

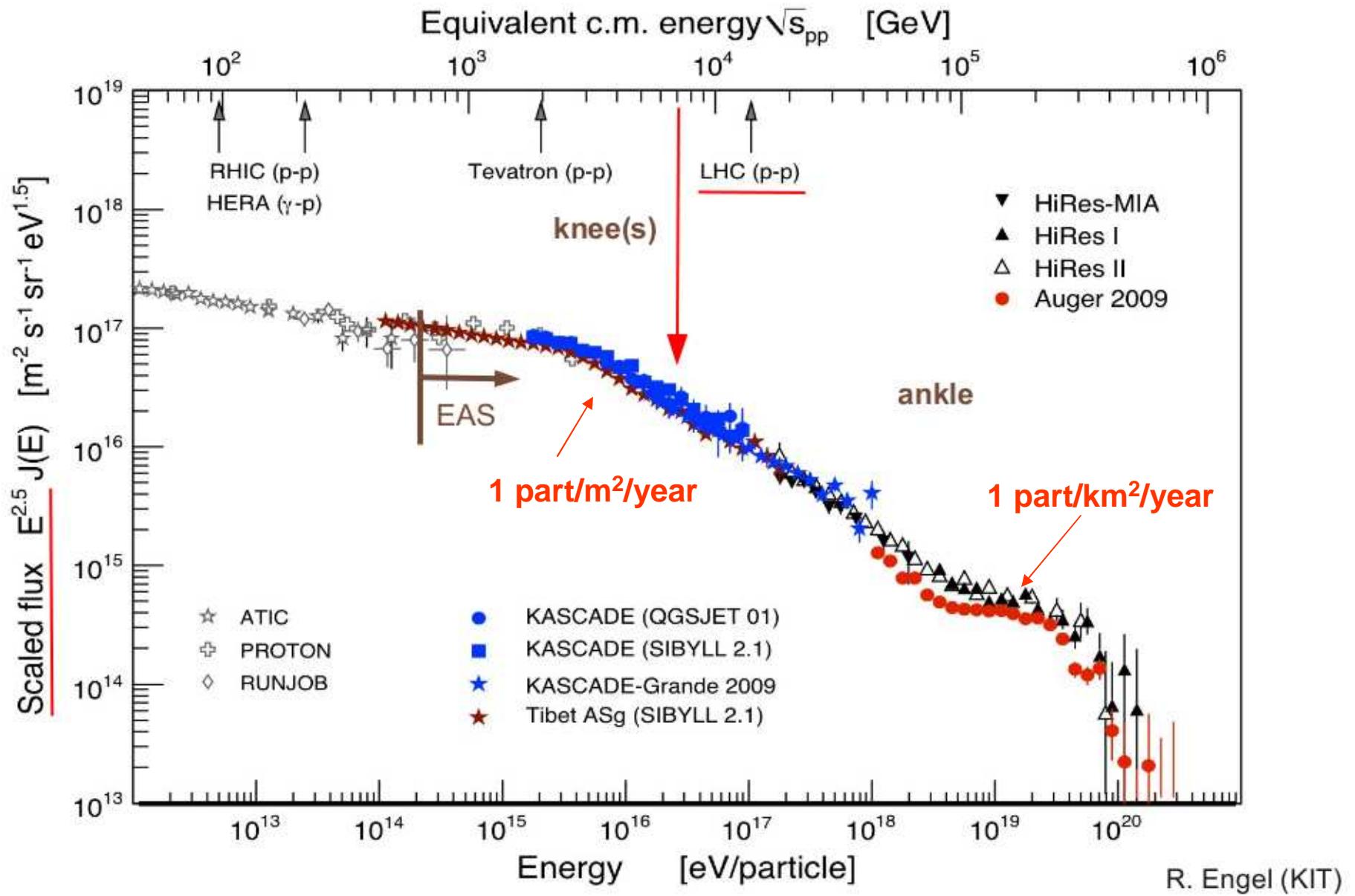
Rassegna cosmici da Terra

M. Bertaina

Univ. Torino & INFN

IFAE 2014, GSSI & LNGS 9-11 Aprile 2014

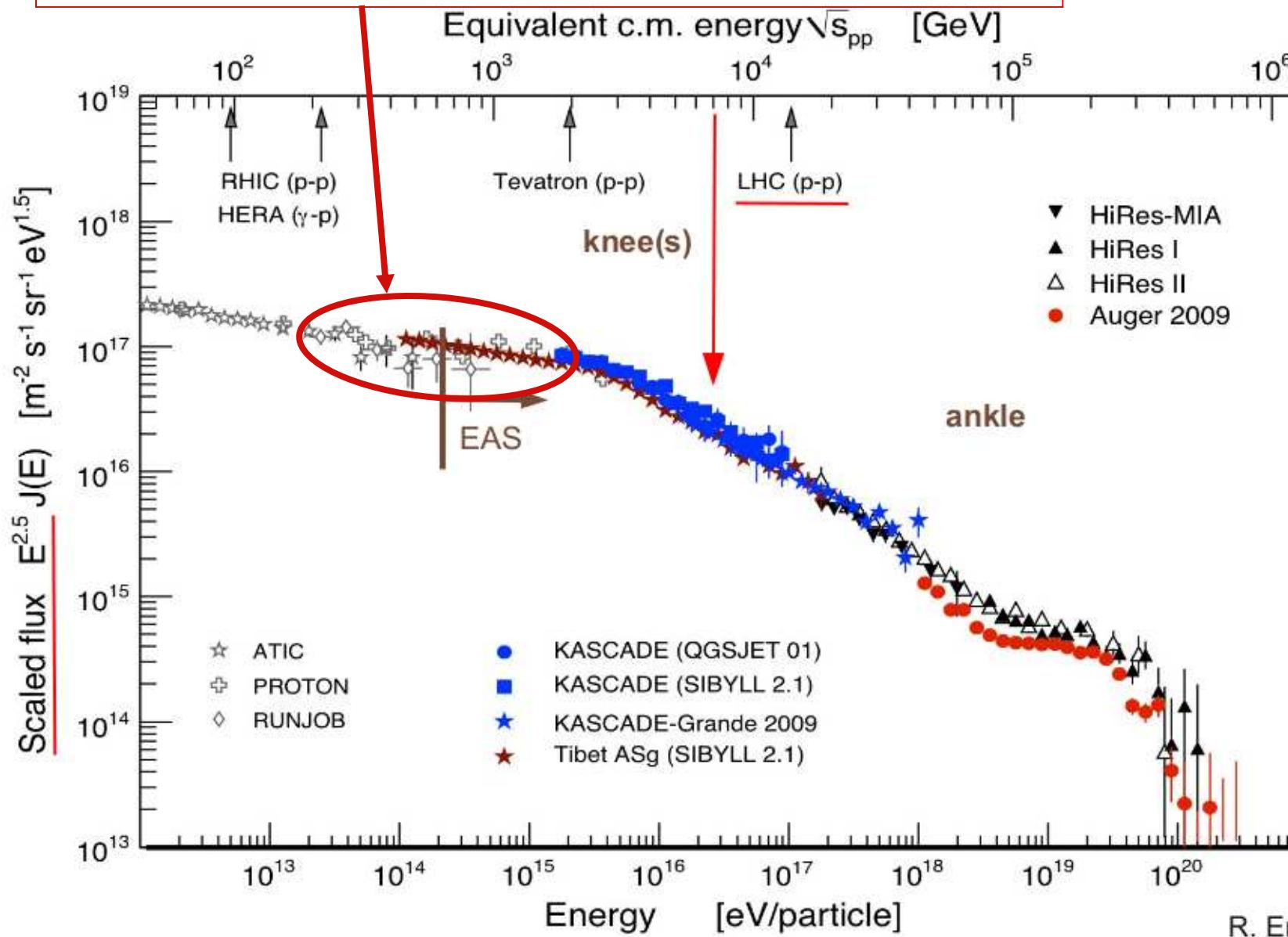
Cosmic Ray Spectrum



R. Engel (KIT)

Cosmic Ray Spectrum

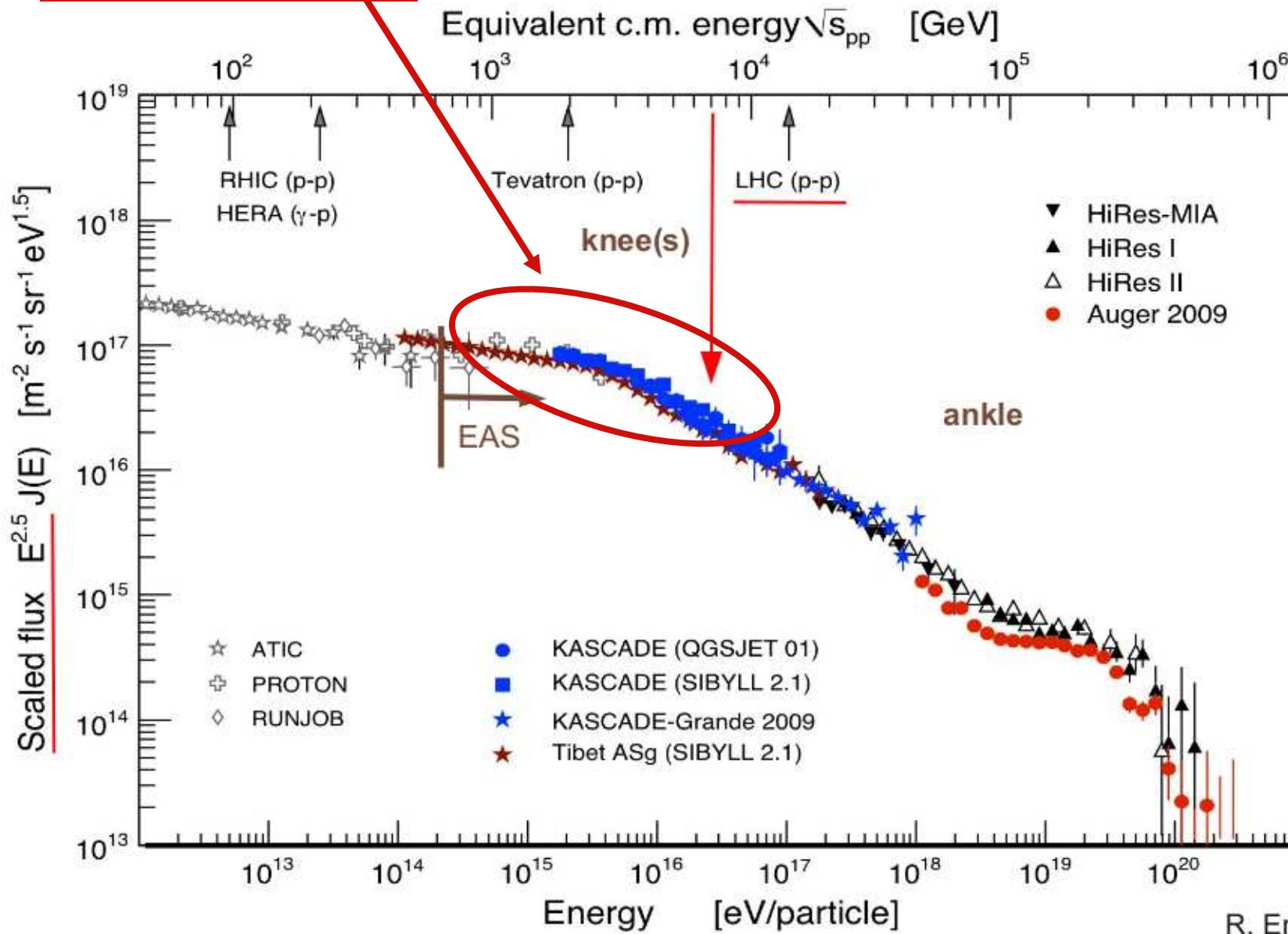
Technical: direct to ground based experiments



R. Engel (KIT)

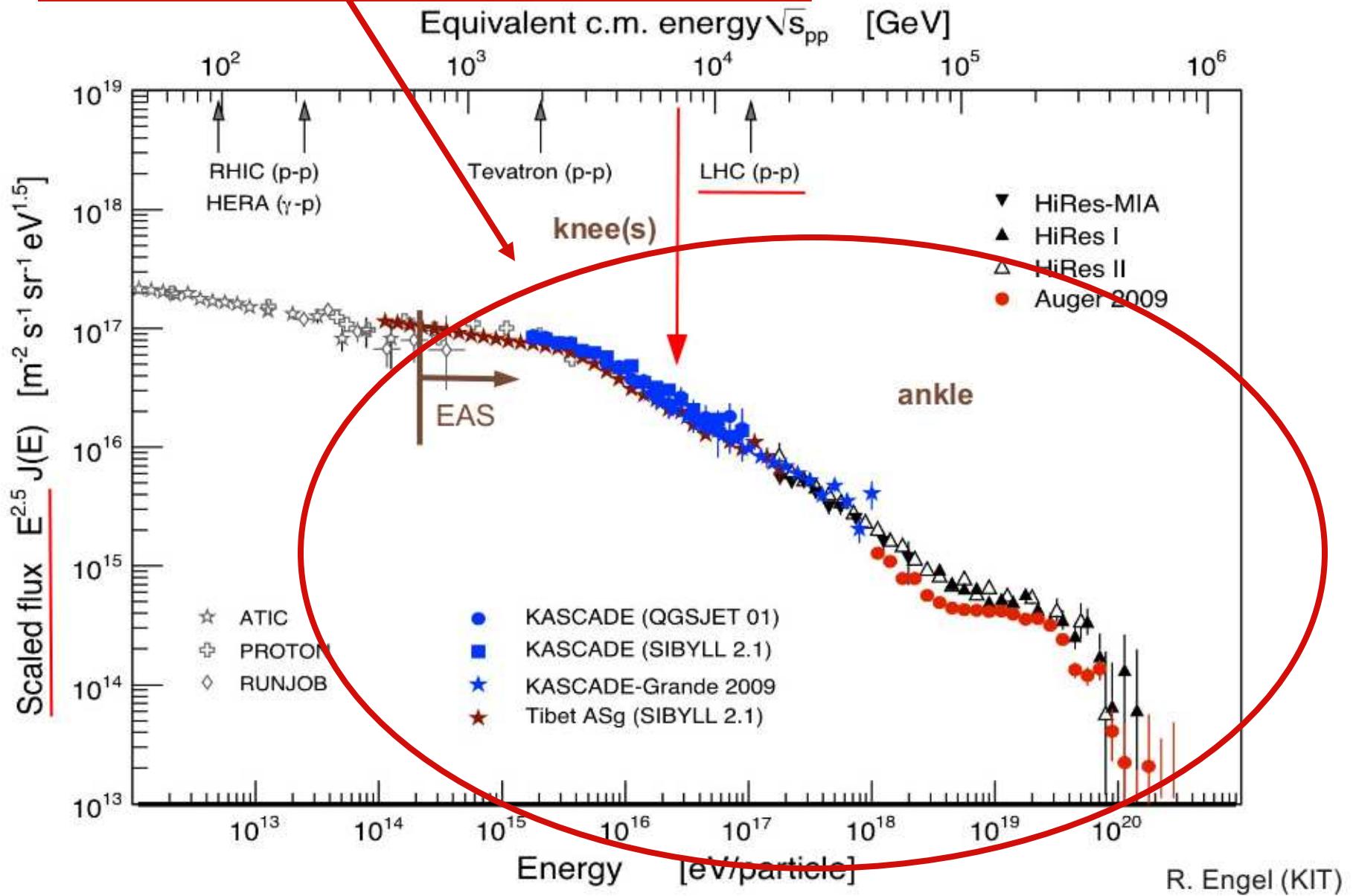
Cosmic Ray Spectrum

“knee”: origin ?



