The KASCADE-GRANDE EXPERIMENT

Air Shower Measurements in the Primary Energy Range from 10^{15}eV to 10^{18}eV

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KASCADE-Grande Collaboration

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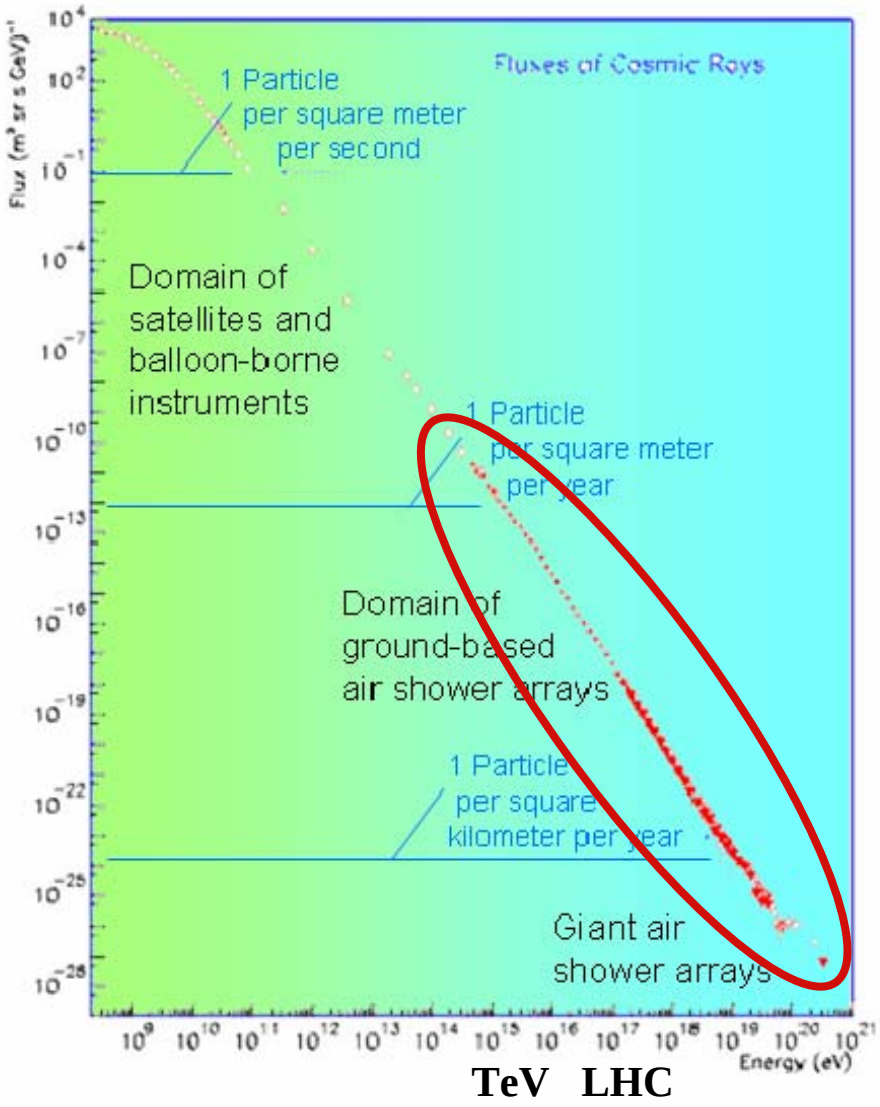
http://www-ik.fzk.de/KASCADE-Grande/

The cosmic ray energy spectrum



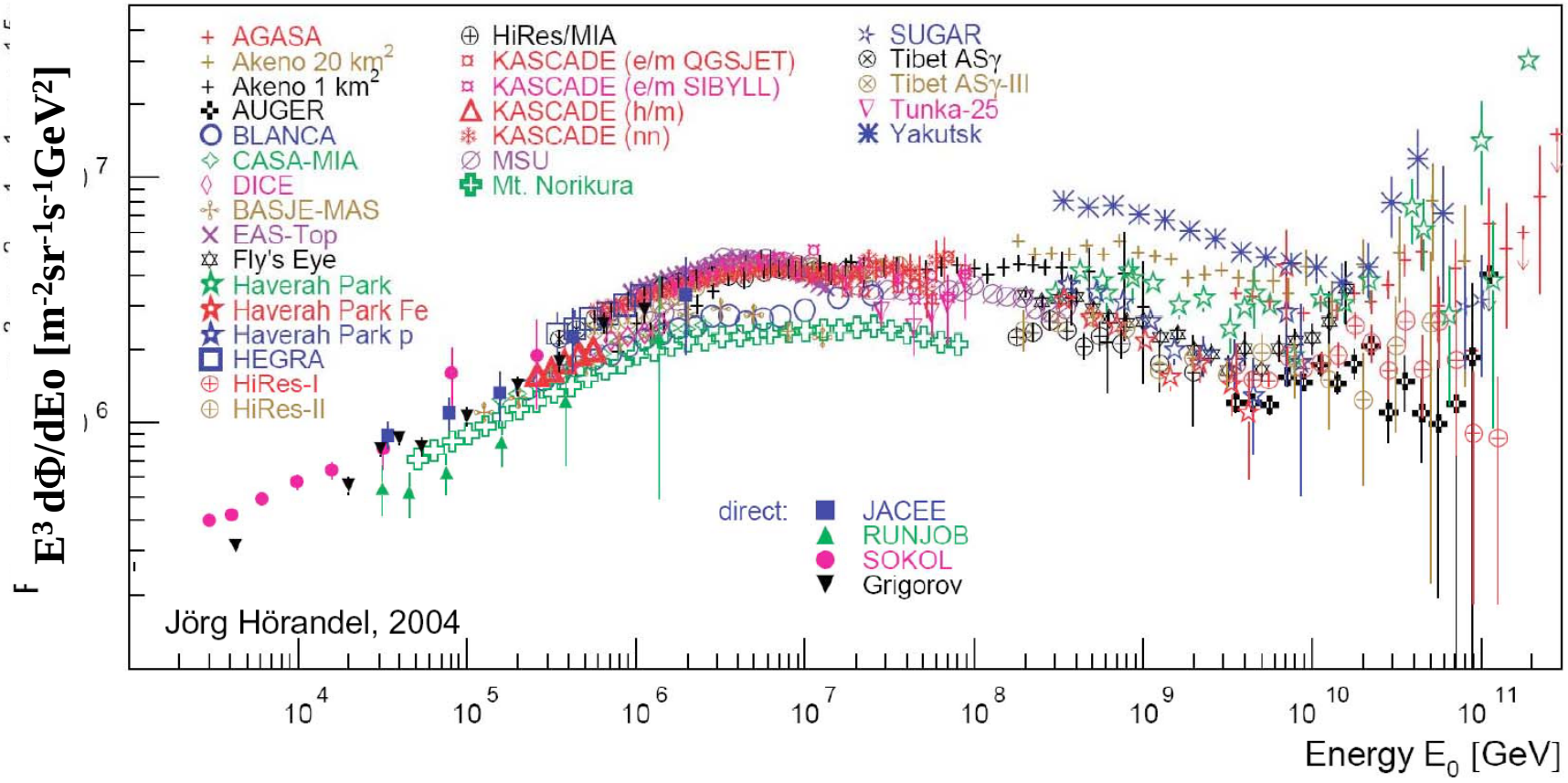
From particles interacting in the detector

to

sampling of their cascades at fixed atmospheric depth

Physics and problems: $S(E_0)*E_0^3$

S[1 event/week] 0.01 0.3 25 2500 3.10^5 5.10^7 m^2



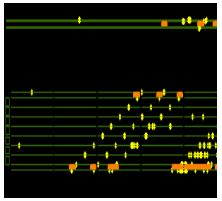
EAS-TOP

LNGS-Campo Imperatore
2000 m a.s.l. 820 g·cm^{-2}

E.M. ARRAY and
GeV MUON DETECTOR
Ne - Nμ analysis at knee

MACRO

Underground
Gran Sasso Labs.
depth: 3100 m w.e.
Eμth ~ 1.3 TeV
76.6 x 12 x 4.8 m^3
σ_θ < 1°
20 m at surface level



Istituto di Fisica dello Spazio Interplanetario
Torino

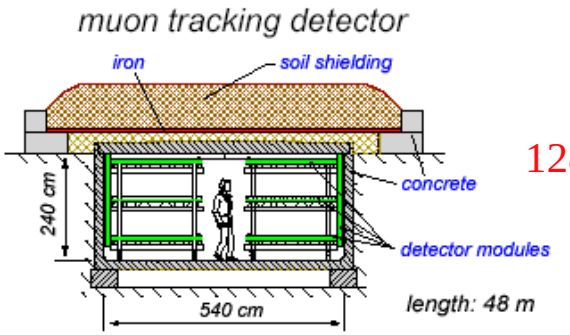
KASCADE

Nucl. Instr. Meth. A513 (2003) 490

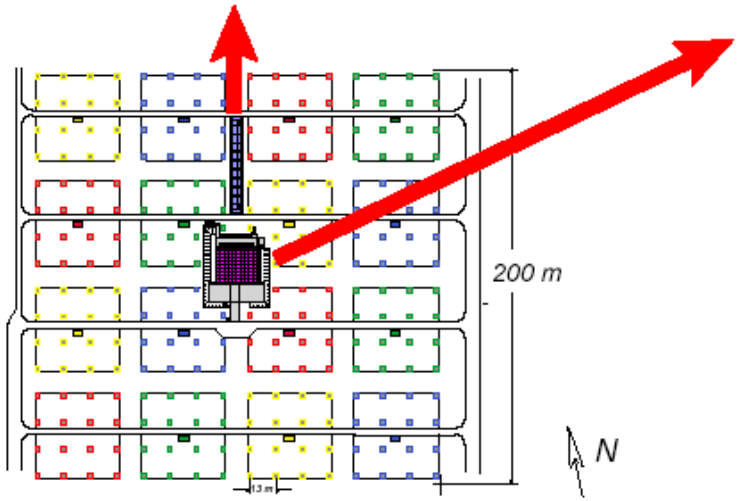
*(**Ka**rlsruhe **S**hower **C**ore and **A**rray **De**tector)*

electron & muon identification

Tunnel:
muon tracking (800 MeV)



128 m^2



determination of electron number, muon number, shower core and arrival direction of air shower

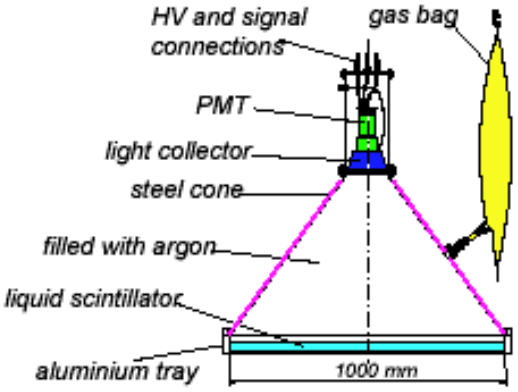
KASCADE array e.m. & muon (230 MeV)

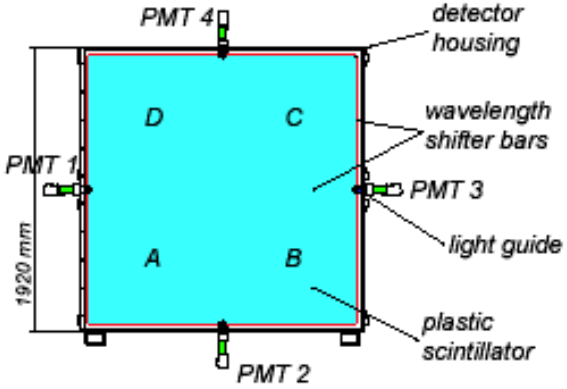
e/γ - detector (liquid scintillator)

lead/iron absorber

20 Xo

muon detector (plastic scintillator)



