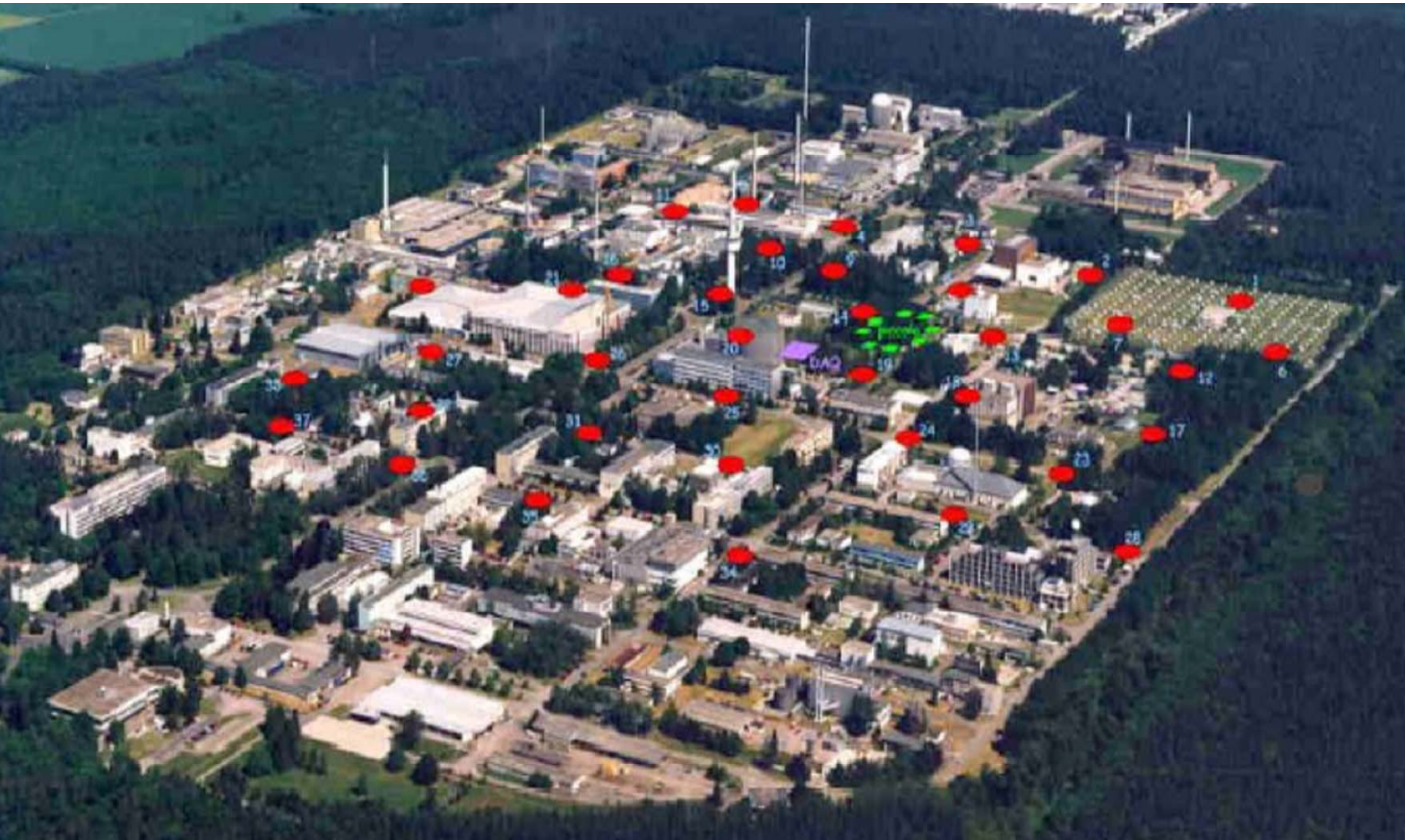
Karlsruhe Institute of Technology

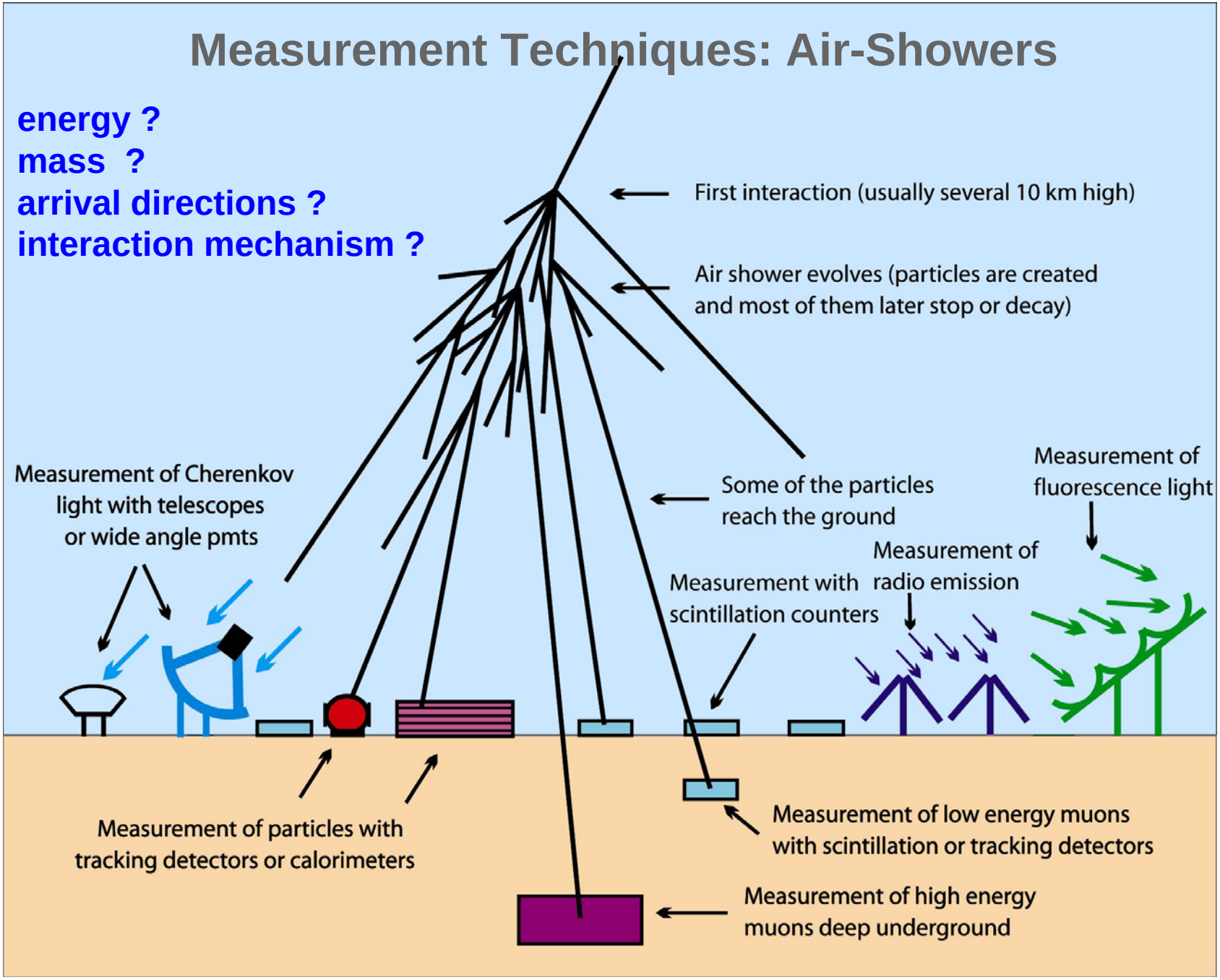
KASCADE-Grande

HEP 2013
Stockholm
18-24 July 2013

…from PeV to EeV: investigating the knee(s)



