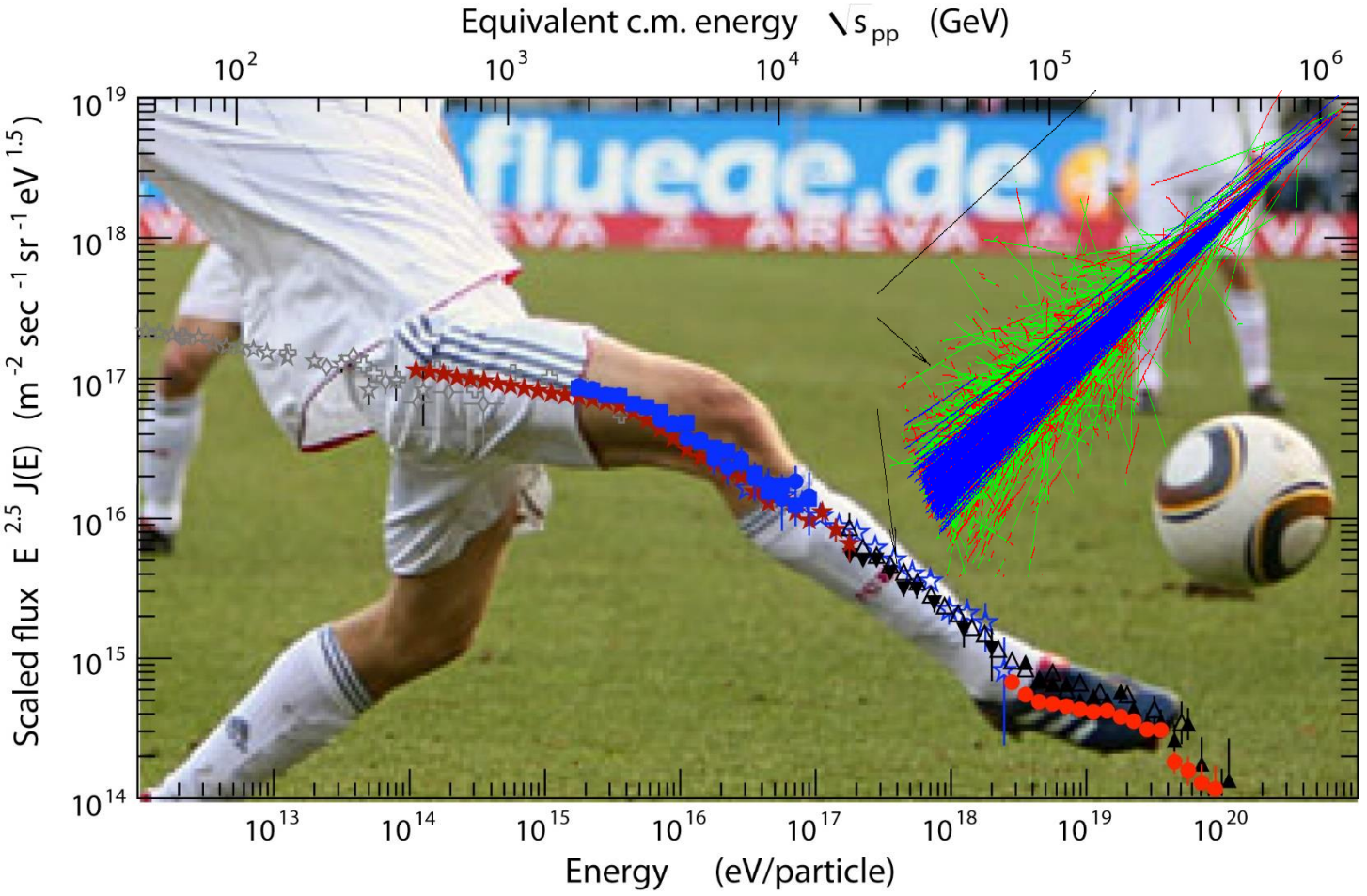
KASCADE-Grande

in the view of the post-LHC hadronic interaction models



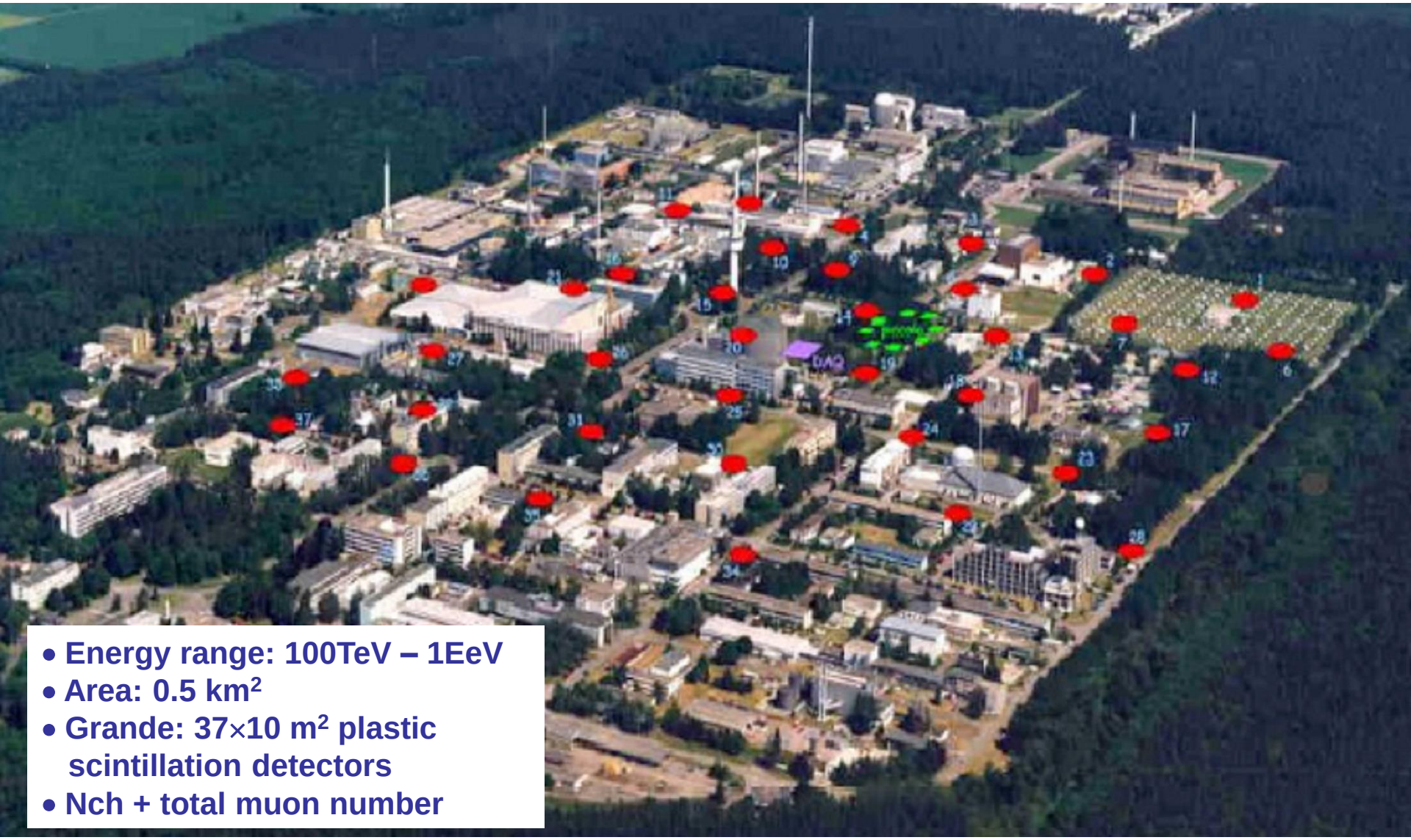
KASCADE

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-Grande



- Energy range: 100TeV – 1EeV
- Area: 0.5 km^2
- Grande: 37×10 m^2 plastic scintillation detectors
- Nch + total muon number

