Università degli studi di Torino
Corso di Laurea in Fisica
Laurea triennale
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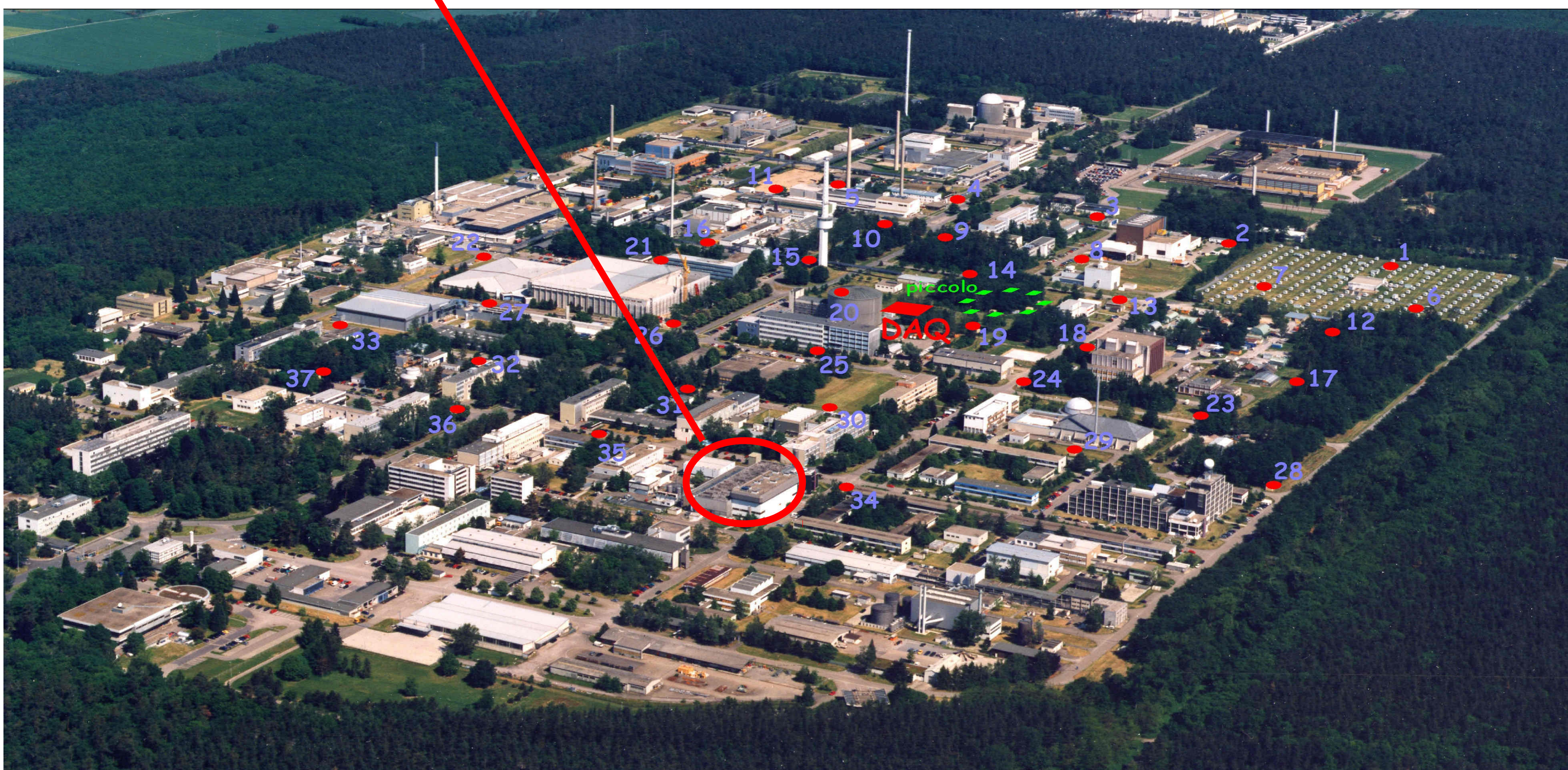
Muon density measurements at KASCADE-Grande and comparison with hadronic interaction models

Candidato: Chiara Stuardi
Relatore: Mario Edoardo Bertaina
Tutor aziendale: Andreas Haungs

