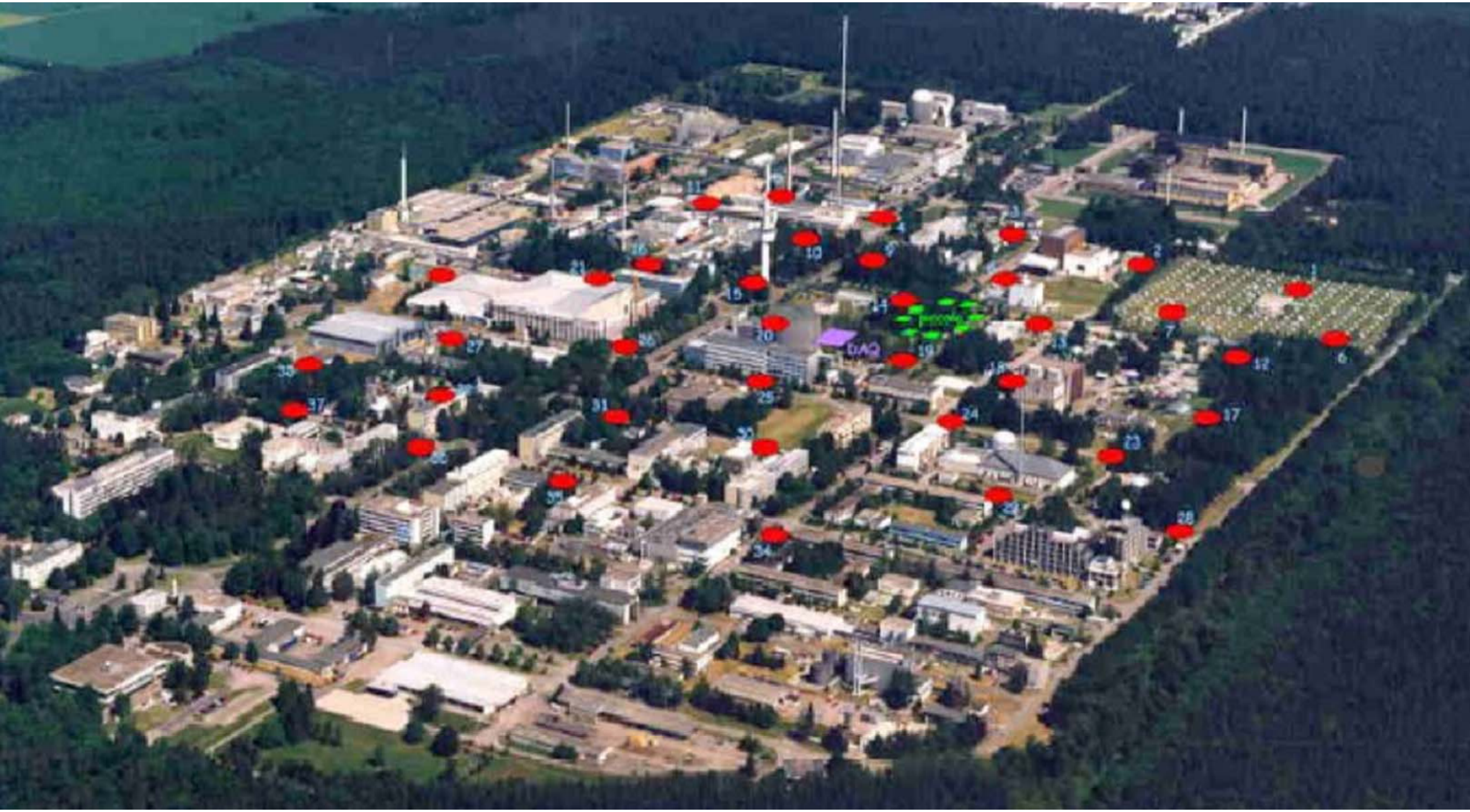
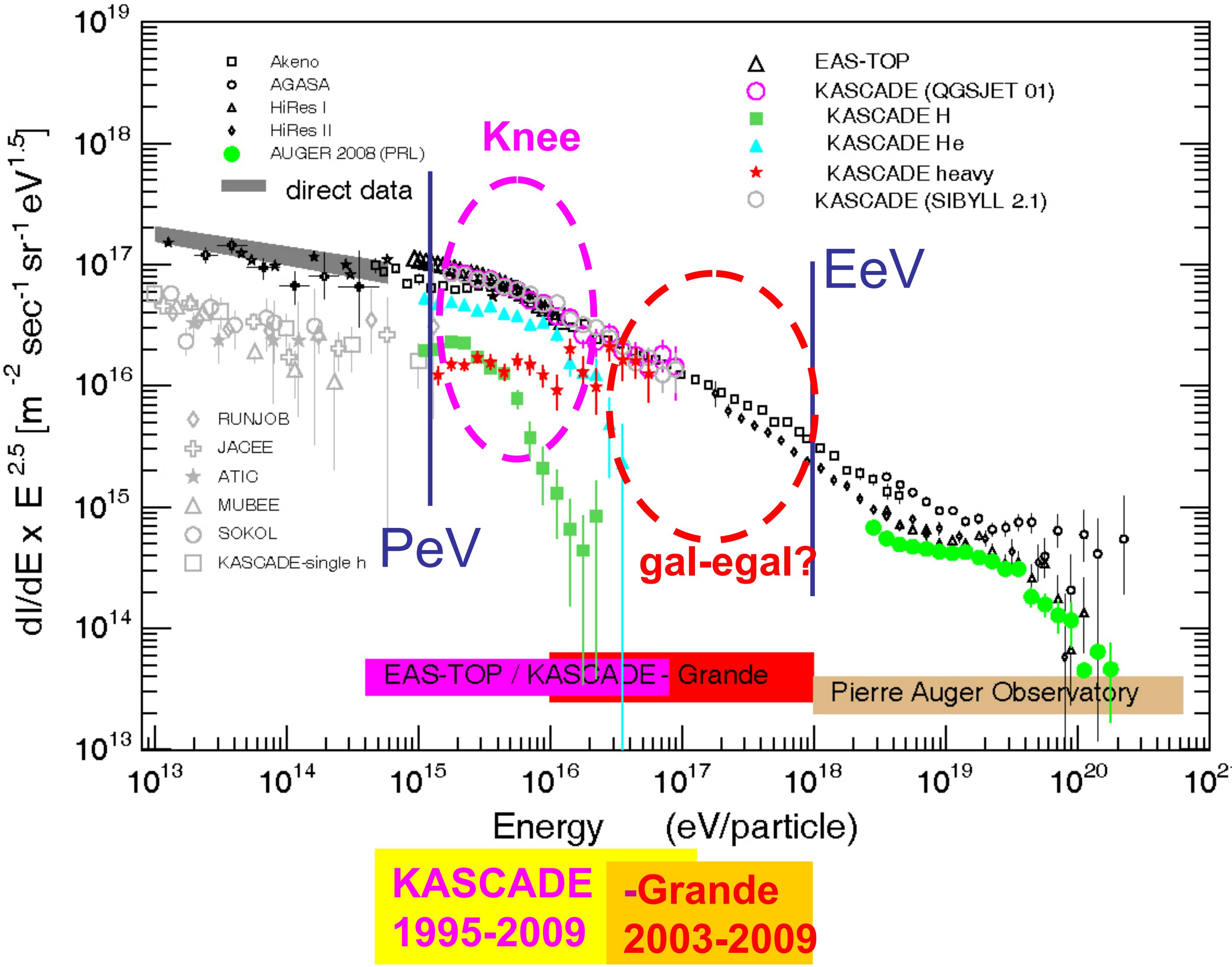
Perspectives of the
KASCADE-Grande EAS facility



Cosmic Rays around the knee(s) ➔ galactic origin of CR



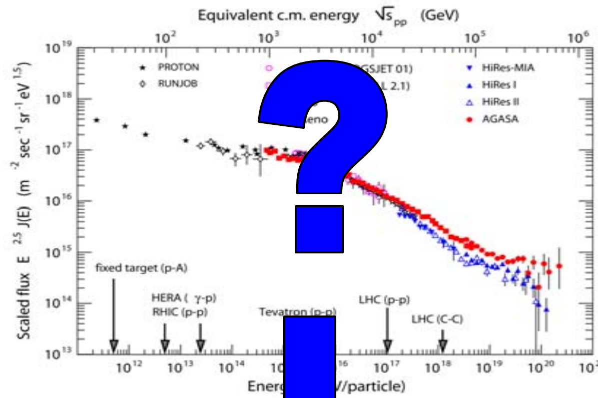
KASCADE
10^{15}-10^{17}eV:

- **knee?**

KASCADE-Grande
10^{16}-10^{18}eV:

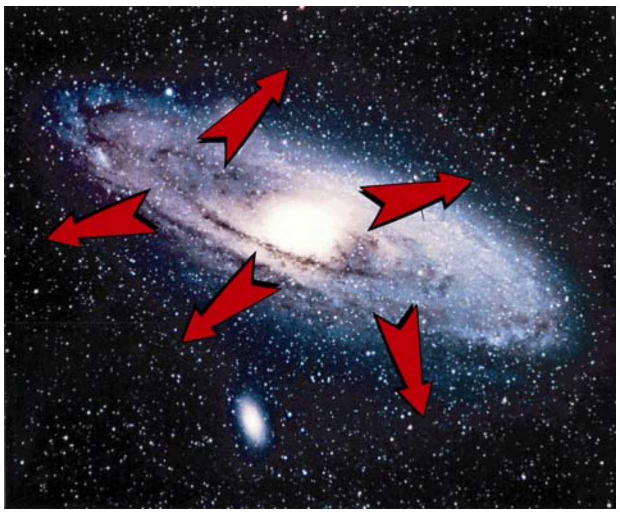
- **Iron knee (rigidity)?**
- **Transition galactic-eg CR?**
- **Second knee?**

What is the origin of the (first) knee?



various theories:

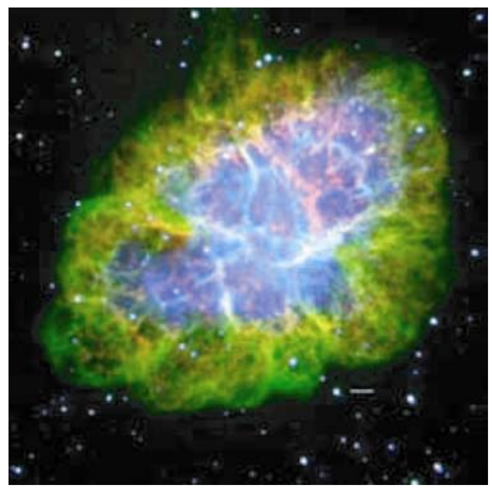
Diffusion



Escape from our Galaxy by diffusion

E(knee) ~ Z

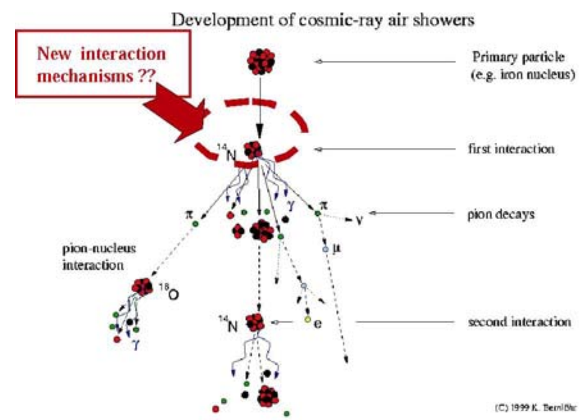
Acceleration



Reach of maximum energy at the acceleration

E(knee) ~ Z

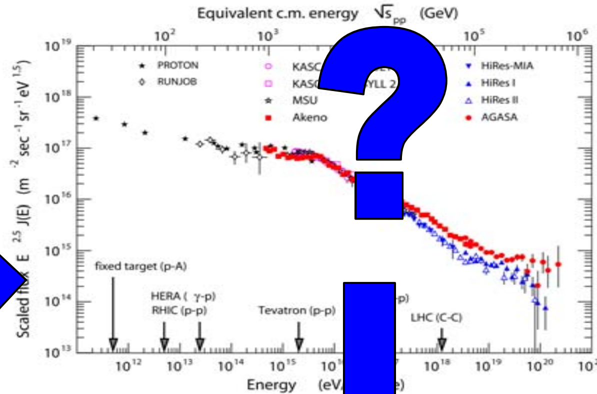
Interaction



Unknown effects of interactions at the air-shower development

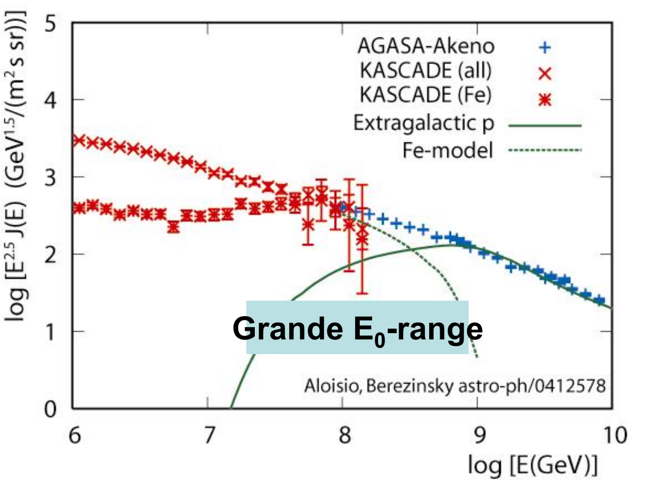
E(knee) ~ A

Motivation for KASCADE-Grande



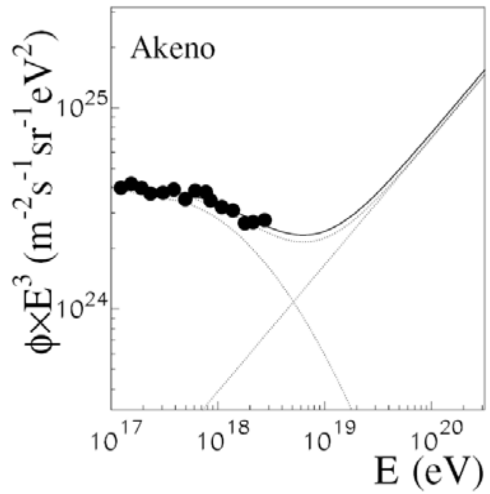
various theories on energy range 10^{17}-10^{19}eV:

e.g. Berezinsky et al
Nucl.Phys.B(Proc.Suppl.)151(2006)497



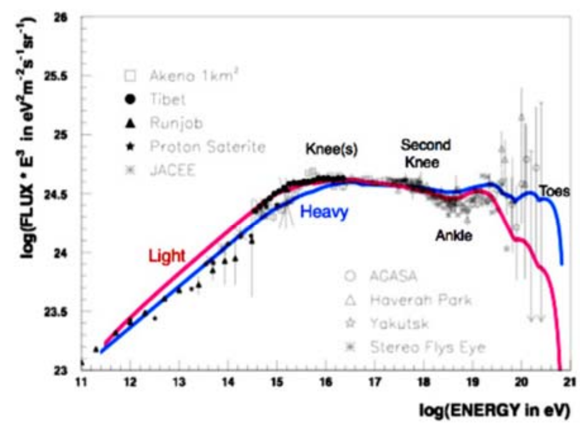
Fe-knee ~10^{17} eV
gal-eg transition ~$10^{17.7}$eV
Ankle = eg characteristics

e.g. Wibig et al
J.Phys.G 31(2005)255



Fe-knee ~10^{18} eV
gal-eg transition ~10^{19}eV = ankle

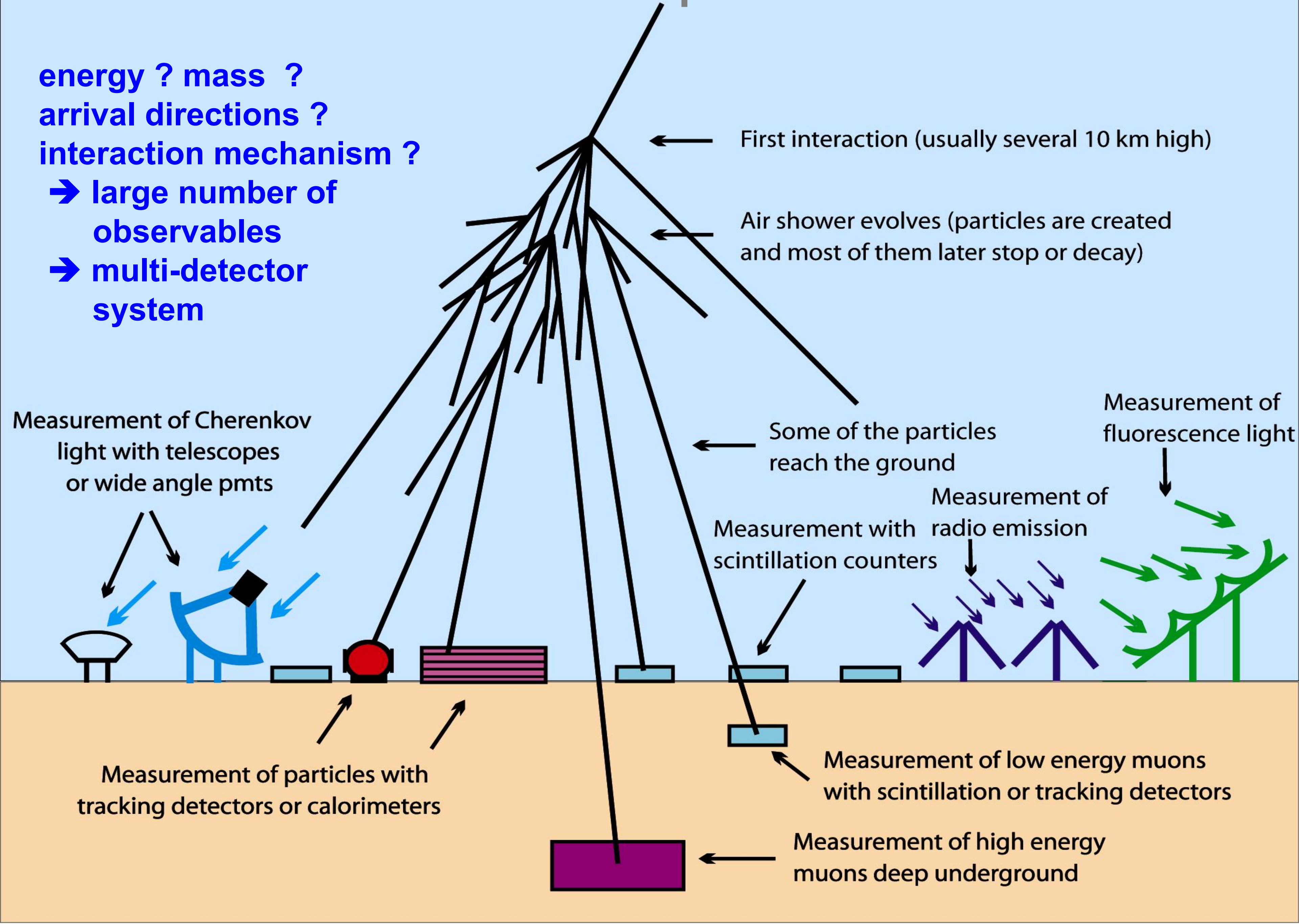
e.g. de Rujula
Nucl.Phys.B(Proc.Suppl.)151(2006)23



Cannonball modell:
Fe-knee ~ 2 10^{17} eV
All is galactic
(knee= elastic scattering)

Measurement Techniques of Air Showers

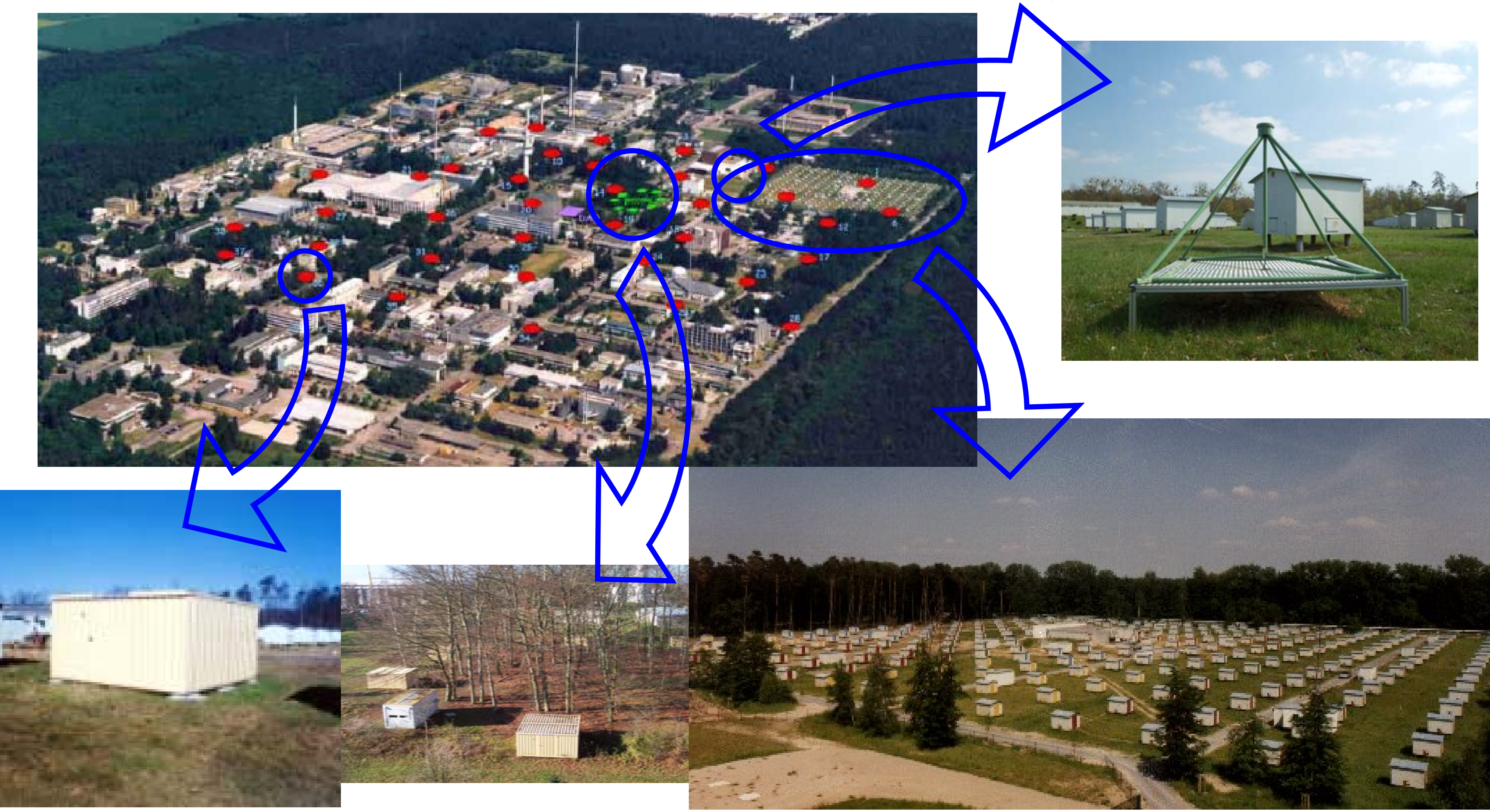
energy ? mass ?
arrival directions ?
interaction mechanism ?
- ➔ **large number of observables**
- ➔ **multi-detector system**