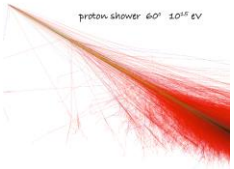
W.D.Apel et al, Nucl.Instr. and Meth. A620 (2010) 202

KASCADE timeline

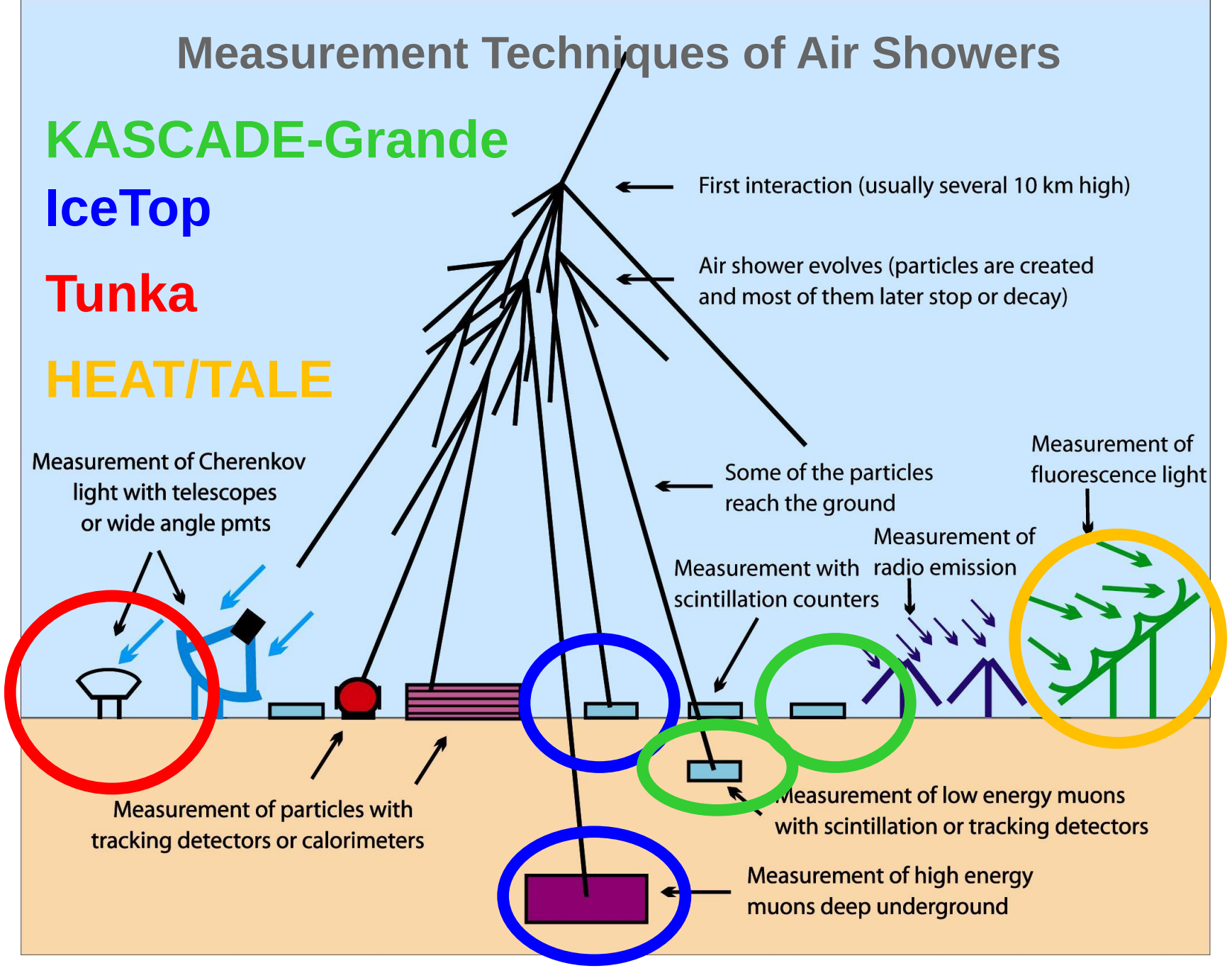
- 56 collaborative papers in reviewed journals (4-5 still in queue, short author list papers not included)
- 56 PhD thesis
- 86 diploma/master thesis

1989 Proposal
1996 KASCADE
2000 KASCADE-Grande
2004 LOPES
2008 Karlsruhe Air Shower Test Facility
2012 CROME
2016 KCDC

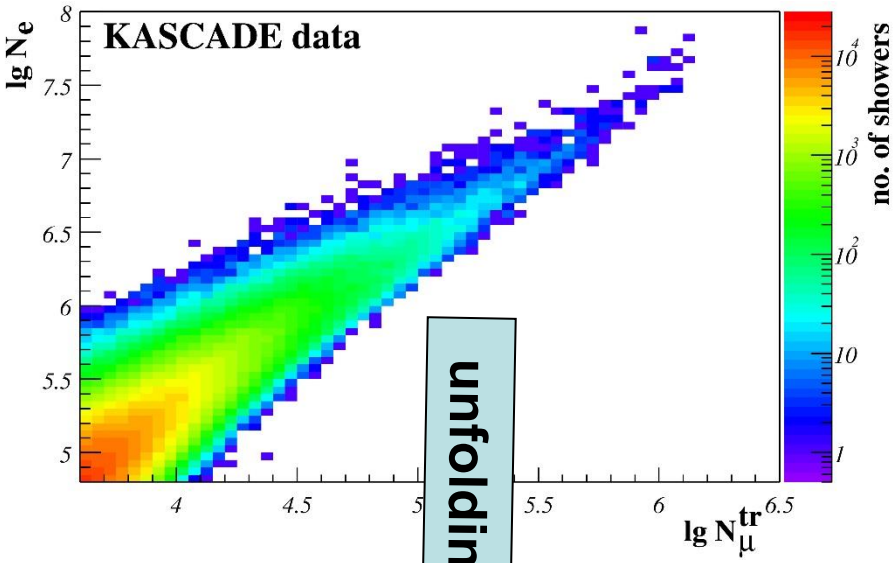
CORSIKA
model tests
light knee
γ limit
(an)isotropy
proof-of-principle radio detection
muon production height
heavy knee
light ankle
EAS GHz emission
Xmax by radio
Cosmic Revelation



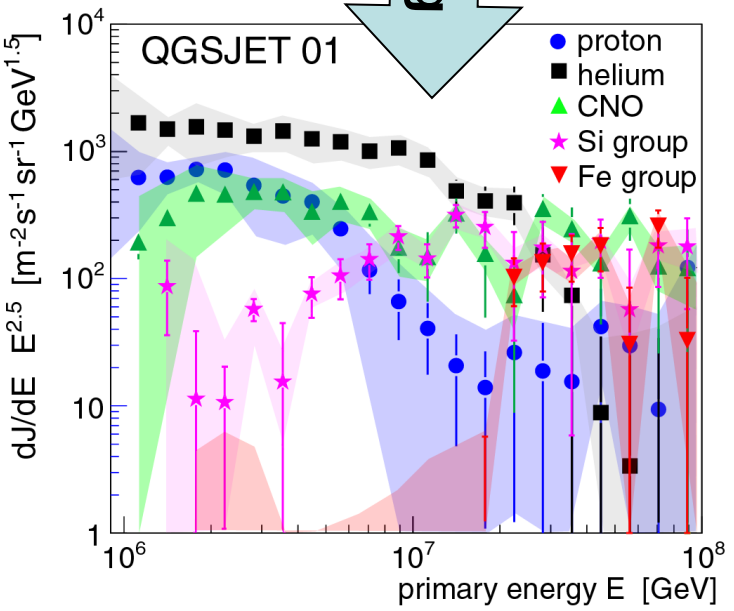
Measurement Techniques of Air Showers

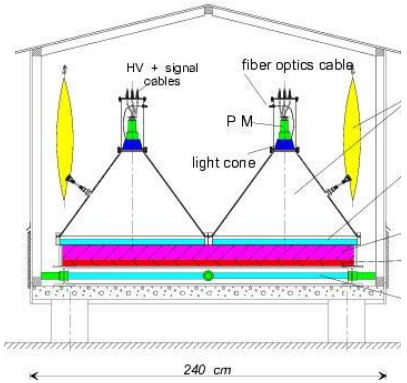


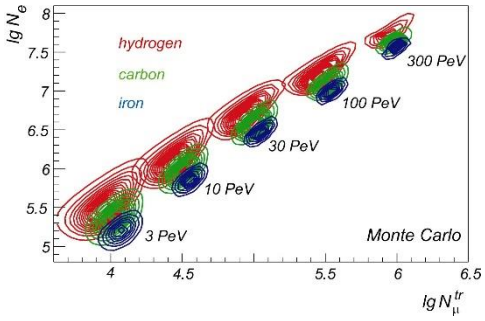
KASCADE : energy spectra of single mass groups



unfolding







Searched:

E and A of the Cosmic Ray Particles

Given:

N_e and N_μ for each single event

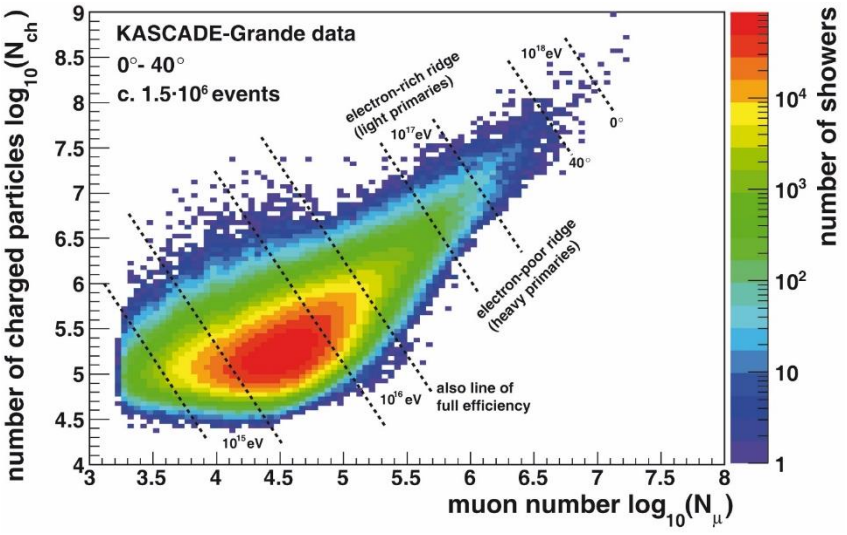
➔ solve the inverse problem

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

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

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

KASCADE-Grande: energy spectra of single mass groups



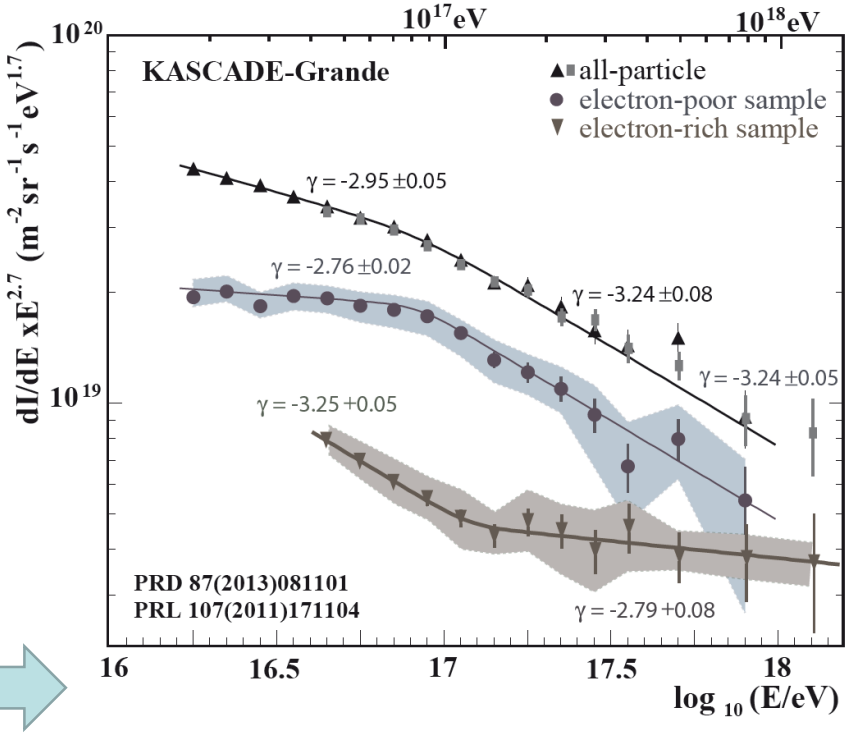
➔ determination of primary energy
➔ separation in "electron-rich" and "electron-poor" event

