Test of Hadronic Interaction Models with KASCADE-Grande

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for the

KASCADE-Grande Collaboration

XXXIII ISMD
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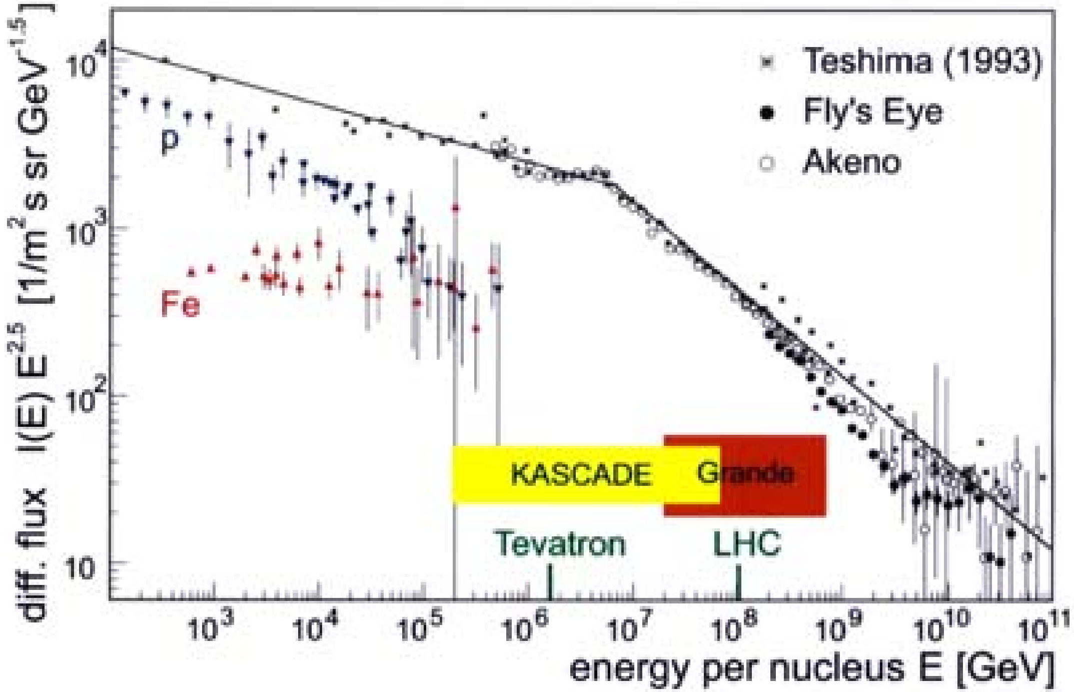
Energy Spectrum of Cosmic Rays

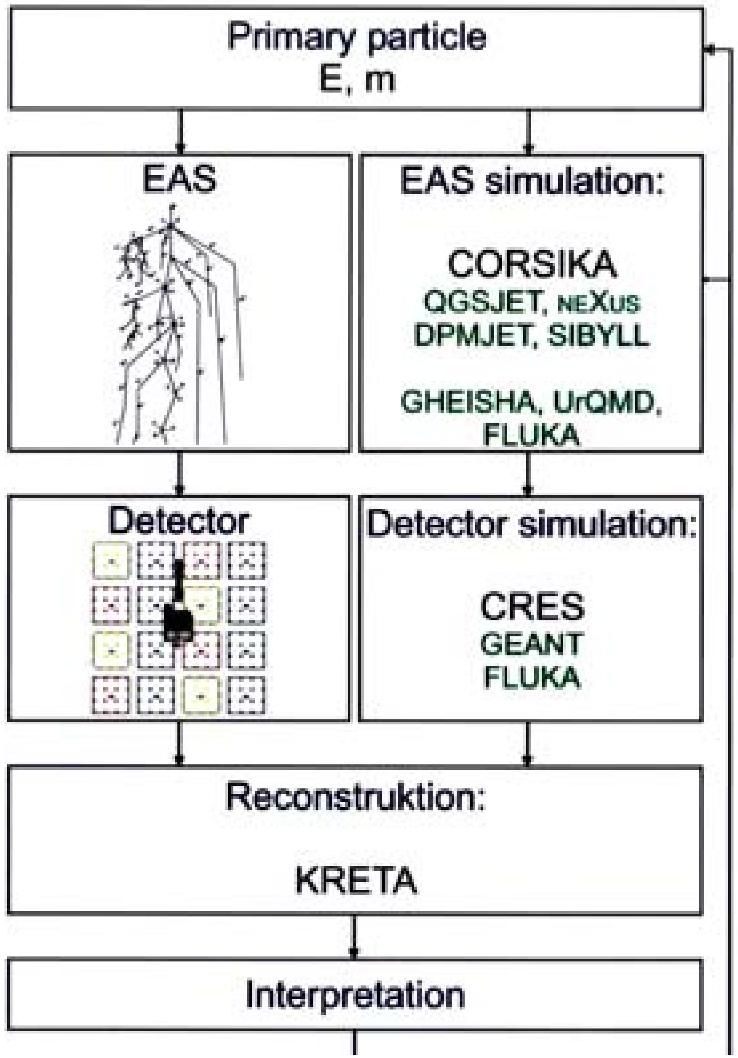


Goals of KASCADE:

- Energy spectra of individual mass groups in the knee region
- Test of hadronic interaction models

⇒ simultaneous measurement of many observables in each shower to reduce uncertainties introduced by shower simulations

