Measurement of muons with KASCADE-Grande

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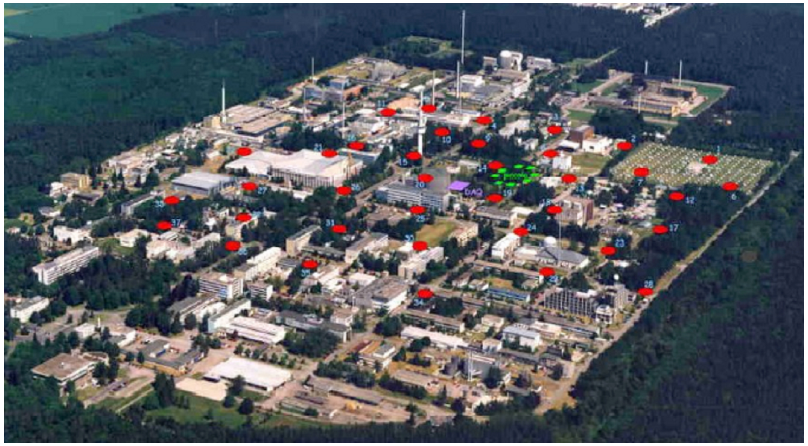
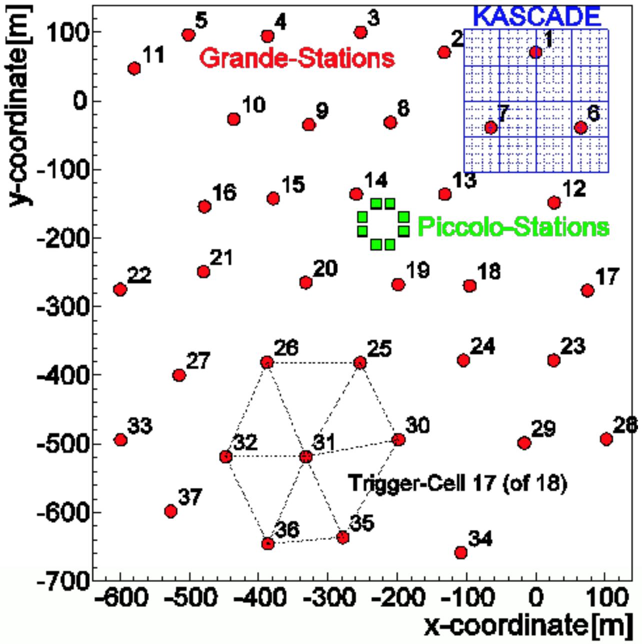


Outline

- KASCADE-Grande and KASCADE detectors
- Single event reconstruction (especially muon number reconstruction)
- Muon reconstruction quality
- Analyses based on the muon number

