EUSO

Extreme Universe Space Observatory

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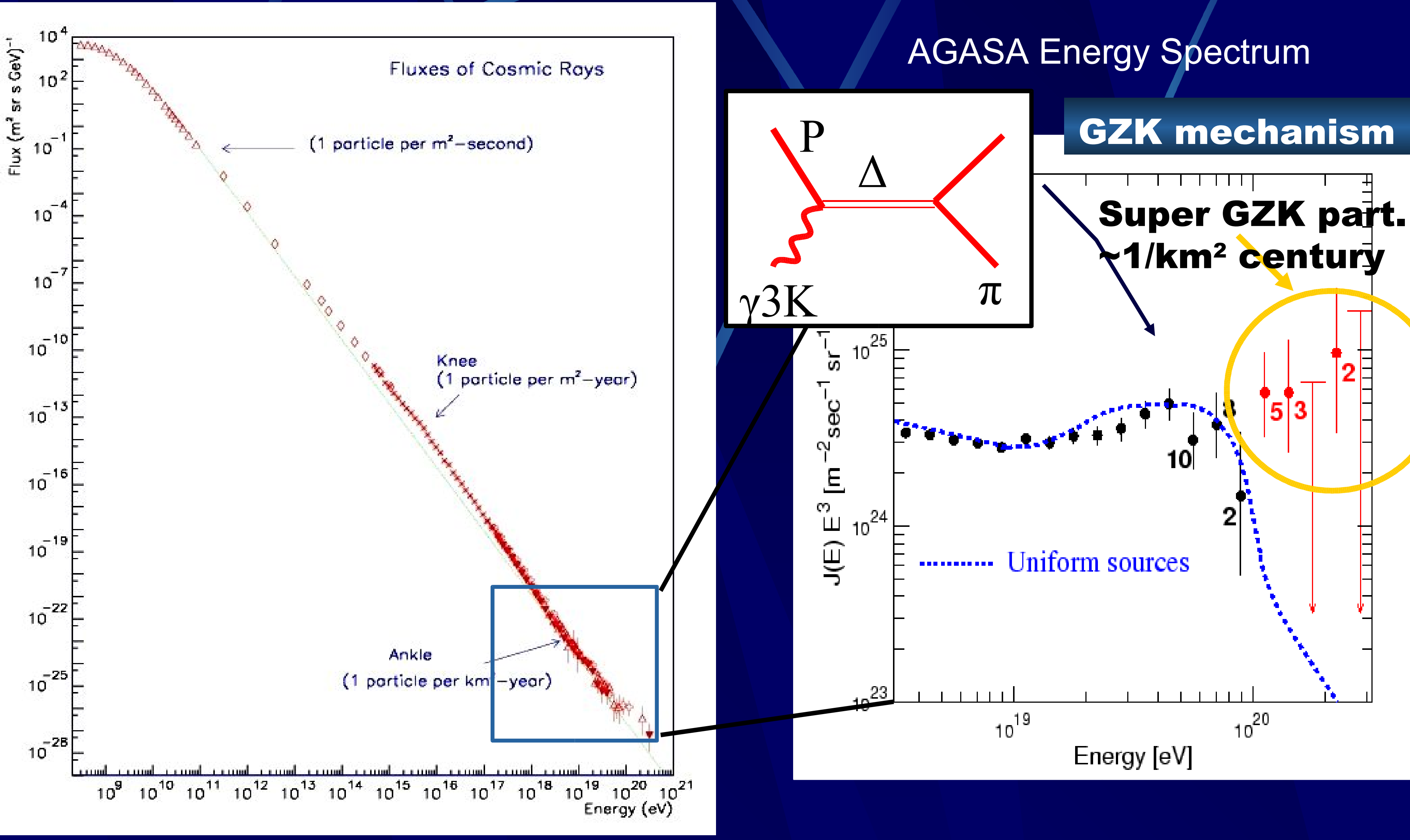
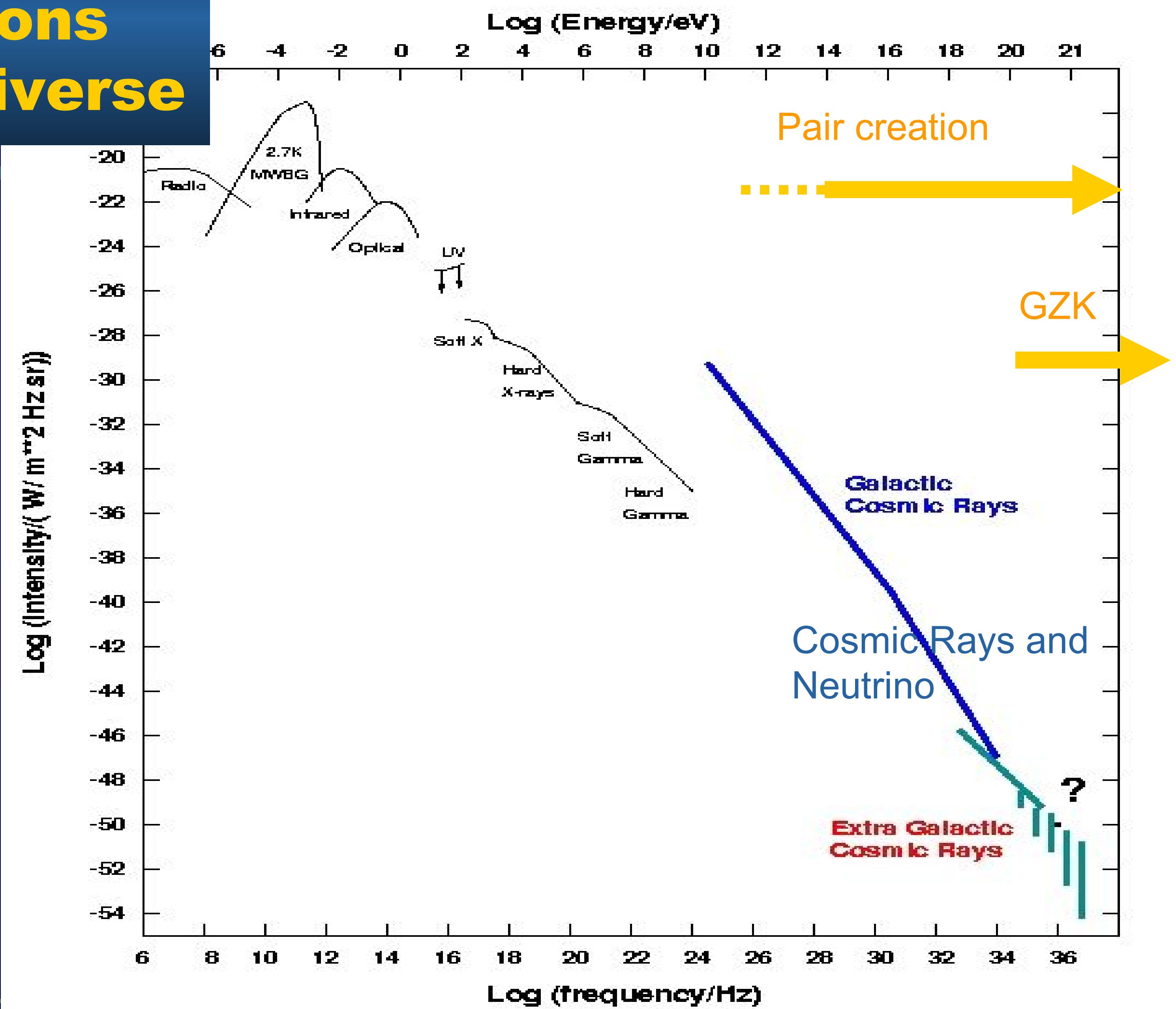
Oct. 2004