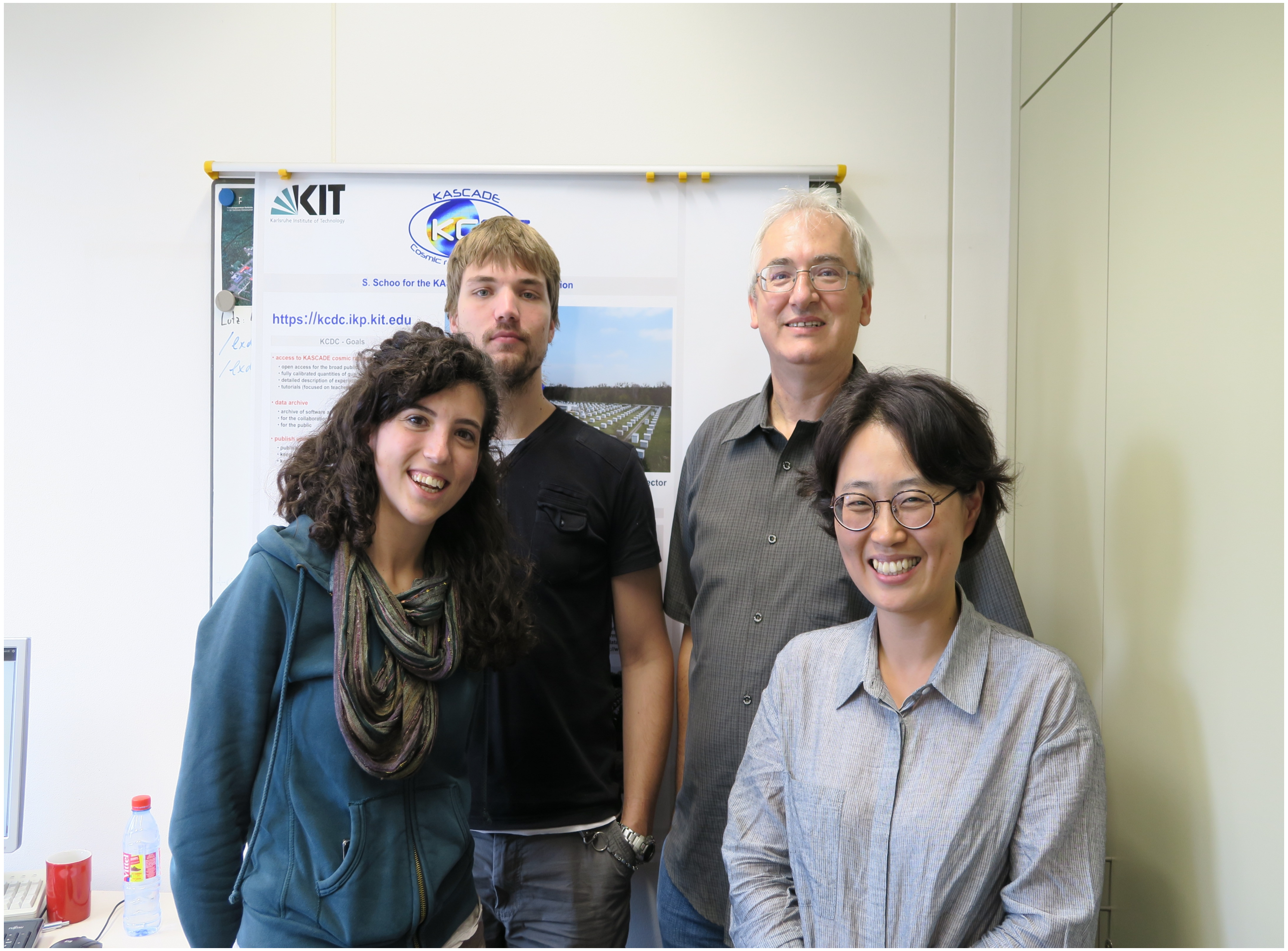
Karlsruhe, Germany

Internship at the Karlsruhe Institute of Technology



Internship period: 15.06.2015 – 15.09.2015

with the contribution of the KASCADE-Grande Collaboration

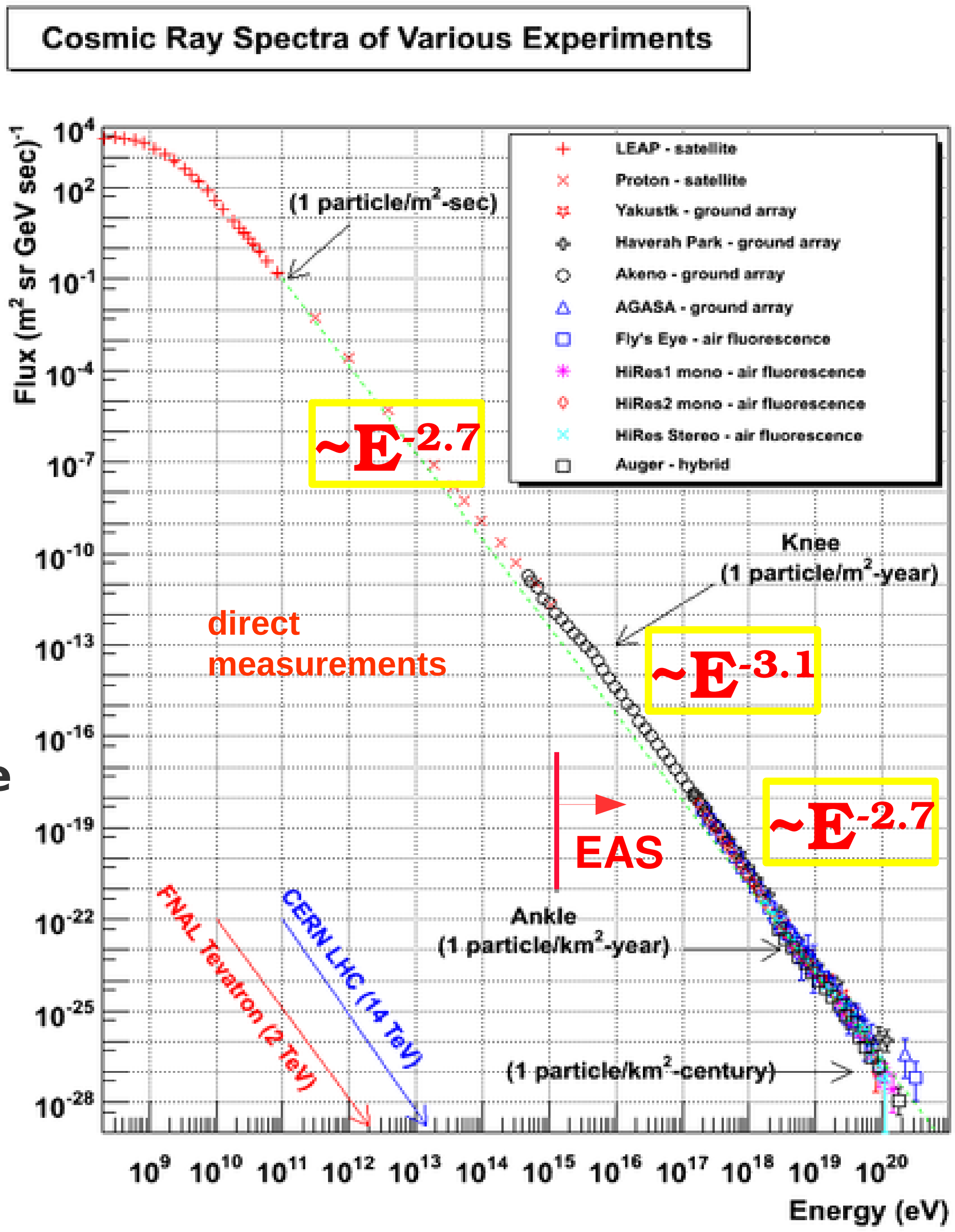


Cosmic rays

Power law energy spectrum:

$dN/dE \propto E^{-\gamma}$

above 10^{15} eV measurements of Extensive Air Shower

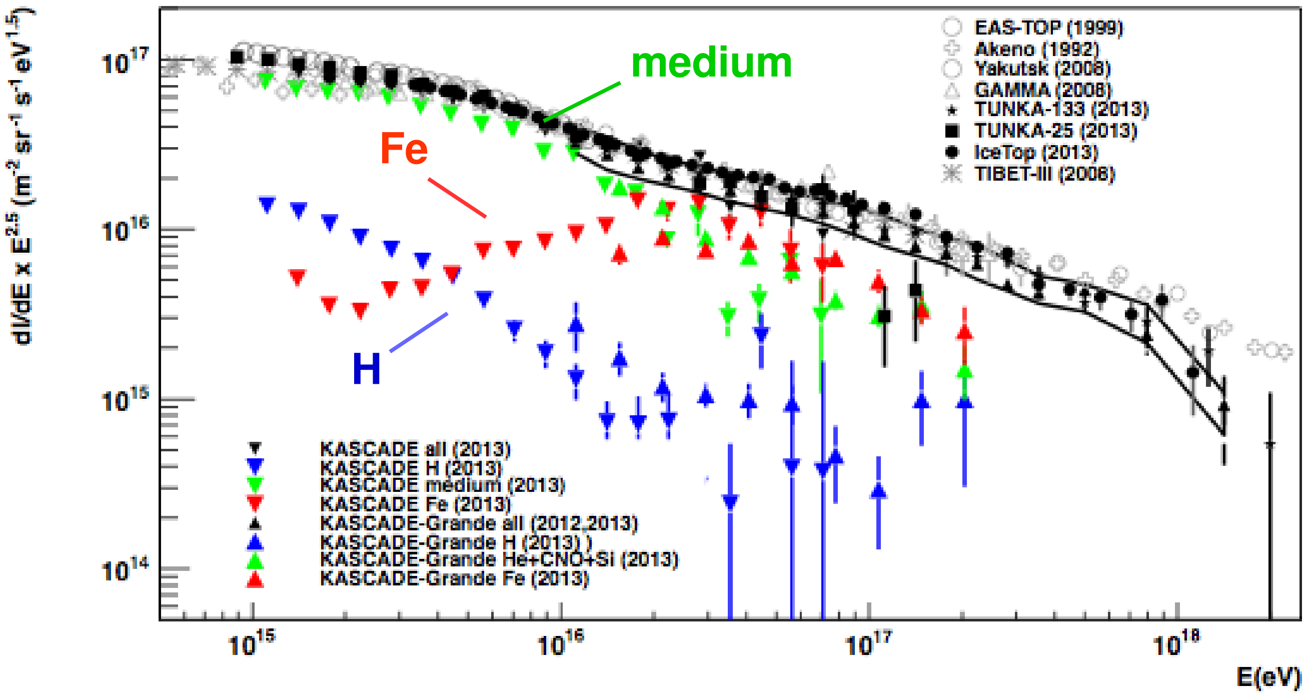


Change of the slope of the cosmic ray energy spectrum around $3 \cdot 10^{15}$ eV

Energetic limit of the acceleration mechanism?

Increase probability to escape galactic confinement?

Unsolved problem: the origin of the knee

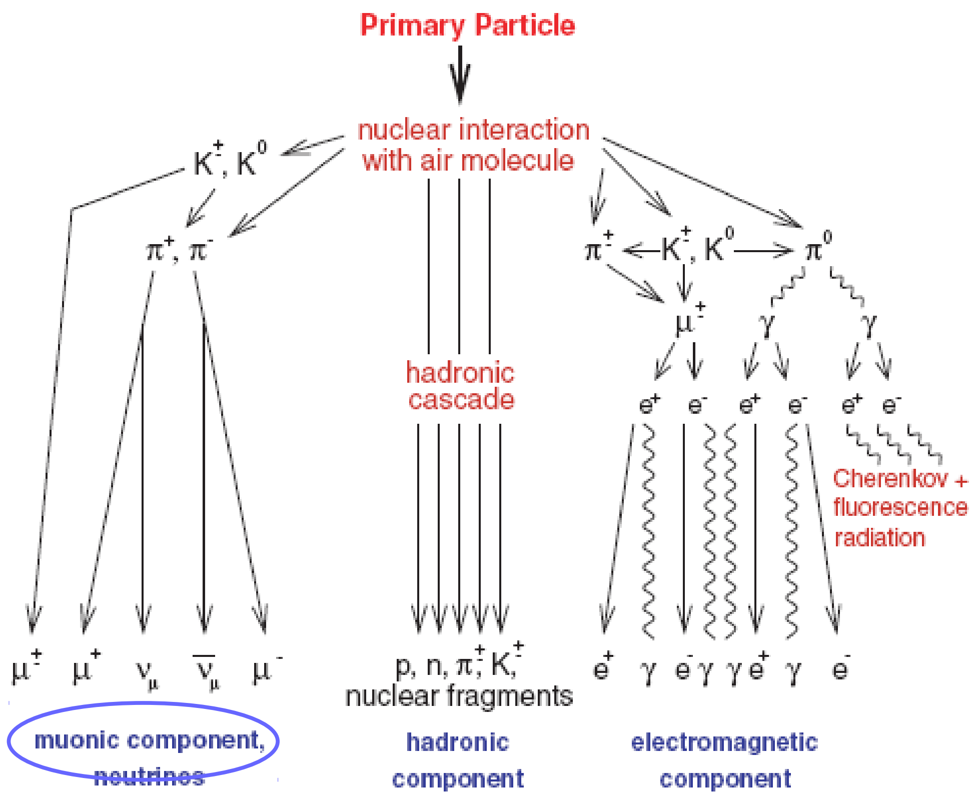


Evidences

- **The position of the knee depends on the primary particle $E_{knee} \propto Z$**
- **Knee is caused by light elements**

BUT: inconsistencies between measurements and hadronic interaction models based on Monte Carlo simulations

