Università degli studi di Torino

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The all-particle energy spectrum measured by KASCADE-Grande in the energy range 10^{16} - 10^{18} eV using the EPOS hadronic interaction model

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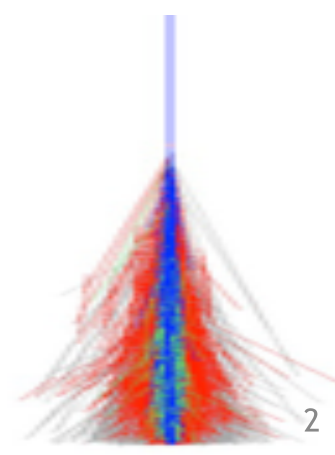
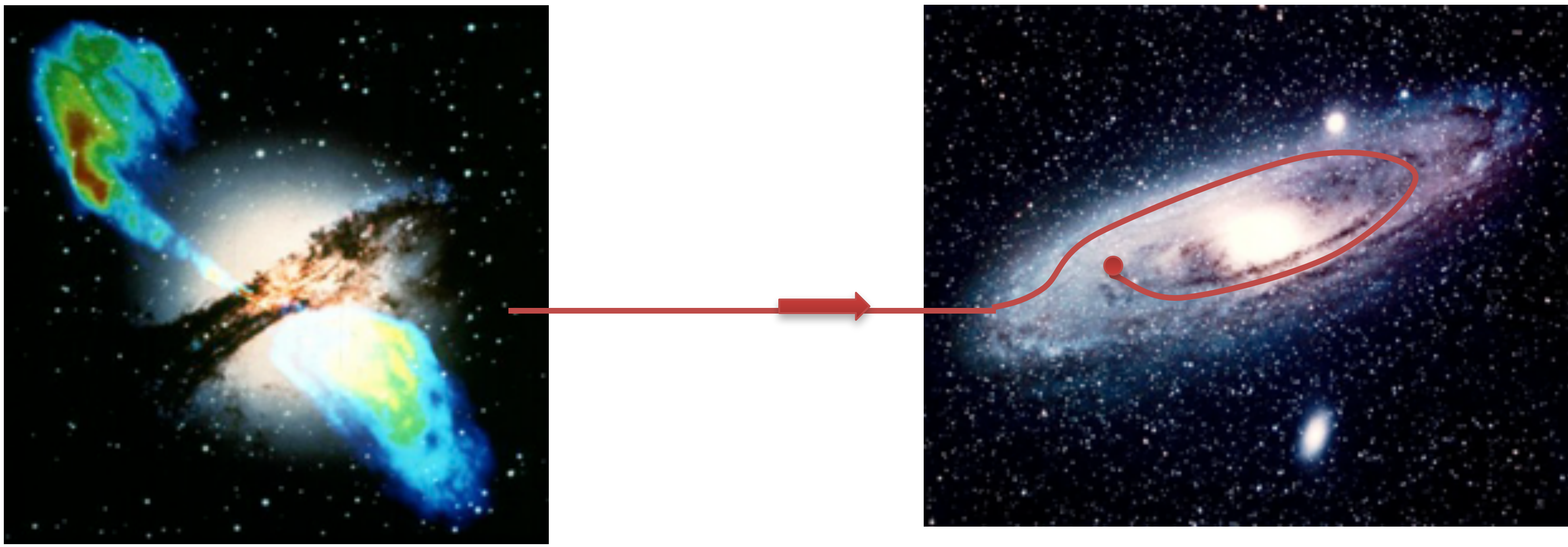
Cosmic rays origin

Source:
supernovae
explosions

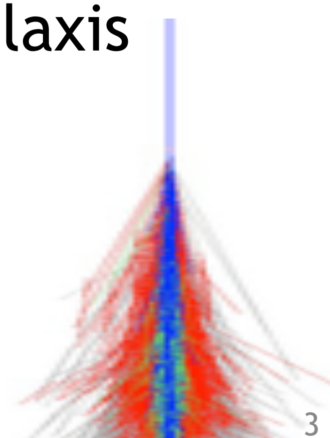


Cosmic rays origin

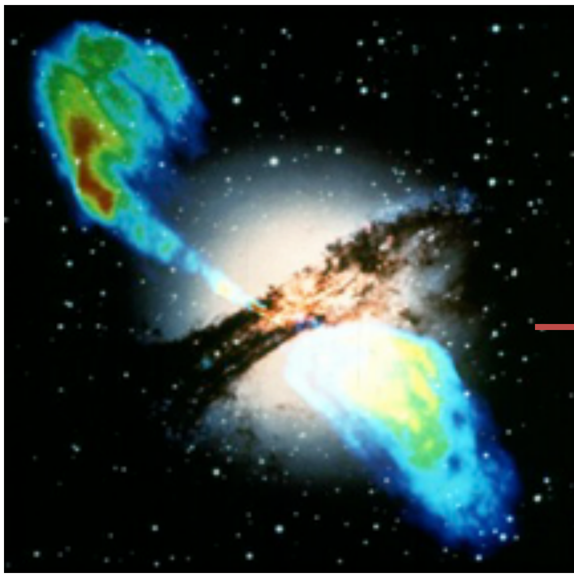


Source:
supernovae explosions

‘Accelerator’: galaxis



Cosmic rays origin



Source:
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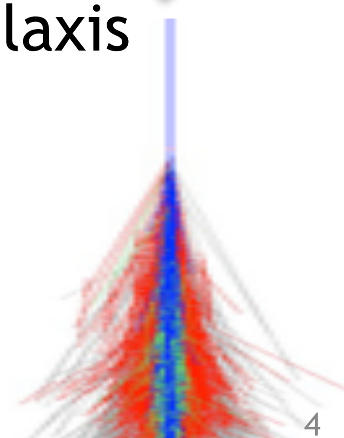


