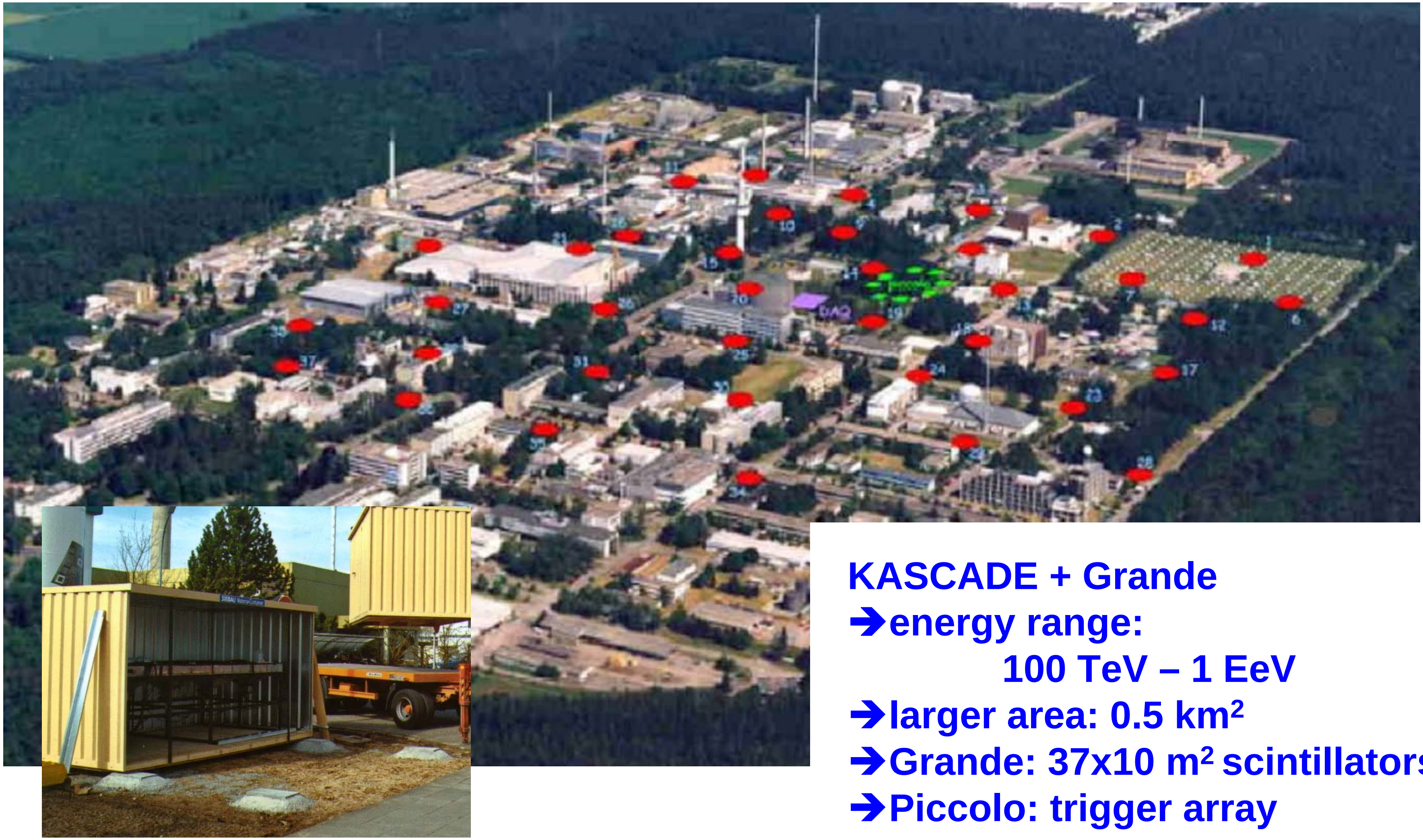
KASCADE-Grande : first results!



KASCADE + Grande

→energy range:

100 TeV – 1 EeV

→larger area: 0.5 km²

→Grande: 37x10 m² scintillators

→Piccolo: trigger array

Reconstruction of the energy spectrum

Application of different methods:

-**Using the shower size (N_{ch}) as observable**

-**Using the muon size (N_{μ}) as observable**

-**Using the density at 500m (S_{500}) as observable**

-**Using combination of N_{μ} and N_{ch} as observables**

→

-**Cross check of reconstruction procedures**

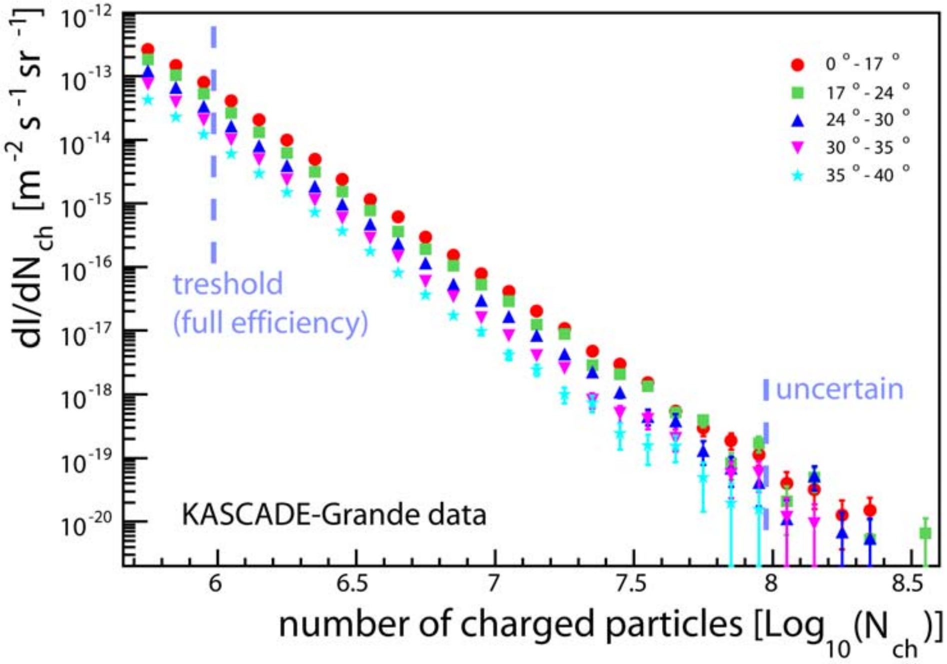
-**Cross check of systematic uncertainties**

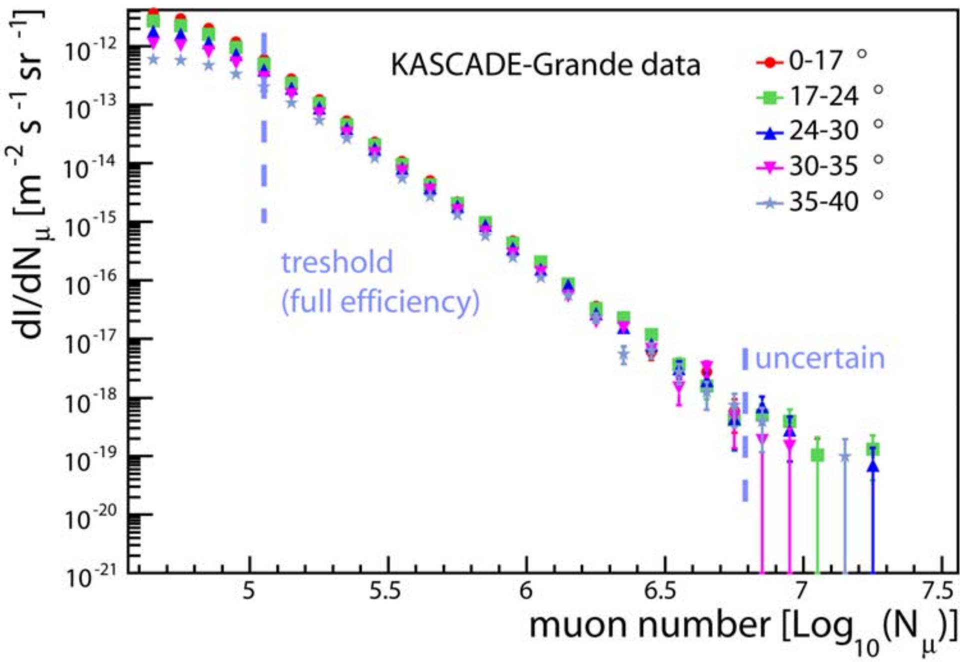
-**Test sensitivity to composition**

-**Cross check of validity of hadronic interaction models**

size spectra (charged particles)

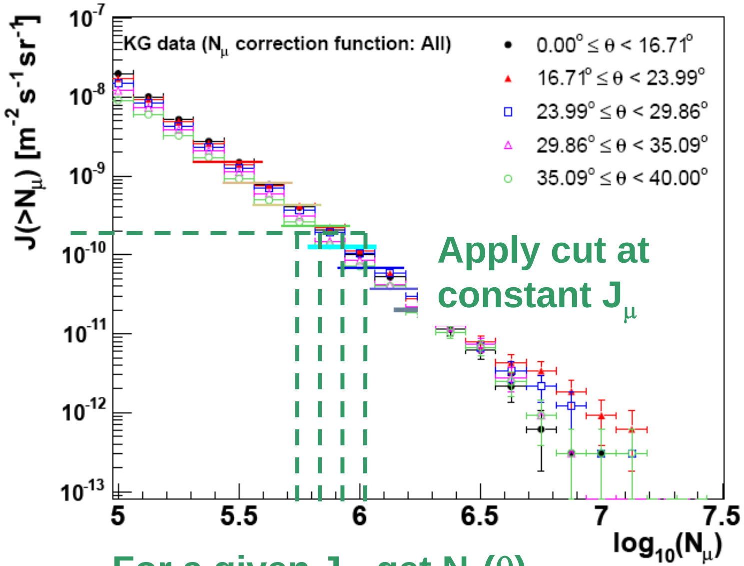
muon number spectra (N_μ ; E_μ>230MeV)





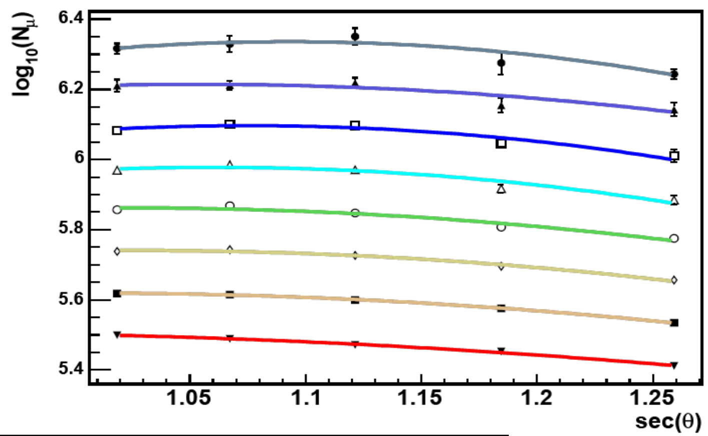
-stable data taking since 2004, c. 900 days effective DAQ time
-performance of reconstruction (and detector) is stable

constant intensity cut method CIC (N_μ, N_{ch}, S_{500}) = correct for the attenuation from data



For a given J_μ, get $N_\mu(\theta)$

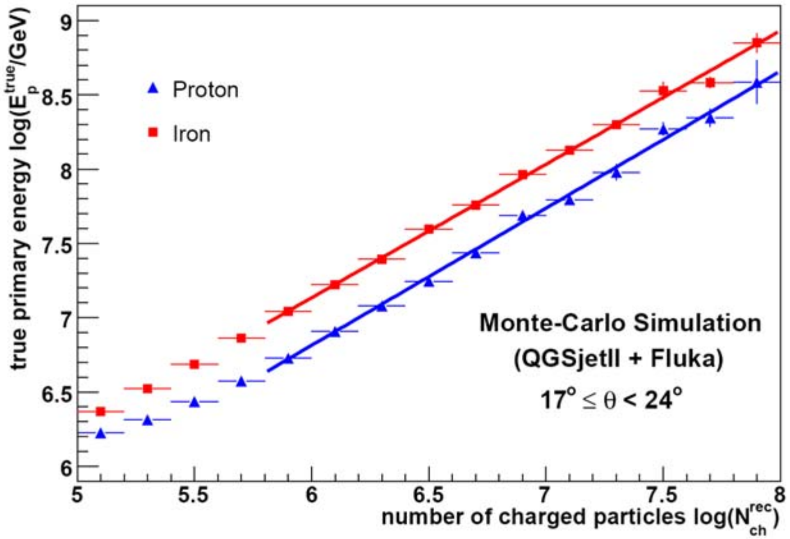
$$\log_{10} N_\mu = a_0 + a_1 \cdot Sec(\theta) + a_3 \cdot Sec^2(\theta)$$



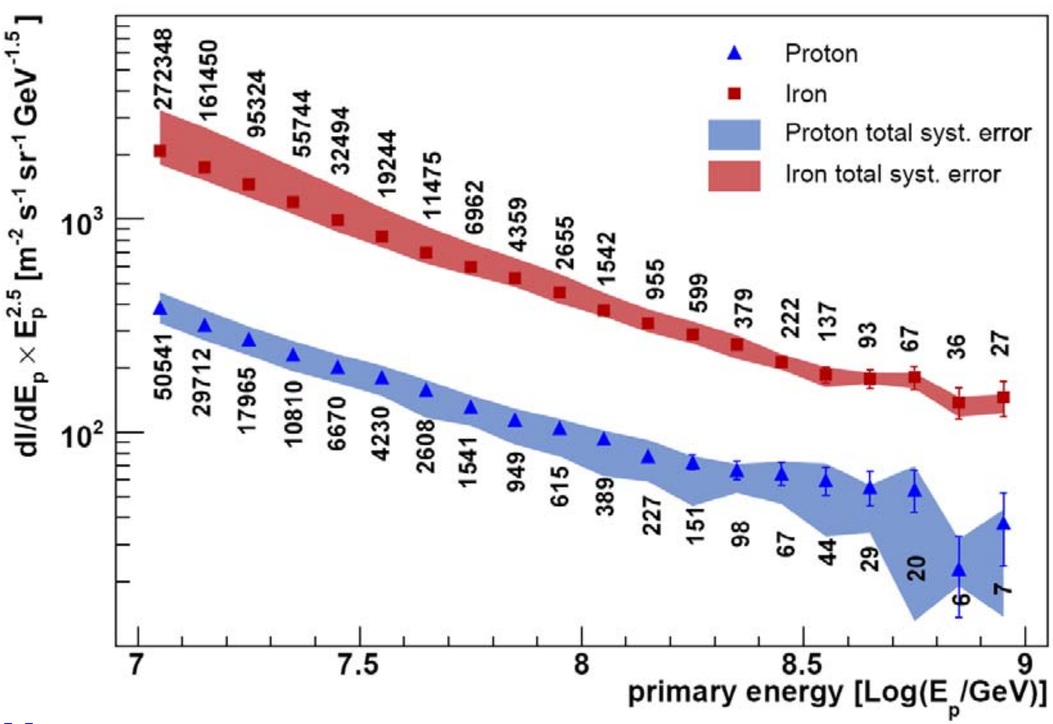
Get attenuation curves

N_μ, N_{ch}, $S_{(500)}$ of each event normalized to a certain zenith angle

Way to all particle energy spectrum : via shower size (N_{ch})



