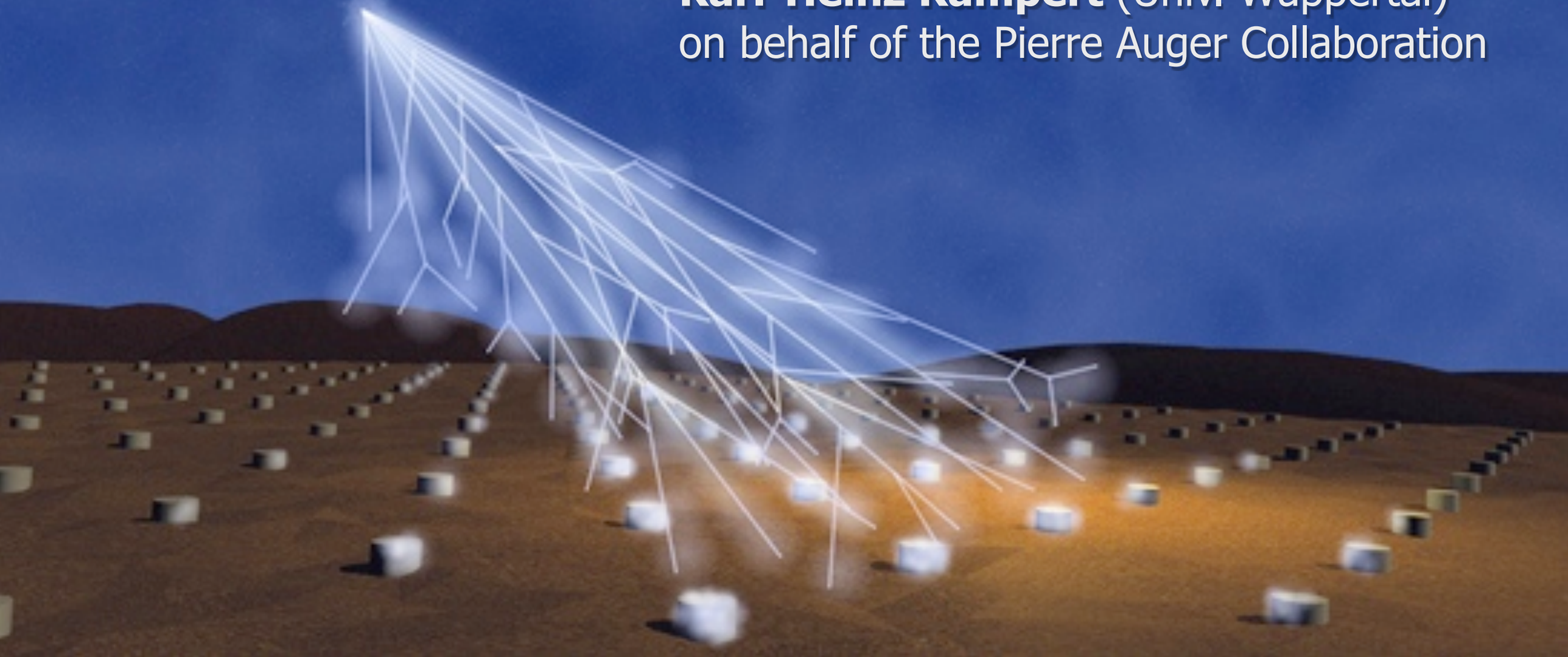
Workshop on Russian-German Perspectives, JINR
Dubna Dec. 8-9, 2011

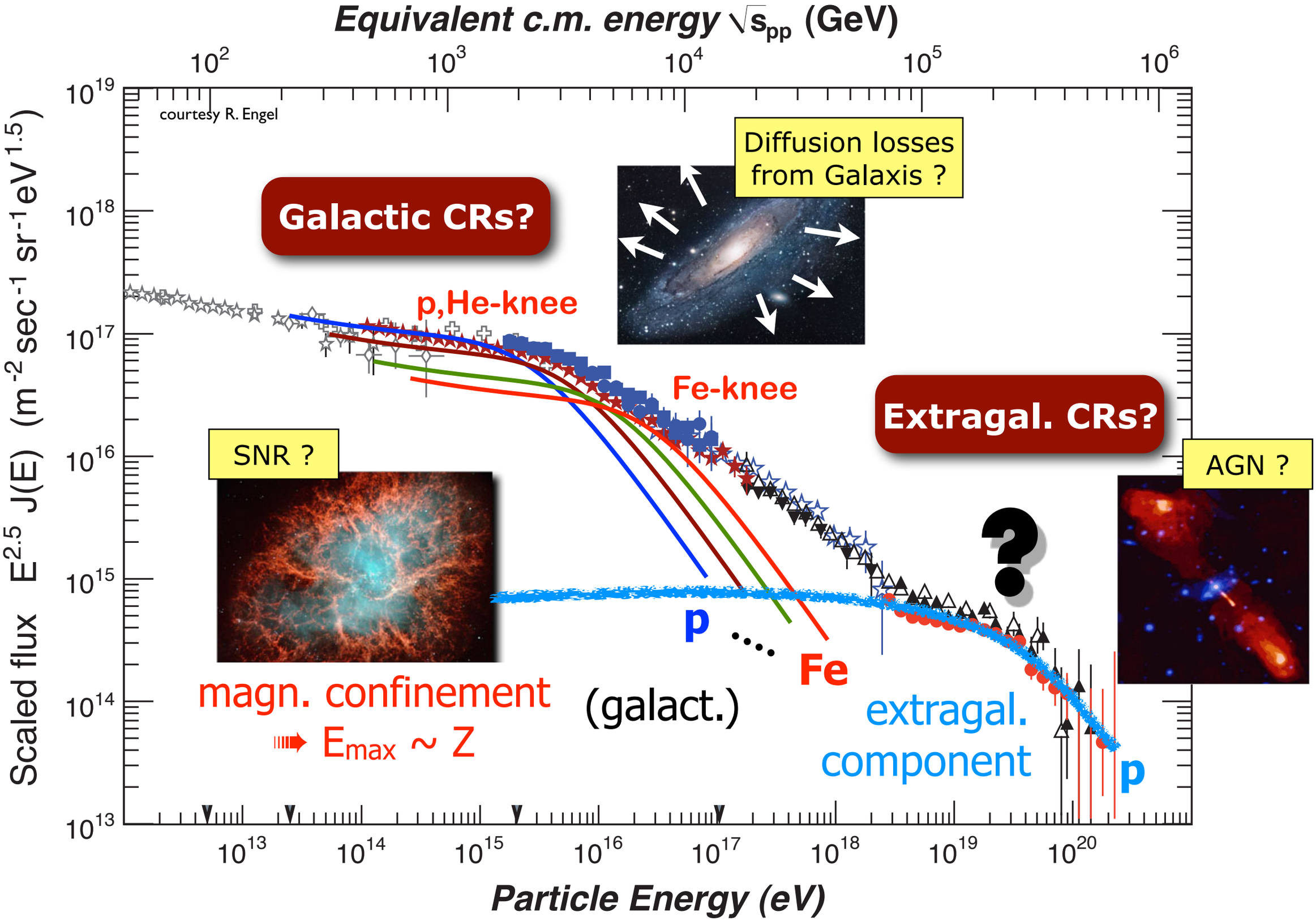
UHE Cosmic Rays: Recent Results from Auger and Future Plans

Karl-Heinz Kampert (Univ. Wuppertal)
on behalf of the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY



Origin of the highest energy CRs



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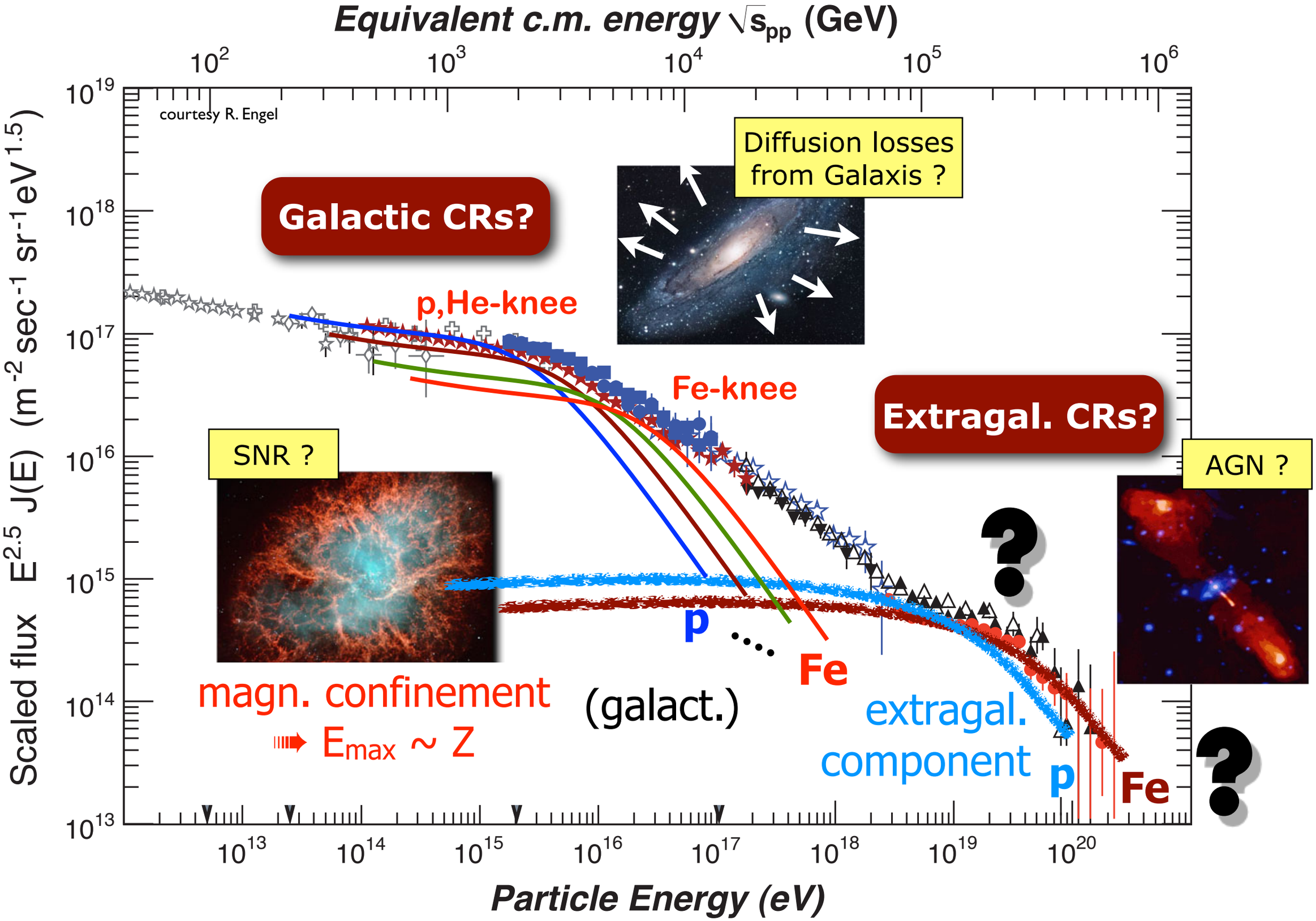
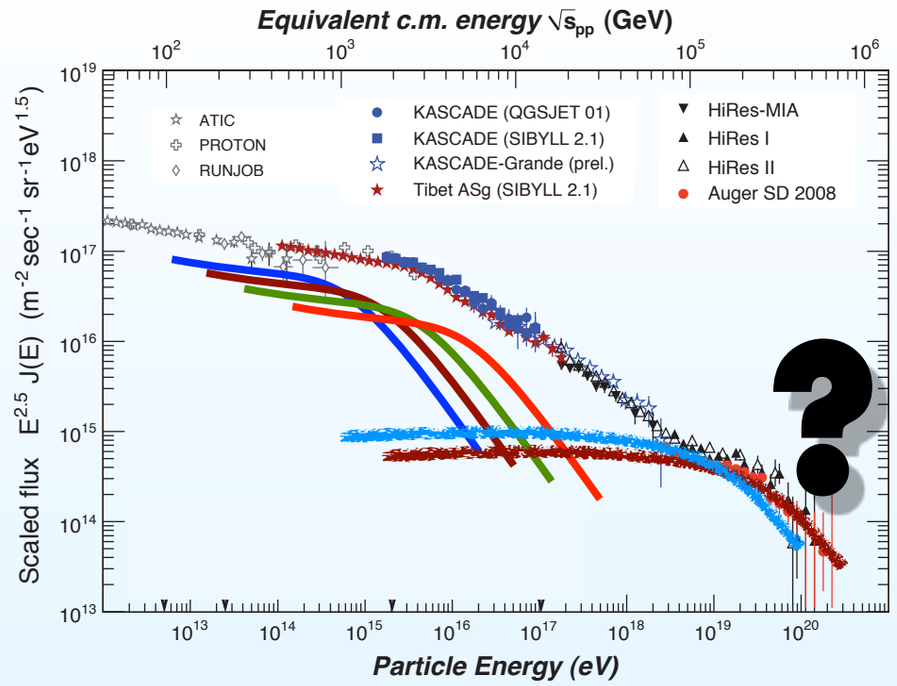


Driving Questions



- **Where do UHECRs come from?**
  - → **What is their composition in the cut-off region?**
  - → **Do we see the GZK or the limiting energy of sources ?**
  - → **Do we see large scale anisotropies or point sources ?**
  - → **How to understand the transition from galactic to EG CRs?**
- **Learn about (particle) physics at the highest energies**

Pierre Auger Observatory in Argentina

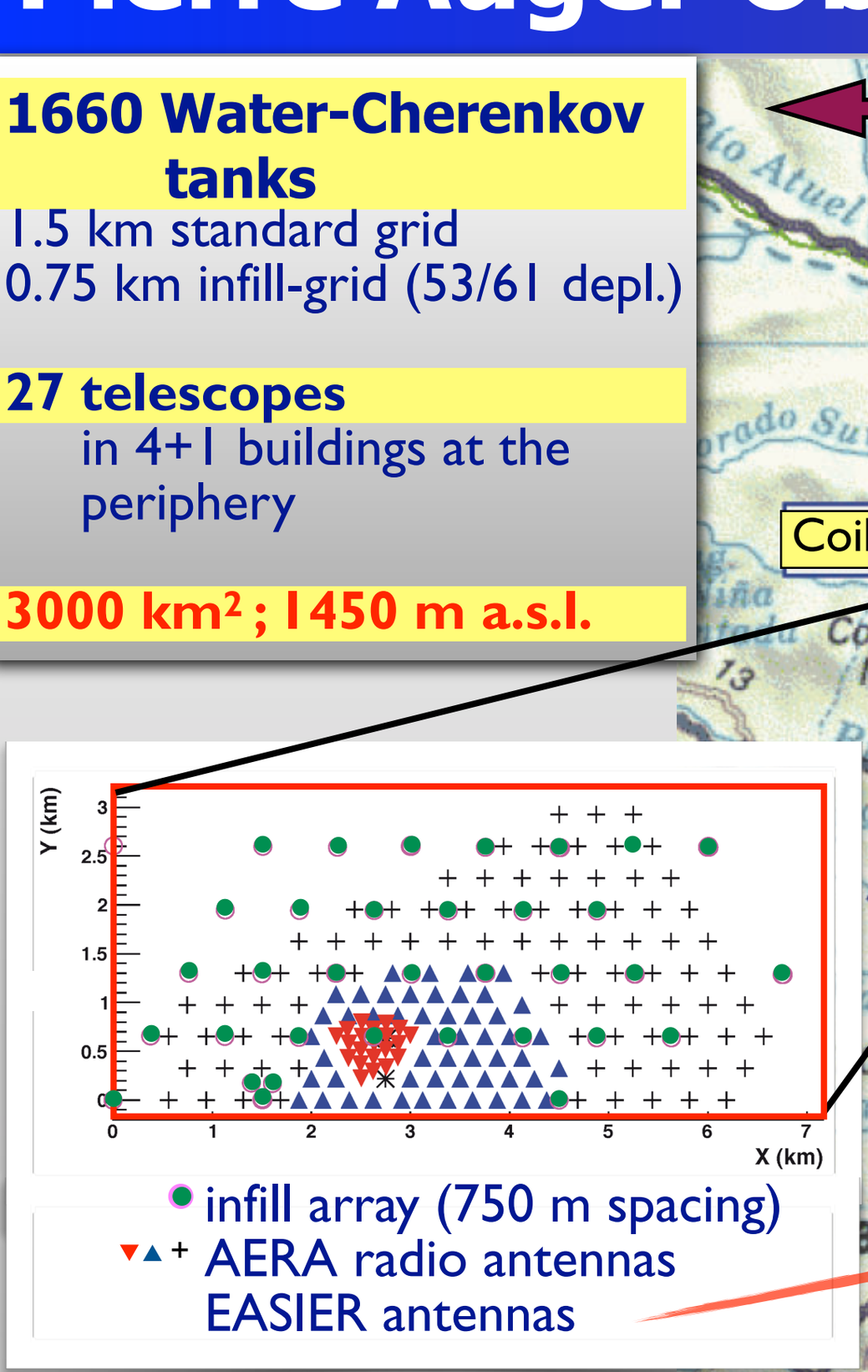
1660 Water-Cherenkov tanks

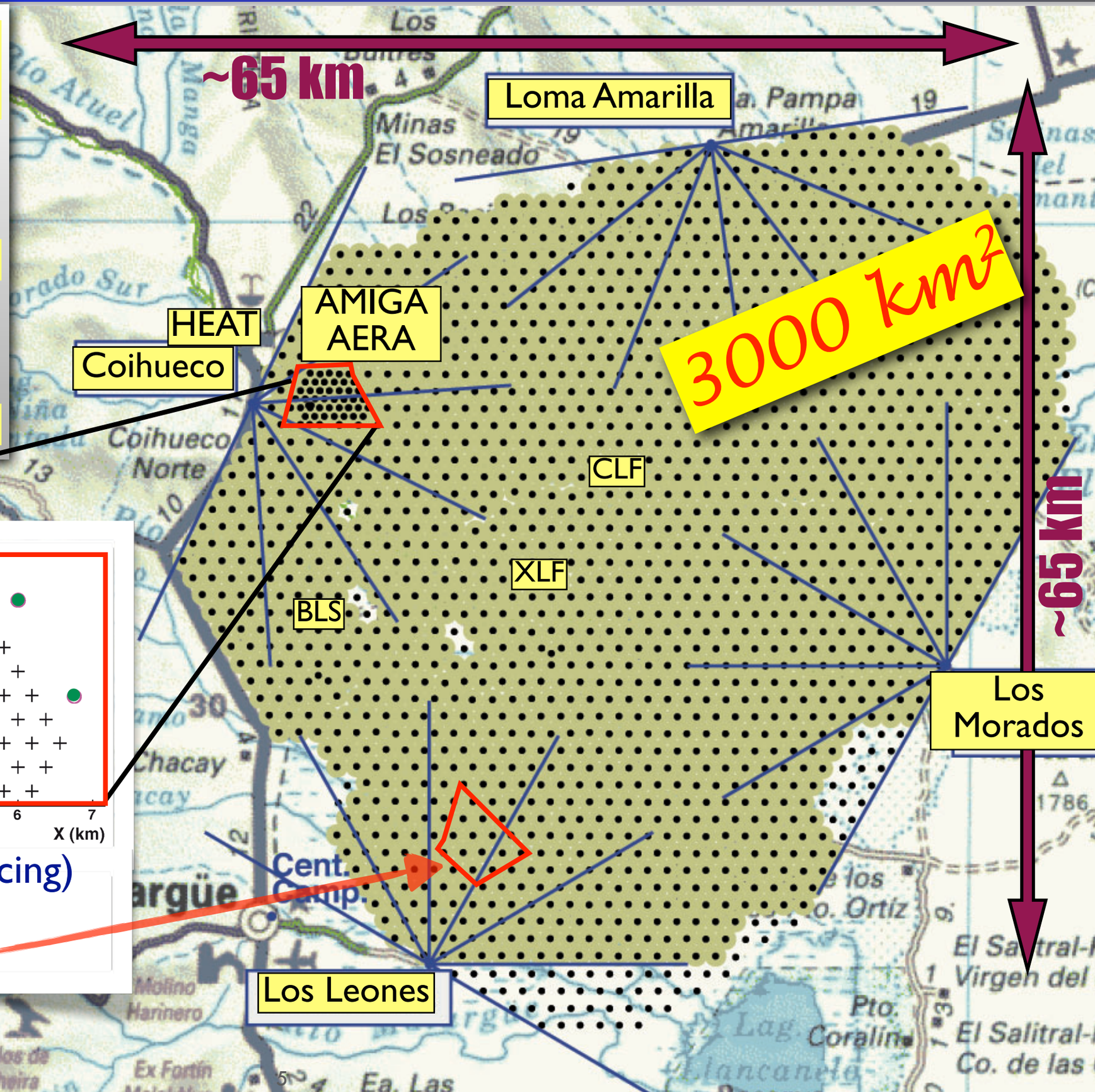
1.5 km standard grid
0.75 km infill-grid (53/61 depl.)

27 telescopes

in 4+1 buildings at the periphery

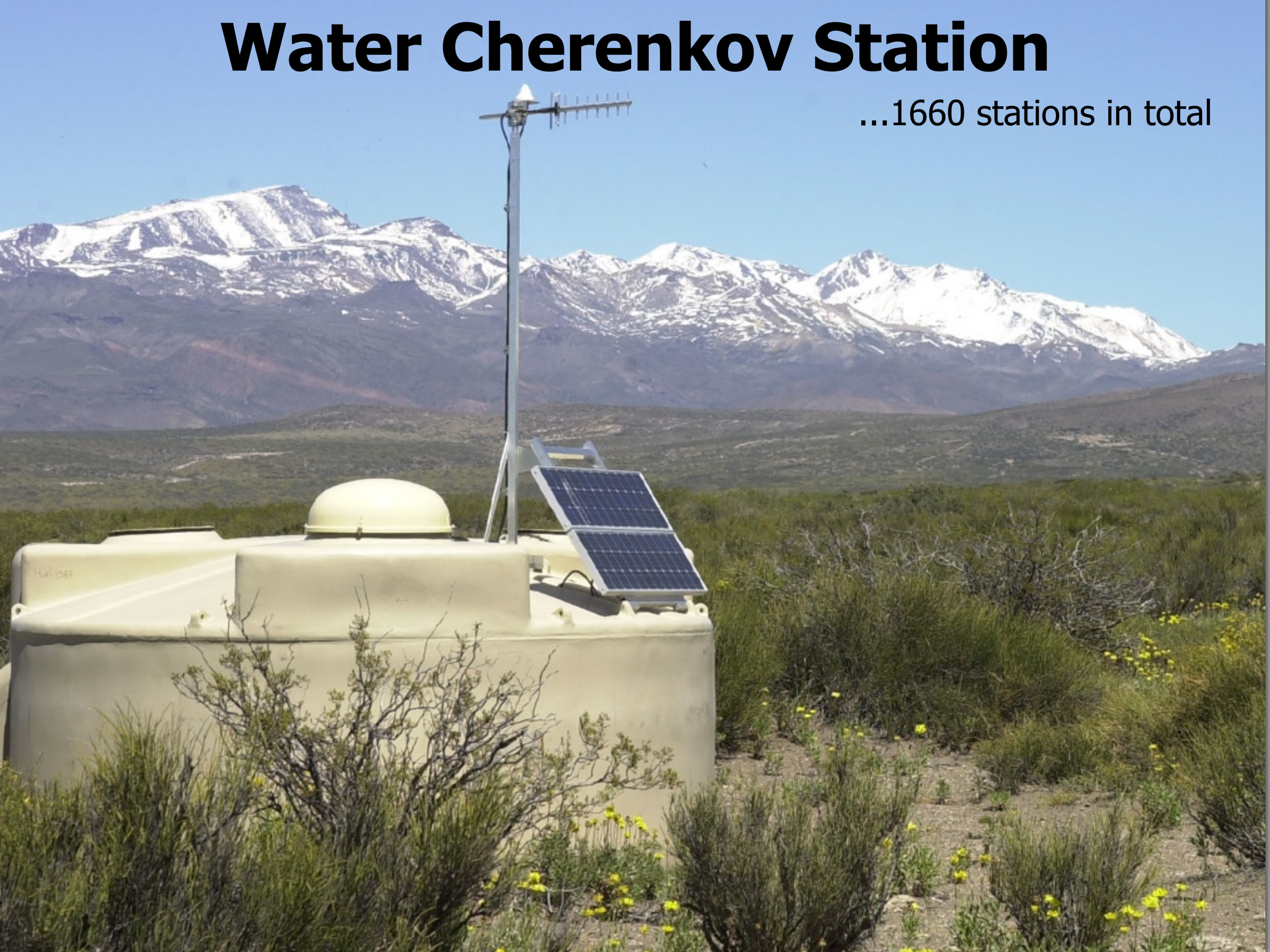
3000 km² ; 1450 m a.s.l.