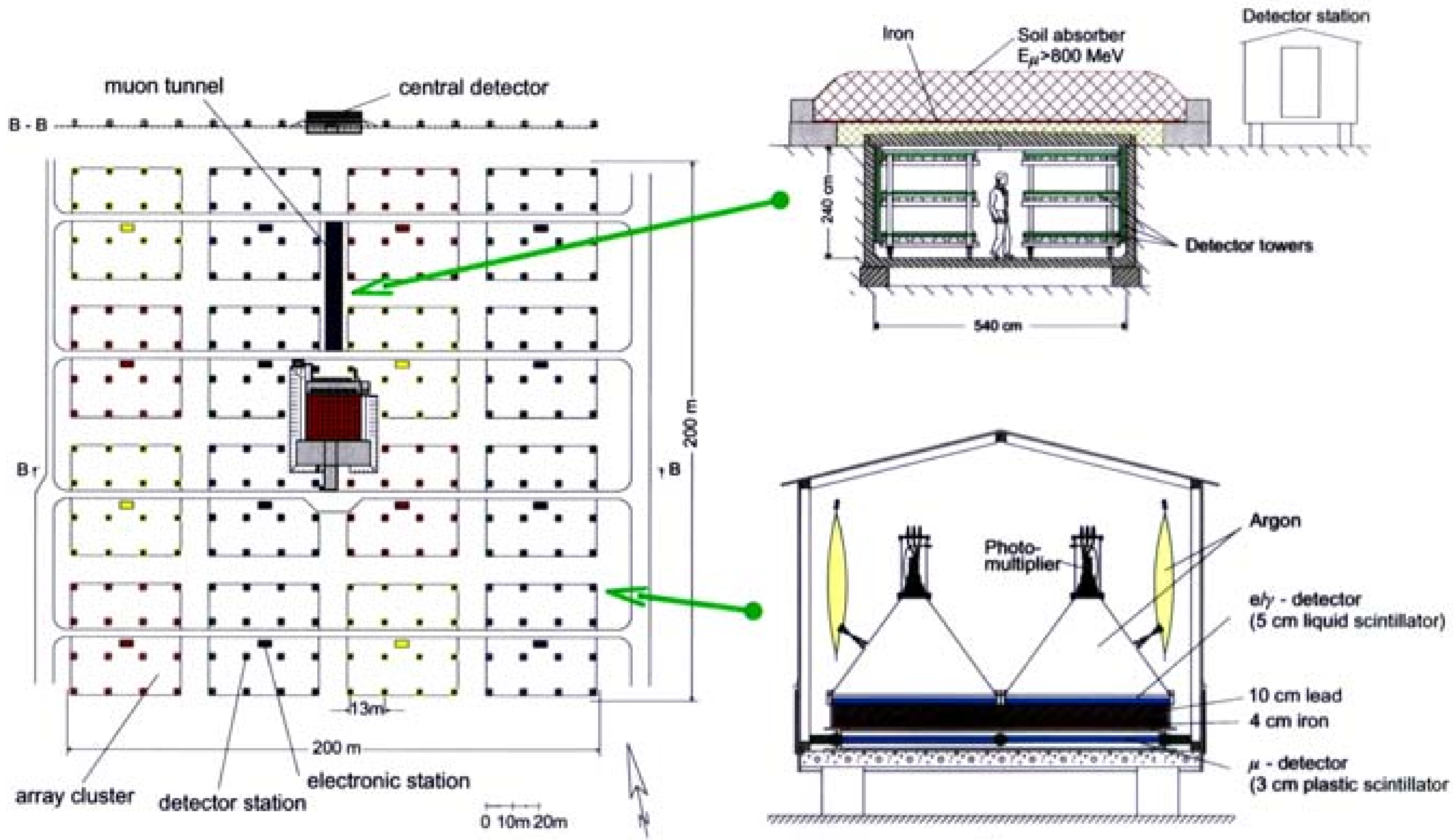
EAS Analysis



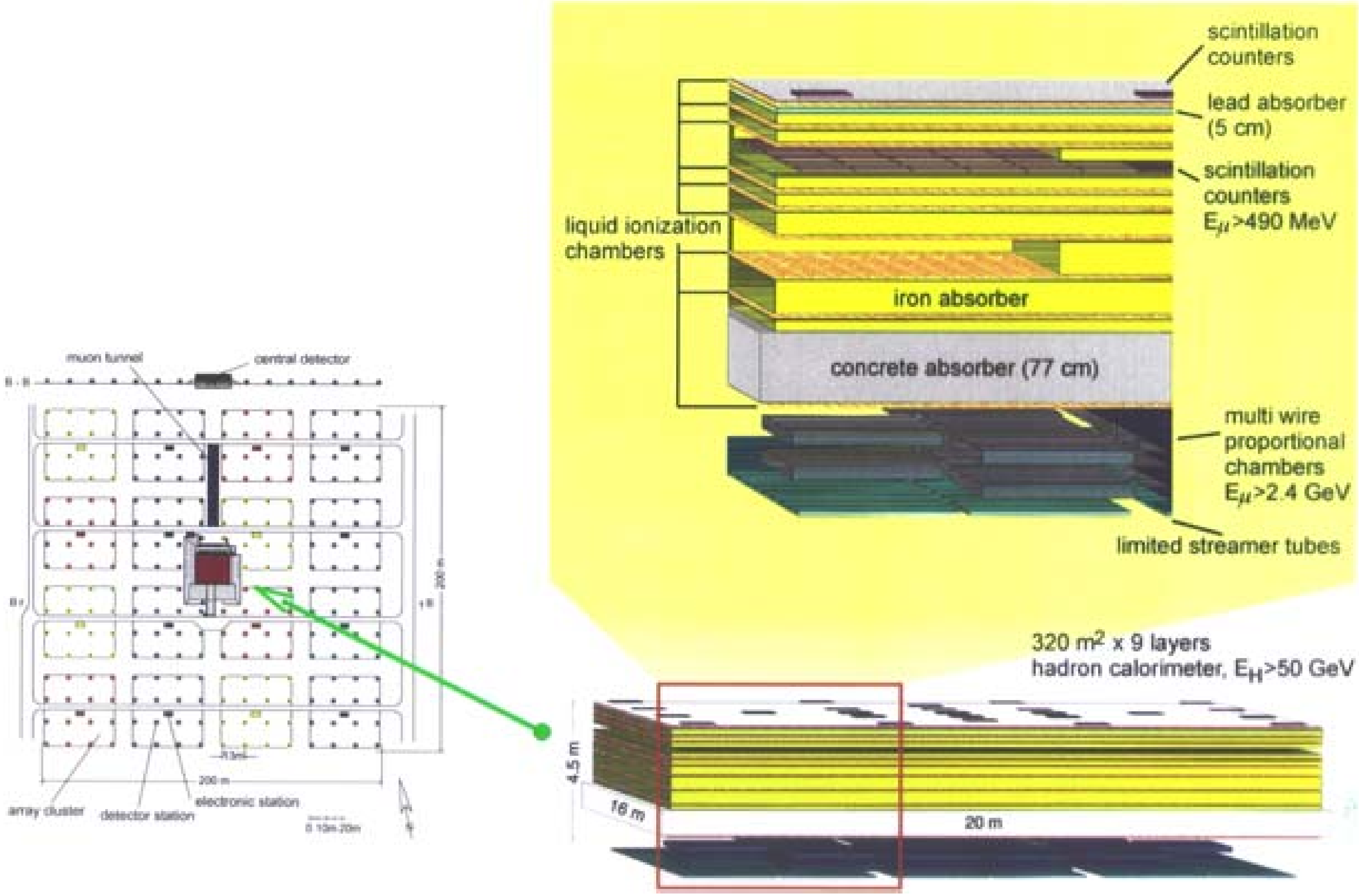
- Comparison of measurements and simulations
- problematic: hadronic interactions
  - ⇒ energy and forward region not covered by collider experiments
  - ⇒ cannot be calculated by QCD

⇒ check of reliability of hadronic interaction models and air shower simulations necessary

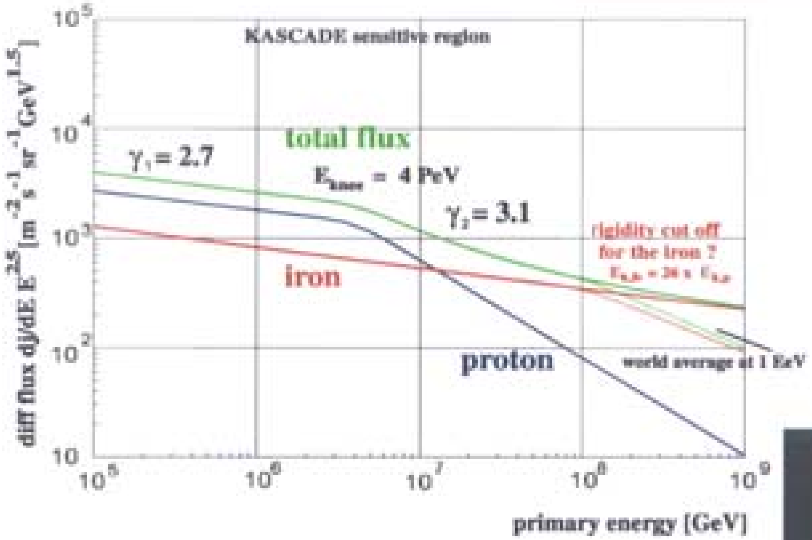
The KASCADE Experiment



KASCADE – Central Detector



KASCADE-Grande



- 700 x 700 m^2
- 37 detector stations
- 10 m^2 plastic scintillator / station

Piccolo:

- 8 trigger stations
- 10 m^2 scintillator / station

KASCADE Observables

per single shower !

Detector array:

- shower direction
- shower core
- shower size
- number of muons
- lateral particle distribution

Calorimeter:

- energy, position, and direction of individual hadrons
- energy spectra
- lateral distributions
- most energetic hadron
- . . .

MWPC-system:

- number of muons ($E_\mu > 2.4$ GeV)
- local muon densities
- hit pattern

Triggerplane:

- number of muons ($E_\mu > 490$ MeV)
- muon arrival times

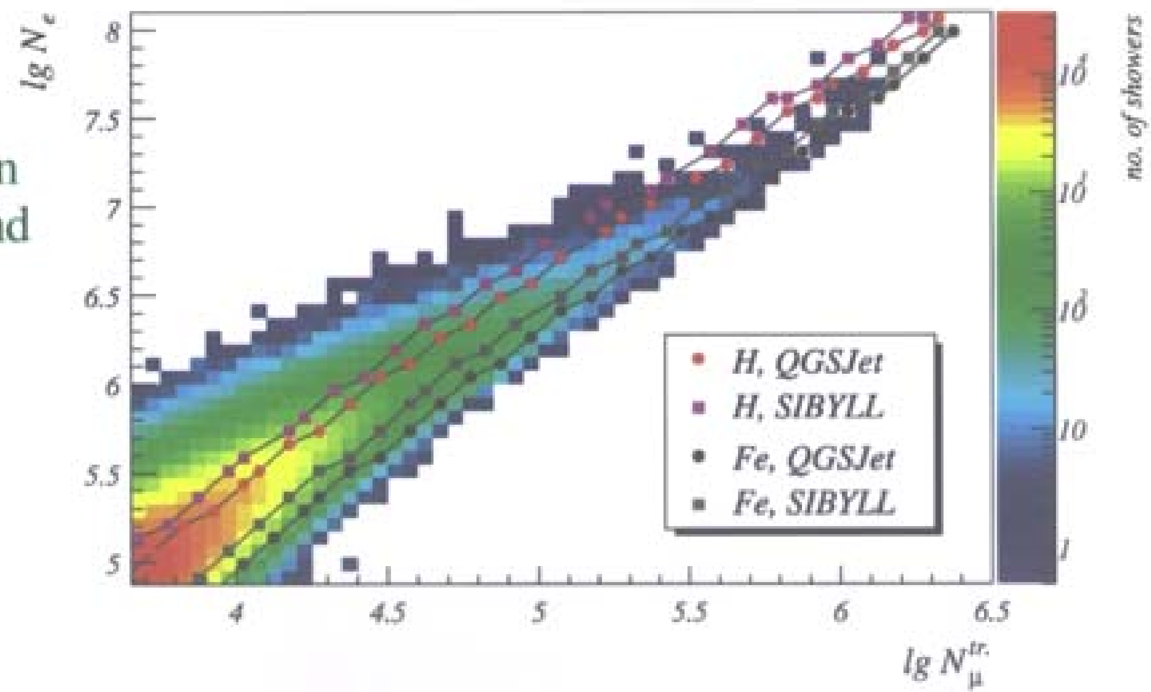
Muon Tracking Detector:

- number of muons ($E_\mu > 800$ MeV)
- angle of muons

2D-N_e-N_μ-Spectra

2 dimensional N_e-N_μ-spectra are used for determination of energy spectra of individual mass groups

