Ultra-High Energy Cosmic Ray Observations

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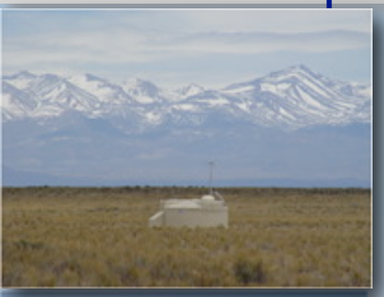
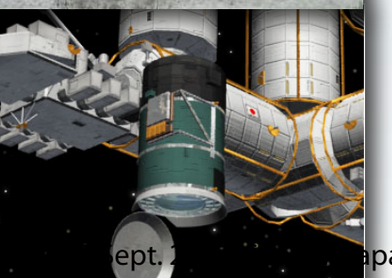




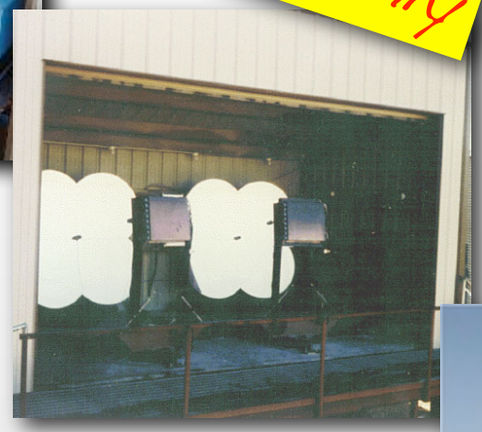


- **Present Status of Detectors**
- **The Issues**
  - *Energy Spectrum*
  - *CR Composition (p,Fe,γ,ν)*
  - *Arrival Directions*
- **The Future**
- **Concluding Remarks**

ept. 2 apan)

UHECR Experiments

analysis only



AGASA

- Understand the origin of CRs
- Find the most power cosmic accelerators
- Learn about CR acceleration
- EHE particle physics

HiRes-I & II

operating

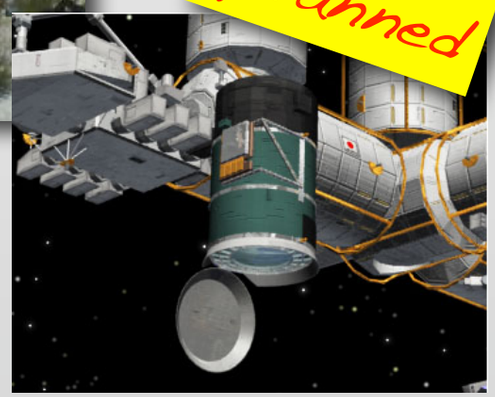
Auger

– Starting the Golden Hybrid Era –

construction

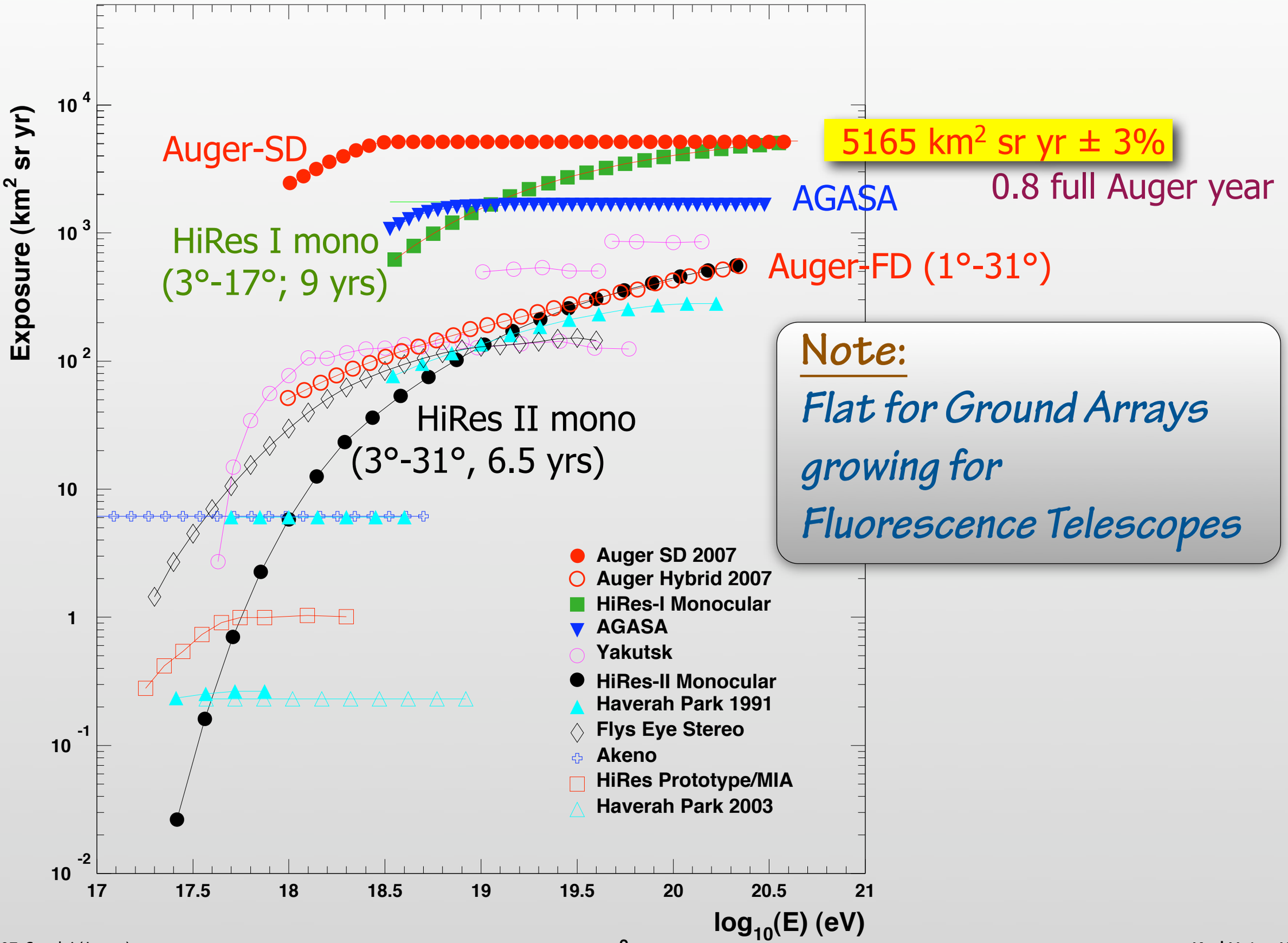
Telescope Array

planned



JEM-EUSO

Exposures 2007



Note:

Flat for Ground Arrays growing for Fluorescence Telescopes

The HiRes Experiment

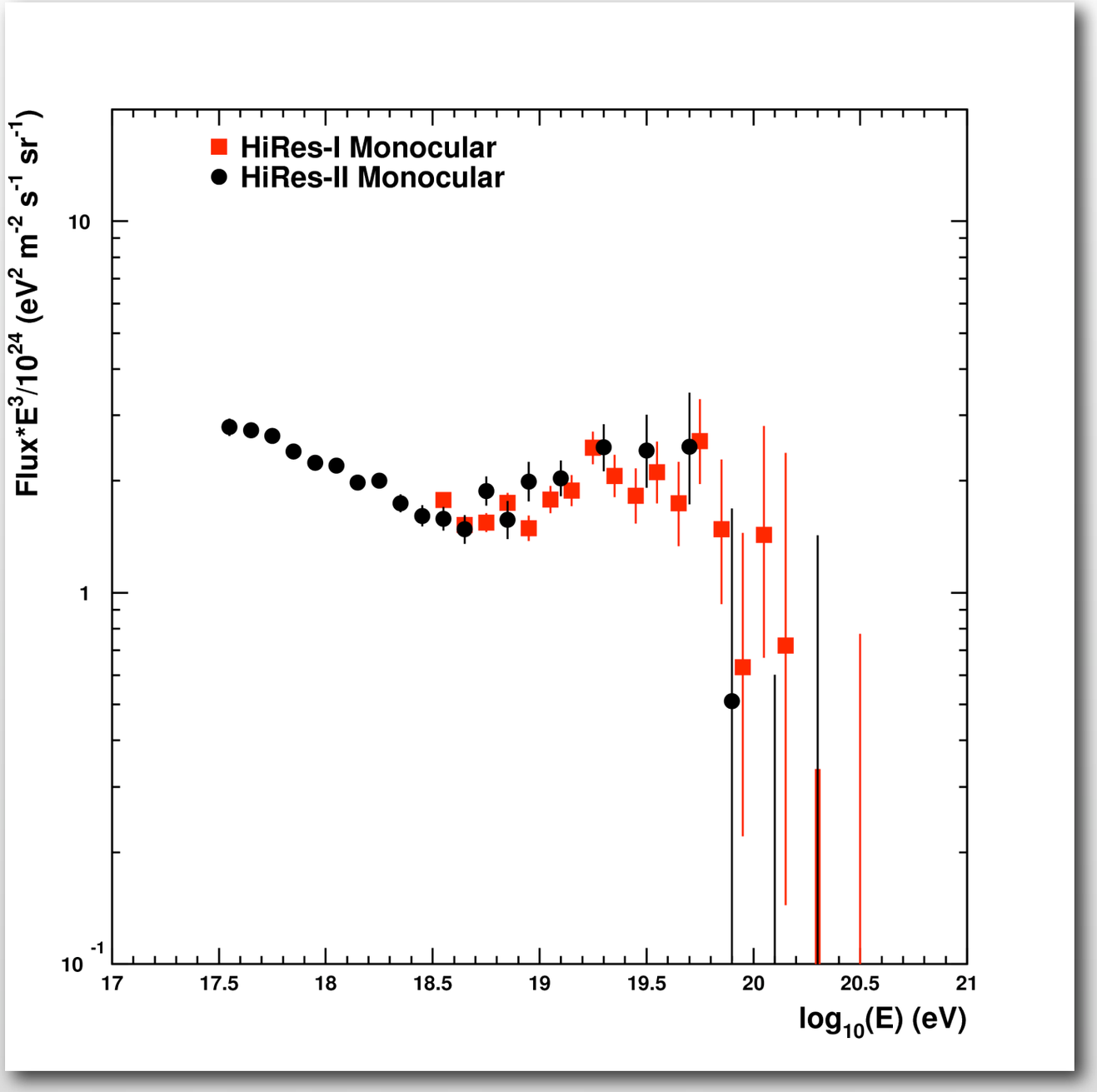
- **HiRes-I**
  - 21 mirrors
  - 1 ring, full azimuth, 3°-17° elevation
  - Sample & Hold DAQ System
  - Took data: June 1997-April 2006

- **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

slide from D. Bergmann

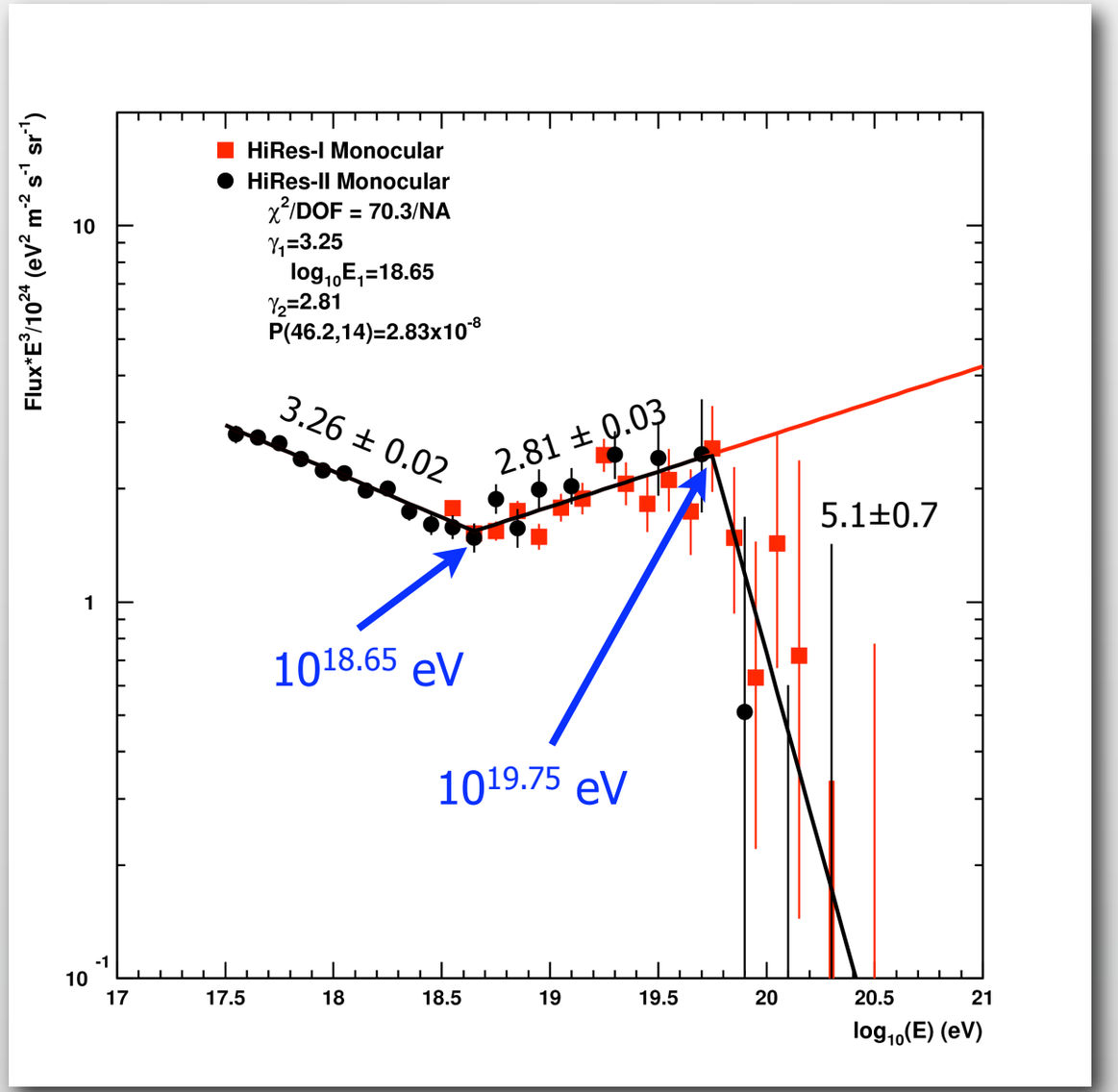
HiRes Monocular Spectra



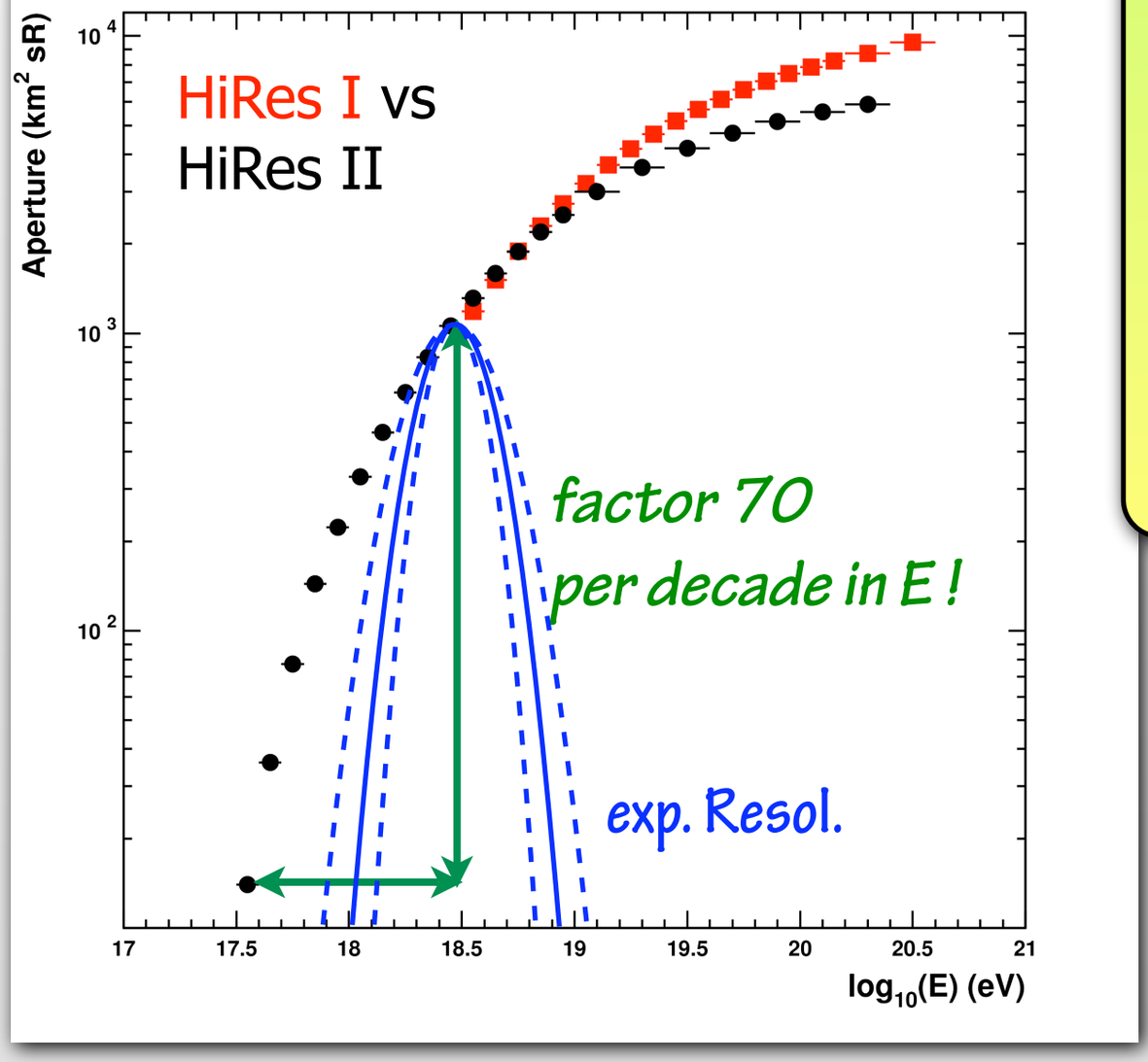
GZK effect

Expect 39.9±3.3, observe 13

P=7x10^{-7} (4.8σ) ; 6.5x10^{-6} (4.3σ)

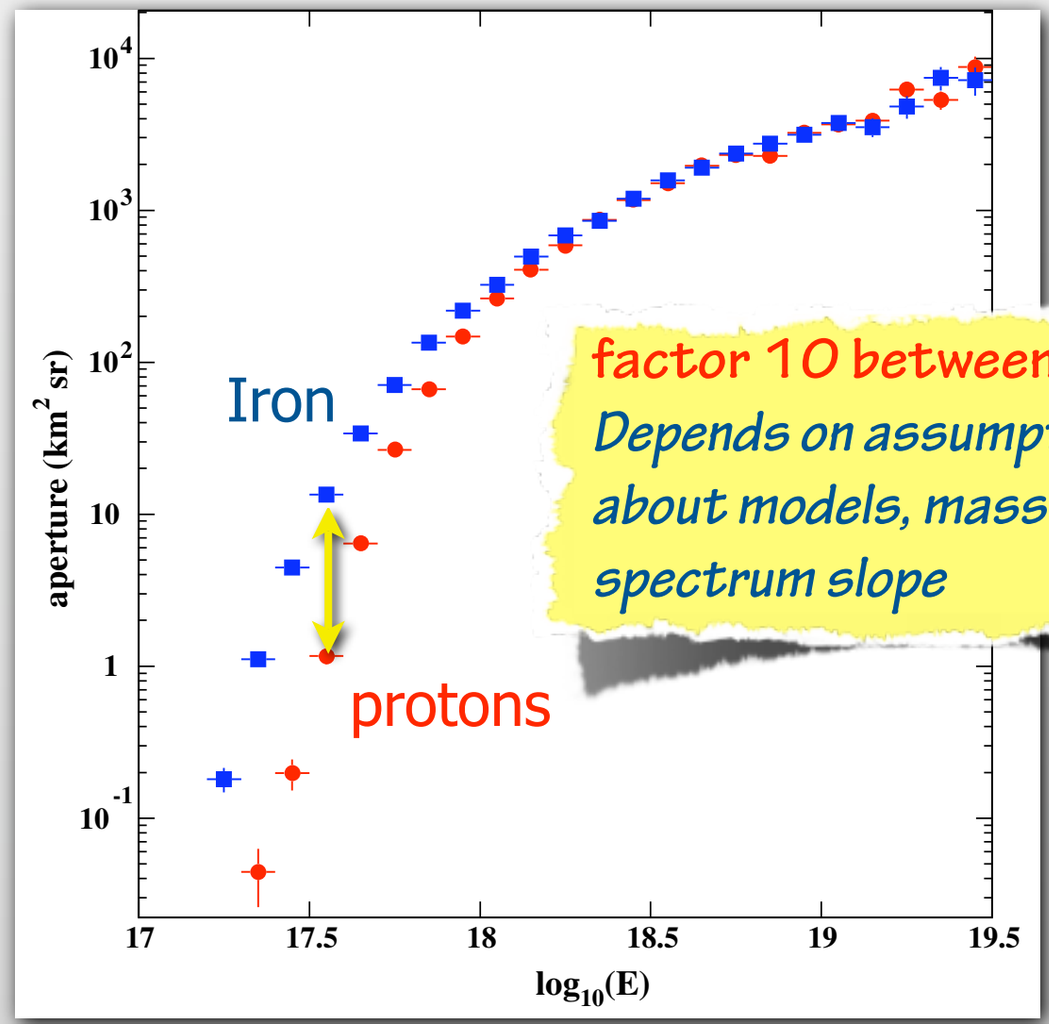


HiRes Aperture & Error Table



HiRes Energy Scale Uncertainties

– Missing Energy	5%
– Energy Loss Rate	10%
– Fluorescence Yield	6%
– Atmospheric Conditions	4%
– Photometric Calibration	10%
• Total Energy Scale Uncertainty	17%



Pierre Auger Observatory

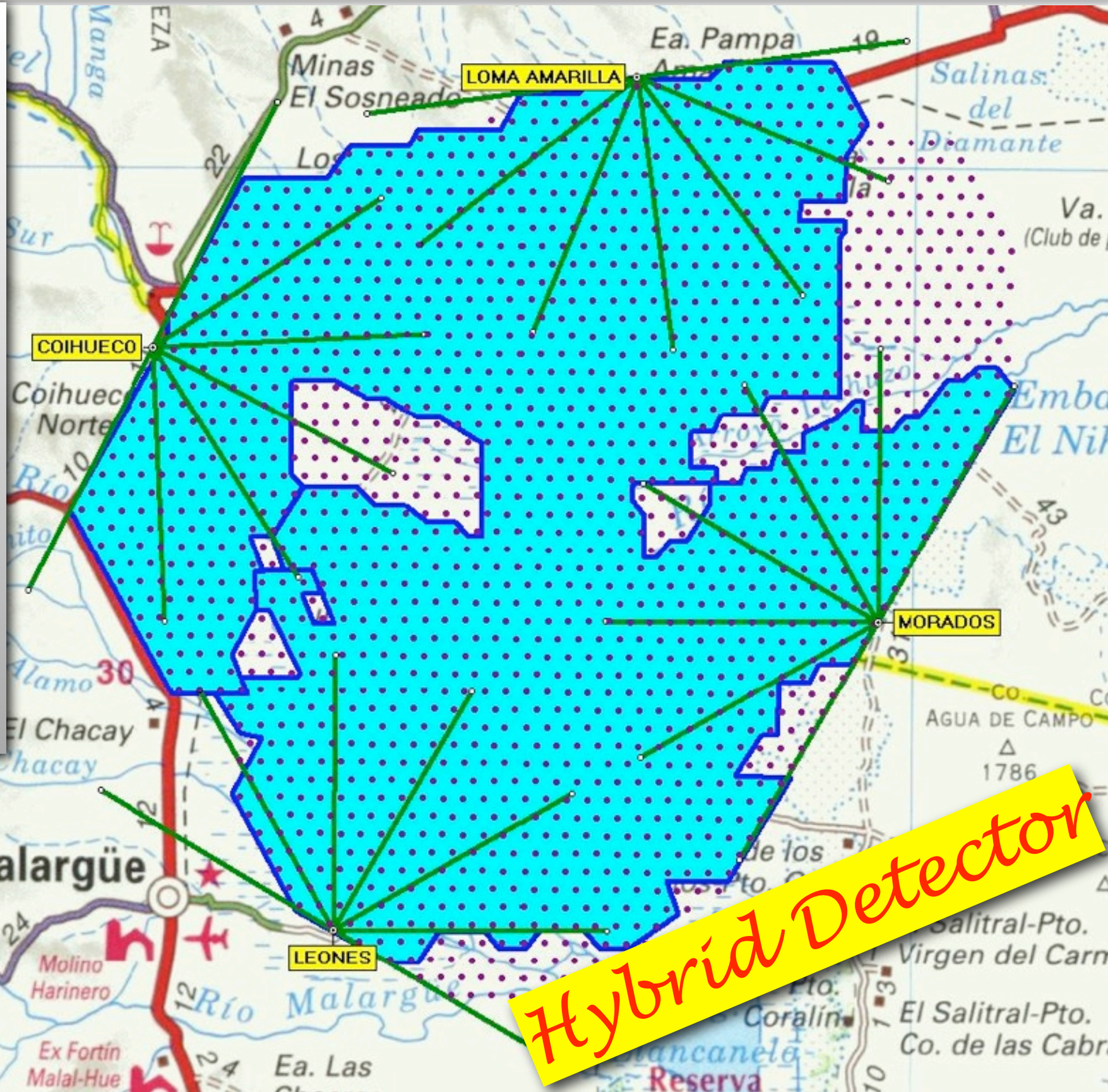
1482 deployed
1436 filled
1364 taking data

