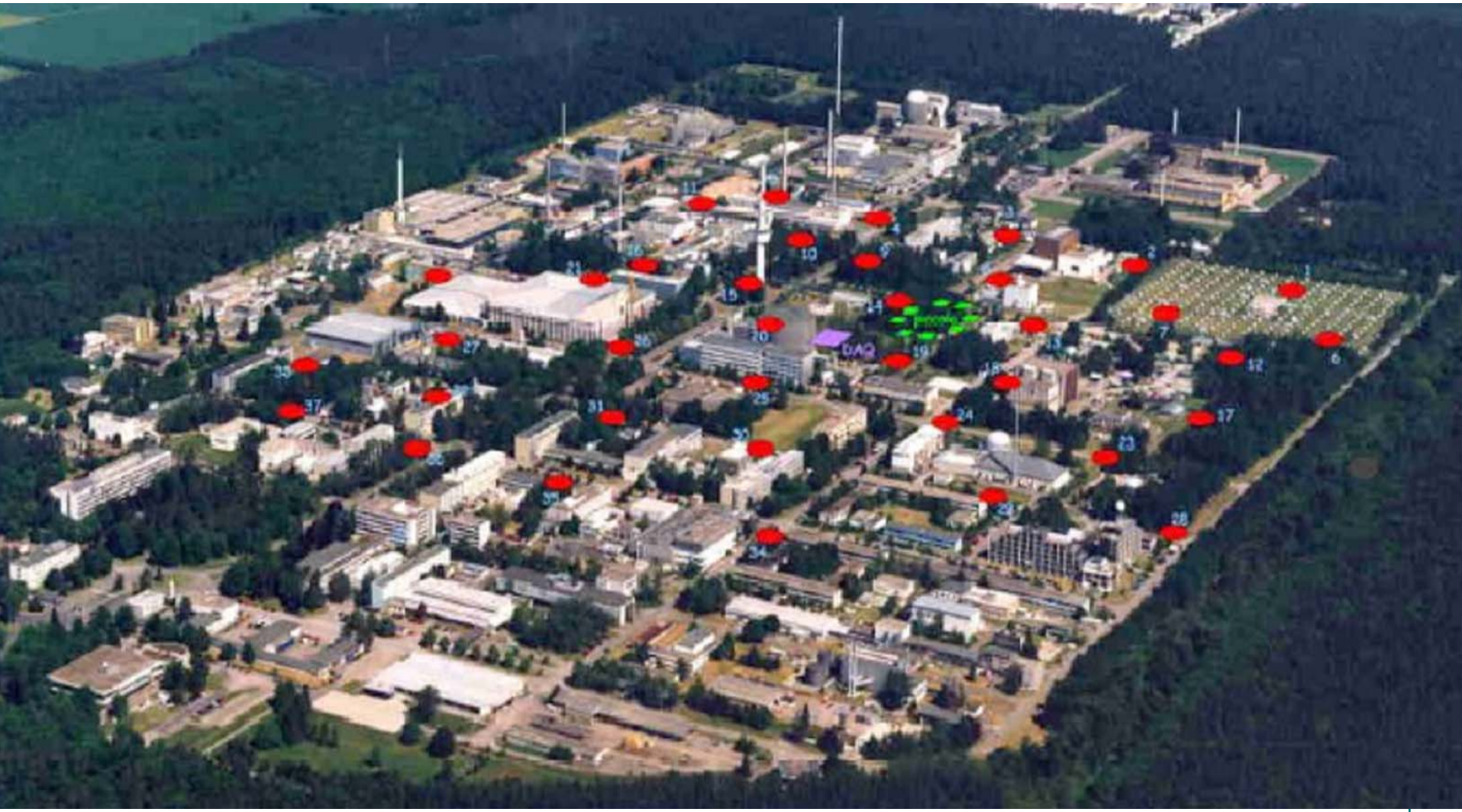
Status
KASCADE-Grande

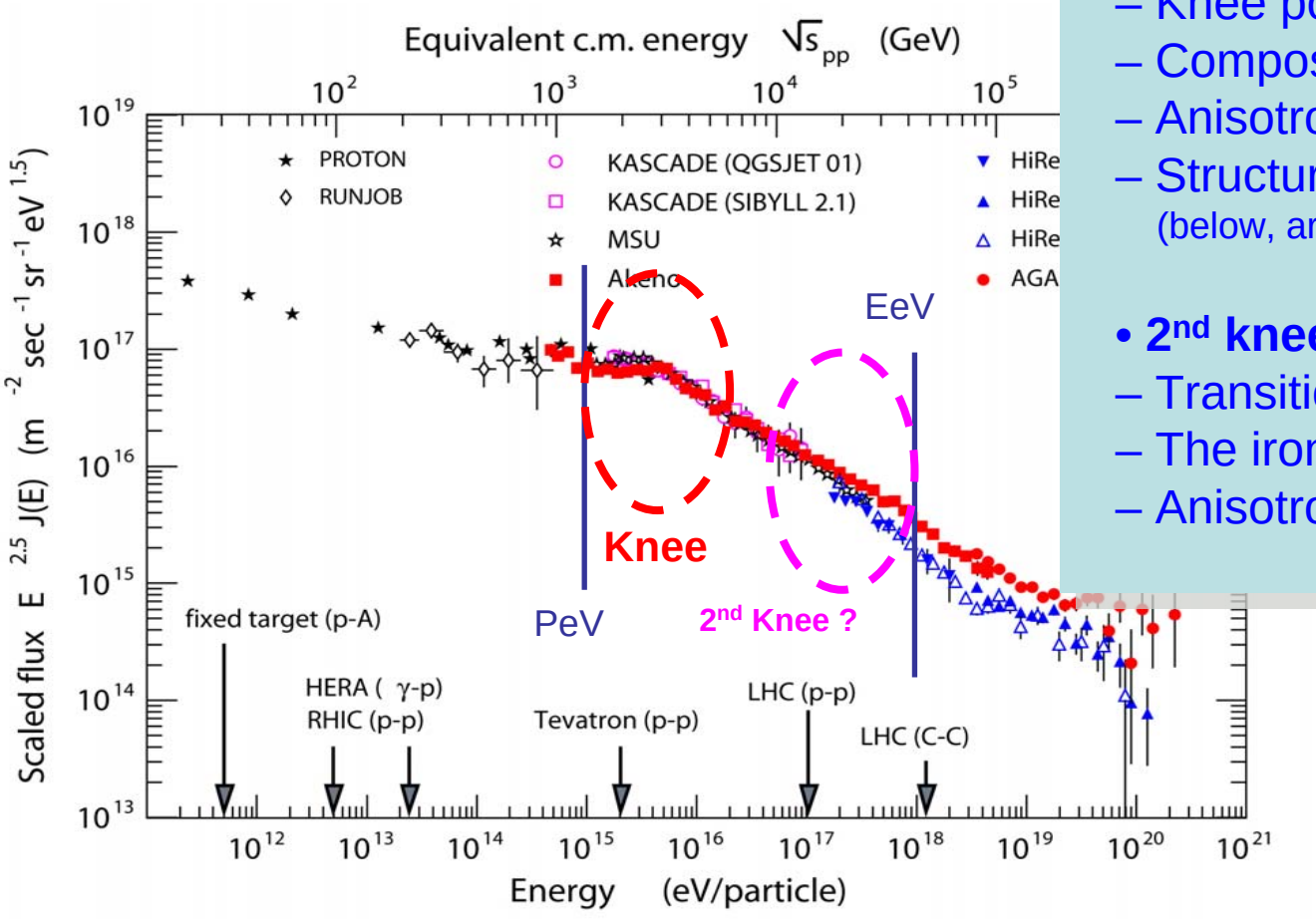


Cosmic Rays around the knee(s)

Astrophysical questions for this energy range:

- **(1st) knee**
  - Knee position
  - Composition at the knee
  - Anisotropy around the knee
  - Structure of spectrum
    (below, around, and above the knee)

- **2nd knee (dip, ankle) ?**
  - Transition to extragalactic CR?
  - The iron knee?
  - Anisotropies, Point Sources?

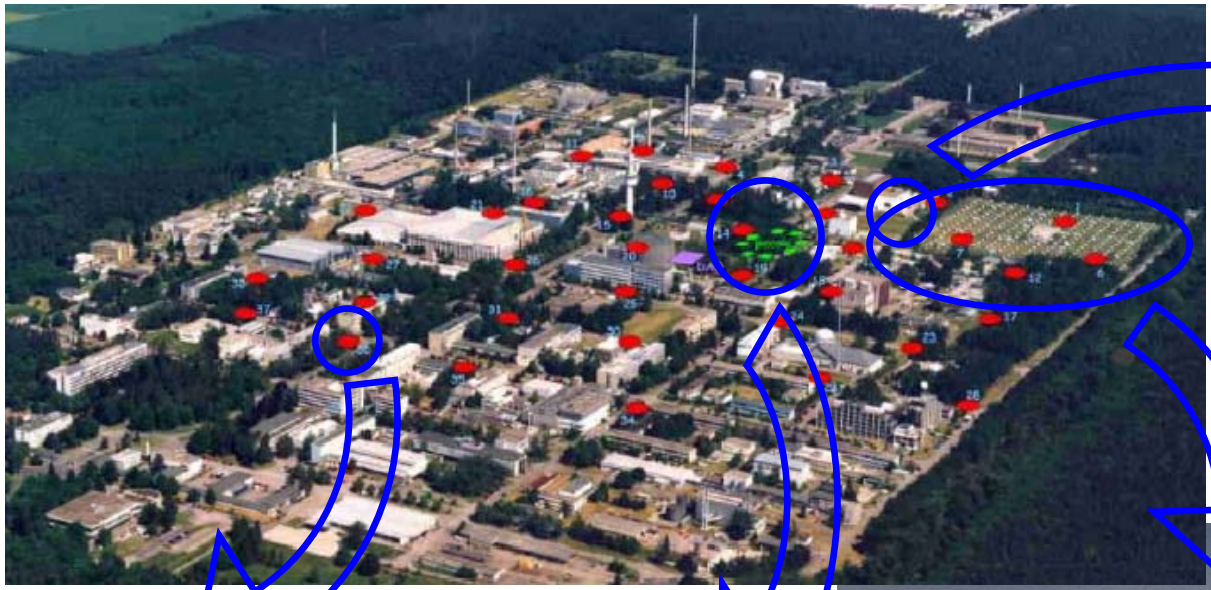


Ralph Engel, 2004

Experiment: KASCADE-Grande

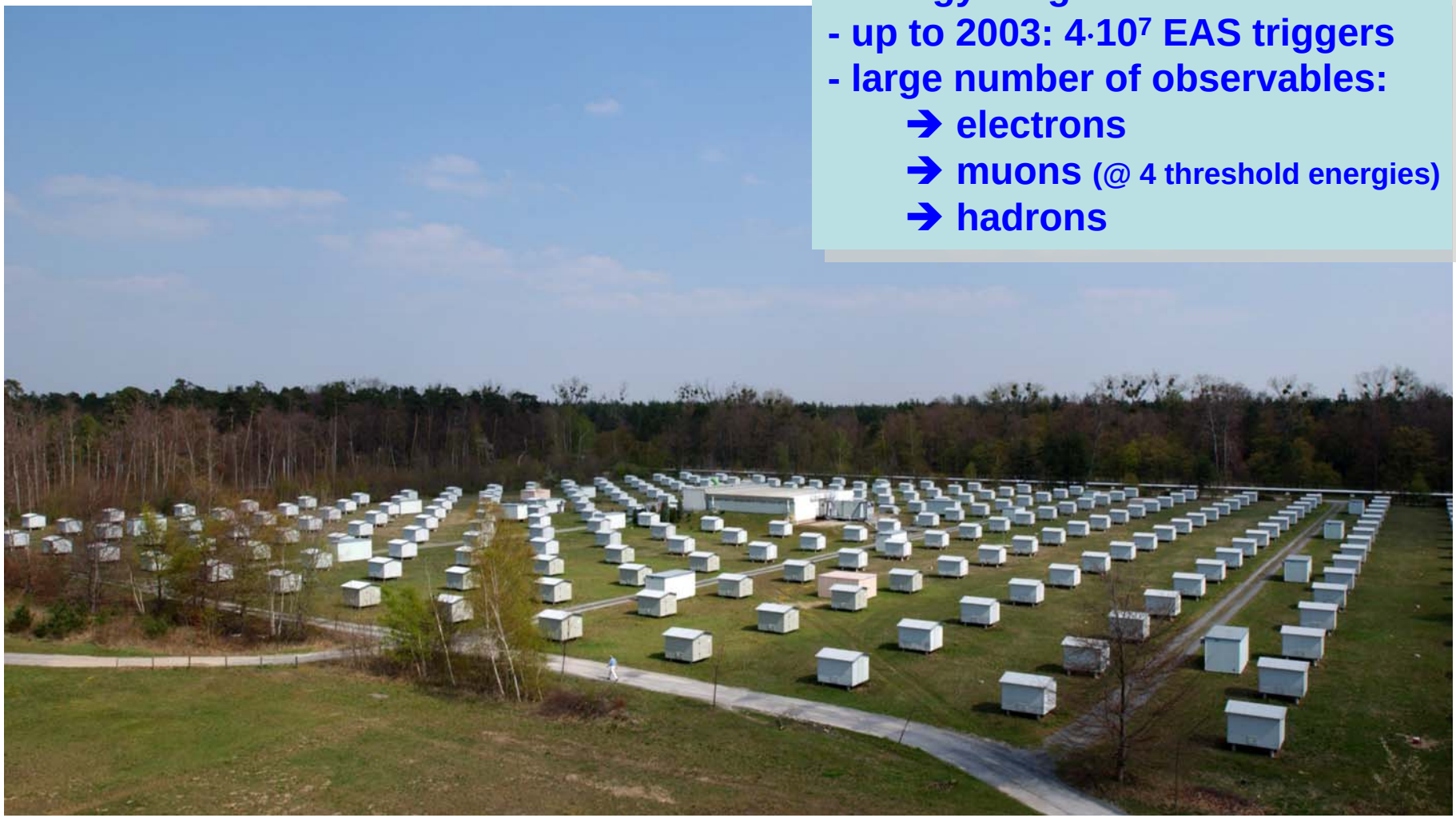
= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

