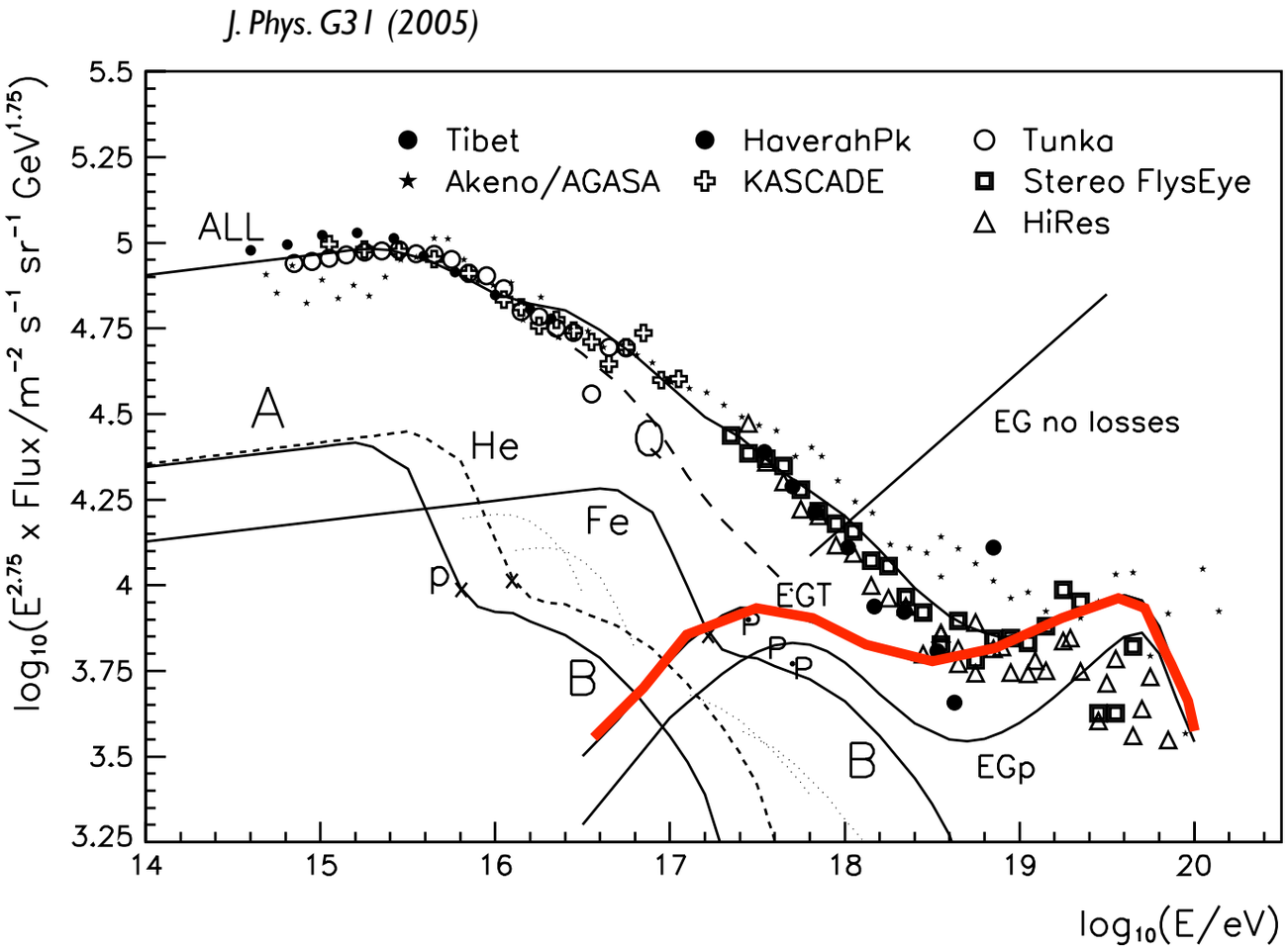
Auger Enhancement Projects:

AMIGA & HEAT

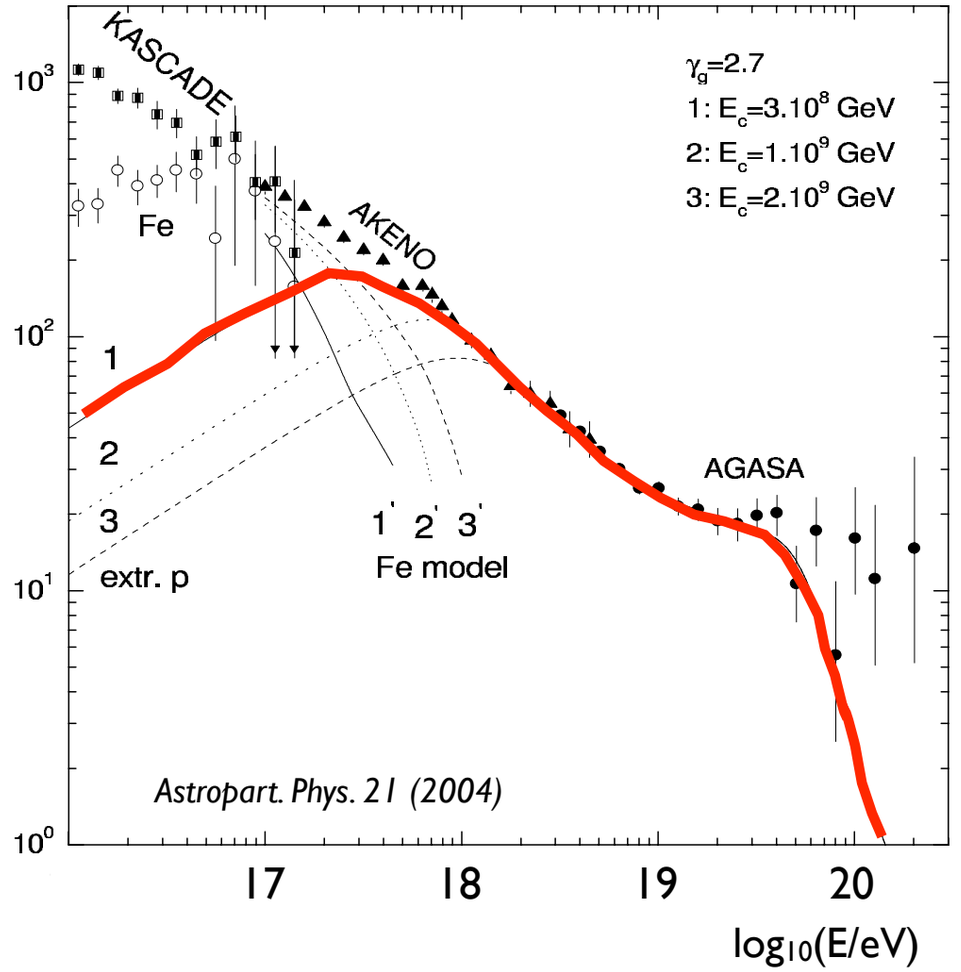
Ralph Engel, for the Pierre Auger Collaboration

Aspen Workshop on Cosmic Ray Physics, April 15 - 19, 2007

Physics motivation: sources



Hillas:
- Ankle is transition galactic to extragalactic cosmic rays
- Injection spectrum ***dN/dE ~ E$^{-2.3}$***

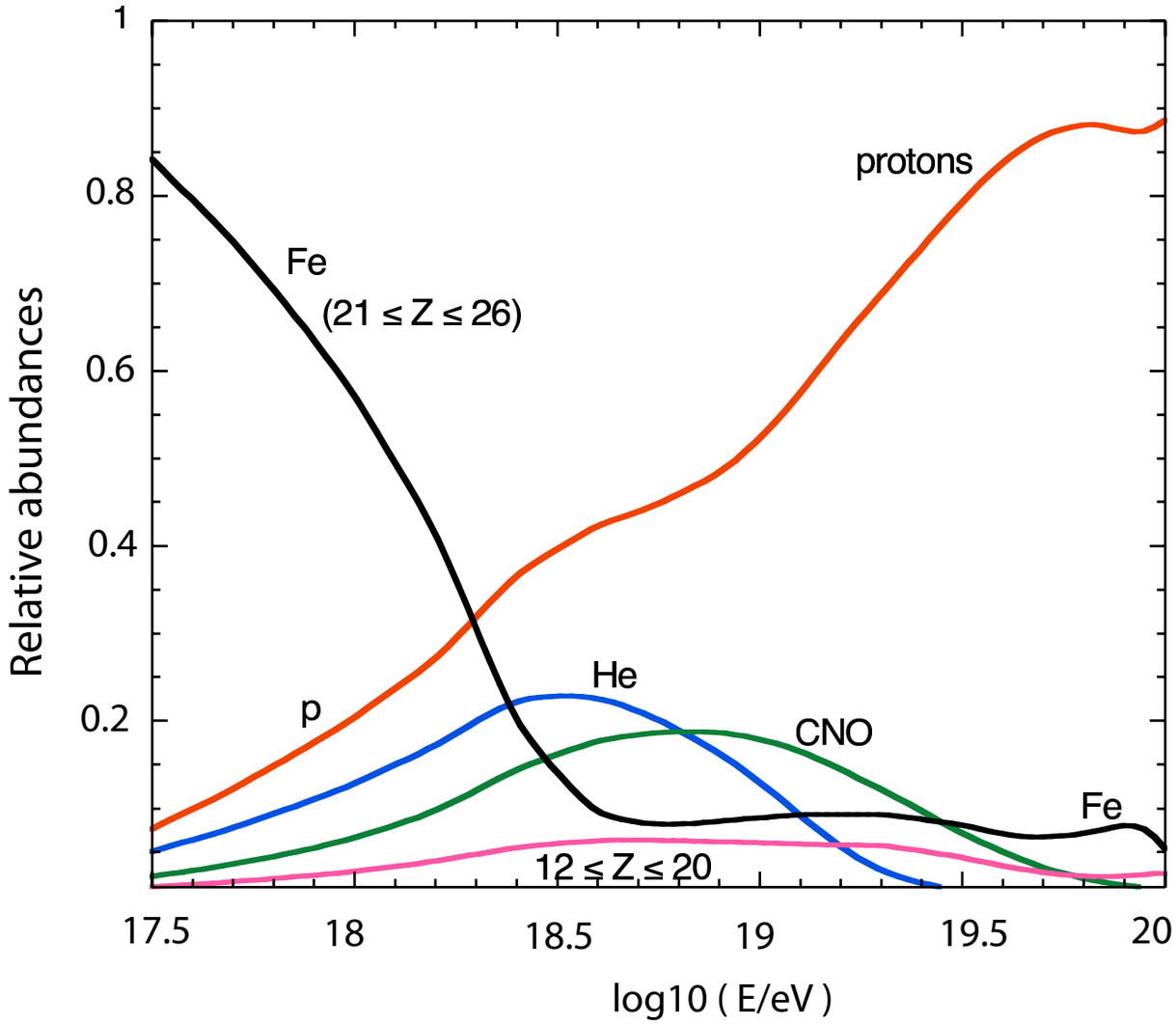


Berezinsky et al.:
- Ankle is feature due to extragalactic proton propagation
- Injection spectrum ***dN/dE ~ E$^{-2.7}$***

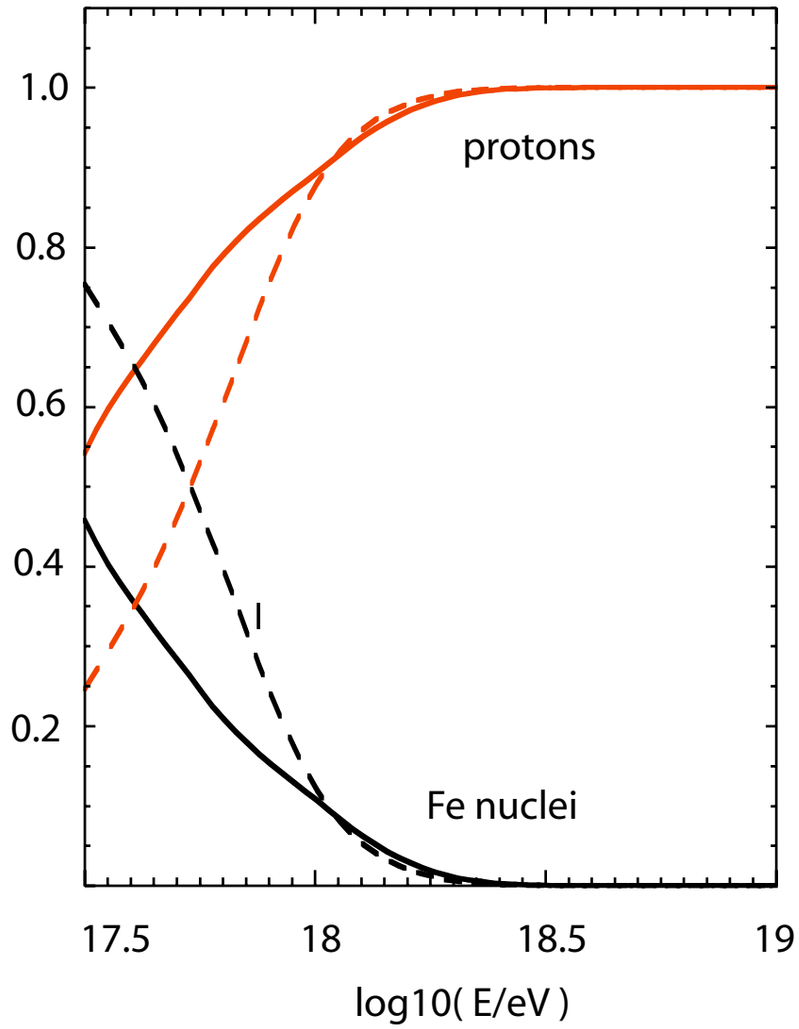
Flux very similar, composition different

