Studio dei raggi cosmici primari tra 10^{16} e 10^{18} eV con l'esperimento KASCADE-Grande

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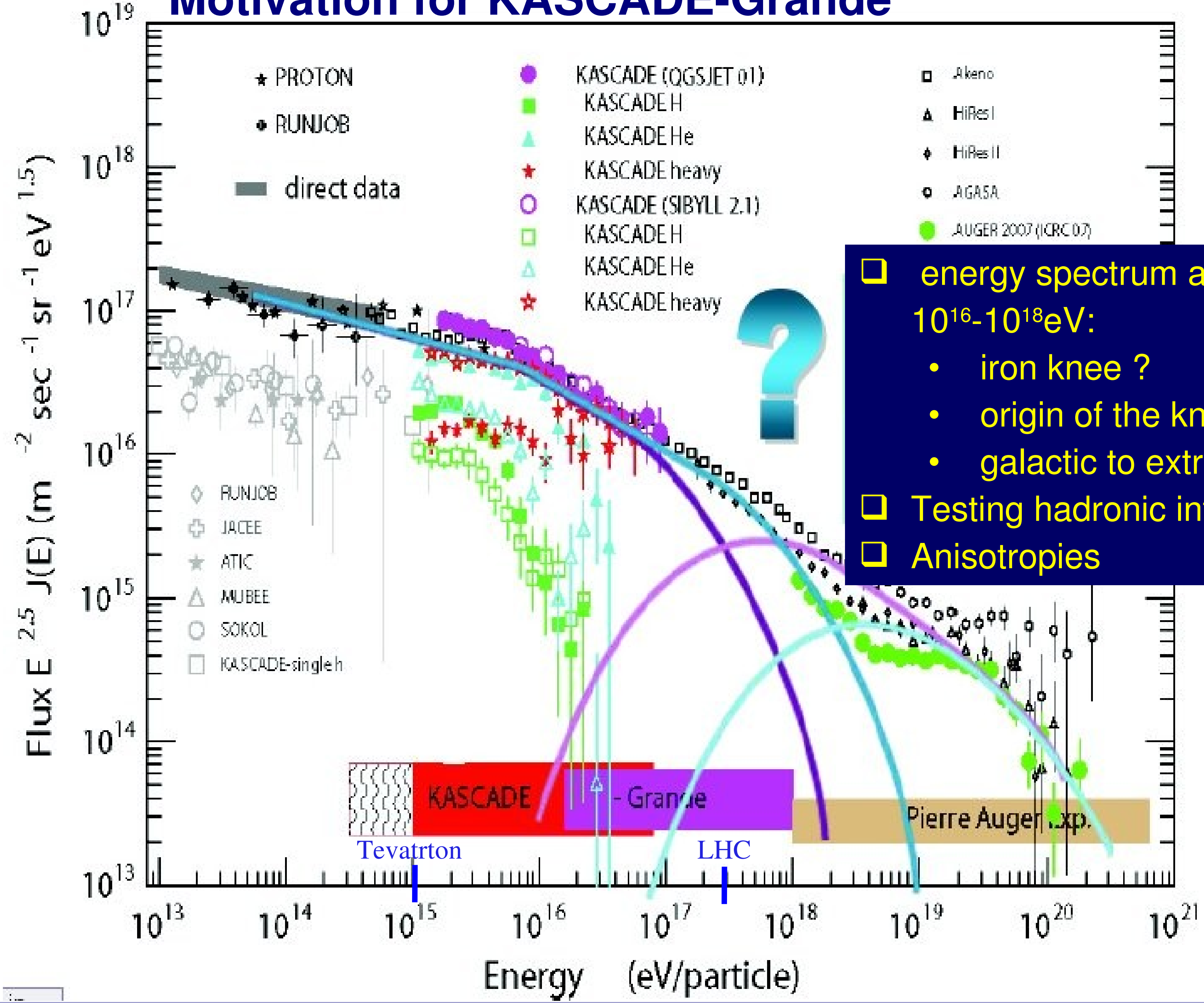
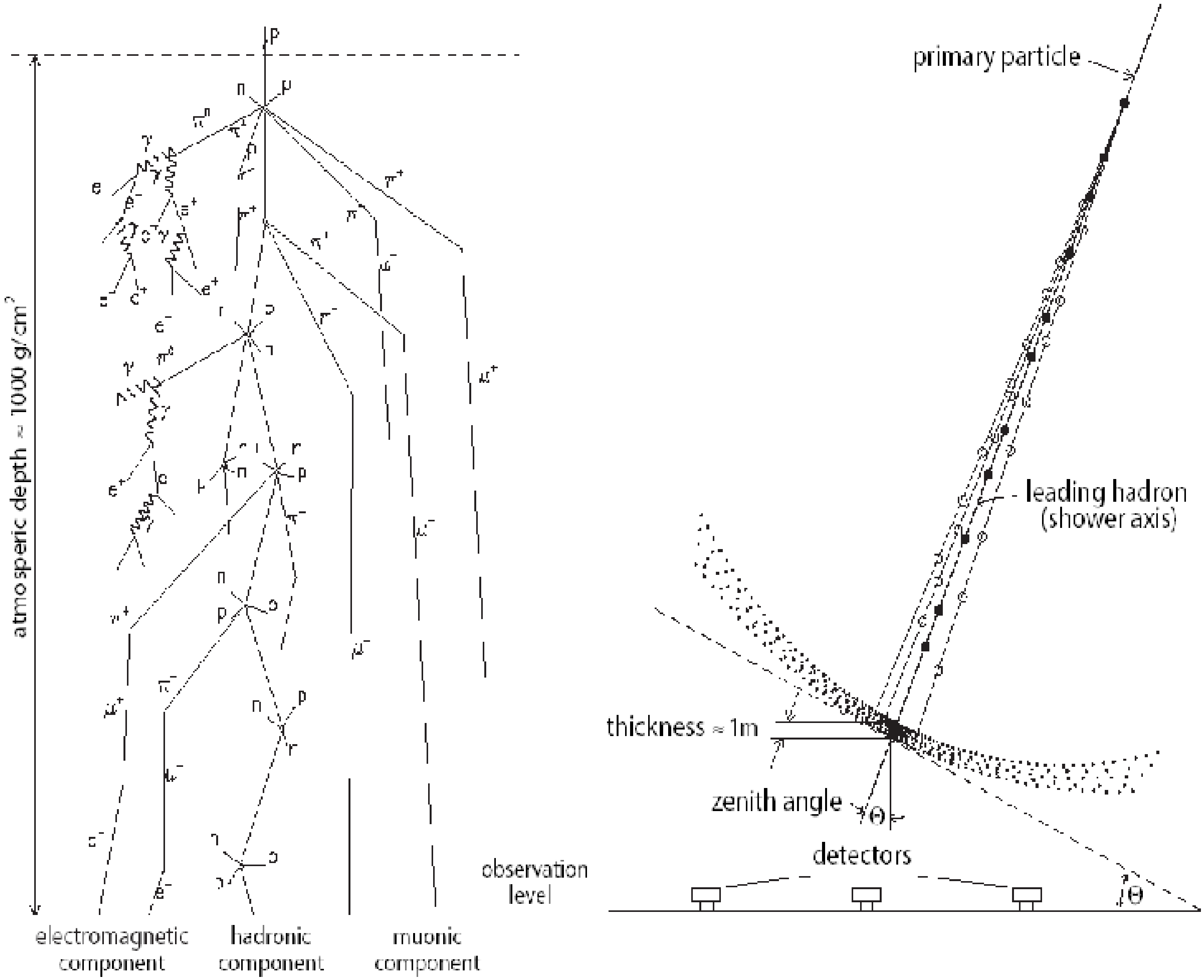
per la Collaborazione KASCADE-Grande

Motivation for KASCADE-Grande

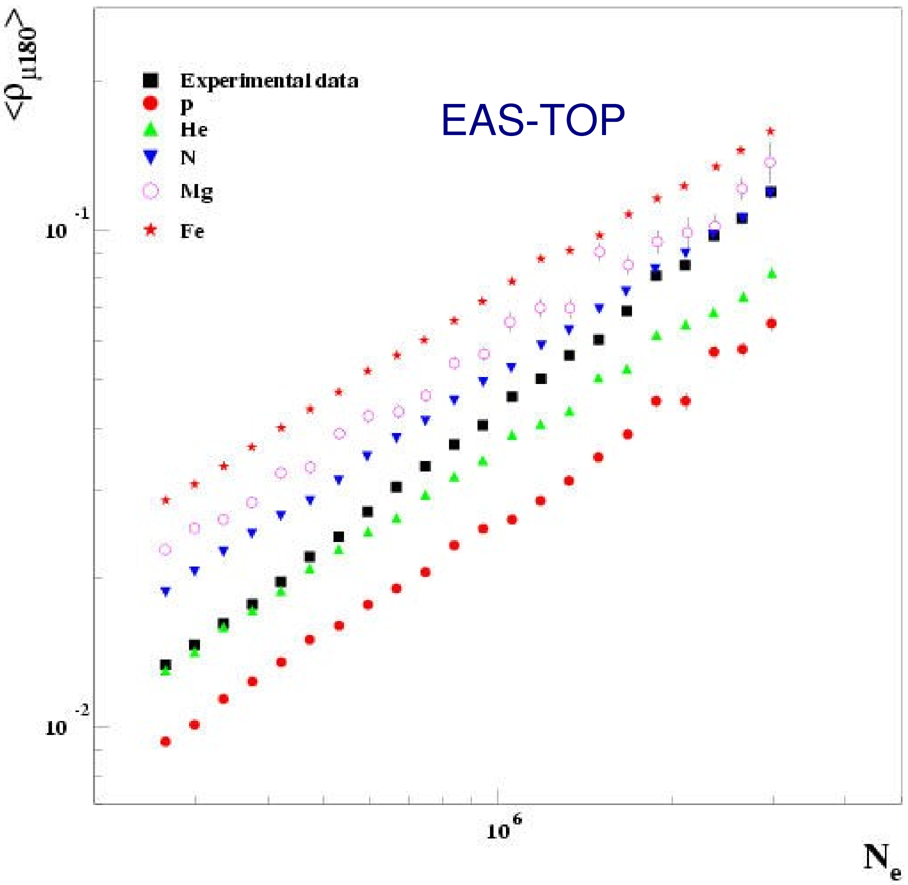


- ❑ energy spectrum and composition 10^{16}-10^{18}eV:
  - iron knee ?
  - origin of the knee ?
  - galactic to extragalactic transition?
- ❑ Testing hadronic interaction models
- ❑ Anisotropies

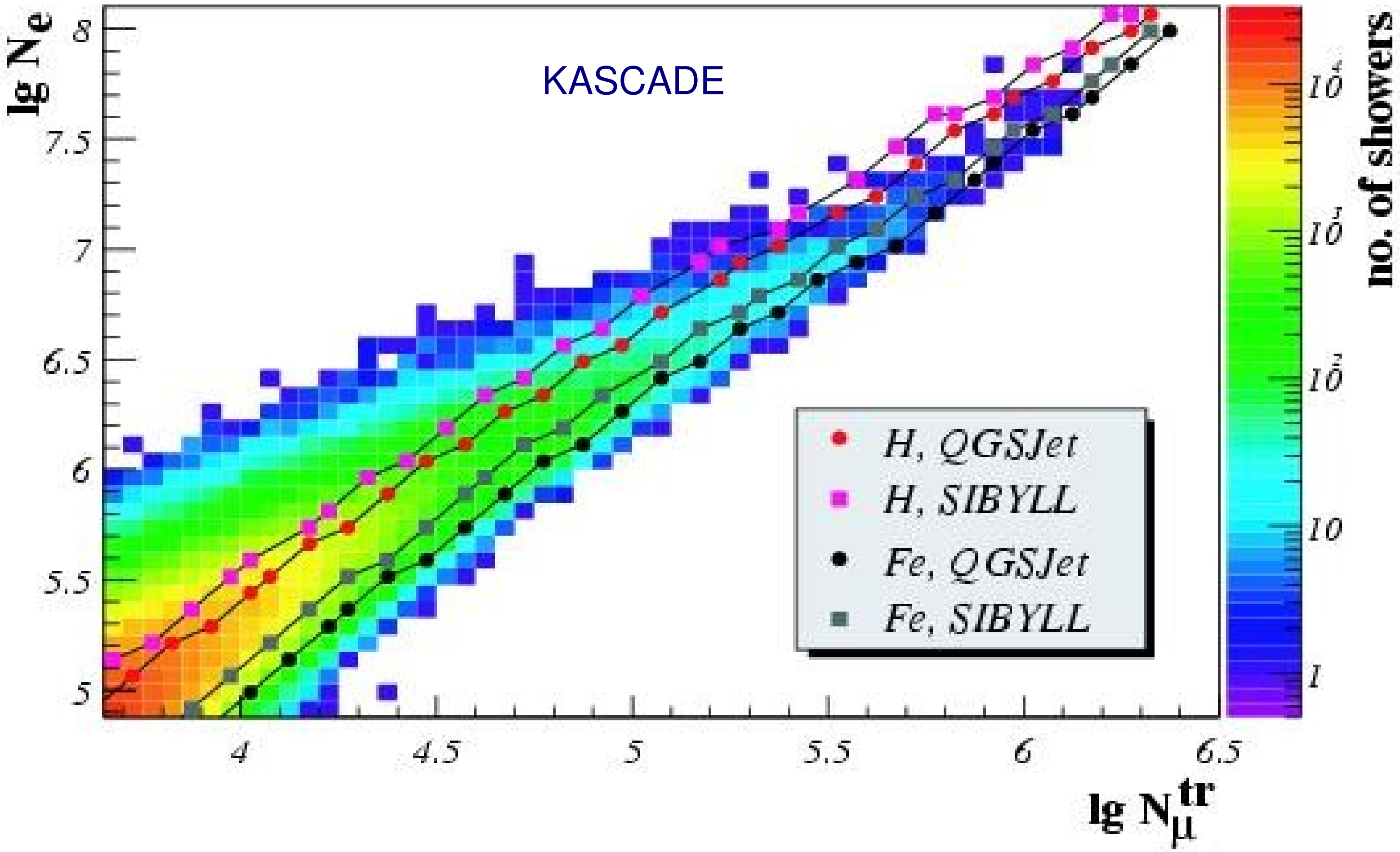
Indirect measurement: Extensive Air Showers (EAS)



