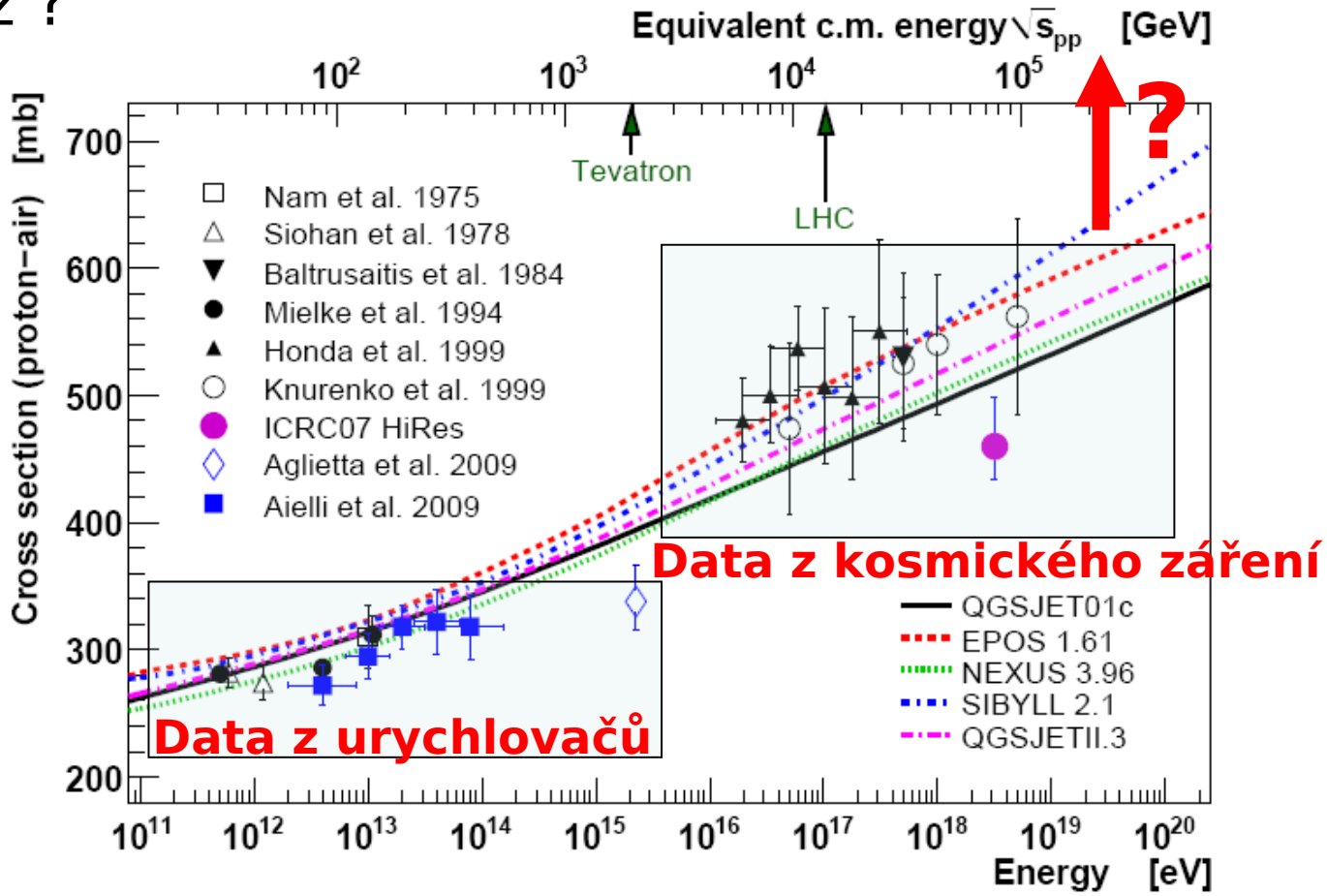
$\sigma_{nové}(10EeV) = f_{19}\, \sigma_{model}(10EeV)$

a nebo je to jinak – např., že prudce roste účinný průřez ?

J. Řídký a P. Trávníček

Účinný průřez

a nebo je to jinak – např., že prudce roste účinný průřez ?