Physics motivation: composition

Classic model of ankle



Pair-prod. model

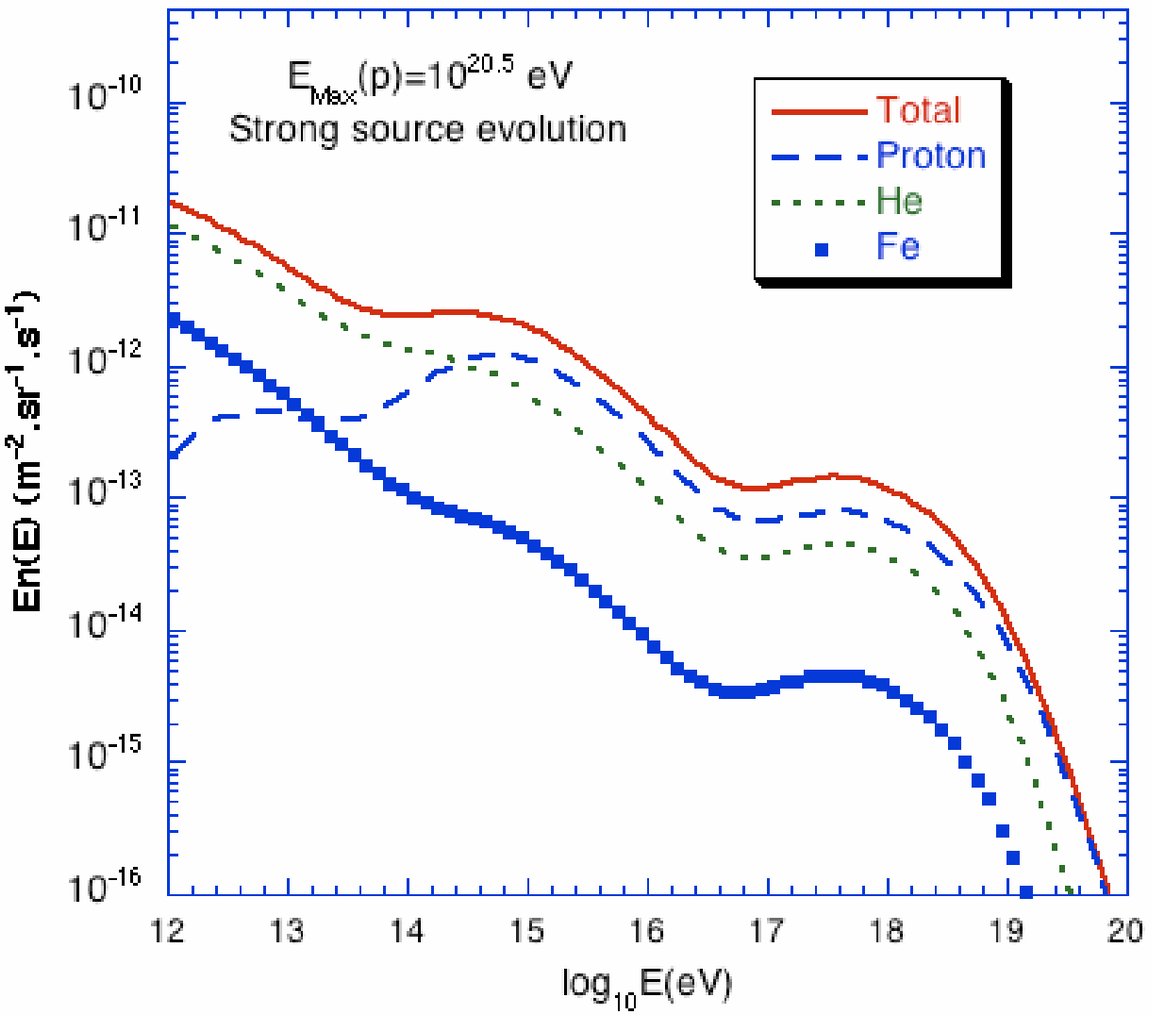


Measurement of composition at low energy (ankle region)

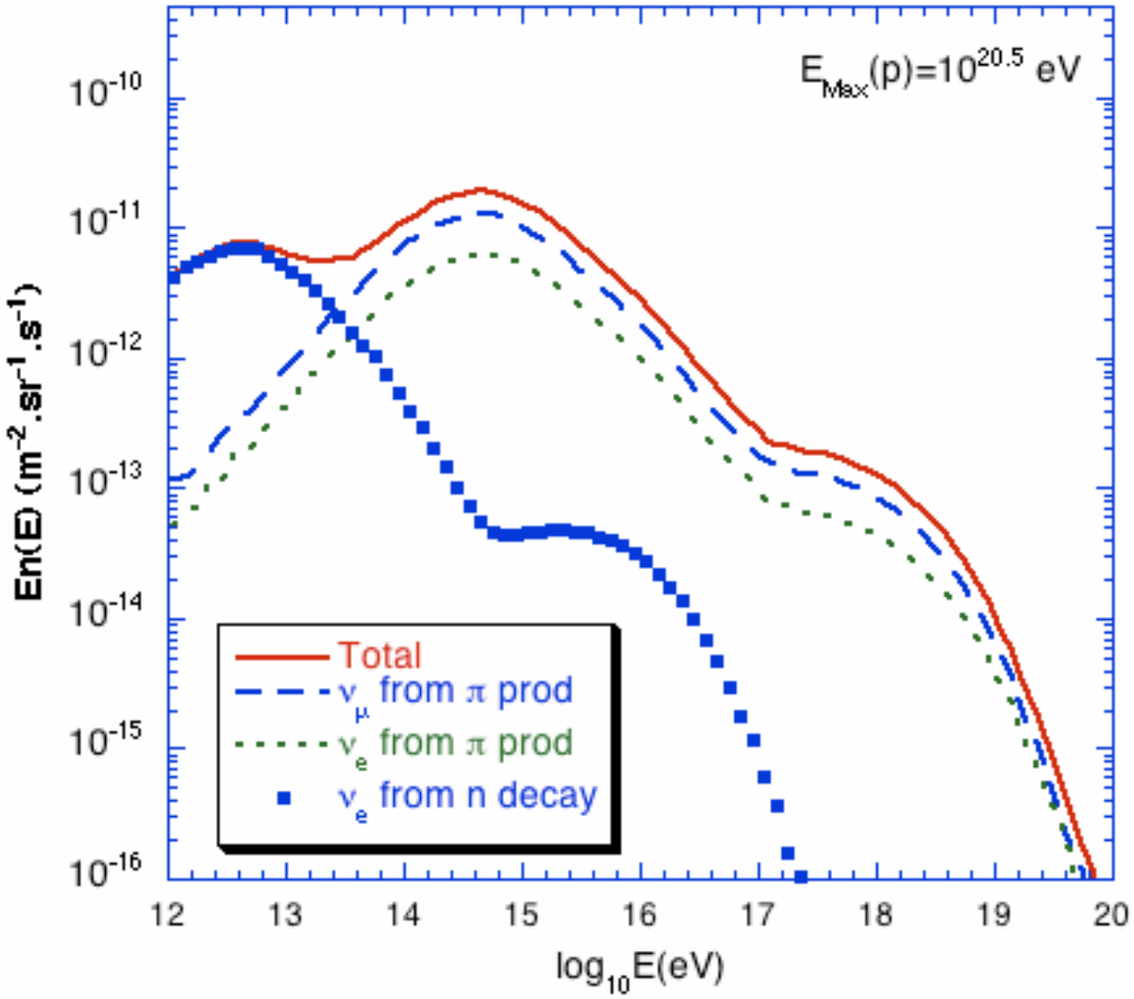
(Allard et al., 2005;Aloisio et al. 2006)

Physics motivation: secondary particles

Classic transition model



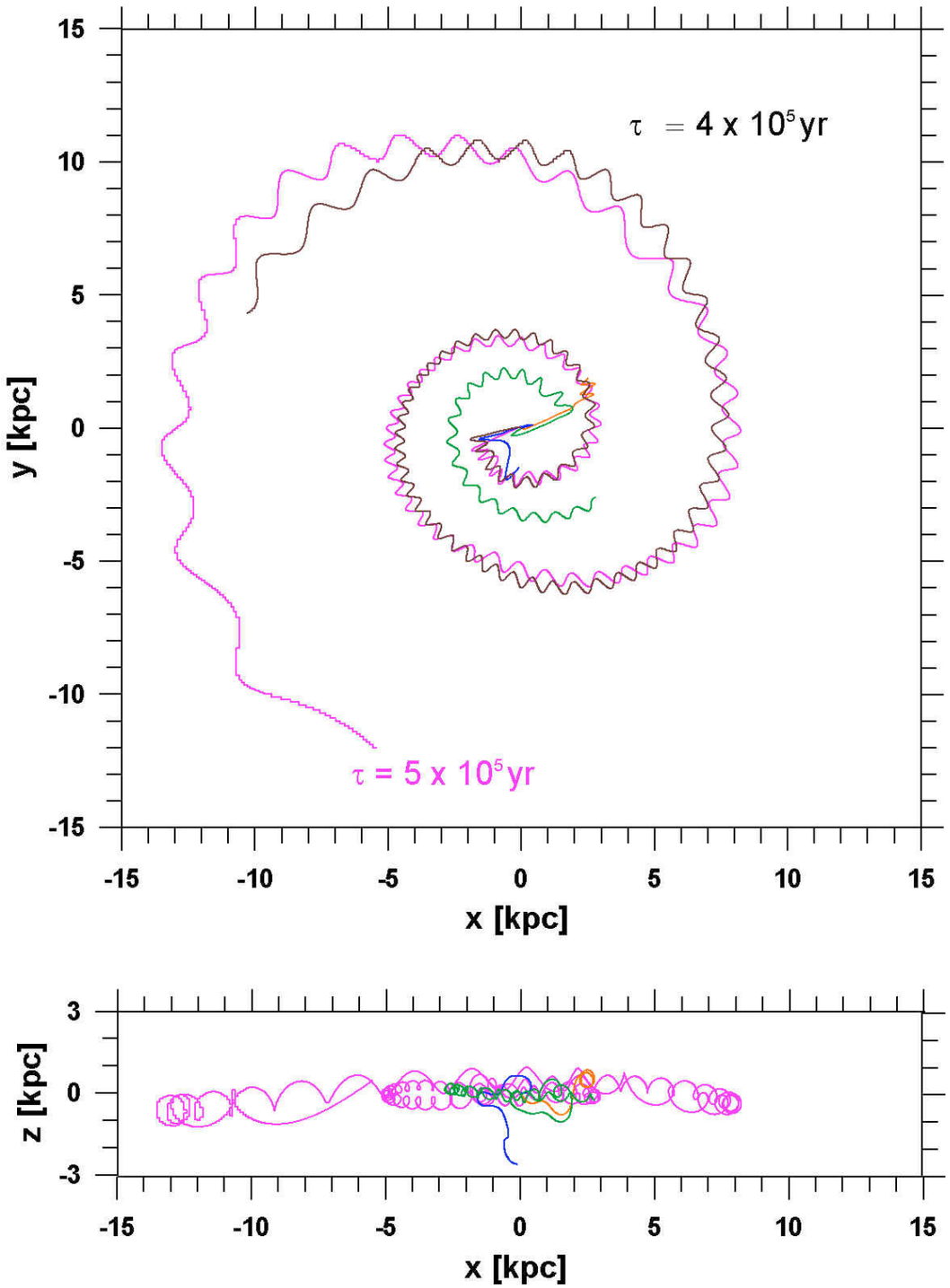
Pair-production model



Possible to measure with neutrino telescopes ?

(Seckel & Stanev PRL 2005; Allard et al., JACP 2006)

Physics motivation: propagation

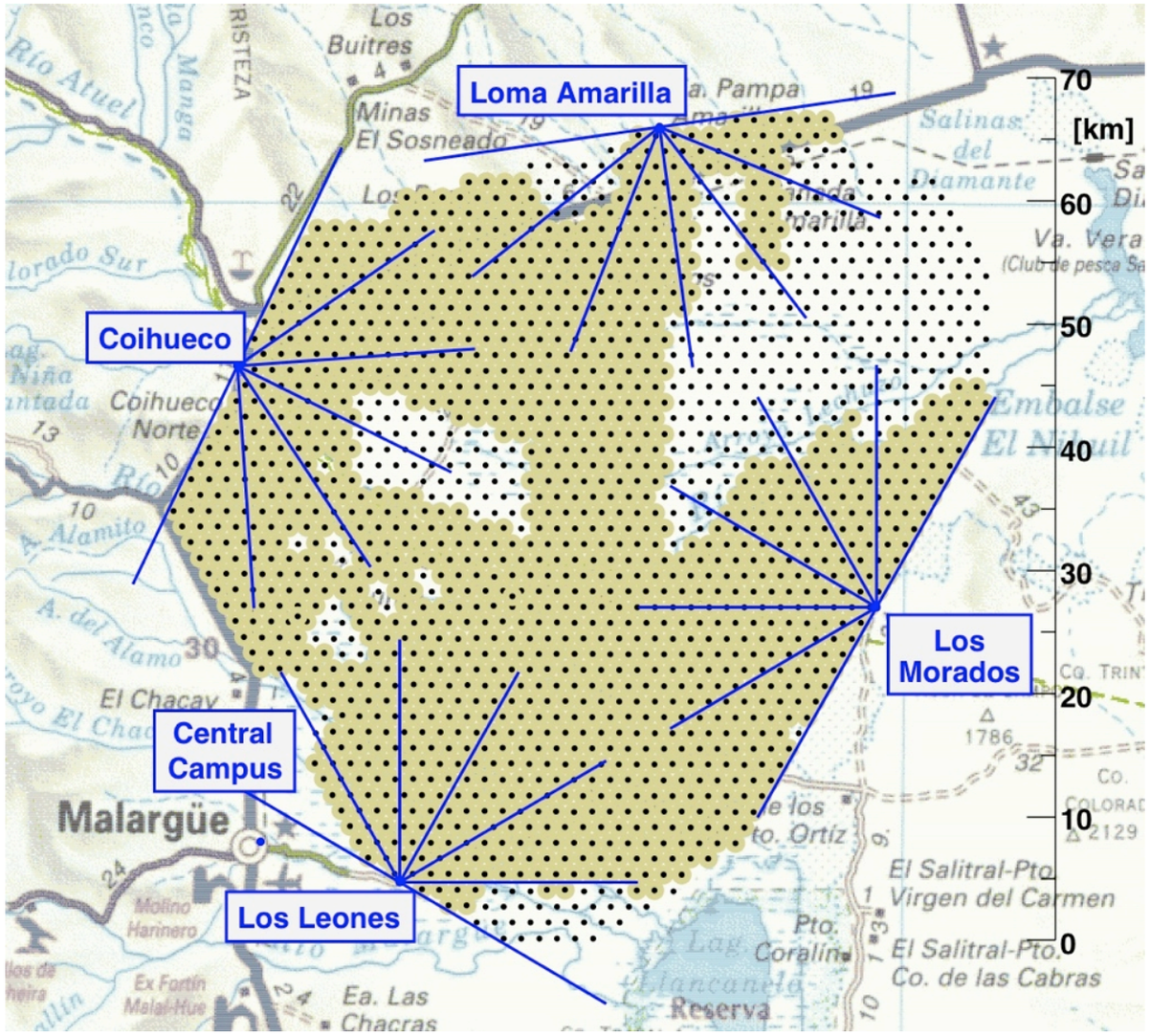


Propagation of 10^{18} eV proton in Galaxy (simulation without random component)

Anisotropies correlated with composition?