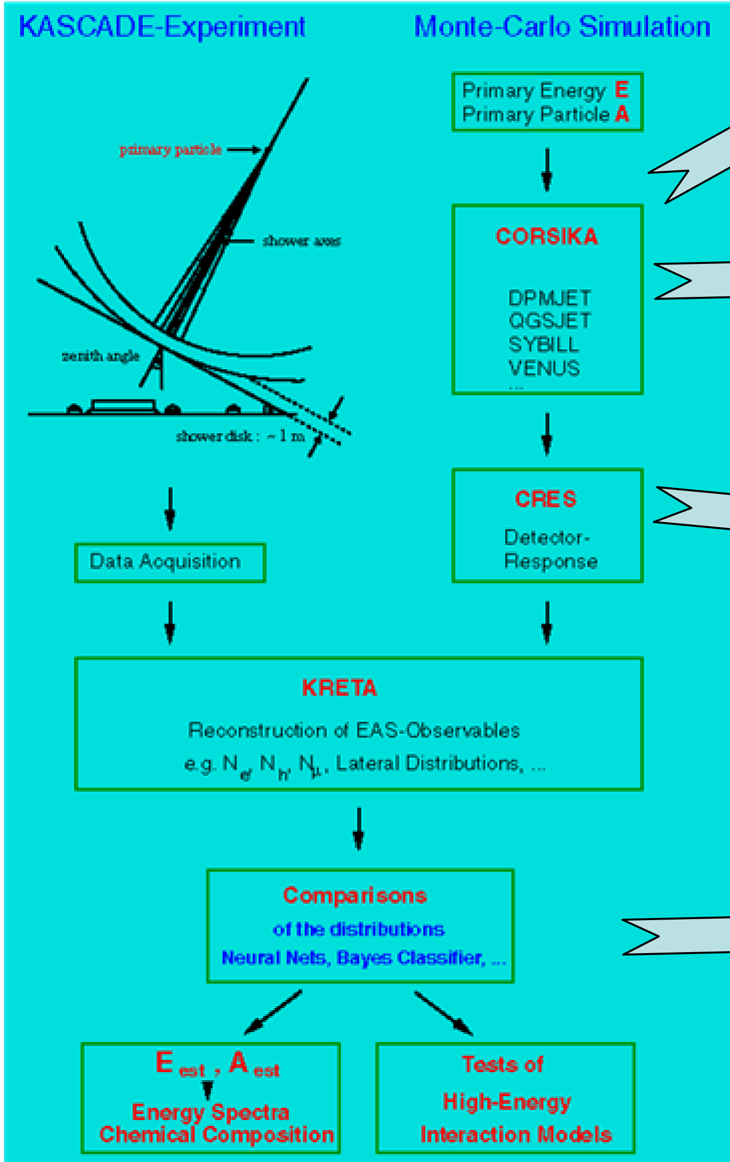
KASCADE-Grande

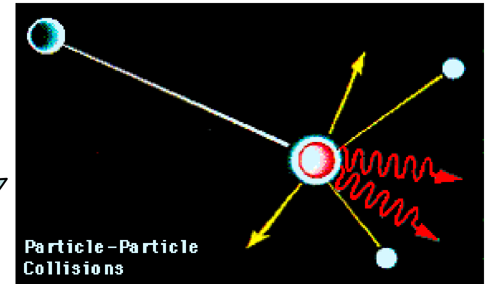
= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

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

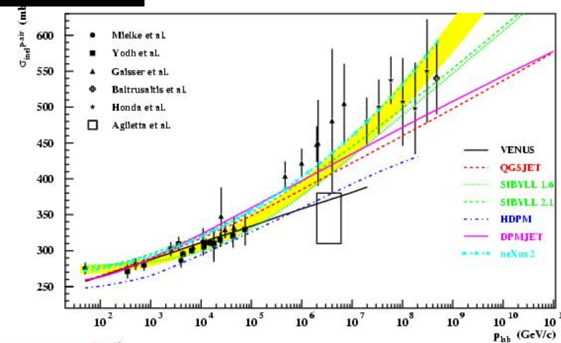


KASCADE - methodics

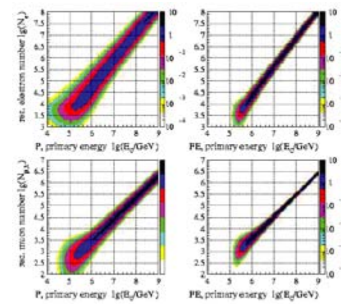




nucleus-nucleus interactions

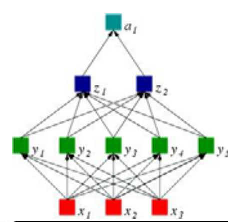


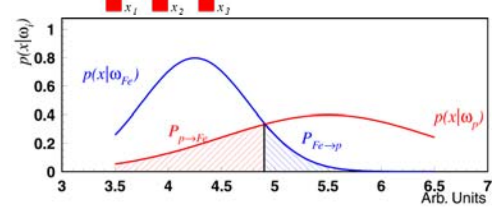
Air shower simulations

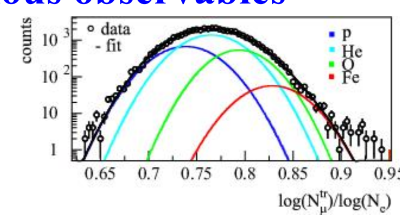


Detector simulations

Multi-parameter analyses of the various observables

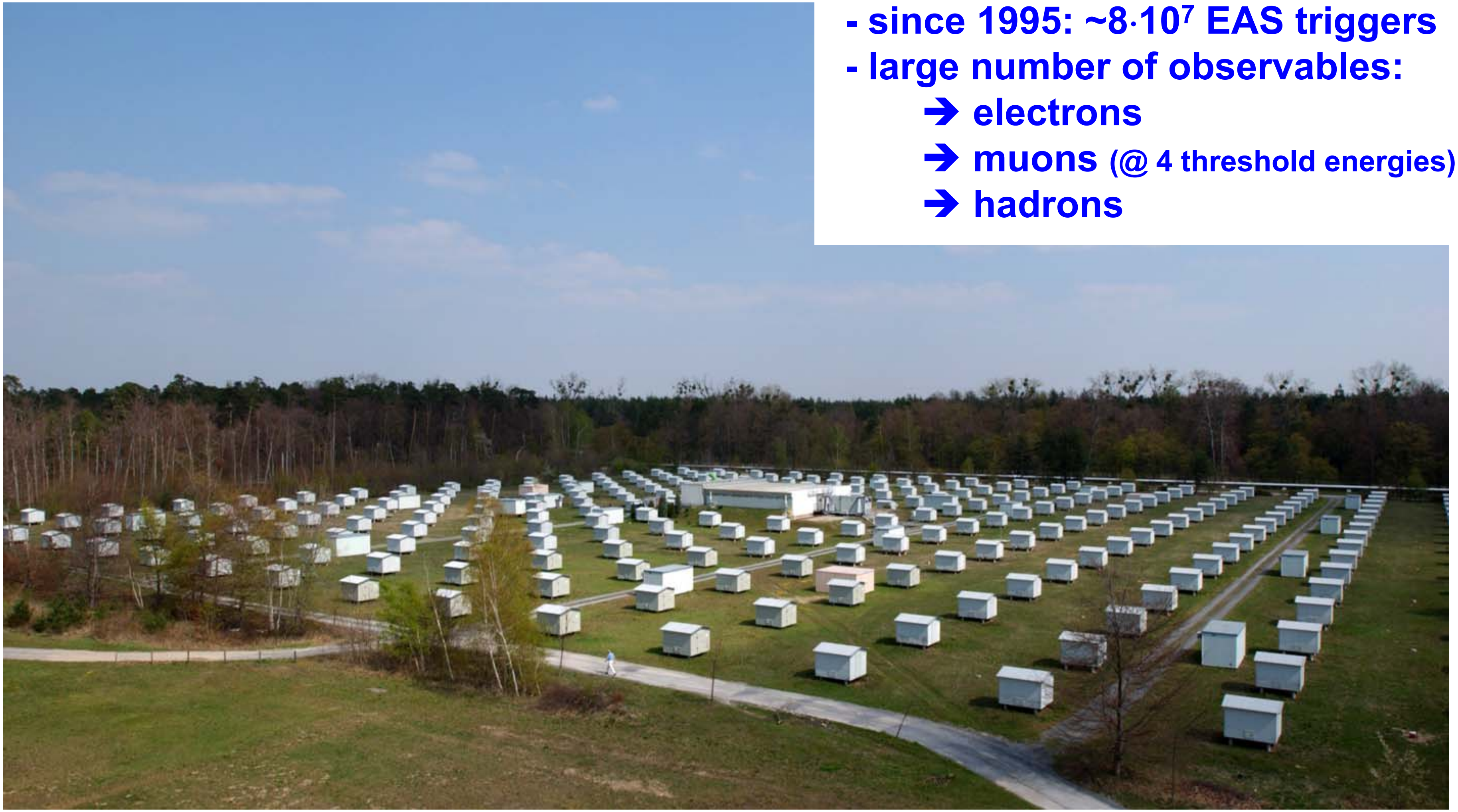






KASCADE : multi-parameter measurements

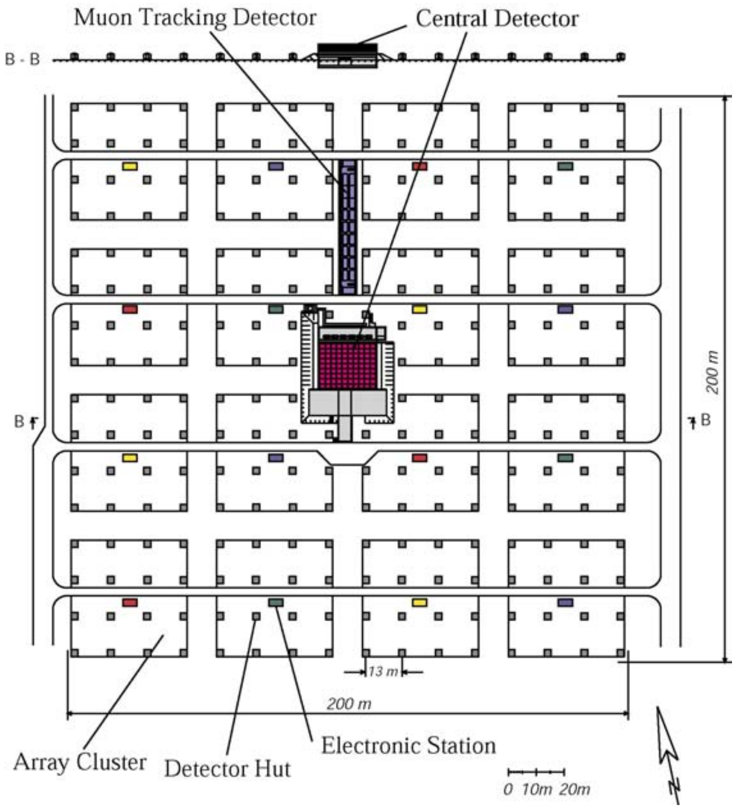
- energy range 100 TeV – 80 PeV
- since 1995: ~$8 \cdot 10^7$ EAS triggers
- large number of observables:
  - ➔ electrons
  - ➔ muons (@ 4 threshold energies)
  - ➔ hadrons



KASCADE set-up

Multi-Detector-Setup !

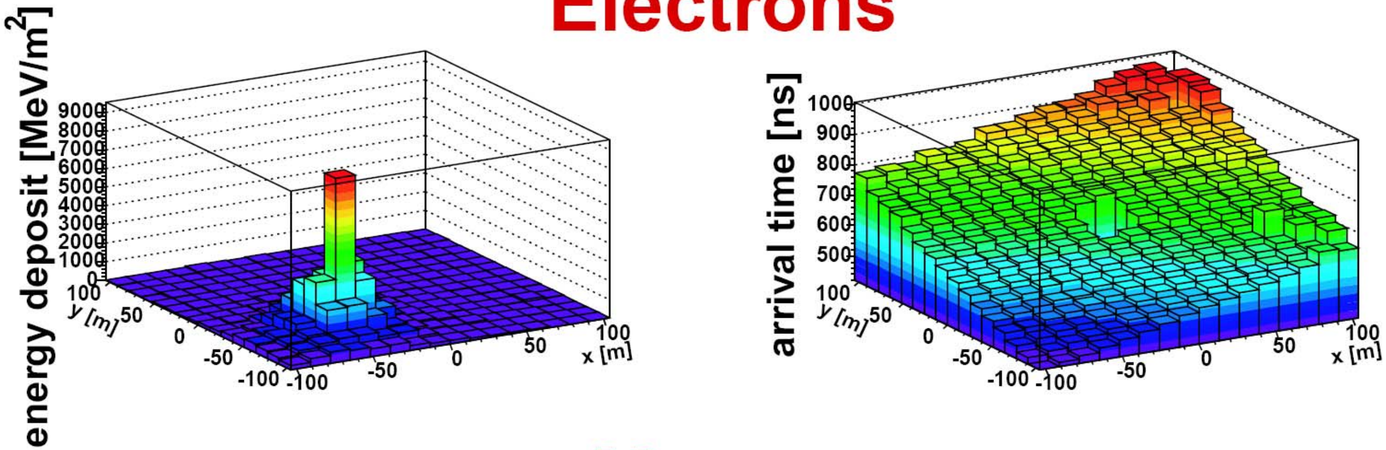
Aim: measure as much as possible observables of the air-shower!



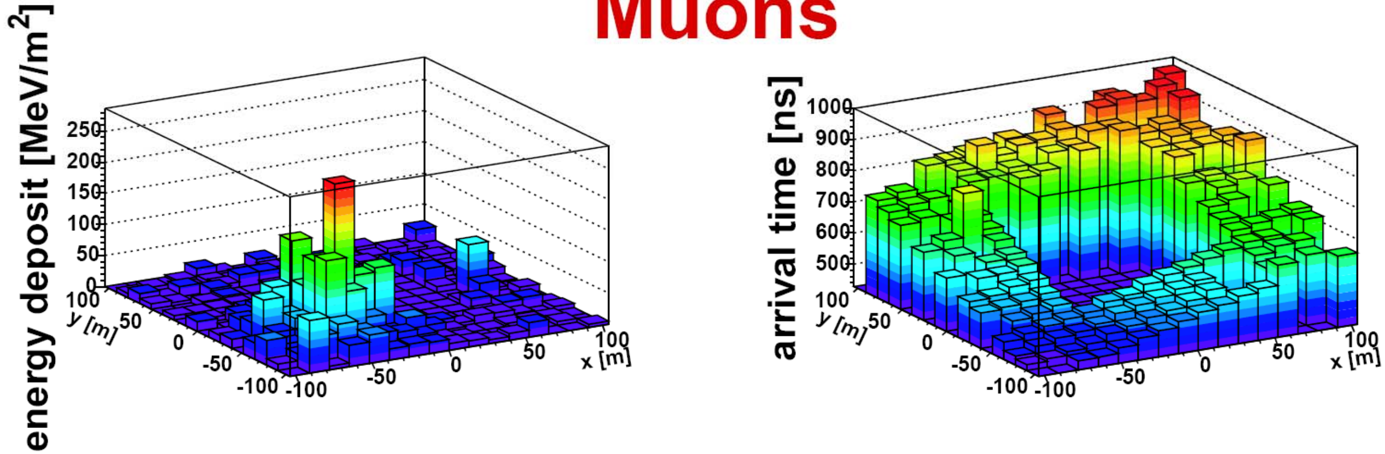
KASCADE

Array

Electrons

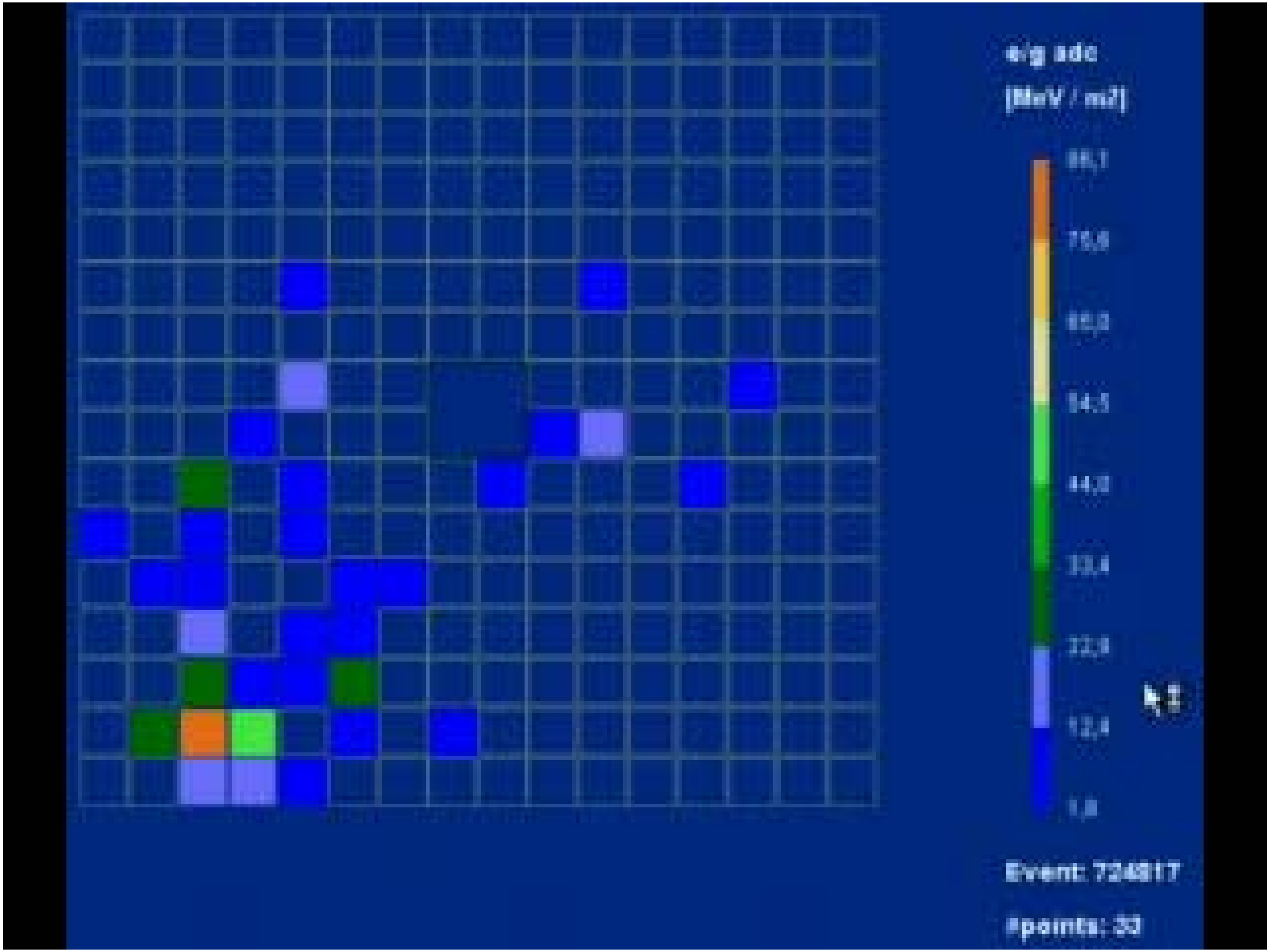


Muons

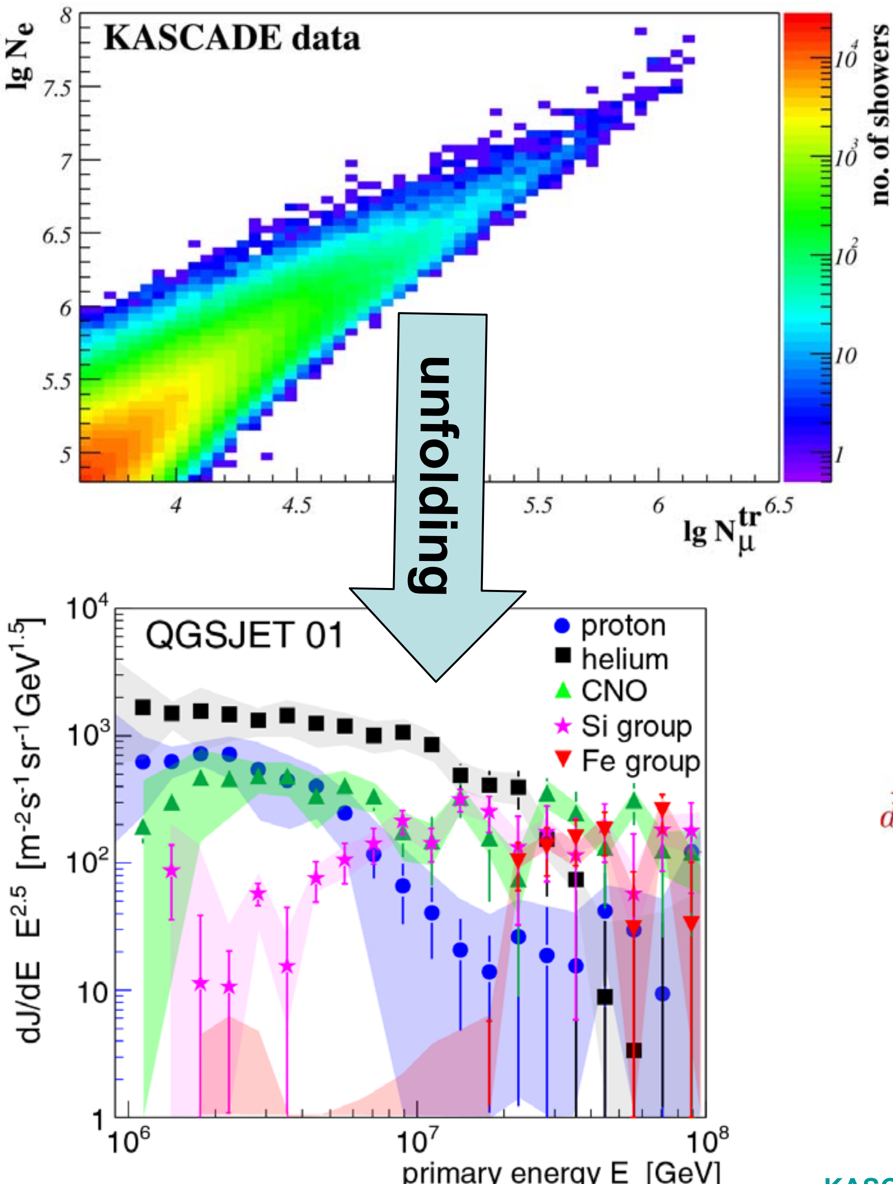


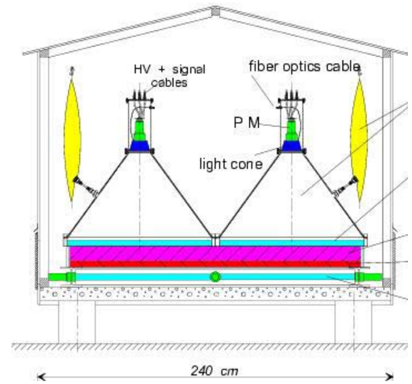
Run 3226, File 2, leve 65041, Ymd 10215, Hms 225810, Neds 250, Npds 138
(Xc,Yc) = (-45.4,-51.0), (Ze,Phi) = (36.7,228.6), log10(Ne)=6.14, log10(Lmuo)=4.66

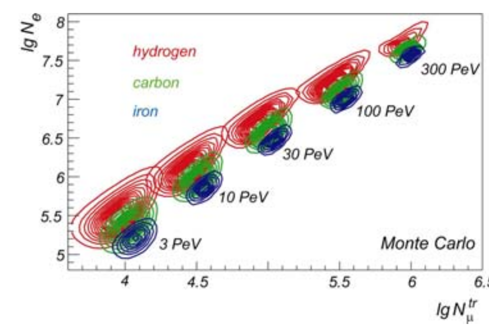
KASCADE event display



KASCADE : energy spectra of single mass groups







Searched:

E and A of the Cosmic Ray Particles

Given:

N_e and N_μ for each single event

➔ solve the inverse problem

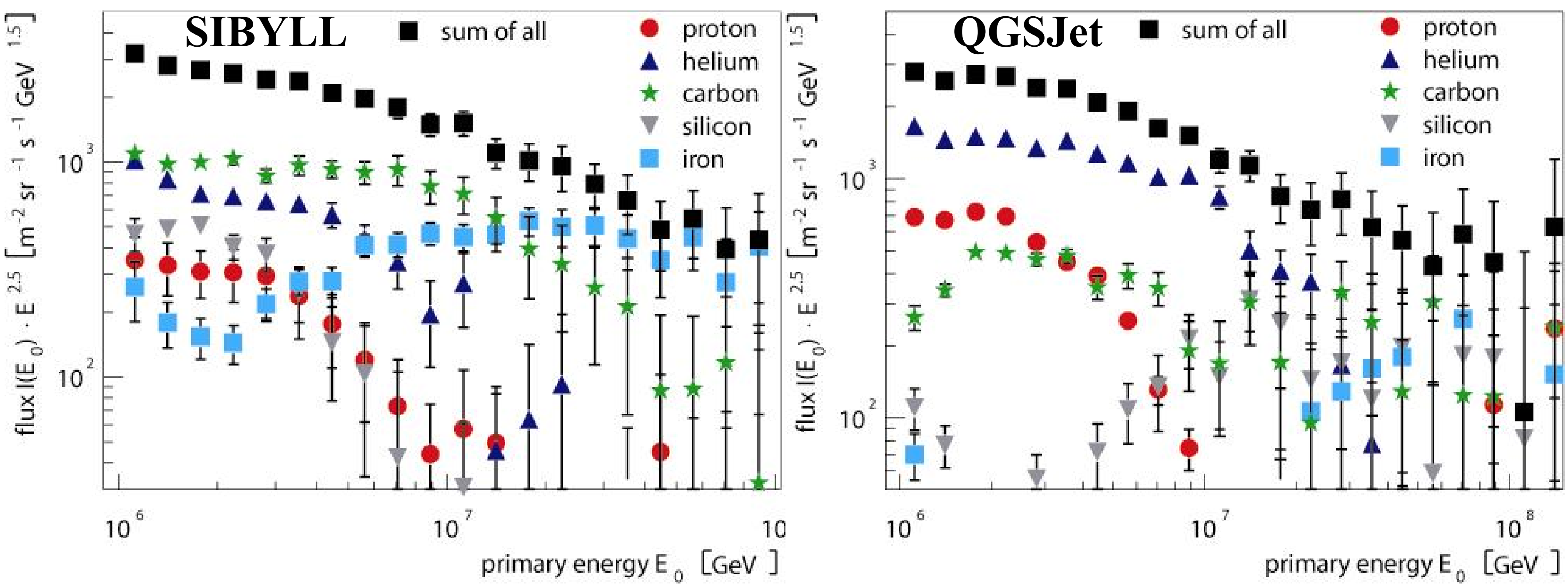
$$\frac{dJ}{d\lg N_e\, d\lg N_\mu^{tr}} = \sum_A \int_{-\infty}^{+\infty} \frac{dJ_A}{d\lg E}\, p_A(\lg N_e, \lg N_\mu^{tr} \mid \lg E)\, d\lg E$$

