Sensitivity of KASCADE-Grande Data to Hadronic Interaction Models

Interpretation of KASCADE-Grande Data using MC

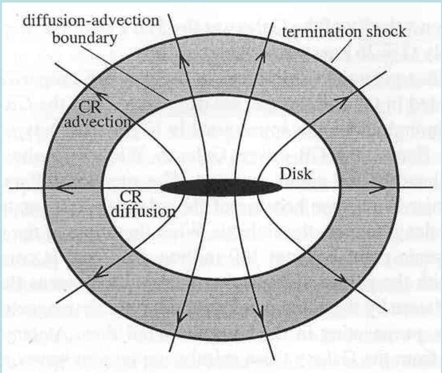
Energy spectrum with QGSJET, SIBYLL, EPOS

Karlsruhe Institute of Technology

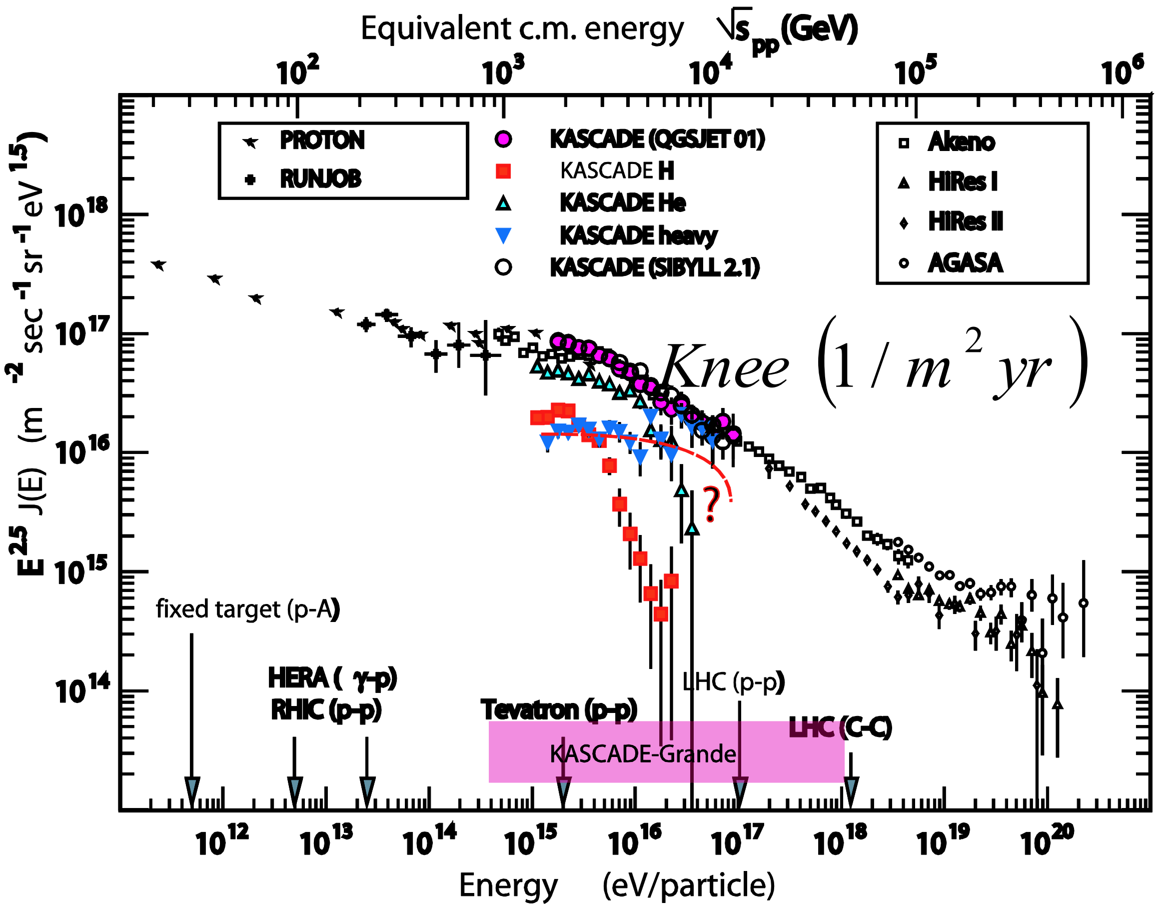
(Doll for KASCADE-Grande)

Study of Cosmic Rays

Cosmic Radiation opens a window to the hight energy processes in the Cosmos. We obtain information from electromagnetic and particle radiation.



H.J.Völk,V.N.Zirakashvili A&A 417(2004)807



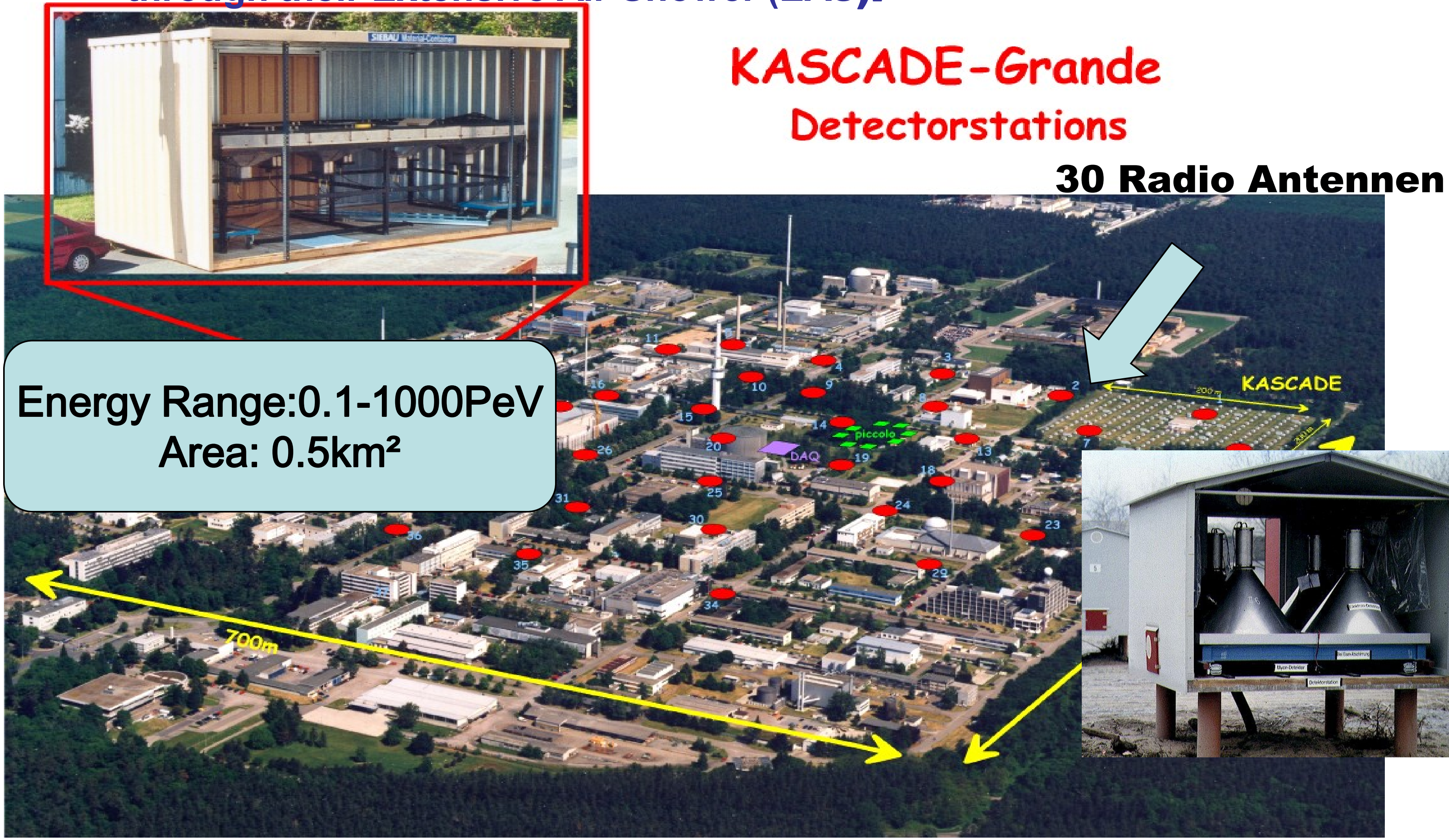
1. Acceleration
2. Propagation
3. Fragmentation in EAS

