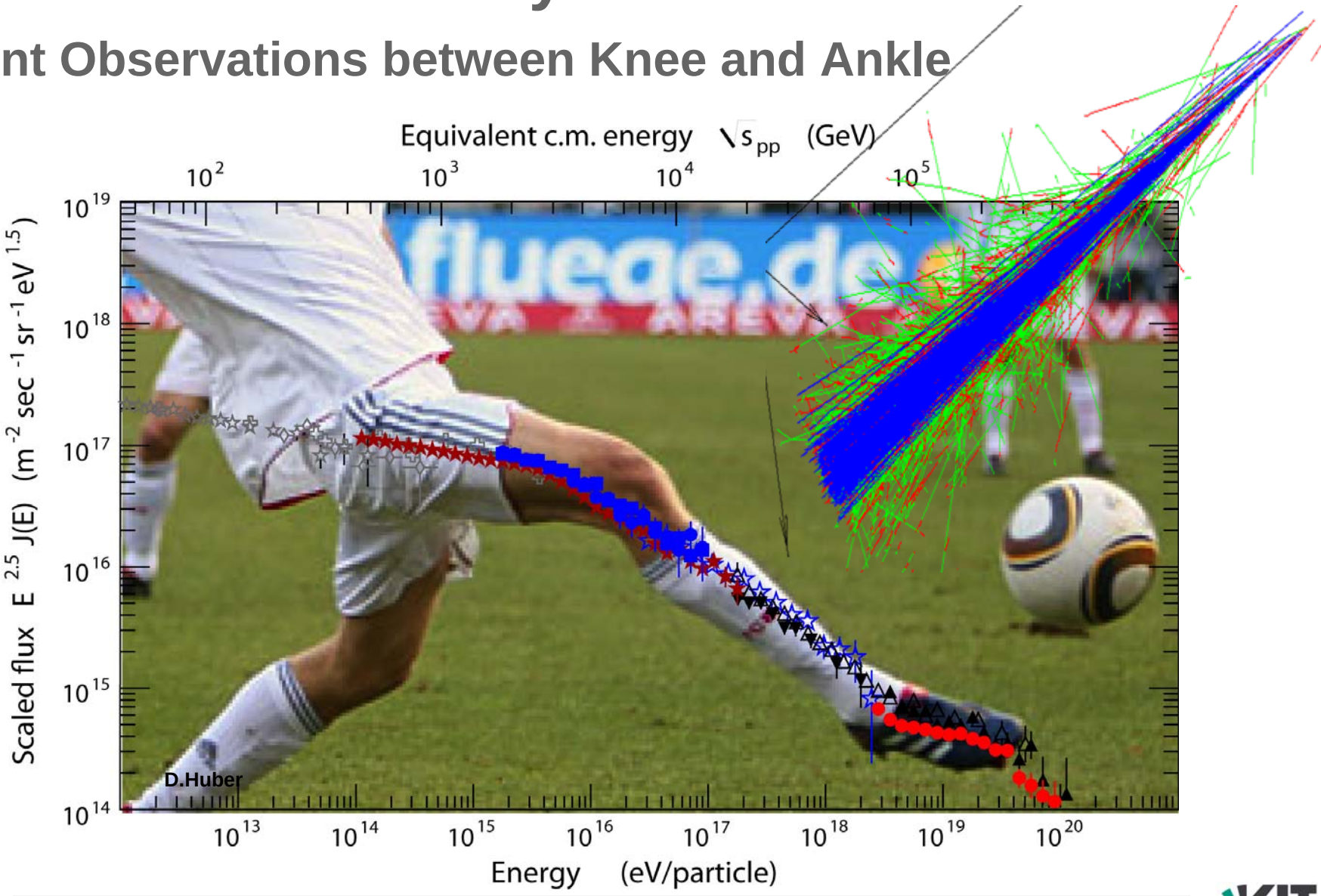
New lessons on galactic sources of cosmic rays?

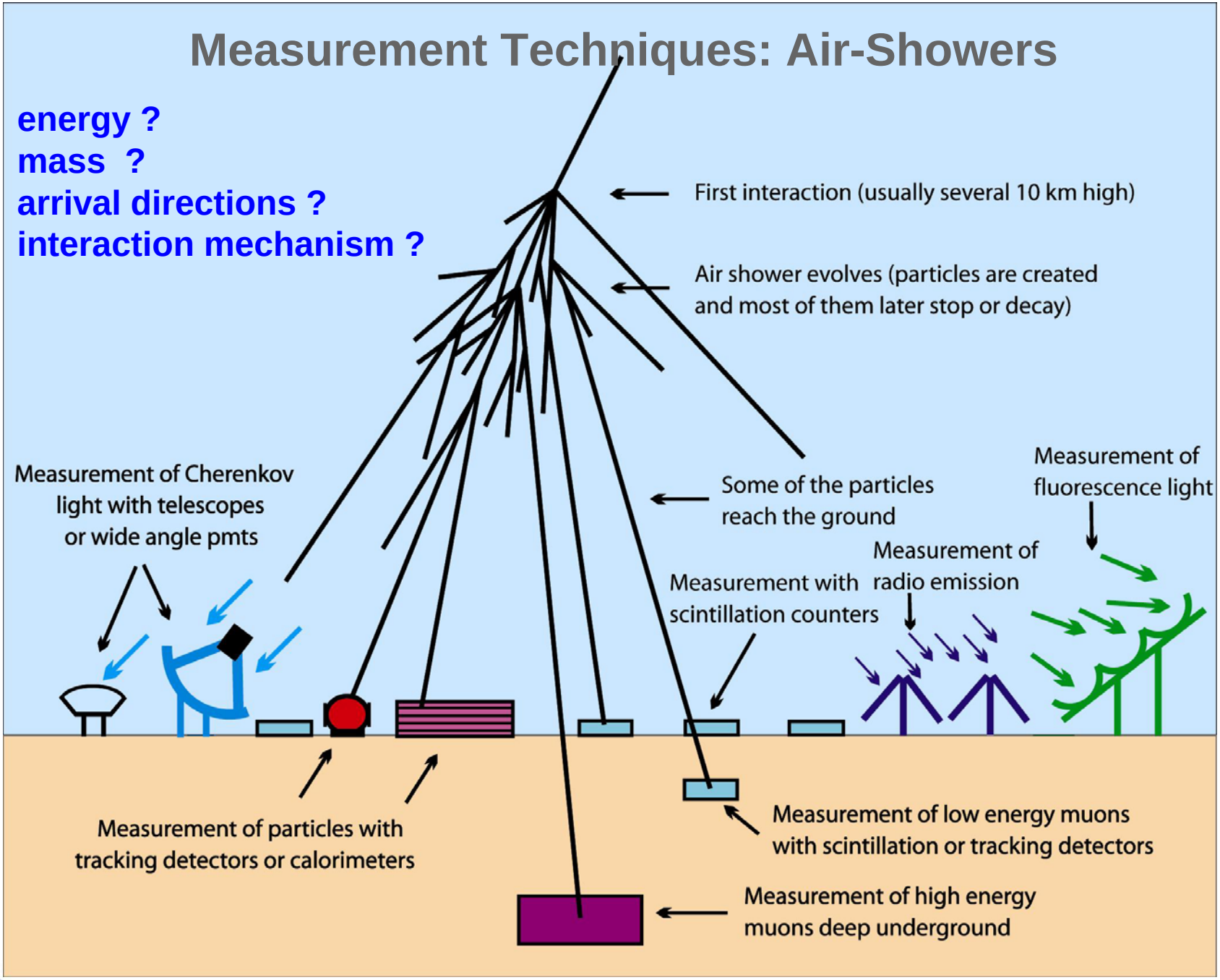
Andreas Haungs
KIT, Germany

Recent Observations between Knee and Ankle

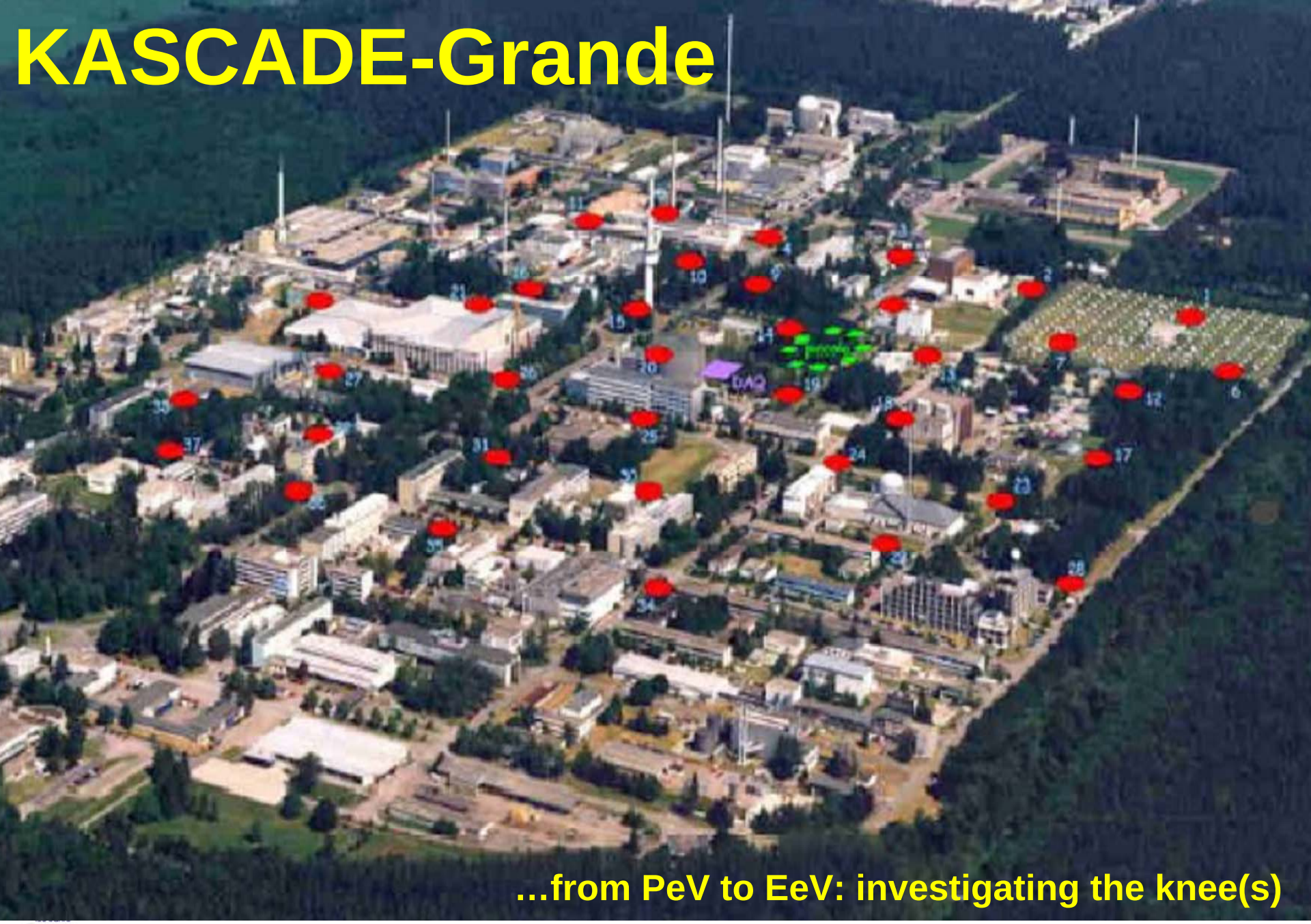


Measurement Techniques: Air-Showers

energy ?
mass ?
arrival directions ?
interaction mechanism ?