EAS-TOP's results



KASCADE's results:



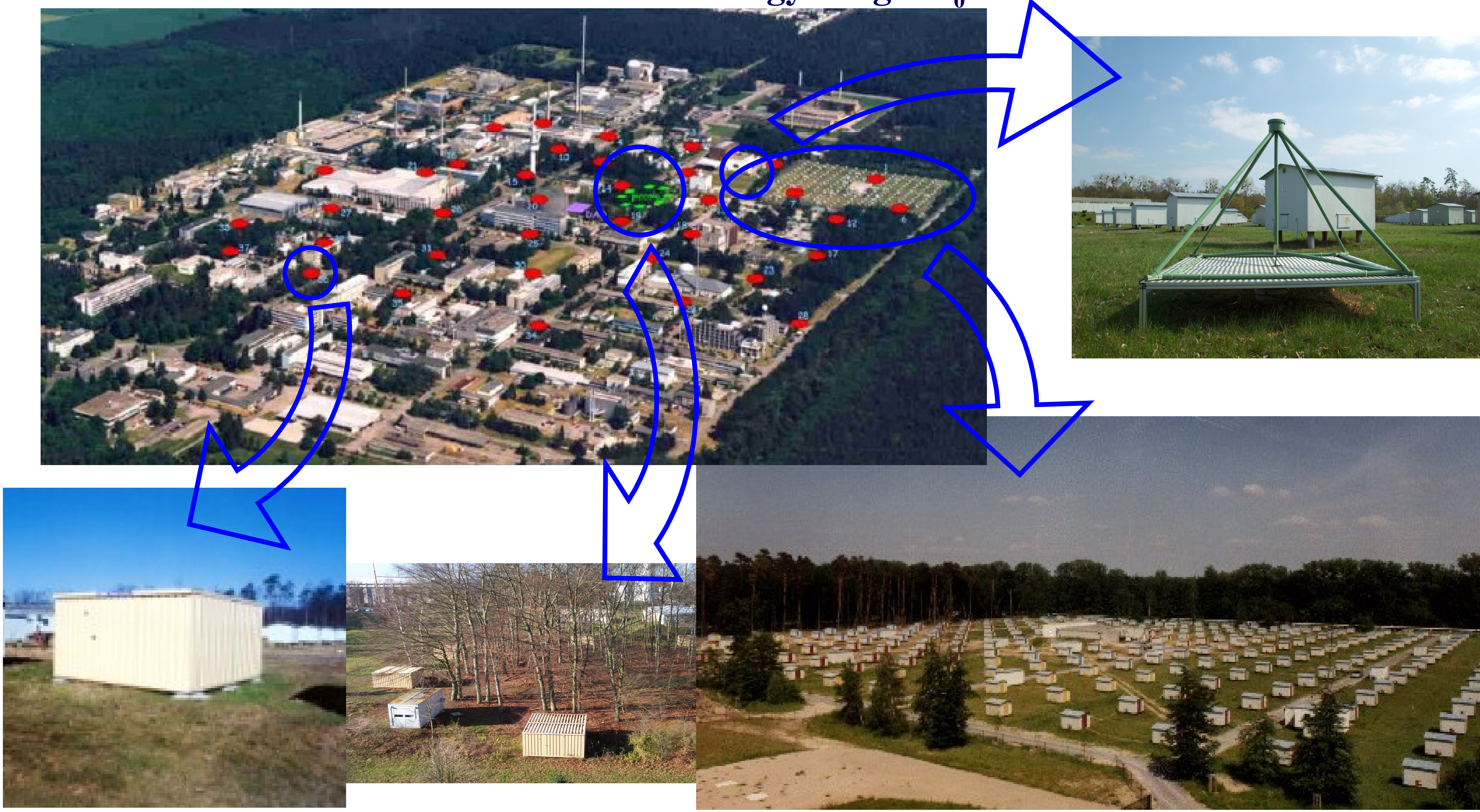
<u>Main results keep stable independent of method or model:</u>

- **knee caused by light primaries**
- **positions of knee vary with primary elemental group**
- **no (interaction) model can describe the data consistently**

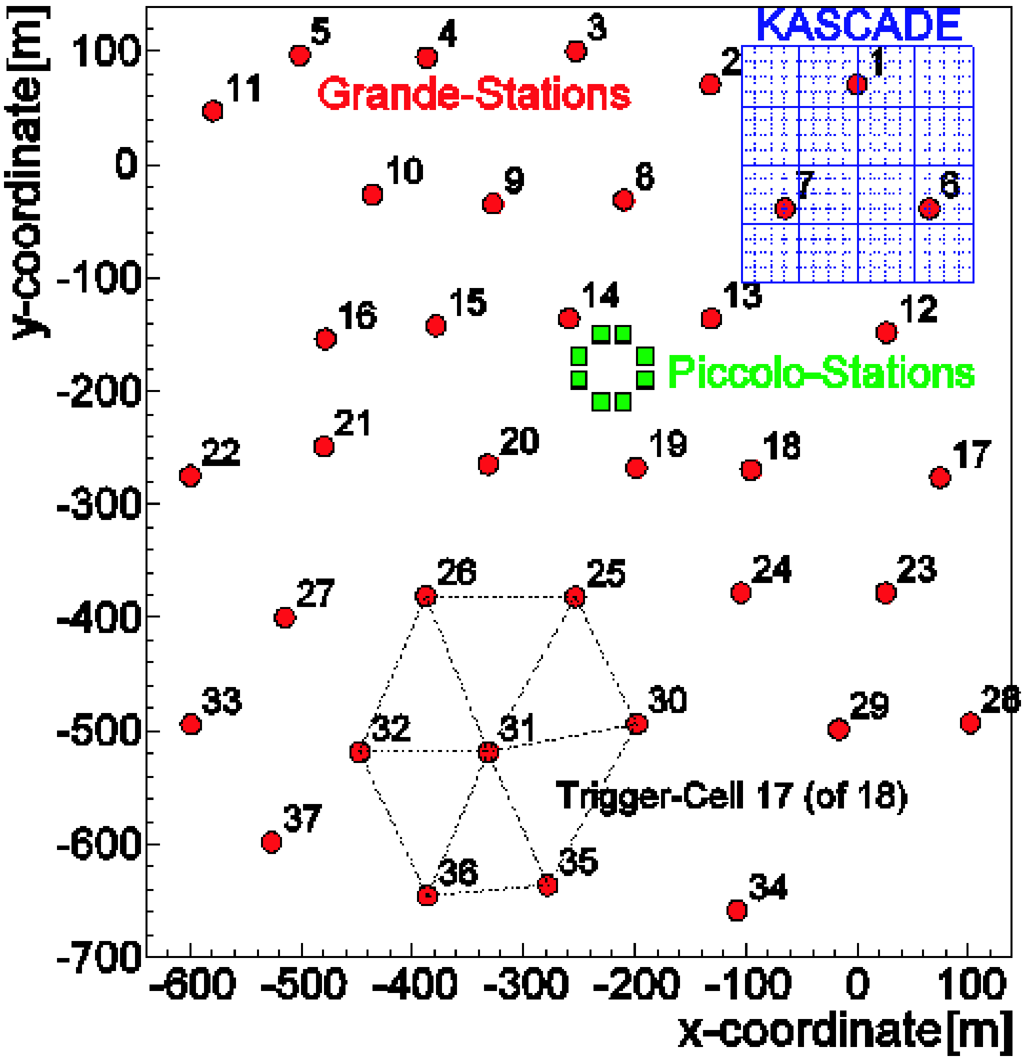
KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

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

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



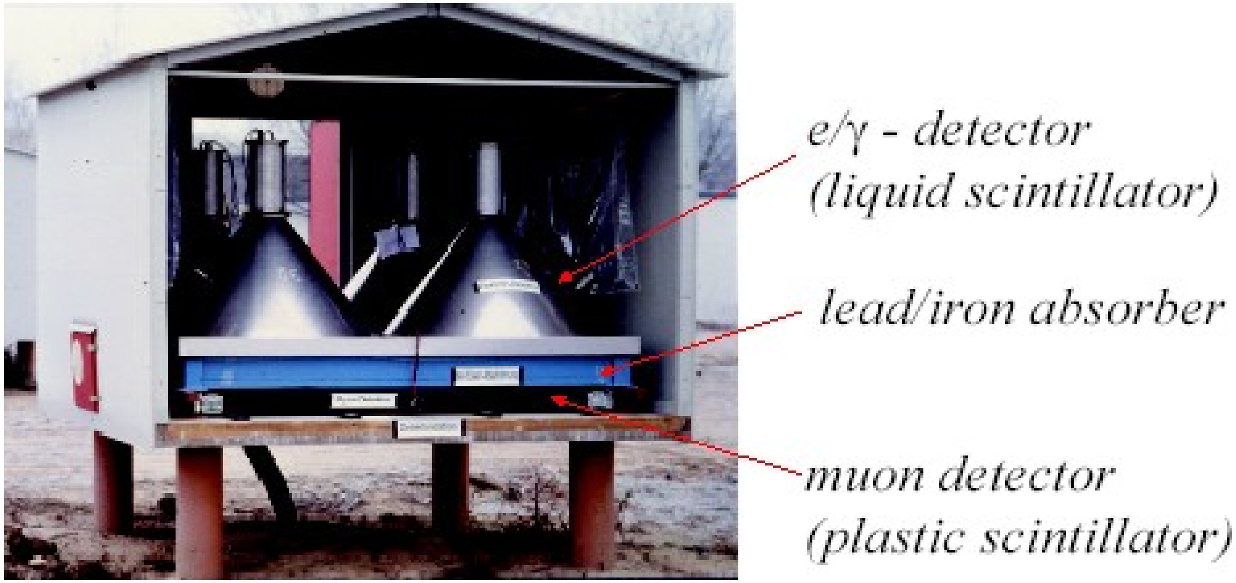
The experimental set-up



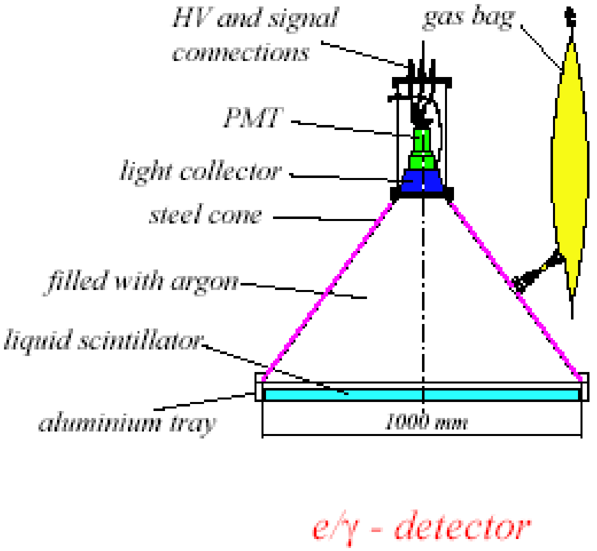
Detector	Detected EAS component	Sensitive area (m2)
Grande	Charged particles	37x10
Piccolo	Charged particles	8x10
KASCADE array e/γ	Electrons, γ	490
KASCADE array μ	Muons ($E\mu^{th}$=230 MeV)	622
MTD	Muons (Tracking) (E μ^{th}=800 MeV)	3x128
MWPCs/LSTs	Muons ($E\mu^{th}$=2.4 GeV)	3x129
LOPES 30	Radio	
Trigger Plane	*Muons ($E\mu^{th}$=490 MeV)*	*208*
Calorimeter	*Hadrons*	*9x304*