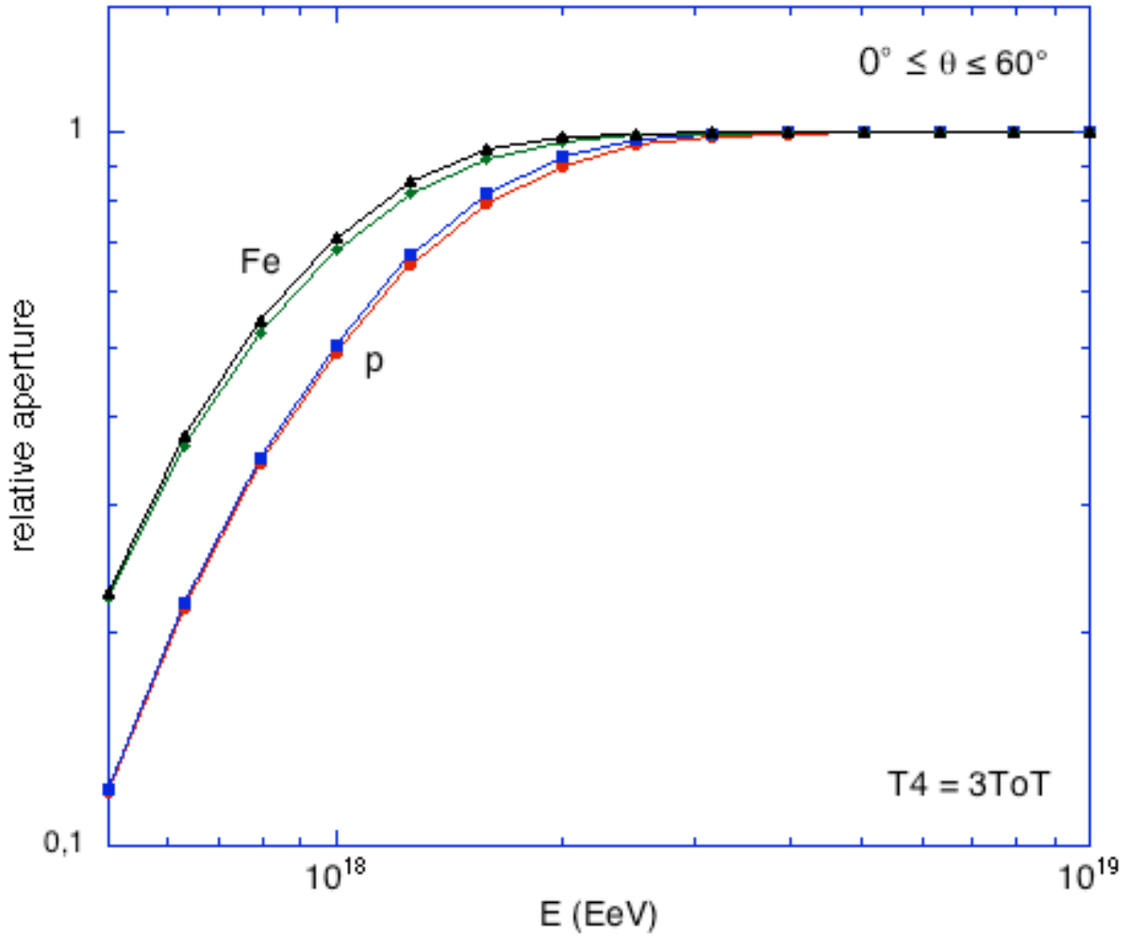
(Medina Tanco & Watson, ICRC 2001)

Current surface detector threshold



(March 2007: ~ 1300 of 1600 SD tanks)

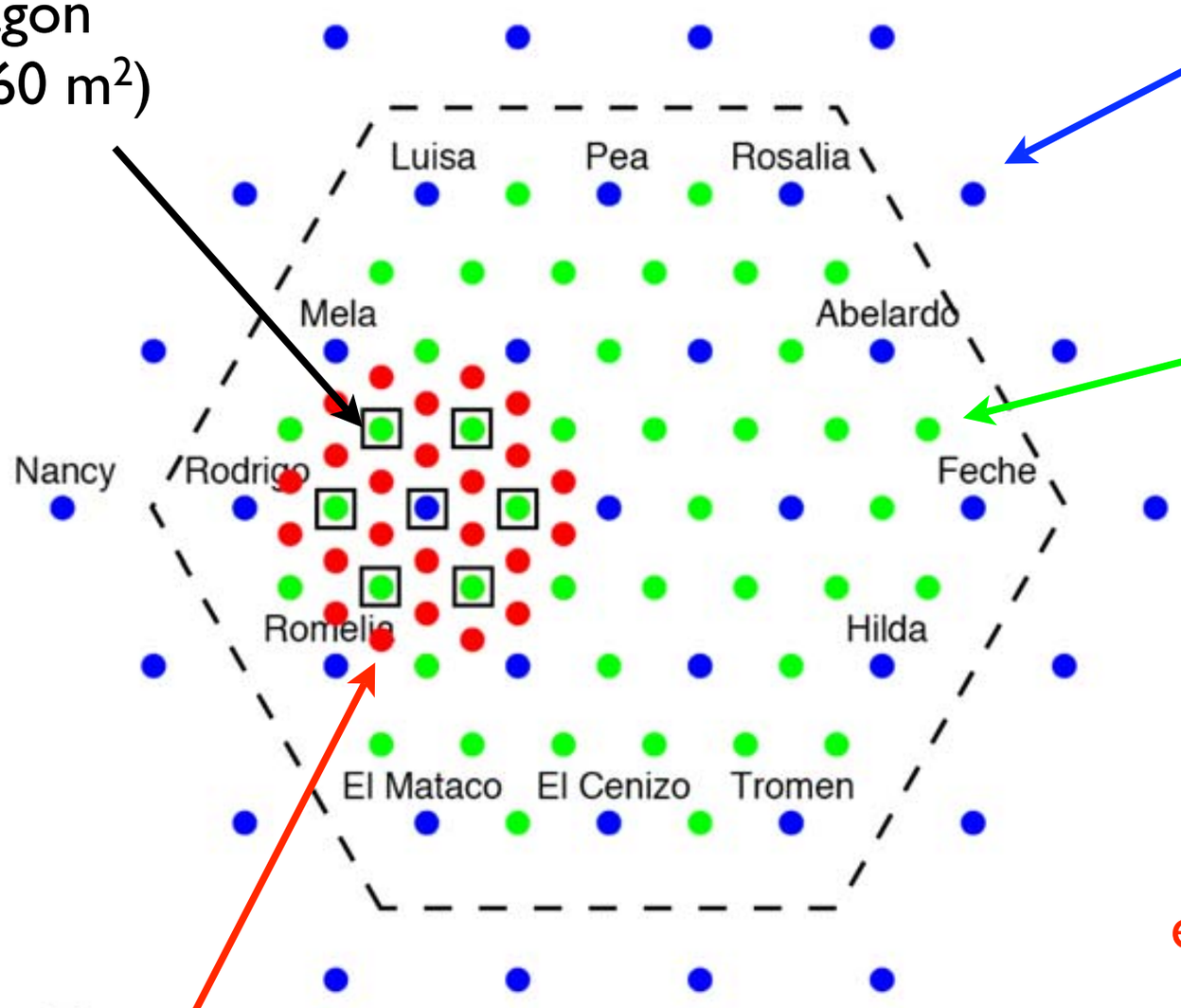
Simulated acceptance



Auger SD array 1500m

AMIGA infill tanks and muon counters

Hexagon
(7 x 60 m^2)

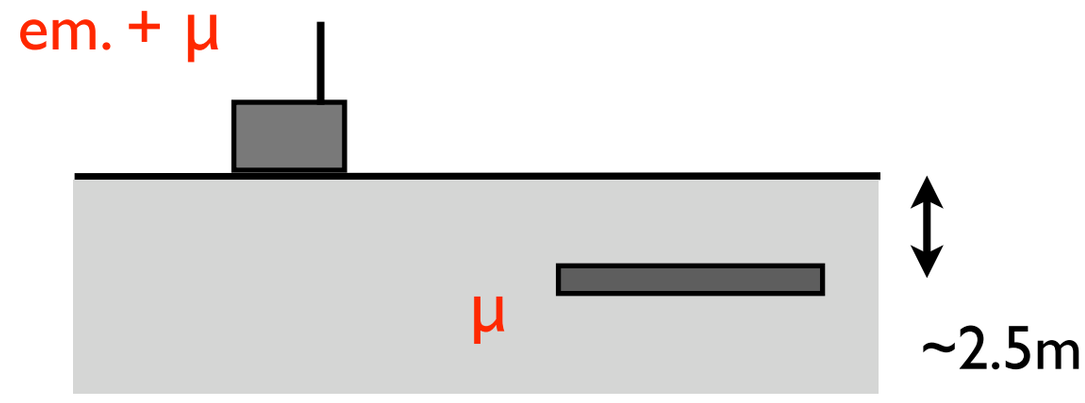


Existing tank array 1500m

Infill array 750m

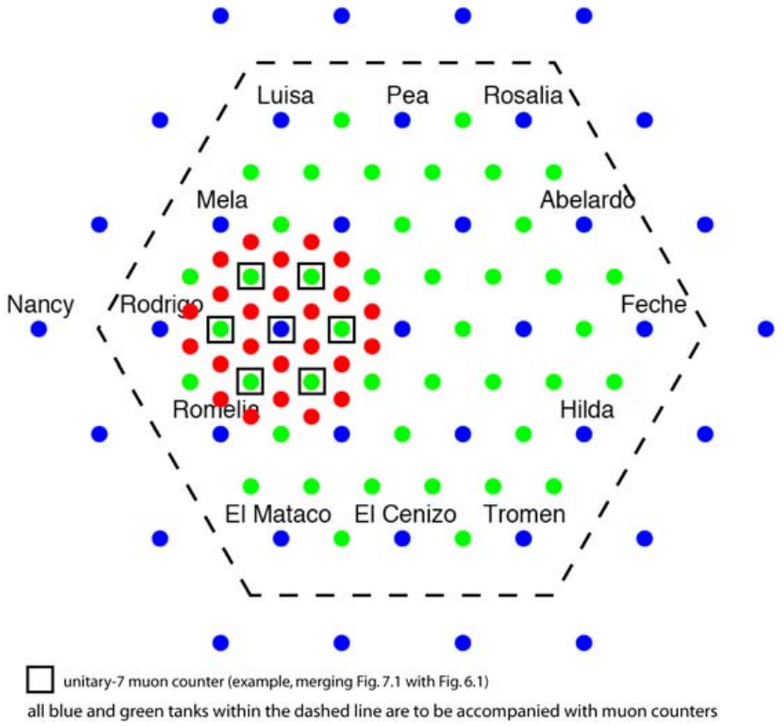
Infill array 433m
Area ~ 5.9 km^2

Muon detectors:
54 (30m^2) + 7 (60m^2)
Cherenkov tanks: 61
Area ~ 23 km^2

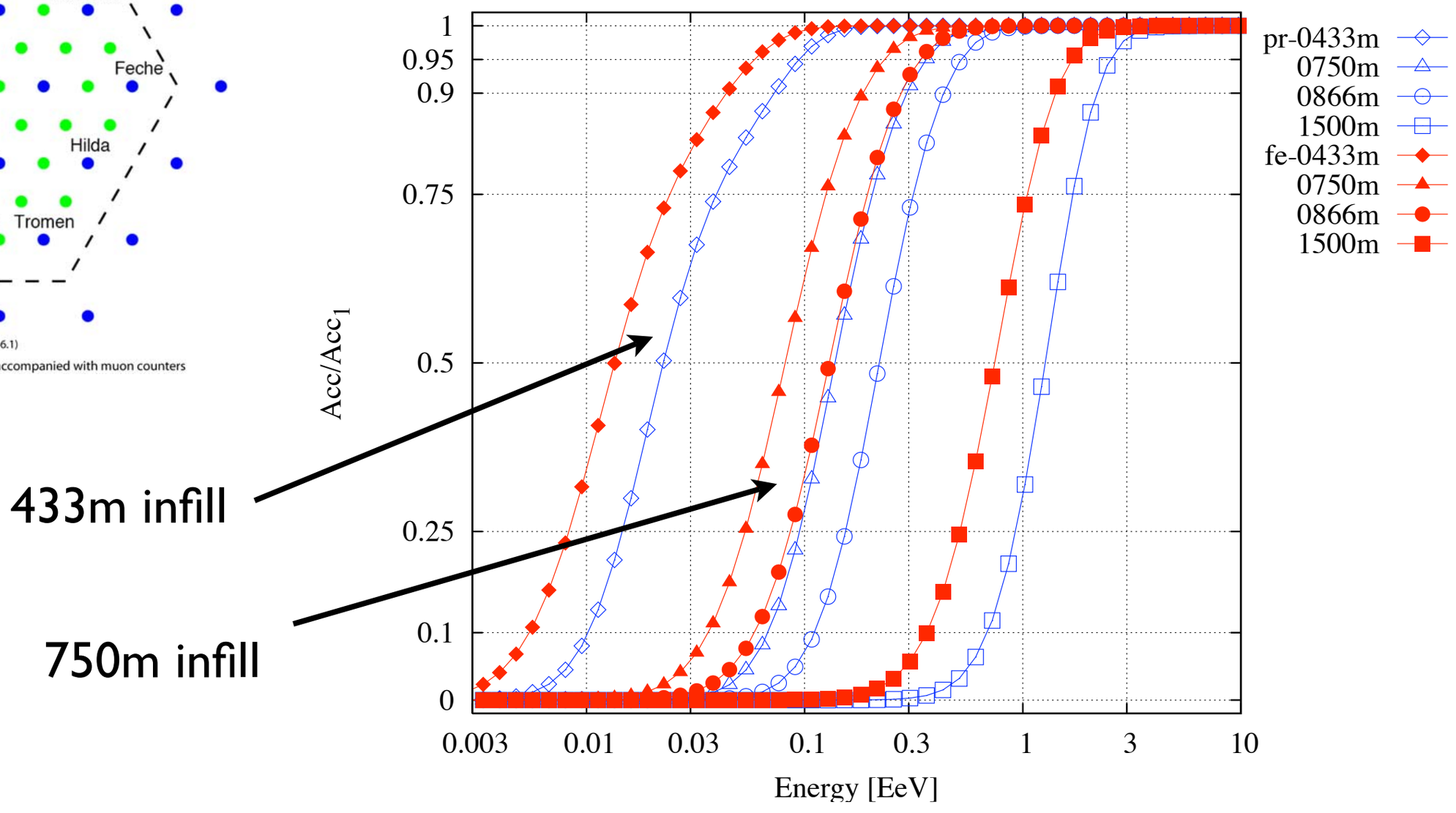


Detector pairs

AMIGA energy threshold



Acceptance for infill Cherenkov tank array



Event rate:

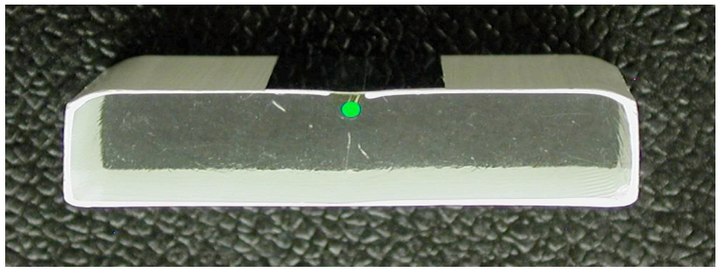
$$N(E > E_0) = 530 \left(\frac{A}{20\mathrm{km}^2} \right) \left(\frac{10^{18}\,\mathrm{eV}}{E_0} \right) \mathrm{yr}^{-1}$$

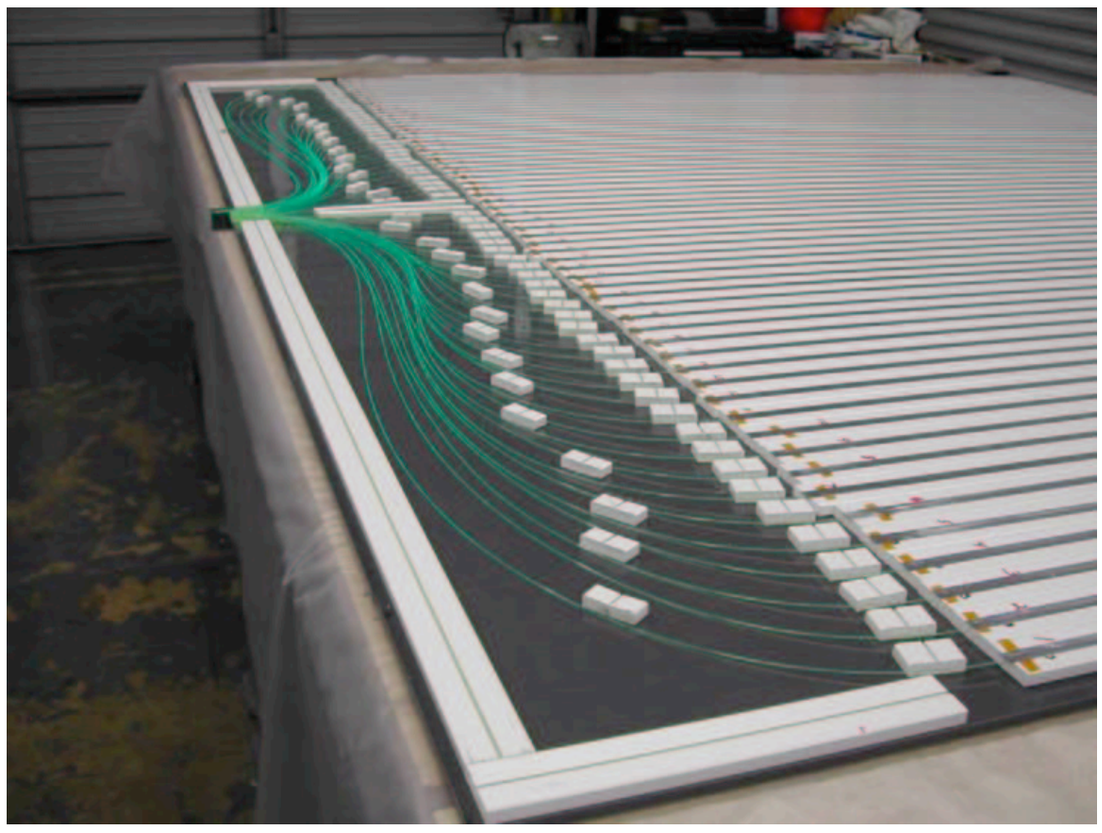
(Medina et al., astro-ph/0607115)

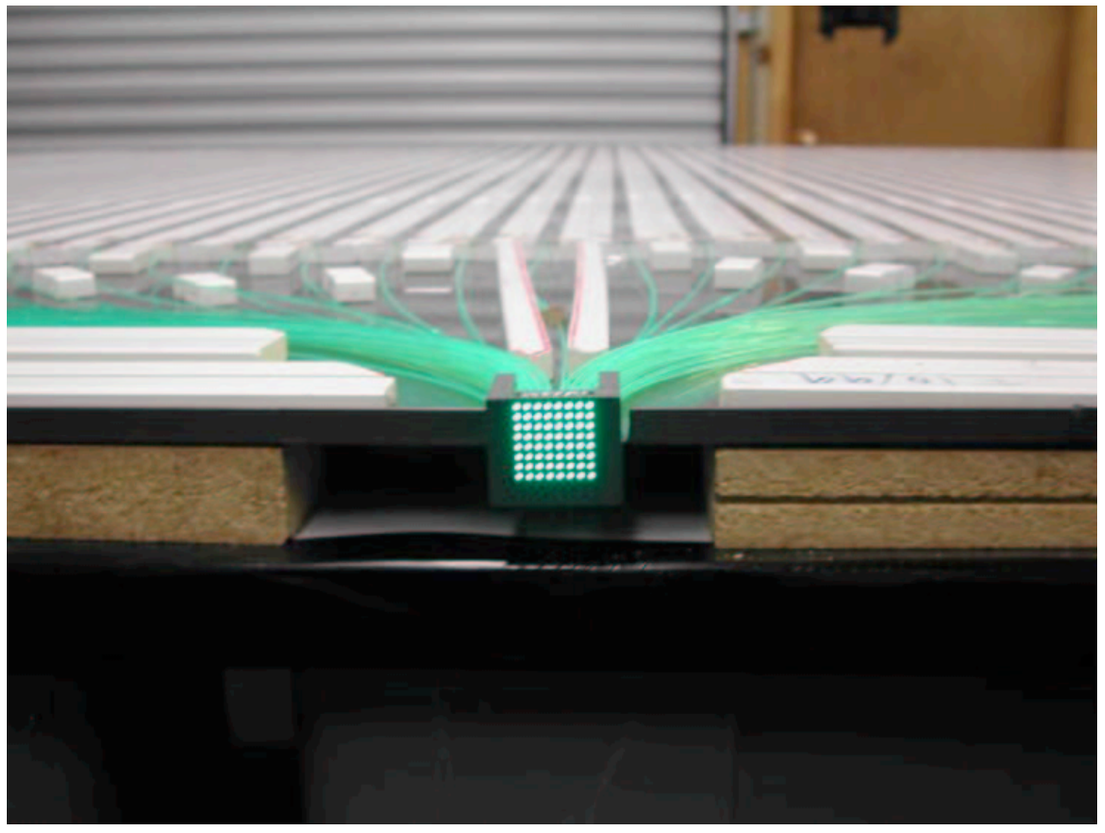
AMIGA scintillator design (i)

Extruded polystyrene doped with fluors,
14 pe per passing muon

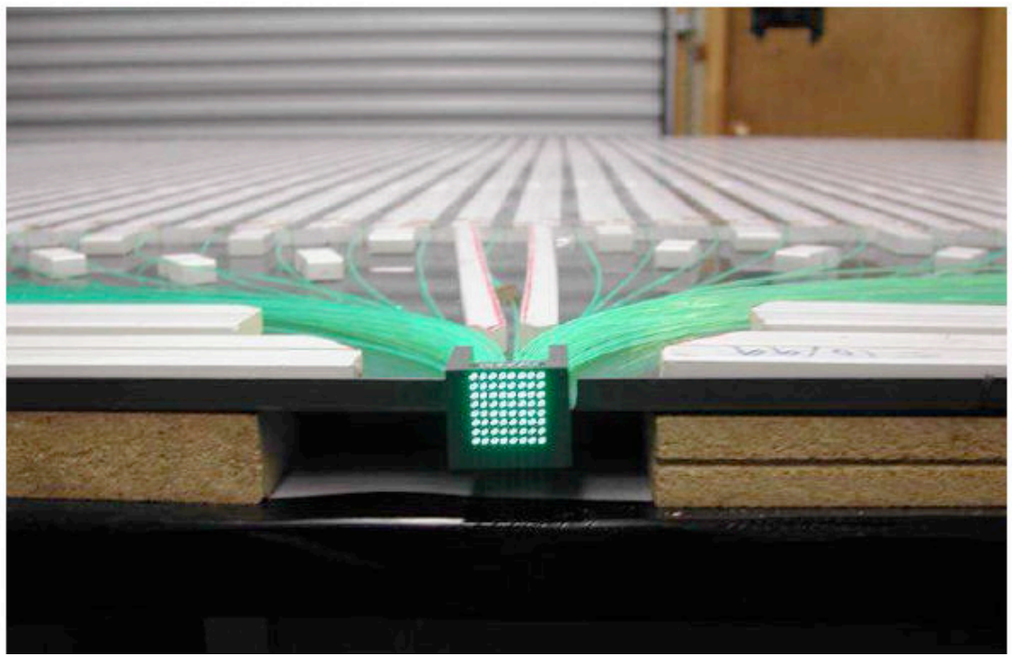
MINOS-type scintillators





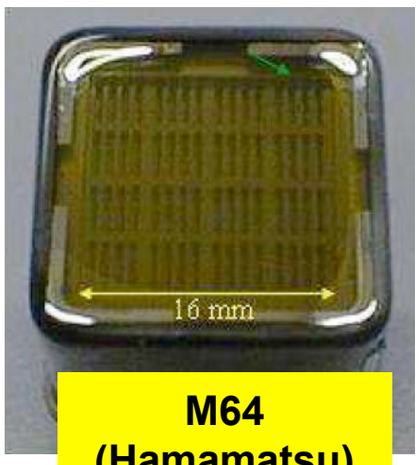


AMIGA scintillator design (ii)



Detector station:

- 3 multi-anode PMTs
- 4m long strips
- PVC housing
- 25 ns, 7 bit electronics
- area ~ 31.5m^2



M64
(Hamamatsu)

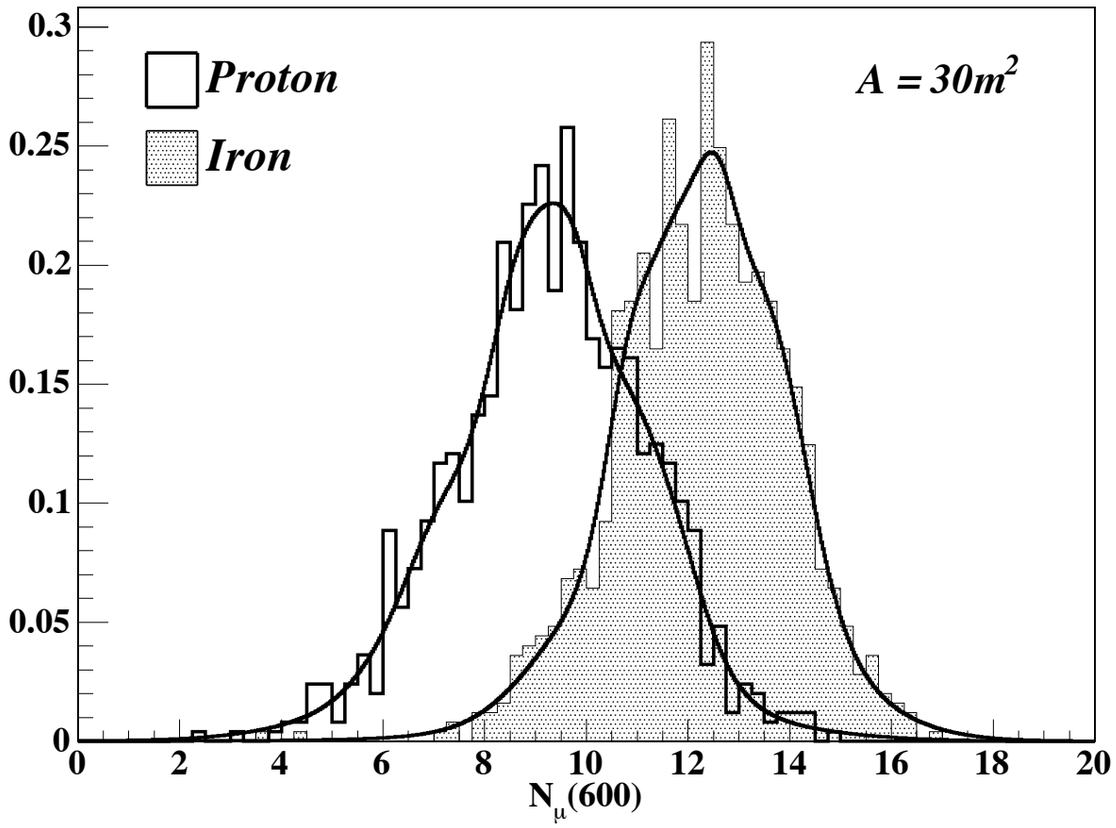
Multi-anode PMT:

- 64 pixels (2 x 2 mm^2)
- gain 10^6
- QE 13.5% at 520 nm

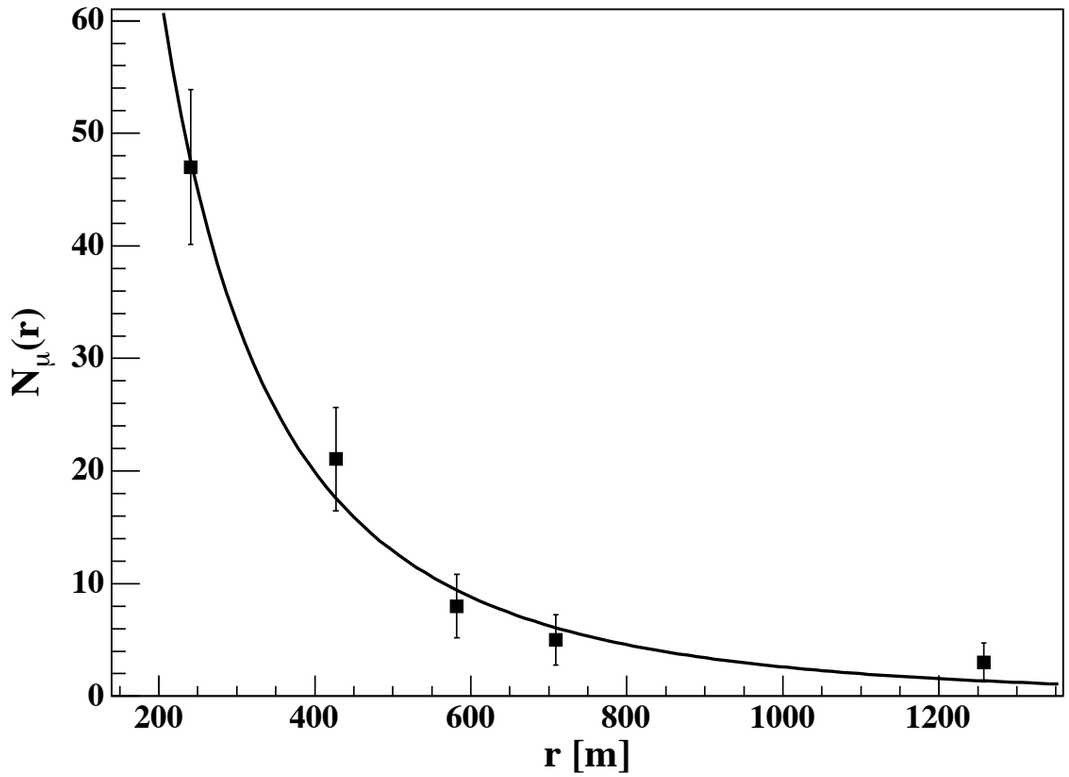
3 m deep hole: no water

Expected performance of muon detectors

Reconstructed muon count rates
for 10^{18} eV showers at 30°



Example:
reconstructed muon lateral
distribution (p, 10^{18} eV, 30°)