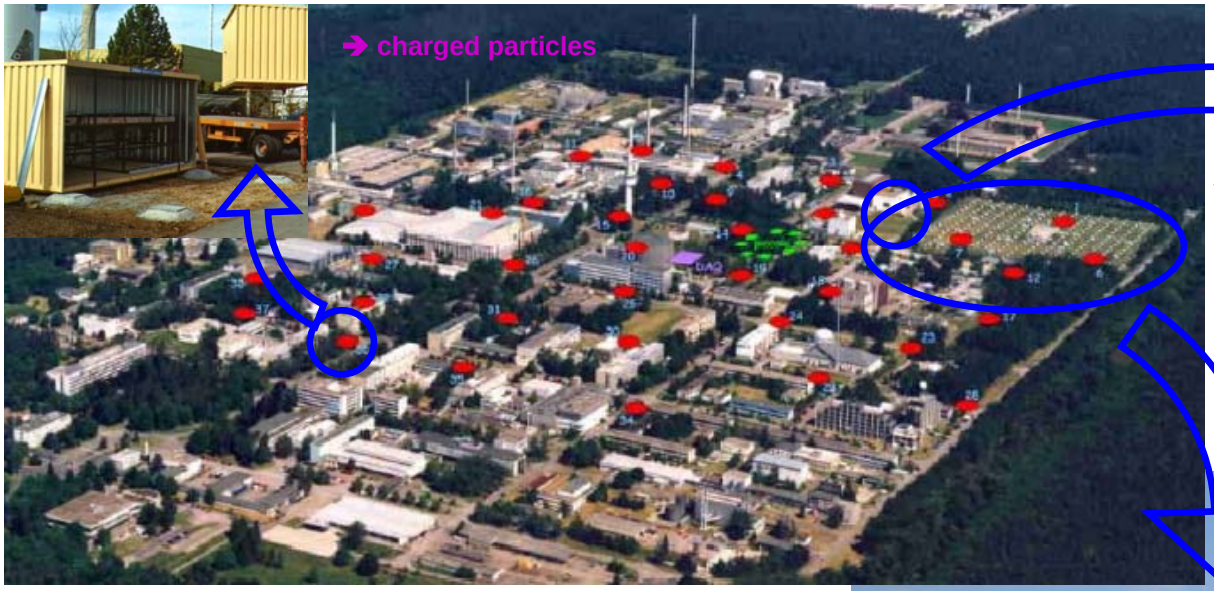
Measurement Techniques: Air-Showers



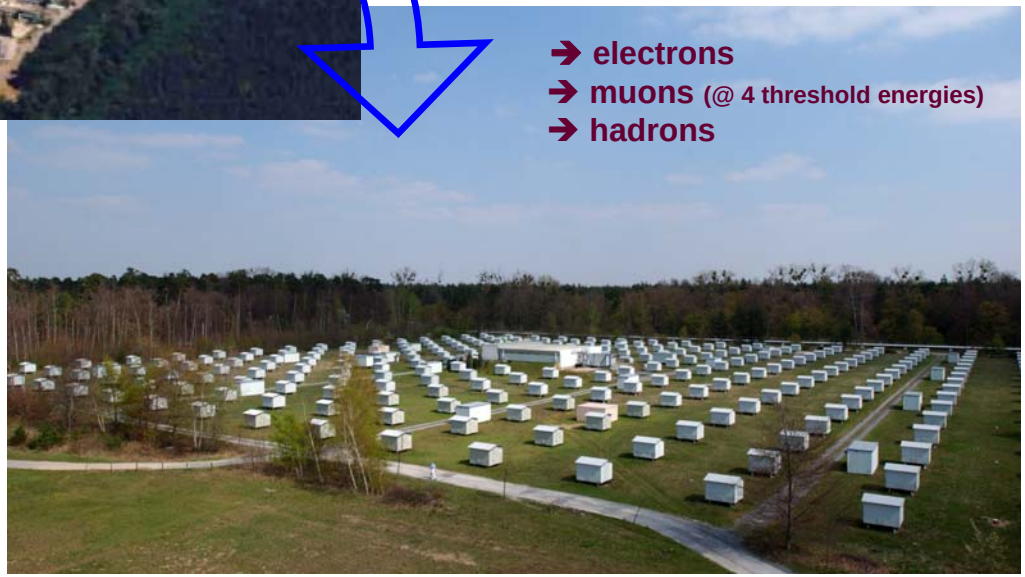
KASCADE-Grande

= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

Measurements of air showers in the energy range E_0 = 100 TeV - 1 EeV

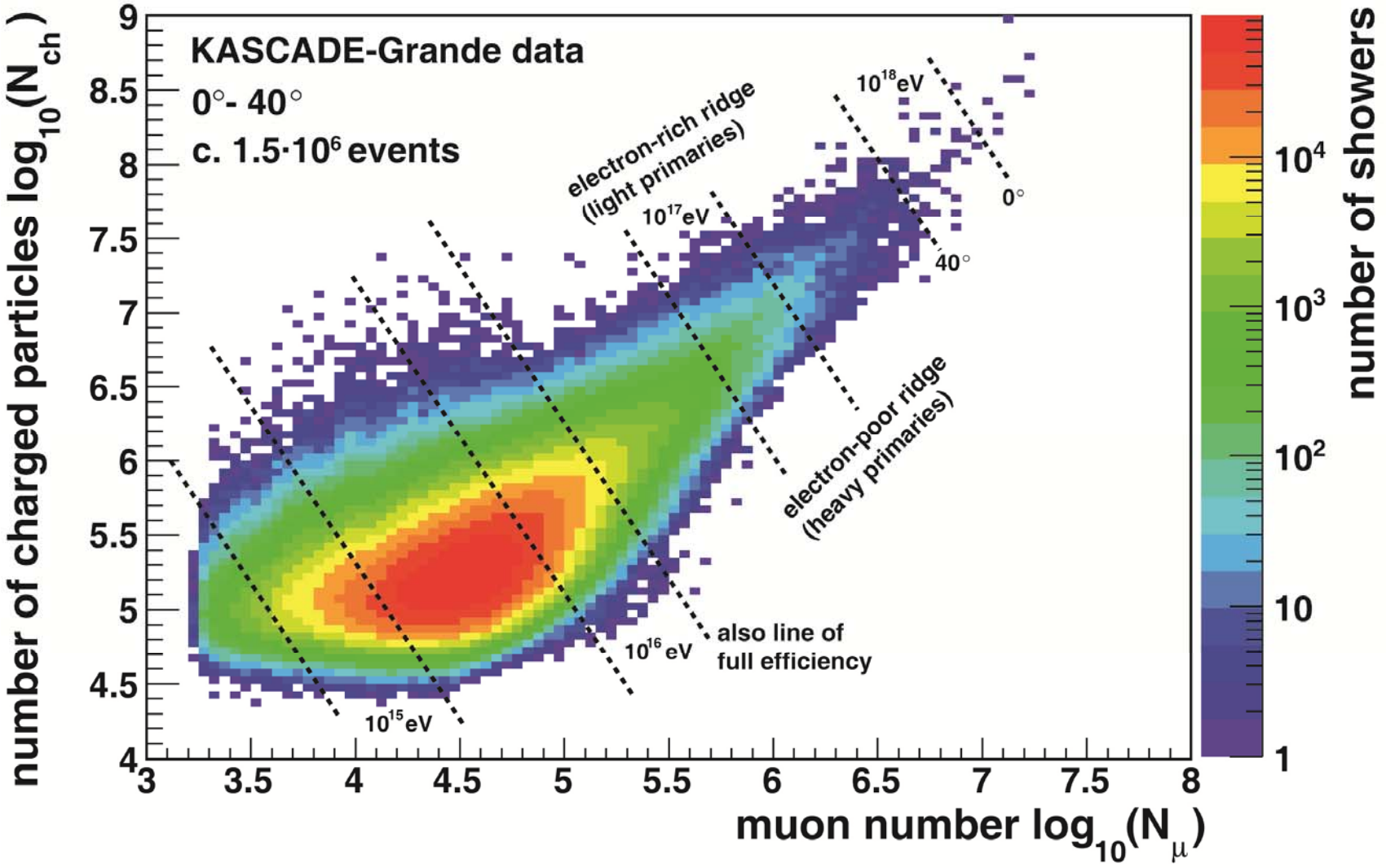


➔ electrons
➔ muons (@ 4 threshold energies)
➔ hadrons



- **core and direction** (from Grande)
- **shower size** (charged particles)
- **muon number** (from KASCADE)
- **local muon density** (from KASCADE)
- **local charged particle density S(500)**
- **...**

2-dimensional shower size spectrum



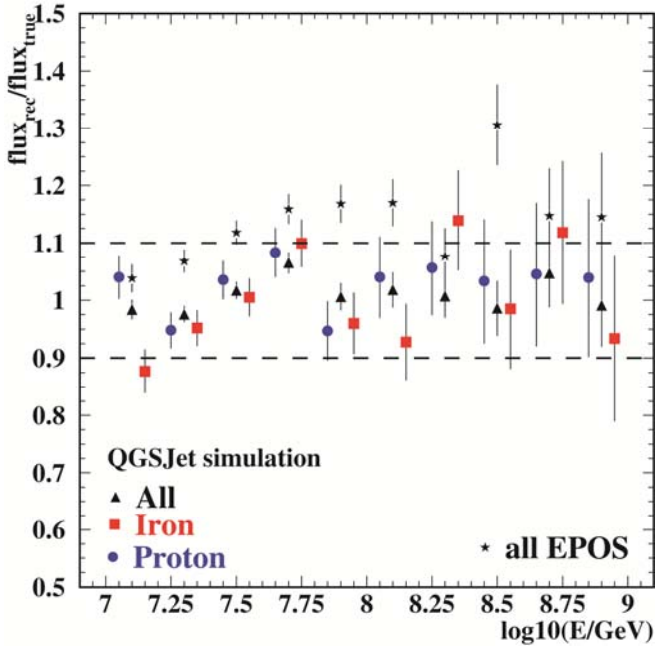
➔ **determination of primary energy**

➔ **separation in "electron-rich" and "electron-poor" event**

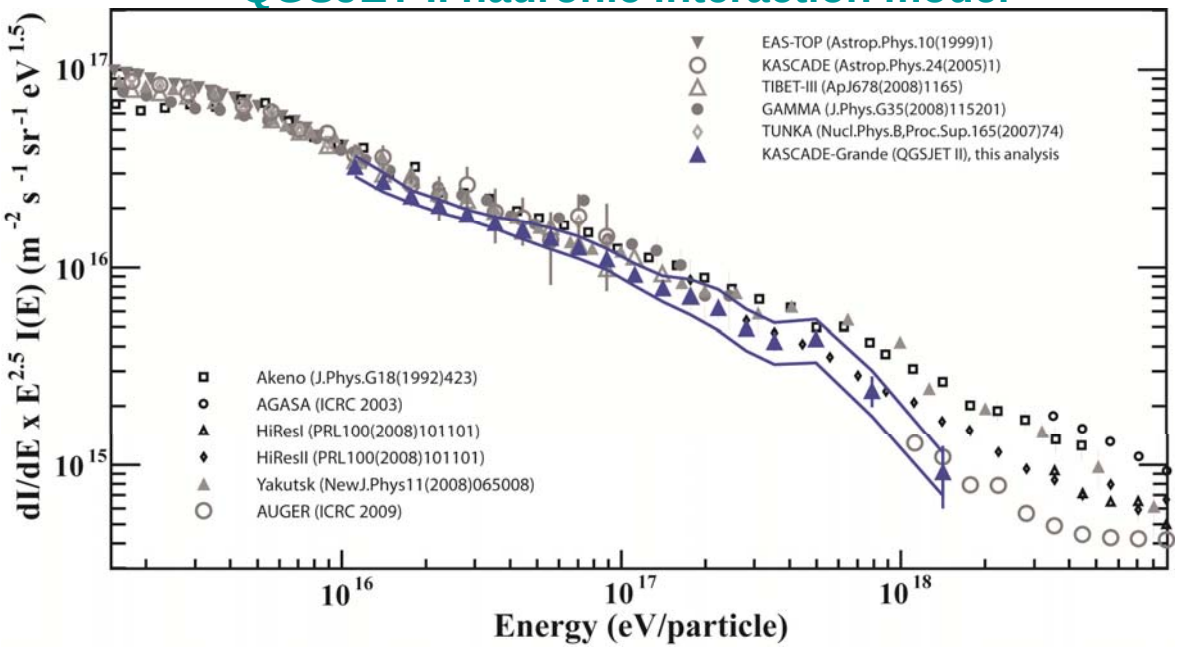
All-particle energy spectrum :

$$\log_{10}(E) = [a_p + (a_{Fe}-a_p)\cdot k]\cdot \log_{10}(N_{ch}) + b_p + (b_{Fe}-b_p)\cdot k$$

$$k = (\log_{10}(N_{ch}/N_\mu) - \log10(N_{ch}/N_\mu)_p) / (\log10(N_{ch}/N_\mu)_{Fe} - \log10(N_{ch}/N_\mu)_p)$$



