Kosmische Strahlung am Knie

Status
und
Perspektiven

Jörg R. Hörandel
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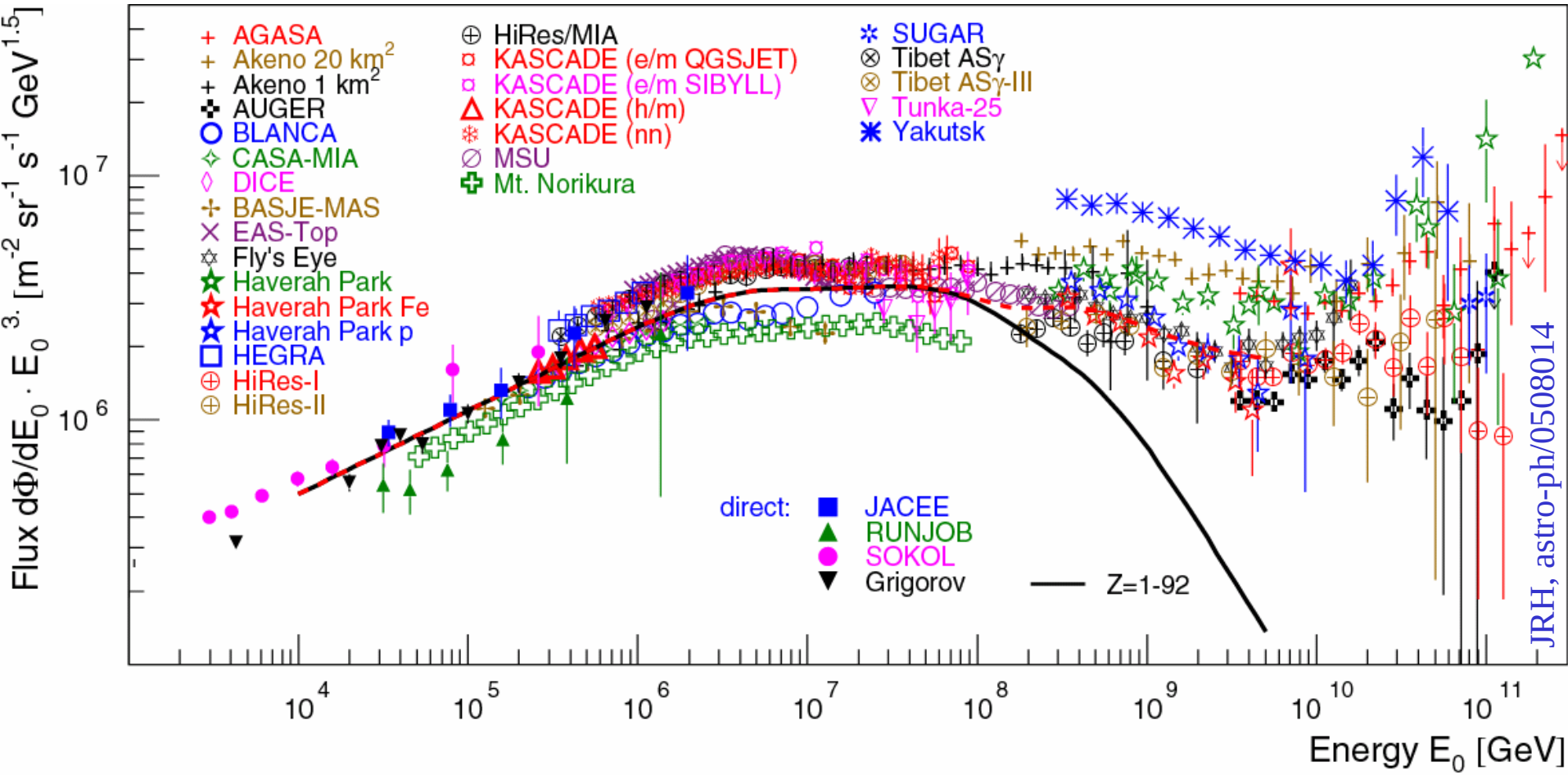
Kosmische Strahlung am Knie



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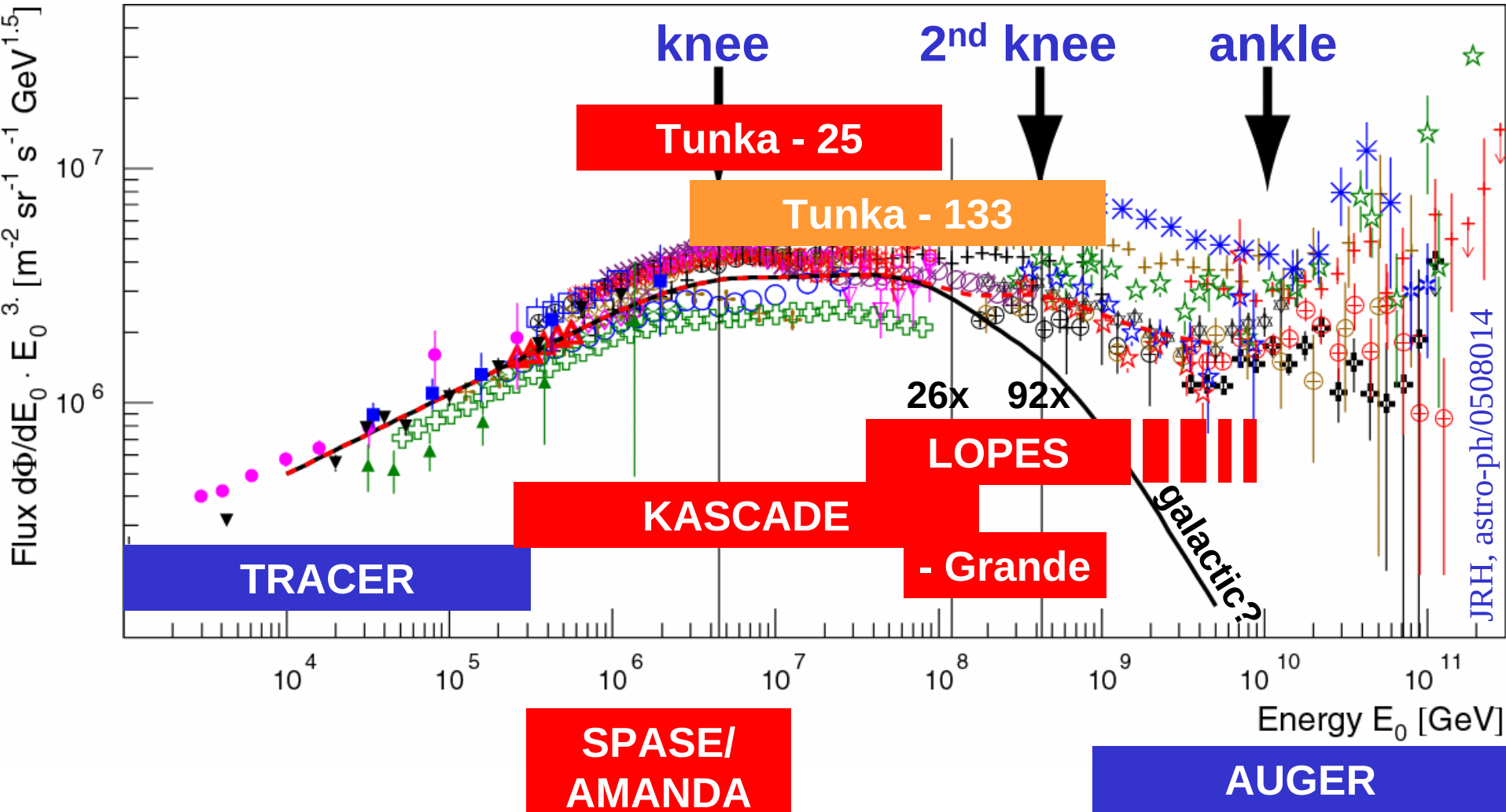
Kosmische Strahlung am Knie



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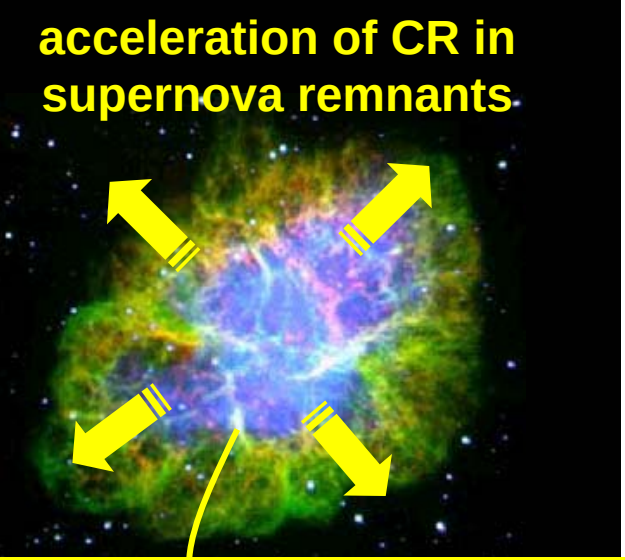
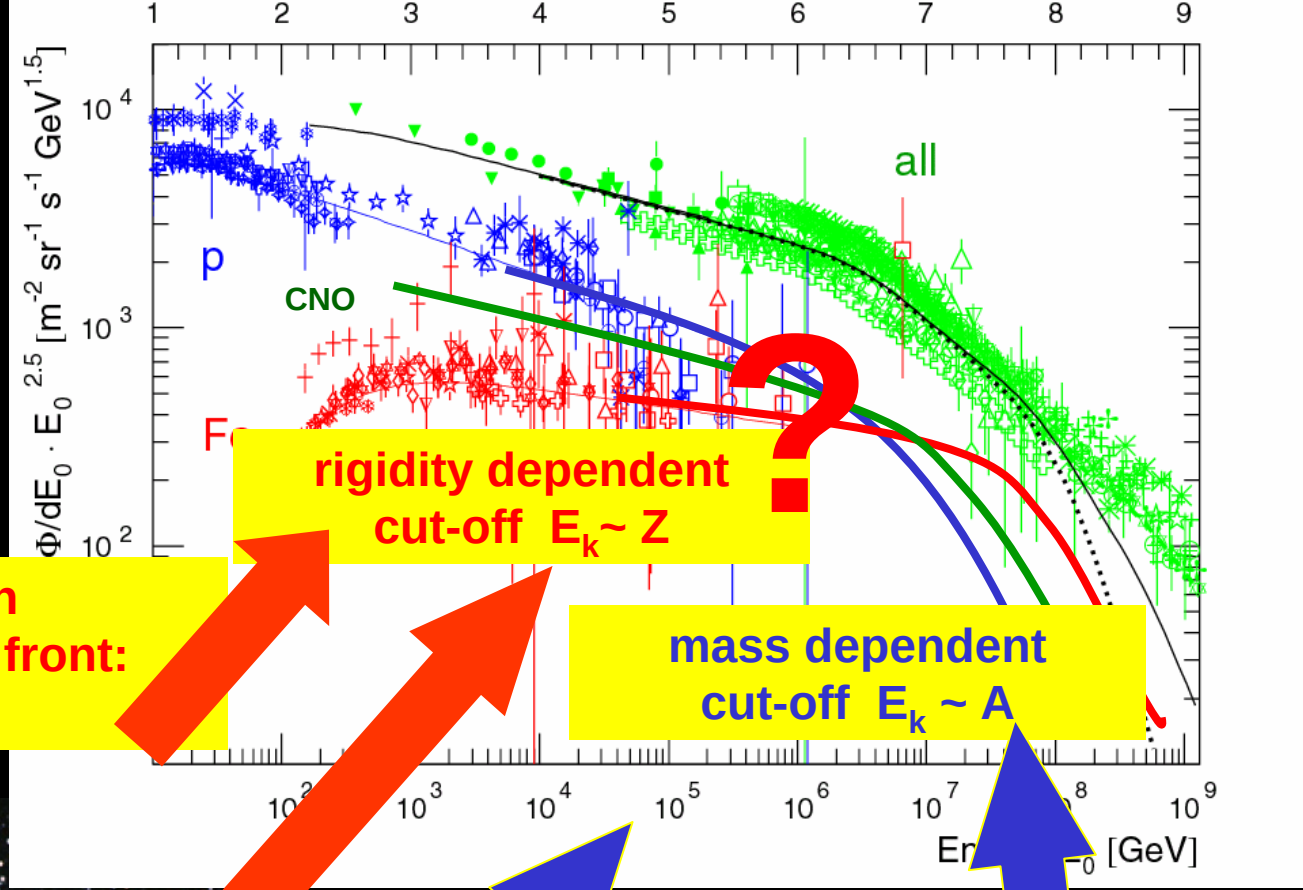
acceleration of CR in supernova remnants





Fermi acceleration
finite lifetime of shock front:
$E_{max} \sim Z \; 10^{15}$ eV

rigidity dependent
cut-off $E_k \sim Z$

mass dependent
cut-off $E_k \sim A$

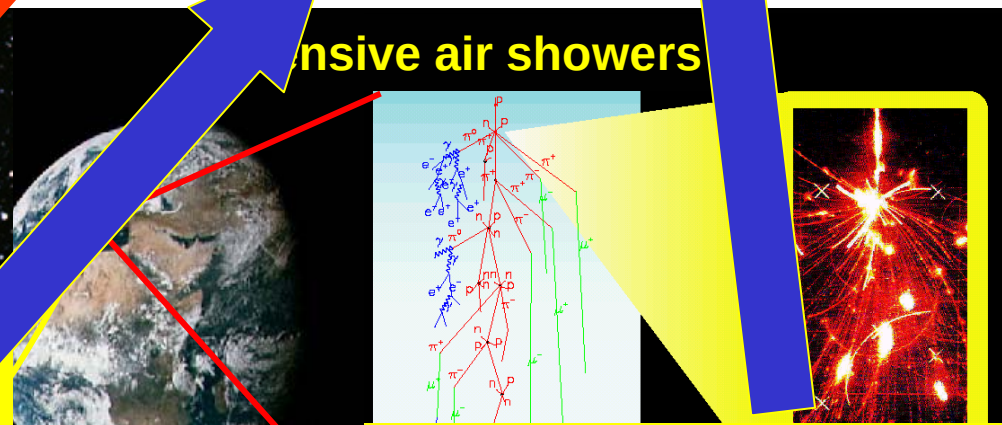
propagation through galaxy

Leakage from Galaxy:
escape probability ~ f(Z)

Interactions with
background particles
(photons, neutrinos)

