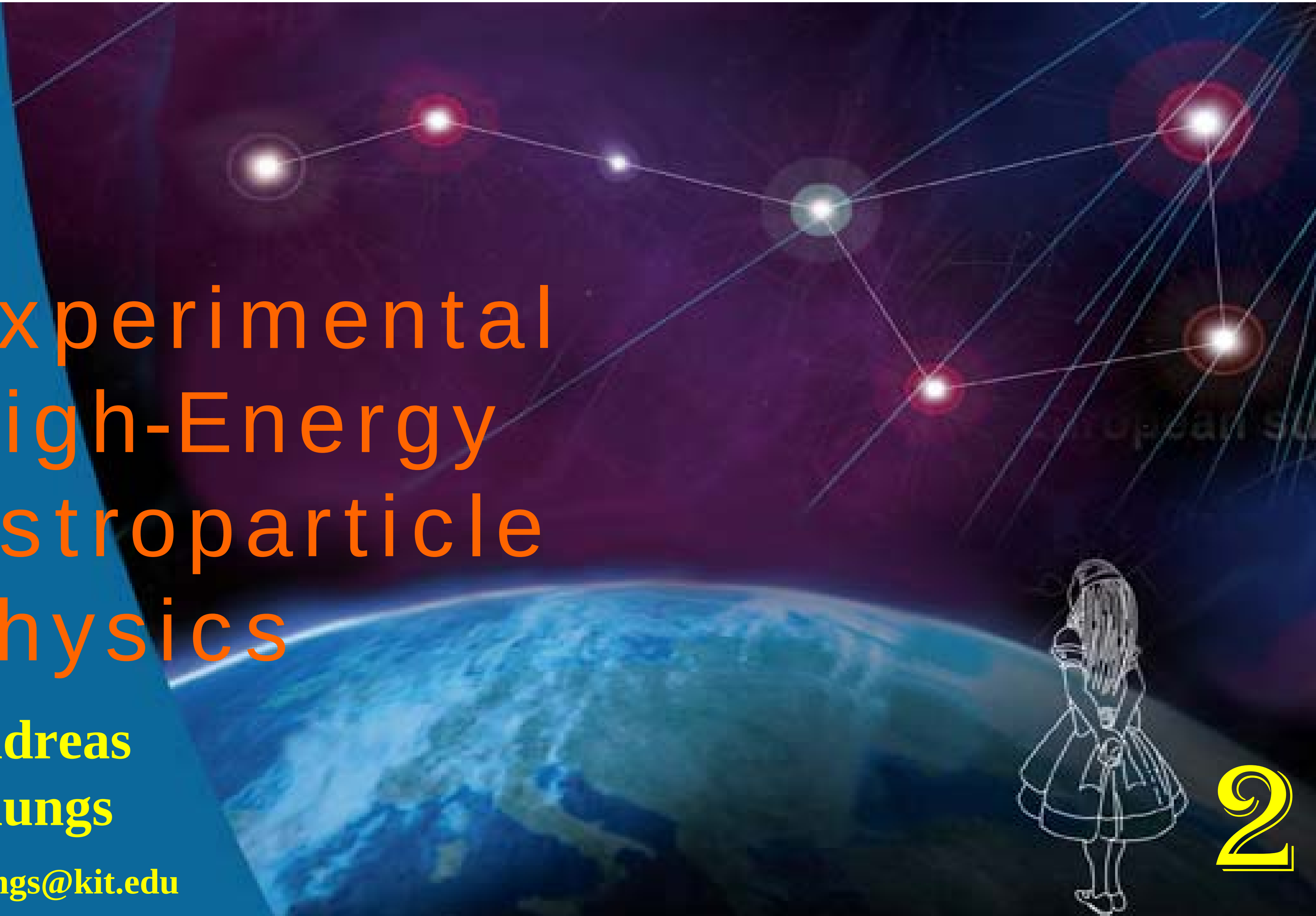
KIT – University of the State of Baden-Württemberg and National Research Center of the Helmholtz Association

Karlsruhe Institute of Technology



Experimental High-Energy Astroparticle Physics

Andreas Haungs

haungs@kit.edu

2

Content:

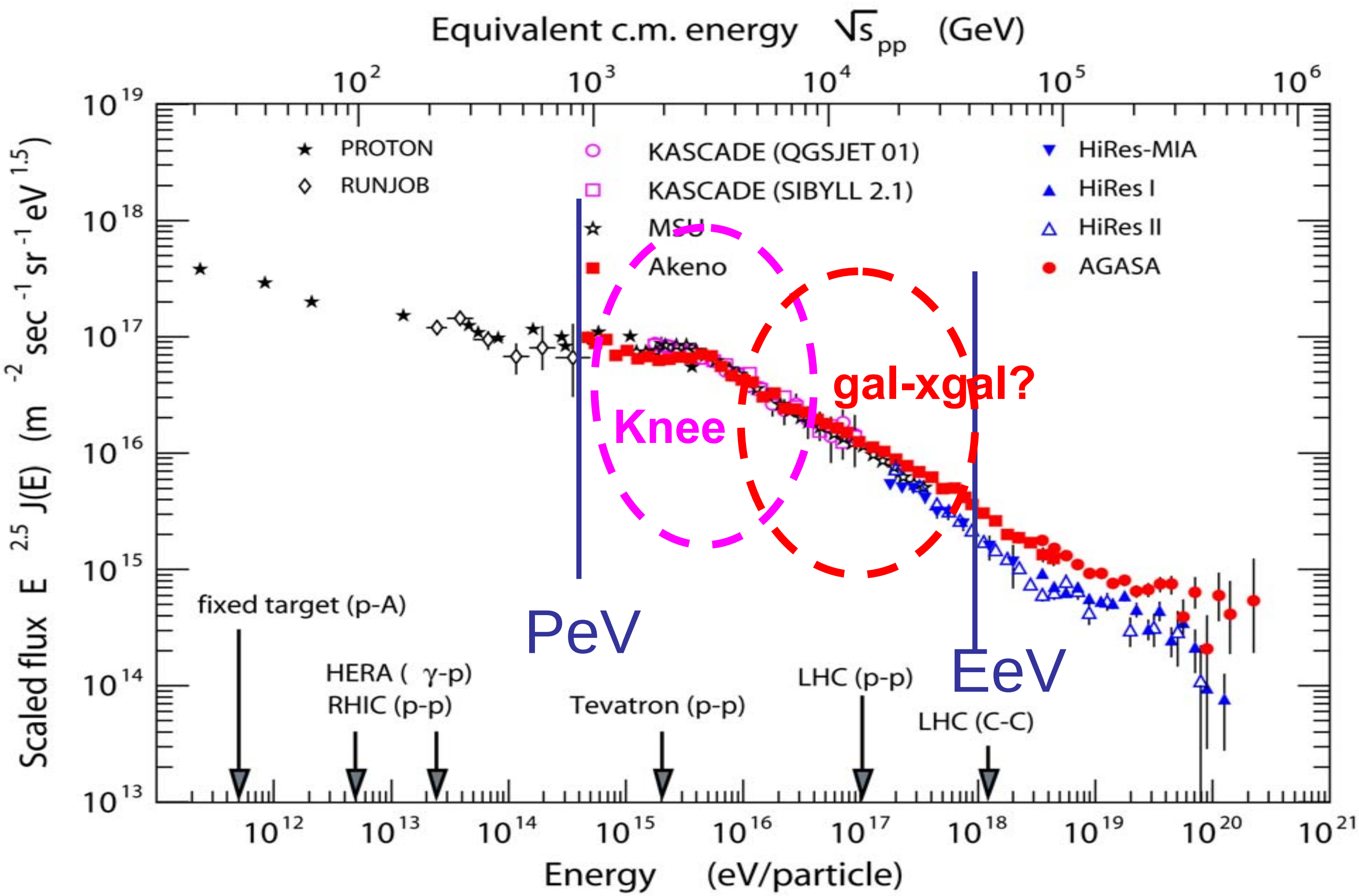
1. **Introduction in HEAP**
   - source-acceleration-transport
   - short history of cosmic ray research
   - extensive air showers
2. **High-Energy Cosmic Rays**
   - KASCADE, KASCADE-Grande and LOPES
3. **Extreme Energy Cosmic Rays**
   - Pierre Auger Observatory, JEM-EUSO
4. **TeV-Gamma-rays & High-energy Neutrinos**
   - TeV gamma rays

     H.E.S.S., MAGIC, CTA
   - high-energy neutrinos

     IceCube and KM3Net

High-Energy Cosmic Ray Investigations with
KASCADE, KASCADE-Grande, and LOPES

Cosmic Rays around the knee(s) ➔ galactic origin of CR



KASCADE
10^{15}-10^{17}eV:

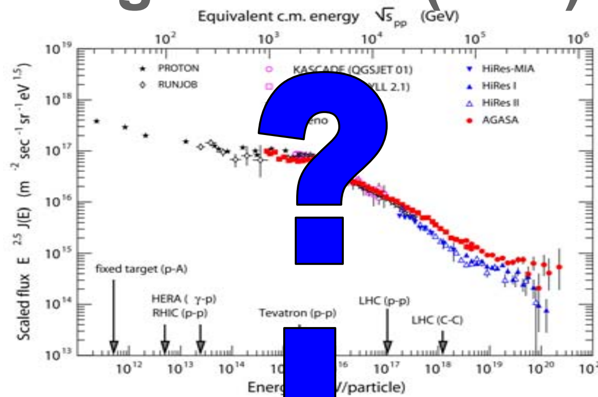
- **knee?**

KASCADE-Grande
10^{16}-10^{18}eV:

- **Iron knee (rigidity)?**
- **Transition galactic-eg CR?**
- **Second knee?**

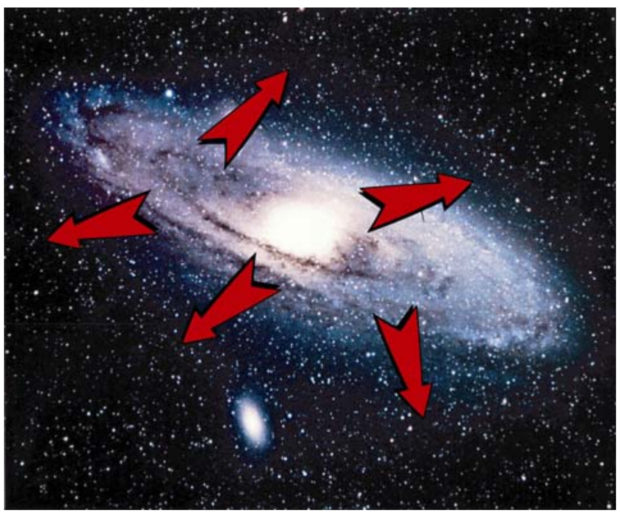
KASCADE 1995-2009 **-Grande 2003-2009**

What is the origin of the (first) knee?



various theories:

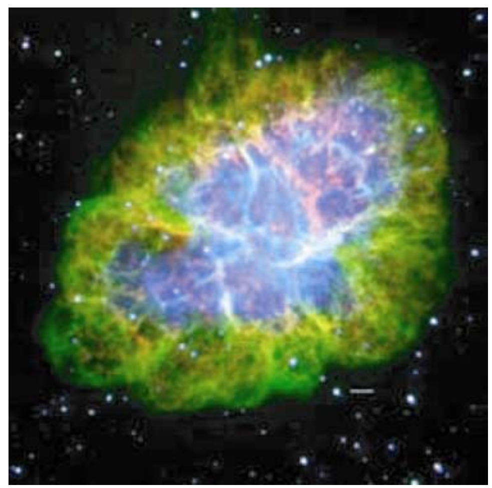
Diffusion



Escape from our Galaxy by diffusion

E(knee) ~ Z

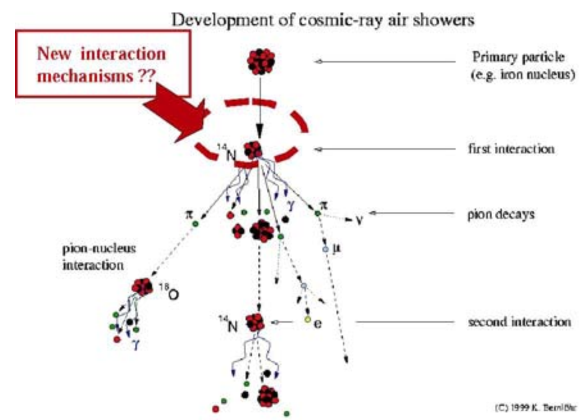
Acceleration



Reach of maximum energy at the acceleration

E(knee) ~ Z

Interaction



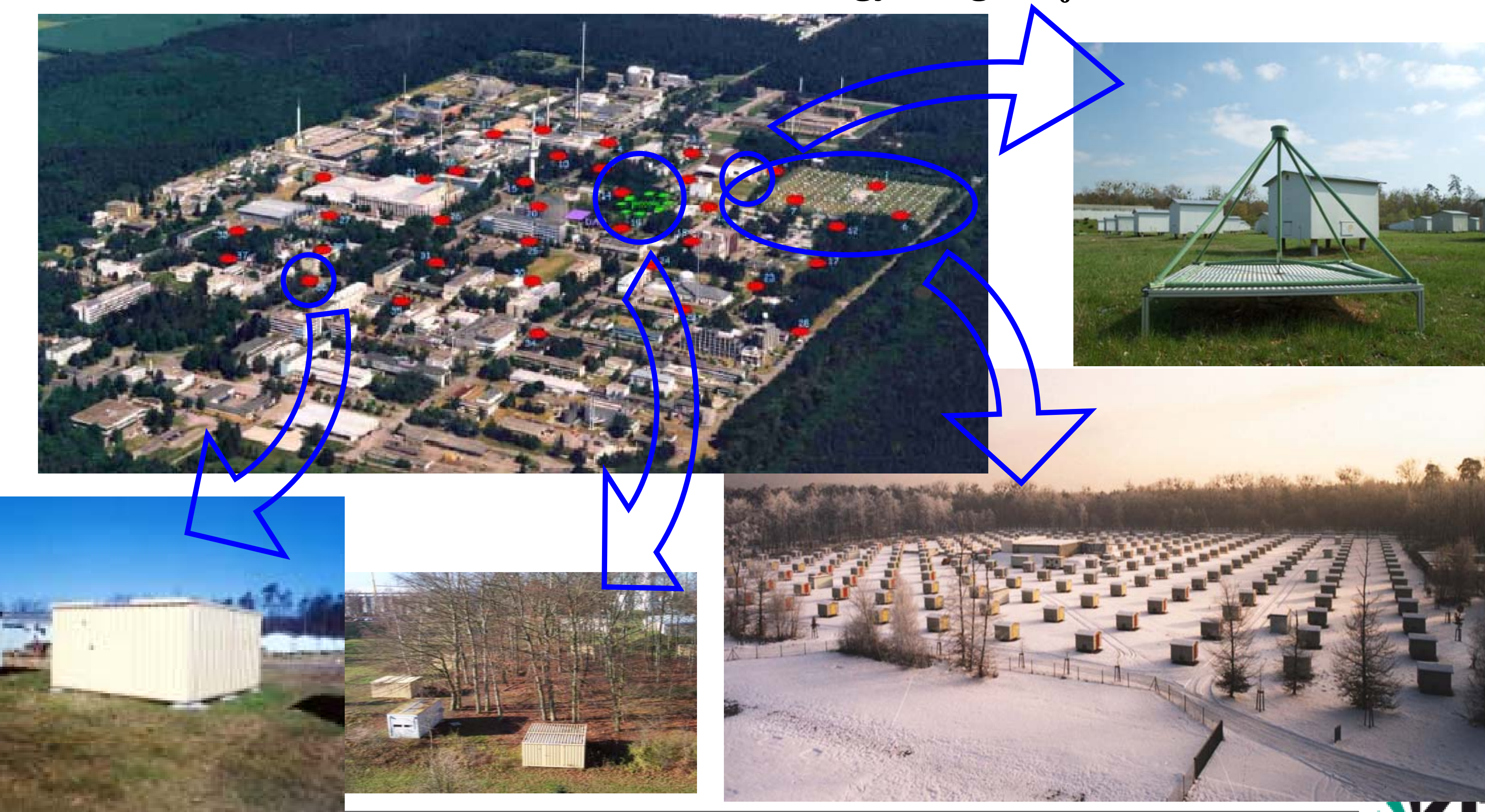
Unknown effects of interactions at the air-shower development

E(knee) ~ A

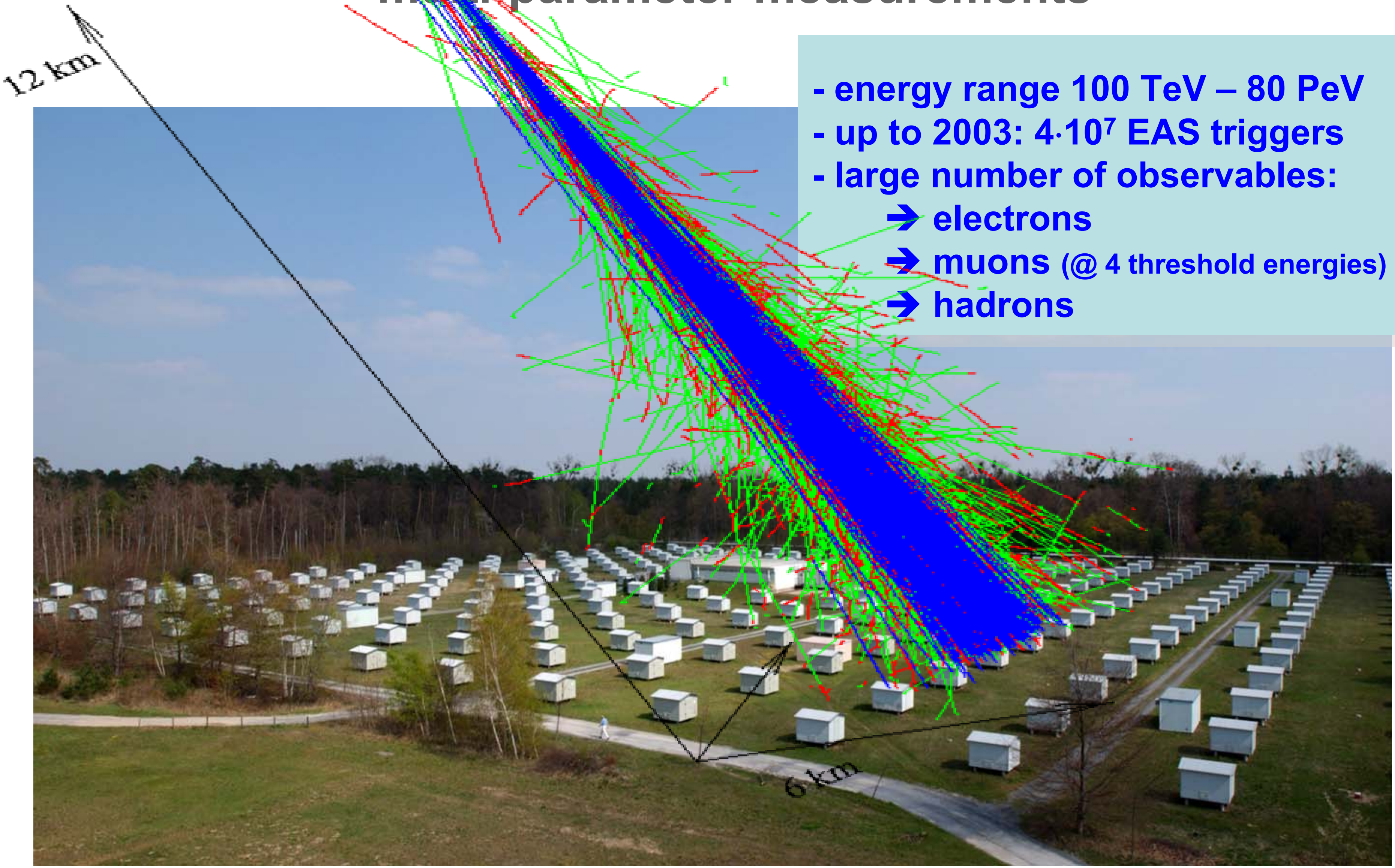
KASCADE-Grande

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

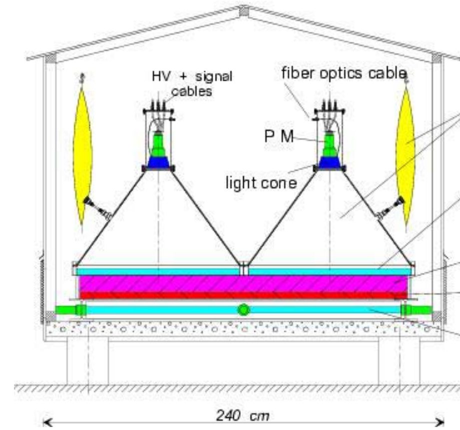


KASCADE: investigating the knee by multi-parameter measurements



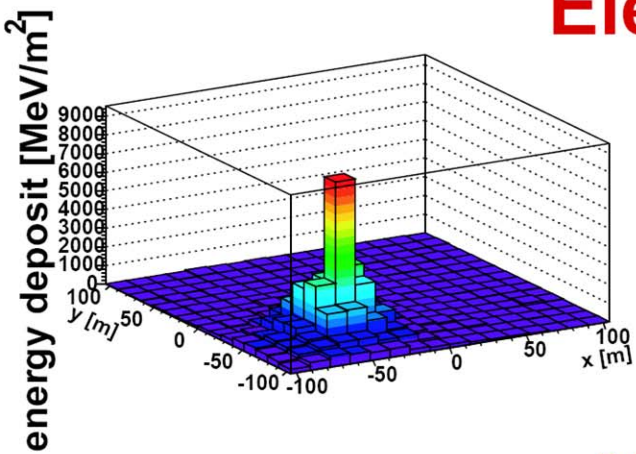
- energy range 100 TeV – 80 PeV
- up to 2003: $4{\cdot}10^7$ EAS triggers
- large number of observables:
    - ➔ electrons
    - ➔ muons (@ 4 threshold energies)
    - ➔ hadrons

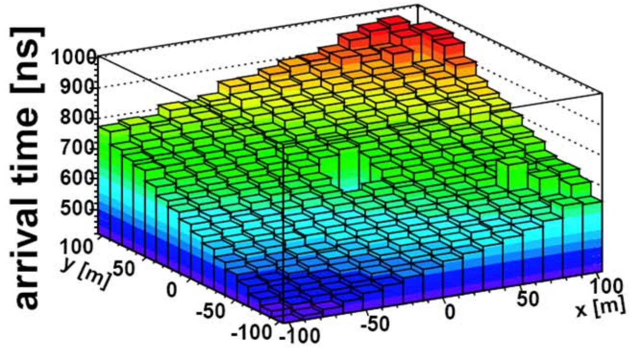
KASCADE



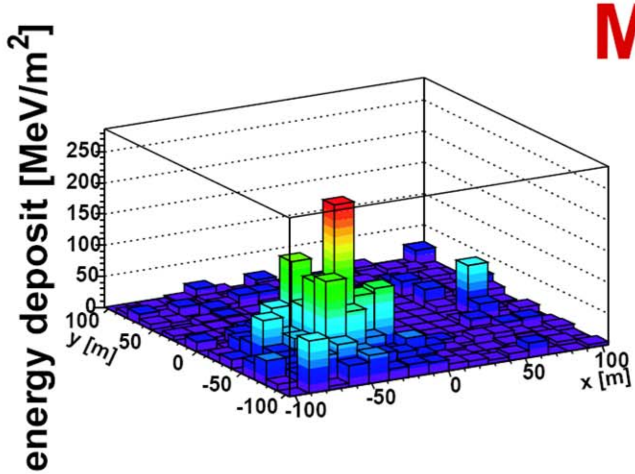
Array

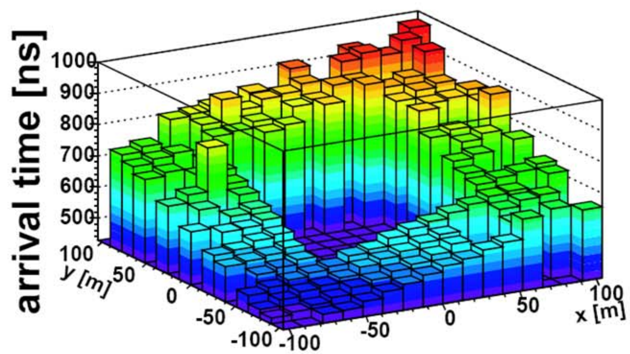
Electrons





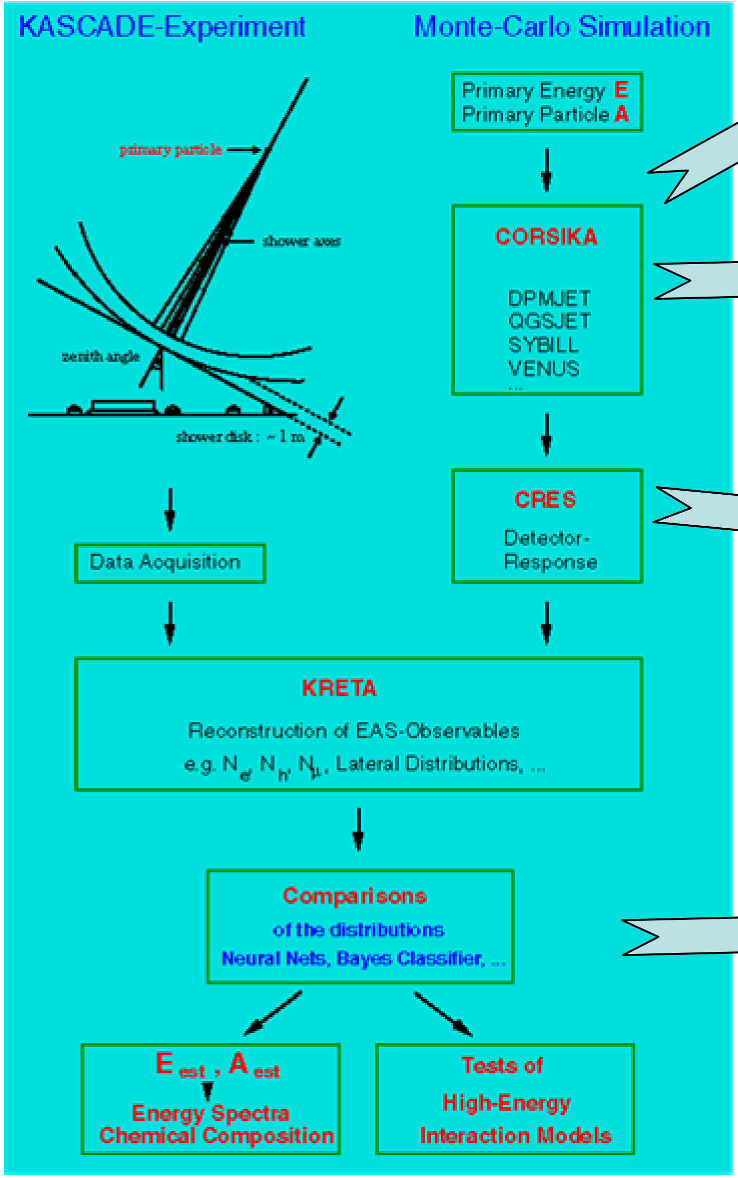
Muons

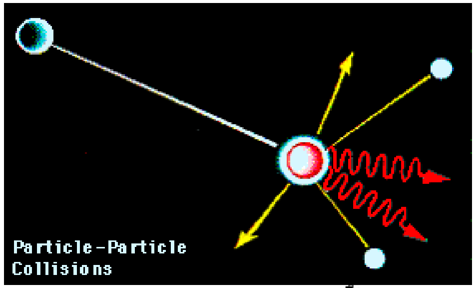




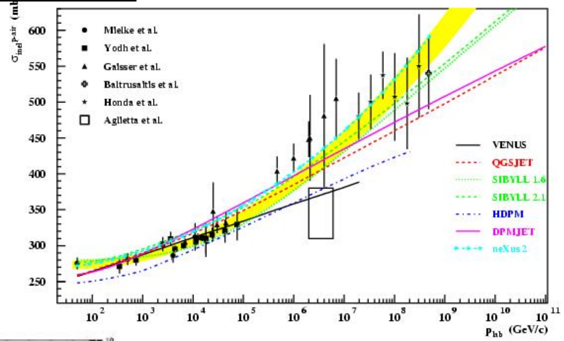
Run 3226, File 2, leve 65041, Ymd 10215, Hms 225810, Neds 250, Npds 138
(Xc,Yc) = (-45.4,-51.0), (Ze,Phi) = (36.7,228.6), log10(Ne)=6.14, log10(Lmuo)=4.66