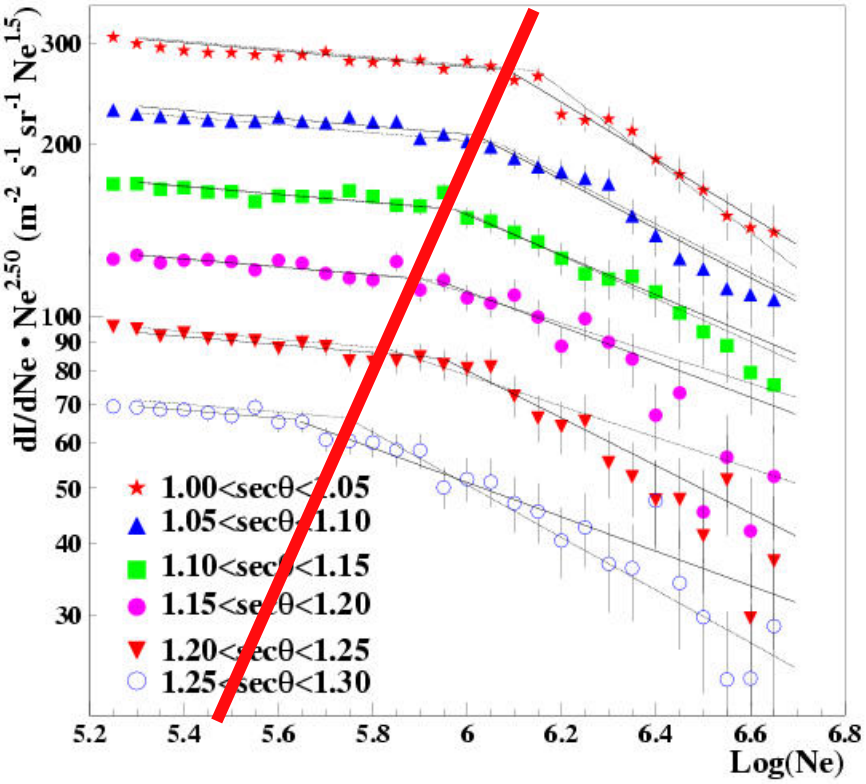


e/γ - detector 490 m^2 muon detector 622 m^2

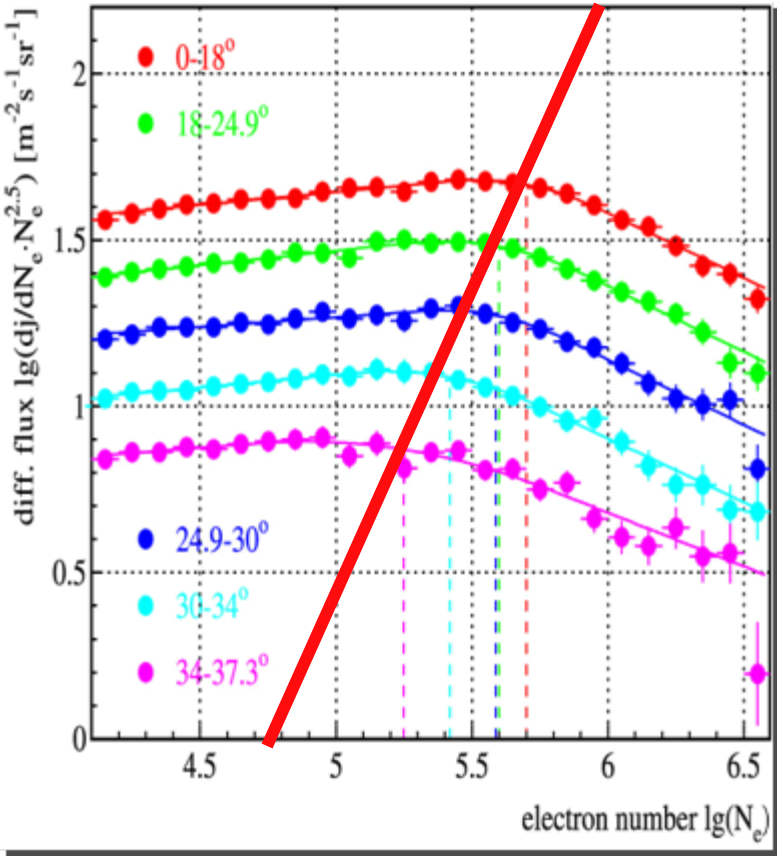
The “knee”

E.M. DETECTORS: Ne spectra in the knee region

EAS-TOP



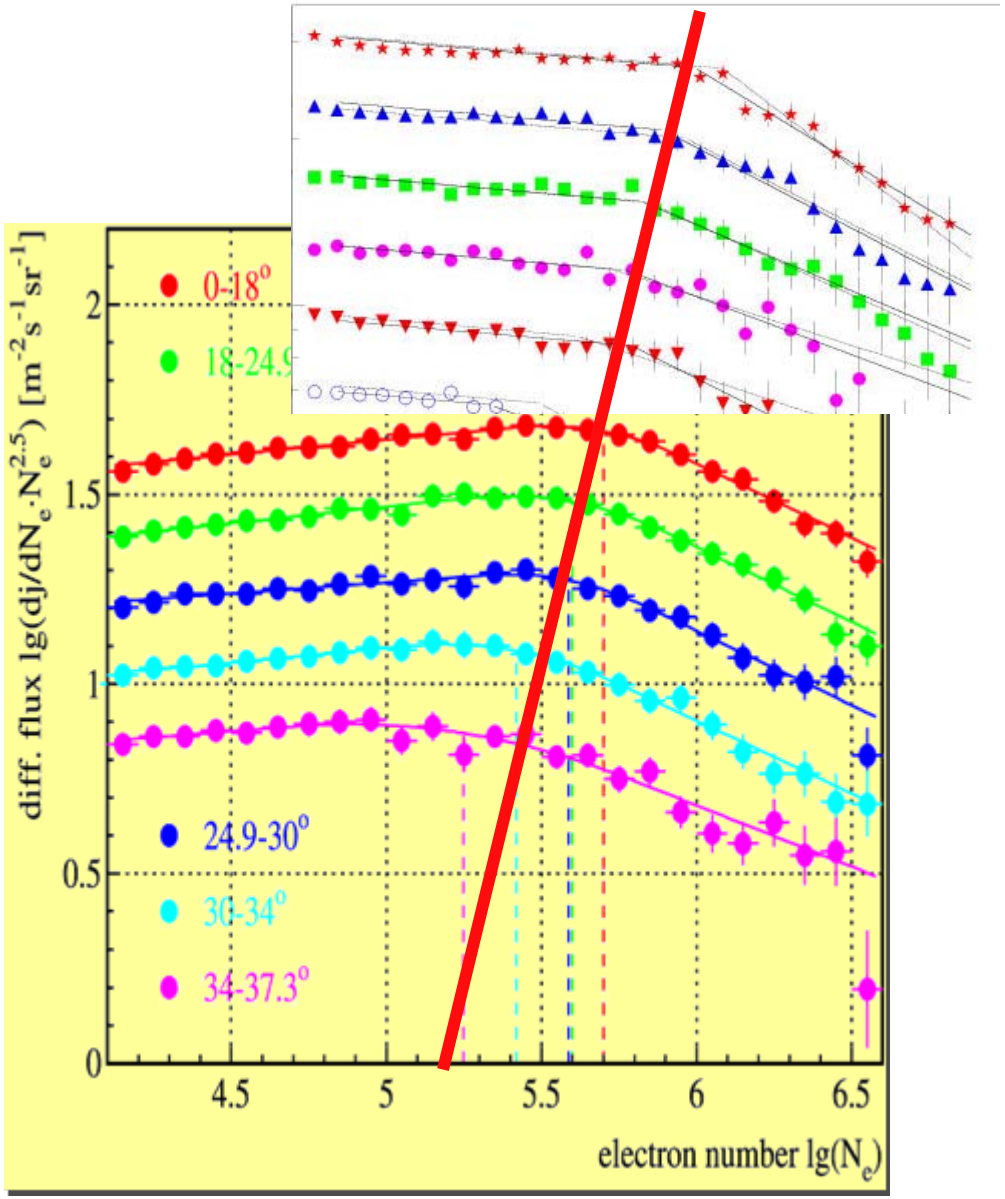
KASCADE



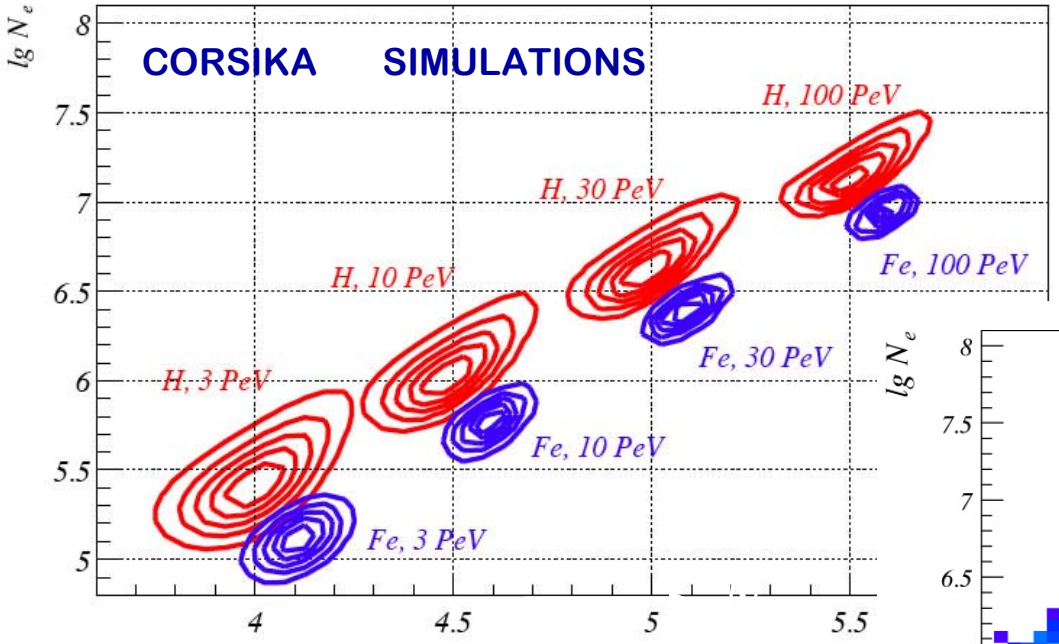
2000 m a.s.l.

