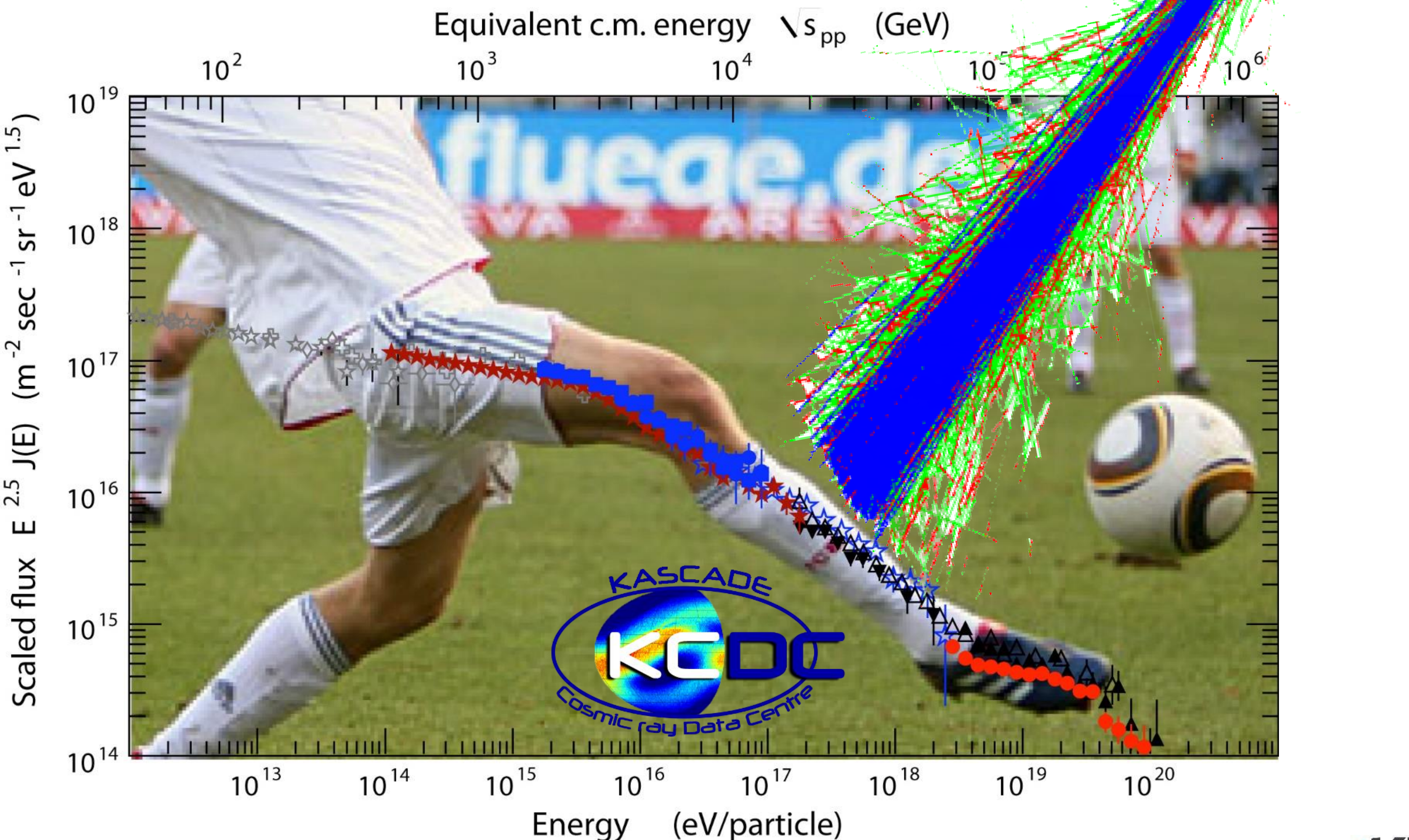
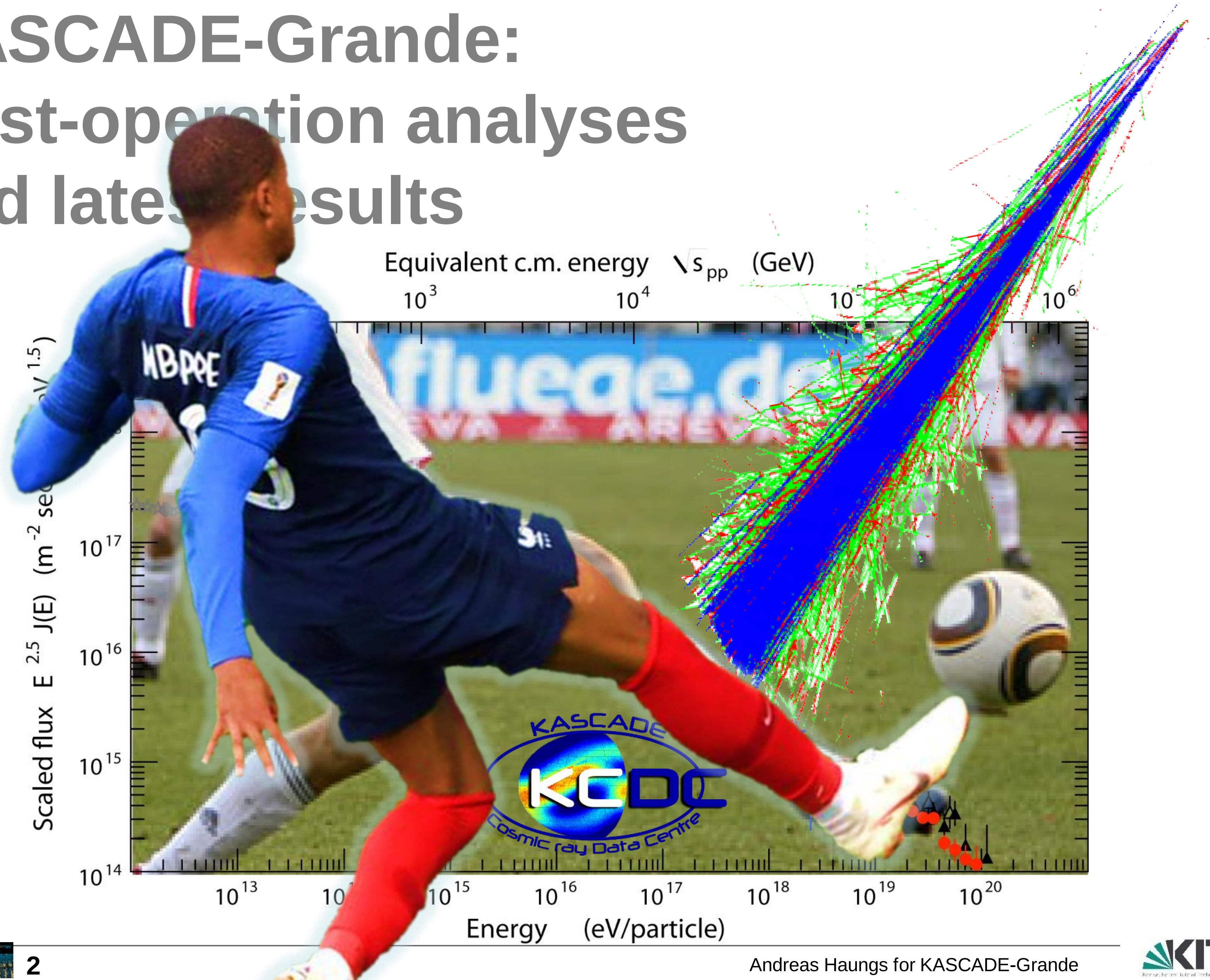
KASCADE-Grande: Post-operation analyses and latest results



KASCADE-Grande: Post-operation analyses and latest results

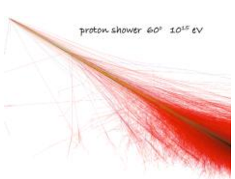


KASCADE timeline

- 59 collaborative papers in reviewed journals (2-3 still in queue, short author list papers not included)
- 56 PhD thesis
- 86 diploma/master thesis

1989
Proposal

CORSIKA



1996

KASCADE

model tests

light knee

2000

KASCADE-Grande

γ limit

LOPES

(an)isotropy

2004

proof-of-principle radio detection

Cosmic Revelation

muon production height

2008

Karlsruhe Air Shower Test Facility

heavy knee

CROME

light ankle

2012

KCDC

EAS GHz emission

Xmax by radio

2016

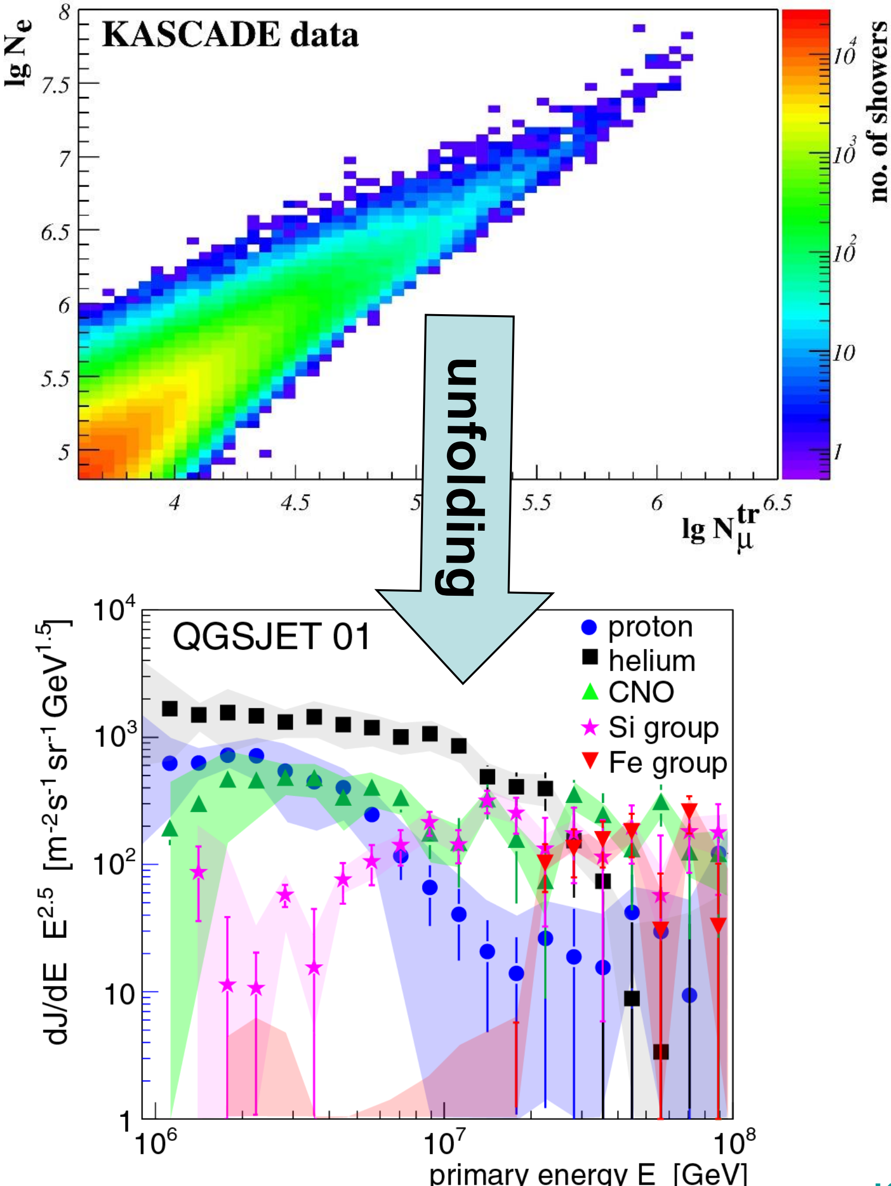
KASCADE

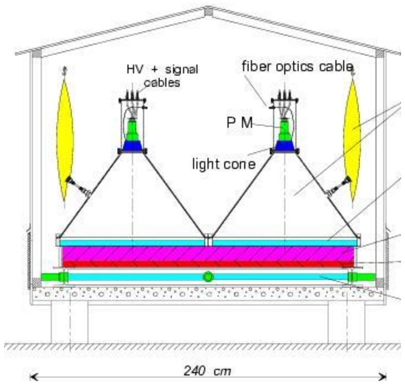
KArlsruhe Shower Core and Array DEtector

