SUMMARY: ground cosmic ray experiments

P. Tinyakov[1,2]

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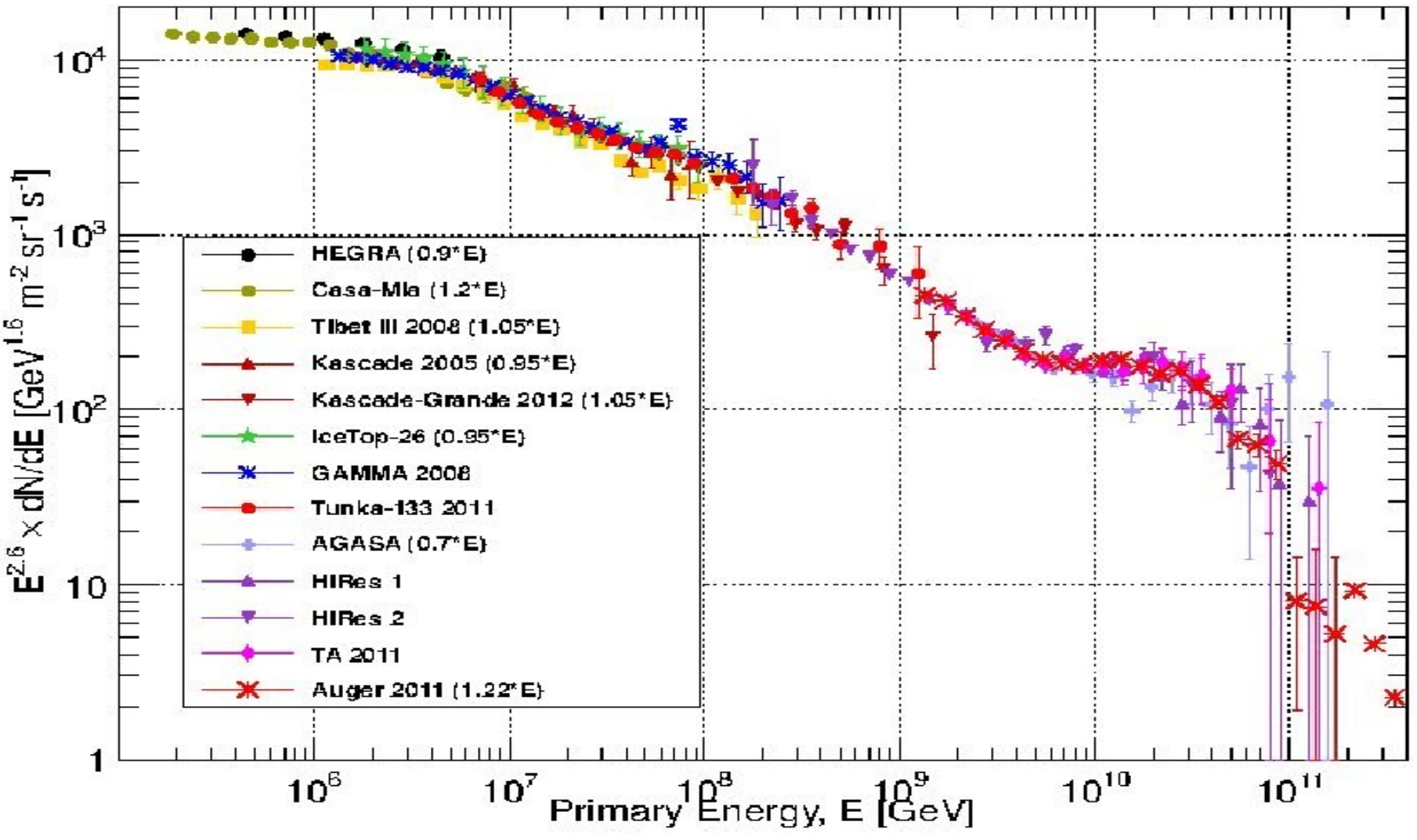
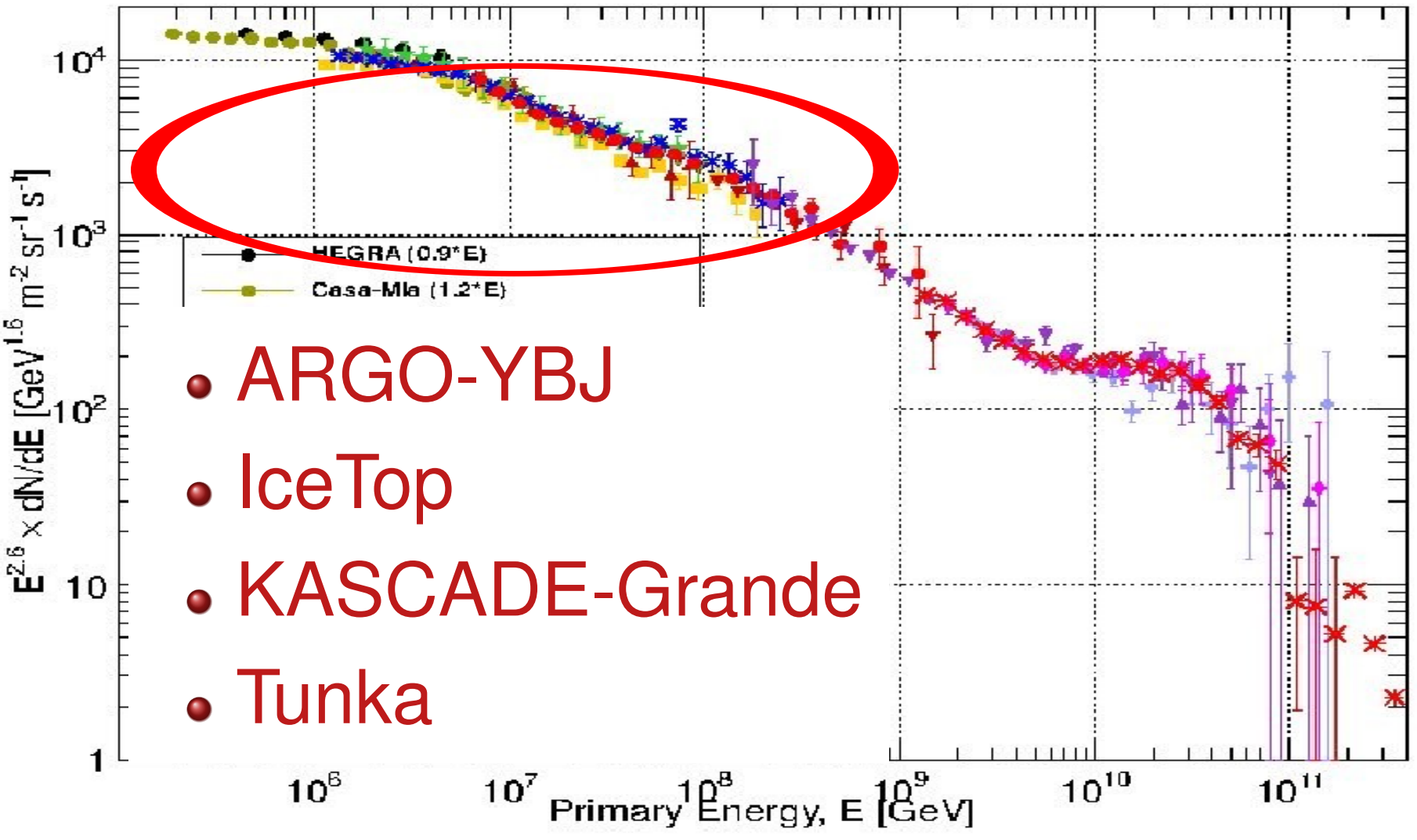
OUTLINE

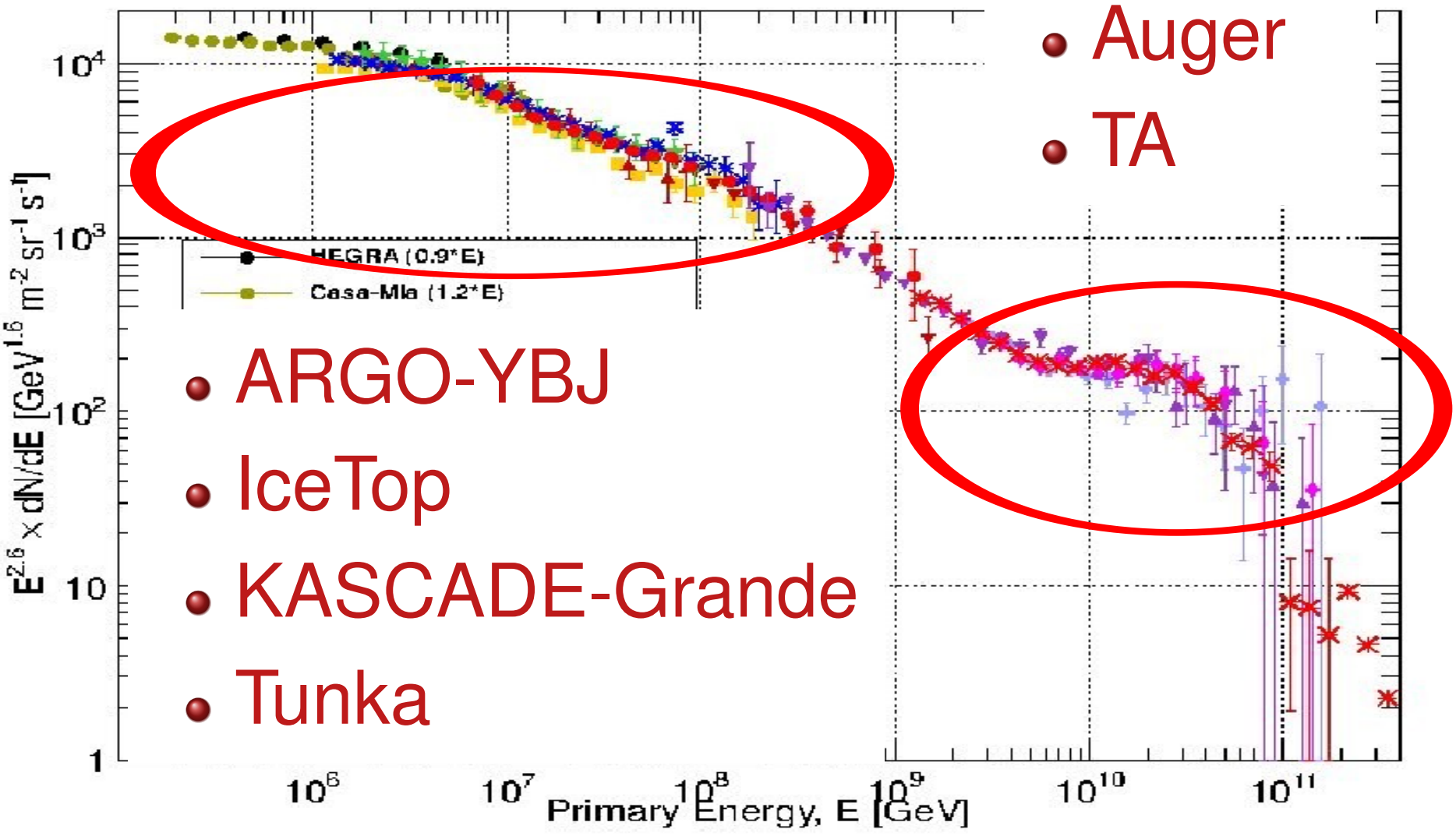

HEGRA (0.9*E)
Casa-Mia (1.2*E)
Tibet III 2008 (1.05*E)
Kascade 2005 (0.95*E)
Kascade-Grande 2012 (1.05*E)
IceTop-26 (0.95*E)
GAMMA 2008
Tunka-133 2011
AGASA (0.7*E)
HIRes 1
HIRes 2
TA 2011
Auger 2011 (1.22*E)
E^2.6 x dN/dE [GeV^1.6 m^-2 sr^-1 s^-1]
Primary Energy, E [GeV]
10^4
10^3
10^2
10
1
10^6
10^7
10^8
10^9
10^10
10^11

OUTLINE



- ARGO-YBJ
- IceTop
- KASCADE-Grande
- Tunka

OUTLINE

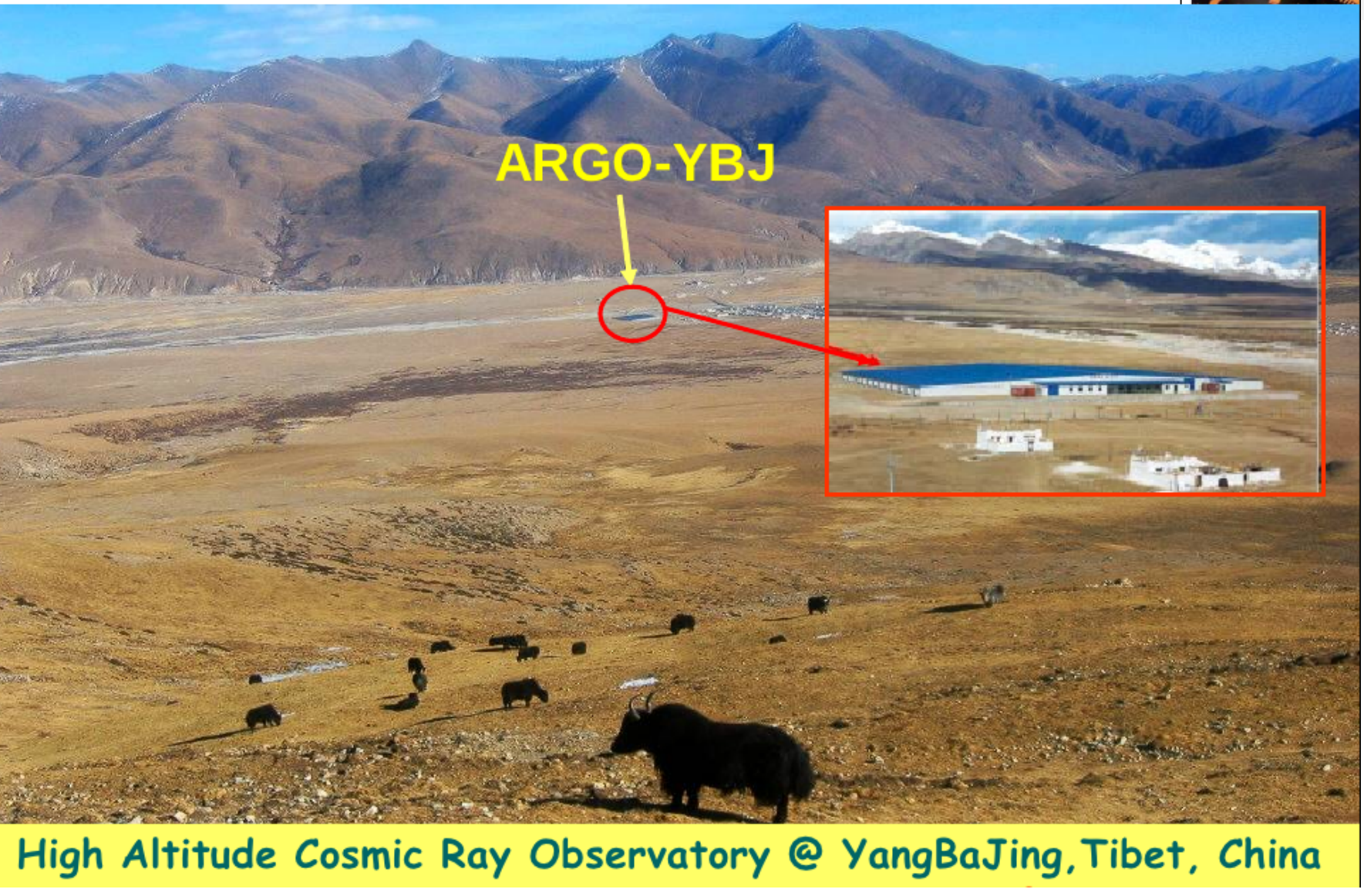


- Auger
- TA
- ARGO-YBJ
- IceTop
- KASCADE-Grande
- Tunka

KEY QUESTIONS:

- spectral features
- composition
- anisotropy

The ARGO-YBJ experiment



- talks by I. De Mitri, P. Montini, Cao Zhen
- size $\sim 100 \times 100$ m

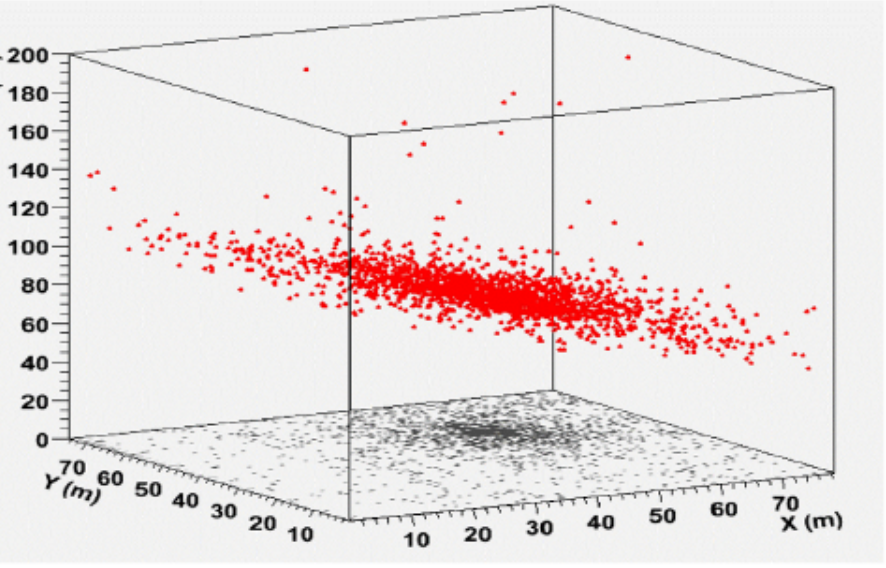
The ARGO-YBJ experiment

Event Rate ~ 3.5 kHz for N_{hit} >20 - Duty cycle ~ 86% - 10^{11} evts/yr – 100TB/yr

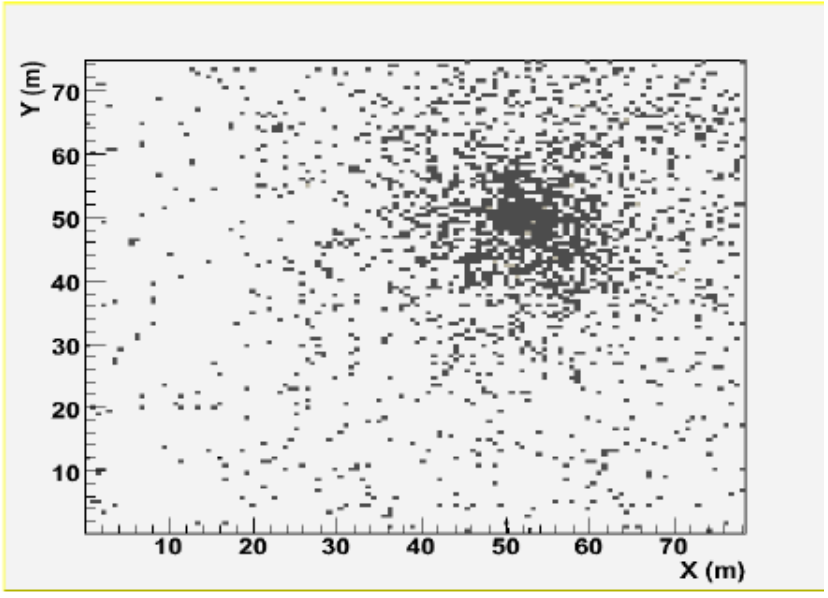
High space/time granularity
+ Full coverage
+ High altitude

→

detailed study on the
EAS space/time structure
with unique capabilities



3-D view of a detected shower

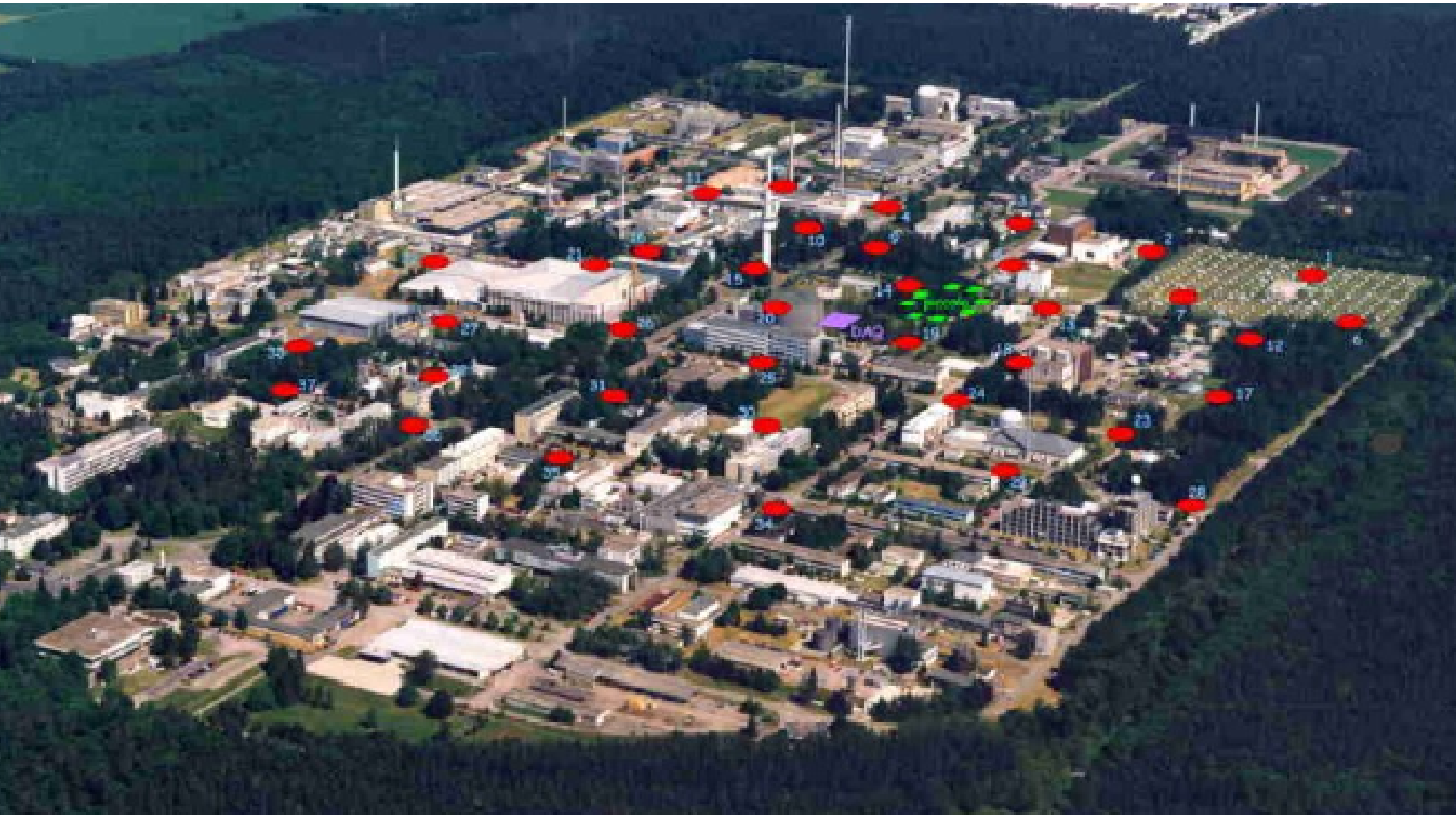


Top view of the same shower

High Altitude Cosmic Ray Observatory @ YangBaJing, Tibet, China

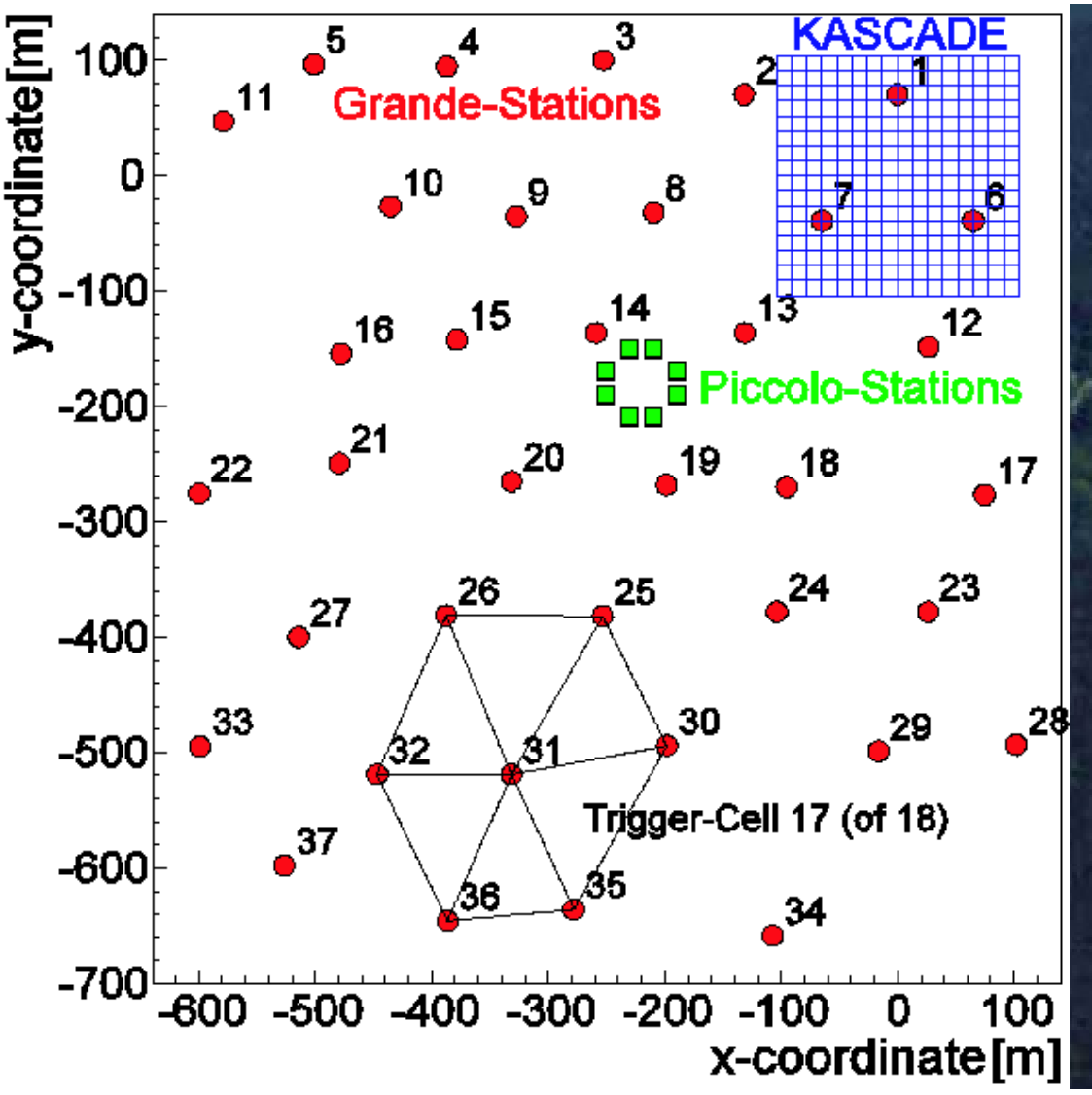
- talks by I. De Mitri, P. Montini, Cao Zhen
- size $\sim 100 \times 100$ m