Introduction

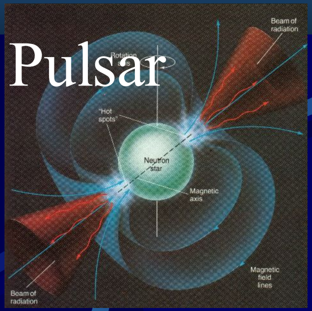
Cosmic Ray Energy Spectrum

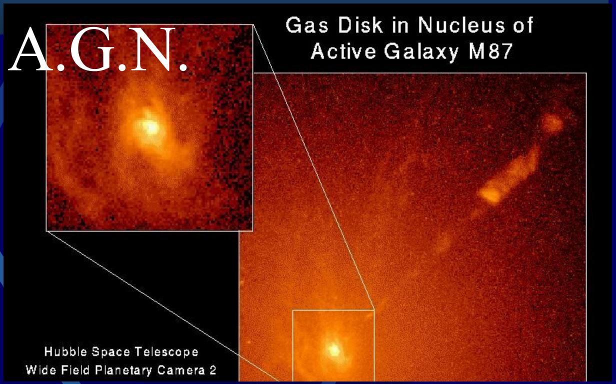


Background Radiations in the universe

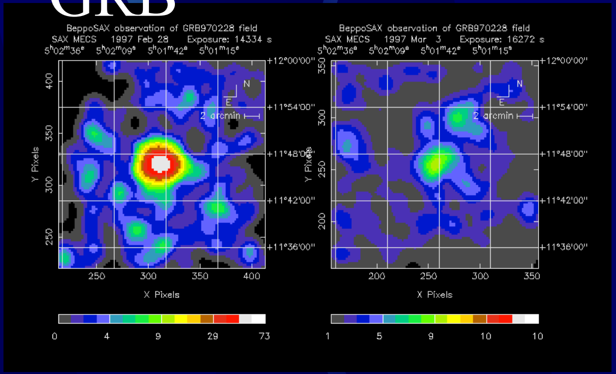


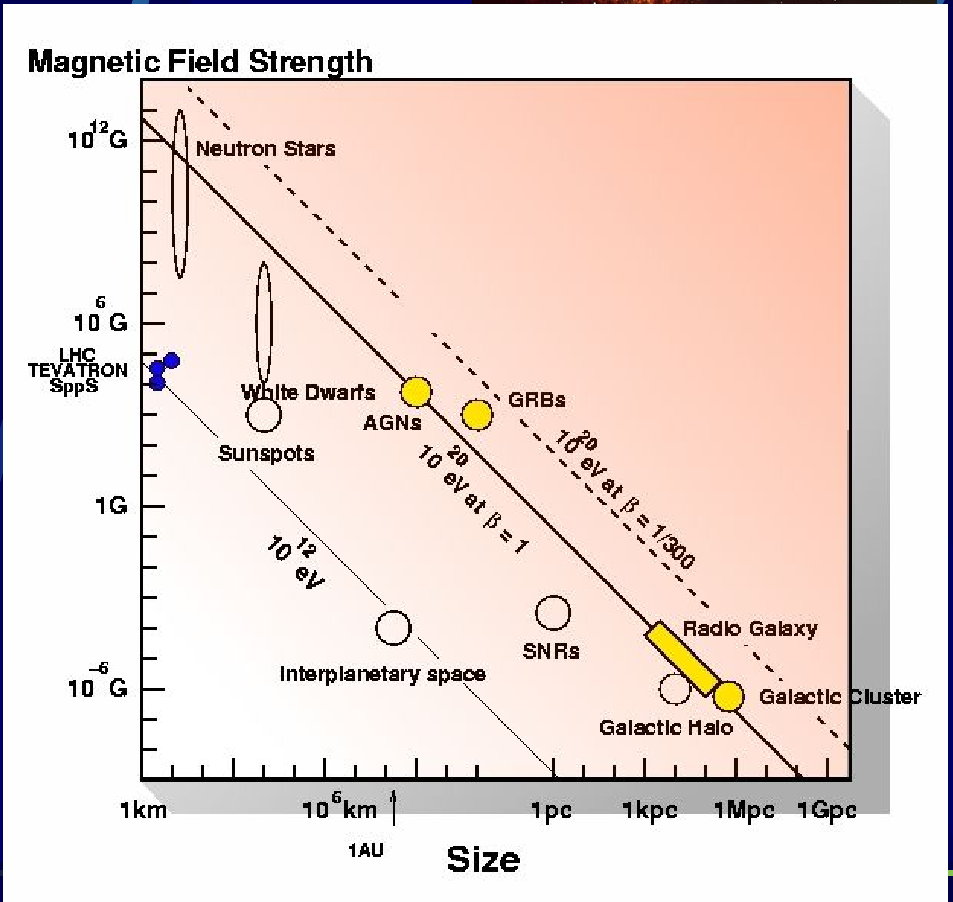
Candidates for UHE C.R. accelerator

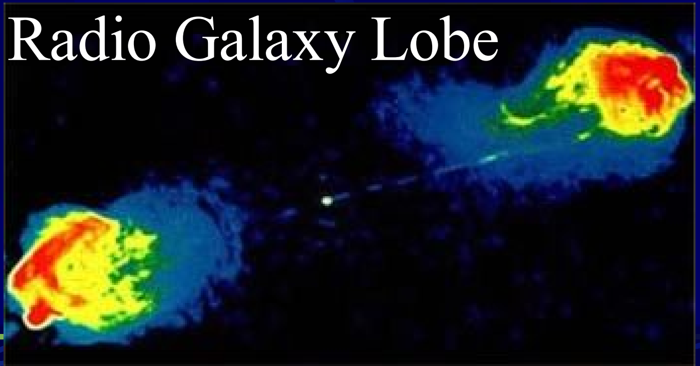




GRB







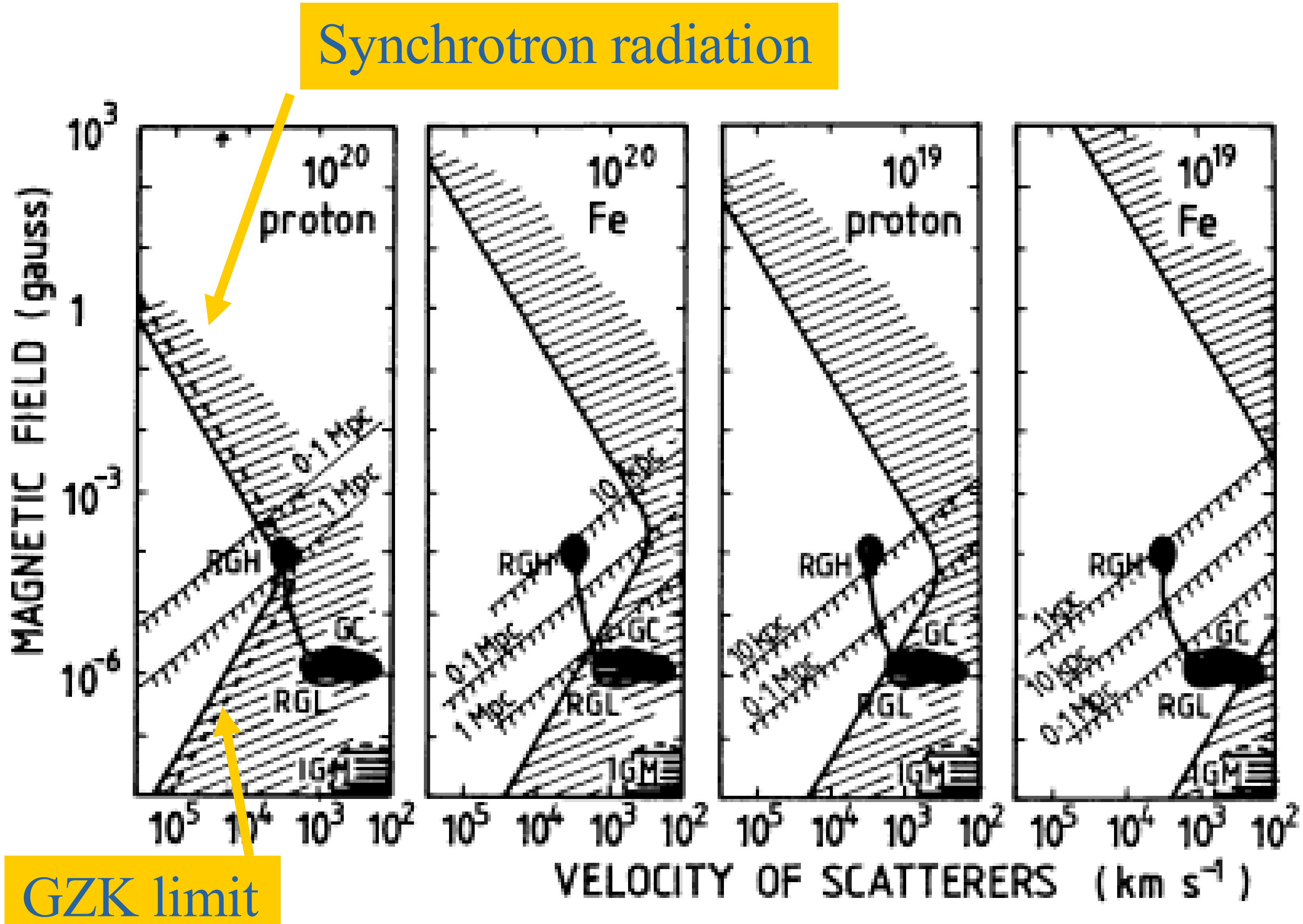


Figure 6 Combinations of magnetic field strength and velocity of scattering centers that allow Fermi acceleration to reach 10^{20} or 10^{19} eV for protons or for iron nuclei. Only the unsh… …ove the uppe… …ust also lie al… …o rapid. Posit… (RGH), and t…