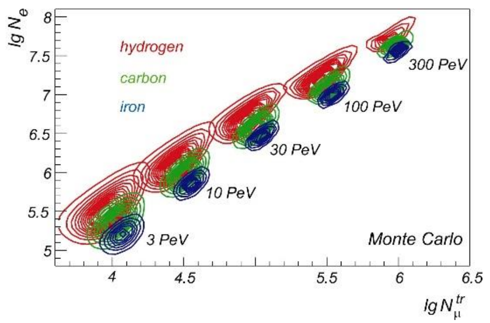
- Energy range 100TeV – 80PeV
- Since 1995
- Large number of observables: electrons, muons@4 thresholds, hadrons

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

KASCADE : energy spectra of single mass groups







Searched:

E and A of the Cosmic Ray Particles

Given:

N_e and N_μ for each single event

➔ solve the inverse problem

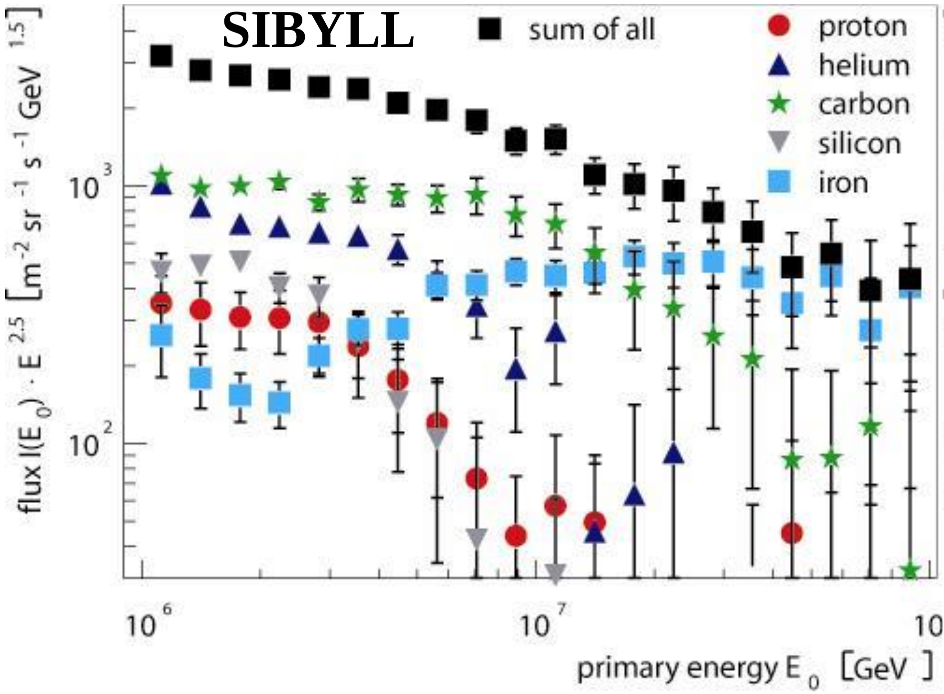
$$\frac{dJ}{d\lg N_e\, d\lg N_\mu^{tr}} = \sum_A \int_{-\infty}^{+\infty} \frac{dJ_A}{d\lg E}\, p_A(\lg N_e, \lg N_\mu^{tr} \mid \lg E)\, d\lg E$$

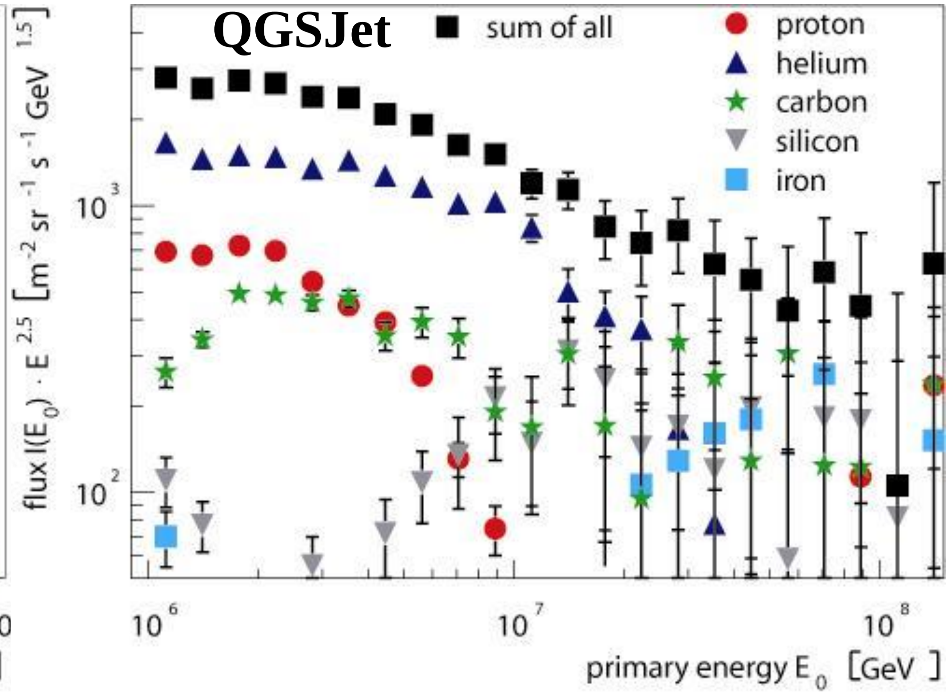
- **kernel function obtained by Monte Carlo simulations (CORSIKA)**
- **contains: shower fluctuations, efficiencies, reconstruction resolution**

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

KASCADE: the rigidity knee

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





- all-particle spectrum similar

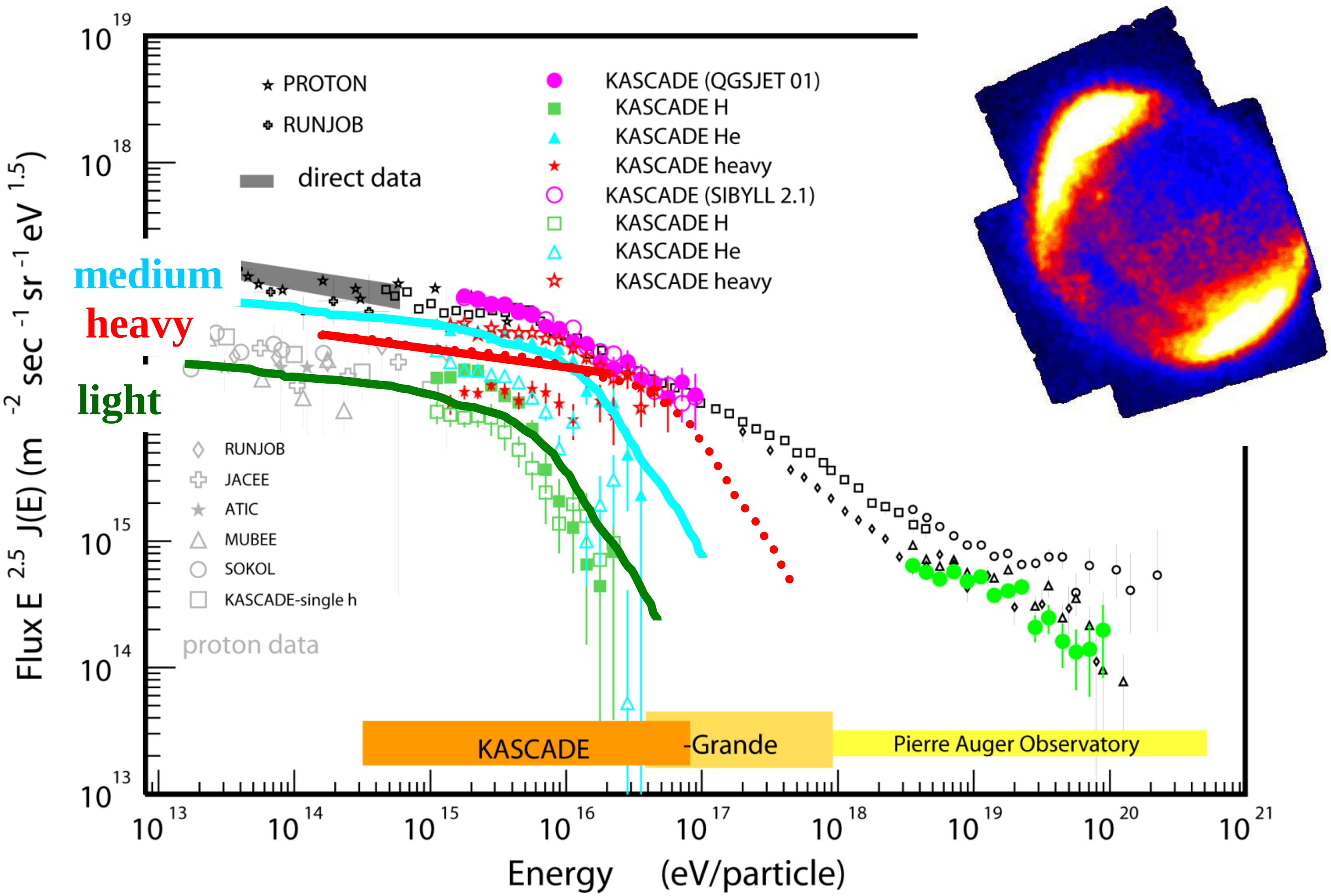
- general structure similar: knee by light component

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

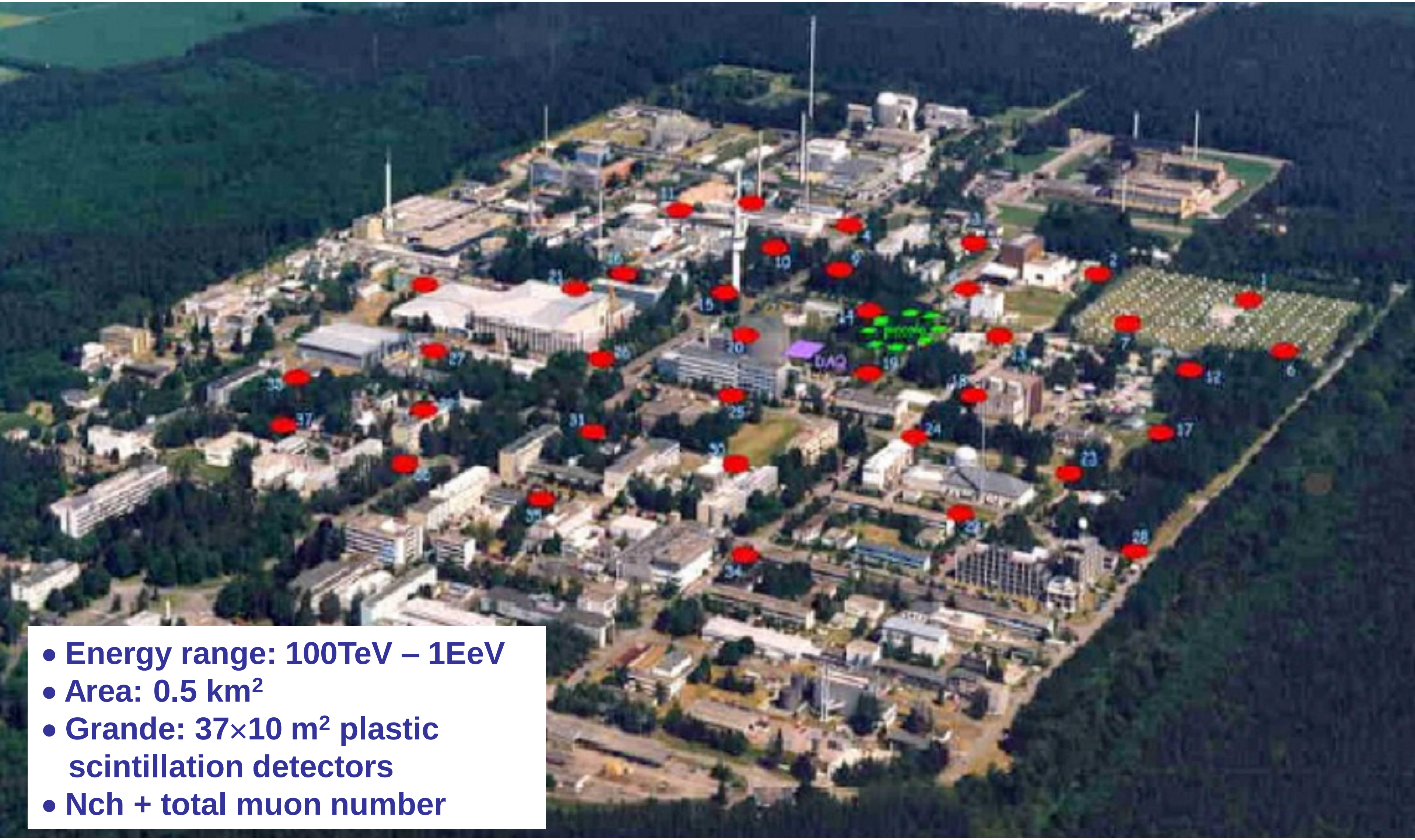
but for many models: proton not the most dominant component!