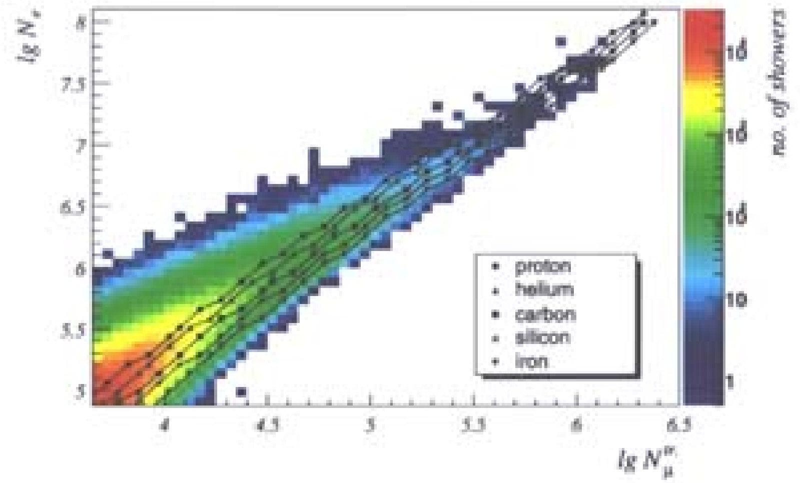
but: Discrepancies between measured N_e-N_μ-spectra and simulations

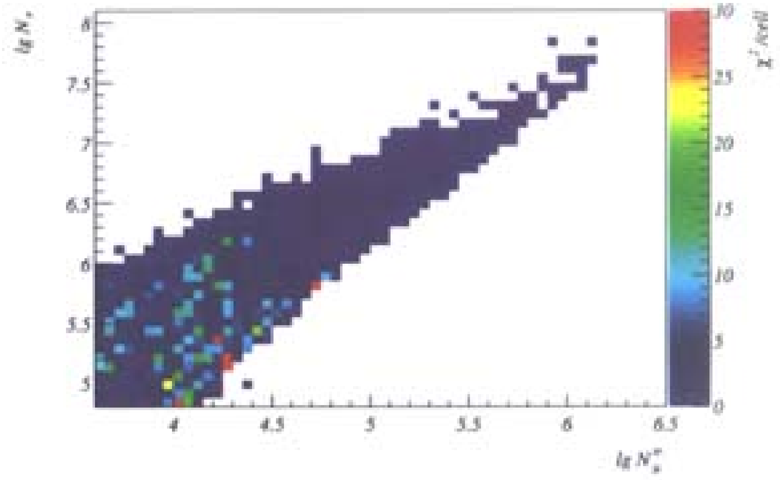


H. Ulrich

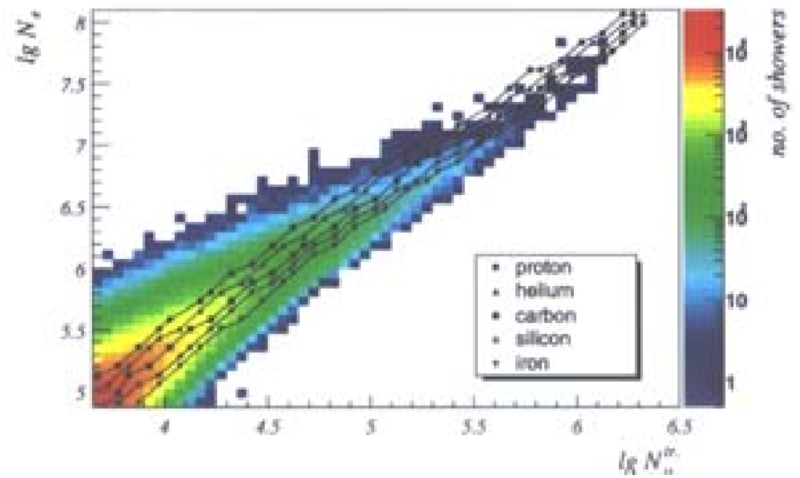
2D-N_e-N_μ-Spectra

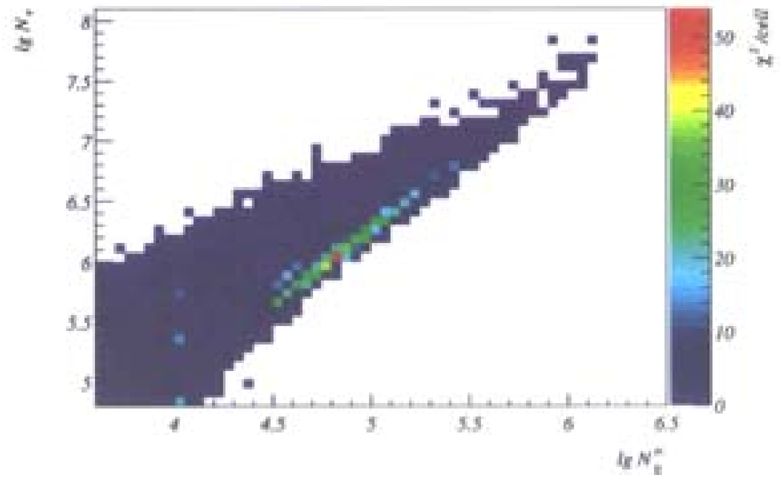
QGSJET:





SIBYLL:

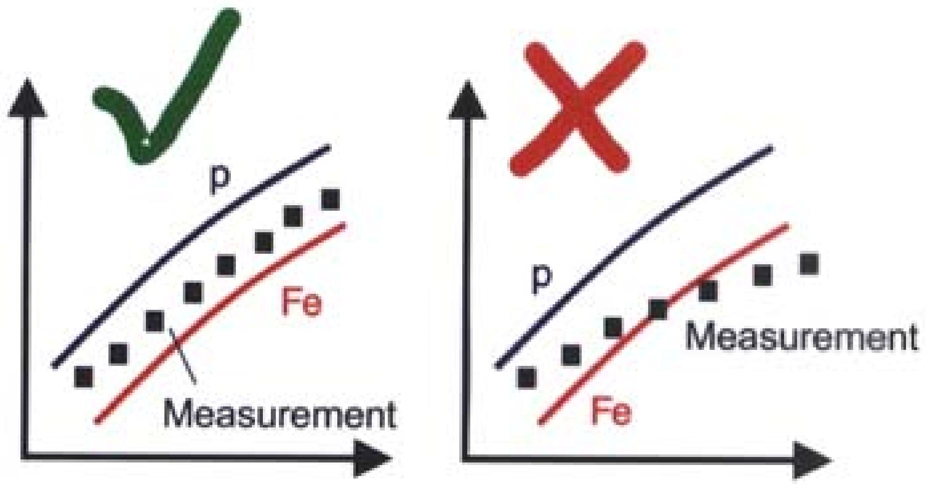


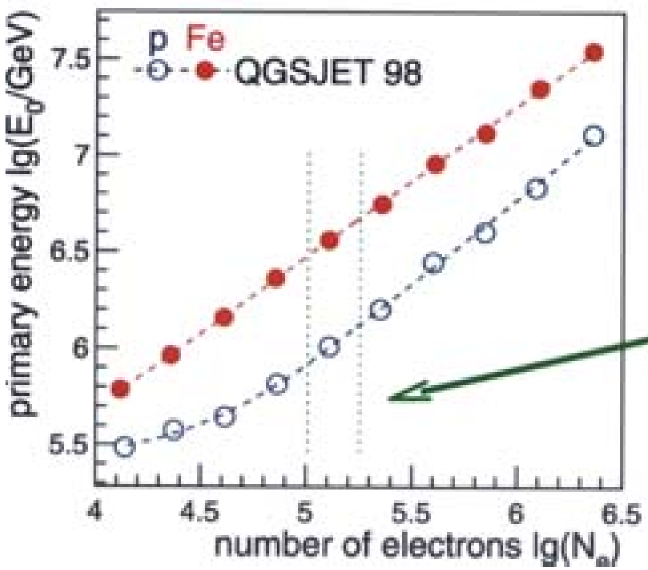


Model Tests with Hadrons

mass composition of cosmic rays unknown

⇒ use proton and iron as extrem assumptions





electron number intervals

⇒ enrichment of proton induced showers

High Energy Models

QGSJET: (N.N. Kalmykov, S.S. Ostapchenko, A.I. Pavlov, Nucl. Phys. B (Proc.Suppl.) 52B (1997) 17)

- Gribov-Regge theory

NEXUS 2: (H.J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, K. Werner, Physics Reports 350 (2001) 93)

- „Parton based Gribov-Regge theory“

SIBYLL 2.1: (R. Engel, T.K. Gaisser, P. Lipari, T. Stanev, Proc. 26th ICRC, 1 (1999) 415)