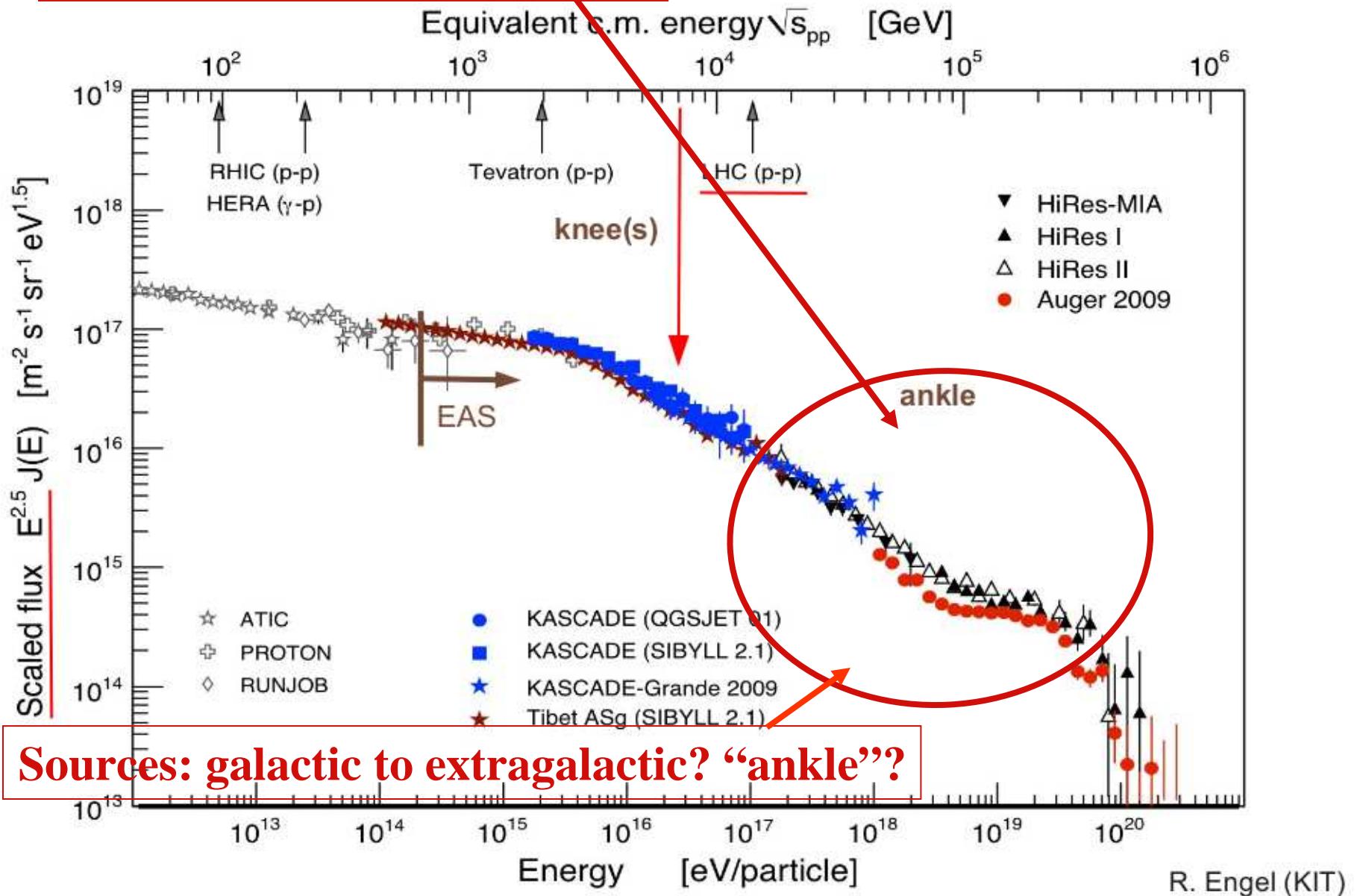
Cosmic Ray Spectrum

Composition / Hadronic interactions



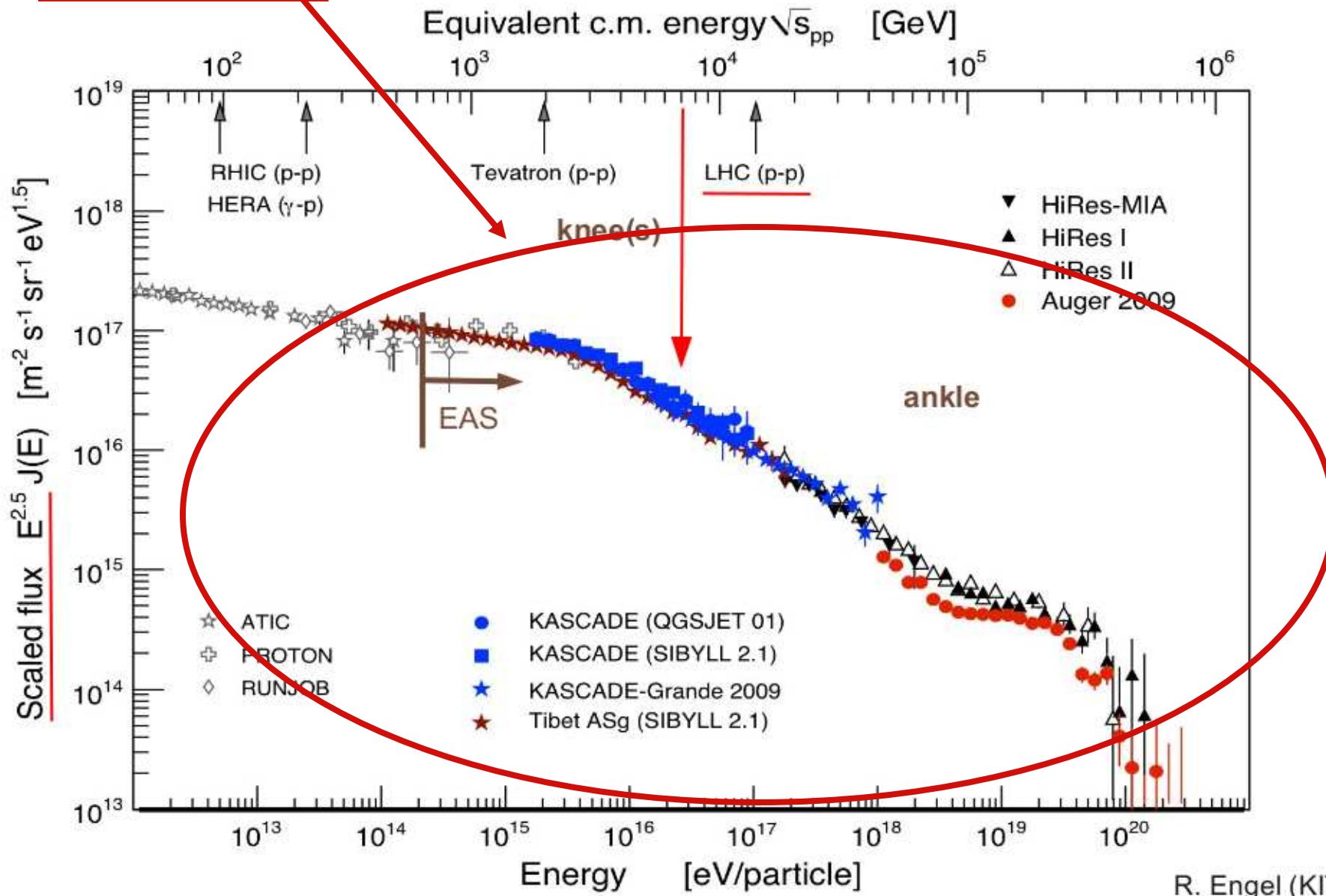
Cosmic Ray Spectrum

Technical: energy calibration



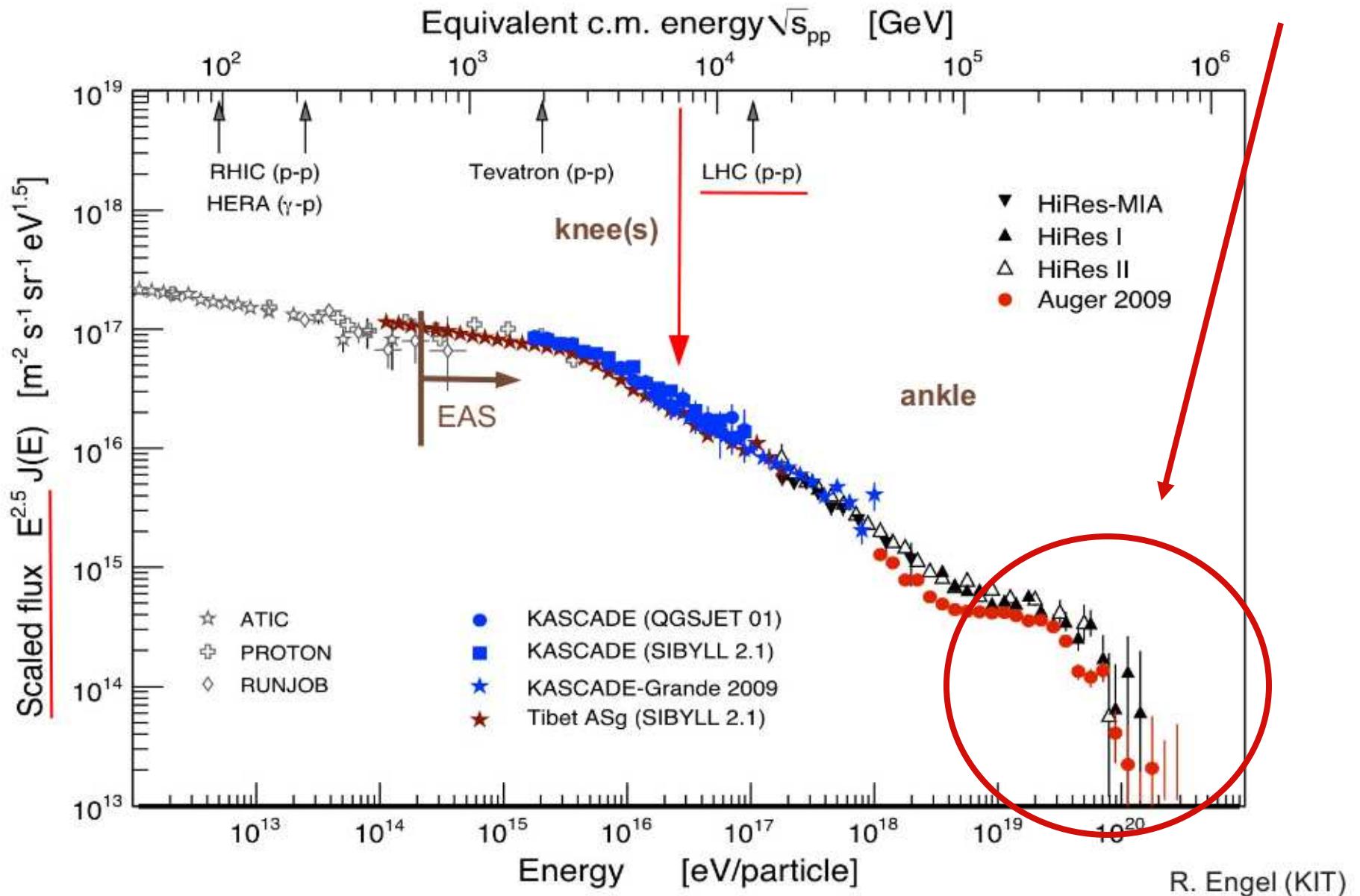
Cosmic Ray Spectrum

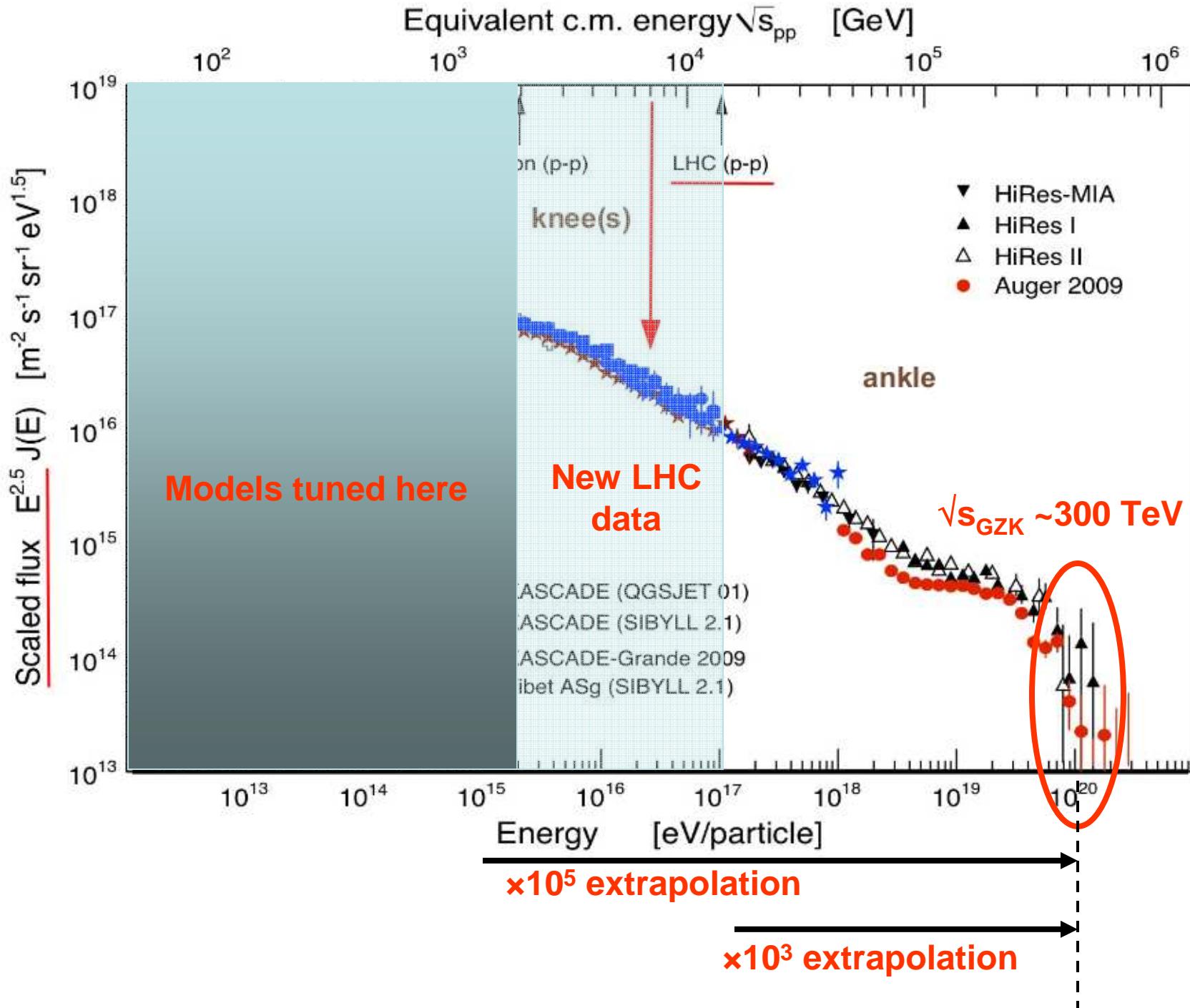
Anisotropies



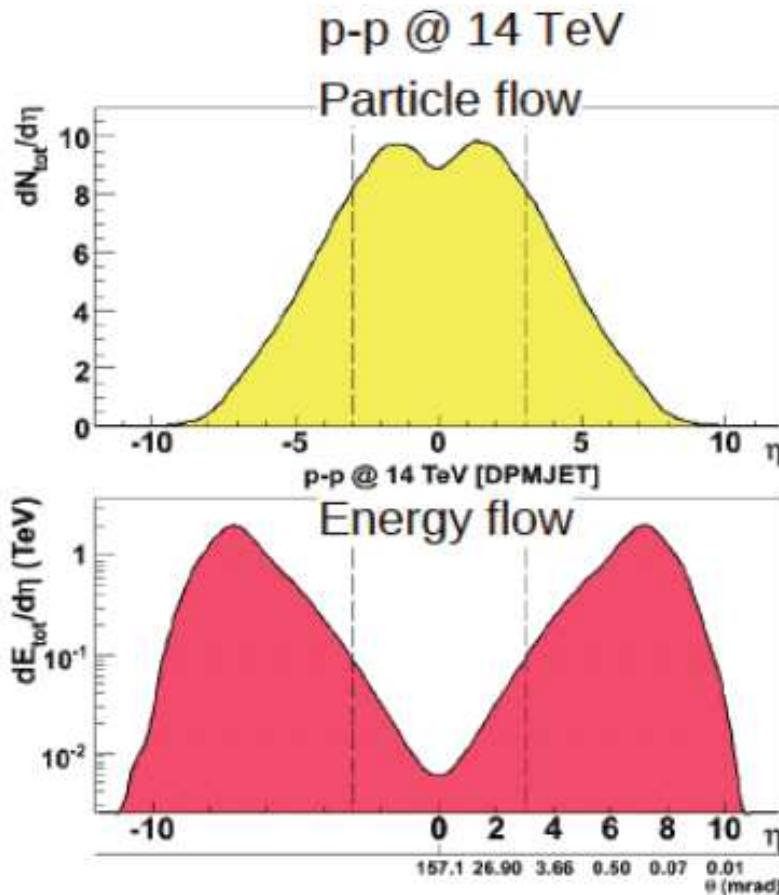
Cosmic Ray Spectrum

End of spectrum?

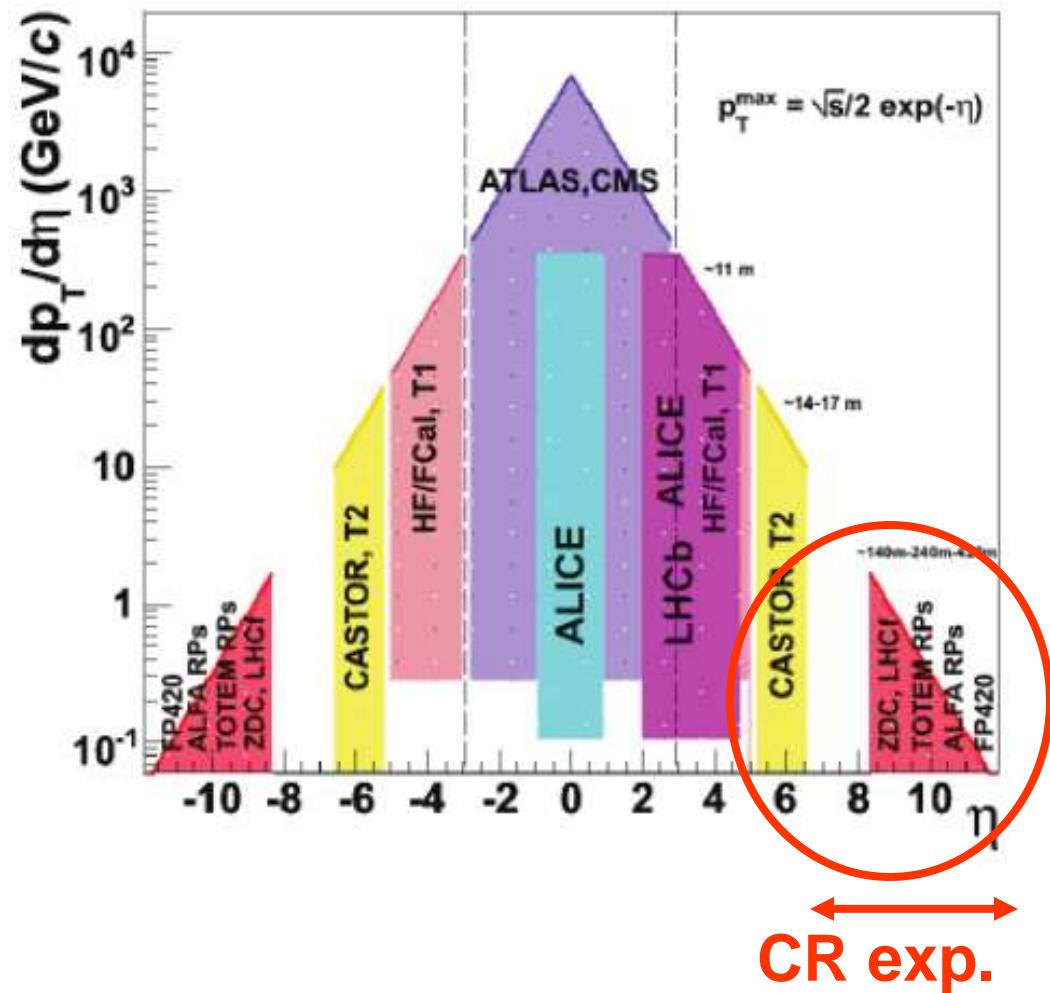




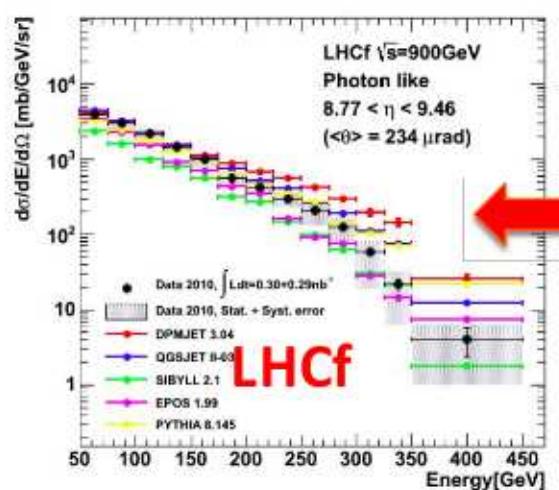
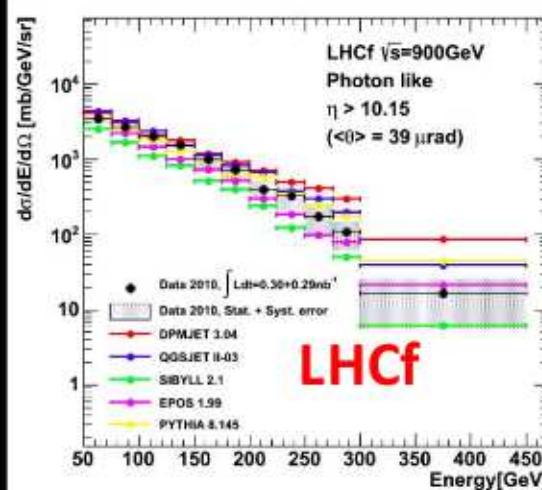
Rapidity regions of CR experiments and LHC detectors



Pinfold, ICRC 2013

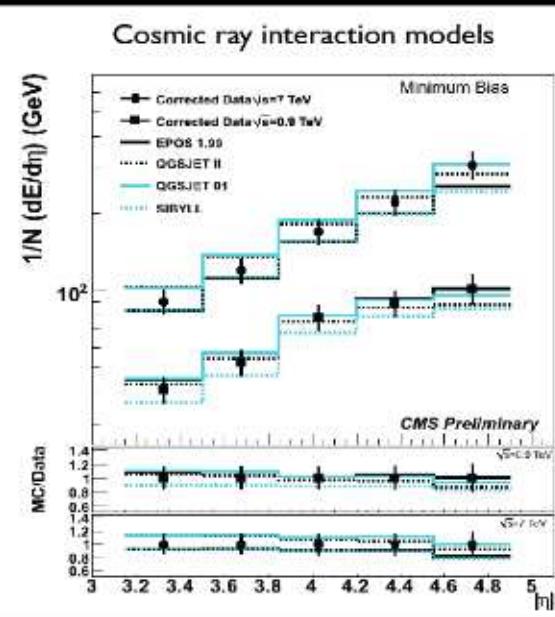
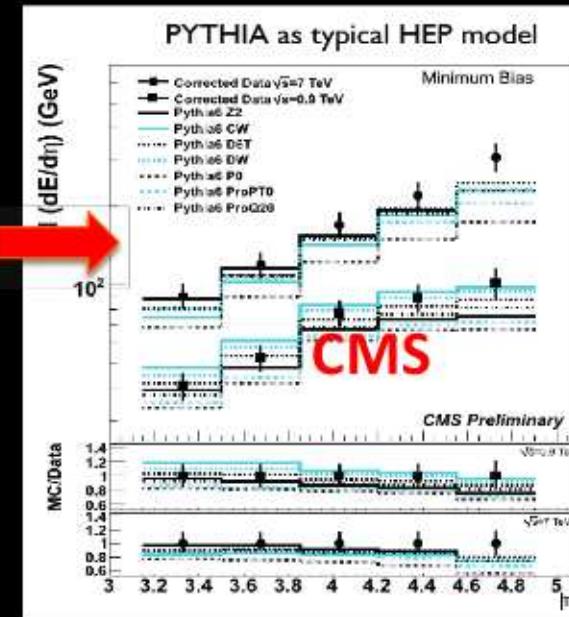