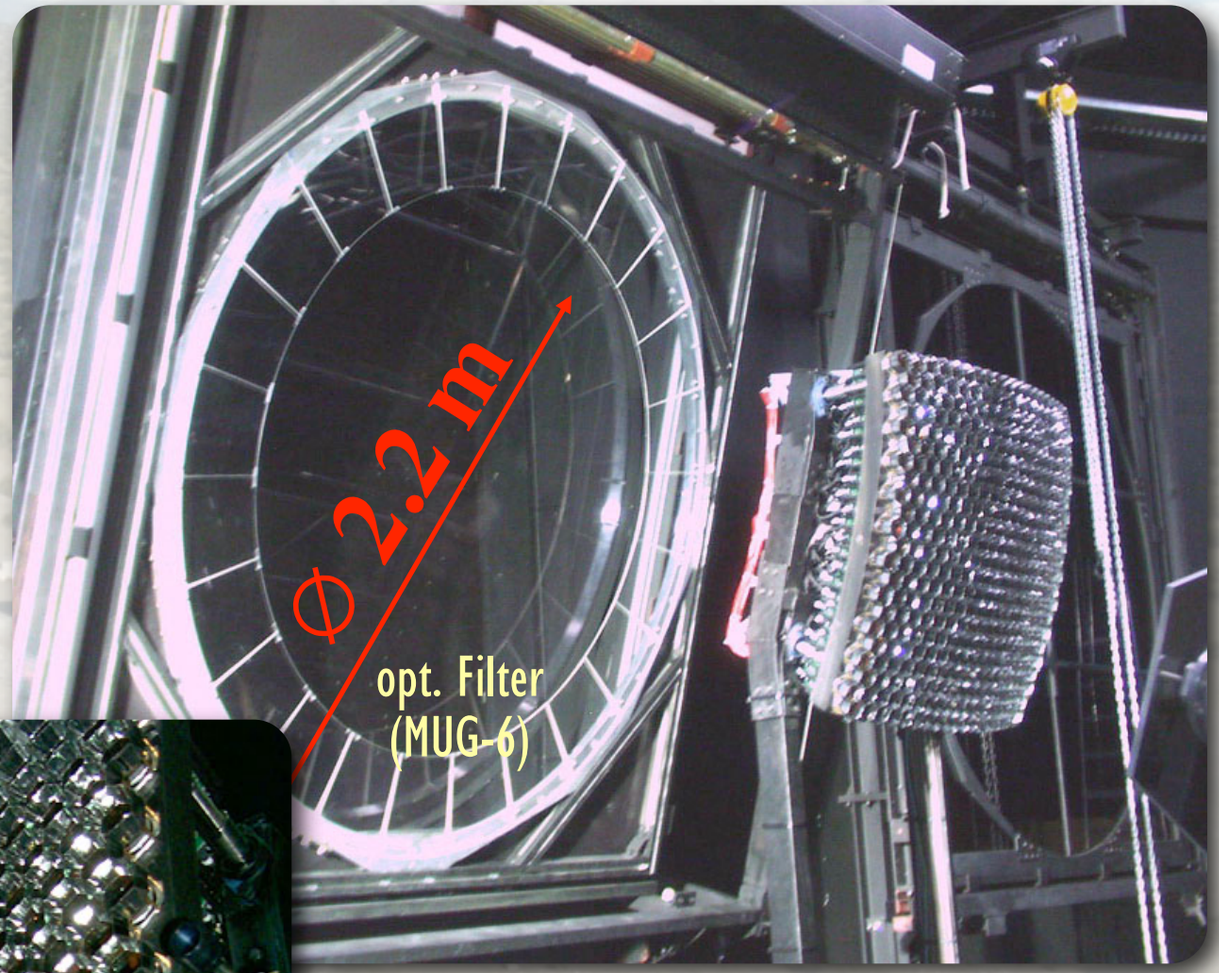
Water Cherenkov Station

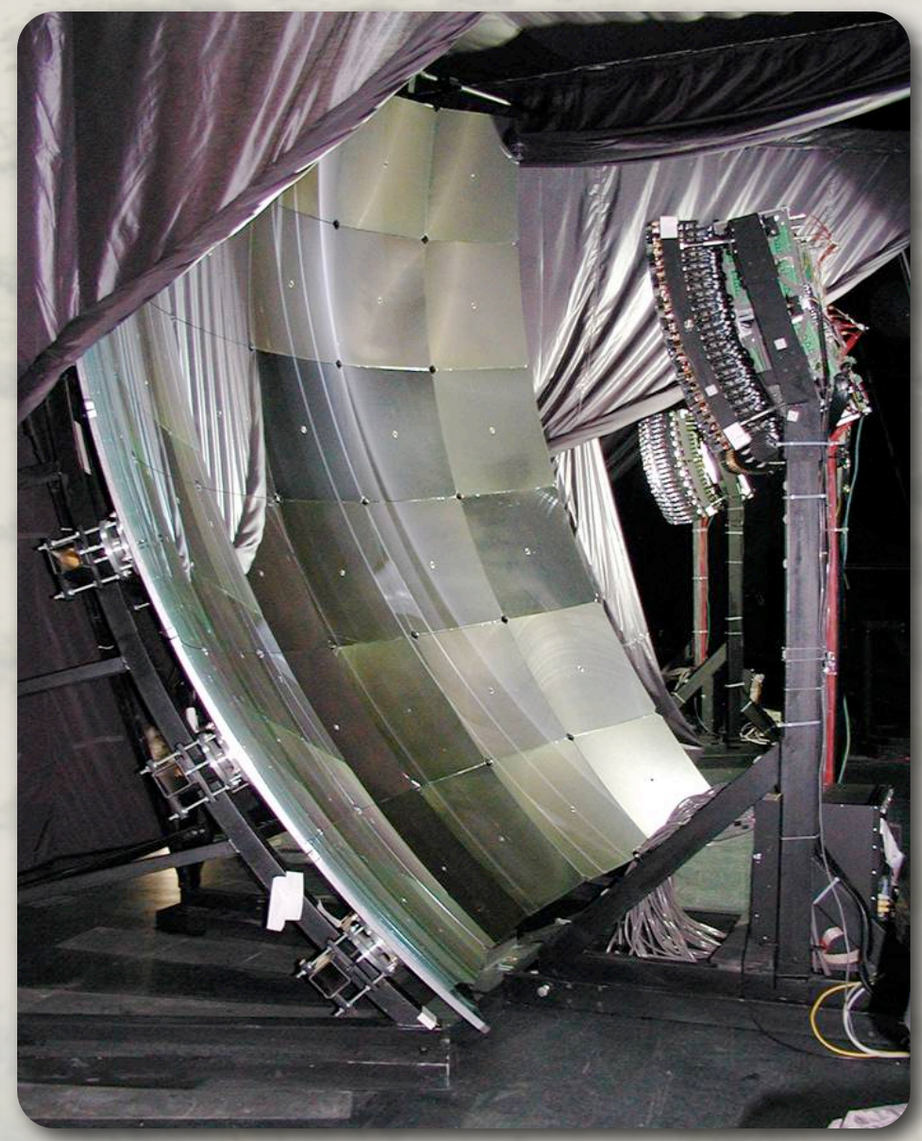
...1660 stations in total

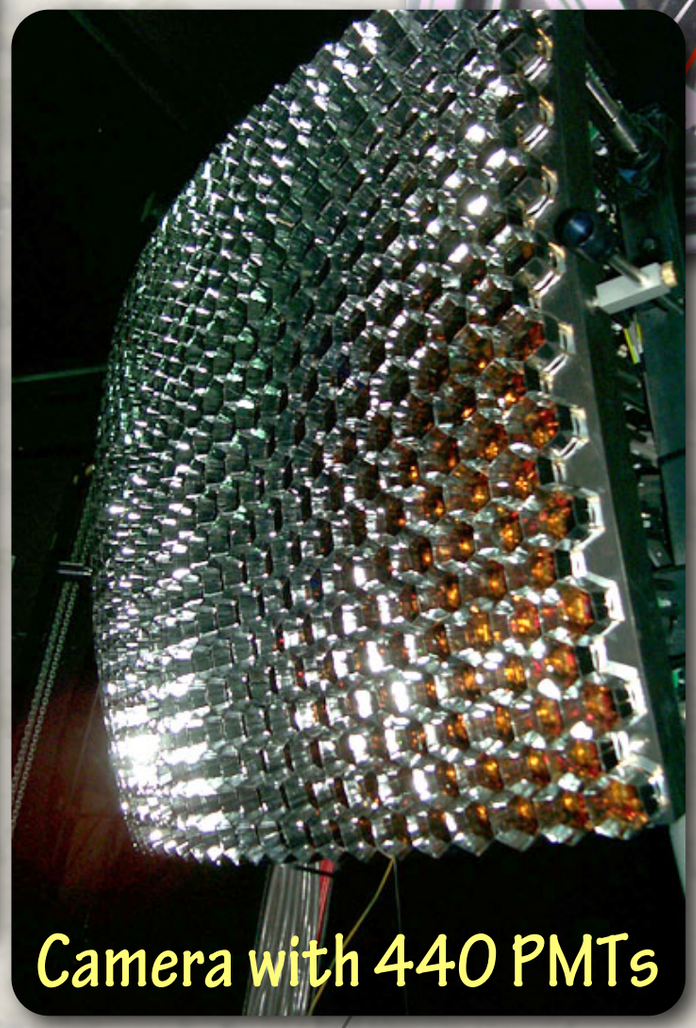


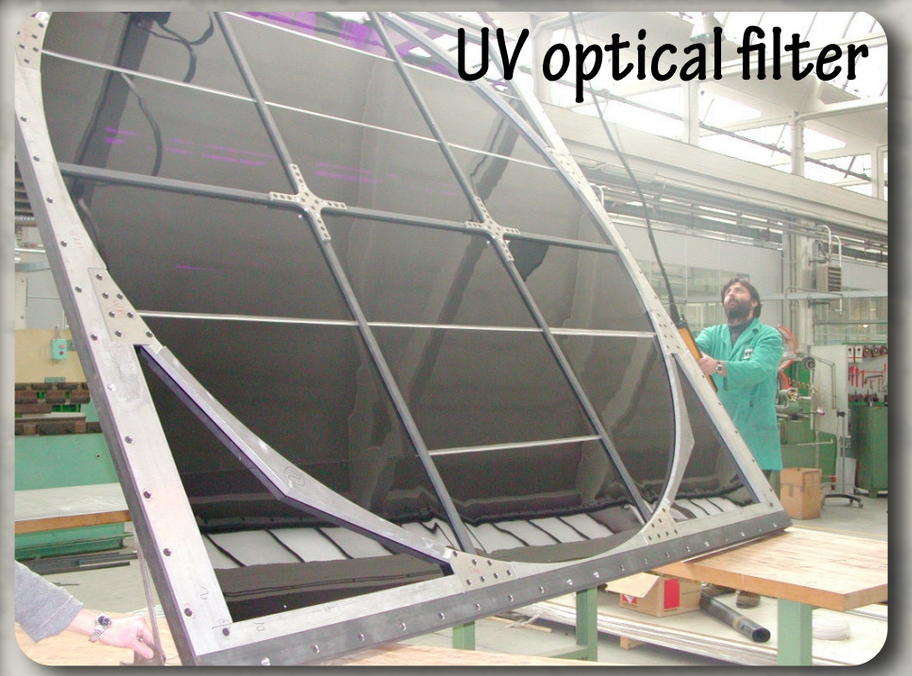
Fluorescence Telescope

24+3 telescopes (6(9) per site)
12 m² mirrors, Schmidt optics
30°x30° deg field of view
440 PMTs/camera (12000 PMTs)
10 MHz FADC readout









Strong R&D Program

Pierre Auger Collaboration

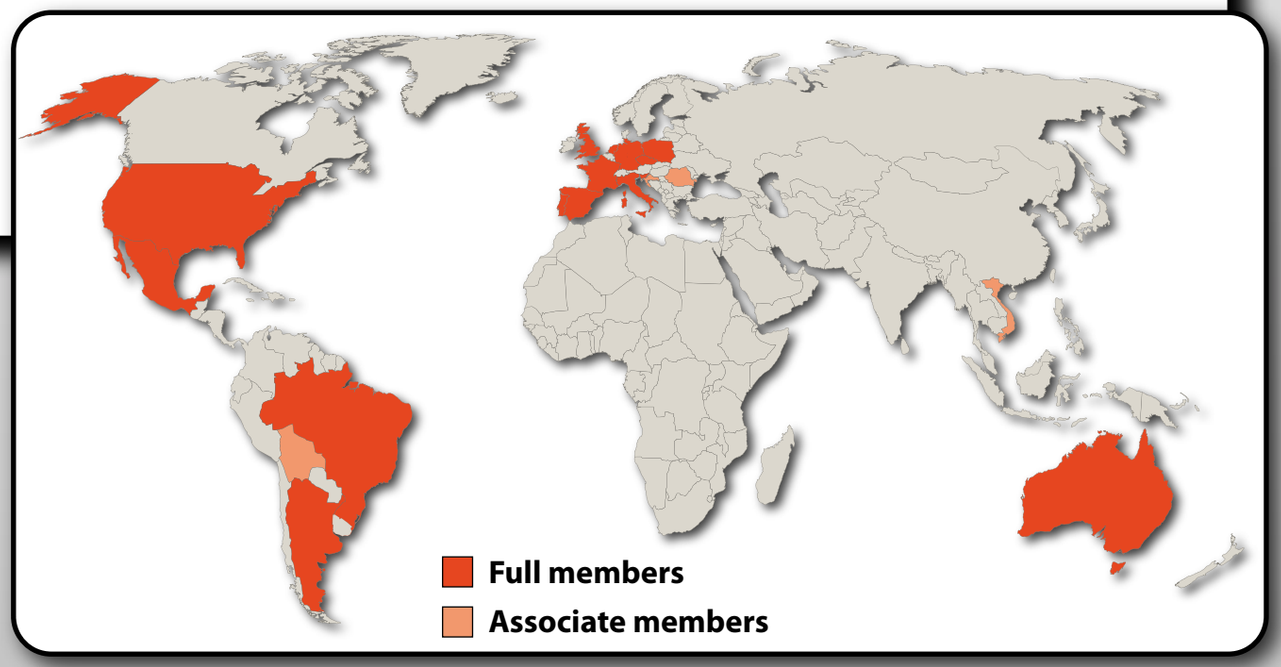
~490 collaboration members in 19 countries:

Argentina
Australia
Brasil
Croatia
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA

Bolivia*
Romania*
Vietnam*

*Associated

PIERRE AUGER OBSERVATORY



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~490 collaboration members in 19 countries:

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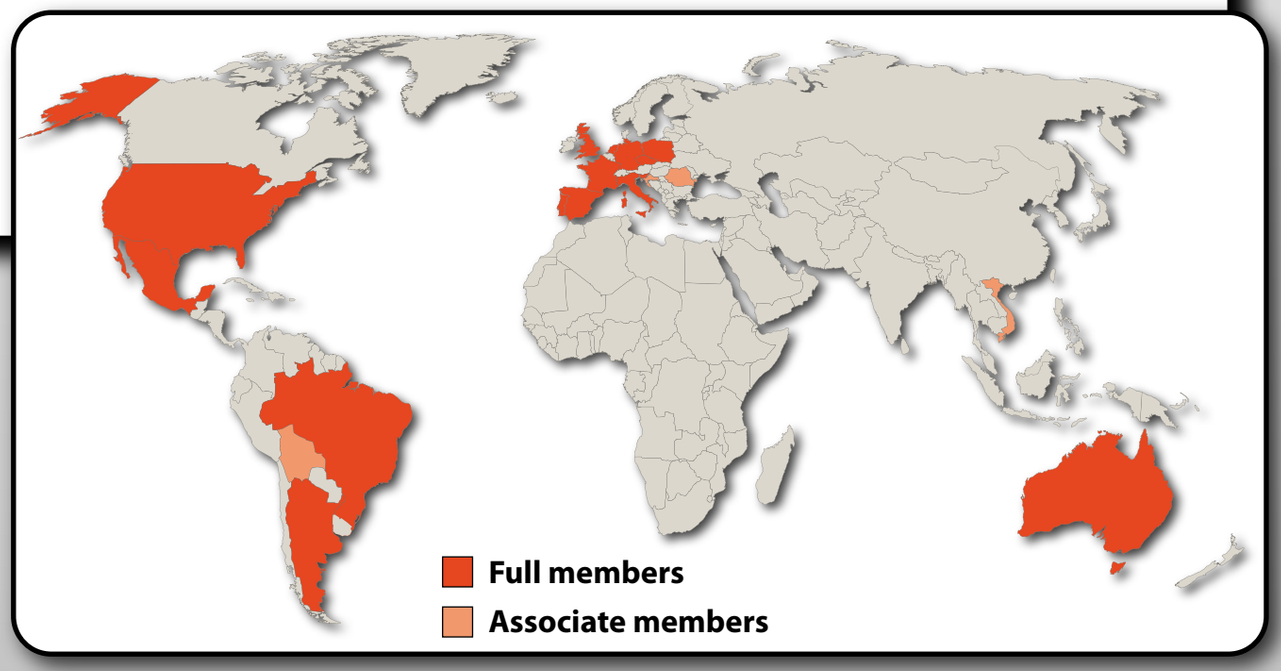
Czech Republic
France
Germany
- Aachen
- Karlsruhe (3)
- Hamburg
- Siegen
- Wuppertal

Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA

Bolivia*
Romania*
Vietnam*
*Associated

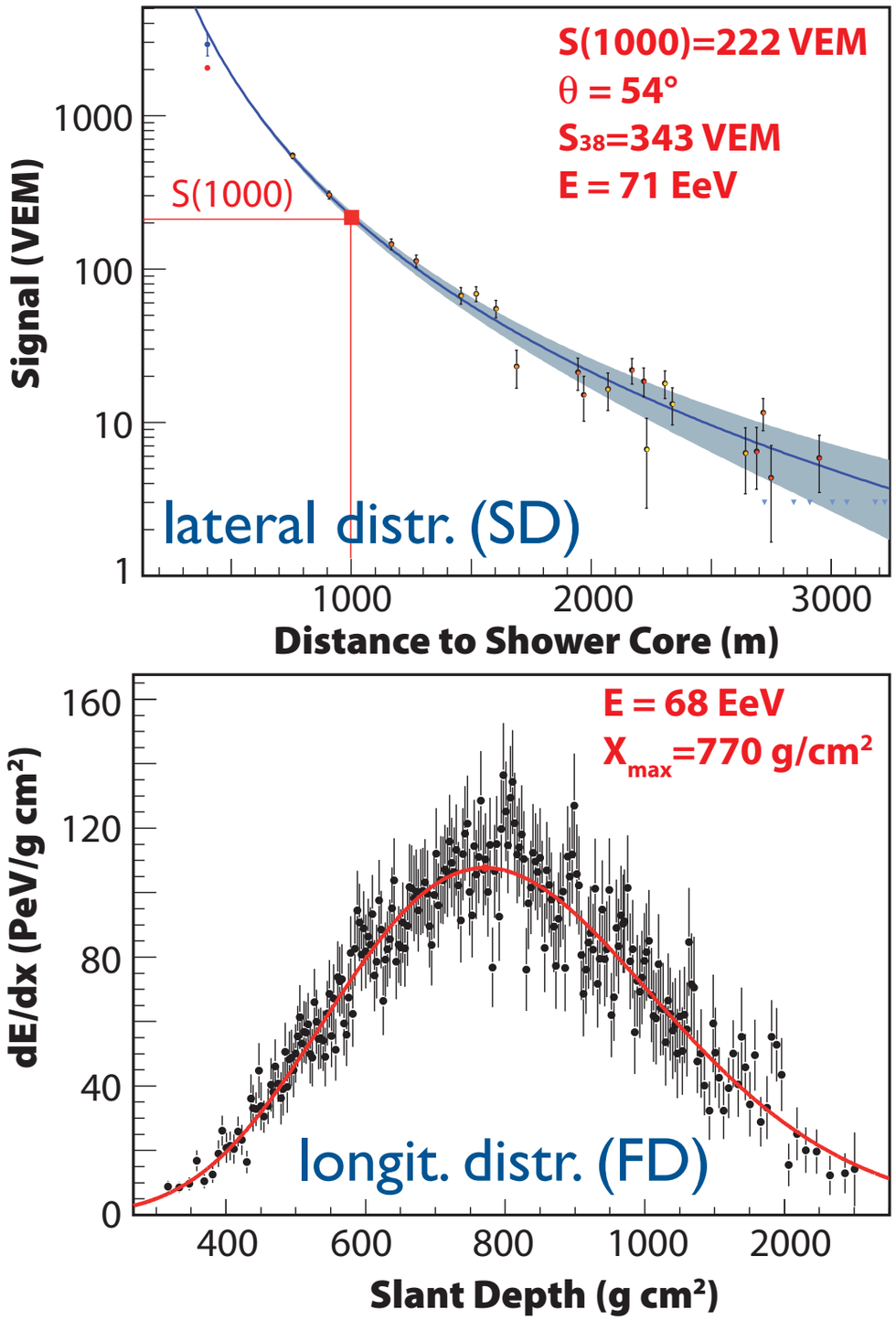
PIERRE AUGER OBSERVATORY

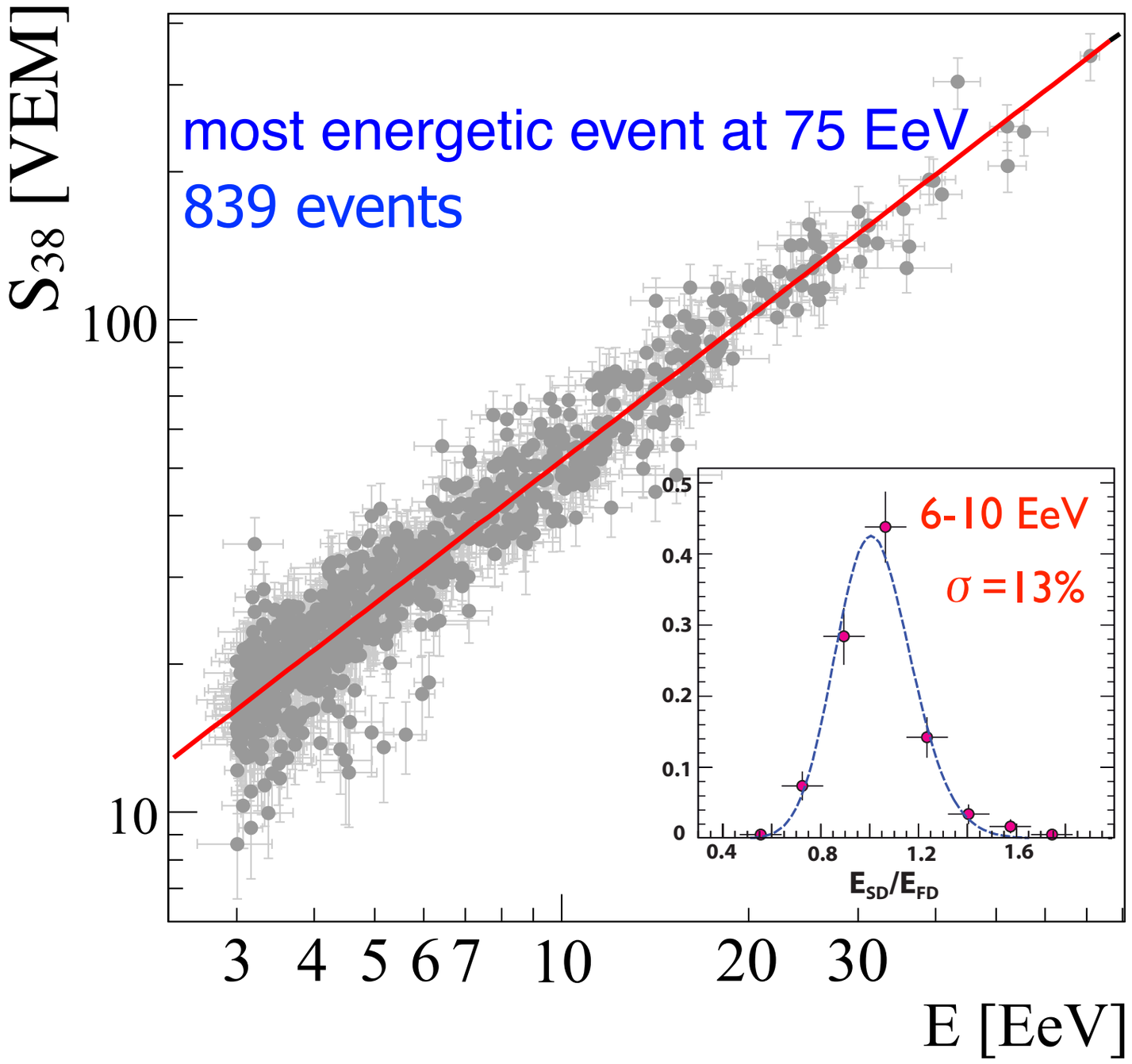
Russia contributed intellectually in the early days but could not sign international agreement