KASCADE-Grange



- talk by A. Chiavassa
- size $\sim 800 \times 800$ m

KASCADE-Grange



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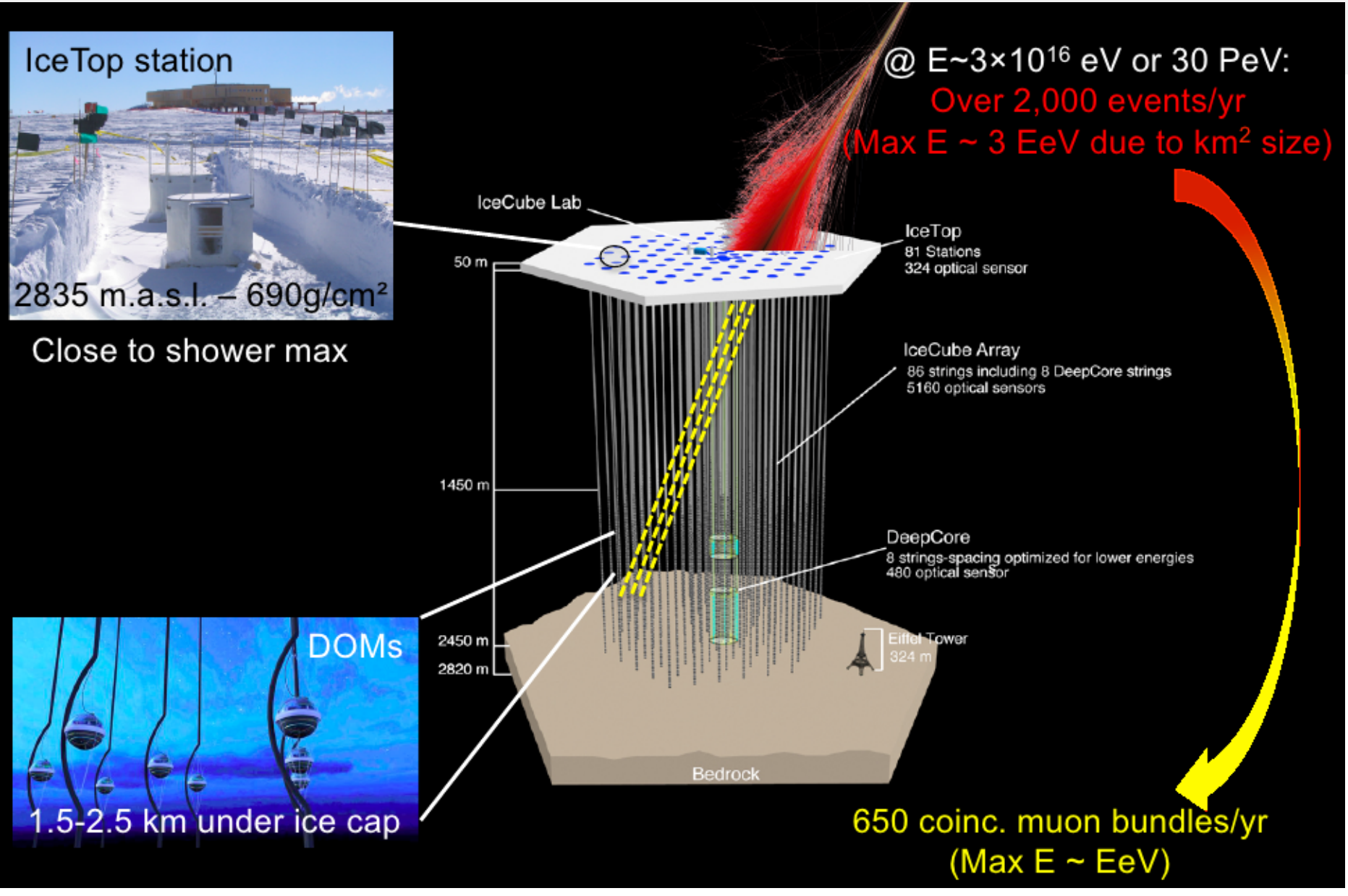
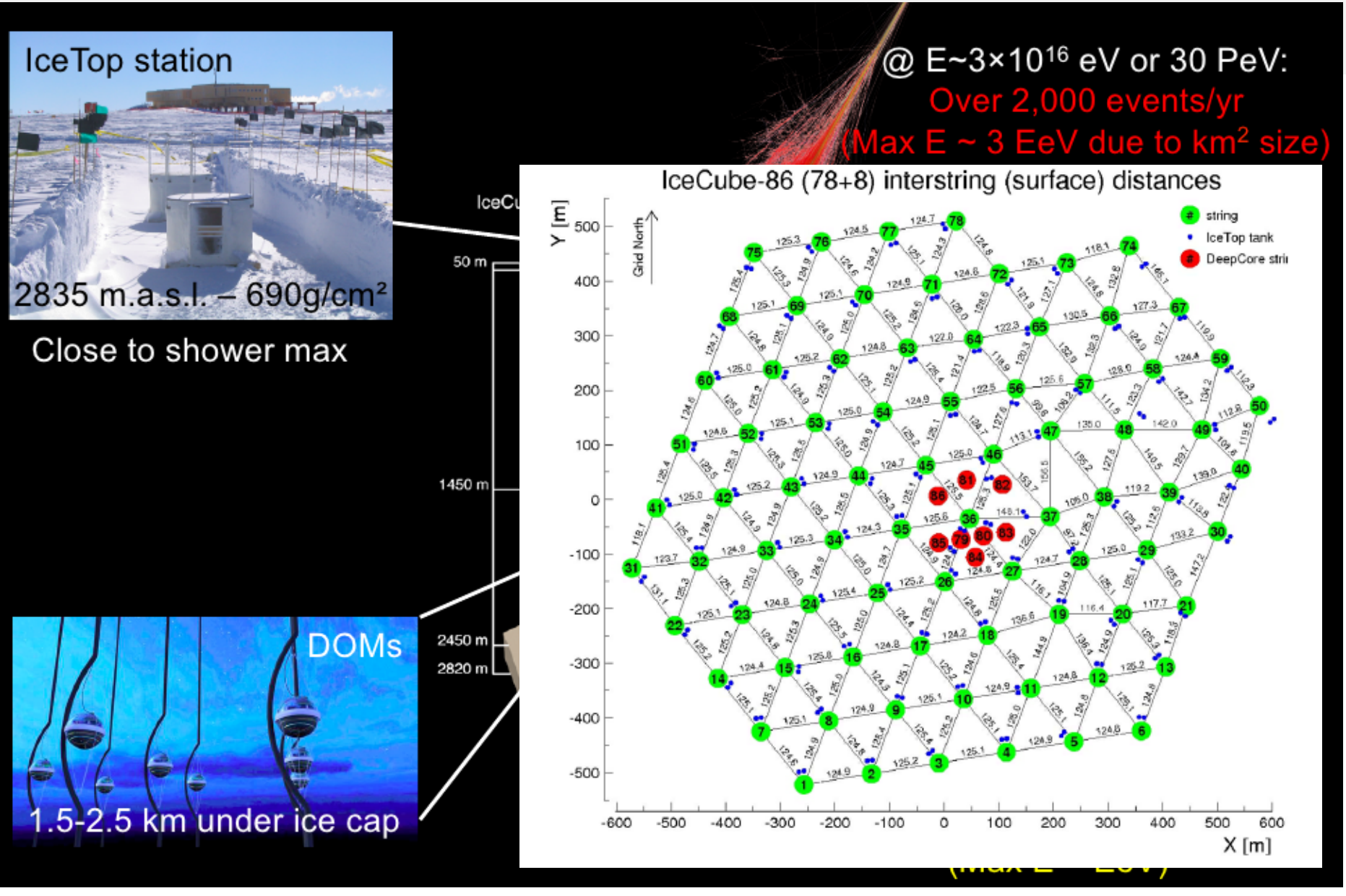
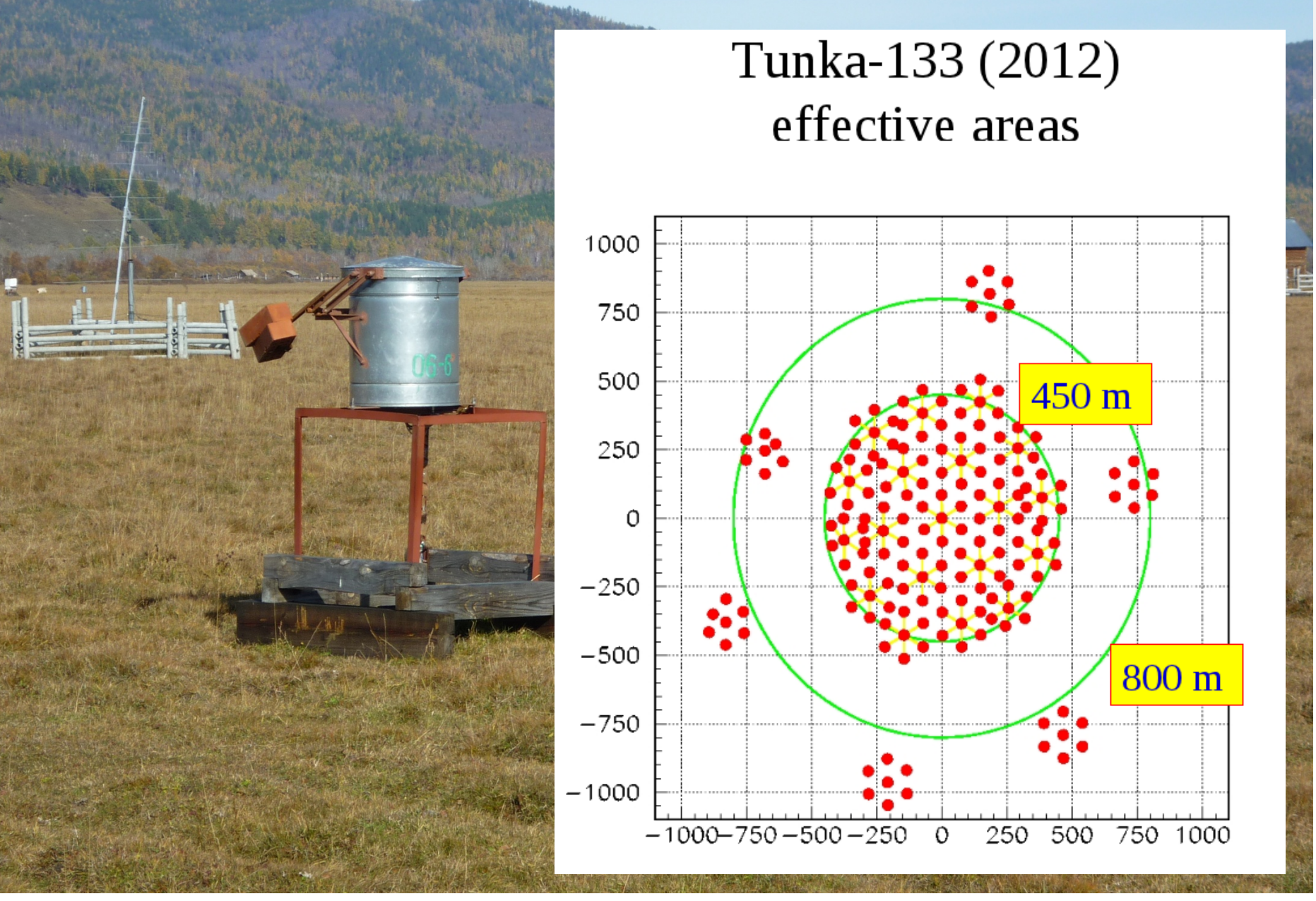


- talks by A. Tamburro, P. Desiati
- size $\sim 1 \times 1$ km



- talks by A. Tamburro, P. Desiati
- size $\sim 1 \times 1$ km

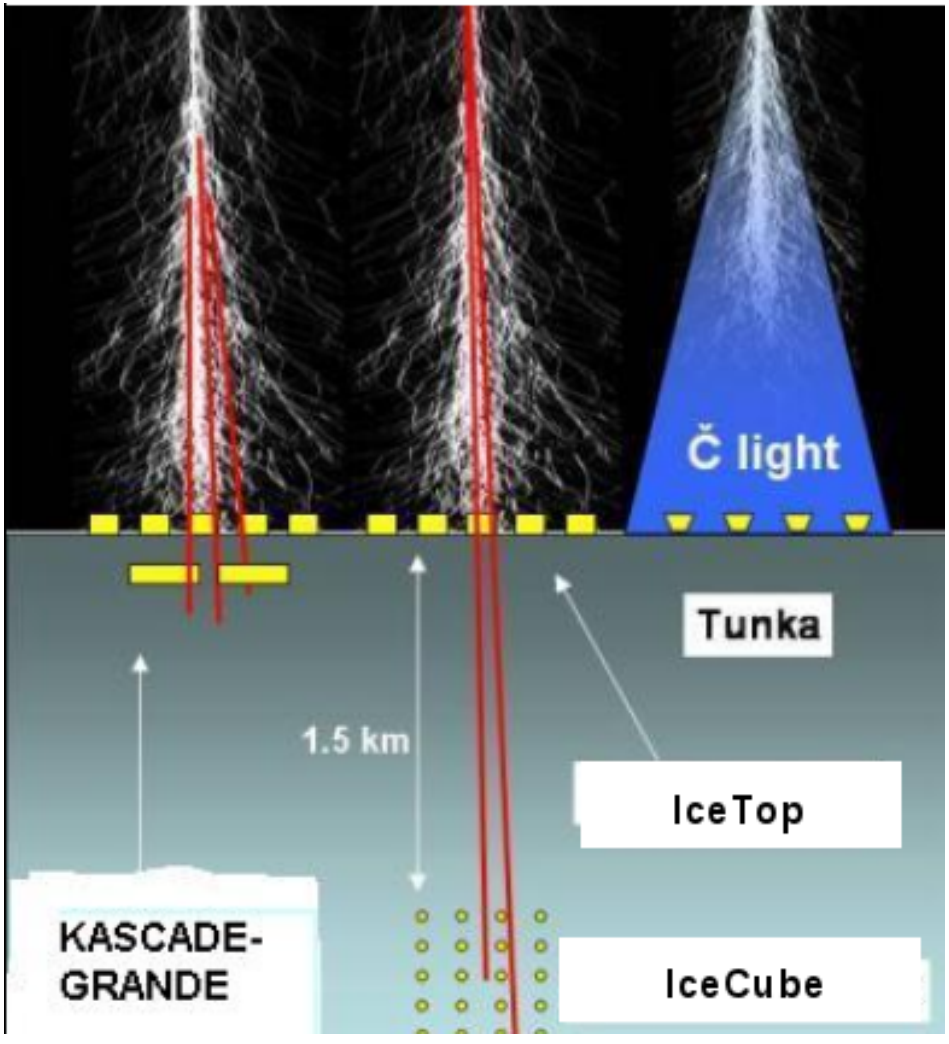
- talks by V. Prosin, D. Kostunin
- size $\sim 1.5 \times 1.5$ km



- talks by V. Prosin, D. Kostunin
- size $\sim 1.5 \times 1.5$ km

Important: different detection methods

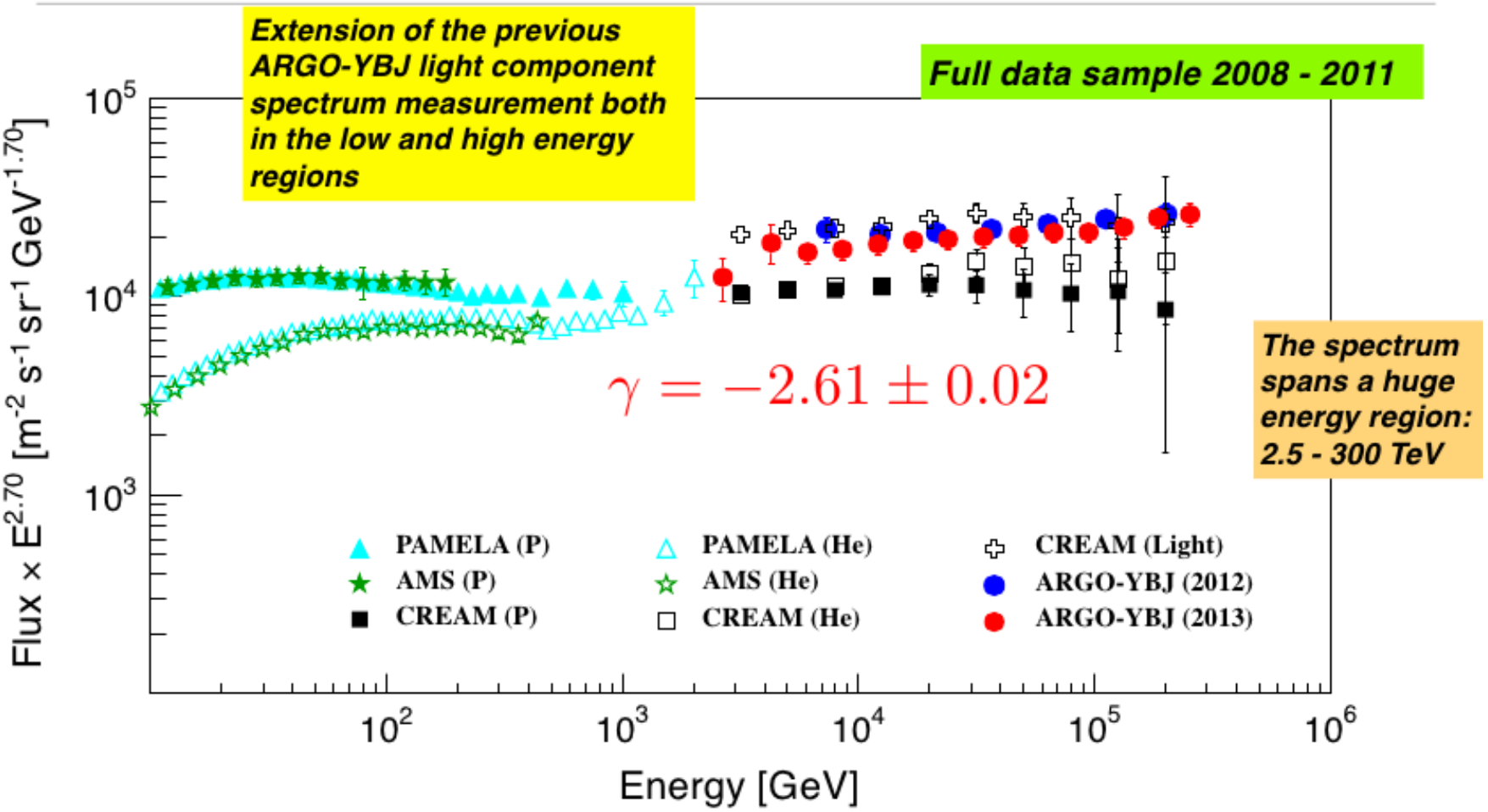
- scintillators
- muon detectors
- Cherenkov detectors



SPECTRUM (LOW ENERGIES)

