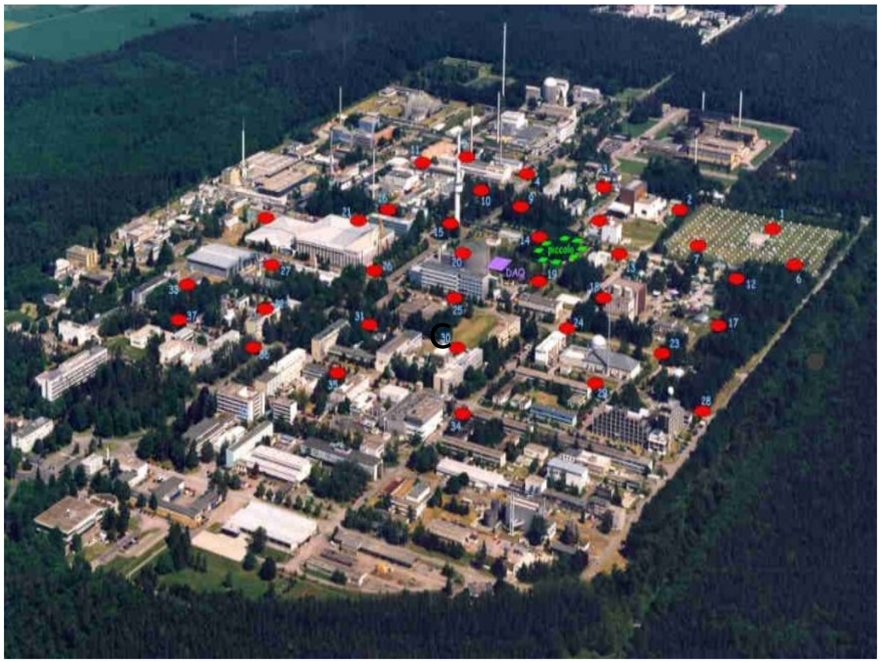
The KASCADE-Grande Experiment



KASCADE-Grande

Vitor de Souza

University of Karlsruhe
desouza@ik.fzk.de

Universidade de São Paulo
vitor@ifsc.usp.br

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, 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

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, D. Borla Tridon, A. Chiavassa, F. Di Pierro, P. Ghia, C. Morello, G. Navarra, G. Trinchero

Soltan Institute for Nuclear Studies, Lodz

P. Luczak, 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/

LOPES Collaboration

LOPES – Radio Emission from Cosmic Ray Air Showers

ASTRON, Dwingeloo, The Netherlands

L. Bähren, H. Butcher, G. de Bruyn, C.M. de Vos, G.W. Kant, Y. Koopman, H.J. Pepping, G. Schoonderbeek, W. van Capellen, S. Wijnholds

Dept of Astrophysics, Nijmegen, The Netherlands

S. Buitink, H. Falcke, A. Horneffer, J. Kuijpers, S. Lafebre, A. Nigl, J. Petrovic, K. Singh

Dipartimento di Fisica Generale dell'Universita, Torino, Italy

M. Bertaina, A. Chiavassa, F. di Pierro, G. Navarra

Univ Wuppertal, Germany

J. Auffenberg, R. Glasstetter, K.H. Kampert, J. Rautenberg

Universität Siegen, Germany

M. Brüggemann, P. Buchholz, C. Grupen, D. Kickelbick, Y. Kolotaev, S. Over, W. Walkowiak

Max-Planck-Institut für Radioastronomie, Bonn, Germany

P.L. Biermann, J.A. Zensus

Istituto di Fisica dello Spazio Interplanetario, Torino, Italy

P.L. Ghia, C. Morello, G.C. Trinchero

Soltan Institute for Nuclear Studies, Lodz, Poland

P. Luczak, J. Zabierowski

National Institute of Physics and Nuclear Engineering Bucharest, Romania

I.M. Brancus, B. Mitrica, M. Petcu, A. Saftiou, O. Sima, G. Toma

Institut für Kernphysik, FZK, Germany

W.D. Apel, J.C. Arteaga, A.F. Badea, K. Bekk, J. Blümer, H. Bozdog, F. Cossavella, K. Daumiller, P. Doll, R. Engel, A. Hakenjos, A. Haungs, D. Heck, T. Huege, P.G. Isar, H.J. Mathes, H.J. Mayer, C. Meurer, J. Milke, S. Nehls, R. Obenland, J. Oehlschläger, S. Ostapchenko, T. Pierog, S. Plewnia, H. Rebel, M. Roth, H. Schieler, H. Ulrich, J. van Buren, A. Weindl, J. Wochele

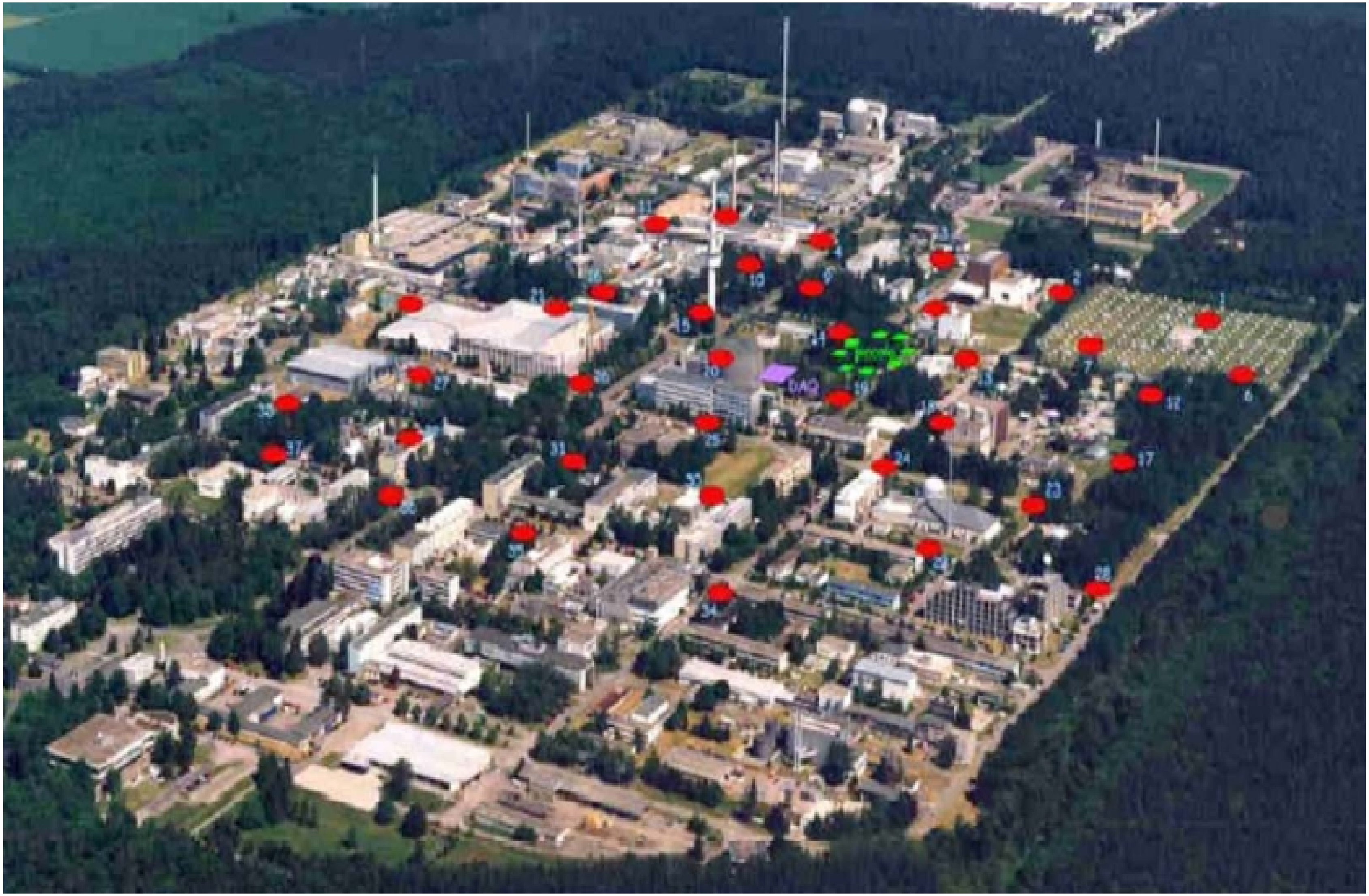
IPE, FZK, Germany

T. Asch, H. Gemmeke, O. Krömer

Univ Karlsruhe, Germany

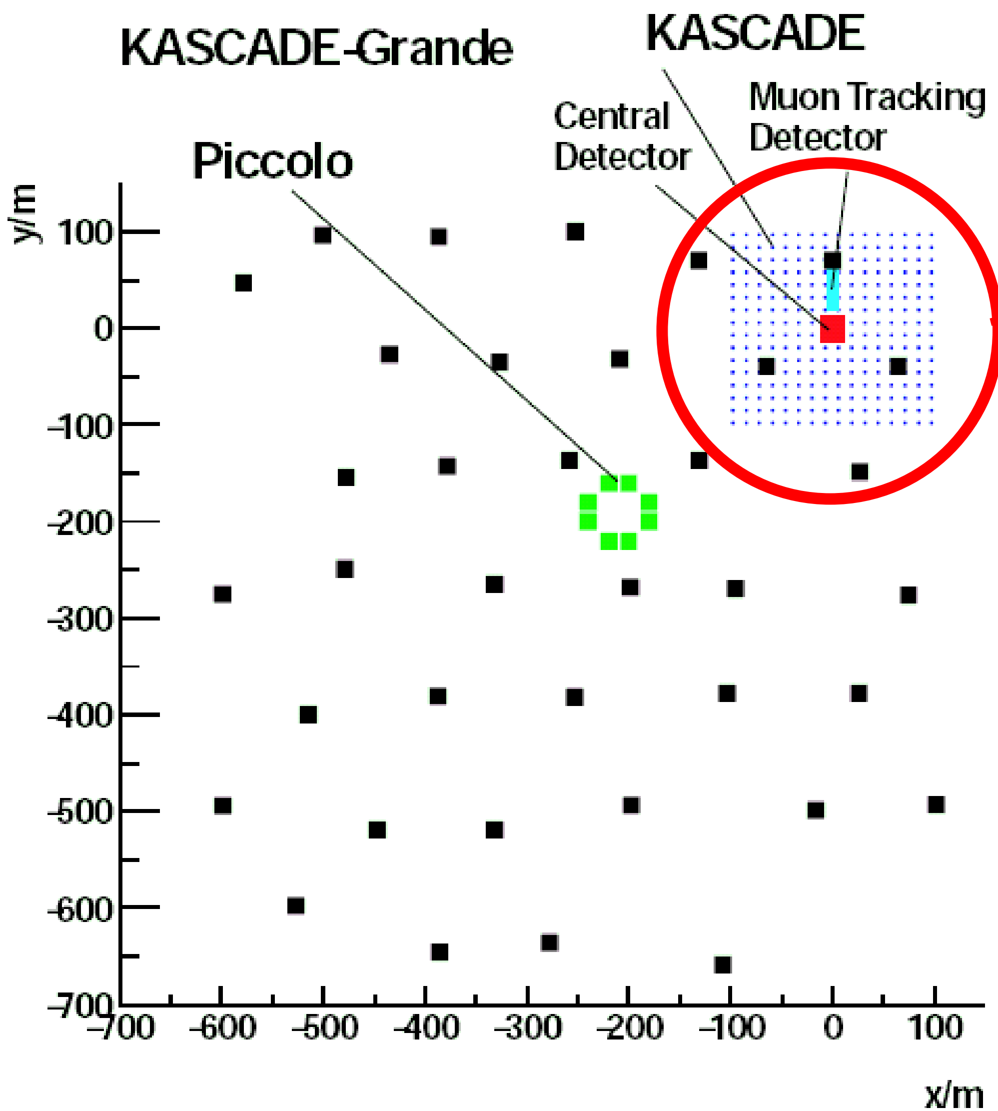
E. Bettini, V. De Souza, A. Hakenjos, J.R. Hörandel, M. Stümpert