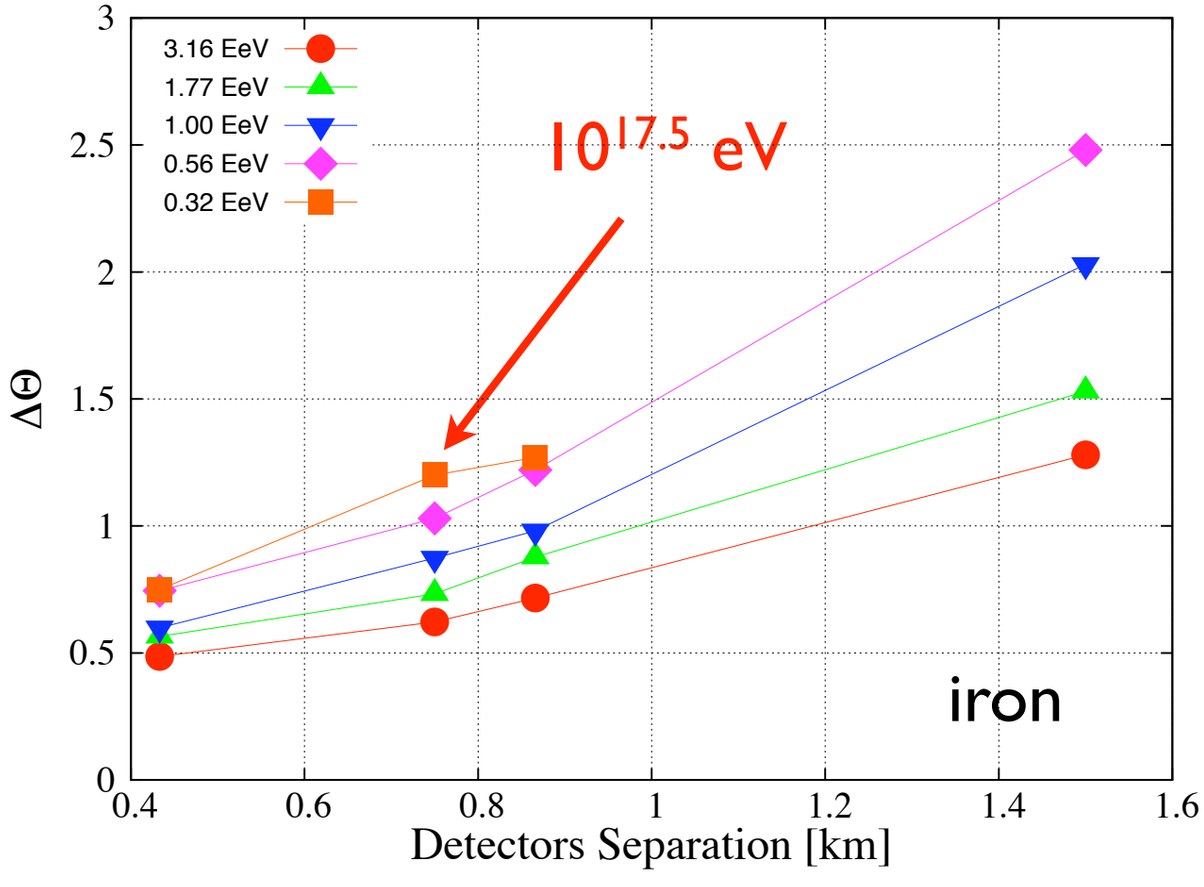


5000 events / year with E > $10^{17.5}$ eV

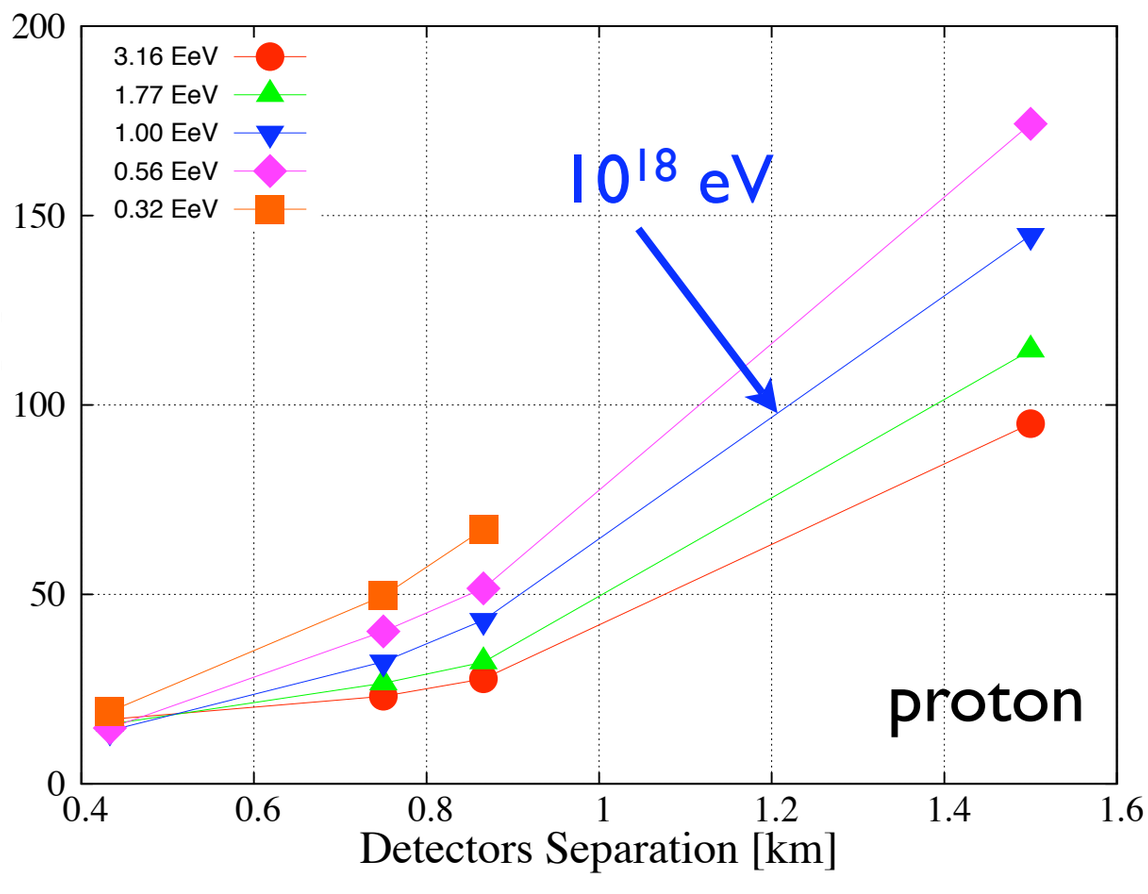
Improved shower reconstruction

Examples: simulations for proton and iron showers at 30°

Arrival direction reconstruction

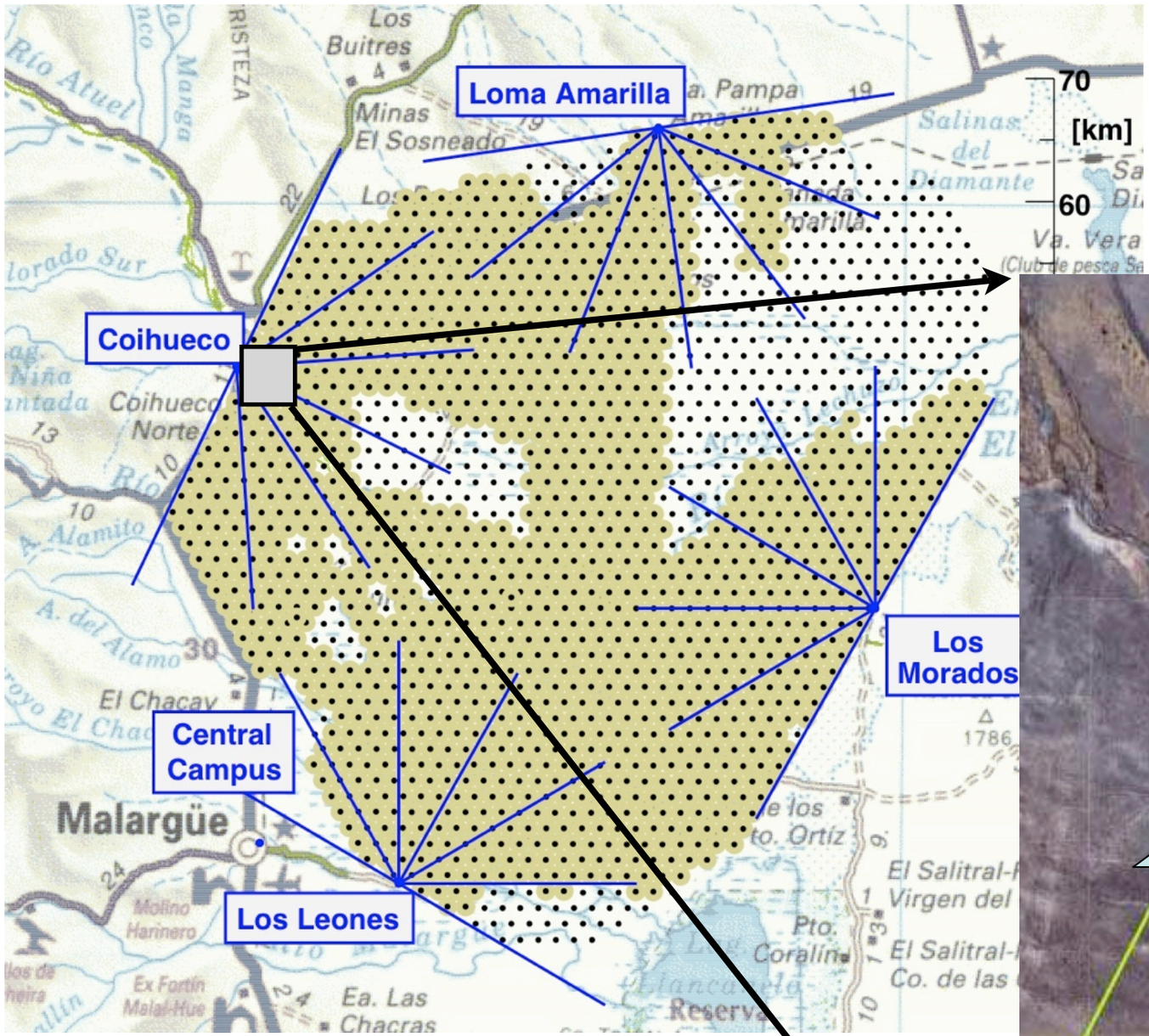


Core position reconstruction

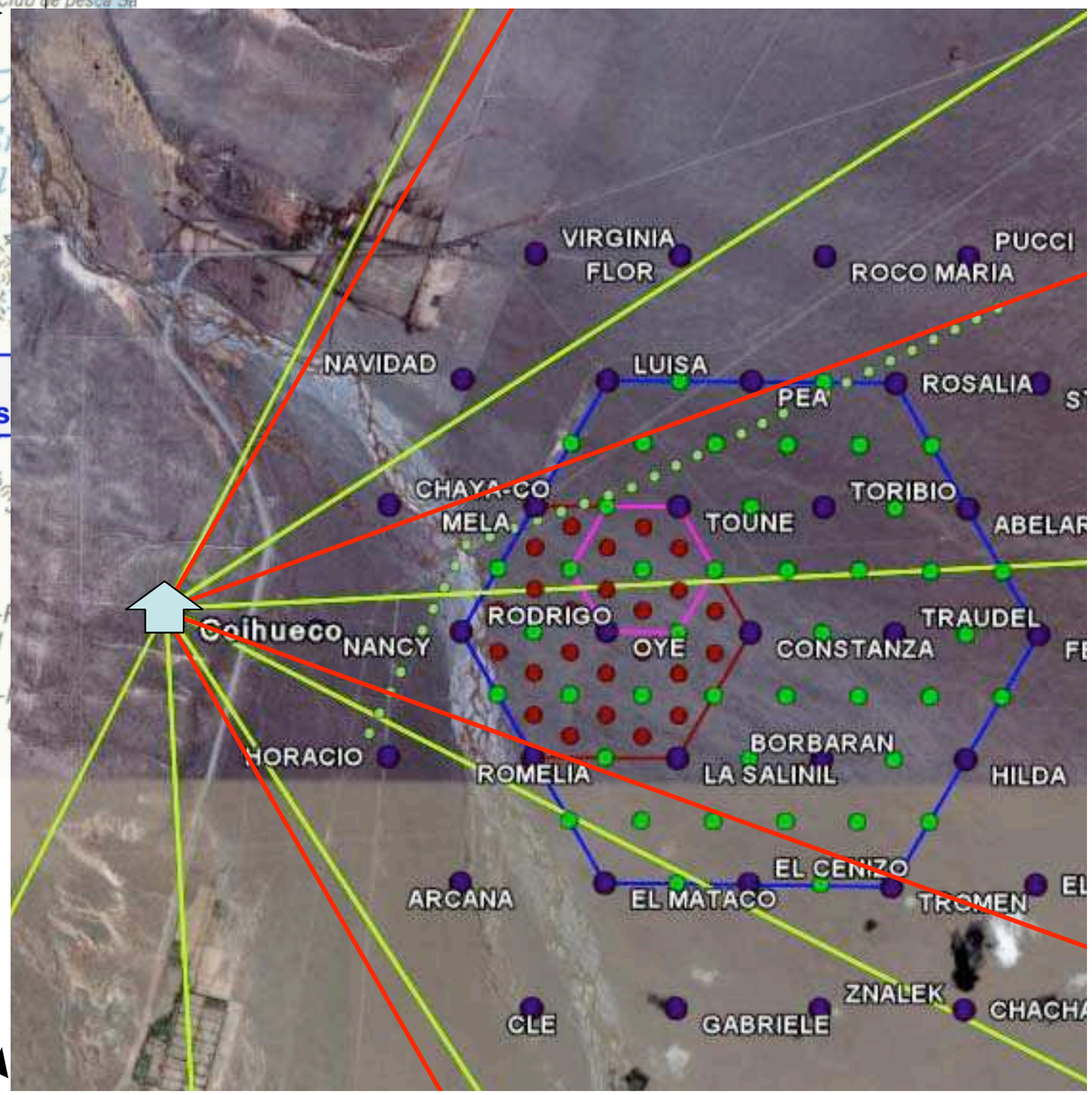


(Medina et al., astro-ph/0607115)

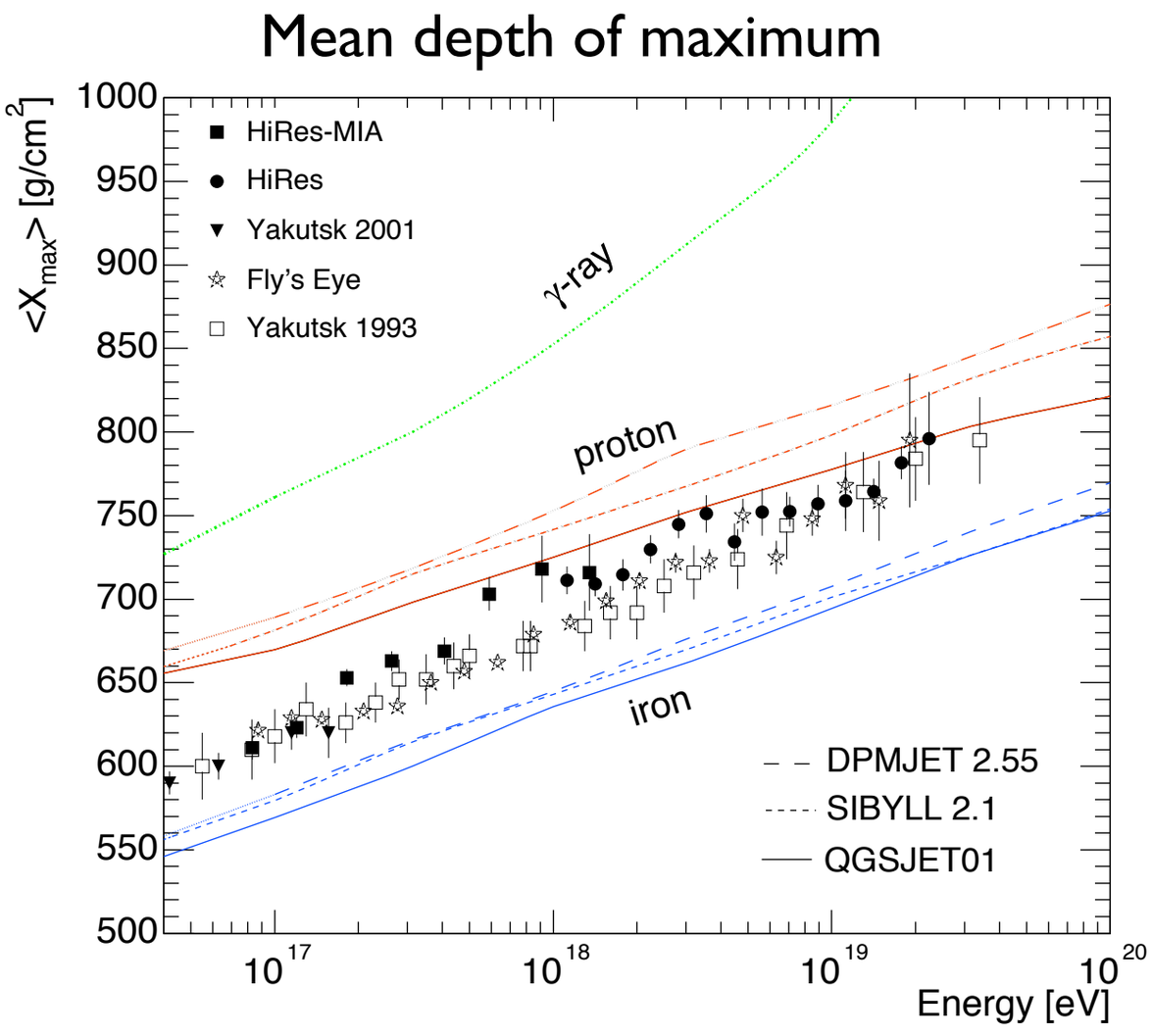
Layout of AMIGA subarray detectors

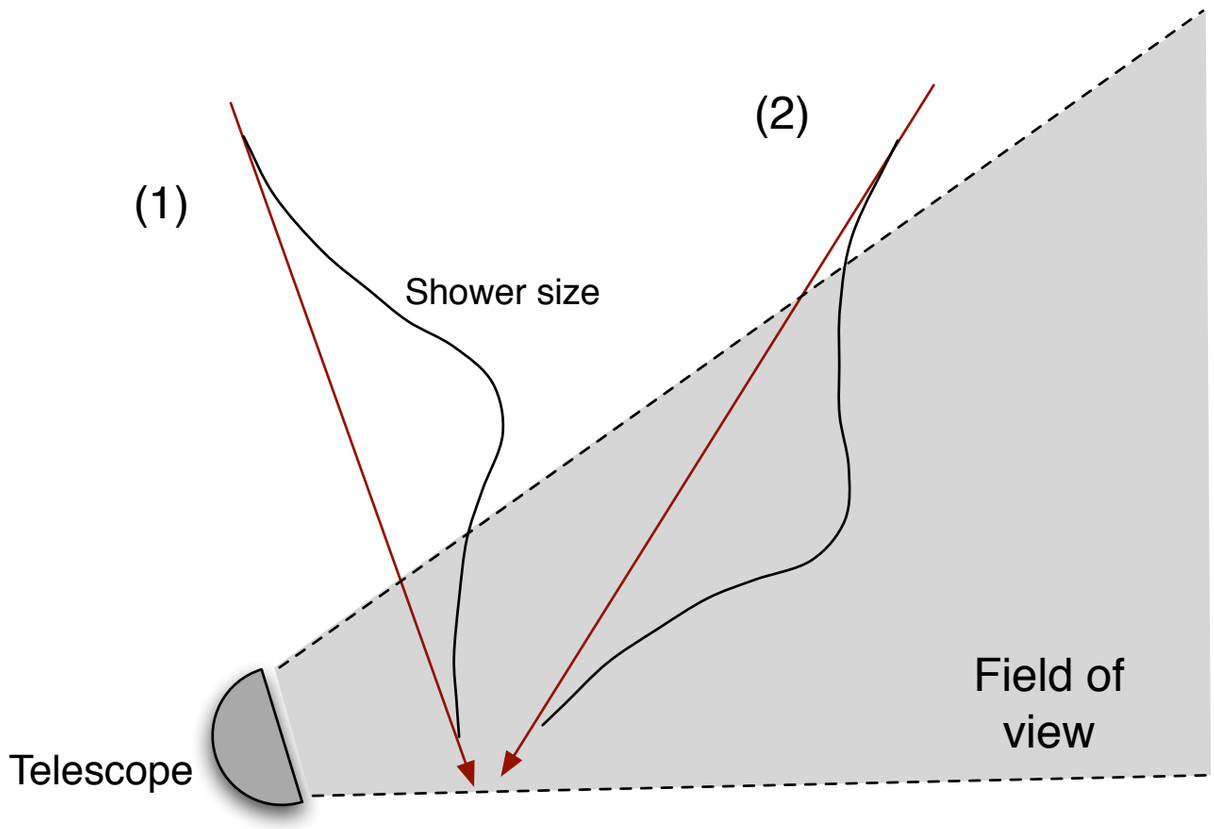


7 km



HEAT (High Elevation Auger Telescopes)

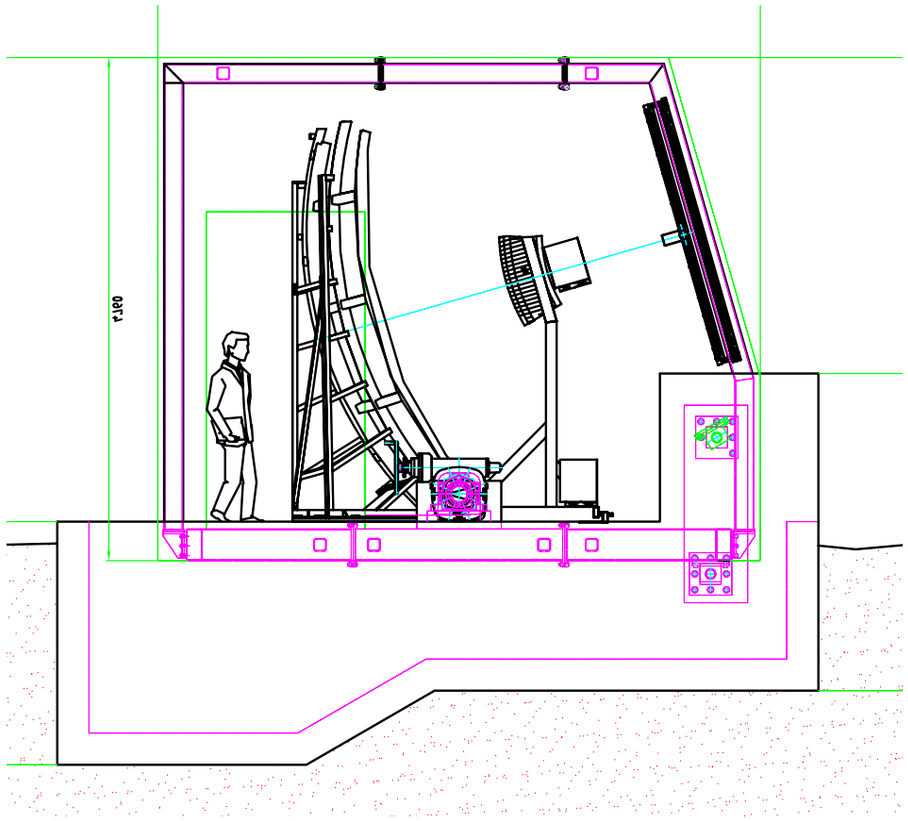




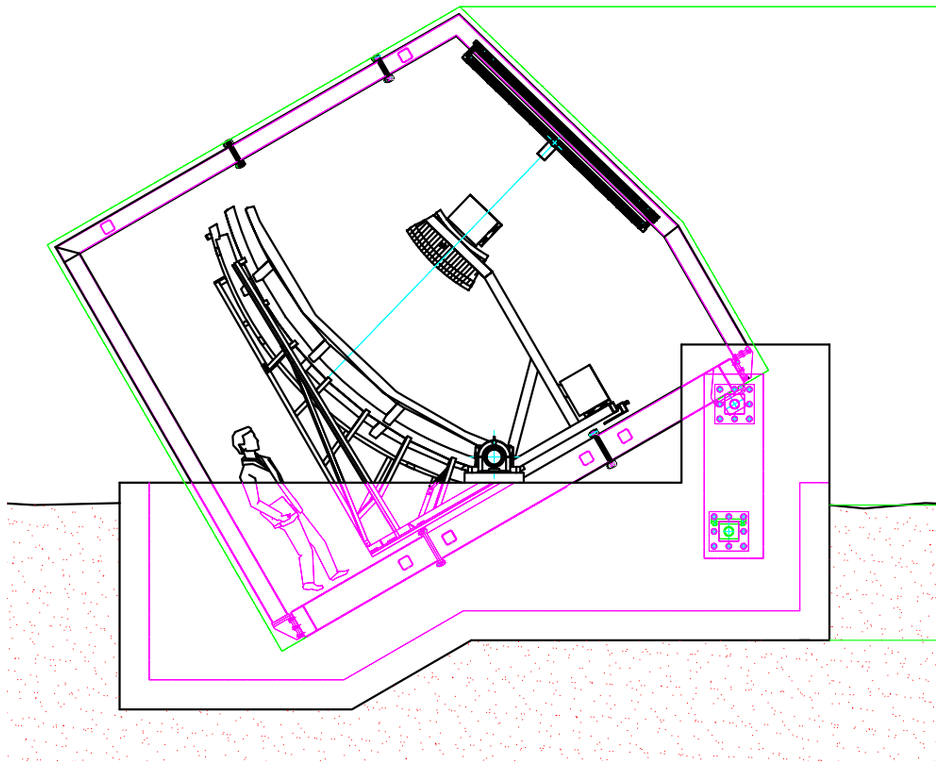
Auger fluorescence telescopes:
1 - 30° FoV (elevation angle)