B = 3 μG

nsive air showers

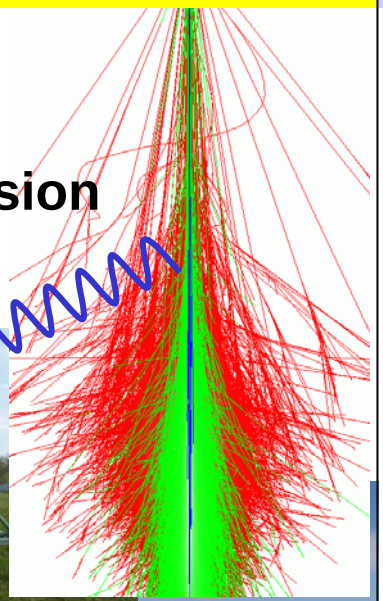


New particle physics in atmosphere

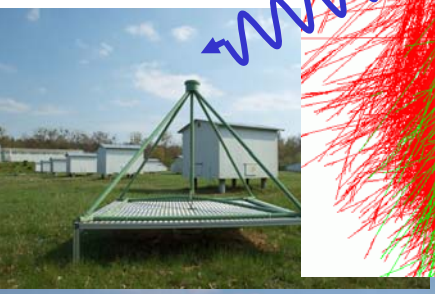
JRH, Astrop. Phys. 21 (2004) 241

Air shower observations

KASCADE-Grande LOPES



radio emission



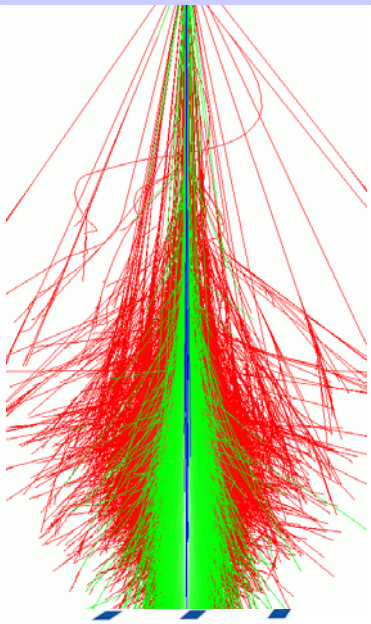
electrons

hadrons

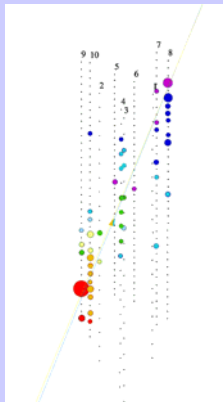
muons

~ MeV - GeV

AMANDA/SPASE ICE-CUBE/ICE-TOP



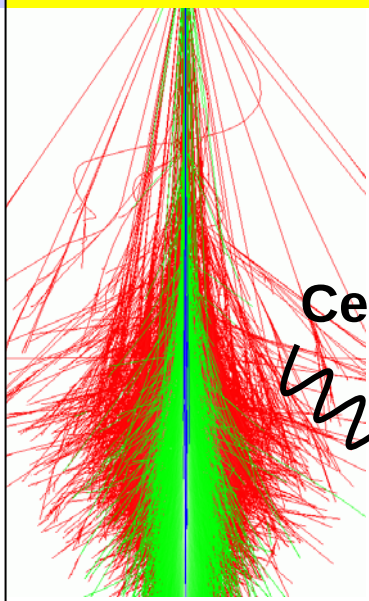
electrons



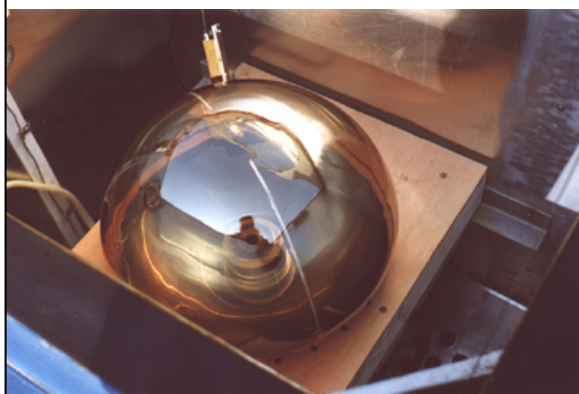
muons

~ TeV

Tunka



Cerenkov light

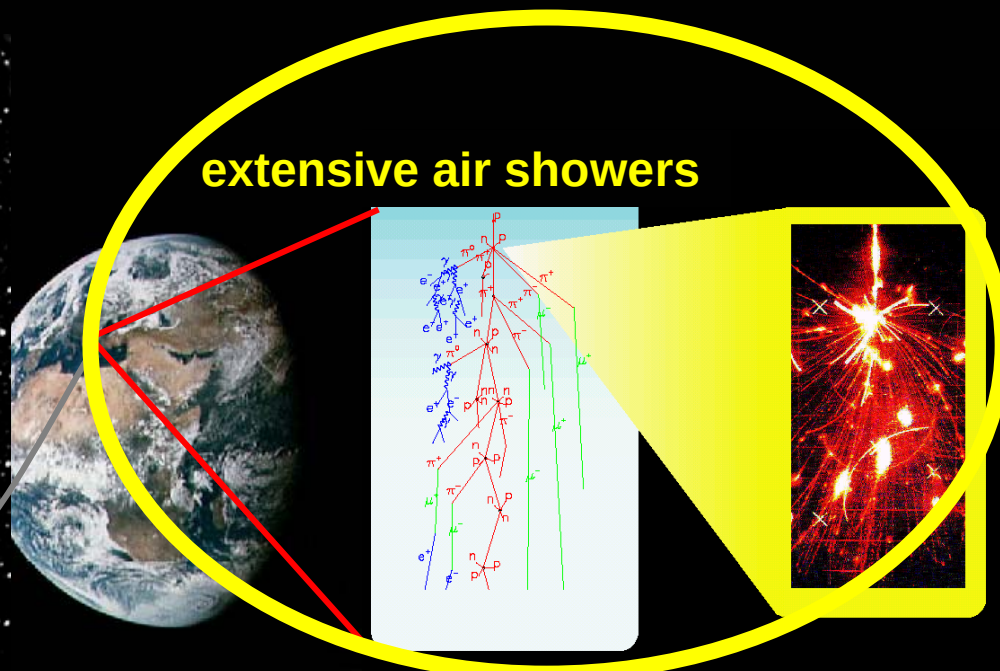


Interactions

acceleration of CR in supernova remnants

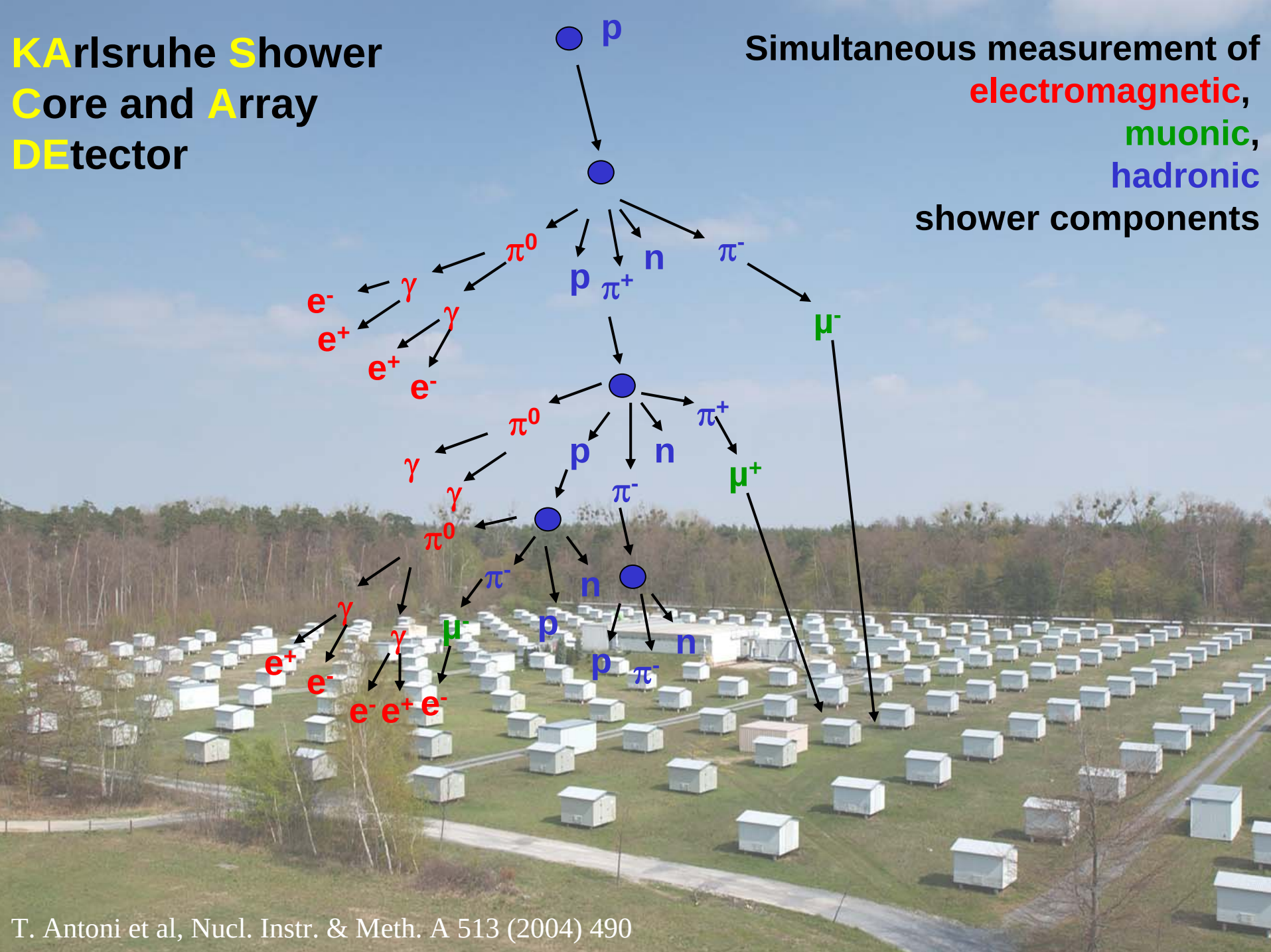
propagation through galaxy

B = 3 μG



KArlsruhe **S**hower
Core and **A**rray
DEtector

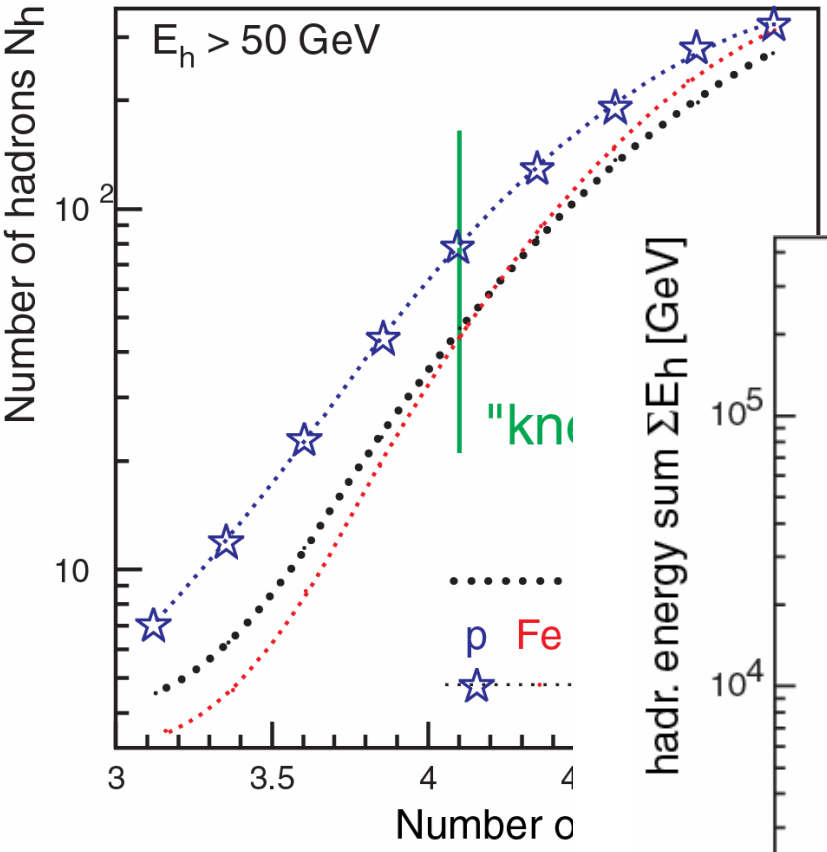
Simultaneous measurement of electromagnetic, muonic, hadronic shower components



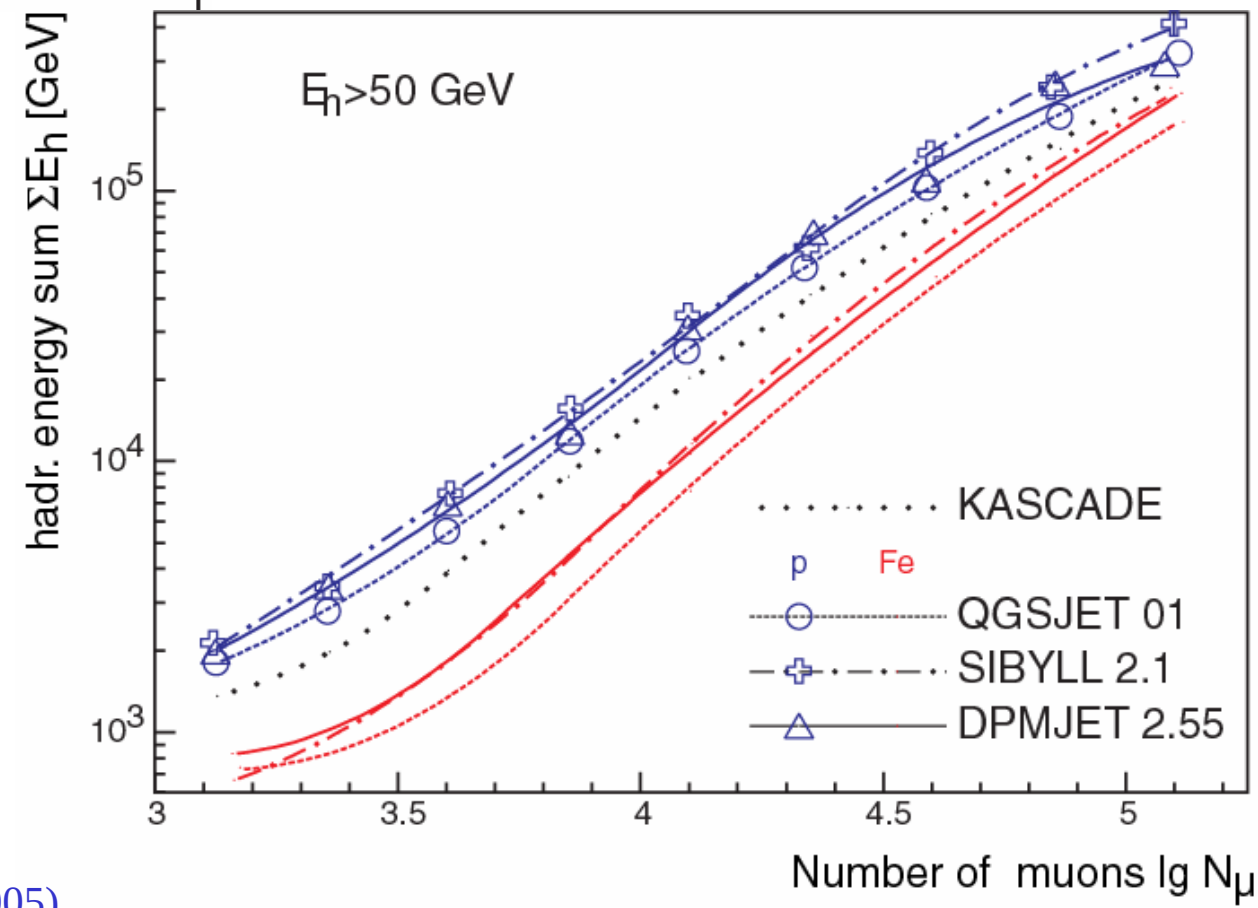
T. Antoni et al, Nucl. Instr. & Meth. A 513 (2004) 490