QGSJET II hadronic interaction model

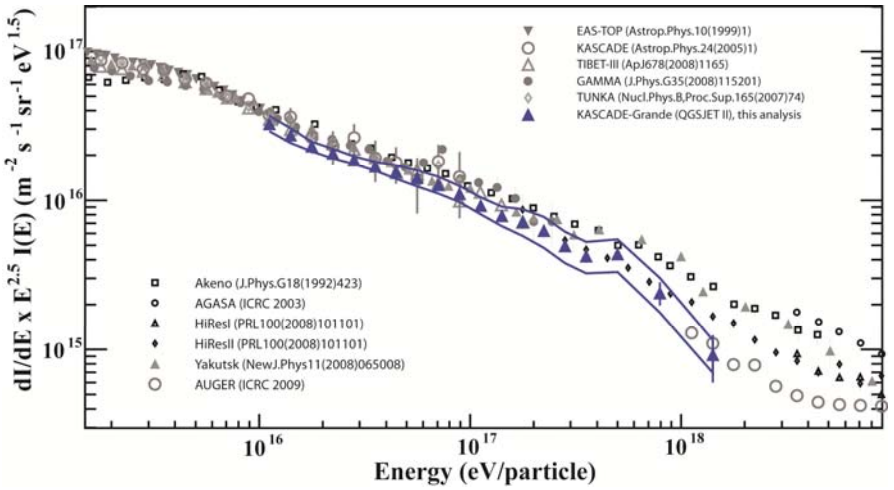


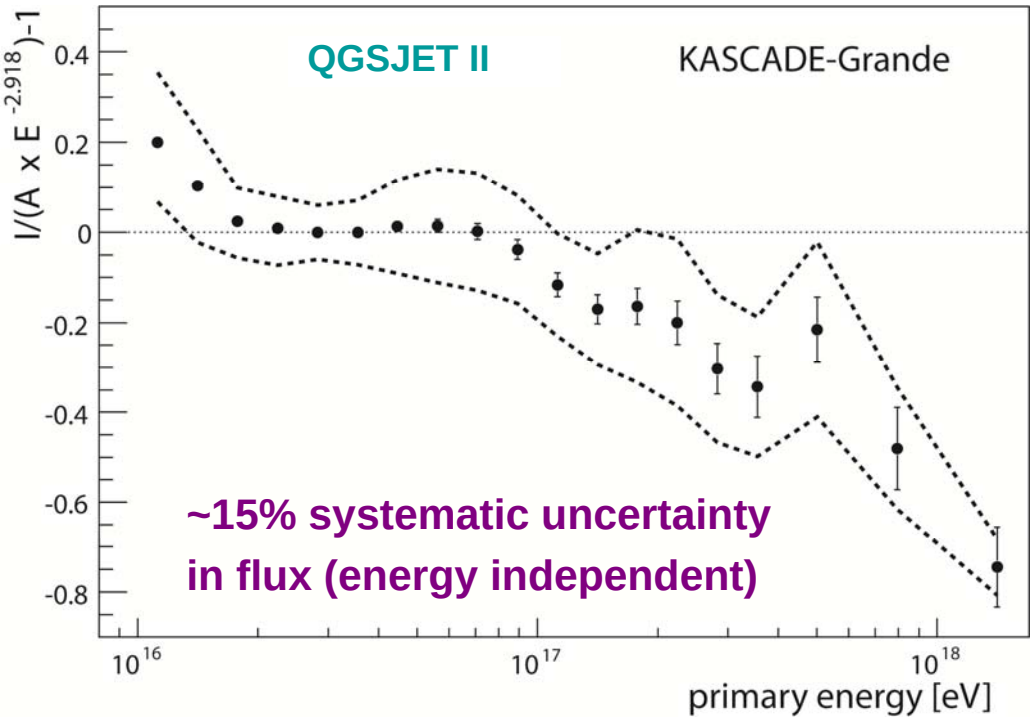
-different zenith angle bins
-no composition dependence

Astroparticle Physics 36 (2012) 183

KASCADE-Grande
all-particle energy spectrum

Astroparticle Physics 36 (2012) 183

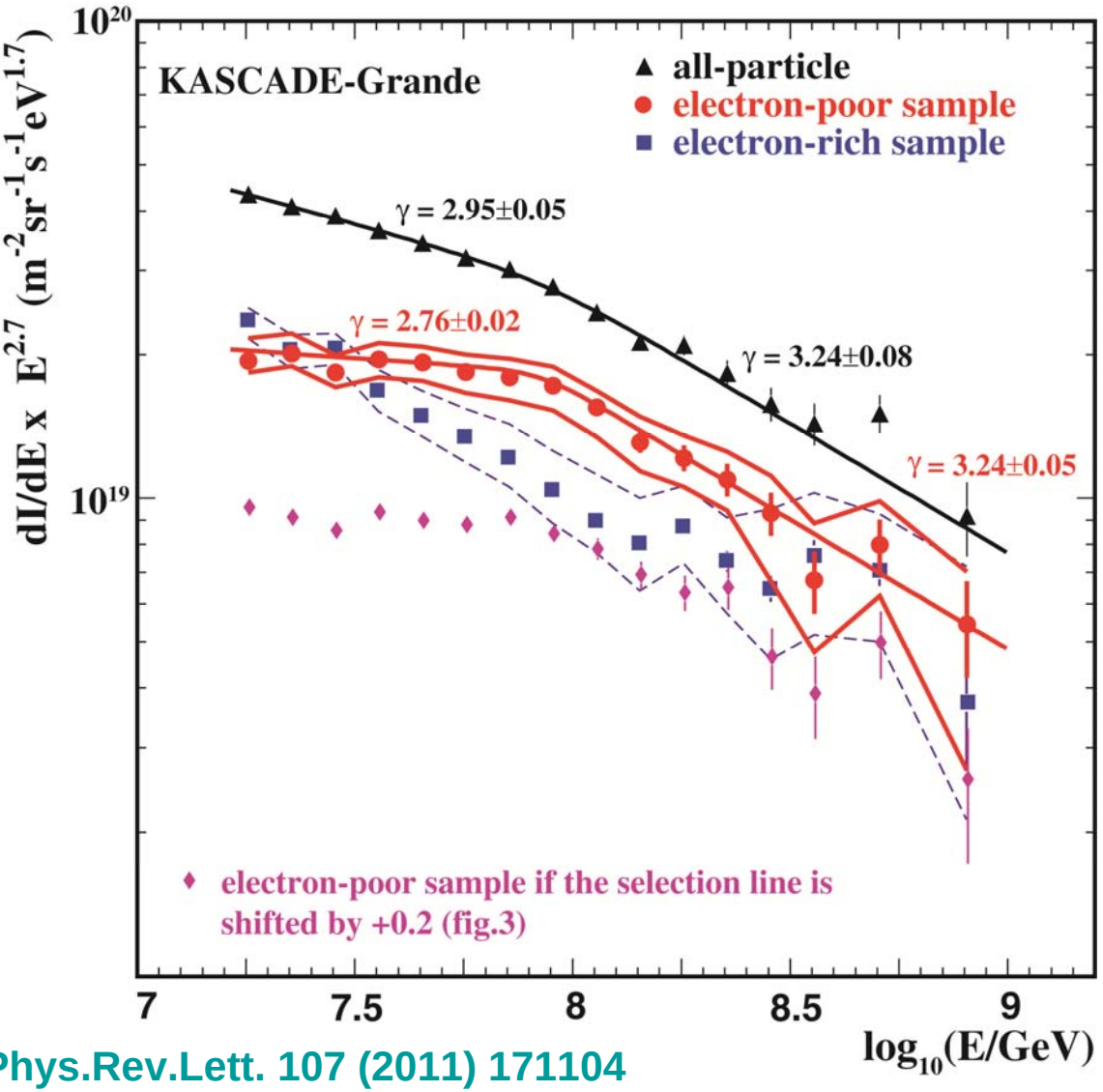




- **spectrum not a single power law**
- **hardening of the spectrum above 10^{16}eV**
- **steepening close to 10^{17}eV (2.1σ)**

KASCADE-Grande: Spectra of individual mass groups

$k = (\log_{10}(N_{ch}/N_{\mu}) - \log10(N_{ch}/N_{\mu})_p) / (\log10(N_{ch}/N_{\mu})_{Fe} - \log10(N_{ch}/N_{\mu})_p)$



Phys.Rev.Lett. 107 (2011) 171104

- spectra of individual mass groups:

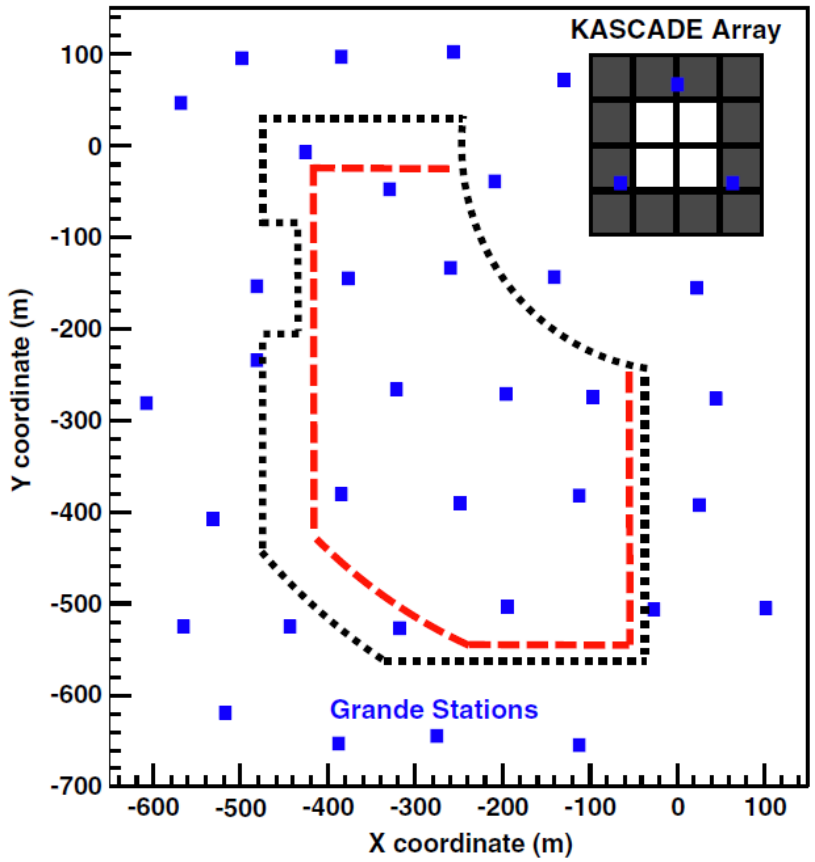
➔ steepening close to 10^{17}eV (2.1σ) in all-particle spectrum