- **kernel function obtained by Monte Carlo simulations (CORSIKA)**
- **contains: shower fluctuations, efficiencies, reconstruction resolution**

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

KASCADE results

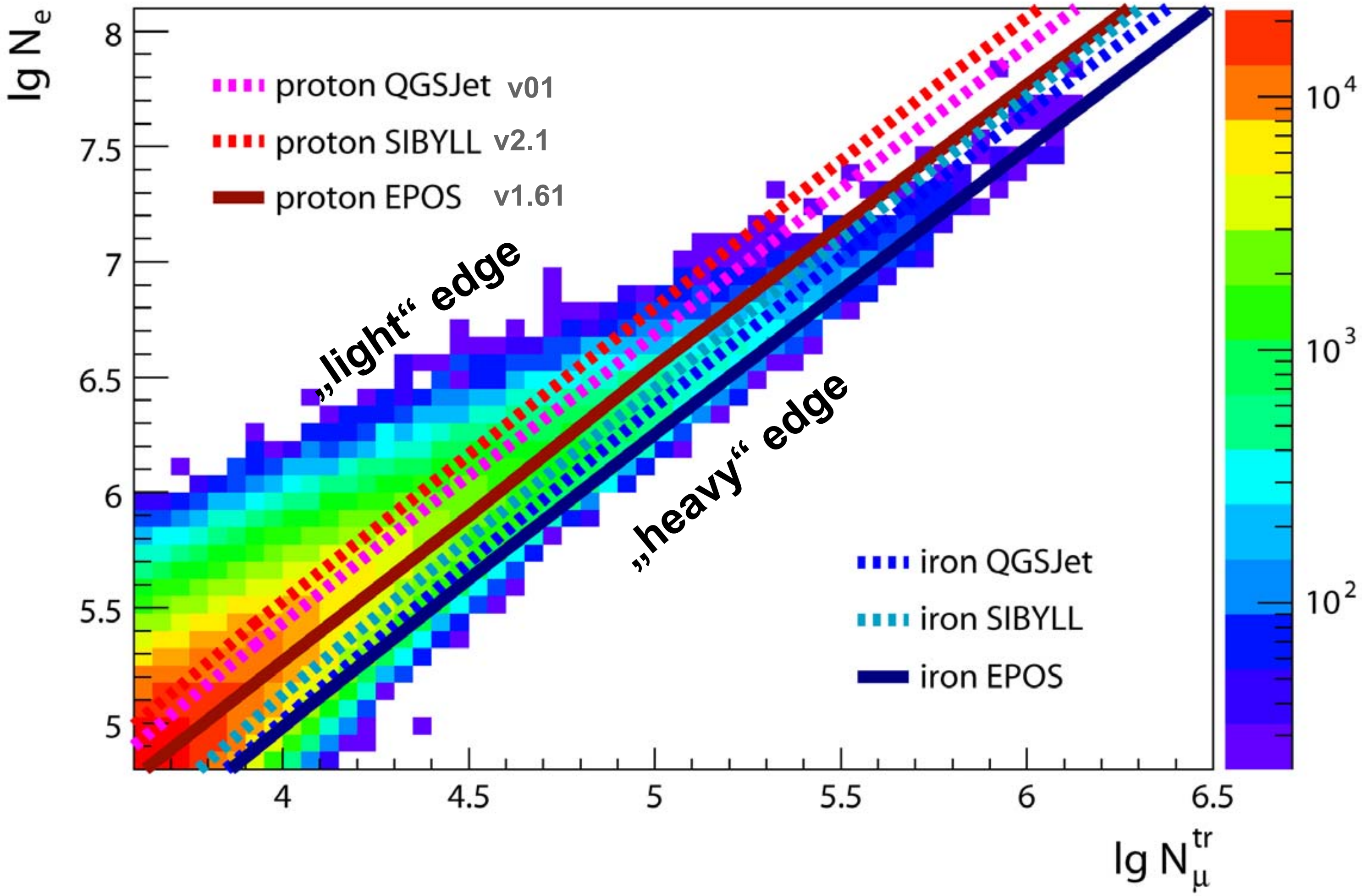
- same unfolding but based on different hadronic interaction models embedded in CORSIKA



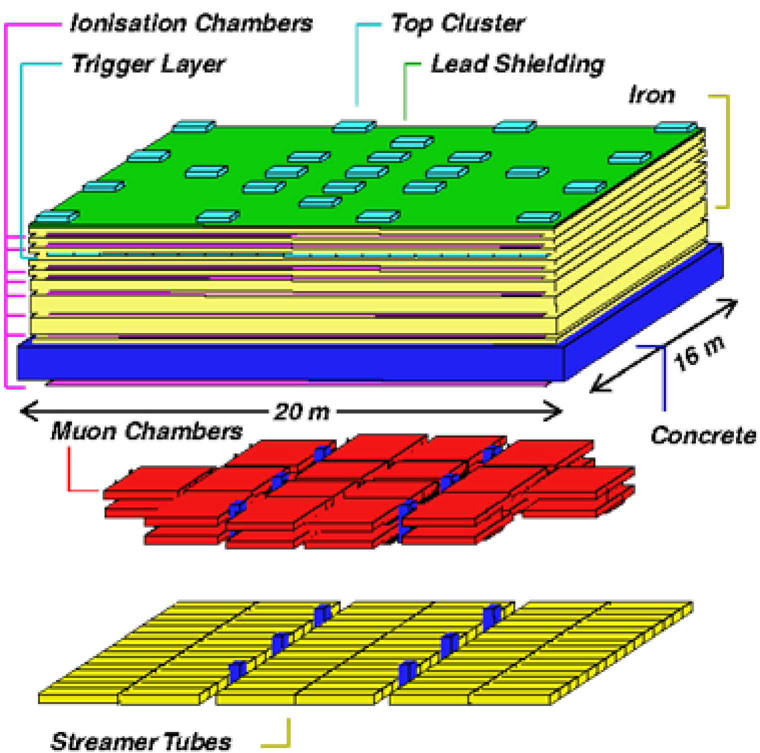
- all-particle spectrum similar
- general structure similar: knee by light component
- relative abundances very different **for different high-energy hadronic interaction models**

KASCADE collaboration, Astrop.Phys. 24 (2005) 1, Astrop.Phys. 31 (2009) 86

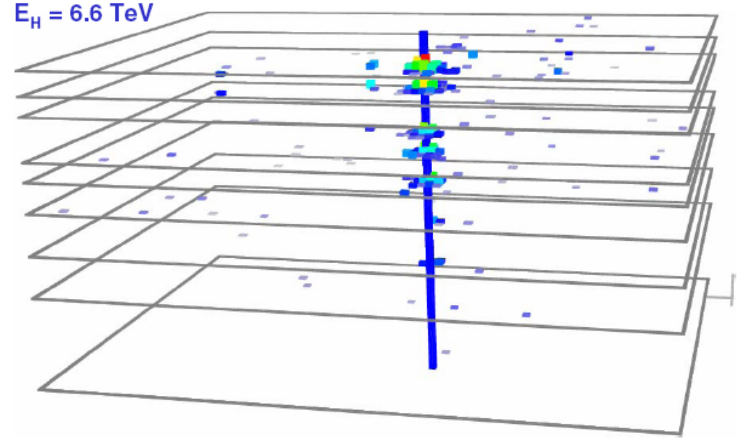
KASCADE : sensitivity to hadronic interaction models



hadrons in air shower cores



Unaccompanied hadron
E_H = 6.6 TeV



spatial resolution:
$\sigma_x \sim 10 - 12$ cm

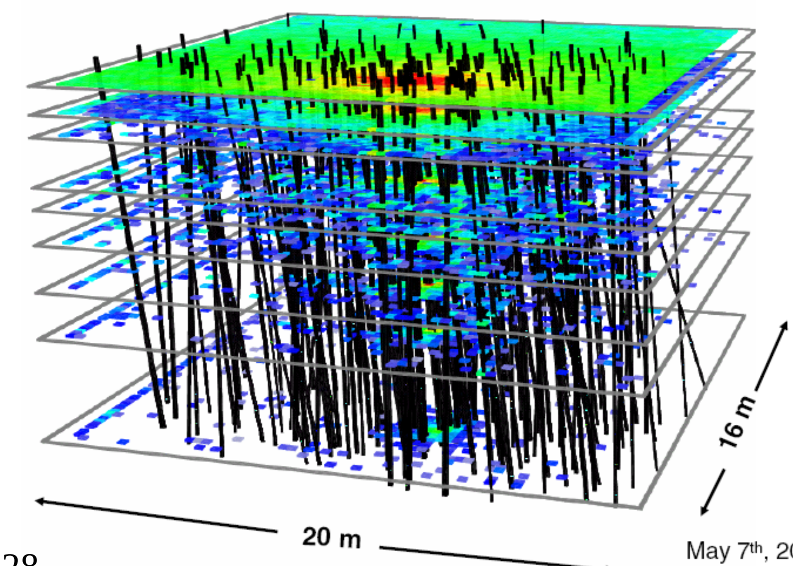
angular resolution:
$\sigma_\Theta \sim 1^\circ - 3^\circ$

energy resolution:

$$\frac{\sigma(E)}{E}[\%] \sim \frac{250}{\sqrt{E/\mathrm{GeV}}}$$

$E_0 \sim 6$ PeV

Number of reconstructed hadrons $N_h = 143$

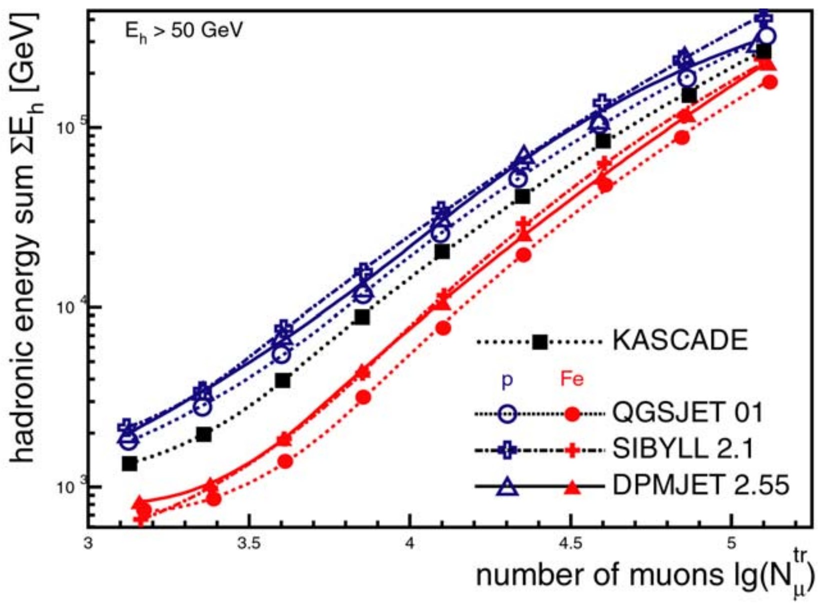


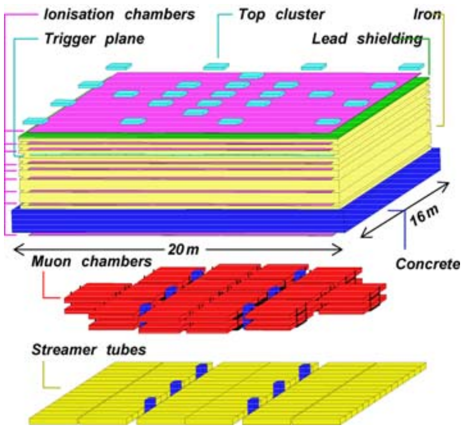
May 7th, 2002 9:45

J. Engler et al., Nucl. Instr. Meth. A 427 (1999) 528

KASCADE : sensitivity to hadronic interaction models

➔ New models are welcome for cross-tests with KASCADE data





Example:
hadrons vs. muons

correlation of observables:

<u>no hadronic interaction model describes data consistently !</u>

➔ tests and tuning of hadronic interaction models !

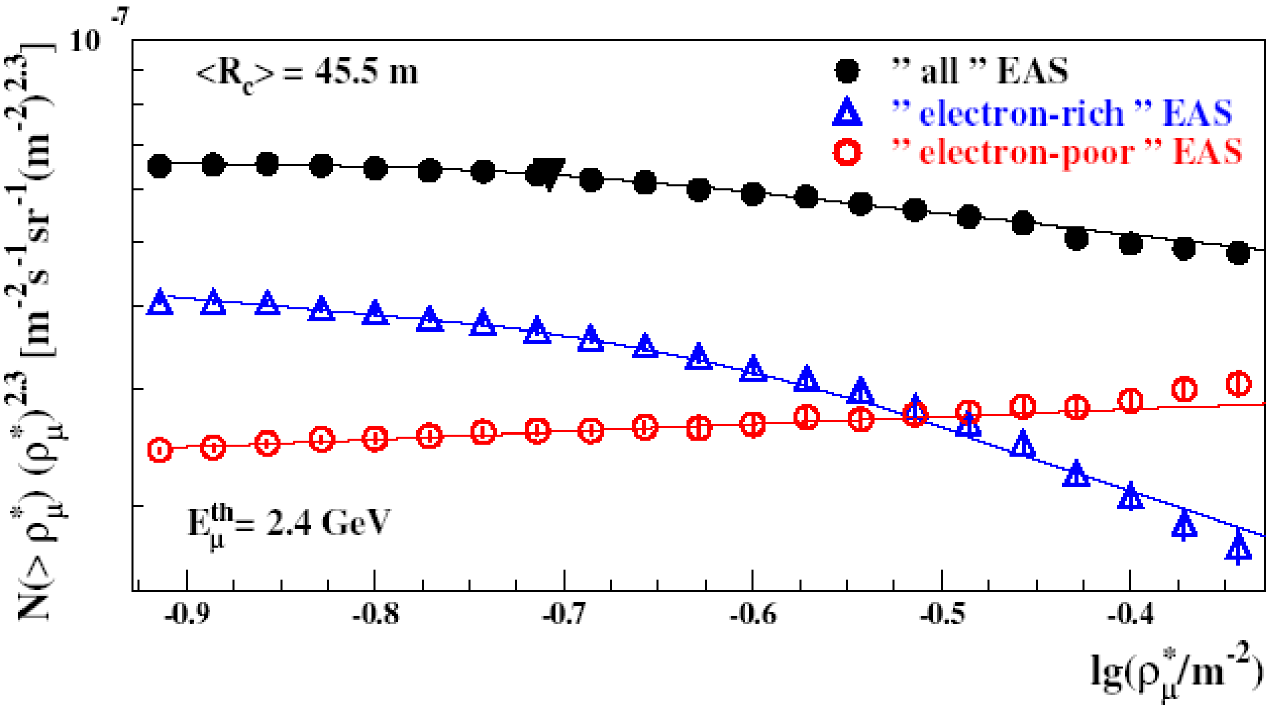
➔ close co-operation with theoreticians (CORSIKA including interaction models)

➔ e.g.:
- **EPOS 1.6 is not compatible with KASCADE measurements**
- **QGSJET 01and SIBYLL 2.1still most compatible models**

KASCADE collaboration, J Phys G (3 papers: 25(1999)2161; 34(2007)2581; (2009)035201)

Model independent: analysis of basic observable

- Total muon number and electron number ➔ mass estimator
- high-energy local muon density ➔ energy estimator

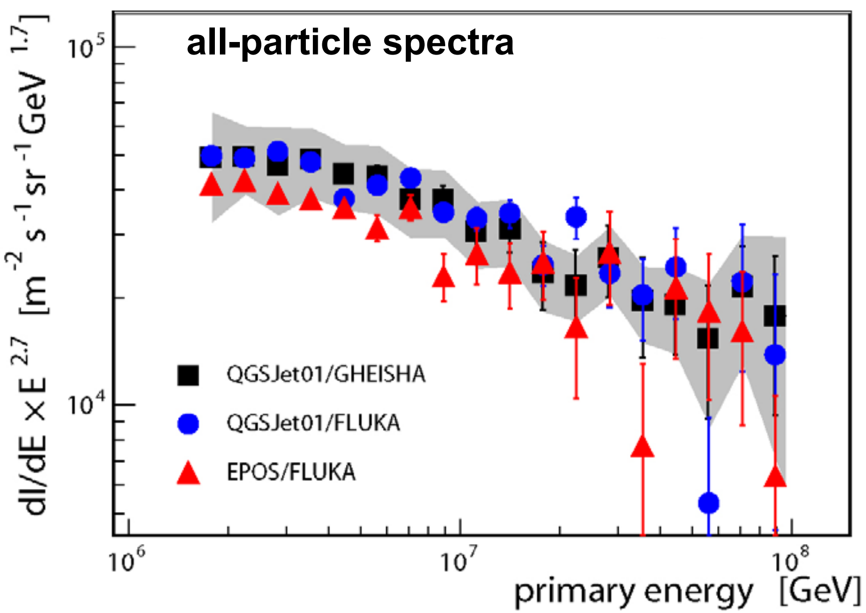


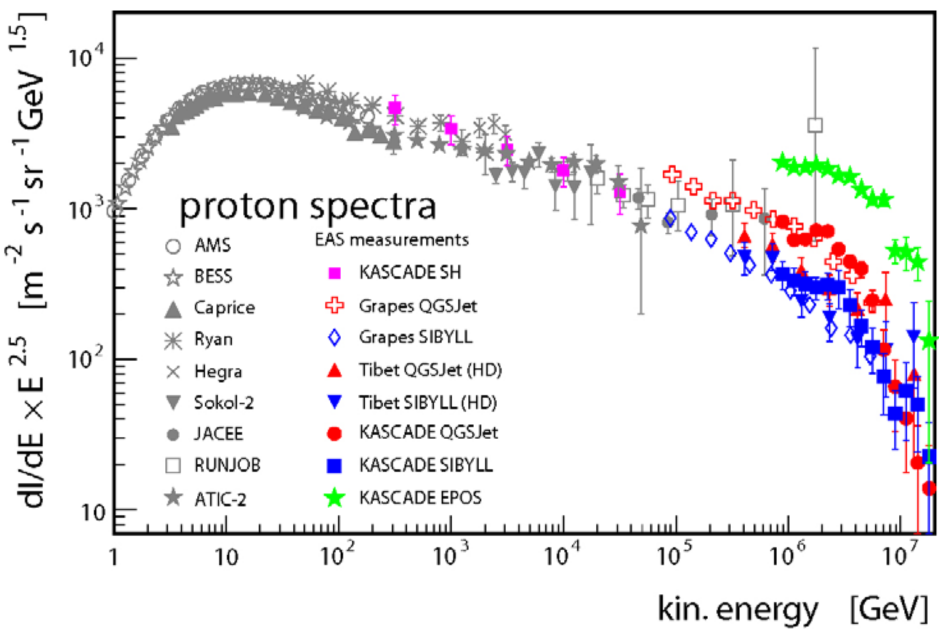
KASCADE : Astroparticle Physics 16 373 2002

- **KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS**
- **Do we need hadronic interaction models?**

  ➔ **yes, for normalization of absolute energy and mass scale!!**

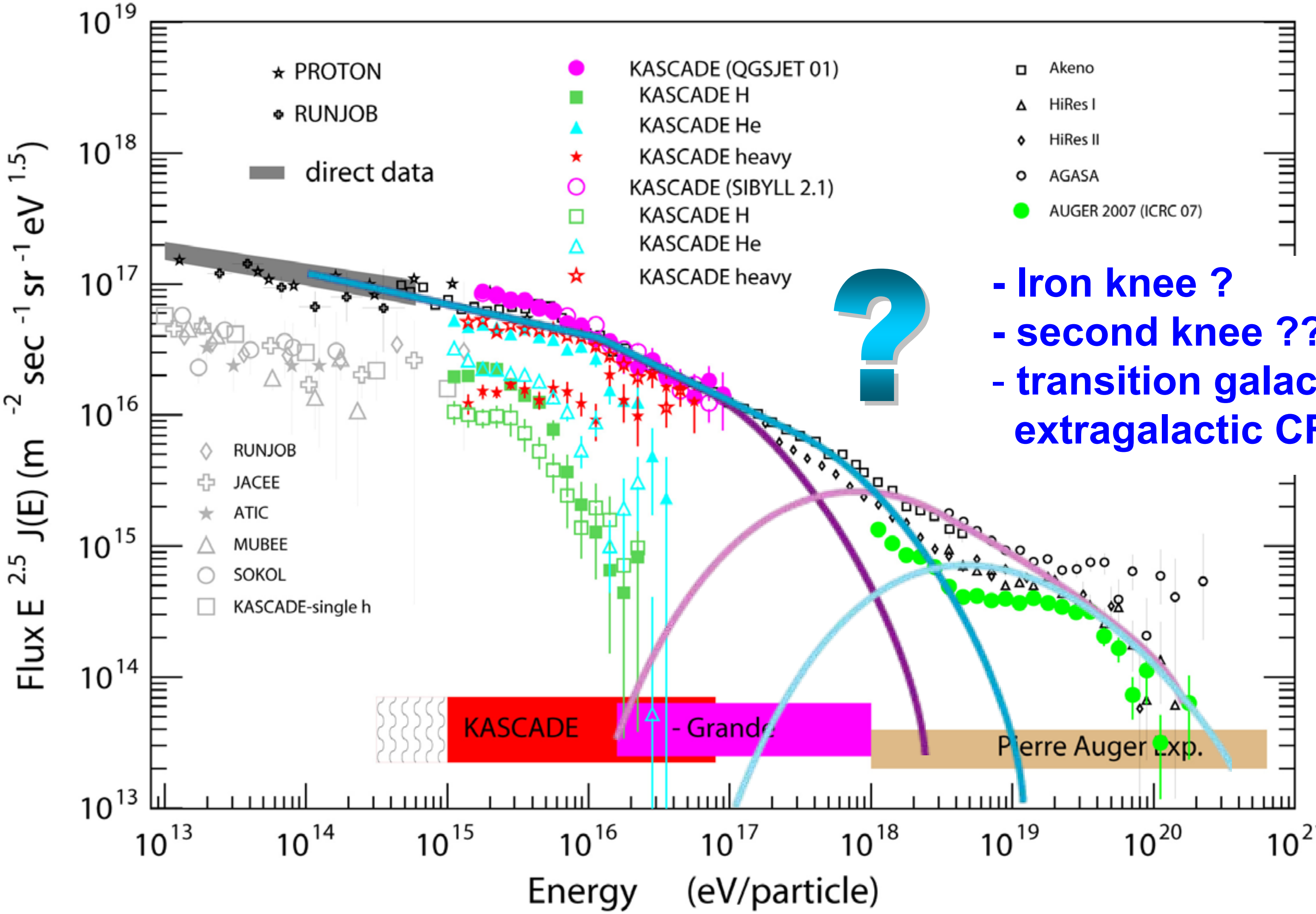
KASCADE Summary





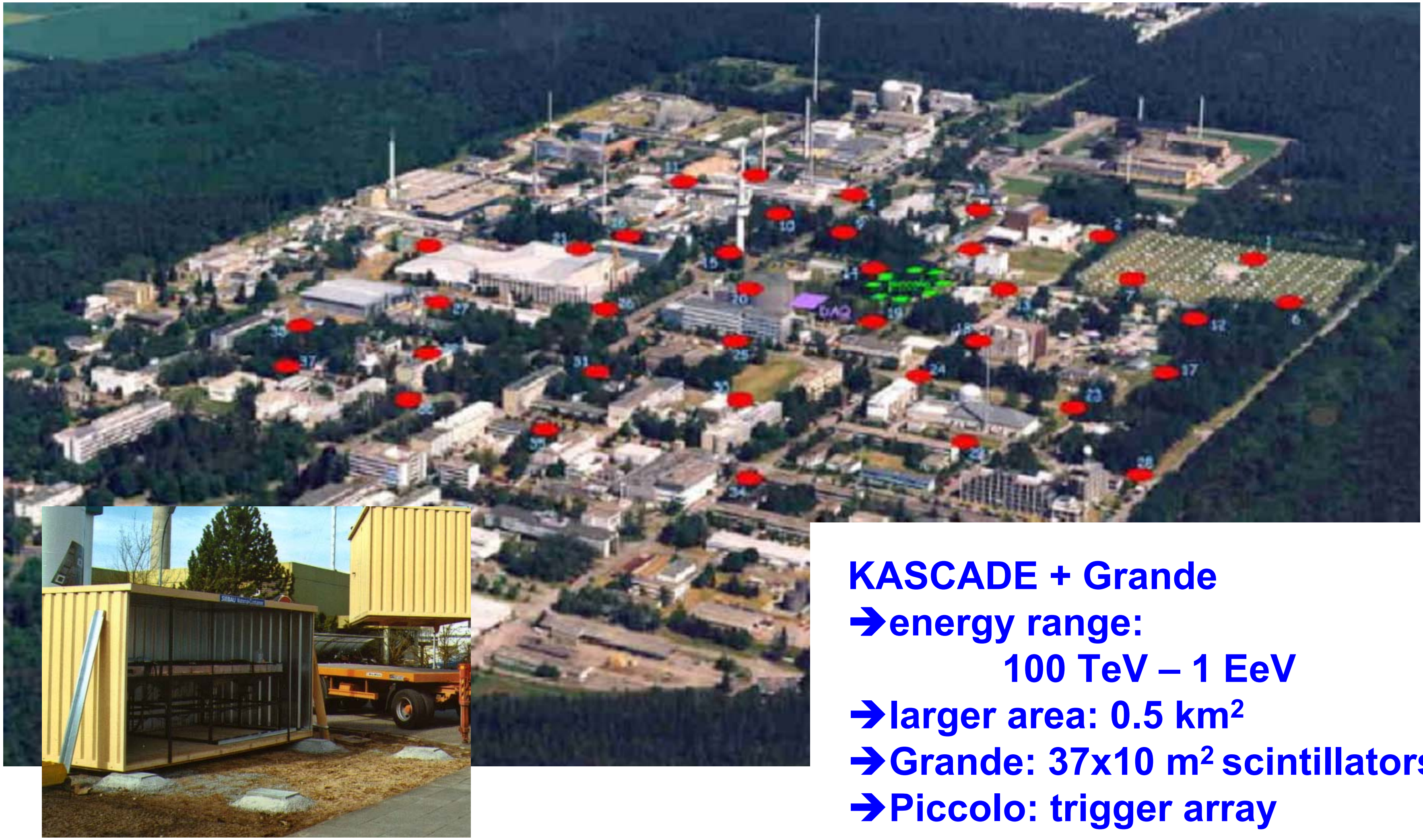
-) knee caused by light primaries ➔ composition gets heavier across knee
-) positions of knee vary with primary elemental group
-) relative abundancies depend strongly on high energy interaction model
-) no (interaction) model can describe the data consistently
-) all-particle spectra agree inside uncertainties (EPOS1.6 a bit lower)
-) proton spectra agree with direct measurements (not for EPOS1.6)

Motivation for measurements 100 – 1000 PeV



- Iron knee ?
- second knee ??
- transition galactic-extragalactic CR ??