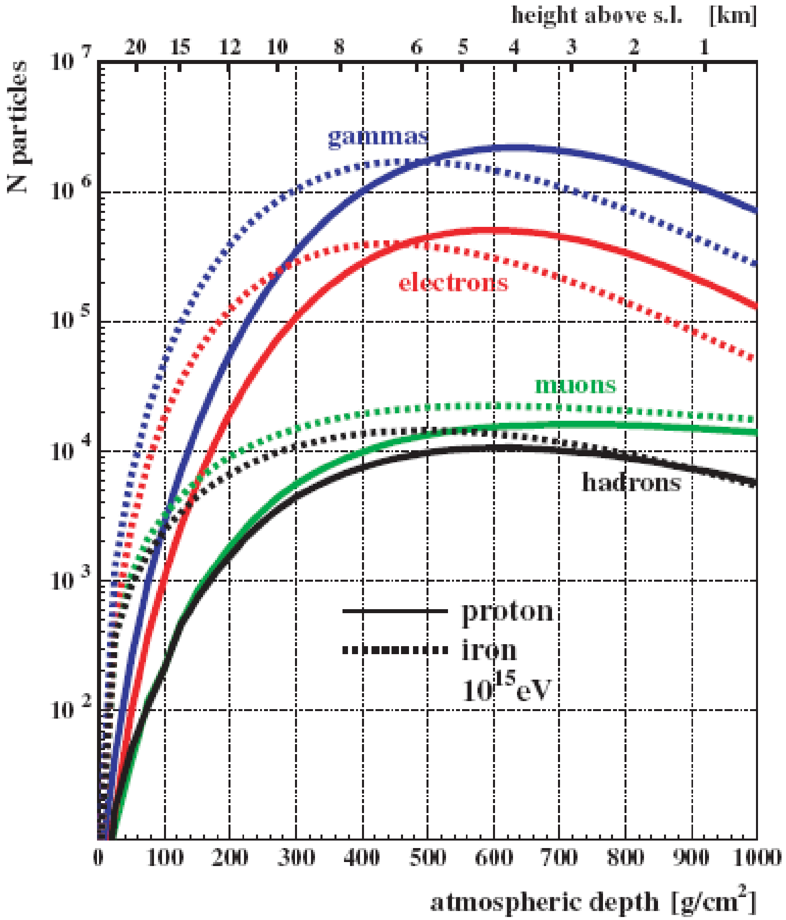
Extensive Air Showers

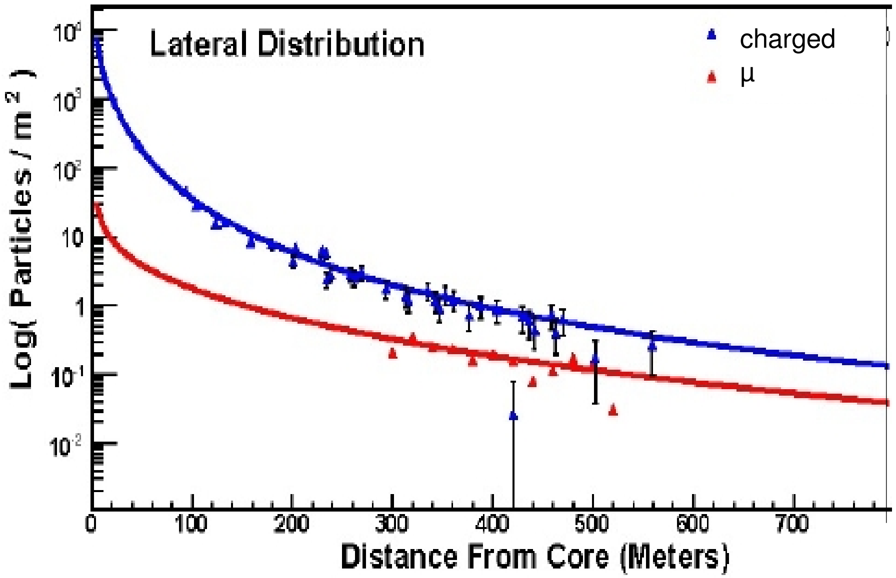


Cascade of secondary particles generated by the interaction of the high energy primary particle with the air nuclei

- **Necessity of a multi detector system to get redundant EAS informations**
- **Elaboration of hadronic interaction models for the reconstruction of the shower**

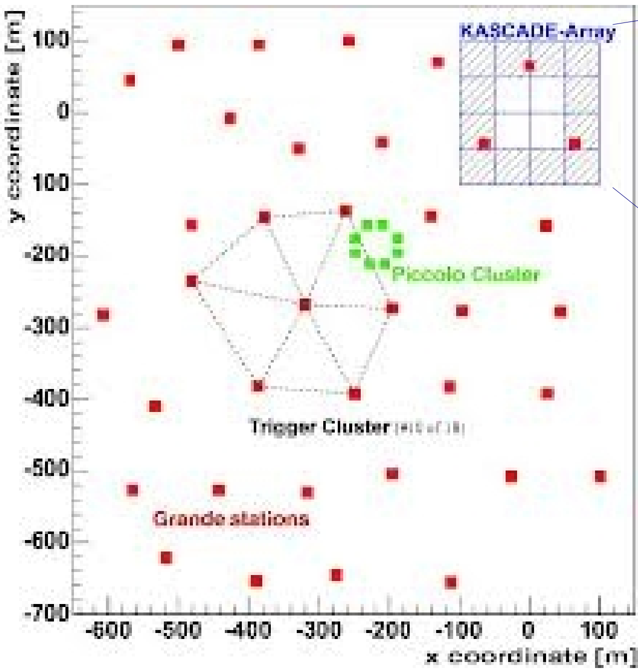
Extensive Air Showers

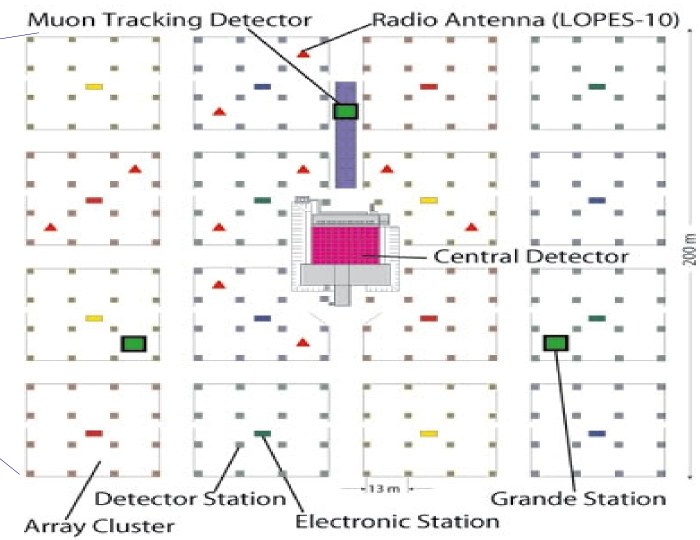




$(N\mu/Ne)_{Fe} > (N\mu/Ne)_H$

KASCADE-Grande experiment





Grande-array

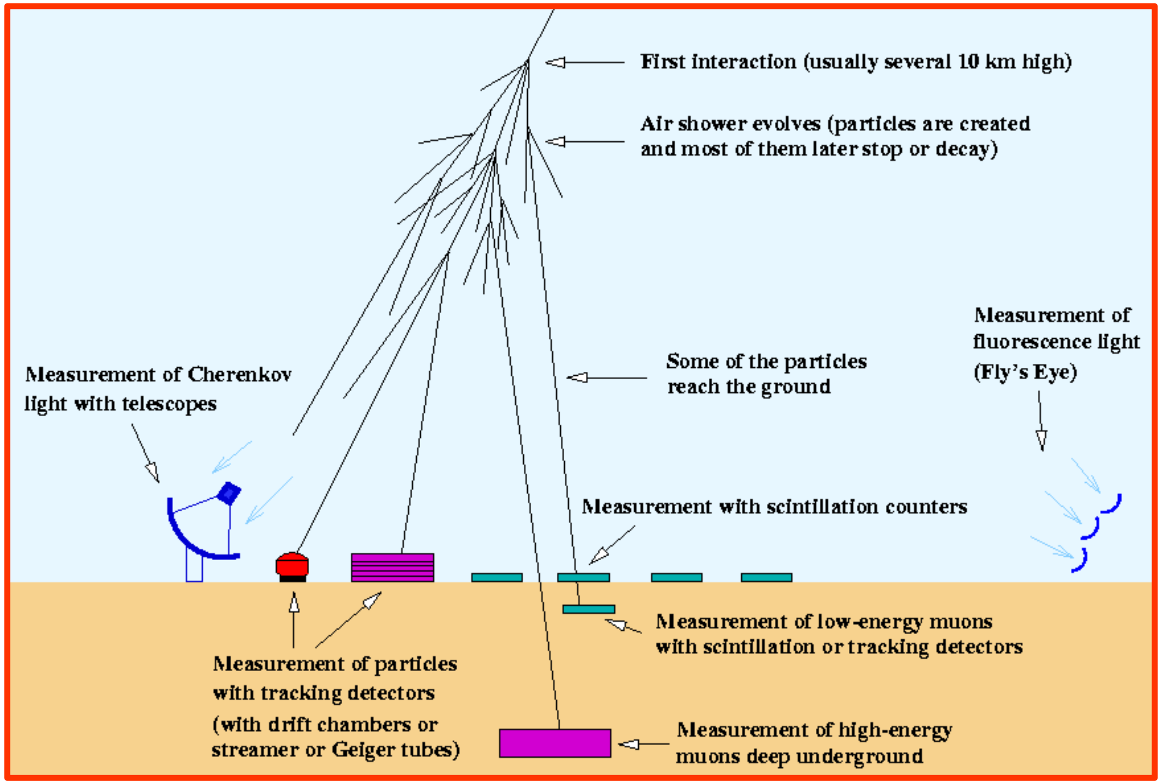
- **37 detectors**
- **Area: 700x700 m²**
- **Measures:**
  number of charged particles
- **Primary energy range:**
  10^{16} -10^{18} eV

KASCADE-array

- **252 scintillation detectors**
- **Area: 200x200 m²**
- **Measures:**
  number of charged particles
  number of muons
- **Primary energy range:**
  10^{14} -10^{17} eV

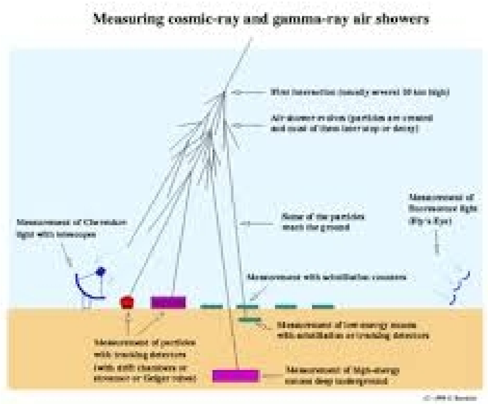
Hadronic interaction models

Test with different models on local muon density



- **QGSJetII-02, 2012: fan diagrams, diffraction, optimized for cosmic ray**
- **EPOS-LHC, 2015: nuclear effect, high density effect, all type of data studied**
- **QGSJetII-04, 2015: loop diagrams, rho0 resonance, optimized for cosmic ray**

EAS observation



Monte Carlo Simulation

Primary particle
A
Primary energy E

CORSIKA
QGSjet
EPOS-LHC
...