KASCADE Cosmic Ray Facility

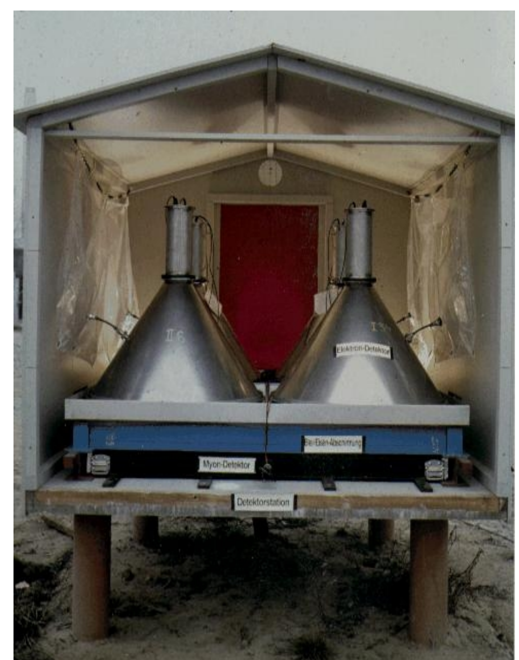


Forschungszentrum Karlsruhe

The Detectors: KASCADE



KASCADE

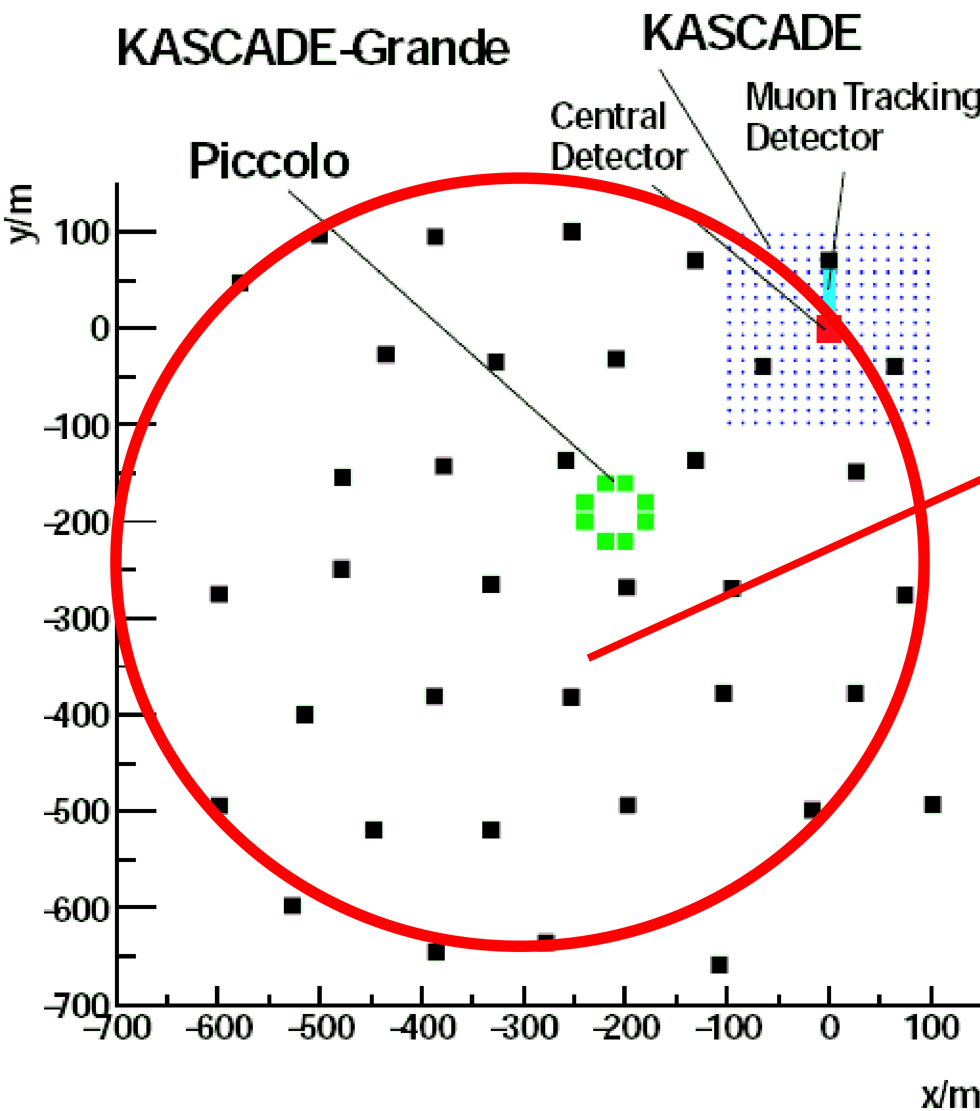


Scintillators

Charged Particles

Muon

The Detectors: KASCADE-Grande



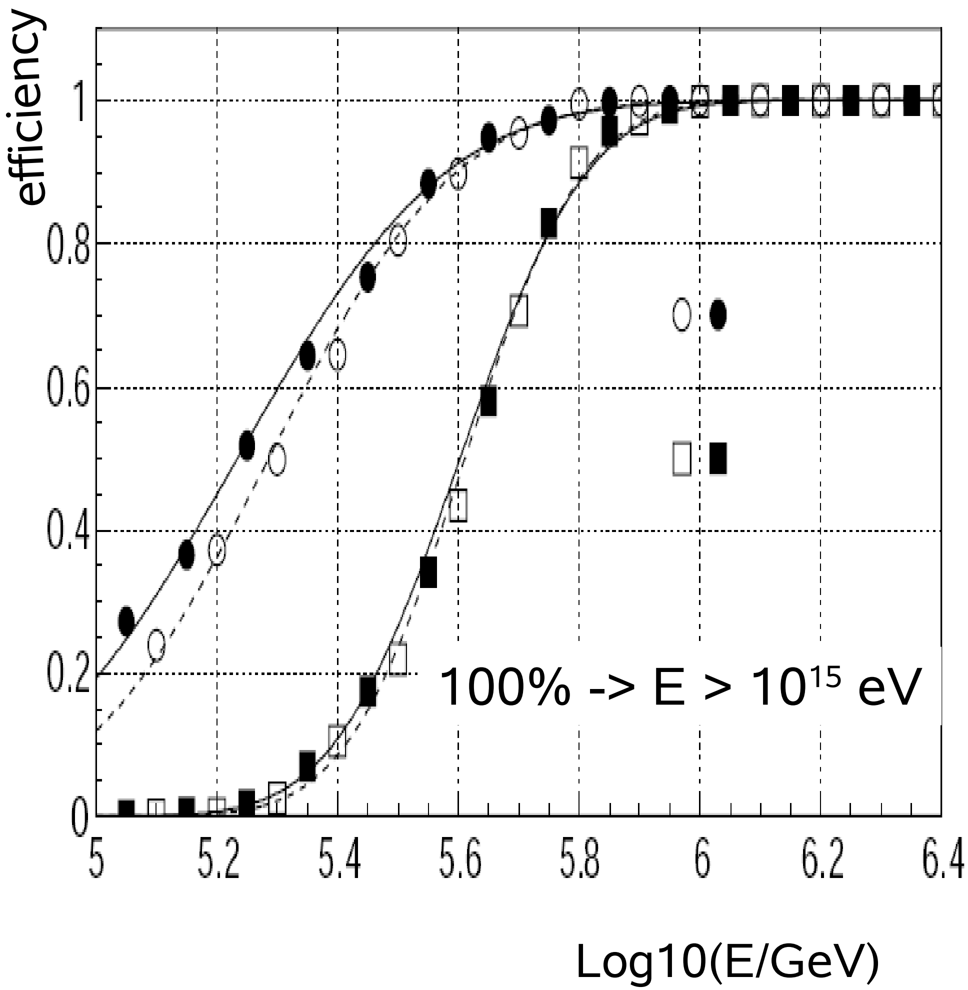
KASCADE-Grande

Scintillators

Detects the Charged Particles

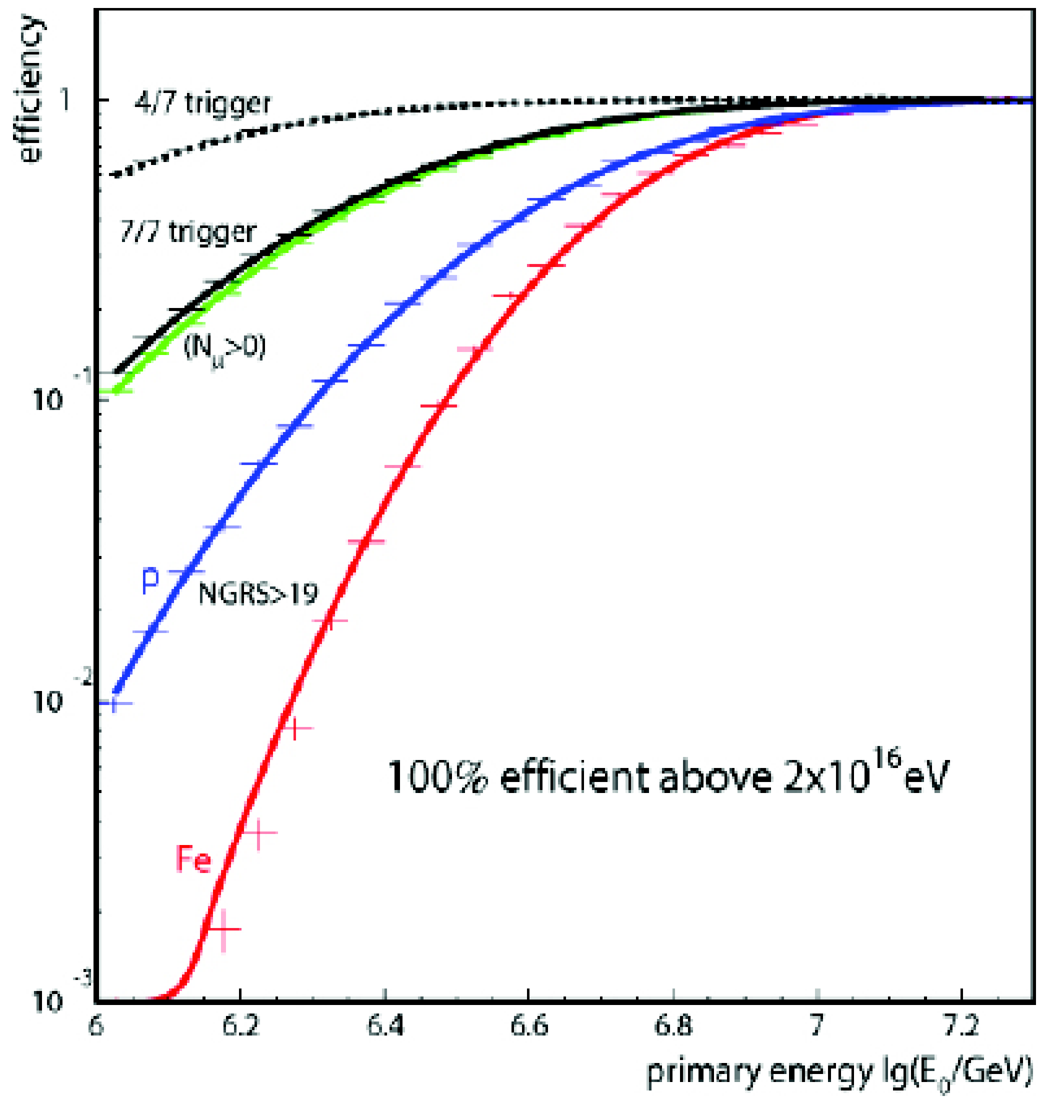
KASCADE

Area = 4×10^4 m^2 = 4×10^{-2} km^2 Spacing = 13 m

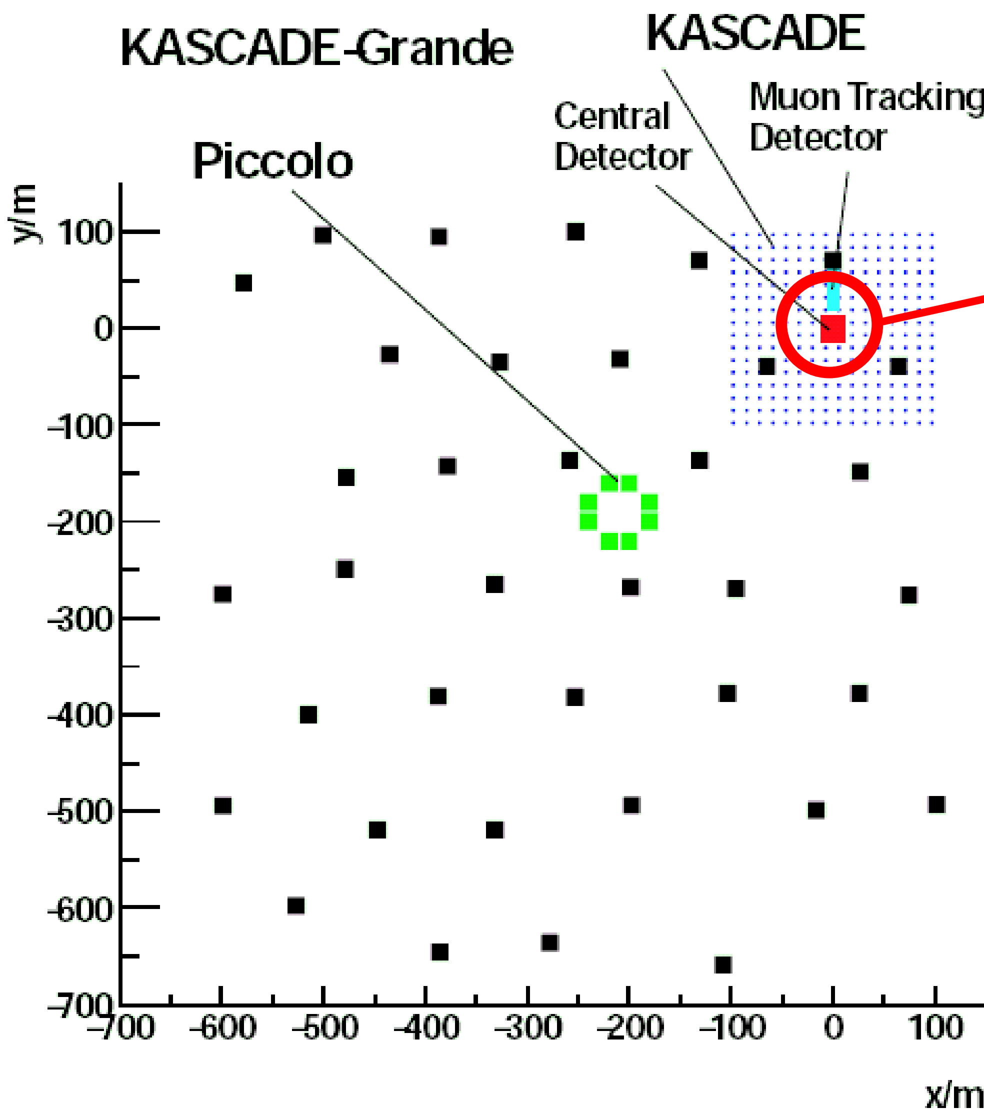


Grande

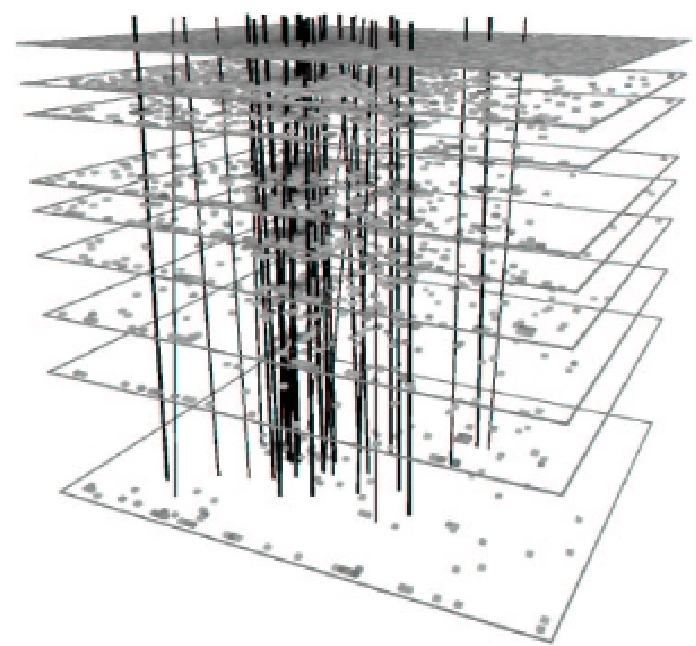
Area = 0.5 km^2 Spacing = irregular



The Detectors: Hadron Calorimeter

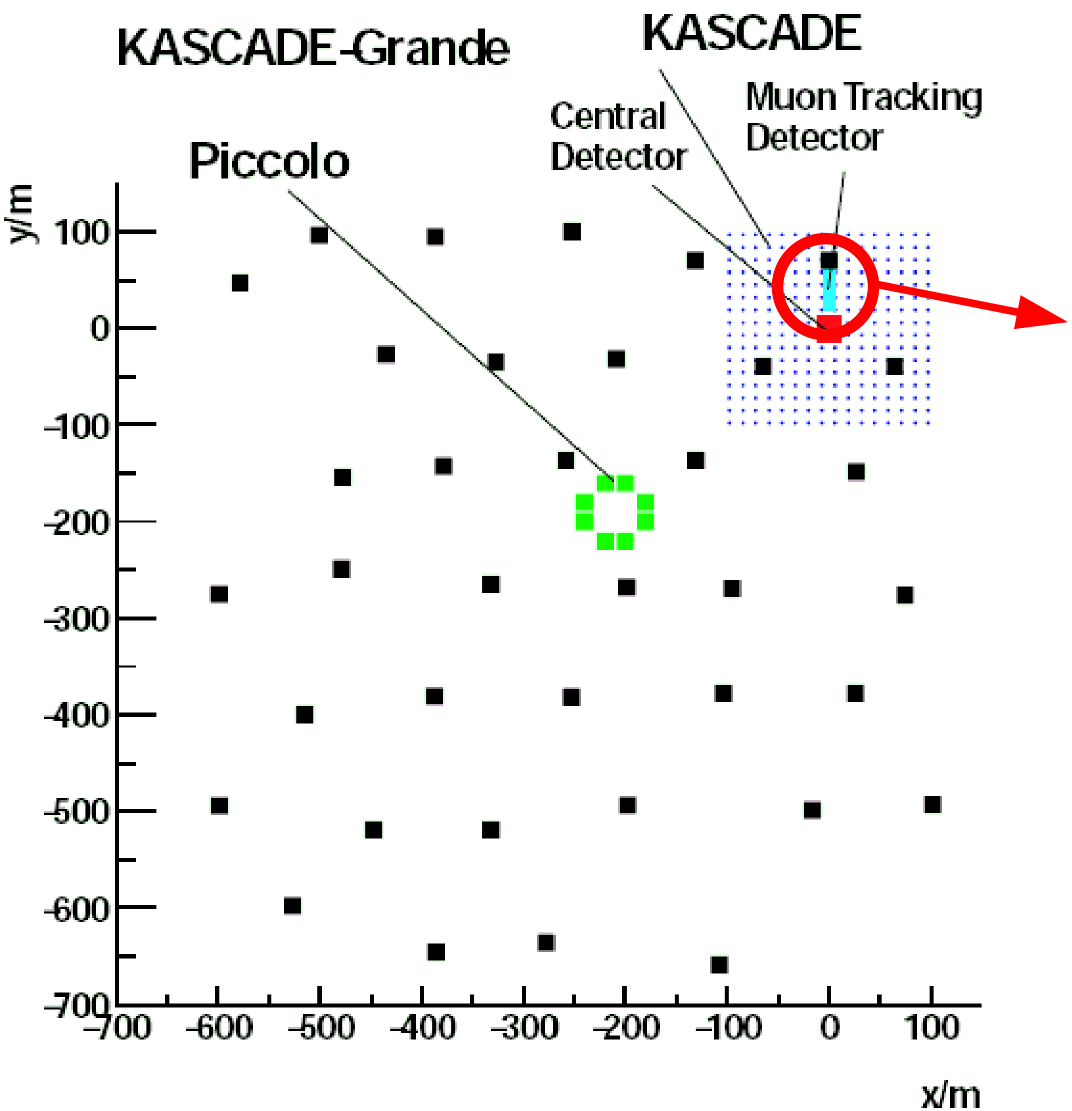


Central Calorimeter



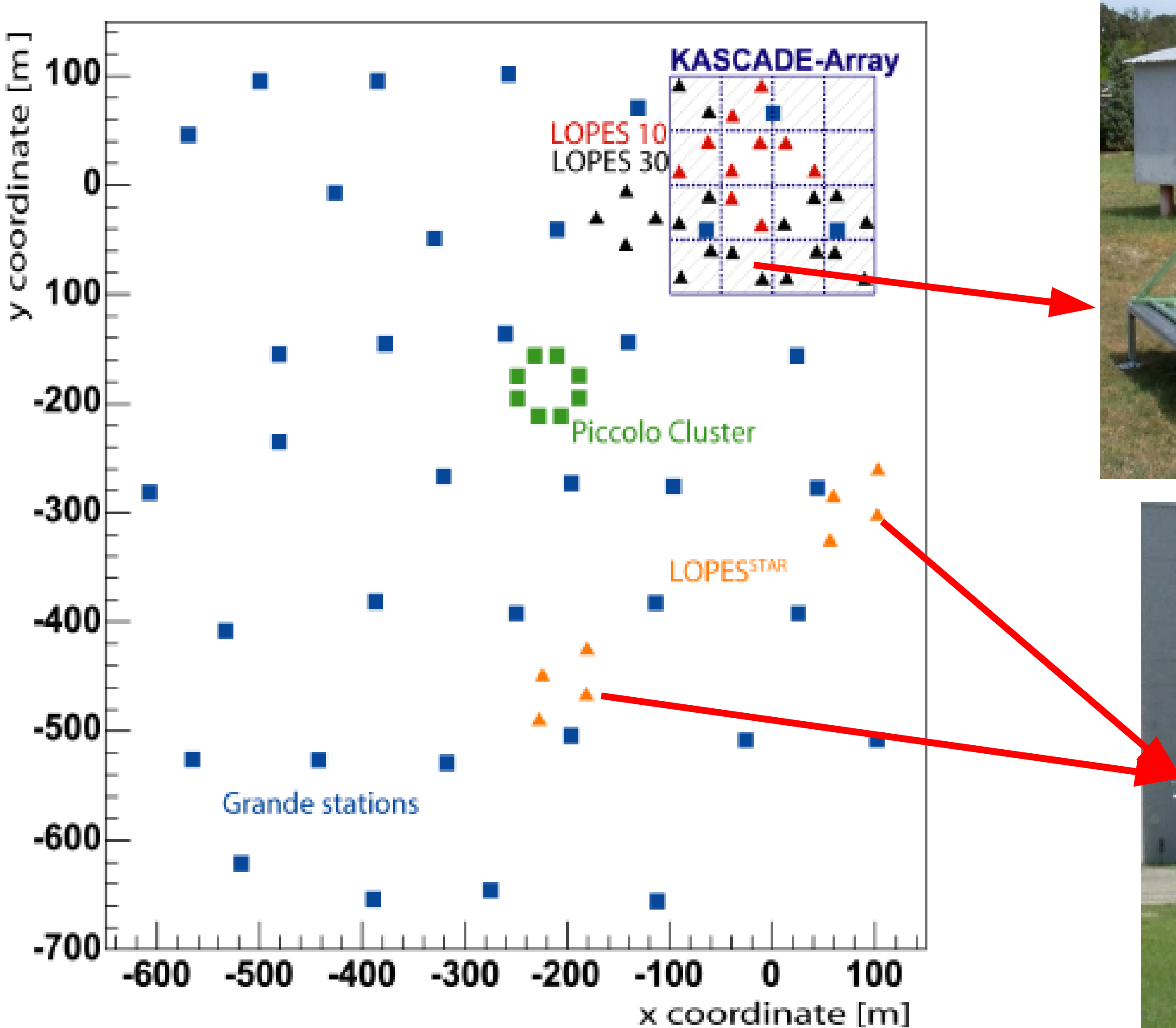
Hadron tracks

The Detectors: Muon Tracking



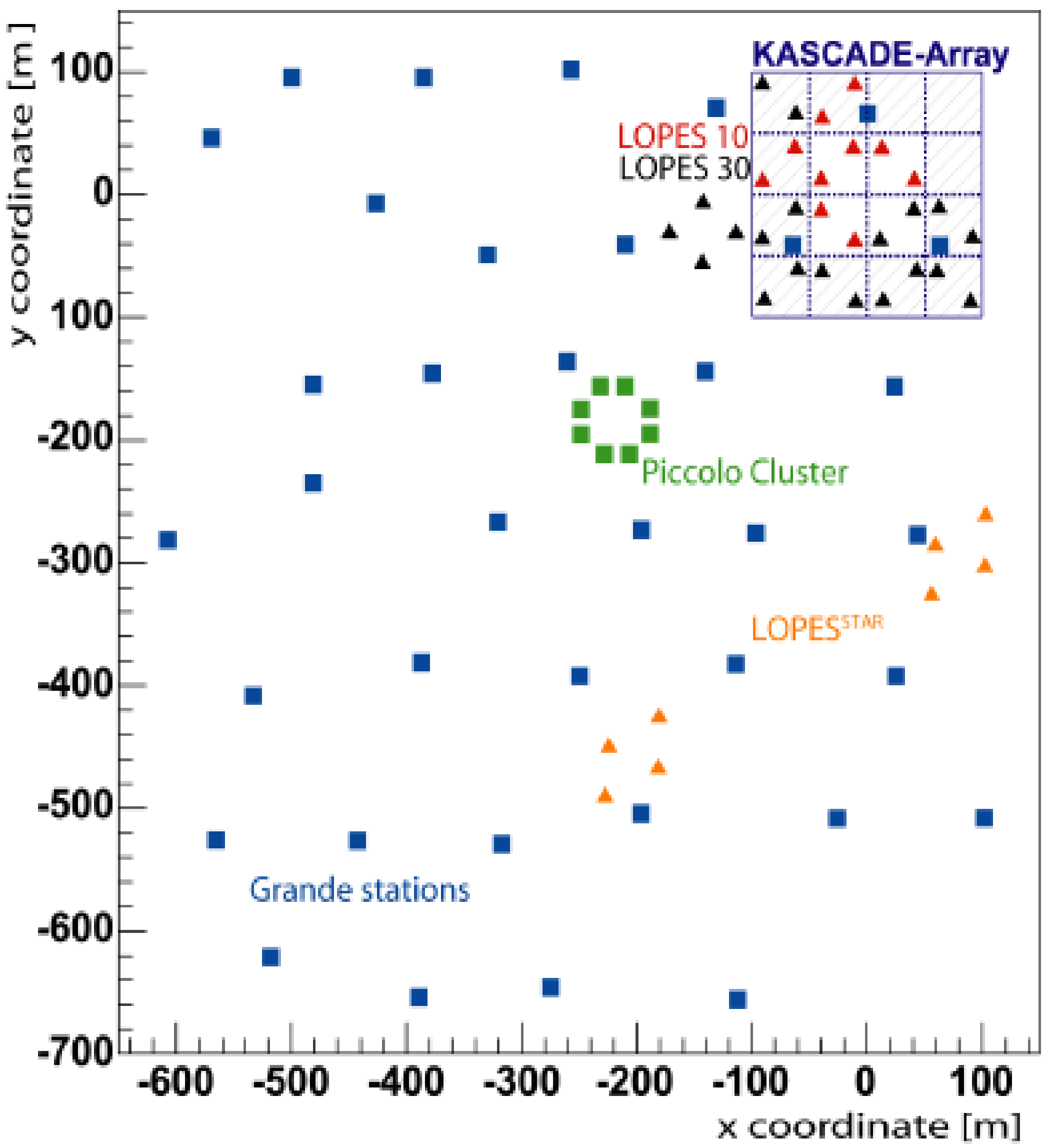
Measures muon production height

The Detectors: Radio Antennas



KASCADE Cosmic Ray Facility

<u>KA</u>rlsruhe **<u>S</u>**hower **<u>C</u>**ore and **<u>A</u>**rray **<u>DE</u>**tector



- <u>KASCADE Array</u>

  e/γ > 5 MeV

  μ > 230 MeV

- <u>Grande Array</u>

  Charged Particles

- <u>Hadron Calorimeter</u>

  Hadrons > 50 GeV

- <u>Muon Tracking Detector</u>

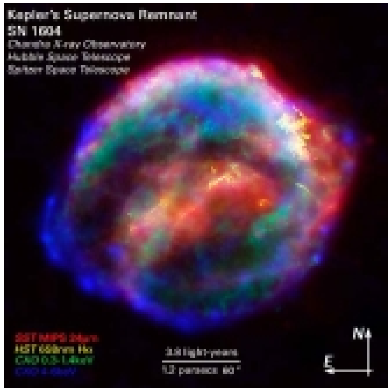
  μ > 800 MeV

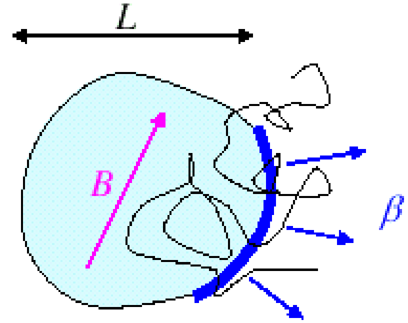
- <u>LOPES</u>

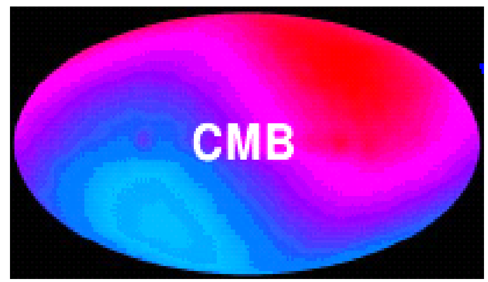
  Radio Measurements

Scientific Motivation for the KASCADE-Grande Experiment

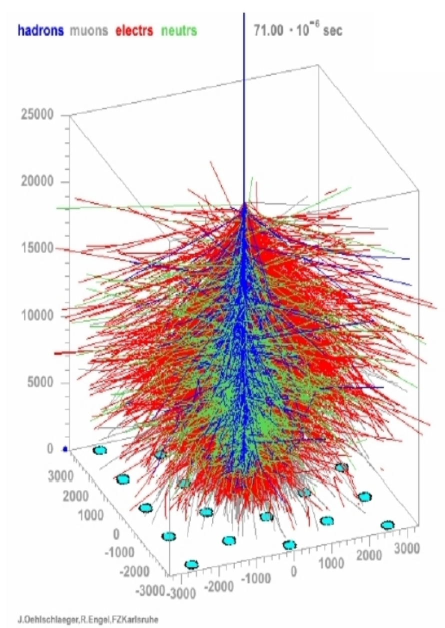
Astroparticle Physics

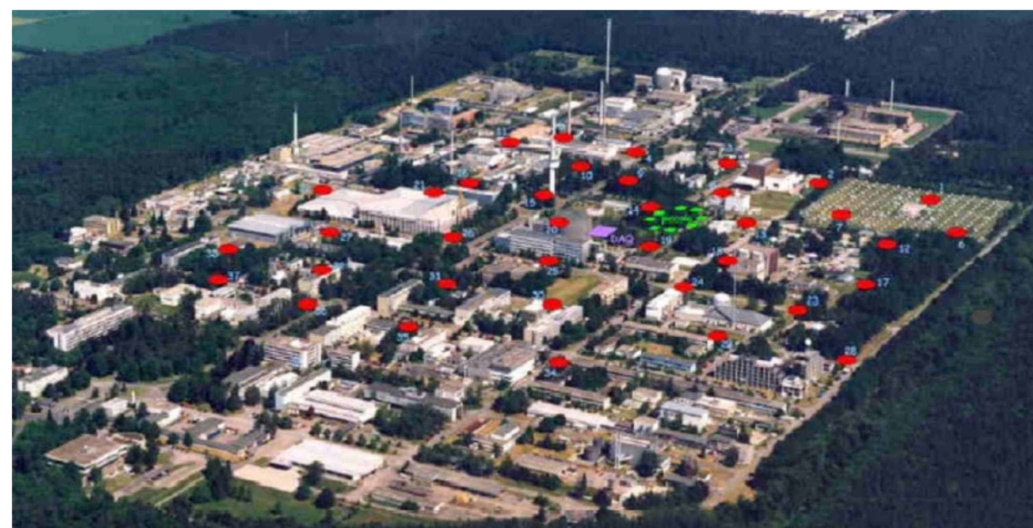




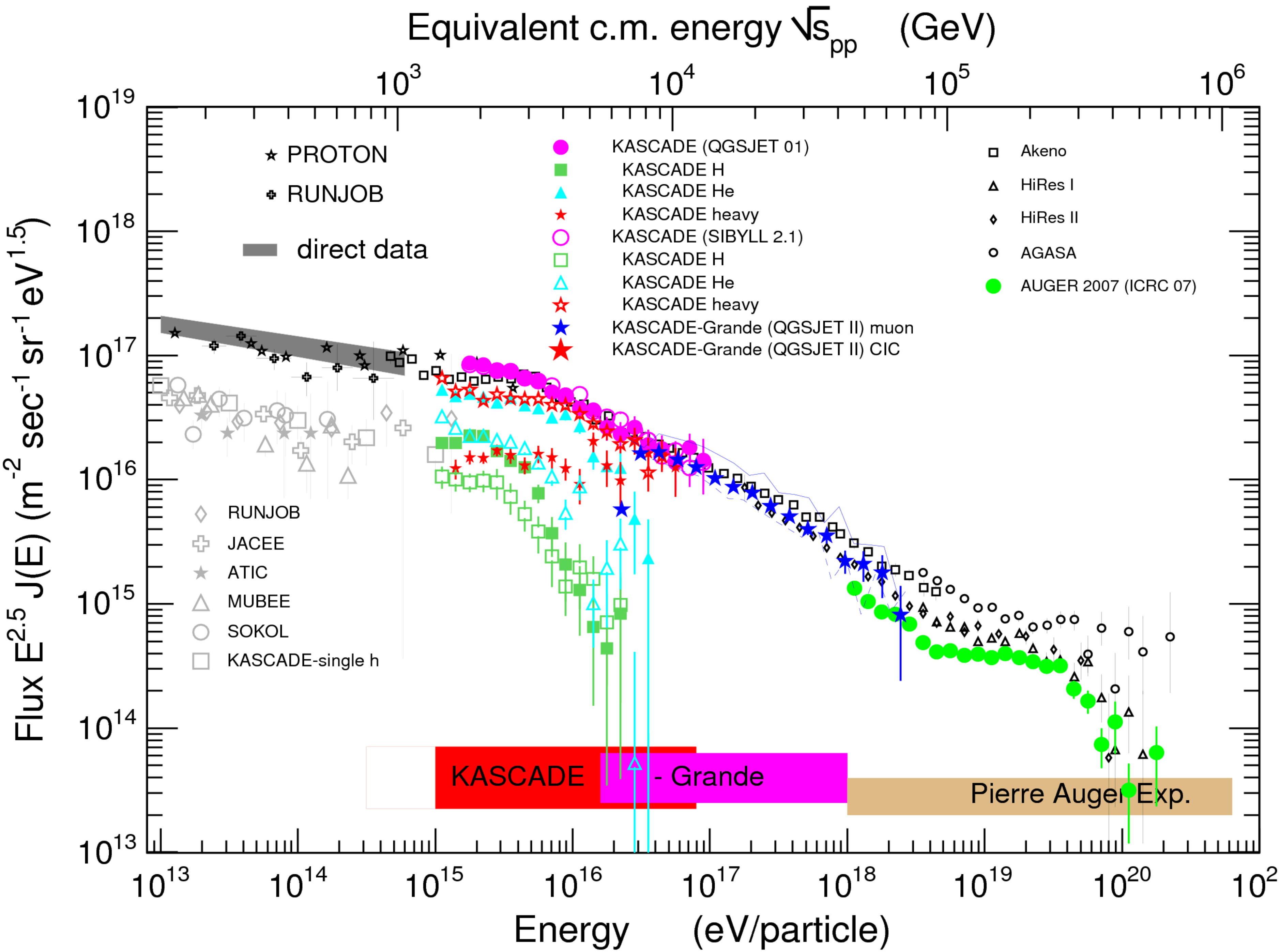


A T M O S P H E R E



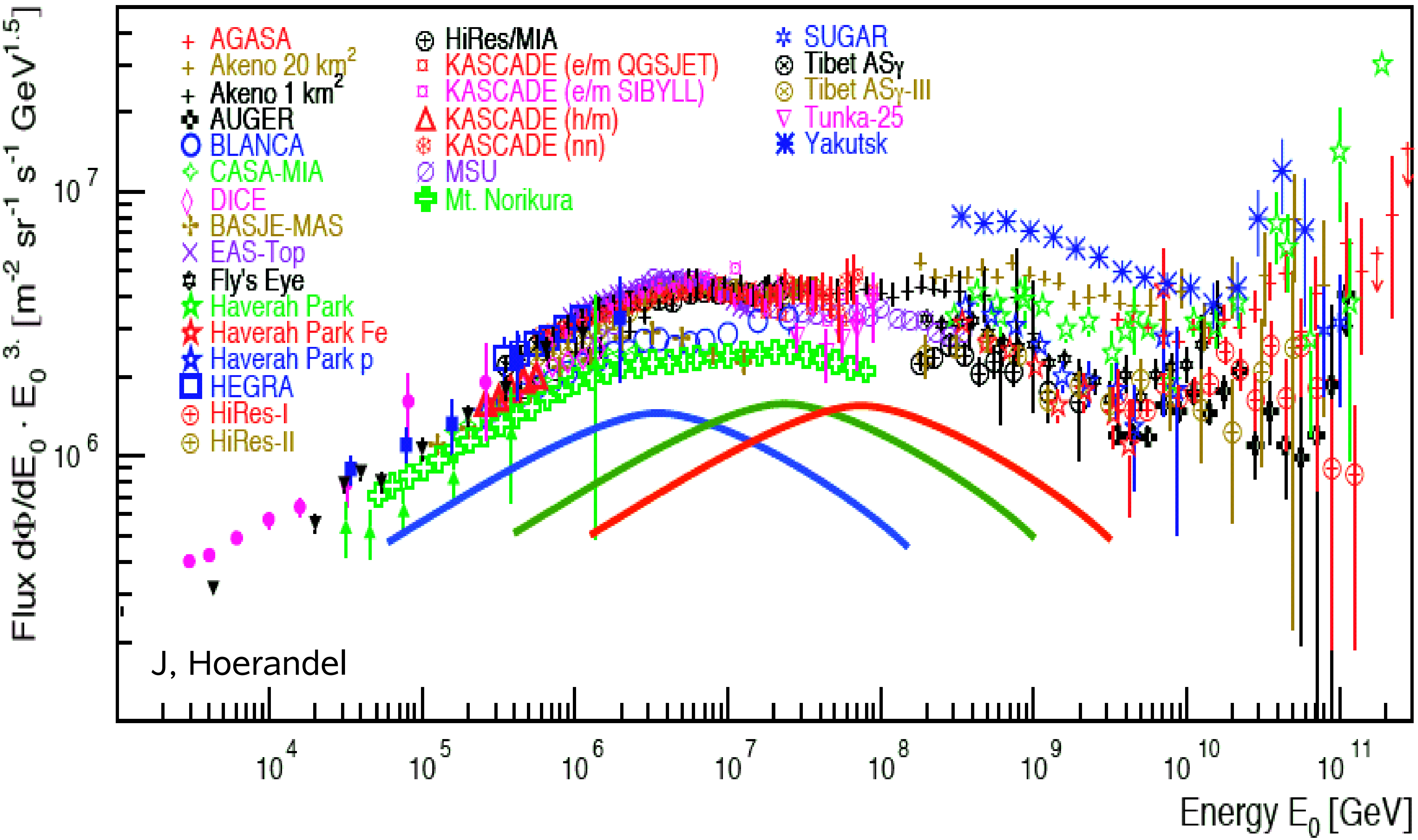


Forschungszentrum Karlsruhe



Equivalent c.m. energy √s_pp (GeV)
10^3
10^4
10^5
10^6
Flux E^2.5 J(E) (m^-2 sec^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
PROTON
RUNJOB
direct data
KASCADE (QGSJET 01)
KASCADE H
KASCADE He
KASCADE heavy
KASCADE (SIBYLL 2.1)
KASCADE H
KASCADE He
KASCADE heavy
KASCADE-Grande (QGSJET II) muon
KASCADE-Grande (QGSJET II) CIC
Akeno
HiRes I
HiRes II
AGASA
AUGER 2007 (ICRC 07)
RUNJOB
JACEE
ATIC
MUBEE
SOKOL
KASCADE-single h
KASCADE
- Grande
Pierre Auger Exp.
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