KASCADE: Test of hadronic interaction models

previously



present

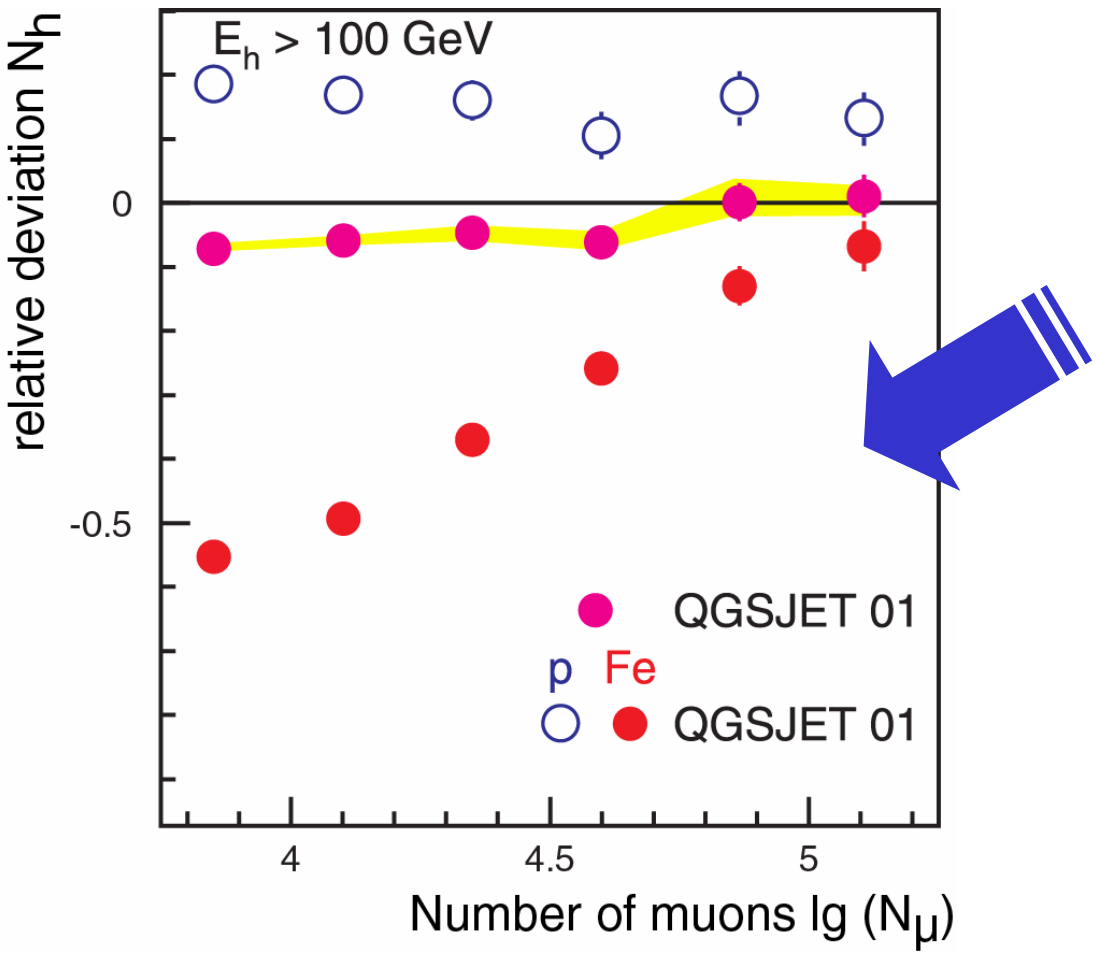


J. Milke et al., 29th ICRC, Pune (2005)

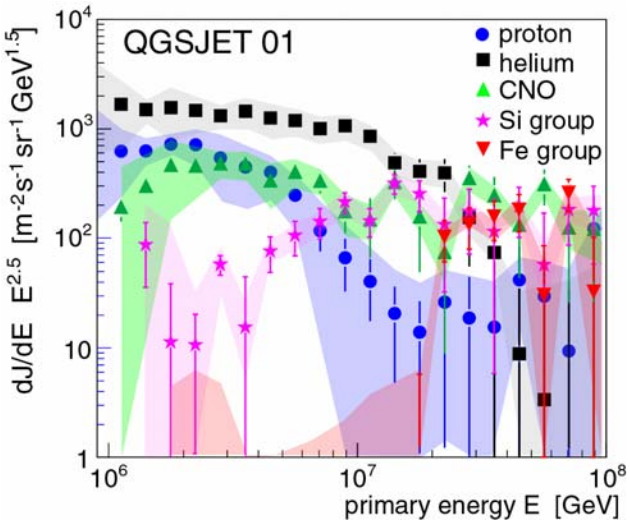
„New“ models with composition

QGSJET 01

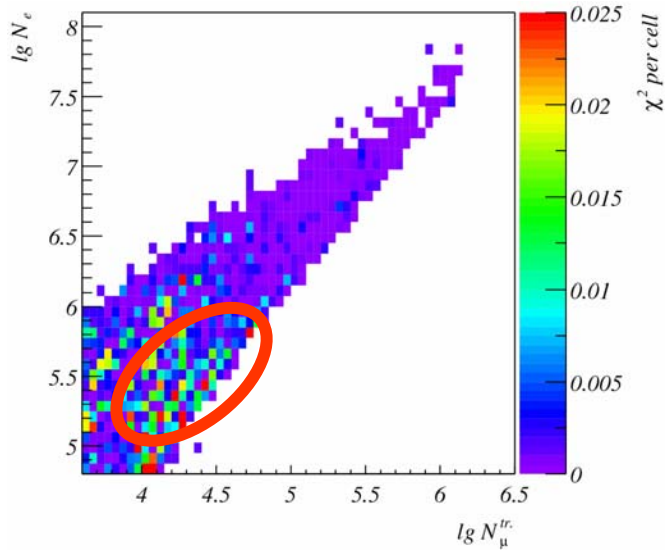
Number of hadrons vs. number of muons



N_e-N_μ analysis



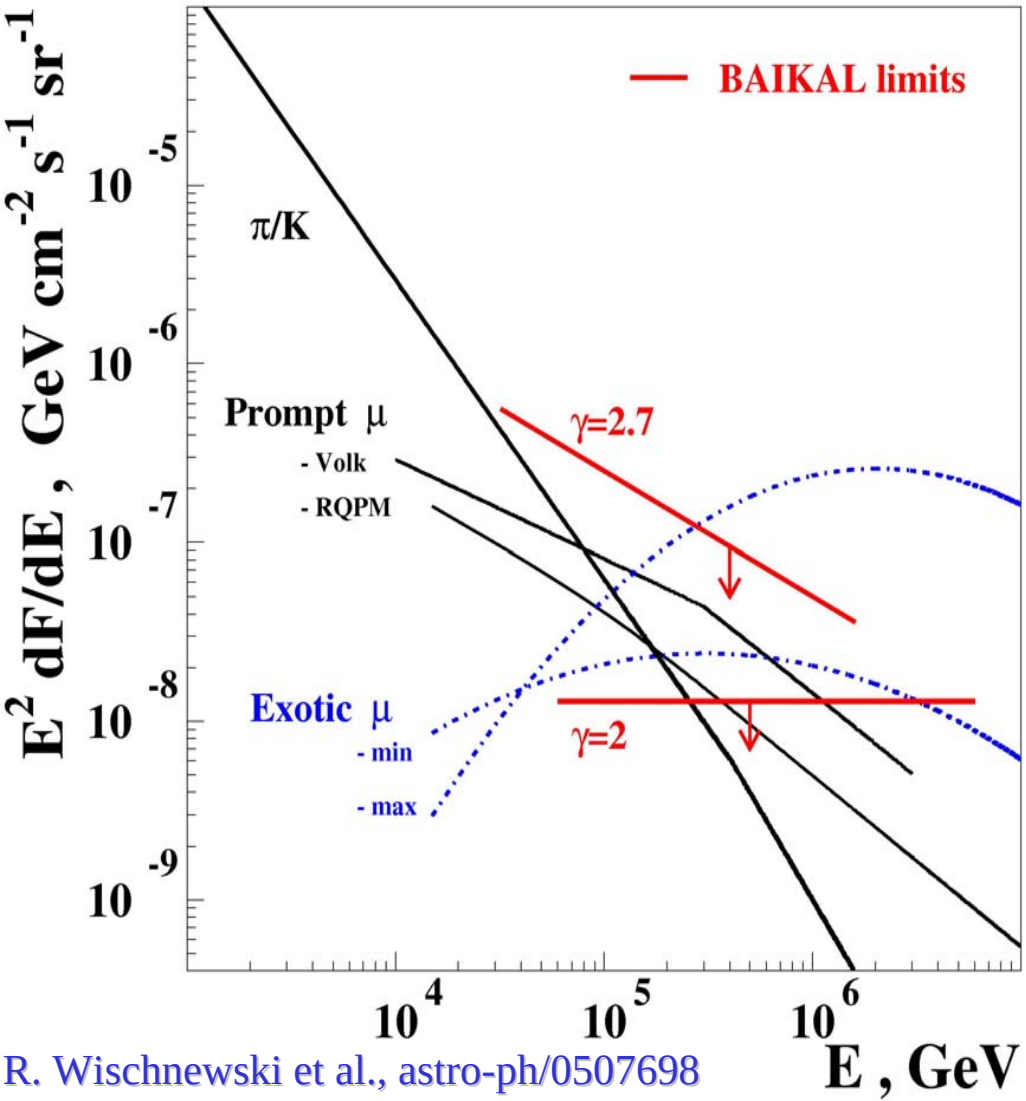
χ^2 distribution



J. Milke et al., 29th ICRC, Pune (2005)

Baikal - Limits on HE Muon Flux : Exotic Muons

Flux prediction and flux limits



R. Wischnewski et al., astro-ph/0507698

Use the *high energy cascade sample* to test various HE muon and/or neutrino signal spectra.

Testing the predicted "Exotic Muon Component" (Petrukhin 1999, 2002) , postulated to explain the CR-knee by the onset of "new physics" at E_{thr}~1 PeV, that pumps EAS energy to exotic muons.

The limit for E^{-2} spectrum (γ=2) shows the model rejection power !

A detailed limit calculation for exotic μ "predictions" is in progress.

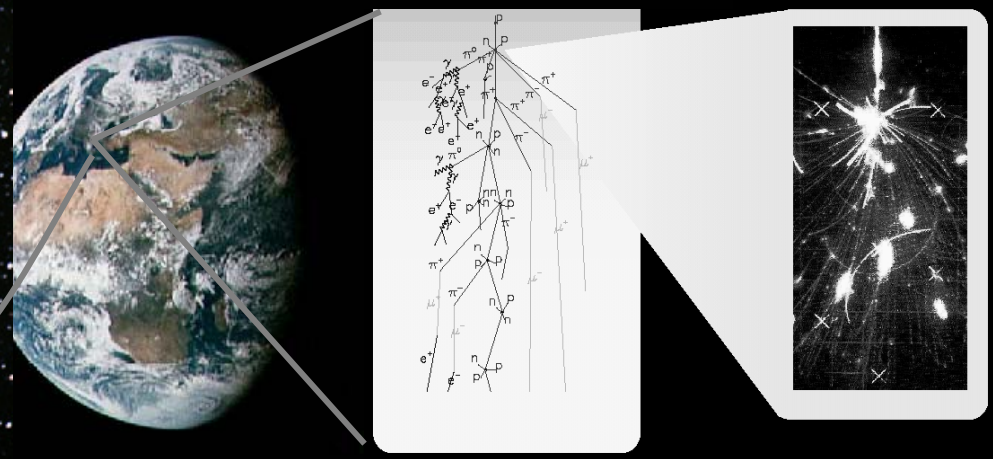
acceleration of CR in supernova remnants

Sources

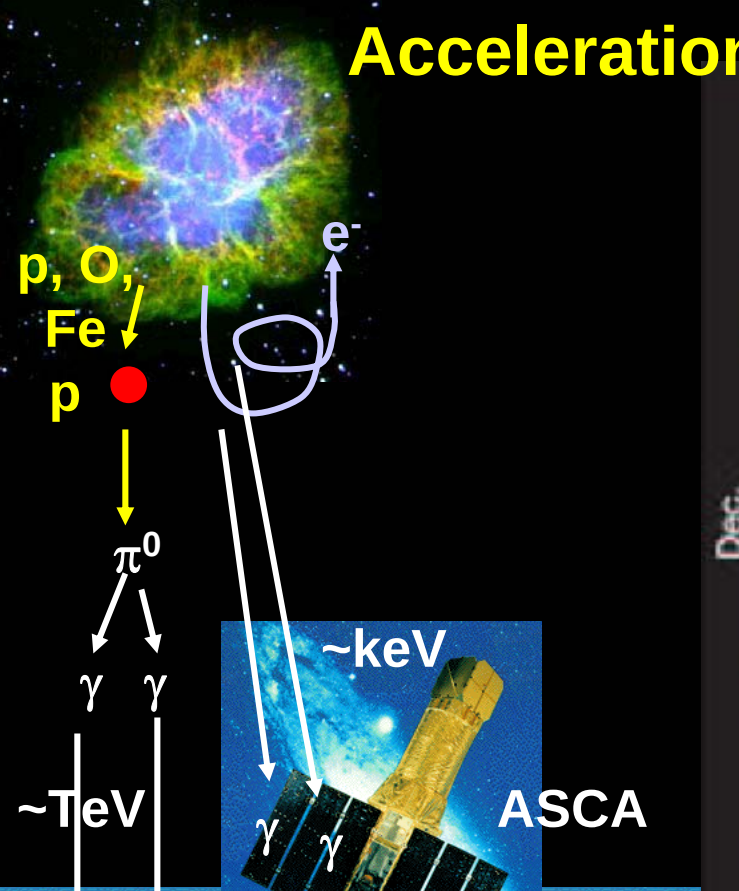
propagation through galaxy

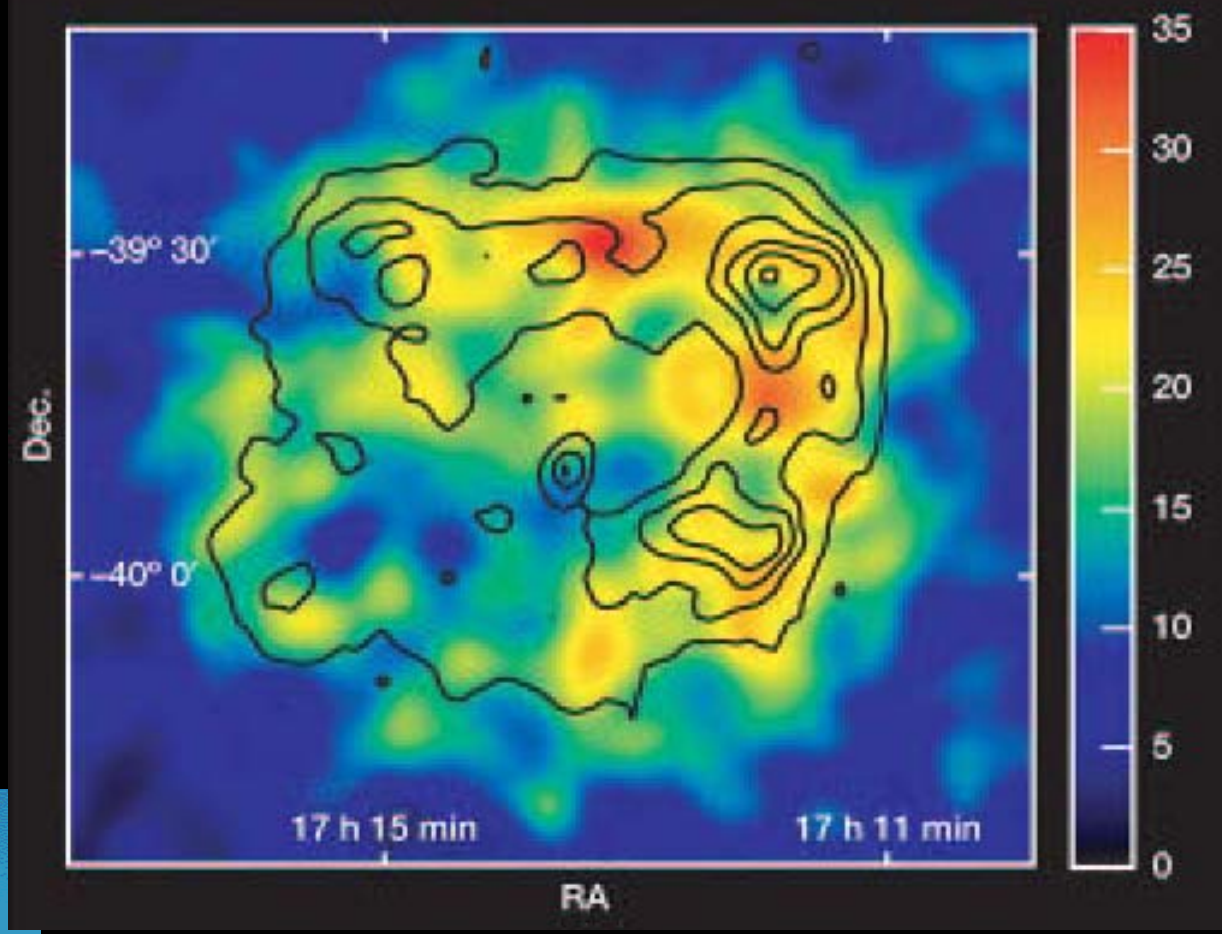
B = 3 μG

extensive air showers



Acceleration of particles in supernova remnant

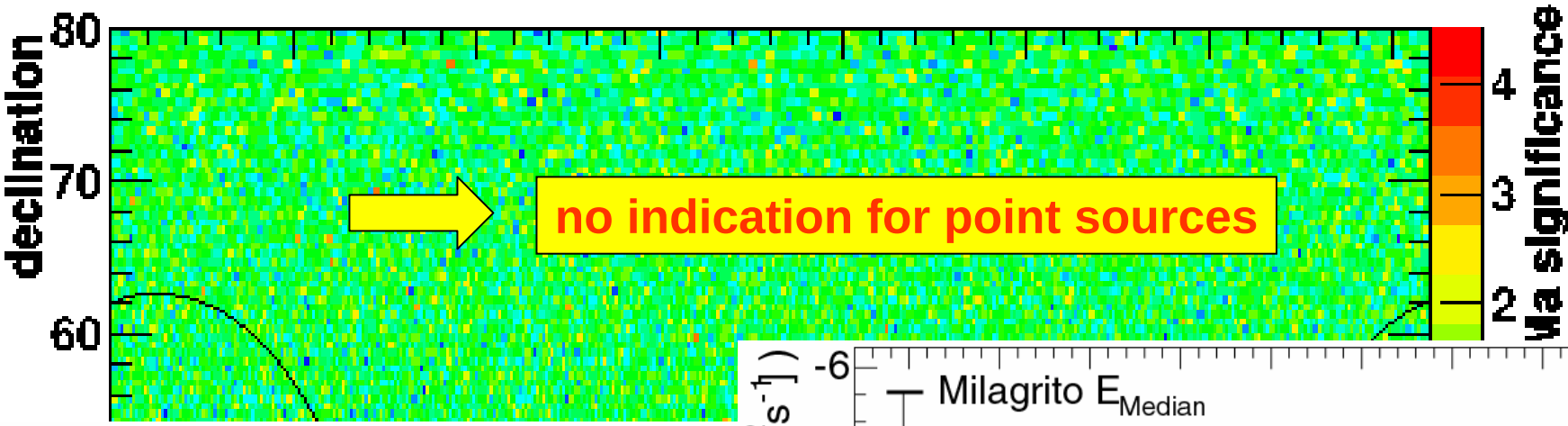


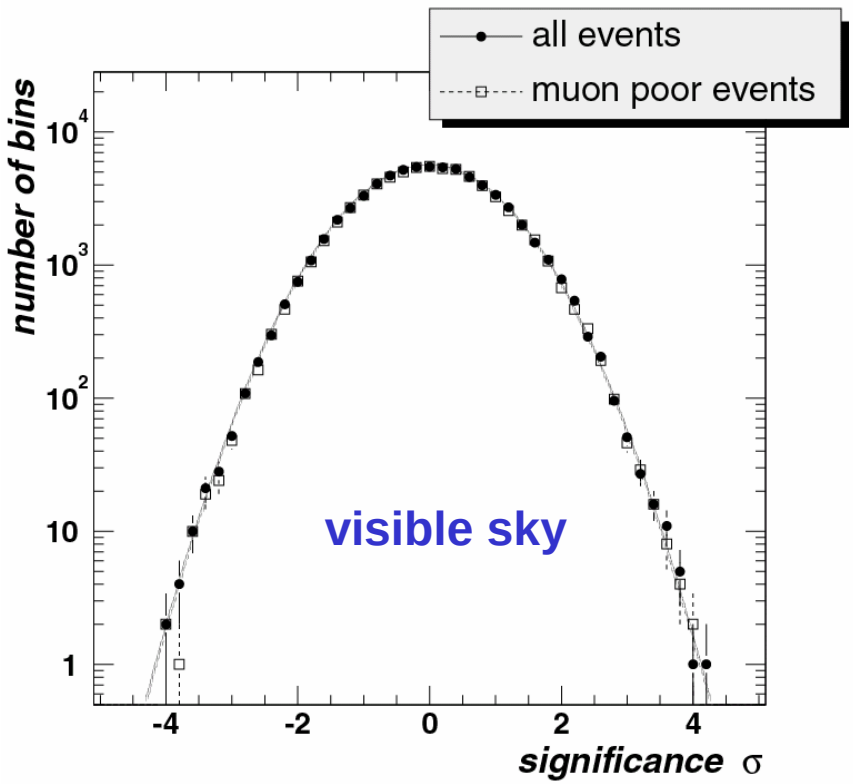


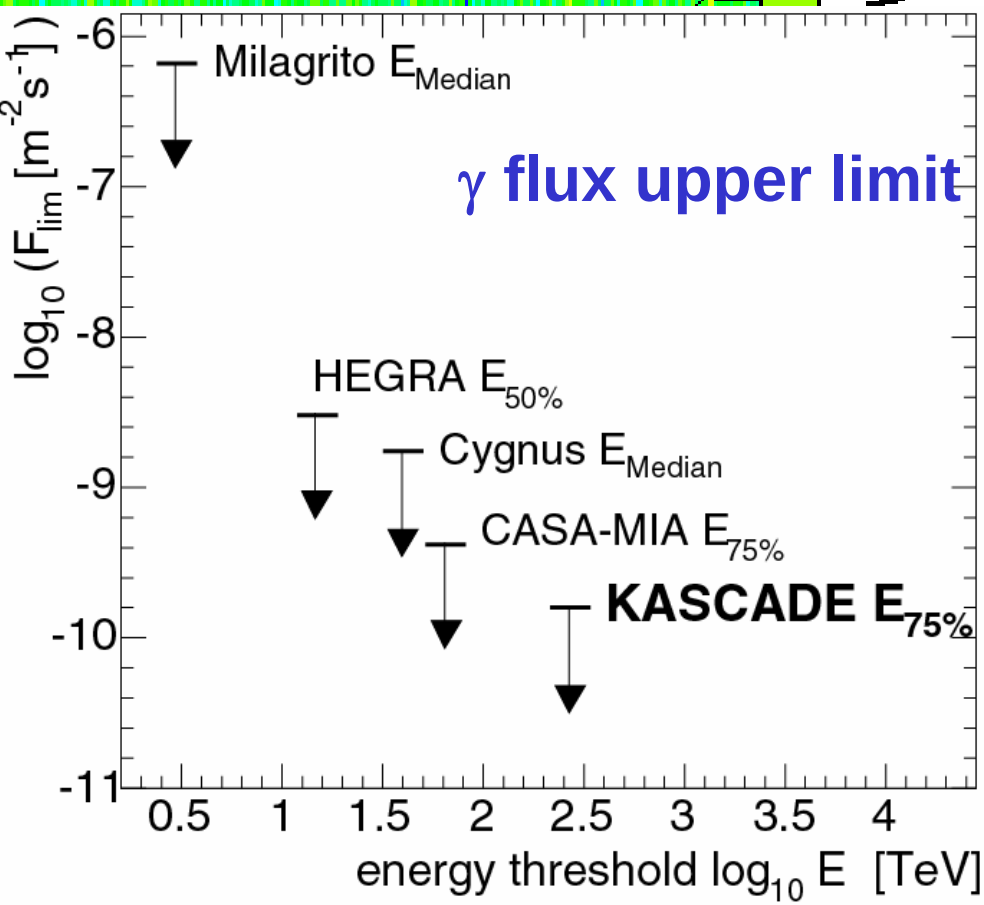
SN R RX J1713.7-3946
H.E.S.S.: TeV-Gamma rays
ASCA: X-rays (keV)