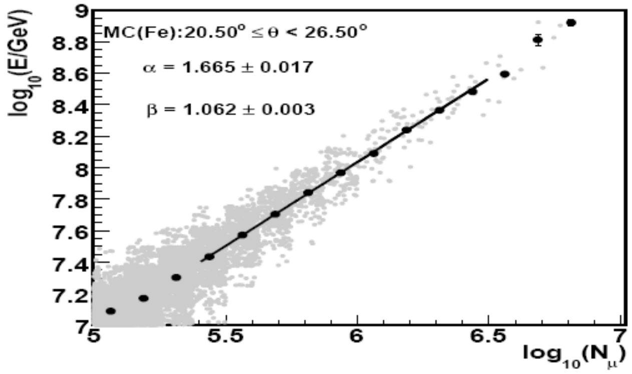
QGSJET II hadronic interaction model

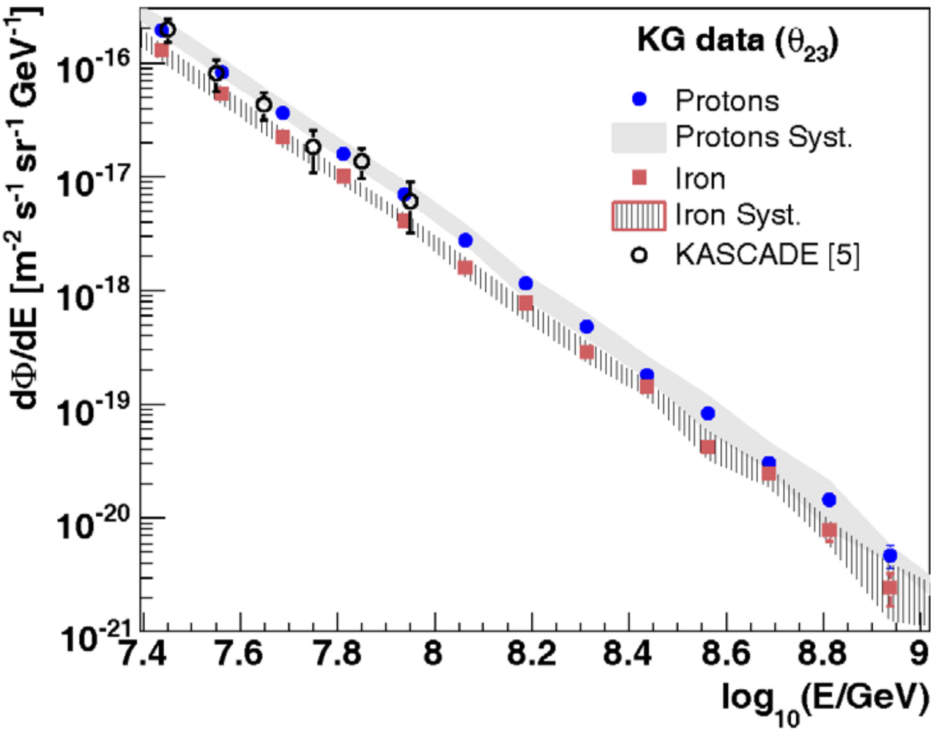


-Good reconstruction accuracy
-Very composition dependent
(need assumption of primary type)

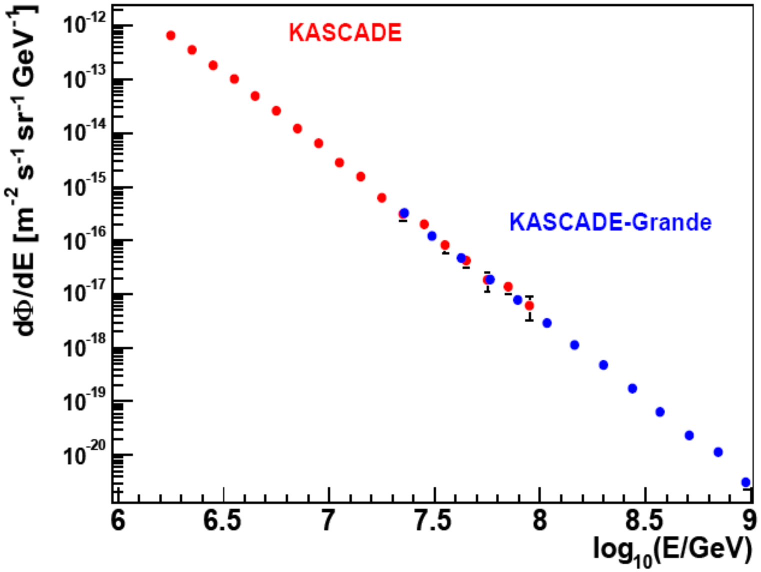
KASCADE-Grande collaboration (D.Kang), ICRC 09

Way to all particle energy spectrum : via muon number (N_μ)





QGSJET II hadronic interaction model



-Less good reconstruction accuracy

-Less composition dependence

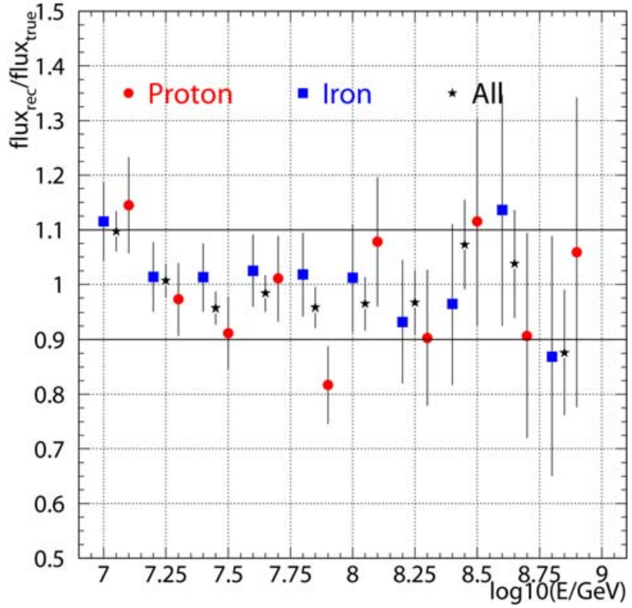
KASCADE-Grande collaboration (J.C.Arteaga-Velazquez), ICRC 09

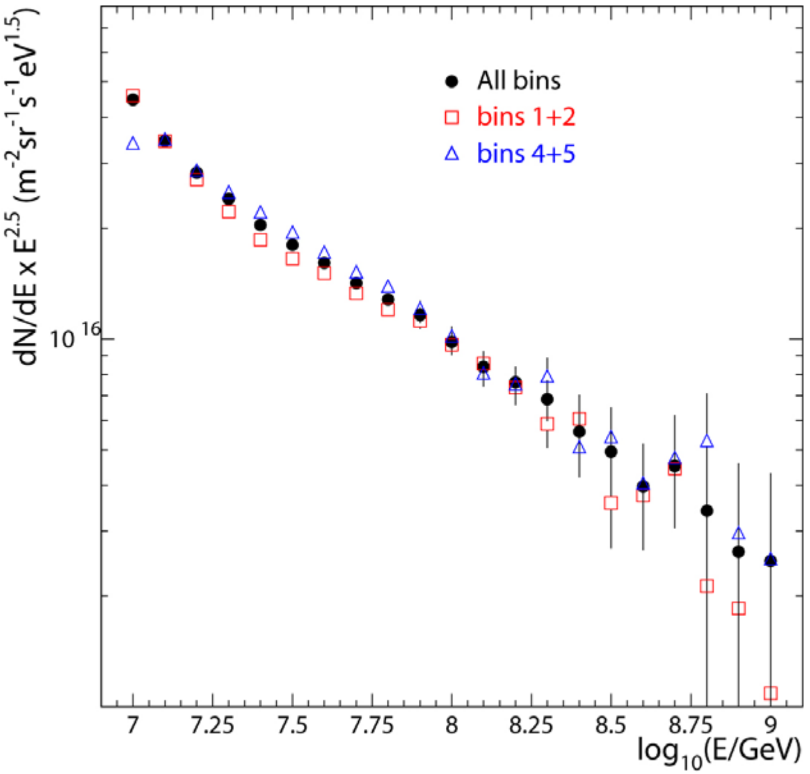
Way to all particle energy spectrum : via combination of N_μ and N_{ch}

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

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

QGSJET II hadronic interaction model

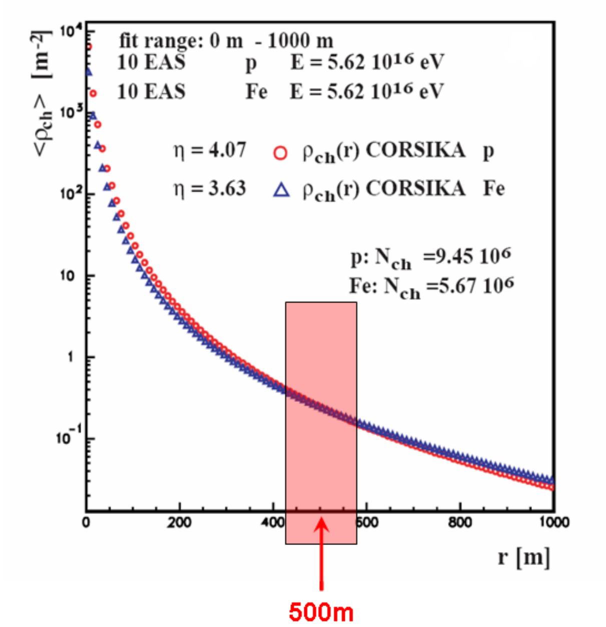




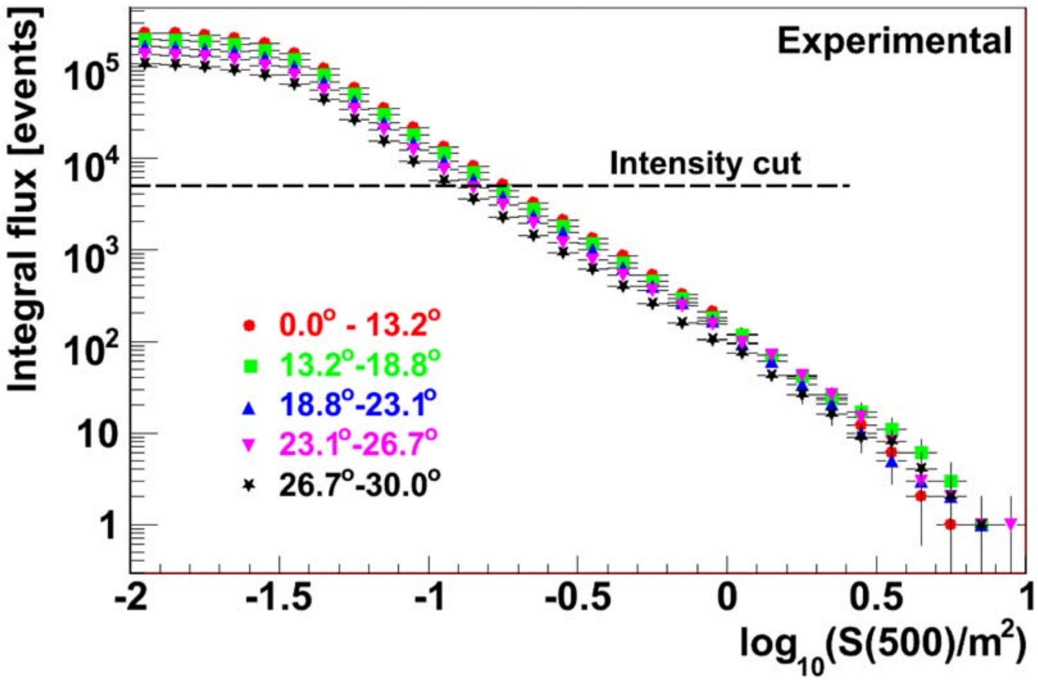
-different zenith angle bins
-no composition dependence

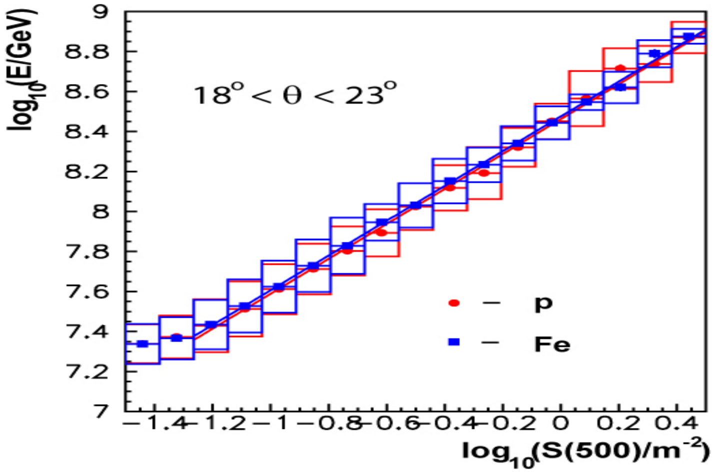
KASCADE-Grande collaboration (M.Bertaina), ICRC 09

Way to all particle energy spectrum : via S(500)