Forward Spectra

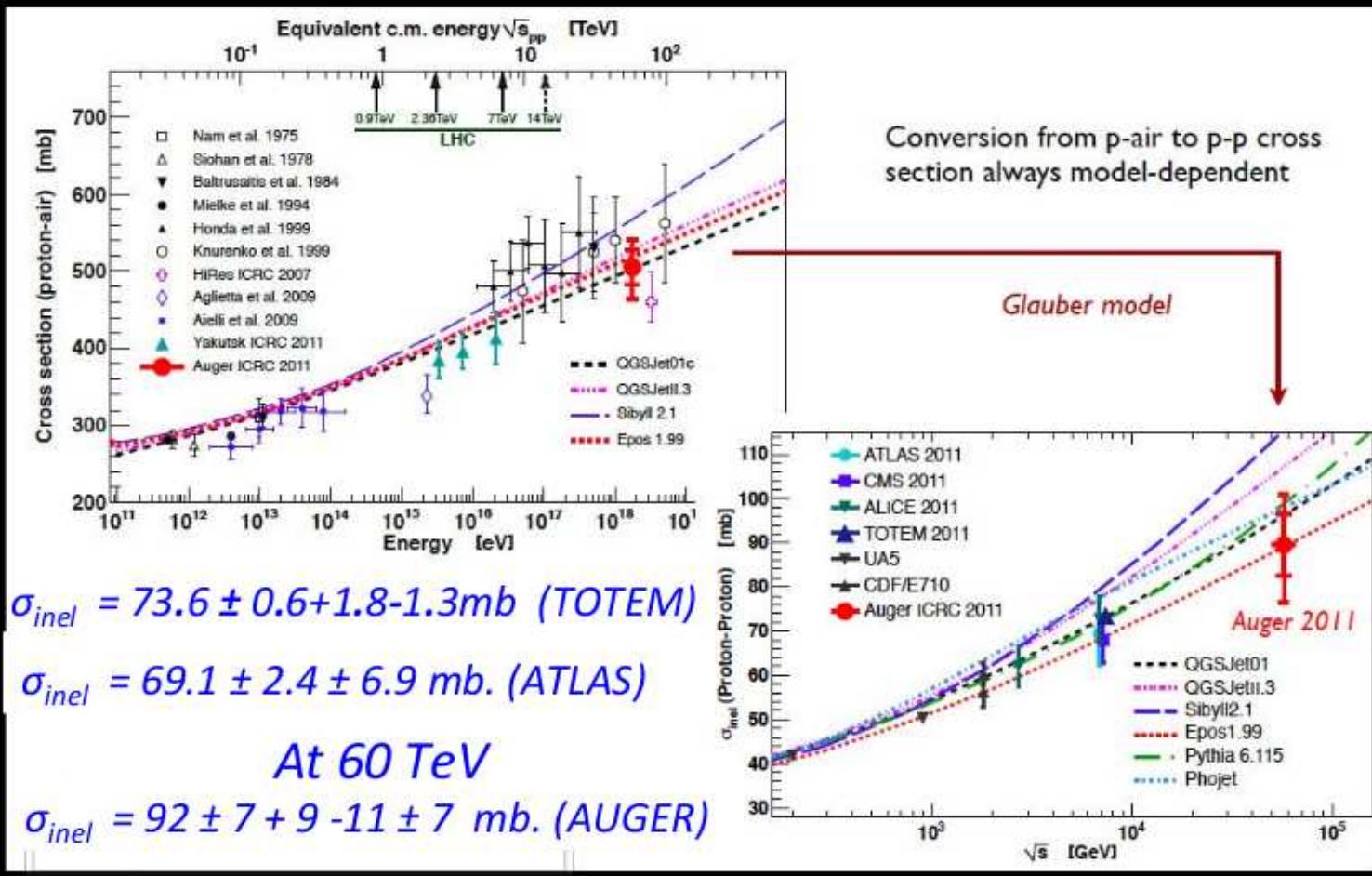


$\text{pp} \rightarrow \gamma + X$
Model predictions
bracket the LHC data

MINIMUM BIAS
CR interaction models
can yield better results
Than HEP models



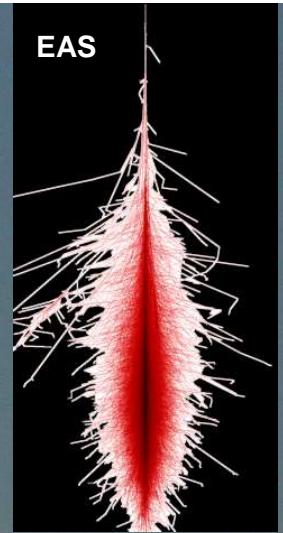
The Inelastic Cross-section Results



- *ATLAS & CMS x-section slightly lower than TOTEM's & ALICE's*
- *The EPOS1.99 model describes the rise in the cross-section out to 60 TeV (Auger)*

ARGO-YBJ

A carpet of RPC covering 110x100 m² at 4300 m to detect CRs and γ rays in the TeV energy range

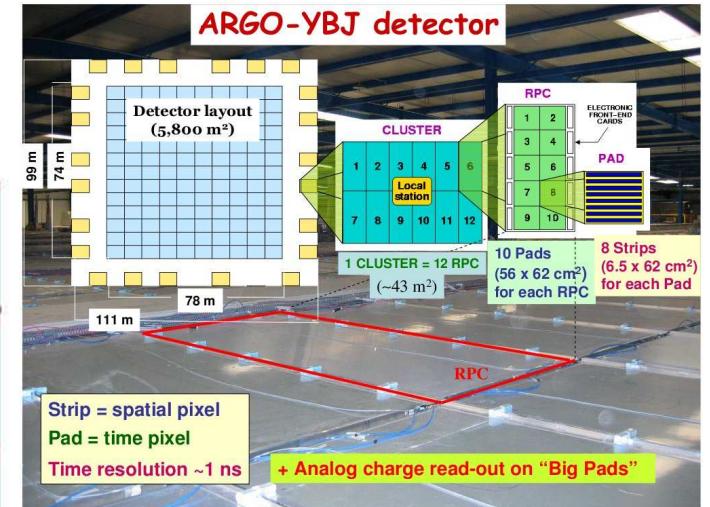
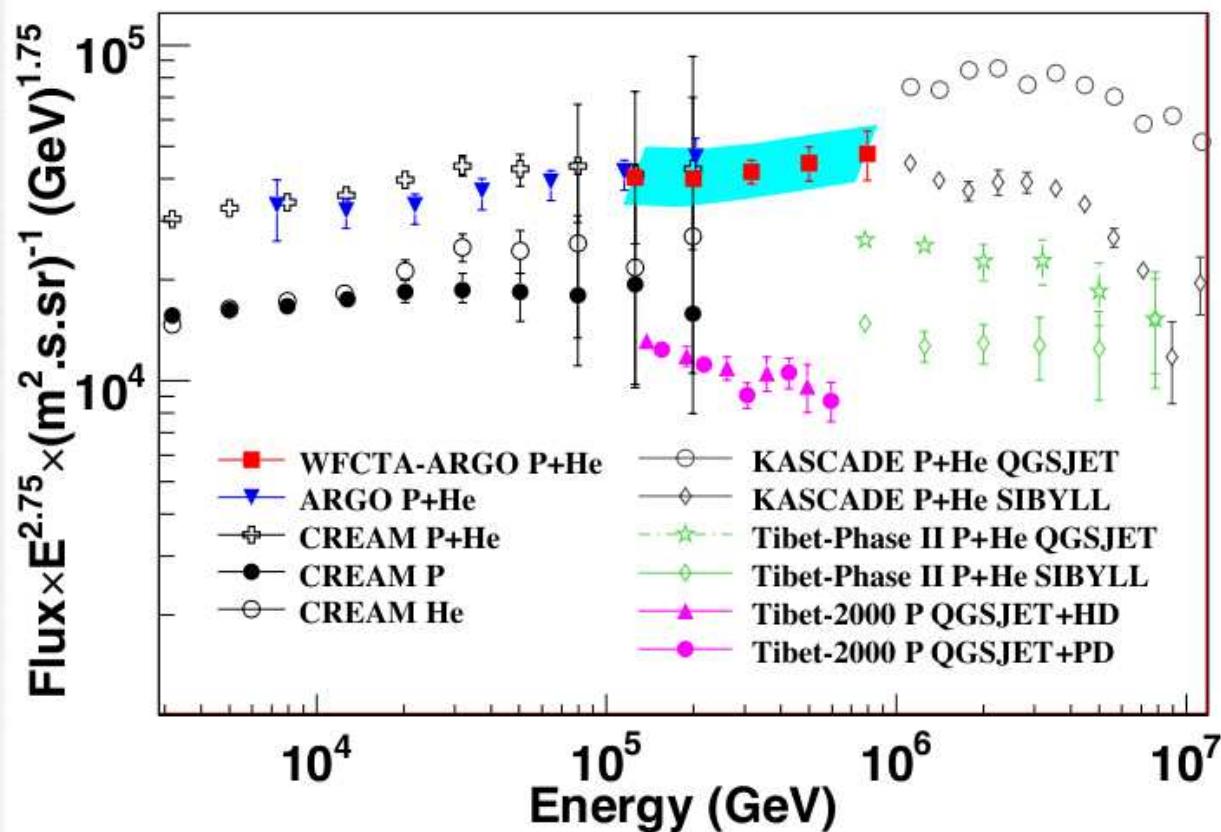


CR event seen by ARGO



The site of the experiment

Light-component (p+He) spectrum of CRs measured by ARGO + WFCTA (5 - 700 TeV)

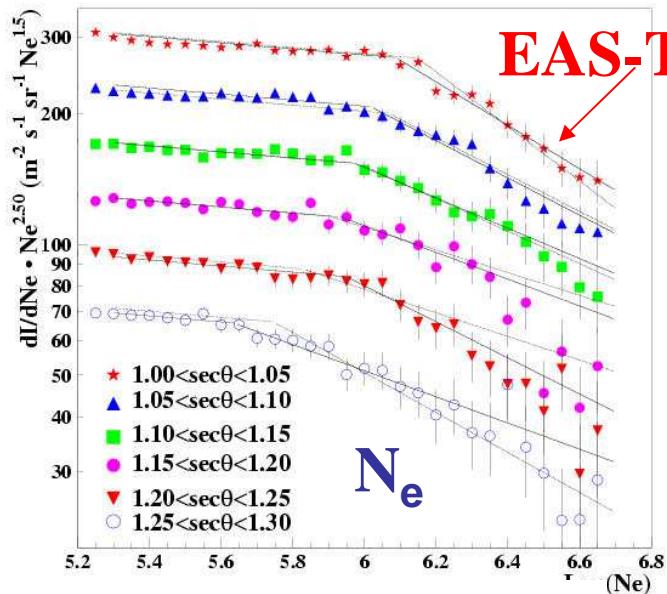


ICRC 2013:
0603 Zhang, ARGO+WFCTA
0866 Mari, ARGO

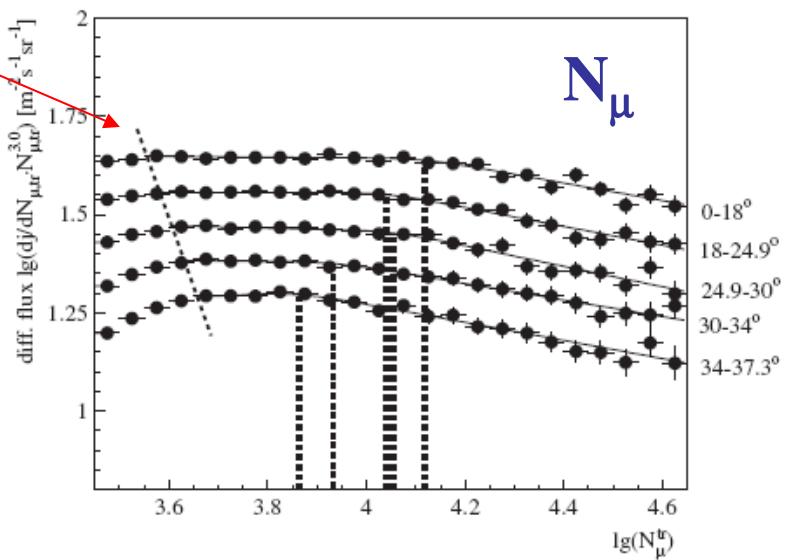
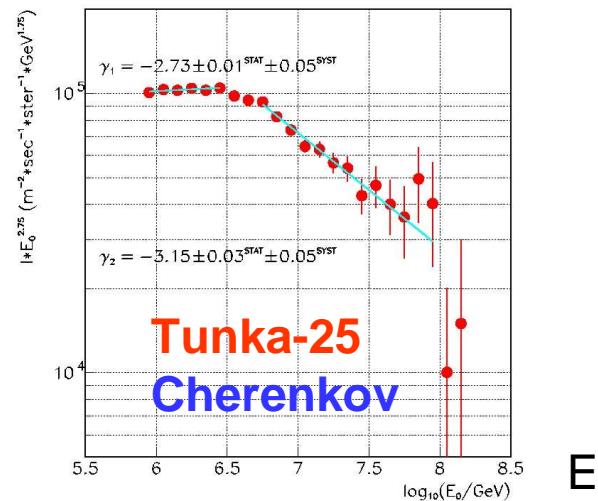
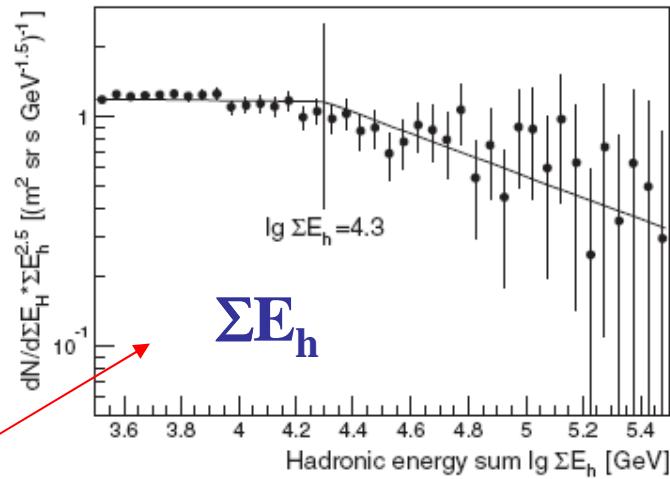
Good agreement with CREAM satellite at low energies,
a nice bridge into the knee region

Experimental results at knee energies ($3-5 \times 10^{15}$ eV)

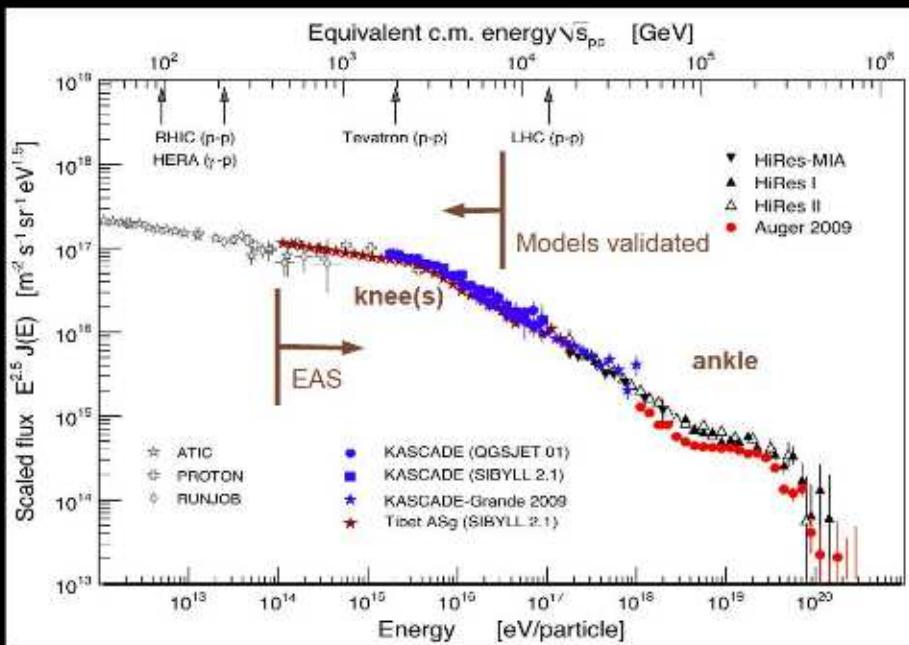
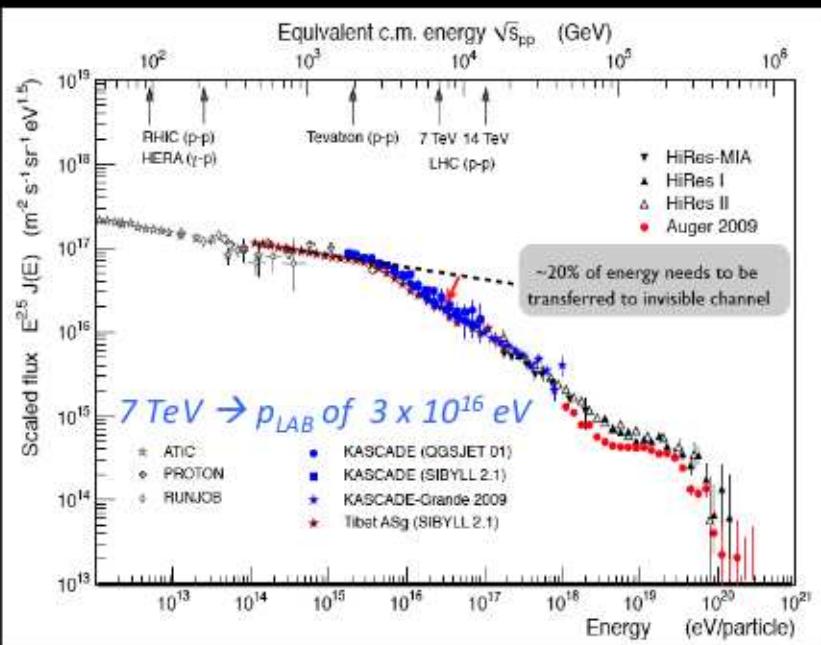
The change of slope is observed in the spectra of all EAS components



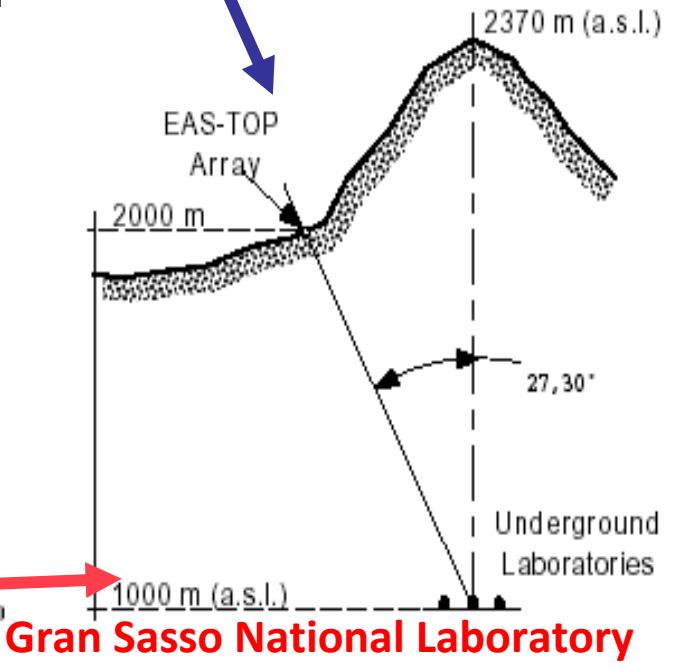
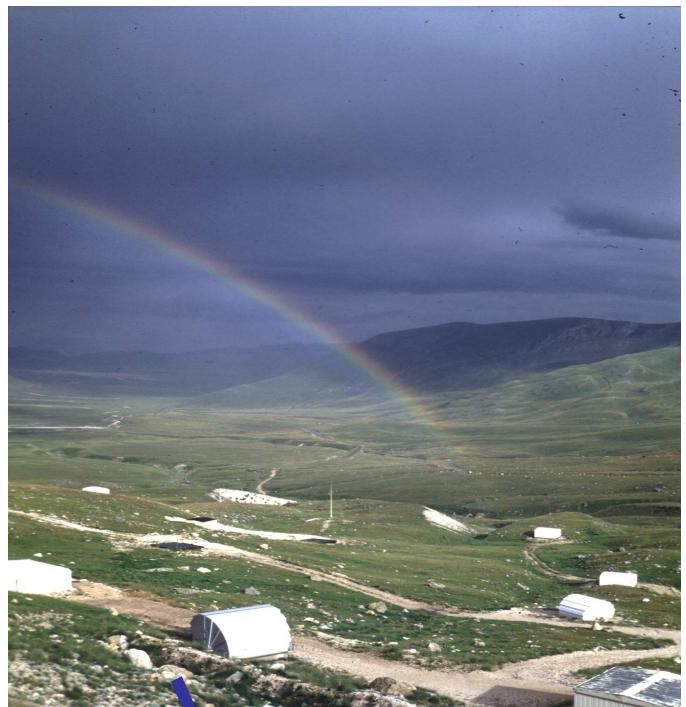
KASCADE



New Physics at the Knee?