Scientific Motivation



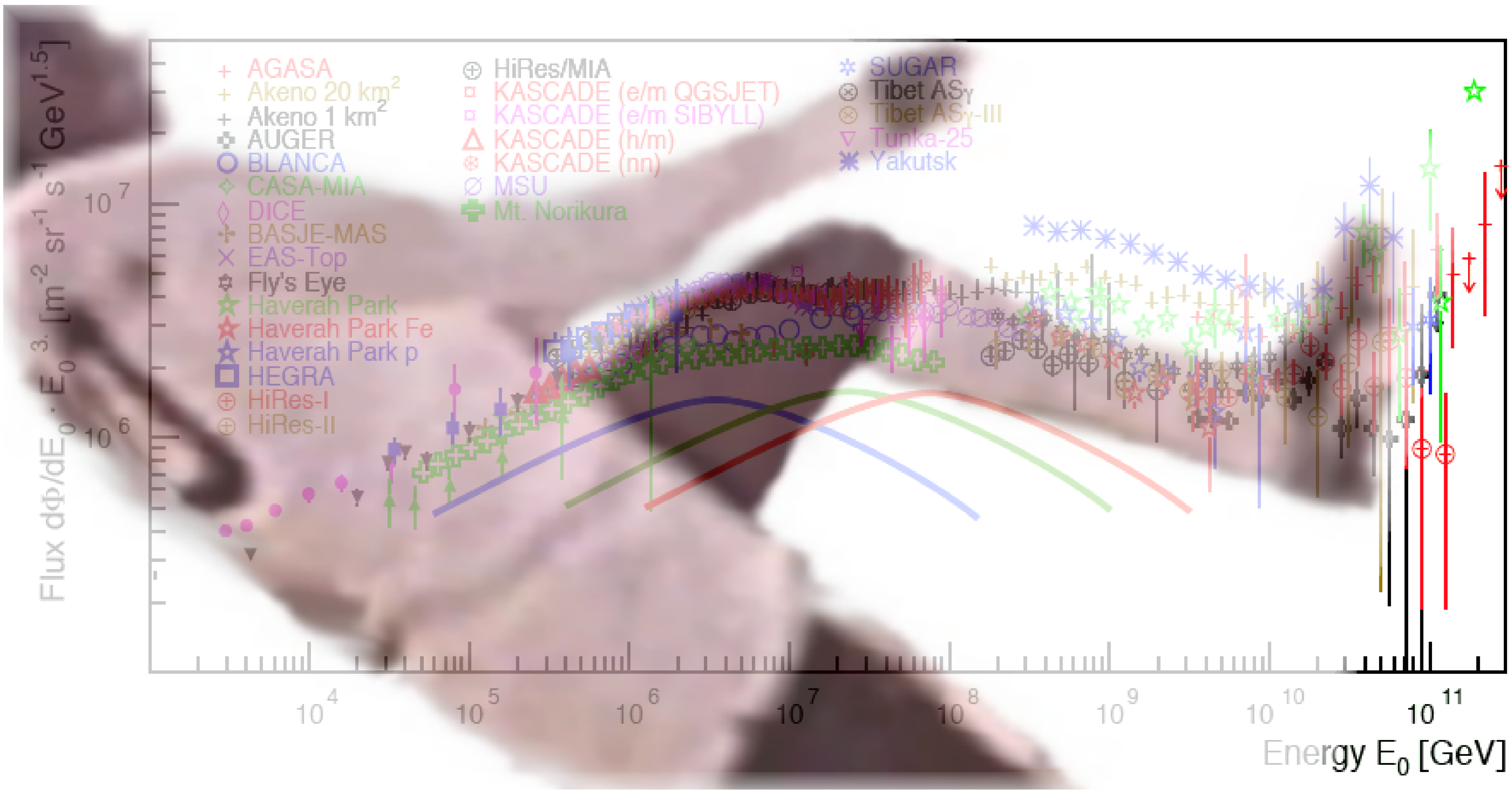
Pelé and the cosmic ray spectrum

1363 matches

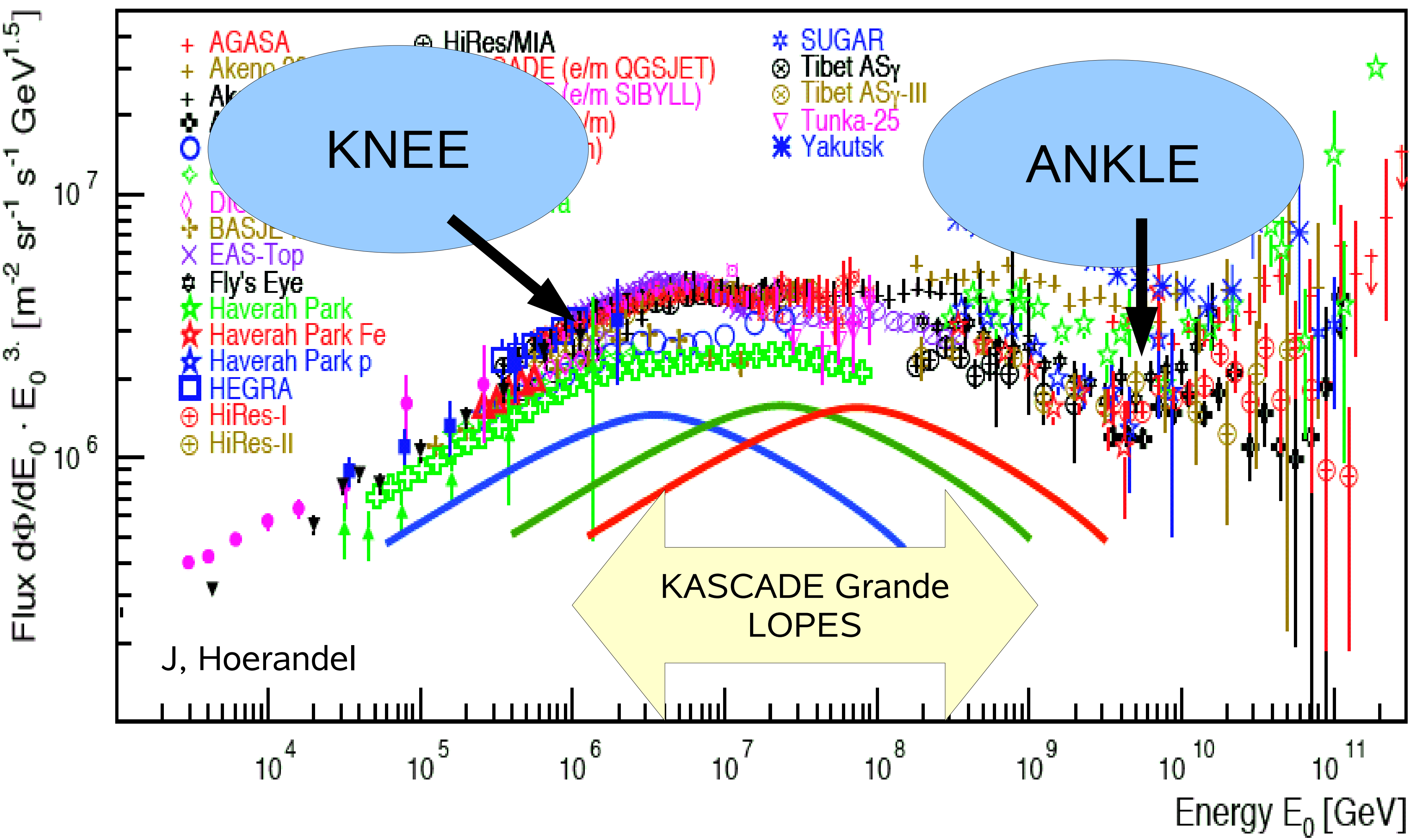
1282 goals

3 World Cups

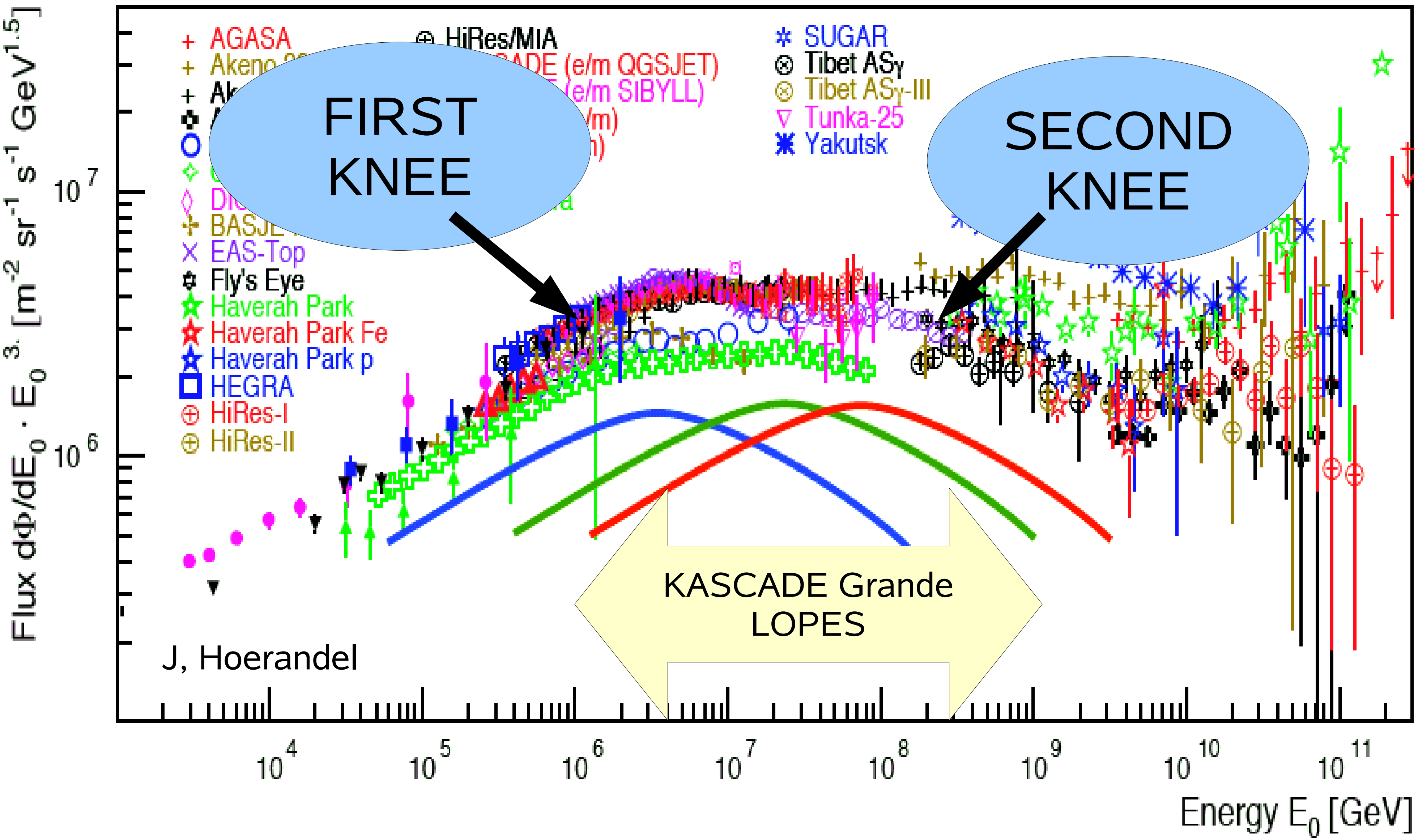
Knees and ankle



Scientific Motivation



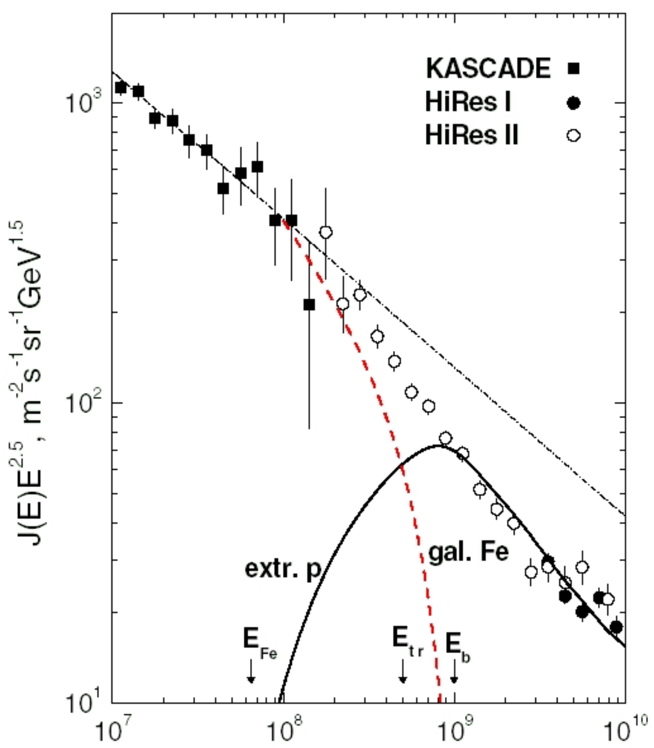
Scientific Motivation



Astrophysical models

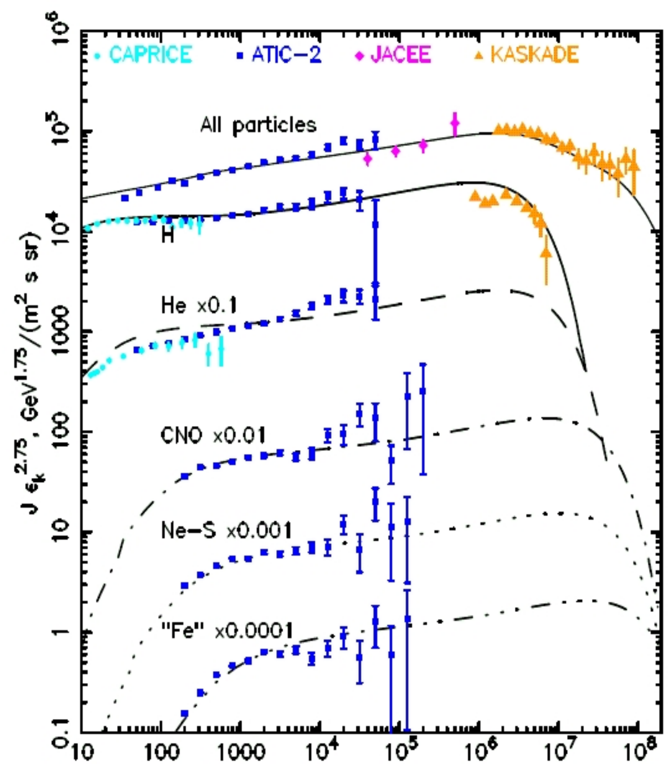
Transition from Galactic to Extragalactic predominance in the flux

Composition change at the sources



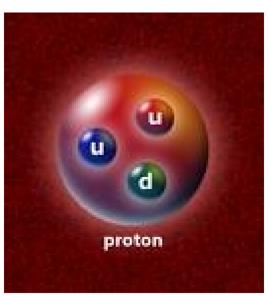
Berezinksy et al.

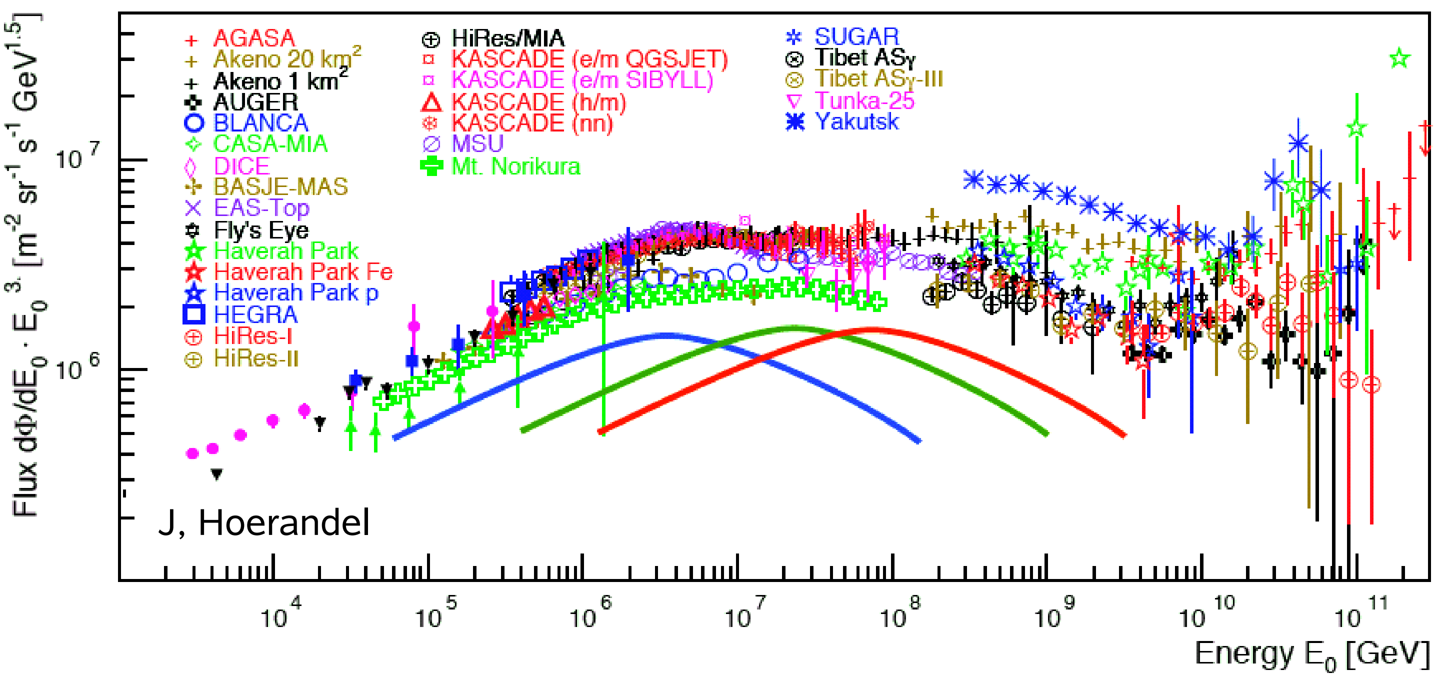
The art of matching spectra

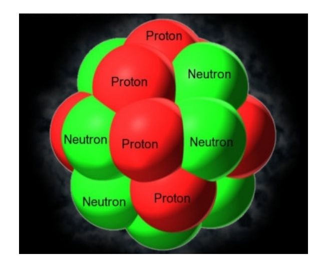


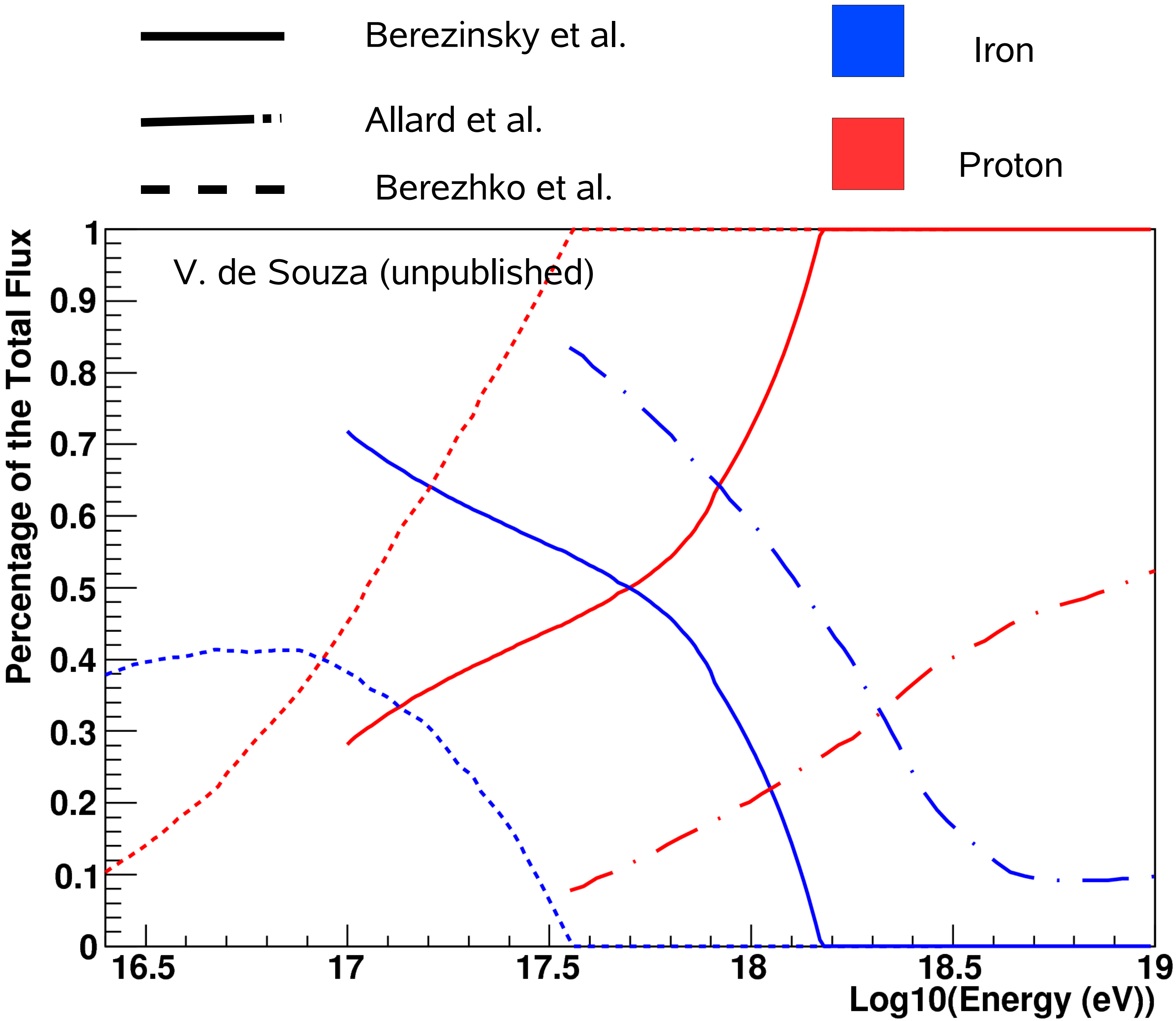
Berezhko et al.

To understand the astroparticle physics with energy between 10^{15} to 10^{18} eV one experiment has to measure the composition evolution between the knees





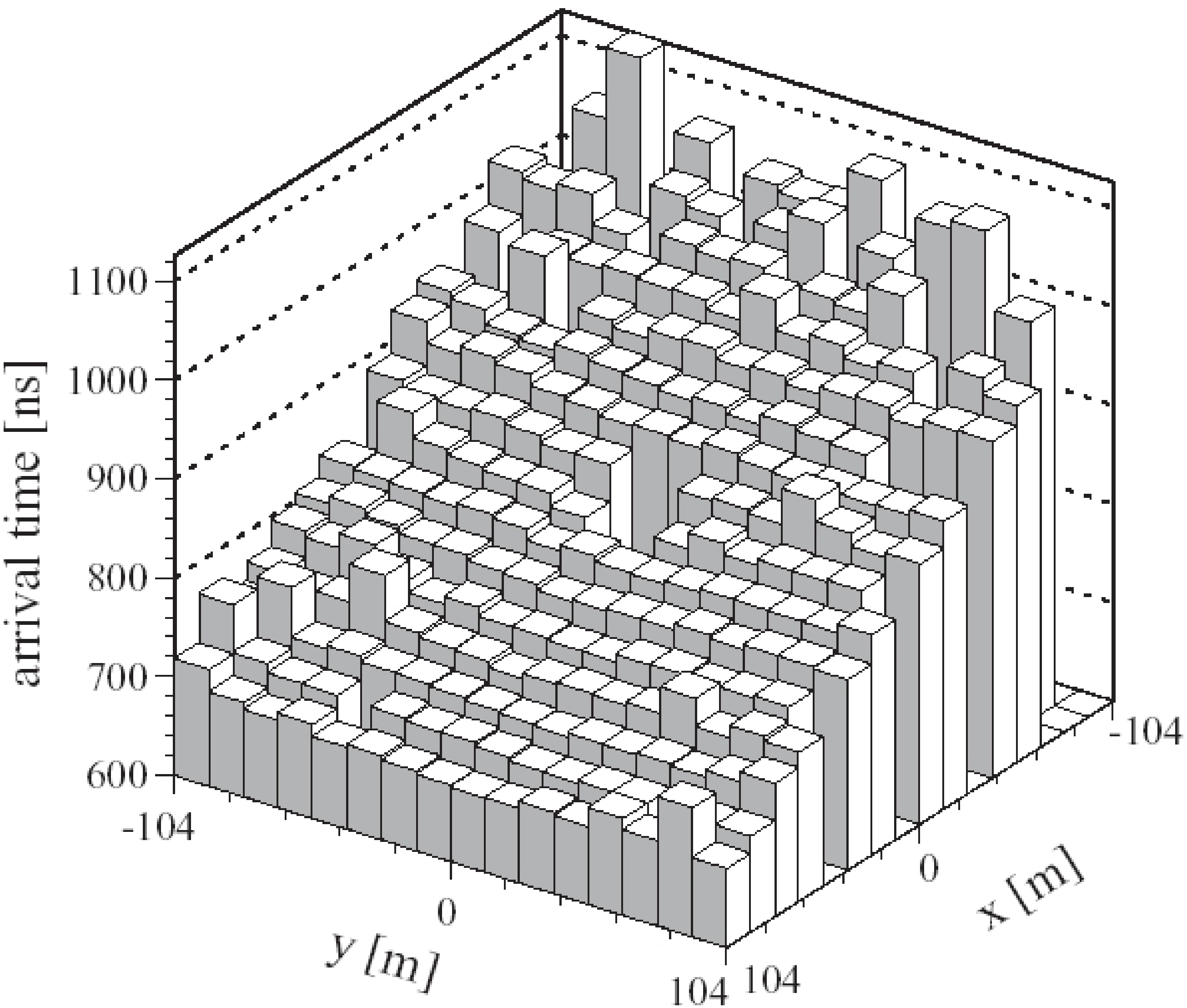




Around the second knee

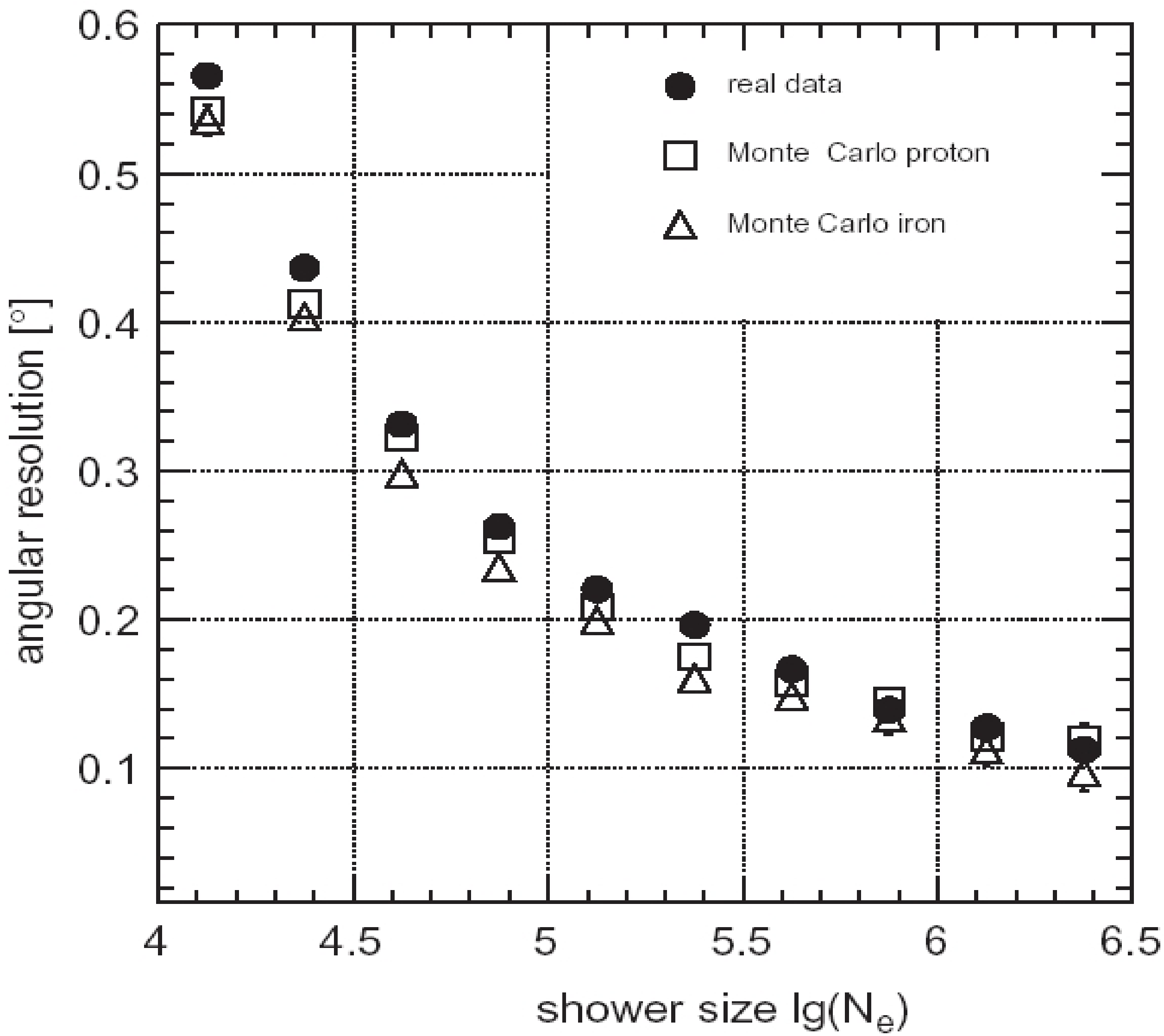
DATA ANALYSIS

Arrival Direction: KASCADE

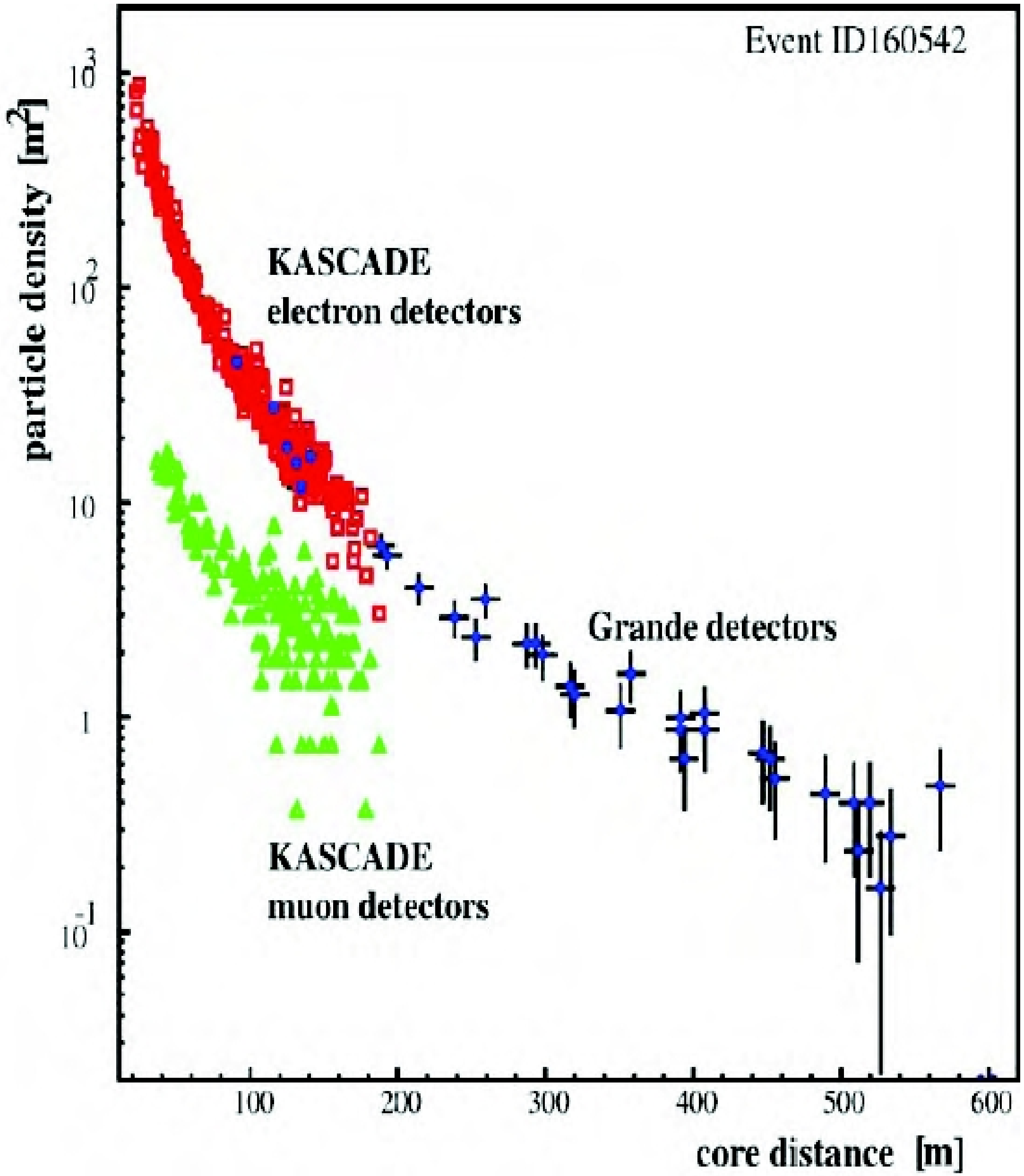


Time Resolution of the Scintilators < 1 ns

Arrival Direction: KASCADE



Reconstruction:



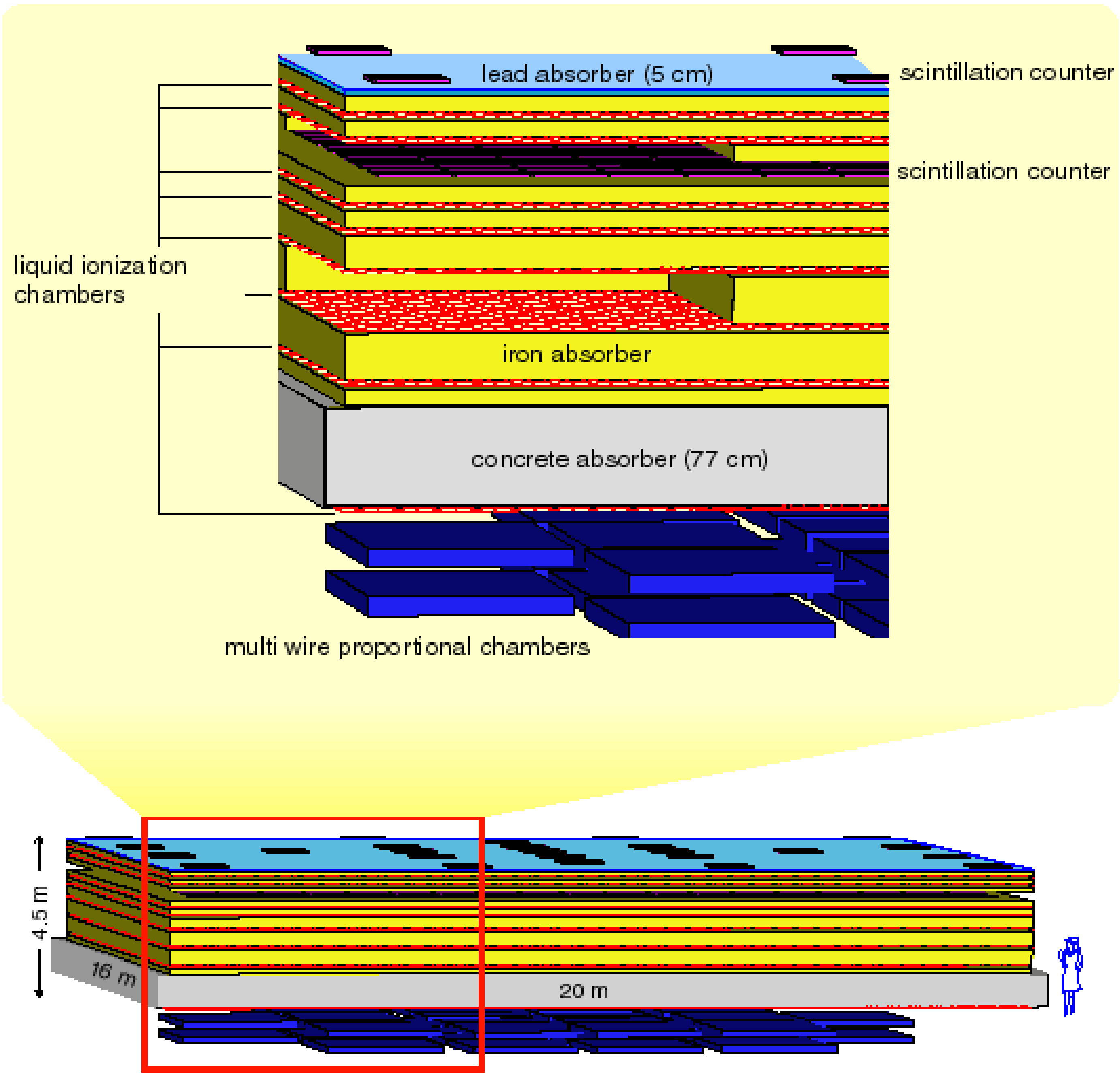
core position
number of electrons
number of muons

Fit a function to the lateral distribution of particles and calculate the total number of muons and electrons

KASCADE	Grande
Area = 4×10^4 m^2 = 4×10^{-2} km^2	Area = 0.5 km^2
Spacing = 13 m	Spacing = irregular
At the First Knee	**At the Second Knee**
Core resolution ~ 1 m	Core resolution ~ 10 m
Direction ~ 0.15^o	Direction ~ 0.5^o
Total Number of Muons ~ 10%	Total Number of Muons ~ 20%
Total Number of Electrons ~ 5%	Total Number of Electrons ~ 20%

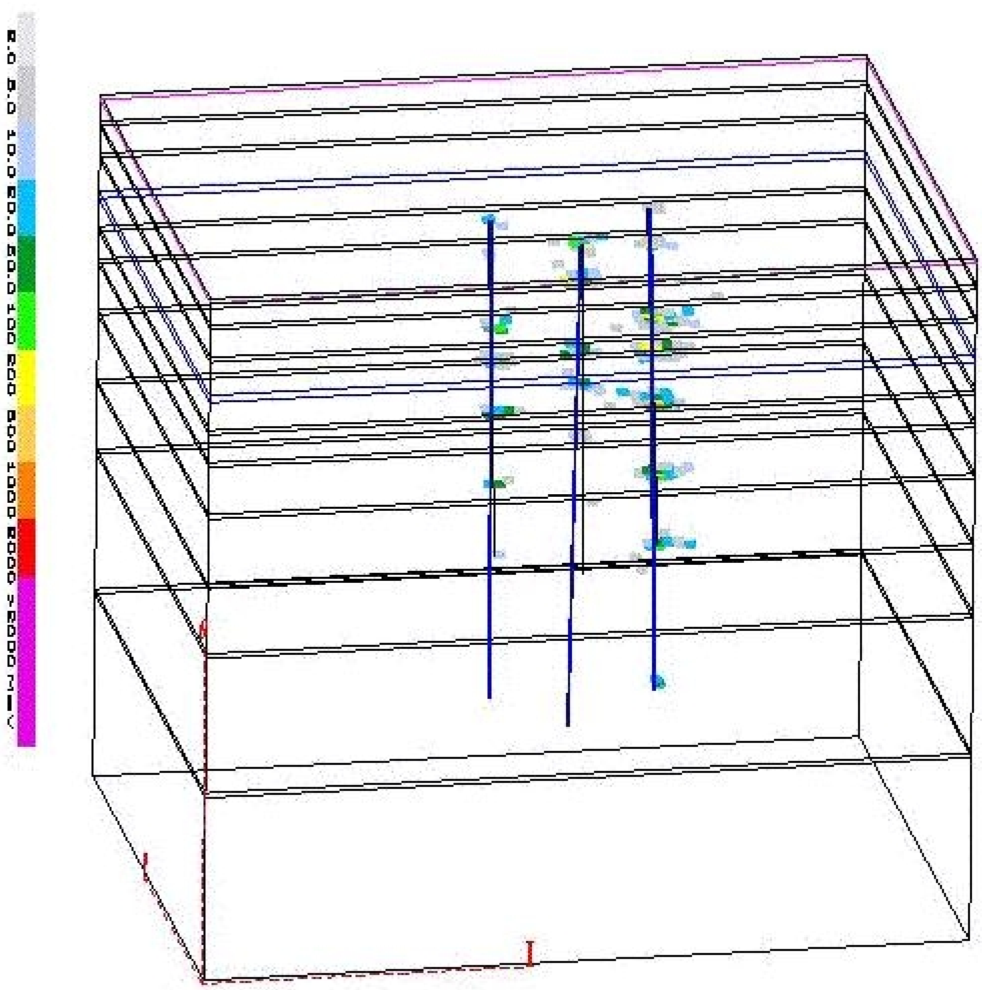
Subset of events with extra information:
hadron + muon tracking + radio

Central Calorimeter

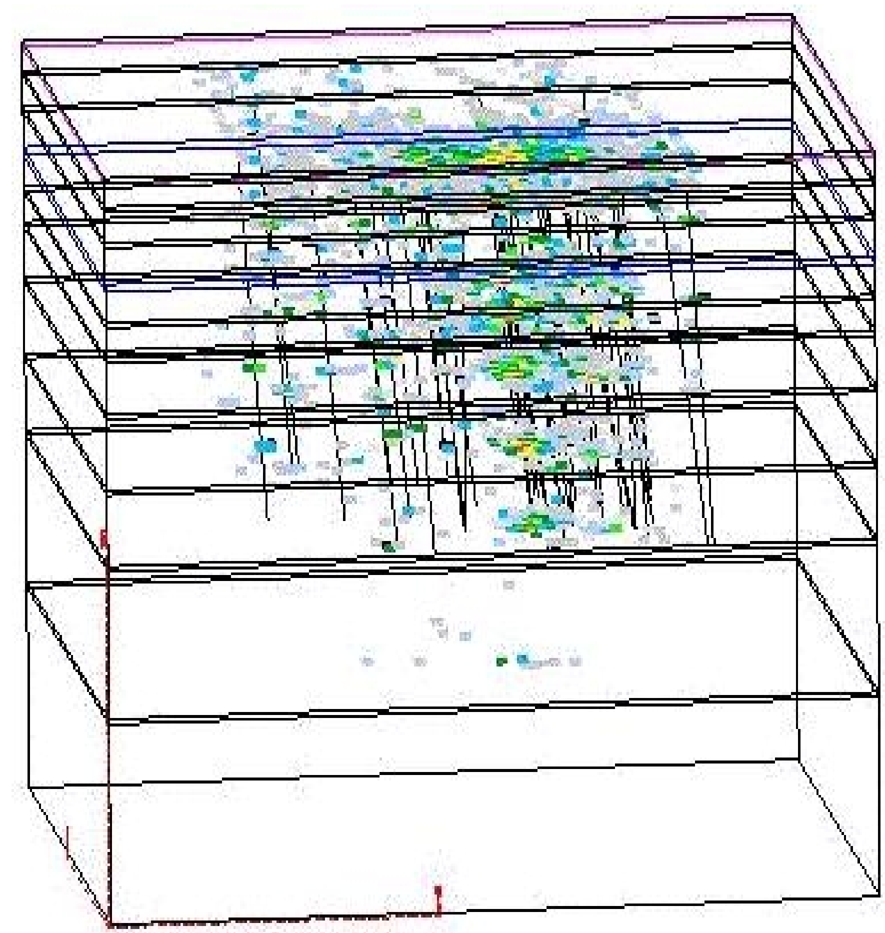


Central Calorimeter

Muon Counting



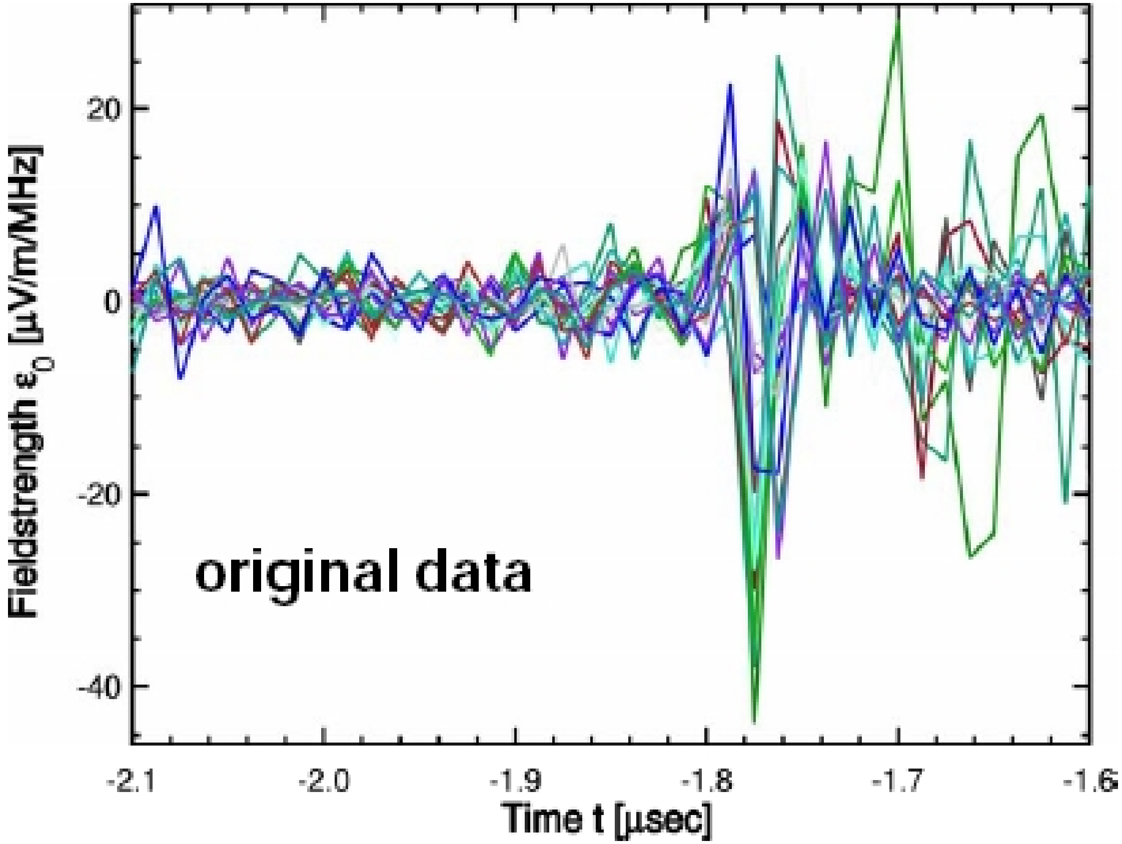
Hadron Counting



Efficiency correction calculated with Monte Carlo simulation

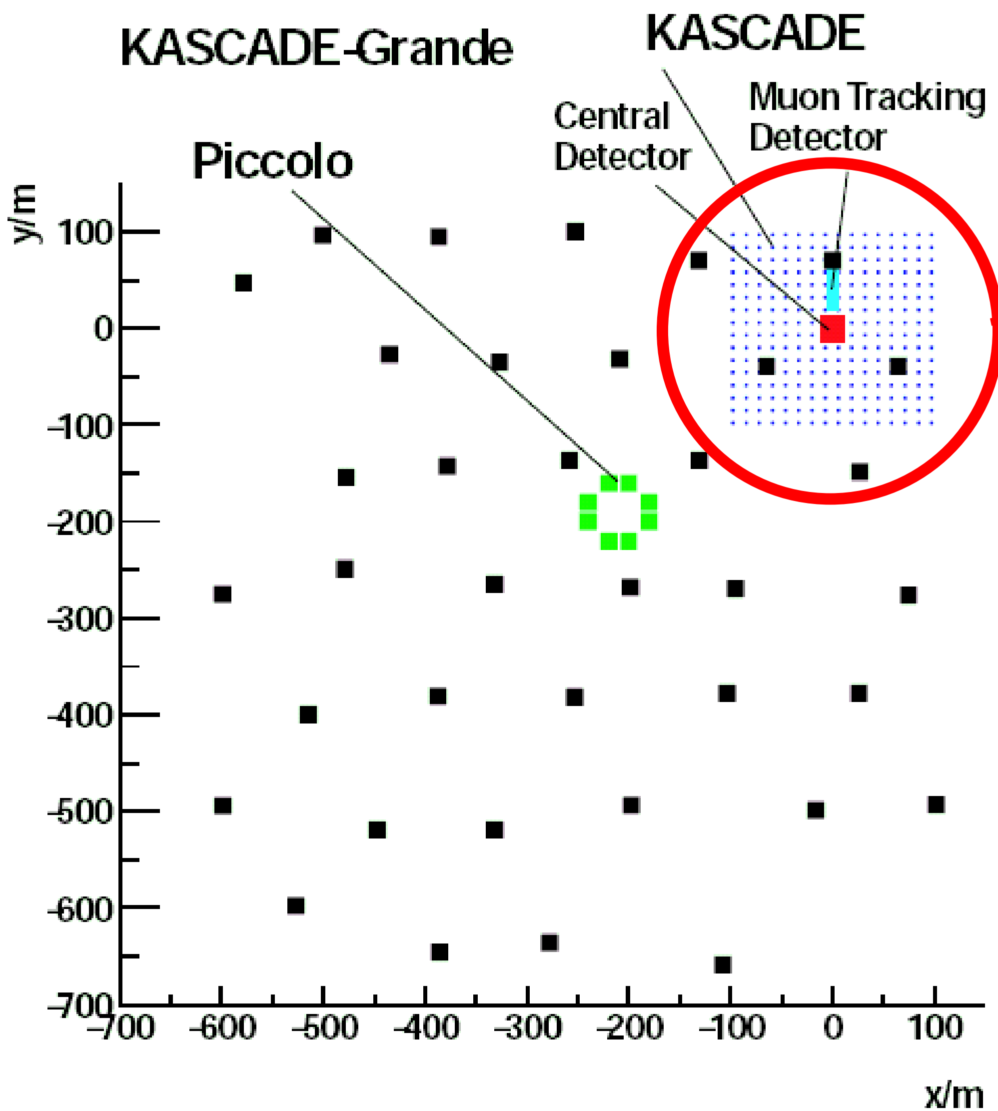
Radio Antennas

Electric field strength changing in time



RESULTS

First Knee (10^{15} – $8x10^{16}$ eV)

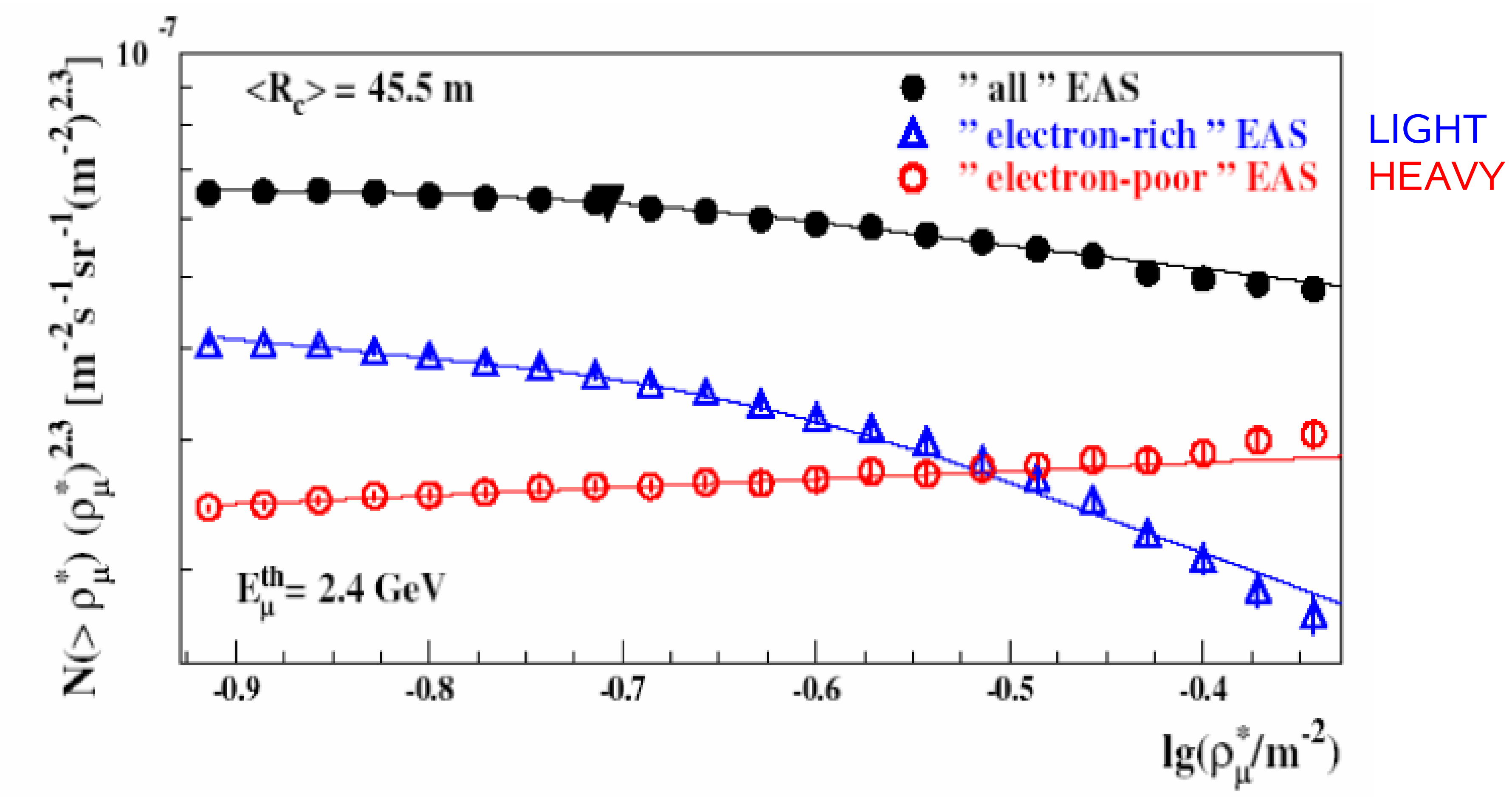


252 stations

10^9 events triggered

10^6 events used for composition

Direct Measurement

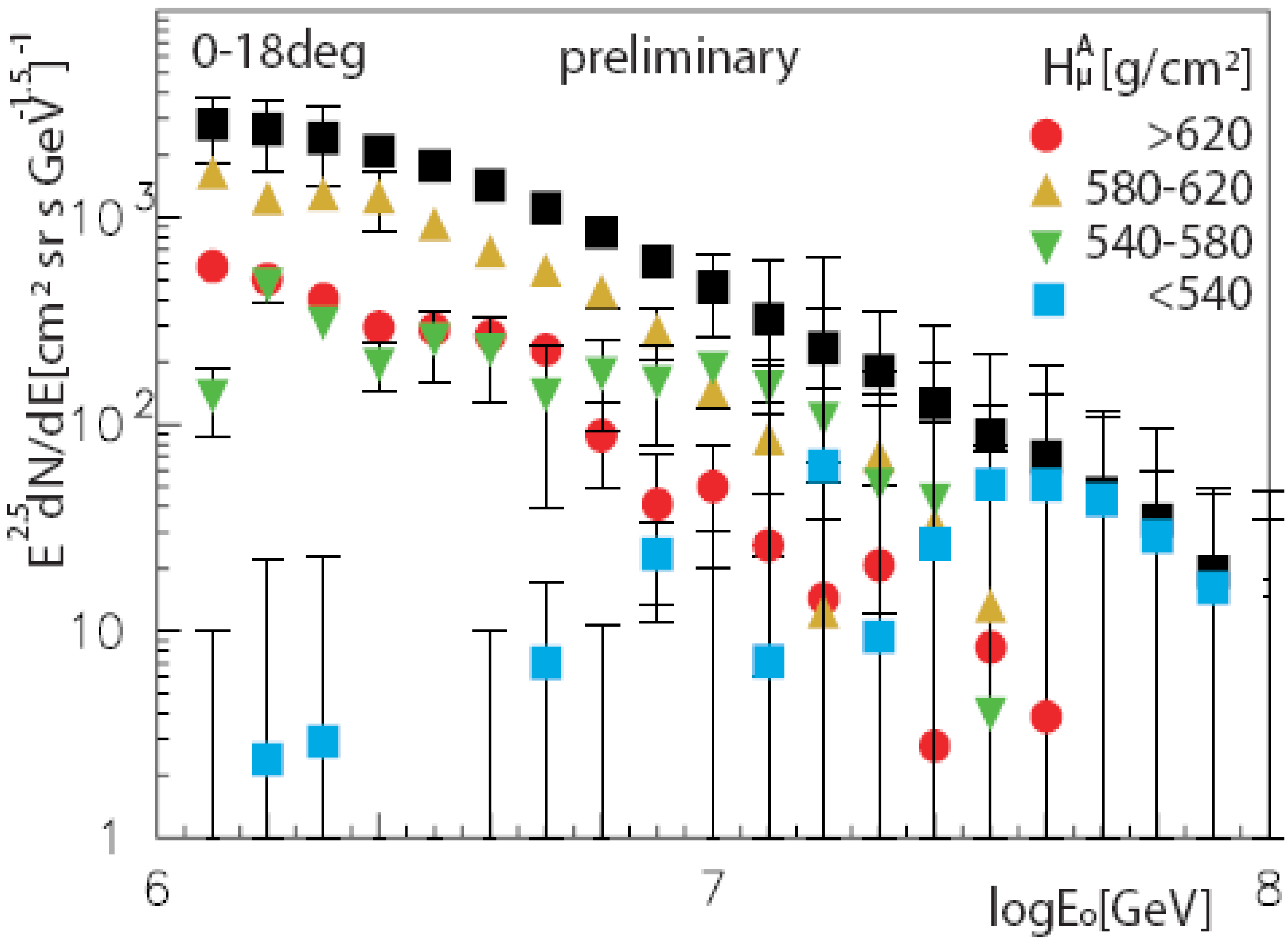


First knee caused by the decreasing flux of light elements.

MC is used only for normalization.