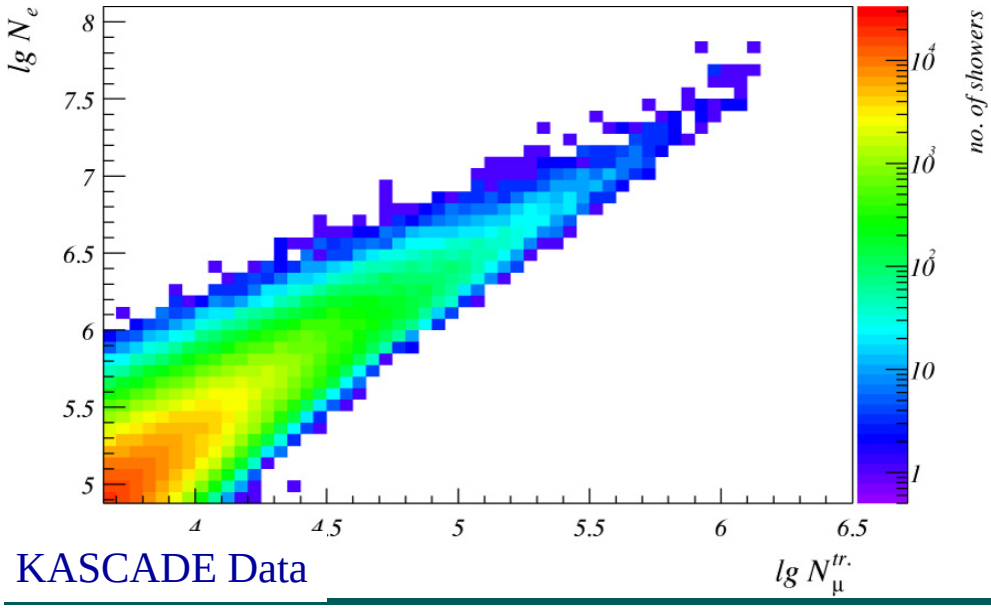
100 m a.s.l.

KASCADE & EAS-TOP Ne (knee) Vs Atmospheric Depth



(N_e , N_μ) ⇔ (Energy , Mass)

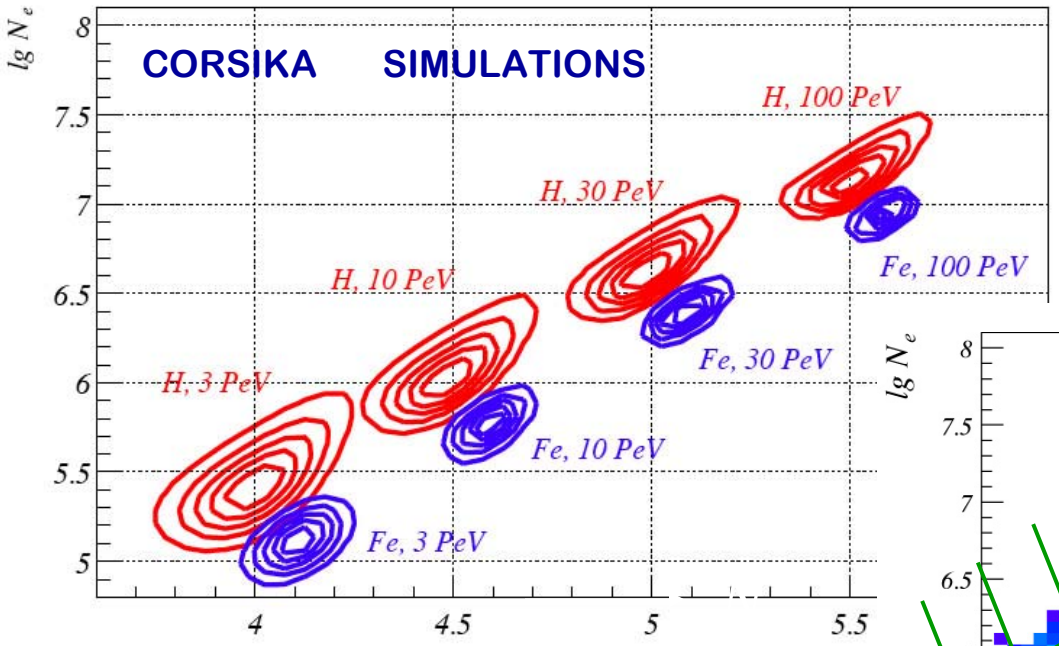


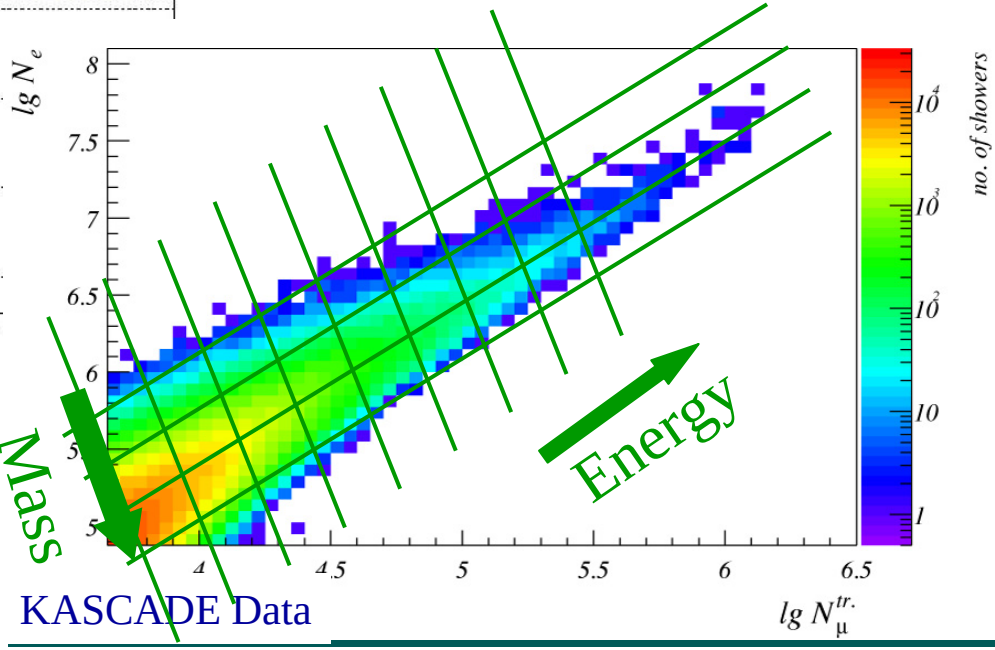


KASCADE Data

P + He + CNO + Si + Fe

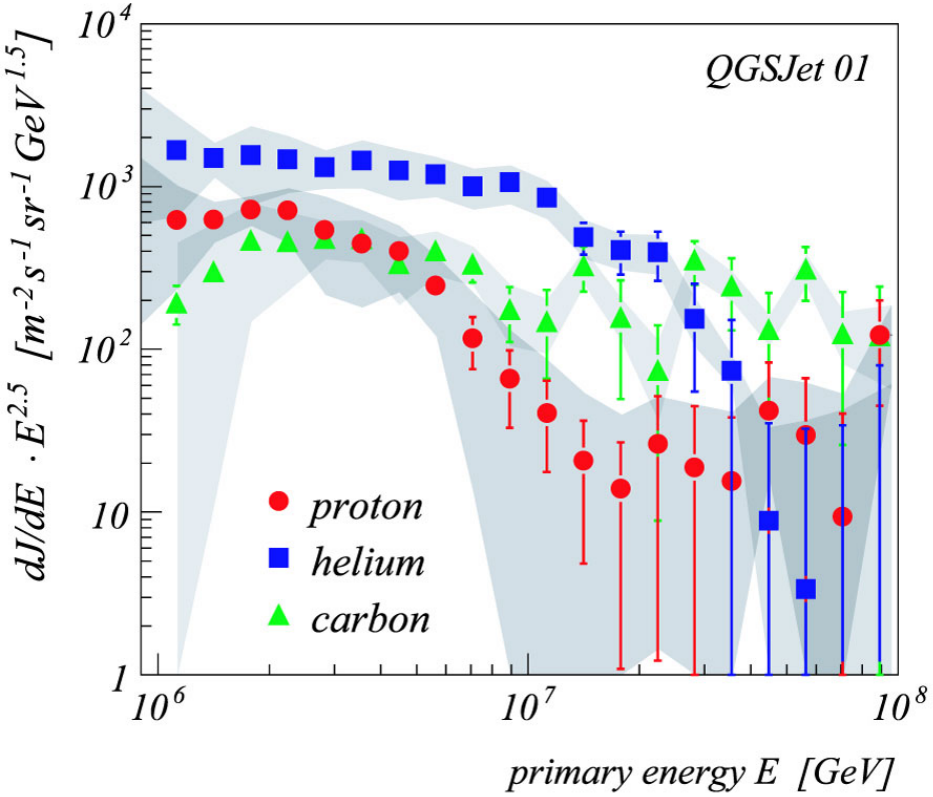
(N_e , N_μ) ⇔ (Energy , Mass)