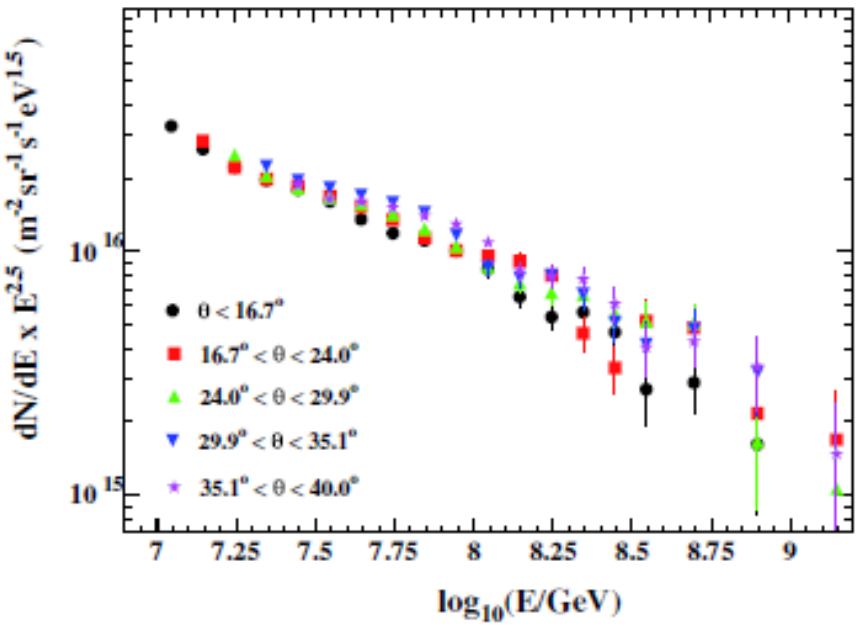
ARGO-YBJ

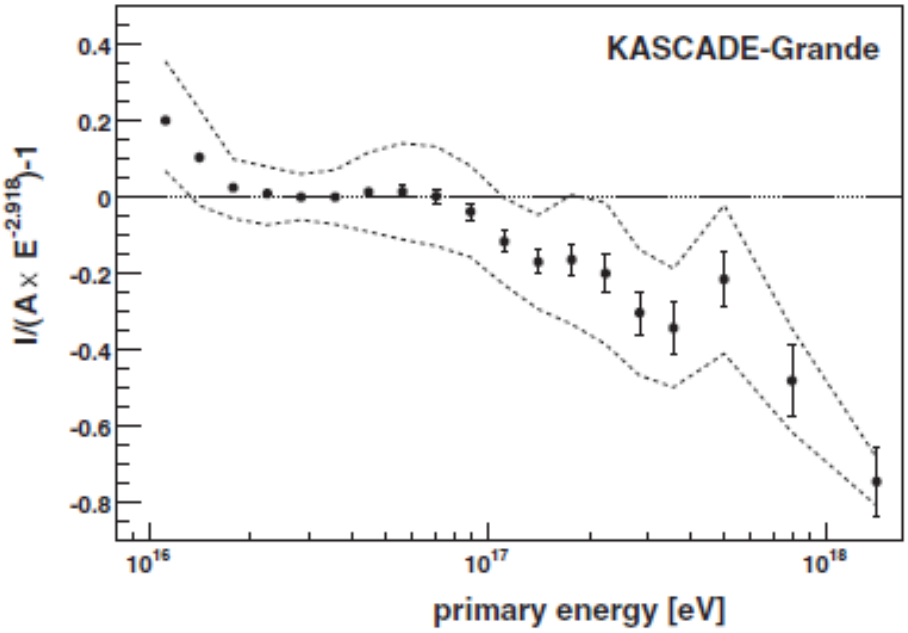
The light component spectrum

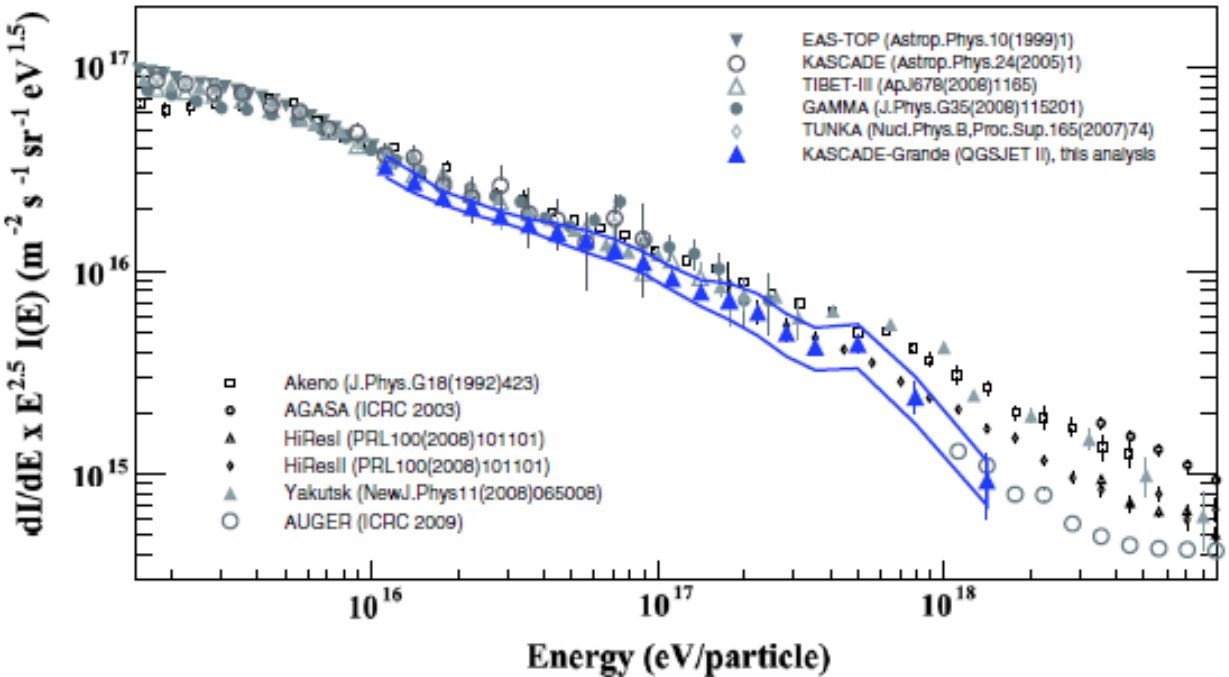


talks by De Mitri, Montini

KASCADE-Grande

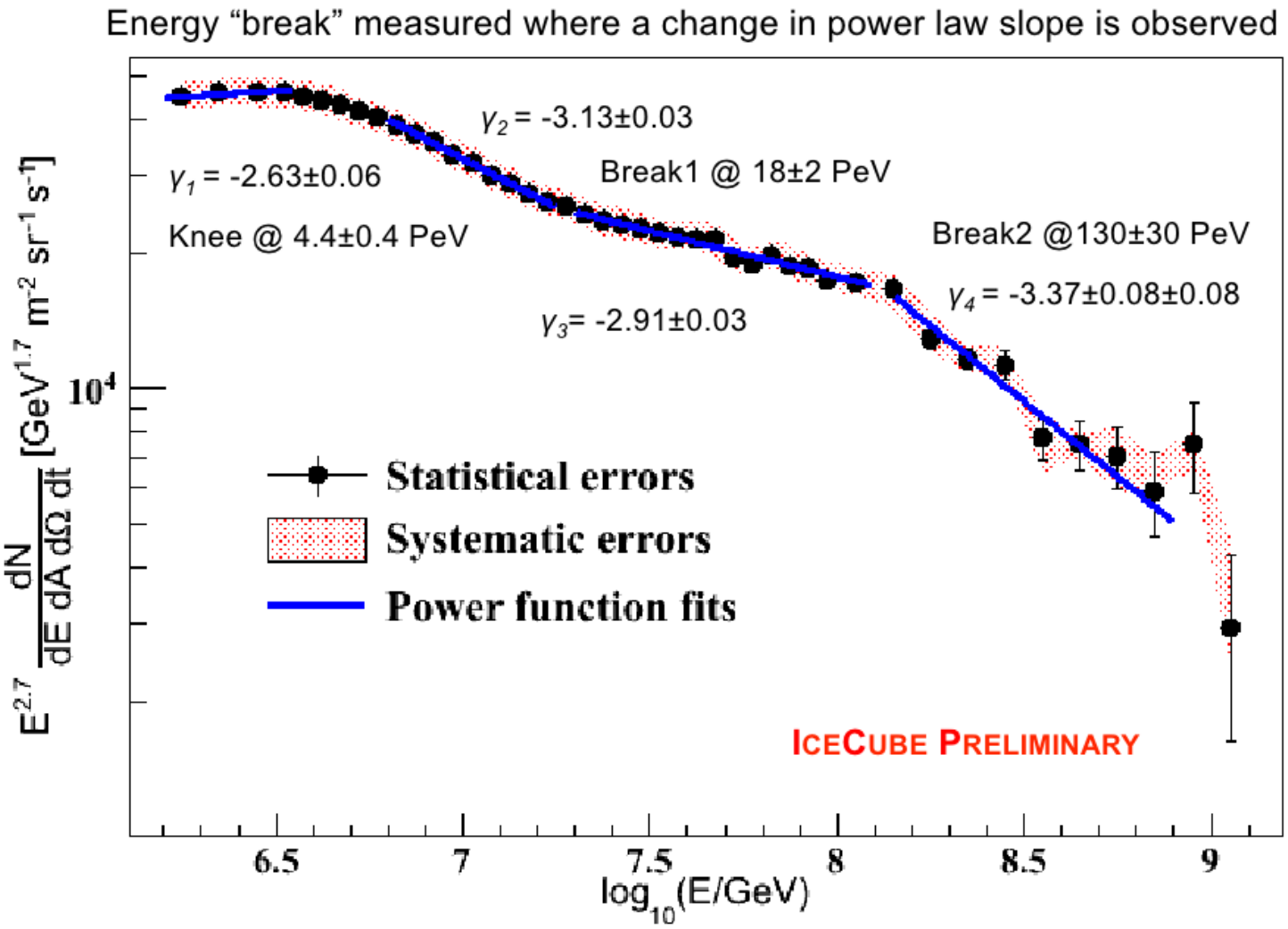






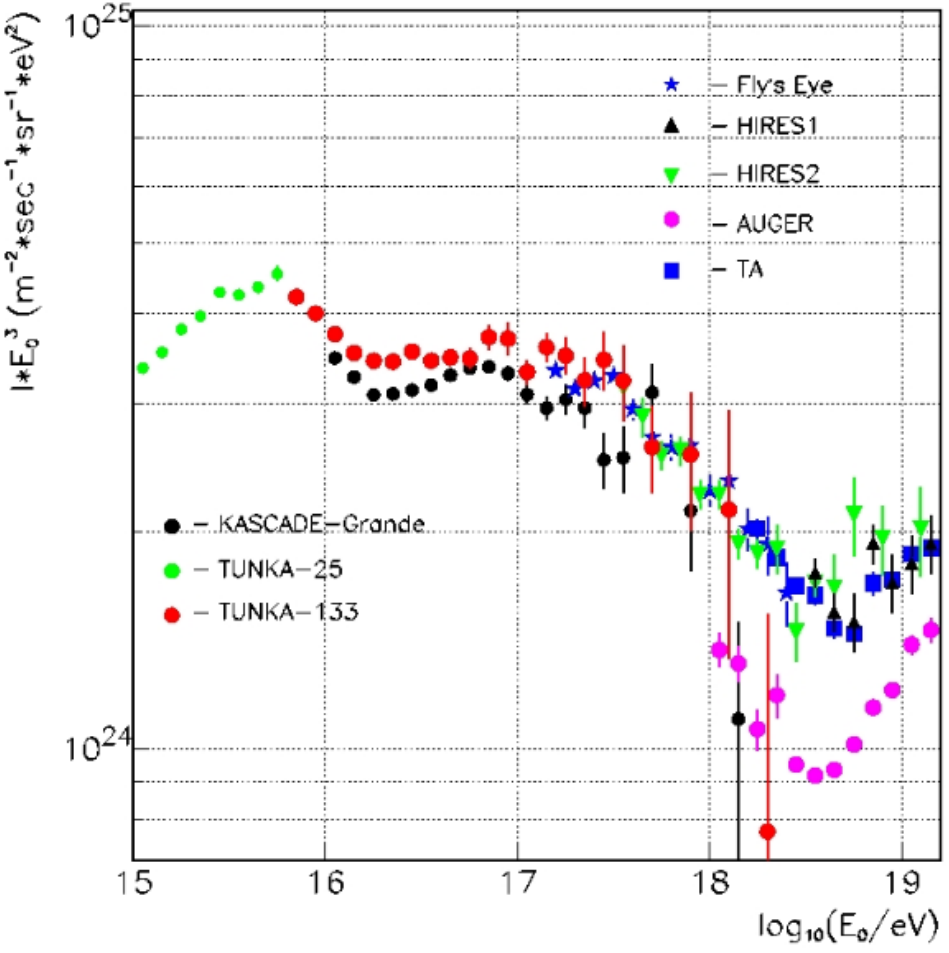
talk by Chiavassa

IceTop



talk by Tamburro

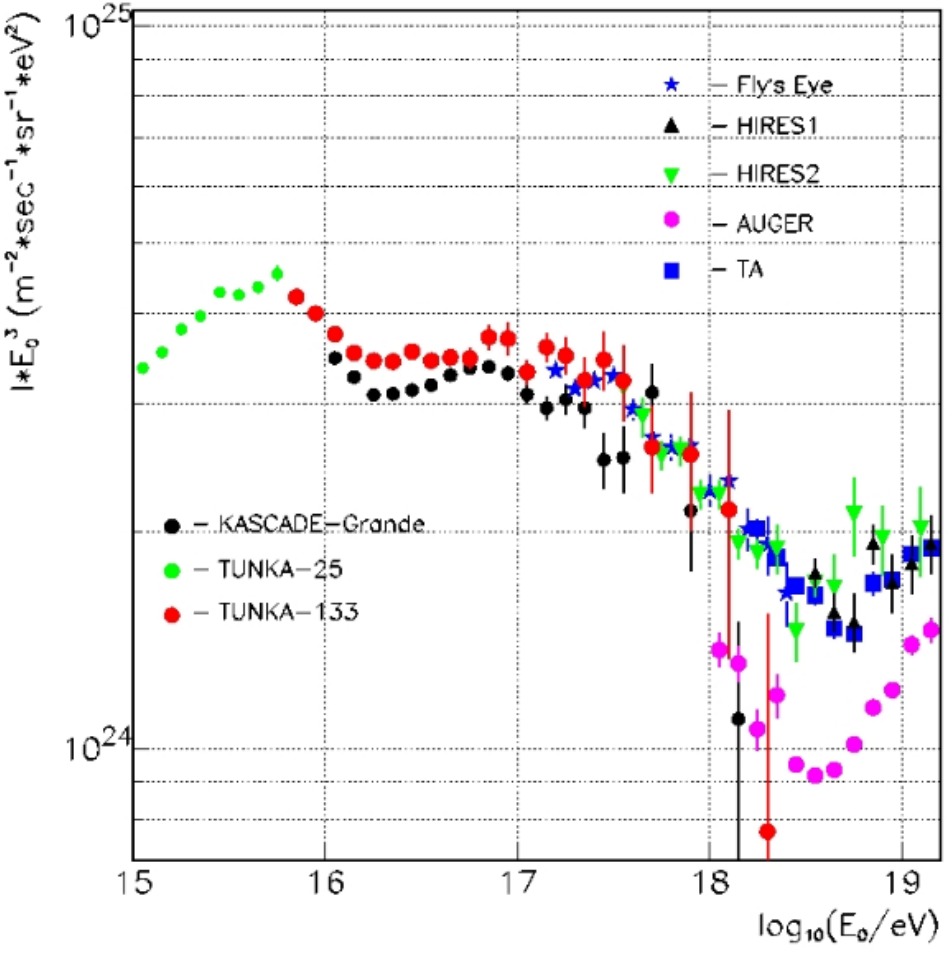
Tunka

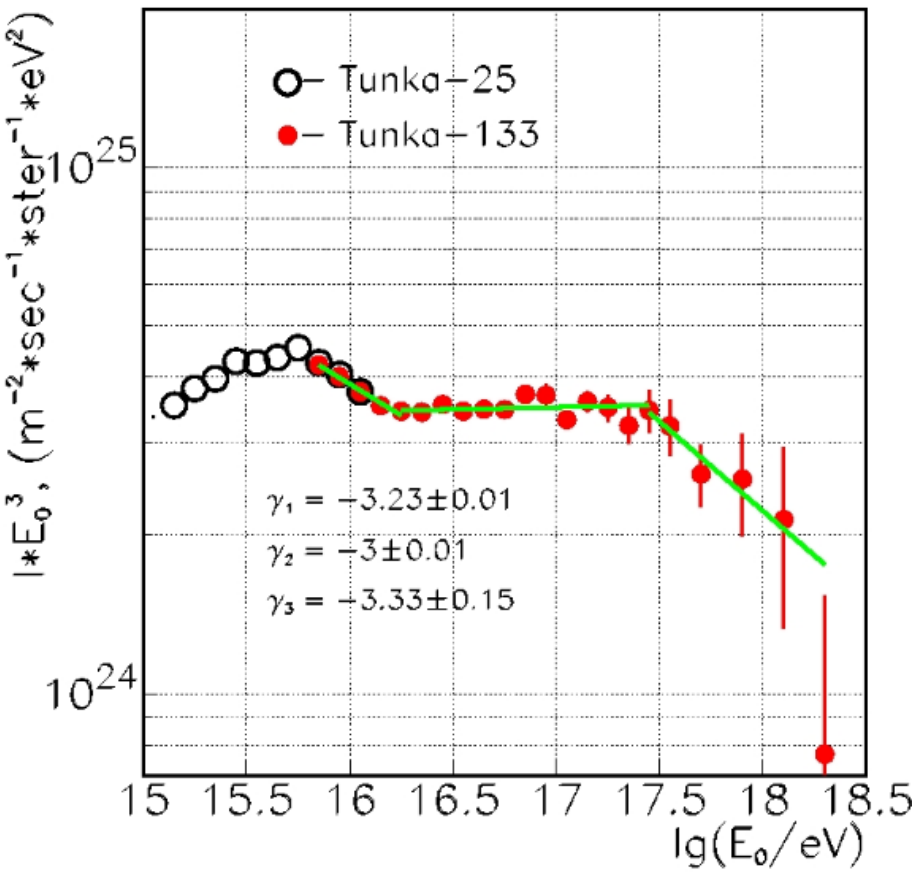


1. Agreement with KASCADE-Grande
2. Agreement with old Fly's Eye, HiRes and TA spectra.

talk by Prosin

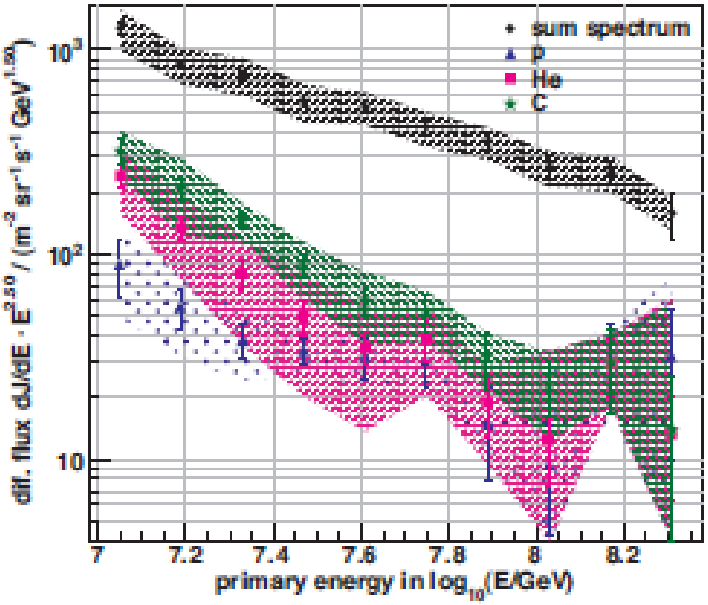
Tunka

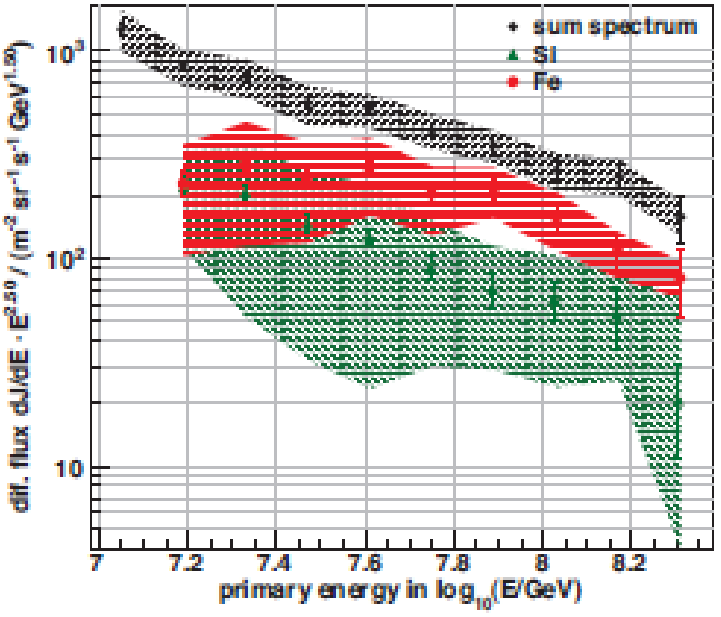


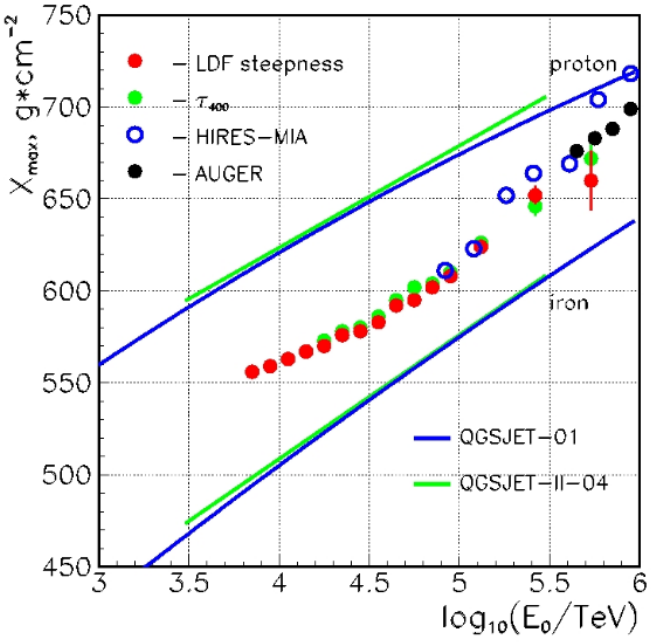


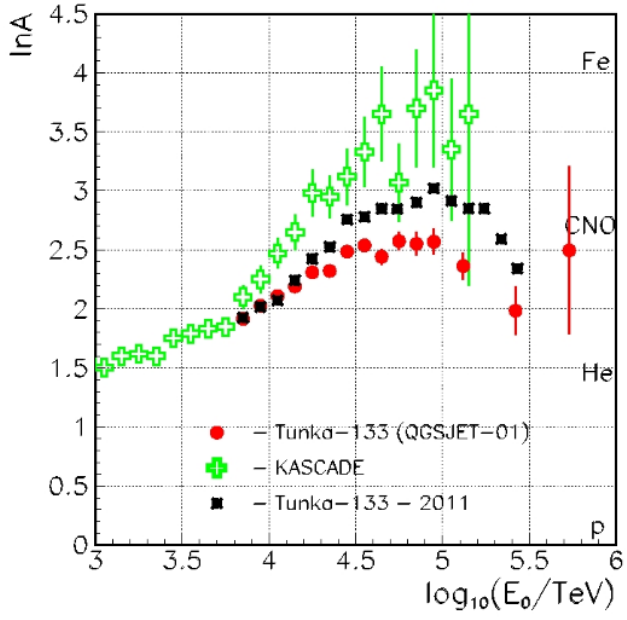
talk by Prosin

COMPOSITION (LOW ENERGIES)


sum spectrum
p
He
C
diff. flux dJ/dE · E^2.50 / (m^-2 sr^-1 s^-1 GeV^1.50)
primary energy in log10(E/GeV)


sum spectrum
Si
Fe
diff. flux dJ/dE · E^2.50 / (m^-2 sr^-1 s^-1 GeV^1.50)
primary energy in log10(E/GeV)


LDF steepness
τ400
HIRES–MIA
AUGER
