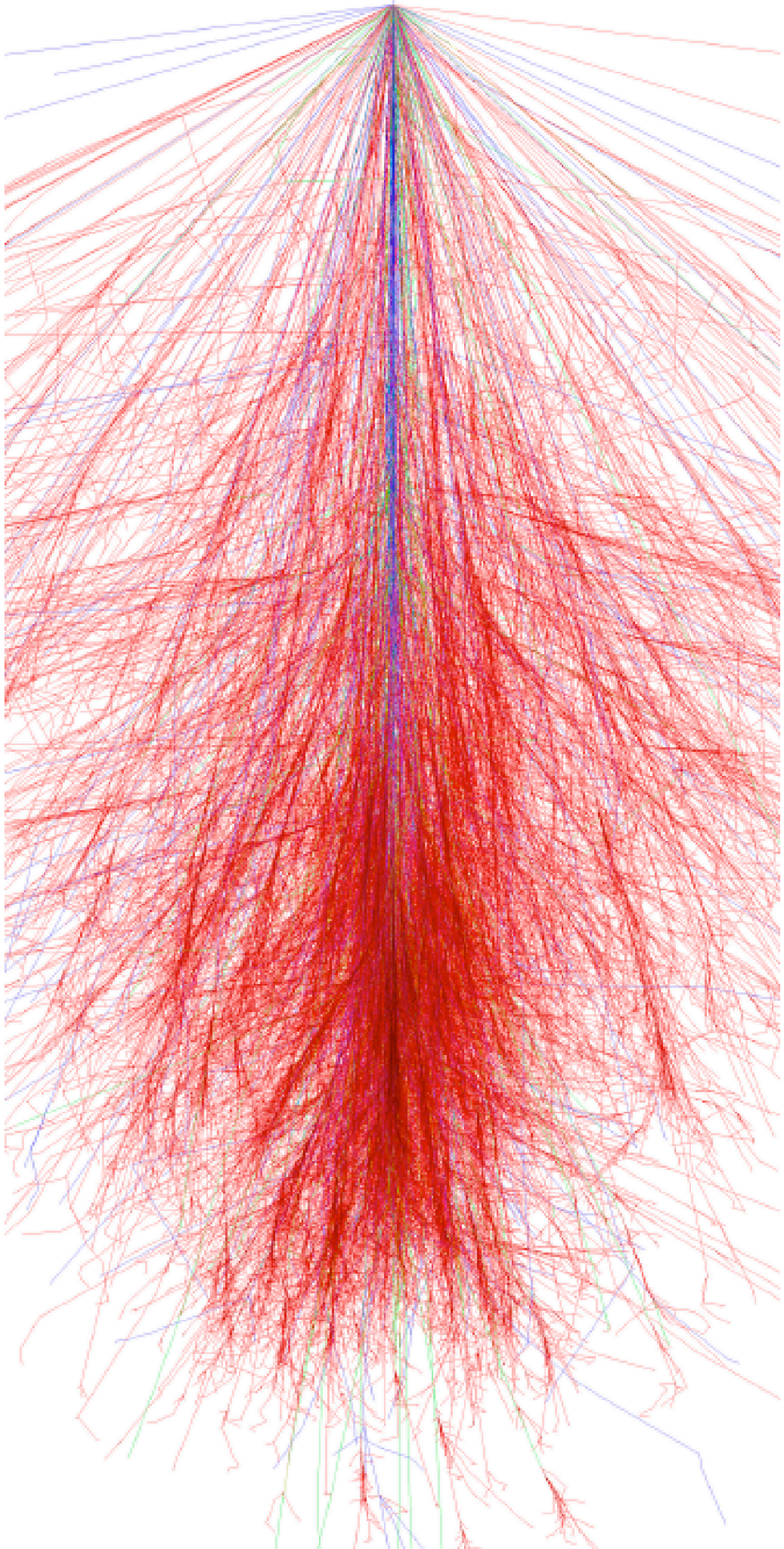
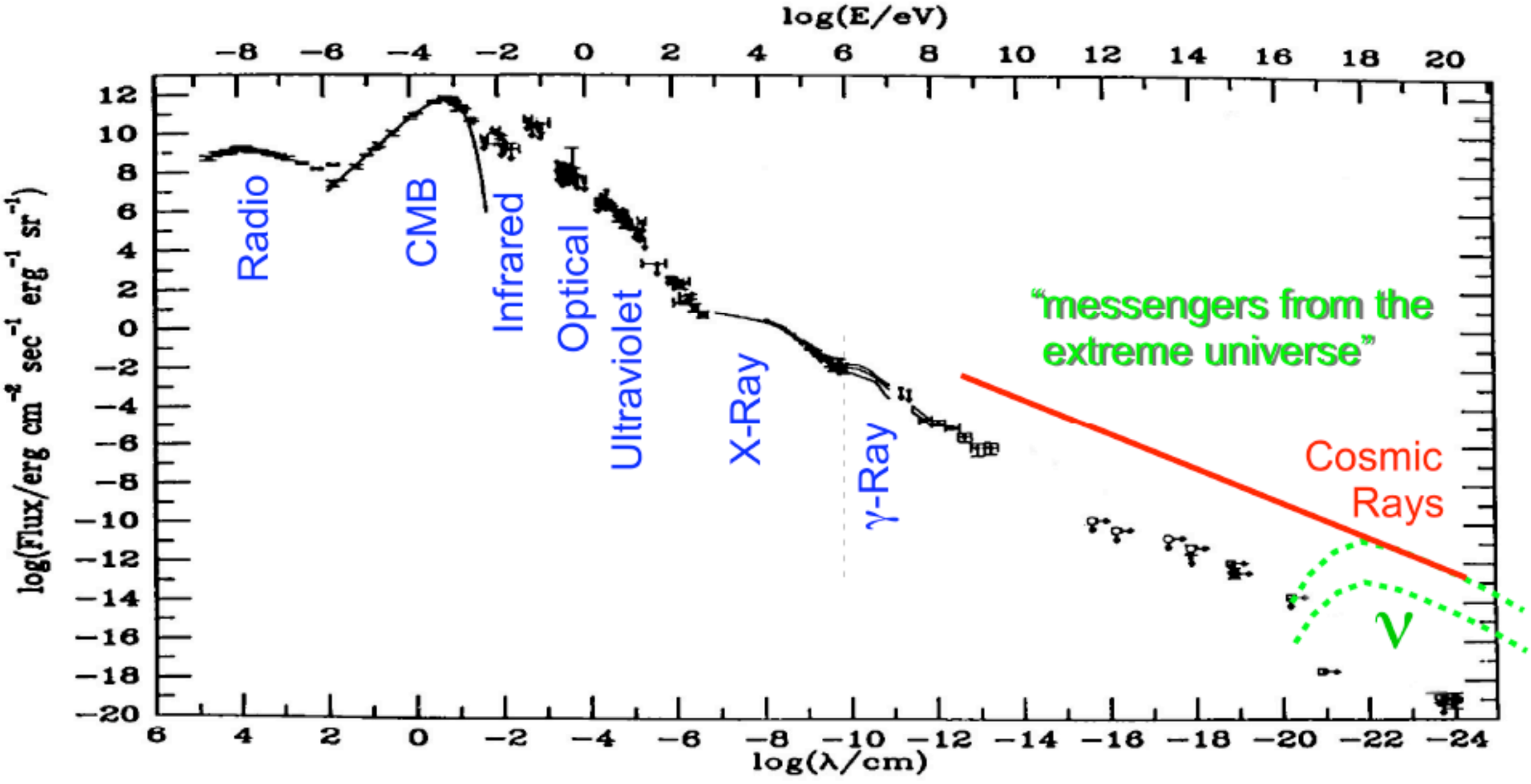


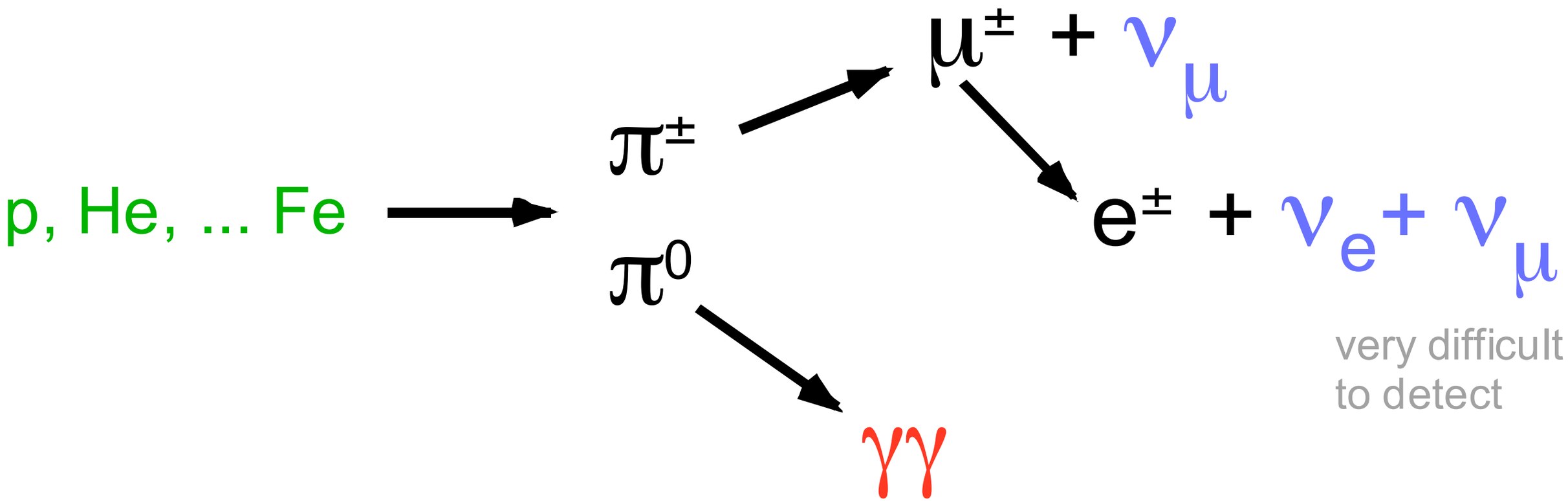
Status & First Results from the Pierre Auger Observatory

- Ultra-High Energy Cosmic Rays
- The Pierre Auger Observatory
- First Results
- The CR - Neutrino link

ARENA Workshop
Newcastle, 28-30 June 2006
J Knapp, U of Leeds

Universal Photon Spectrum





Cosmic rays, gammas and neutrinos are linked.

So far only CRs are detected at $E > 10^{14}$ eV.

Ultra-High Energy Cosmic Rays

Cosmic Ray Flux:

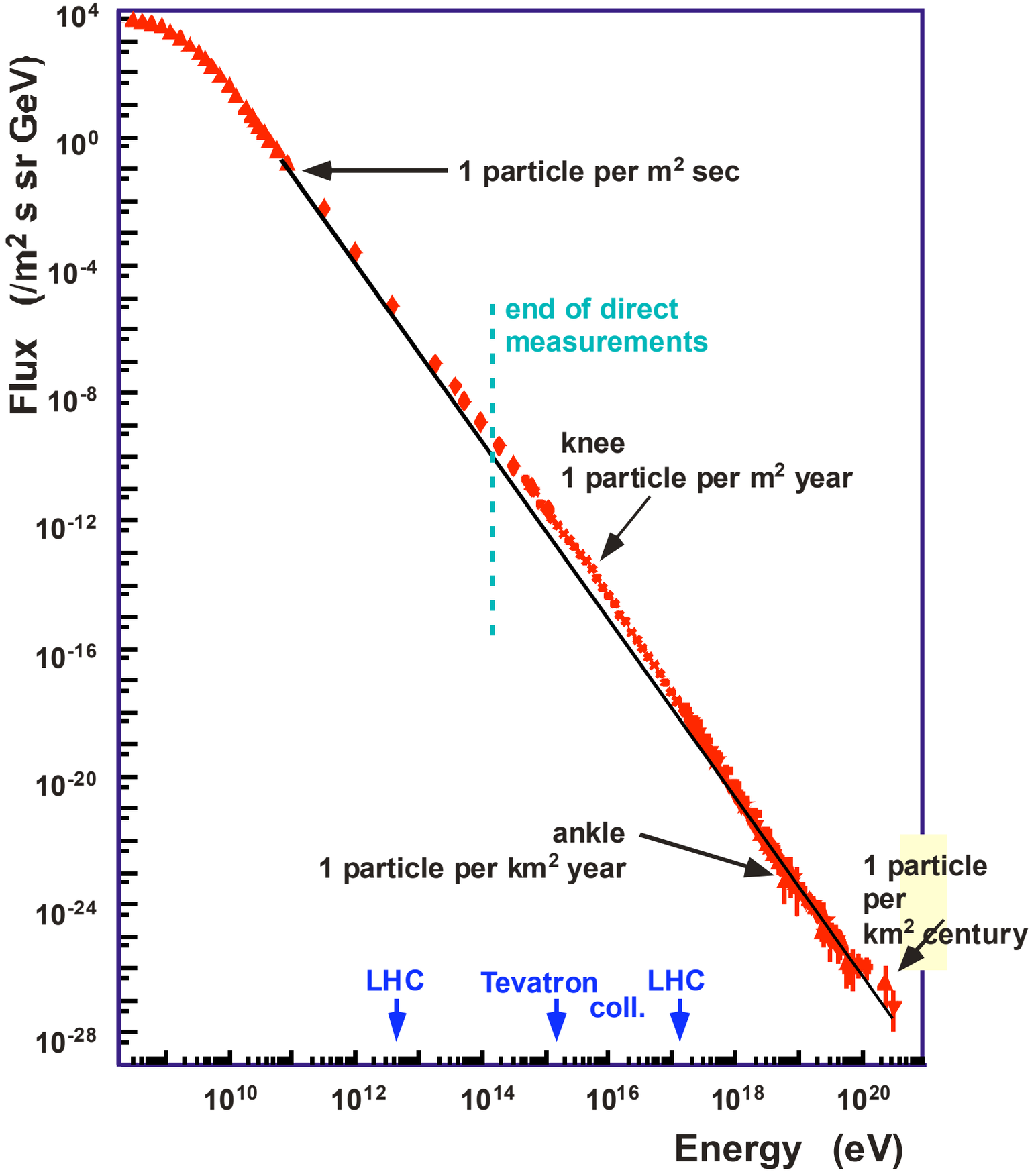
steeply falling:

x 10 up in energy

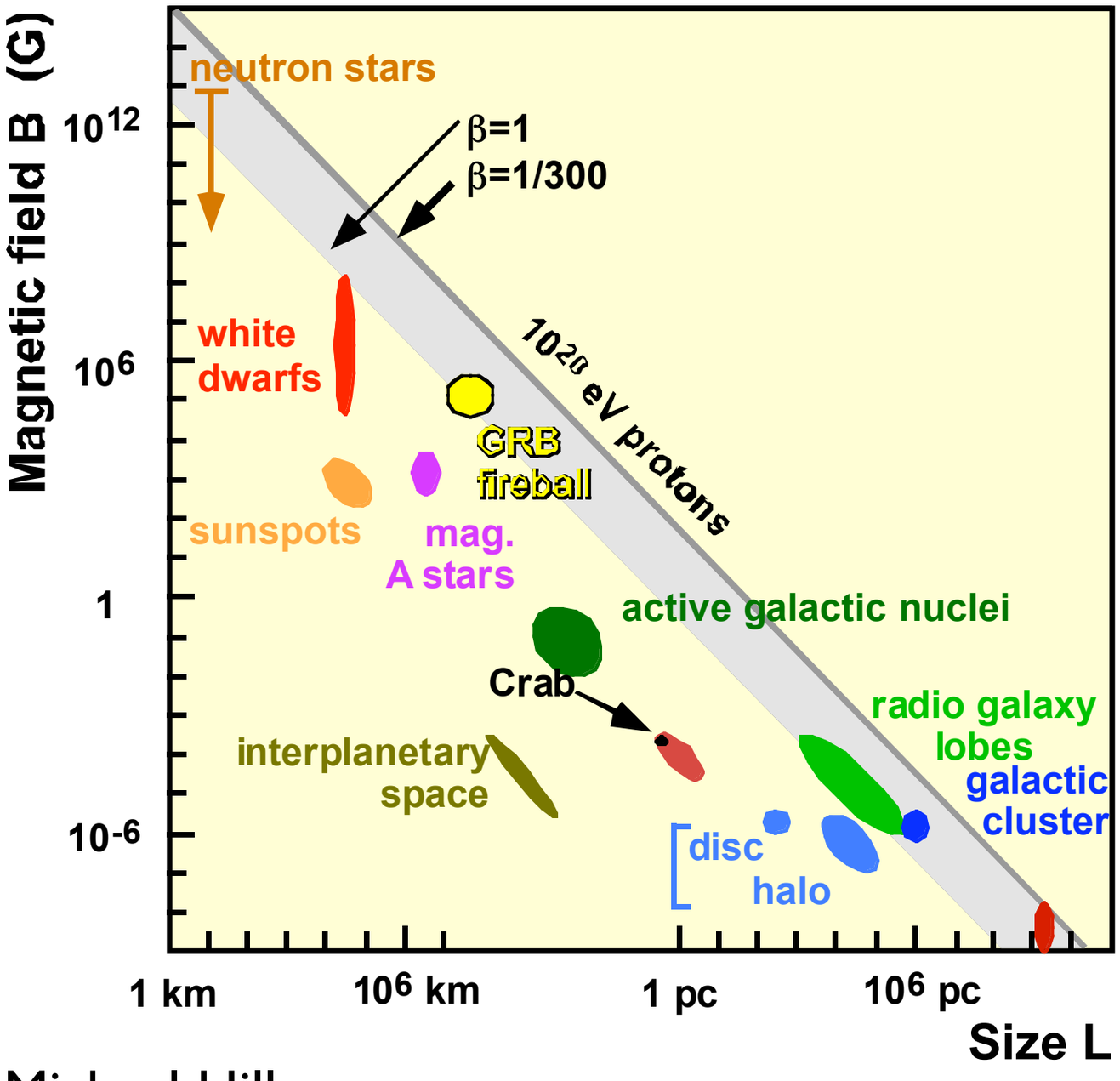
1/500 down in flux

no upper end (so far)

real high-energy physics!



Possible Acceleration Sites to 10^{20} eV



Michael Hillas

$B_{\mu G} \times L_{kpc} > 2\, E_{EeV} / Z$

$B_{\mu G} \times L_{kpc} > 2\, (c/v)\, E_{EeV} / Z$

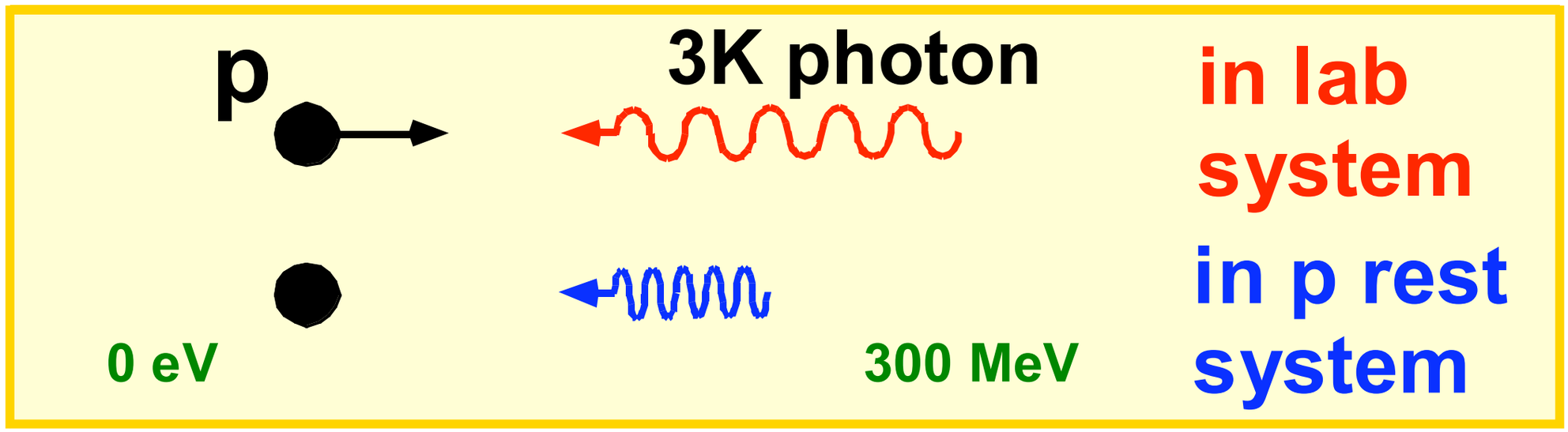
to fit gyroradius within L and to allow particle to wander during energy gain

But also:
gain should be more rapid than losses due to magnetic field (synchrotron radiation) and photo-reactions.

No obvious candidates ....

GZK Cut-Off

Greisen Zatsepin Kuzmin



$p + \gamma_{3K} \longrightarrow \Delta^{+} \longrightarrow p + \pi^{0}$ (γ) Photopion production

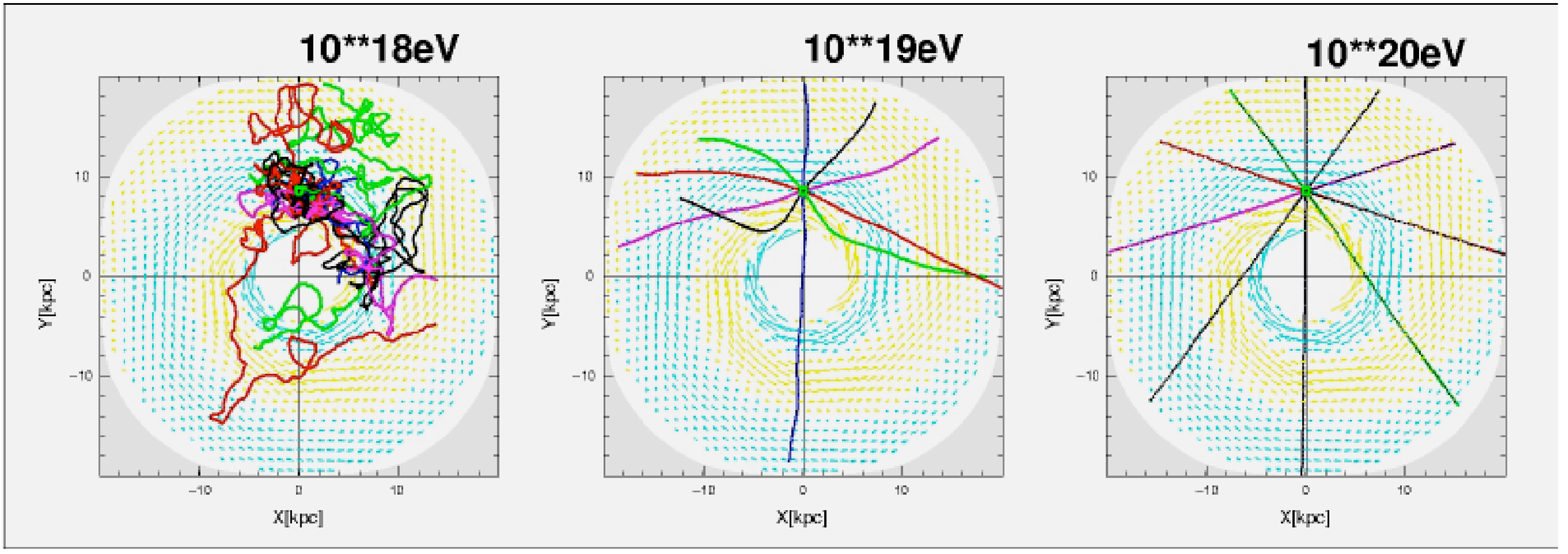
$\longrightarrow n + \pi^{+}$ (ν)

$^{56}Fe + \gamma_{3K} \longrightarrow {}^{55}Fe + n$ Photo dissociation

Universe is opaque for $E > 4 \cdot 10^{19}$ eV

Are CRs protons? Does Lorentz invariance hold?

Highest energy particles must be extragalactic



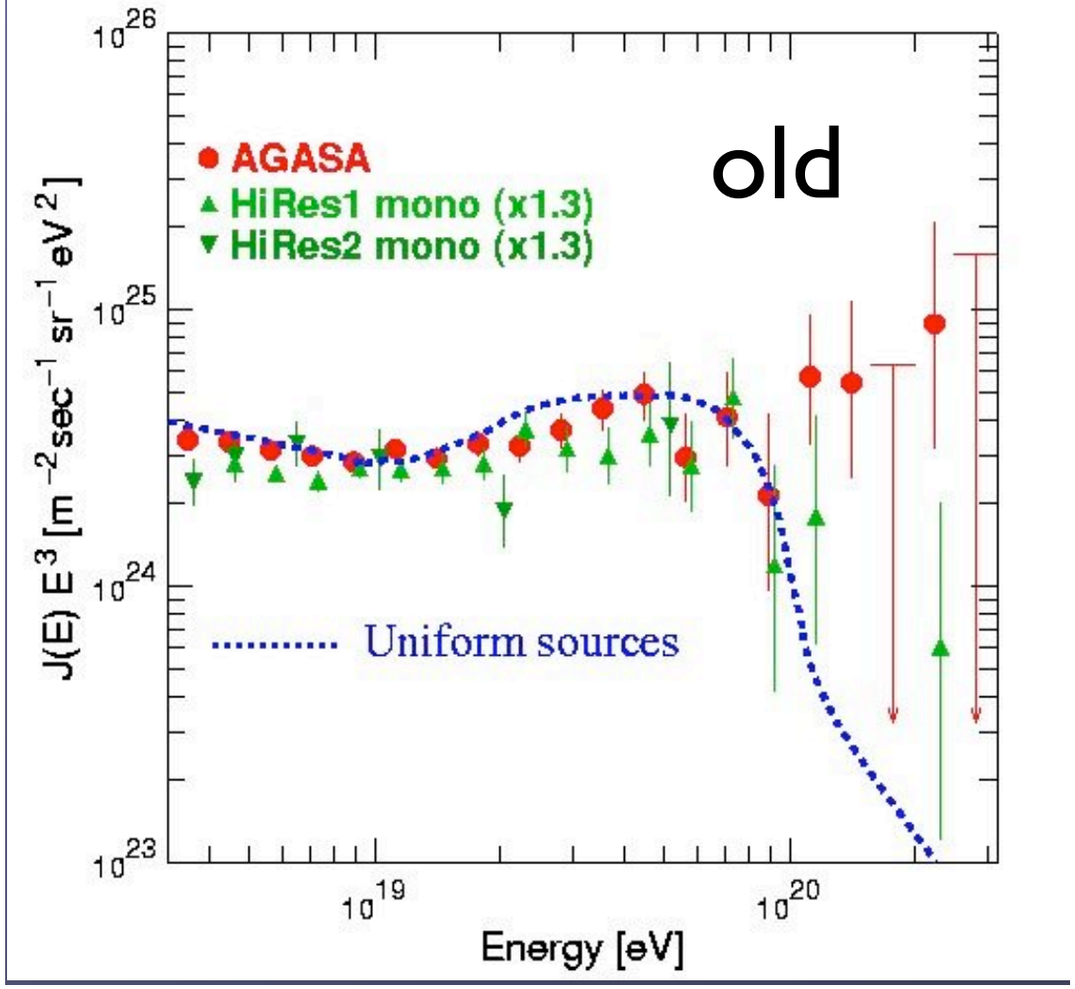
deflection < 1°

AGASA: re-analysis on basis of CORSIKA

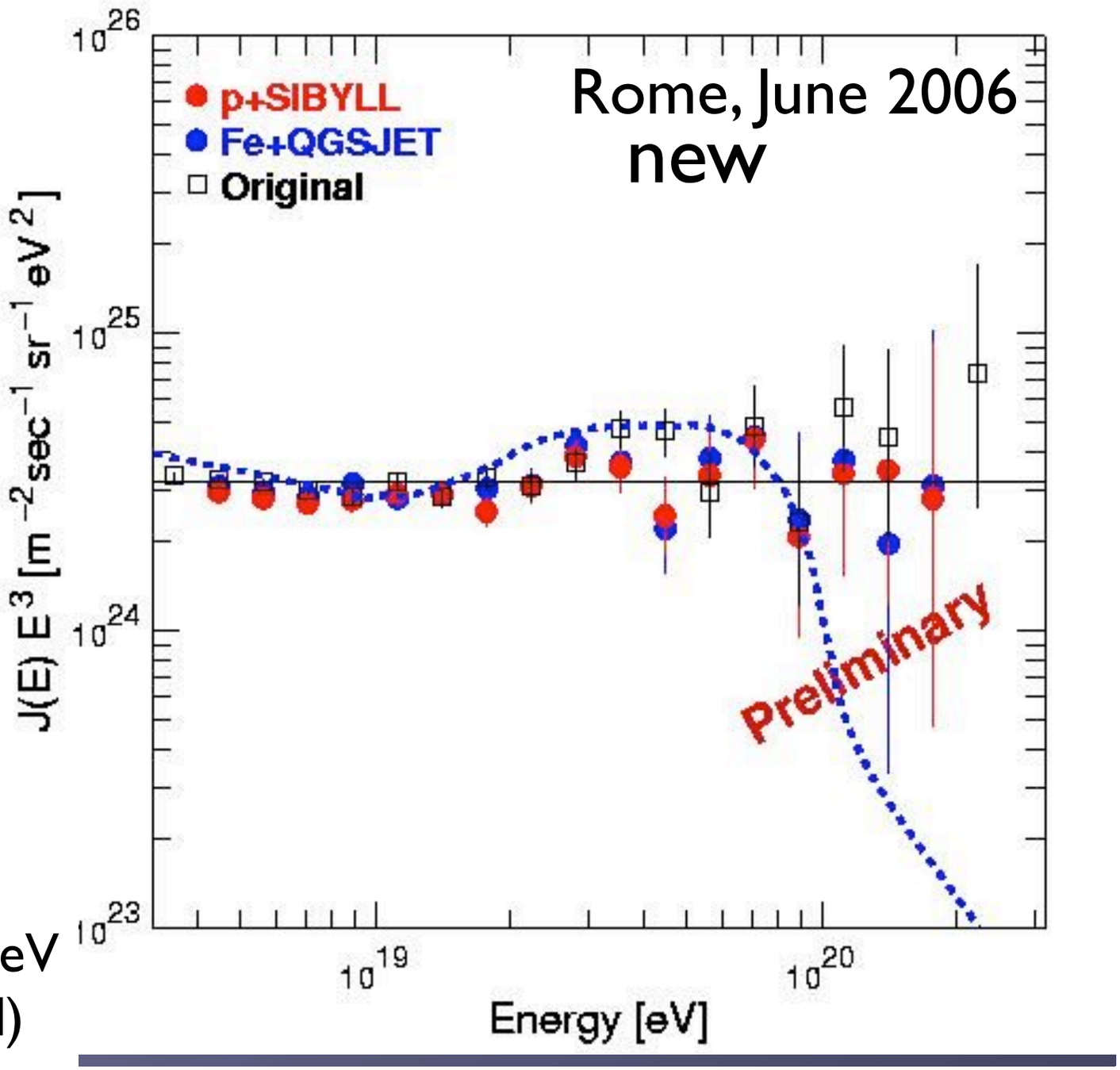
extreme cases: p SIBYLL, Fe QGSJET no sign. difference.

energies come down (10-20% at medium zenith angles, within quoted errors)

spectrum becomes flatter & featureless ($\gamma \sim 2.95$)



11 evts $>10^{20}$ eV
(1.8 expected)