Xmax of low-energy showers seen only at large distance

HEAT telescope design

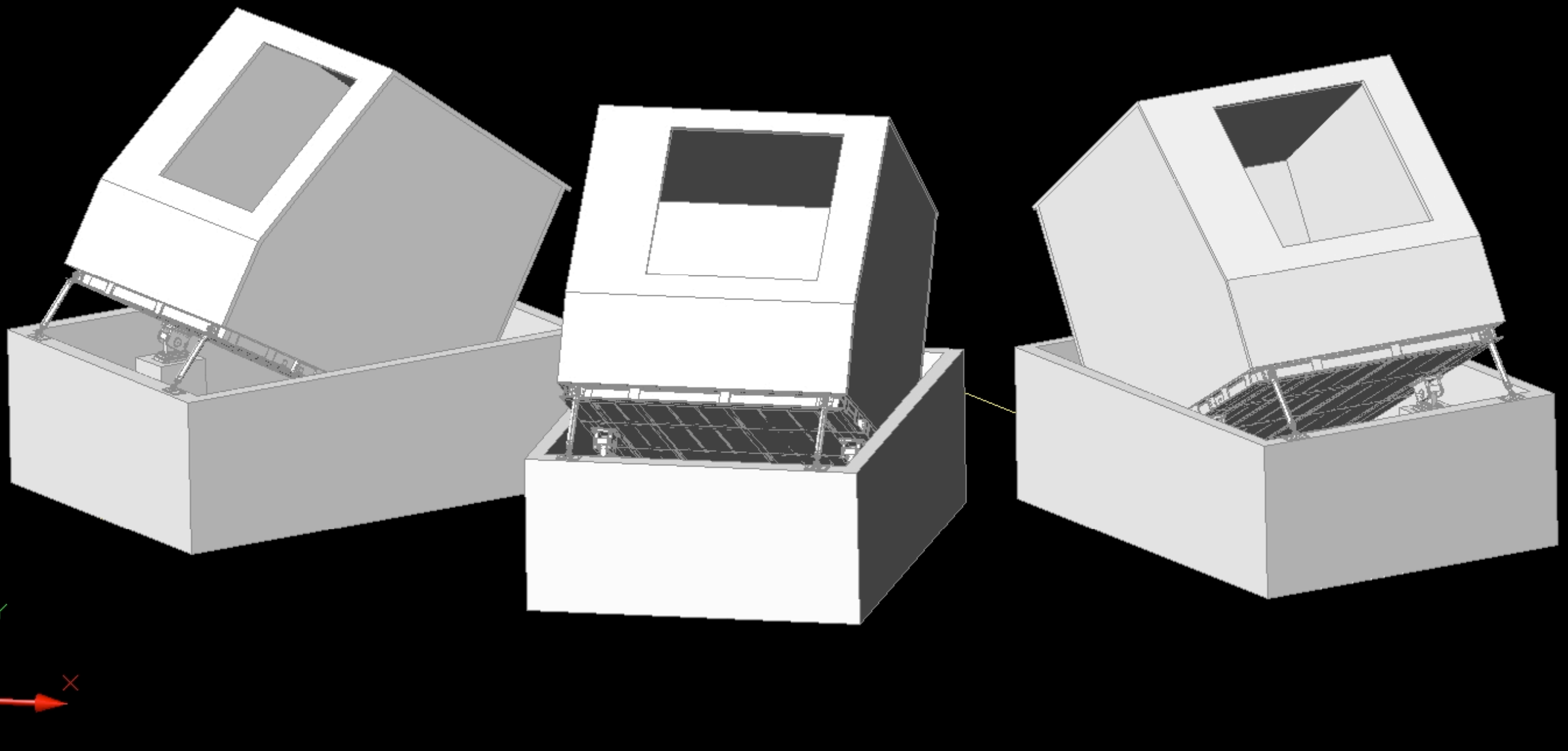


Calibration & maintenance position

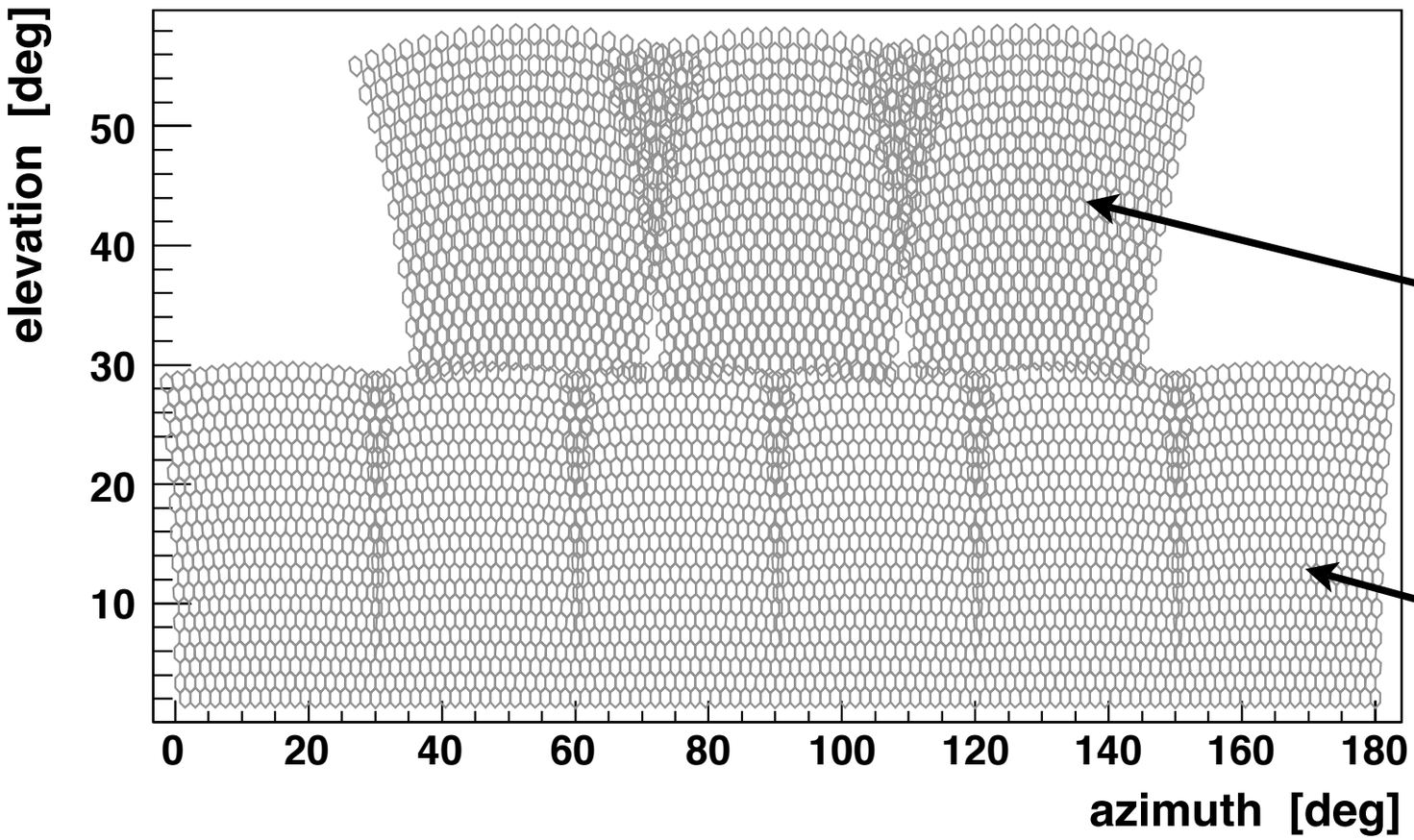


Data taking position

- 3 ``standard´´ Auger telescopes tilted to cover 30 - 60° elevation
- Custom-made metal enclosures
- Prototype studies for northern Auger Observatory


Y
X

Combined field of view

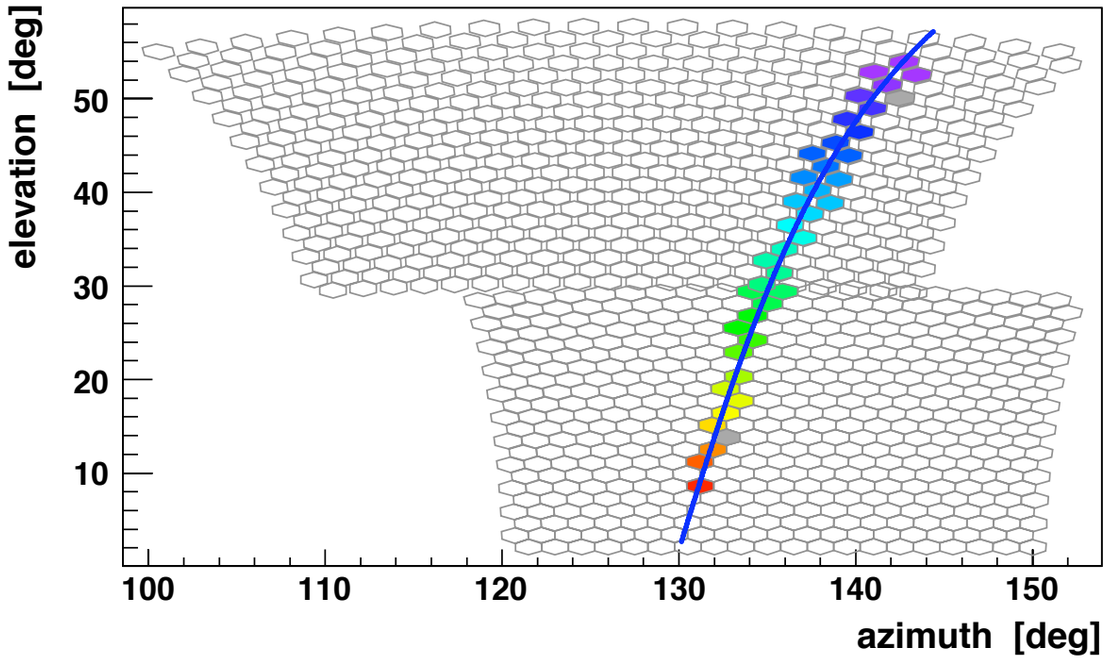


HEAT telescopes (40° separation)

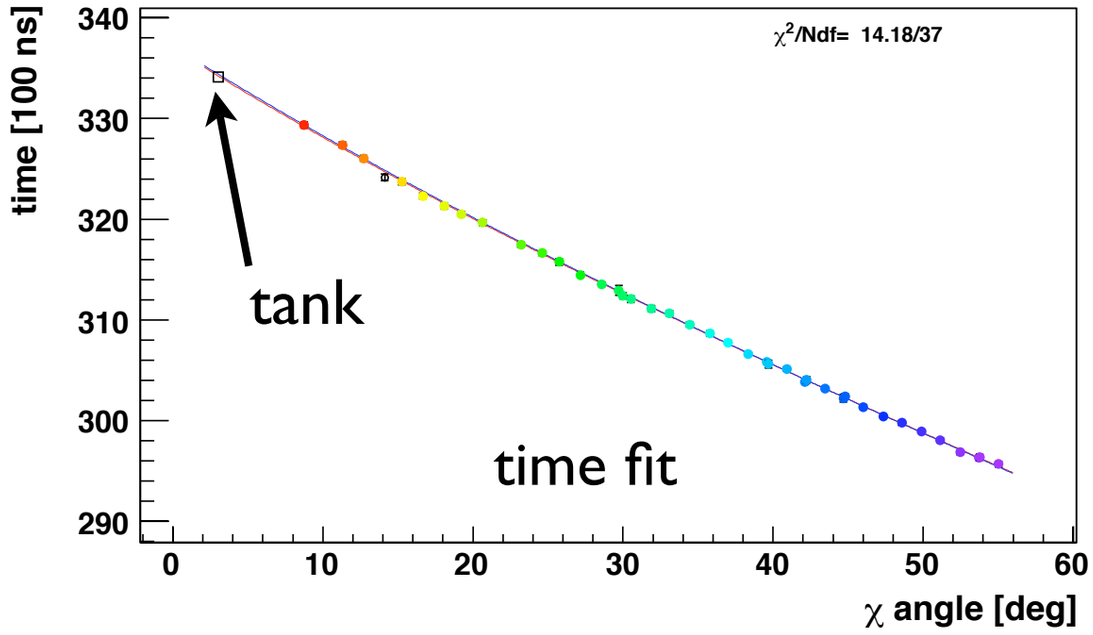
Standard Auger telescopes

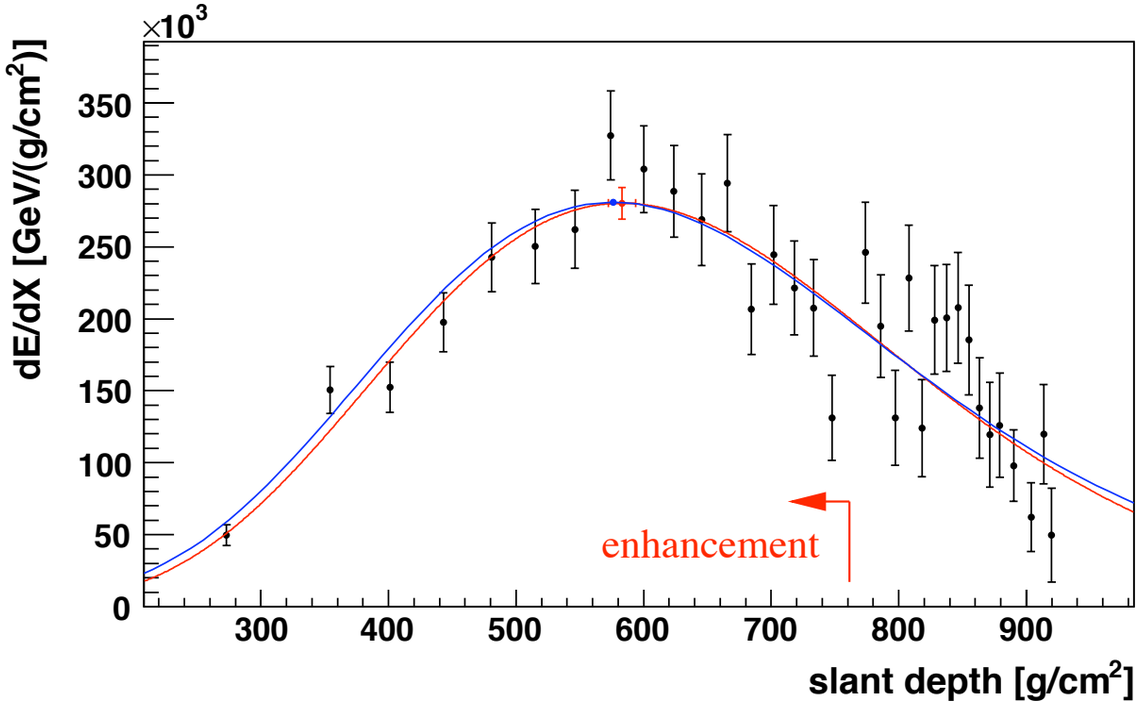
Hybrid event rate with AMIGA (750m):
~200 high quality events / year in energy region ~10^{18} eV