Muon Tracking Detector

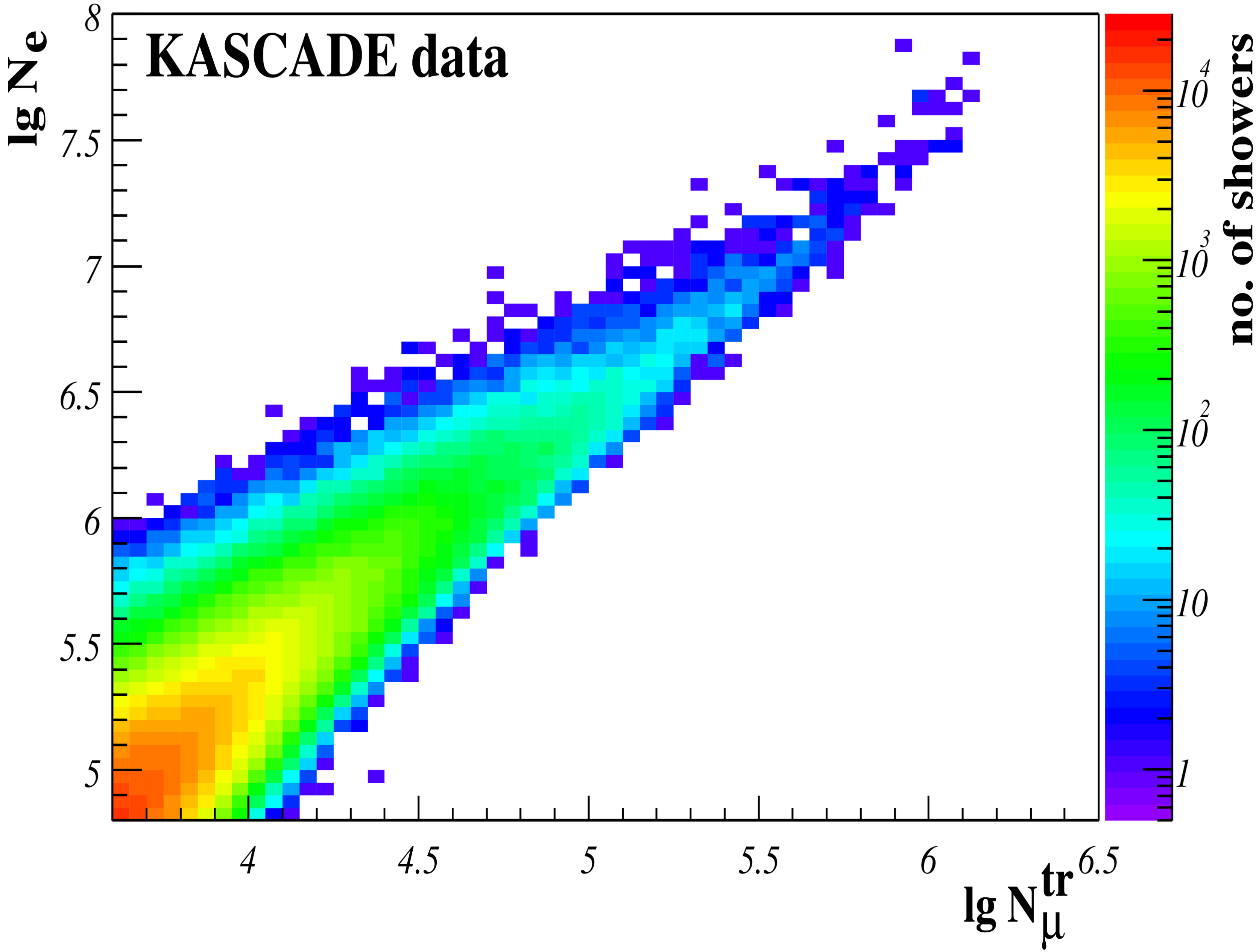
Muon production height used as a estimation of the particle mass



light
heavy

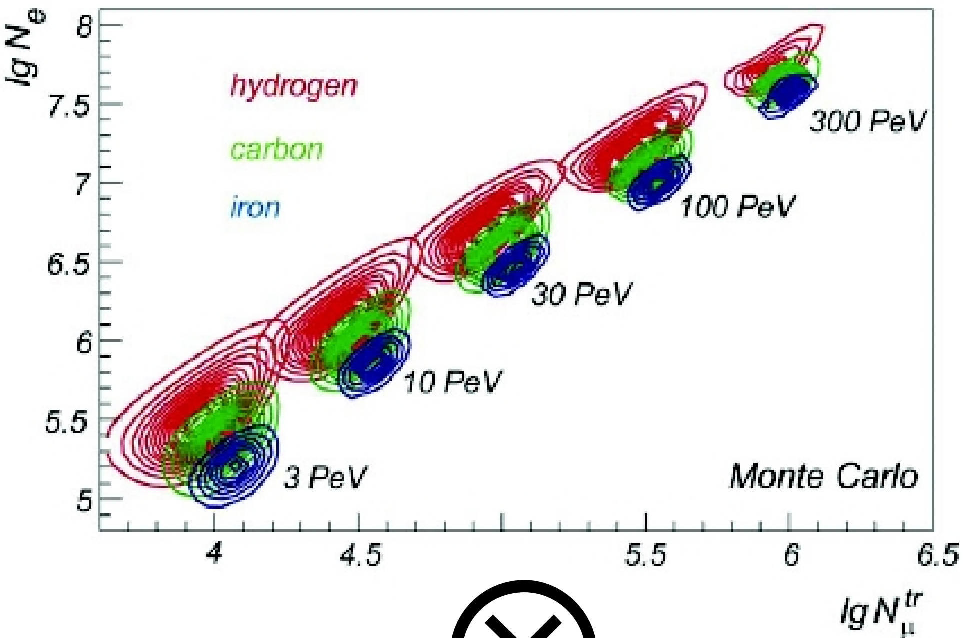
P. Doll et al., ICRC2007

2D Spectrum

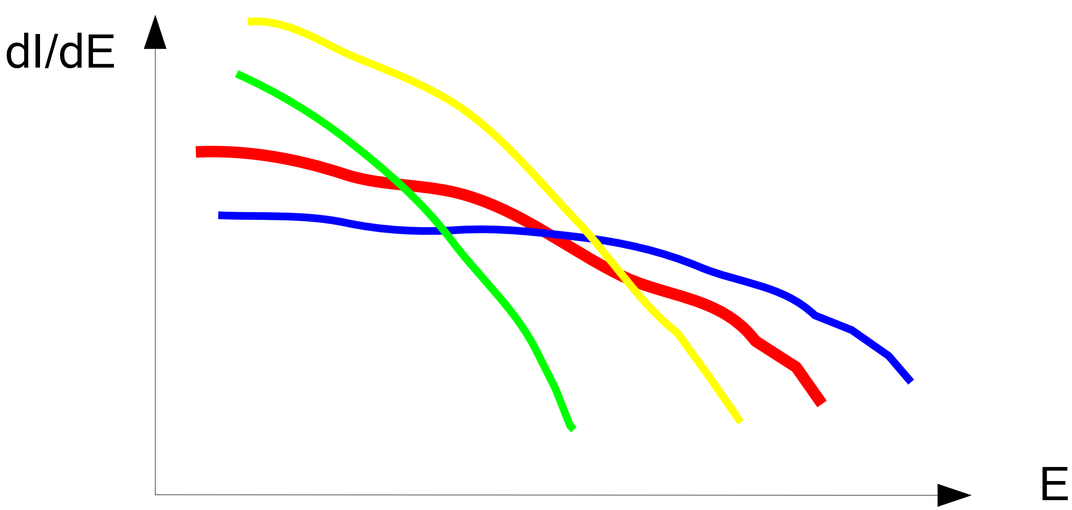

KASCADE data
lg Ne
8
7.5
7
6.5
6
5.5
5
4
4.5
5
5.5
6
6.5
lg N_μ^{tr}
no. of showers
10^4
10^3
10^2
10
1

2D Spectrum

Simulation

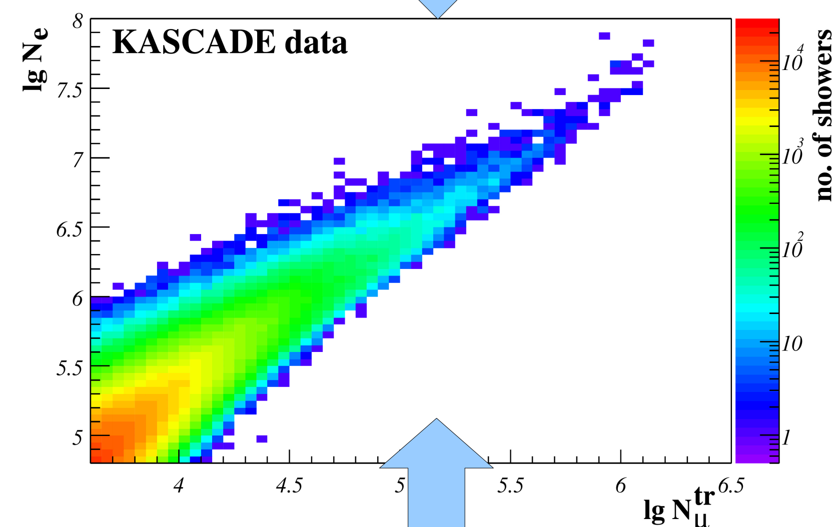


$\otimes$



=

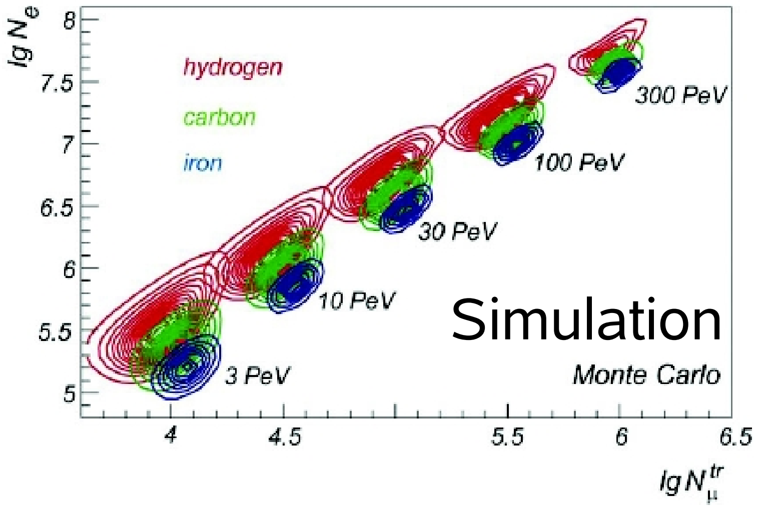
Probability Density



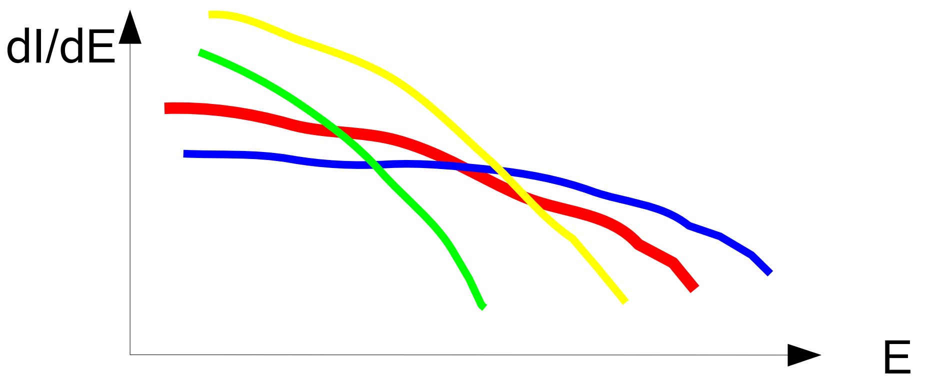
Energy spectrum of each mass component

Unfold the 2D Spectrum

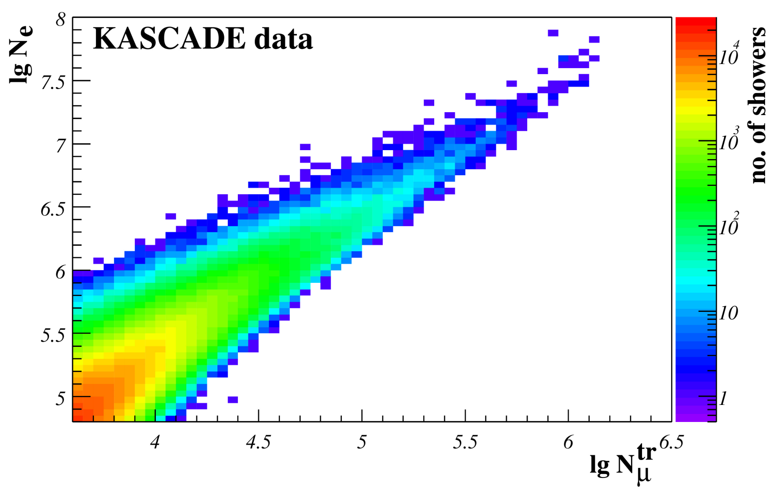
Given a probability density distribution



what is the energy spectrum of each mass component

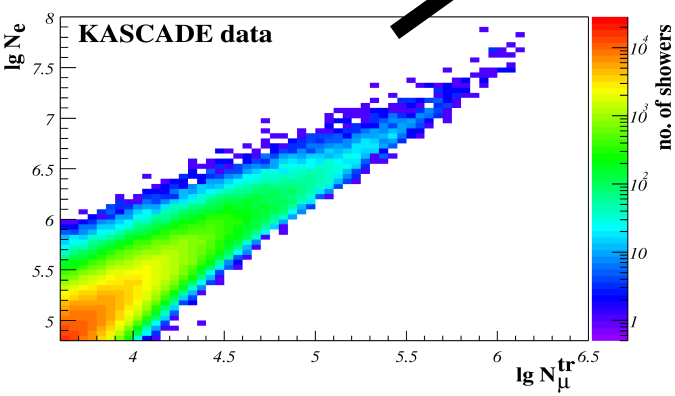


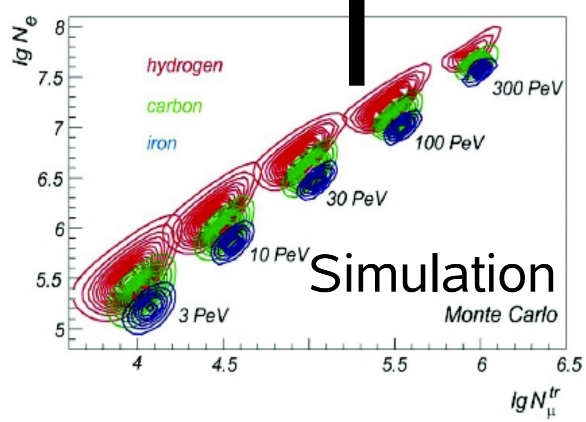
that best describes the data ?

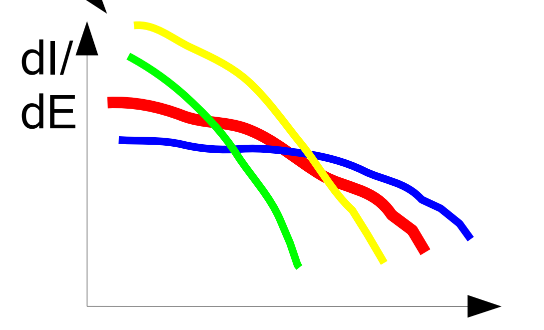


Unfolding: Math

$$\vec{Y} = R \ \vec{X}$$



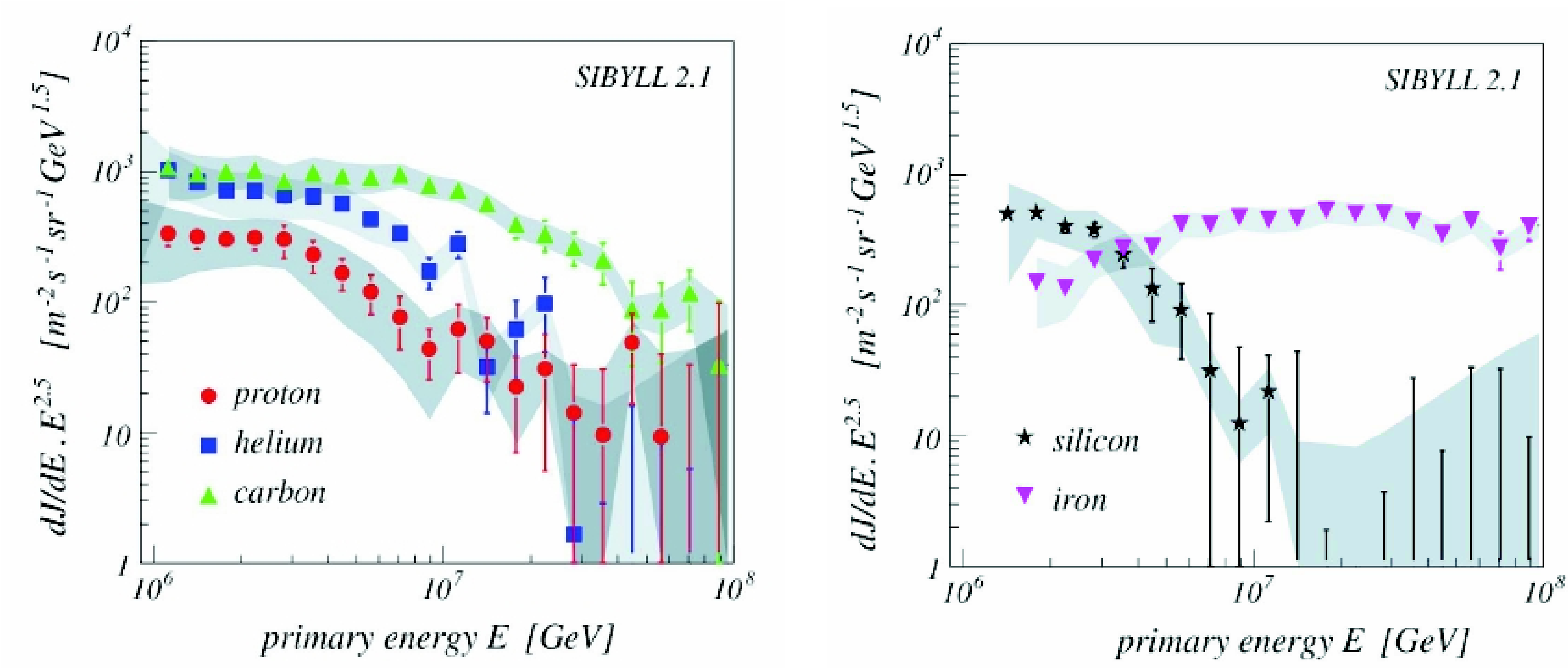




For details and full equations see:

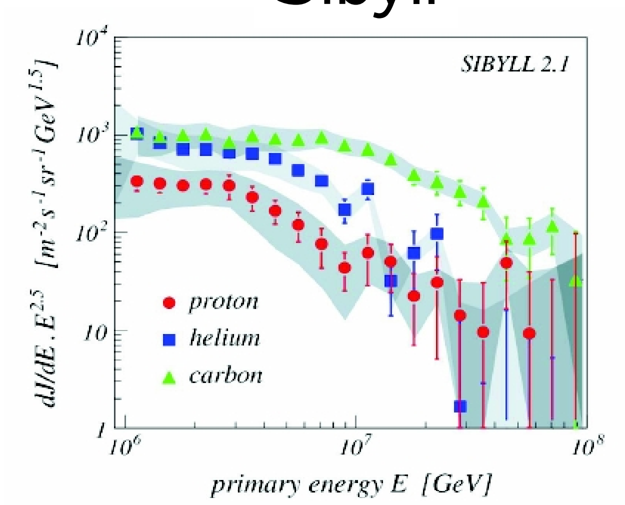
KASCADE Collaboration,
Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

Particles Spectra

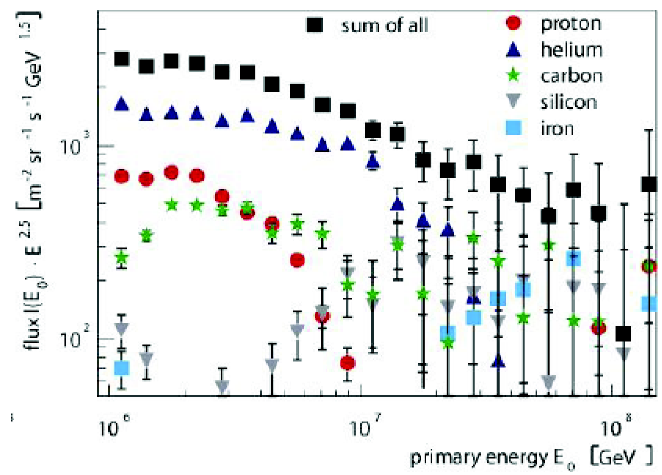


Light elements

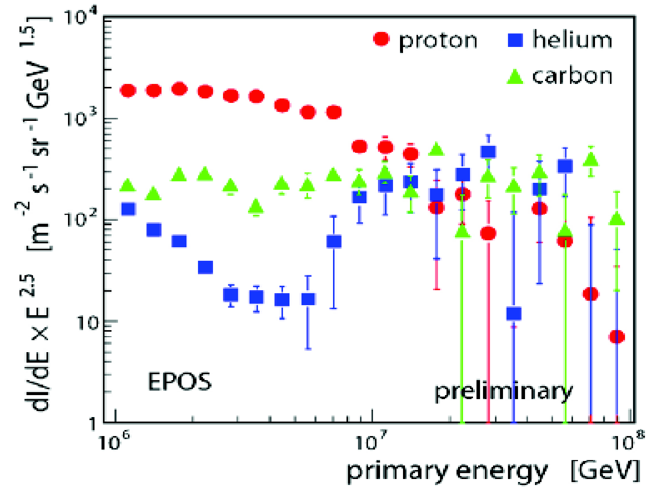
Sibyll



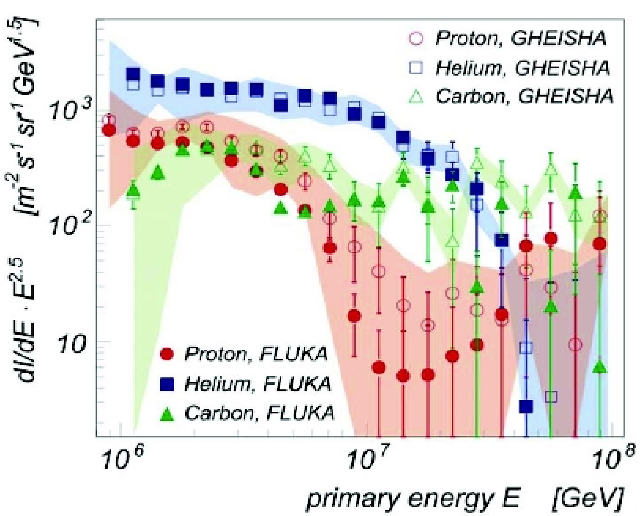
QGSJet 01



EPOS

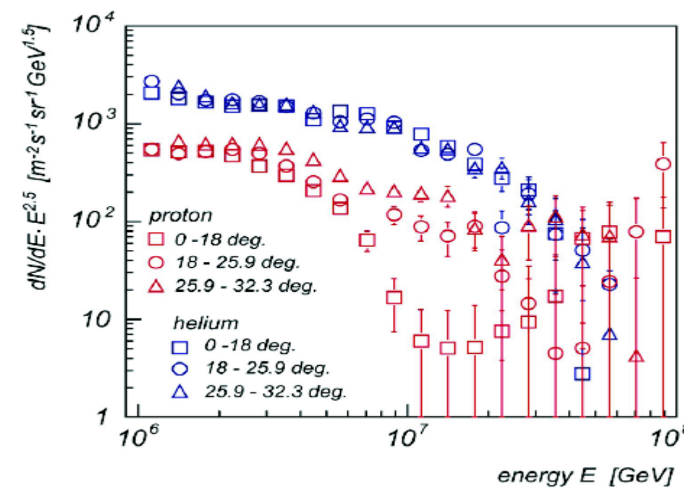


GHEISHA/FLUKA



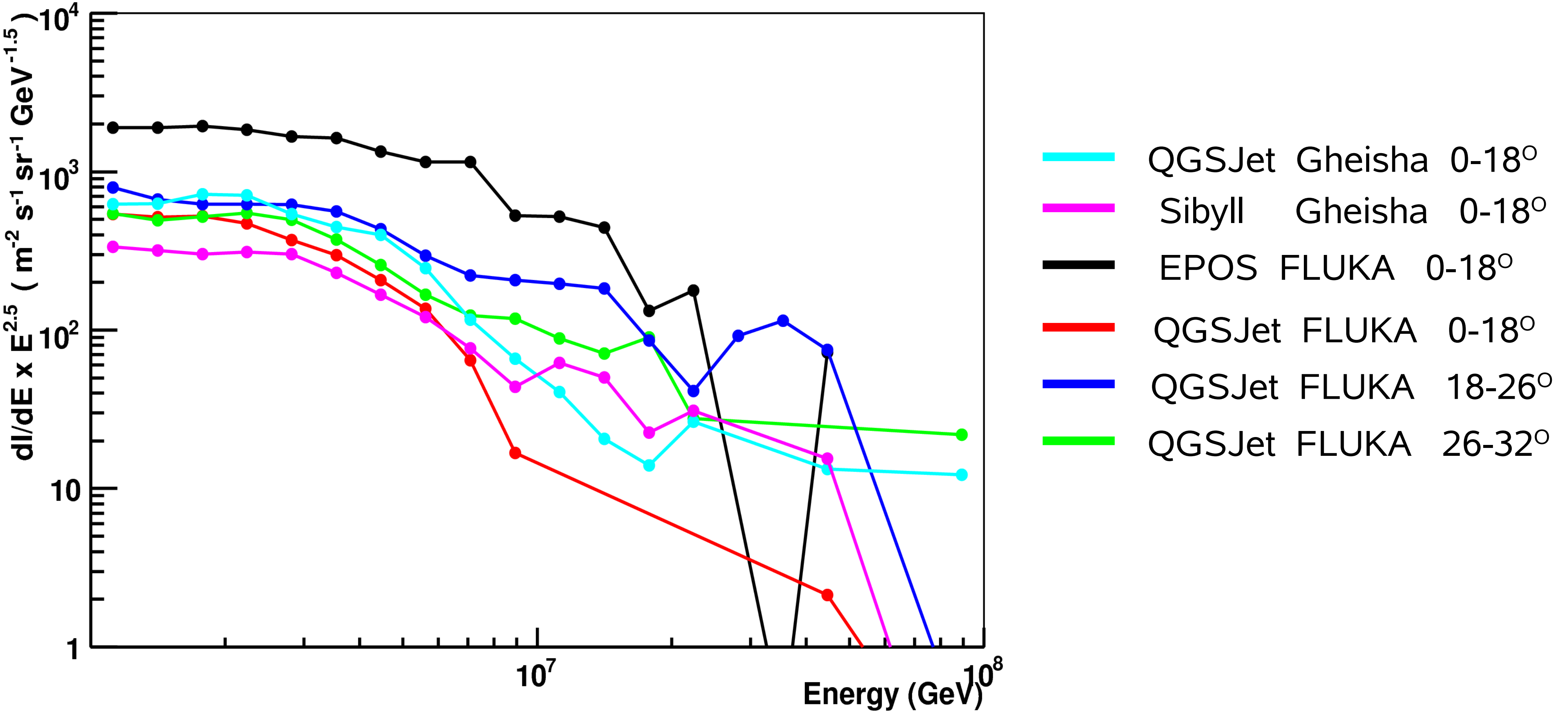
FIRST KNEE IS CAUSED BY THE DECREASING FLUX IN THE LIGHT COMPONENT

ZENITH ANGLE

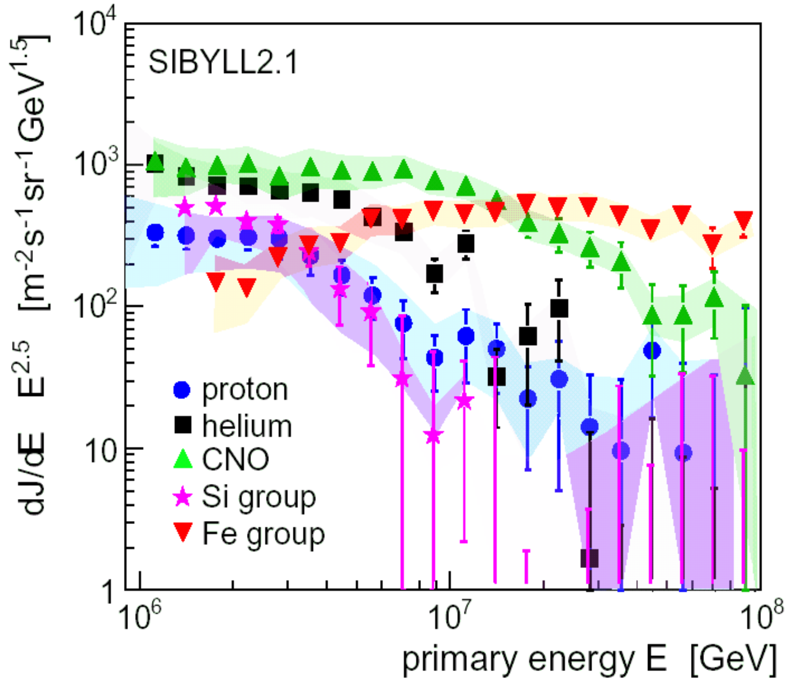


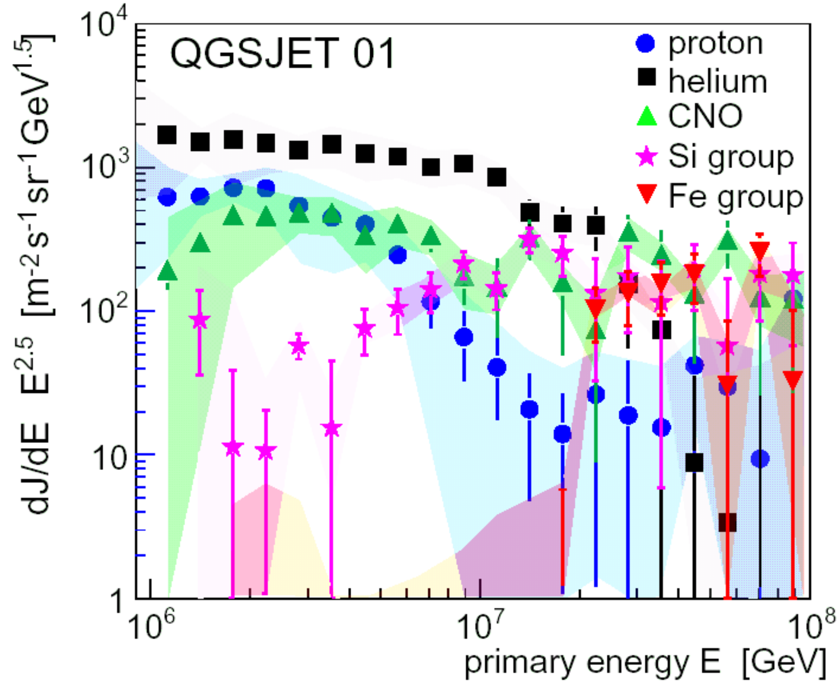
Proton Flux

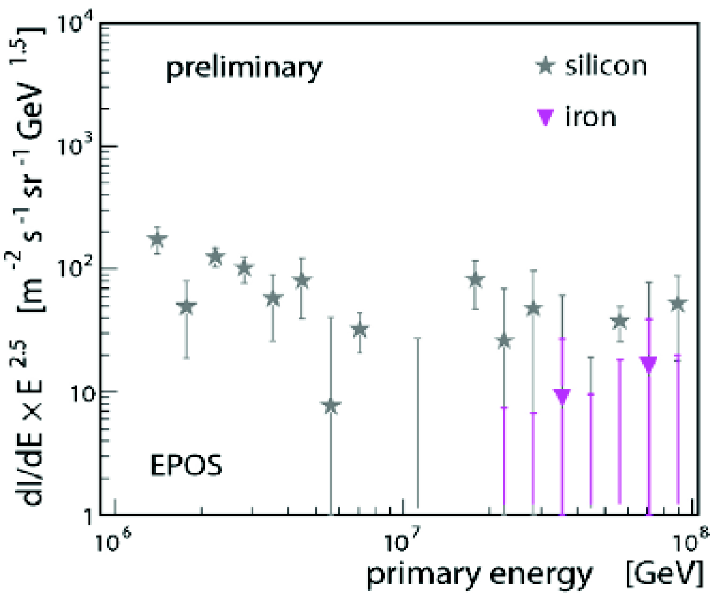
First knee is caused by the decreasing flux in the light component



