KASCADE 1988-2015

KASCADE
Karlsruhe Shower Core
and Array Detector

KASCADE - timeline

- 53 collaborative papers in reviewed journals (8 still in queue, short author list papers not included)
- 55 PhD thesis
- 86 diploma/master thesis

1992 Proposal
CORSIKA

1996 KASCADE
model tests

2000 KASCADE-Grande
light knee

2004 LOPES
γ limit
(an)isotropy

2008 Cosmic Revelation
proof-of-principle radio detection

2012 Karlsruhe Air Shower Test Facility
CROME
muon production height
iron knee

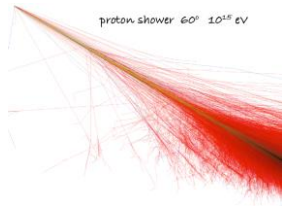
2016 KCDC
EAS GHz emission
light ankle
Xmax by radio


Konzeptstudie für ein Detektorsystem zur Untersuchung ausgedehnter Luftschauer für Primärenergien zwischen 10^{14} und 10^{17} eV

J. Engler, H. J. Gils, D. Heck, W. Heeringa, H. Keim, H. O. Klages, J. Knapp, H. Rebel, G. Schatz, T. Thouw, B. Zeitnitz

Kernforschungszentrum Karlsruhe, Institut für Kernphysik

Juni 1988



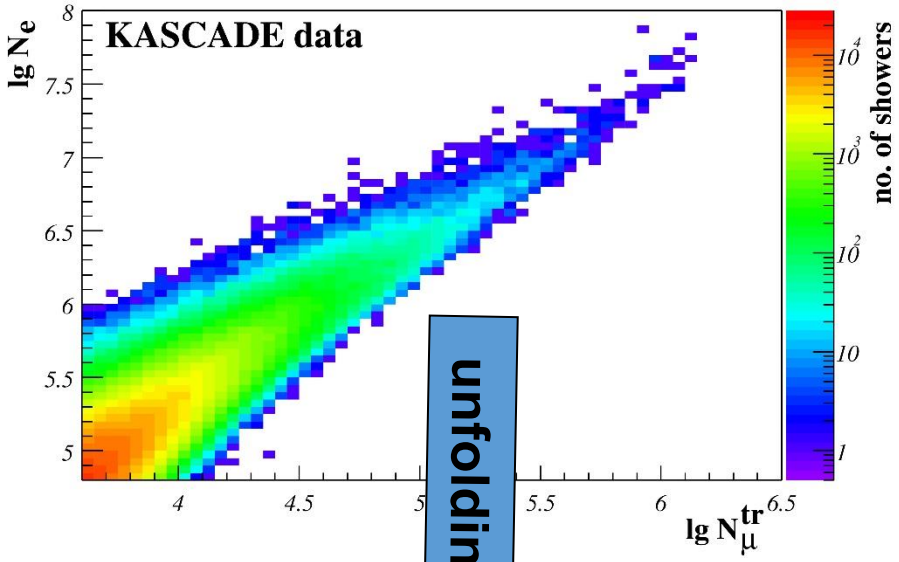
KASCADE

KArlsruhe Shower Core and Array DEtector

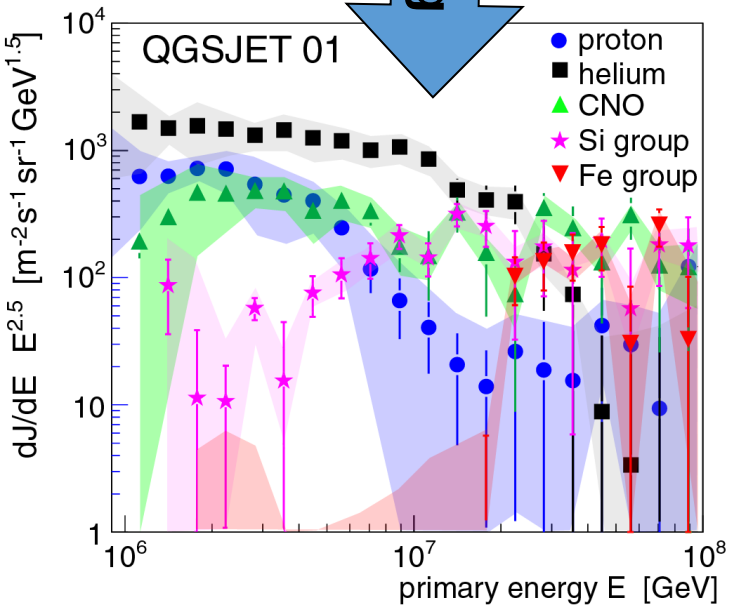
T.Antoni et al. NIM A513 (2003) 490

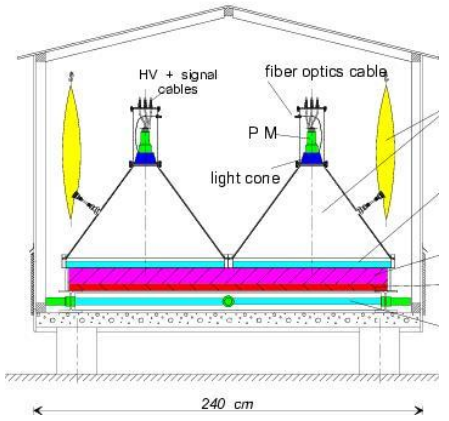
- Energy range 100TeV – 80PeV
- Since 1995
- Large number of observables: electrons, muons@4 thresholds, hadrons

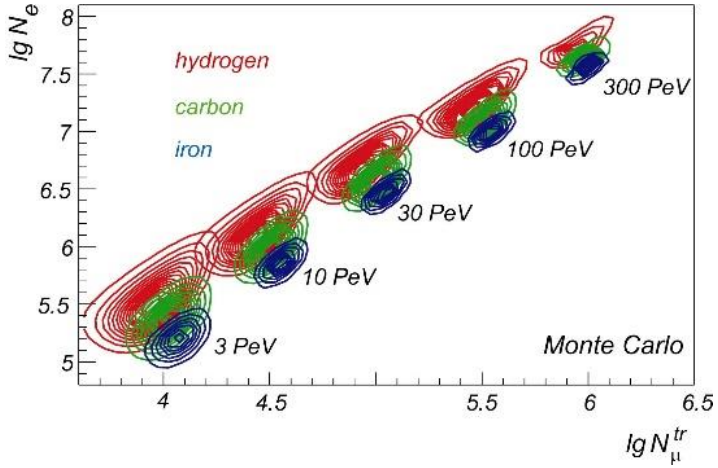
KASCADE : energy spectra of single mass groups



unfolding







Searched: E and A of the Cosmic Ray Particles

Given: N_e and N_μ for each single event

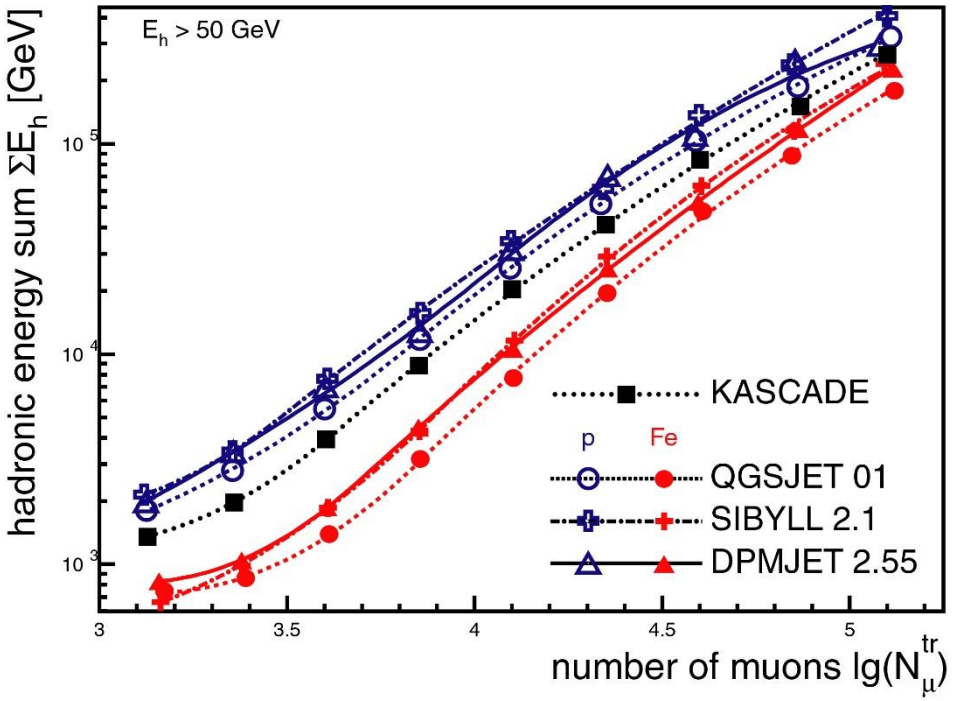
➔ **solve the inverse problem**

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

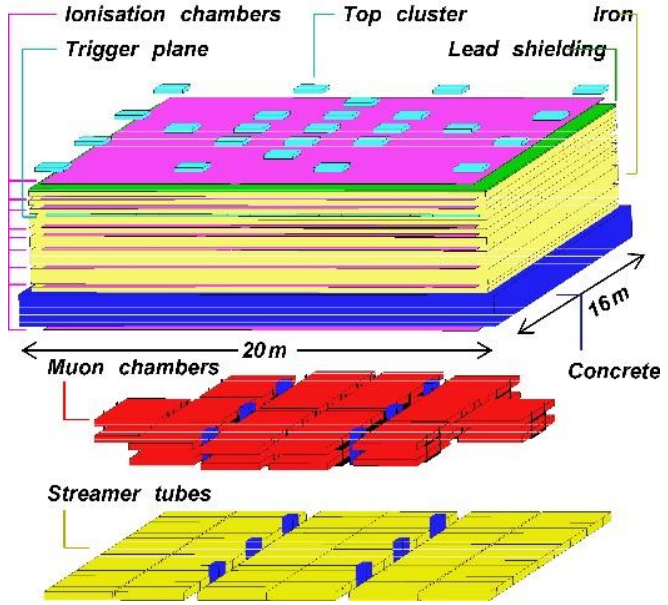
- kernel function obtained by Monte Carlo simulations (CORSIKA)
- contains: shower fluctuations, efficiencies, reconstruction resolution

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

KASCADE : sensitivity to hadronic interaction models



Example:
hadrons vs. muons



correlation of observables: no hadronic interaction model describes data consistently !

➔ tests and tuning of hadronic interaction models !

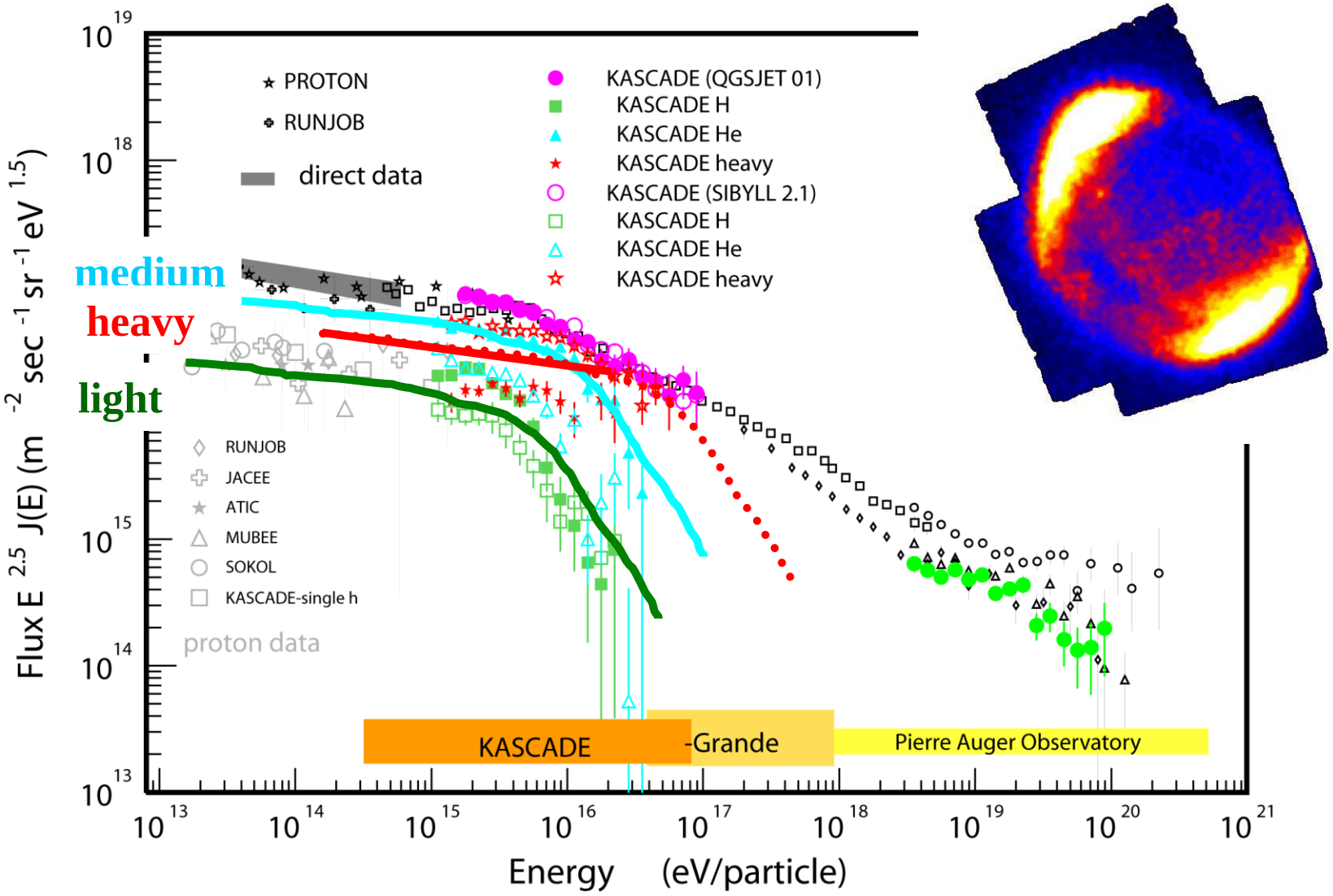
➔ close co-operation with theoreticians (CORSIKA including interaction models)