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

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

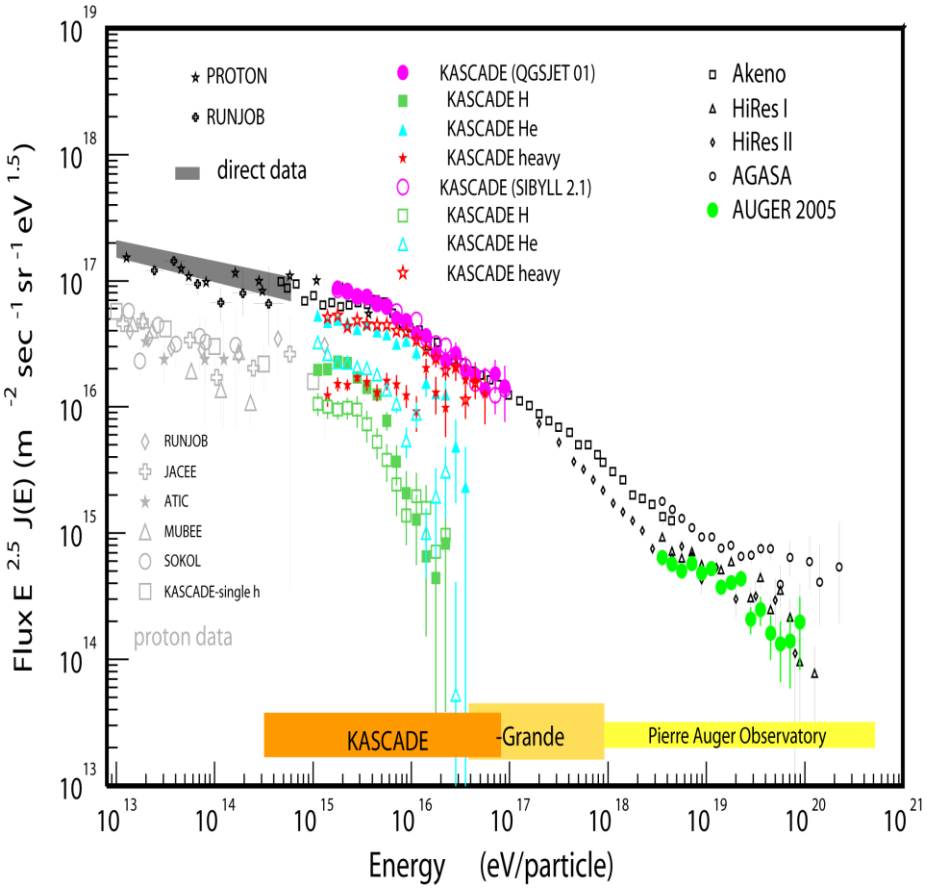
Phys.Rev.Lett. 107 (2011) 171104

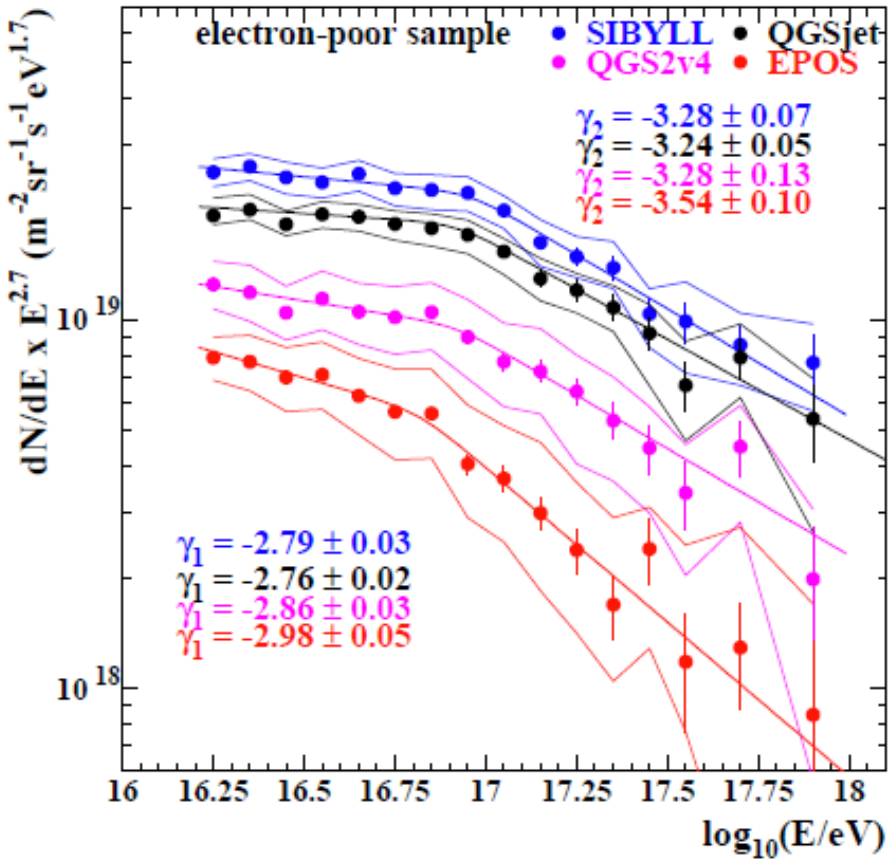
Phys.Rev.D (R) 87 (2013) 081101



- steepening due to heavy primaries (3.5σ)
- hardening at $10^{17.08}$ eV (5.8σ) in light spectrum
- slope change from γ = -3.25 to γ = -2.79!

KASCADE / KASCADE-Grande: model dependence



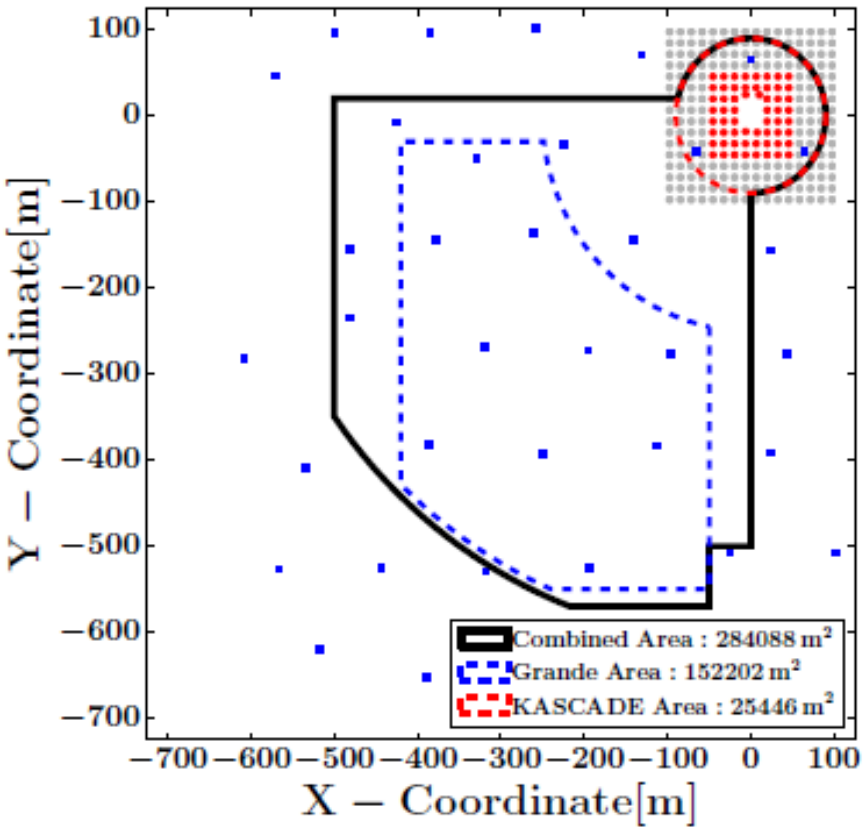


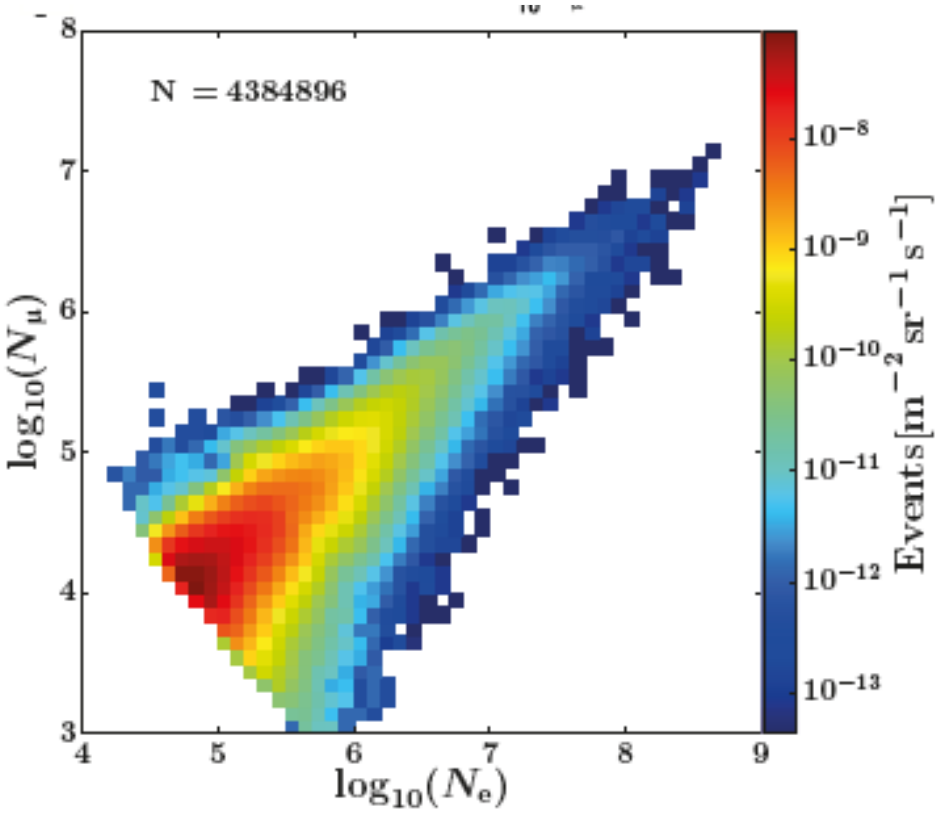
- **Structures of all-particle, heavy and light spectra similar**
- **knee by light component and heavy component; ankle by light component**
- **relative abundances different** for different high-energy hadronic interaction models