Heavy elements







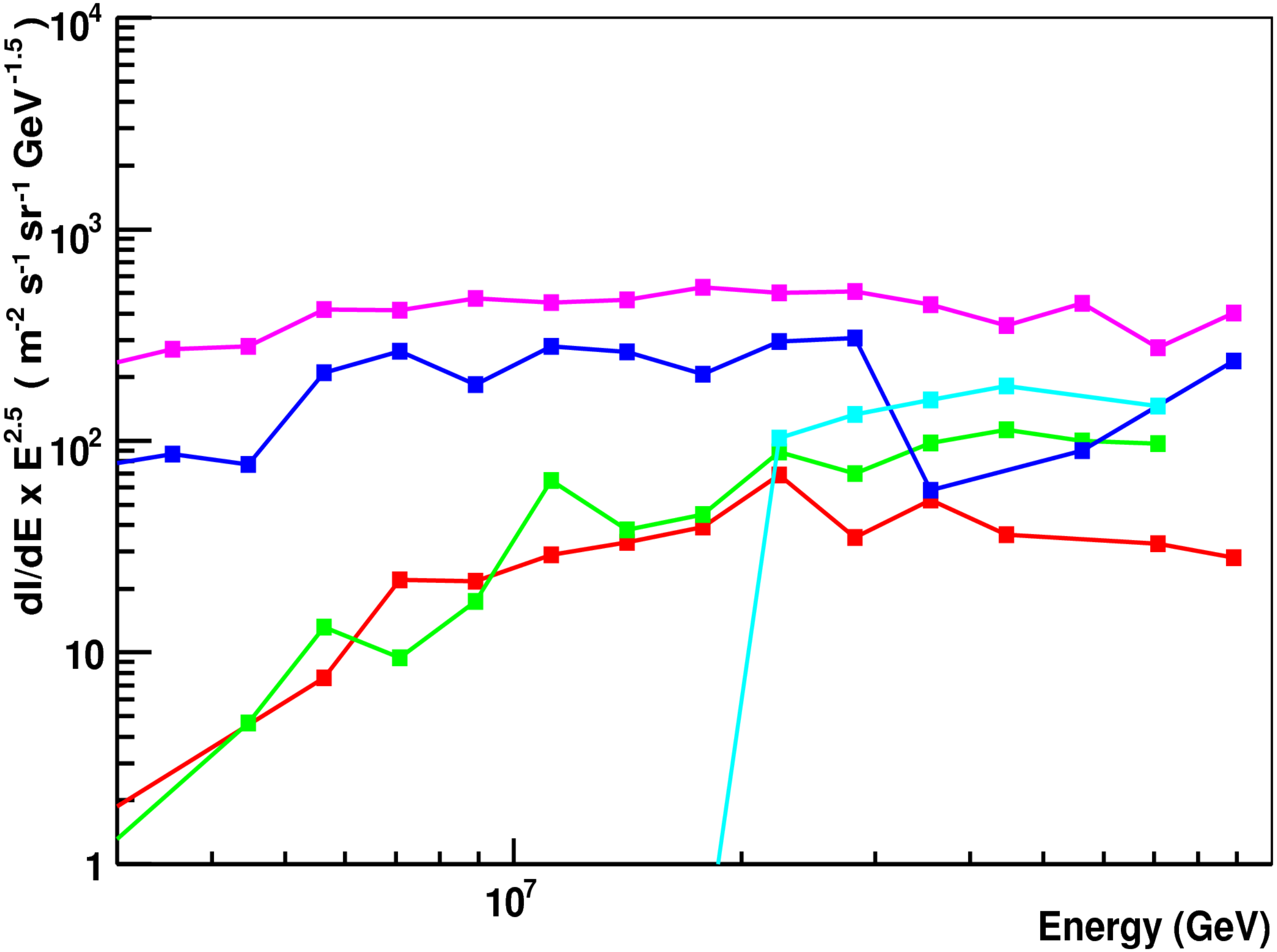
LARGER DEPENDENCE ON HADRONIC INTERACTION MODEL

Iron Flux

Few events

Larger dependence on models

Iron flux seems not to decrease up to 10^{17} eV.



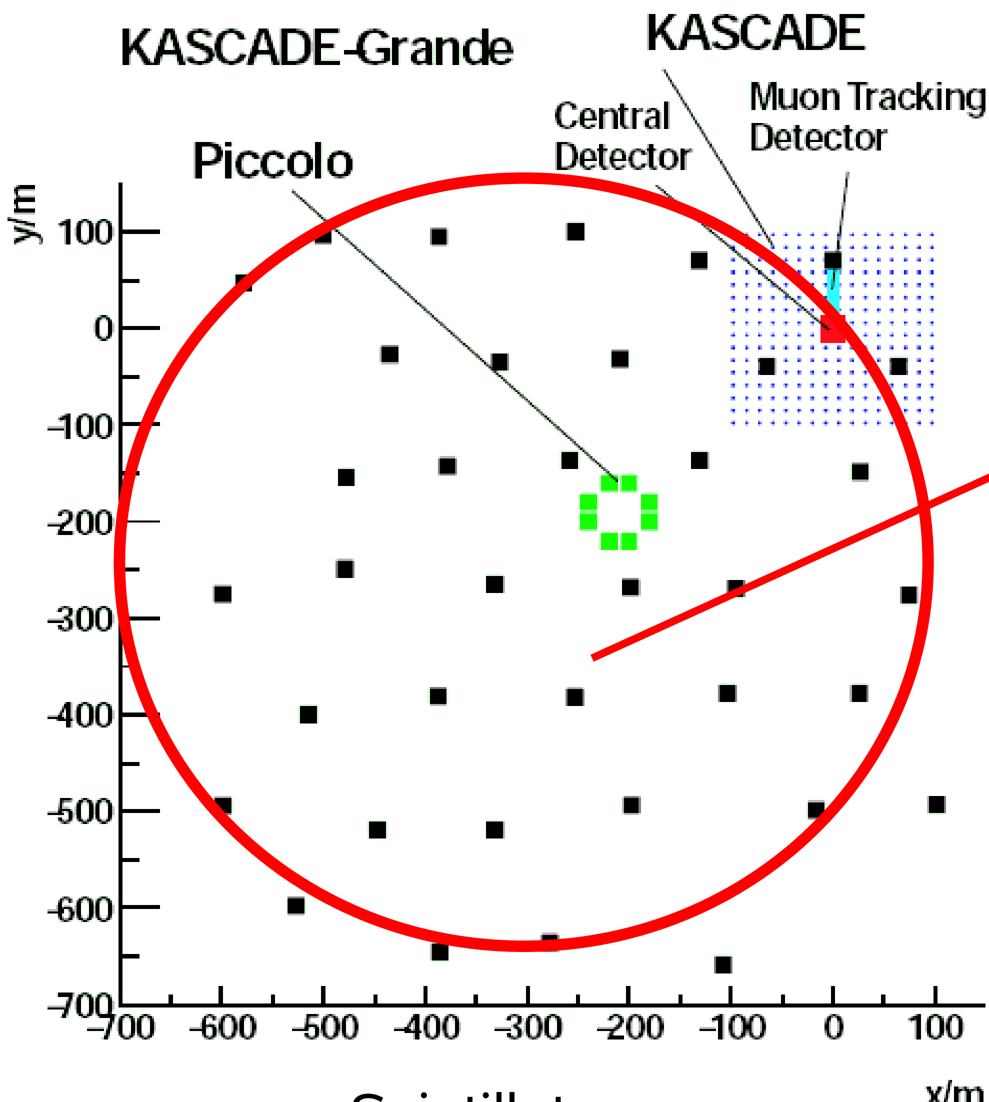
EPOS FLUKA 0-18°

NO IRON

FIRST KNEE IS WELL MEASURED

LET'S GO FOR THE SECOND KNEE

The Detectors: KASCADE-Grande



Scintillators
Detects the Charged Particles

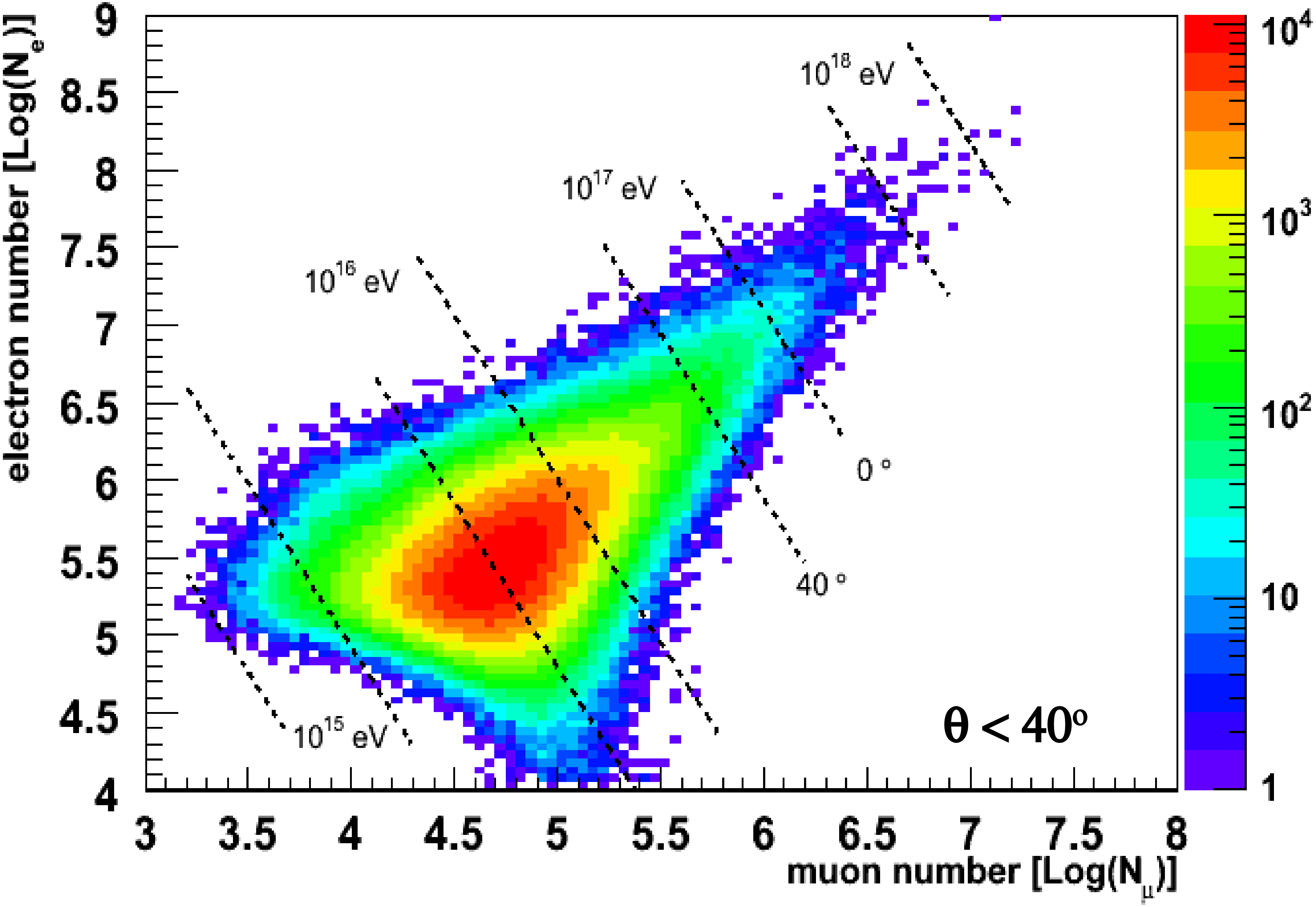
2.5 year of data

Preliminary results

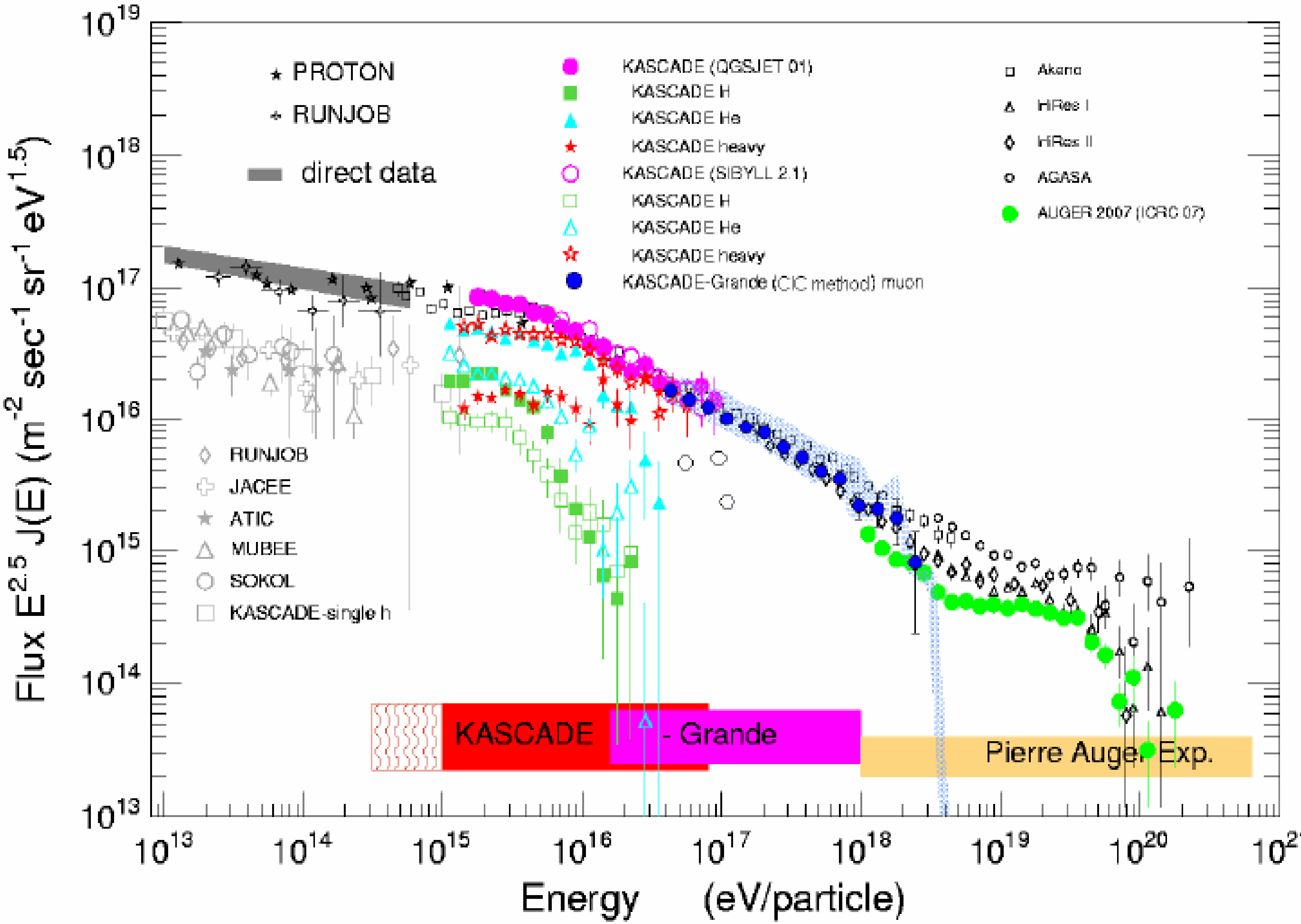
Analysis in progress

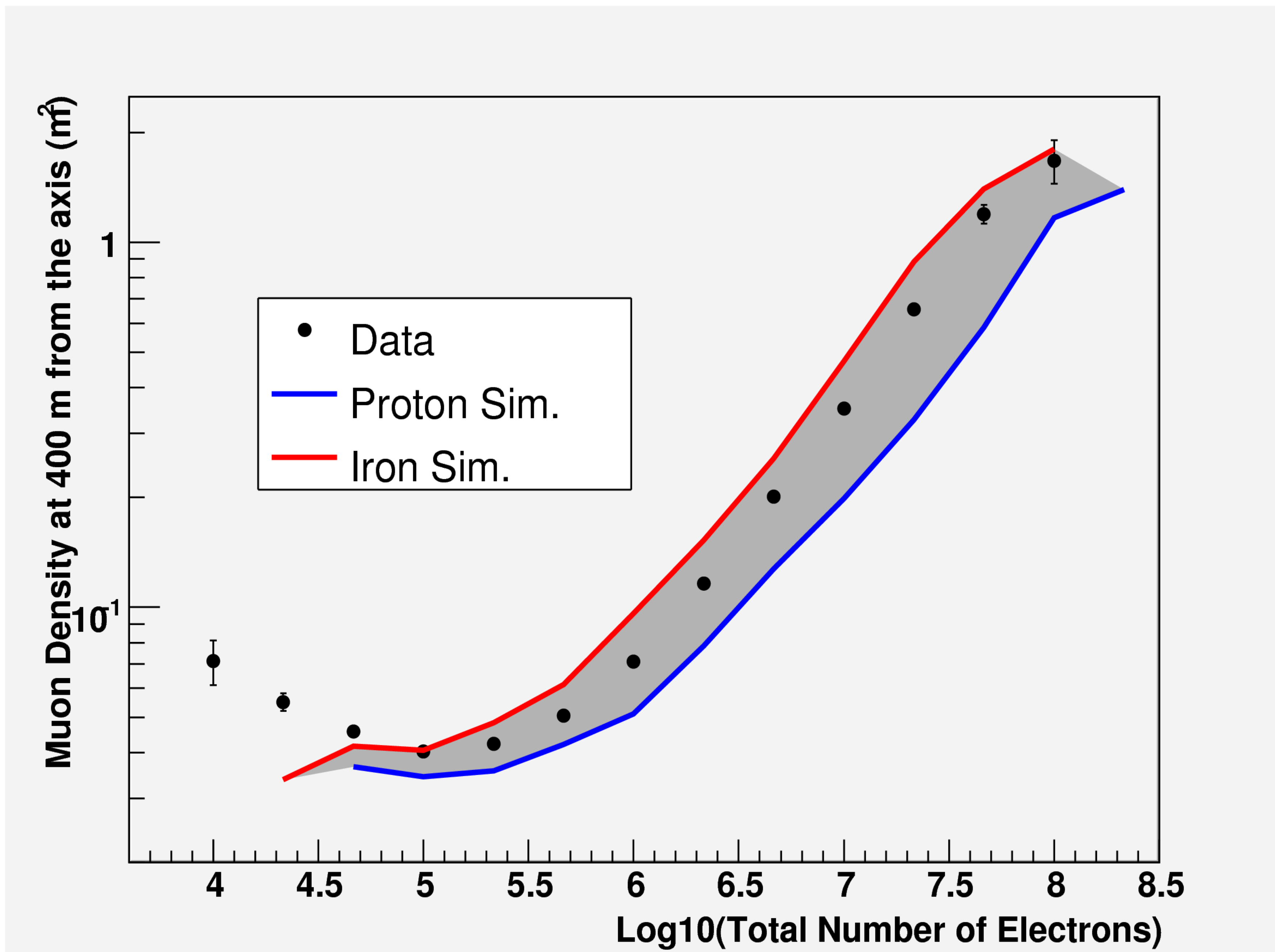
2×10^6 events

Basis for composition



Energy Spectrum





V. de Souza, ICRC 2007

CORSIKA (QGSJet II)

Second knee is being studied

The data is good

News coming soon

HADRONIC INTERACTION MODELS

EPOS

SIBYLL

QGSJET

Test of hadronic interaction models

Idea: perform full simulations (air shower & detector) using
CORSIKA & GEANT3
Check consistency of results for extreme assumptions (p & Fe induced showers)
Check all air shower components:
electromagnetic, muonic, and hadronic

QGSJET 98 VENUS SIBYLL 1.6	J. of Phys. G: Nucl. and Part. Phys. 25 (1999) 2161
DPMJET II.55 QGSJET 01 SIBYLL 2.1 NEXUS 2	DPMJET II.5 J. of Phys. G: Nucl. and Part. Phys. 34 (2007) 2581
EPOS 1.6	today

J. Hörandel

Test of hadronic interaction models

Idea: perform full simulations (air shower & detector) using
CORSIKA & GEANT3
Check consistency of results for extreme assumptions (p & Fe induced showers)
Check all air shower components:
electromagnetic, muonic, and hadronic