F.A. Aharonian, Nature 432 (2004) 75

KASCADE: Small scale anisotropy – point source search







T. Antoni et al., ApJ 608 (2004) 865

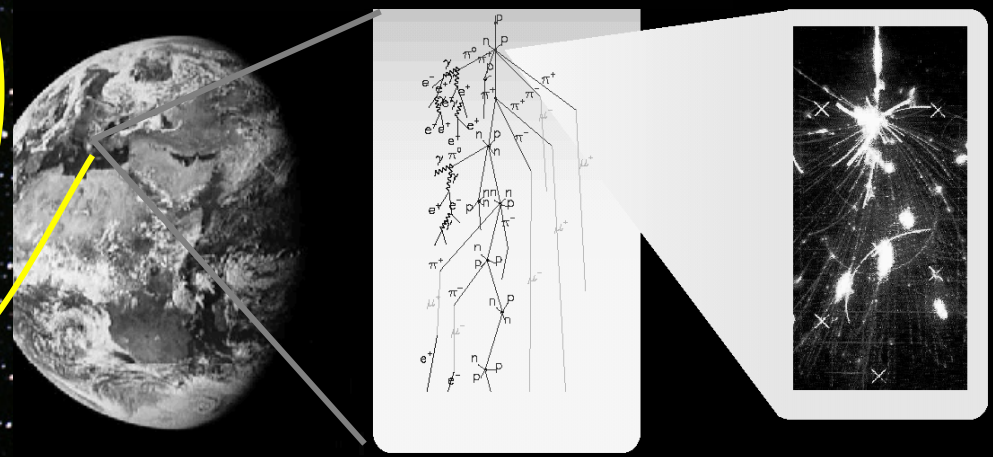
Propagation

acceleration of CR in supernova remnants

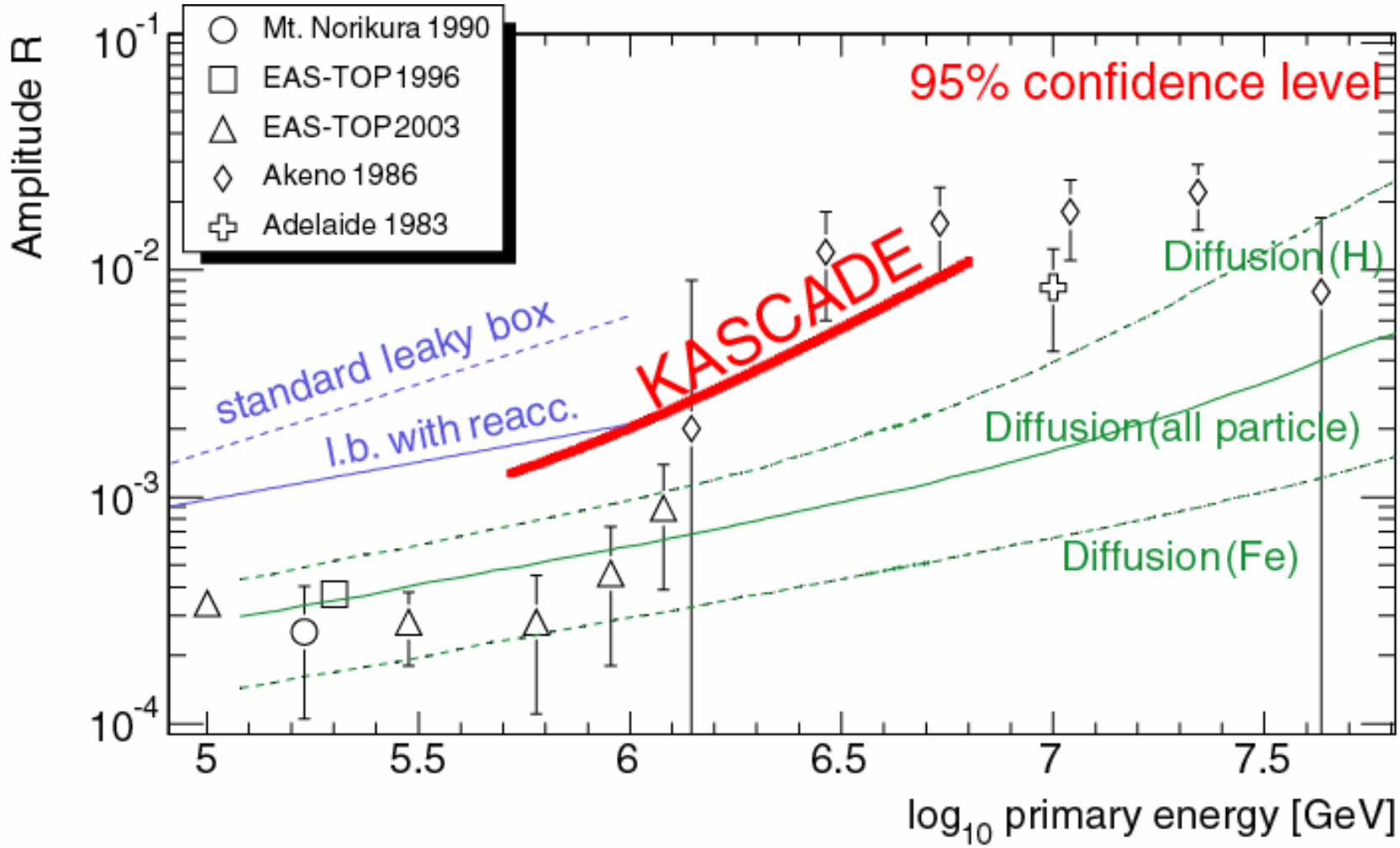
propagation through galaxy

B = 3 μG

extensive air showers



Anisotropy amplitude vs energy

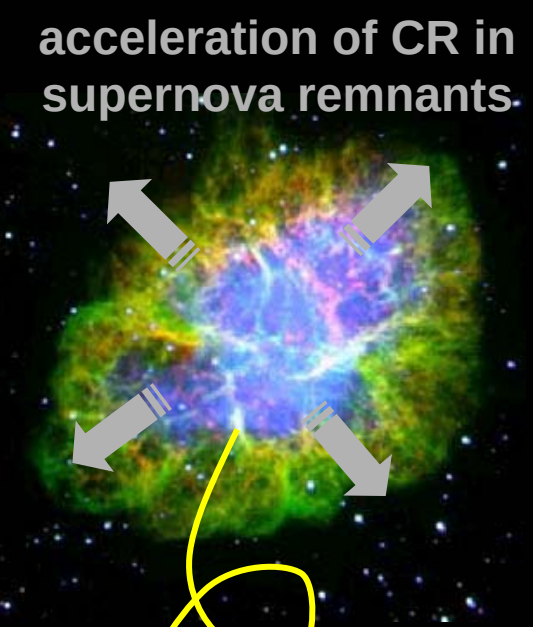


Rayleigh vector $$\left|\vec{R}\right| = \left(\frac{2}{n}\sum_{i=1}^{n}\sin\alpha_i\right)^2 + \left(\frac{2}{n}\sum_{i=1}^{n}\cos\alpha_i\right)^2$$

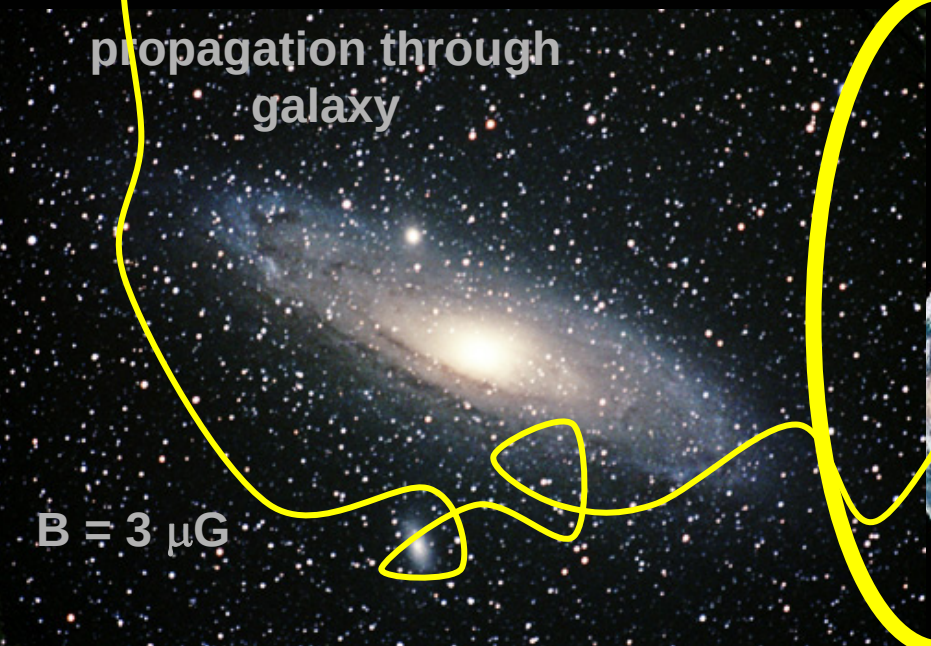
T. Antoni et al, ApJ 604 (2004) 687

Energy spectra & Mass composition

acceleration of CR in supernova remnants



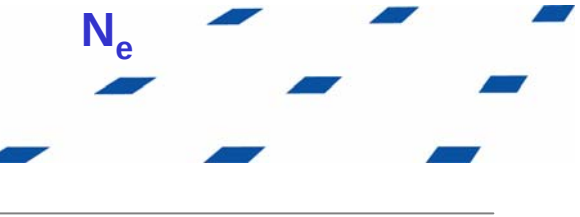
propagation through galaxy

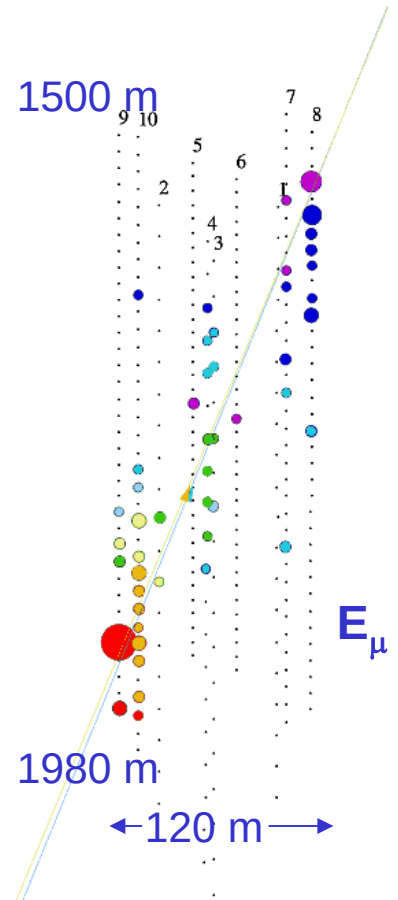


B = 3 μG

extensive air showers

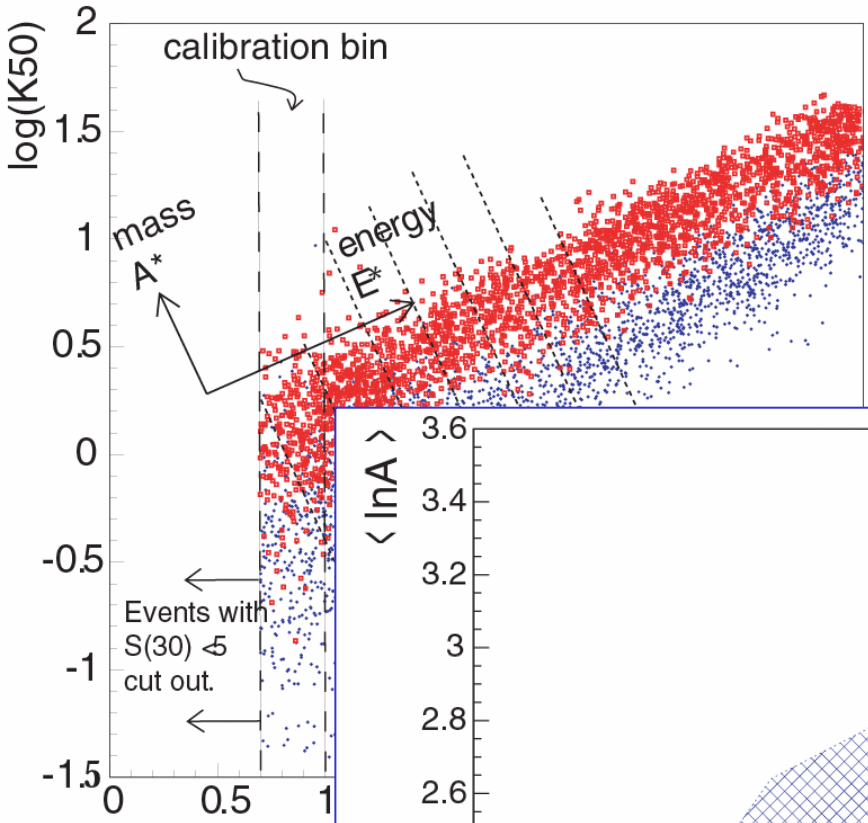
SPASE-2 / AMANDA-B10 (South Pole)