Grande detectors

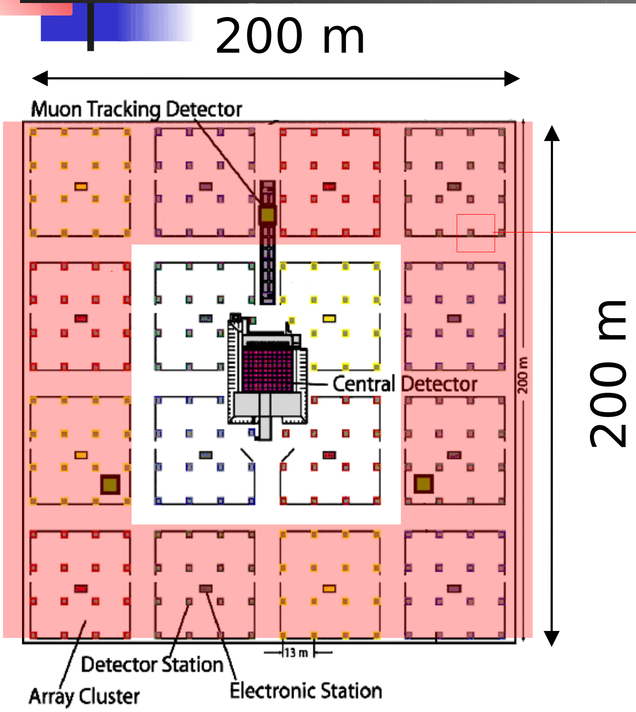


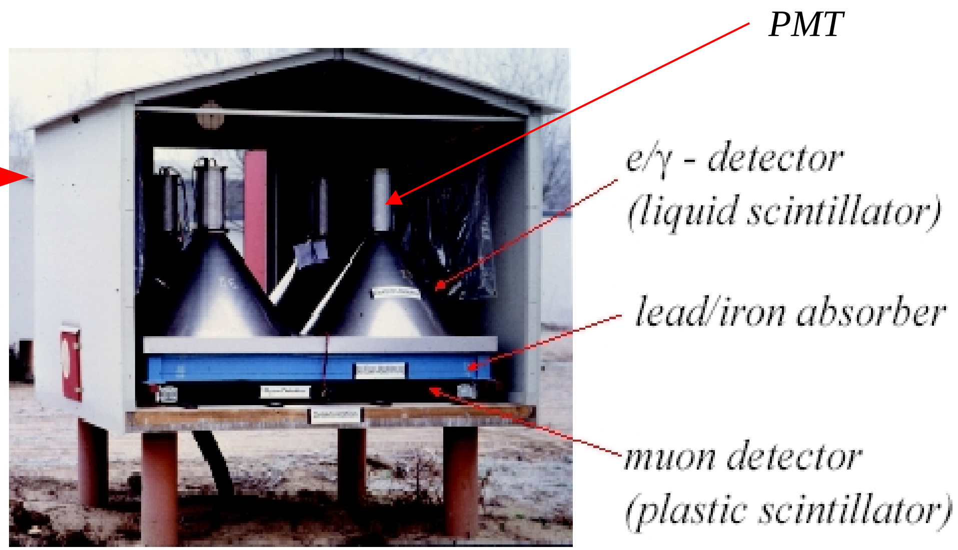
photomultiplier

- 16 plastic scintillators p. station: e/γ +μ ,
- threshold: 5 MeV
- 10 m² detection area p. station

to distinguish between muons and electrons one need the information from the KASCADE detectors