Data acquisition

CRES : Detector response

KRETA
Reconstruction of EAS observables

Comparison of the distributions

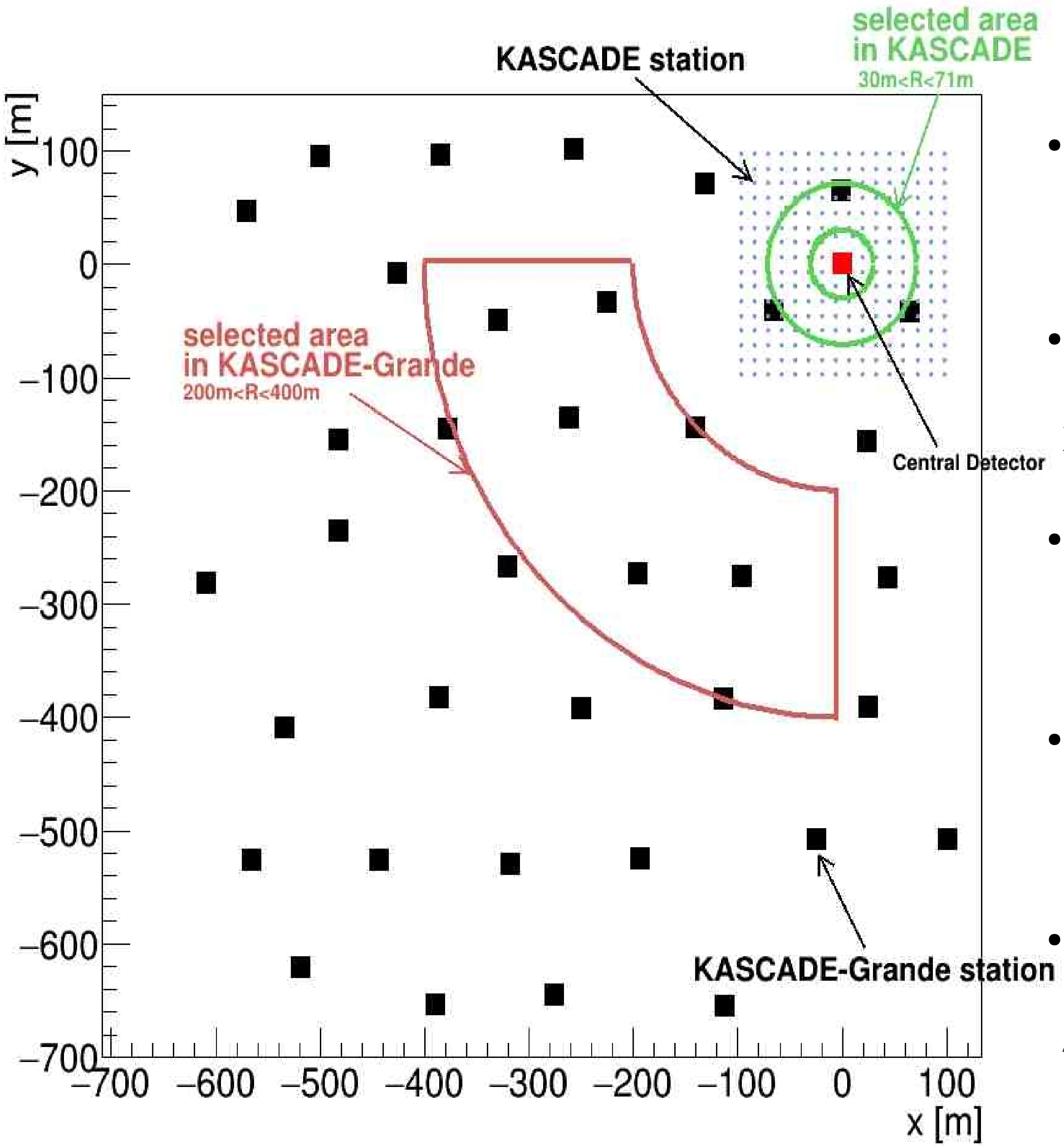
Experimental E, A
Energy spectra
Chemical composition

Tests of Interaction Models

The presented work consisted in:

- **selection of the data sets for two different distances from the shower core (applying general quality cuts)**
- **analysis of the variables relating to the local distribution of muon density**
- **comparison of the data with three different models**

Two selected areas



Informations from each EAS:

- **Shower direction:**

  Θ, Φ

- **Shower core:**

  x_c, y_c

- **Shower size:**

  $N_e \propto E$

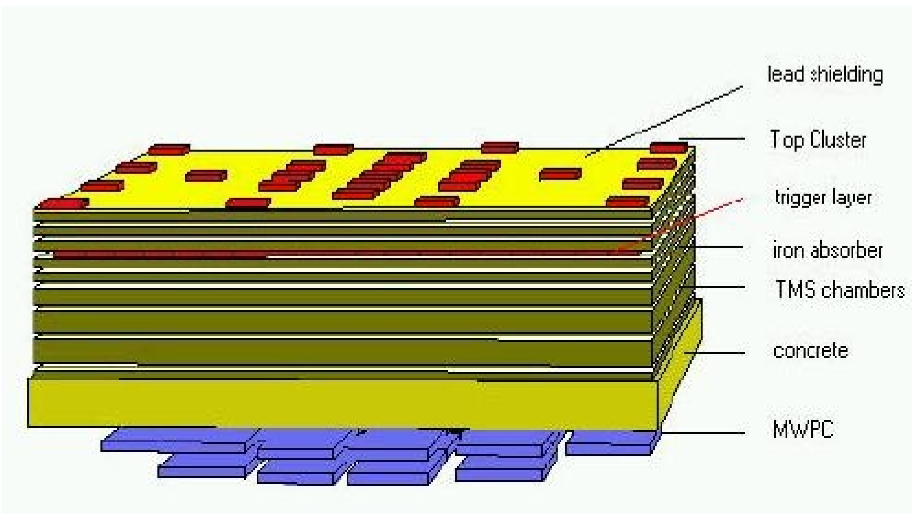
- **Muon size:**

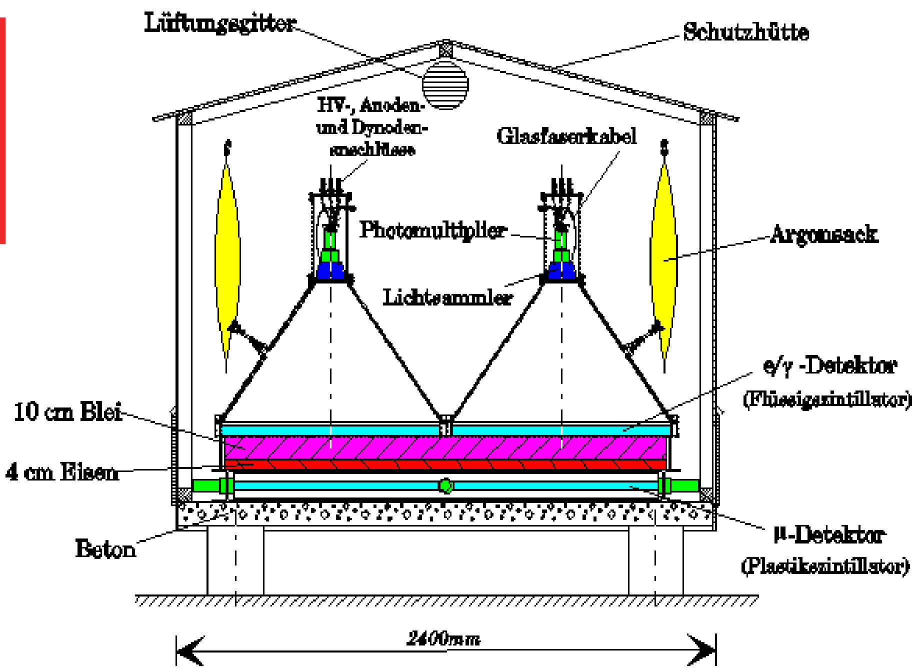
  N_μ

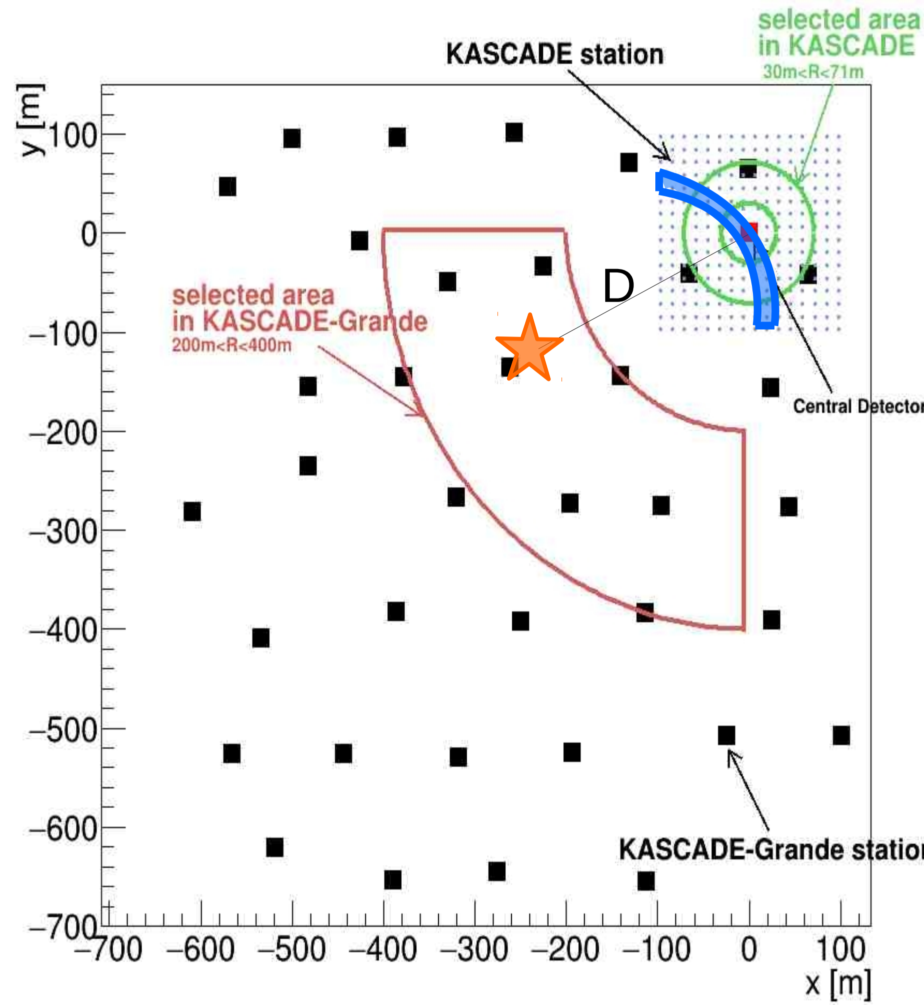
- **Detector sensitive area:**

  A

Measurements of local muon density



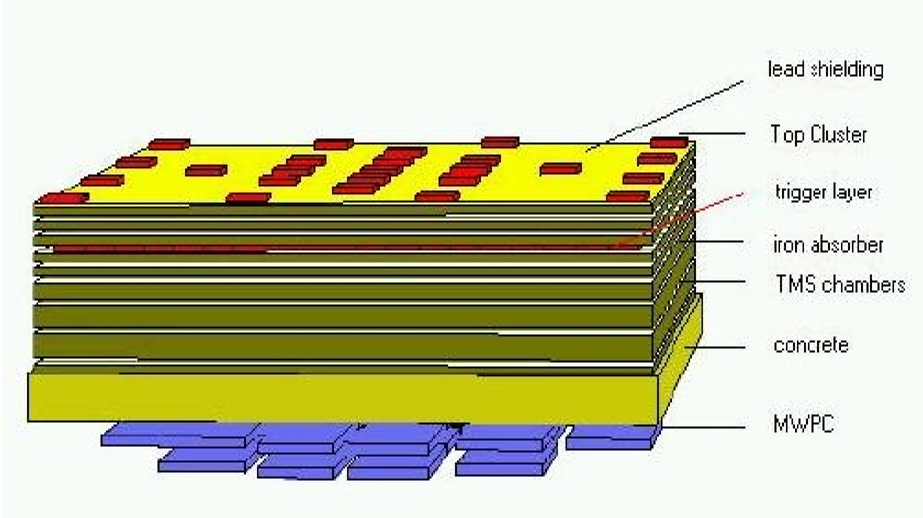




Kascade-array stations selection

$D - 10\ m < d < D + 10\ m$

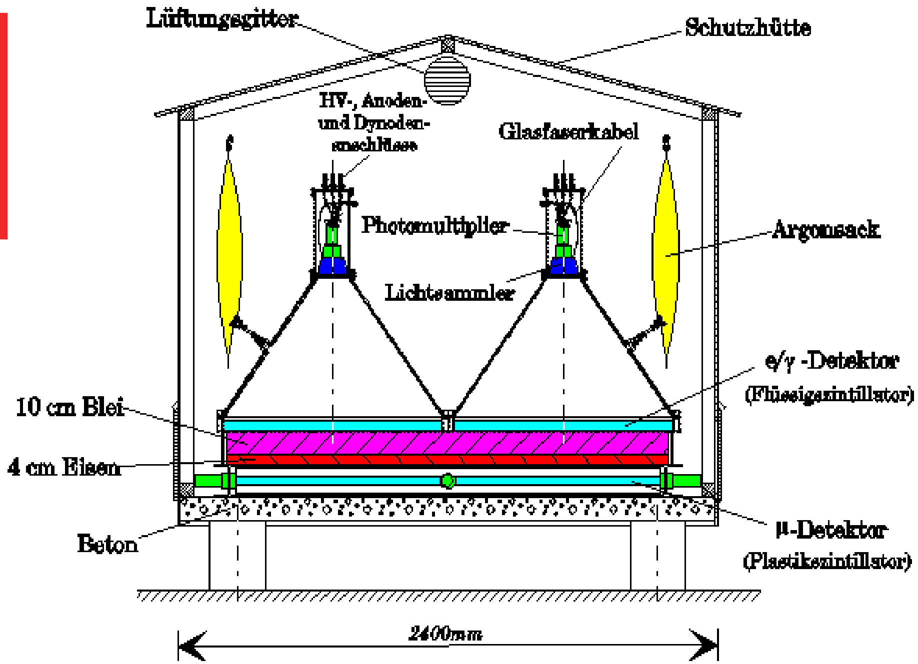
Measurements of local muon density



Multi Wire Proportional Chambers(Central Detector)

Energy threshold: 2.4 GeV

→ $\rho^{2.4\,GeV} = N_\mu^{2.4\,GeV}/A^{CD}$



Kascade-array stations (plastic shielded scintillators + photomultipliers)

Energy threshold: 230 MeV

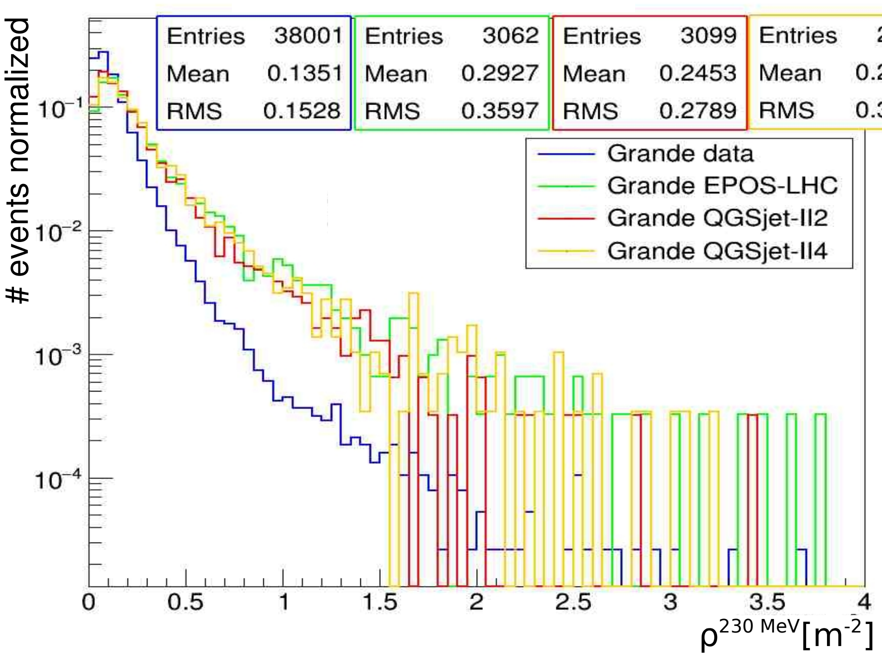
→ $\rho^{230\,MeV} = N_\mu^{230\,MeV}/(A^{st} \cdot n^{st})$