KASCADE-Grande



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

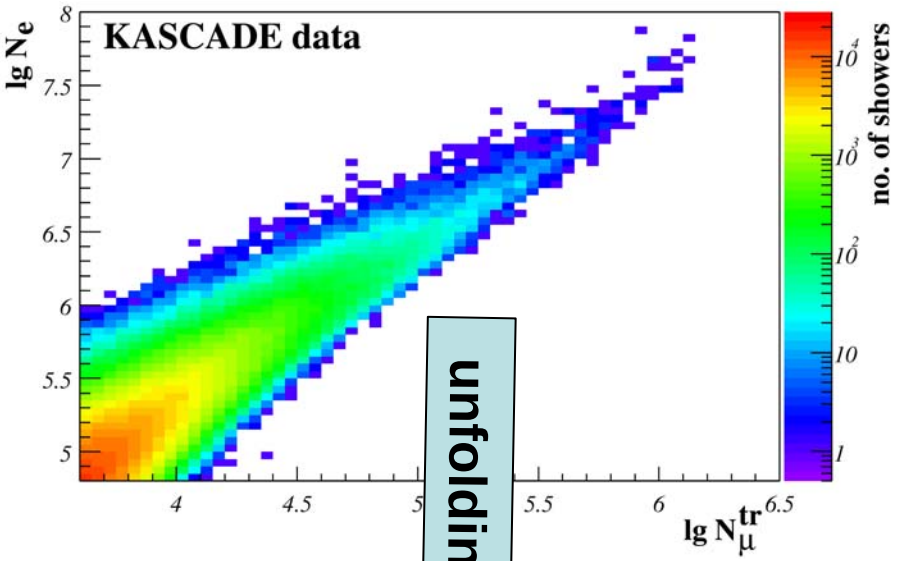
KASCADE

KArlsruhe Shower Core and Array DEtector

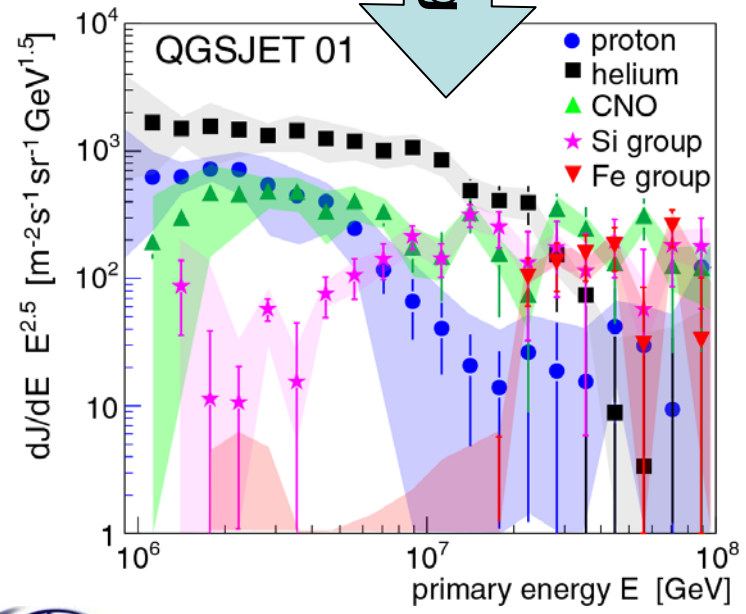
- Energy range 100TeV – 80PeV
- Since 1995
- Large number of observables: electrons, muons@4 thresholds, hadrons

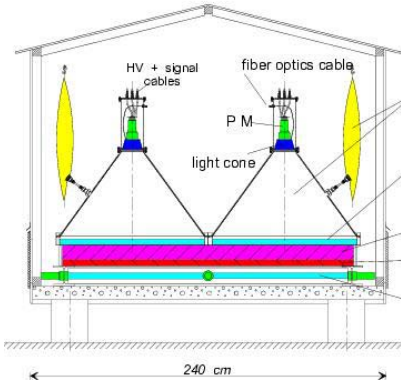
T.Antoni et al. NIM A513 (2003) 490

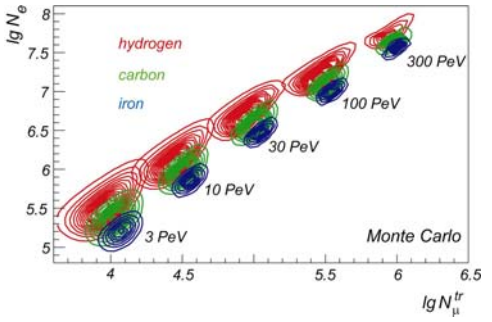
KASCADE : energy spectra of single mass groups



unfolding







Searched:

E and A of the Cosmic Ray Particles

Given:

N_e and N_μ for each single event

➔ solve the inverse problem

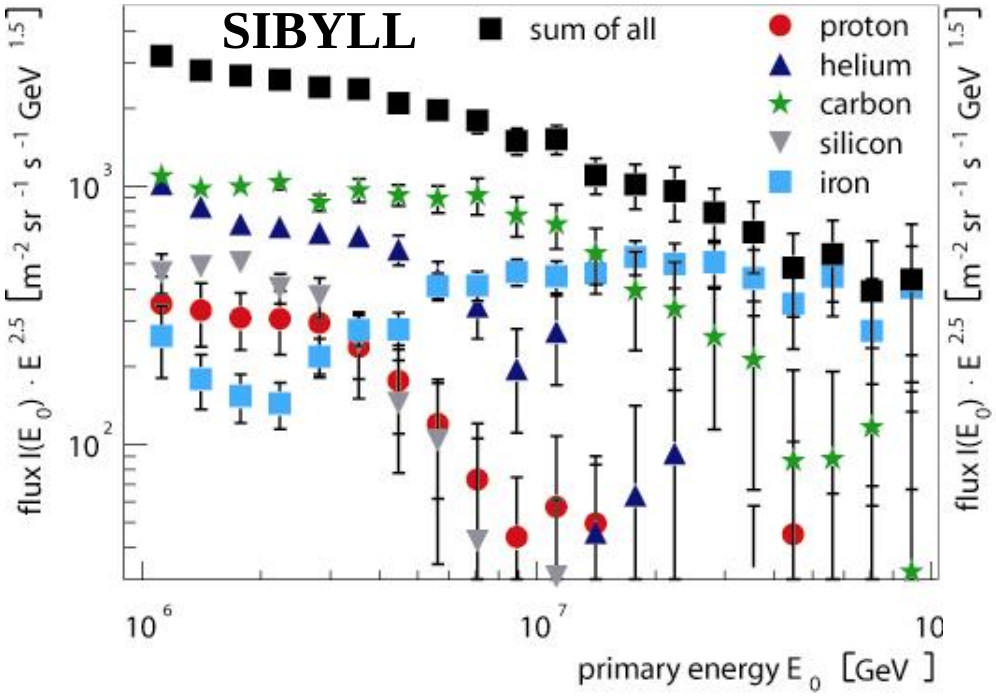
$$\frac{dJ}{d\lg N_e\, d\lg N_\mu^{tr}} = \sum_A \int_{-\infty}^{+\infty} \frac{dJ_A}{d\lg E}\, p_A(\lg N_e, \lg N_\mu^{tr} \mid \lg E)\, d\lg E$$

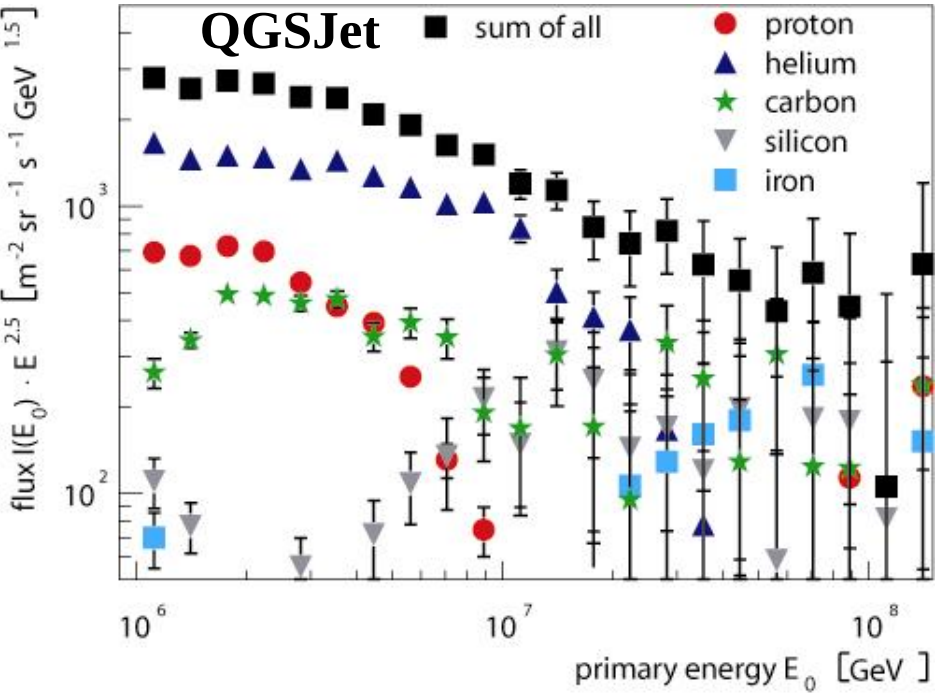
- kernel function obtained by Monte Carlo simulations (CORSIKA)
- contains: shower fluctuations, efficiencies, reconstruction resolution

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

KASCADE results

- same unfolding but based on different hadronic interaction models embedded in CORSIKA

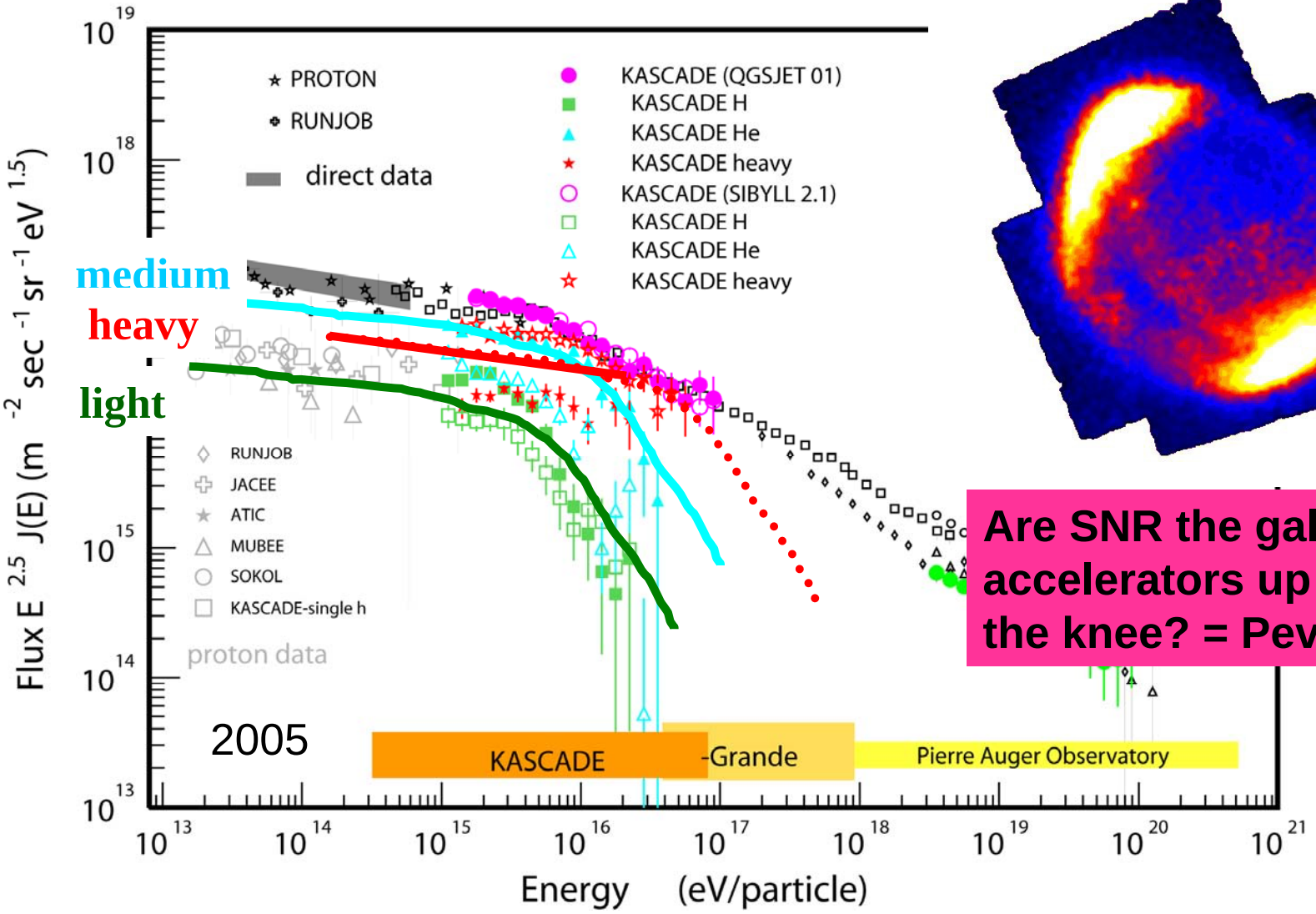




- all-particle spectrum similar
- general structure similar: knee by light component
- relative abundances very different for different high-energy hadronic interaction models