KASCADE detector station

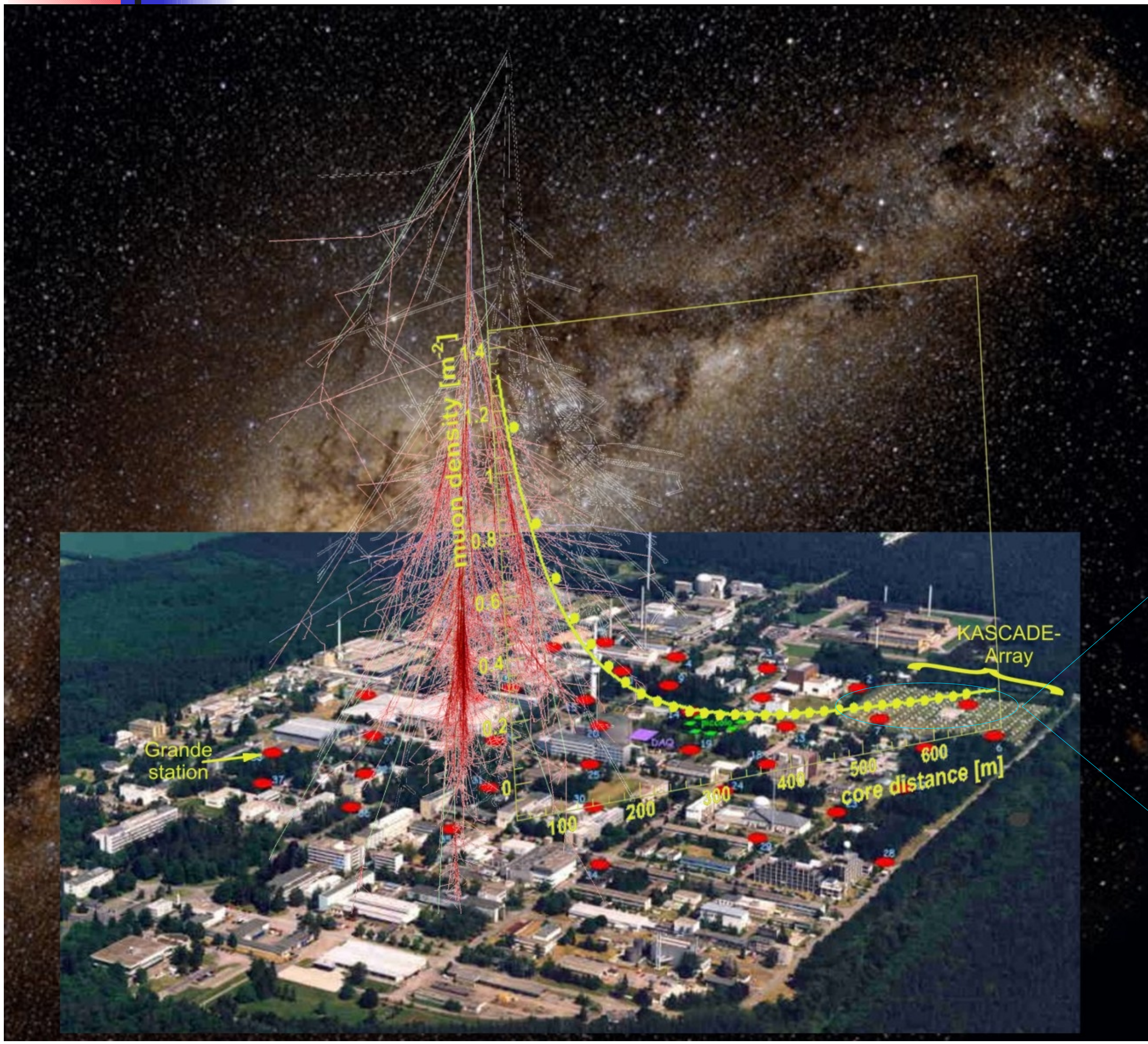




12 outer clusters:

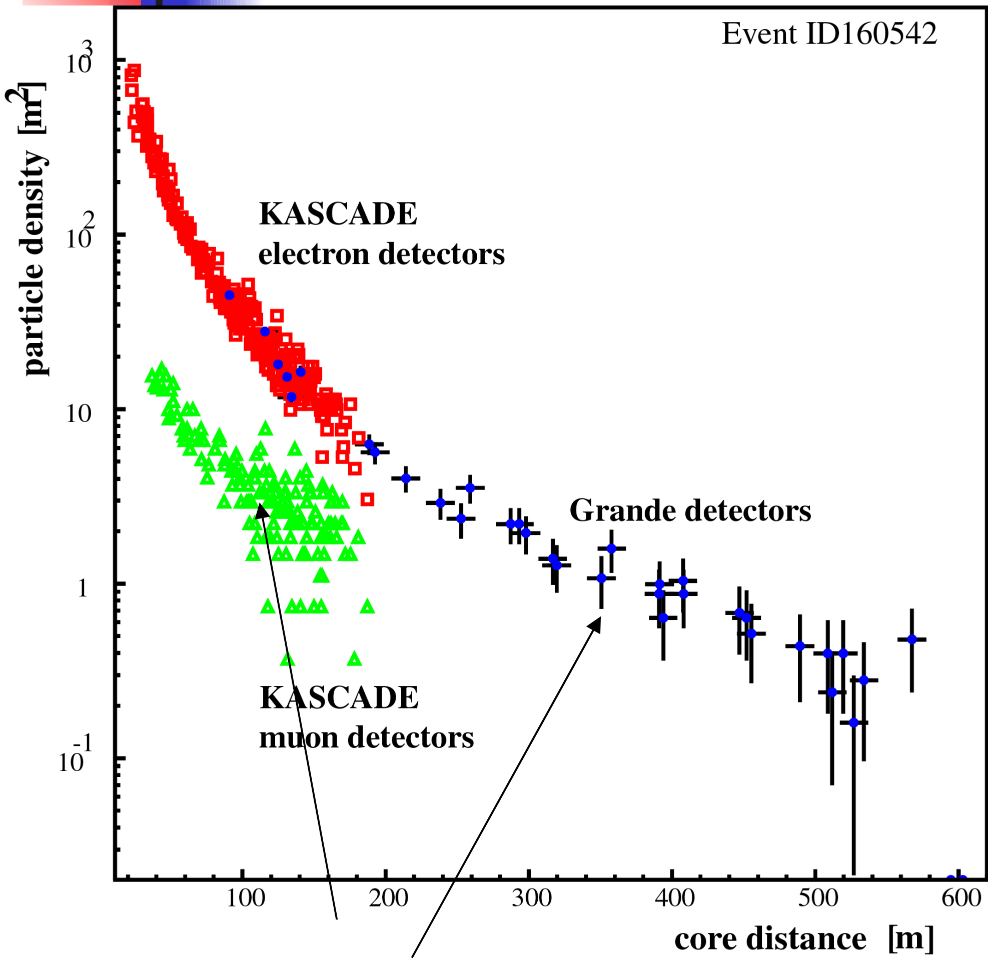
In addition to the e/γ each station also contains μ detectors beneath an iron/lead absorber (230 MeV threshold = 20 radiation lengths)