n^{st} = number of Kascade-array station used for each shower

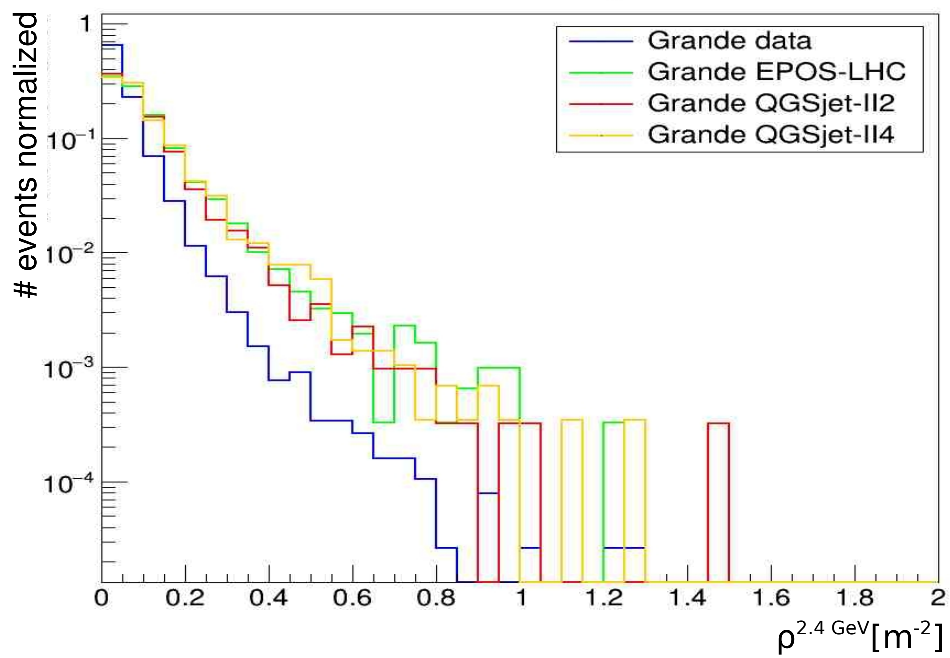
Measurements of local muon density

**Number of events with a certain muon density
for both energy thresholds
in Grande selection**

230 MeV



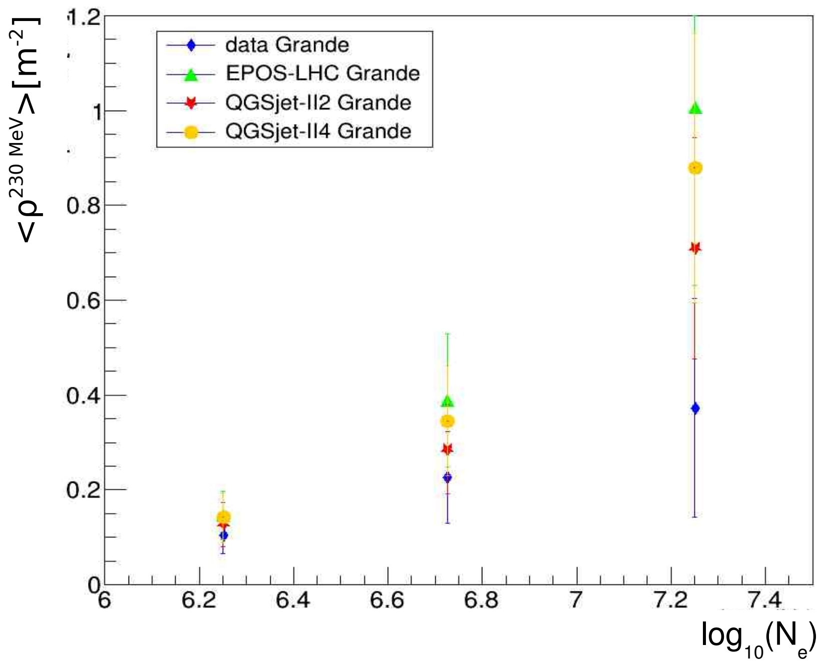
2.4 GeV



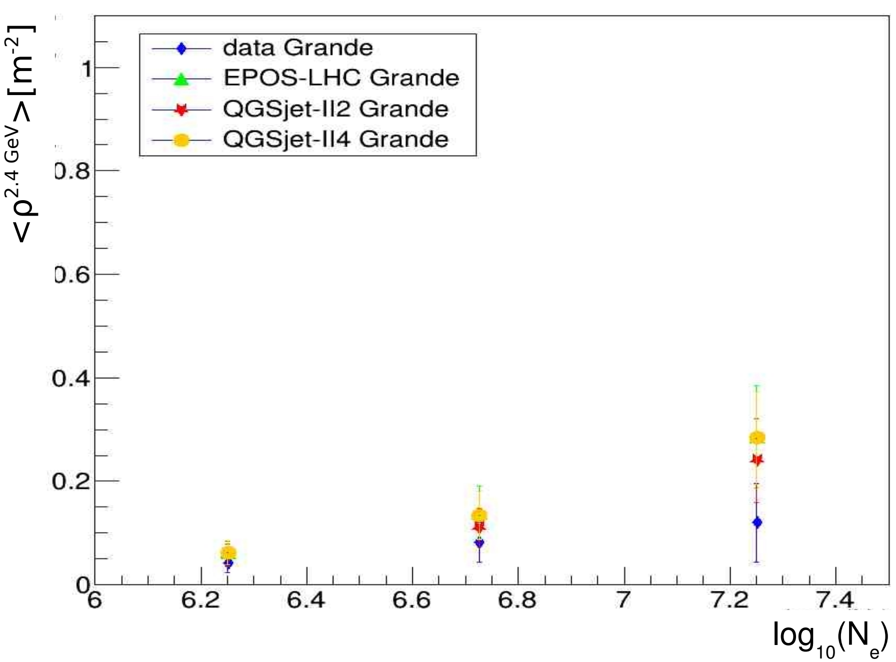
Measurements of local muon density

Distribution of mean density with N_e for both energy thresholds in Grande selection

230 MeV



2.4 GeV



Useful to observe differences between the models but not comparable with data

- **Pure density is dependent from primaries energy spectrum, total muon number and composition**
- **Possible errors in the shower reconstruction**

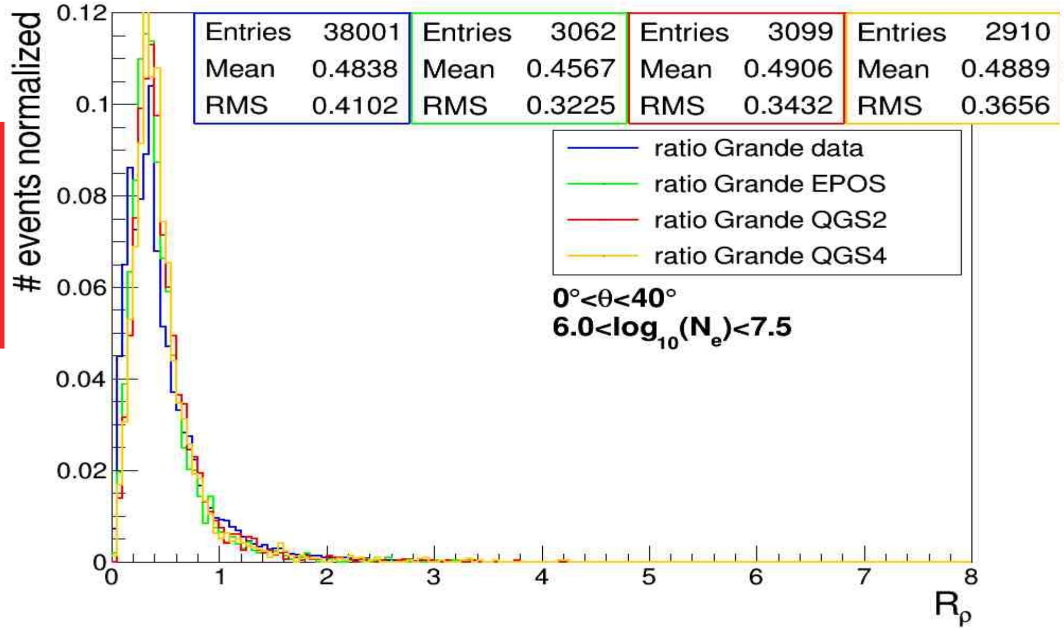
Density ratio: a good parameter

R_ρ is:

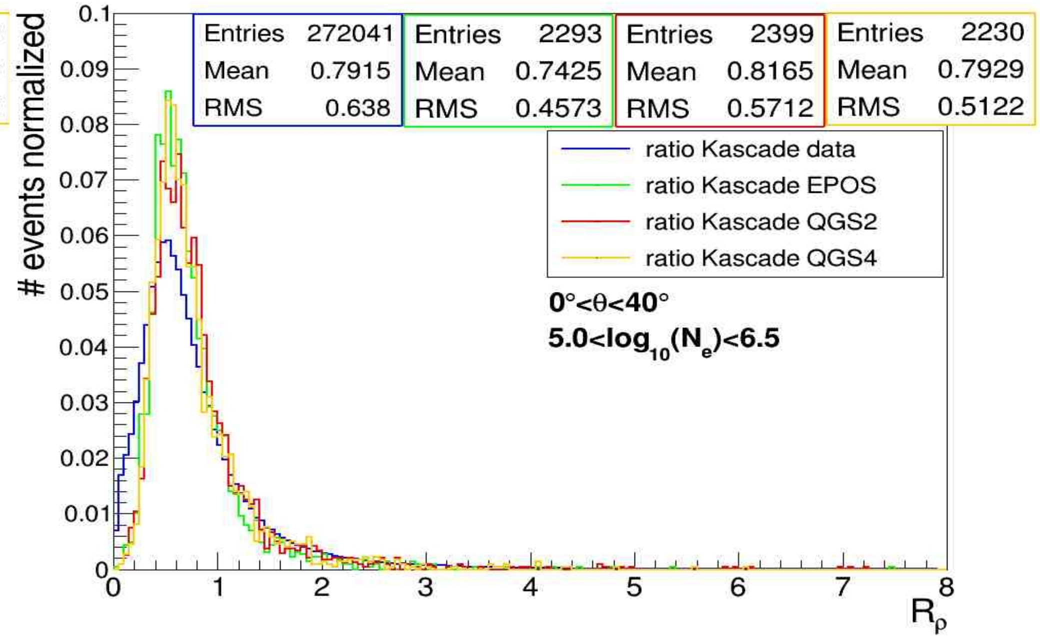
- insensitive to primaries energy spectrum
- insensitive to total muon number
- nearly independent on the composition
- not affected from reconstruction errors
- model dependent