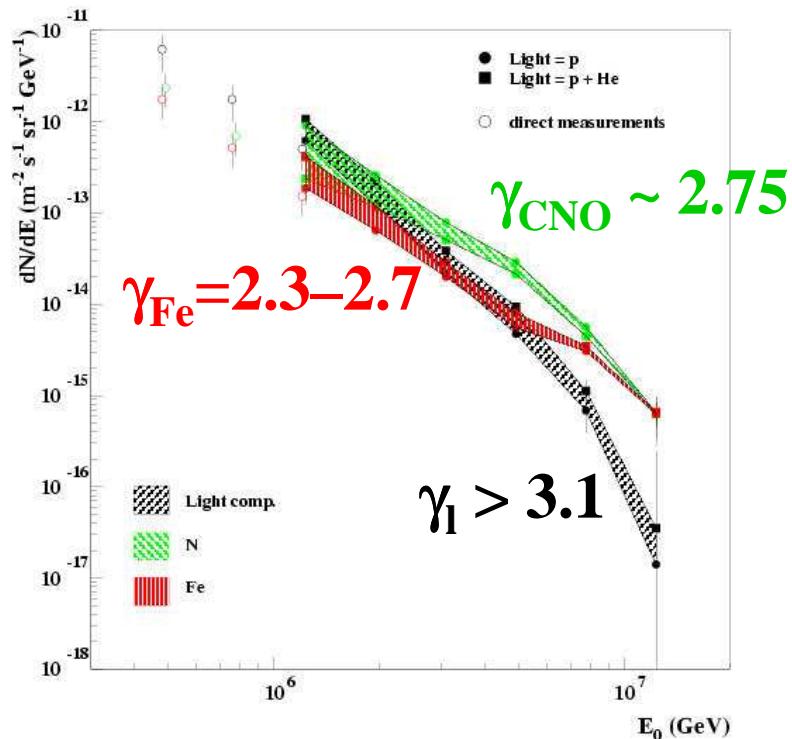


- CR validated by the LHC
 - Reasonable description of the main observables
 - Data bracketed by CR Models
- Origin of the Knee?
 - Most likely NOT due to exotic hadronic interactions
 - Probable dependence on primary CR composition

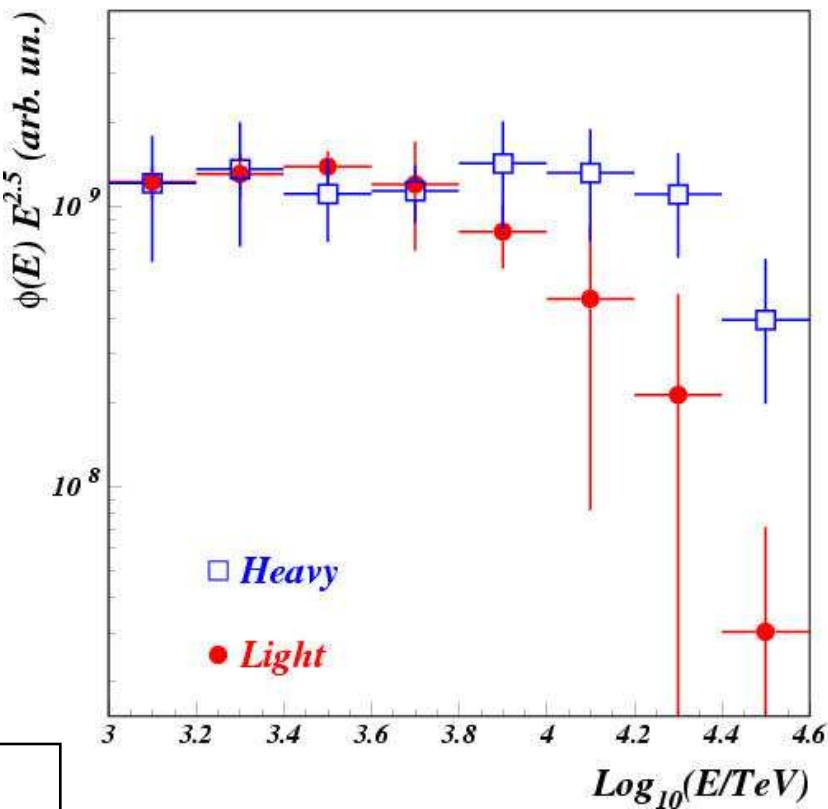


EAS-TOP (2005 m a.s.l.) & MACRO

EAS-TOP Ne-N μ (GeV)



EAS-TOP/MACRO Ne-N μ (TeV)



Average power law index
of different mass groups (γ)
Heavier primary spectra harder
→ $E_k \propto Z ?$

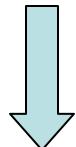
Astrop. Phys. 21 (2004) 583

$$L = p + He \quad H = Mg + Fe$$

Astrop. Phys. 20 (2004) 641

- Knee is not related to a change in the interaction mechanism.
- Knee can be interpreted as the maximum energy for acceleration in SNR and/or diffusion in the galaxy.
- Spectra of different elements are compatible with a change of slope at energy $E_{\text{knee}}^{\text{Z}} = Z E_{\text{p}}^{\text{knee}}$
- The SNR spectrum would extend to a maximum energy for iron $E_{\text{Fe}}^{\text{max}} = 26 E_{\text{p}}^{\text{max}}$

Need to precisely measure the spectrum & composition at $10^{16} \text{ eV} < E < 10^{18} \text{ eV}$



KASCADE-Grande, Tunka-133, IceTop

KASCADE-Grande features and performances

- **KASCADE:**

- energy range $10^{14} - 10^{16}$ eV
- 252 detector stations over 200×200 m²
- in a station: measurement of e and μ separately with **two co-located types of detector scintillators**

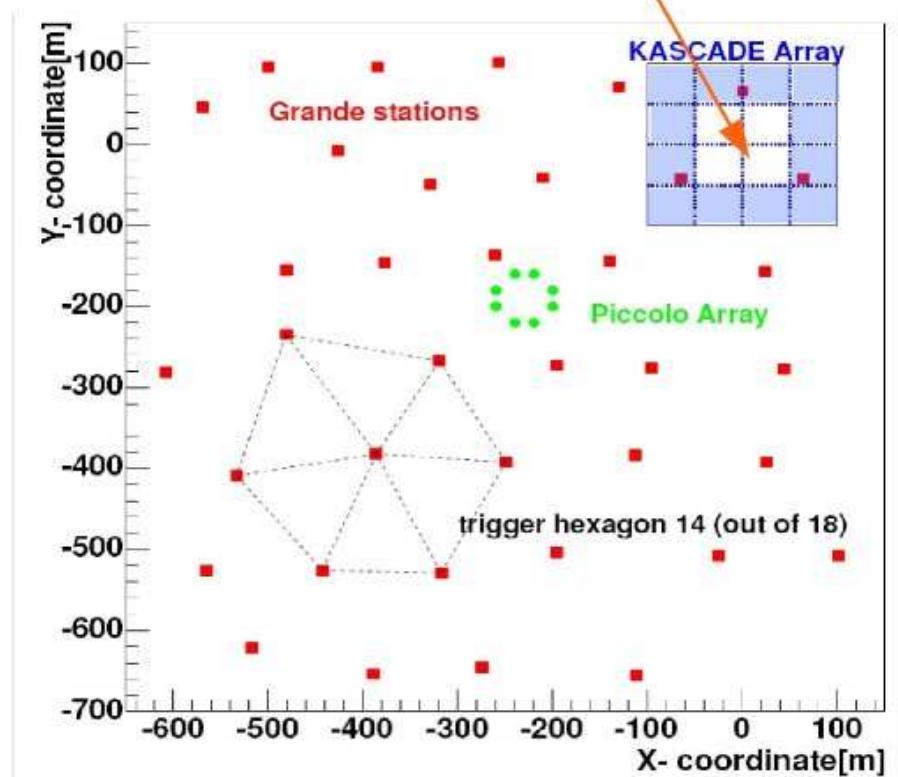


- **Grande:**

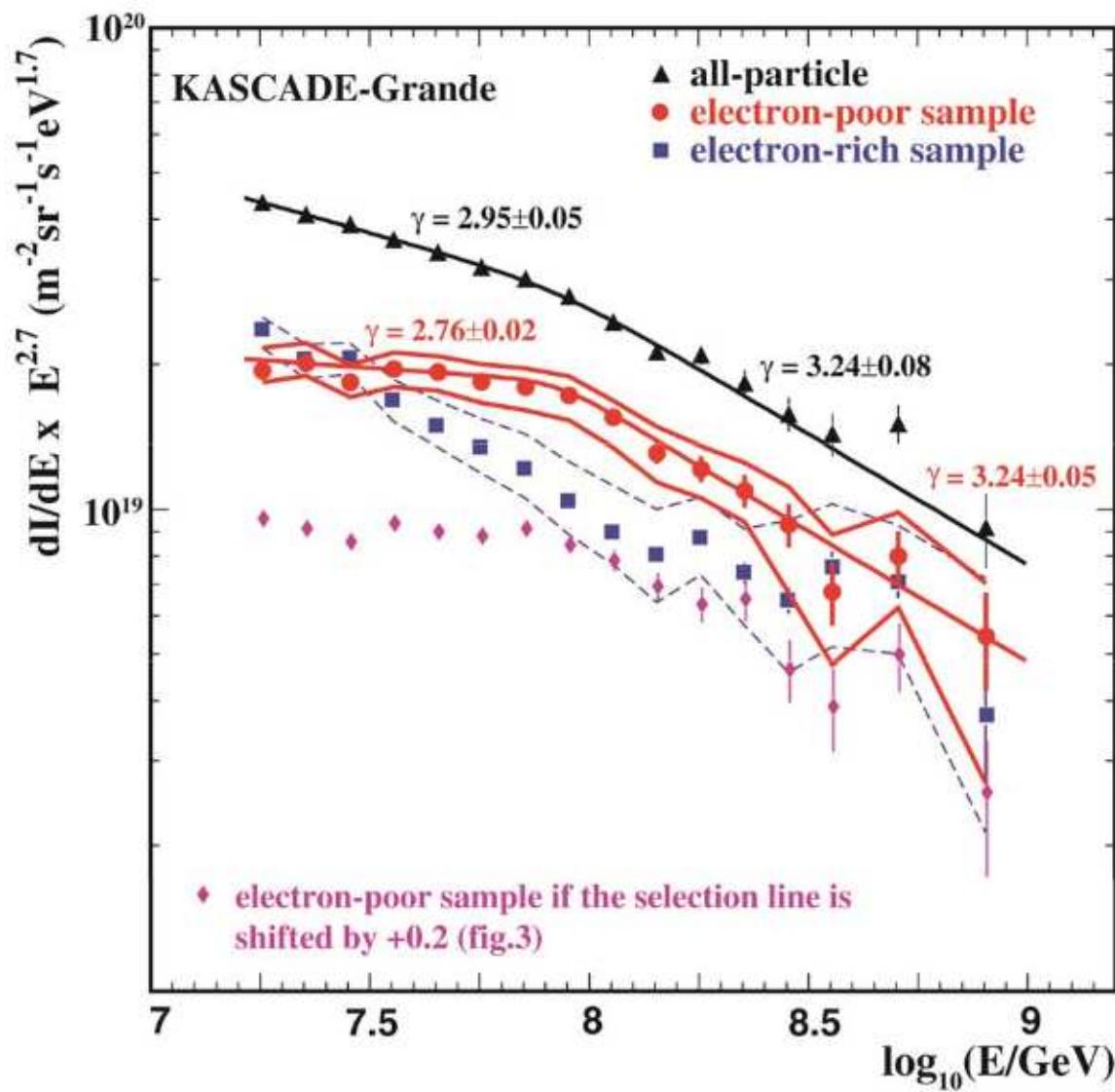
- 37 detector stations 10 m² each spread over 700×700 m²
- in a station: measurement of all-charged e + μ
- 18 hexagonal clusters. 7 out-of-7 coincidence triggers data acquisition



Upper view and Bottom view of a Grande station



KASCADE-Grande: Spectra of individual mass groups



- spectra of individual mass groups:

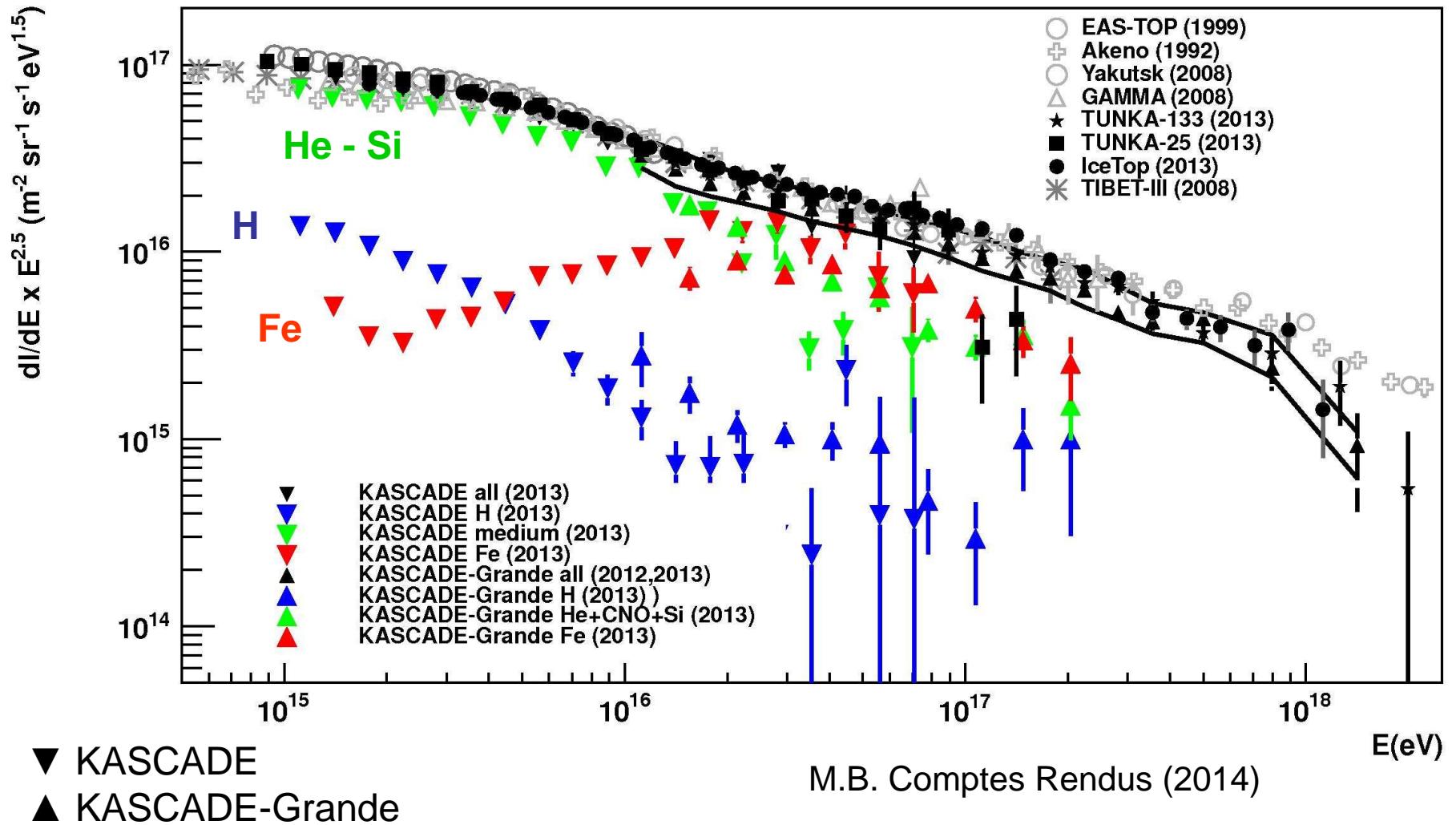
→ steepening close to 10^{17}eV (2.1σ) in all-particle spectrum

→ steepening due to heavy primaries (3.5σ)

→ spectrum of more enhanced heavy sample has harder spectrum before break.

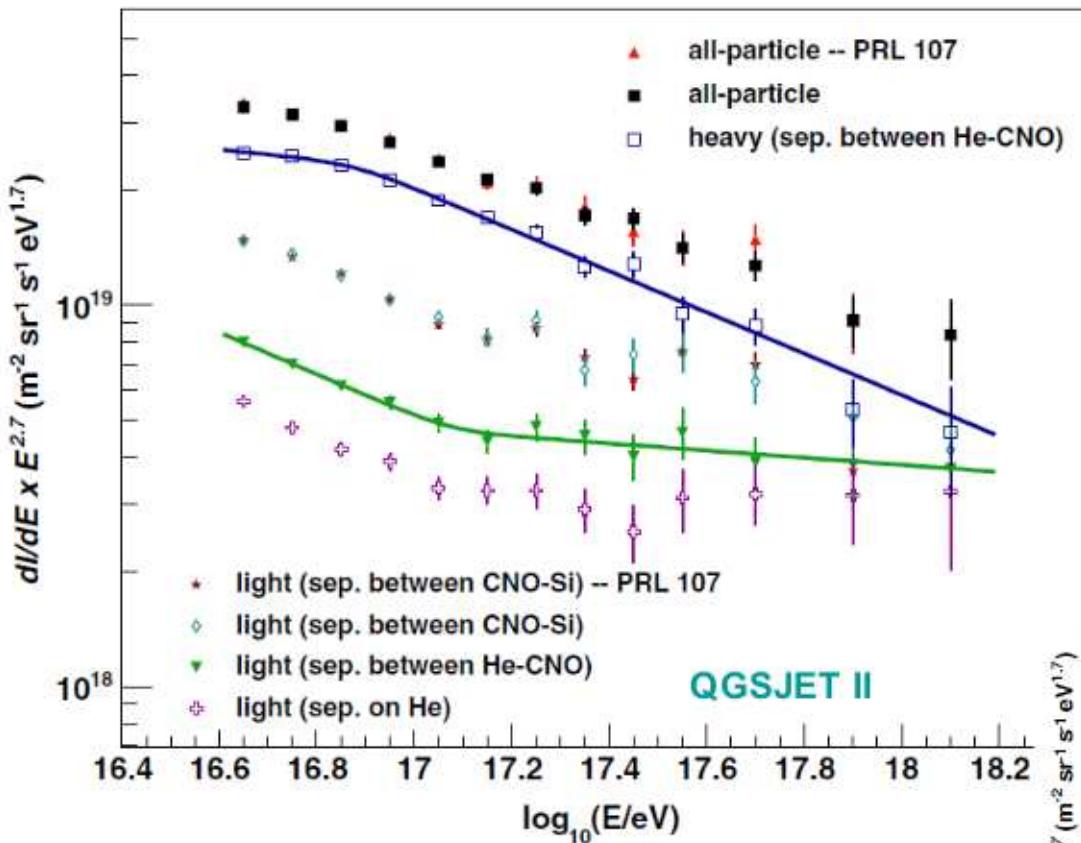
→ light+medium primaries show steeper spectrum, but fit by power law okay
→ possibility for hardening above 10^{17}eV

KASCADE-Grande energy spectrum in the contest of the knee measurements



**KASCADE & K-Grande results match well and give an overall picture of the knee
Compatible with a rigidity dependence of the knees**

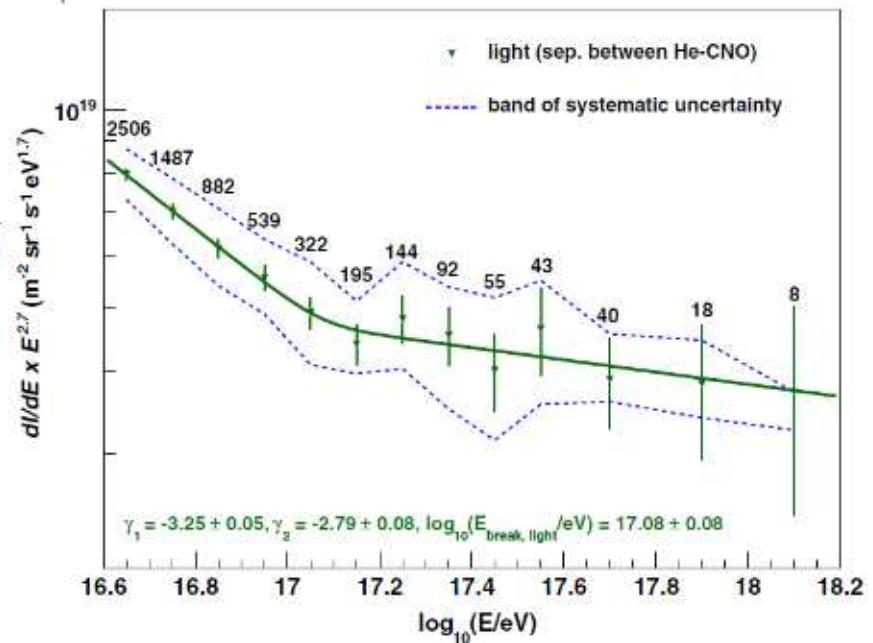
KASCADE-Grande: spectrum of light primaries



