ICRR Review sep 28, 2007

Highest energy cosmic rays

Yoshiyuki Takahashi

The University of Alabama in Huntsville, USA

and

RIKEN, Japan

Outline

- Experimental updates from major stations
  - Dramatic Advancement of new data-taking by Auger lab.
  - Steeper spectrum above about E_{GZK}
  - Conflicting compositions by Hi-Res vs Auger analyses
  - Pointing unsuccessful, requires Super-GZK energies > $7\ 10^{19}$ eV
  - Super-GZK-energy exploration is tough: need 10^6 L
  - Varieties of trivial/non-trivial systematics getting better understood
- Astronomical/Astrophysical perspectives
  - Localization and Horizons: Effects of GMF and EGMF getting perceived and non-isotropy is predicted
- Super-LHC/beyond-SM physics yet to be explored
- Generally-conceived Roadmap for explorations

UHECRs
Energy Spectrum

- Refs from 28th ICRC papers (Merida)

summarized by

(1) A. Watson / Highlight paper

(2) M. Teshima / Rapporteur paper

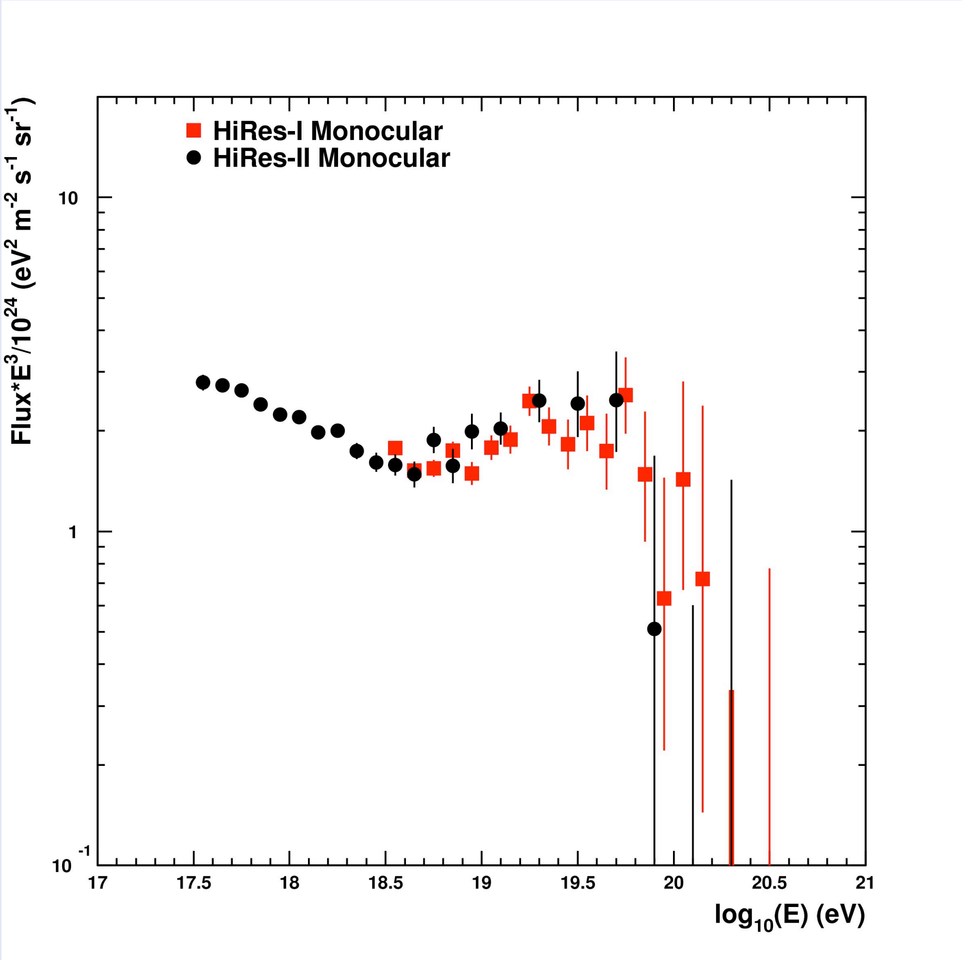
Thanks to Alan and Masahiro

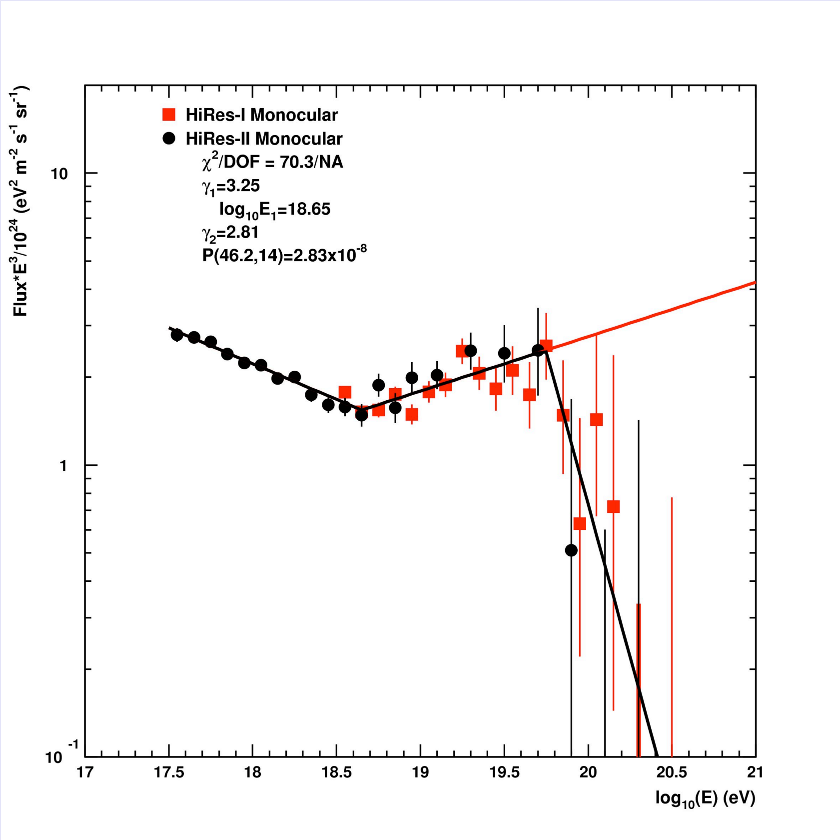
and

- APC Workshop (Paris) May 2007

HiRes Spectrum
Broken power law fits

- Expect 46.2, observe 14
  - $P = 7\text{x}10^{-7}$ (4.8_)





Systematic Error in HiRes Mono Energy Spectrum

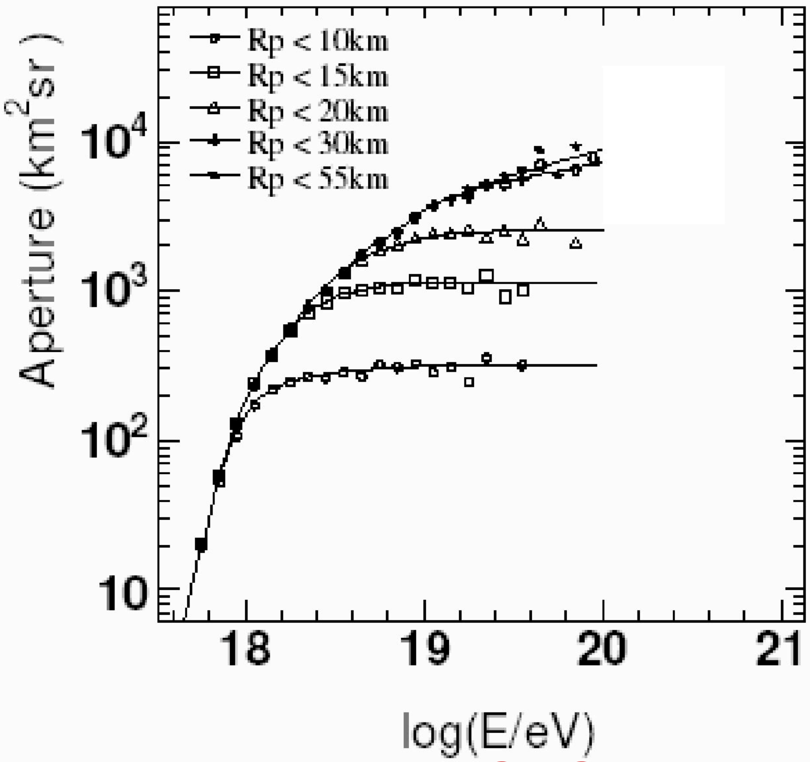
- Energy Scale Uncertainties
  - Missing Energy 5%
  - Energy Loss Rate 10%
  - Fluorescence Yield 6%
  - Atmospheric Conditions 4%
  - Photometric Calibration 10%
  - Aperture ?% can be large

- Total Energy Scale Uncertainty 17% (+?: F-yield)
  - Flux Uncertainty (with β=2.8) 30%

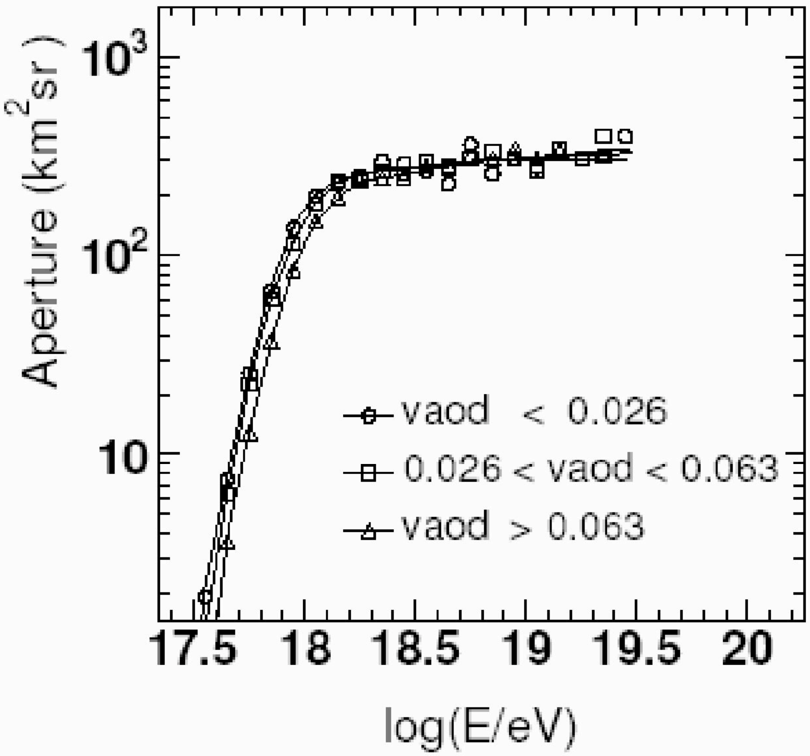
HiRes Mono / Stereo Aperture for Energy Spectrum

Ground-based FD has a severe proximity and extinction problems - need multi-eyes

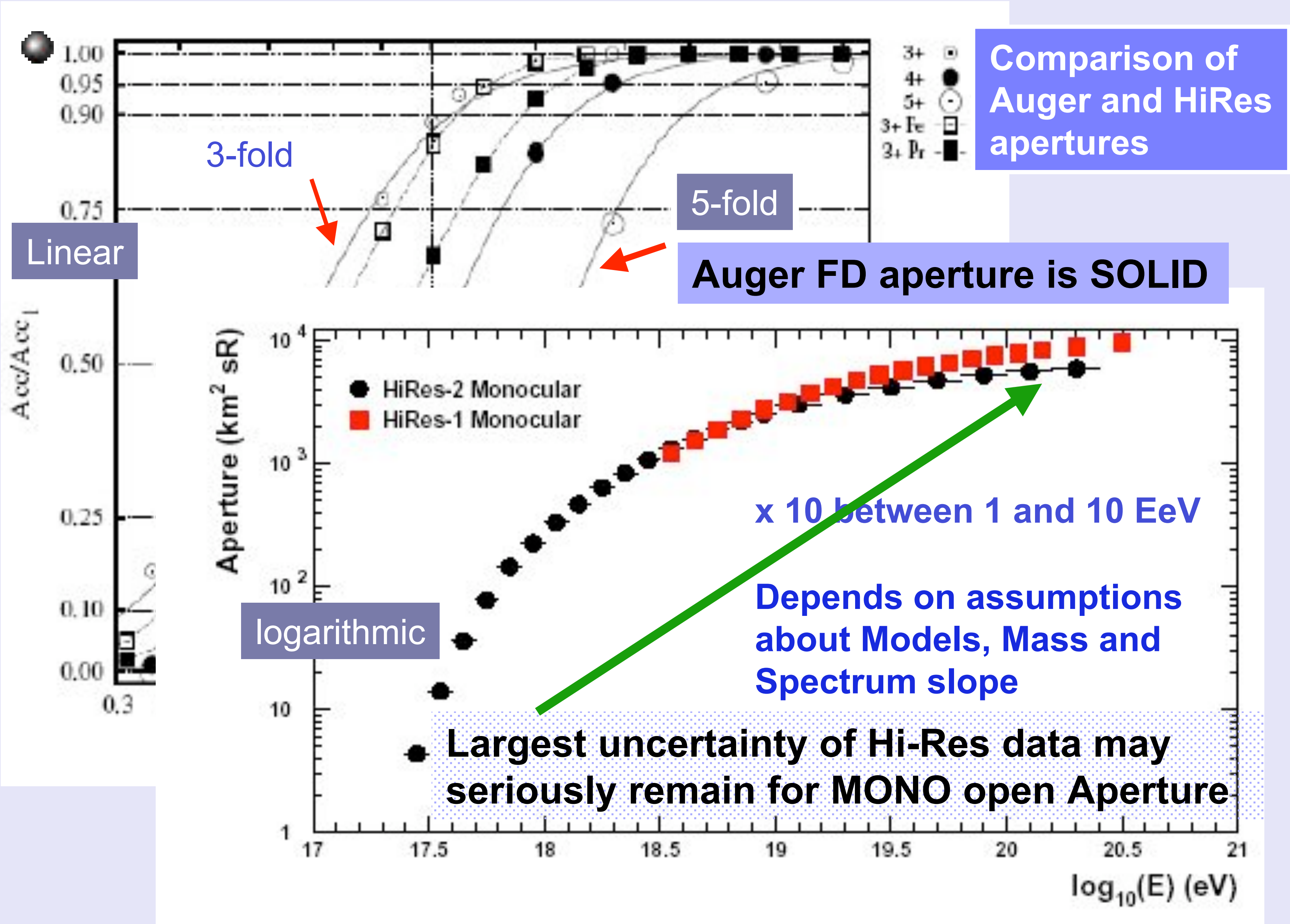
MONO - more fragile values



STEREO -very firm values



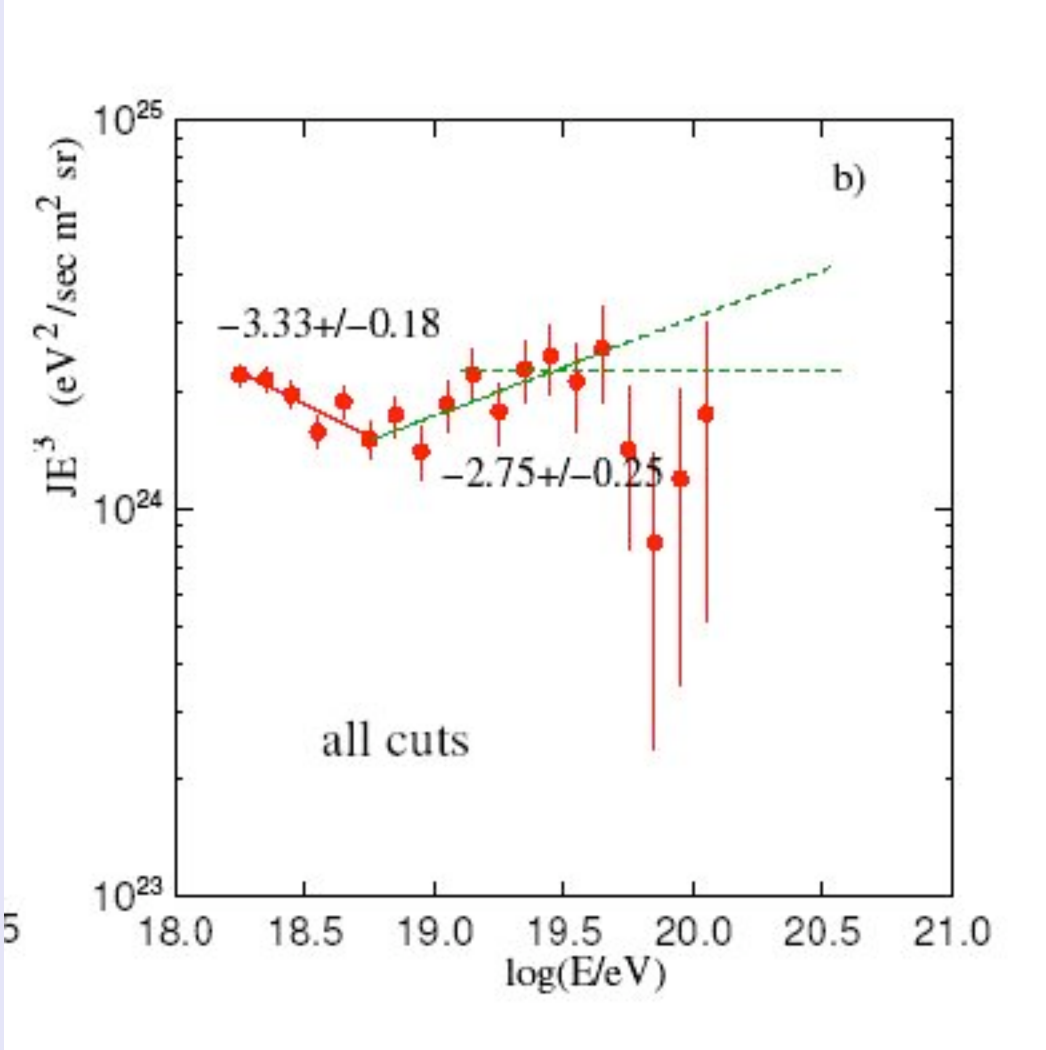
MONO data dominated the statistics



Comparison of Auger and HiRes apertures
3-fold
5-fold
Linear
Auger FD aperture is SOLID
logarithmic
HiRes-2 Monocular
HiRes-1 Monocular
Aperture (km² sR)
log10(E) (eV)
Acc/Acc
3+
4+
5+
3+ Fe
3+ Pr
x 10 between 1 and 10 EeV
Depends on assumptions about Models, Mass and Spectrum slope
Largest uncertainty of Hi-Res data may seriously remain for MONO open Aperture

HiRes Stereo Energy Spectrum

- With geometrical constraint
- Statistically Consistent with Mono spectrum
  (& may be flat spectrum, too)
  But with much limited aperture
- 11 observed, where 37.4 / 29.8 expectation
  (AGASA and flat)
  -4.3 σ, -3.4 σ deviation



Auger

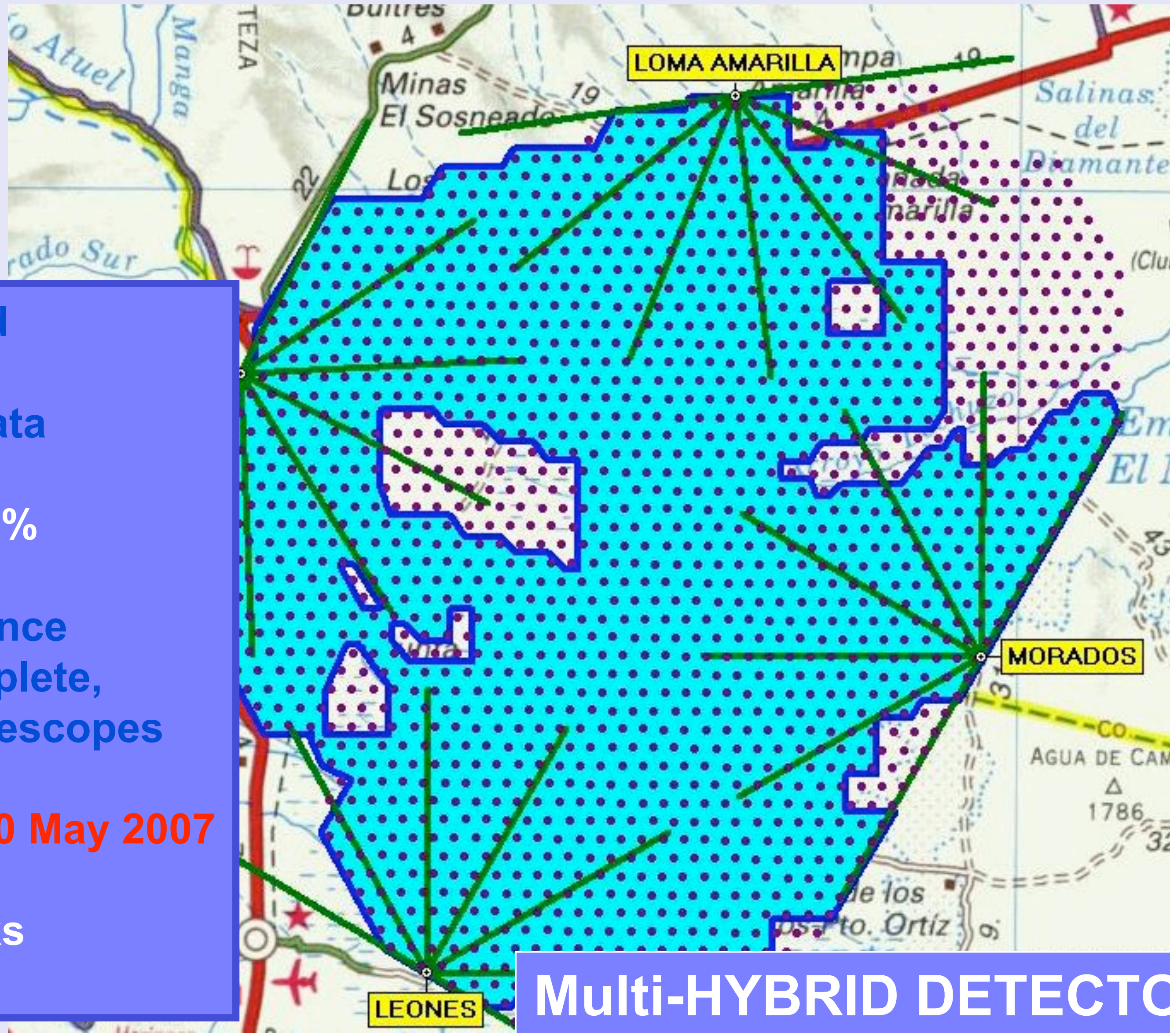
1438 deployed
1400 filled
1364 taking data

090707 ~ 85%

All 4 fluorescence buildings complete, each with 6 telescopes

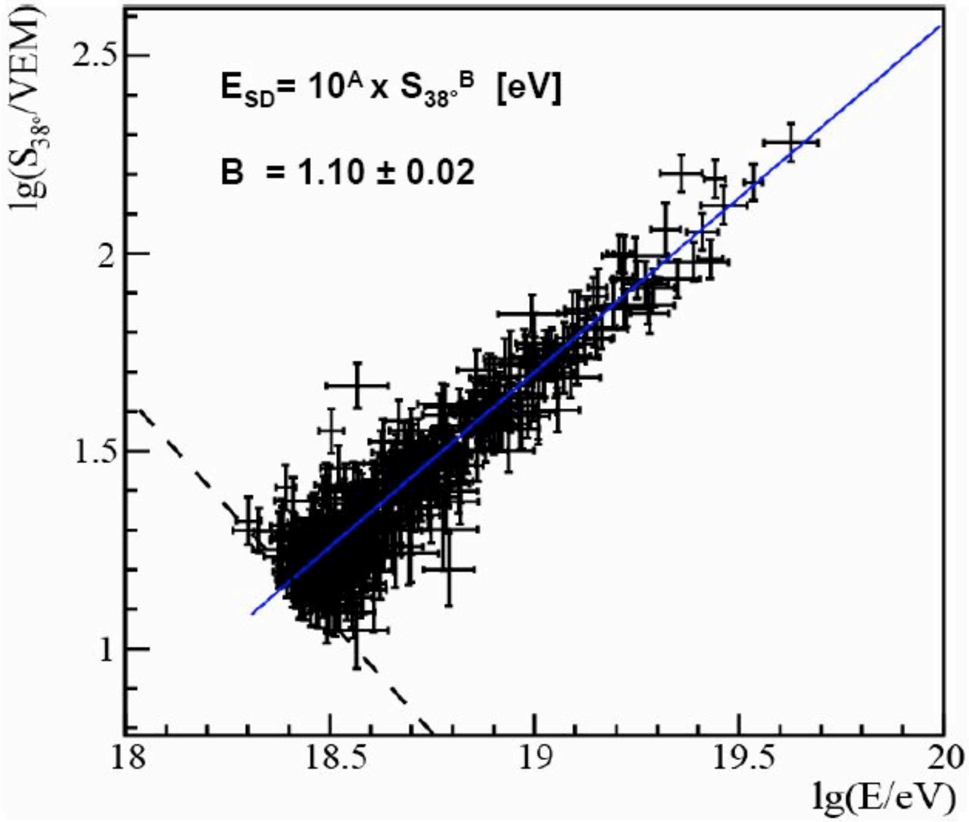
1st 4-fold on 20 May 2007

AIM: 1600 tanks



Multi-HYBRID DETECTOR

Auger: Energy Calibration - firm up to E19.5 eV



Selection of high quality hybrid data without introducing biases
(talk on elongation rate by M. Unger [Auger Collaboration])

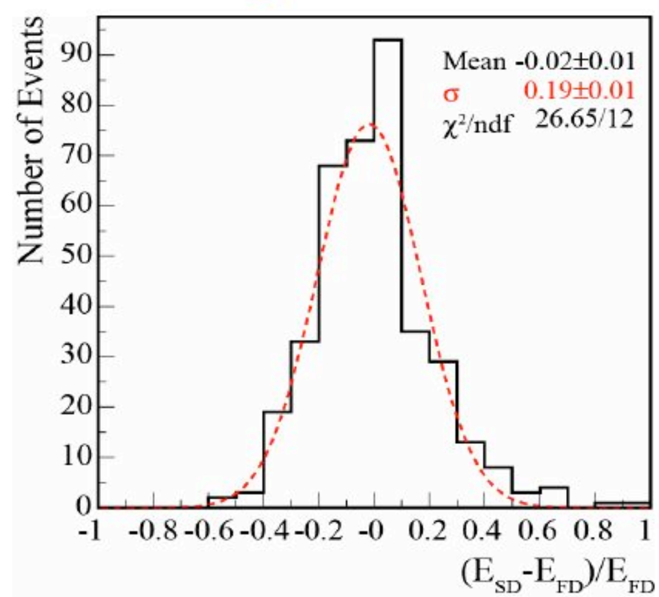
⇨ 387 events

⇨ Correlation of $S_{38°}$ and E_{FD}

$$\frac{\sigma_E}{E} = \frac{\sigma_{E_{SD}(\sigma_{S_{38°}})}}{E_{SD}} \otimes \frac{\sigma_{E_{FD}}}{E_{FD}} = 18\%$$

16% 8%

Energy resolution

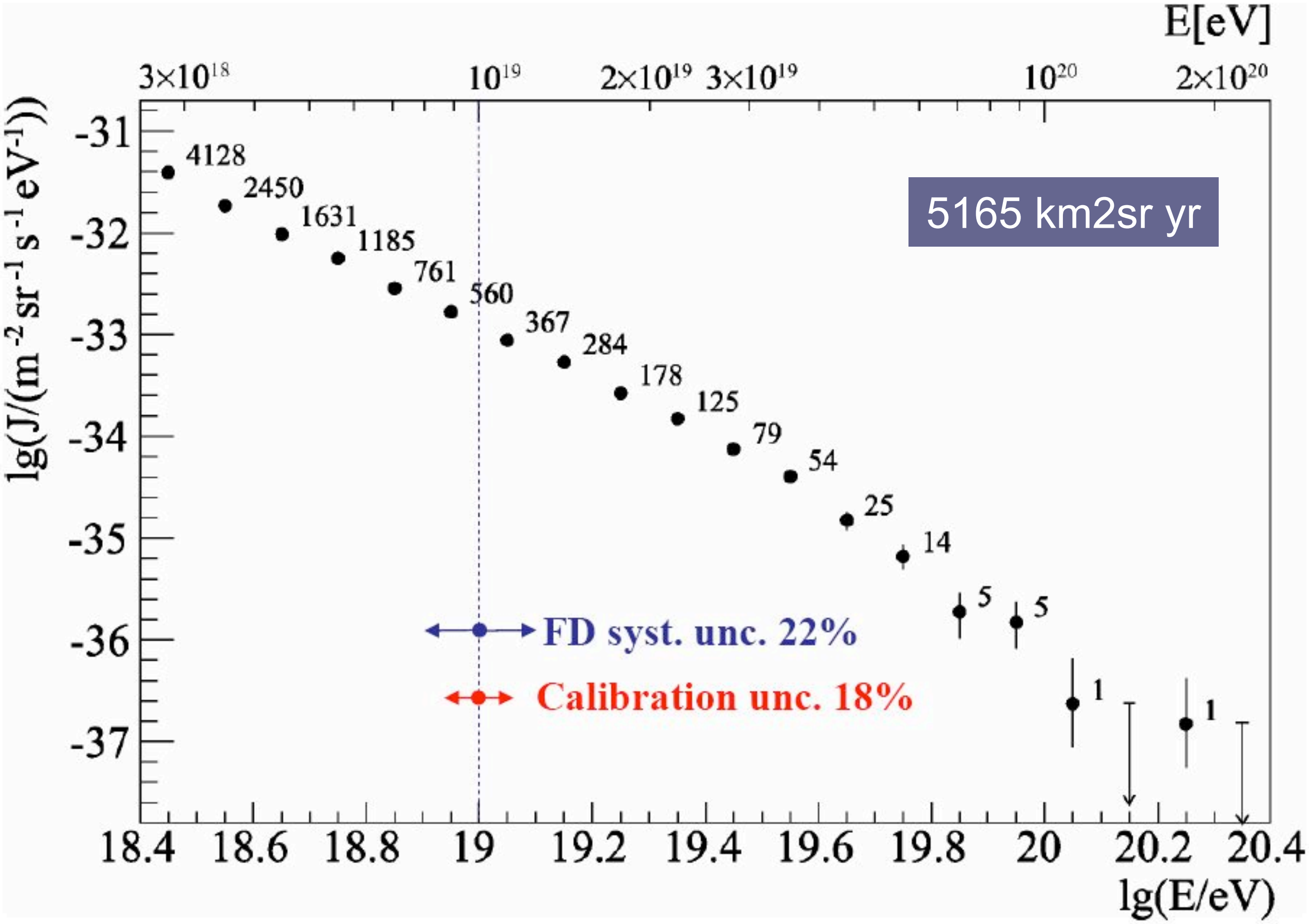


Auger SD Energy Spectrum

Cross-checks:

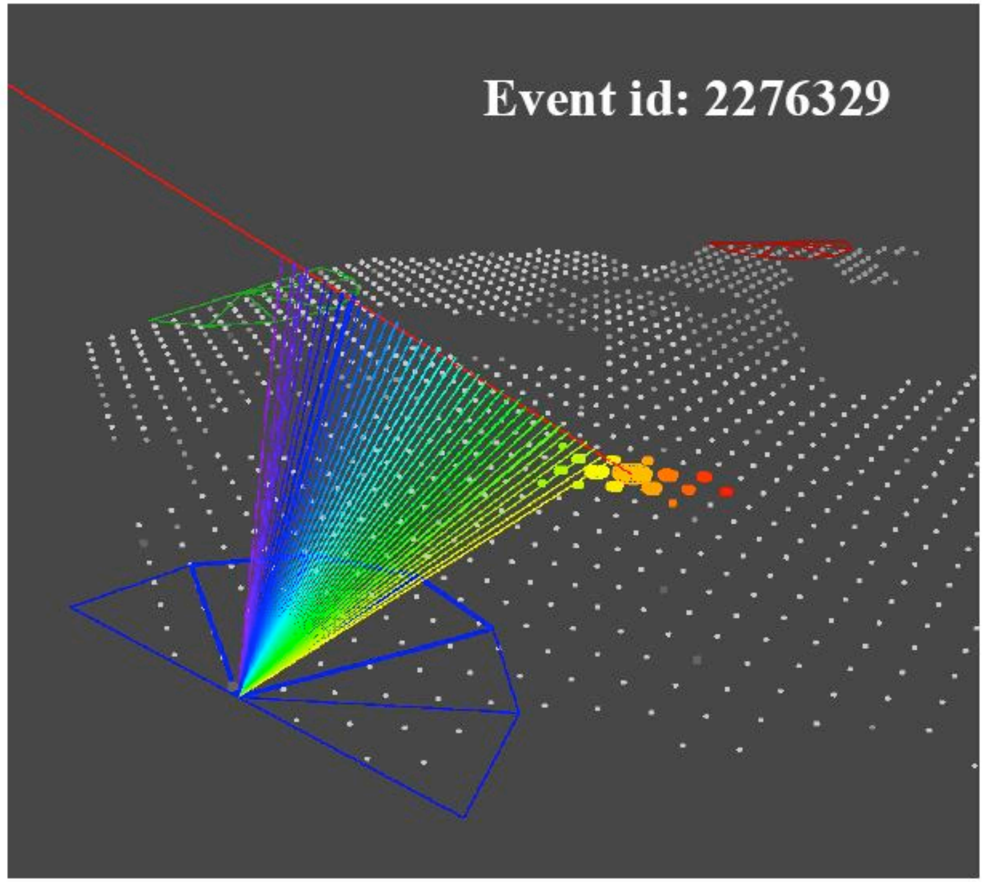
- Different reconst. methods
- $\cos^2\theta$
- Different portions of the array
- Different time periods
- Temperature