- Mini-jet model

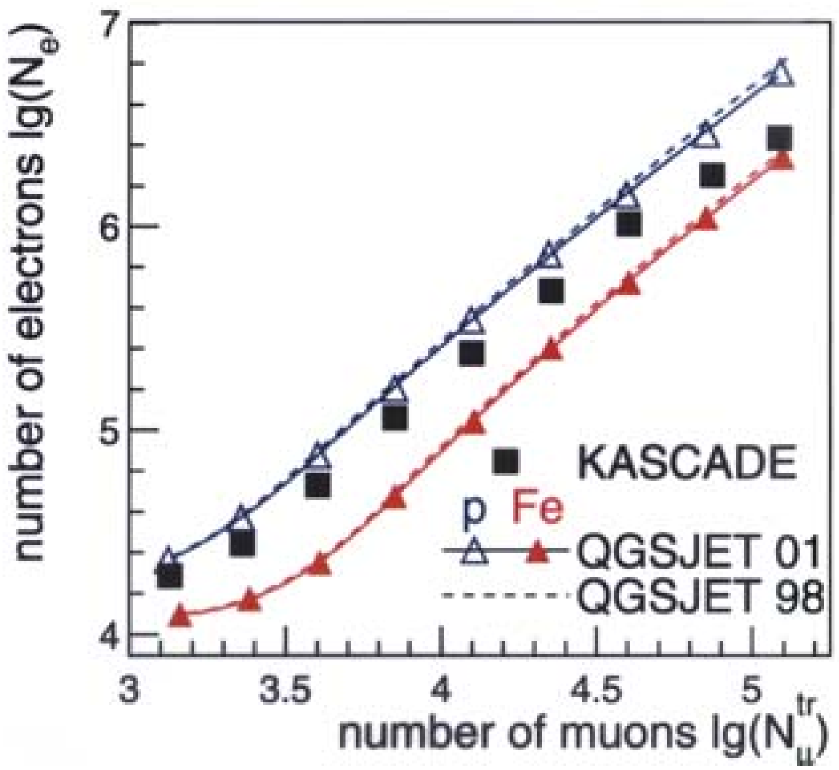
QGSJET 98 / 01

improved description of diffractive reactions in QGSJET 01

⇒ reduction of the elasticity
⇒ faster shower development

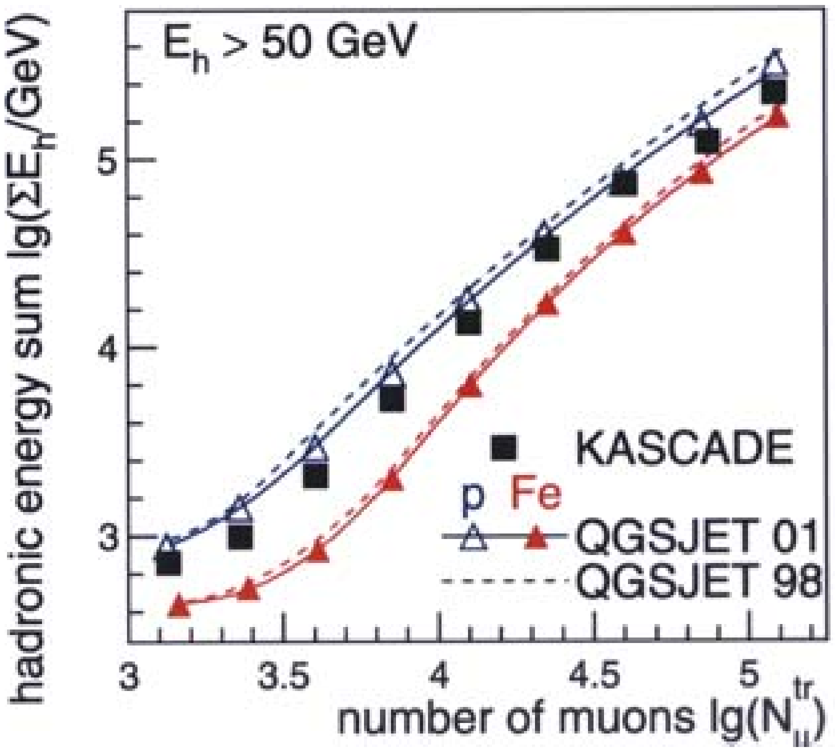
⇒ reduced electron and hadron numbers

correlation of electromagnetic and muonic components

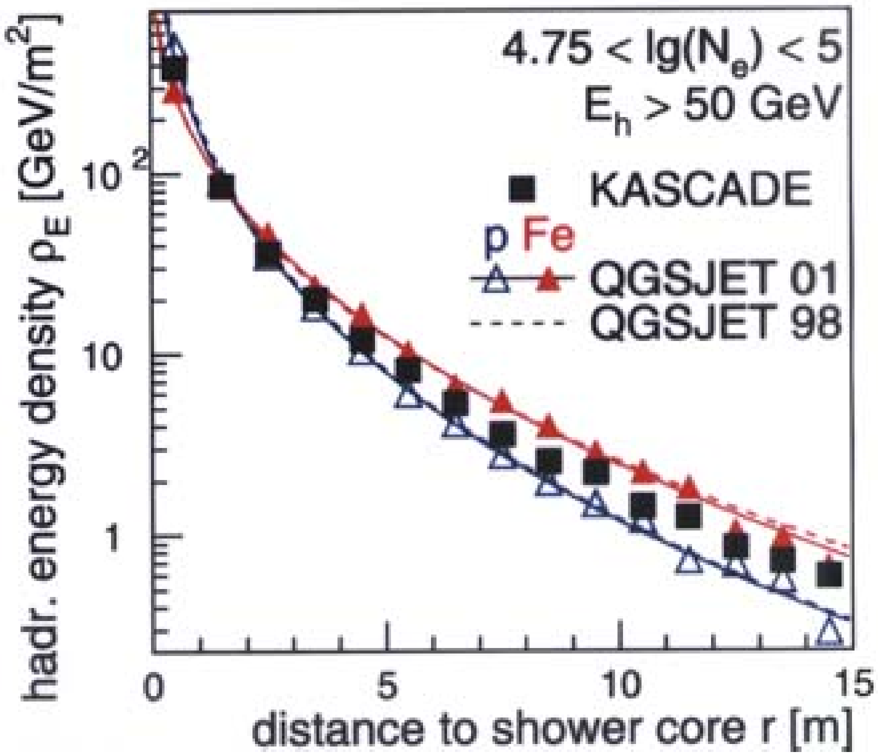


QGSJET 98 / 01

correlation of the hadronic
and muonic shower components

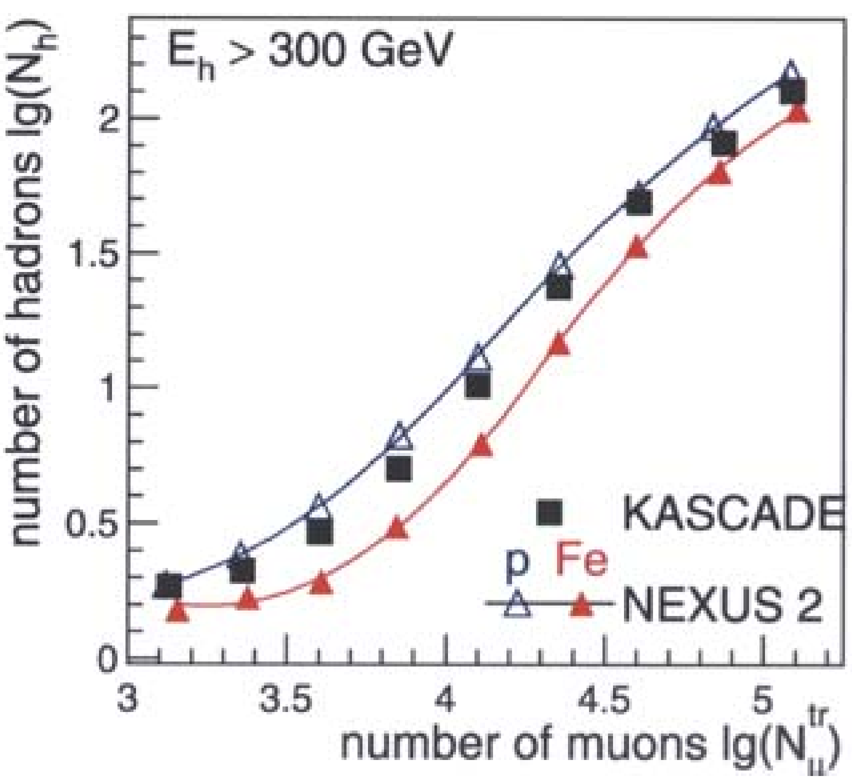


correlation of the hadronic and
electromagnetic shower components

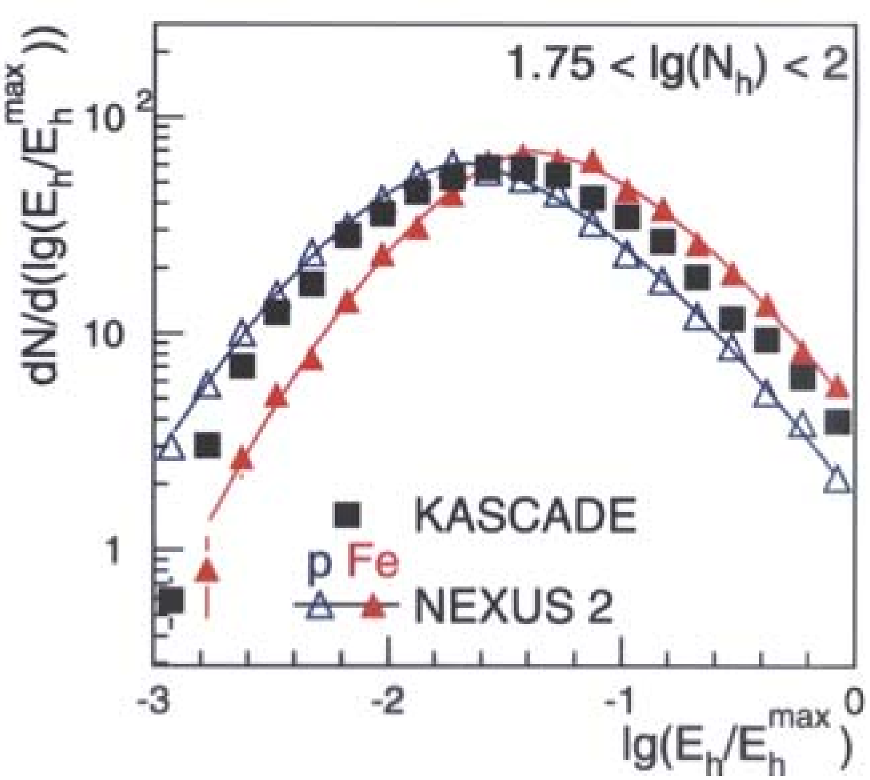


NEXUS 2

correlation of the hadronic and muonic shower sizes

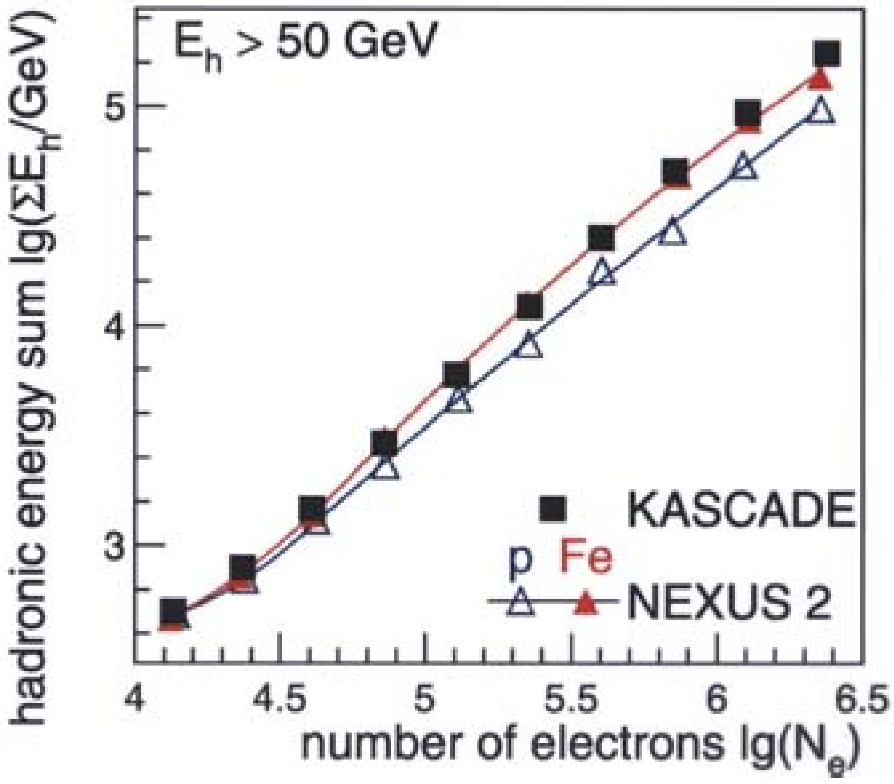


correlation of different hadronic observables



NEXUS 2