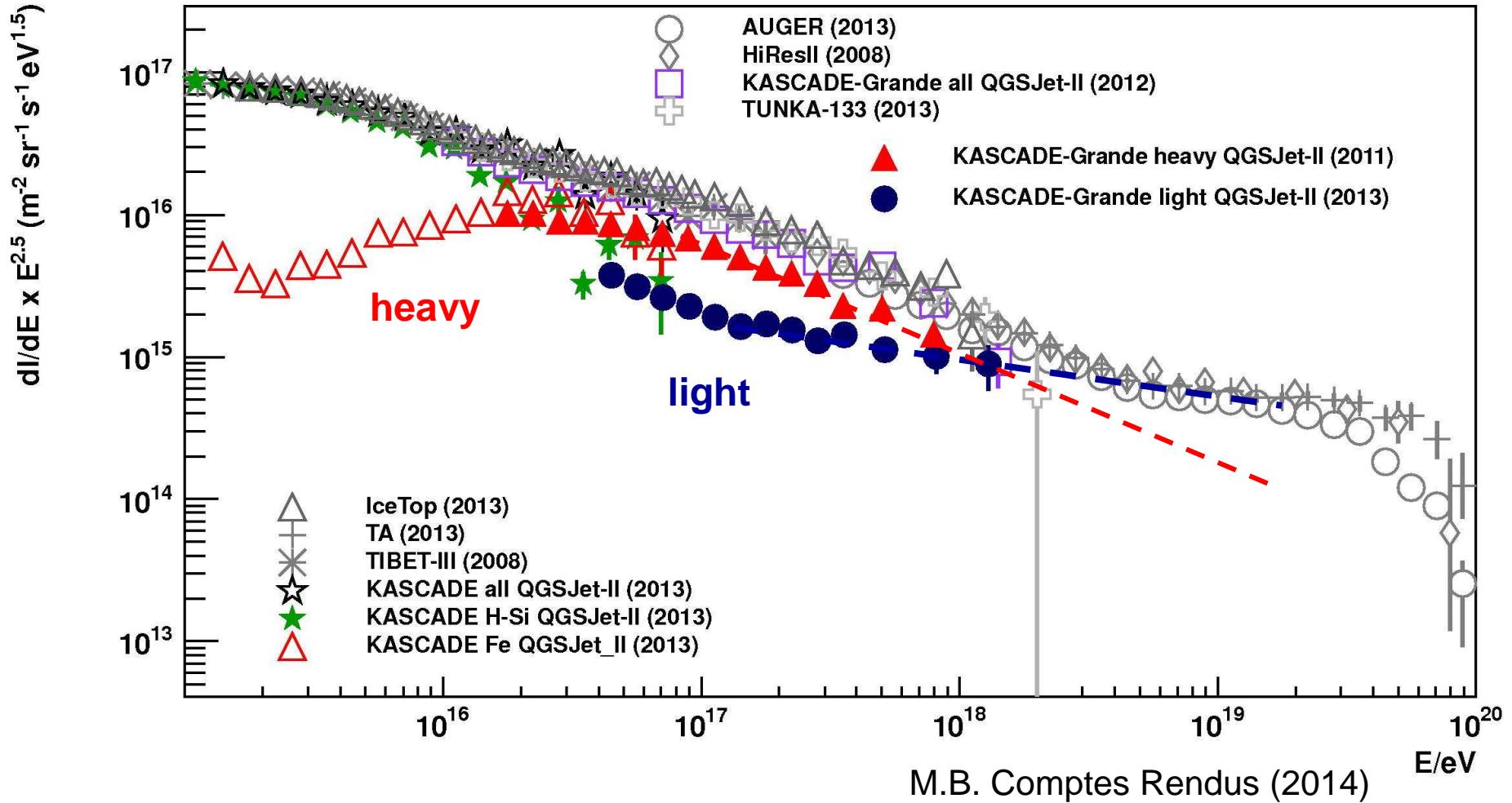
Phys.Rev.D (R) 87 (2013) 081101
S.Schoo ICRC2013 4/7

→ hardening at $10^{17.08}$ eV (5.8 σ) in light spectrum

→ slope change from $\gamma = -3.25$ to $\gamma = -2.79$!



KASCADE-Grande energy spectrum in the contest of Auger & TA



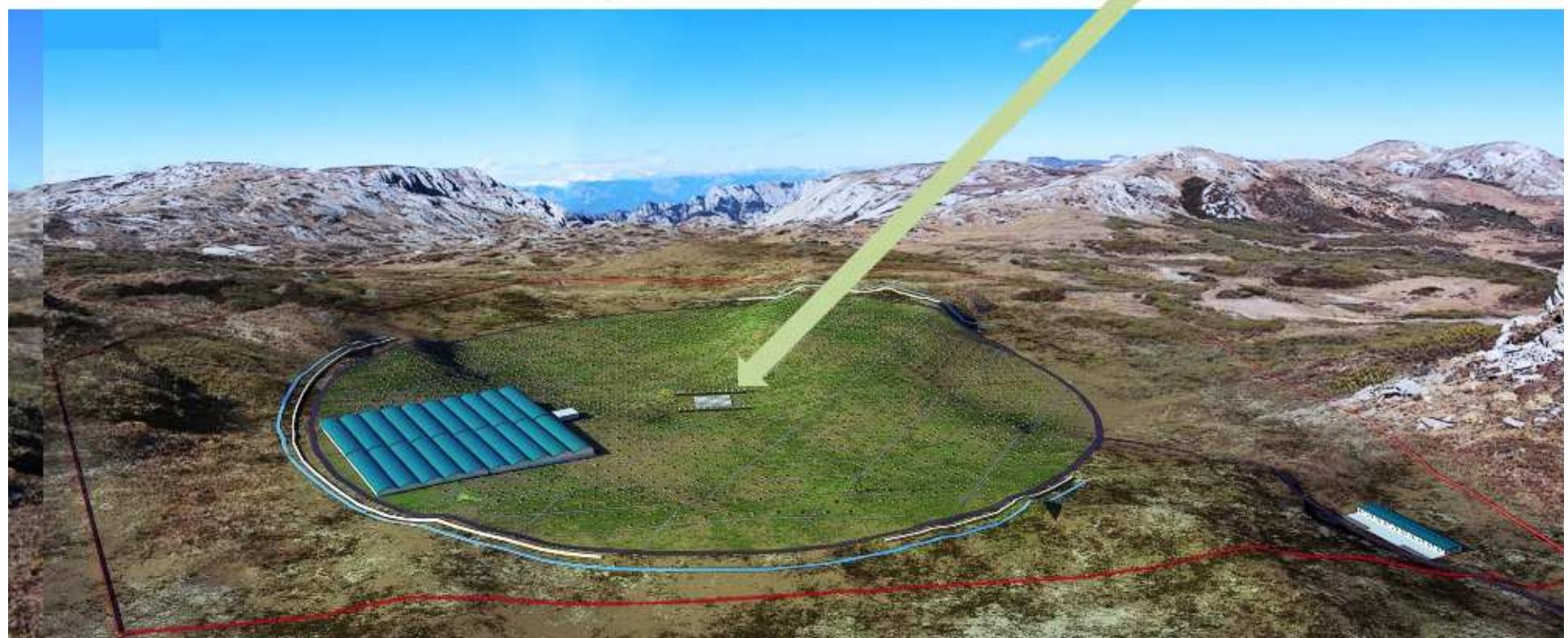
The extrapolation of K-Grande components foresees a domination of the light component around the ankle region.

First signature of extragalactic component of CRs?

LHAASO layout

Central detector
array for
cosmic rays

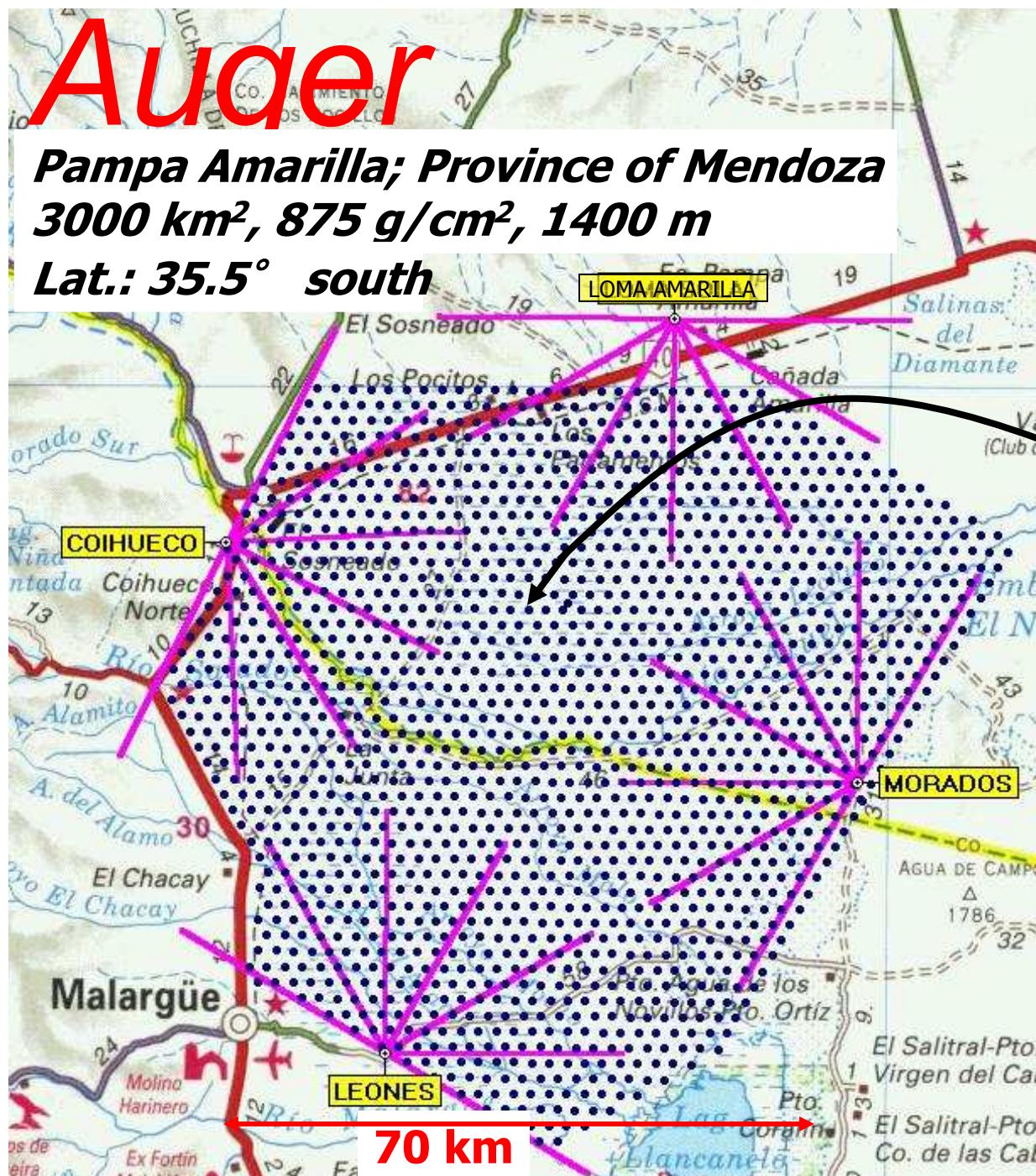
90k m² gamma ray survey telescope
1M m² surface EAS detector array