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

Result KASCADE ➔ Motivation KASCADE-Grande



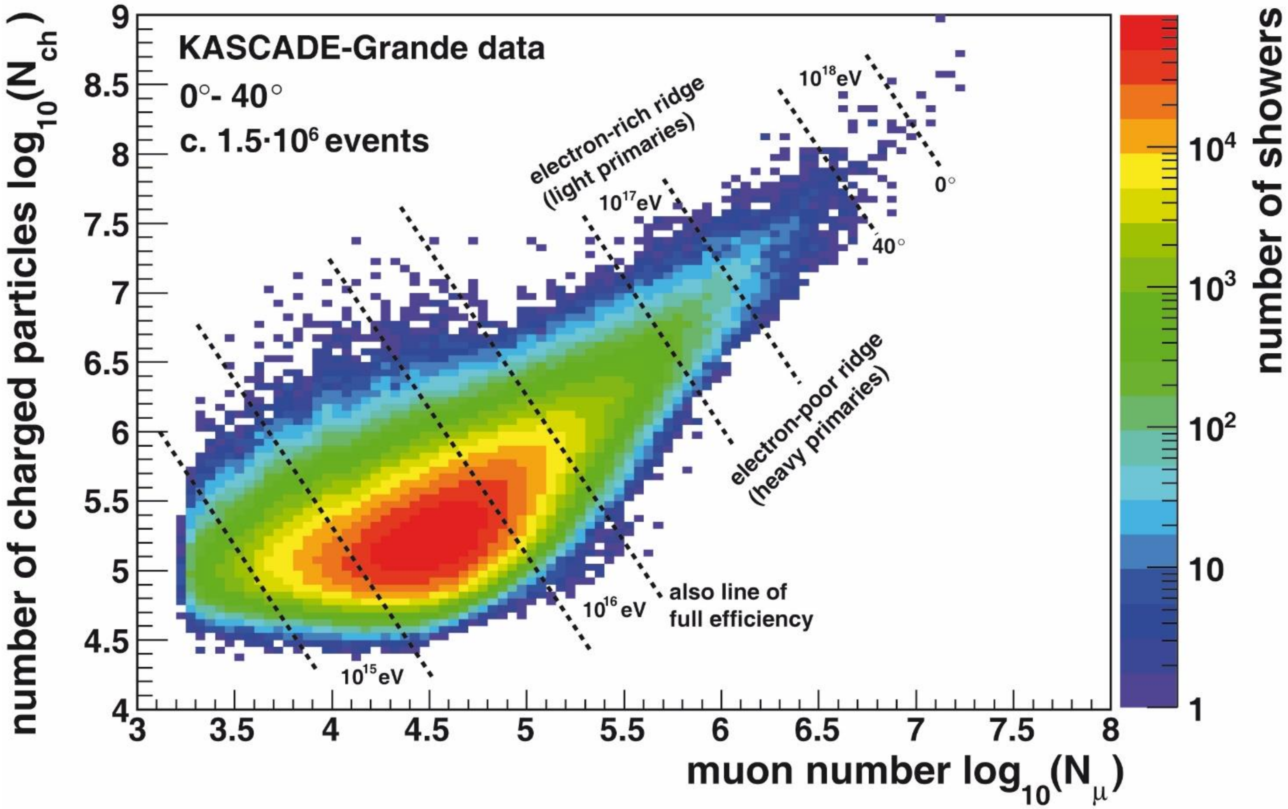
KASCADE-Grande



- 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

2-dimensional shower size spectrum



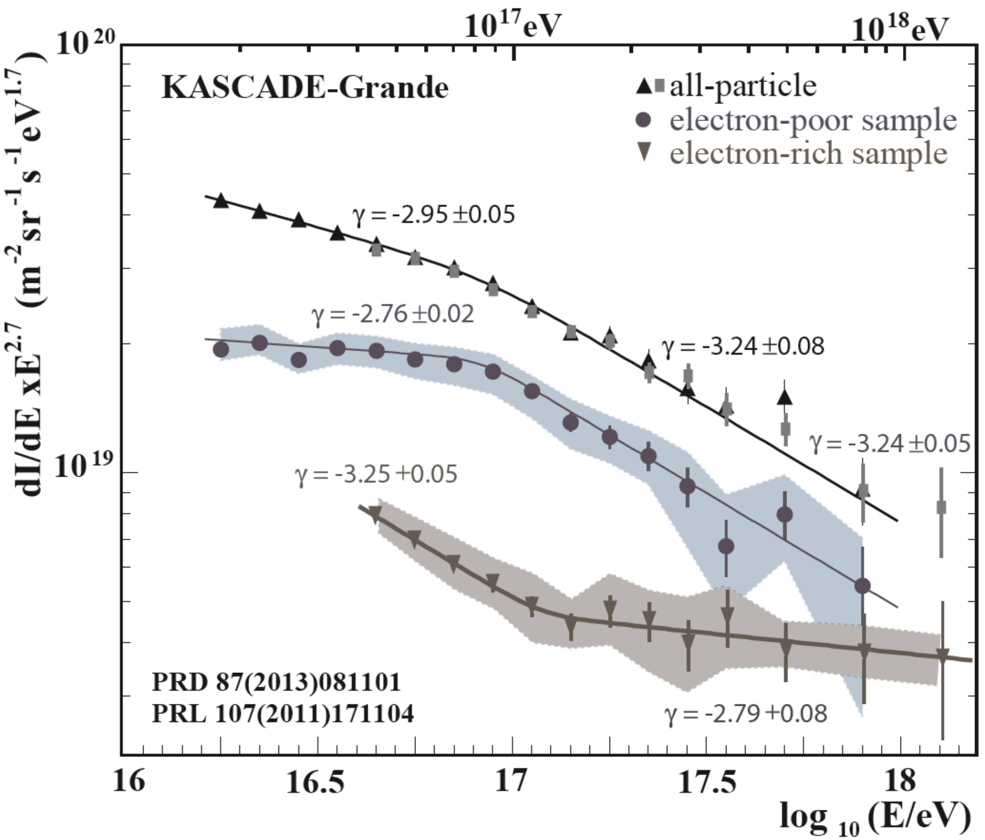
➔ **determination of primary energy**

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

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

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

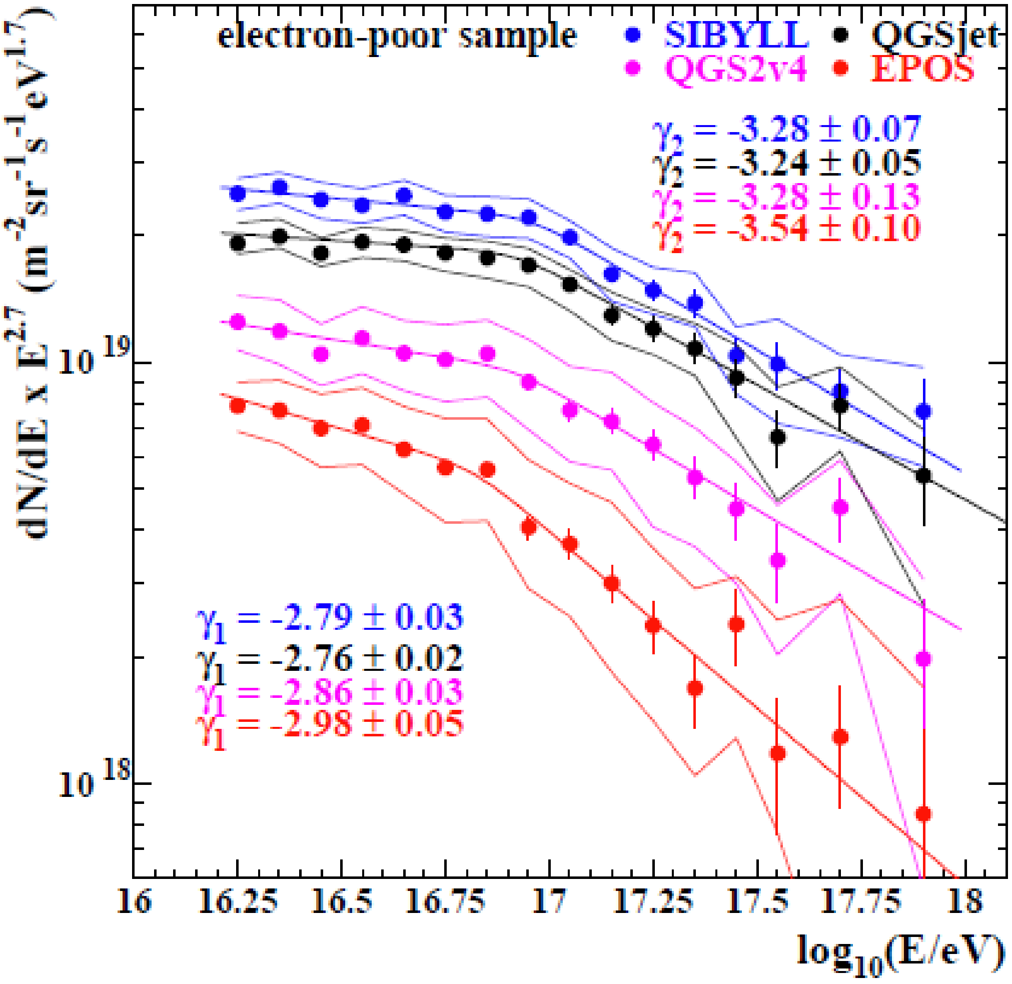
KASCADE-Grande
energy spectra of mass groups



- **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!**

Phys.Rev.Lett. 107 (2011) 171104
Phys.Rev.D (R) 87 (2013) 081101

KASCADE-Grande: model dependence



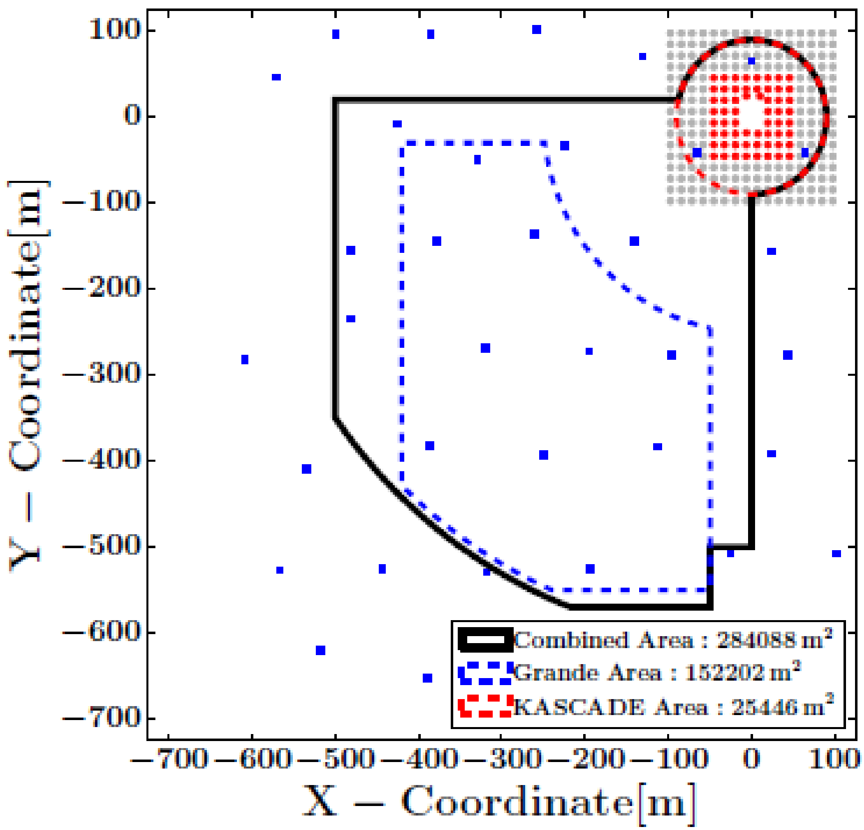
- Spectra of heavy primary induced events