proton
iron
QGSJET–01
QGSJET–II–04
Xmax, g*cm^-2
log10(E0/TeV)


lnA
Fe
CNO
He
p
Tunka–133 (QGSJET–01)
KASCADE
Tunka–133 – 2011
log10(E0/TeV)

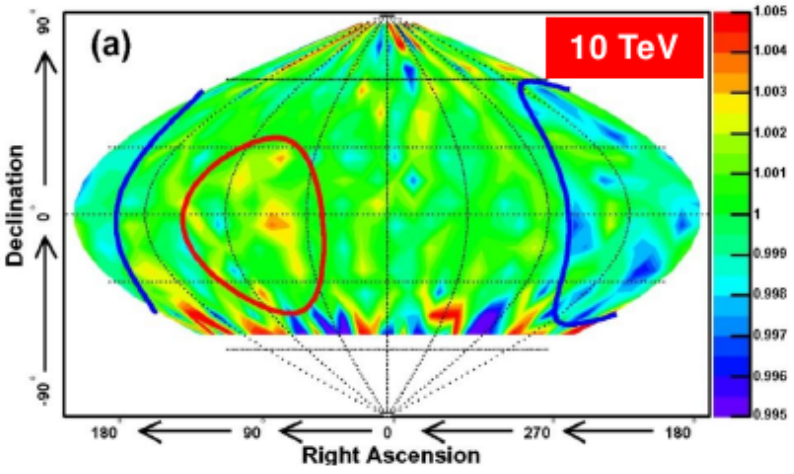
COMPOSITION FROM ICETOP:

WAITING FOR ICRC

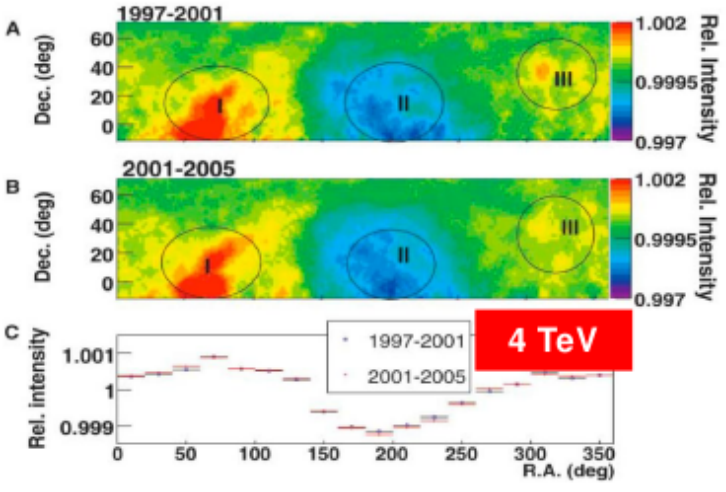
ANISOTROPY (LOW ENERGIES)

Large-angle anisotropy observed at the permil level

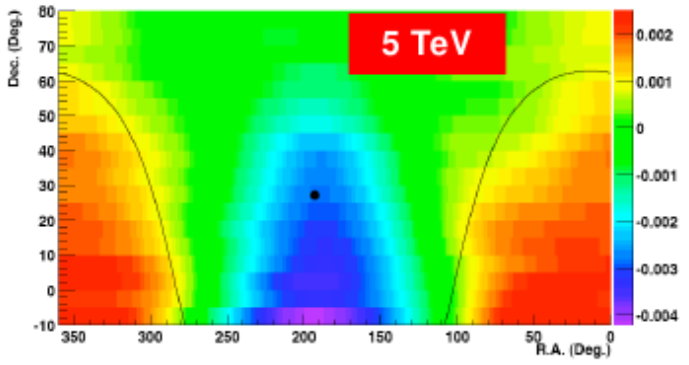
Recent observations of the CR anisotropy



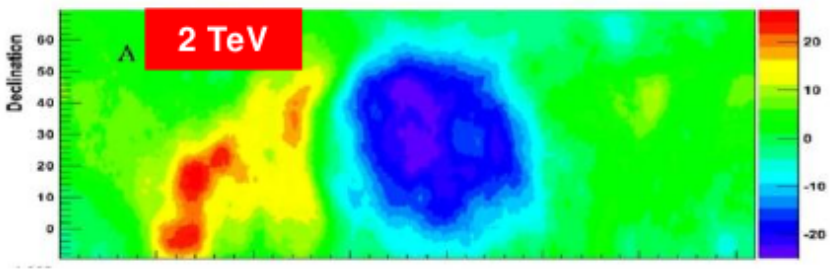
Super-Kamiokande – ICRC 2007 Proceedings



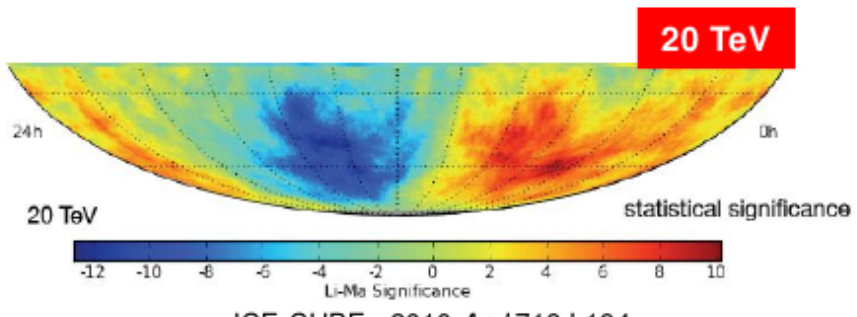
Tibet AS-γ - *Science* 20 October *2006*:
Vol. 314 no. 5798 pp. 439-443



MILAGRO - 2009 *ApJ* **698** 2121



ARGO-YBJ– ICRC 2011 Proceedings

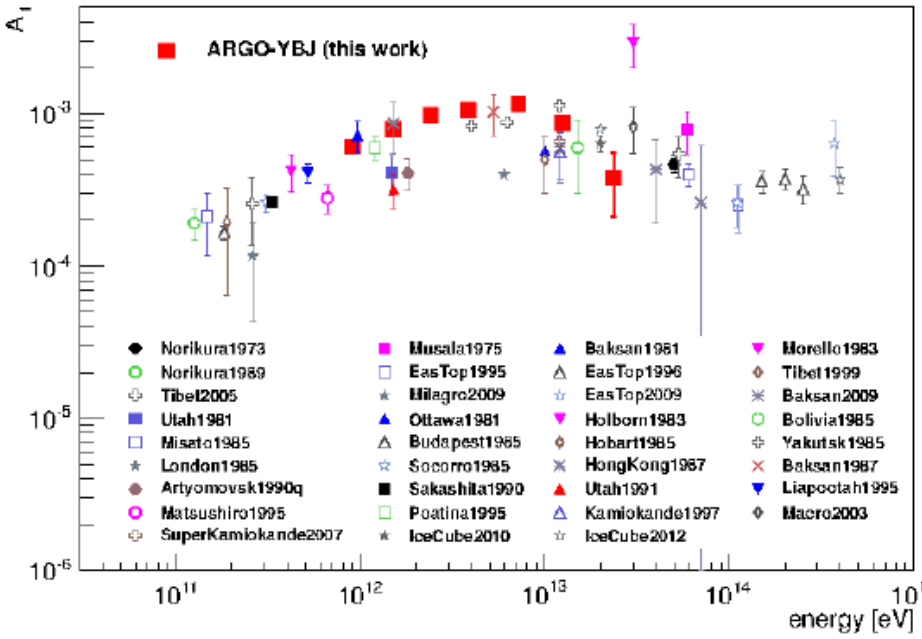


ICE-CUBE - 2010 *ApJ* 718 L194

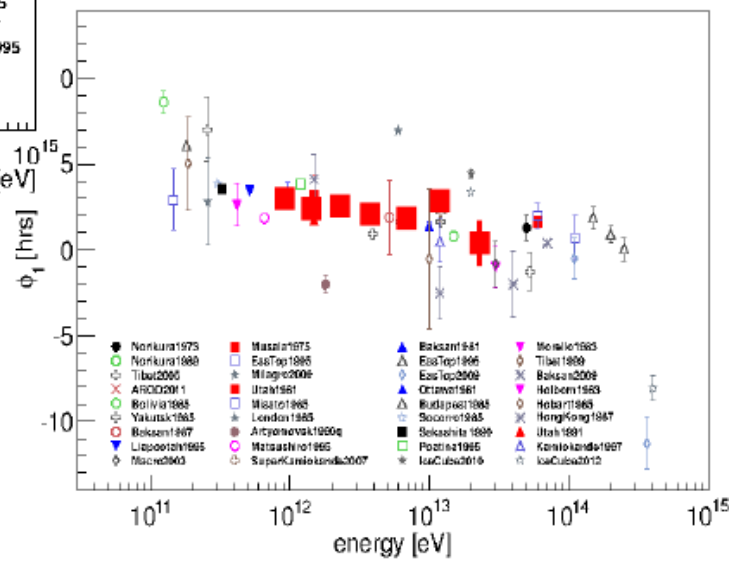
talk by Iuppa

Harmonic analysis

LSA First harmonic amplitude and phase



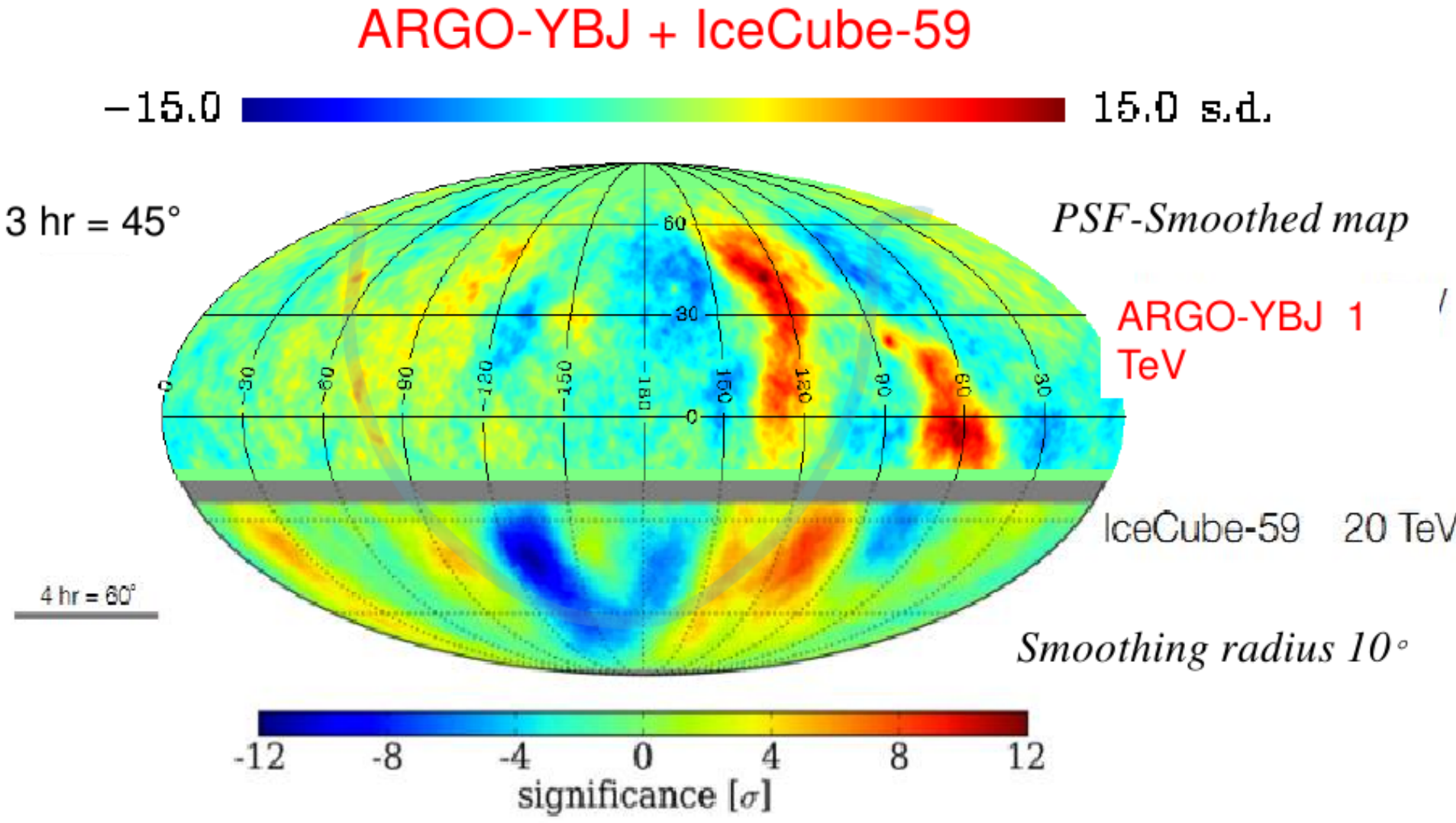
Measurement covering either the rise and the fall of the signal