⇨ **All compatible within uncert. (few %)**



Auger Multi-Hybrid Concept

The Auger Observatory combines independent measurement techniques



Surface Detector Array (SD)

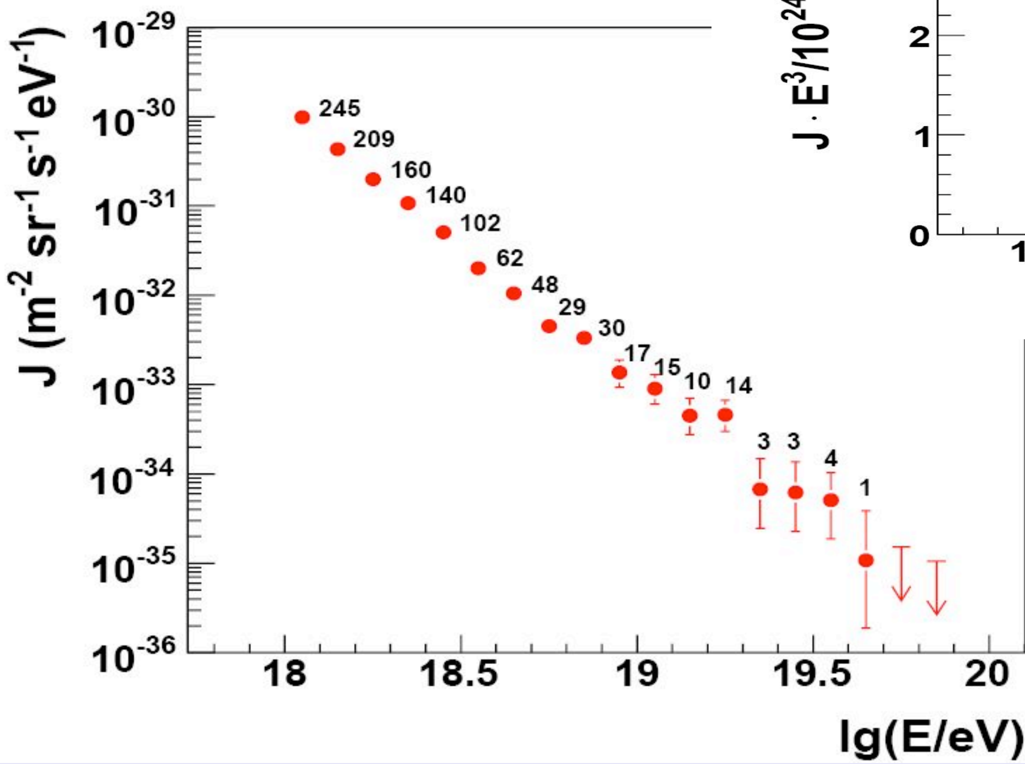
Air Fluorescence Detectors (FD)

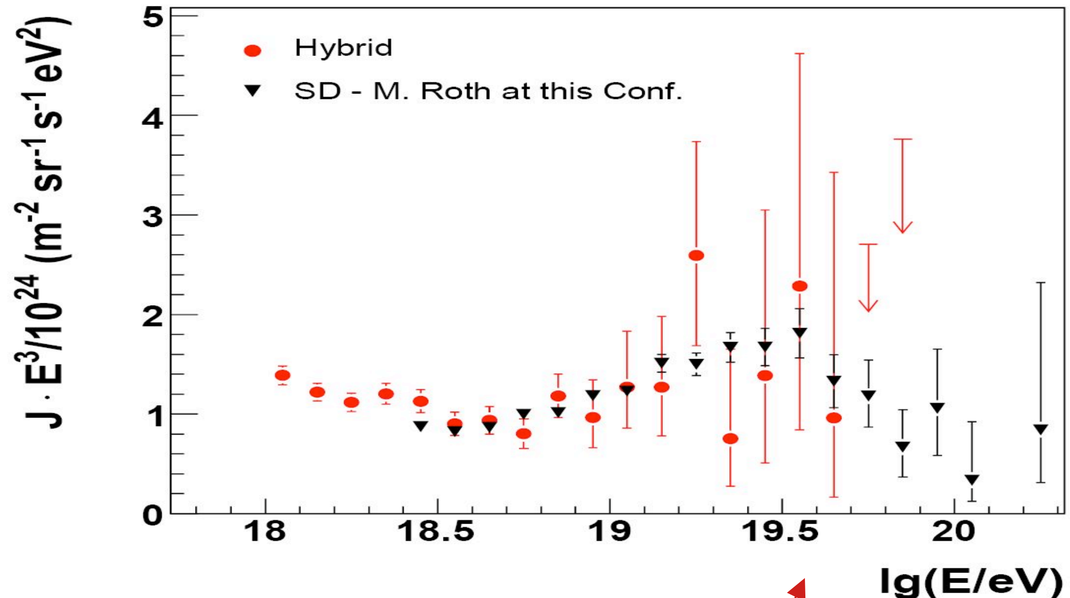
- reliable geometry and energy measurement
- mass composition studies in a complementary way

***Hybrid* data set used for this analysis:**

fluorescence events in coincidence with a least one SD station

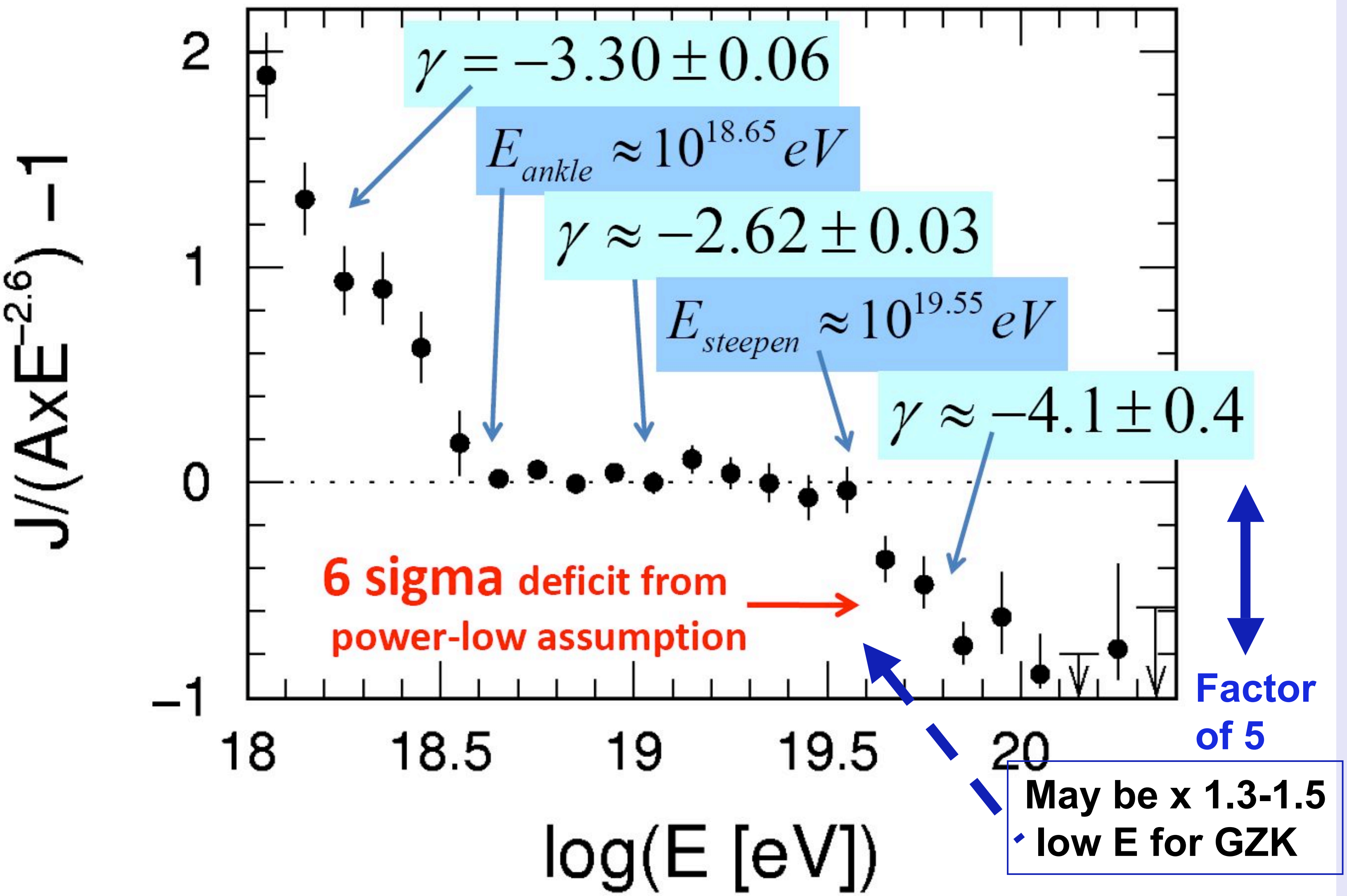
Auger Hybrid Energy Spectrum





Firm Hybrid ranges to E19.2 eV,
Not yet confirming the steepening

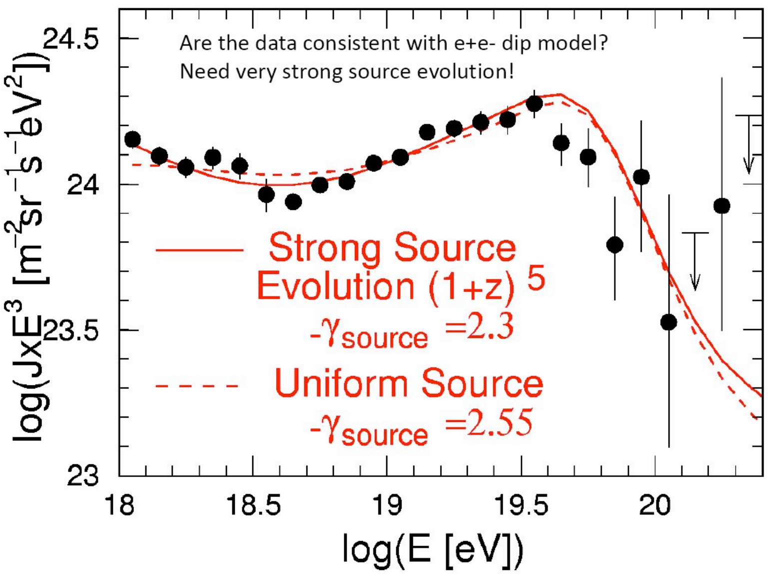
Auger Residual plot



Auger Spectrum

comparisons with Proton Model and with Mixed composition model - not like p-GZK

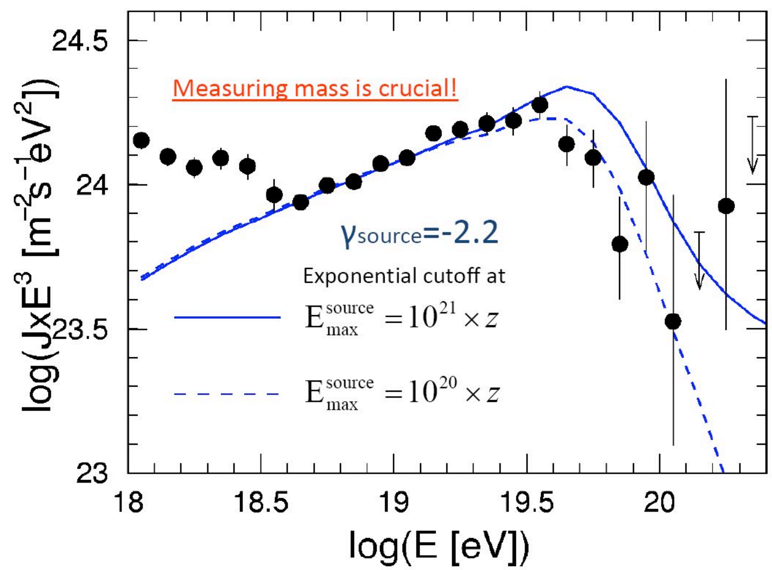
Comparison with Pure Proton Model



(→ Invited talk by Venya Berezinsky)

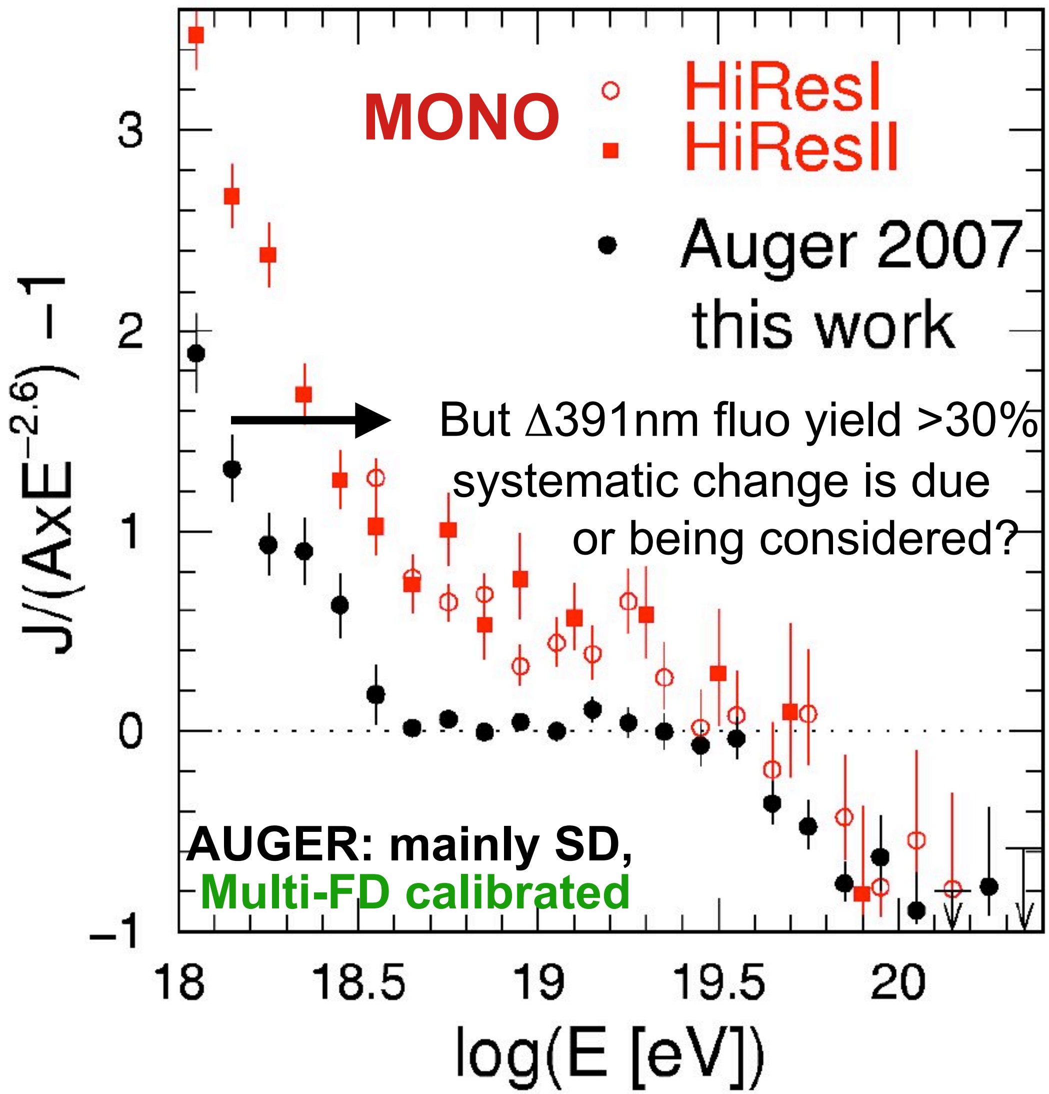
Nucleus Model

CR abundance is same as low energy Galactic components



D.Allard, *et al.* Astropart.Phys., **27**, 61, (2007); astro-ph/0512345

HiRes vs. Auger



Uncertainty in Energy scale is achieved to be **22%** and still being reduced.

A significant difference from HiRes spectrum at below 10 EeV.

Slope at Highest End

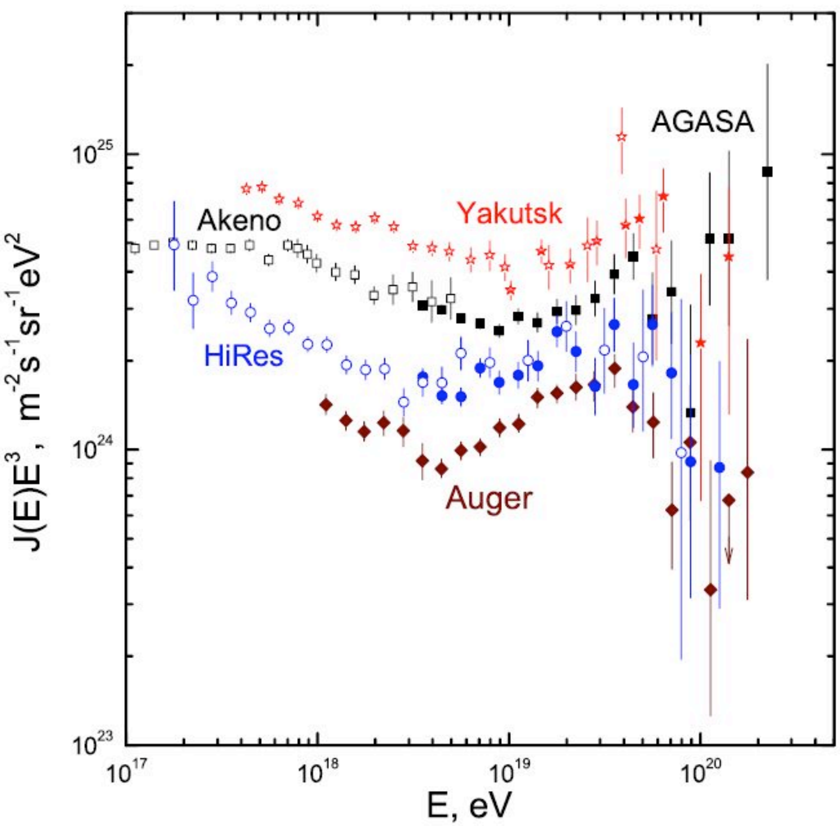
Auger $\gamma = -4.1 \pm 0.4$

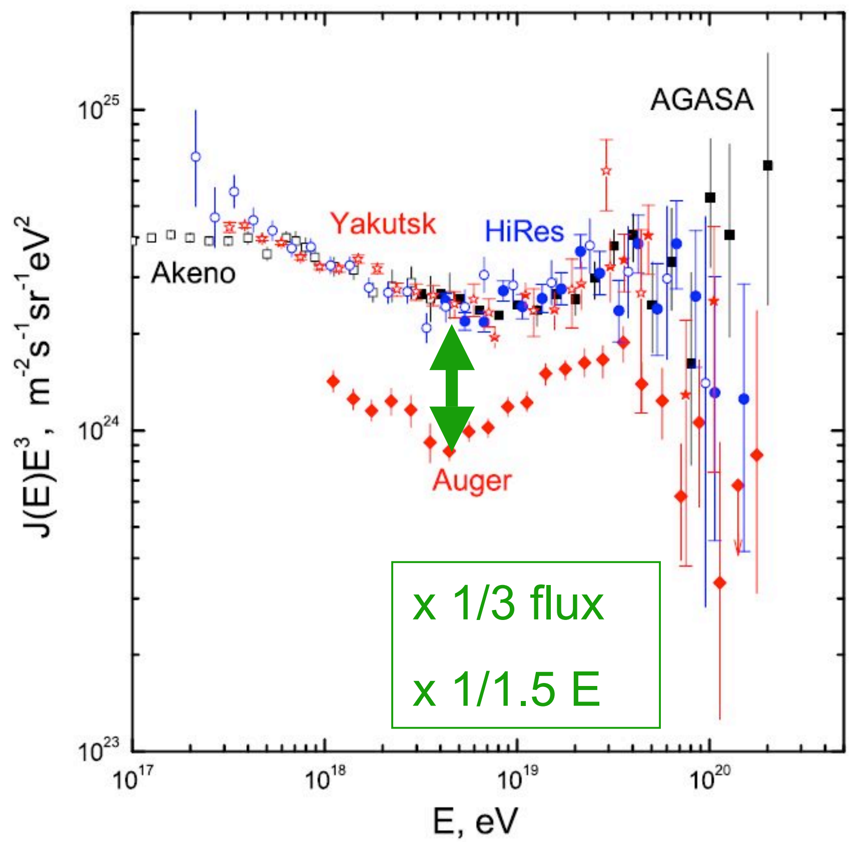
HiRes $\gamma = -5.1 \pm 0.7$

Pair creation DIP

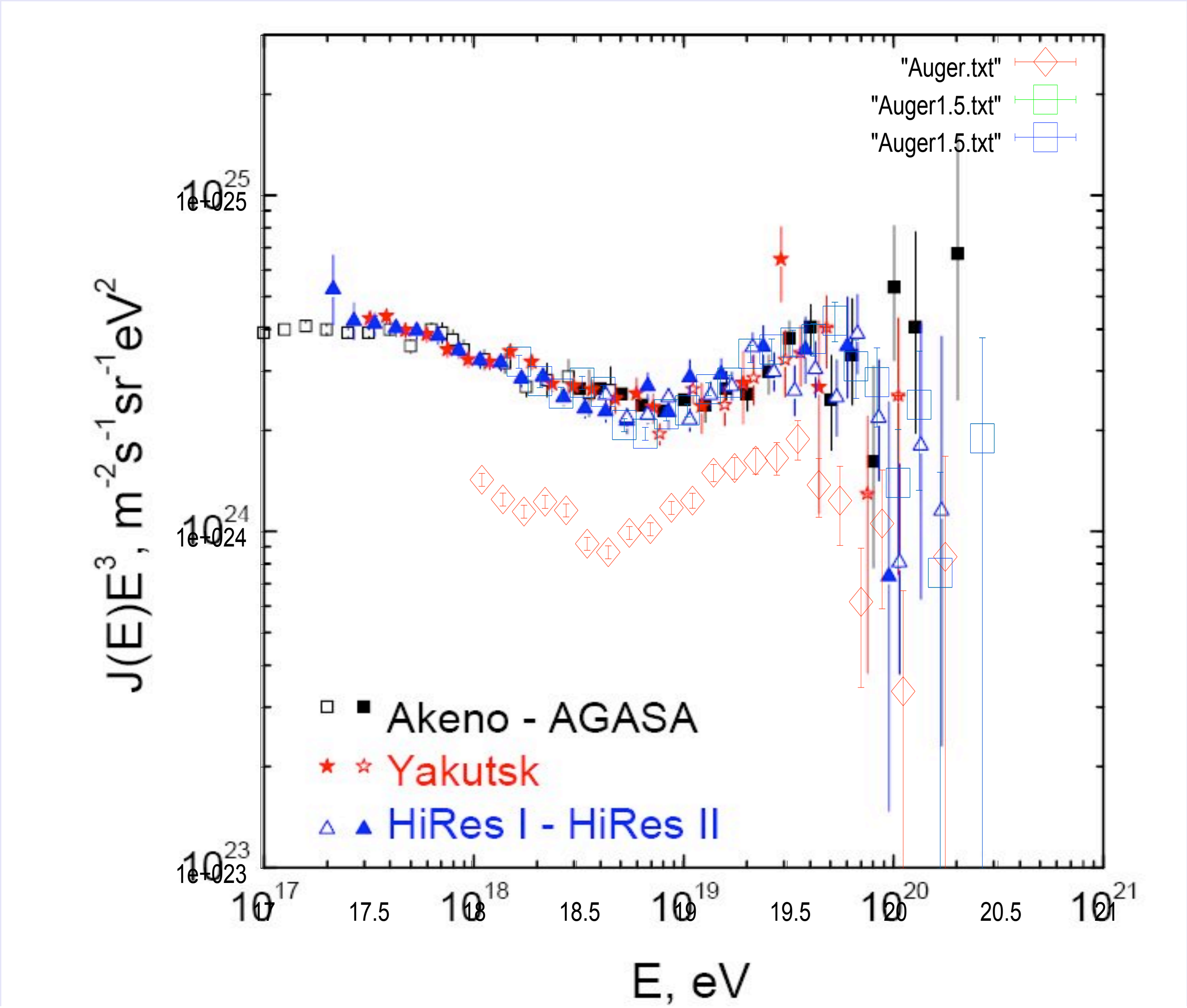
by V.Berezinsky

Dip
V.Berezinsky





Auger Spectrum x 1.5 re-scaling M.Teshima (may be more)

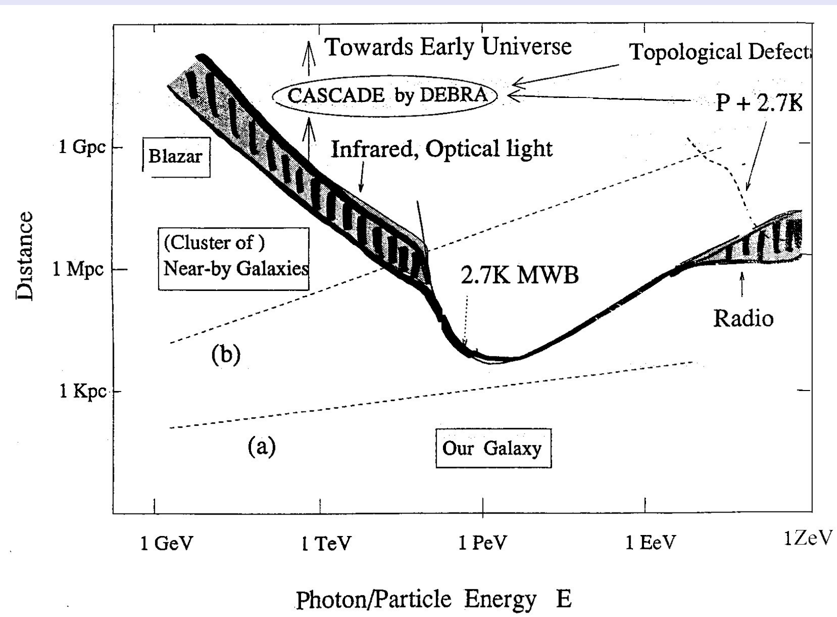


UHECRs
photon limit

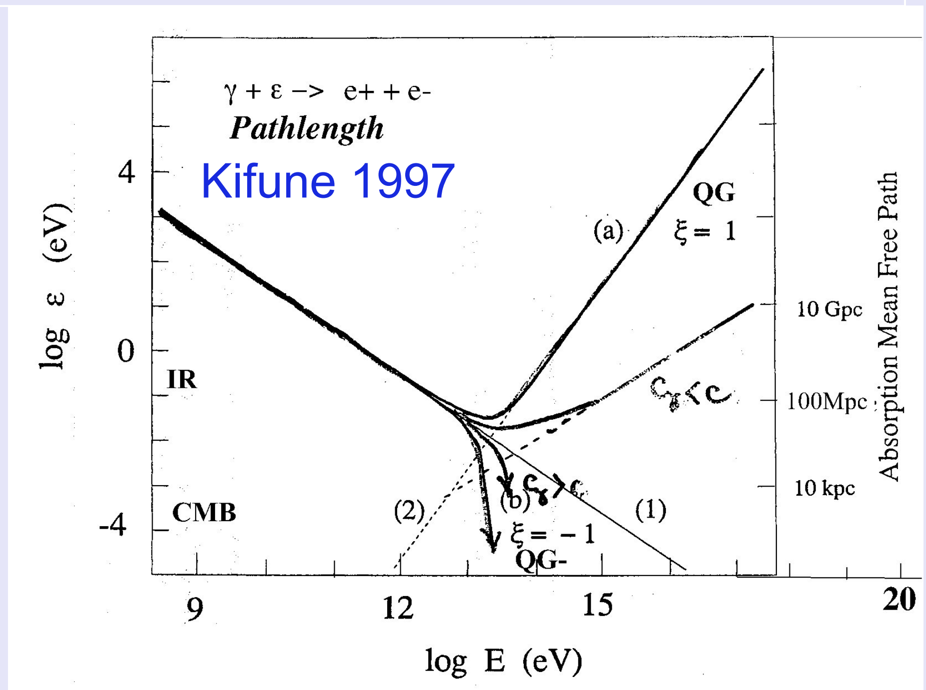
EHE γ -rays does not travel much distance, unless
Coleman-Glashow e- pair production in 2.7K CMB-filled Vacuum

EHE γ-rays travel > Gpc only in Quantum Gavity or C-G vacuum

- $E(\gamma)$ ε (10^{-3}K) $E^2 - (pc)^2 \geq \sum m_i^2 c^4$
- $4\varepsilon E - \xi \geq 4m_e c^4$ → LHS -RHS **≤ 0** at E > 10 TeV



Ordinary Vacuum

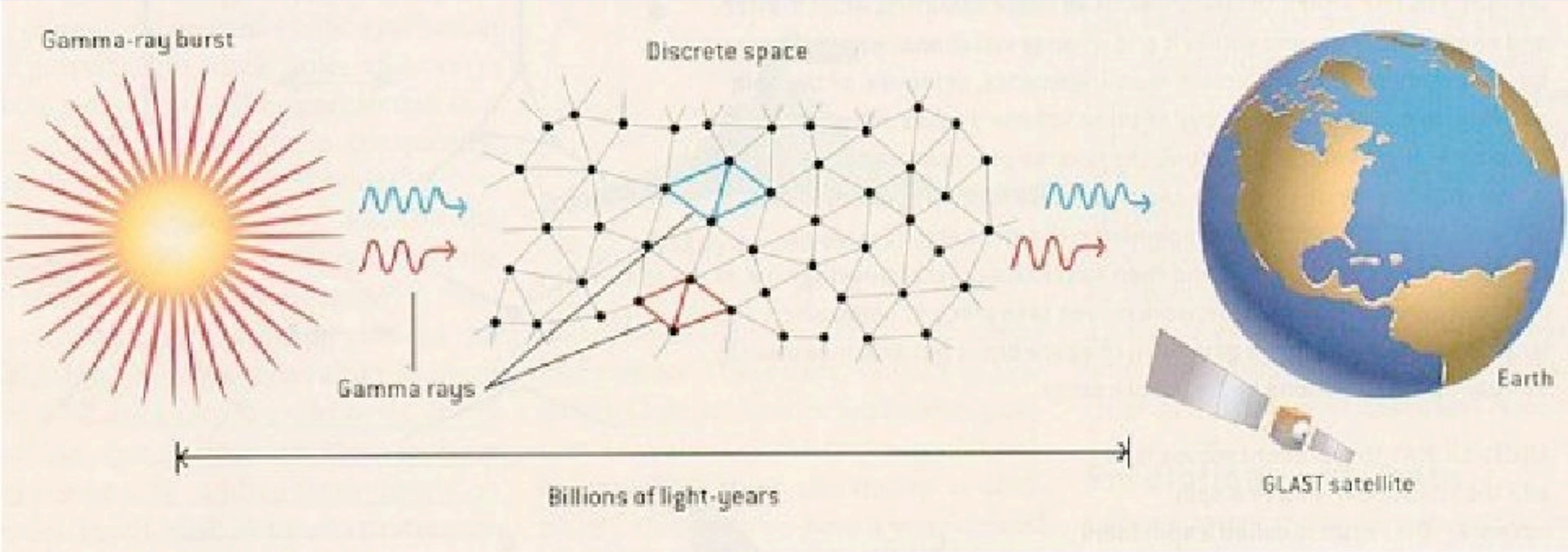


Coleman-Glashow

and/or Quantum Gravity Vacuum

Exploration 3: Test of vacuum of Loop Quantum Gravity

- Spin network makes time ticks discretely in geometry of non-Cartesian zigzags



- Lorentz Invariance is not mandatory with QG;
- Dispersion of QG medium causes delay of c (E) < c_o → γ comes to us

E >> 10 TeV for $\varepsilon = 10^{-3}$, $4\, m_e c^4 = E^2 - (pc)^2 = E^2\, (\varepsilon/E - \xi\, E/E_0) < 0.$

Quantum gravitational medium effect

(Ellis et al, 1992; Amelino-Camelia et al. 1998)

- General photon dispersion relations* of quantum gravity granular vacuum

  $E_{QG} \approx 1/L_{min}$, where $L_{min} \approx L_P \approx 10^{-33}$ cm.

