The KASCADE-Grande experiment: recent results about the energy spectrum

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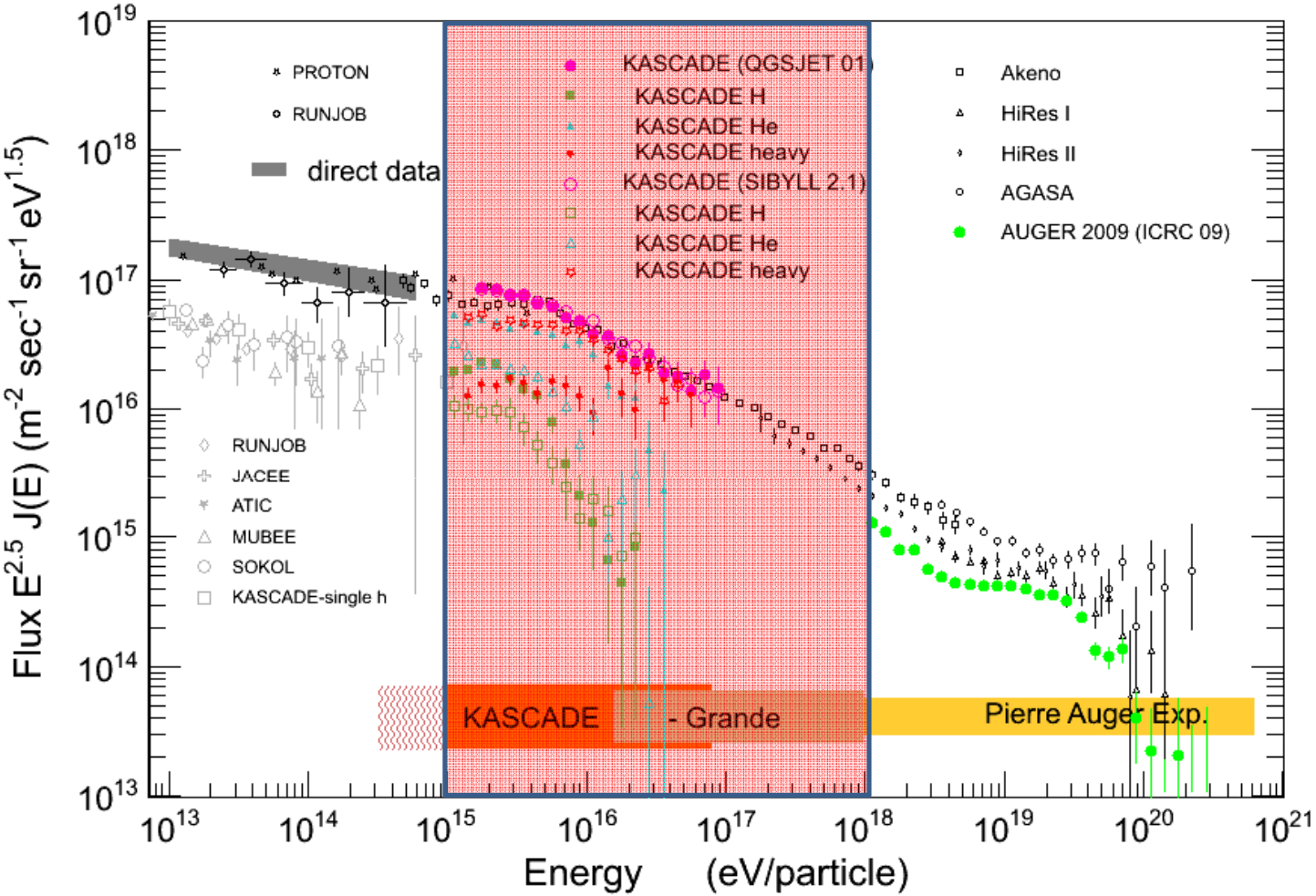


Questions

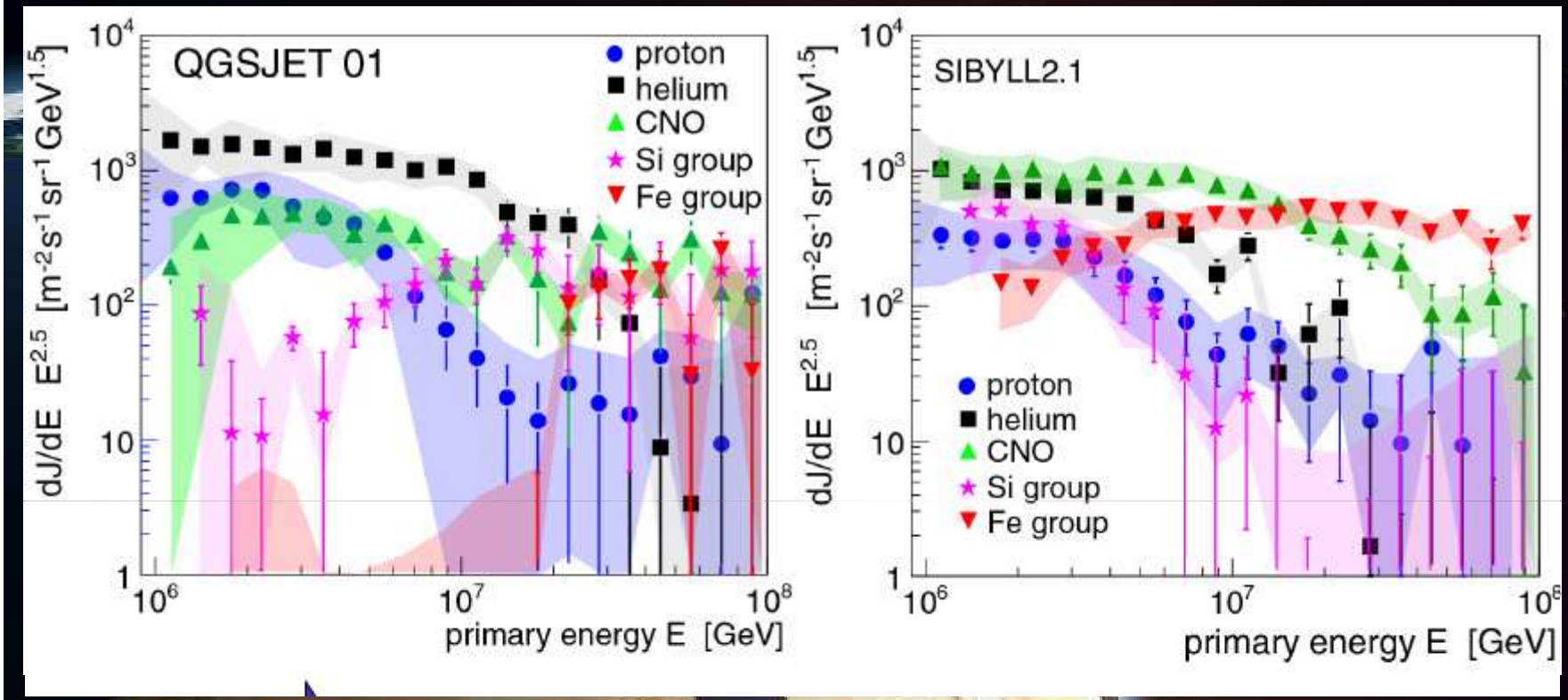
- -Knee origin
- -Second knee?
- -Iron knee?
- -Galactic to extragalactic transition
- -Sources
- -Propagation
- -Acceleration

Data

- -Spectrum
- -Composition
- -Arrival direction
- -γ/ν

Karlsruhe Shower Core and Array Detector

- Components:
  - Ground array with 252 e/γ and μ scintillator detectors
  - Central detector (Calorimeter, μ detectors)
  - Muon tracking detector
- Observables:
  N_e, N_μ, H_{hadron}
- $E = 10^{14} – 10^{17}$ eV

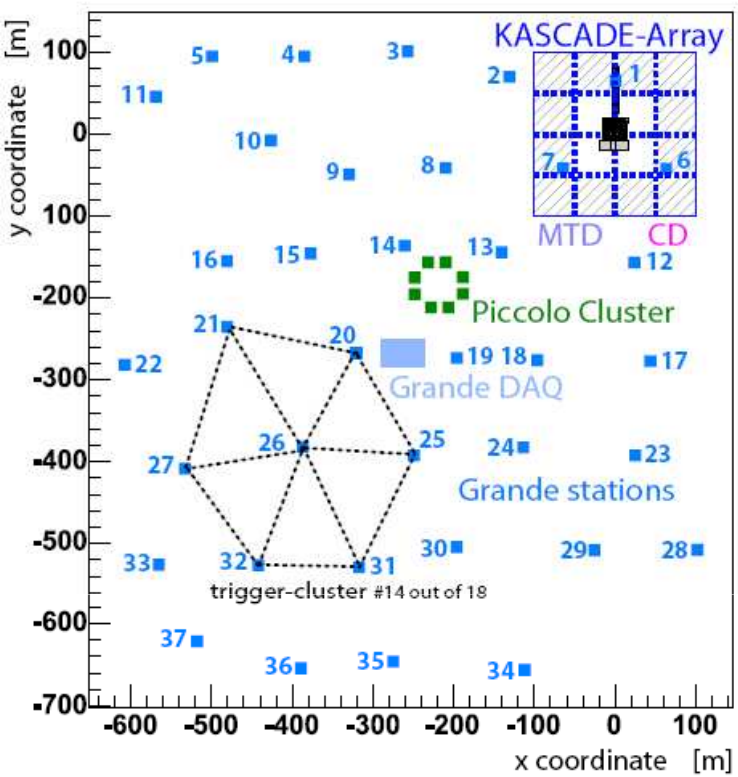


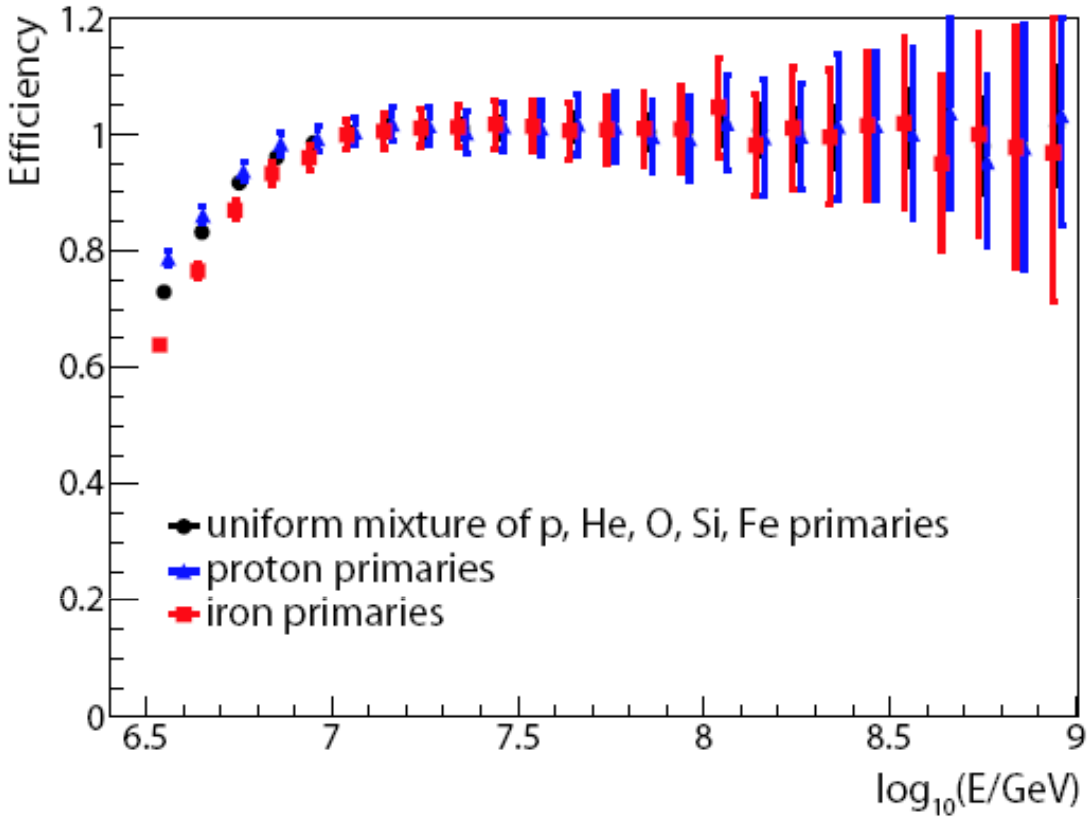
Results

- Knee produced by light component
- Relative abundances show dependence with hadronic interaction model
- Knee position change with composition (E_{knee} α Z or A?)
- E^{Fe}_{knee} ~ 10^{17} eV?