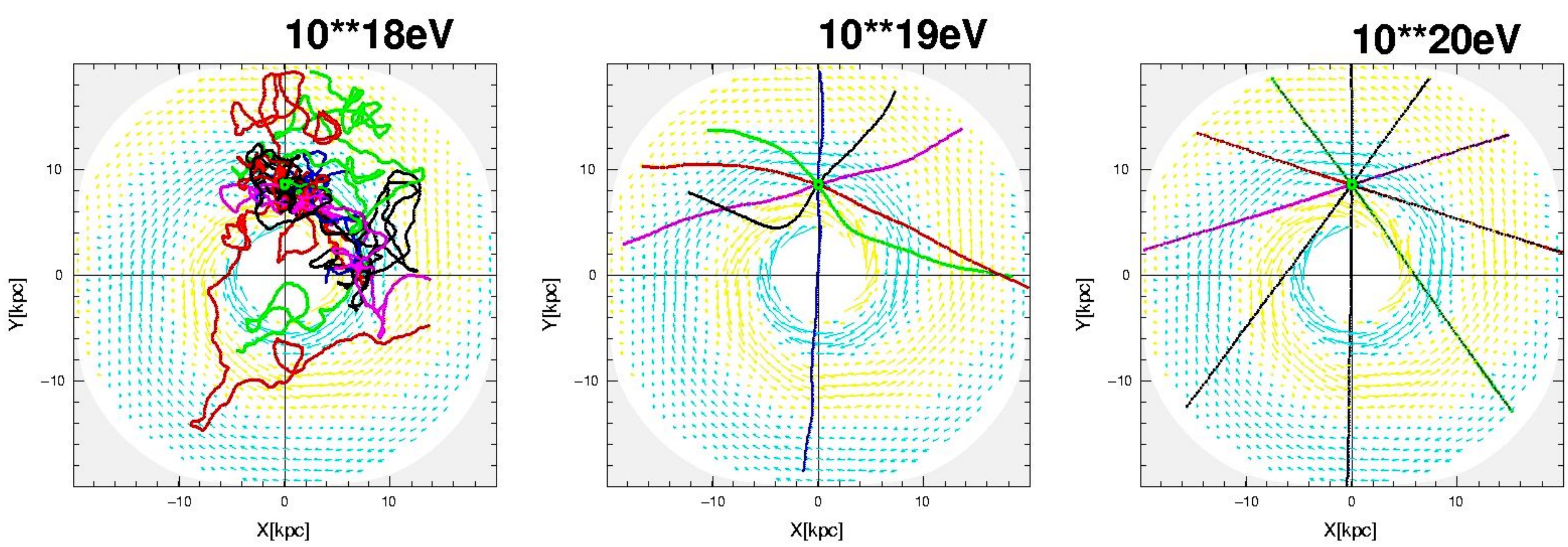
Hidden HILLAS PLOT II

Ann. Rev. Astron. Astrophys. 1984, 22; p425-444

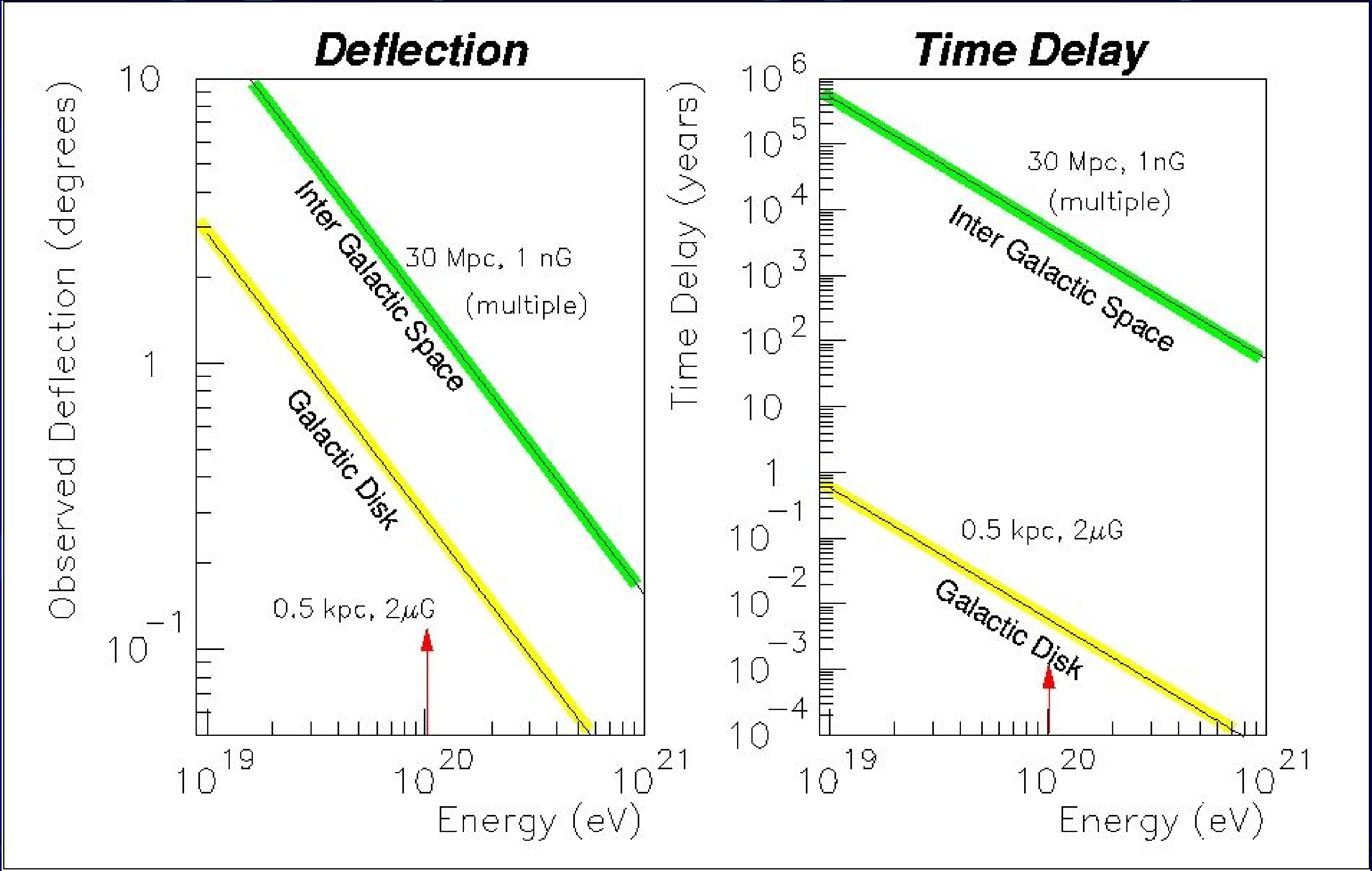
Cosmic Ray Propagation in our Galaxy

- Deflection angle ~ 1 degree at 10^{20}eV

  Astronomy by hadronic particles?