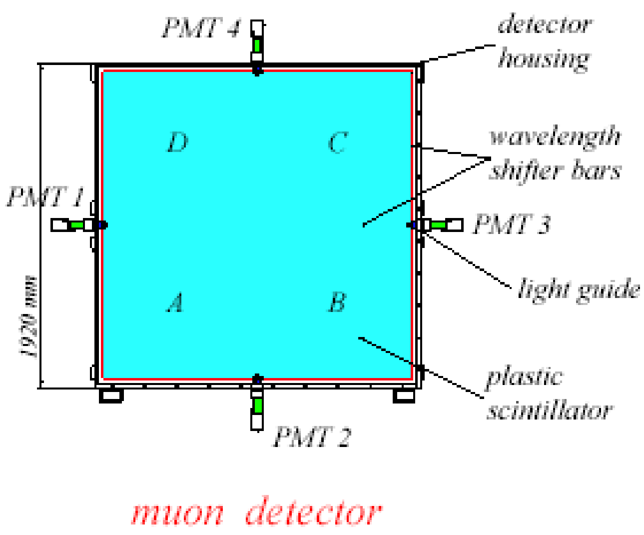
The strength of KASCADE-Grande is the multi observables information

The KASCADE Array



- 252 detectors
- 3.2 m² each
- 13 m distant
- 200 x 200 m²
- **e/γ** : liquid, 48 mm
- **μ** : plastic, 30 mm

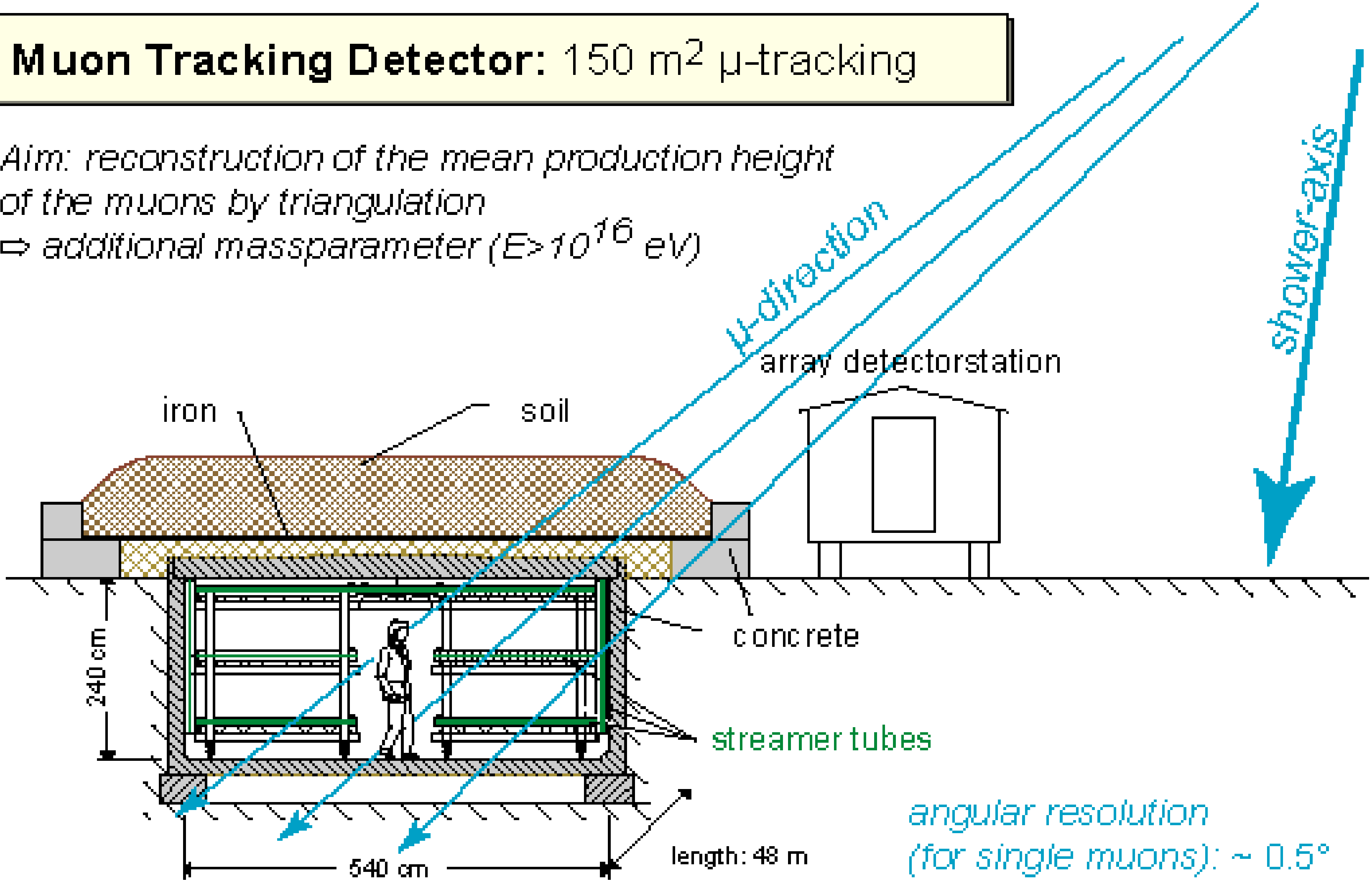




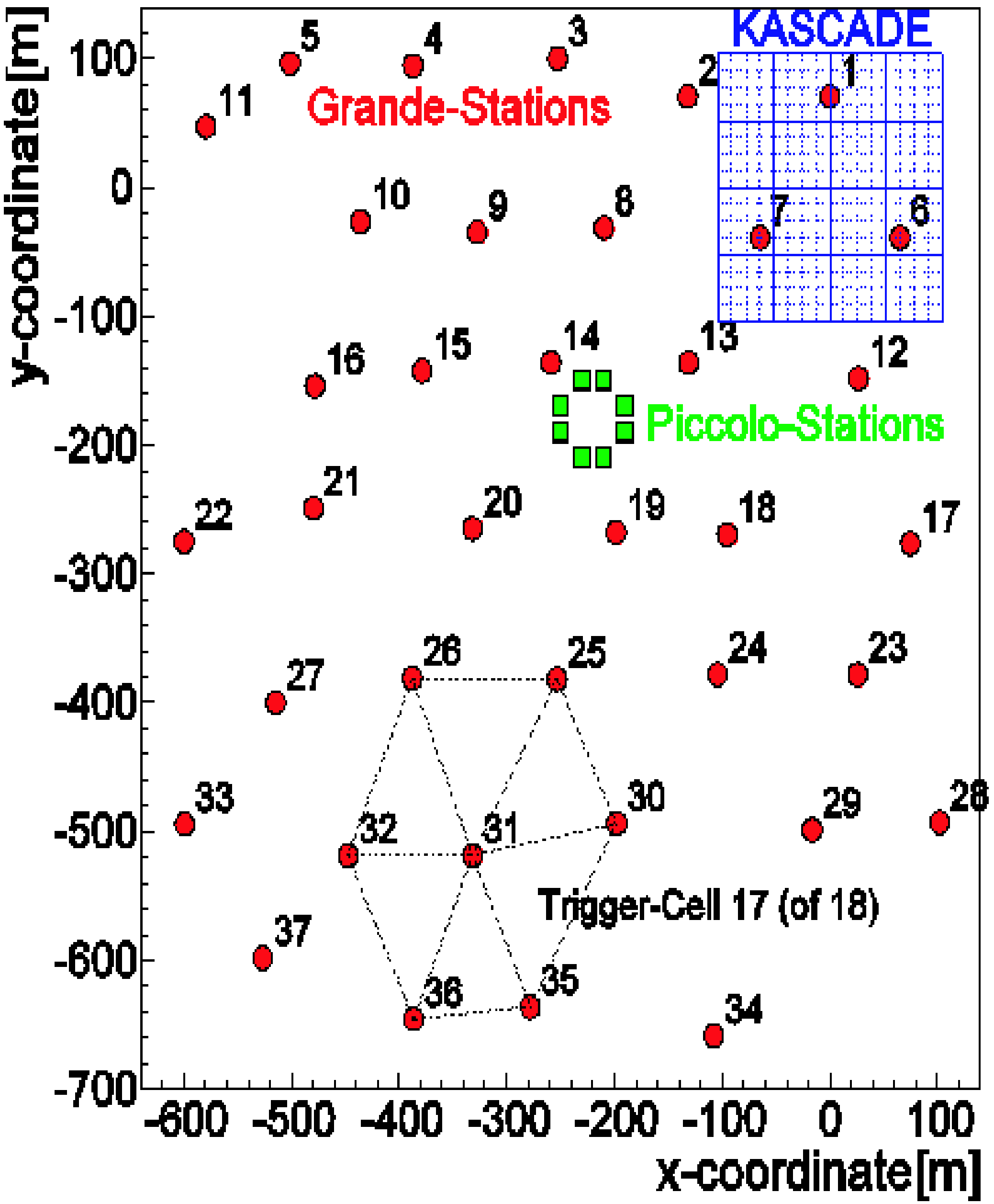
The muon tunnel

Muon Tracking Detector: 150 m^2 μ-tracking

Aim: reconstruction of the mean production height of the muons by triangulation
⇨ additional massparameter (E>10^{16} eV)



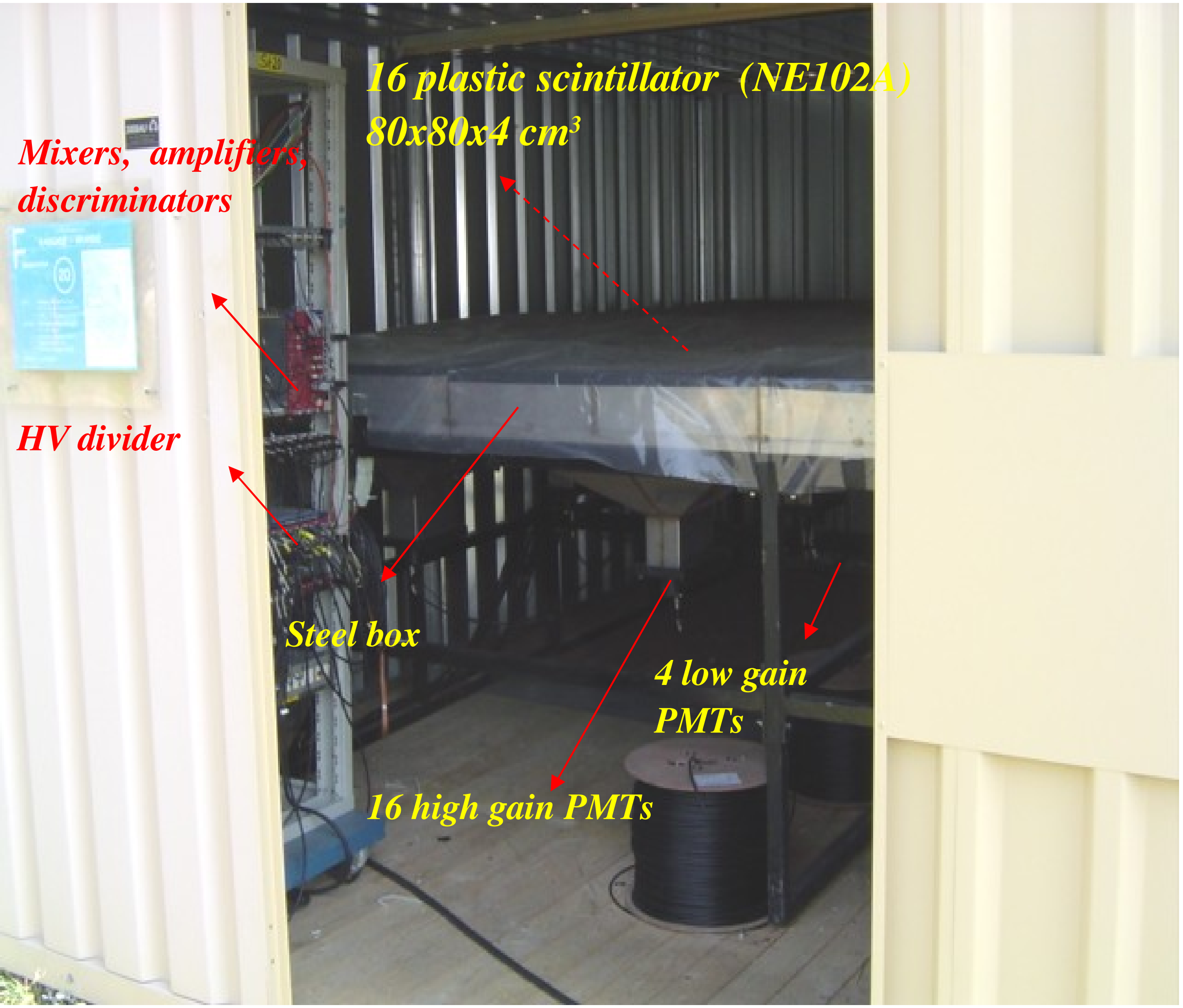
KASCADE-Grande: the Grande array



37 stations (from EAS-TOP)
10 m^2 of plastic scintillators
140 m average distance
0.5 km^2 total surface