~ 85%

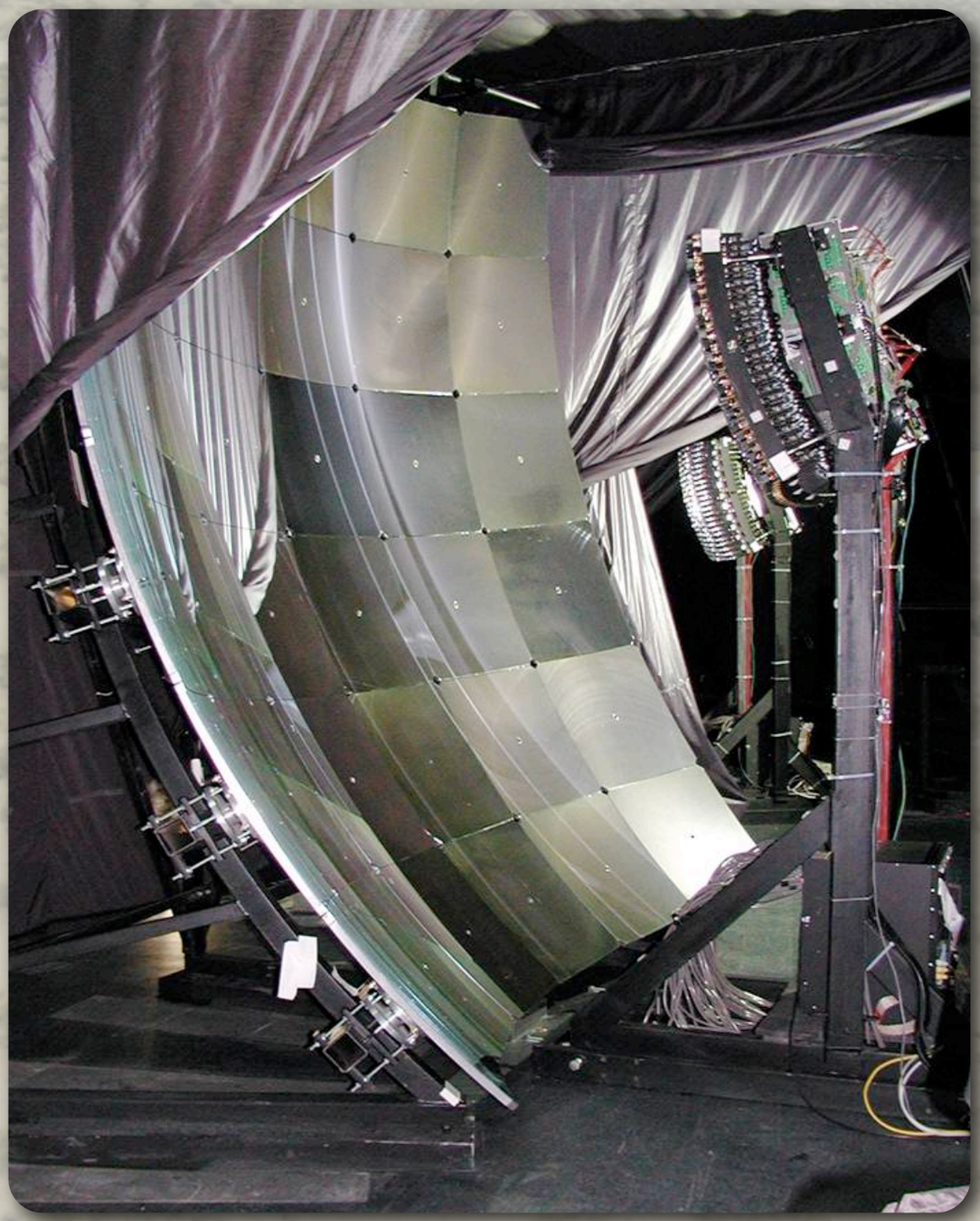
All 4 fluorescence buildings complete, each with 6 telescopes

Final: 1600 tanks

August 1, 2007



The Auger Hybrid Observatory

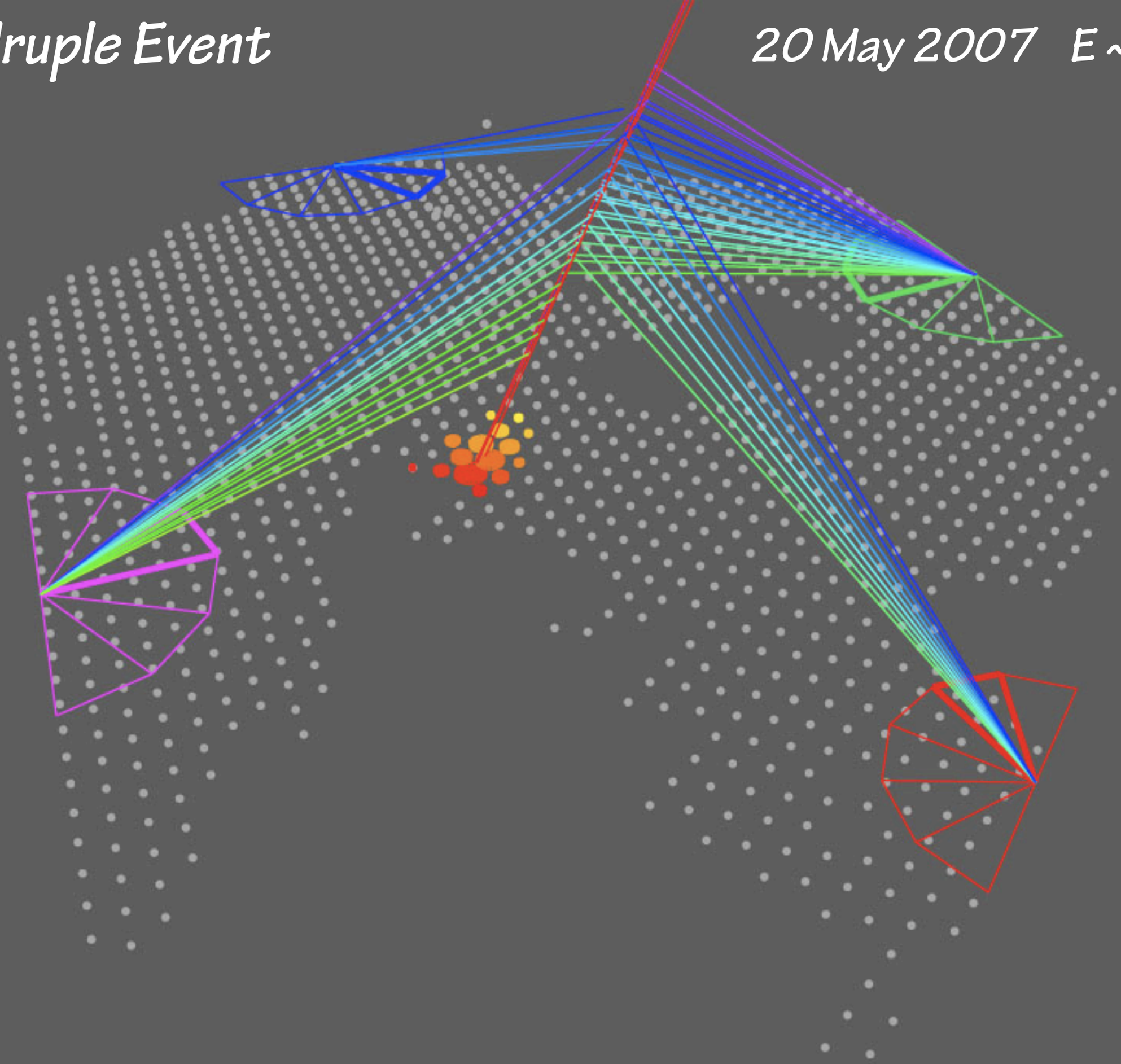


24 fluorescence telescopes...

...1600 Water Cherenkov tanks

Quadruple Event

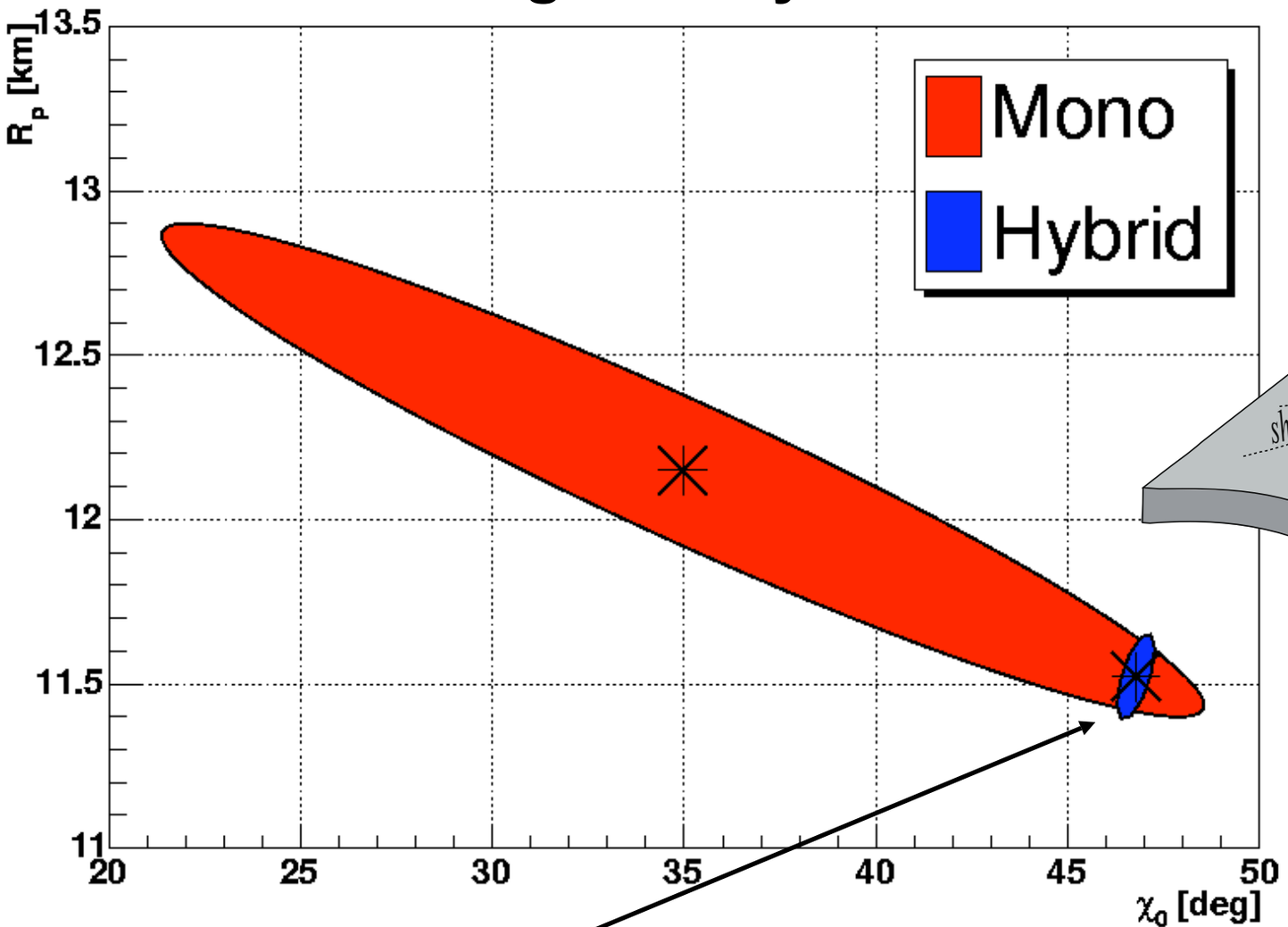
20 May 2007 $E \sim 10^{19}$ eV

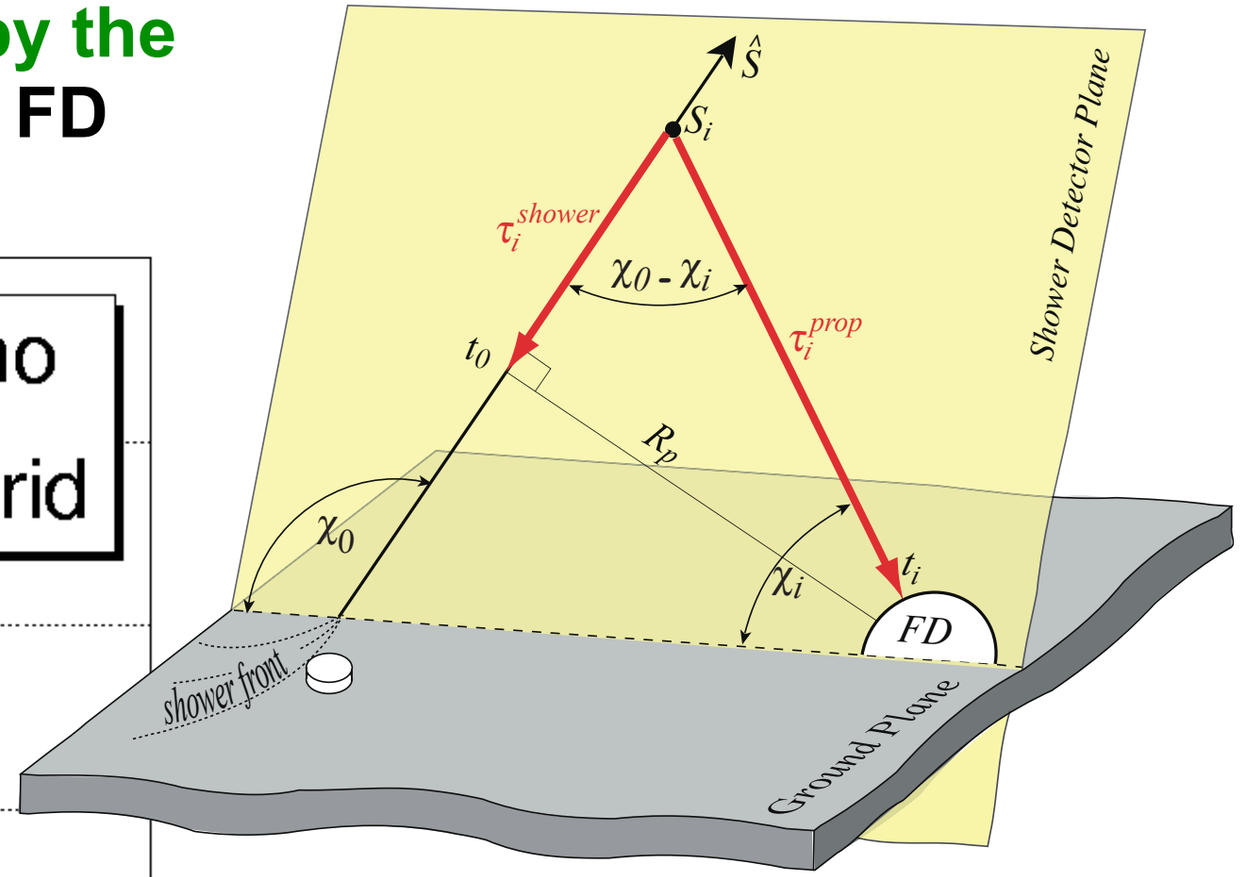


Hybrid - Precise Shower Geometry

first step towards precise energy, depth of maximum

Arrival time at ground provided by the SD, removes degeneracy in the FD geometry fit





Get T_0 from SD tank!
Geometry uncertainties shrink!

$$t(\chi) = T_0 + \frac{R_p}{c} \tan\left[\frac{(\chi_0 - \chi)}{2}\right]$$

The Power of Hybrid

	Hybrid	SD-Only	FD-only
Angular Resolution	**~ 0.2°**	**~ 1 - 2°**	**~ 3 - 5°**
Aperture	**Flat model ind.**	**Flat model ind.**	**growing model depend.**
Energy	**model ind.**	**model dep.**	**model ind.**

The combination is more than the sum of the individuals !

FD-mono-Uncertainties: HiRes vs Auger

	Auger	HiRes	
Fluorescence Yield	14%	6%	11,6
Energy loss rate		10%	
p, T, & humidity effects on yield	7%	4%	
Photometric Calibration	9,5%	10%	
Invisible Energy	4%	5%	
Reconstruction	10%	?	
Total	**21%**	**17%**	

if reconstruction uncertainty is ignored: 19 %

Note: this causes an integral

flux uncertainty (γ =3.0) of: **46 %** **37 %**

(on top of effect of acceptance uncertainty)

FD energy calibration

Fluorescence yield is at present the dominant error contribution

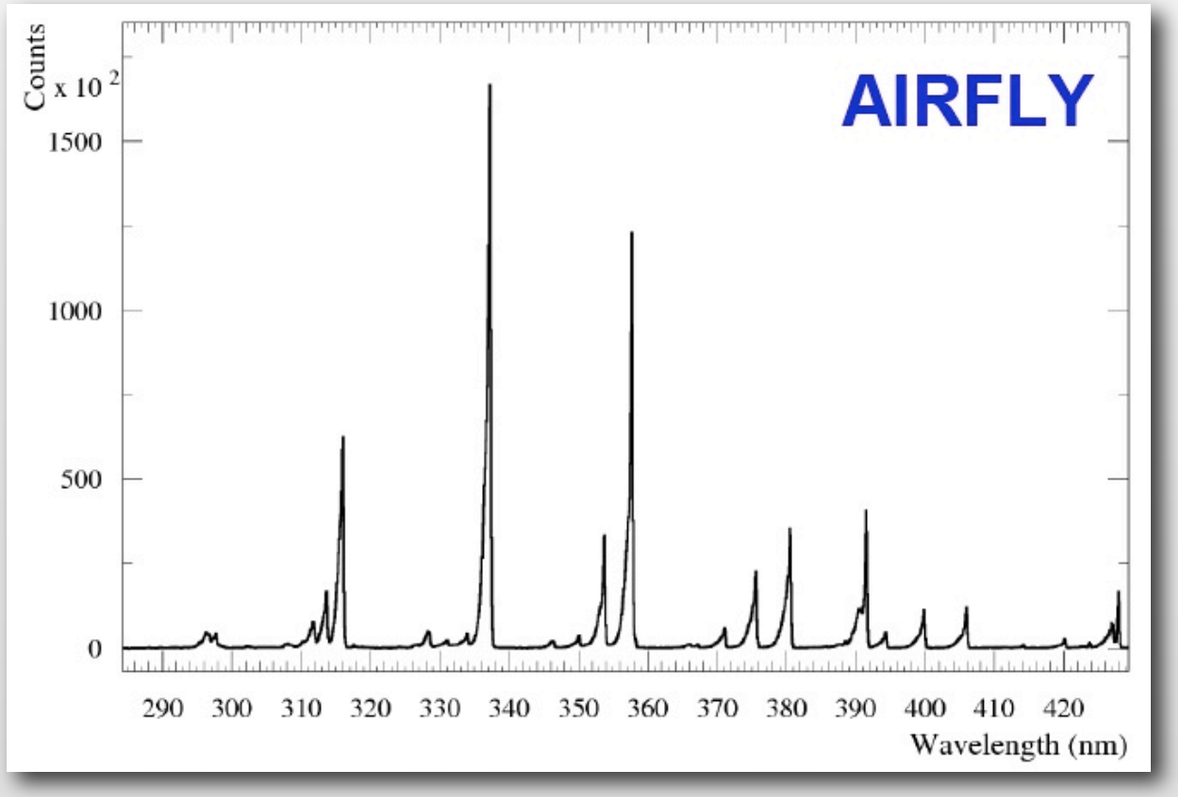
also: Auger uses Nagano et al, HiRes uses Kakimoto et al.

New (better) data will become available from:

AIRFLY using test beam at DAΦNE and elsewhere measuring p, T, and humidity dependence of abs. yield

FLASH using test beam at SLAC

MACFLY using CERN-SPS test beam

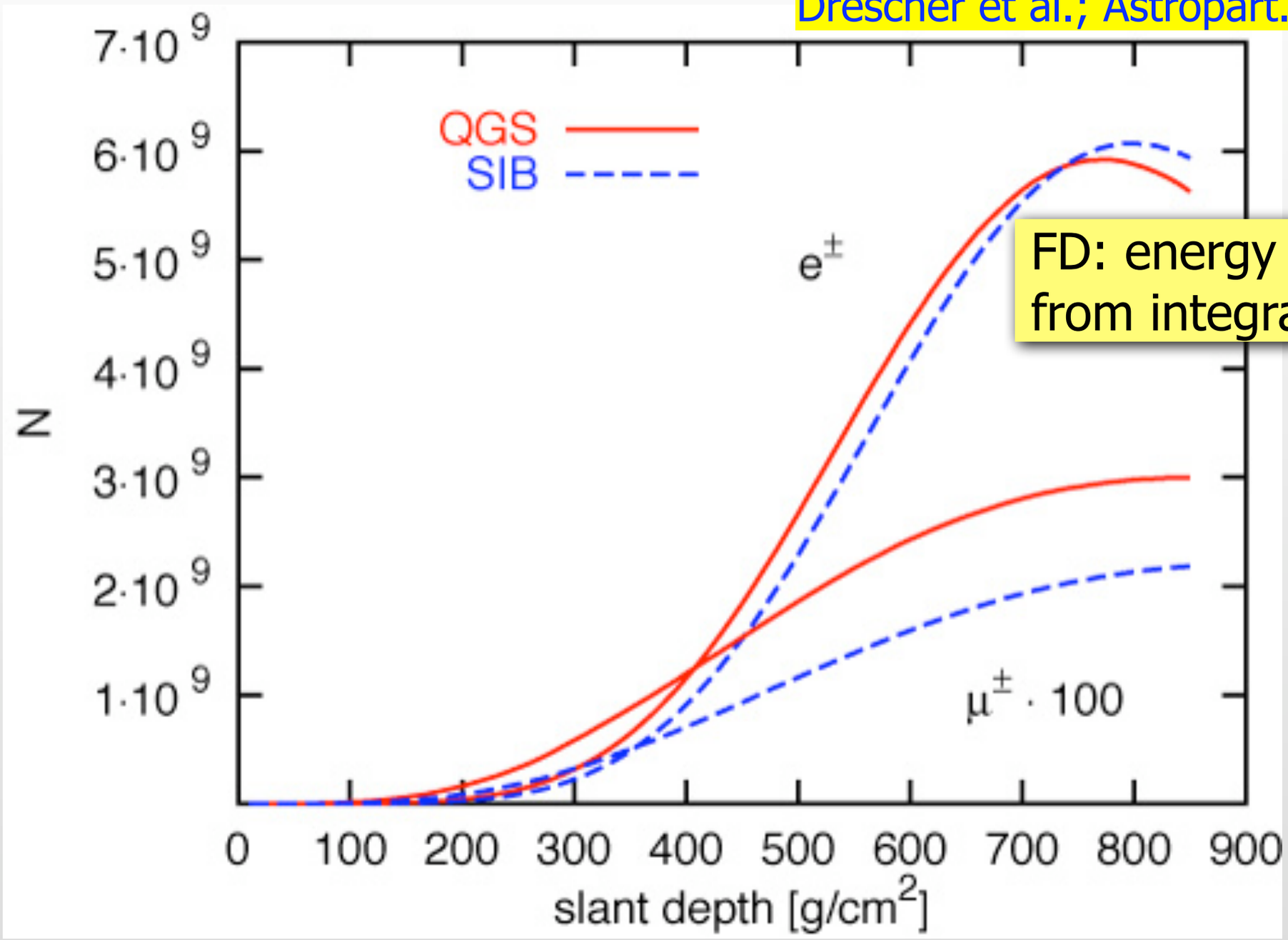


Goal: reach 1 % level

Data on abs. yields expected to be released at workshop in Spain next week

FD Systematics by Interaction Models

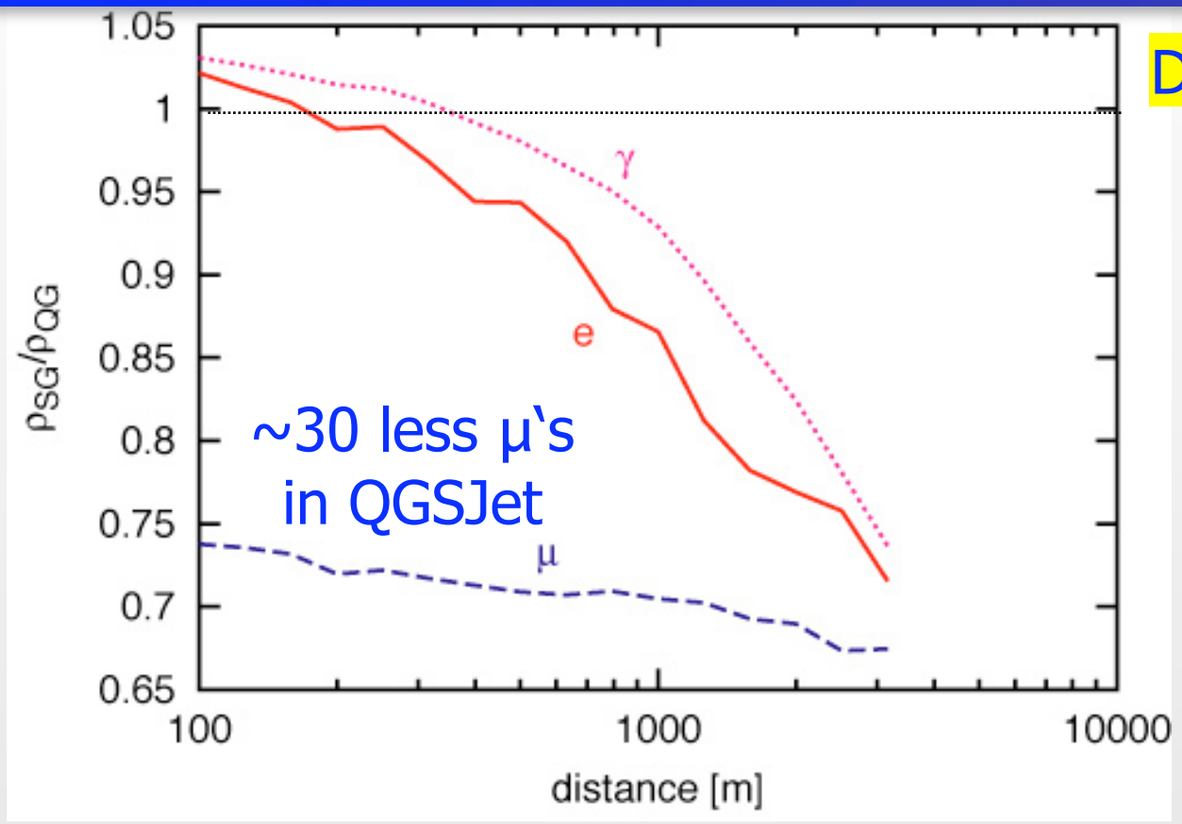
Drescher et al.; Astropart. Phys. 21 (2004) 87