=> e/γ and μ can be measured separately

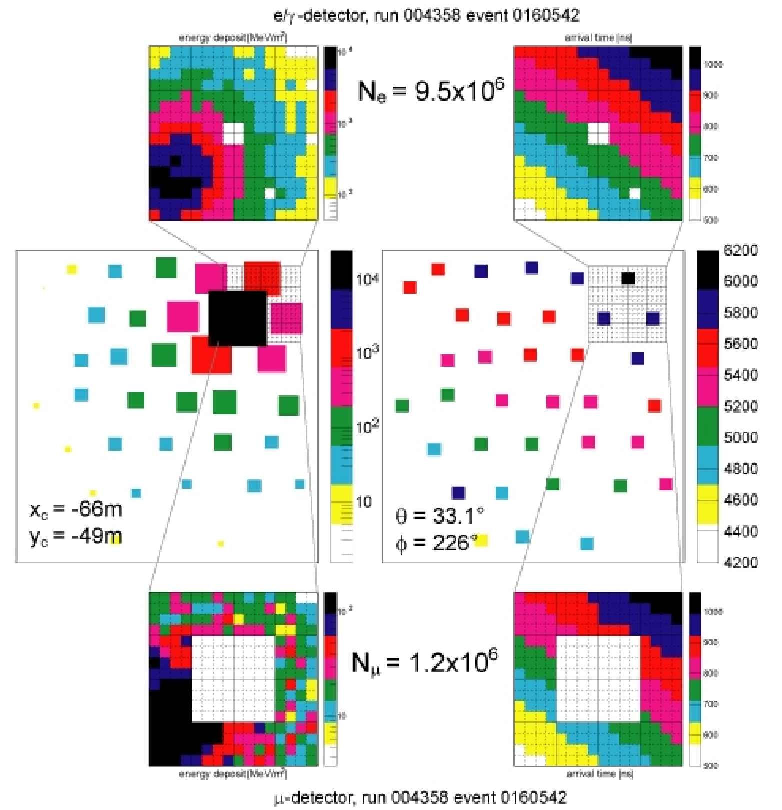


- Even if the shower core is outside the KASCADE-array ("Grande-Events"), the muonic component can be measured separately from the electronic one by using the muon detectors of KASCADE
- Using muon LDF => total number of muons
- charged particles (Grande) – muons = total number of electrons