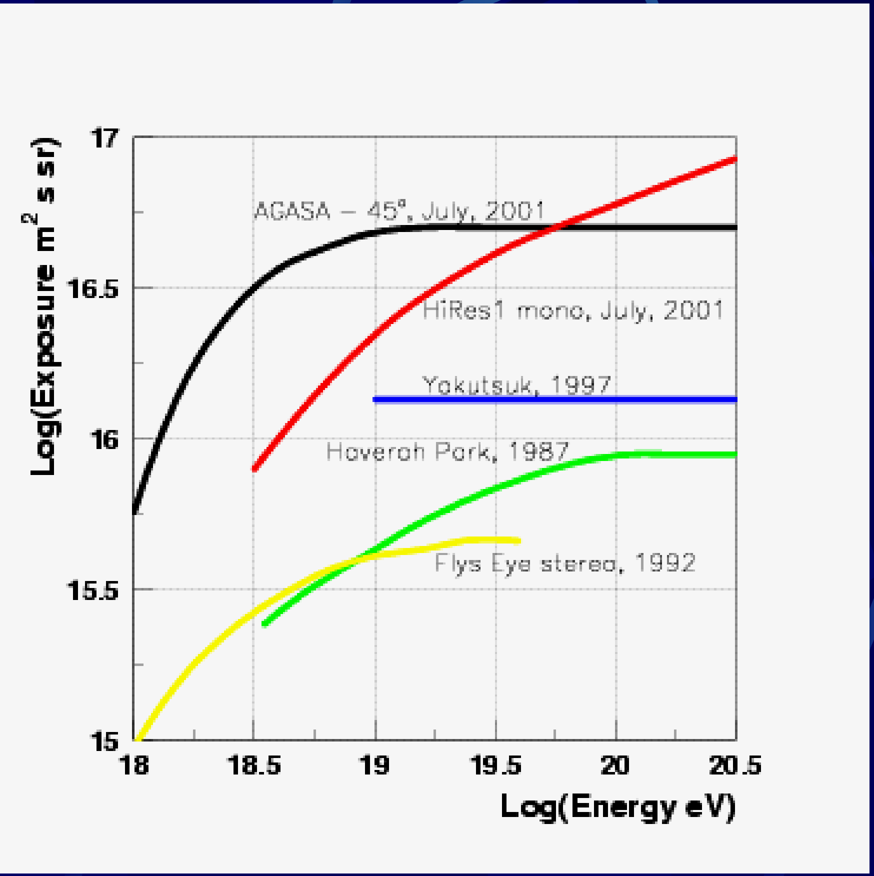
Cosmic Ray Propagation in Galactic Disk and Inter Gal.