Air Shower

Cosmic rays: general aspects

Atomic nuclei H, …, Fe

Flux $\propto E^{-\gamma}$

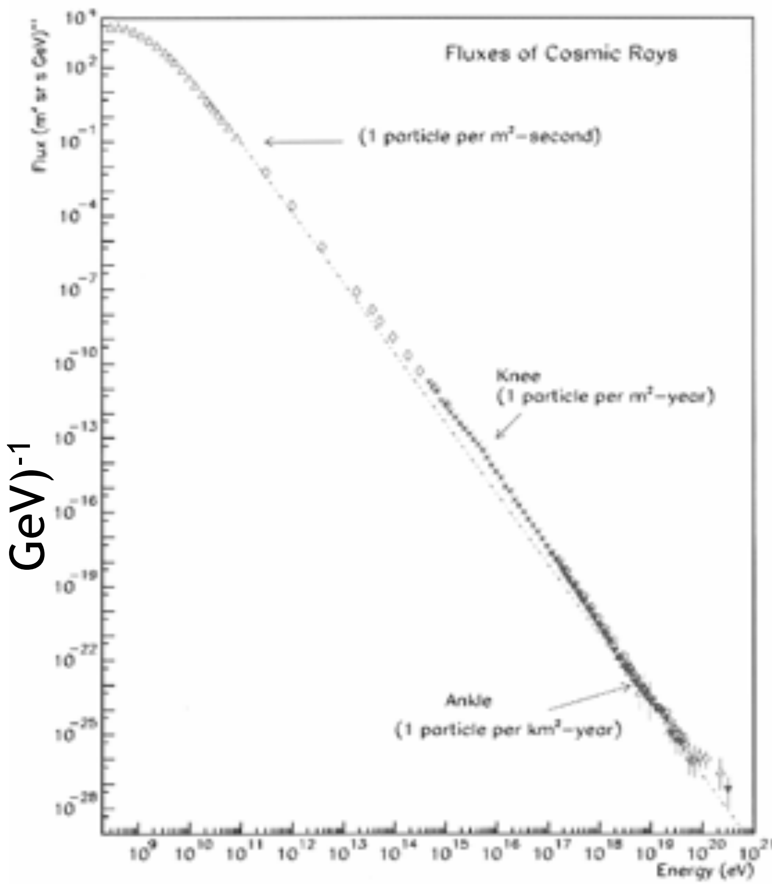
'Knee' : spectral index γ changes

from 2.7 to 3.1 at energies

at a few 10^{15} eV

KASCADE-Grande: energy range

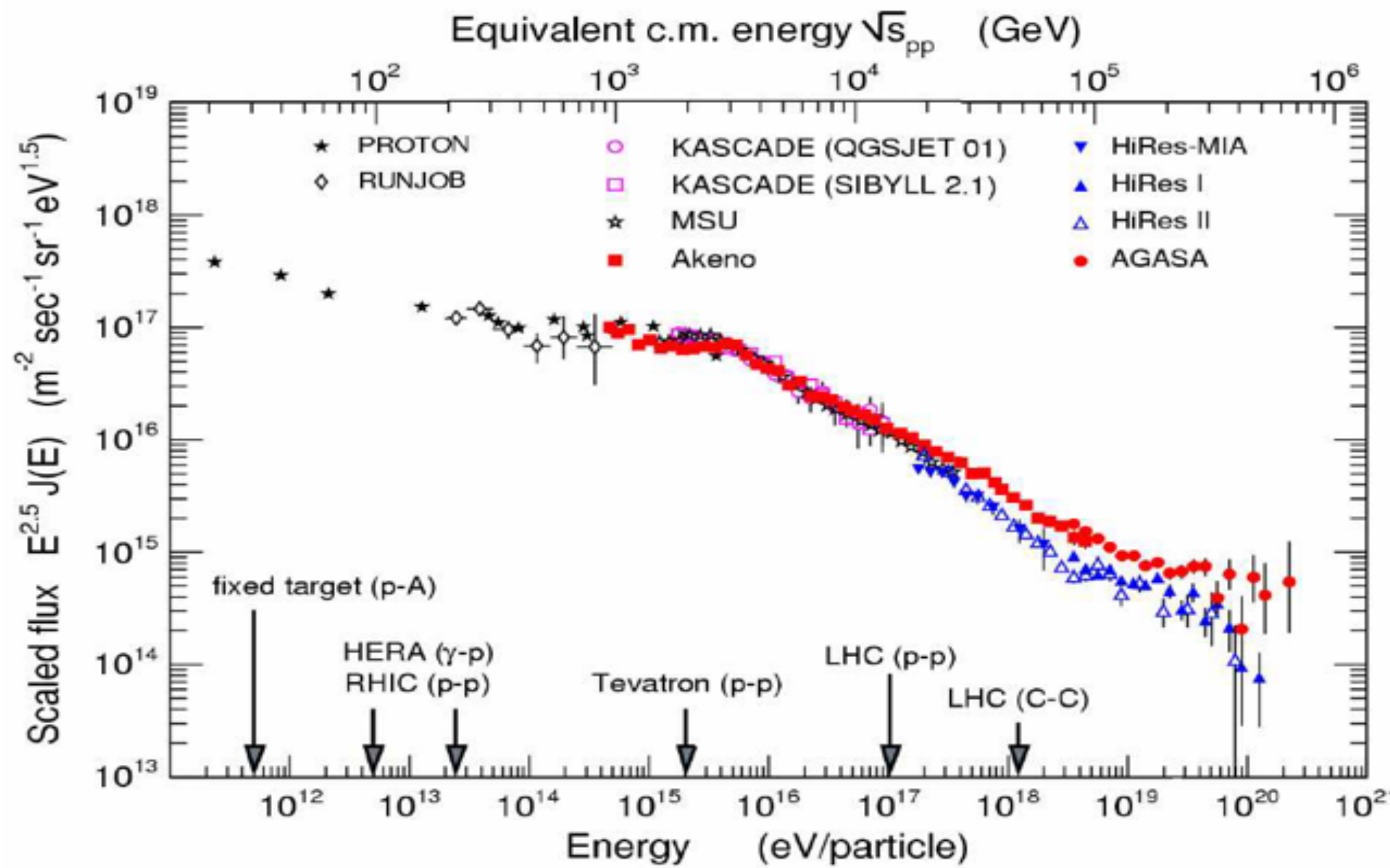
10^{16} - 10^{18} eV



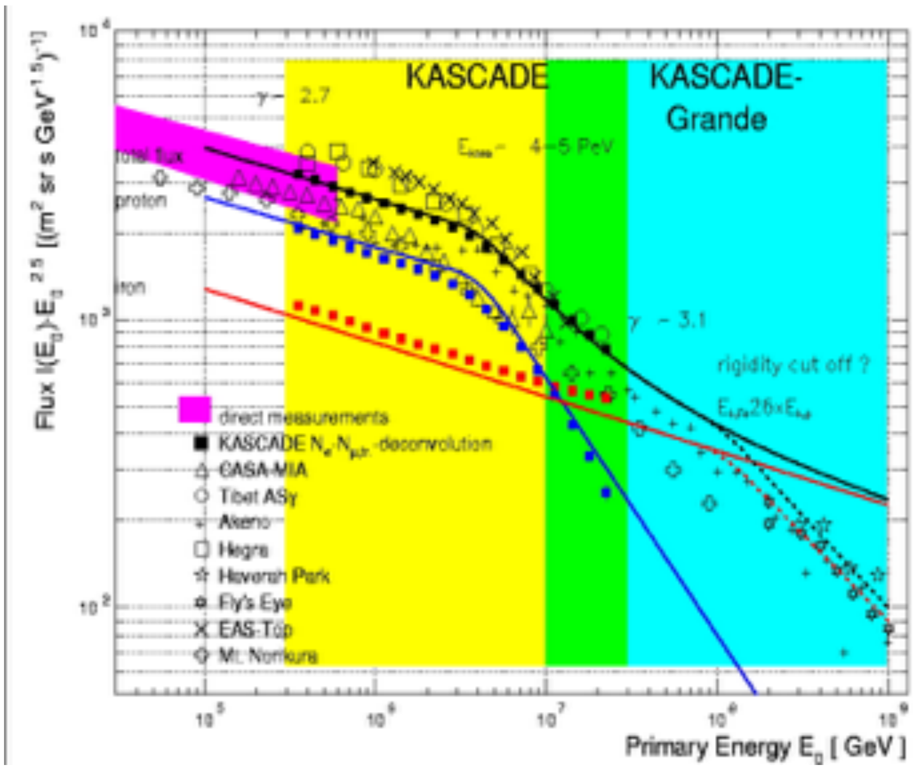
Flux $(m^2\ sr\ s\ GeV)^{-1}$

Energy(eV)

All-particle spectrum measured by different experiments



Cosmic rays: the knee



- The experiments KASCADE and EAS-TOP observe a knee generated by the ‚light‘ component of the cosmic rays at 3-4 · 10^{15} eV
- In the energy range of KASCADE-Grande a knee of the ‘heavy’ component is expected

$$R = \frac{E}{Ze}$$

$$E_{knee}^{H} = R_{\mathrm{limit}} Ze \approx 3 - 4 \cdot 10^{15}\, eV$$

$$E_{knee}^{Fe} = 26 \cdot R_{\mathrm{limit}} = 26 \cdot E_{knee}^{H} \approx 7 - 10 \cdot 10^{16}\, eV$$

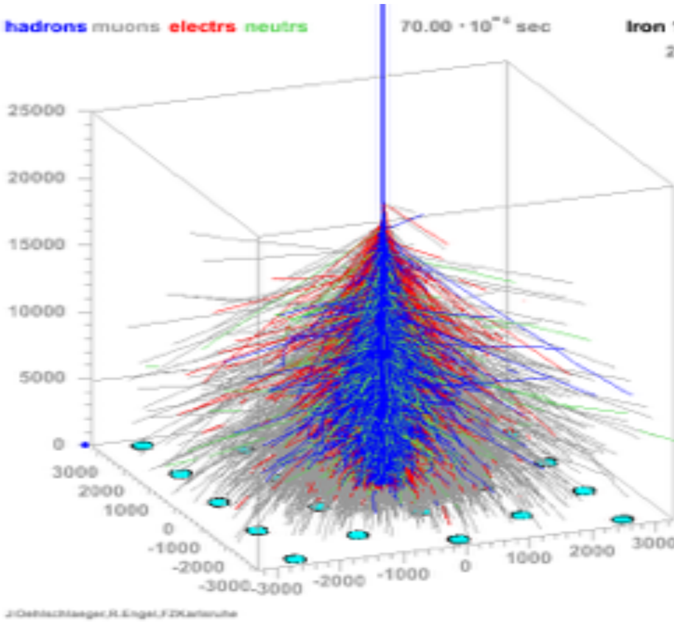
Interaction between primary and atmosphere: Extensive Air Shower

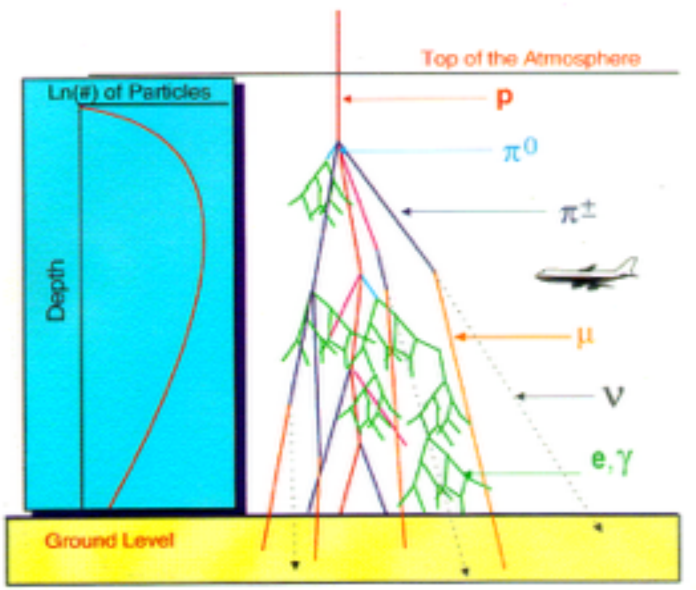
Possible measurements of EAS:

Lateral distribution

Arrival time

Number of detected particles: N_{ch}, N_{μ}, N_e





Extensive Air Showers

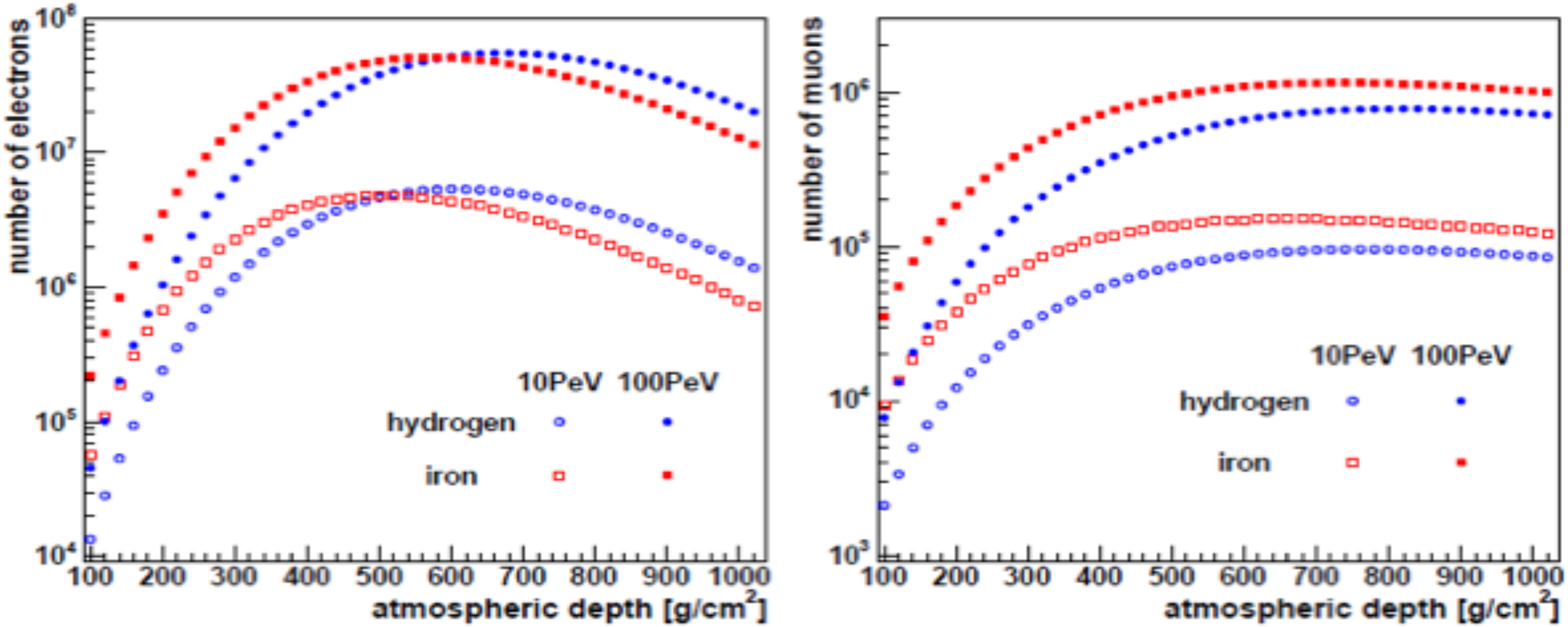
With these parameters it is possibly to reconstruct:

arrival direction of the primary

Energy

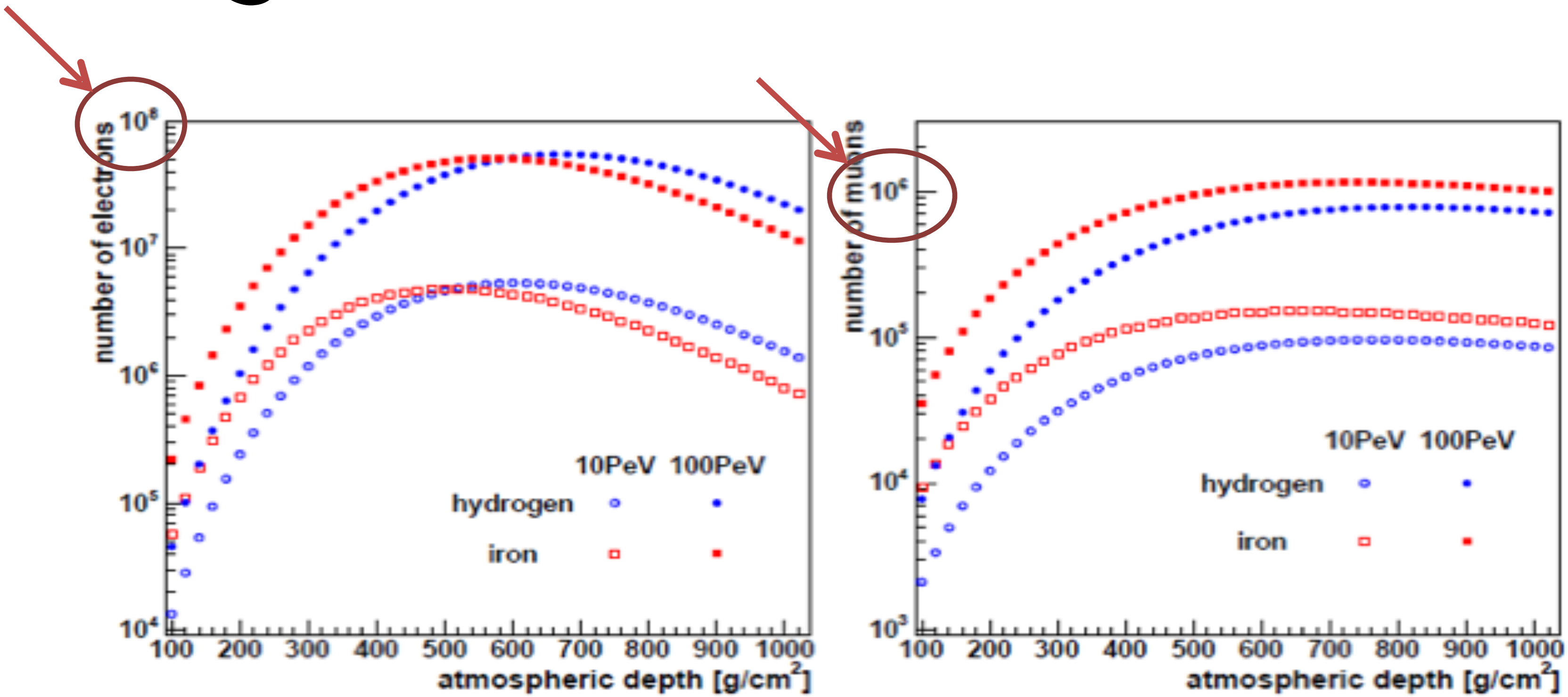
Chemical composition

Longitudinal distribution of EAS



Hydrogen primaries produce more e- and less muons at ground level

Longitudinal distribution of EAS

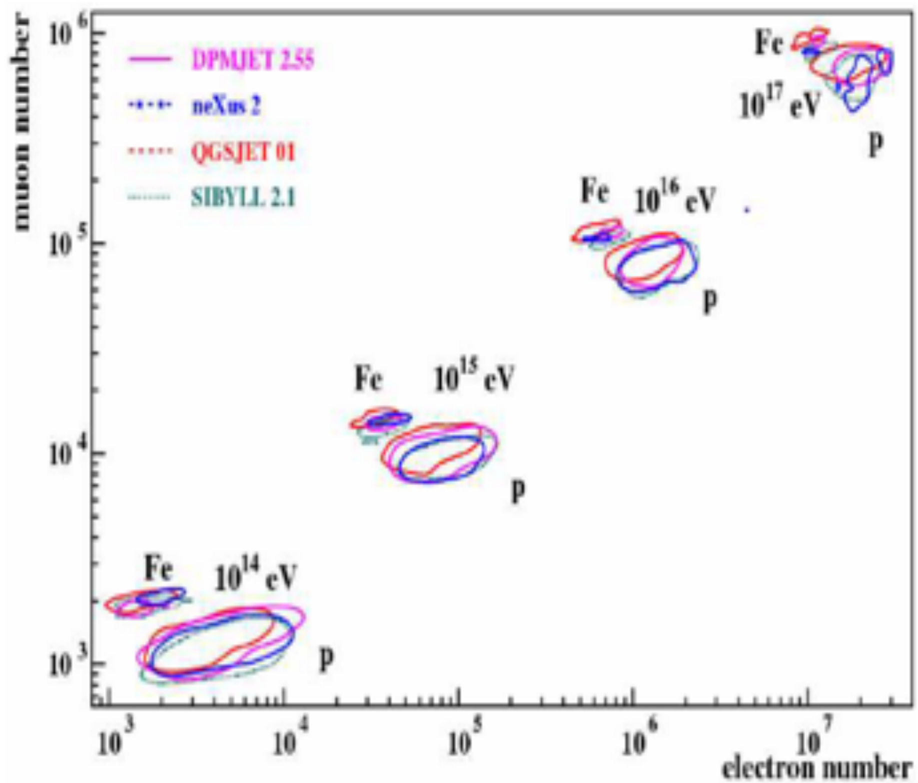


Hydrogen primaries produce more e- and less muons at ground level

$N_{ch} = N_e + N_\mu \approx N_e$

Simulation of 2-dim spectrum

- Fe and protons have a different $N_{ch}(N_e)$and N_μ sizes
- Protons produce more e- and Fe more muons
- All other primaries have a N_{ch} (N_e) and N_μ sizes between the 2 circles



Experiment **KA**rlsruhe **S**hower **C**ore and **A**rray **DE**tector - Grande

KASCADE:

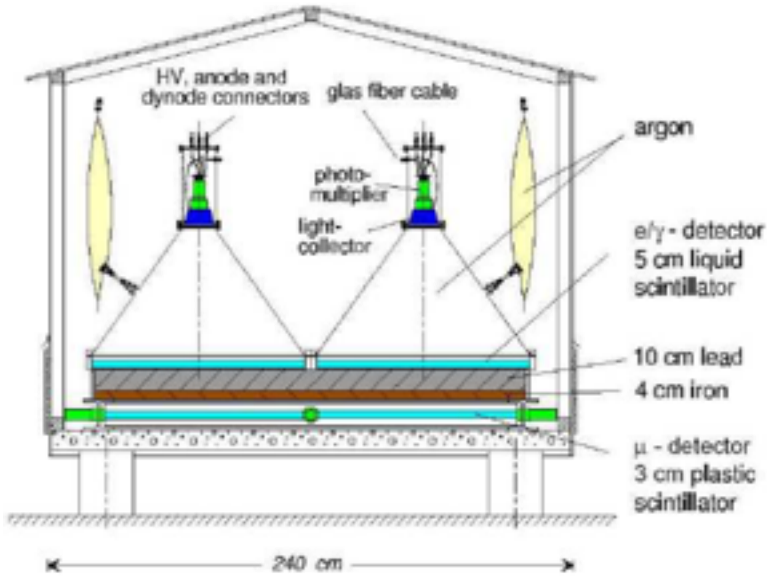
array of 252 detector over 200x200m^2

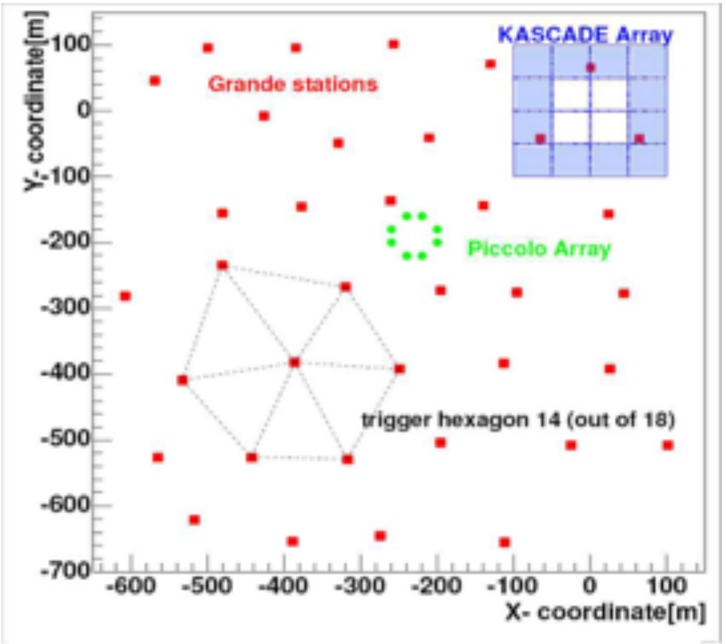
Detected particles: μ,e

Grande:

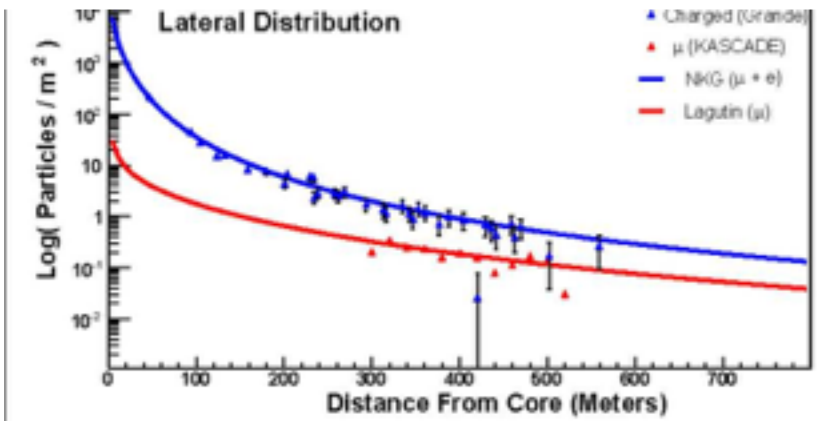
Array of 37 detectors over 700x700m^2

Detected particles:μ+e (charged particles)





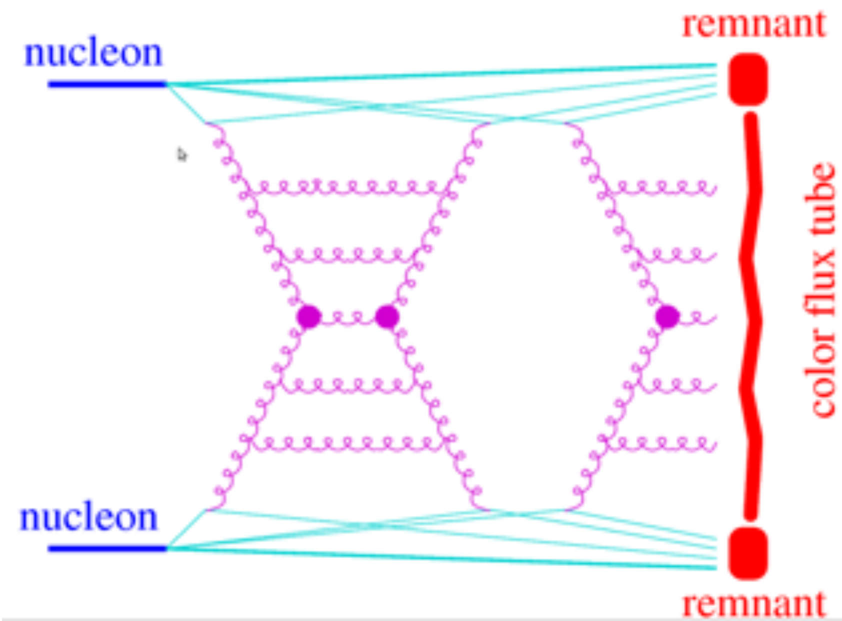
Lateral distribution of Nch and Nμ



$$\rho_\mu(r) = N_\mu \cdot f_\mu(r) = N_\mu \cdot \frac{0.28}{r_0^2}\left(\frac{r}{r_0}\right)^{p_1}\left(1+\frac{r}{r_0}\right)^{p_2}\left(1+\left(\frac{r}{10\cdot r_0}\right)^2\right)^{p_3}$$

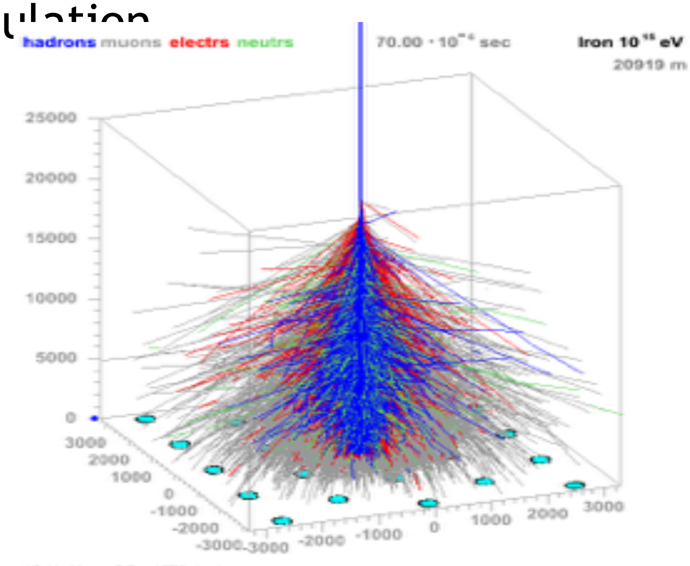
$$\rho_{ch}(r) = N_{ch} \cdot f_{ch}(r) = N_{ch} \cdot C(s)\left(\frac{r}{r_0}\right)^{s-\alpha}\left(1+\frac{r}{r_0}\right)^{s-\beta}$$