FD: energy obtained from integral

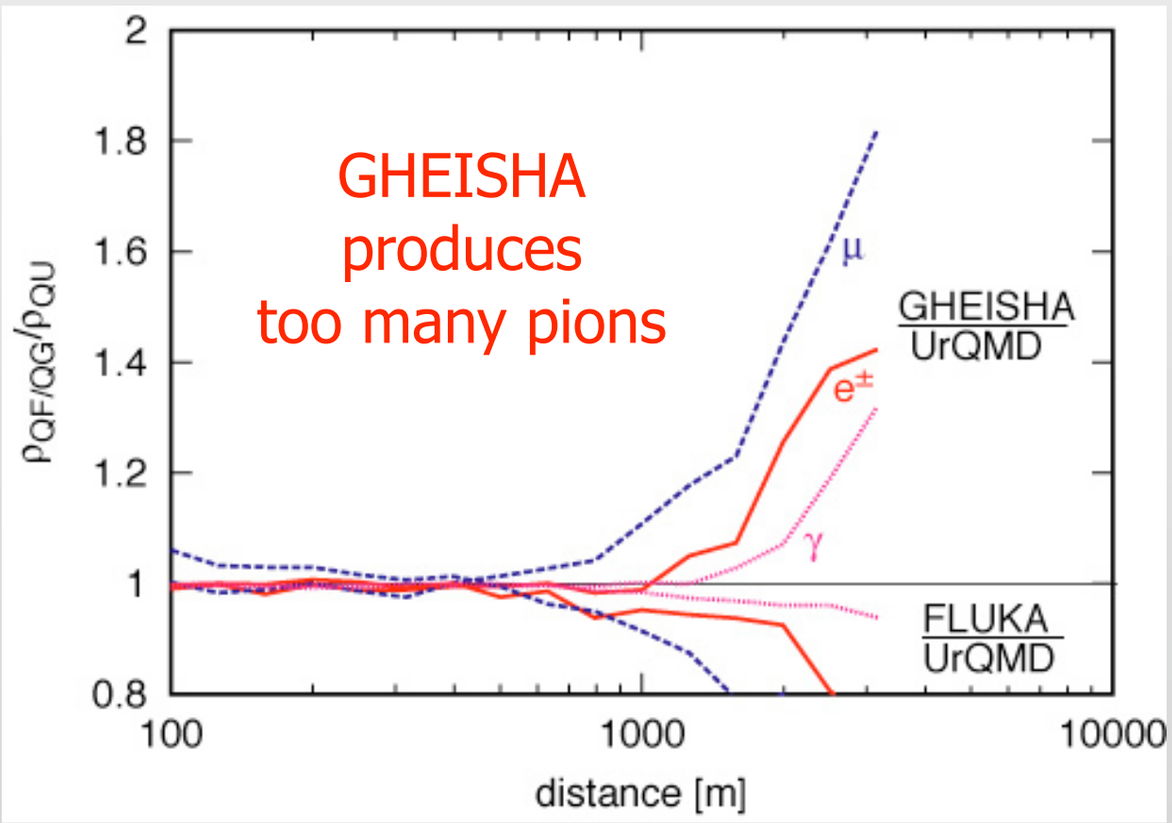
QGSJet & SIBYLL agree within a few percent

SD Systematics by Interaction Models



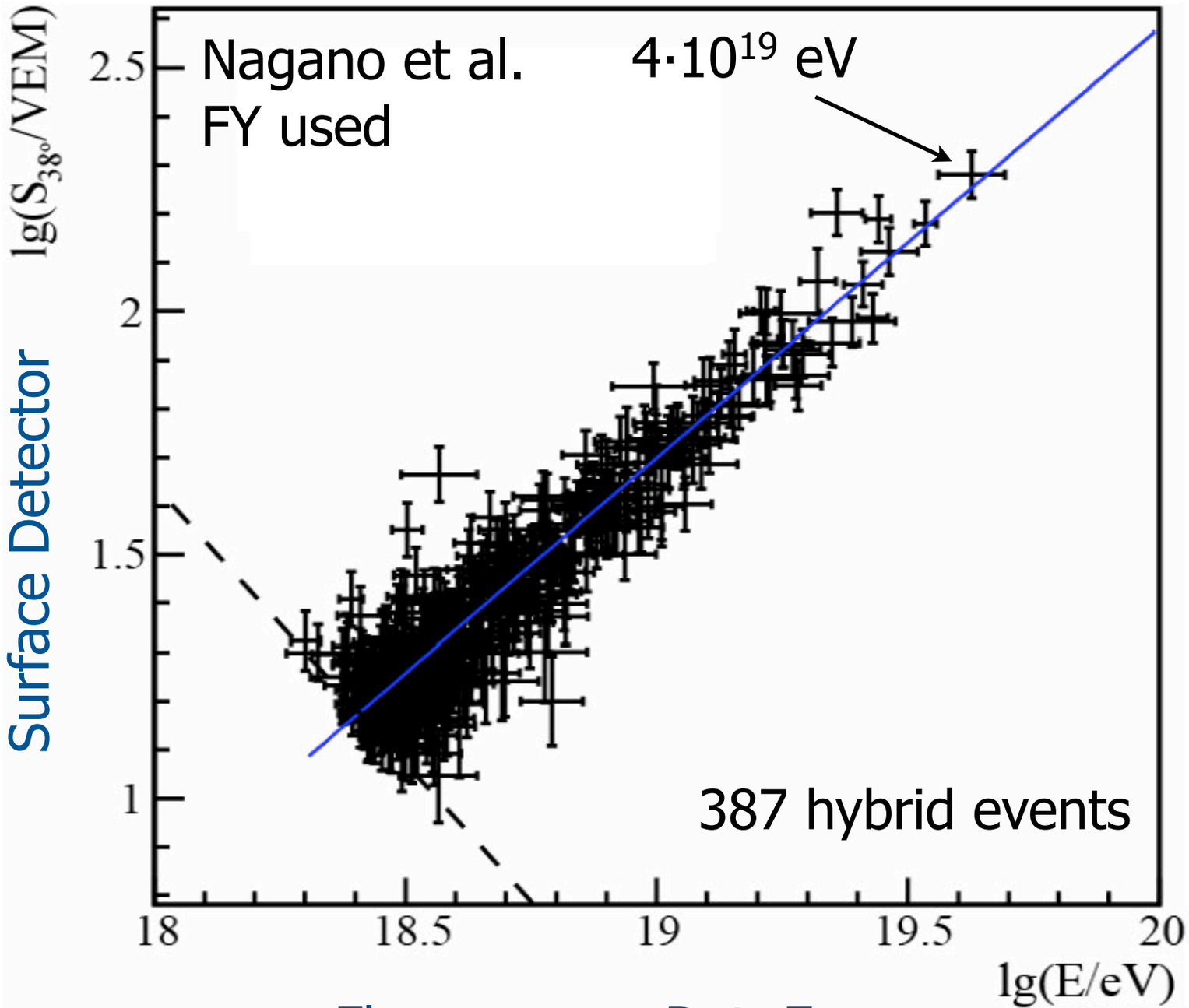
Drescher et al.; Astropart. Phys. 21 (2004) 87

Effect of **High-Energy Interaction Model**:
Sibyll / QGSJet (Gheisha)
~ 30 % effect to E



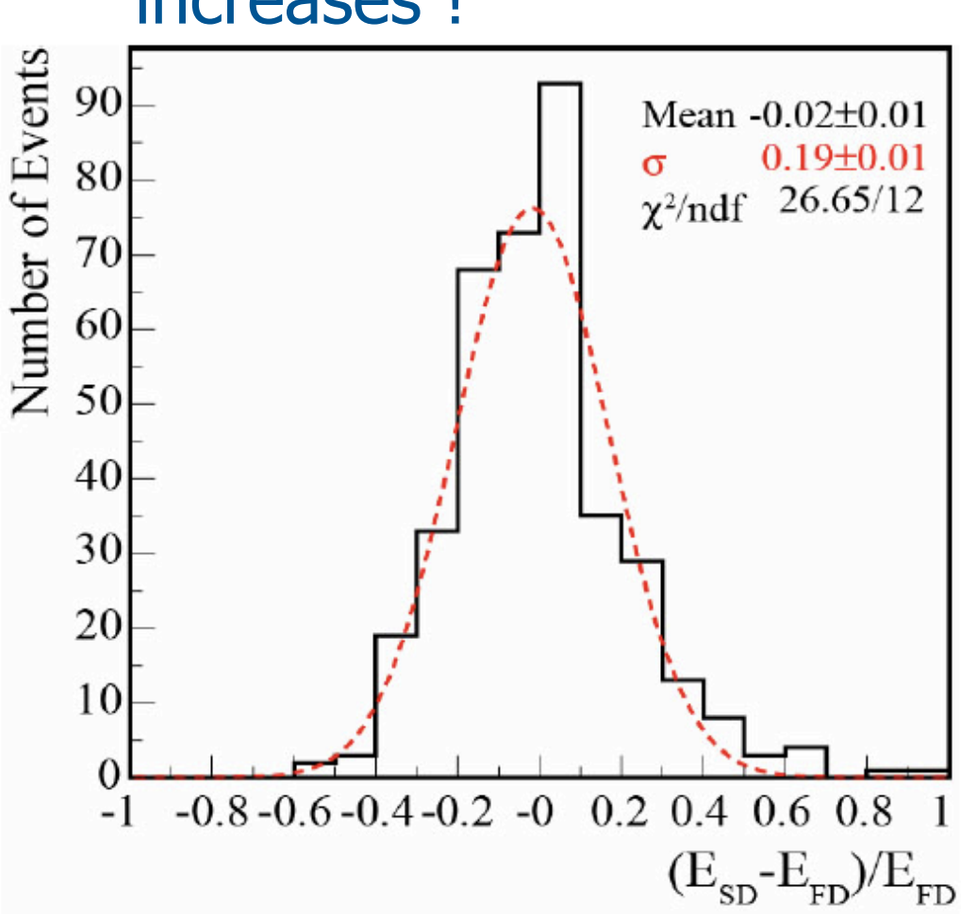
Effect of **Low-Energy Interaction Model**:
GHEISHA & FLUKA / UrQMD
~ 10-20 % effect to E

Auger: SD Calibration by FD



$\sigma(E_{FD}\text{-}E_{SD})$= 19%

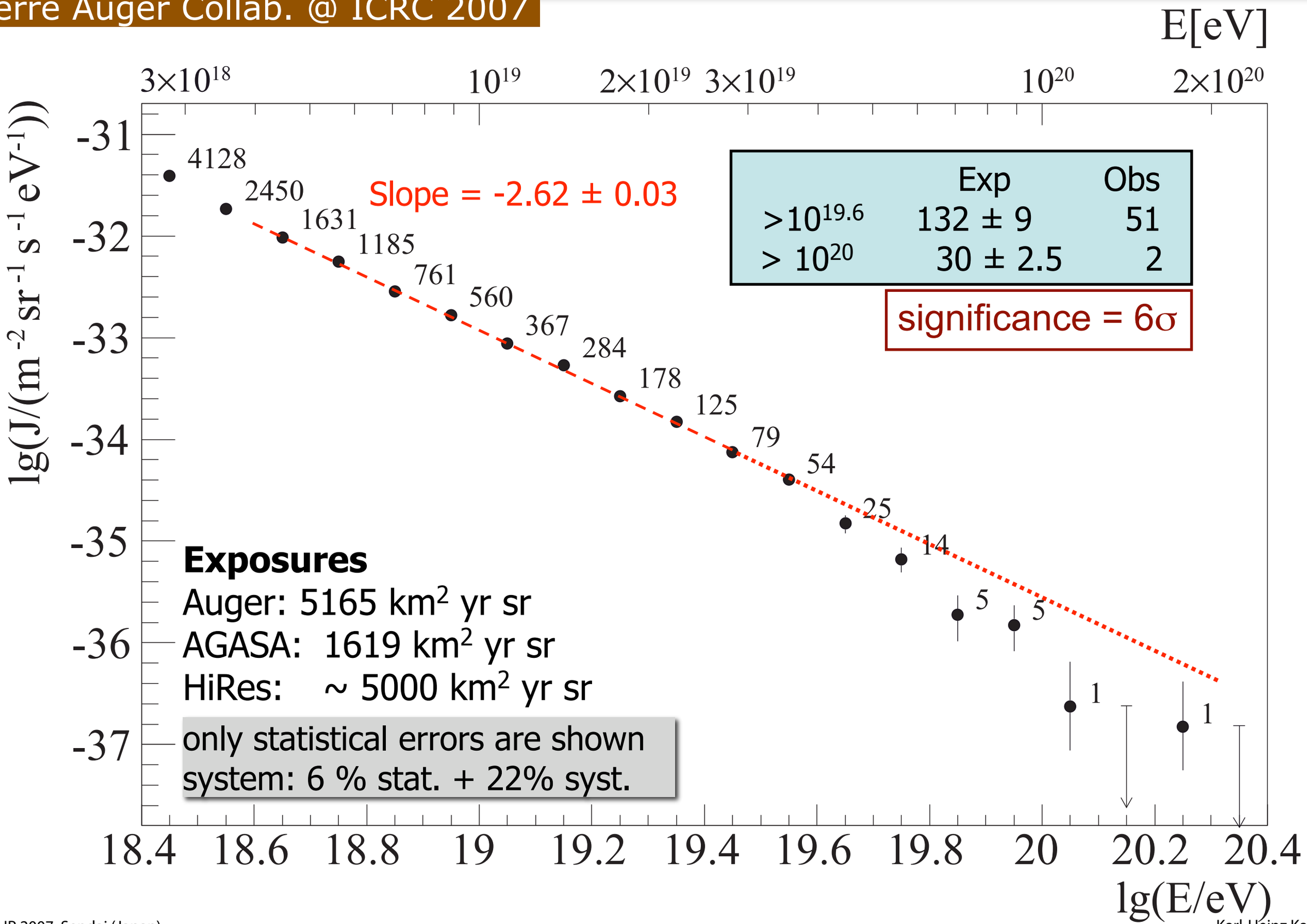
... improves as energy increases !



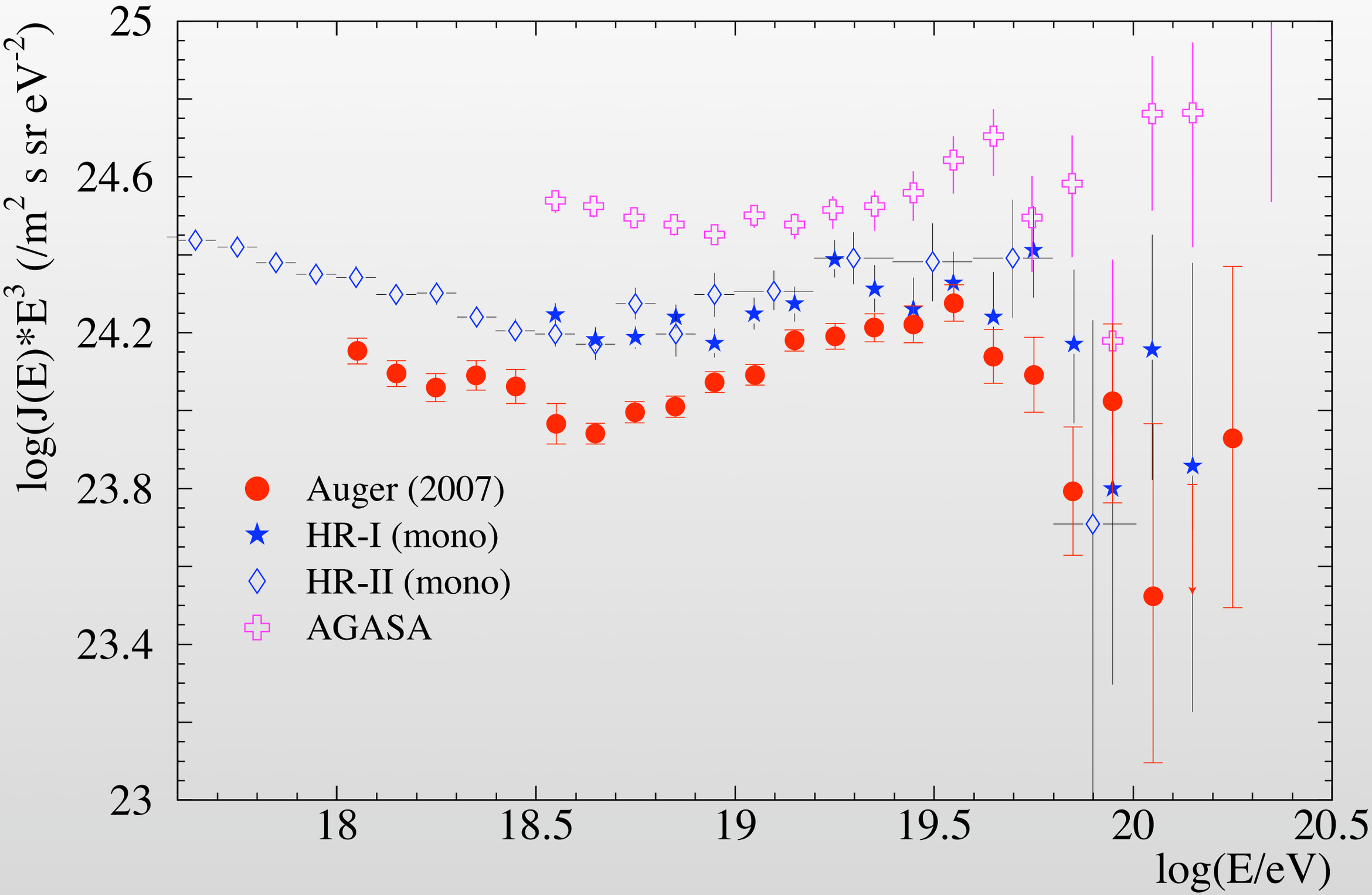
Energy Spectrum

Auger E-Spectrum (Θ< 60°)

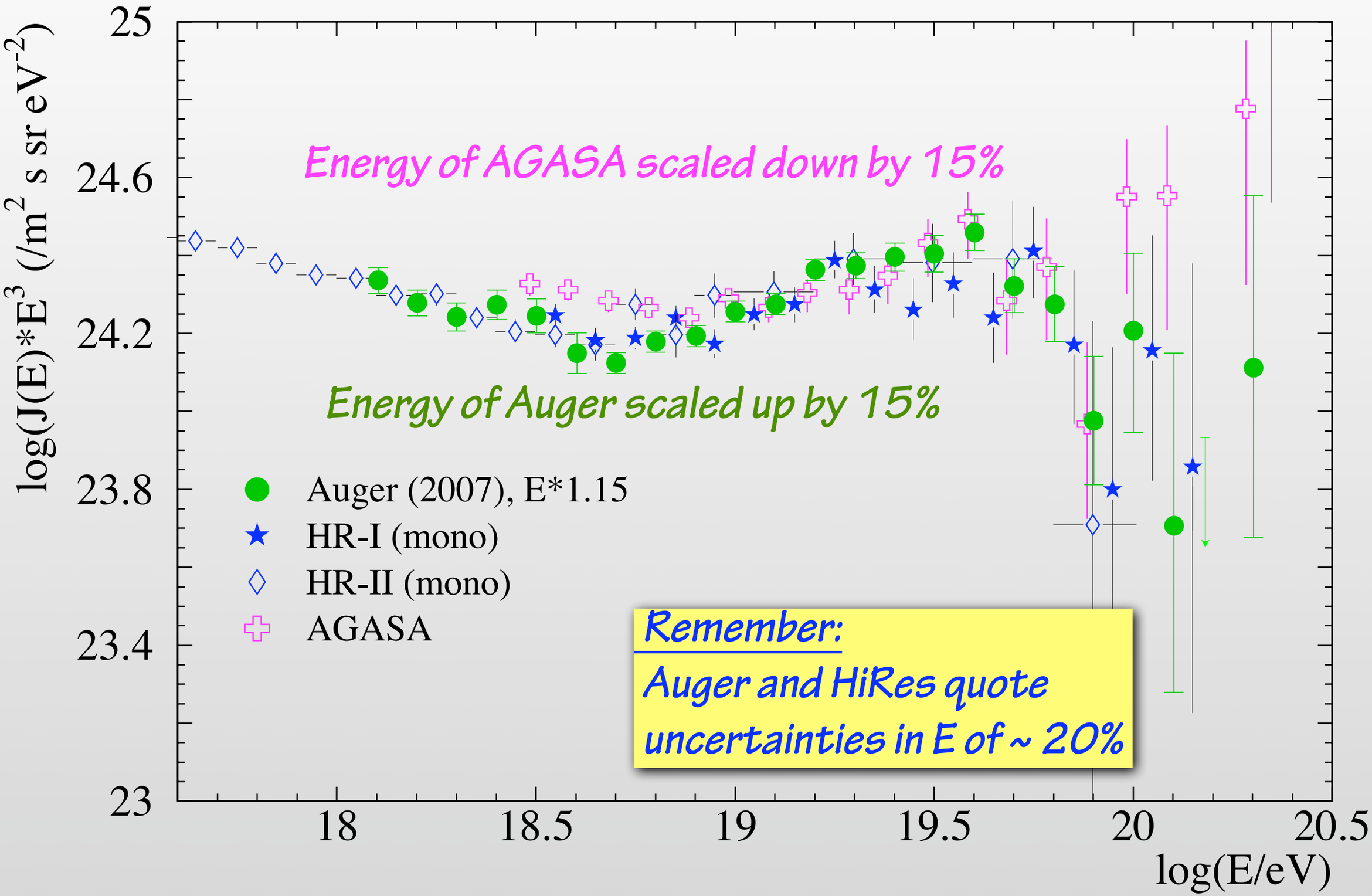
Pierre Auger Collab. @ ICRC 2007



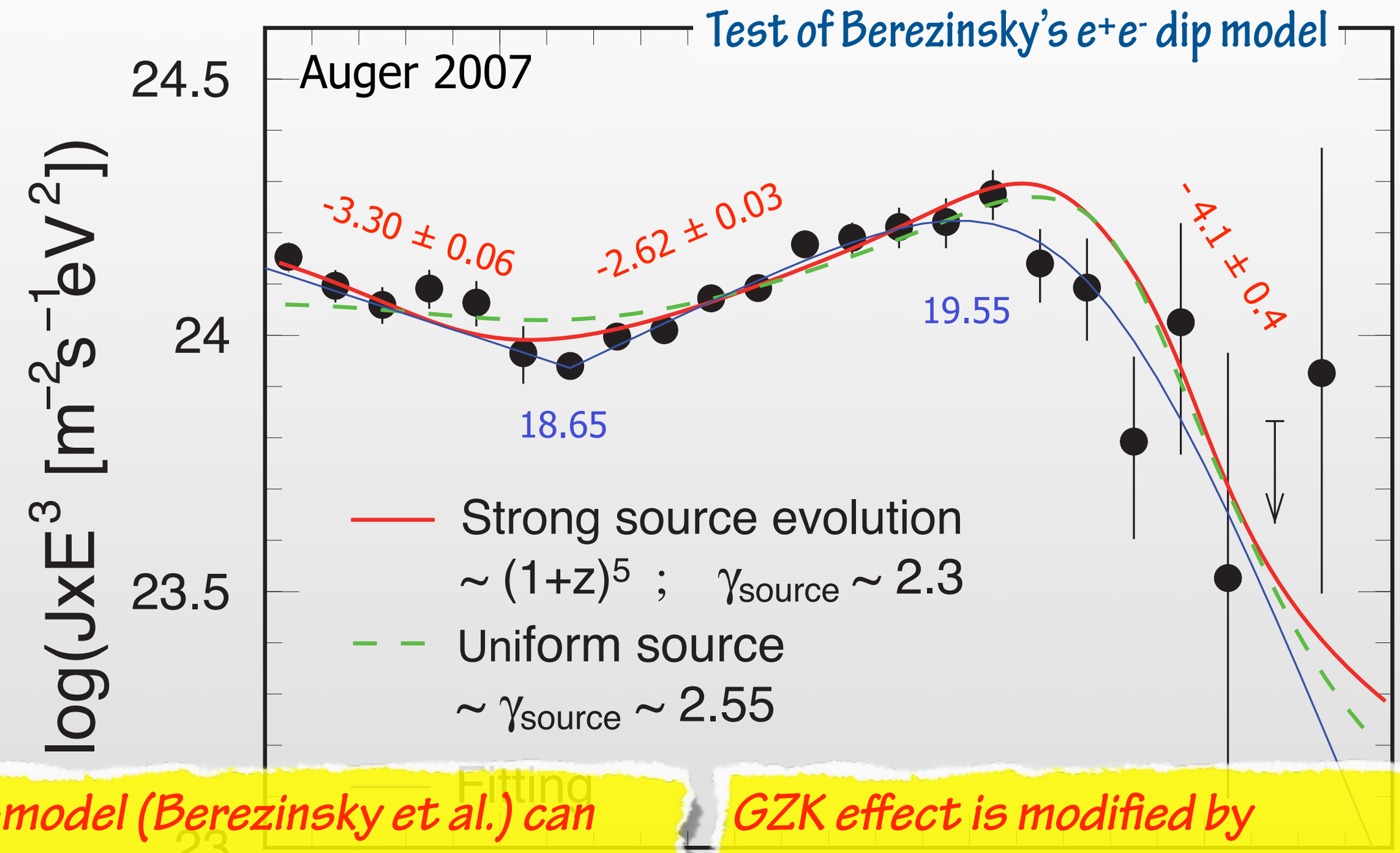
Energy Spectra: Comparison



Energy Spectra: Comparison



Auger Spectrum & Source Distr.



dip-model (Berezinsky et al.) can describe E-spectra...