KASCADE-Grande detector

$E = 10^{16} - 10^{18}$ eV





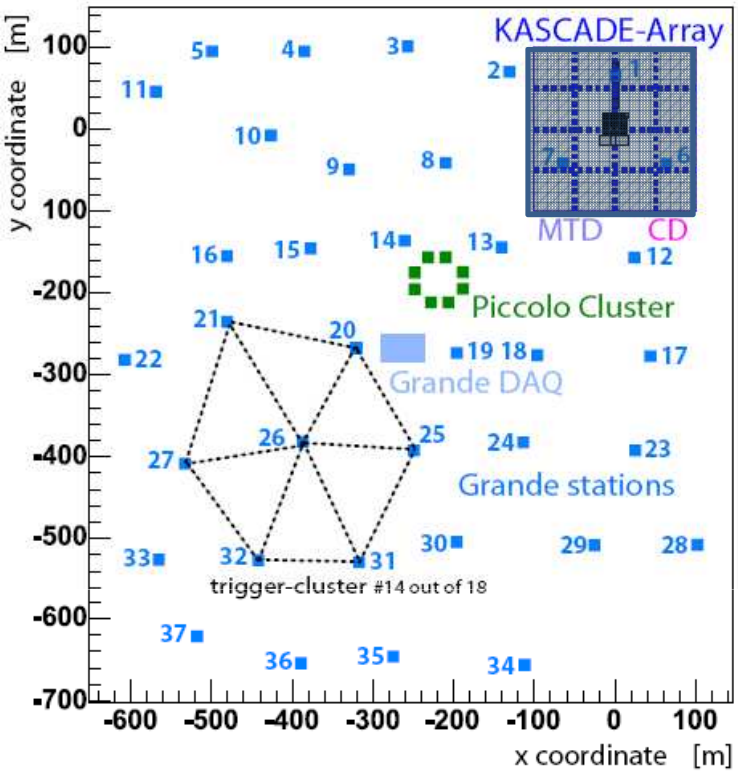
Data acquisition

-Stable since December 2003
-Trigger: Hexagon + central detector
- Rate = 0.5 Hz

Efficiency

$E \geq 10^7$ GeV

KASCADE-Grande Coll., NIMA, 2010 (In press)



KASCADE Muon Detectors (ρ^{μ}_{k})

Lateral fit (Lagutin)

N_{μ}

Grande array (ρ^{ch}_{j}, Δt_{j})

Lateral **E** correction function

χ^2 → Core position

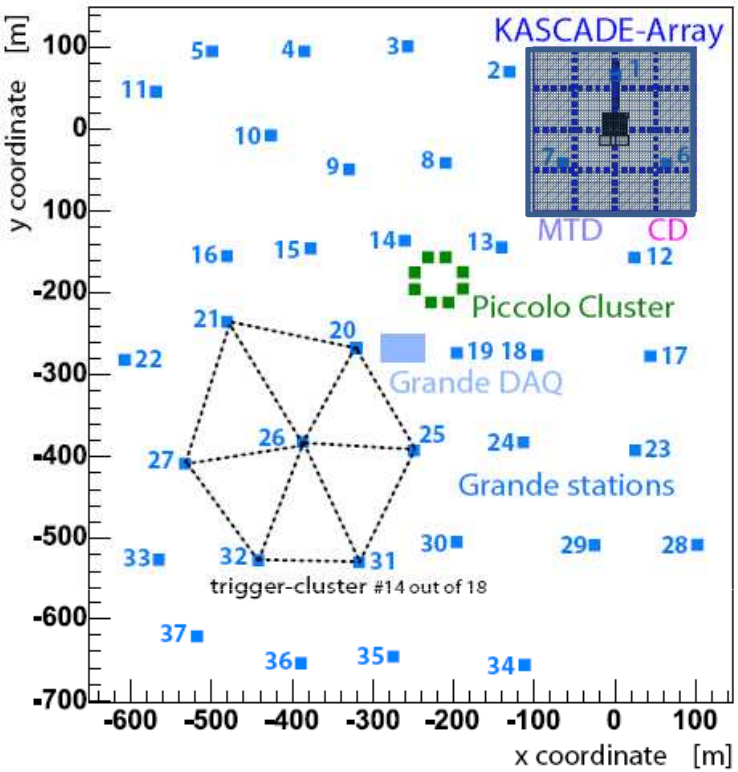
χ^2 → Incidence angle

Core position, Incidence angle → Lateral fits

NKG → N_{ch}

Lateral fits → Age

Linsley → S(500)



Grande array
(ρ^{ch}_j, Δt_j)

Lateral **E** correction function

χ^2 → Core position

χ^2 → Incidence angle

KASCADE Muon Detectors (ρ^{μ}_k)

Lateral fit (Lagutin) → N_μ

N_μ → N_e

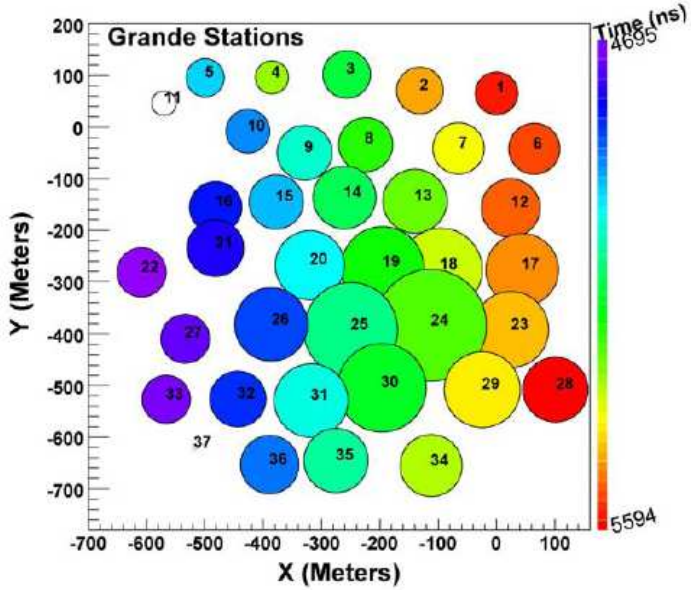
NKG → N_{ch}

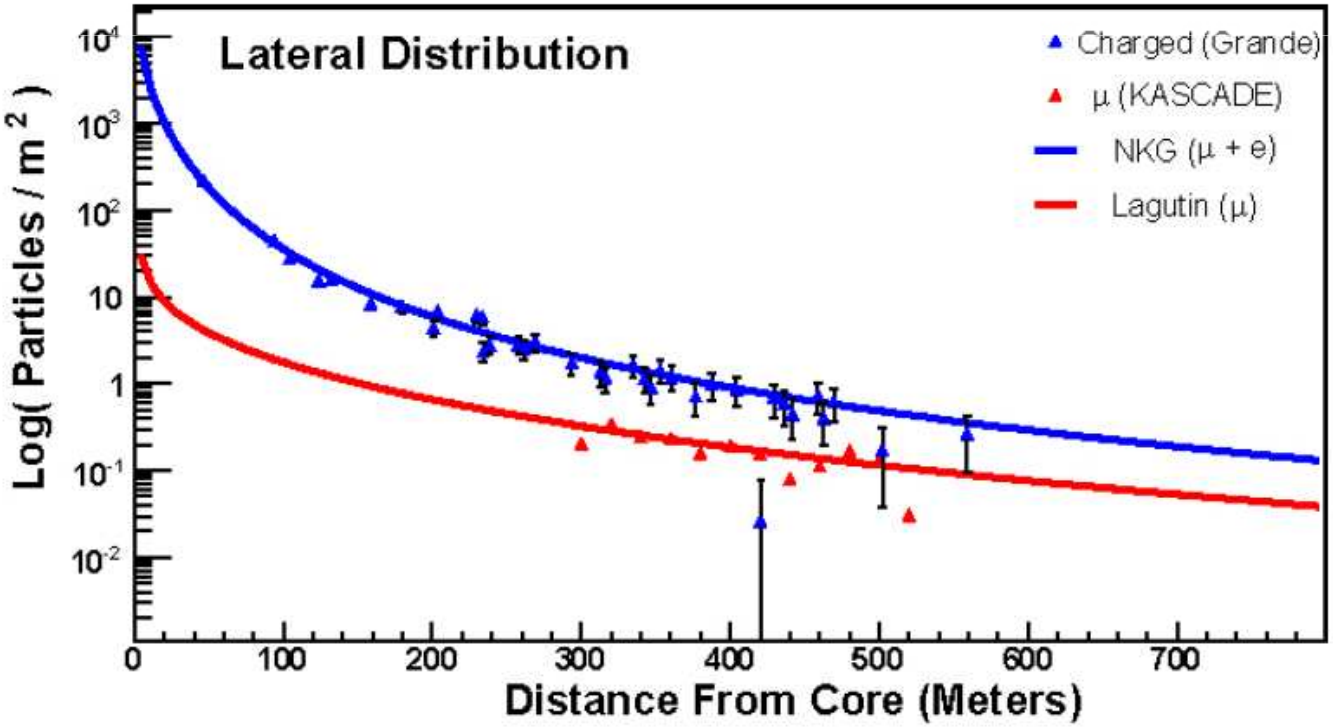
Lateral fits → Age

Linsley → S(500)

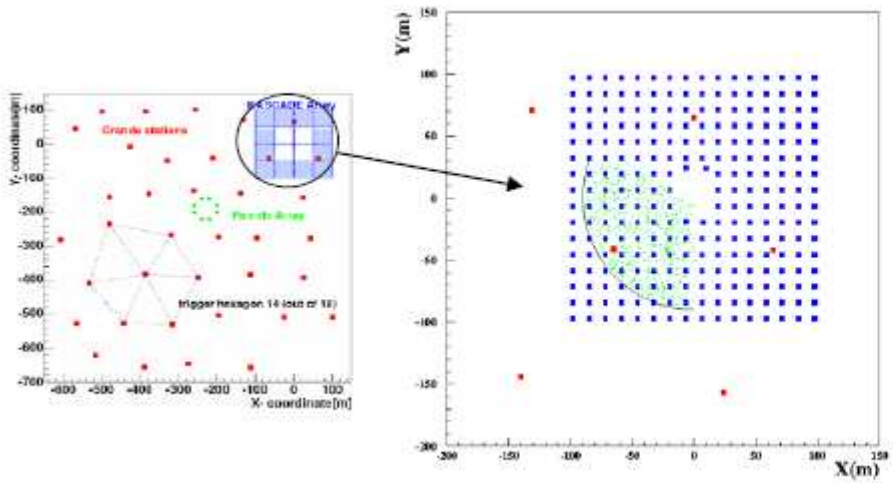
Event reconstruction

- Recorded on July 8 2005 at 12:11 UTC
- Core: (-155, -401) m
- $\log_{10}(N_{ch})$ = 7.0
- $\log_{10}(N_{\mu})$ = 5.7
- Zenith : 24.2°
- Azimuth: 28.4°

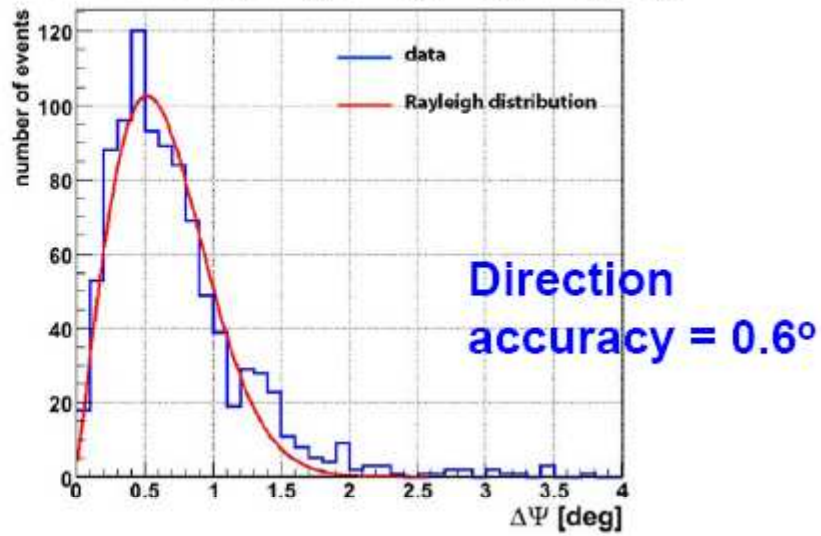




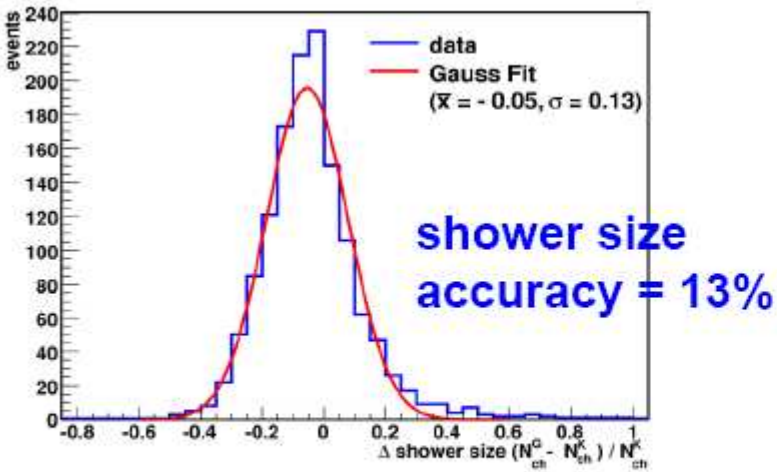
KASCADE-Grande Accuracy: Direct comparison with KASCADE