Berezinsky et al., Nucl.Phys.B(Proc.Suppl.)151(2006)497
Wibig et al., J.Phys.G 31(2005)255
de Rujula et al., Nucl.Phys.B (Proc.Suppl.)151(2006)23

KASCADE-Grande Collaboration

Air Shower Experiment KASCADE-Grande

At high energies the particles of the cosmic radiation are detected through their Extensive Air Shower (EAS).



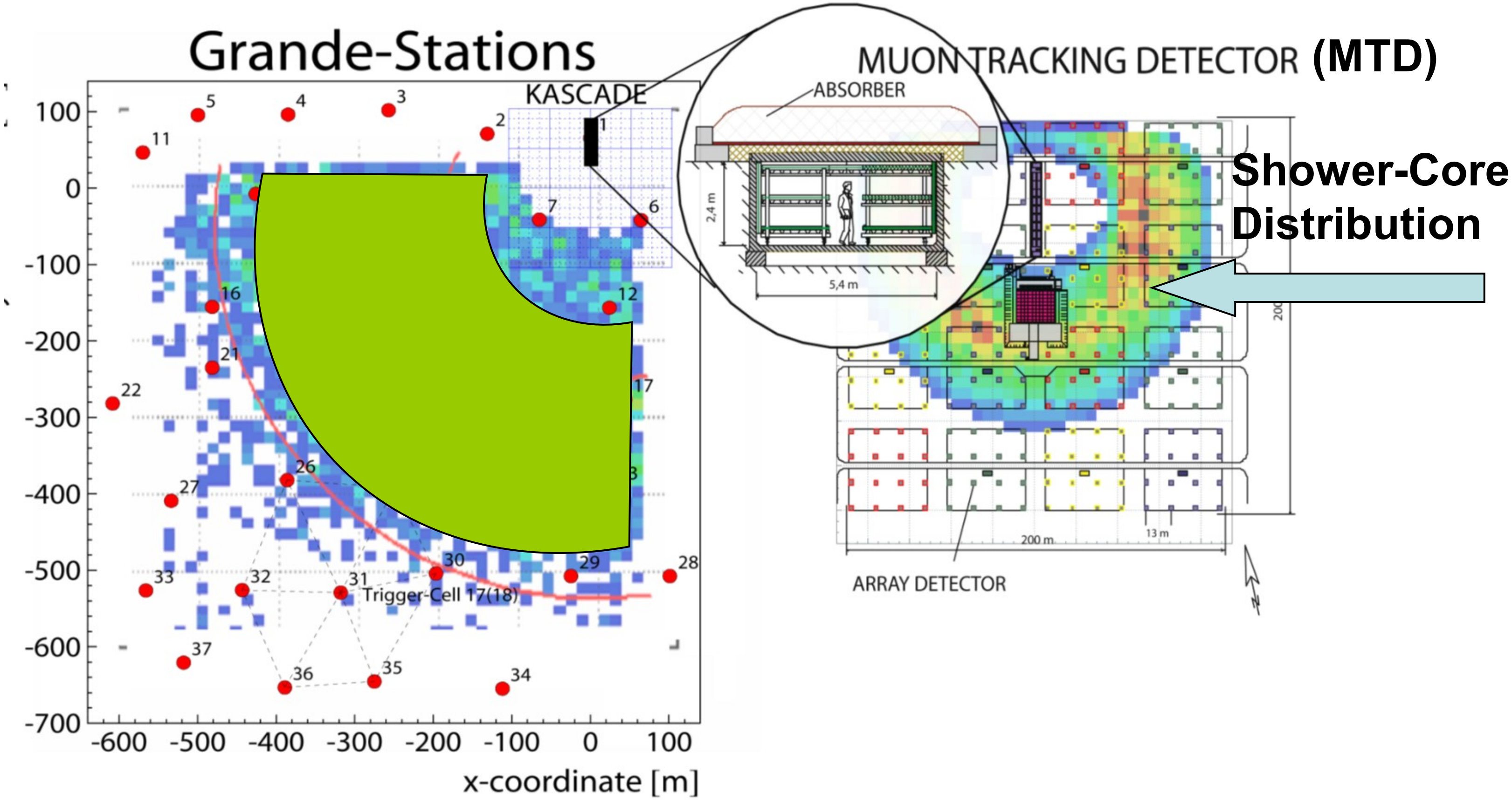
Energy Range:0.1-1000PeV
Area: 0.5km²

KASCADE-Grande Collaboration

J.Wochele priv.communication
T.Antoni et al., KASCADE, Nucl.Instr.Meth.A513(2003)429
G.Navarra et al., KASCADE-Grande, Nucl.Instr.Meth.A518(2004)207

Air Shower Experiment KASCADE-Grande

Total effective area: 0.5 km² , large array of 37 stations, average spacing of 137m.