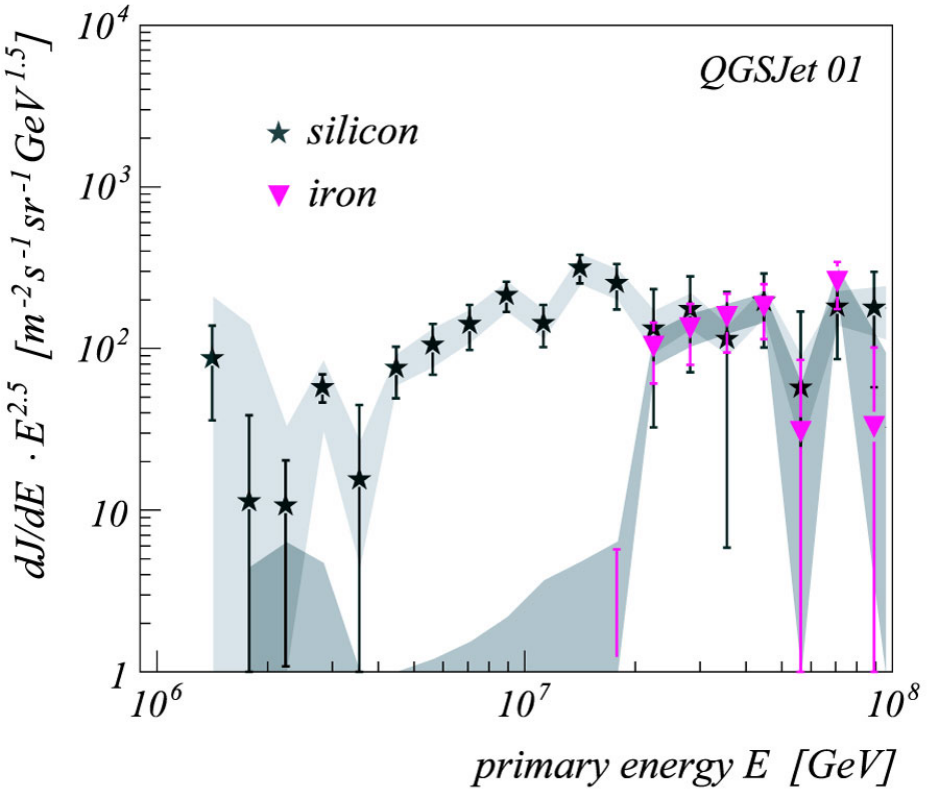




P + He + CNO + Si + Fe

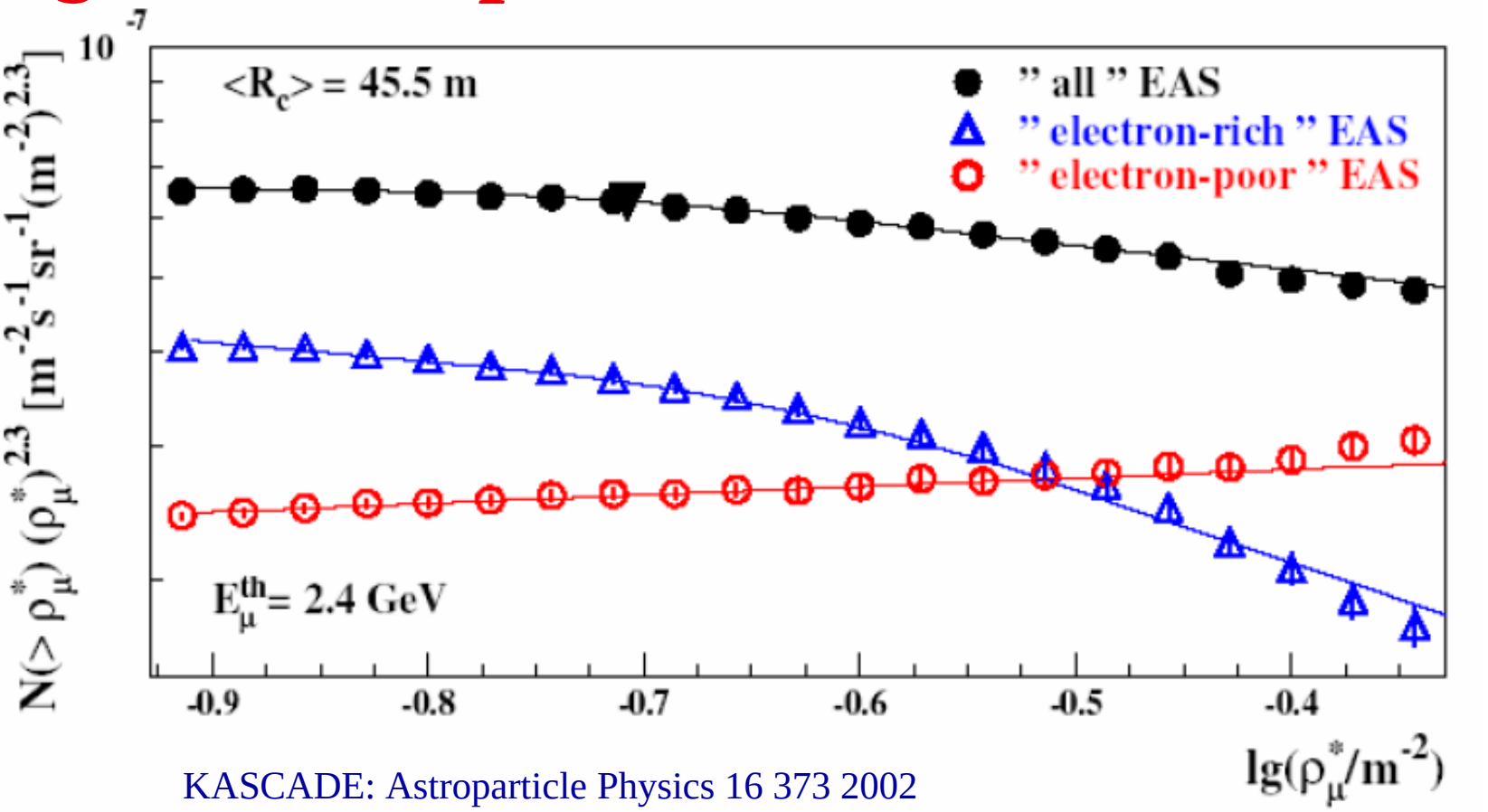
Steepening of the lightest components (E_μ < GeV)





…model dependences, but not of general result

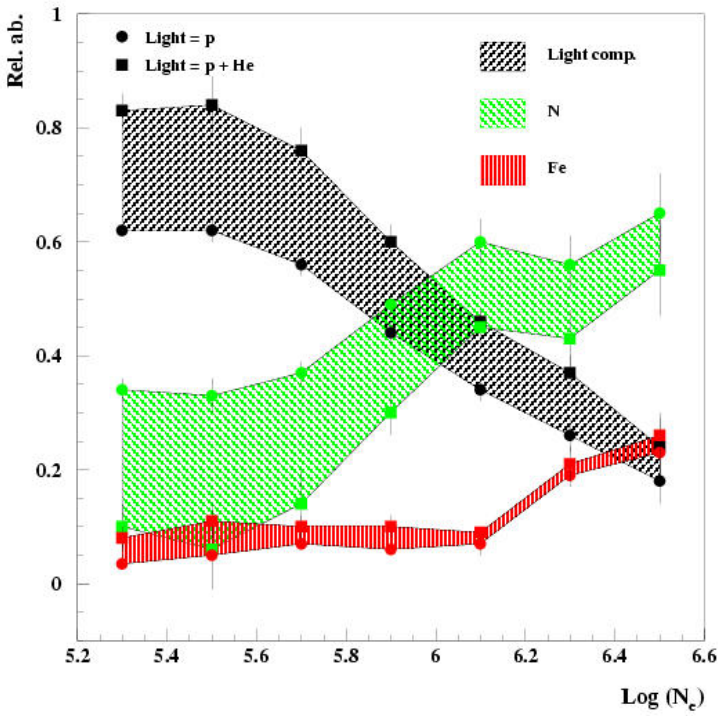
Steepening of the lightest components

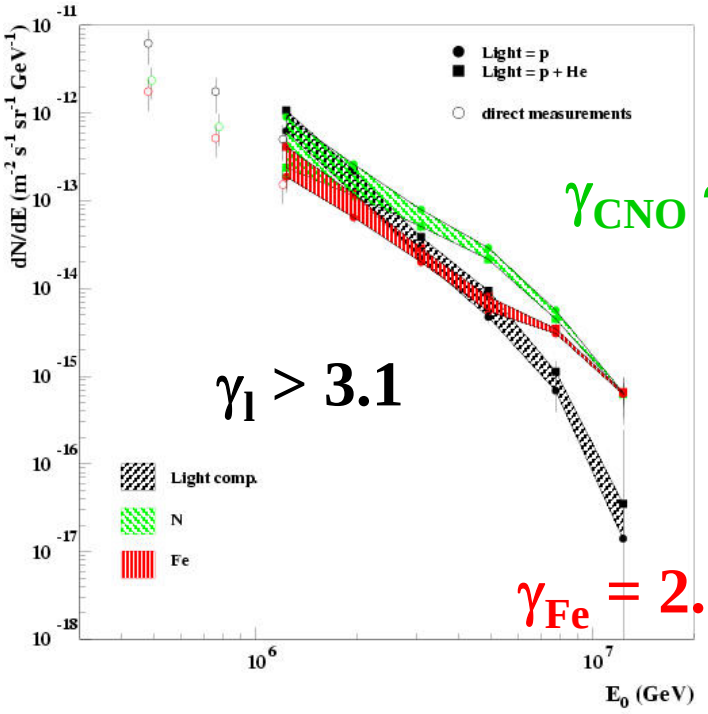


KASCADE: Astroparticle Physics 16 373 2002

KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS

The composition in the 'knee' region
EAS-TOP





$\gamma_{CNO} \sim 2.75$

$\gamma_I > 3.1$

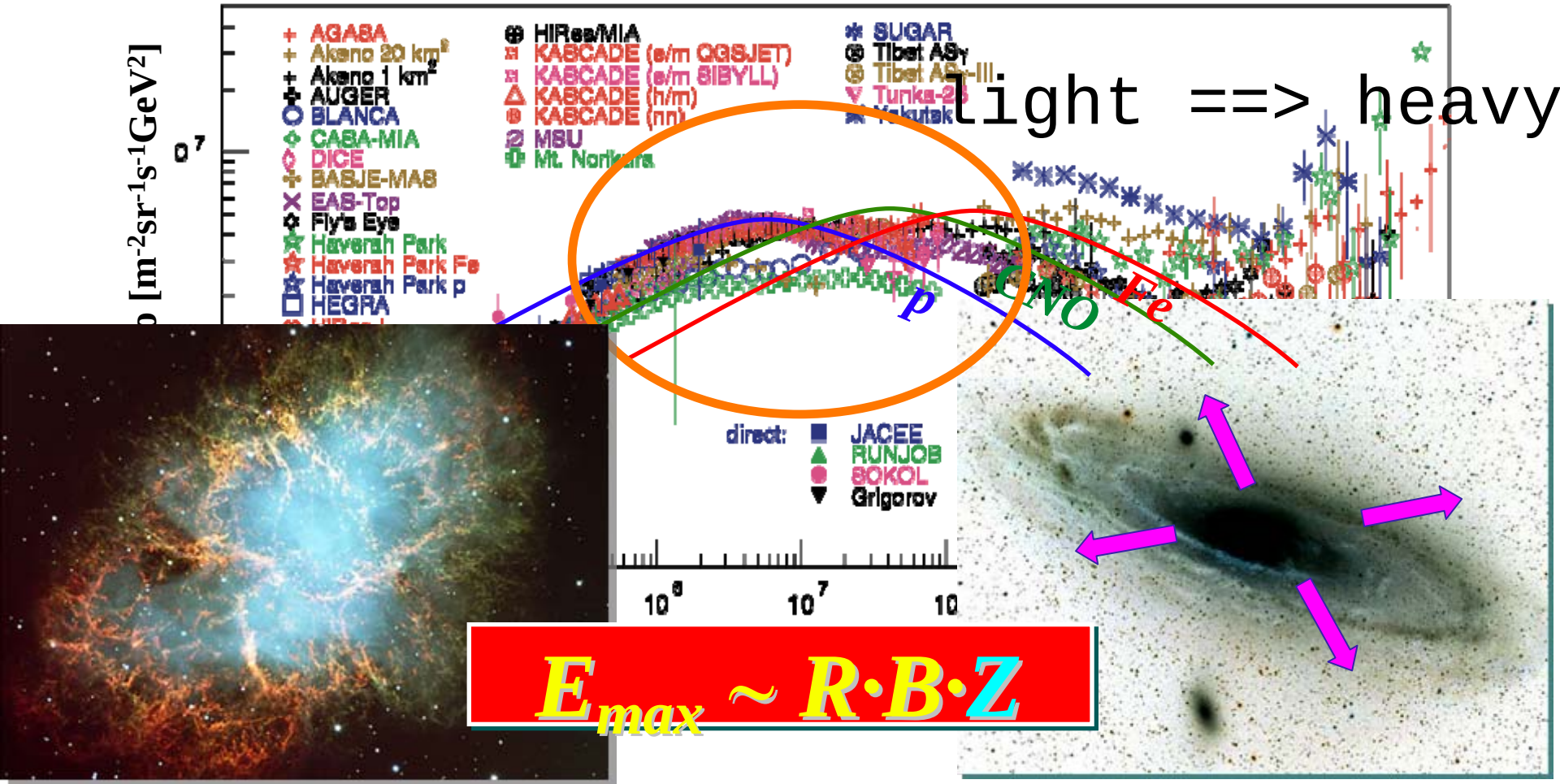
$\gamma_{Fe} = 2.3 - 2.7$

Steepening of iron? not seen

Mass group γ

Heavier primary spectra harder ➔ $E_k \propto Z$?