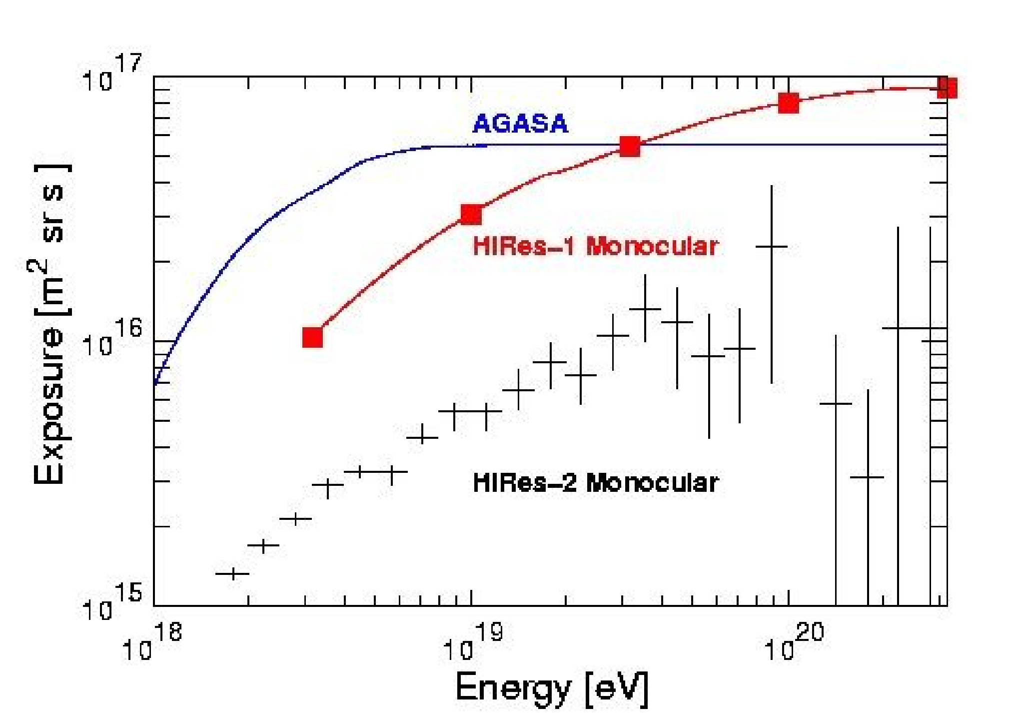


Important Aspects of UHECRs

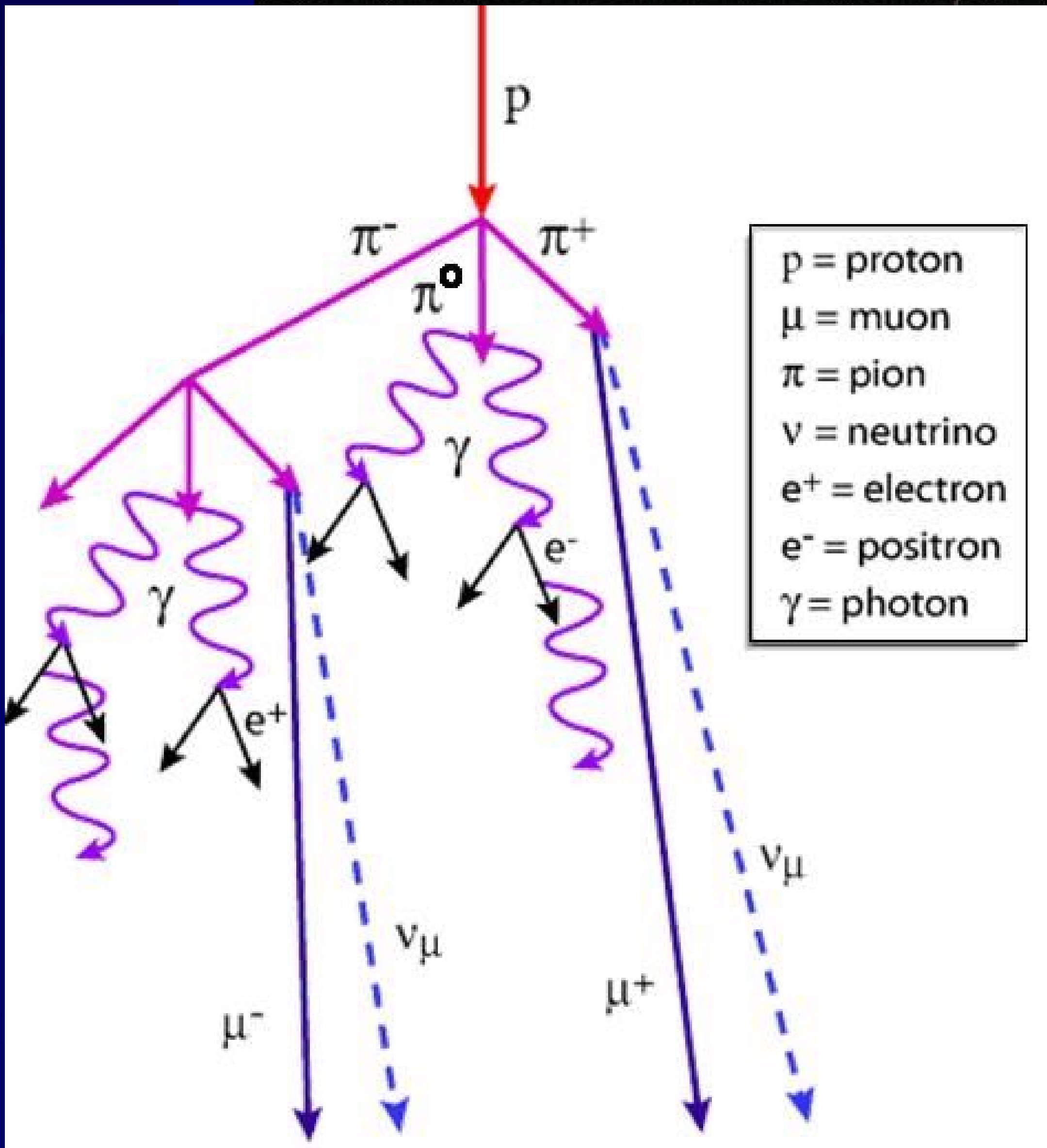
- GZK mechanism
  - Sources must be nearby
  - Secondary Gamma rays, neutrinos
- Limited candidates of accelerators in the Universe
  - AGNs, GRBs
  - Heavy relic particles in our galactic Halo
- Rectilinear propagation
  - Clusters of events

