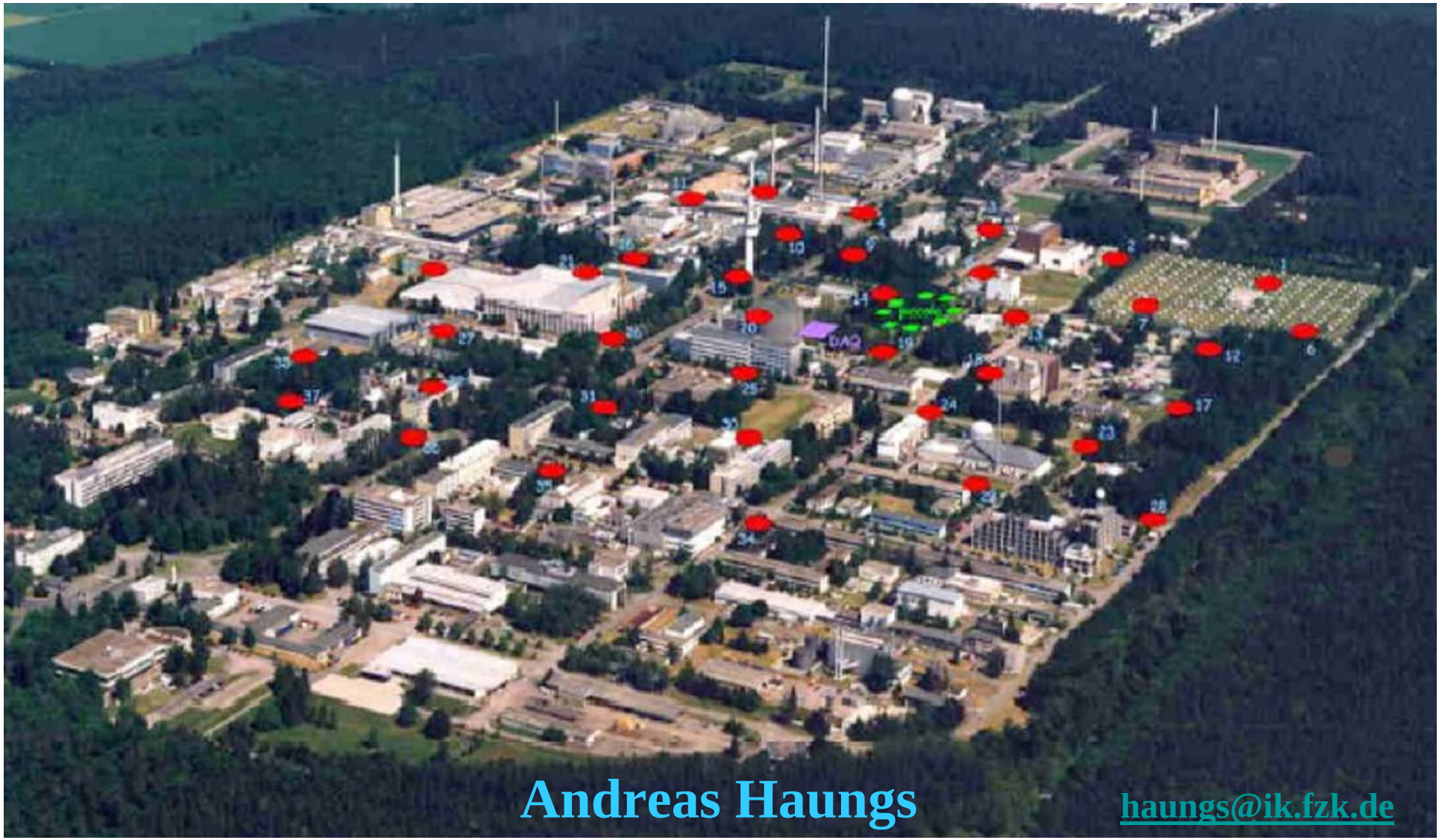
Forschungszentrum Karlsruhe
in der Helmholtzgemeinschaft

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

HELMHOLTZ GEMEINSCHAFT

Investigating the 2nd Knee: KASCADE-Grande



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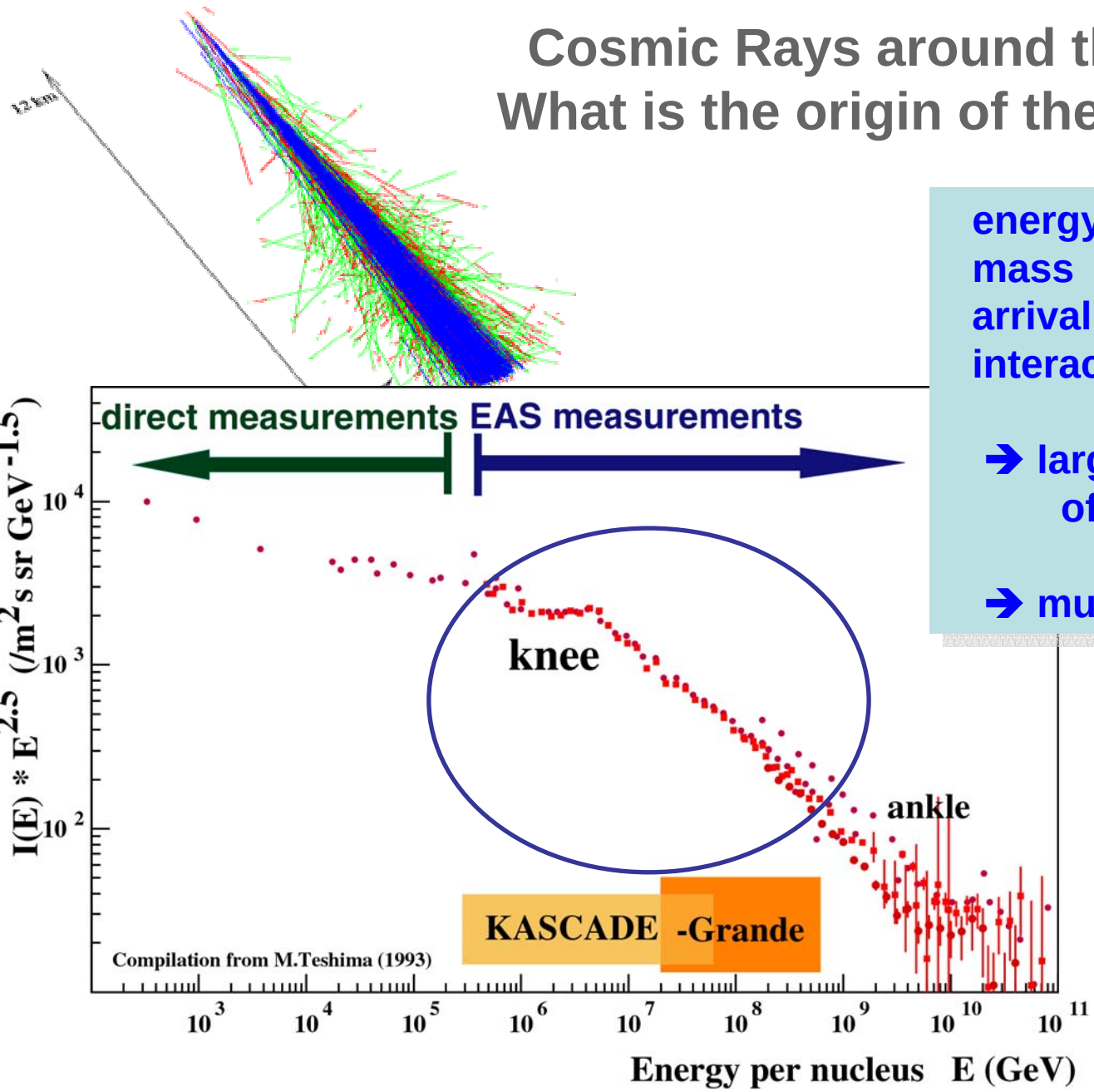
Cosmic Rays around the knee: What is the origin of the knee(s)?



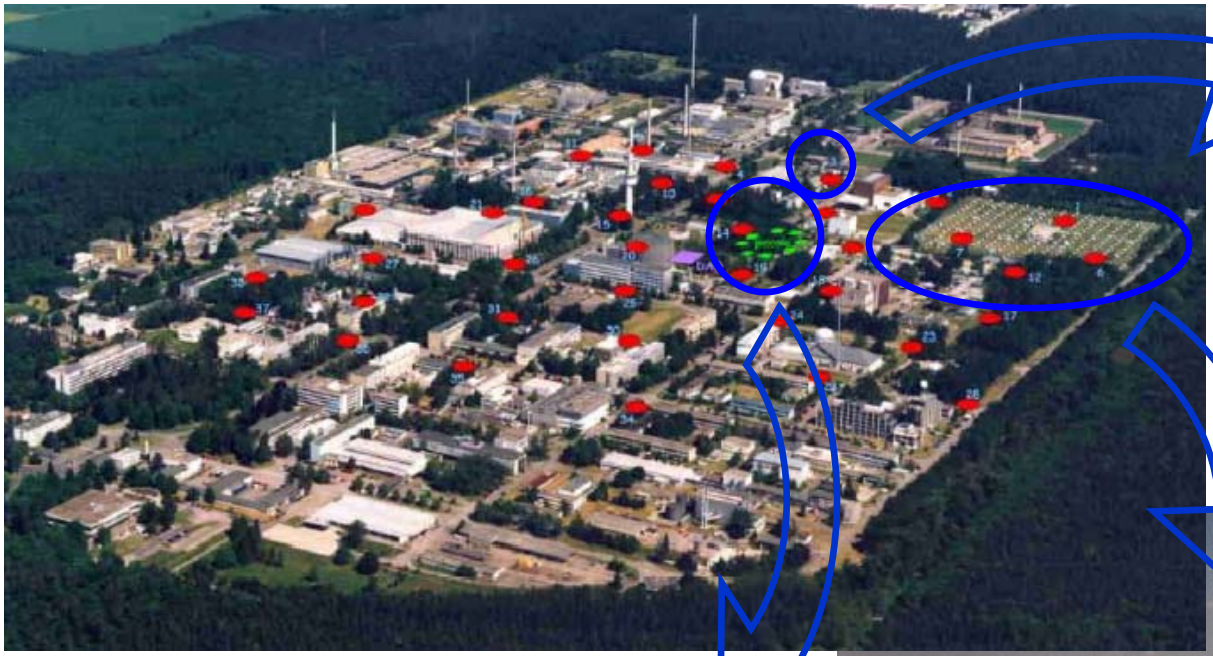
energy ?
mass ?
arrival directions ?
interaction mechanism ?