QGSJET II hadronic interaction model

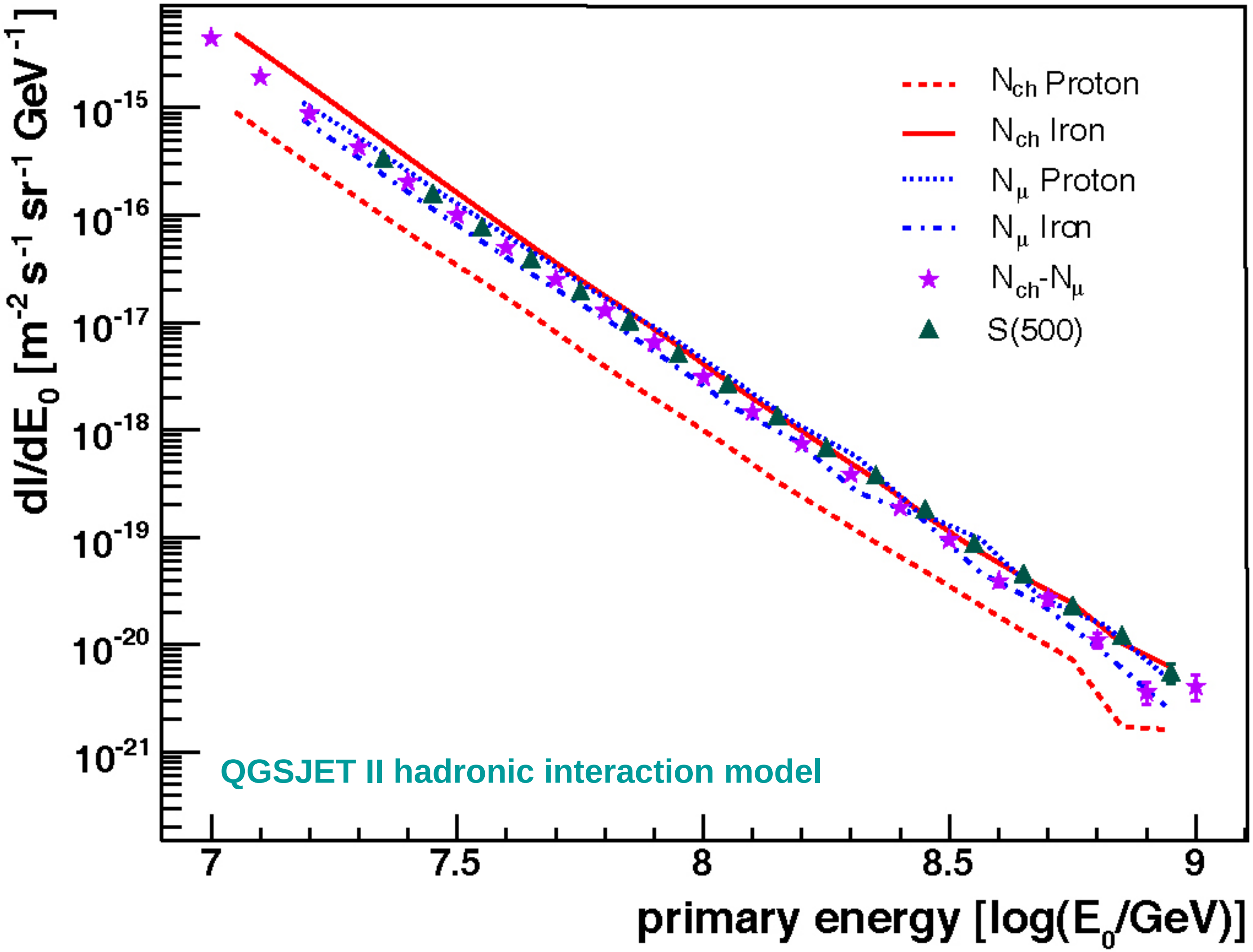




-Problem reconstruction accuracy
-No composition dependence

KASCADE-Grande collaboration (G.Toma), ICRC 09

The all-particle energy spectrum



- very good agreement between results of different methods

Systematic Uncertainties

Sources of uncertainty:

1) Observable reconstruction

2) CIC method, attenuation

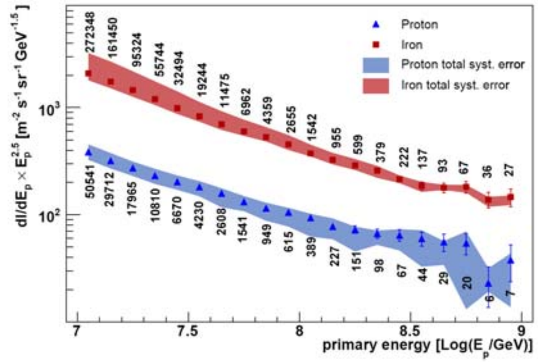
3) Energy vs N_μ relation

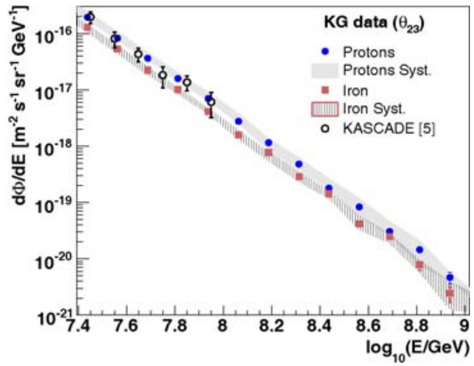
4) Influence of MC statistics

5) Spectral index in MC sample

6) Composition assumption

….





Uncertainty in flux:

Systematic uncertainty in flux at 10^{17}eV (QGSJet/FLUKA)

N_{ch}-N_μ : 20% (incl. composition)

S(500): 37% (incl. composition)

N_{ch}: 12%,20% (for primary iron, proton)

N_μ : 11%,14% (for primary iron, proton)

Single event measurement:

Energy resolution
σE/E [%] at 10^{17}eV
(QGSJet/FLUKA)

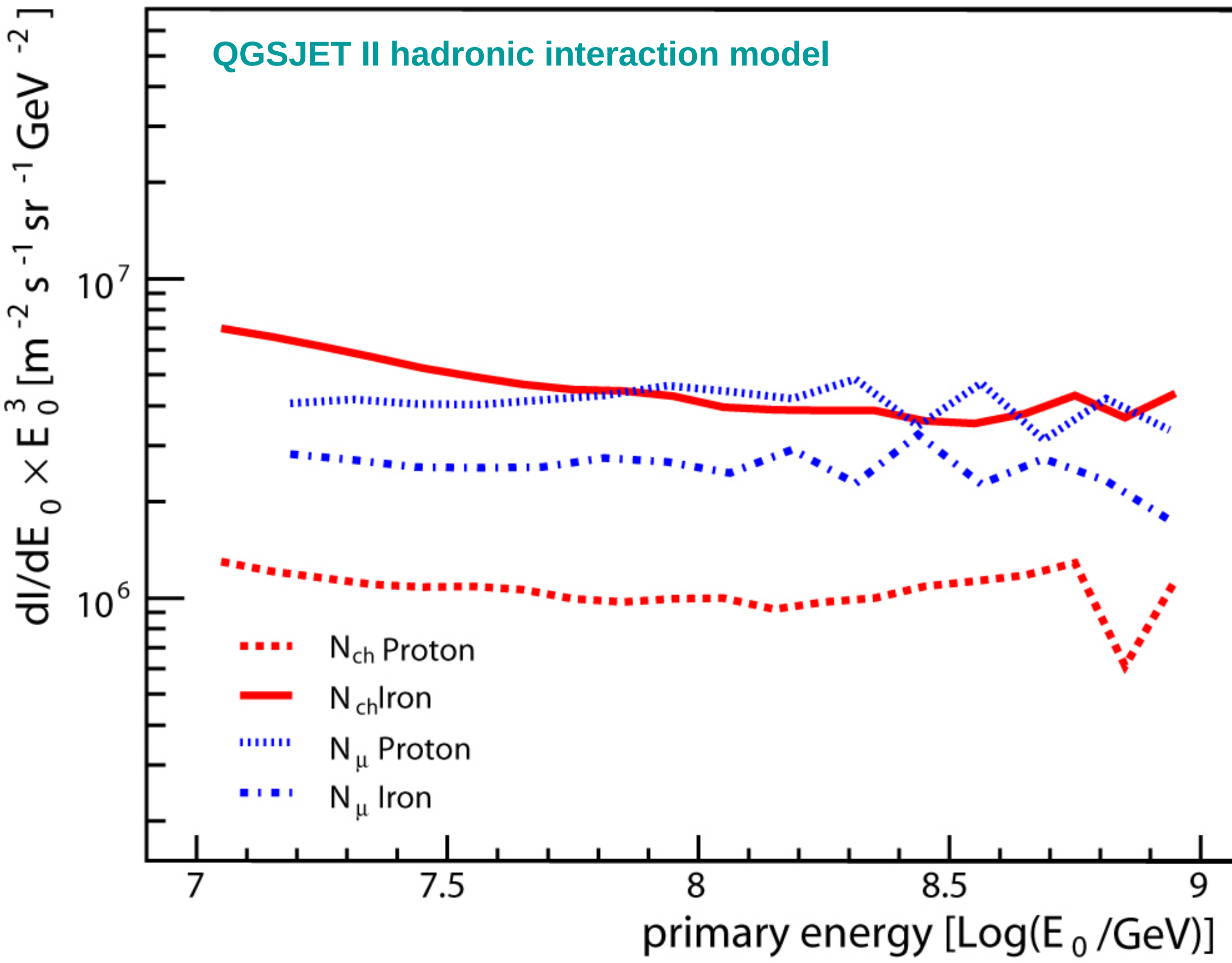
N_{ch}-N_μ : 22% (incl. composition)

S(500): 22% (incl. composition)

N_{ch}: 15%,31% (for primary iron, proton)

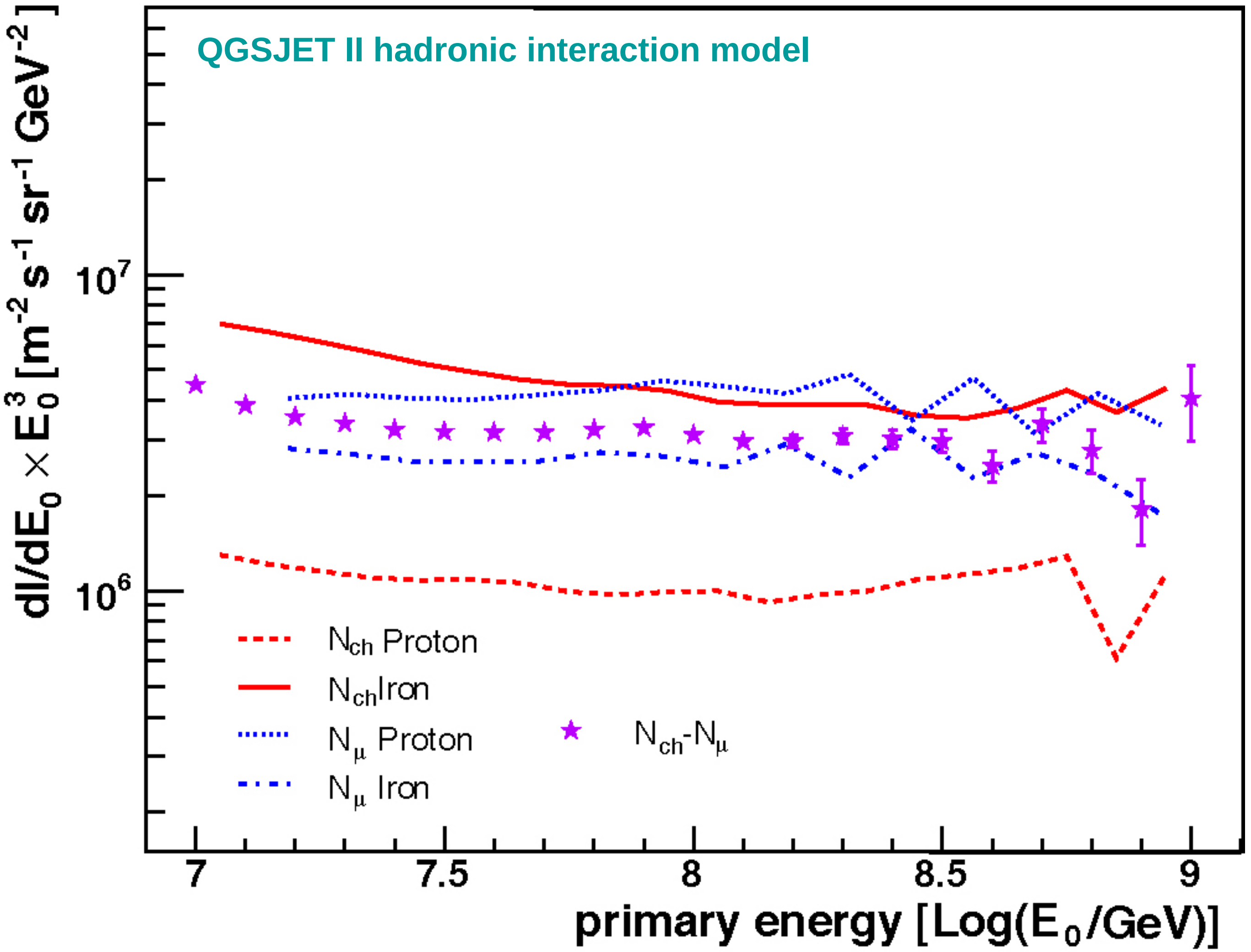
N_μ : 19%,28% (for primary iron, proton)