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



KASCADE : multi-parameter measurements

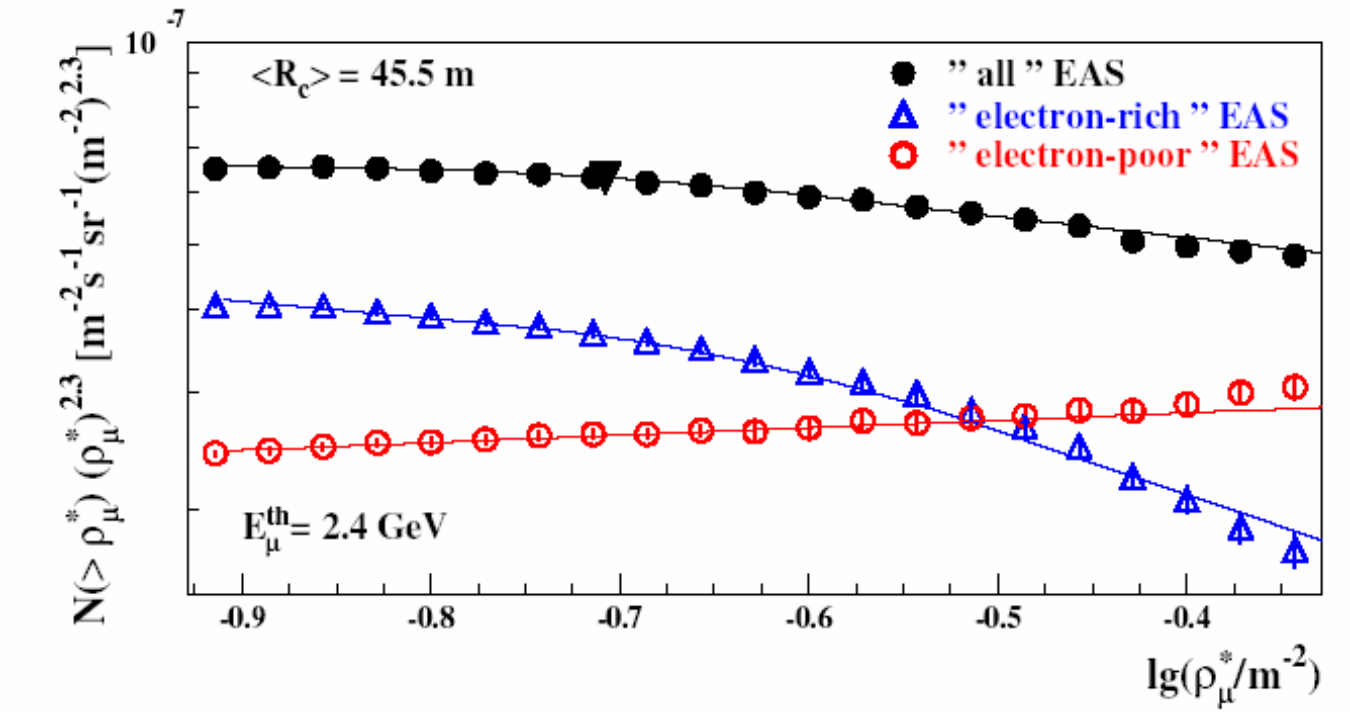
- energy range 100 TeV – 80 PeV
- up to 2003: $4 \cdot 10^7$ EAS triggers
- large number of observables:
  - ➔ electrons
  - ➔ muons (@ 4 threshold energies)
  - ➔ hadrons



Suggestion A.Watson

(Summary ISVHECRI 2006):

basic observable analysis first

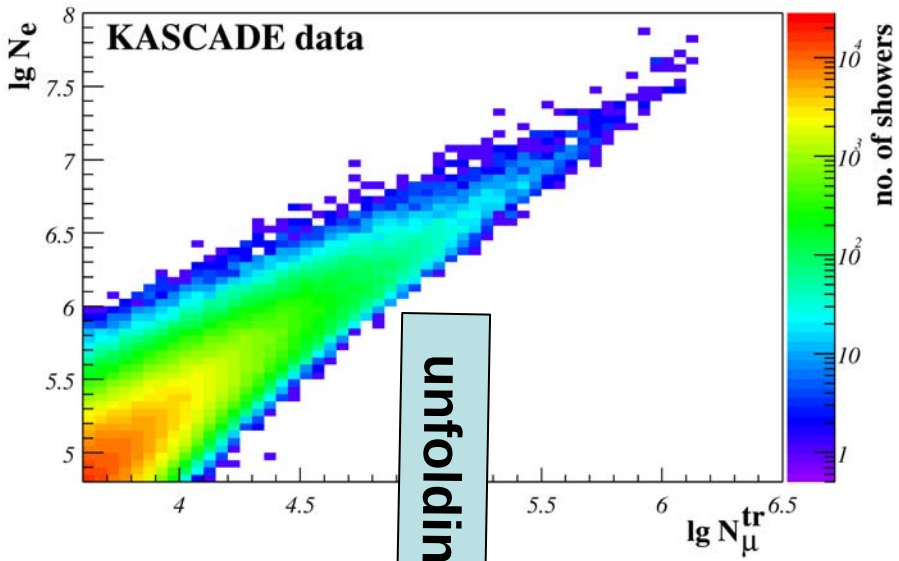


KASCADE : Astroparticle Physics 16 373 2002

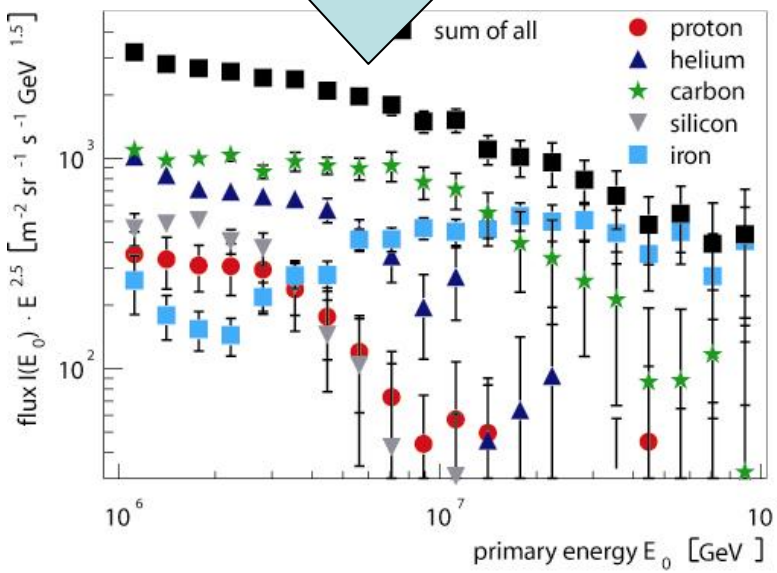
- **KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS**
- **Do we need hadronic interaction models?**

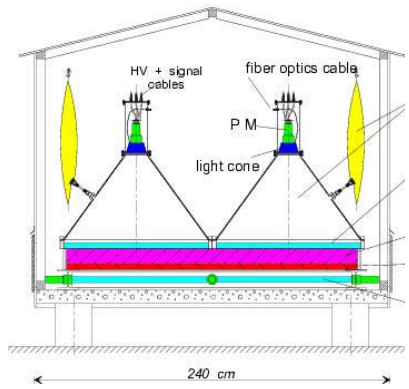
  ➔ **yes, for normalization of absolute energy and mass scale!!**

KASCADE : energy spectra of single mass groups



unfolding





Measurement:
KASCADE array data
900 days;
0-18° zenith angle
0-91m core distance
lg N_e > 4.8;
lg N_μ^{tr} > 3.6
➔ 685868 events

Searched:
E and A of the Cosmic Ray Particles
Given:
N_e and N_μ for each single event

➔ solve the inverse problem

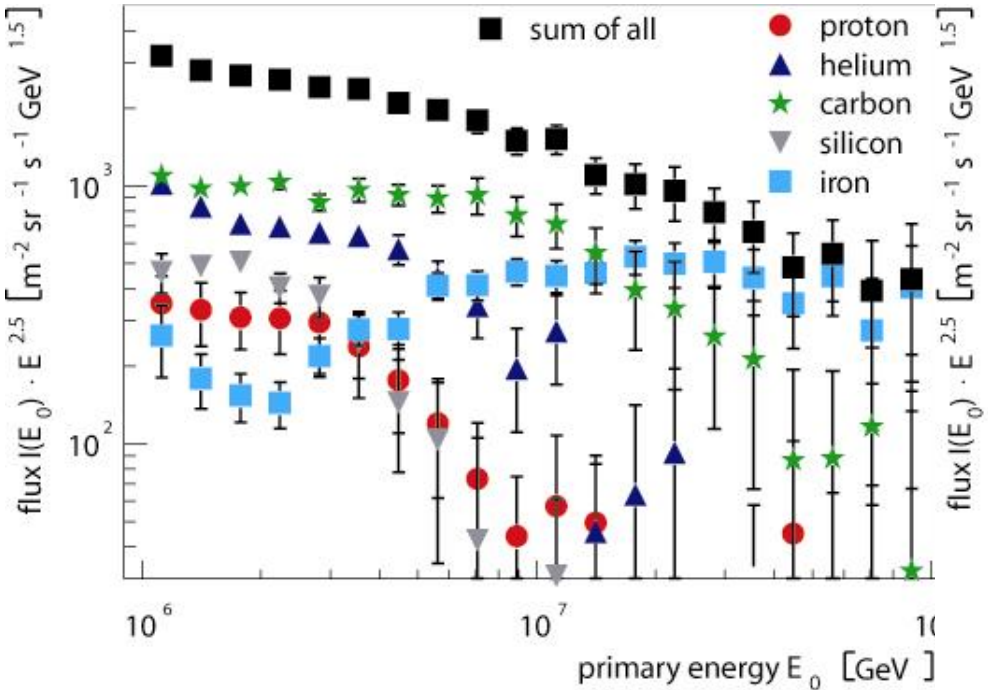
$$g(y) = \int K(y,x)p(x)dx$$

with y=(N_e,N_μ^{tr}) and x=(E,A)

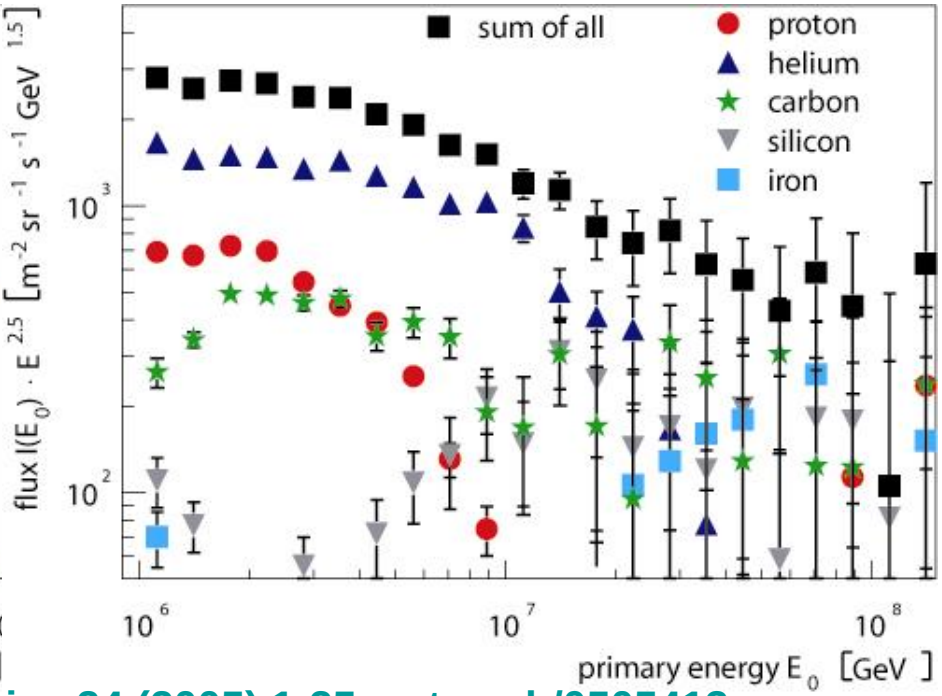
KASCADE results

- same unfolding but based on two different interaction models:
- SIBYLL 2.1 and QGSJET01 (both with GHEISHA 2002) all embedded in CORSIKA

SIBYLL



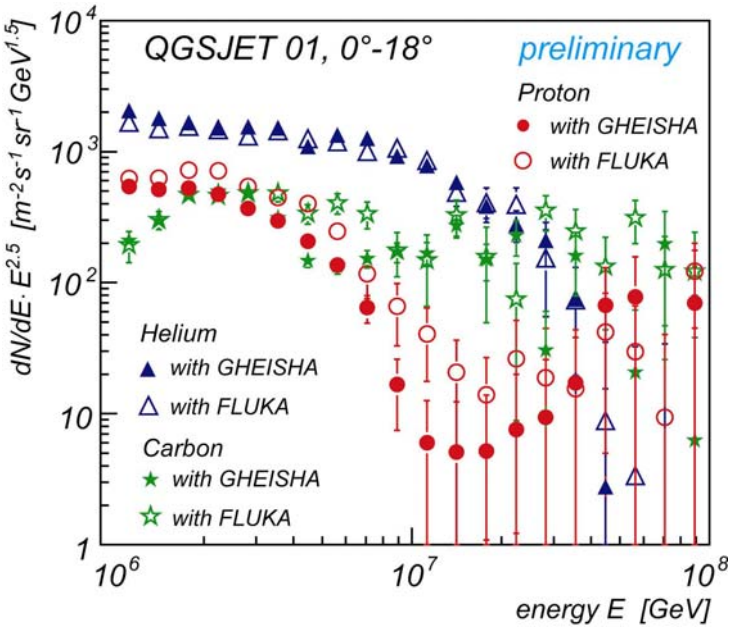
QGSJet

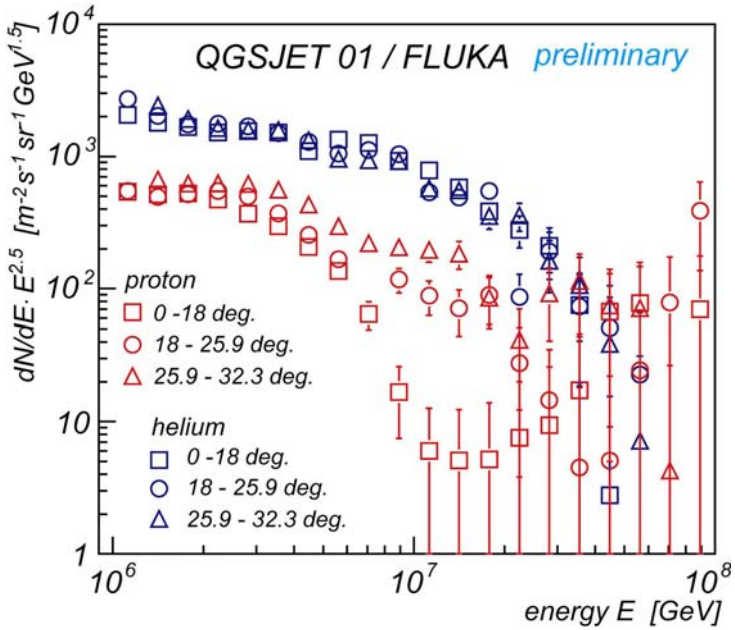


KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

KASCADE results: confirmation

- same unfolding but based on two different low energy interaction models and different zenith angle ranges:
- GHEISHA 2002 and FLUKA (both with QGSJET01)
- 0-18°, 18-25.9°, 25.9-32.3° (all with QGSJET01/FLUKA)