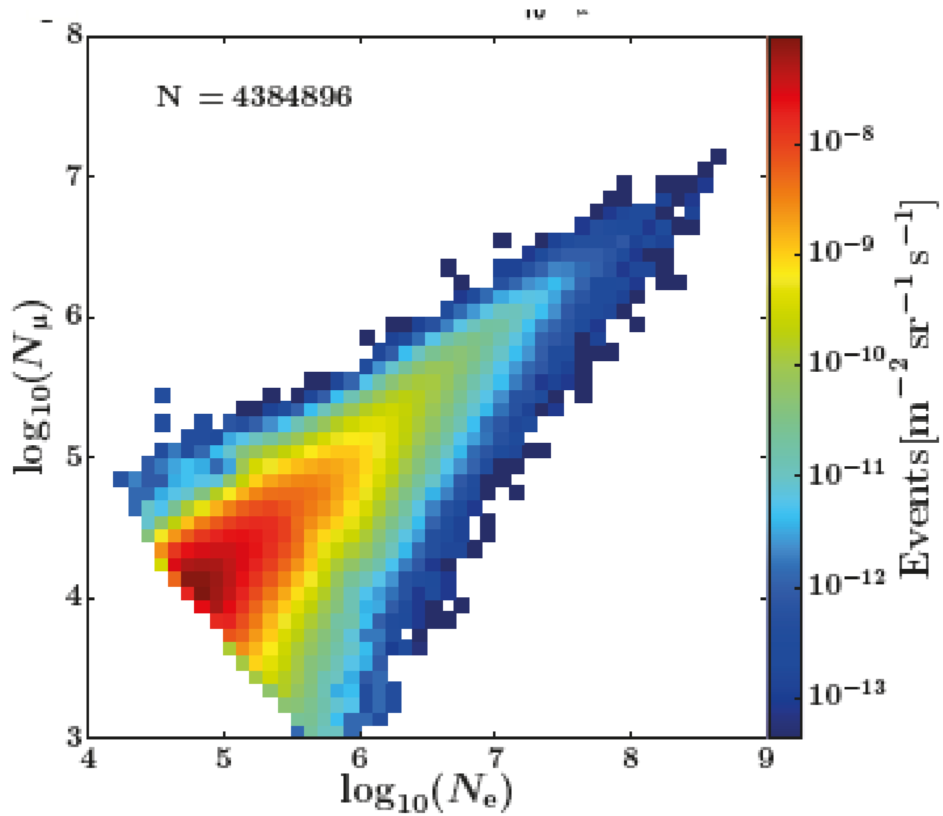
➔ a knee structure at the heavy component

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

Advances in Space Research 53 (2014) 1456

KASCADE-Grande: Combined Analysis





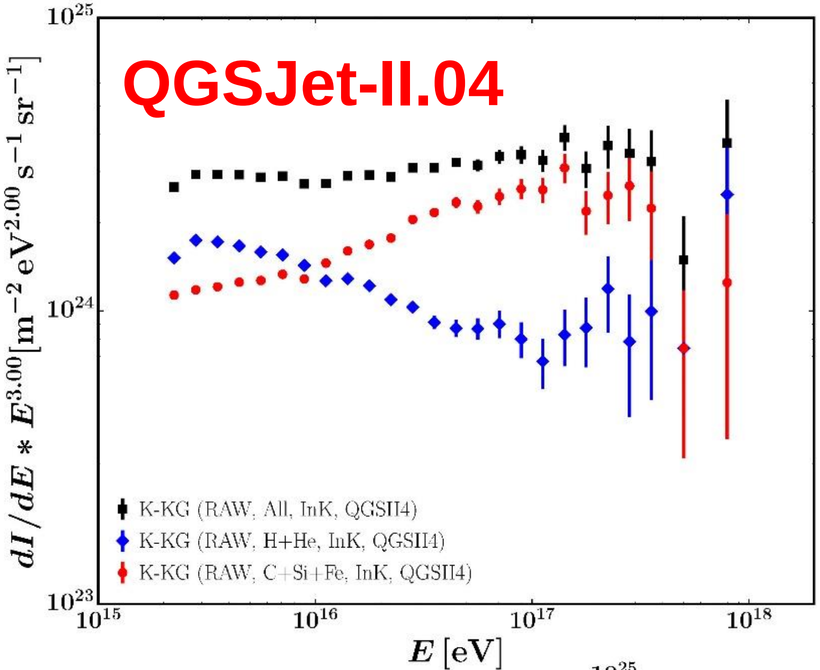
- **for KASCADE: additional stations at larger distances**

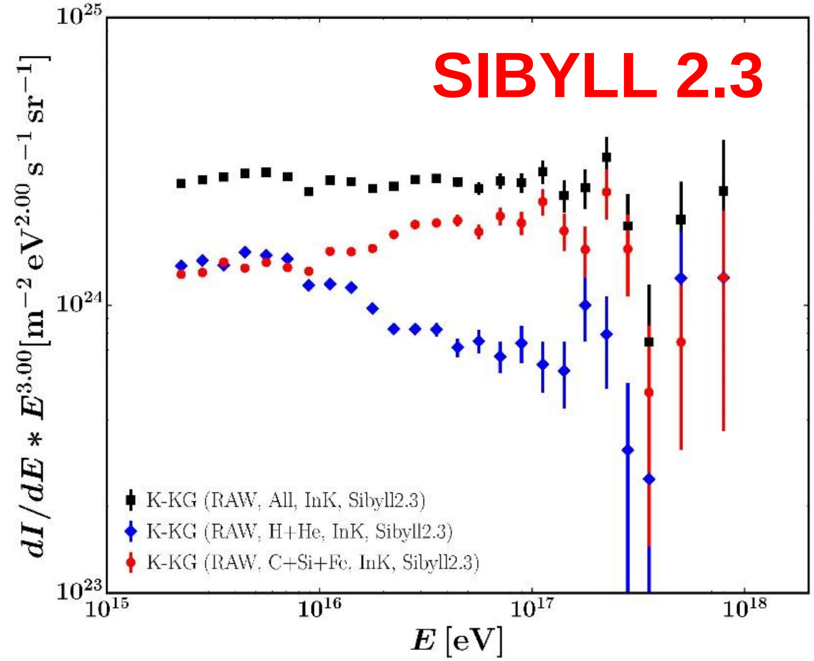
  ➔ higher energies

- **for Grande: additional 252 stations**

  ➔ higher accuracy

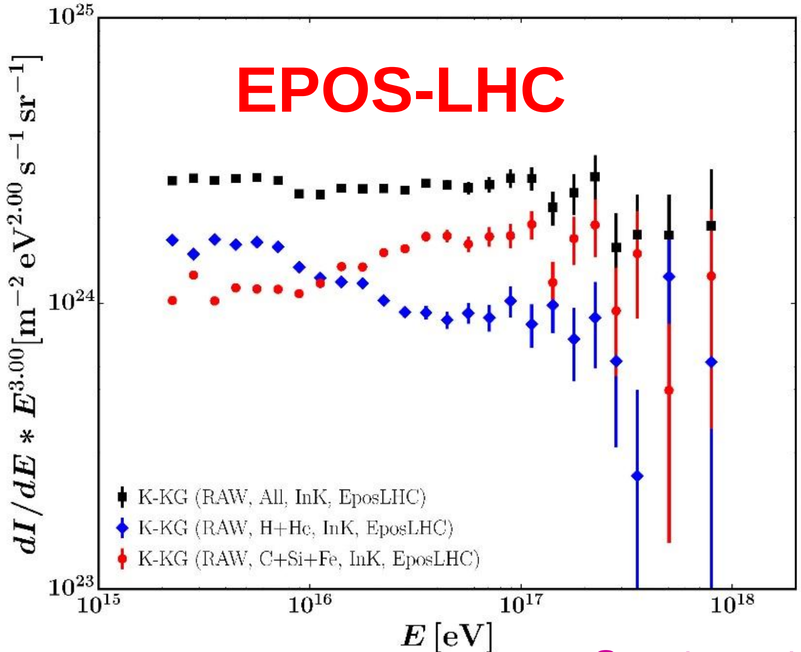
Sven Schoo, KIT, PhD 2016





- **structures confirmed**

- **all particle spectrum good agreement**



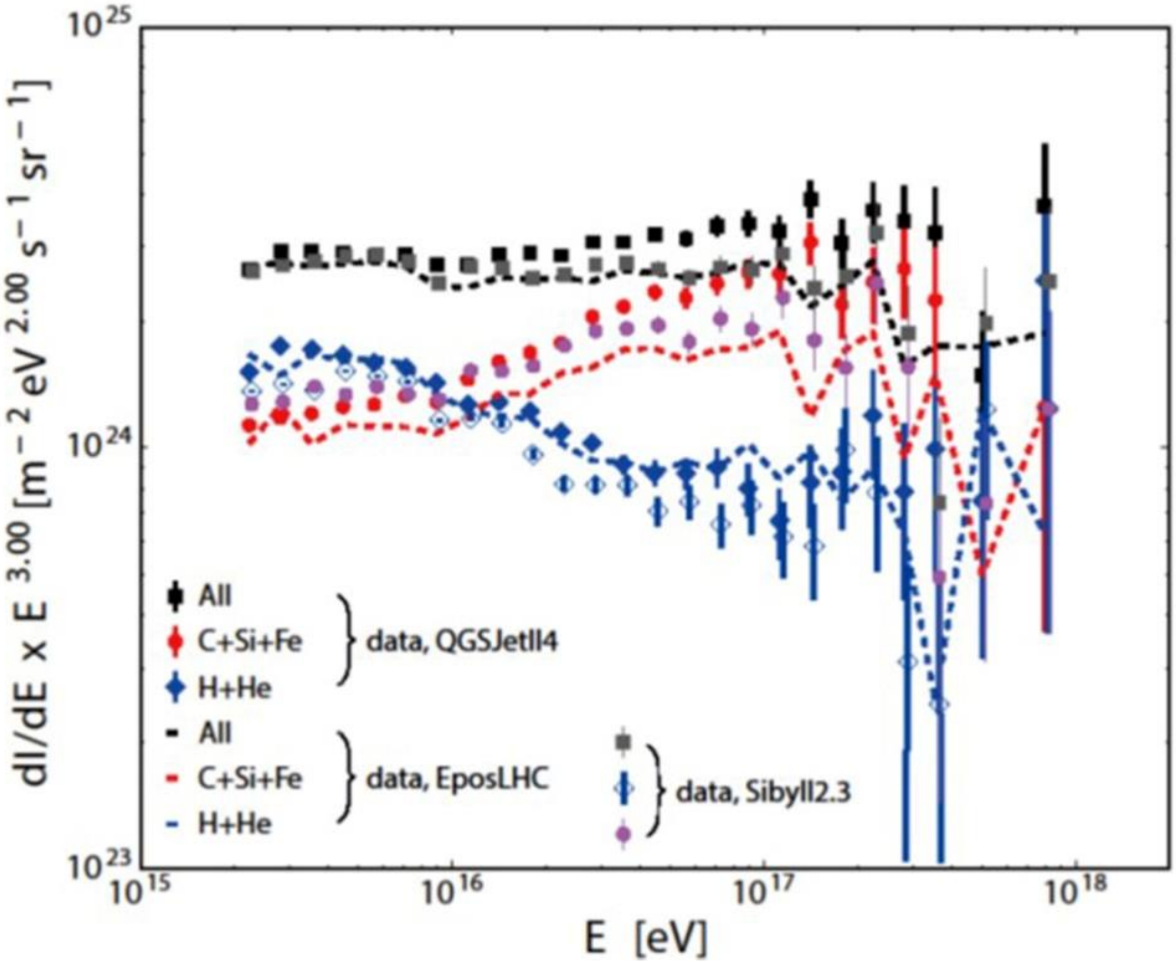
- **relative abundance of light and heavy quite different**