➔ **Problem in models for describing absolute mass scale**

Advances in Space Research 53 (2014) 1456

KASCADE-Grande: Combined Analysis





- **for KASCADE: additional stations at larger distances**

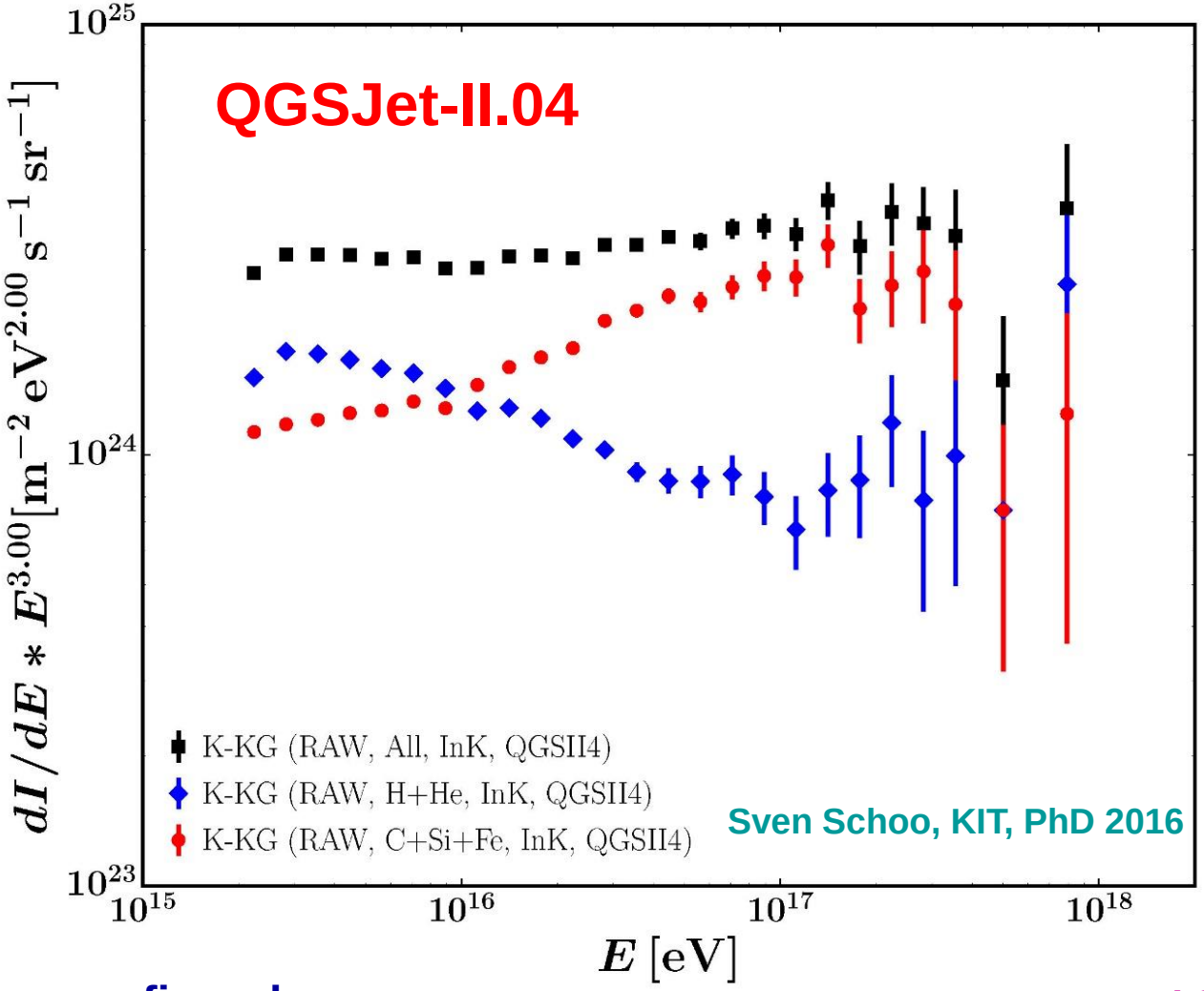
  ➔ higher energies

- **for Grande: additional 252 stations**

  ➔ higher accuracy

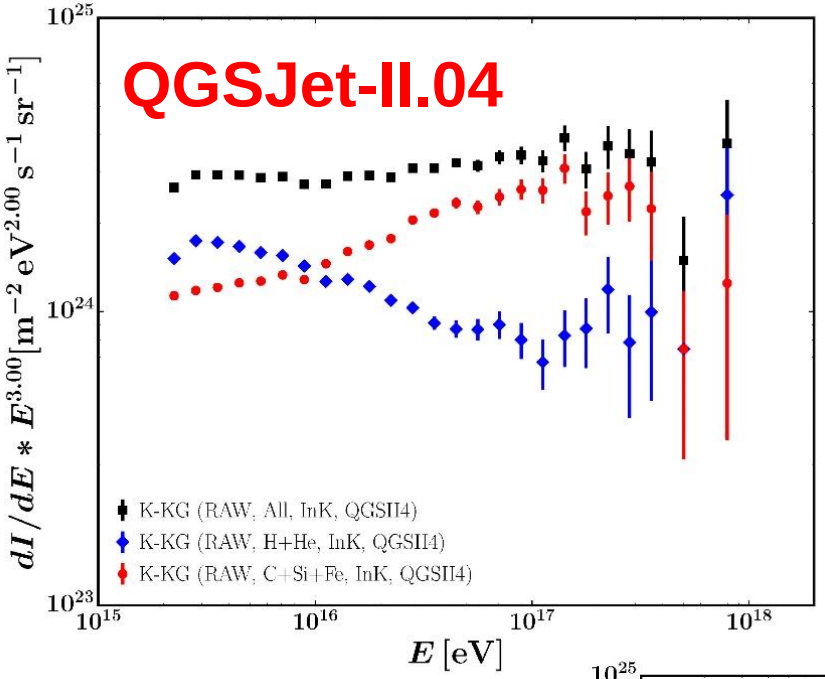
Sven Schoo, KIT, PhD 2016

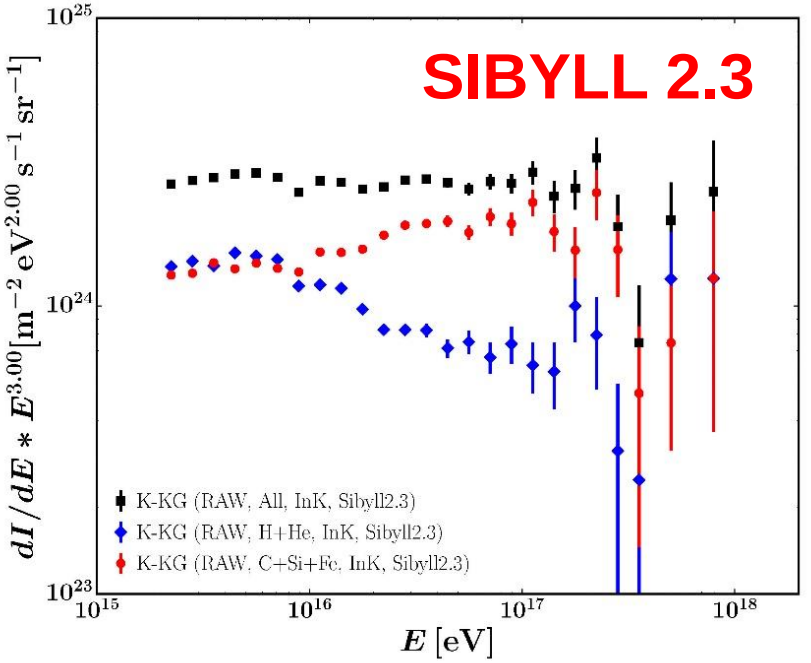
KASCADE-Grande: Combined Analysis resulting energy spectra (post-LHC hadronic interaction models)