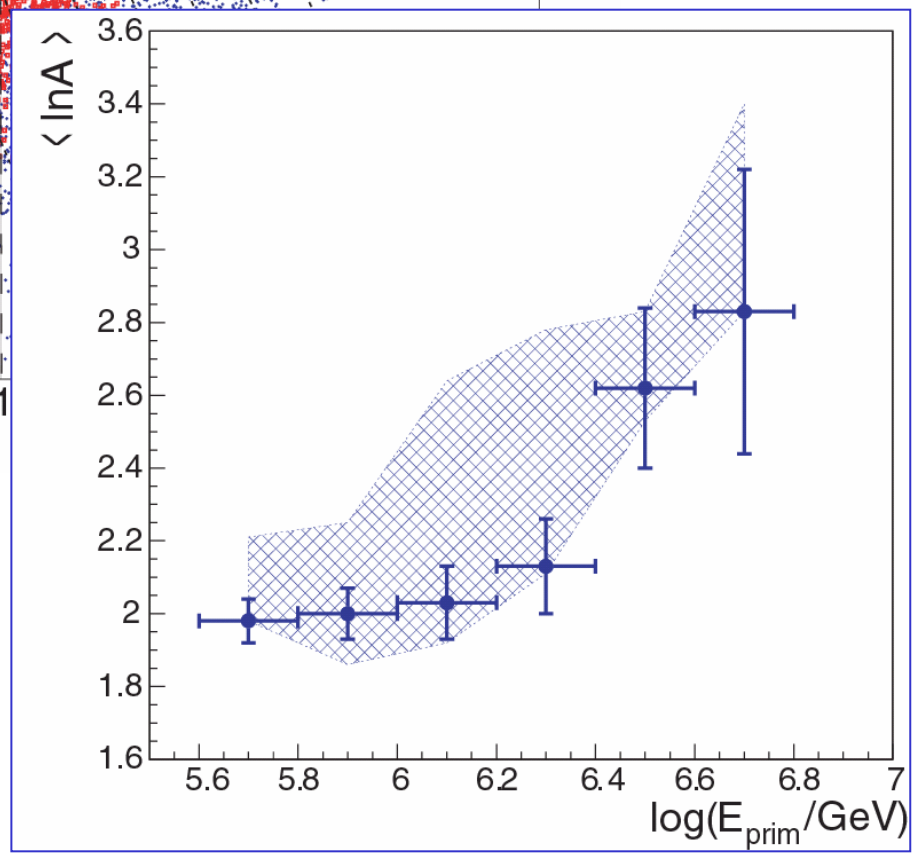




E_μ > 300 GeV

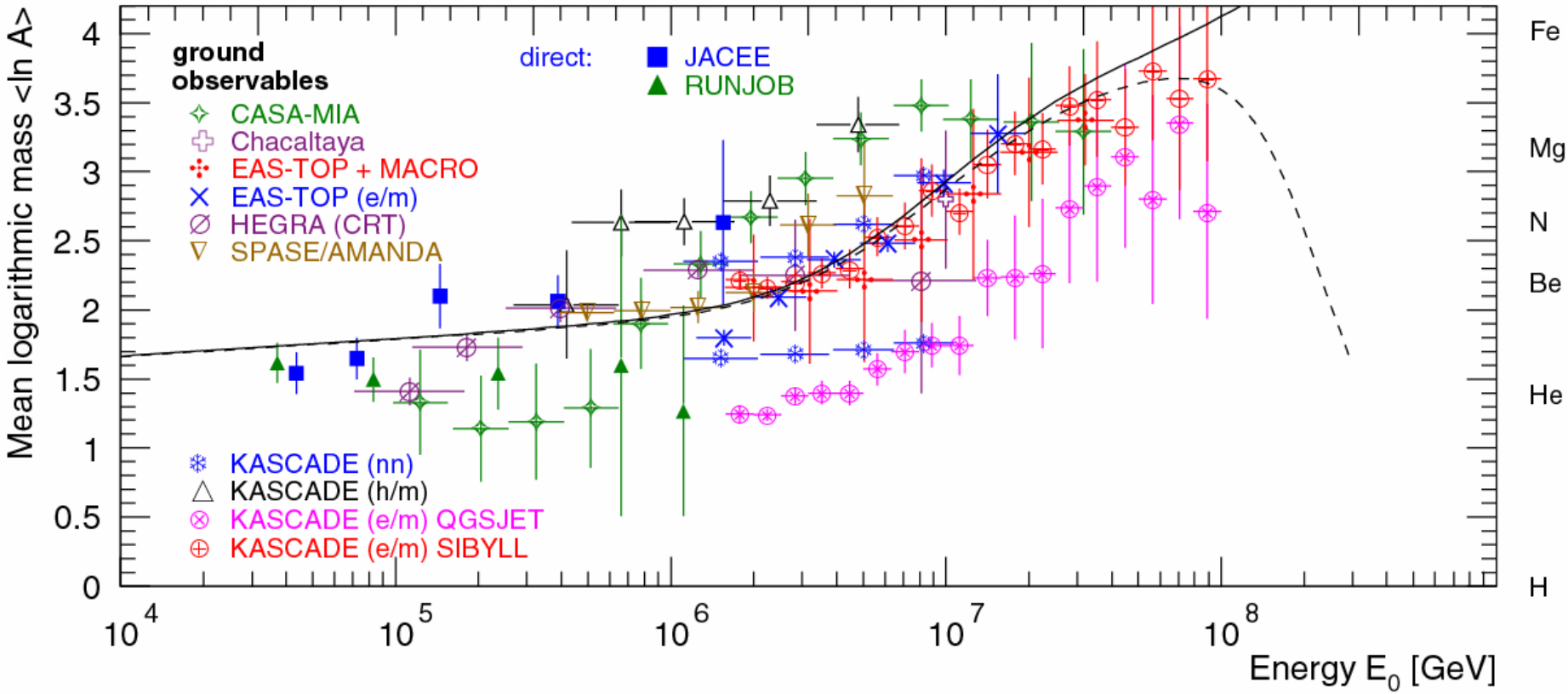
E_μ





Rawlins et al, Proc. 28th ICRC, Tsukuba 1 (2003) 173

Mean logarithmic mass



$$< \ln A >= \sum r_i * \ln A_i$$

JRH astro-ph/0508014

Tunka - 25

Light intensity

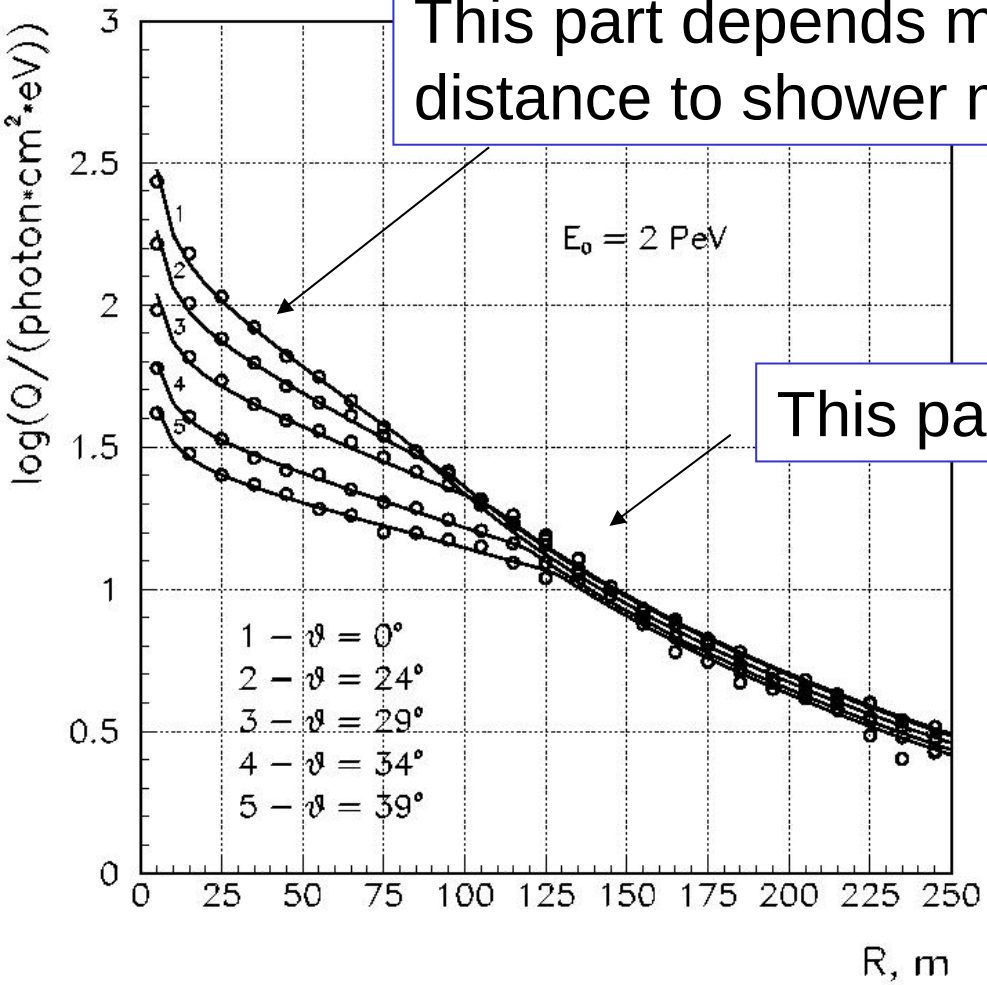
Corsika,2000 m

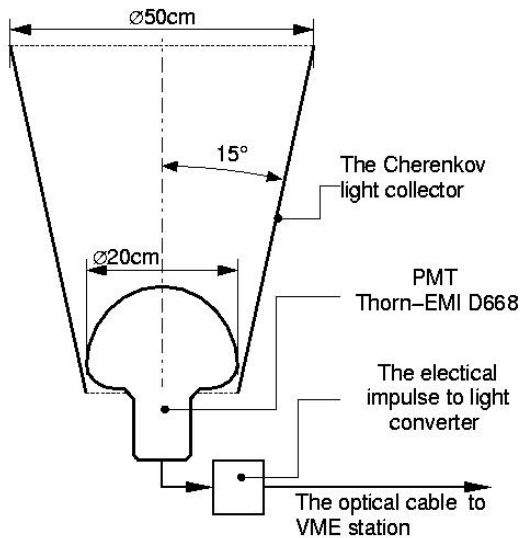
This part depends mainly on distance to shower maximum