18 trigger cells of 7 stations
rate $\simeq$ 0.5 Hz
efficiency $\simeq 1$, $E_0 > 2 \cdot 10^{16}$ eV

The detector stations



Measurements of:

- **timing**: TDC (CAEN V767)
  0.8 ns (electronic resolution)
- **amplitude**: Peak-Sensing ADCs

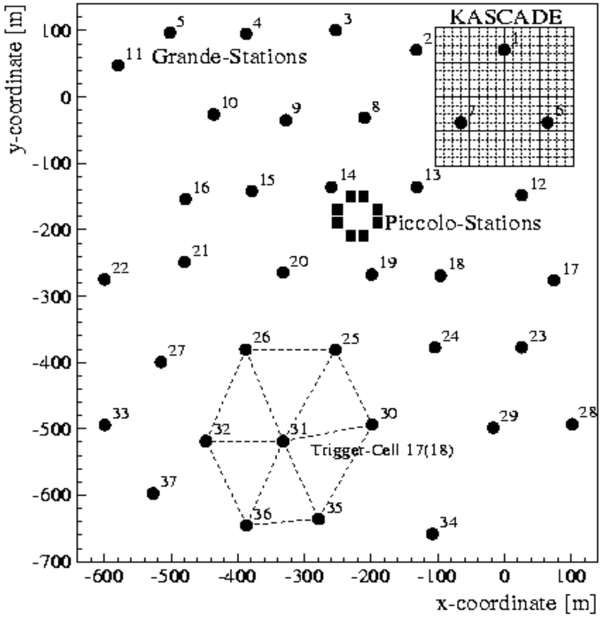
PMTs:

16 High Gain (10 m^2):
range 1 = 0.03-8 particles/m^2
range 2 = 2-80 particles/m^2

4 Low Gain (2.5 m^2):
range 3 = 20-800 particles/m^2

Signal threshold = 0.3 particles

KASCADE-Grande : Reconstruction steps



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

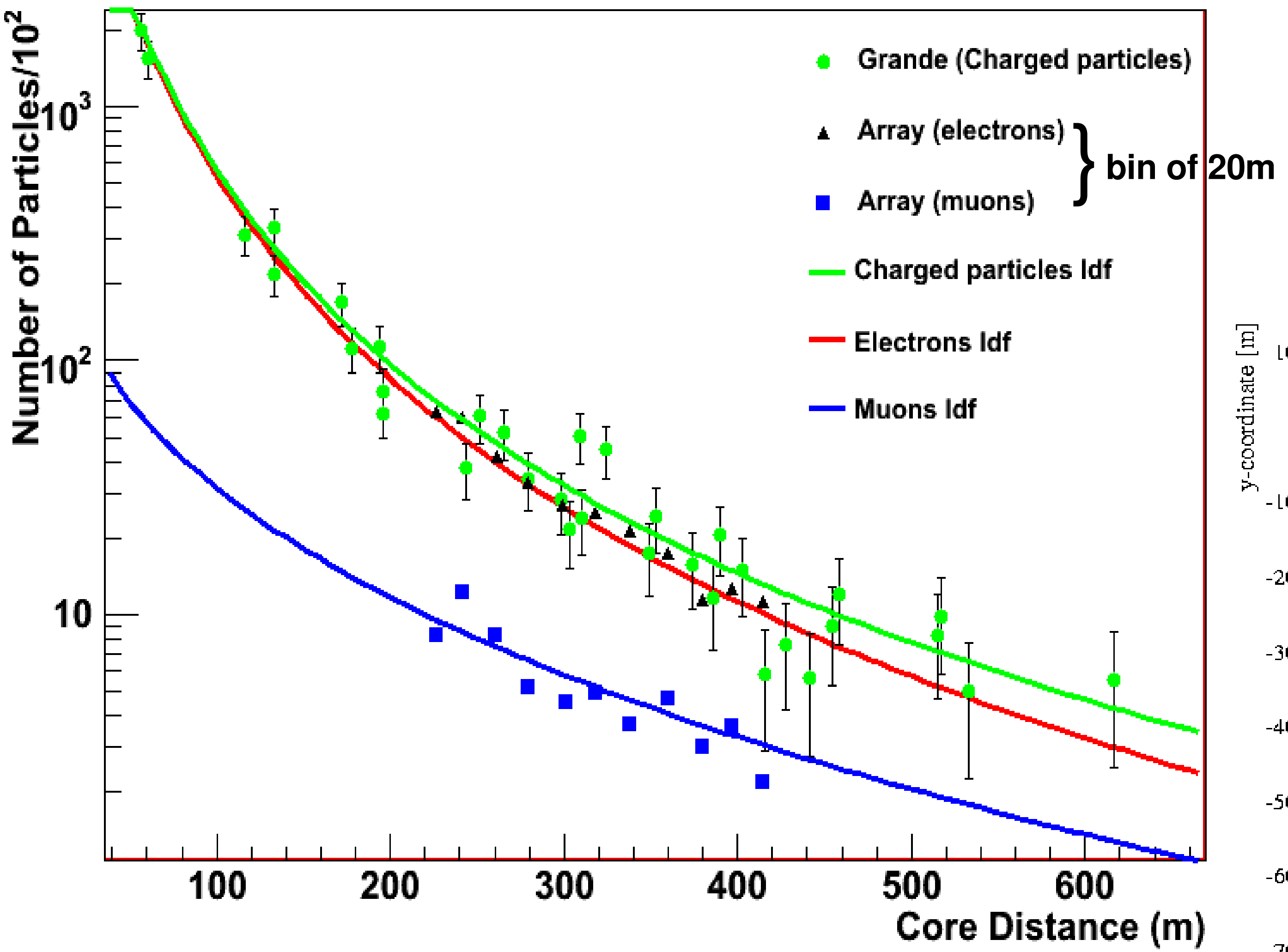
2a) shower size (charged particles)
from Grande array data