Uniform phase decrease

talk by De Mitri

Need full sky coverage:



talk by Iuppa

Low-energy summary

- SPECTRUM:
  - not a simple power law — several features beyond the knee. Hardening $\sim 10^{16}$ eV; steepening $\sim 8 \times 10^{16}$ eV
  - different features for different components
  - explanation: cut-off in acceleration spectrum? local propagation effects?
- COMPOSITION:
  - difficult measurement; no full agreement between experiments
  - common trend: change from lighter to heavier at energies $10^{15} - 10^{17}$ eV
- ANISOTROPY:
  - observed at the permil level
  - low multipoles: local sources + diffusion?
  - medium-scale anisotropy: not inexplicable, but *unexplained*

[see talks by Iuppa and M Ageles Perez Garcia]

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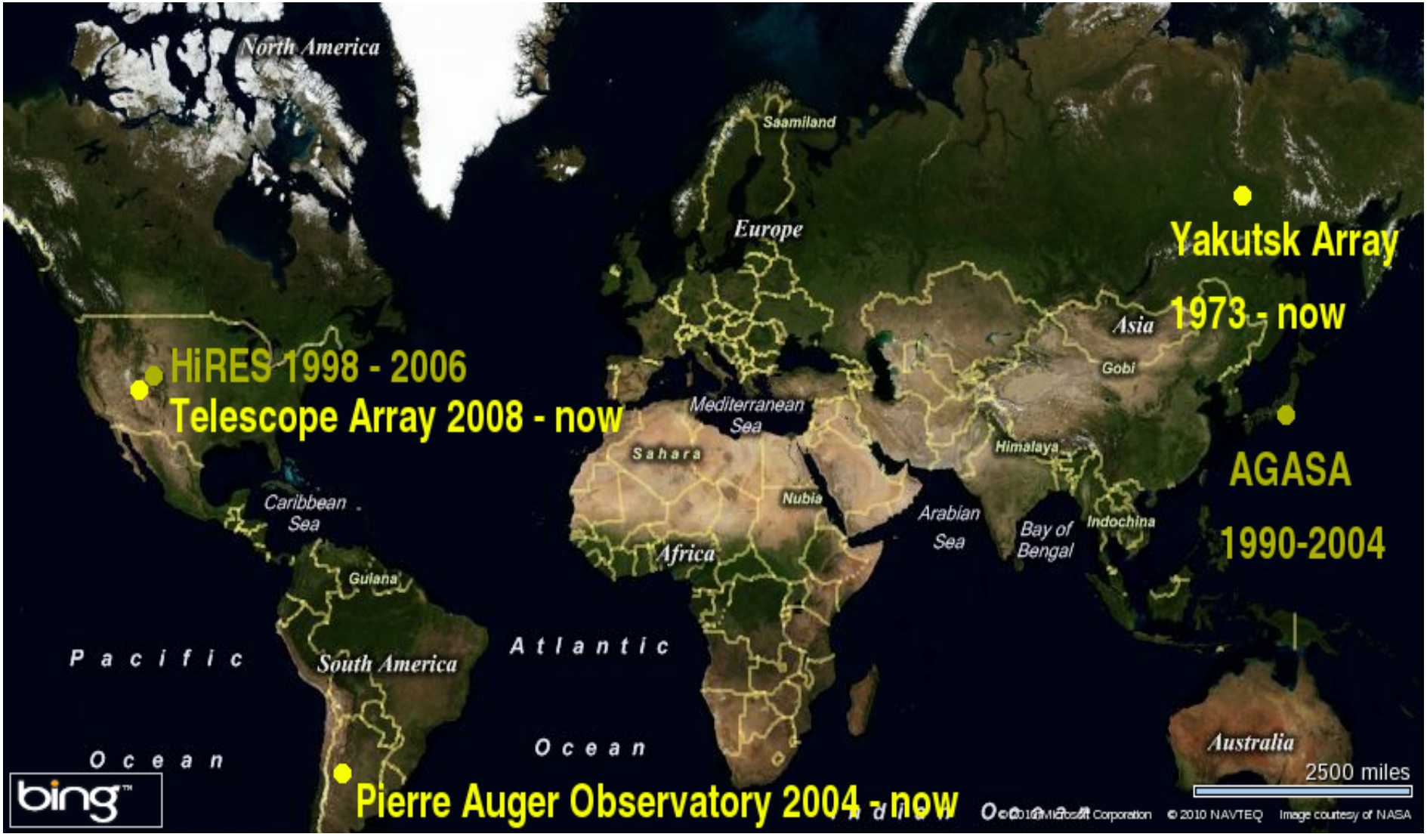
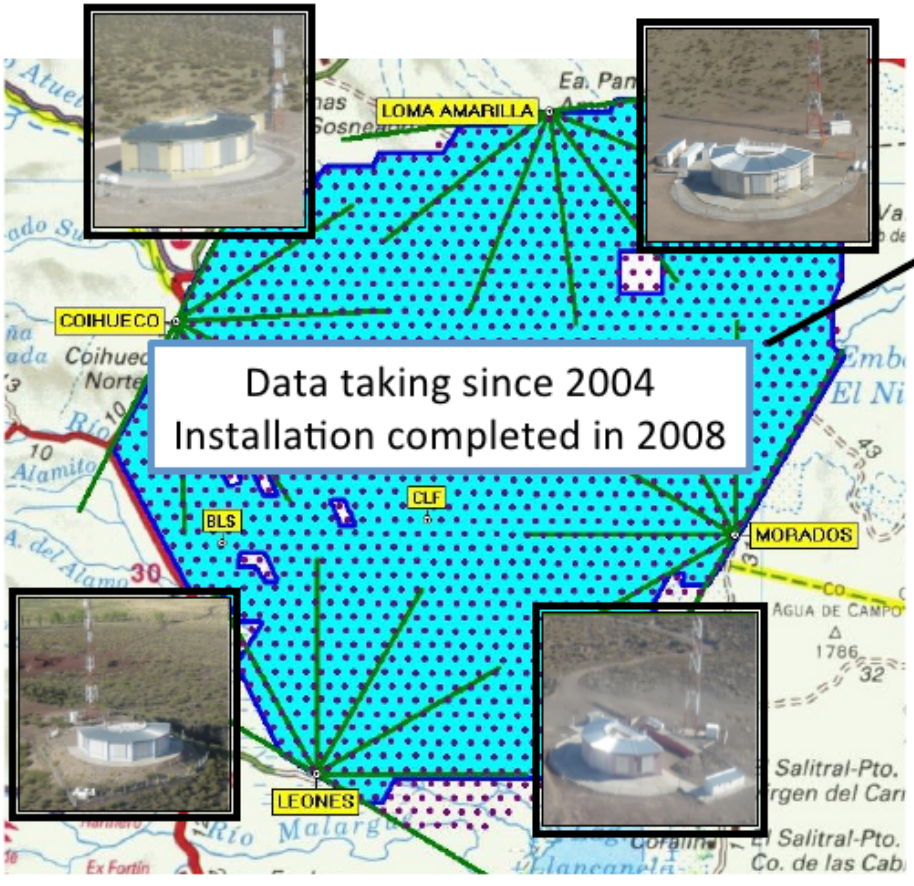
[see talks by Iuppa and M Ageles Perez Garcia]

HIGH ENERGIES

Modern UHECR experiments

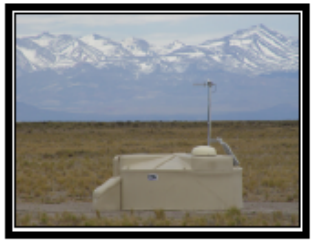


The Pierre Auger Experiment



~ 60 km

- 4 Fluorescence Detectors (FD)
- 6 x 4 Fluorescence Telescopes



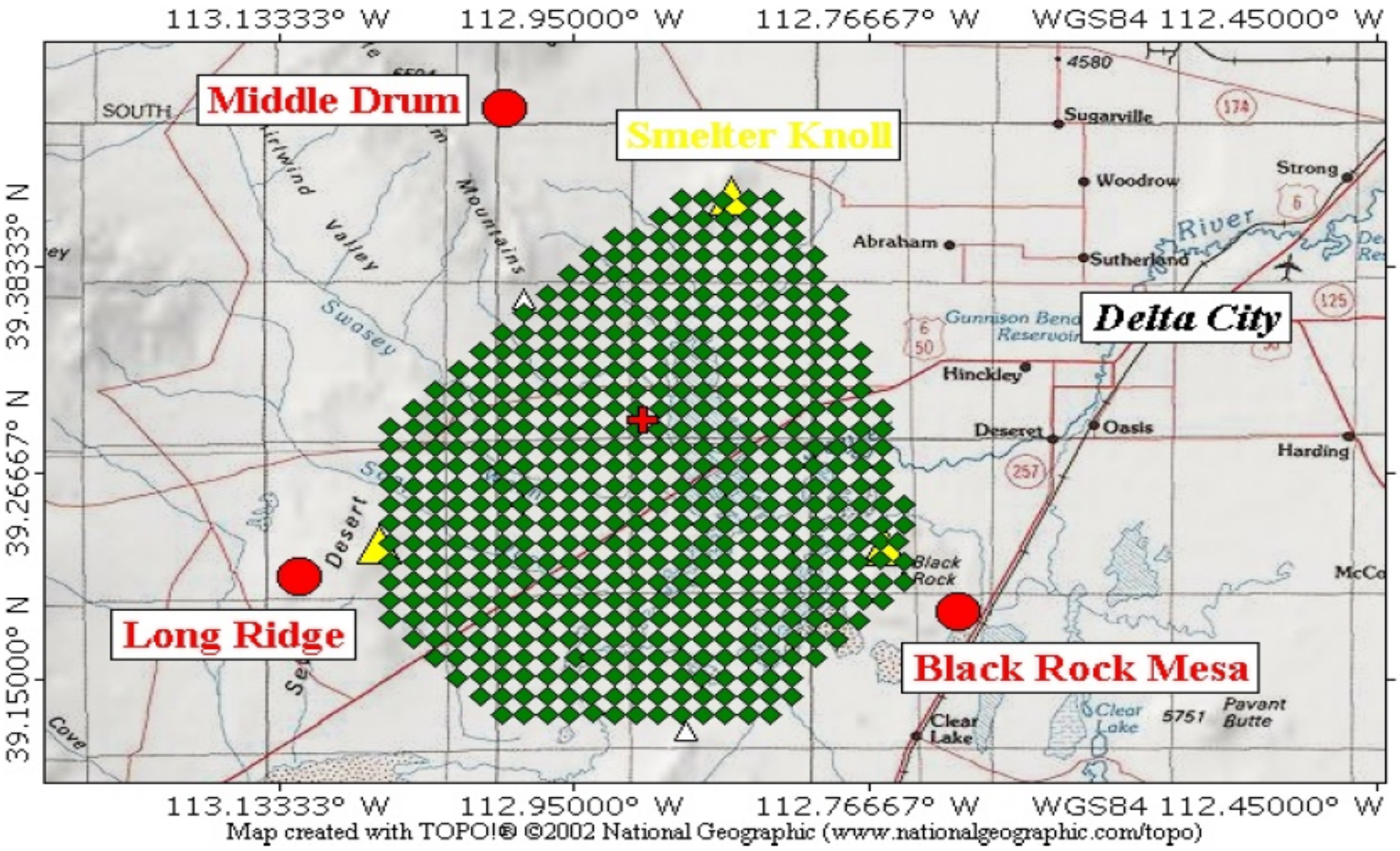
- ~ 1600 Surface Detector (SD) Stations
- 1.5 km spacing
- 3000 km^2

Low energy extension

- Aim to E ≈ 10^{17} eV
- AMIGA
  - Denser array plus muon detectors
- HEAT
  - 3 additional FD telescopes with a high elevation FoV

- talks by D. Martello, D. Boncioli, G. Rodrigues Fernandez

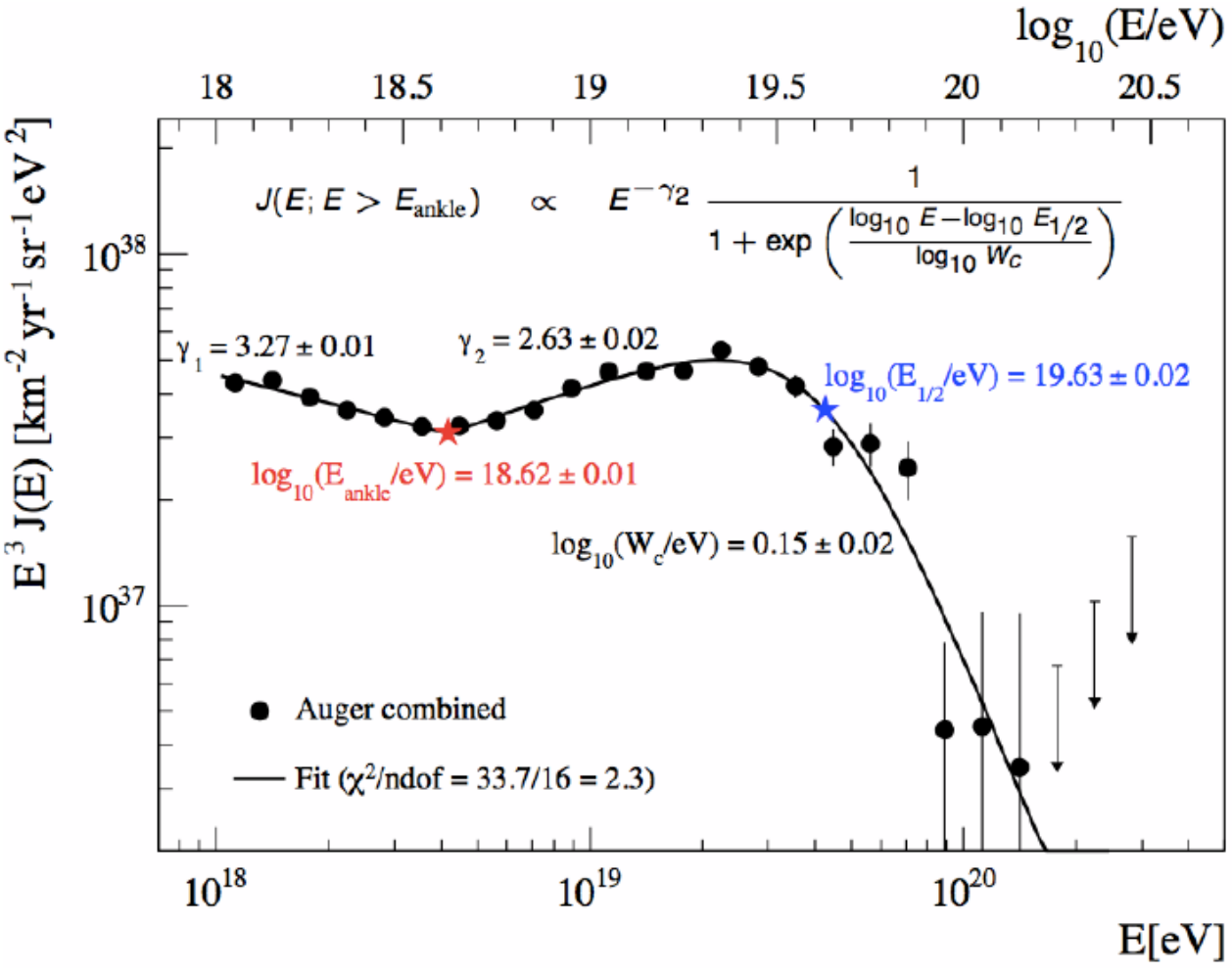
TELESCOPE ARRAY DETECTOR



- 507 scintillator detectors covering 680 km^2
- 3 fluorescence sites, 38 telescopes
- SD relative size: TA $\sim 9 \times$ AGASA $\sim$ PAO/4