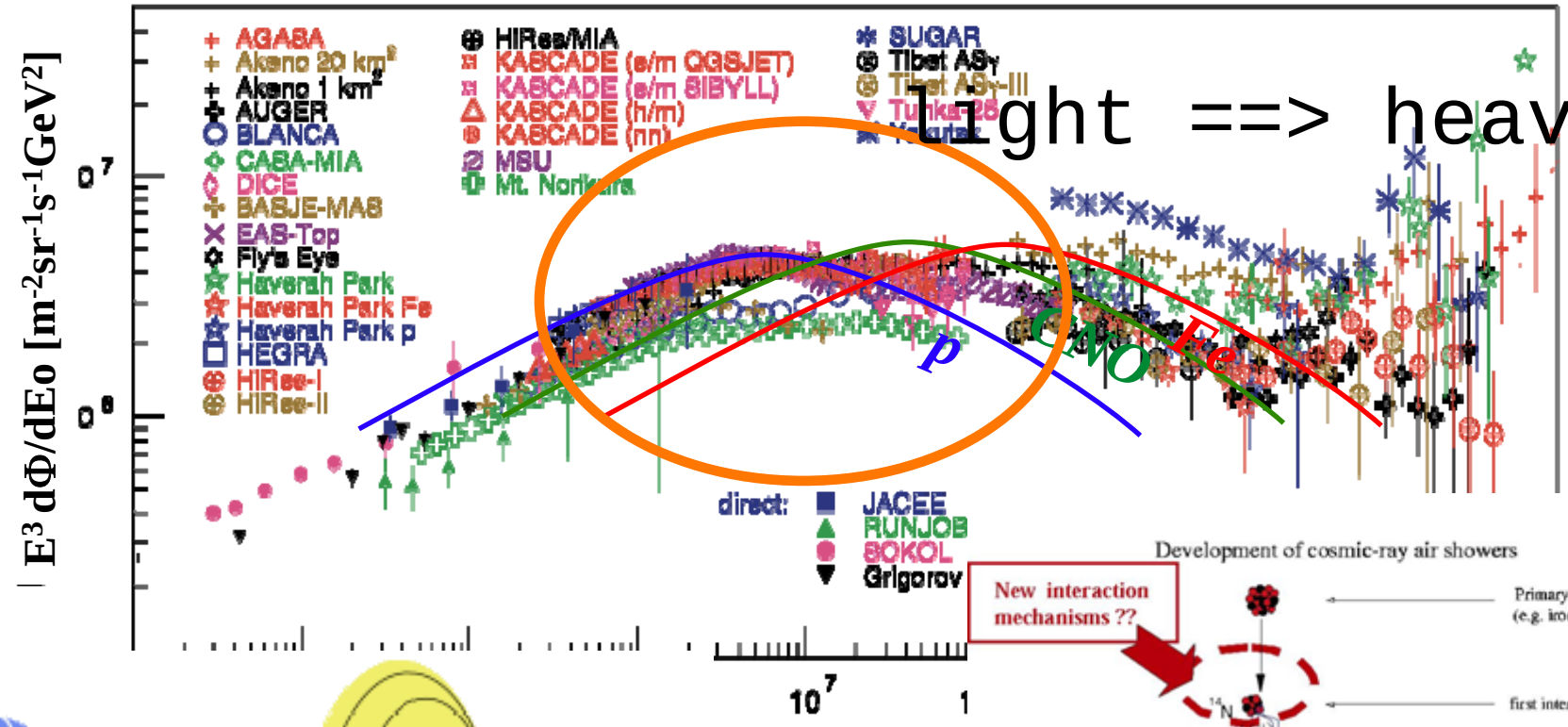
HE Galactic CR Astrophysics

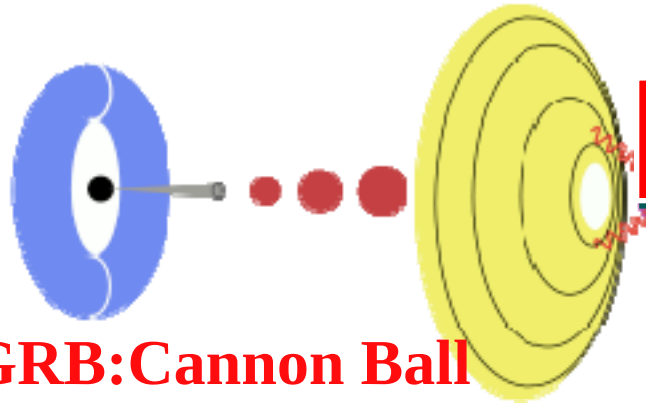


Maximum energy of galactic accelerators ?

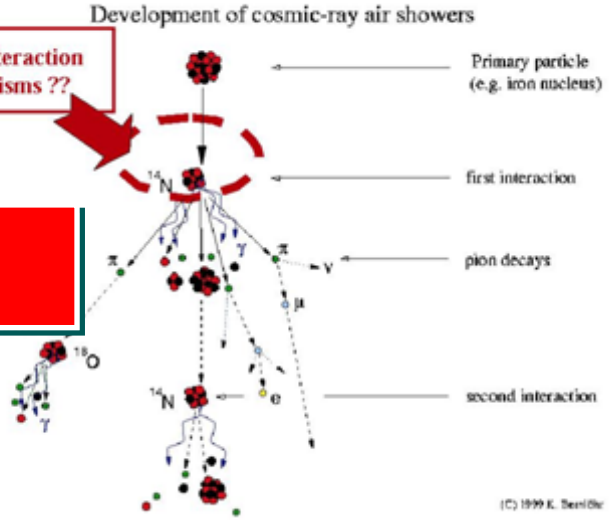
Diffusion Losses from Galaxy ?

HE Galactic CR Astrophysics



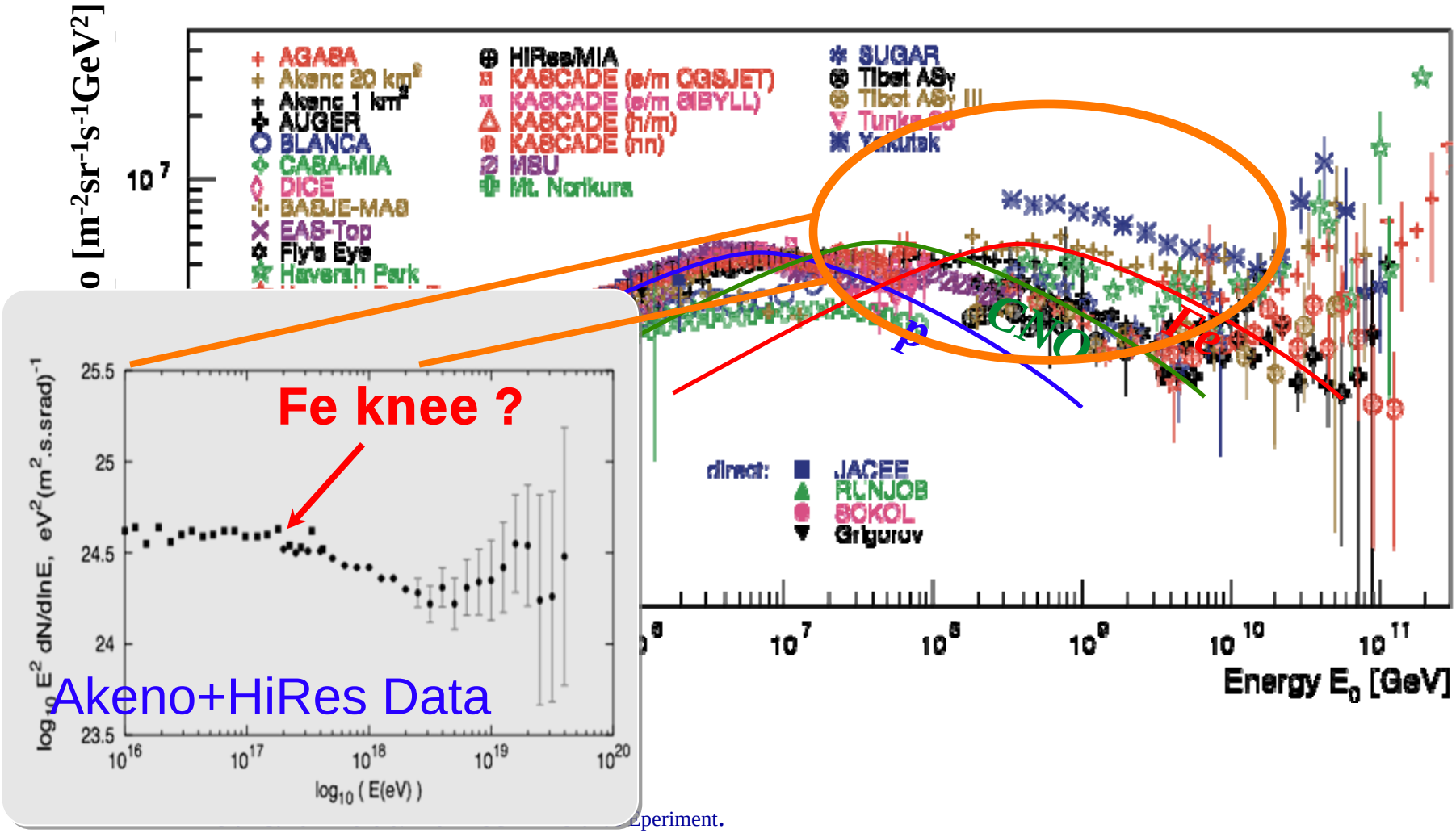


$E_{max} \sim A$



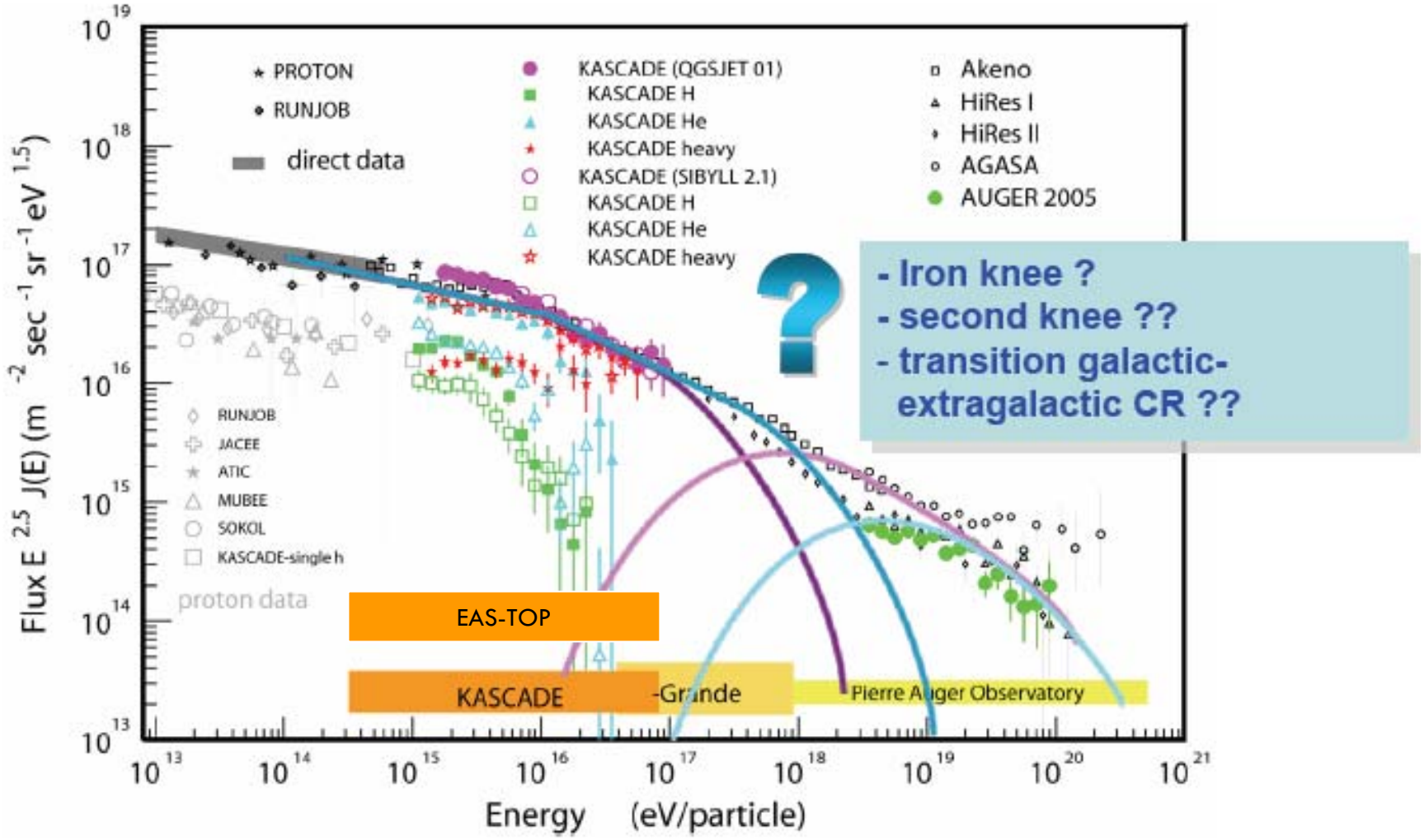
GRB:Cannon Ball

Fe knee



Experiment.