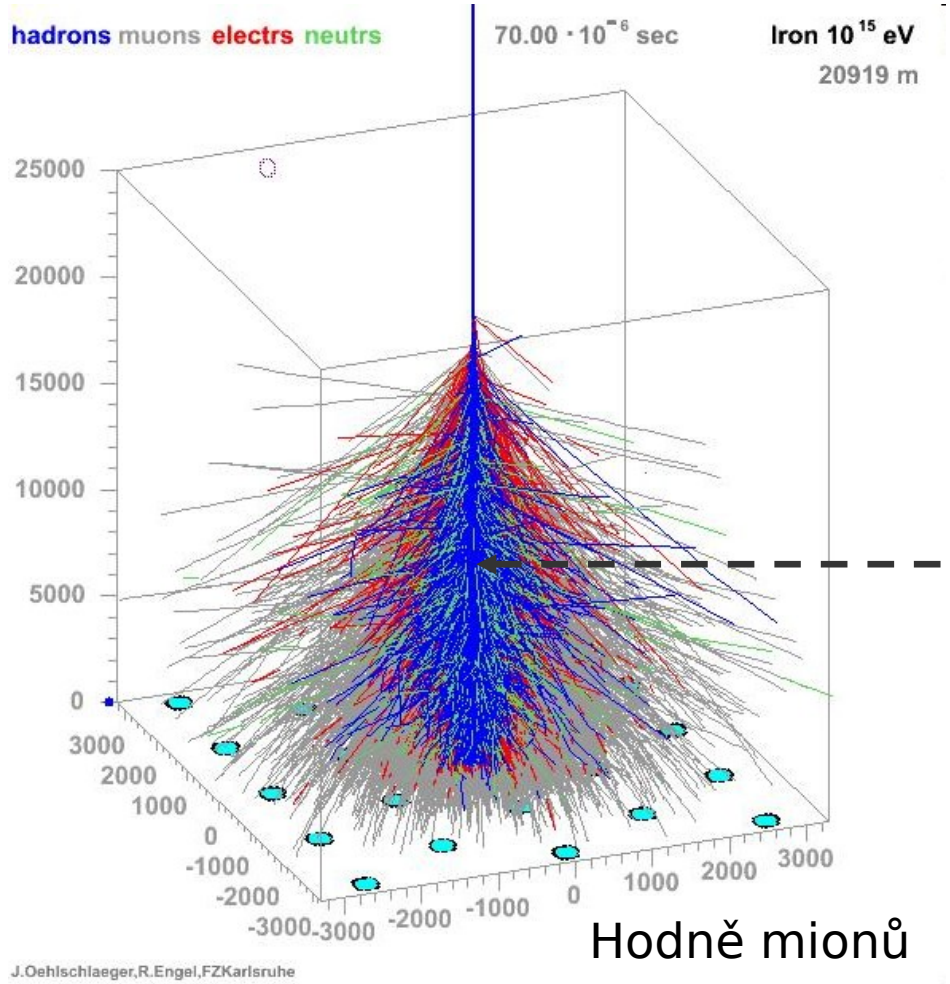


Budoucnost: Měření účinného průřezu i na observatoři AUGER

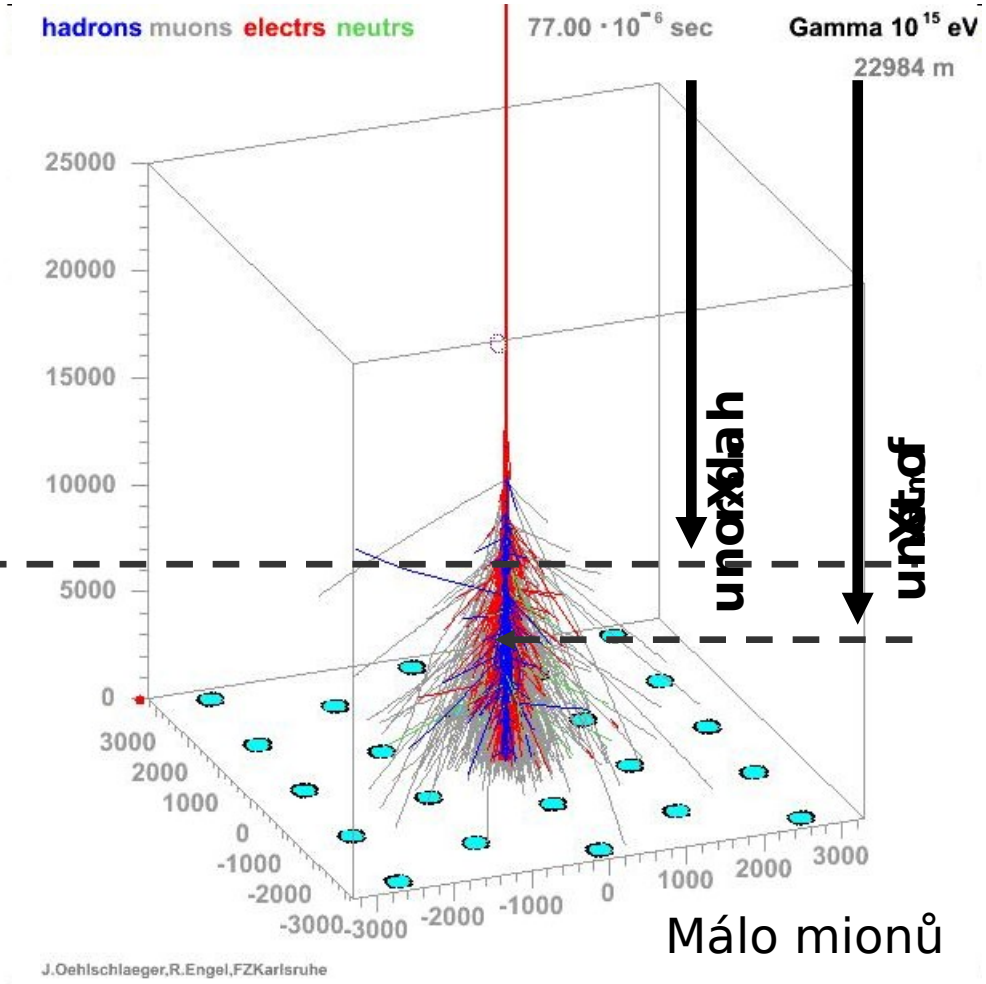
J. Řídký a P. Trávníček

Jak poznat foton?

Hadronové a fotonové spršky se značně liší. Najít v datech primární fotony lze podle **maxima spršky (FD)** a podle **počtu mionů (SD) .**