➔ 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: spectrum of light primaries



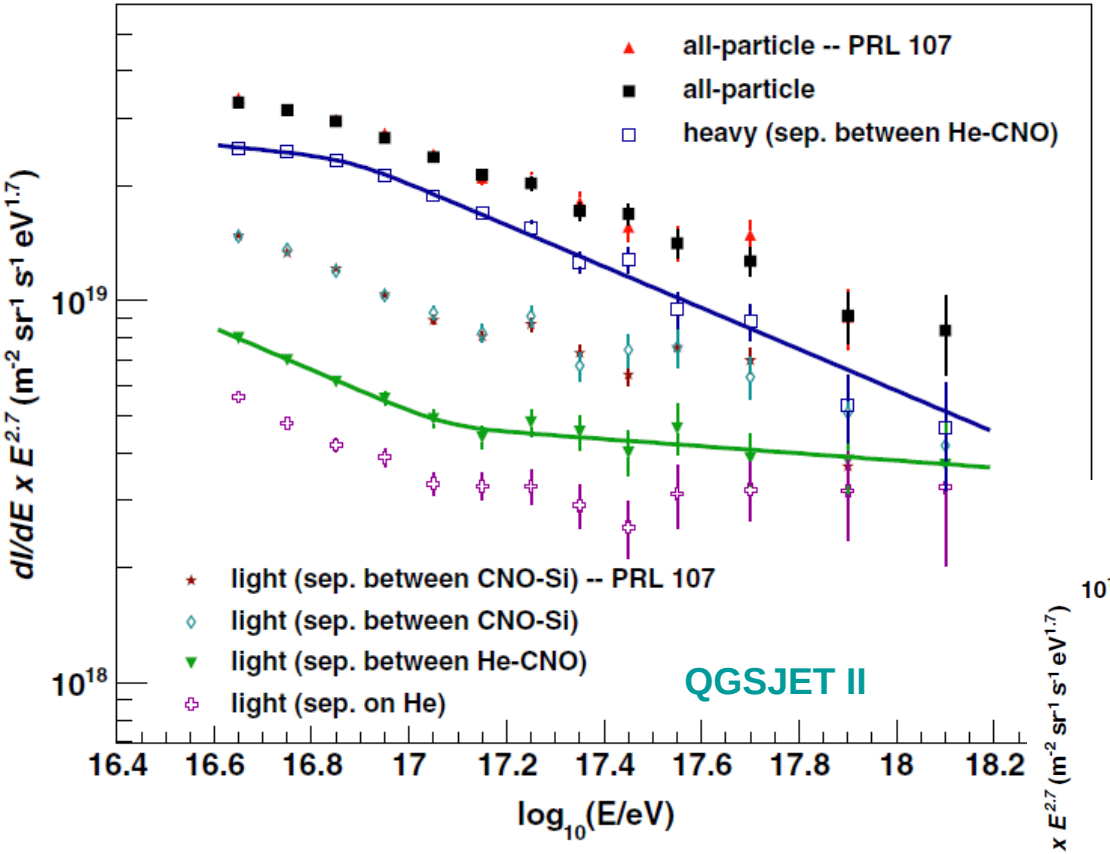
- **re-investigation of the spectrum of light primaries:**

➔ **increased area (higher threshold)**
➔ **1 year more data**
➔ **improved selection cut**

Phys.Rev.D (R) 87 (2013) 081101

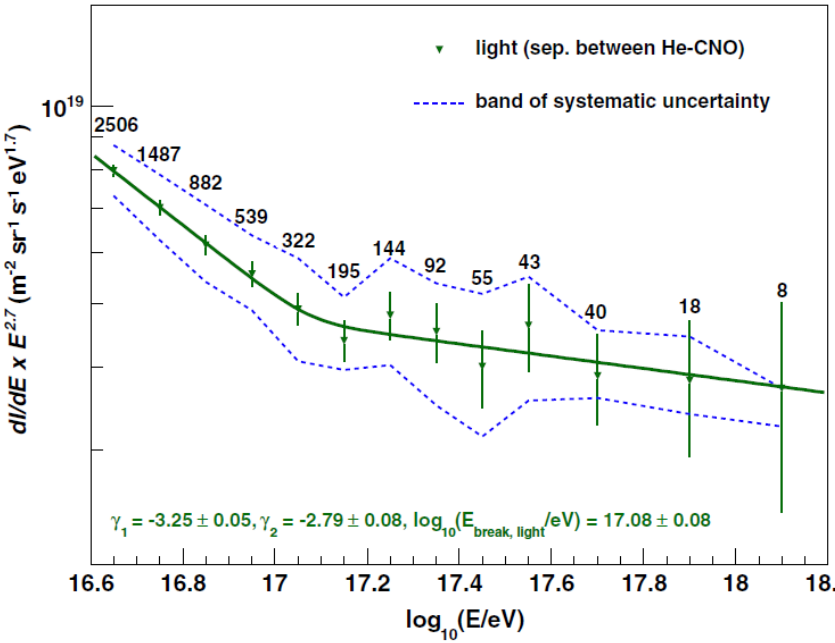
KASCADE-Grande: spectrum of light primaries

observation of a „light“ ankle at 1-2·10^{17} eV



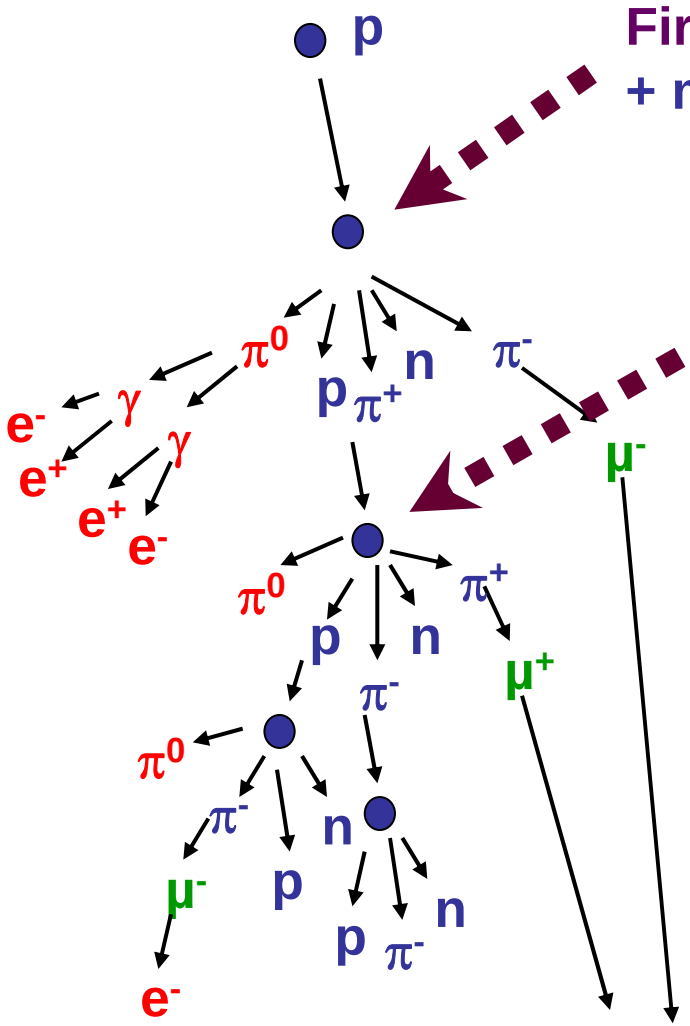
➔ hardening at 10$^{17.08}$ eV (5.8σ) in light spectrum

➔ slope change from γ = -3.25 to γ = -2.79!