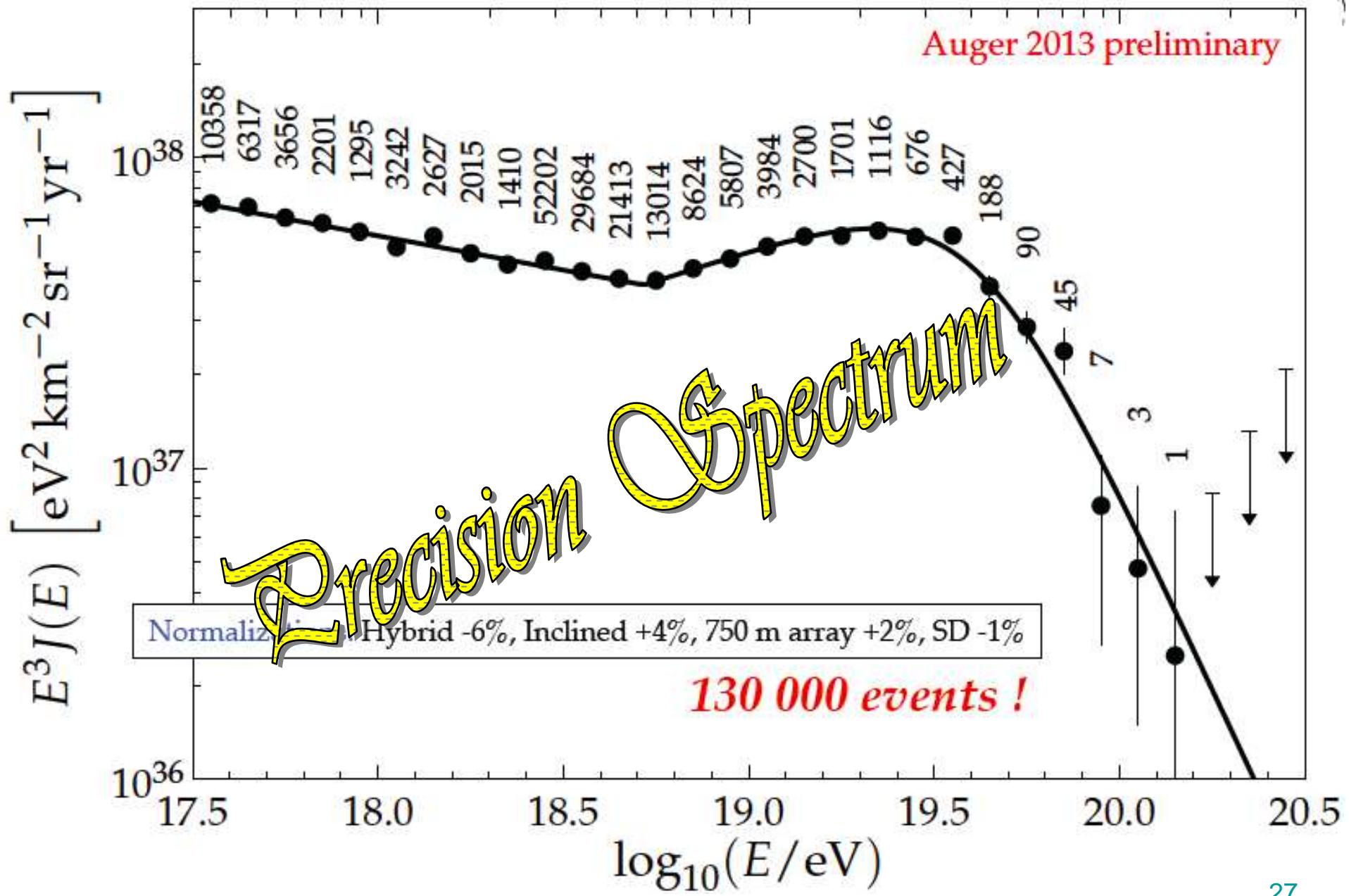


Aufer

Pampa Amarilla; Province of Mendoza
3000 km², 875 g/cm², 1400 m

Lat.: 35.5° south

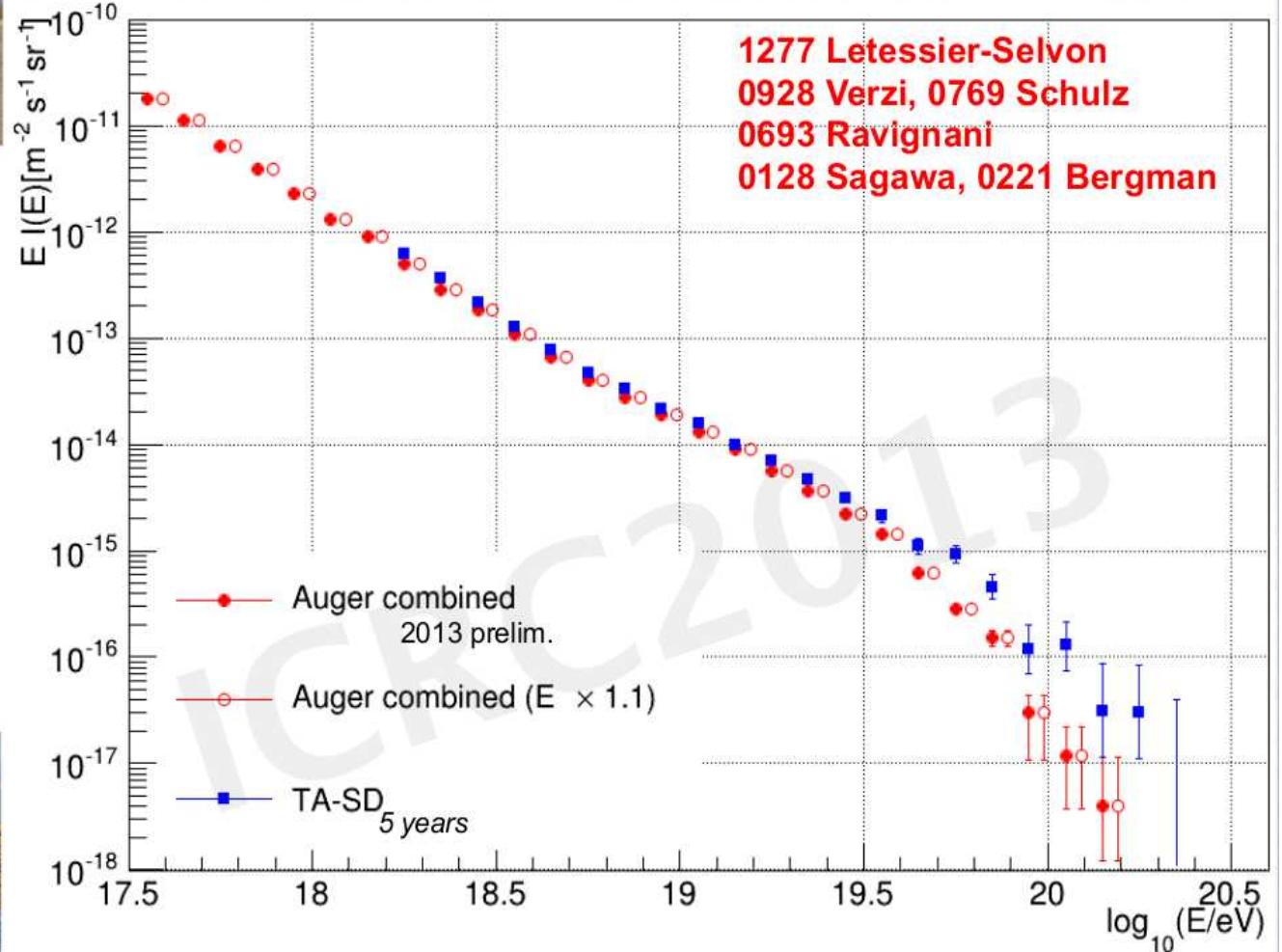


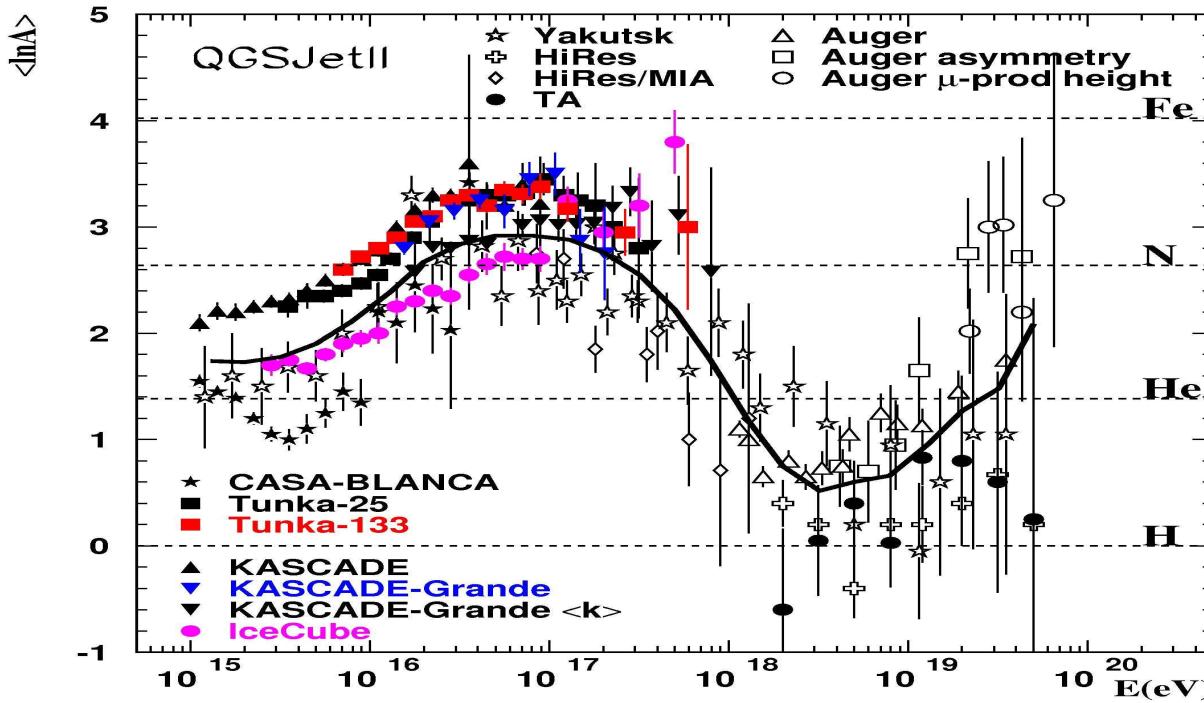


Energy Spectrum $E > 10^{17.5}$ eV

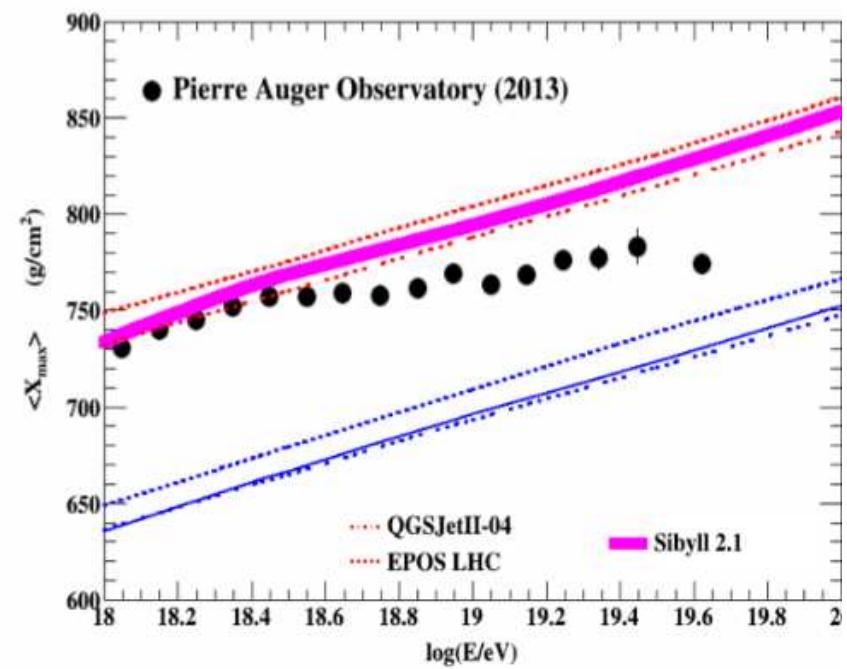
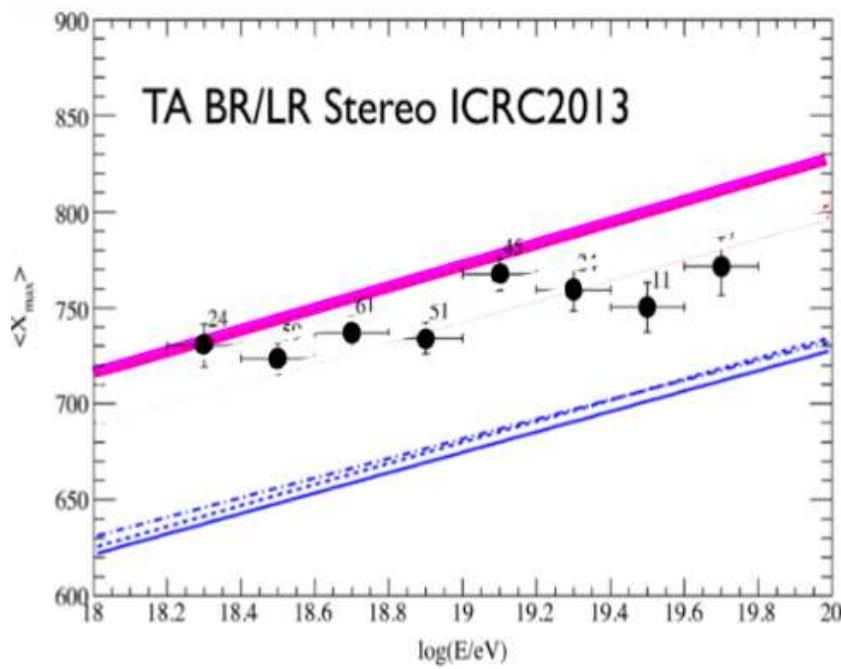


- TA 4-year spectrum published ---> updated to 5 years
- Auger energy scale updated by 16~10%, energy dependent, within prev. uncertainties.
- Auger energy uncertainty improved from 22% to 14%.

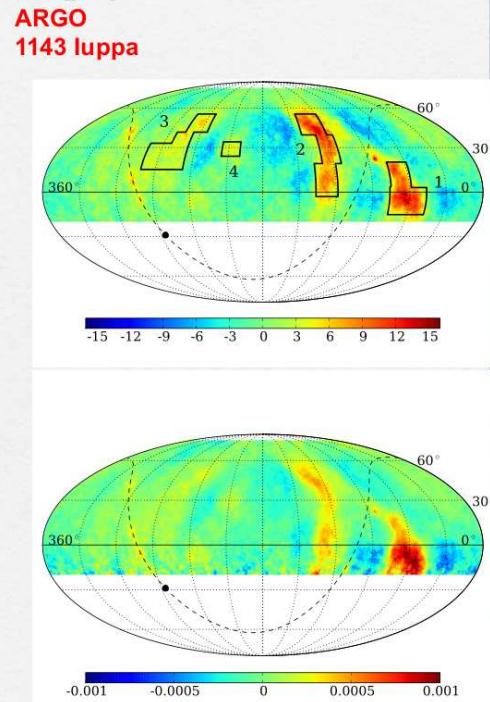
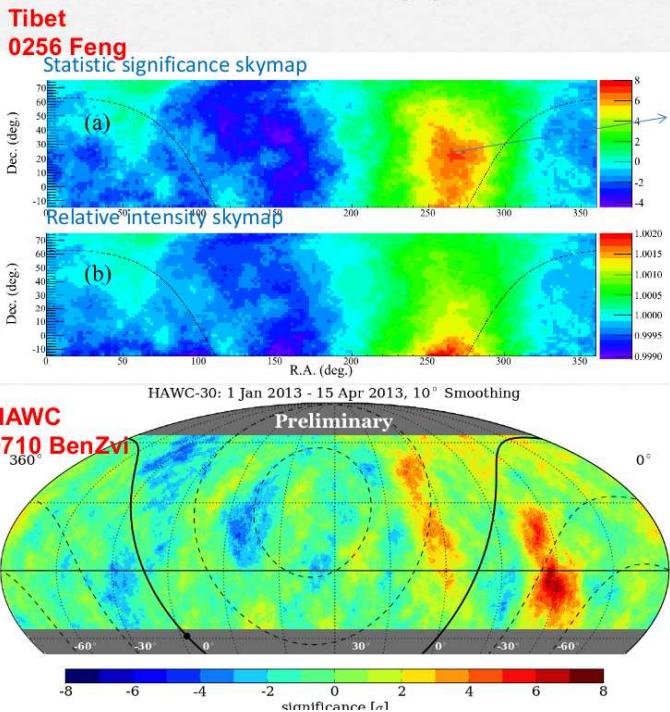




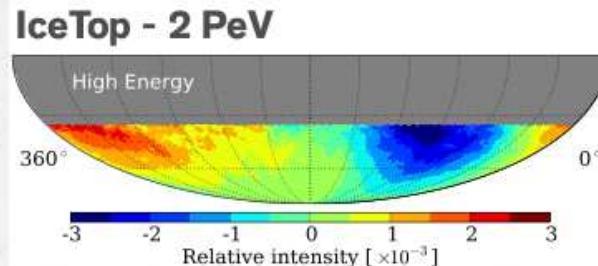
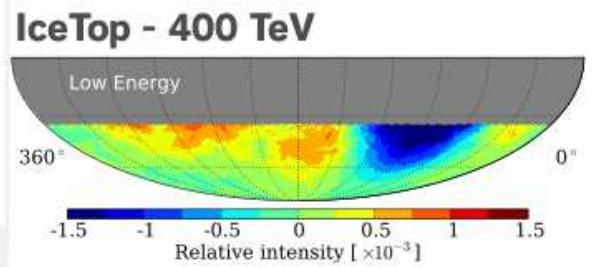
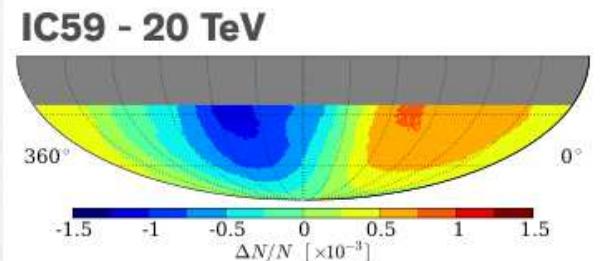
CR composition:
<lnA> & X_{max}



Low-Energy Anisotropy



IceCube & IceTop

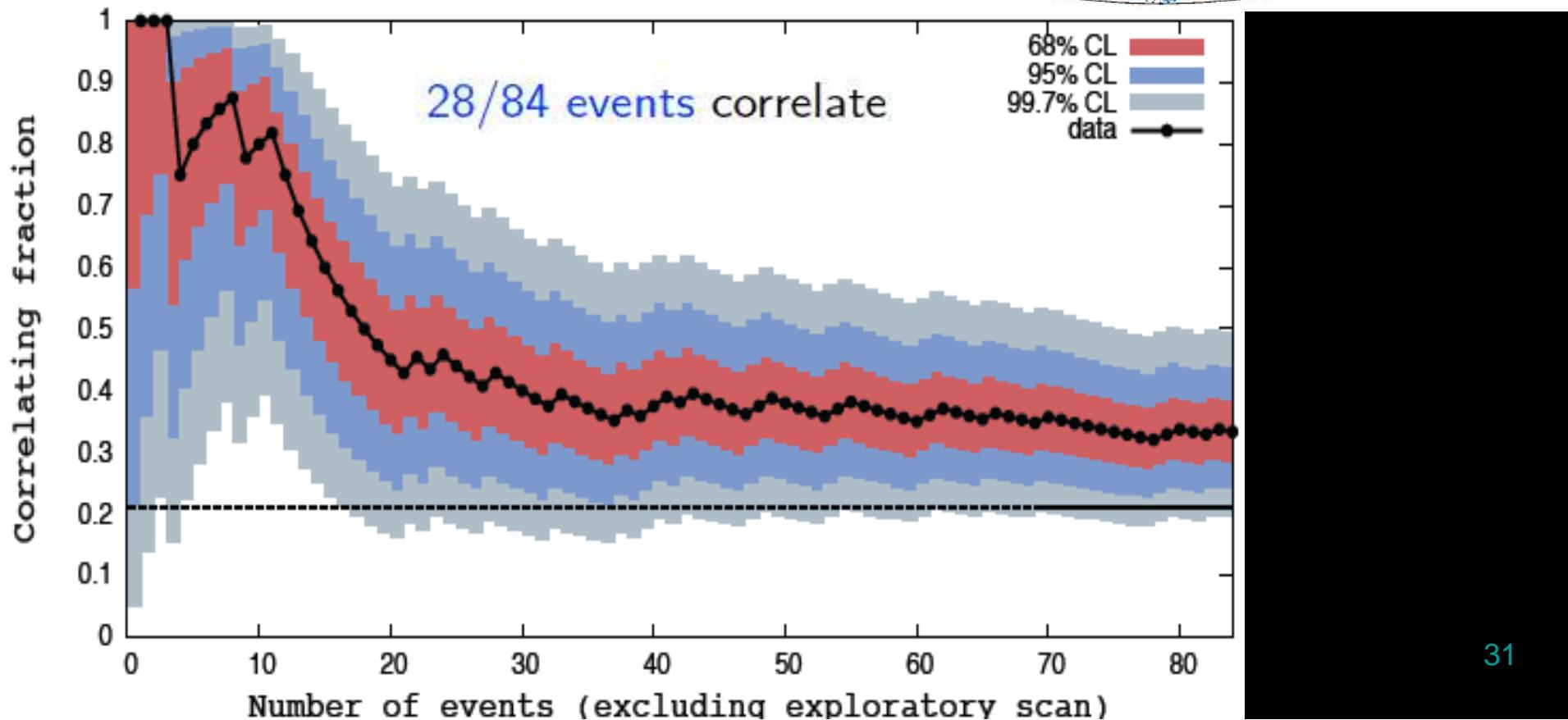
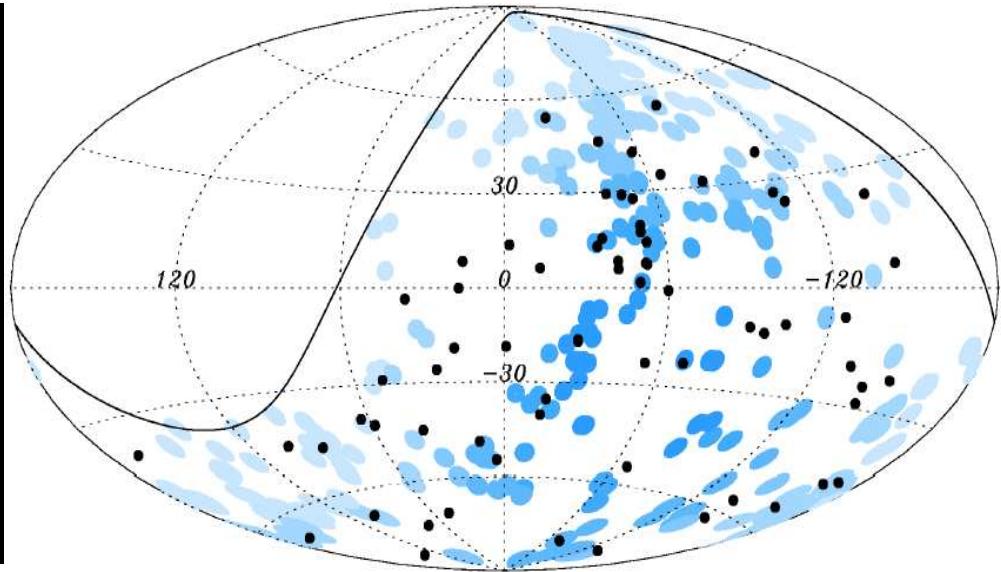


Where does this anisotropy comes from?
Why it changes above hundred TeV?

Tsunesada, ICRC 2013

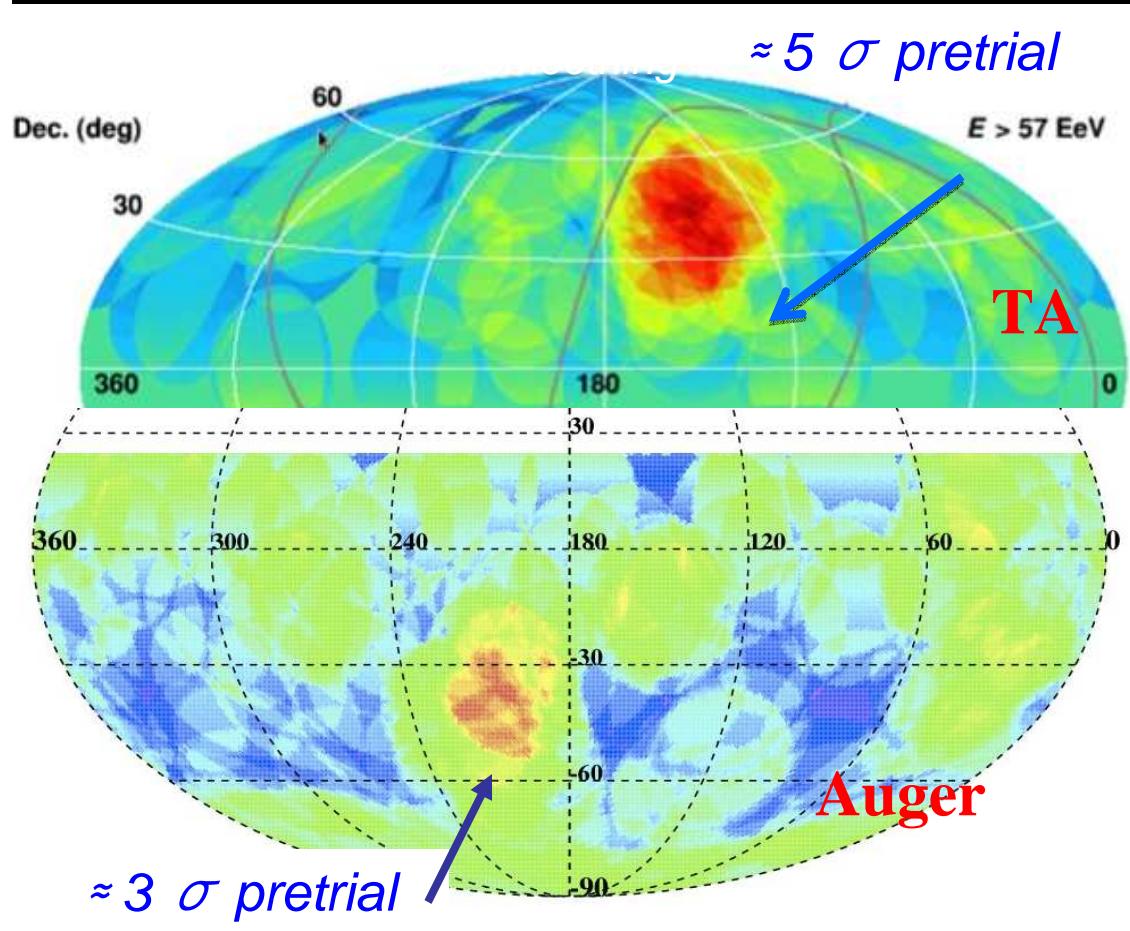
**Auger: consistent
with Anisotropy
above 60 EeV**