KASCADE collaboration, Astrop.Phys. 24 (2005) 1 , Astrop.Phys. 31 (2009) 86

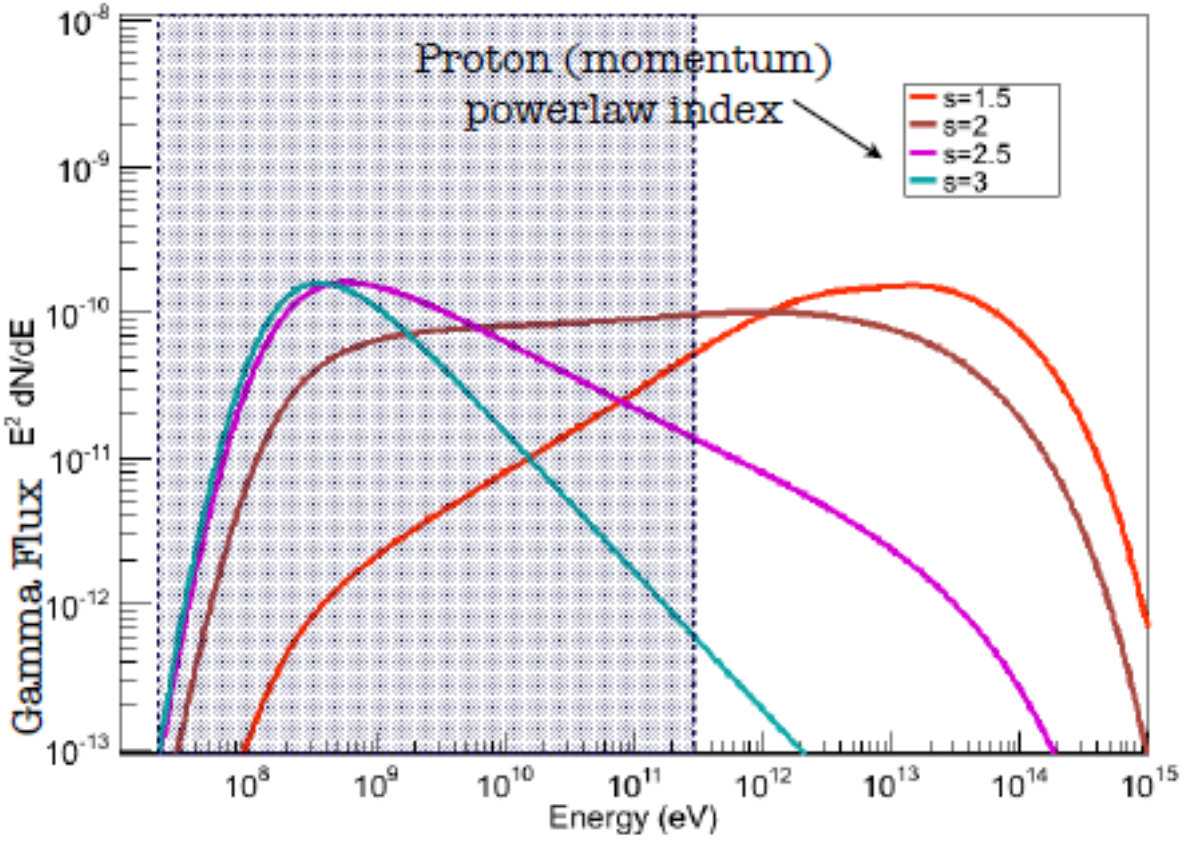
Main result KASCADE



Are SNR the galactic accelerators up to the knee? = Pevatrons

Gamma-ray astronomy

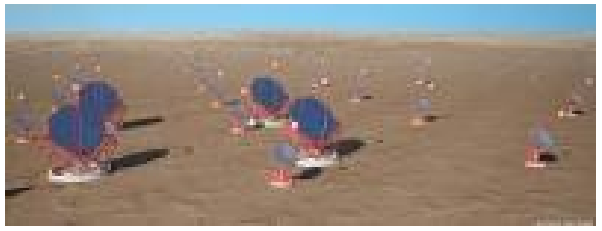
- **Do shell-type SNR accelerate protons? (via π^0-decay!)**
- **To which energy? (up to 10^{15}eV?)**
- **Distinguishable from electron acceleration?**



Stefan Funk, TAUP 2013, Asilomar, CA, US

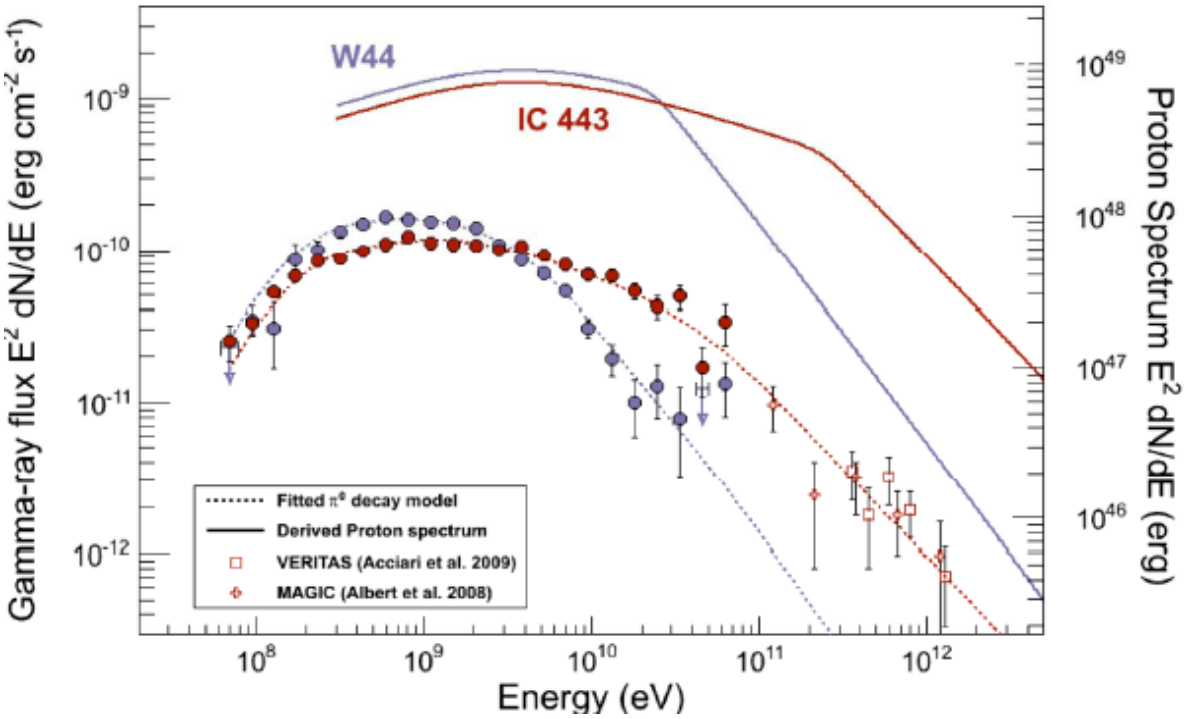
Expected gamma flux (π^0 –bump) for different proton injections

- **Fermi-Lat**
- **TeV γ-ray Cherenkov**



Gamma-ray astronomy: Fermi

- **IC 443 and W44 are the two brightest SNRs in the Fermi-LAT range**



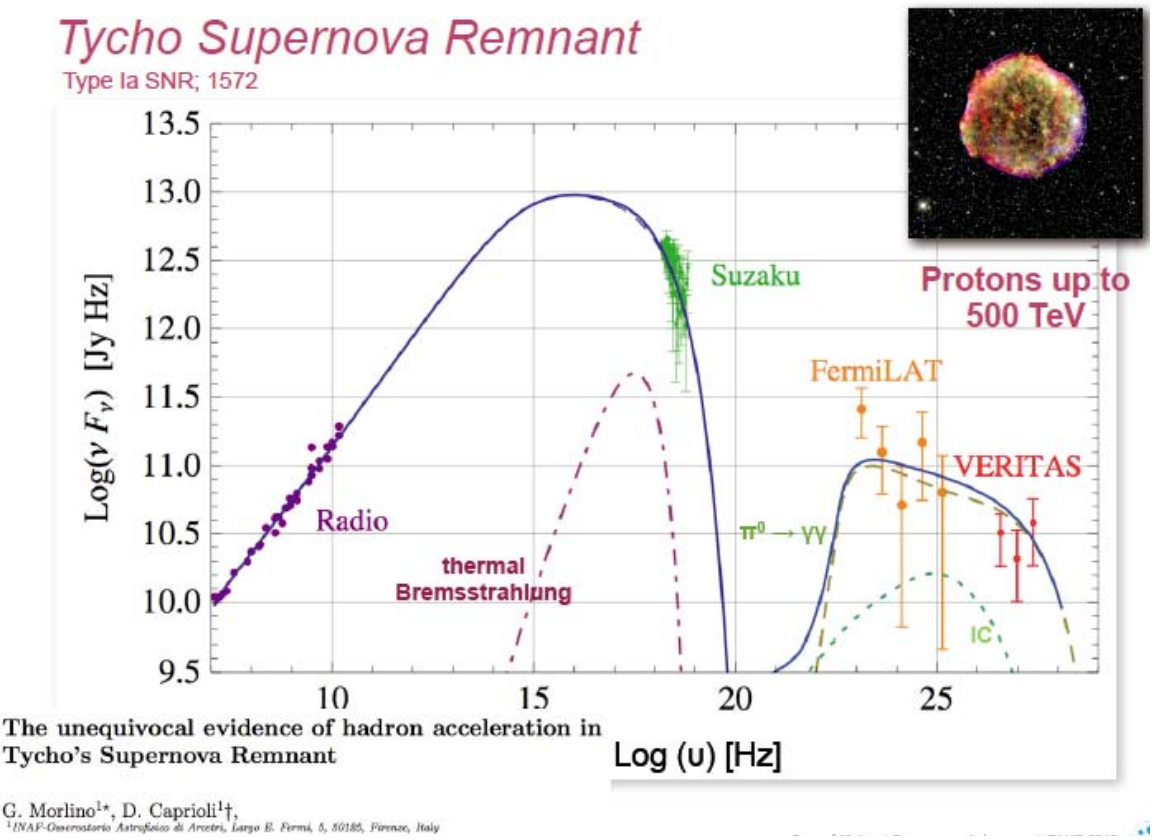
Measured gamma-rays and calculated proton spectrum

Proton acceleration yes
but only up to TeV?
← Dependent on age of SNR?

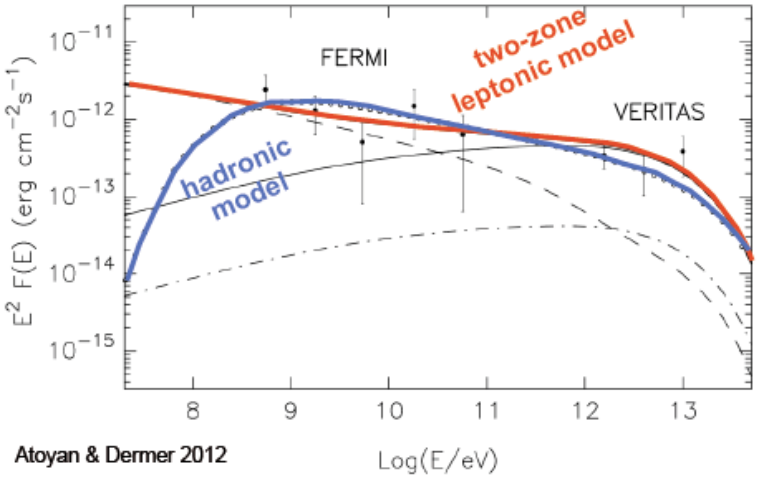
Stefan Funk, TAUP 2013, Asilomar, CA, US
TGudlaugur Johannesson (Island) , talk later the day….

Gamma-ray astronomy: IACT

-problems: gas density for hadronic
magnetic fields for leptonic



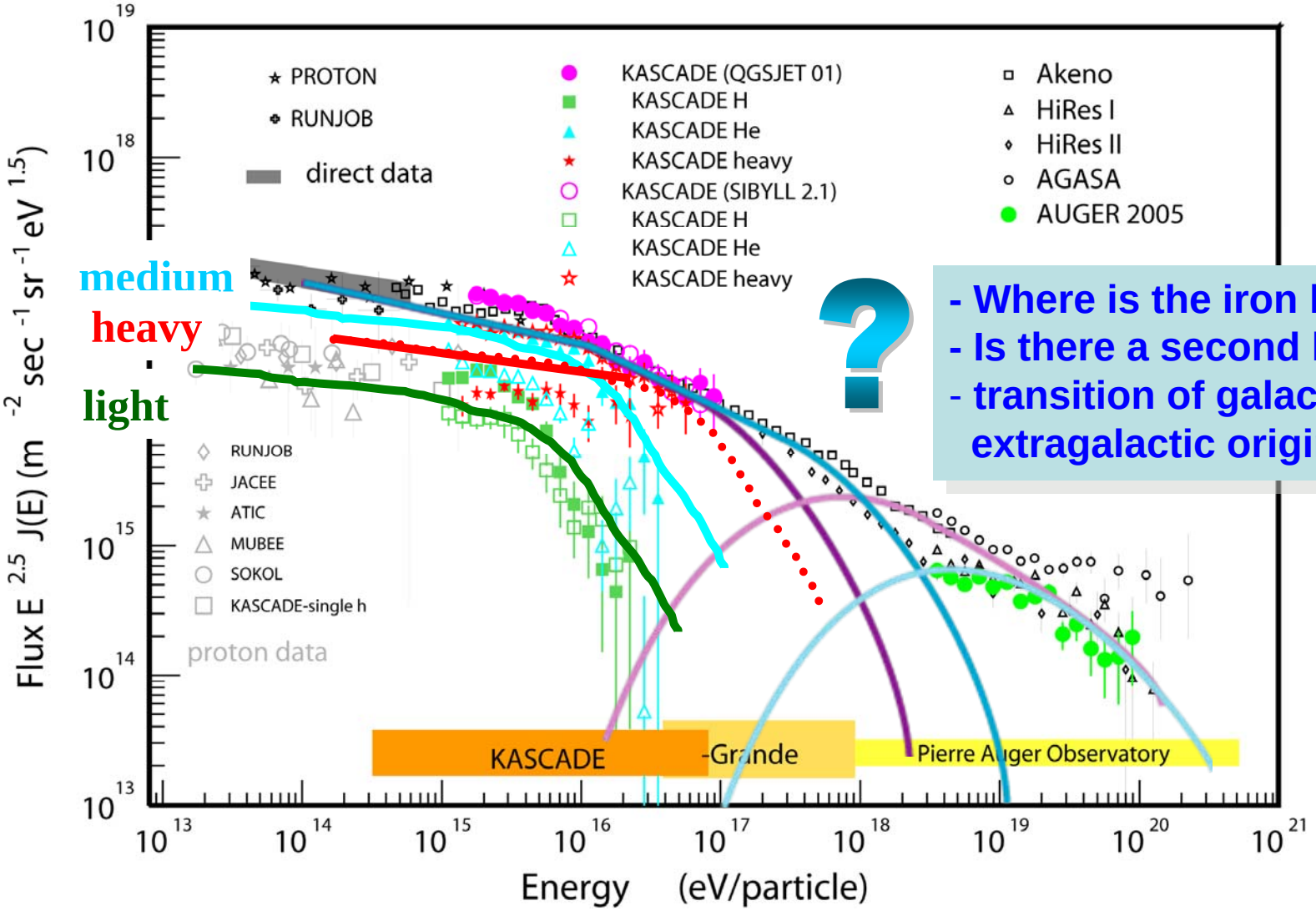
Measurement also explainable by hadronic and leptonic models



← Still no proof that SNR accelerate protons up to the knee, but also no exclusion….