... as ankle model can do

... and mixed model

GZK effect is modified by

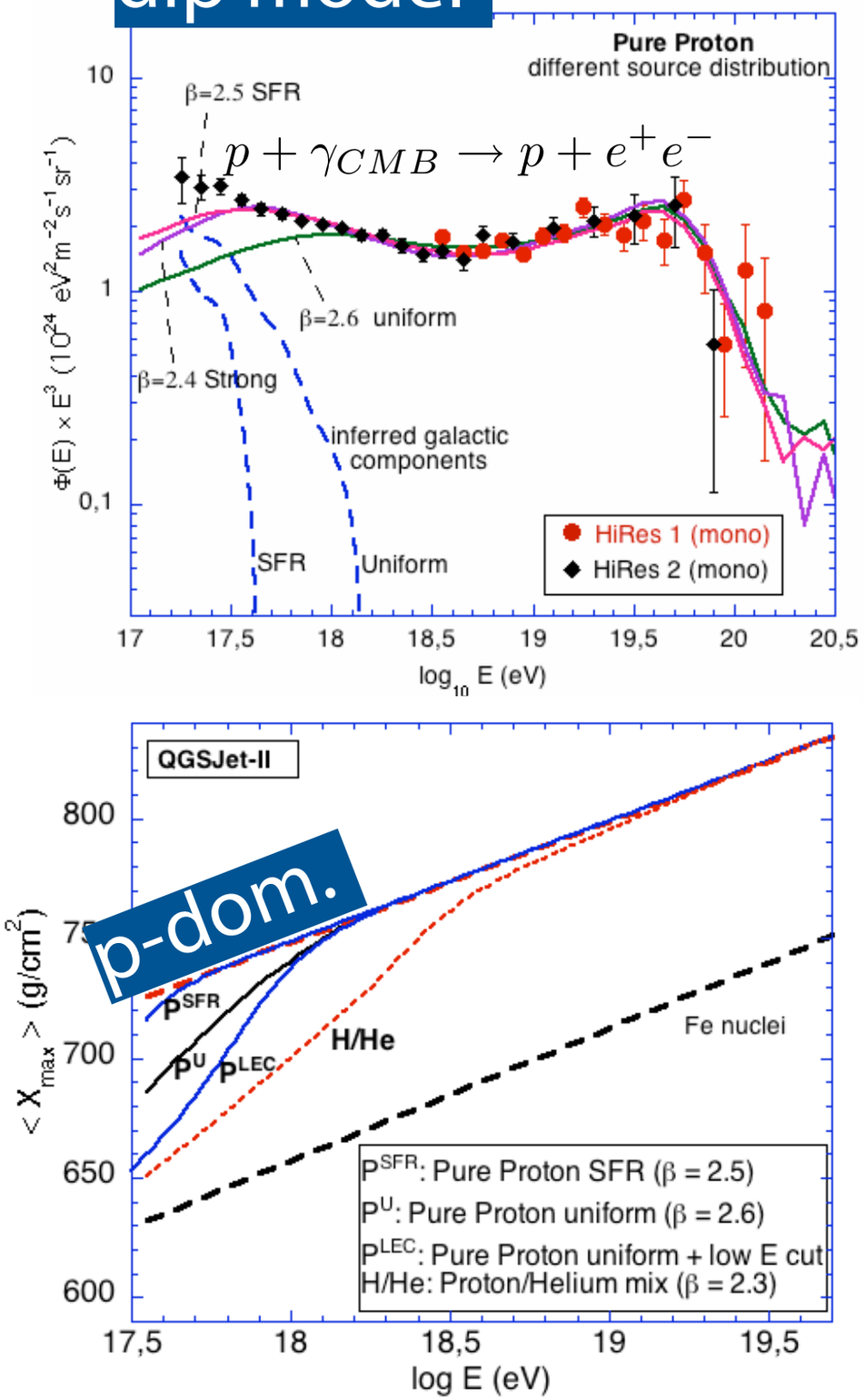
- *E-distribution of source*
- *source local overdensity/deficit*
- *different values of E_{max}*

Composition

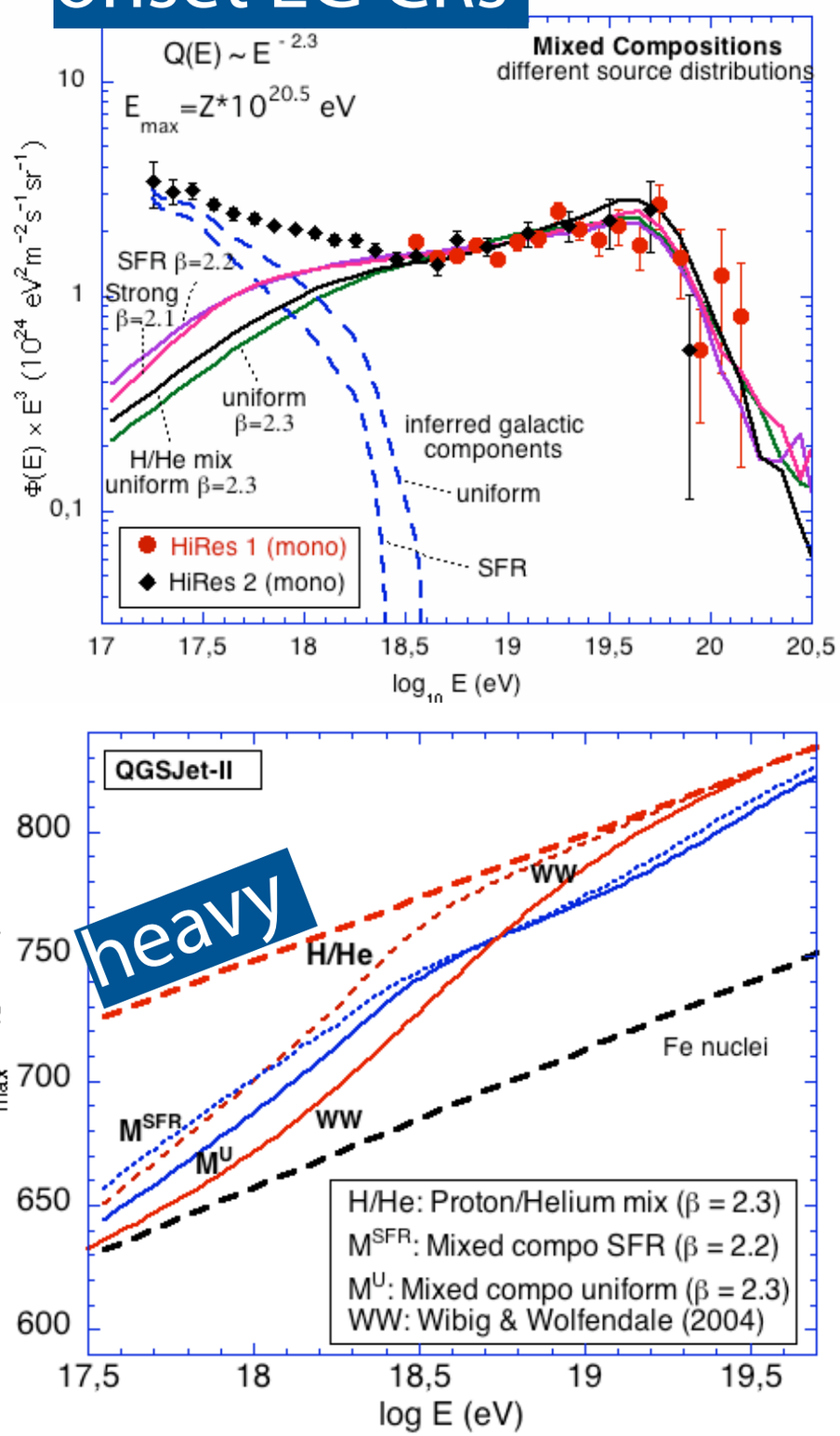
Ankle: Measurement of composition is crucial !

Allard, Olinto, Parizot; astro-ph/0703633

dip model

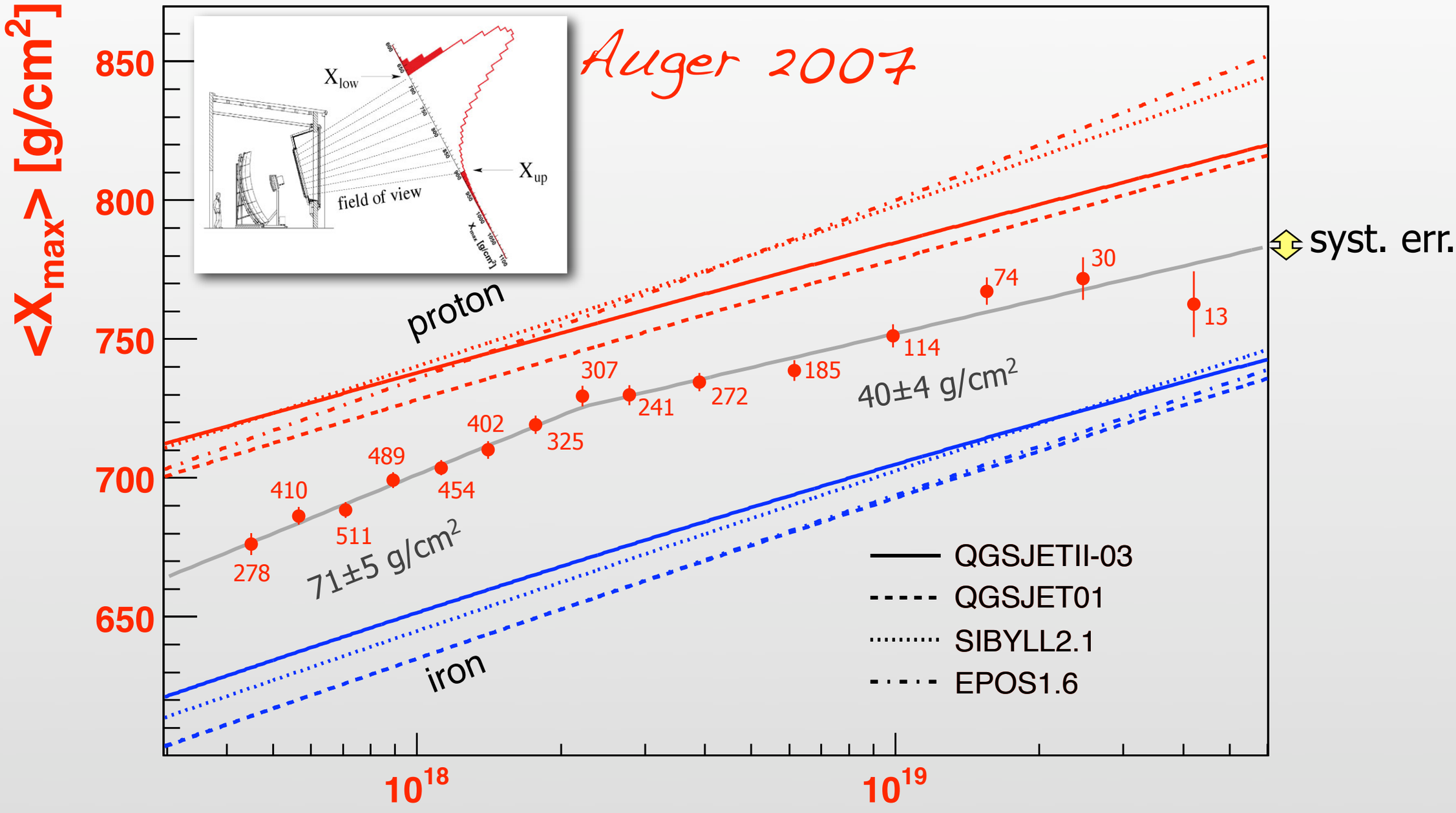


onset EG CRs



Mass from X_{max} observations

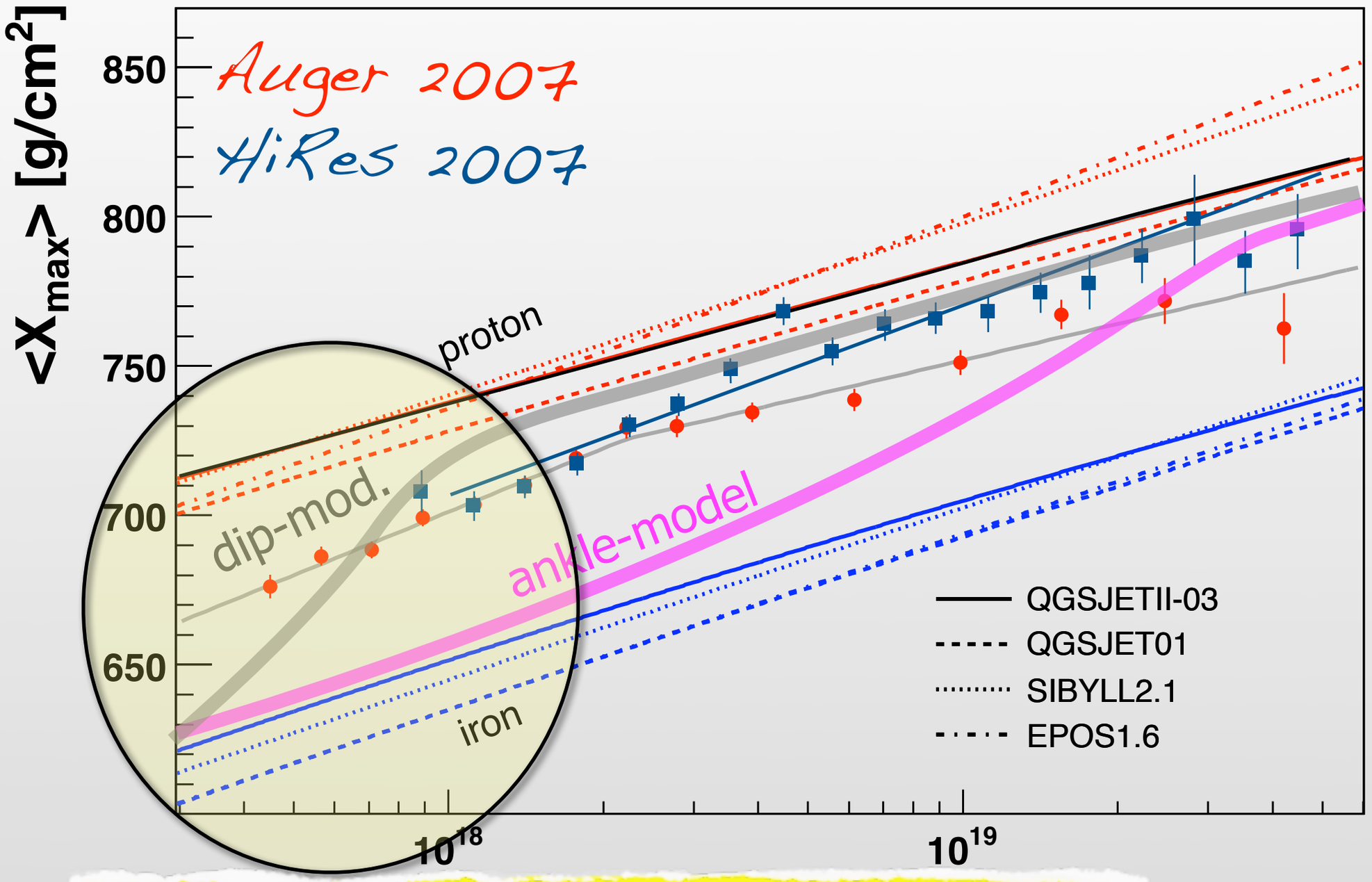
Pierre Auger Collab. @ ICRC 2007



Straight line fit of elongation rate: P < 3%

Systematic error of X_{max}: <15 g/cm2 @ <10^{18} eV; < 12 g/cm^2 @ > 10^{18} eV

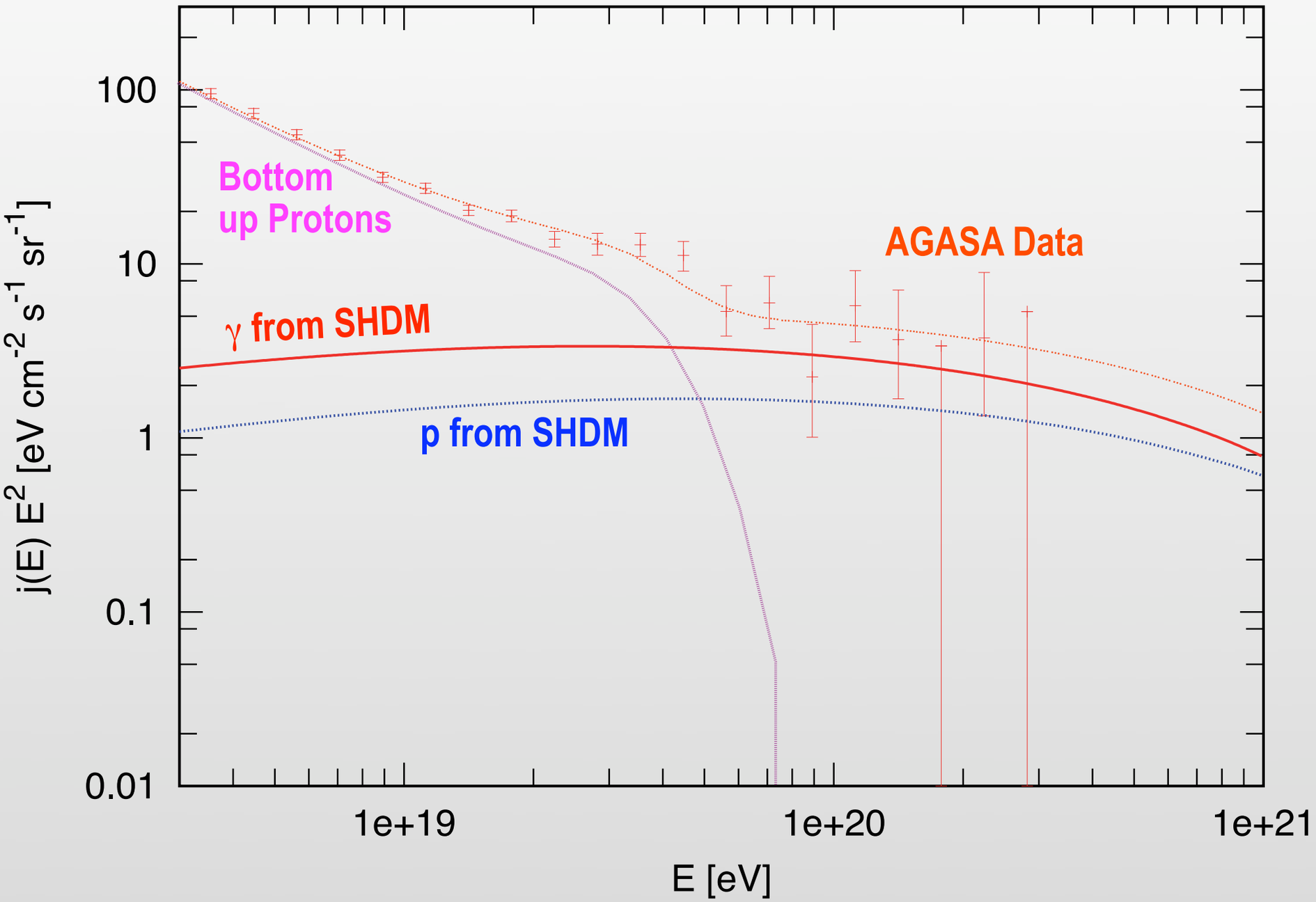
Mass from X_{max} observations



Elongation rate will be the most sensitive tool to settle quest about G-EG-Transition

UHE Photons ? *Expected by Top-Down models*

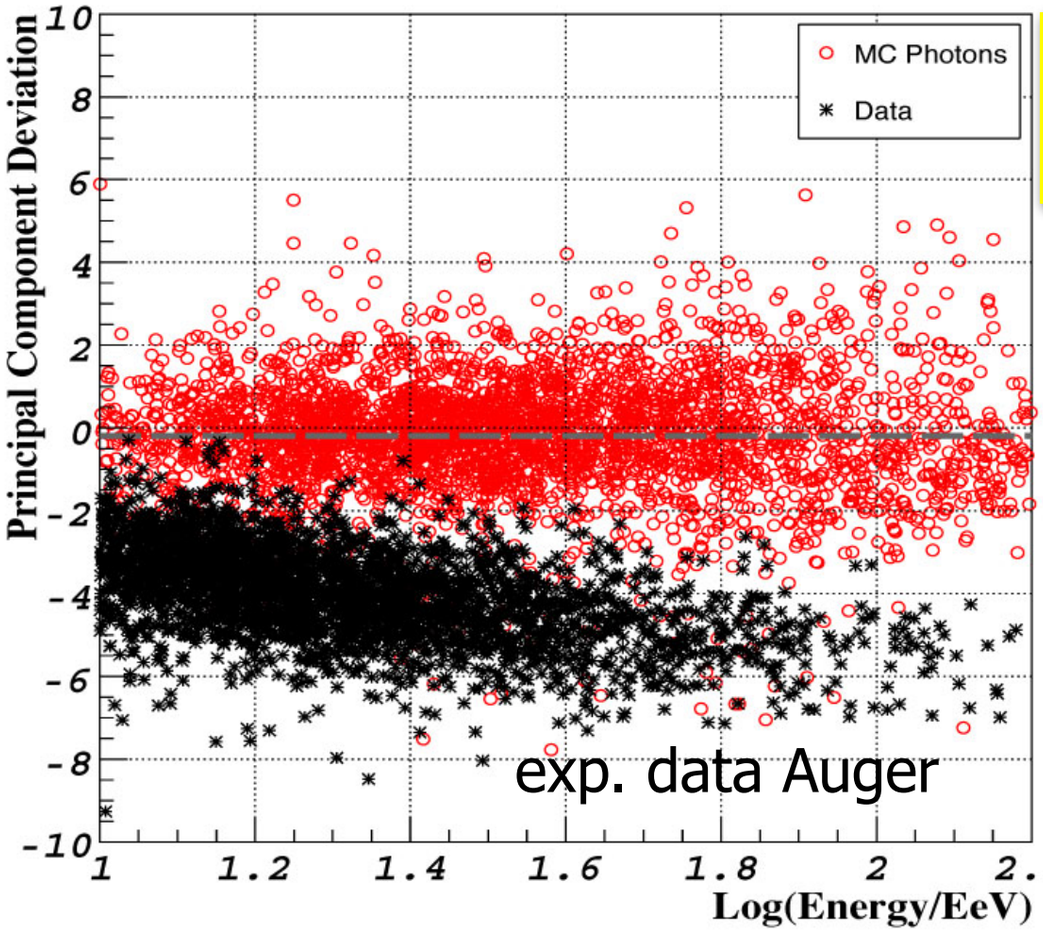
e.g.: **S**uper **H**eavy **D**ark **M**atter fit to AGASA



Gelmini, et al, astro-ph/0506128

UHE-Photon Limits from Ground Array

Pierre Auger Collab. @ ICRC 2007

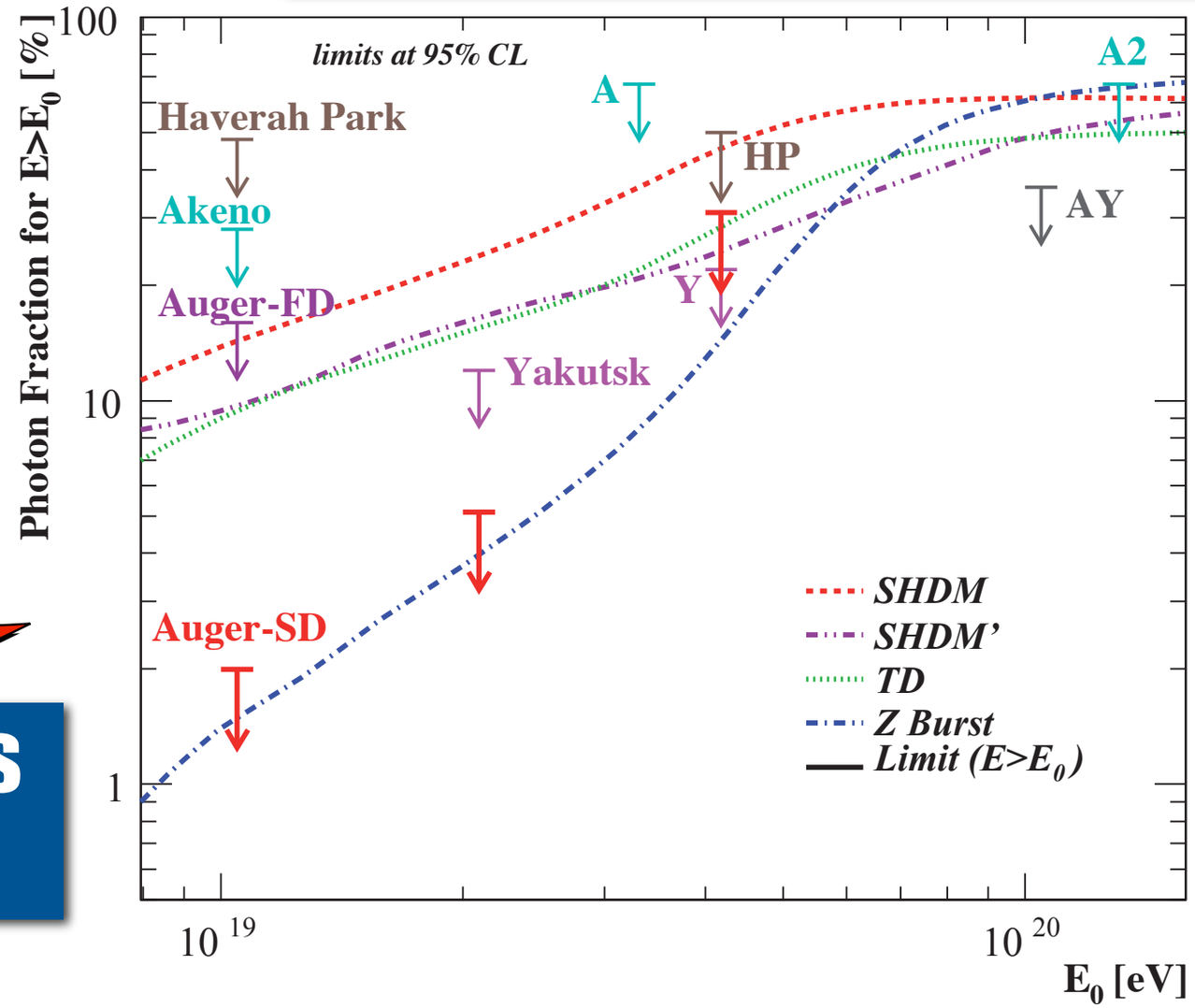


SD-Data: rise-time & shower-front curvature ⇔ μ # ⇔ primary mass

γ -simulation

← (median)