➔ **large number of observables**

➔ **multi-detector system**

KASCADE-Grande
= KArlsruhe Shower Core and Array DEtector + Grande

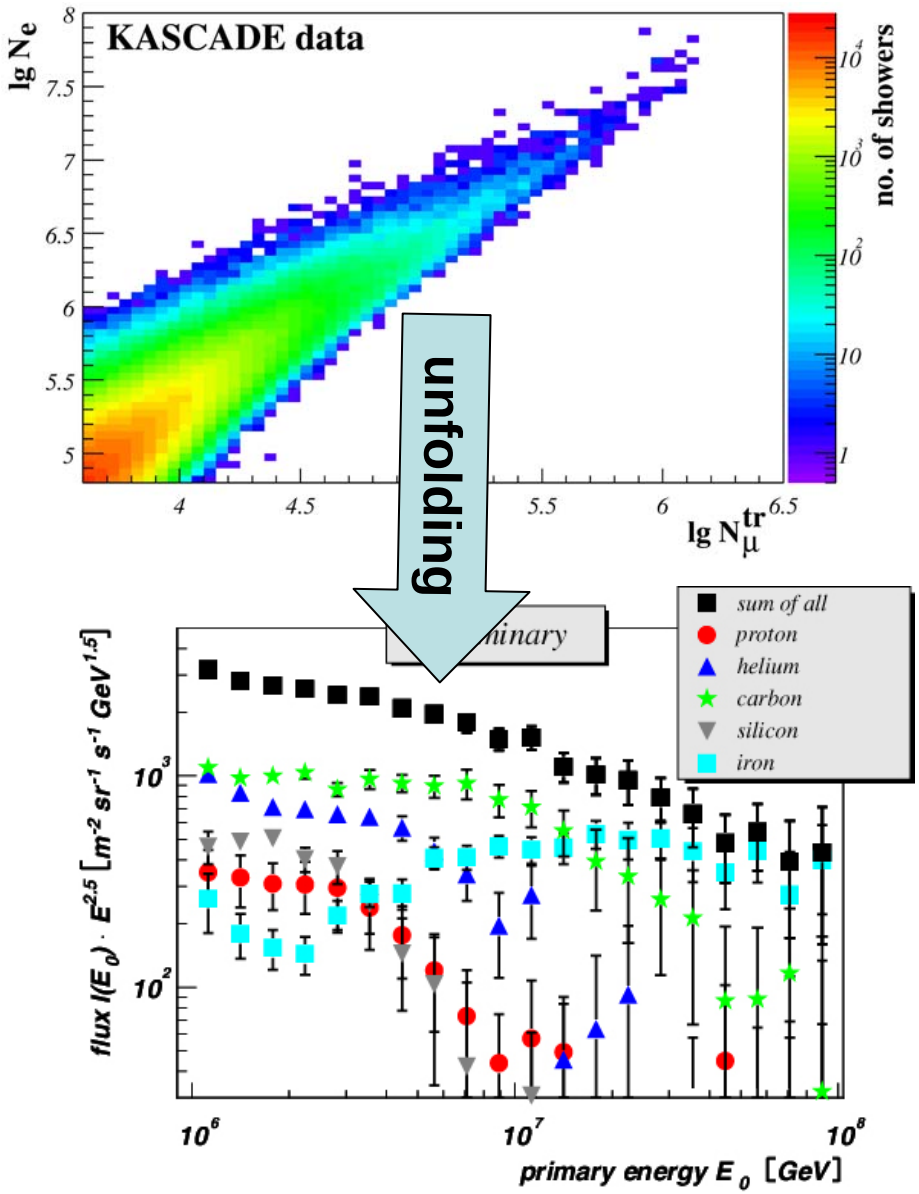
Measurements of air showers in the energy range E_0 = 100 TeV - 1 EeV



KASCADE : multi-parameter measurements

- energy range 100 TeV – 80 PeV
- up to 2003: $4 \cdot 10^7$ EAS triggers
- large number of observables:
  - ➔ electrons
  - ➔ muons (@ 4 threshold energies)
  - ➔ hadrons

KASCADE: energy spectra of single mass groups



Measurement:
KASCADE array data
900 days; 0-18° zenith angle
0-91 m core distance
lg N_e > 4.8; lg N_μ^{tr} > 3.6
➔ 685868 events

Searched:
E and A of the Cosmic Ray Particles
Given:
N_e and N_μ for each single event

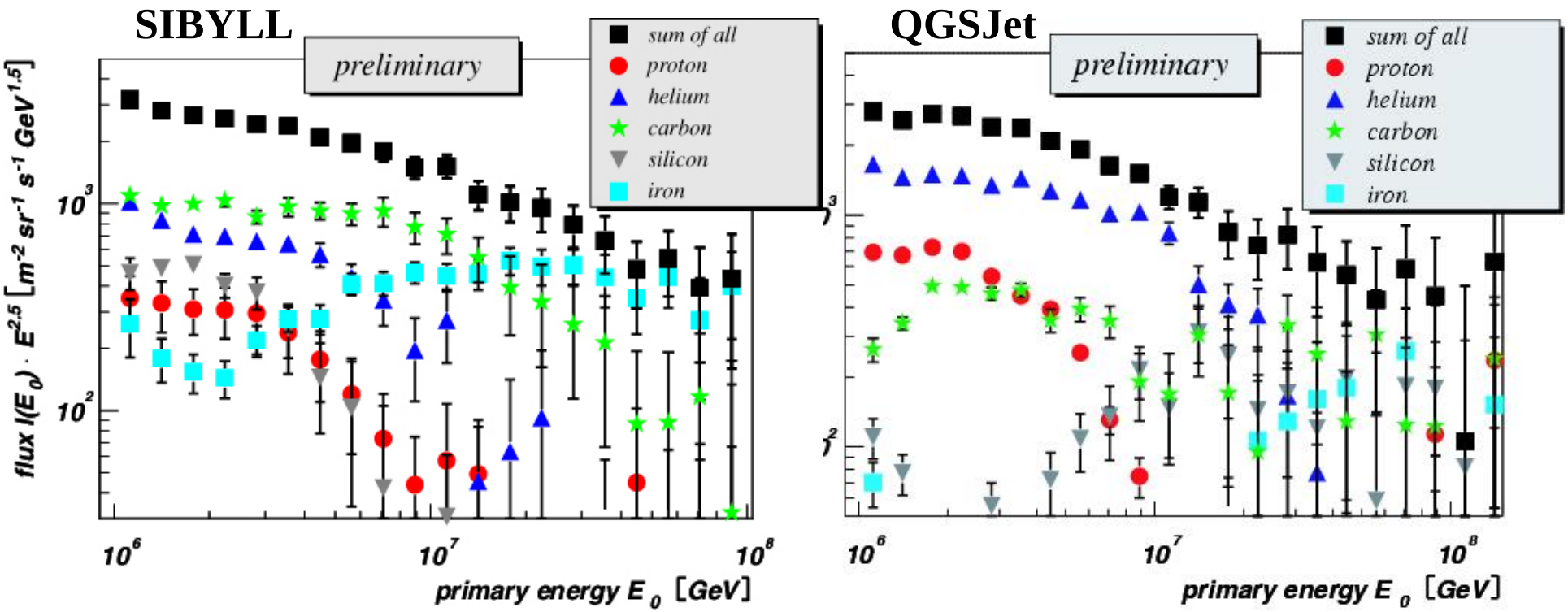
➔ solve the inverse problem

$$g(y) = \int K(y,x)p(x)dx$$

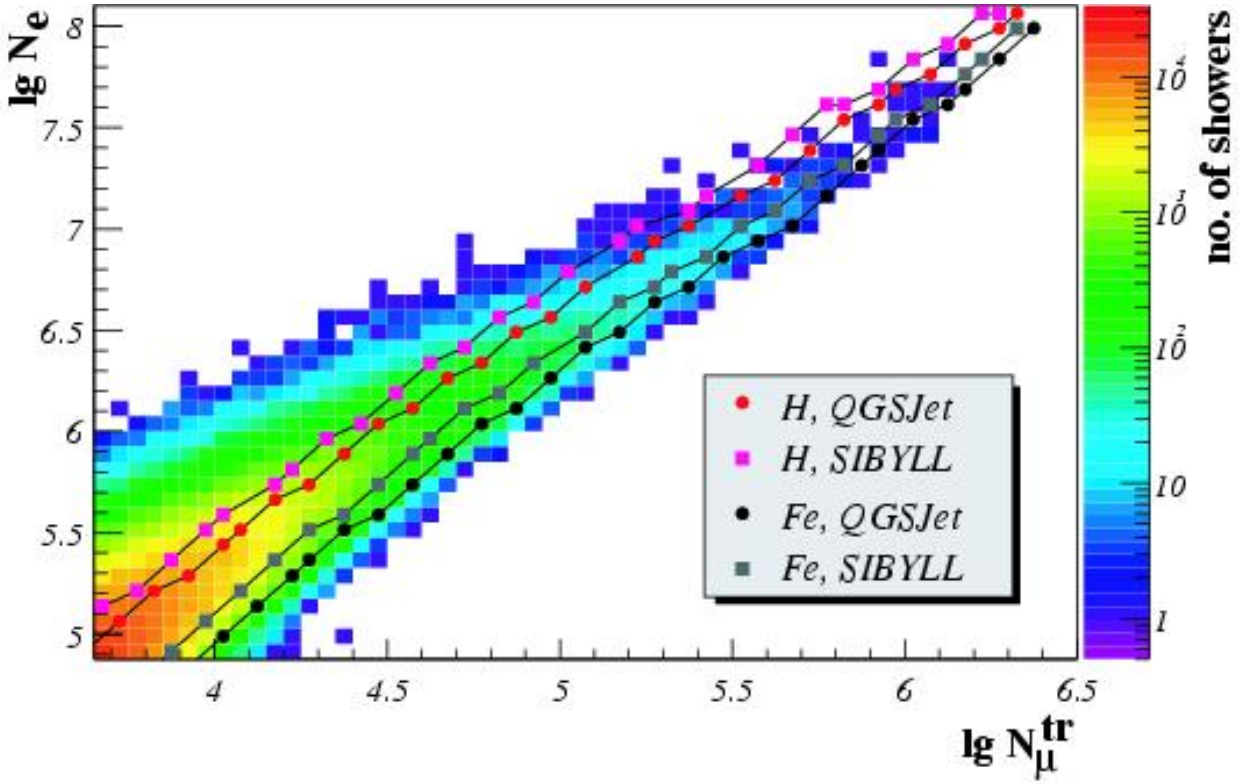
with y=(N_e,N_μ^{tr}) and x=(E,A)