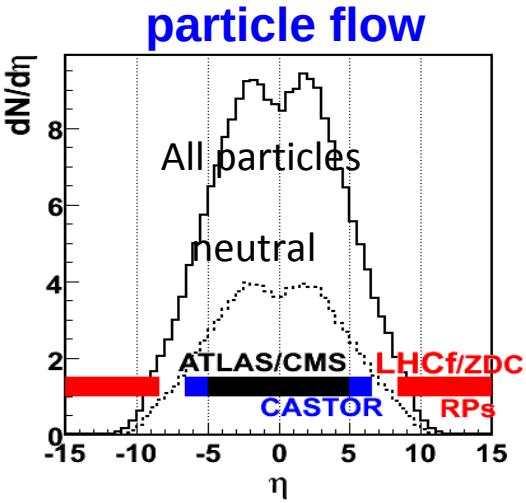
Phys.Rev.D (R) 87 (2013) 081101

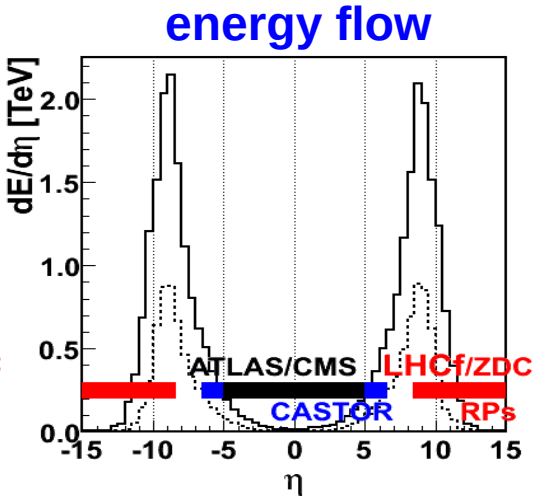
Validity of Hadronic Interaction Models



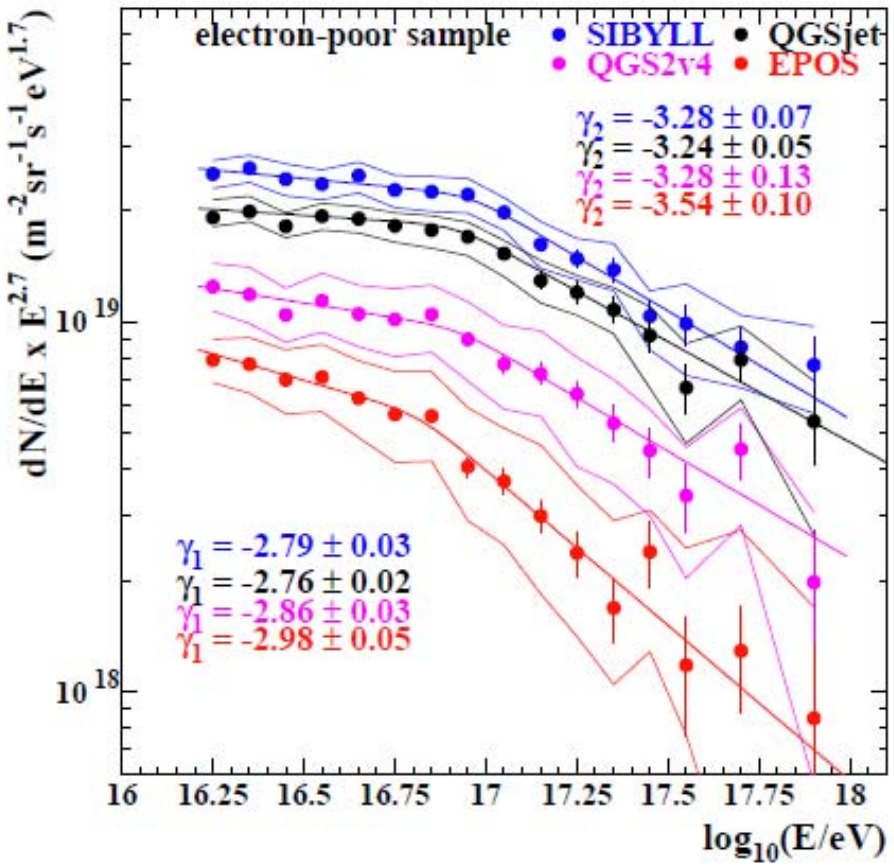
First, high energy interaction: LHC
+ multiparameter measurements EAS

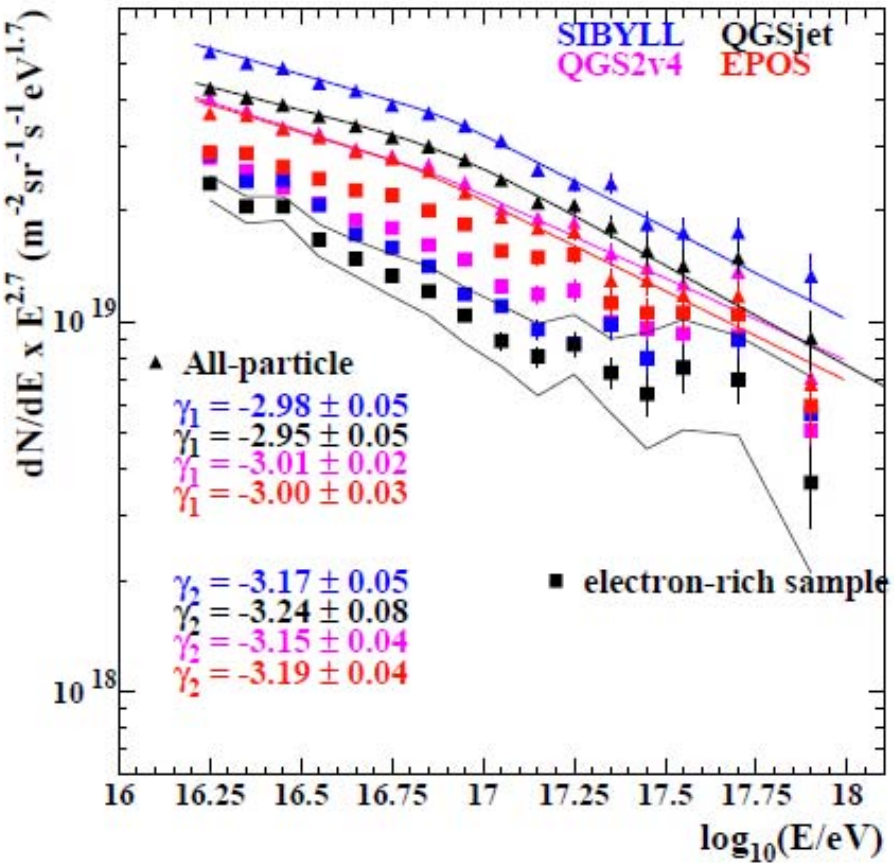
Secondary interactions:
Fix target experiments
+ multiparameter measurements EAS





KASCADE-Grande: model dependence





- Structures of all-particle, heavy and light spectra similar

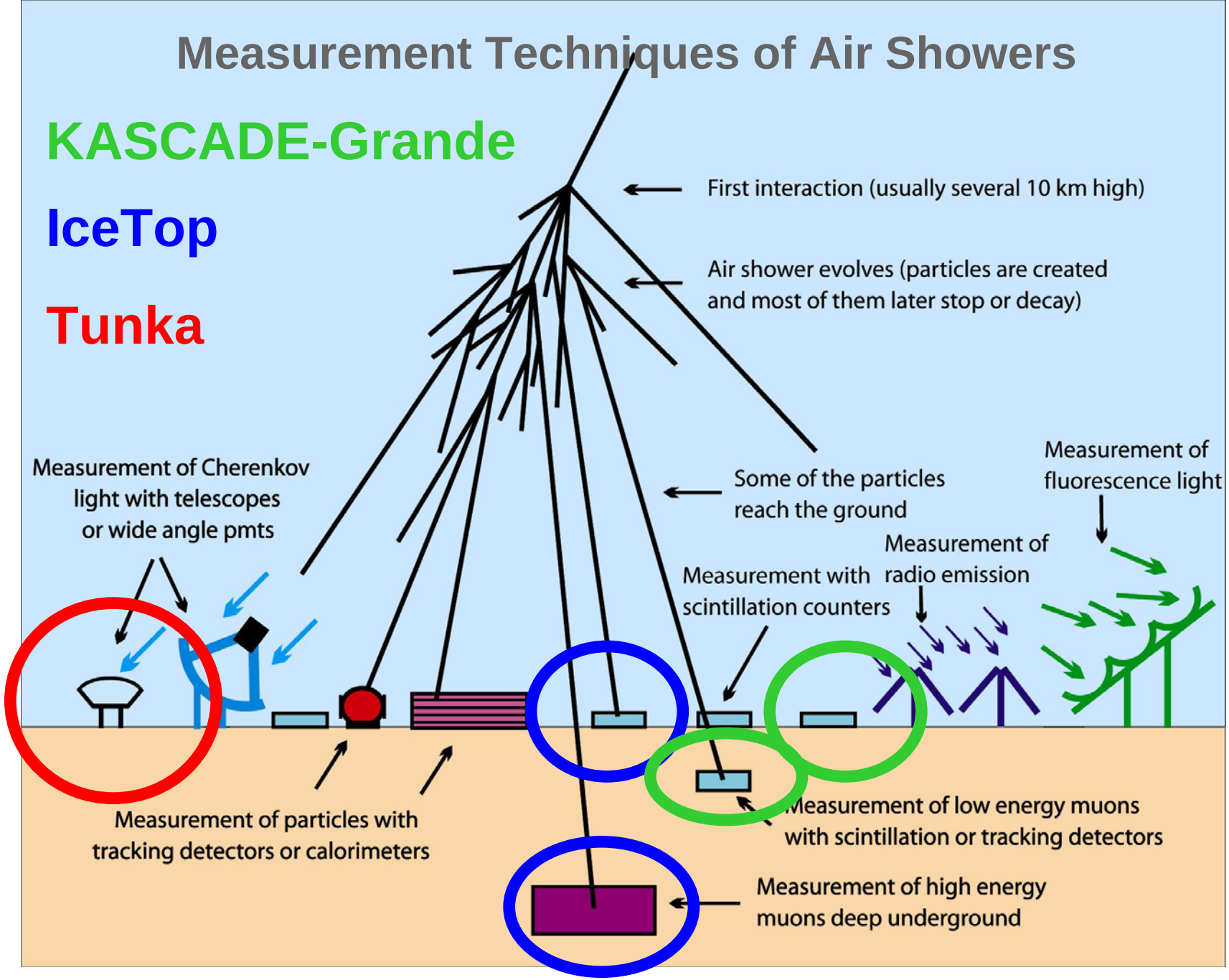
➔ knee by light component and heavy component; ankle by light component

- relative abundances different for different high-energy hadronic interaction models

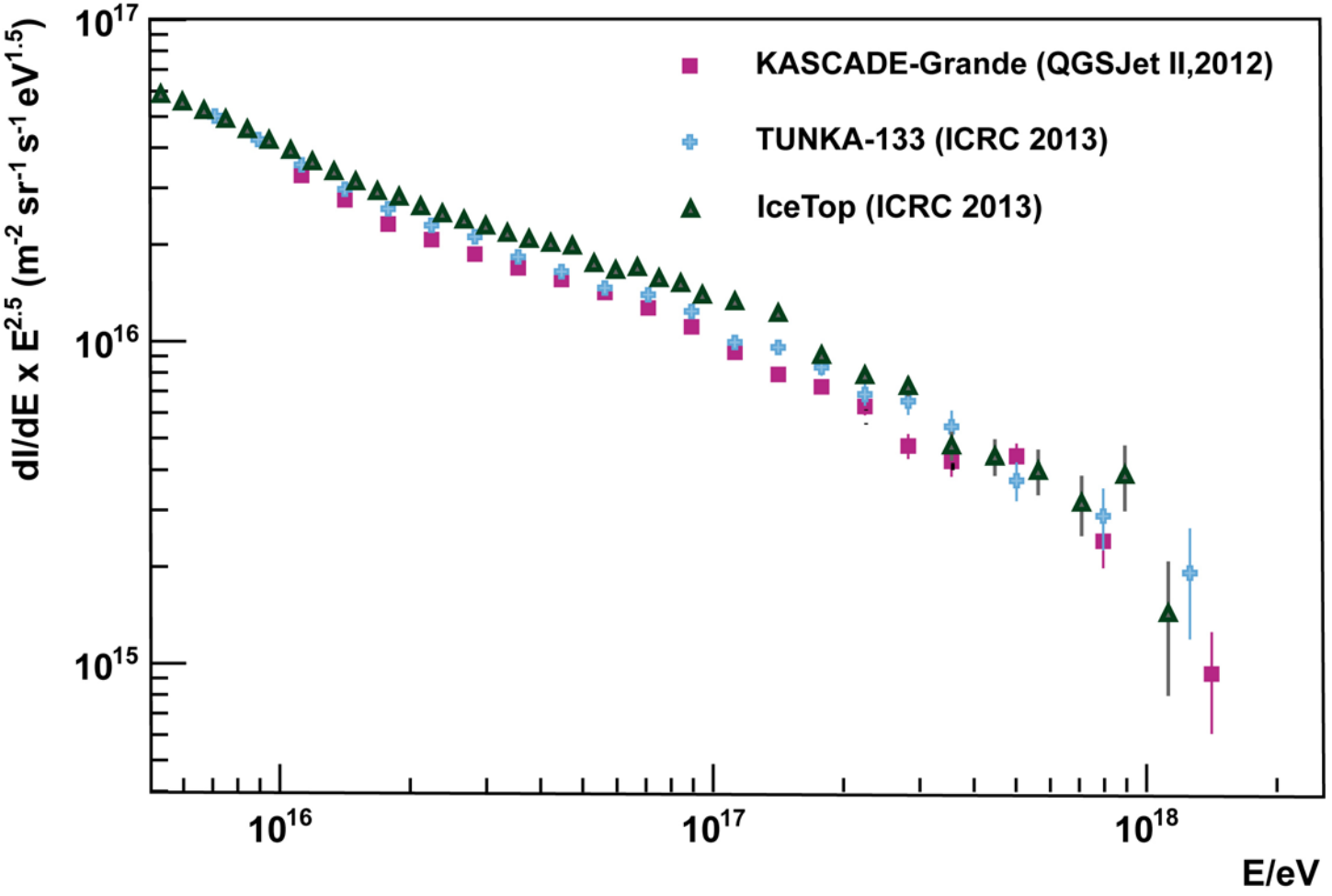
Advances in Space Research (2013) accepted - dx.doi.org/10.1016/j.asr.2013.05.008