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

Single event lateral distributions

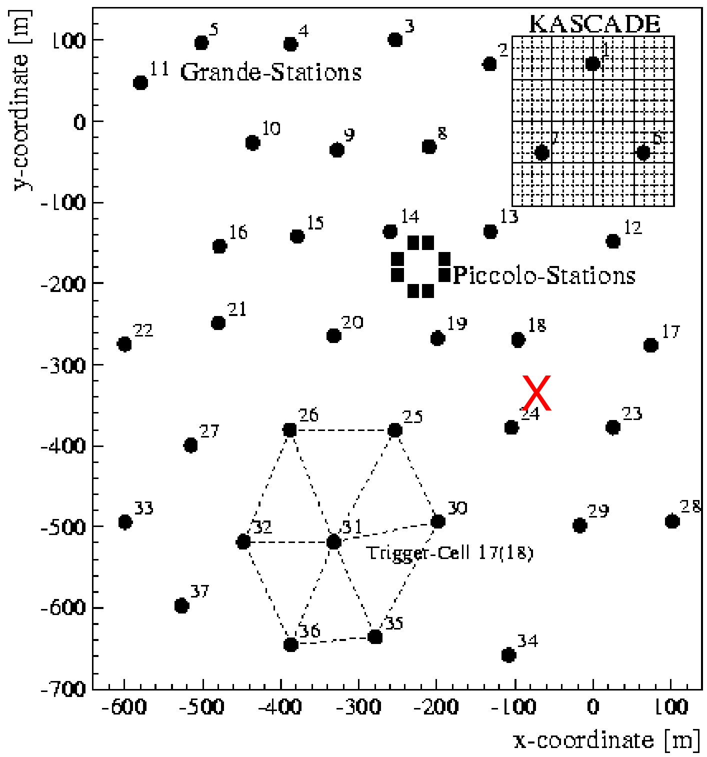


Log Ne = 7.1

Log Nμ = 6.0

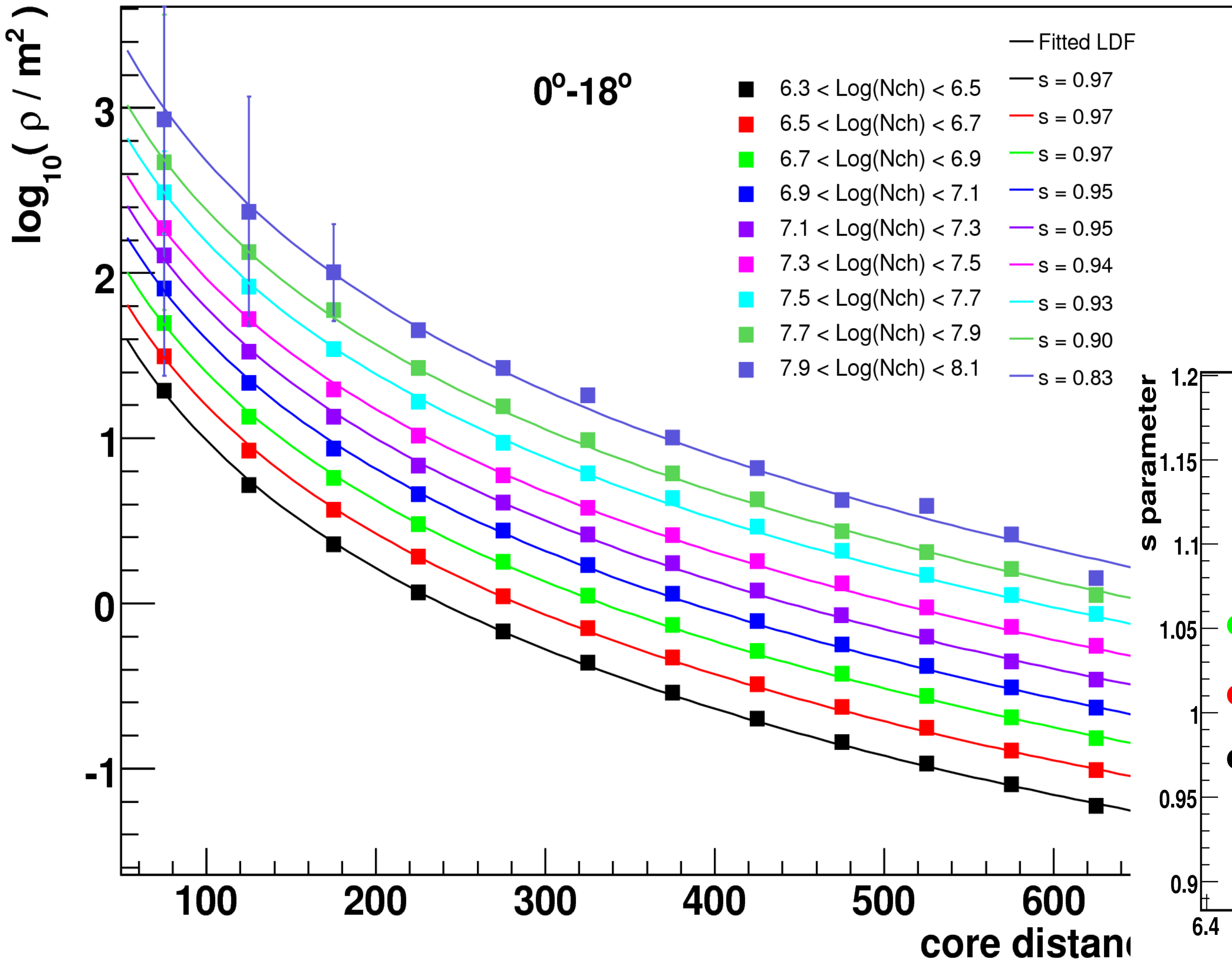
θ = 19.2^o

ϕ = 78.5^o

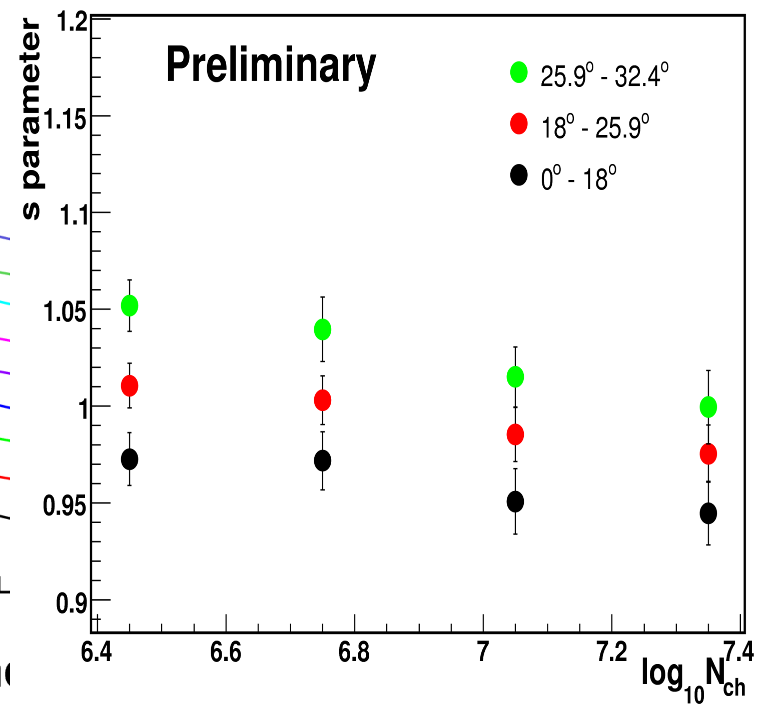


Mean lateral distribution

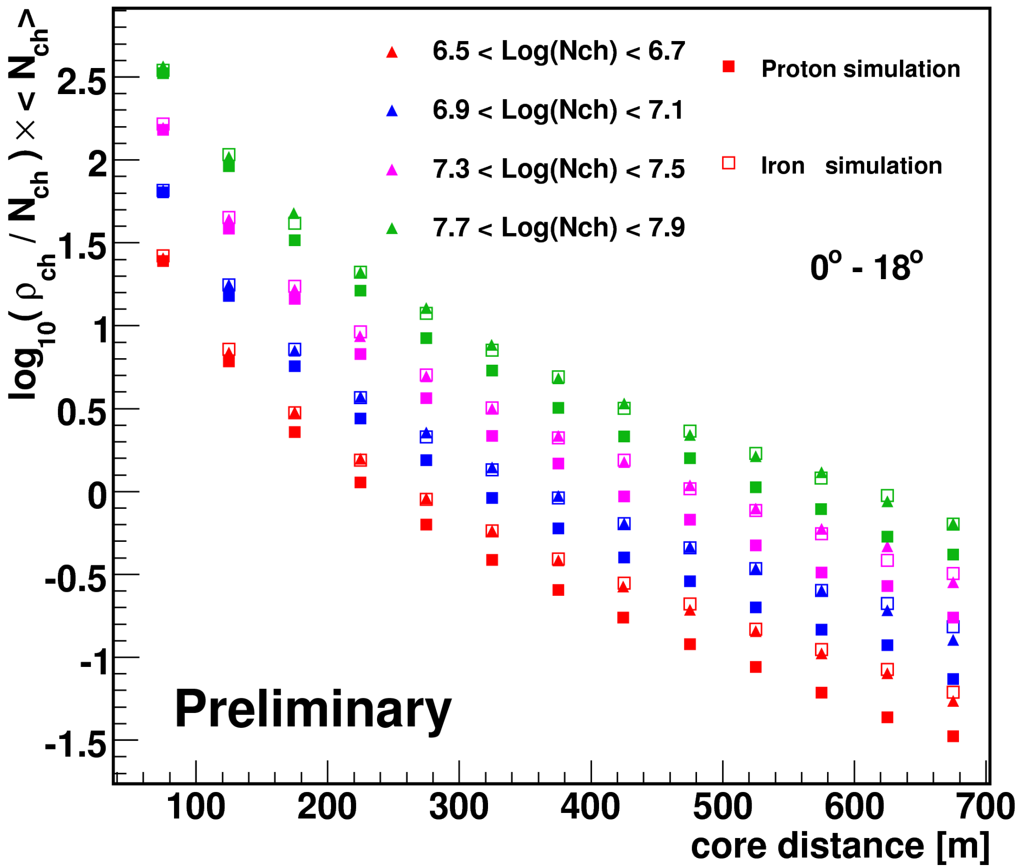
$$(1) \quad \rho_{ch} = N_{ch} \cdot C(s) \cdot \left(\frac{r}{40\mathrm{m}}\right)^{s-1.5} \left(1 + \frac{r}{40\mathrm{m}}\right)^{s-3.6}$$



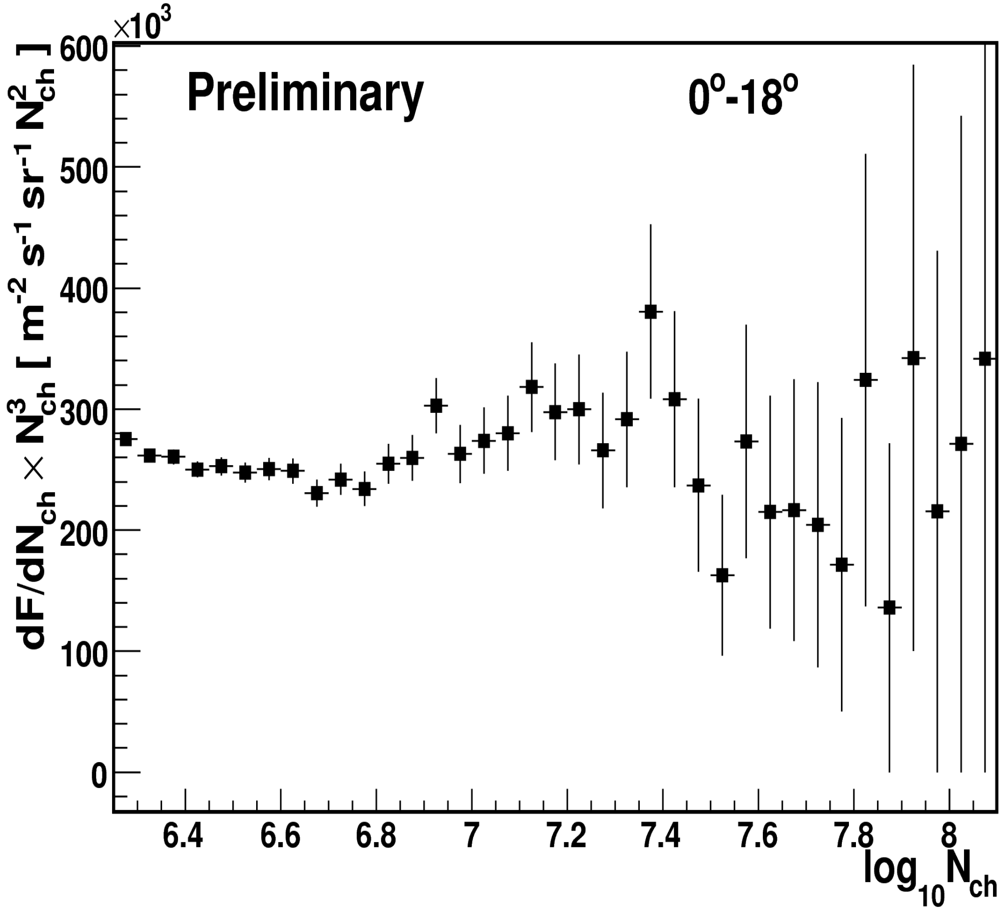
- vertical showers
- mean lateral distributions in shower size (Nch) bins
- fitted with the LDF (1)



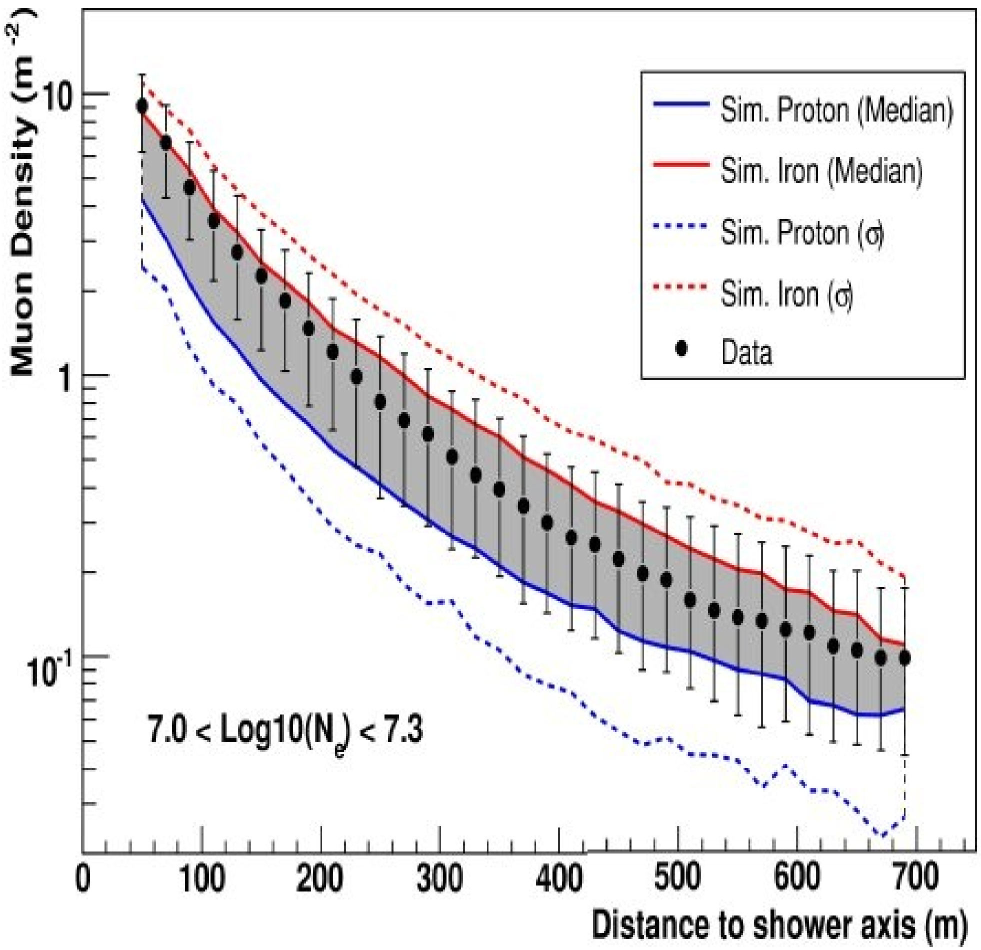
Lateral distribution (charged particles)