- Dispersion: $c^2p^2 = E^2[1 + \xi E/E_{Q}$ … $^2/E_{QG}^2)], \xi = \pm 1.$

- Energy-dependent velocities $v = \partial E/\partial p \approx c(1 - \xi E/E_{QG} +$ … $_{G}^2))$

  Delay of arrival time $\Delta t \approx \xi$, (or $\Delta t^* \approx \pm EL/E_P c$)

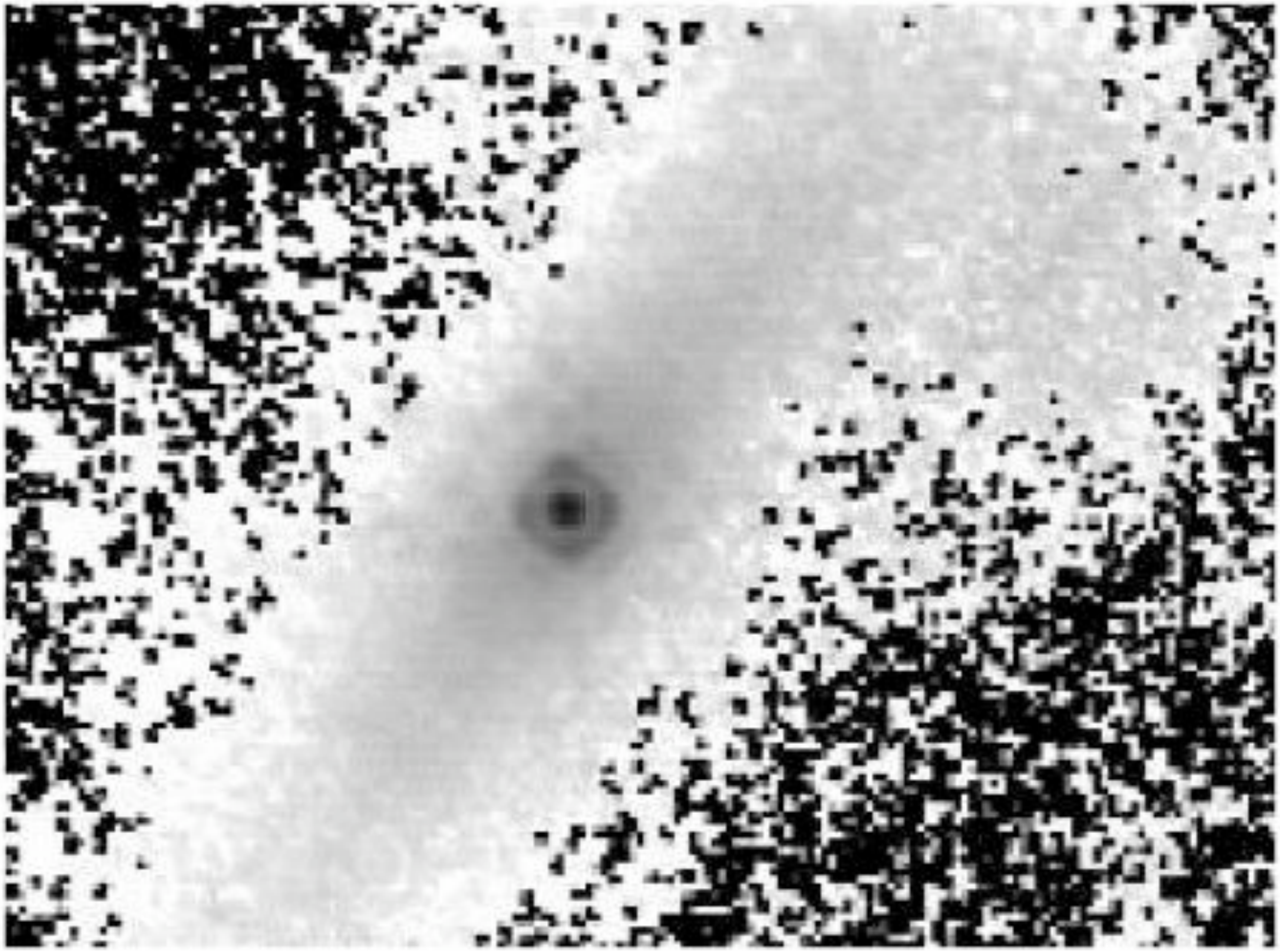
- S/N-Sensitivity factor $\eta \equiv |\Delta t^*|/\delta t$: [$\delta t \geq 1ms$ (GRB), $\geq 1\ \mu s$ (pulsar)]

GRB 20 MeV γ	GRB lensing	Pulsar AXAF x	Pulsar (1 eV)	EHE γ 10^{20} eV
~ 1 (Δt ~ ms)	10^{-6}	10^{-8}	10^{-10}	10^{10} (Δt ~ year)

Note: insensitive except EHE γ

However, HST quasar diffraction rings already denied the 1st order

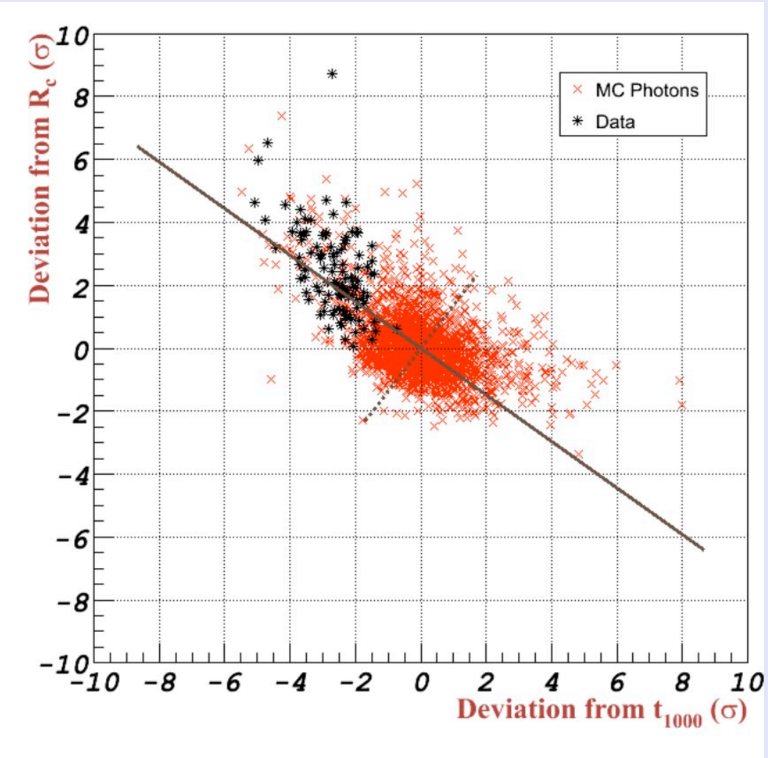
HST quasar diffraction rings deny 1st-order QG medium effect

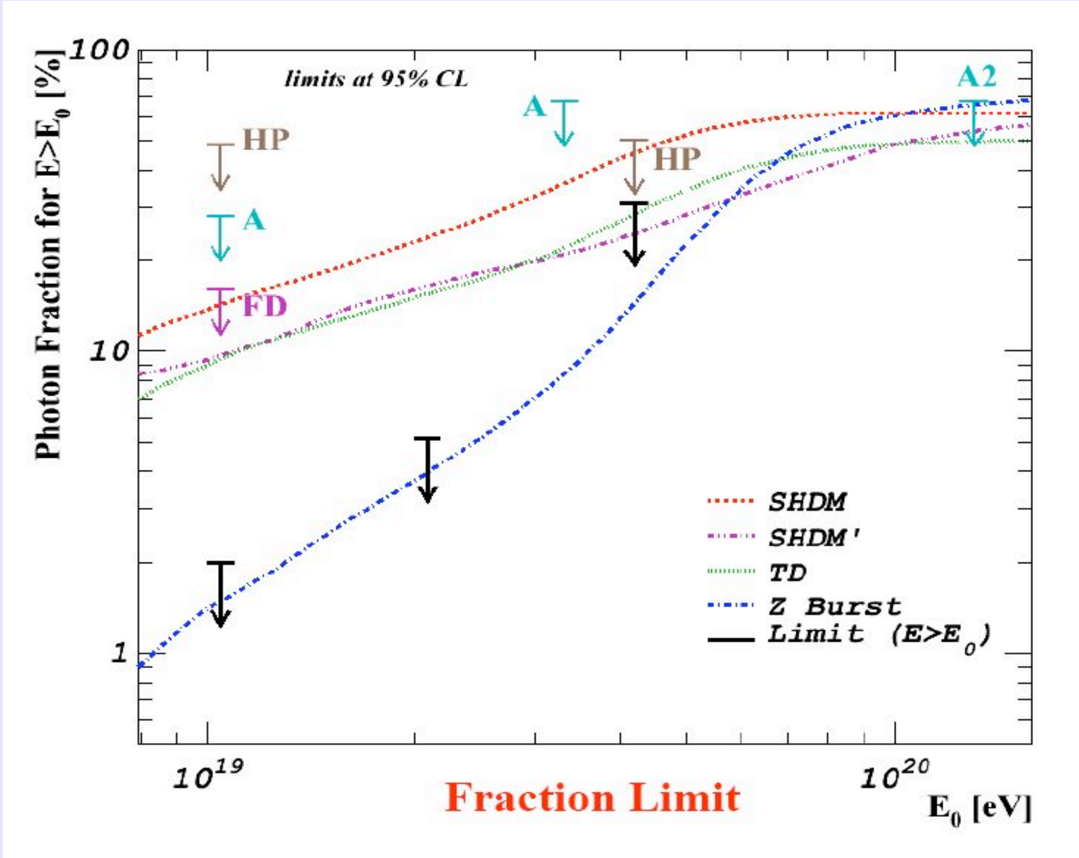


Bubble burster. Irislike "Airy ring" around quasar PKS 1413+135 (black dot, *center*) may nix some versions of quantum foam.

Auger: Photon limit

Rise time in shower front
Curvature of shower front



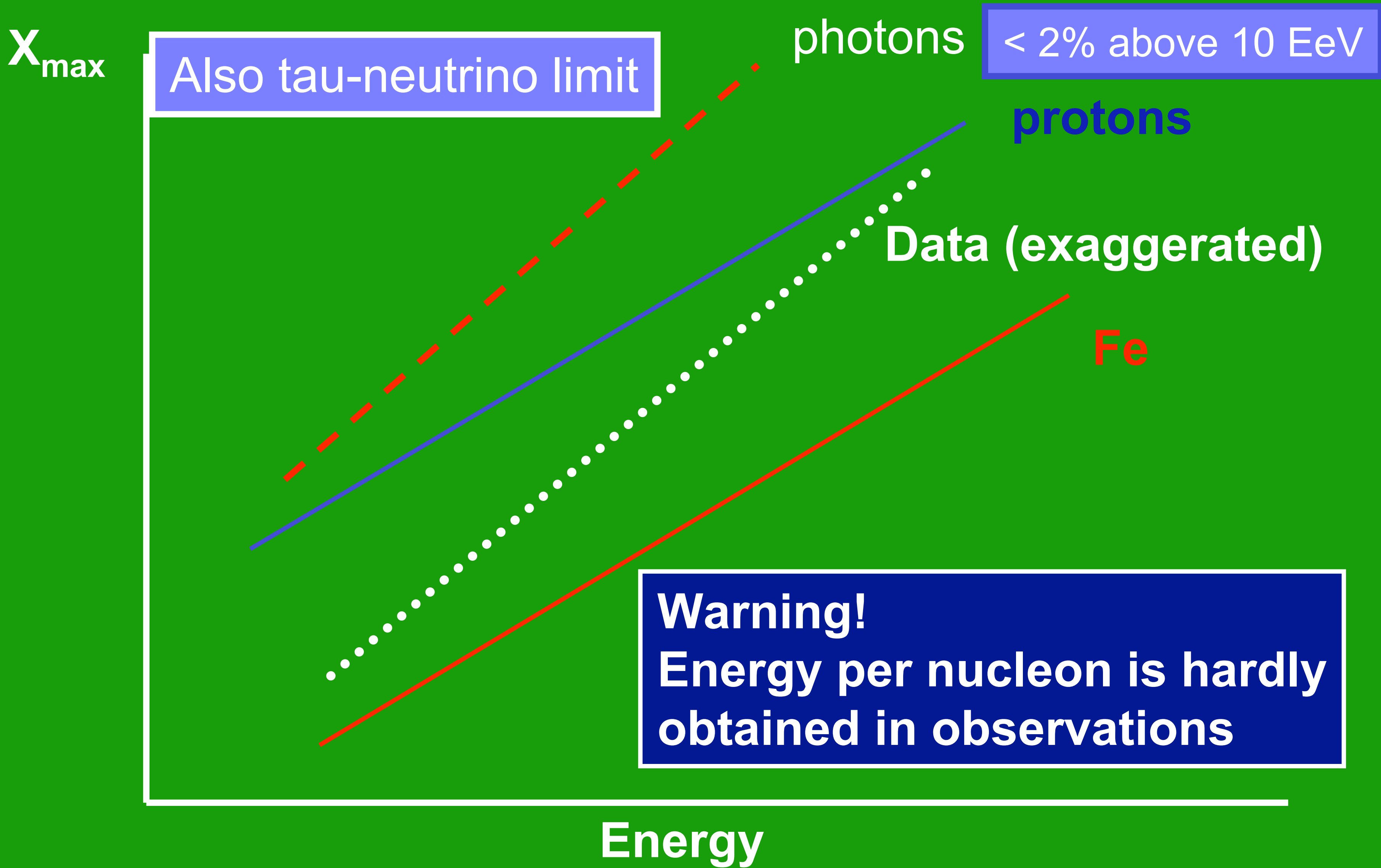


No photons to support SHDM/TD models and Coleman-Glashow

Auger 20years operation will reach GZK gamma flux of ~0.1%

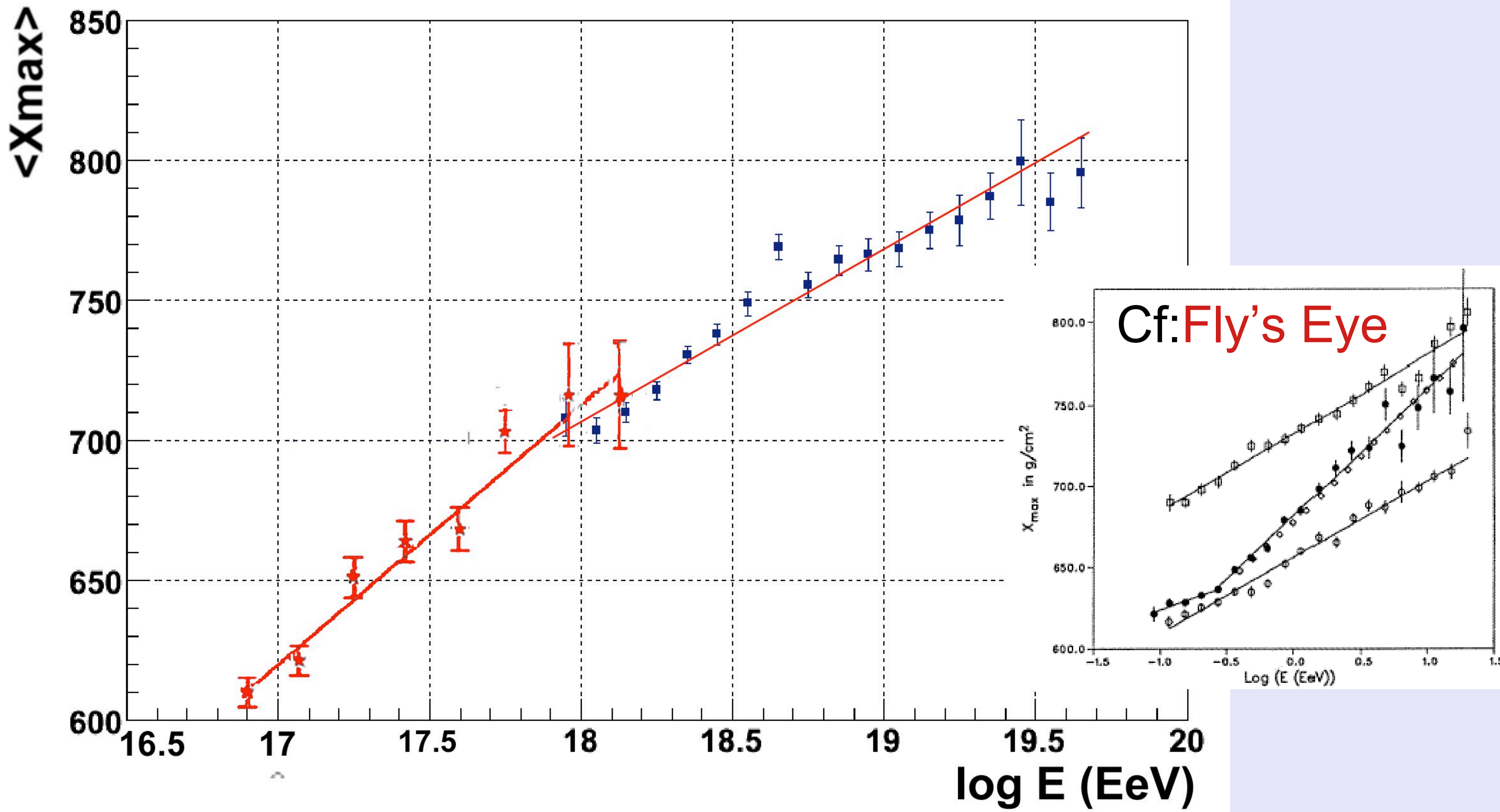
UHECRs
Xmax
and Chemical composition

Elongation rate:
How we try to infer the variation of mass with energy



HiRes
Xmax distribution

Very different



Questionable H_{max} for the separation of p/Fe

Fly's Eye & HiRes-mono Xmax distribution

* (except hybrid-Auger) No past experiments are capable of determining H_{max} from the true top of the atmosphere, $H = 0$ g/cm^2, with the precision < 50 g/cm^2 required for the statistical separation of p/Fe by H_{max}.

• H_{max} should not be that estimated for the shower max density ρ converted from the height measured from the ground-level.

• It has to be measured from the top, $H = 0$ g/cm^2, which involves errors > 50 g/cm^2 due to the angular errors O (a few degs) alone, as well as due to more errors in H_{max} (km) by density ρ.

* Famous 3×10^{20} eV (Fly's Eye) event, that favored Fe curve, is uncertain, because it has 2 - 5 deg errors (horizontal axis is uncertain to > 50 g/cm^2, and the H_{max} from the ground-level is also that much uncertain.)

(1) It is unclear whether the event-by-event correction was made for the varying atmospheric pressure of the ground-level (which varies to ± 20 g/cm²) .

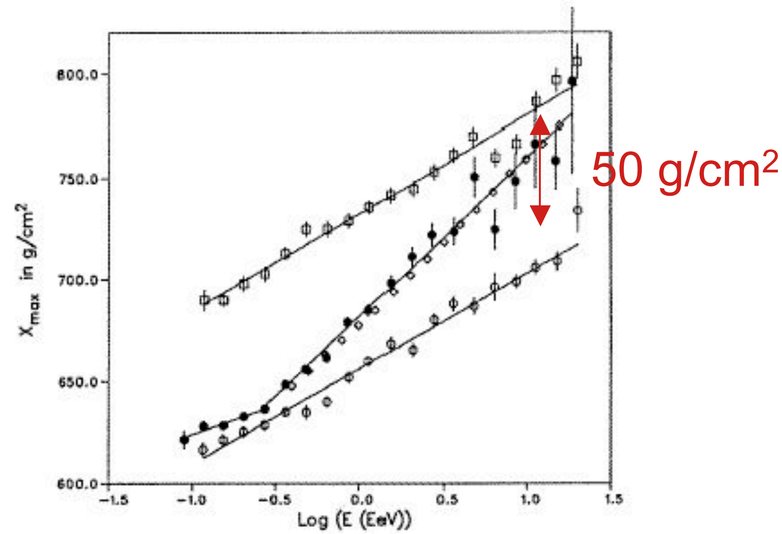
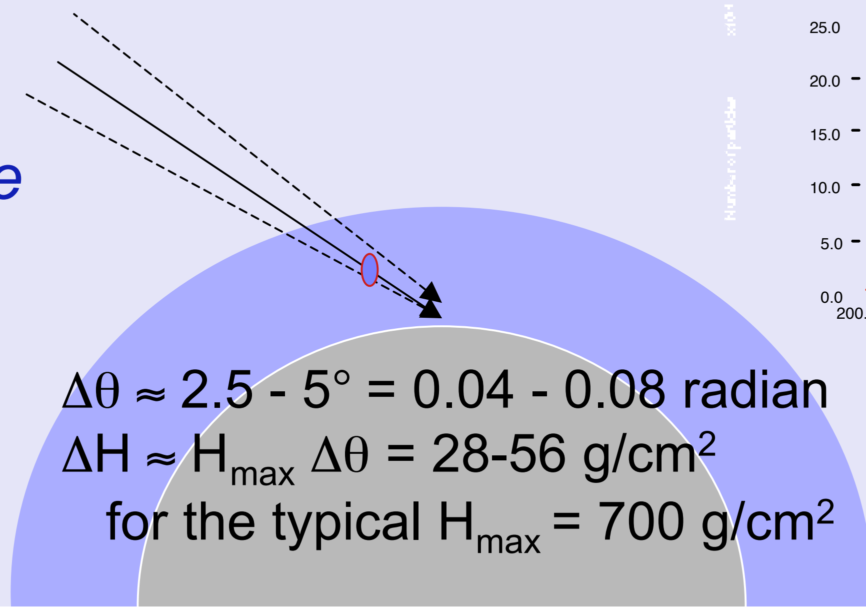


FIG. 1.7: The average X_{max} as a function of primary energy obtained by Fly's Eye. Two upper and lower lines correspond to pure proton and pure iron primaries. The energy dependence of X_{max} can be interpreted as a change in the chemical composition from heavier to lighter between 10^{17}eV and 10^{19}eV.

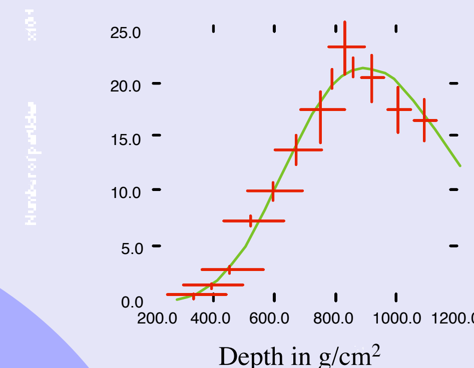
(2) FE/Hi-Res mono didn't have accurate angles for each event to give accurate H_o (Top) = 0 g/cm² to define the true X_{max}, for which angular error alone should make X_{max} errors larger than 20-50 g/cm² for each event.



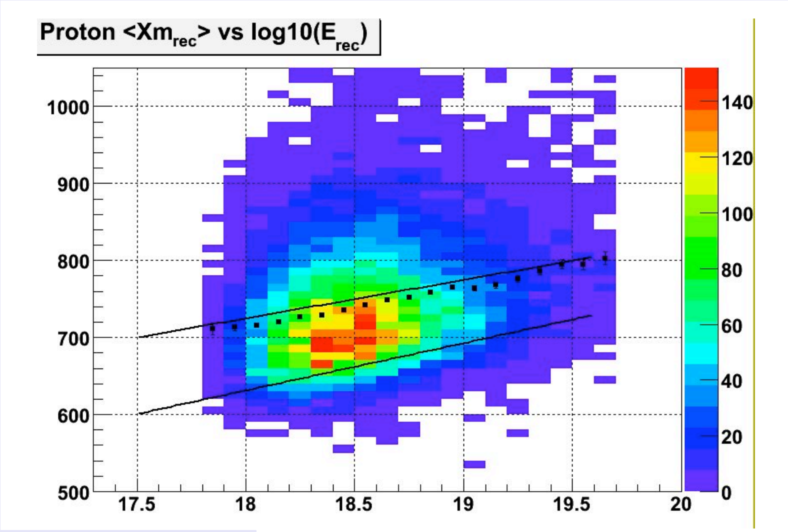
$\Delta\theta \approx 2.5 - 5° = 0.04 - 0.08$ radian

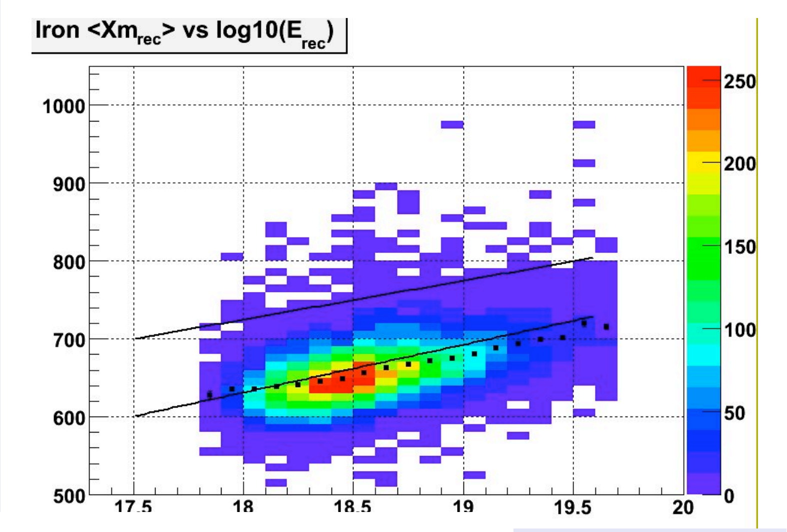
$\Delta H \approx H_{max}\, \Delta\theta = 28\text{-}56$ g/cm²

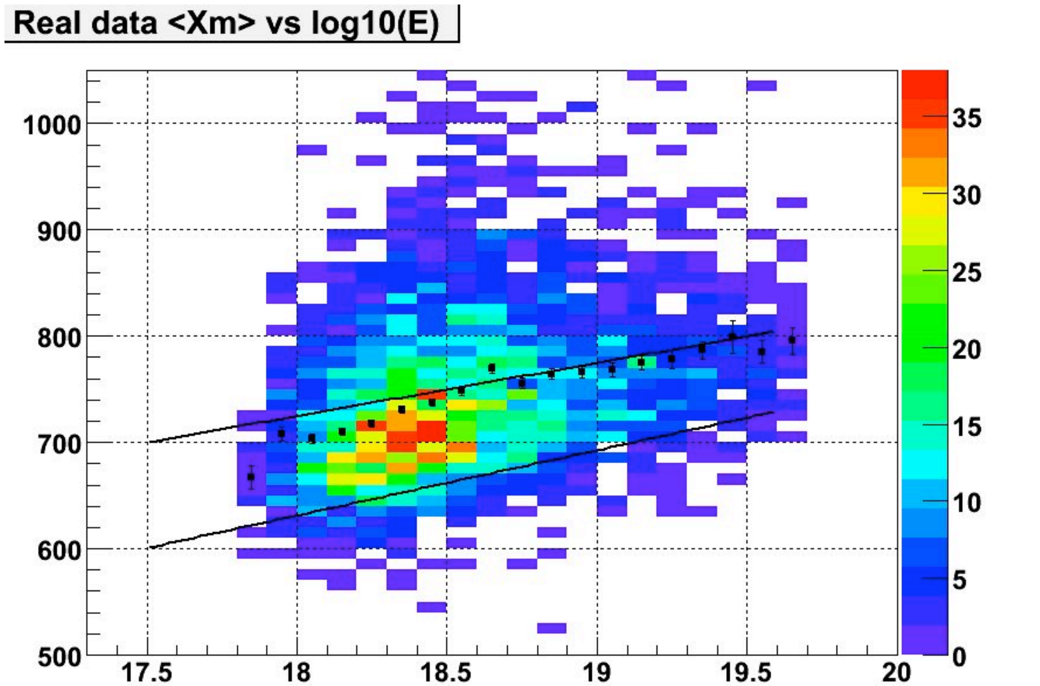
for the typical $H_{max} = 700$ g/cm²



HiRes Xmax

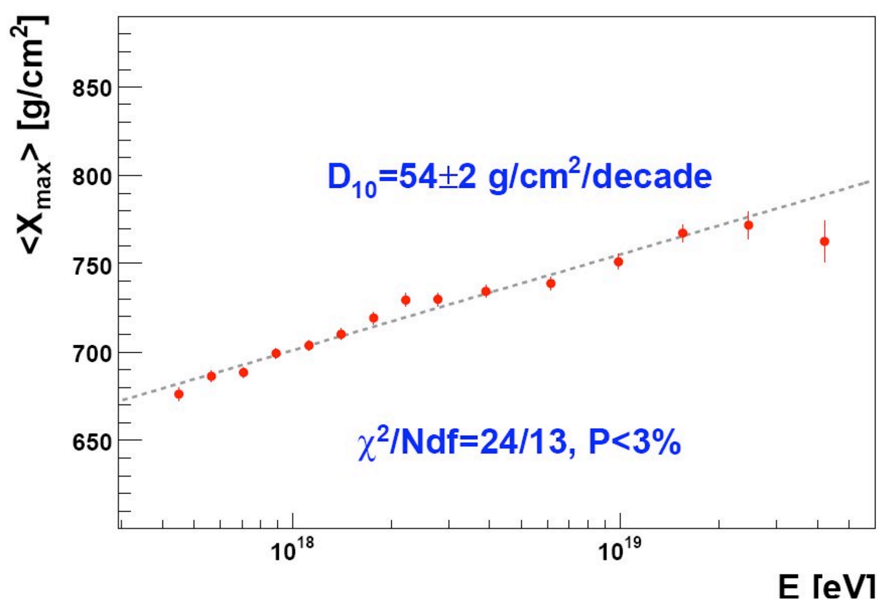

Proton <Xm$_{rec}$> vs log10(E$_{rec}$)
1000
900
800
700
600
500
17.5
18
18.5
19
19.5
20
140
120
100
80
60
40
20
0


Iron <Xm$_{rec}$> vs log10(E$_{rec}$)
1000
900
800
700
600
500
17.5
18
18.5
19
19.5
20
250
200
150
100
50
0

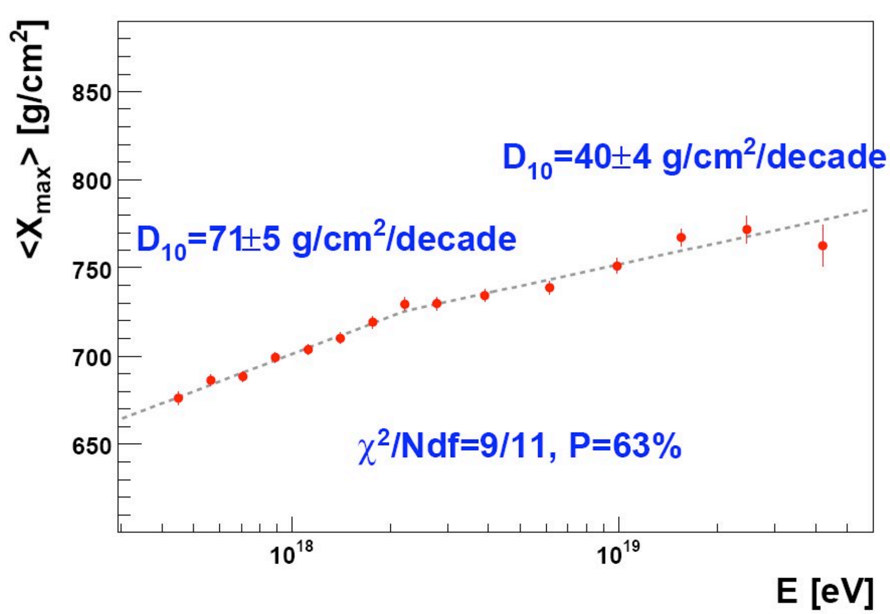

Real data <Xm> vs log10(E)
1000
900
800
700
600
500
17.5
18
18.5
19
19.5
20
35
30
25
20
15
10
5
0

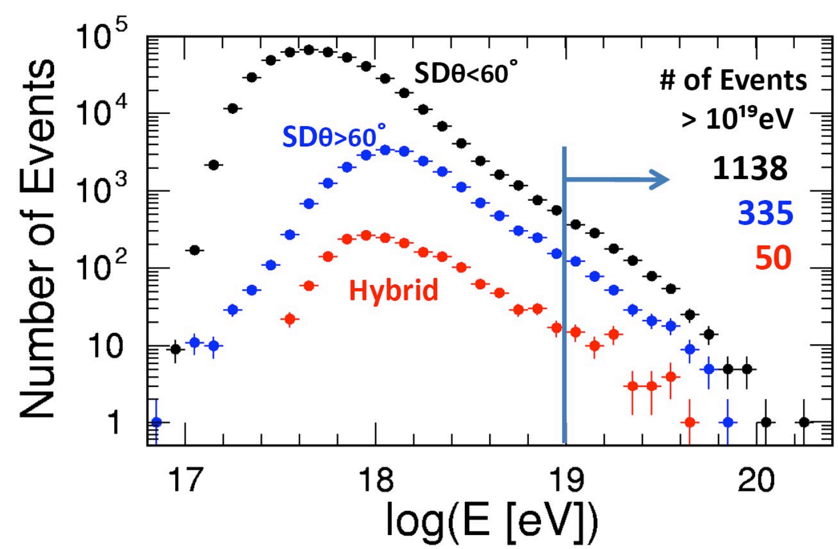
Auger Xmax distribution

Results



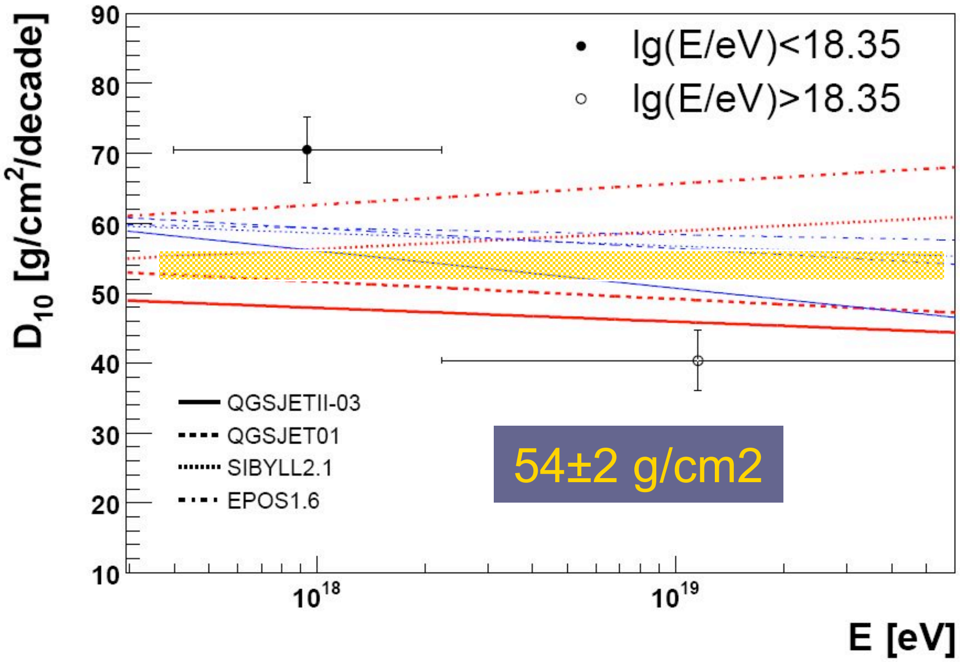
Results

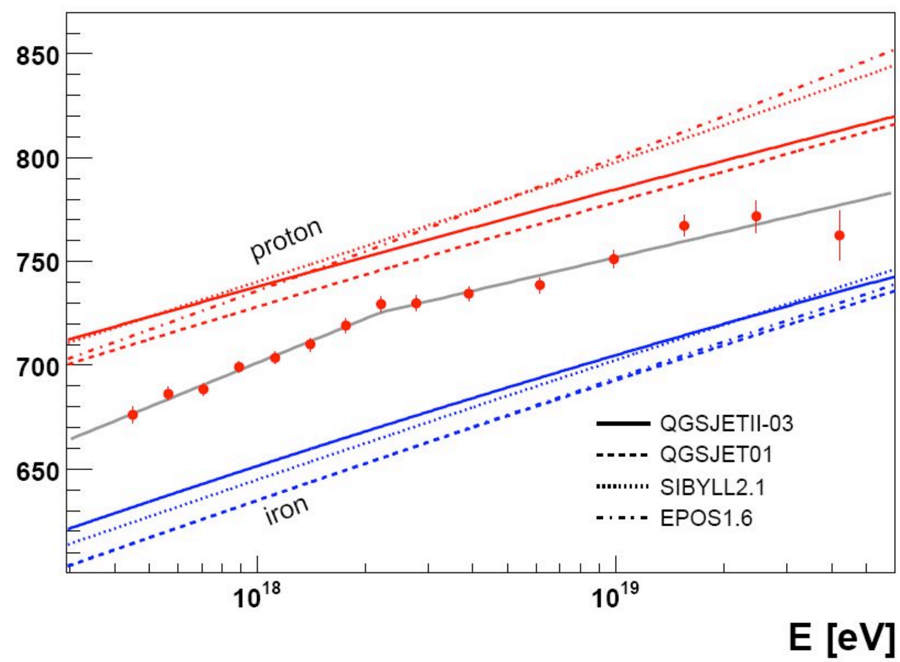




Energy scale is measured with Hybrid Observation

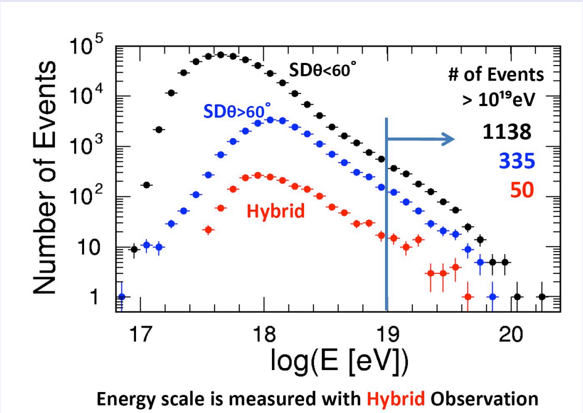
Less increasing elongation rate & comparison with M.C. - A problem





Red: Proton
Blue: Iron

Single line fit gives a better agreement with M.C..