Gernot Maier, TAUP 2013, Asilomar, CA, US
Peter Eger (Heidelberg), talk later the day….

Result KASCADE ➔ Motivation KASCADE-Grande

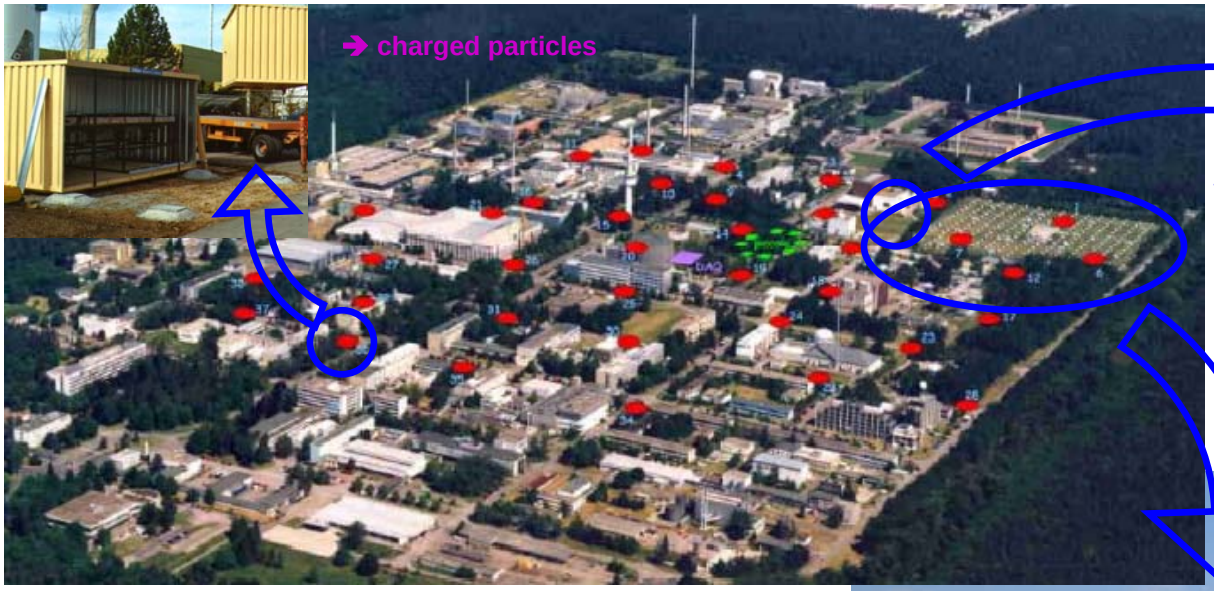


- Where is the iron knee ?
- Is there a second knee ??
- transition of galactic to extragalactic origin ?

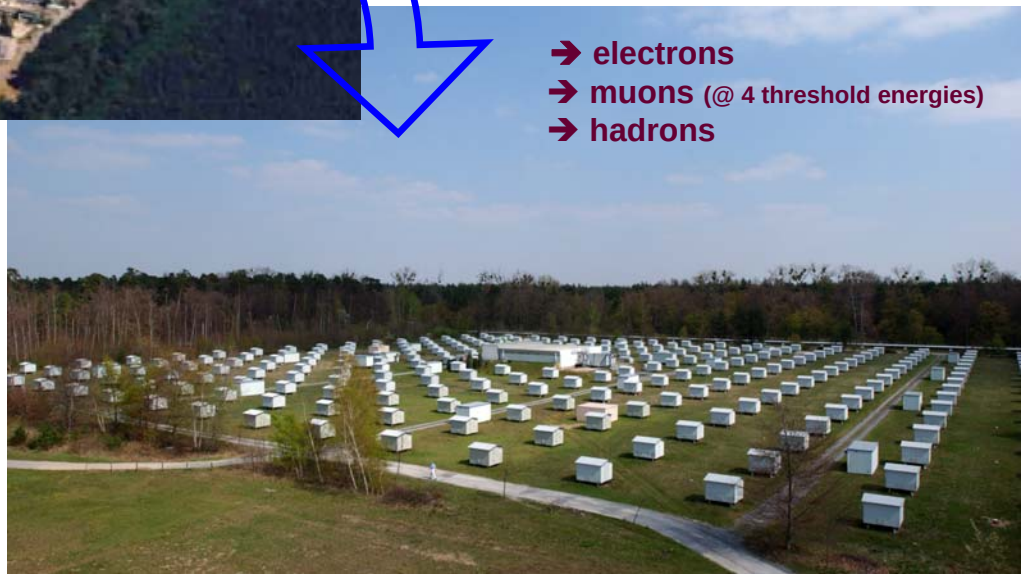
KASCADE-Grande

= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

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

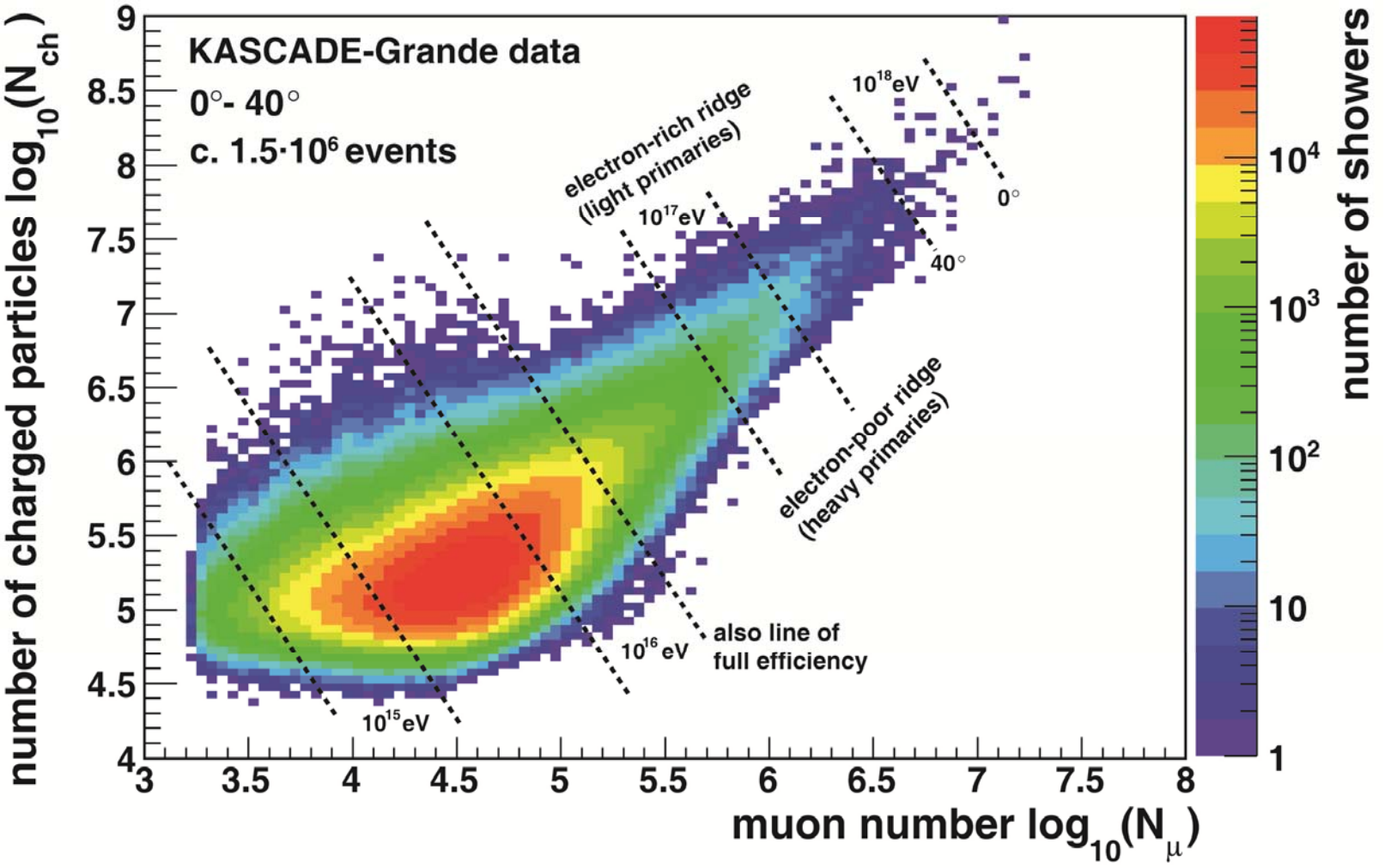


➔ electrons
➔ muons (@ 4 threshold energies)
➔ hadrons



- **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



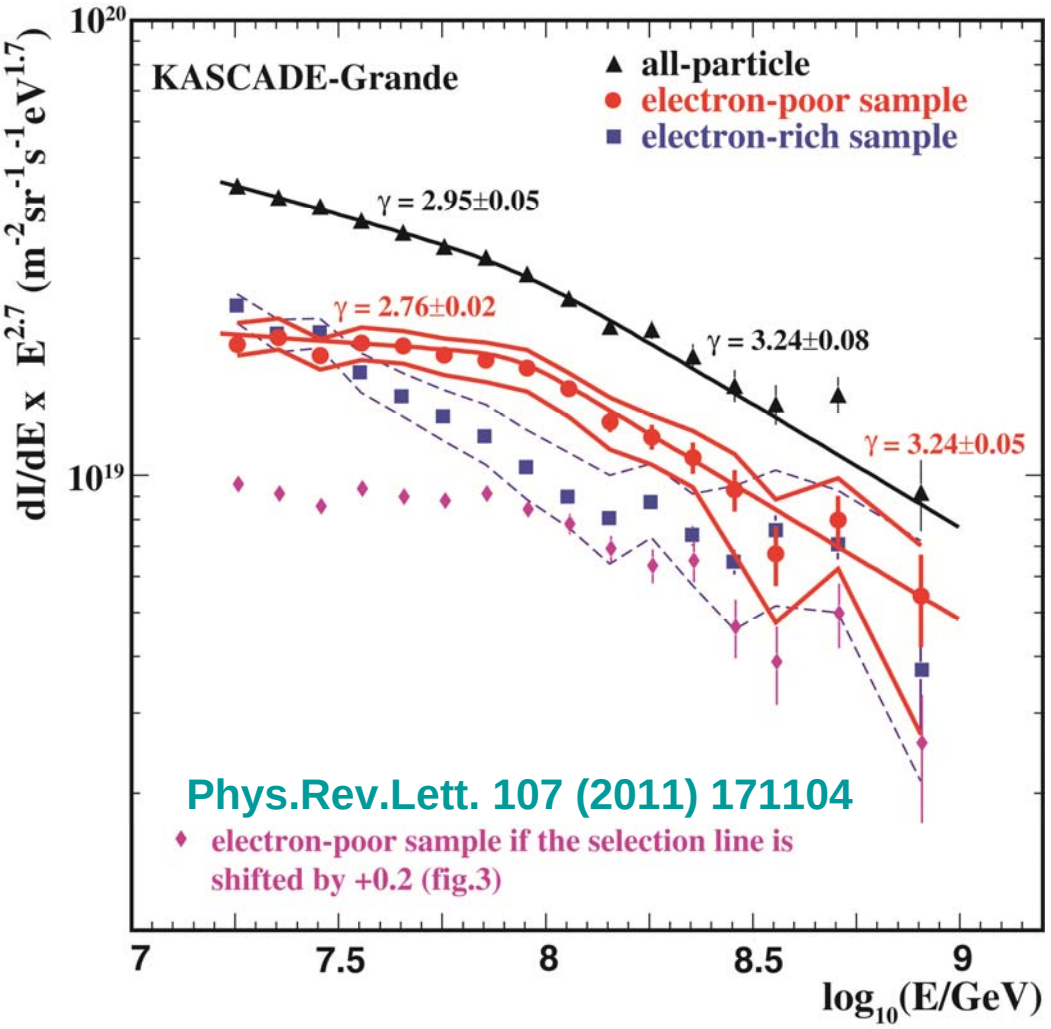
➔ **determination of primary energy**

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

Astroparticle Physics 36 (2012) 183

KASCADE-Grande: Spectra of individual mass groups

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



observation of a „heavy“ knee at 8-9·10^{16} eV

- spectra of individual mass groups:

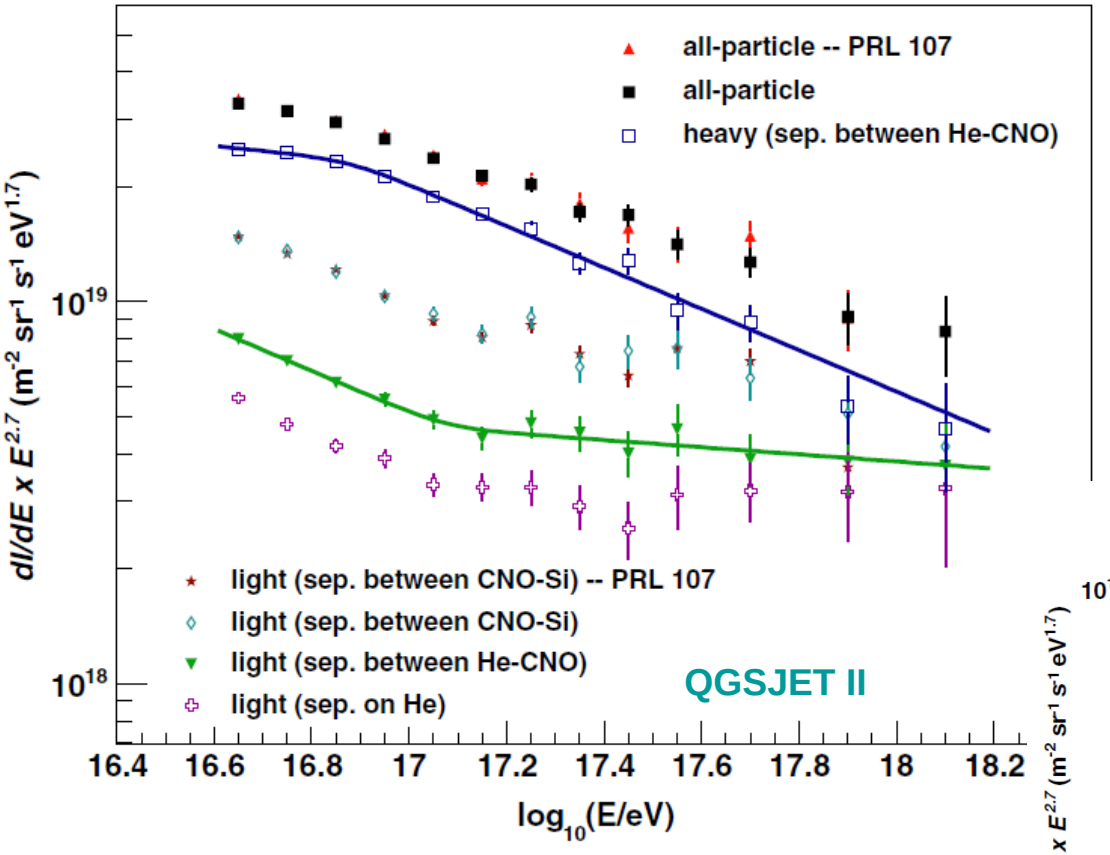
➔ steepening close to 10^{17}eV (2.1σ) in all-particle spectrum

➔ steepening due to heavy primaries (3.5σ)

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

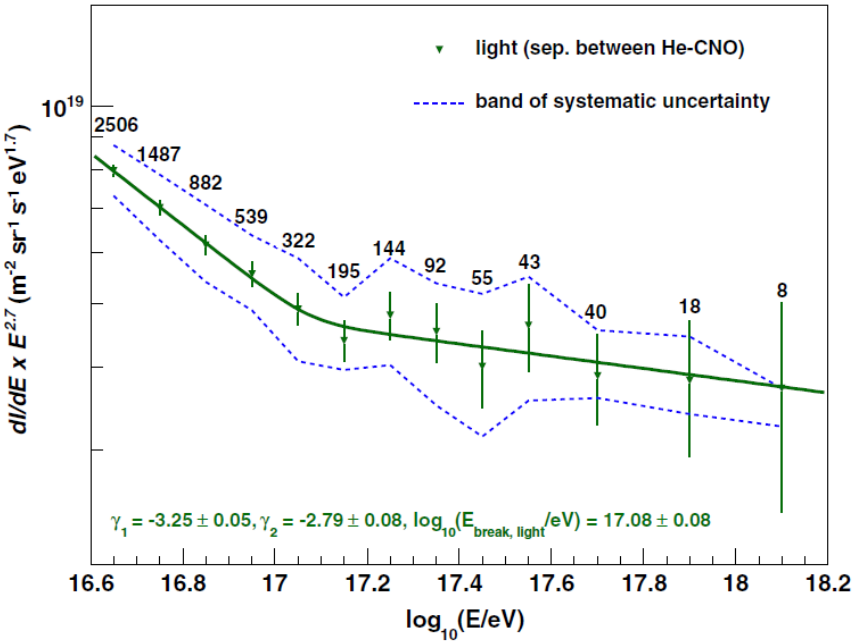
➔ light+medium primaries show steeper spectrum, but fit by power law okay
➔ possibility for hardening above 10^{17}eV

KASCADE-Grande: spectrum of light primaries



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

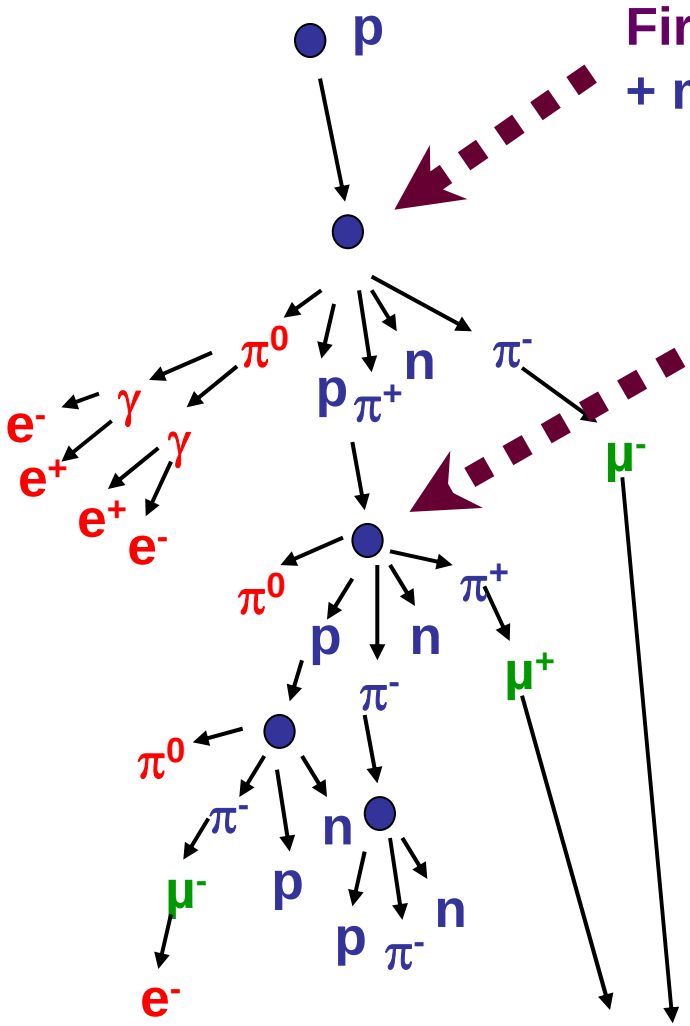
➔ **slope change from γ = -3.25 to γ = -2.79!**



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

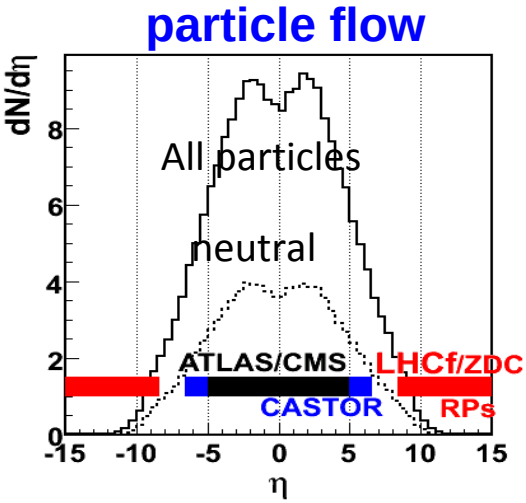
observation of a „light“ ankle at 1-2·10^{17} eV

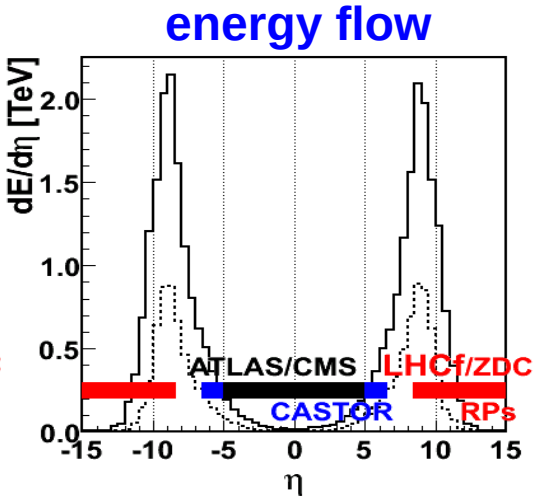
Validity of Hadronic Interaction Models



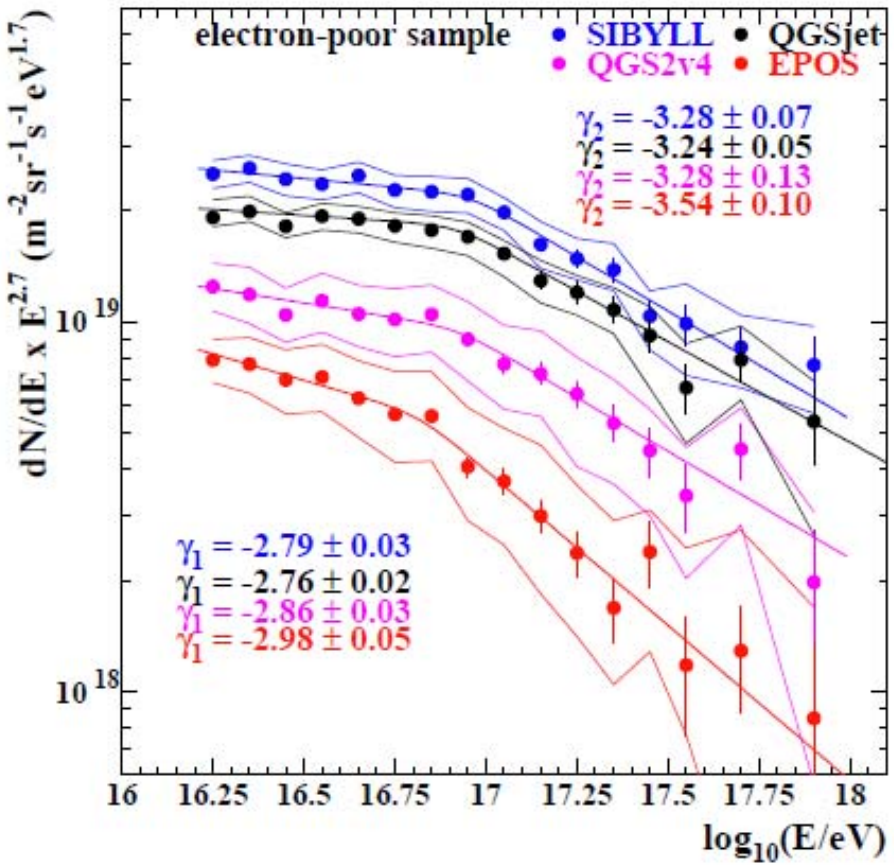
First, high energy interaction: LHC
+ multiparameter measurements EAS