AGN catalog test

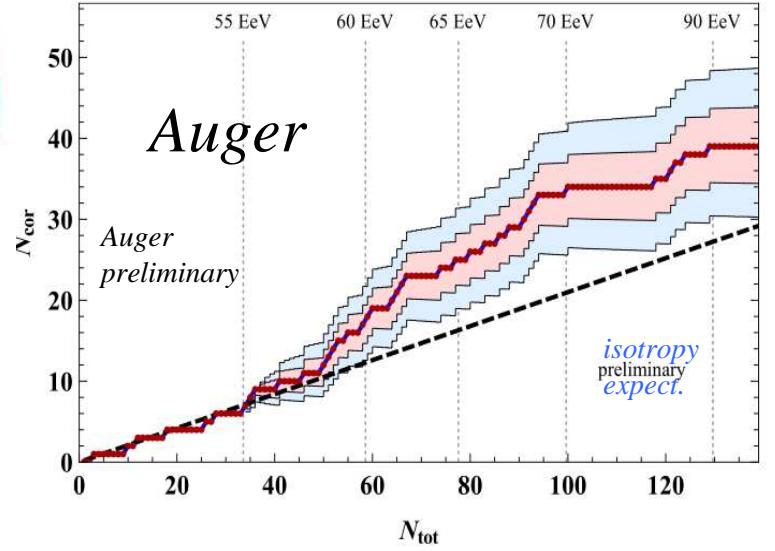


Anisotropy Hints >60 EeV

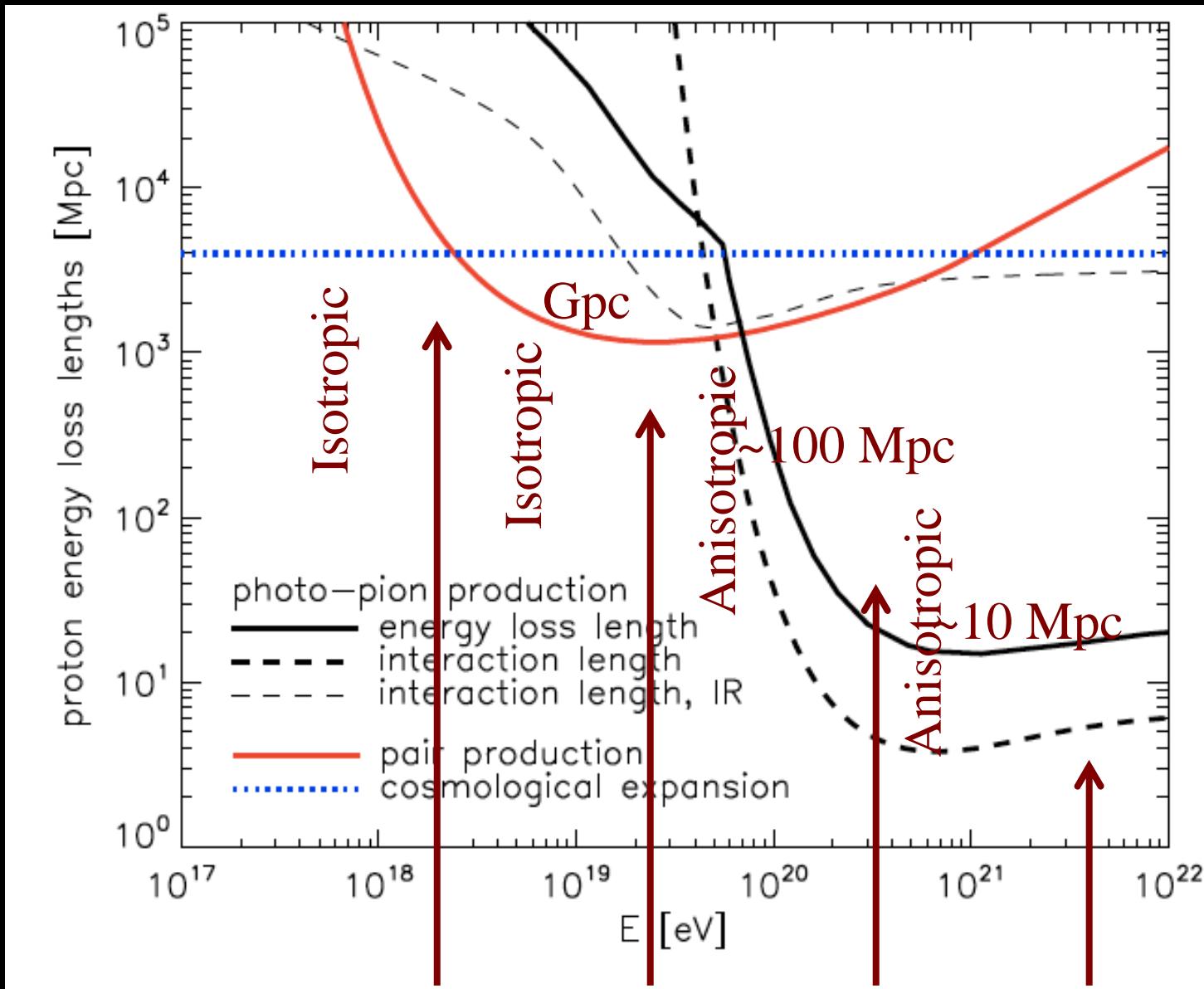
Statistically limited evidence for Cosmic Ray Anisotropy above 5.7×10^{19} eV in the North and South



of events correlating with AGN,
ordered in energy (integral plot)



Greisen-Zatsepin-Kuzmin effect



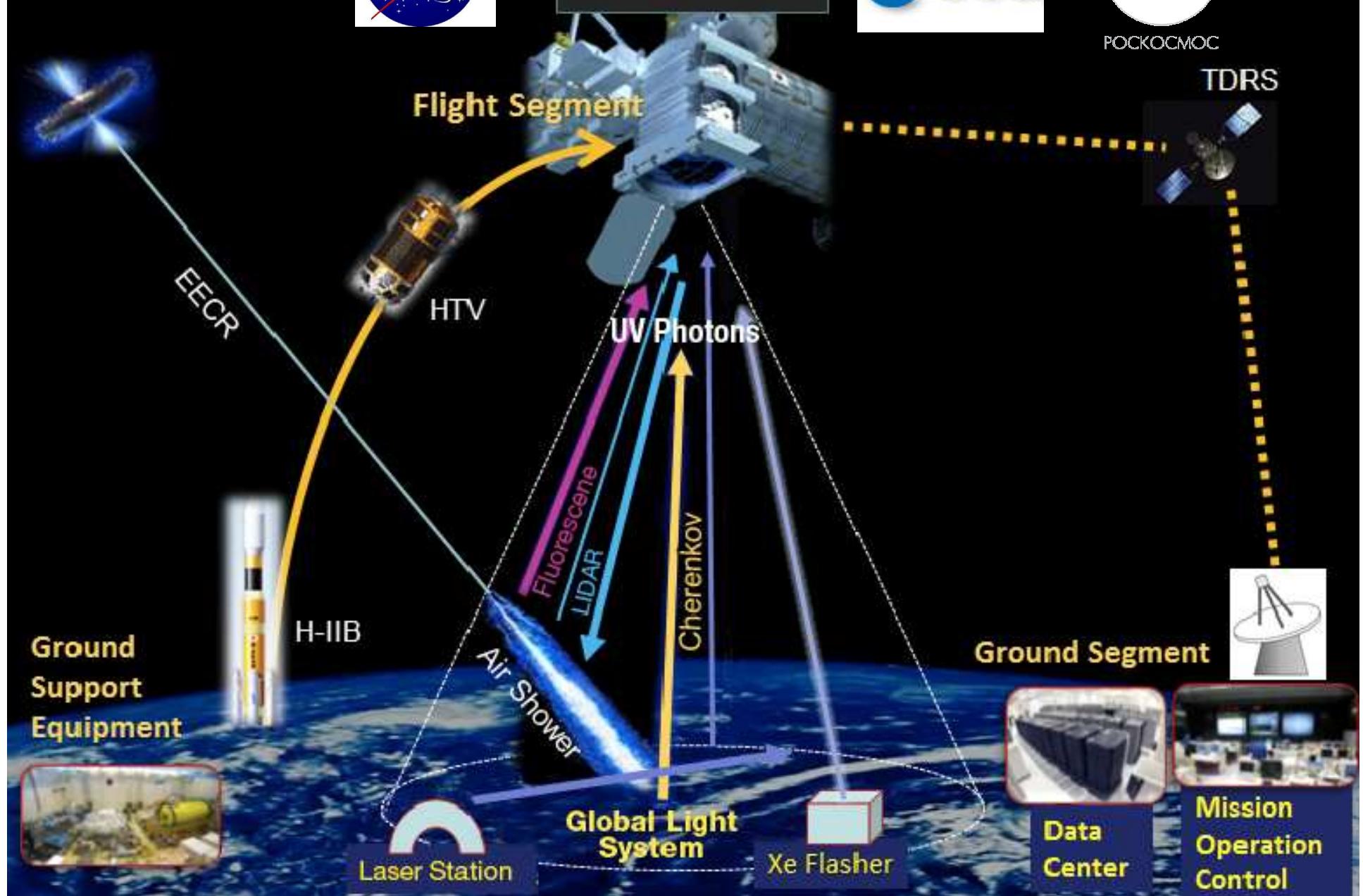


RIKEN

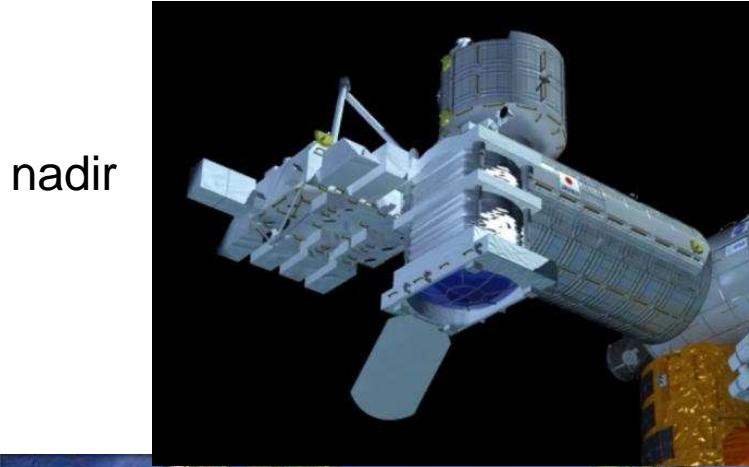
JEM-EUSO



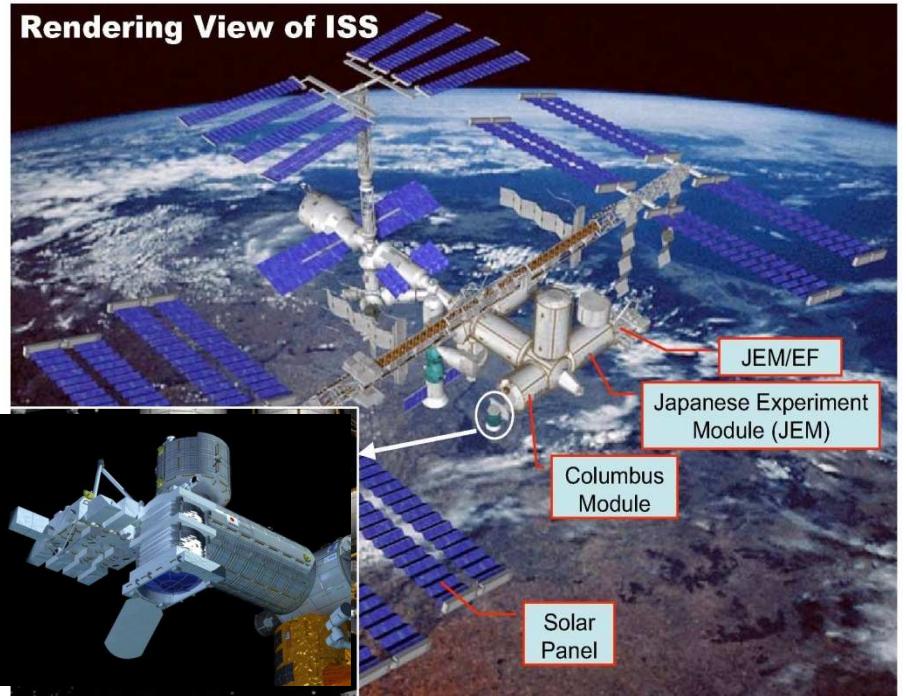
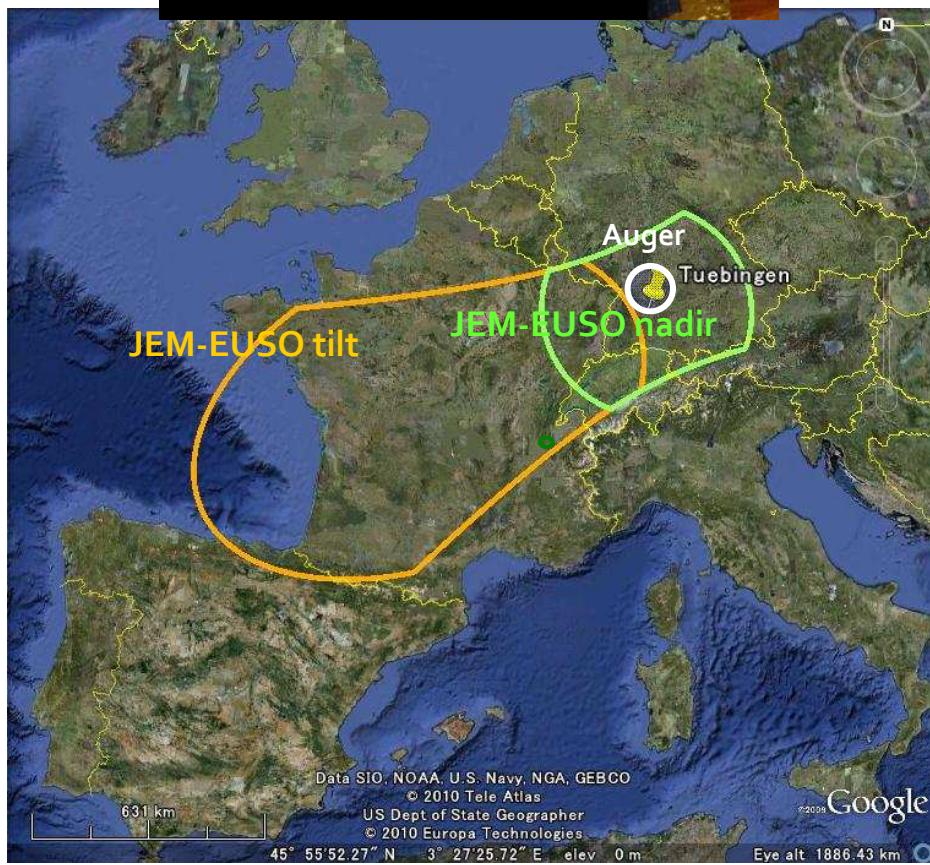
TDRS



JEM-EUSO telescope



tilt



How many UHECRs > 60 EeV?

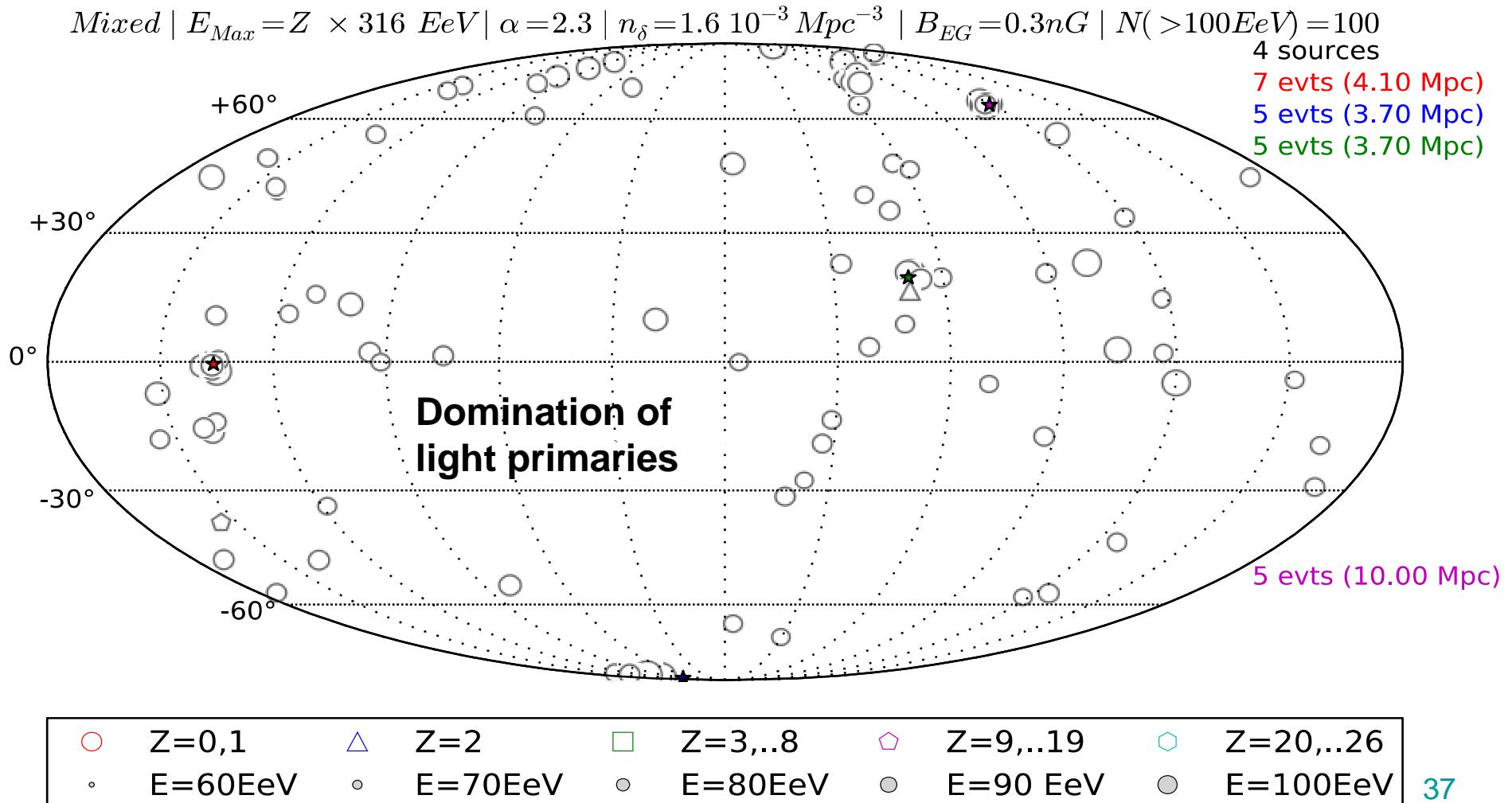
- Auger + TA ~30 events/yr
- **JEM-EUSO**
- **~200 events/yr > 60 EeV**
- Earth - surface $\sim 5 \cdot 10^8 \text{ km}^2$