KASCADE result: influence on hadronic interaction model

same unfolding but based on two different interaction models: SIBYLL 2.1 and QGSJET01 (both with GHEISHA 2002)



KASCADE result: sensitivity to hadronic interaction models



Main results keep stable independent of method or model:

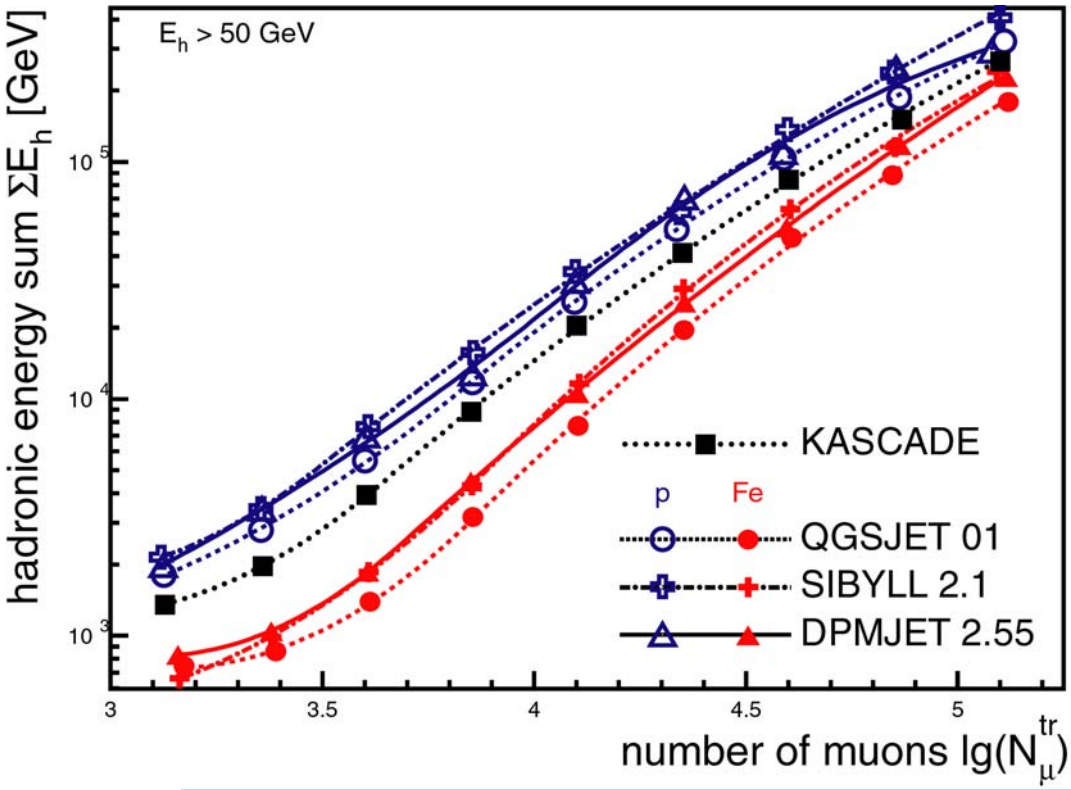
-) knee caused by light primaries

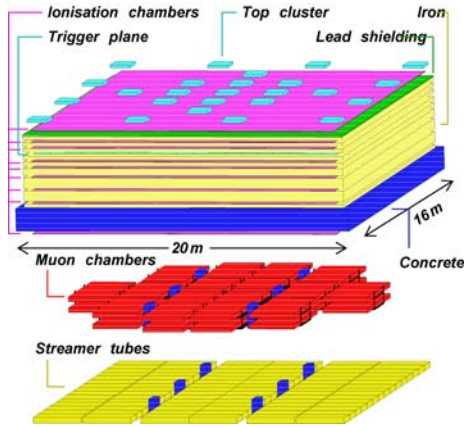
-) positions of knee vary with primary elemental group

-) no (interaction) model can describe the data consistently

KASCADE collaboration, Astroparticle Physics (2005), accepted

KASCADE data analyses: shower observable correlations





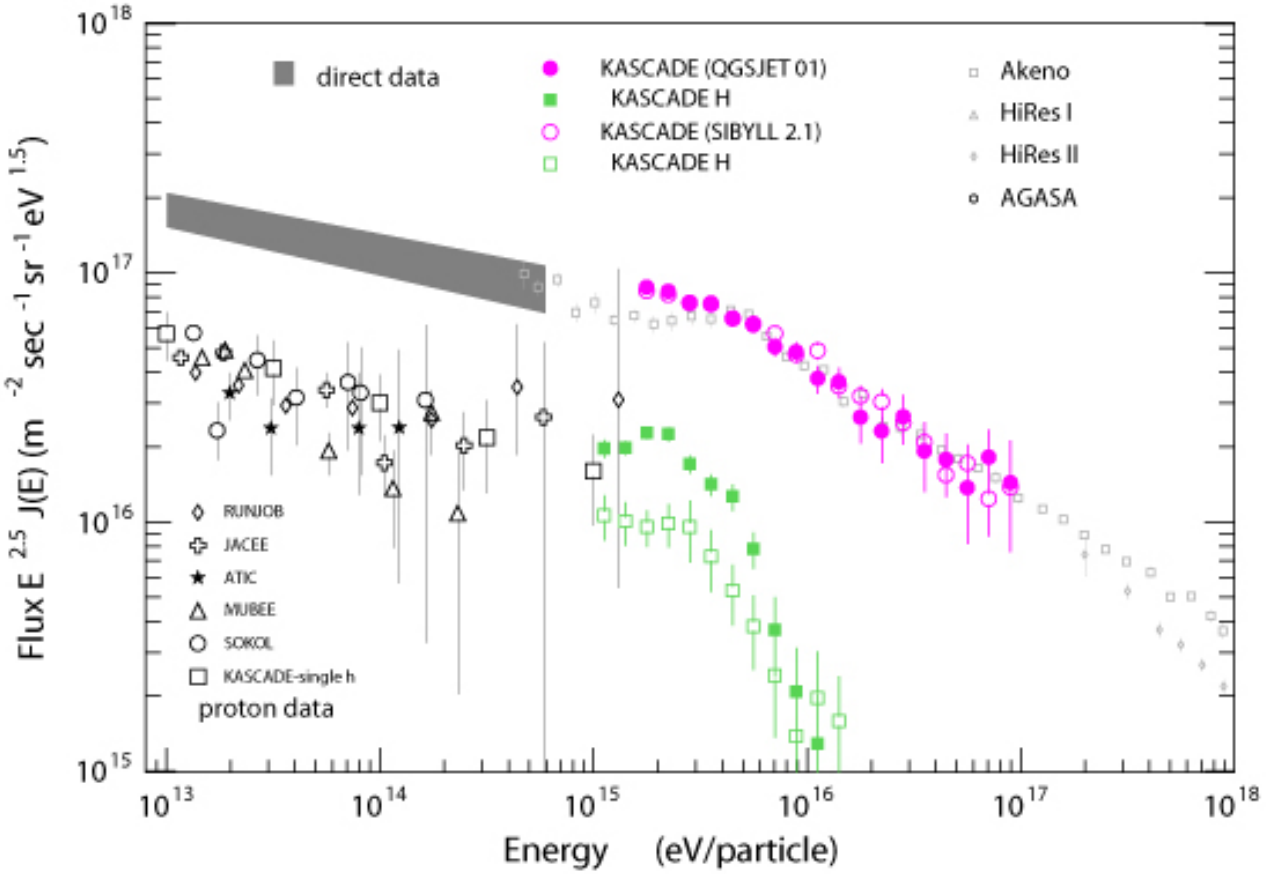
Example: hadrons vs. muons

correlation of observables:
no hadronic interaction model describes data consistently !
➔ tests and tuning of hadronic interaction models !
➔ close co-operation with model builders

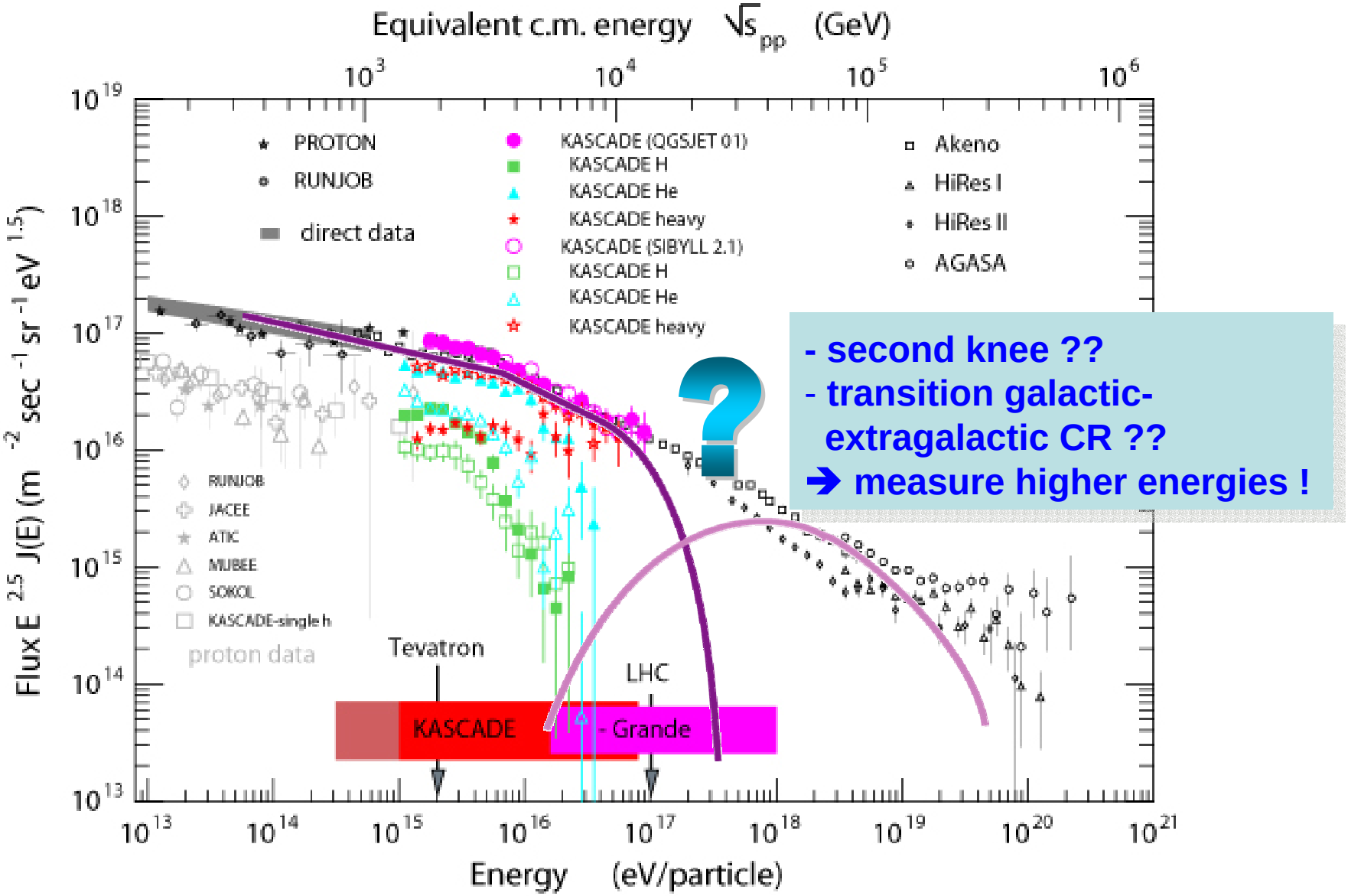
recent highlights of KASCADE data analyses