correlation of hadronic and electromagnetic shower sizes



consistent with measurement:

- correlation of hadrons and muons
- correlations of different hadronic observables

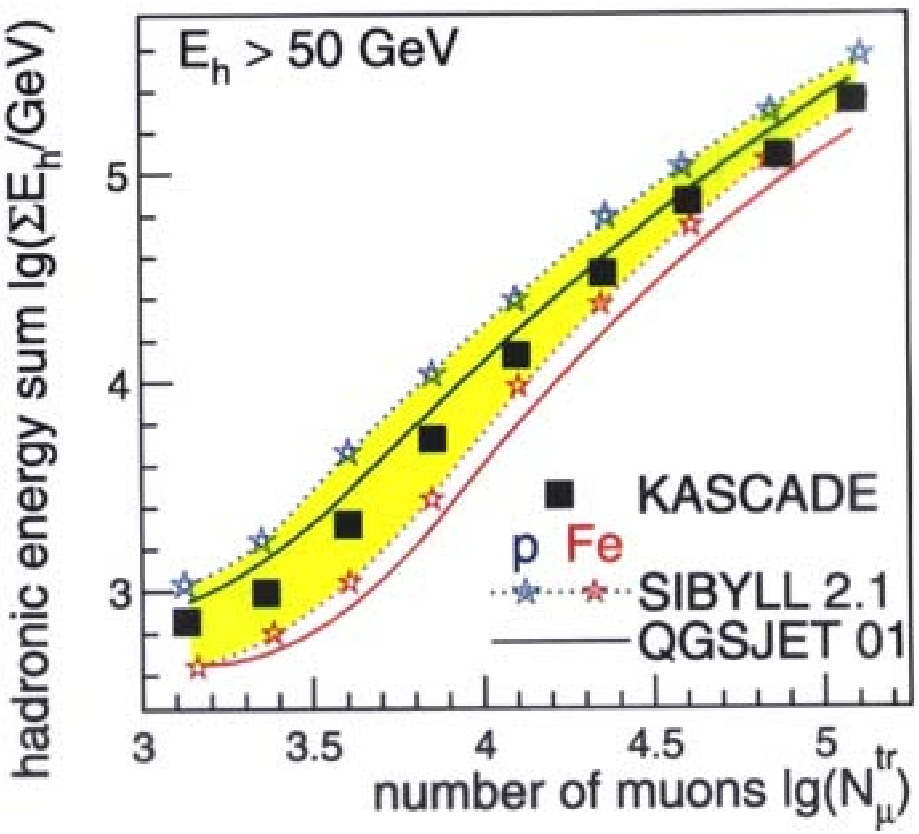
inconsistent:

- correlation of hadronic and electromagnetic components
  - ⇒ hadrons underestimated for given electron number

SIBYLL 2.1

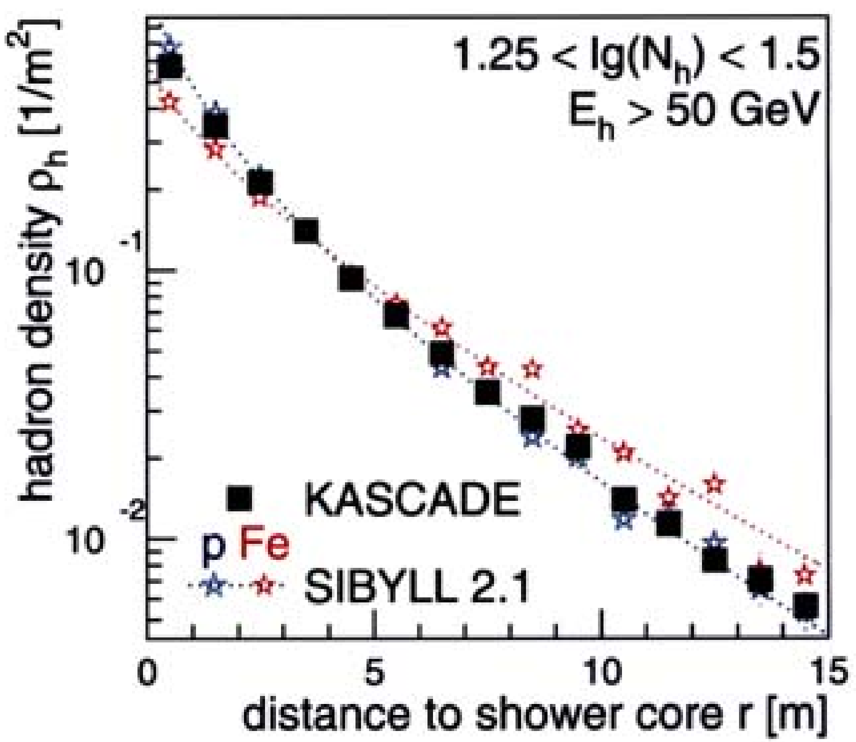
comparison of SIBYLL and QGSJET:

- SIBYLL produces fewer muons
- SIBYLL produces more hadrons and electrons

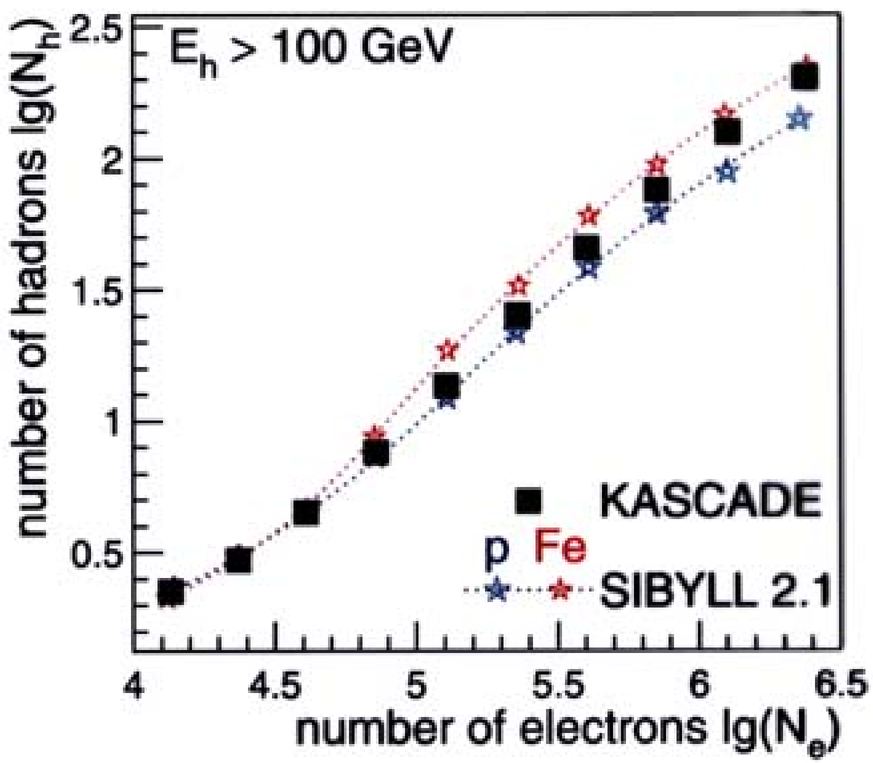


SIBYLL 2.1

Hadron lateral distribution



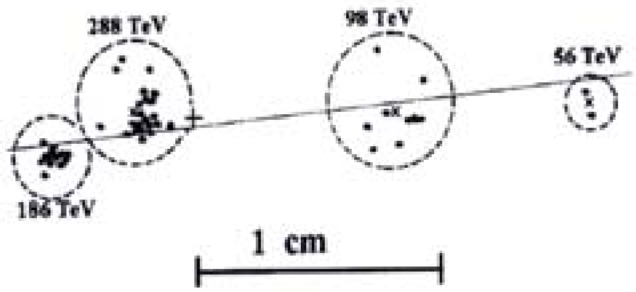
Correlation of hadrons and electrons



Differences between QGSJET and SIBYLL,
but both models compatible with measurements