95% CL on photon fraction



SHDM & TD models largely ruled out

GZK-effect: Yes

UHE Photons: No

Top is Down
Bottom is Up

Test of Lorentz Invariance Violation

Galaverni & Sigl
arXiv:0708.1737

LIV → may modify photon dispersion relation

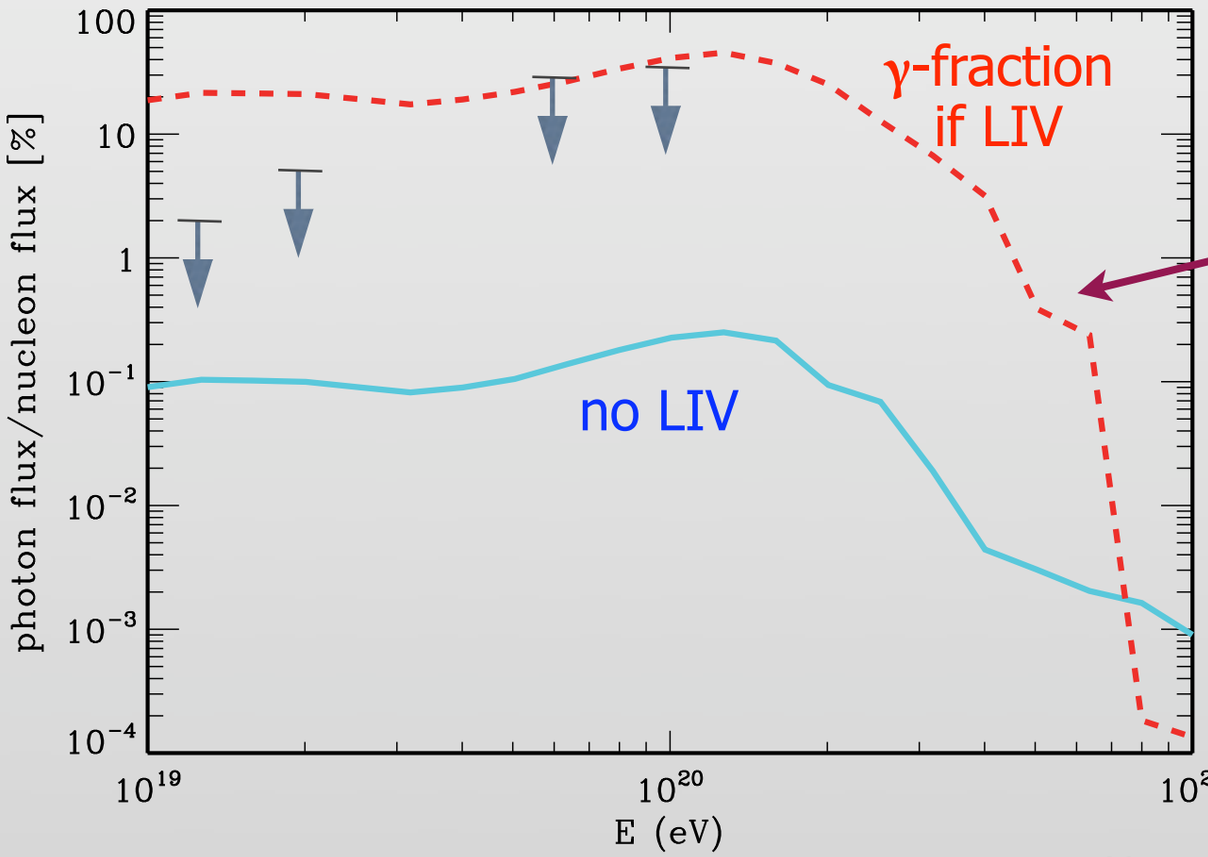
$$\omega^2 = k^2 + m^2 + \xi_n k^2 (k/M_{Pl})^n$$

→ affect the threshold for e^+e^- pair production

→ $p + \gamma_{CMB} \rightarrow \Delta \rightarrow n + \pi^0$

↳ $\gamma\gamma \not\rightarrow e^+e^-$

cascading of UHE photons suppressed



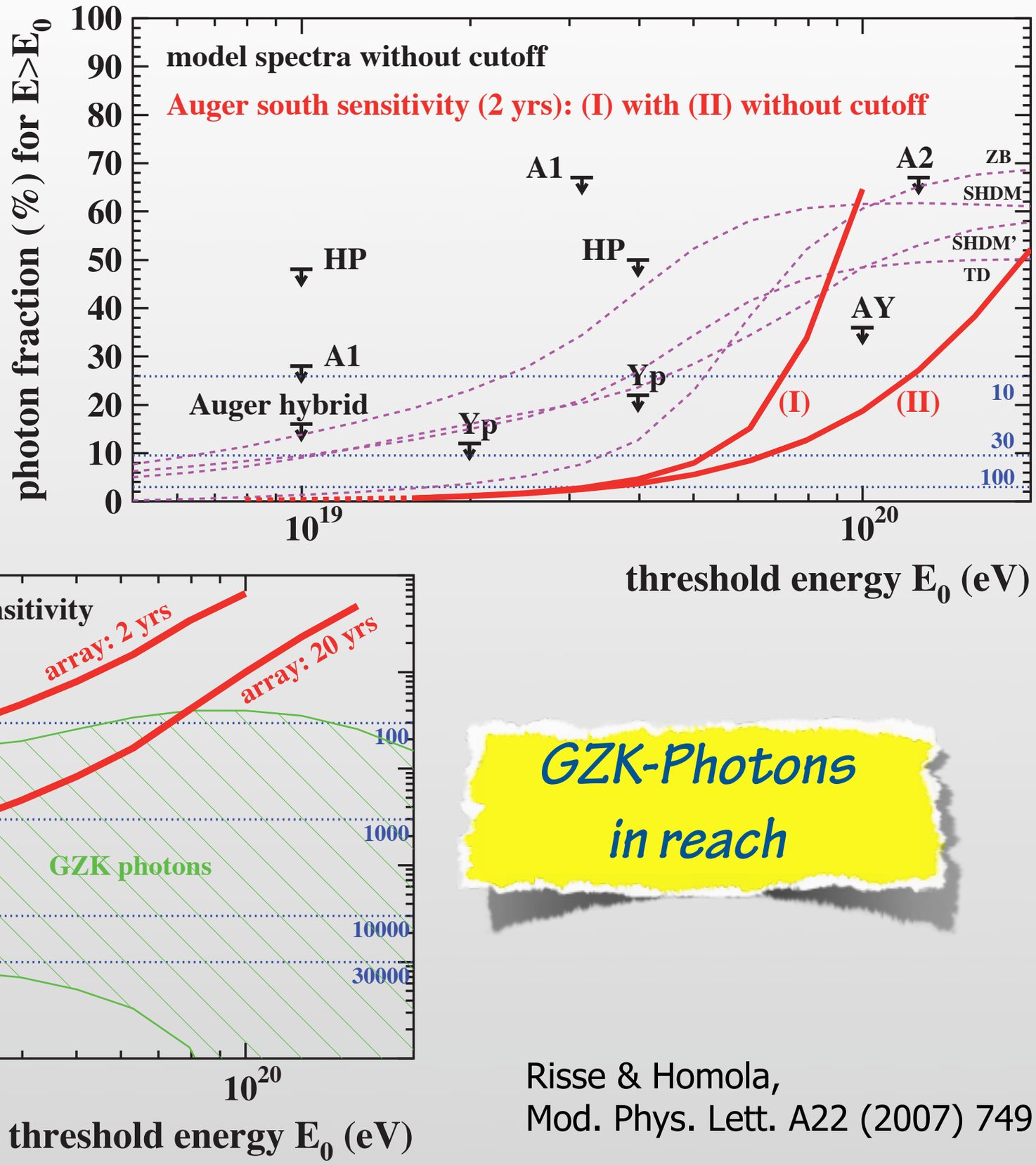
expect significant photon fraction above ~ 10^{19} eV

$$\xi_1 \leq 2.4 \times 10^{-15}$$
$$\xi_2 \geq -2.4 \times 10^{-7}$$

7 orders of magnitudes better than previous limits!

UHE Photon Physics: Future

better limits on Top-Down Models

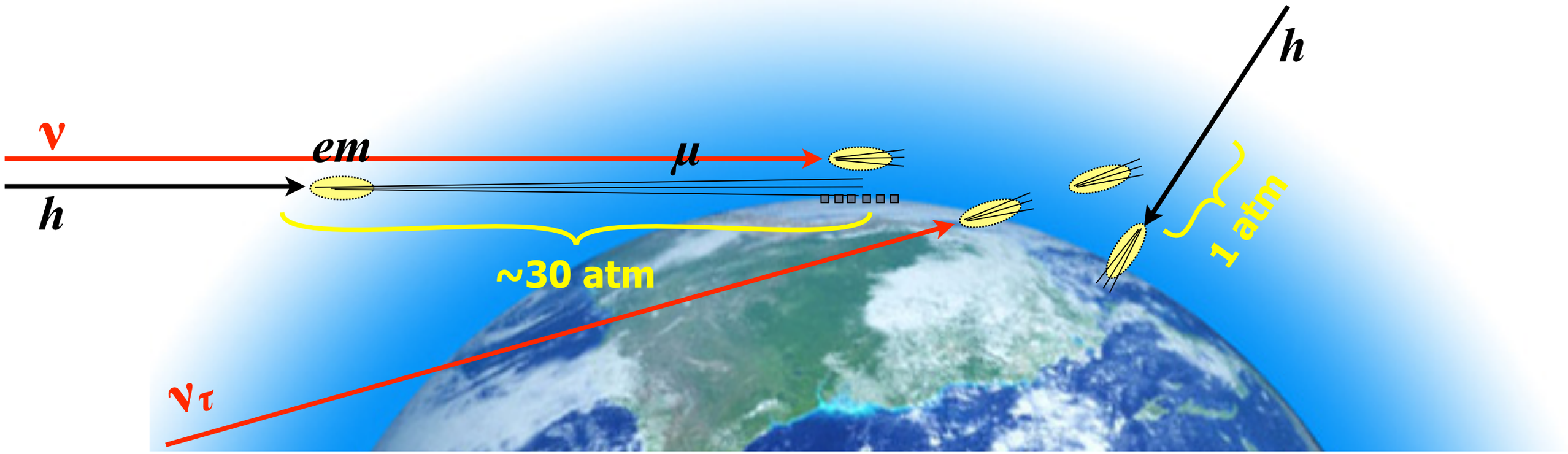


GZK-Photons in reach

Risse & Homola,
Mod. Phys. Lett. A22 (2007) 749

Neutrinos by Horizontal EAS

Only a neutrino can induce a young horizontal shower !



shower front

after 1 atm

electromagn. cascade

after 3 atm

hard muons

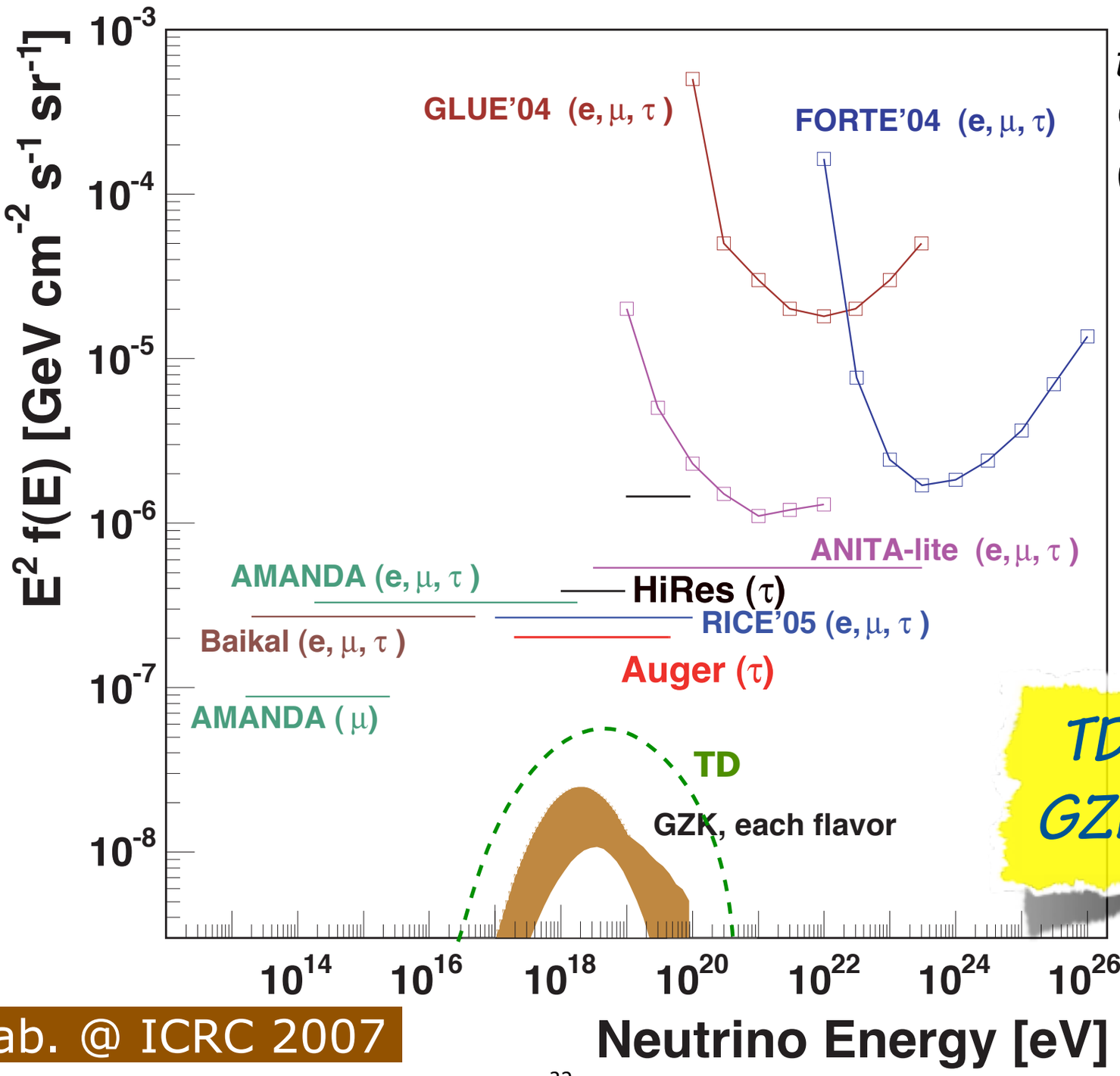
+ 20% electrons in equil. with muons

'young' showers (*ν*)
- Wide time distribution
- Strong curvature
- Steep lateral distribution

'old' showers (*h*)
- Narrow time distribution
- Weak curvature
- Flat lateral distribution

Search for Earth-skimming ν_τ

HiRes: events ± 10° from horizon, background events in MC, ~100 laser events
Auger: Surface Det. ; using signal traces & direction, background-free



talk by O. Deligny (Wednesday)

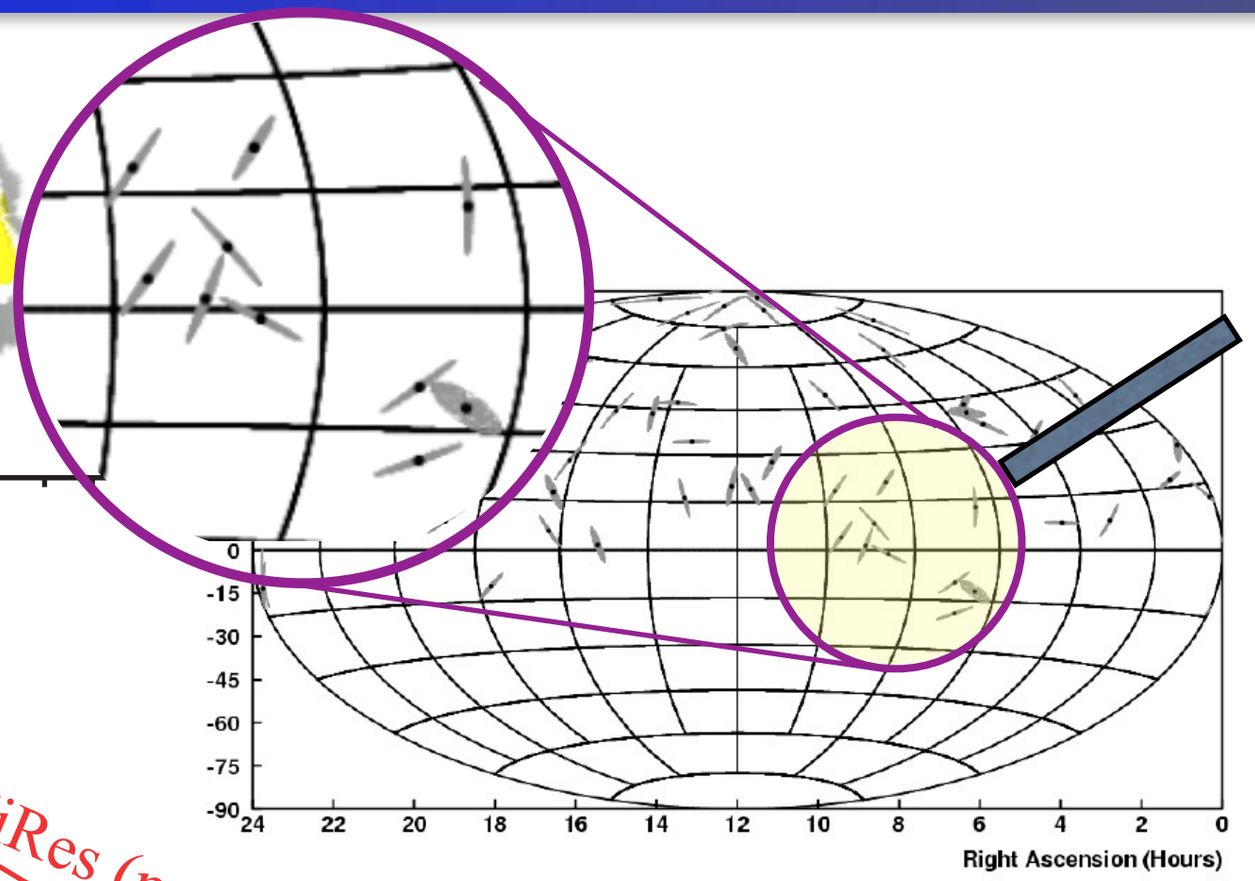
TD-ν's in reach... GZK-ν's difficult...

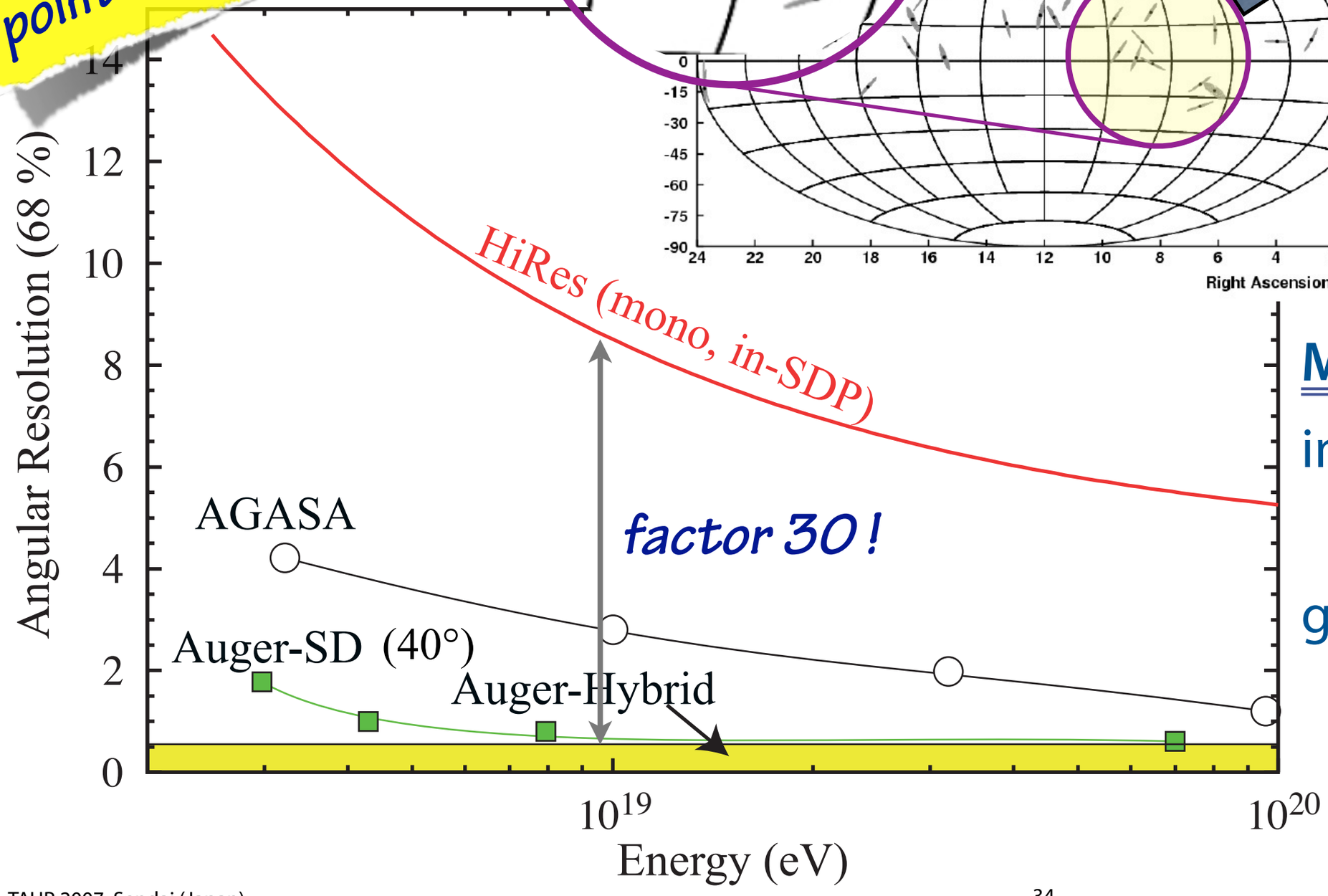
Pierre Auger Collab. @ ICRC 2007

Arrival Directions

Angular Resolution

FD-mono:
very bad for
point-source searches





Magnetic Deflection

intergalactic *O*(2-3)°

40 EeV 100 Mpc

galactic *O*(1-2)°

40 EeV off disc

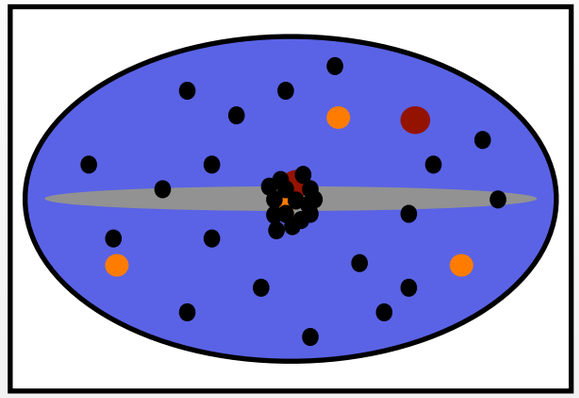
Anisotropy Searches

1 Galactic Center

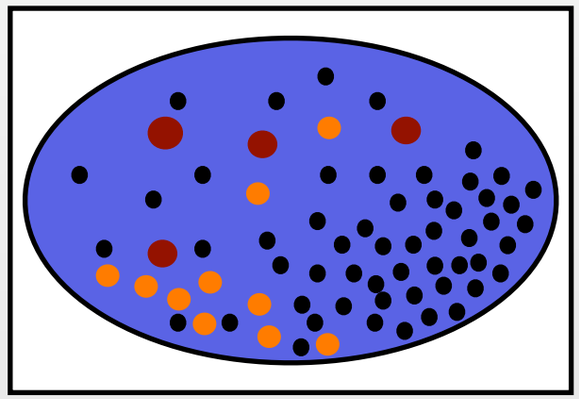
2 Multipole Search
(Large scale anisotropy)

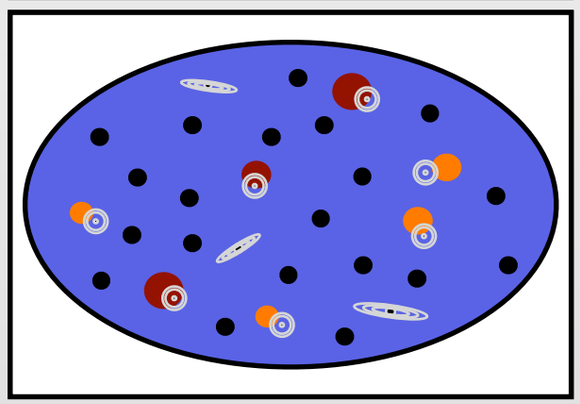
3 Correlation BL Lacs
(more general: point sources)