Comparison with direct measurements

Reconstruction of the primary cosmic ray proton spectrum

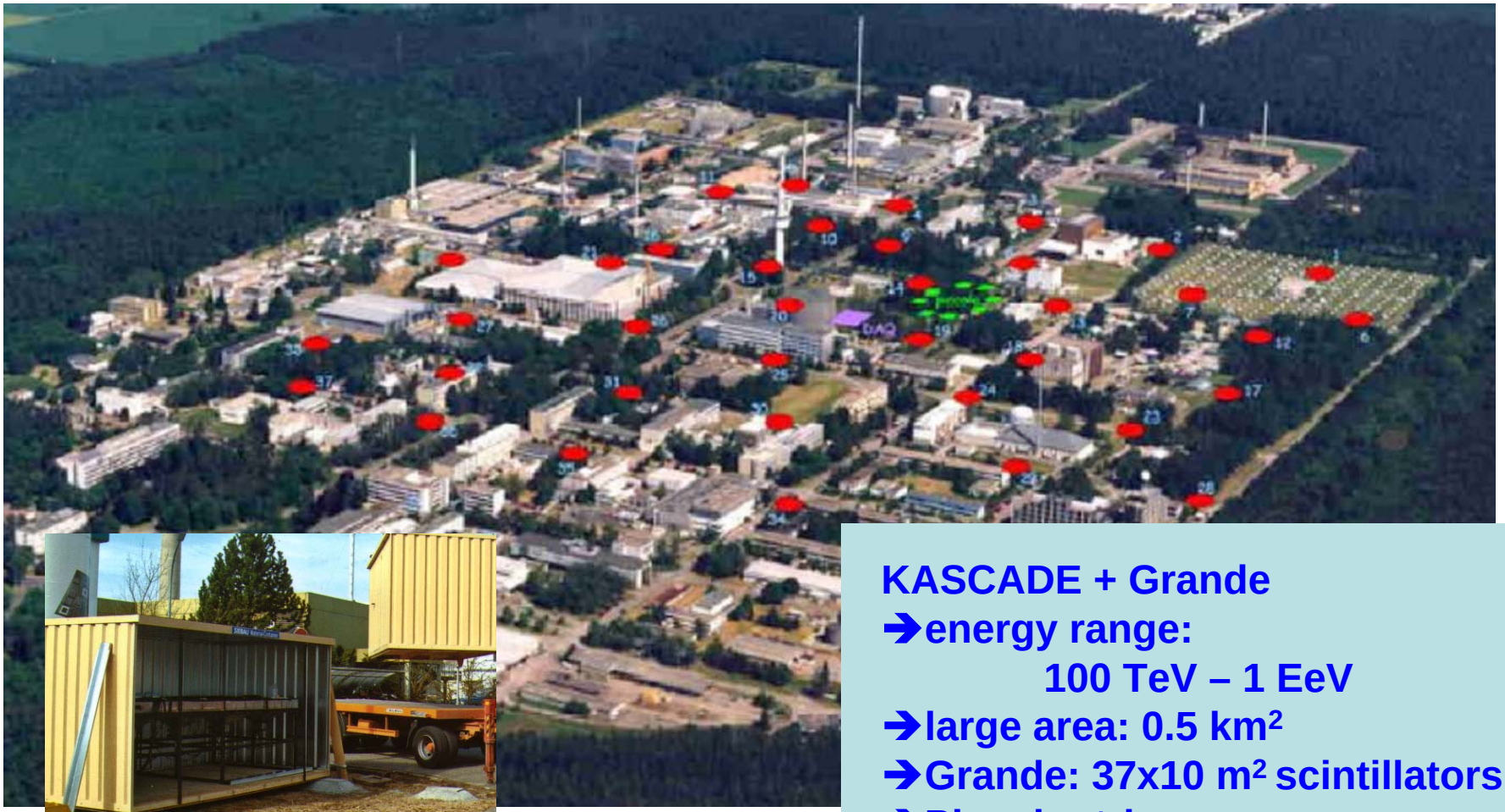


Motivation for KASCADE-Grande



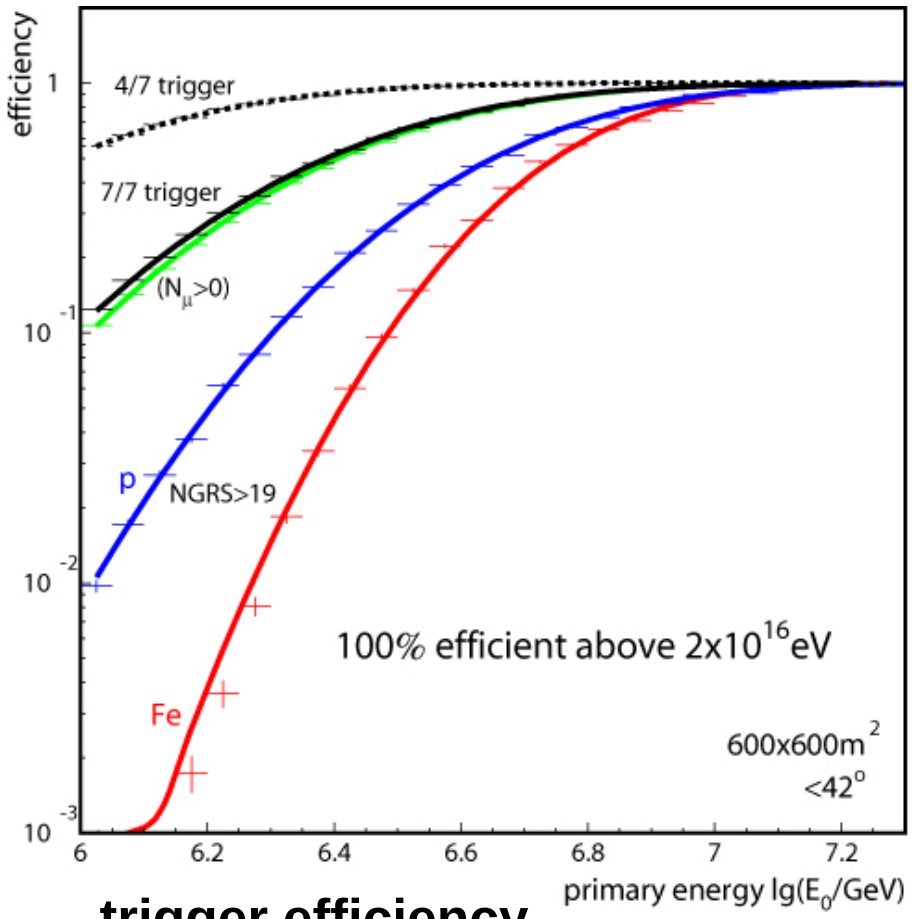
- second knee ??
- transition galactic-extragalactic CR ??
➔ measure higher energies !

KASCADE-Grande : multi-parameter measurements



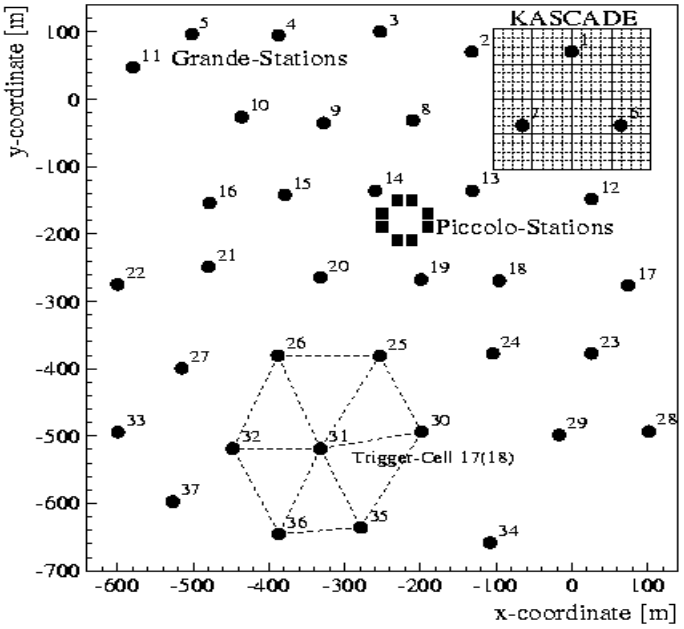
KASCADE + Grande
➔energy range:
100 TeV – 1 EeV
➔large area: 0.5 km^2
➔Grande: 37x10 m^2 scintillators
➔Piccolo: trigger array