KASCADE - methodics

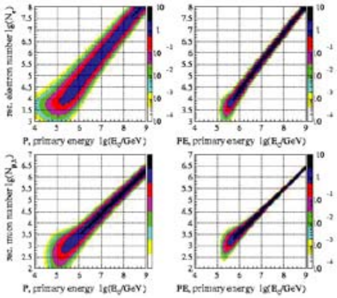




nucleus-nucleus interactions

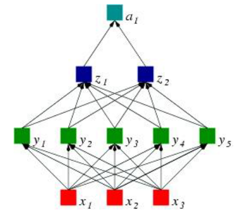


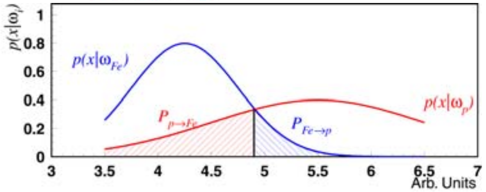
Air shower simulations

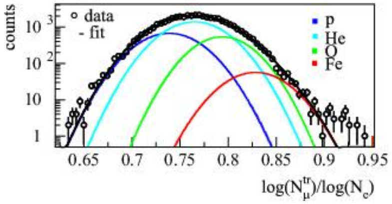


Detector simulations

Multi-parameter analyses of the various observables





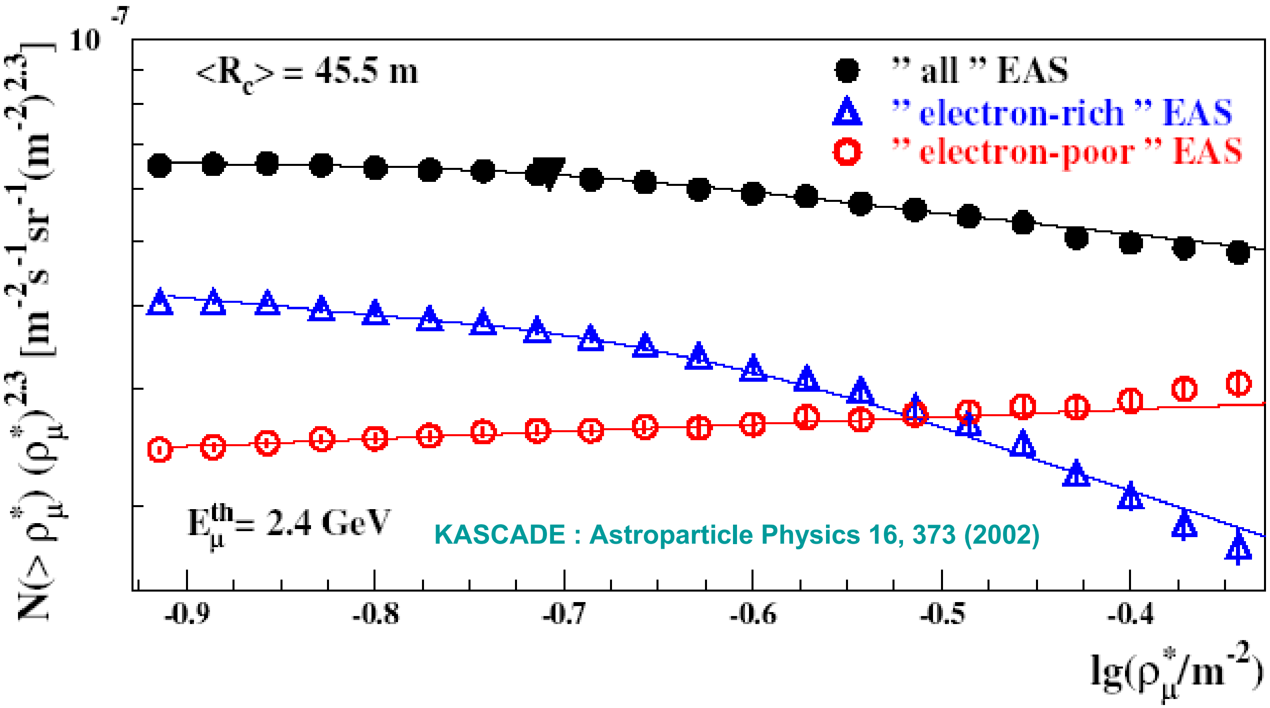


Model independent multi-parameter analysis

Use of three observables:

- high-energy local muon density ➔ energy estimator

- Total muon number and electron number ➔ mass estimator

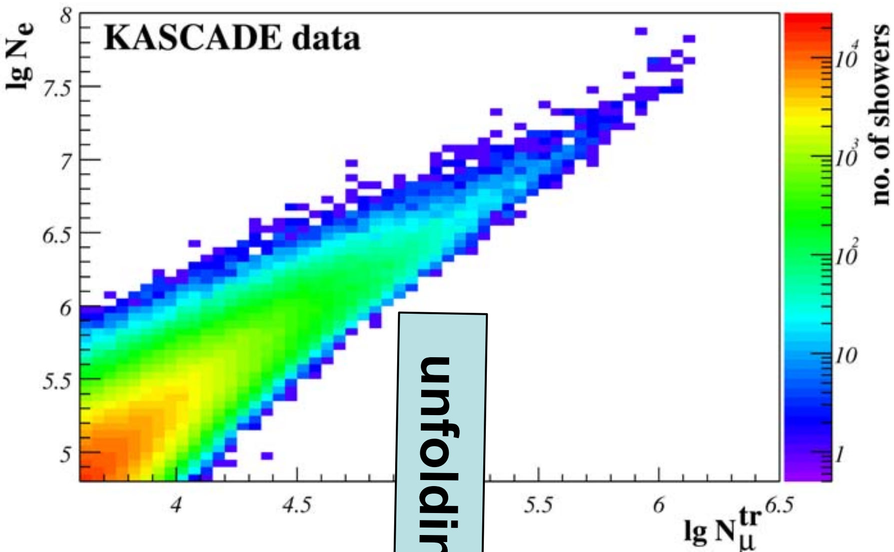


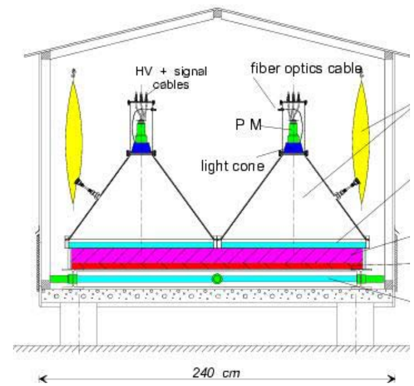
- **KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS**
- **Do we need hadronic interaction models?**

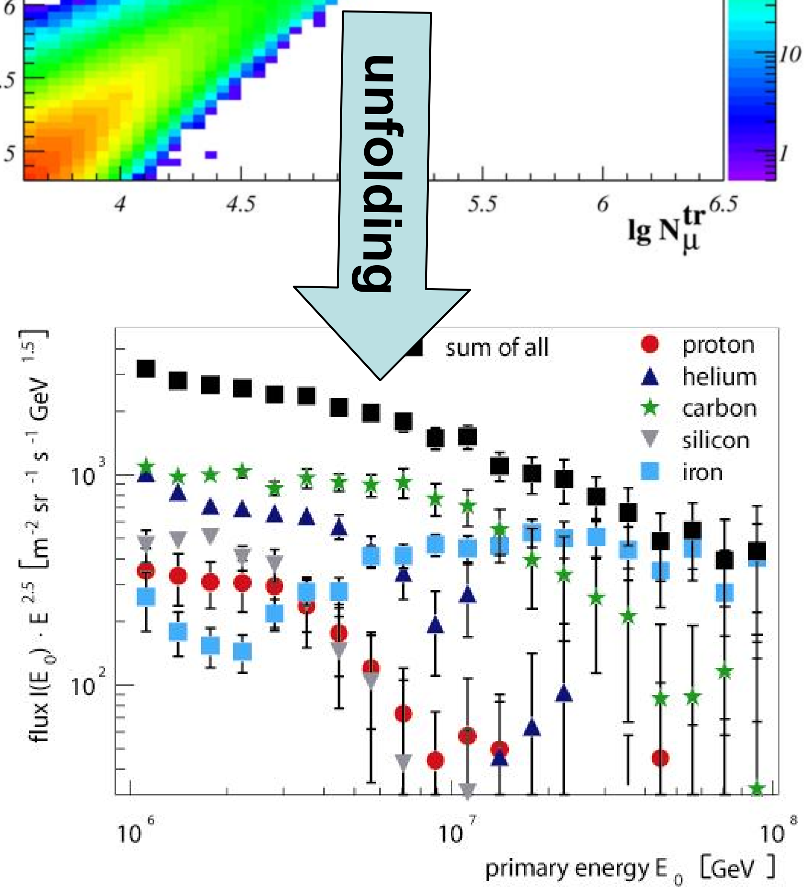
➔ yes, for normalization of absolute energy and mass scale!!

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

KASCADE : energy spectra of single mass groups







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

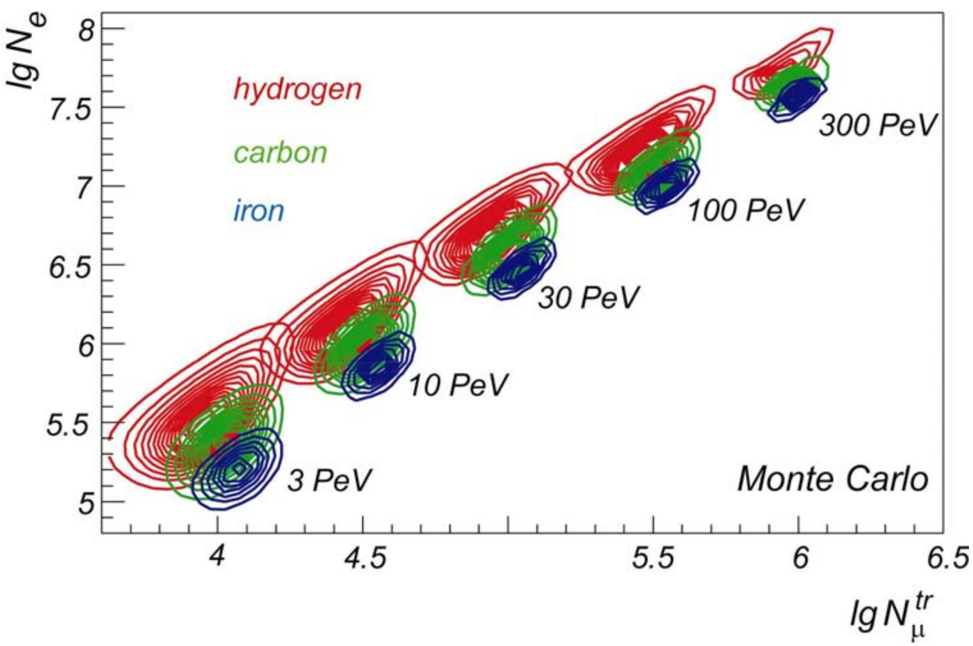
$$g(y) = \int K(y,x) p(x) dx$$

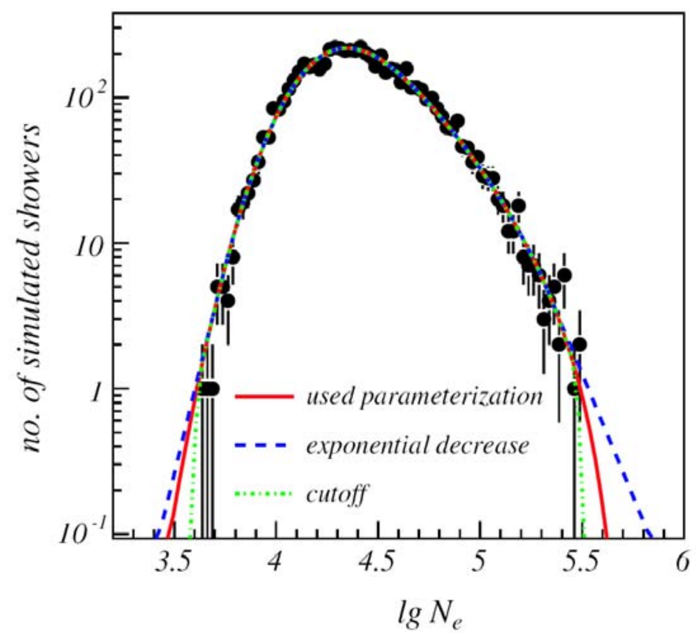
with y=(N_e,N_μ^{tr}) and x=(E,A)

KASCADE Unfolding procedure

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

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



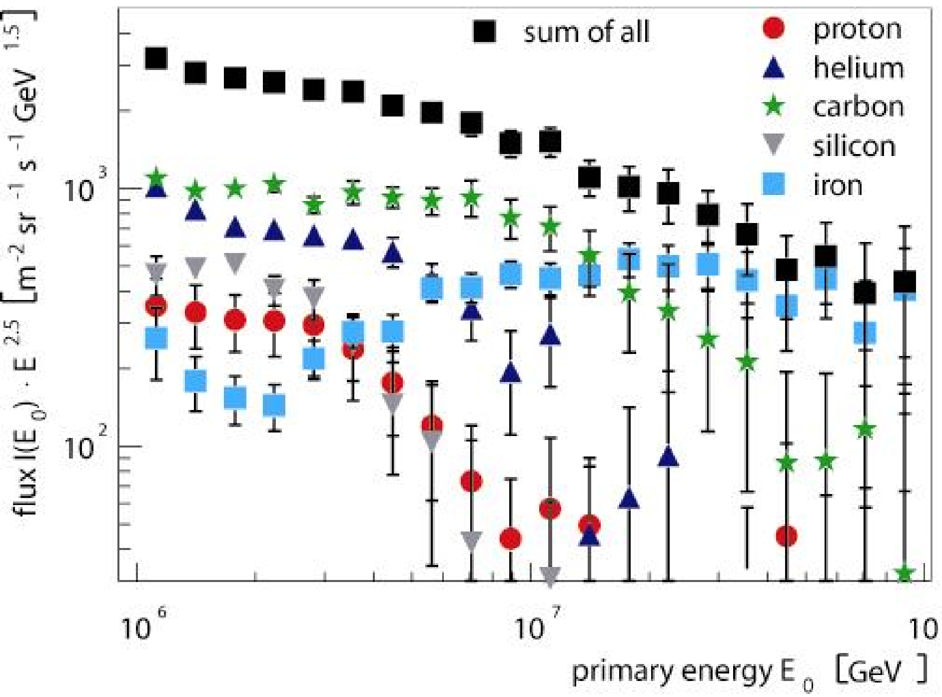


KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

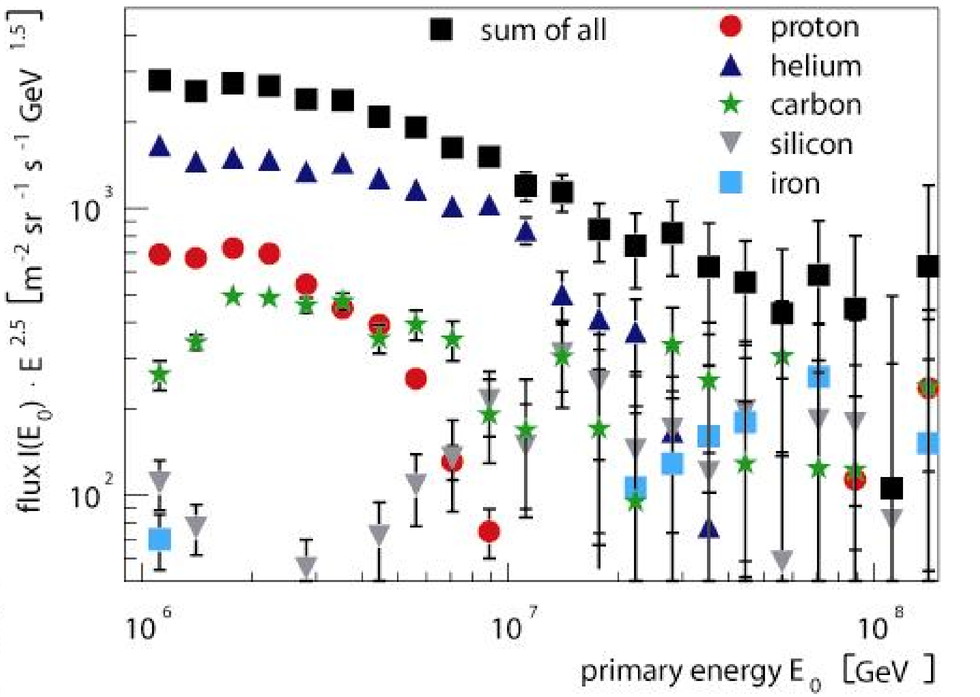
KASCADE results

- same unfolding but based on different interaction models:
- SIBYLL 2.1 and QGSJET01 (both with GHEISHA 2002) all embedded in CORSIKA
- also for different low energy interaction models: FLUKA and GHEISHA
- also for different zenith angular ranges

SIBYLL

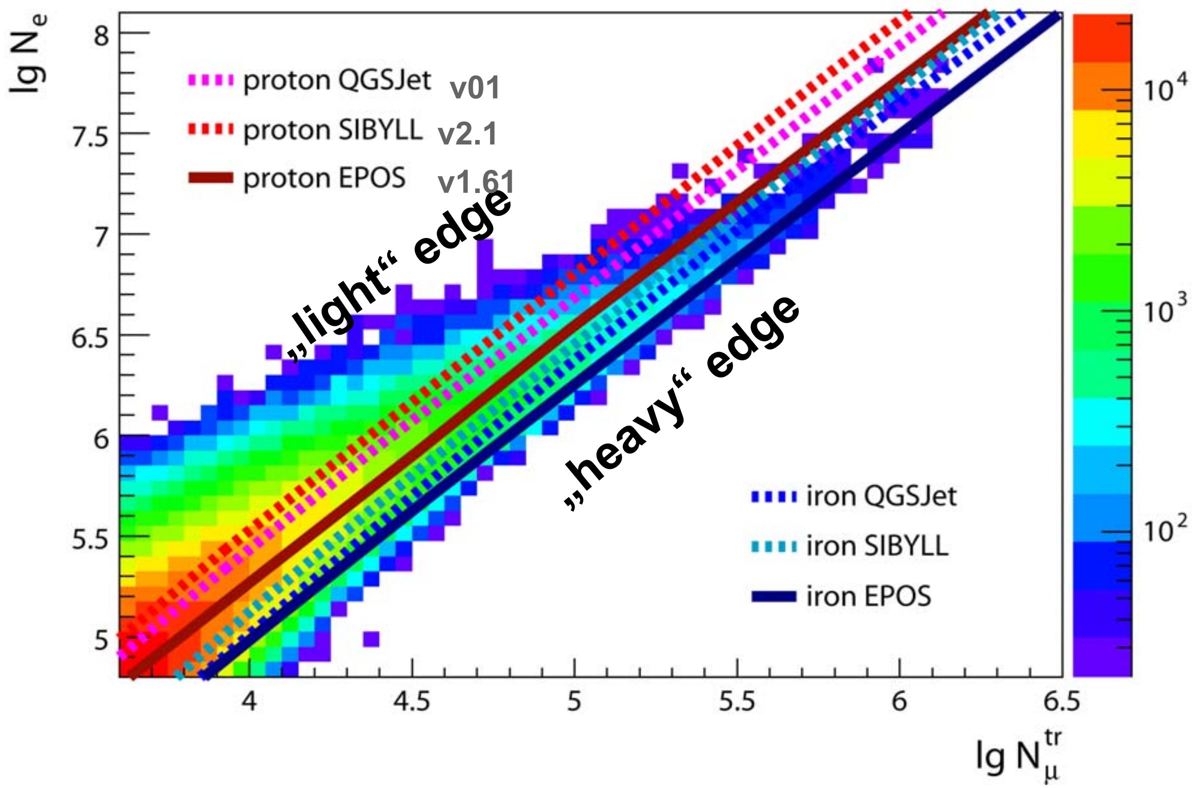


QGSJet



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

KASCADE: sensitivity to hadronic interaction models



Main results keep stable independent of method or model:

-) knee in data structure

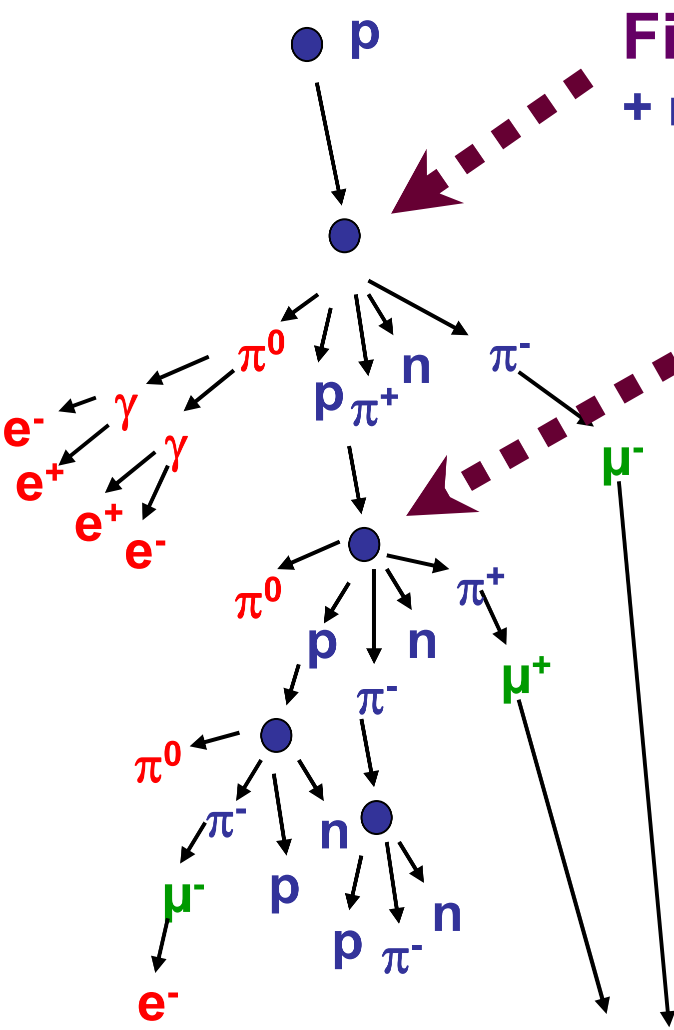
-) knee caused by light primaries

-) 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

Validity of Hadronic Interaction Models



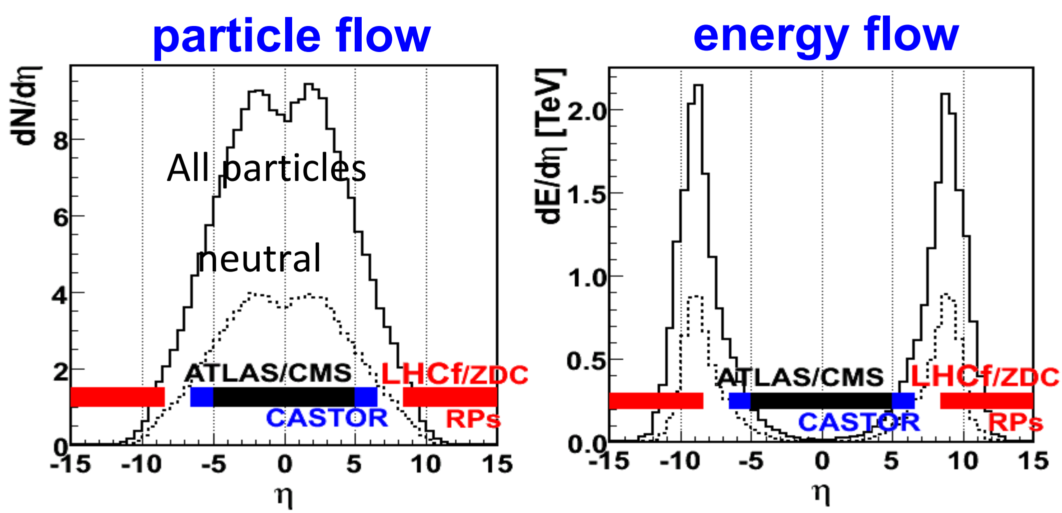
First, high energy interaction: LHC

+ multiparameter measurements EAS

Secondary interactions:

Fix target experiments

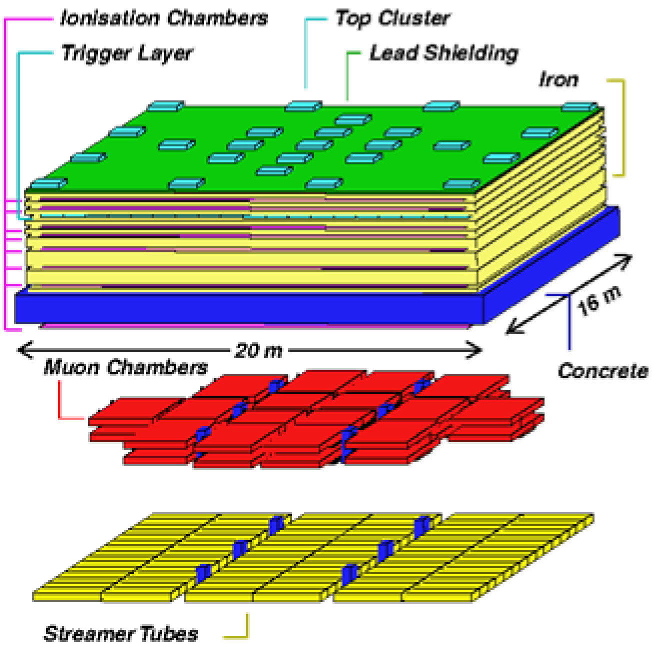
+ multiparameter measurements EAS

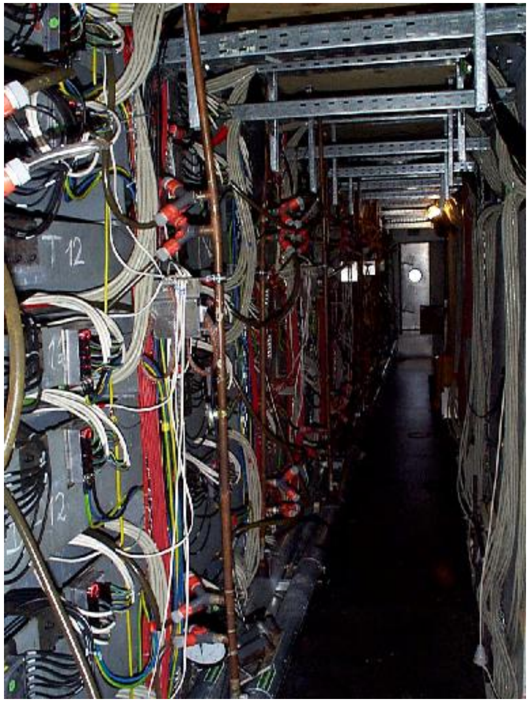


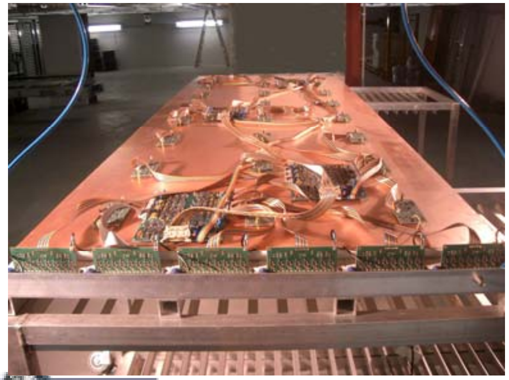
KASCADE set-up

Multi-Detector-Setup !

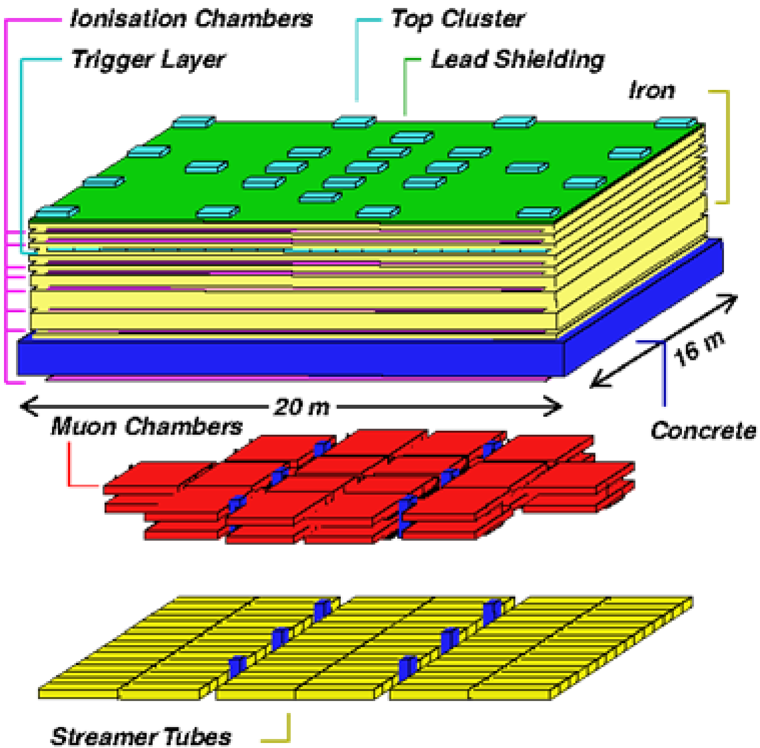
Aim: measure as much as possible observables of the air-shower !



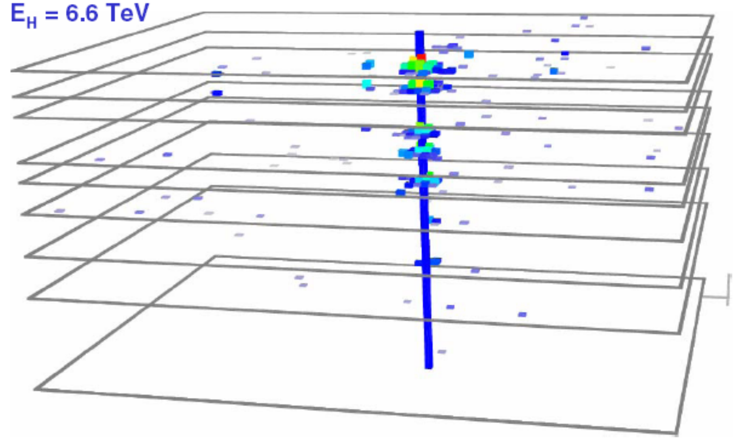




hadrons in air shower cores



Unaccompanied hadron
E_H = 6.6 TeV



spatial resolution:
$\sigma_x \sim 10 - 12$ cm

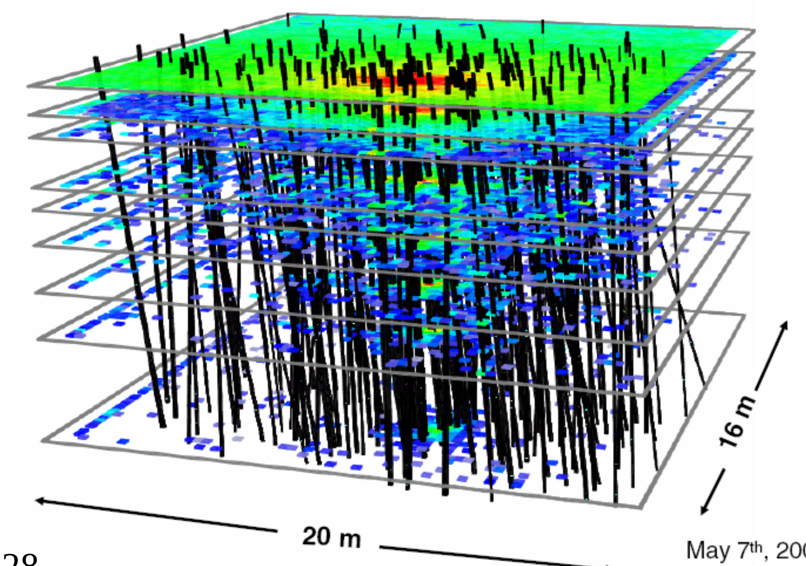
angular resolution:
$\sigma_\Theta \sim 1° - 3°$

energy resolution:

$$\frac{\sigma(E)}{E}[\%] \sim \frac{250}{\sqrt{E/\mathrm{GeV}}}$$

$E_0 \sim 6$ PeV

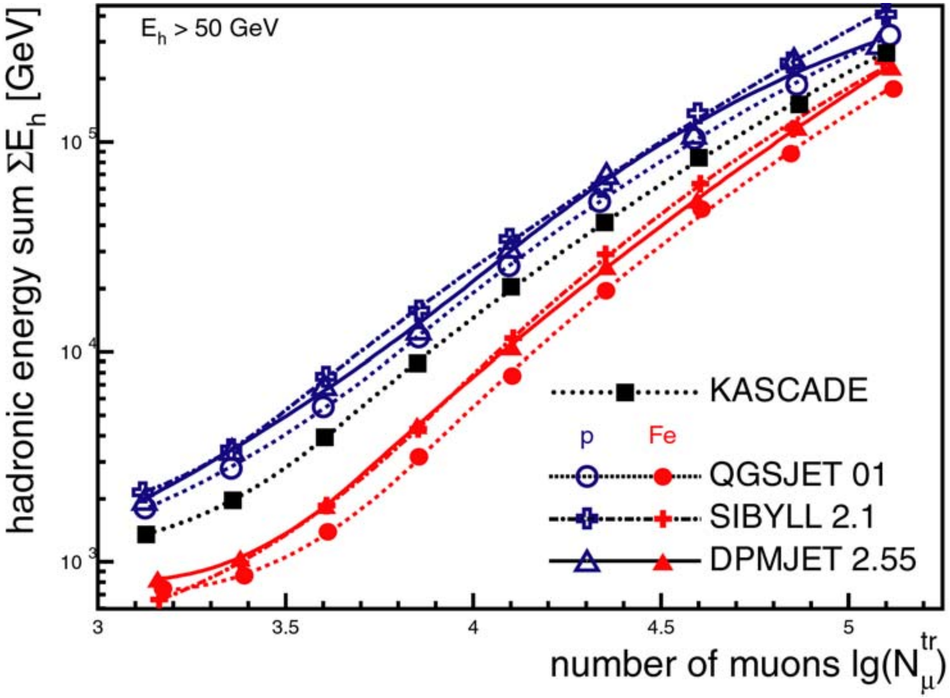
Number of reconstructed hadrons N_h = 143

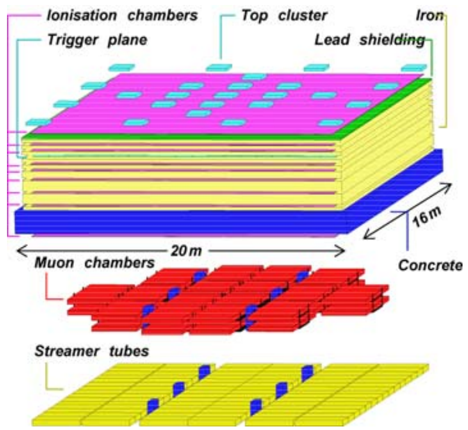


J. Engler et al., Nucl. Instr. Meth. A 427 (1999) 528

KASCADE : sensitivity to hadronic interaction models

➔ New models are welcome for cross-tests with KASCADE data





Example:
hadrons vs. muons

correlation of observables:

no hadronic interaction model describes data consistently !

➔ tests and tuning of hadronic interaction models !

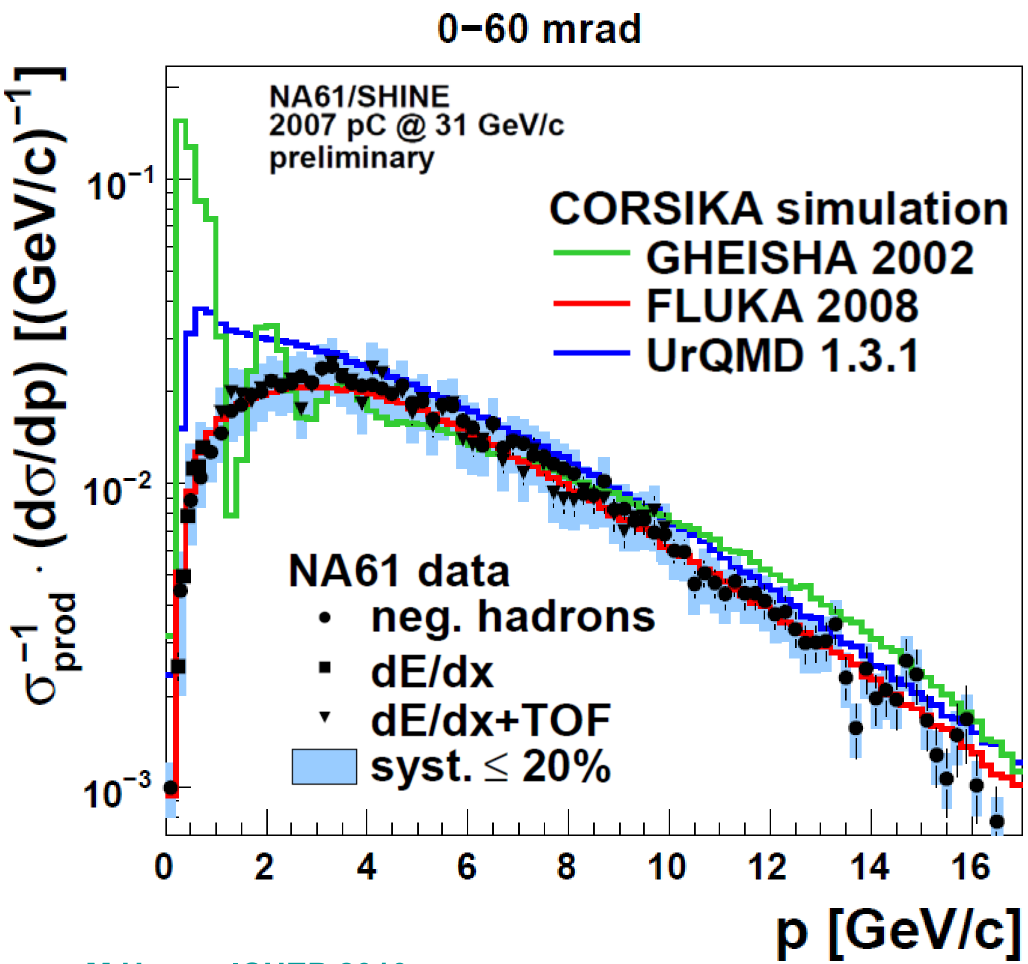
➔ close co-operation with theoreticians (CORSIKA including interaction models)

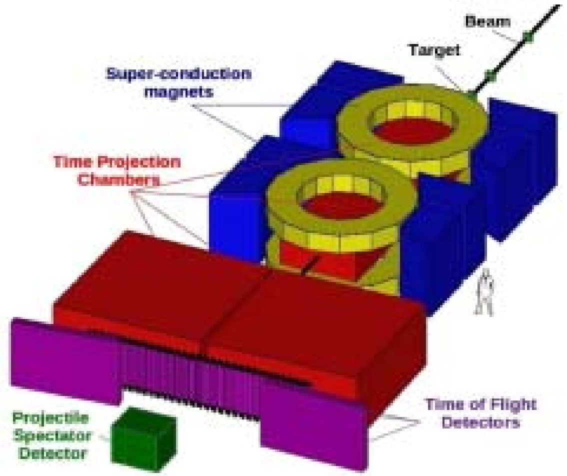
➔ e.g.: •EPOS 1.6 is not compatible with KASCADE measurements
•QGSJET 01and SIBYLL 2.1still most compatible models

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

SHINE (NA61) @ SPS/CERN

- had (and will have) dedicated cosmic ray runs
  pp (13-158GeV), pC (31-158GeV), πC (158-350GeV)
- particle identification with TDC and ToF



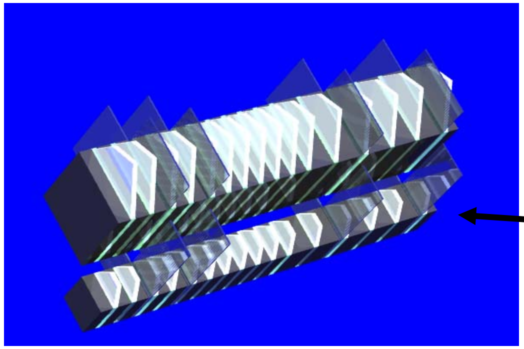


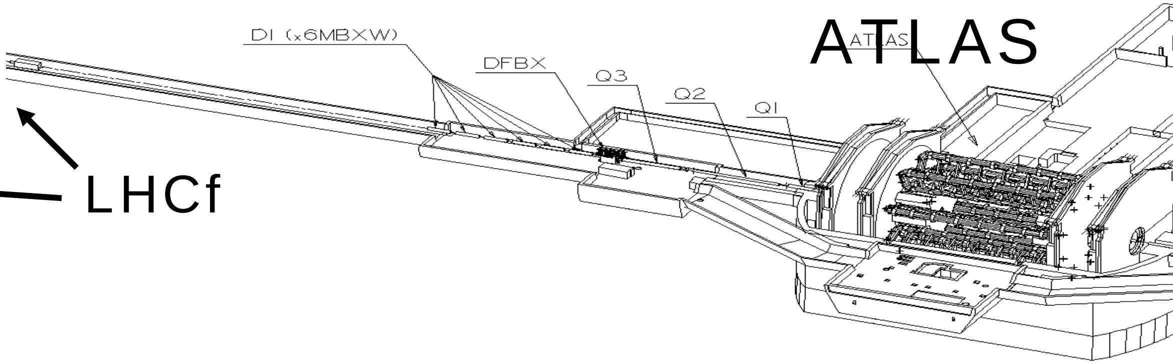
Inclusive π^- - spectra

(pilot run 2007)
p + C at 31 GeV/c

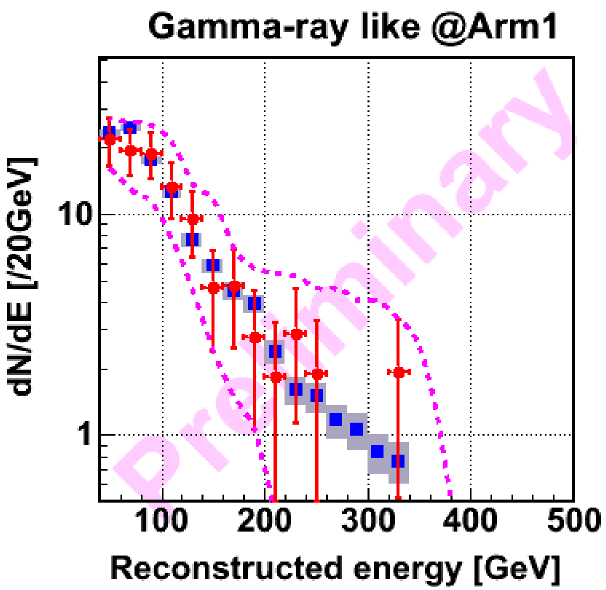
M.Unger, ICHEP 2010

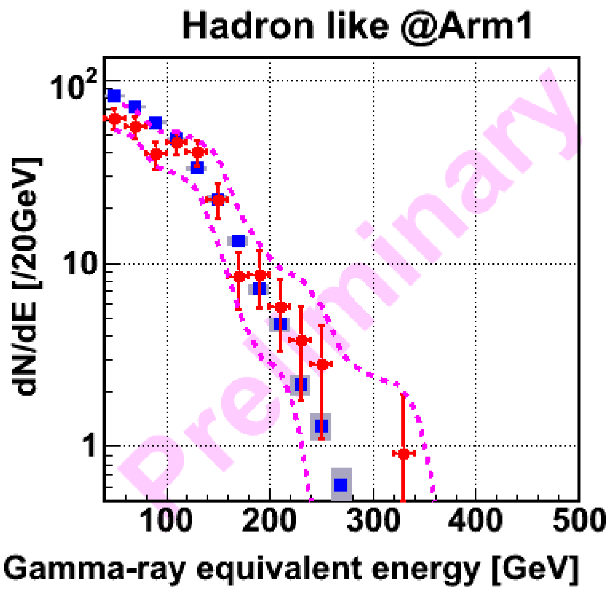
LHCf @ LHC





- Measures very forward (η >8.4; including 0 degree)
- Measures neutral particles at LHC p-p (ion-ion) collisions
- Tungsten calorimeter with plastic scintillators

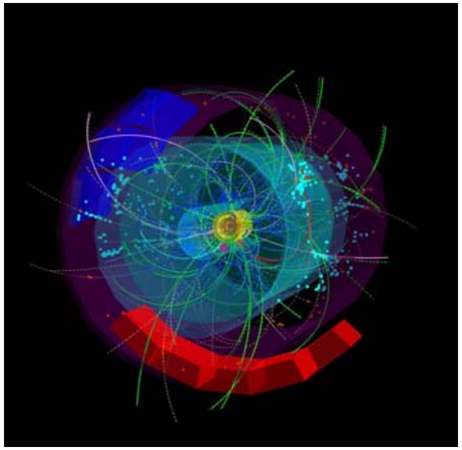




Spectra Comparison with MC (QGSJET2)