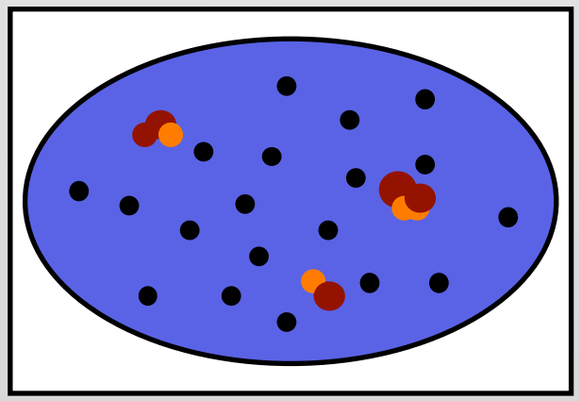
4 Cluster Search
(Autocorrelation)



$E_1 < E_2 < E_3$

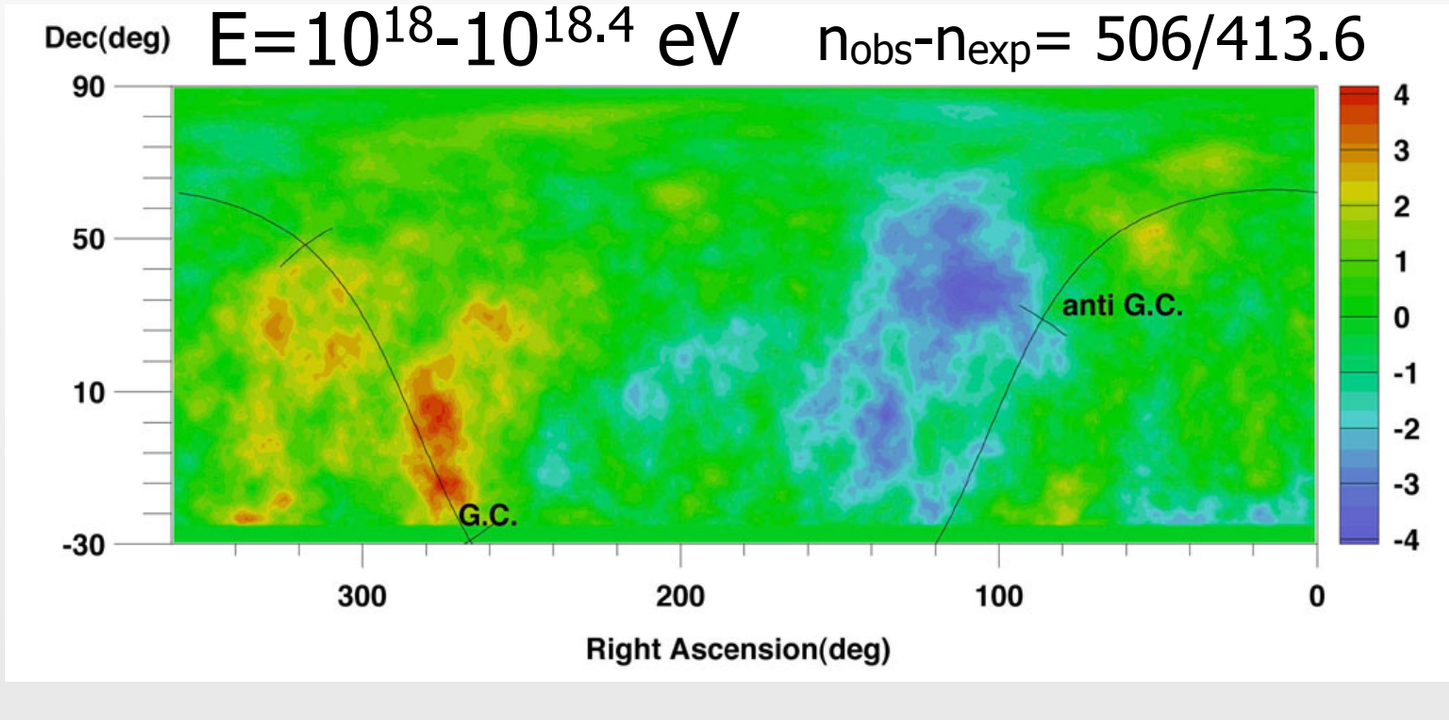






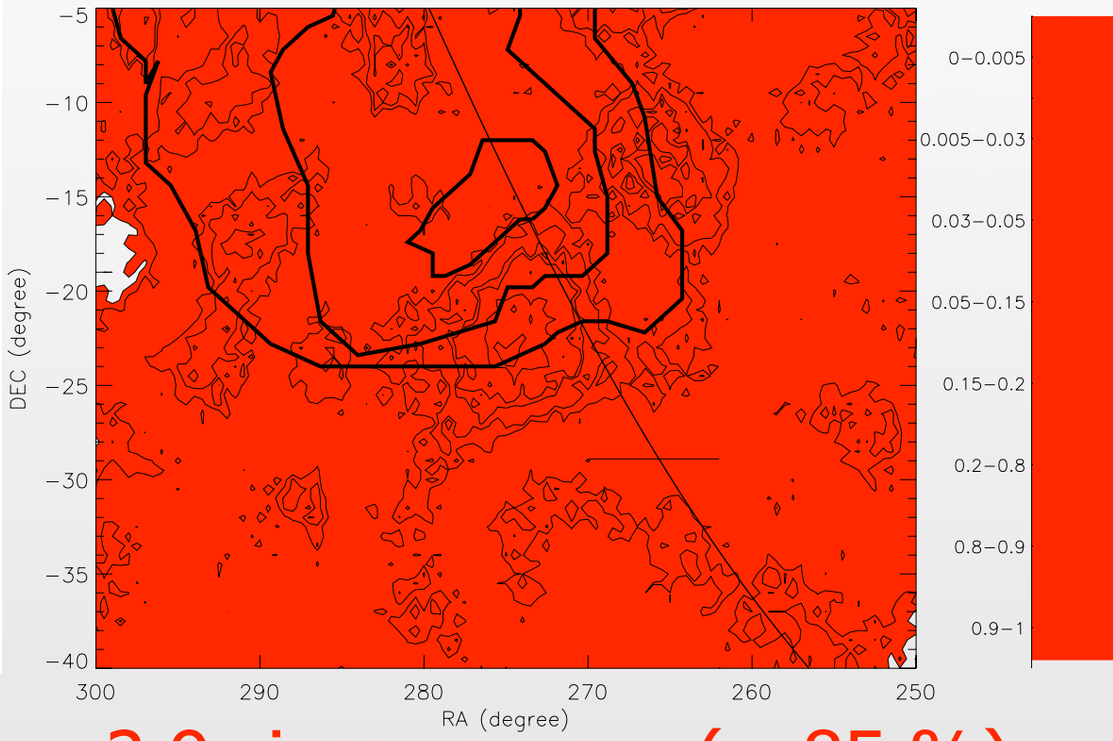
Galactic Centre

Agasa Collab., Astropart. Phys. **10** (1999) 303



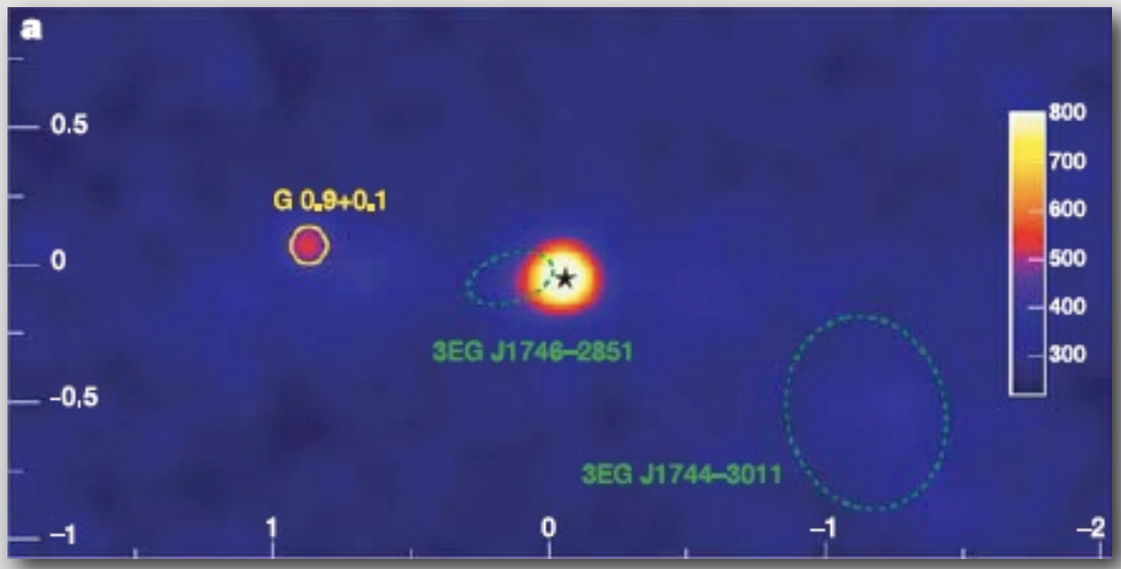
4.5 sigma excess (~ 22 %)

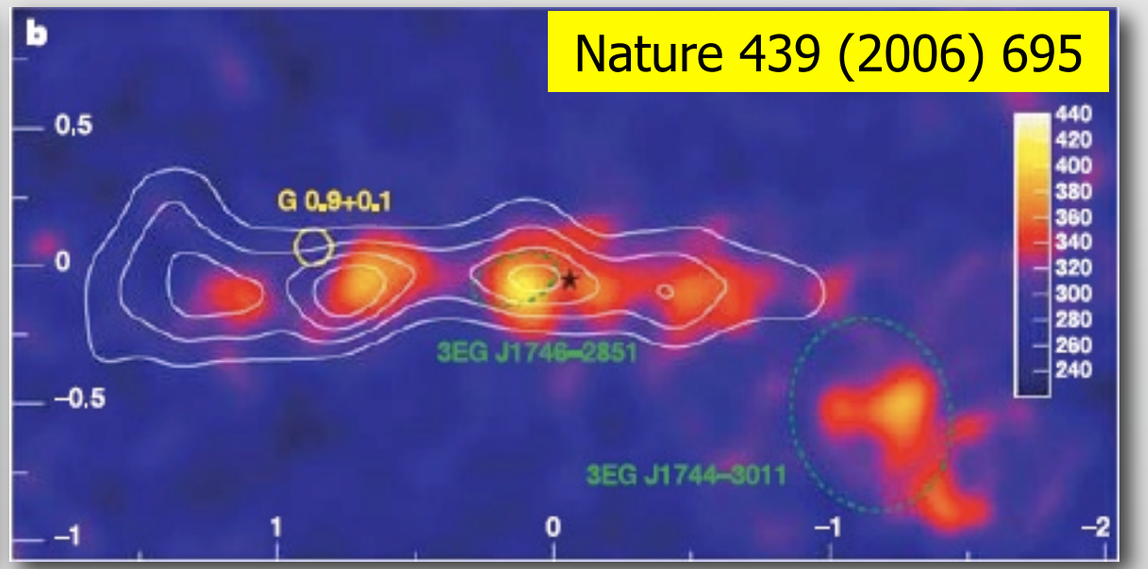
SUGAR Collab., Astropart. Phys. **15** (2001) 167



2.9 sigma excess (~ 85 %)

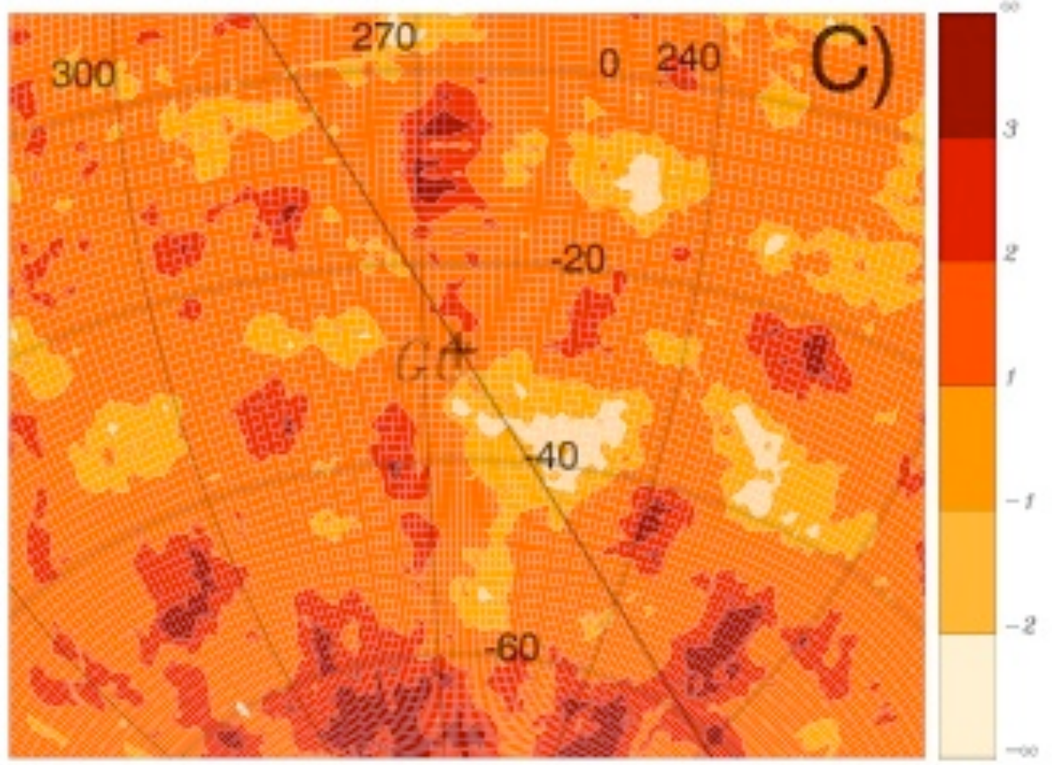
H.E.S.S: gamma ray observation Sgr A and Molecular Cloud





Auger: Galactic Centre Region

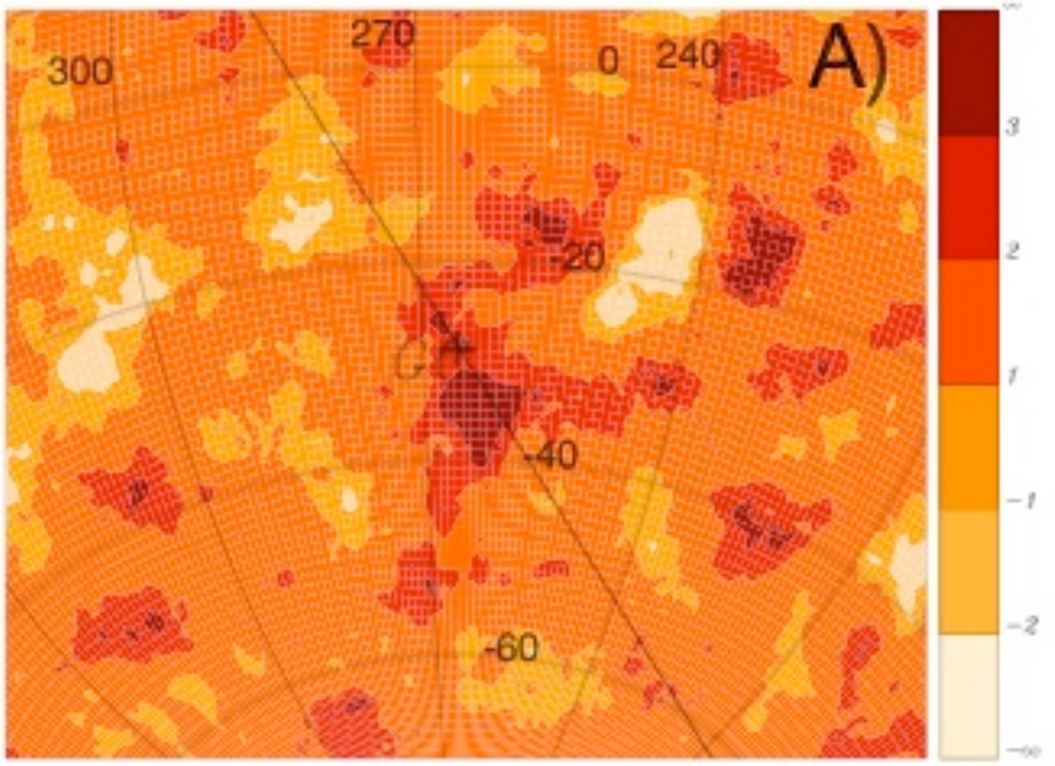
Pierre Auger Collab. @ ICRC 2007



0.1 < E < 1 EeV

search	window size	n_{obs}/n_{exp}
extended	10° (TH)	5663/5657 = 1.00 ± 0.02(stat) ± 0.01(syst)
	20° (TH)	22274/22440 = 0.99 ± 0.01(stat) ± 0.01(syst)
point-like	1.3° (G)	192.1/191.2 = 1.00 ± 0.07(stat) ± 0.01(syst)

No Excess seen



1 < E < 10 EeV

search	window size	n_{obs}/n_{exp}
extended	10° (TH)	1463/1365 = 1.07 ± 0.04(stat) ± 0.01(syst)
	20° (TH)	5559/5407 = 1.03 ± 0.02(stat) ± 0.01(syst)
point-like	0.8° (G)	16.9/17.0 = 0.95 ± 0.17(stat) ± 0.01(syst)

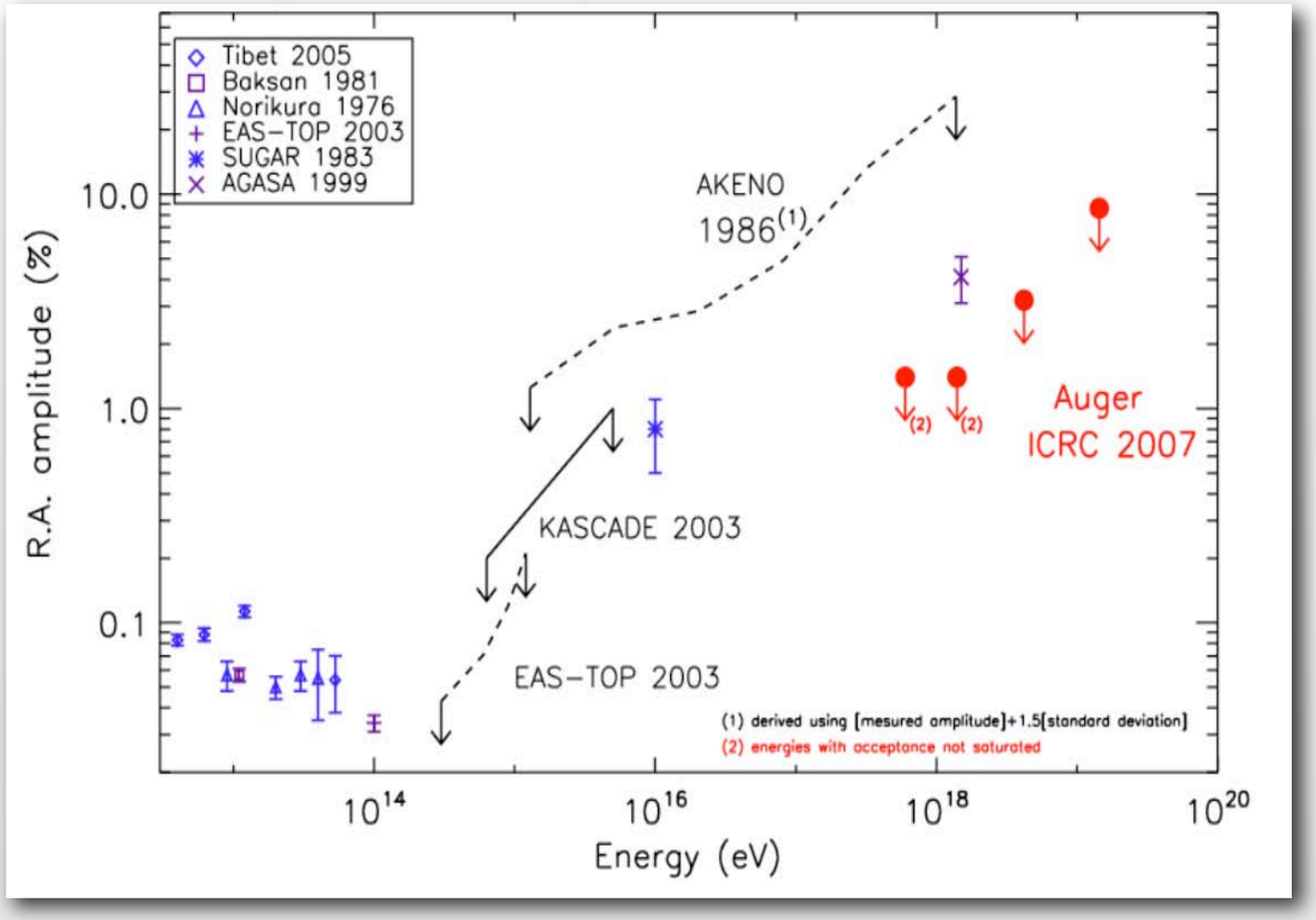
AGASA 22% excess
would give a 16 σ excess in Auger
SUGAR 85% excess
would give a 30σ excess in Auger

Data: Jan 2004 - March 2007

Earlier Results: Astropart. Phys. 27 (2007) 1

Other Searches (Auger)

Pierre Auger Collab. @ ICRC 2007



No evidence for dipole or multipole.

No significant observation of CR-Clusters: Previously reported by *AGASA*

No correlation with BL-Lacs: Previously reported based on *data from AGASA, Yakutsk and HiRes E>10EeV*

despite of having collected 6 times more events above 10 EeV....

But: *Two prescriptions are running...*

Where is Our Crab?

Whipple 1989

HESS, MAGIC, VERITAS, Cangaroo 2007

based on Angela Olinto (TeV 2007)

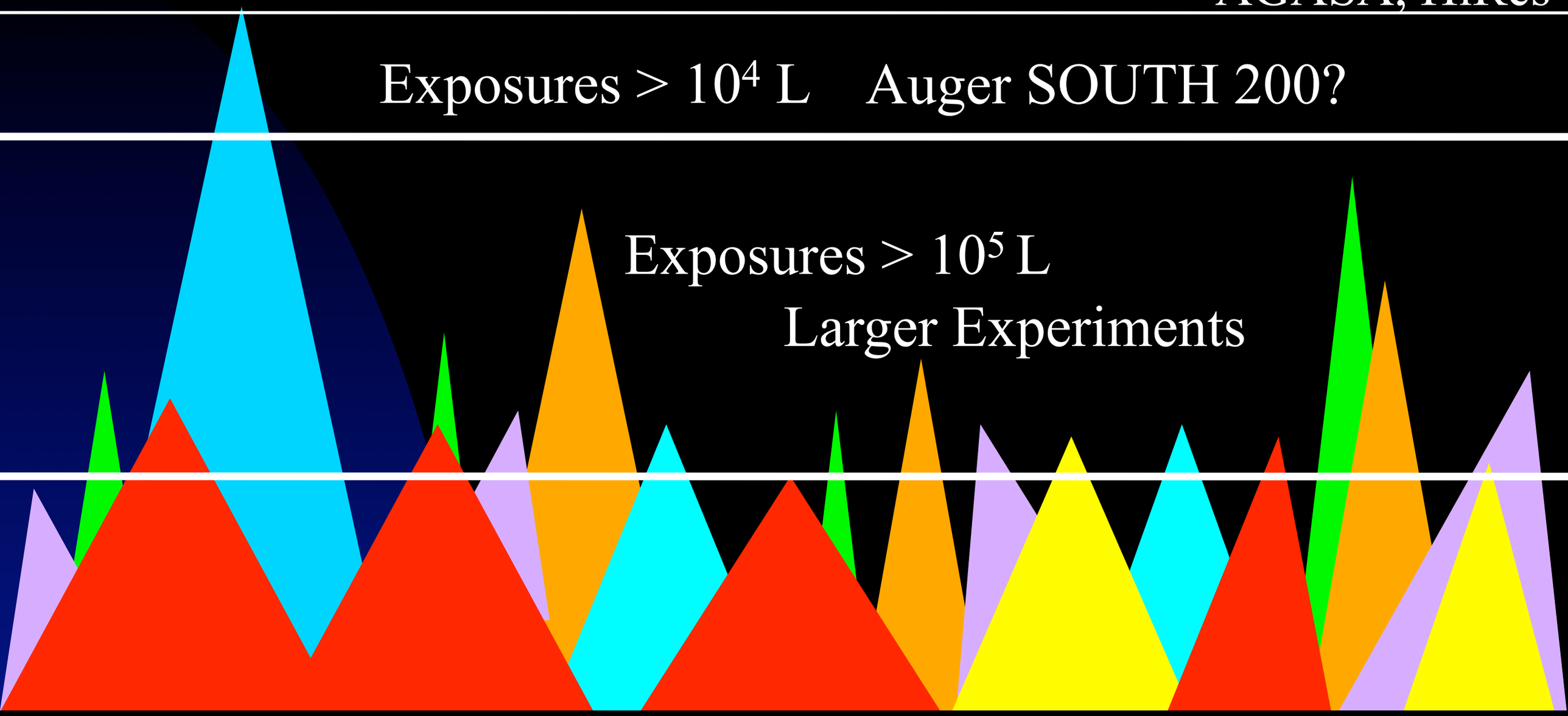
Where is Our Crab?

AGASA, HiRes

Exposures > 10^4 L Auger SOUTH 200?