Reconstruction of the energy spectrum



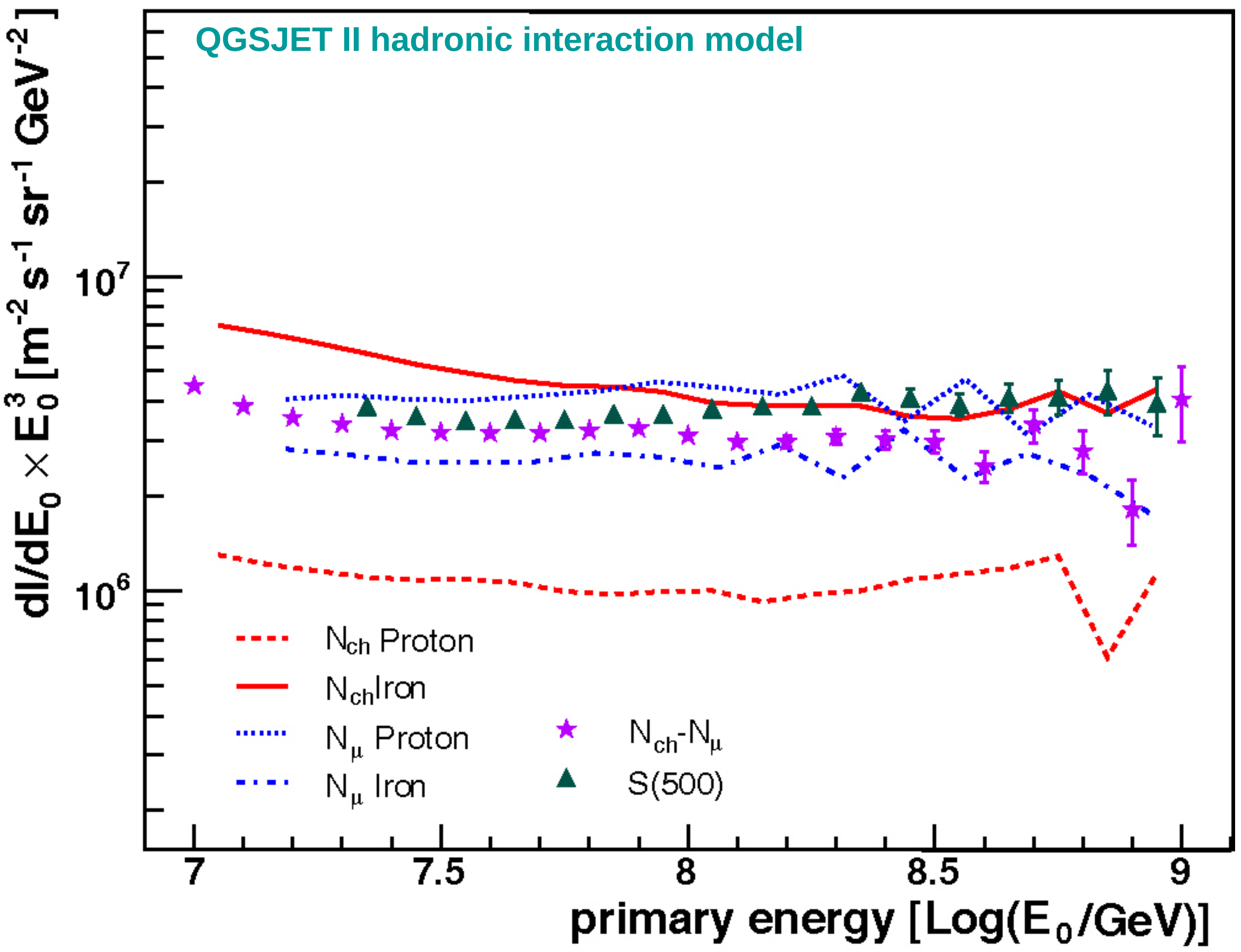
- note: proton and iron have inverted order for the 2 methods!

Reconstruction of the energy spectrum



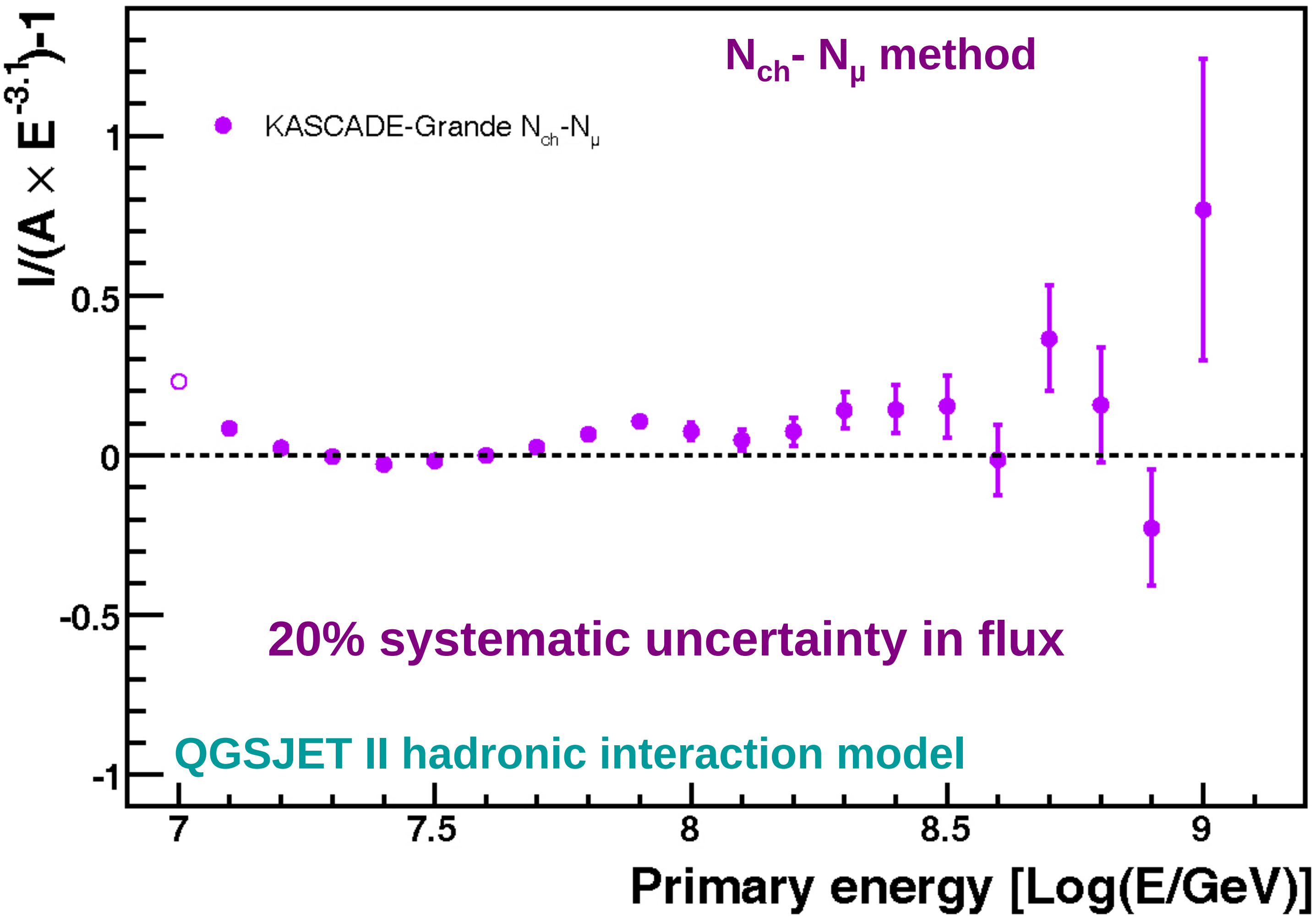
- QGSJet II: heavy composition preferred

Reconstruction of the energy spectrum



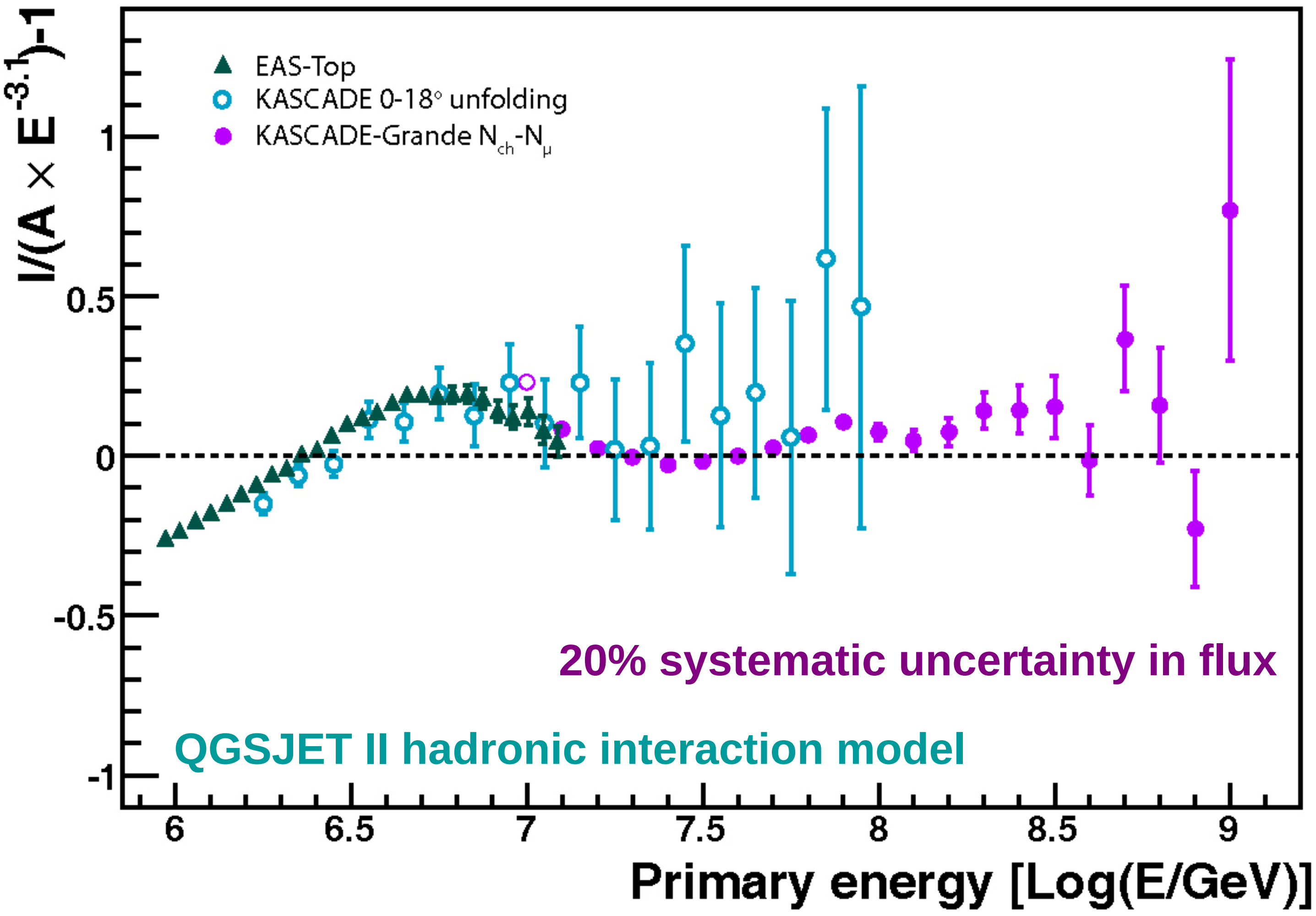
- Differences due to different sensitivity to composition?

The all-particle energy spectrum



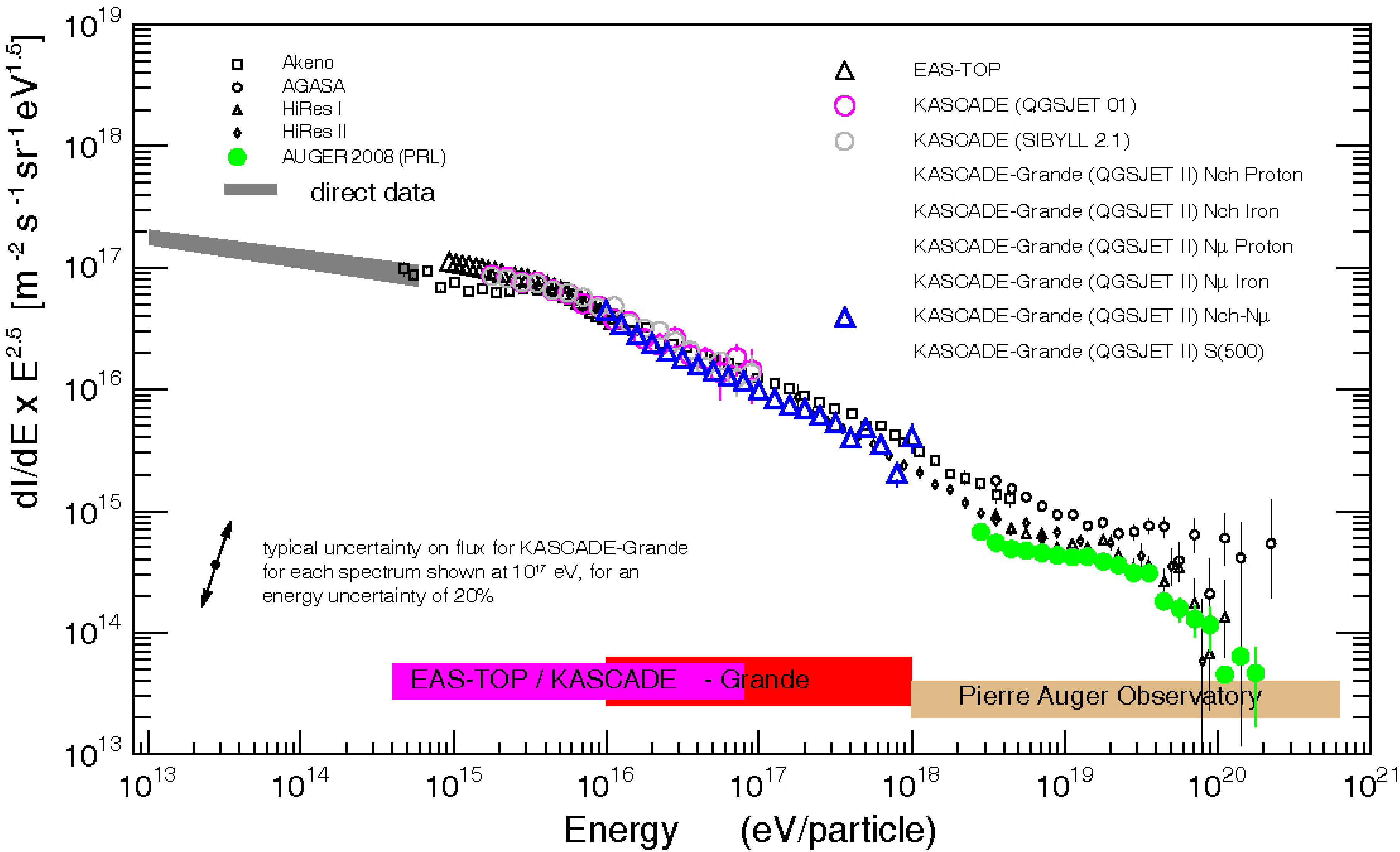
- spectrum not describable by a single power law at 10^{16}-10^{18}eV