Varying mixed composition?

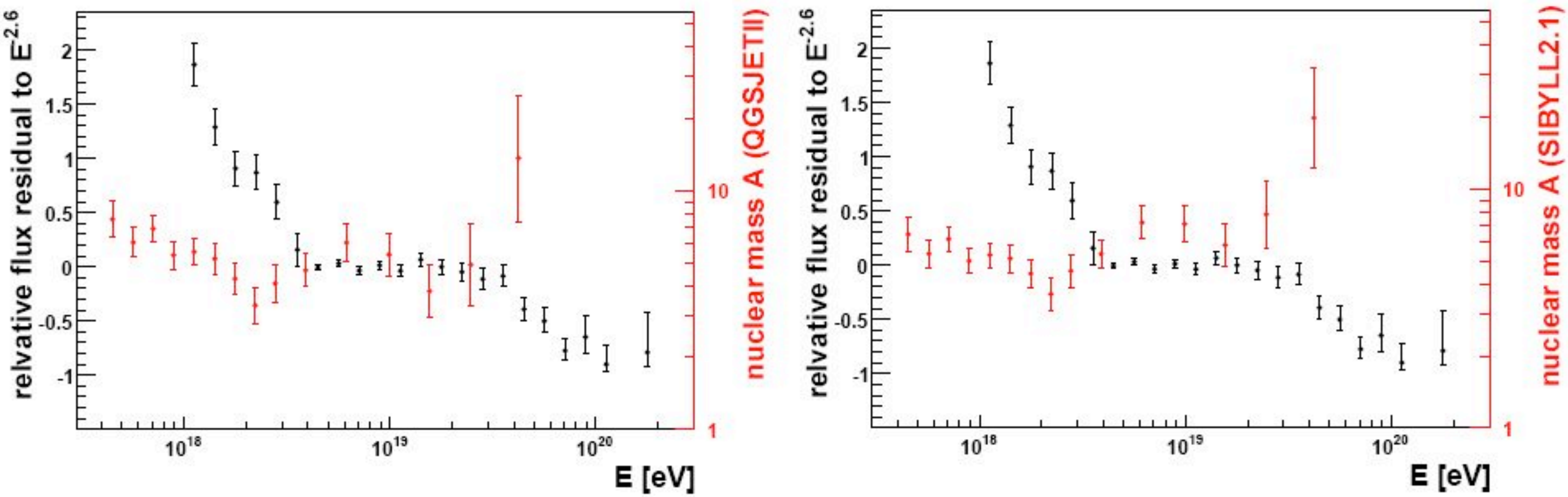
or

interaction changing? EPOS?

Bias in Low energy range?

Auger: Chemical composition study

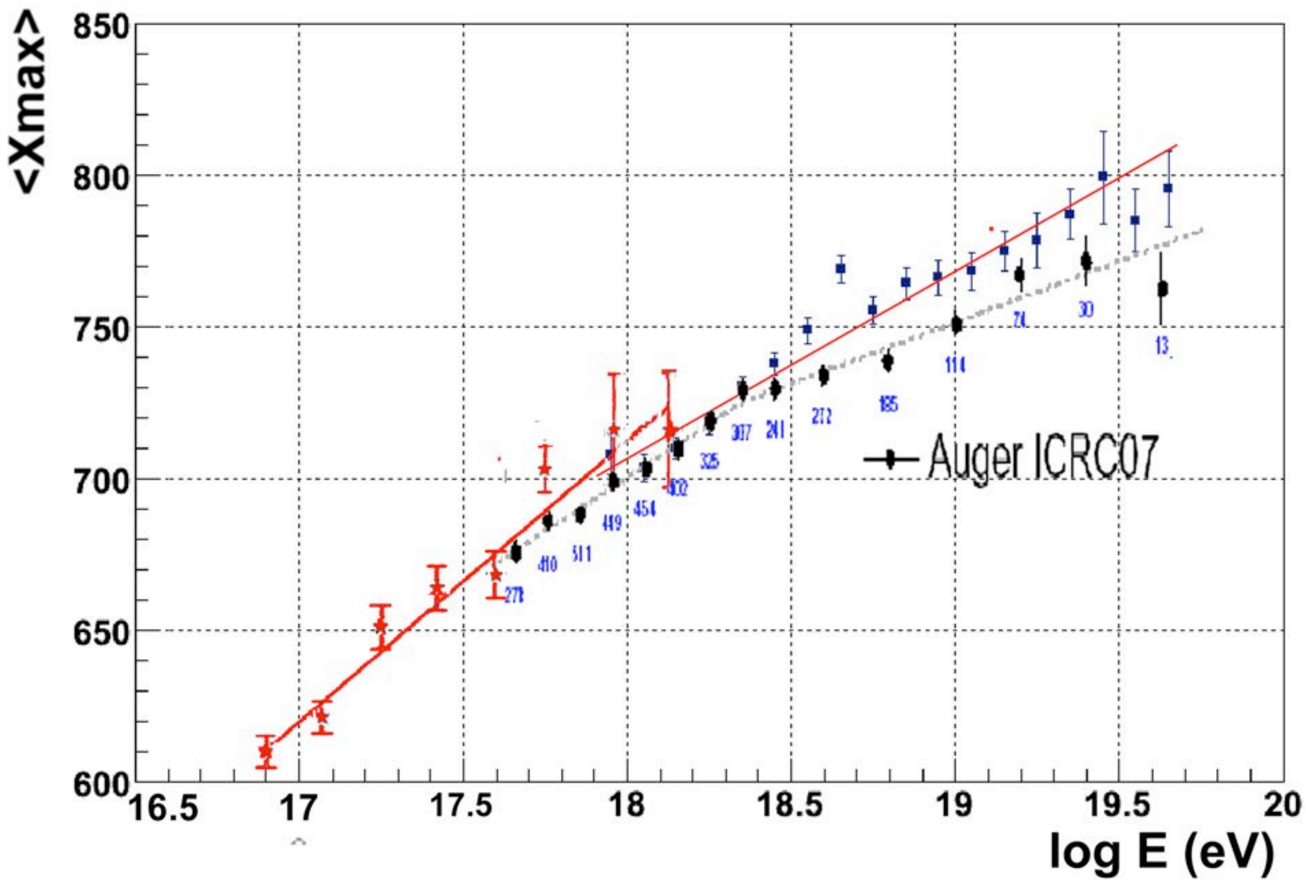
QGSJETII SIBYLL



Summary:

- excellent $X_{\max}$ resolution ($\approx$ 20 g/cm^{2}at high energies)
- $X_{\max}$ scale uncertainty $\leq$ 15 g/cm^2
- significantly different D_{10} above and below $10^{18.35}$ eV
- shower simulations $\rightarrow$ mixed composition at all energies

Xmax Auger and HiRes - mutually in conflict, too



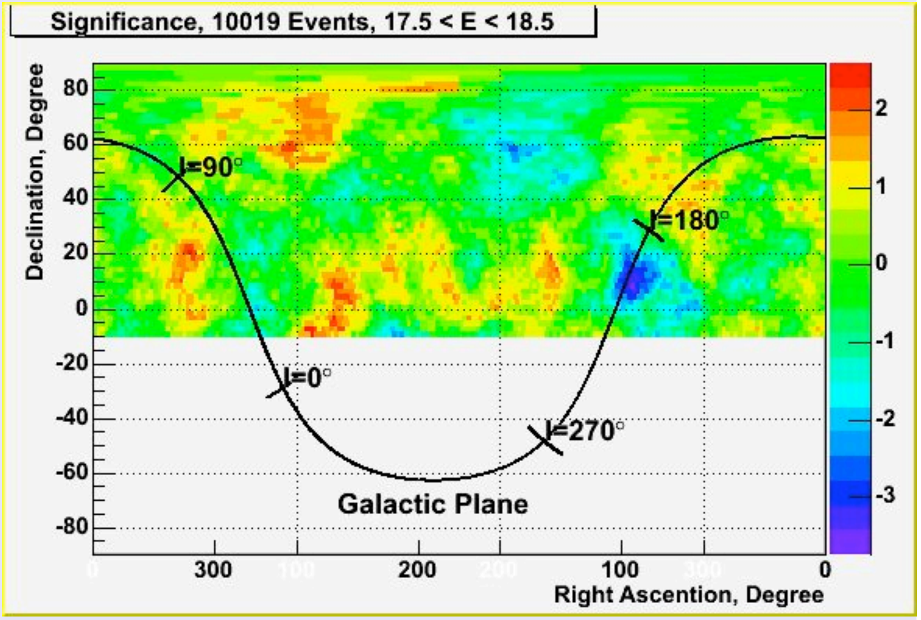
Come in here, TA!

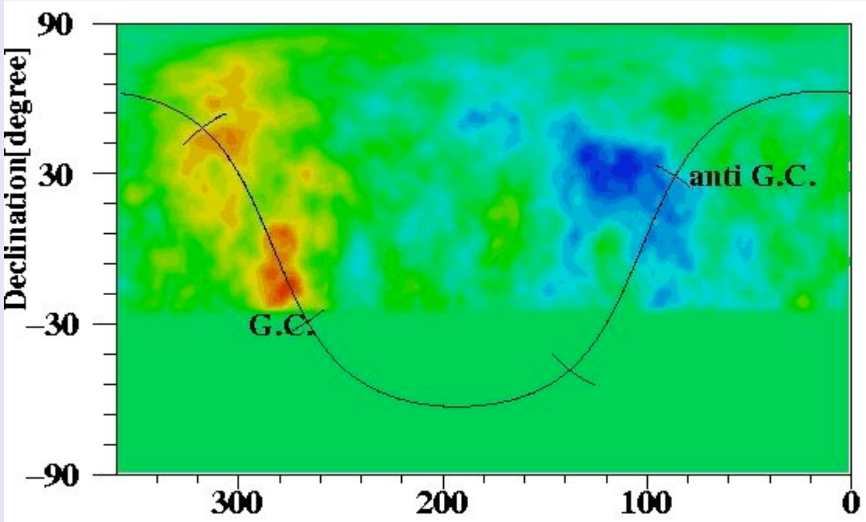
Yes, soon!

UHECRs Anisotropy

HiRes Anisotropy
Negative excess at Anti-G.C.

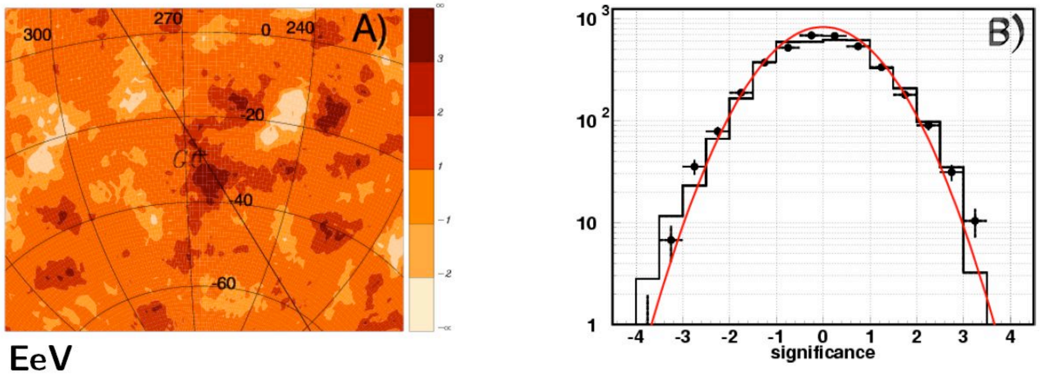
- Integrate over 20º circles
  - Data
  - Significance plot for $10^{17.5} < E < 10^{18.5}$ eV.
  - Akeno/AGASA result



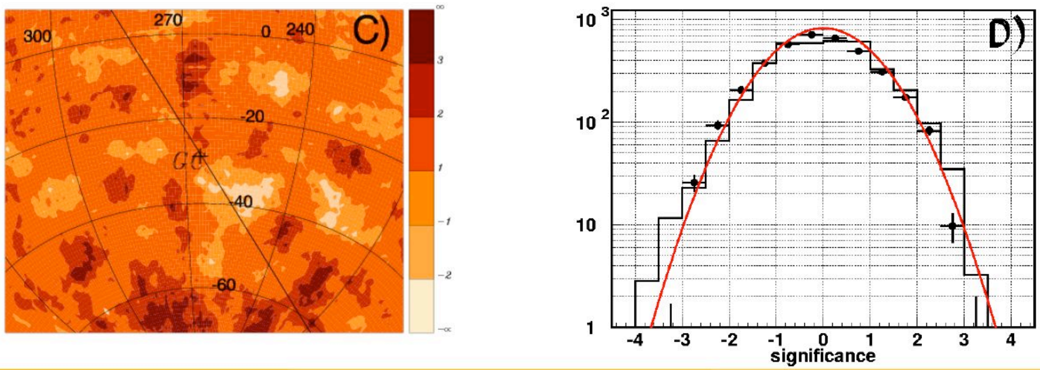


Auger: Galactic Center

$1 < E < 10$ EeV



$E < 1$ EeV



Results

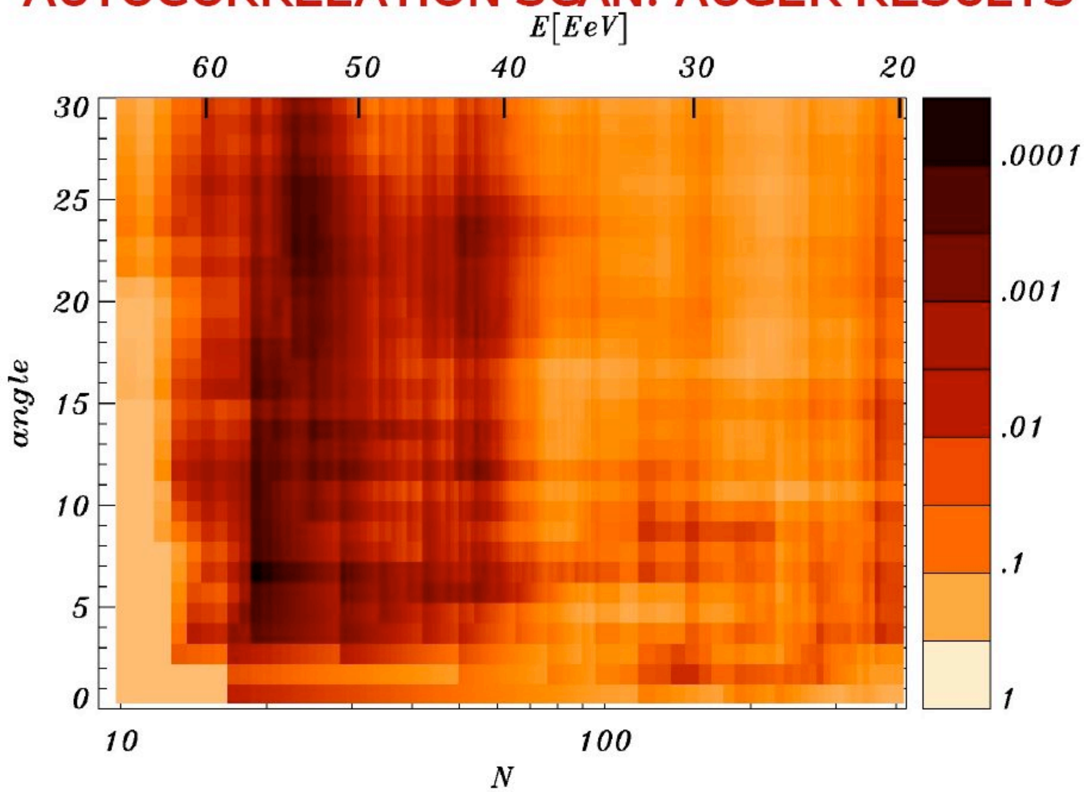
insignificant:

$1 < E < 10$ EeV - Search for point-like/extended souces

search	window size	n_{obs}/n_{exp}	n_s^{95}
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)	5.6

Auger results:
Medium scale anisotropy

AUTOCORRELATION SCAN: AUGER RESULTS



positive?

CORRELATION EXCESS AT INTERMEDIATE ANGLES AND LARGE ENERGIES

MINIMUM: $\theta = 7^\circ$, E > 57.5 EeV (N = 19), obs/exp = 8/1, $P_{min} = 10^{-4}$

CHANCE PROBABILITY: P = 2%

Is this a Hint of broad clustering? 6~25 degrees scale?

TEST OF SIGNALS FROM PREVIOUS EXPERIMENTS

SMALL SCALE CLUSTERING: $\theta = 2.5^{o}$ and $E > 40$ EeV

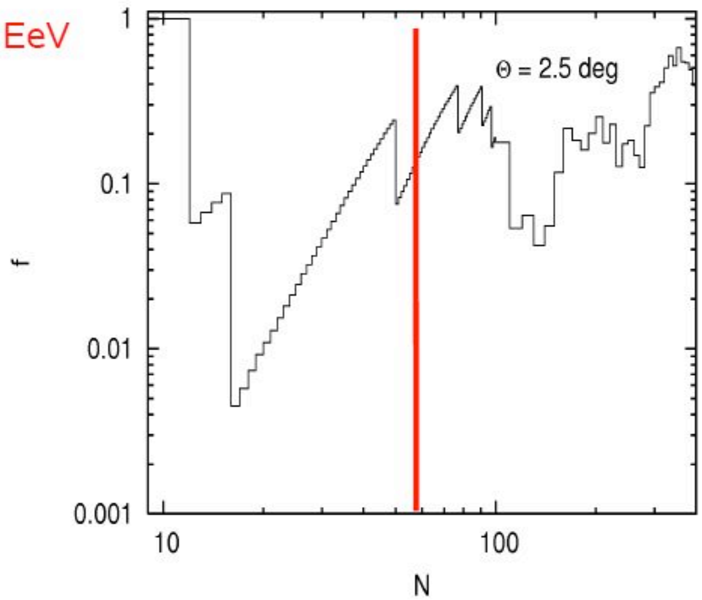
AGASA: obs/exp = 7/1.45 (for N=57)

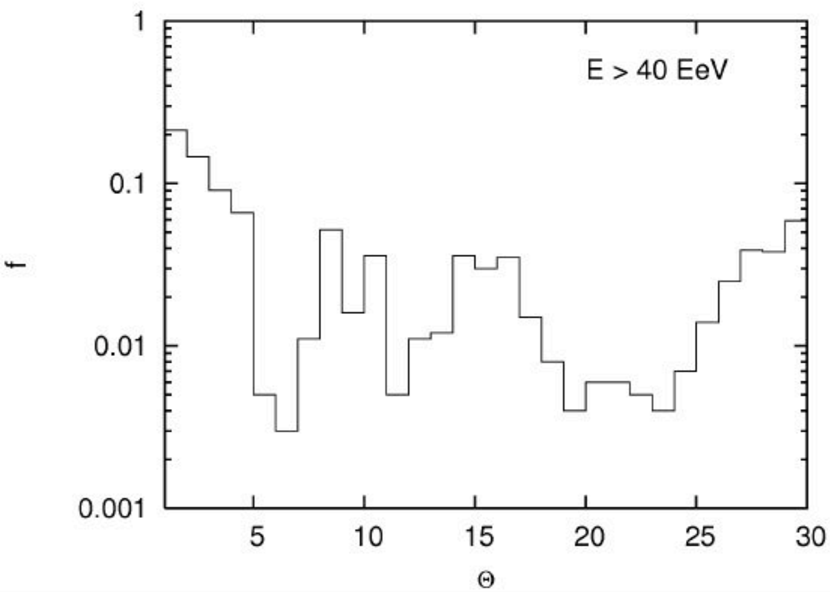
AUGER: obs/exp = 2/1.5

COMPATIBLE WITH ISOTROPIC FLUX

Does a signal appear at a smaller energy?
(possible energy calibration mismatch)

For N =150 events (E > 30 EeV) obs/exp = 14/8.5
No strong excess in the relevant range





INTERMEDIATE SCALE CLUSTERING:
$\theta = 25^{o}$ and $E > 40$ EeV

SOME HINT OF CLUSTERING IS PRESENT, ALTHOUGH WEAKER THAN AT HIGHER ENERGIES

Stimulating

UHECRs
Clusters?
Any point source correlation?

Tkachev

UHECR deflections

- Galactic Magnetic Field
  - Deflections in regular component $\sim 2^\circ$ for $E \sim 10^{20}$ eV
  - Deflections in turbulent component are several times smaller.
- Extra-galactic Magnetic Field
  - For now we have to rely on numerical simulations.
    Expected deflections are small according to

Dolag, Grasso, Springel & I.T. (2003)

Bruggen, M. Ruszkowski, A. Simionescu, Hoeft, & Vecchia (2005)

See however Sigl, F. Miniati & T. Ensslin (2003)

Charged particle astronomy can be possible.

Predictions for all

Predictions BL Lacs only and surely requires UHE energy

Assume: set of 156 BL Lacs is uniform (this may not be the case!)

Experiment	$\sqrt{2}\sigma$	N	S	B	$\Delta n_{95\%}$	N_0
HiRes, original	0.85°	271	7.46	3.54		
HiRes (stereo)	0.85°	190	5.23	2.48	1-17	271
AGASA	3.39°	1500	43.4	310	308-417	3870
PAO (surface)	1.98°	8000	87.9	216	239-413	3517
PAO (hybrid)	0.85°	2000	24.8	9.10	15-66	467
TA (surface)	2.19°	8000	239	710	785-1235	1560
TA (hybrid)	0.88°	2000	58.6	30.3	47-161	277

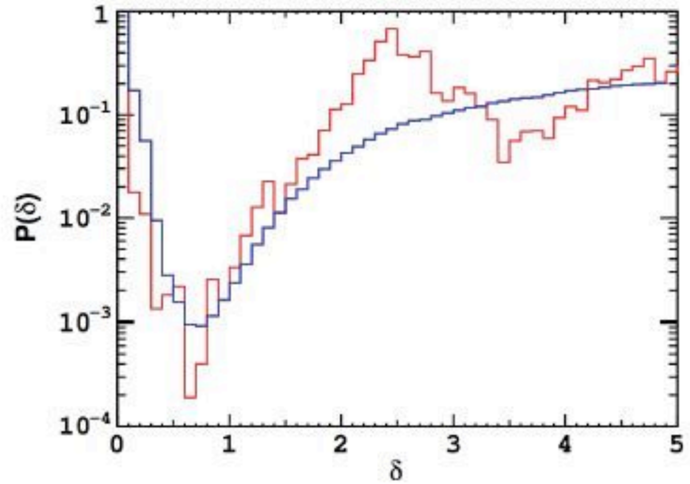
S — events from sources

B — chance coincidences

$\Delta n_{95\%}$ — 95% interval for the number of coincidences

N_0 — number of events needed to match sensitivity of HiRes

HiRes-stereo and BL Lacs



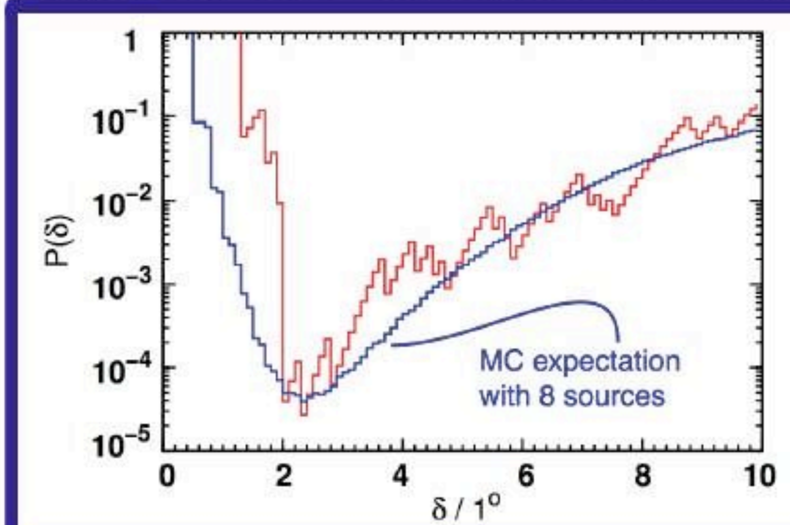
Recent HiRes analysis:

$E > 10^{19}$ eV	$P = 2 \times 10^{-4}$
$E < 10^{19}$ eV	$P = 6 \times 10^{-3}$

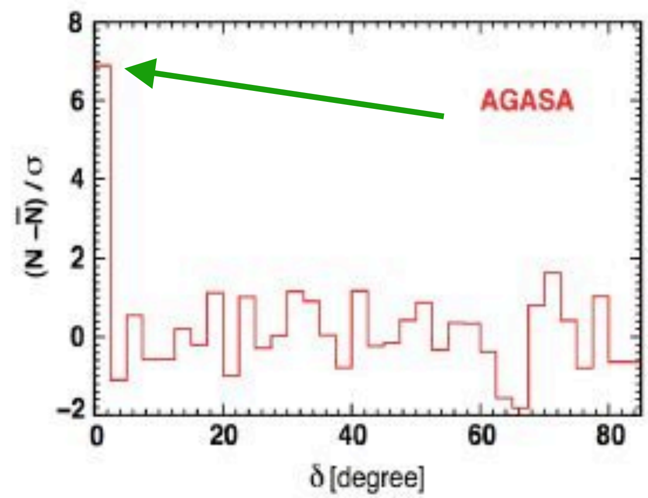
Finley et al, HiRes Collaboration (2005)

Correlations with BL Lacs in the AGASA data

Significant correlations were claimed for the following subsets

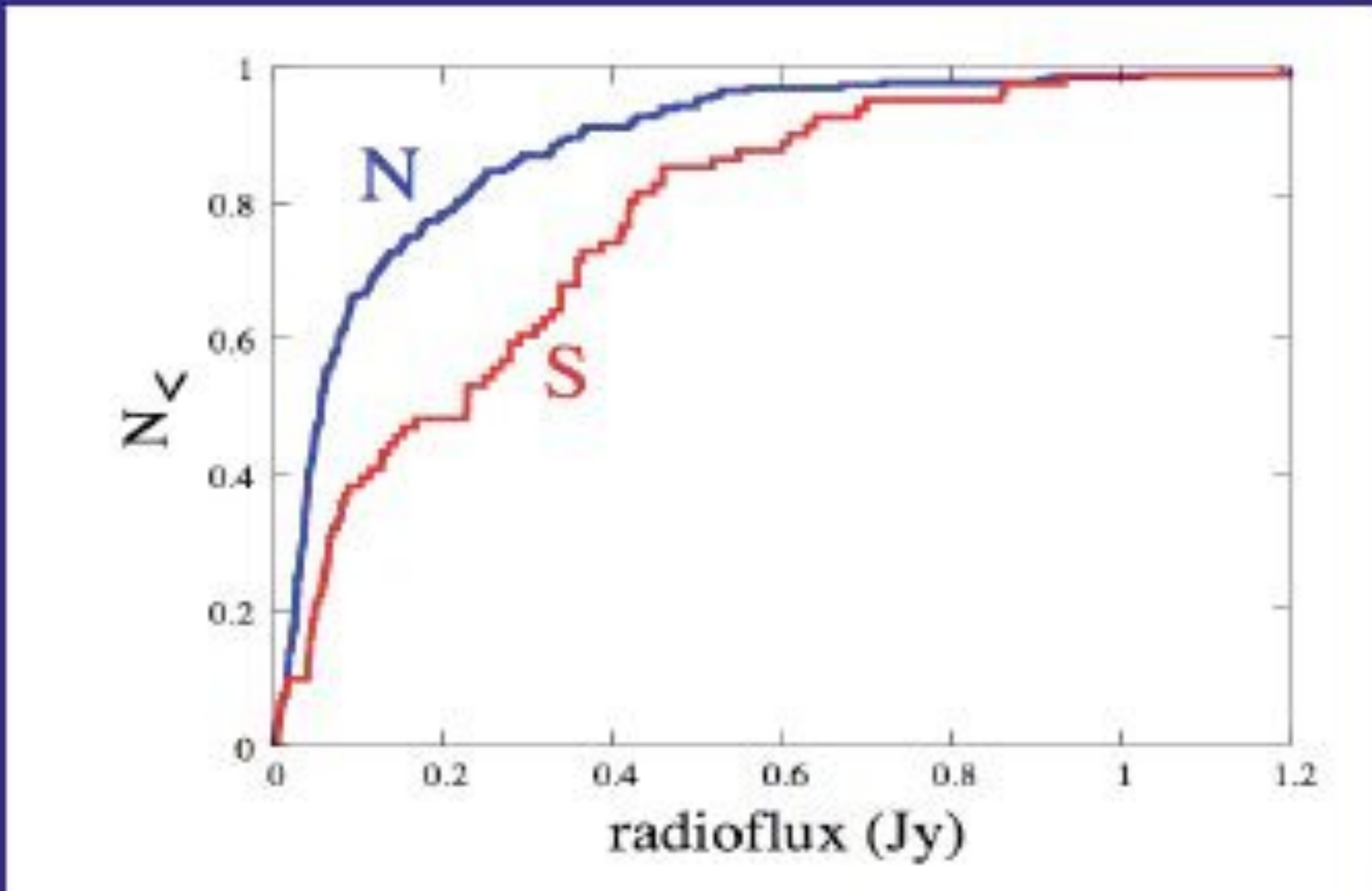


Most autocorrelated subset of UHECR (AGASA+Yakutsk) &
Subset of 22 brightest BL Lacs.