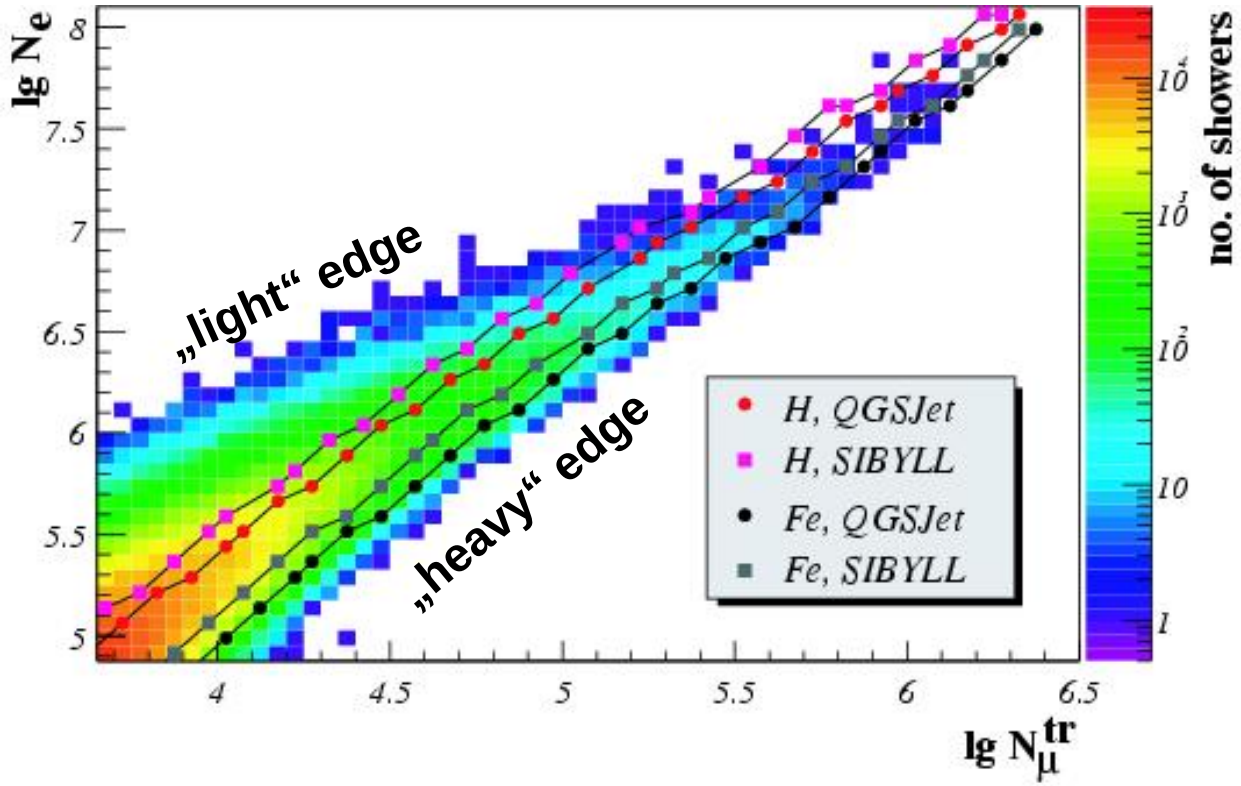




- Less dependence for unfolding based on different low energy hadronic interaction models
- Weak dependence on zenith angular binning (not significant)

H.Ulrich, XIV ISVHECRI, Weihai, China 2006

KASCADE result: sensitivity to hadronic interaction models



Main results keep stable independent of method or model:

-) knee in data structure

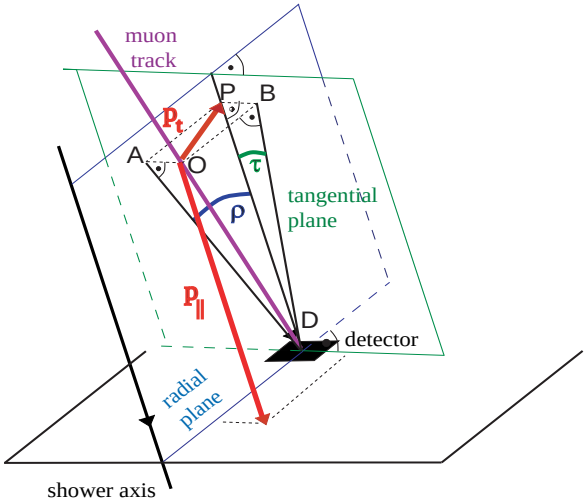
-) knee caused by light primaries

-) positions of knee vary with primary elemental group

-) no (interaction) model can describe the data consistently

KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

KASCADE analysis: muon production height

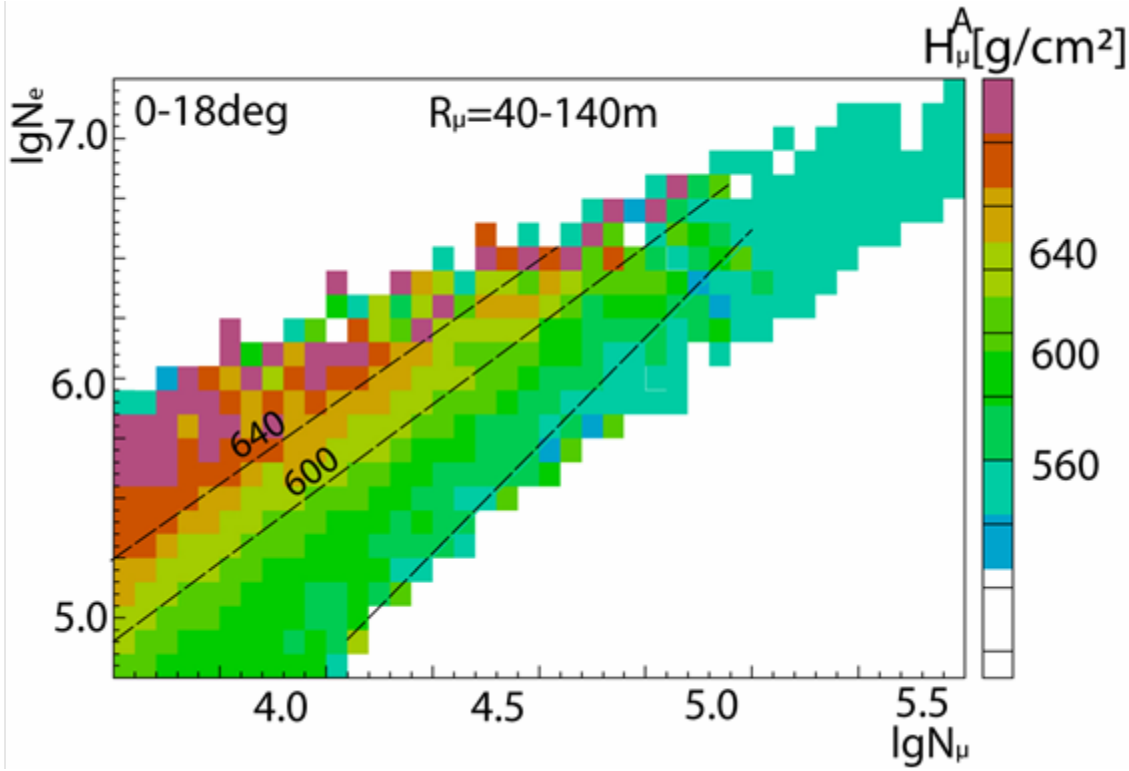


good angular resolution allows to determine the relative angles between muons and shower axis

triangulation

muon production height

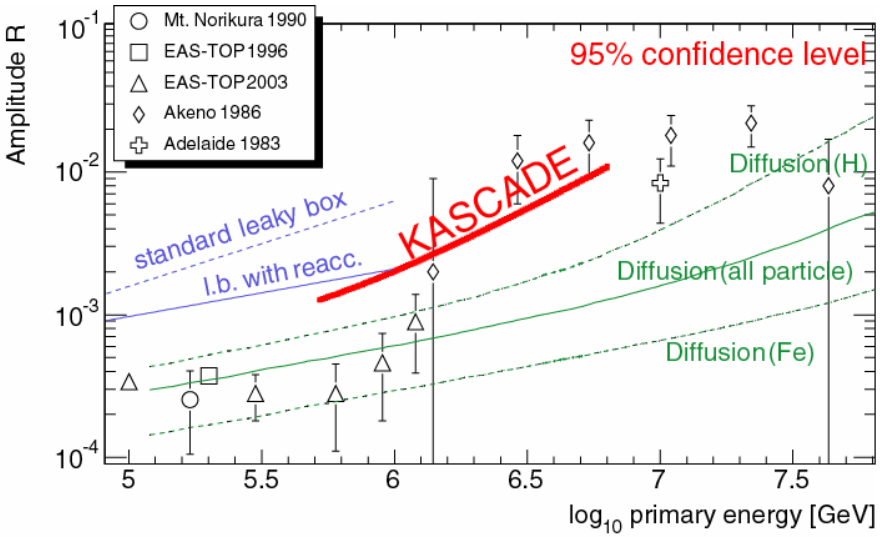
Sensitivity to composition & models !

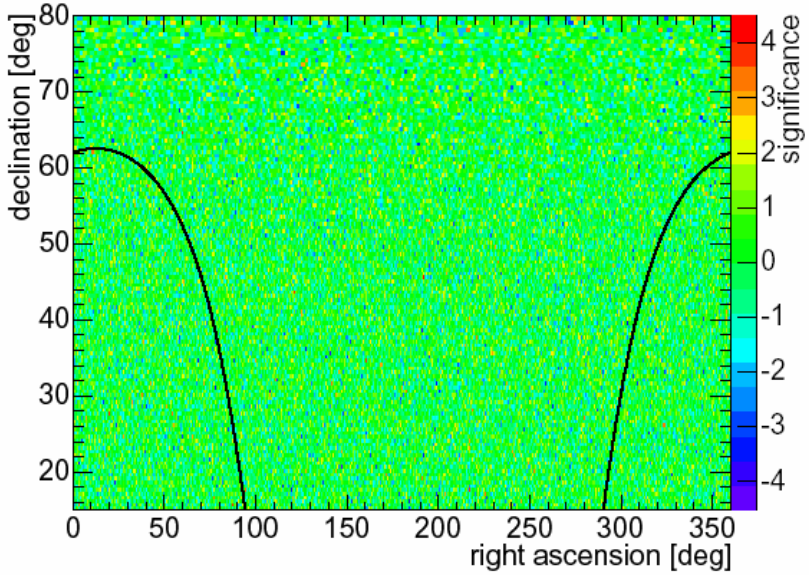


Paul Doll et al. – KASCADE-Grande coll., ICRC (2007)

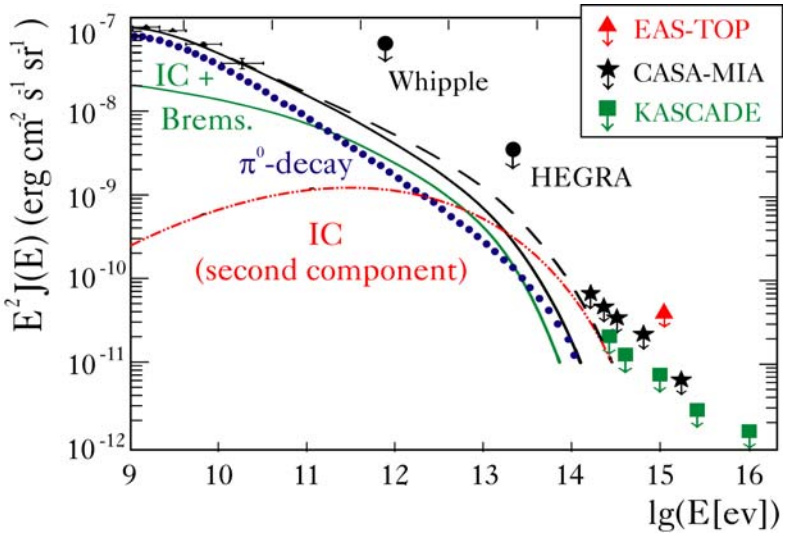
KASCADE result: analyses of anisotropies

large scale, point sources, photon limit



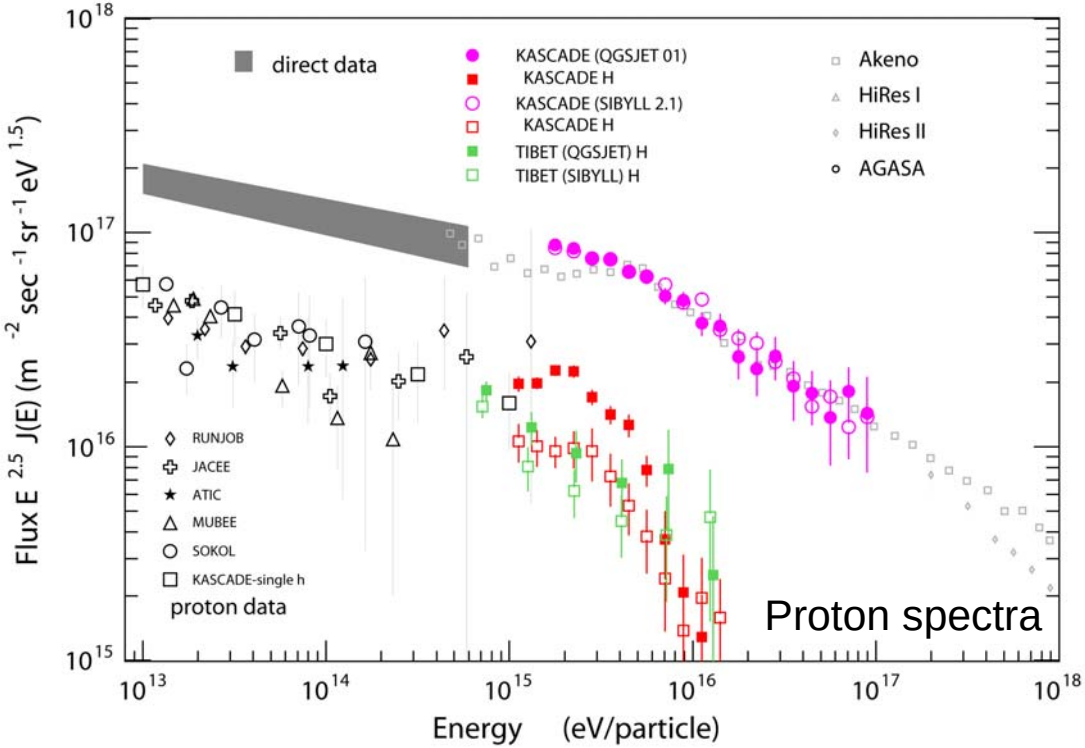


-no large scale anisotropy observed
-no positive signal from point sources
-no positive gamma signal observed
best limits for the diffuse flux