Energy Spectrum p-Air, pp X-sections Interaction Models

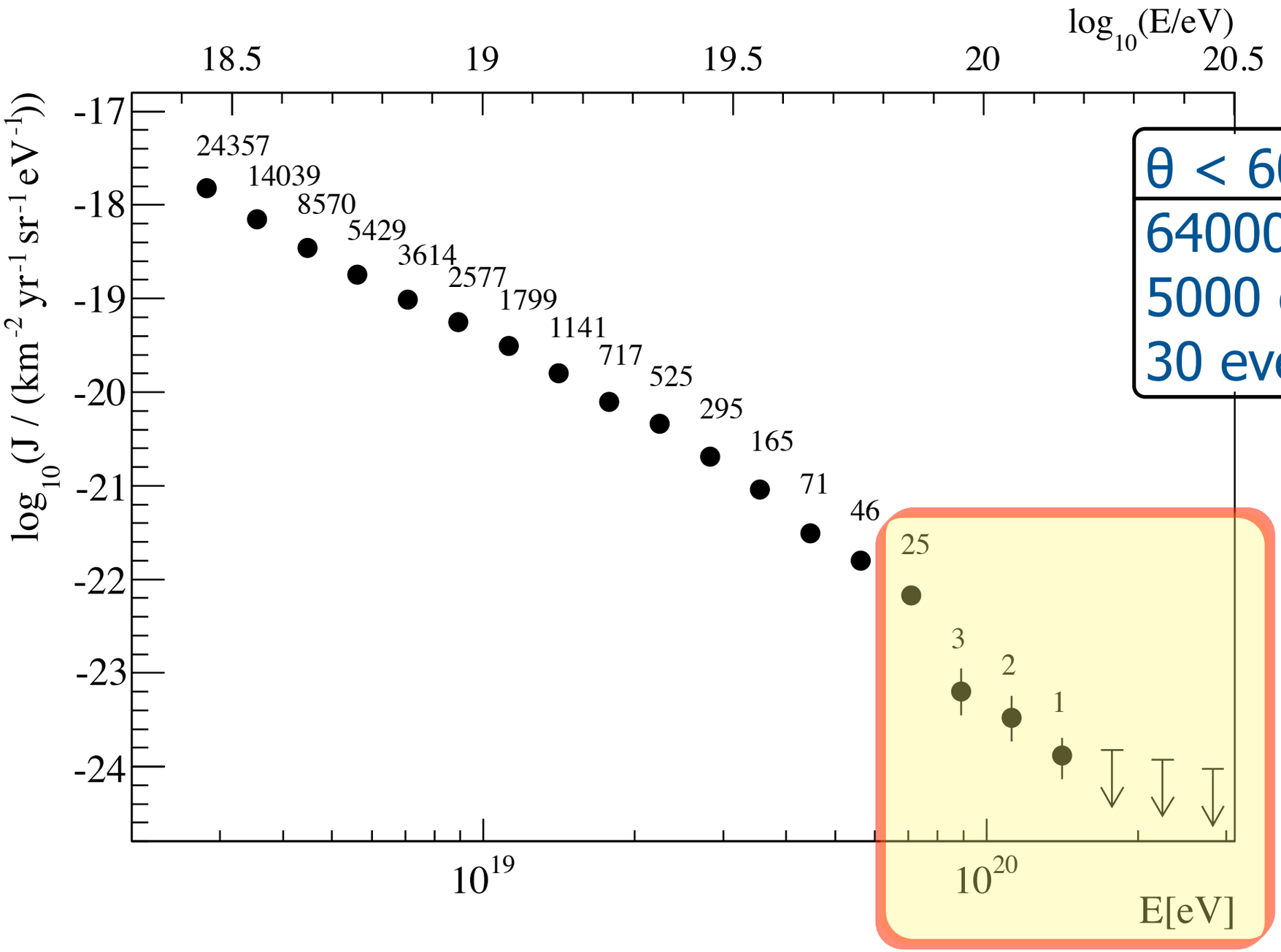
SD Energy Calibration by FD





Systematic uncertainty 7% (15%) at 10 EeV (100 EeV)
Total uncertainty of E-scale: 22% (dominated by Fl.-yield. 14%)

Surface Detector Spectrum (calibrated by FD)



θ < 60°

64000 events > 3 EeV

5000 events > 10 EeV

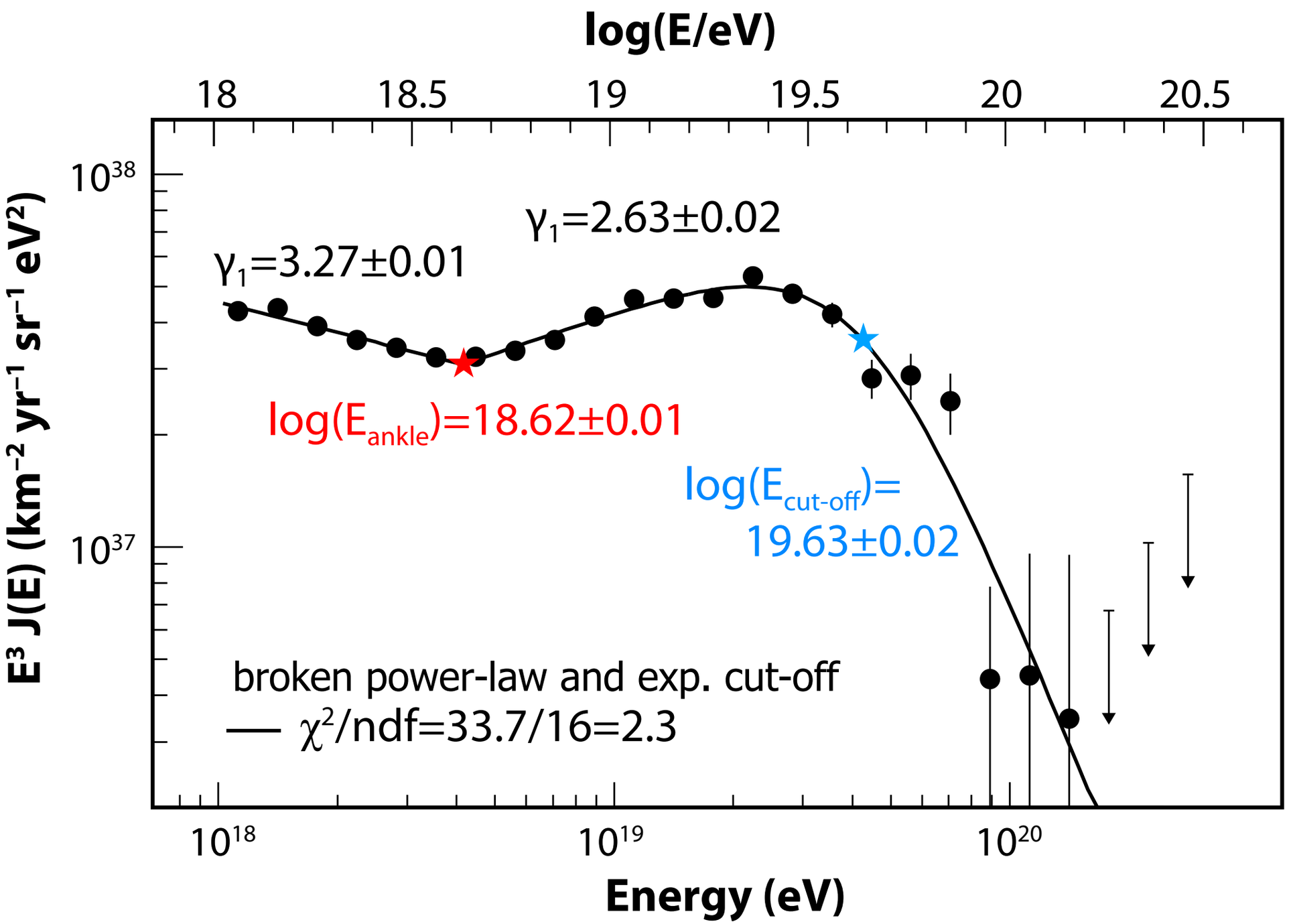
30 events > 60 EeV

data in GZK domain still scarce

Not corrected for energy resolution

Uncertainty in exposure < 3%

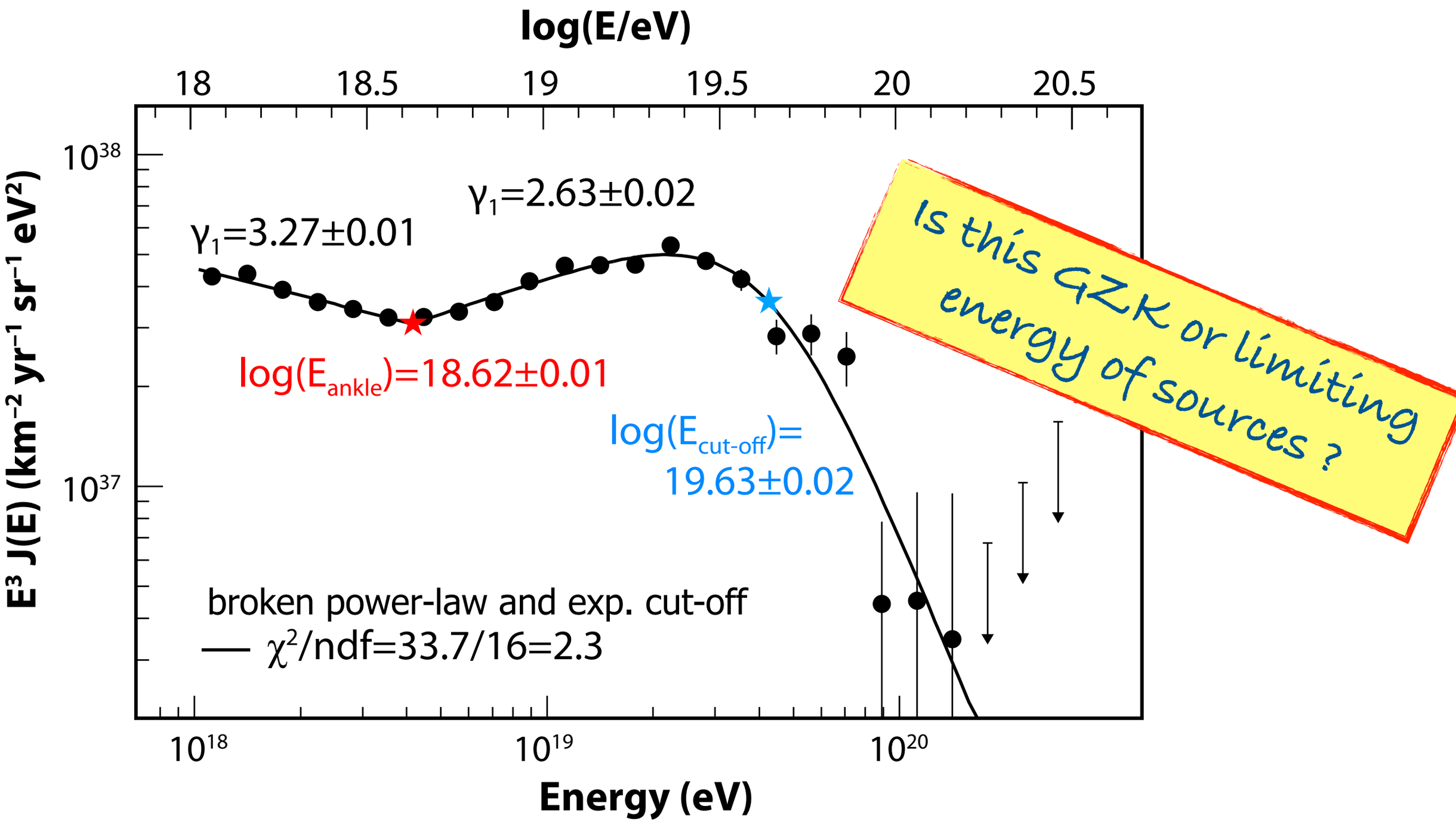
SD+Hybrid Combined Spectrum



Exposure = 20905 km² sr yr (60% increase over PLB 685 (2010) 239)

Inclined showers add another 5300 km² sr yr

SD+Hybrid Combined Spectrum

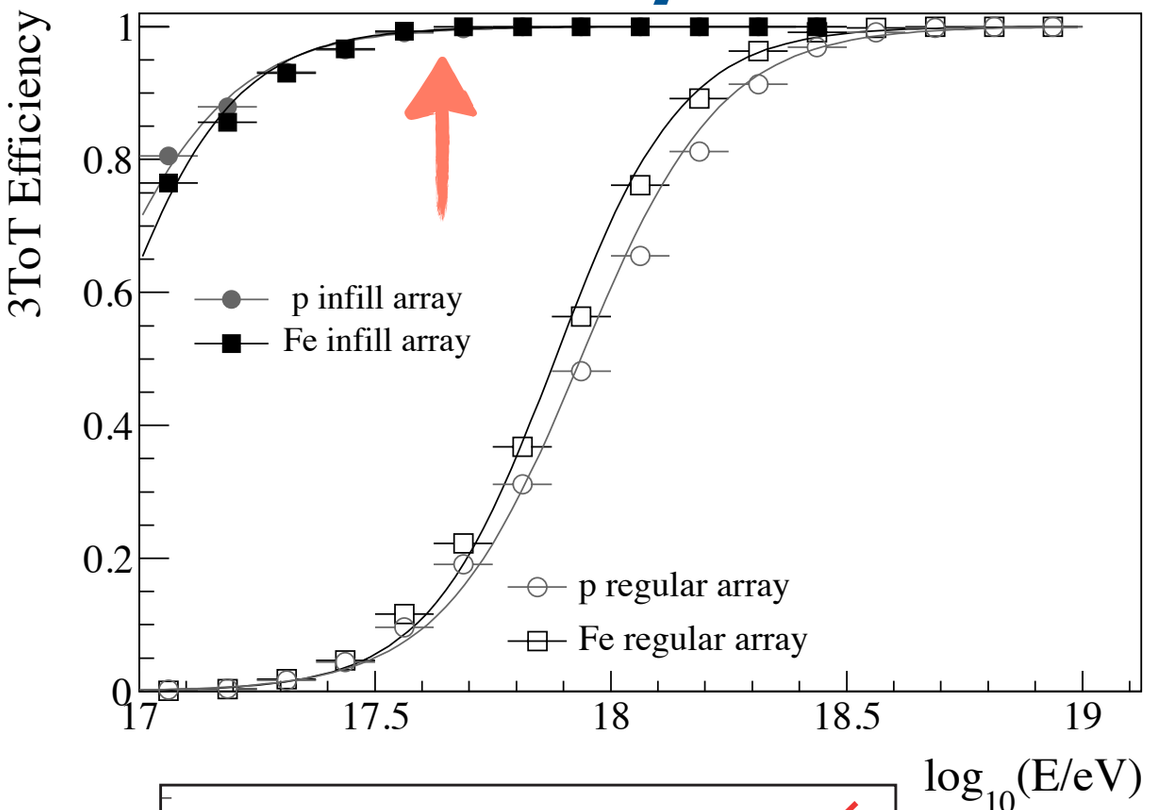


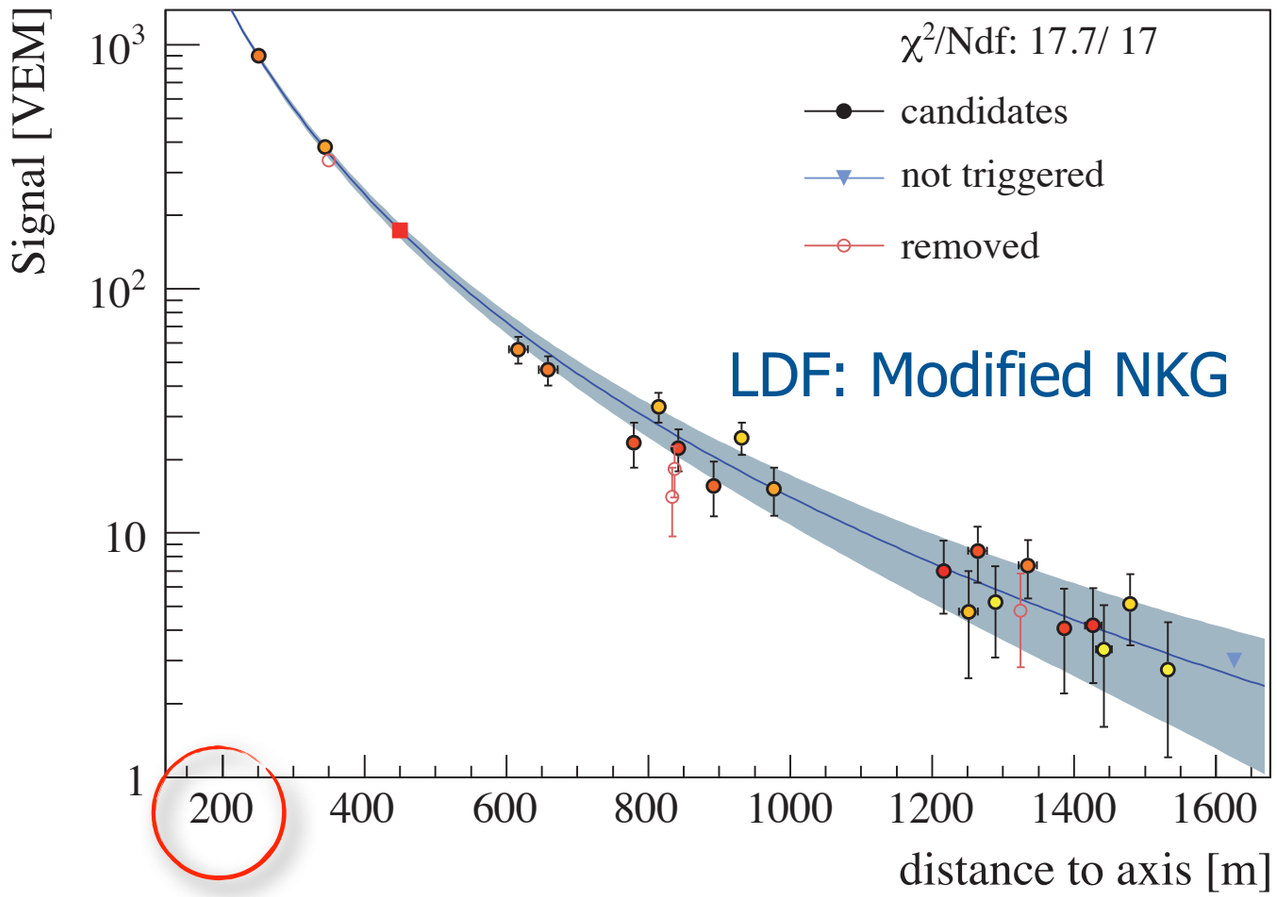
Exposure = 20905 km² sr yr (60% increase over PLB 685 (2010) 239)

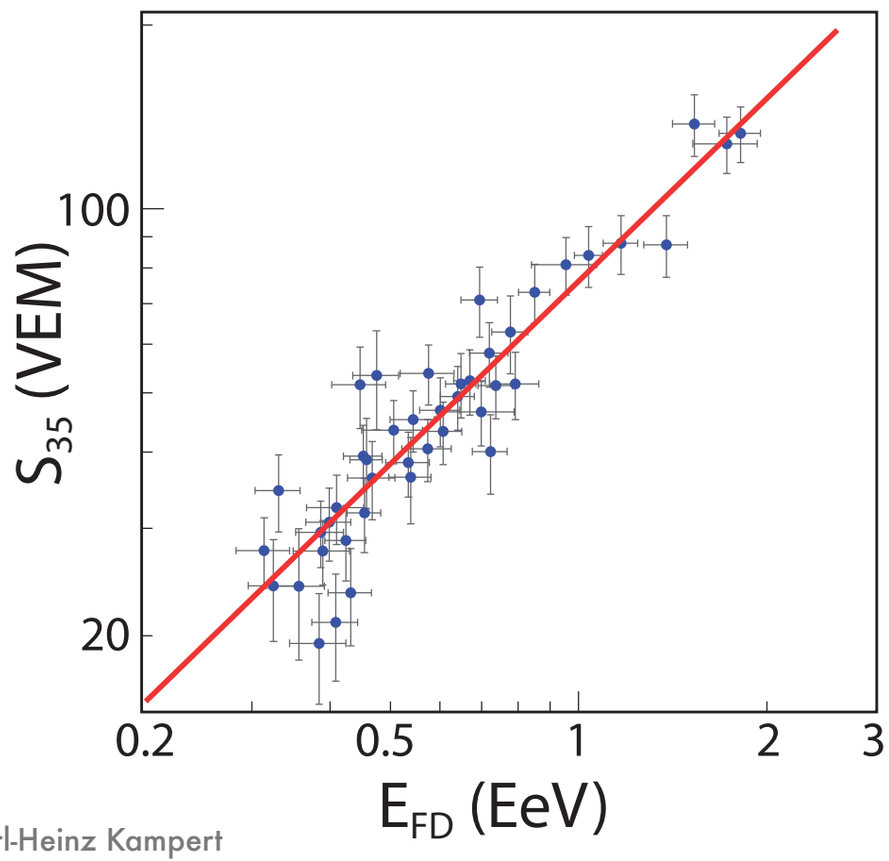
Inclined showers add another 5300 km² sr yr