The all-particle energy spectrum

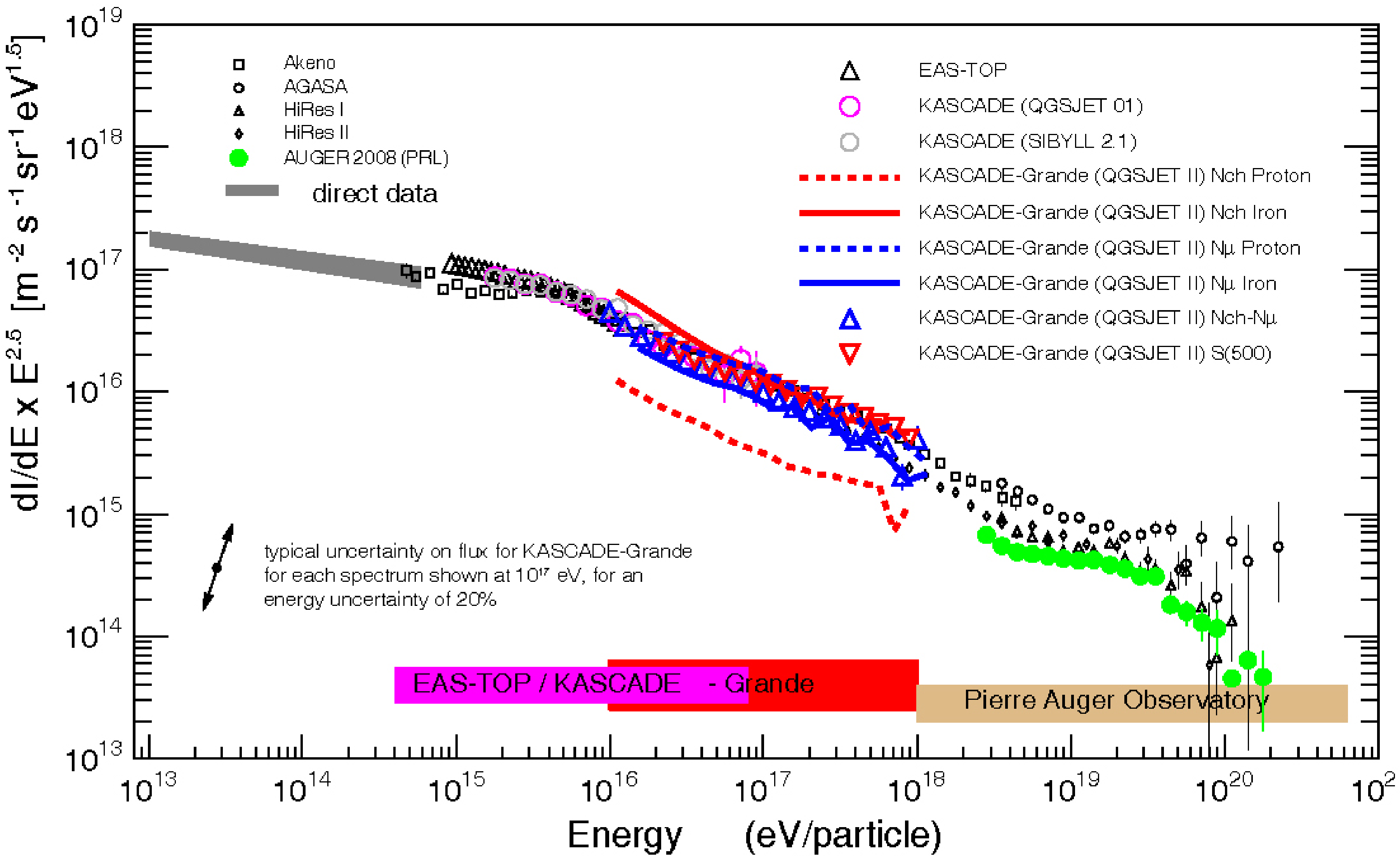


- good agreement with other experiments

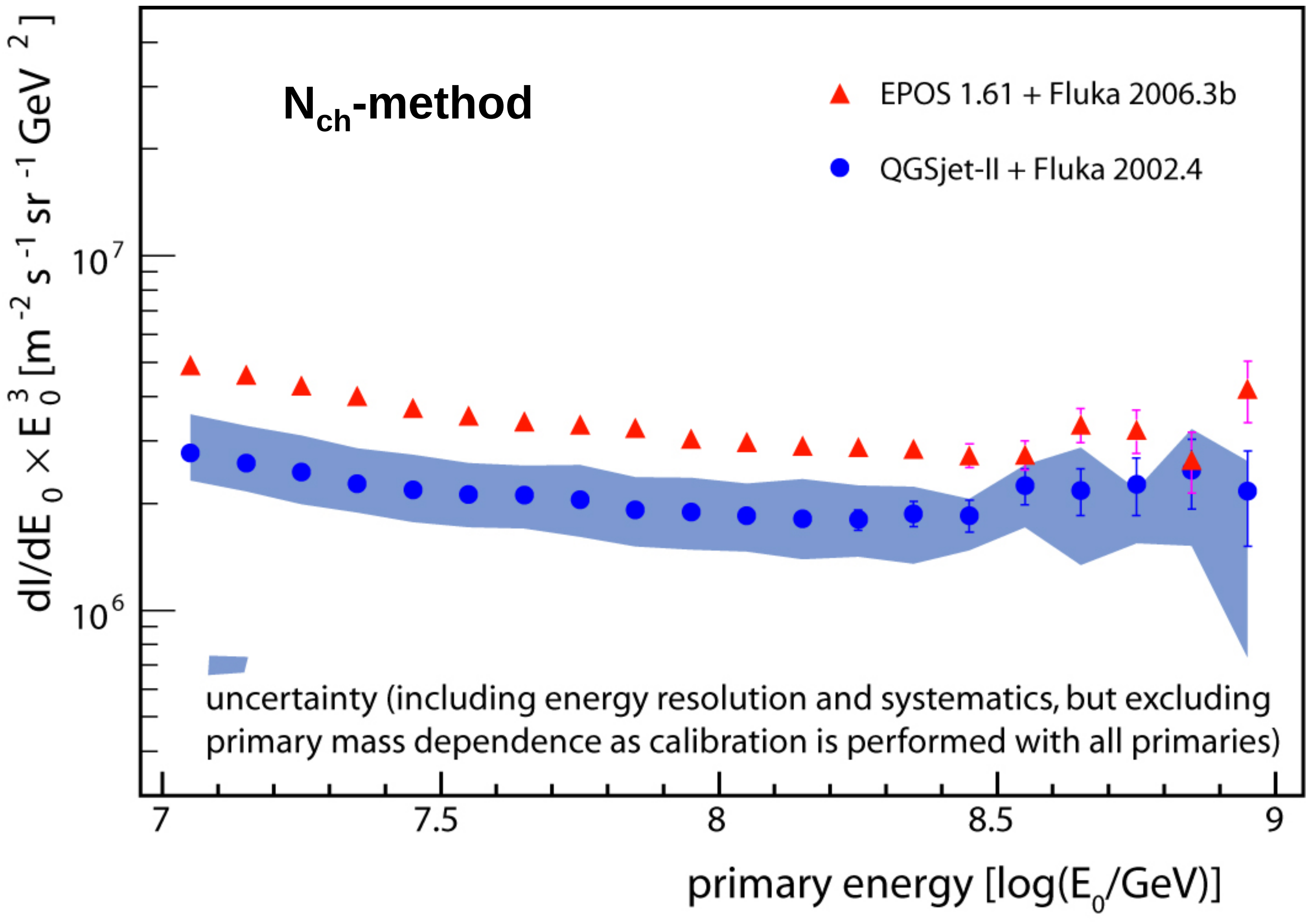
KASCADE-Grande all-particle energy spectrum



KASCADE-Grande all-particle energy spectrum



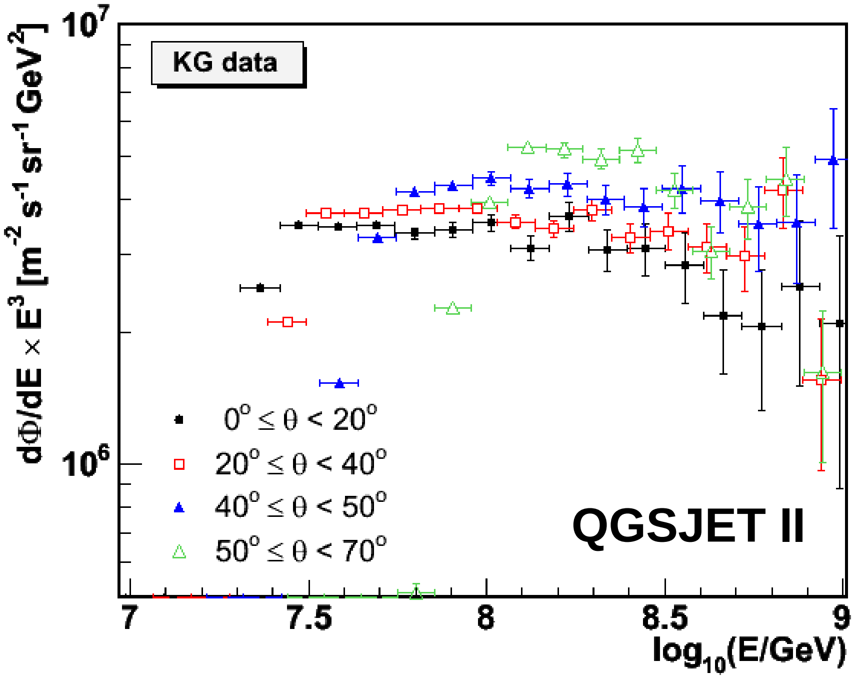
systematic checks: hadronic interaction model



-KASCADE: EPOS 1.61 is not compatible with data
➔ waiting for EPOS 1.99

Muon reconstruction at inclined showers

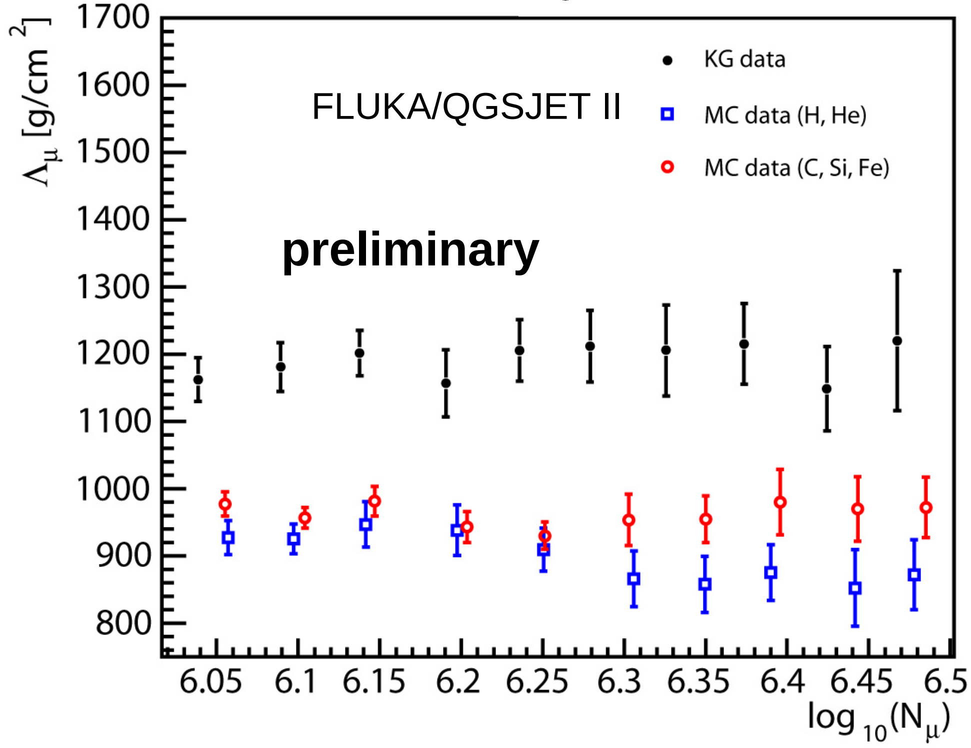
Energy reconstruction without CIC



Discrepancy between energy spectra from vertical and inclined showers

Muon shower size attenuation length

$$N'_\mu = N_\mu e^{-X_o Sec\theta/\Lambda_\mu}$$



Difference between MC and KASCADE-Grande muon attenuation lengths

Ways to elemental composition :

Application of different methods:

- **Local muon densities**

- **High-energy muon investigations**

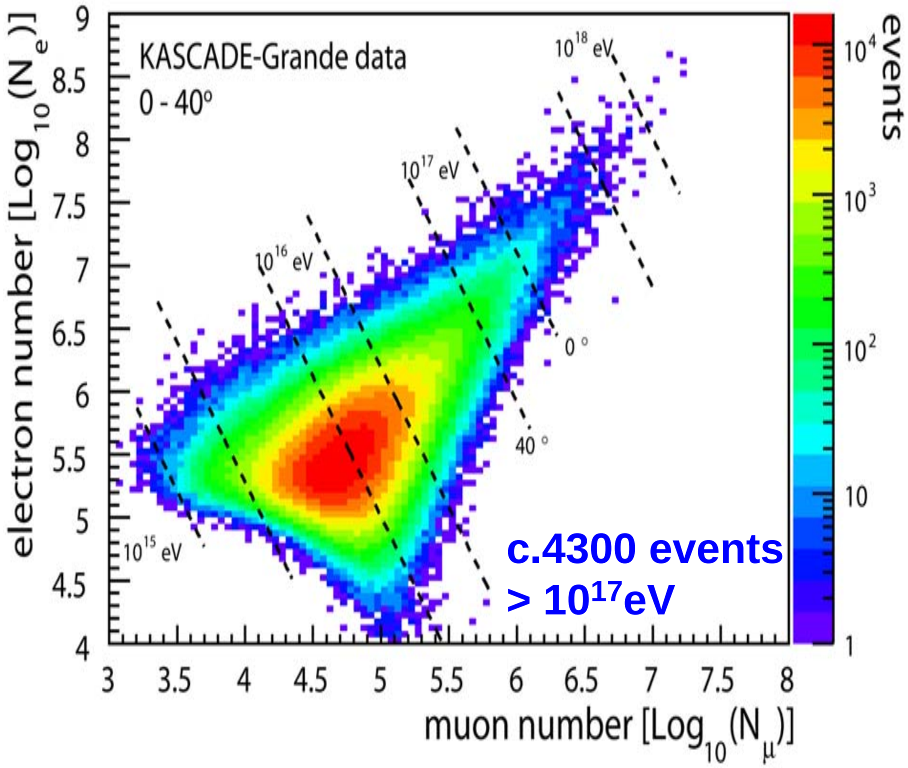
- **Parametric combination of N_{ch} , N_μ**