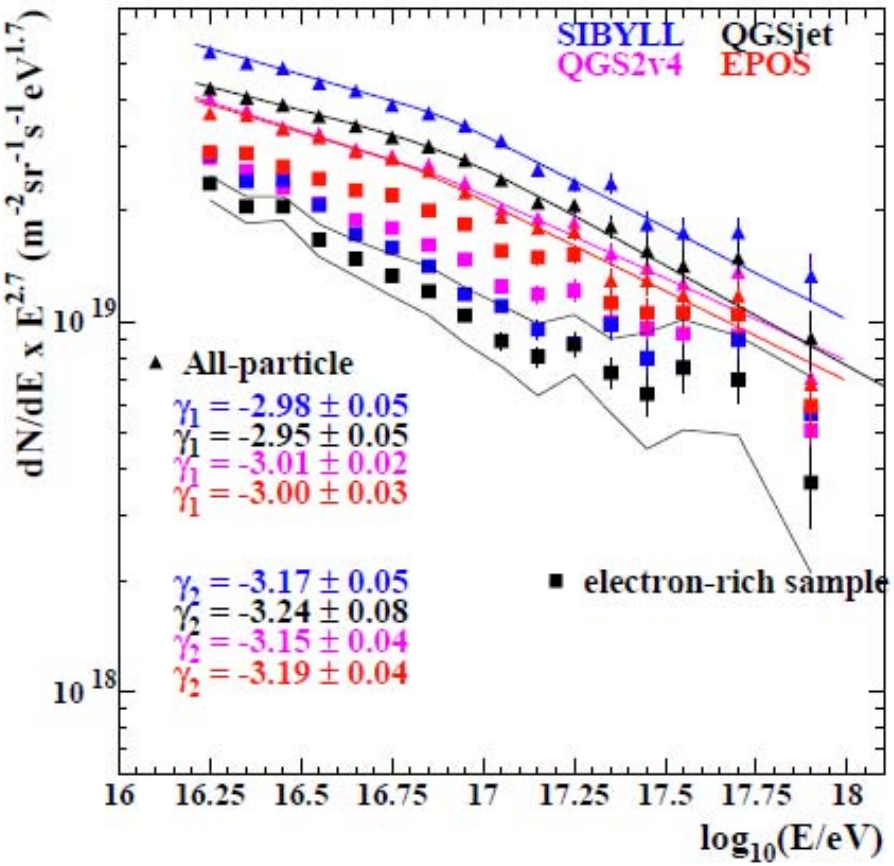
Secondary interactions:
Fix target experiments
+ multiparameter measurements EAS





KASCADE-Grande: model dependence





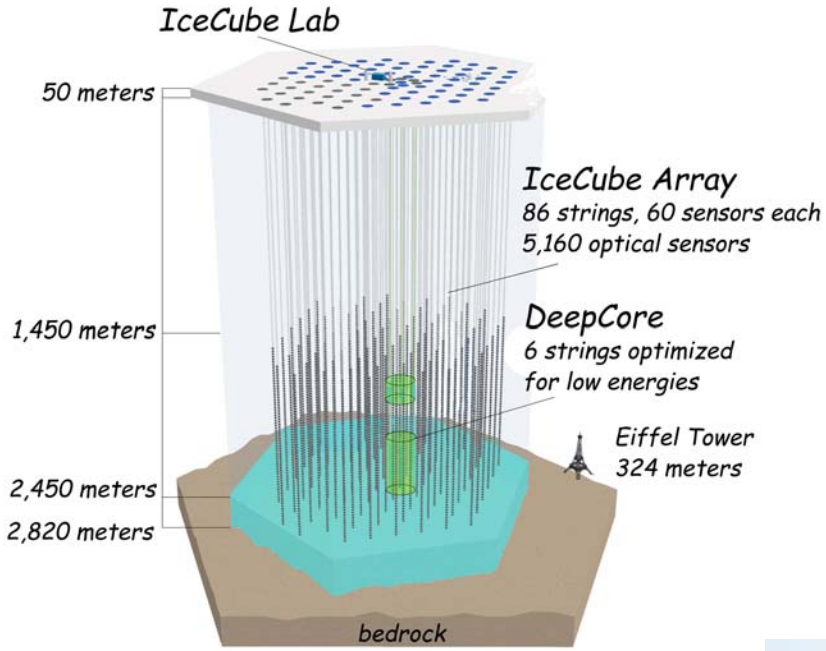
- Structures of all-particle, heavy and light spectra similar

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

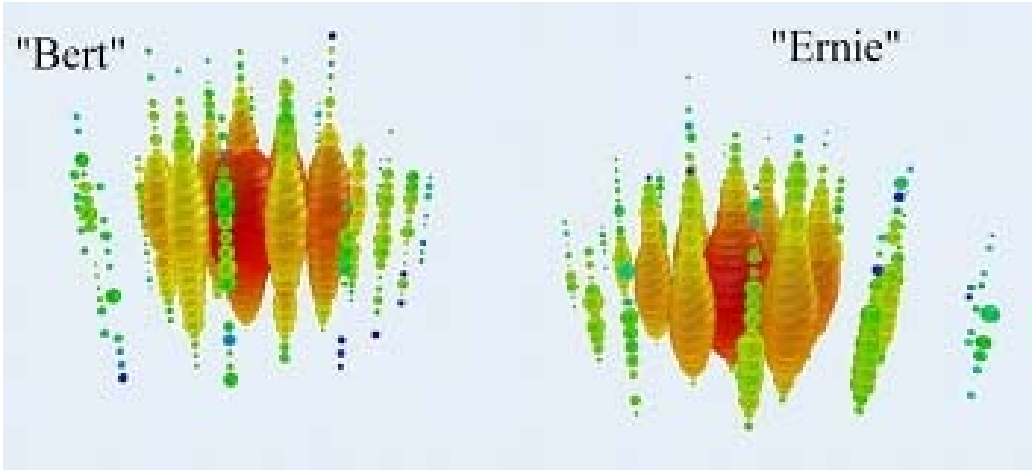
- relative abundances different for different high-energy hadronic interaction models

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

Neutrino astronomy: IceCube



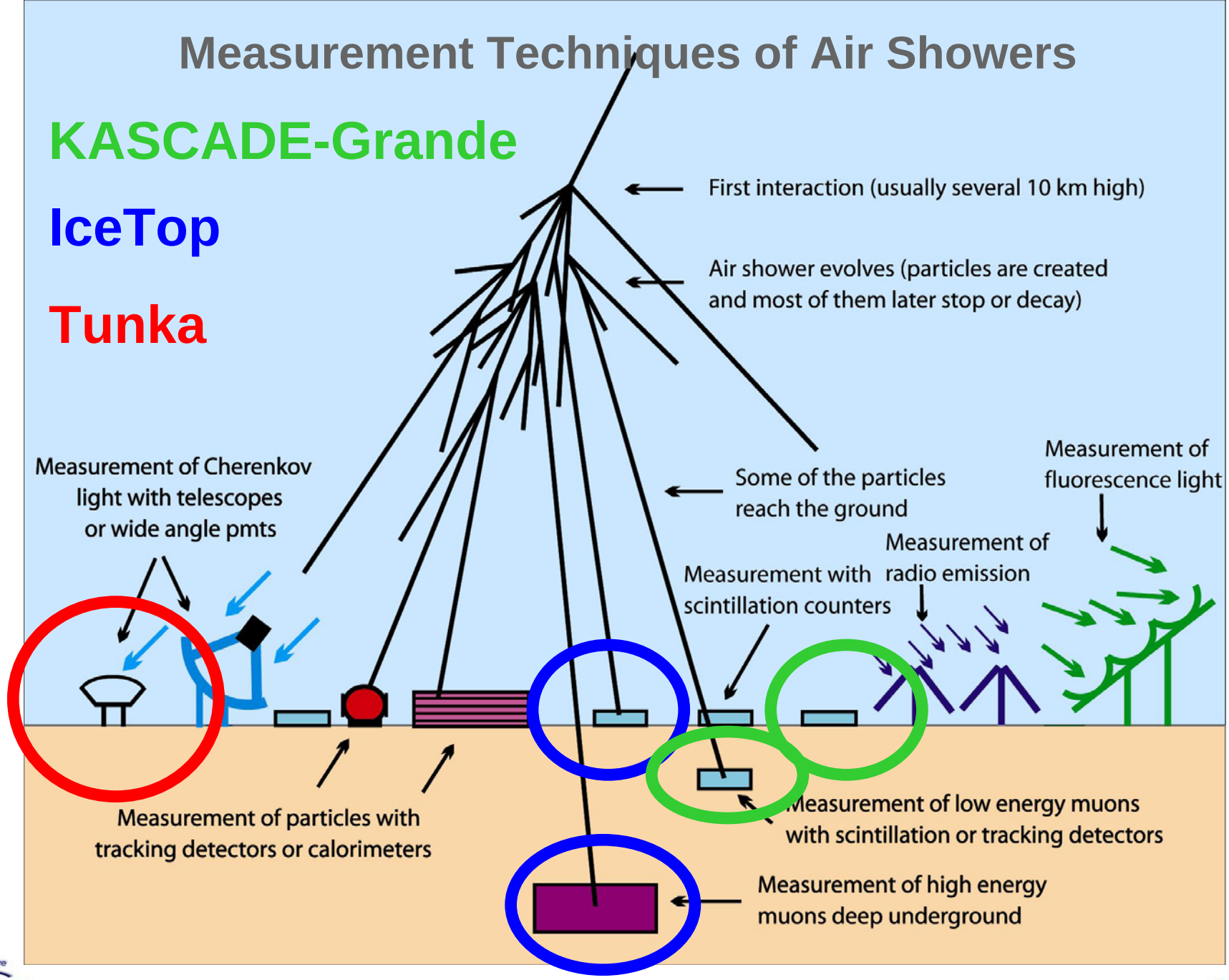
- cosmic neutrinos from IceCube correspond to 10^{17}eV protons
🡐 galactic or extragalactic source?



Measured PeV-neutrinos by IceCube

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

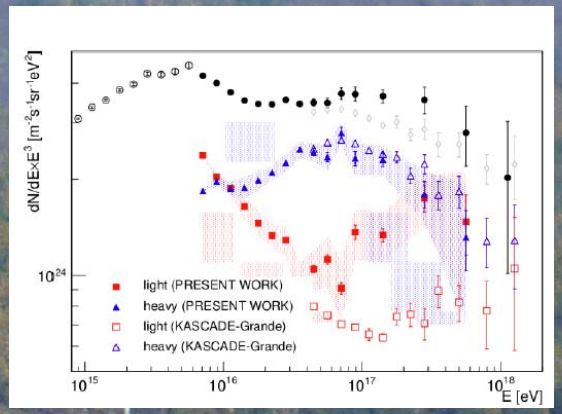
Measurement Techniques of Air Showers

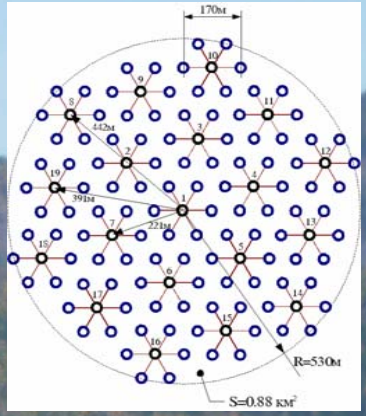


Tunka-133

light flux at core distance 200 m Q_{200} **~ Energy**

steepness of LDF P = Q(100)/Q(200) ➔ X_{max}

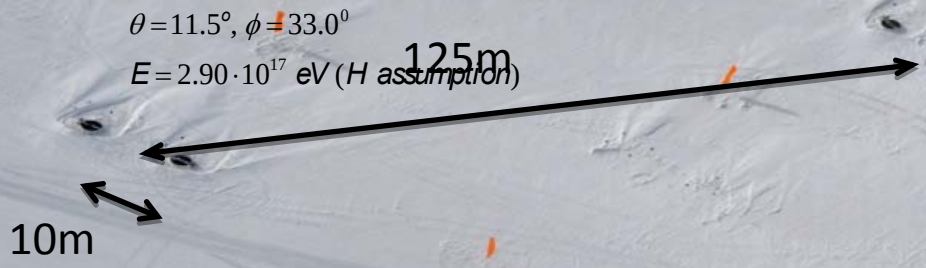


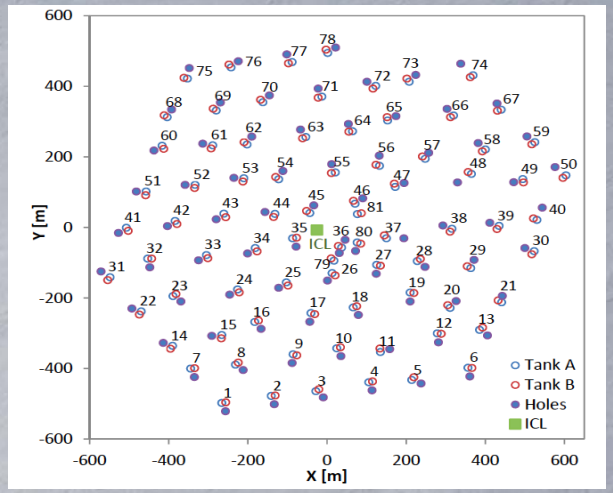


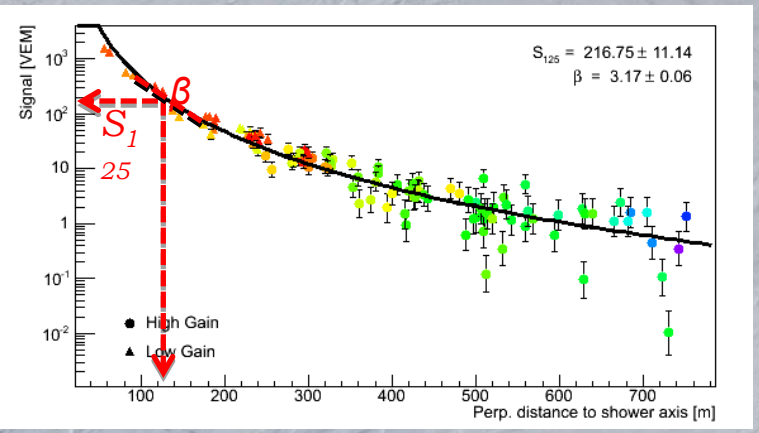
- **Energy range: 100TeV – 1EeV**
- **Area: >1 km²; 675m asl**
- **Cherenkov-experiment: LDF**
- **2011: Tunka-133 is extended by 6 distant external clusters**