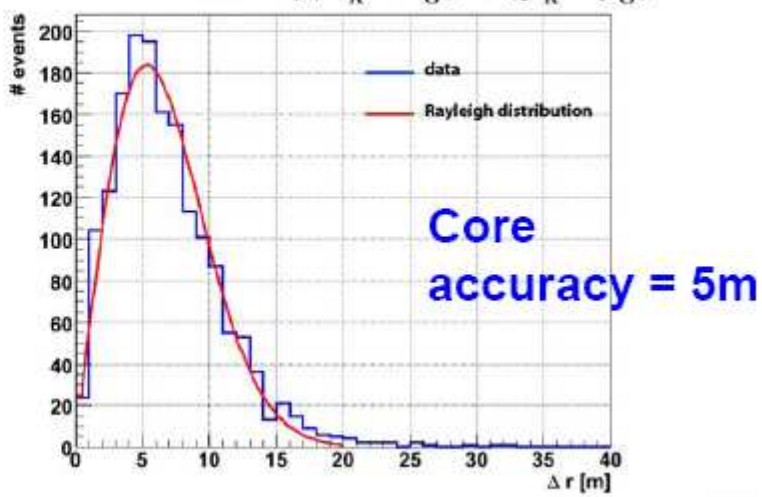
$$\Delta\psi = \arccos(\cos(\theta_K)\cdot\cos(\theta_G)+\sin(\theta_K)\cdot\sin(\theta_G)+\cos(\phi_K-\phi_G))$$



$$x = (N_{ch}^{G} - N_{ch}^{K}) / N_{ch}^{K}$$

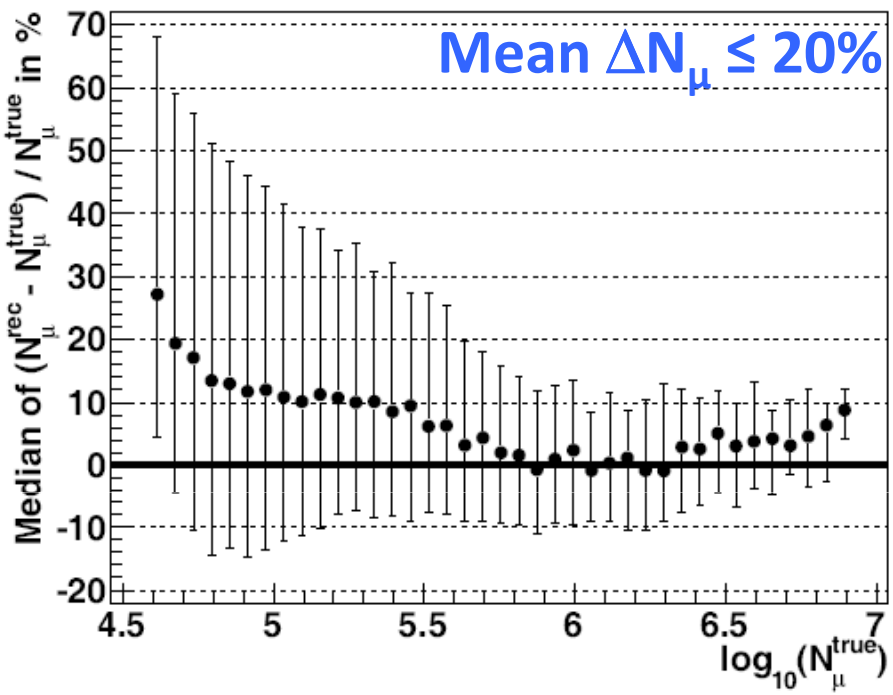


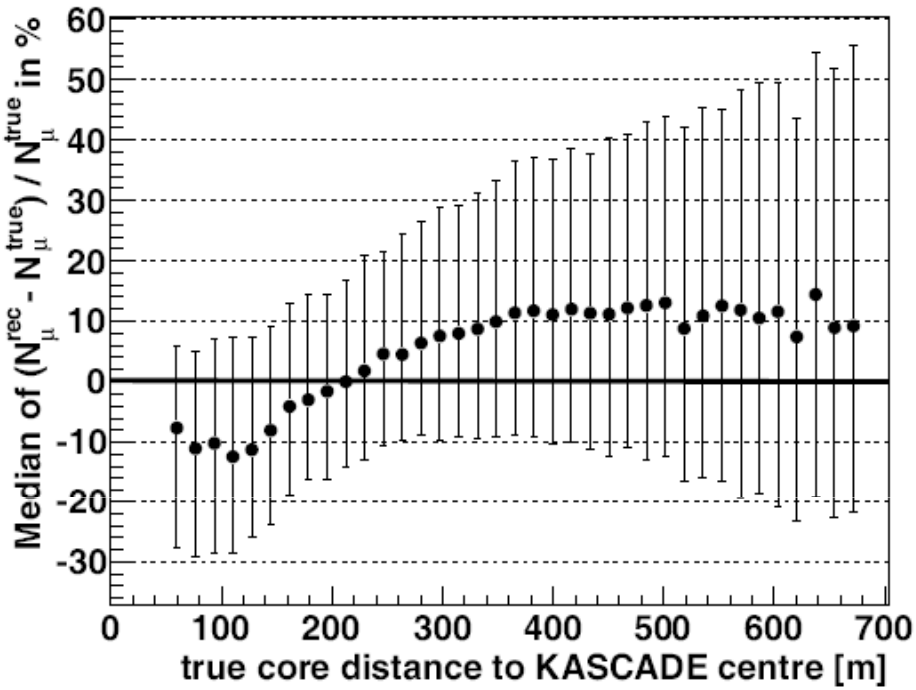
$$\Delta r = \sqrt{(x_K - x_G)^2 + (y_K - y_G)^2}$$



KASCADE-Grande Coll., NIMA, 2010 (In press)

KASCADE-Grande Accuracy: MC studies (CORSIKA QGSJETII/FLUKA)

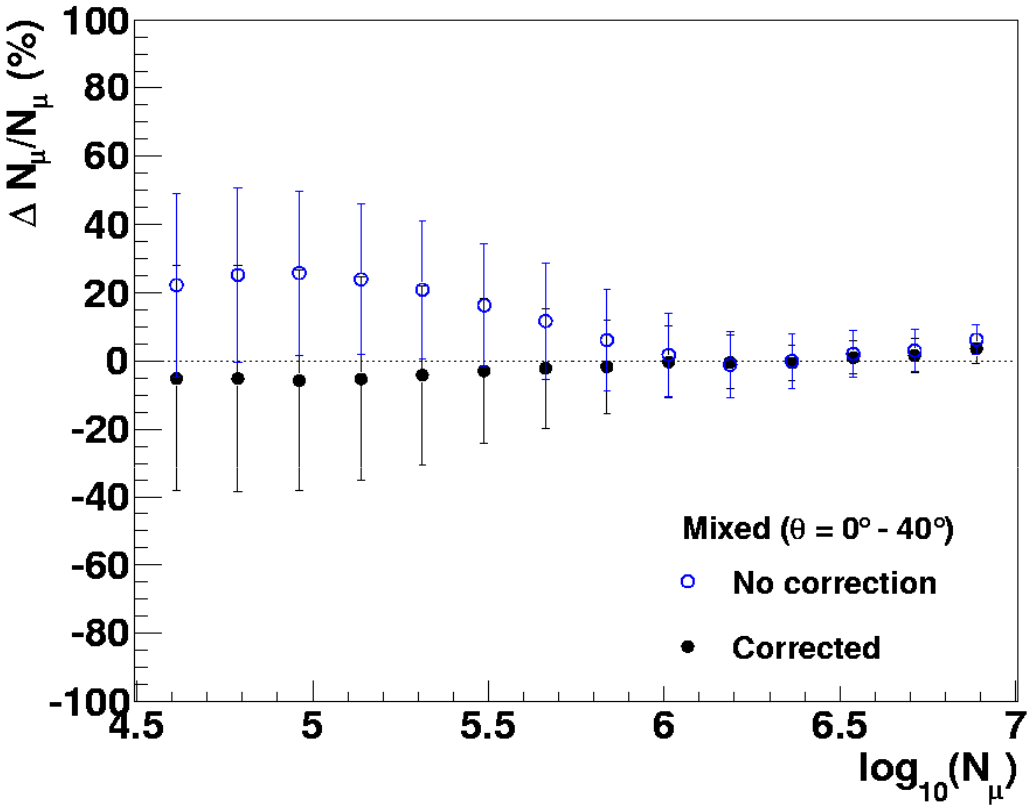




ΔN_μ dependence on muon number, core position, zenith angle is well understood and can be parameterized

Correction function for N_μ

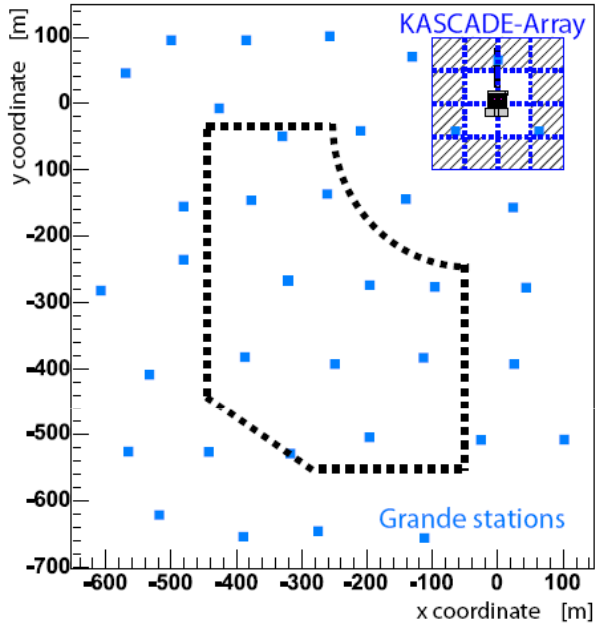
KASCADE-Grande Accuracy: MC studies (CORSIKA QGSJETII/FLUKA)

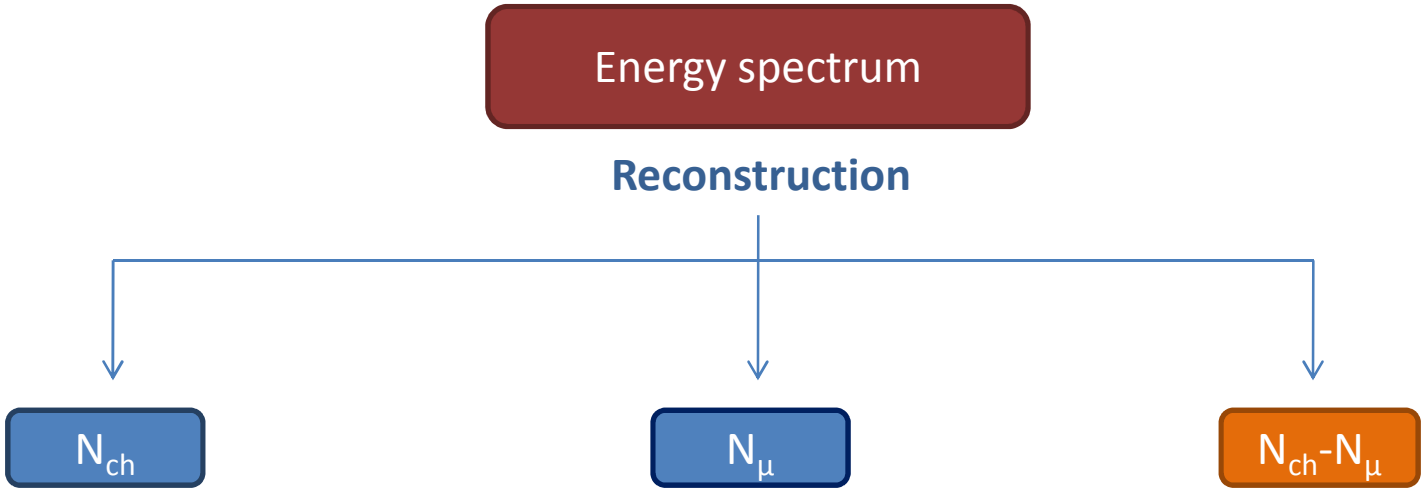


Energy spectrum

Experimental data set

- 1173 days of effective DAQ time.
- Performance of reconstruction and detector is stable.
- $\theta < 40°$
- Exposure: $2 \cdot 10^{17}$ $cm^2 \cdot s \cdot sr$





- Cross check of reconstruction procedures
- Cross check of systematic uncertainties
- Test sensitivity to composition
- Cross check of validity of hadronic interaction models