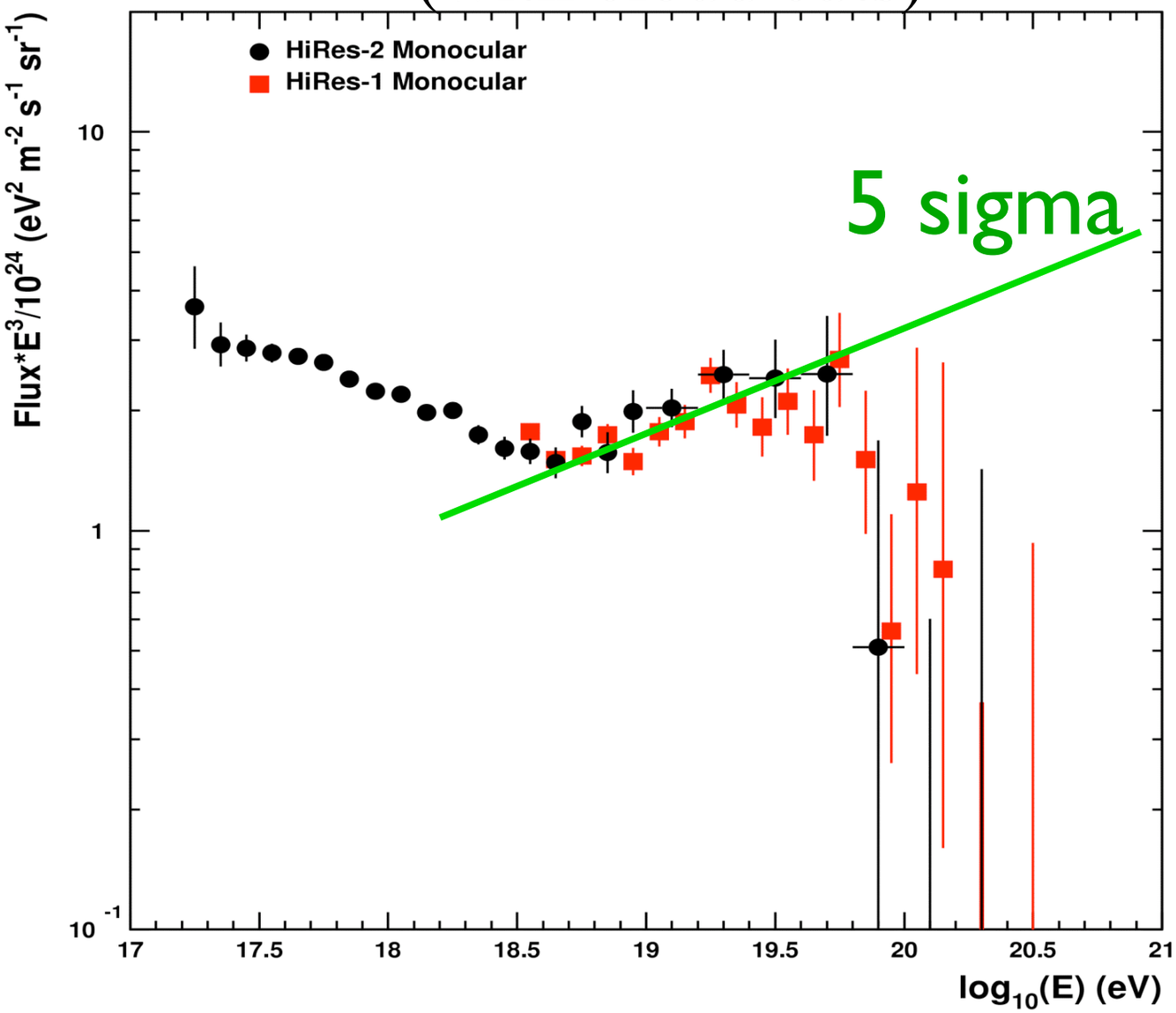


5-6 evts $>10^{20}$ eV
(1.2 expected)

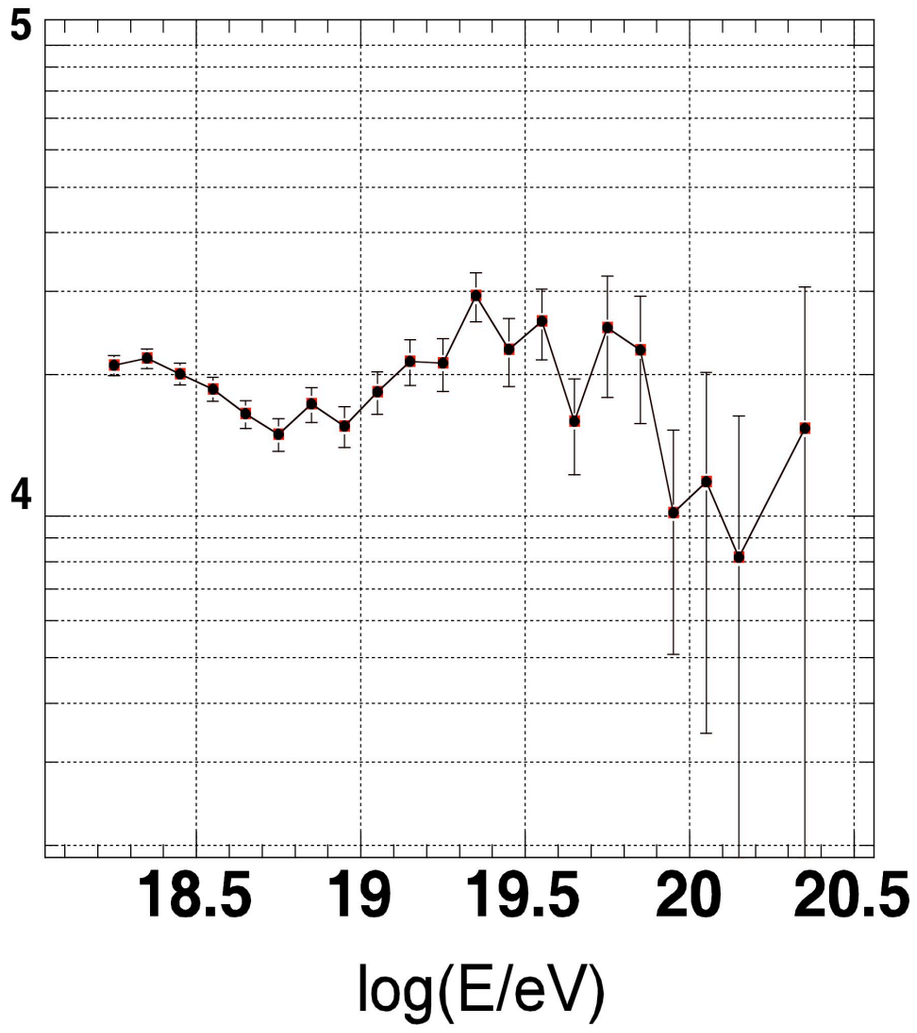
HIRES: (June 2006)

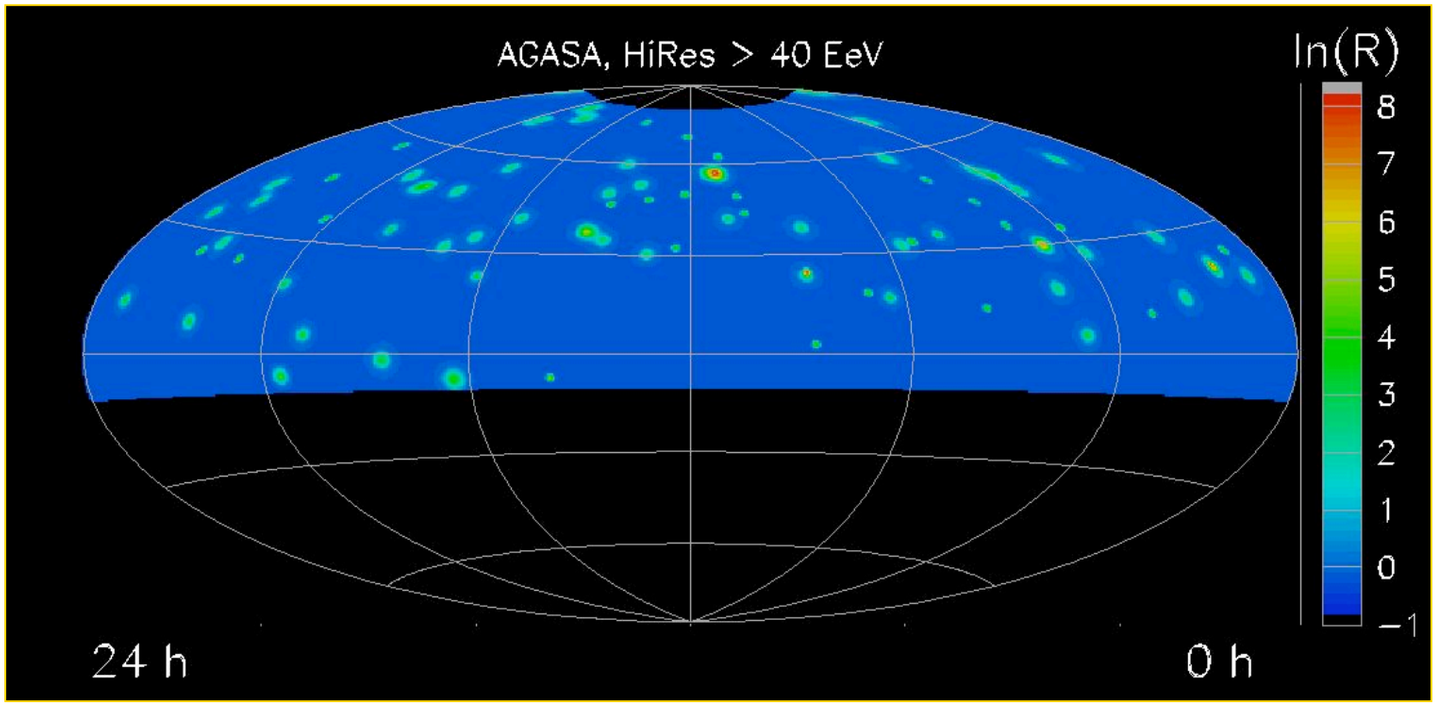
"The GZK cutt-off is present.
We see the Ankle clearly."

Most recent Mono spectrum
(with cloud cuts)



New "fully efficient" stereo
Spectrum - no cloud cuts





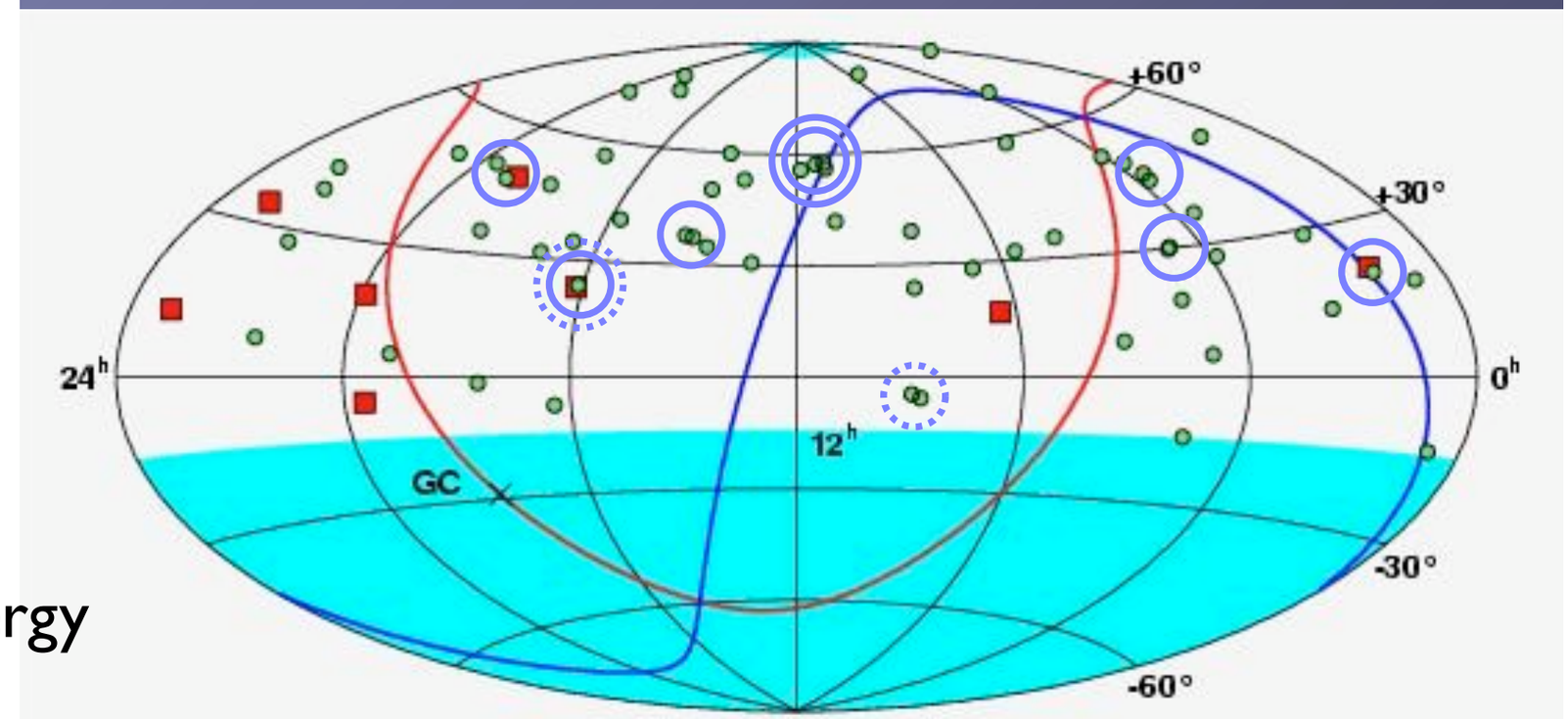
For the **AGASA and HiRes combined data set** above 40 EeV, the highest value of ln(R) is ln(R) = 8.54 n_s=2.9, at the location of the AGASA triplet. **The fraction of Monte Carlo sets with greater ln(R) is 28%.**

HIRES:

no source, but

correlation with BL-Lacs

- Isotropic in large scale → Extra-Galactic
- But, Clusters in small scale ($\Delta\theta$<2.5deg)
  - 1triplet and 6 doublets (2.0 doublets are expected from random)



AGASA:

clusters !

3.2 σ, growing with energy

Proposed Solutions (1/week)

Hot Spots in AGN-Jets	Biermann
AGNs	Biermann
Pulsars	Bell
Galaxy collisions, wind shocks	Cesarsky, Morfill, Jokipii
Shocks at formation of gal. clusters	Biermann et al
GRBs	Milgram, Usov, Waxman, Vietri

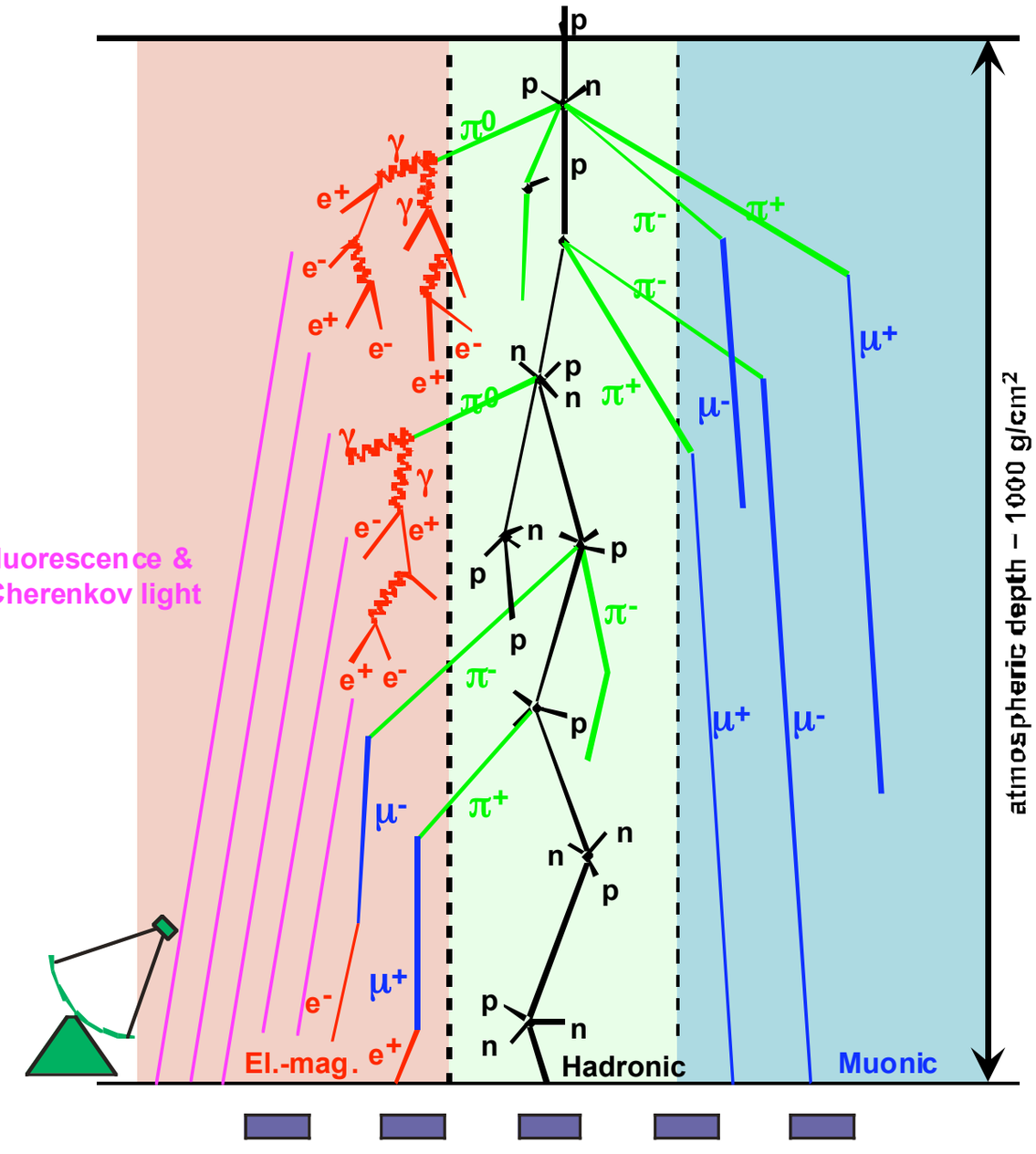
ν annihilation with relic-ν	Weiler et al.
Superheavy relic particles	Ellis, Sarkar et al.
Topologic defects - Monopoles	Schramm, Sigl
- Necklaces	Berezinsky et al.
Dirac Monopoles	Weiter & Kiphart et al.

New SUSY particles S_0 (uds+gluino: 2 GeV)	Farrar et al.
UHECRON (m ~ 10 GeV)	Farrar & Kolb
Deviation from Lorentz invariance	Coleman & Glashow

Schematic Shower Development

energy
particle type
direction

???



detector response: energy deposits, times, efficiencies, thresholds, ...

Shower development depends on:

- hadronic interactions,
- electromagnetic interactions,
- particle production,
- decays,
- transport, ...

Complex interplay of many effects:

- no analytic solution possible
- no test beam for calibration available

(at least for really high energies)

Need an air shower model:

- simulate showers for specific primaries
- get realistic detector responses
- find algorithms for reconstruction of primary shower parameters

Forward particles carry energy into the atmosphere & drive shower development

Auger

Auger Hybrid Detector

unprecedented statistics at

$E > 10^{19}$ eV (~3000 evts / year)

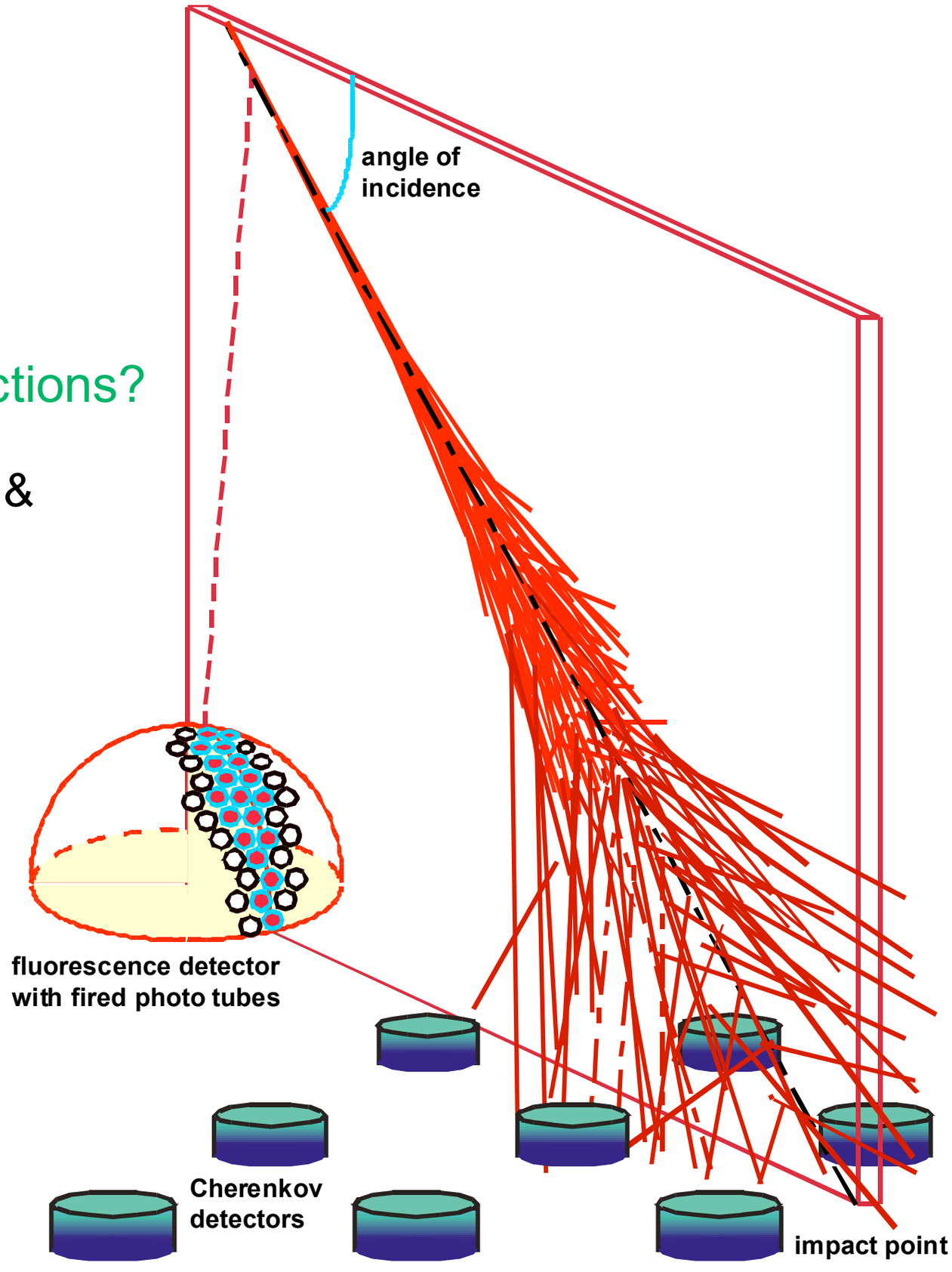
$E > 10^{20}$ eV (~30 evts / year)

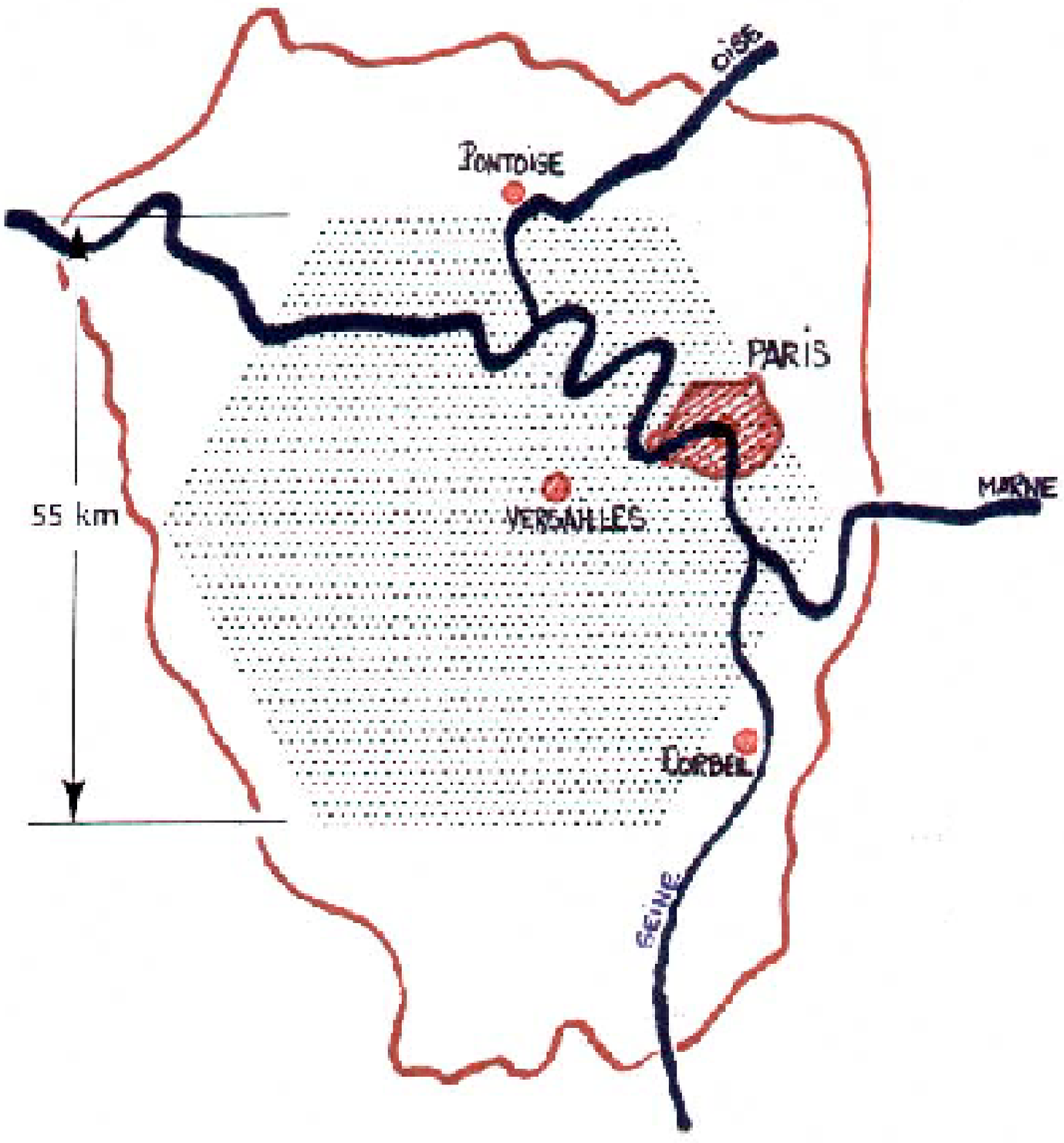
Is there a cut-off in the spectrum?
Are there anisotropies in the arrival directions?

Array of particle detectors at ground (100%) &
fluorescence detectors (10%)
allows cross-calibration of energy
and control of systematics.

24 fluorescence telescopes (30º x 30º)
1600 water Cherenkov detectors
on 3000 km^2 arranged in hexagonal grid
with 1.5 km grid spacing

Full-sky coverage with 2 observatories
in southern & northern hemisphere.





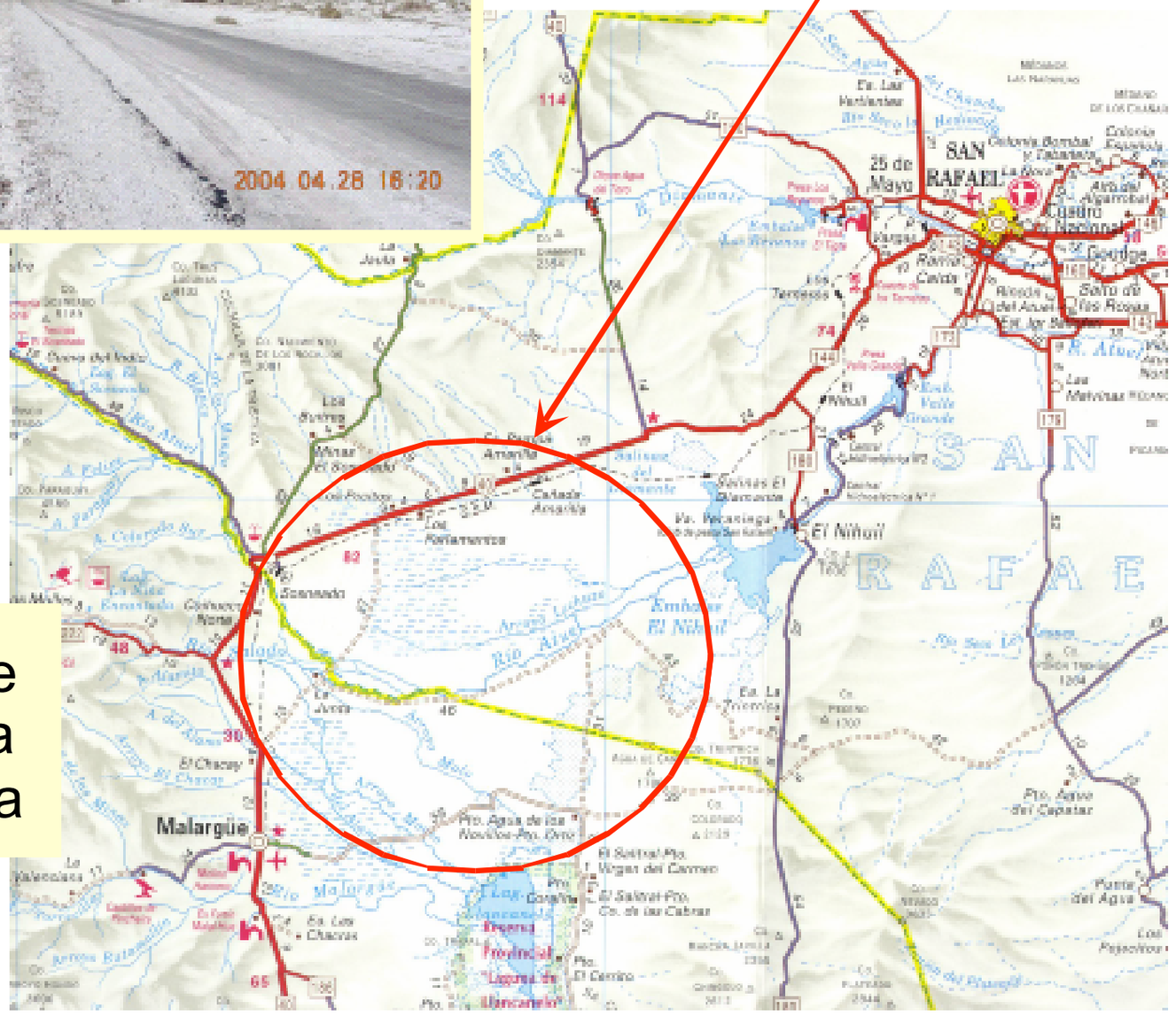
3000 km^2

F: 25x size of Paris

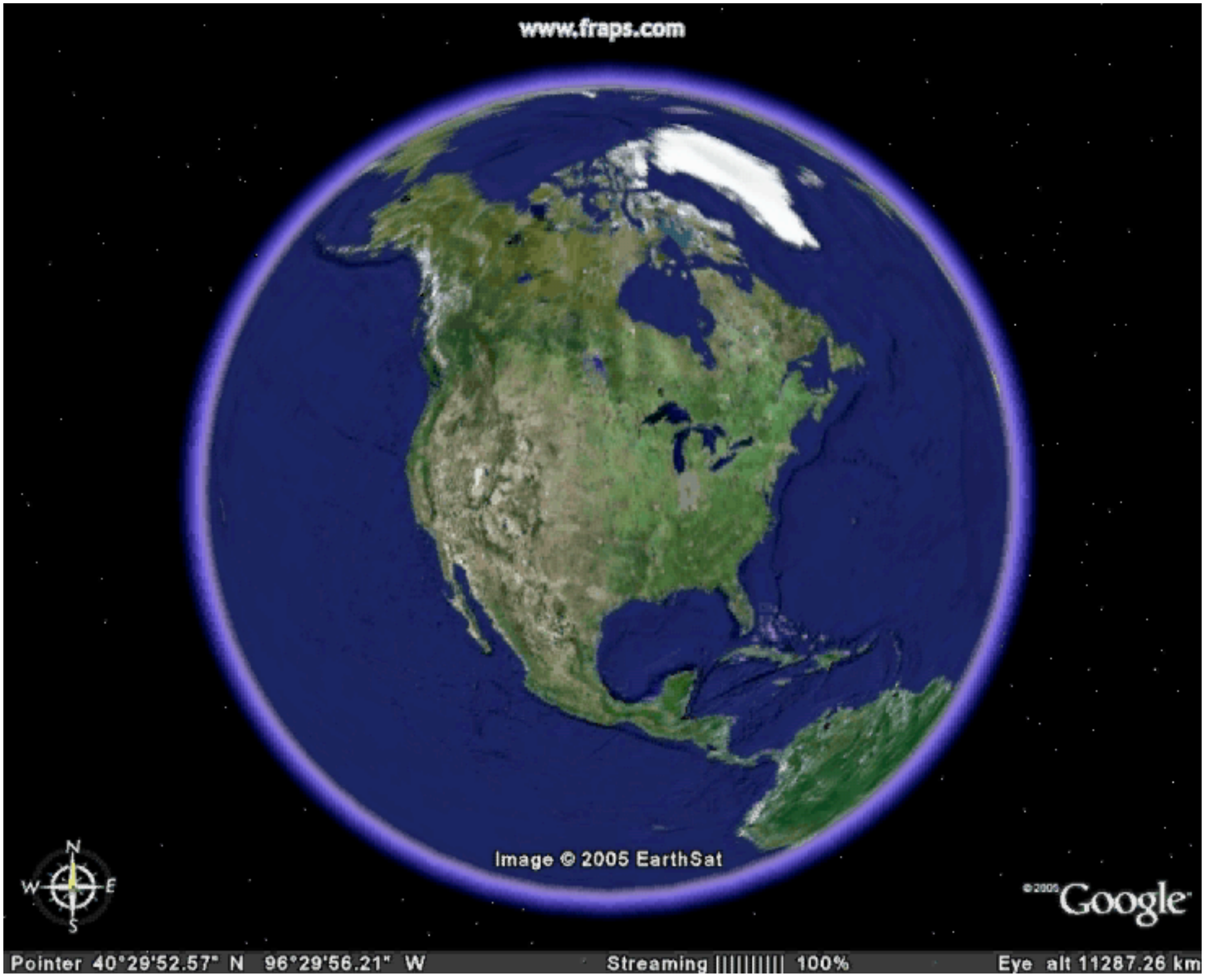
UK: size of Lancashire area inside M25

D: size of Saarland

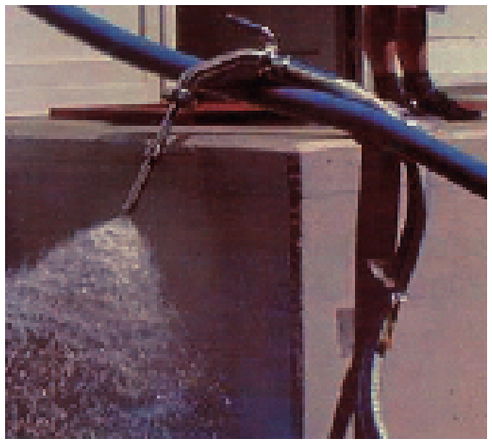
Auger South
(1400 m a.s.l.,
35.2° S, 69.2° W)