Sven Schoo, KIT, PhD 2016

Spectra not corrected for uncertainties

KASCADE-Grande: Combined Analysis

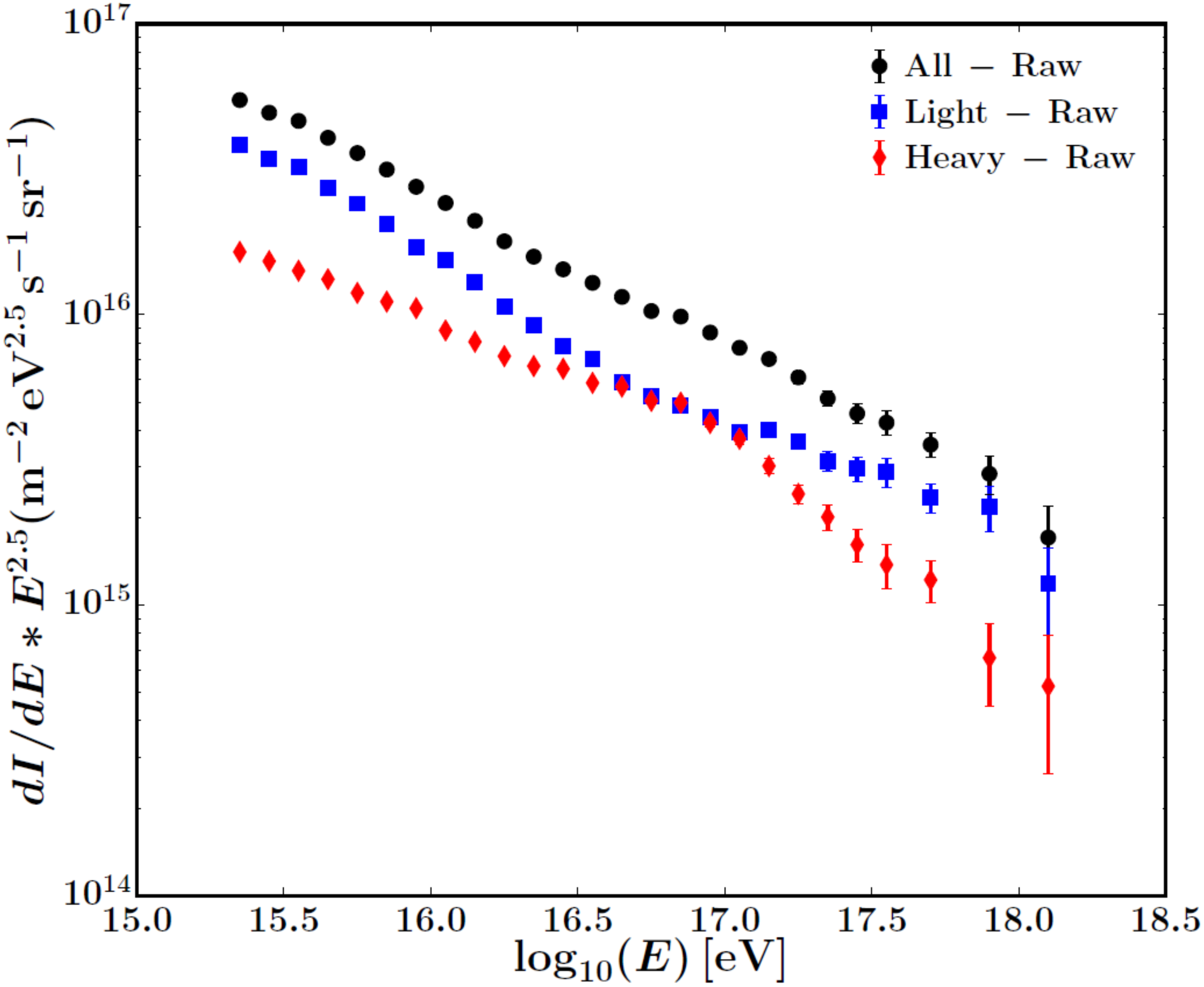
resulting energy spectra based on hadronic interaction models



QGSJet-II.04 vs. EPOS-LHC vs. SIBYLL 2.3

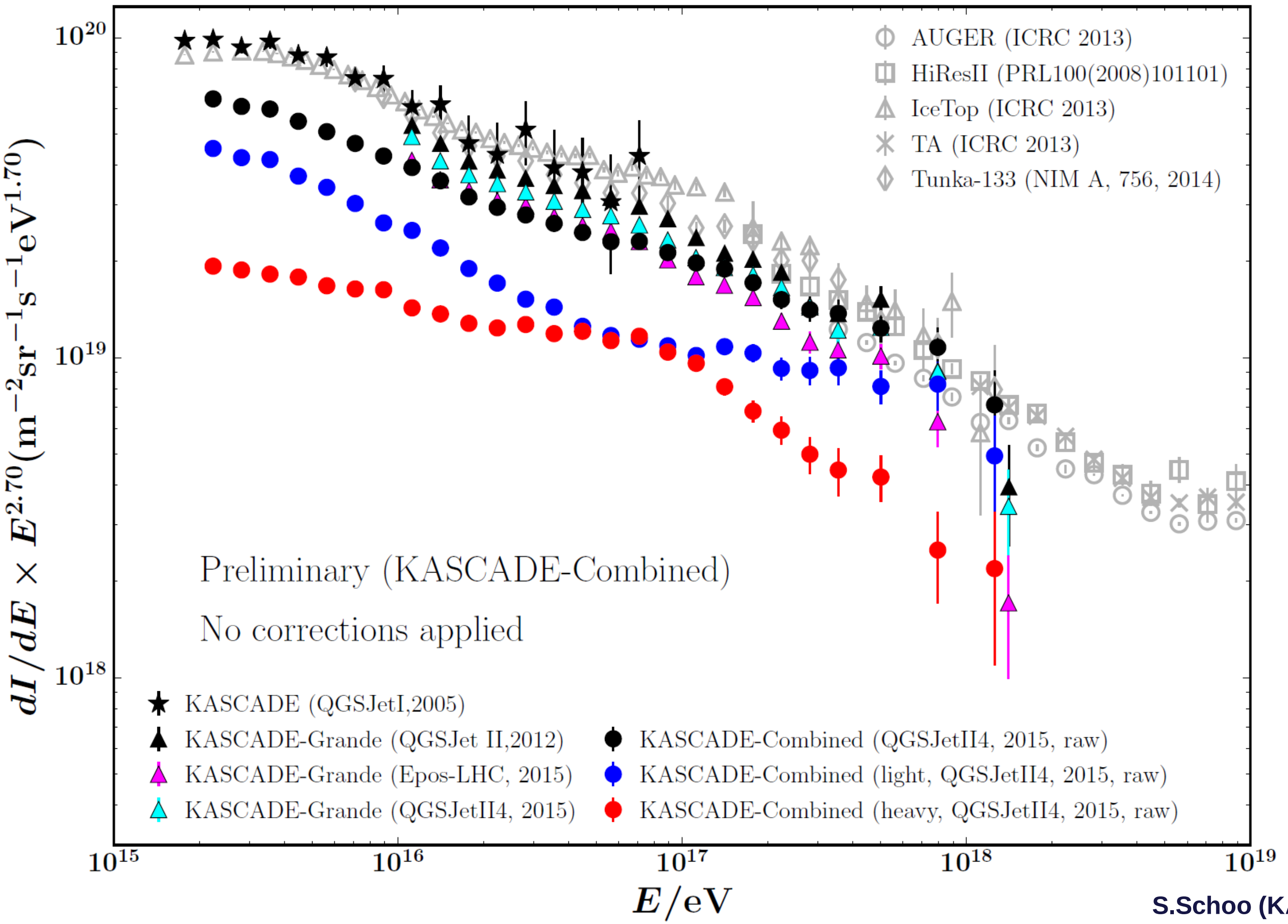
- **Post LHC models**
  light primary interactions okay?
  heavy primary interactions show differences

Coherently reconstructed energy spectrum



- **all-particle, light and heavy spectra from KASCADE-Grande (QGSJet-II-04)**

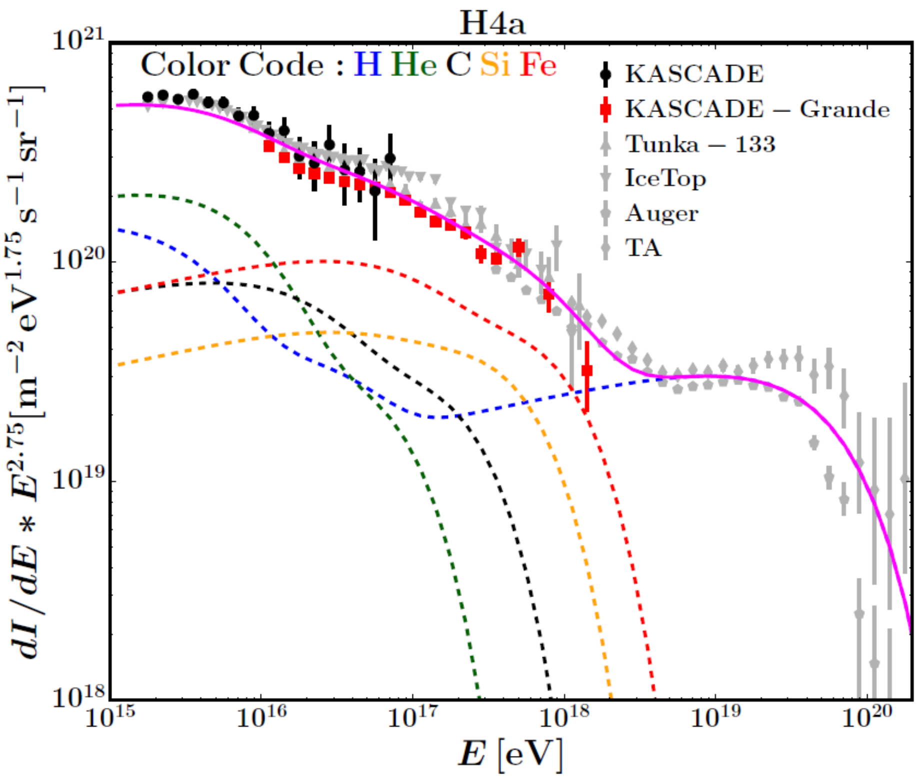
Coherently reconstructed energy spectrum

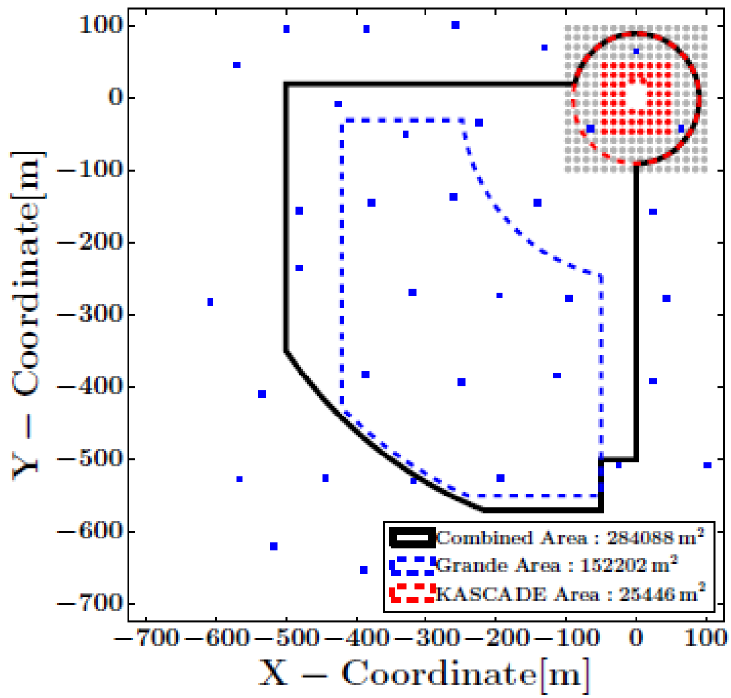


S.Schoo (KASCADE-Grande)
PoS(ICRC2015)263

- **all-particle, light and heavy spectra from KASCADE-Grande (QGSJet-II-04)**

KASCADE-Grande: combined analysis
Check Hadronic Interaction Models





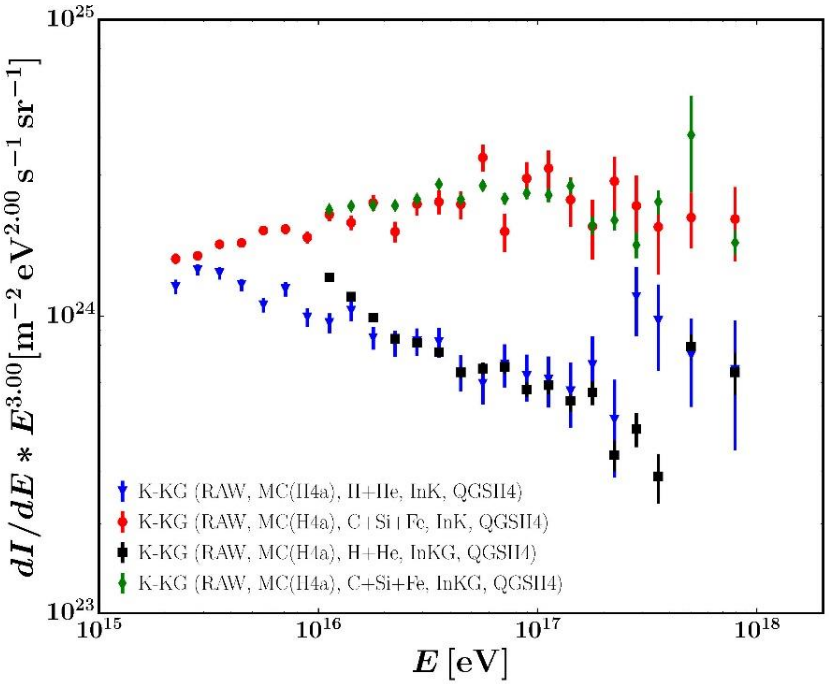
- **assume a composition model: H4a by Tom Gaisser**