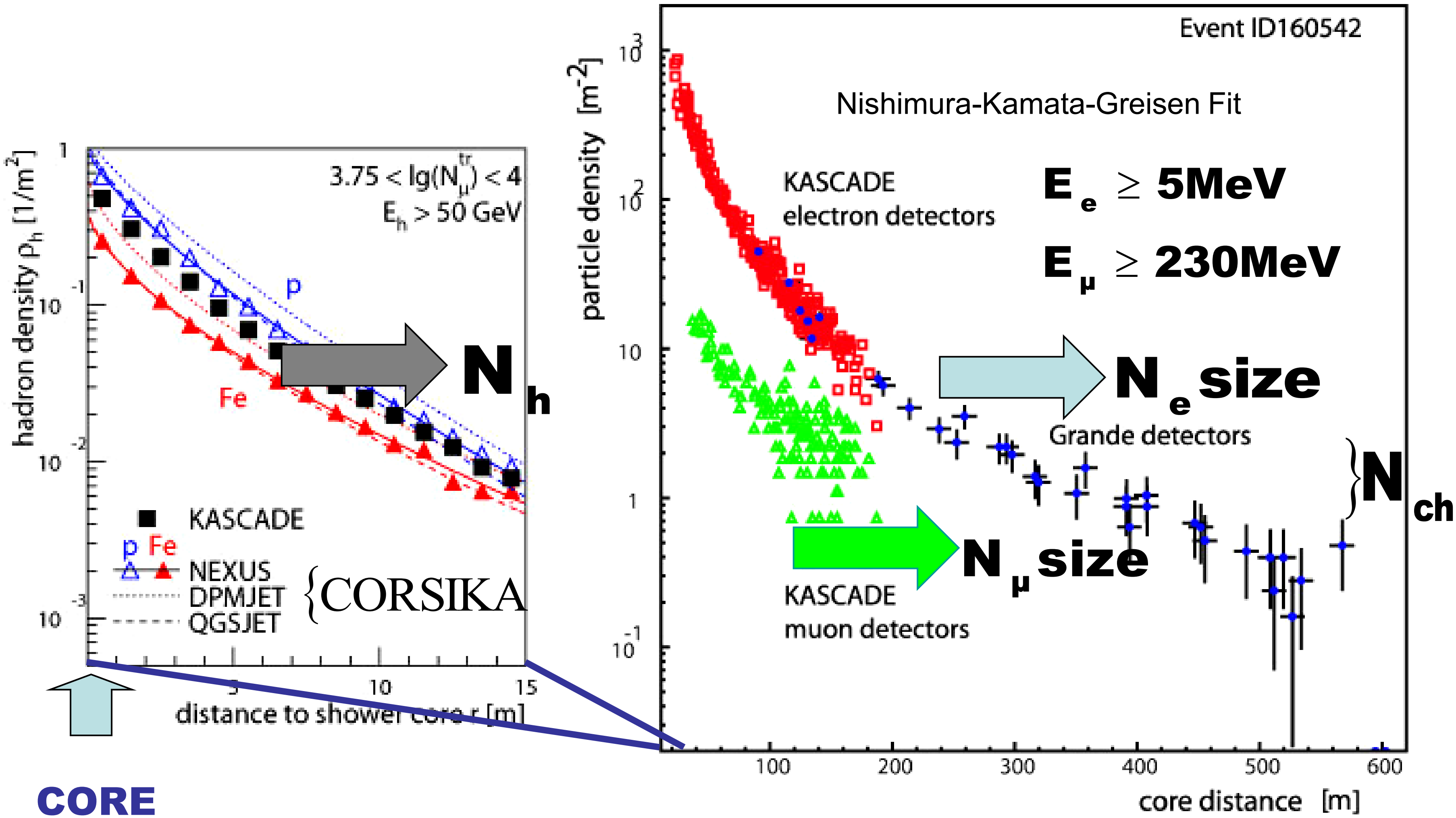


$$N_e, \theta_s, \varphi_s, N_\mu, \theta_\mu, \varphi_\mu, N_h, E_h$$

(Doll for KASCADE-Grande)

Hadron/Electron/Muon Distributions

The density distributions lead to the total particle numbers (SIZE).