Towards Lower Energies with Infill-Array

750 m infill: **fully efficient at $3 \cdot 10^{17}$ eV and θ<55°**



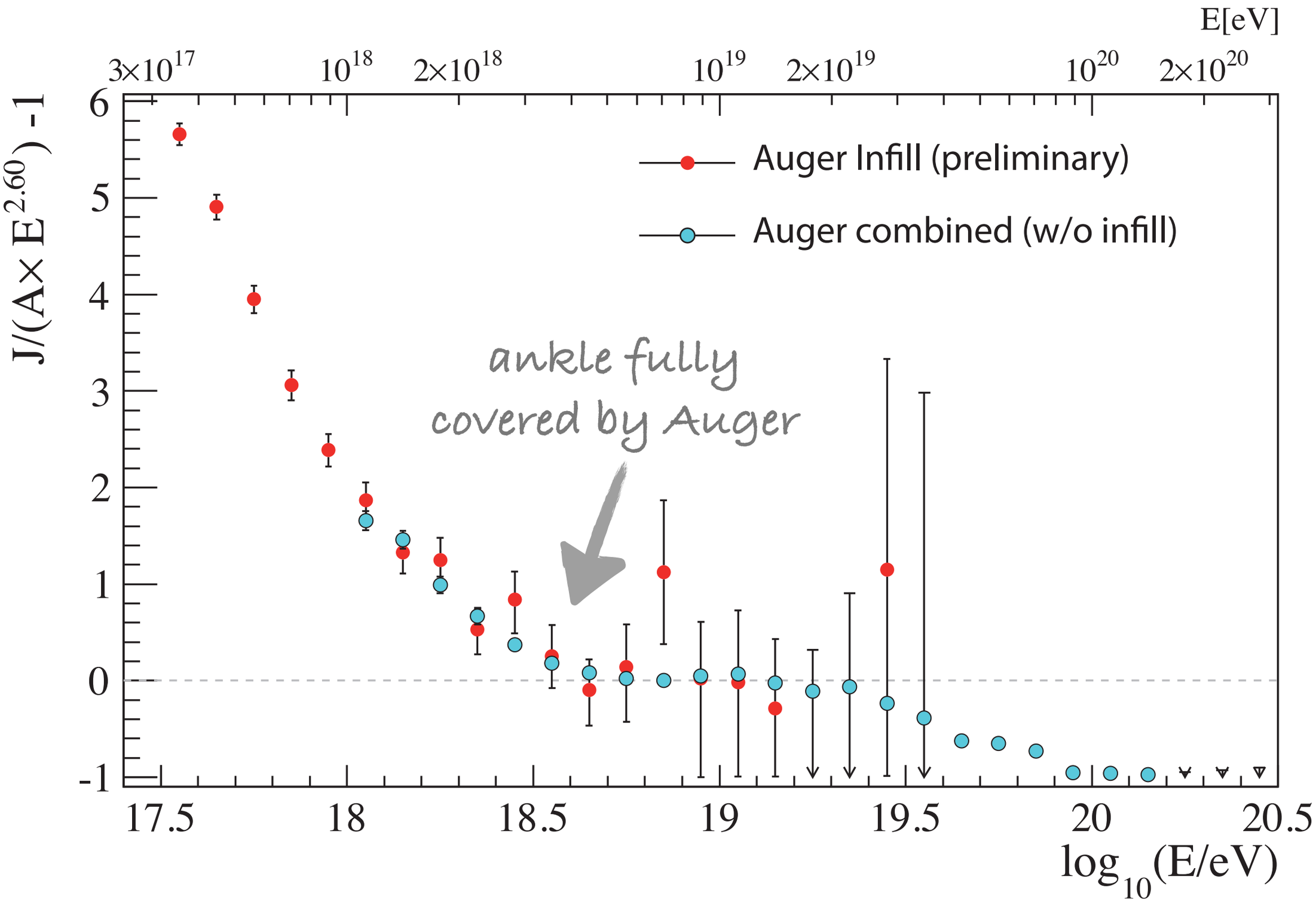




Energy calibration again with FD

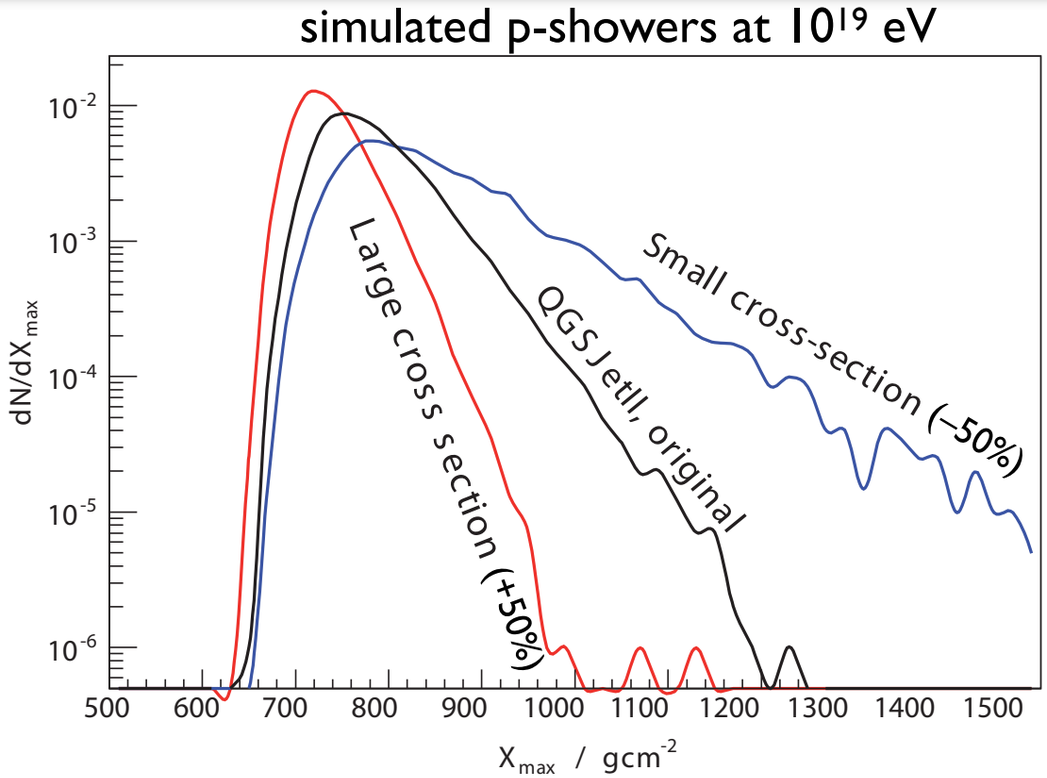
- event selection to assure an unbiased energy calibration
- strong quality cuts and fiducial field of view cuts
- 44 events with 0.3 EeV < E_{FD} < 2 EeV

Preliminary Infill Energy Spectrum



Exposure of infill array: (26.4±1.3) km² sr yr

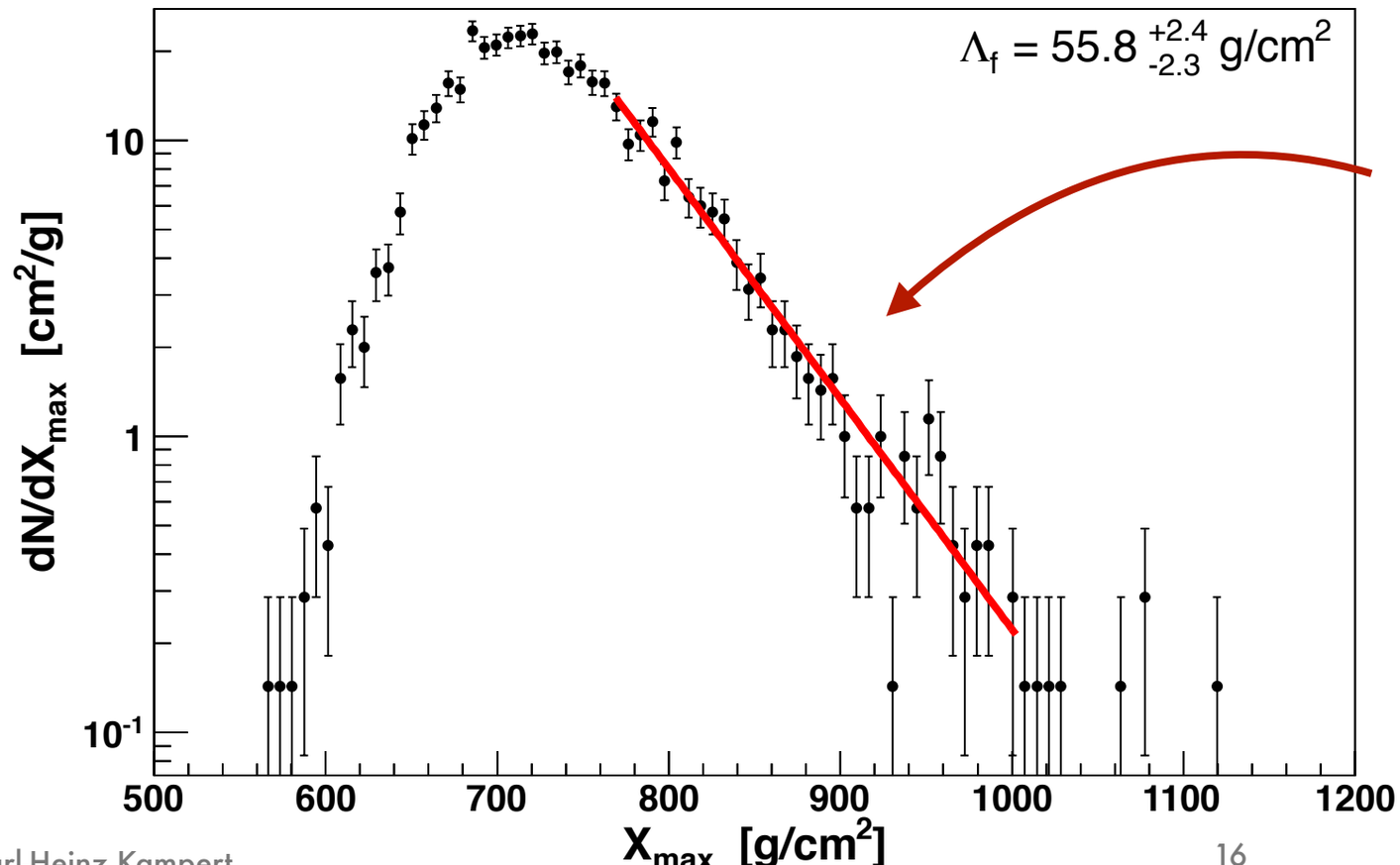
p-Air & pp Cross-Section at √57 TeV



Tail of X_{max} distribution

⇕

Inelastic cross-section



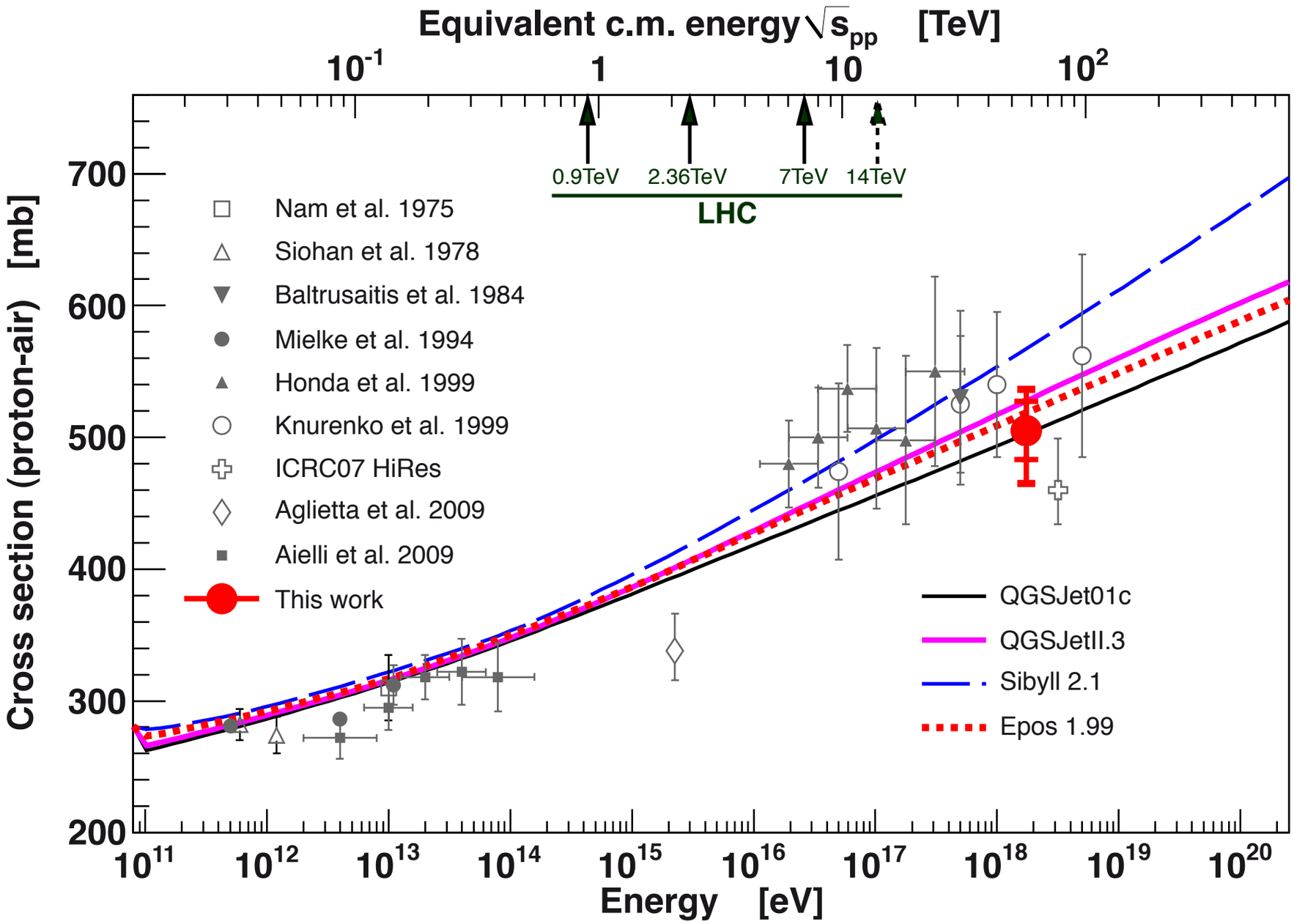
10^{18} eV < E < $10^{18.5}$ eV

tail dominated by protons

$$dN/dX_{max} \propto \exp\left(-X_{max}/\Lambda_{\eta}\right)$$

$\Lambda \rightarrow \sigma_{p\text{-}Air}$
by tuning models to
describe tail seen in data

p-Air Cross-Section

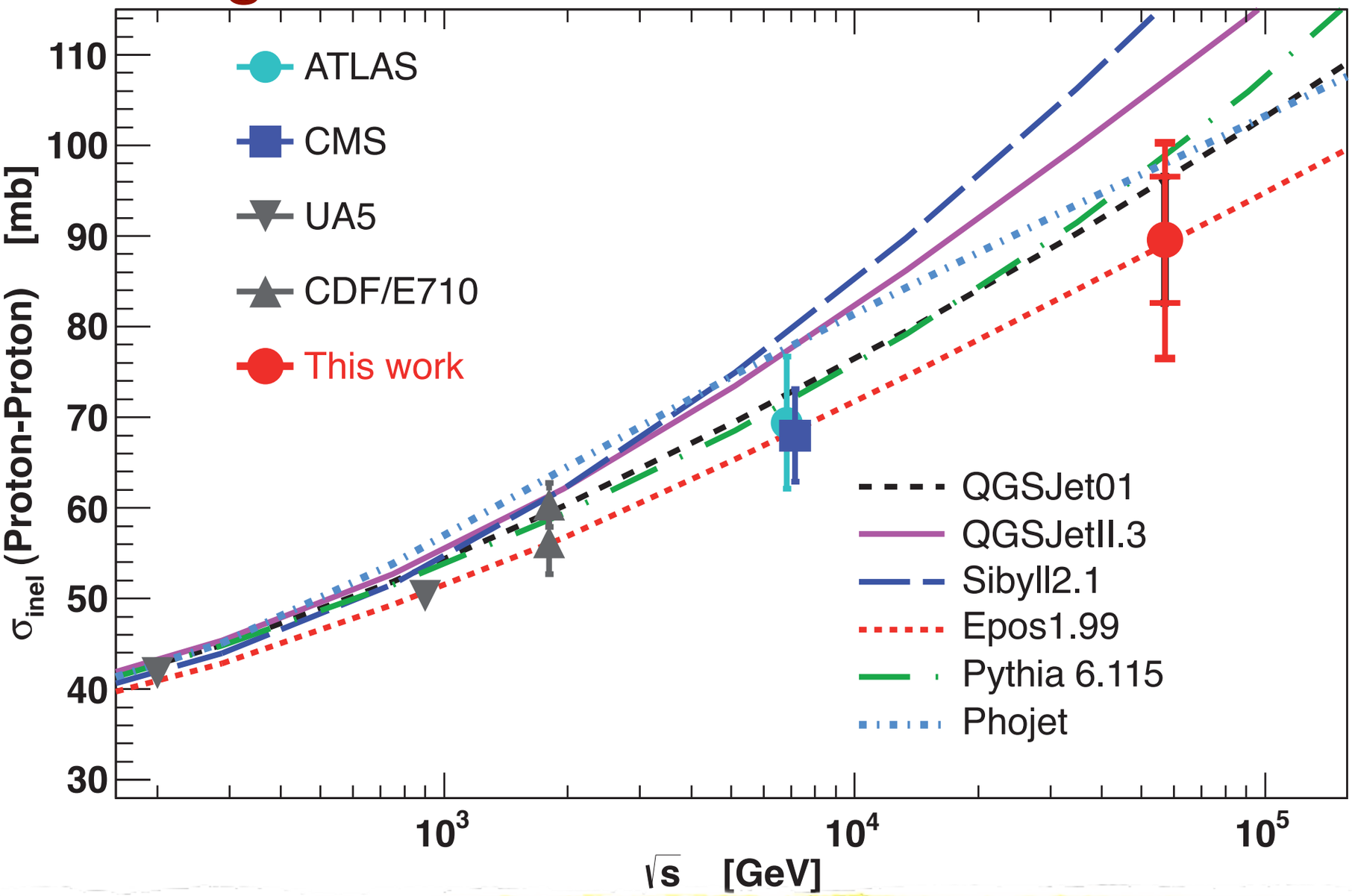


$$\sigma_{p\text{-}Air} = (505 \pm 22_{stat} \, (^{+26}_{-34})_{sys}) \text{ mb}$$

systematic uncertainties assume <0.5% photons and <25% He

p-p Cross-Section at √57 TeV

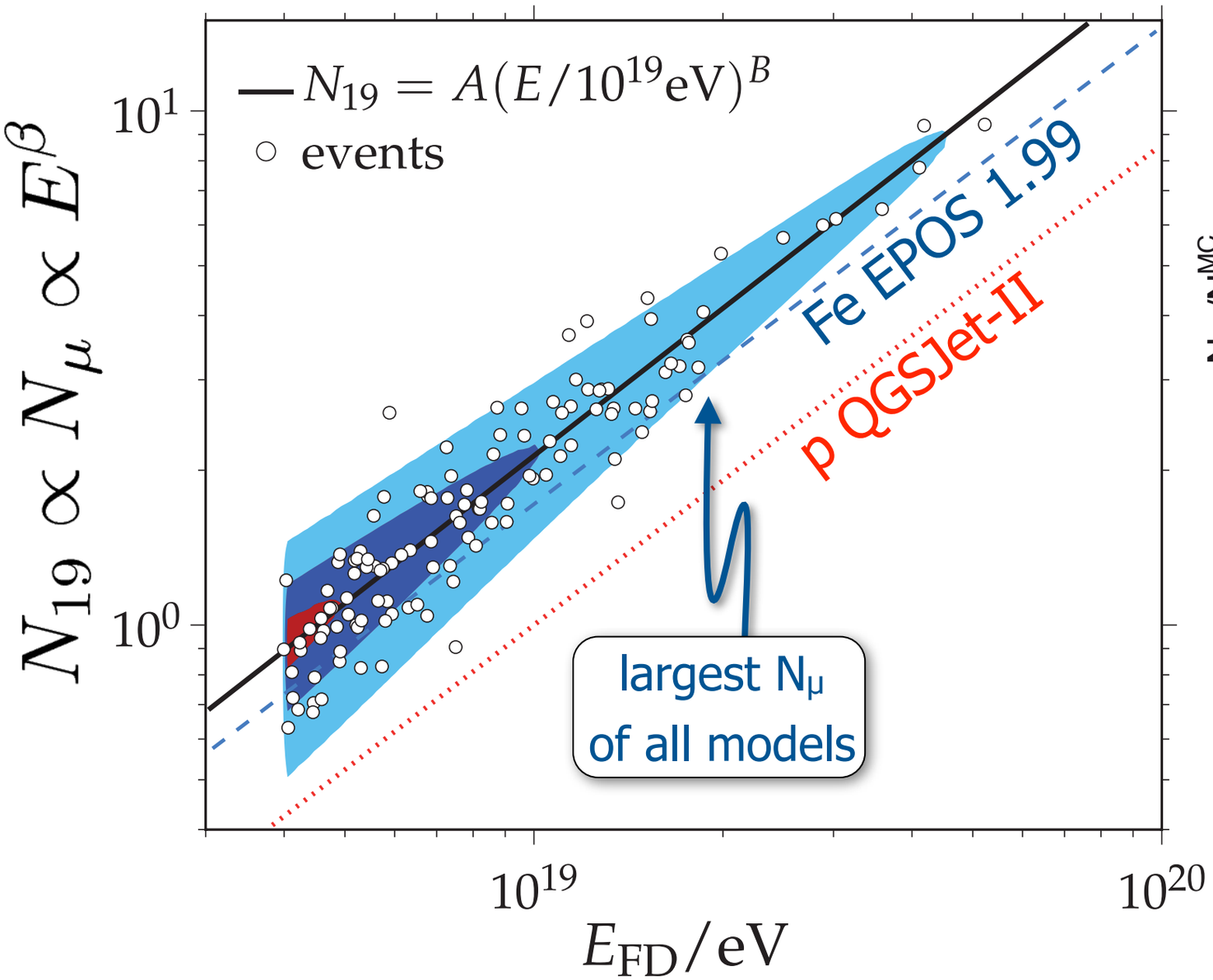
using Glauber model

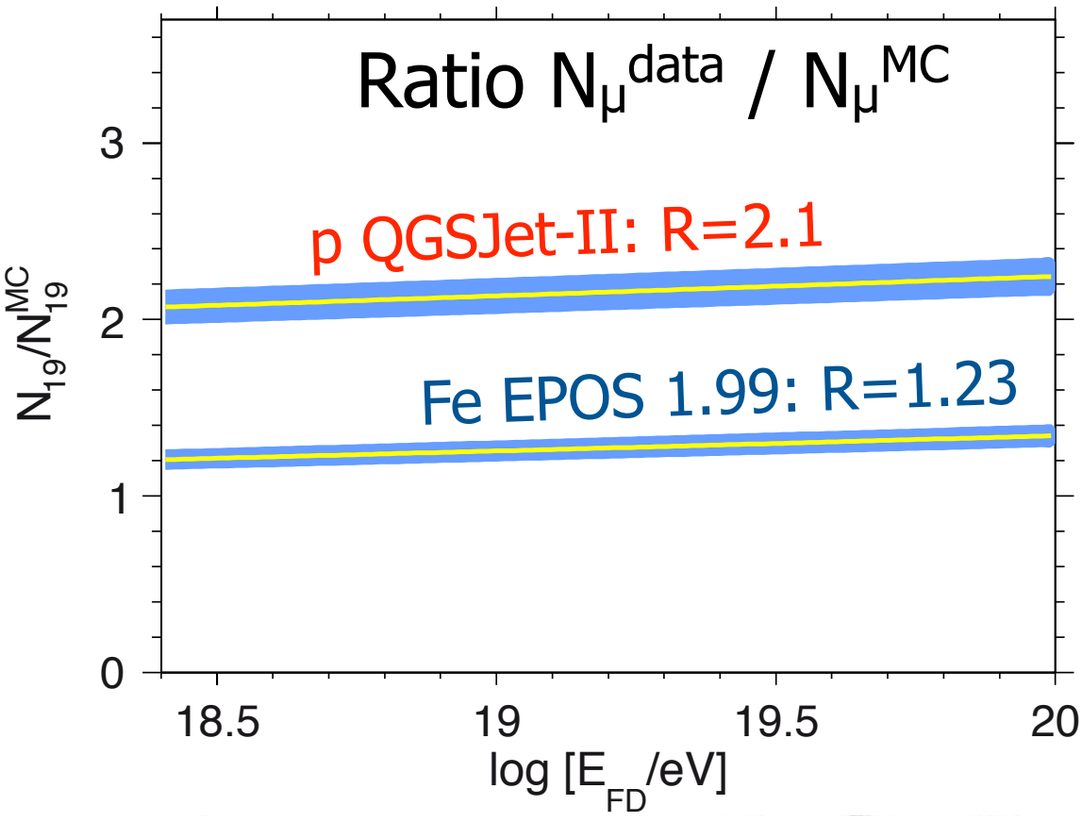


$$\sigma_{pp}^{inel} = (90 \pm 7_{stat} (^{+8}_{-11})_{sys} \pm 1.5_{Glauber})\ mb$$