KASCADE collaboration
Astrophysical Journal 604 (2004) 687
Astrophysical Journal 608 (2004) 865
paper in preparation, F.Feßler, ICRC 2003

Summary KASCADE Results (first knee):



-) Analysis: Correlation studies are required (➔ multiparameter measurements needed)

(Analyzing mean values of data and simulations appears inadequate)

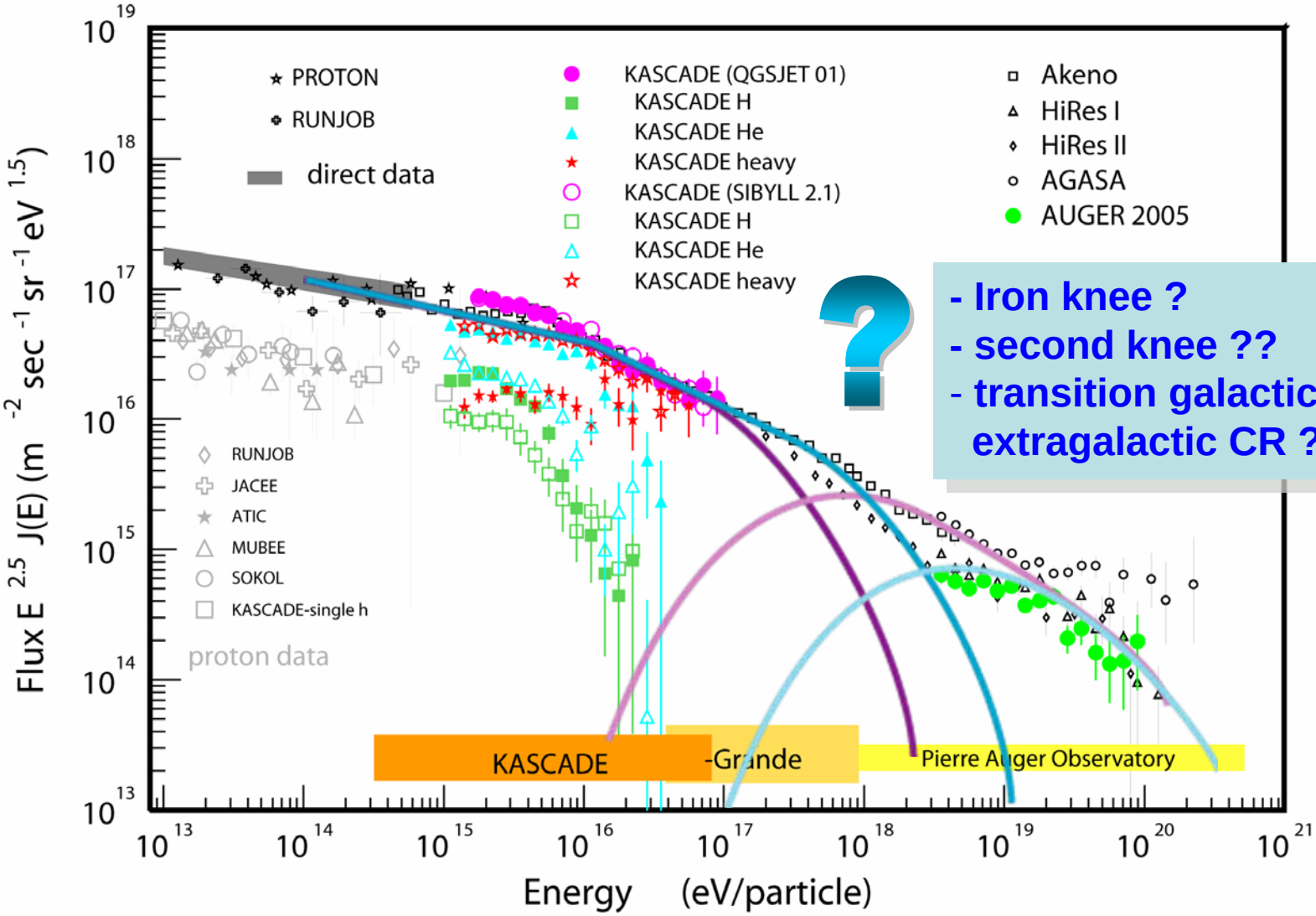
-) Knee is due to decrease in flux in light primaries! (model independent; most experiments)

-) How precise are the models ? (no new physics needed, compare proton spectrum)

-) Distinguishing between astrophysical models (Investigation of Anisotropy for different primaries)

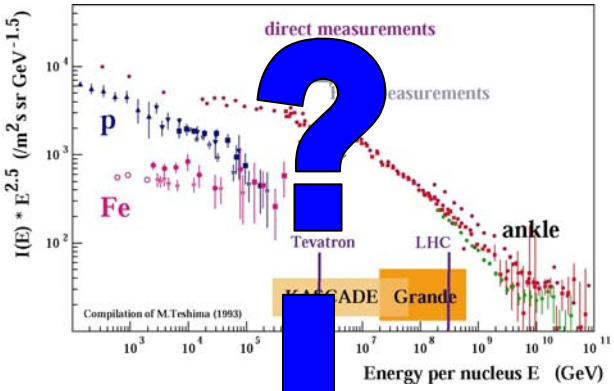
-) Knee position dependence: $\propto$ Z or $\propto$ A ?

Motivation for measurements 100 – 1000 PeV



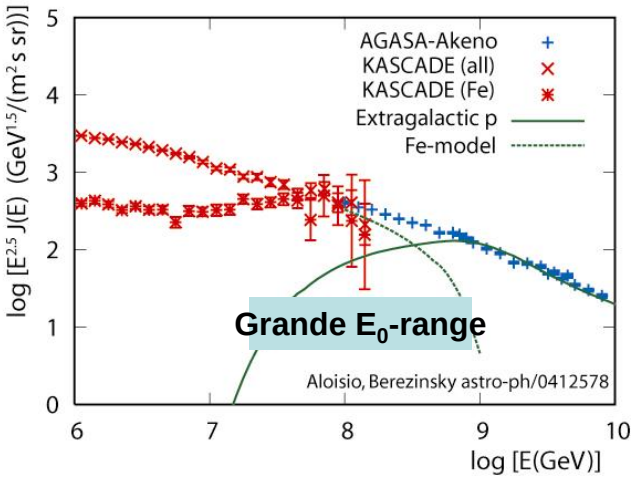
- Iron knee ?
- second knee ??
- transition galactic-extragalactic CR ??

Motivation for KASCADE-Grande



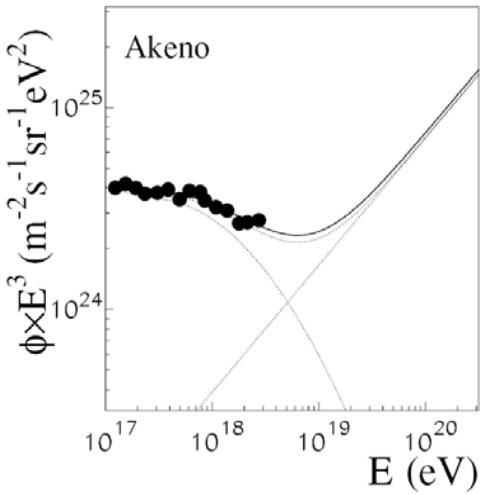
various theories on energy range 10^{17}-10^{19}eV:

e.g. Berezinsky et al
Nucl.Phys.B(Proc.Suppl.)151(2006)497



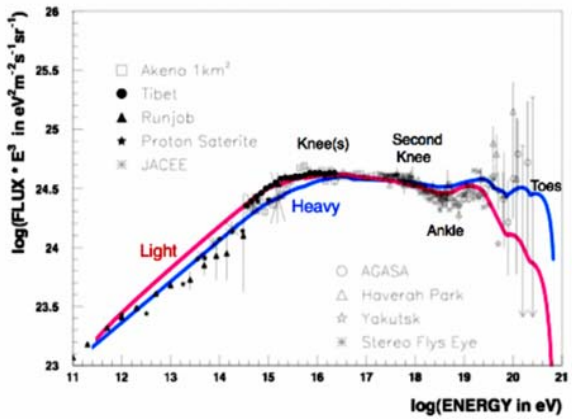
Fe-knee ~10^{17} eV
gal-eg transition ~$10^{17.7}$eV
Ankle = eg characteristics

e.g. Wibig et al
J.Phys.G 31(2005)255



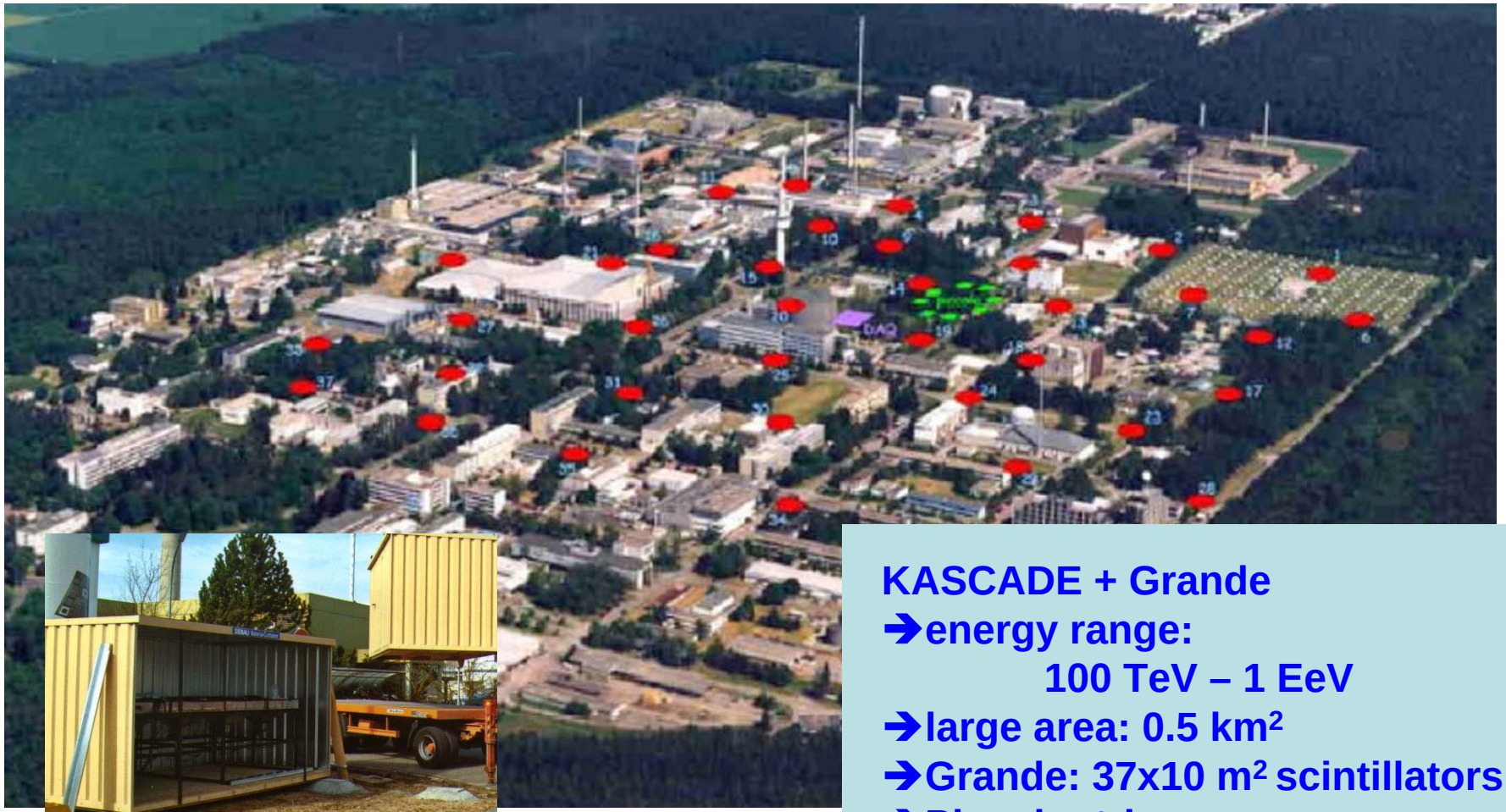
Fe-knee ~10^{18} eV
gal-eg transition ~10^{19}eV
= ankle

e.g. de Rujula
Nucl.Phys.B(Proc.Suppl.)151(2006)23



Cannonball modell:
Fe-knee ~ 2 10^{17} eV
All is galactic
(knee= elastic scattering)