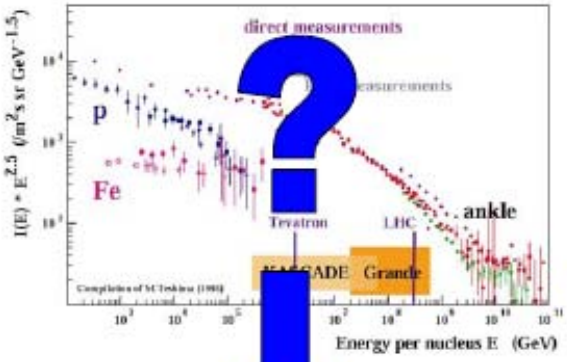
KASCADE-Grande: 0.5 km^2



KASCADE+ EAS'TOP E.M.:

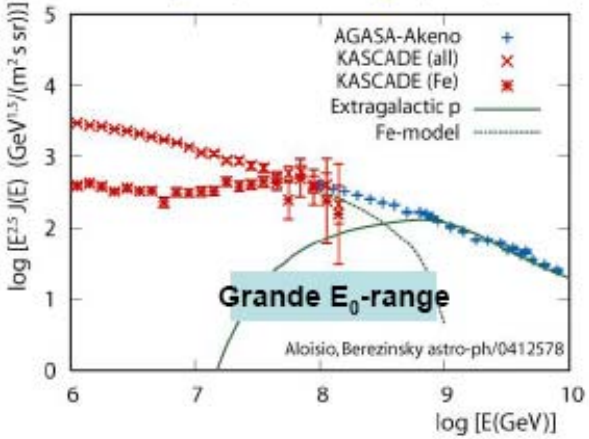
Extension of KASCADE (10 x) without significant loss in accuracy

Motivation for KASCADE-Grande



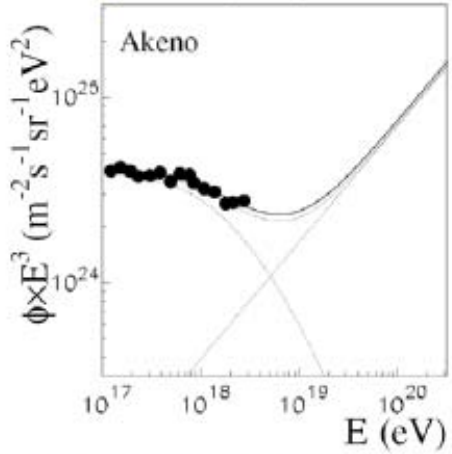
various theories on energy range 10^{17}-10^{19}eV:

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



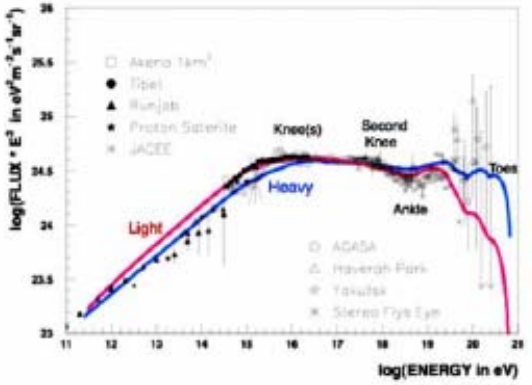
Fe-knee ~10^{17} eV
gal-eg transition ~$10^{17.7}$eV
Ankle = eg characteristics

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

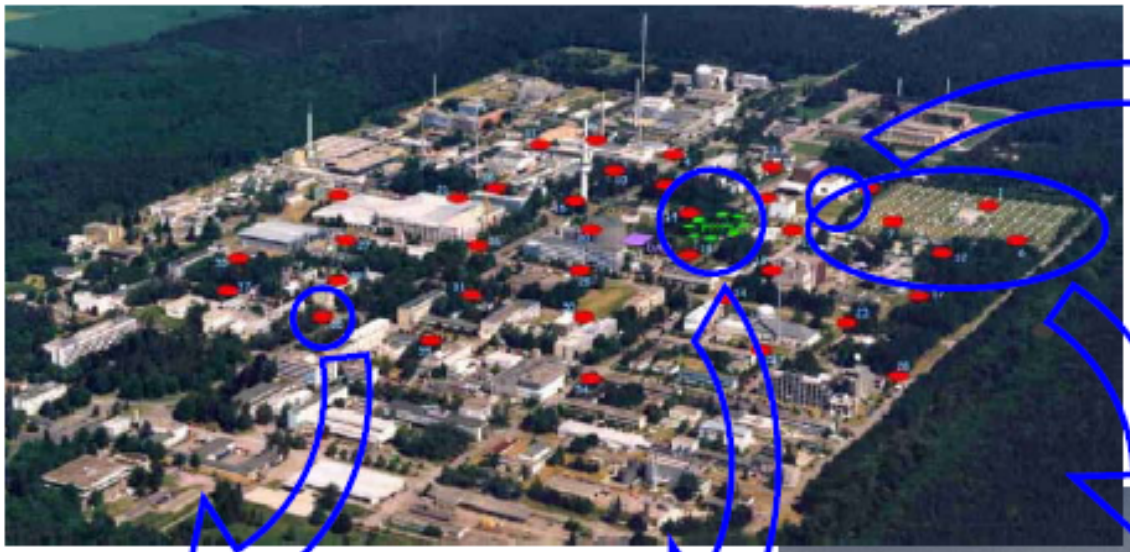


Cannonball modell:
Fe-knee ~ 2 10^{17} eV
All is galactic
(knee= elastic scattering)

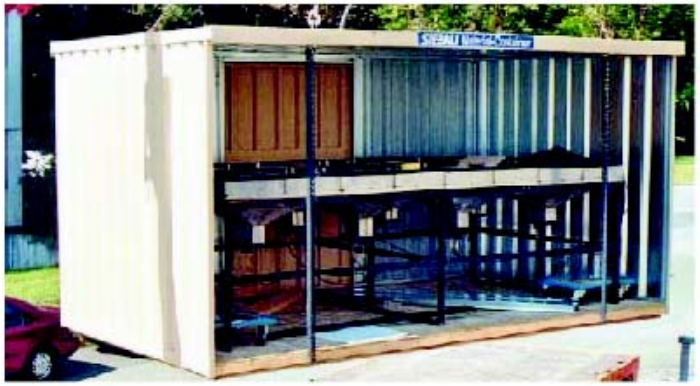
Experiment: KASCADE-Grande

= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

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



The KASCADE and Grande arrays



Grande stations:

- 16 x 0.64 m^2 scintillators
- 16 high-gain PMT
- 4 low-gain PMT
- dynamic range: 0.3 - ~10000 mip

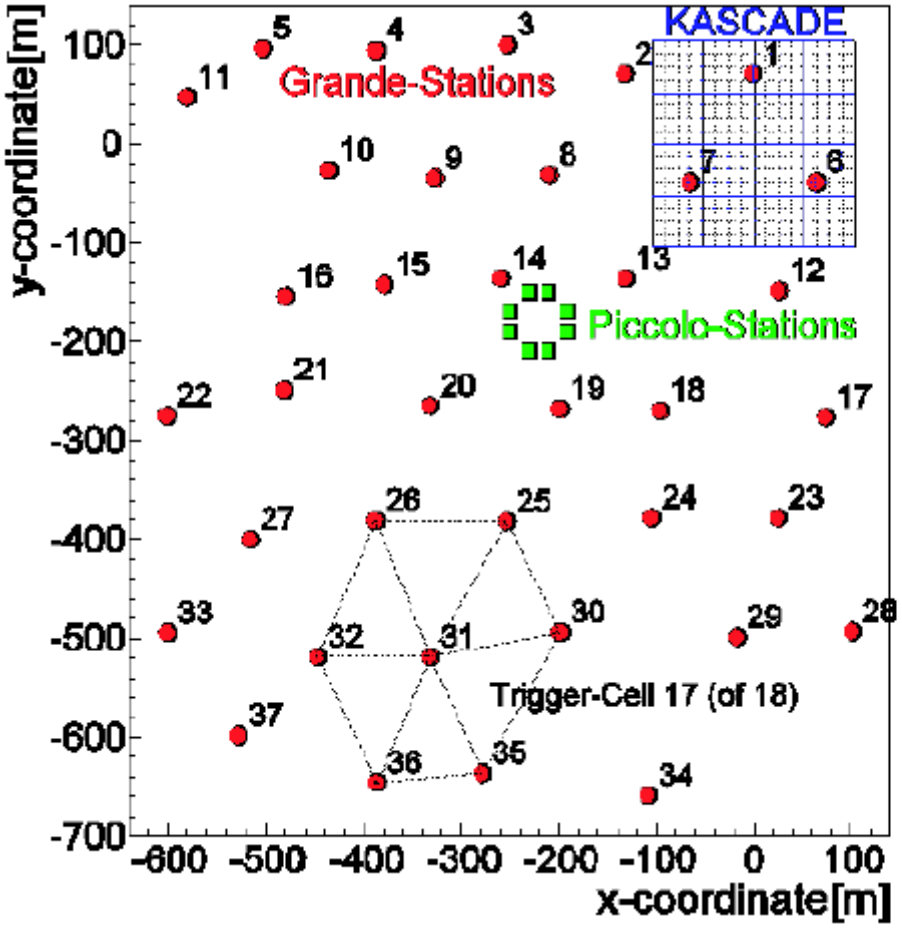
➔ Charge particle detection

KASCADE array stations:

- 2 or 4 unshielded liquid scintillators (0.94 m^2)
- lead/steel shielding
- 3.2 m^2 plastic scintillators