Inclined Showers: Models Unterestimate μ-Number

- Inclined showers (62°-80°) dominated by HE muons
- show broken circular symmetry; accounted for by μ-map
- small EM contribution subtracted from signals → N_μ





Models underestimate HE μ-Number by

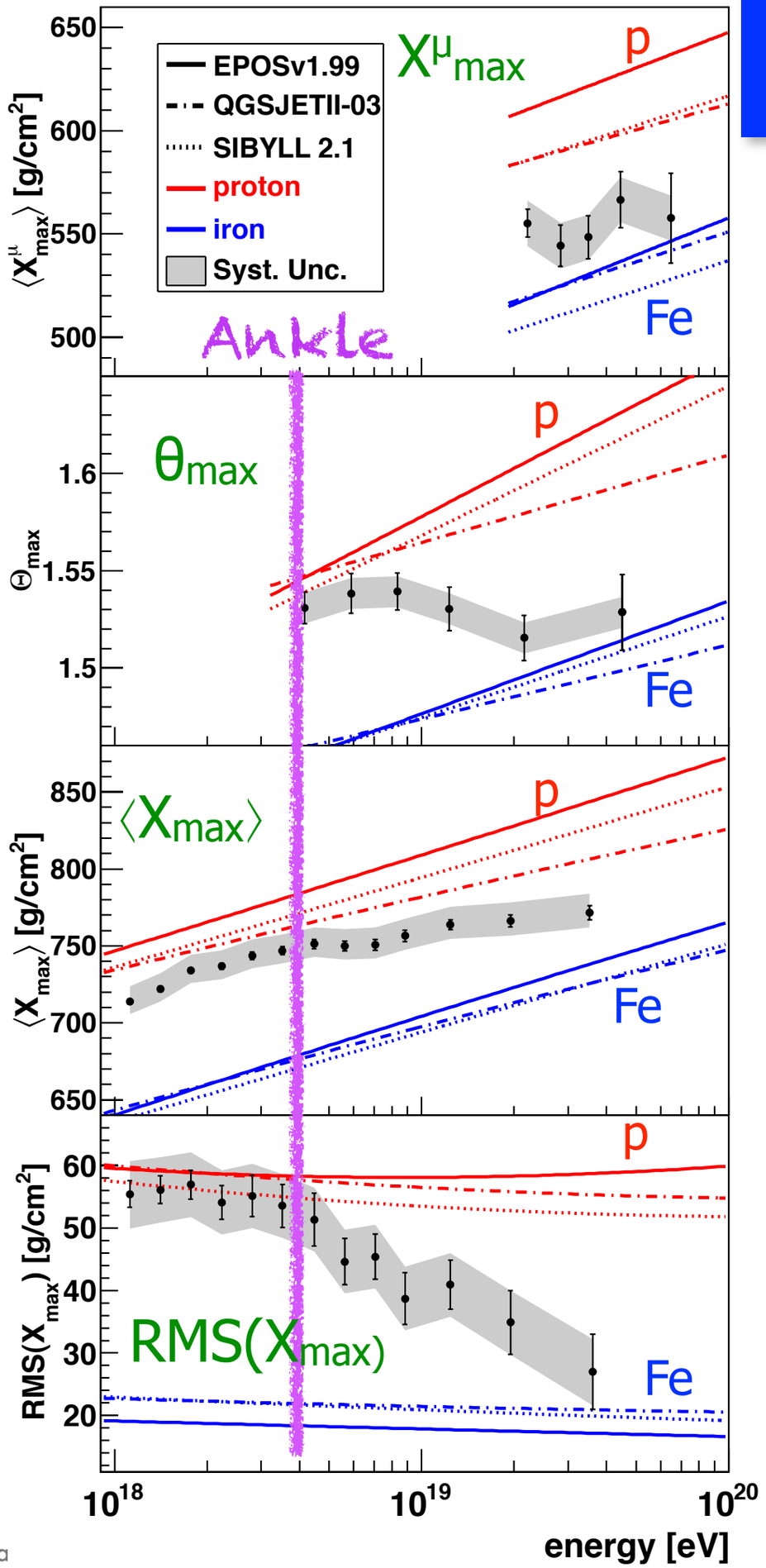
~25 % (if data were pure Fe)

~ 100% (if data were pure p)

very difficult to account for by models!

Mass Composition Photons, Neutrinos

Compositon from FD & SD



Muon Production Depth from timing differences

Shower Depth from asymmetry of rise times

First results from SD → confirm FD

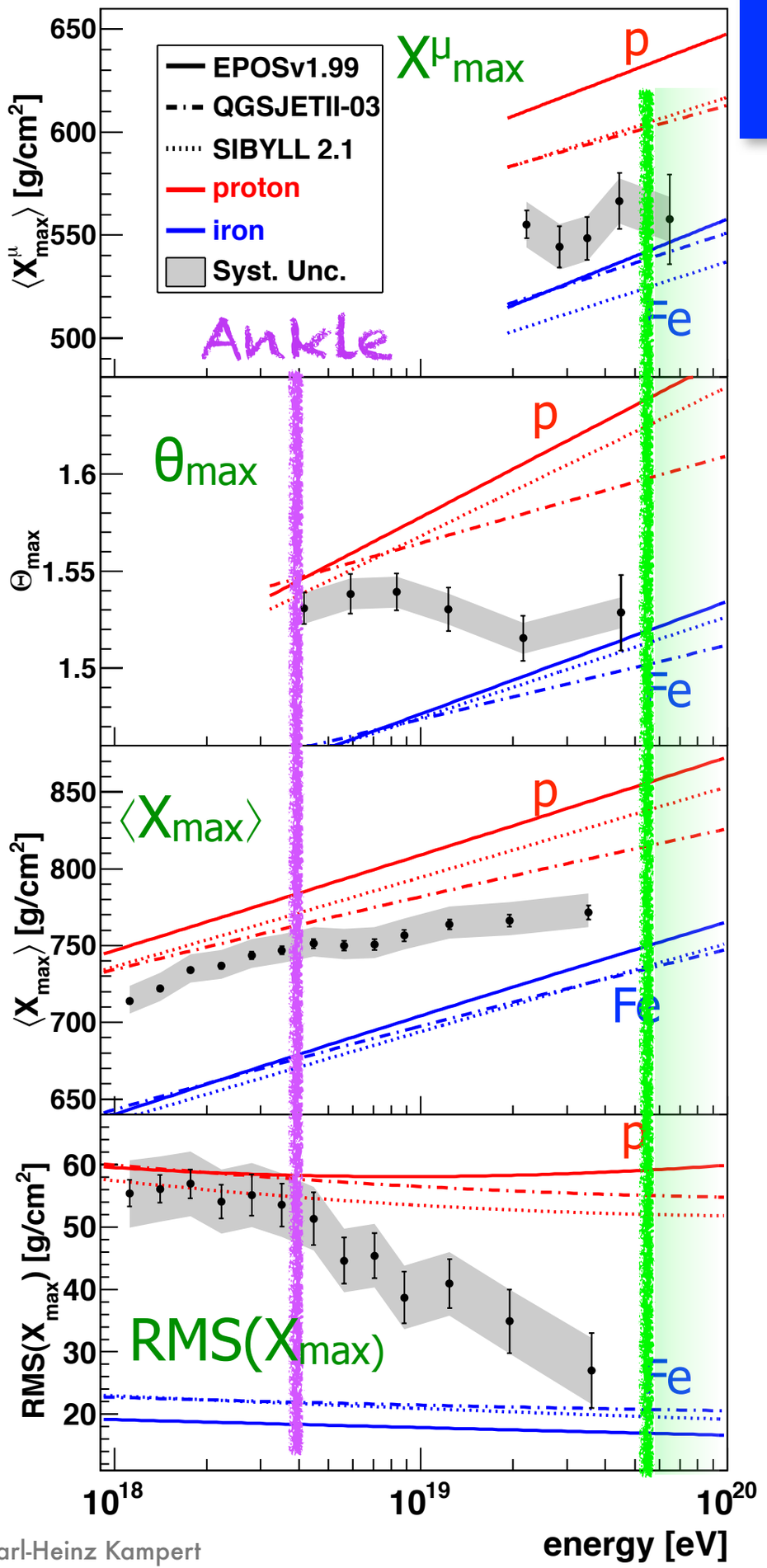
X_{max} observation by FD

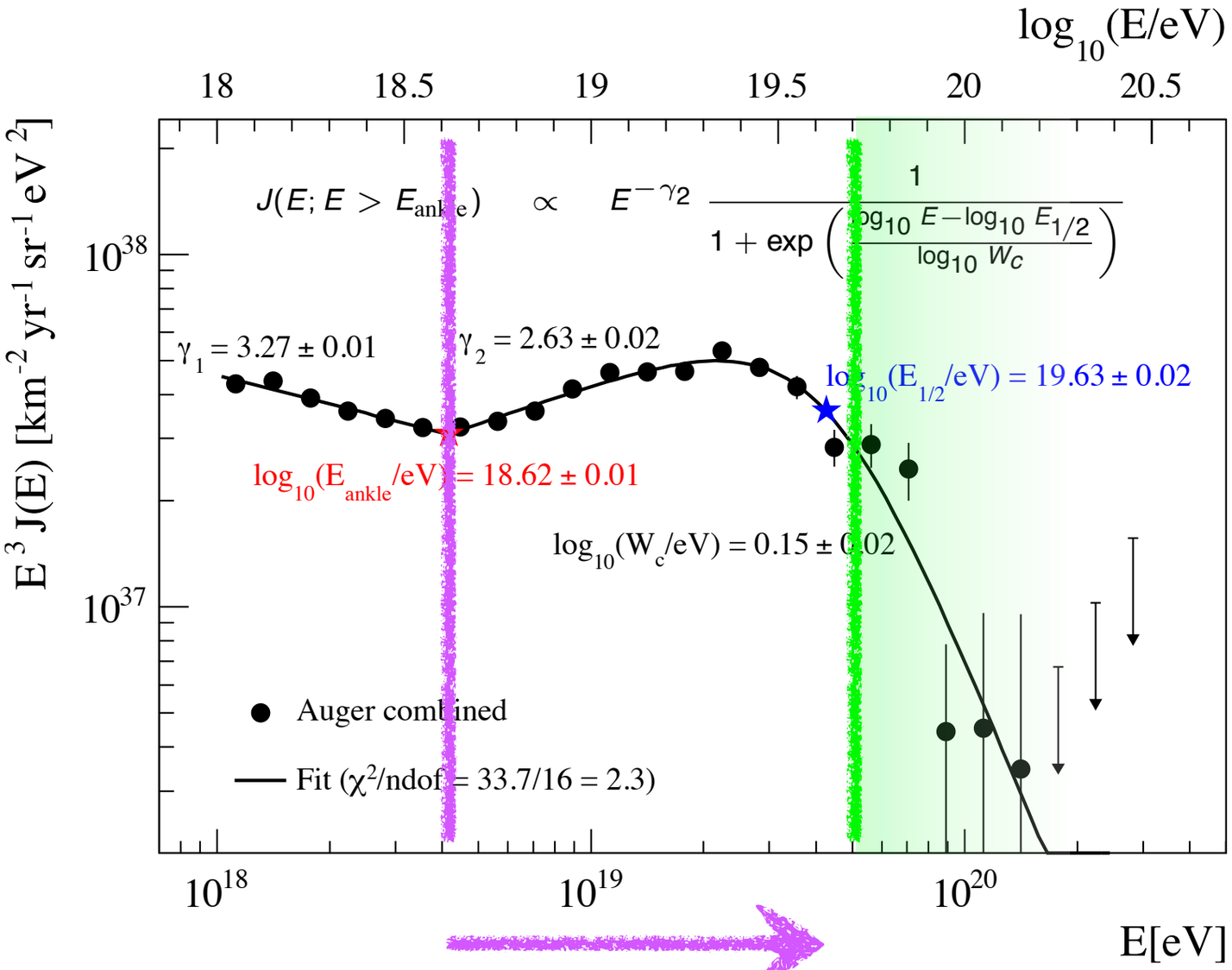
→ **$\langle X_{max} \rangle$**

and RMS(X_{max})