Malargüe
Mendoza
Argentina


www.fraps.com
Image © 2005 EarthSat
©2005 Google
Pointer 40°29'52.57" N 96°29'56.21" W
Streaming ||||||||| 100%
Eye alt 11287.26 km

Tank deployment

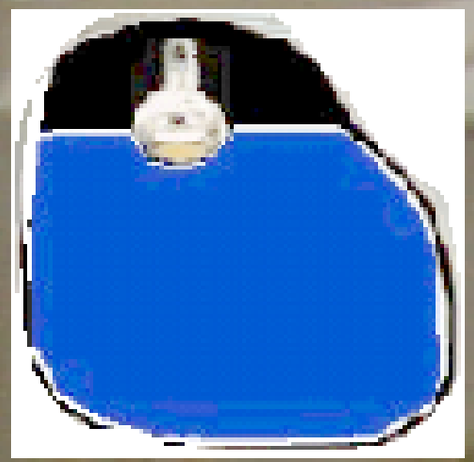


Communications antenna

GPS antenna

Electronics enclosure

Solar Panels



3 x 9" PMTs

Plastic tank
12 m^3 water

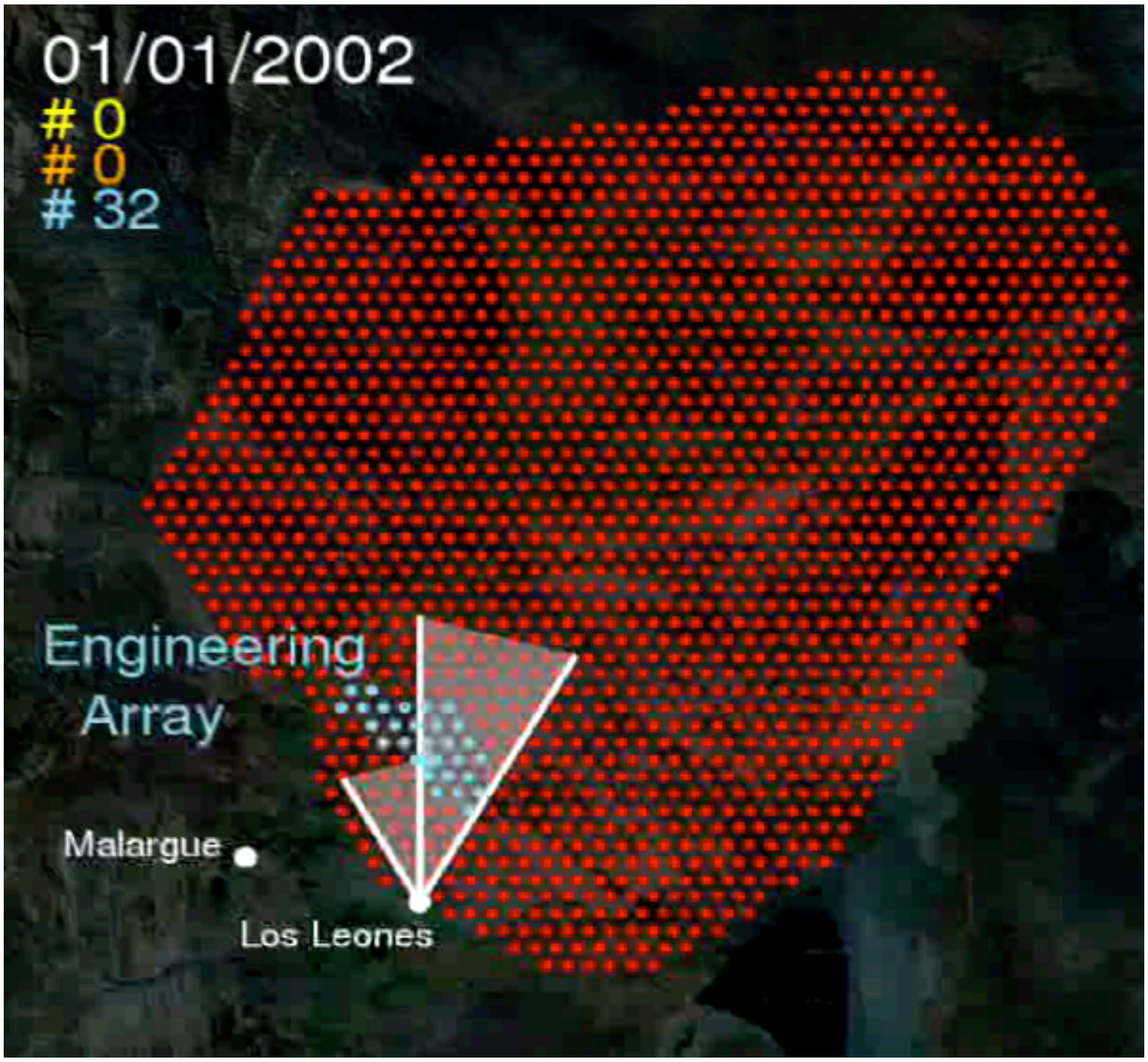
Battery box

water Cherenkov detectors:
12 m^3 water, 3 PMTs, GPS,
radio, electronics,
solar panel & battery

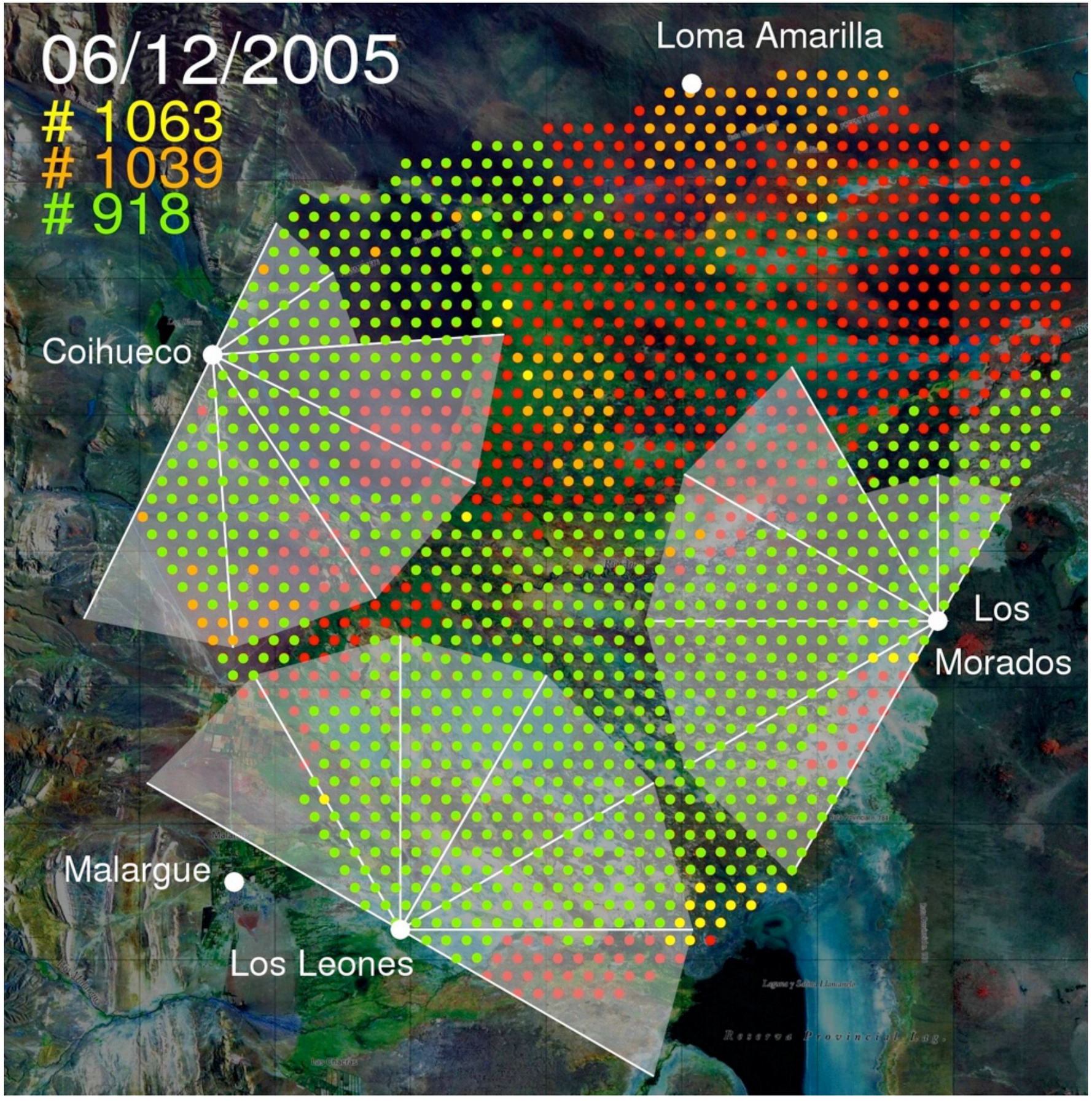
1600 tanks on 3000 km^2

Installation of Auger detectors: the movie

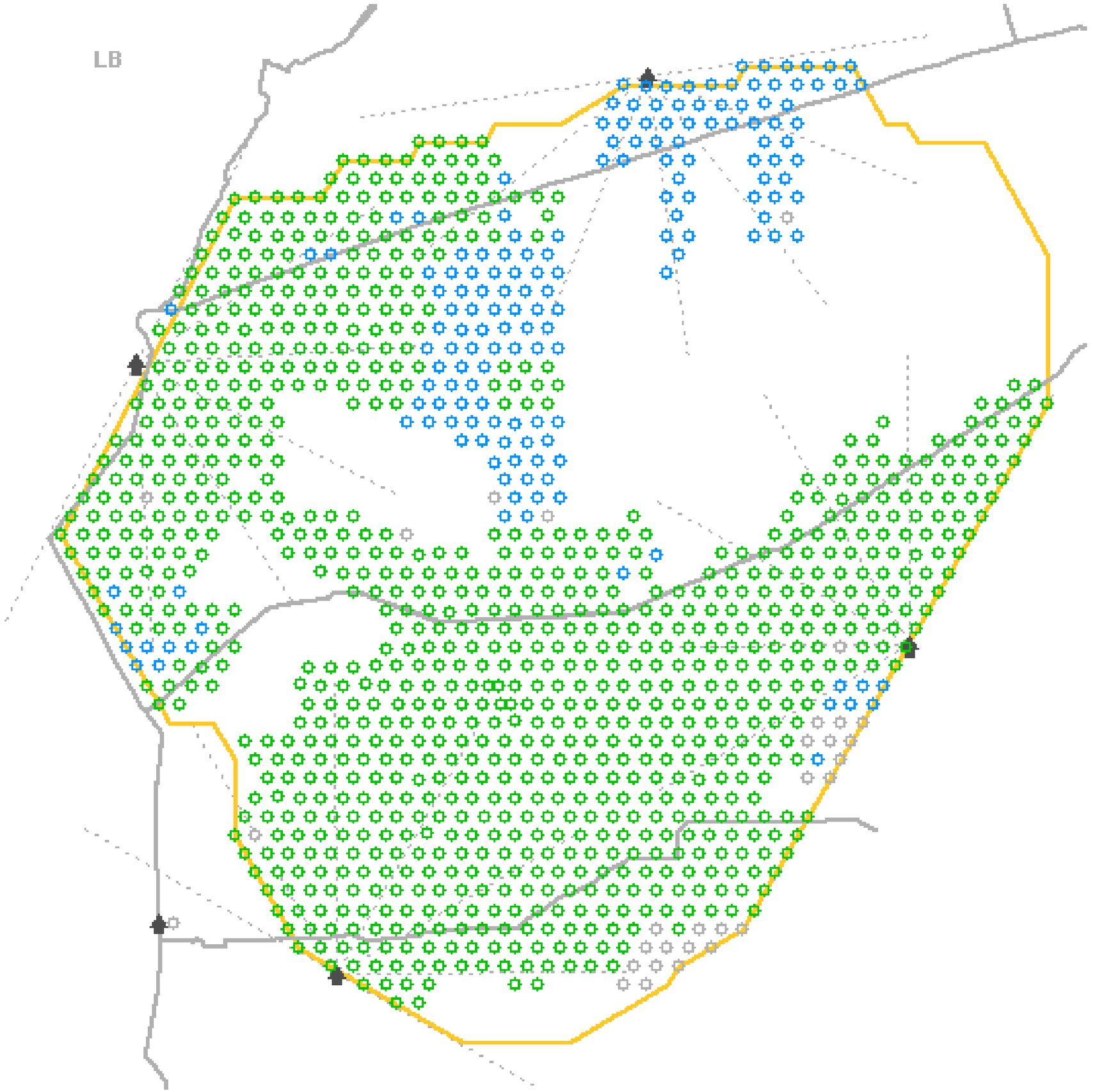
planned
tank deployed
with water
send data

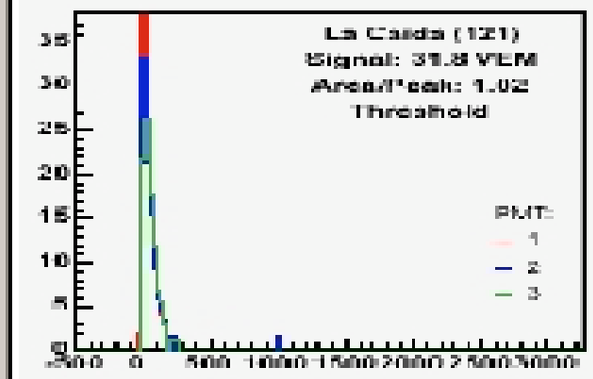


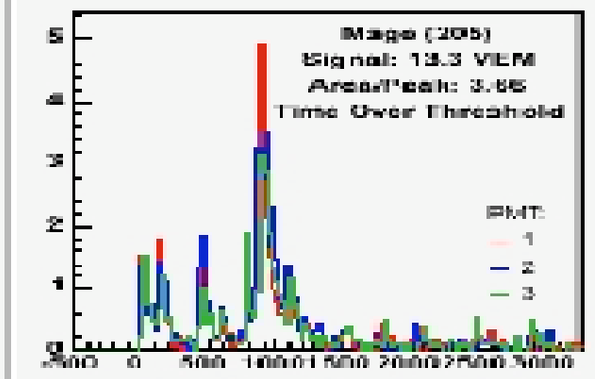
planned
tank deployed
with water
send data

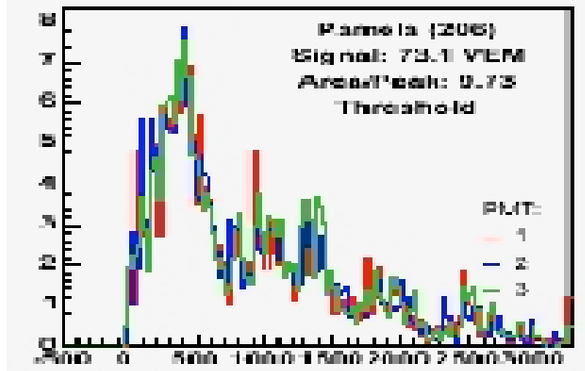


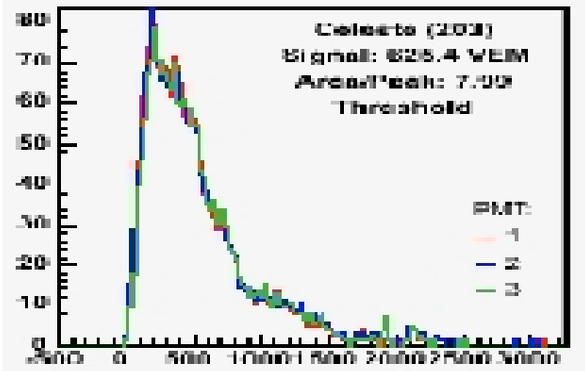
SD deployment status

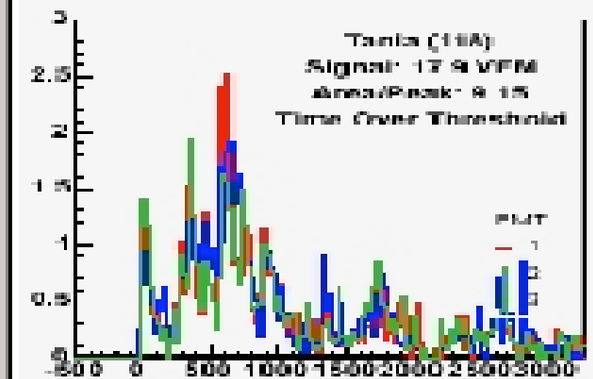


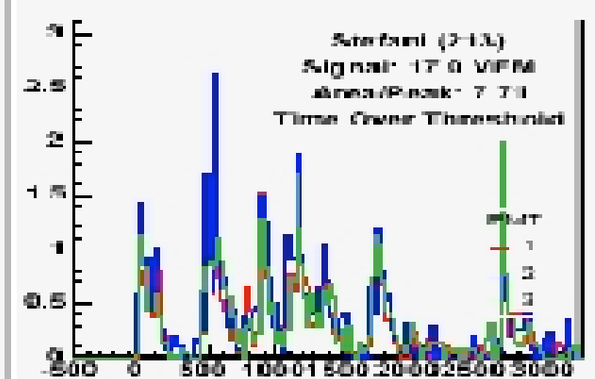


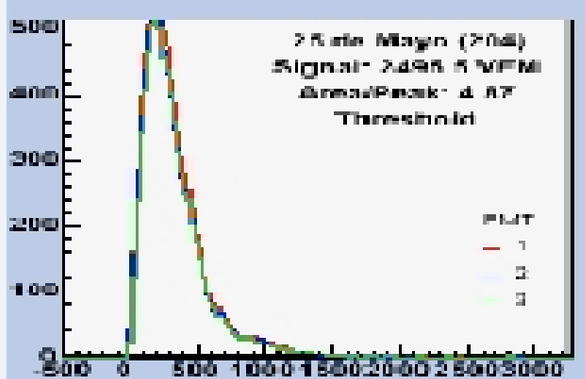


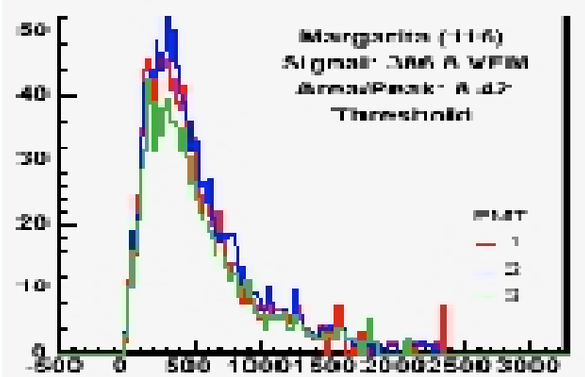


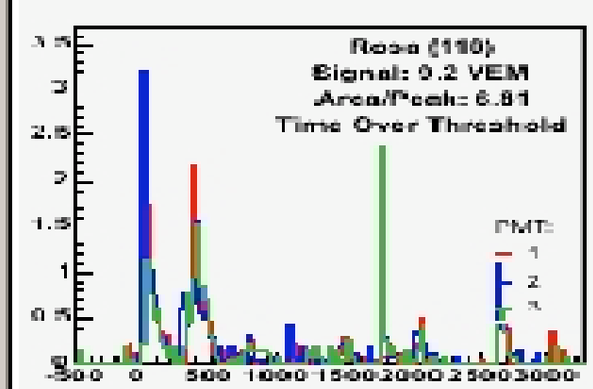


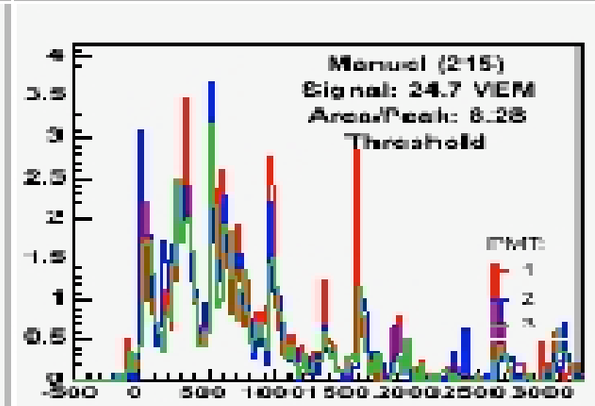


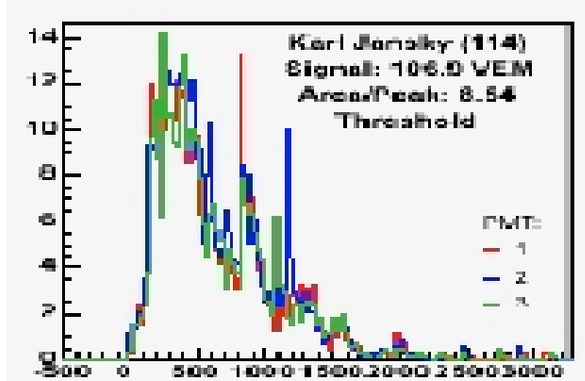


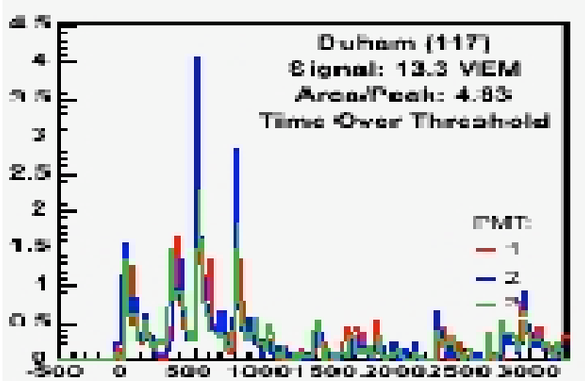


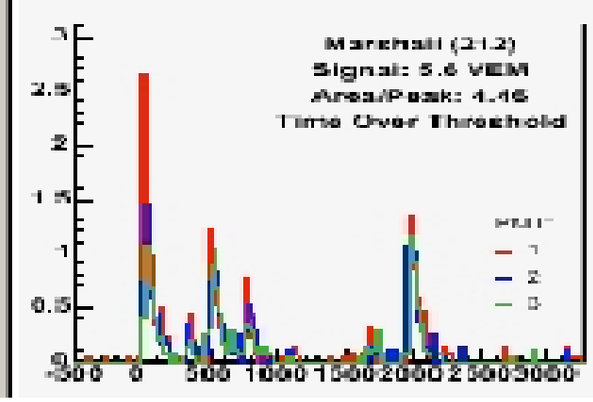


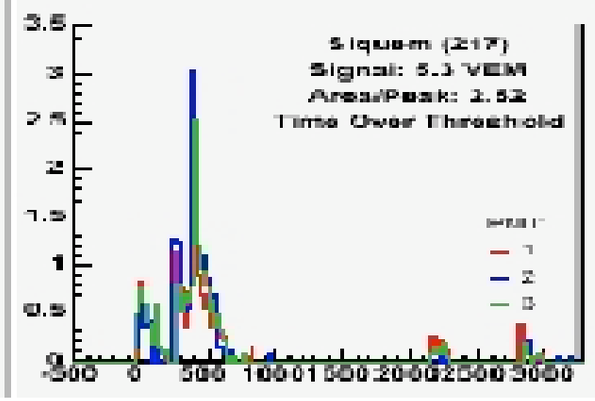


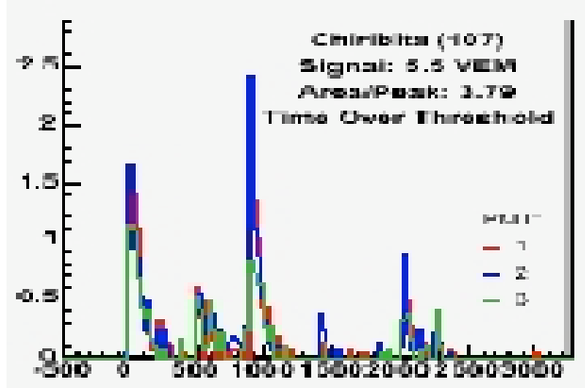


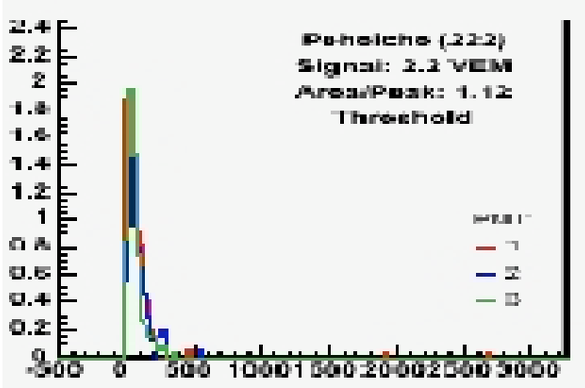








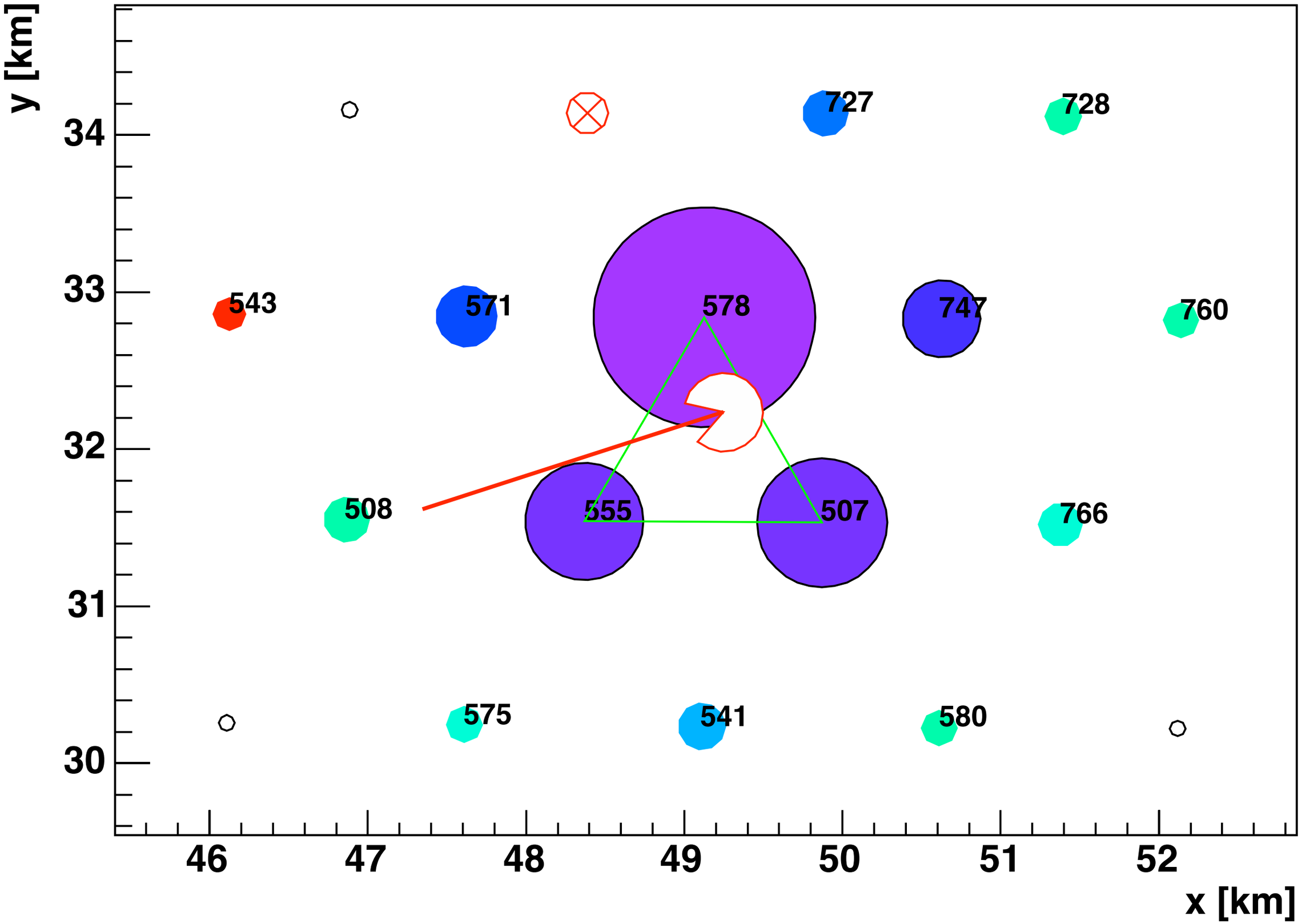




High & smooth pulses close to shower core, low & spiky pulses far away.