Single Event: Example



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



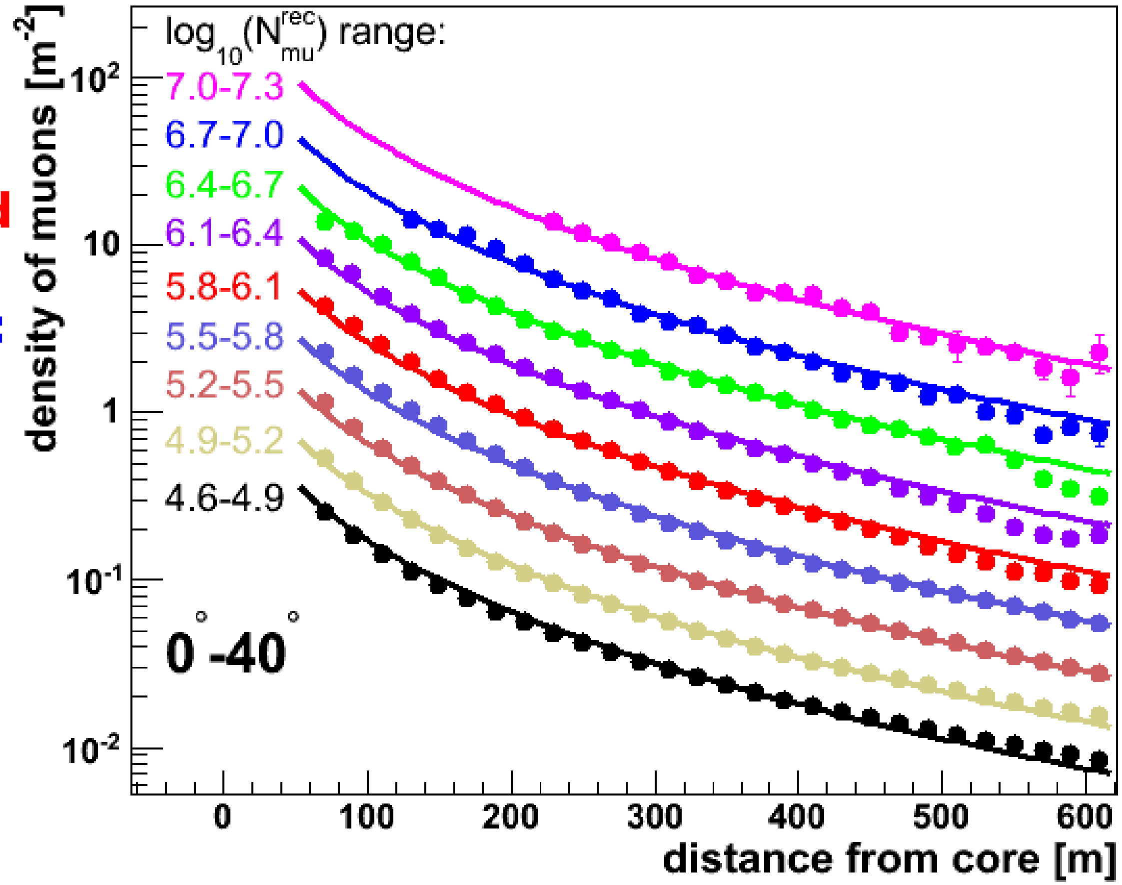
deposited energy [MeV/m^2] arrival time [ns]

Grande analyses use the number of charged particle from the Grande detectors and the muon number from the KASCADE detectors.

Lateral distribution function (LDF)

Comparison of direct measured μ-densities (points) with reconstructed total muon number (represented by solid line):

1) performance of measurements stable
2) reconstruction and analysis of shower sizes possible



$$\rho_\mu(r) = N_\mu \cdot f(r)$$

LDF:

$$f(r) = \frac{0.28}{r_0^2}\left(\frac{r}{r_0}\right)^{-0.69} \cdot \left(1 + \frac{r}{r_0}\right)^{-2.39} \cdot \left(1 + \left(\frac{r}{10 \cdot r_0}\right)^2\right)^{-1.0}$$

fixed scaling parameter r_0 = 320 m

Reconstruction of Muon Number: Maximum Likelihood Estimation

- Mean muon number m_i at the KASCADE detector i **predicted** by LDF f :

$$m_i = N_\mu \cdot f(r_i) \cdot \underbrace{A_i^{eff}}_{A_i \cdot \cos(\theta)}$$

- The **measured** muon number n_i in the detector is in general rather small => Poisson distribution:

$$P(n_i) = \frac{m_i^{n_i}}{n_i!} \cdot e^{-m_i}$$

- The likelihood function assuming all k detectors:

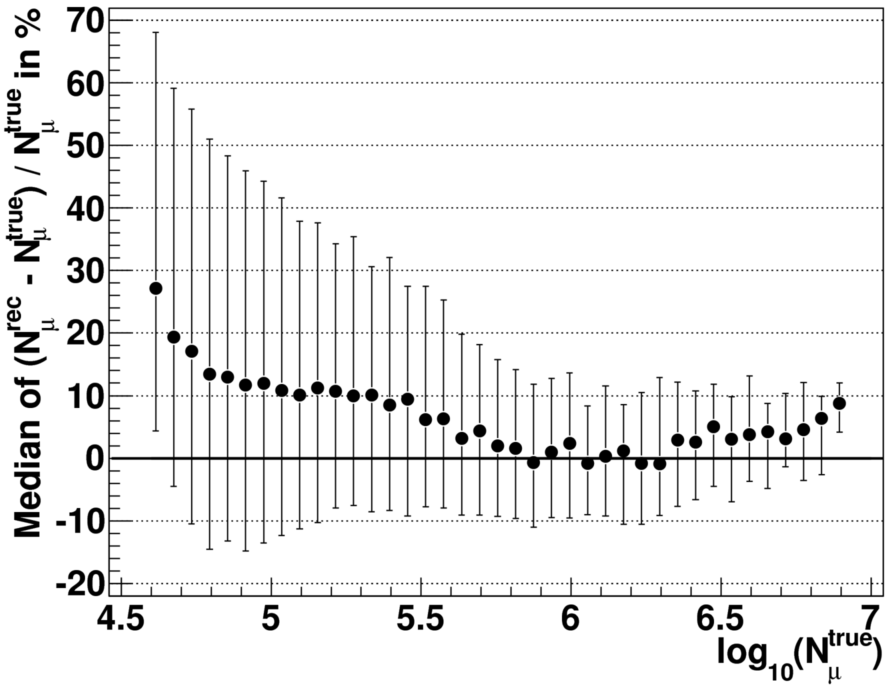
$$L = \prod_{i=1}^{k} \left\{ \frac{m_i^{n_i}}{n_i!} \cdot e^{-m_i} \right\}$$

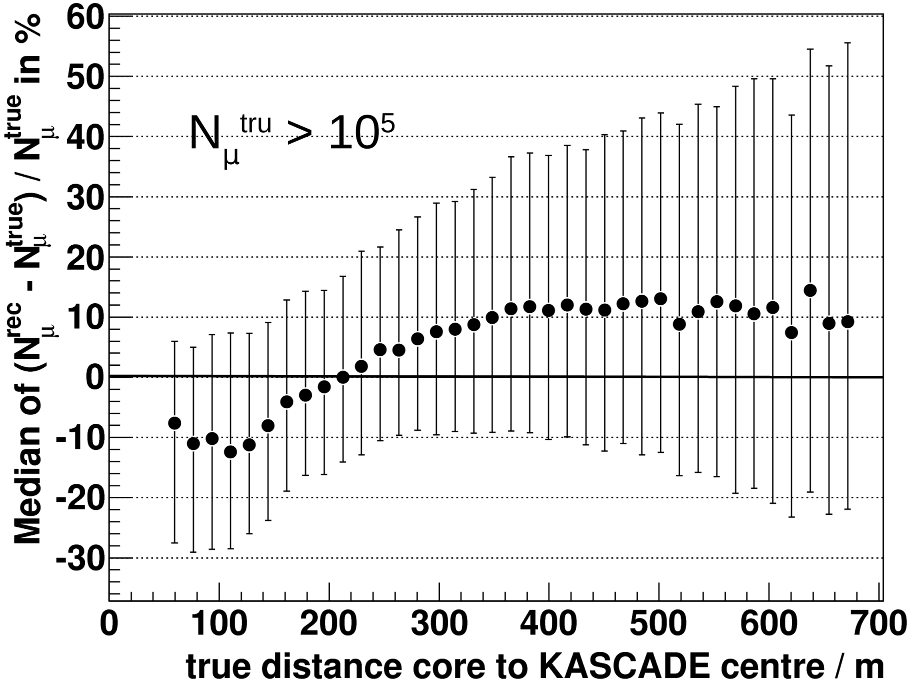
- The maximum of likelihood function gives the most probable total muon number N_μ :