- **kNN method**

- **Fit of N_μ/N_e -ratios in fixed size/ energy bins**

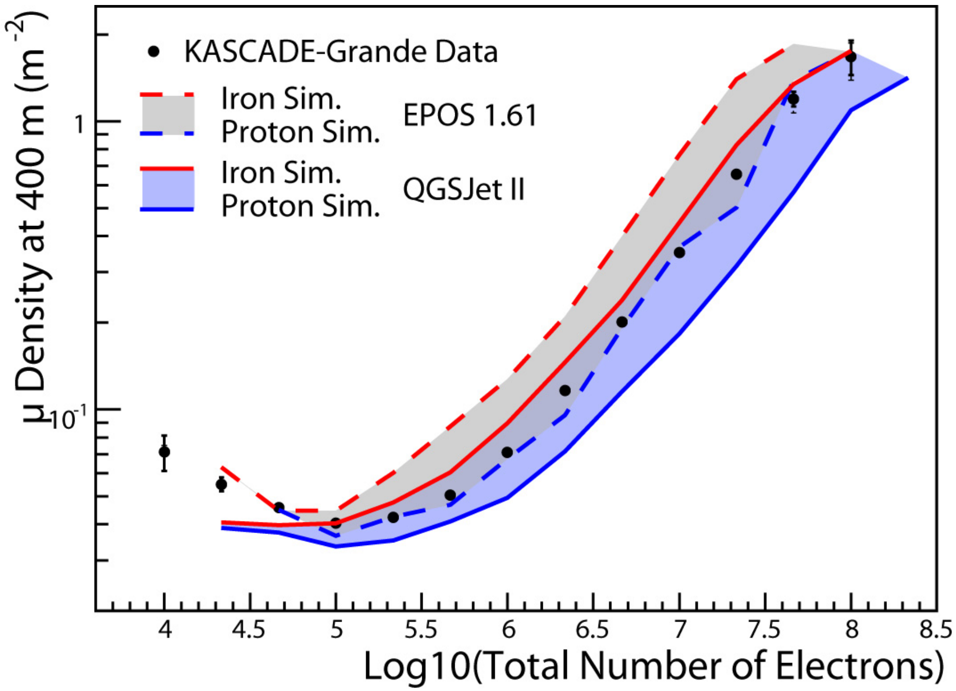
- **Unfolding of the 2-dimensional shower size spectrum**

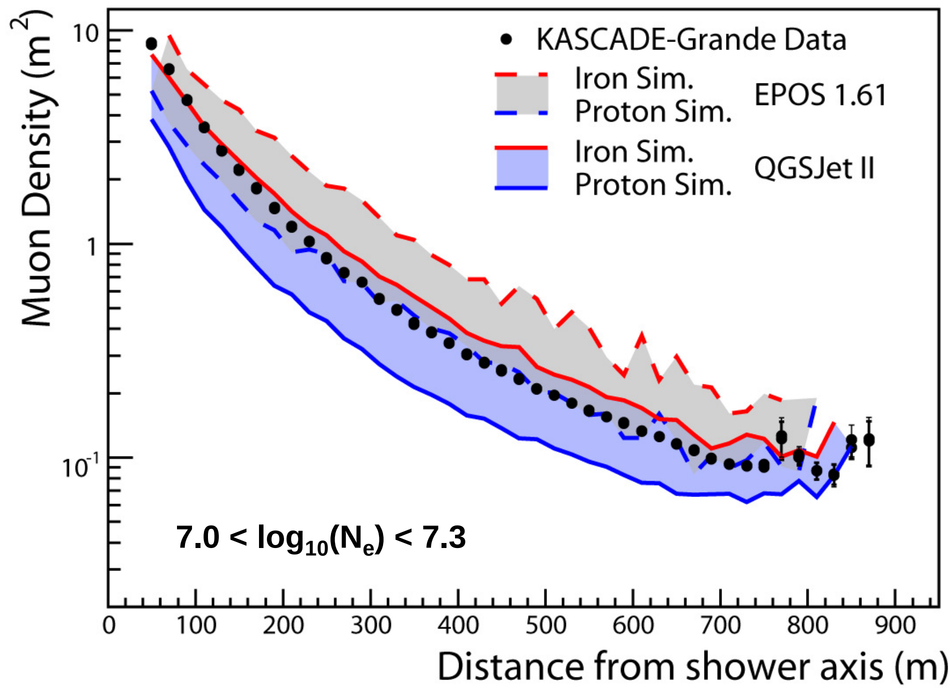
  ➔ **energy & composition**
  ➔ **still improvements in systematics needed**
  ➔ **higher statistics**



c.4300 events > 10^{17}eV

Way to elemental composition : muon density investigations





- **muon (local) density reconstruction for different, but fixed distances**

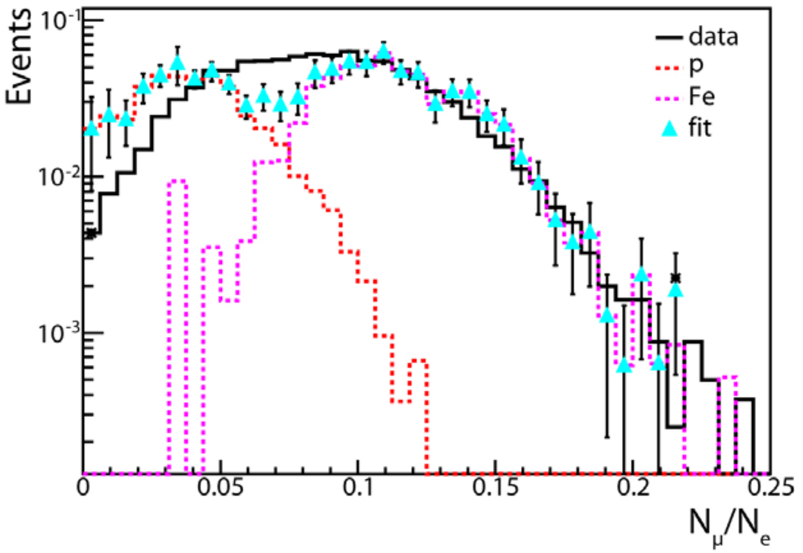
➔ **composition sensitive**

➔ **model tests: "heavy" for QGSJet, "light" for EPOS**

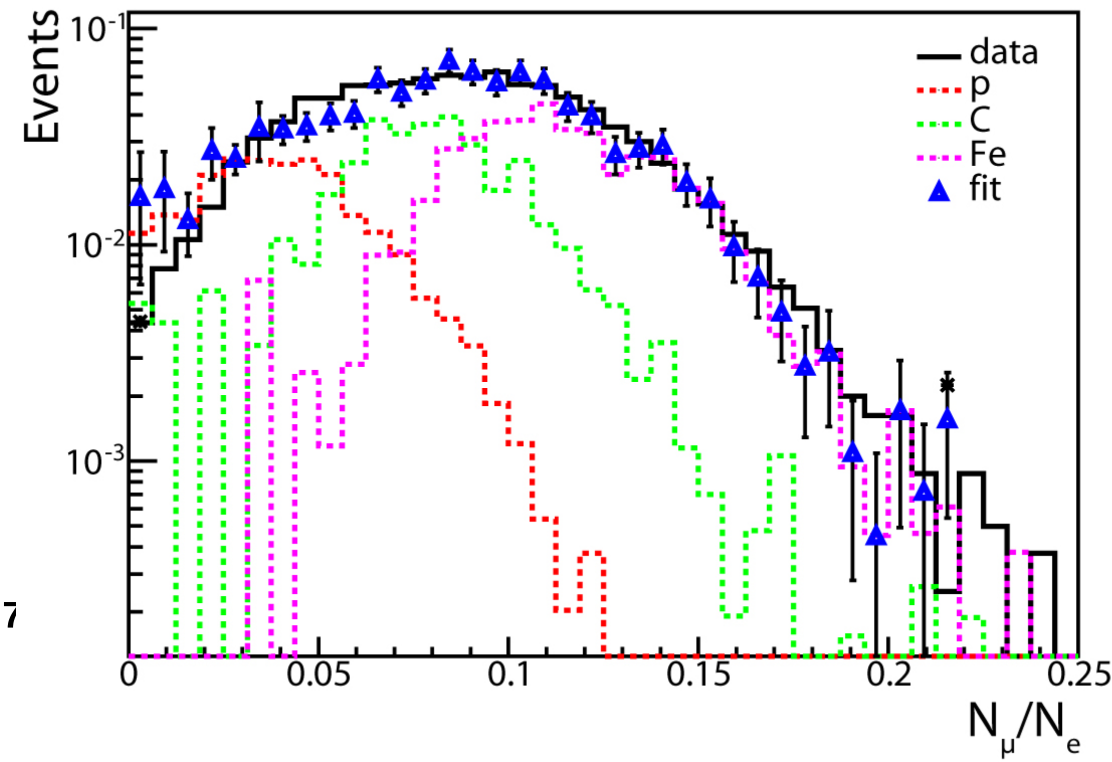
KASCADE-Grande collaboration (V. de Souza), ICRC 09

Way to elemental composition : N_μ / N_e-ratio

QGSJET II hadronic interaction model



6.5 < $\log_{10}(N_e)$ < 6.7



- **shower size ratio: investigation of mean and rms**

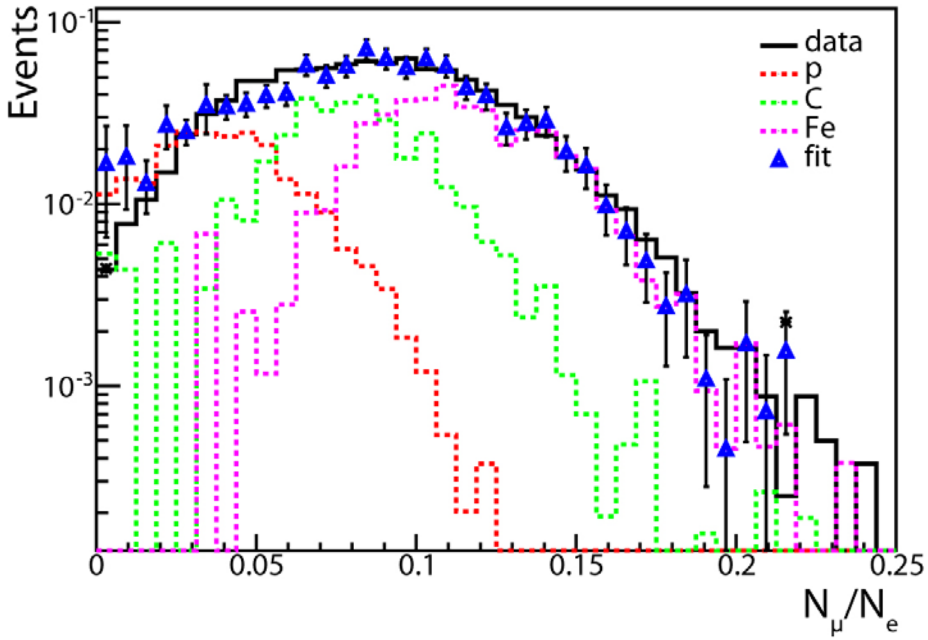
➔ **rms of simulated distributions less model dependent than mean**

➔ **composition: more than 2 components needed; consistent with KASCADE in overlapping range**

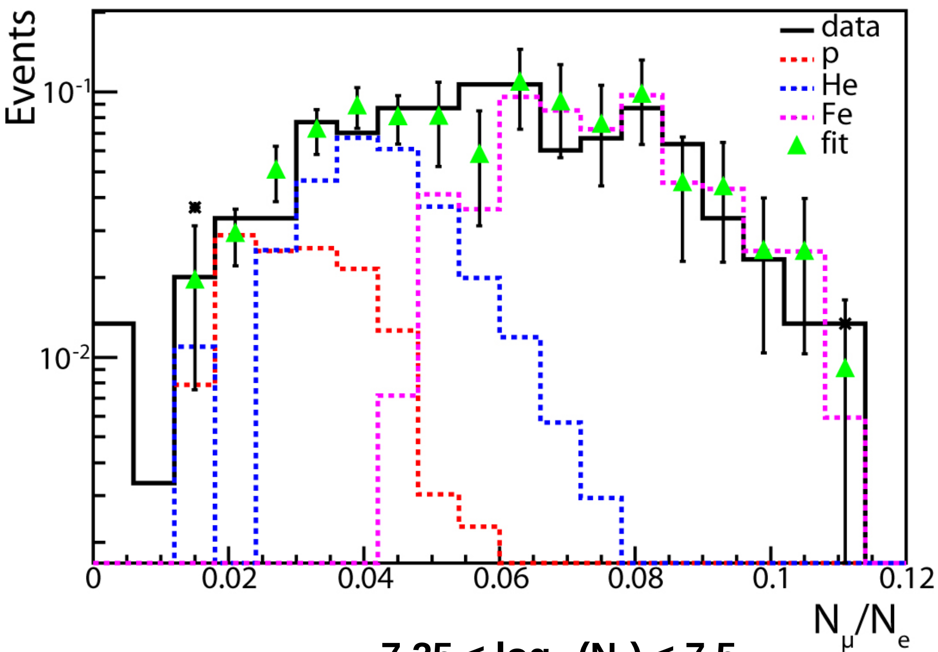
KASCADE-Grande collaboration (E. Cantoni), ICRC 09