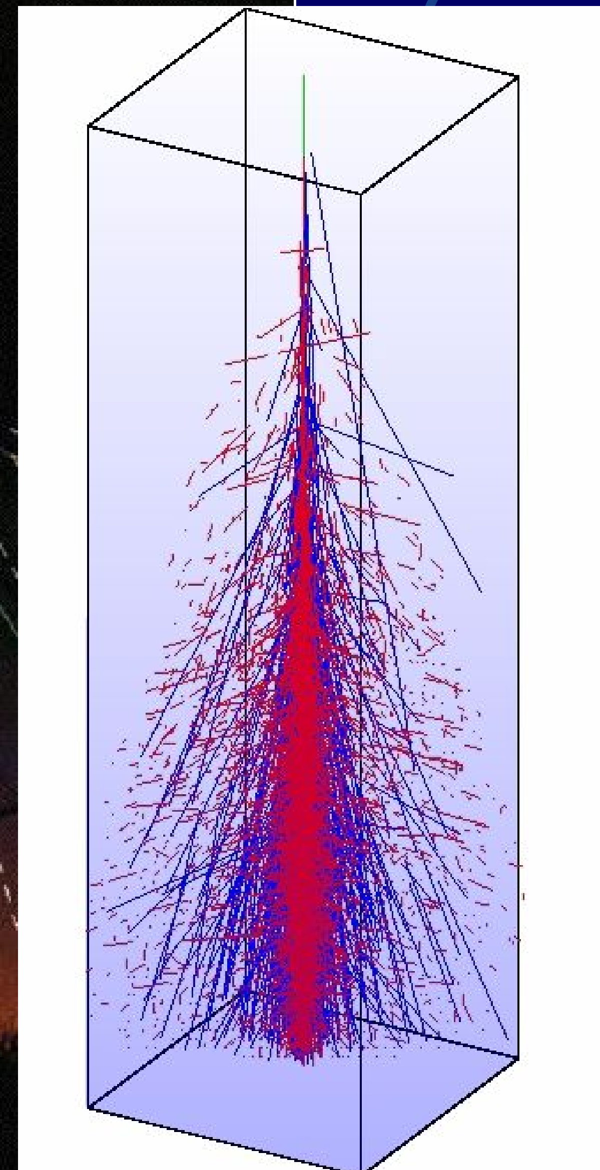
Exposure in ICRC2003

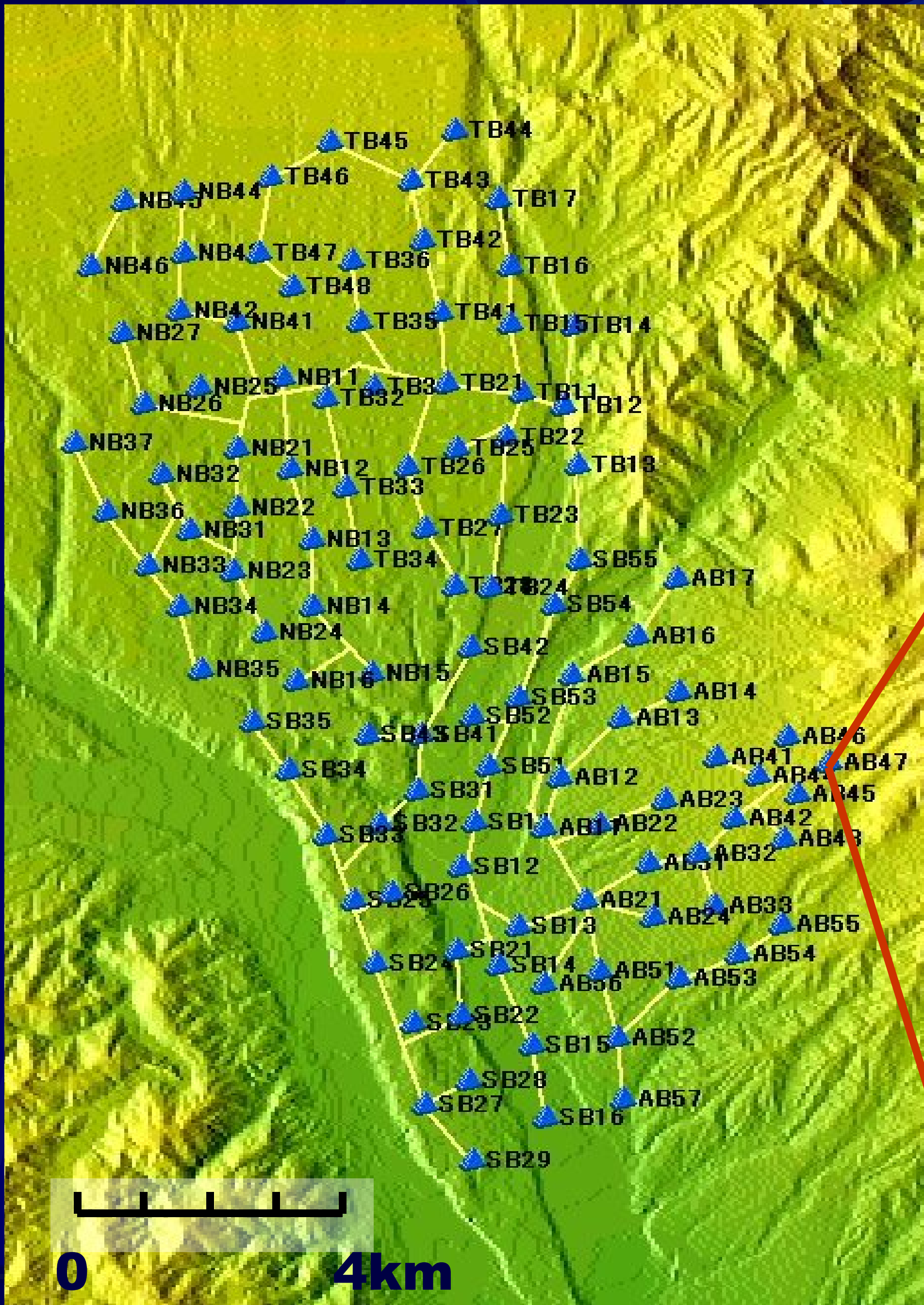




Air Shower Phenomena