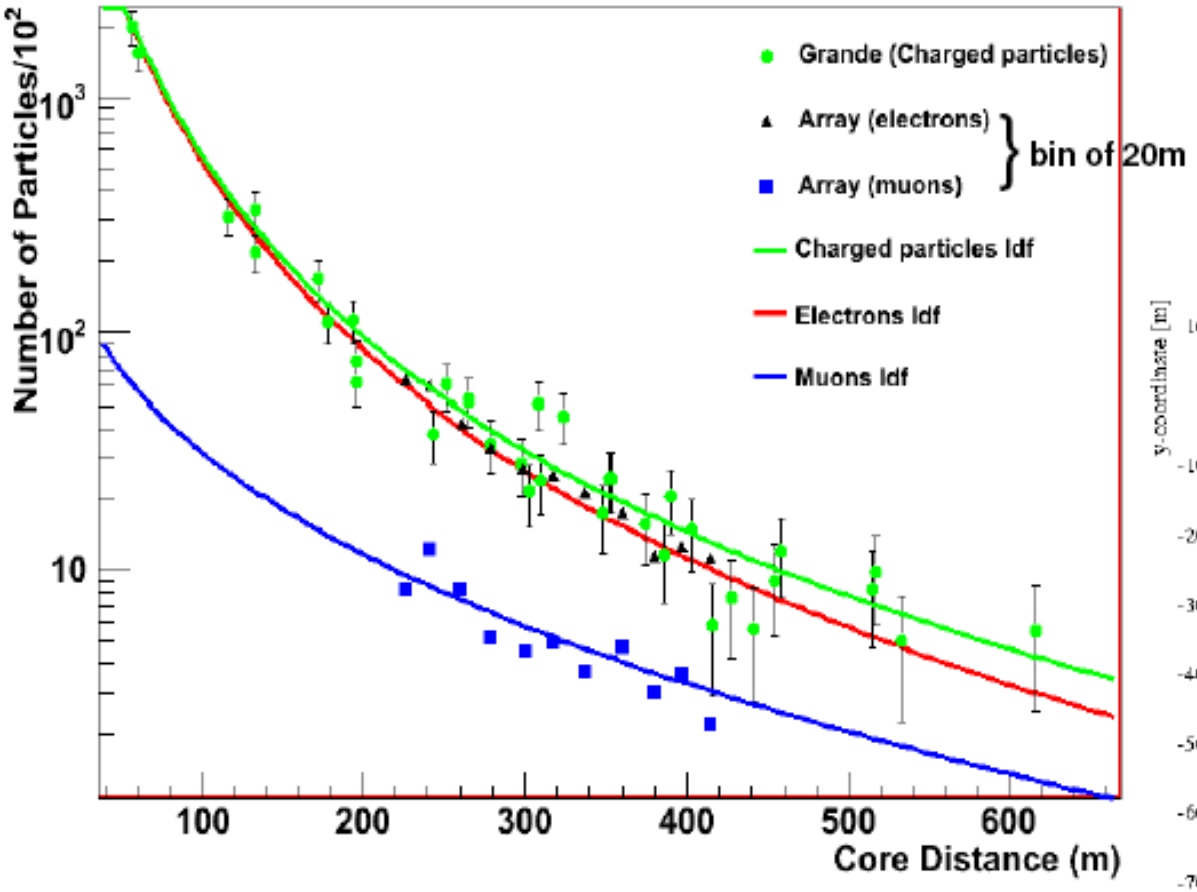
➔ charge particle detection
➔ Muon detection (E_μ>230 MeV)

KASCADE-Grande: detectors

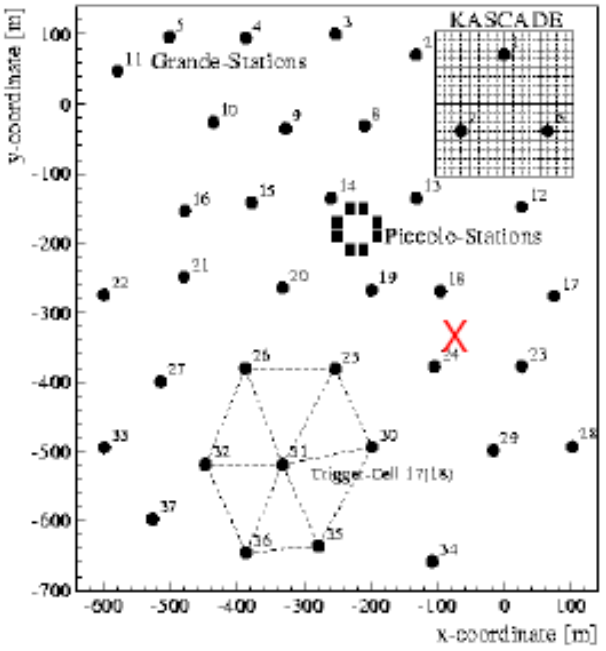


Detector	Detected EAS component	Sensitive area (m2)
Grande	Charged particles	37x10
Piccolo	Charged particles	8x10
KASCADE array e/γ	Electrons, γ	490
KASCADE array μ	Muons ($E\mu^{th}$=230 MeV)	622
MTD	Muons (Tracking) ($E\mu^{th}$=800 MeV)	3x128
MWPCs/LSTs	Muons ($E\mu^{th}$=2.4 GeV)	3x129
LOPES 30	Radio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

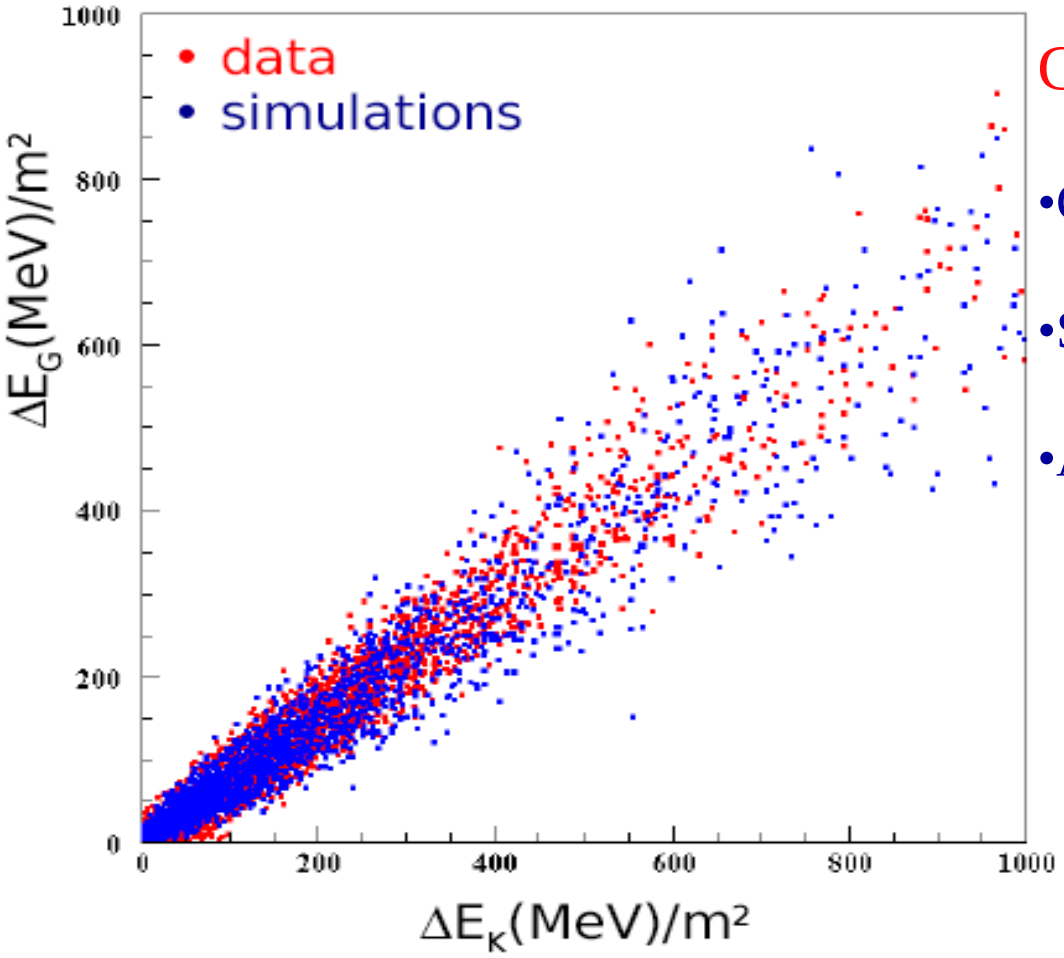
An event: Grande and KASCADE data



Log Ne = 7.1
Log Nμ = 6.0
θ = 19.2°
ϕ = 78.5°



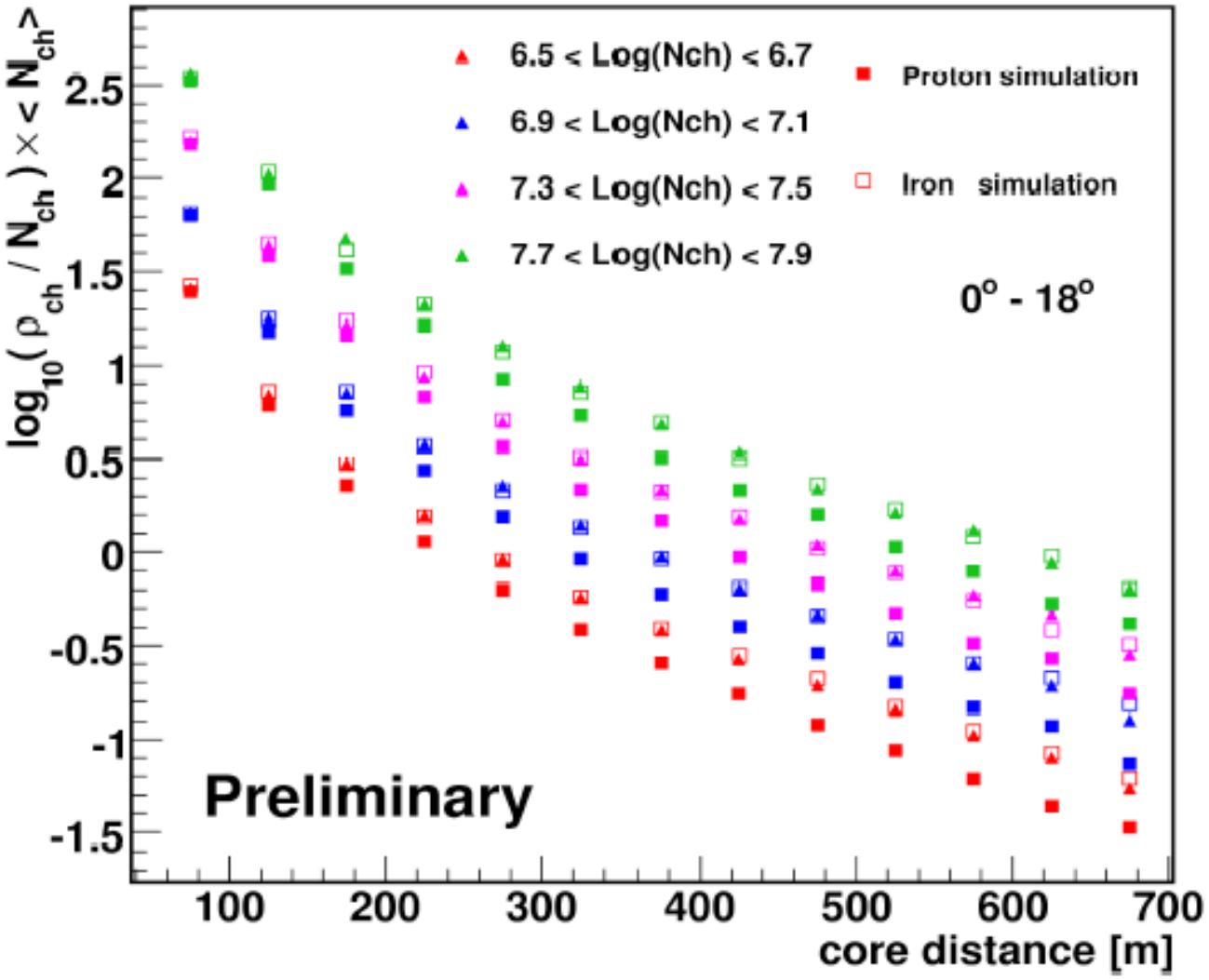
KASCADE & Grande



Grande accuracies

- Core position: 6.4 m
- Size:syst -5%, sing. ev fluct 13%
- Arrival direction: 0.6°

Comparison Data - Simulations



- QGSjet II + FLUKA
- proton and iron
- showers in Nch bins
- measured particle densities are normalized to the shower size

- simulations reproduce experimental lateral distributions up to 700 m

- it's not a composition analysis: simulations must reproduce consistently all the other observables (work in progress...)