➔ e.g.:

- **EPOS 1.6 is not compatible with KASCADE measurements**
- **QGSJET 01and SIBYLL 2.1still most compatible models**
- **EPOS 1.99 is providing unphysical results**
- **post-LHC models QGSJET-II-04, EPOS-LHC still needs to be tested**

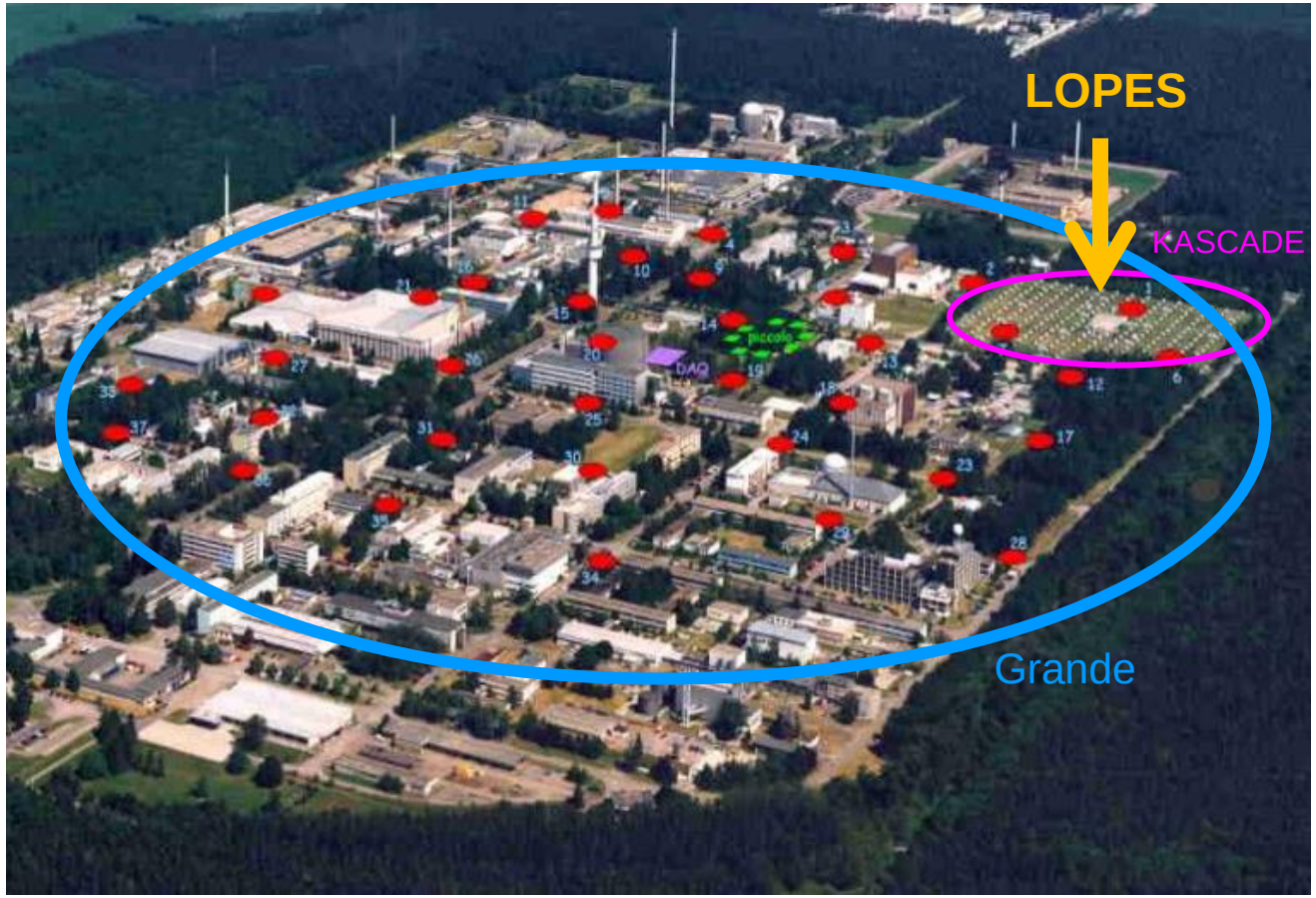
KASCADE collaboration, J Phys G (3 papers: 25(1999)2161; 34(2007)2581; (2009)035201)

Result KASCADE ➔ Motivation KASCADE-Grande



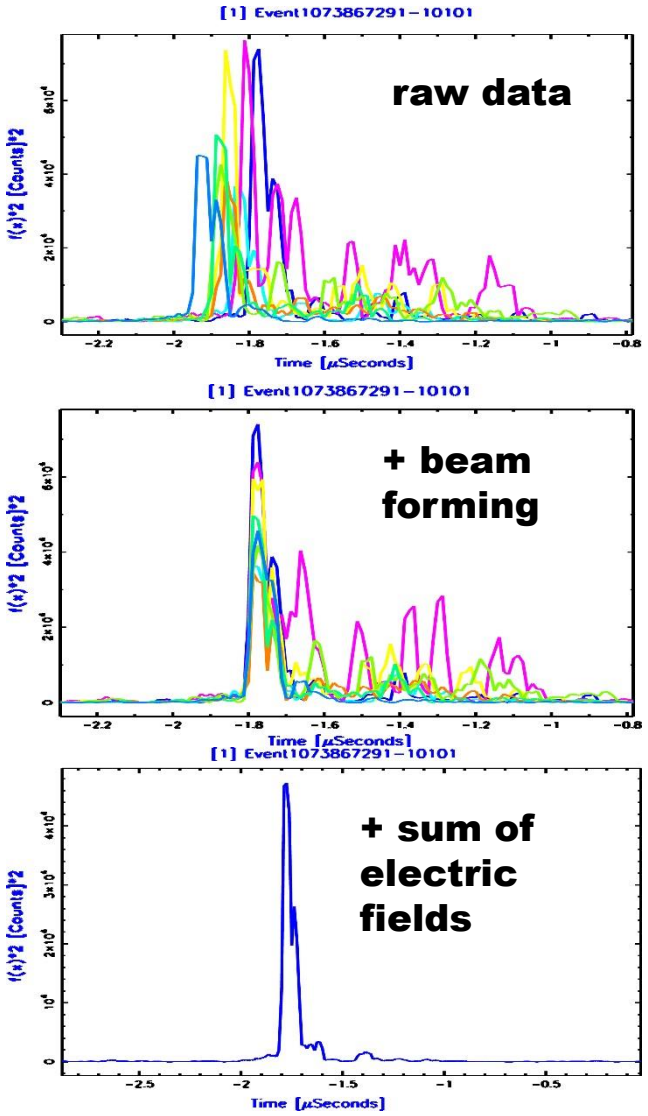
LOPES

LOPES collaboration:
-) KASCADE-Grande
-) U Nijmegen, NL
-) MPIfR Bonn, D
-) Astron, NL
-) IPE, FZK, D



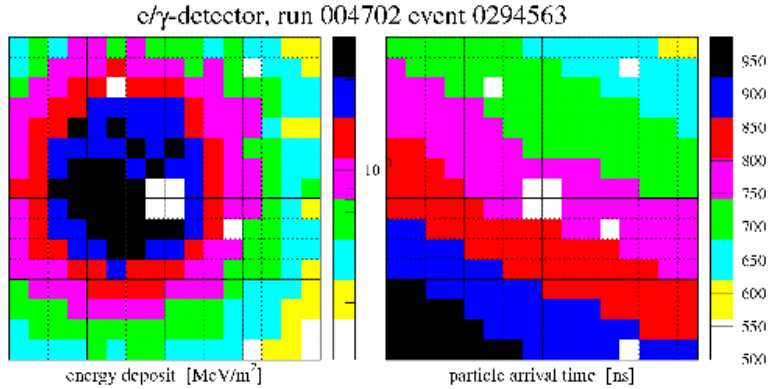
➔Development of a new detection technique!