Caveat (in case of PAO):

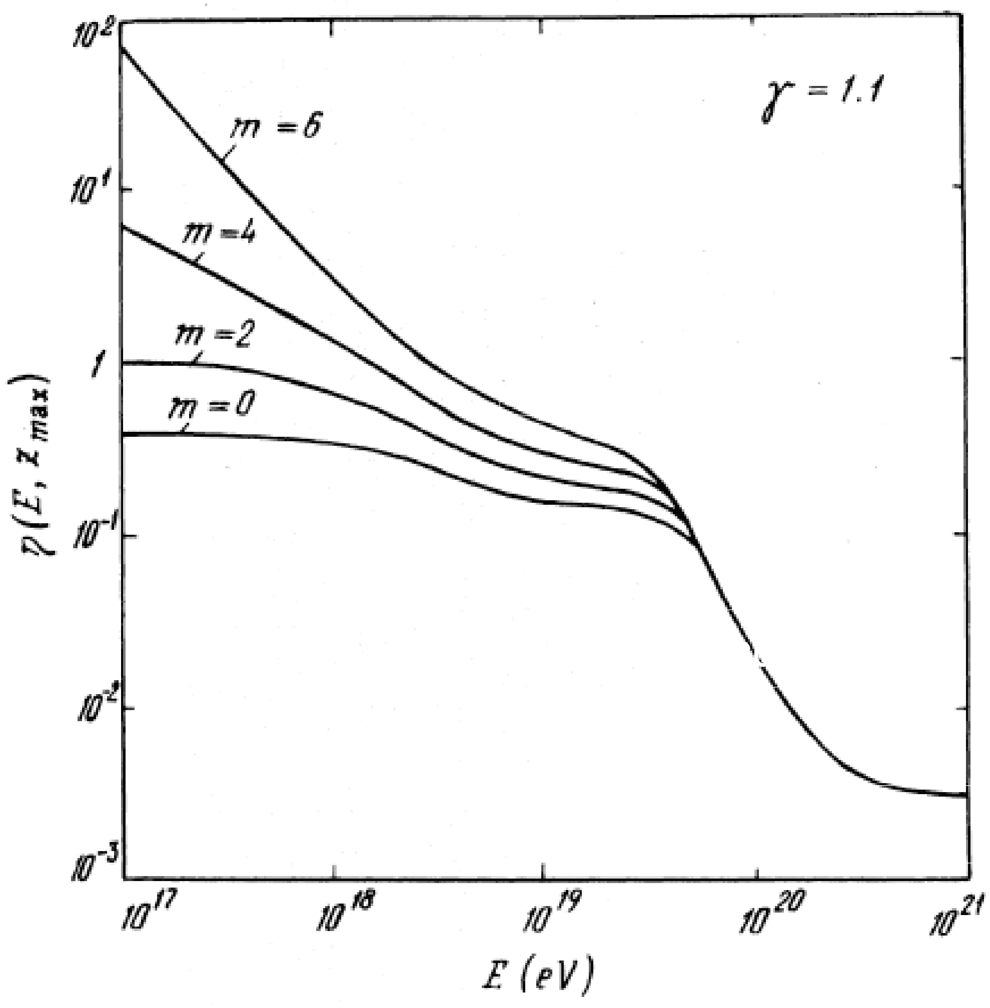
Southern and Northern BL Lacs may be different



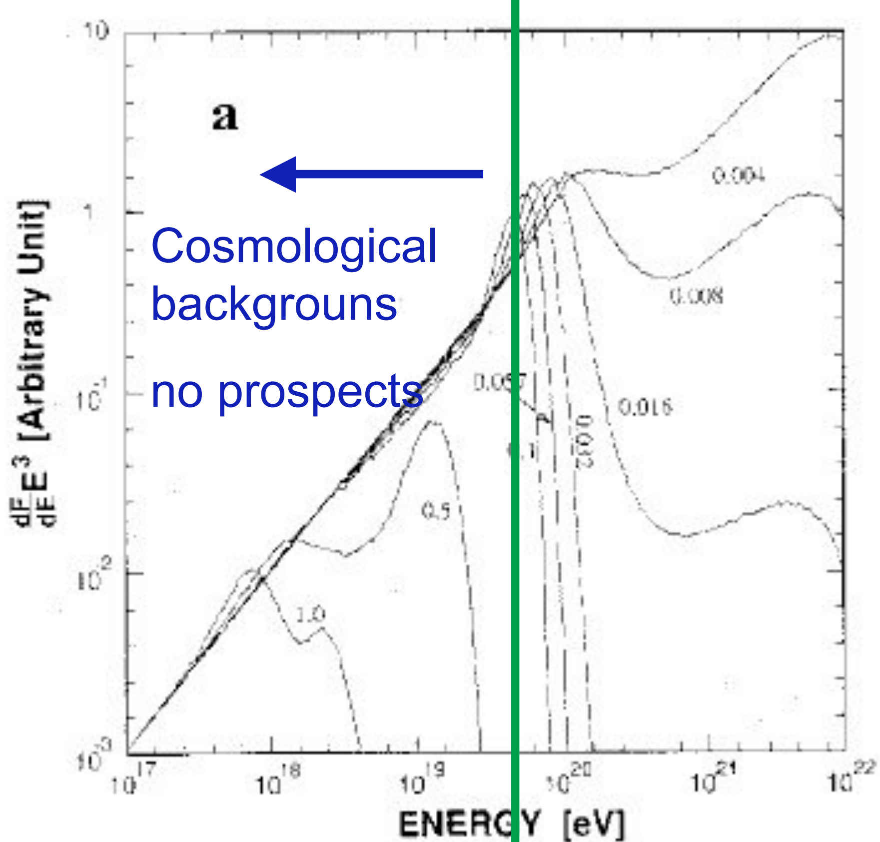
Distributions in radio flux are different: $P_{KS} \sim 10^{-6}$

More cautions on the search for Point Sources

Super-GZK allows point-source' sharp IDs, but Sub-GZK is overwhelmed by backgrounds

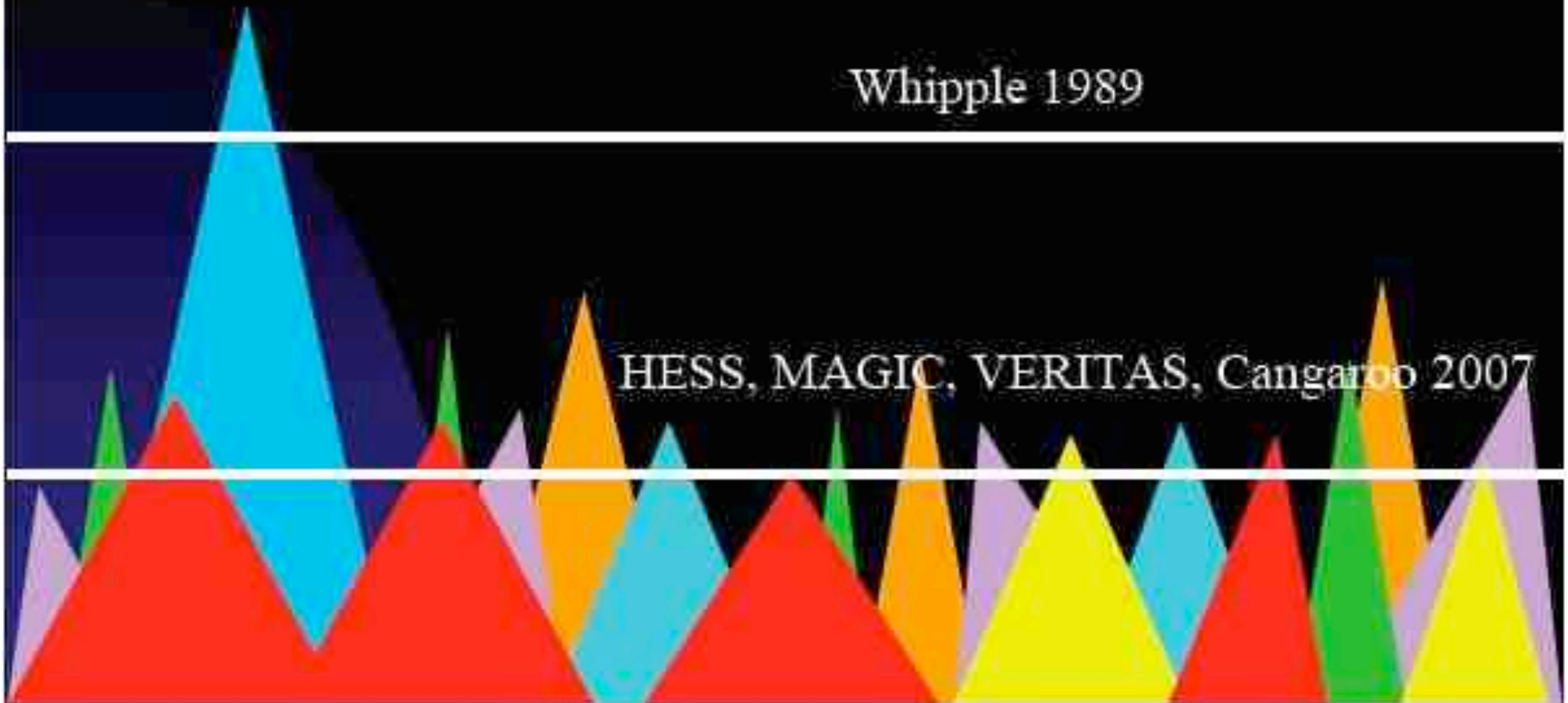


Berezinsky&Grigorieva 1988



All the Super-GZK particles from sources within ~ 200 Mpc can be seen above 5 x 10^{19} eV, If linearly traceable

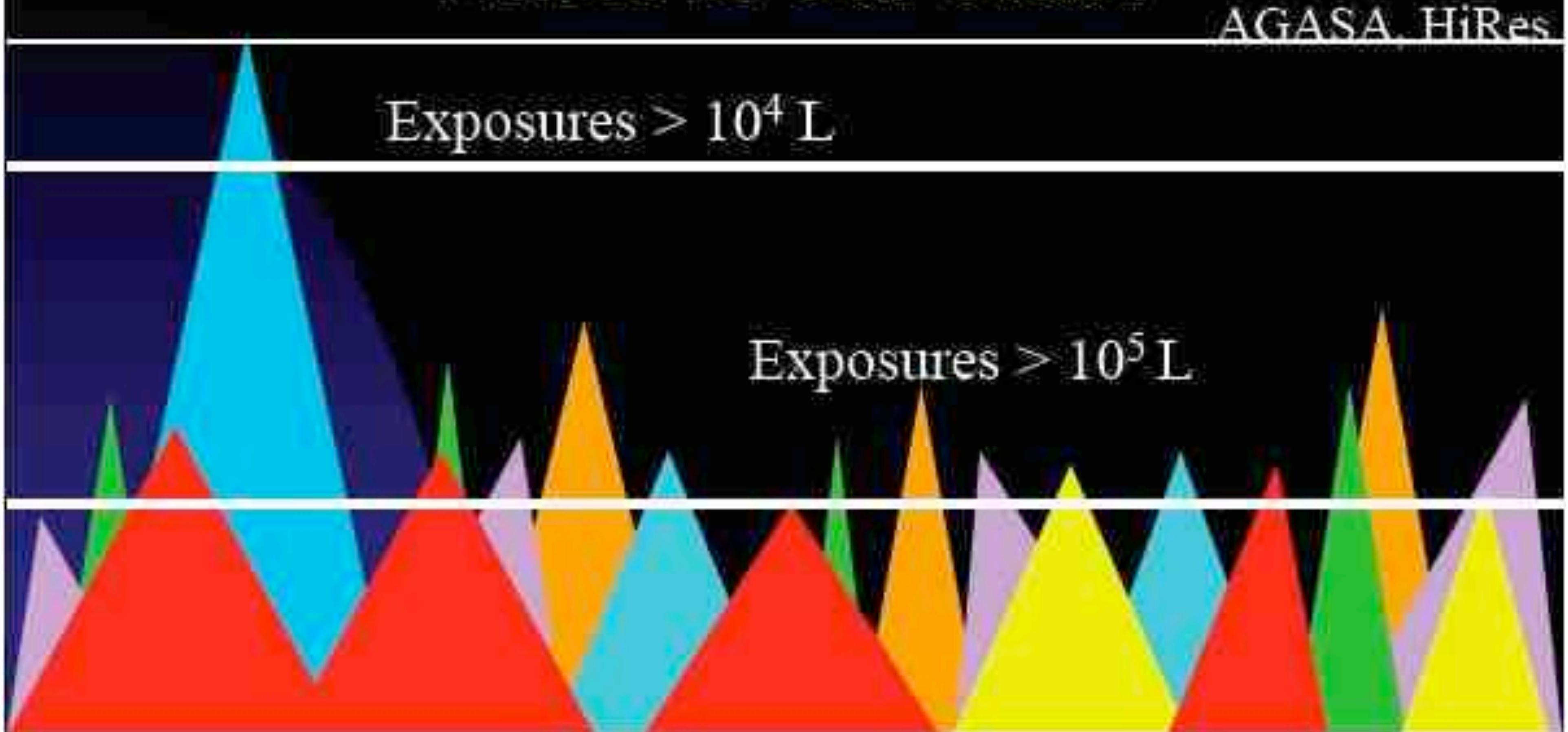
Where is Our Crab? VHE gamma



Next few slides

- by A. Olinto 2007

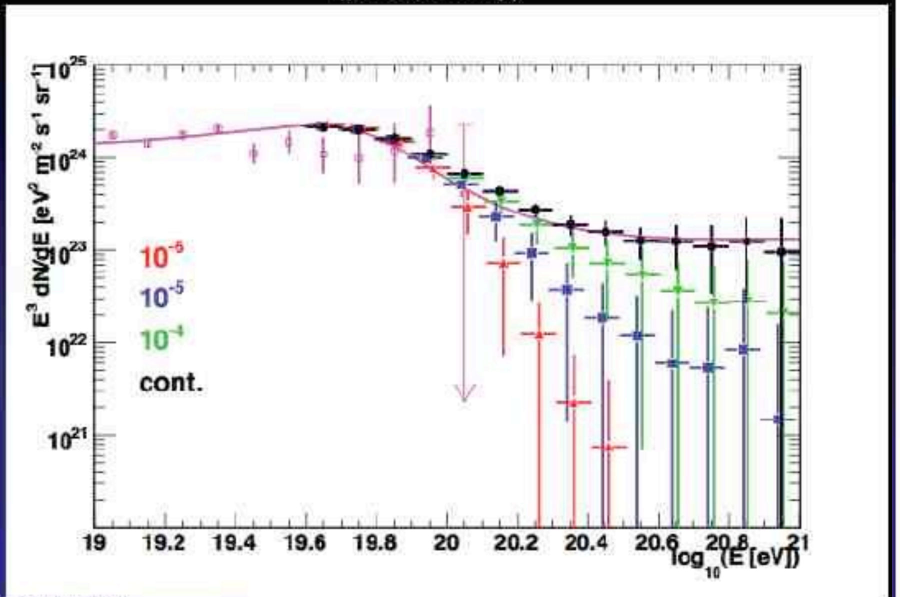
Where is Our Crab?



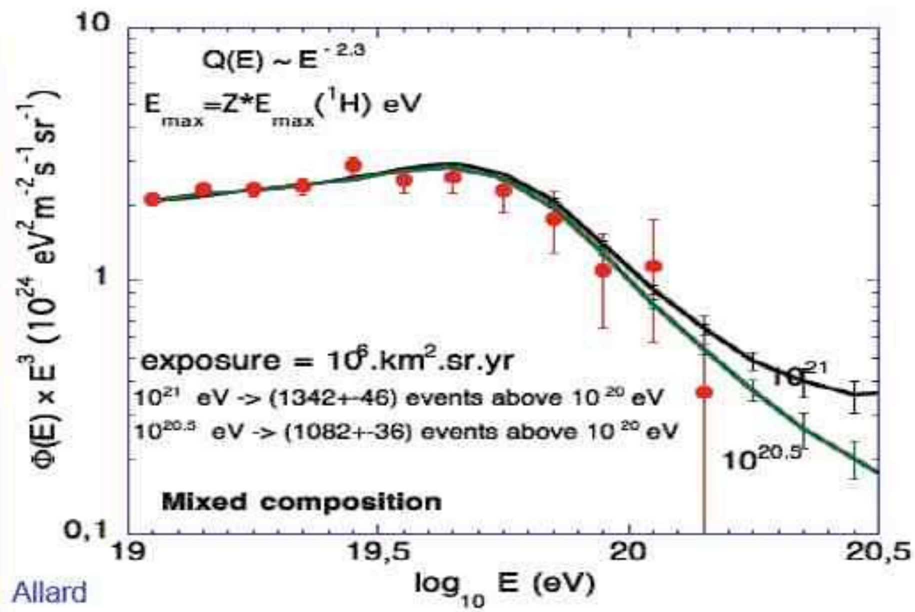
$L = 1\ km^2\ sr\ yr$ - Linsley

AGASA = $1.63\ 10^3\ L$

Spectra with 7 10^5 L
(protons only)

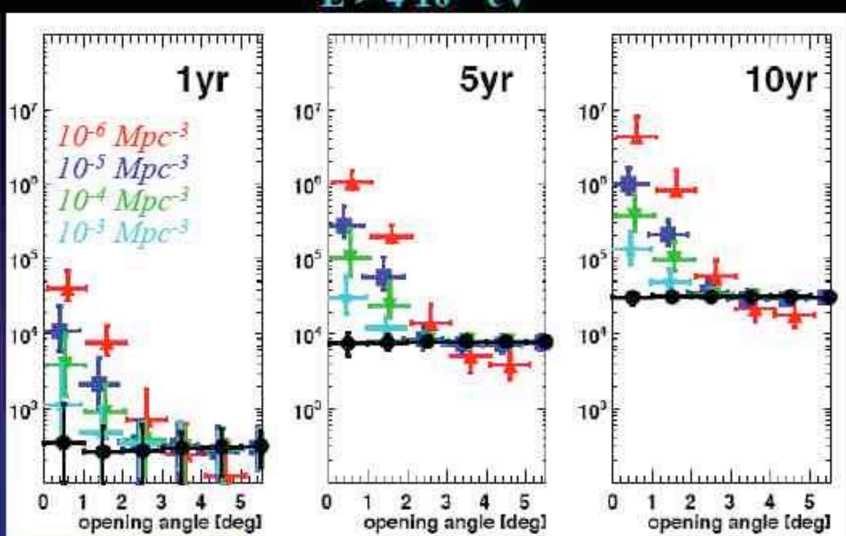


Mixed injected - exp 10^6 L



Allard

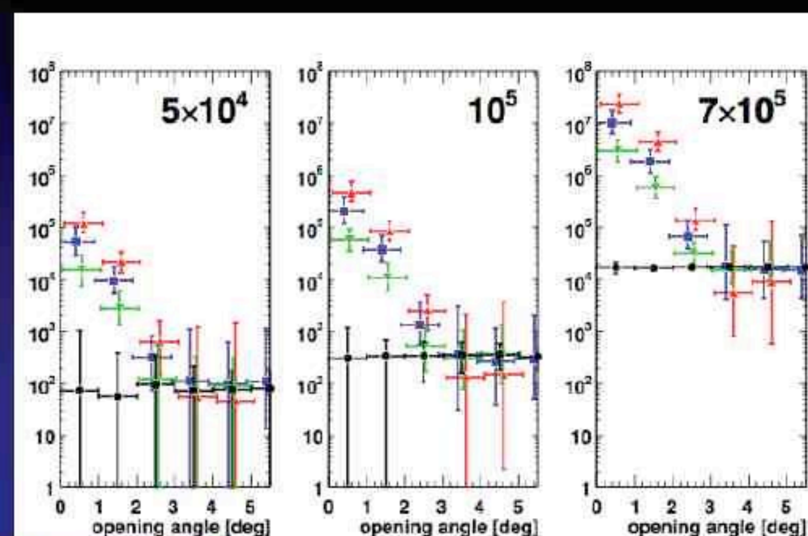
Auger South 2-point
$E > 4\ 10^{19}$ eV



Source densities from galaxies to clusters

DeMarco et al '06

2-point Correlation at 10^{20} eV Large Exposures



DeMarco

Cosmic Variance Dominated

Auger: Correlation with BL-Lacs
No correlations with point source

BUT!

News will come soon for positve sources above 7E19 eV?

TEST OF PREVIOUS CORRELATION SIGNALS

Test A: 22 BL Lacs   m < 18   z > 0.1 or unknown   F6 > 0.17 Jy   (9^{th} catalog)
(8 in f.o.v.)

Test B: 157 BL Lacs   m < 18   (10^{th} catalog)
(76 in f.o.v.)

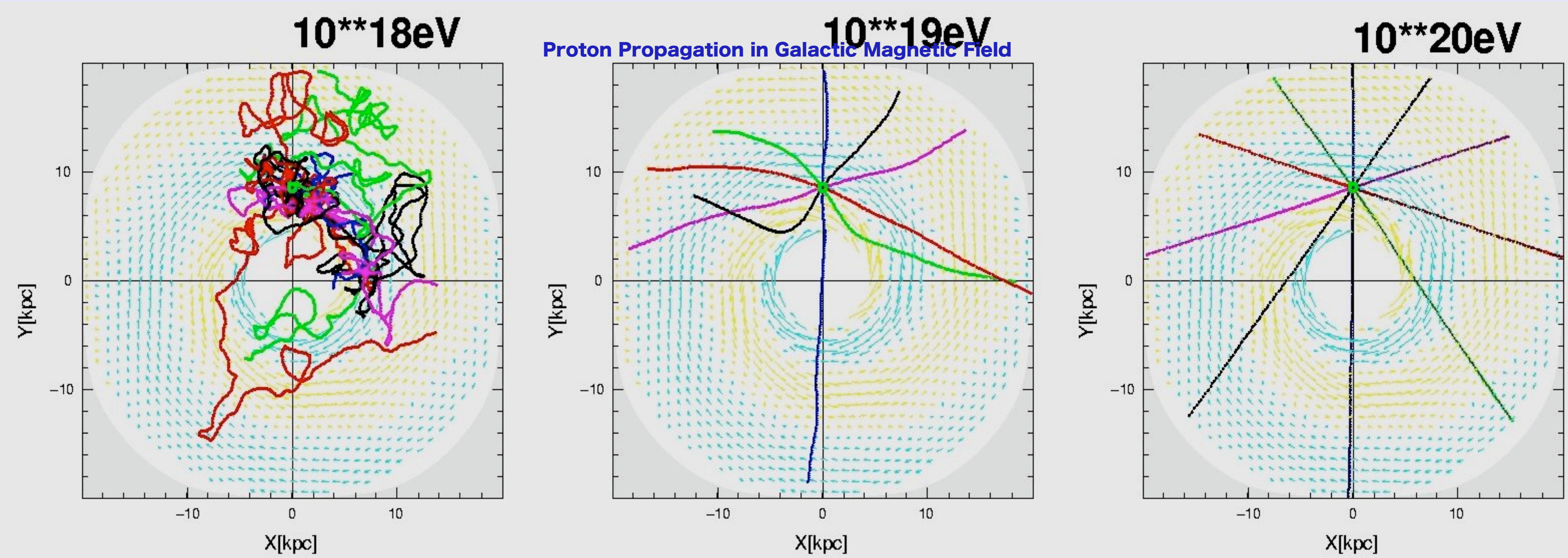
Test C: 14 BL Lacs selected by possible association with EGRET sources
(3 in f.o.v.)

Test D: 204 BL Lacs   m < 18   (10^{th} catalog)
Subclasses: a) 157 BL (76 in f.o.v.)   b) 47 HP (30 in f.o.v.)

Test	E_{th} (EeV)	Number of events	Angular size	Observed	Expected (isotropic)	Probability
A	24	267	2.5°	1	1.0	0.63
B	40	62	2.5°	2	2.5	0.71
C	24	267	2.9°	1	0.5	0.41
D				11	12.1	0.66
a)	10	1672	0.9°	8	8.9	0.67
b)				3	3.2	0.62

OUR DATA DOES NOT SUPPORT ANY OF THESE PREVIOUSLY REPORTED EXCESSES OF CORRELATION

10^{20}eV proton can be traced back to a point source



⇨ **Particle Astronomy is with > 10^{20} eV**

All-sky Freedom*
from GM
above 10^{20} eV

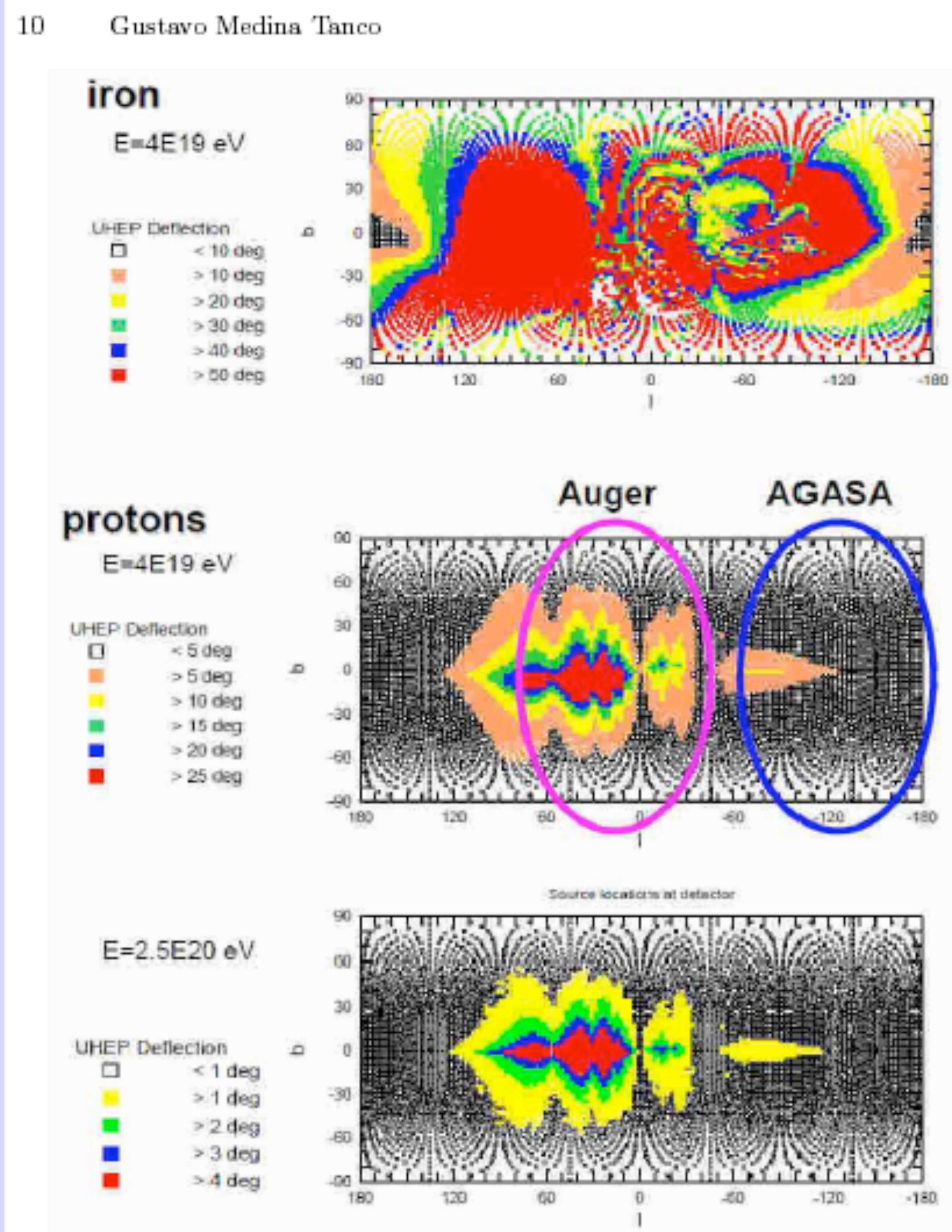
Achtung!

Auger data are NOT sensibly qualified for point-source tracking:

(1)Mostly sub-GZK and,

(2) GMF of the southern sky is **high** and very **unfriendly,** below energies less 10^{20} eV

Astro-ph/0607543v1 2006



UHECR
Astronomical Theories

-

large-scale anisotropy
could appear with
statistics > 1000
if stellar origin
(or cosmological)

Galaxy Cluster（Inoue 2006)

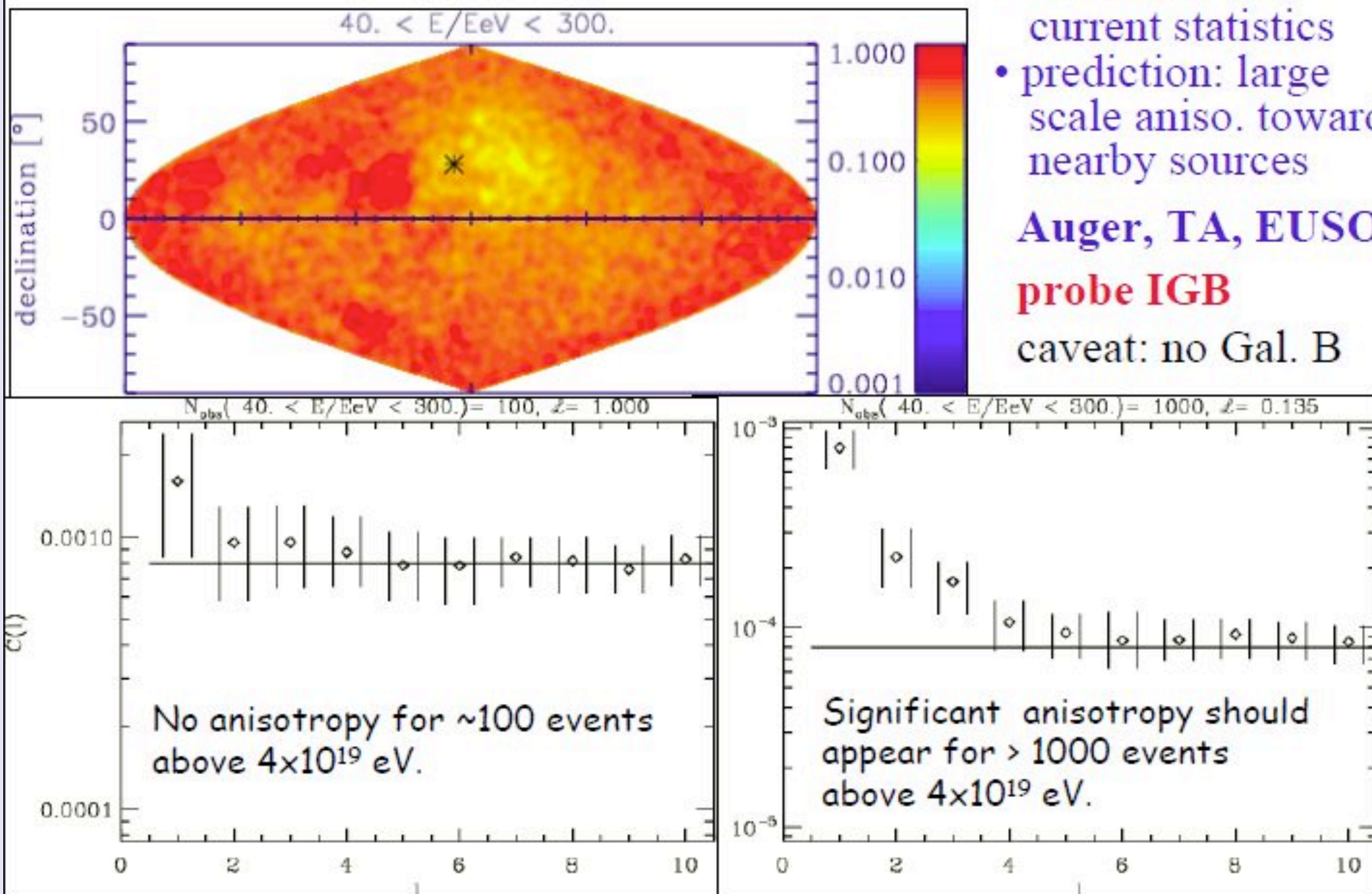
results: anisotropy

anisotropy
- consistent with current statistics
- prediction: large scale aniso. toward nearby sources

Auger, TA, EUSO

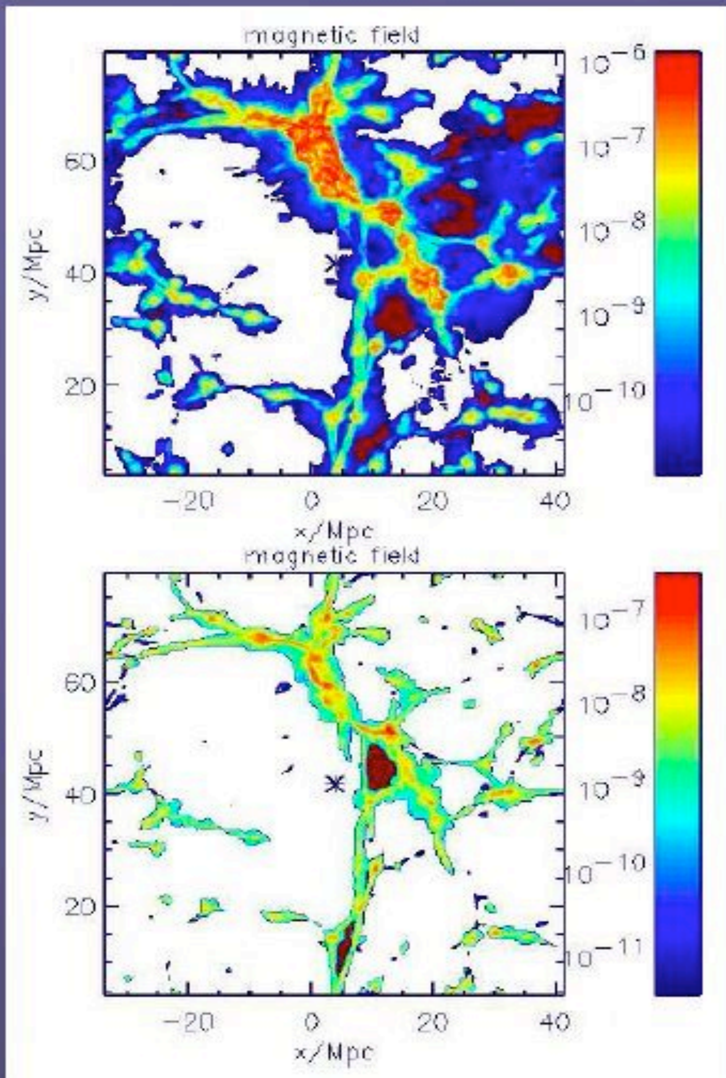
probe IGB

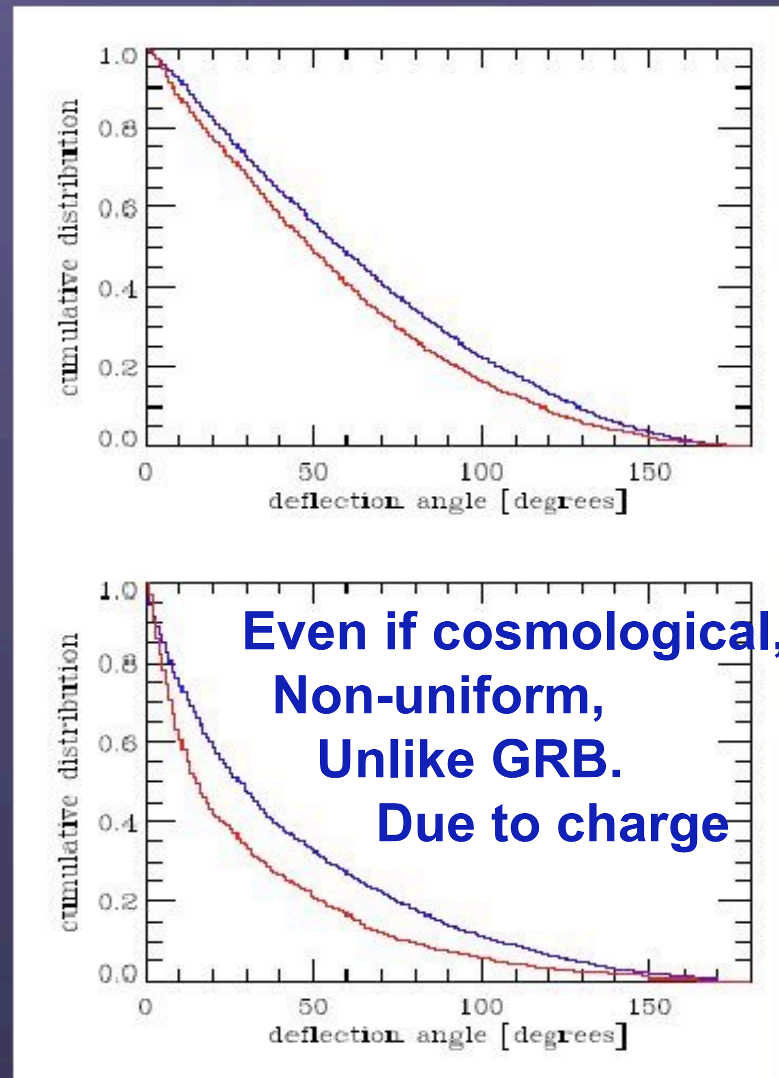
caveat: no Gal. B



Weak Dipole component toward the Virgo Cluster

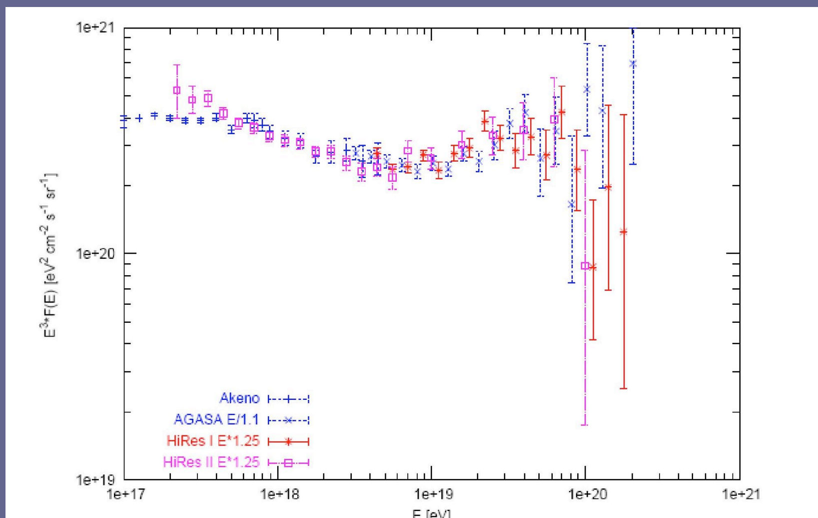
Magnetic field and large scale structure of Universe by G. Sigl et al.