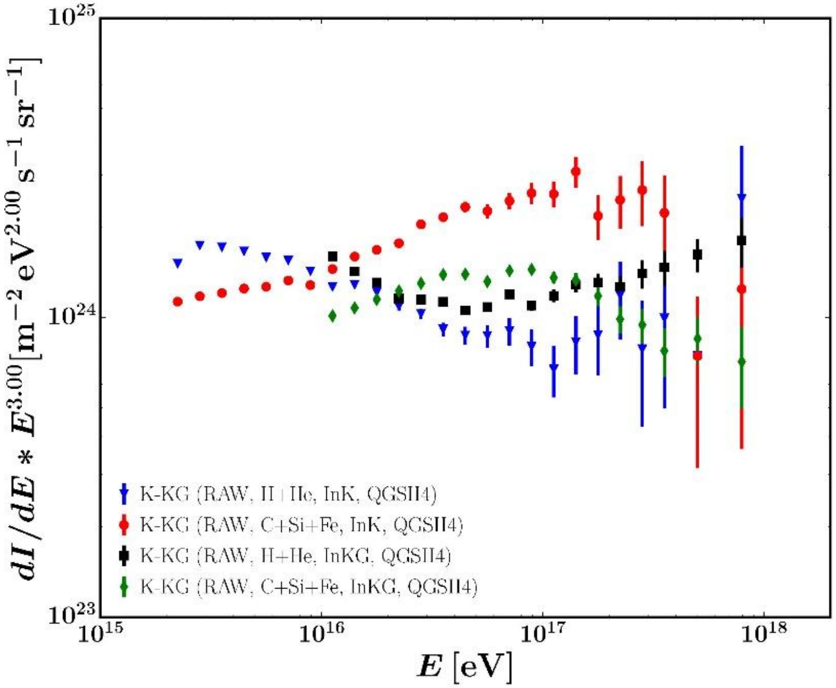
- **two selections: core located in KASCADE, core located in Grande**
  ➔ we measure "different" muons

KASCADE-Grande: Combined Analysis

QGSJet-II.04

Test of models





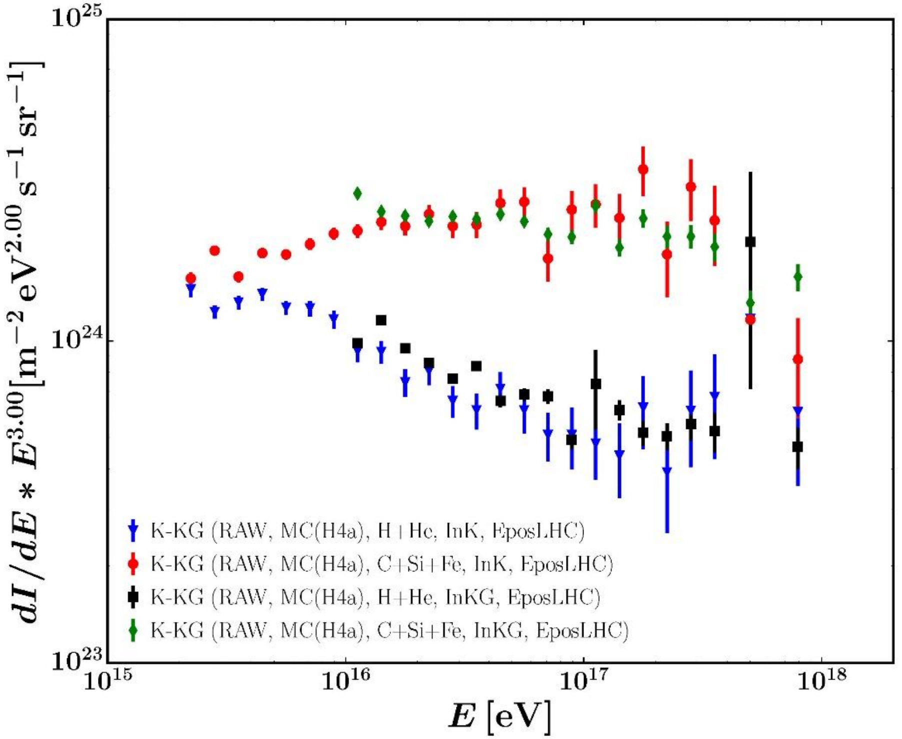
- **One model, but two selections:**
  Simulations okay, but strong differences in data
  (similar result for QGSJet-II.04, EPOS-LHC, SIBYLL 2.3)

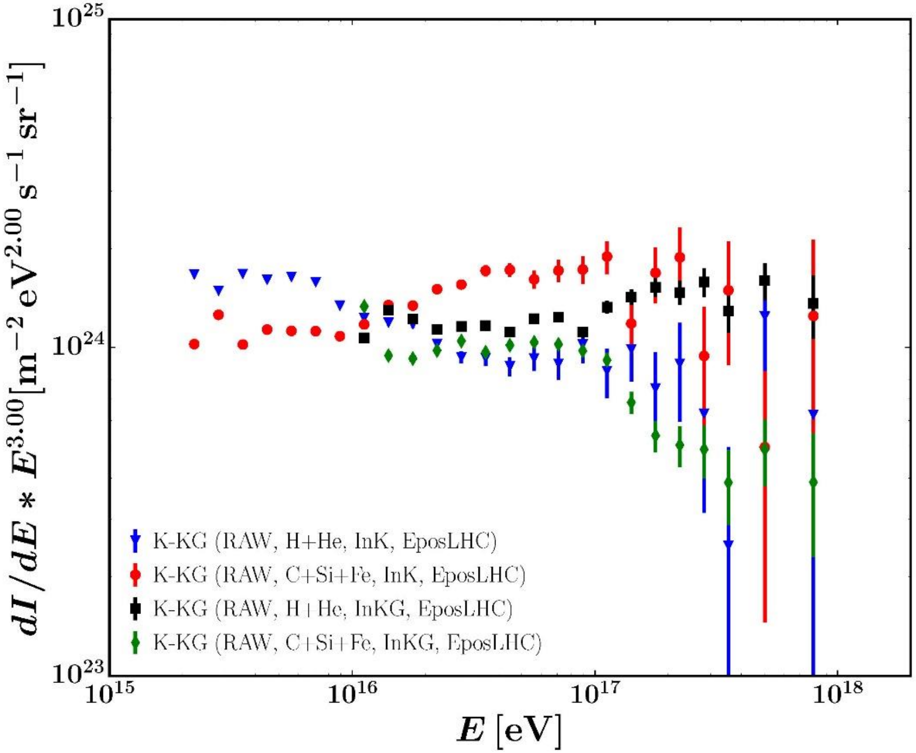
➔ Muon component not sufficiently described

KASCADE-Grande: Combined Analysis

EPOS-LHC

Test of models





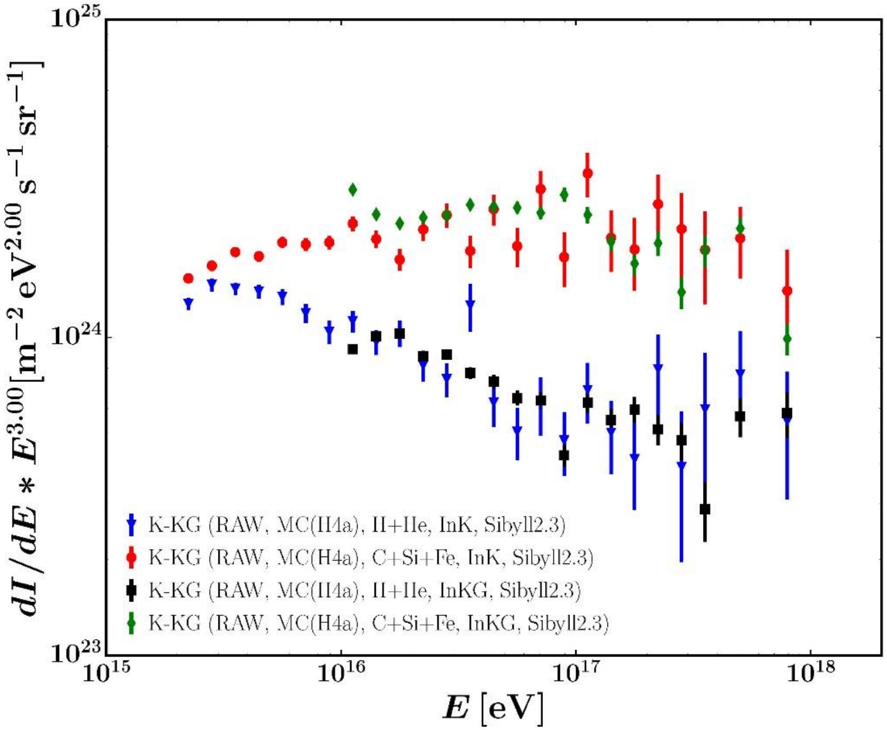
- **One model, but two selections:**
  Simulations okay, but strong differences in data

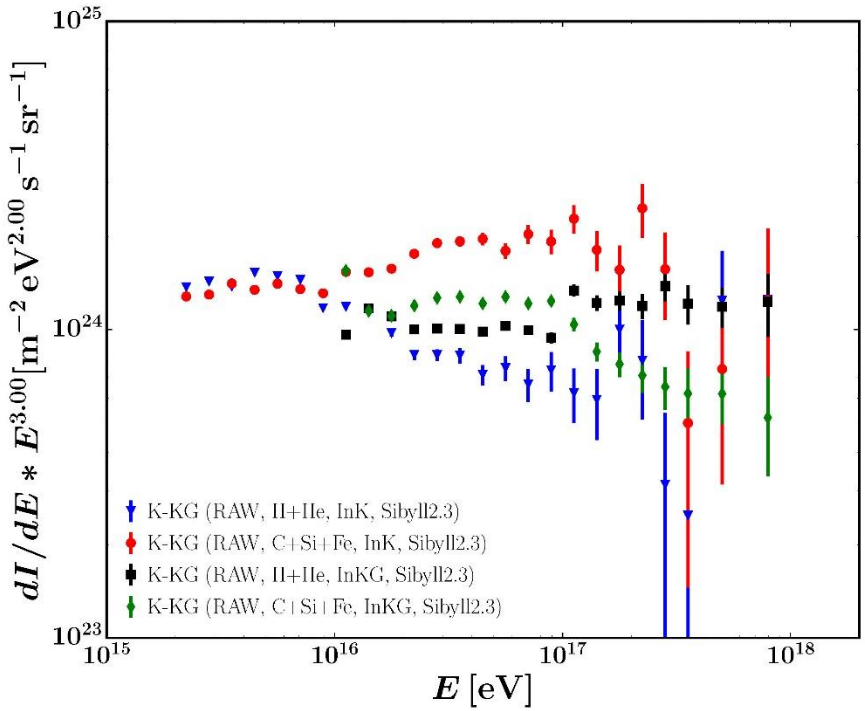
➔ **Muon component not sufficiently described**

KASCADE-Grande: Combined Analysis

SIBYLL 2.3

Test of models





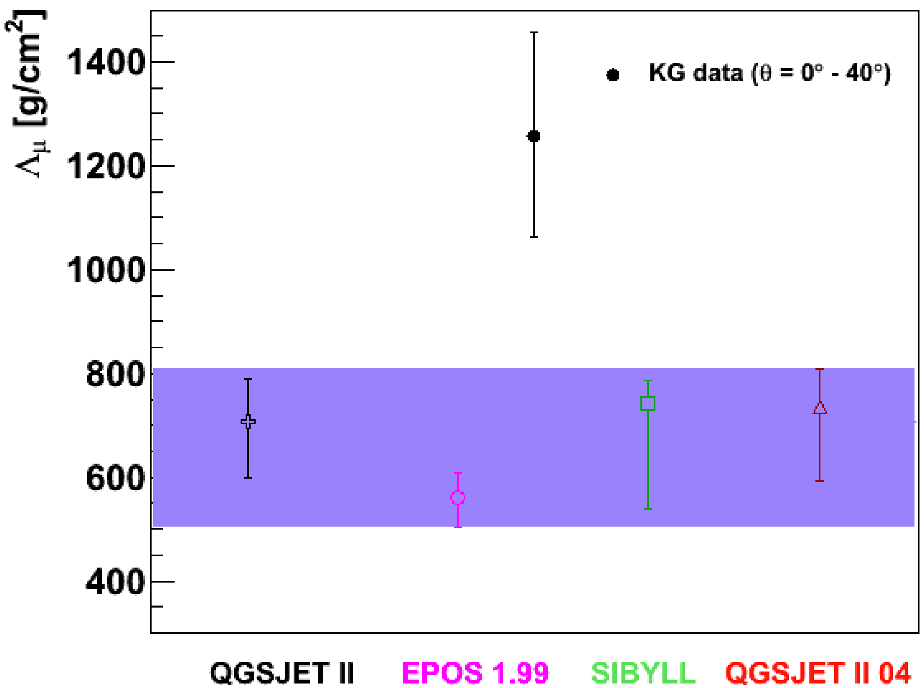
- **One model, but two selections:**
  Simulations okay, but strong differences in data