KASCADE-Grande : Status



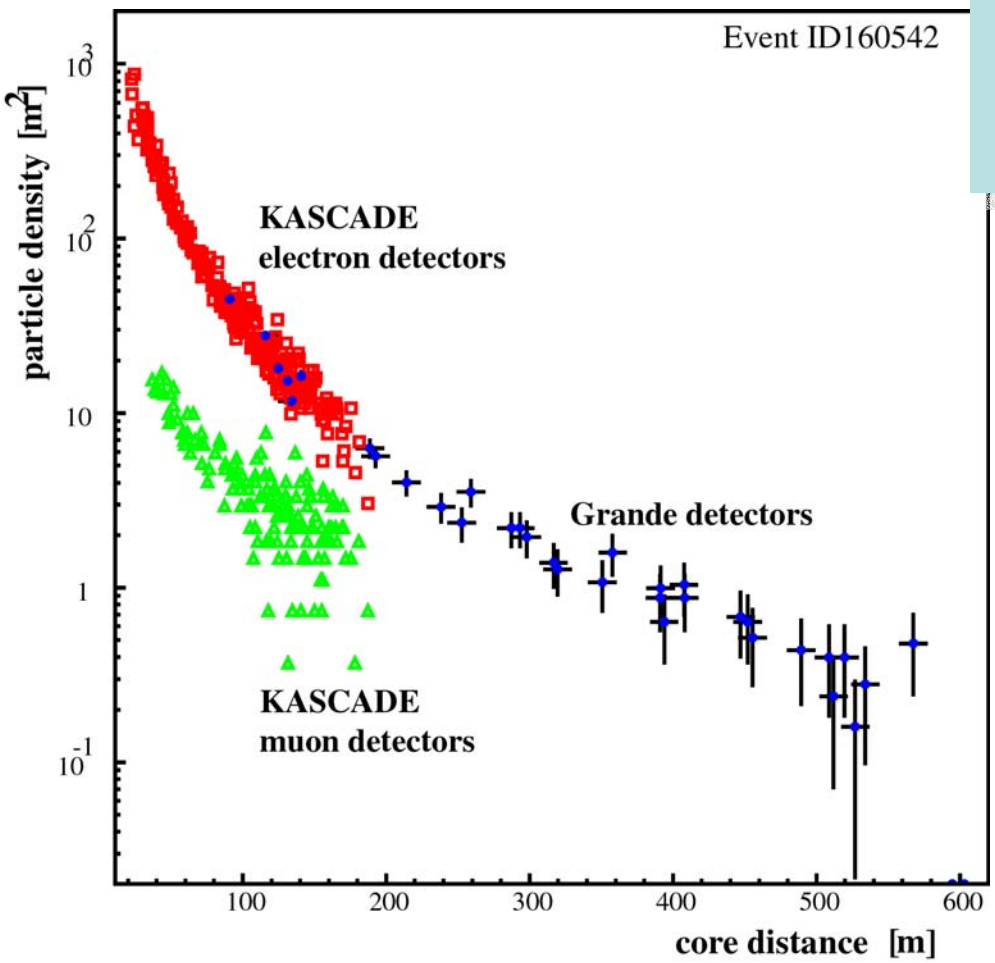
trigger efficiency

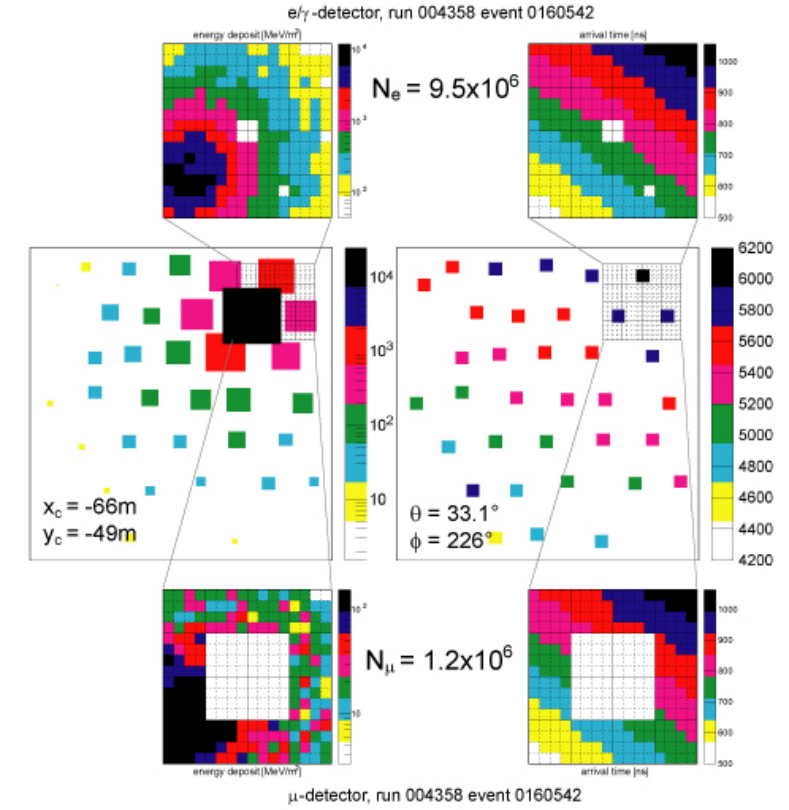
- **Common events (all detector components) measured since December 2003**
- **Trigger: 7of 7 stations at one of 18 hexagons**



KASCADE-Grande : Status

lateral distribution of a single event measured by KASCADE-Grande: $E_0 \approx 2 \cdot 10^{17}$eV, $\Theta = 33^o$





KASCADE-Grande : Reconstruction

1) core position and angle-of-incidence
   from Grande array data

➔

2a) shower size (charged particles)
   from Grande array data

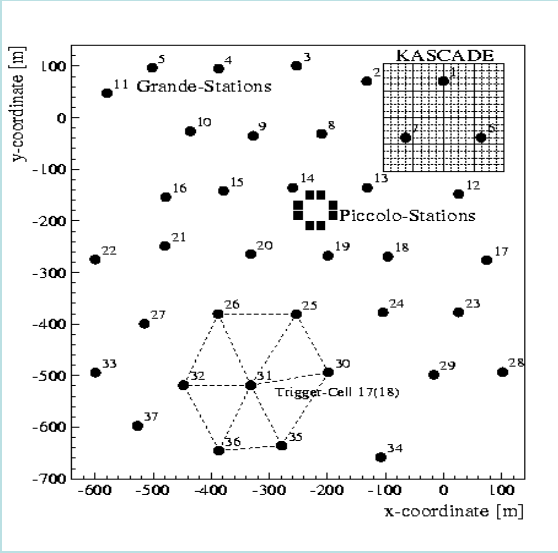
2b) muon number
   from KASCADE muon detectors

➔

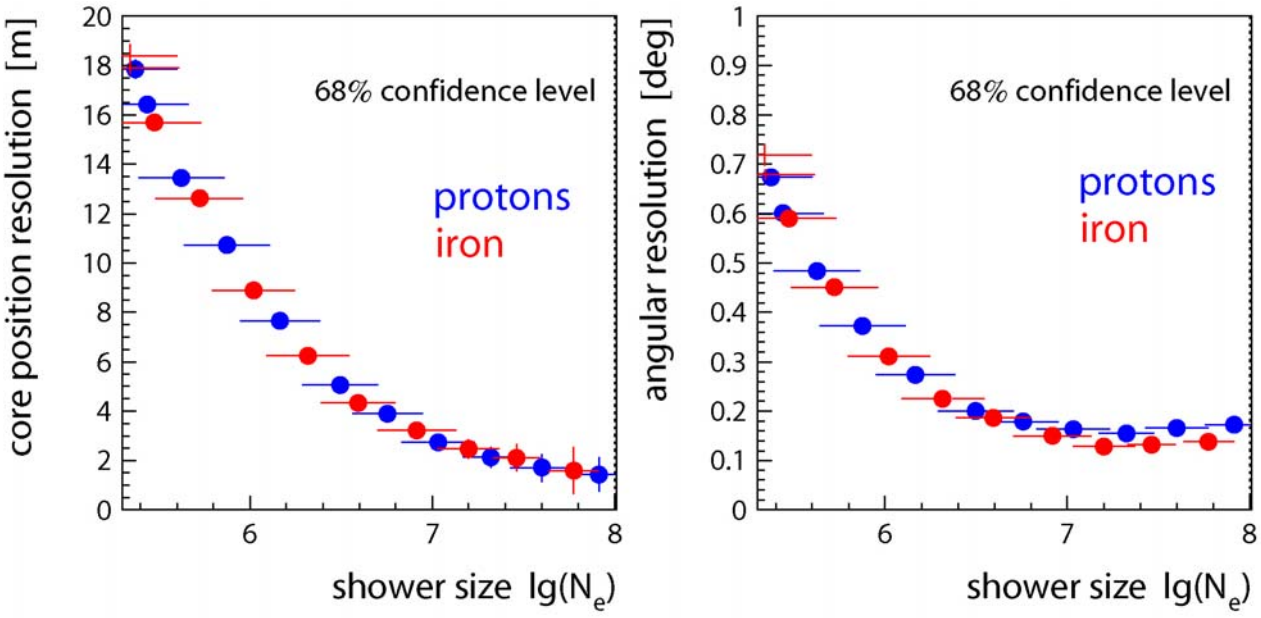
3) electron number
   from Grande by subtraction of muon content