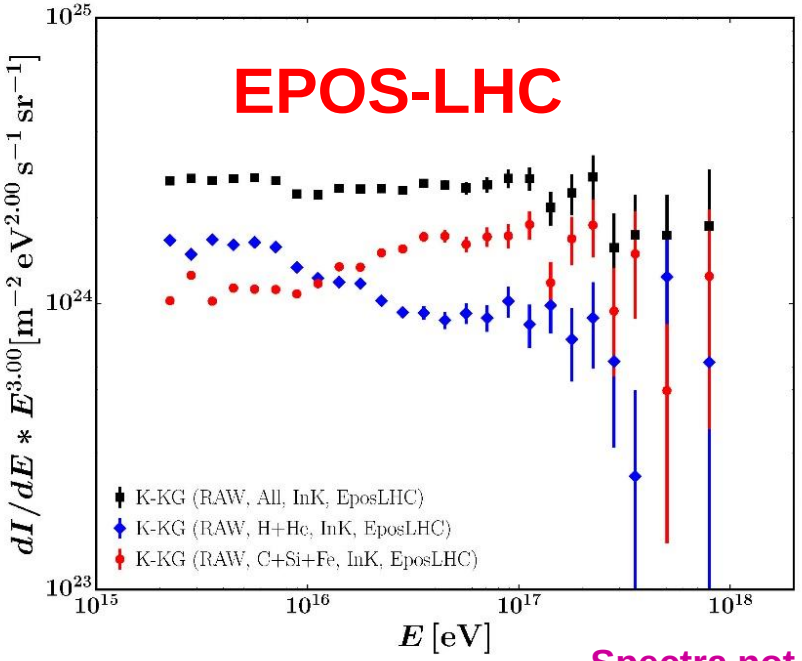


all structures confirmed

Spectra not corrected for uncertainties







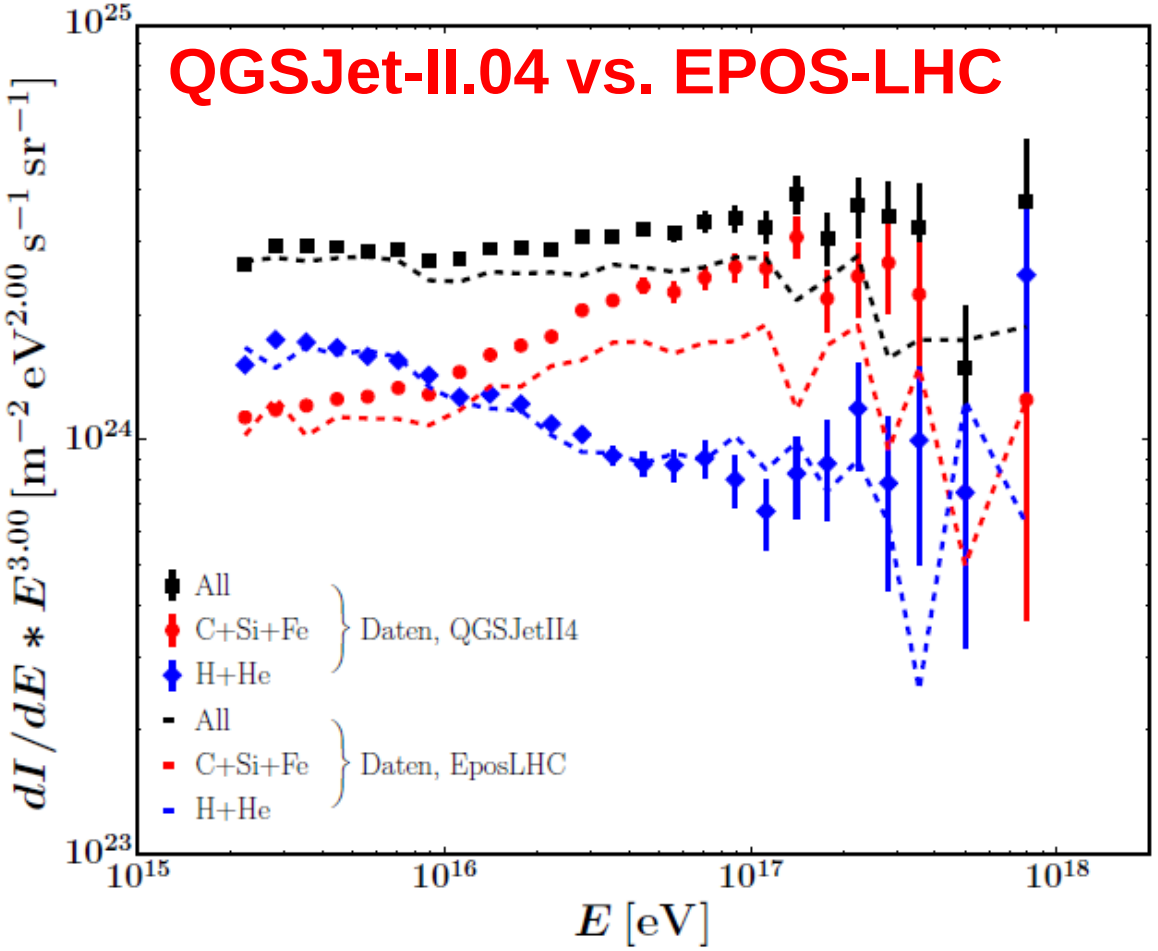
- **structures confirmed**
- **all particle spectrum good agreement**
- **relative abundance of light and heavy quite different**