2. Radio data analysis

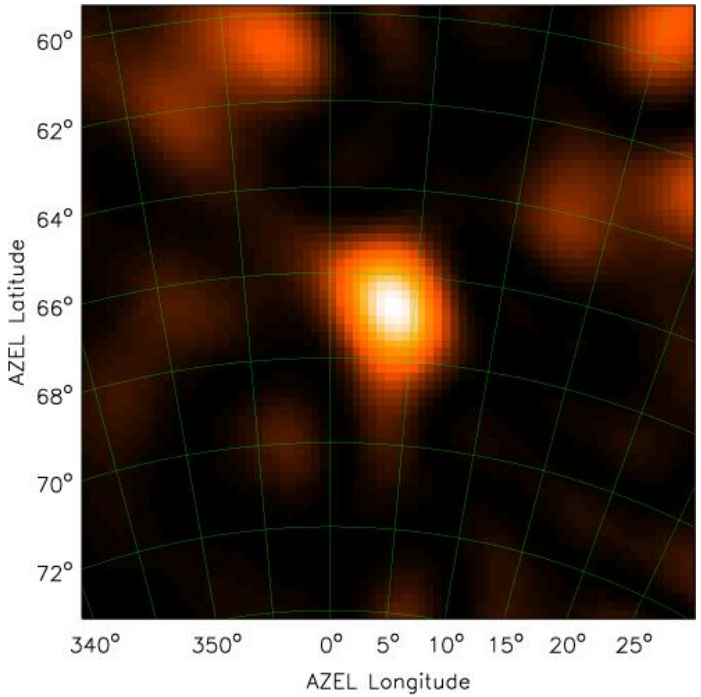


LOPES: Proof of principle

1. KASCADE measurement

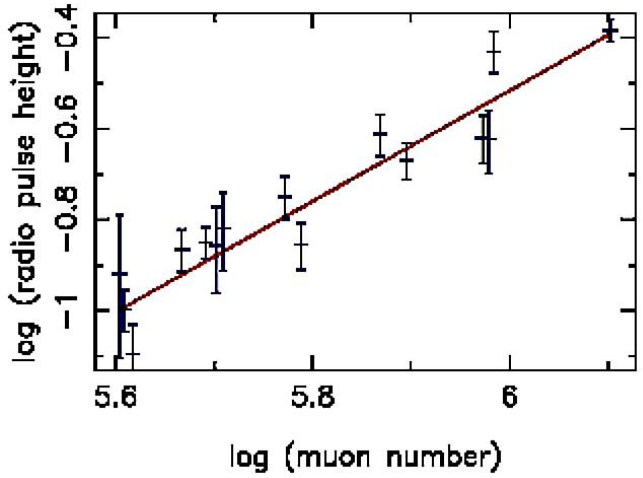


3. Skymapping



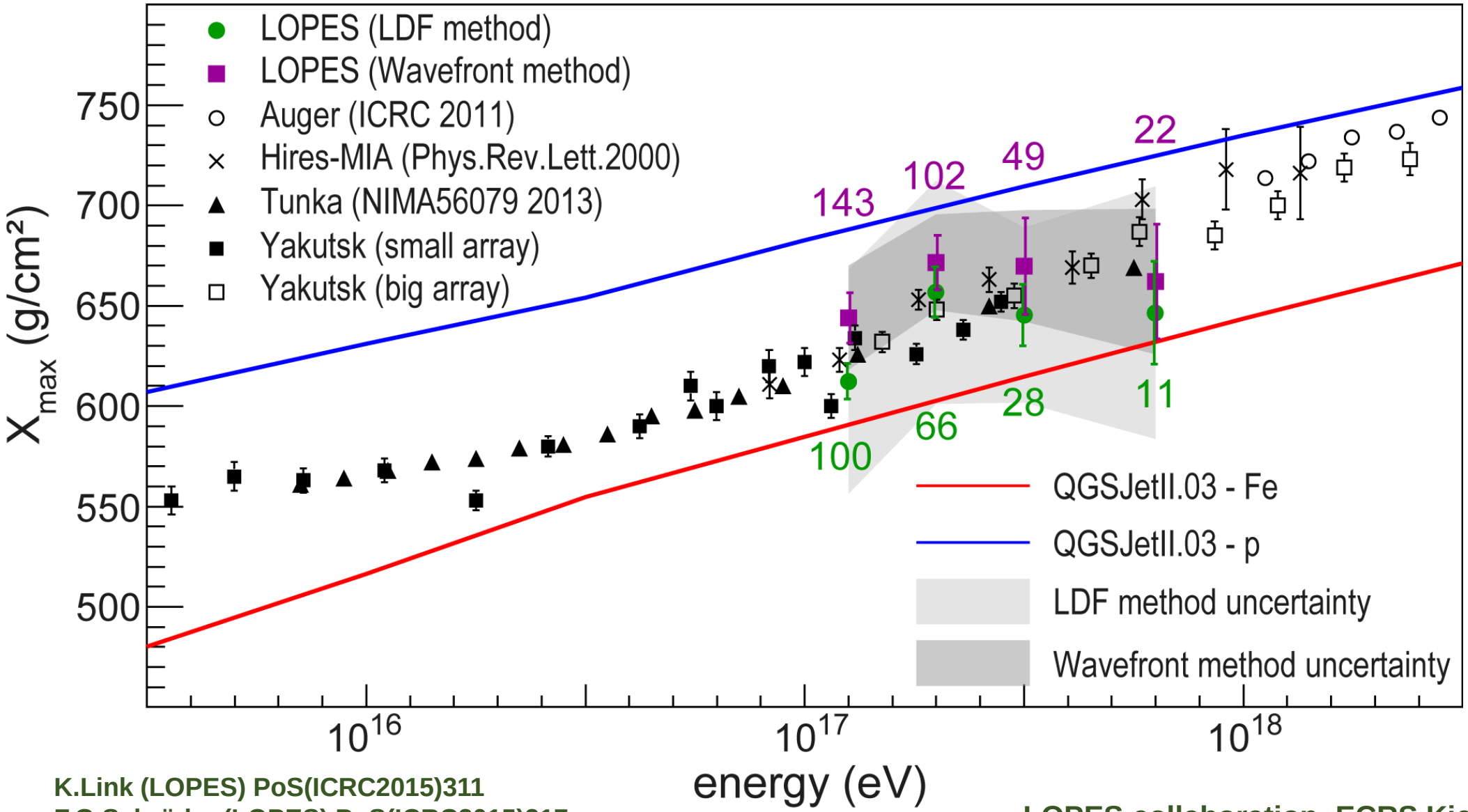
4. Many events

meanwhile >500 events



LOPES collaboration, Nature 425 (2005) 313

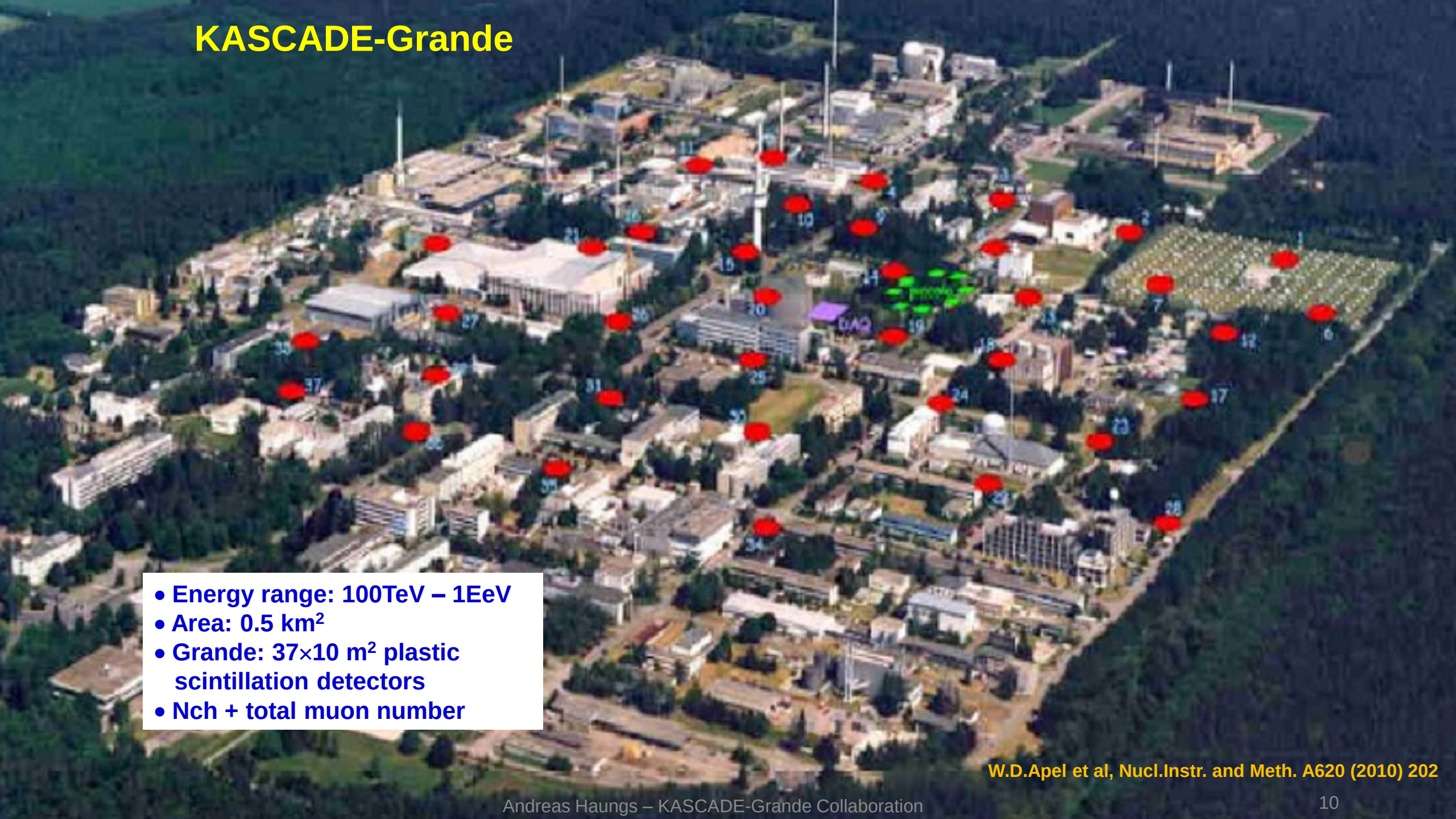
Composition measurements by LOPES



K.Link (LOPES) PoS(ICRC2015)311
F.G.Schröder (LOPES) PoS(ICRC2015)317

LOPES collaboration, ECRS Kiel, 2014

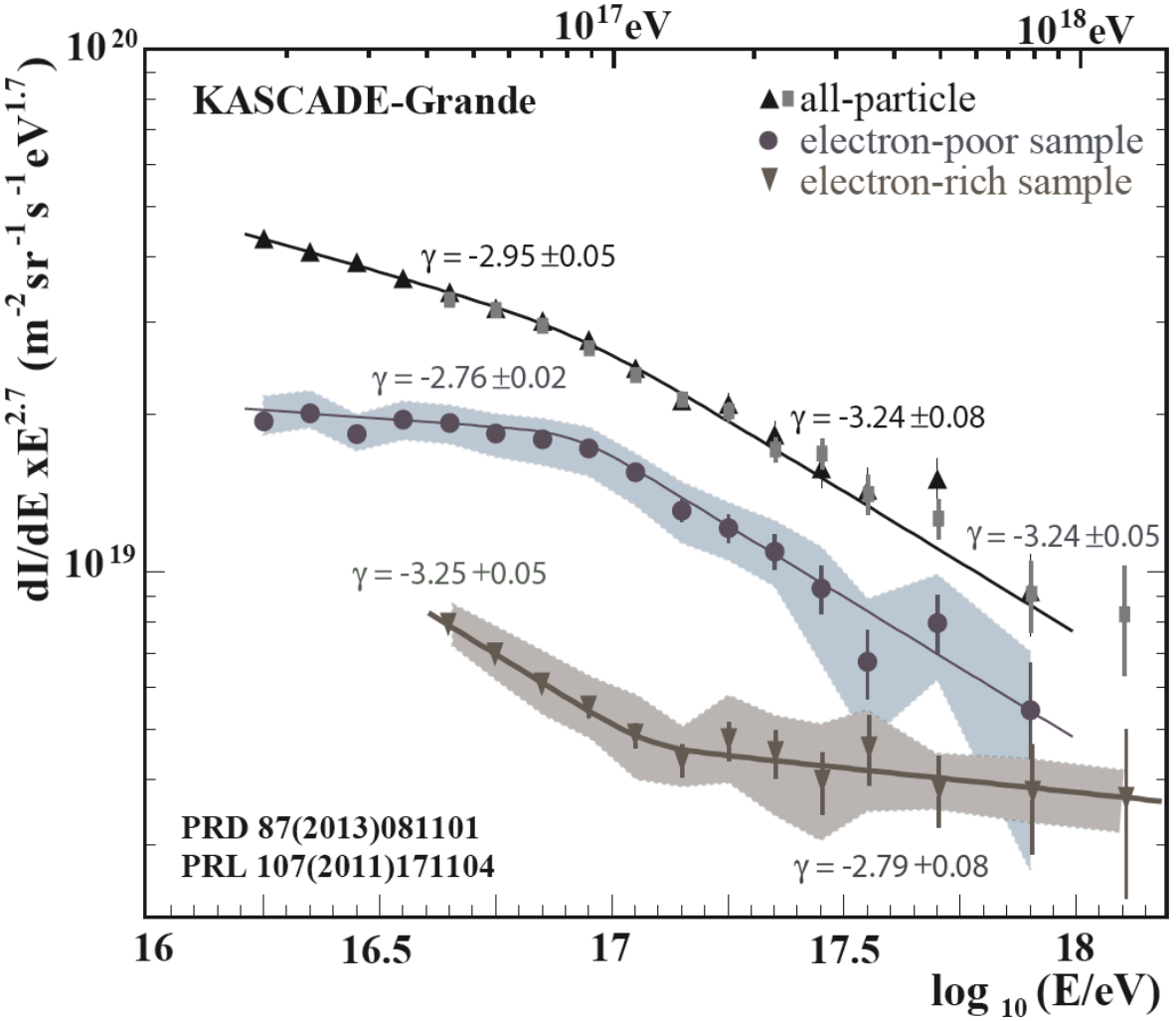
KASCADE-Grande



- 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-Grande
energy spectra of individual mass groups

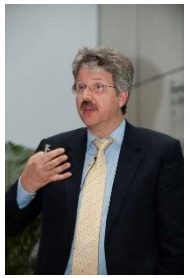


- **steepening due to heavy primaries (3.5σ)**
- **hardening at $10^{17.08}$ eV (5.8σ) in light spectrum**
- **slope change from γ = -3.25 to γ = -2.79!**

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

M.Bertaina (KASCADE-Grande) PoS(ICRC2015)???
J.C. Arteaga (KASCADE-Grande) PoS(ICRC2015)314

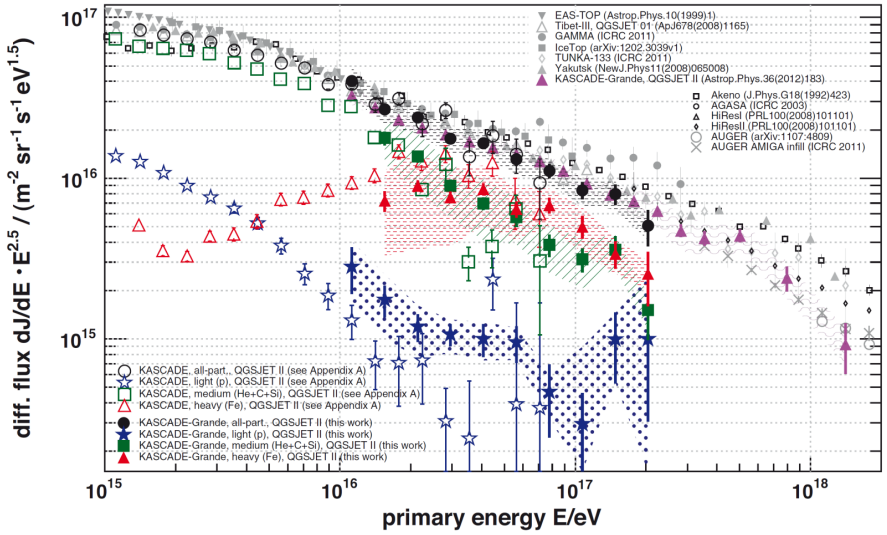
30 March 2009 – official closure ceremony



KASCADE-Grande: Next

- **KASCADE + KASCADE-Grande**
  - finally closed end 2012
  - now dismantled
  - detectors (partly) are used elsewhere