Way to elemental composition : N_μ / N_e-ratio

QGSJET II hadronic interaction model



6.5 < $\log_{10}(N_e)$ < 6.75

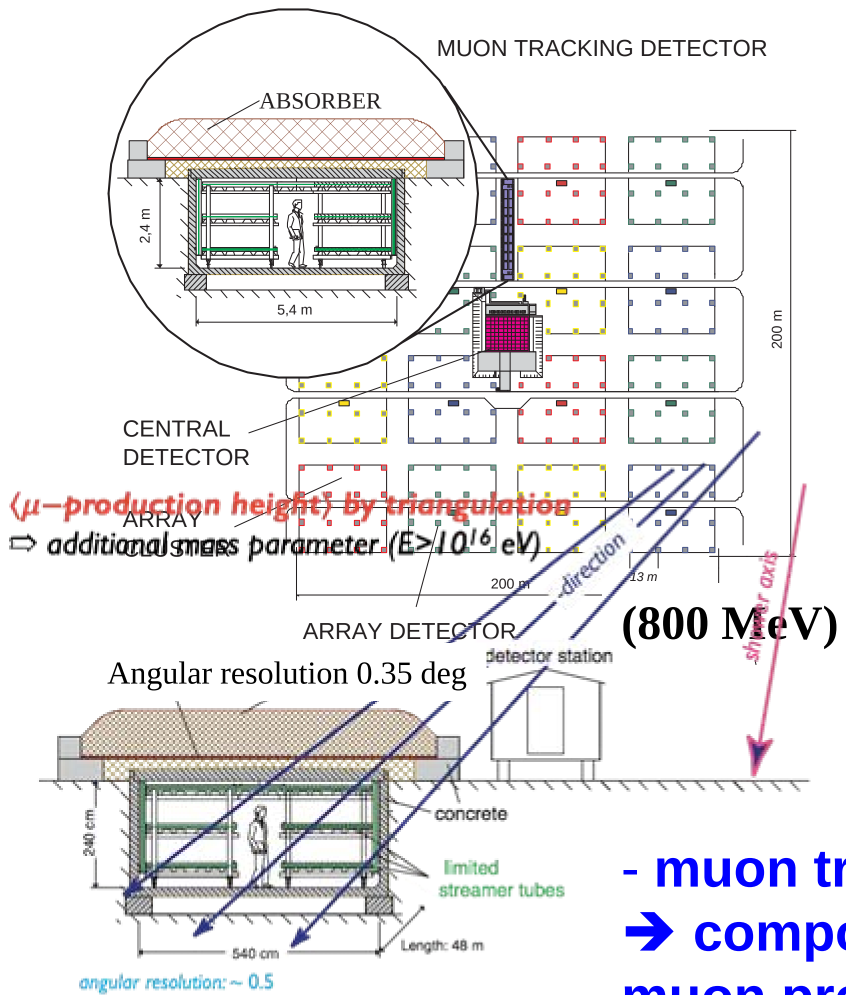


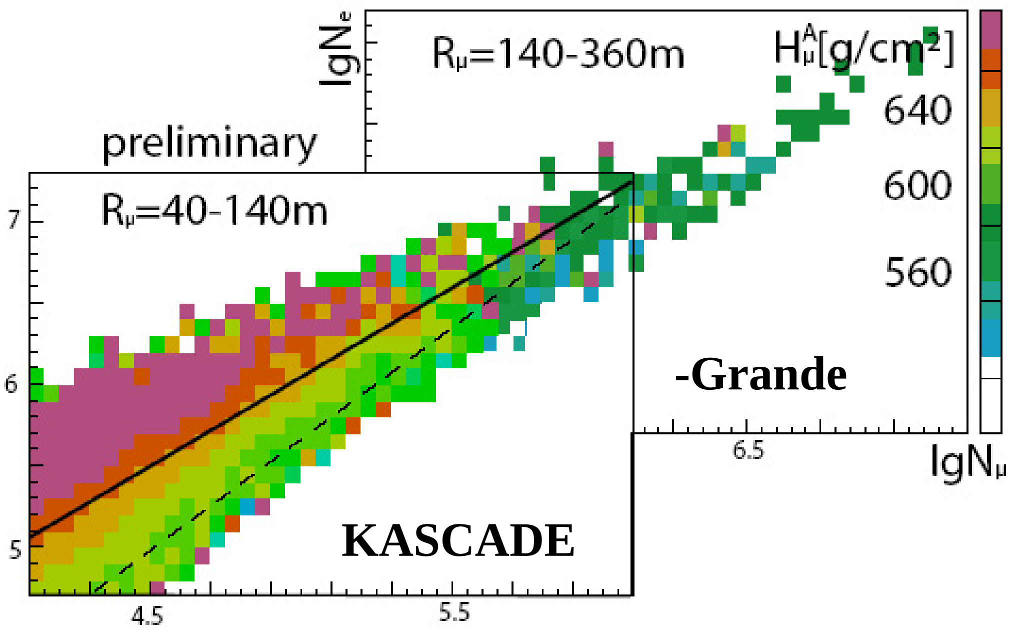
7.25 < $\log_{10}(N_e)$ < 7.5

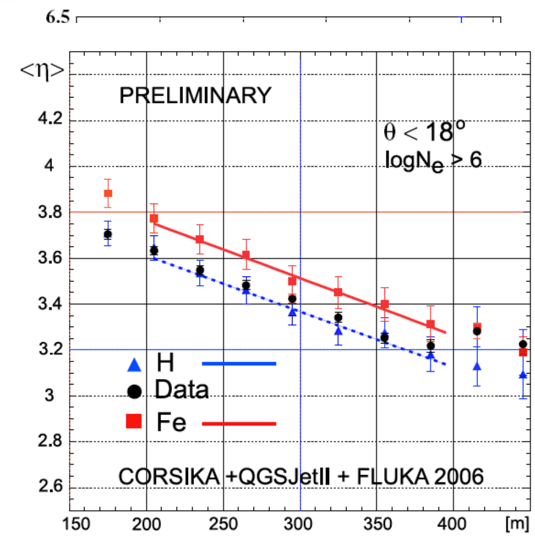
➔more than 2 components also needed at higher energy