Structure of EAS Cores

aligned event in emulsion chamber:



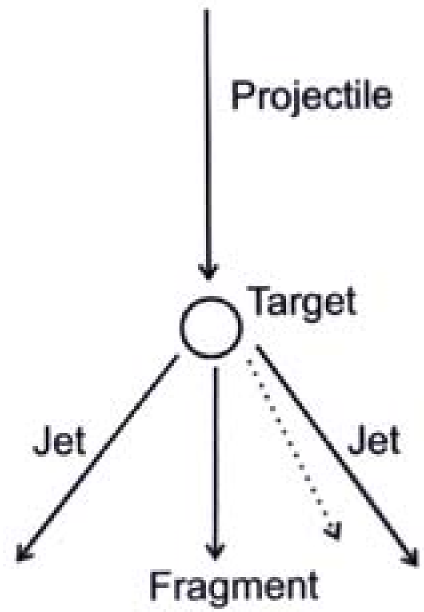
Capdevielle J.N., Slavatinsky S.A.,
Nucl. Phys. B (Proc.Suppl.) 75A (1999) 12

Alignment parameter λ_N:

$$\lambda_N = \frac{\sum_{i \neq j \neq k}^{N} \cos\left(2\phi_{ij}^{k}\right)}{N(N-1)(N-2)}$$

Motivation of aligned events:

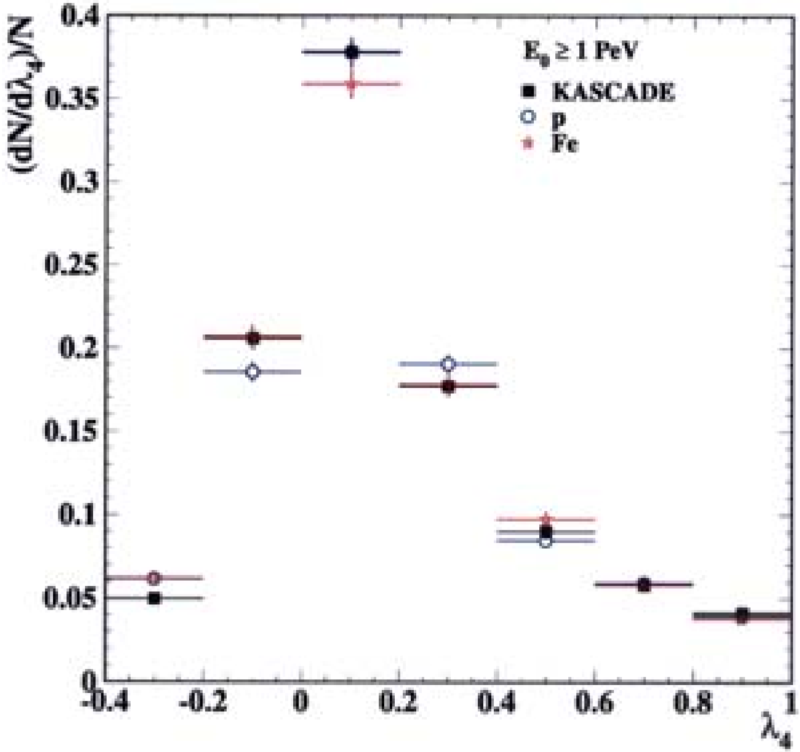
F. Halzen and A. Morris,
Phys. Rev. D 42 (1990) 1435



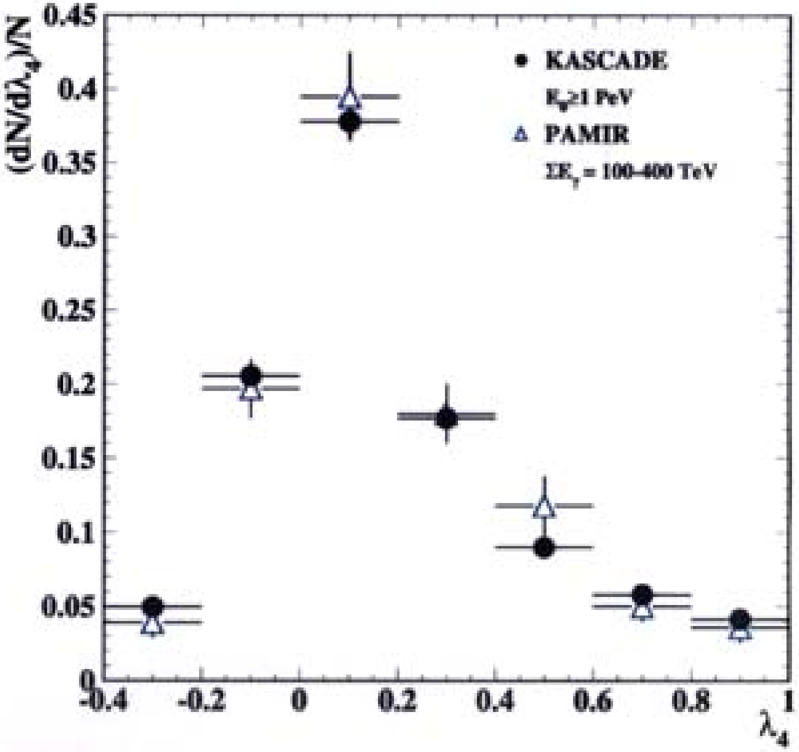
A. Iwan, ICRC 2003

Structure of EAS Cores

KASCADE measurement - simulation (CORSIKA/QGSJET)



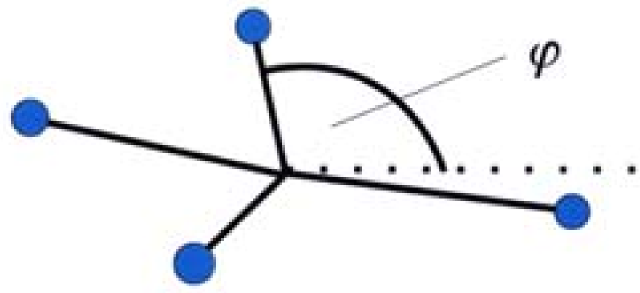
KASCADE - PAMIR

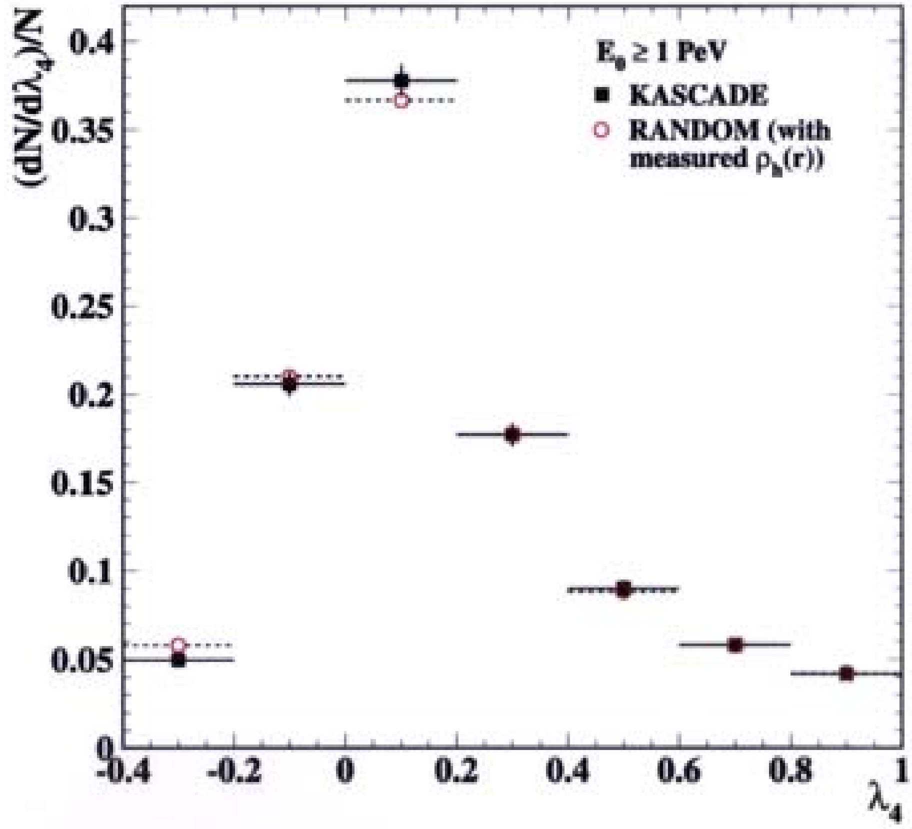


A. Iwan, ICRC 2003

Structure of EAS Cores

Sensitivity analysis:



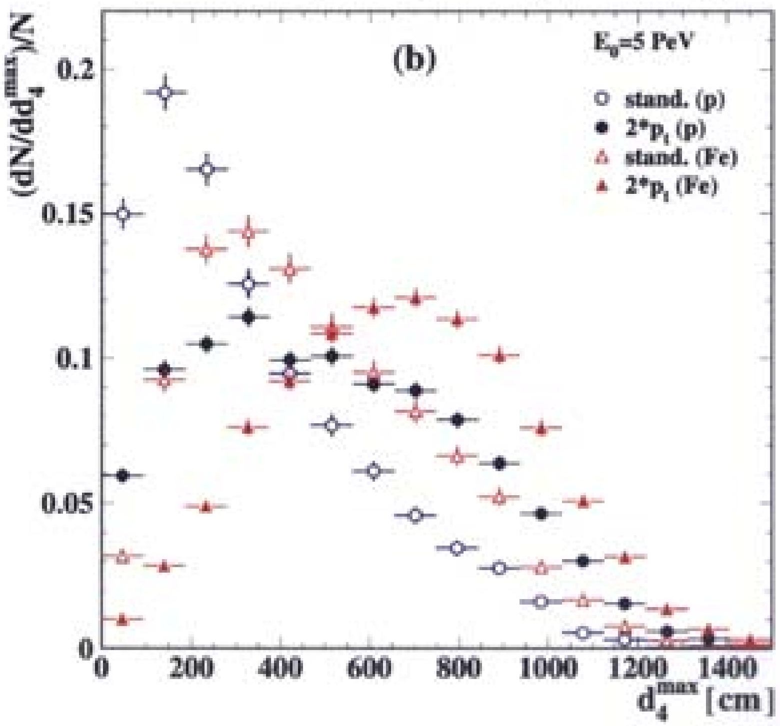


⇒ λ_4-distribution determined by hadron lateral distribution

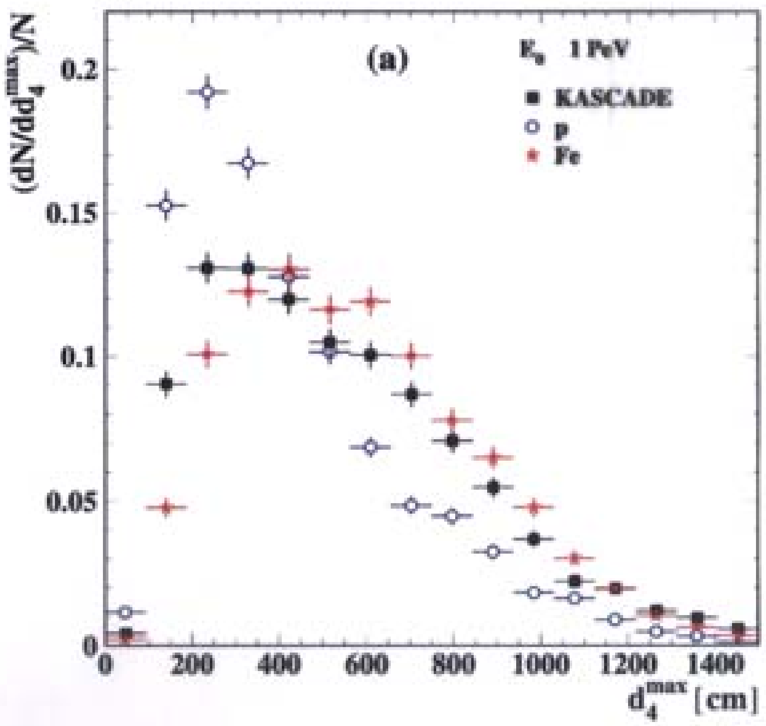
A. Iwan, ICRC 2003

Structure of EAS Cores

sensitivity analysis: $p_T \rightarrow 2\,p_T$



comparison measurement - simulation

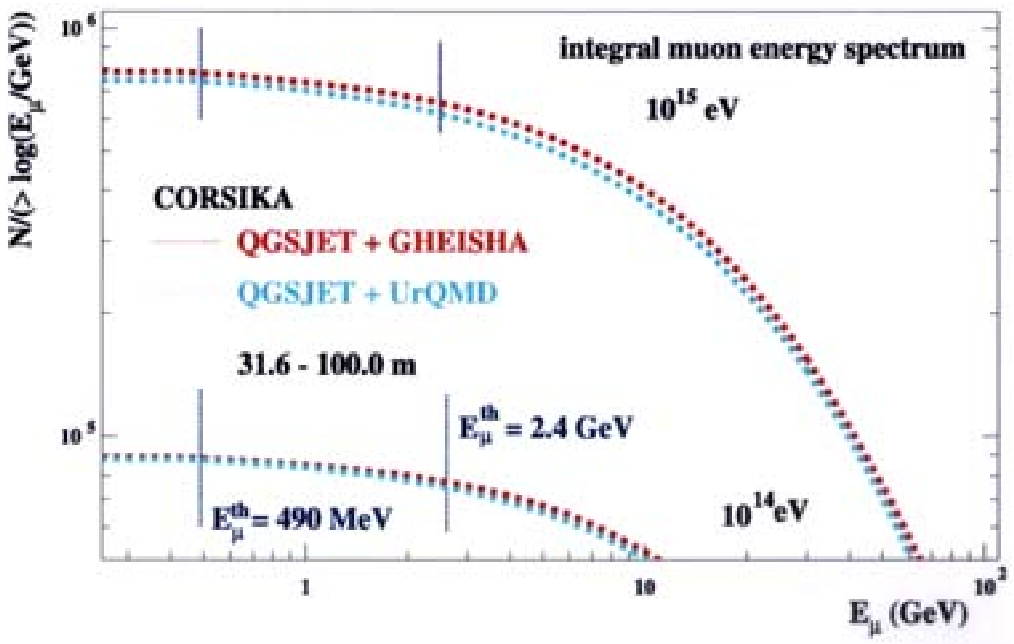


A. Iwan, ICRC 2003

Muon Densities

measurement of hadrons (E_H>50 GeV) ⇒ high energy interaction model

measurement of muons ⇒ additional low energy interaction model



measurement of muons
at different energy thresholds

⇒ „muon energy spectrum"

A. Haungs, ICRC 2003

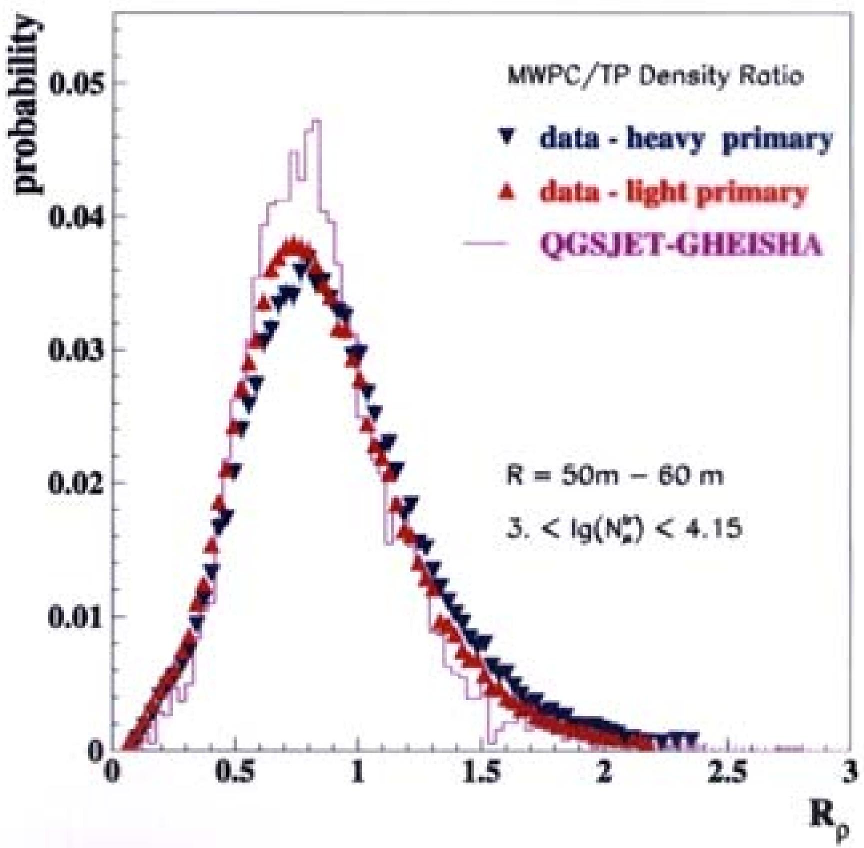
Muon Densities

sensitive parameter:

$$R_\varrho = \frac{\varrho_\mu^{\star}}{\varrho_\mu^{TP}}$$

at MWPC: $\varrho_\mu^{\star}$ $(E_\mu > 2.4\ \text{GeV})$

at TP: ϱ_μ^{TP} $(E_\mu > 490\ \text{MeV})$



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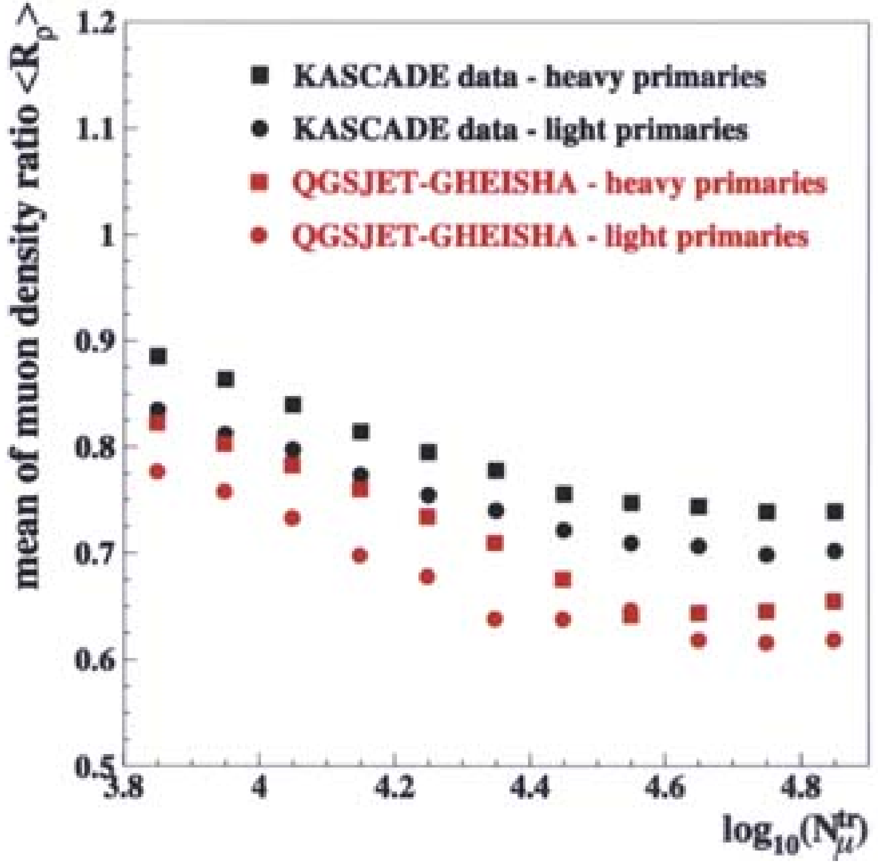
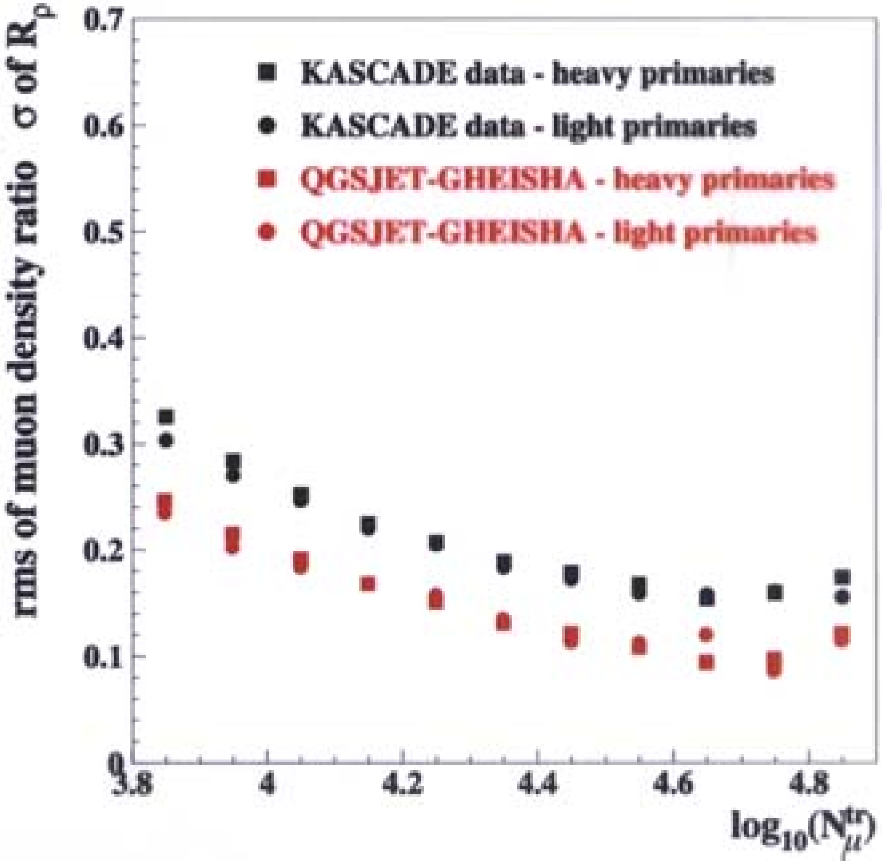
Muon Densities

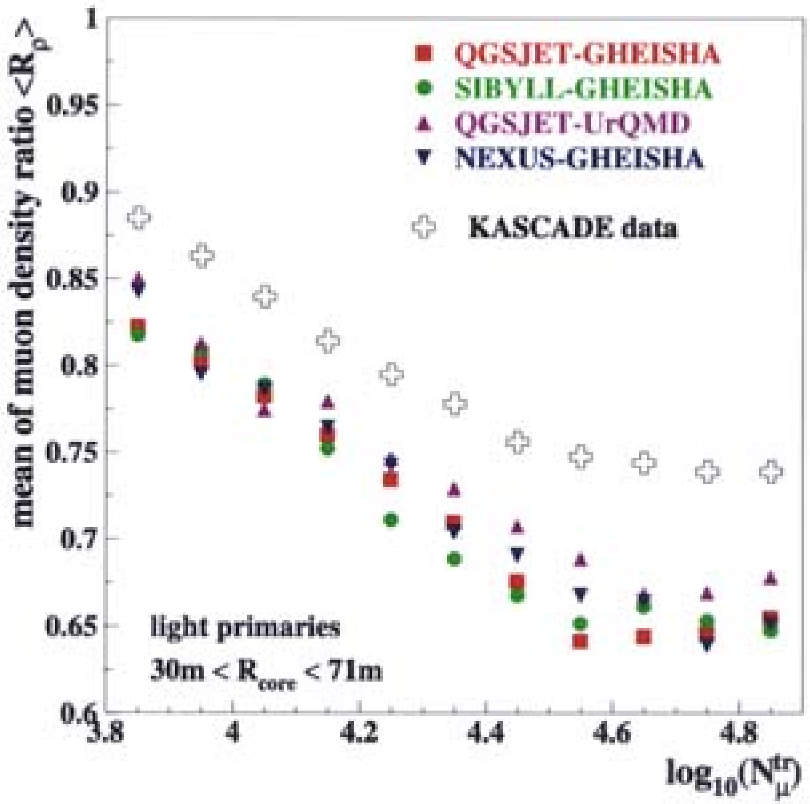
comparison measurement - simulation:

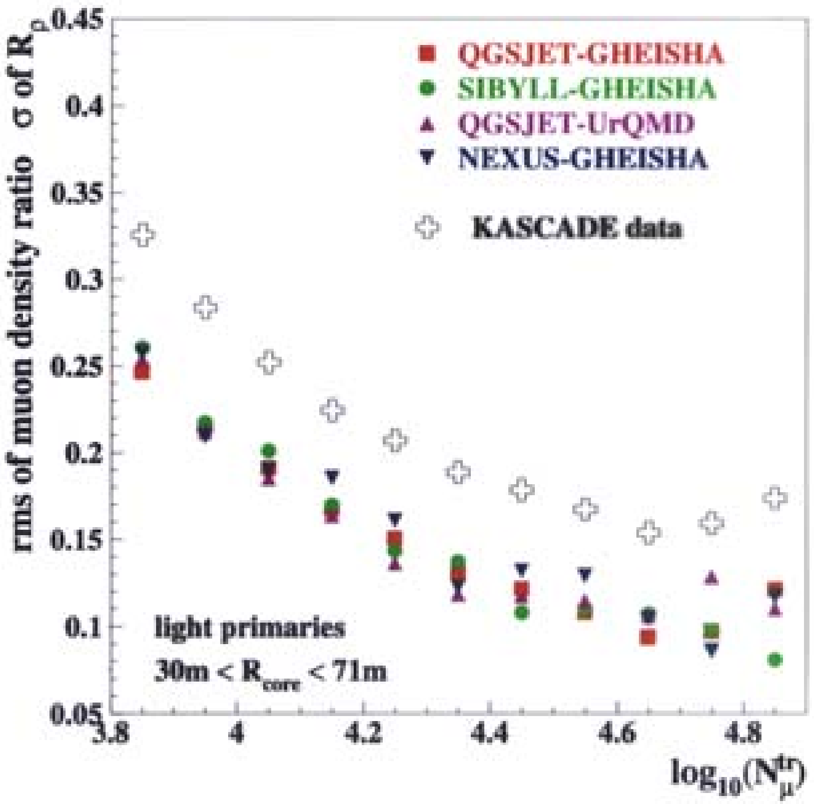




Muon Densities

comparison of different model combinations:





⇒ no model combination describes measured data

A. Haungs, ICRC 2003

Summary

- Test of hadronic interaction models necessary
  ⇒ check of reliability of EAS simulations

- KASCADE measures different air shower components simultaneously
  ⇒ model test possible by checking the correlation
  between shower components

- up to now: no model describes all correlations simultaneously

KASCADE-Grande Collaboration

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