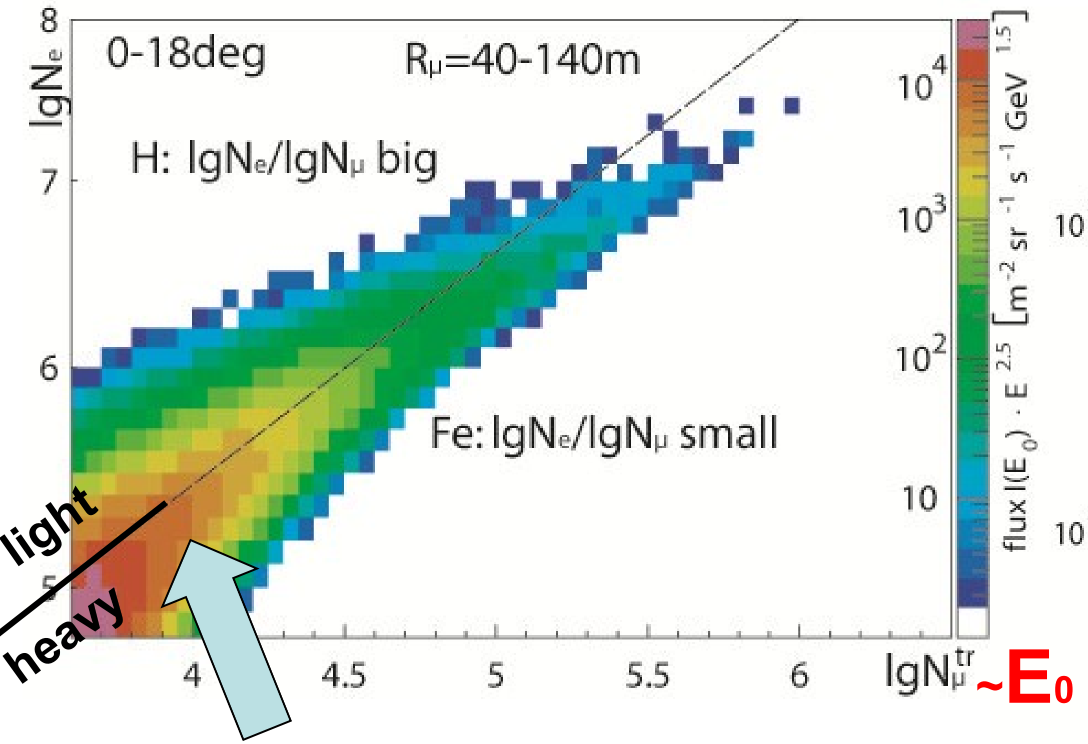
CORE

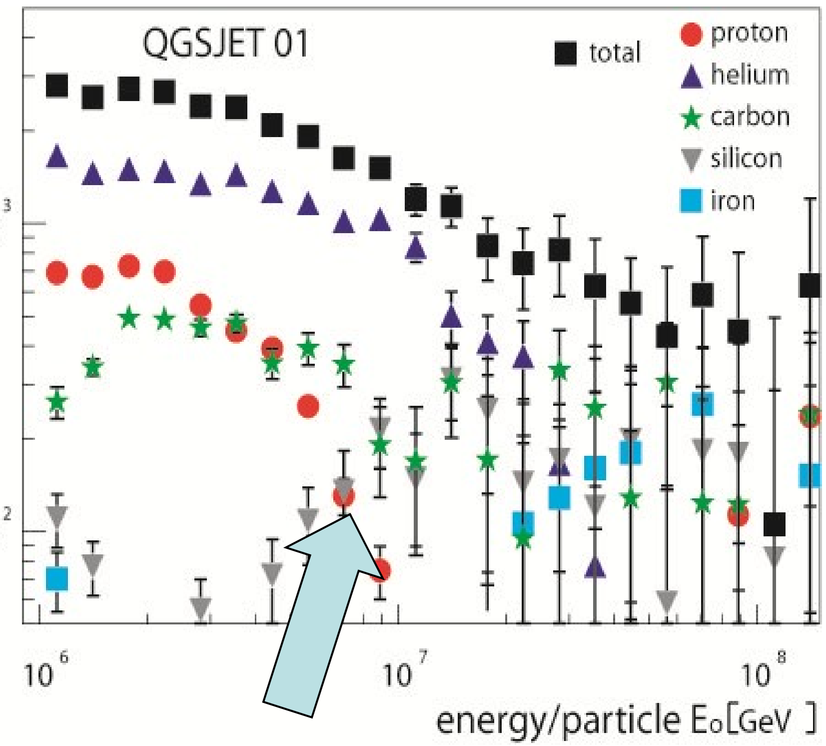
J.Milke et al., KASCADE, 29th ICRC Pune (2005)
R.Glasstetter et al., KASCADE-Grande, 29th ICRC Pune (2005)

Unfolding lgNe/lgNμ Size using CORSIKA-simulations:

$$p_A\left(\left(\lg N_e, \lg N_\mu^{tr}\right)_i \middle| \lg E_0\right)$$

Each cell in the lgNe/lgNμ presentation has contributions from different cosmic ray particles A and different particle energy Eo.





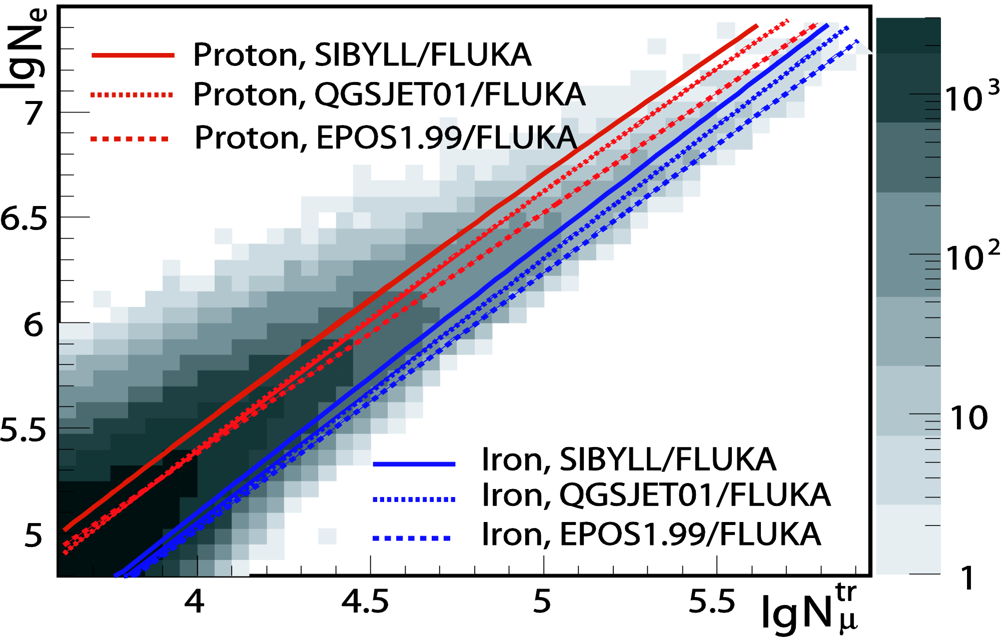
$$\left(\frac{dJ}{d\lg N_e\, d\lg N_\mu}\right)_i = \sum_A \int_{-\infty}^{+\infty} p_A\left(\left(\lg N_e, \lg N_\mu\right)_i \middle| \lg E_0\right) \frac{dJ_A}{d\lg E_0}\, d\lg E_0$$

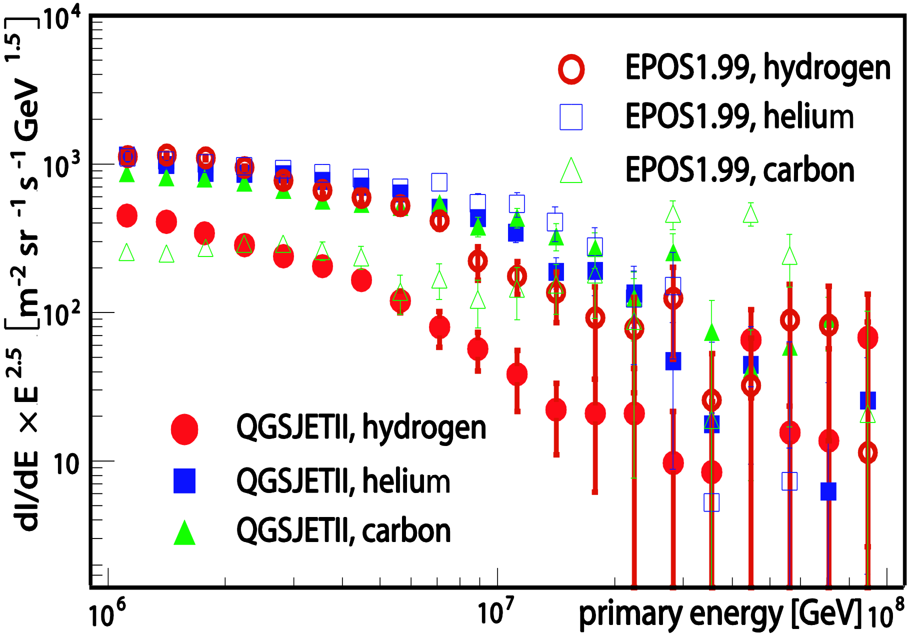
(Doll for KASCADE-Grande)

T.Antoni et al. KASCADE, Astropart.Phys. 24(2005)1
H.Ulrich et al. KASCADE-Grande,ISVHECRI, Weihei China (2006)

KASCADE-Grande Sensitivity to:

Same unfolding based on three different interaction models: SIBYLL 2.1 and QGSJET-01 and EPOS1.99 in CORSIKA.