The hadronic interaction model EPOS



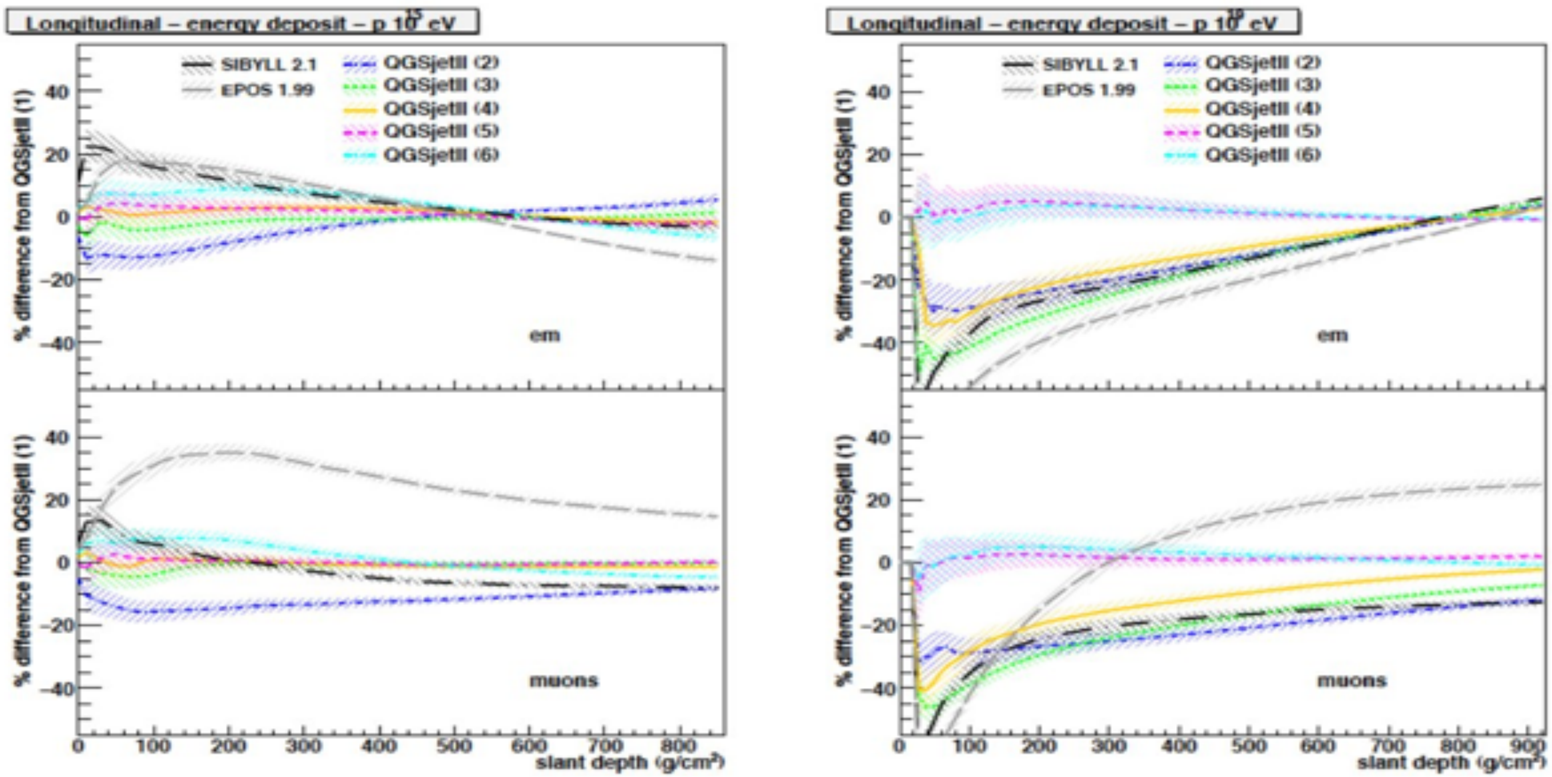
EPOS is a parton model, with many binary parton-parton interactions, each one creating a parton ladder.