Example: simulated nearby event



Simulated shower with core distance
R_p = 1.2 km, E = $10^{17.25}$ eV





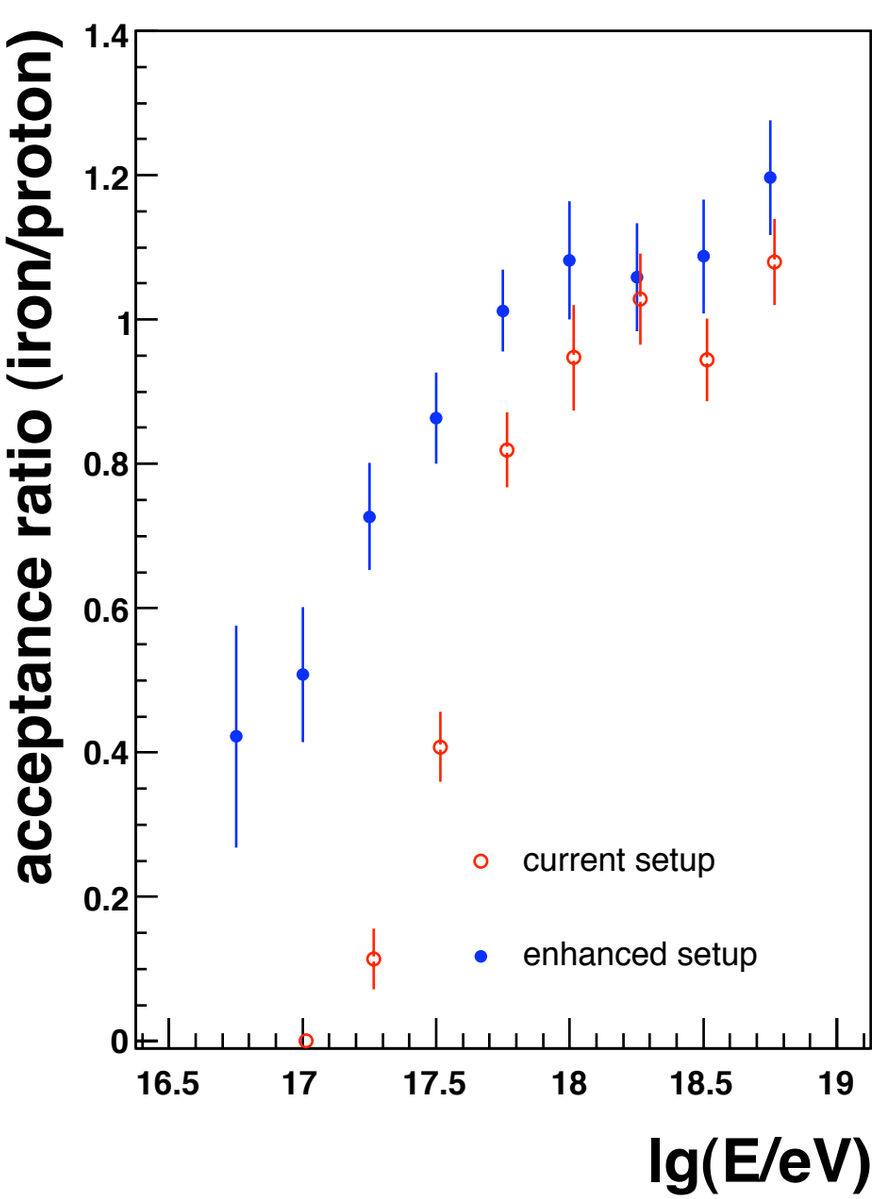
- simulated profile

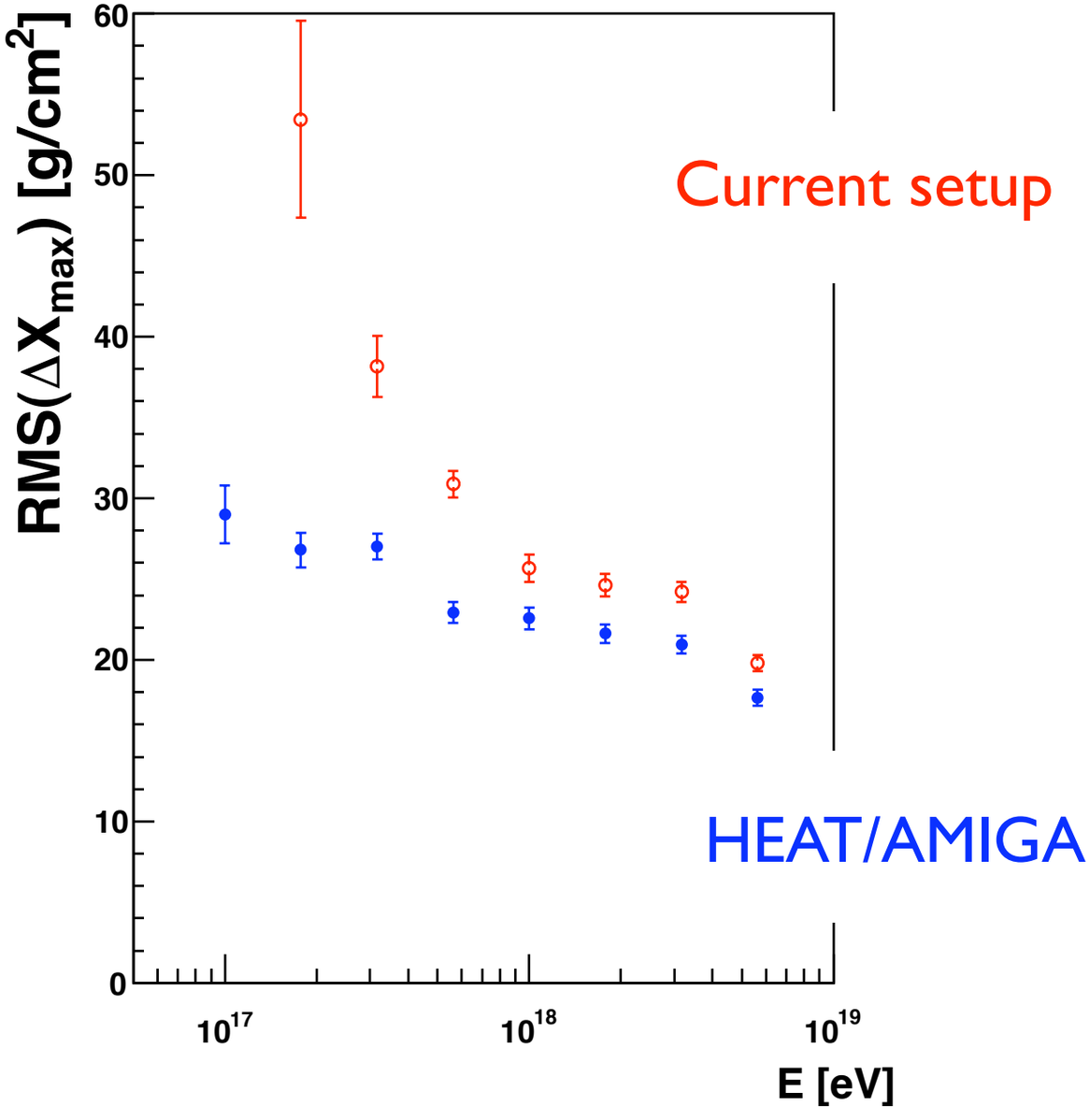
- reconstructed profile

Expected acceptance

Acceptance strongly selection cut dependent, here shown for high quality cuts (mean X_{max})

Threshold lowered to ~10^{17} eV





Conclusions and outlook

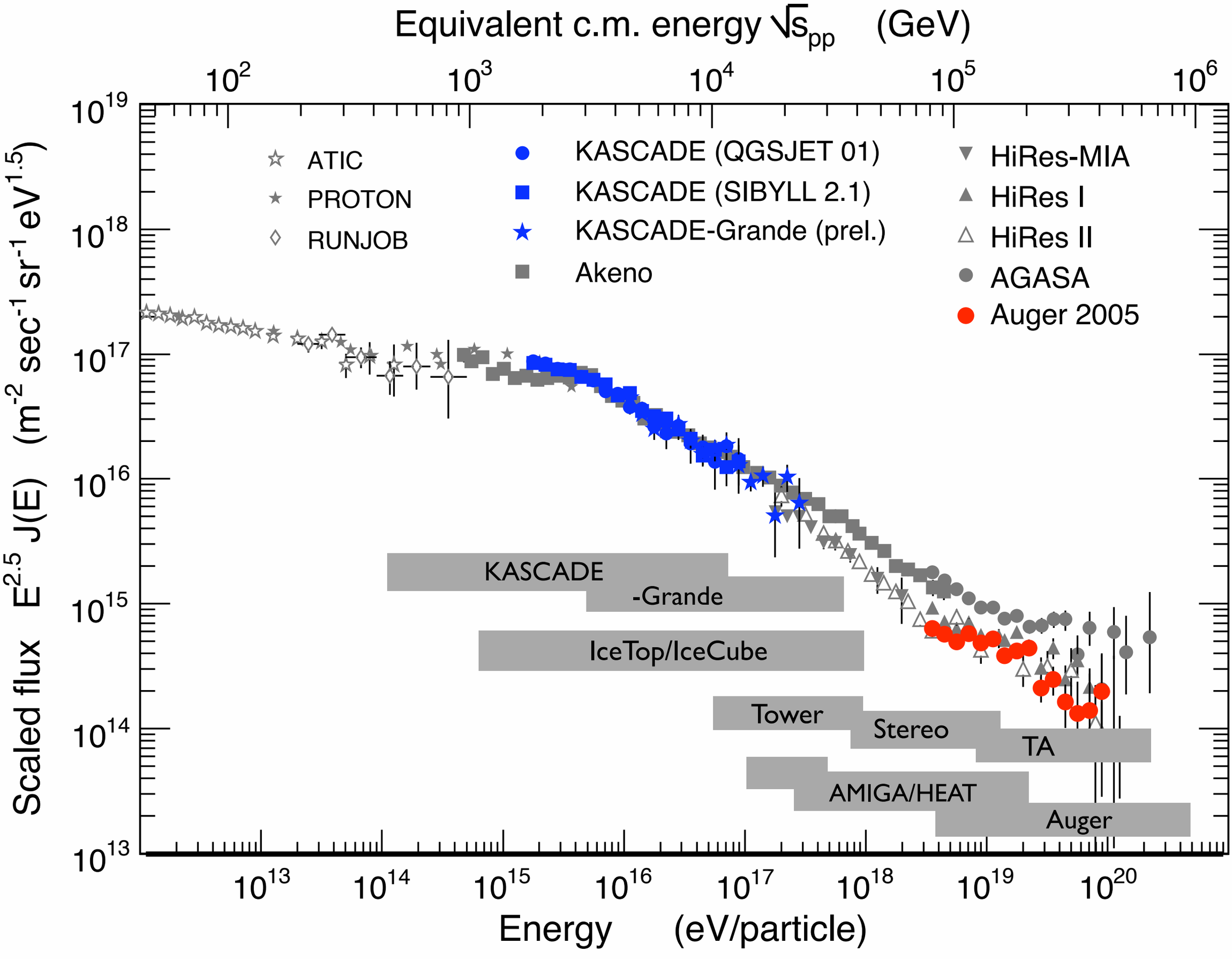
Auger enhancement detectors

- lower detection thresholds to few times 10^{17} eV
- add muon information
- improve reconstruction quality

- AMGIA: tanks and muon scintillators *(details: A. Etchegoyen)*
- HEAT: high elevation telescopes *(details: H. Klages)*

Construction has begun

- HEAT operational in 2008
- AMIGA prototype cluster 2007/2008
- AMIGA 750m array (23 km^2) in 2009
- AMIGA 433m array (5.9 km^2) under discussion (2009?)


Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
Scaled flux $E^{2.5}$ J(E) (m^{-2} sec^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande (prel.)
Akeno
HiRes-MIA
HiRes I
HiRes II
AGASA
Auger 2005
KASCADE
-Grande
IceTop/IceCube
Tower
Stereo
TA
AMIGA/HEAT
Auger
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Energy (eV/particle)