update of data published in PRL

Compositon & Spectrum





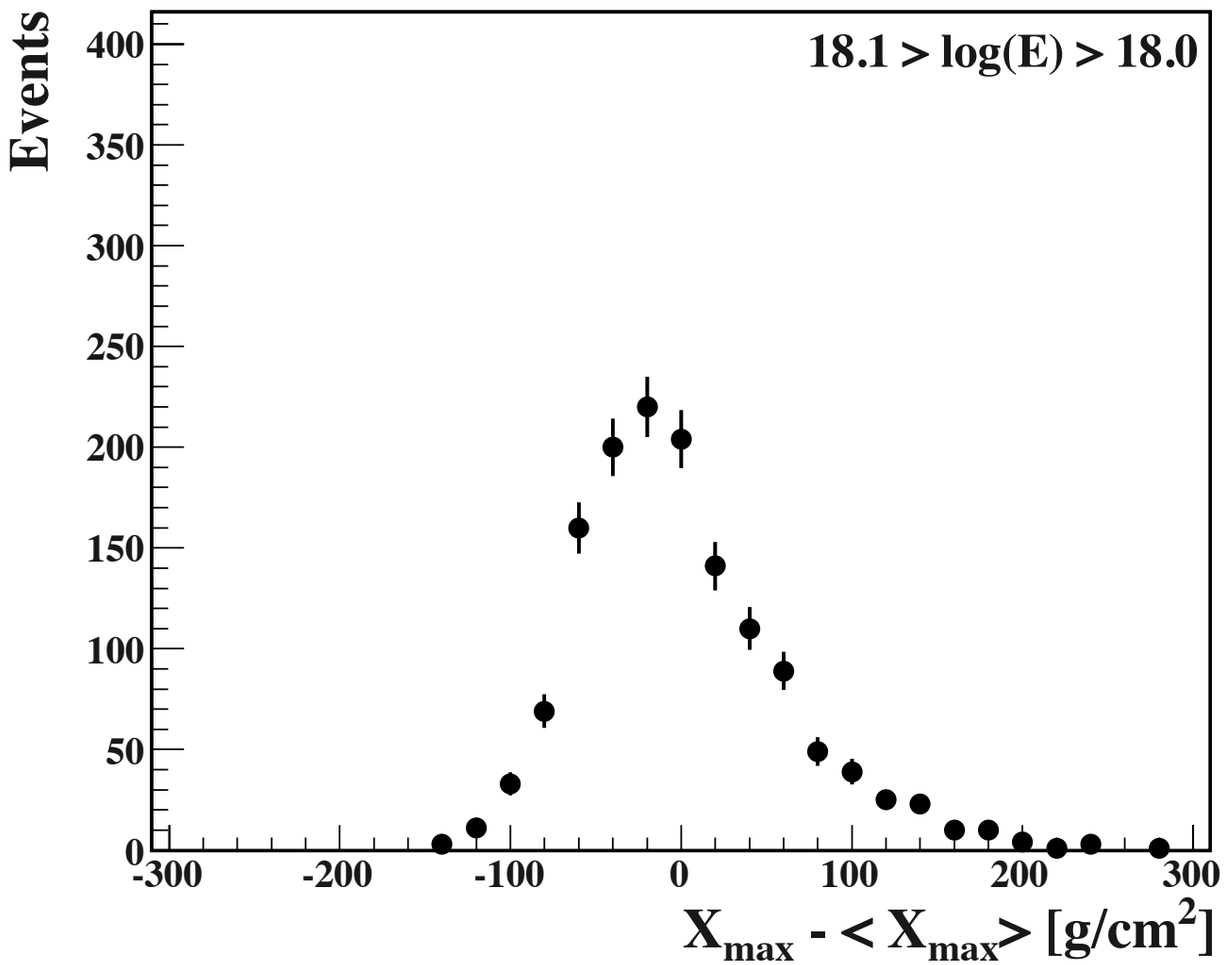
light → heavy

anisotropies

no composition measured at GZK energies, yet

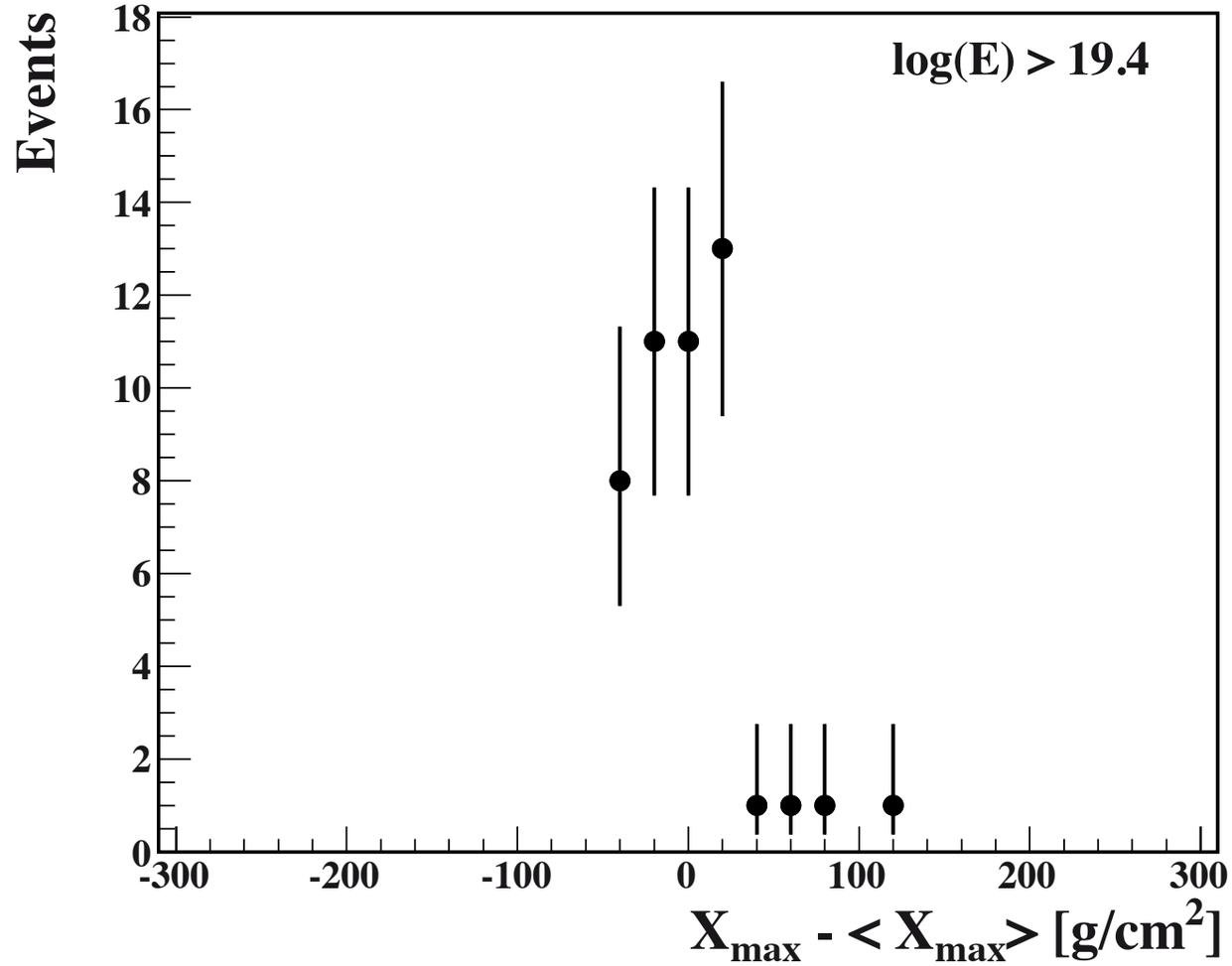
X_{max} Distributions vs Models

10^{18} eV



- **wide distribution**

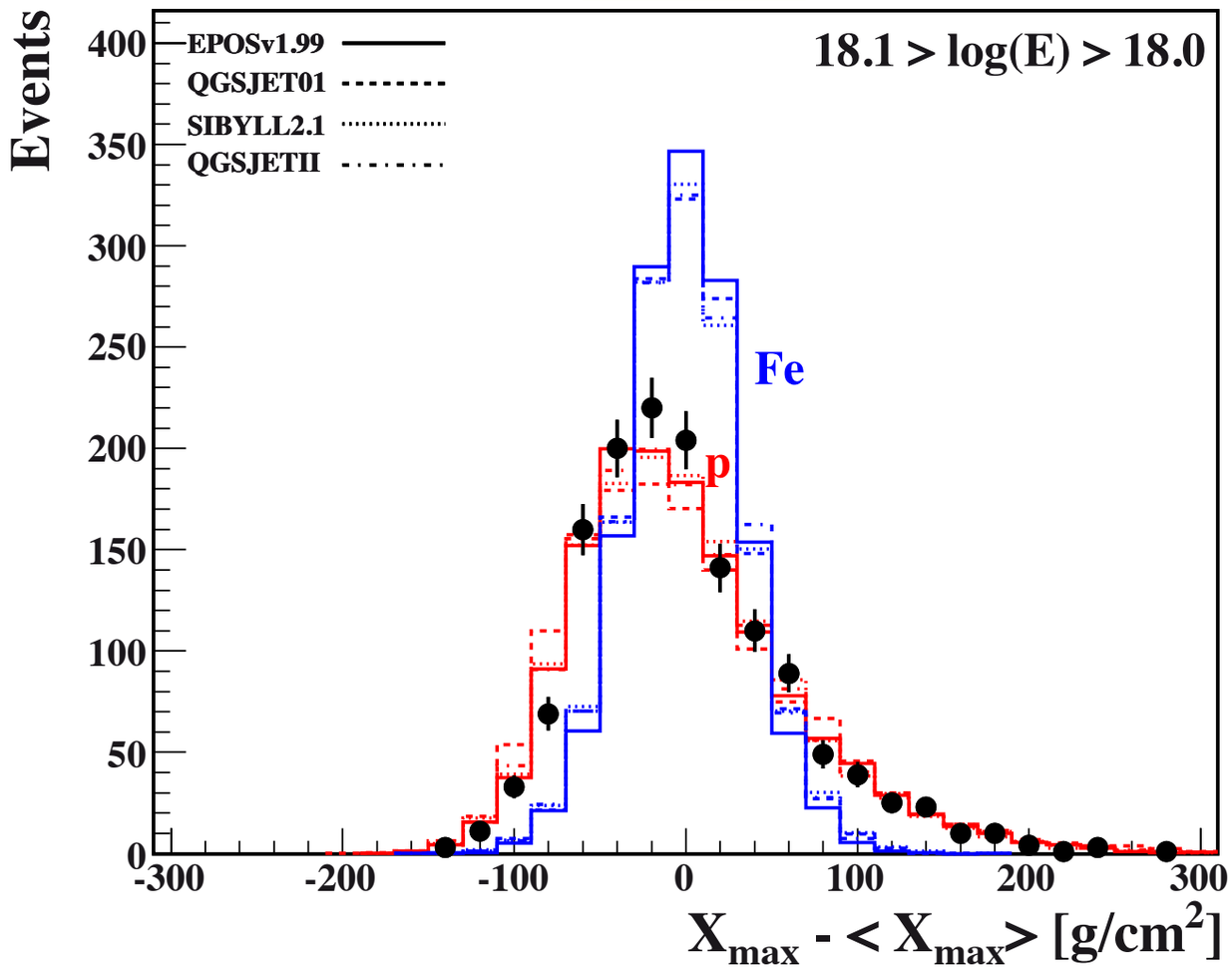
> $10^{19.4}$ eV



- **narrow distribution**

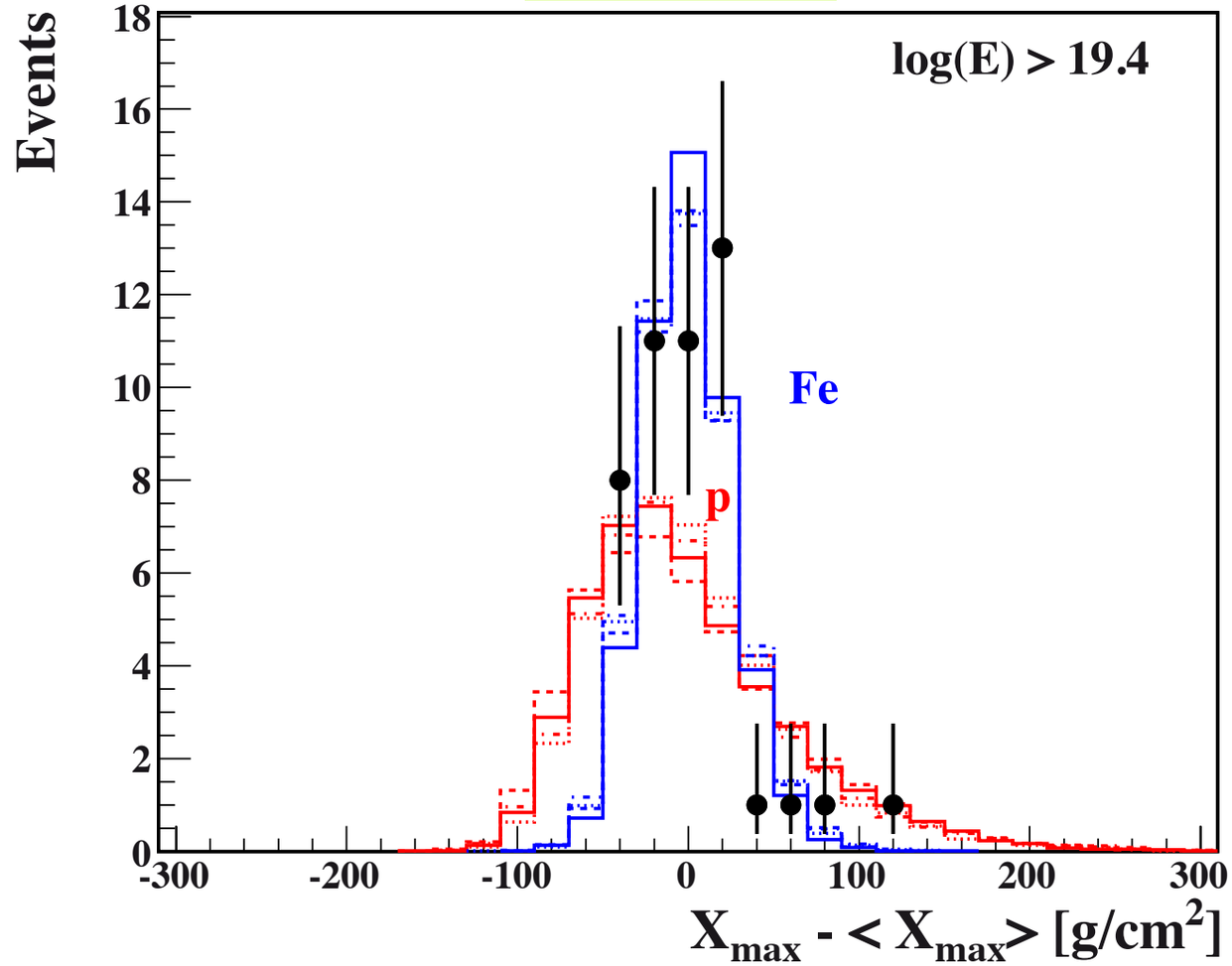
X_{max} Distributions vs Models

10^{18} eV



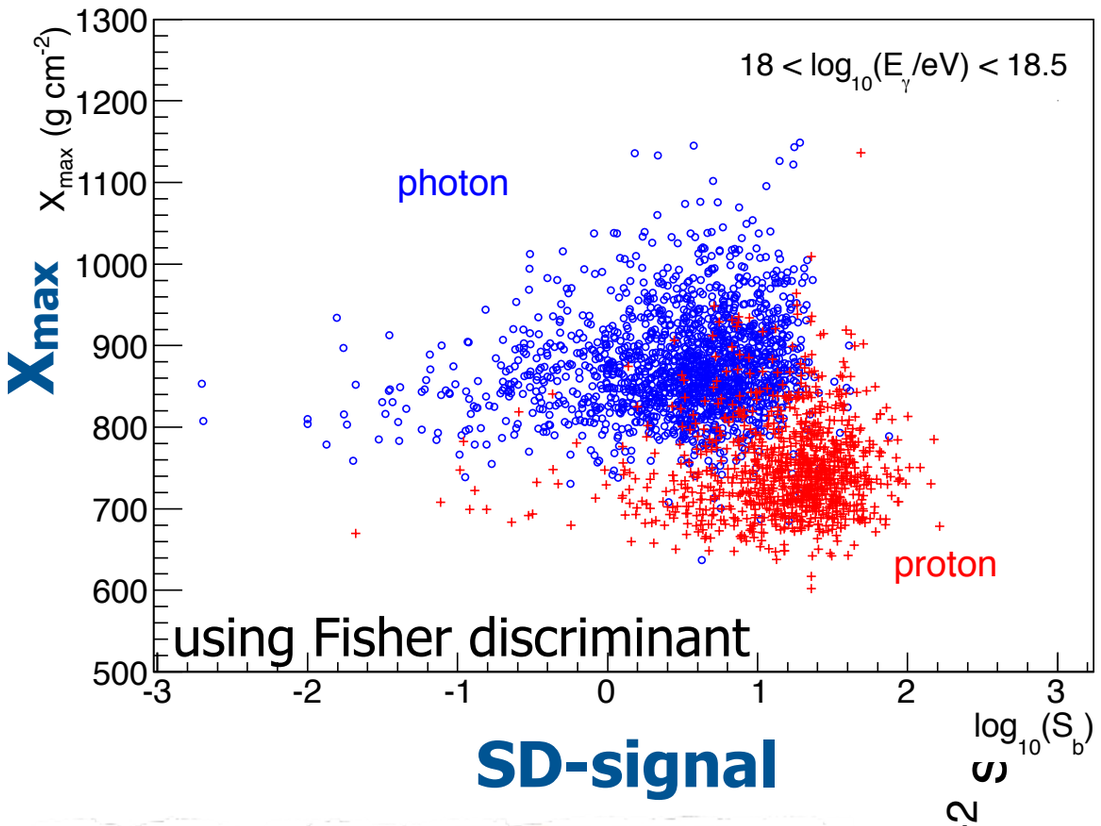
- **wide distribution**
- **well described with a substantial fraction of protons**

> $10^{19.4}$ eV



- **narrow distribution**
- **compatible with significant fraction of heavy nuclei**

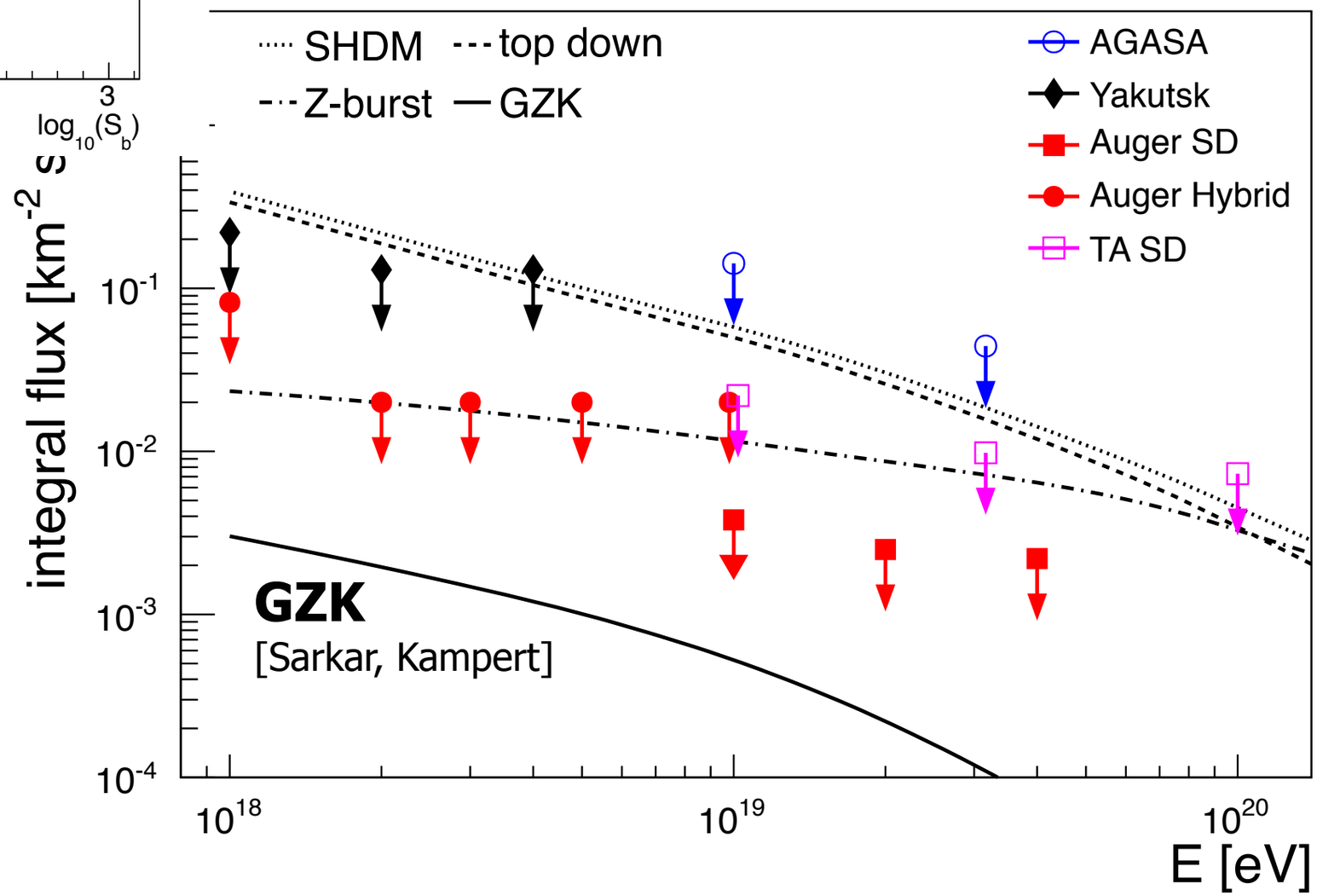
Photon Limits disfavor Top-Down UHECR-Origin



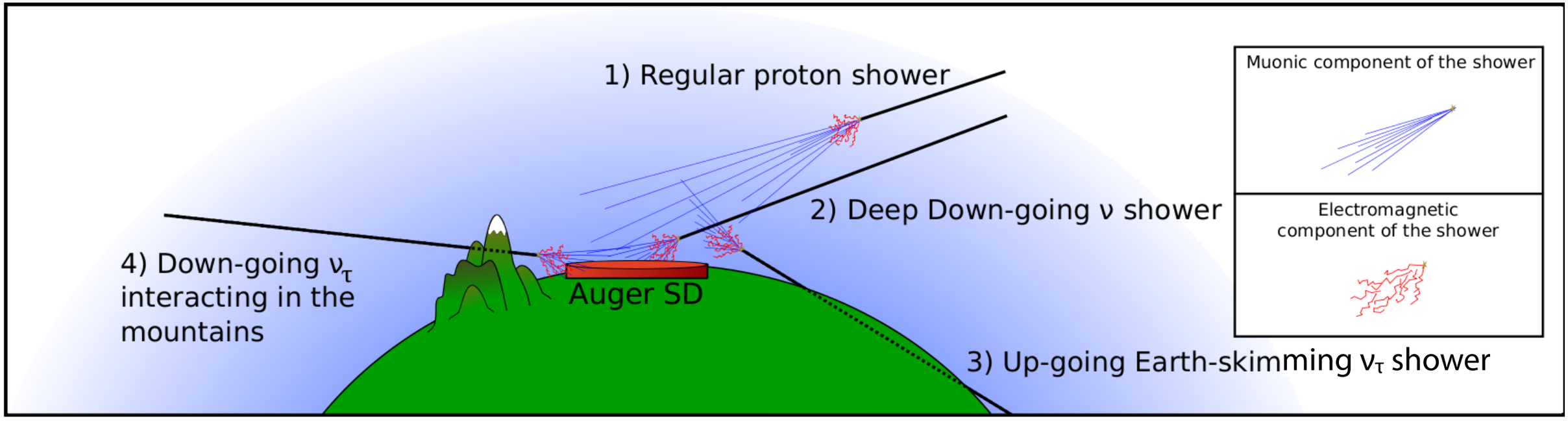
Photons characterised by:

- **deep X_{max} in FD**
- **small signal in SD**

- **Exotic Models disfavoured down to 1 EeV**
- **→ Astrophysics origin of UHECR**
- (optimistic) **GZK in reach**



Update of Neutrino Limits



Search for

- **up-going Earth-skimming showers**
- **down-going Neutrino showers**

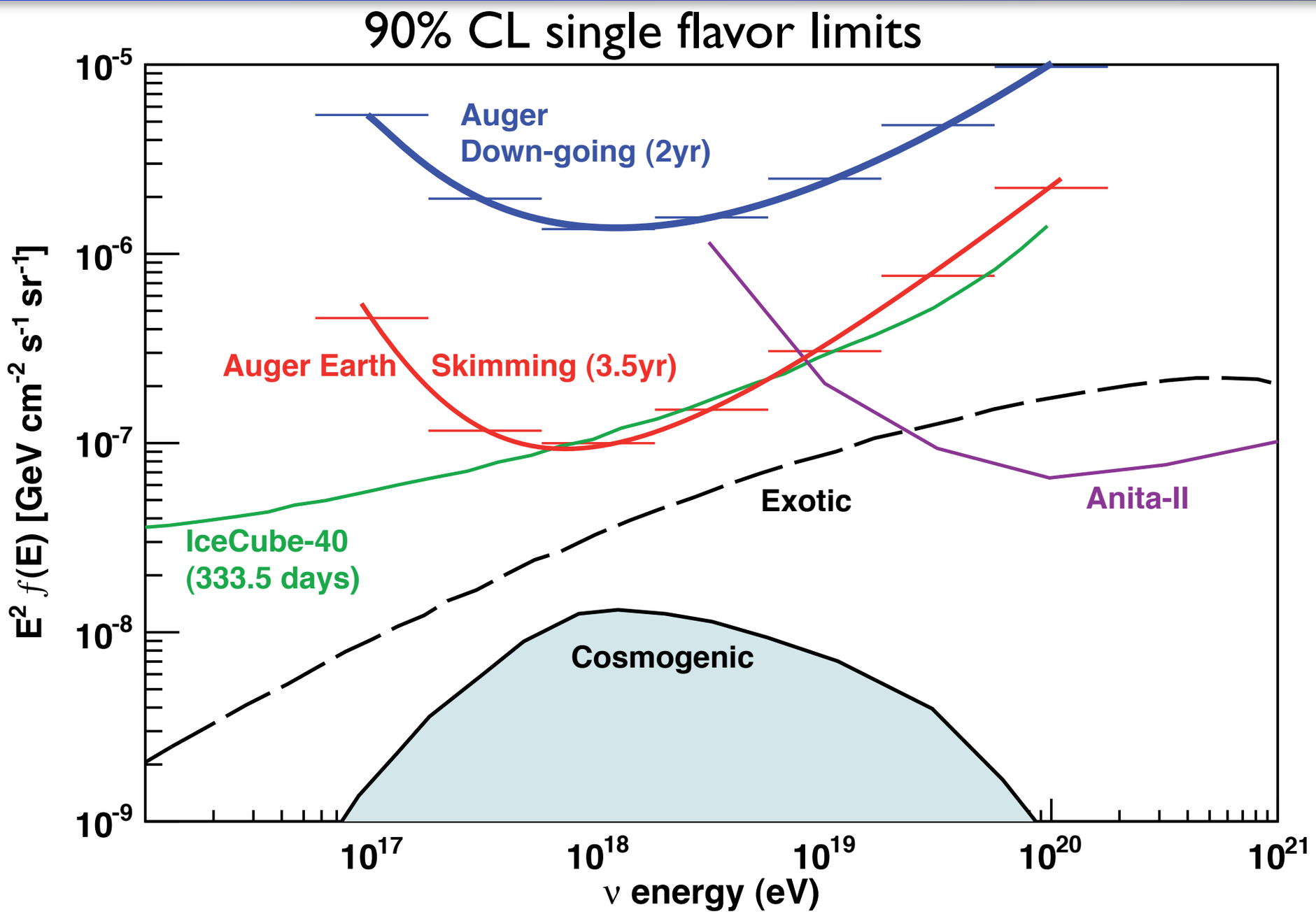
Search criteria

- young **ν** induced showers ➙ wide time distribution in tanks
- elongated footprint of inclined shower
- propagation speed of shower front at ground

} **no candidates found**

sensitive to all flavors

Diffuse Neutrino Limits

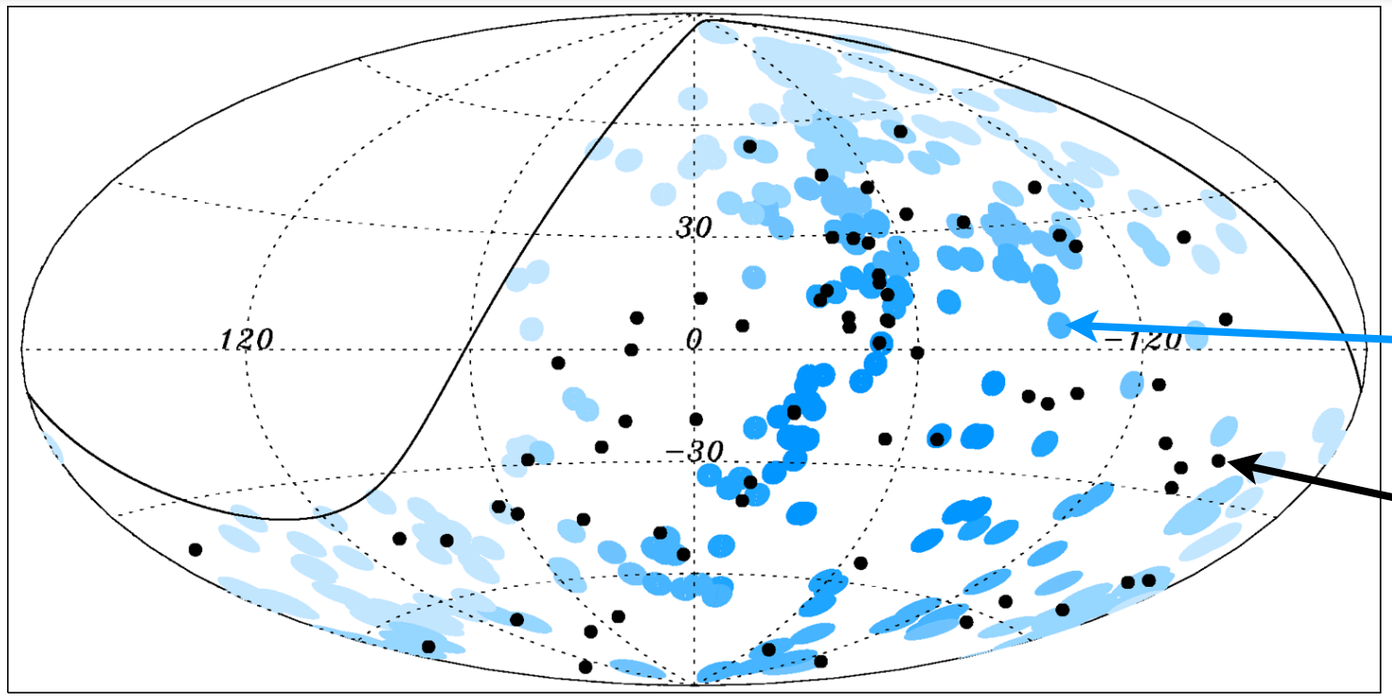


Integral: $k < 2.8 \cdot 10^{-8}$ GeV cm^2 s^{-1} sr^{-1} from $1.6 \cdot 10^{17}$ - $2.0 \cdot 10^{19}$ eV (ν_T)

$k < 1.7 \cdot 10^{-7}$ GeV cm^2 s^{-1} sr^{-1} from $1.0 \cdot 10^{17}$ - $1.0 \cdot 10^{20}$ eV (all ν)

Anisotropies Astrophysics

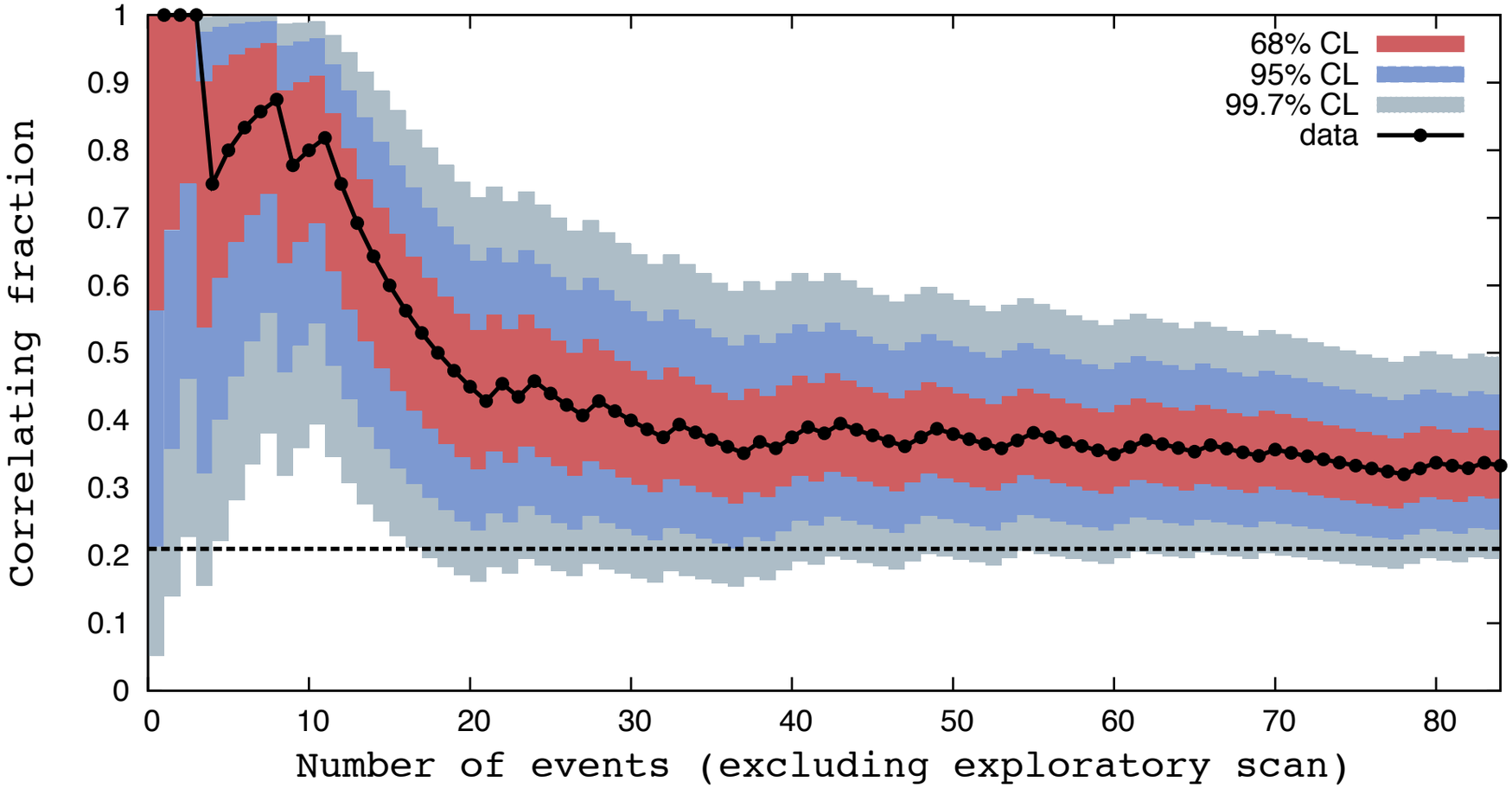
Update of Correlation with VCV-AGN



Astropart. Phys. 34 (2010) 314

AGN position
(3.1° circle)