Air shower simulation



T. Pierog and K. Werner, Nucl. Phys. B (Proc. Suppl.) 196(2009)

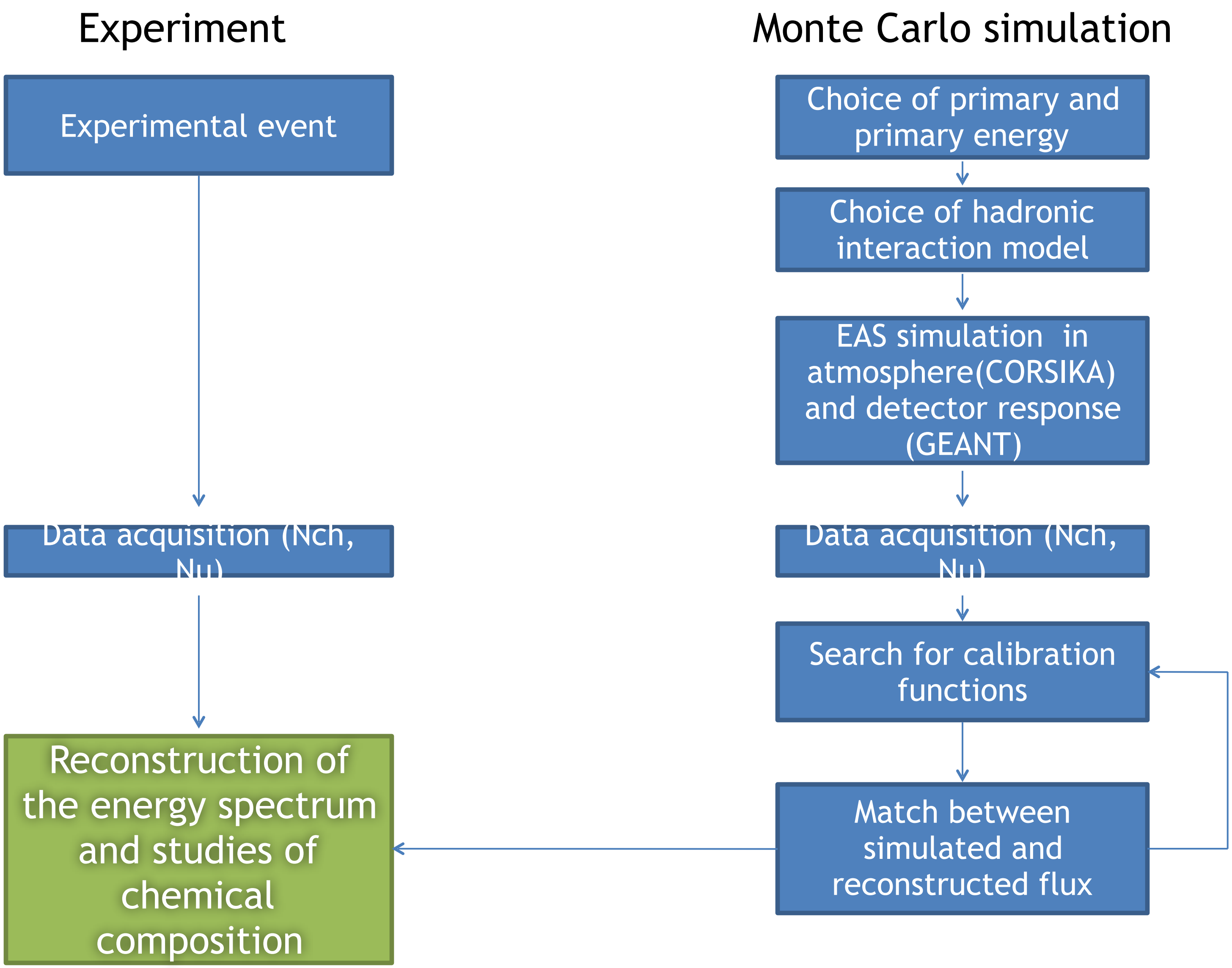
Comparison of the interaction models



Johannes Knapp, Ooty, 2010

Longitudinal distibutions for 2 different energies

EAS studies: montecarlo simulation guide for the experimental data



Reconstruction of the simulated and experimental data using EPOS

EPOS simulation: searching for the calibration functions for H and Fe

Data divided in 5 angular bins → 5 calibration functions

Bin 1: $0<\theta<16.7^\circ$

Bin 2: $16.7^\circ<\theta<24.0^\circ$

Bin 3: $24.0^\circ<\theta<29.9^\circ$

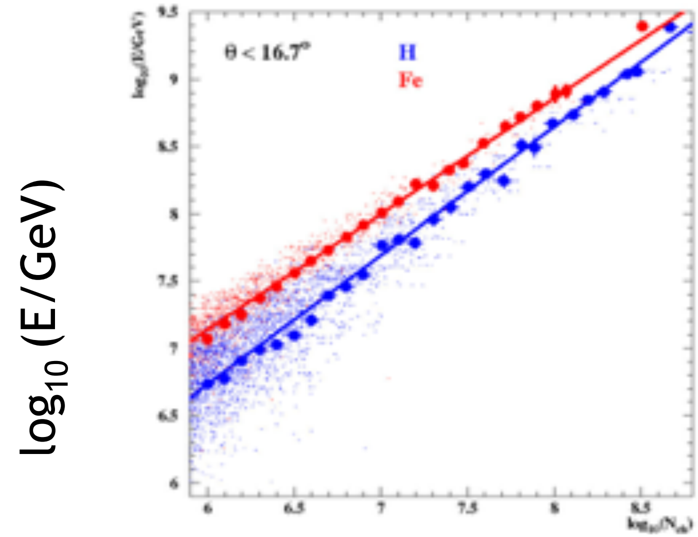
Bin 4: $29.9^\circ<\theta<35.1^\circ$

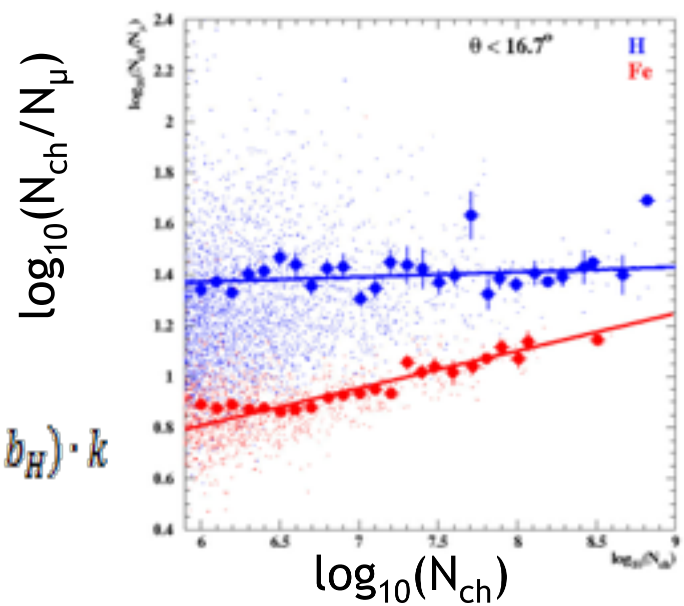
Bin 5: $35.1^\circ<\theta<40.0^\circ$

$$\log_{10}(N_{ch}/N_{\mu})_{p,Fe} = c_{p,Fe}\cdot\log_{10}(N_{ch}) + d_{p,Fe}$$

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

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





Simu

EPOS simulation: searching for the calibration functions for H and Fe

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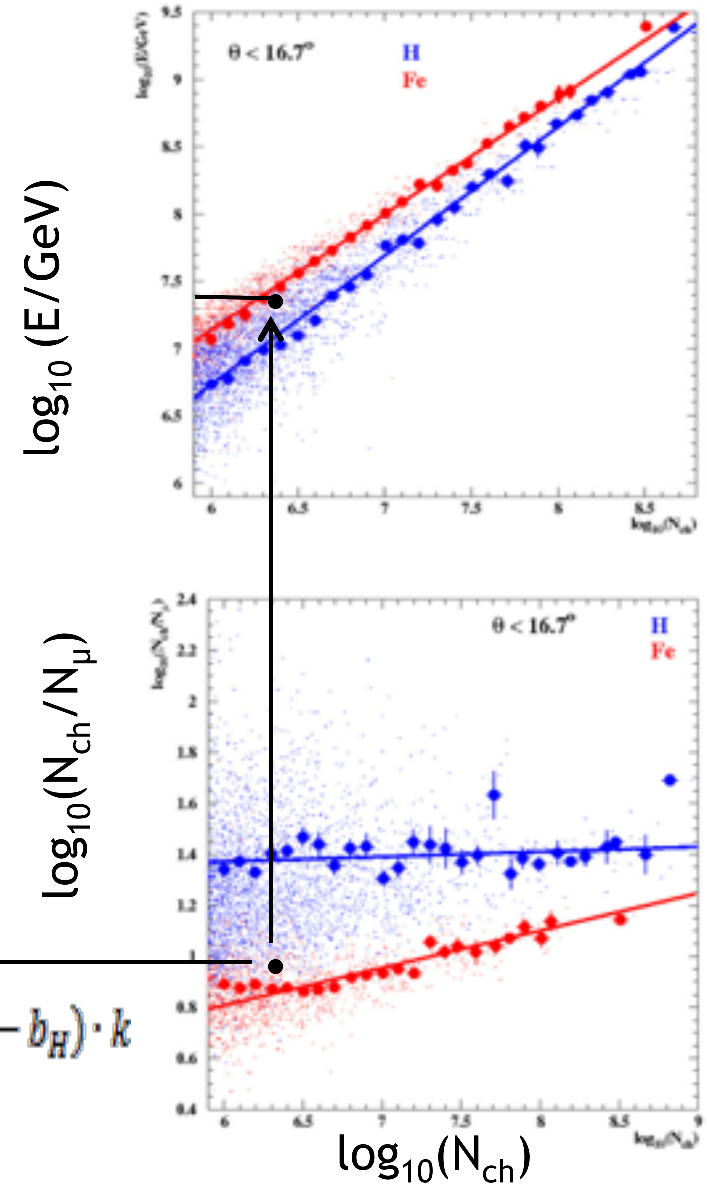
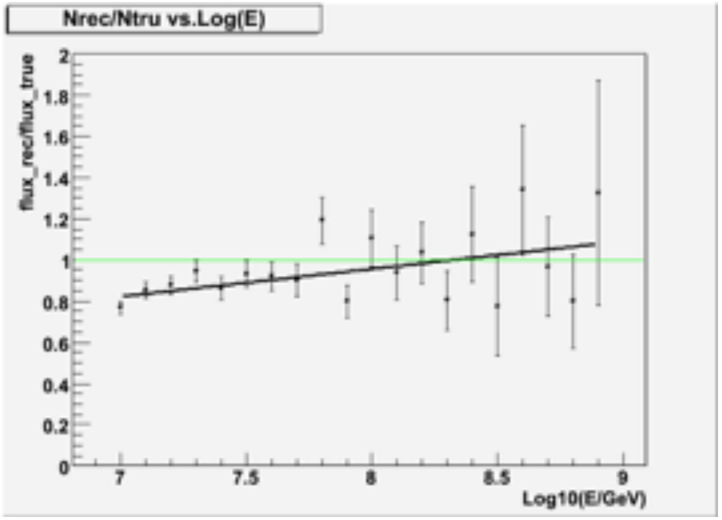
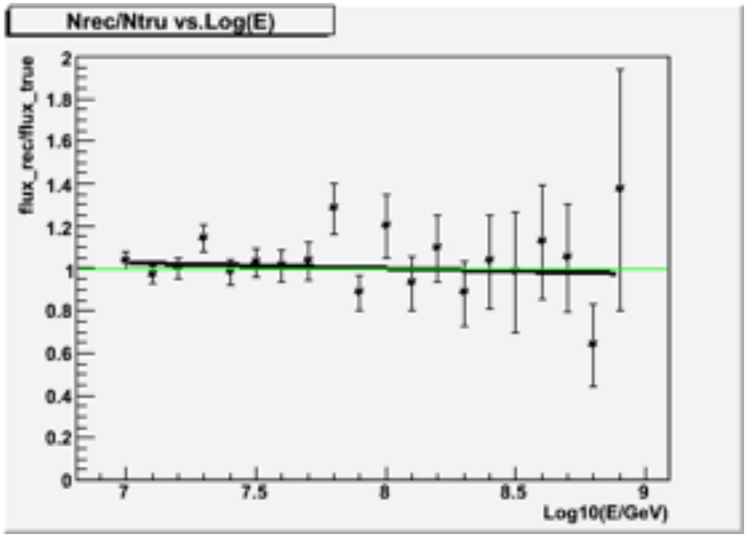
$$\log_{10}(E[GeV]) = [a_H + (a_{Fe} - a_H) \cdot k] \cdot \log_{10}(N_{ch}) + b_H + (b_{Fe} - b_H) \cdot k$$