E = 2 PeV

up to $\mathcal{R}$ ~ 30 m: exponential

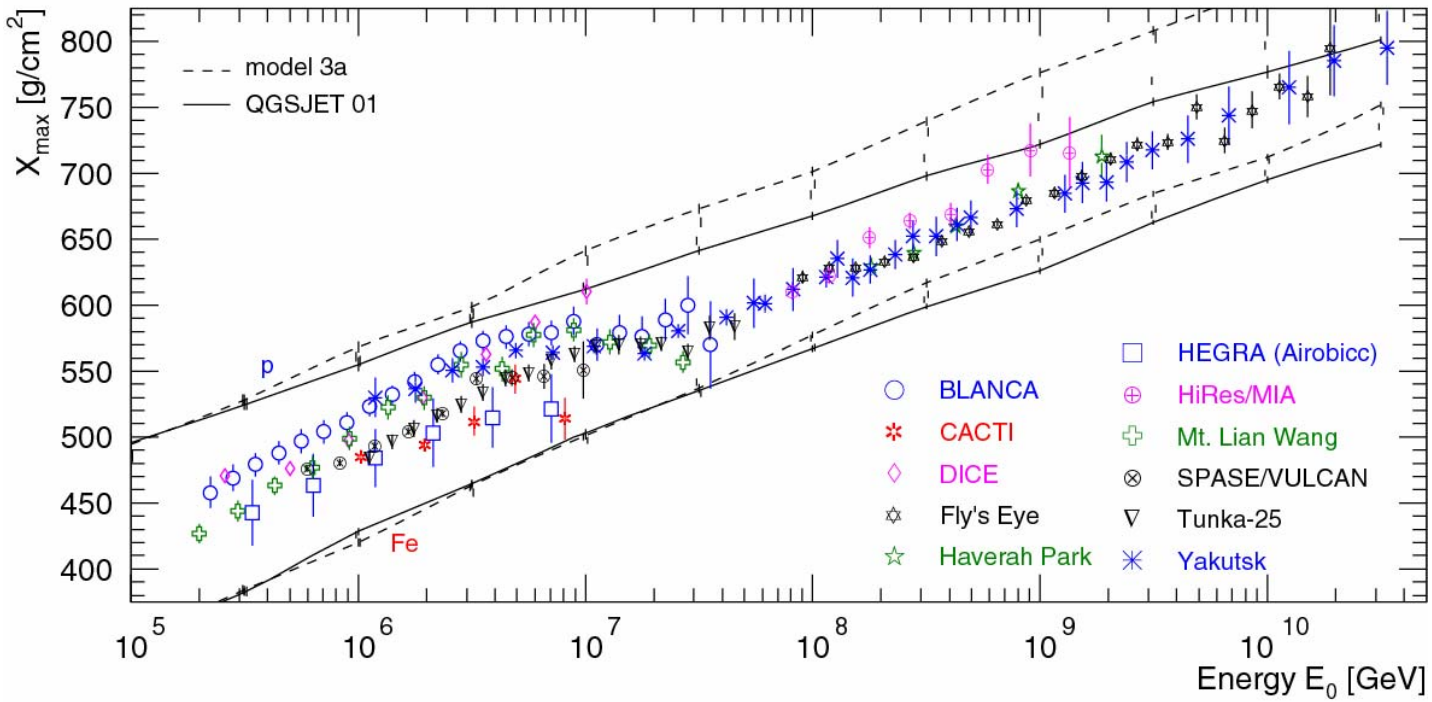
This part depends mainly on energy



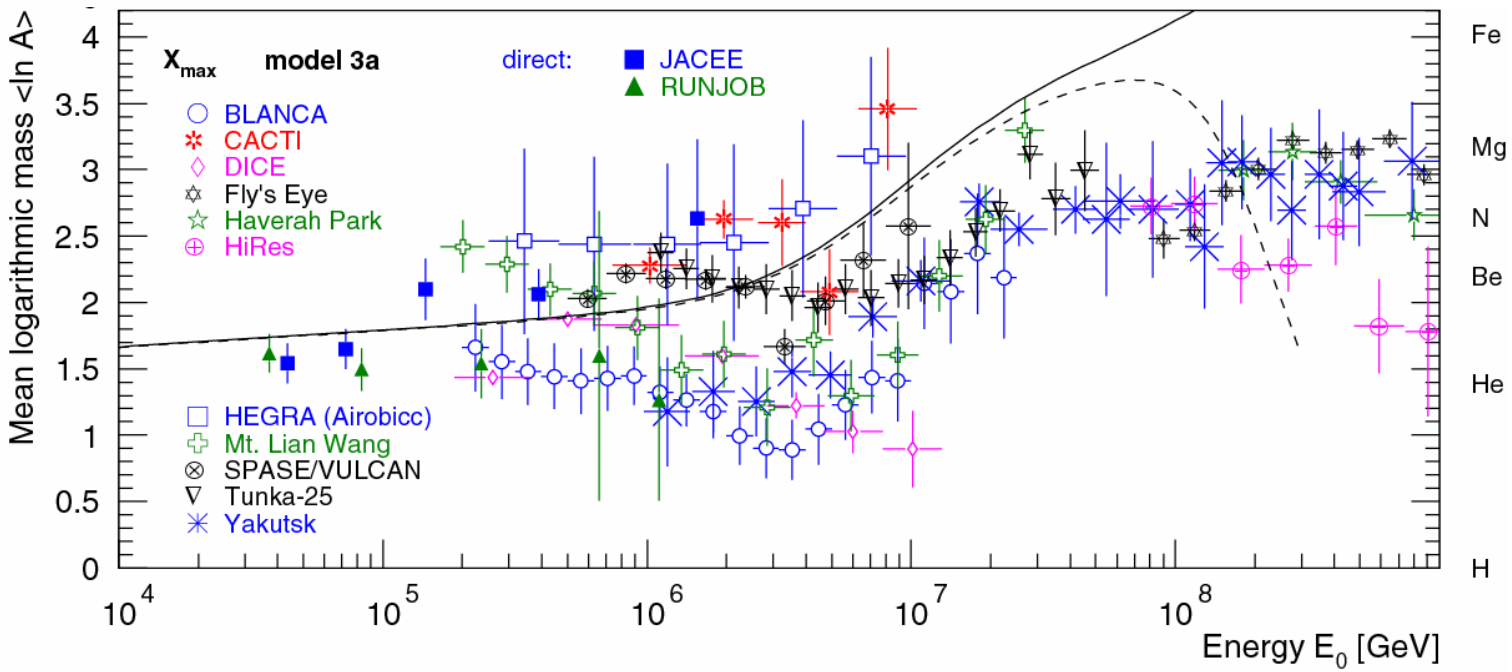


Ch. Spiering, DPG 2005

X_{max}



<lnA>

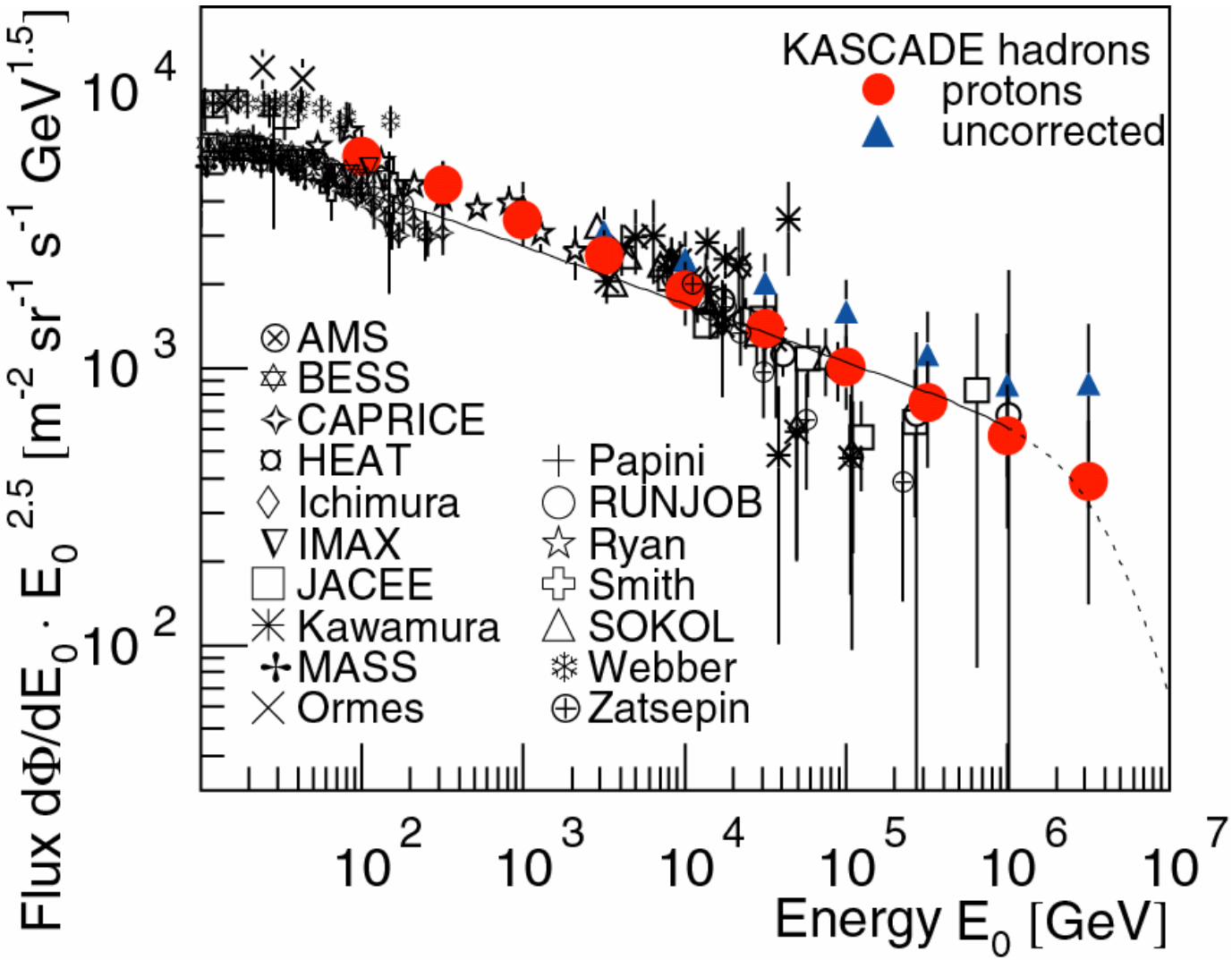


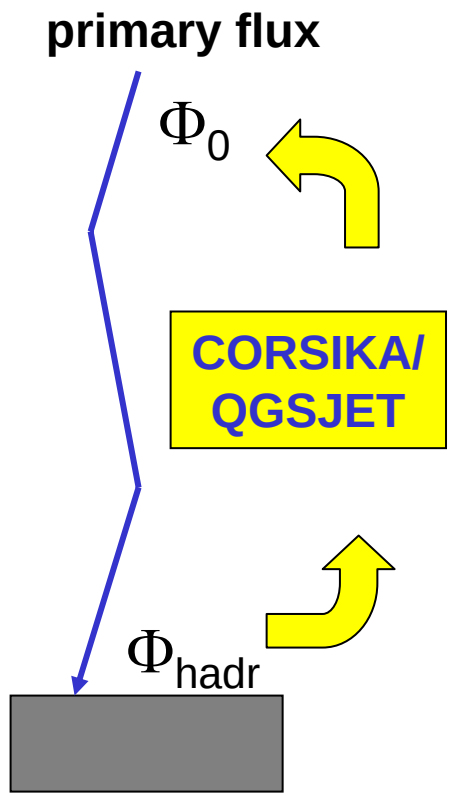
JRH astro-ph/0508014

J. Phys. G, 29 (2003) 2439

KASCADE: Primary proton spectrum

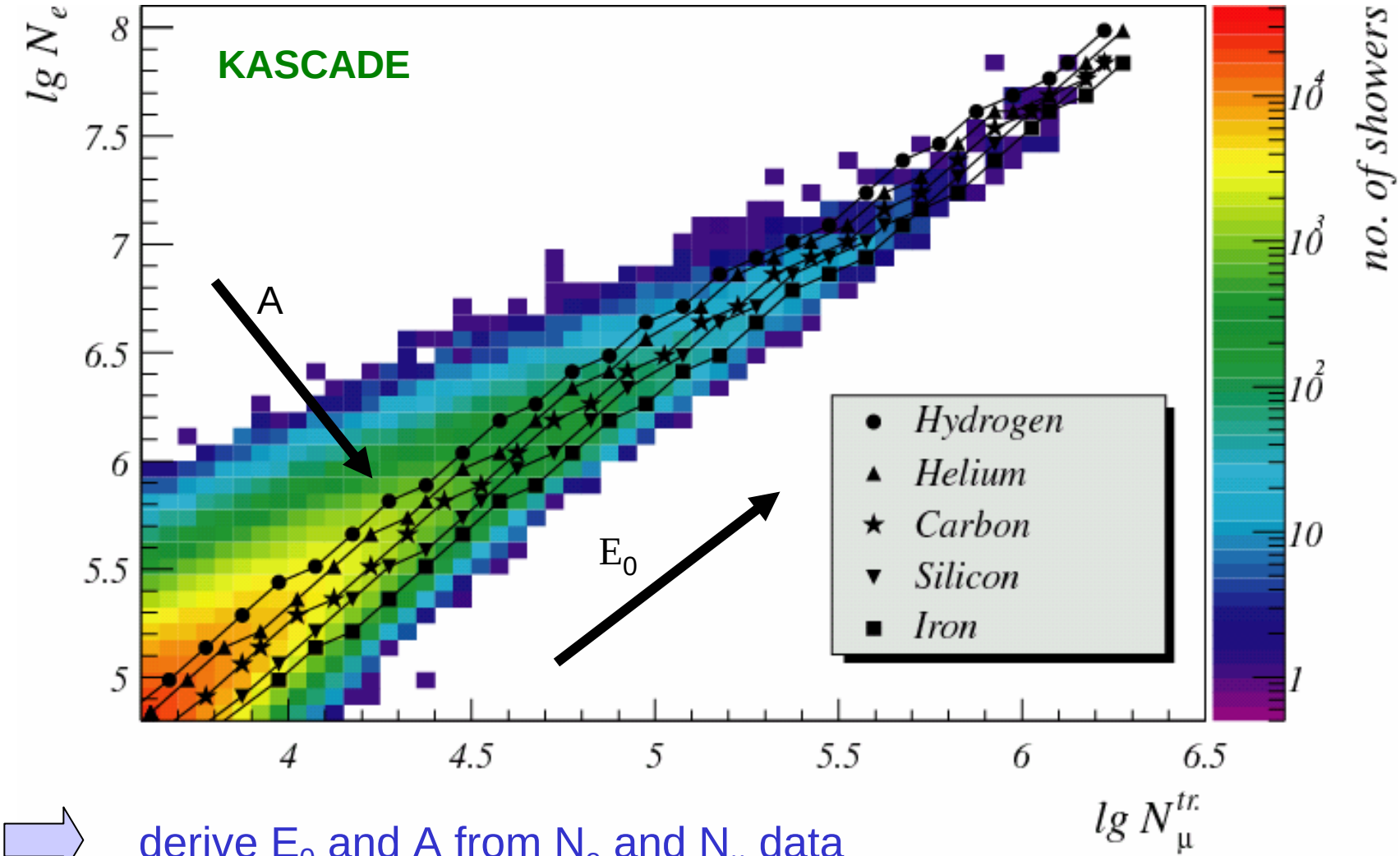
reconstructed from unaccompanied hadrons





T. Antoni et al, ApJ 612 (2004) 914

Two dimensional shower size spectrum lg N_e vs. lg N_μ



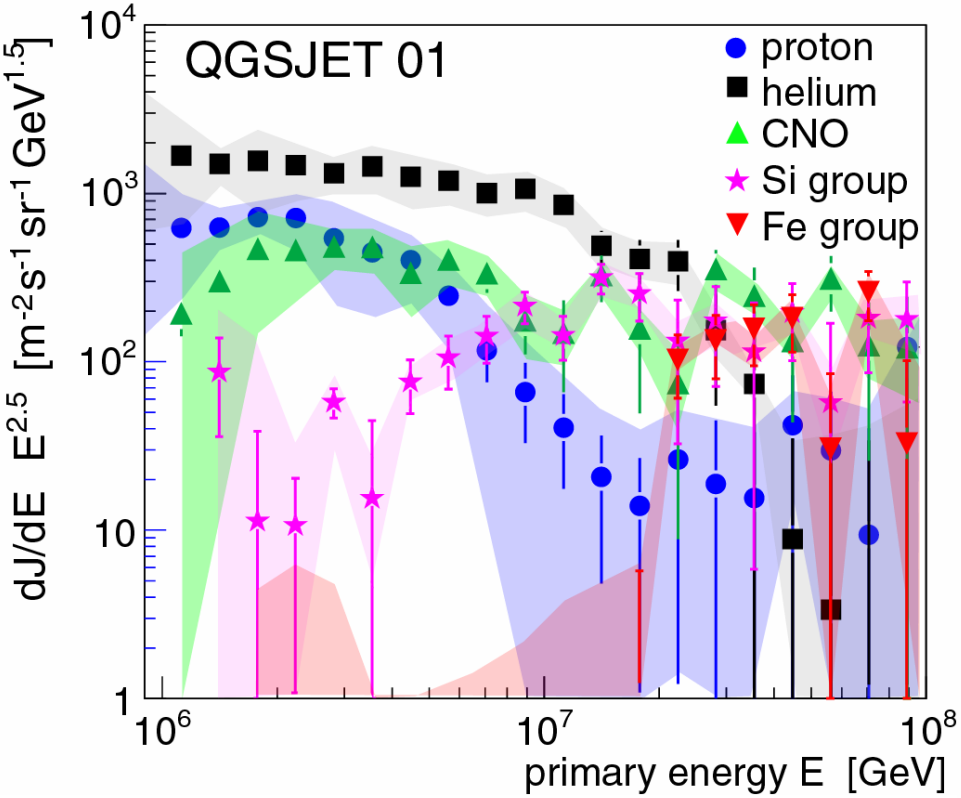
derive E_0 and A from N_e and N_μ data

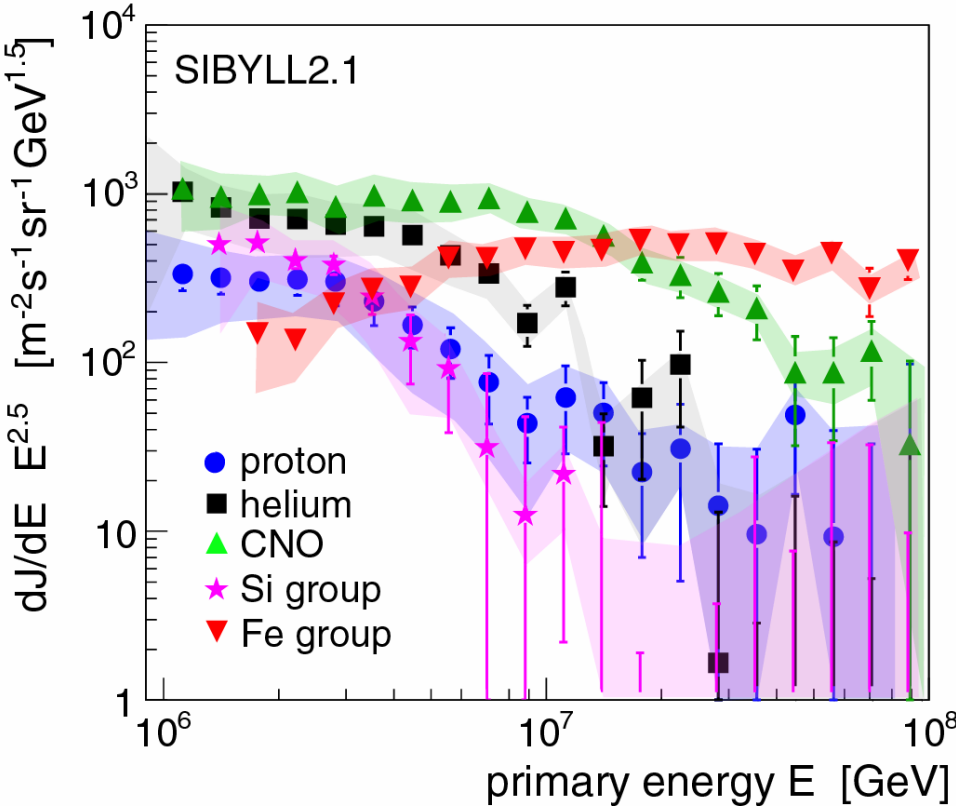
Fredholm integral equations of 1st kind:

$$g_i(\lg N_e, \lg N_\mu) = \int_0^\infty t_i(\lg N_e, \lg N_\mu \mid E)\, p_i(E)\, dE$$

T. Antoni et al., Astropart. Phys. 24 (2005) 1

KASCADE: Energy spectra for elemental groups

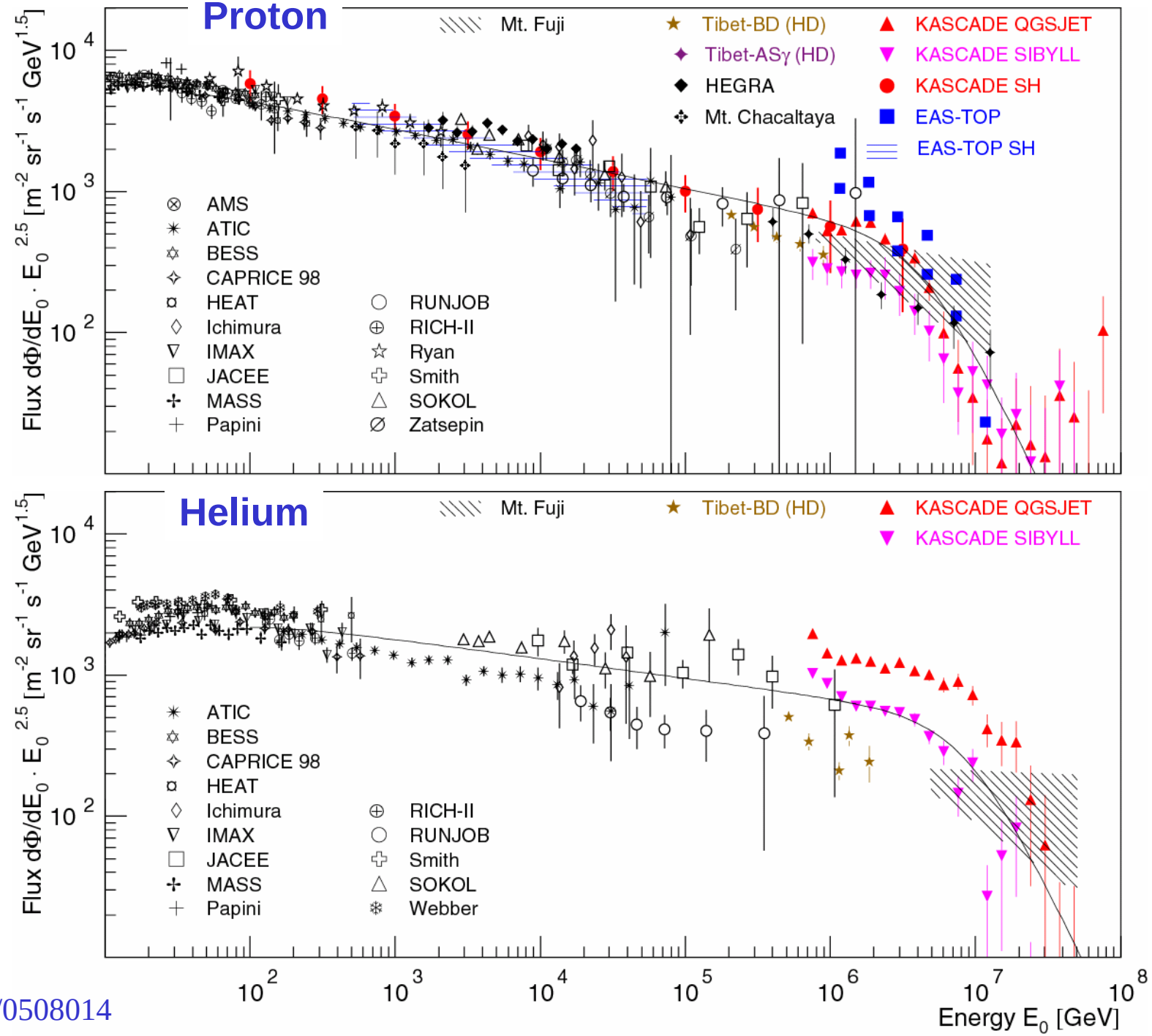




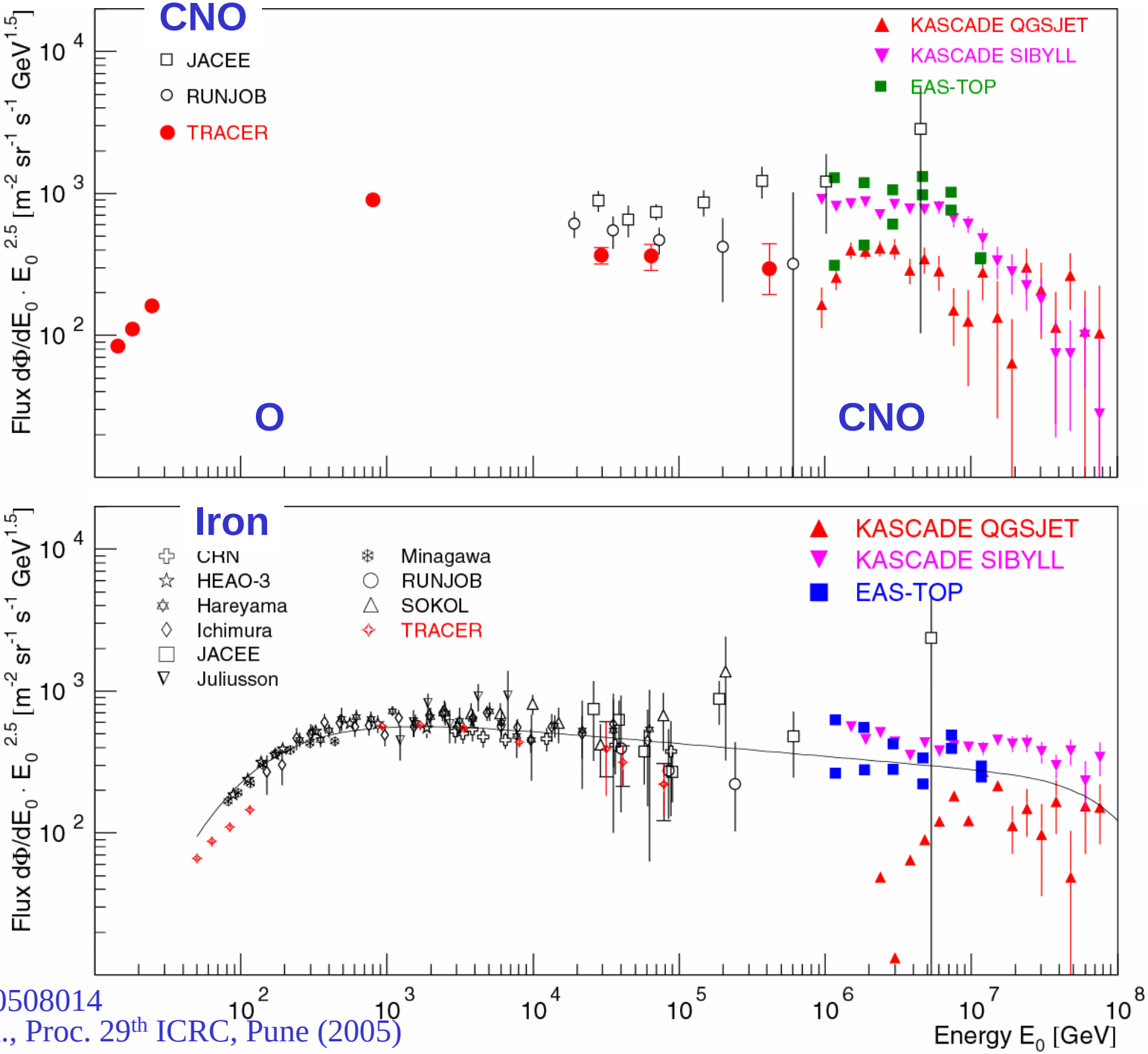
Knee caused by cut-off for light elements