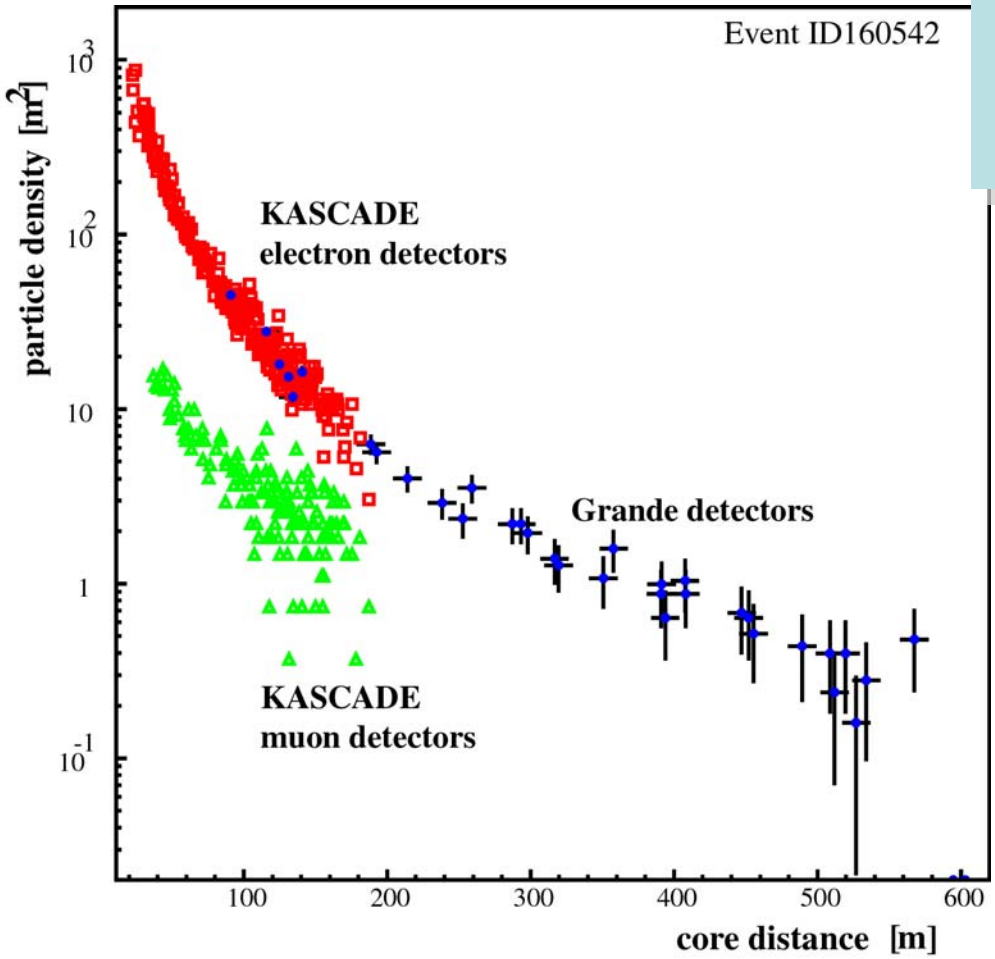
KASCADE-Grande : multi-parameter measurements

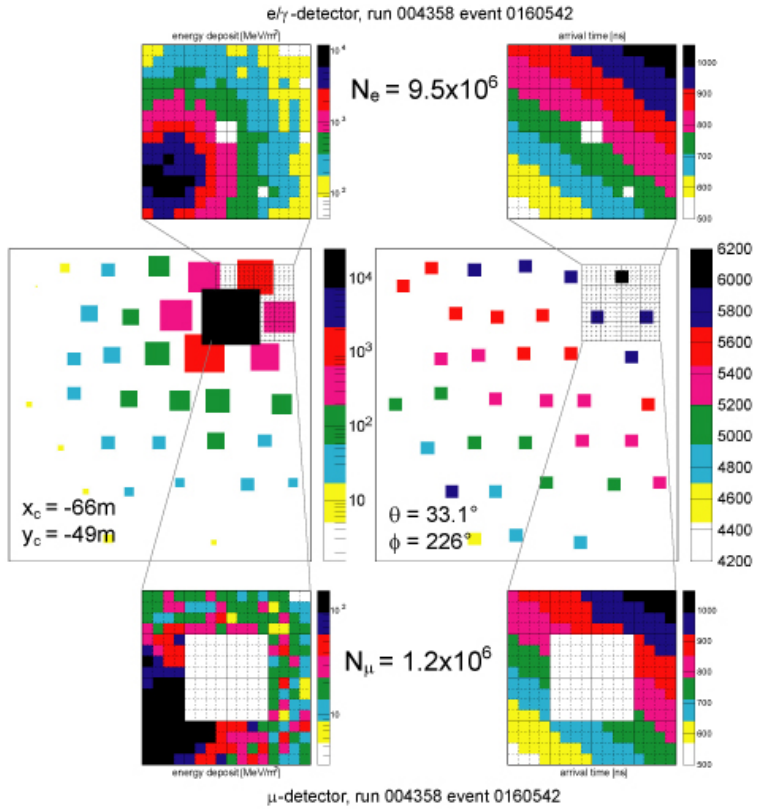


KASCADE + Grande
➔energy range:
100 TeV – 1 EeV
➔large area: 0.5 km²
➔Grande: 37x10 m² scintillators
➔Piccolo: trigger array

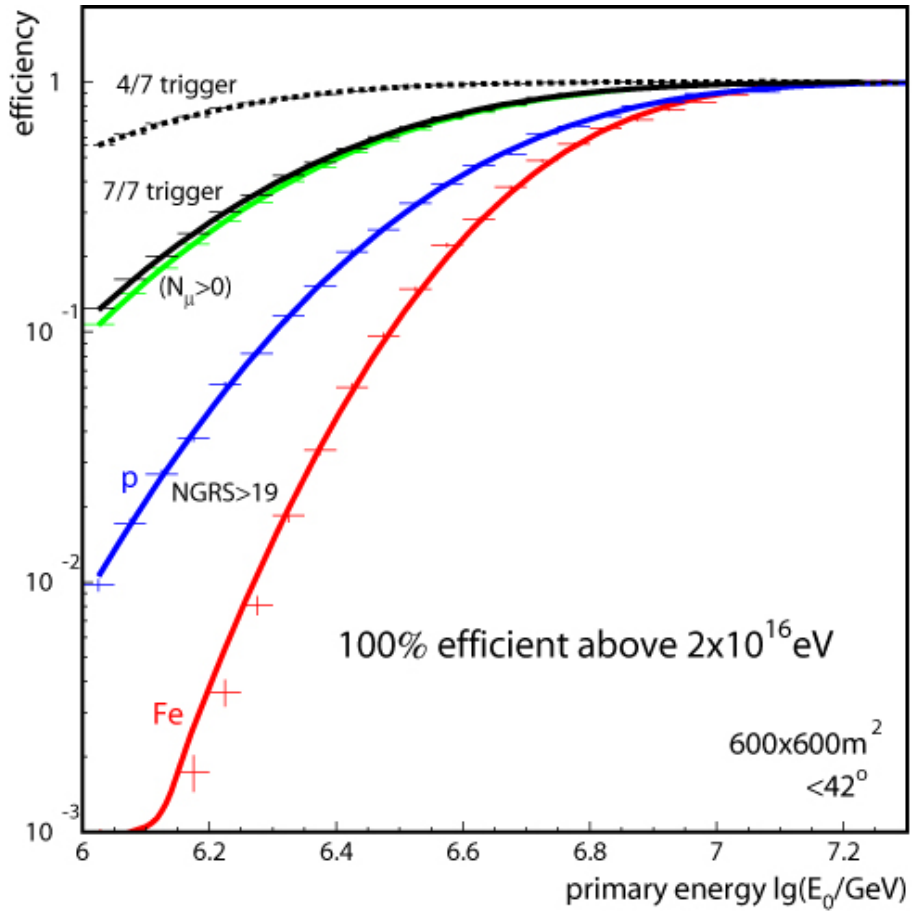
KASCADE-Grande : Single event measurement

lateral distribution of a single event measured by KASCADE-Grande: $E_0 \approx 2 \cdot 10^{17}$eV, $\Theta = 33^o$

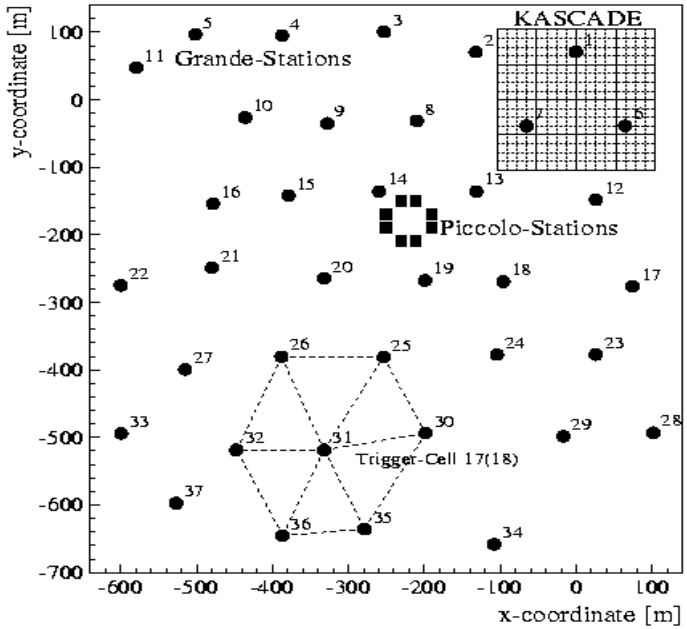




KASCADE-Grande : Efficiency



- **Common events (all detector components) measured since December 2003**
- **Trigger: 7of 7 stations at one of 18 hexagons**



KASCADE-Grande : Reconstruction

1) core position and angle-of-incidence
   from Grande array data

➔

2a) shower size (charged particles)
   from Grande array data

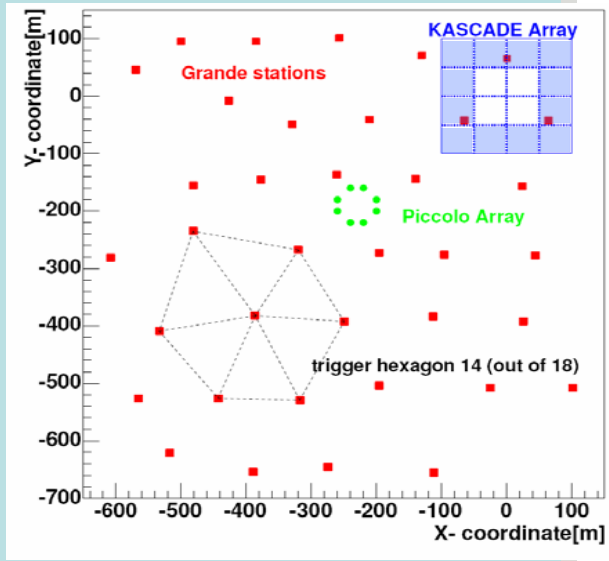
2b) muon number
   from KASCADE muon detectors

➔

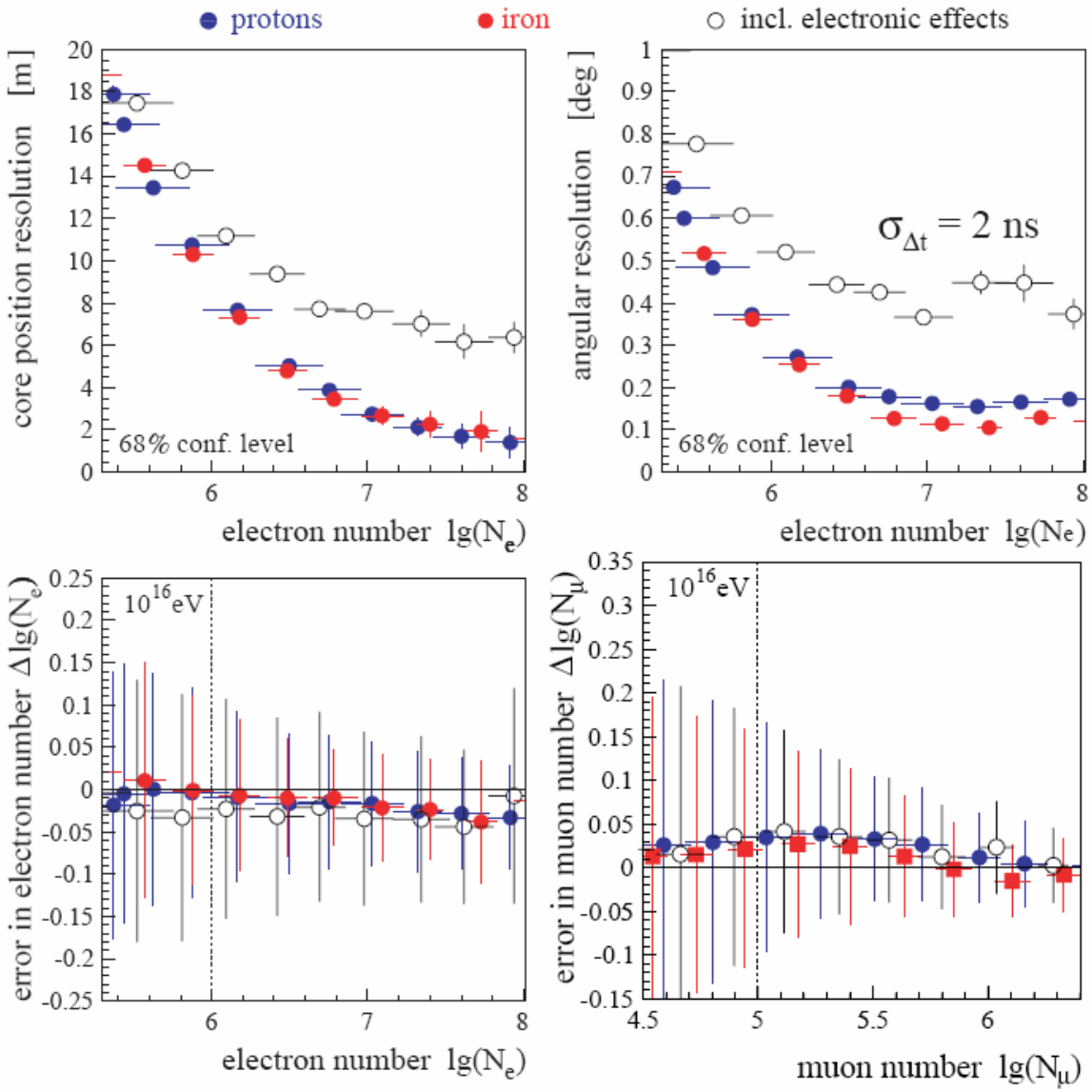
3) electron number
   from Grande by subtraction of muon content