Sako, ISVHECRI 2010

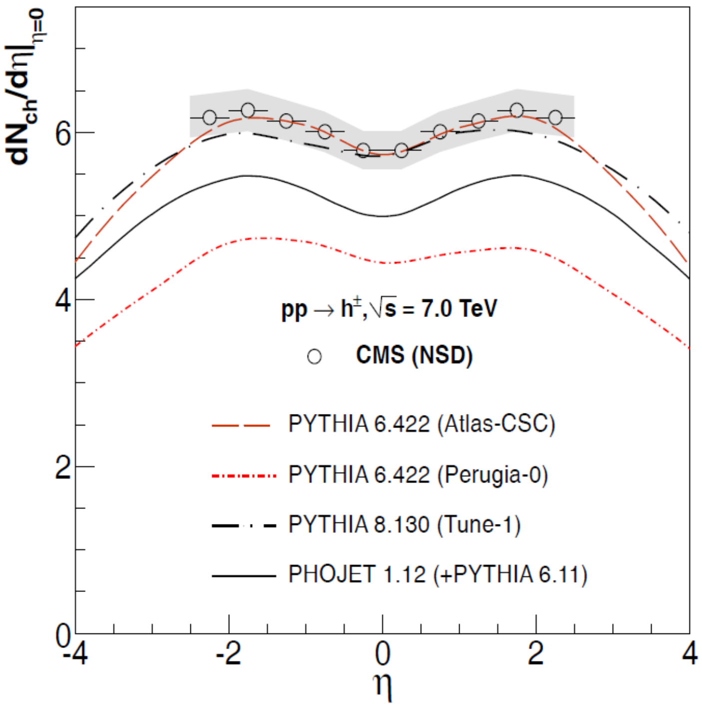
ALICE @ LHC

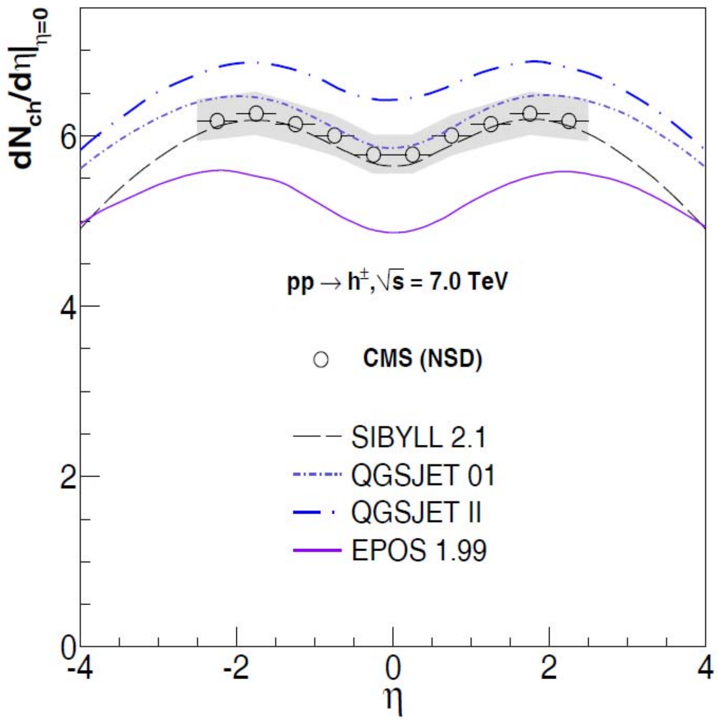


- **Multiplicity distributions and dNch/d η at 0.9, 2.36 and 7 TeV**

➔ **significantly larger increase from 0.9 to 7 TeV than in HEP- MCs**

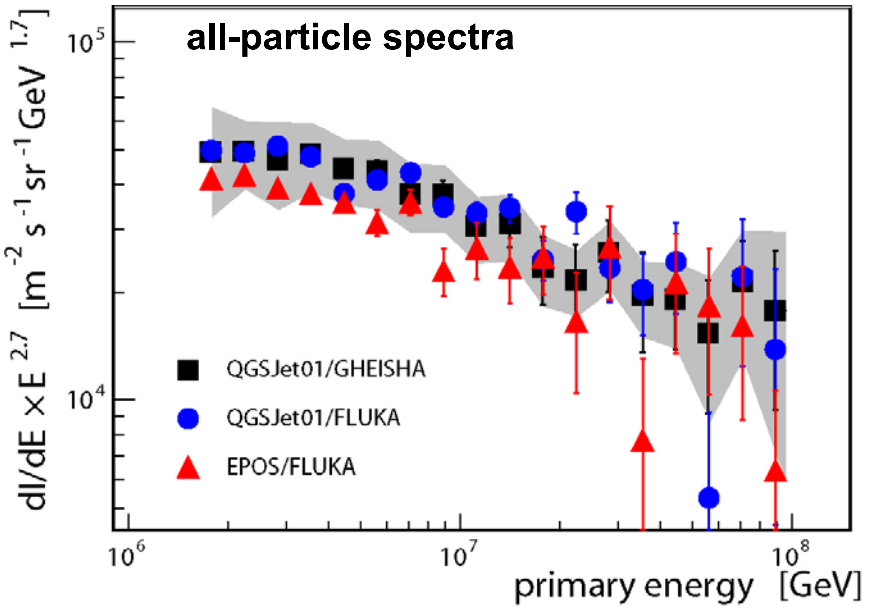
➔ **CR- MCs seems to better agree**

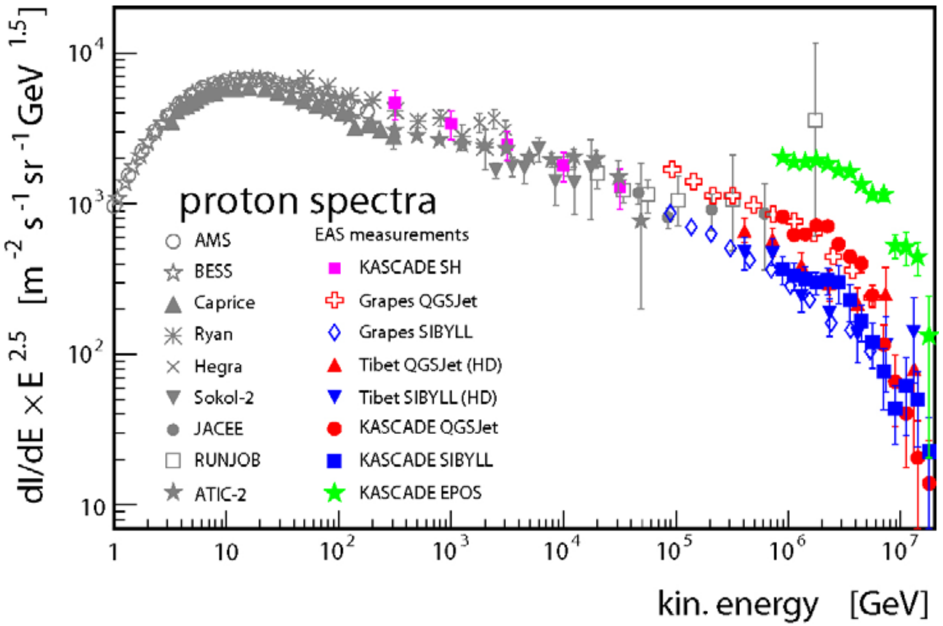




Henner Büsching for the ALICE collab., ISVHECRI 2010 // David D'Enterria et al, arXiv:1101.5596

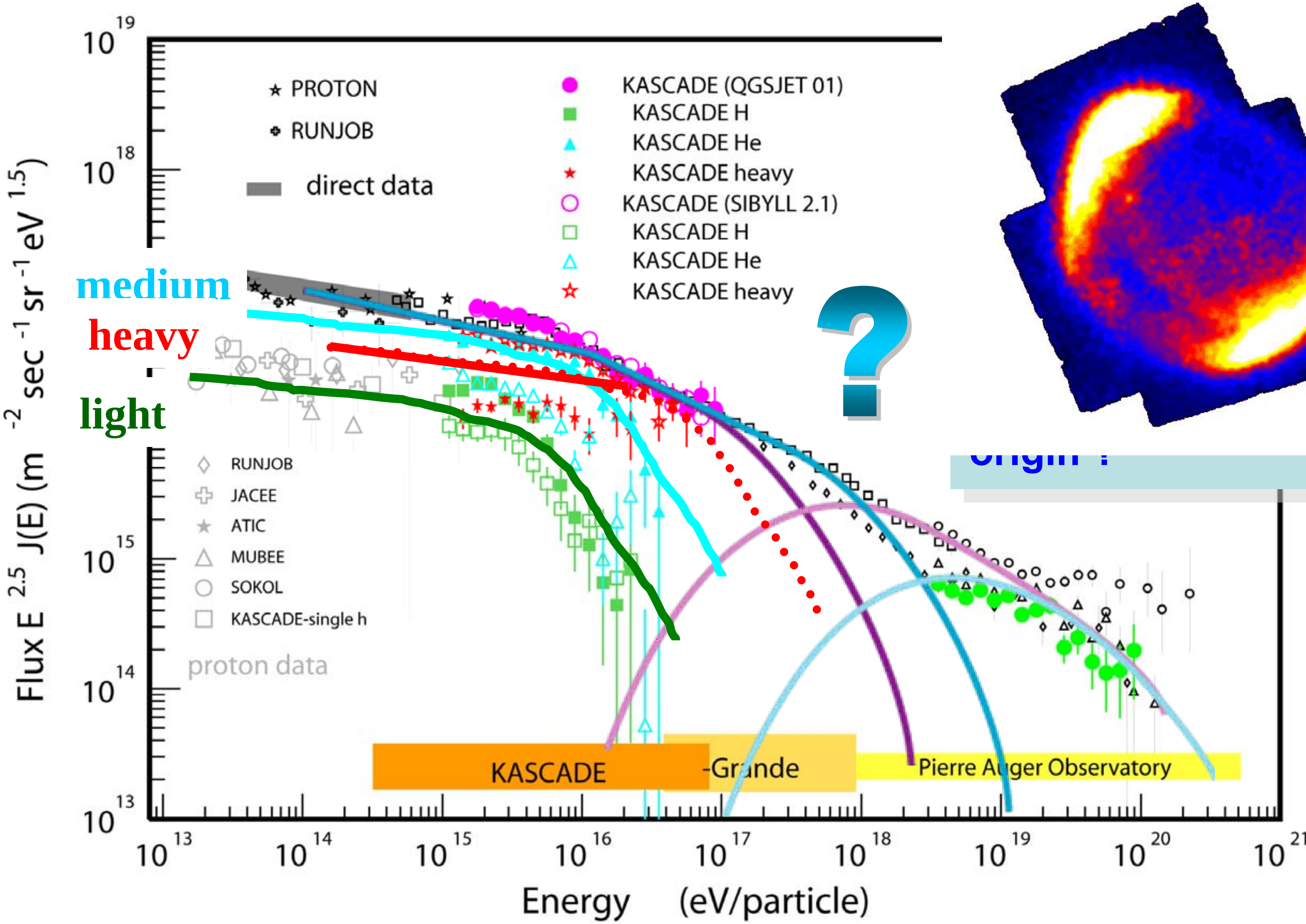
KASCADE Summary



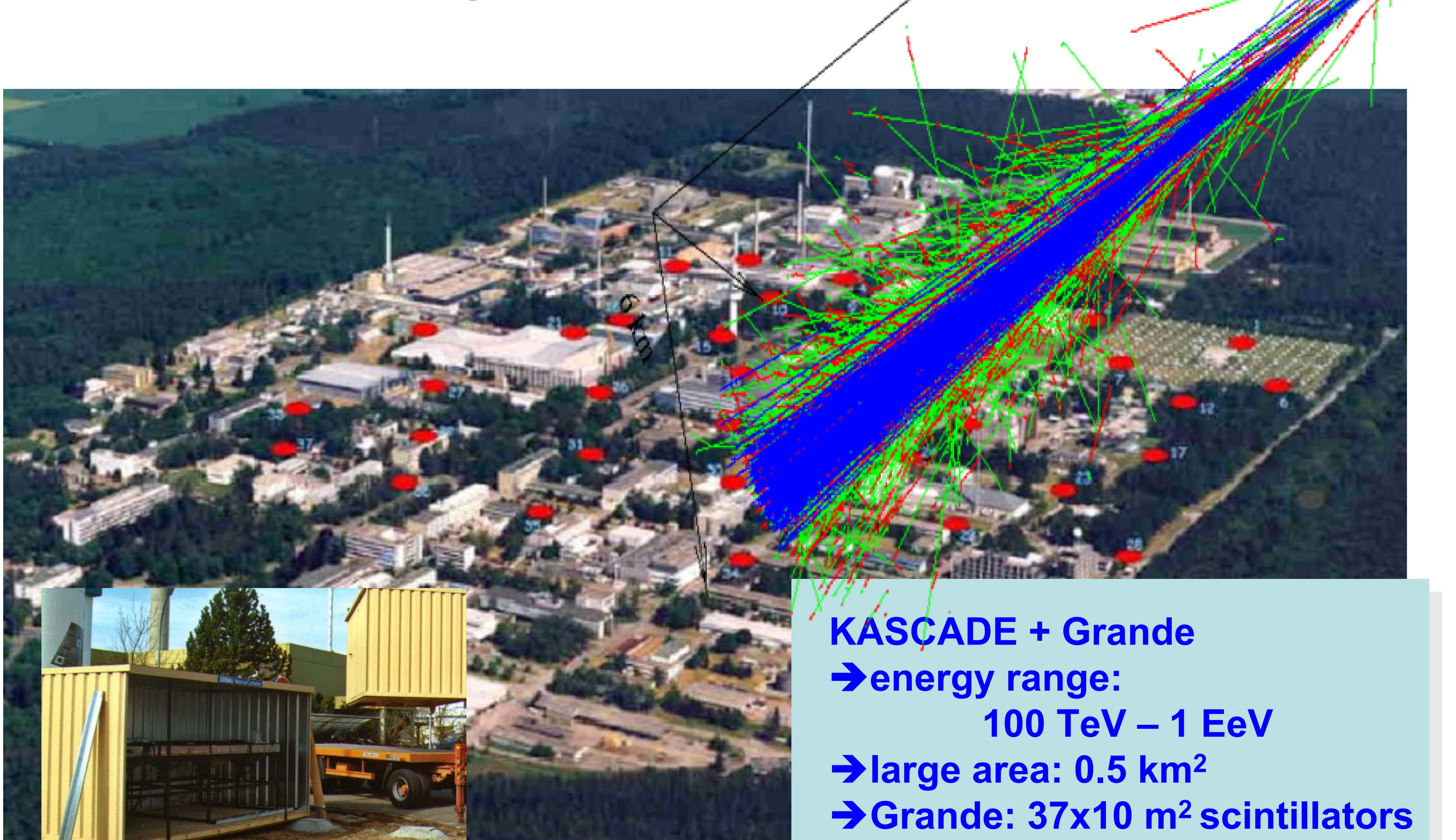


-) knee caused by light primaries ➔ composition gets heavier across knee
-) positions of knee vary with primary elemental group
-) relative abundancies depend strongly on high energy interaction model
-) no (interaction) model can describe the data consistently
-) all-particle spectra agree inside uncertainties (EPOS1.6 a bit lower)
-) proton spectra agree with direct measurements (not for EPOS1.6)

KASCADE ➔ KASCADE-Grande



KASCADE-Grande : multi-parameter measurements

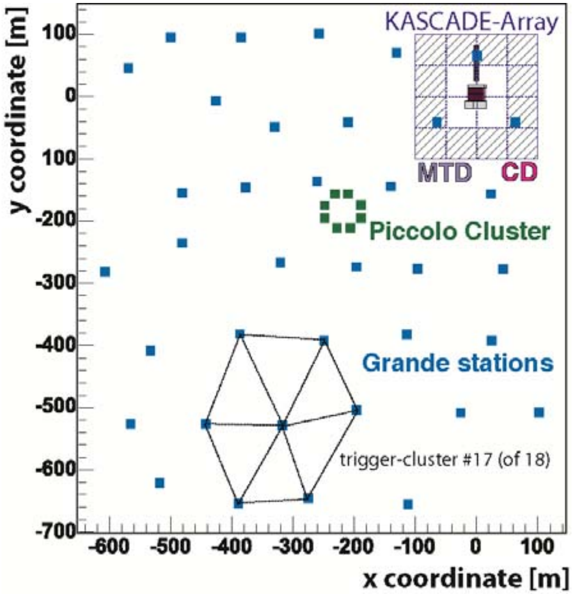


KASCADE + Grande

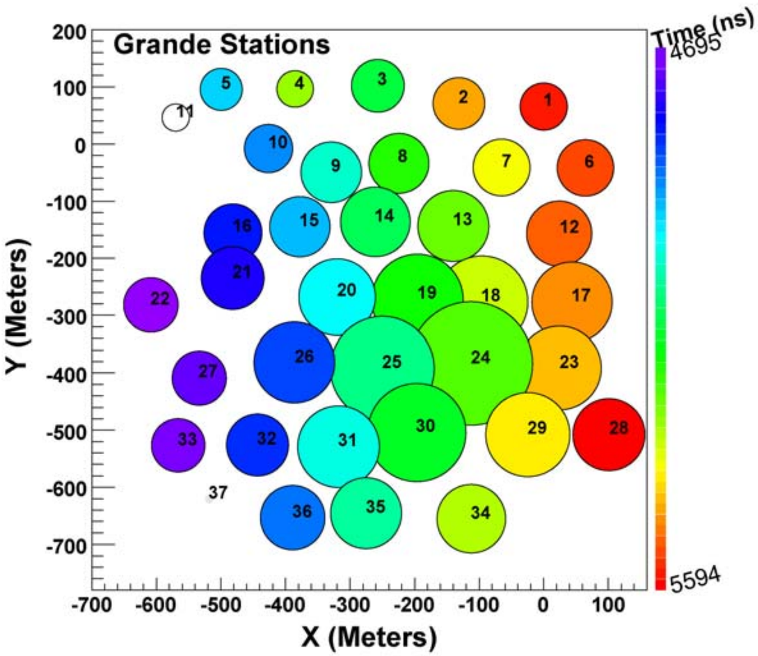
- ➔ energy range: 100 TeV – 1 EeV
- ➔ large area: 0.5 km²
- ➔ Grande: 37x10 m² scintillators
- ➔ Piccolo: trigger array

Reconstruction

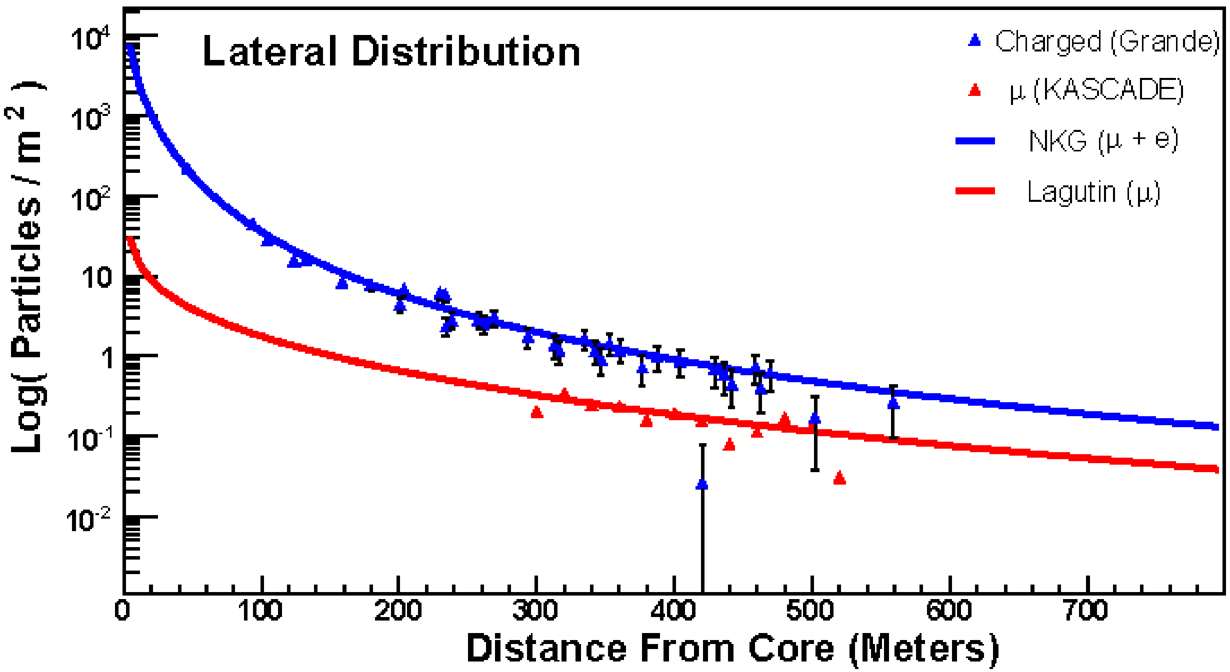
1) **core position and angle-of-incidence**
from Grande array data
➔
2a) **shower size** (charged particles)
from Grande array data
2b) **muon number**
from KASCADE muon detectors
➔
3) **electron number**
from Grande
by subtraction of muon content
➔
4a) **two dimensional size spectrum**
for the composition analyses
4b) **high-energy muons / muon tracking**
for hadronic interaction tests



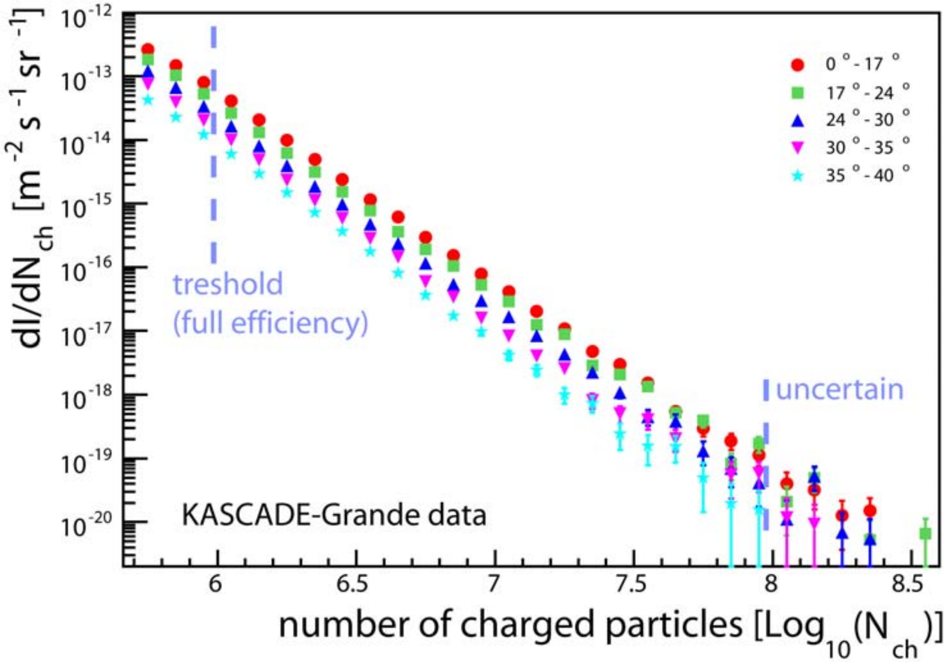
Single event reconstruction



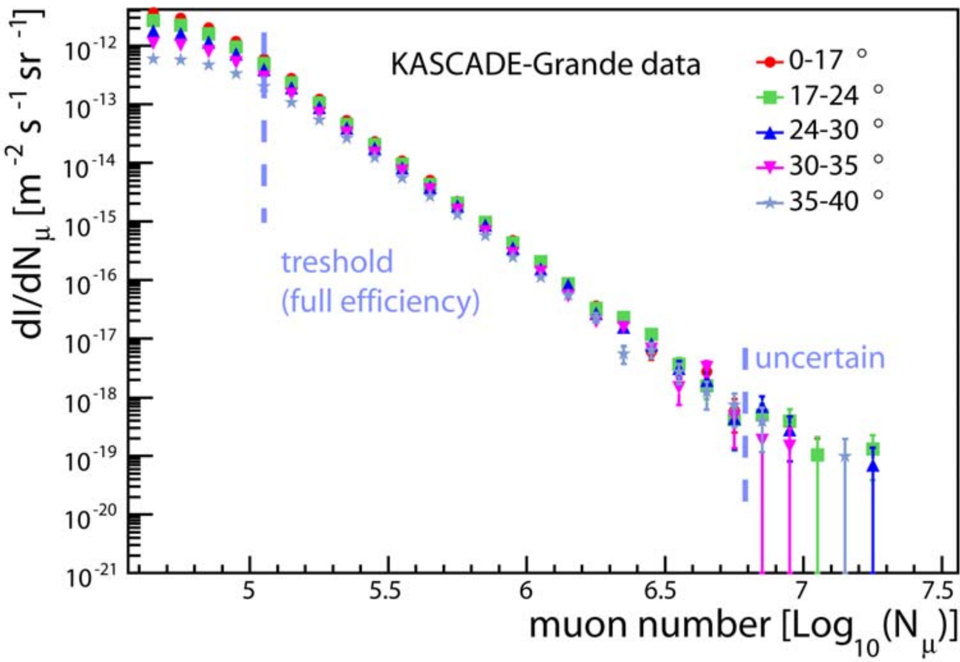
a single event measured by KASCADE-Grande:
core (-155,- 401) m
$\log_{10}(N_{ch}) = 7.0$
$\log_{10}(N_{\mu}) = 5.7$
No saturation
Zenith: 24.2°
Azimuth: 284°
Recorded on 8 July 2005 at 12:11 (UTC)



size spectra (charged particles)



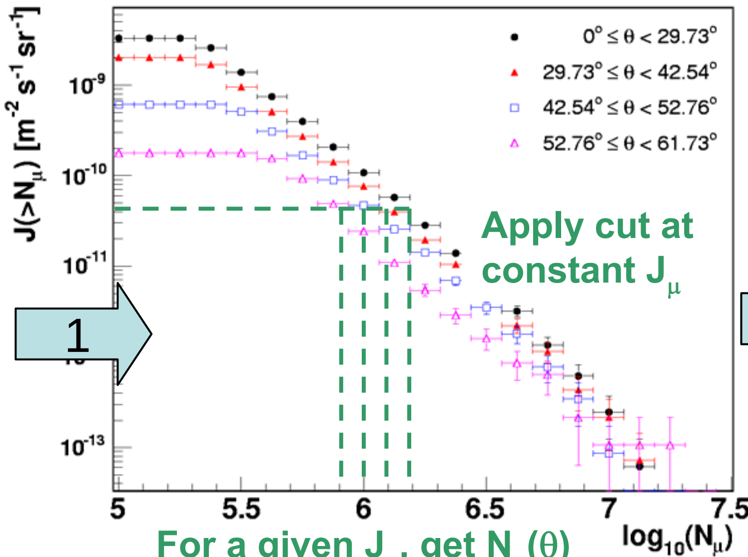
muon number spectra (N_μ ; E_μ>230MeV)



-stable data taking since 2004, c. 1200 days effective DAQ time
-performance of reconstruction (and detector) is stable

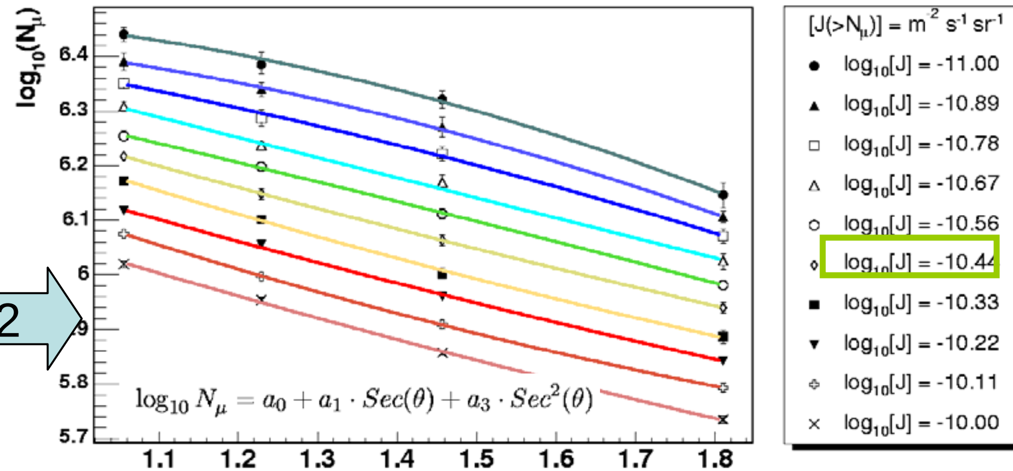
KASCADE-Grande: constant intensity cut method CIC