$\sim 3.4 \cdot 10^6 \text{ events/yr}$



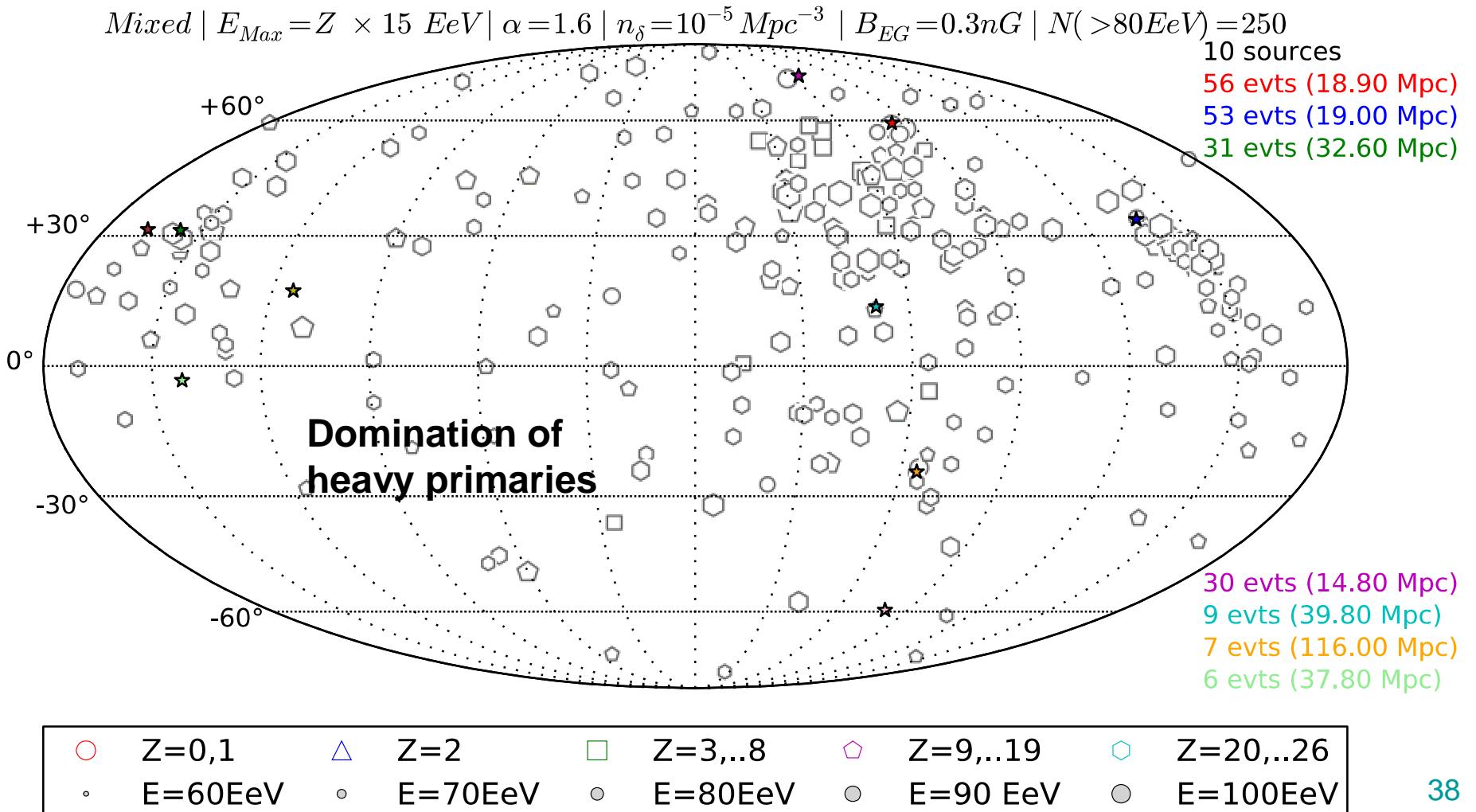
To detect sources

- Increase statistics: ~1,000 events > 60 EeV
- ~100 events > 100 EeV



To detect sources

- Increase statistics: ~1,000 events > 60 EeV
- ~100 events > 100 EeV



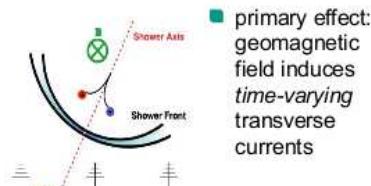
15 Radio Measurements



Understanding the Emission Mechanisms

0661 Huege

Radio emission physics as predicted by theory



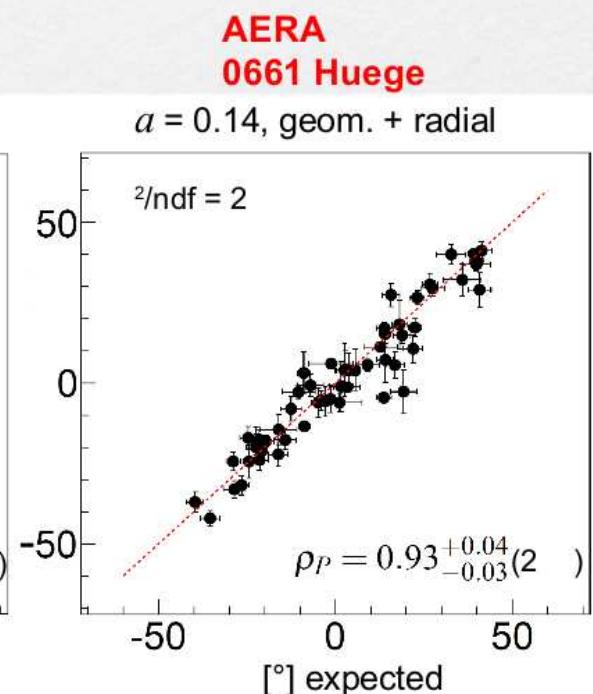
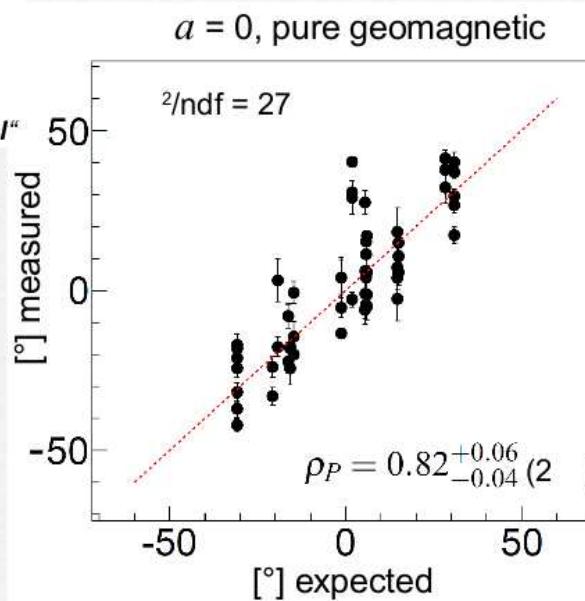
- primary effect:
geomagnetic field induces
time-varying transverse currents



- secondary effect:
time-varying net charge excess
(Askaryan effect)



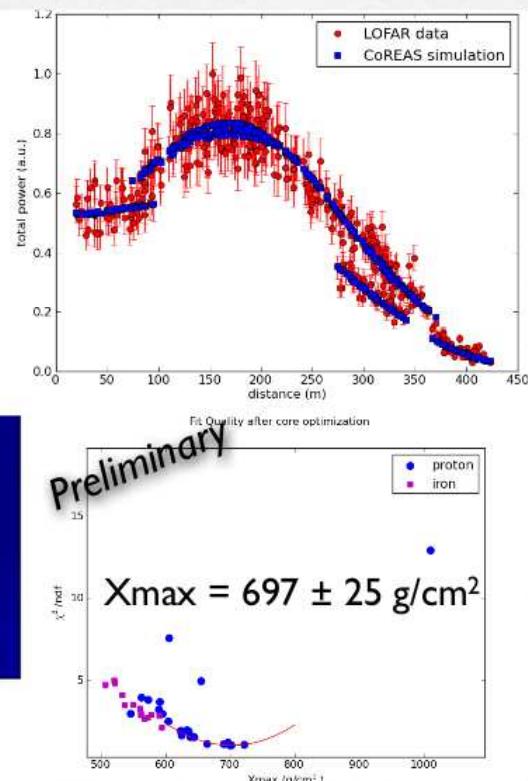
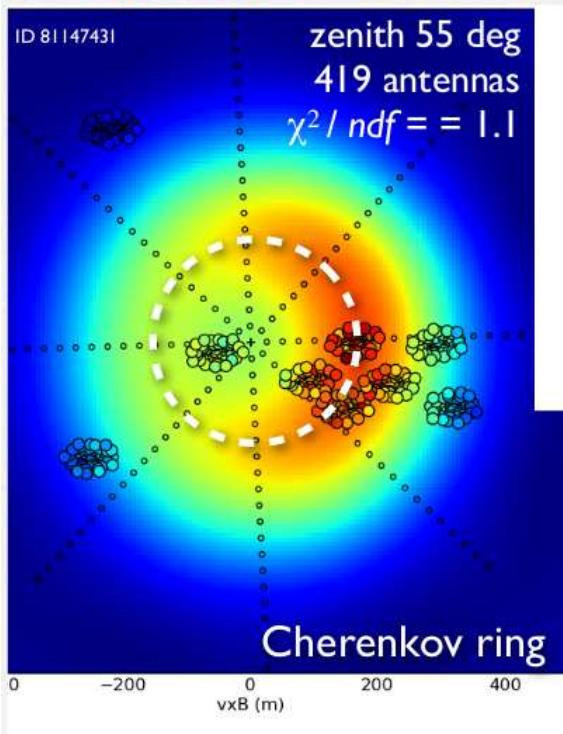
„ $v \times B$ “
(polarization patterns show unit vectors in the shower plane)



- adding a radial component with $a=0.14$ clearly improves agreement

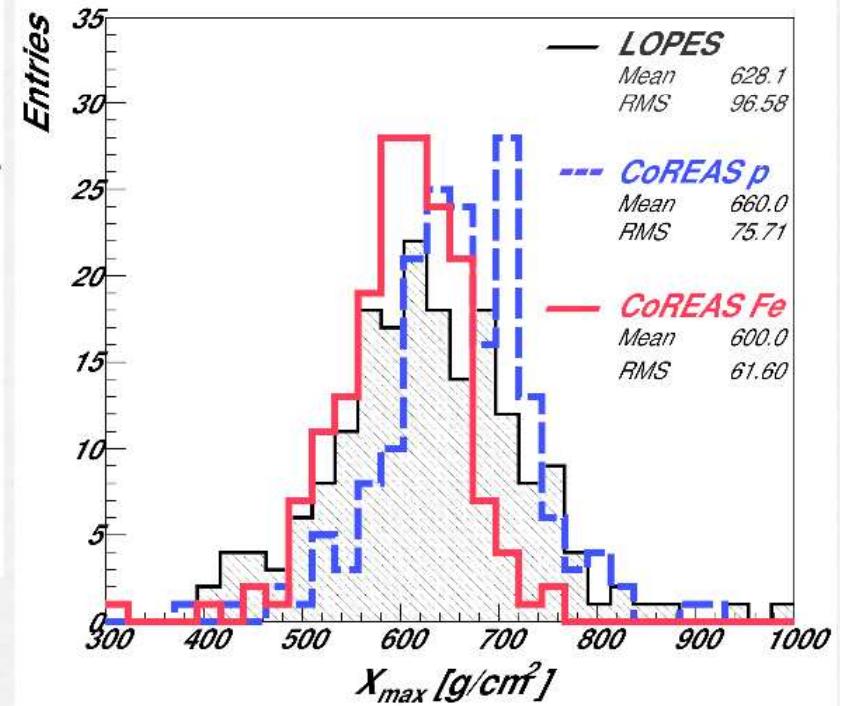
Radio Tells Us X_{\max}

LOFAR
0579 Buitink



LOPES
0439 Palmieri

$$X_{\max} = a_i [\ln(b_i \varepsilon_{\text{ratio}})]^{c_i}$$



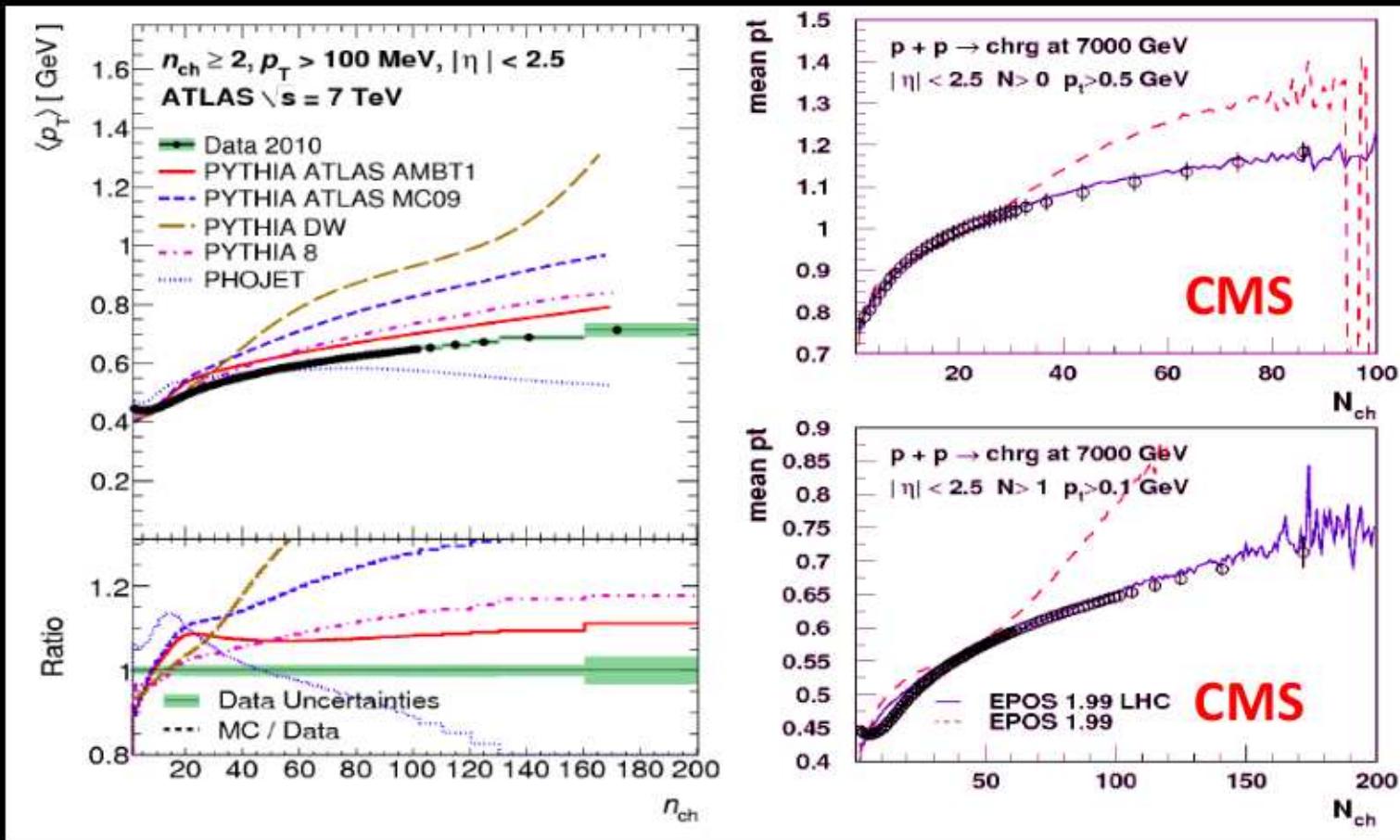
Tsunesada, ICRC 2013

CONCLUSIONS

- a) CRs and particle physics: a fruitful interplay.
- b) ARGO: a bridge between direct measurements and EAS experiments at the knee.
- c) KASCADE-Grande results seem to give a coherent picture of the knee region, with a rigidity dependence of the knees and a first indication of a transition between galactic and extra-galactic components around 10^{17} eV
- d) Very nice agreement between TA and Auger results on energy spectrum.
- e) Composition measured by Auger and TA is also in agreement inside the systematic uncertainties and it shows a tendency for an increase in the average mass towards the highest energies.
- f) Anisotropies are seen on middle and large scale at all energies, however, there is not a clear understanding of the origin of their evolutions.
- g) LHAASO is under development to give a more detailed description of the knee(s) region (from 10^{14} eV to a few 10^{18} eV).
- h) Auger infill will look close into the transition region 10^{17} - 10^{19} eV
- i) JEM-EUSO hopefully will see the first CRs sources in the sky.

THANK YOU

Average P_T

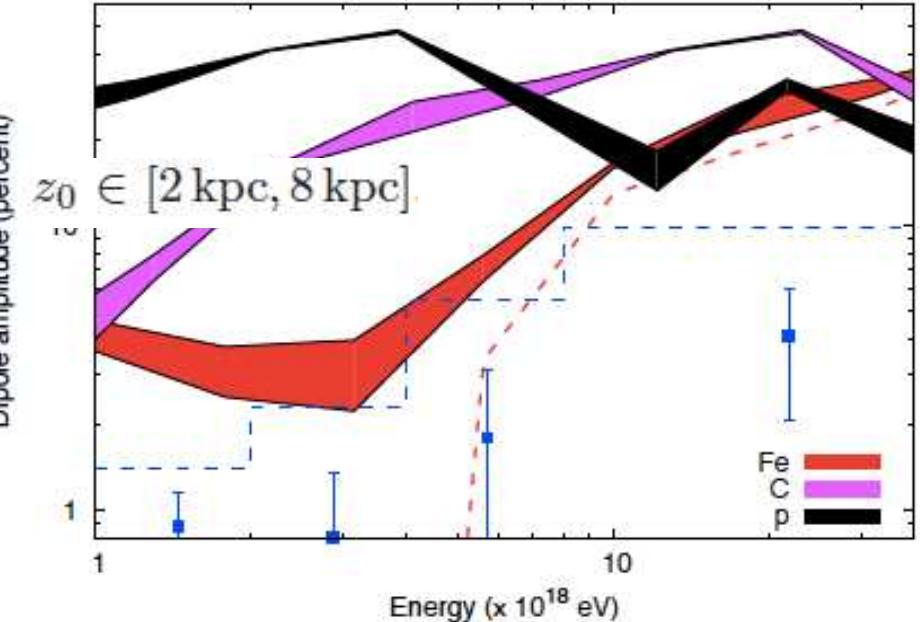
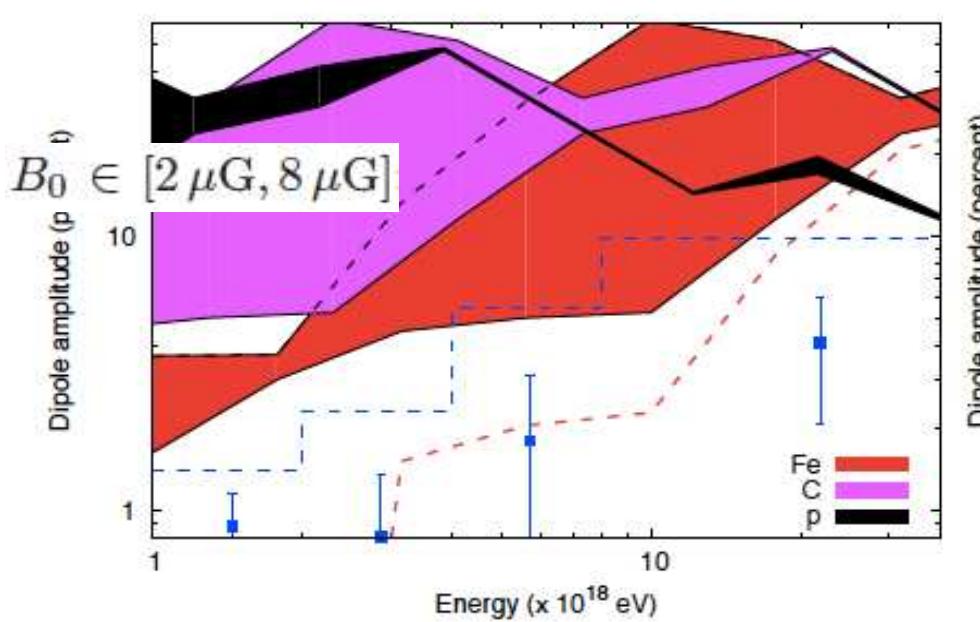


- *The average P_T distribution is not well modeled by standard HP MCs – but is well modeled by EPOS LHC*

Recent Results

- $E > 20$ EeV Cosmic Rays are EXTRAGALACTIC

Auger Anisotropy limits: rule out Galactic protons to CNO as dominant CR component $E > 1$ EeV and Fe above 20 EeV



Giacinti et al '11

Current Status

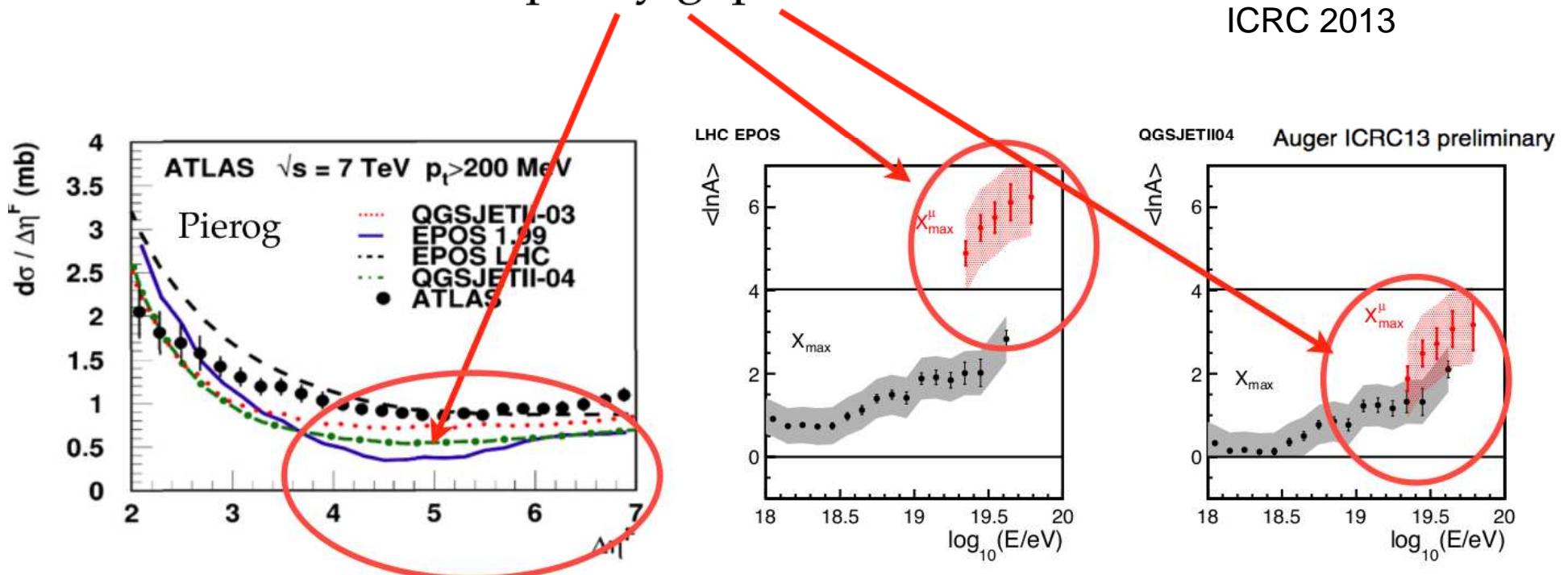
- Leading Observatories:
 - Pierre Auger Observatory: 3,000 km² Argentina
 - Telescope Array: 700 km² Utah, USA
- Agreement on the shape of the spectrum
- Energy scale: 10% difference bet. Auger and TA
- Composition: from light to heavy (?)
- Anisotropies: hints above 60 EeV – no >5 σ signal
- Need significant INCREASE in STATISTICS $E > 60$ EeV = EECR (extreme energy cosmic rays)

MASS COMPOSITION VII

$\langle \ln A \rangle$ from MPD & $\langle X_{\max} \rangle$

Different rapidity gap distributions

A.Letessier-Selvon
ICRC 2013



Still room to improve description of hadronic interaction models ...

To detect sources

- Observe at higher energies – fewer sources