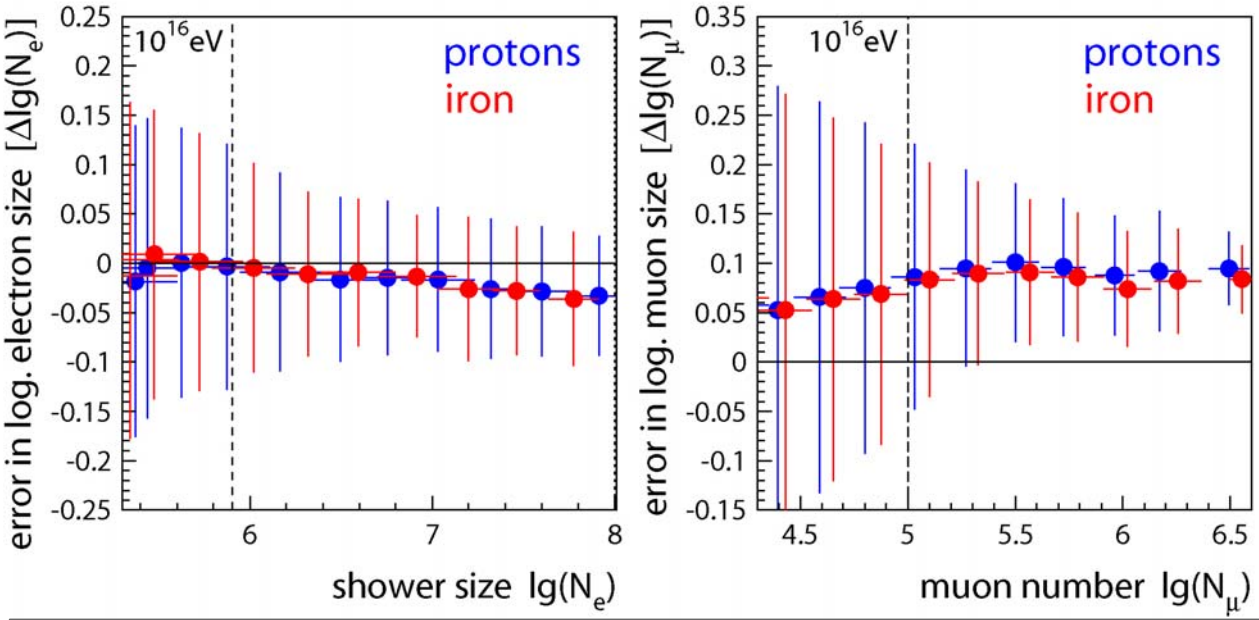
➔

4) two dimensional size spectrum
   for the analysis



KASCADE-Grande : Reconstruction

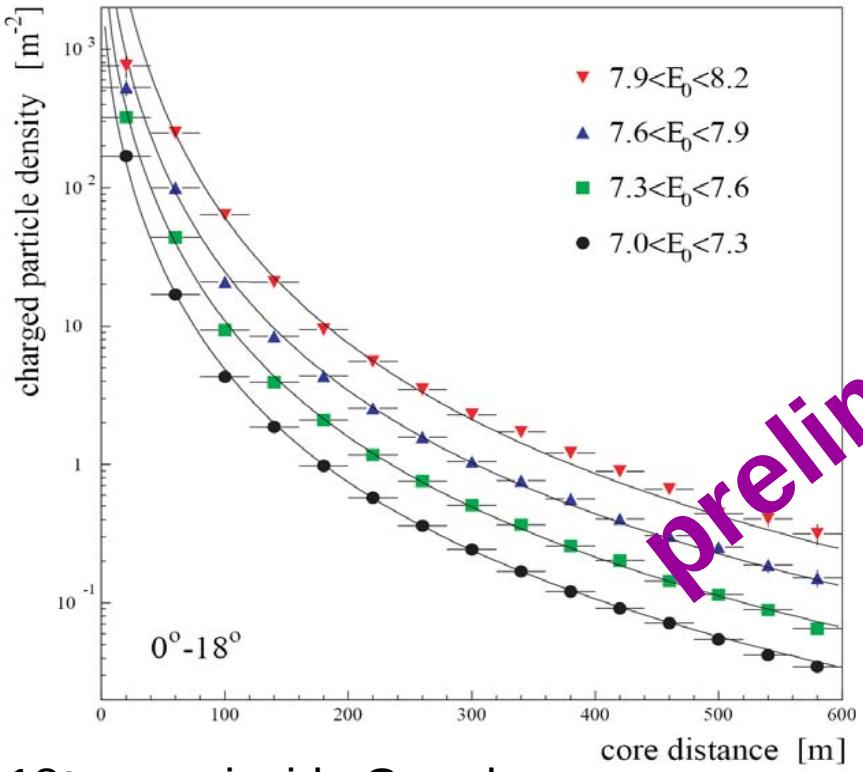


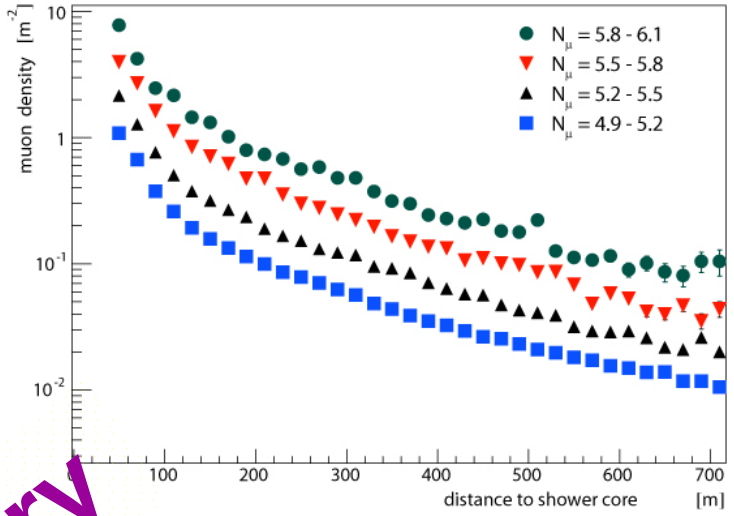


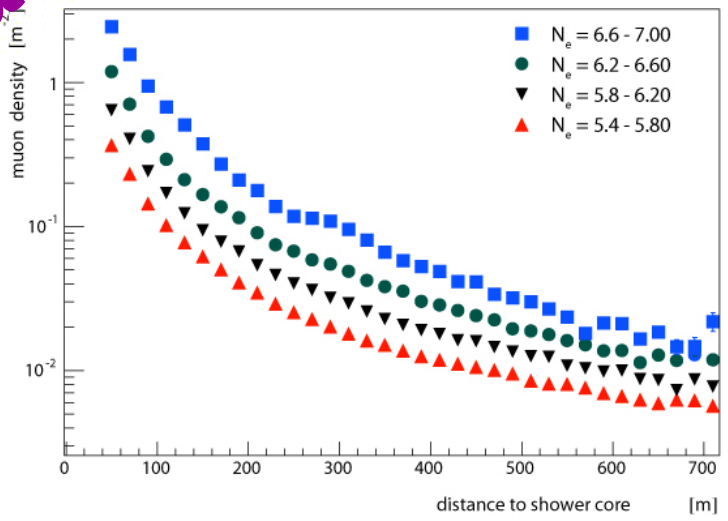
Monte-Carlo studies:
➔
Sufficient reconstruction accuracies for
-core
-direction
-shower size, and
-muon number

KASCADE-Grande : lateral distributions

➔Averaged electron lateral distribution
➔Averaged muon lateral distribution per
- reconstructed total muon number
- electron shower size