1



For a given J_μ, get $N_\mu(\theta)$

2

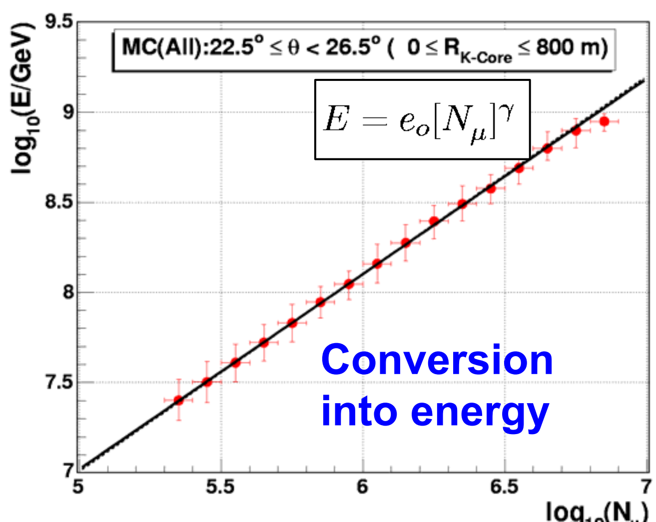


Get attenuation curves

3

$N_\mu(24^\circ)$ of each event

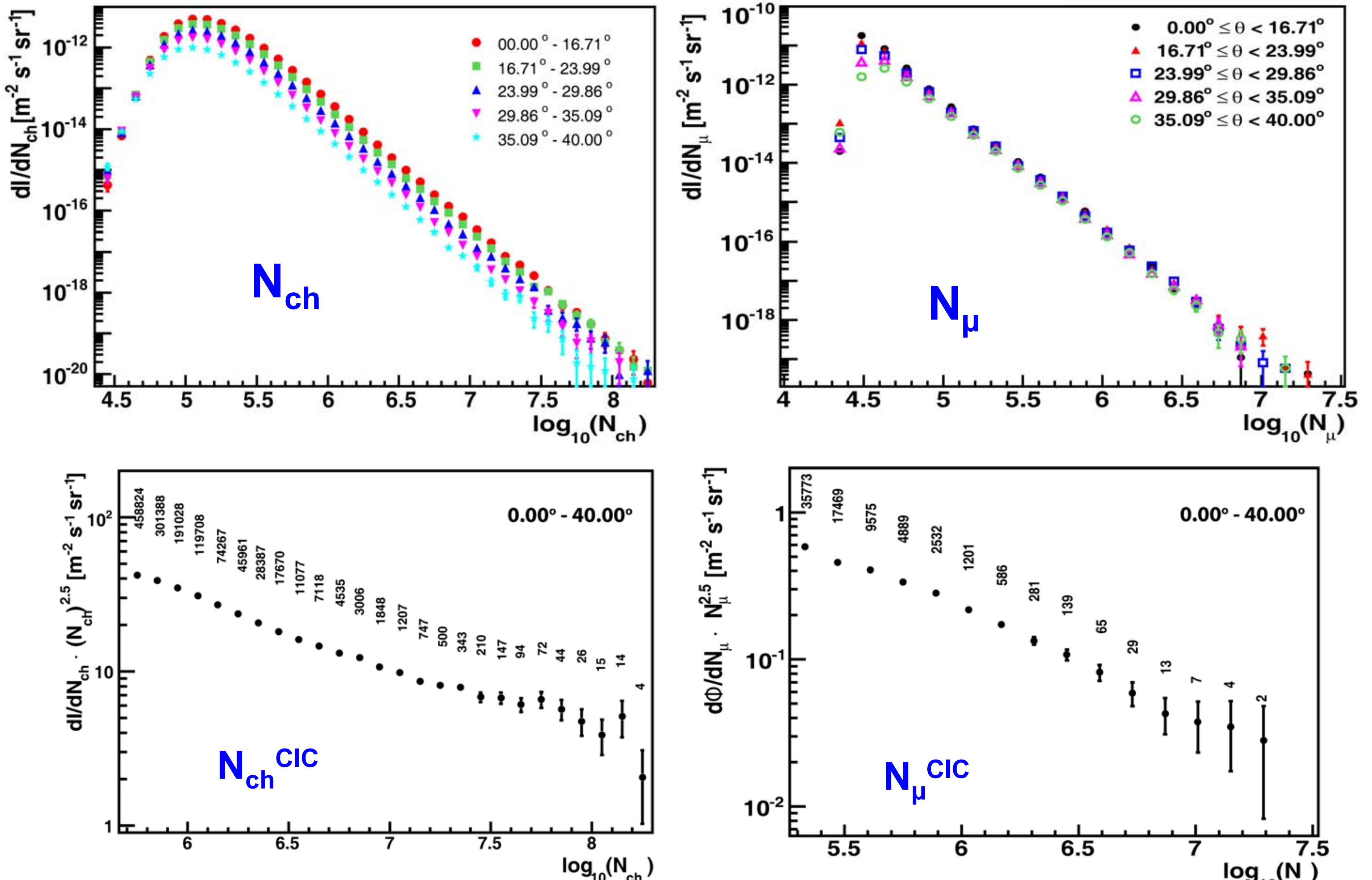
4



5

Energy spectrum

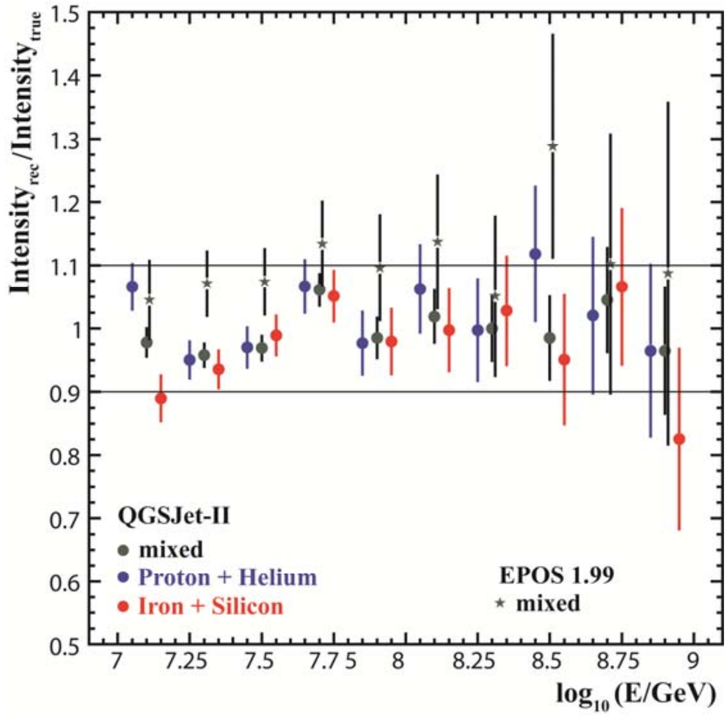
Shower size spectra

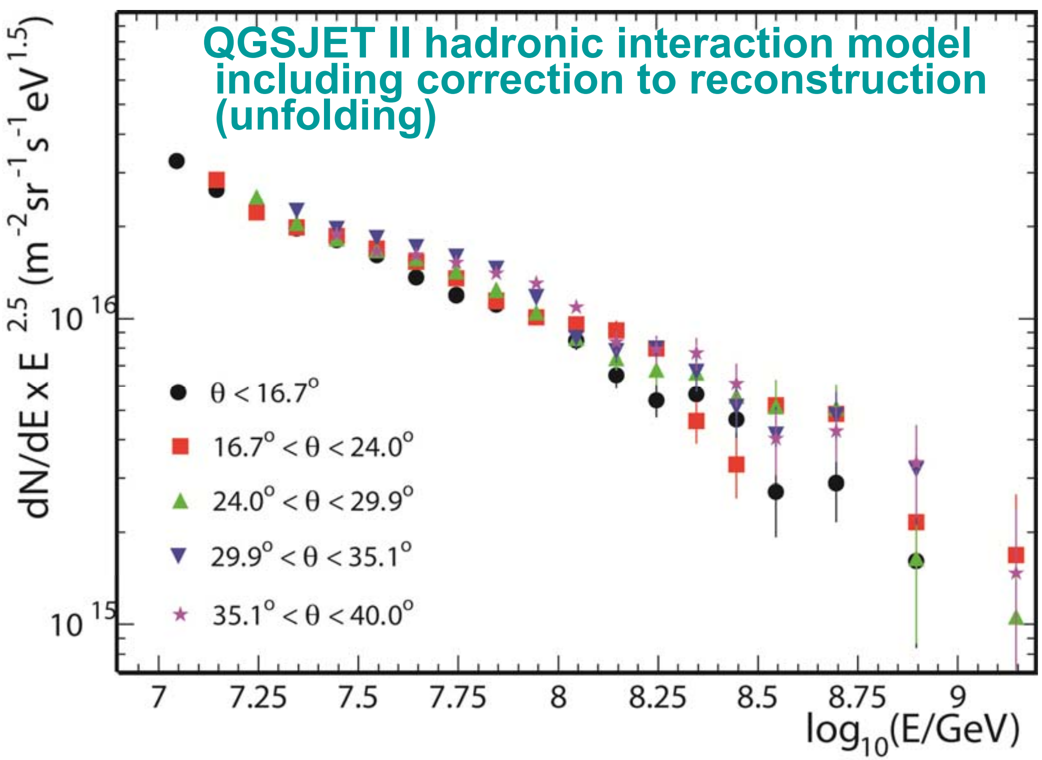


All-particle energy spectrum via combination of N_μ and N_{ch}

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

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



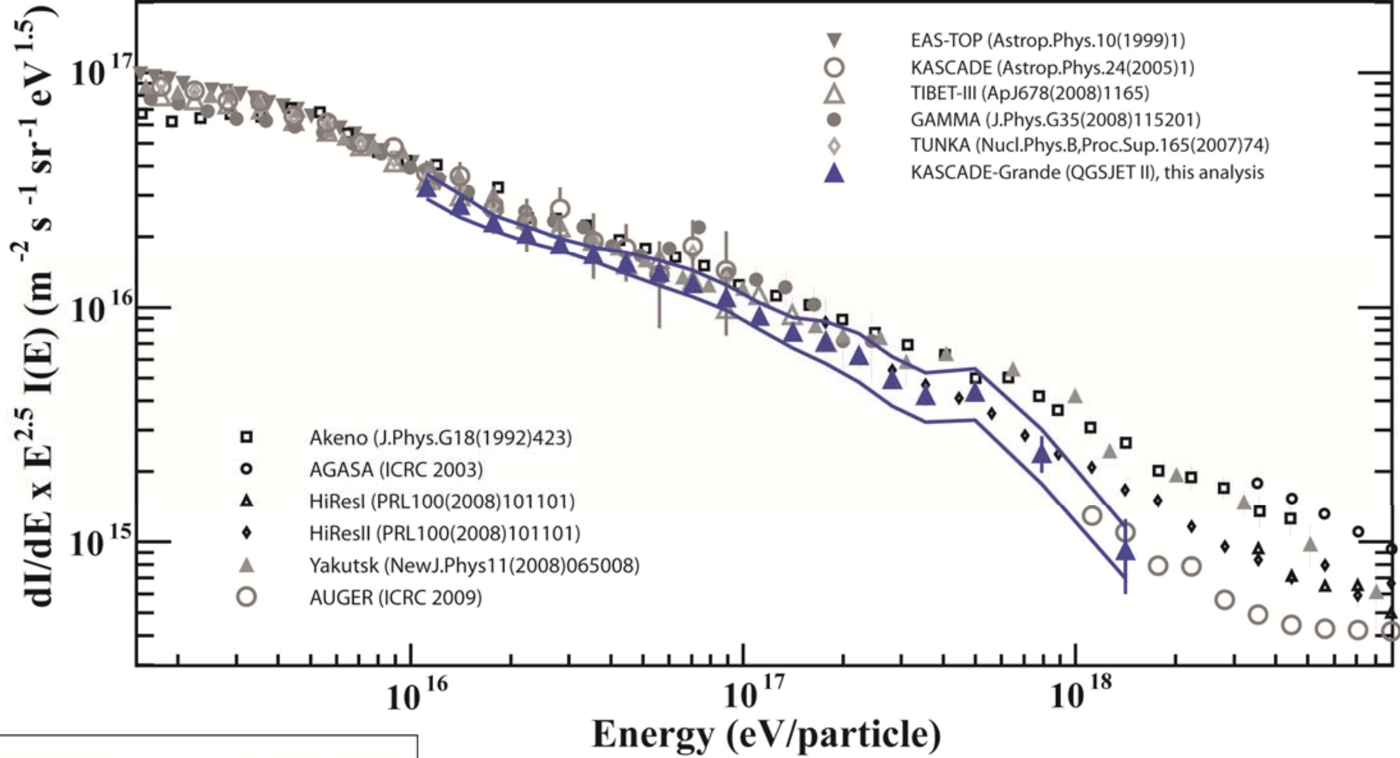


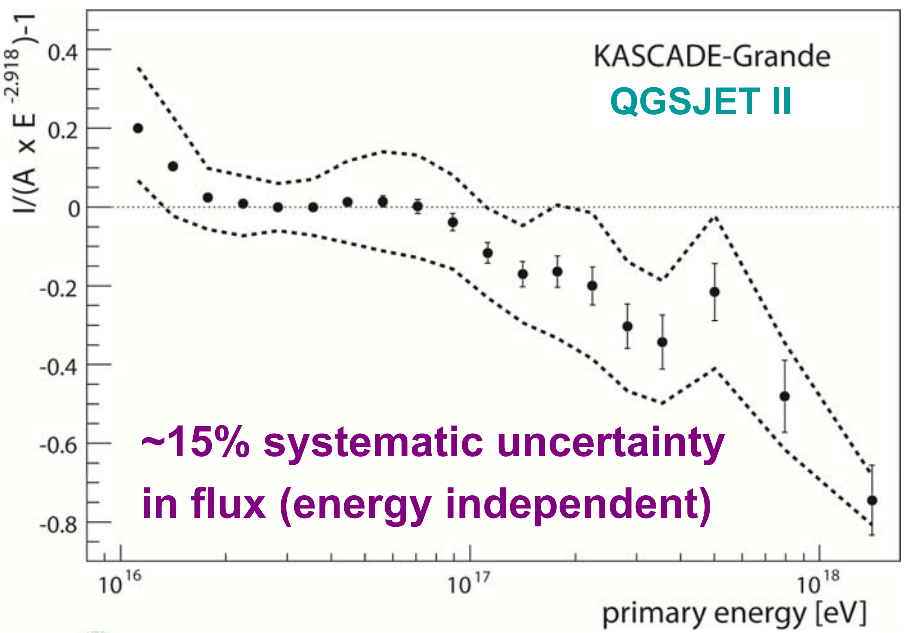
- different zenith angle bins
- no composition dependence

Astroparticle Physics 36 (2012) 183

KASCADE-Grande all-particle energy spectrum

Astroparticle Physics 36 (2012) 183

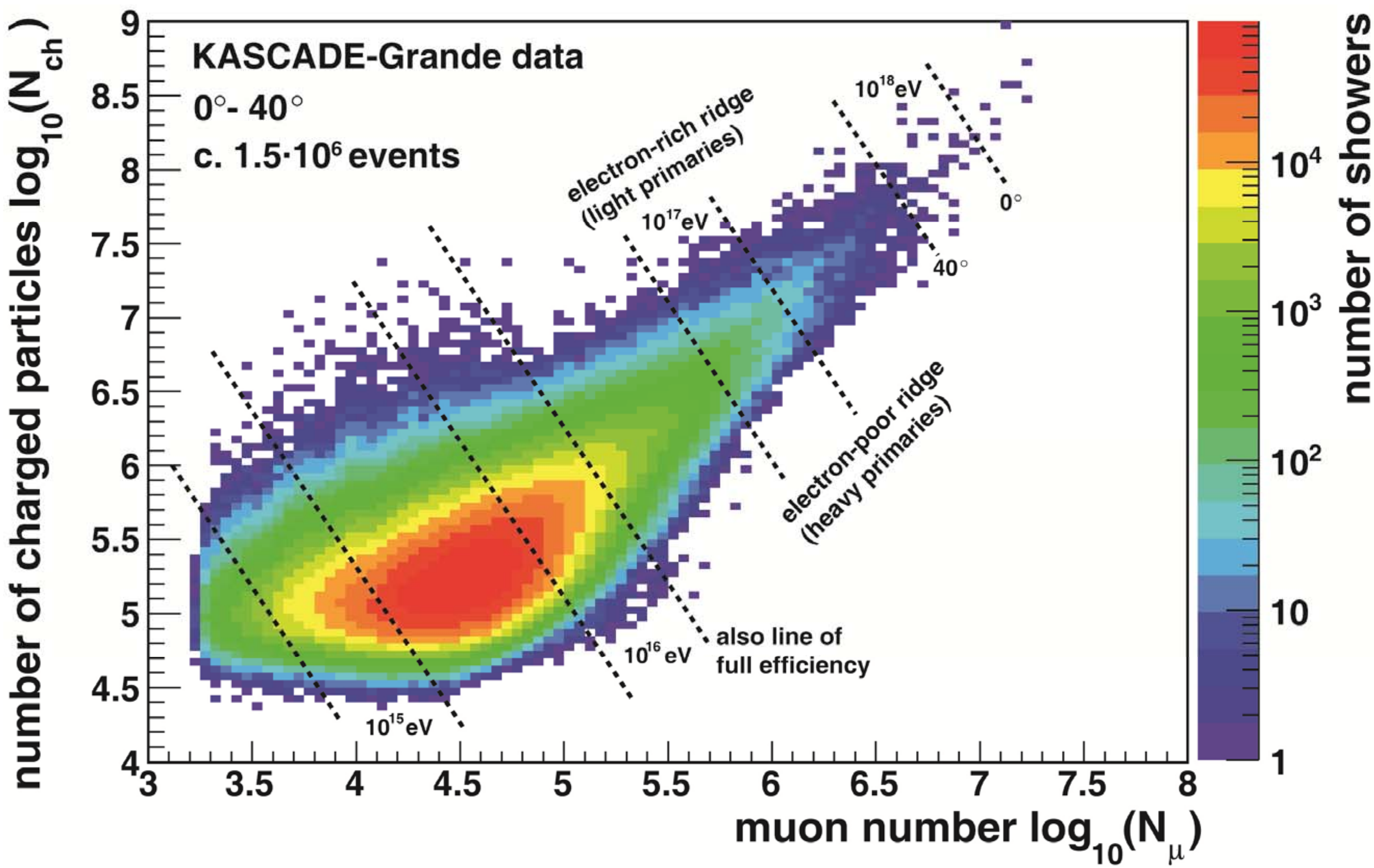




~15% systematic uncertainty in flux (energy independent)

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

Elemental composition : model independent way



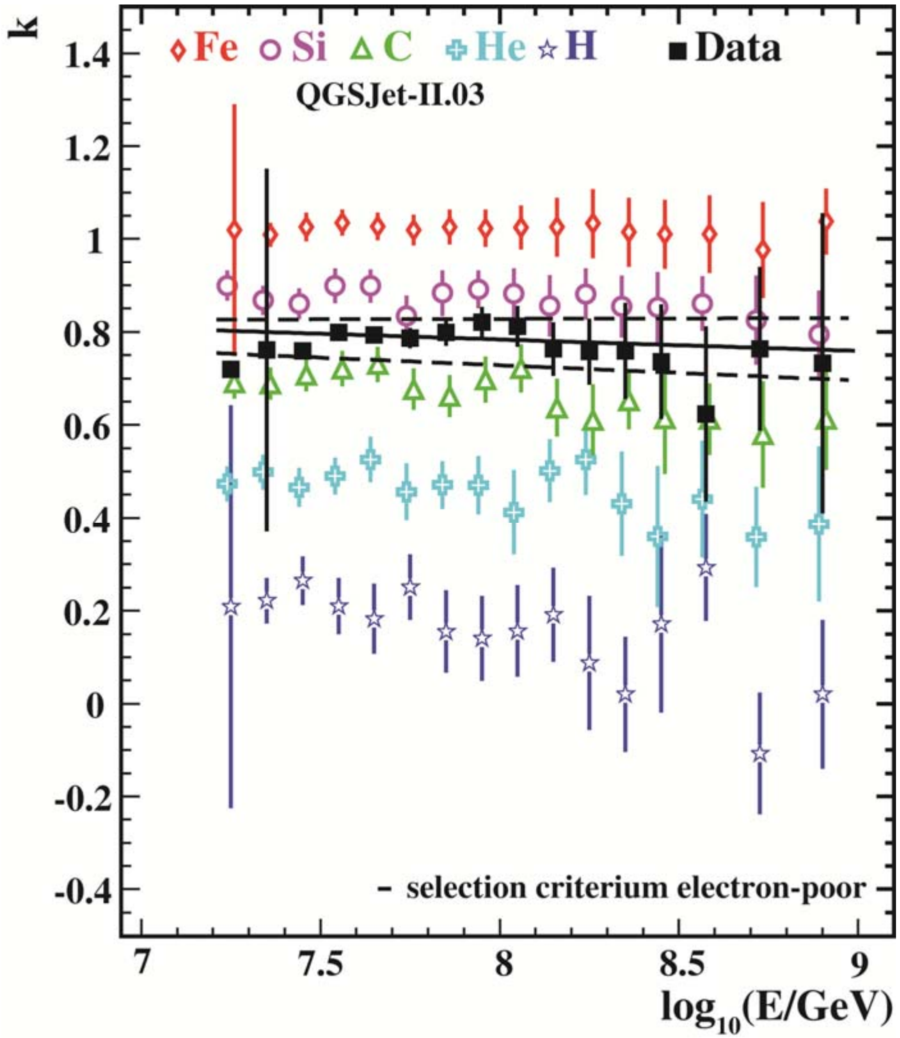
- **2-dimensional shower size distribution**

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

Composition via shower size ratio :

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

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

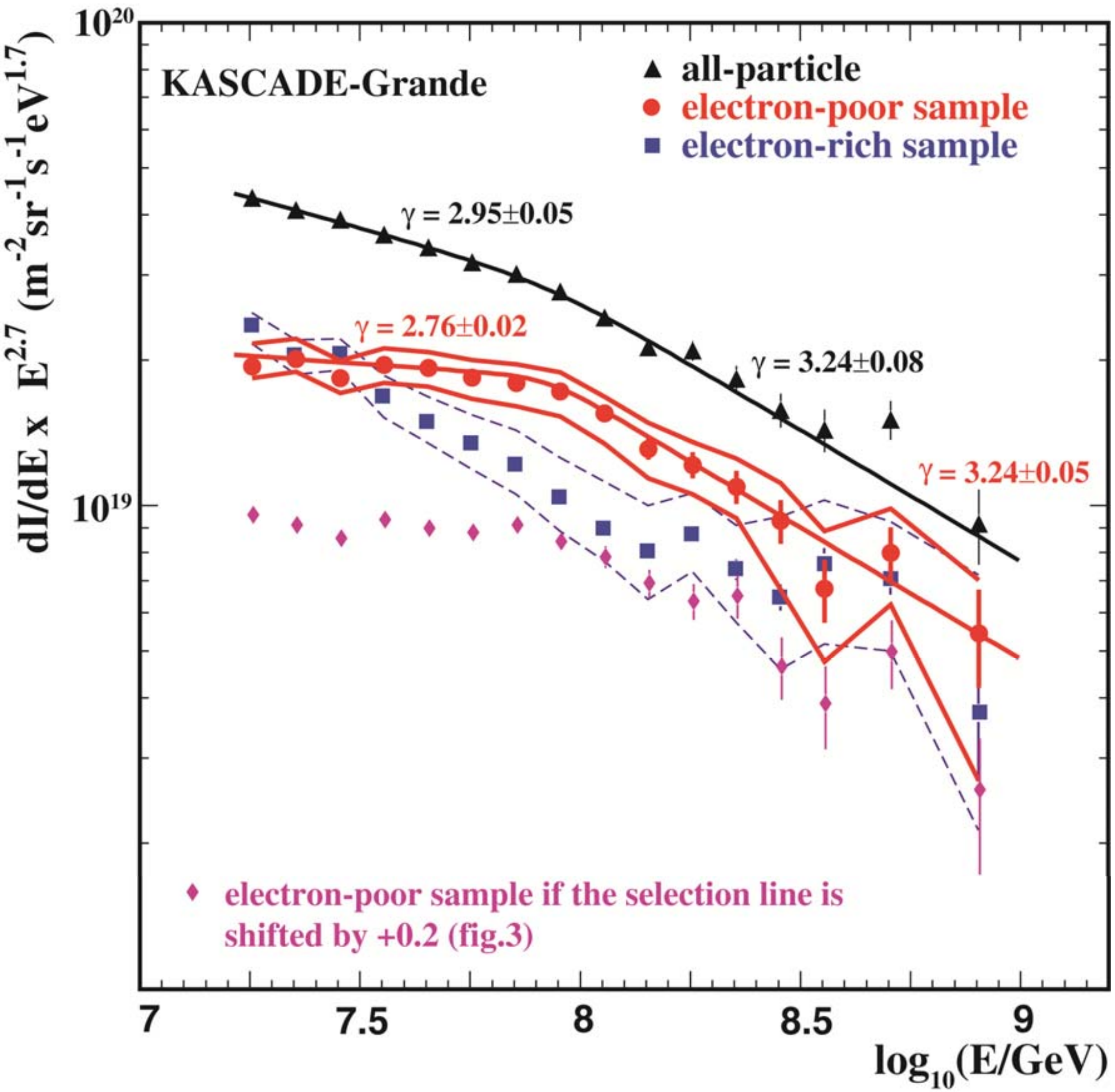


- k-parameter = normalized shower size ratio

➔ composition sensitive

➔ separation in
electron-rich (light)
electron-poor (heavy)
event samples!