Exposures > 10^5 L

Larger Experiments



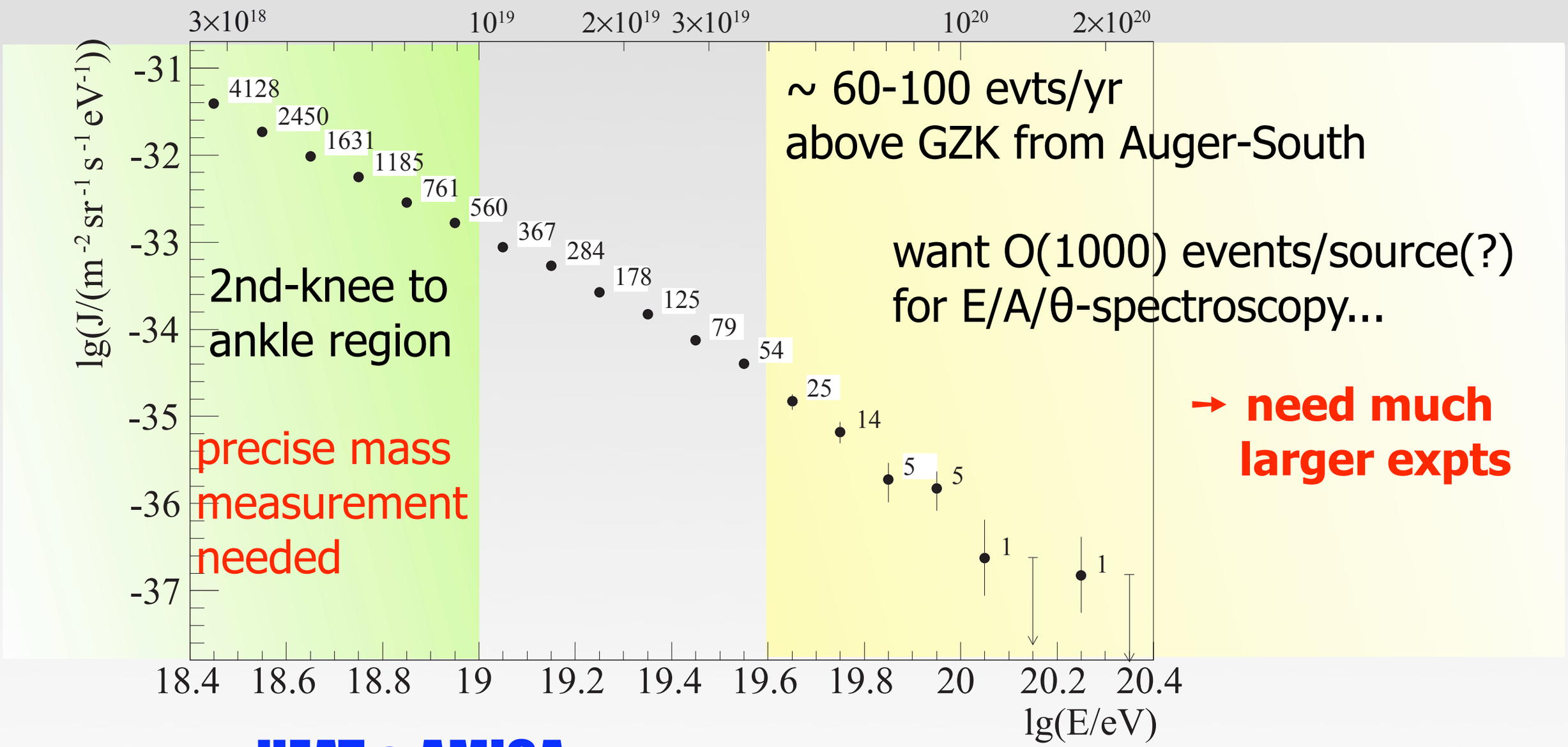
L = 1 km^2 sr yr - Linsley

based on Angela Olinto (TeV 2007)

AGASA = 1.63 10^3 L

New Projects & Directions

Exposure: ~ 5 kL



(Auger-South) **HEAT & AMIGA**

(TA) **TALE**

Telescope Array

Auger-North (10000 - 25000 km²)

JEM-EUSO (~10⁶ km²)

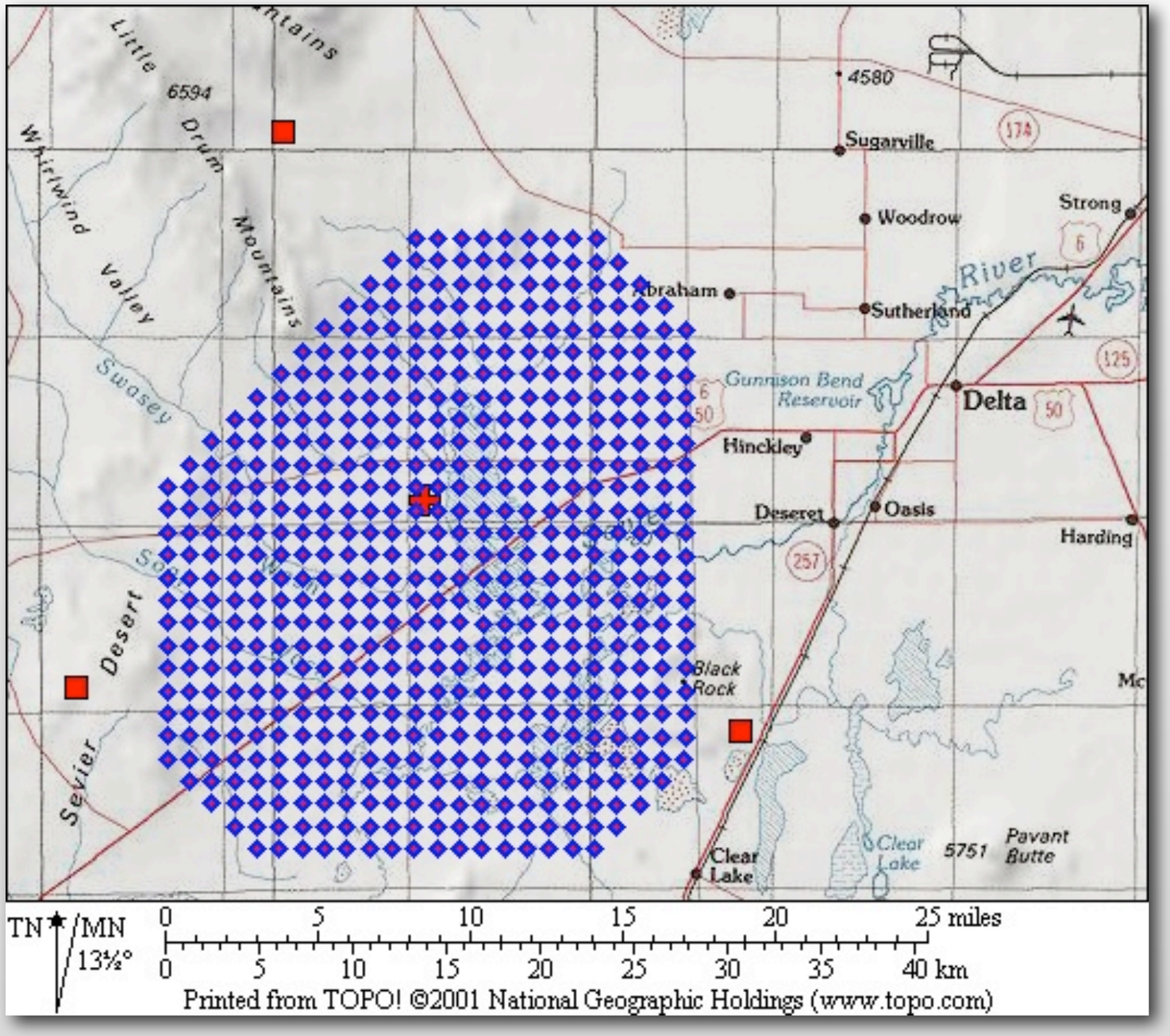
Telescope Array (TA)

Surface detector:

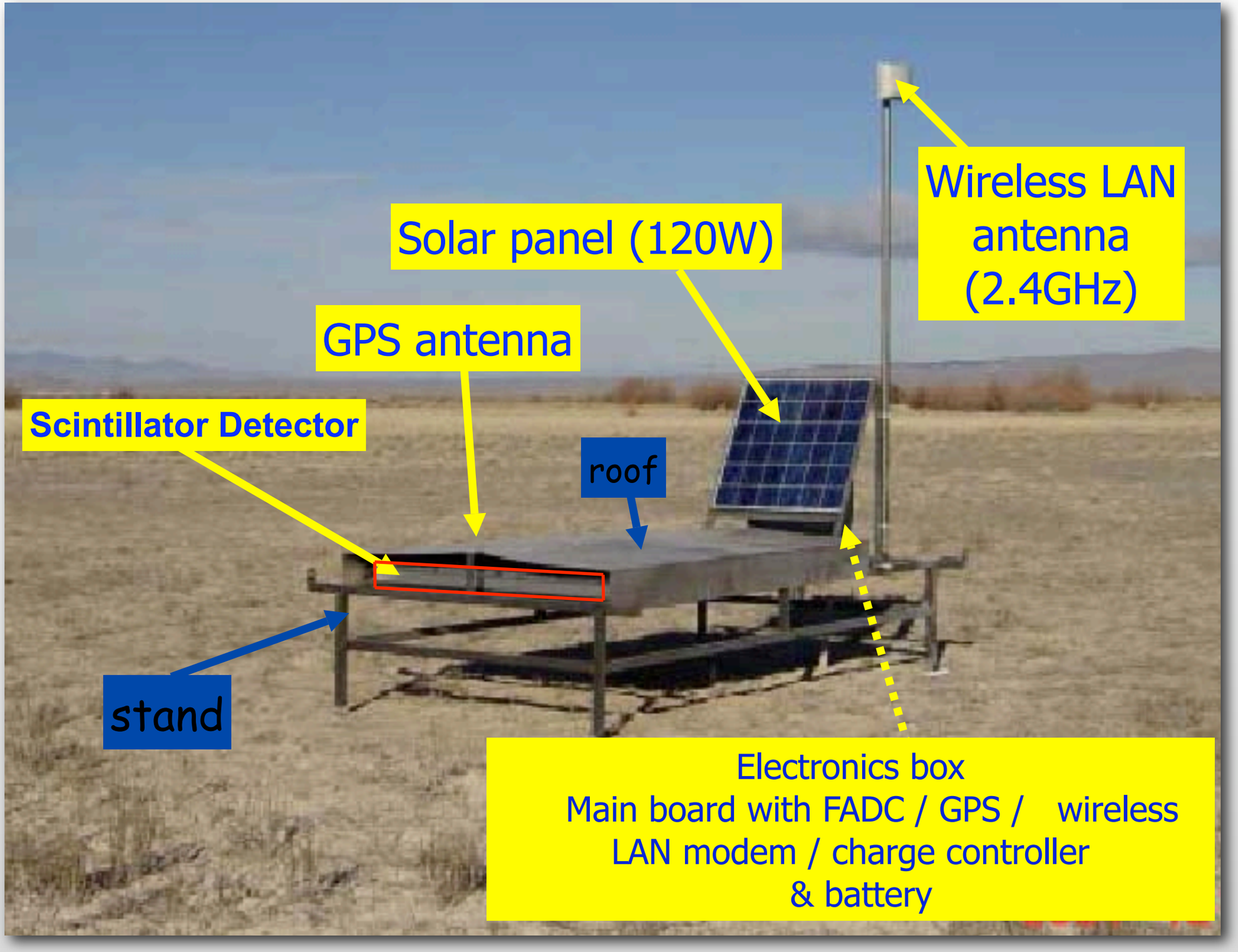
512 scintillation counters
on 1.2 km grid (~ 600 km^2)
95% deployed
Commissioning in progress.

Fluorescence detectors

3 sites; 100% deployed
Commissioning in progress.
Study spectrum, composition, anisotropy
Will be taking data in October, 2007.



TA Surface Detectors (SD)



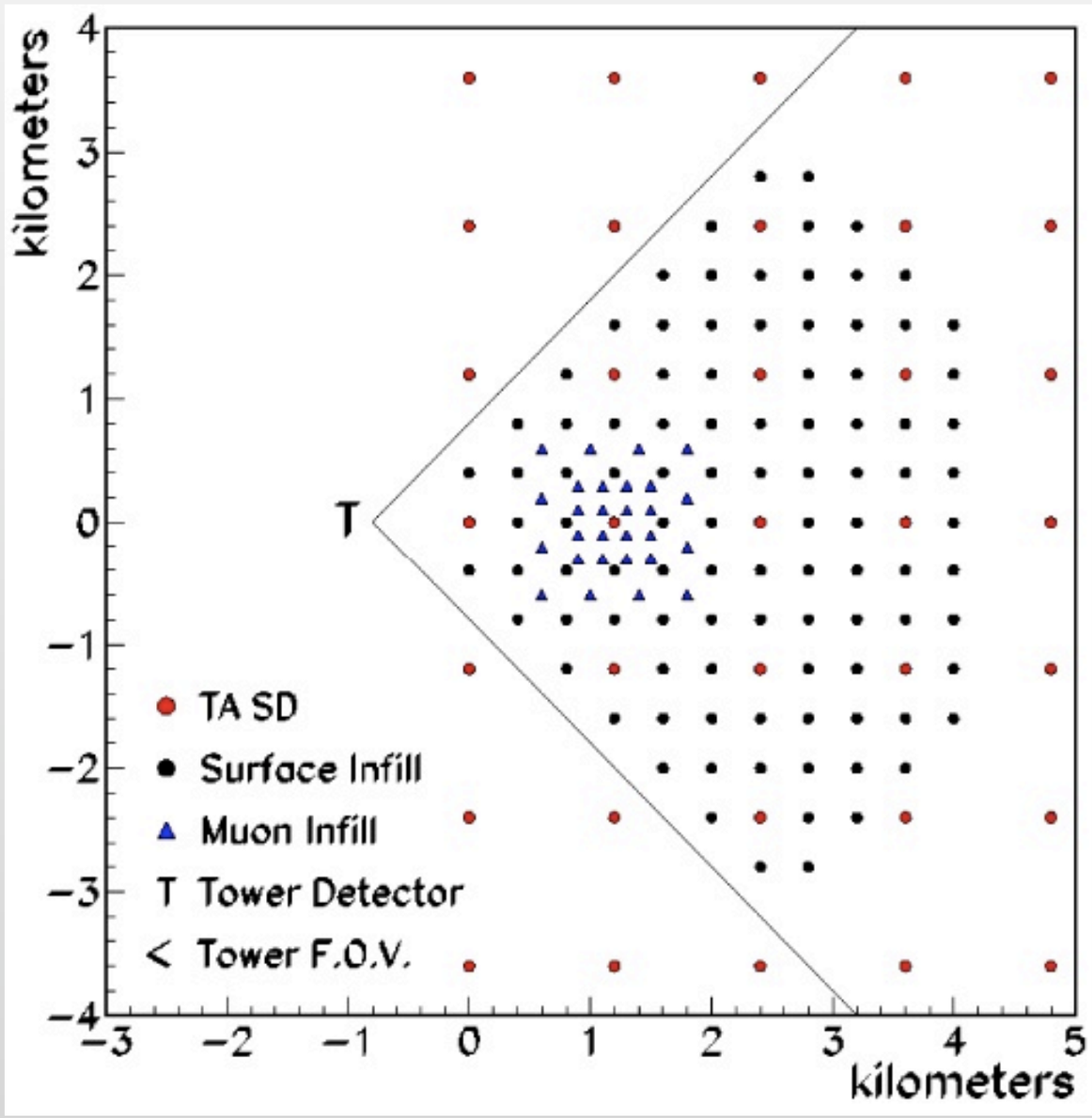
TALE @ Telescope Array

TALE @ Telescope Array
prototype
up to 72° elevation

proposed
Low Energy
extension

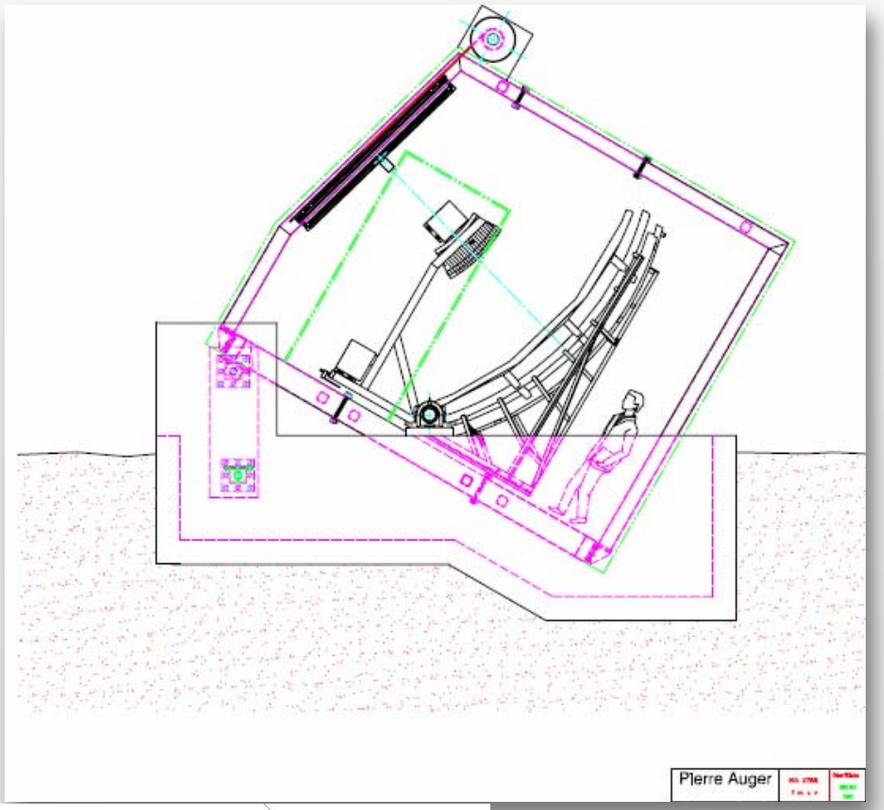
- standard TA: 1.2 km grid
- Surface infill: ~ 100 detectors on 0.4 km grid
- Muon stations: 16 on 0.2 km

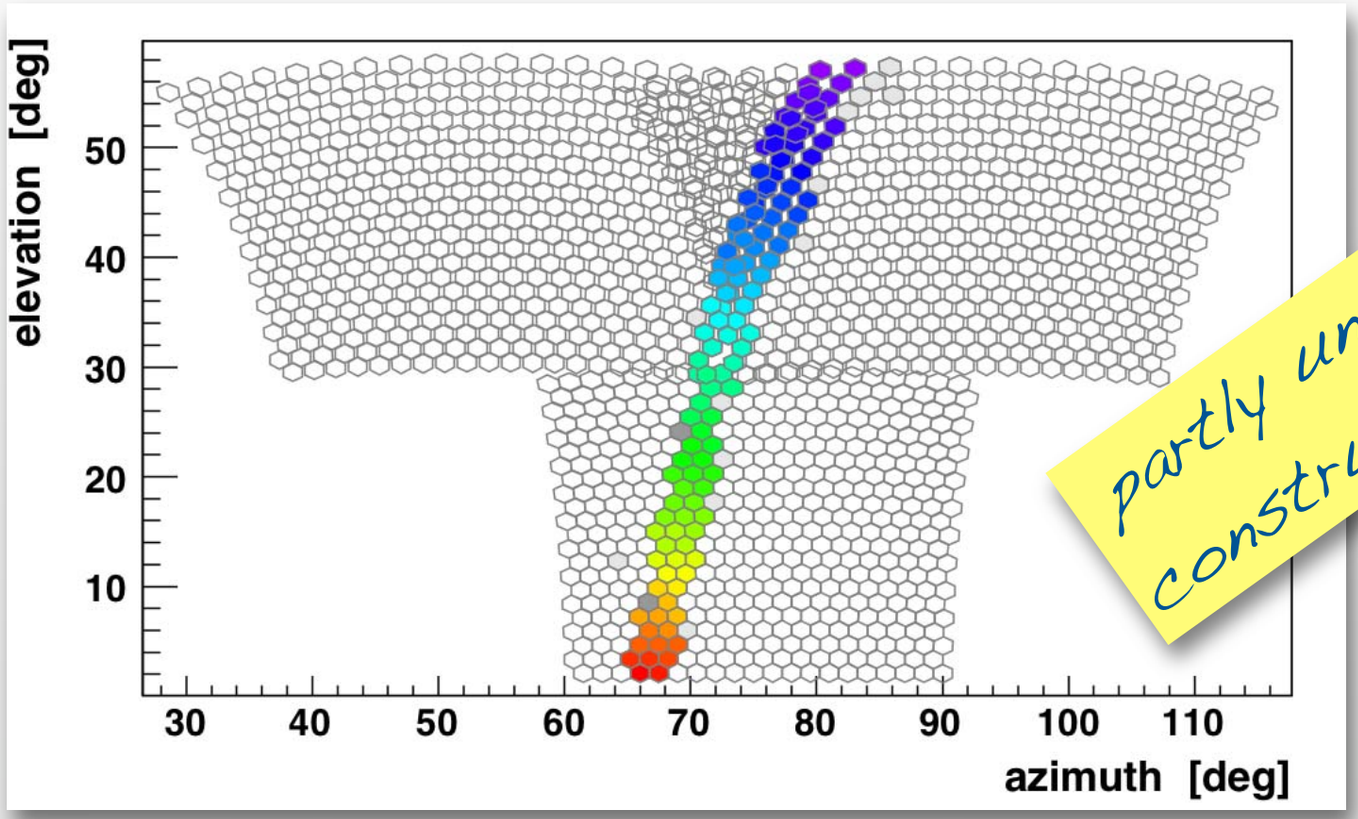
InFill Array

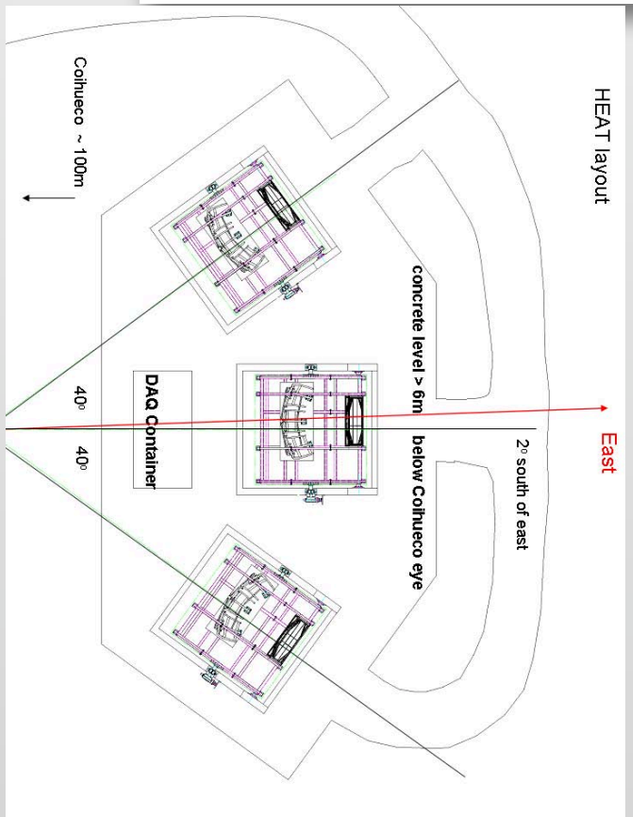


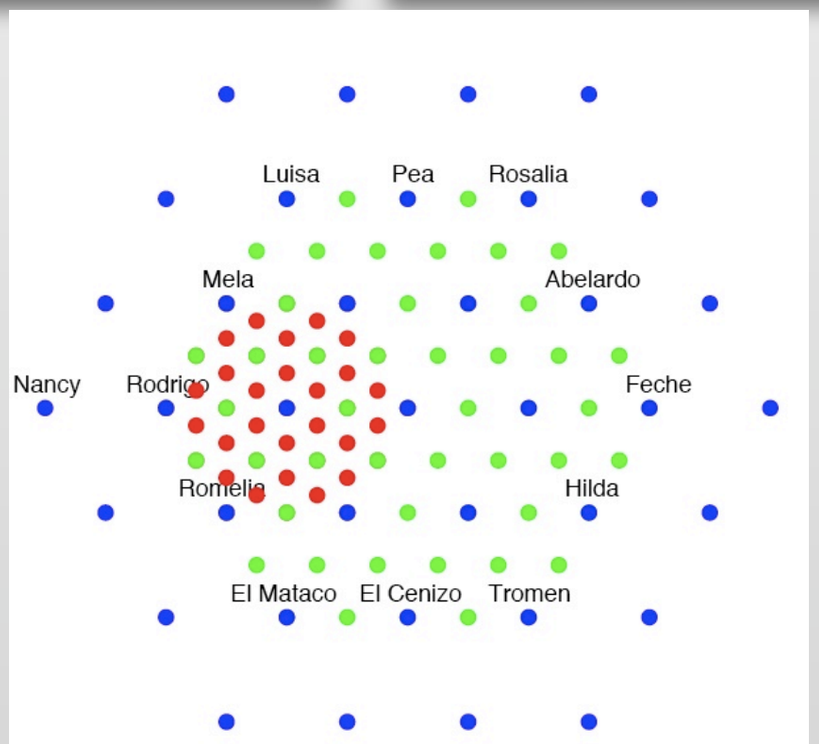
HEAT & AMIGA in Auger-South

High Elevation Auger Telescopes (HEAT) 30° - 60° elevation







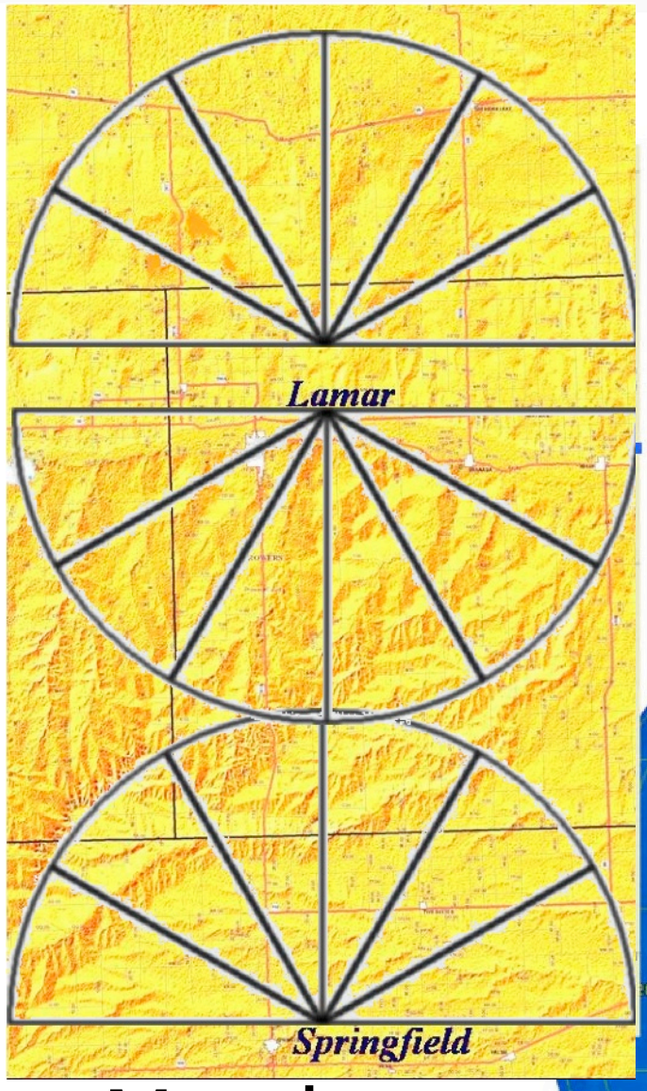


- standard Auger: 1.5 km grid
- infill 1: ~ 42 detectors on 750 m grid
- infill 2: ~ 24 detectors on 433 m grid