If EHE sources are cosmological like Topological Defects

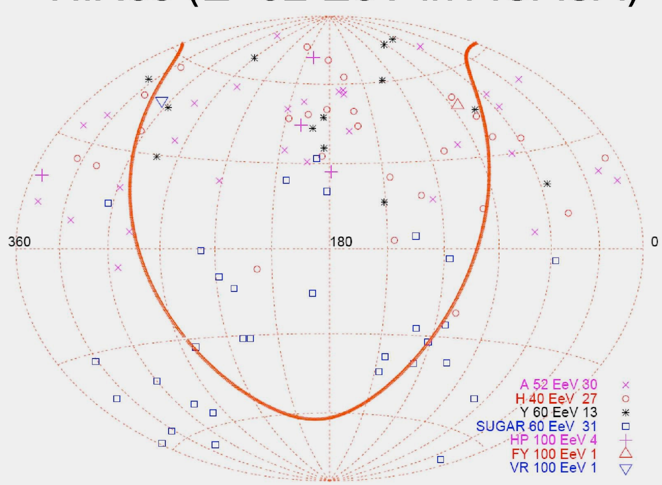
Medium Scale Anisotropy
M.Kachelriess & D.Semikoz



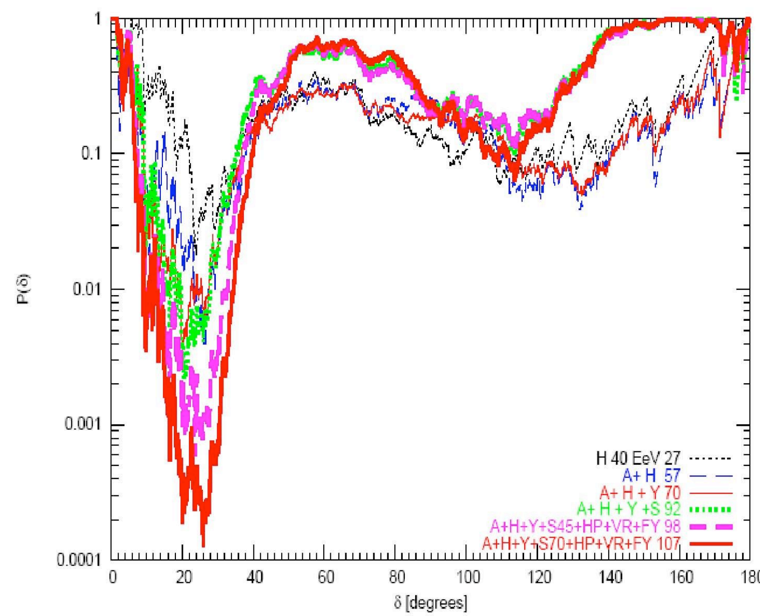
>4x10^{19}eV after Global Energy Scaling

After including penalty ➔ Pch~3x10^{-3}

Arrival directions for E>40 EeV in HiRes (E>52 EeV in AGASA)

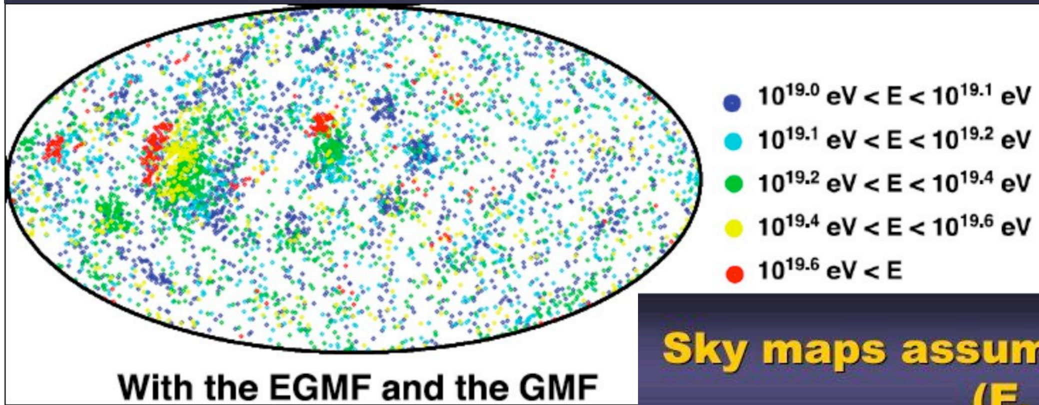


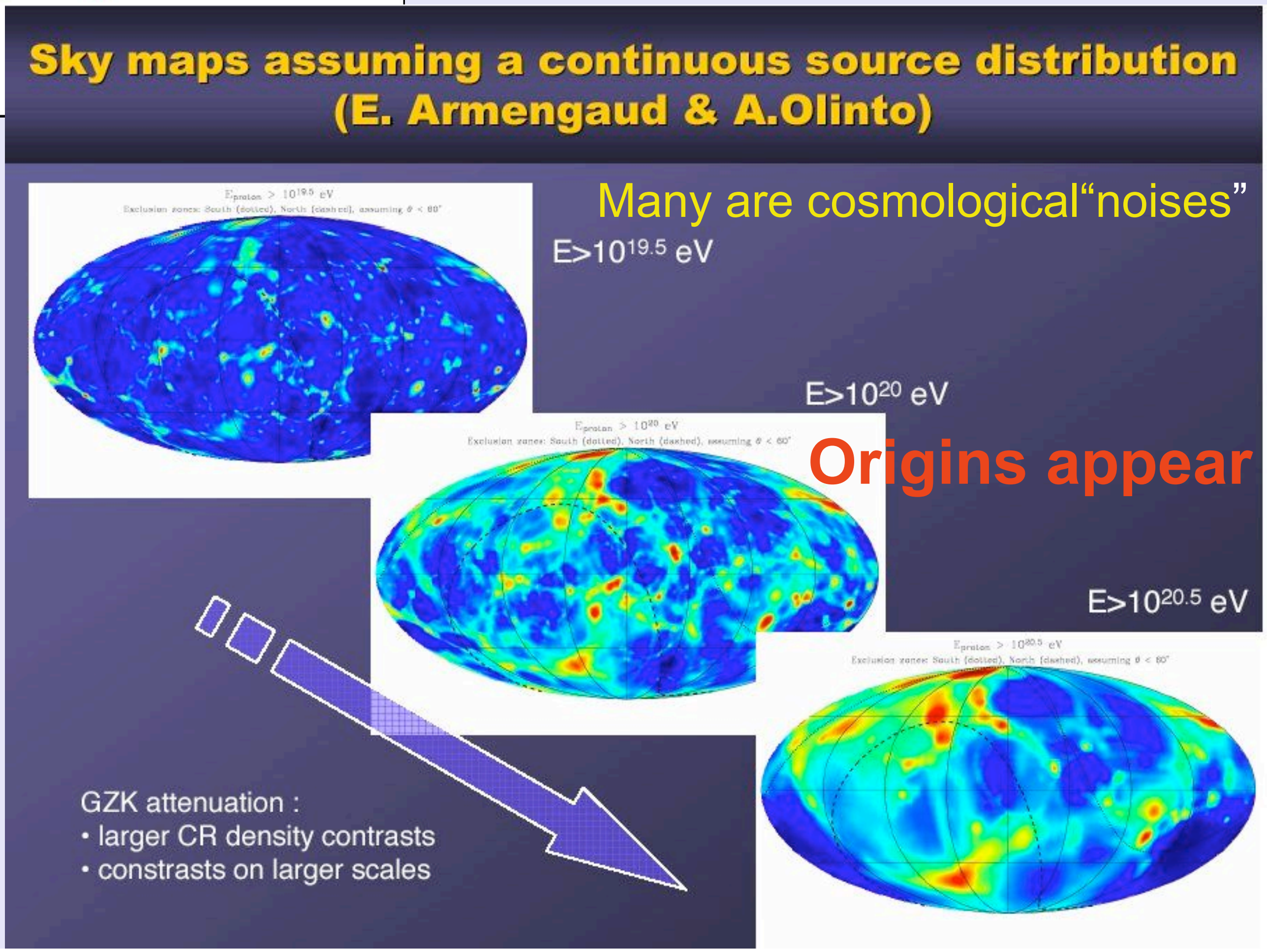
Probability of autocorrelation



M.Kachelriess and D.S., astro-ph/0512498

Bright Galaxies (Takami - Sato 2006; Olinto et al 2007)



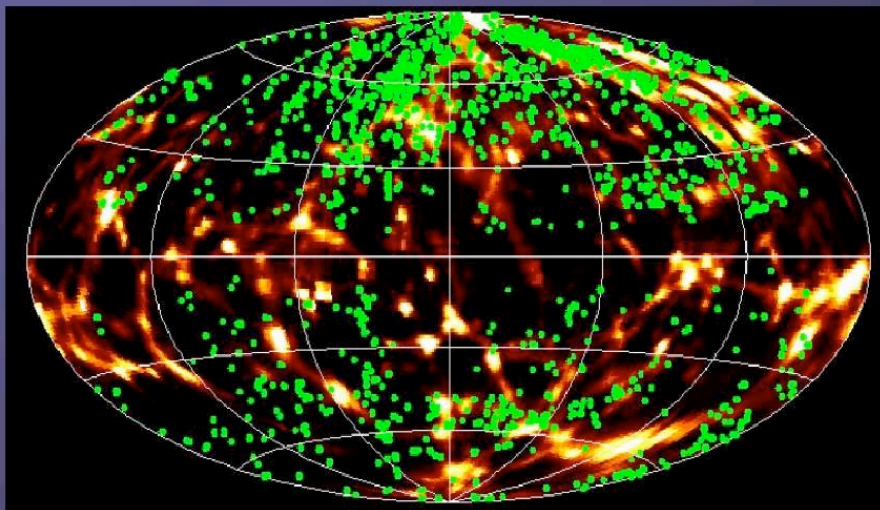


Many are cosmological"noises"

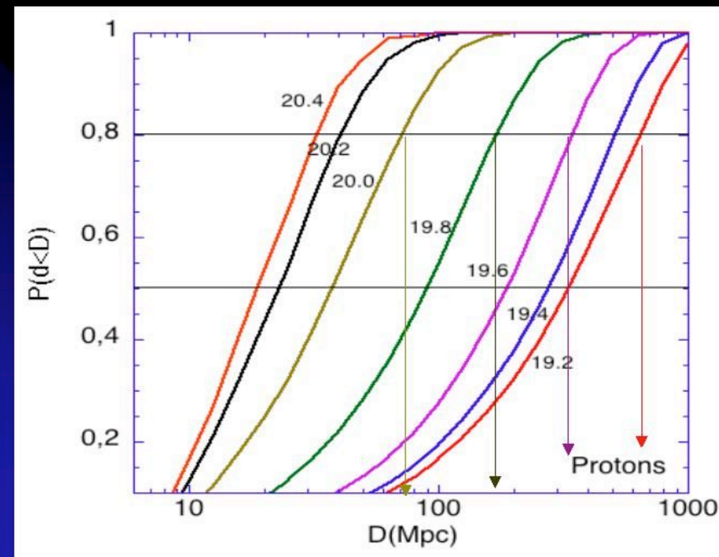
Origins appear

Matter (90Mpc) and Galaxies(45Mpc)

By A.Kravtsov

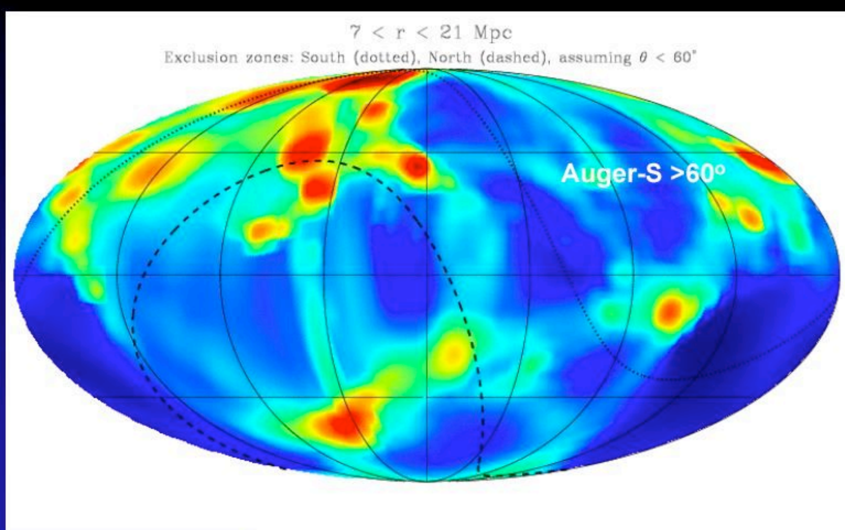


Proton Horizon



Allard

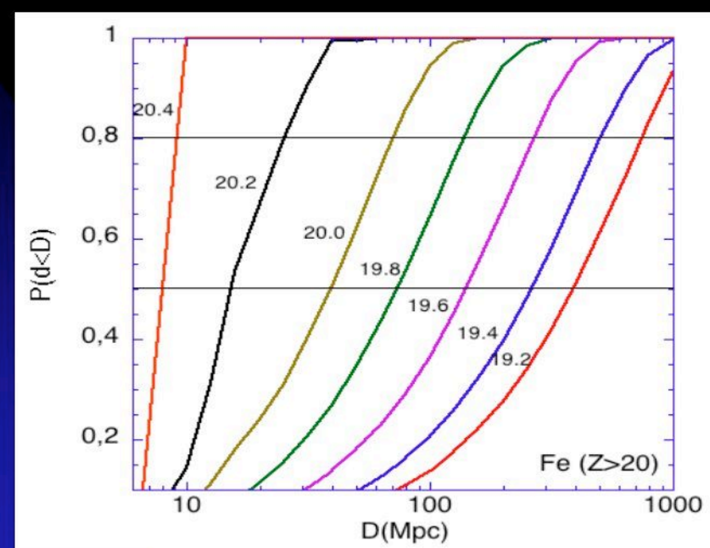
Dark Matter within 20 Mpc



Galactic Center in the Center!!!

Kravtsov, Armengaud

Fe Horizon

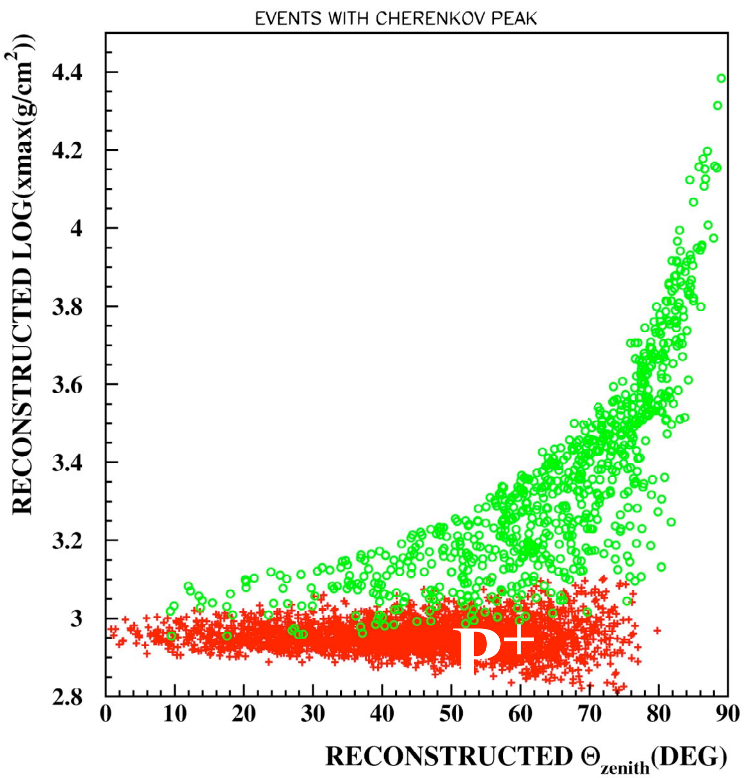


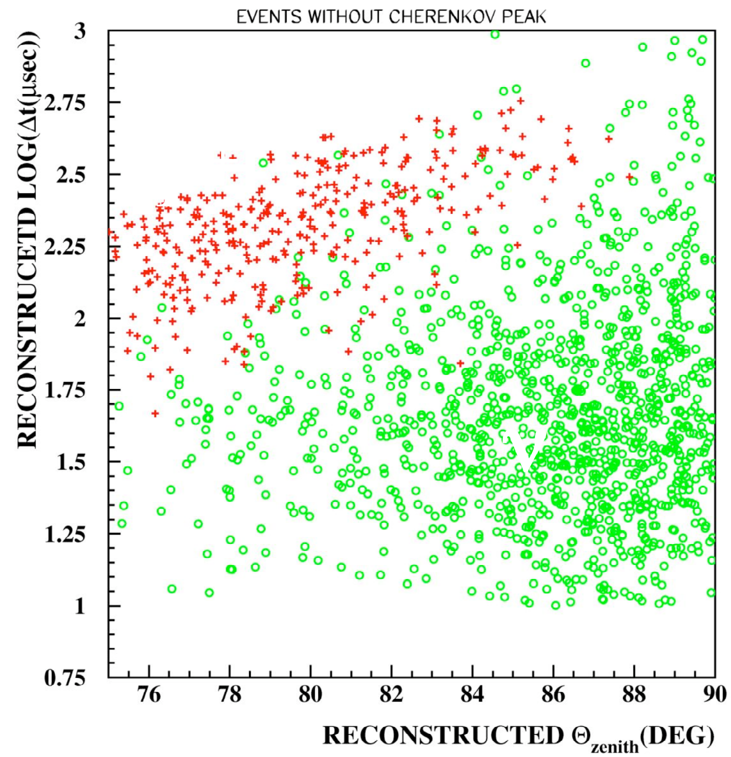
Allard

Exploratory Test Objectives

Neutrinos
Super-LHC Physics
Atmospheric Transients

FLUORESCENT EVENTS : PROTON - NEUTRINO SEPARATION





Rejection > 10^{-4} but for Ethr=10^{18}eV rejection>10^{-6} are needed

EXPLORATION : Extra-dimension

Neutrino cross section gets very high if higher dimension → > 1 μb at 10^{20} eV

Anchordoqui, Feng, Goldberg, Shapere Phys Rev D65, 124027 (2002)

Mary Hall 2005

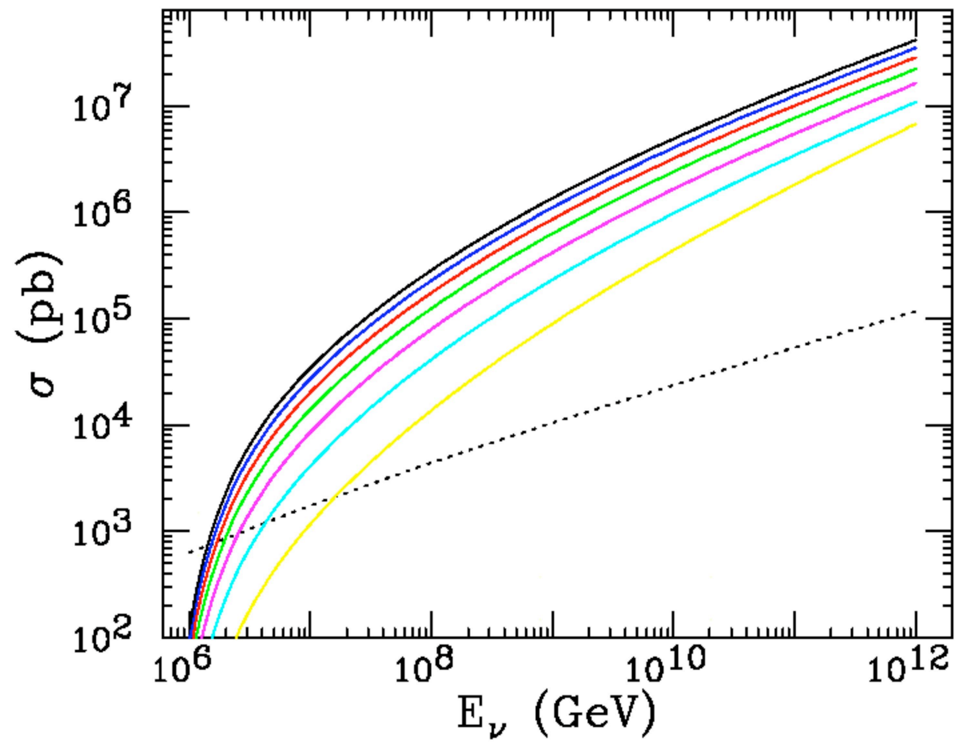
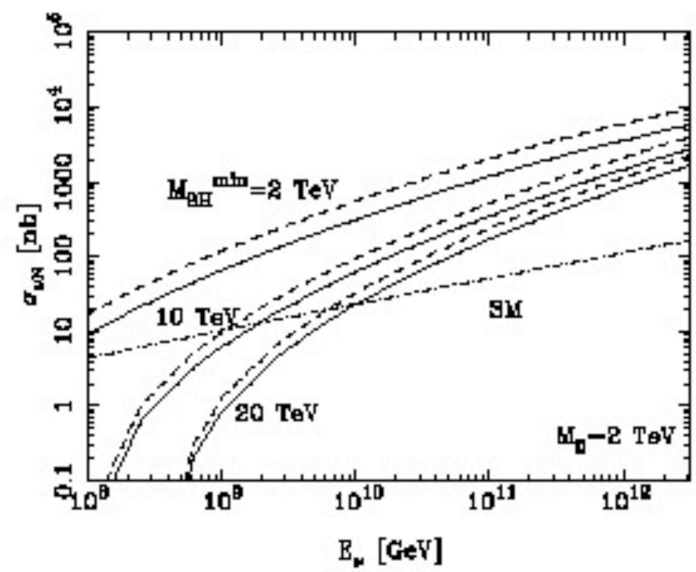


FIG. 28: Cross sections $\sigma_{\nu N \to \mathrm{BH}}$ for $n = 1, \ldots, 7$ (bottom to top) for $M_D = 1$ TeV, $x_{\min} = 1$. The SM cross section [124] is indicated with a dotted line. Published in Ref. [253].



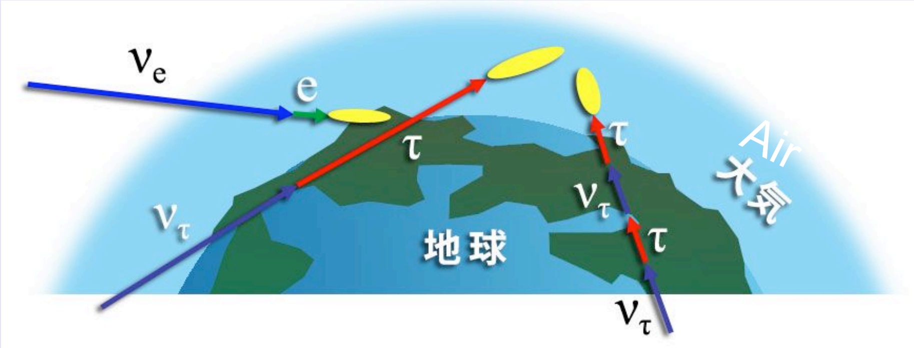
In these mini-black hole calculations, one takes the neutrino-parton cross section to be

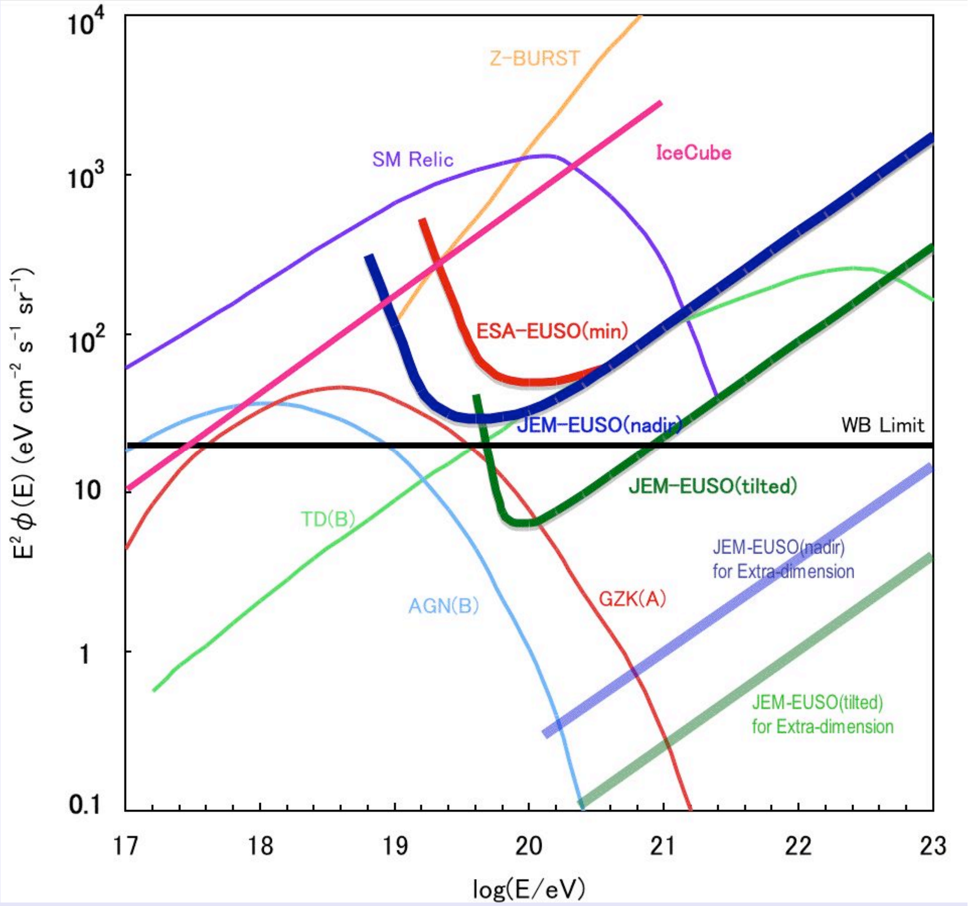
$$\hat{\sigma}(\nu j \to BH) = \pi R_s^2 \,|_{M_{BH}=\sqrt{\hat{s}}}\, \theta(\sqrt{\hat{s}} - M_{BH}^{\min}) \quad (11)$$

where the Schwarzschild radius R_S is given by

$$R_S = \frac{1}{M_D}\left[\frac{M_{BH}}{M_D}\left(\frac{2^n \pi^{\frac{n-3}{2}} \Gamma(\frac{3+n}{2})}{2+n}\right)\right]^{\frac{1}{1+n}} . \quad (12)$$

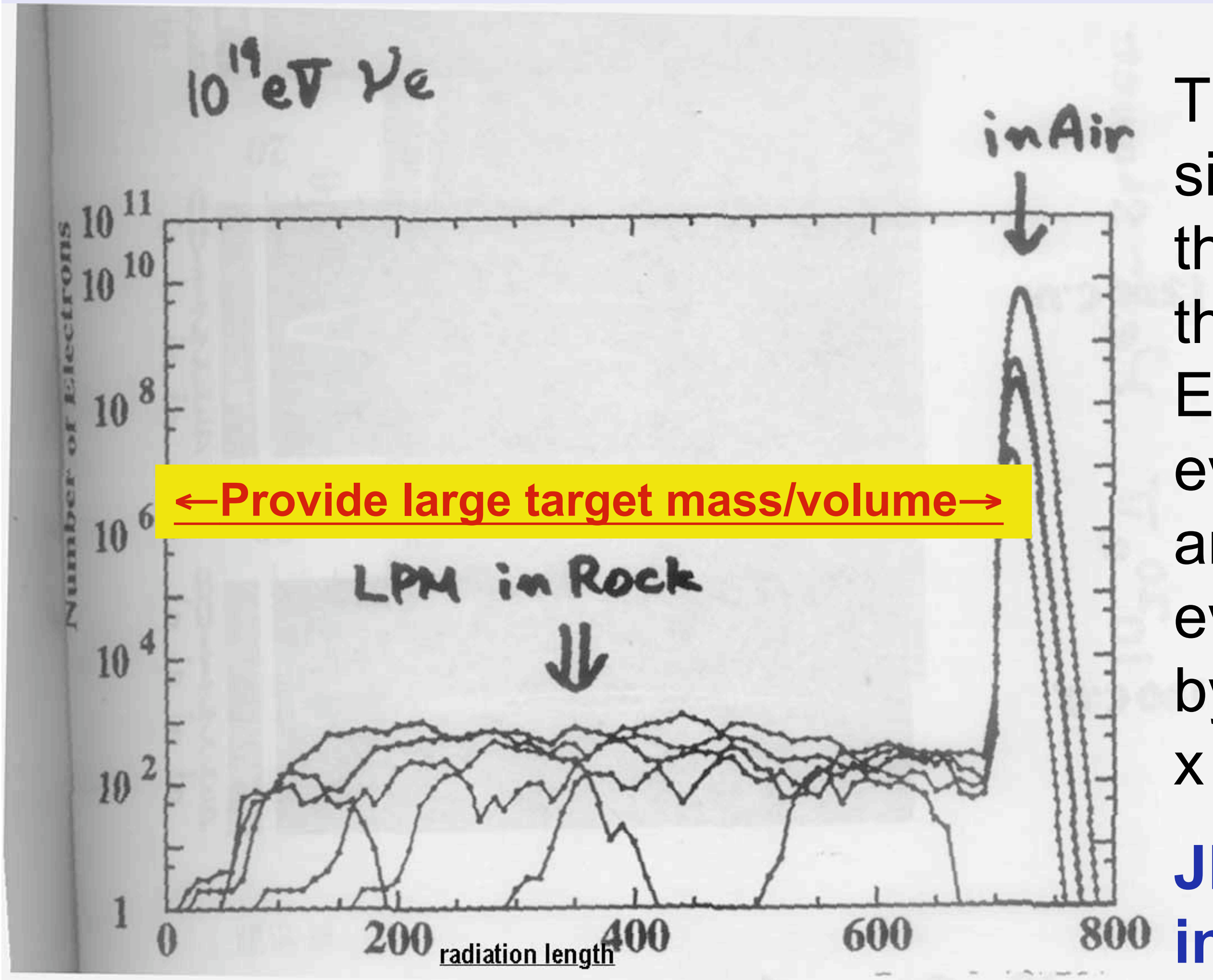
JEM-EUSO maximum sensitivity for Neutrinos with extra* dimesnsions (preliminary; TBC)





*Hundreds of neutrino events

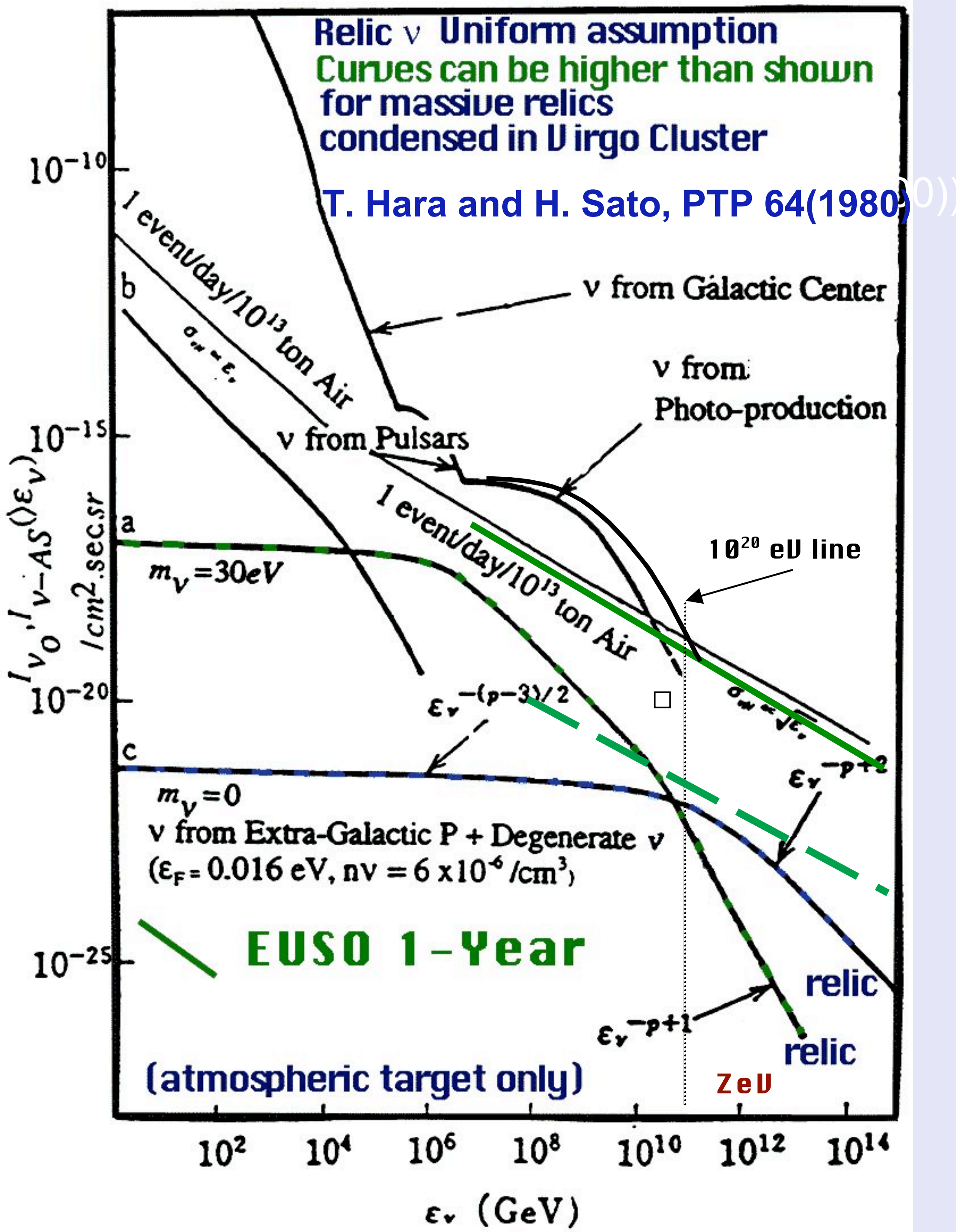
Positive role of LPM for earth-skimming neutrino observation



The LPM effect would significantly increase the detectability of the Earth-skimming events (10^{19} - 10^{21} eV) and Upward neutrino events at $10^{16\text{-}19}$ eV by enhancement of ~ x 50 effective target.