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



- **KCDC**
  - **KASCADE Cosmic ray Data Centre**

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

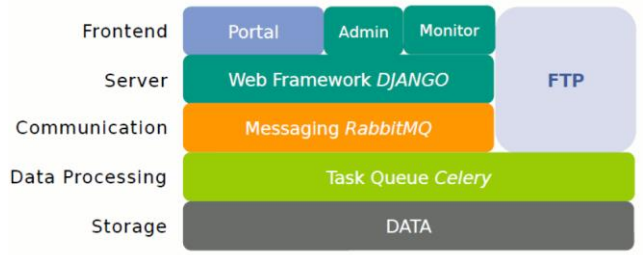
- KCDC = publishing research data
  from the KASCADE experiment

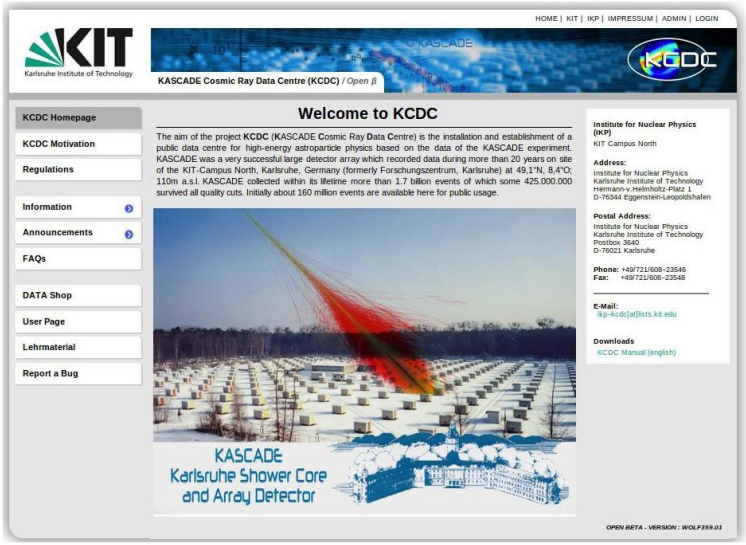
- **Motivation and Idea of Open Data:**
  general public has to be able to access and use the data
  the data has to be preserved for future generations

- **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

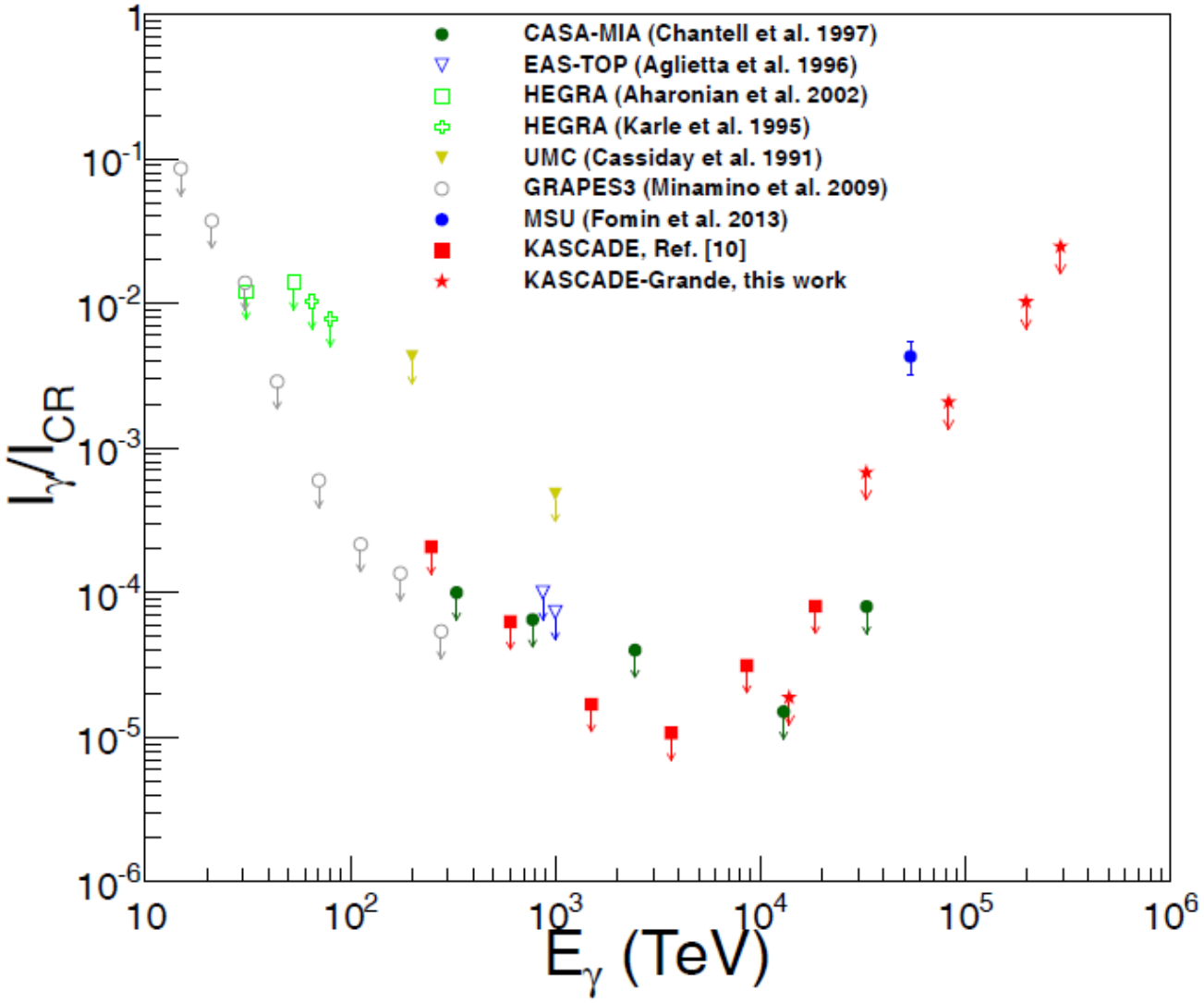
- **Data access:**
  $1.6 \cdot 10^8$ EAS events of first data release is now available

S.Schoo (KASCADE-Grande)
PoS(ICRC2015)262





Synergy with Neutrino and Gamma-ray astronomy



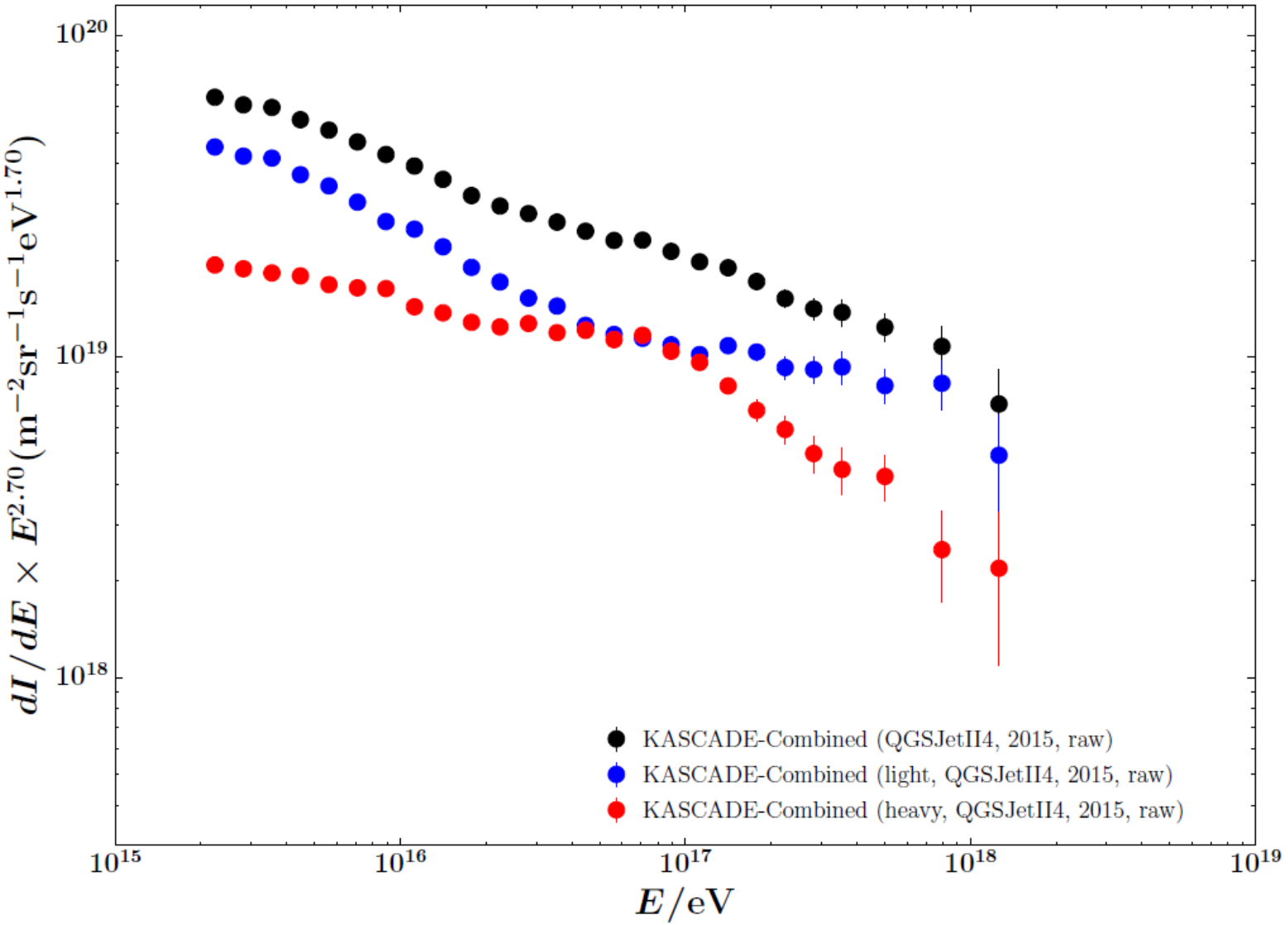
- limits on diffuse Gamma-ray flux constrain the origin of IceCube-neutrinos

← Reject the model of IceCube excess coming from <20kpc in the galaxy

← Reject the positive Gamma-ray signal from MSU at 10^{17} eV

D.Kang (KASCADE-Grande) PoS(ICRC2015)785
Z.Feng (KASCADE-Grande) PoS(ICRC2015)823
D. Kang (KASCADE-Grande) PoS(ICRC2015)788

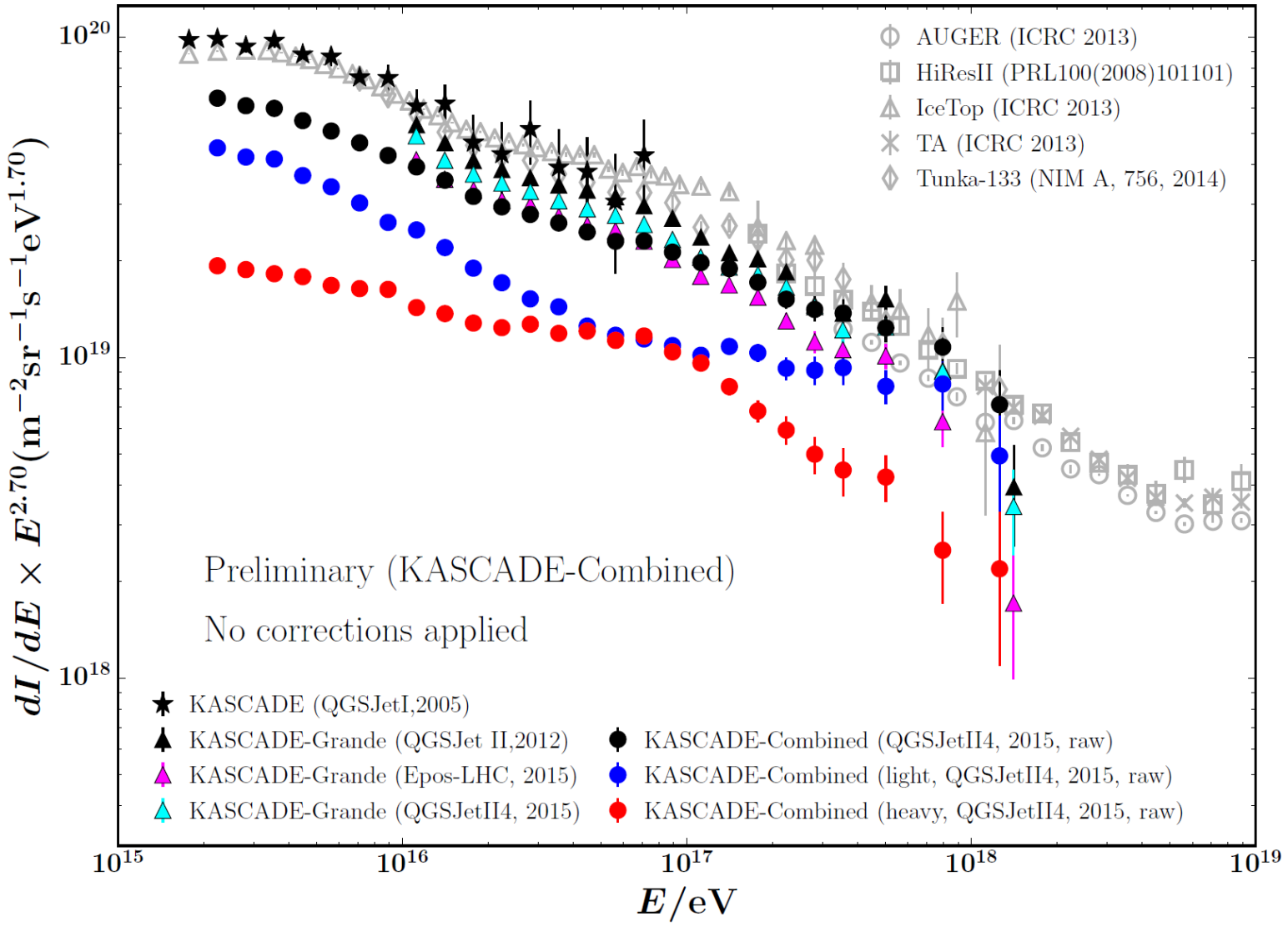
Coherently reconstructed energy spectrum



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

- **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)**

http://www.hap-astroparticle.org/

click: calendar (upcoming events)

Topics:

- Spectrum, Anisotropy and Elemental Composition of Cosmic Rays in the PeV-EeV range
- Systematics due to Hadronic Interaction Models
- Astrophysical Interpretation of the data and galactic-extragalactic transition models

Lessons learned
from the >25-years KASCADE facility

It is essential to provide:

- **spectra of individual mass groups!!**
- **multi-parameter EAS measurements to validate hadronic interaction models**
- **multi-messenger detection (need muons!!?)**
- **high statistics in a large energy range (mainly for composition dependent anisotropy studies)**
- **the right observation altitude**
- **room for R&D studies for future, improved technologies**
- **outreach and public data access**

A.Haungs (KASCADE-Grande) PoS(ICRC2015)278

KASCADE-Grande: Mission Accomplished !!