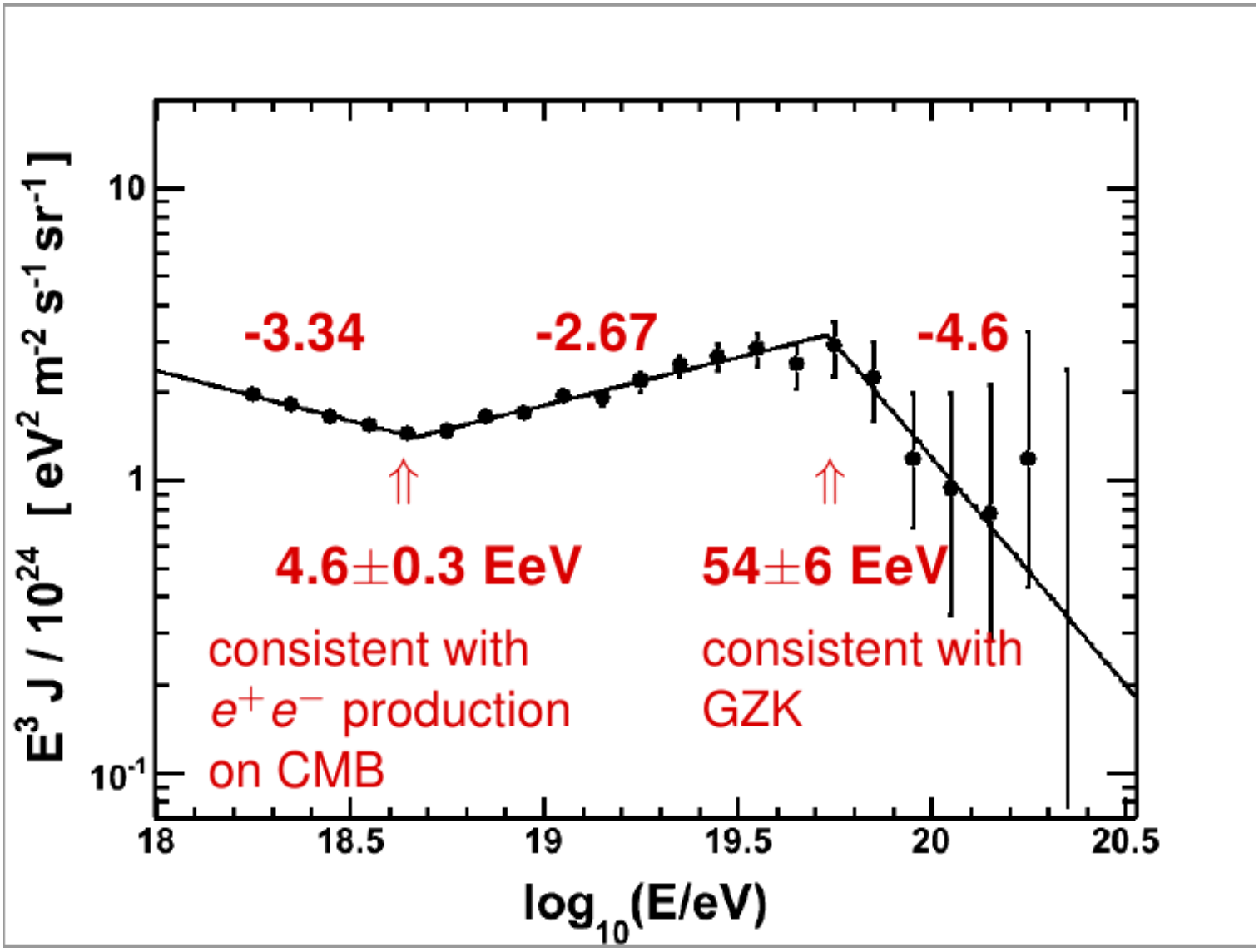
SPECTRUM (HIGH ENERGIES)

Combined Auger Spectrum (FD+SD)



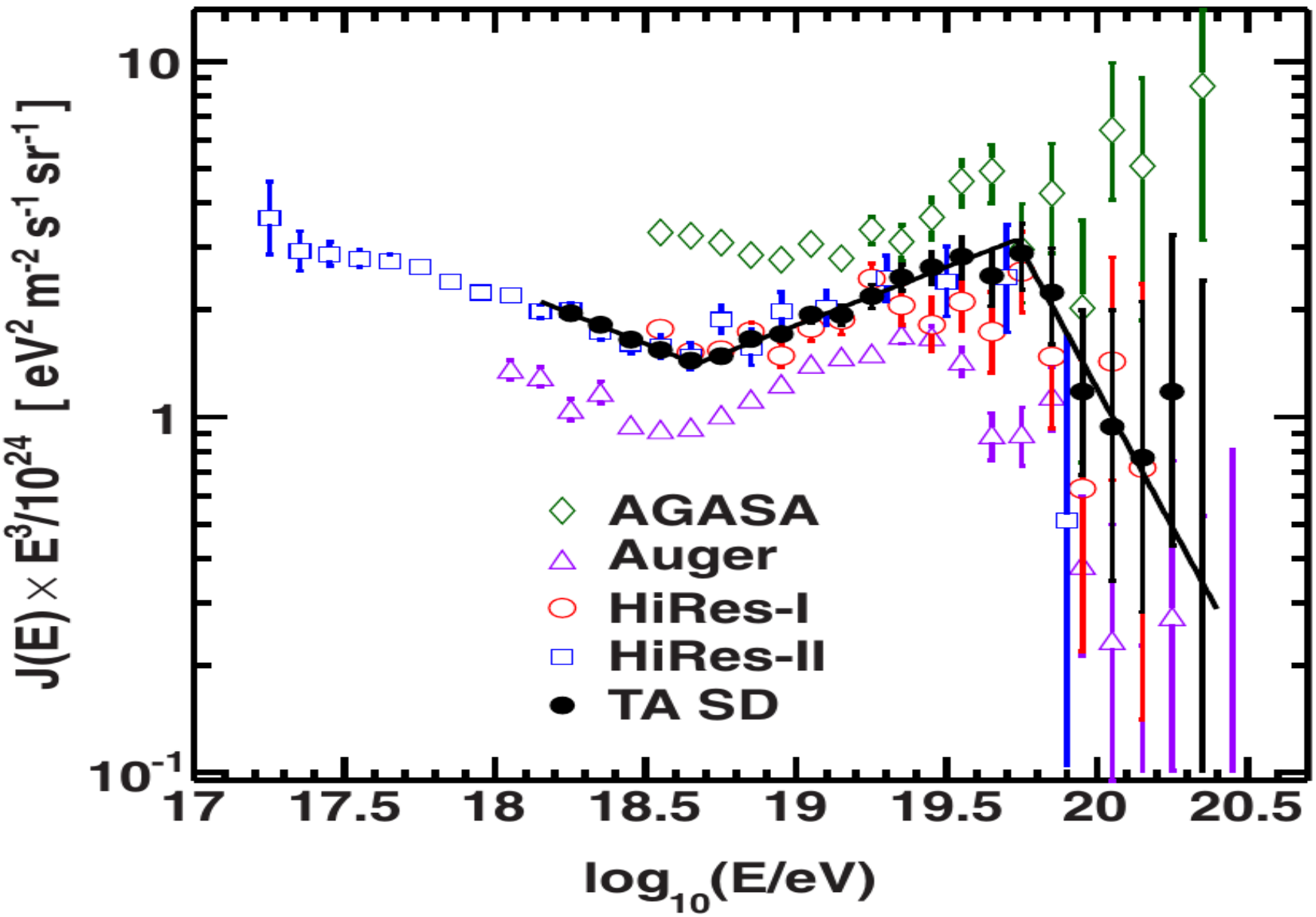
[talk by Rodrigues Fernandez]

TA SD spectrum

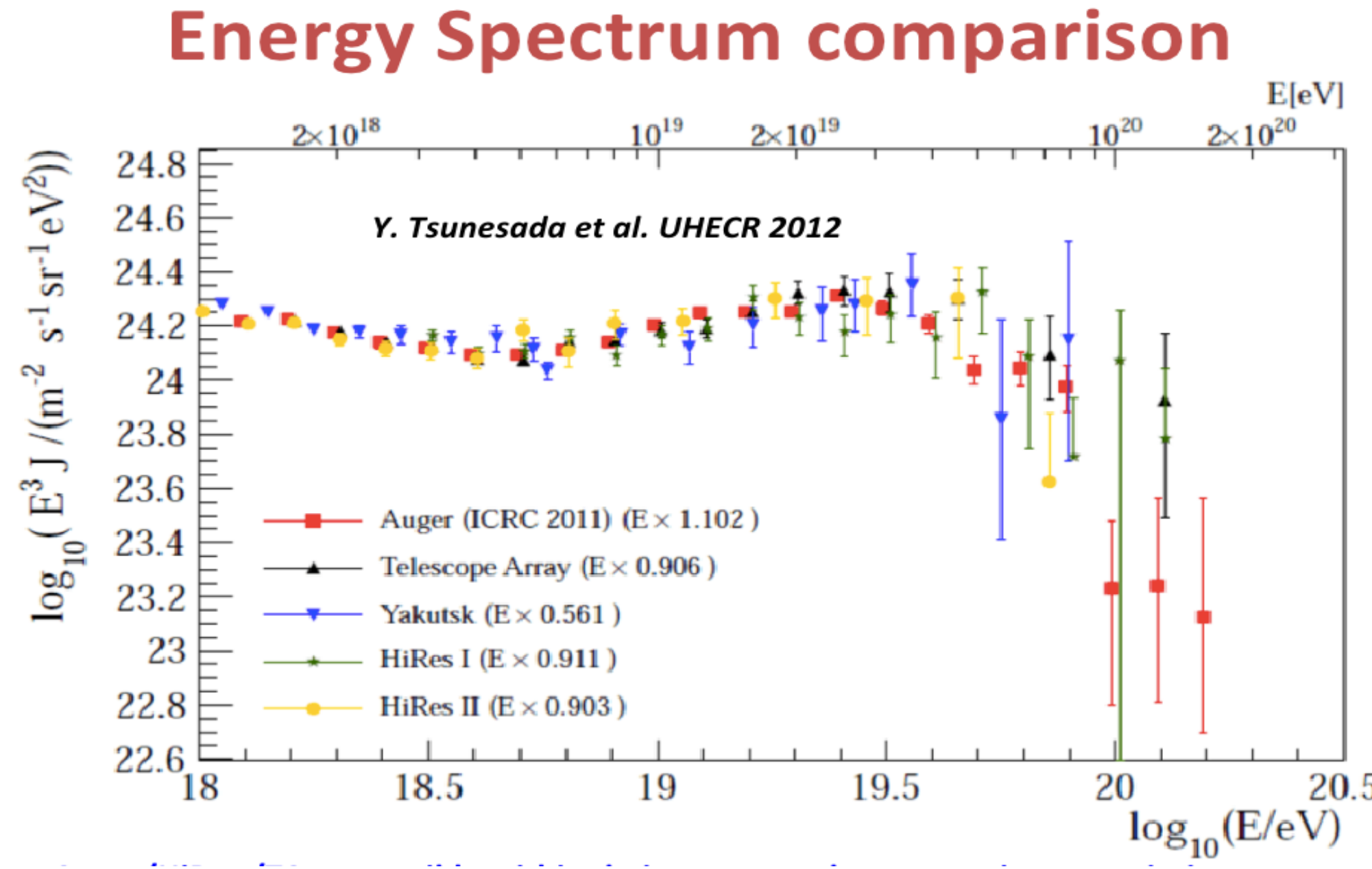


[talk by Tinyakov]

Comparison of different experiments

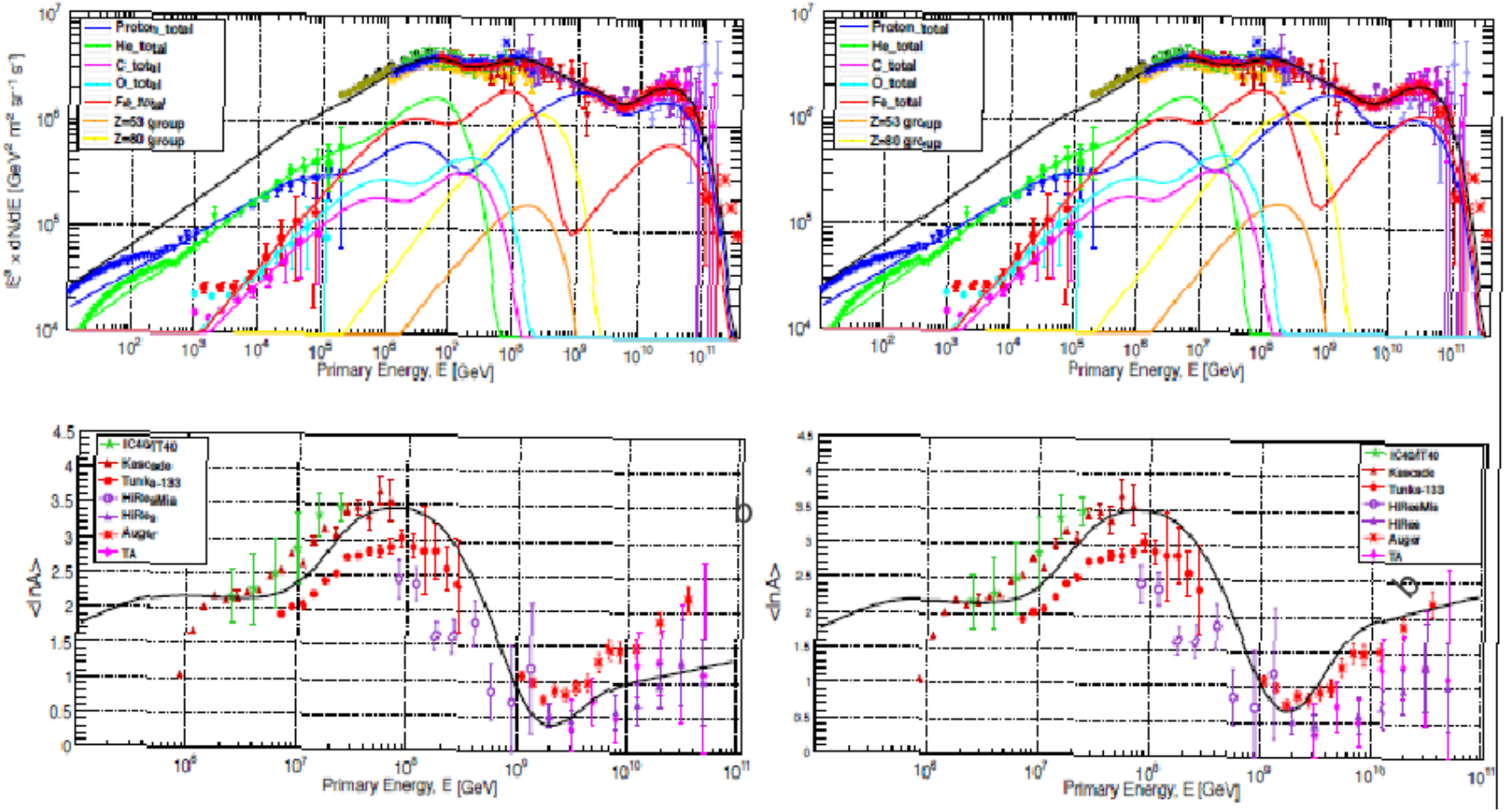


Auger-TA WG result



Do these spectra fit anything?

— Yes, they both can be fitted!