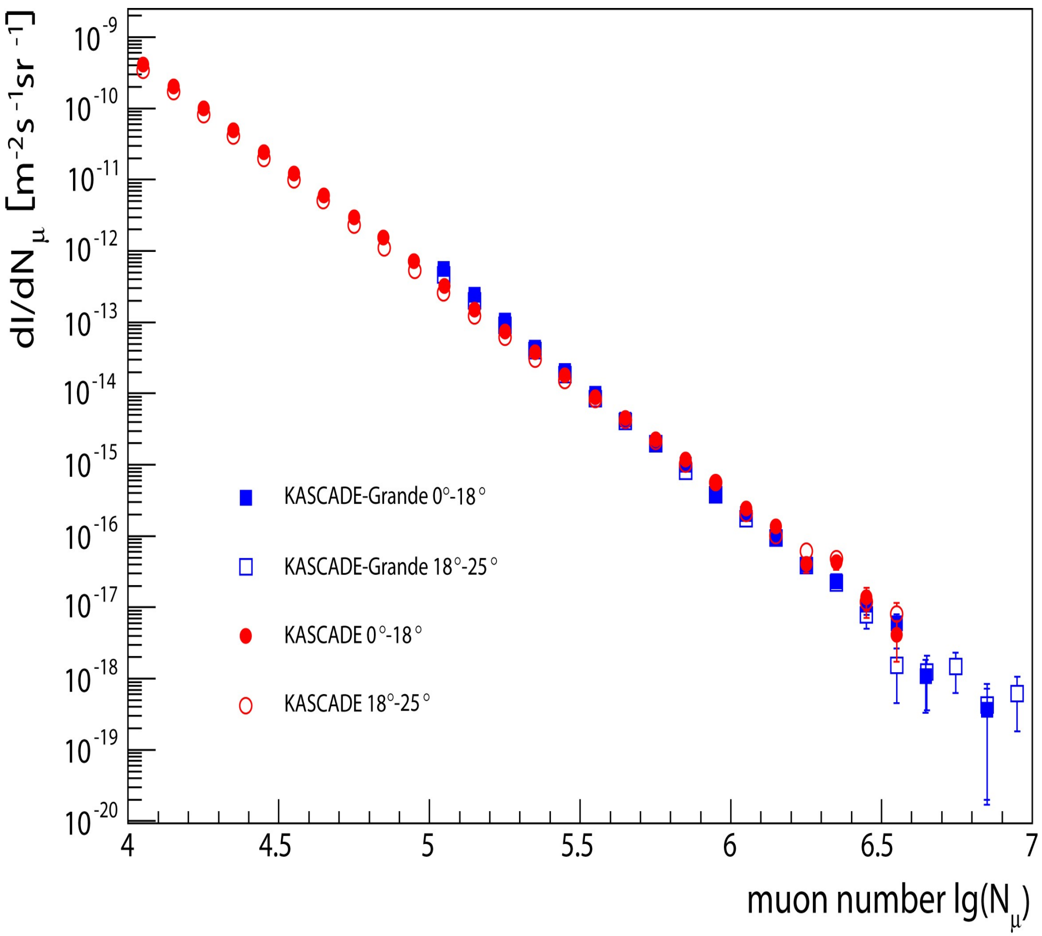
Shower size spectrum



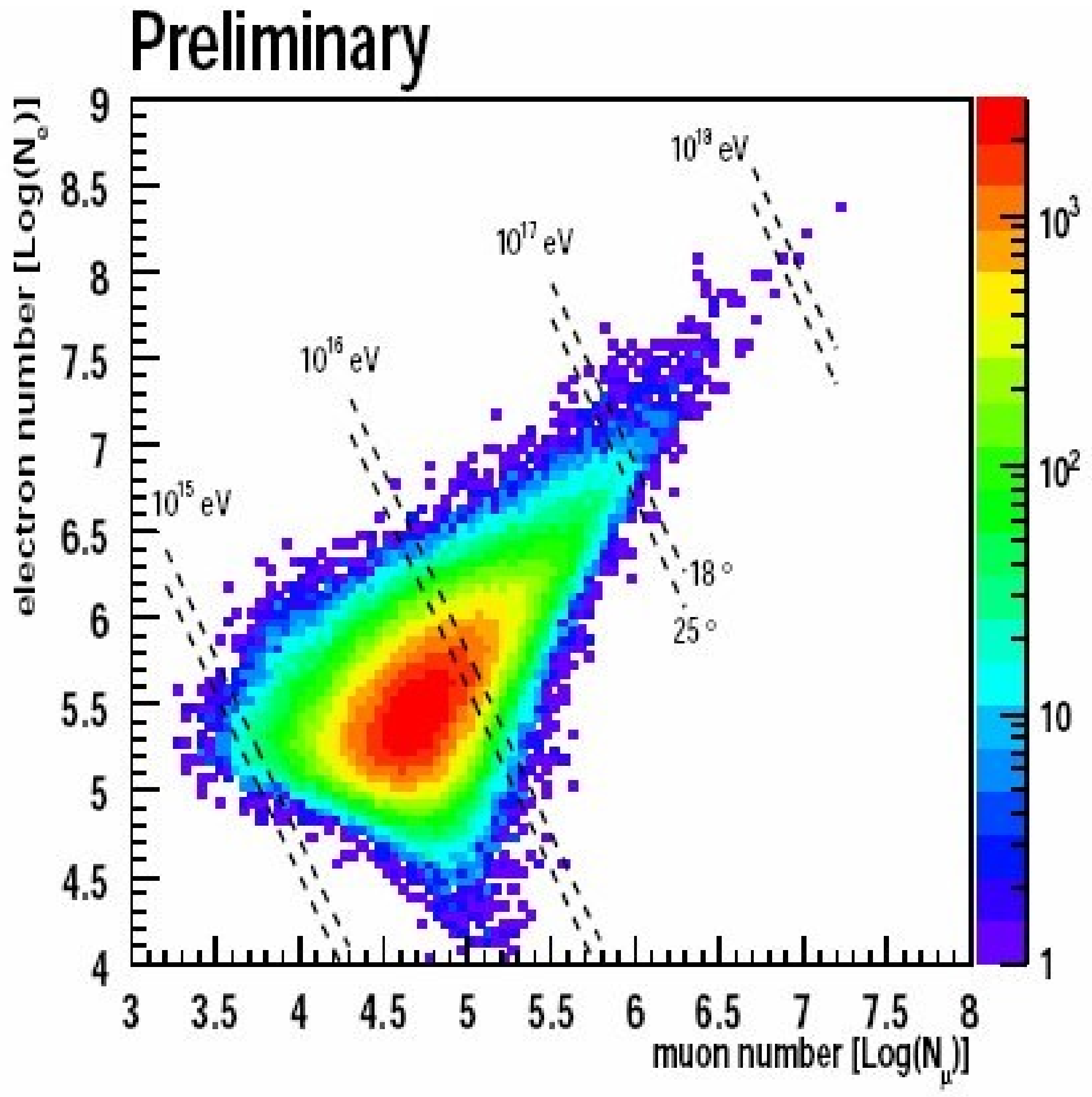
Lateral distribution (muons)



Muon Number Spectrum

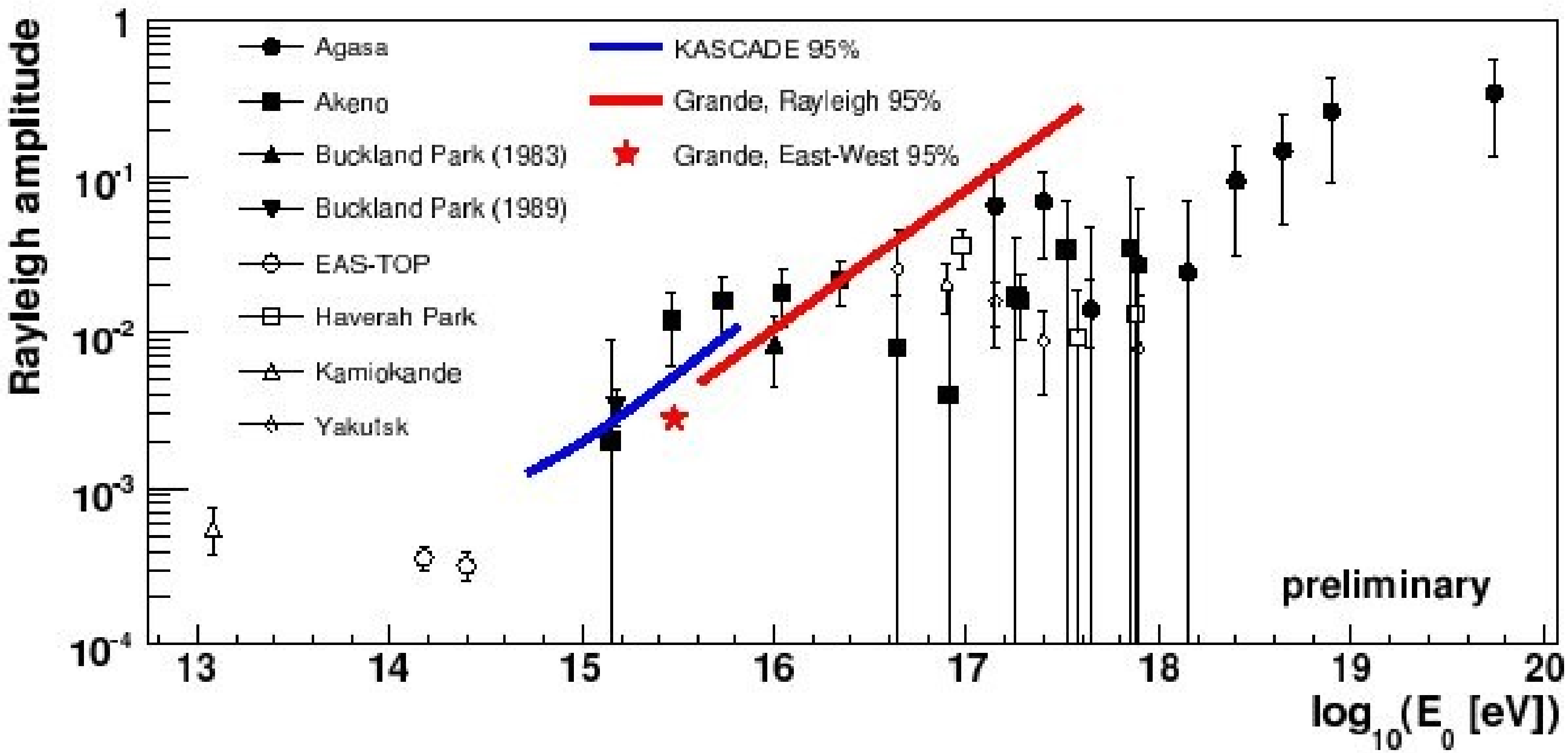


2-dimensional Ne-Nμ spectrum



Unfolding of 2-dimensional shower size spectrum possible
➔ energy & composition

Large scale anisotropies



Anisotropy expected from diffusion leakage from Galaxy

Measuring radio emission from EAS @ KASCADE-Grande: LOPES

A bit of history….

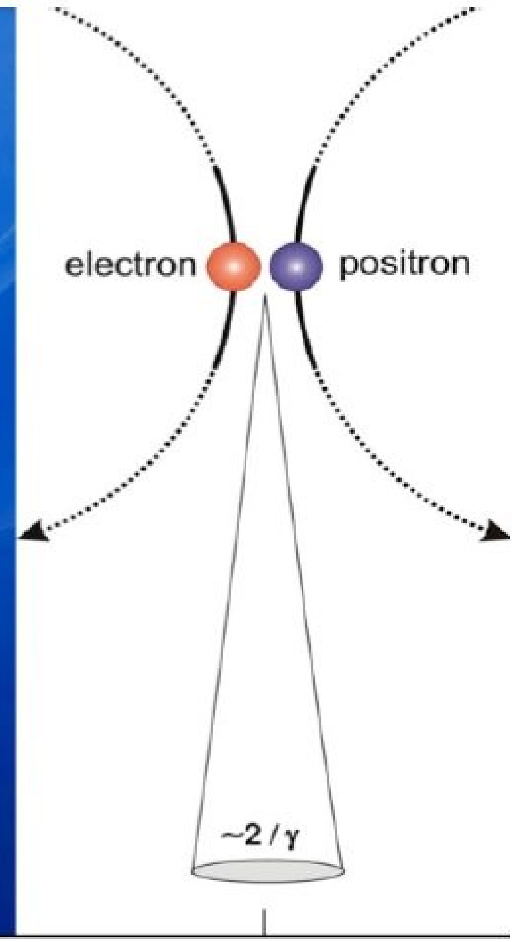
- First discovery: Jelley et al. (1965), Jodrell Bank at 44 MHz.
- Theory papers by Kahn & Lerche (1968) and Colgate (1967)
- coherence if λ_{rad} < thickness of shower disk (some 10 MHz)
- e^+e^- separation in geomagnetic field?
- or geosynchrotron radiation? (Gorham/Falcke)

Allan formula (1971) from his review:

$$\varepsilon_\nu = 20\left(\frac{E_p}{10^{17}\,\mathrm{eV}}\right)\sin\alpha\cdot\cos\theta\cdot\exp\left(-\frac{R}{R_0(\nu,\theta)}\right)\left[\frac{\mu V}{\mathrm{m}\cdot\mathrm{MHz}}\right]$$

ε_ν: field strength; α: angle to B-field; θ: zenith angle;
R distance from core; R_0=110 m at 55 MHz

K.-H. Kampert



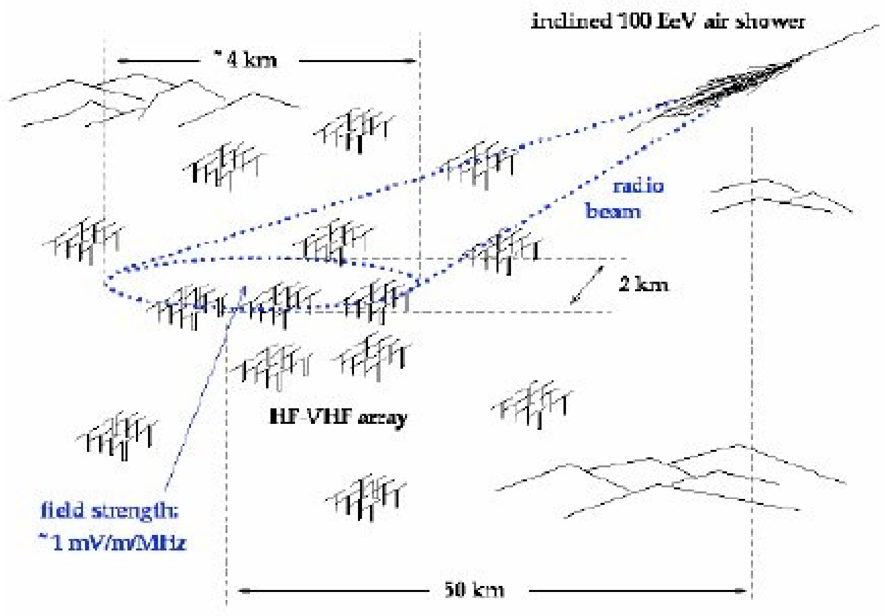
A 10^{17} eV airshower produces a 1 GJy radio flare in 25 ns (40 MHz bandwidth)!