JEM-EUSO Phase-A incorporates this.

Kusano, Inoue (Saitama Univ., 2000)



Important Cosmic Relic ν's (1.95 K),

ν kicked upward in E to EHE via pν elastic scattering in ν-rich (x10^2) and in EHE-rich (x10^2) clusters

It could become **observable** if extra-dimension is true. Need tests by CR ν

$$P_{EHE} + \nu_{1.95K} \rightarrow \nu_{EHE} + P$$

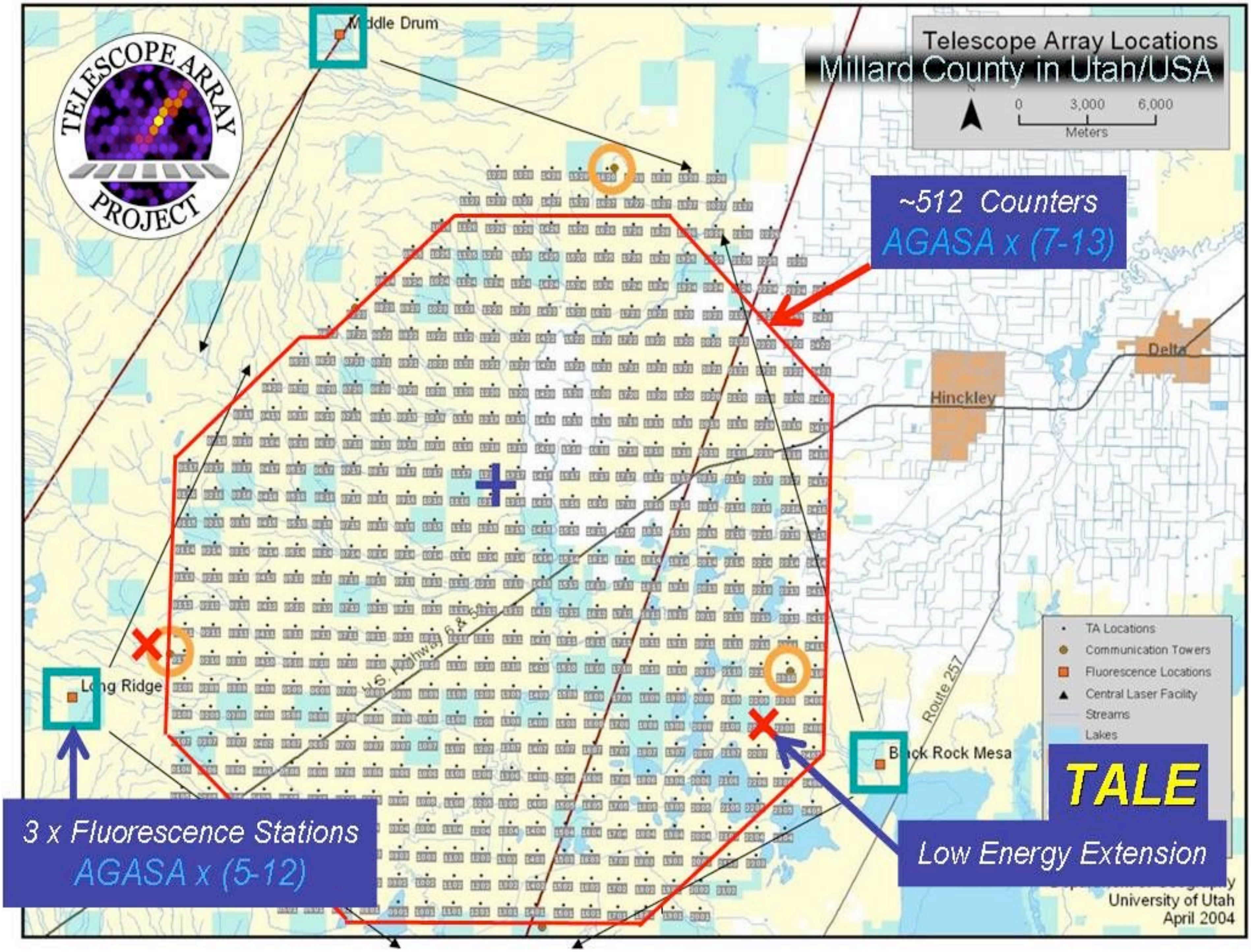
New Projects

1. TA is in commissioning phase
   - Full operation from autumn 2007
   - TALE will follow to extend coverage toward lower energies (Transition from galactic to extragalactic)
2. Auger North (200,000 km2 sr yr at 2014) considered
3. From Space
   - TUS (by FSA), JEM-EUSO (by JAXA) being selected;
   - Super-EUSO discussed (in ESA)
   - JEM-EUSO goes to ~M km2 sr yr (L) (2013 →)

- R&D for radio detection ➔ H. Falcke's talk at APC/ICRC
  - LOPES, CODALEMA
  - Looks promising
- New photodetector
  - SiPM ➔ Improve HEAP experiments
- Air Florescence yield measurements
  - Flash, Airfly
  - Final results will come soon

Telescope Array

- Balanced SD ~ FD hybrid for UHECRs
- Aperture = AGASA x (12 ~ 23)
- Complimentary to Auger South
- Energy spectrum: by SD and FD independently
  - both are from EM component measurements
- GZK cutoff, Cluster in North ?
- Construction ～95% completed, commissioning phase
- Autumn 2007, Full Data Collection starts.
- Low Energy extension TALE planned.

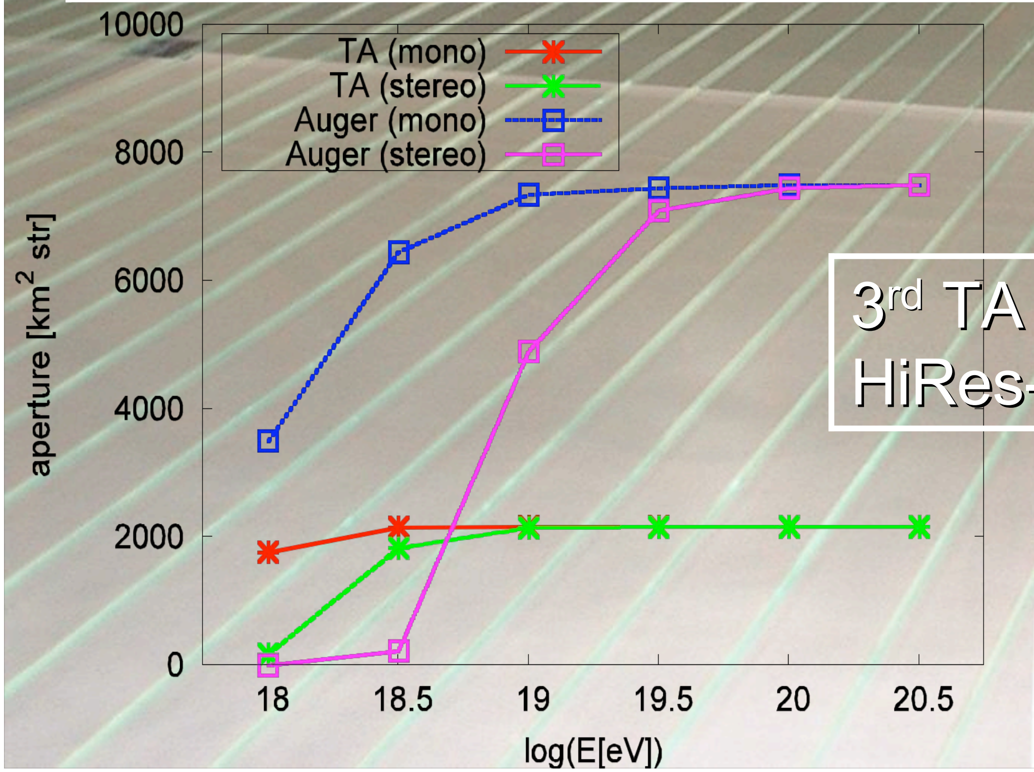


TELESCOPE ARRAY PROJECT
Middle Drum
Telescope Array Locations
Millard County in Utah/USA
N
0
3,000
6,000
Meters
~512 Counters
AGASA x (7-13)
Delta
Hinckley
U.S. Highway 6 & 50
Route 257
Long Ridge
Black Rock Mesa
TA Locations
Communication Towers
Fluorescence Locations
Central Laser Facility
Streams
Lakes
TALE
Low Energy Extension
3 x Fluorescence Stations
AGASA x (5-12)
University of Utah
April 2004

TA / SD

2 layers of plastic scintillators, 1 mm t Fe in between

	area	thickness	readout	electronics	CTR spacing
AGASA	2.2 m^2	50 mm	Direct PMT	Log Amp.	1.0 km
TA / SD	3.0 m^2	12 mm	WLS fiber	FADC	1.2 km



3rd TA / FD station is a transfer of HiRes-1

same optics (1^0 pixel)	Mirror 5.2 6.8 m^2

Why Plastic Scintillator ?

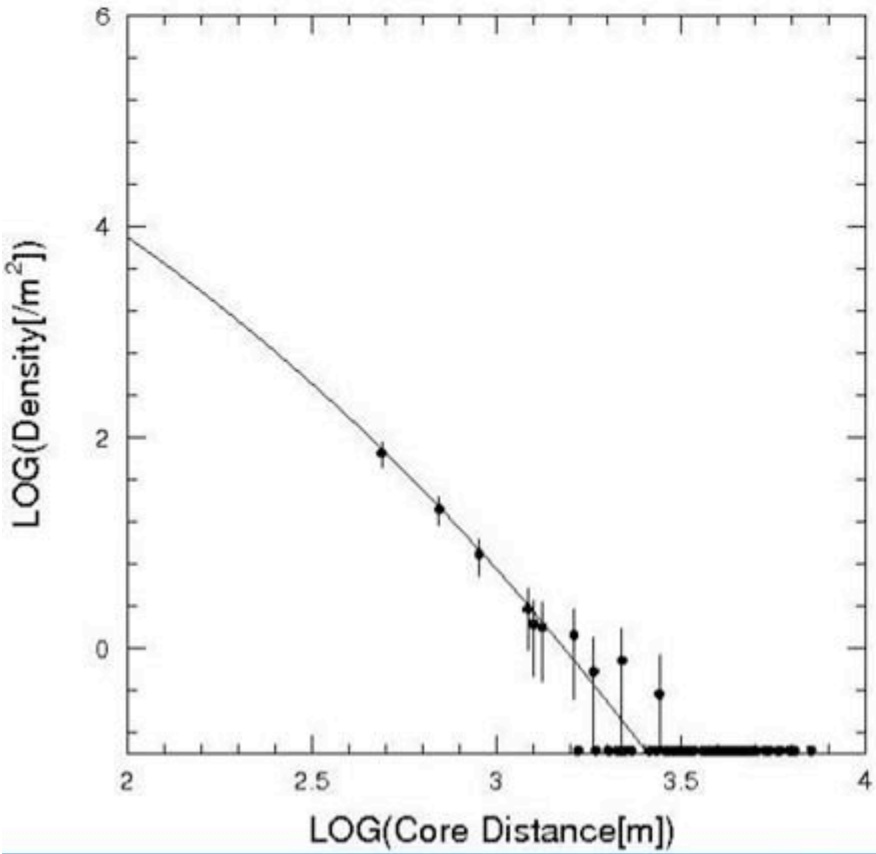
- Conserve AGASA energy scale
- Sample electromagnetic shower (~90% of Eprimary)
  >>> less dependent on
  - primary composition
  - hadronic interaction @EHE

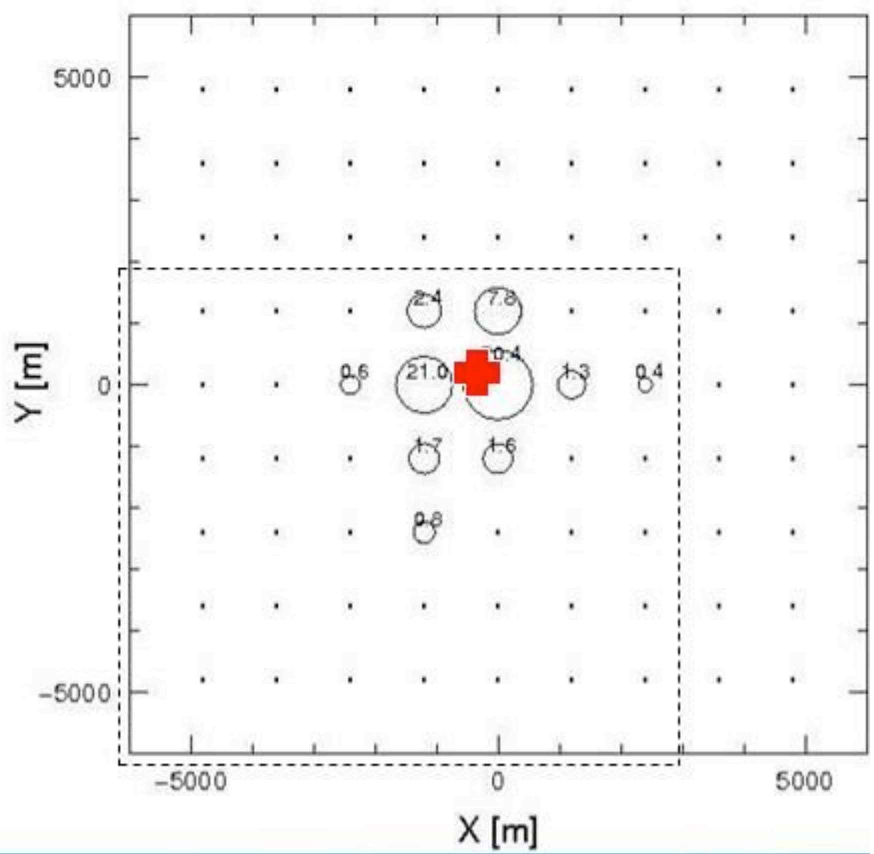
may vary over GZK energy

Why 2 Layers ?

- Trigger & Calibration
- Extension of Dynamic Range
- ID of EM shower

A shower event recorded by TA-SD





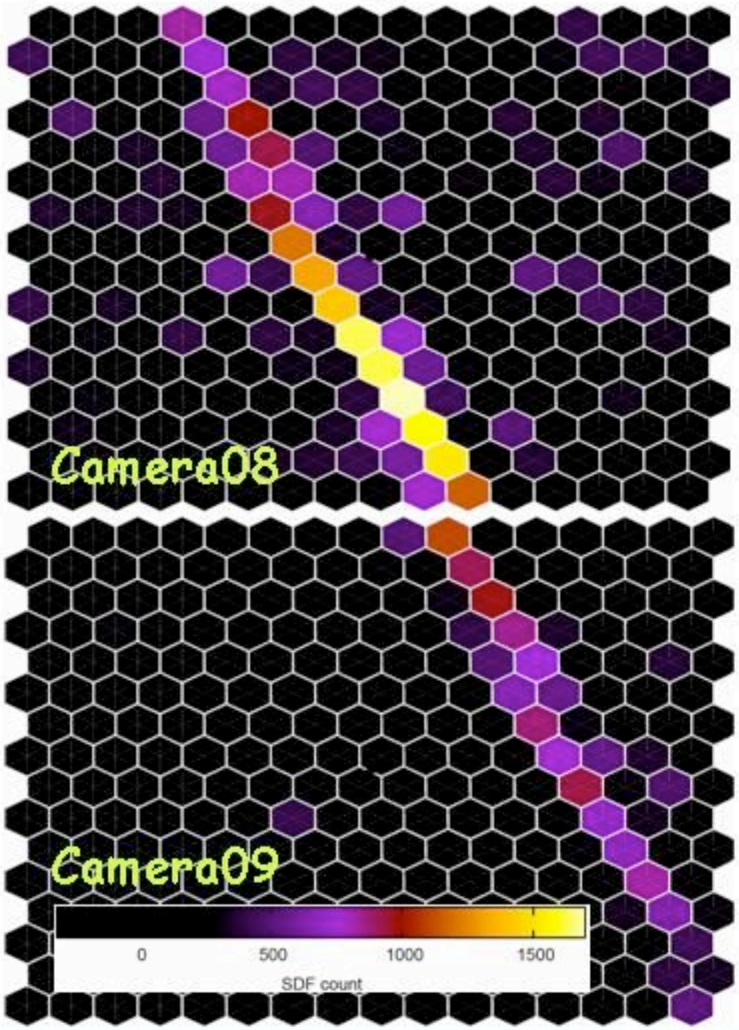
Trigger>3MIPs

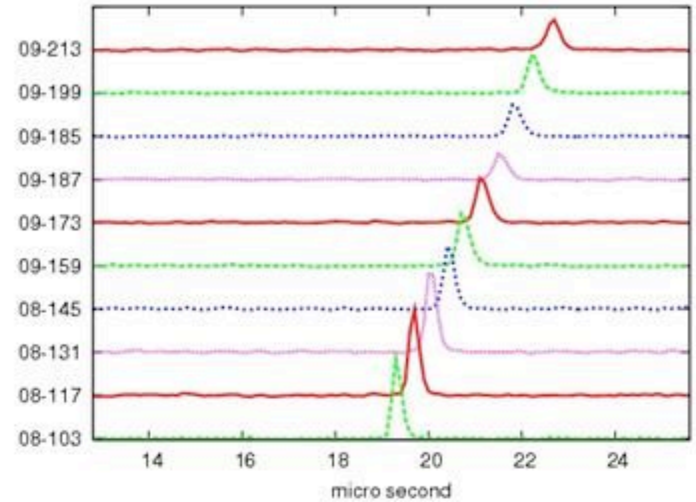
Very preliminary

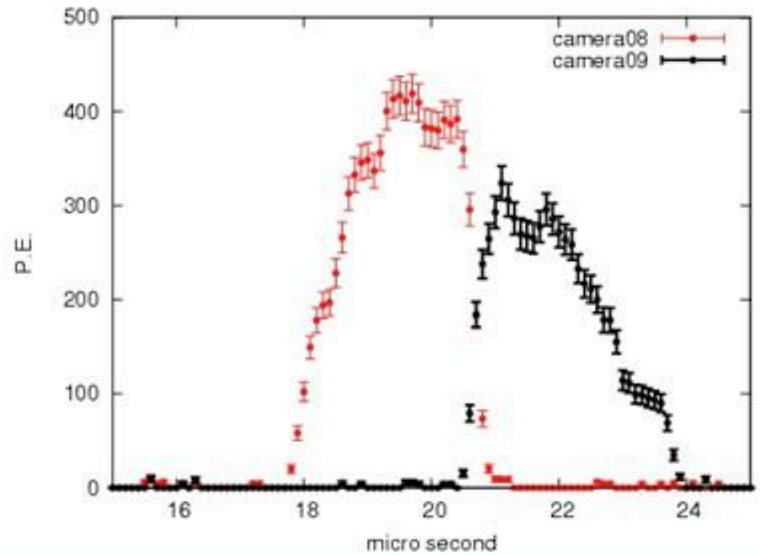
Log(E[eV])=19.1
Zenith=36.3[deg]
Azimuth=241.2[deg]

Example: shower event

June 20, 08:18:21(UTC), trigger ID 0000169

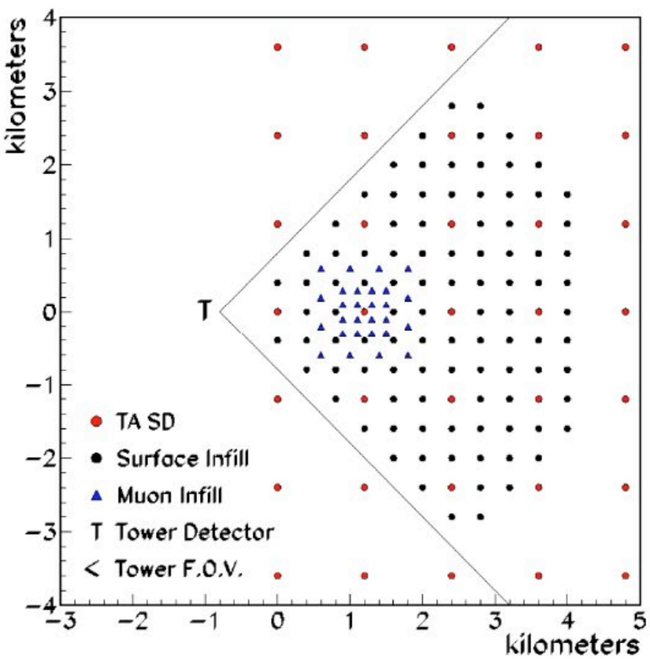




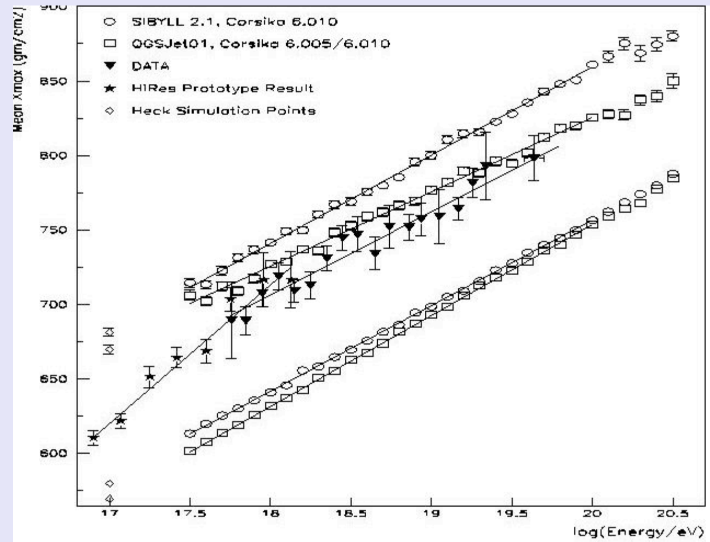


TALE $10^{16.5}$eV~$10^{18.5}$eV

TALE Infill Array



- Standard TA: 1.2 km grid
- Surface Infill: ~100 detectors on 0.4 km grid
- Muon stations: 16 on 0.2 km grid, additional detectors on larger grid



Galactic/Extragalactic Transition:
HiRes/MIA hybrid experiment, and HiRes Stereo, results show transition from heavier to lighter composition, complete by about 1018 eV.

Complimentary to Kaskade-Glande
+ tower FD

Auger North

The Pierre Auger Observatory – 2 Sites

Need for 2 sites realized since beginning of project

PIERRE AUGER OBSERVATORY

Northern Site: Colorado

- Retain features & functionality of Southern Site
  - Hybrid detection & energy calibration
  - Water Cherenkov surface array
    - 4000 stations, 10,370 km^2
    - 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 km^2
  - 1.5 km triangular grid
- Completion end 2007
- Science flowing – 38 papers here

Auger South upgraded by HEAT & AMIGA

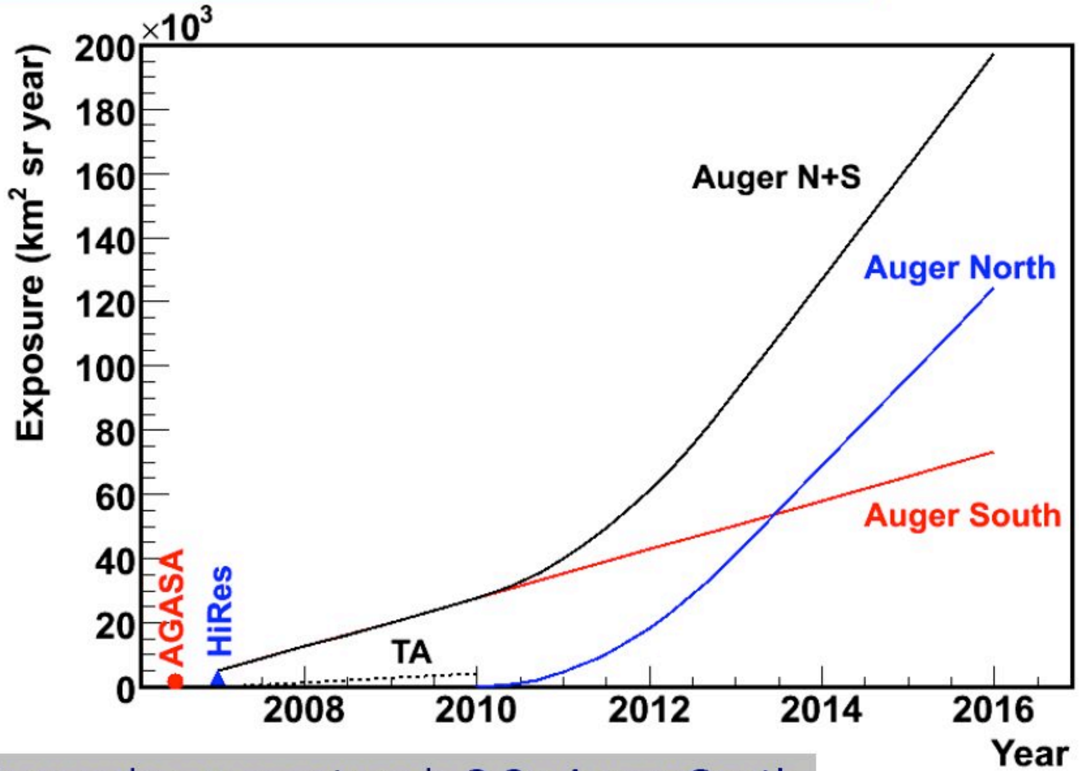
Auger North

PIERRE AUGER OBSERVATORY

Exposure

- It is time to design the Northern Site
- Build upon lessons learned in the South

- Assumes:
  - Auger South finished end of 2007
  - Auger North construction starts 2009
  - Auger North construction finished 2012



- Auger North cosmic ray aperture is 3.3x Auger South
- Auger North neutrino aperture 2x Auger South

Radio R&D (new way of viewing showers) to be established

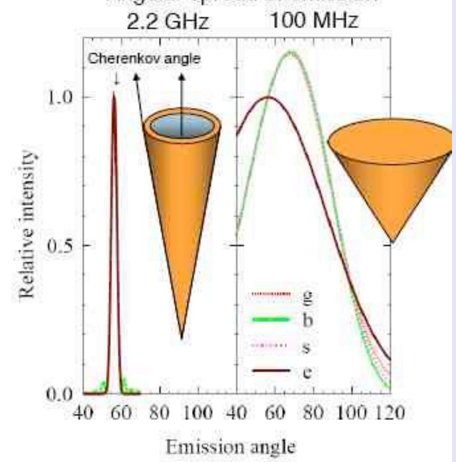
Astroparticle Physics: Radio Detection of Particles

- Cosmic Rays in atmosphere:
  - Geosynchrotron emission (10-100 MHz)
  - Radio fluorescence and Bremsstrahlung (~GHz)
  - Radar reflection signals (any?)
  - VLF emission, process unclear (<1 MHz)
- Neutrinos and cosmic rays in solids: Cherenkov emission (100 MHz - 2 GHz)
  - polar ice cap (balloon or satellite)
  - inclined neutrinos through earth crust (radio array)
  - CRs and Neutrinos hitting the moon (telescope)

Radio Observations of the Moon: Different Frequencies

- The shower is ~10 cm wide but 2 m long!
- Cherenkov emission is anisotropic:
  - maximum emission in narrow forward ring at GHz frequencies
  - Lower emission but almost isotropic at lower frequencies
- Low Frequencies have longer attenuation lengths and sample larger volume.

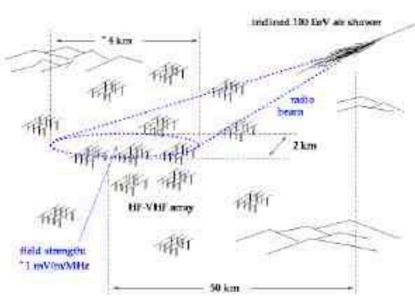
Angular spread of emission



Scholten, et al. (2006, in press)

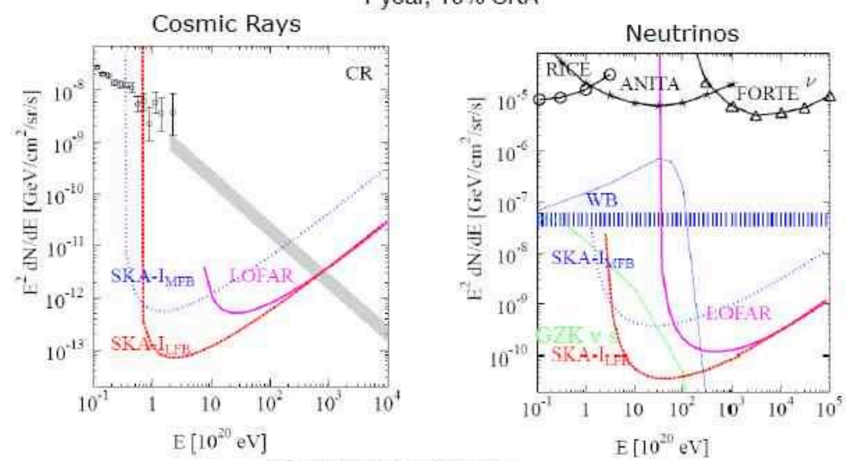
Advantages of Radio Emission from Air Showers

- High duty cycle (24 hours/day minus thunderstorms)
- Low attenuation (can see also distant and inclined showers)
- Bolometric measurement (integral over shower evolution)
- Also interesting for neutrinos
- Potential problems:
  - Radio freq. interference (RFI)
  - size of footprint
  - only practical above $\sim 10^{17}$ eV.