Present Main Experiments 10^{16}-10^{18}eV

Measurement Techniques of Air Showers



All-particle spectra

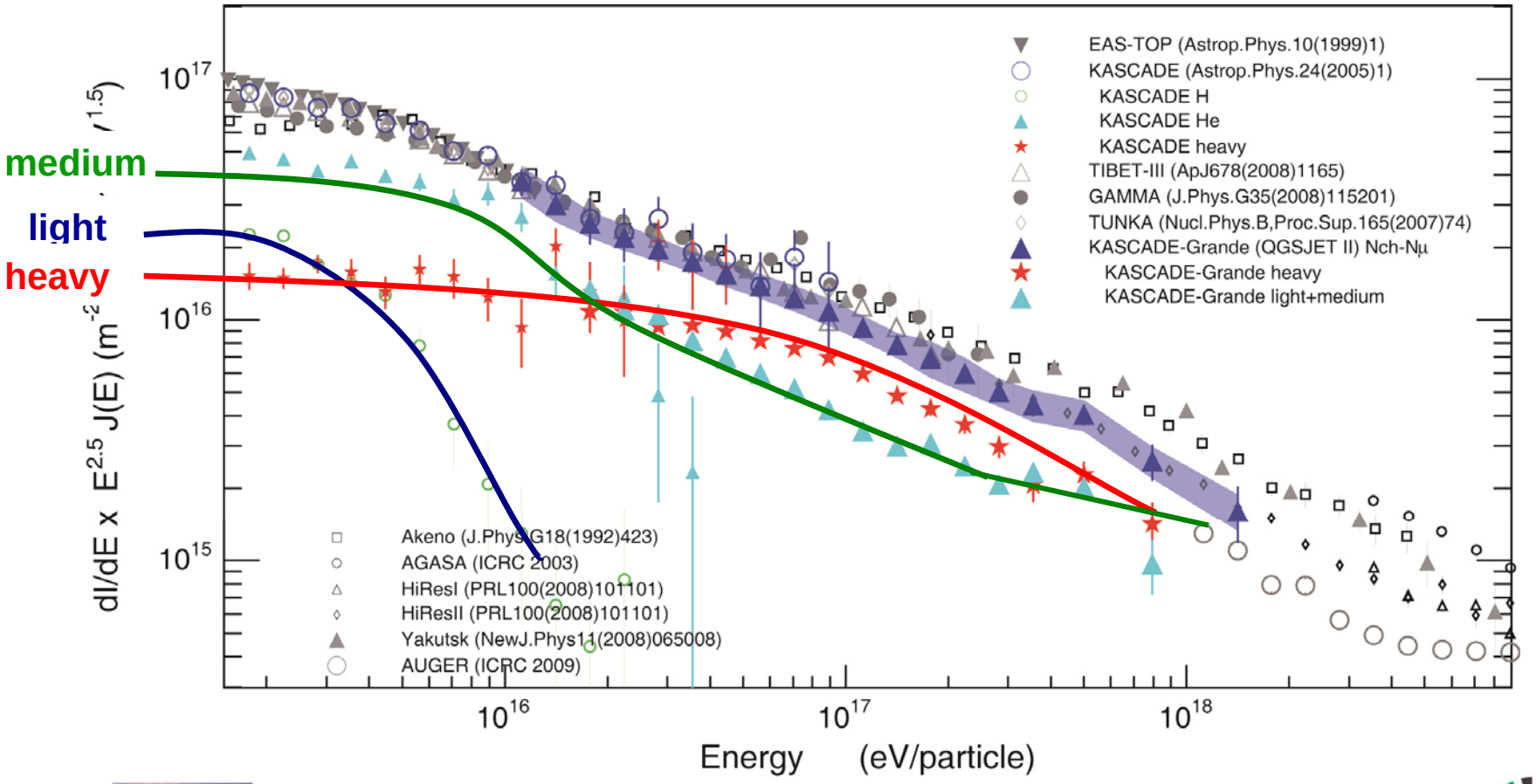


- Structures of all-particle spectra similar (in the level of 15%)

KASCADE-Grande results

- ➔ KASCADE: knee of light primaries at ~$3 \cdot 10^{15}$eV
- ➔ Hardening at 10^{16}eV due to knee of medium component
- ➔ KASCADE-Grande: knee of heavy primaries at ~$9 \cdot 10^{16}$ eV
- ➔ heavy knee less distinct compared to light knee
- ➔ mixed composition for 10^{15} to ~ $8 \cdot 10^{17}$ eV
- ➔ light ankle at 1-2·10^{17} eV

knee position $\propto Z$



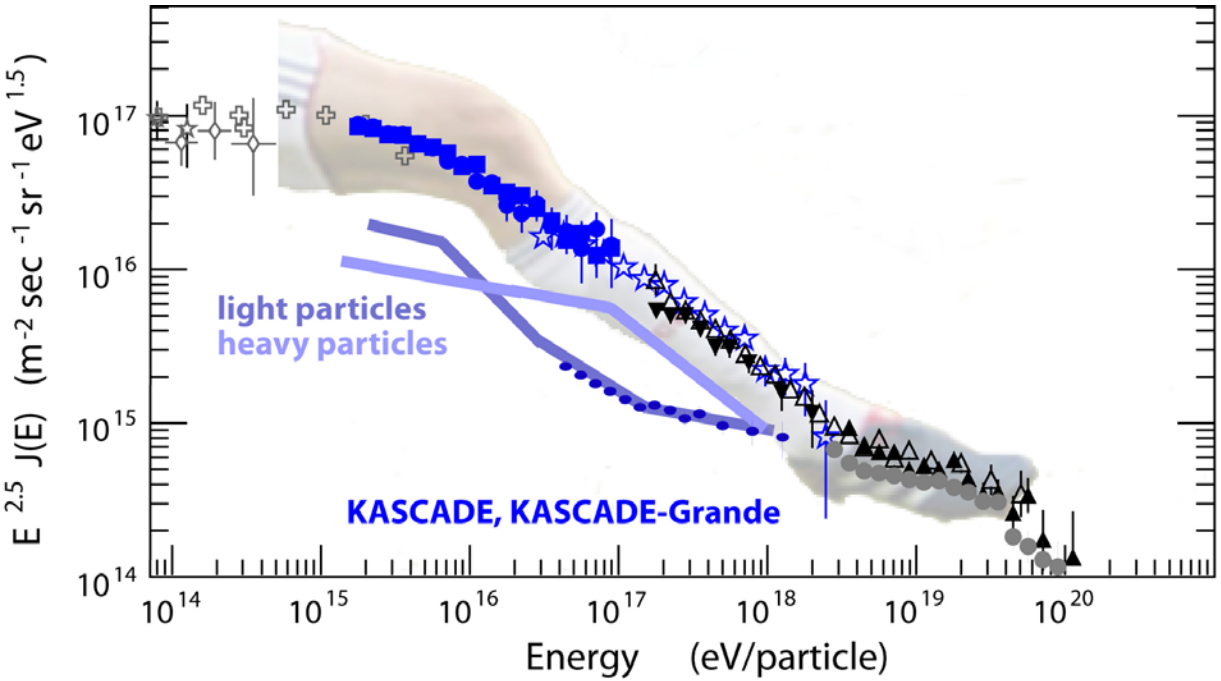
Light and Heavy Knees, Ankles, and Transition

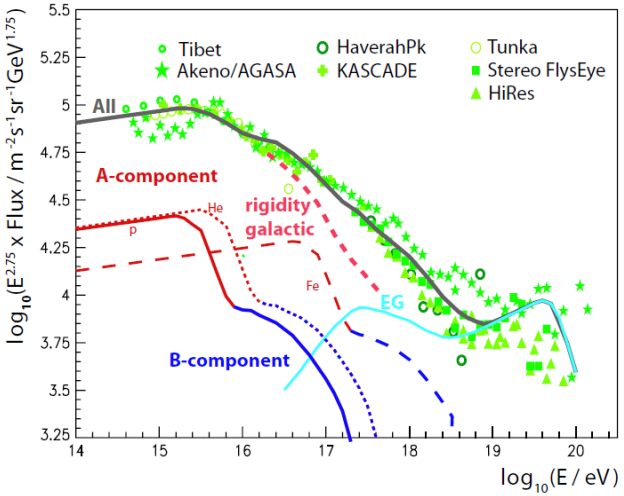
Questions:

- which astrophysical scenario (model) describes the data?