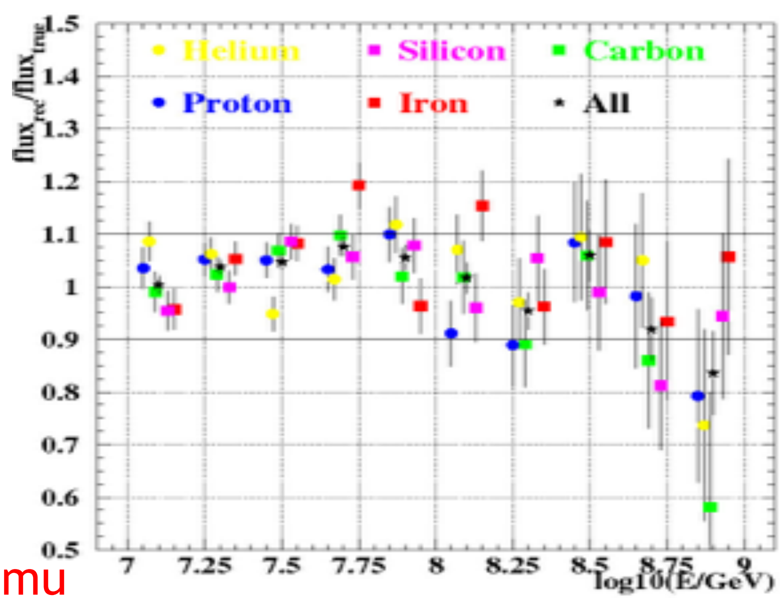


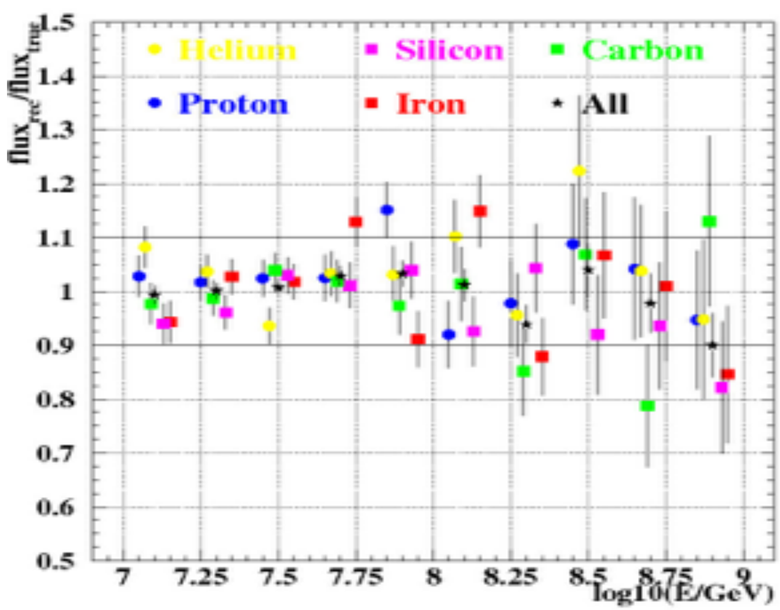
Simu

EPOS simulation: selection for the calibration functions









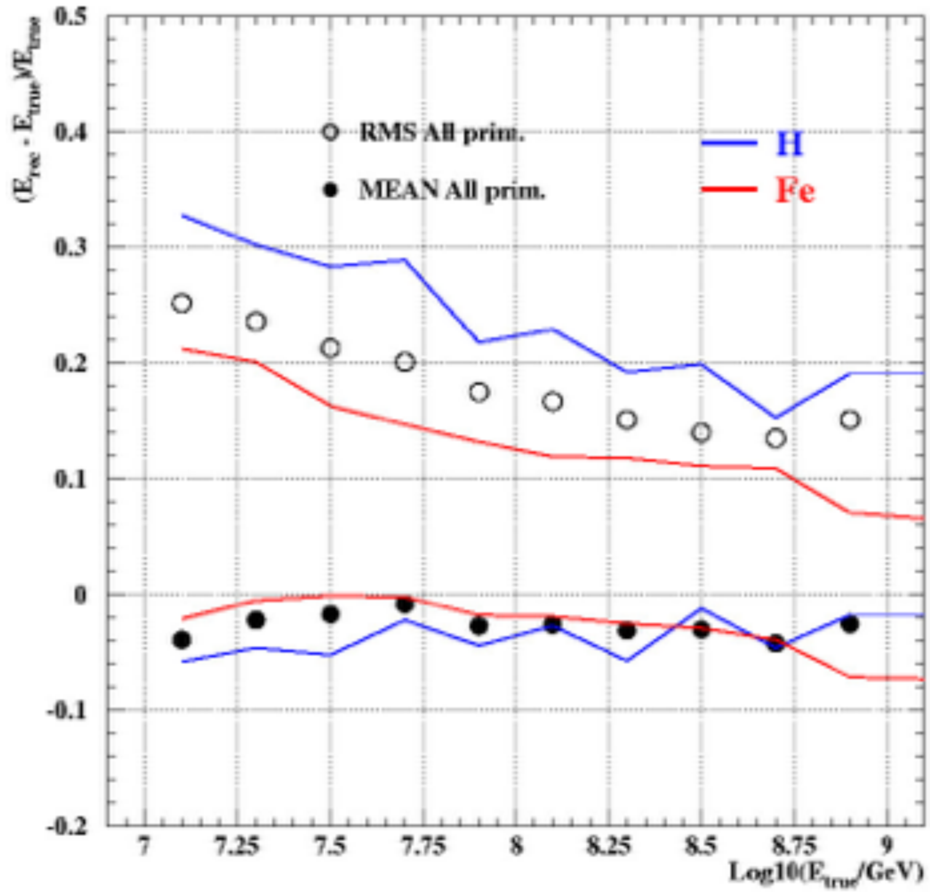
Simu

Difference of the energy event-by-event

Mean and root mean square for all primaries, H and Fe

H fluctuates more than Fe

Slight offset to compensate the slope in the power law



E_{rec}-E_{true}/E_{true}

$\log_{10}$(E/GeV)

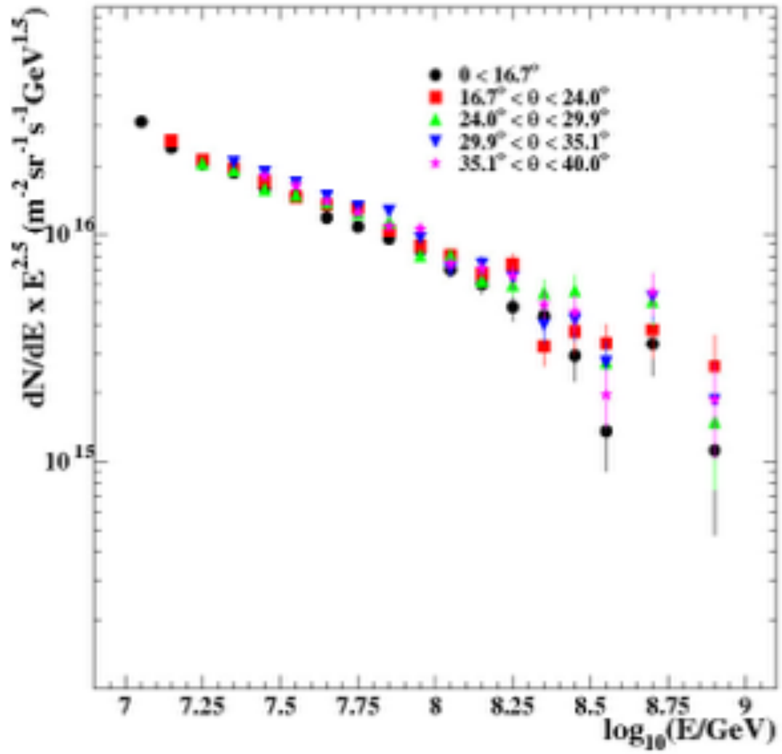
Simu

Reconstruction of the all-particle spectrum using the calibration for EPOS

Differential reconstructed flux multiplied by $E^{2.5}$
and divided in angular bins to see finer structures

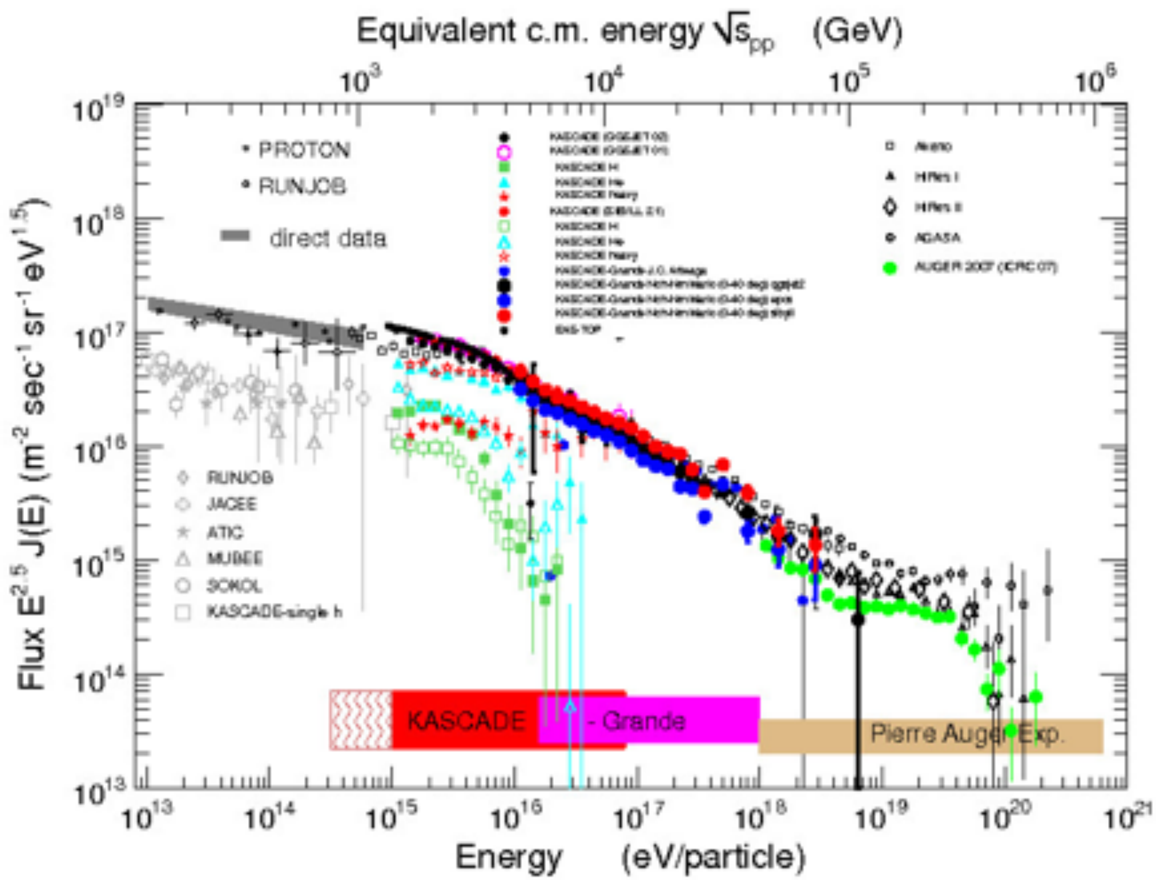
The same behavior for all bins,
bigger angles have higher flux

More elevated energies: more fluctuations because of less statistics



Exp data

Updated all-particle spectrum analysed by different hadronic interaction models



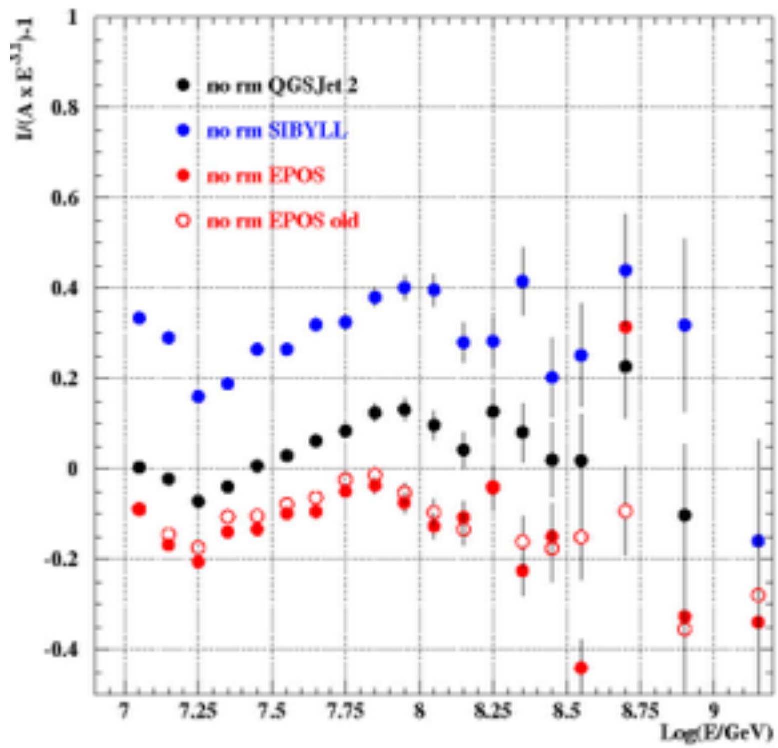
Exp data

Comparison of the different interaction models

View at the interesting energy range 10^{16} -10^{18} eV

Choice of calibration parameters is insignificant in comparison of choice of interaction model