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

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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Nuclear Research, Lodz
P. Łuczak, J. Zabierowski

Institute of Physics and Nuclear Engeneering and University Bucharest
I.M. Brancus, B. Mitrica,
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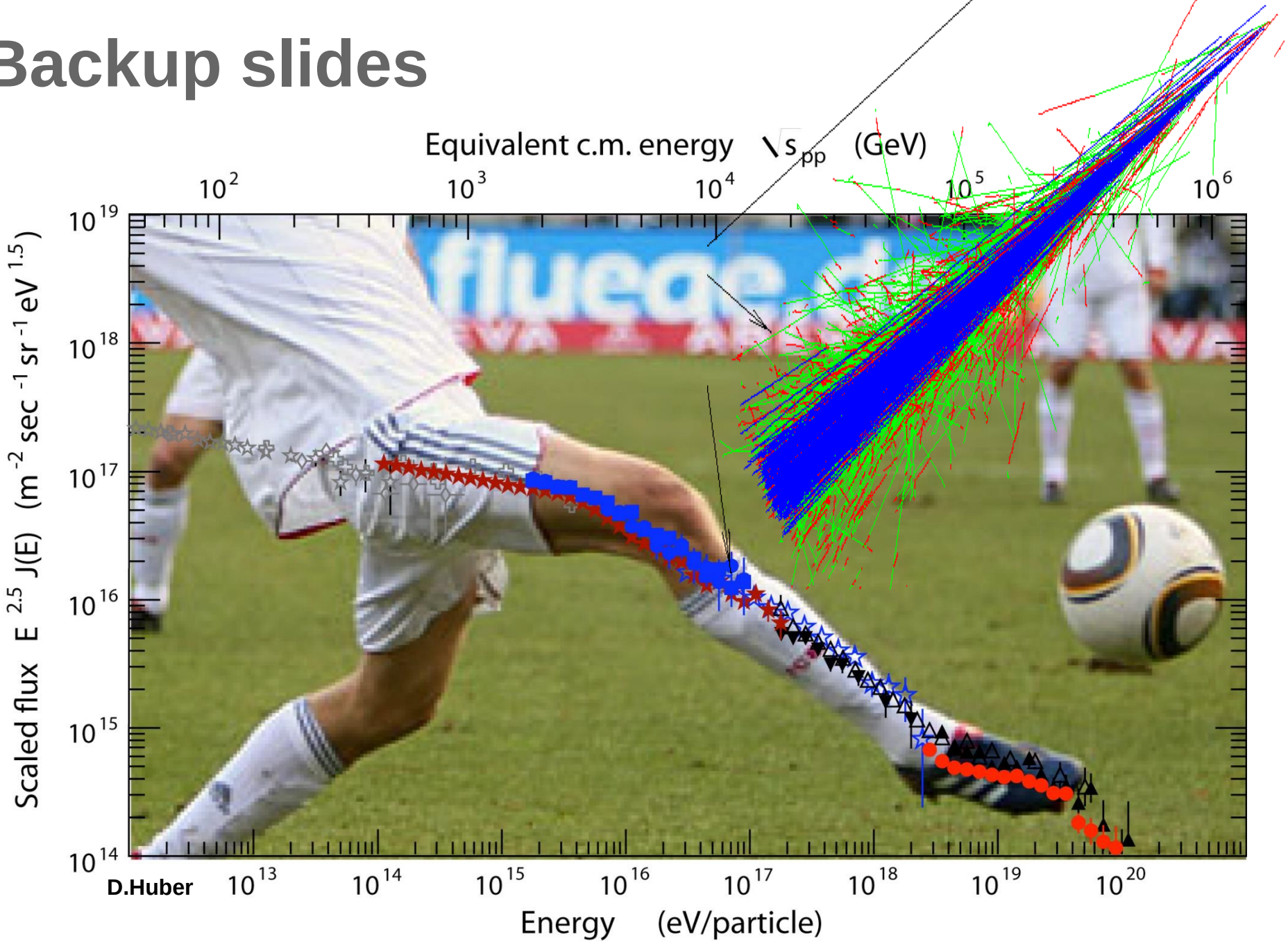
Universidade Sao Paulo, Brasil
V. de Souza

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

email spokesperson: haungs@kit.edu

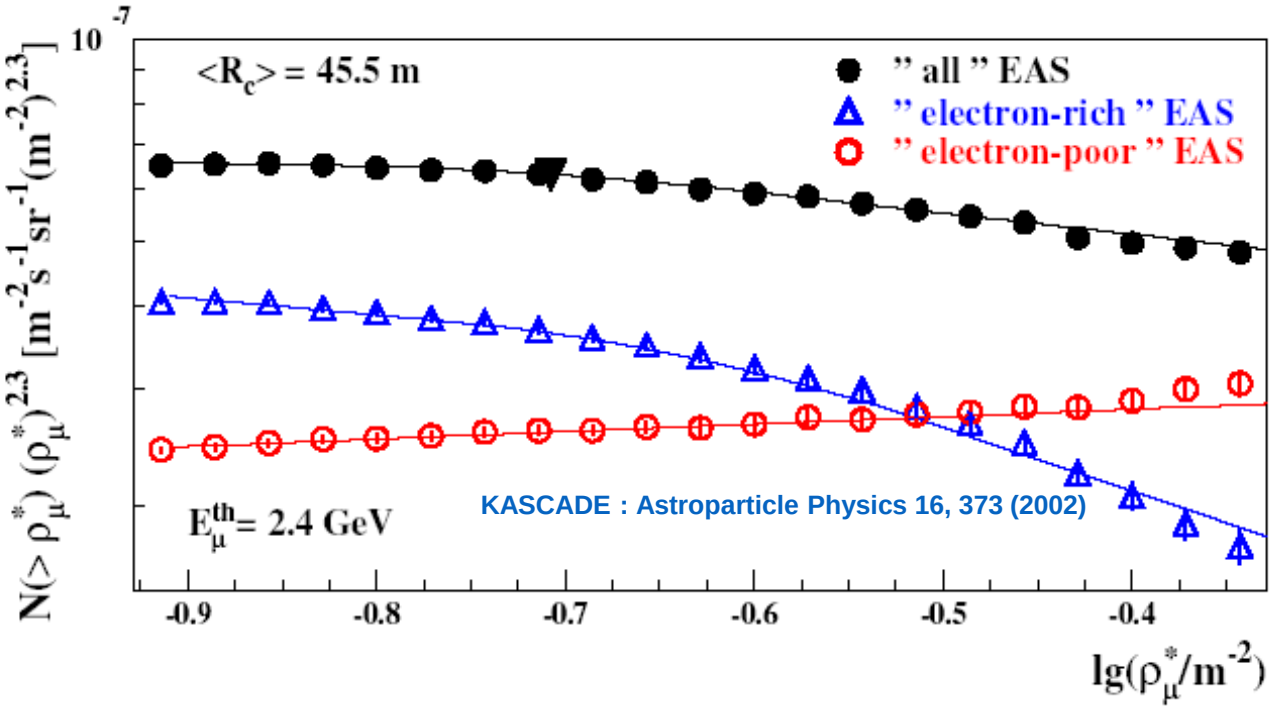
Backup slides



Model independent multi-parameter analysis

Use of three observables:

- **high-energy local muon density ➔ energy estimator**
- **Total muon number and electron number ➔ mass estimator**



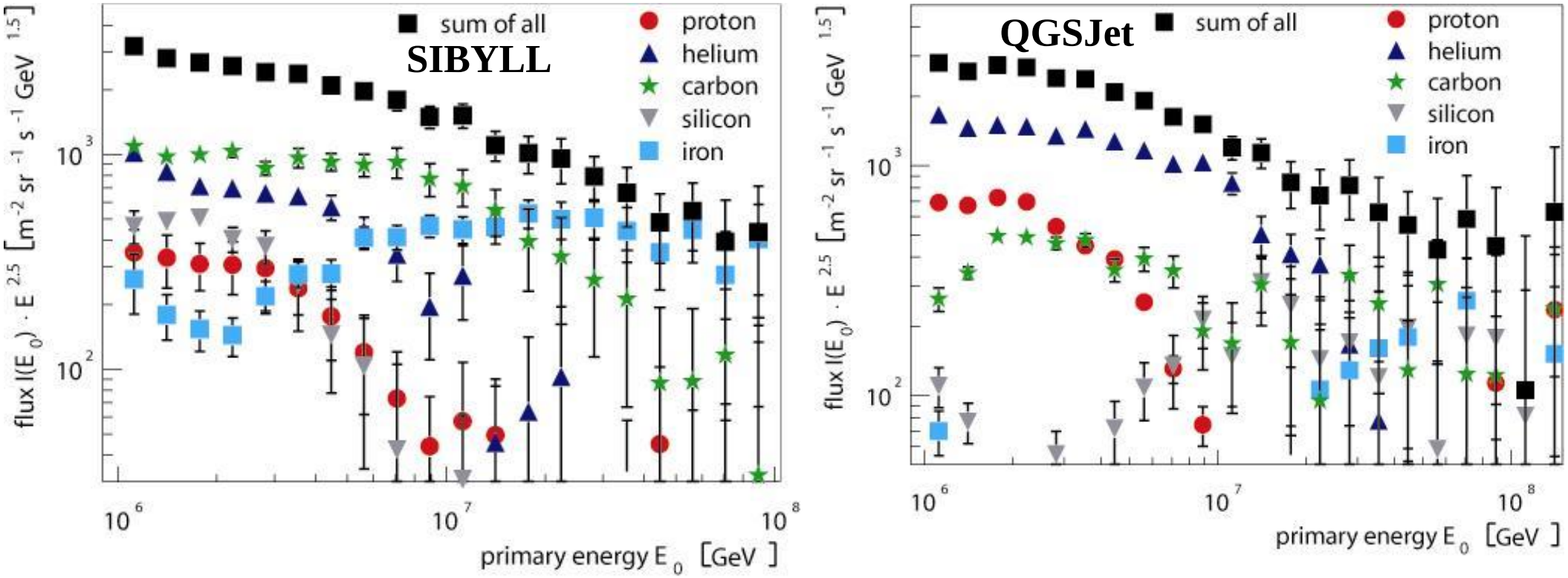
- **KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS**
- **Do we need hadronic interaction models?**

  ➔ yes, for normalization of absolute energy and mass scale!!