➔

4) two dimensional size spectrum
   for the analysis



KASCADE-Grande : Reconstruction

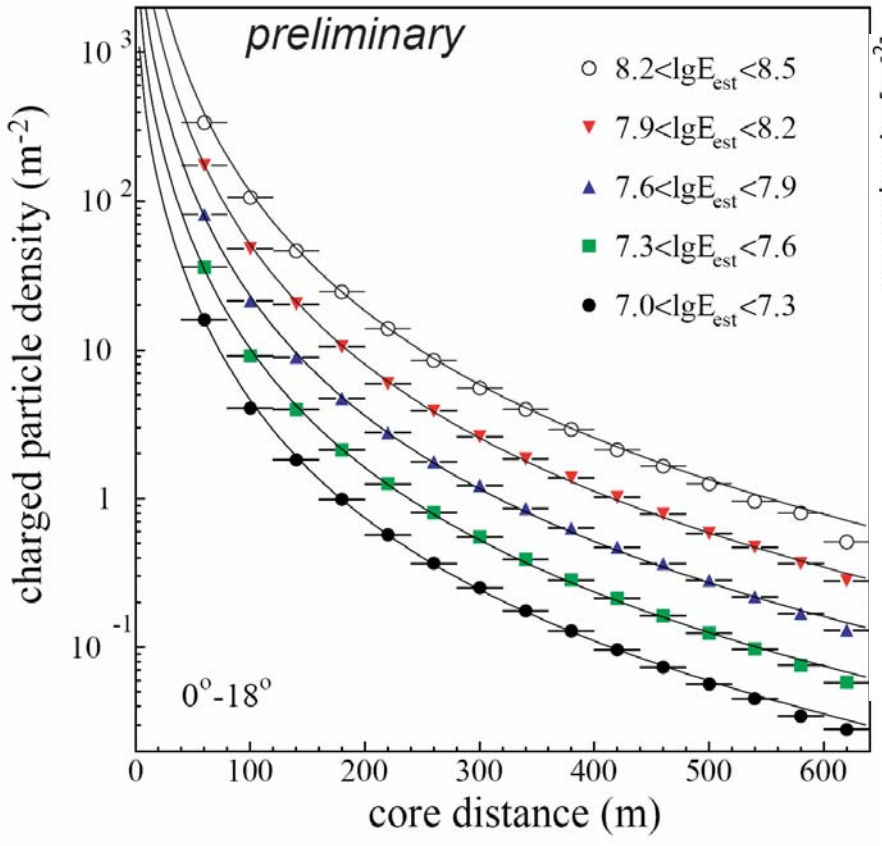


Monte-Carlo studies:
➔
Sufficient reconstruction accuracies for
-core
-direction
-shower size, and
-muon number

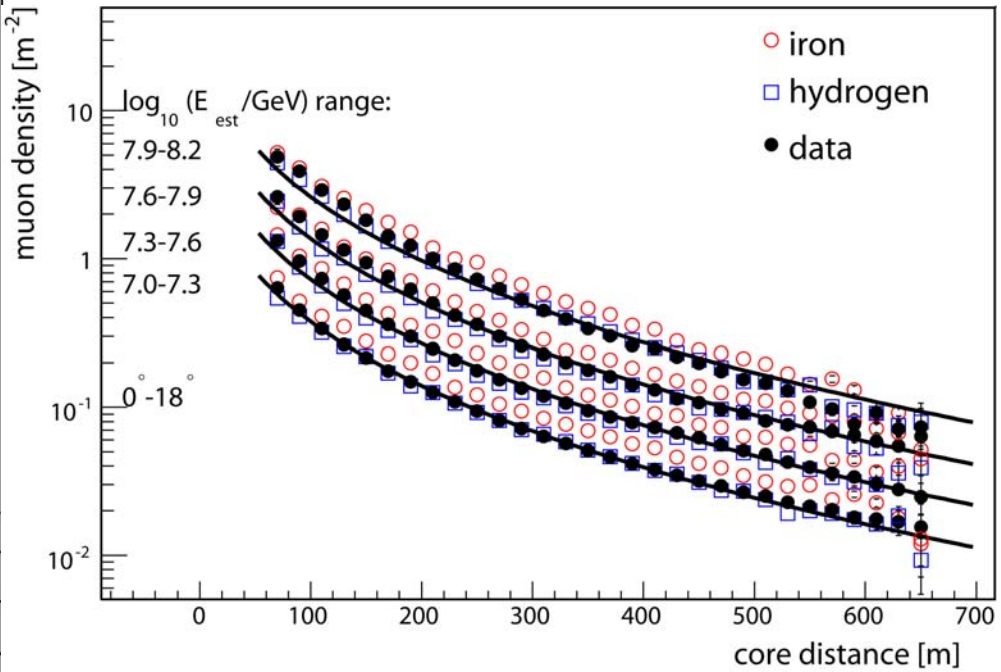
(E_μ > 230MeV)

KASCADE-Grande : lateral distributions

charged particle lateral distribution

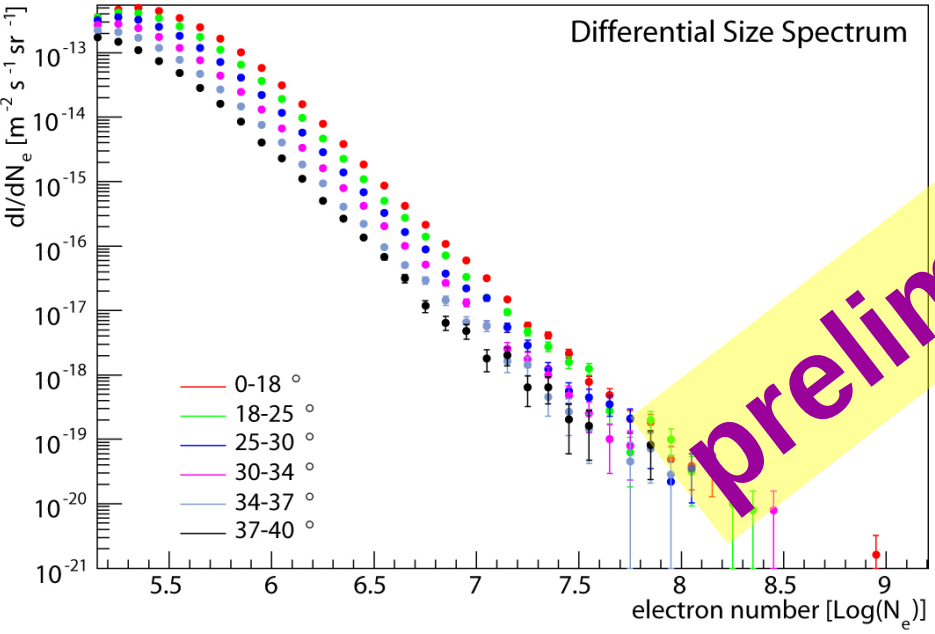


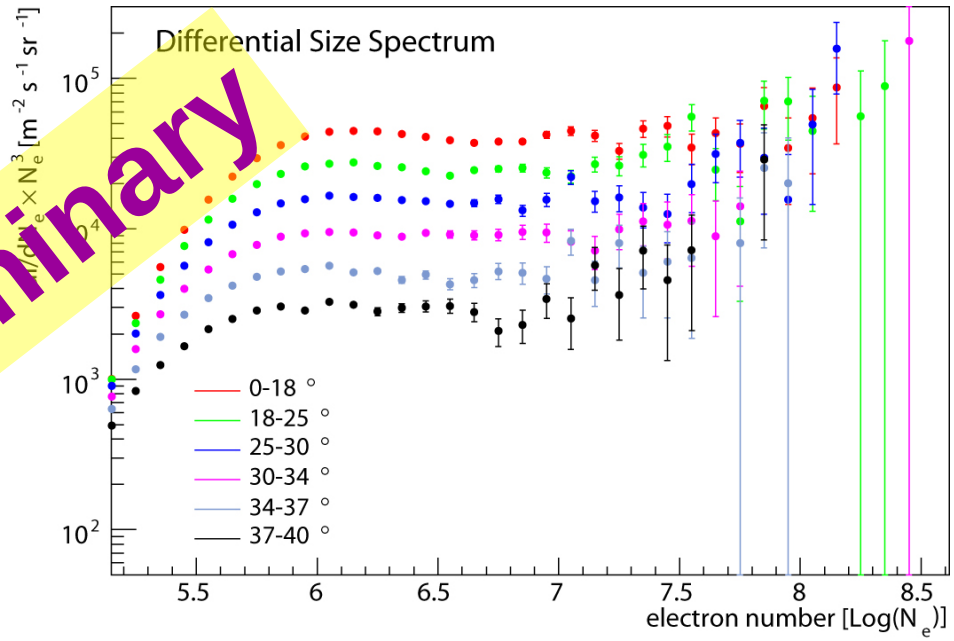
muon lateral distribution



1-year data, core inside Grande array, $E_{est} = f(N_\mu, N_e, \Theta)$ [Monte-Carlo based]

KASCADE-Grande : first analyses
electron size spectra





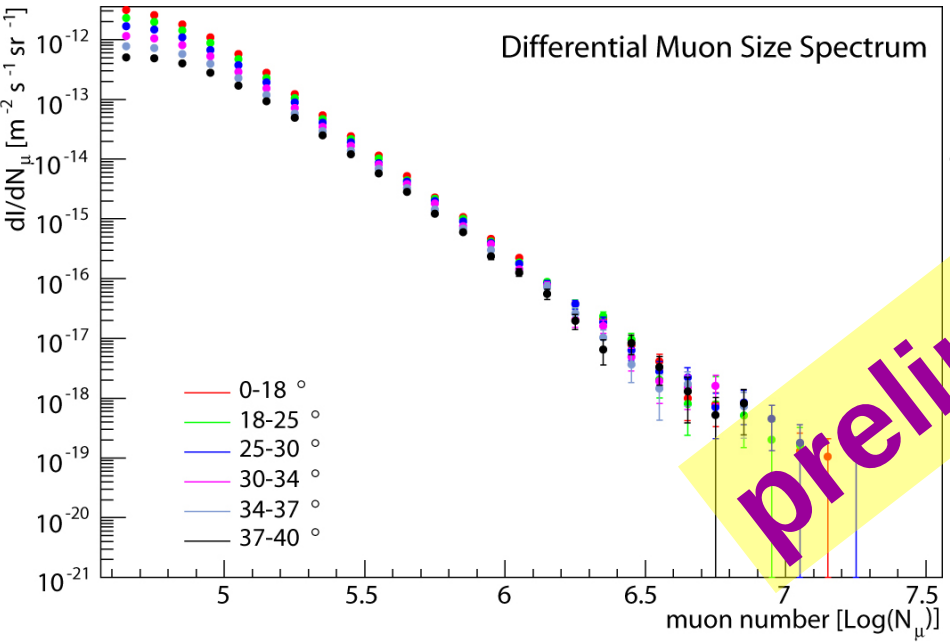
preliminary

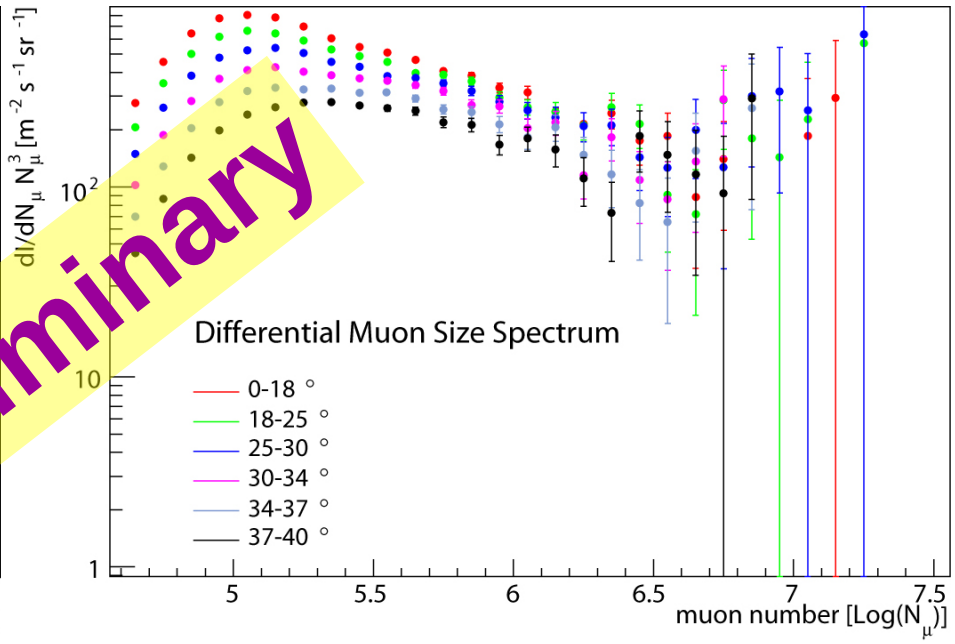
-stable data taking since 2004
-performance of array looks promising
-reconstruction gives reasonable spectra
-careful checks of systematic effects in work

Here and following plots:
2-years data

Fabiana Cossavella et al. – KASCADE-Grande coll., ICRC (2007)