KASCADE-Grande : extension to higher energies where is the end of galactic cosmic rays?



KASCADE + Grande

→ **energy range: 100 TeV – 1 EeV**

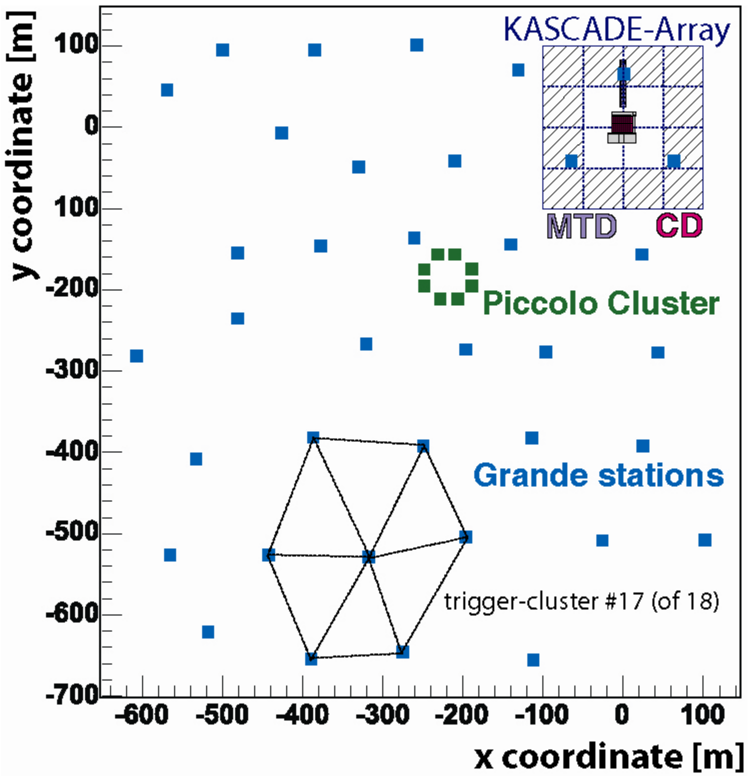
→ **larger area: 0.5 km^2**

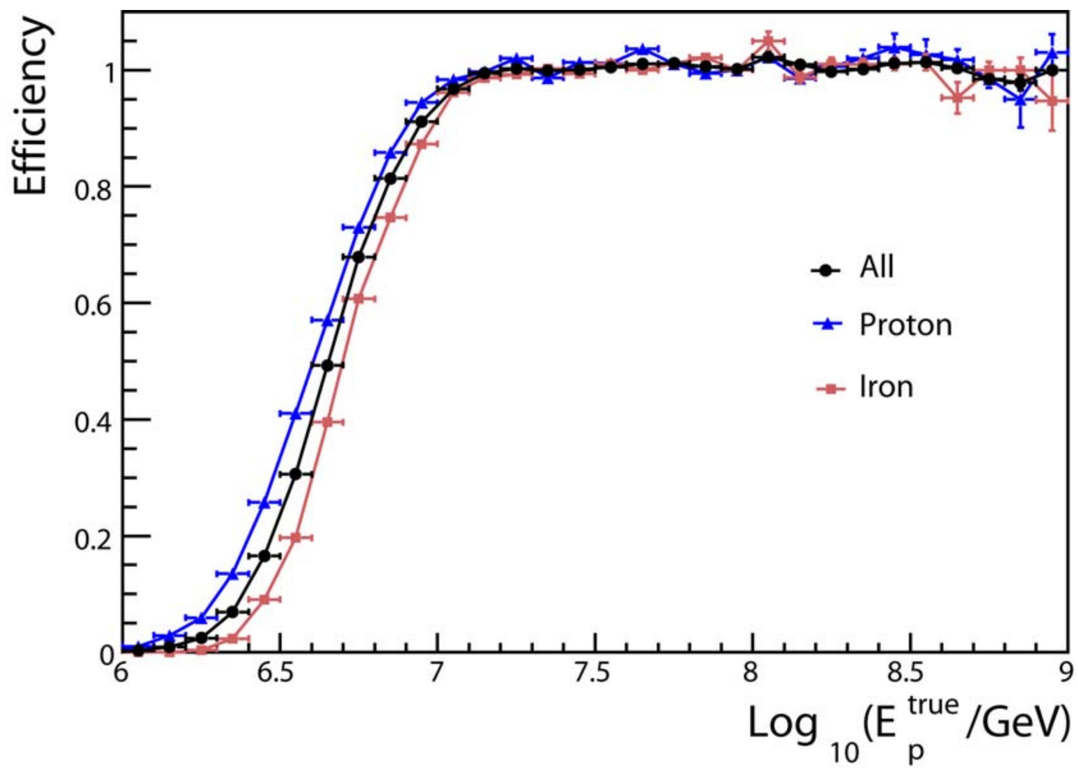
→ **Grande: 37x10 m^2 scintillators**

→ **Piccolo: trigger array**

Efficiency

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





Reconstruction

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

➔

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

2b) local density $S_{(500)}$ (charged particles)
from Grande array data

2c) muon number
from KASCADE muon detectors

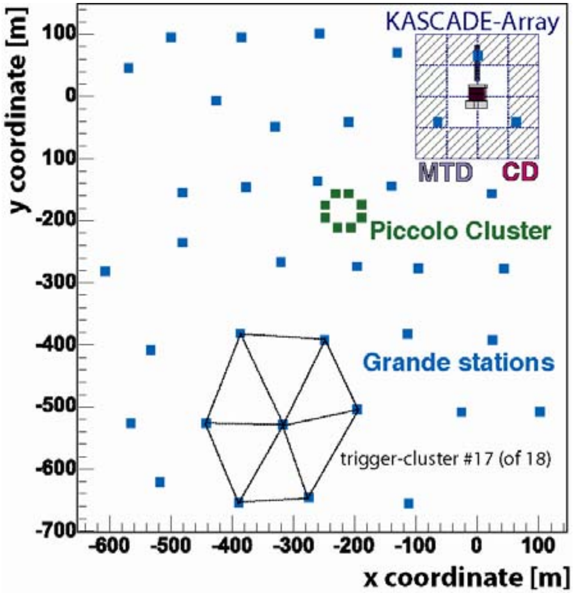
➔

3) electron number
from Grande by subtraction of muon content

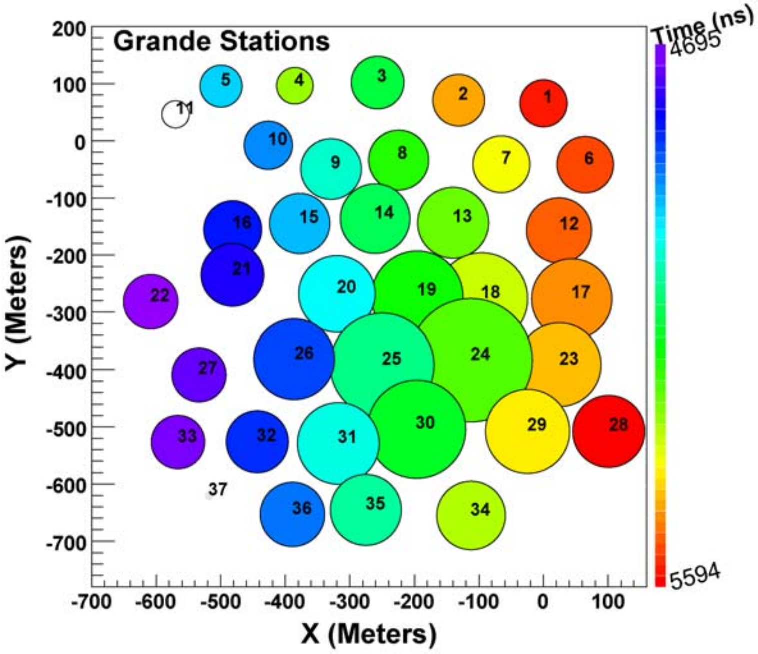
➔

4a) two dimensional size spectrum
for the composition analyses

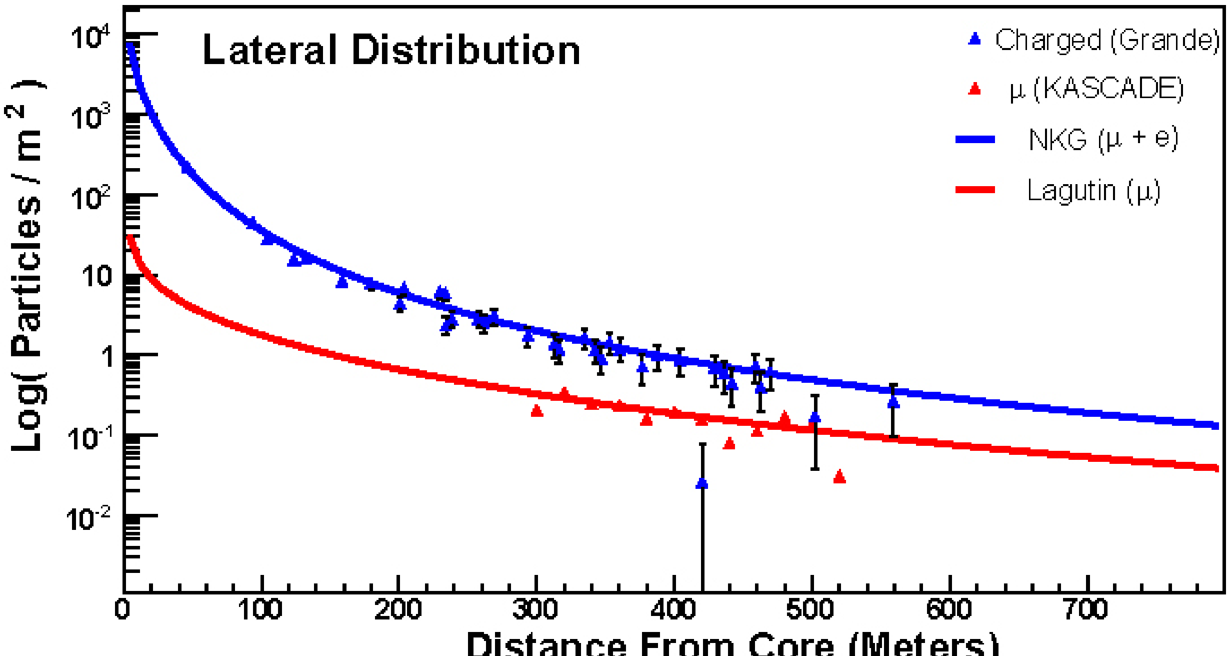
4b) high-energy muons / muon tracking
for hadronic interaction tests



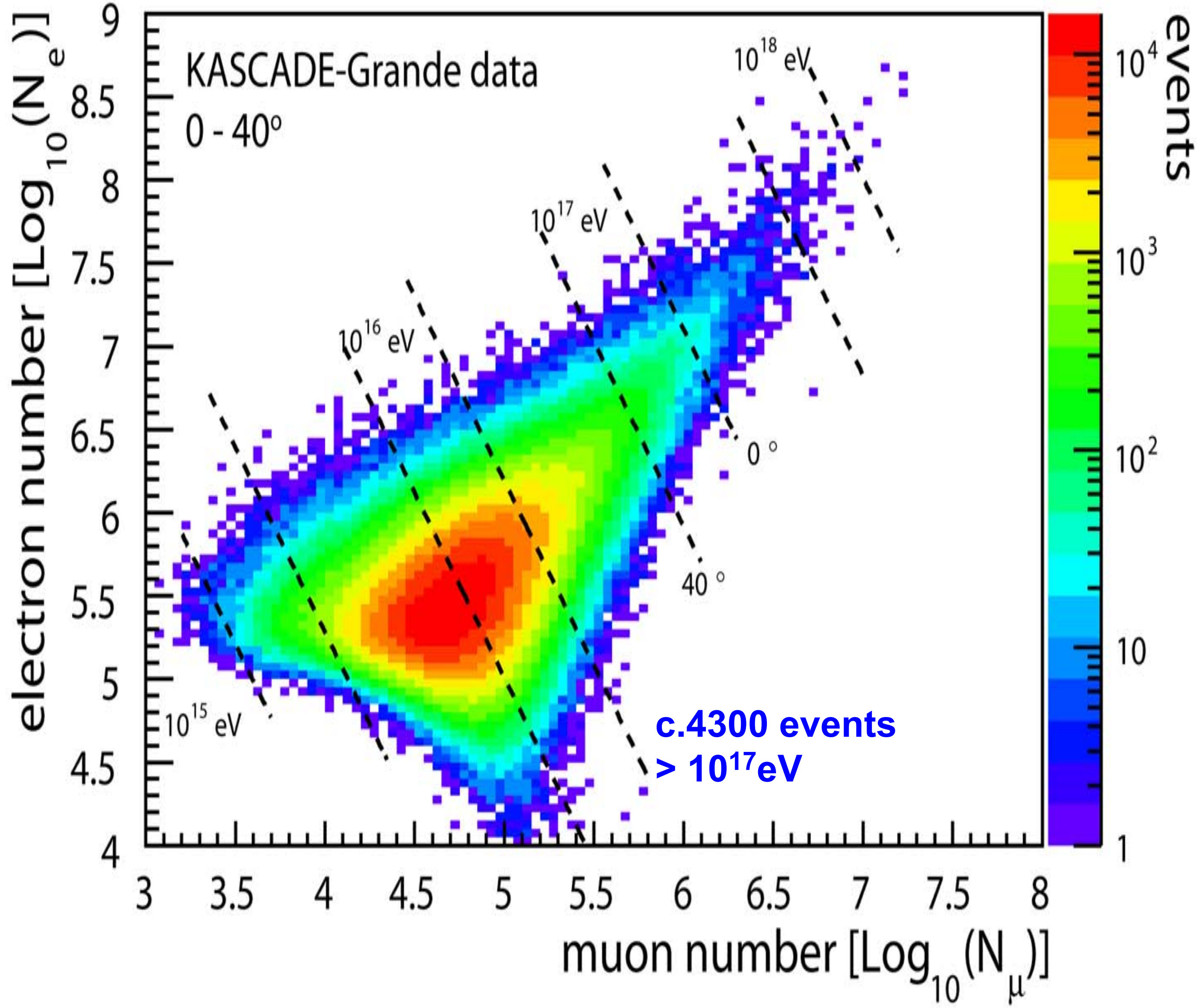
Single event reconstruction



a single event measured by KASCADE-Grande:
core (-155,- 401) m
$\log_{10}(N_{ch}) = 7.0$
$\log_{10}(N_{\mu}) = 5.7$
No saturation
Zenith: 24.2°
Azimuth: 284°
Recorded on 8 July 2005 at 12:11 (UTC)

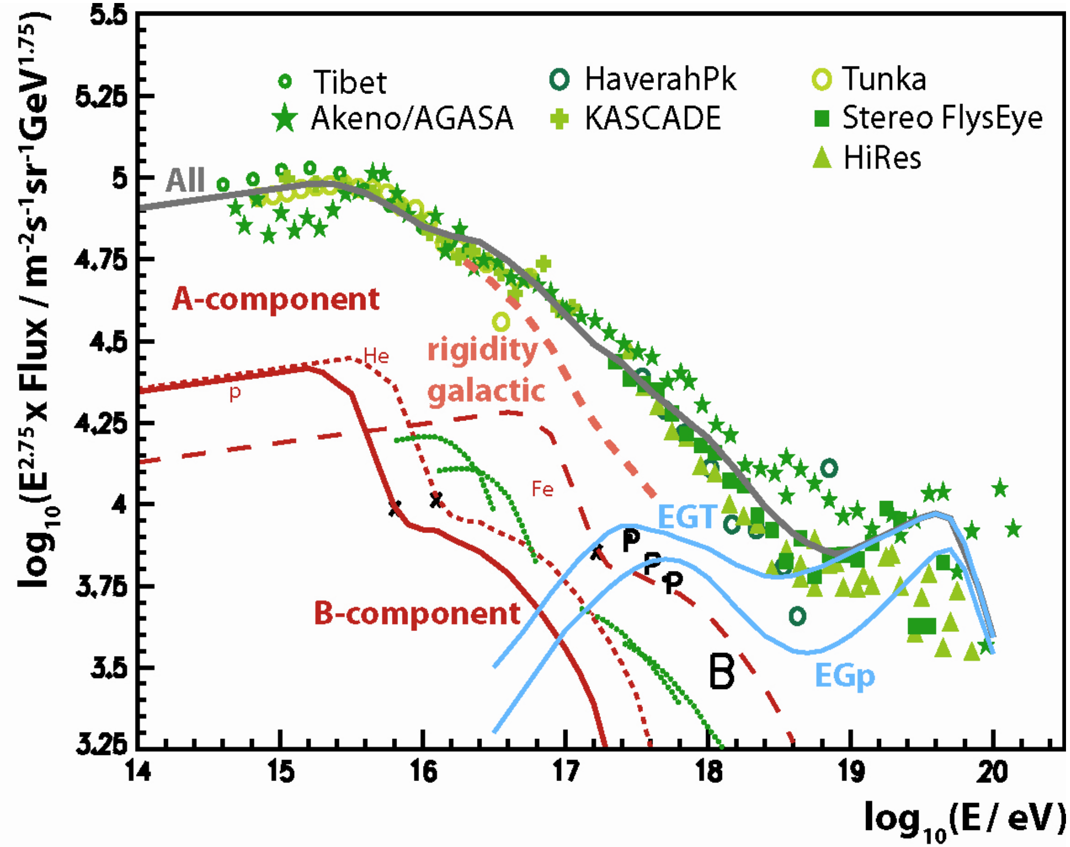


Grande 2-Dimensional Size Distribution :