Energy spectrum

Reconstruction

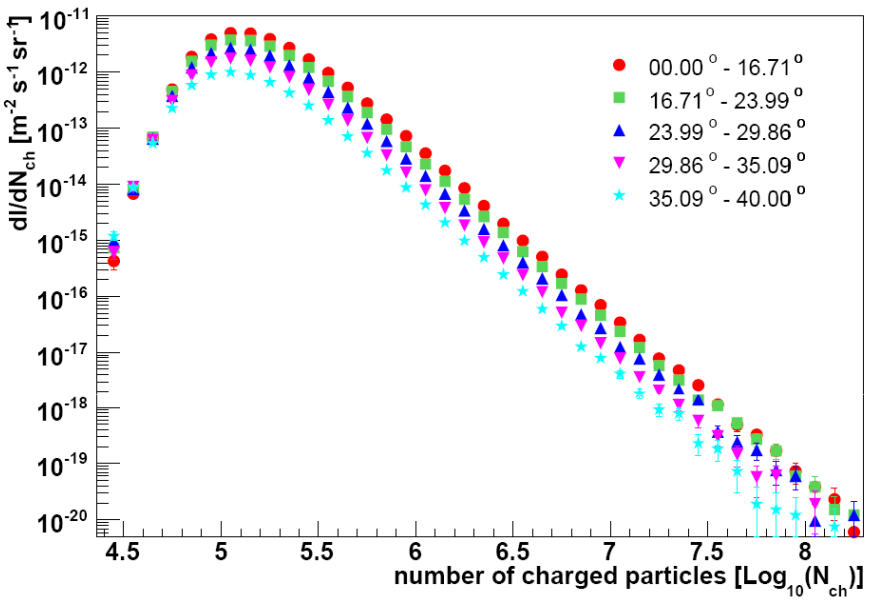
N_{ch} | N_{μ} | N_{ch}-N_{μ}

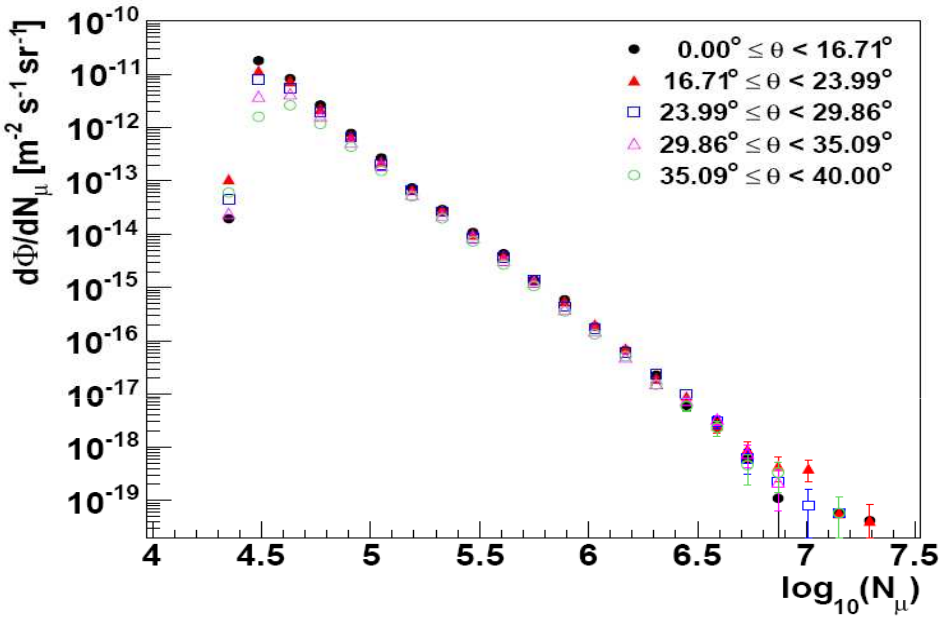
- Constant Intensity Cut method
- Correction for atmospheric attenuation: Model independent
- Calibration function QGSJET II: Shower size (N_{ch} or N_{μ}) vs E
- Composition dependend

- Composition independent
- Correction for atmospheric attenuation: Model dependent
- Calibration function QGSJET II : N_{ch}-N_{μ} vs E

Size spectra (charged particles)

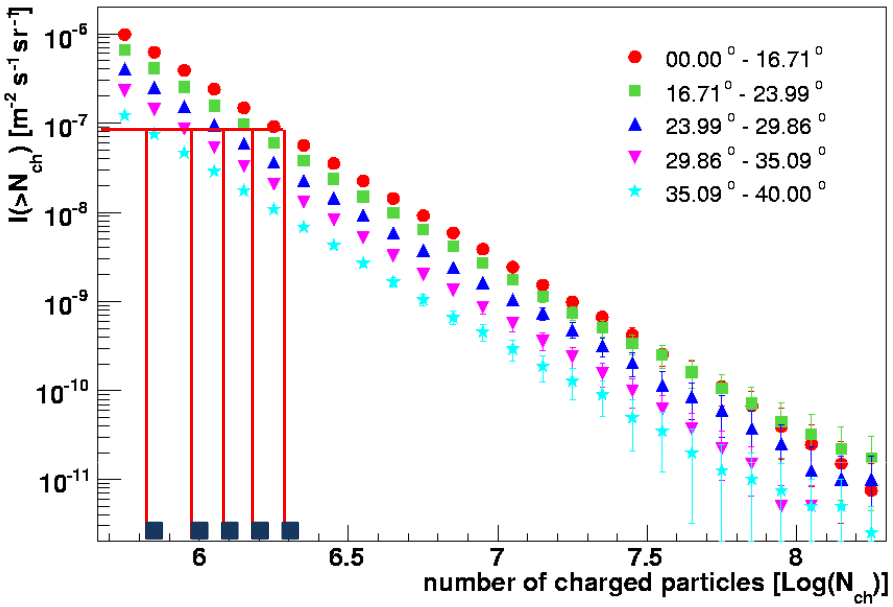
Muon size spectra (E_μ > 230 MeV)

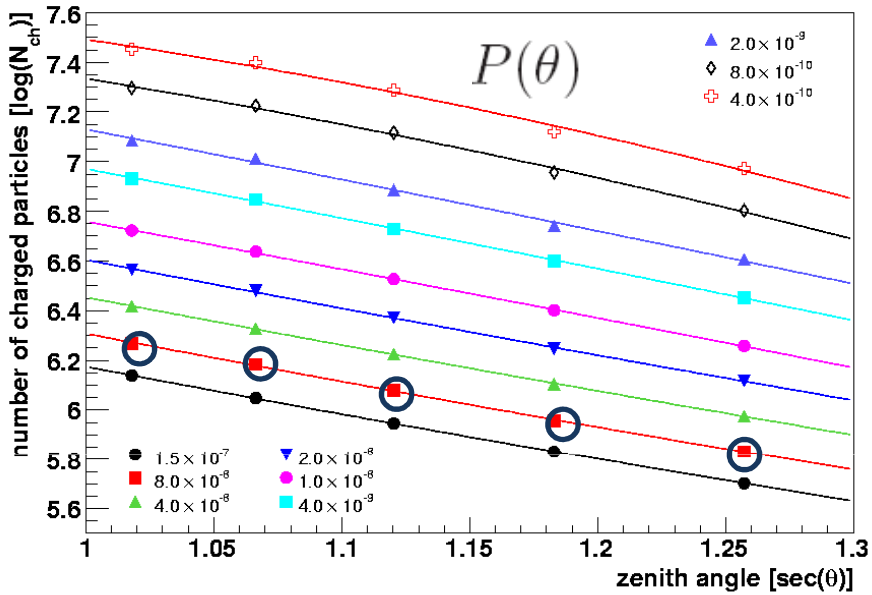




Correct for atmospheric attenuation

Constant intensity cut method

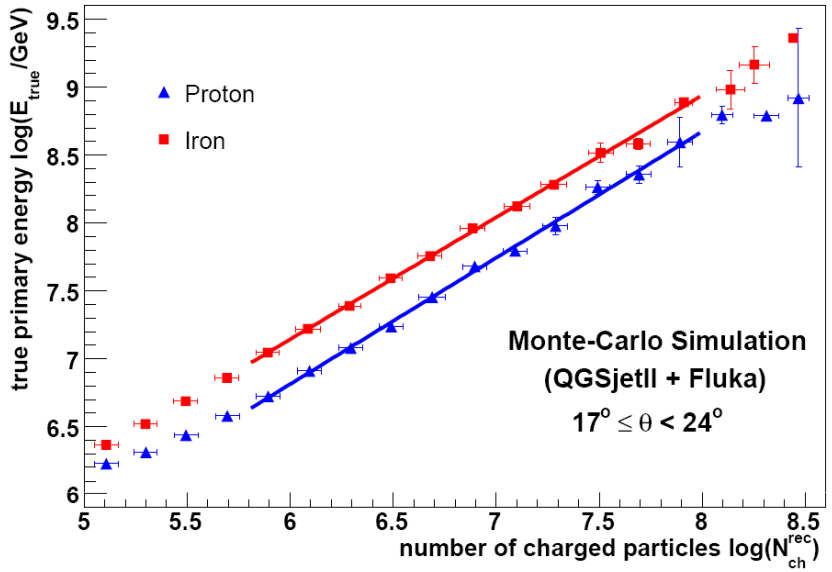




$$N_{ch(\mu)}(\theta_{ref}) = N_{ch(\mu)}(\theta)\exp\left[P(\theta_{ref}) - P(\theta)\right]$$