➔ **Muon component not sufficiently described**

KASCADE-Grande: Muon Attenuation Length

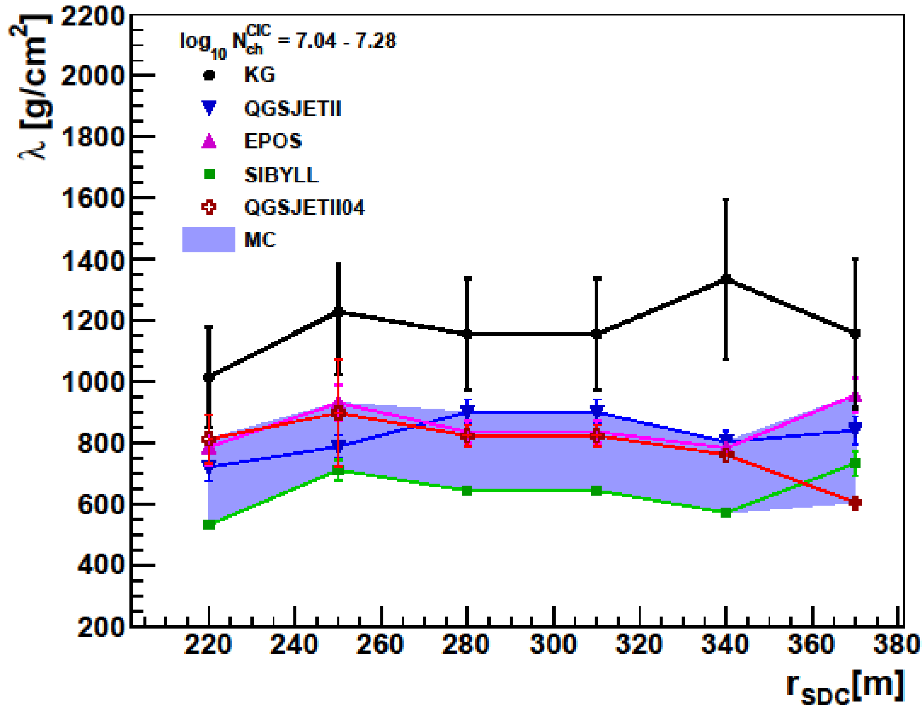
total muon number

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



local muon density

$\rho_\mu(r) = \rho_{\mu,0}(r) \exp[-X_0 \sec(\theta) / \lambda_\mu(r)]$



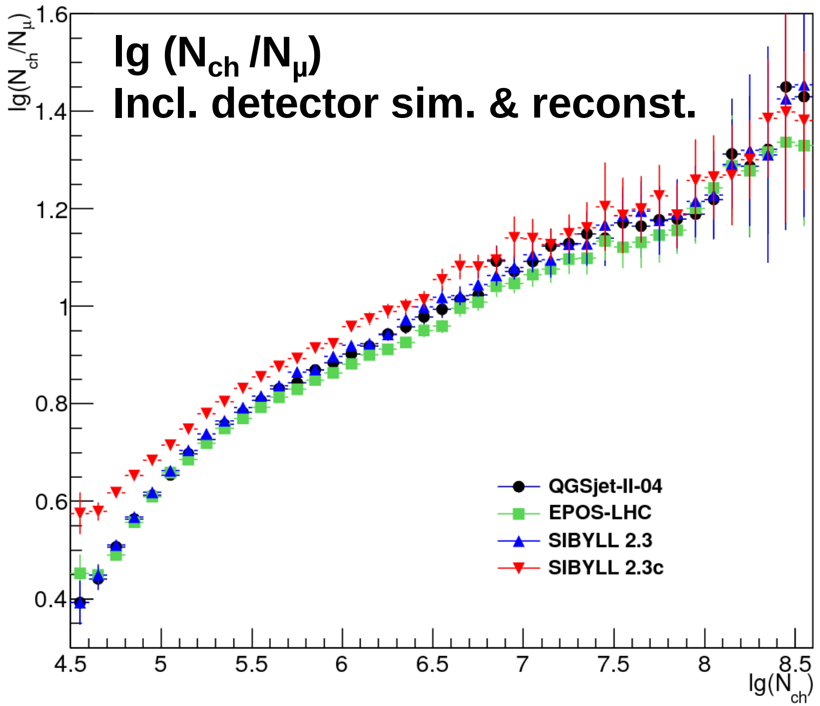
attenuation length measured is different from the predictions of Monte Carlo

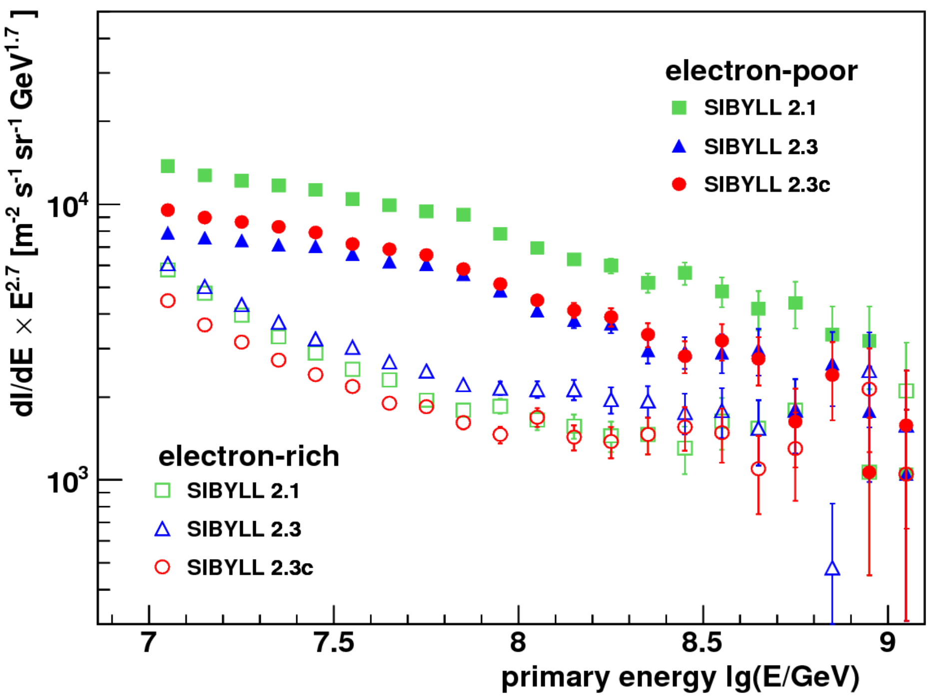
➔ observed evolution of the muon content of EAS in the atmosphere is not described by the hadronic interaction models

➔ influences absolute energy and mass scale, but not spectral features

KASCADE-Grande, Astroparticle Physics 95 (2017) 25-43

First tests with SIBYLL 2.3c (Grande only)

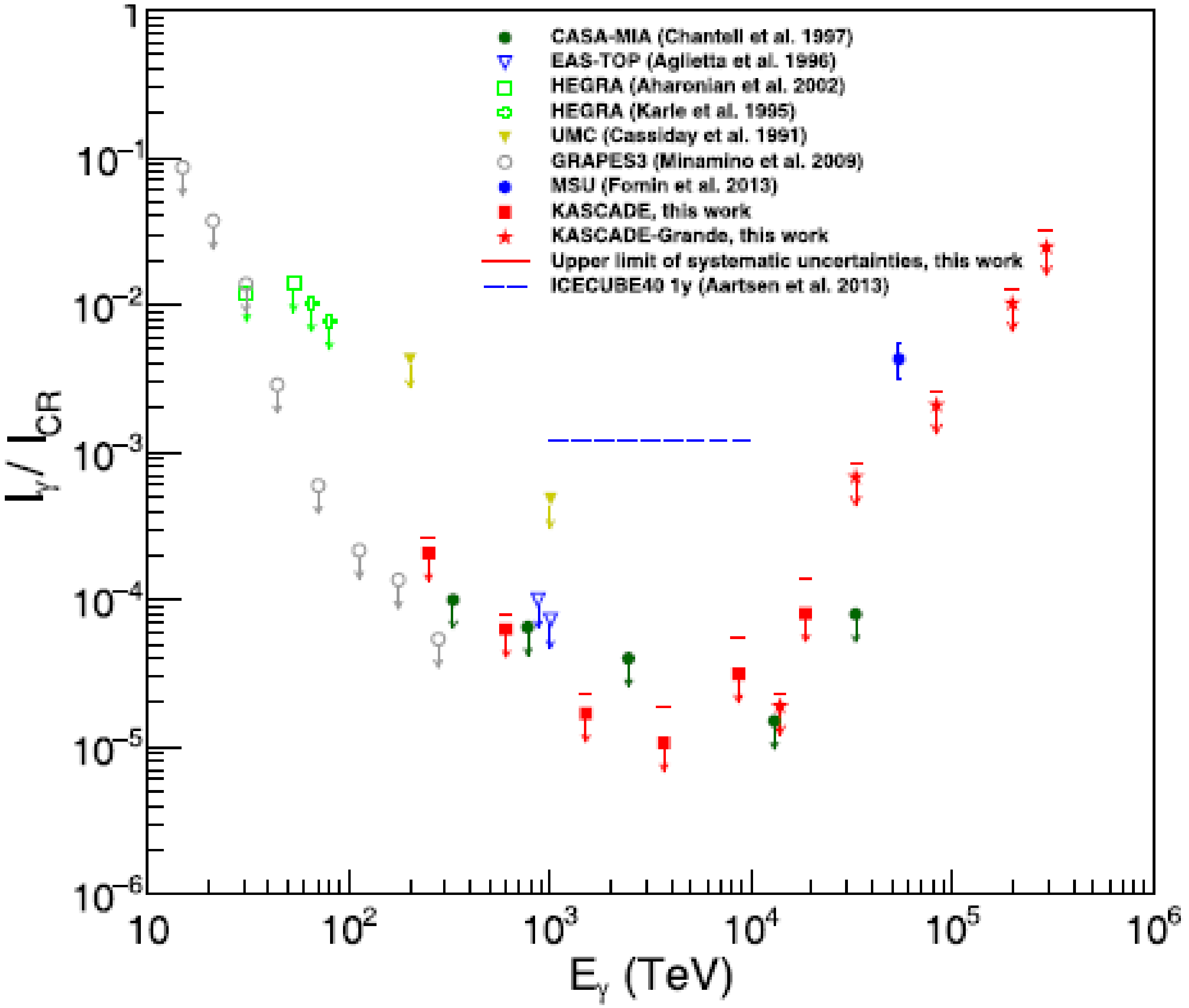




- **Visible effect in predicted particle numbers**
- **SIBYLL 2.3c predicts higher size/muon ratio**
- **Results in smaller energy assignment and different composition**