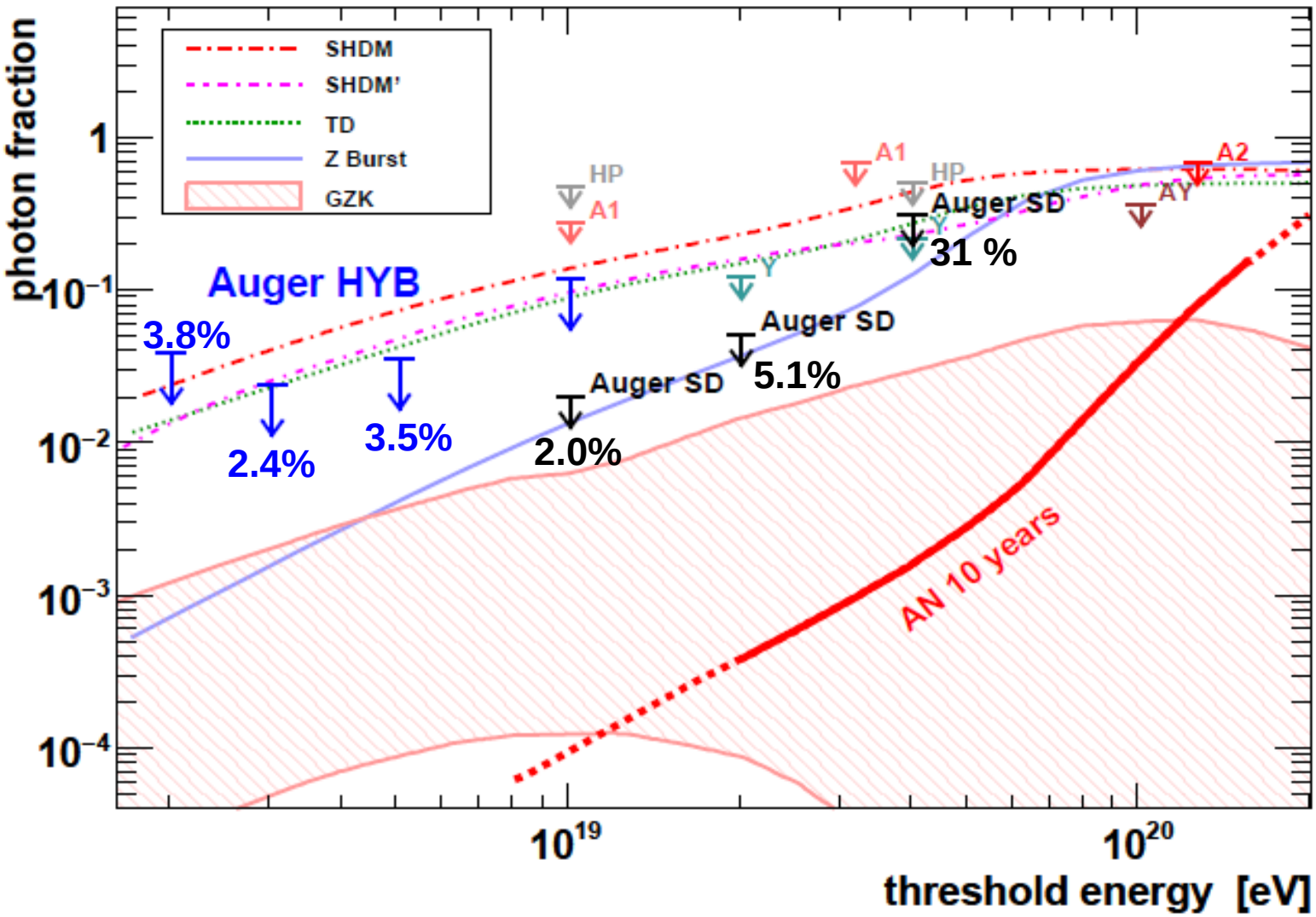


Hodně mionů



Málo mionů

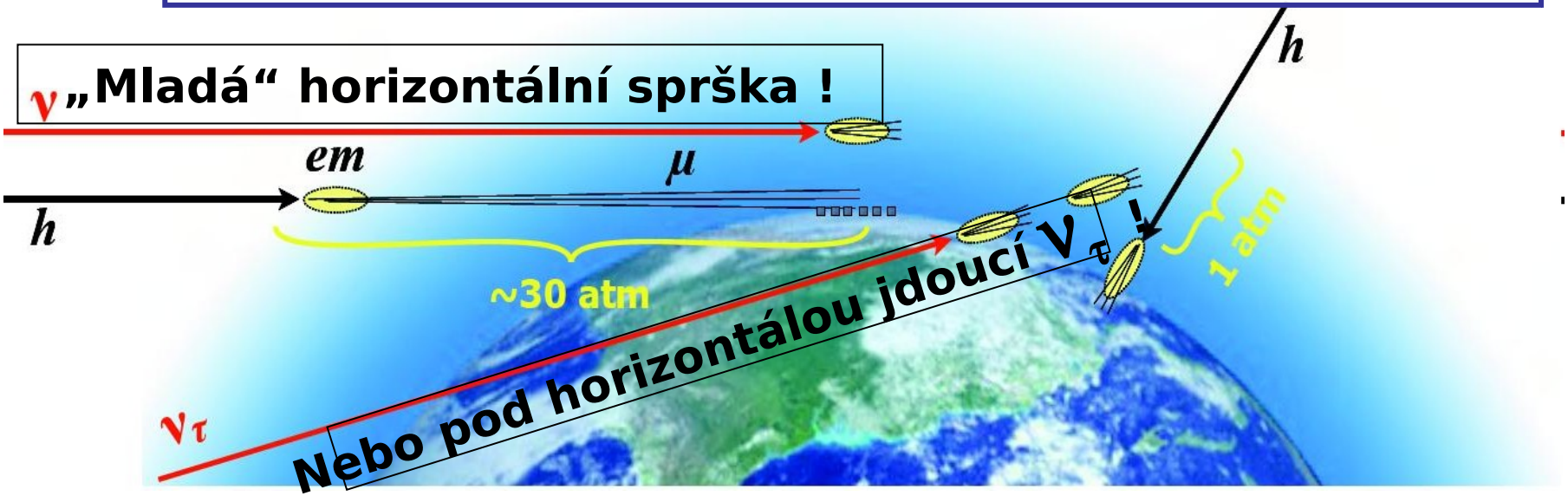
Photon limit



Piotr Homola (Pierre Auger Coll.), ICRC'09, Lodz; arXiv 0906.2347

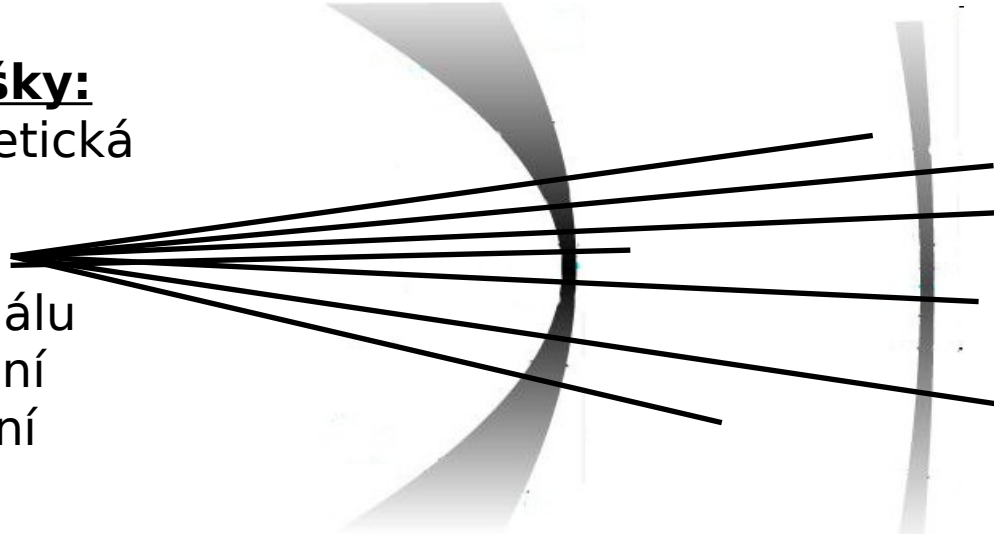
J. Řídký a P. Trávníček

Jak poznat neutrino?