T.Antoni et al. Astroparticle Physics 16 (2002) 373

KASCADE: the rigidity knee

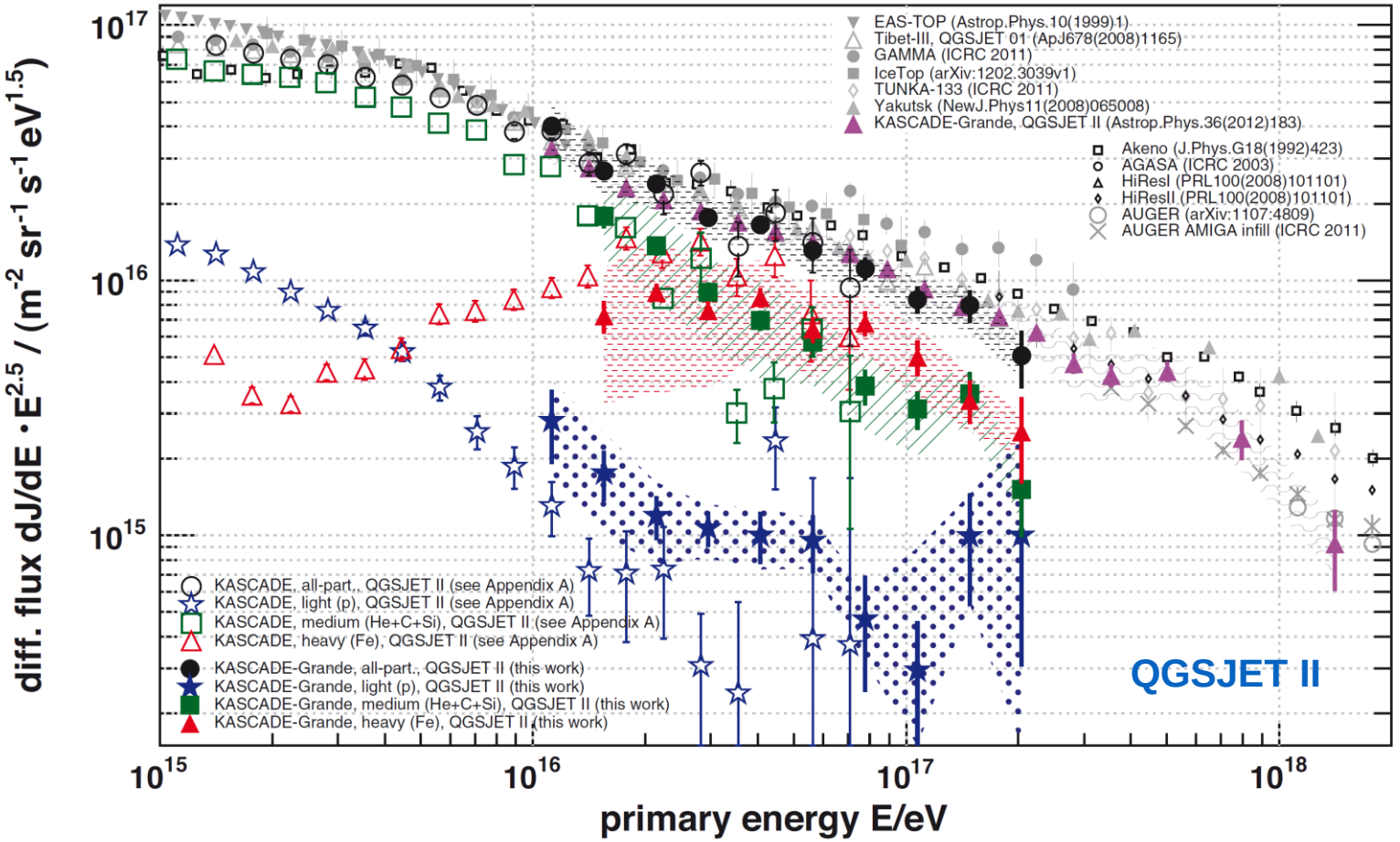
- same unfolding but based on different hadronic interaction models embedded in CORSIKA



- 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

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 47 (2013) 54

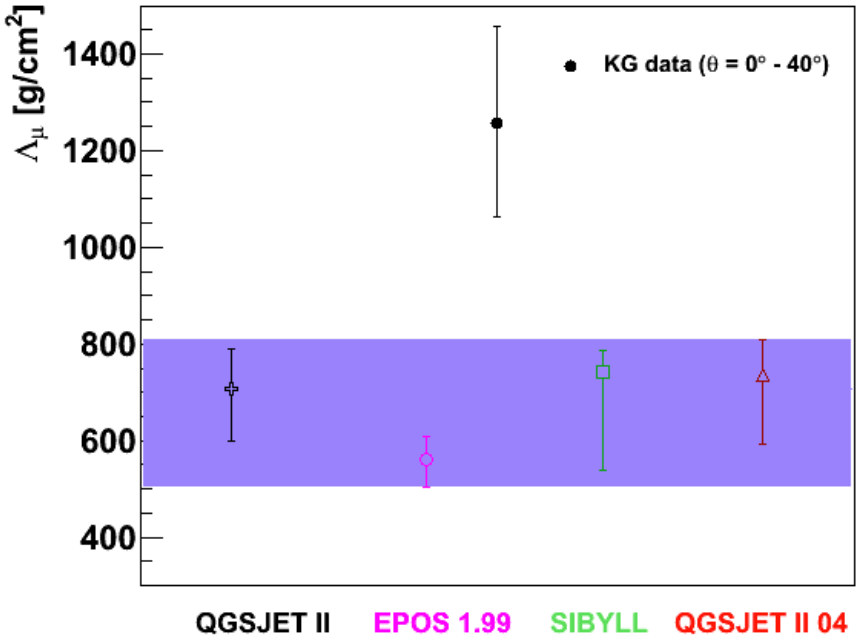
KASCADE-Grande: Muon Attenuation Length

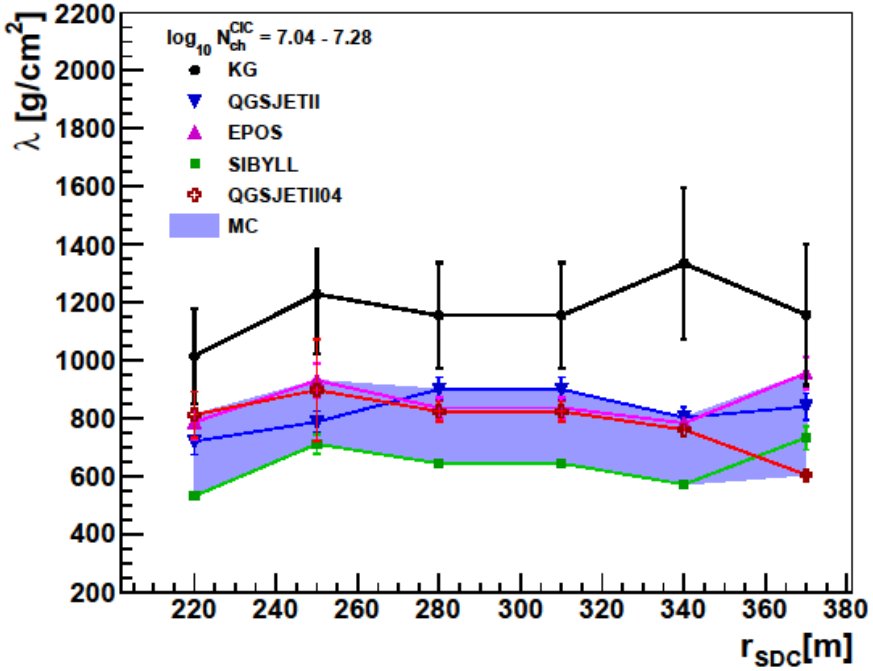
total muon number

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

local muon density

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



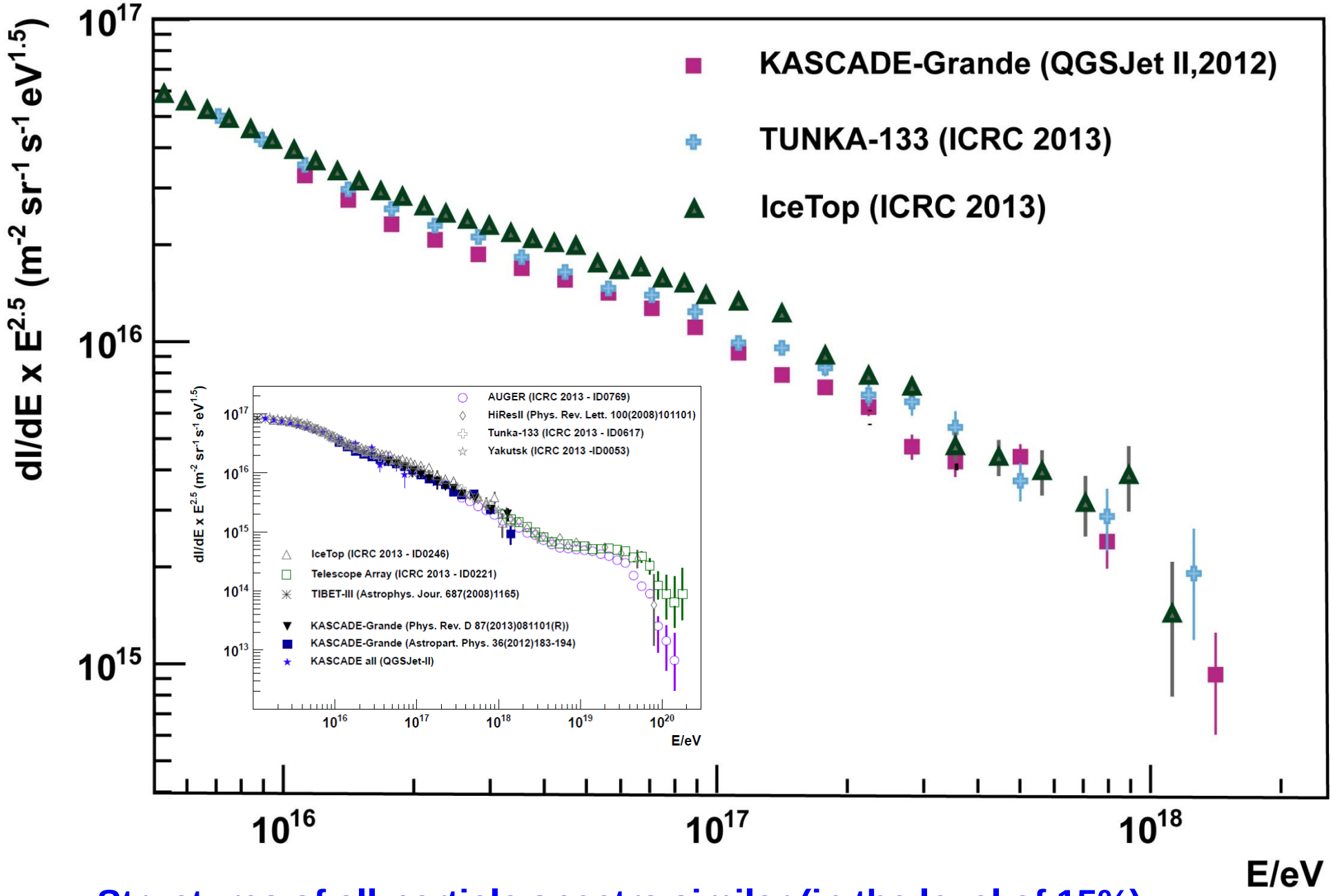


attenuation length measured is different from the predictions of Monte Carlo

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

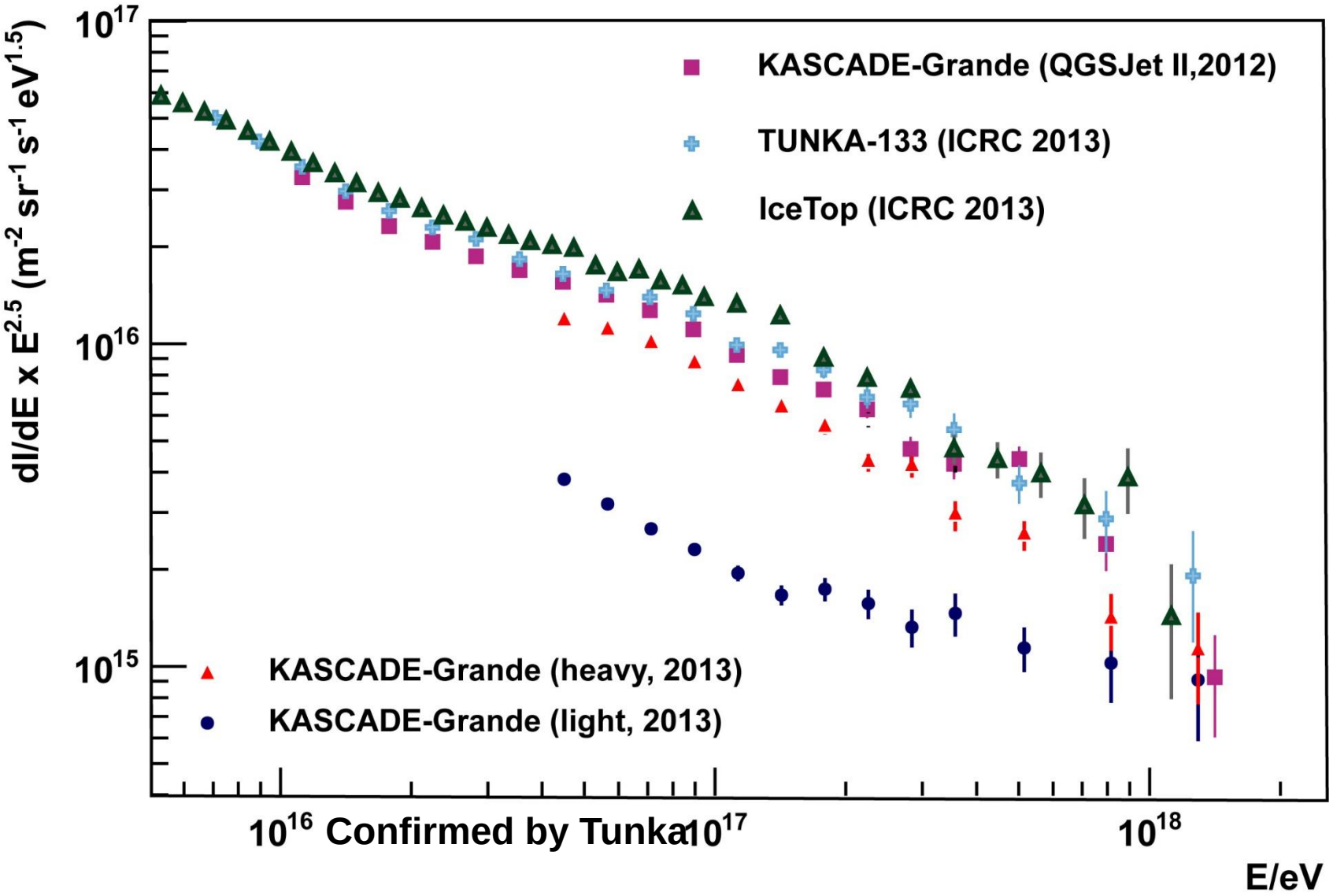
➔ influences absolute energy and mass scale, but not spectral features