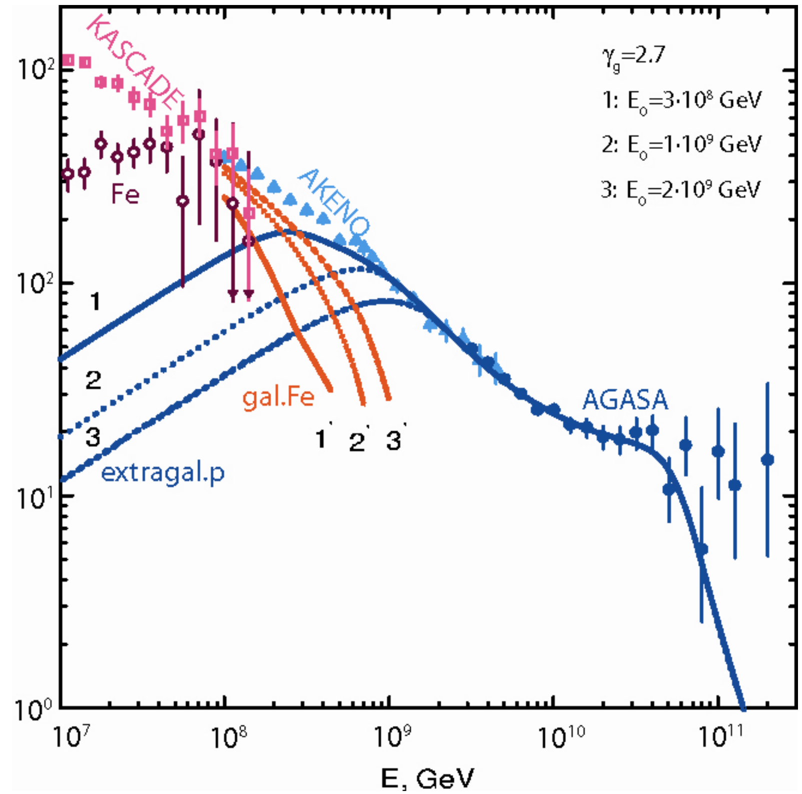


c.4300 events
> 10^{17}eV

Implications



A.M.Hillas, J. Phys. G: Nucl. Part. Phys. 31 (2005) R95



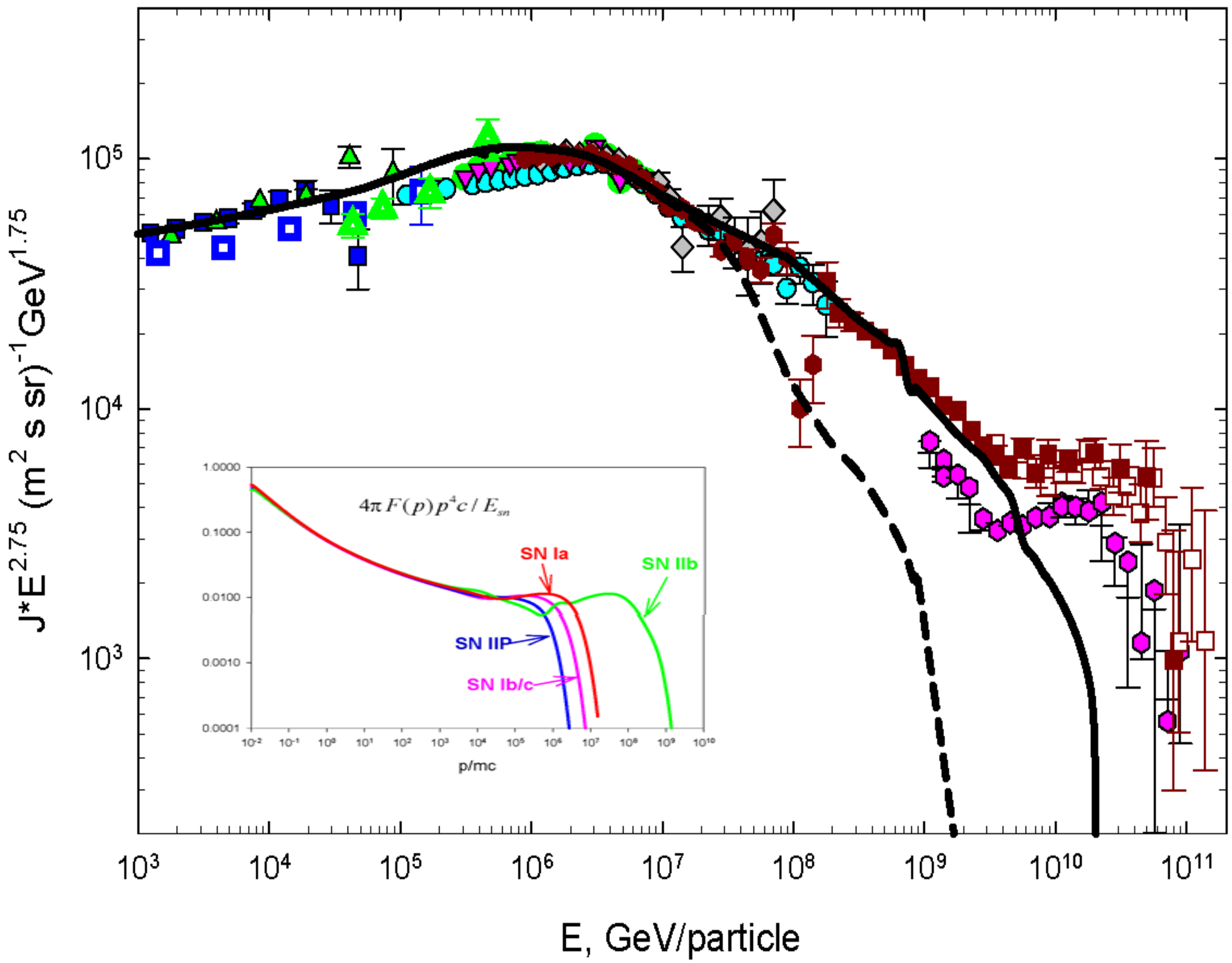
V.Berezinsky, astro-ph/0403477

Left: mixed composition at 10^{16}-10^{18}eV

Right: pure iron at 10^{17}eV and pure proton at 10^{18}eV

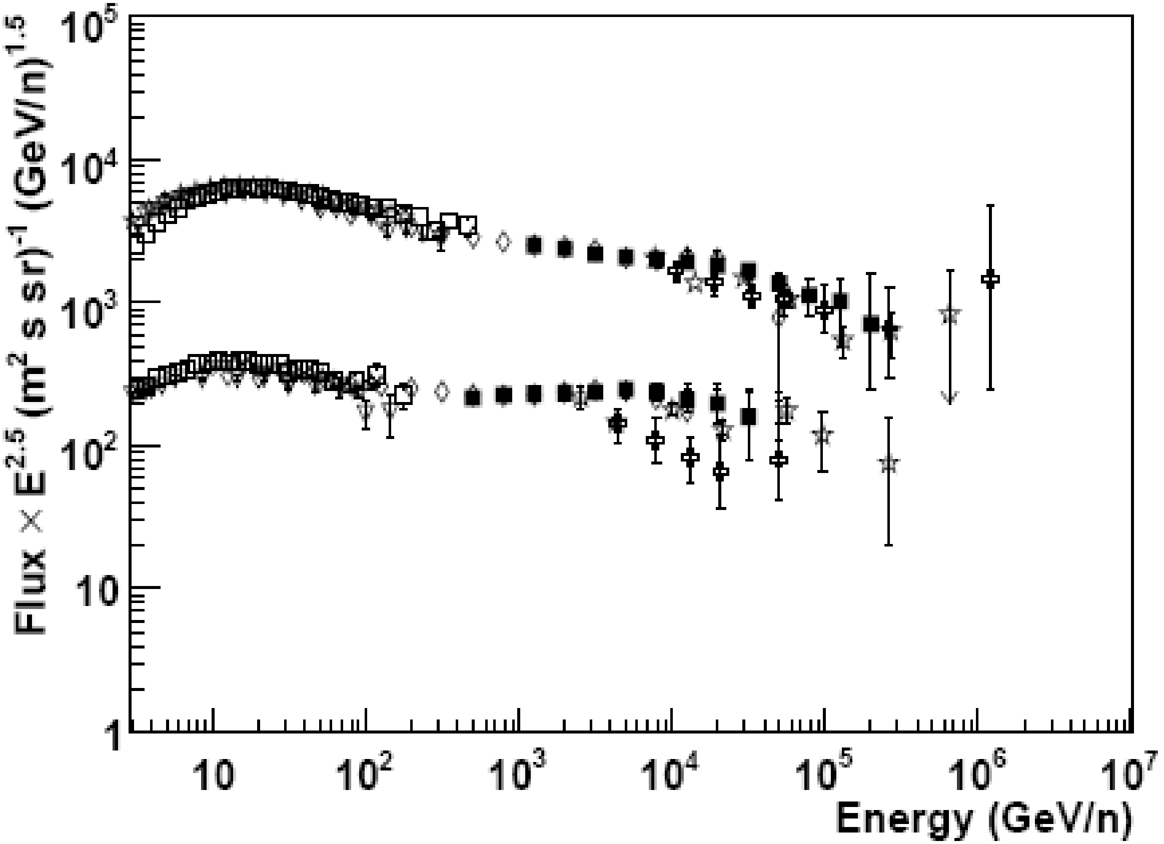
Different question: what could component B be?

Hardening around 10PeV?



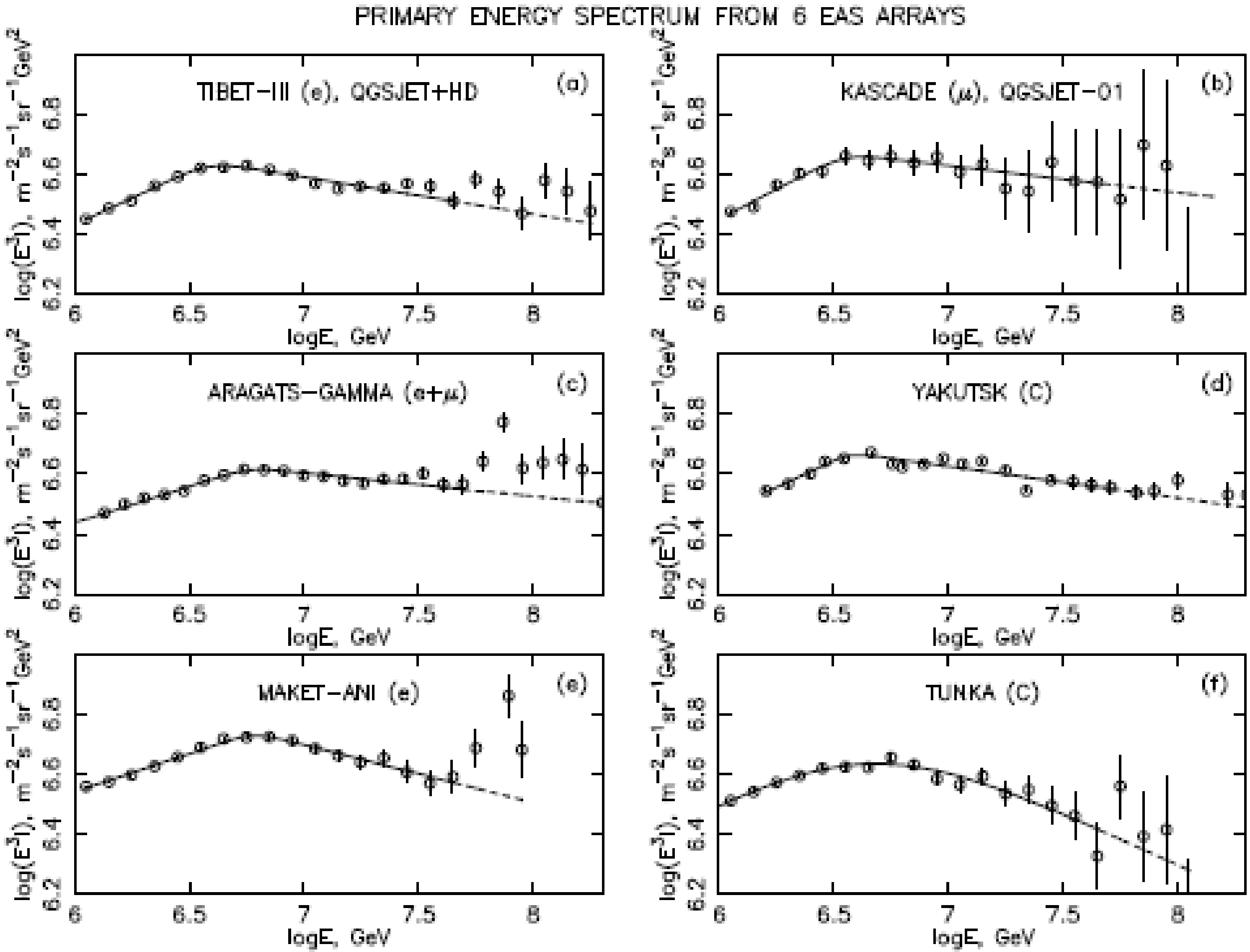
- Ptsukin, ICRC2009

Hardening around 10PeV?



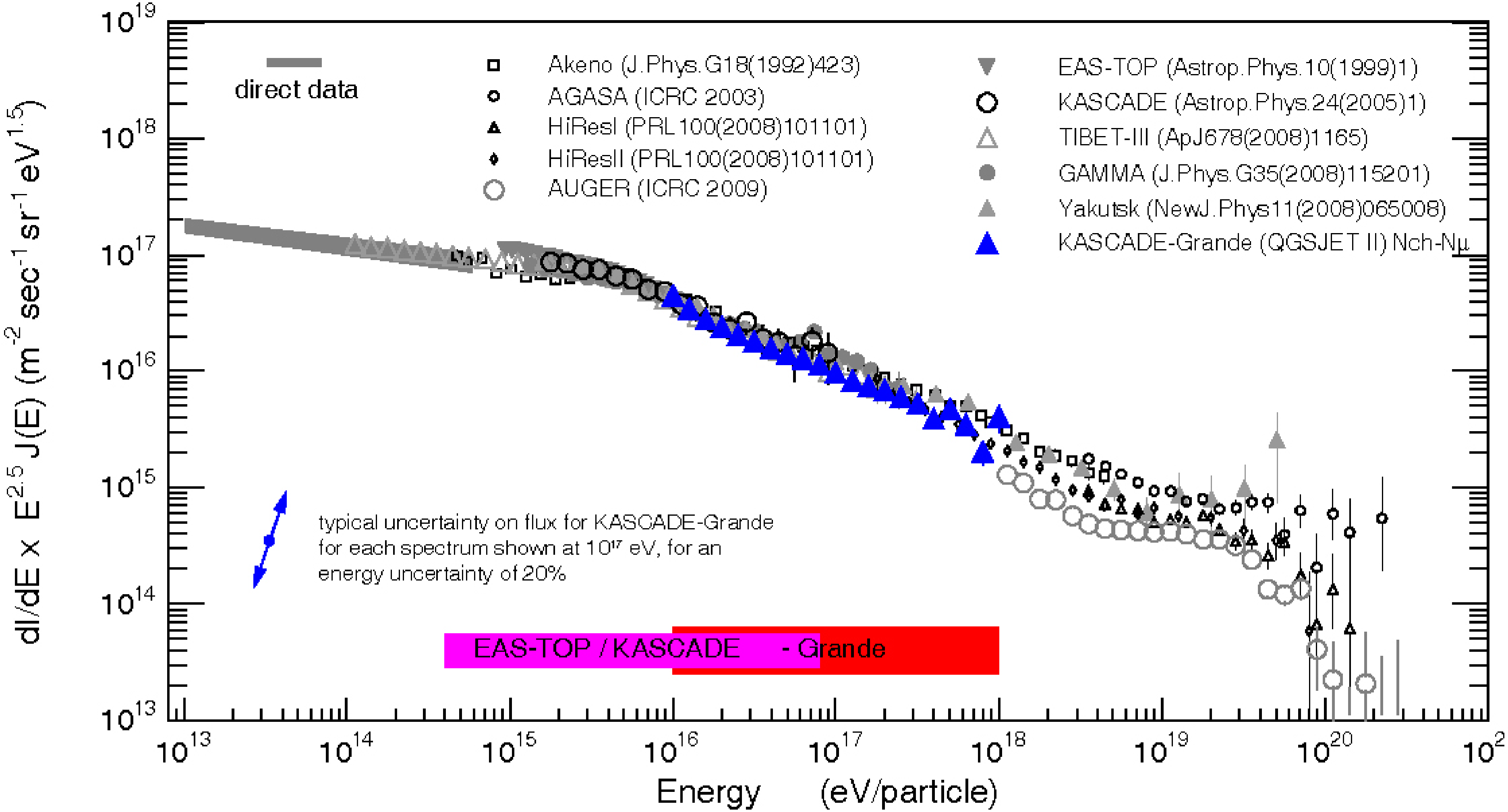
(a) Preliminary CREAM-III proton and helium spectra

- CREAM, ICRC2009



A.Erlykin, ICRC2009; astro-ph/0906.3949.

KASCADE-Grande



KASCADE-Grande Collaboration

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W.D. Apel, F. Badea, K. Bekk, J. Blümer, H. Bozdog, F. Cossavella, K. Daumiller, P. Doll, R. Engel, J. Engler, M. Finger, H.J. Gils, A. Haungs, D. Heck, T. Huege, P.G. Isar, D.Kang, H.O. Klages, H.-J. Mathes, H.J. Mayer, J. Milke, S. Nehls, J. Oehlschläger, T. Pierog, H. Rebel, M. Roth, H. Schieler, F. Schröder, M. Stümpert, H. Ulrich, A. Weindl, J. Wochele, M. Wommer

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Universidade Sao Paulo, Brasil
V. de Souza

http://www-ik.fzk.de/KASCADE-Grande/

30 March 2009 – official closure ceremony

30 March 2009 – official closure ceremony

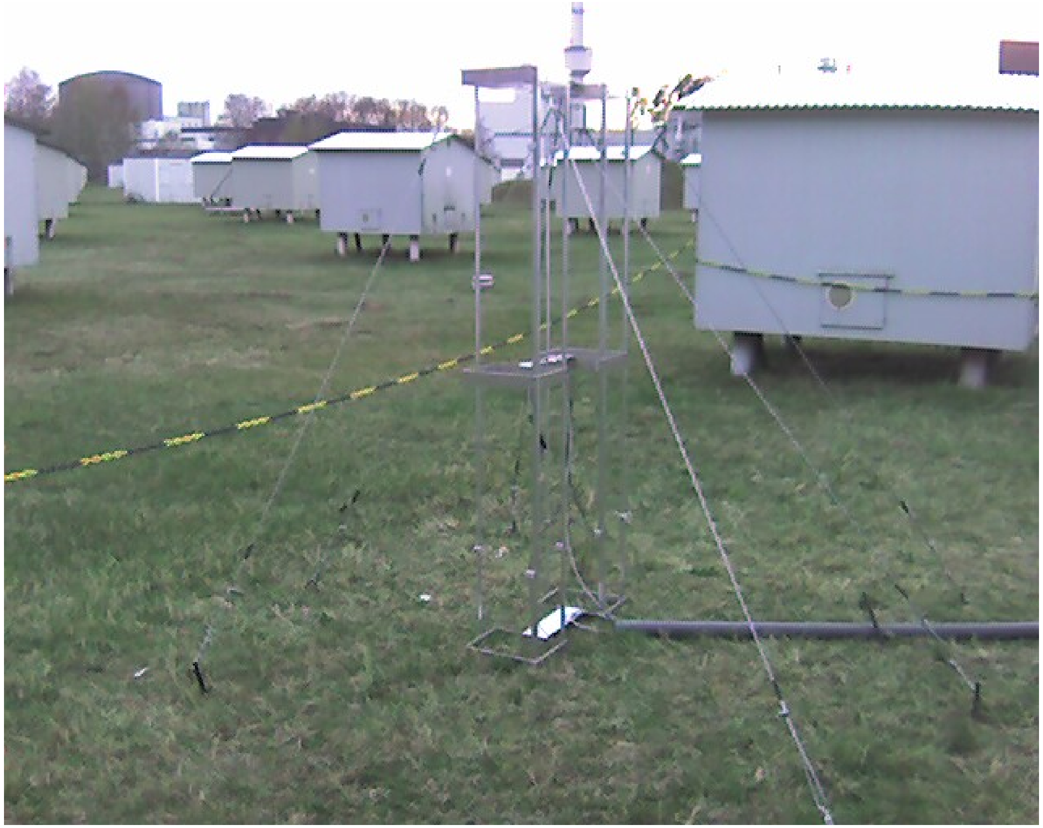
The KASCADE-Grande
EAS facility

The facility KASCADE-Grande: TAUWER

TAUWER: Tau Neutrino shower detection

Goal: Muon/Electron separation sensitivity

Partners: Univ Roma La Sapienza



Deliverable: trigger from Cluster 12
shower parameters
particle densities at detector locations

We get: common publication, if any

The facility KASCADE-Grande: HiSPARC

HiSPARC: School project for cosmic ray air shower detection

Goal: Energy calibration of small EAS

Partners: NIKHEF Nijmegen/Amsterdam

Deliverable: trigger from Cluster 12
shower parameters
particle densities at locations

We get: common publication, if any

The facility KASCADE-Grande: Lightning mapping

lightning: Lightning mapping array

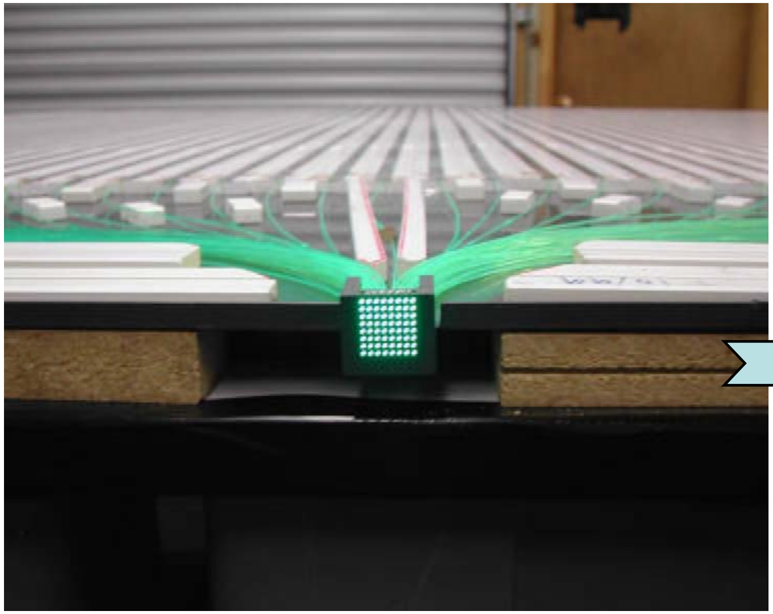
Goal:
- correlation lightning-EAS
- lightning data for LOPES

Partners: Paul Krehbiel, US

Deliverable: trigger time from KASCADE
trigger from LOPES

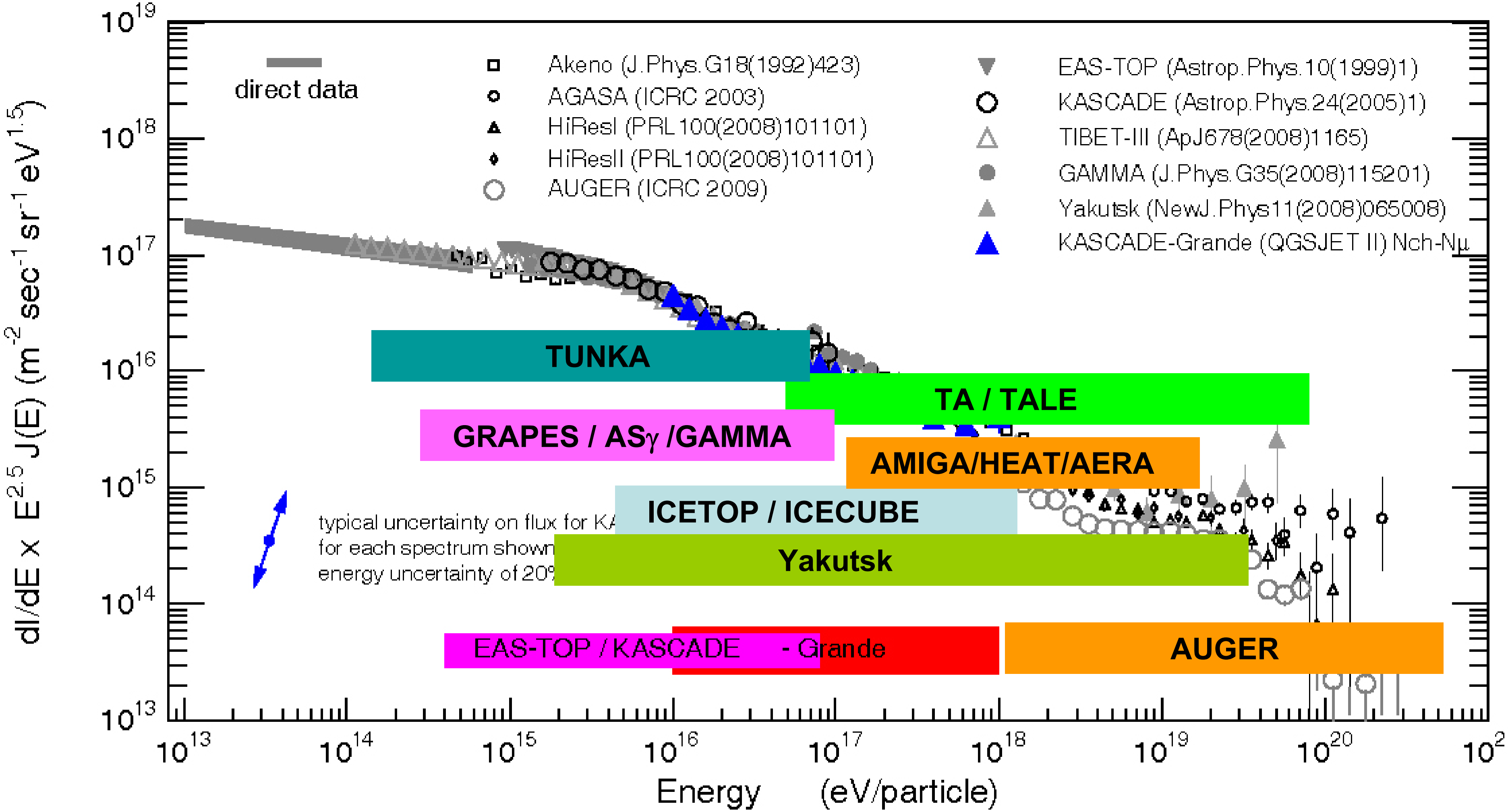
We get: E-field data
lightning data
common publication, if any

The facility KASCADE-Grande:
AMIGA ?