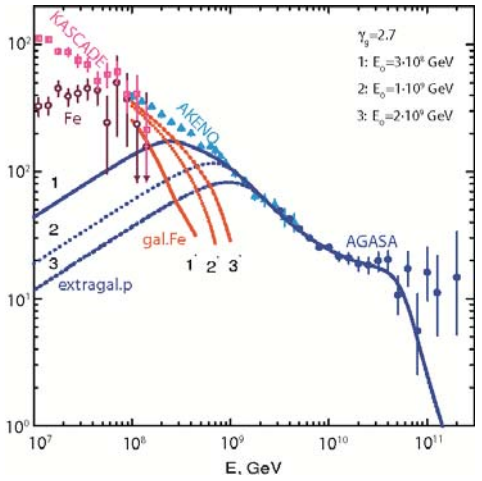
- exact energy and mass scale?

- spectral forms?

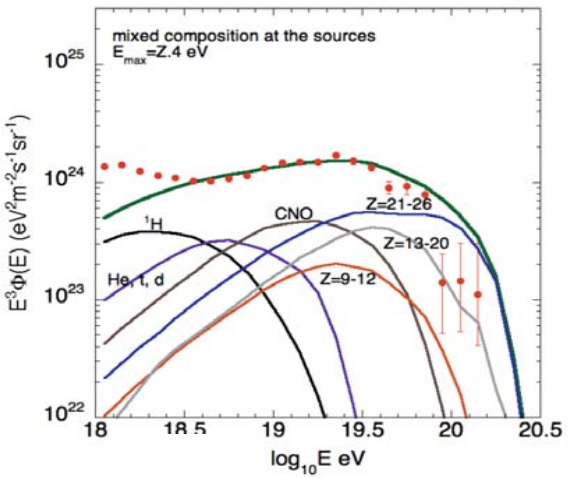




A.M.Hillas, J. Phys. G: Nucl. Part. Phys. 31 (2005) R95



V.Berezinsky, astro-ph/0403477

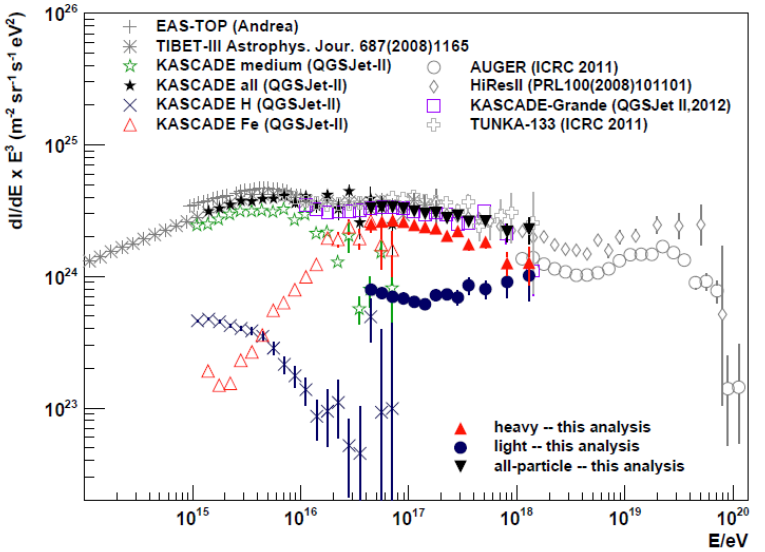


D.Allard, astro-ph/1111.3290

KASCADE-Grande: Next

- **KASCADE + KASCADE-Grande**
  - finally closed end 2012
  - presently dismantled

- **combined analysis**
  - for coherent spectrum and composition 10^{14}-10^{18} eV



- **detailed data analysis** (20y high-quality data)
  - testing hadronic interaction models
  - anisotropy studies
  - radio (LOPES and CROME)

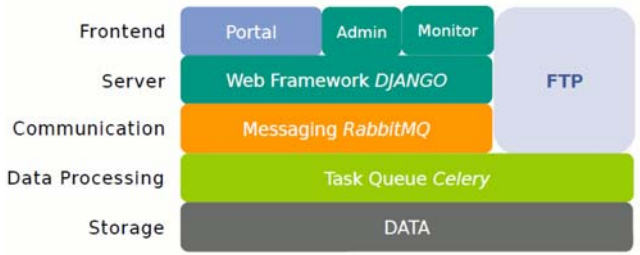
- **KCDC**
  - KASCADE Cosmic ray Data Center

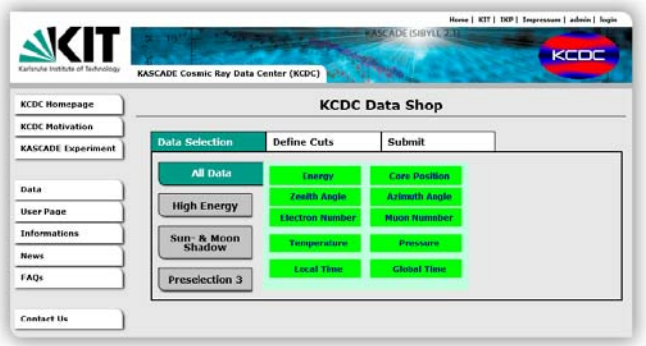
- **KCDC = publishing research data**
  from the KASCADE experiment

- **Motivation and Idea of Open Data:**
  general public has to be able to
  access and use the data
  the data has to be preserved for
  future generations

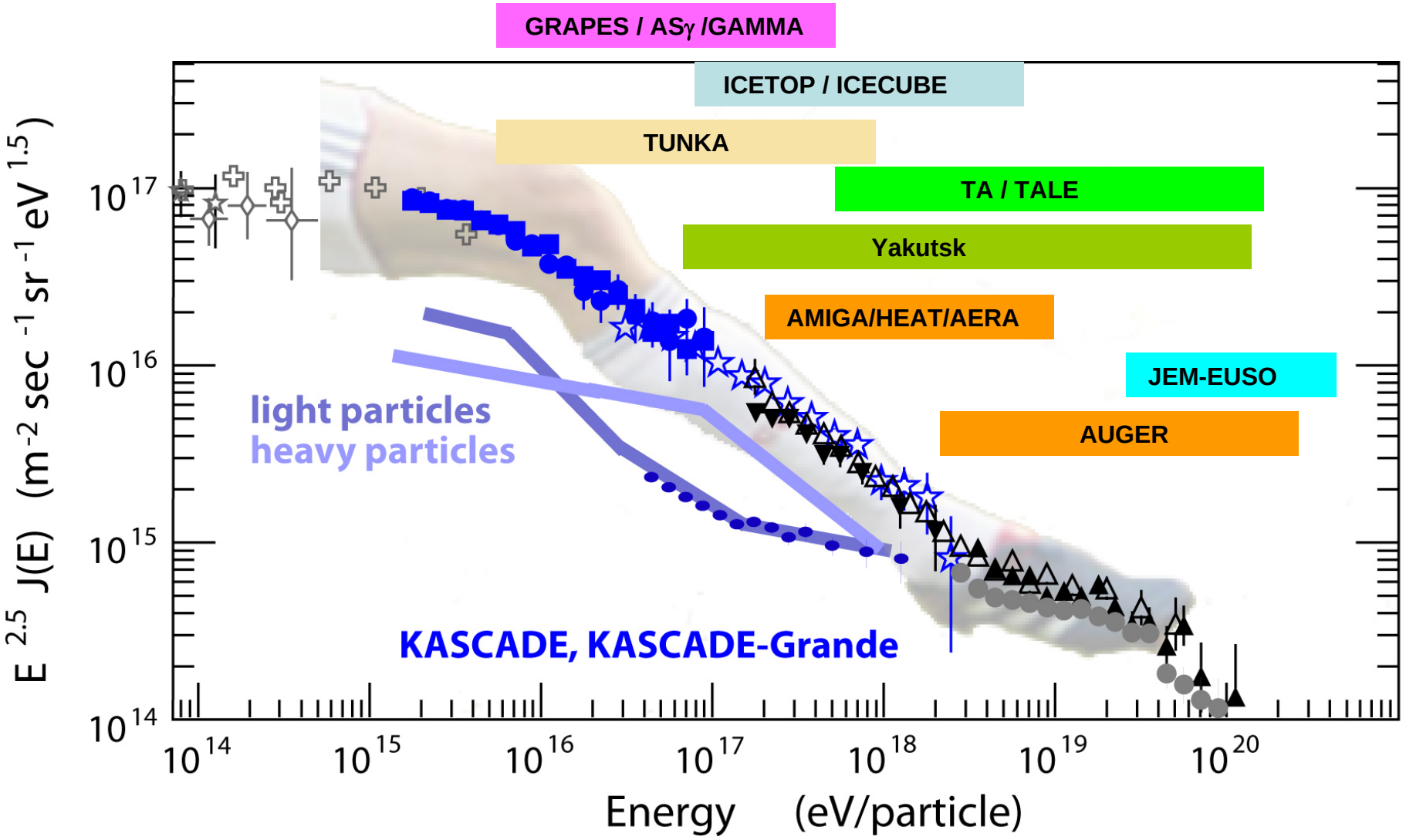
- **Web portal:**
  providing a modern software solution
  for publishing KASCADE data
  for a general audience
  In a second step: release the software
  as Open Source for free use by
  other experiments

- **Data access:**
  $4.5 \cdot 10^8$ EAS events in first data release
  planned October 2013





Summary



answers only by combining all information: stay tuned!