Shower size normalized to a certain zenith angle

Energy spectrum: N_{ch}

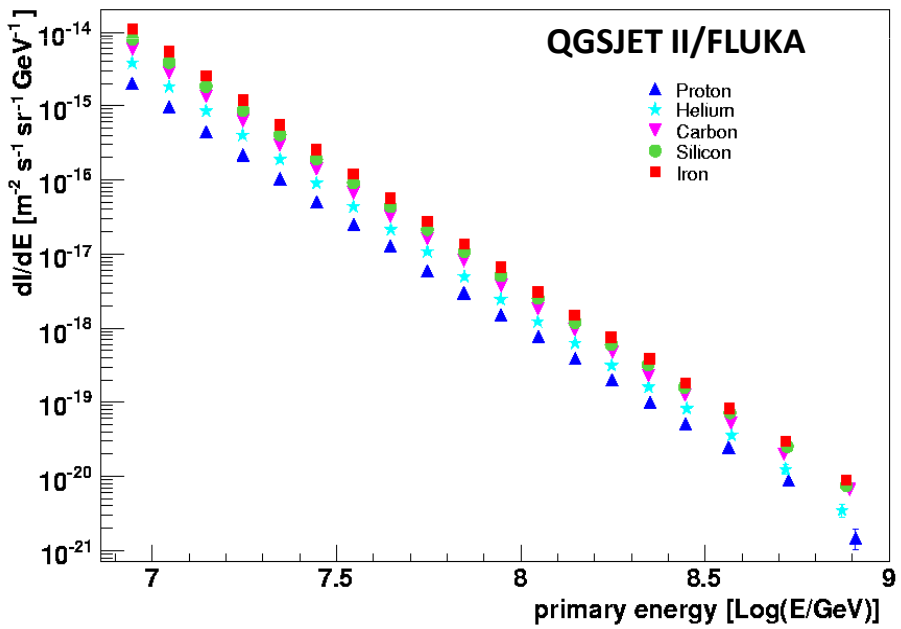


Calibration function

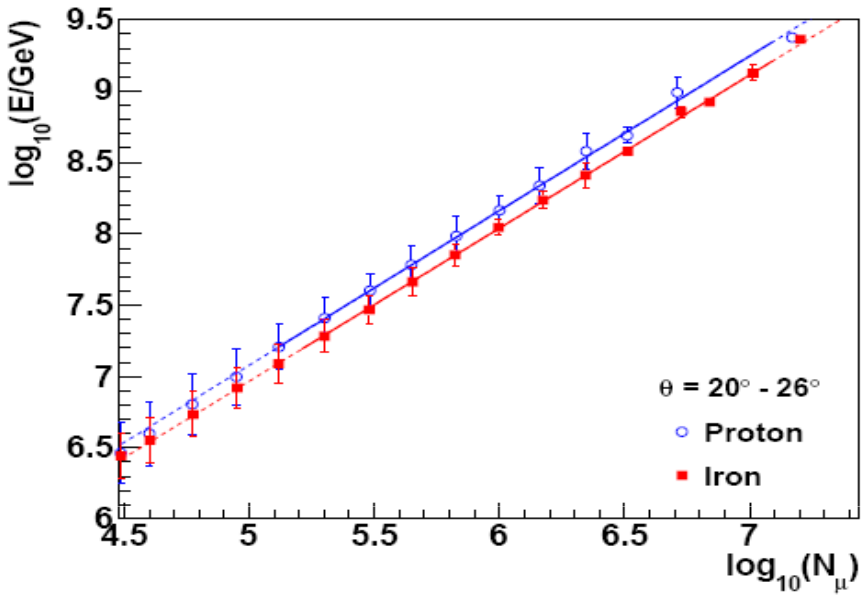
$$\log E_0 = a + b \cdot \log N_{ch}$$

Energy spectra

Composition dependent

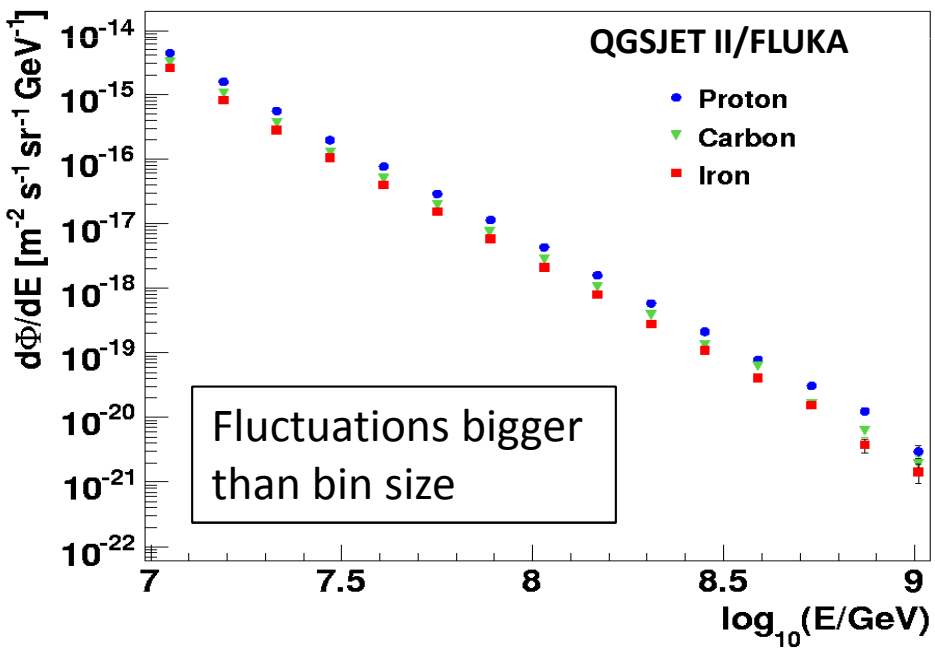


Energy spectrum: N_μ



Calibration function

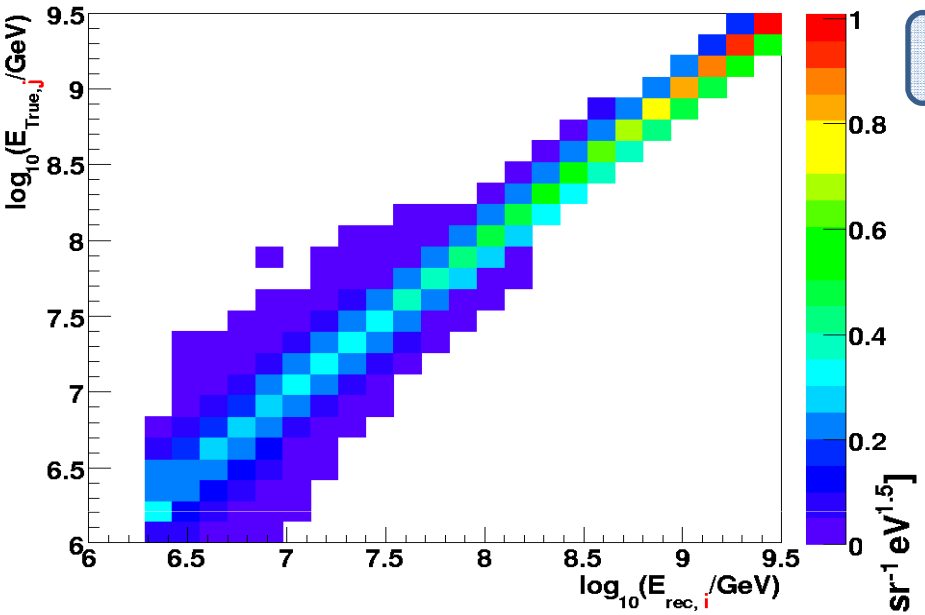
$$\log_{10} E = a_\mu + b_\mu \cdot \log_{10} N_\mu$$



Energy spectra

Composition dependent

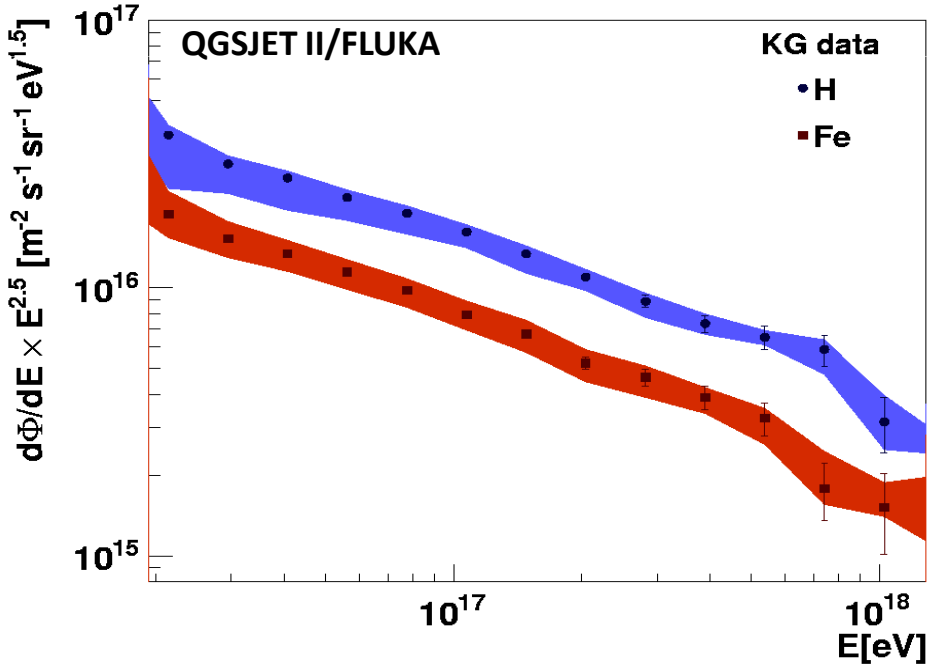
Energy spectrum: N_μ



Unfolding: Response matrix

Prob. distributions

$$\sum_{j=1}^{N} R_{ij} = 1$$



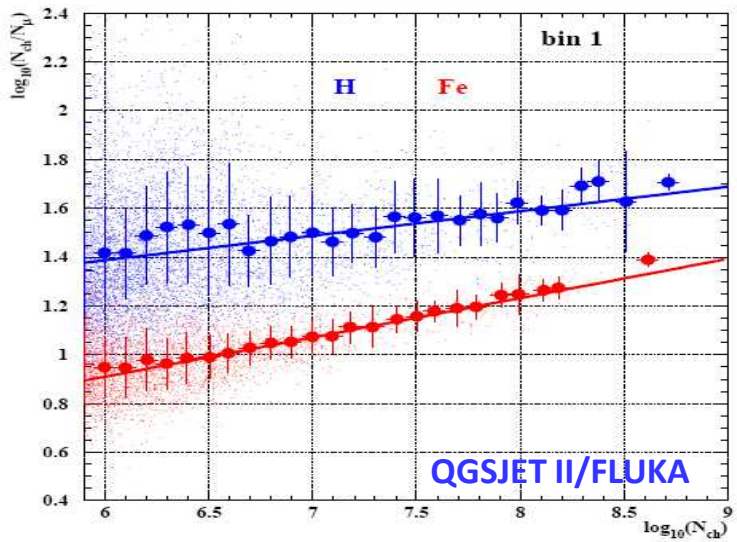
$$n_j^{true} = \sum_{i=1}^{N} R_{ij} n_i^{exp}$$

Energy spectrum: N_{ch}-N_{μ}

For each zenith angle bin

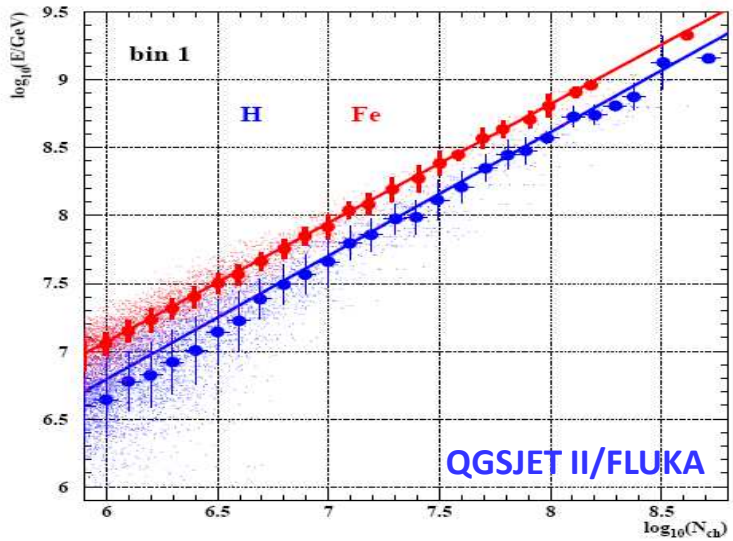
Consideration of N_{ch}-N_{μ} correlation

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

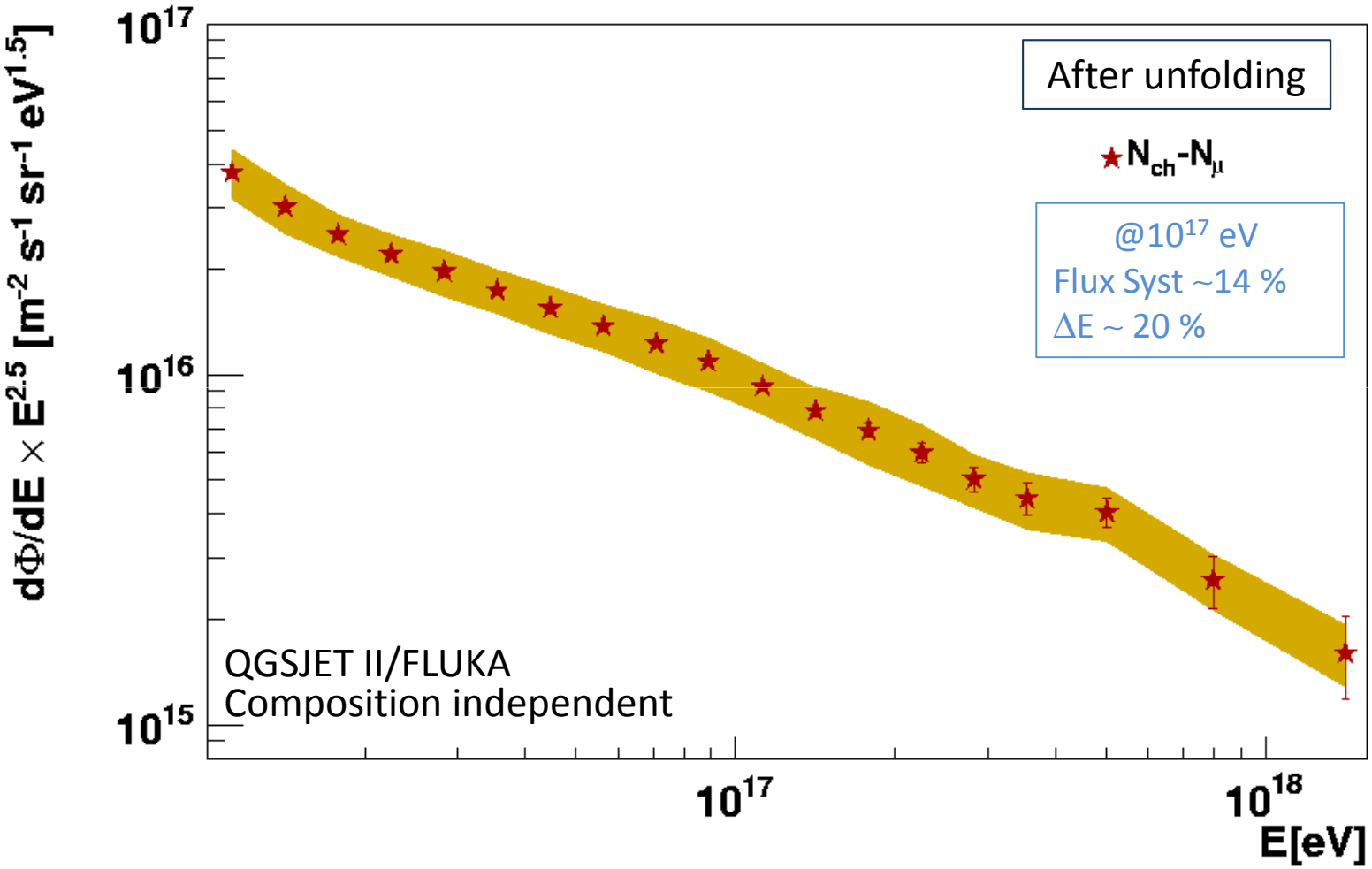


Calibration function according to primary

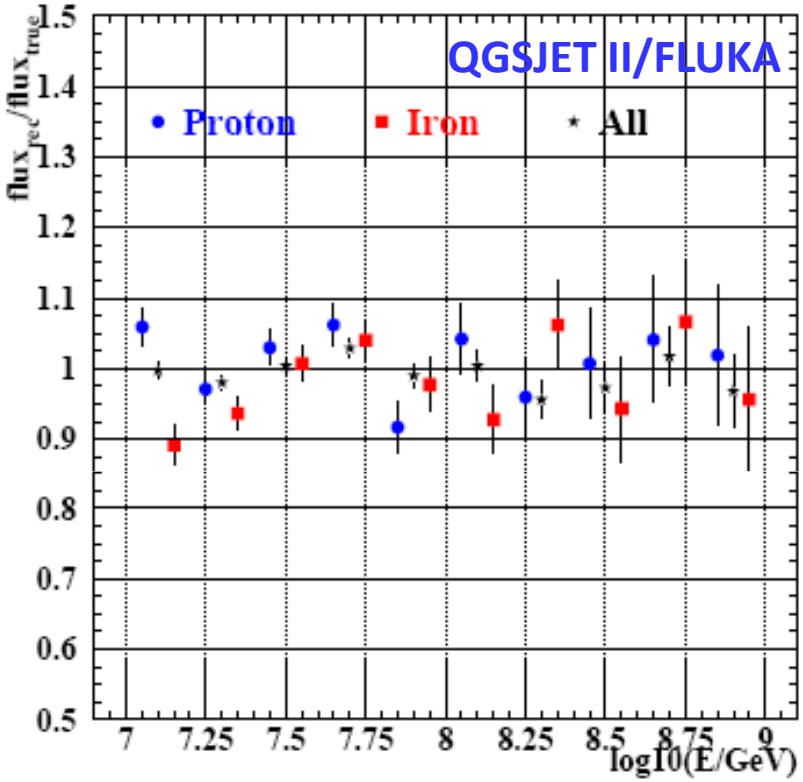
$$log_{10}(E[GeV]) = [a_p + (a_{Fe} - a_p) \cdot k] \cdot log_{10}(N_{ch}) + \\ + b_p + (b_{Fe} - b_p) \cdot k$$