event position



Update including June 2011

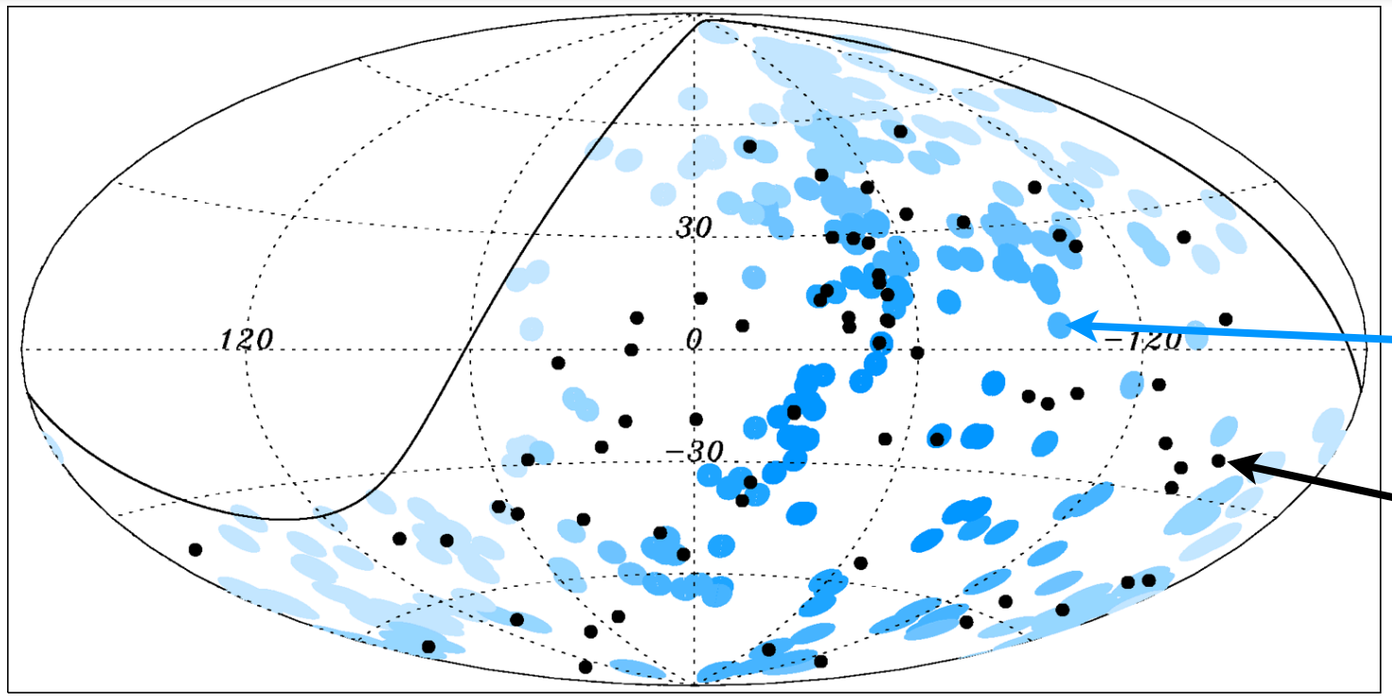
33±5%

Total: 28/84

P=0.006

Telescope Array:
8/20 = 40%
with iso-bkg = 24%

Update of Correlation with VCV-AGN



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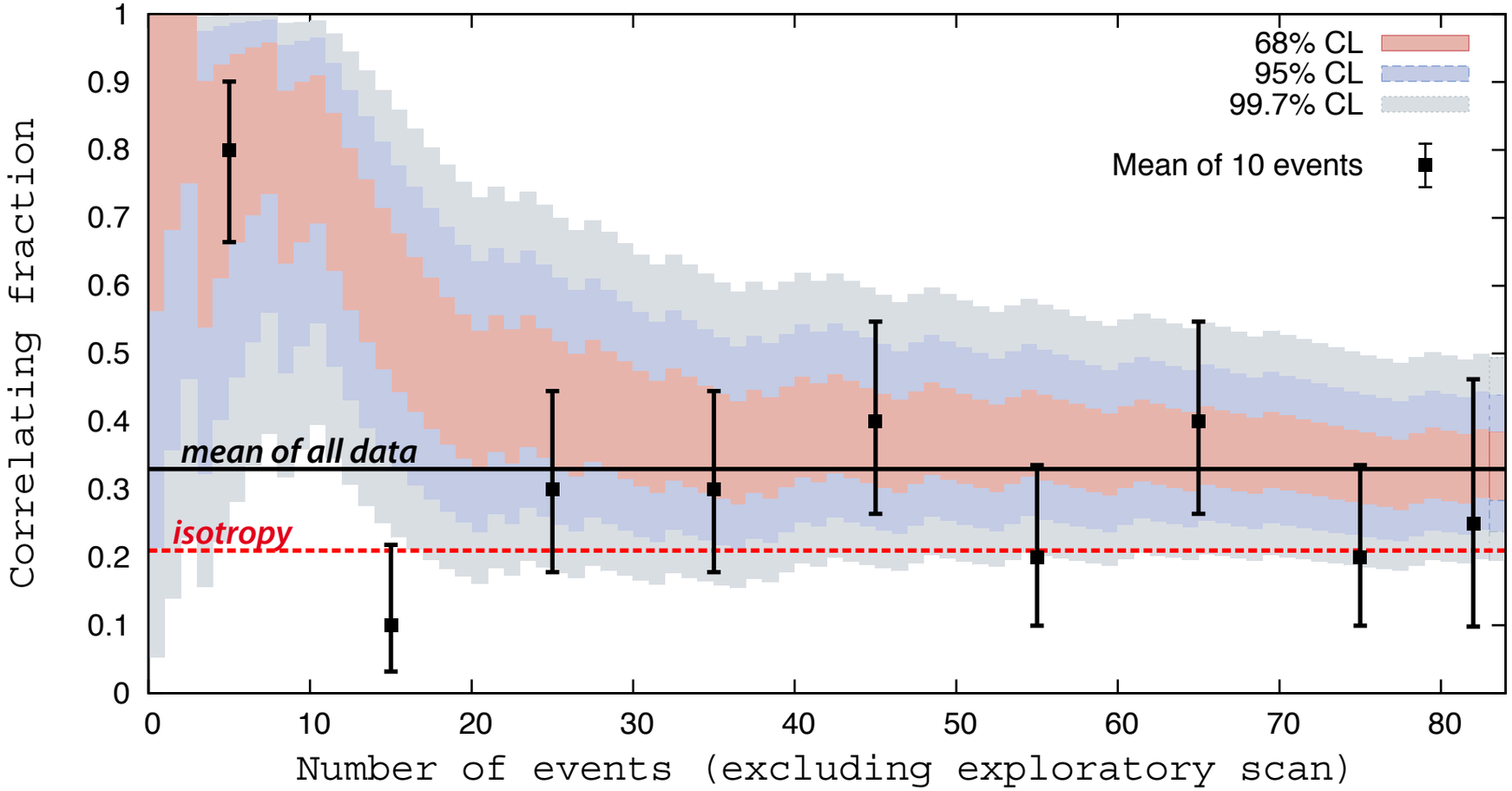

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Telescope Array:
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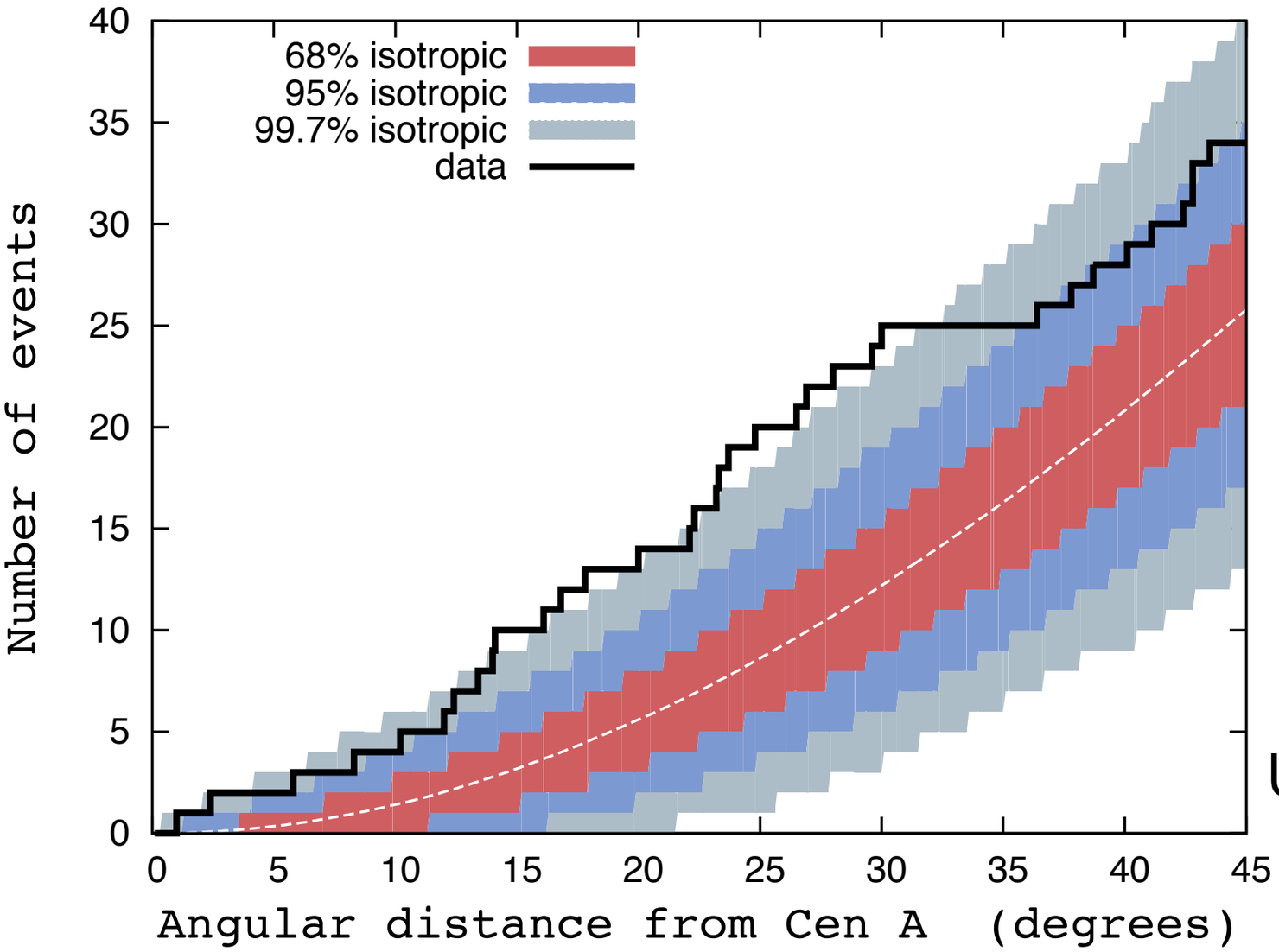
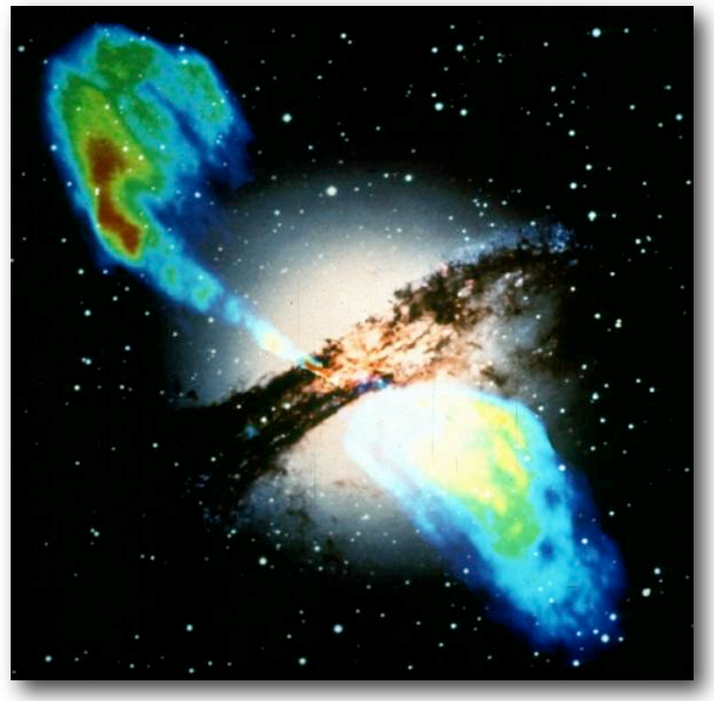
Update on Cen A





Update including June 2011

KS test: 4% isotropic probability

Largest departure at 24°: 19 observed / 7.6 expected

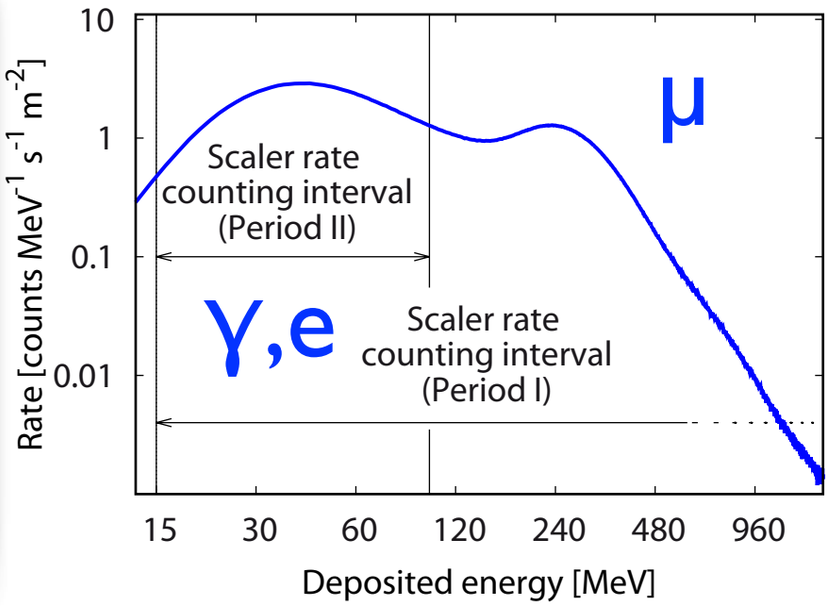
Binomial P = $3 \cdot 10^{-4}$; Li -Ma: 3.3 σ

Serendipity Observations & Triple-Hybrids

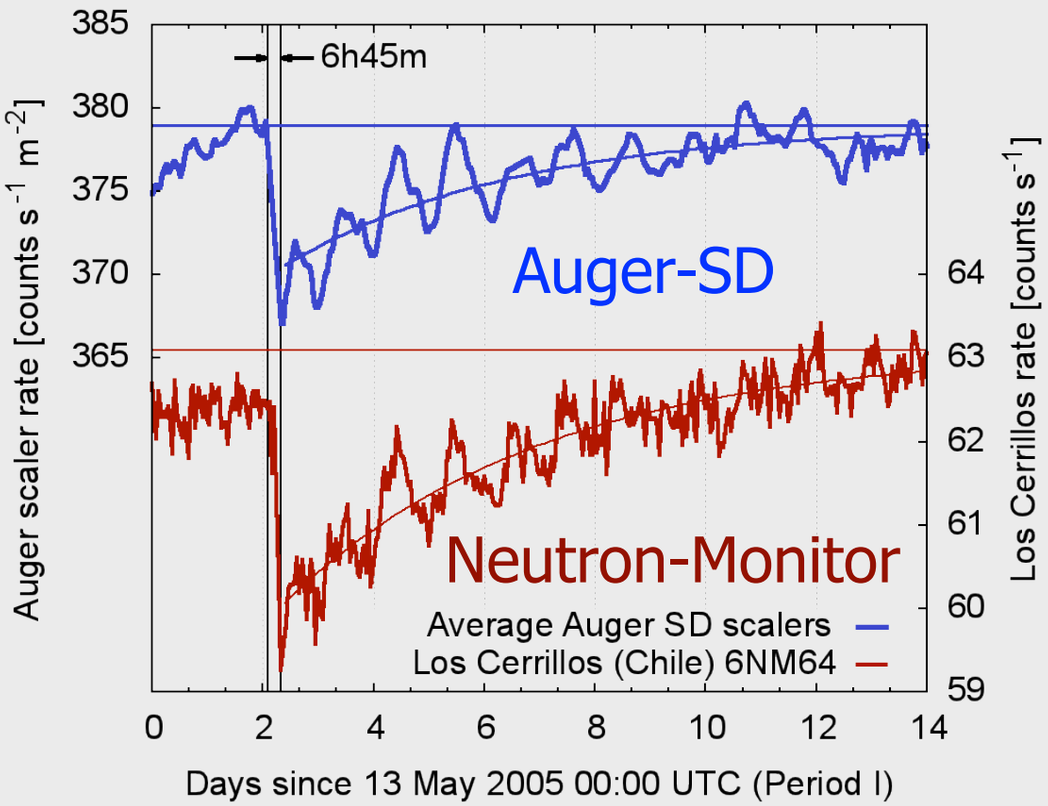
Solar & Environonomental Physics with Auger

1660 water Cherenkov tanks count 10^8 particles/min

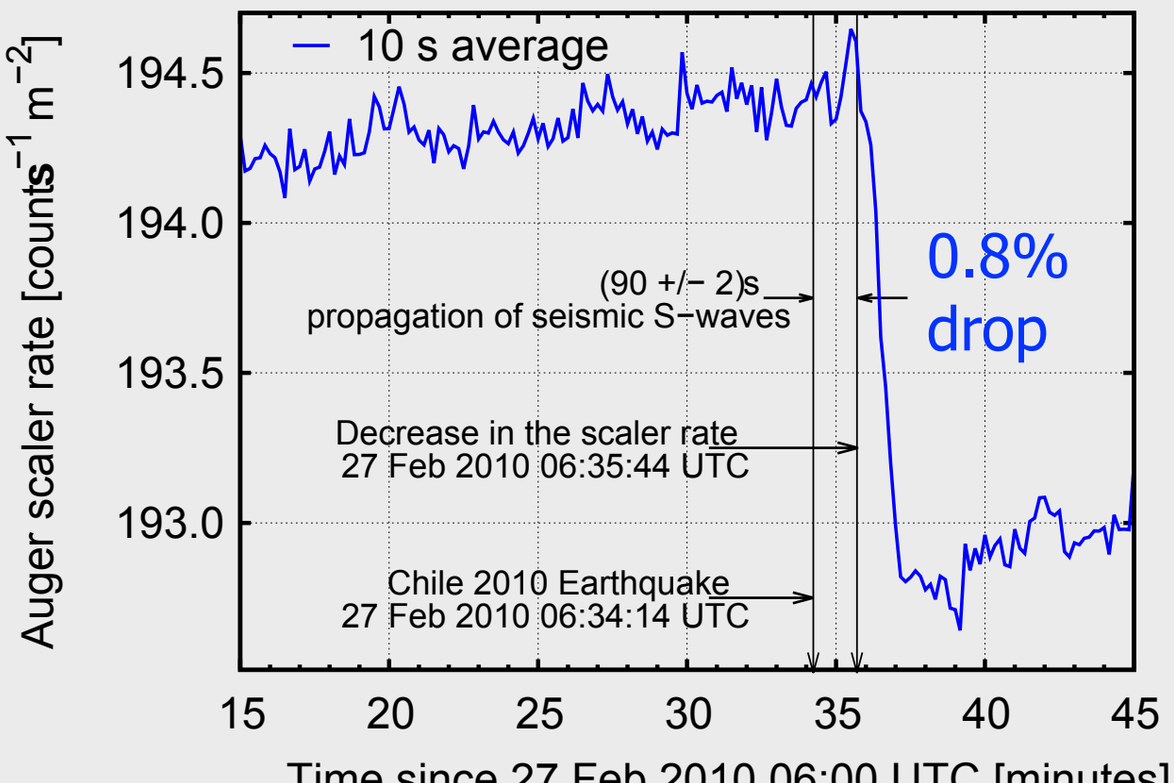
15-minute average of the scaler data are publicly available at www.auger.org