$$R_\rho = \frac{\rho^{2.4\,GeV}}{\rho^{230\,MeV}}$$

Grande selection



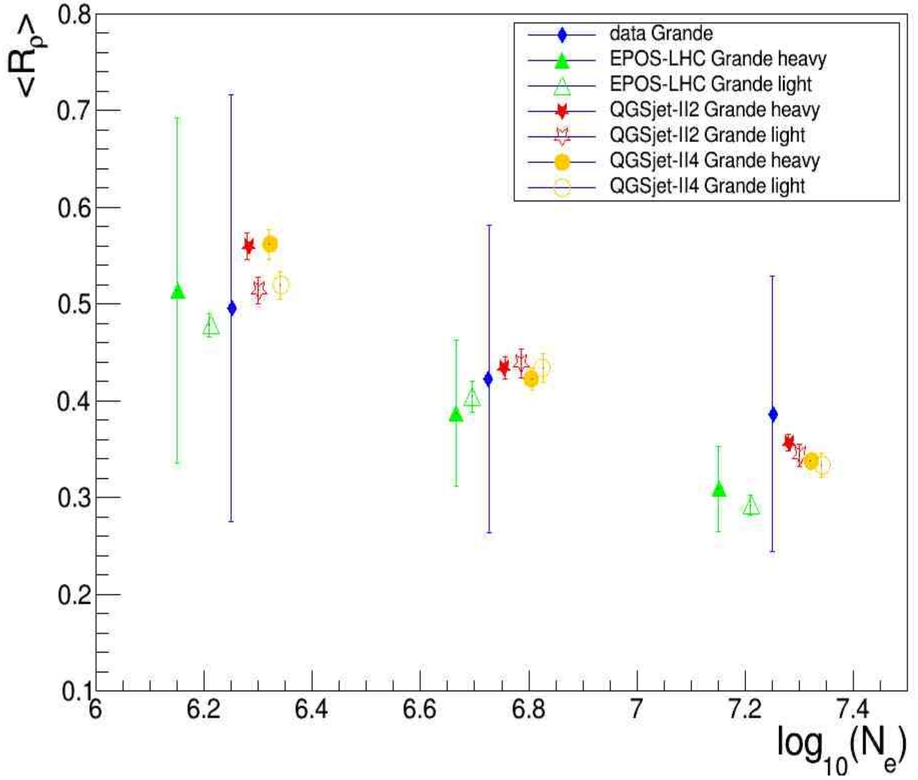
Kascade selection



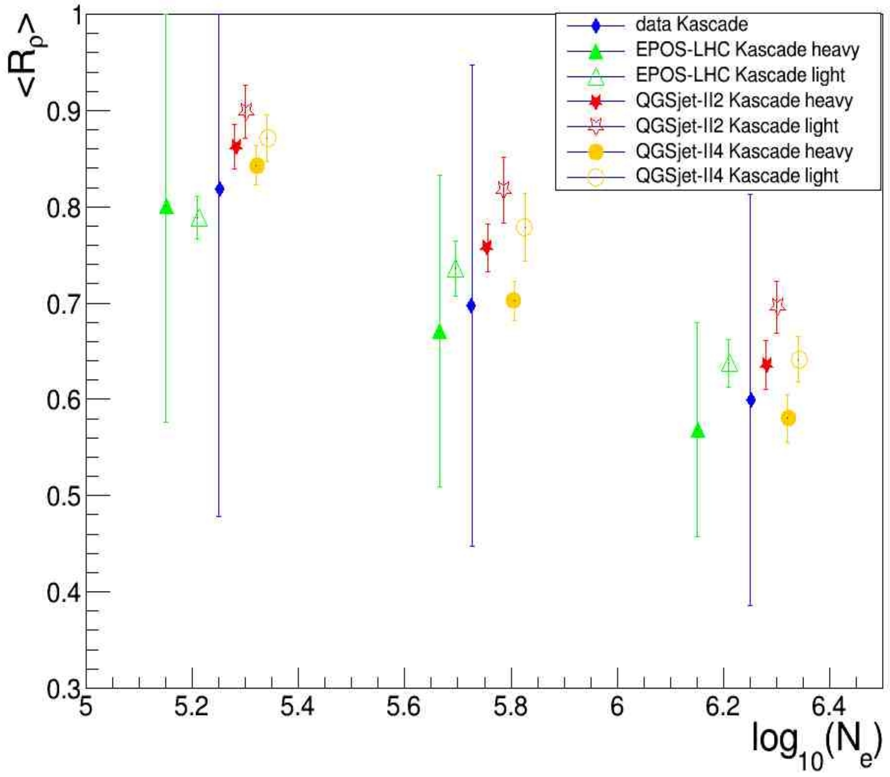
Comparison: light and heavy primaries

Distribution of mean ratio with Ne for both selections:
light (H, He) and heavy (C, Si, Fe) separated in the simulations

Grande selection

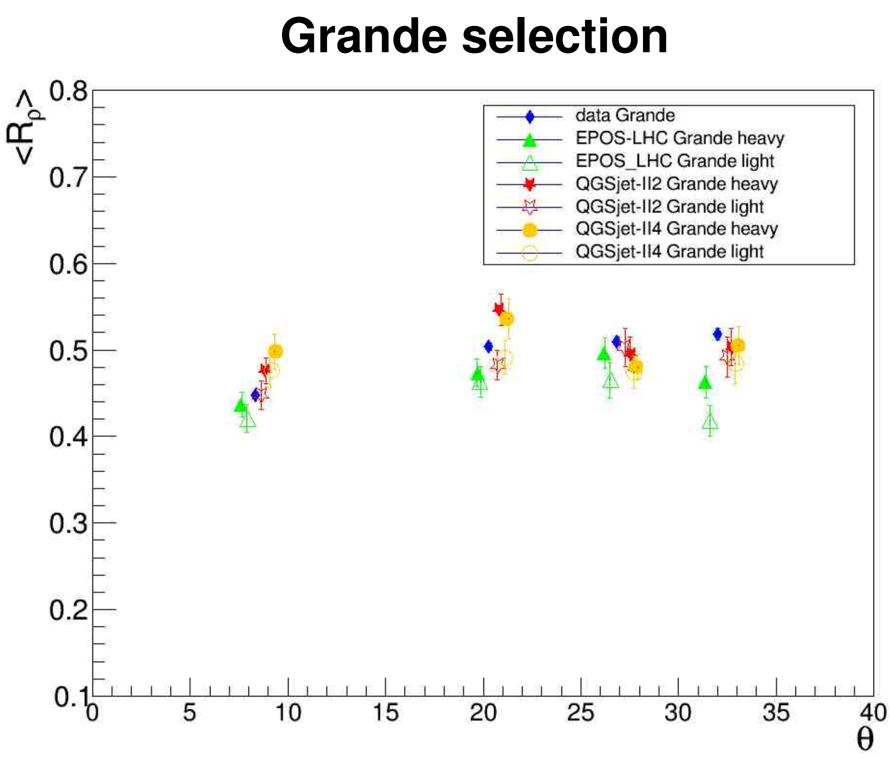


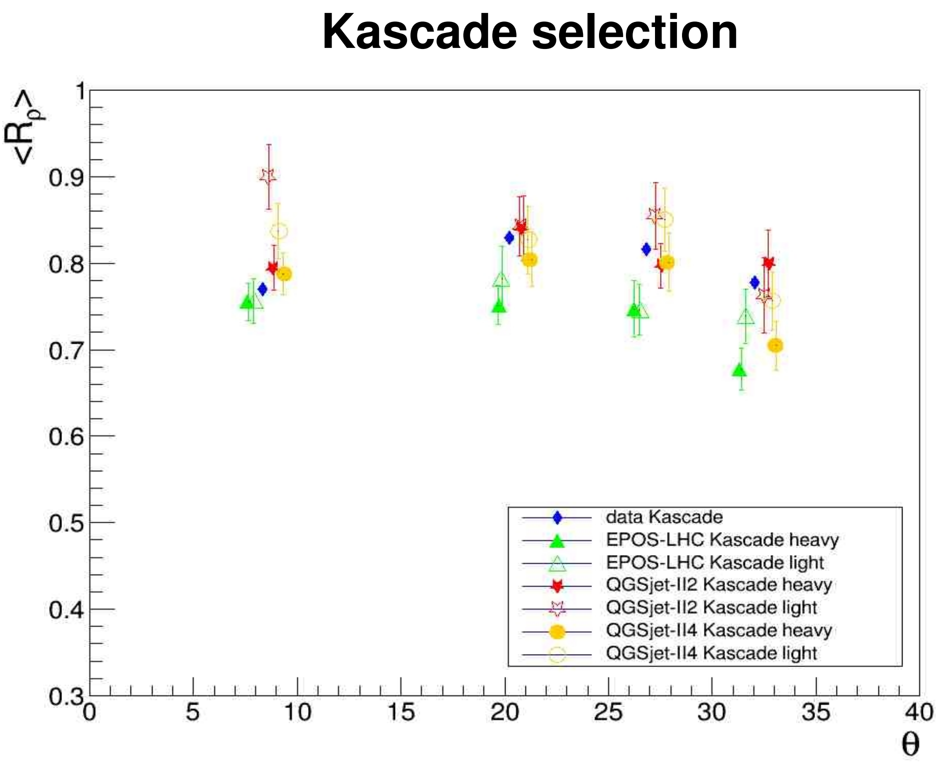
Kascade selection



- **Greater ratio for Kascade selection → high-energy interaction region**
- **Downward trend: more energetic is the shower, the higher is the number of low-energy muons produced in it at fixed distance**