QGSJET 98
~~VENUS~~
~~SIBYLL 1.6~~

J. of Phys. G: Nucl. and Part. Phys. 25 (1999) 2161

DPMJET II.55
QGSJET 01
SIBYLL 2.1
~~NEXUS 2~~

~~DPMJET II.5~~

J. of Phys. G: Nucl. and Part. Phys. 34 (2007) 2581

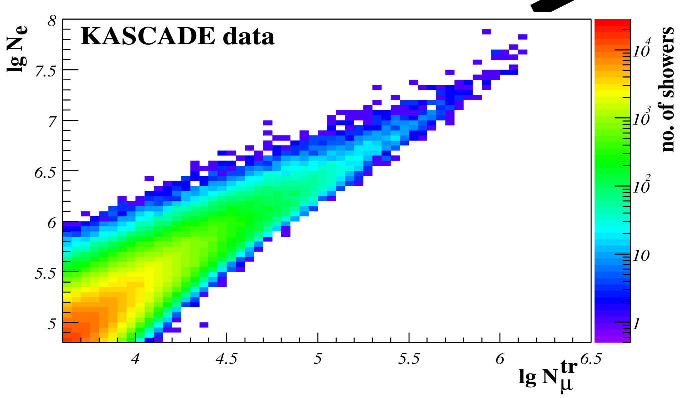
EPOS 1.6

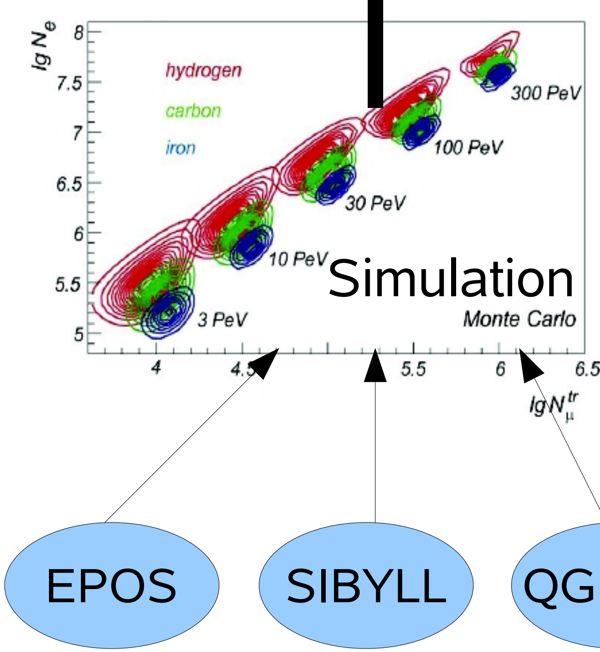
today

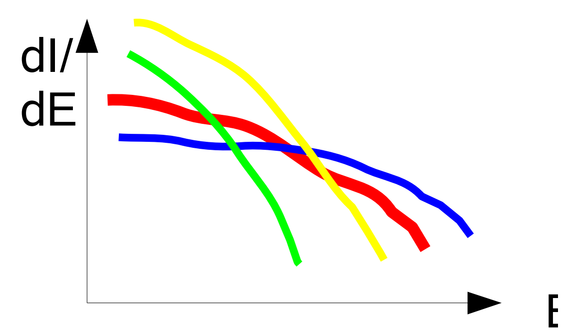
J. Hörandel

Unfolding: Math

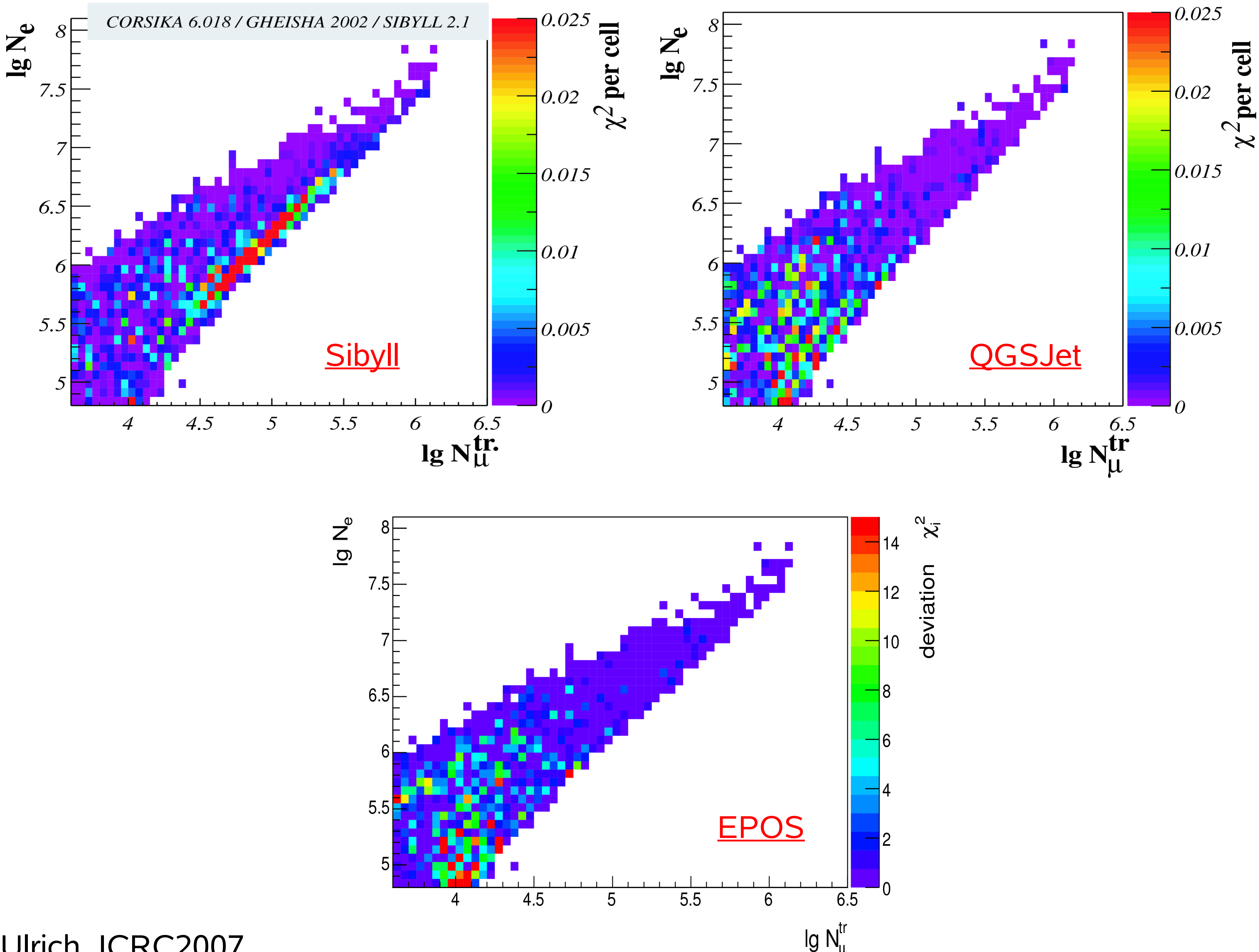
$$\vec{Y} = R \ \vec{X}$$







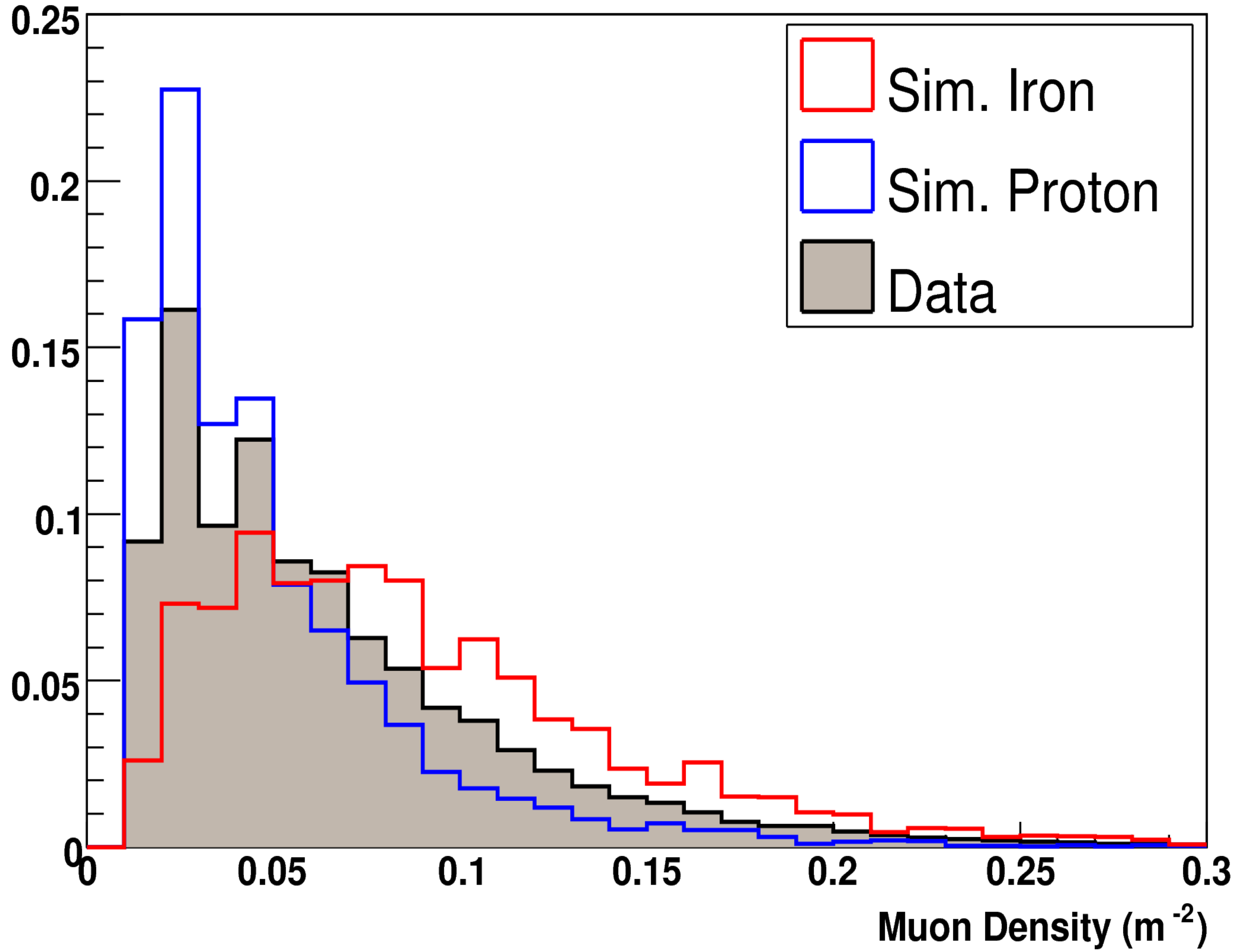
Calculate a Chi-square for each model



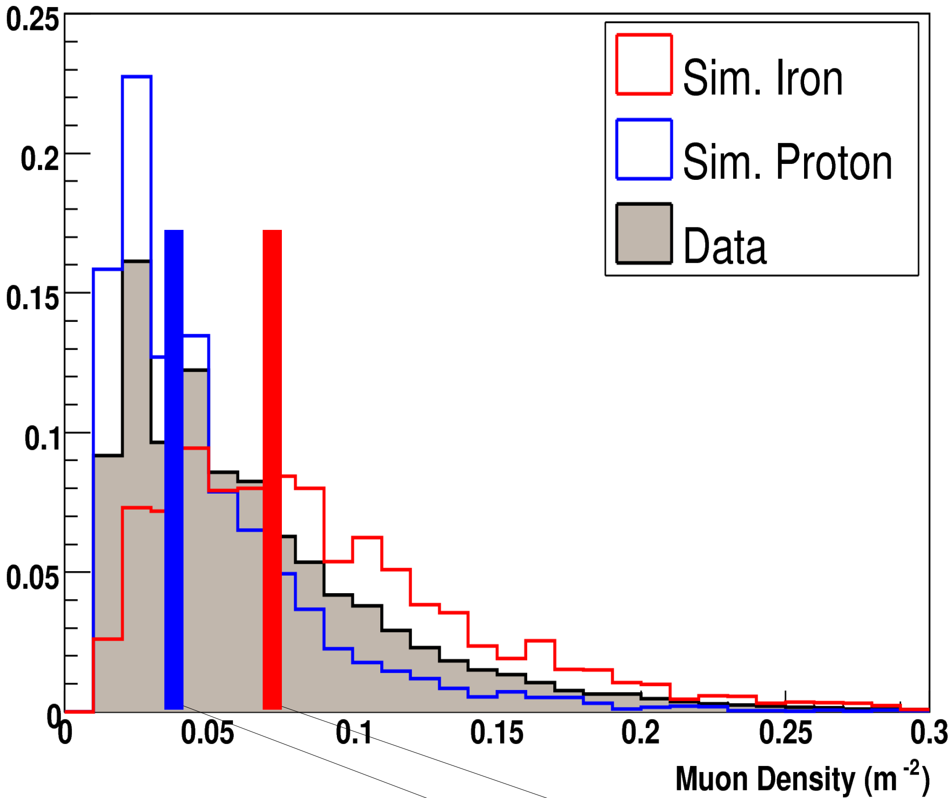
H. Ulrich, ICRC2007

Hadronic Interaction Models

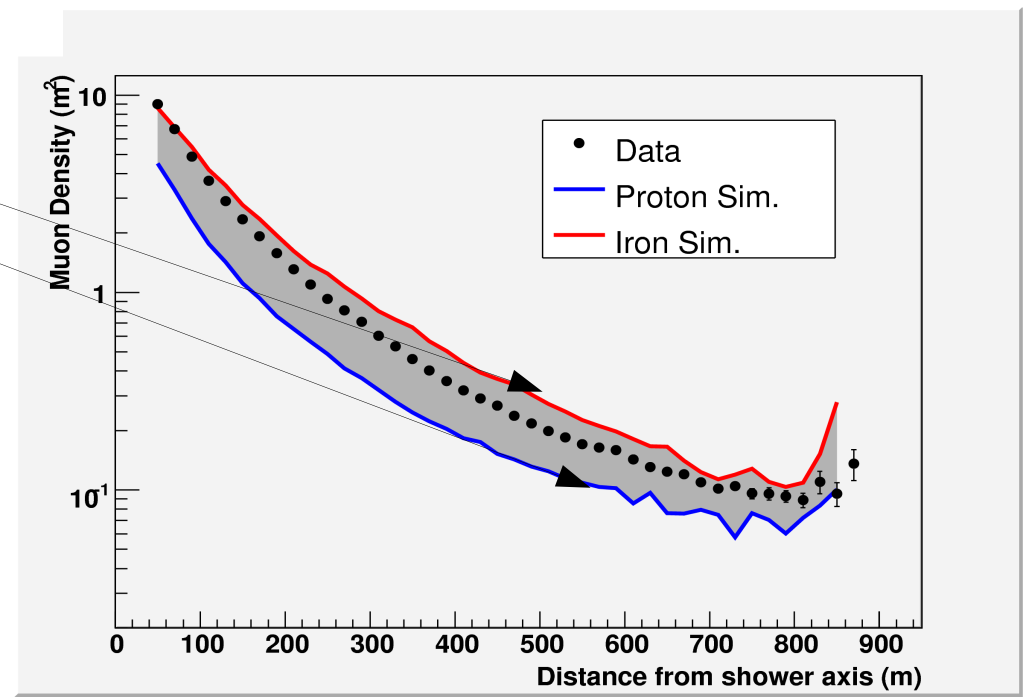
- Muon density measured by KASCADE
- Direct measurement
- Bins of 20 meters distance of the shower axis
- Minor dependency on LDFs fit
- Total number of electrons and energy are used only for binning purposes



CORSIKA (QGSJet II)



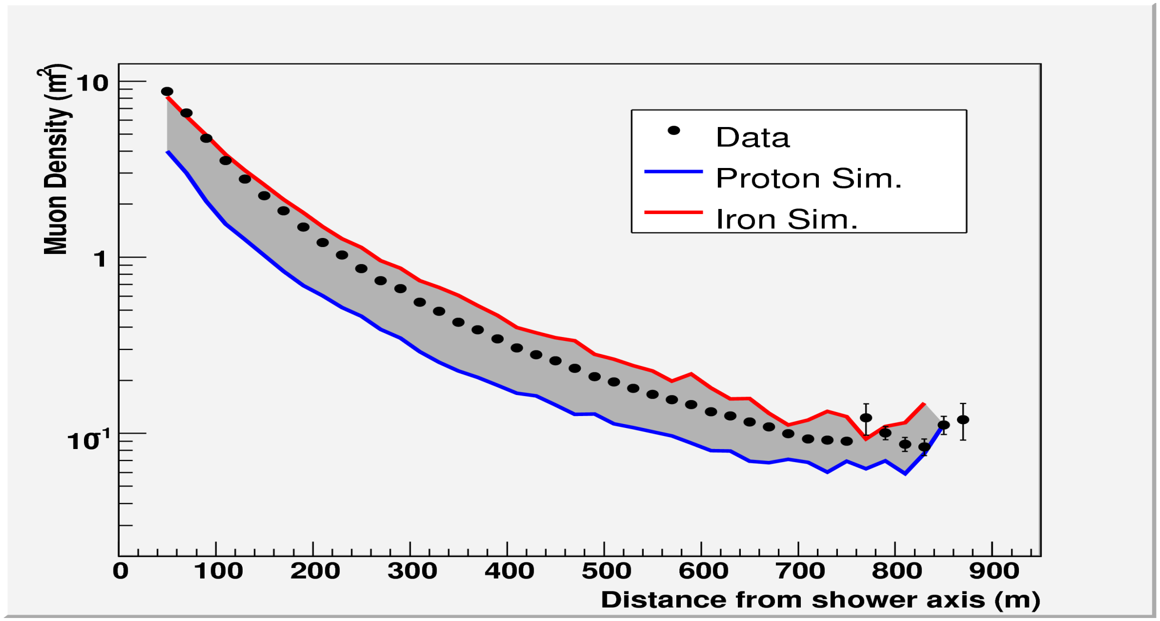
Evolution of mean values. Error bars gives the error of the mean.