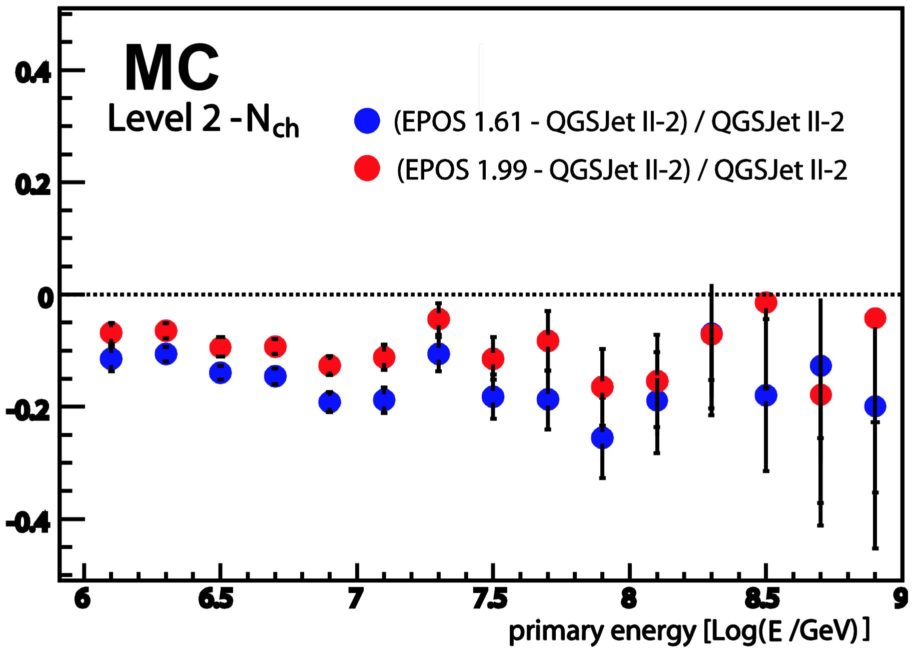
(Proton dominant for EPOS 1.61)

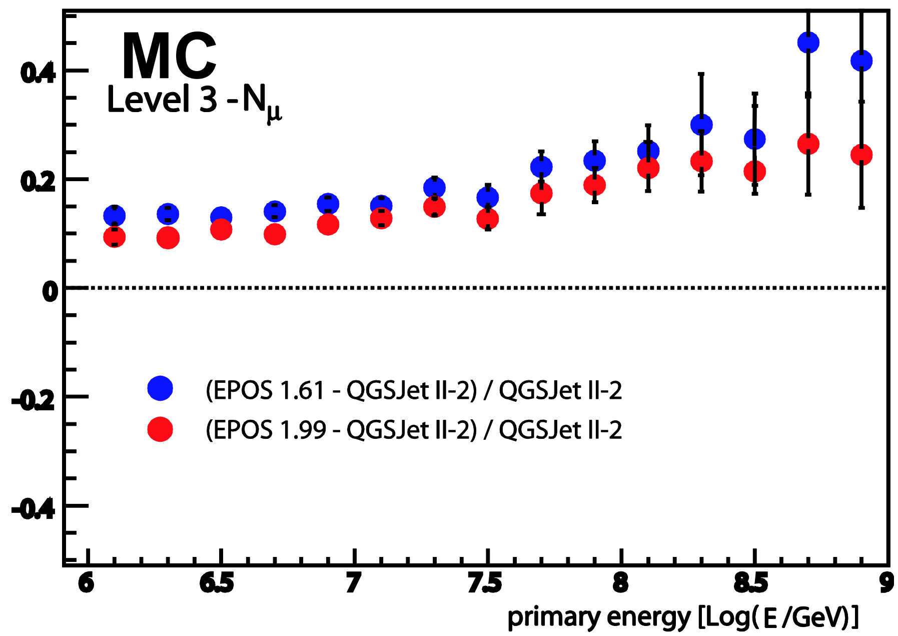
(Finger for KASCADE-Grande)

QGSJET 01: N.N.Kalmykov et al., Nucl.Phys.(Proc.Suppl.)B 52(1997) 17
SIBYLL 2.1: E-J.Ahn et al., Phys.Rev.D 80 (2009) 094003
EPOS 1.99: T.Pierog et al., Proc. 31th ICRC (2009), Lodz, 428

Deviation of EPOS relative to QGSJET

EPOS has less Nch and more muons Nμ with respect to QGSJET (~ 10%)



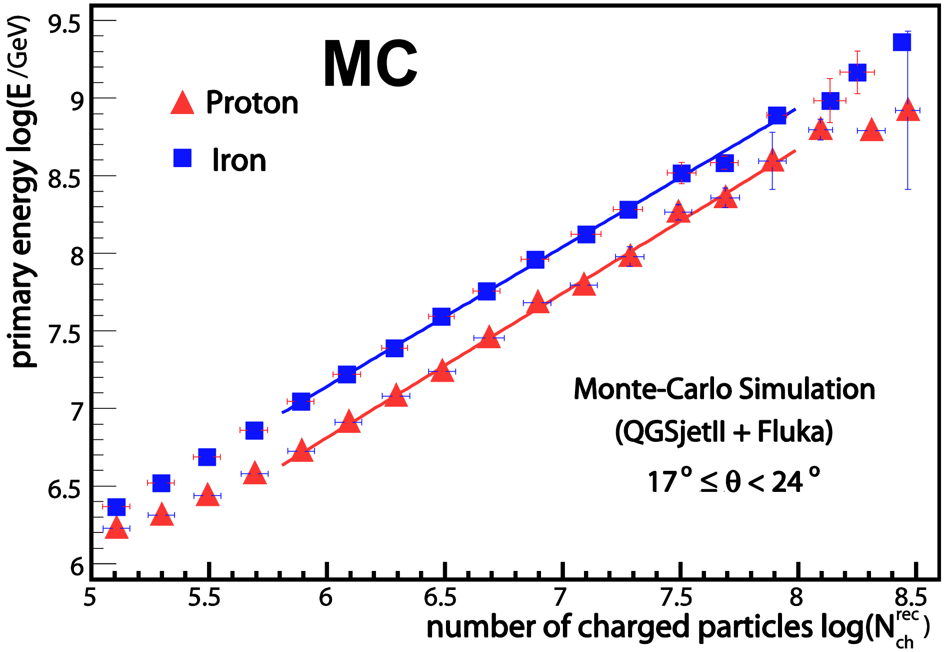


D.Kang et al, http://arxiv.org/abs/1009.4902
QGSJET II: S.Ostapchenko, Phys.Rev.D 74 (2006) 014026
EPOS 1.99: T.Pierog et al., Proc. 31th ICRC (2009), Lodz, 428

(Kang for KASCADE-Grande)