KASCADE-Grande collaboration (E. Cantoni), ICRC 09

Muon Tracking Detector







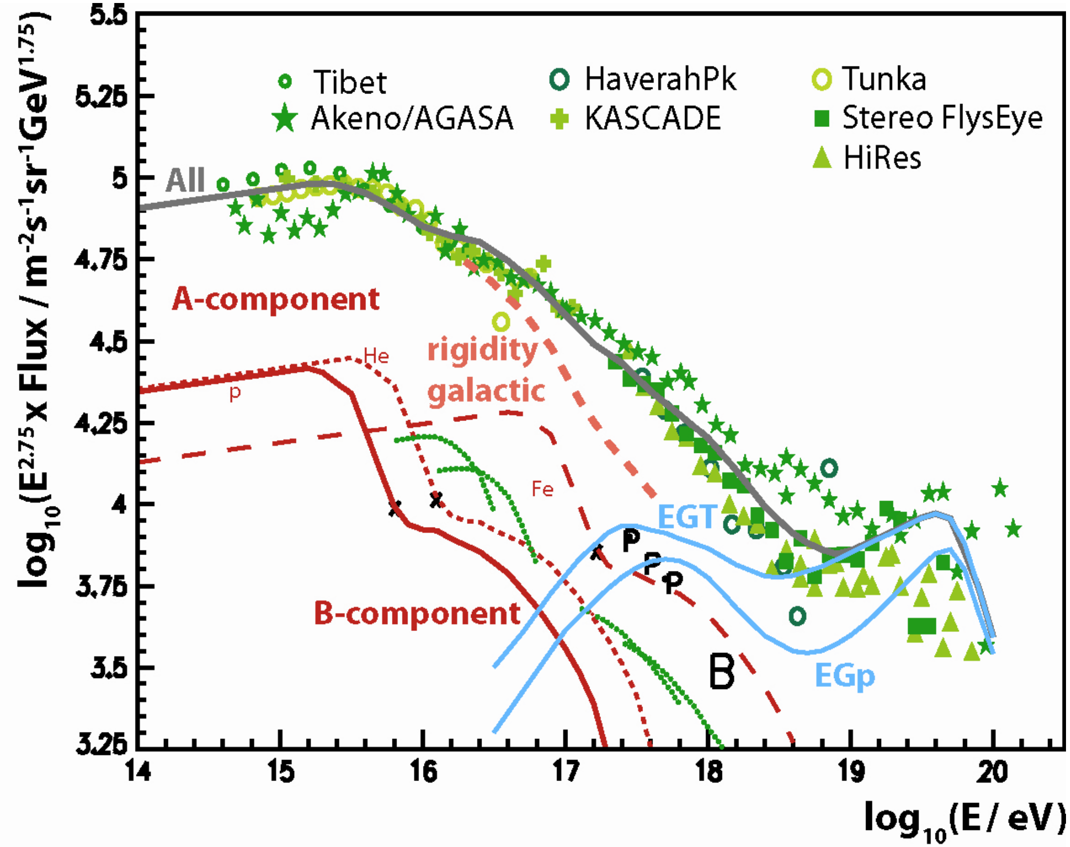
- **muon tracking:**

➔ composition sensitivity muon production height

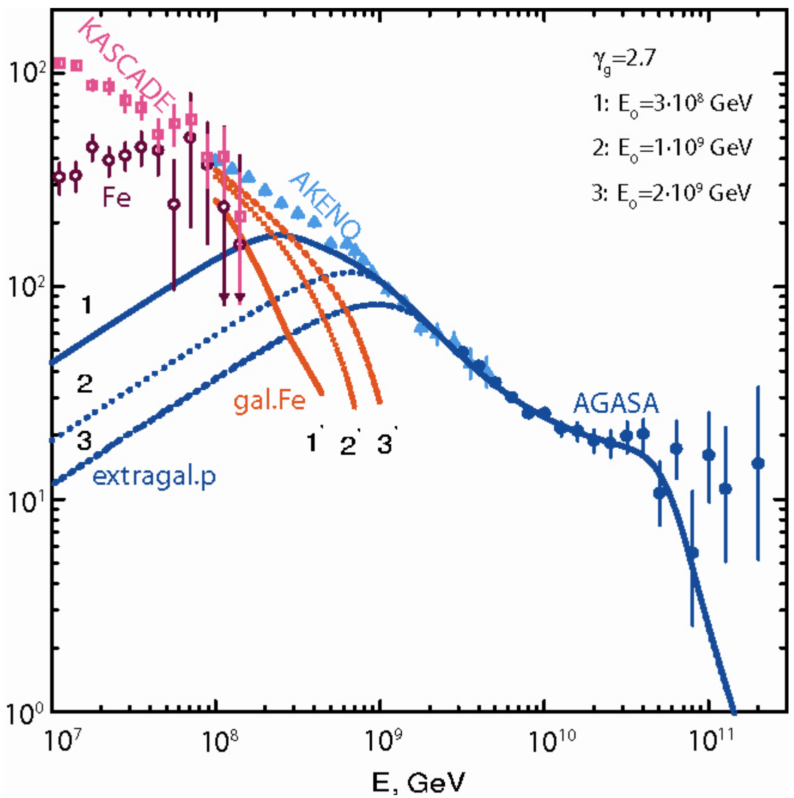
➔ model tests pseudorapidity

KASCADE-Grande coll. (J.Zabierowski, P. Luczak, P.Doll), ICRC 09

Implications



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



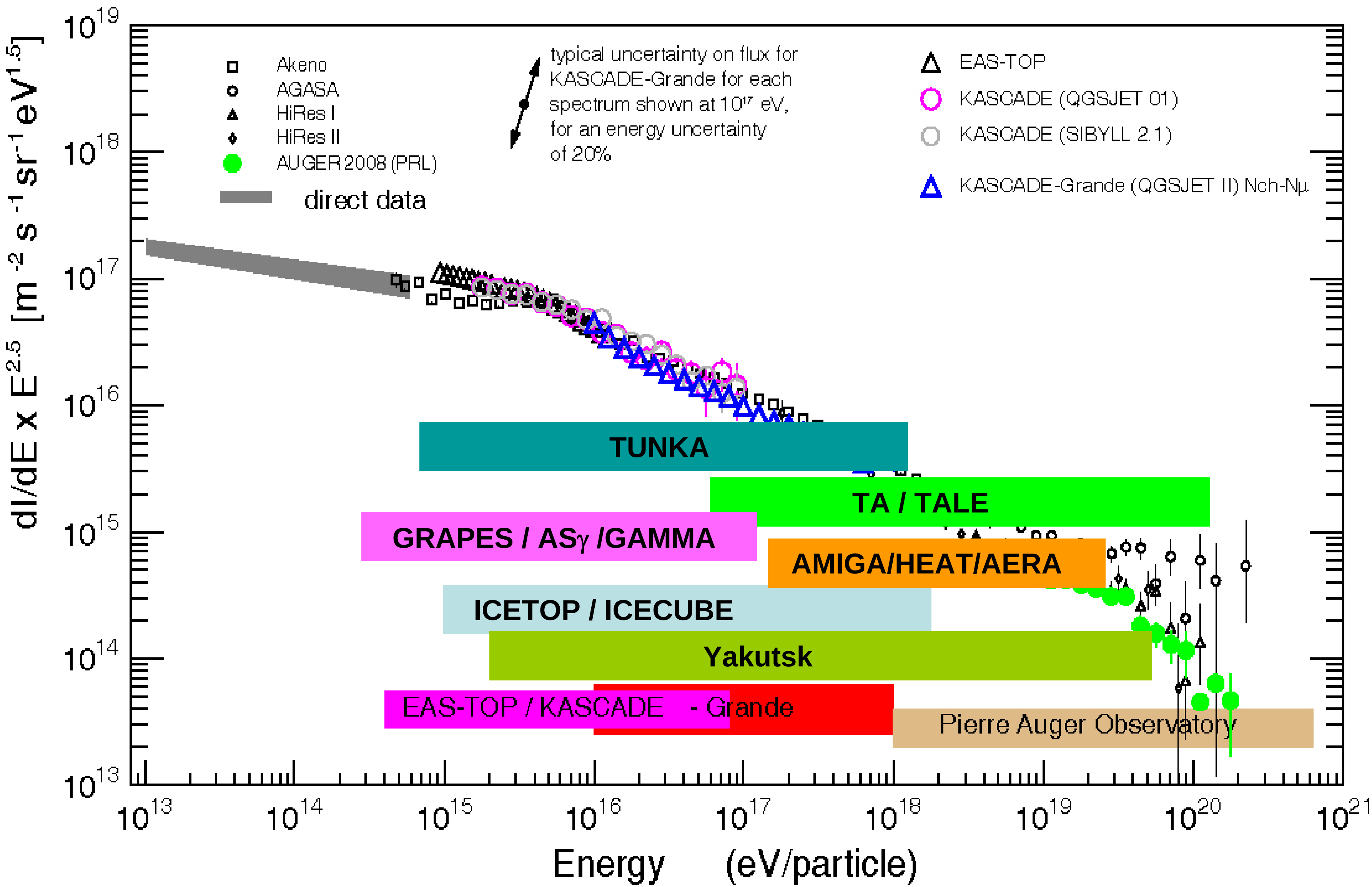
V.Berezinsky, astro-ph/0403477

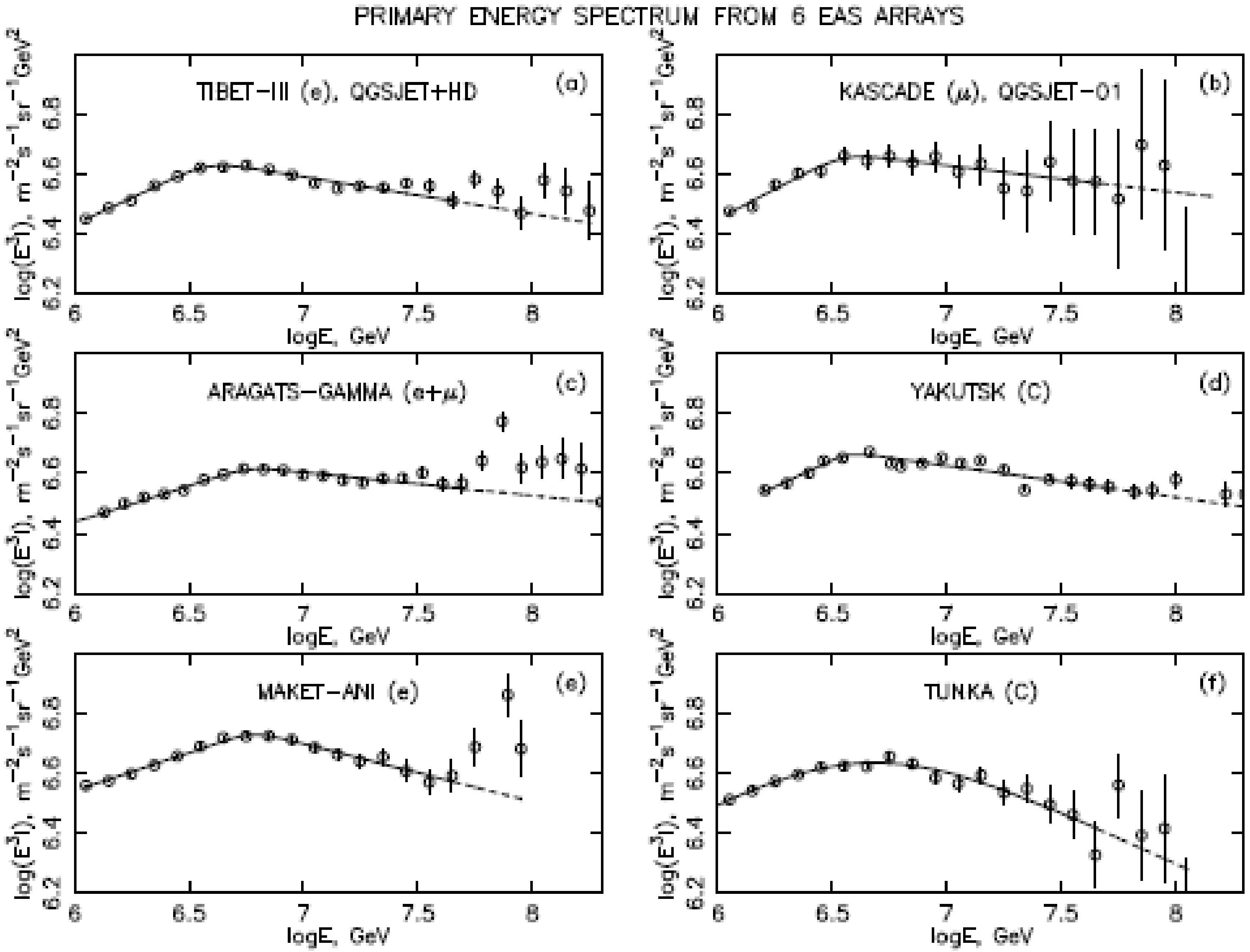
KASCADE-Grande: spectrum without distinct structure
mixed composition

➔

- **pure rigidity model unlikely**
- **at 10^{18}eV eg-protons only unlikely**

KASCADE-Grande





A.Erlykin, ICRC2009; astro-ph/0906.3949.

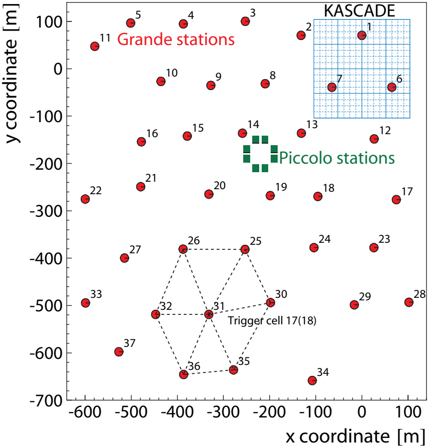
KASCADE-Grande unfolding analysis

Marcel Finger

Zeuthen

February 2010

KASCADE-Grande



KASCADE:

- 200m x 200m, 252 detector stations
- muon and electron detectors

Grande:

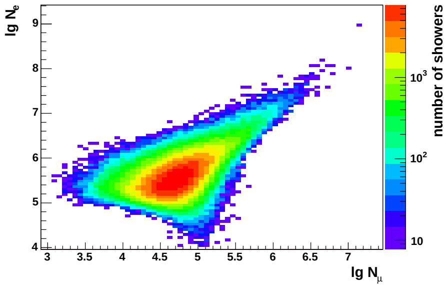
- 700m x 700m, 37 detector stations
- measures muons+electrons
- muon detectors of KASCADE are used to reconstruct muon number

basis of analysis

$$N_i = const. \cdot \sum_{A=1}^{N_A} \int_{\theta_1}^{\theta_2} \int_{-\infty}^{+\infty} \frac{dJ_A}{\mathrm{d}\lg E} \times p_A((\lg N_e, \lg N_\mu)_i | \lg E) \times f(\theta) \mathrm{d}\lg E \, \mathrm{d}\theta$$

- N_i: number of showers in one cell
- A: mass number of primary (H, He, C, Si, Fe)
- $\frac{dJ_A}{\mathrm{d}\lg E}$: sought-after energy spectrum
- p_A: probability to reconstruct sizes $\lg N_e$ and $\lg N_\mu$

$\Longrightarrow$ solution with Gold deconvolution



probability p_A

$$p_A = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} s_A \epsilon_A r_A \, \mathrm{dlg} N_e^{true} \mathrm{dlg} N_\mu^{true}$$

The probability p_A includes:

- s_A: shower fluctuations
- ϵ_A: efficiencies
- r_A: reconstruction uncertainties

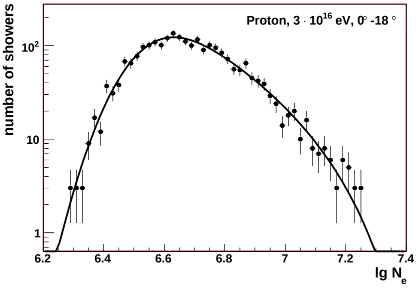
$\Longrightarrow$ determination of s_A, ϵ_A and r_A by Monte Carlo simulations

simulation sets

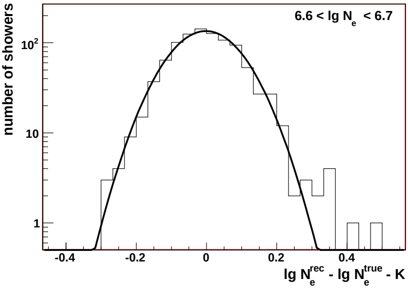
used hadronic interaction models: **QGSJetII + FLUKA**

- Parameterization of shower fluctuations:
  - thinned showers
  - fixed energies (2, 5, 10, 30, 100, 300, 1000, 3000 PeV)
- Determination of efficiencies and reconstruction uncertainties:
  - fully simulated CORSIKA showers + detector simulation

shower fluctuations and reconstruction uncertainties

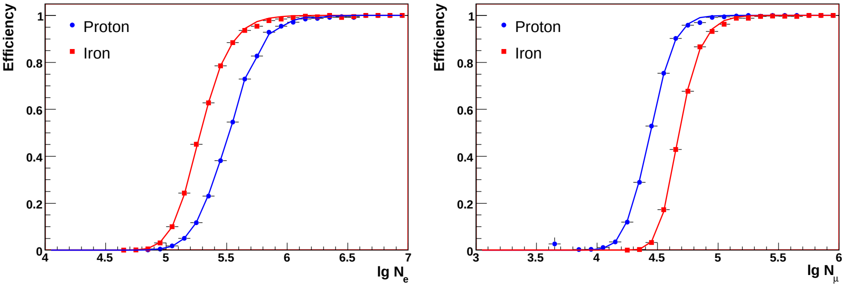


shower fluctuations



statistical reconstruction uncertainties

efficiencies



full efficiency for all primaries

- at $\lg N_\mu \approx 5$
- at $\lg N_e \approx 6$

test spectra

Rigitidity dependant knee positions:

$$\frac{dI(E)}{dE} \propto E^{\gamma} \left(1 + \left(\frac{E}{E_K}\right)^{\epsilon}\right)^{(\gamma_2 - \gamma_1)/\epsilon}$$

E_K: energy of the knee

γ_1: index before the knee

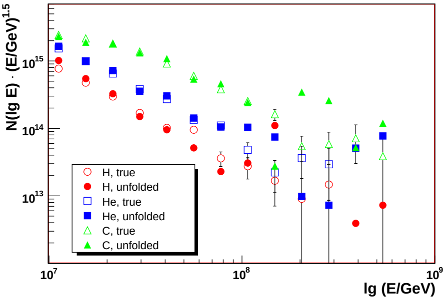
γ_2: index after the knee

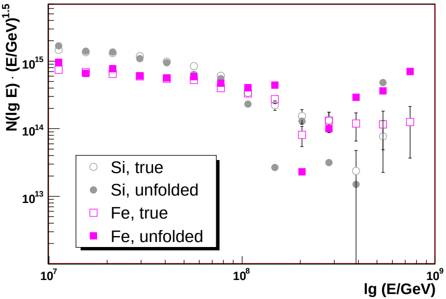
ϵ: width of the knee region

test spectra

- test spectra with primary dependent knee positions
- forward folding of test spectra with response matrices
  $\Longrightarrow$ 2-d shower size spectra
- deconvolution of 2-d size spectra and compare true and reconstructed spectra

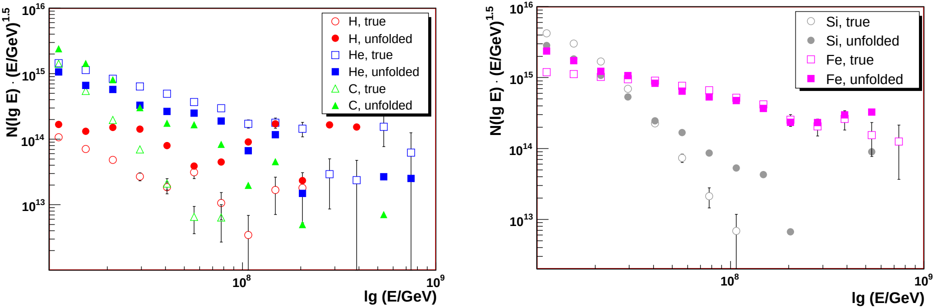
test spectra





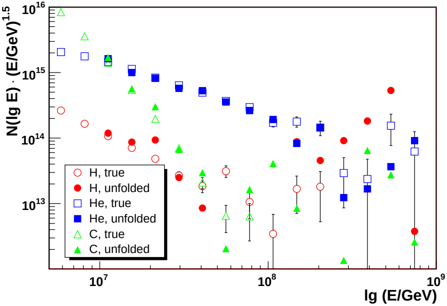
- 5 mass groups used for deconvolution
- arbitrarily chosen test spectra
- good agreement of true and reconstructed spectra

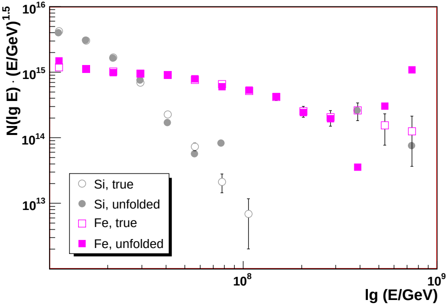
test spectra



- 5 mass groups used for deconvolution
- arbitrarily chosen test spectra
- reconstruction fails

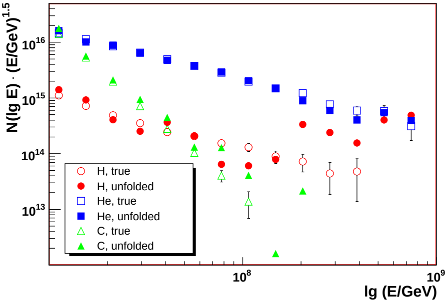
test spectra

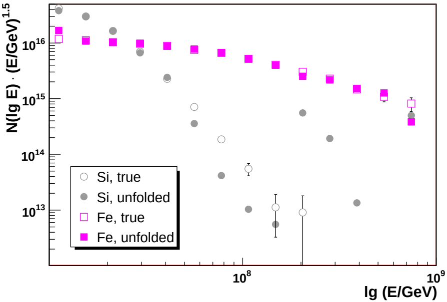




- 5 mass groups used for deconvolution
- arbitrarily chosen test spectra
- only shower fluctuations are taken into account
- no detector effects

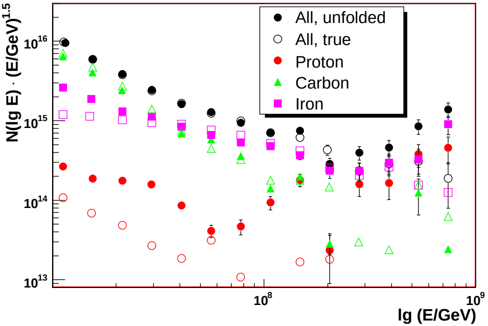
test spectra





- 5 mass groups used for deconvolution
- only shower fluctuations are taken into account
- no detector effects
- 10 times more events than in the set shown before

test spectra



- 5 mass groups used for deconvolution
- carbon represents sum of He, C and Si

summary

- only low statistics especially for showers with $\mathrm{E} > 10^{17}$eV in Grande data
- misreconstructed spectra are due to low statistics combined with resolution effects of the detector
- good agreement of unfolded all particle spectra from KASCADE and Grande
- heavy composition

- outlook
  - investigate systematical and statistical uncertainties