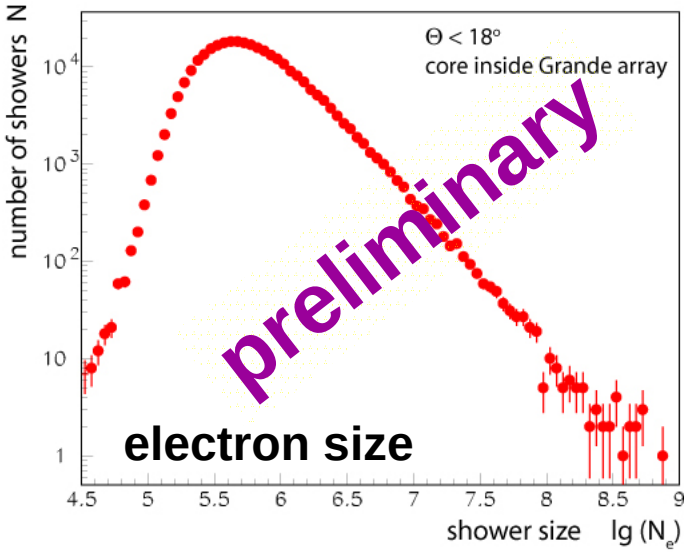


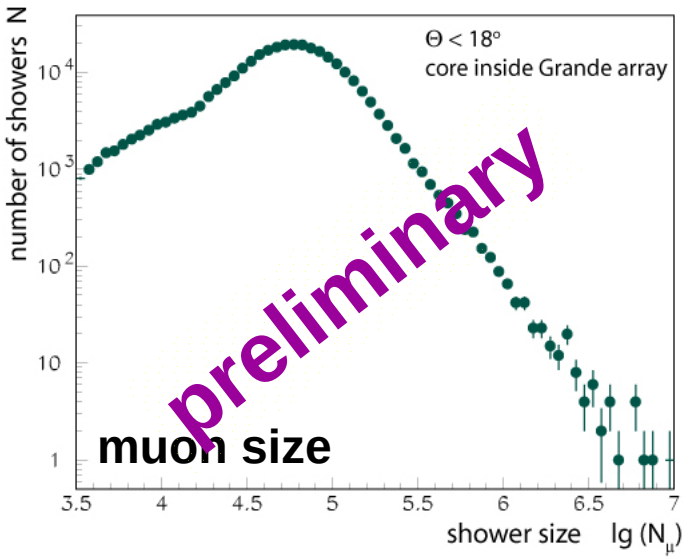


preliminary

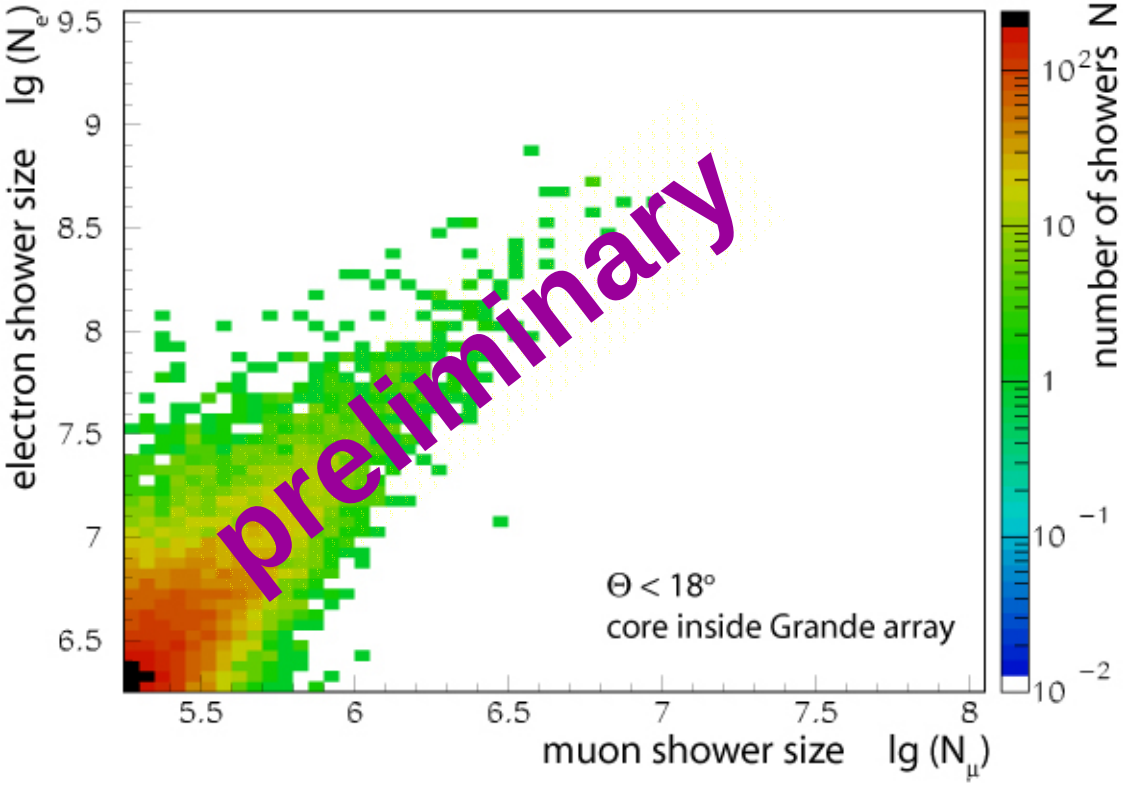
Θ<18° ; core inside Grande array

KASCADE-Grande : first analyses





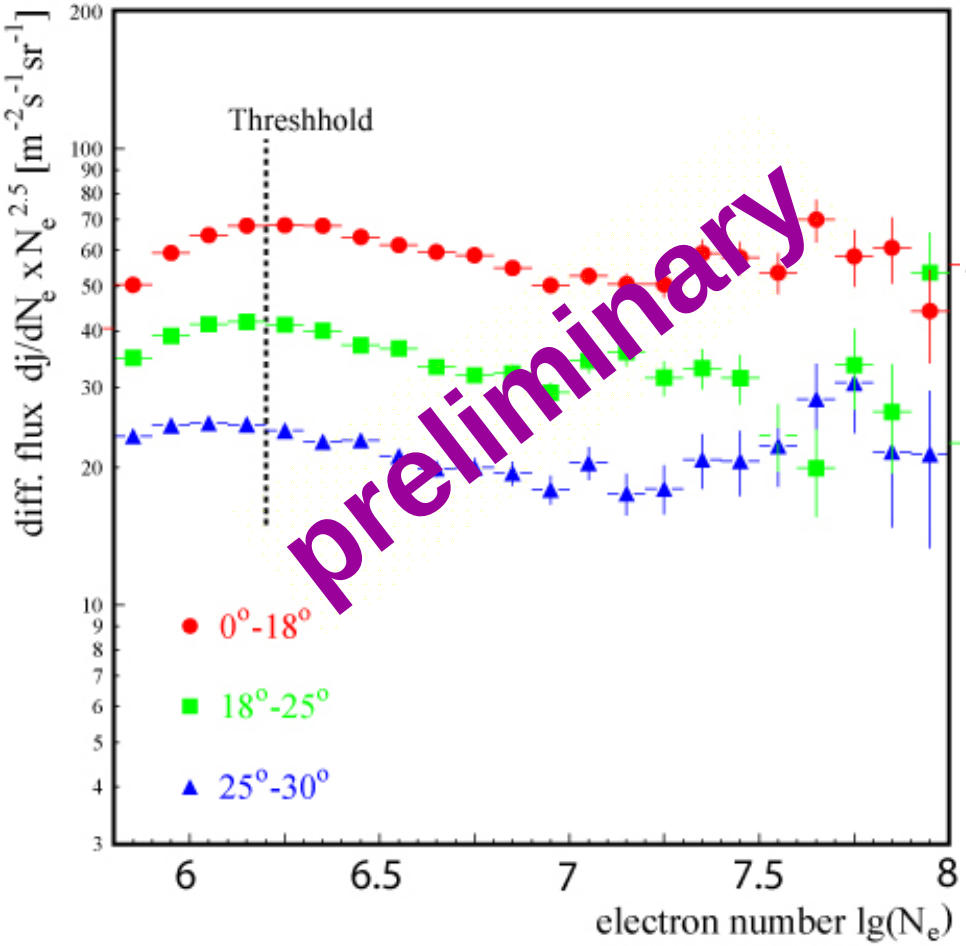
Unfolding of 2-dimensional shower size spectrum
➔ composition



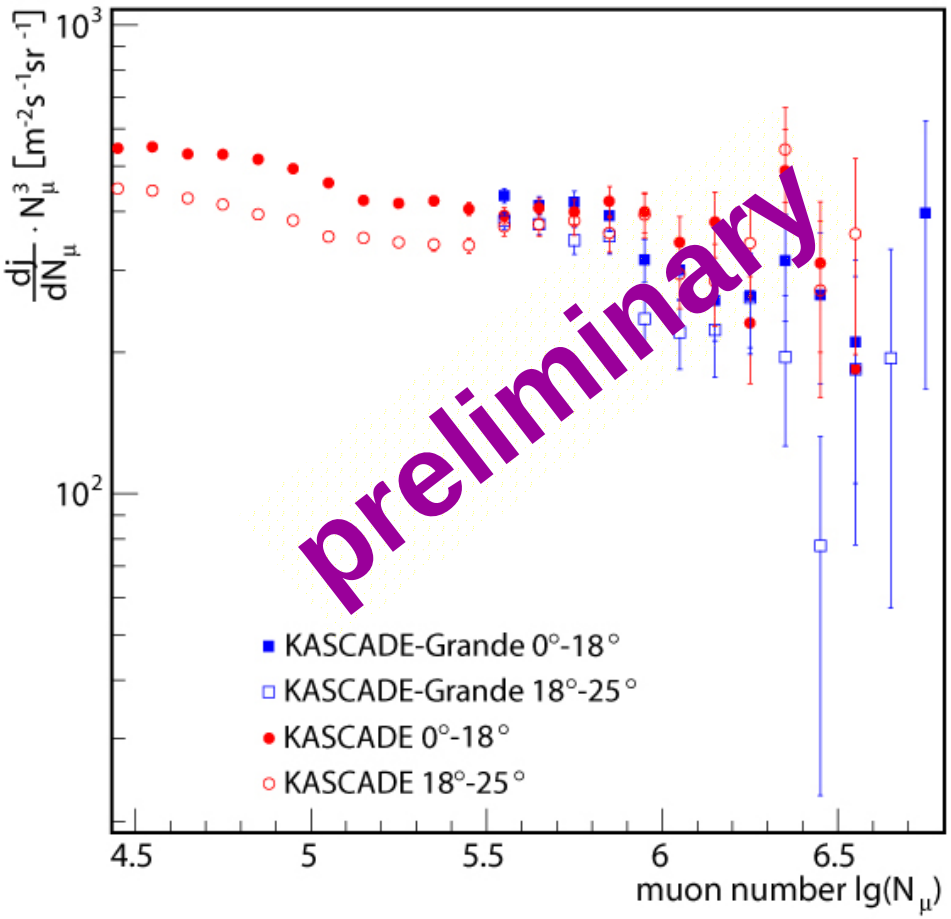
KASCADE-Grande : size spectra

1-dimensional shower size spectra after ~1 year of Grande measurements

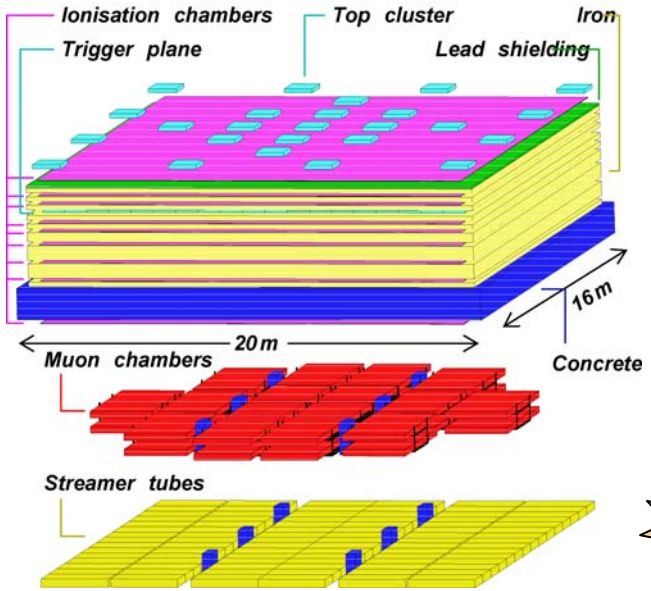
electron size



muon size



KASCADE-Grande : muon density measurements



redundant shower information enables Monte-Carlo tests !

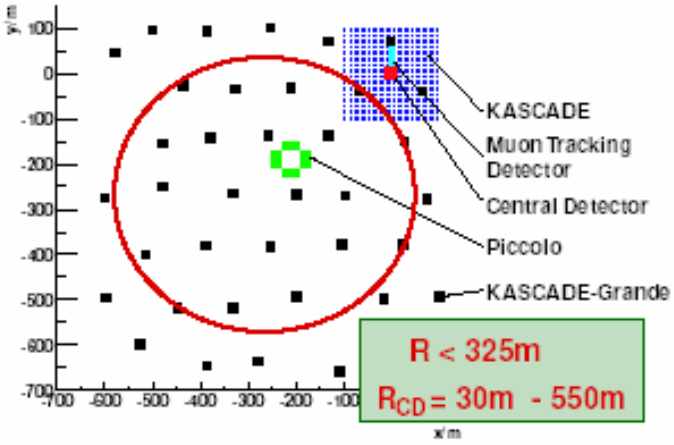
➔

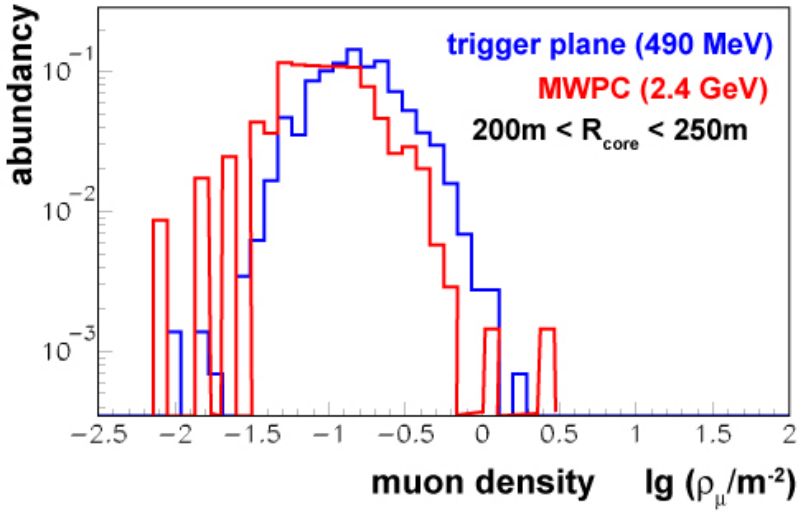
Sensitive parameters for consistency checks of the simulated air-shower development up to $10^{17.8}$ eV primary energy.