Spectra of individual mass groups :



Phys.Rev.Lett. 107 (2011) 171104

- spectra of individual mass groups:

➔ steepening close to 10^{17}eV (2.1σ) in all-particle spectrum

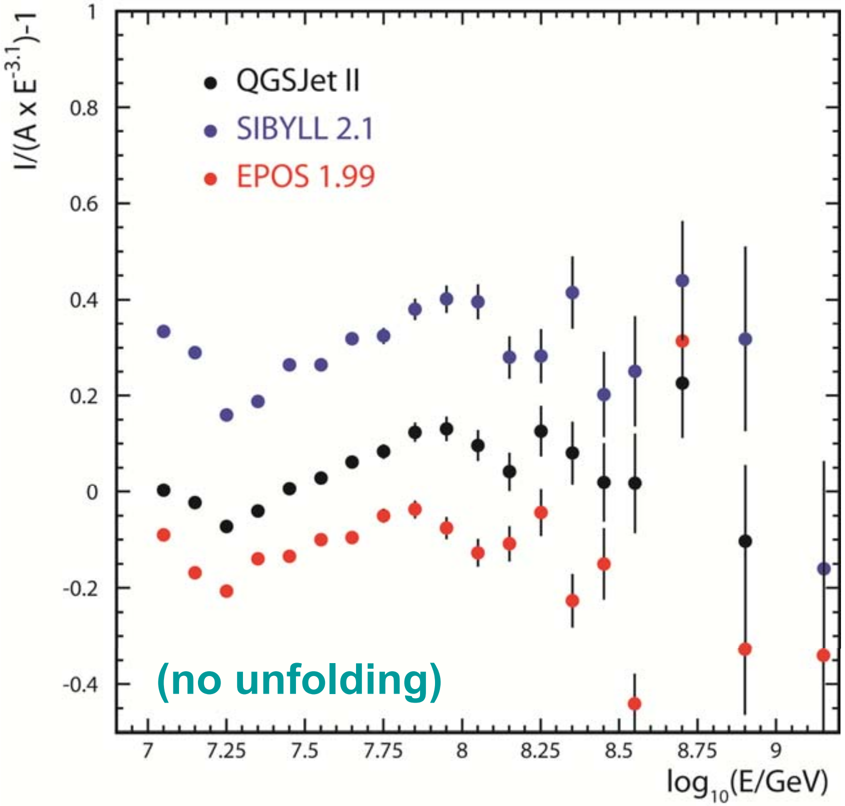
➔ steepening due to heavy primaries (3.5σ)

➔ light+medium primaries show steeper spectrum,
➔ fit by power law okay
➔ possibility for hardening above 10^{17}eV

➔ spectrum of more enhanced heavy sample has harder spectrum before break.

Hadronic Interaction Model

all-particle spectrum



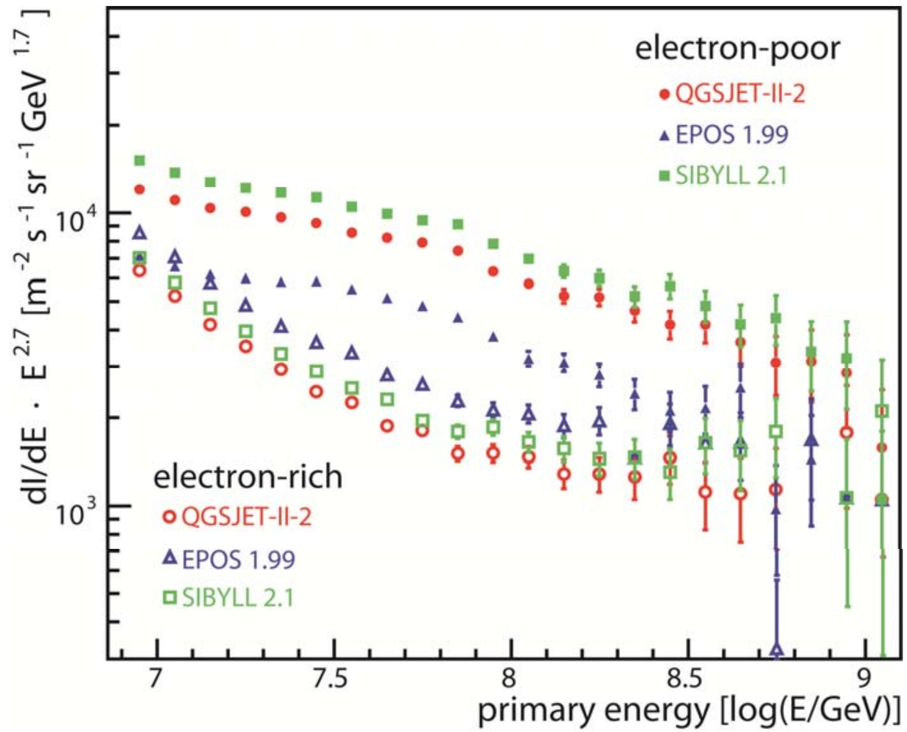
- **all-particle spectrum (N_μ-N_{ch}) by different models**

➔Structures similar

➔ total flux shifted (10-20%)

➔ results confirmed!!

light-heavy spectra



- **individual spectra by Y_{CIC}**

Y_{CIC}=log N_μ^{CIC} / log N_{ch}^{CIC} ; E by N_{ch} only

based on different models

➔ Structures similar

➔ total flux shifted

➔ results confirmed!!

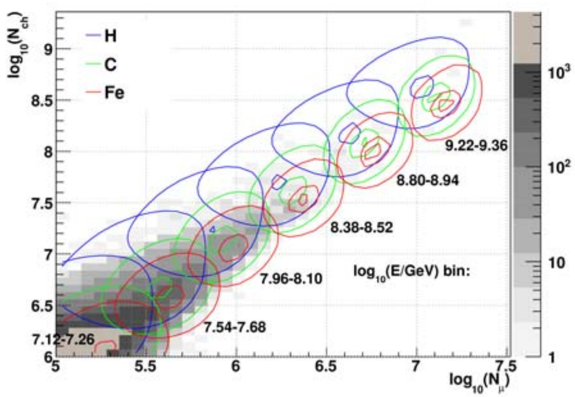
Unfolding of 2-dim shower size distribution :

Like in KASCADE!

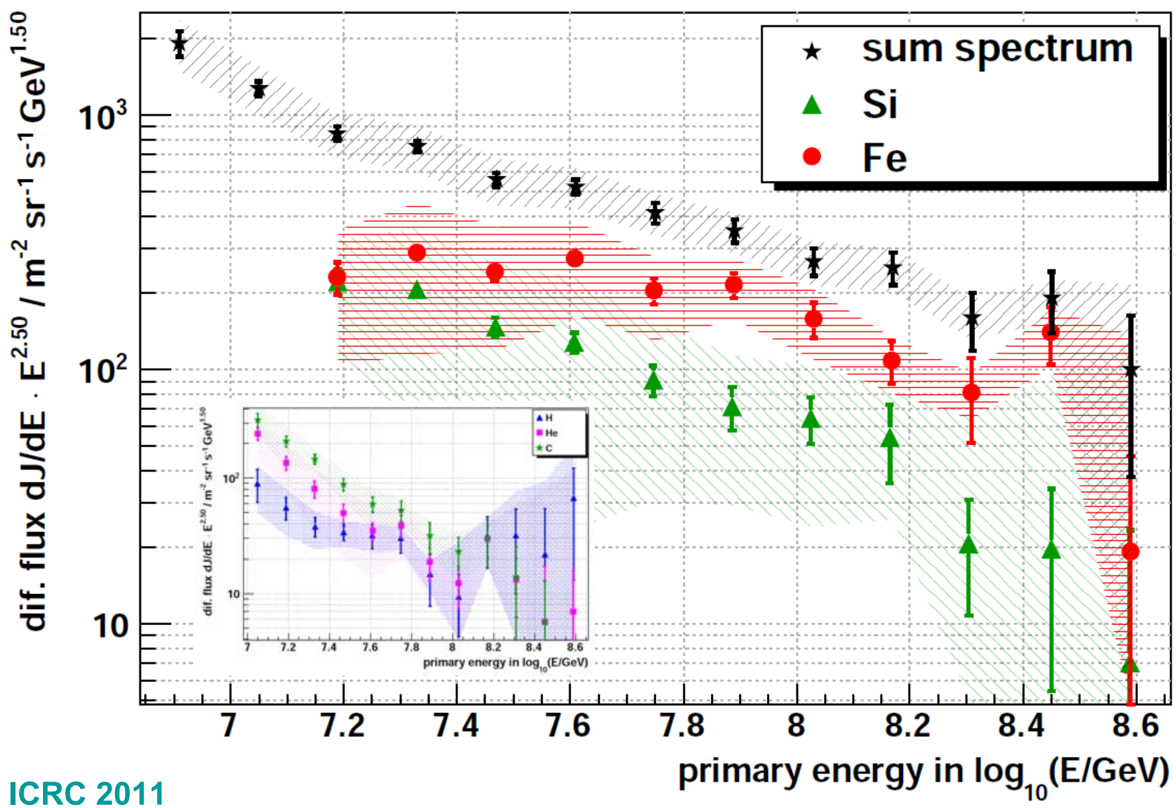
Searched: E and A of the Cosmic Ray Particles
Given: N_e and N_μ for each single event
➔ solve the inverse problem

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

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

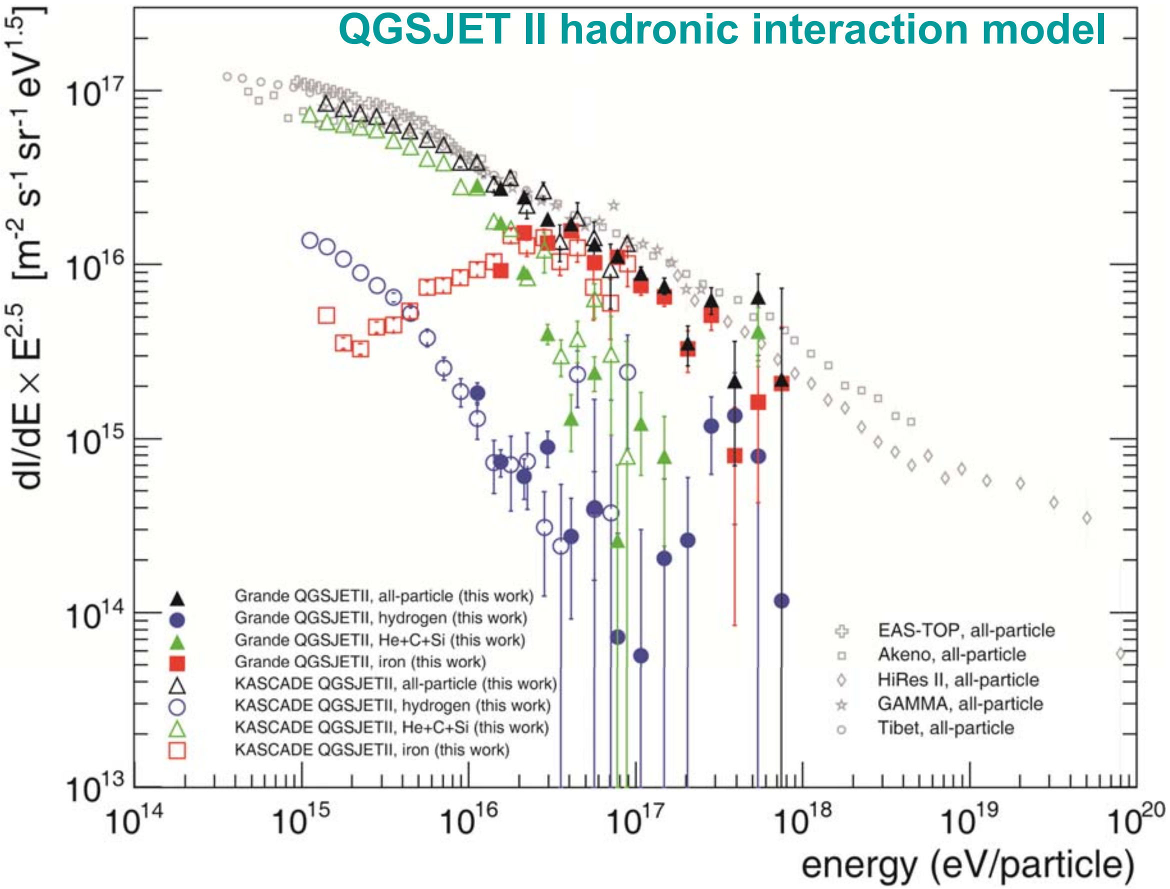


➔`knee´ in Fe-component only!!



D.Fuhrmann et al – KASCADE-Grande, ICRC 2011

Unfolding results
KASCADE ←→ KASCADE-Grande



- spectra of individual mass groups:
  - proton
  - medium (He+C+Si)
  - iron

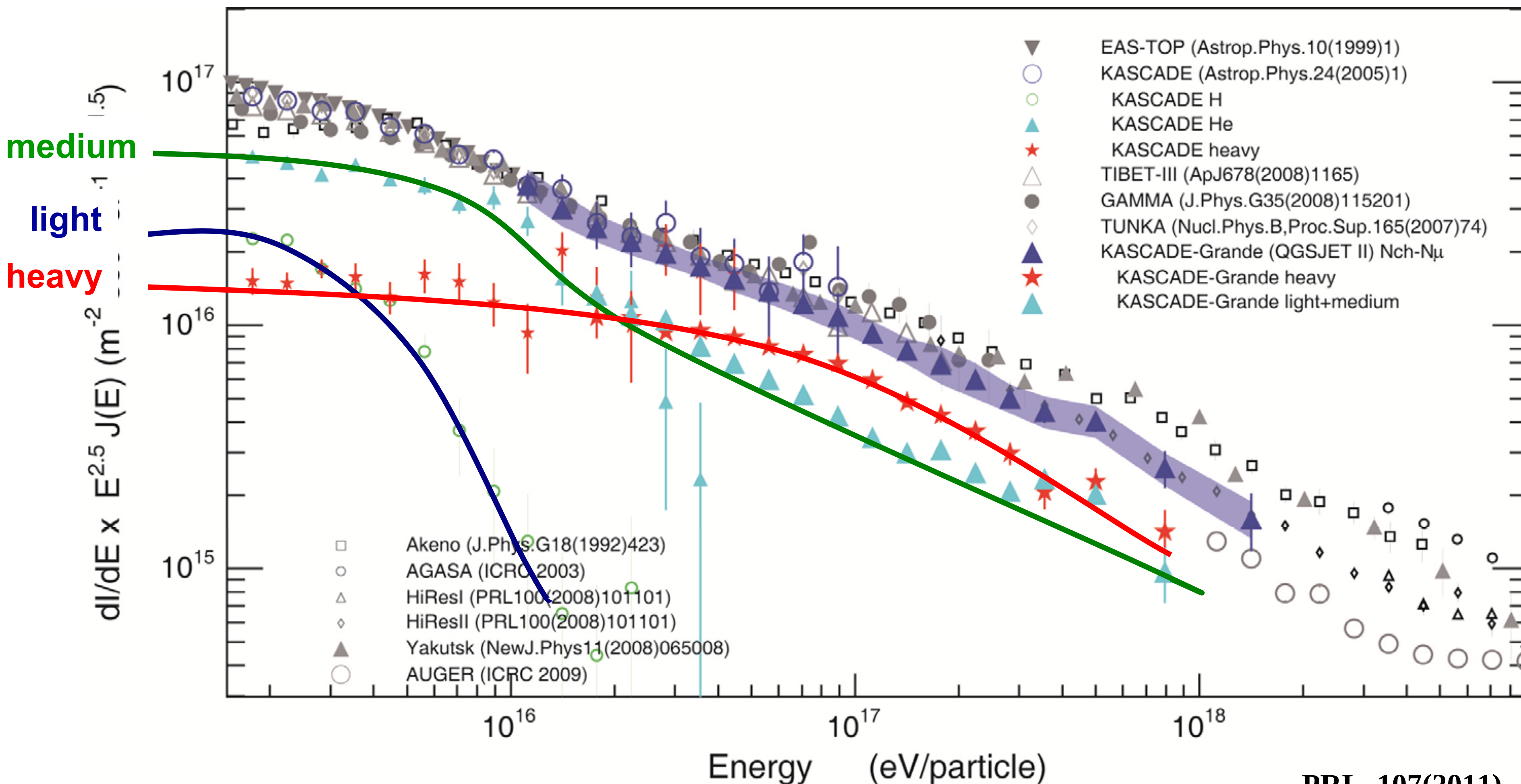
→ all spectra overlap and agree well!

→ all three show a knee-like feature!!

M.Finger, KASCADE-Grande, PhD thesis, June 2011

Light and Heavy Knees

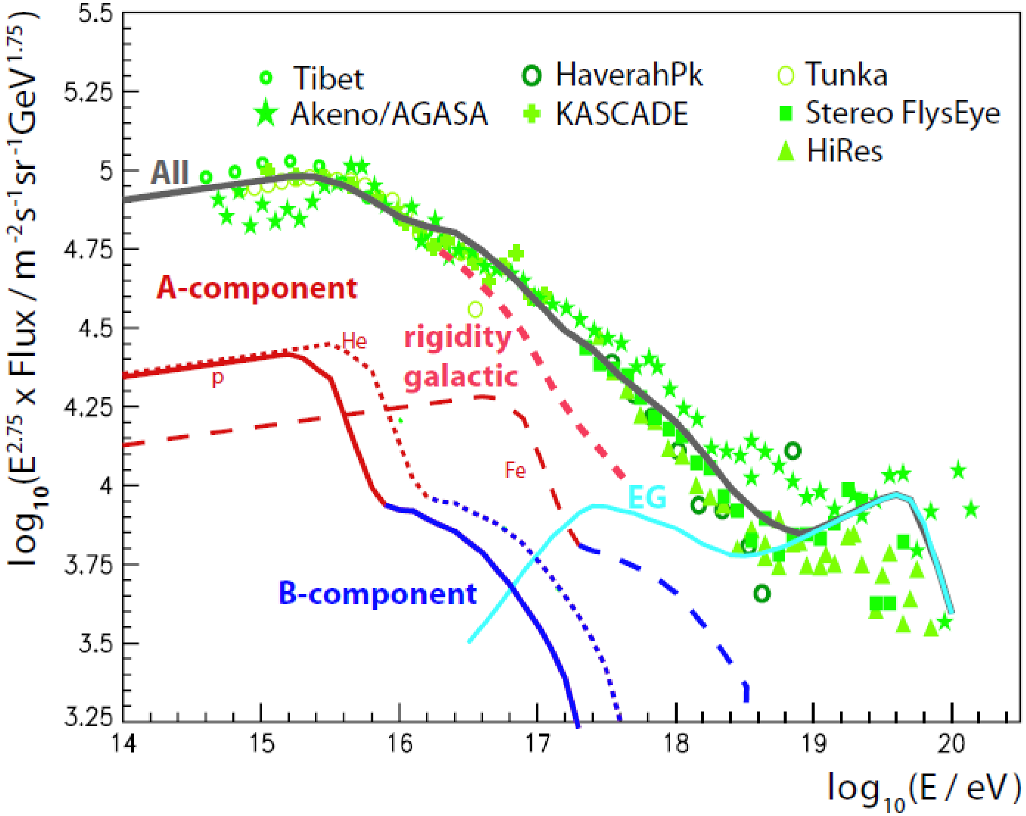
knee position ∝ Z



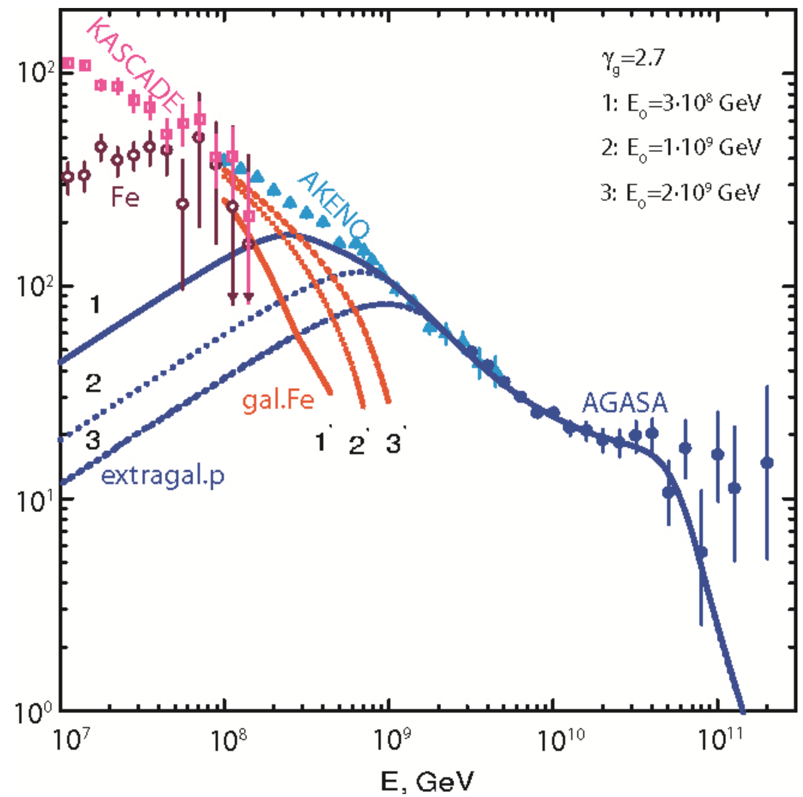
PRL, 107(2011)

➔ **KASCADE: knee of light primaries at ~$3 \cdot 10^{15}$eV**
➔ **KASCADE-Grande: knee of heavy primaries at ~$9 \cdot 10^{16}$ eV**

Implications



A.M.Hillas, J. Phys. G: Nucl. Part. Phys. 31 (2005) R95



V.Berezinsky, astro-ph/0403477

KASCADE-Grande:

- **light knee above 10^{15}eV**
- **spectrum concave at 10^{16}eV**
- **heavy knee at 10^{17}eV**
- **mixed composition**

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, F.Garino, 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

Universität Siegen
Experimentelle Teilchenphysik
C.Grupen

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

University Trondheim, Norway
S. Ostapchenko

IFSI, INAF and University of Torino
M. Bertaina, E. Cantoni, A. Chiavassa, F. Di Pierro, C. Morello, G. Trinchero

Universidad Michoacana
Morelia, Mexico
J.C. Arteaga

Radboud University
Nijmegen
J.R.Hörandel

National Centre for Nuclear Research, Lodz
P. Łuczak, J. Zabierowski

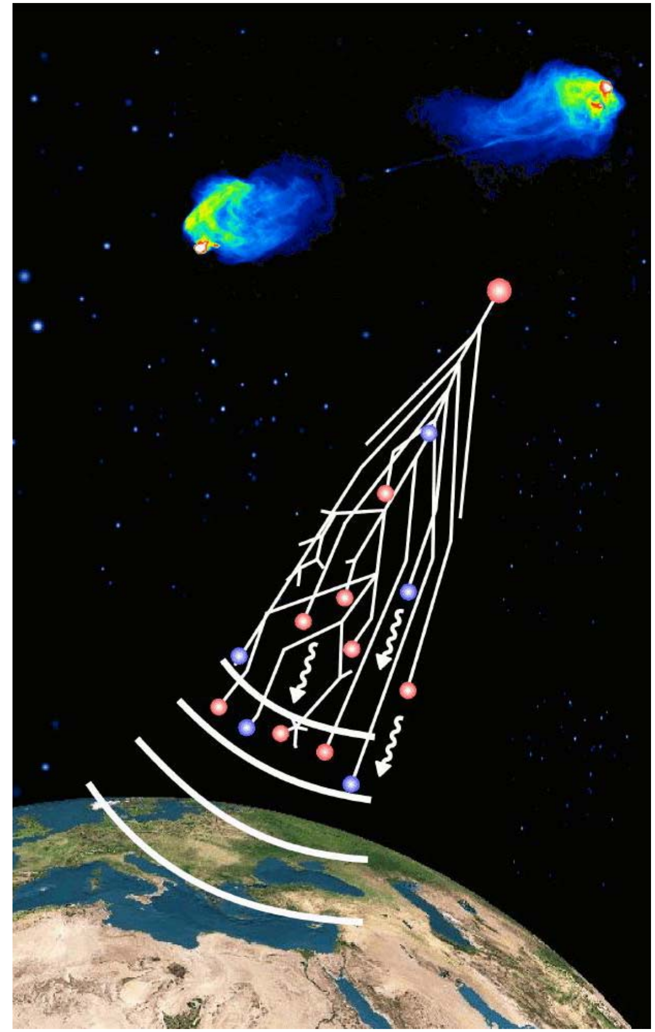
Institute of Physics and Nuclear Engeneering and University Bucharest
I.M. Brancus, B. Mitrica, M. Petcu, O. Sima, G. Toma

Universidade Sao Paulo, Brasil
V. de Souza

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

LOPES :
radio detection of air-showers

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



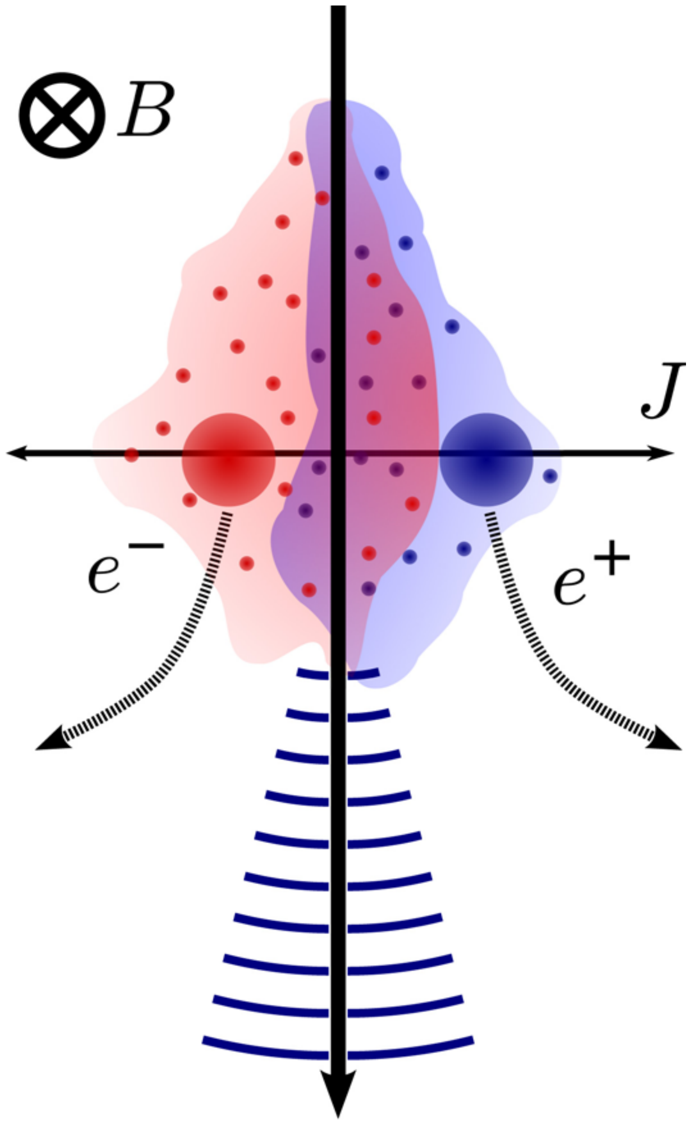
➔ Development of a new detection technique!