Astrophysical interpretation limited by description of interactions in the atmosphere

T. Antoni et al., Astropart. Phys. 24 (2005) 1



JRH astro-ph/0508014



JRH astro-ph/0508014
D. Müller et al., Proc. 29th ICRC, Pune (2005)

Kosmische Strahlung am Knie

Status
und
Perspektiven

Jörg R. Hörandel
Universität Karlsruhe

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KASCADE GRANDE Array

37 detector stations

370 m^2 e/γ: Scintillation counter

ASCADE

0 m x 200 m

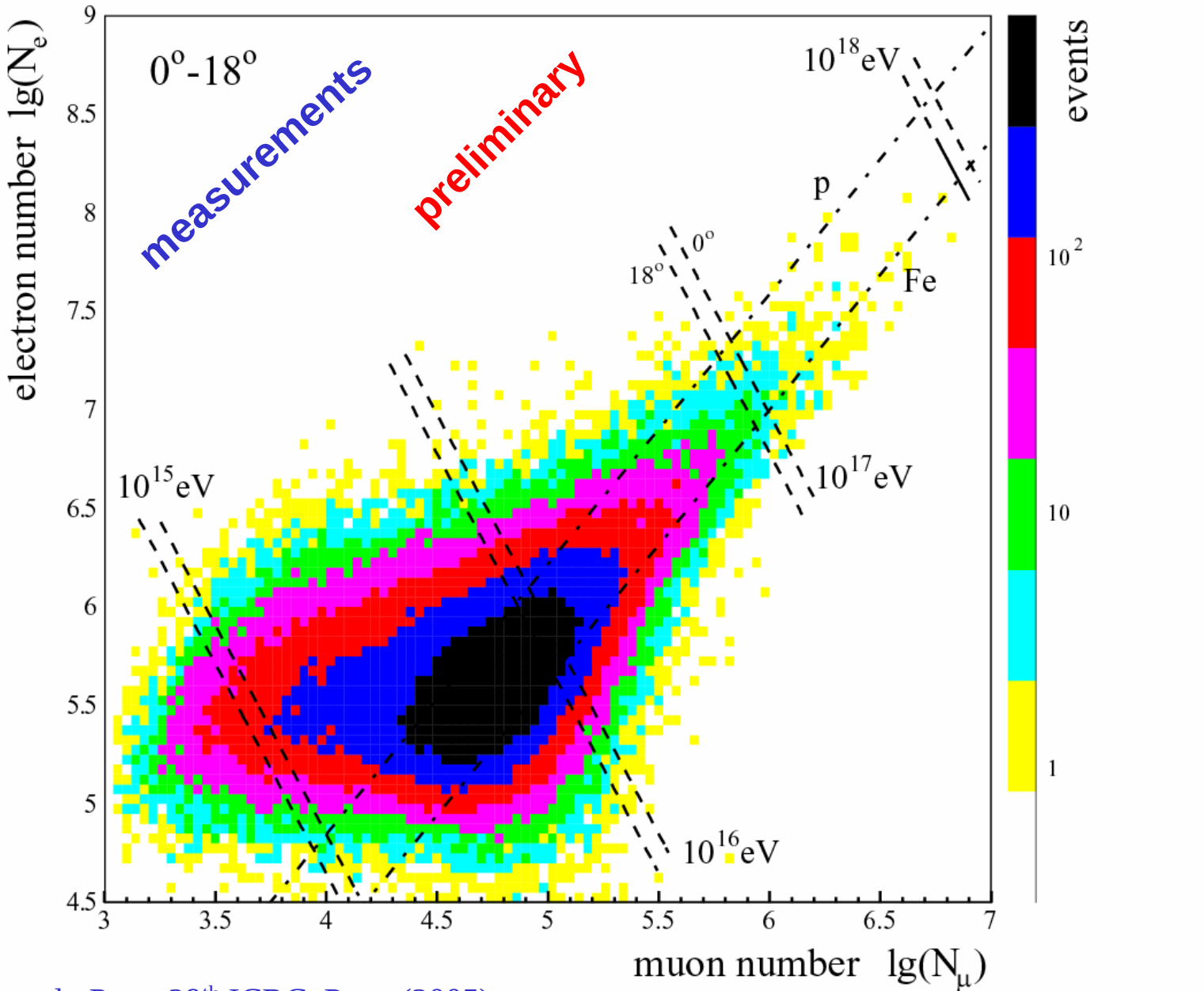
700 m

700 m

Installation of FADC system in progress

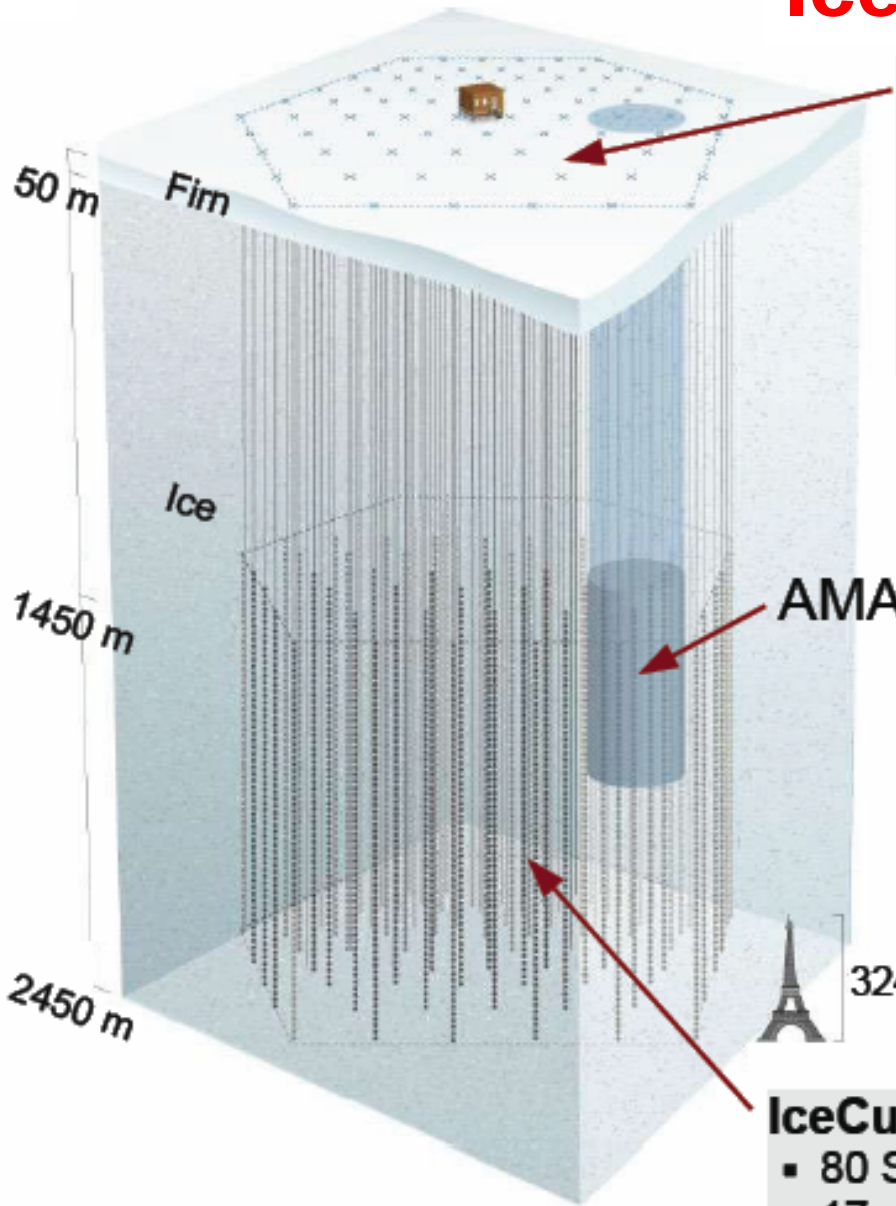
G. Navarra et al., Nucl Instr & Meth A 518 (2004) 207

KASCADE-Grande – N_e-N_μ correlation



R. Glasstetter et al., Proc. 29th ICRC, Pune (2005)

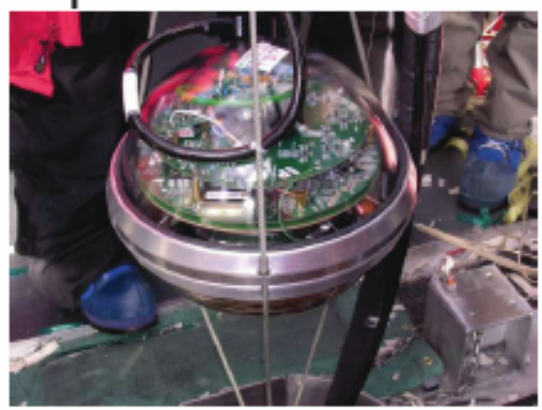
Ice Cube/Ice Top



IceTop: air shower array

- 80 Stations / 2 Tanks each
- 2 DOMs each per tank
- 125 m grid, 1 km^2 at 690 g/cm^2
- E_{thres} ~ 300 TeV for ≥ 4 stations
- Useful rate up to ~EeV

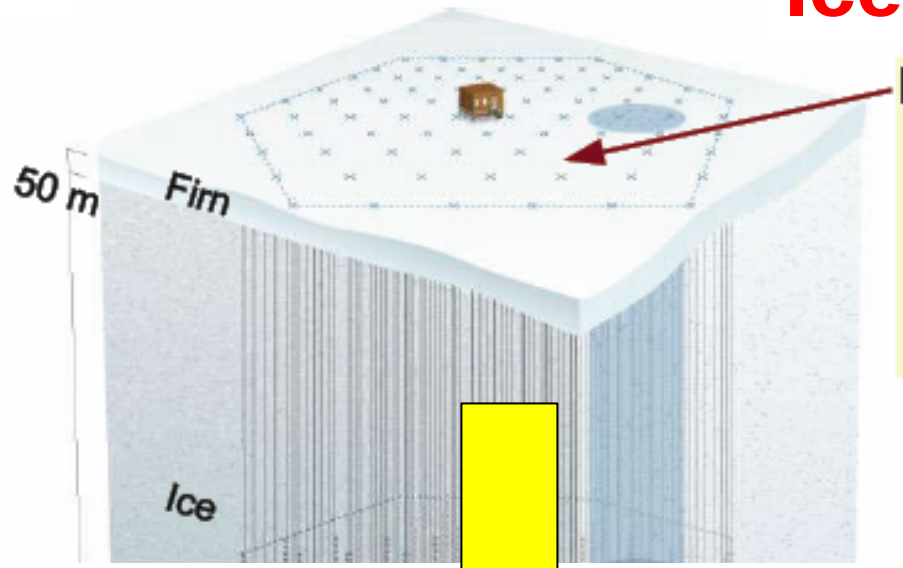
Digital **O**ptical **M**odule



IceCube: deep ice array

- 80 Strings / 60 DOMs each
- 17 m DOM spacing
- 125 m between strings
- 1 km^3 instrumented

Ice Cube/Ice Top



IceTop: air shower array

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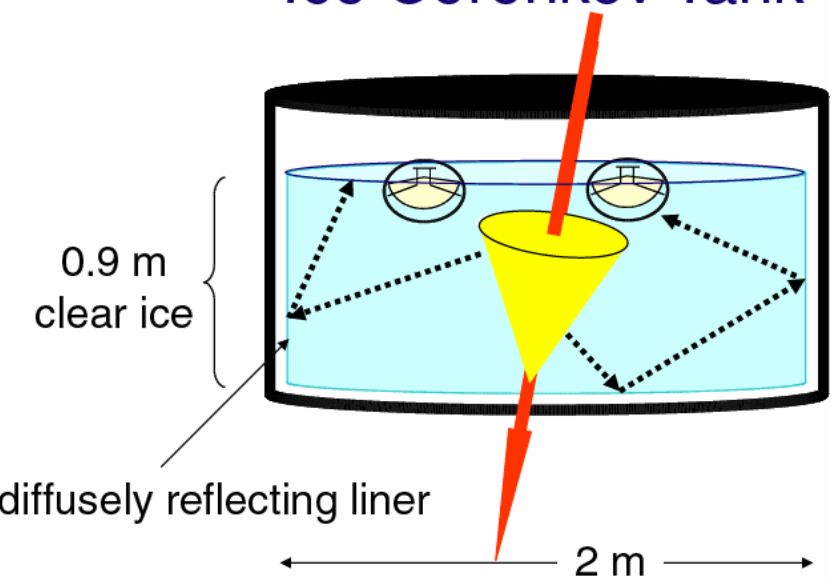
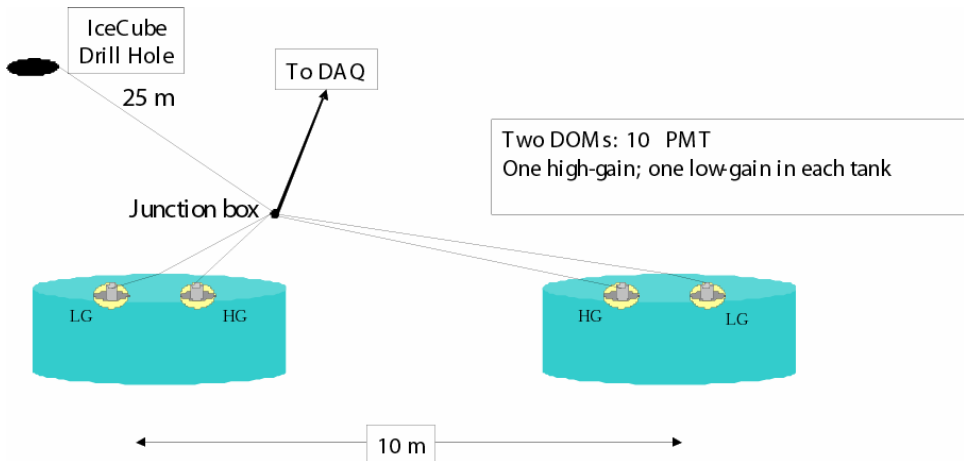
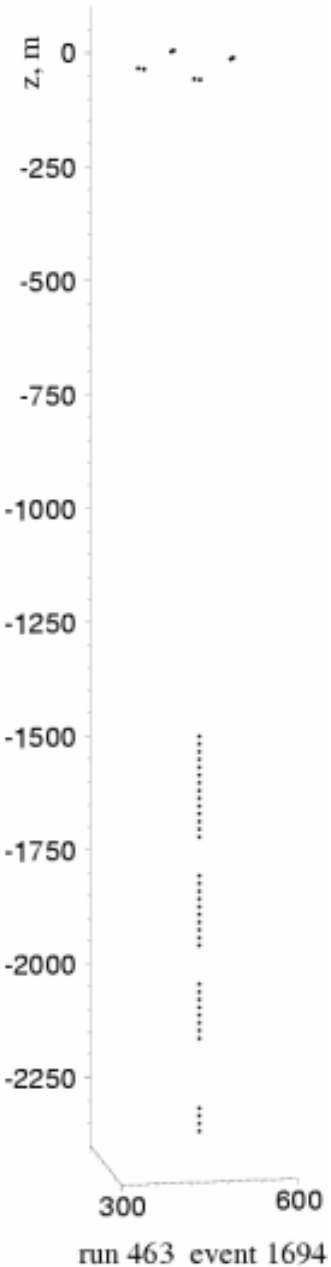
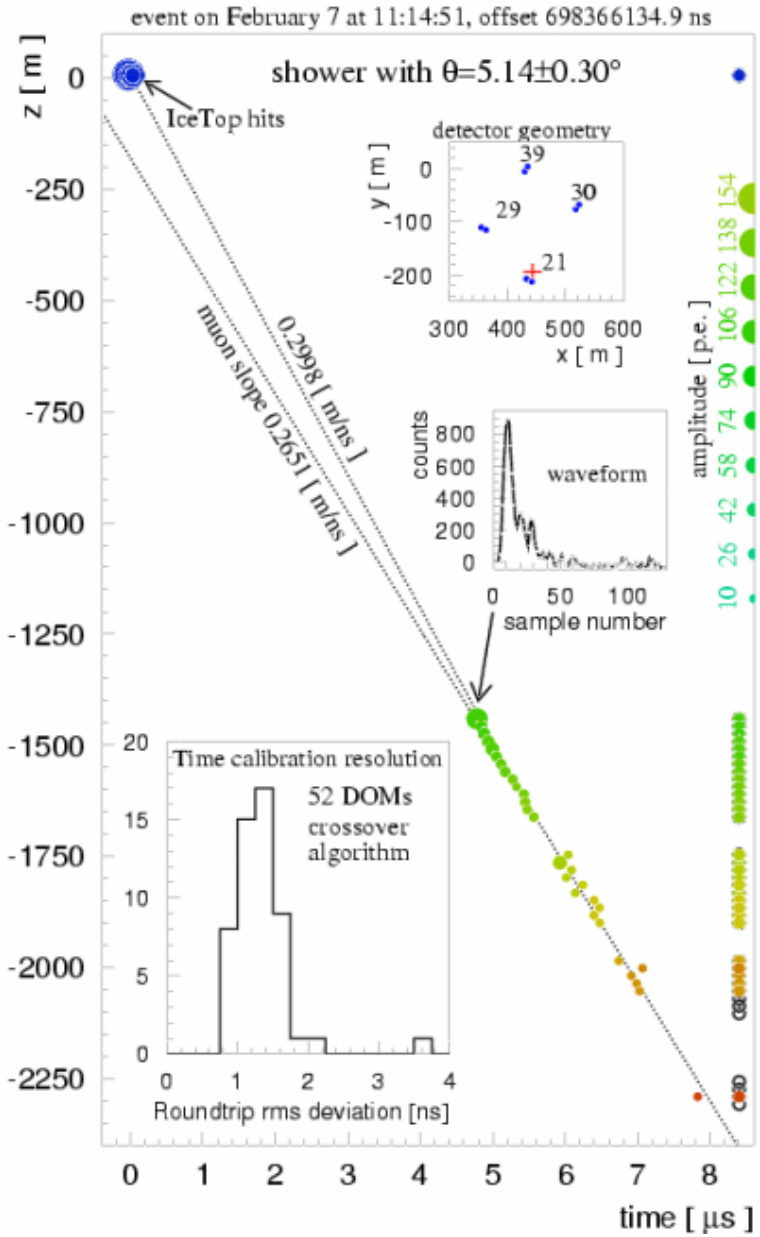
- 2 DOMs each per tank
- 125 m grid, 1 km^2 at 690 g/cm^2
- E_{thres} ~ 300 TeV for ≥ 4 stations
- Useful rate up to ~EeV