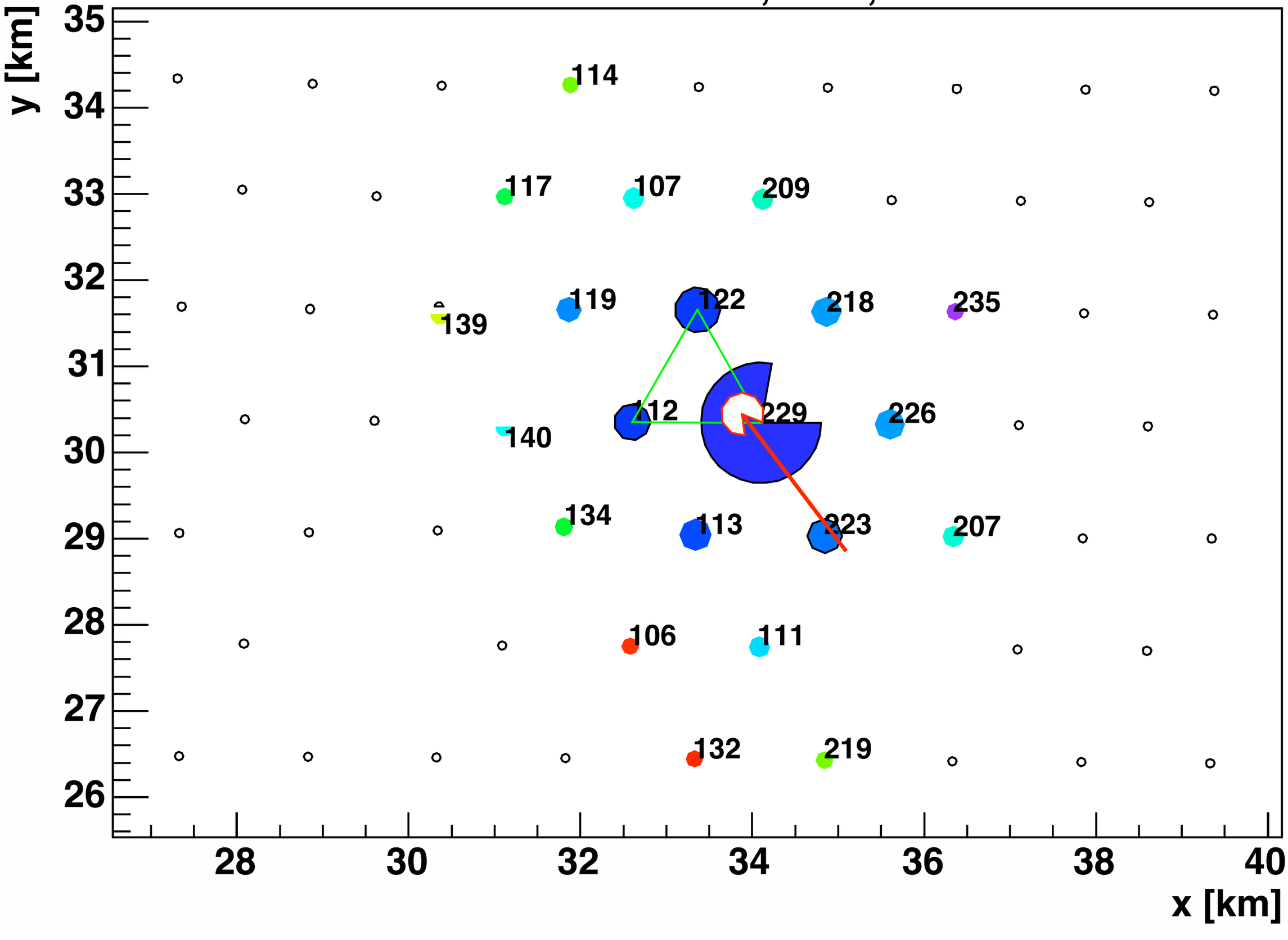
Event 1225537

14 tanks, 34°, 79 x 10^{18} eV



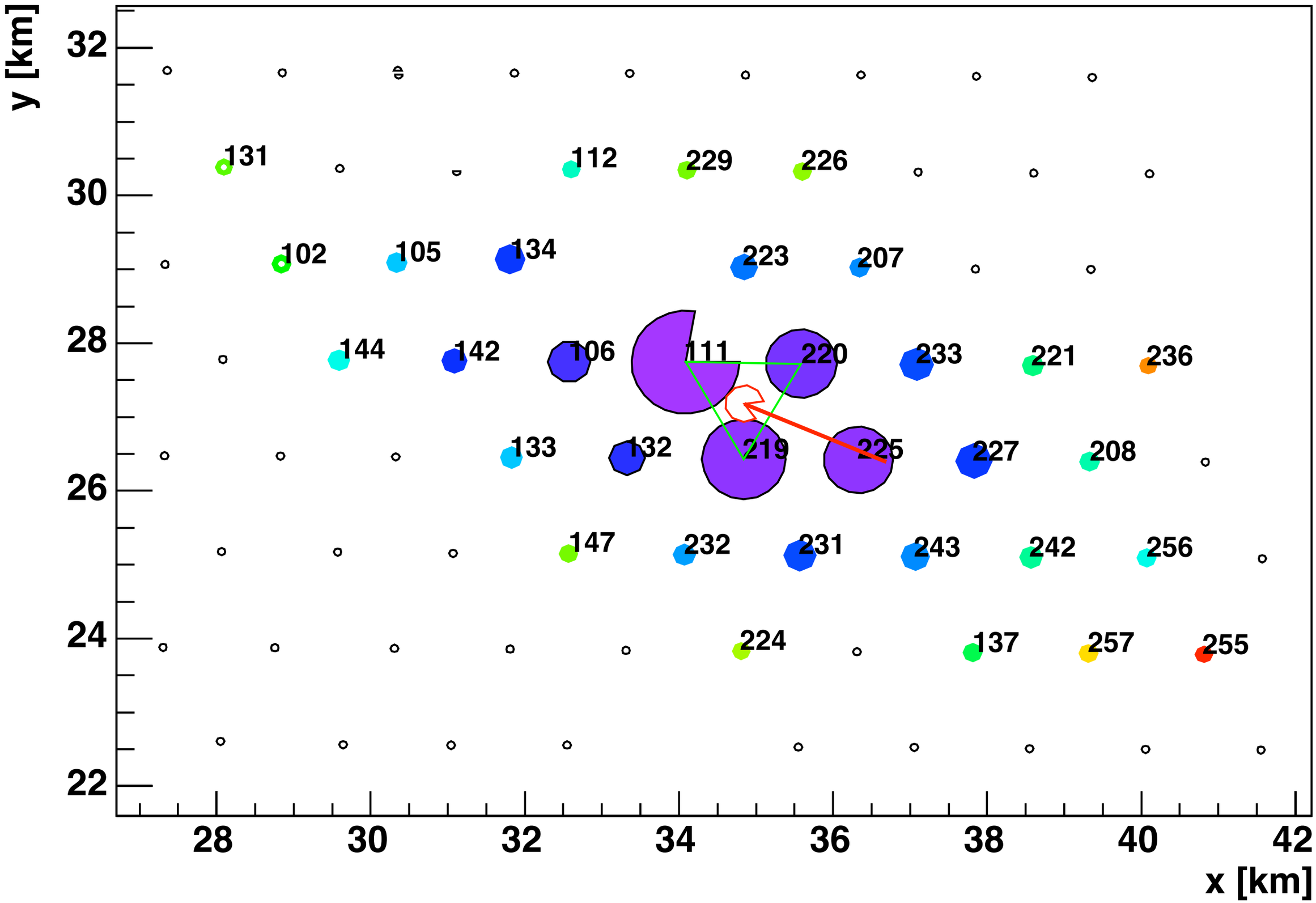
Event 1096757

21 tanks, 45°, 86 x 10^{18} eV



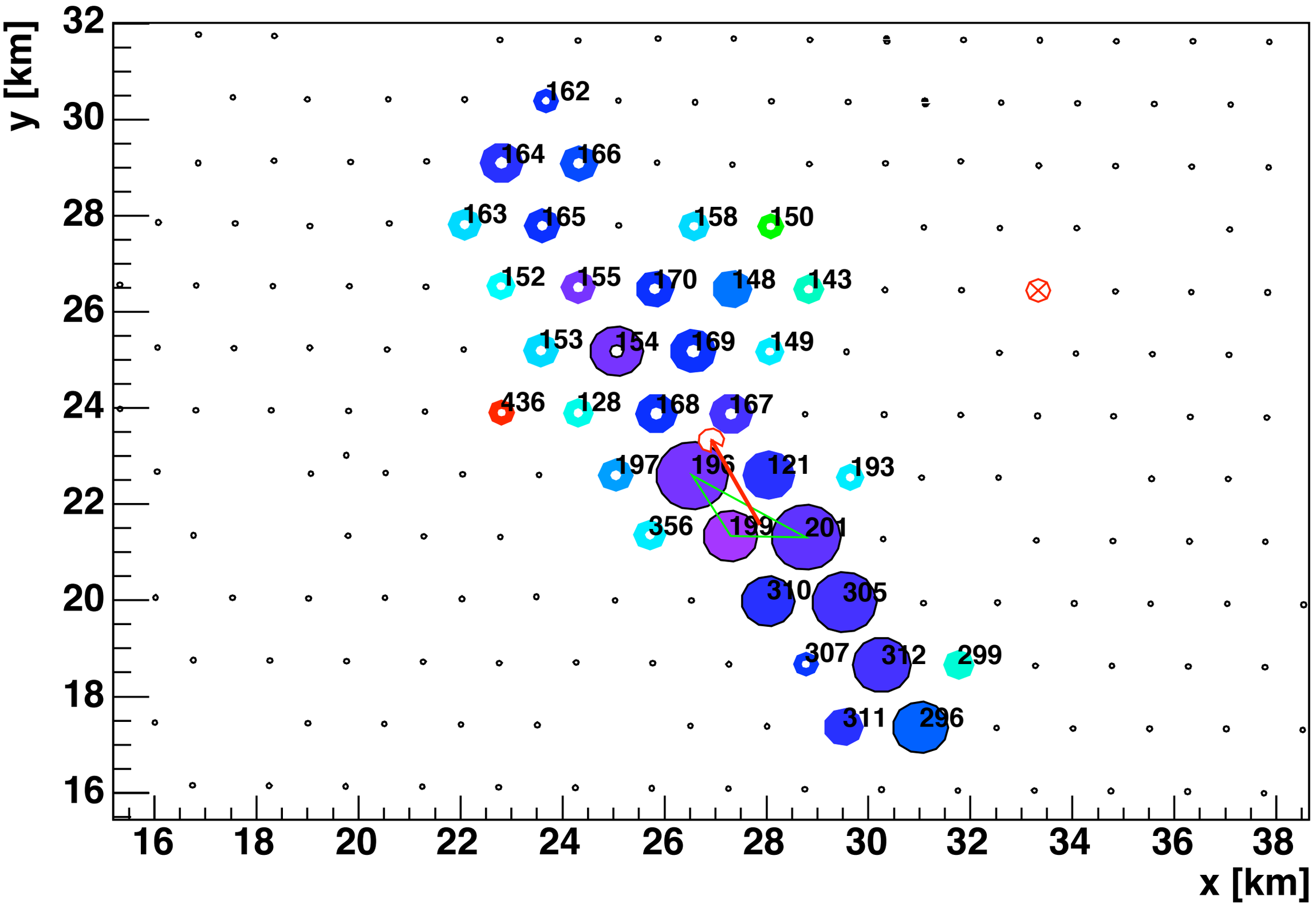
Event 787469

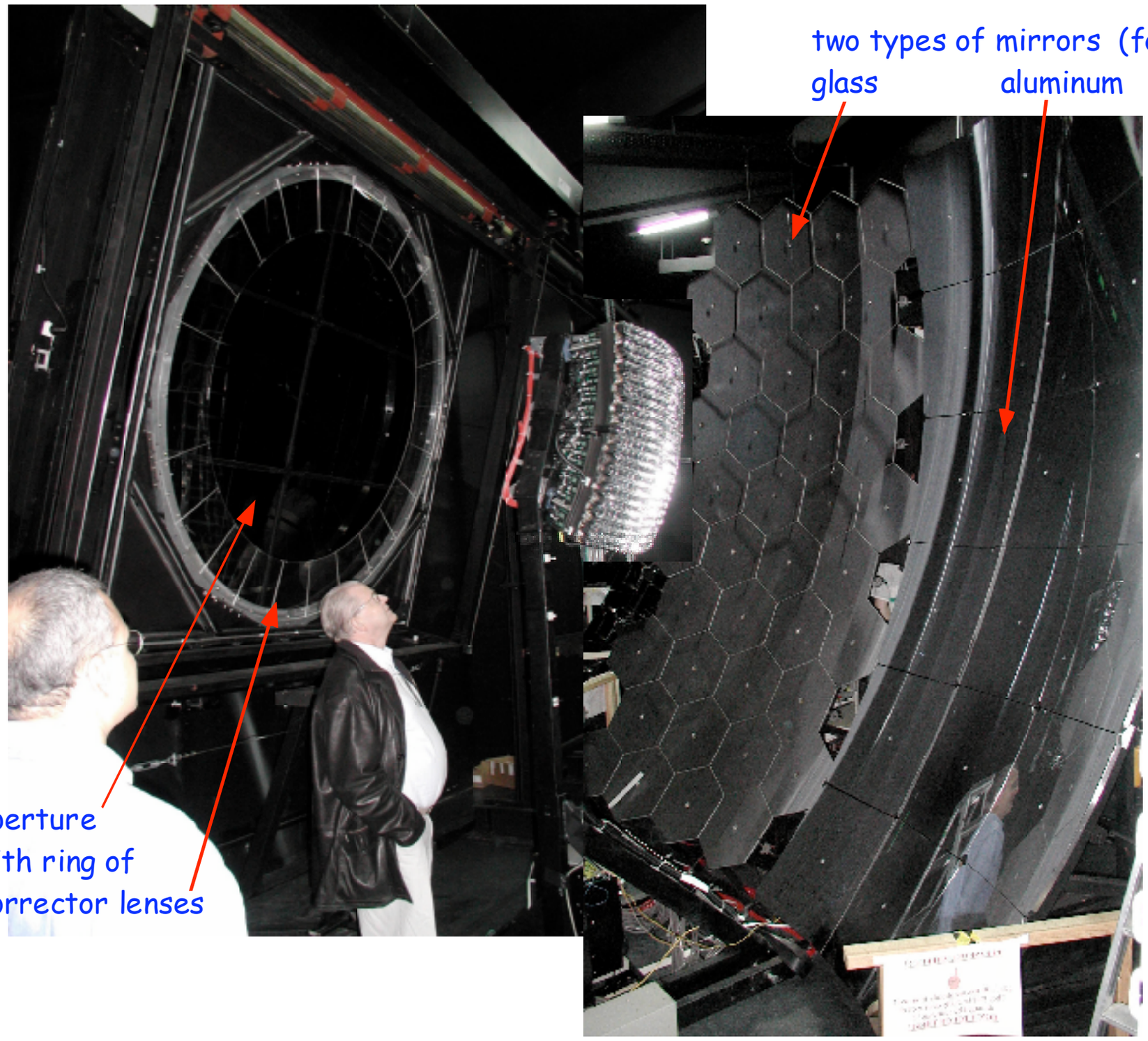
31 tanks, 60º, 76 x 10^{18} eV

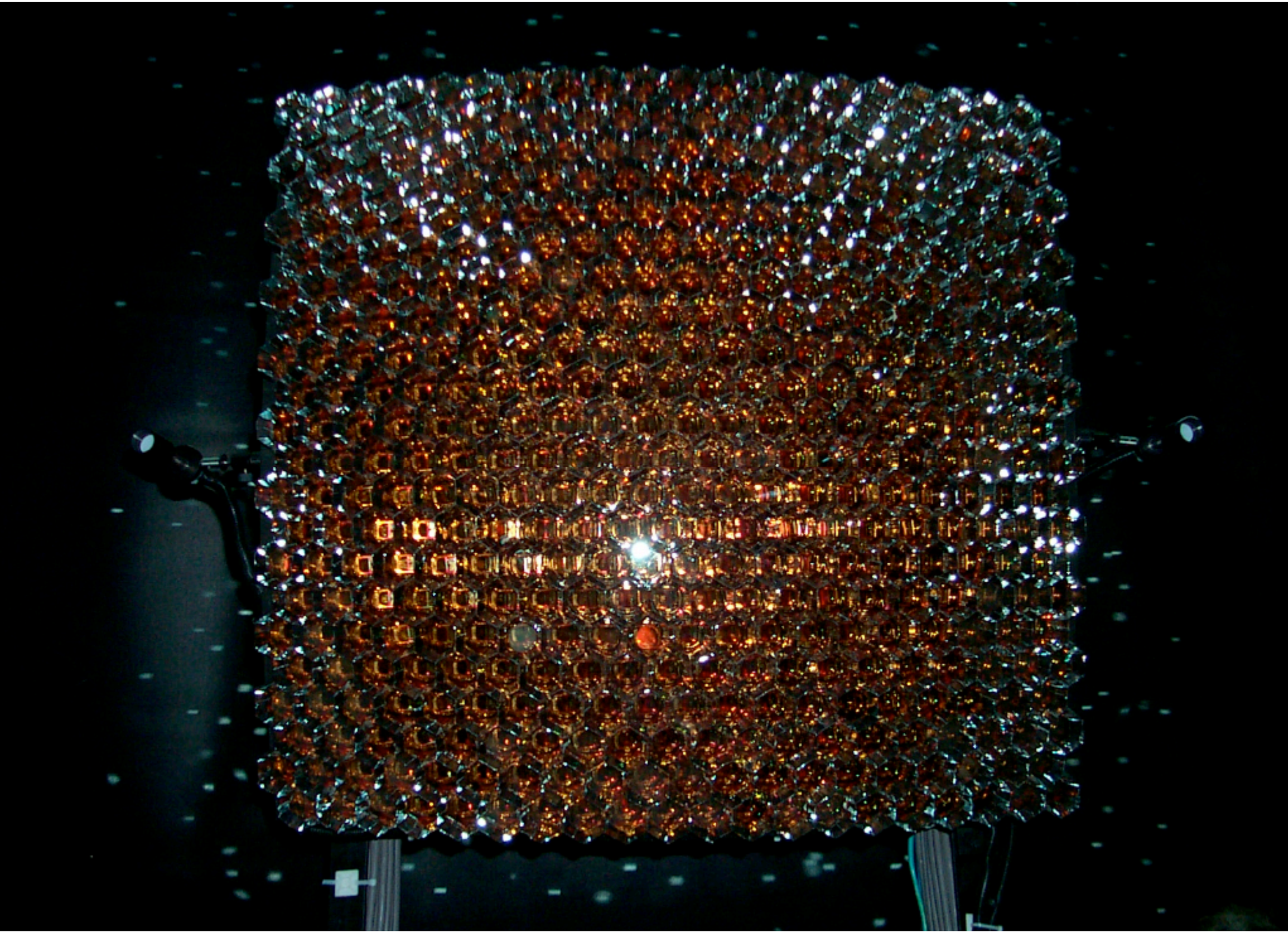


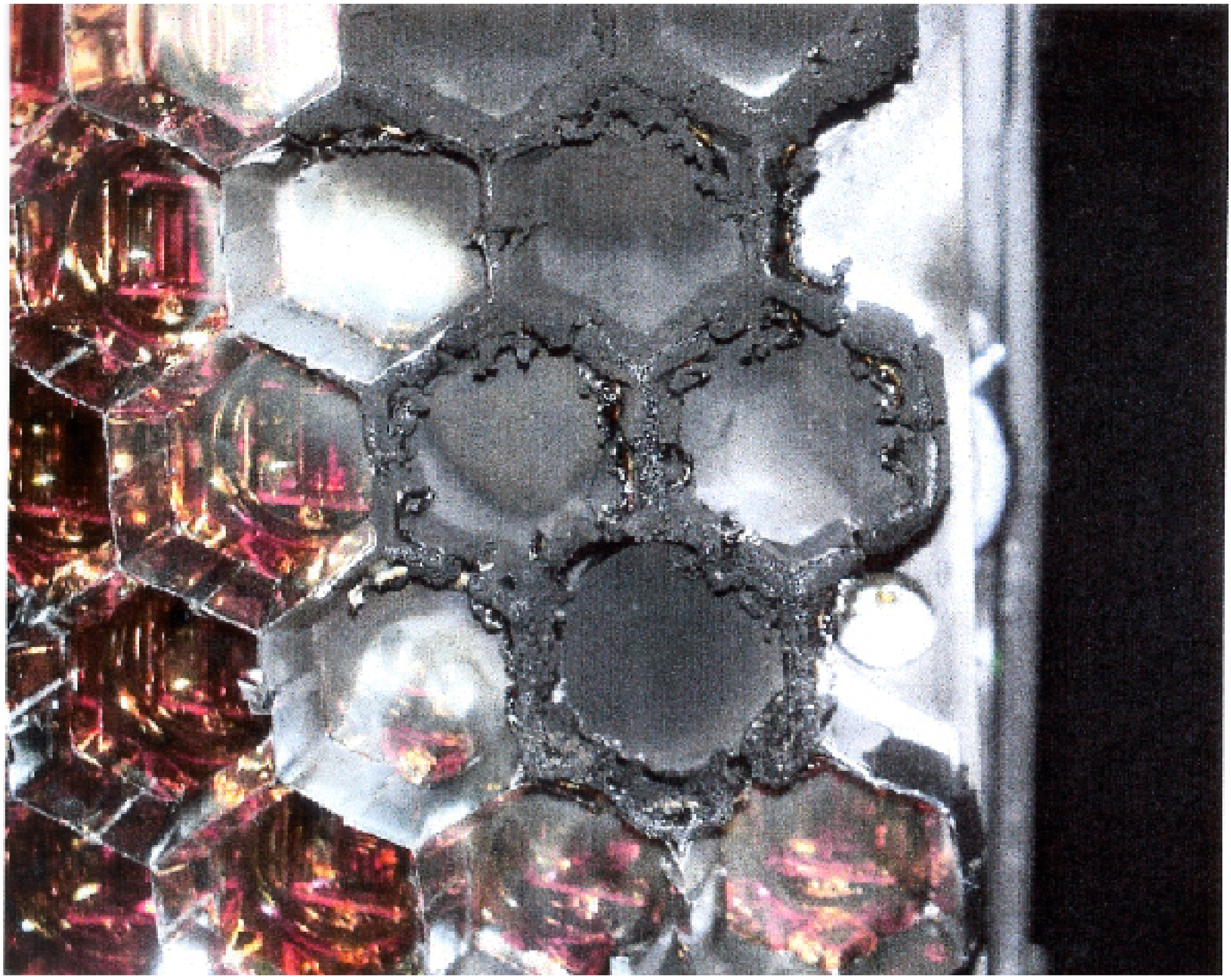
Event 1099180

34 tanks, 82°, ~10 x 10^{18} eV

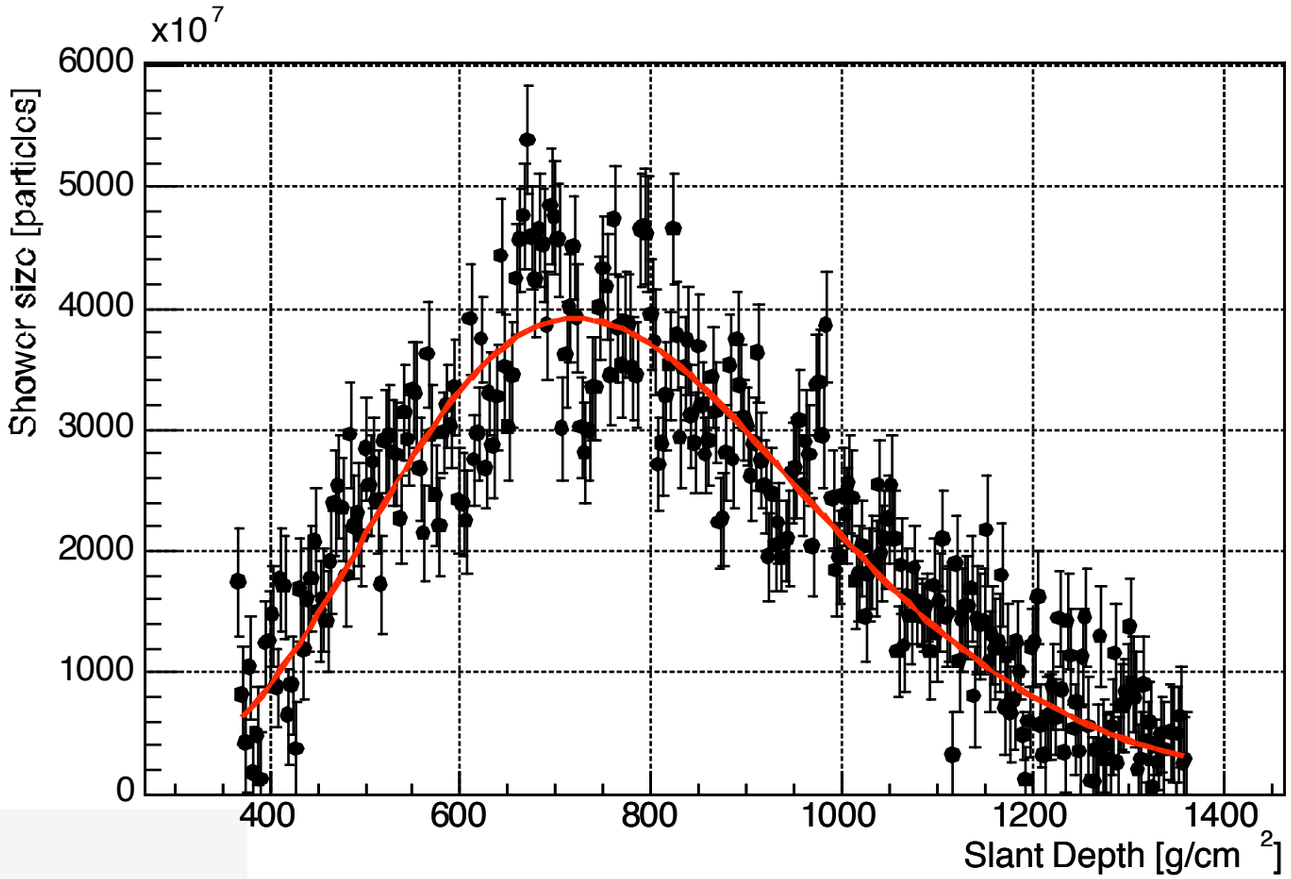


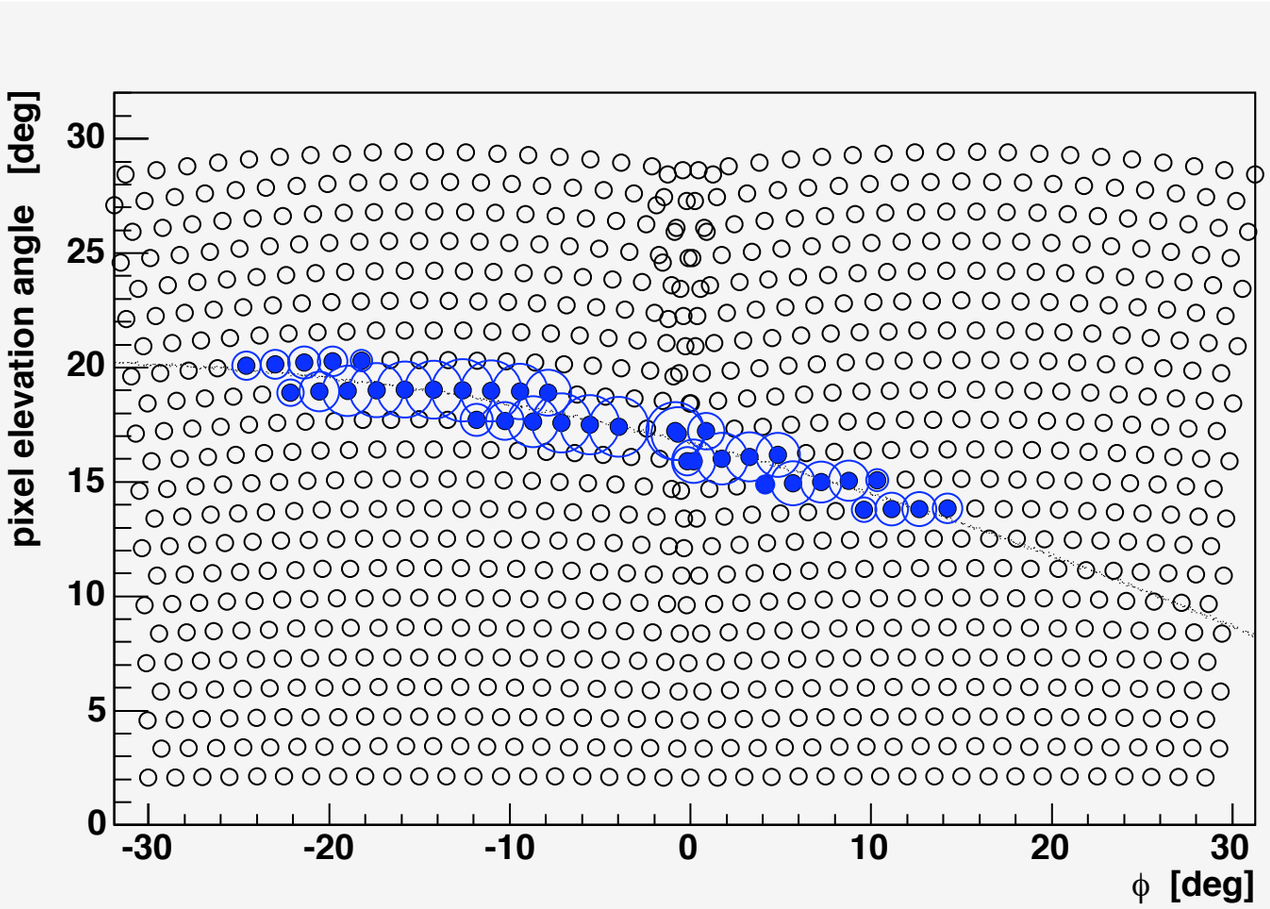

two types of mirrors (for testing)
glass
aluminum
aperture
with ring of
corrector lenses



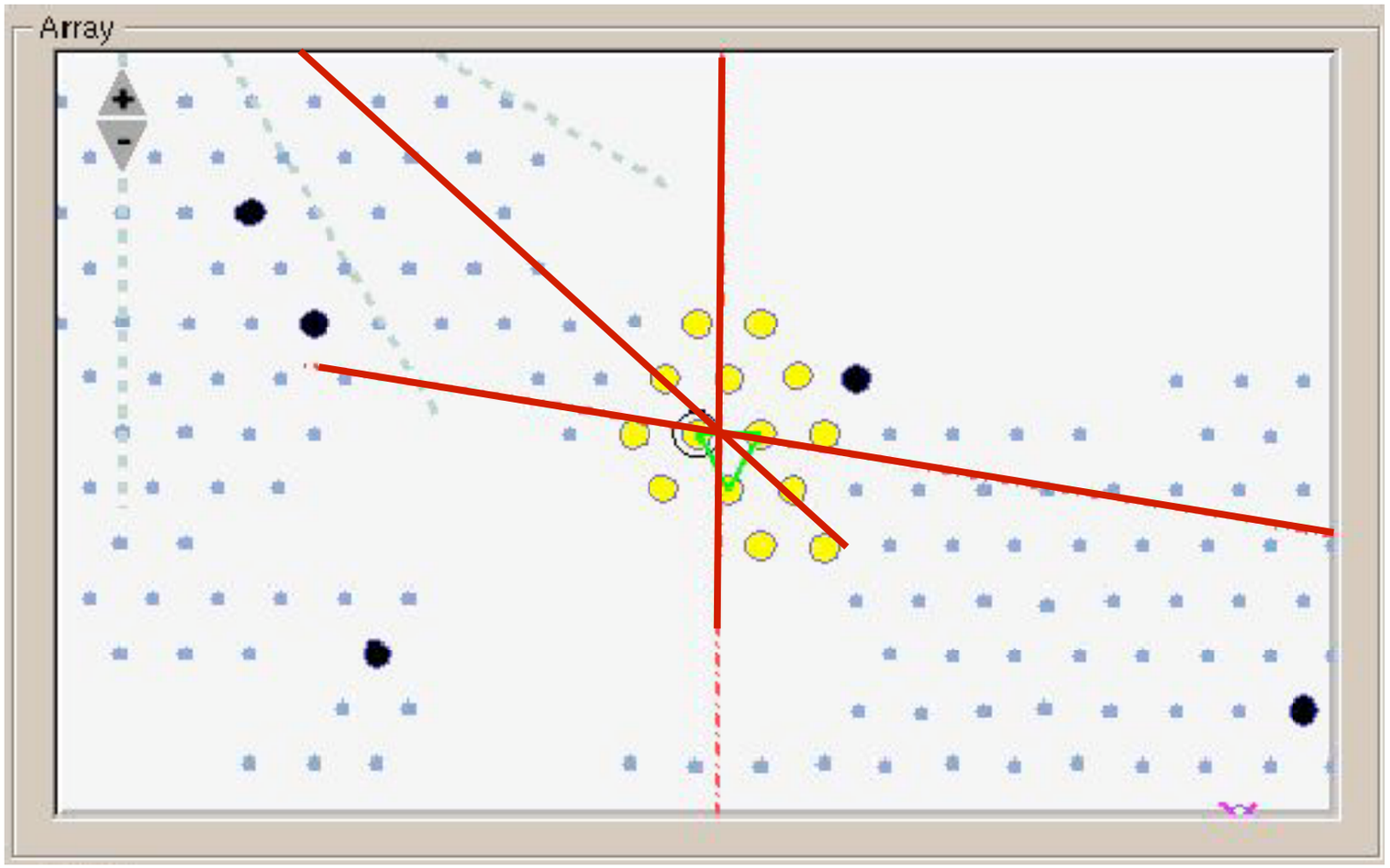


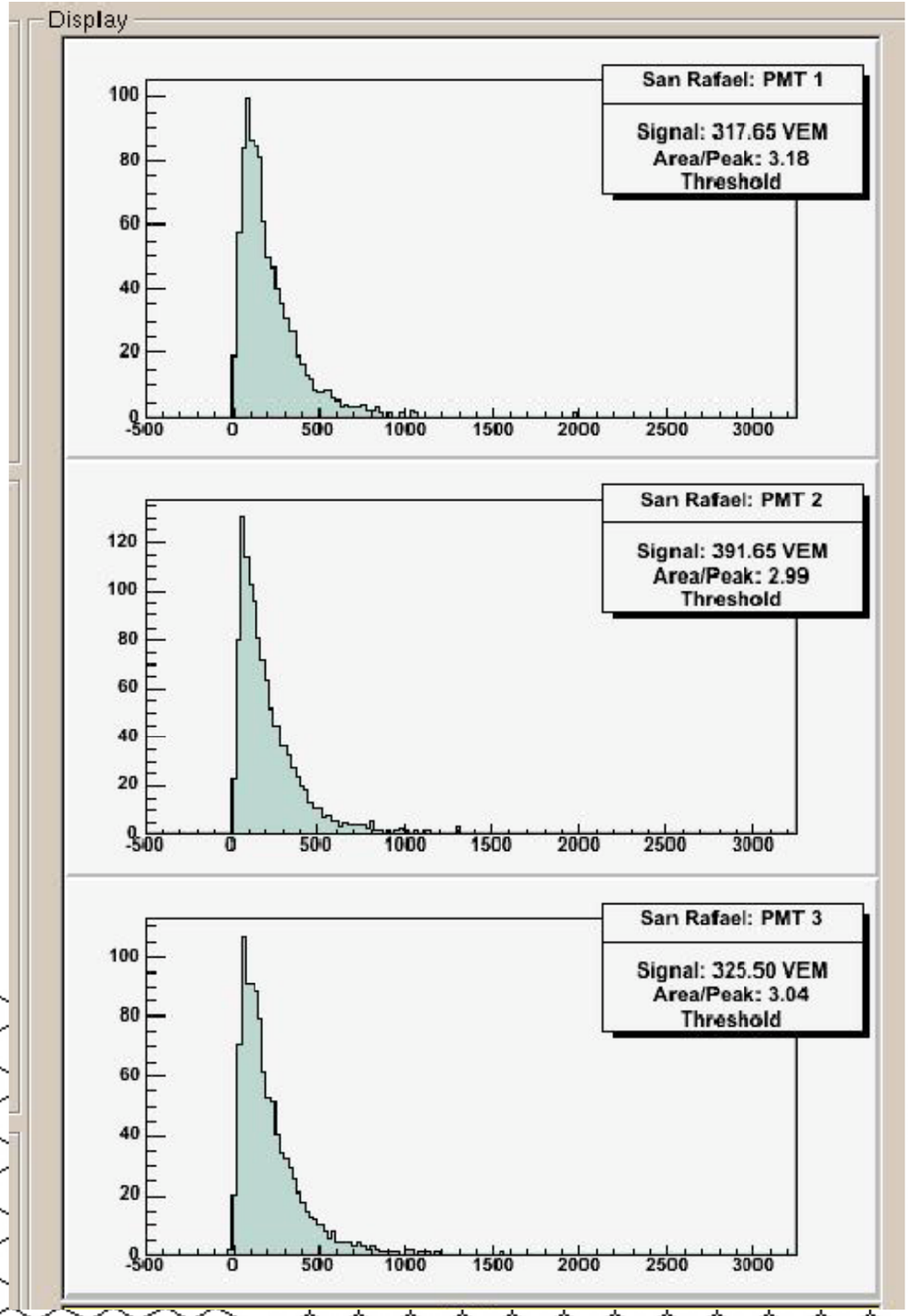
FD: longitudinal profile
calorimetric energy
X_{max} for mass comp.