KASCADE-Grande Collaboration

Institut für Kernphysik & Institut für Experimentelle Kernphysik
KIT - Karlsruhe Institute of Technology

W.D.Apel, K.Bekk, J.Blümer, H.Bozdog, F.Cossavella, K.Daumiller, P.Doll, R.Engel, J.Engler, M.Finger, B.Fuchs, H.J.Gils, A.Haungs, D.Heck, D.Huber, T.Huege, D.Kang, H.O.Klages, K.Link, M.Ludwig, H.-J.Mathes, H.J.Mayer, M.Melissas, J.Milke, J.Oehlschläger, N.Palmieri, T.Pierog, H.Rebel, M.Roth, H.Schieler, S.Schoo, F.G.Schröder, H.Ulrich, A.Weindl, J.Wochele, M.Wommer

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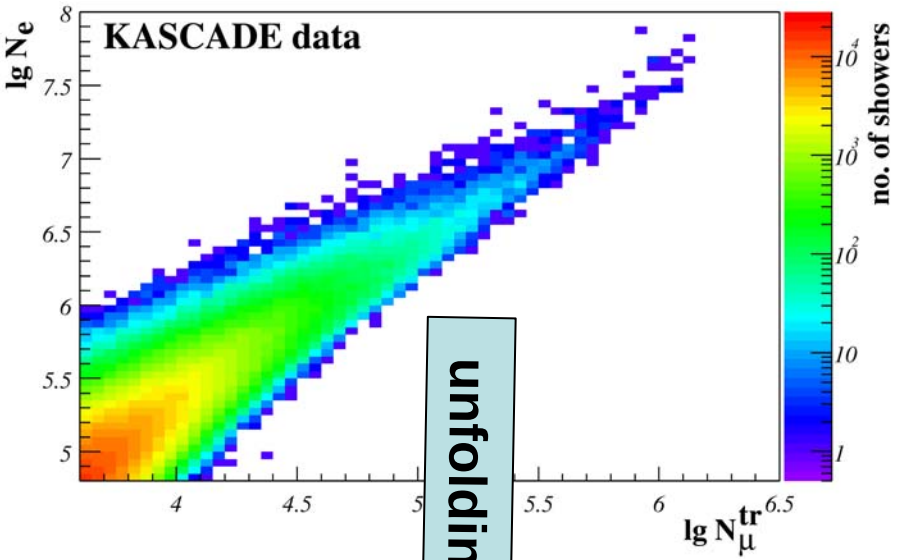
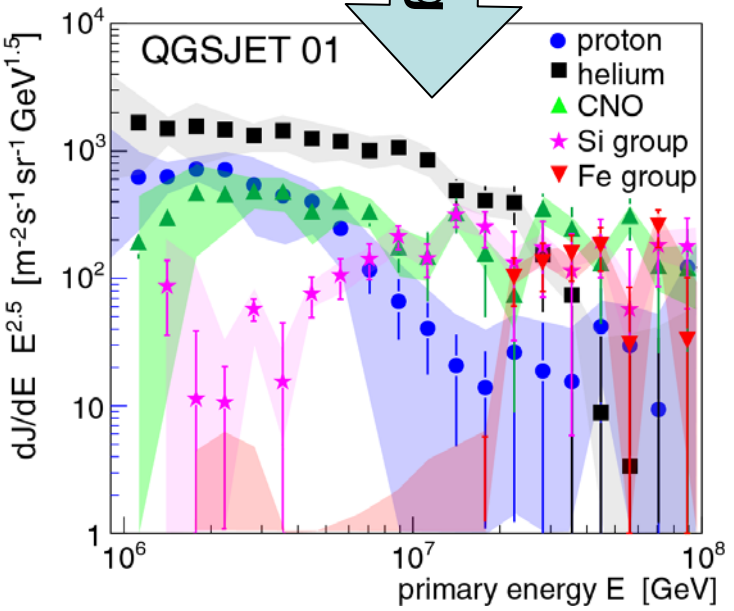
http://www-ik.fzk.de/KASCADE-Grande/

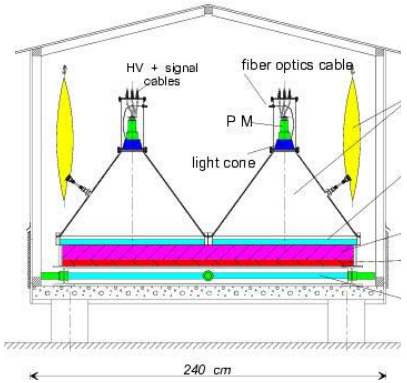
email spokesperson: haungs@kit.edu

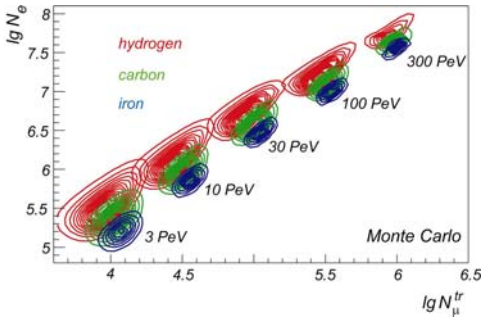
KASCADE : energy spectra of single mass groups



unfolding







Searched:

E and A of the Cosmic Ray Particles

Given:

N_e and N_μ for each single event

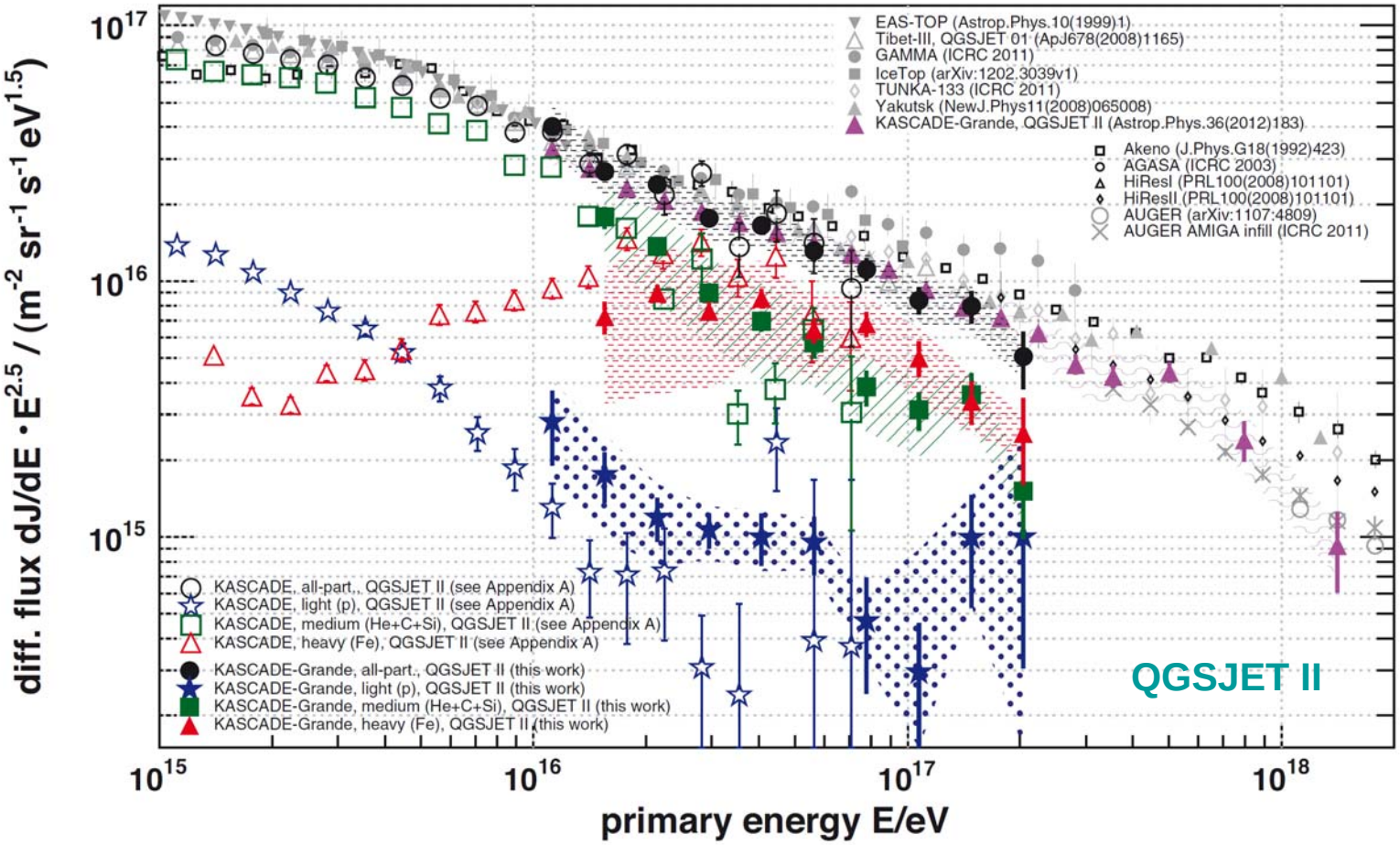
➔ solve the inverse problem

$$\frac{dJ}{d\lg N_e\, d\lg N_\mu^{tr}} = \sum_A \int_{-\infty}^{+\infty} \frac{dJ_A}{d\lg E}\, p_A(\lg N_e, \lg N_\mu^{tr} \mid \lg E)\, d\lg E$$

- kernel function obtained by Monte Carlo simulations (CORSIKA)
- contains: shower fluctuations, efficiencies, reconstruction resolution

KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25

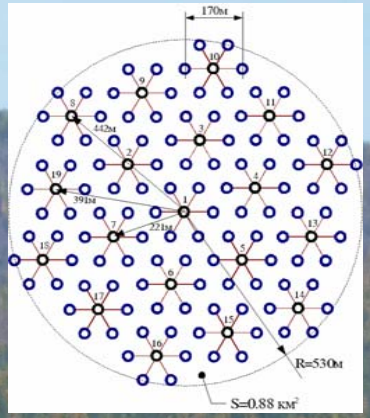
Unfolding results: KASCADE and KASCADE-Grande



spectra of individual mass groups:
proton medium (He+C+Si) iron
➔ all spectra overlap and agree well!
➔ all three show a knee-like feature!!

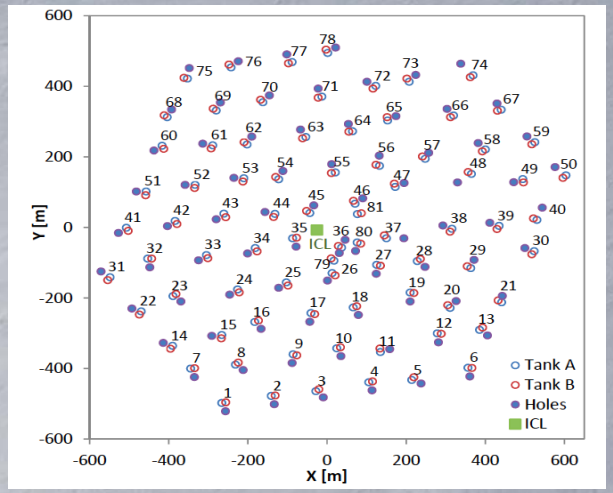
Astroparticle Physics (2013) accepted
arXiv:1306.6283

Tunka-133



- **Energy range: 100TeV – 1EeV**
- **Area: >1 km^2; 675m asl**
- **Cherenkov-experiment: LDF**
- **2011: Tunka-133 is extended by 6 distant external clusters**

IceTop



125m

10m

Dense Core

- Energy range: PeV – 1EeV
- Area: 0.5 km^2
- 2835m altitude (680 g/cm^2)
- 79 ice cherenkov stations
- LDF + particle density at 125m
- in-ice high-energy muons