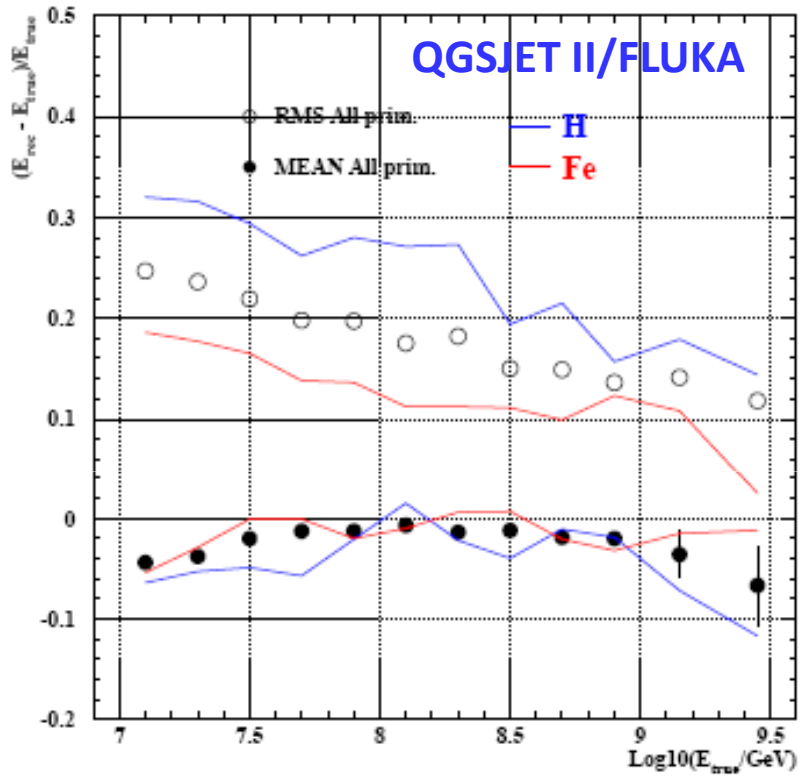
Energy spectrum: N_{ch}-N_{μ}



Energy spectrum: N_{ch}-N_{μ}

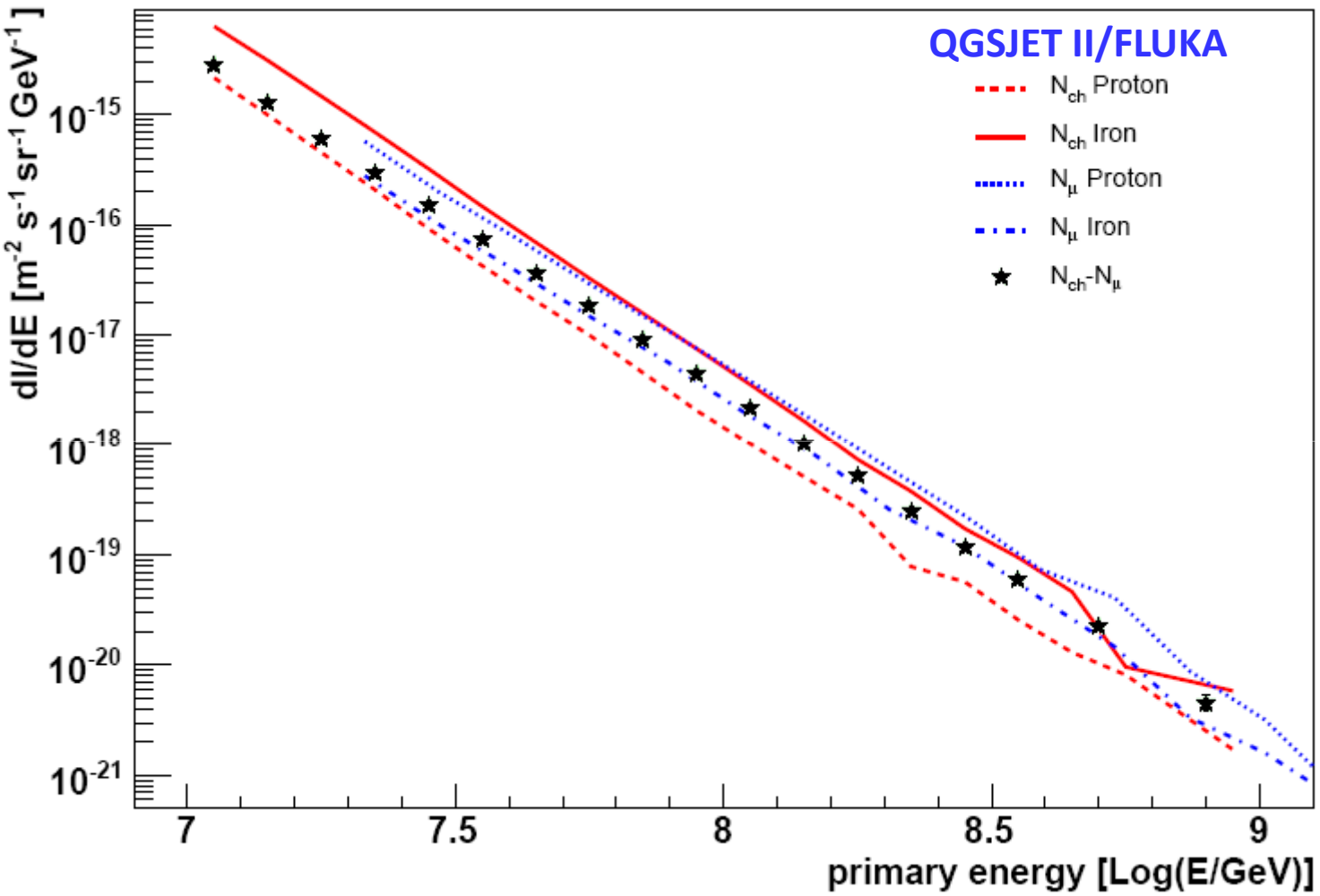


Ratio of reconstructed to true spectrum using MC simulations



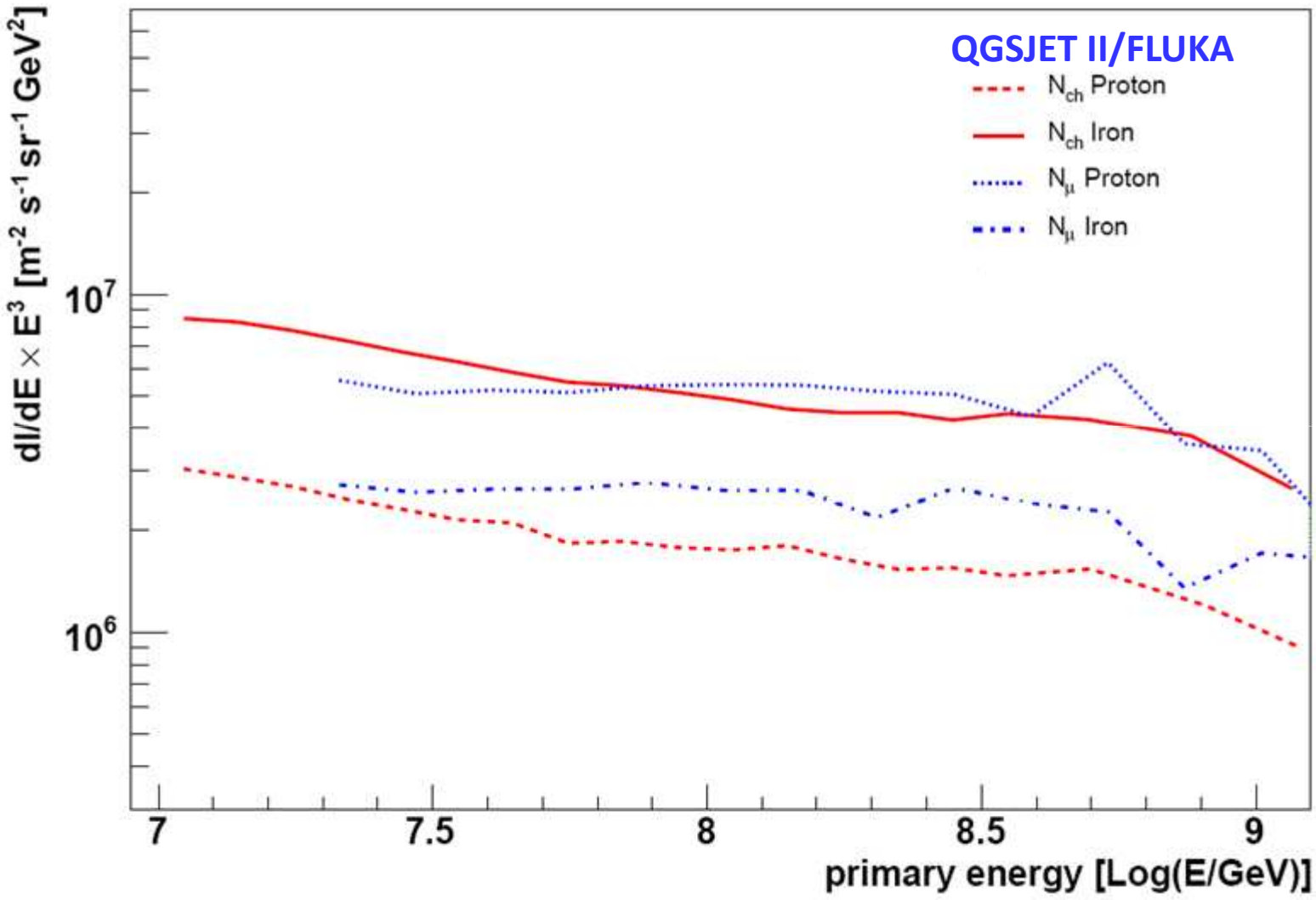
Energy resolution from MC simulations

All particle energy spectrum



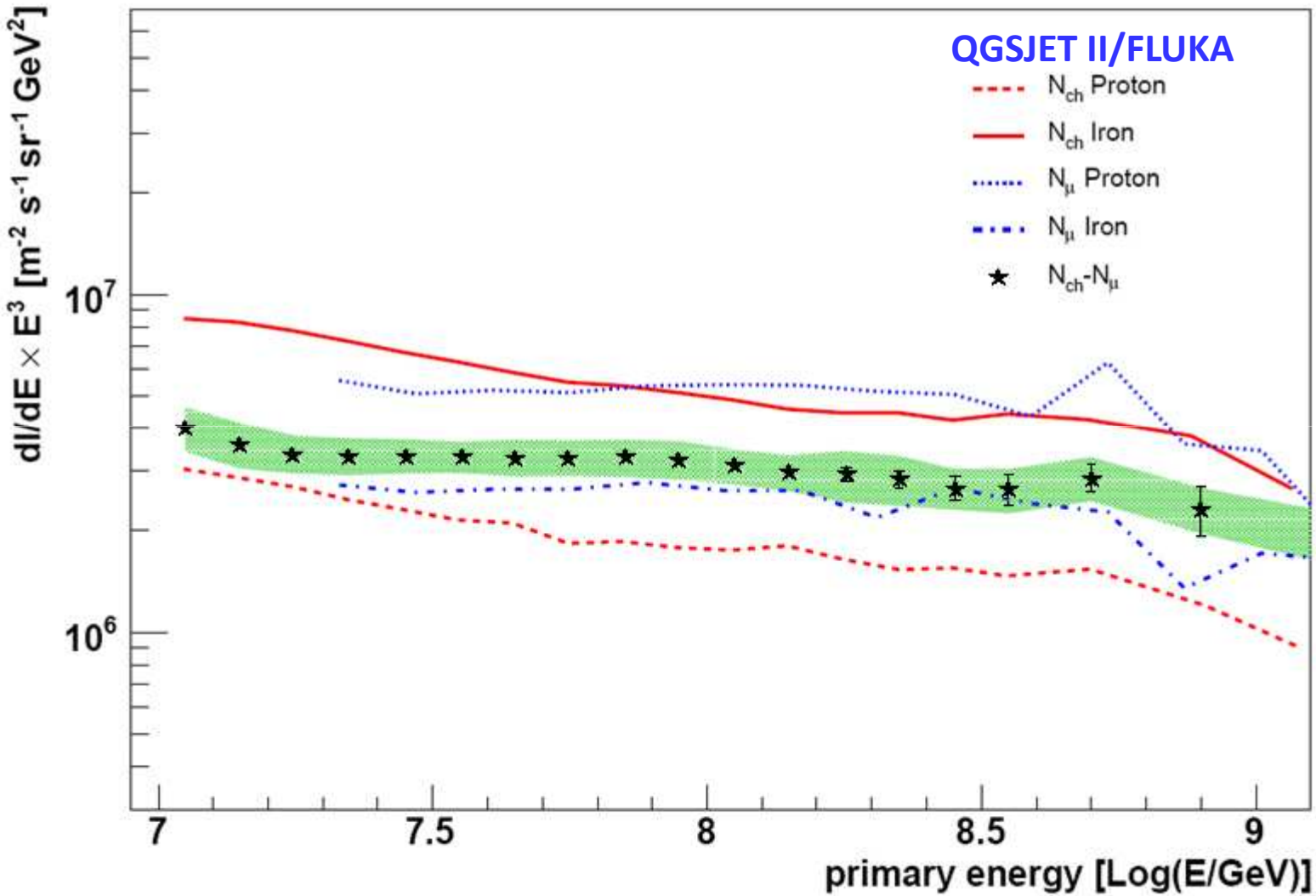
Good agreement between different methods