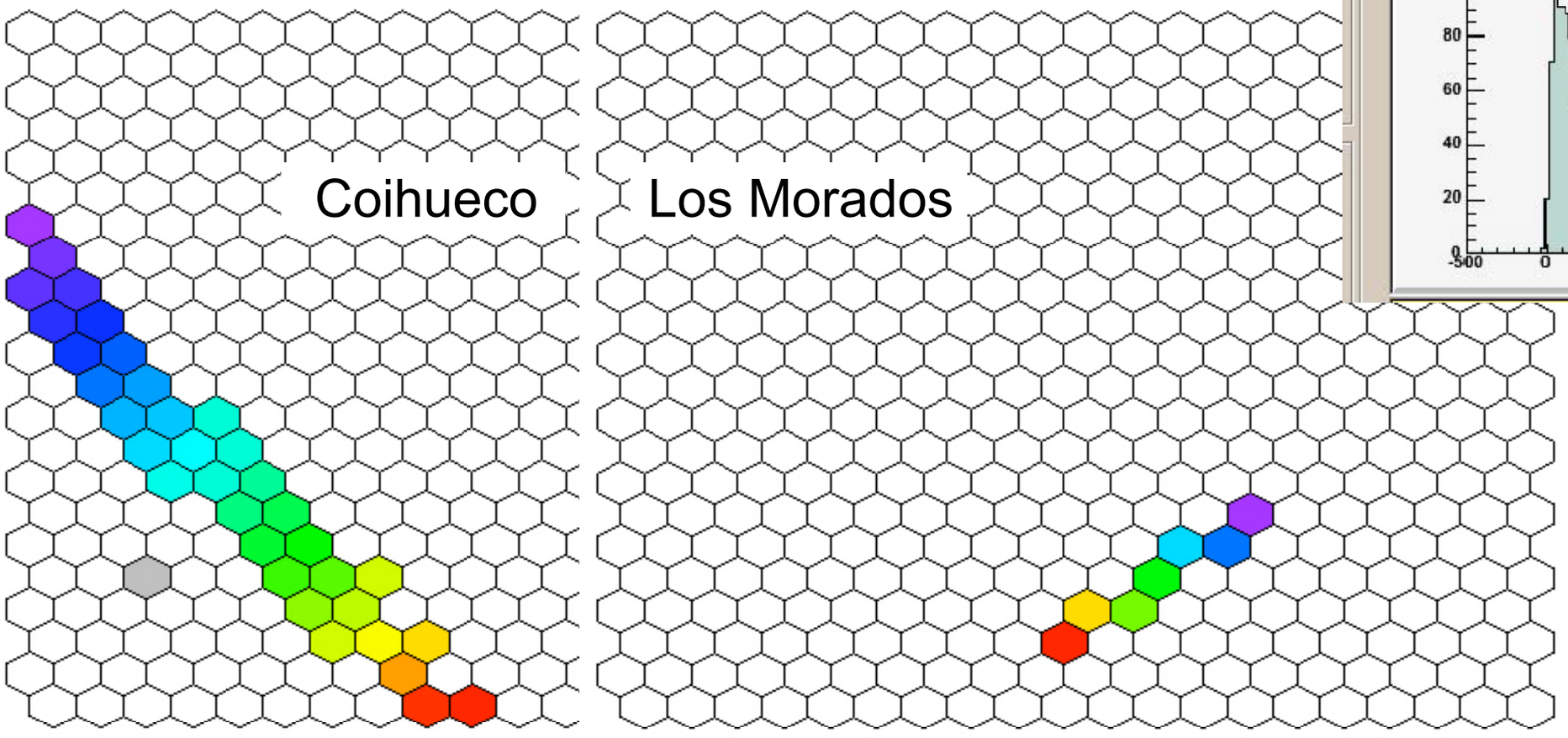


SD &FD: hybrid,
very good geometry
cross-calibration

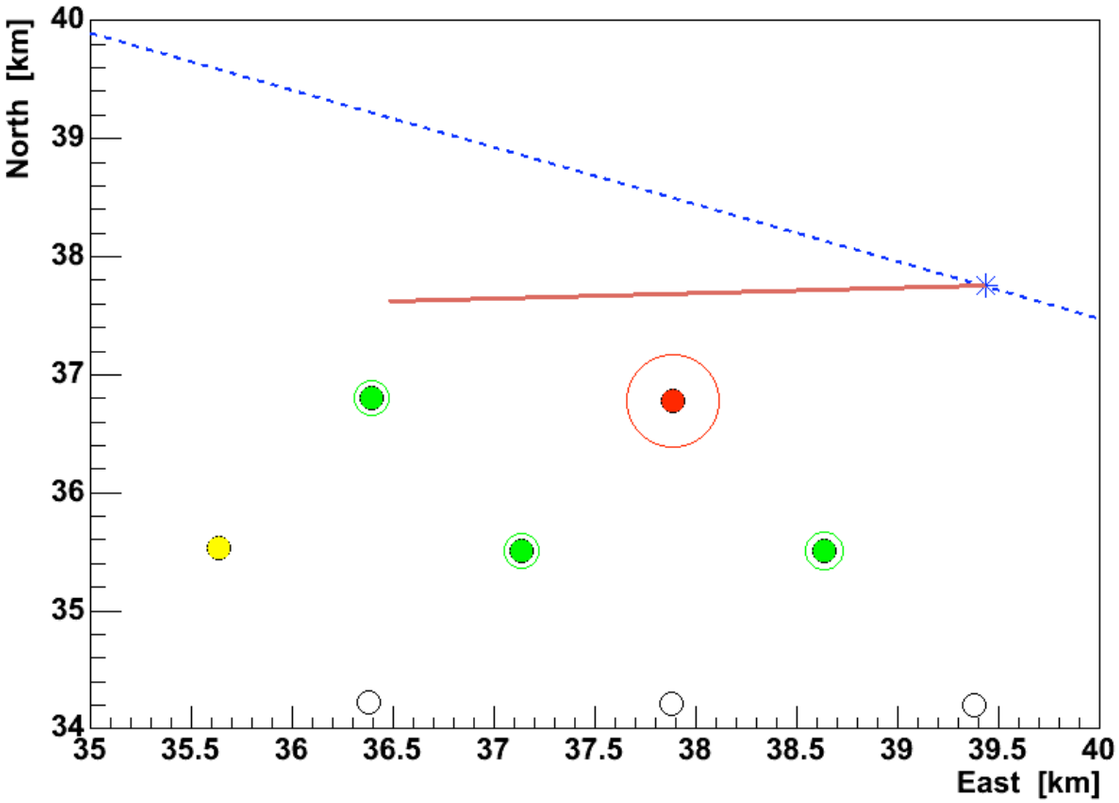


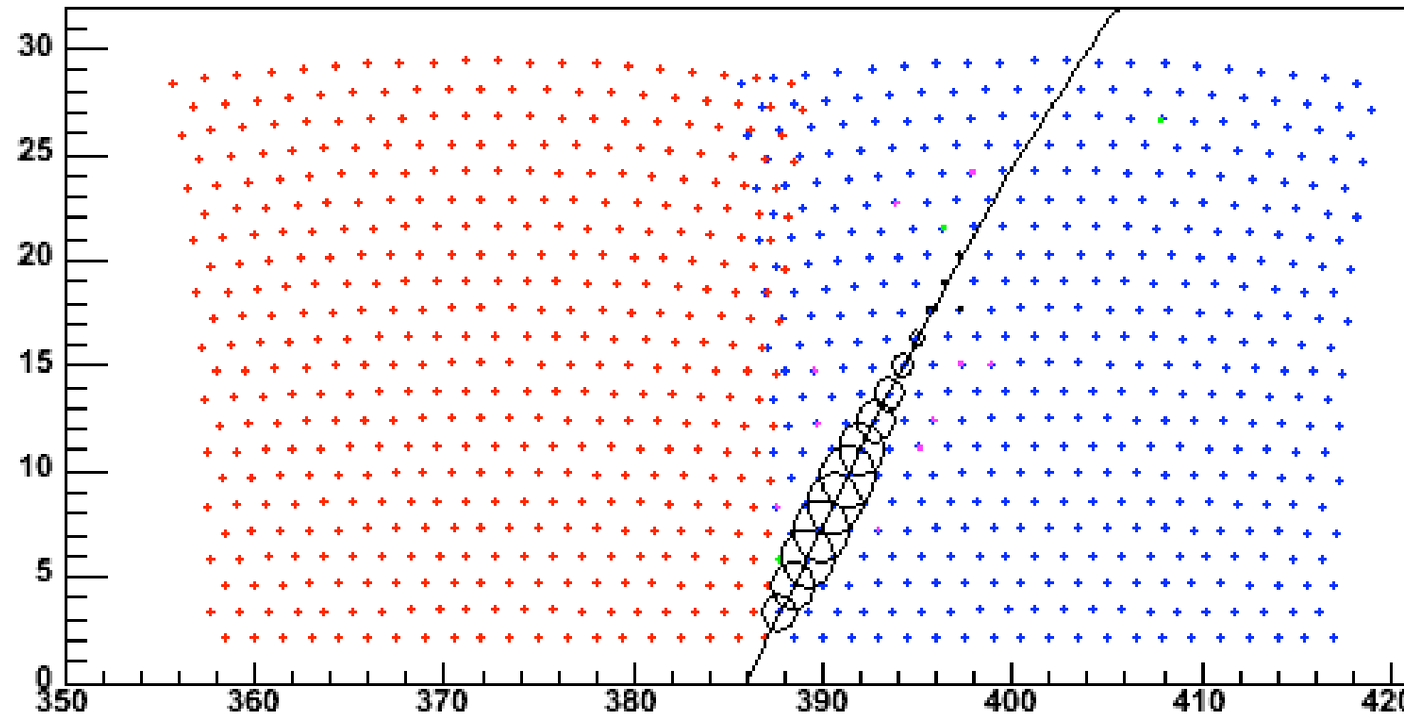


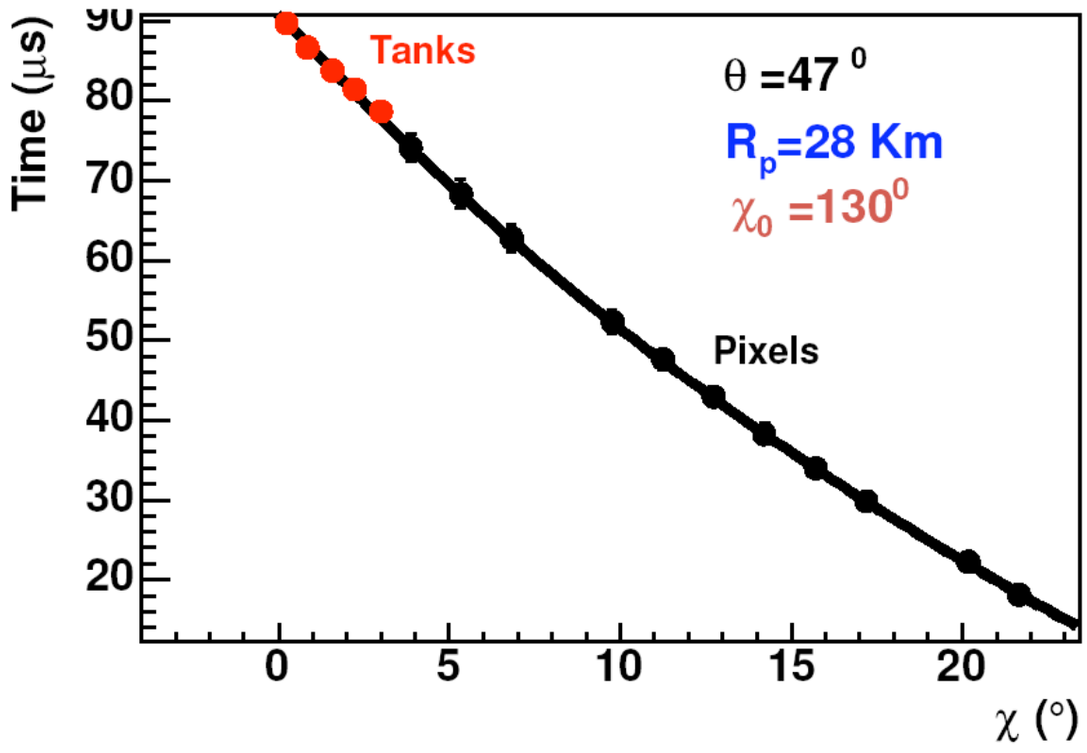
platinum event: 3 FDs + SD

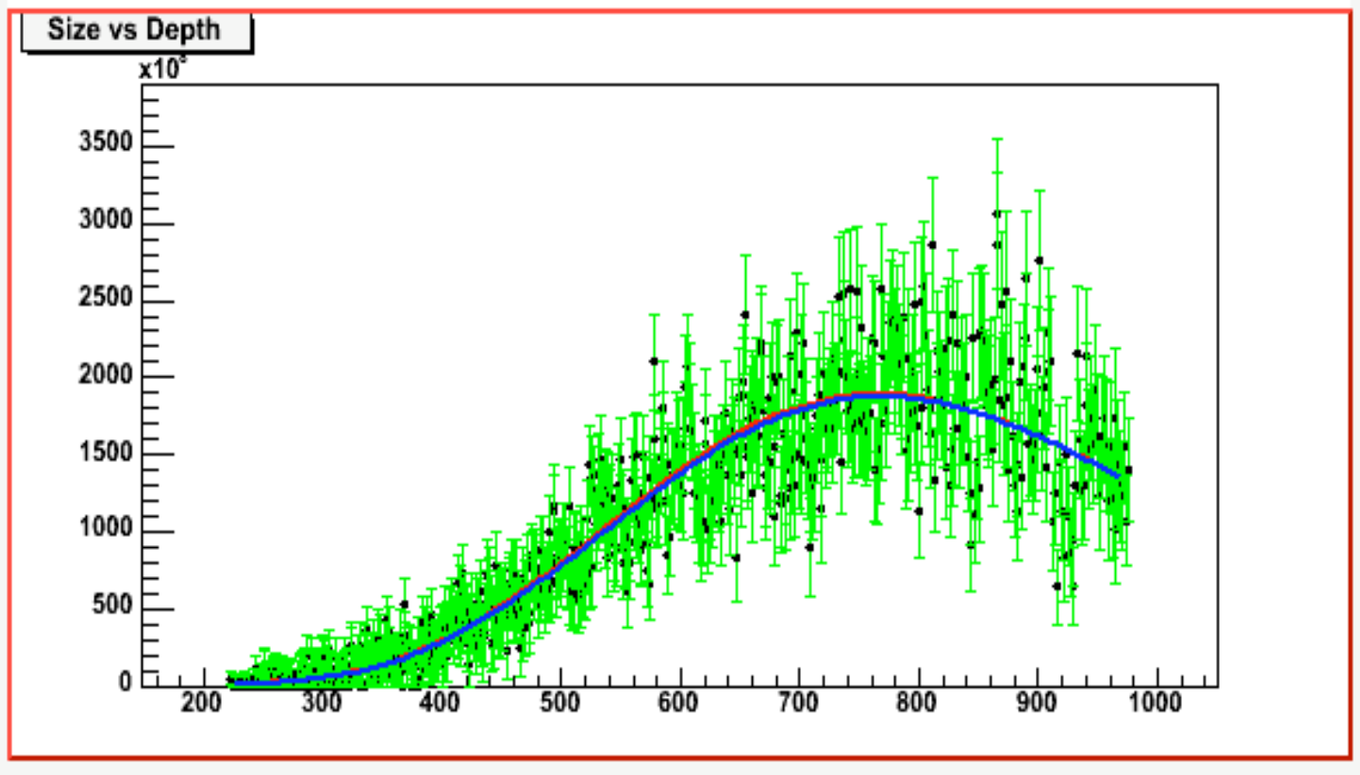


A big event that got away: E ≈ 140 EeV

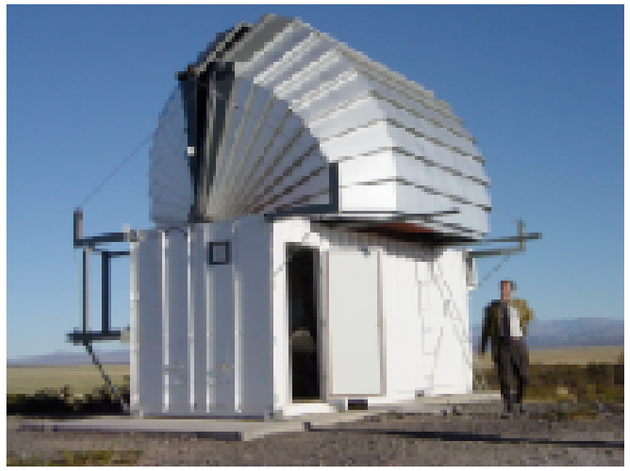








Atmospheric Monitoring and Calibration



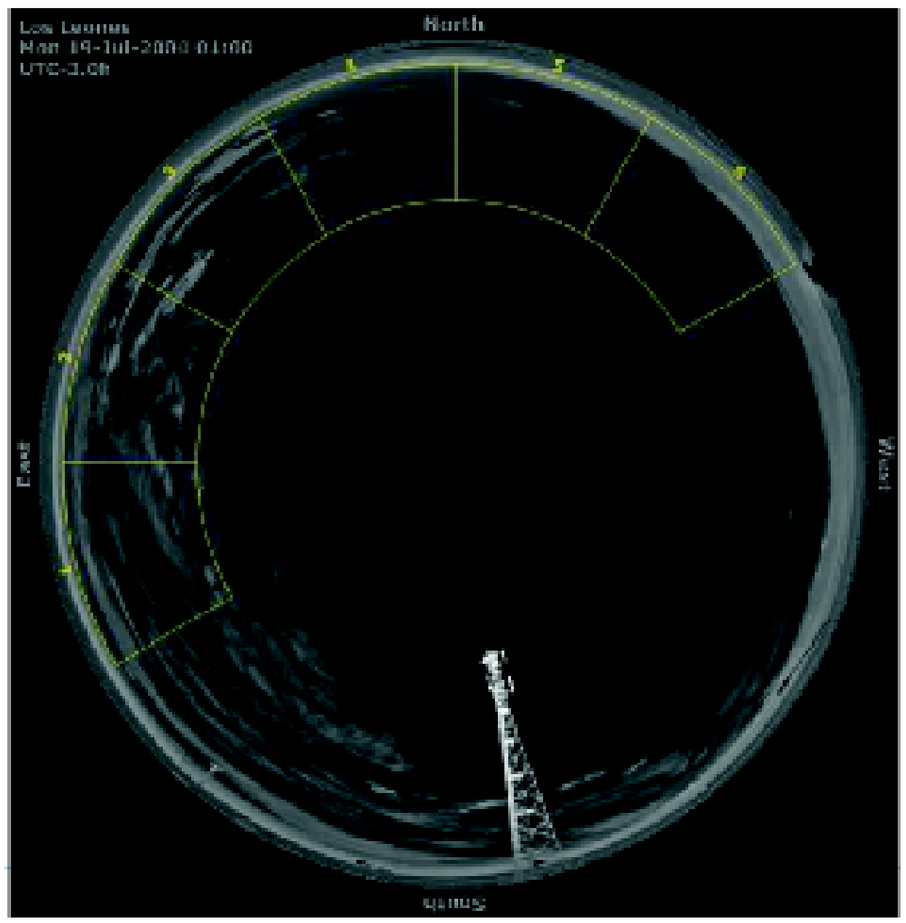
Lidar for atmospheric profiling and
“shooting the shower”
at each Fluorescence building

Central Laser Facility
(laser linked to adjacent tank)

End-to-end absolute calibration
(Drum for uniform illumination
of FD camera)

Balloon borne
atmospheric measurements

Cloud monitor



Spectrum

Energy: straight forward from FD

(but FD only active for 10% of time)

model dependent from SD

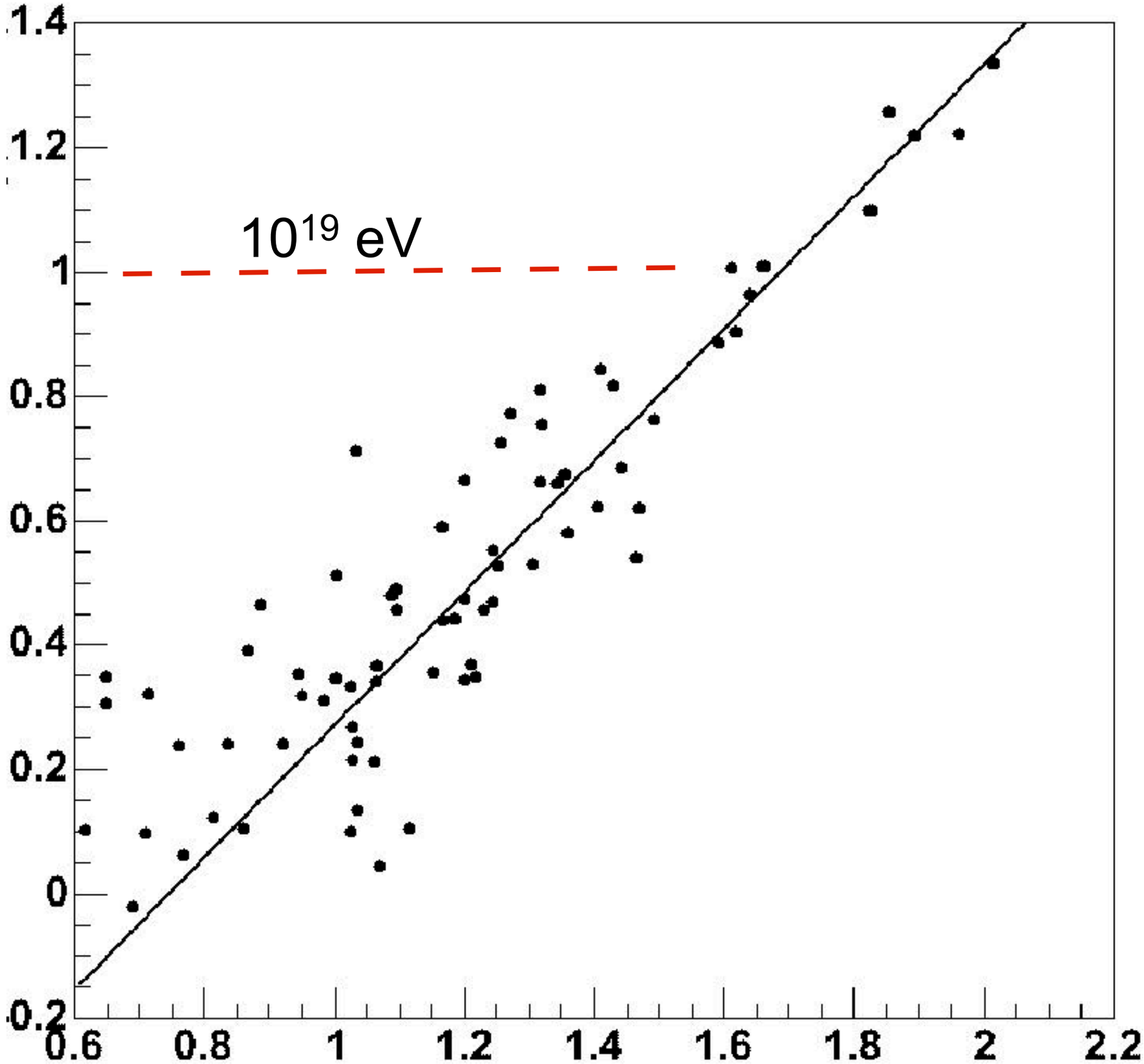
(SD active for 100% of time)