The first IceCube-IceTop coincident event





Status after 04/05 deployment season:

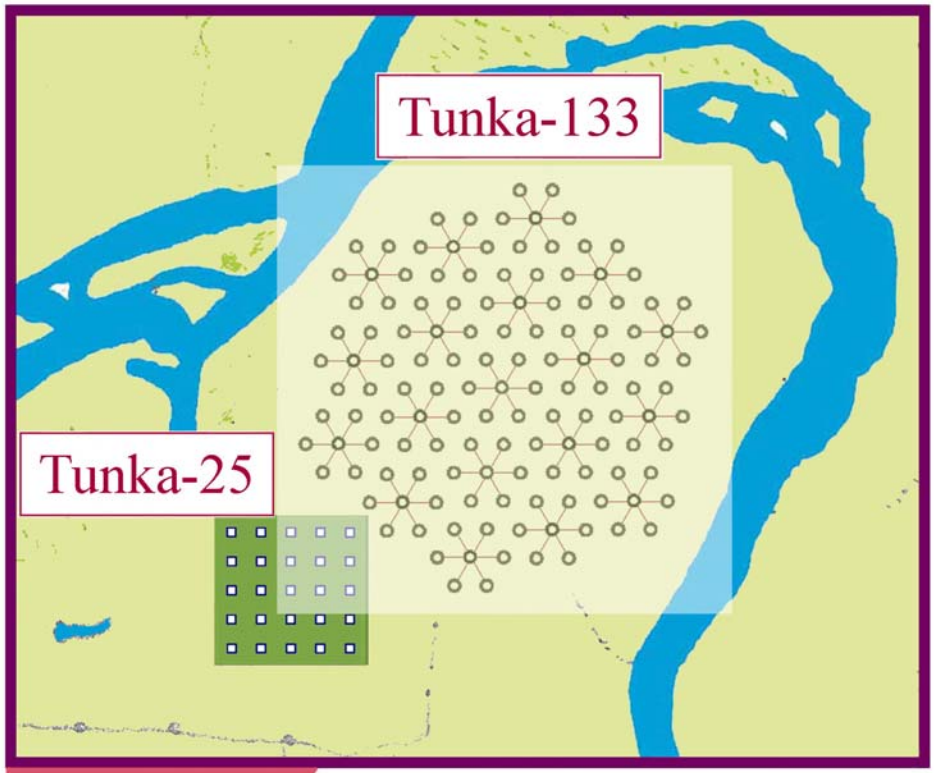
4 Ice Top stations (2 tanks each) deployed in December 2004

1st Ice Cube string deployed in January 2005

Plan for 2006:

12 stations → 0.12 km²
10 IceCube strings

TUNKA-133



Expected statistic
from 1 year operation
(400 hours):

$> 3 \cdot 10^{15}$ eV ~ $3.0 \bullet 10^{5}$ events

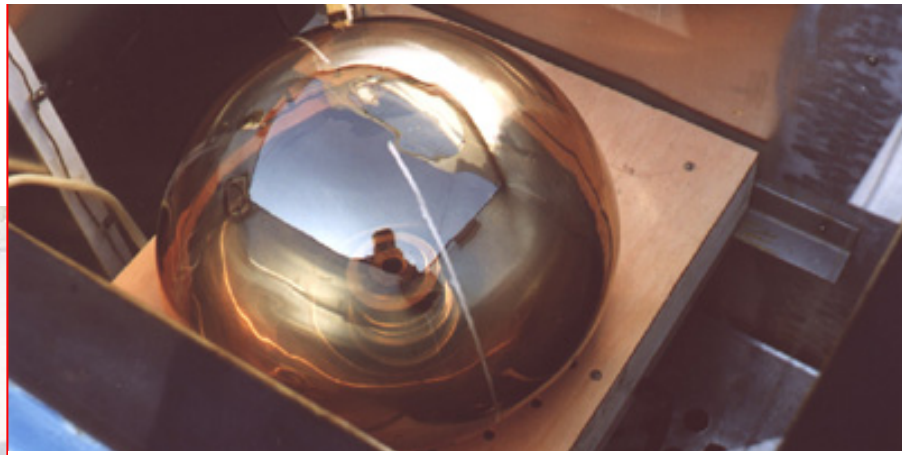
$> 10^{17}$ eV ~ 200 events

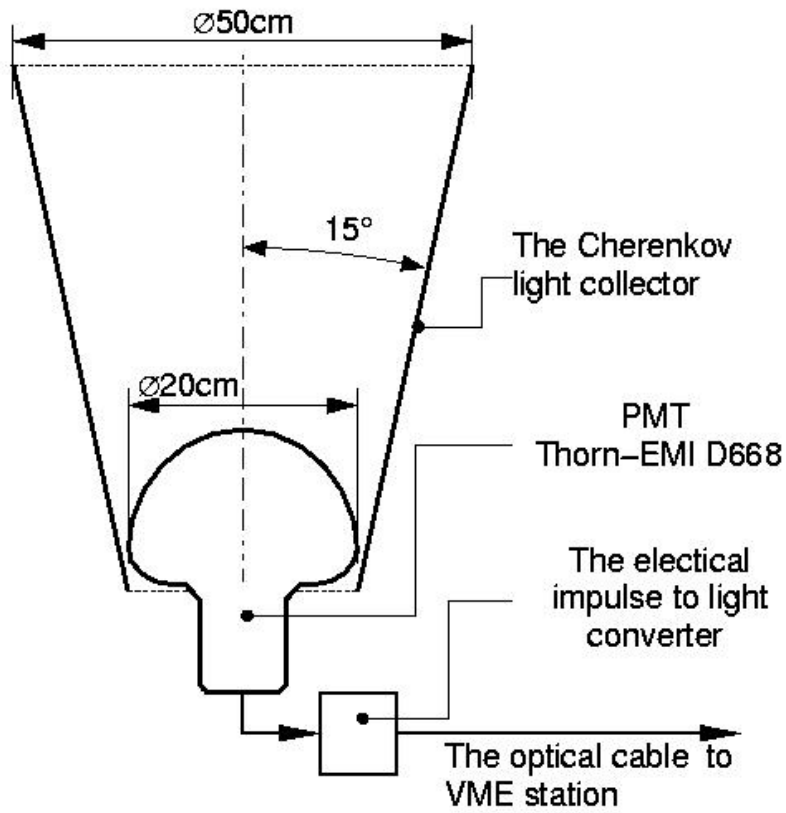
$> 10^{18}$ eV ~ 5 events

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

Tunka-133

EMI D668 for pulse form analysis

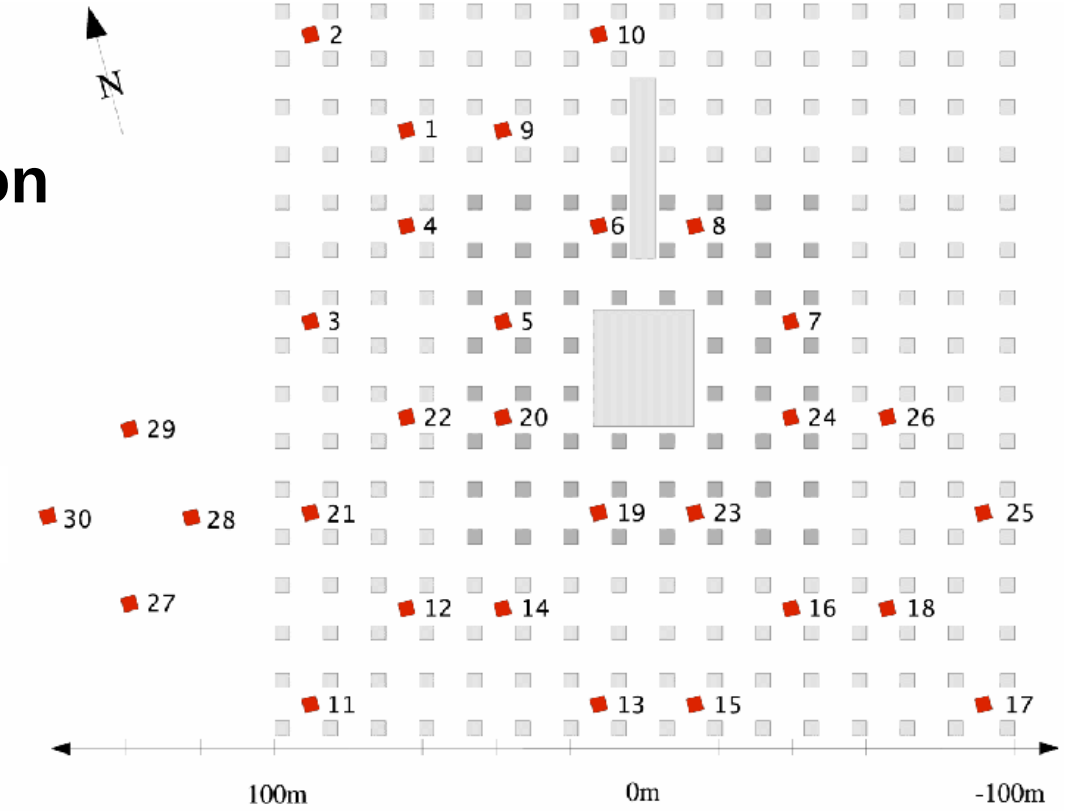




LOPES

Detection of radio emission from air showers

30 antennas operating at KASCADE-Grande



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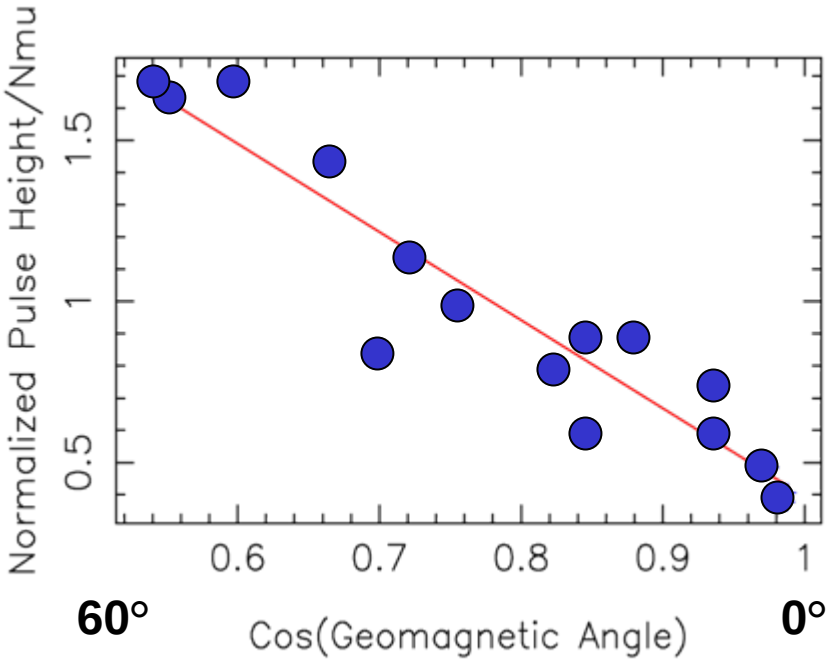
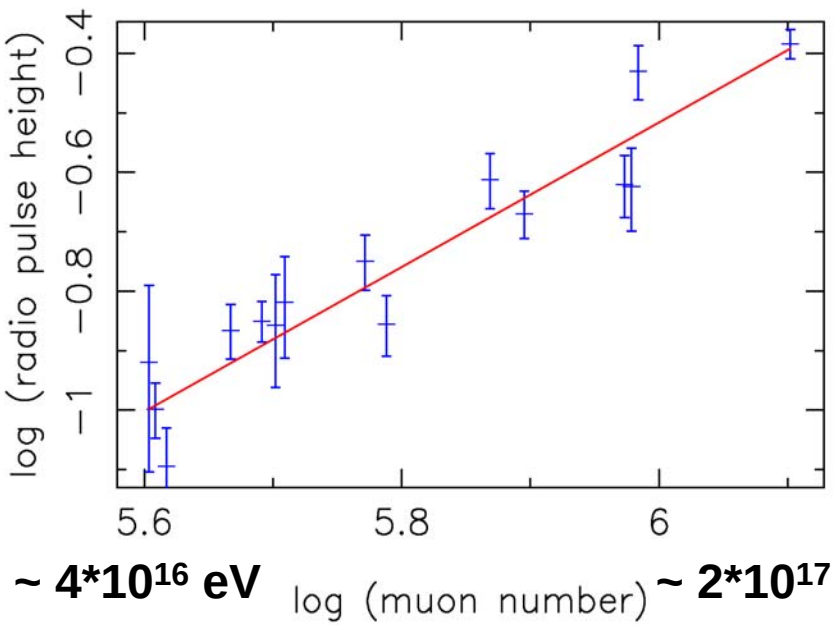
Radio signal – dependence on

angle with respect to geomagnetic field



60° **0°**

number of muons (i.e. primary energy)



~ $4*10^{16}$ eV **~ $2*10^{17}$ eV**

Geosynchroton emission

Radio signal increases with energy

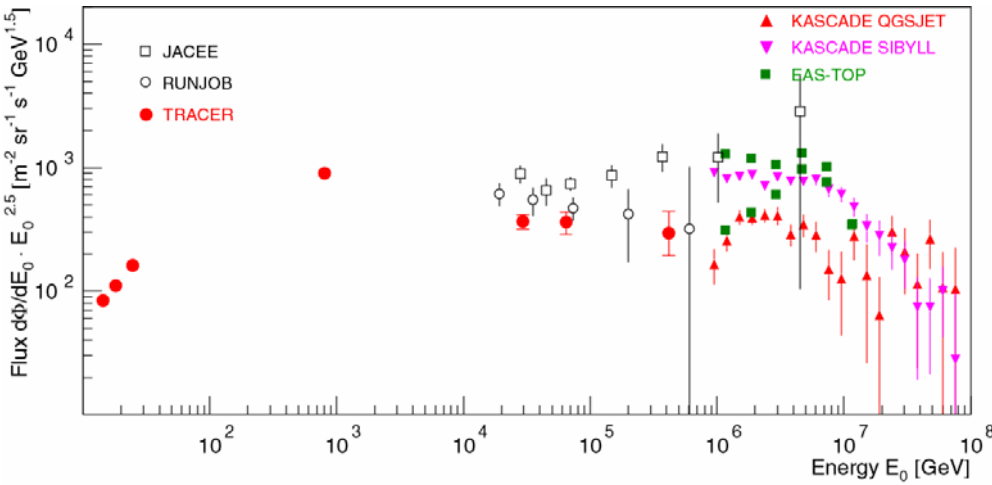
Nature 435 (2005) 313

Overlap between direct and indirect measurements

Aspen workshop, April 2005: “Below the knee” Working Group

Direct measurements of heavy nuclei

Next generation TRD on long duration balloon flight or in space



Hadrons at high altitude → surviving protons

calorimeter @ 500 g/cm² — **1 PeV: ~ 6.5 λ_i**

320 m² sr → **0.5 m² sr effective**

ideal: combination with air Cerenkov detector for calibration

Kosmische Strahlung am Knie

Status:

- Beschreibung der Wechselwirkungen in der Atmosphäre verbessert
- Mittlere Masse steigt als Funktion der Energie an (Kniebereich)
- Knie verursacht durch Abbruch des Flusses leichter Elemente
- Astrophysikalische Interpretation limitiert durch Verständnis der WW in der Atmosphäre

Perspektiven (neue/aktuelle Experimente):

- KASCADE-Grande
- LOPES (Nachweis von Radiosignalen)
- Ice Cube/Ice Top
- Tunka-133

} galaktisch → extragalaktisch 10^{18} eV

- Direkte Messung schwerer Elemente mit TRD
- Hadronen in großer Höhe → Protonspektrum

} direkt ←→ indirekt 10^{15} eV