$$\frac{\partial L}{\partial N_\mu} \overset{!}{=} 0 \quad \Leftrightarrow \quad \boxed{N_\mu = \frac{\overbrace{\sum_{i=1}^{k} n_i}^{n_{tot}}}{\sum_{i=1}^{k} f(r_i) A_i^{eff}}}$$

with $\boxed{\Delta N_\mu = \frac{\sqrt{n_{tot}}}{\sum_{i=1}^{k} f(r_i) \cdot A_i^{eff}}}$

Reconstruction Quality



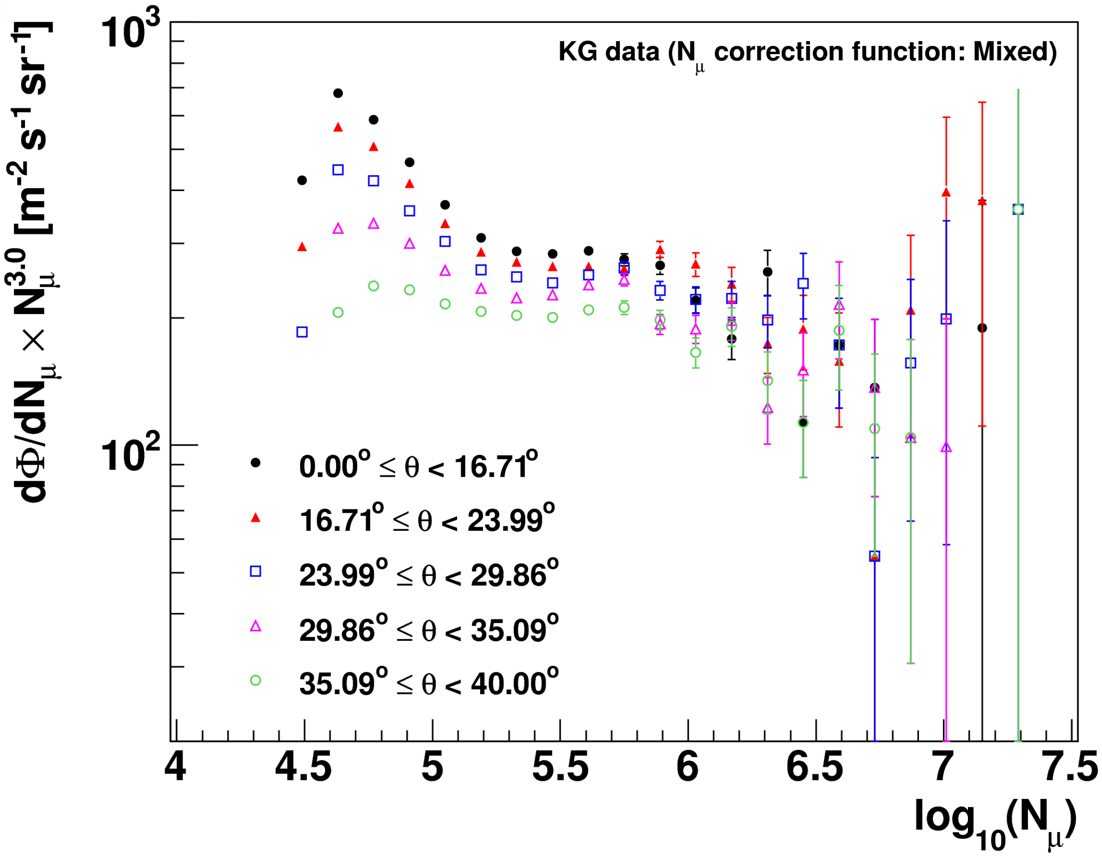


- The muon number resolution gets better with increasing energy (from around 30% at a threshold of 10^5 muons (100% efficiency) to 10%)
- The reconstruction bias is below 10% (in case of 100% efficiency)

- The muon number resolution gets better in case of events closer to the μ-detectors.
- The reconstruction bias is below 10%.