Radio from Air Showers

Detection principle:

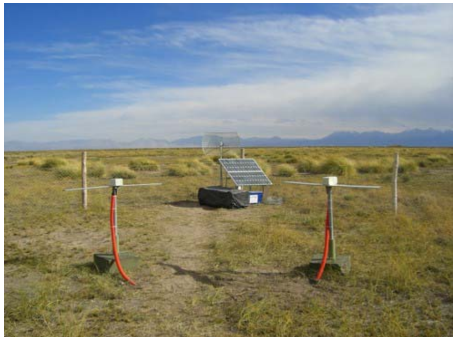
-Geomagnetic deflection of electrons and positrons
-Time-variation of number of charged particles
-Time-variation of charge excess radiation
-and possibly more (refraction index)

➔ lead to coherent emission in atmospheric air showers (initiated by UHECR)
- MHz frequency range !
- µV/m-range amplitude
- few ns duration



Radio from Air Showers

~3-4000 cosmic ray events unambiguously detected by

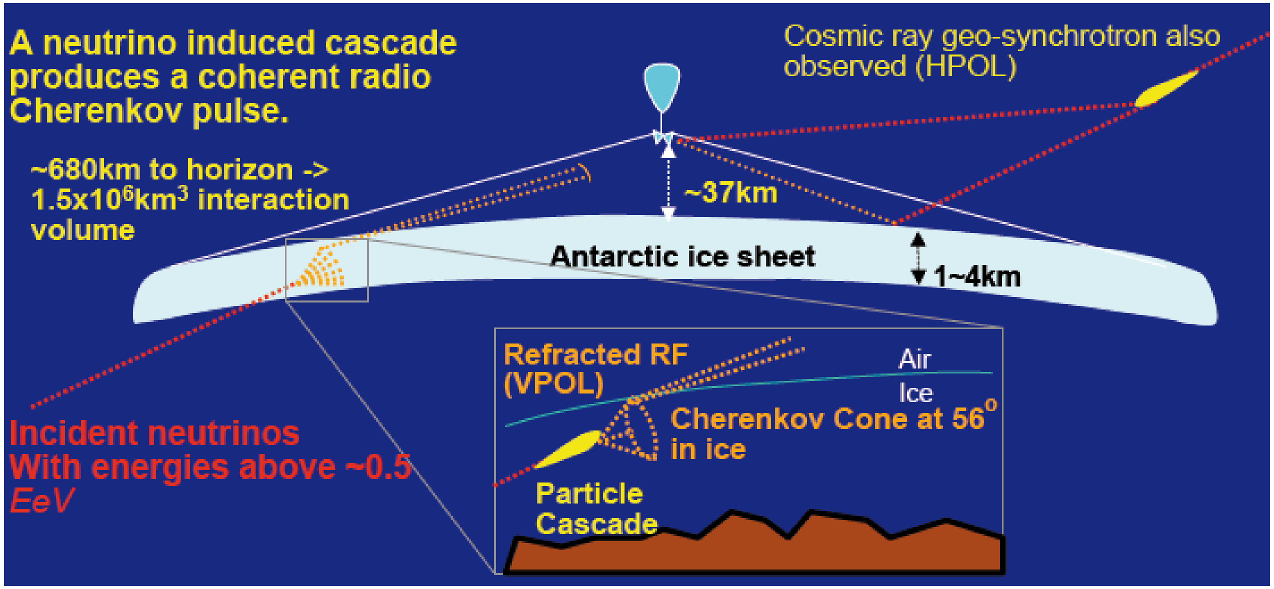


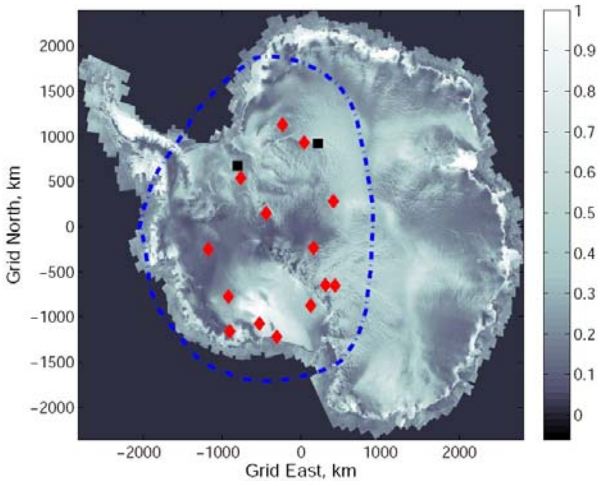
LOPES
CODALEMA
Radio Prototypes@Auger
AERA
TREND
ANITA
Tunka-Rex

(and of course the historical experiments, partly re-analyzed: MSU, Yakutsk, e.g.)

➔Now: do we understand the signals?

ANITA :
ANtarctic Impulsive Transient Antenna



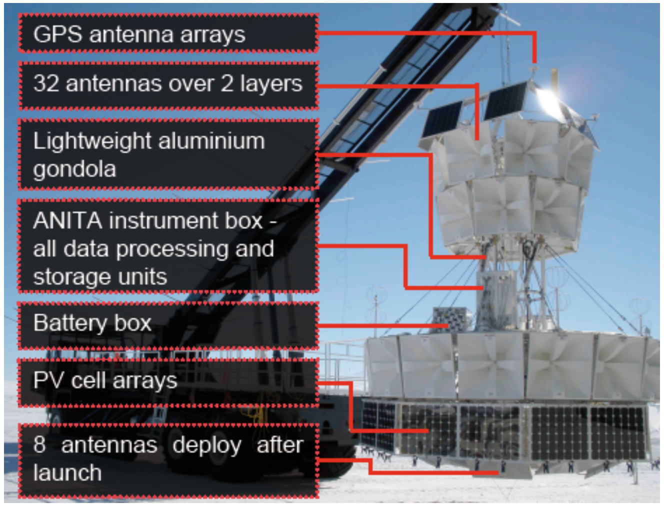


Horn antennas 300MHz-1GHz

➔ 16 EAS candidates (Energy ~10^{19}eV)

➔ No neutrino candidate

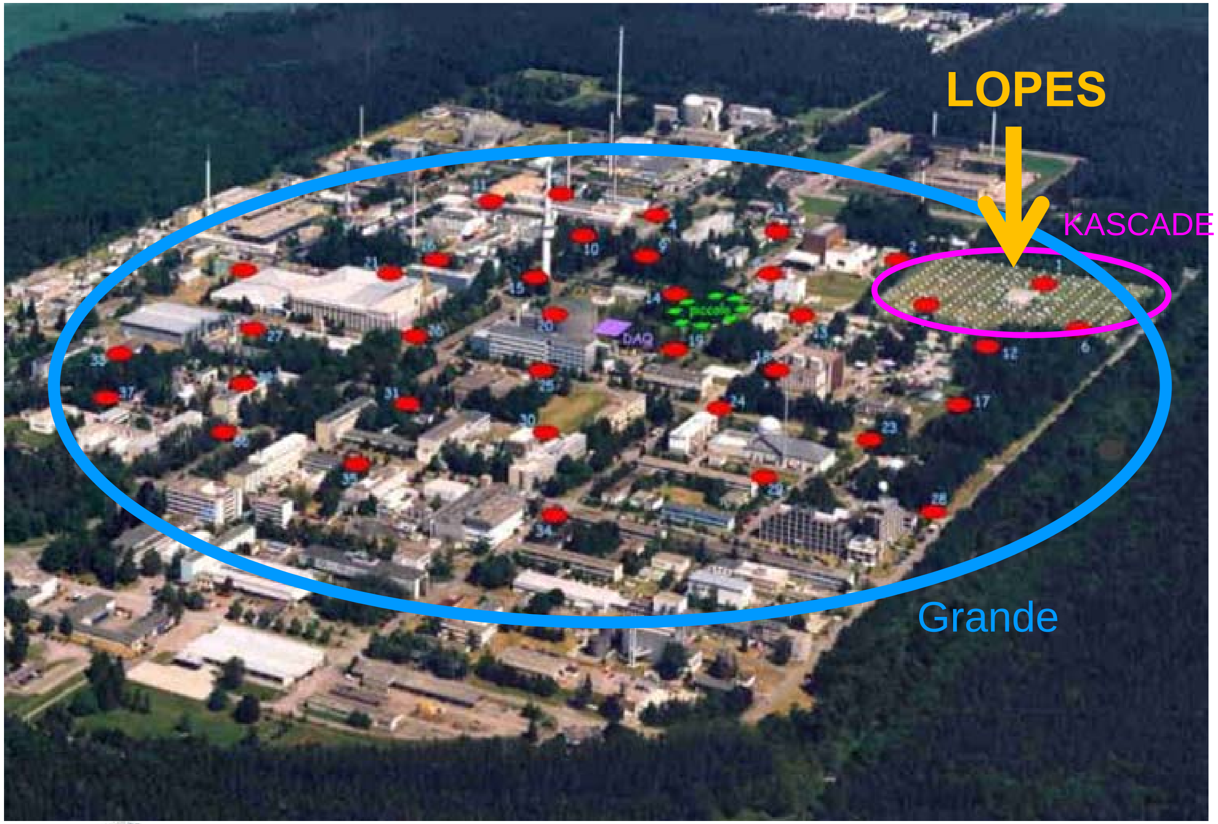
➔2012 next (CR optimized) flight



A.Romero-Wolf, ARENA 2010, Nantes
S.Hoover et al. - Phys.Rev.Lett.105:151101,2010.

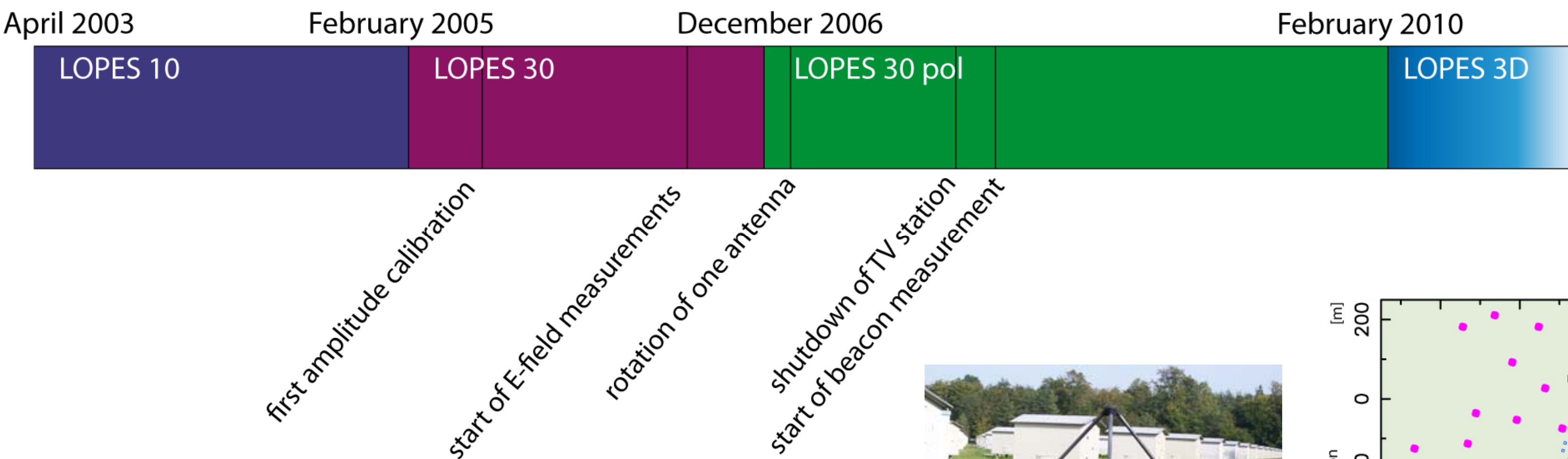
LOPES

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

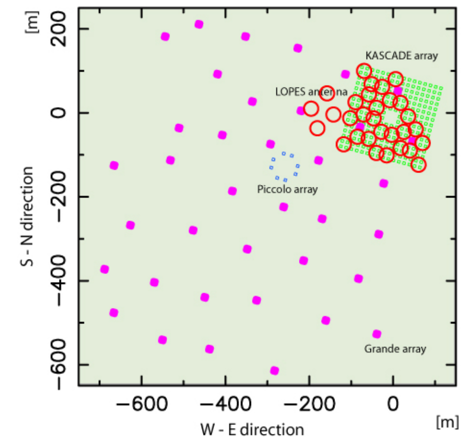


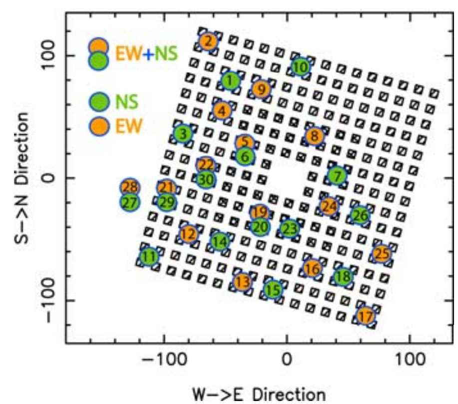
➔Development of a new detection technique!

Evolution of LOPES



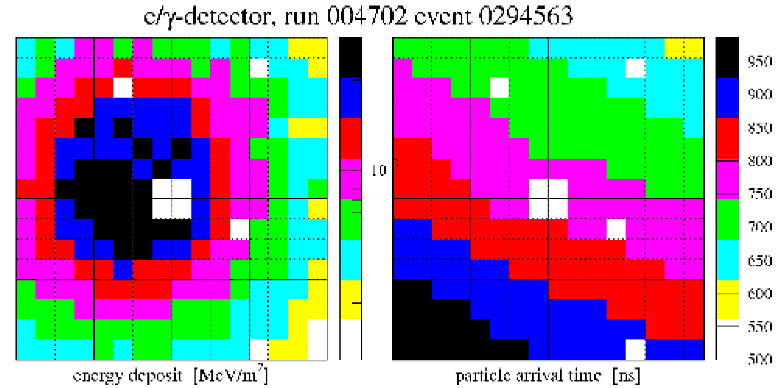
- **LOPES 10**
  - **„proof of principle“**
- **LOPES 30 east-west**
  - **calibration of signal**
- **LOPES 30 pol**
  - **polarization dependencies**
- **LOPES 3D**
  - **complete E-field-vector**



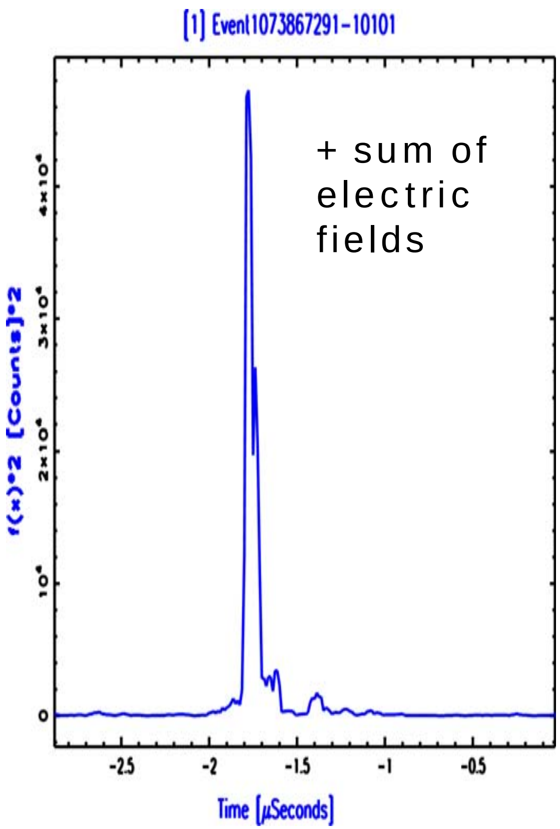


LOPES: Proof of principle

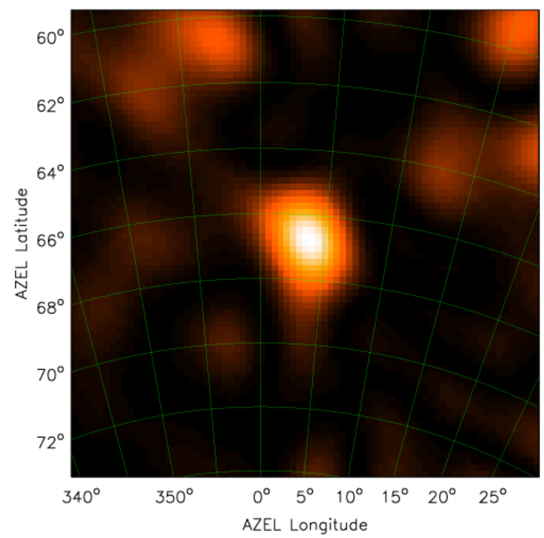
1. KASCADE measurement



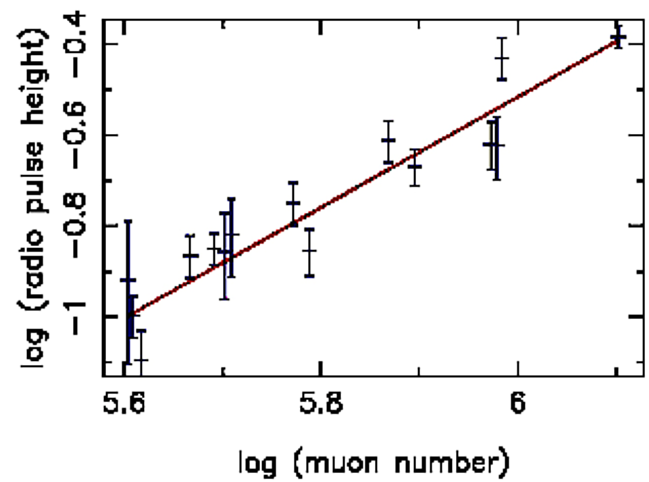
2. Radio data analysis



3. Skymapping



4. Many events



5. Publication

LOPES collaboration, Nature 425 (2005) 313

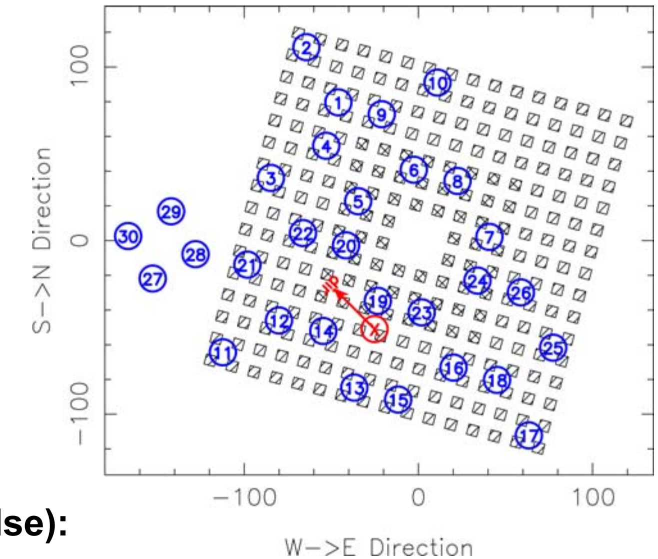
6. Be happy

LOPES 30 event example

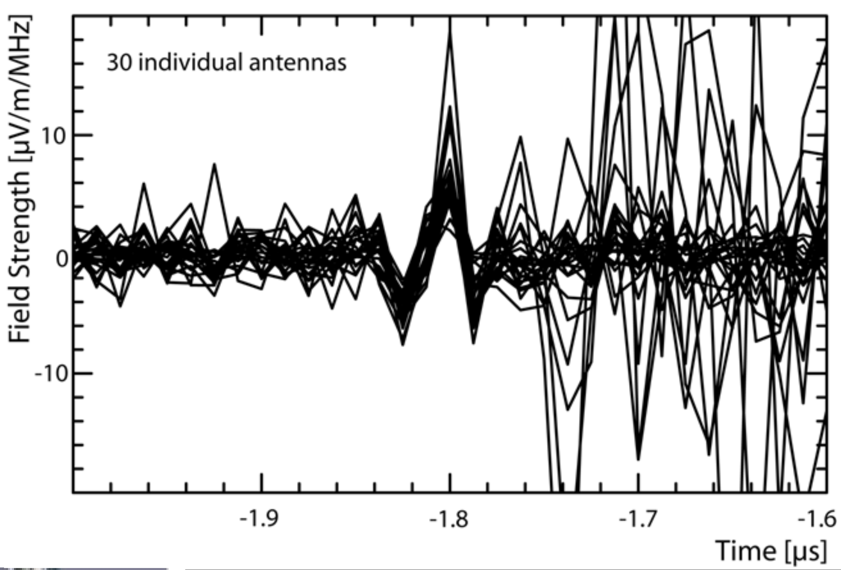
-radio reconstruction inclusive calibration factors of antennas
➔CC-beam value (per event)
➔Field strength (per antenna)

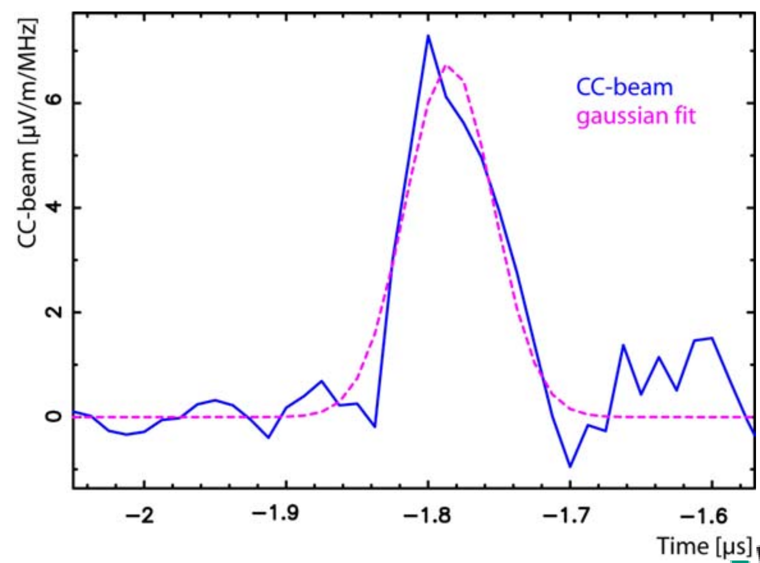
$$cc[t] = \pm\sqrt{\left|\frac{1}{N_{Pairs}}\sum_{i=1}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]\right|}$$

(degree of correlation ➔ extract coherent pulse):

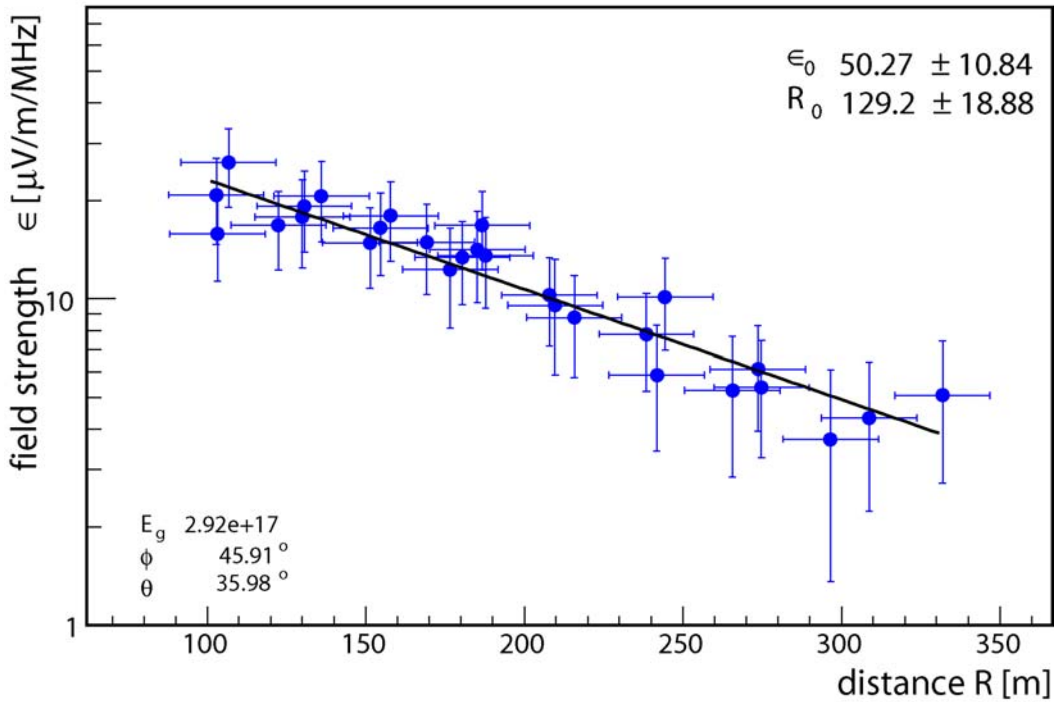


Event:
Φ = 15° θ = 306°
core = in KASCADE
$lg(N_e)$ ~ 7.4
$lg(N_\mu)$ ~ 6.0
E_0 ~ $1.6\cdot10^{17}$ eV