All particle energy spectrum



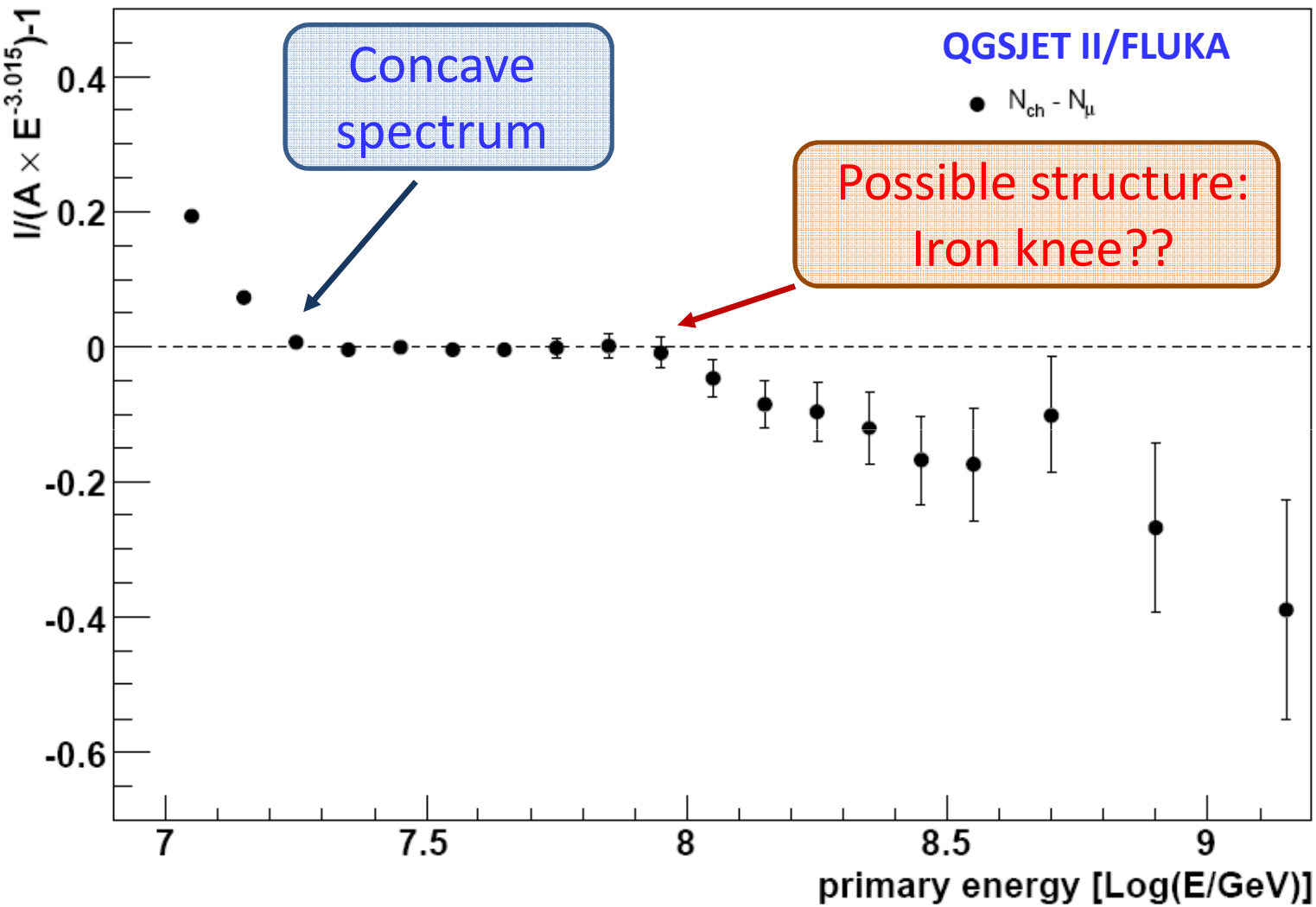
P and Fe are in different order for both methods