Energy calibration from FD

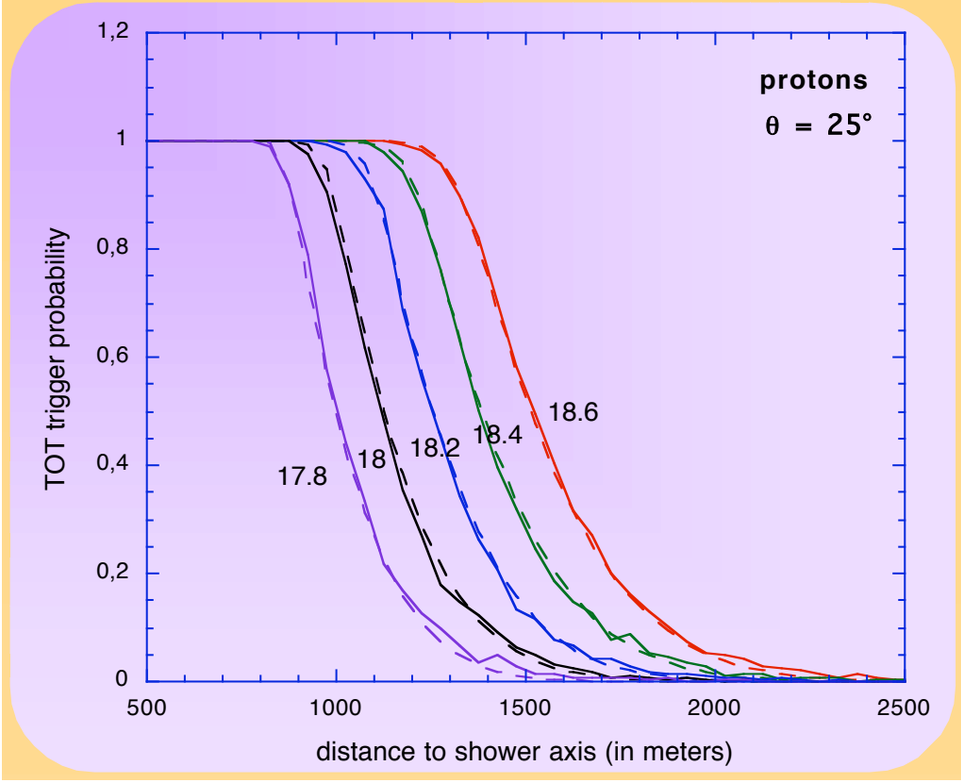
high statistics from SD

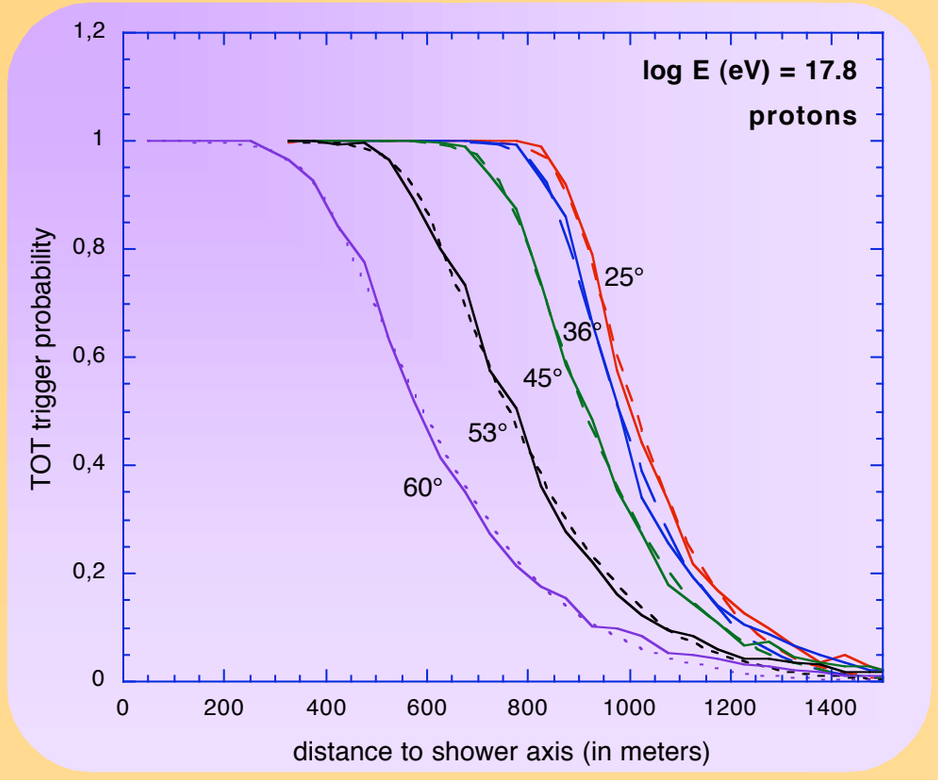
Rate = Flux · aperture · time

log (E/EeV)
from FD



Aperture Calculation

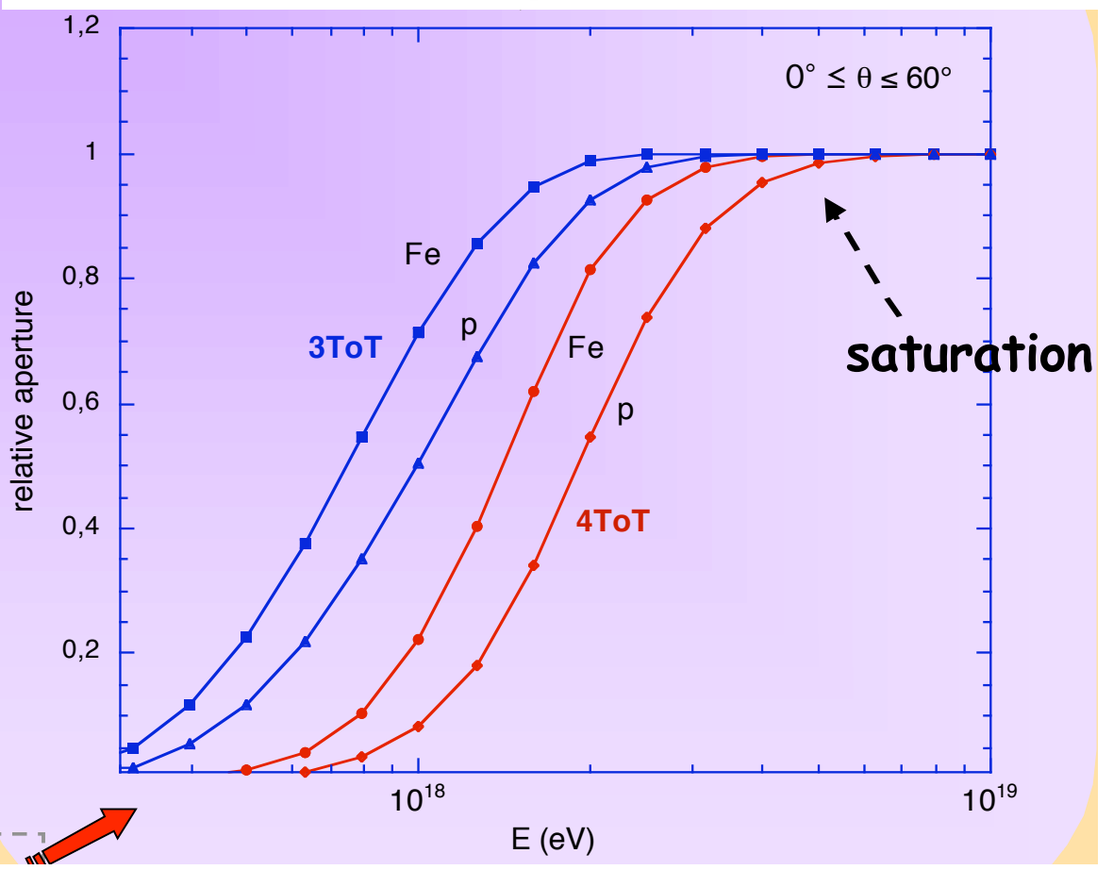


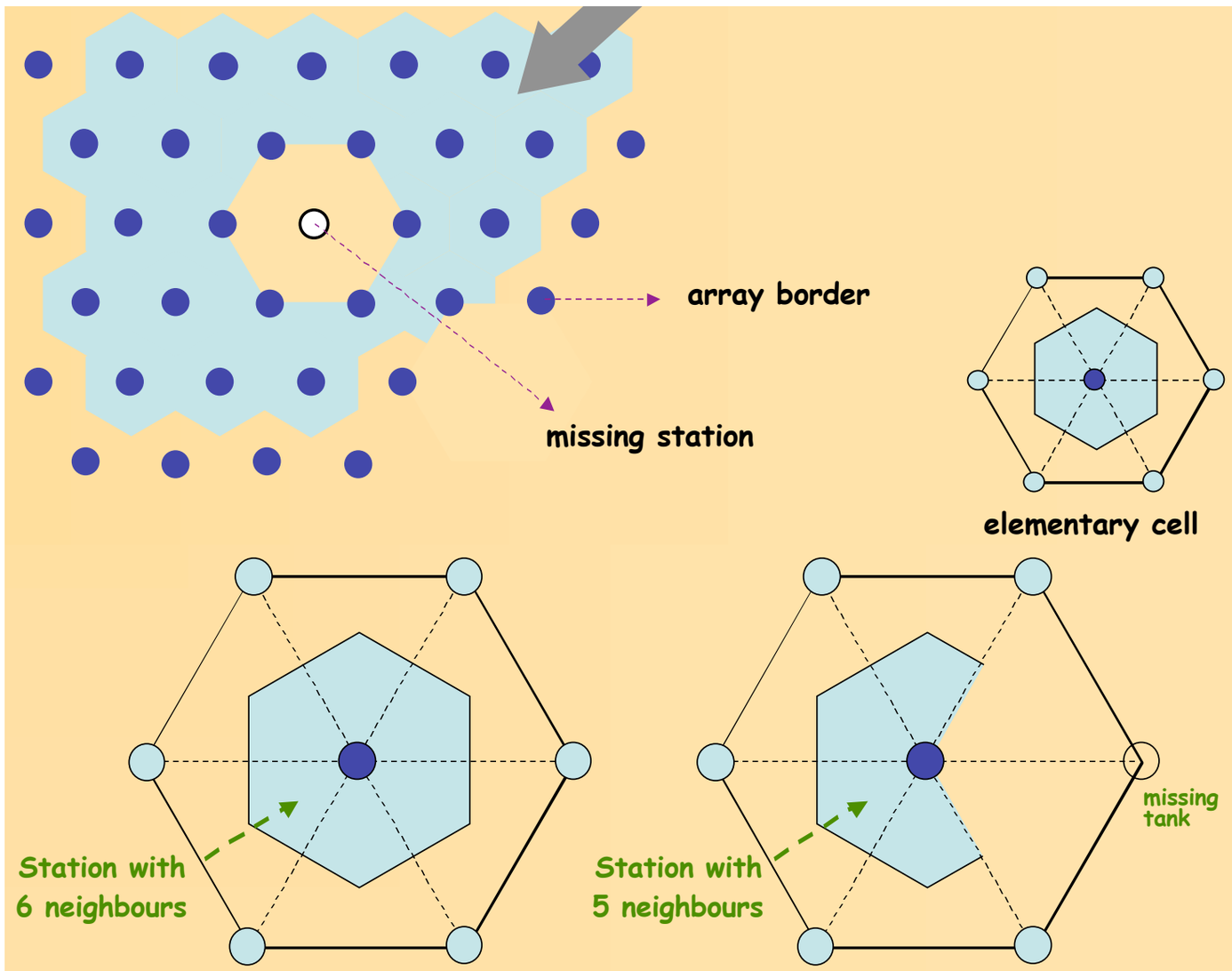


Exposure:
1750 km^2 sr yr

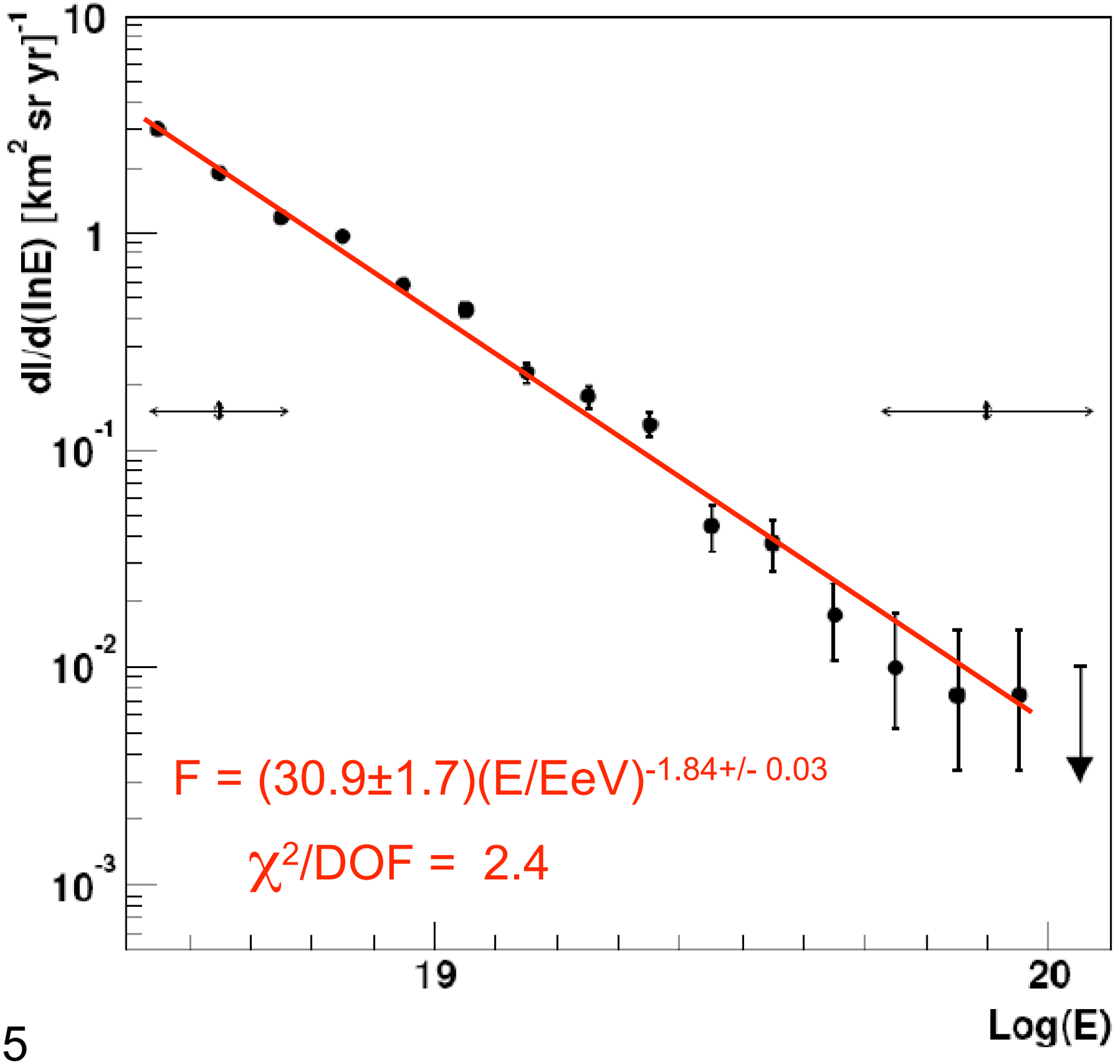
lateral trigger probability

relative aperture

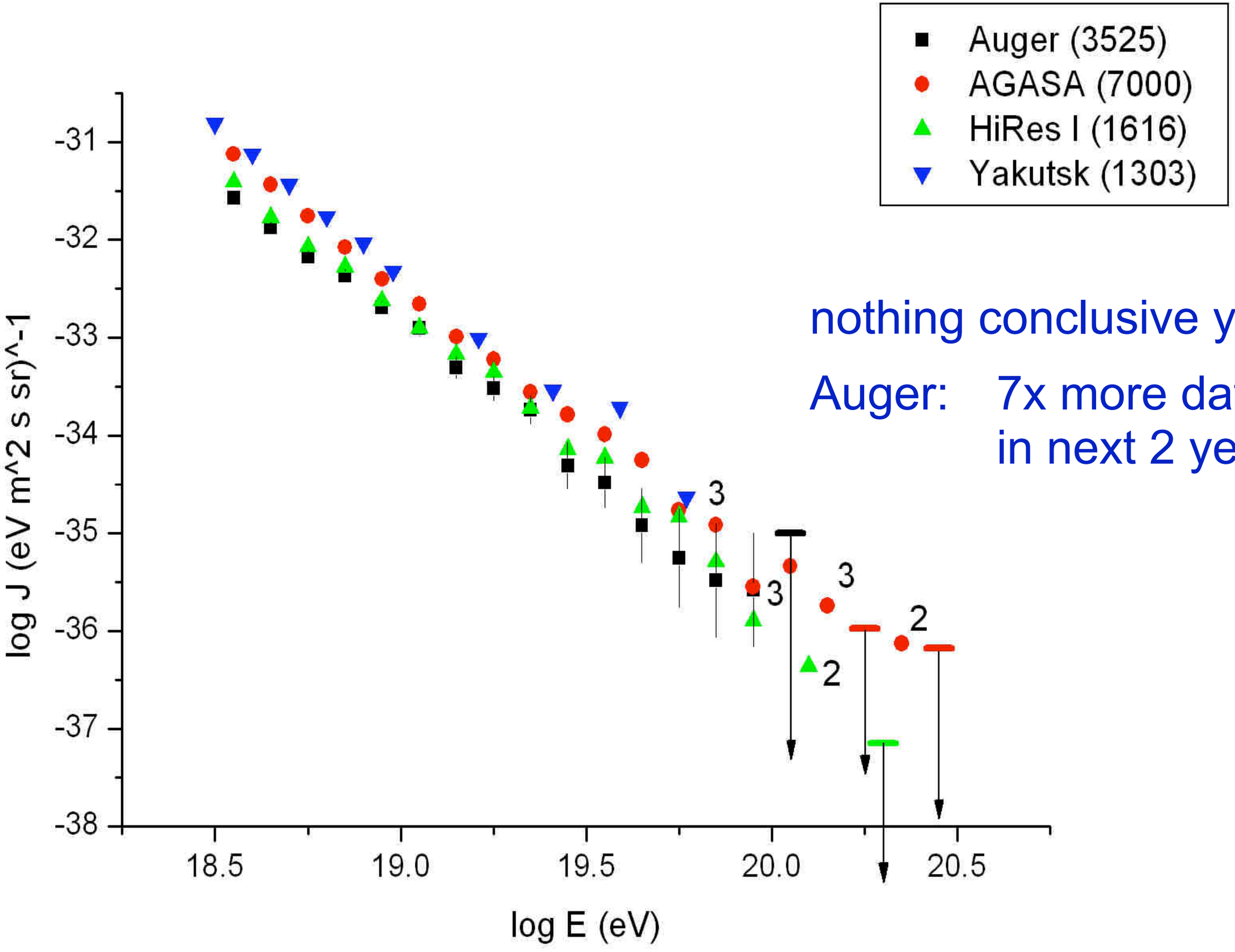




Auger spectrum



1 Jan 2004 – 5 June 2005
zenith angle: 0-60°
3525 events > $10^{18.5}$ eV

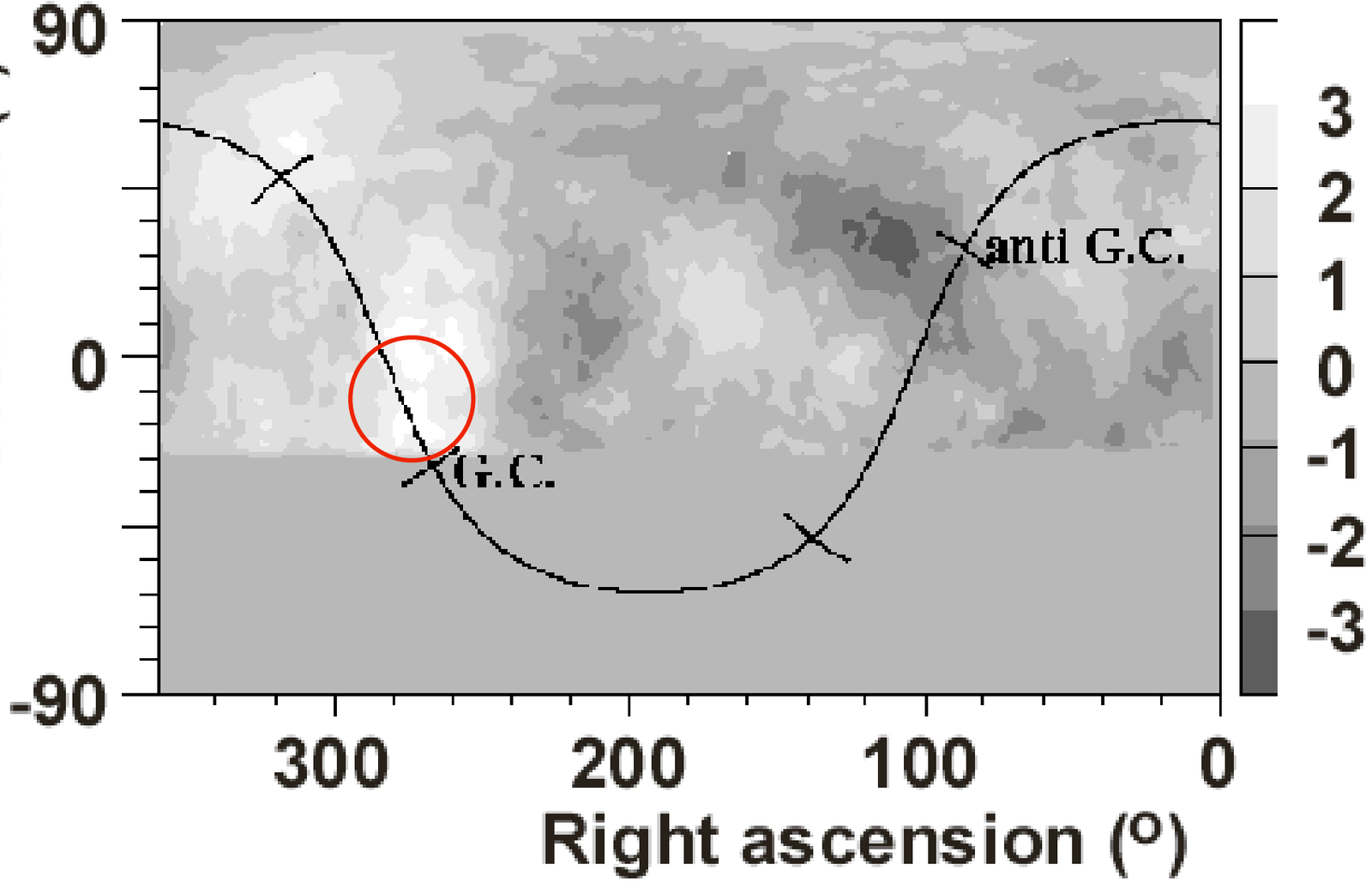


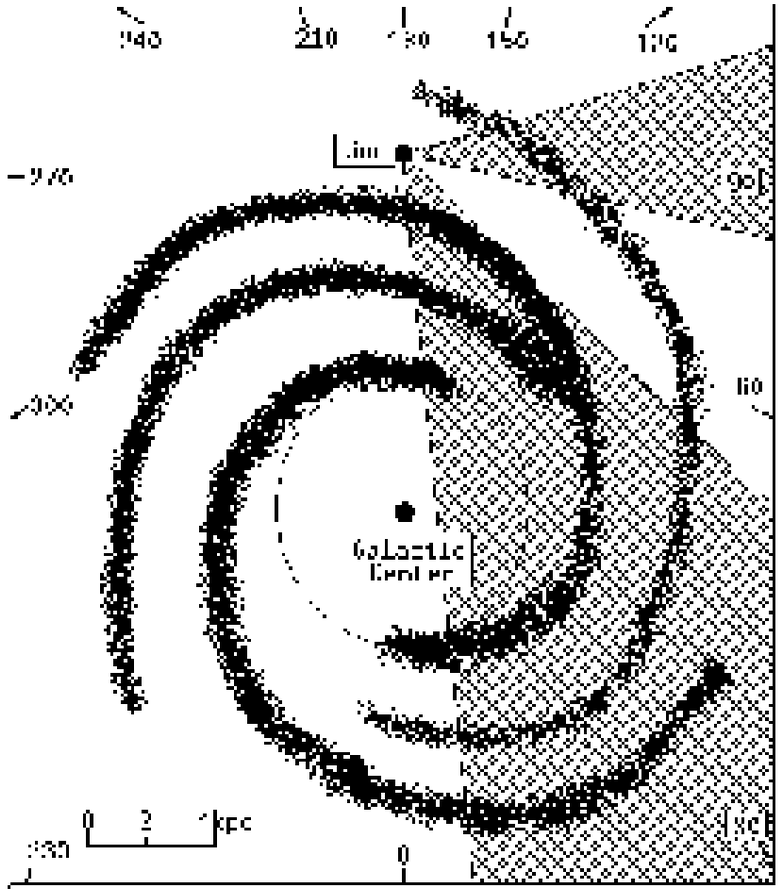
nothing conclusive yet.

Auger: 7x more data in next 2 years

Anisotropy

AGASA : 4% anisotropy at 10^{18} eV





506 observed
414 expected

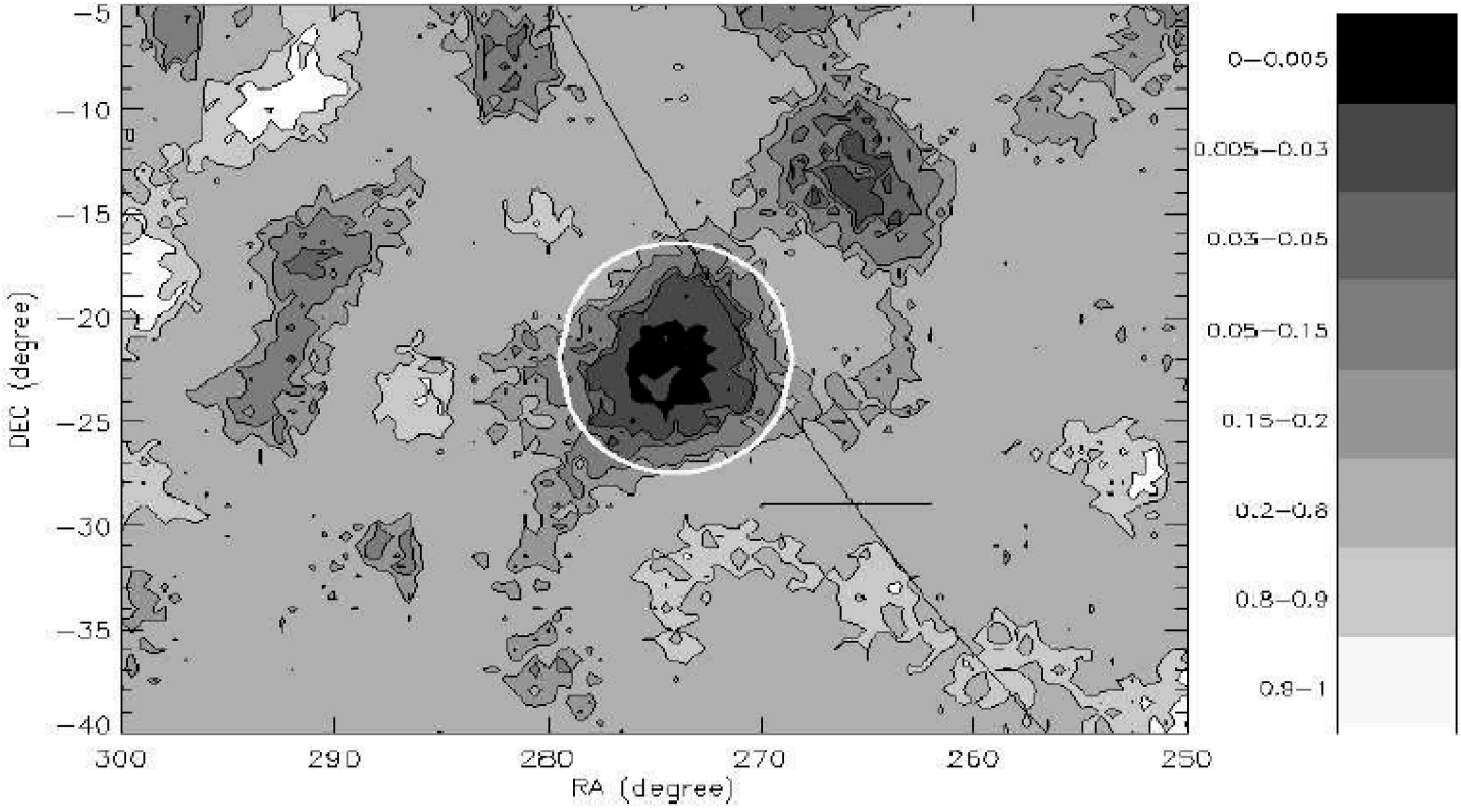
+22% or +4.5s

SUGAR galactic center search ($10^{17.9}$ – $10^{18.5}$ eV)

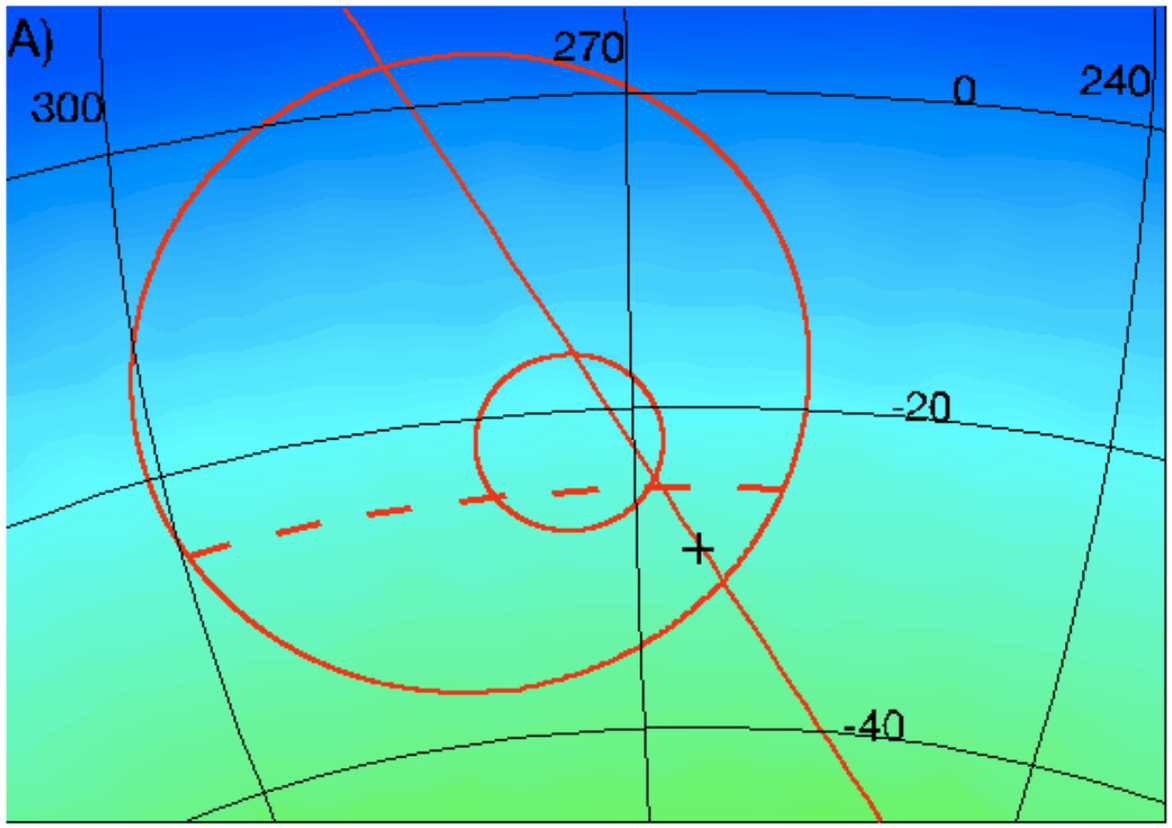
5.5° cone around $(\delta, \alpha)=(-22,274)$

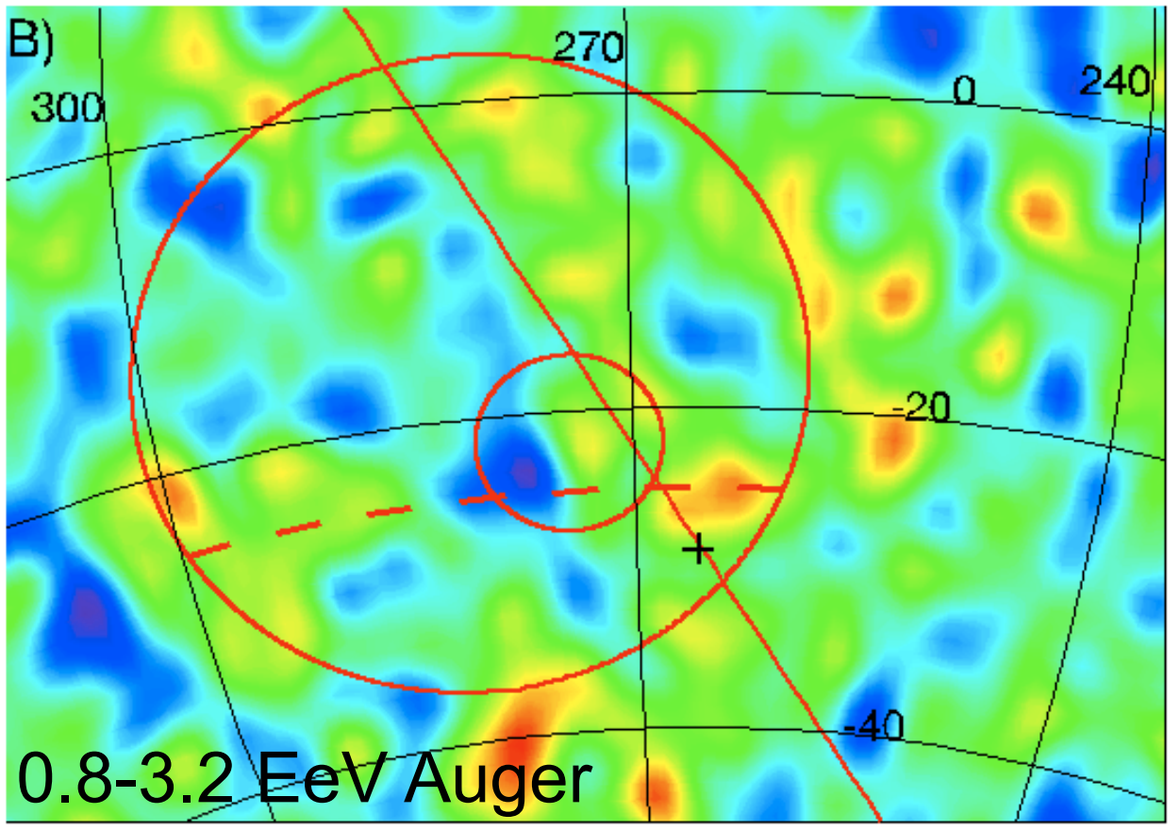
$$\frac{observed}{expected}=\frac{21.8}{11.8} \quad (+2.9\sigma)$$

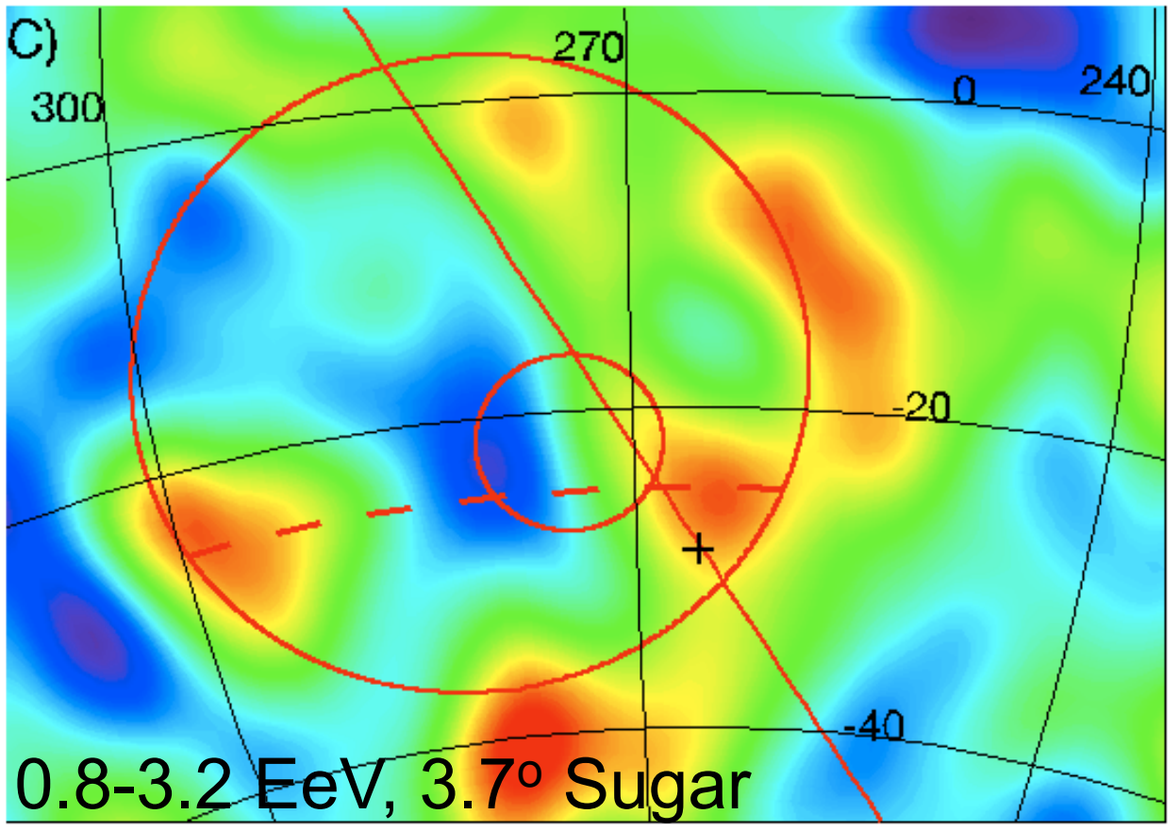
(85% excess)