Low-Frequency Observations of the Moon: SKA

1 year, 10% SKA



Scholten 2006, SKA book +

νMoon Collaboration: Scholten, Bacelar, Braun, de Bruyn. Falcke, Stappers Strom

TUS Mission
Launch 2009-2010

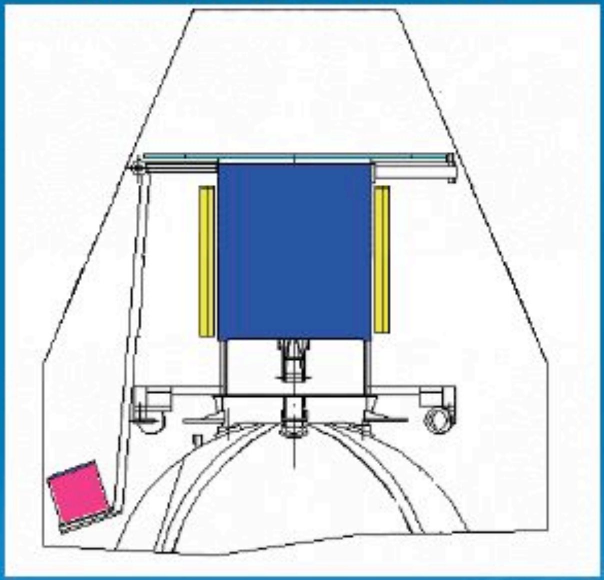
The TUS detector will be launched on a new platform separated from the main body of the "Foton" satellite (RosCosmos project, Samara enterprise, launching in 2009-2010).

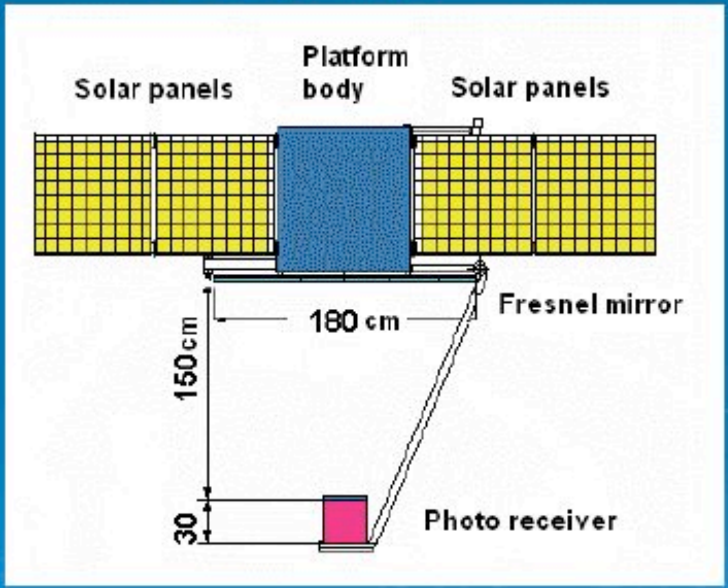
Satellite limits for the scientific instrument are:

mass 60 kg, electric power 60 Wt, orientation to nadir ±3° .

Preliminary TUS design:

1- in the transportation mode, 2 – in operation.



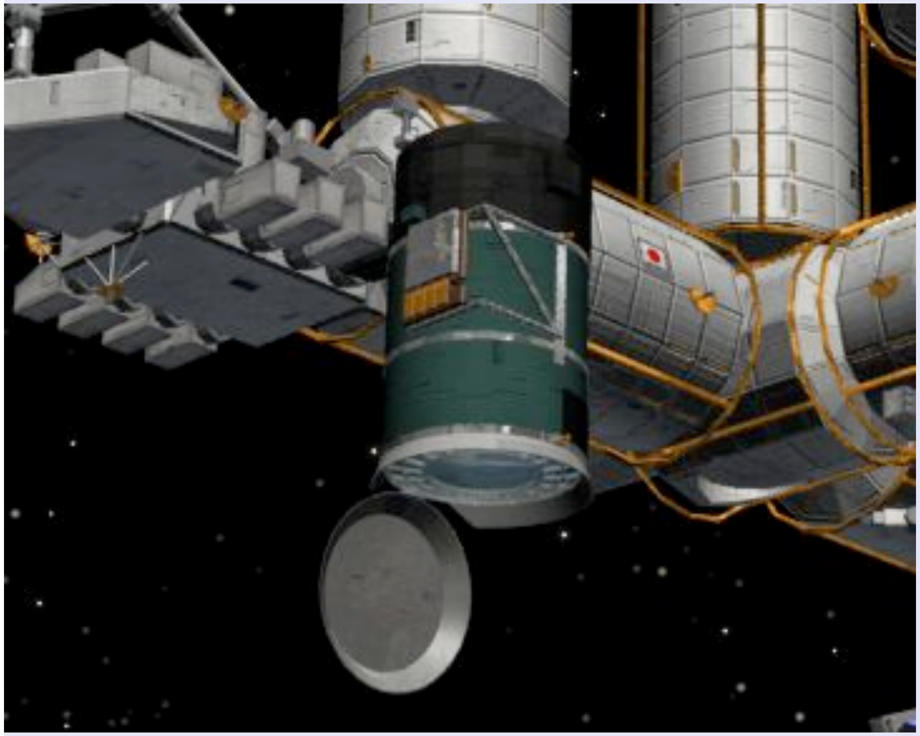


Mirror area is up to 2 m^2, pixels cover 4000 km^2 of the atmosphere (orbit height 400 km).

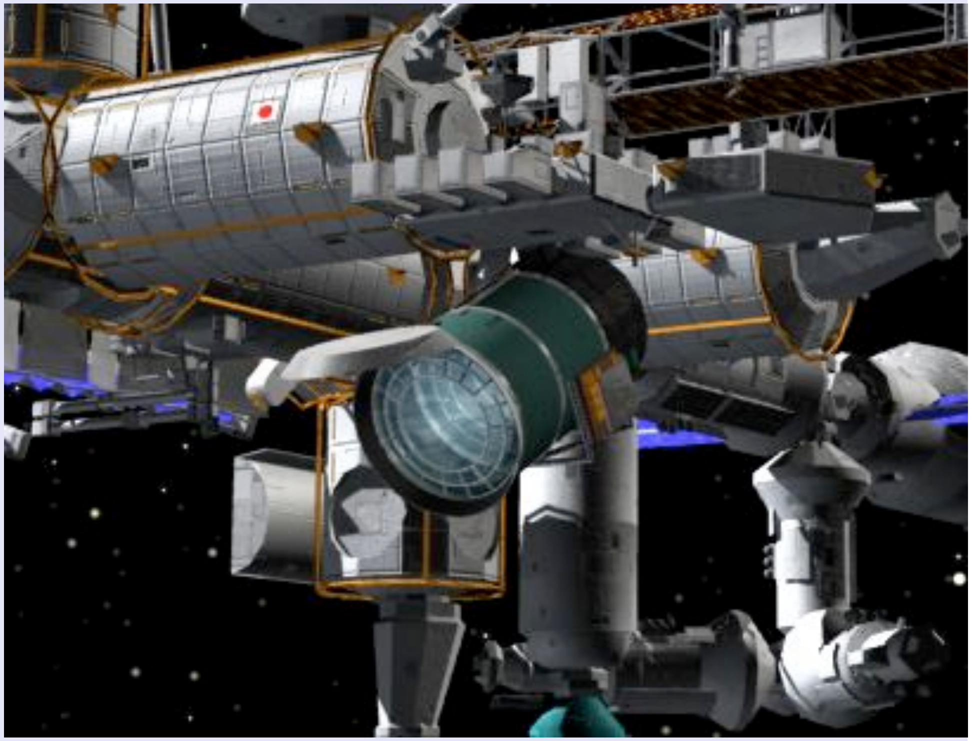
Space

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



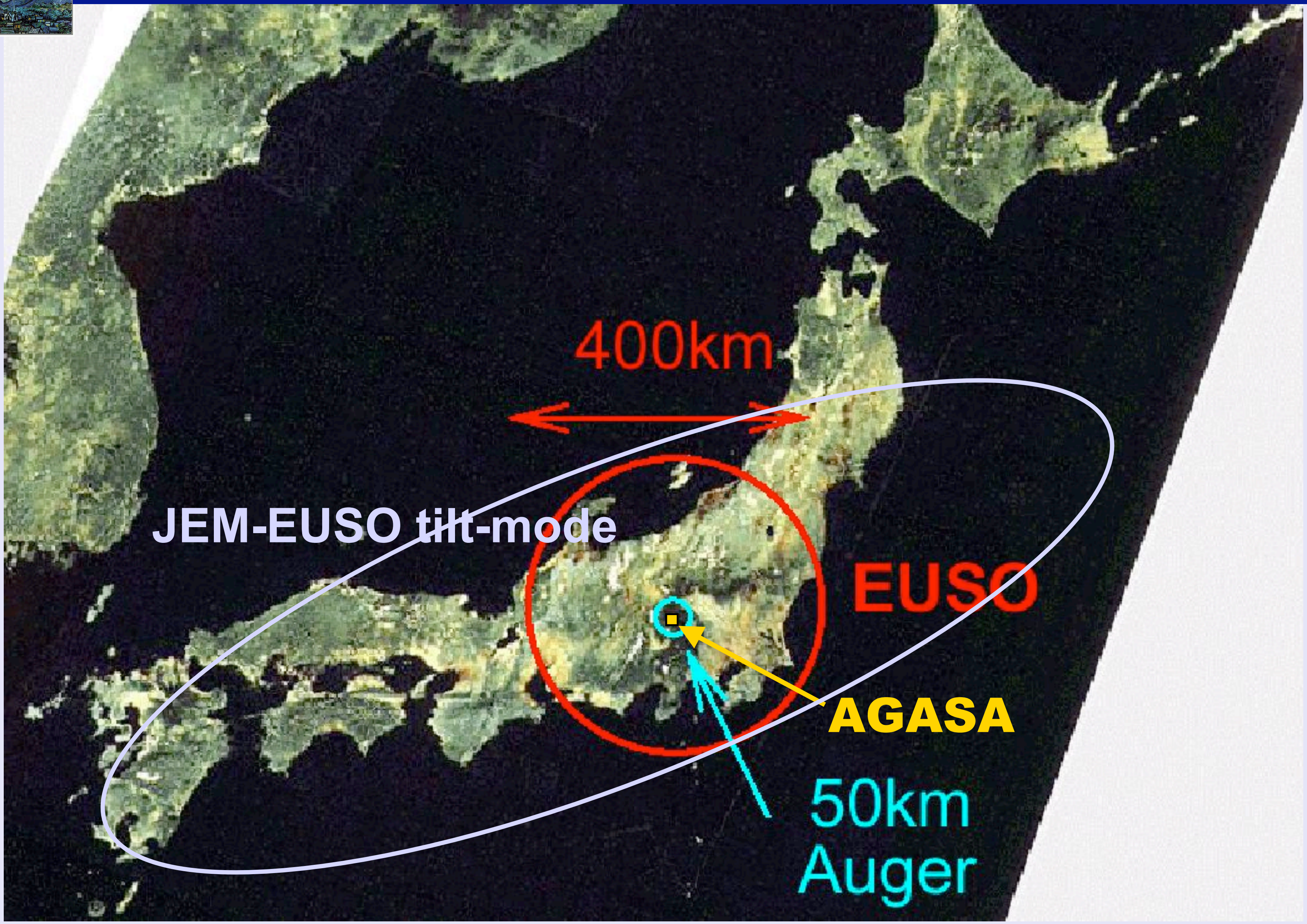
Tilted Mode

Larger effective area (x5) with ~35°tilt

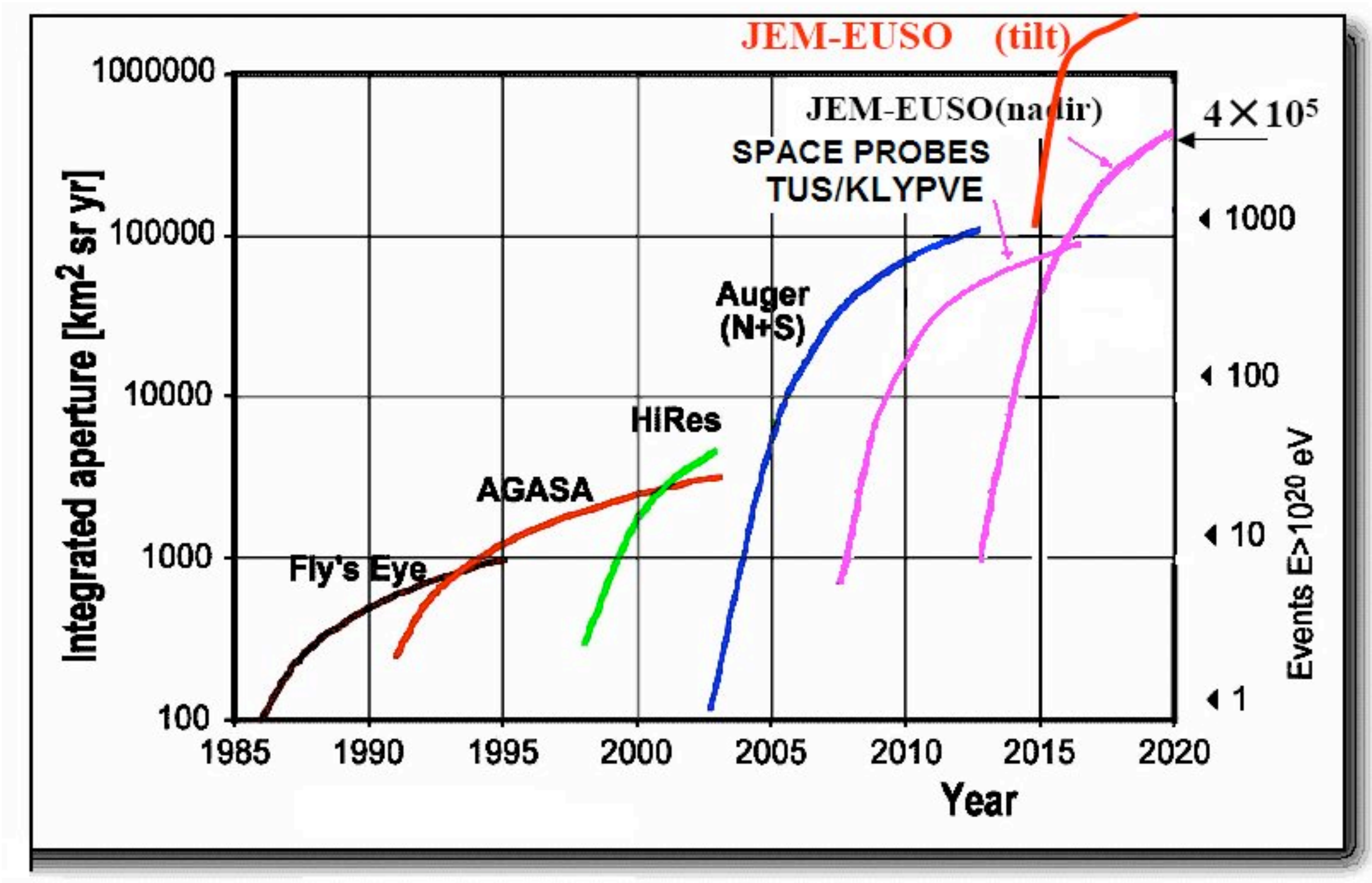
EUSO

EUSO ~ 300 x AGASA ~ 10-50 x Auger > 10^6 (L)

EUSO (Instantaneous) ~3000-15000 x AGASA ~ 100-500 x Auger



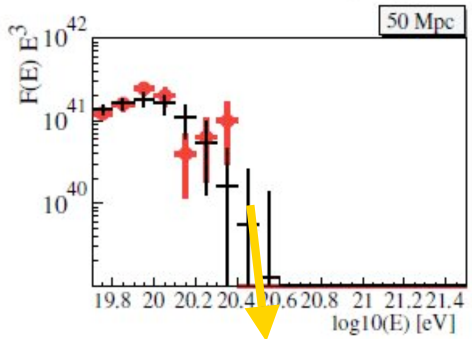
Progress of the study of EECR expected in the near future:



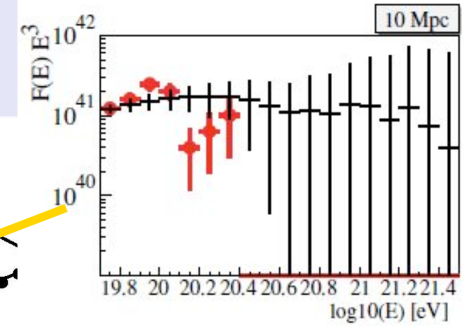
by Boris Khrenov 2006

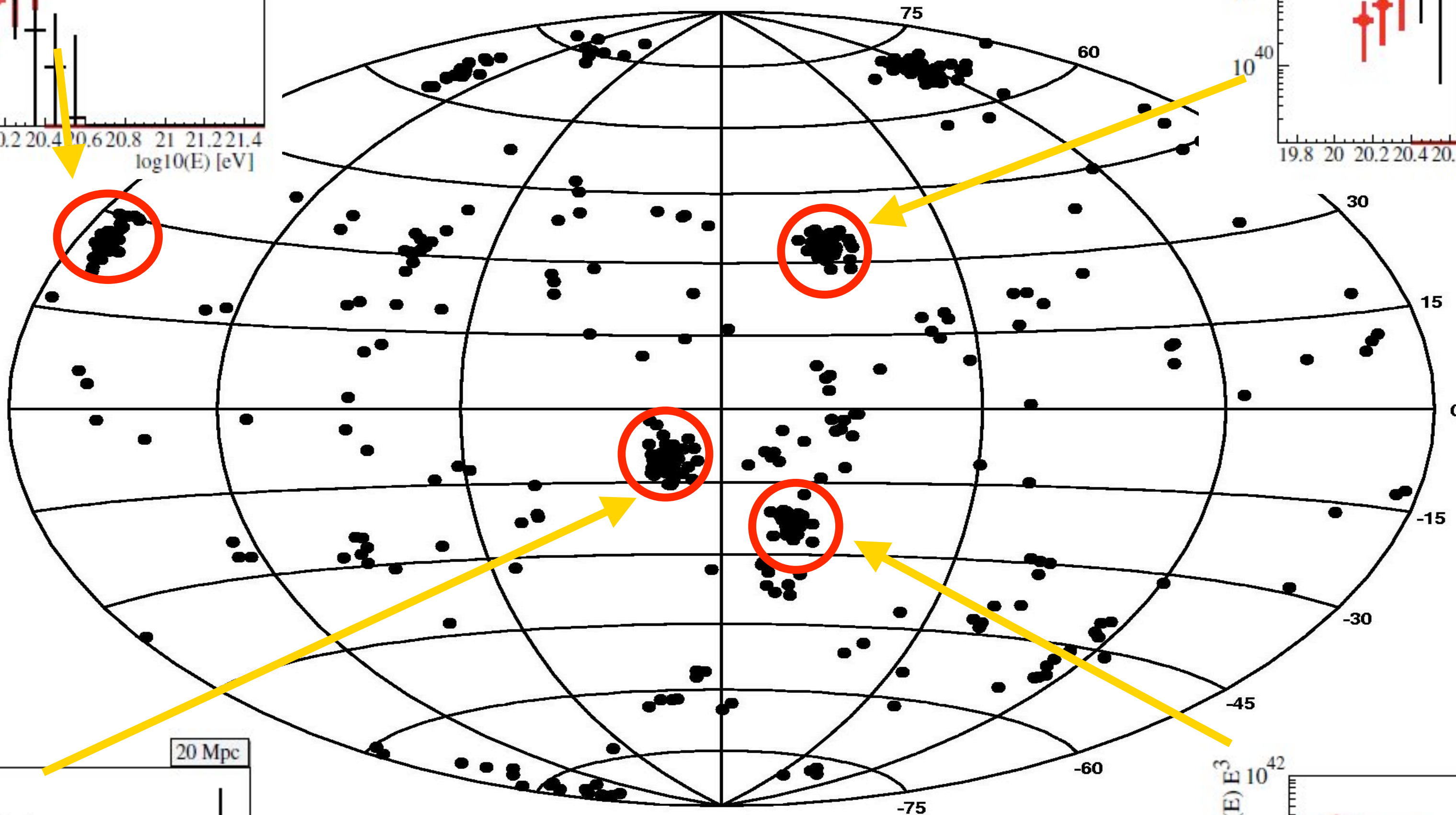
JEM-EUSO ~1M km^2 sr yr, >1000events above 7×10^{19}eV

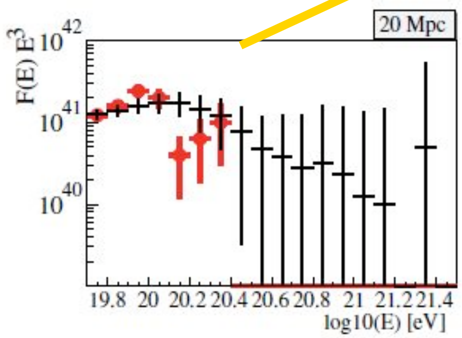
Particle Astronomy can begin

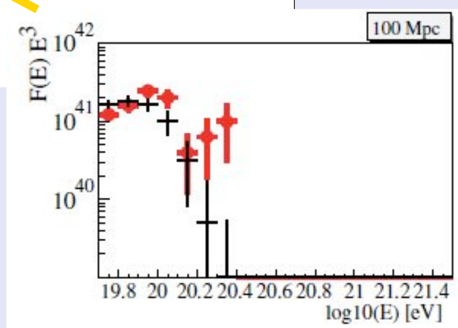


If we get >1,000 events,









- 1,000 events : E> 10^{20} eV
- Several dozen clusters are expected
- All sky coverage
- Acceleration can be studied

Summaries

- based on Highlights by Watson/ICRC

-based on Summary by Teshima/ICRC

Today's summary for ICRR

Summary of Auger Highlights: (A. WATSON)

Auger-South more than 80% complete

More events > 10 EeV than from AGASA or HiRes
(close to, or more than their total)
AND with superior angular and energy resolution

- **Arrival Directions:**
  No evidence of point sources
  – **but** relatively few events at the very highest energies: **Auger is just starting to see something**

- **Spectrum:** ankle and steepening confirmed
  - with model-independent measurement and analyses at 4.5×10^{18} - 3.55×10^{19} eV

ICRC Summary - Teshima rapporteur

- **Energy Spectrum of UHECRs**
  - HiRes and Auger saw the steepening of the spectrum above $4x10^{19}$eV with 5 sigma and 6 sigma
  - GZK cutoff? **(or else?)**

- **Chemical compostion of UHECRs - in conflict**
  - Auger Xmax suggests mixed composition
  - HiRes claimed proton dominance above10^{18}eV

- **Anisotropies**
  - No galactic center excess was found with Auger around 10^{18}eV
  - HiRes: deficit in the direction of anti-galactic center is reported.

  - Small scale anisotropy was not found with Auger
    - The effect of galactic magnetic field must be considered → **Higher E**

  - Hint of medium scale anisotropy with Auger
  - World data also shows medium scale anisotropy
    - Related to **the large scale structure?**

Many open questions that arose in 2007

- **Energy scale problem**
  - 1.2~1.5 factor difference between Auger and other experiments
  - FD energy (FY) ←→ SD energy (MC-Calibration energy)
- **What is ankle?**
  - Pair creation dip → V.Berezinsky; Beautiful results (requires proton dominance)
  - or Transition from galactic to extragalactic
- **Chemical composition at UHE (EHE: not known for Super-GZK)**
  - A. Proton dominance ? → it supports pair creation dip hypothesis
  - B. Mixed composition → photodisintegration energy (Eth ~increase with A)
    → small elongation ratio D10 → Auger Xmax?
- **Break in energy spectrum at $4x10^{19}$eV**
  - GZK Cutoff? - Too darly?
  - Acceleration limit? - Too universal?
  - Drop off of lighter elements?
- **Medium scale anisotropy**
  - Relating with large scale structure?
  - Deflected images of point sources (North-South asymmetry)

Today's critiques - and Recommendations (1)

1. Steeper Spectrum > 4×10^{19} eV by Hi-Res/Auger
   - ***Unclear, inconsistent, if it is GZK profile of protons***

   (i) Need overwhelming statistics when discussing the steepening

   (ii) Unsettlingly obscure Hi-Res aperture - it can easily mimic steepening - if p-GZK,nearby source pointing should be stronger

   (iii) Inconsistent (Auger) for GZK with the mixed composition data*

   (if acceleration limit, it cannot be *a priori* universal at all the sources, either)

2. Source pointing - Auger < 10^{20}eV is "naturally" negative
   - ***but not qualified to deny Auger/Hi-Res/Yakutsuk data***

   (i) High Galactic magnetic field in the southern sky eraces signals

   (ii) Known that there are much fewer sources (BL-lac) in the South

* Doubt exists that Auger under-estimated energy (by FD)

Today's critiques - and Recommendations (2)

1. More e/μ separating observations (Auger/TA) are desired - and possibly, with large-scale in-fill+
   a. Clarify the long-lasting big puzzle of anomalous elongation rate (well known in Japan since Norikura/Miyake 1979 ICHEP and BASJE/Suga-Mizumoto:).
   b. Allow some studies of super-LHC physics in the energy-frontier.

2. Make ~10^6 L Highest-energy astronomy/astrophysics experiments (e.g., JEM-EUSO, Super-EUSO, Auger N+)

3. Find overwhelming means to really detect neutrinos (no more upper-bounds as a manifest of incapability)

4. R&Ds for Radio and new photo-sensors

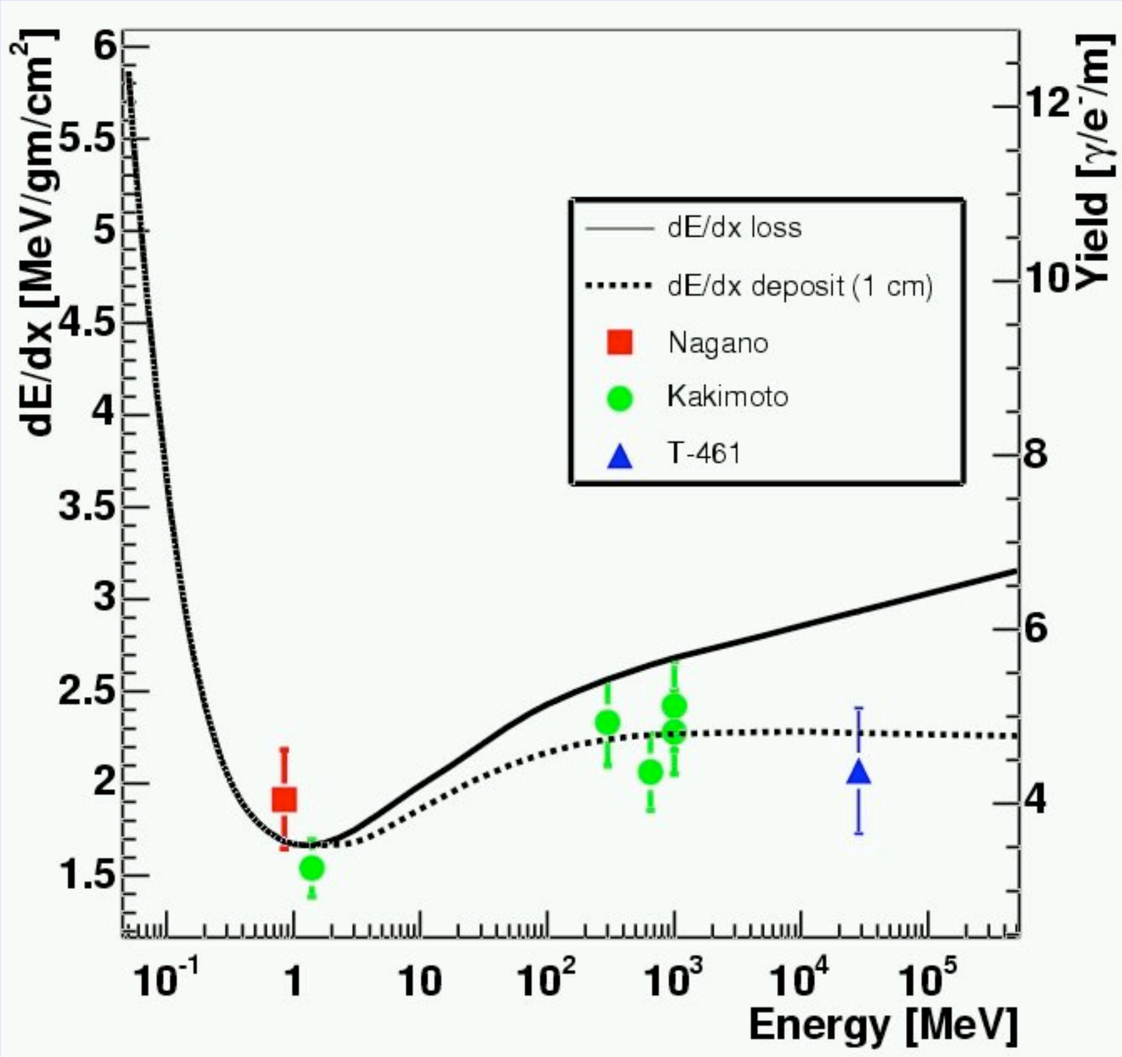
Thanks

Improve the FD accuracy!

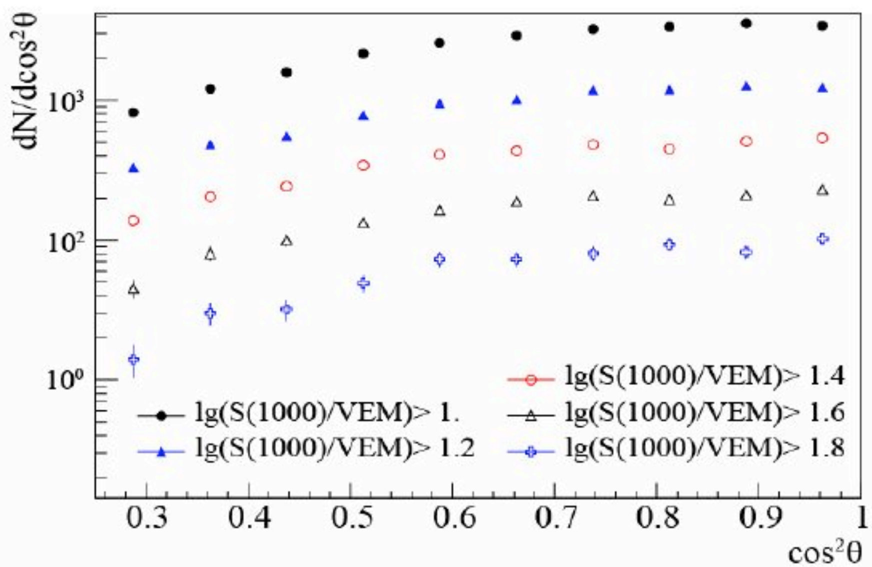
Previous Measurement of the Absolute Fluorescence Yield

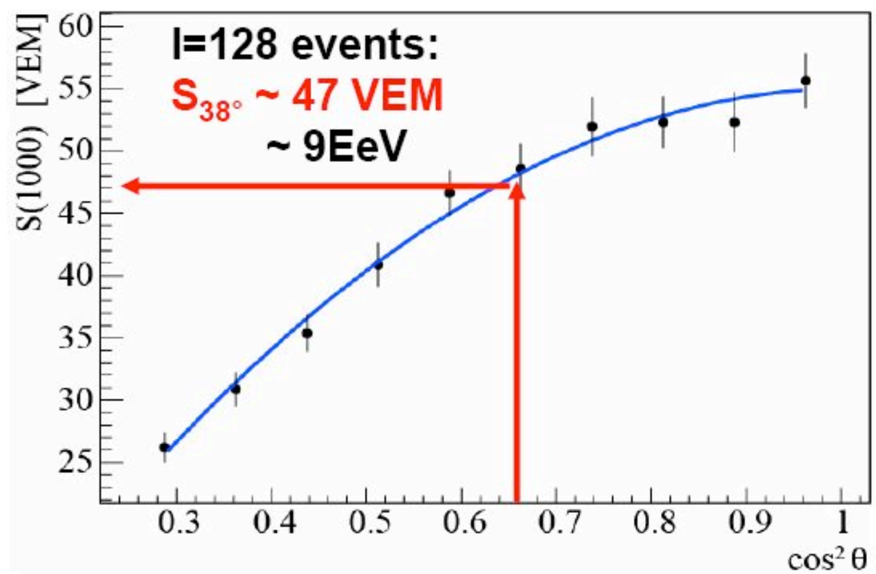
- Sampling of Previous Results: Kakimoto *et al*., Nagano *et al*., and T461 (FLASH test run).
- Ratio of fit to (Kakimoto, Nagano, and T461) to fit to Kakimoto

  = 1.00 ± 0.06
- FLASH result will be shown at the air fluorescence conference at El Escorial in Sept.



Auger: Attenuation curve and CIC





Attenuation curve parameterisation

$S(1000) = S_{38°} (1 + a\,x + b\,x^2)$

$ = S_{38°}\,\mathrm{CIC}(\theta)$

$x = \cos^2\theta - \cos^2 38°$

$a = 0.96 \pm 0.06$

$b = -1.21 \pm 0.27$

$S_{38°}$ may be regarded as the signal the shower would have produced if it had arrived at 38°

i.e. $S_{38°} = S(1000)/\mathrm{CIC}(\theta)$

$\sigma^2_{S38°} = \sigma^2_{S38°}(\mathrm{CIC}) + \sigma^2_{\cos\theta} + \sigma^2_{S(1000)}$

(Watson continuing)

But what does this all mean?

Is the ankle marking a galactic/extra-galactic change?

Have we seen the GZK effect?

Is it a 'bump' from a more local effect?

Are the accelerators just 'tired' in part?

What can we deduce from propagation models if there is no spatial annisotropy?

Deducing the MASS is troubling: mixed at highest energy?

Larger σ and/or more muons (EPOS?)

Certainly not expected by many, except **BASJE/Norikura**

– do hadronic models need some modification?

Could it help to reconcile AGASA, HiRes and Auger at the higher energies?