Auger North

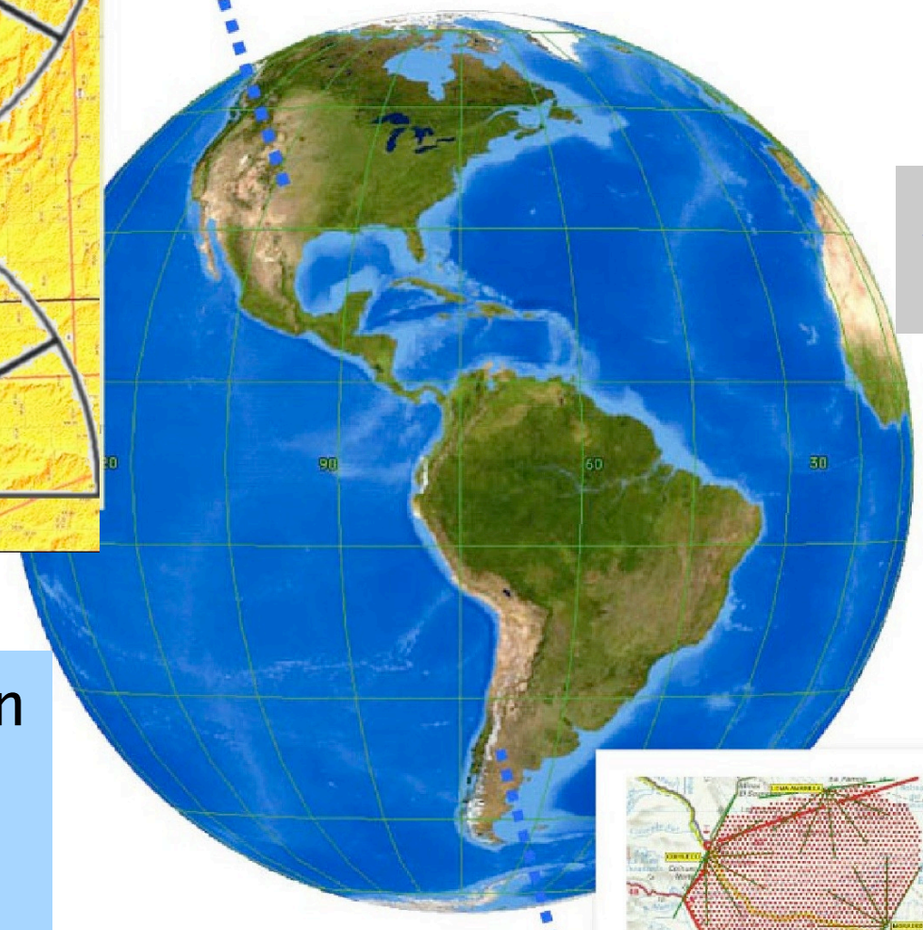
Need for two sites realized from the early beginning

expandable to ~ 25,000 km²



Northern Site: Colorado

- Retain features & functionality of Southern Site
  - Hybrid detection & energy calibration
  - Water Cherenkov surface array
    - 4000 stations, 10,370 km²
    - Square mile grid

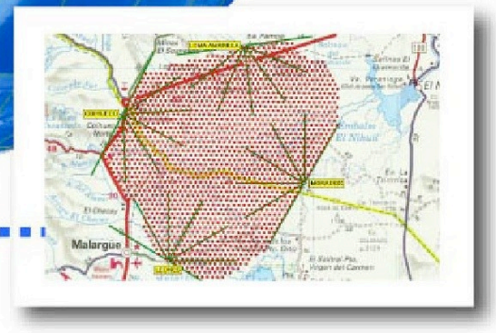


Altitude and latitude are similar

Southern and Northern sites are shown at the same scale

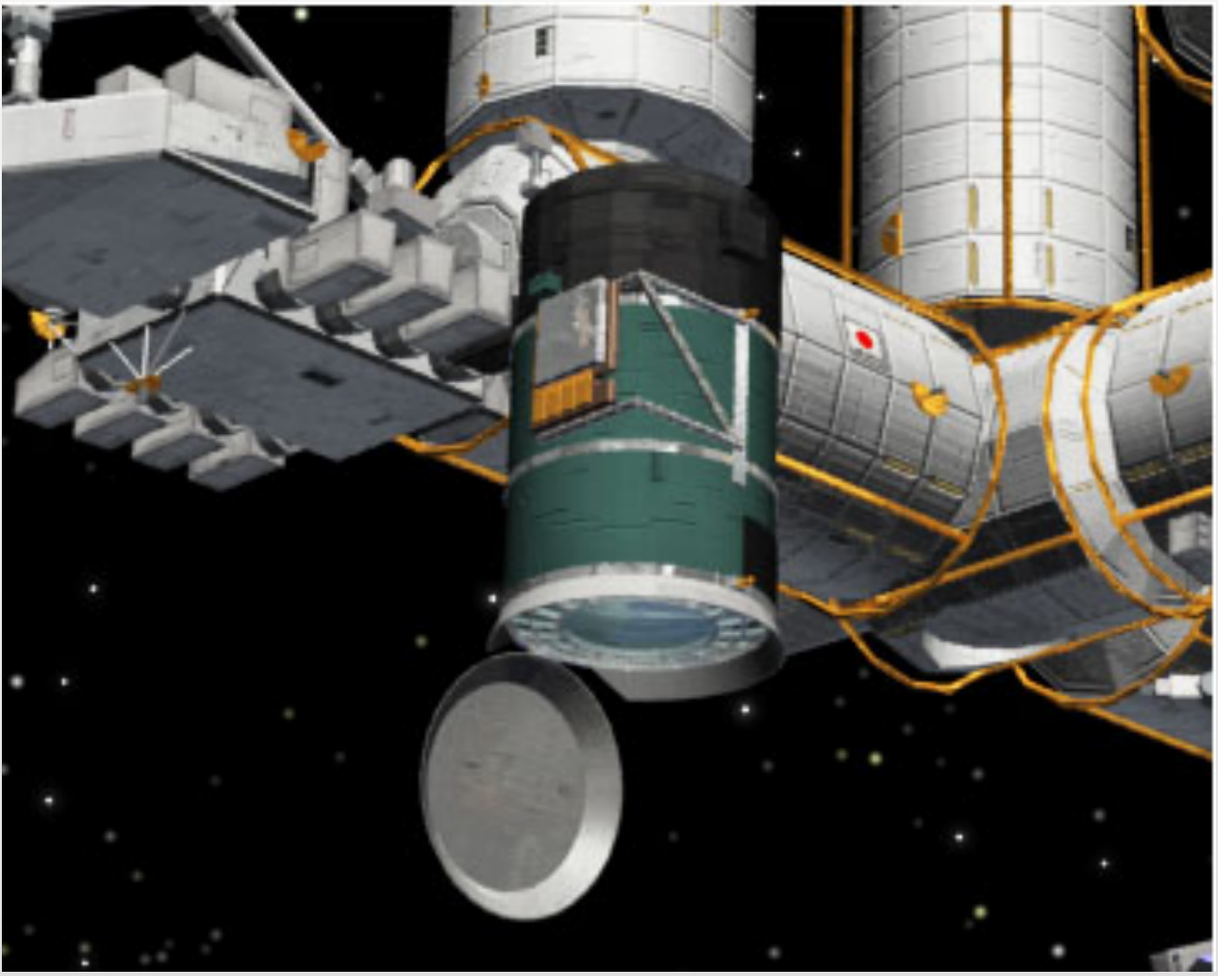
Southern Site: Mendoza

- Hybrid detection & energy calibration
- Water Cherenkov surface array
  - 1600 stations, 3000 km²
  - 1.5 km triangular grid
- Completion end 2007



JEM-EUSO Telescope on ISS

JEM-EUSO Telescope will be attached to Exposure Facility of Japanese Experiment Module (JEM/EF) of ISS in 2013



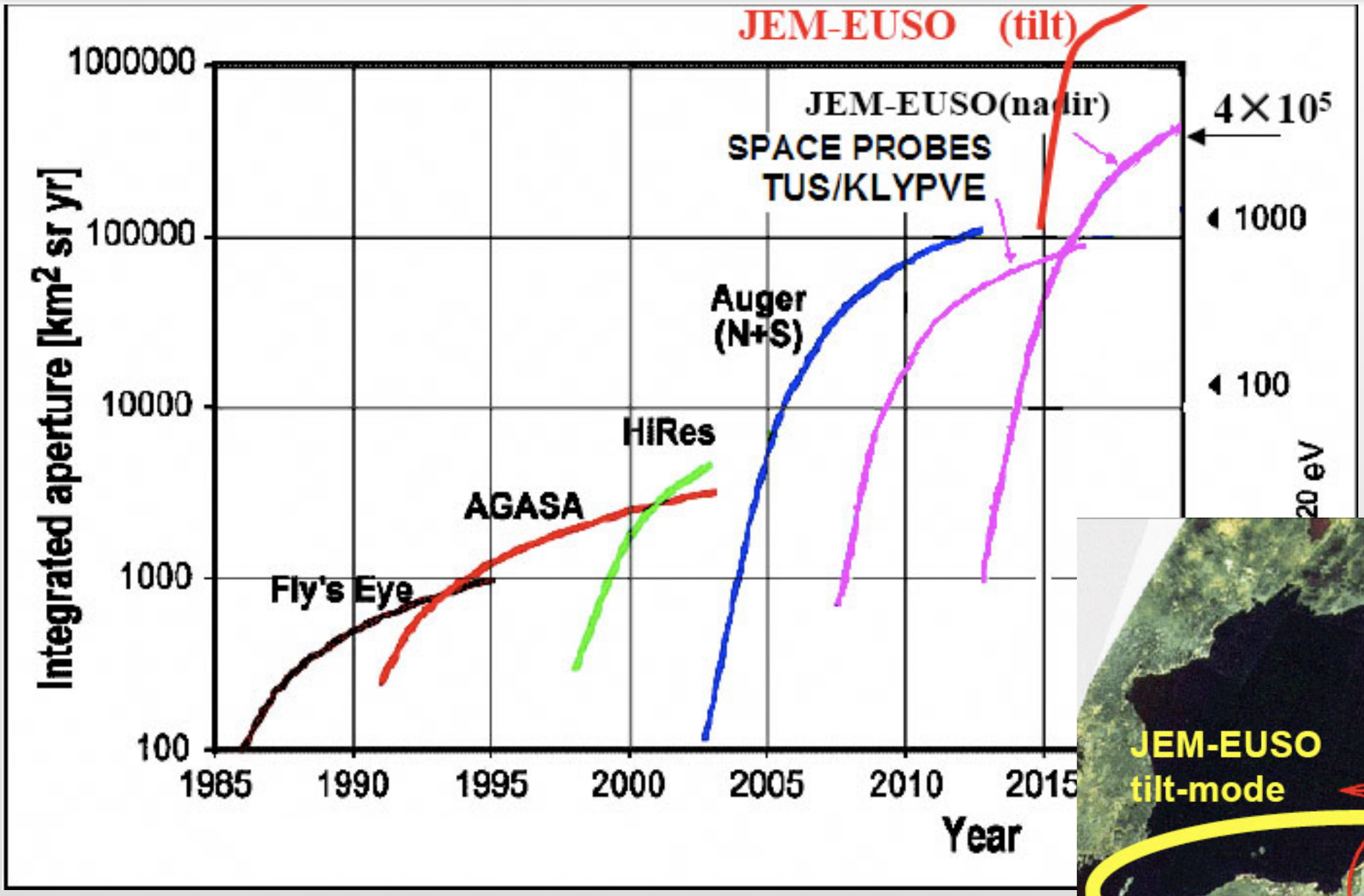
Vertical Mode

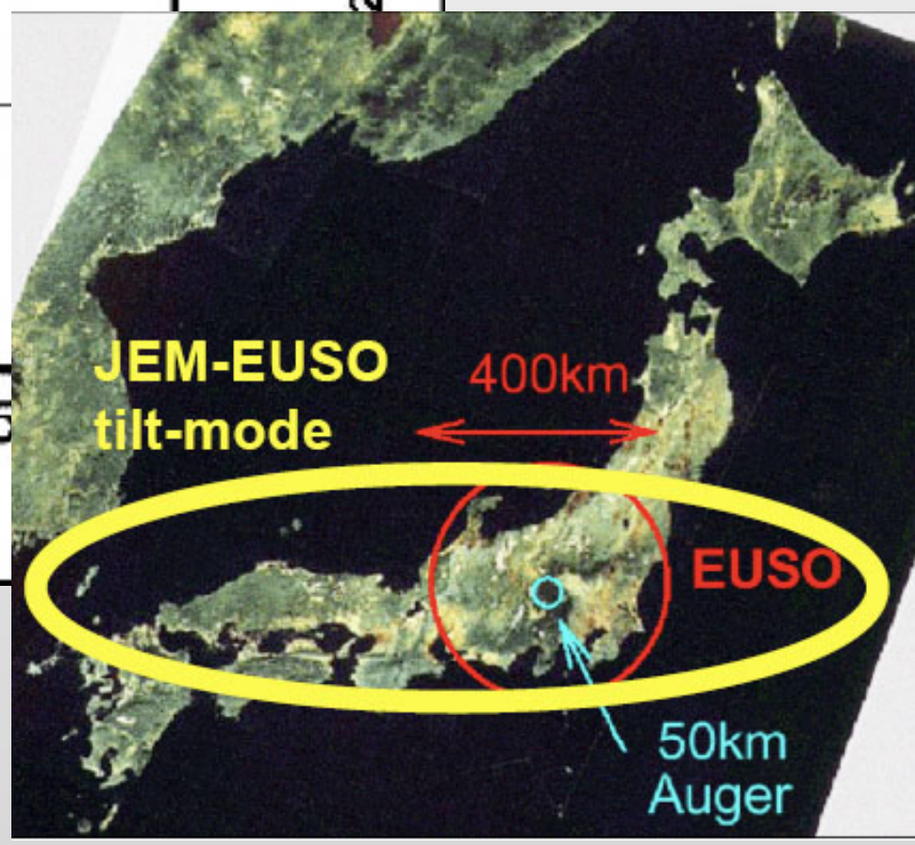
Tilted Mode

Larger effective area (x5) with ~35°tilt

talk by Y. Takahashi (Wednesday)

JEM-EUSO Telescope on ISS





Radio Emission from Air Showers

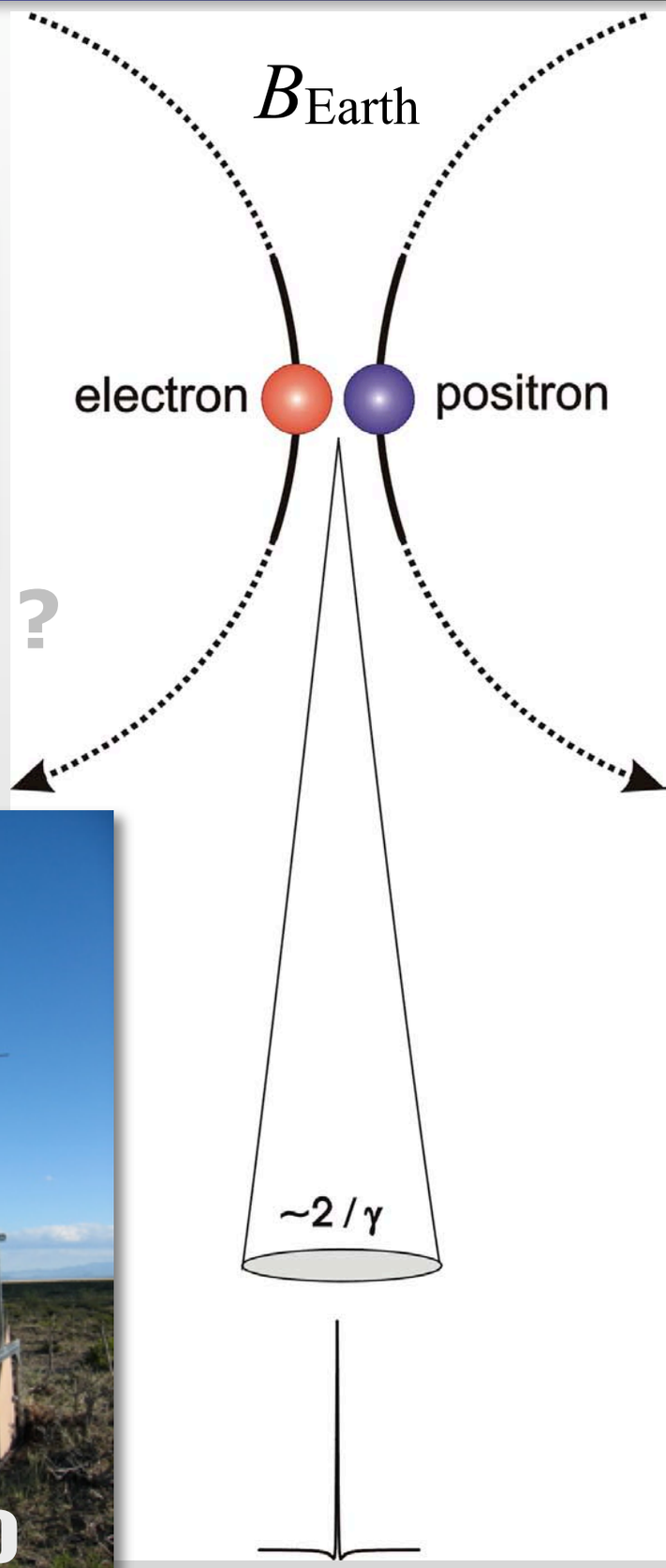
First discovery:

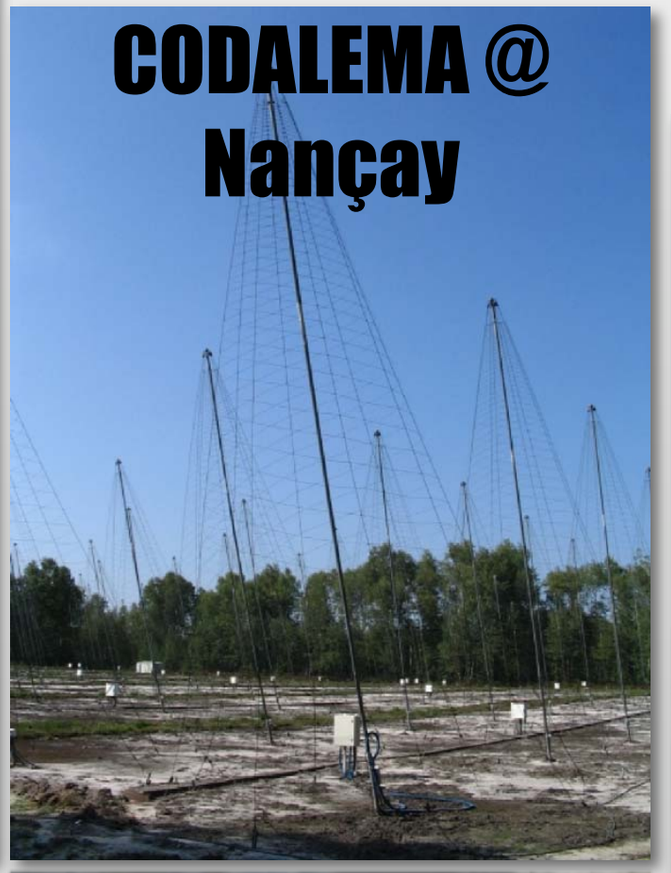
Jelley et al. (1965), Jodrell Bank at 44 MHz.

A 10^{17} eV airshower produces a 1 GJy radio flare in 25 ns (40 MHz bandwidth)!

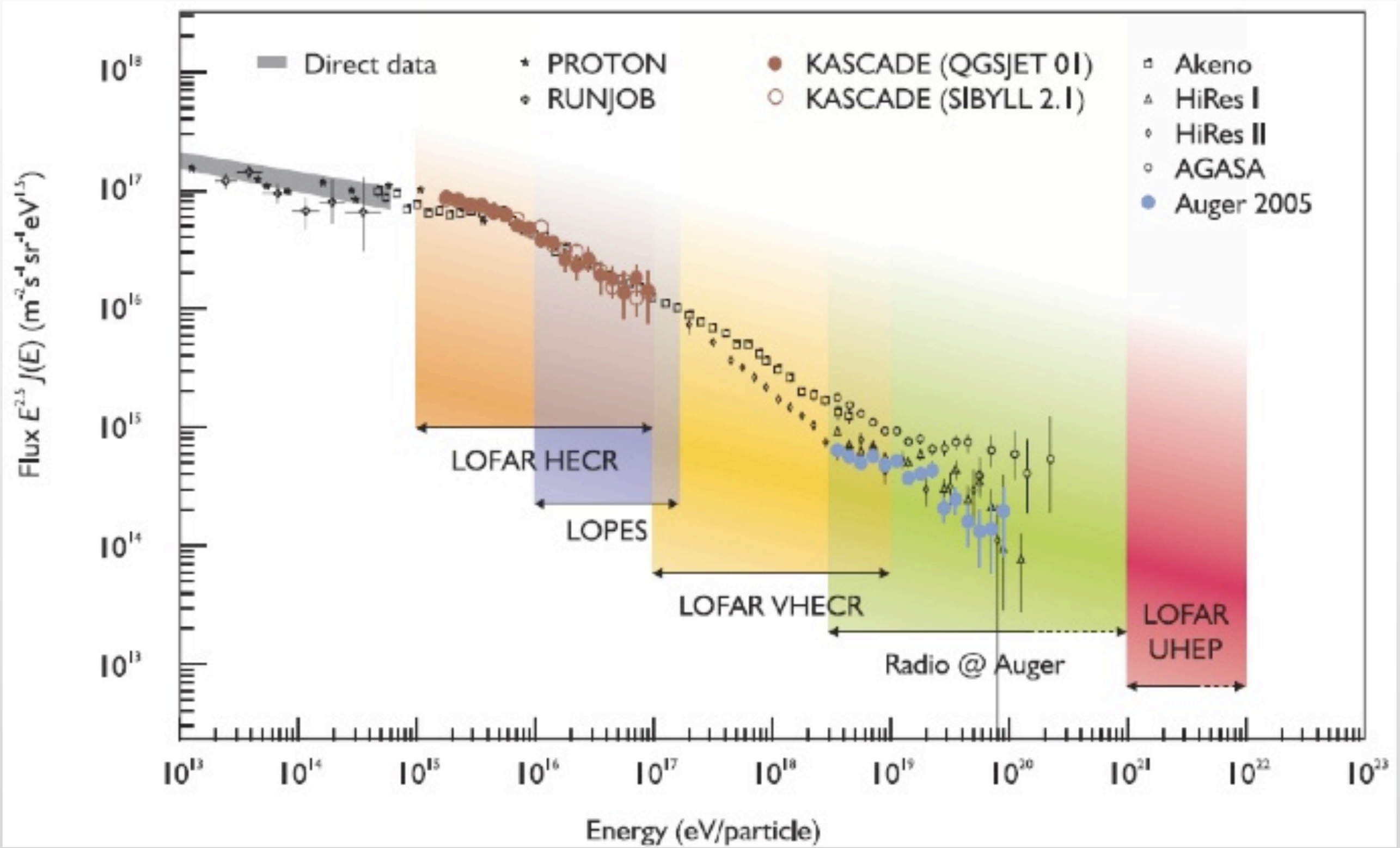
The brightest radio source, the sun, has 1MJy.

Geo-Synchrotron Effect ?





Cosmic Rays in the Radio



Concluding Remarks

- **Enormous progress during last two years !**
  GZK established ; Top-Down models almost **ruled out**
- Need to understand
  - Energy spectrum
  - Mass composition
  - Angular distribution

  } consistently !
- **Multi-Messengers:** started by ν and γ limits
  if CR sources seen ⇨ verify in ν and γ telescopes
- Spectrum from 10^{18} to $>10^{20}$ eV: **Ankle or Dip**
  GZK or E_{max} ?
- Need for precise mass measurements (ankle region)
  and for much larger experiments (trans Greisen region)
- Get prepared for charged particle astronomy @ TAUP09