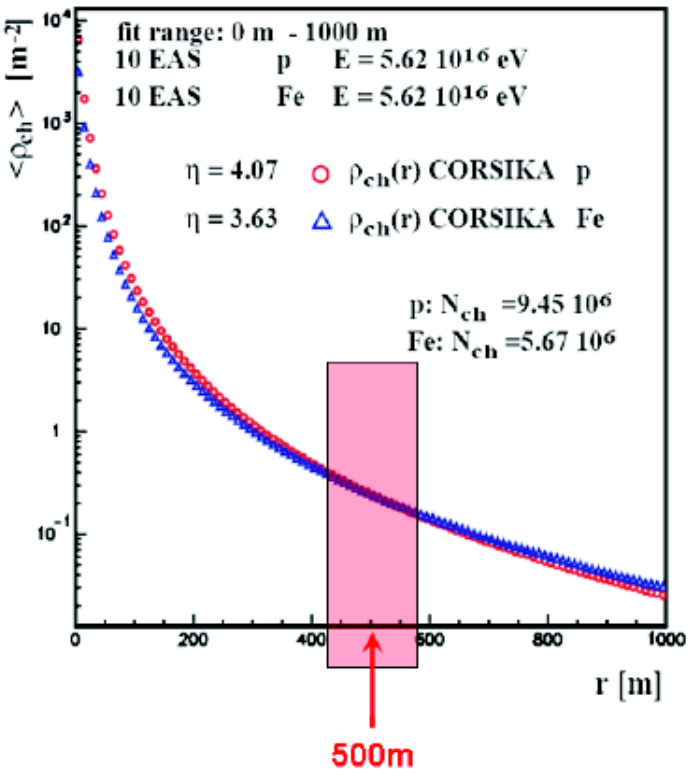
S(500)

Idea of the study – $S(r)$ at $r = 500$ m

H. Rebel et al, ICRC (2005) 6, 297.300

M. Brancus et al, ICRC (2005) 6, 361.364

G. Toma et al, ECRS, Lisbon,Portugal,2006



$E_0 \rightarrow S(500)$

$A \not\rightarrow S(500)$

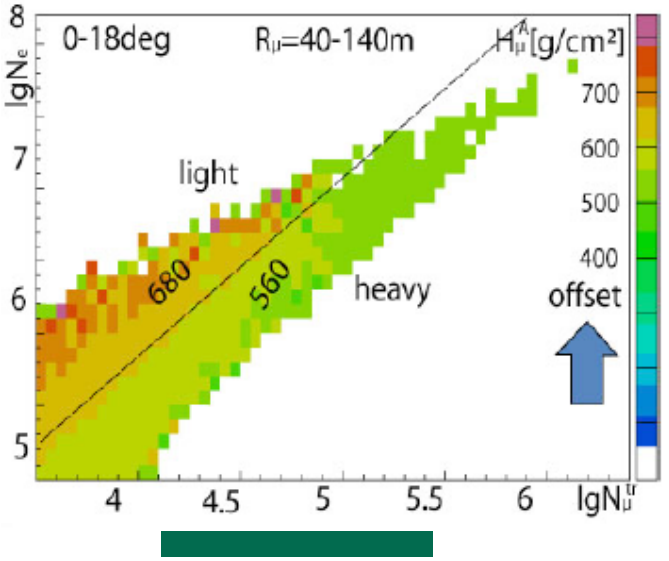
S(500), appealing estimator for primary energy

New tools

cross checks of results

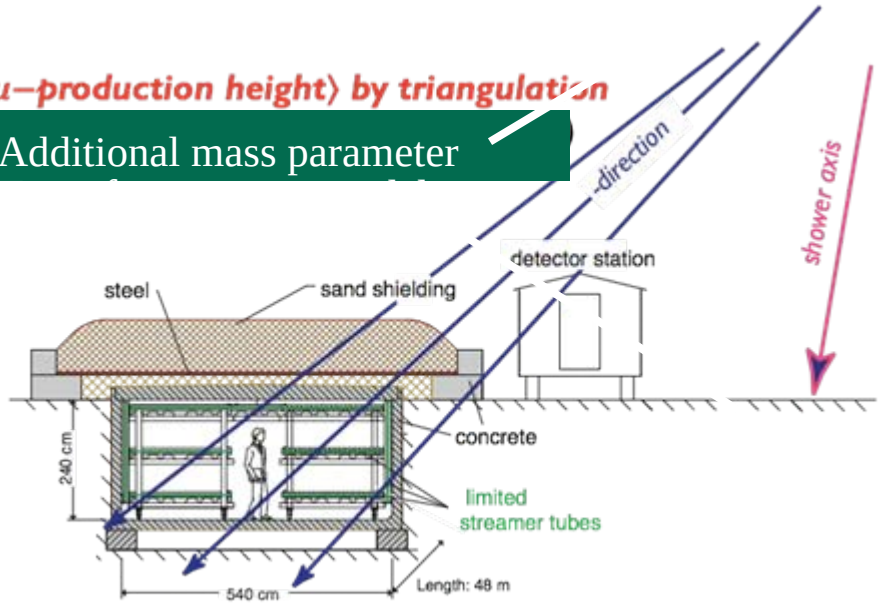
I.M. Brancus, 30th ICRC, Merida, Mexico, 2007

KASCADE –Grande muon tracking



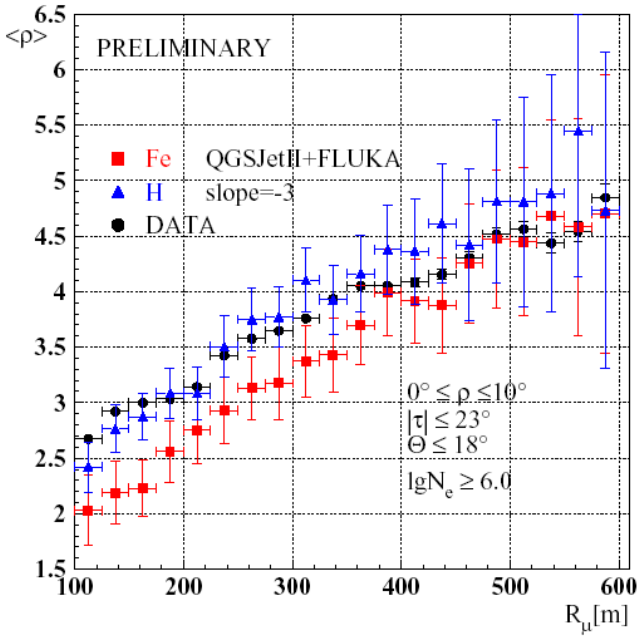
⟨μ–production height⟩ by triangulation

Additional mass parameter

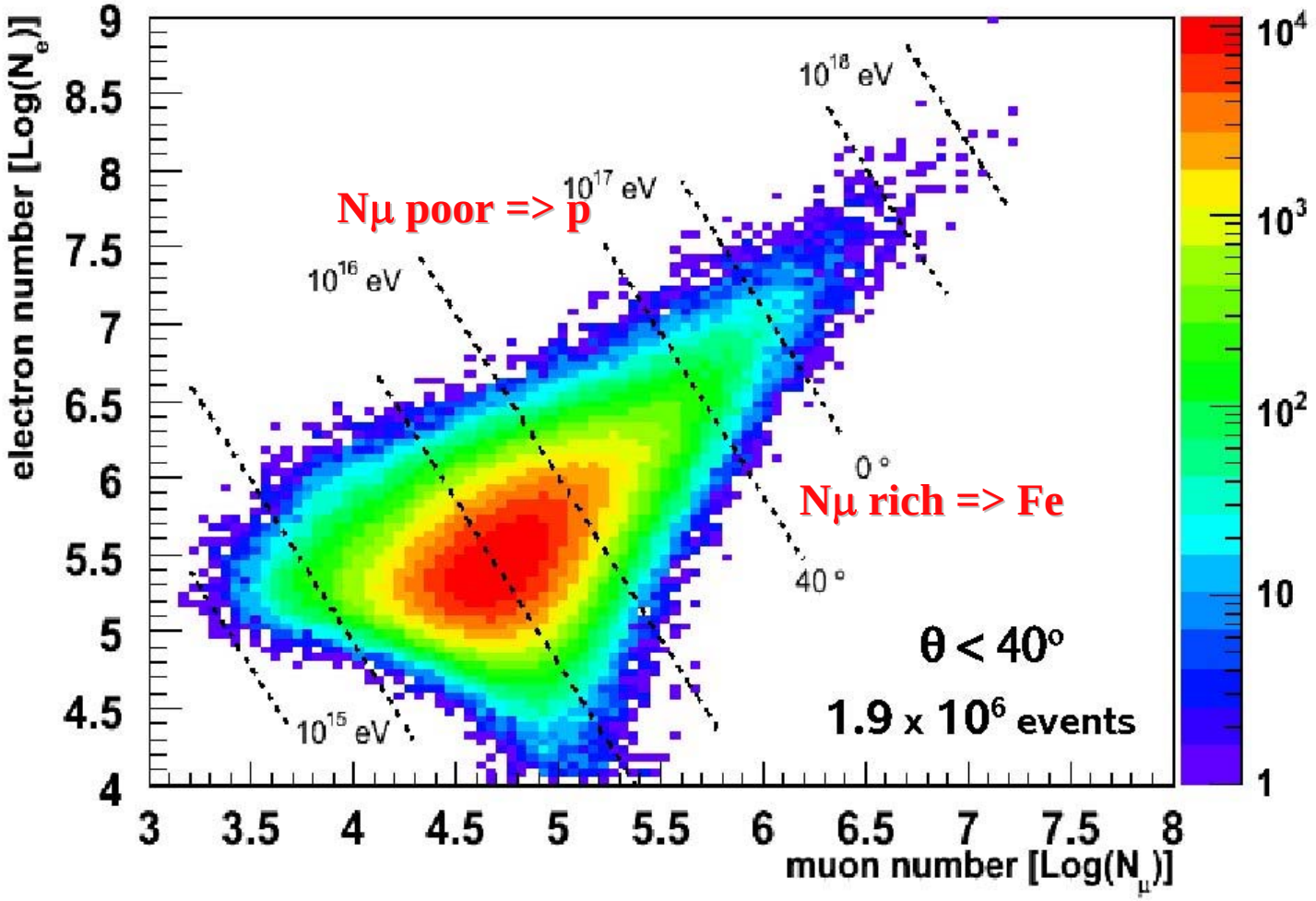


Angular resolution 0.35 deg

(800 MeV)



Basis for composition



SUMMARY

- KASCADE-Grande is in continuous and stable data taking since January 2004
- KASCADE-Grande data taking completed
- KASCADE-Grande results will cover whole “knee” range to find the iron-”knee”
- Different data analysis
- Physical results soon available