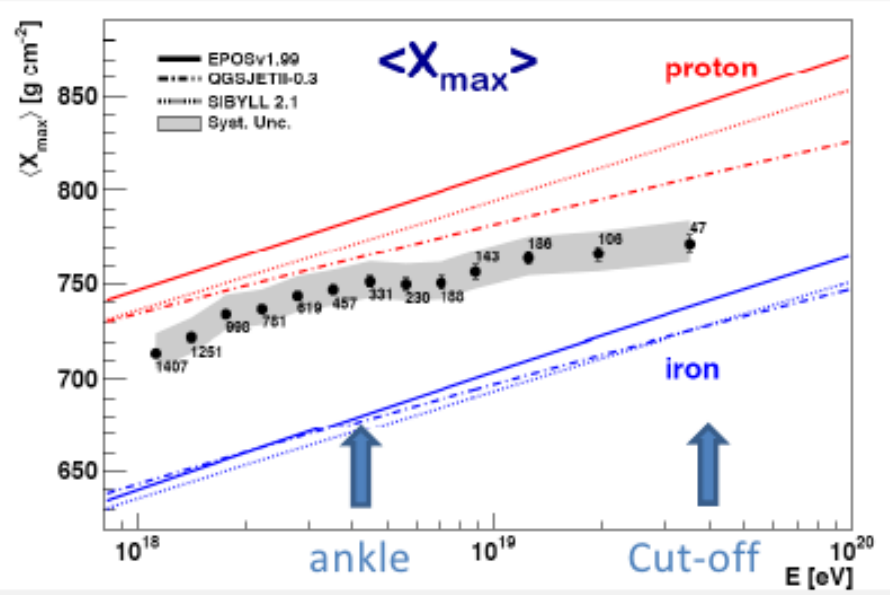


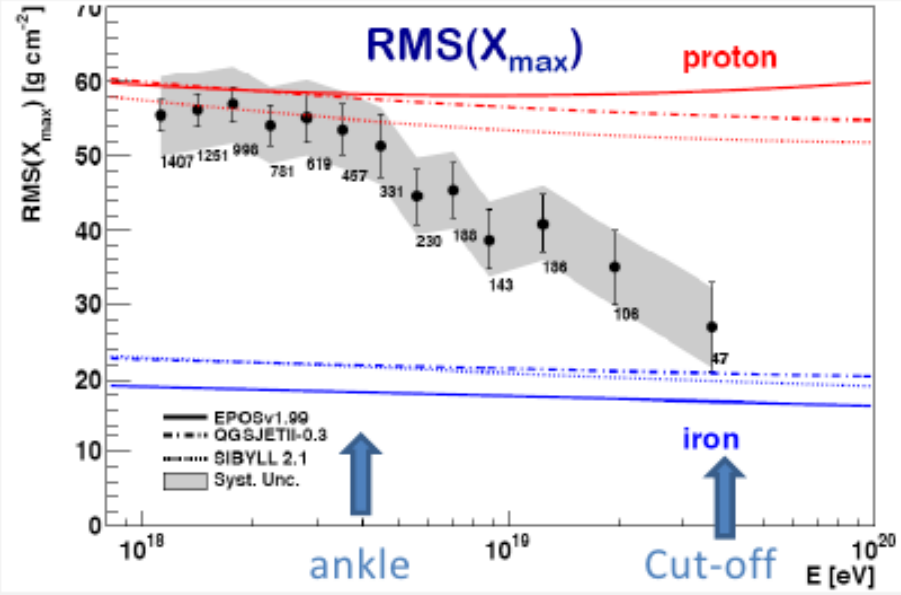
[see talk by Stanev]

[see talk by Batista for propagation effects]

COMPOSITION (HIGH ENERGIES)

Auger composition



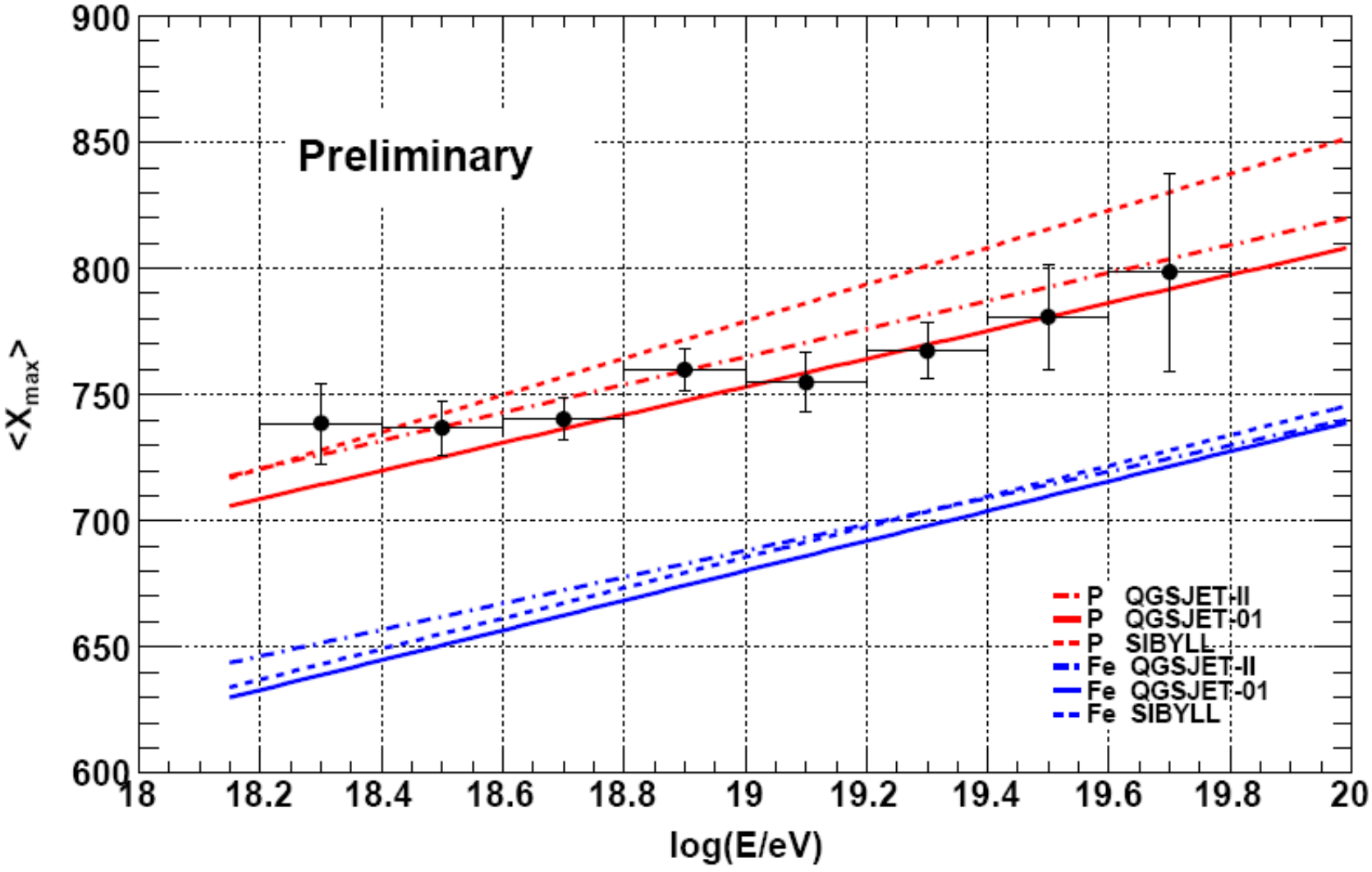


Syst uncertainty < 13 g cm^{-2}
X_{max} resolution ~ 20 g cm^{-2}

$<X_{max}>$ became lower with energy

X_{max} distributions become narrower with energy

TA composition



ANISOTROPY (HIGH ENERGIES)

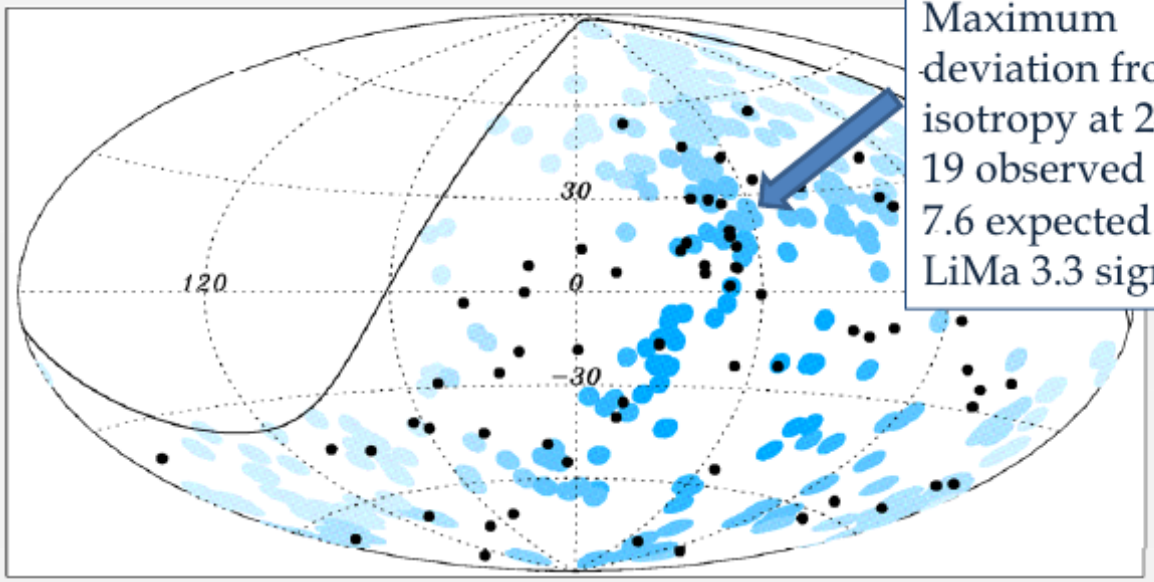
Auger: anisotropy at highest energies

Anisotropy

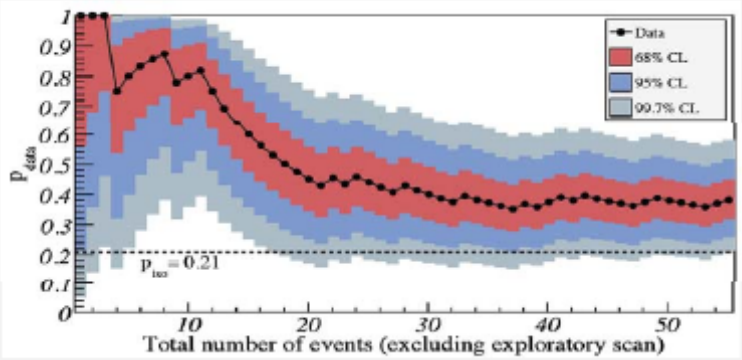
Astropart. Phys. 34 (2010) 314

The 69 events with Energy > 55 EeV detected by the Pierre Auger Observatory

Blue circles of radius 3.1° centered at the positions of the 318 AGNs < 75 Mpc in the VCV catalog.



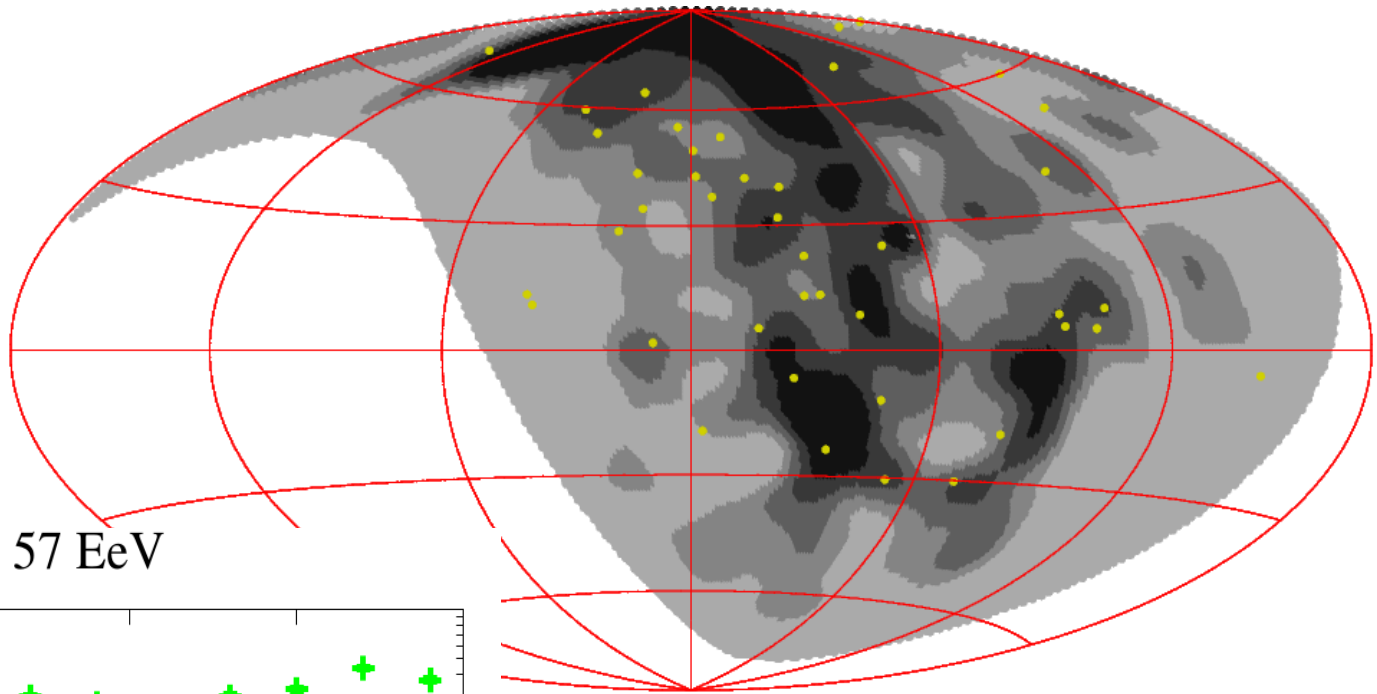
CenA:
Maximum deviation from isotropy at 24°
19 observed vs 7.6 expected
LiMa 3.3 sigma

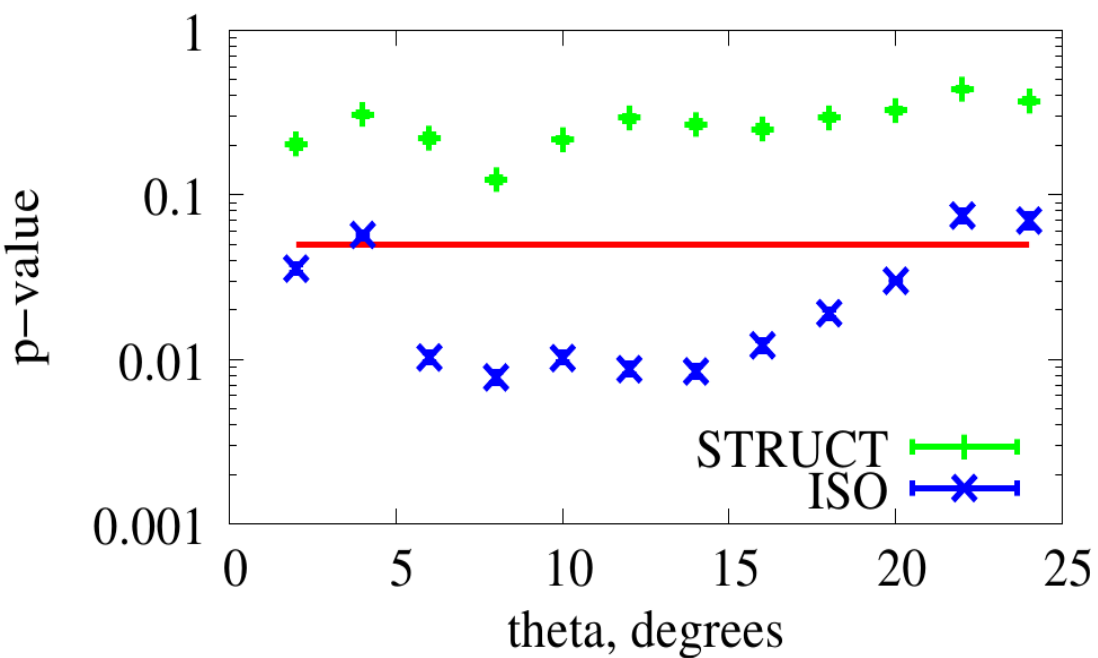


The exposure weighted fraction of the sky covered by the blue circles is 21%.
Chance probability for a isotropic source distribution < 1%

TA results can not exclude this conclusions

TA: anisotropy at highest energies





High-energy summary

- SPECTRUM:
  - Spectra roughly agree up to an overall shift $\sim 20\%$
  - Interpretation depends on the absolute energy scale: GZK cutoff or cutoff in the sources? e^+e^- on CMB or Galactic-extragalactic transition?
  - Why SD and FD energies differ?
- COMPOSITION:
  - key question for the future of the field
  - disagreement between Auger and TA
  - Auger-TA WG is looking into this issue
  - related to muon puzzle? *[see talk by Petrukhin]*
  - can light nuclei solve all problems? *[see talk by Fargion]*
- ANISOTROPY:
  - no significant anisotropies found
  - hints in Auger and TA at high energies: are we finally starting to see deviations from isotropy?
  - common Auger + TA harmonic analysis is on the way

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- Upgrades & extensions
  - LHASSO, LAWCA *[see talk by Cao Zhen]*
  - Tunka-Rex *[see talk by D.Kostunin]*
  - Low-energy extensions in Auger and TA
- New detection techniques
  - AERA *[see talk by J.Maller]*
  - CODALEMA *[see talk by I.Martin]*
  - LOFAR *[see talk by S.Thoudam]*
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  - go to space? (JEM-EUSO) *[see talk by P.Picozza]*
  - build large ground detector?

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