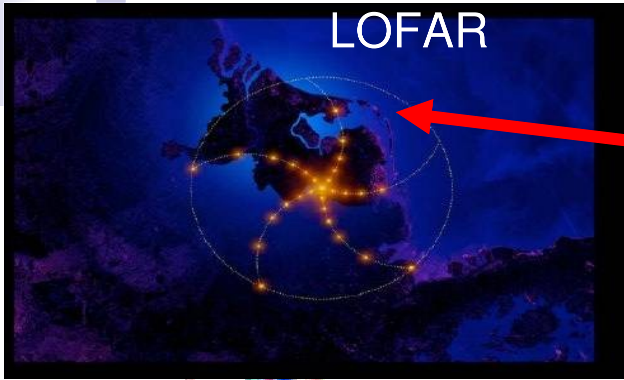
(The brightest radio source, the sun has 1MJy.)

1Jy = 10^{-26}Wm^{-2}Hz^{-1}

Advantages of Radio Emission from Air Showers

- Cheap detectors, easy to deploy
- High duty cycle (24 hours/day minus thunderstorms)
- Low attenuation (can see also distant and inclined showers)
- Bolometric measurement (integral over shower evolution)
- Also interesting for neutrinos
- Potential problems:
  - Radio freq. interference (RFI)
  - size of footprint
  - correlation with other parameters unclear
  - only practical above ~10^{17} eV.



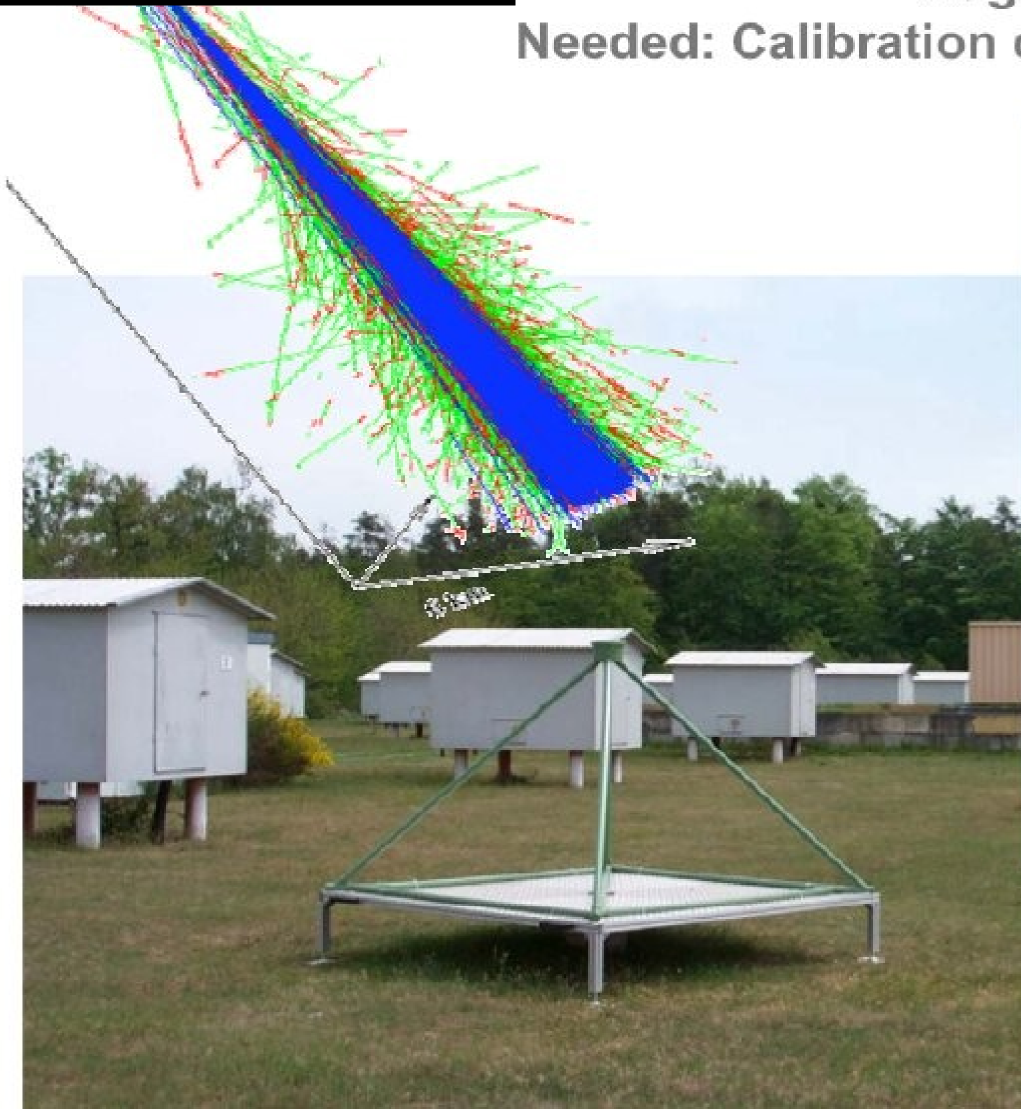


LOPES = LOfar PrototypE Station

Question: LOFAR as Cosmic Ray Detector ?

Auger with radio antenna array ?

Needed: Calibration of the radio emission in air showers !



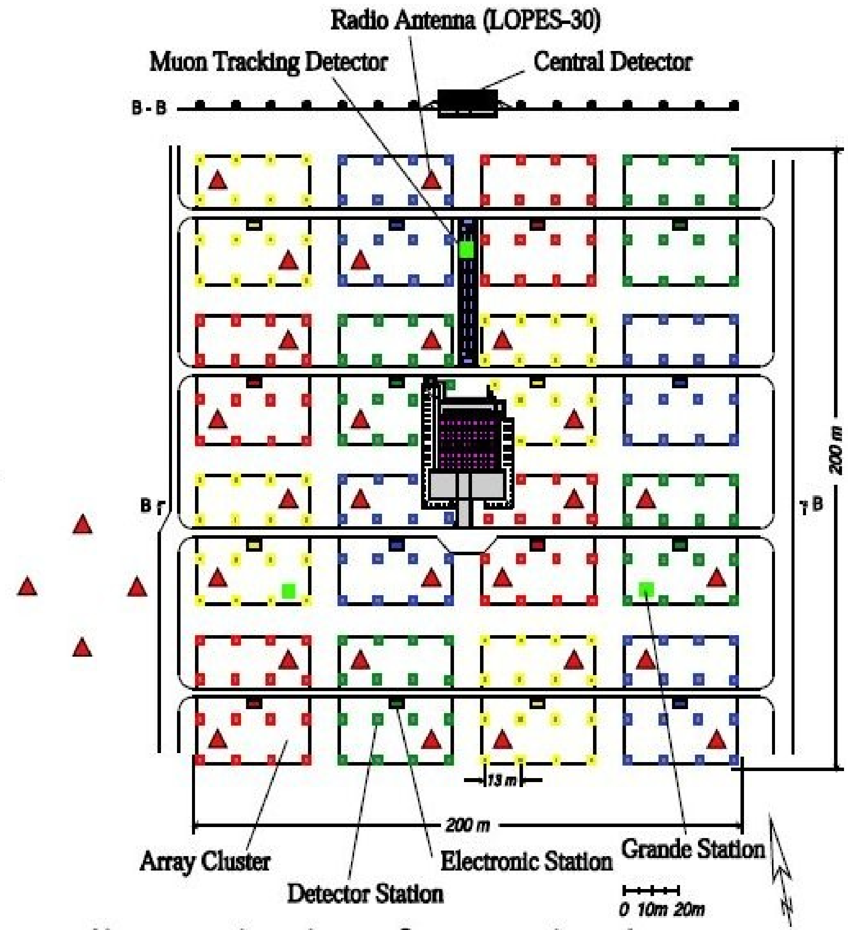
- -Detection threshold
- -Signal dependence on
  - primary energy
  - primary mass
  - geomagnetic angle
  - zenith angle
- -Lateral extension

➔ „known“ air showers

➔ well-calibrated air shower experiment

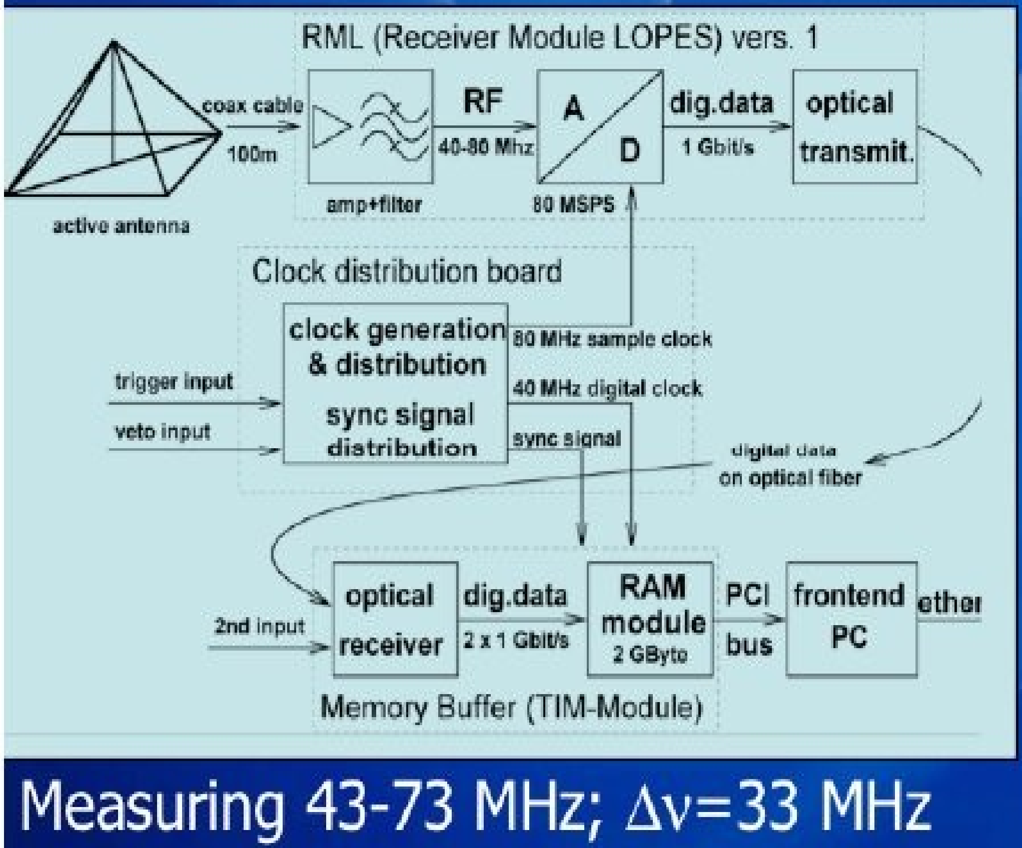
LOPES set-up

- Set up at the KASCADE-Grande site
- Frequency range of 40 – 80 MHz
- Triggered by large event trigger
- 10 antennas in the first phase, 30 antennas in second phase