KASCADE-Grande: Energy calibration

Energy calibration for QGSJET-II-2 & EPOS 1.99



Fit with $: \log E = a + b \cdot \log N_{ch}$

QGSJETII:
- $H : a = 1.23,\ b = 0.93$
- $Fe : a = 1.75,\ b = 0.90$

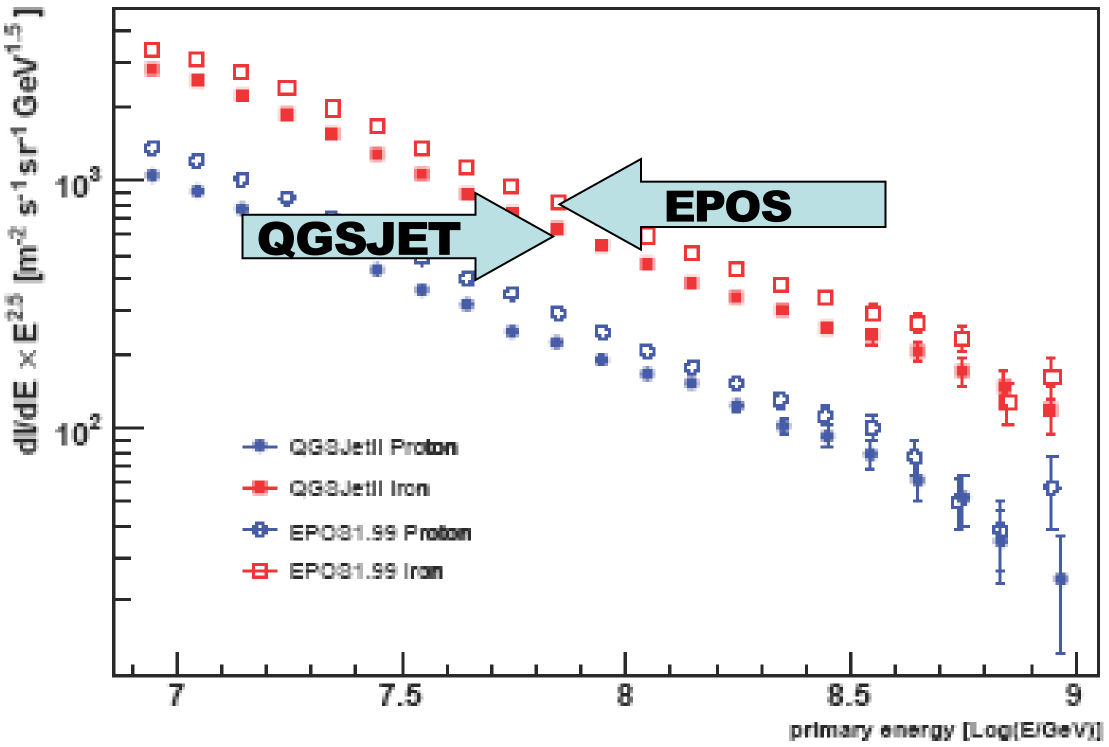
EPOS1.99:
- $H : a = 1.51,\ b = 0.90$
- $Fe : a = 1.92,\ b = 0.88$

(Kang for KASCADE-Grande)

D.Kang et al, http://arxiv.org/abs/1009.4902
QGSJET II: S.Ostapchenko, Phys.Rev.D 74 (2006) 014026
EPOS 1.99: T.Pierog et al., Proc. 31th ICRC (2009), Lodz, 428

CR Spectrum with QGSJETII&EPOS1.99

EPOS leads to a significantly higher flux compared to the QGSJET-II.

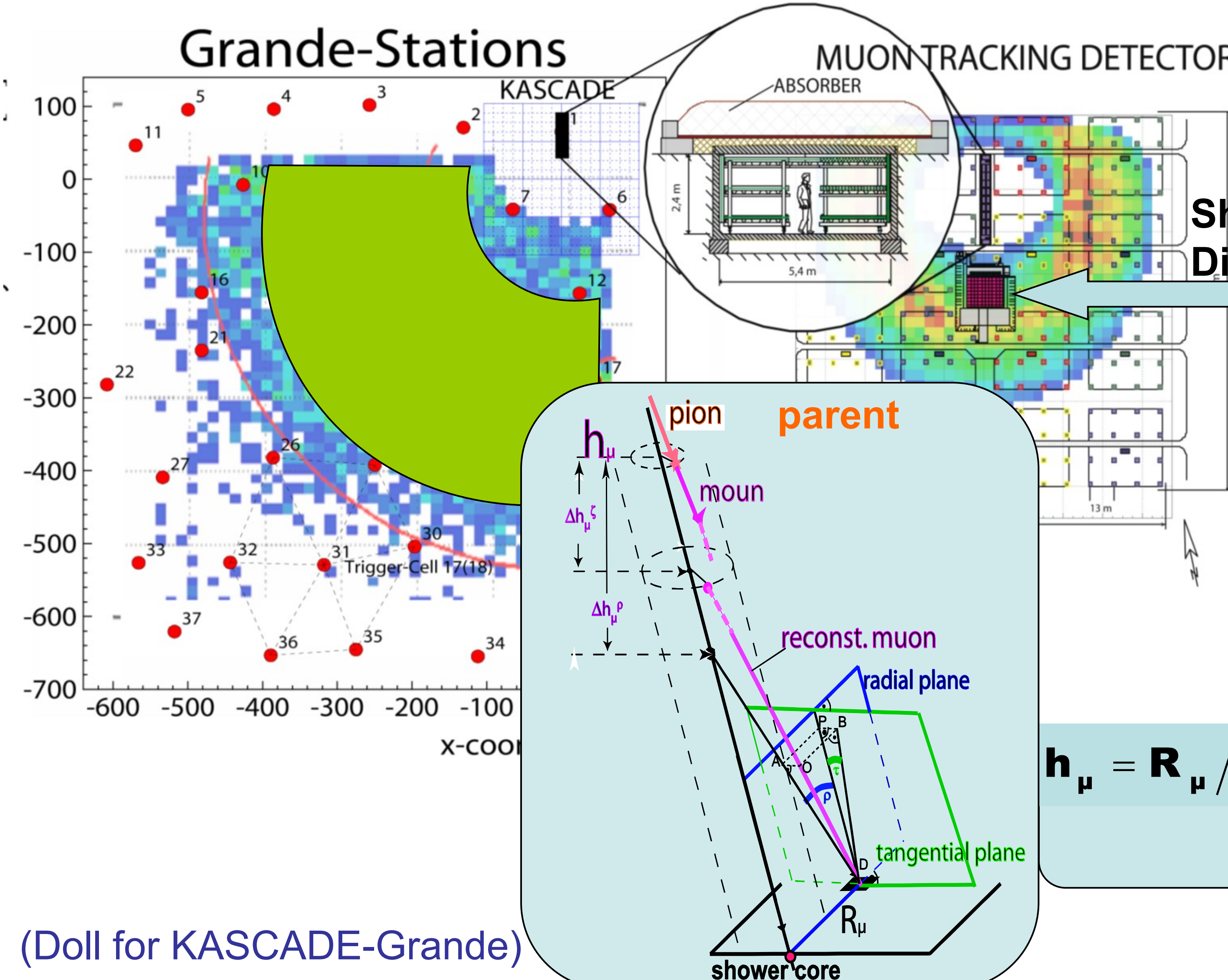


(Kang for KASCADE-Grande)