Lateral distribution

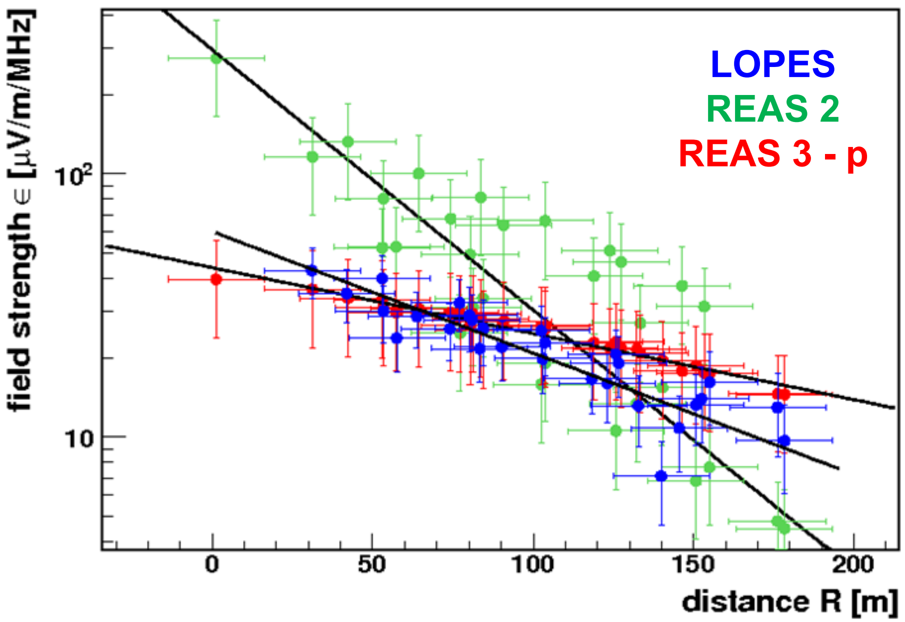


W.D. Apel et al. (The LOPES Collaboration), Astroparticle Physics 2010

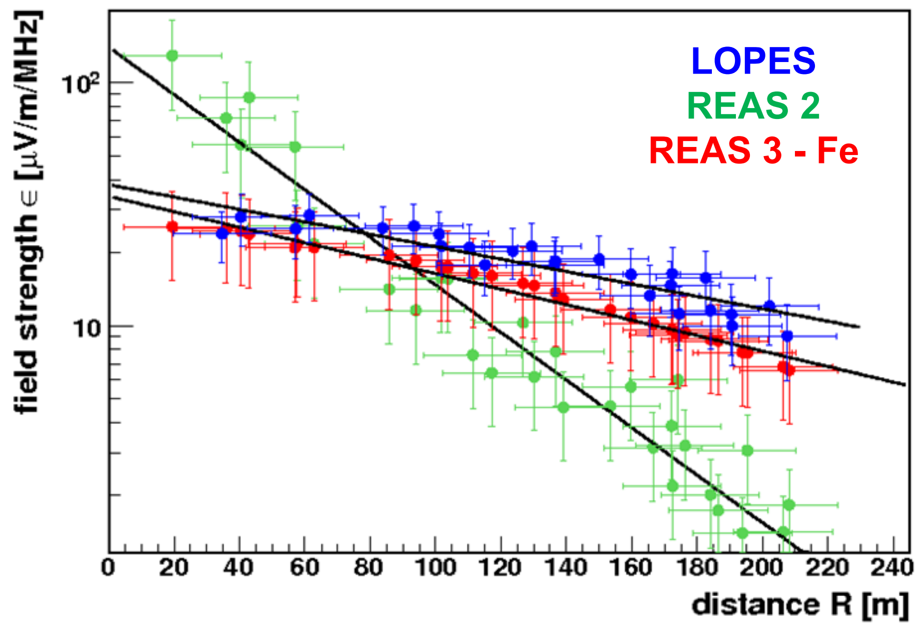
- **Field strength of individual antennas**
- **Fit with exponential function $\varepsilon(R) = \varepsilon_0 \exp -(R/R_0)$**
  - **80% exponential with R_0~100-200 m**
  - **20% total flat events or flat at small distances**

Lateral distribution
Comparison of data with simulations

event A



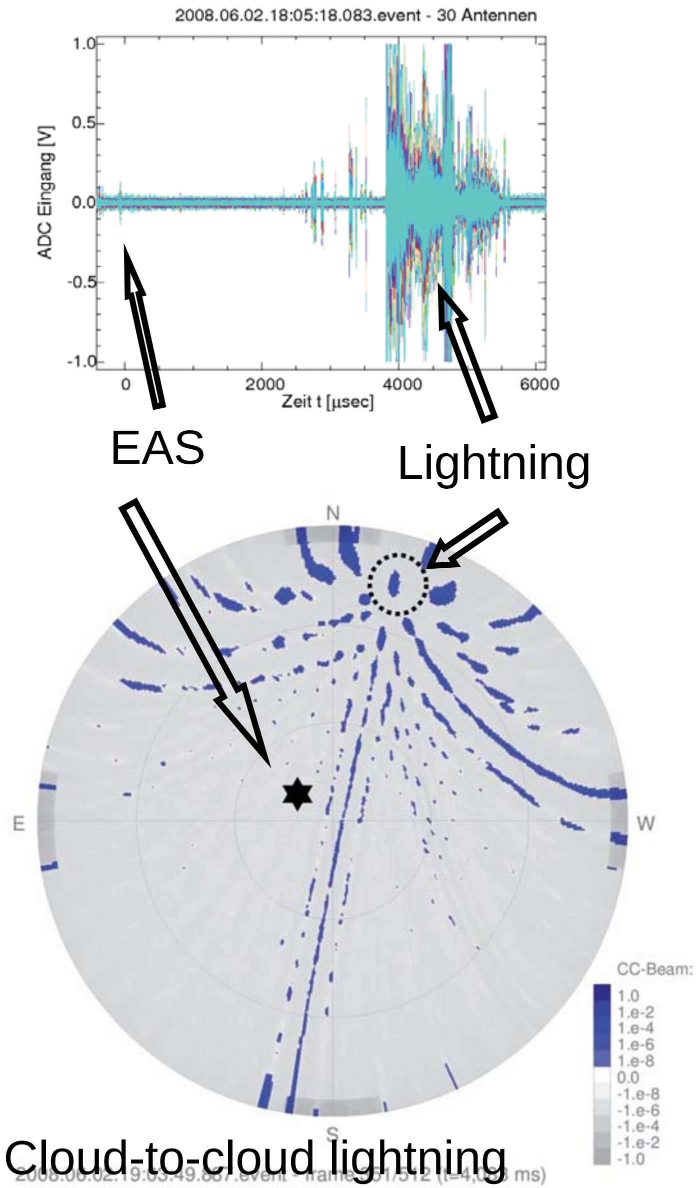
event B



- **Simulation of measured events**
- **REAS2 often too steep**
- **REAS3 fits well, explains also most flat events**

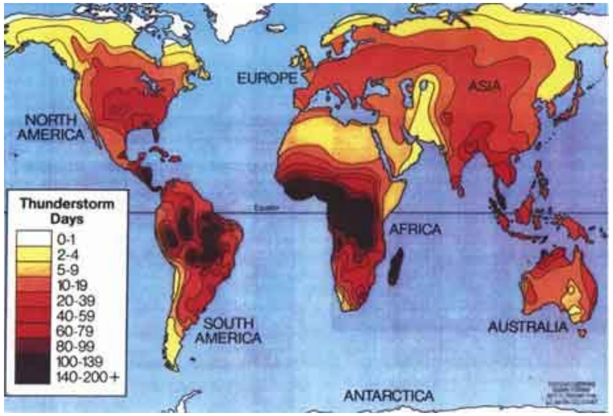
REAS3: Huege, Ludwig, Astroparticle Physics 2010
LOPES data: F.Schröder, PhD thesis, Feb 2011

LOPES: Lightning vs. EAS



- **Problem: how lightning are initated?**
- **One solution: by EAS**

➔Radio good oportunity to measure lightning development



LOPES coll, accepted Advance Space Research (2011)

Connection particle array – radio array:

Radio detection technique is still in developing phase
hardware, software, analysis, emission mechanism(s?), … ➔
Calibration (understanding) radio emission
- **Dependencies of radio signal**
- **Understanding emission mechanism(s)**

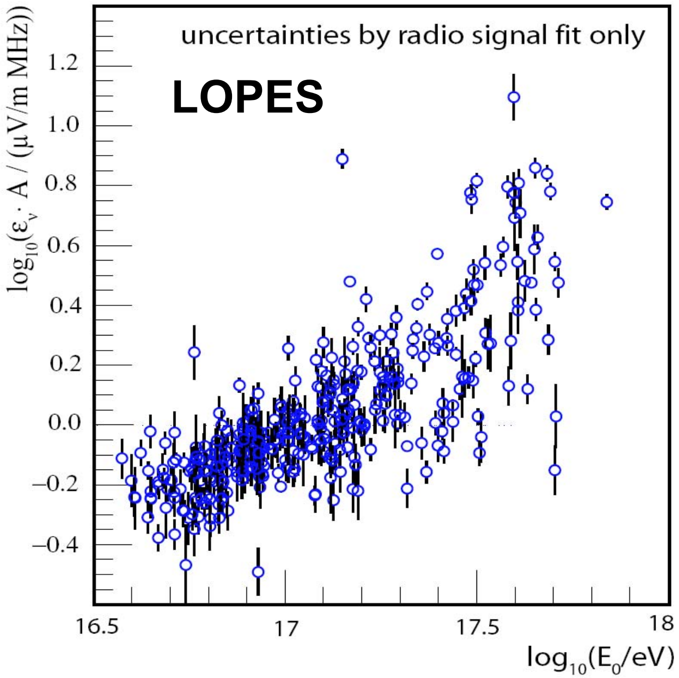
Capability of the radio detection technique?

Sensitivity and resolution to
- **primary energy?**
- **arrival direction?**
- **composition ?**

EAS radio detection for CR (and neutrino) measurements:
stand alone or hybrid technique?

Hybrid with particle arrays, not fluorescence technique (duty cycle).

Primary Energy



- Radio-Emission seems coherent !
- Energy sensitivity via electric field strength
- Radio signal (electric field) scales with primary energy:

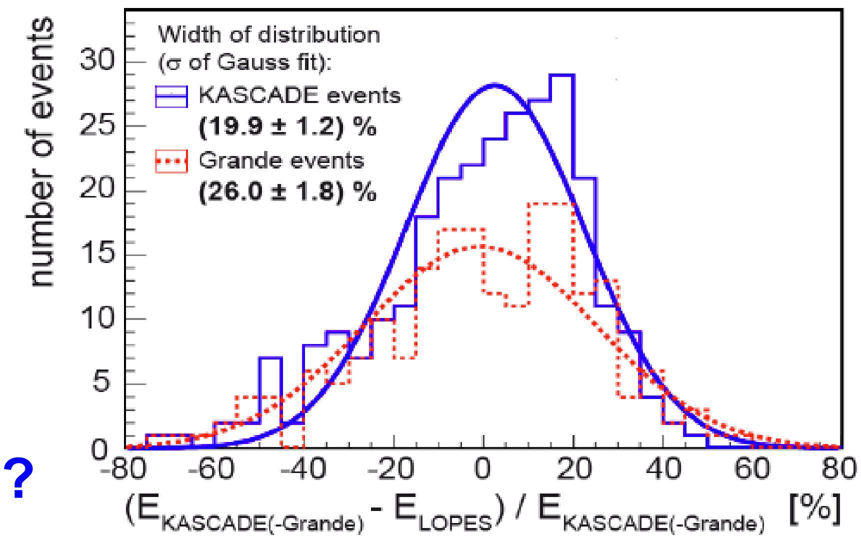
$$\varepsilon_\nu \sim E_0^{\approx 1}$$

➔ **Power of electric field scales approximately quadratically with primary energy !**

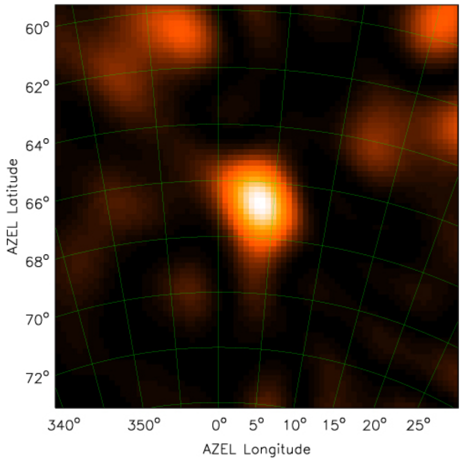
- Sensitivity and resolution

  $\Delta E/E \sim 20\text{-}25\%$
- Particle array: 10-20%

➔ is energy resolution really worse?
Model dependence?
Emission mechanism?
Geometry of shower (polarization)?



Arrival Direction

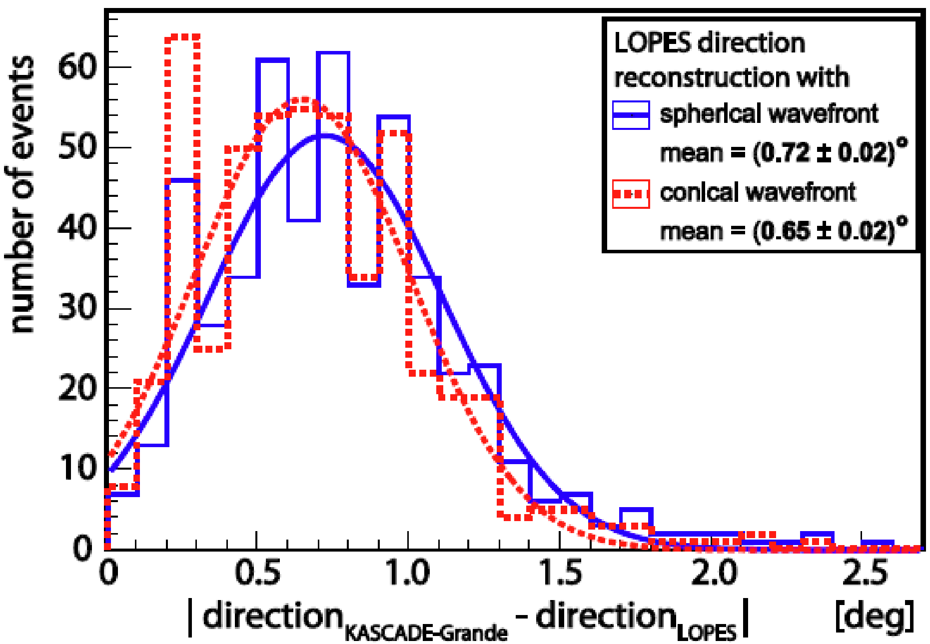


- sensitivity via pulse arrival time and phase
- systematic studies of direction resolution: KASCADE vs. LOPES

➔ resolution better 1°

(by beam forming; Better with increasing field strength, but number of antennas?)

➔ ~1ns time resolution needed

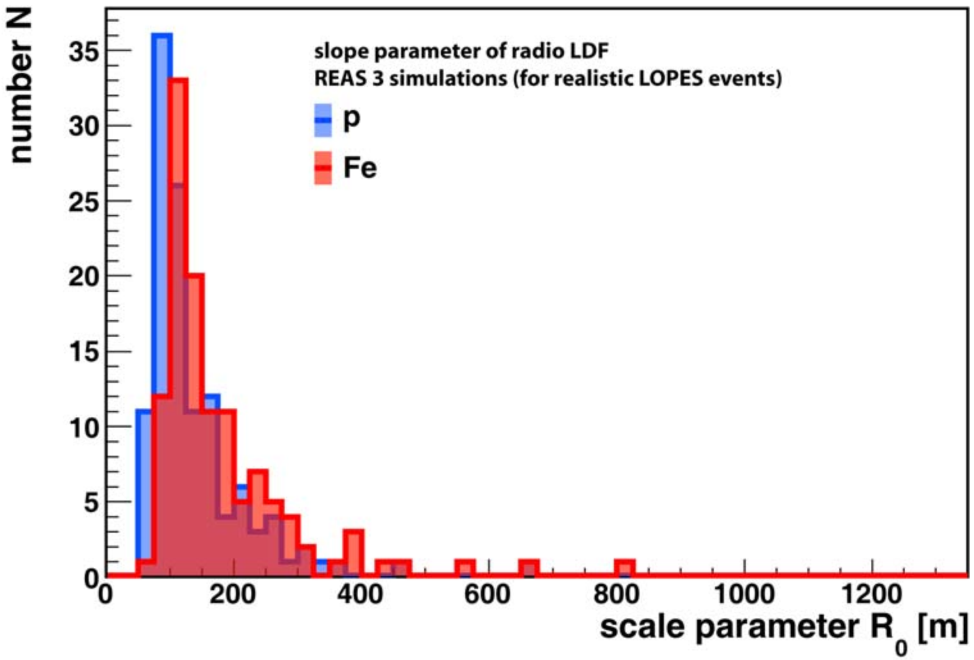


- Sensitivity and resolution

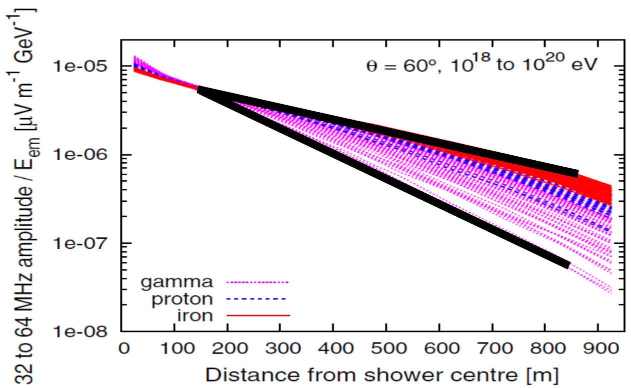
σ(direction) << 1°

F.Schröder et al., NIM A 615 (2010) 277

Composition



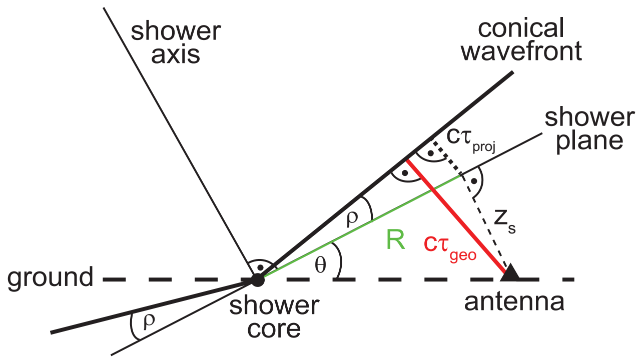
- Lateral distributions have composition sensitivity!
- model dependence?



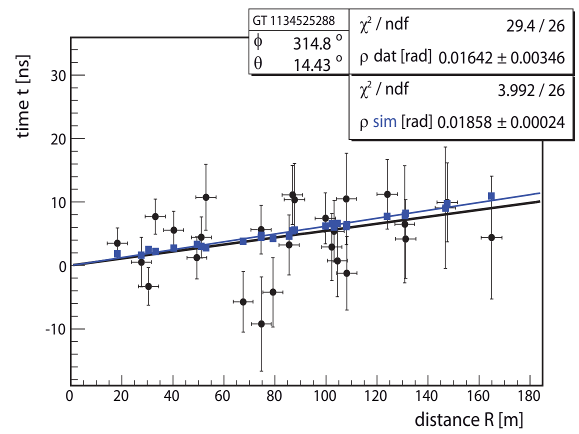
- Sensitivity and resolution **??**
- Particle array: unknown (large) uncertainty (FD better)
  - ➔ by lateral sensitivity (pattern) ….seems possible
  - ➔ by longitudinal sensitivity:
    - pulse shape
    - wave front
    - frequency spectrum
    - ….

= Xmax (shower maximum) sensitivity needed!!

Composition II



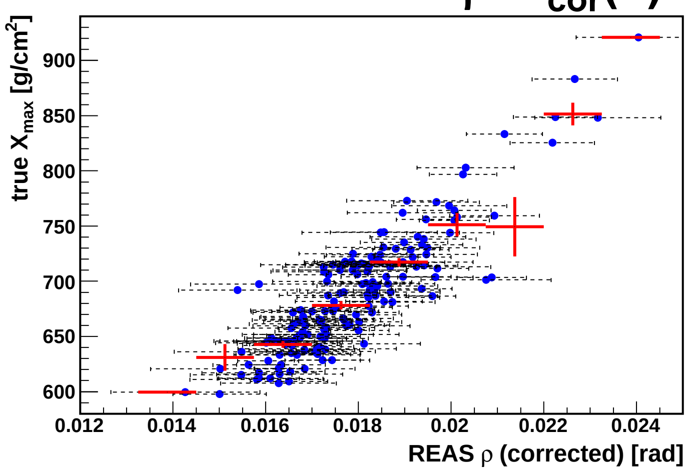
Cone parameter ρ, geometrical delay τ_{geo}, lateral distance to shower axis R



Conical wave front good approximation in data and simulations!

- **wave front is conical and has composition sensitivity!**
- **model dependence?**
- **distance dependence?**

$Xmax = const \cdot \rho \cdot f_{cor}(\theta)$



➔ **X_{max} (shower maximum) sensitivity is given**

- **Resolution:**
  in REAS3: 30g/cm²
  in LOPES: 200g/cm²

F.Schröder, PhD thesis, Feb 2011

EAS Radio detection

- as new CR detection technique established $E_{threshold} \approx 10^{17}$eV
- successful and sensitive to
  - primary energy $\varepsilon \sim E_0^{\gamma}$ ($\gamma \approx 1$) $\Delta E/E \sim$ 20-25%
  - arrival direction beam forming resolution better 1°
  - composition LDF-slope; wave front $\Delta A/A$ still unknown
- still many question open to emission mechanism(s)

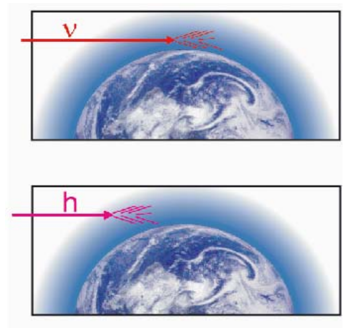
→ *suitable for hybrid measurements ?* ***yes!!***

As stand-alone technique? ***will see!!***

Next: AERA@Pierre Auger Observatory / LOFAR / Tunka-Rex /
ANITA-CR optimization / TREND / IceCube surface Radio Array = RASTA / Yakutsk

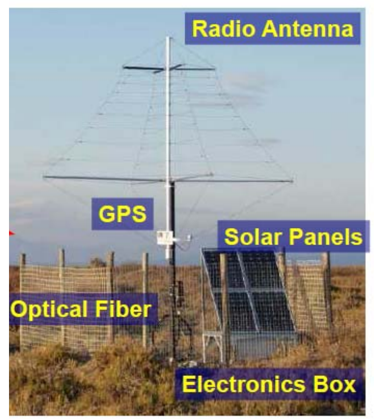
Next steps in R&D

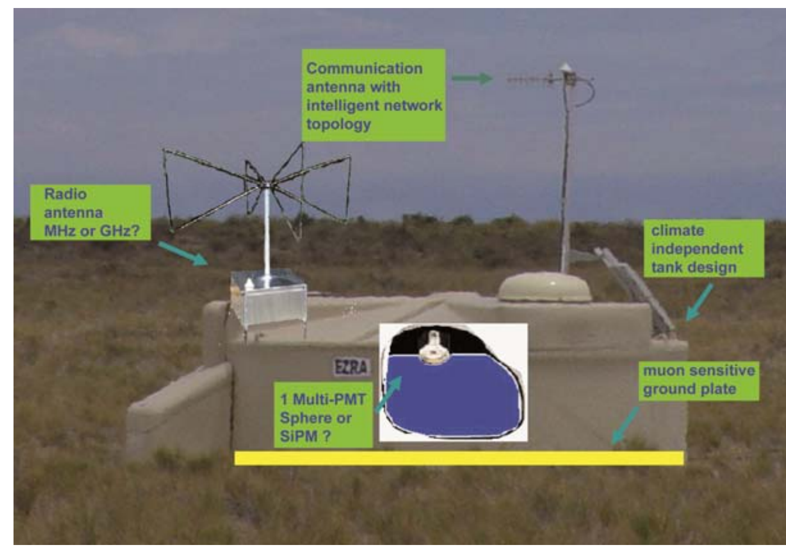
- Horizontal sensitivity (for Neutrinos)
- Scalability of stations to hundreds of antennas
- Embedded radio detection in surface particle detectors



>80°: sensitivity for neutrinos

>70°: 35% of the total solid angle: larger rate for charged cosmic rays





Work package of ASPERA „AugerNext“ innovative R&D studies (second call)
➔ Start funding in 2012

Summary / Status

- **KASCADE: knee by light primaries (maybe Helium dominant)**
- **KASCADE-Grande: high quality data at 10^{16} – 10^{18} eV to identify the „iron“- knee and transition galactic–extragalactic cosmic rays!**
- **first results KASCADE-Grande:**
  - **energy spectrum :**
    - **➔ no single power law (concave form at 1-2 10^{16} eV)**
  - **elemental composition**
    - **➔ knee of heavy primaries at around 8-9 10^{16}eV**
  - **anisotropy studies**
    - **➔ no anisotropy seen yet**
  - **interaction models**
    - **➔ muon attenuation, muon production height, etc…**
- **30/03/2009: KASCADE-Grande closure symposium**
  - **KASCADE-Grande ➔ EAS test facility until 2012**
  - **➔ data analysis continued…**
- **new detection techniques:**
  - **➔ LOPES – radio detection of air showers in MHz**
  - **➔ support of GHz EAS detection (CROME)**

Discussion / Question / Exercise

- **expectations on spectral features in transition region?**
- **ideal accelerator experiment for cosmic ray physics?**
- **why radio could be better than fluorescence?**

Discussion / Question / Exercise

- expectations on spectral features in transition region?
  - should not be smooth
  - galactic ends with iron; extragalactic starts with proton
  - anisotropy
- ideal accelerator experiment for cosmic ray physics?
  - p….Fe ←→ N beam
  - forward detector
  - cross-sections / multiplicities
- why radio could be better than fluorescence?
  - 95% duty cycle
  - weather independent
  - cheaper (larger area)