Sven Schoo, KIT, PhD 2016

Spectra not corrected for uncertainties

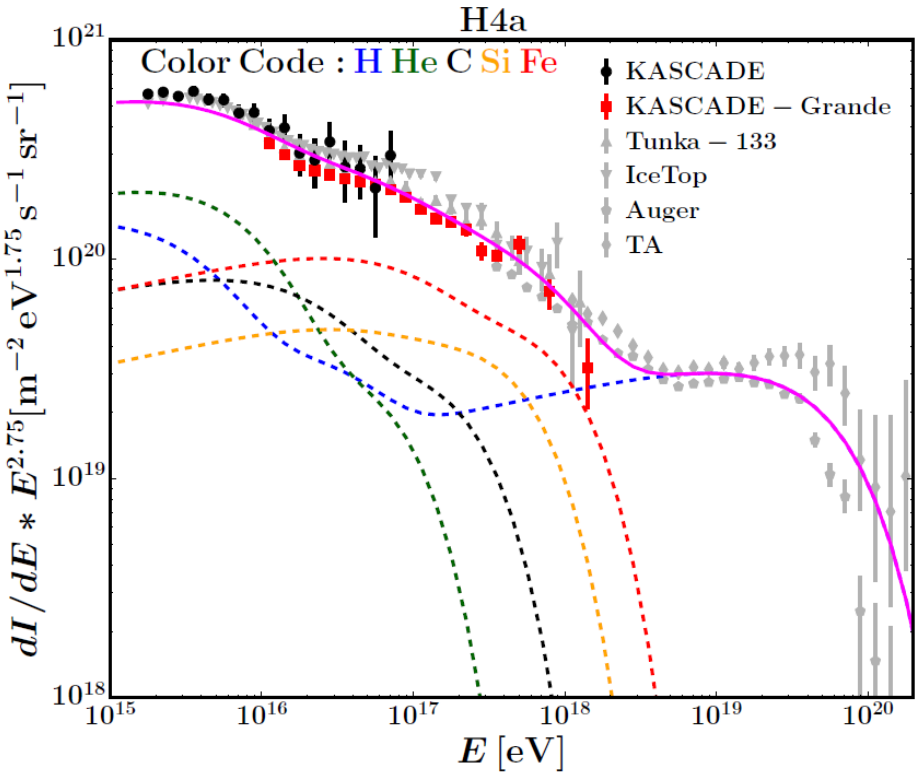
KASCADE-Grande: Combined Analysis

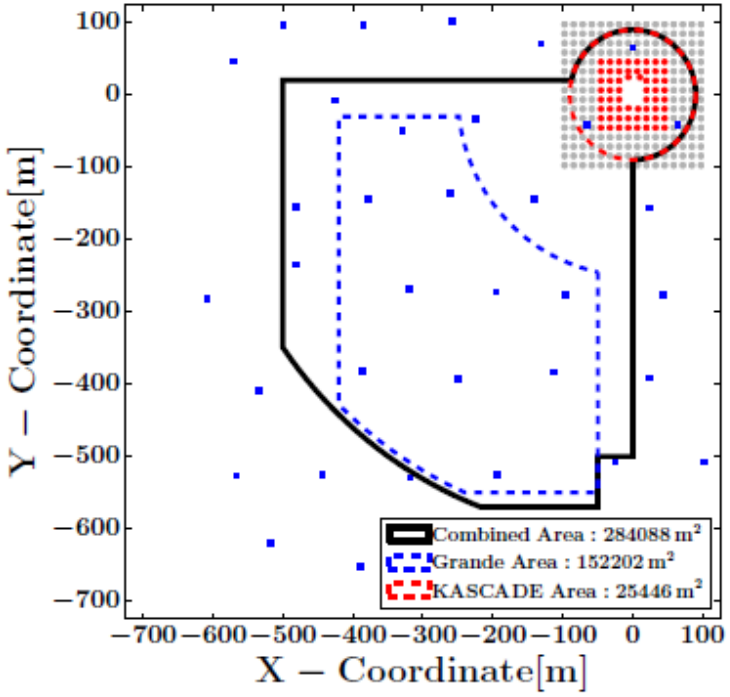
resulting energy spectra based on two hadronic interaction models



- **Post LHC models**
  - **light primary interactions okay?**
  - **heavy primary interactions show differences**

KASCADE-Grande: combined analysis
Check Hadronic Interaction Models





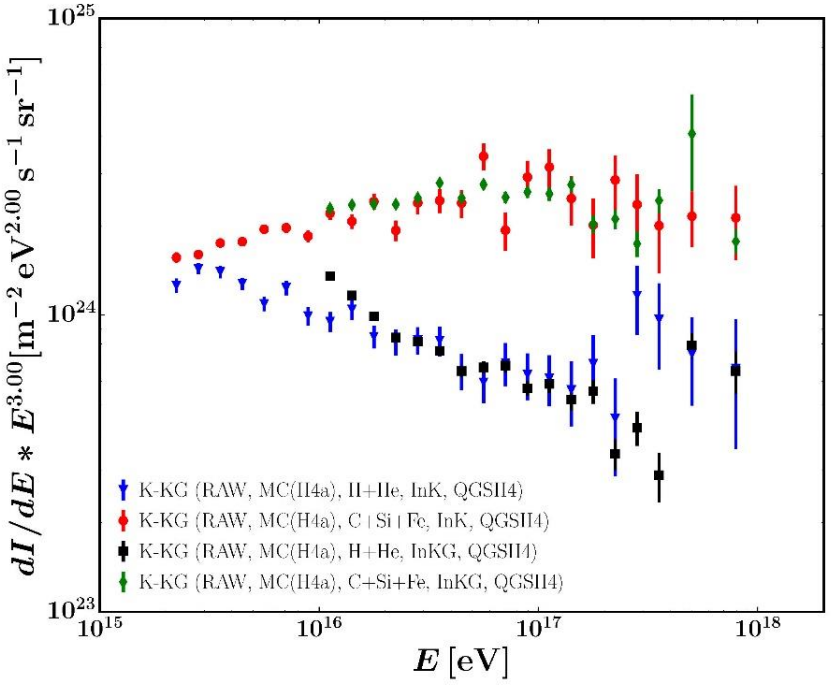
- **assume a composition model: H4a by Tom Gaisser**

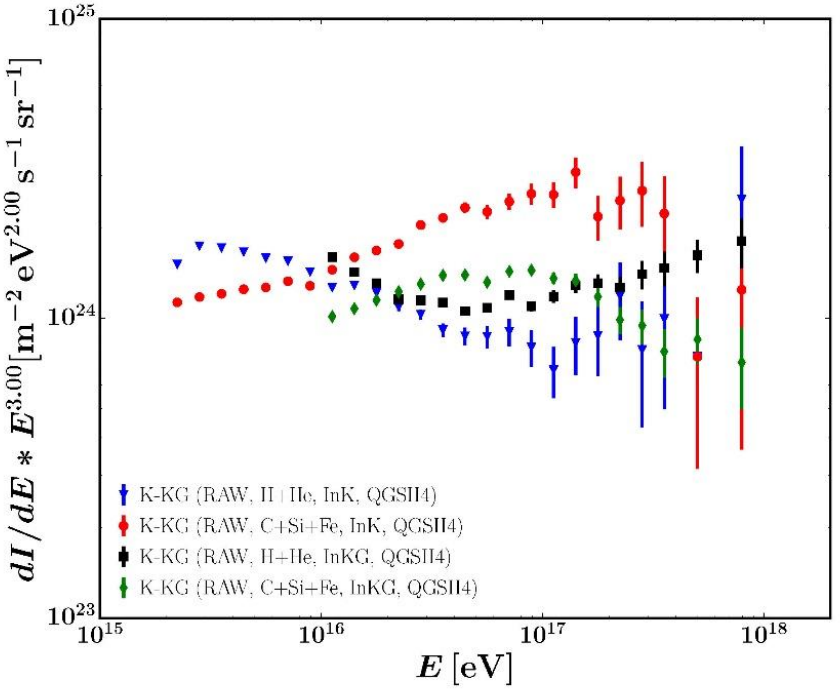
- **two selections: core located in KASCADE, core located in Grande**
  ➔ we measure “different” muons

KASCADE-Grande: Combined Analysis

Test of models

QGSJet-II.04



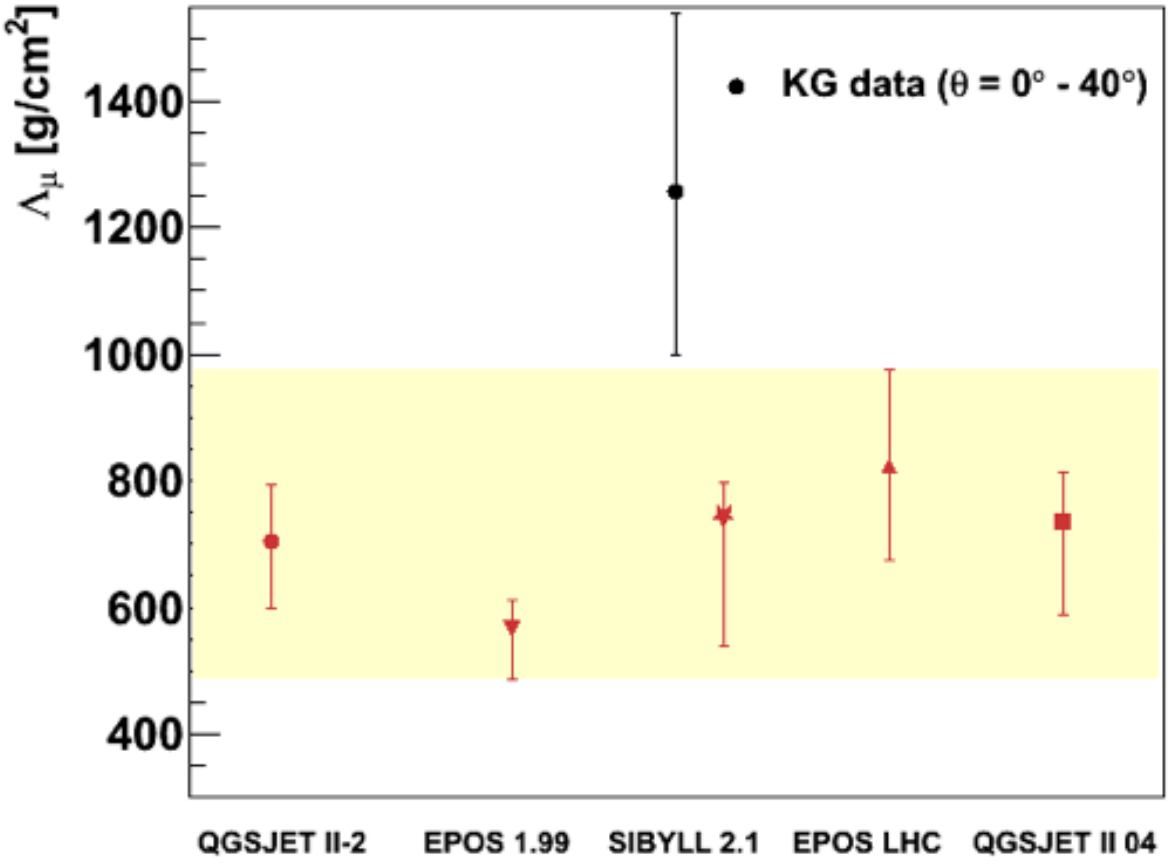


- **One model, but two selections:**
  Simulations okay, but strong differences in data
  (similar result for QGSJet-II.04, EPOS-LHC, SIBYLL 2.3)