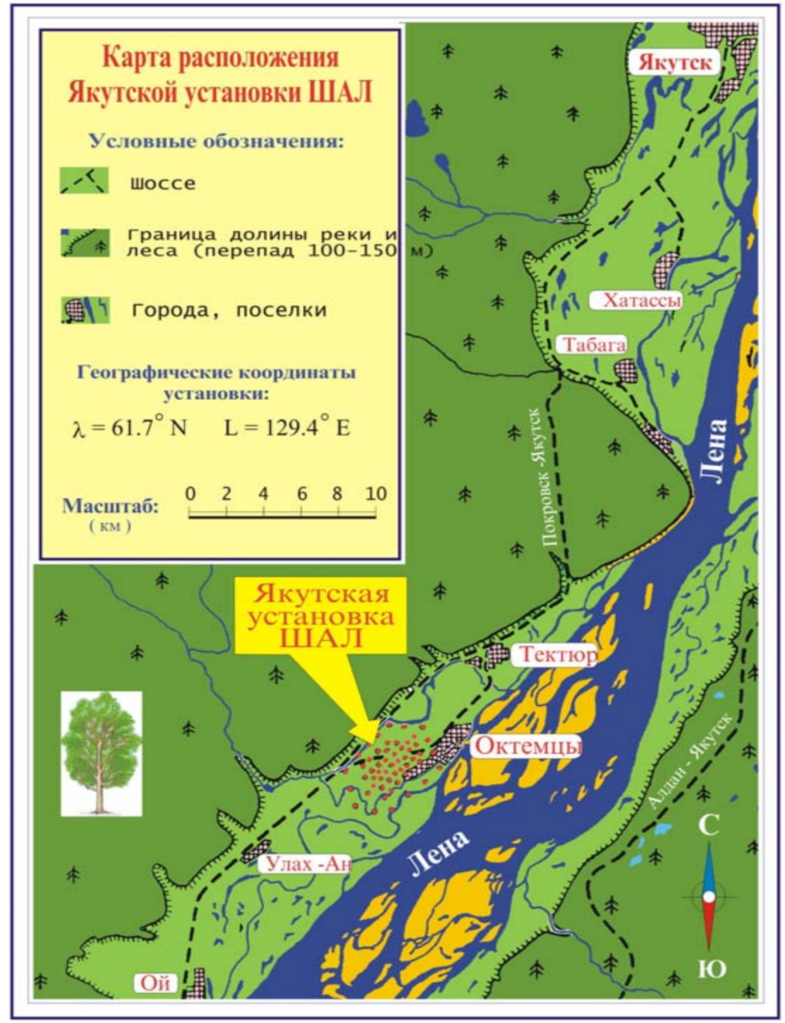
- Idea:
Auger AMIGA muon detector calibration@KASCADE-Grande

KASCADE-Grande



Yakutsk

Yakutsk EAS array **10 km^2 (18 km^2 in 1973-1990)**



MI Pravdin, Tunka workshop 2009

Yakutsk

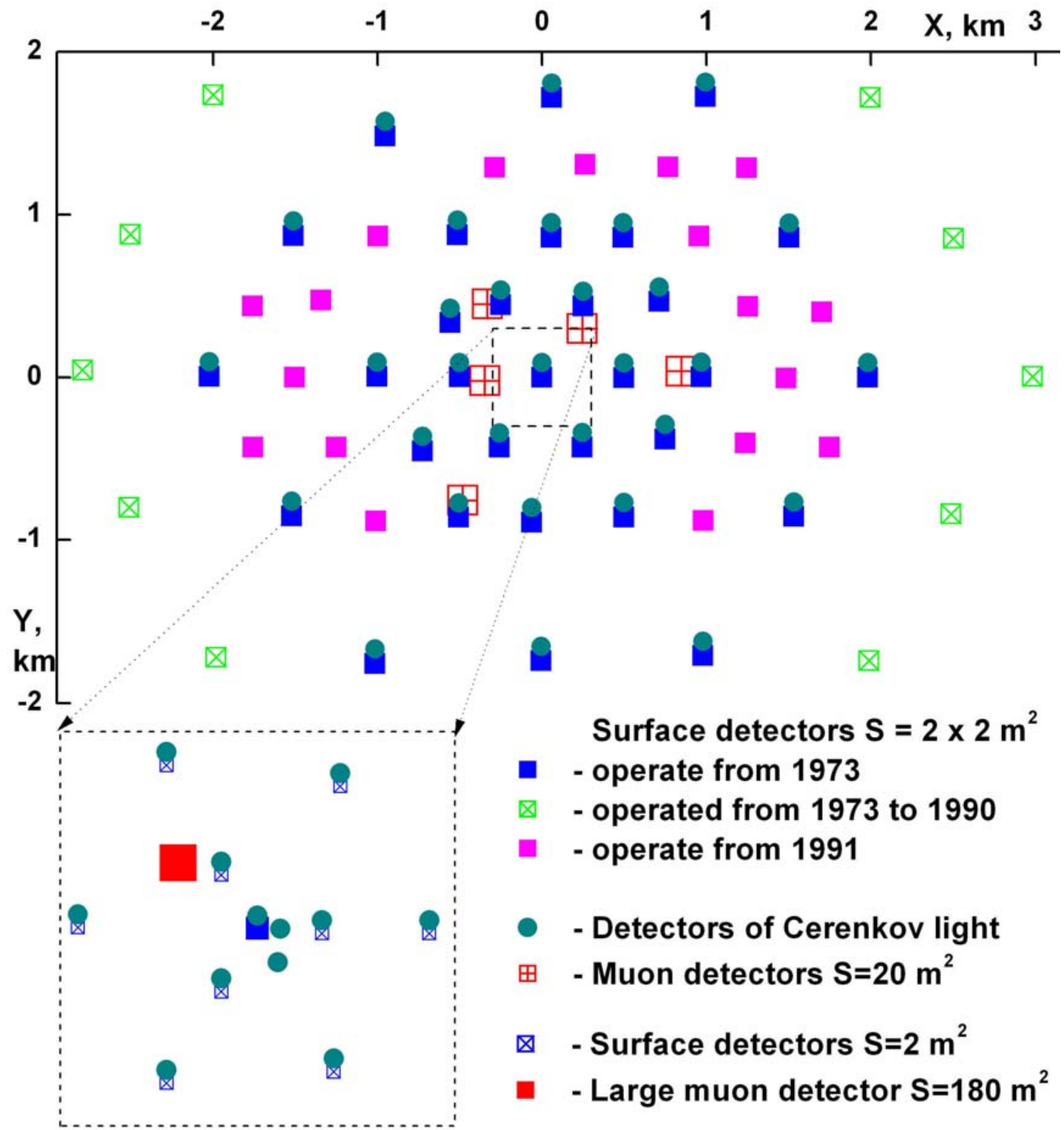
Area - 12 km²
(18 km² in 1973-1990)

49 detector stations
S_{det}=2x2 m²;

9 detector stations
S_{det}=2 m² in center;

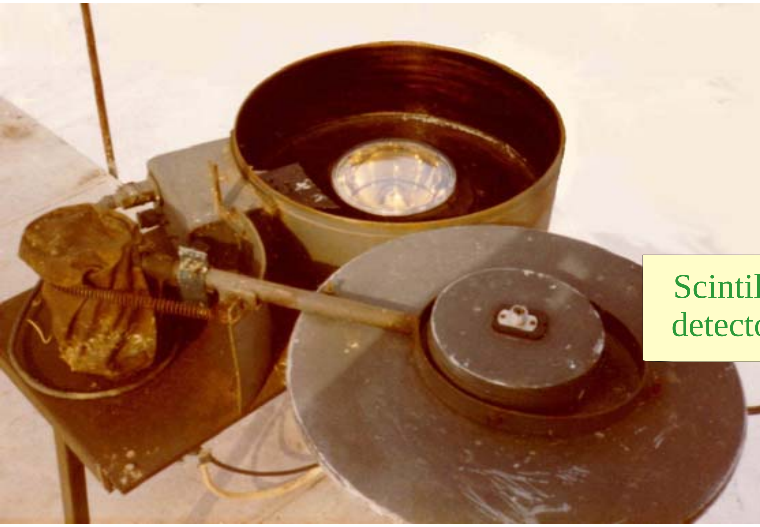
31 detectors of Cerenkov light

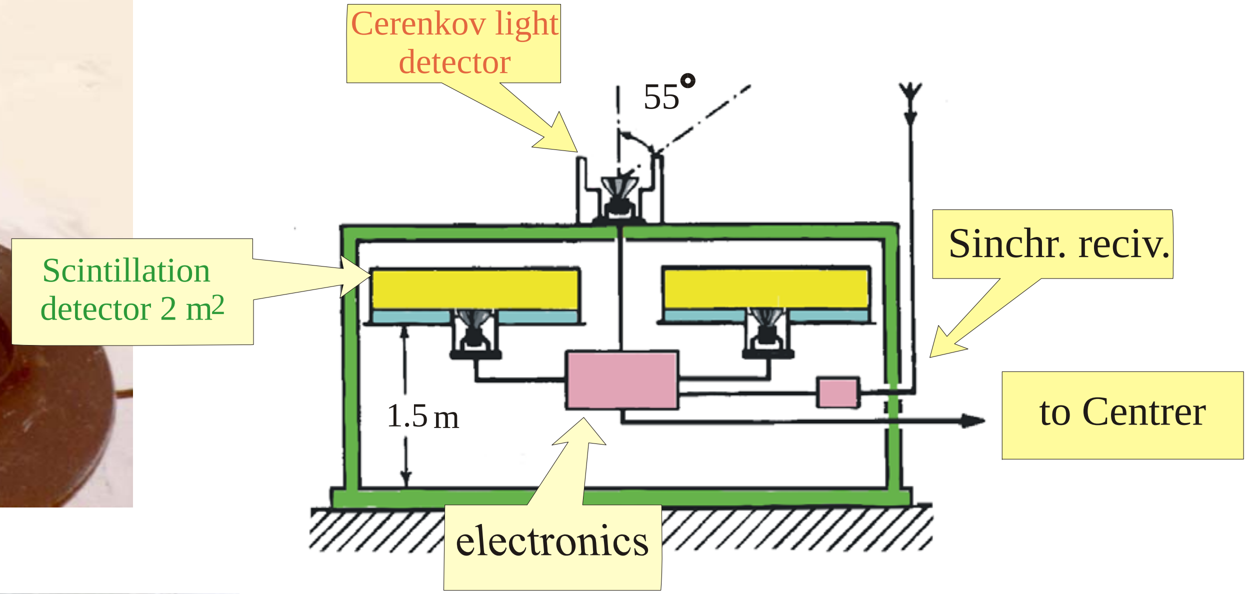
Distance between detectors – 500 m



Yakutsk scintillator array

Yakutsk

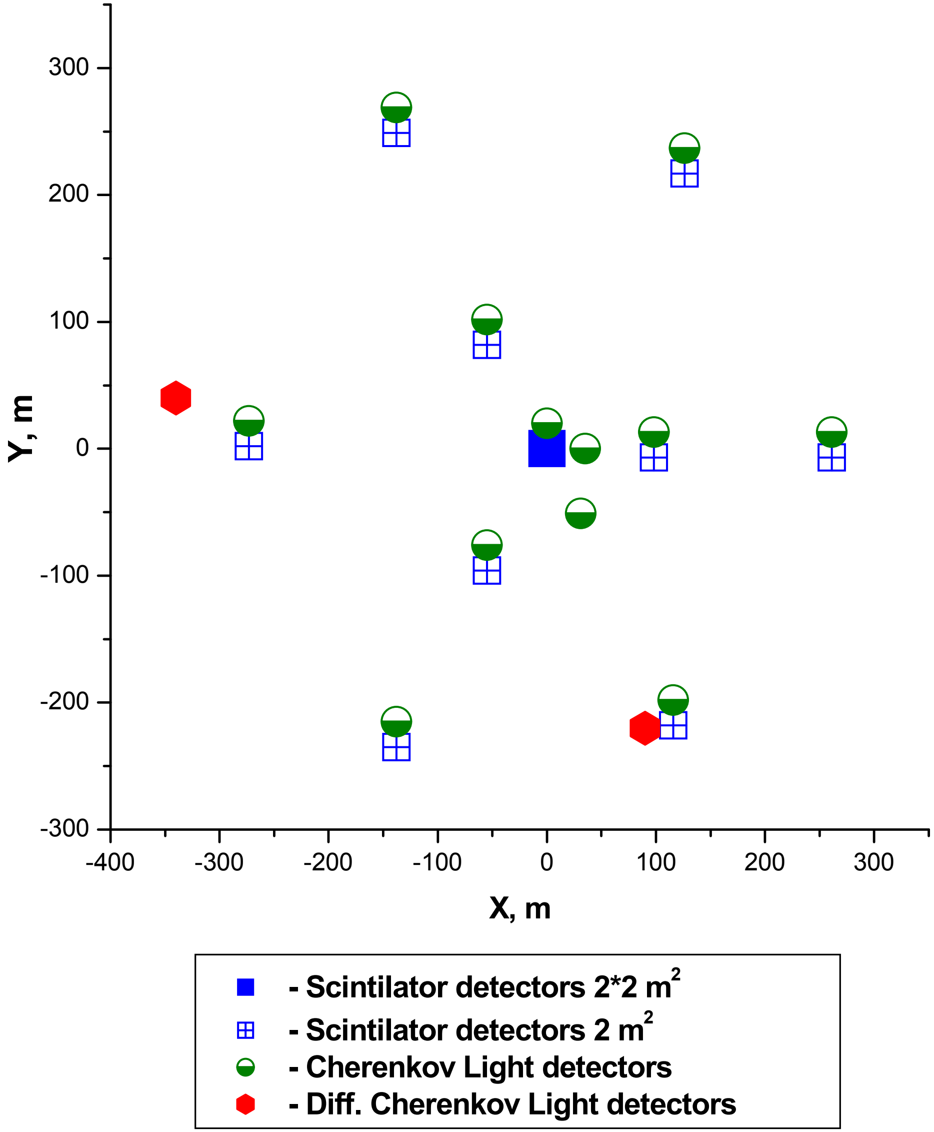




Yakutsk

Yakutsk EAS array

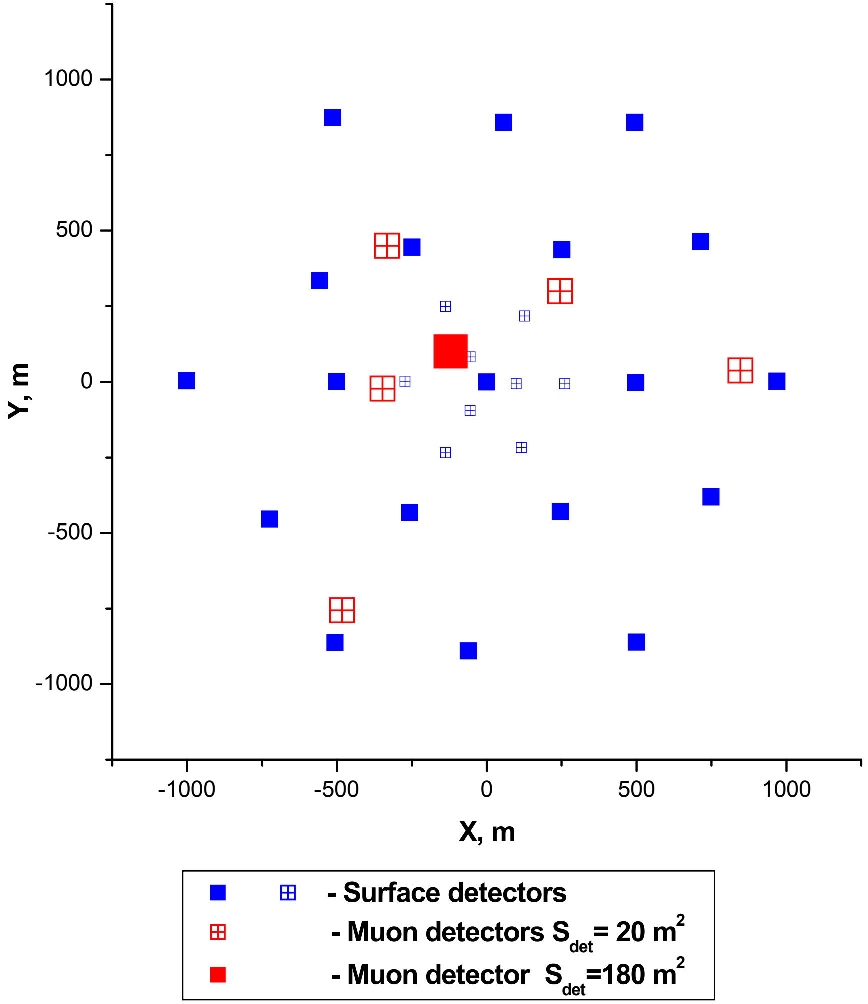
Small Cherenkov Light Trigger



Yakutsk

Yakutsk EAS array

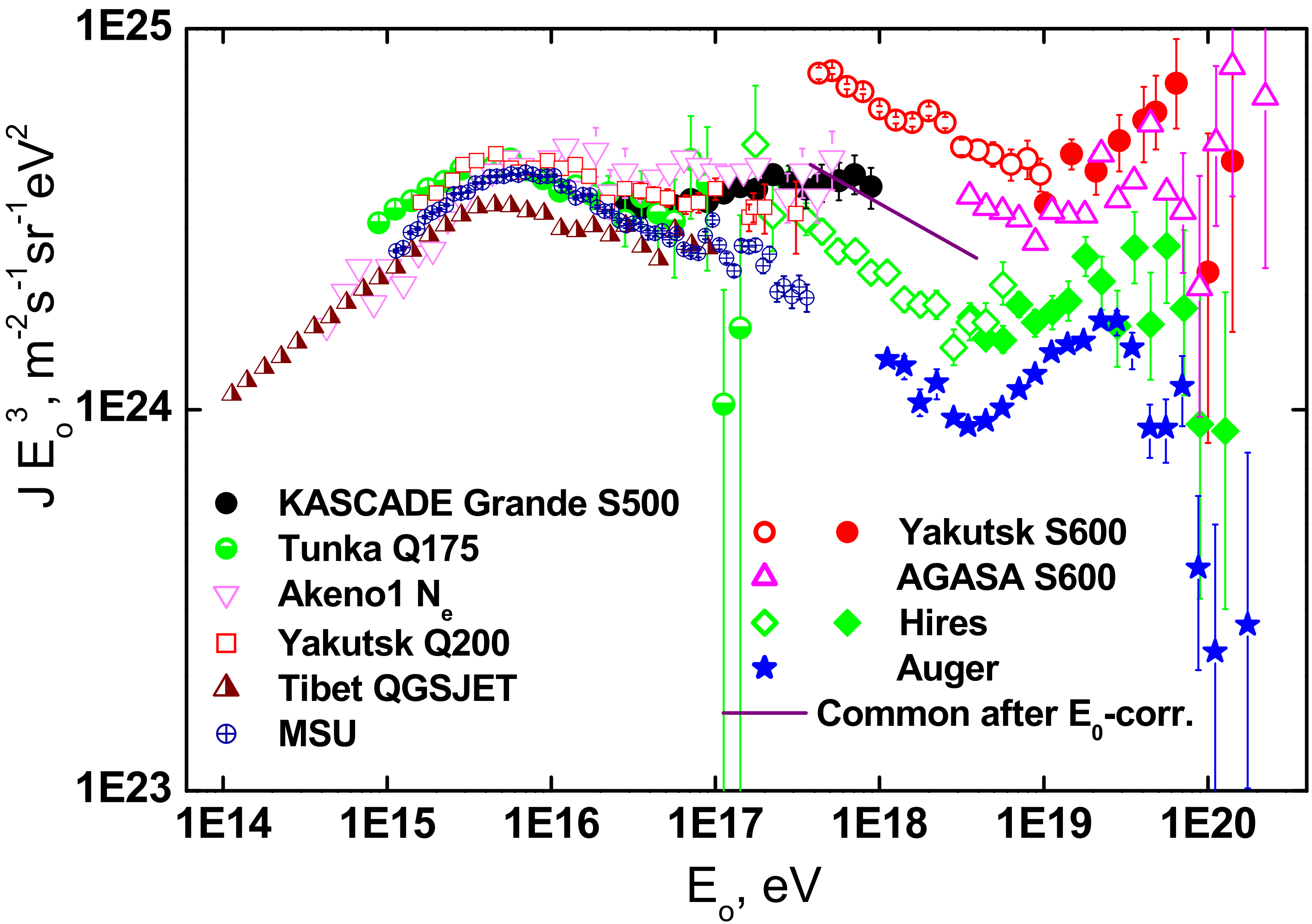
Muon detectors



S_{det}=20.25 m^2(2 det.) or S_{det}=20 m^2(3 det.), E_{Th} = 1/ cos(θ) GeV

Muon detector large area - S_{det}=180 m^2, E_{Th} = 0.5/ cos(θ) GeV

Yakutsk

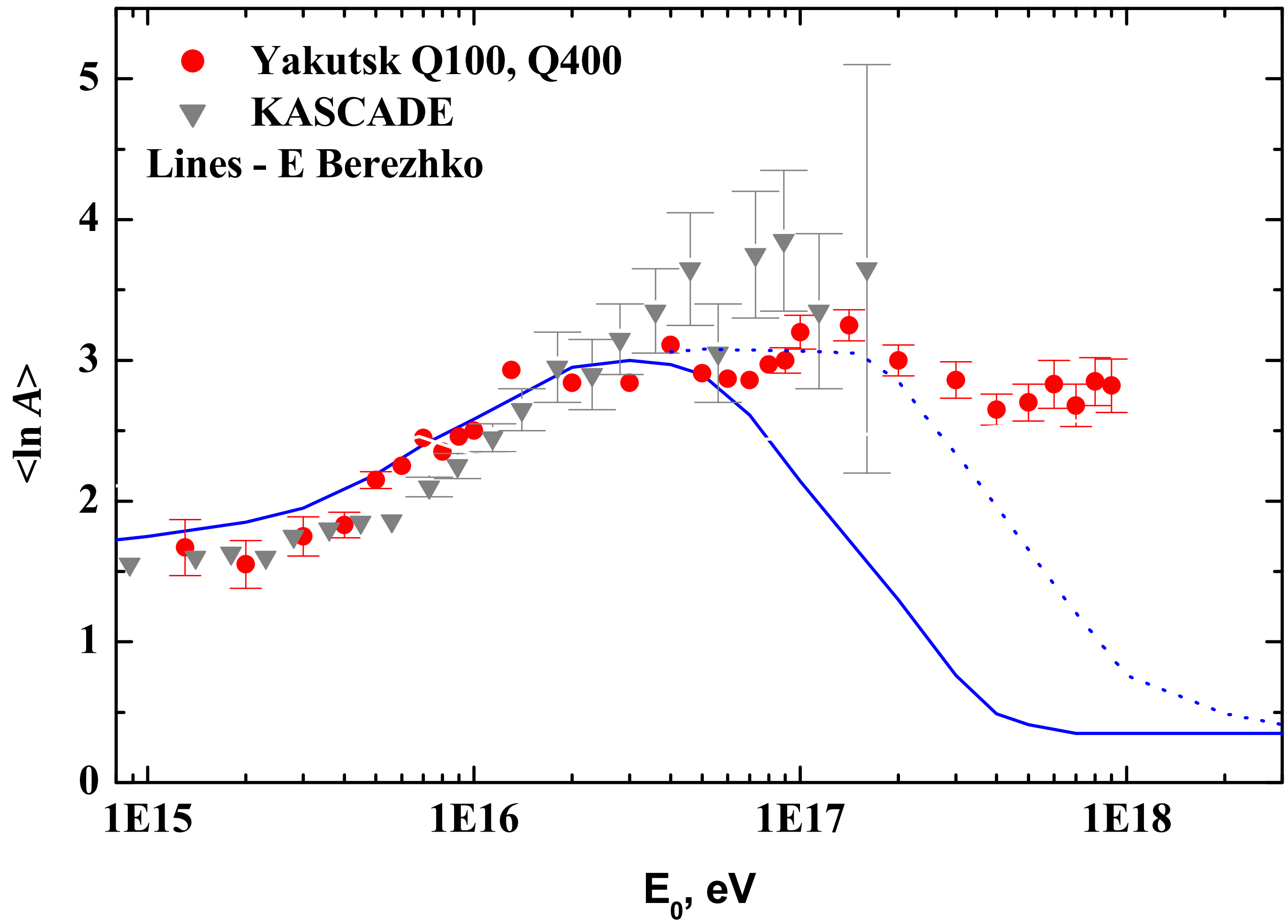


1E25
1E24
1E23
1E14
1E15
1E16
1E17
1E18
1E19
1E20
$J\,E_o^3,\ m^{-2}s^{-1}sr^{-1}eV^2$
E_o, eV
KASCADE Grande S500
Tunka Q175
Akeno1 N_e
Yakutsk Q200
Tibet QGSJET
MSU
Yakutsk S600
AGASA S600
Hires
Auger
Common after E_0-corr.