1 atmosféra 3 atmosféry

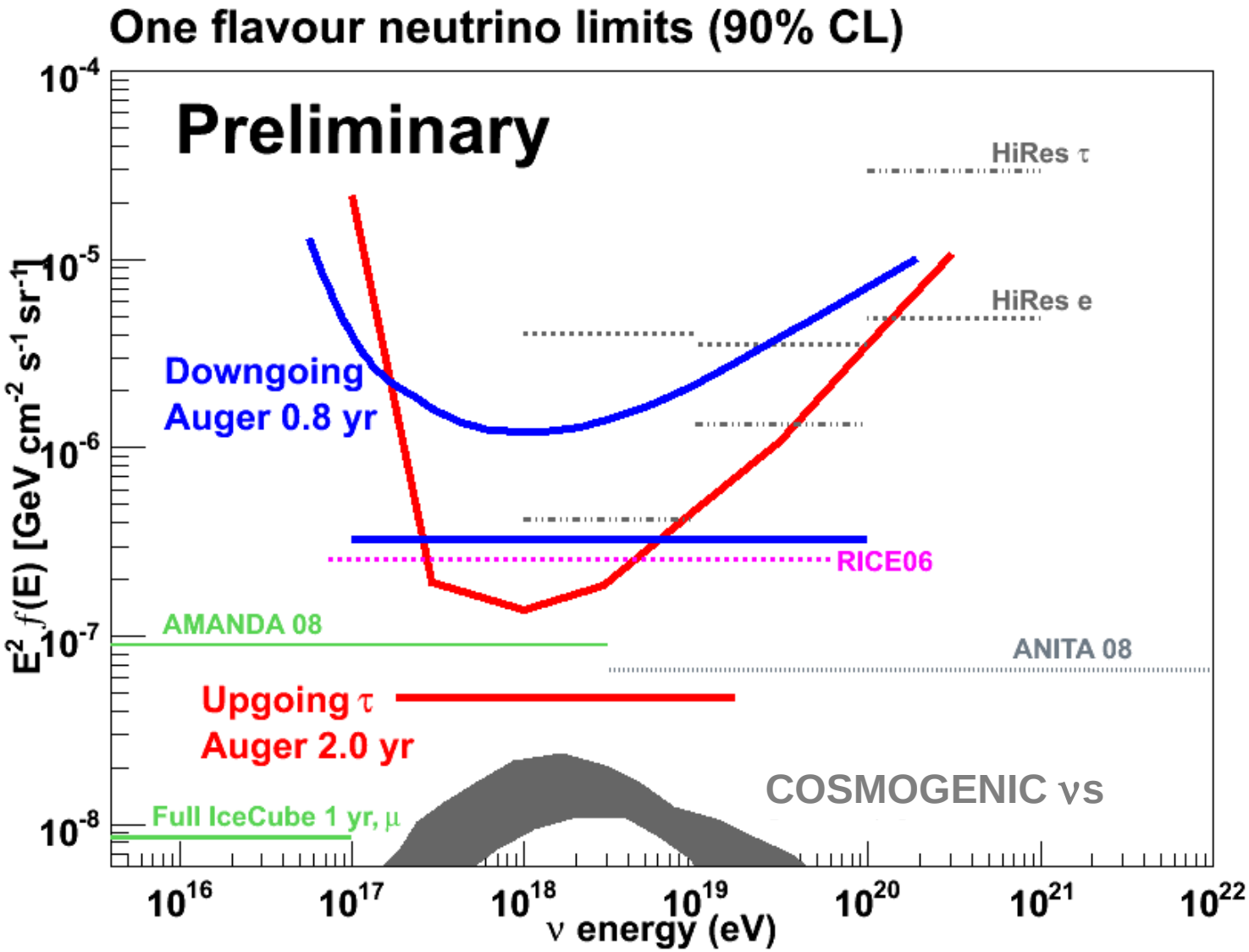
„Mladé“ spršky:
- elektromagnetická komponenta
-široká časová distribuce signálu
- velké zakřivení
- strmá laterální distribuce



„Staré“ spršky
- tvrdé miony
- úzká časová distribuce signálu
- malé zakřivení
-plochá laterální distribuce

čelo mladé spršky čelo staré spršky

Neutrino limit



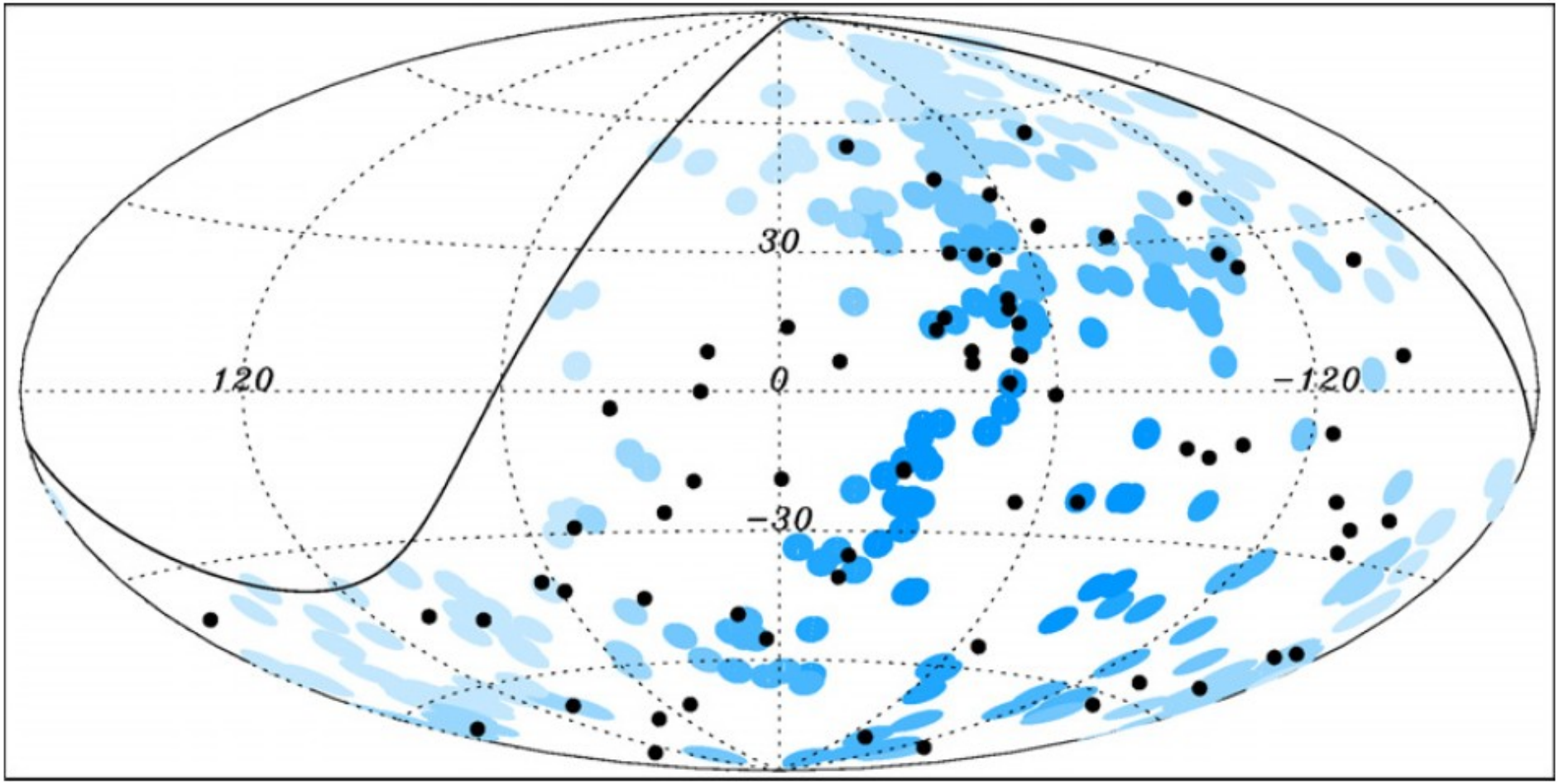
J. Tiffenberg (Pierre Auger Coll.), ICRC'09, Lodz; arXiv 0906.2347