D.Kang et al, http://arxiv.org/abs/1009.4902
QGSJET II: S.Ostapchenko, Phys.Rev.D 74 (2006) 014026
EPOS 1.99: T.Pierog et al., Proc. 31th ICRC (2009), Lodz, 428

Muon Production Height

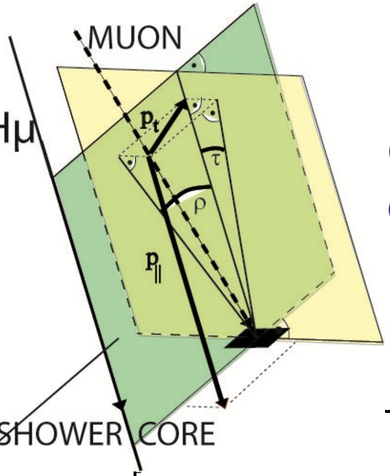
Muon Tracking Detector (MTD) measures direction of muons with respect to the shower axis.



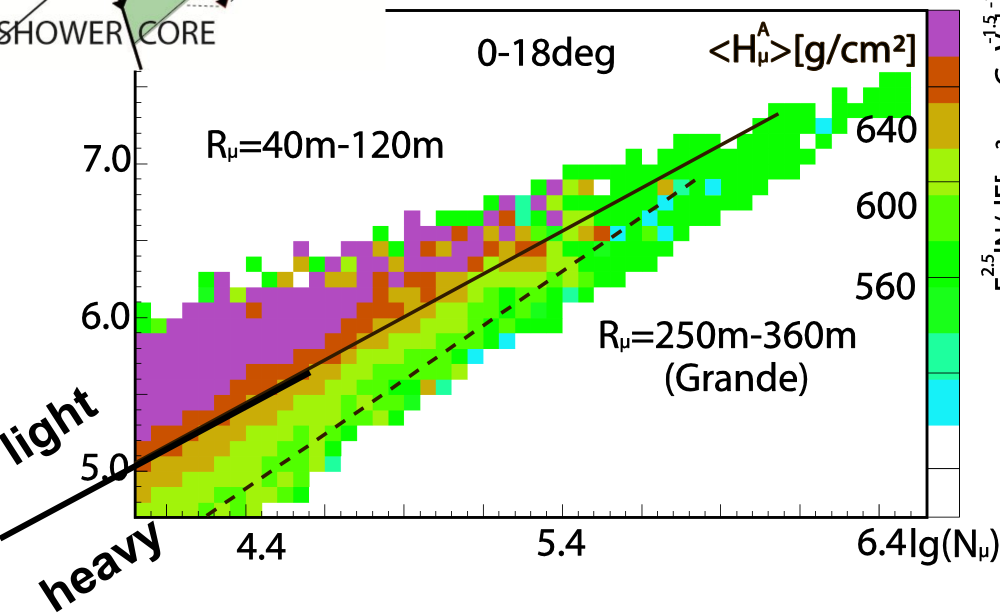
$$h_{\mu} = R_{\mu} / \tan(\rho - |\tau|)$$

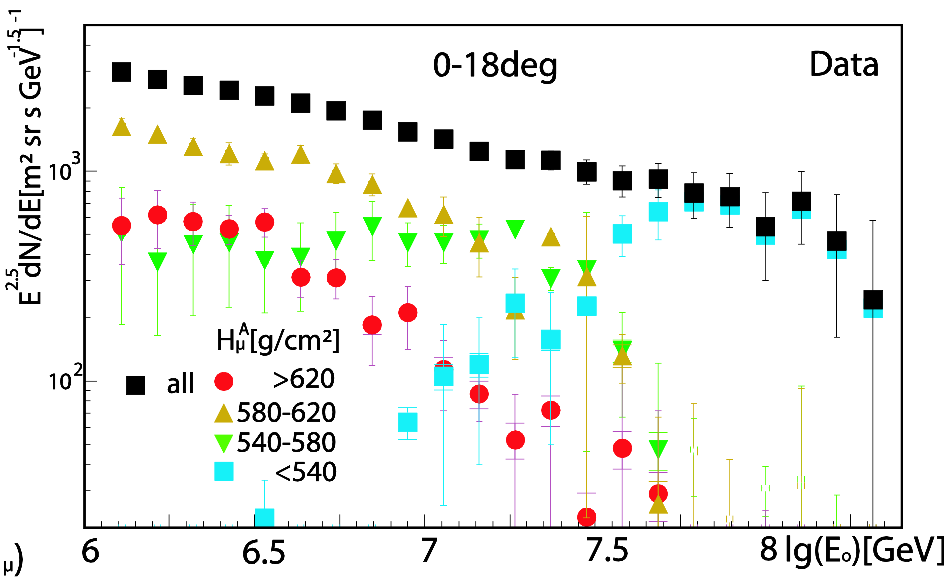
(Doll for KASCADE-Grande)

Muon Production Height for different CR-Mass.



Muon Tracking Detector can study the logitudinal shower development. Correcting the production height hμ for the elongation leads to: H_μ^A





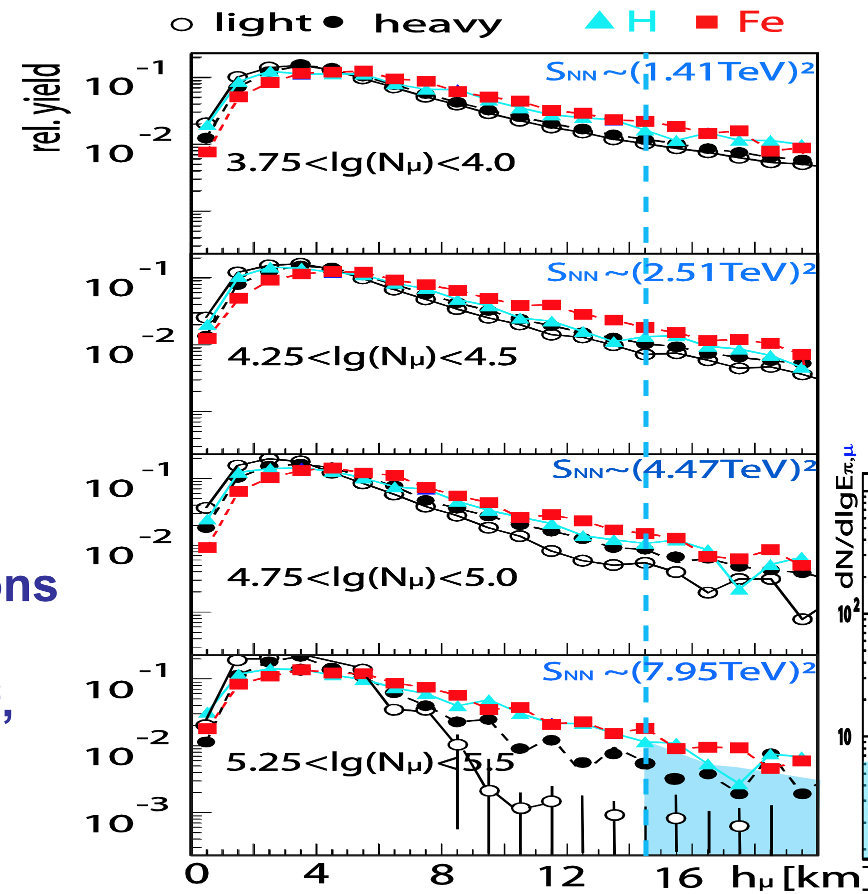
$$\langle h_\mu \rangle \sim \lg E_0 = \alpha \lg N_\mu^A - \beta \lg A$$