D. Kang, KASCADE-Grande

Limits on diffuse Gamma-ray Flux

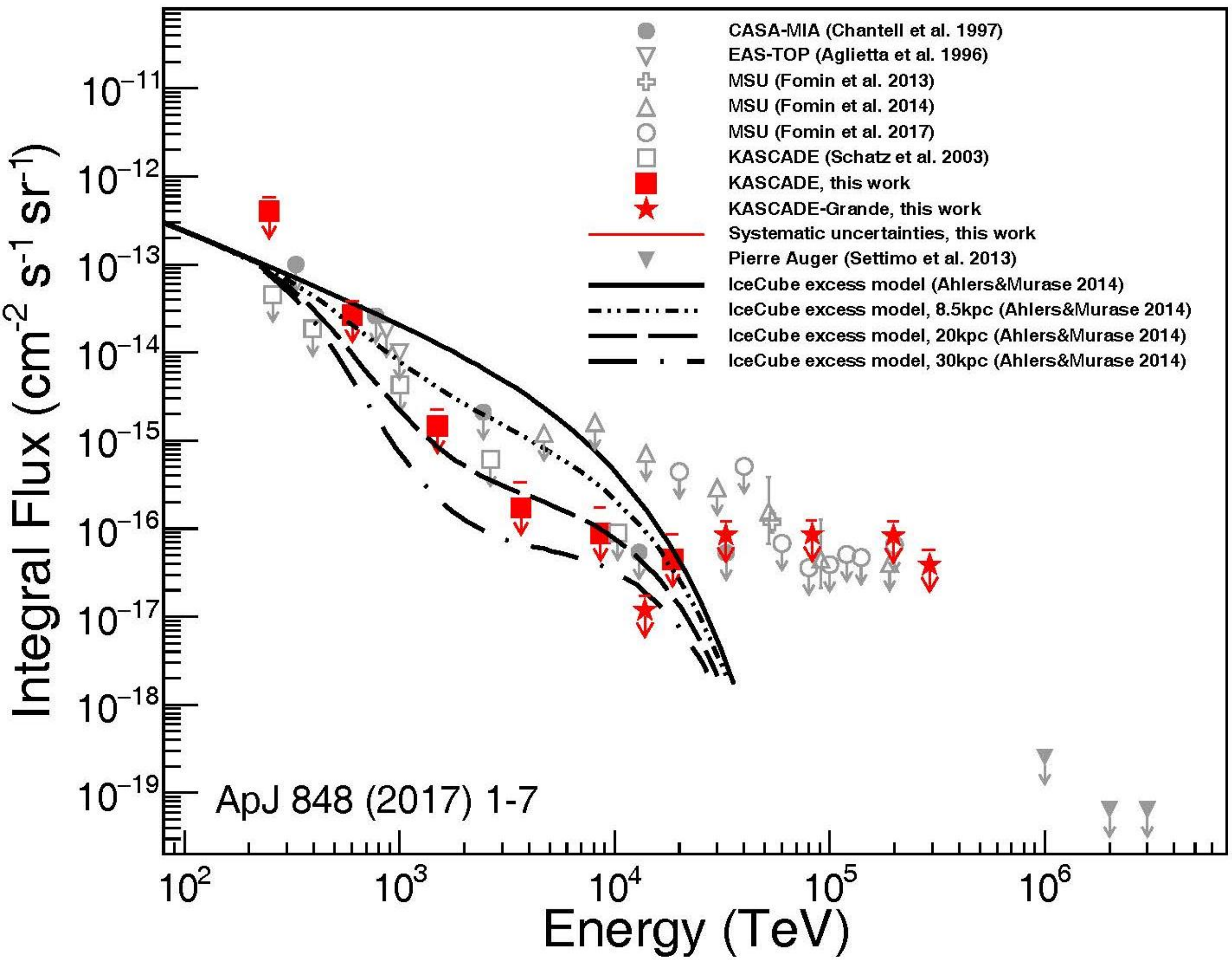


- selection of muon-poor events

- limits on ratio of primary gammas to hadrons

KASCADE-Grande, ApJ 848 (2017) 1-7

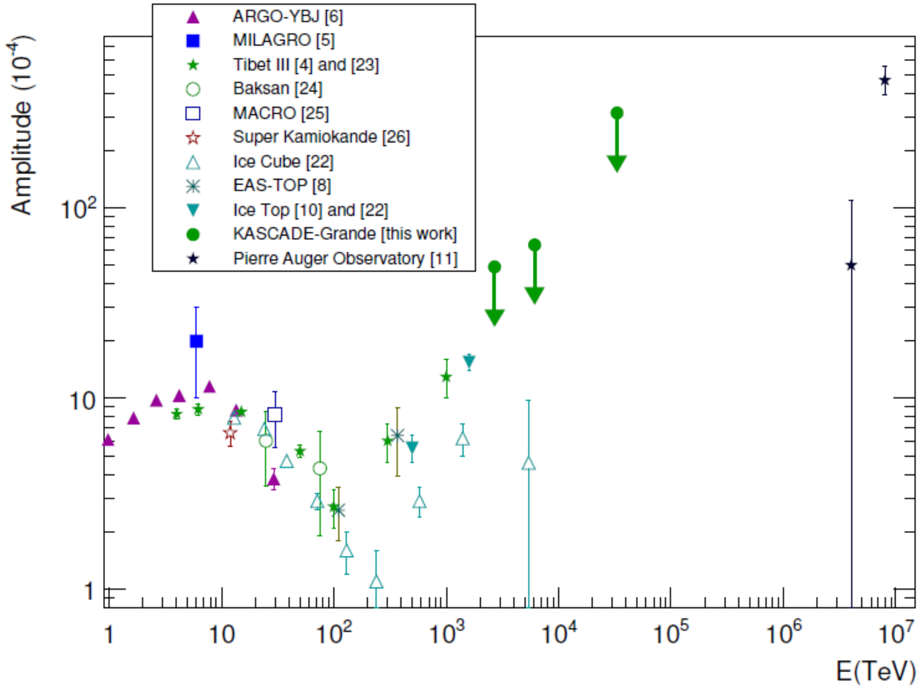
Limits on diffuse Gamma-ray Flux

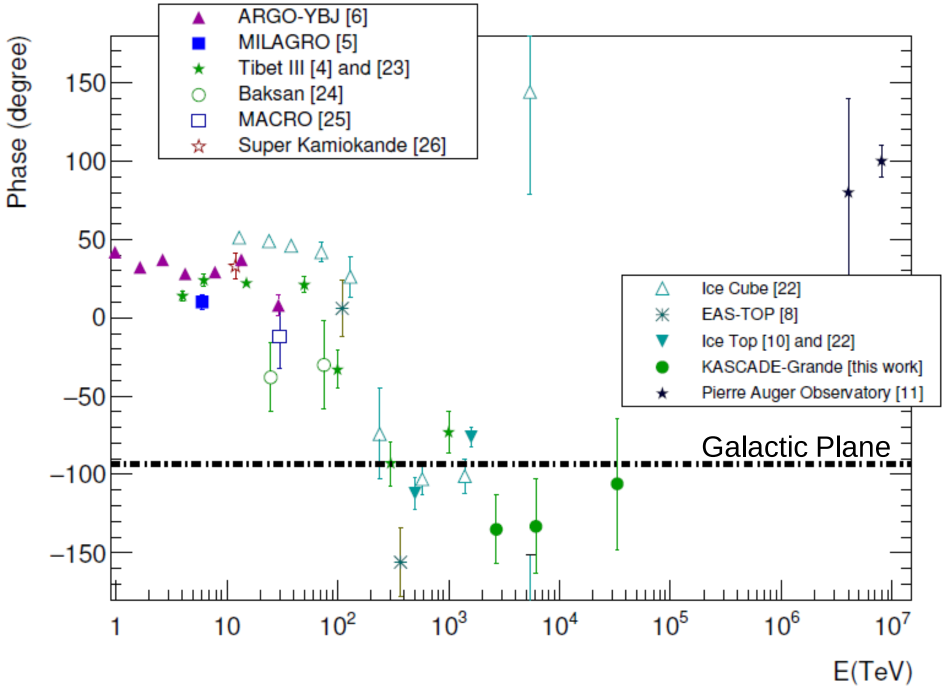


- **selection of muon-poor events**
- **limits on ratio of primary gammas to hadrons**
- **limits on diffuse Gamma-ray flux constrain the origin of IceCube-neutrinos**

🡐 Reject the model of IceCube excess coming from <20kpc in the Galaxy

KASCADE-Grande, ApJ 848 (2017) 1-7





Anisotropy

- **study large-scale anisotropies by the East-West method**

- **limits on amplitude**

- **phase determined**

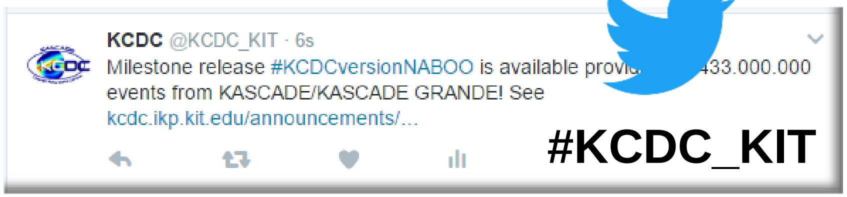
🡐 Confirms flip in phase at around 100 TeV - 1 PeV

A. Chiavassa et al.,
Nucl.Part.Phys.Proc. 279-281 (2016) 56-62
KASCADE-Grande coll.; submitted

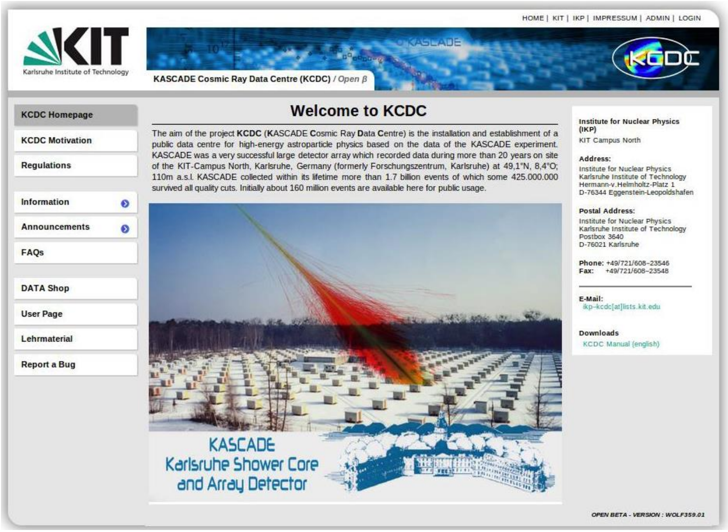

https://kcdc.ikp.kit.edu
KASCADE
KCDC
Cosmic ray Data Centre
Andreas Haungs for KASCADE-Grande

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
  $4.3 \cdot 10^8$ EAS events are available
  including energy deposits
  corresponding simulations
  >90 spectra of EAS experiments

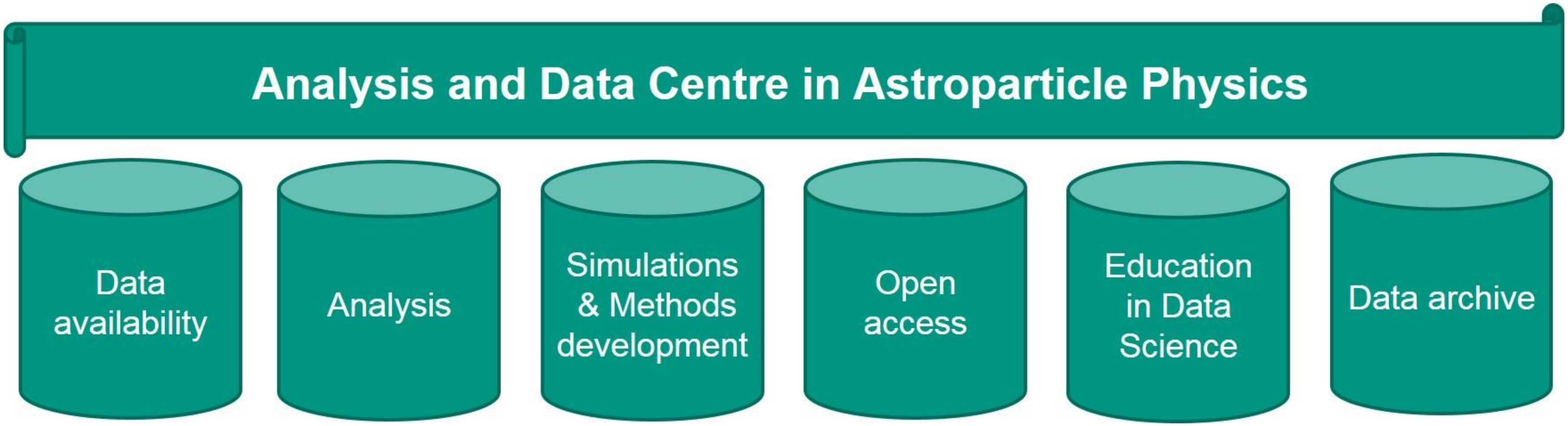


#KCDC_KIT



A.Haungs (KASCADE-Grande)
Eur. Phys. J. C (2018) 78:741 (arXiv:1806.05493)

Towards a



Motivation:

- Astroparticle Physics requests for multi-messenger analyses.
- This needs an experiment-overarching platform
- High demand in (German and international) community
- APP Observatories are globally distributed (no CERN or ESA)

Important steps:

- Develop an open science system (based on KCDC and the LHC-Tier environments)
- Develop solutions of distributed data storage algorithms and techniques
- Allowing community to perform multi-messenger analyses with deep learning methods
- Providing platform for public access to scientific data

Conclusions – open points

- Light and heavy knee established
- Light ankle probably there
- 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 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, PAO, NEVOD, HAWC?
- Global Data Centre for Astroparticle Physics envisaged