NIM A (2013) accepted - http://dx.doi.org/10.1016/j.nima.2013.09.018

IceTop



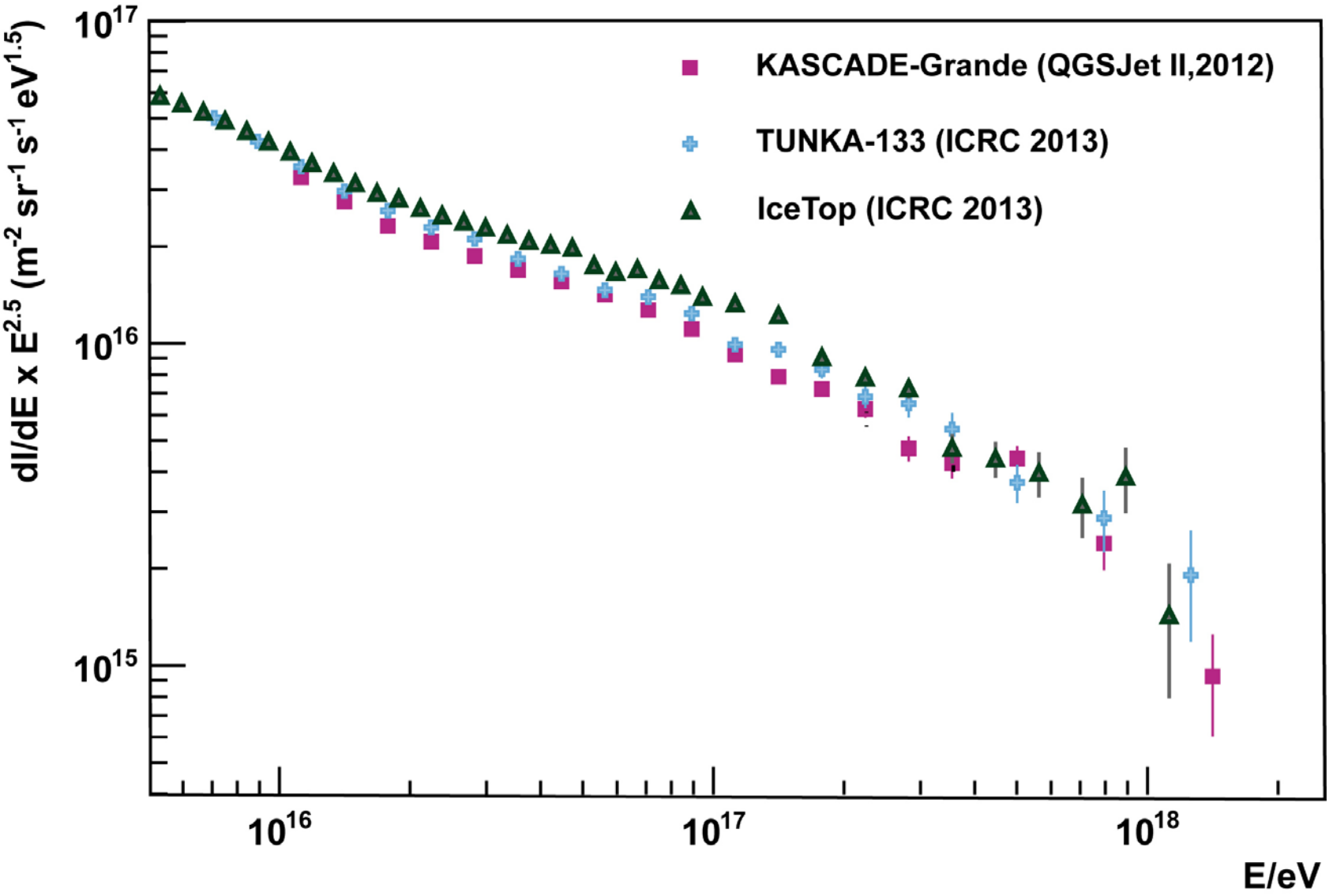




- **Energy range: PeV – 1EeV**
- **Area: 1 km^2**
- **2835m altitude (680 g/cm^2)**
- **81 ice cherenkov stations**
- **LDF + particle density at 125m**
- **in-ice high-energy muons**

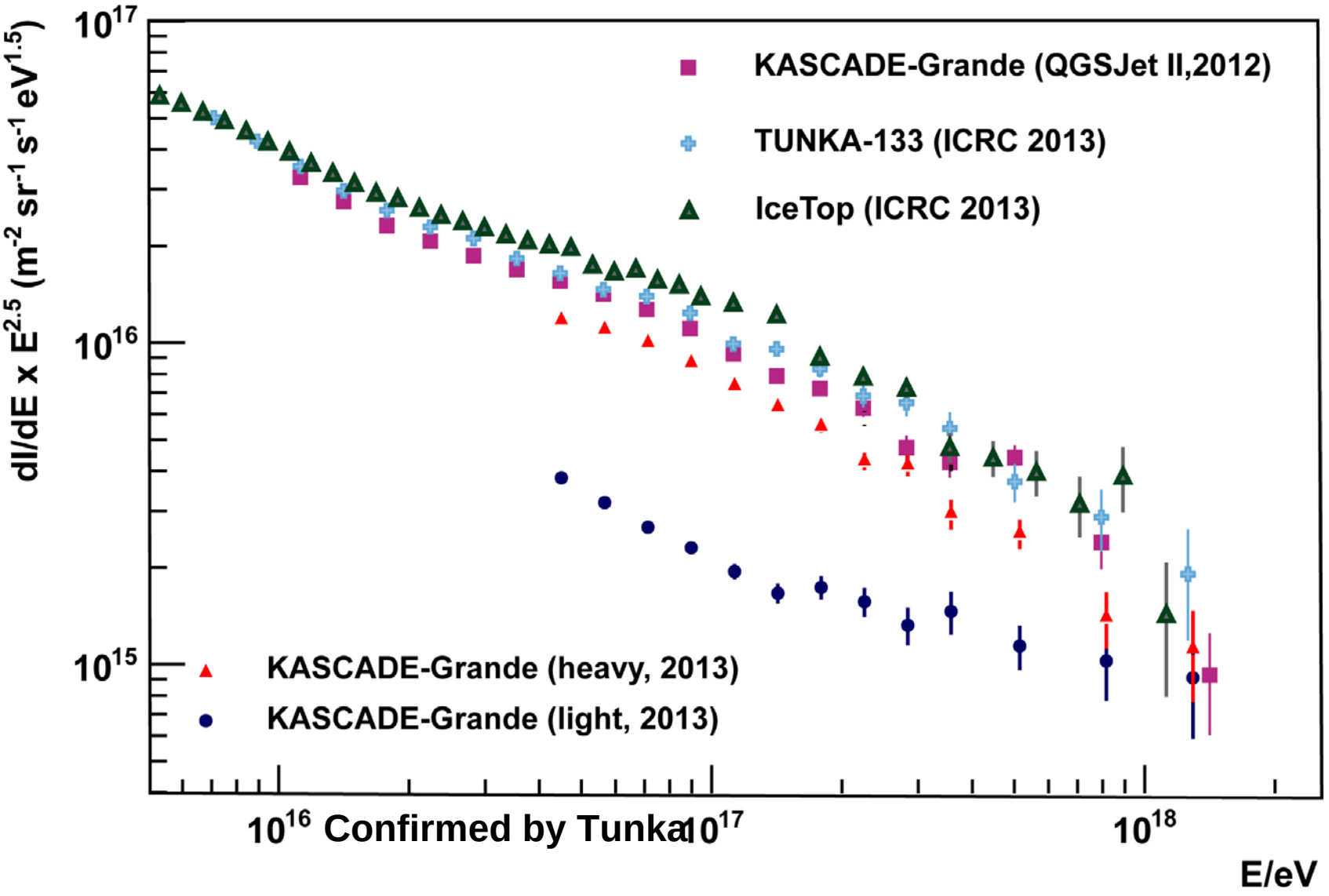
Phys Rev D (2013) accepted - dx.doi.org/10.1016/j.asr.2013.05.008 ??????

All-particle spectra



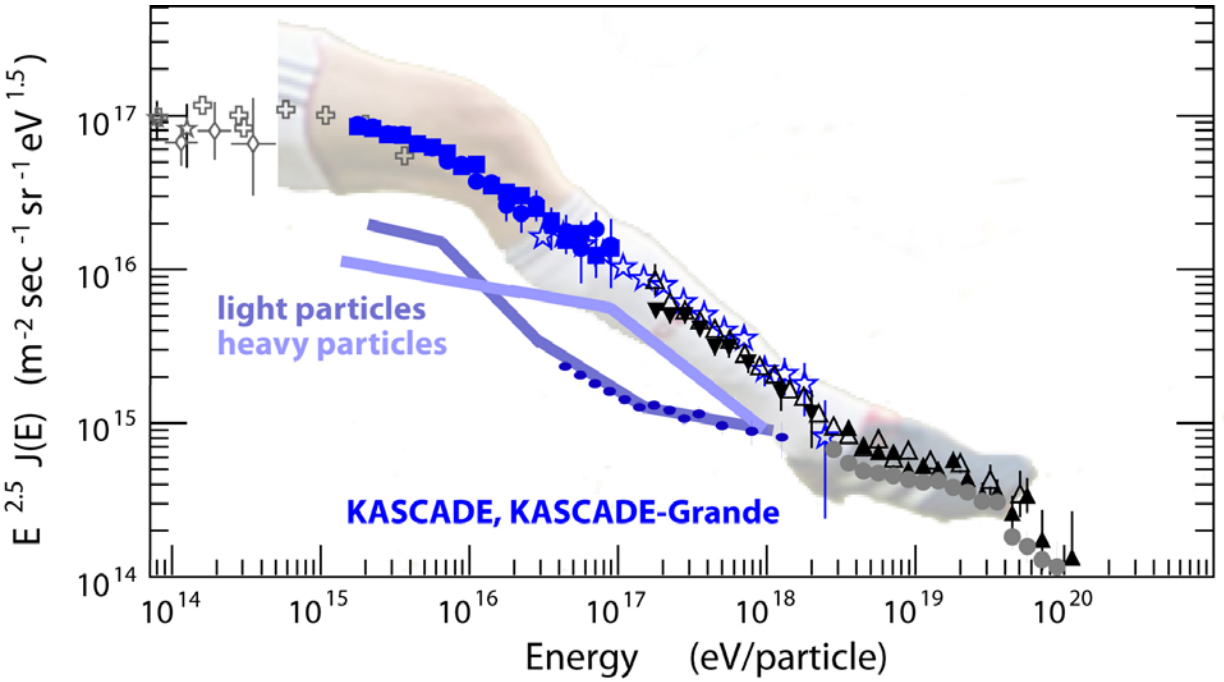
- Structures of all-particle spectra similar (in the level of 15%)