KASCADE-Grande, ICRC 2013 #0772, paper in preparation



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

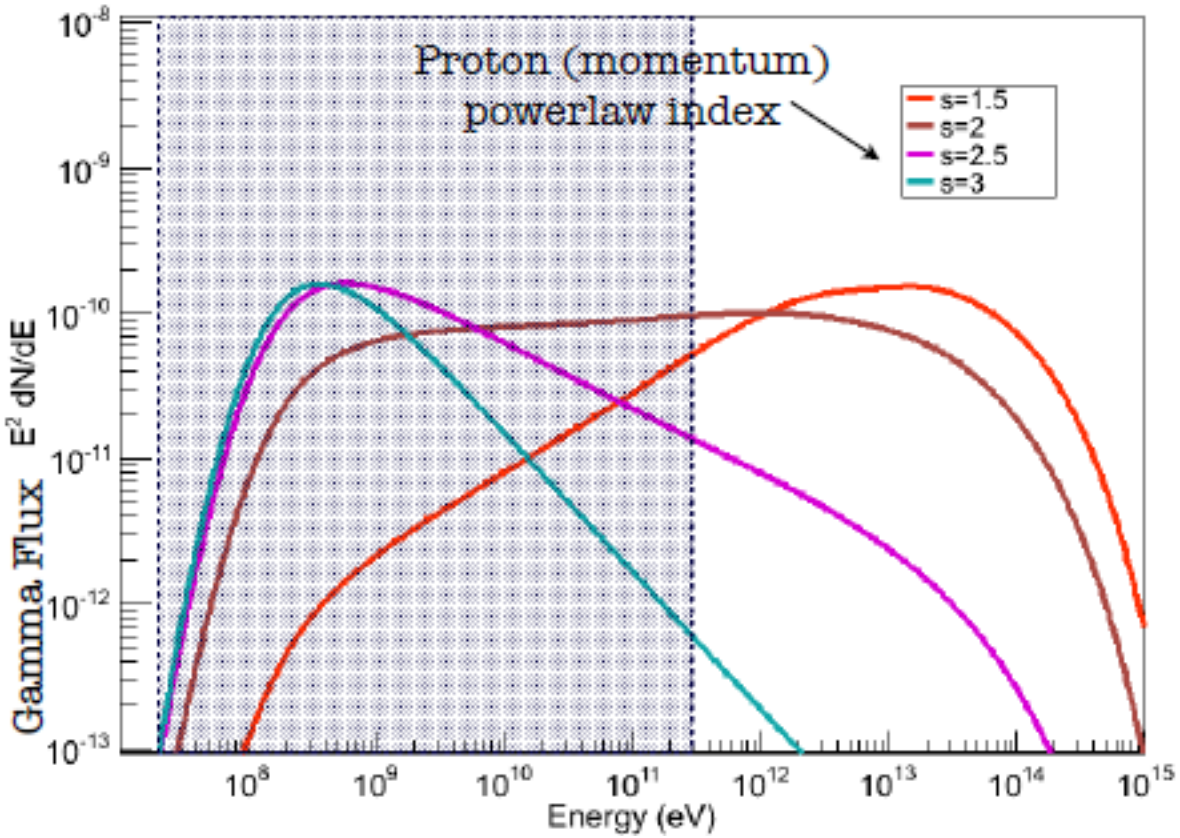
All-particle spectra



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

Synergy with Gamma-ray astronomy

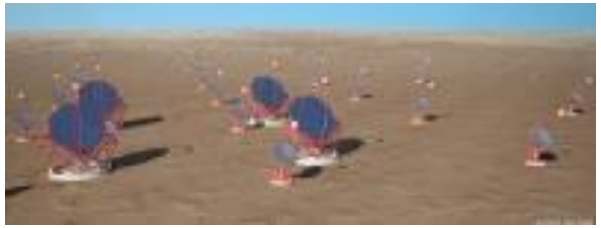
- **Do shell-type SNR accelerate protons? (via π^0-decay!)**
- **To which energy? (up to 10^{15}eV?)**
- **Distinguishable from electron acceleration?**



Stefan Funk, TAUP 2013, Asilomar, CA, US

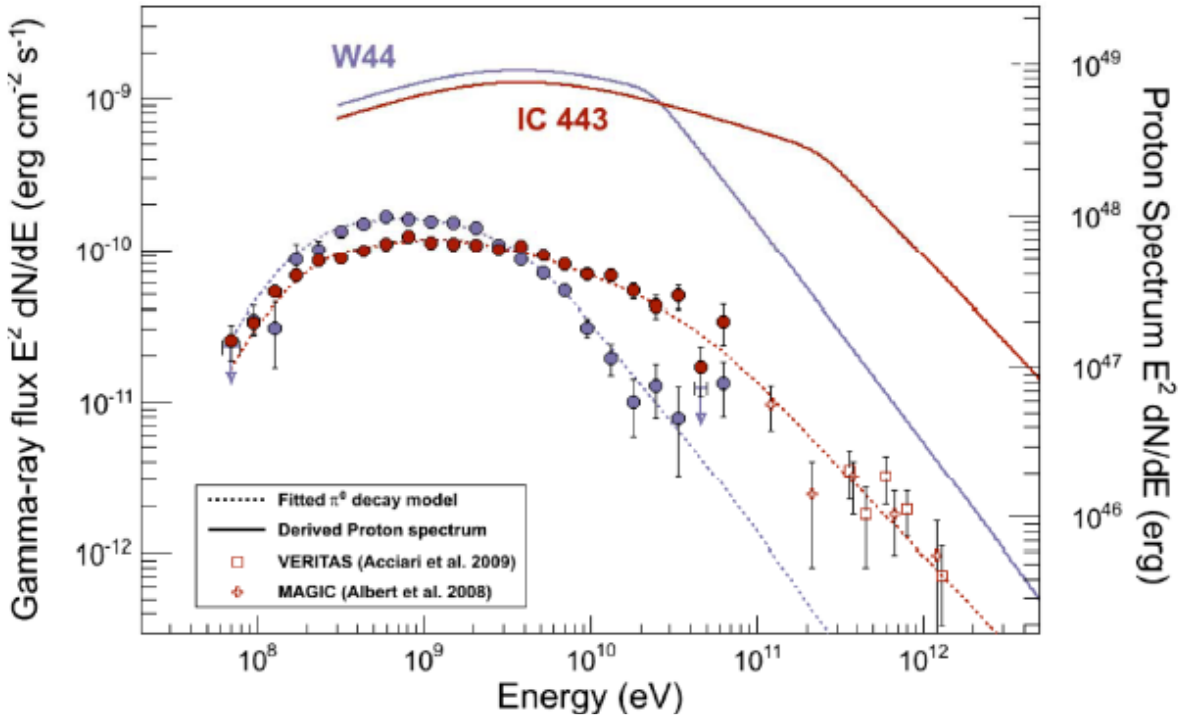
Expected gamma flux (π^0 –bump) for different proton injections

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



Gamma-ray astronomy: Fermi

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



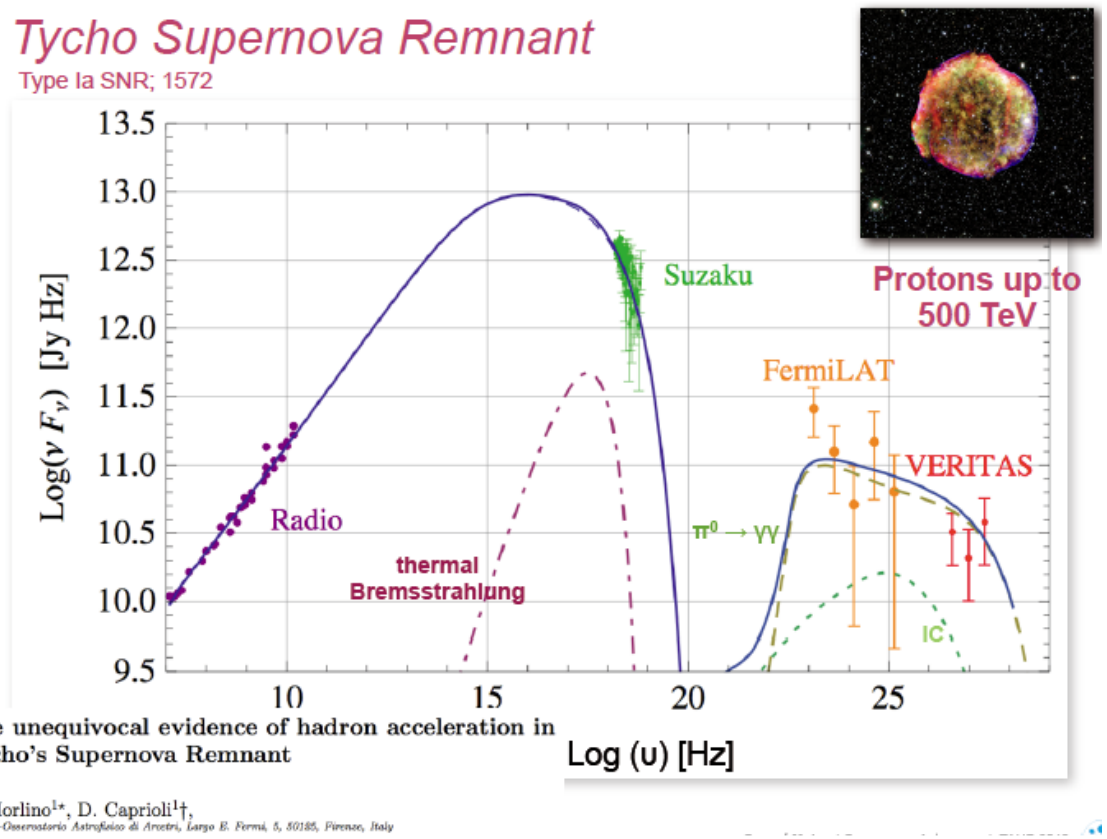
Measured gamma-rays and calculated proton spectrum

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

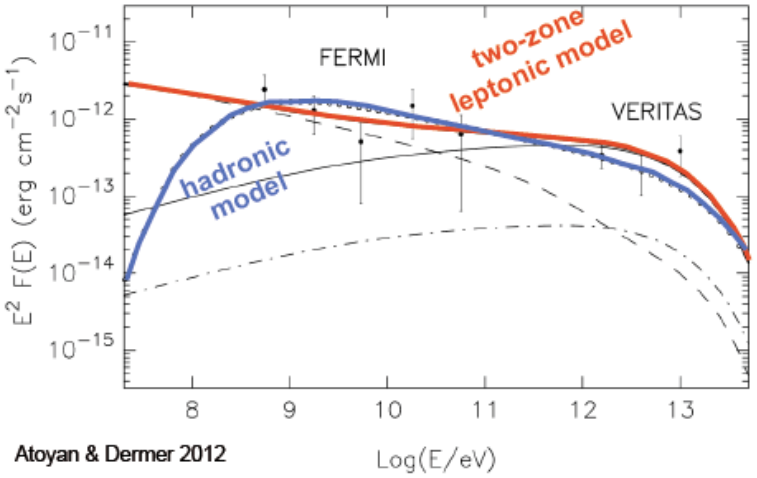
Stefan Funk, TAUP 2013, Asilomar, CA, US