9 November 2007 | $10

Science

AAAS

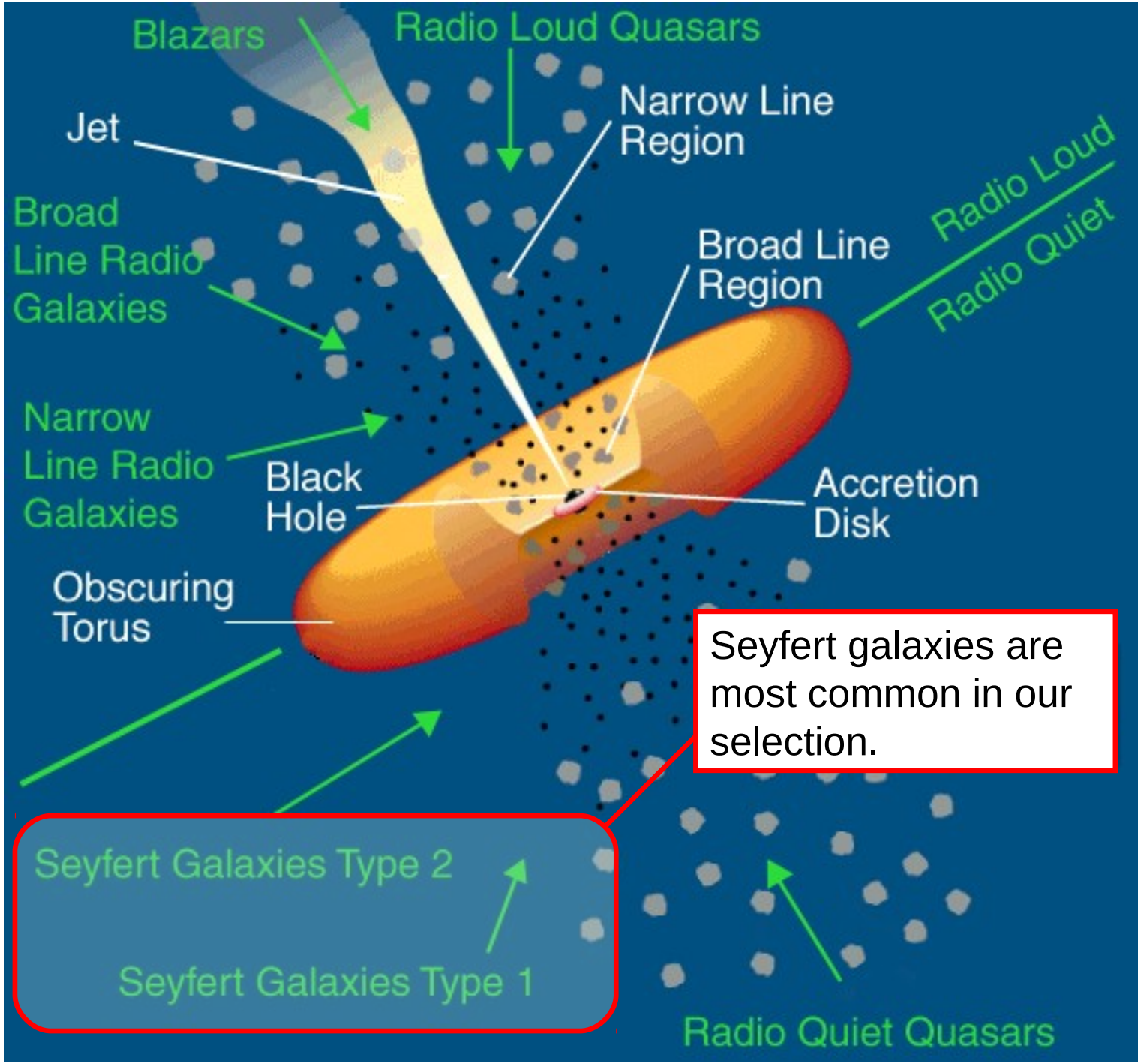
The best agreement is with the distribution of nearby active galaxies.



Black dots – arrival directions of CRs with E > 55 EeV
Blue circles – active galactic nuclei (AGNs) with distance < 75 Mpc
– in agreement with our expectations (GZK cutoff)