All-particle spectra



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

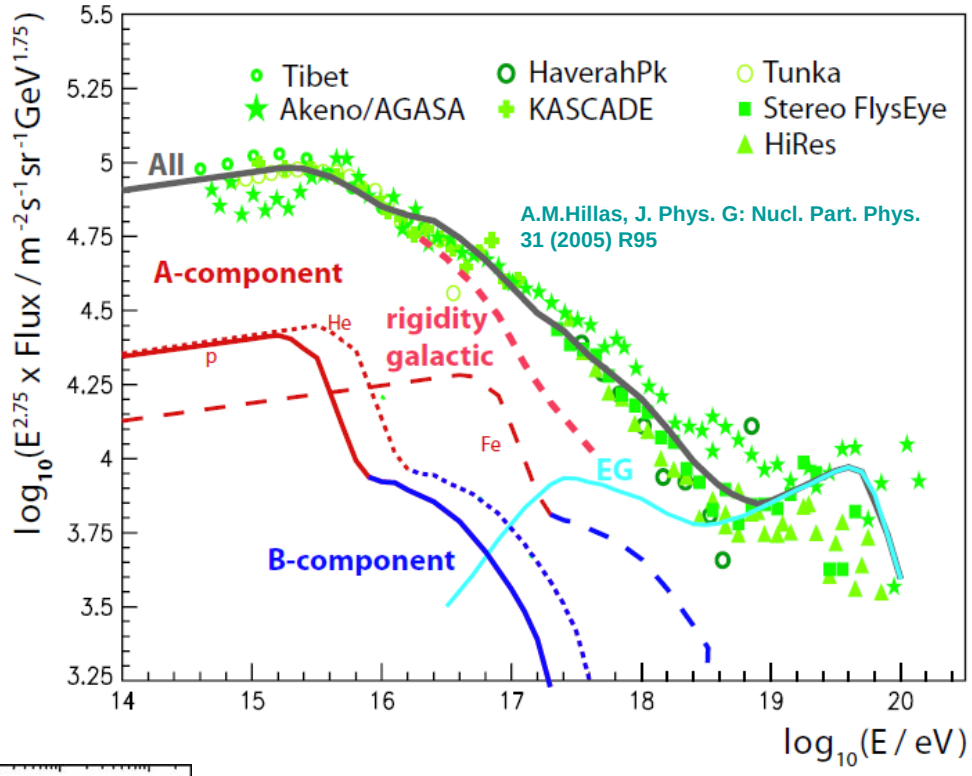
Light and Heavy Knees, Ankles, and Transition

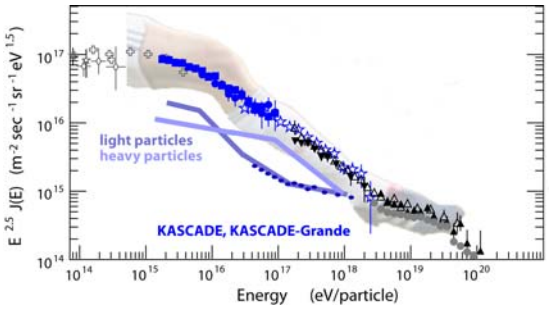


- ➔ **KASCADE: knee of light primaries at ~3·10^{15}eV**
- ➔ **Hardening at 10^{16}eV due to knee of medium component**
- ➔ **KASCADE-Grande: knee of heavy primaries at ~9·10^{16} eV**
- ➔ **heavy knee less distinct compared to light knee**
- ➔ **mixed composition for 10^{15} to ~ 8·10^{17} eV**
- ➔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

knee position $\propto Z$

Light and Heavy Knees, Ankles, and Transition



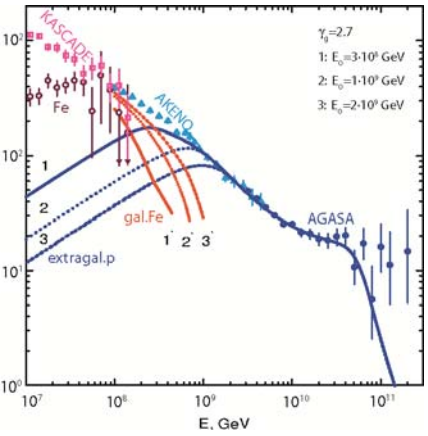


Questions:

- which astrophysical scenario (model) describes the data?

- exact energy and mass scale?

- spectral forms?

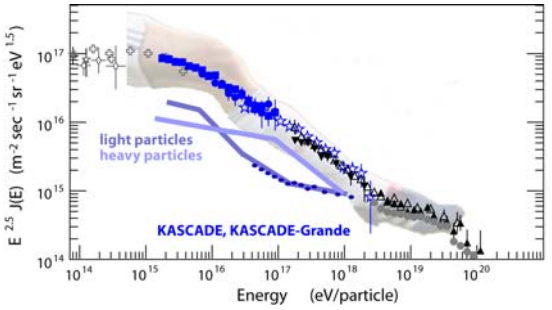


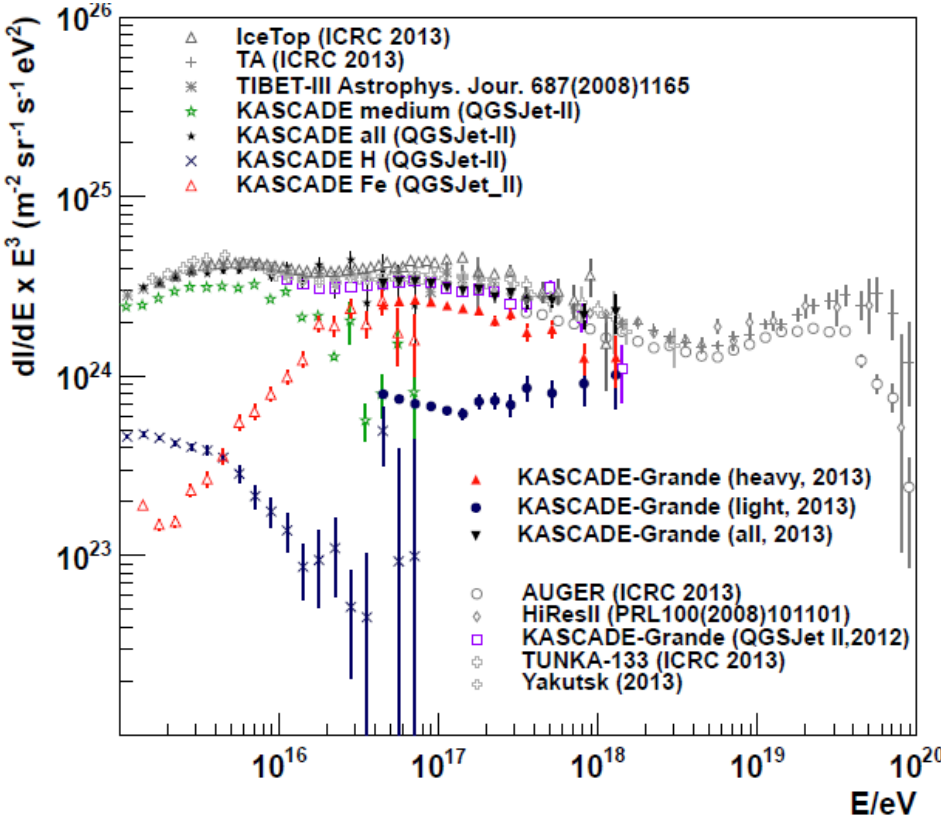
B-component: e.g. Sveshnikova et al: different types of SN
(J.Phys.Conf. 409 (2013) 012062)

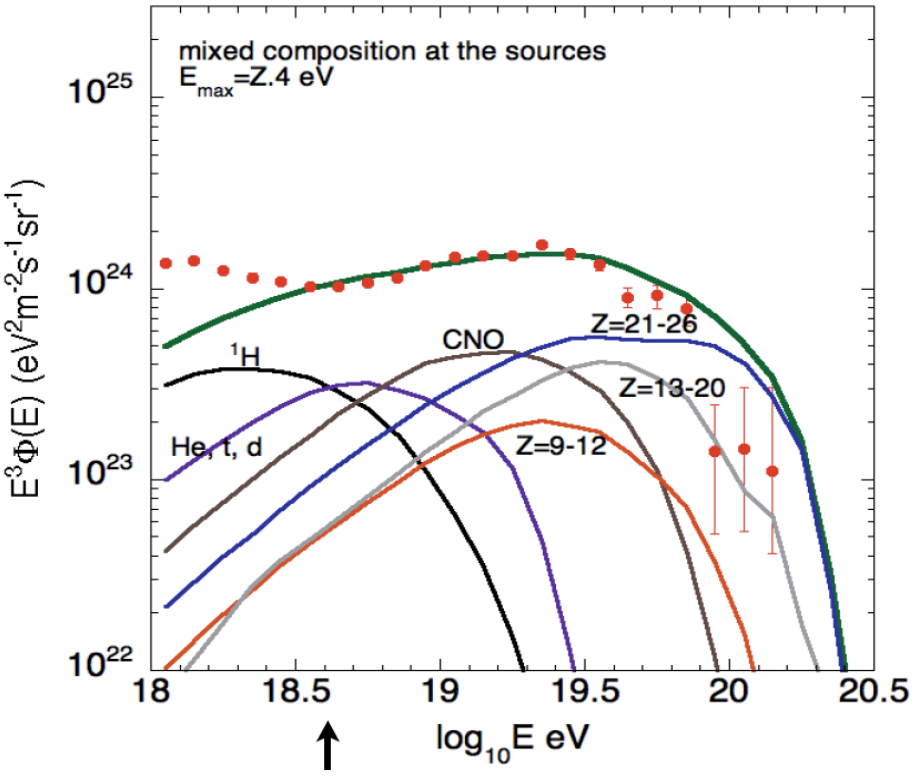
V.Berezinsky, astro-ph/0403477

Light and Heavy Knees, Ankles, and Transition

- Is the light component after the ankle already of extragalactic origin?



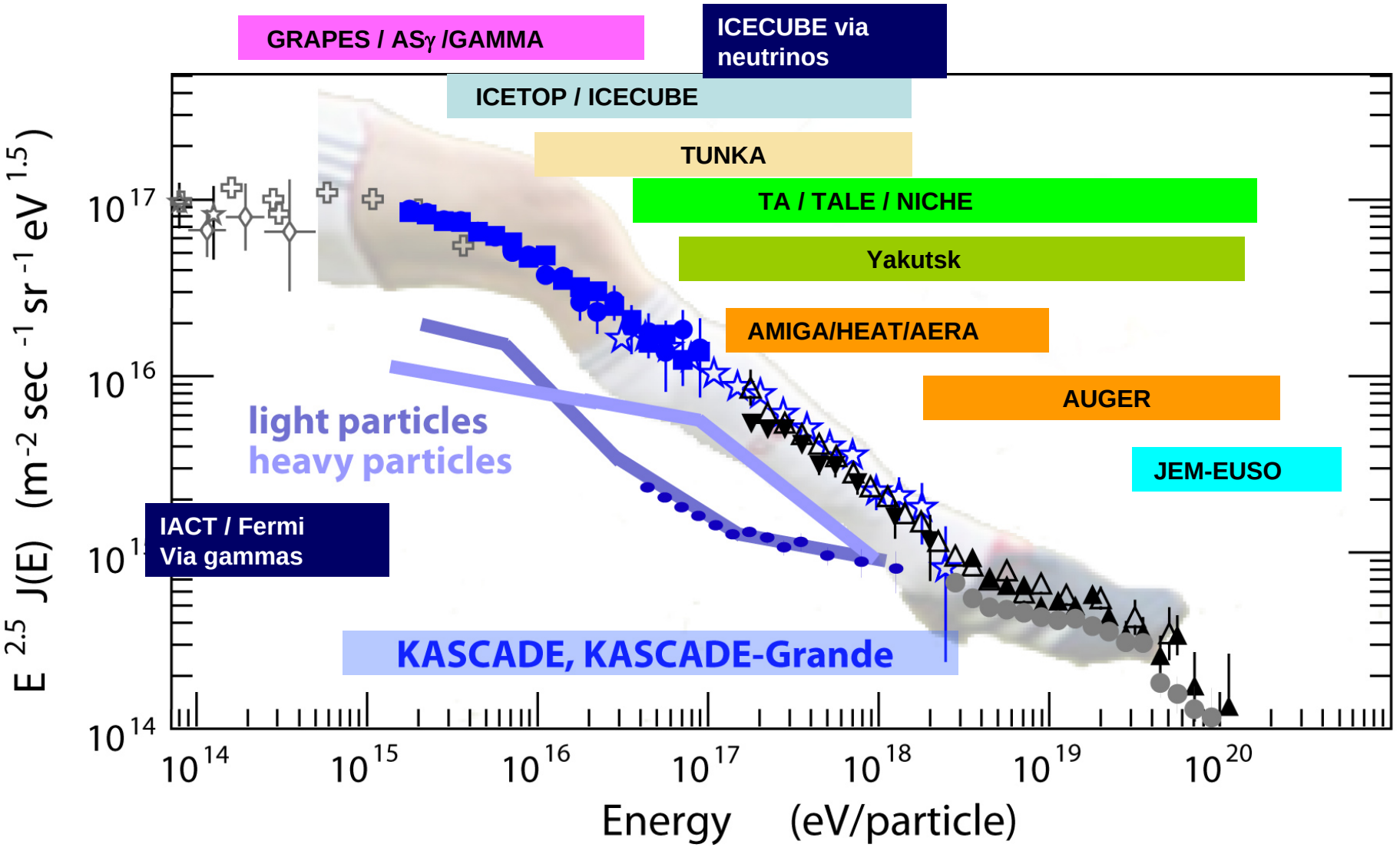




- Model of Allard et al.: early extragalactic and charge dependent maximum energy

D.Allard, astro-ph/1111.3290

Summary



….better answers only by combining all information: stay tuned!