KASCADE-Grande : first analyses
muon size spectra



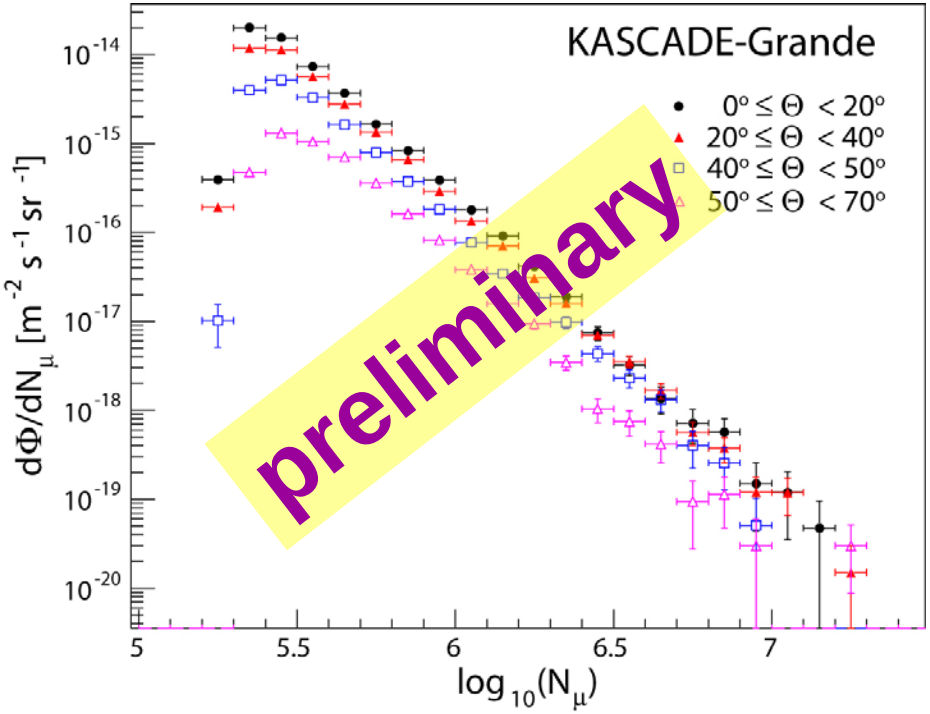


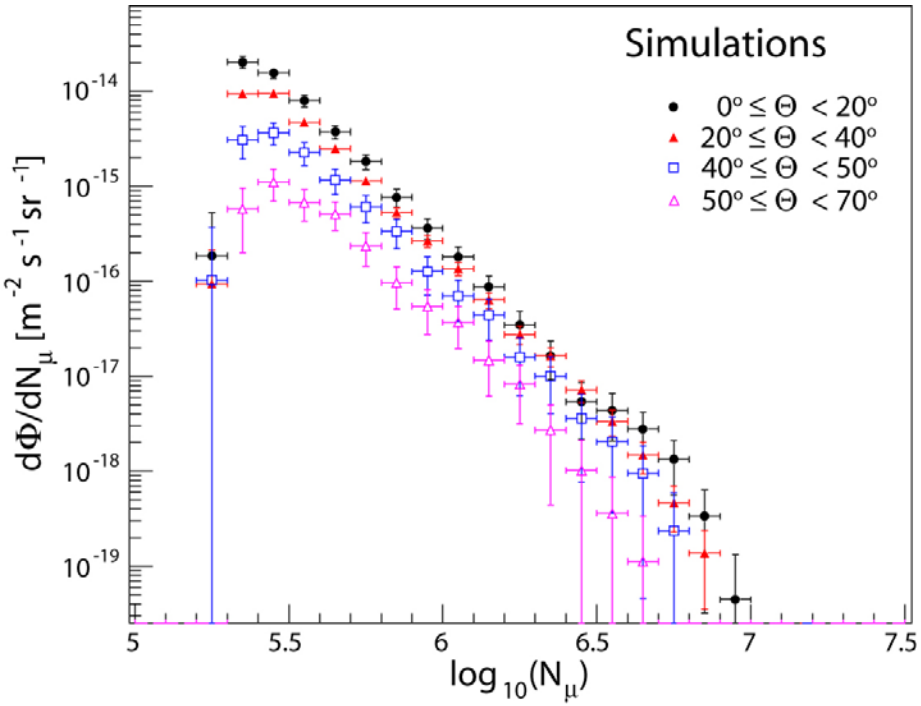
preliminary

-stable data taking since 2004
-performance of array looks promising
-reconstruction gives reasonable spectra
-careful checks of systematic effects in work

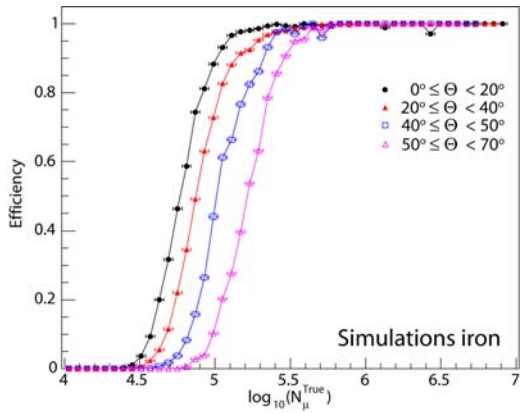
Fabiana Cossavella et al. – KASCADE-Grande coll., ICRC (2007)

KASCADE-Grande : first analyses
muon reconstruction at inclined showers



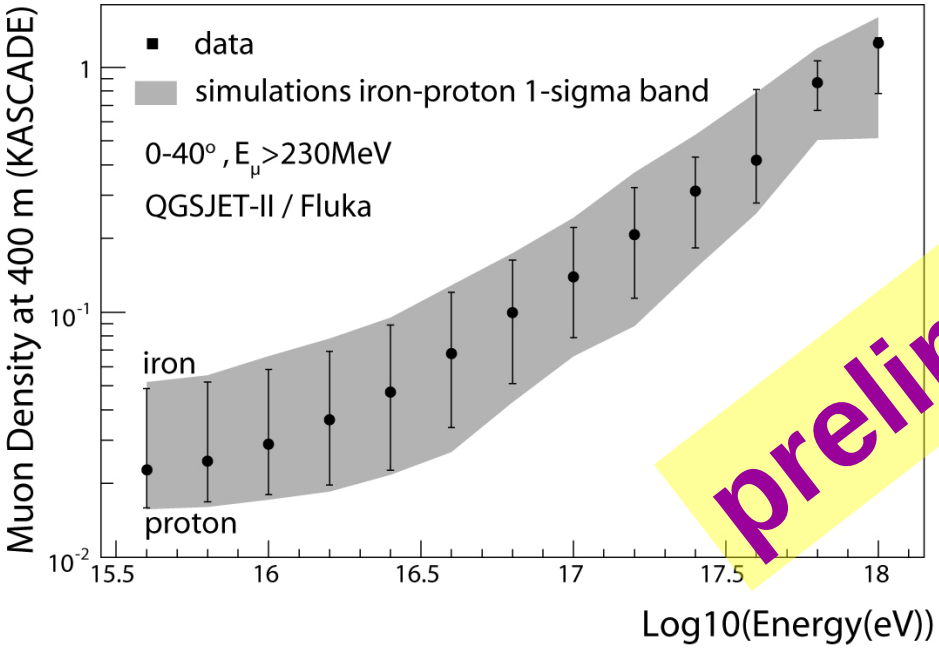


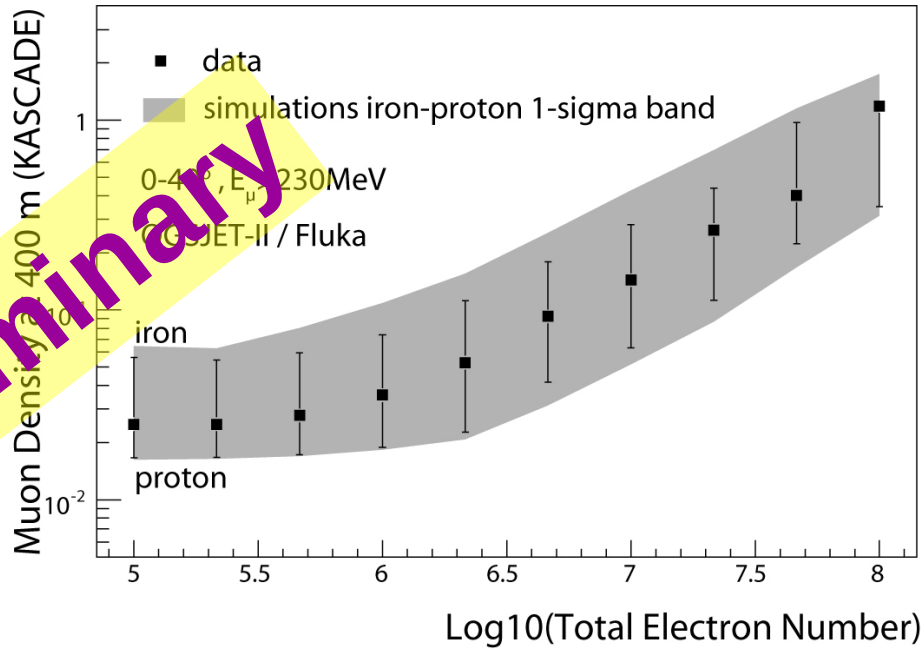
-muon number reconstruction possible up to 70°
-investigation of attenuation of muon component
➔model tests
➔Increasing of KASCADE-Grande statistics



Juan Carlos Arteaga et al. – KASCADE-Grande coll., ICRC (2007)

KASCADE-Grande : first analyses
muon density investigations



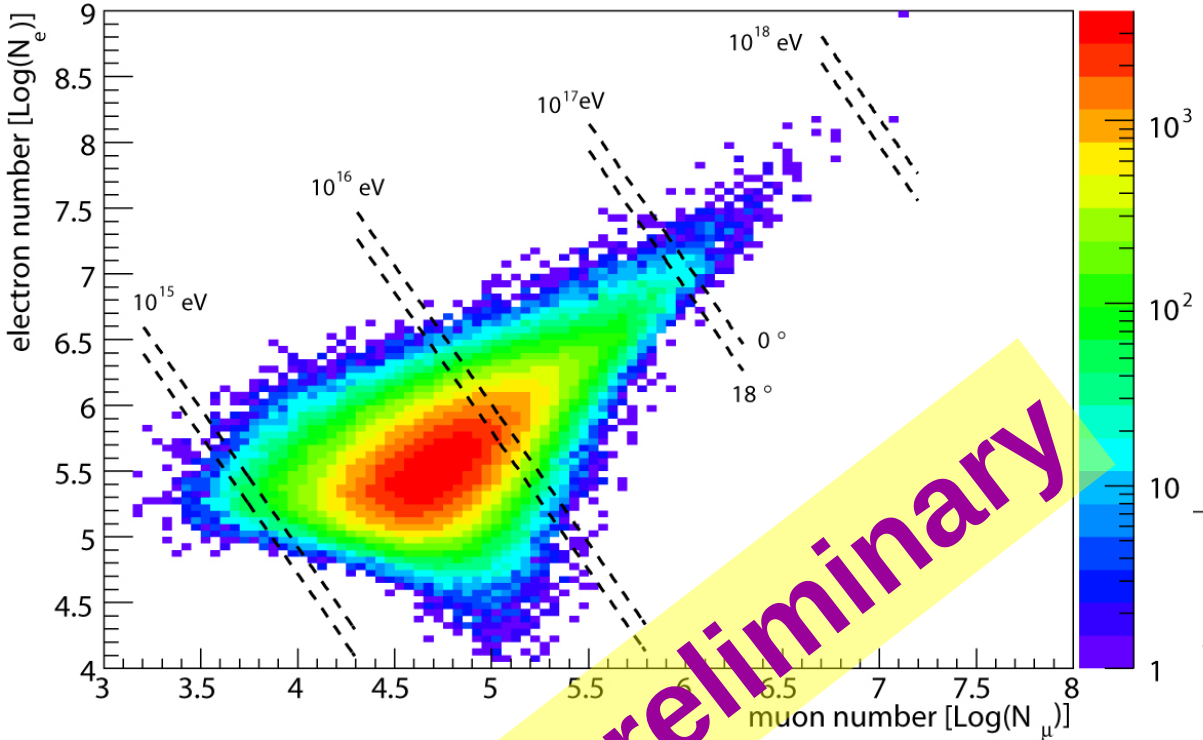


preliminary

-muon density reconstruction possible for different distances
-muon density reconstruction possible by direct measurement or via LDF
➔composition sensitivity
➔model tests

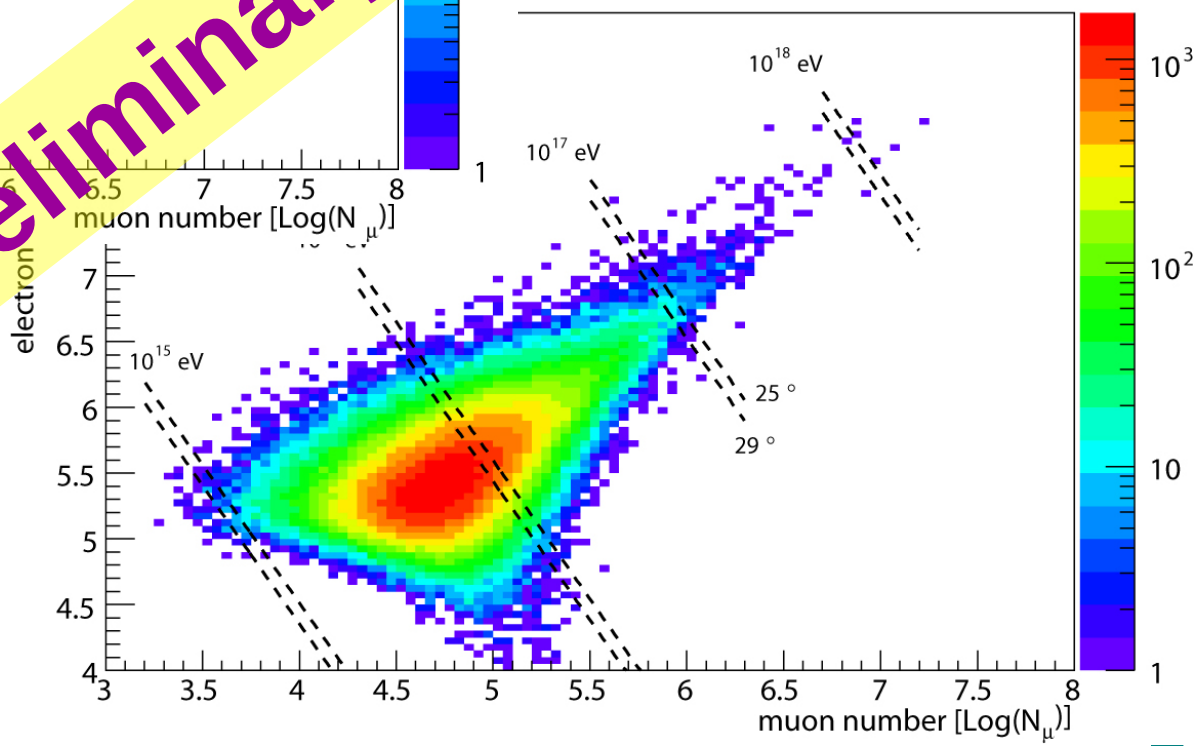
Jurriaan van Buren, Vitor de Souza et al. – KASCADE-Grande coll., ICRC (2007)

KASCADE-Grande : first analyses



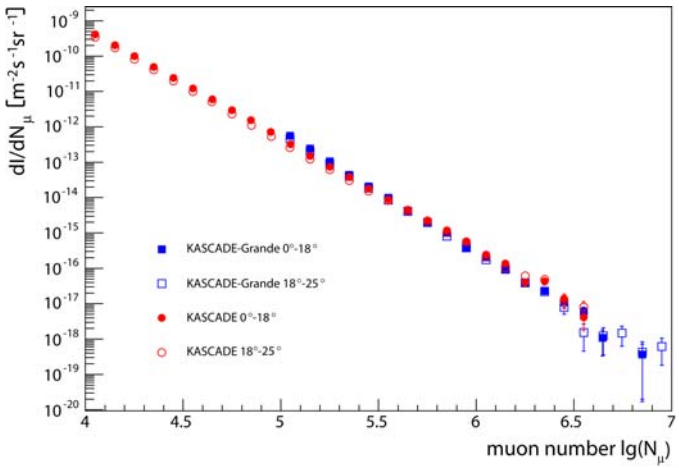
preliminary

Unfolding of 2-dimensional shower size spectrum possible
➔ energy & composition
➔ still improvements in systematics needed