➔ **Muon component not sufficiently described**

KASCADE-Grande: Muon Attenuation Length

total muon number : $N_\mu = N_{\mu,0} \exp[- X_0 \sec(\theta) / \Lambda_\mu]$

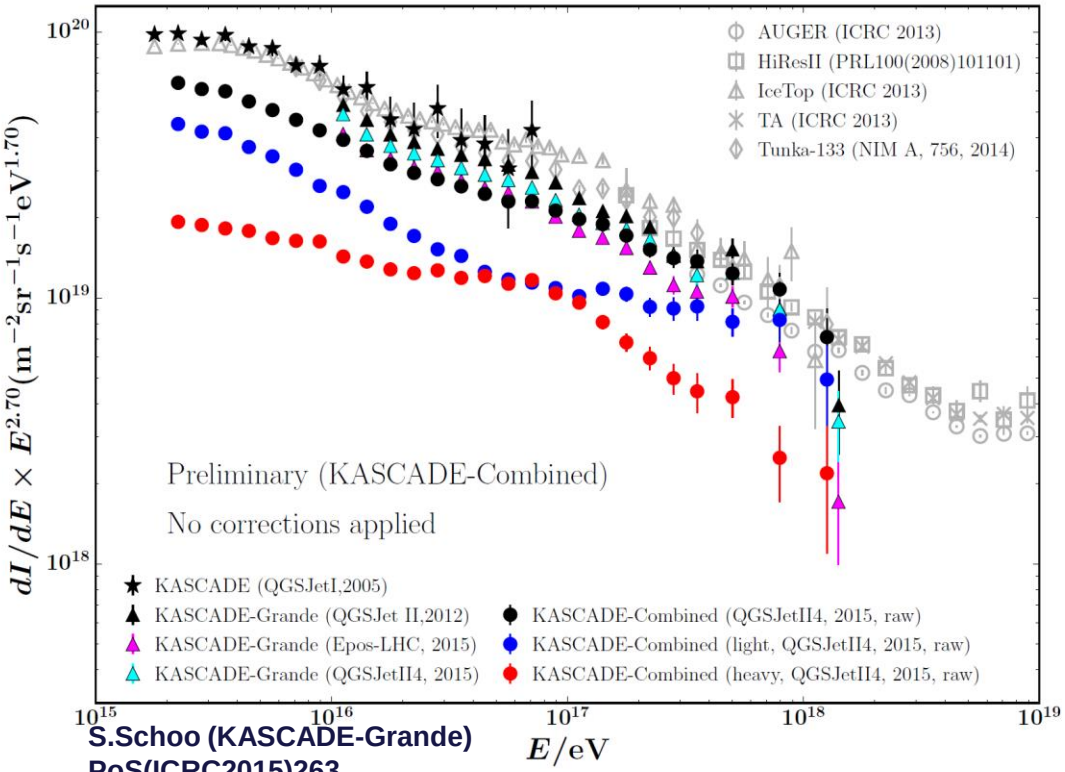


SIBYLL 2.3 model is presently under investigation
Distance dependent muon absorption under investigation

Juan Carlos Arteaga, submitted to AstroP.Phys.

Conclusion new analysis:

All particle, light and heavy spectra for 3 orders of magnitude



S.Schoo (KASCADE-Grande)
PoS(ICRC2015)263

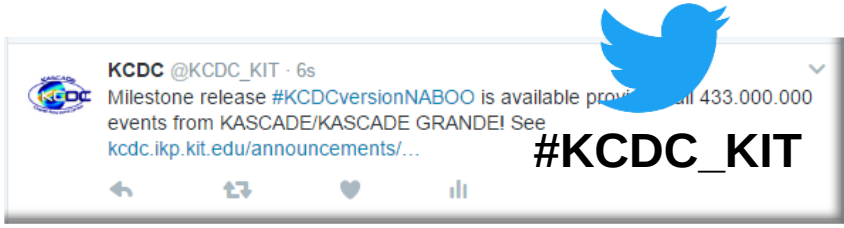
Paper in preparation
Analysis by Sven Schoo

- **Structures of spectra confirmed**
- **H4a model probably not far away from real composition**
- **Hadronic models still do not agree to each other and to data**
- **Light component seems to agree better than heavy**
- **Problem probably in the muons (known due to special selection)**
- **Around 10^{15} eV still (again) no clear picture**

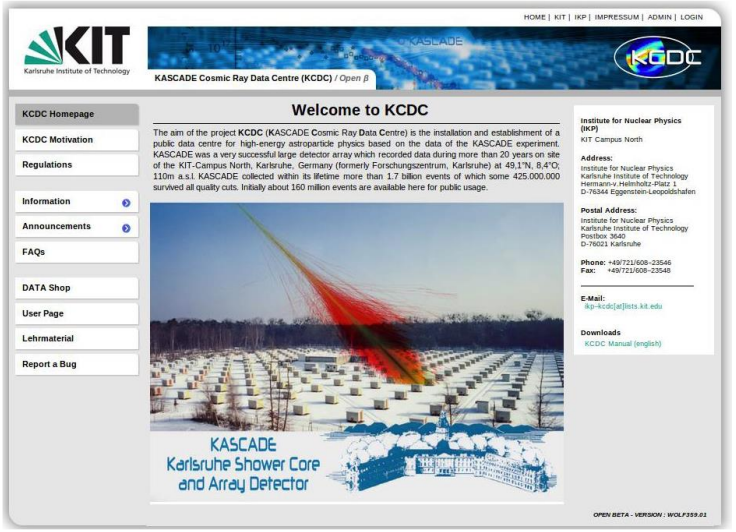

https://kcdc.ikp.kit.edu
KASCADE
KCDC
Cosmic ray Data Centre
Andreas Haungs, KASCADE-Grande

https://kcdc.ikp.kit.edu/

- **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:**
  Version NABOO is released (Feb.2017)
  $4.3 \cdot 10^8$ EAS events are available

Paper in preparation

KASCADE-Grande: Mission Accomplished !!

open access to research data
https://kcdc.ikp.kit.edu

KASCADE-Grande: Mission Accomplished !!

open access to research data
https://kcdc.ikp.kit.edu

Conclusions – open points

- Light and heavy knee established
- Light ankle probably there

Confirmed by IceTop and Tunka-133 (?)!

- Difficult to compare experiments due to different observables
  what is contribution of MHz-Radio?
- Yet no conclusive result due to insufficient hadronic interaction models
- Continuation in improving hadronic interaction models required
- Still main problem: absolute mass scale
- Confrontation of the data with astrophysical models still challenging
- Future: (mass dependent) Anisotropy studies
- Future: Multi-messenger Analyses (cosmic rays, γ-rays, neutrinos)
- IceTop(-Gen2), TAIGA, LHAASO, GRAPES, TALE, Auger-HEAT, HAWC?
- Global Data Centre for Astroparticle Physics envisaged