Comparison: light and heavy primaries

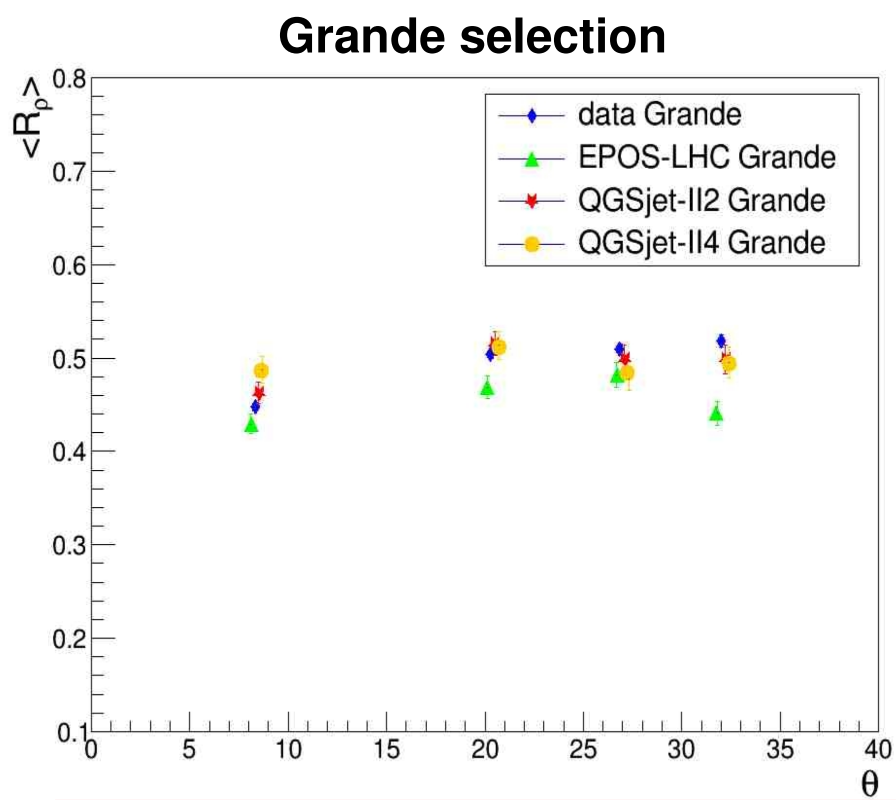


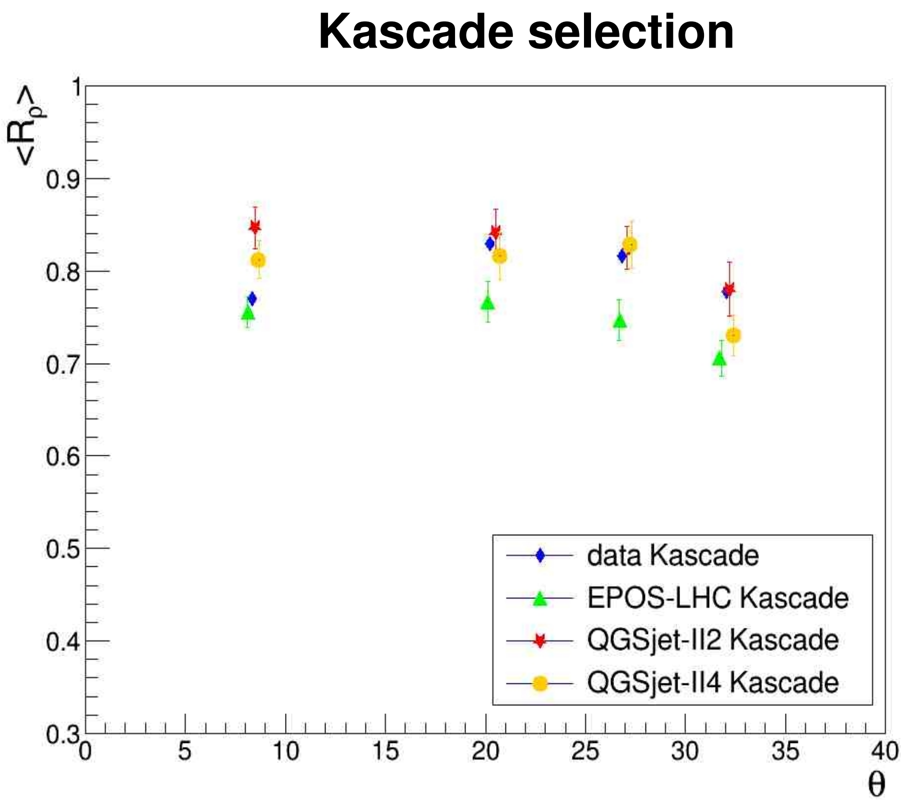


- **Uncertainties on data composition**
- **Small deviation between light and heavy compatible with deviation between data and models**

} **Mixed composition analysis**

Comparison: mixed composition



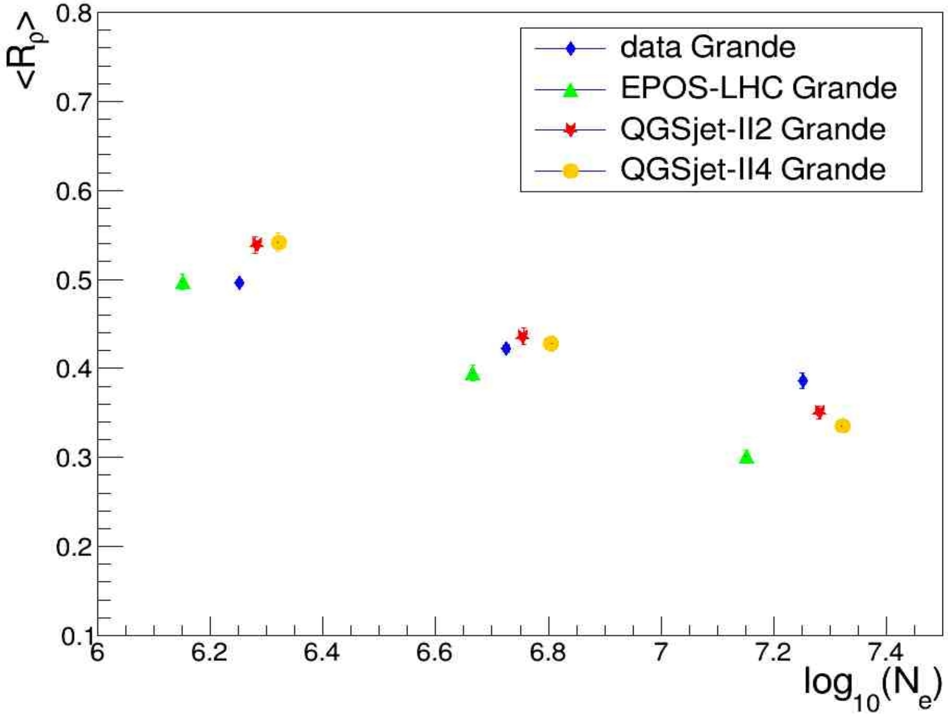


Grande selection		Kascade selection	
light -heavy deviation	model-data deviation	Light-heavy deviation	model-data deviation
0.027 ± 0.005	0.026 ± 0.005	0.035 ± 0.007	0.034 ± 0.008

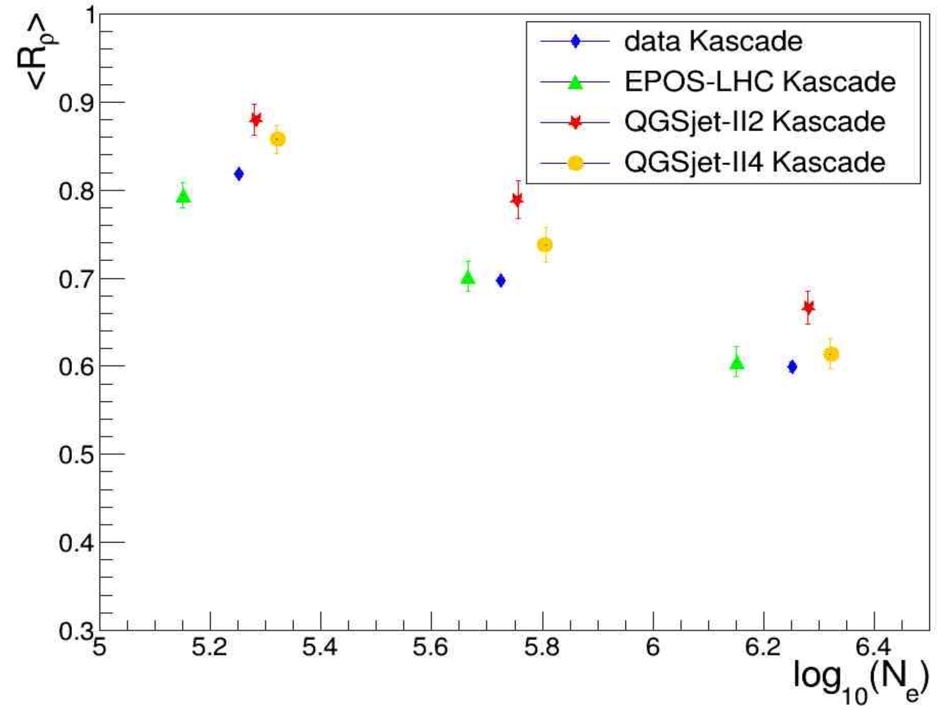
- **Flat trend as expected**
- **EPOS-LHC has a lower ratio in comparison with the data → few high energy muons**

Comparison: mixed composition

Grande selection



Kascade selection



- **Same trend for all models that well reproduces the behavior of data**
- **Different behavior at different distances from the shower core**
- **Systematic differences between models**

Conclusions

- **This work provides a basis for a more detailed analysis: with this method it is possible to separate models, understand their differences and compare with data.**
  Future analysis will have a larger number of simulated events and will be performed with appropriate statistical methods, taking account of systematic errors.

- **The use of two area selections allows to observe different behaviors at different distances from the shower core.**

- **For this level of analysis it seems that the more representative models are EPOS-LHC and QGSjet-II04 while in most cases QGSjet-II02 provides too many high-energy muons.**

The complete work is exposed in the report done at the end of the internship period :

Muon density measurements
@ KASCADE-Grande and comparison with
hadronic interaction models

Period of internship at the IKP : 15.06.2015 – 15.09.2015

Chiara Stuardi

Supervisor: Andreas Haungs
Tutor: Sven Schoo

THANK YOU