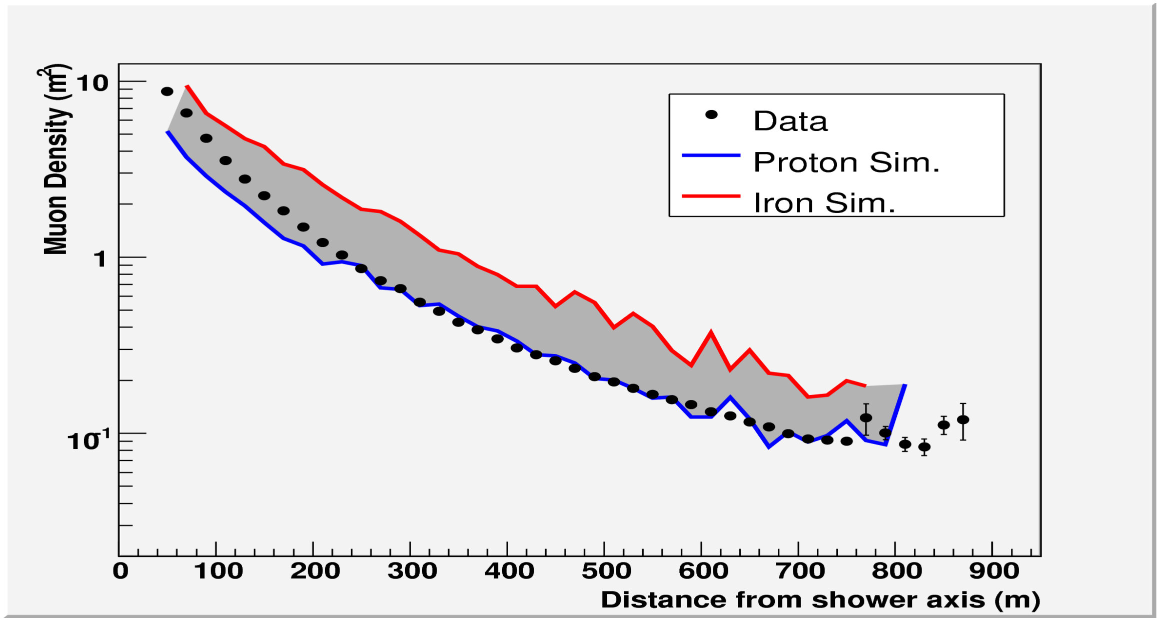
Mean limit of the simulation

Hadronic Interaction Models

QGSJet II



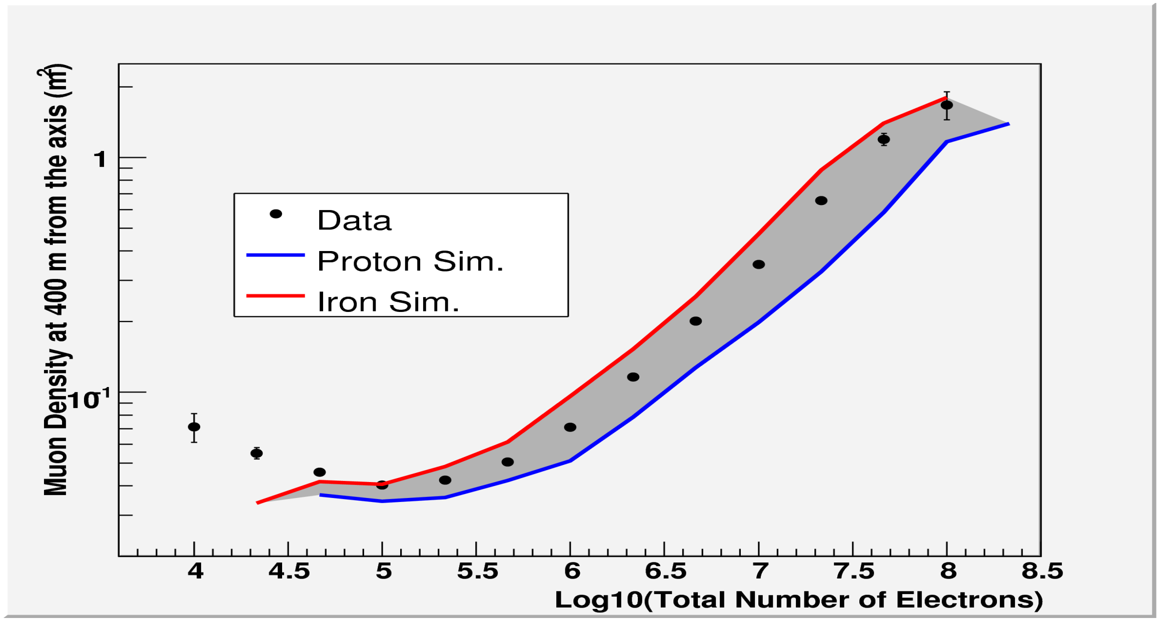
EPOS



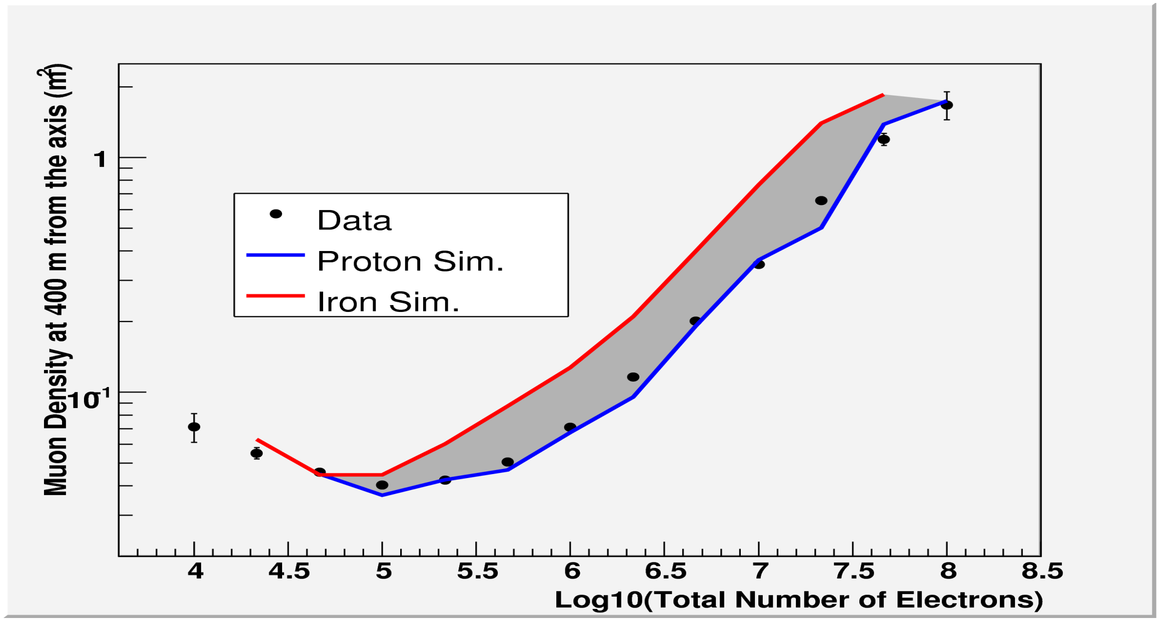
7.0 < Log10 (Number of Electrons) < 7.3

Hadronic Interaction Models

QGSJet II



EPOS

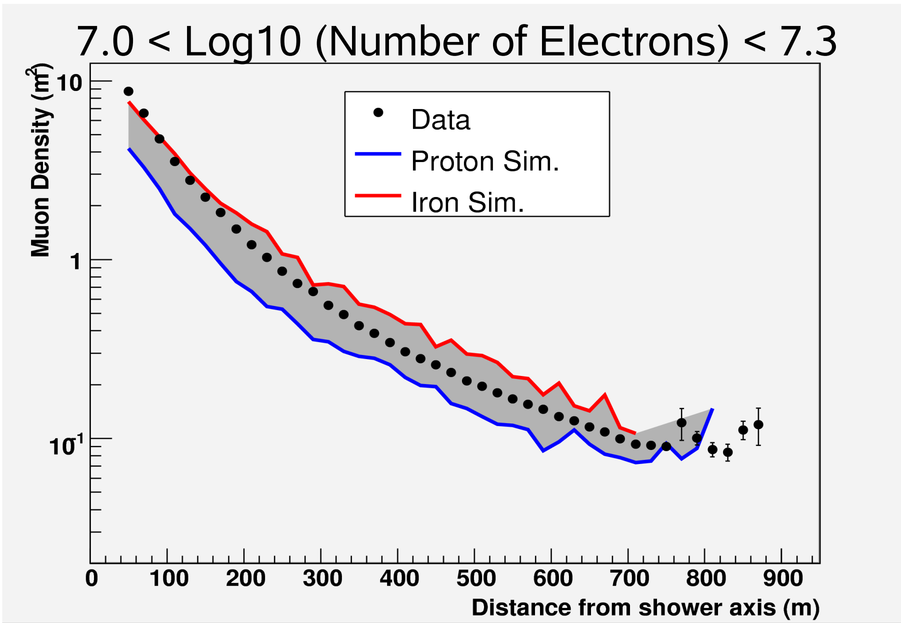


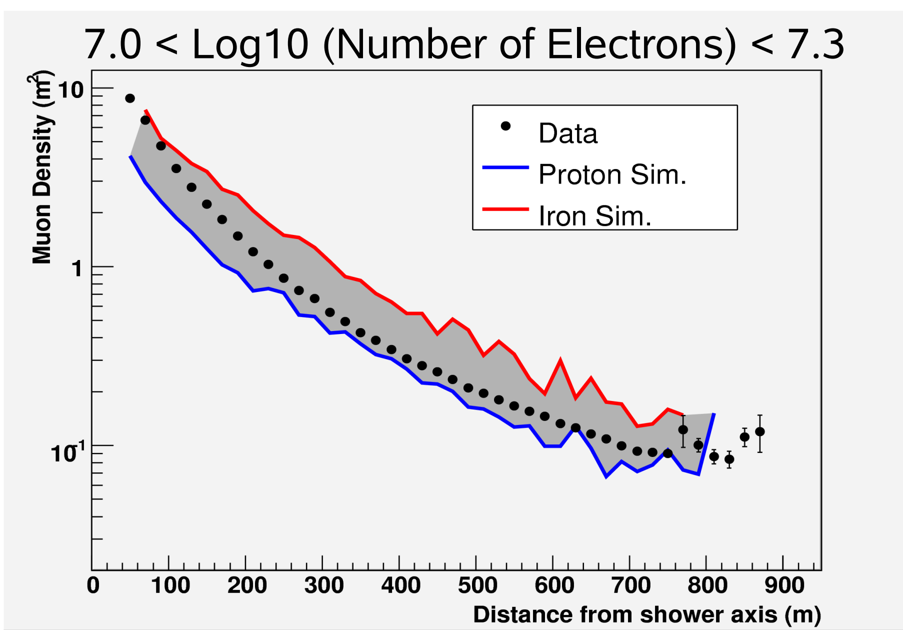
Remark

EPOS can not describe the muon data

QGSJet II is in good agreement with the muon data

Hints for EPOS





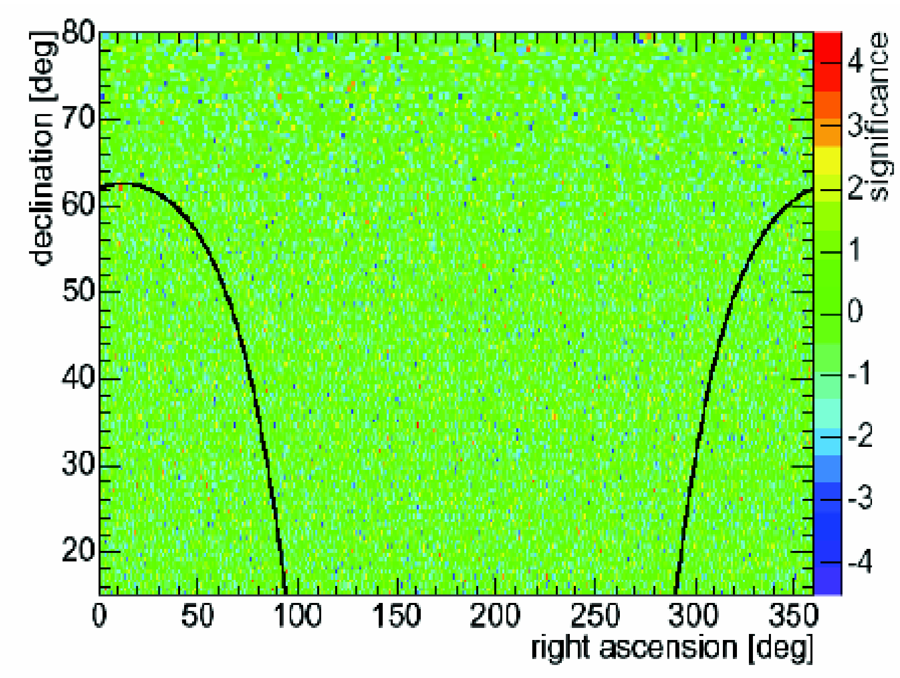
Electrons up by 50 %

Arbitrary Shift

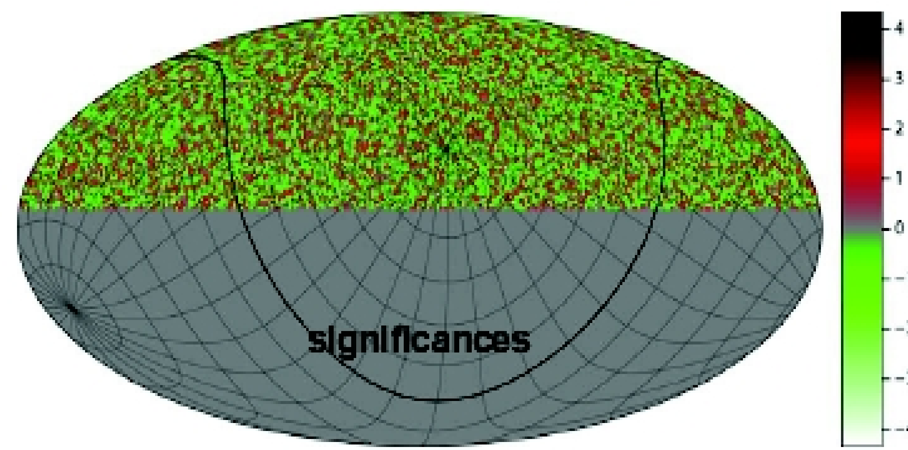
Muons down by 20 %

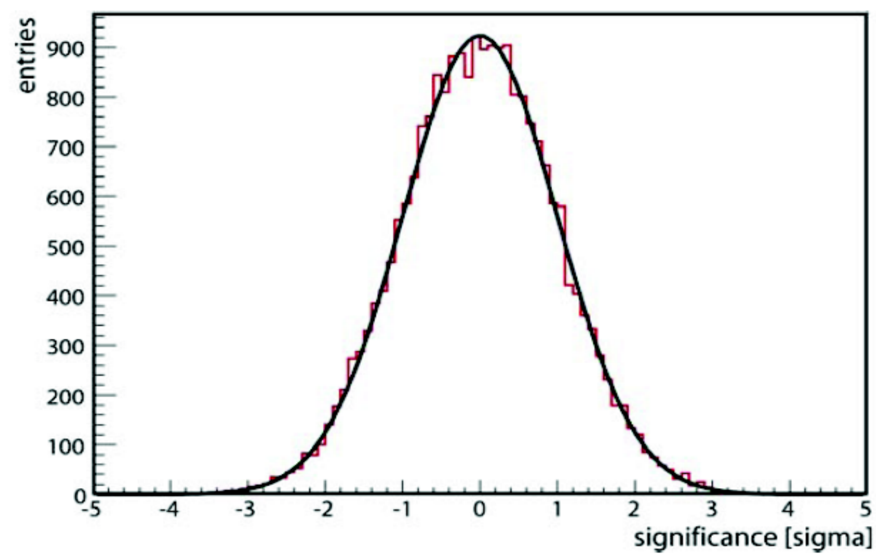
Anisotropy

KASCADE



GRANDE



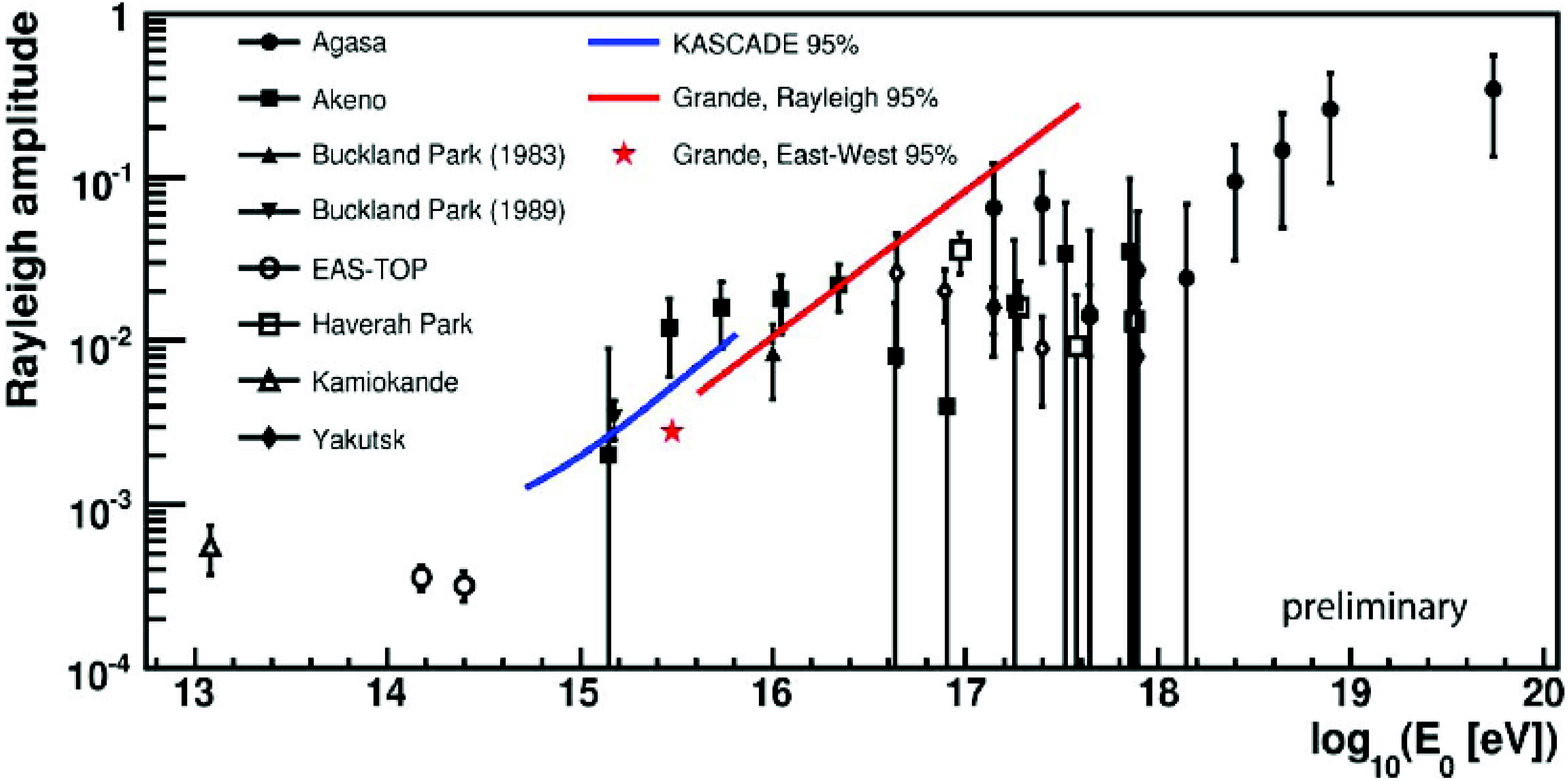


Significance distribution

NO POINT SOURCES

$10^{15} < E < 10^{18}$ eV

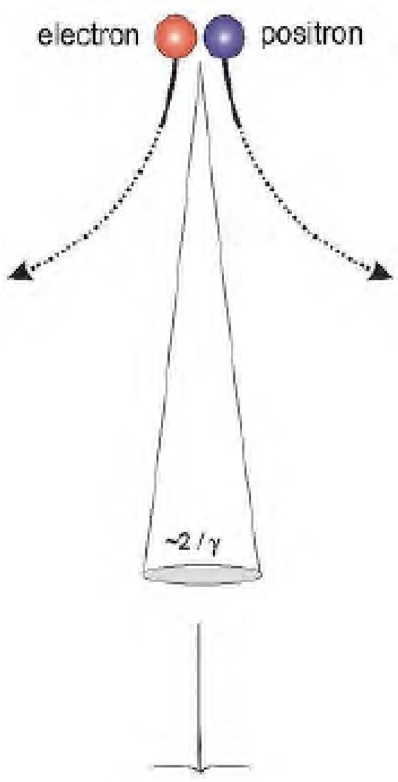
Anisotropy



NO LARGE SCALE ANISOTROPY

S. Over, ICRC2007

Radio Emission



- Charge separation in Earth‘s magnetic field

classical electric dipole

- Gyration of particles

emission of synchrotron radiation

- Particles are in a shower thin disk

coherent emission

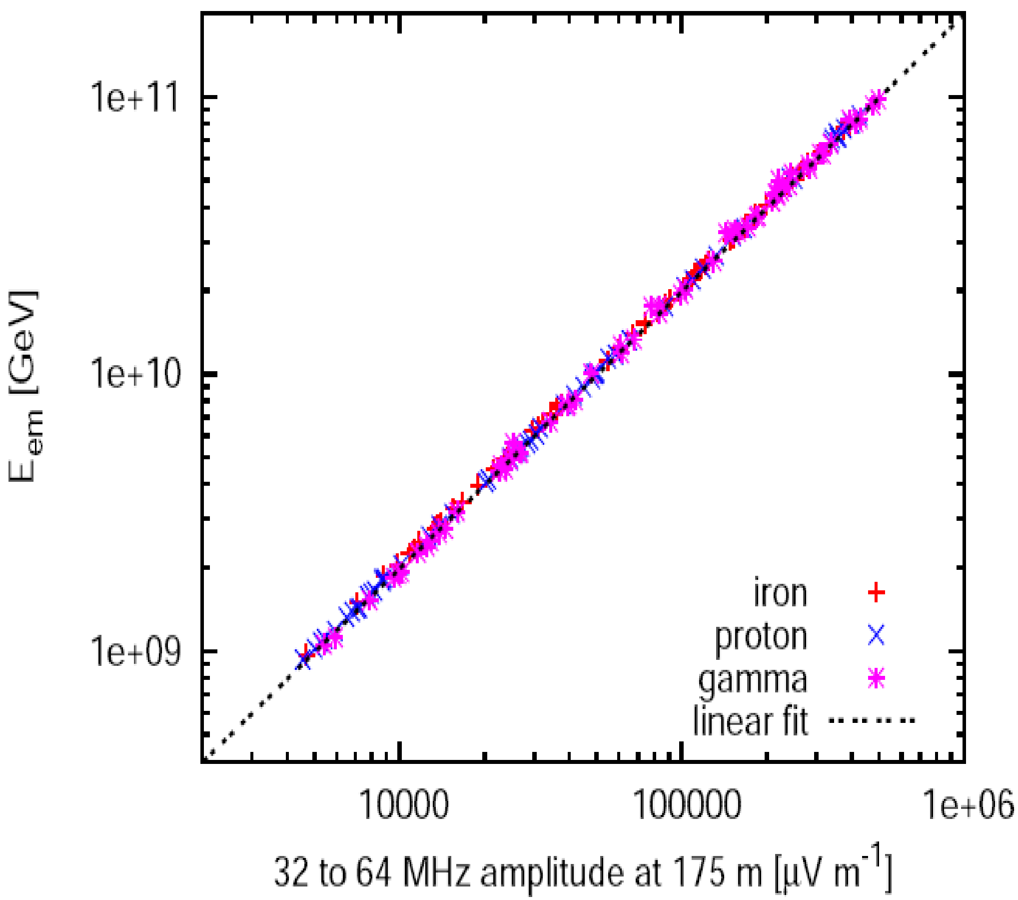
beamed into propagation direction

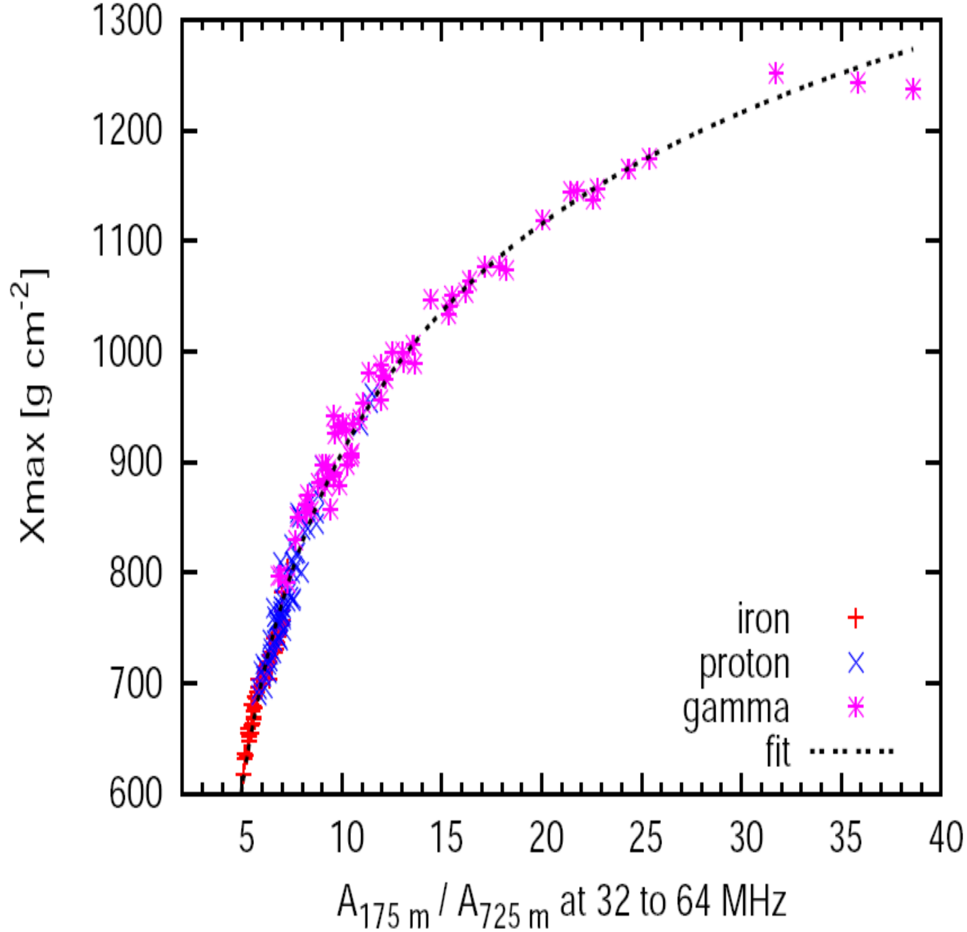
- Timescales for pulses are relativistically shortened

pulse 10-100 ns

Radio Signal

Monte Carlo simulation





Energy reconstruction

Composition

T. Huege et al. astro-ph 0806.1161

Hardware of LOPES

LOPES-Antenna

• short dipole
• beamwidth 80°-120° (parallel/ perpendicular to dipole)

Receiver Module

• direct sampling with minimal analog parts: amplifier, filter, AD-converter
• sampling with 80MSPS in the 2nd Nyquist domain of the ADC

Memory Buffer

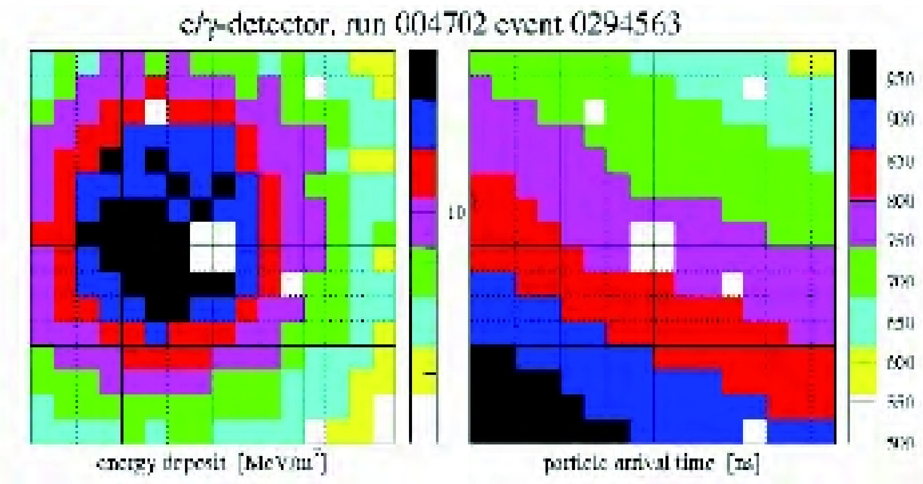
• uses PC133-type memory
• up to 6.1 s per channel
• pre- and post-trigger capability

Clock and Trigger Board

• generates and distributes clock and accepts and distributes trigger

First light

KASCADE

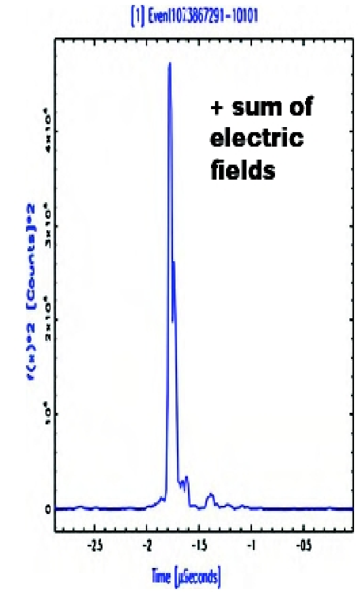


Energy ≈ 10^{17}eV

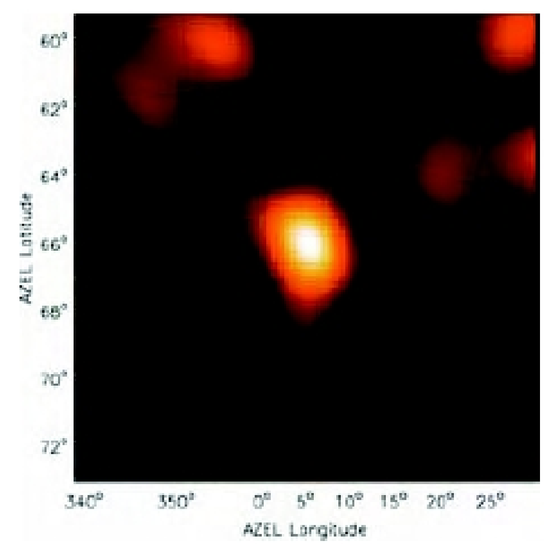
Core surrounded by antennas

$\Theta = 25.5^{o}$, $\Phi = 42.5^{o}$

TRIGGER

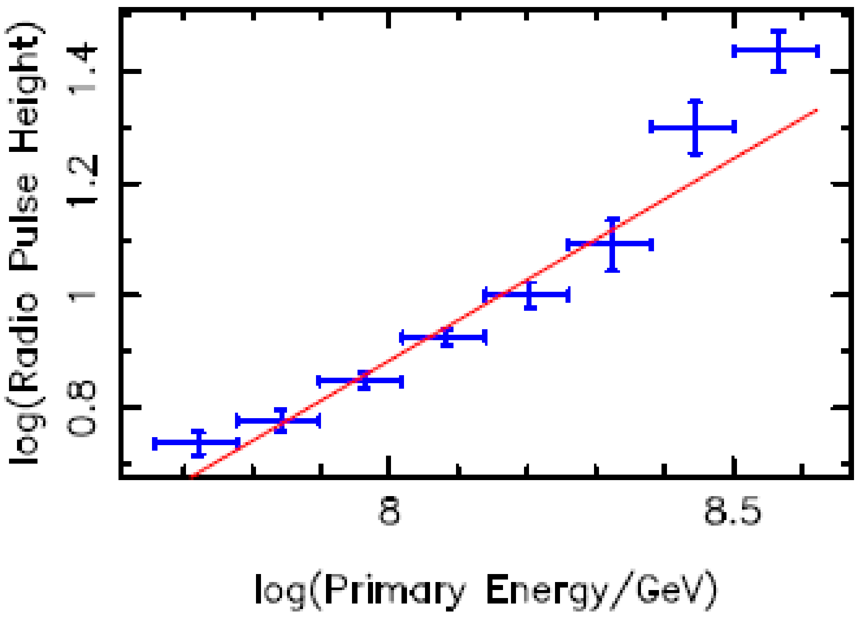


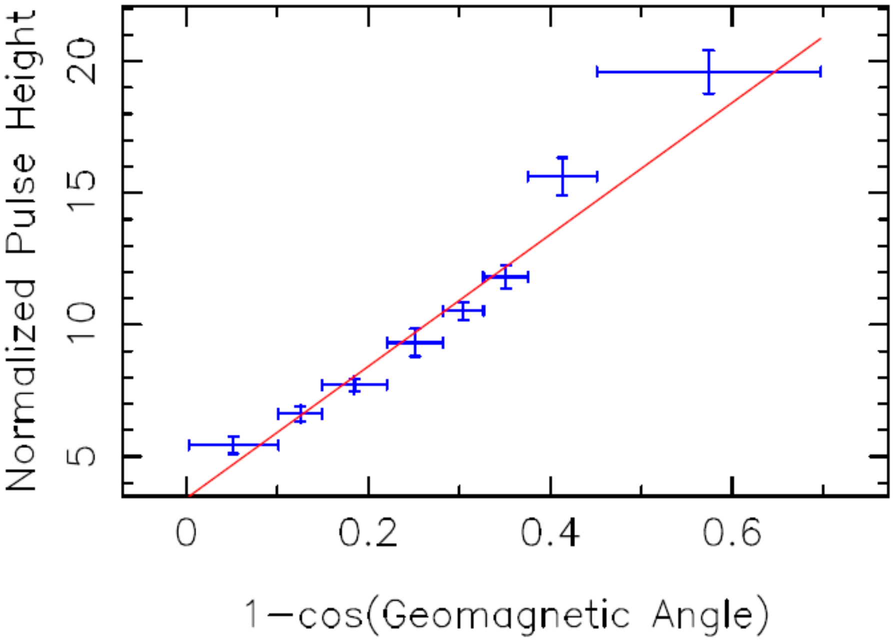
LOPES Collaboration, Nature 425 (2005) 313



LOPES

LOPES Results





<u>LOPES References:</u>

A. Saftoiu et al., ICRC 2007

Petrovic et al., A&A 462 1 (2007) 389

Apel et al., Astrop.Phys. 26 (2006) 332

Horneffer et al., ICRC 2005

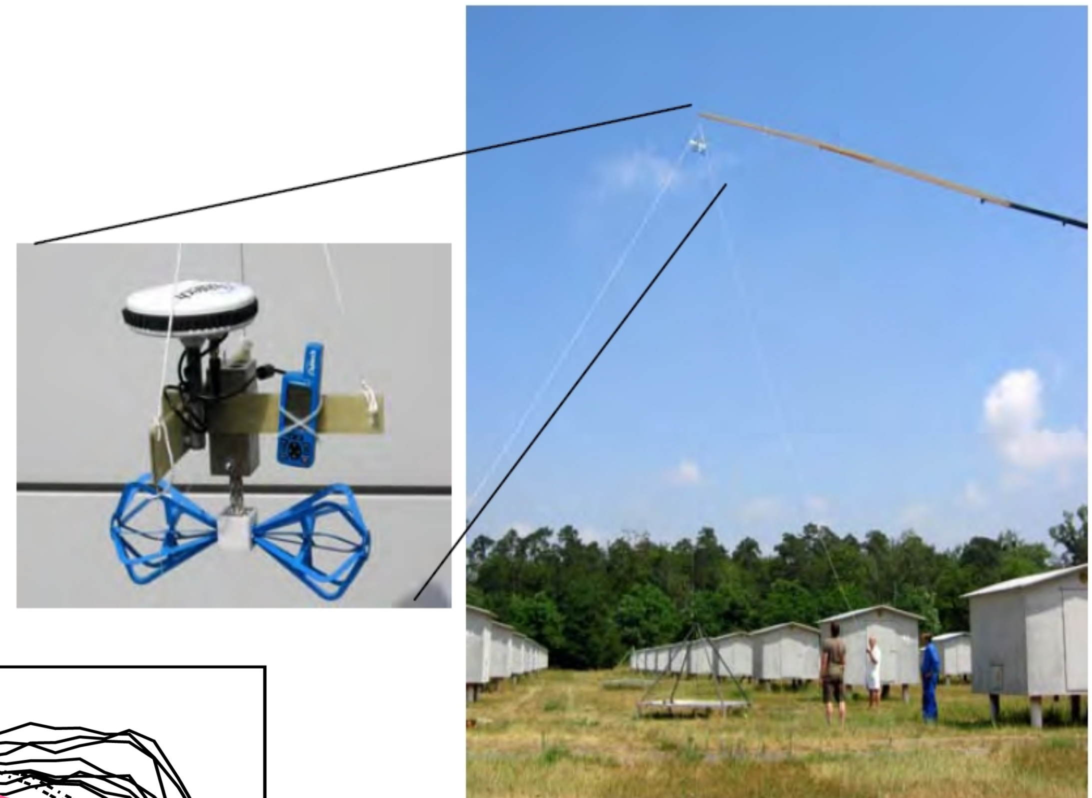
LOPES 30

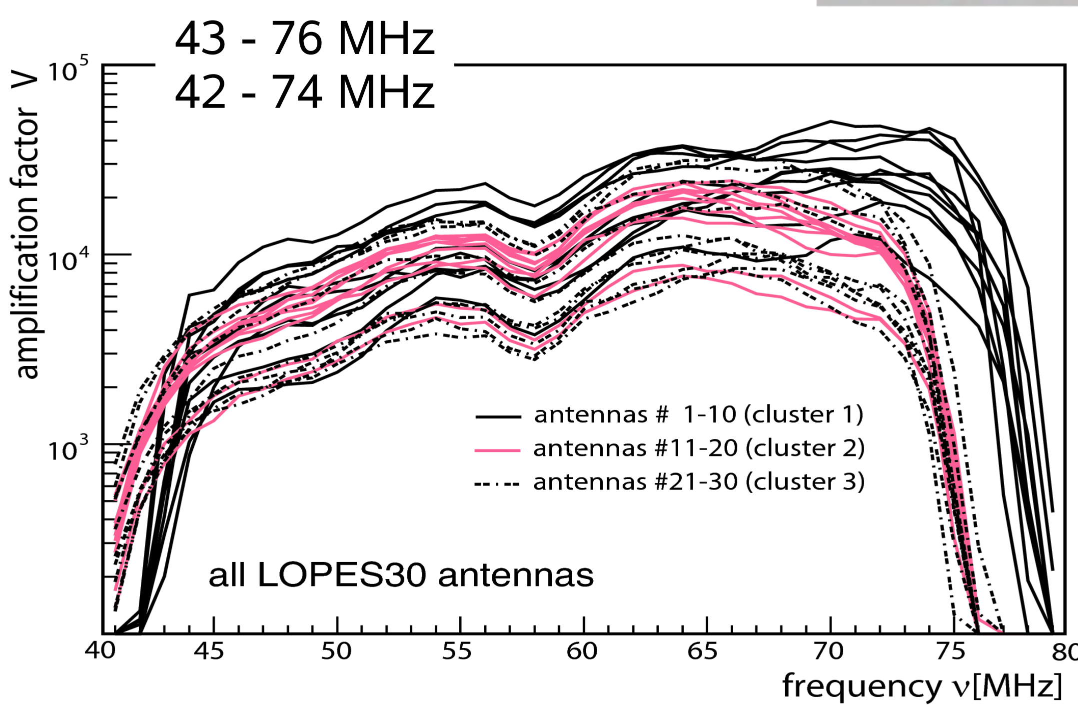
30 antennas

Absolute Calibration

Trigger from:

KASCADE + Grande



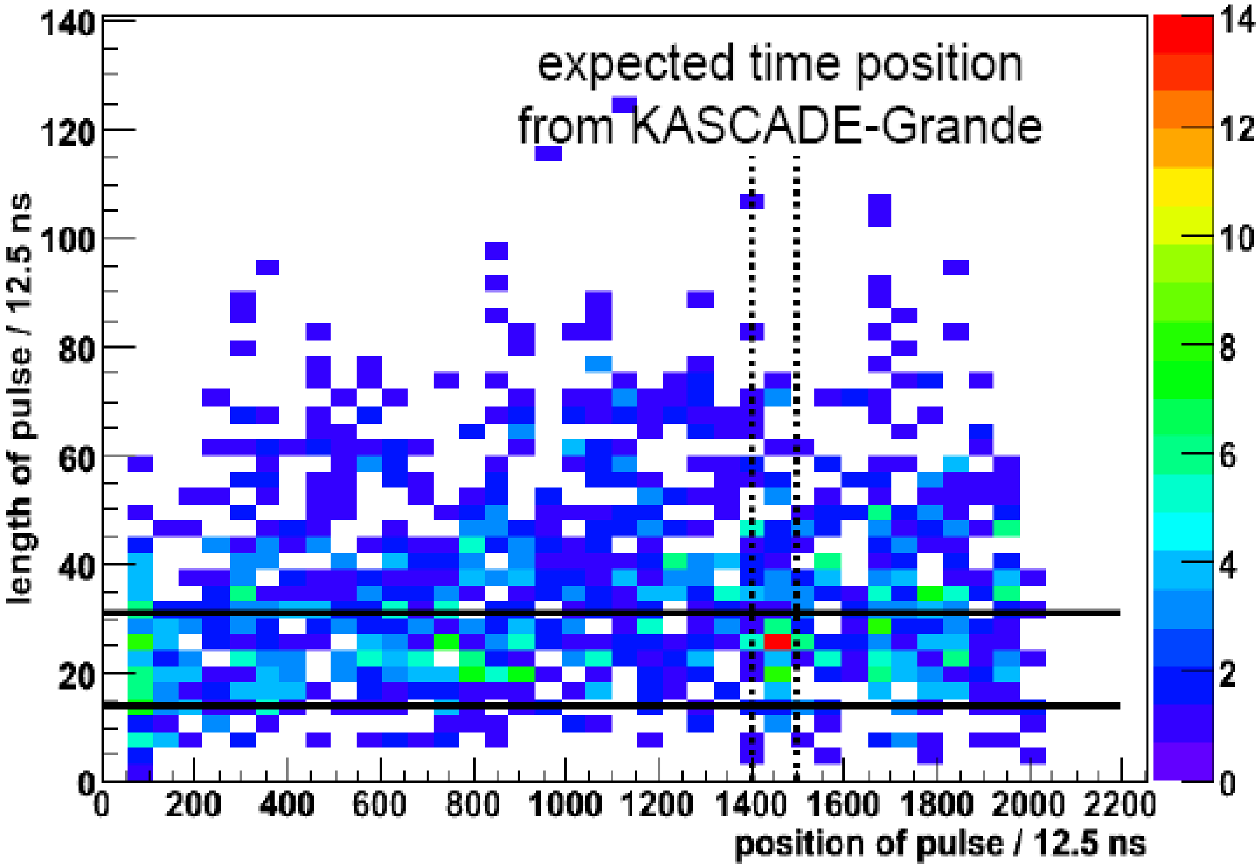


G. Isar et al., ICRC2007

S. Nehls et al., ICRC2007

T. Asch, ICRC2007

LOPES STAR



27 days of data

102000 Triggers

12 Selected Candidates

5 Correlates with KASCADE-Grande events

Final Remarks

- Independent analysis show the decrease of the light component flux
  - lateral distribution of muon
  - total muon number versus total electron number
  - muon production height
- The knee position vary with the primary particle
- No knee in the iron component was measured but results depends on hadronic interaction model

Final Remarks

- New data from KASCADE-Grande
  - Total number of electron and muon spectra
  - Few events around 10^{18} eV
  - Energy spectrum in agreement with KASCADE
- No anisotropy seen, limits on flux were set
- High level of activity in radio: detection, simulation and analysis.

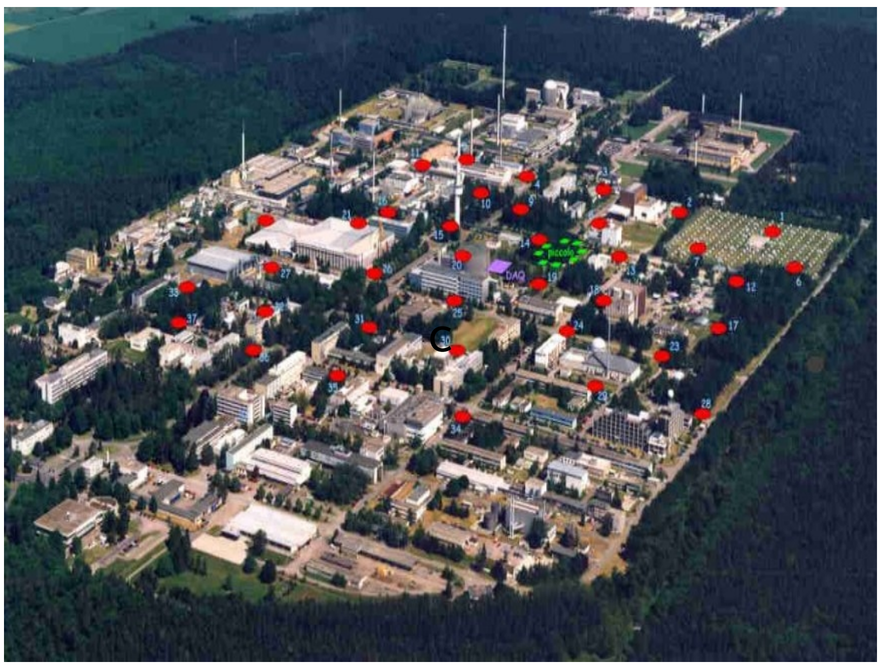
Final Remarks

- Hadronic Interaction Models
  - First knee can be safely studied
  - Second knee might need some new analysis procedures
  - All hadronic interaction models have problems to fully describe the data in a consistent way

Final Remarks

- QGSJet
  - good agreement muon number
  - problems at lower energies to reproduce a combined electron and muon measurements
- Sibyll
  - severe problems to describe the intermediate range (Log10 N_μ ~ 5 and Log10 N_e ~ 6)
- EPOS
  - version 1.6 has problems to describe the data
  - new EPOS version is being prepared

Thanks to the Organizing Committee



KASCADE-Grande

LOPES
RADIO EMISSION FROM COSMIC RAY AIR SHOWERS

Vitor de Souza

vitor@ifsc.usp.br