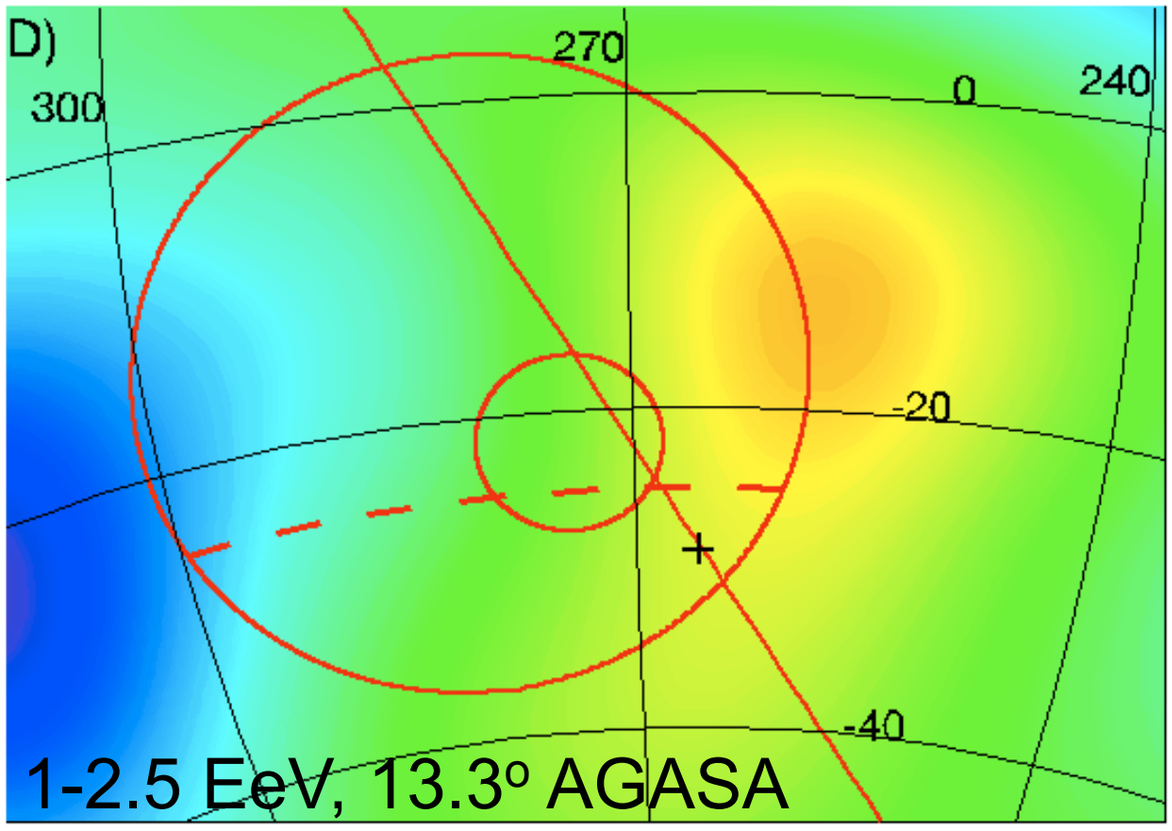


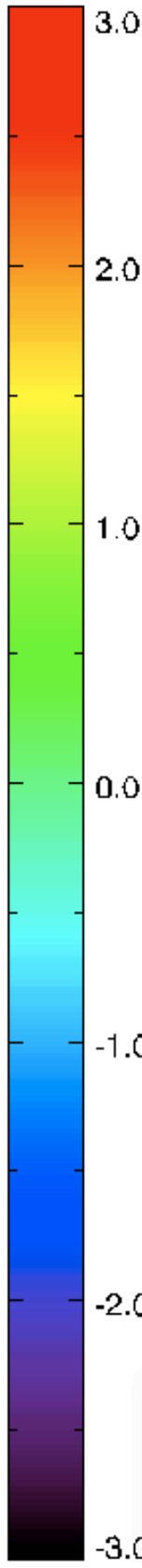
Auger: Galactic Centre











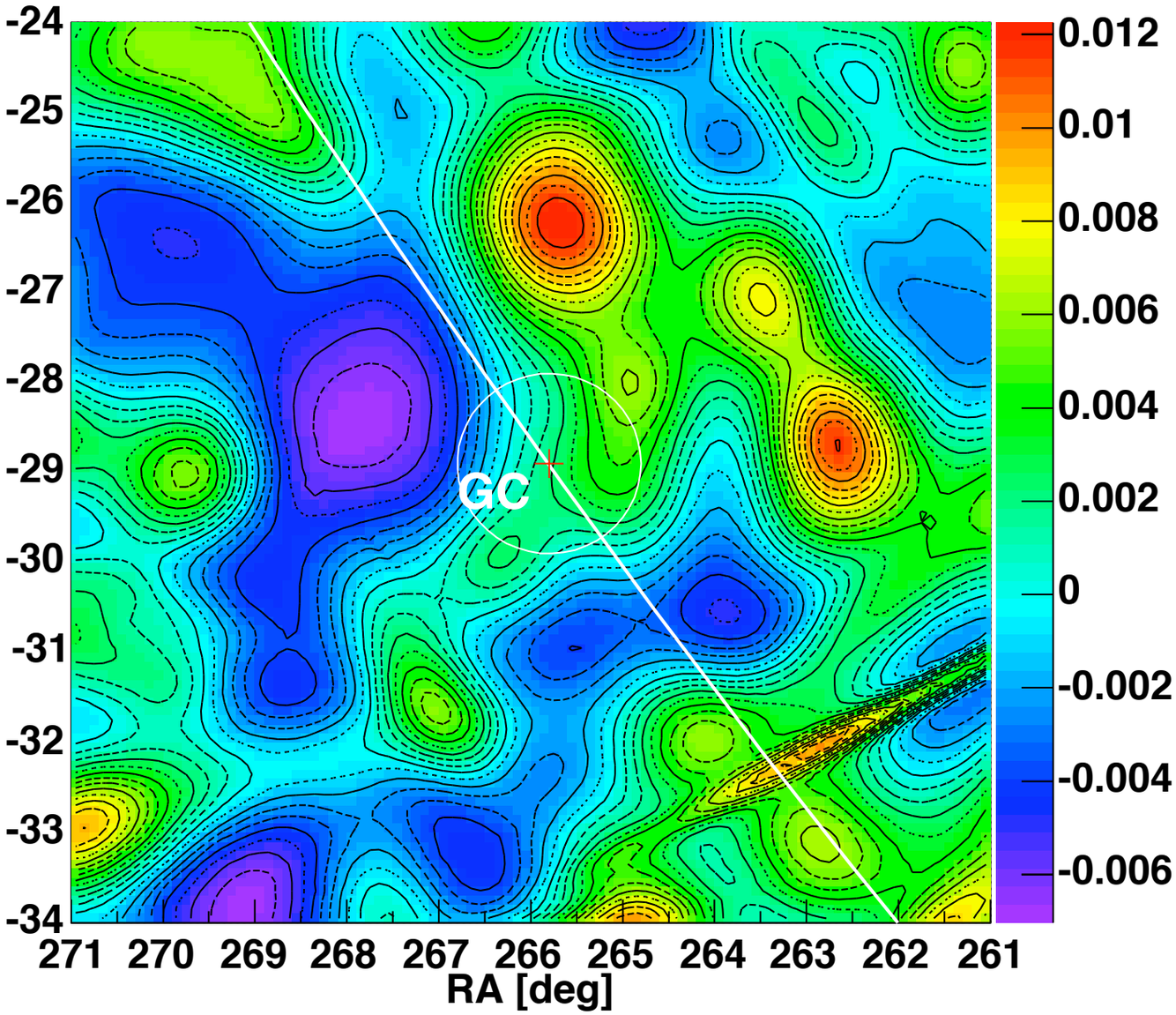
1.0-2.5 EeV AGASA:
506/414
+4.5σ or +22%

Auger:
1155/1160
(22% excess would give +1415 evts. or +7.5σ)

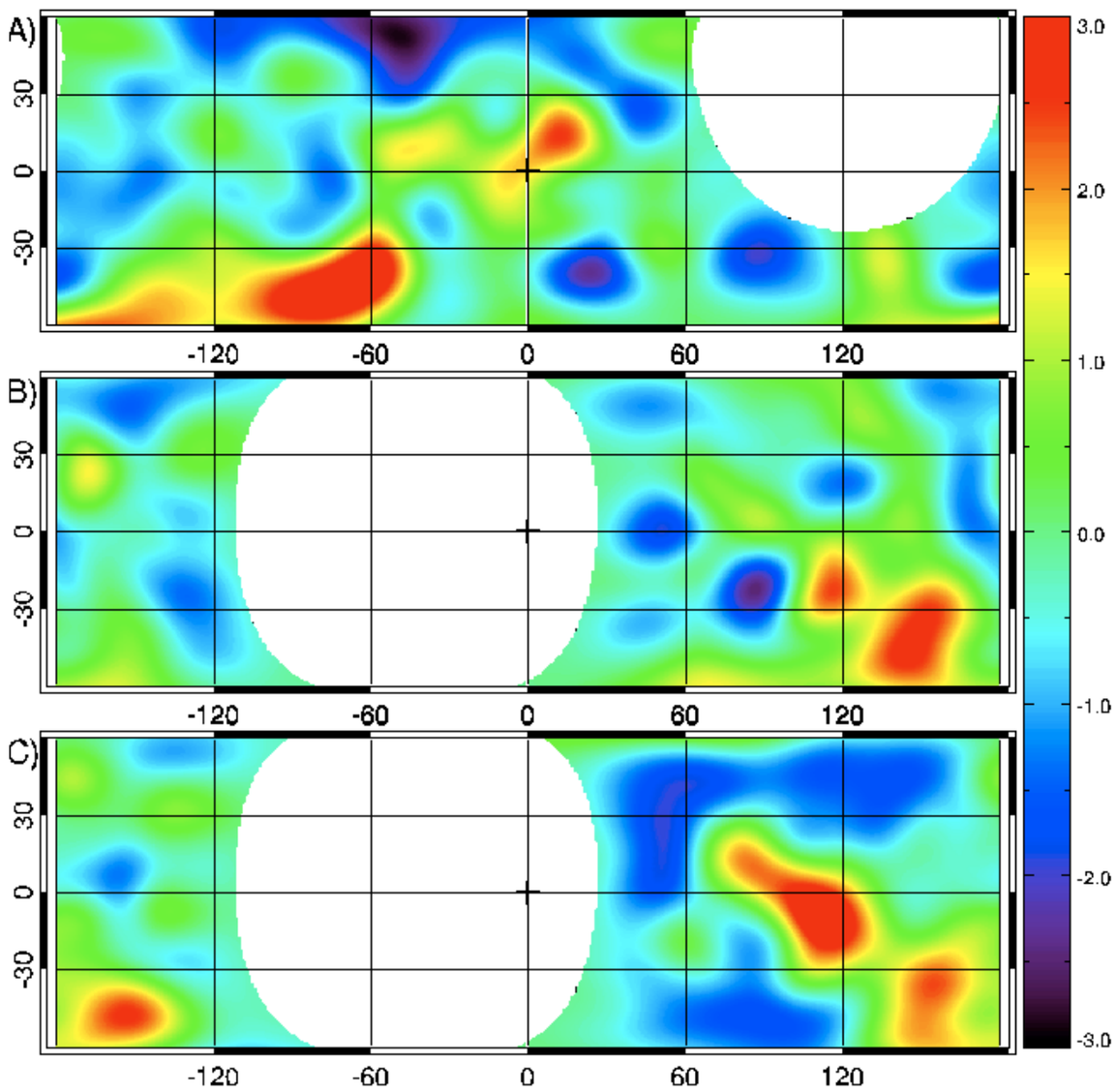
0.8-3.2 EeV Sugar:
22/12
+2.9σ or +85%

Auger:
144/151
(85% excess would give +279 evts. or +10.5σ)

no point source

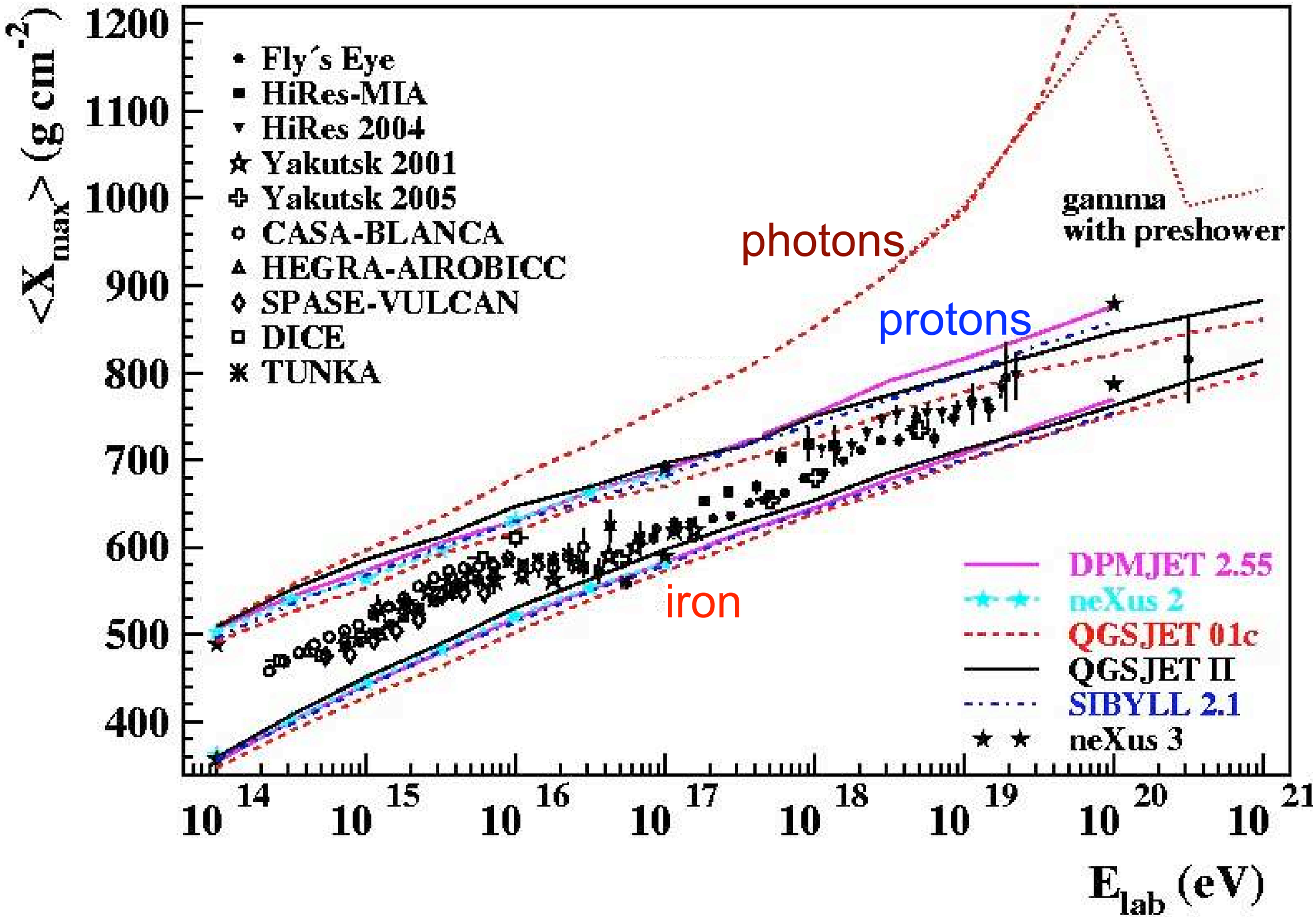


no correlation with galactic or super galactic plane

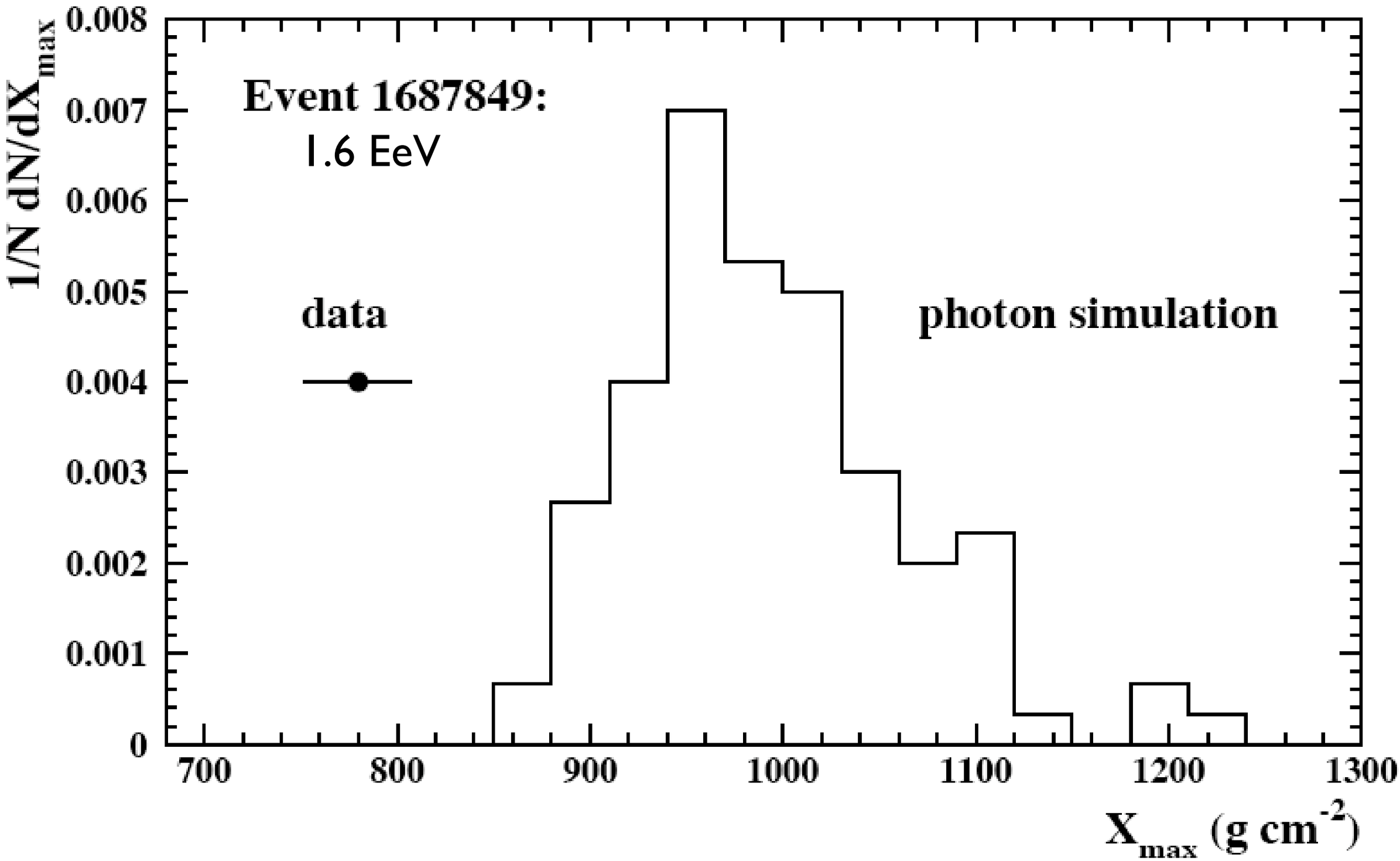


Photon Limit

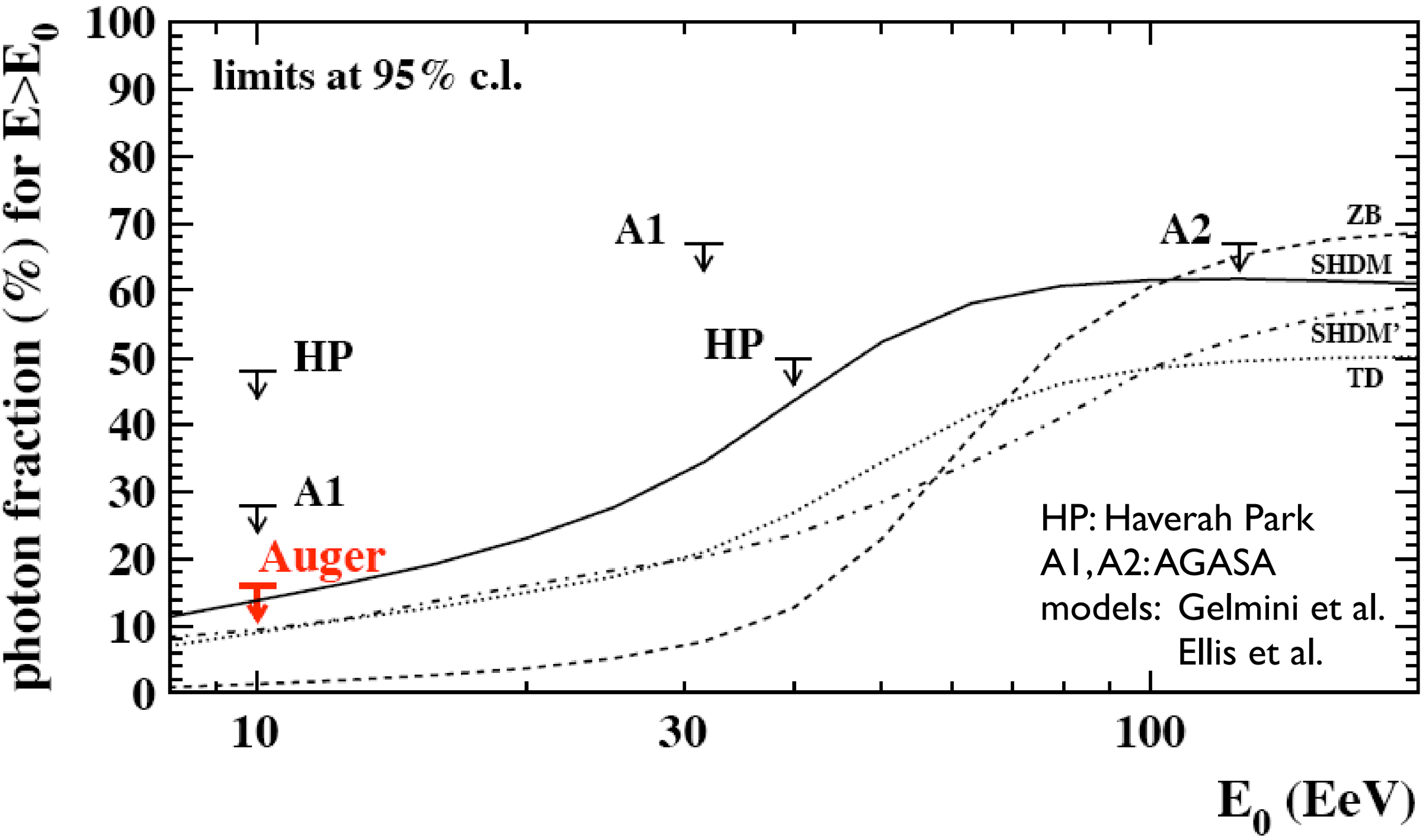
Photon limit: photon showers penetrate deeper



Hybrid events, E>10^{19} eV



compare each event with photon simulations
combine probabilities for all events



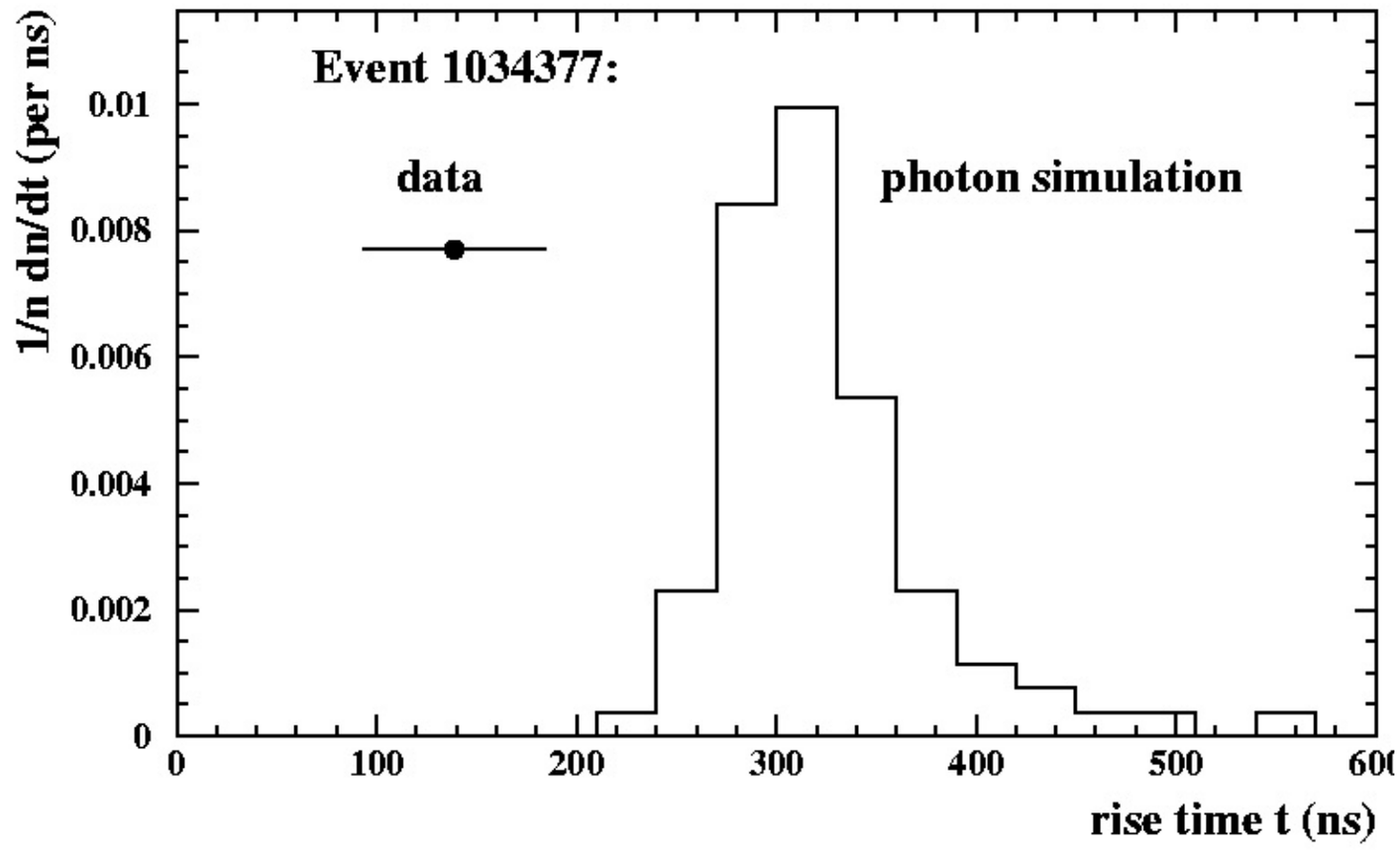
based on 29 events
photon fraction < 16% (95 % CL)

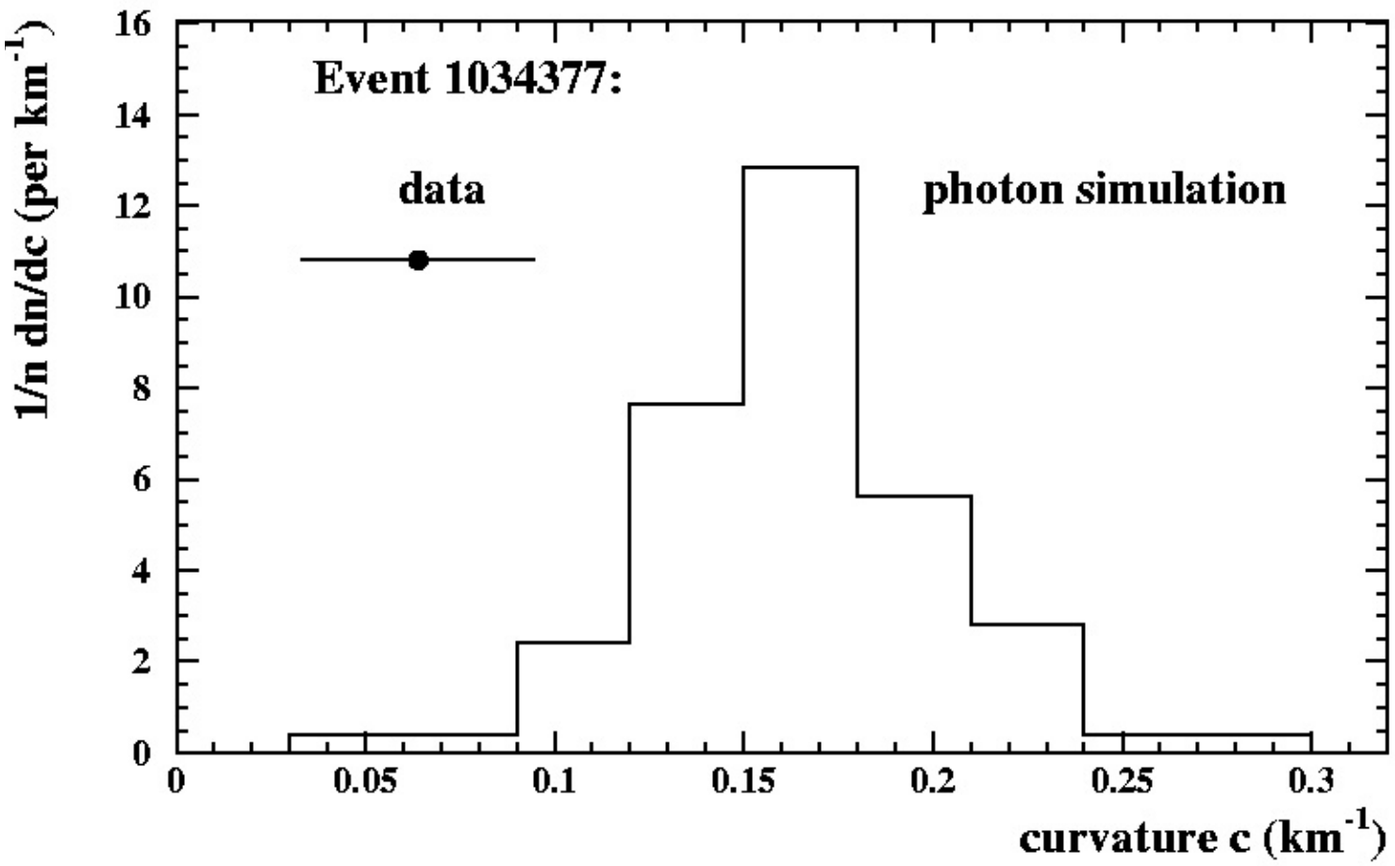
astro-ph/0606619

SD only variables:

- signal rise time
- curvature of shower front

SD: much larger statistics, but energy reconstruction not mass independent





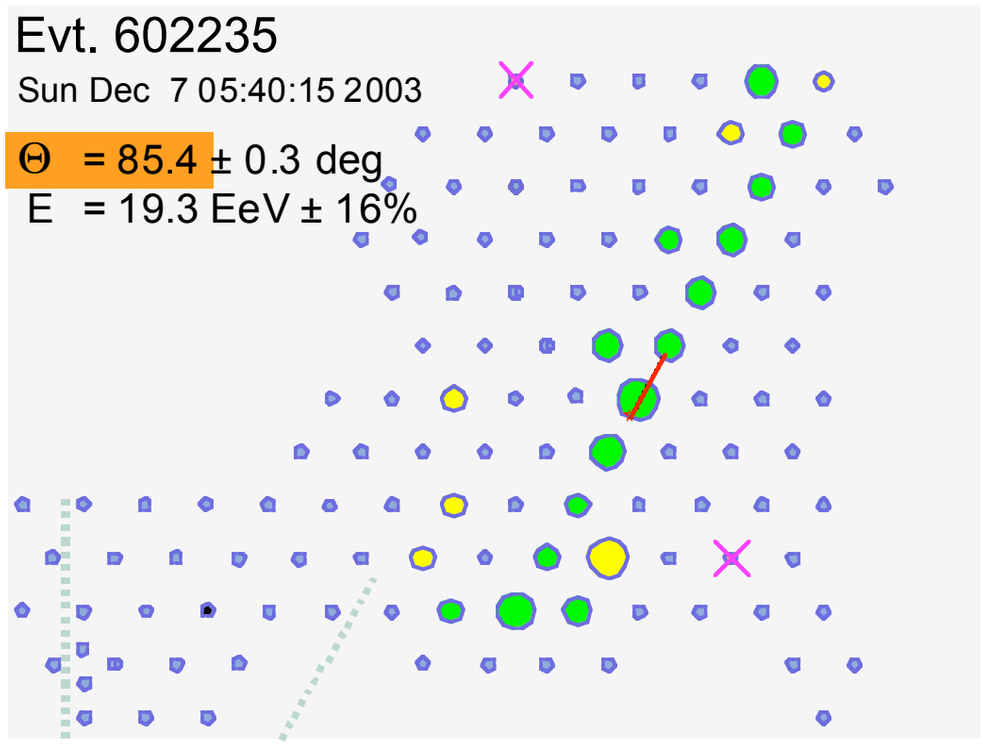
Neutrinos

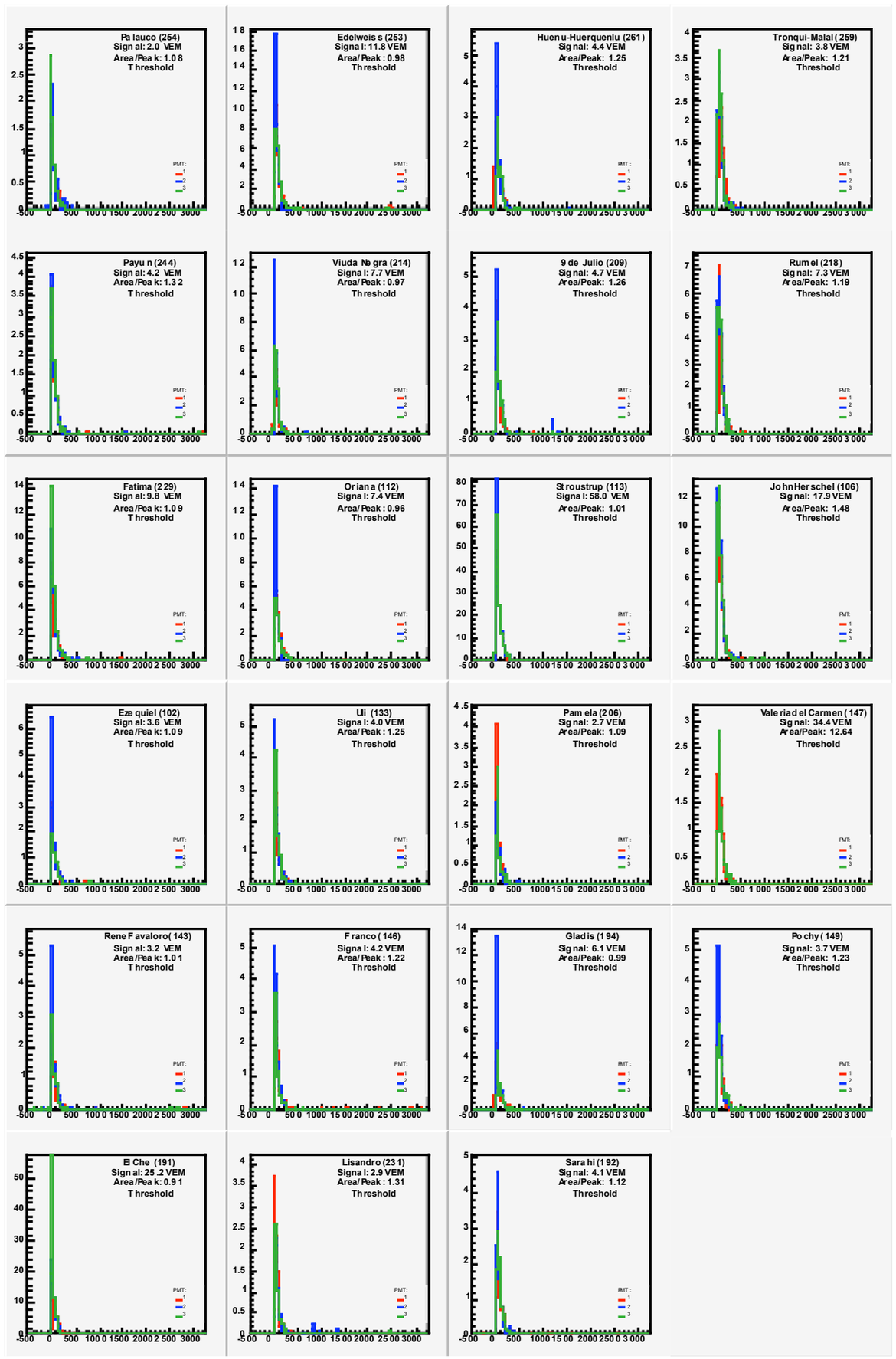
Horizontal showers

Due to water tanks (1.2 m high) the Auger SD has sensitivity for nearly-horizontal showers ($\Theta > 60^o$)