KASCADE-Grande Collaboration

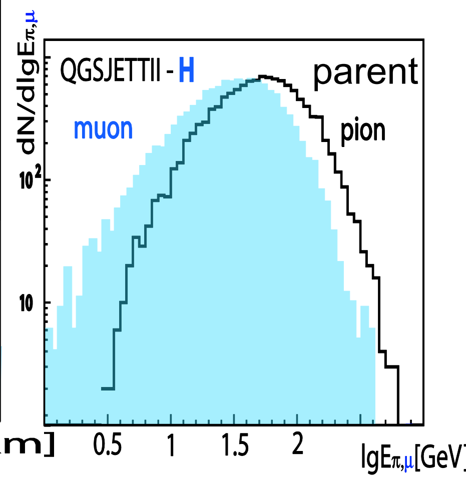
R.Obenland et al. KASCADE-Grande, 29th ICRC Pune (2005)
W.Apel et al., DOI:10.1016/j.astropartphys.2010.10.016

Development of Muon Production Height

The absence of secondary hadron production in the energy fragmentation region in the frist interactions of shower development is observed at ~8 TeV.



Nikolsky proposes production of bosons and hadrons with masses>400GeV/c², instead of leading low mass hadrons.

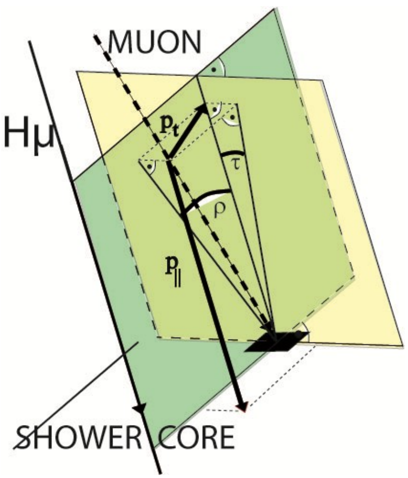


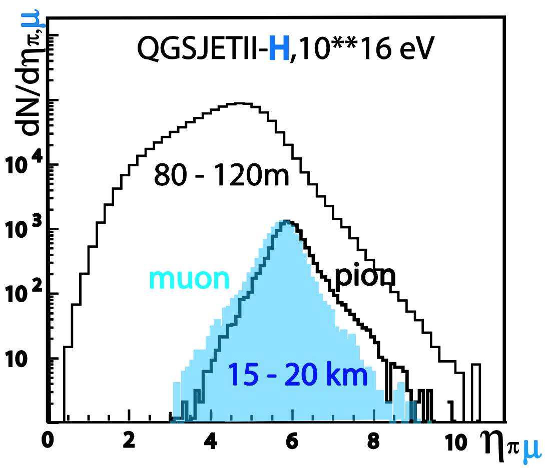
S.I.Nikolsky, Nucl.Phys. B (Proc.Suppl.) 39A(1995) 228
P.Doll et al., http://arxiv.org/abs/1010.2702
QGSJET II: S.Ostapchenko, Phys.Rev.D 74 (2006) 014026

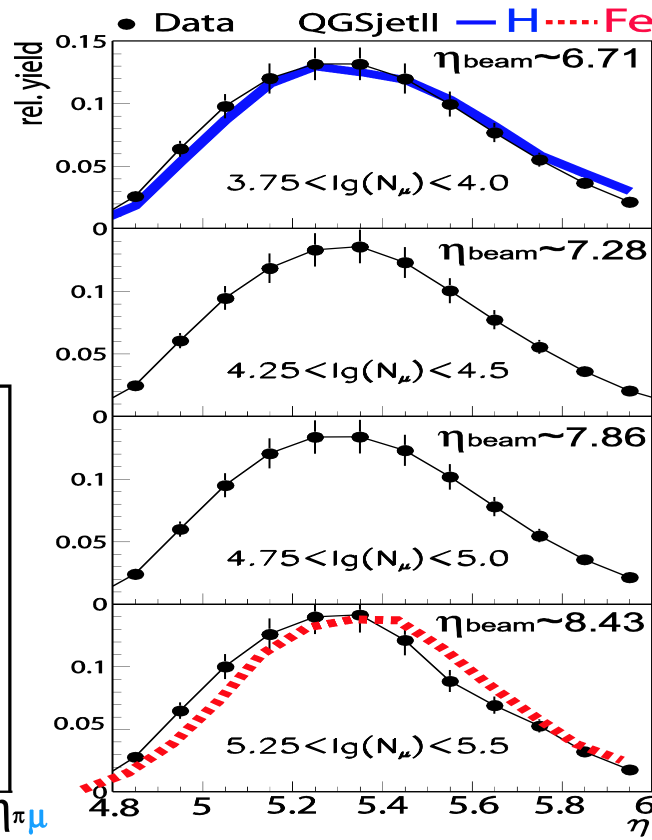
KASCADE-Grande Collaboration

μ-Pseudorapidity in Fragmentation Region

$$\eta \cong \ln(p_{\parallel}/p_T) \cong -\ln(\sqrt{\rho^2+\tau^2}/2)$$







Estimation of η_{peak} consider rapidity of a single nucleon or quark in projectile:

$$\cong \ln\sqrt{s} = \ln\sqrt{2kE_o}, k \approx 0.33$$

$$\Rightarrow \ln\sqrt{2kE_o/A}$$

$$\eta_{peak} = (1/1+\lambda)(\tilde{\eta}_{beam} - \ln A^{1/6})$$

(Zabierowski for KASCADE-Grande)

P.Doll et al., http://arxiv.org/abs/1010.2702
QGSJET II: S.Ostapchenko, Phys.Rev.D 74 (2006) 014026

OUTLOOK

1. QGSJET 01 and SIBYLL 2.1 compatible models for KASCADE-Grande data.
2. EPOS1.99 prefers light primary particles in order to fit the data.
3. The interpretation of the KASCADE-Grande data with EPOS1.99 leads to significantly higher flux compared to the QGSJET-II-2 result.
4. QGSJETII can not describe muon yield from first interactions for ~ 8TeV.