Structures in all 3 models
→structures present in data, not a reason of the interaction model



Exp data

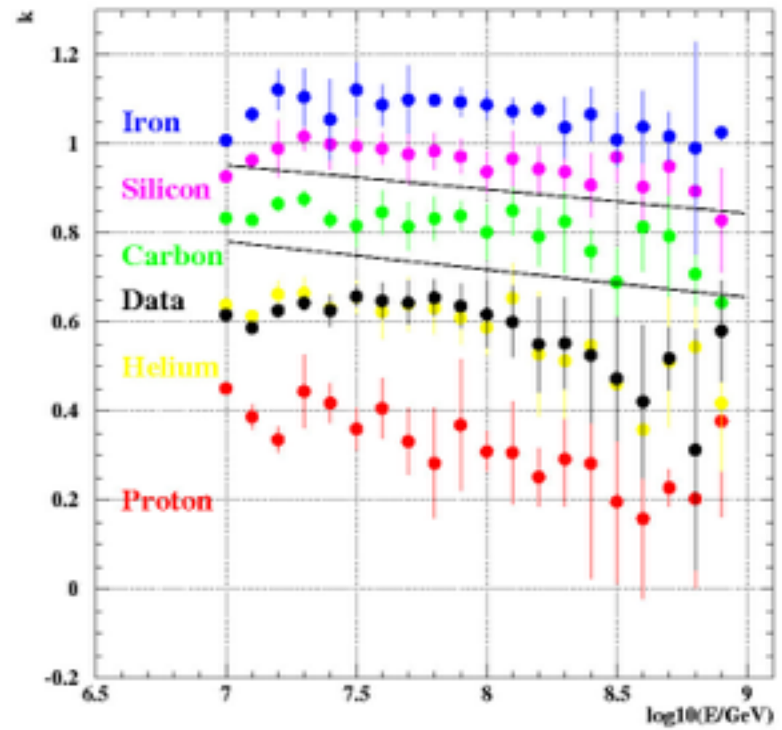
Chemical composition analysis using parameter k

Evolution of k for every primary

Black lines to divide primaries in
mass groups as an event-by-event
reconstruction is not possible

Data tends to overlap Helium

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



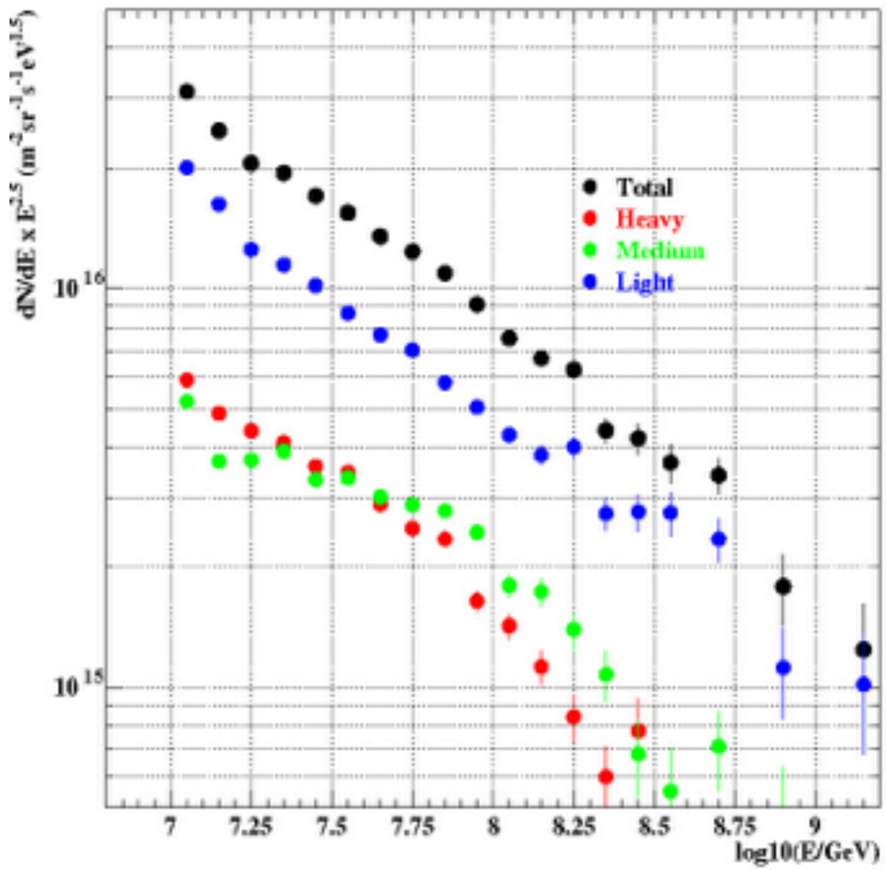
Exp data

Spectrum reconstruction of light, medium and heavy component with EPOS

Flux divided in mass groups

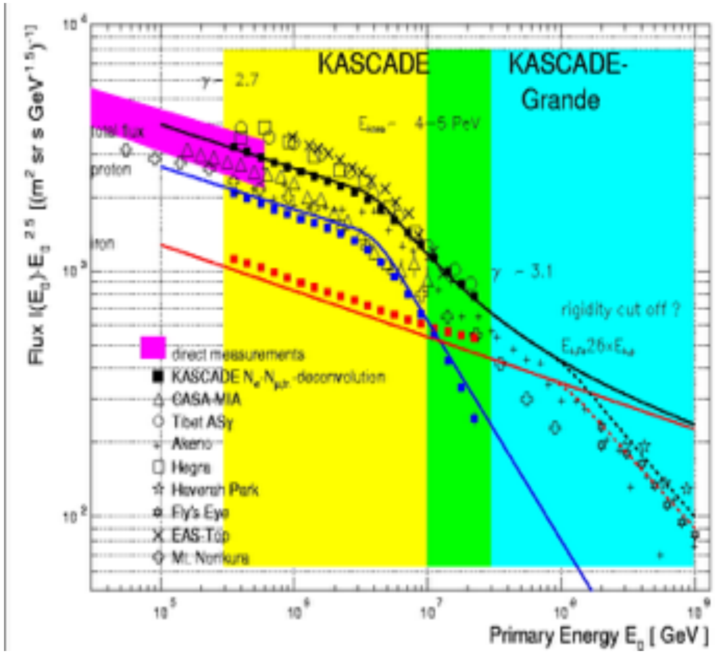
Knee for the heavy and medium component evident

The light component has no changing of spectral index

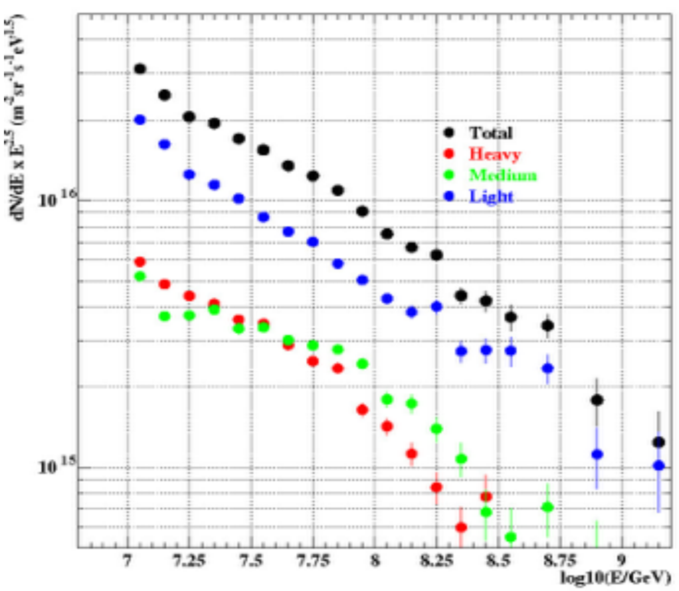


Exp data

The rigidity model



$$E^{H}_{knee} = R_{\lim it} Ze \approx 3 - 4 \cdot 10^{15}\, eV$$



Rigidity model foresees bend down at 7-10·10[16] eV

$$E^{Fe}_{knee} = 26 \cdot R_{\lim it} = 26 \cdot E^{H}_{knee} \approx 7 - 10 \cdot 10^{16} eV$$

Conclusions

- Complete analysis of KASCADE-Grande data using hadronic interaction model EPOS
- Good accordance with experiments at lower and higher energy
- Differences using different interaction models: EPOS gives a lower flux than QGSJet II and SIBYLL, but observed structures are similar
  →origin has to be physical
- Differences between simulations with different calibration functions are small compared to different interaction models
- Observation of the heavier component knee at circa 10^{17} eV using the parameter k, no knee for light component
- Results support rigidity model