Special event reconstruction techniques
(by Ave, Watson, Zas et al.)
first applied to Haverah Park data

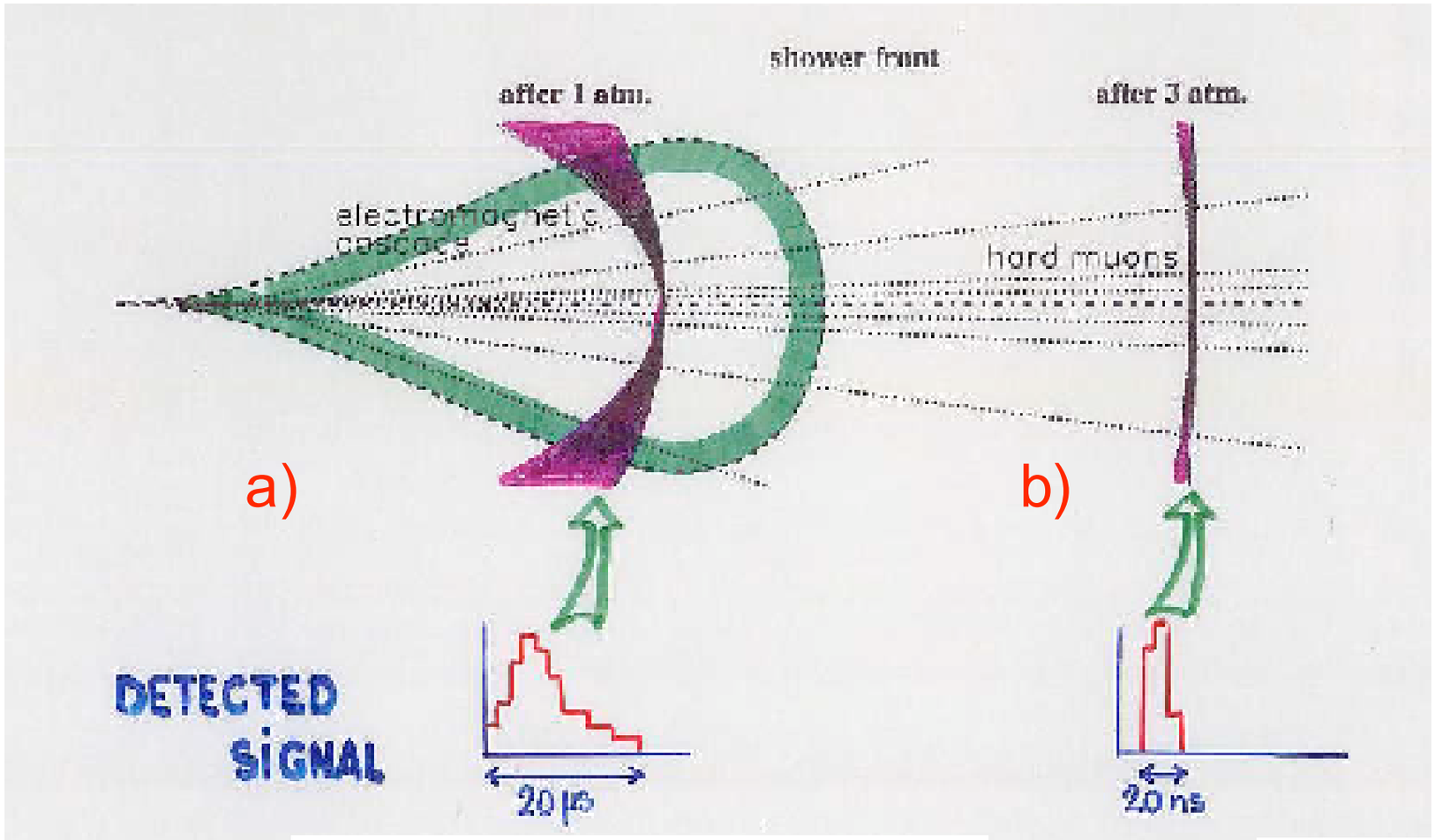
~ doubles aperture for CR events
increases sky coverage
sensitivity also to neutrinos





Neutrino detection with Auger

horizontal showers from hadrons: el.mag. component absorbed, muons only



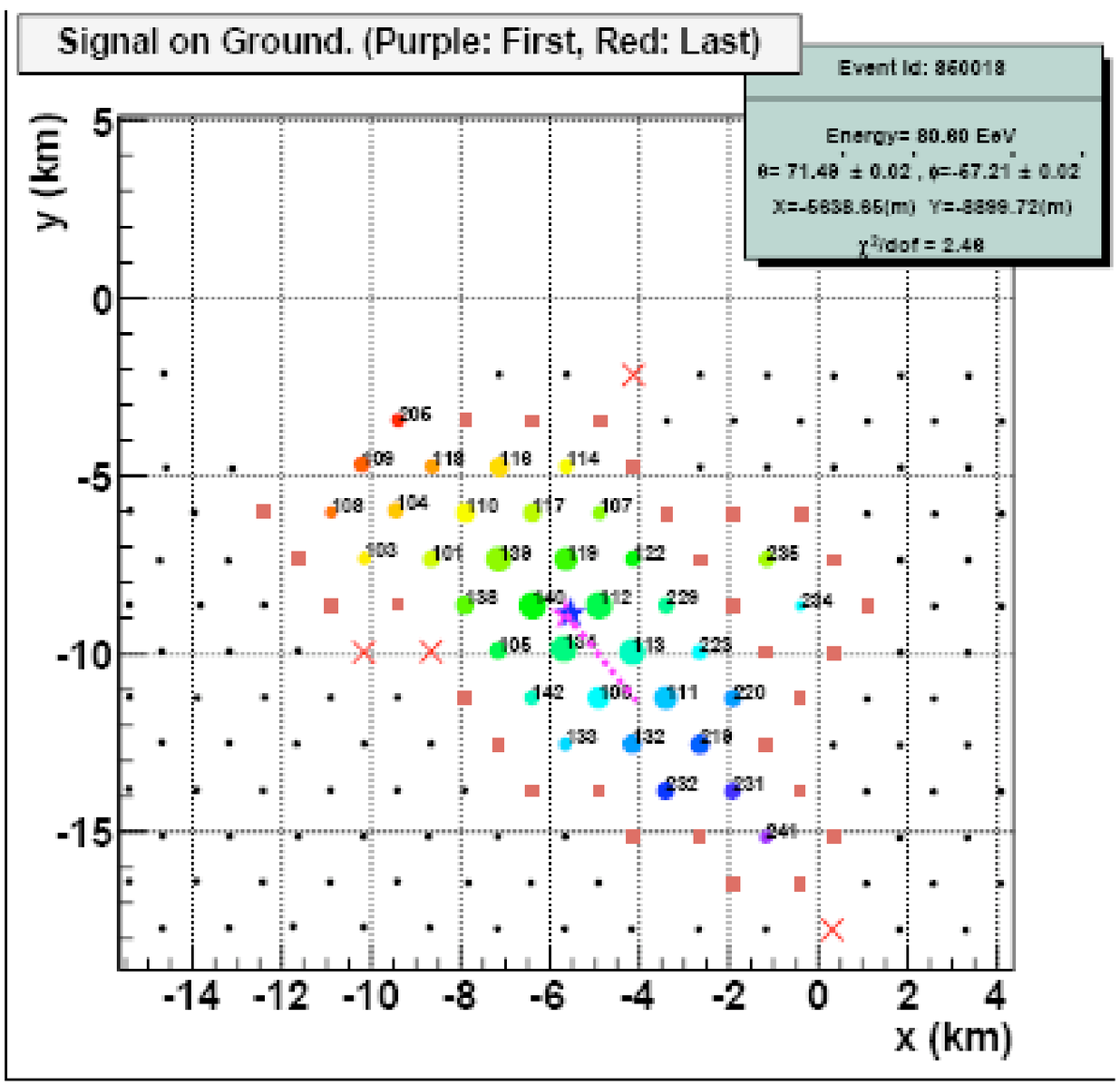
full el.mag. component,
curved shower front,
broad arrival time distribution

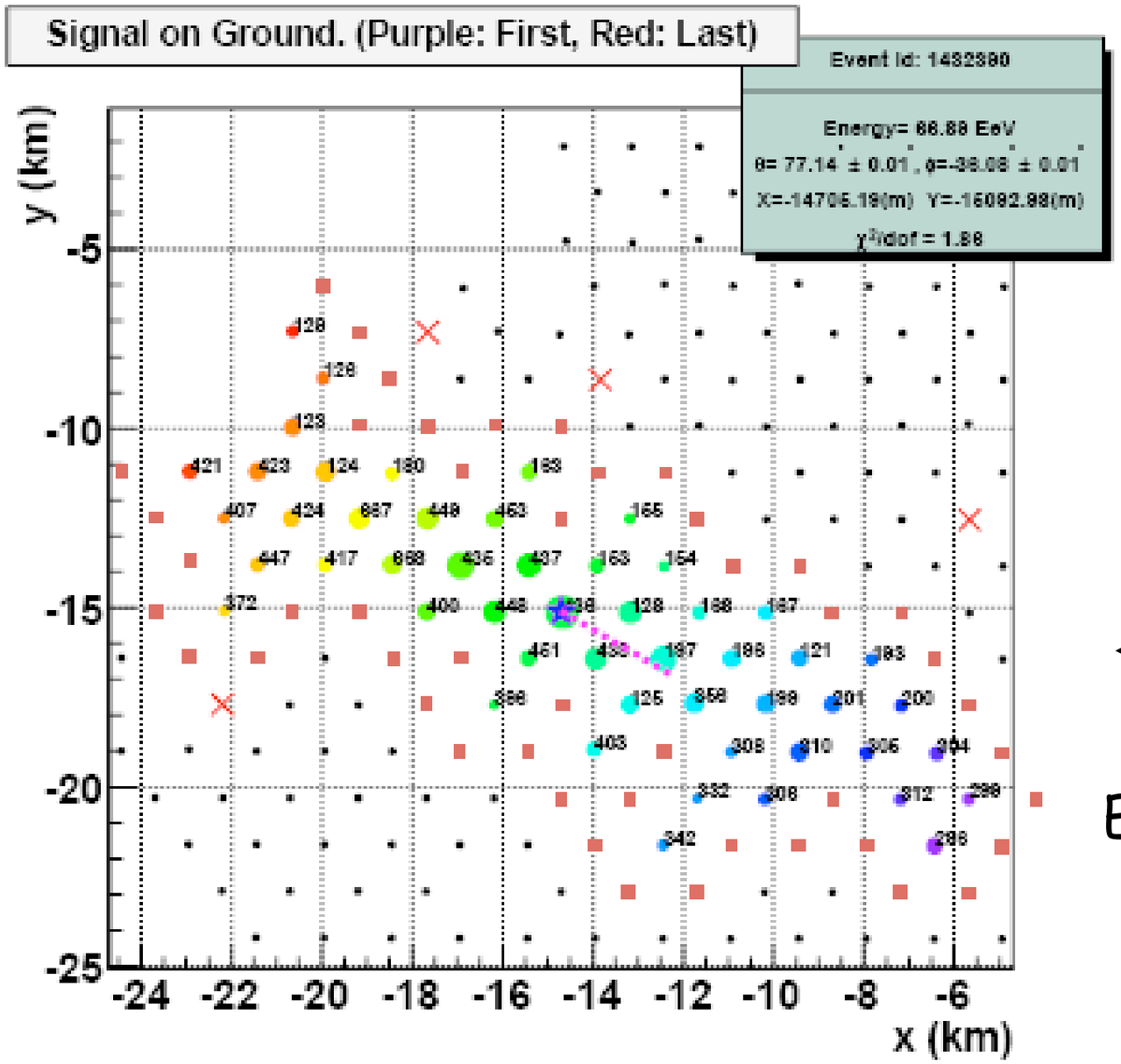
no el.mag. component,
plane shower front,
sharp arrival times

horizontal showers from neutrinos: look like a) after > 3 atmospheres

Event 850018

Θ = 71.5±0.02
ϕ = -57.2±0.02
E = 80.6
R= 22.9 km
χ/dof =2.4
NTanks =48

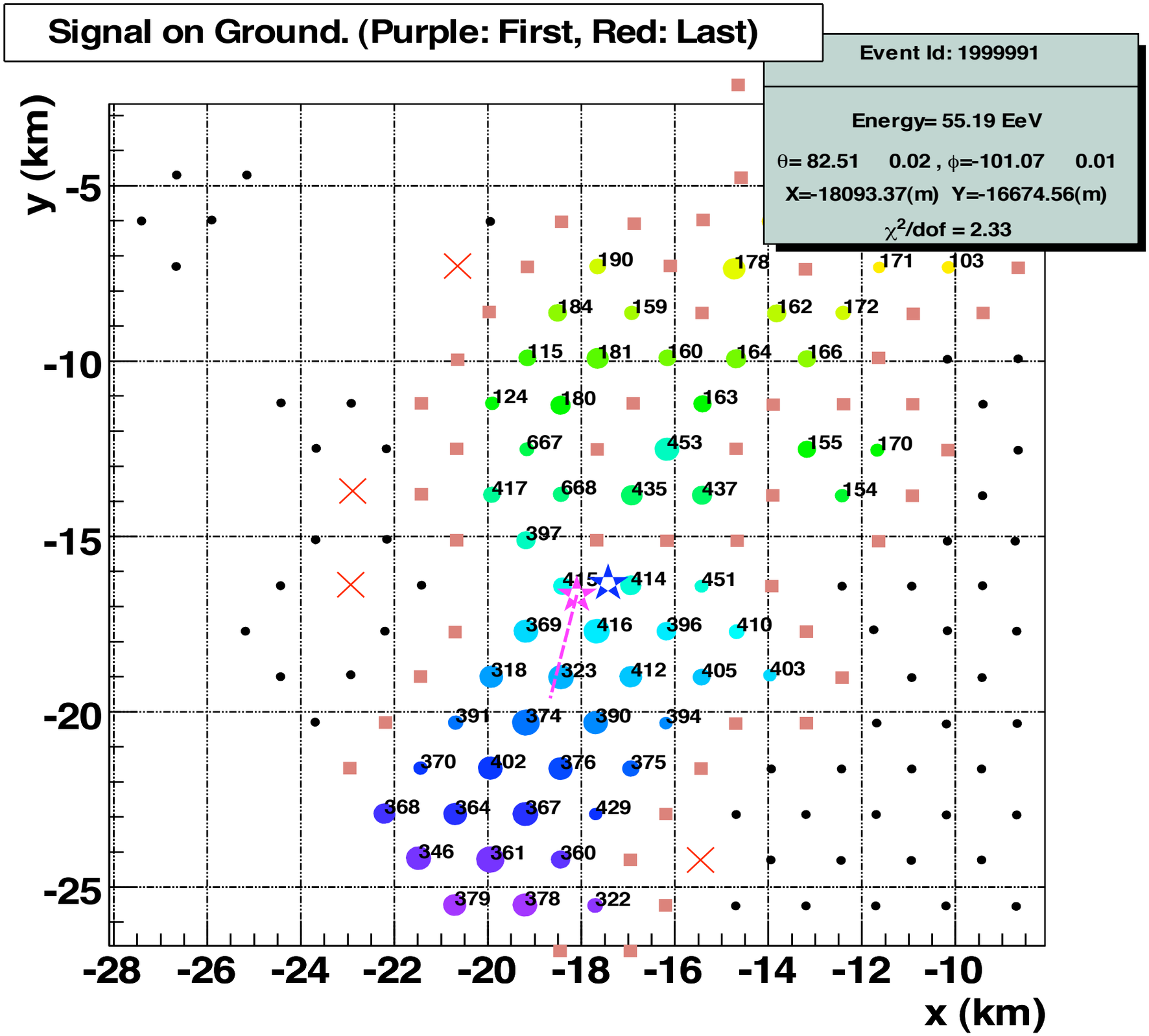




Event 1432390

Θ = 77.1± 0.01
ϕ = -36.1 ± 0.01
E = 66.9
R= 33.11
χ/dof =1.81
NTanks = 59

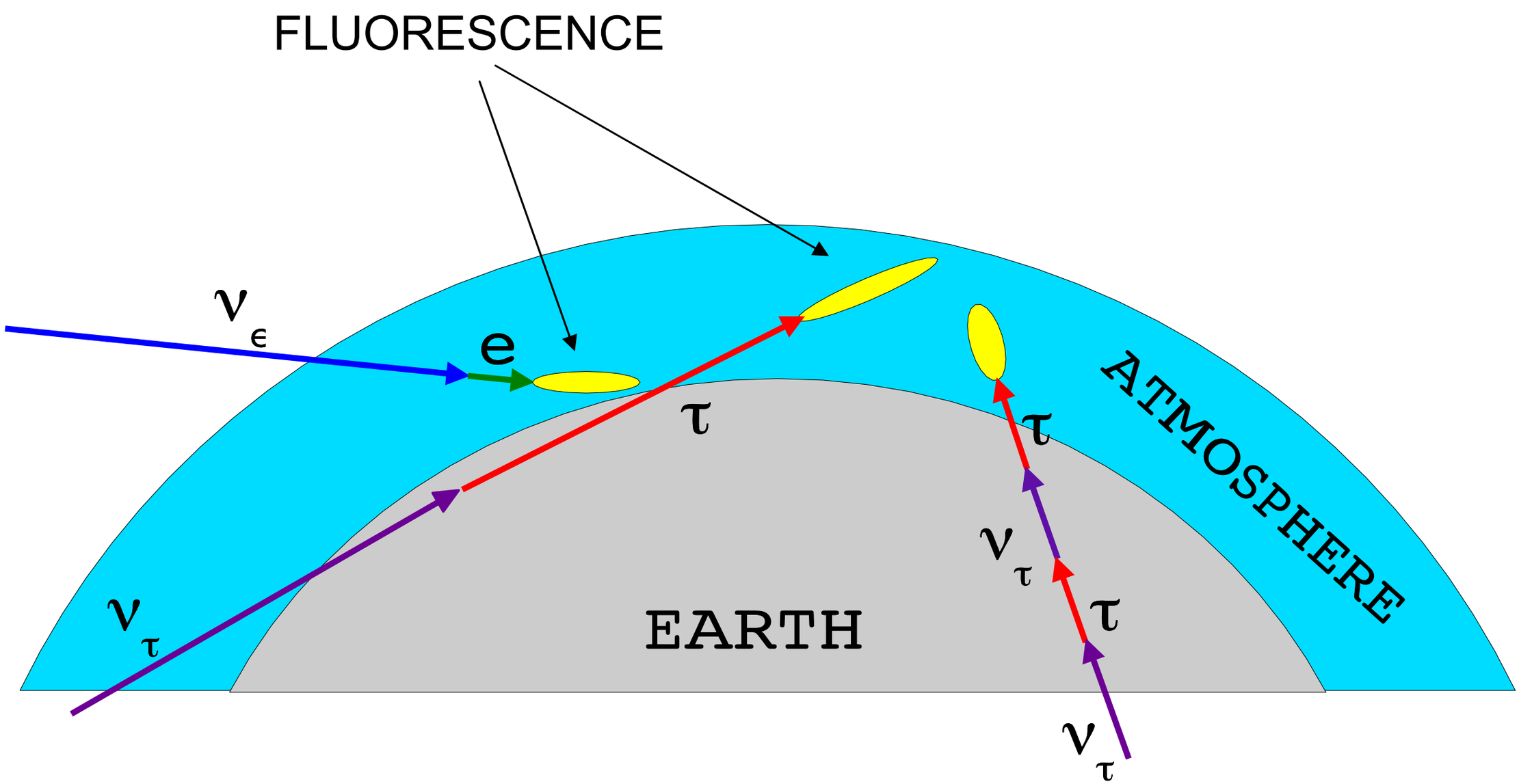
Event 1999991



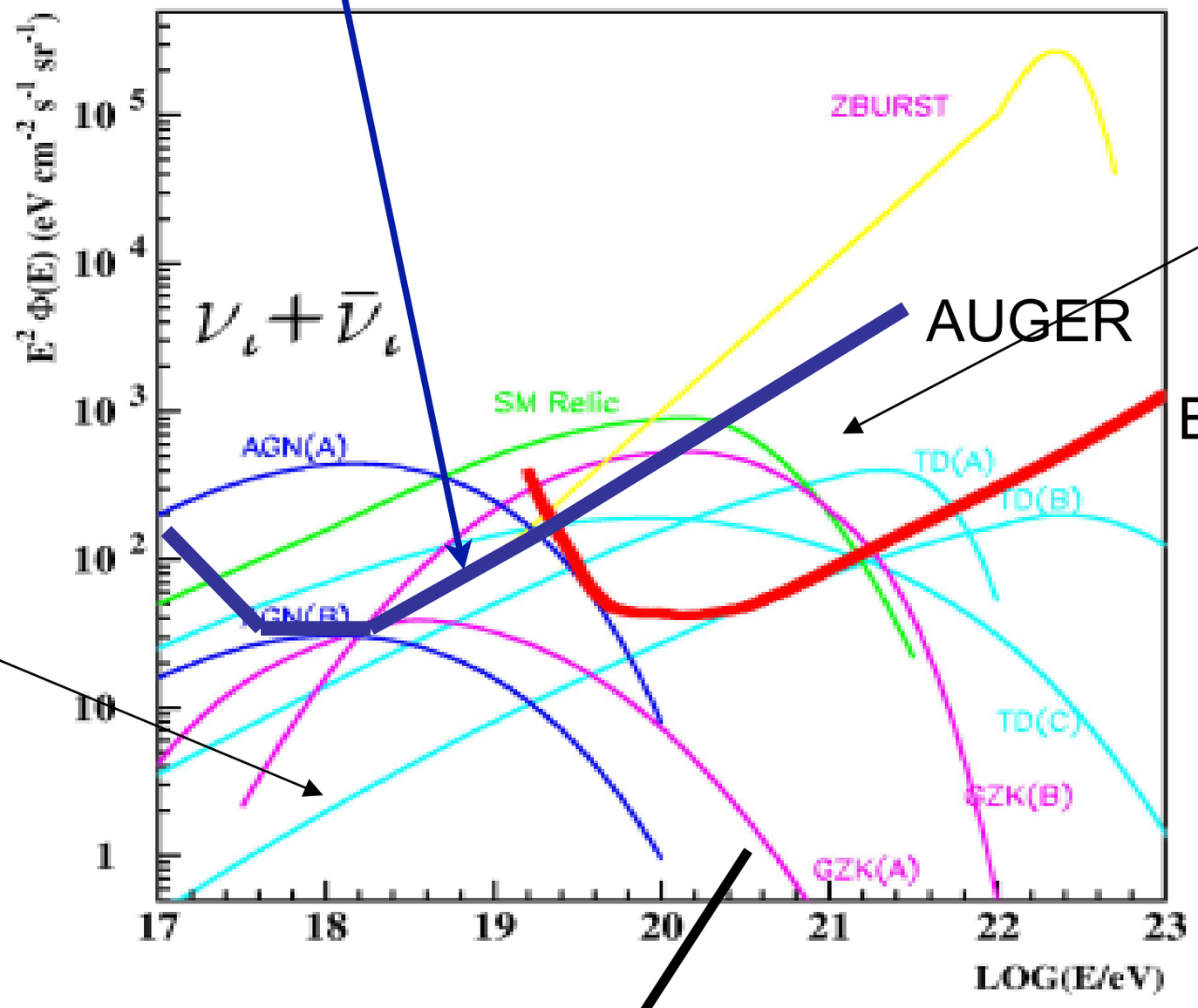
Θ = 83
ϕ = -102
E = 55.2
R = 22 km
χ/dof = 2.3
NTanks = 61

NEUTRINO EVENTS IN ATMOSPHERE

detection of Tau neutrinos



1 evt /yr/decade in E



SOME EVENTS FROM HIGHER TOP DOWN FLUXES

AUGER

EUSO

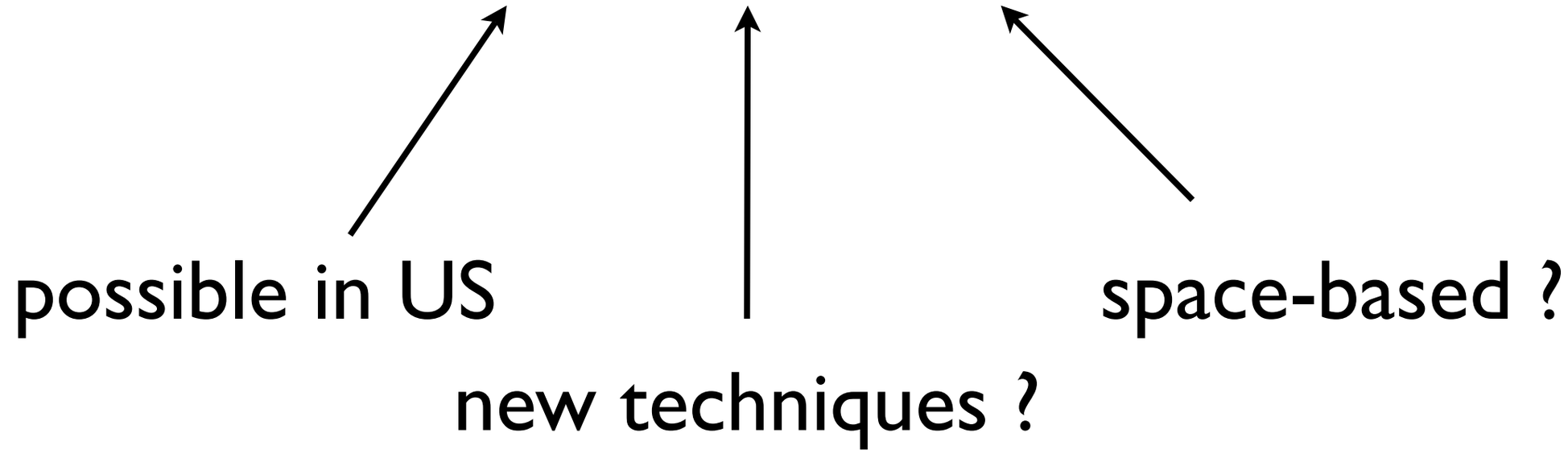
region for 'safe' neutrino astronomy ?

~0.3 events/year in EUSO

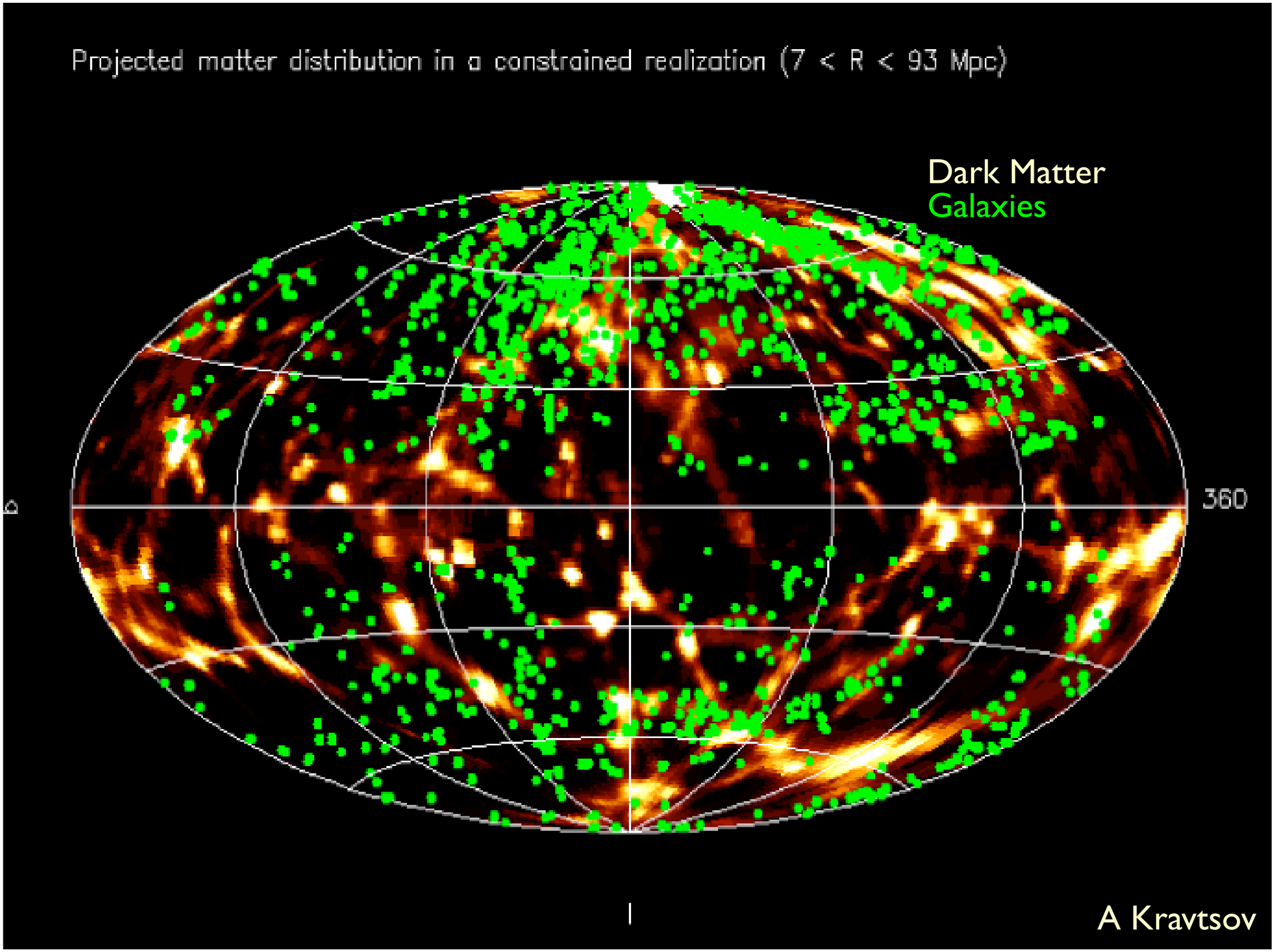
Auger S: very few neutrino events per year
too small for neutrino astronomy

Auger North:
Cosmic Rays & Neutrinos

$3x10^3$ ... 10^4 ... 10^5 ... 10^6 km^2 ??



Auger North: Northern sky is different



Summary:

Auger is taking data
Performance according to specs

Calibration & cross checking phase
Tune reconstruction algorithms
Evaluate accuracies ...

First science paper submitted,
others in preparation.

Watch this space.....