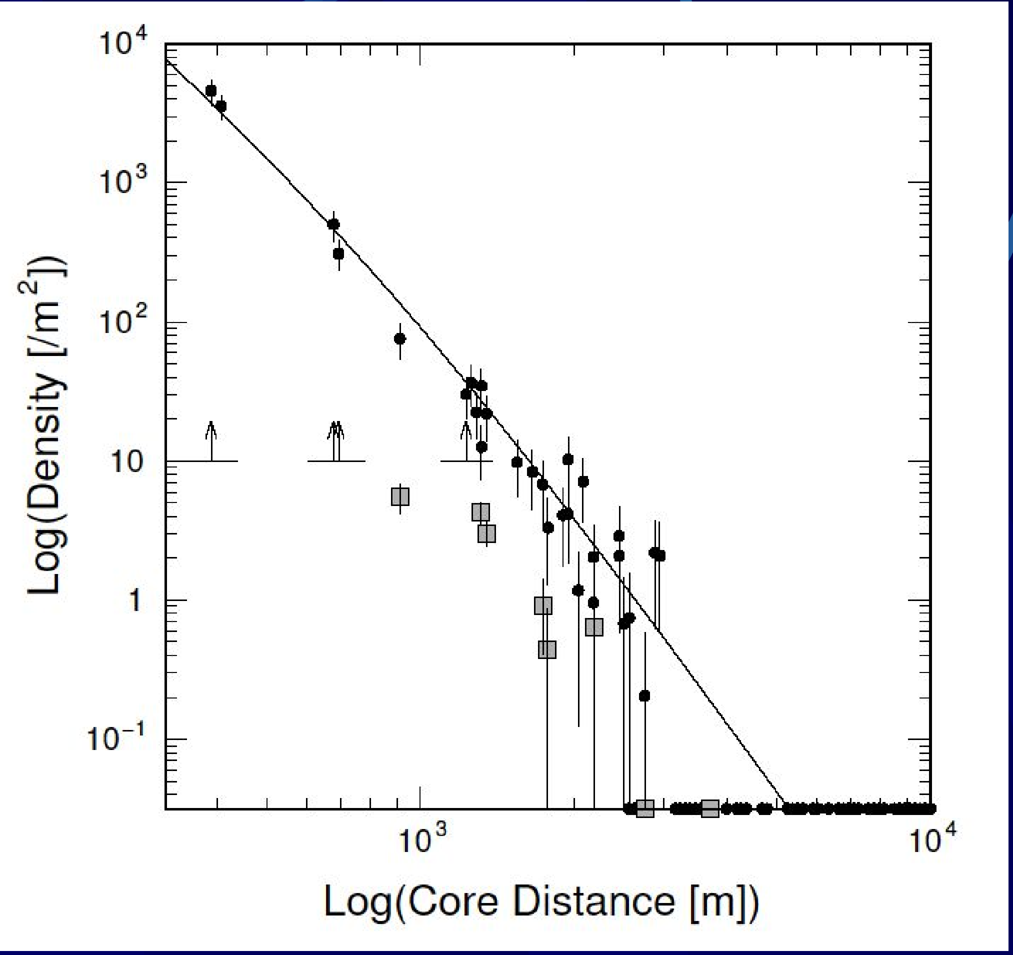
AGASA

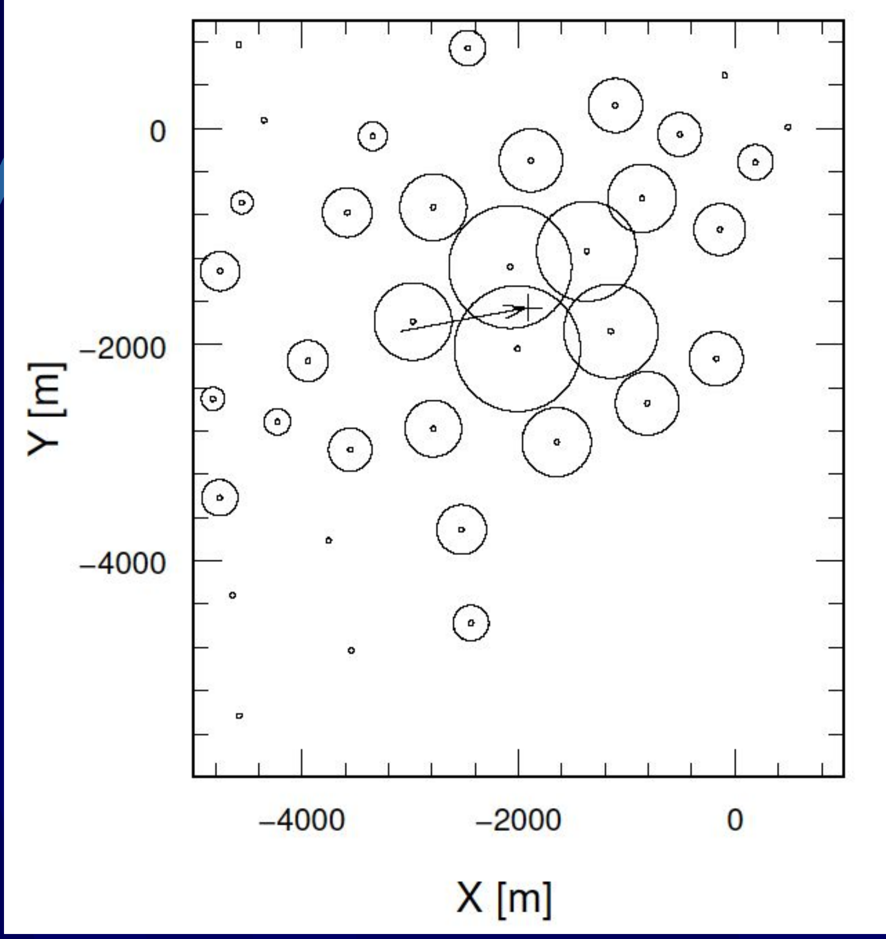
Akeno Giant Air Shower Array