Gamma-ray astronomy: IACT

-problems: gas density for hadronic
magnetic fields for leptonic



Measurement also explainable by hadronic and leptonic models

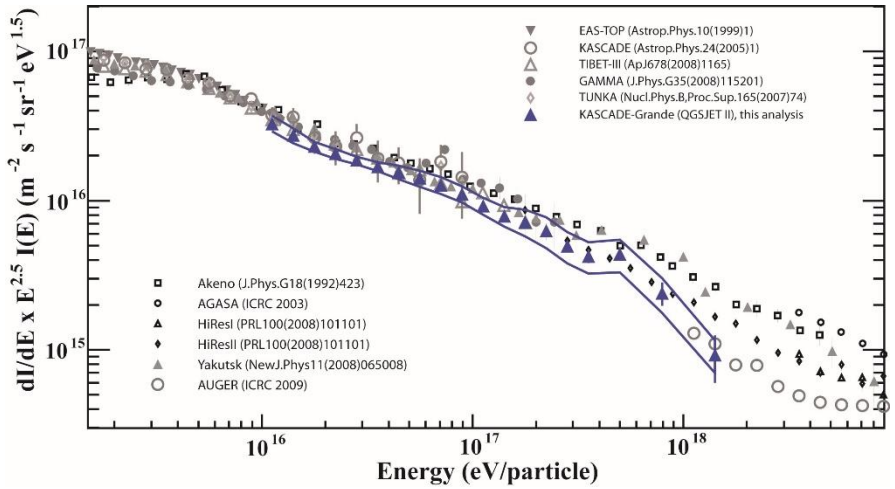


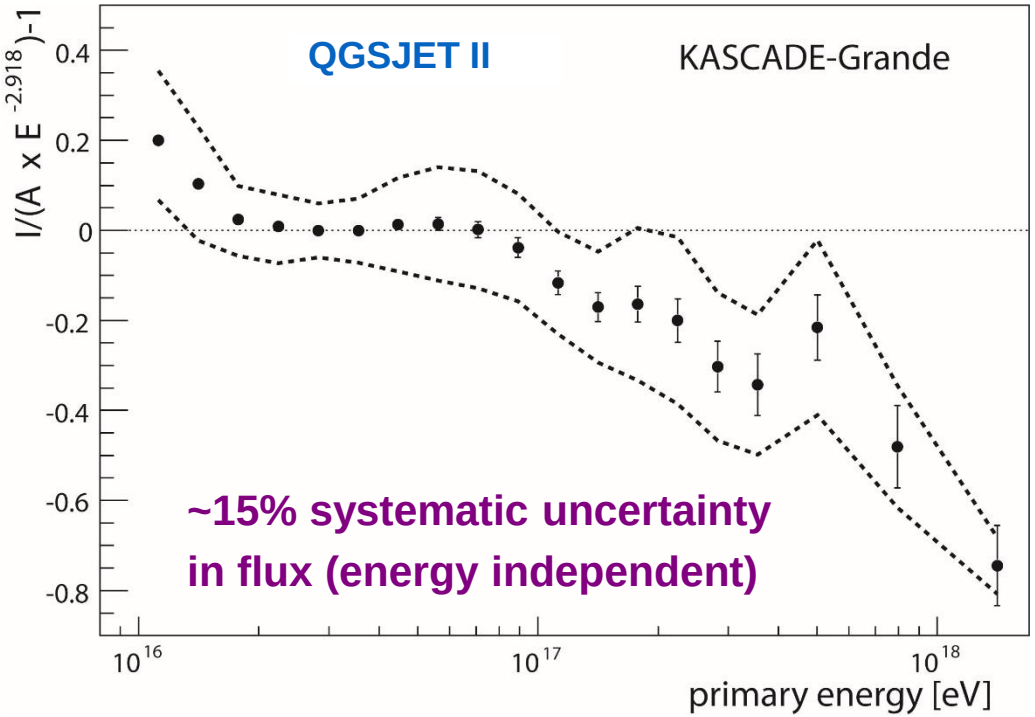
← Still no proof that SNR accelerate protons up to the knee, but also no exclusion….

Gernot Maier, TAUP 2013, Asilomar, CA, US

KASCADE-Grande
all-particle energy spectrum

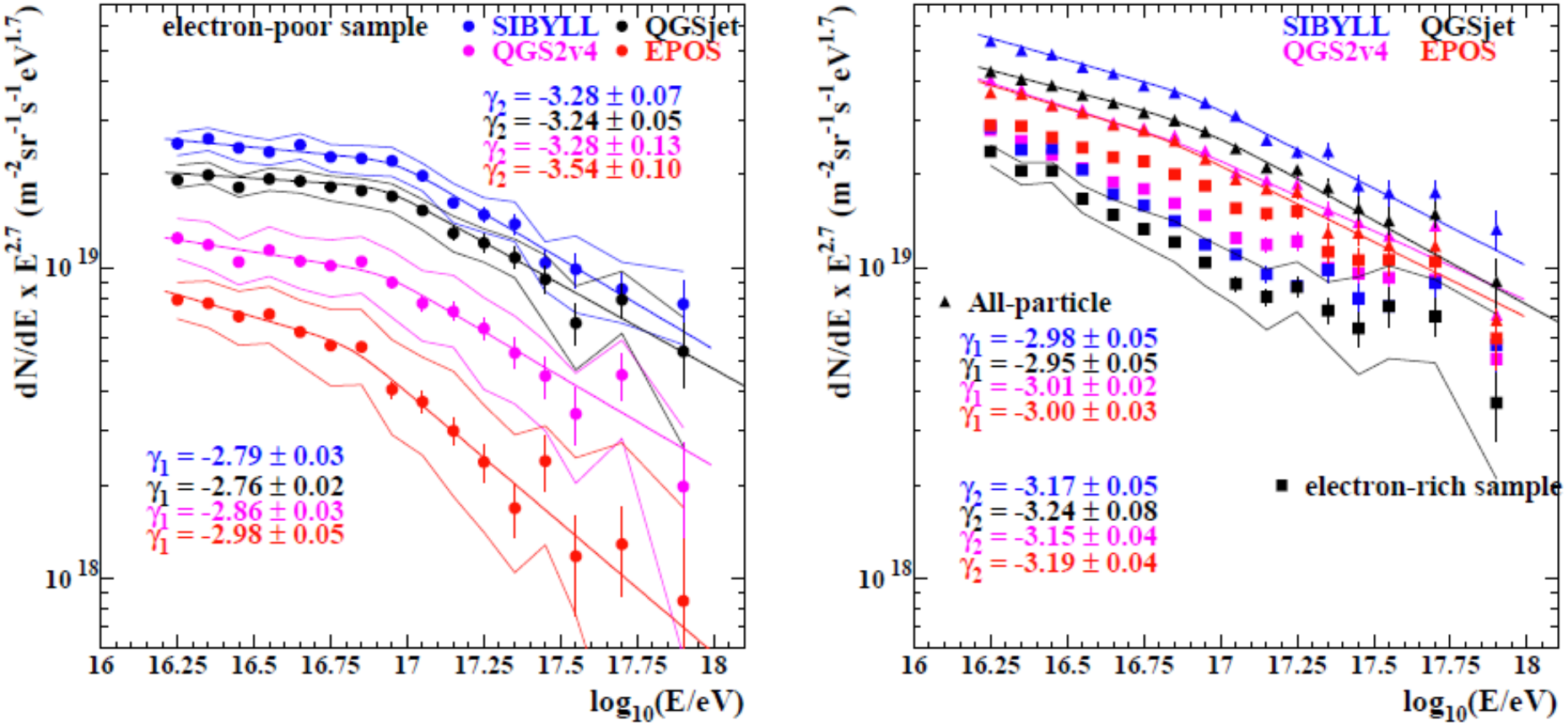
Astroparticle Physics 36 (2012) 183





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

KASCADE-Grande: 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

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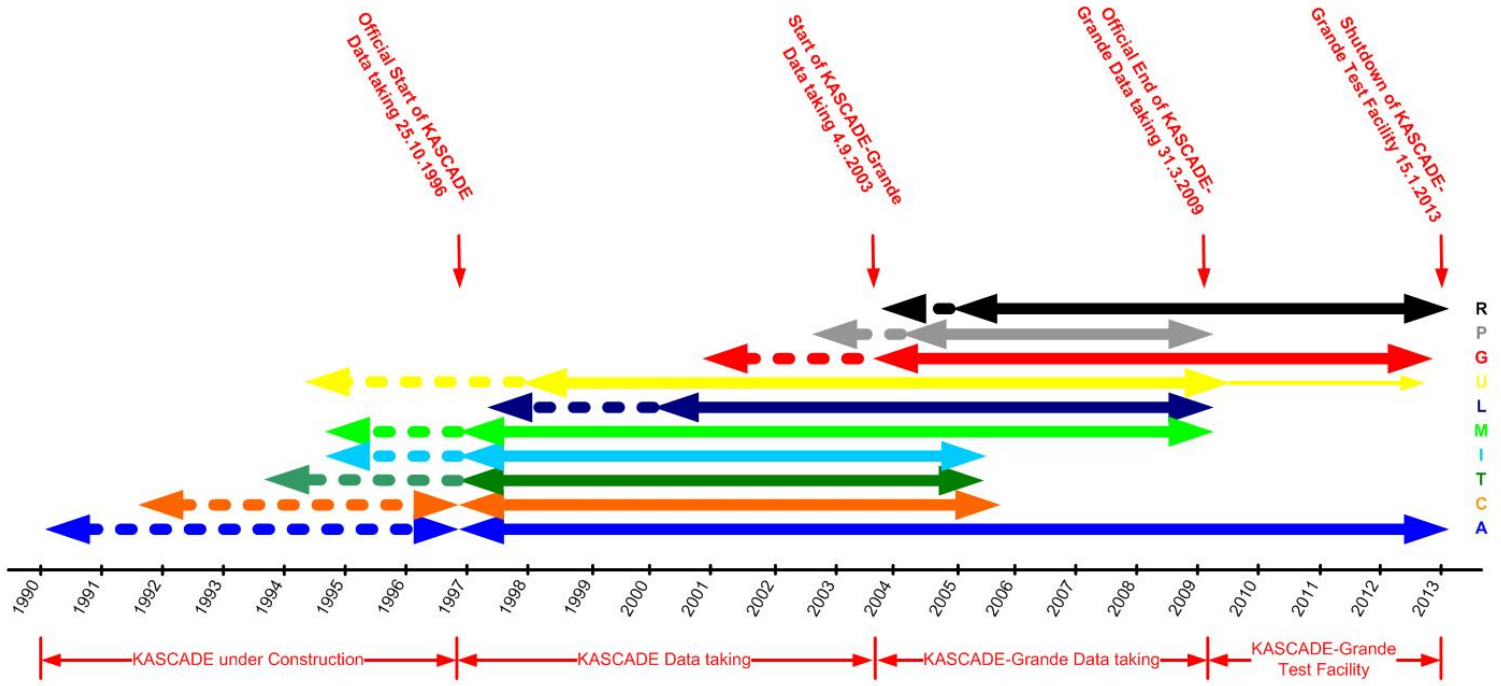
Processing

Data A little Statistics

Run time	25.10.1996 14:19 - 15.1.2013 9:40 UTC
Number of Runs	7.082
Number of Files	54.910
Number of Events	1.759.527.079

Events analyzed in different selections

KASCADE	428.596.253
Grande	90.551.699
LOPES	8.229.031



Schedule of the ‚active time' of various Detector Components of KASCADE and KASCADE-Grande

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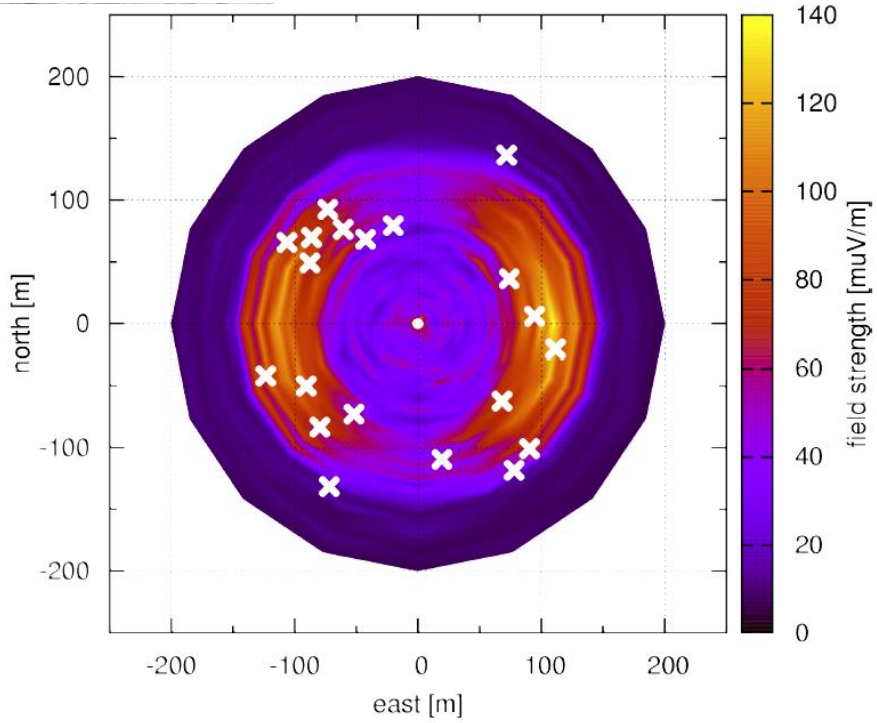
EAS Radio detection in GHz range: CROME

- **core distances between 80m and 150m**
  ➔ring structure hints towards Cherenkov cone

REAS3 simulations predict such a ring structure in the GHz-frequency range

Iron primary
Total field strength
Simulated with REAS3



F.Werner – CROME; ARENA conf 2012
CROME: PRL accepted November 2014