The muon reconstruction is well understood and thus can be improved by applying correction functions!

Muon spectra



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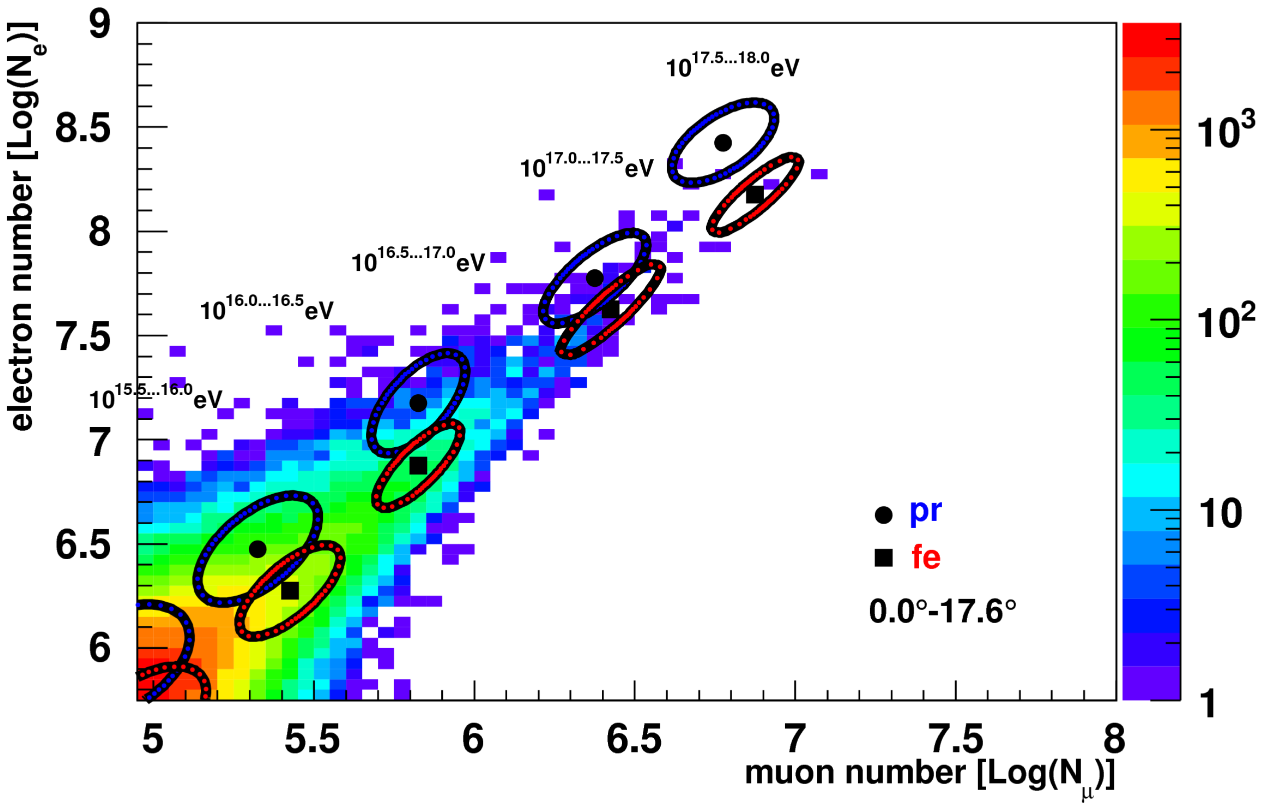
Starting with the muon spectra and applying the constant intensity cut method (CIC), an energy calibration function and unfolding methods one can derive the total energy spectrum of cosmic rays in the KASCADE-Grande energy range.

Composition analyses



Unfolding methods → energy spectra for different mass groups

- Based on the 2d shower size spectrum the energy spectra for different mass groups were obtained with the KASCADE Experiment.
- Same efforts are now made using the KASCADE-Grande data extending the KASCADE results to higher energies.

Conclusion

- Taking into account the fact that quite small particle densities across a small detection area are measured the muon reconstruction works very satisfactory.
- The reconstruction is understood very well and results can be improved using correction methods.
- Many promising analyses based on the muon number are currently performed.