All particle energy spectrum



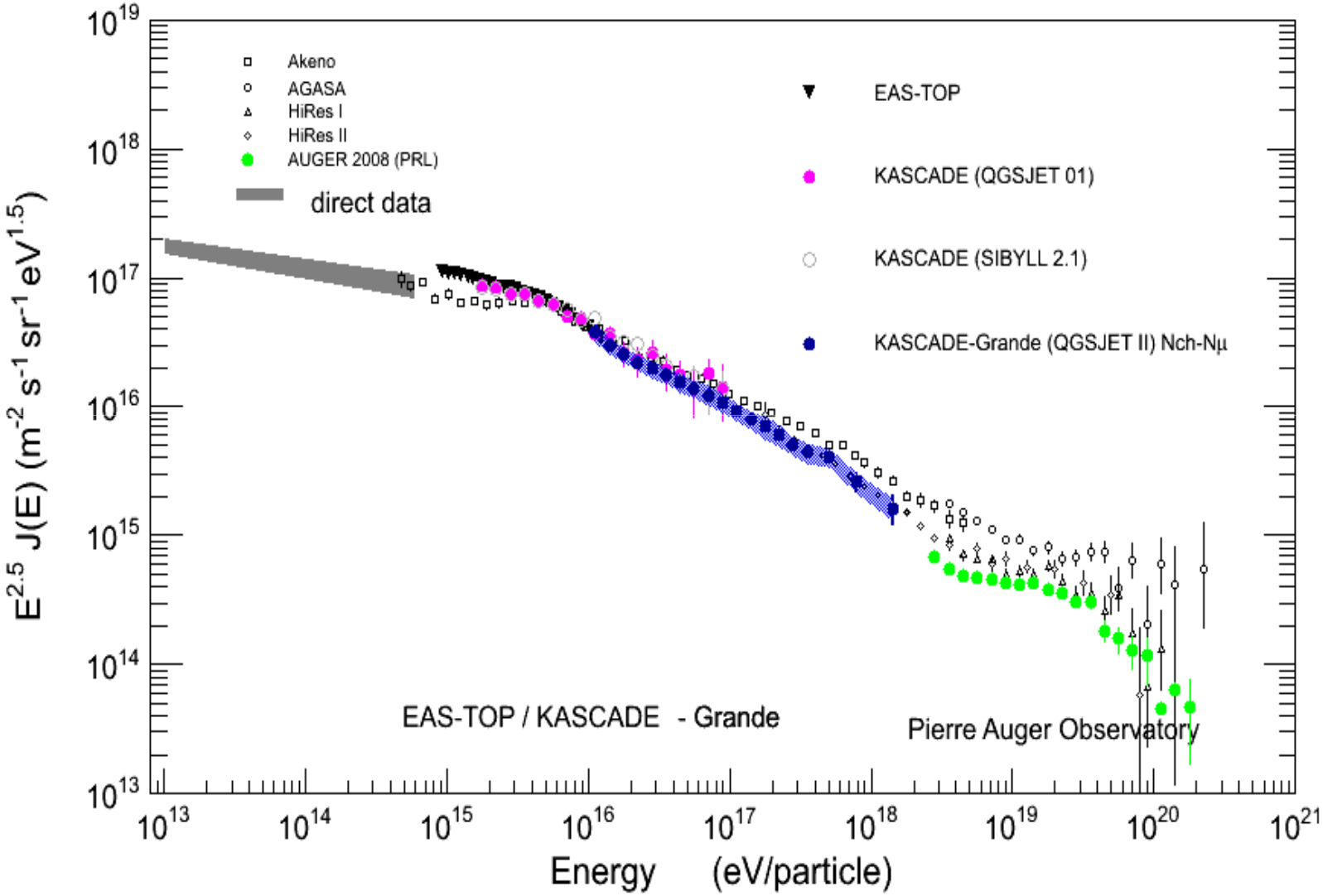
QGSJET II: Heavy composition preferred

All particle energy spectrum



QGSJET II: Spectrum is not described by a single power law

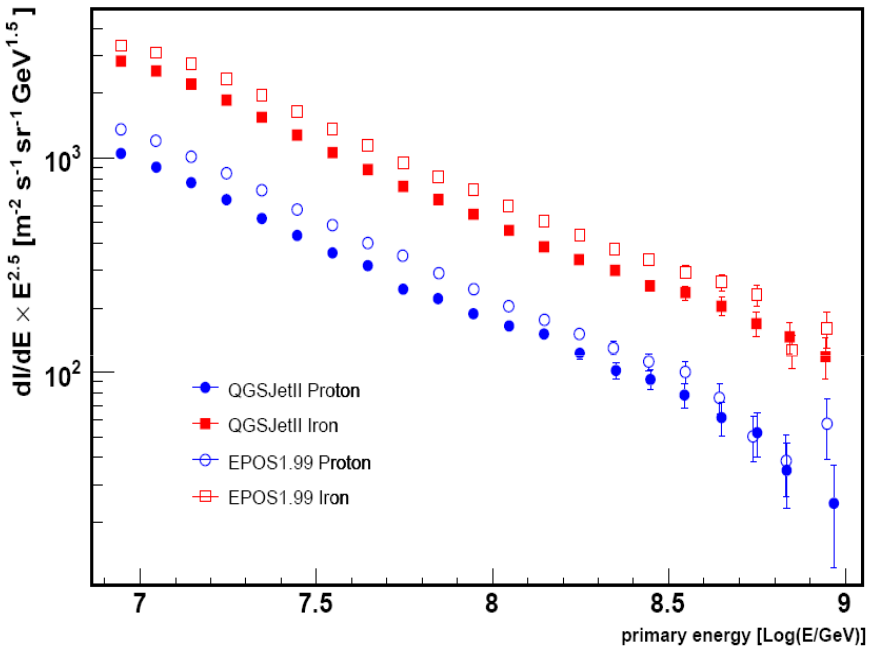
All particle energy spectrum



Good agreement with other experiments

Hadronic interaction models

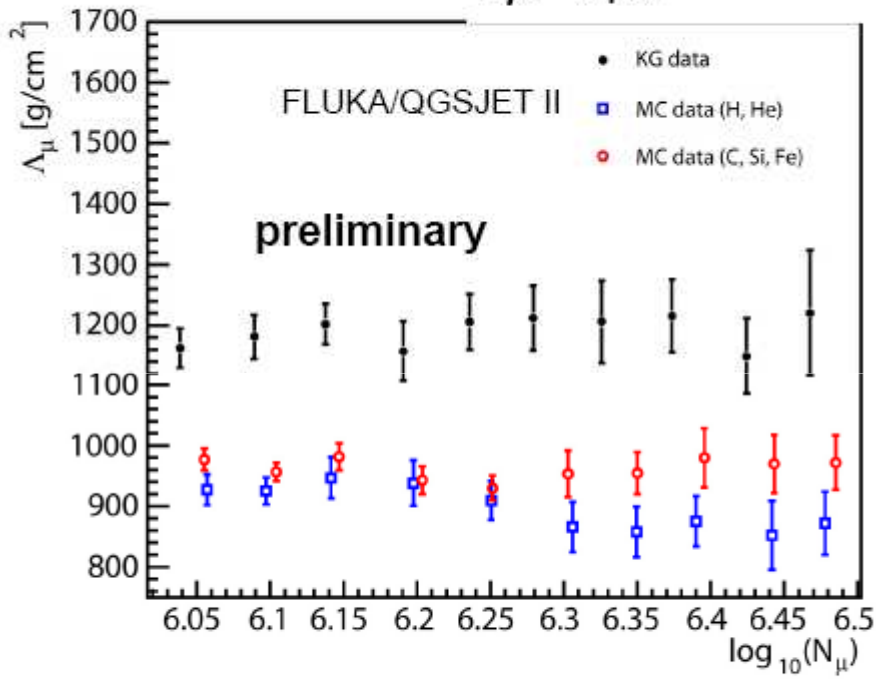
Influence on reconstruction of spectrum



D. Kang (ISVHECR 2010)

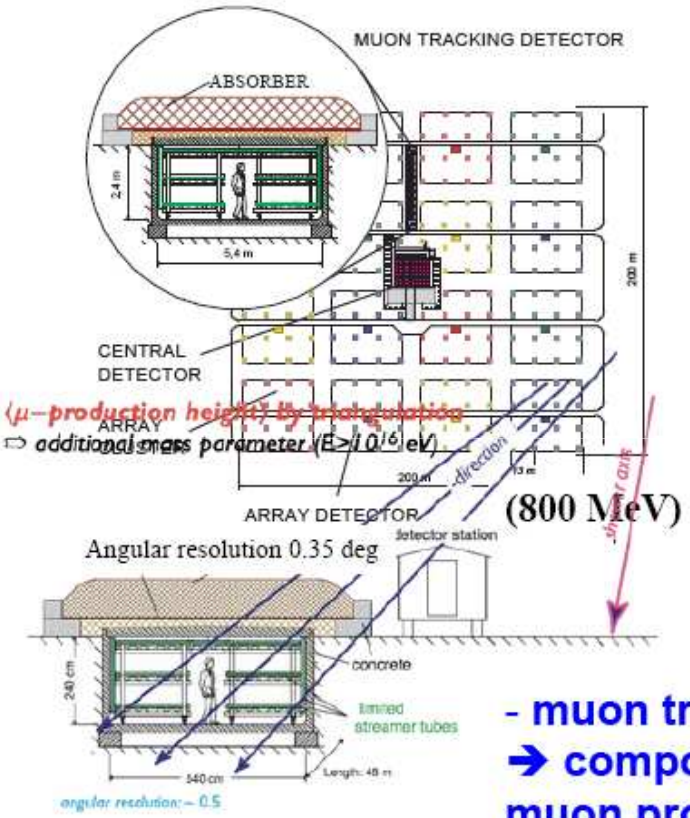
Muon shower size attenuation length

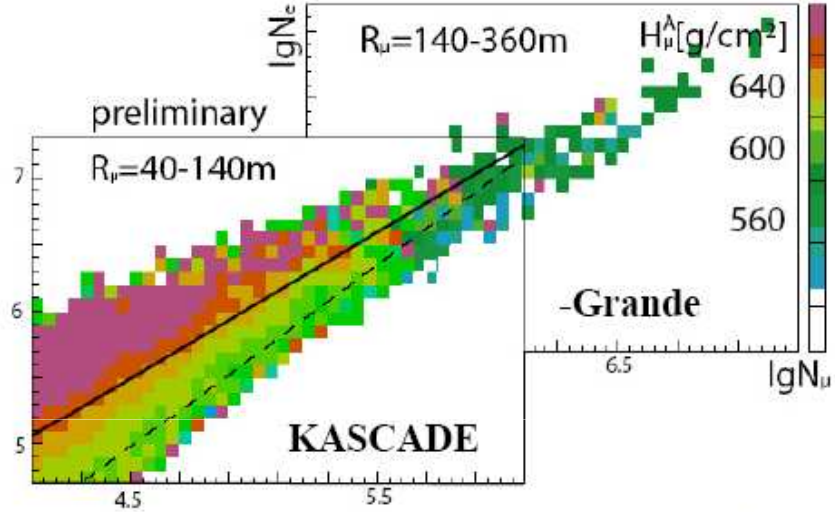
$$N'_\mu = N_\mu e^{-X_0 \mathrm{Sec}\theta/\Lambda_\mu}$$

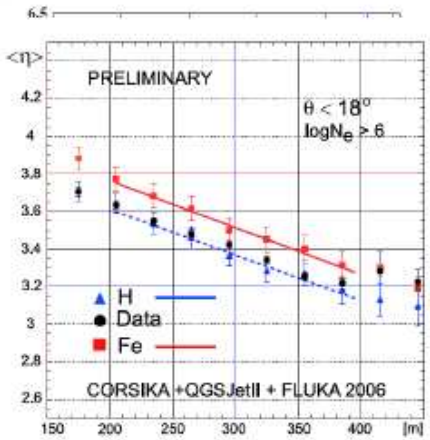


Difference between MC and KASCADE-Grande muon attenuation lengths

Muon tracking detector







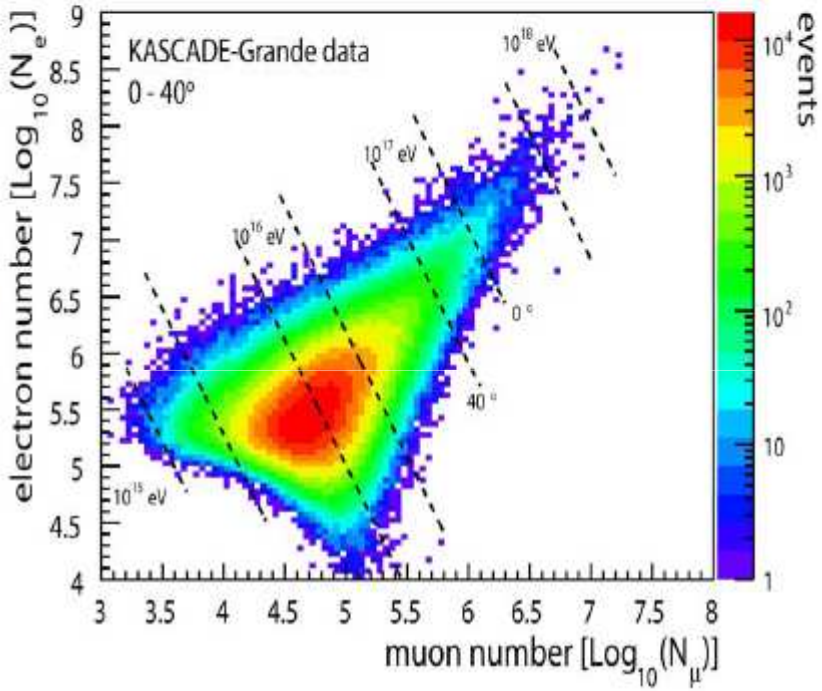
- muon tracking:
  - ➔ composition sensitivity
  - muon production height
  - ➔ model tests
  - pseudorapidity

See P. Doll´s talk

Paths to elemental composition

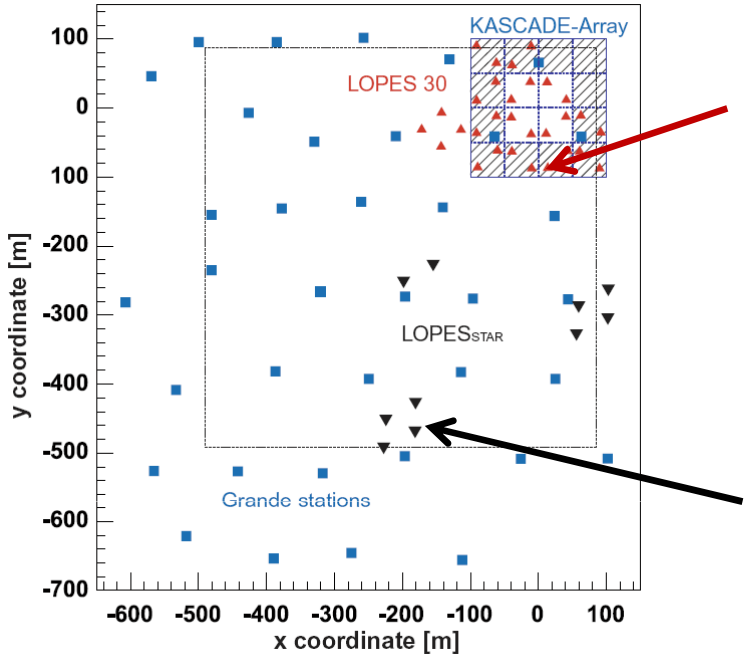
Application of different methods:

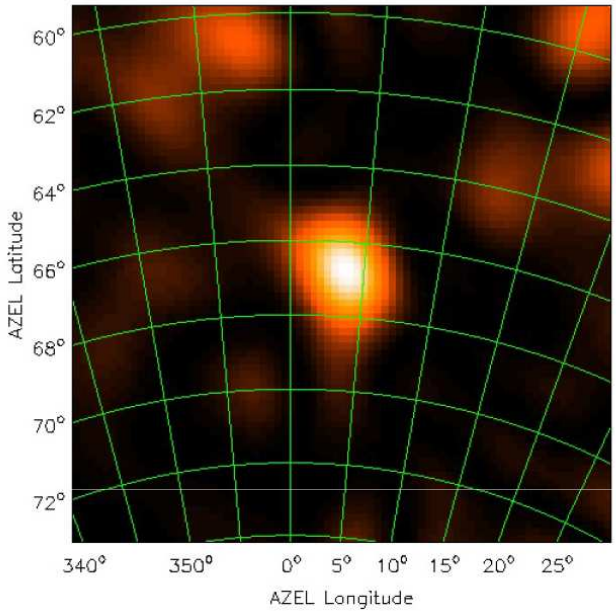
- Local muon densities
- High-energy muon investigations
- Parametric combination of N_{ch} , N_{μ}
- kNN method
- Fit of N_{μ}/N_e -ratios in fixed size/ energy bins
- Unfolding of the 2-dimensional shower size spectrum
  - ➔ energy & composition



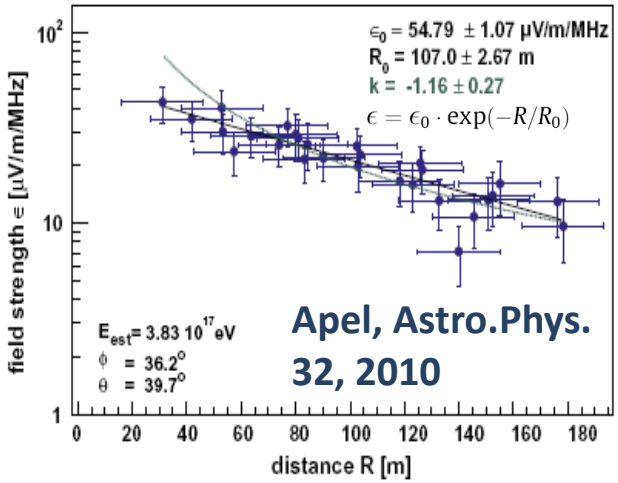
Work in progress!

Radio studies: LOPES

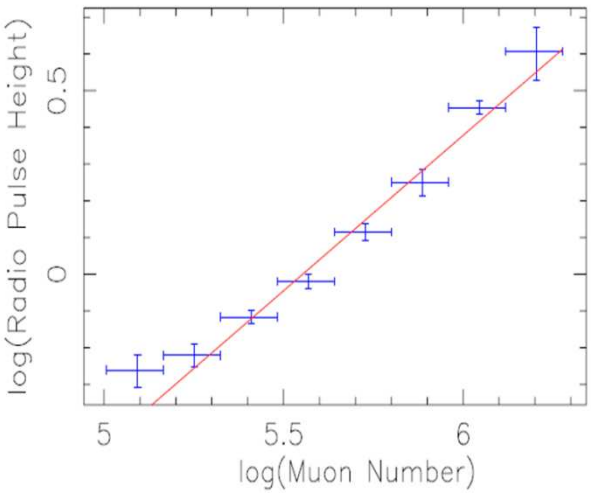


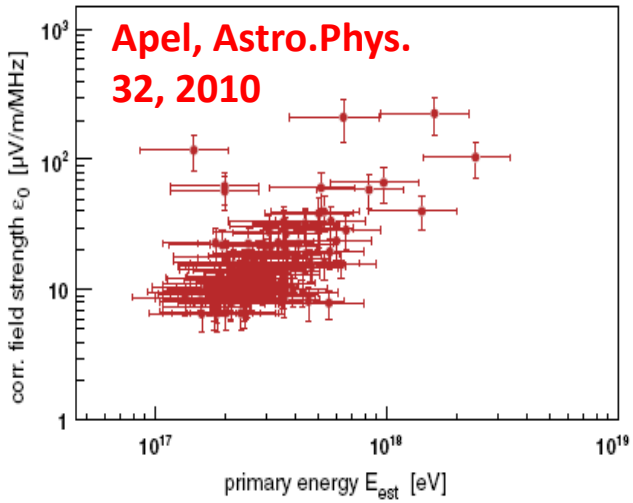


Nigl, A&A 487, 2008



Apel, Astro.Phys. 32, 2010





Apel, Astro.Phys. 32, 2010

Summary

KASCADE-Grande has collected a high quality data set at 10^{16} – 10^{18} eV which will be the basis to look for the "iron knee " and the galactic-extragalactic transition in the cosmic ray spectrum.

Recent results of KASCADE-Grande regarding the all-particle energy spectrum:

- ✓No single power law.
- ✓Concave spectrum around 10^{16} eV(Possible reason: see recent CREAM paper *ApJ* **714** L89, 2010).
- ✓ Possible structure at 10^{17} eV: may be iron-knee?
- ✓ Agreement between different reconstruction methods.
- ✓ Inside the framework of QGSJET II heavy composition is preferred.
- ✓ Agreement with other experiments.

Work in progress:

- ✓ Composition analysis with different approaches.
- ✓ Looking for the "iron knee".
- ✓ Search for a possible galactic-extragalactic transition below 10^{18} eV.
- ✓ Cross check hadronic interaction models

KASCADE-Grande Collaboration

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