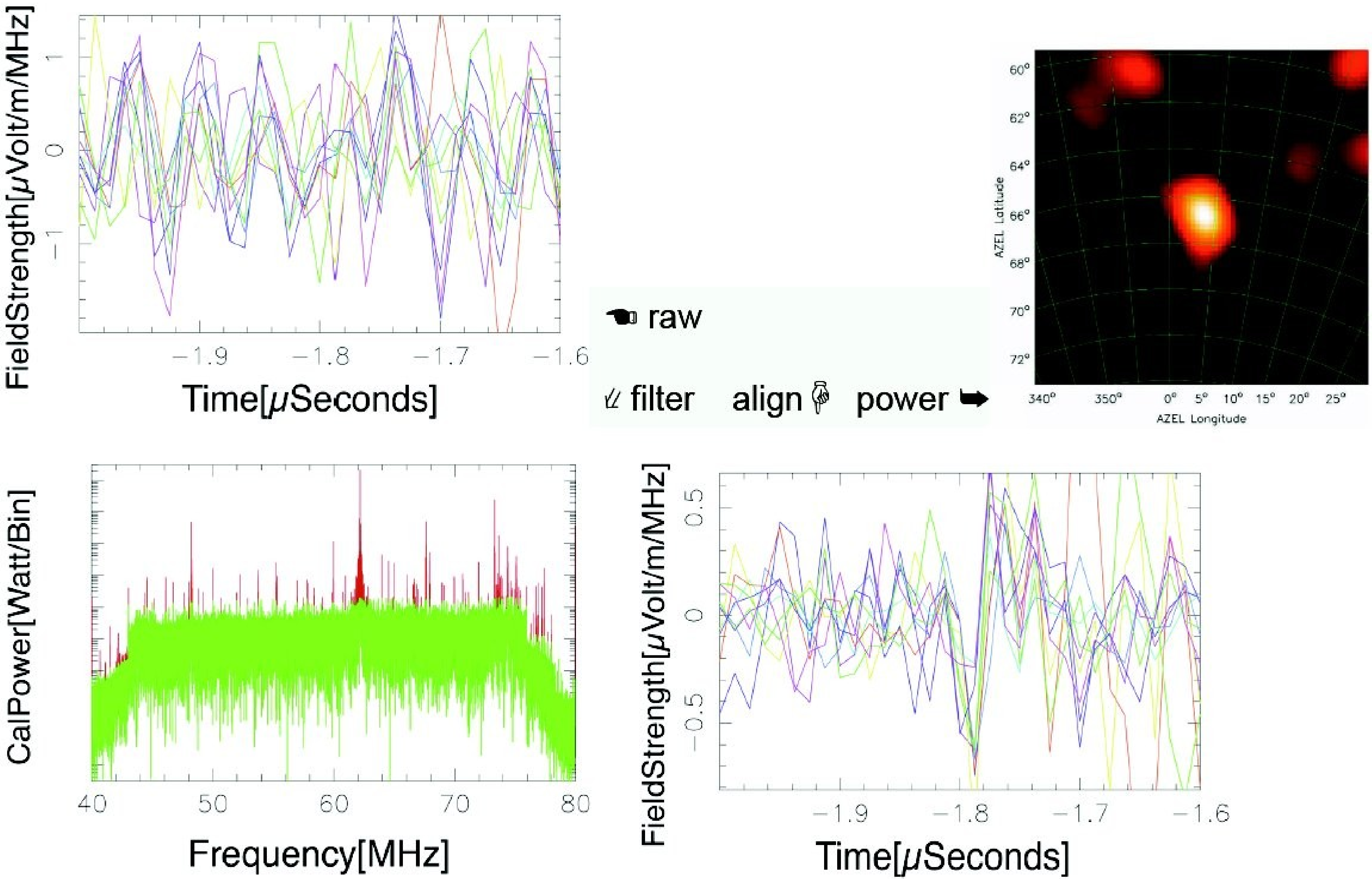


- Goals:
  - Develop techniques to measure the radio emission from air showers
  - Determine the radiation mechanism of air showers
  - Calibrate the radio data with theoretical and experimental values from an existing air shower array

The electronics

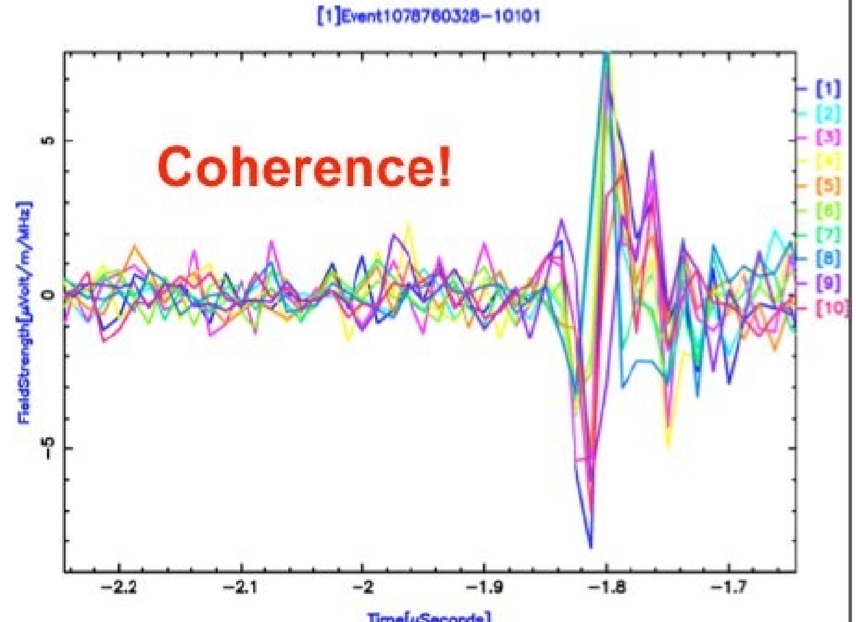


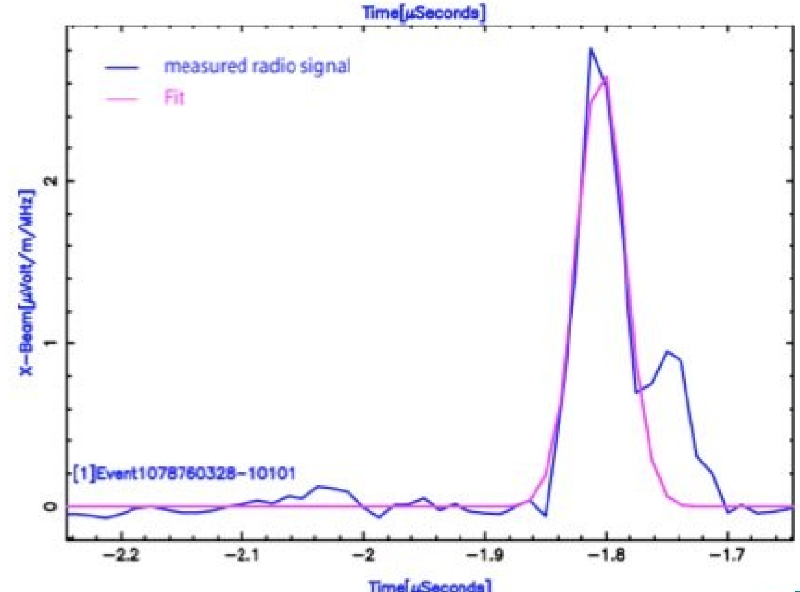
How it works - digitally

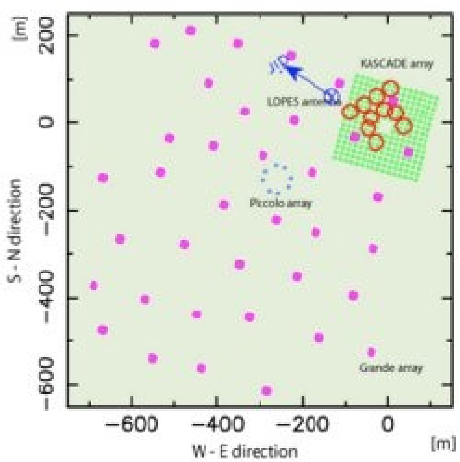


LOPES 10 :
Interplay of radio and particle measurements

Event:	search for maximum coherence
Φ= 302.18°	= 301.58°
θ = 41.01°	= 40.61°
α = 57.91°	
X_c = -142.85 m	= -137.85 m
Y_c = 40.27 m	= 30.28 m
lg(E/eV) = 17.73	
ln(A) = 3.16	
curvature = 3250 m	= 4250 m

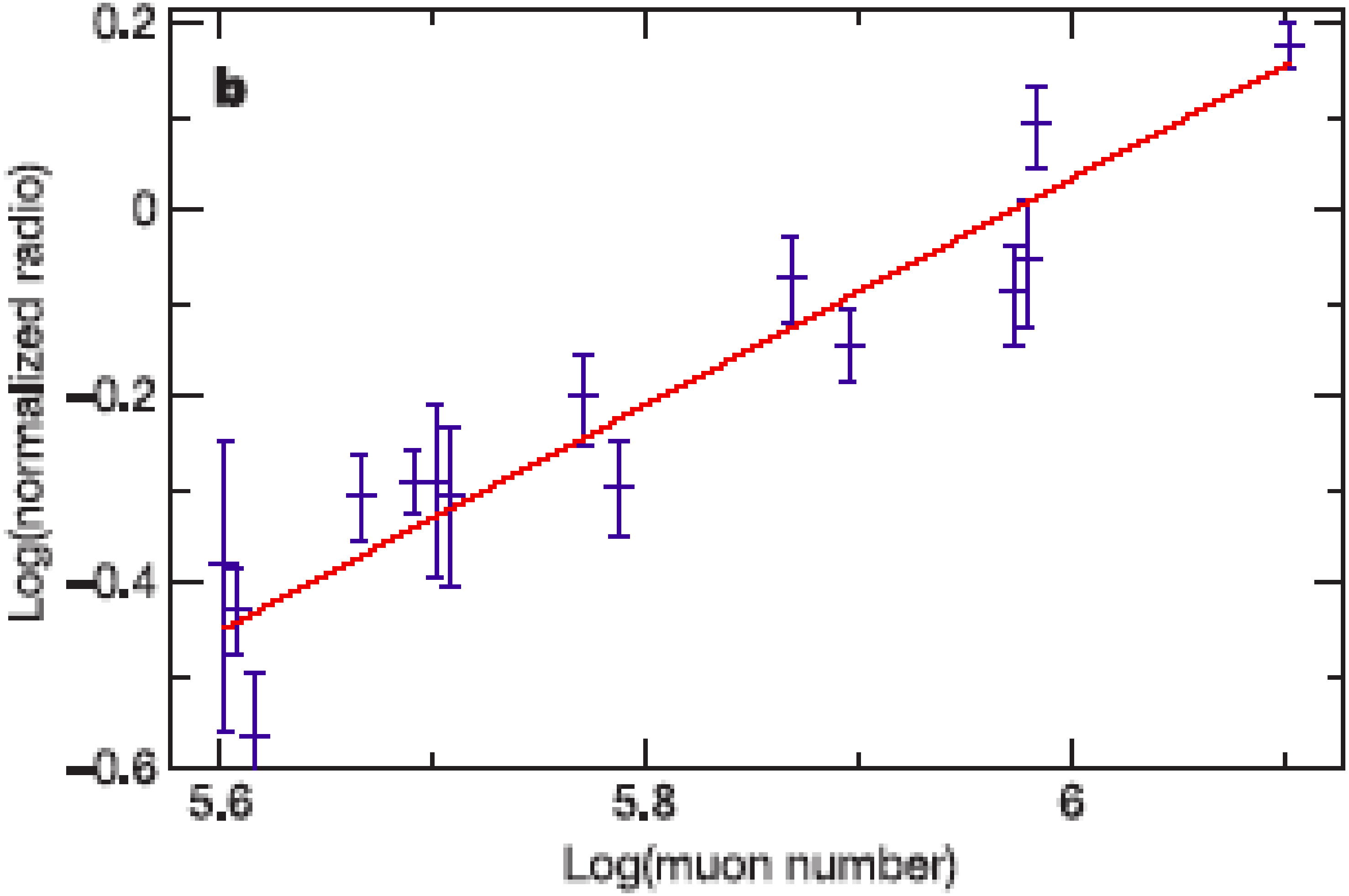






A.Haungs

Radio signal vs muon number



Measured EAS, Falcke et al. Nature 435 (2005)

CONCLUSIONS

• KASCADE-Grande has been presented
• It's in continuous and stable data taking since Jan 2004
• Checks of shower observables show good data quality
• First Analysis have been reported
•The LOPES experiment and the “radio” technique have been presented