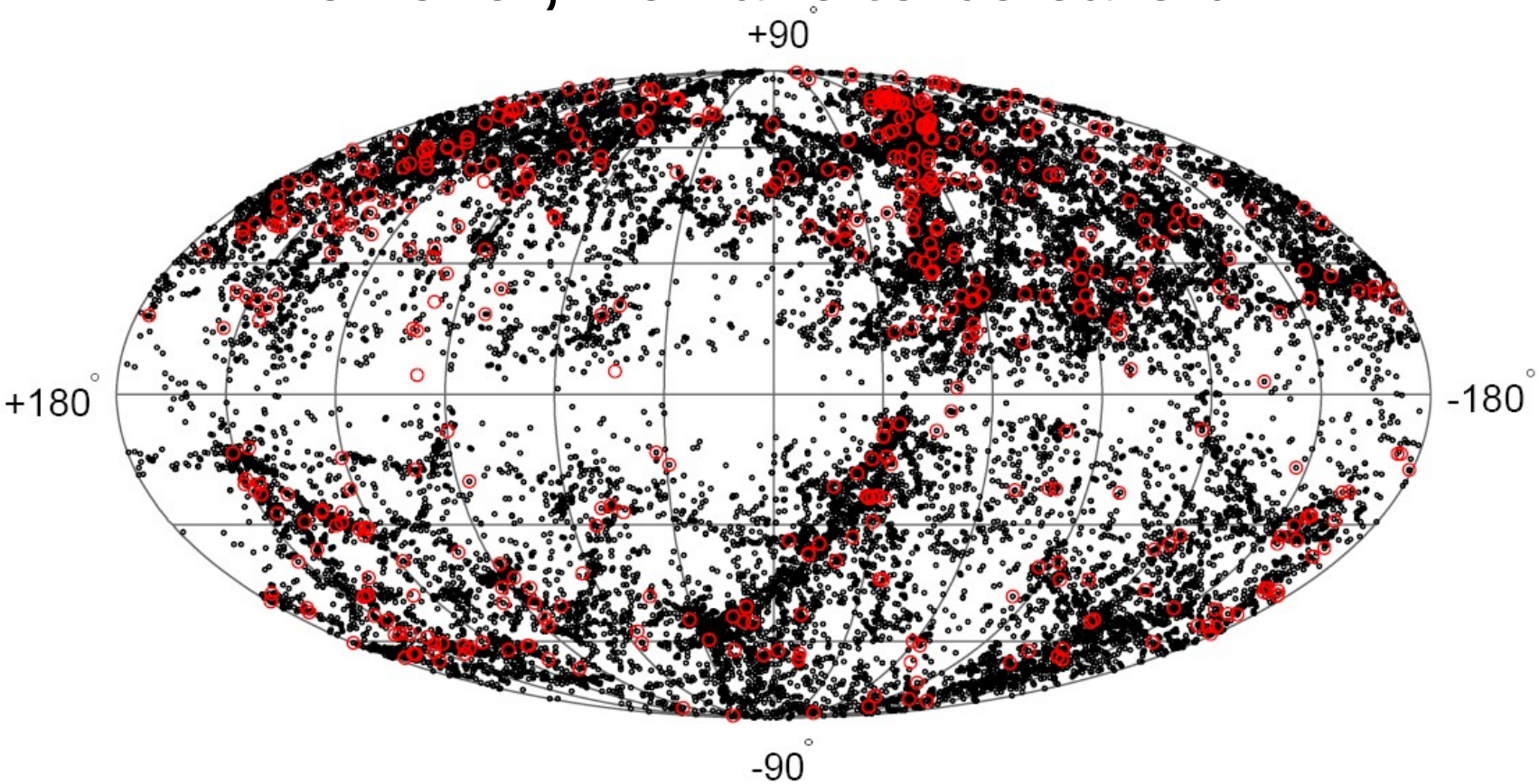
So, what are active galactic nuclei?

- galaxies with supermassive black holes in their centers; black hole mass in order of 10^7 - 10^8 solar masses; enough matter nearby to be swallowed



Seyfert galaxies are most common in our selection.