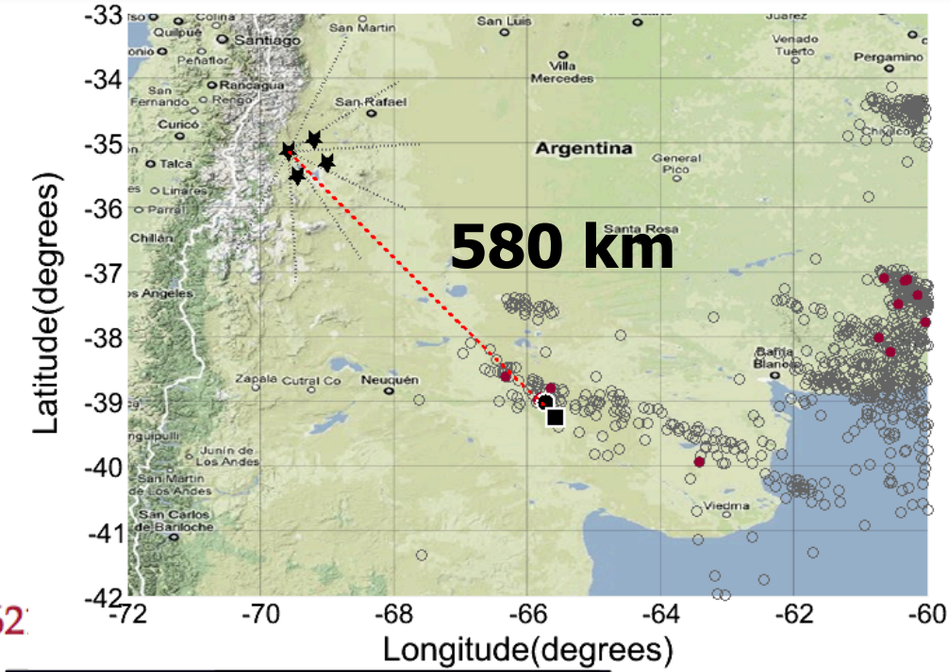
15 May 2005 Forbush decrease



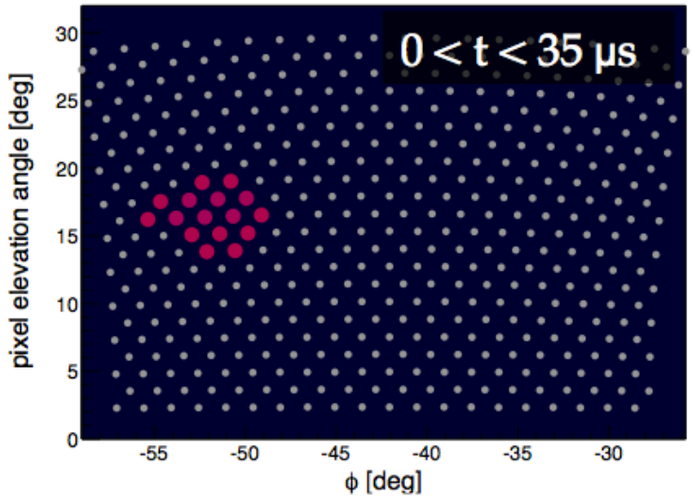
Chile Feb. 2010 earthquake

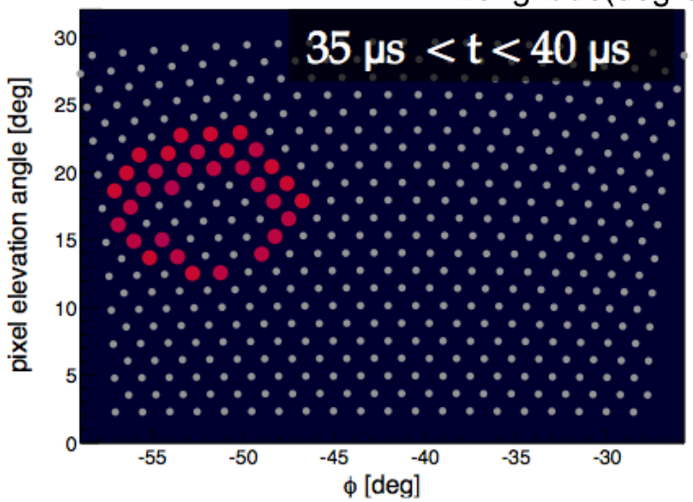


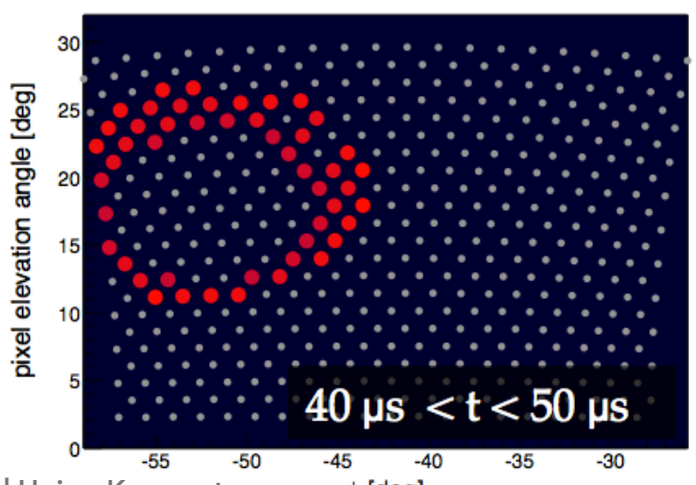
Observation of Elves

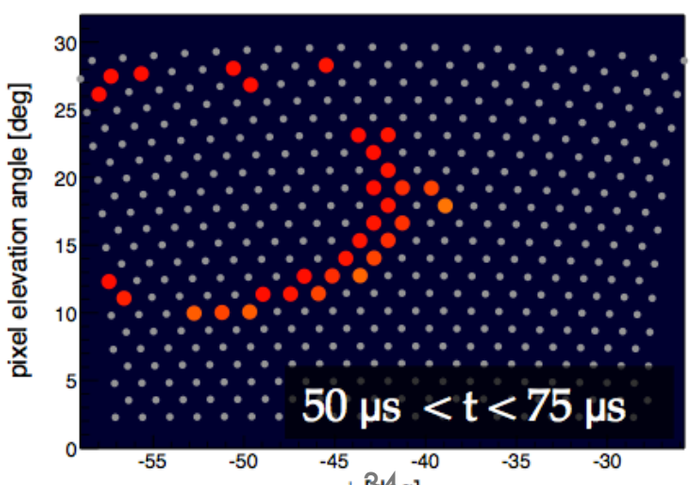


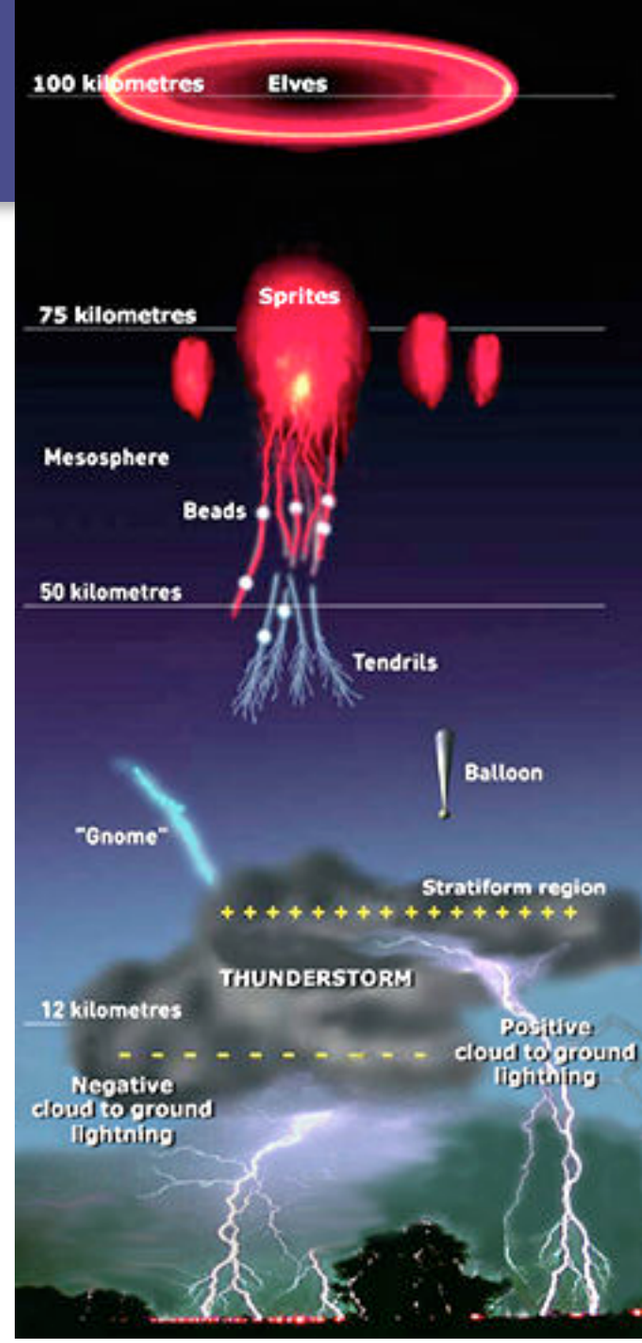
GPS sec: 8608062











interesting opportunity to study the elve evolution with an unprecedented time resolution

Summary

Rich Harvest of Data for upcoming years
Broad and enlarged Science Program
Stable operation + Enhancements + Exp. Breakthroughs

- **Calorimetric Energy Calibr. by FD is of crucial importance**
- **Models underestimate Muon-Numbers by ~25 - 100%**
- **First p-Air and pp Cross-Section much beyond LHC energies**
- **FD and SD provide consistent composition information**
- **Anisotropies stabilizing**
- **Photons and Neutrinos nearing GZK-regime → verify GZK**

Future Plans

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Still suffering from limited statistics
→ Collect data for ~ 10 more years

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Enhance capabilities by infill array, improved muon counting

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Develop and test new EAS detection technologies: MHz-GHz Radio

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Develop and test new EAS detection technologies: MHz-GHz Radio

Prepare - in a worldwide effort - for a much larger Observatory

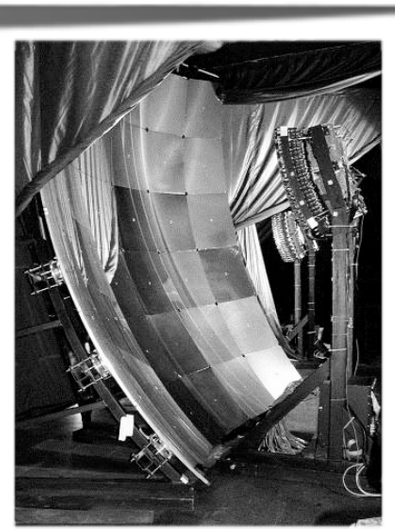
Radio Observations @ Auger

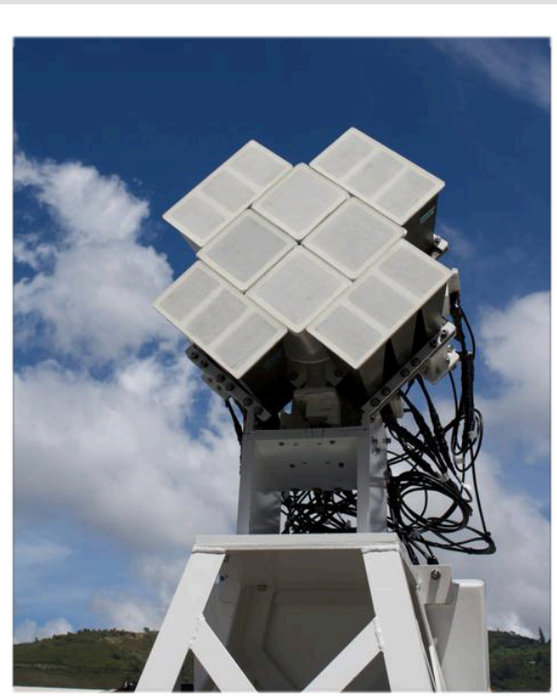
- **Radio EAS observations (MHz & GHz)**

➙ world wide unique site & infrastructure allows multi-hybrid observation

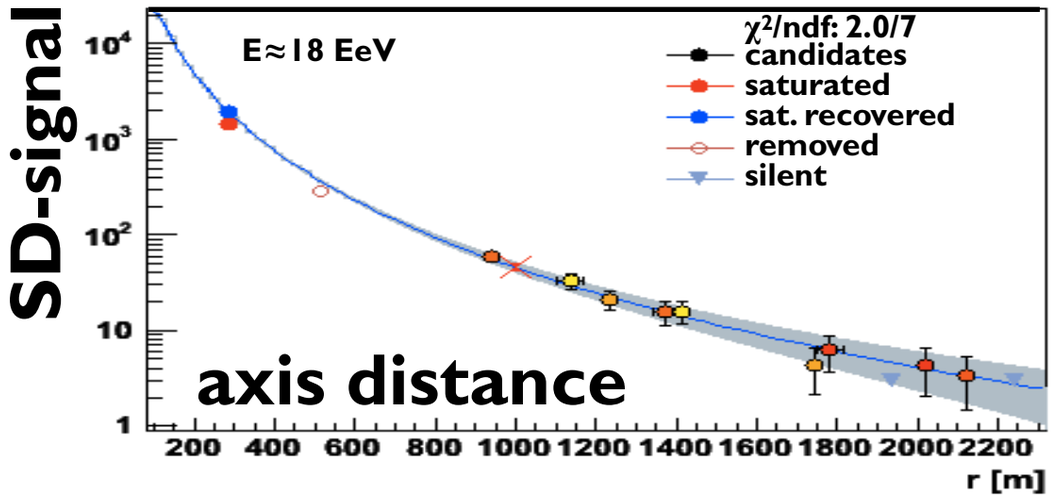
➙ currently 100 km^2 of MHz (AERA) and GHz (Easier) antennas being installed + other GHz techniques (AMBER, MIDAS, CROME, FDWave)

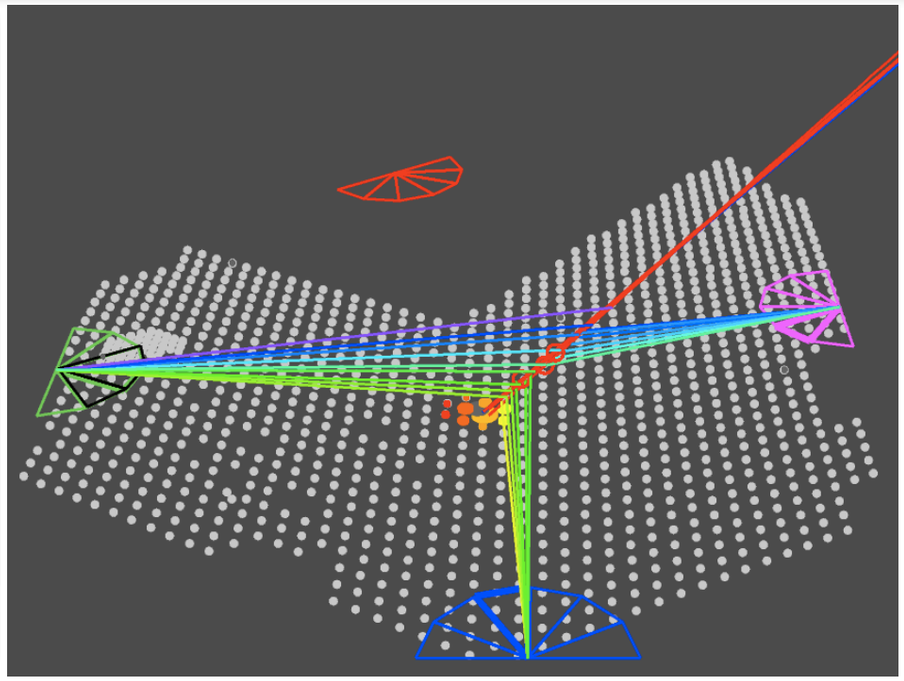
These initiatives will give definite answers about the potential of EAS Radio-Observations and will improve present physics capabilities

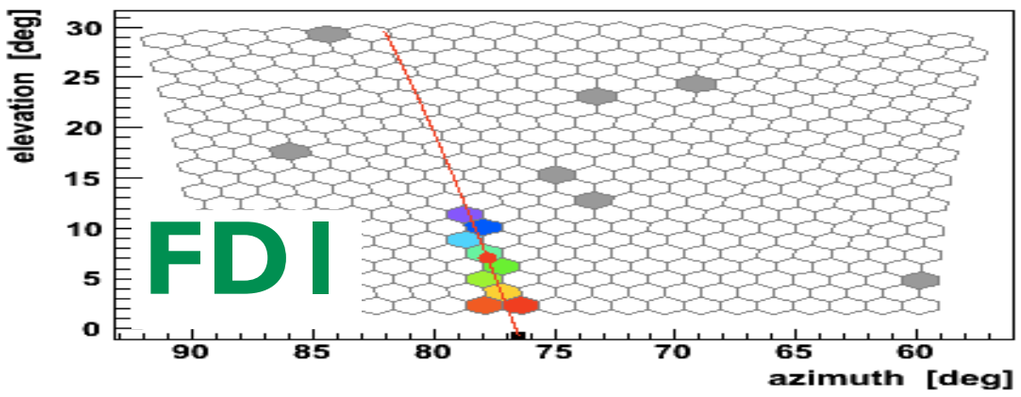


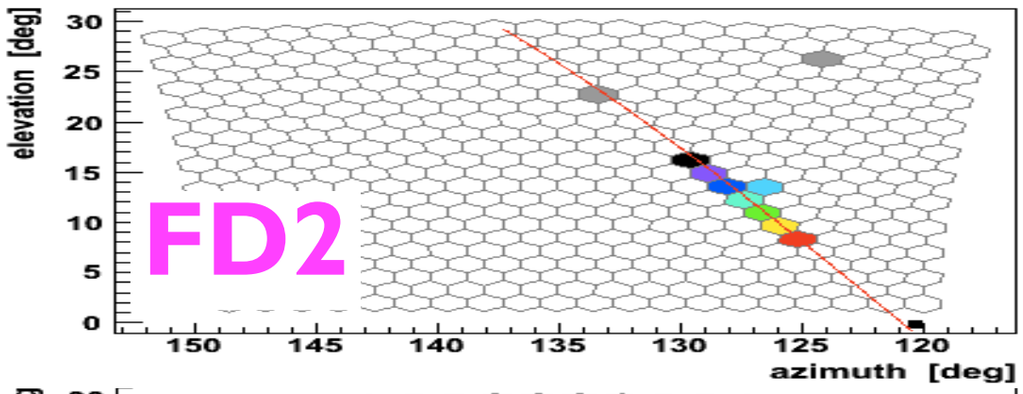


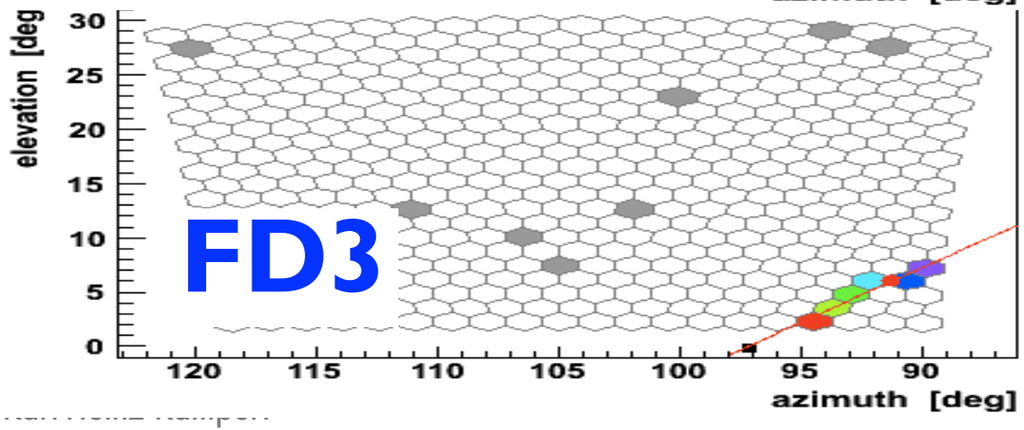
Birth of Super-Hybrid: SD+FD+Radio

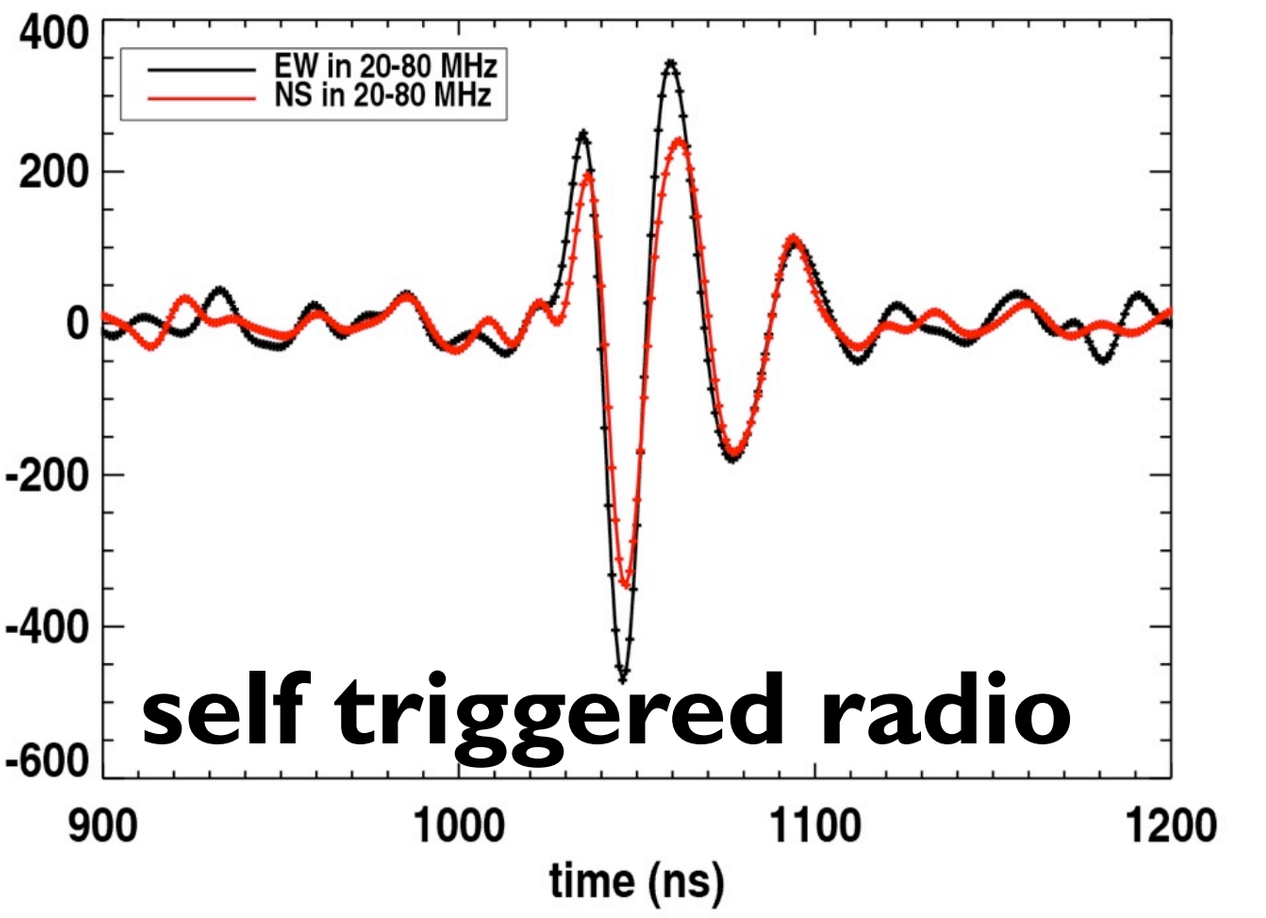


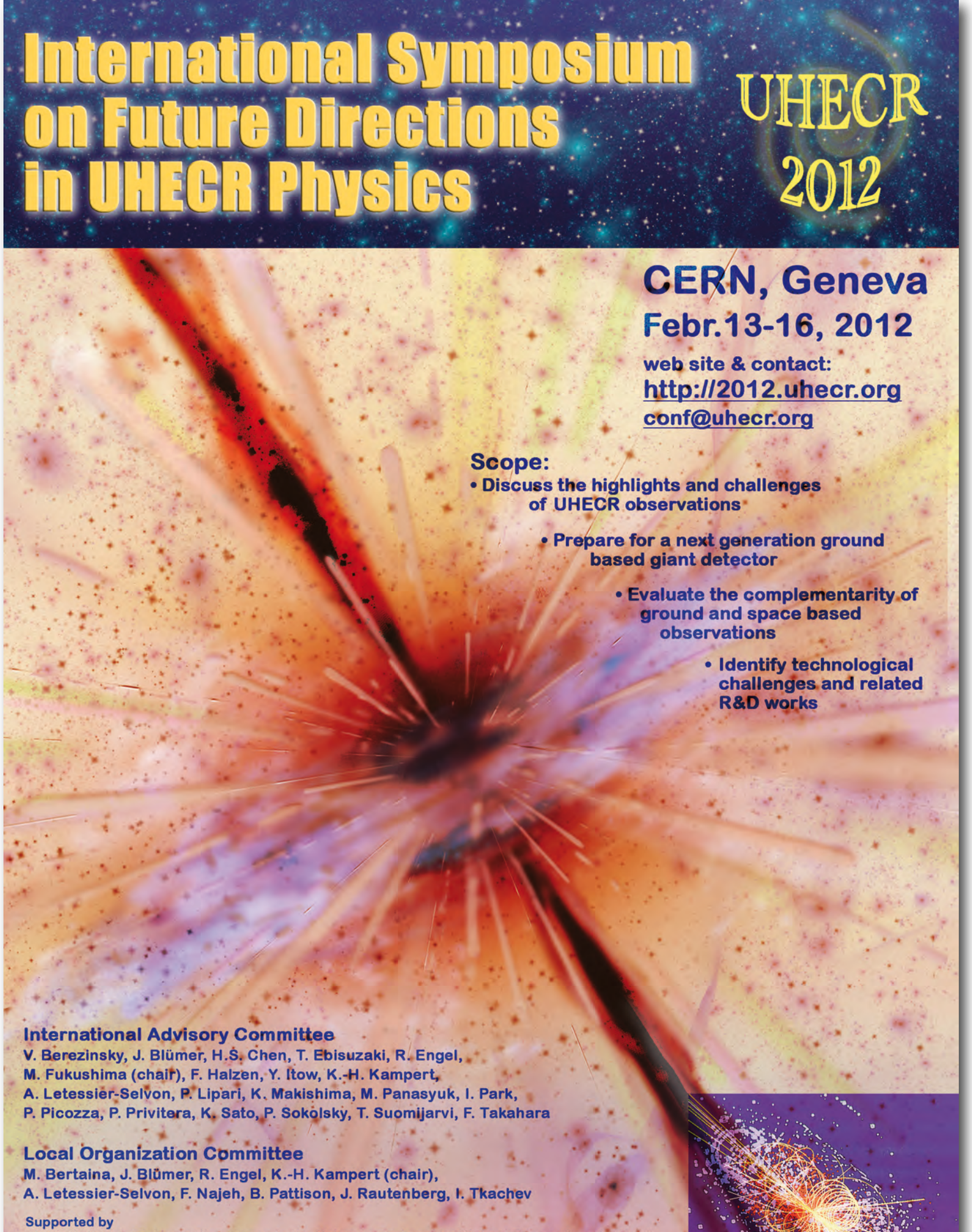












CERN
February 13-16, 2012

http://2012.uhecr.org

conf@uhecr.org

Major Scope of Workhop:

- UHECR physics questions for the future
- New detection techniques and detector designs
- Start world-wide coherent effort

if you want to participate, please register quickly !

(running short of accomodation)


W 50°
W 30°
W 10°
Prime Meridian
E 10°
E 30°
E 50°
E 70°
E 90°
E110°
E130°
E150°
E170
N70°
Arctic Circle
N50°
N30°
Tropic of Cancer
N10°
Equator
S10°
Tropic of Capricorn

You are warmly invited to participate!

Search for sites of
~ 30 000 km²

Fluorescence ?

Water-Cherenkov ?

Scintillators ?

Radio ?

electronics

distributed DAQ

communications