$$R_\rho = \frac{\rho_\mu^\star}{\rho_\mu^{tp}}$$

at MWPC $\rho_\mu^\star$: $E_\mu^{th} = 2.4$ G

at TP ρ_μ^{tp}: $E_\mu^{th} = 490$ MeV





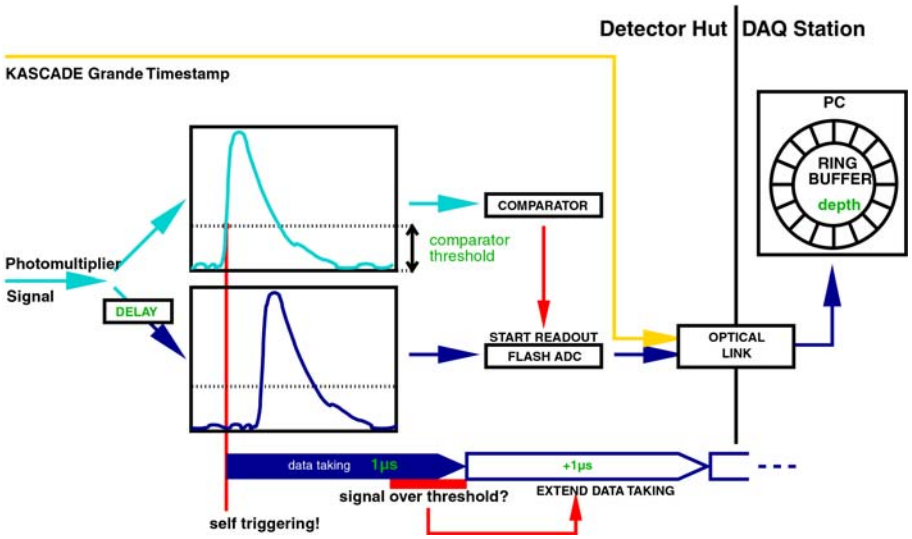
KASCADE-Grande : Flash ADC system

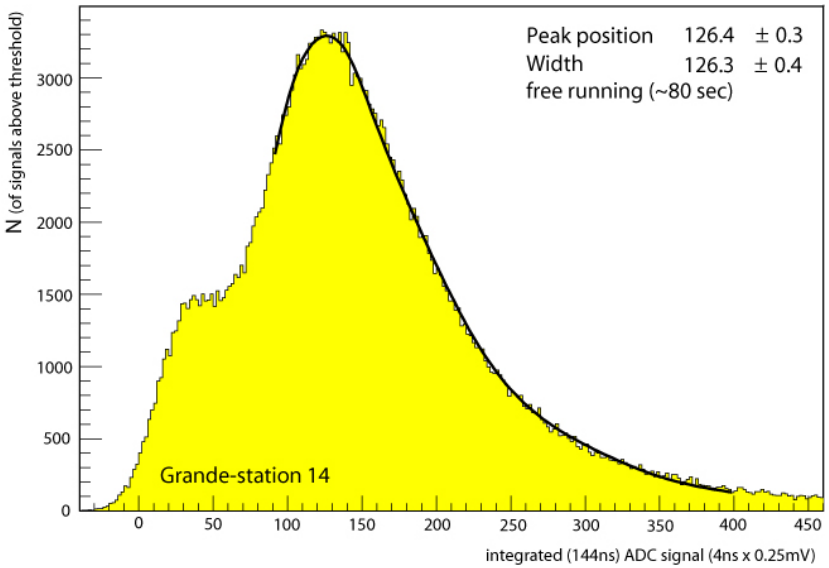
- **Flash-ADC system for the Grande array**

with optical links and a ring buffer system

➔ self triggering **➔ full signal information of the detectors**

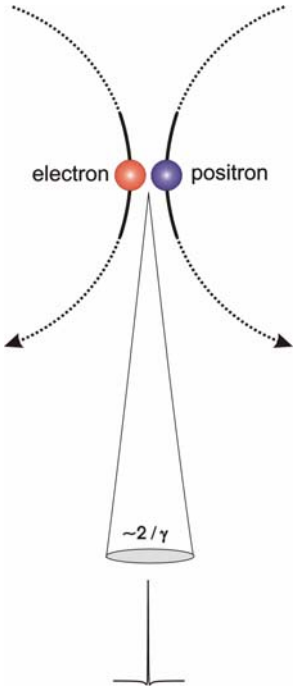
➔ high time resolution **➔ intrinsic electron muon separation**





➔High precision data from Grande array

KASCADE-Grande : Radio shower detection



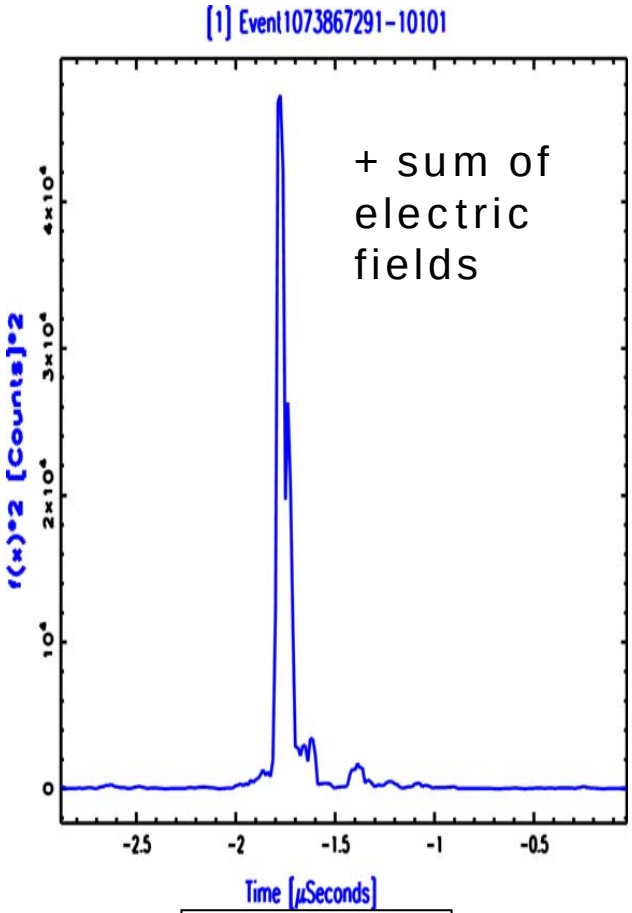
•deflection of electron-positron pairs in the Earth's magnetic field
➔coherent emission at low frequencies

•with radio detection
➔ see shower development
➔ observe 24 hrs/day

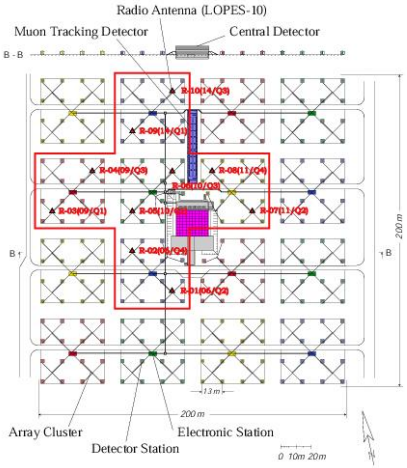
LOPES collaboration:
-) KASCADE-Grande
-) U Nijmegen, NL
-) MPIfR Bonn, D
-) Astron, NL
-) IPE, FZK, D

- 30 dipole antennas at KASCADE-Grande
- calibration of radio emission
- theory of radio emission and implementation in CORSIKA
- improvement/optimisation hardware (for application in Auger)

LOPES : Radio shower detection



Event analysis



- 10 antennas at KASCADE
- frequency band 40-80 MHz
- trigger: >10/16 cluster of KASCADE ($E_0 > 10^{16}$ eV)
- 2005:
- ➔ sample of events for detailed analysis
- ➔ upgrade to 30 antennas

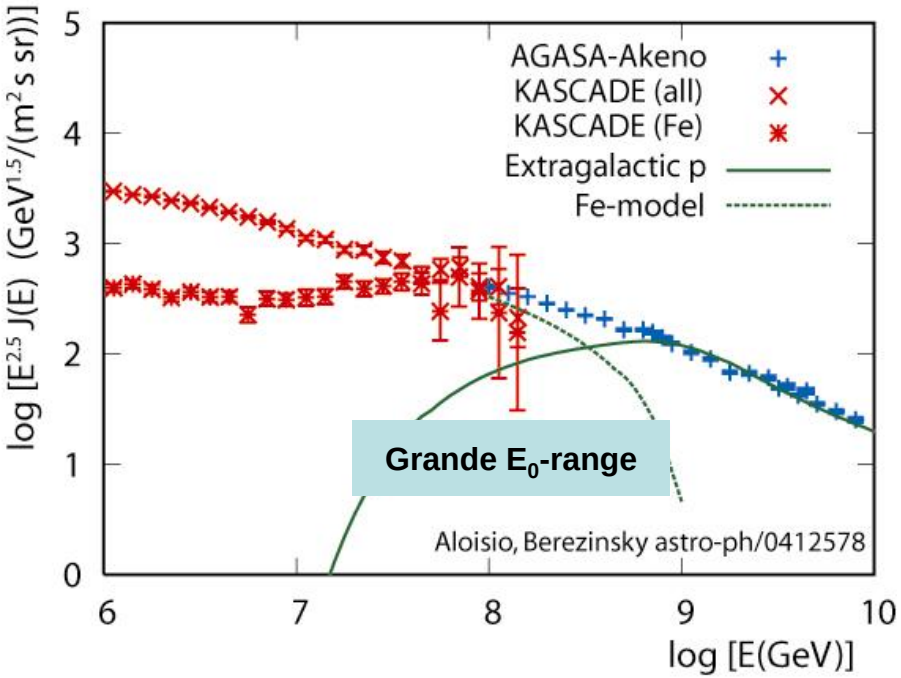
KASCADE-Grande : Summary

- **Single element spectra reconstruction is possible by EAS measurements (KASCADE)**

➔ **Knee is caused by light primary elements, cosmic rays are isotropic around the knee**

- **Data distributions are not consistent with Monte Carlo predictions**

➔ **Interaction models have to be further improved**



- **KASCADE-Grande will cover whole „knee“ range to find the „iron“-knee !**
- **Radio detection as new technique for UHECR measurements**

KASCADE-Grande Collaboration

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