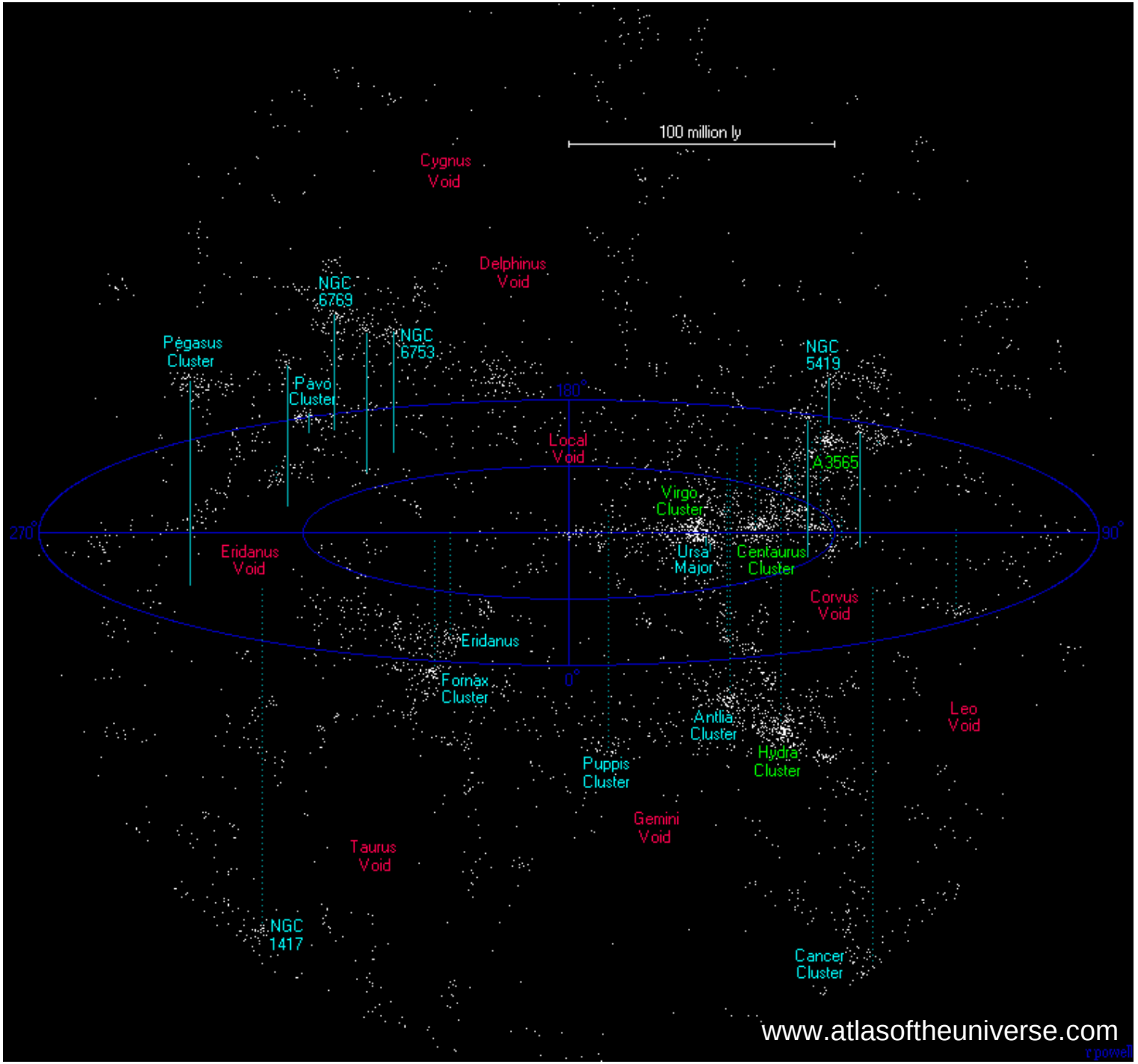
However, we have to be careful…

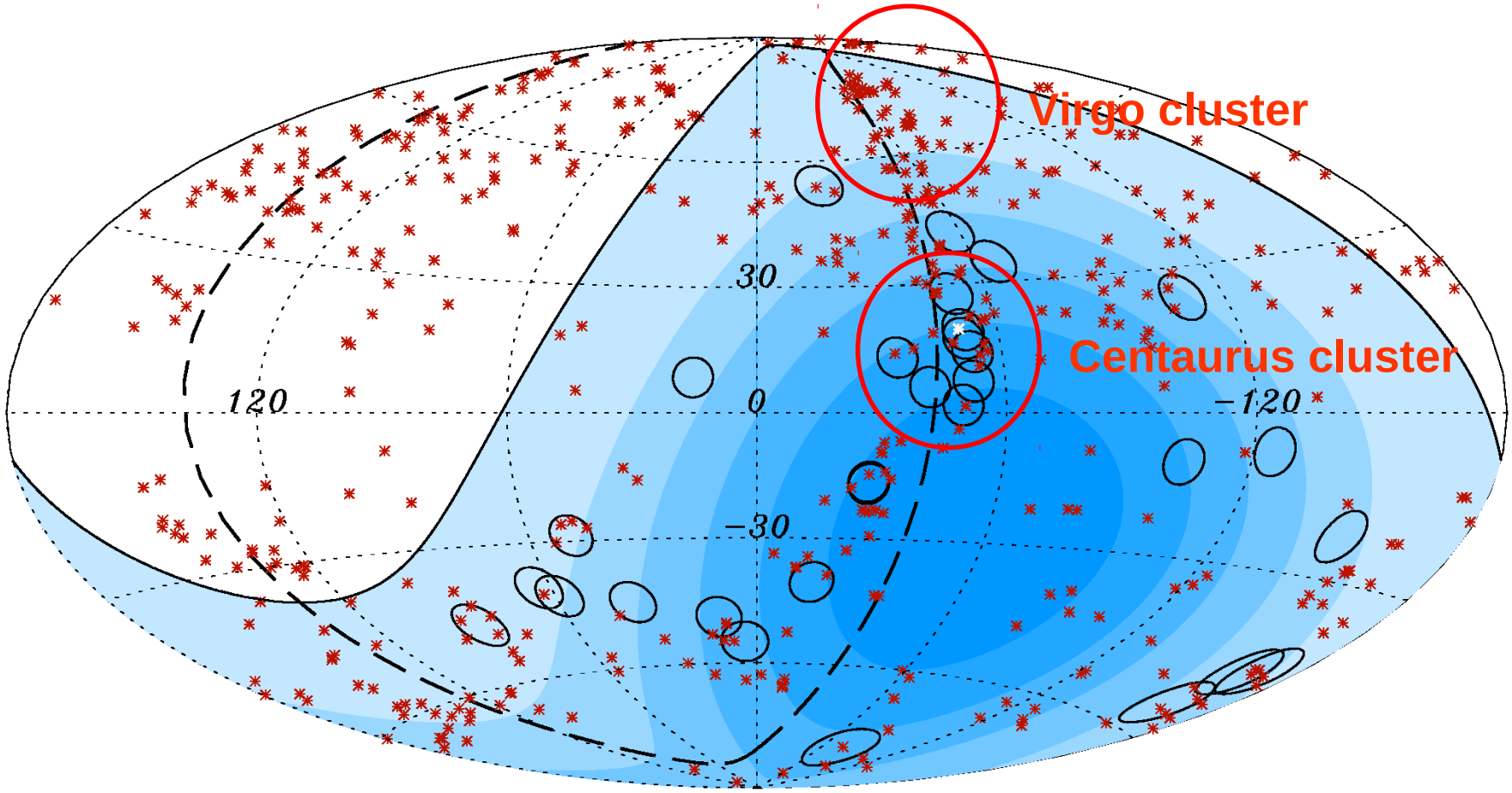


Red circles – (again) AGNs closer than 75 Mpc
Black dots – all galaxies closer than 75 Mpc (HyperLEDA catalogue)

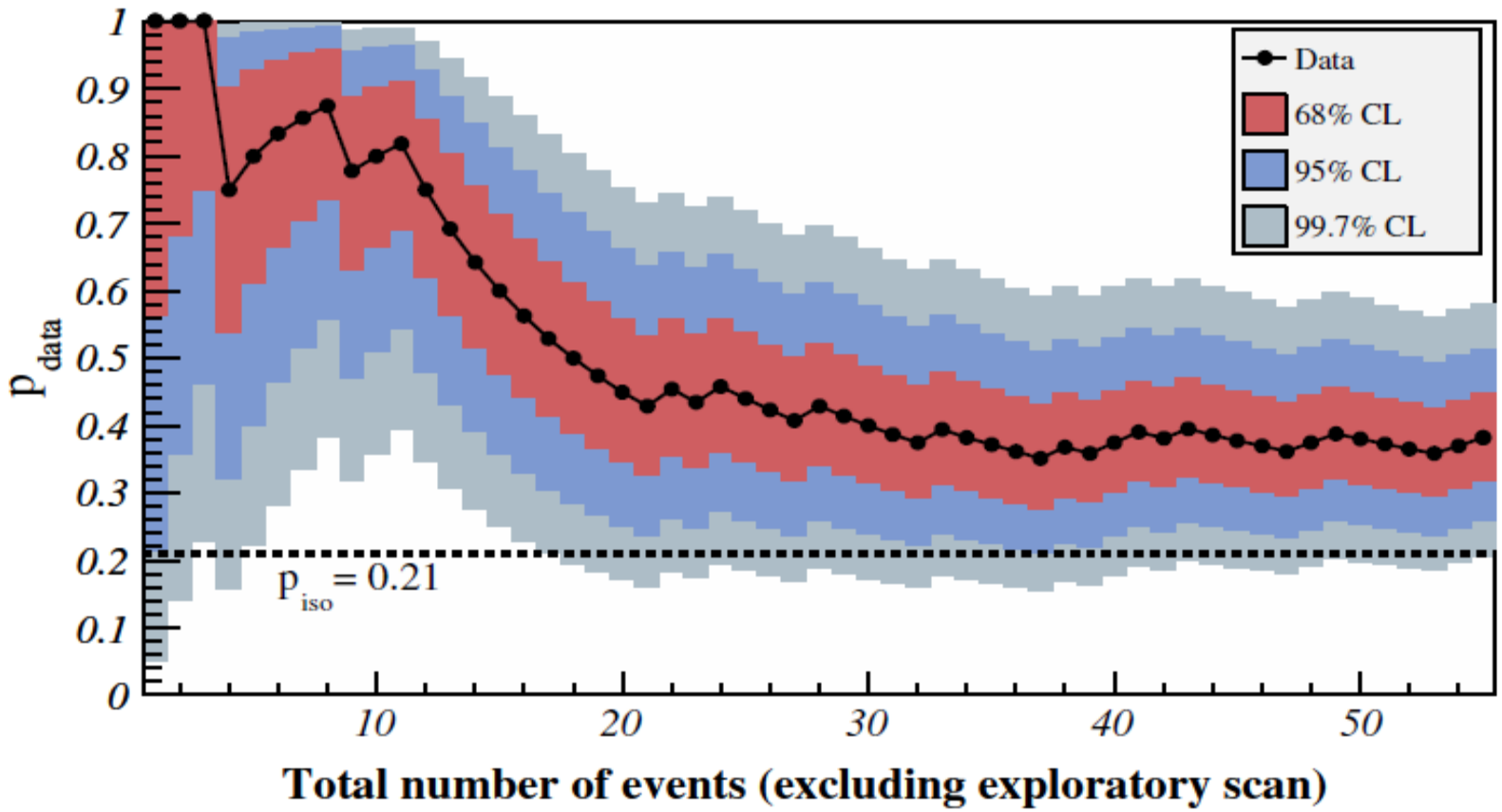
Distribution of ordinary galaxies (and matter in general) and of AGNs is very similar!