Yakutsk

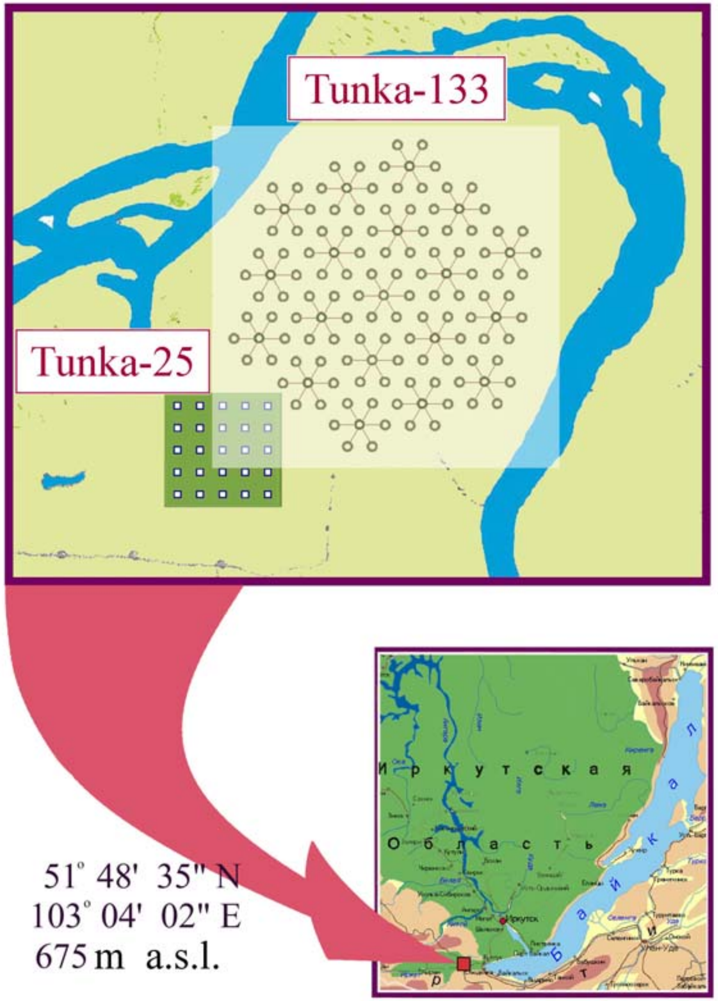
Composition

The average logarithm of mass number



TUNKA

Tunka-133 – 1 km² "dense" EAS Cherenkov light array



51° 48' 35'' N
103° 04' 02'' E
675 m a.s.l.

Energy threshold ~ 10^{15} eV
Statistics for one winter (400 hours):
> $3\cdot10^{15}$ eV – $5\cdot10^{5}$ events
> 10^{17} eV – ~ 300 events

Accuracy: core location ~ 6 m
energy ~ 15%
X_{max} < 25 $g\cdot cm^{-2}$

TUNKA

Approach to the mass composition

Primary nucleus $\mathbf{E_0}$, **A**?

$<\mathbf{X_{max}}> \sim <\mathbf{lnA}>$

X_{max} measurement:

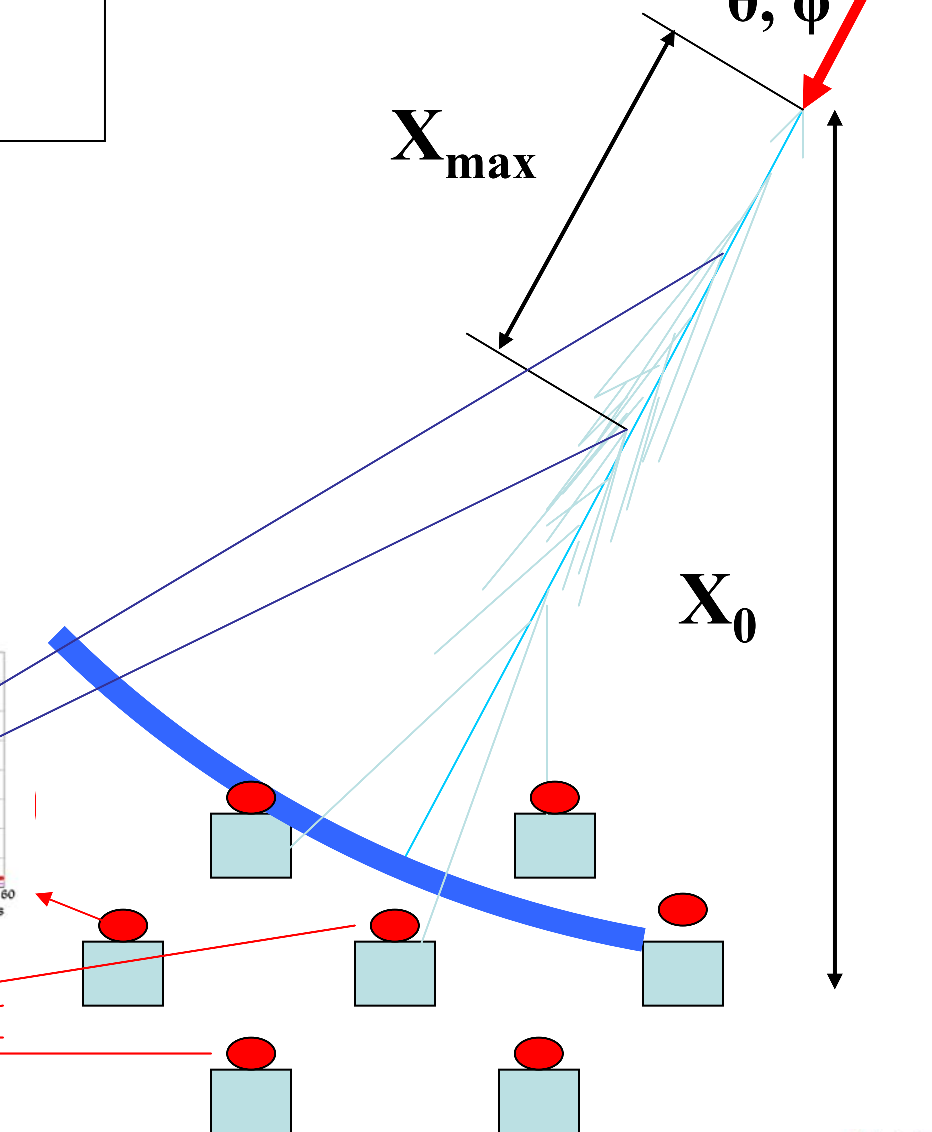
(model independent)

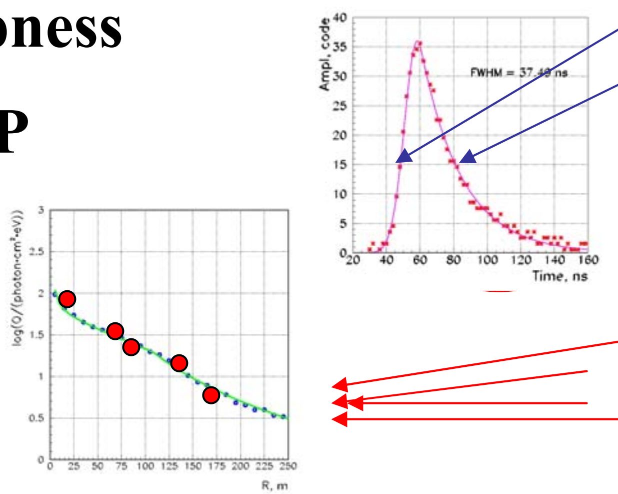
2. FWHM ~ ΔX g/cm²

$$\Delta X = X_0/\cos\theta - X_{max}$$

1. LDF steepness

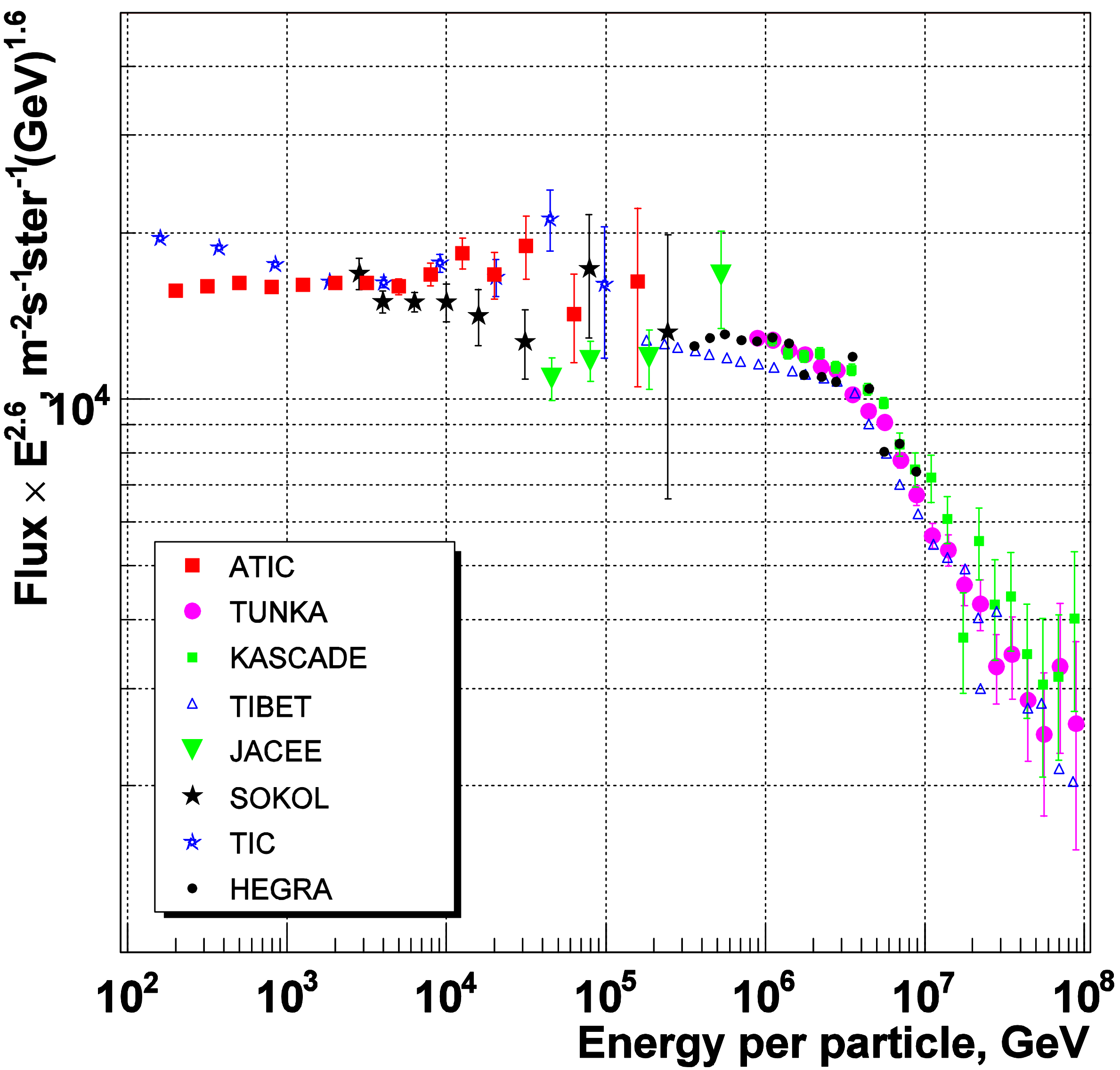
$$H_{max} = a - b \cdot P$$



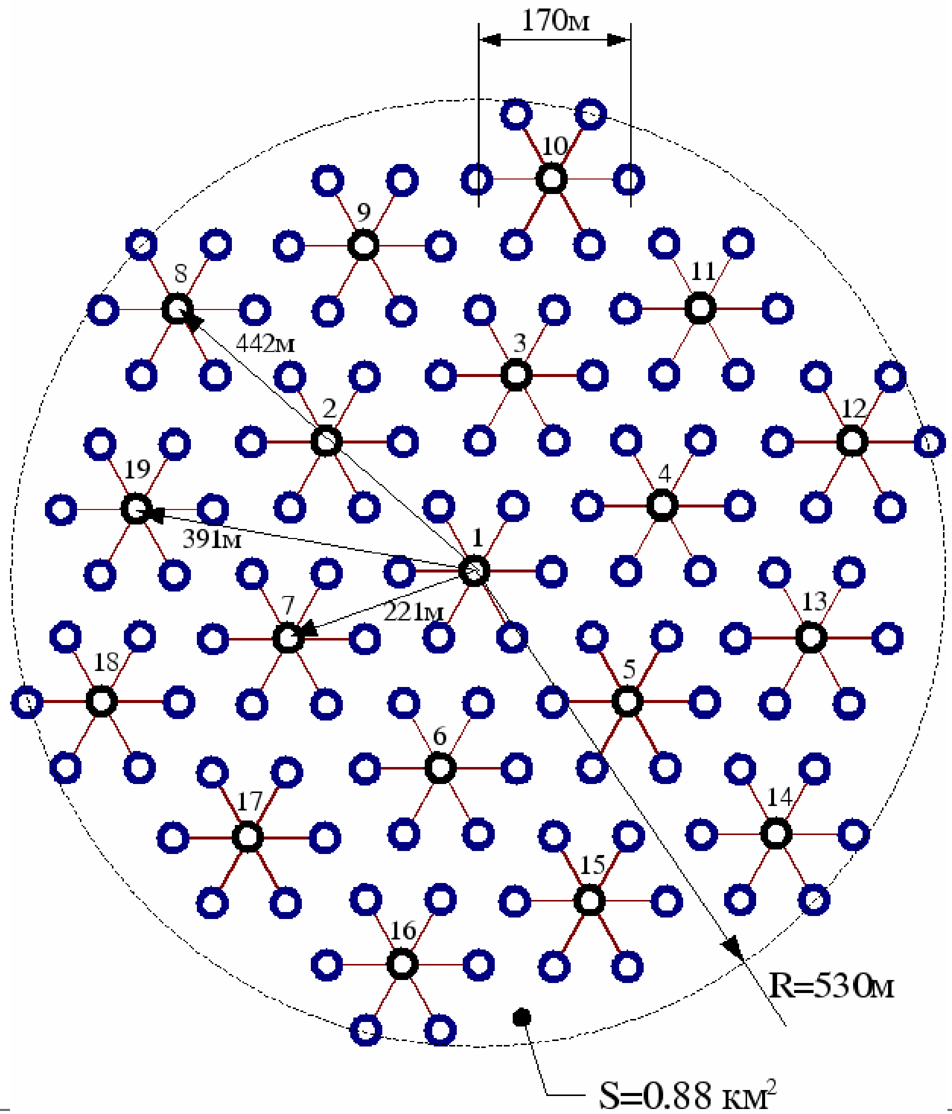


TUNKA

All particle spectrum



Tunka-133: 19 clusters, 7 detectors in each cluster



DAQ center

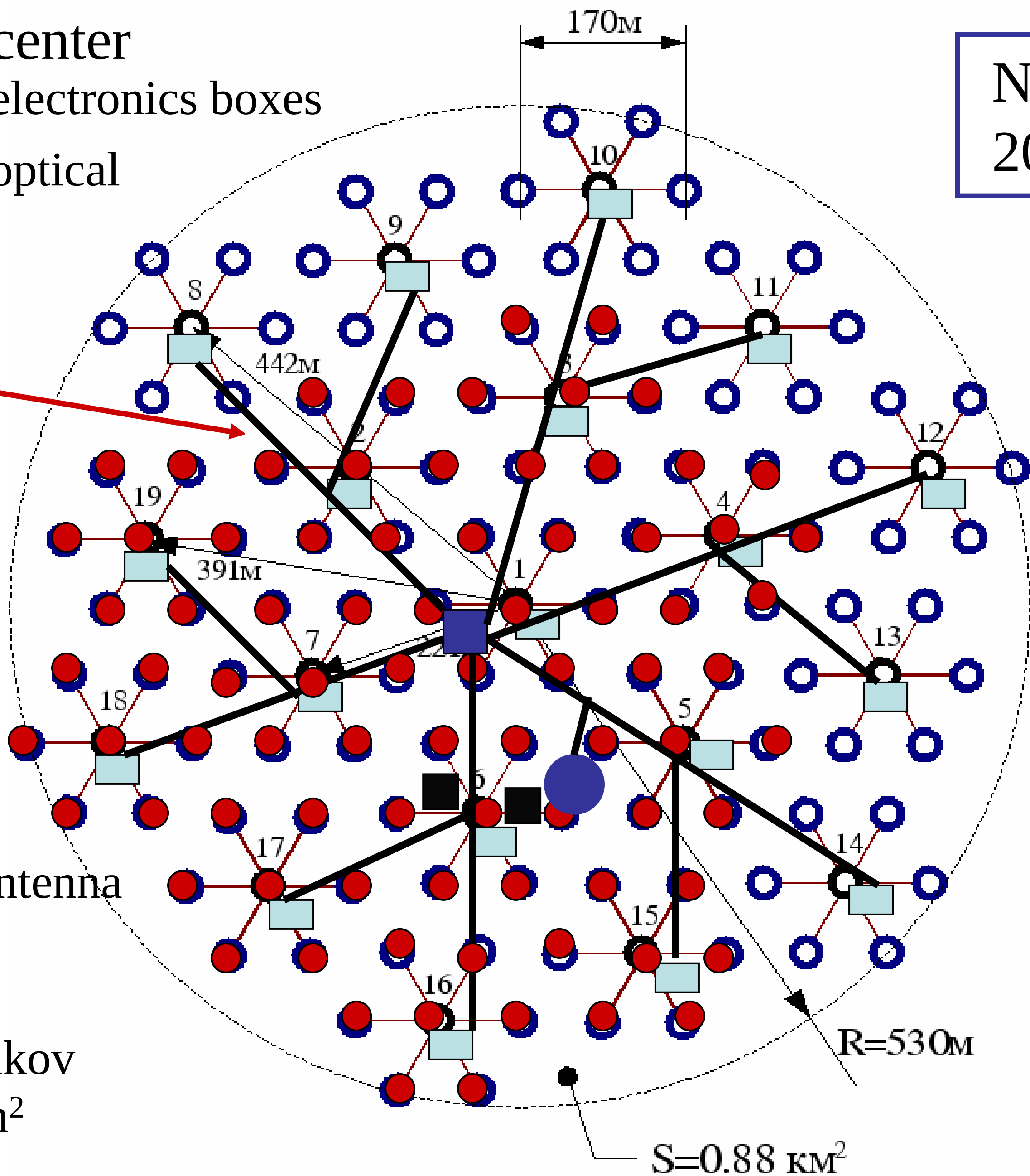
Cluster electronics boxes

Installed optical detector

Optical cable

- Radio-antenna

Water Cherenkov Tank S=10 m²



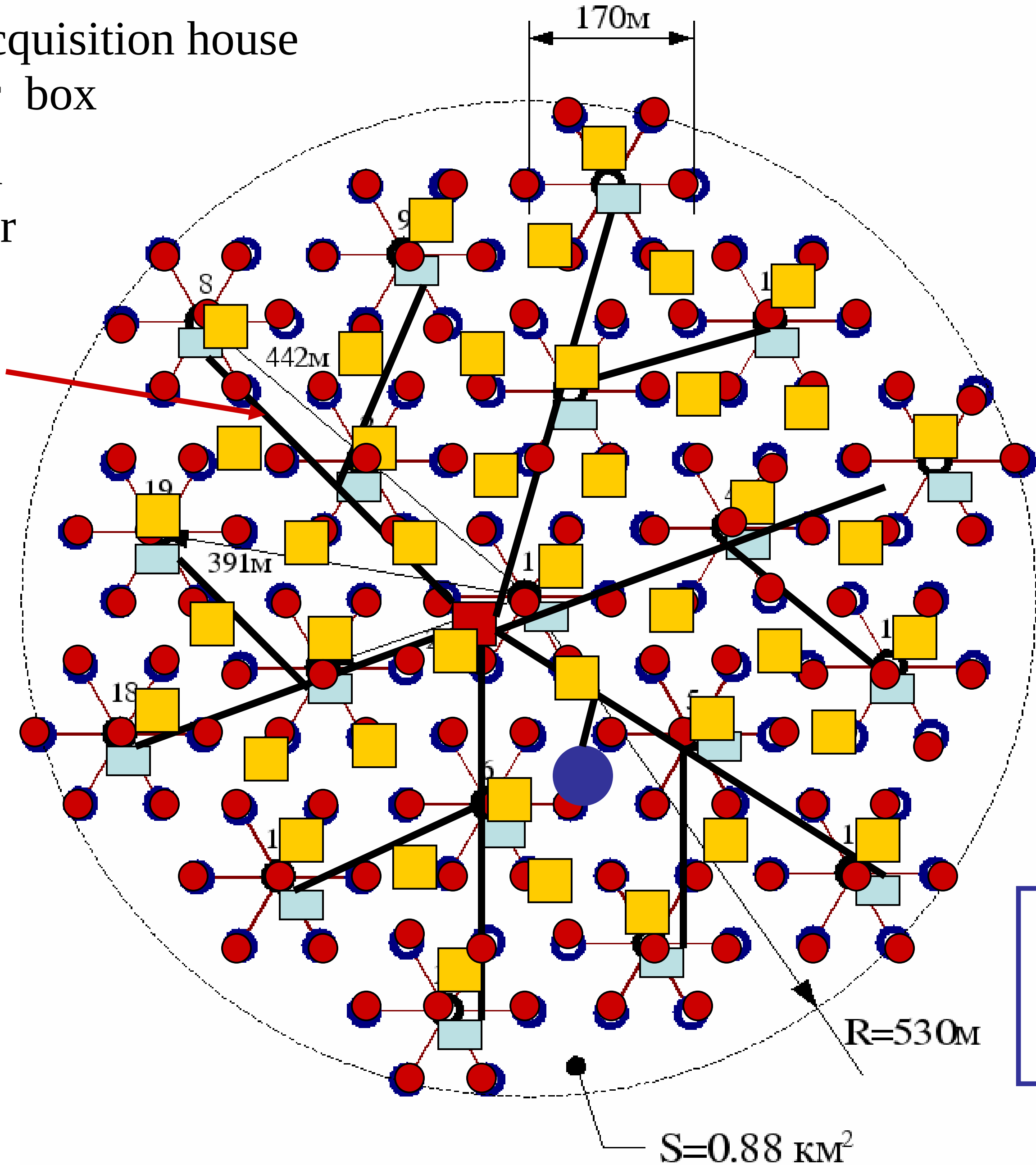
November 2008

In operation:
84 optical detectors
and 2 antennas

Data acquisition house

Cluster box

Optical detector



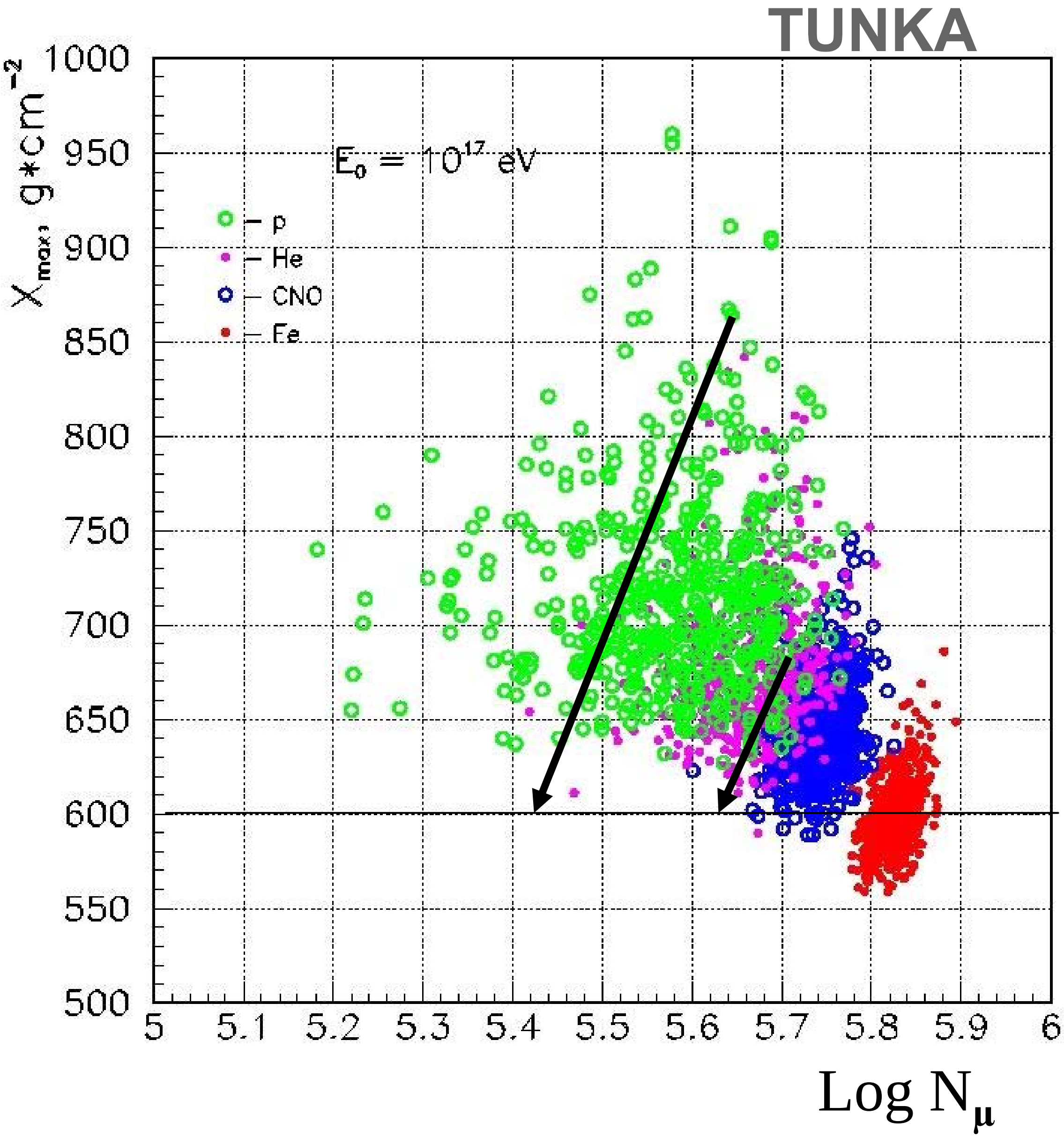
2010-2011

38 muon detectors + net of radio antennas

Scintillator 8-10 m²

Water tank

Accuracy of N_μ Reconstruction ≈10%



Projection to the level Xmax = 600 g ·cm^{-2}


GAMMA experiment:
present status, recent results and near future
Romen Martirosov
on behalf of the GAMMA collaboration
KASCADE Symposium, Karlsruhe, March 30-31, 2009