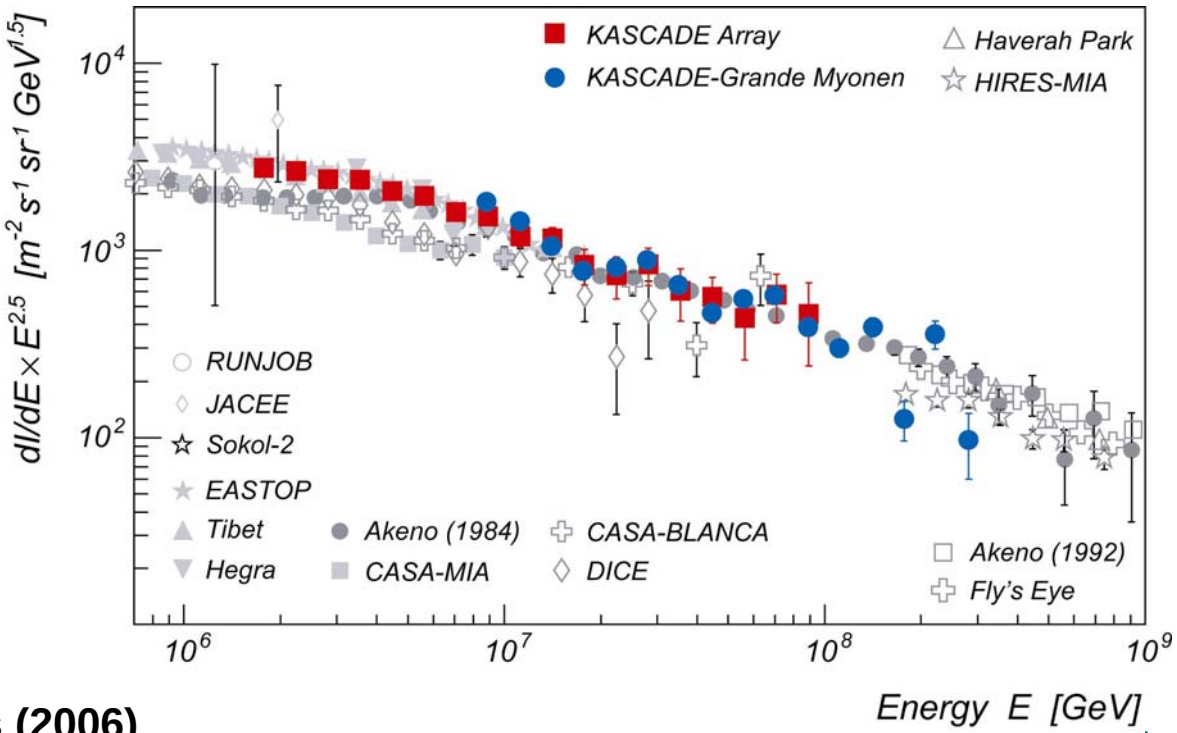
Fabiana Cossavella et al. – KASCADE-Grande coll., ICRC (2007)

Myon number estimate and 1-dim unfolding



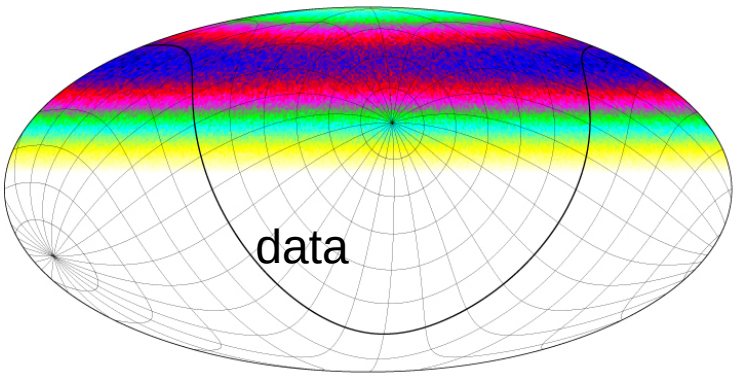
First energy spectrum (by muon number only)

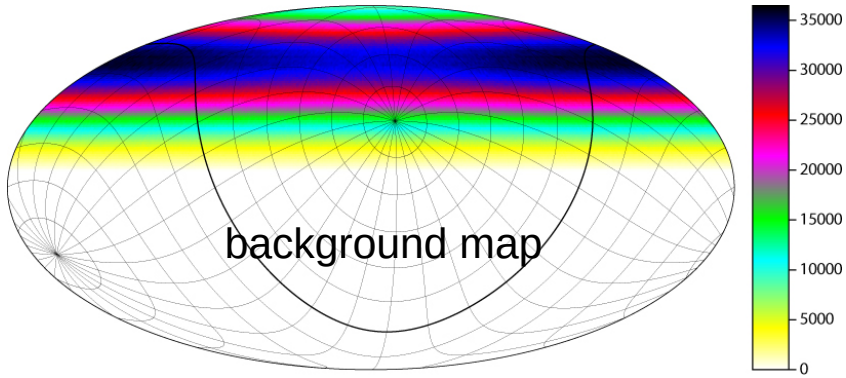
1dim-unfolding

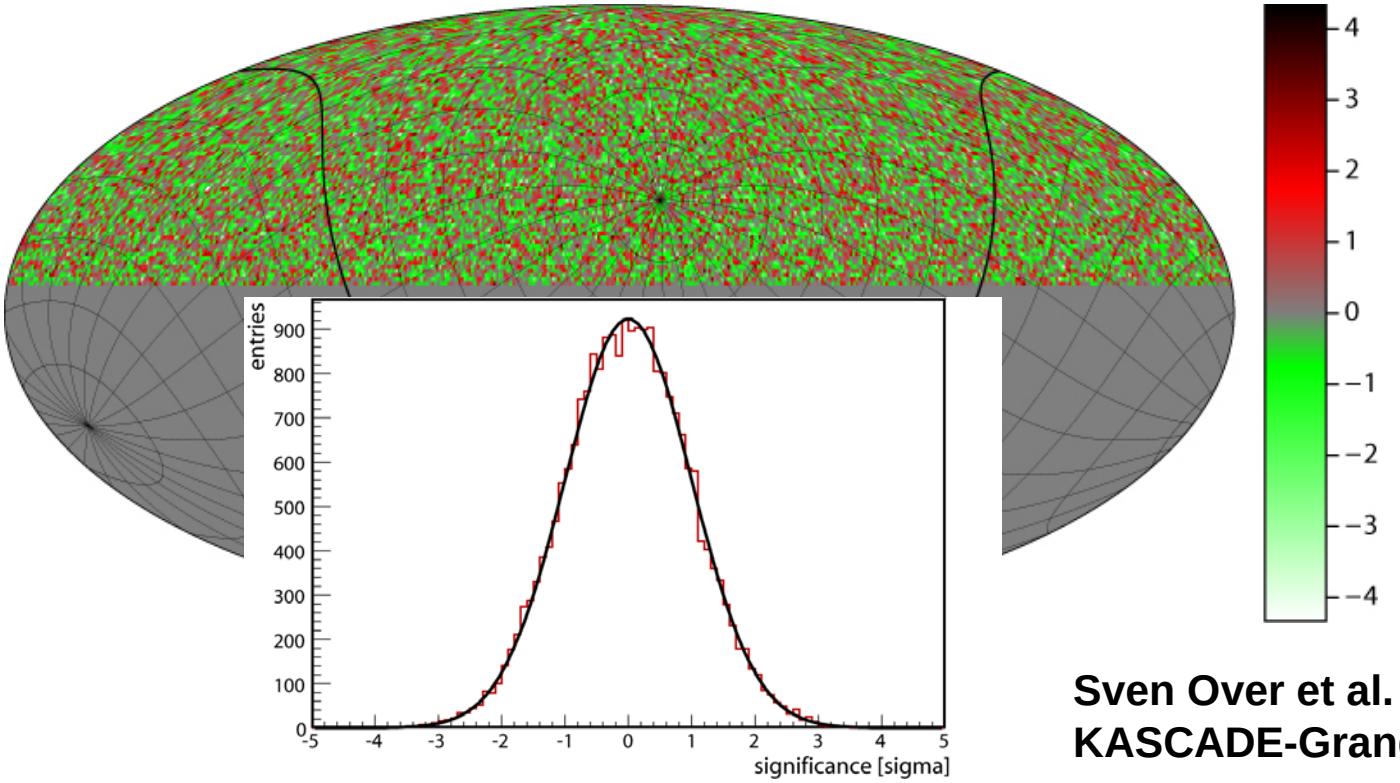


Jurriaan van Buren, PhD thesis (2006)

KASCADE-Grande: first analyses: point sources



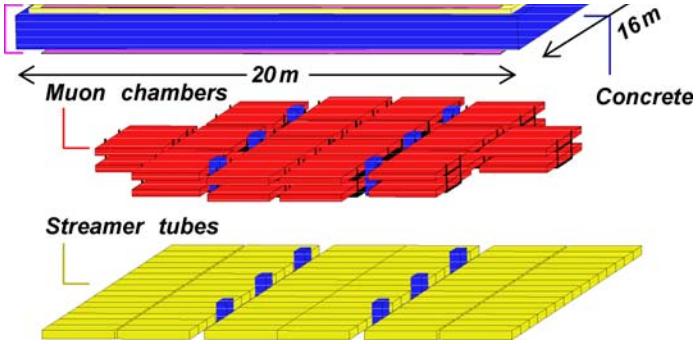


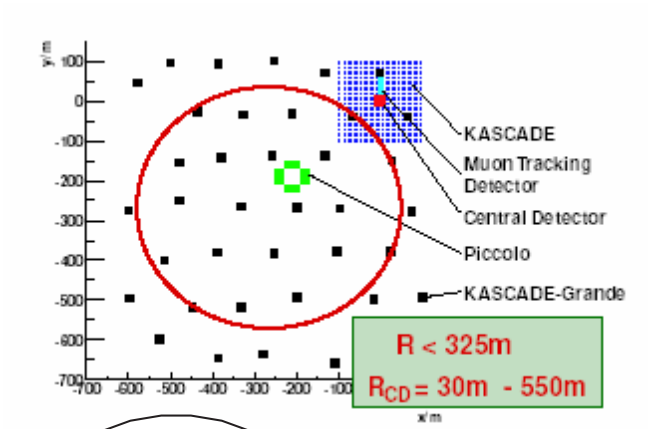


Until now no hint for point source (very preliminary)

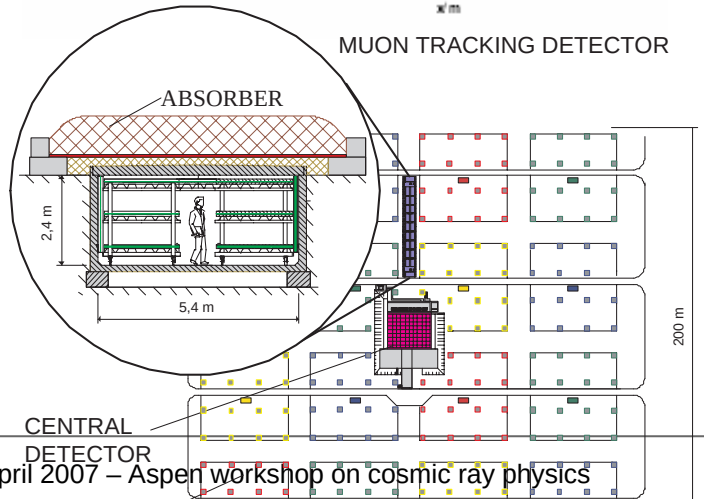
Sven Over et al. – KASCADE-Grande coll., ICRC (2007)

HE Muon Measurements at KASCADE-Grande





MUON TRACKING DETECTOR



- **Central Detector muon facility**

  $E_\mu^{thresh} = 2400$ MeV

➔ **Muon Density measurements** $\rho_\mu^{2.4GeV}$
➔ **Lateral distributions**
➔ **Model tests (muon energy spectrum)**

$$R_\rho^{2.4/0.23} = \rho_\mu^{2.4GeV} / \rho_\mu^{0.23GeV}$$

- **Muon Tracking Detector**

  $E_\mu^{thresh} = 800$ MeV

➔ **Measurement of radial and tangential angles** ρ_μ, τ_μ
➔ **Muon production height**
➔ **Lateral distributions**
➔ **Model tests** (pseudorapidity)

$$\eta_\mu = -\ln(\zeta/2) \quad \zeta = p_t/p_{||} = \sqrt{(\rho^2+\tau^2)}$$

KASCADE-Grande : Summary

- knee physics needs (still) air-shower investigations
- sophisticated experiments and analyses needed
- knee is caused by light primary elements
- cosmic rays are isotropic around the knee
- consistency of data is not given if
  compared to Monte Carlo predictions
- interaction models have to be further improved
- knee physics do not need ´new´ particle physics
- KASCADE-Grande will cover whole „knee“ range
  ➔ promising status and first data !
- radio detection as new technique (LOPES)?

Still a Vital Field of Research

KASCADE-Grande Collaboration

Institut für Kernphysik
Forschungszentrum and University of Karlsruhe

W.D. Apel, J.C. Arteaga, F. Badea, K. Bekk, J. Blümer, H. Bozdog, F. Cossavella, K. Daumiller, V. de Souza, P. Doll, R. Engel, J. Engler, M. Finger, H.J. Gils, A. Haungs, D. Heck, D. Hildebrand, J.R. Hörandel, T. Huege, P.G. Isar, H.O. Klages, H.-J. Mathes, H.J. Mayer, C. Meurer, J. Milke, A. Morales, S. Nehls, J. Oehlschläger, S. Ostapchenko, T. Pierog, S. Plewnia, H. Rebel, M. Roth, H. Schieler, M. Stümpert, H. Ulrich, J. van Buren, A. Weindl, J. Wochele

Universität Siegen
Experimentelle Teilchenphysik
T. Bäcker, M. Brüggemann, P. Buchholz, C. Grupen, D.Kickelbick, Y. Kolotaev, S. Over, W. Walkowiak

Universität Wuppertal
Fachbereich Physik
D. Fuhrmann, R. Glasstetter, K-H. Kampert

IFSI, INAF
and University of Torino
M. Bertaina, A. Chiavassa, F. Di Pierro, P. Ghia, C. Morello, G. Navarra, G. Trinchero

Soltan Institute for Nuclear Studies, Lodz
P. Luczak, A. Risse, J. Zabierowski

Institute of Physics and Nuclear Engeneering, Bucharest
I.M. Brancus, B. Mitrica, M. Petcu, O.Sima, G.Toma

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