So, our first guess that the particles with the highest energies come from AGNs is not correct → we need more data from both South and North ...


100 million ly
Cygnus Void
Delphinus Void
NGC 6769
NGC 6753
Pegasus Cluster
Pavo Cluster
NGC 5419
180°
Local Void
A3565
Virgo Cluster
270°
90°
Eridanus Void
Ursa Major
Centaurus Cluster
Corvus Void
Eridanus
Fornax Cluster
0°
Antlia Cluster
Leo Void
Hydra Cluster
Puppis Cluster
Gemini Void
Taurus Void
NGC 1417
Cancer Cluster
www.atlasoftheuniverse.com
rpowell

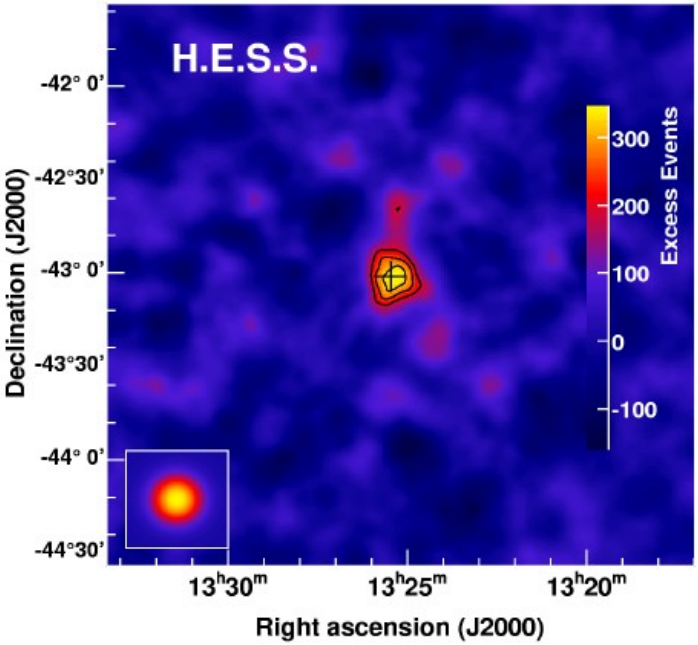

Virgo cluster
Centaurus cluster
30
0
−30
120
−120

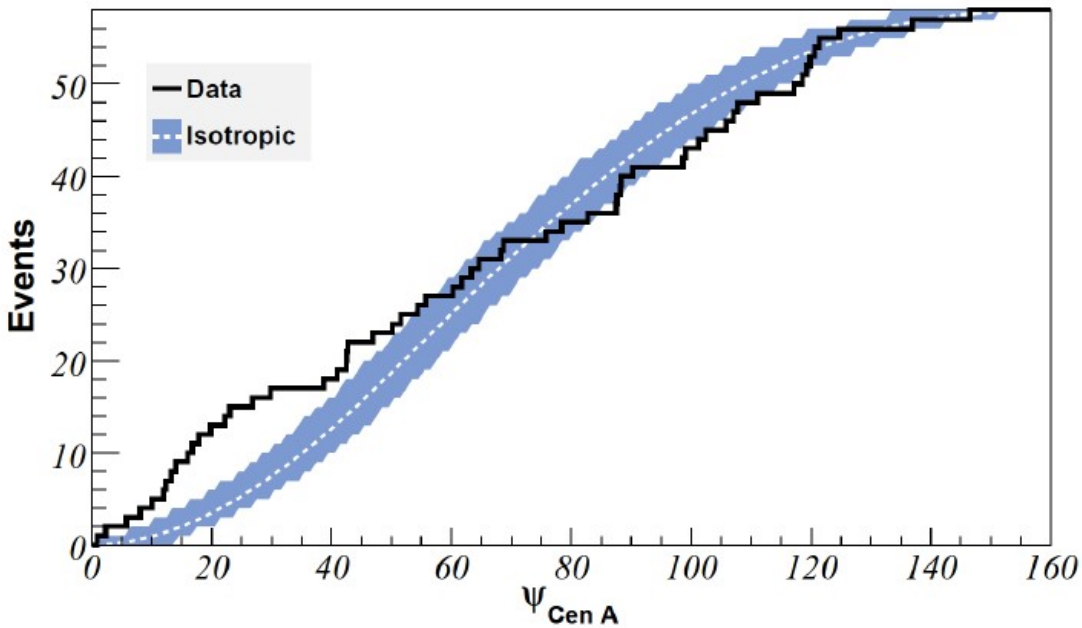
Anizotropie



„Míra korelace“ klesla z 70% na 40%, ale izotropie je stále vyloučena

Anizotropie – Centaurus A





- Velice nadějný kandidát
- Nejbližší AGN (4 Mpc)
- Zdroj fotonů do škály TeV
- AUGER: přebytek událostí – 12 událostí do 18°, 2,7 události očekáváno, pravděpodobnost 2%