GAMMA

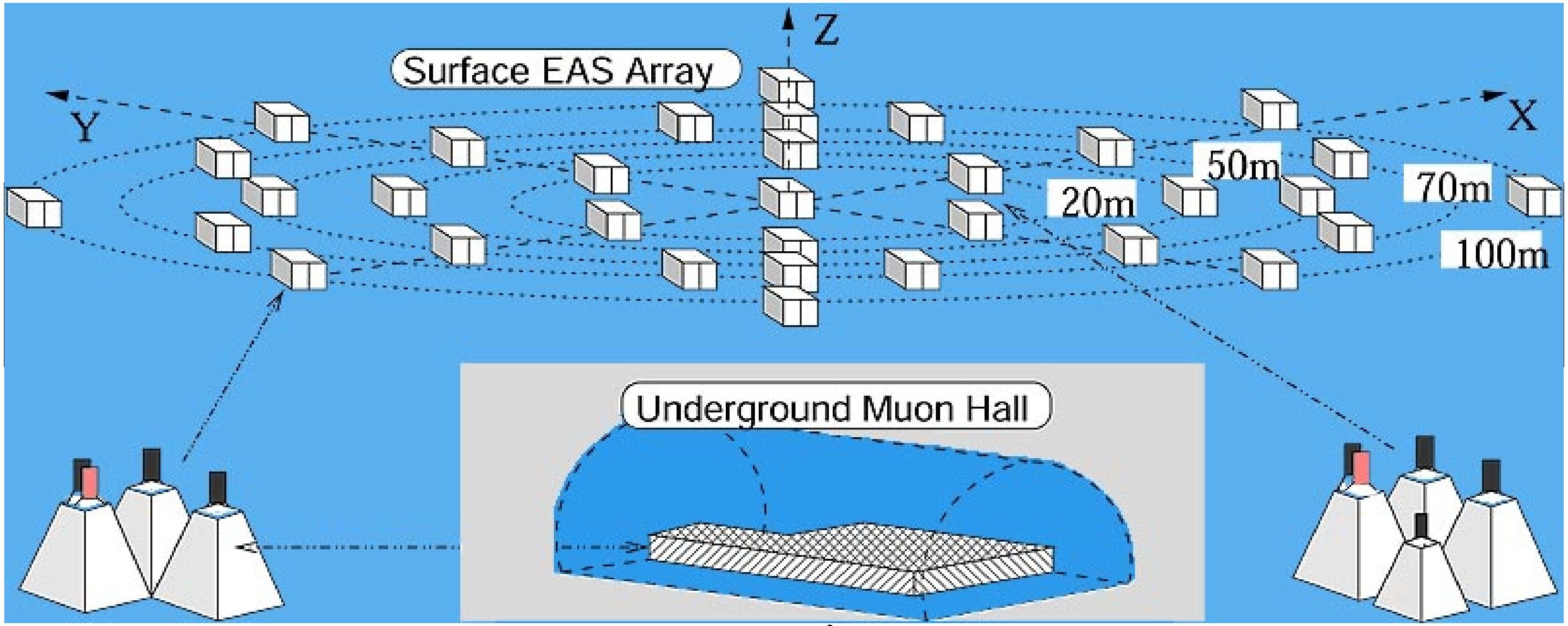
ARAGATS scientific station (late autumn)

Hill sides of the Mt. Aragats, Armenia, 65 km from Yerevan

Elevation: 3200 m a.s.l. (700 g/cm^2 of atmospheric depth)

Geographical coordinates: Latitude = 40.470 N, Longitude = 44.180 E

GAMMA facility



0.09m^2

GAMMA

Energy estimator

$$\boxed{Ln(E_0) \approx Ln(E_1) = f(N_{ch}, N_\mu, s, cos\theta)}$$

where N_{ch}, N_μ, s, cos θ – experimentally measured parameters

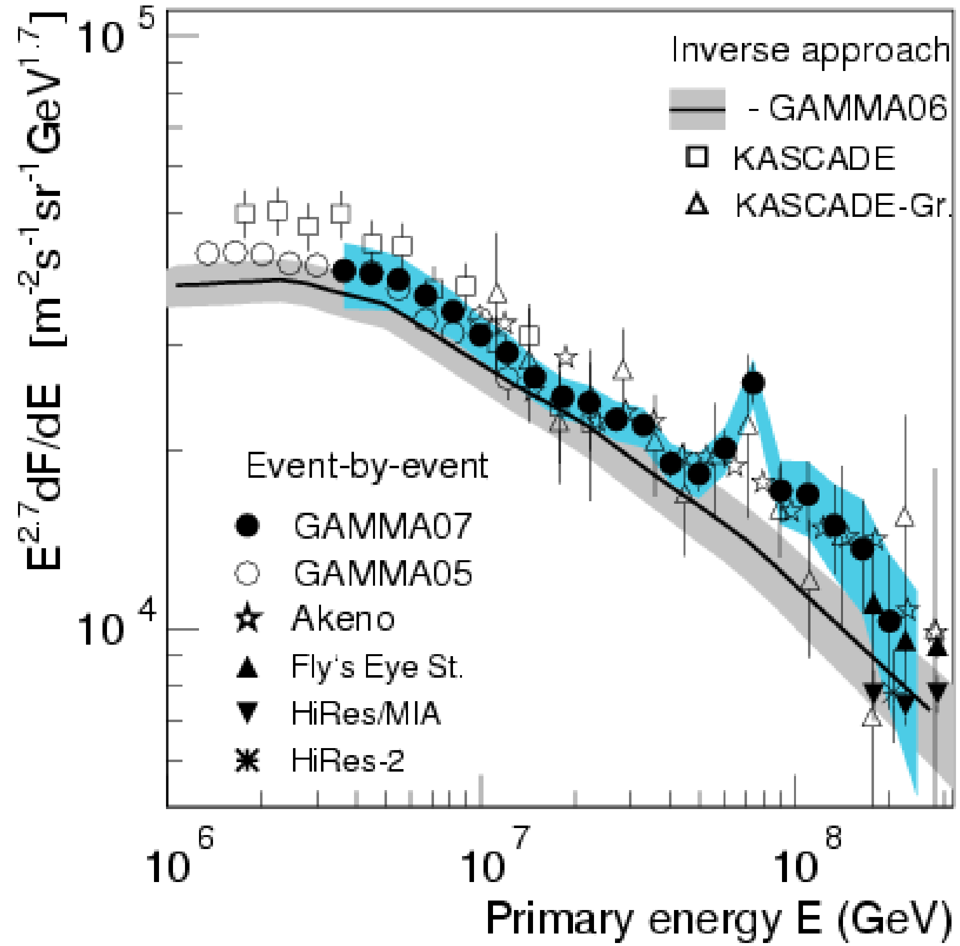
The best energy estimations as a result of $\chi^2_{min}(E_0,E_1)$ were achieved for the 7-parametric fit:

$$\boxed{LnE_1 = a_1 x + a_2\sqrt{s}/c + a_3 c + a_4 + a_5/(x - a_6 y) + a_7 y e^s}$$

where x = LnN_{ch}, y = LnN_μ (R<50m), c = cos(θ)

GAMMA

All-Particle Energy Spectrum



GAMMA05: R < 25m; Q < 30^0
GAMMA07: R < 50m; Q < 45^0

All-particle energy spectrum in comparison with the results of EAS inverse approach (GAMMA-06, KASCADE, KASCADE-Grande), our preliminary data and results of other experiments

59

Possible origin of irregularities

Rigidity-dependent primary-energy spectra cannot describe the phenomenon of ageing of EAS at energies (5-10) x 10^{16} eV which was observed in mountain-altitude experiments.

It is reasonable to assume that an additional flux of heavy nuclei (Fe-like) is responsible for the bump at these energies. Besides, the sharpness of the bump points out the local origin of this flux from compact object.

We carried out the test of this hypothesis using the inverse approach on the base of GAMMA data and the hypothesis of two-component origin of cosmic ray flux:

so-called **Galactic component** is the power-law energy spectra with rigidity-dependent knees at energies $E_k=E_R \cdot Z$ and power indices $\gamma = \gamma_1$ and $\gamma = \gamma_2$ for $E < E_k$ and $E > E_k$ respectively;

so-called **pulsar component** is an additional power-law energy spectrum with cut-off energies $E_{c,Fe}$ and indices $\gamma_p = \gamma_{1,p}$ and $\gamma_p = \gamma_{2,p}$ for $E < E_{c,Fe}$ and $E > E_{c,Fe}$ respectively.

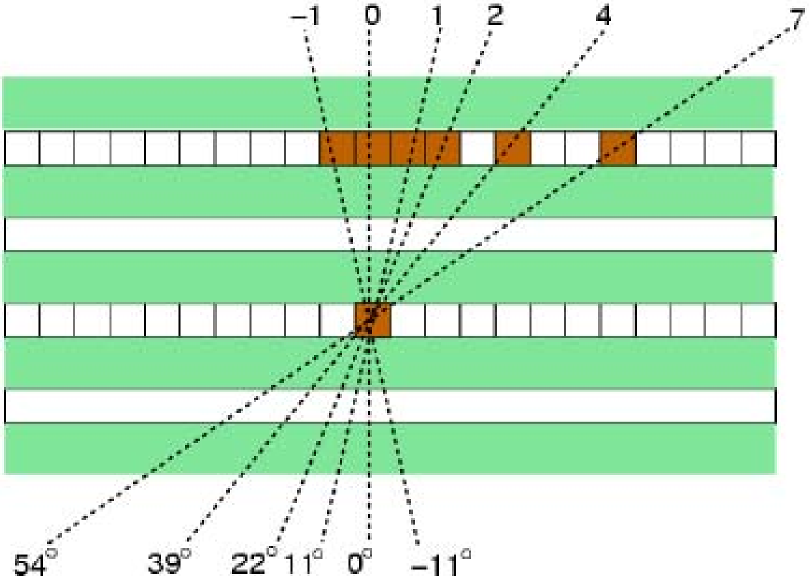
GRAPES

The GRAPES-3 Experiment, An Overview
Sunil K. Gupta

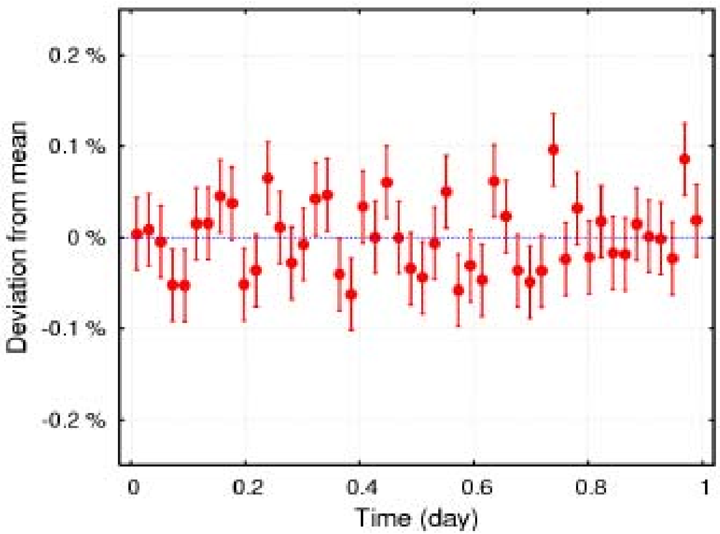
Dr. Homi J. Bhabha Centenary
3rd Workshop on Astroparticle Physics, Ooty
18 December 2008

GRAPES

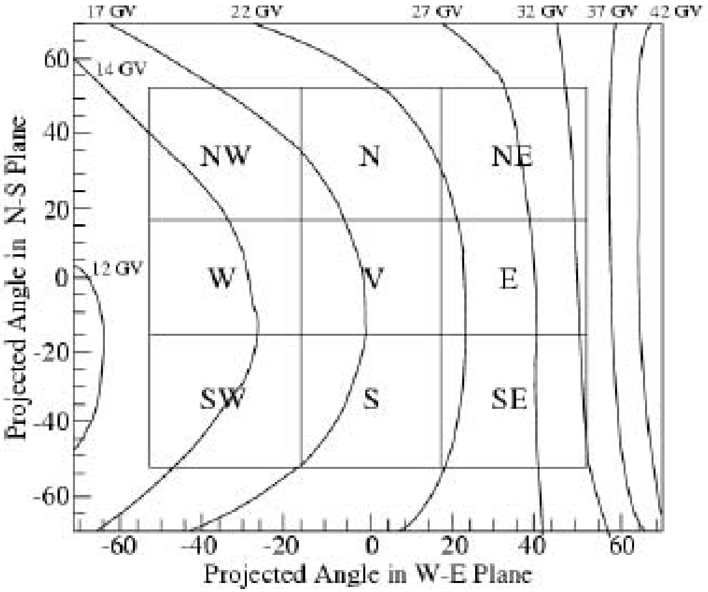
GRAPES



−1
0
1
2
4
7
54°
39°
22°
11°
0°
−11°



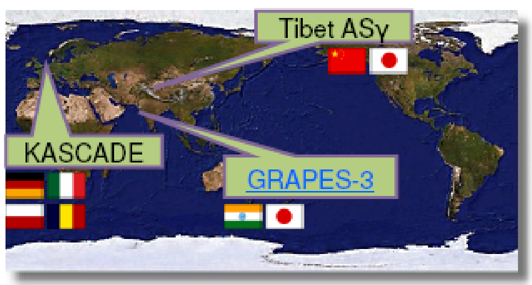
Deviation from mean
0.2 %
0.1 %
0 %
-0.1 %
-0.2 %
0
0.2
0.4
0.6
0.8
1
Time (day)



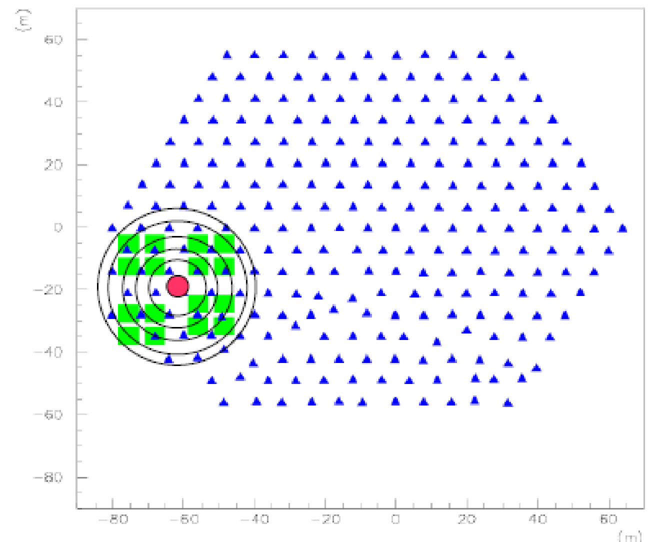
17 GV
22 GV
27 GV
32 GV
37 GV
42 GV
14 GV
12 GV
NW
N
NE
W
V
E
SW
S
SE
Projected Angle in N-S Plane
Projected Angle in W-E Plane
60
40
20
0
-20
-40
-60

Air Shower Experiments

	GRAPES-3	KASCADE	Tibet AS
Obs. Height	2200m	100m	4300m
Density of Particle Detector	1 det / 55m² 1.8%	1 det / 167m² 1.3%	1 det / 56m² 0.9%
Other Observations	560m² Muon Det.	800m² Muon Array 300m² Hadron Det. 128m² MTT etc.	80m² Burst Det.
Features	**Larger Statistics Lower E Threshold**	Larger Statistics	Lower E Threshold



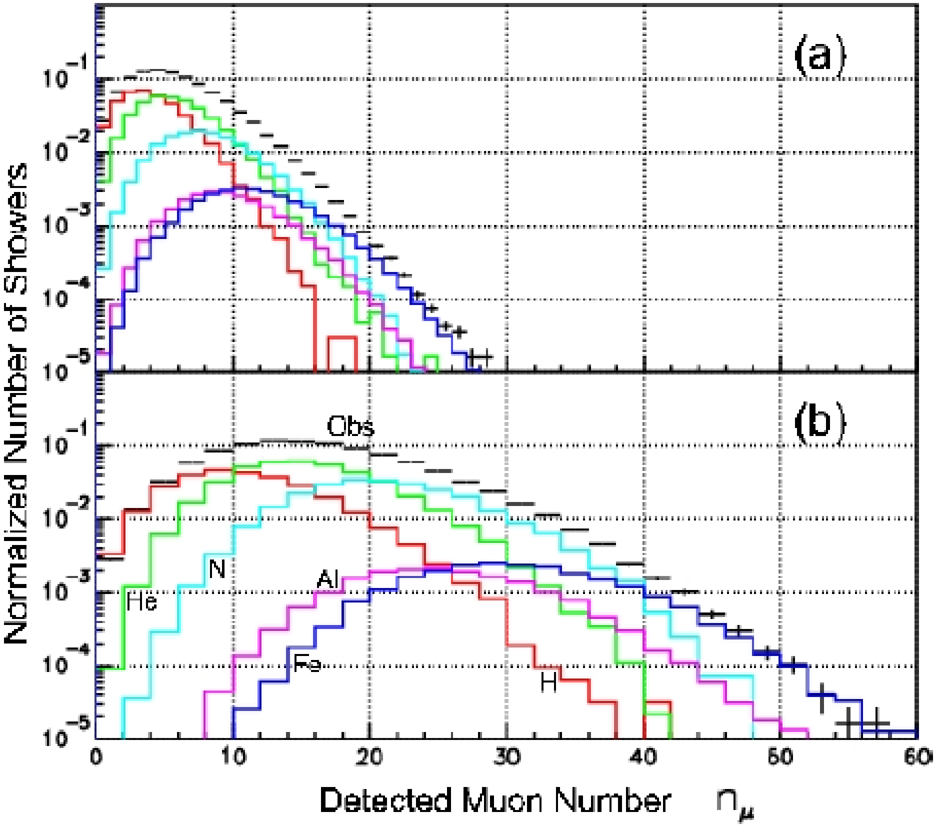
GRAPES-3 has both of a dense array and a large area muon detector at the high altitude.



GRAPES

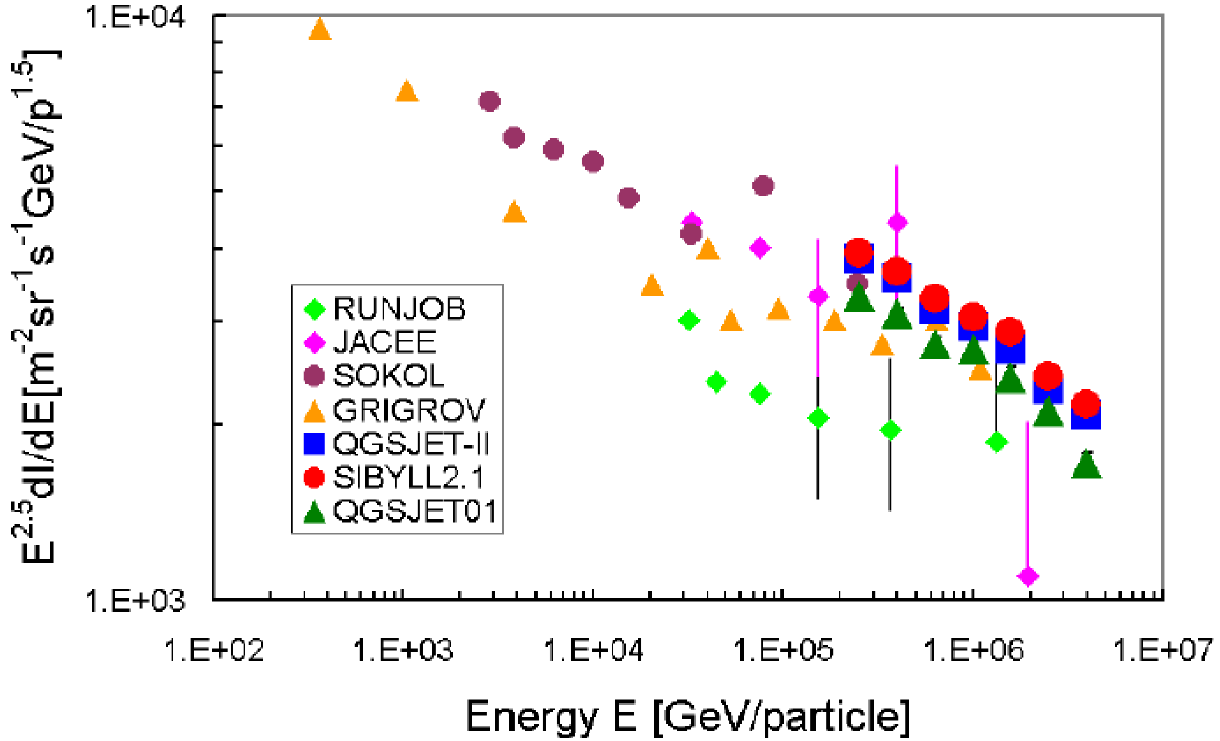
(a) Shower Size `N_e' $10^{4.4}$-$10^{4.6}$

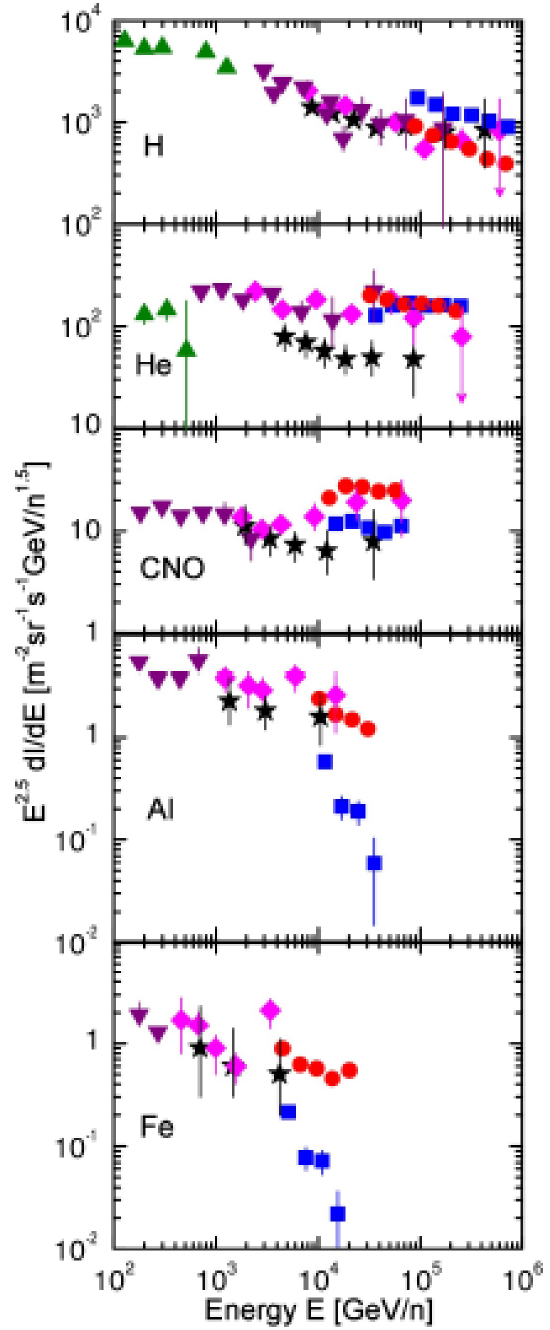
(b) Shower Size `N_e' $10^{5.0}$-$10^{5.2}$



GRAPES

All-particle Spectrum





GRAPES

Future Expansion Plans

- Expansion to an area of 1 km^2 using widely spaced detectors with in-situ signal digitization
- Increase of muon detector area from 560 to 1120 m^2
- Installation of a multi-element, wide-angle, steerable Cerenkov telescope
- Installation of neutron monitors for solar studies
- Installation of low frequency dipole array for detection of radio emission from showers

KASCADE-Grande