111 Electron Det.

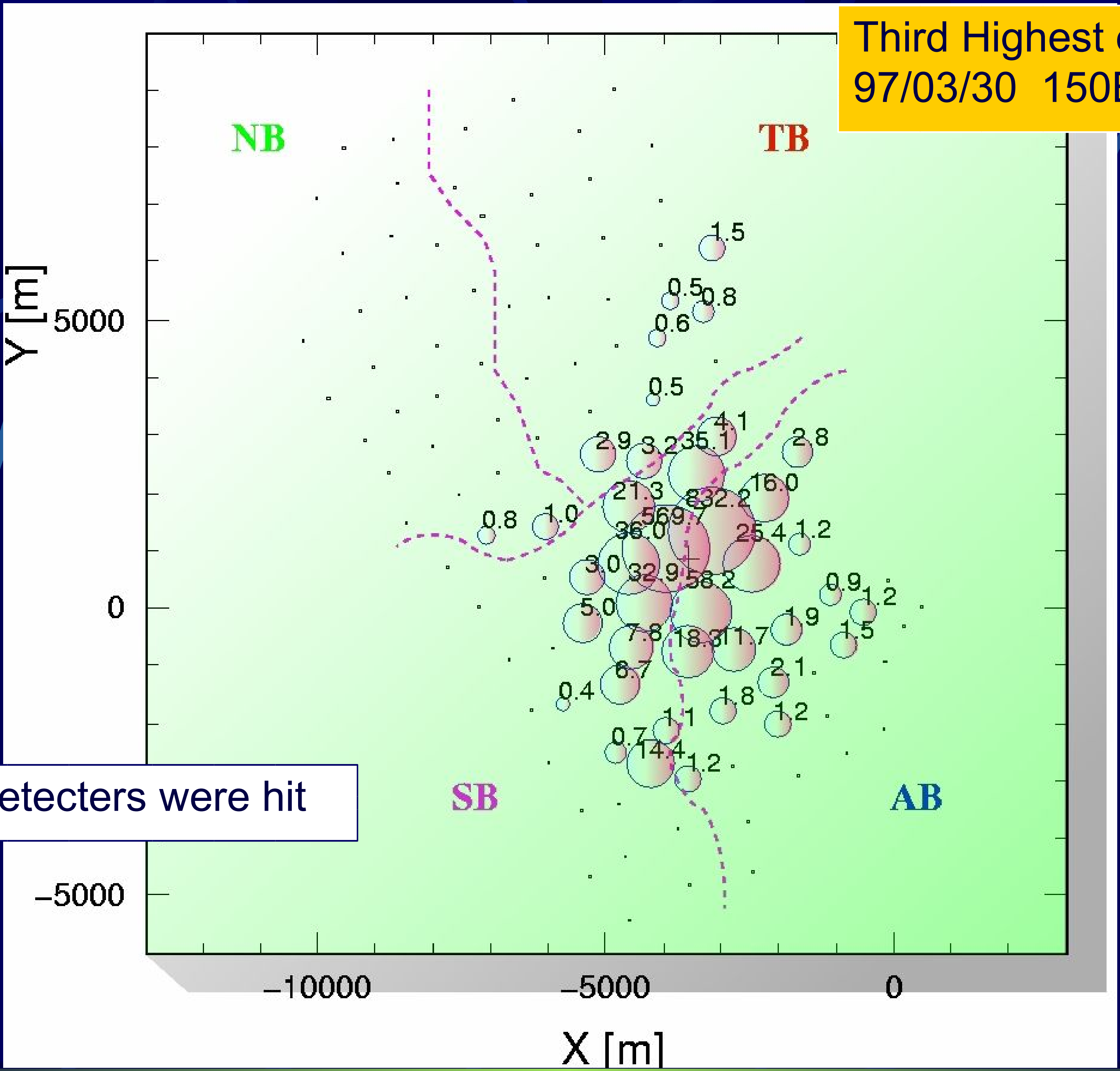
27 Muon Det.

The Highest Energy Event
(~2.46 x10²⁰eV)
on 10 May 2001



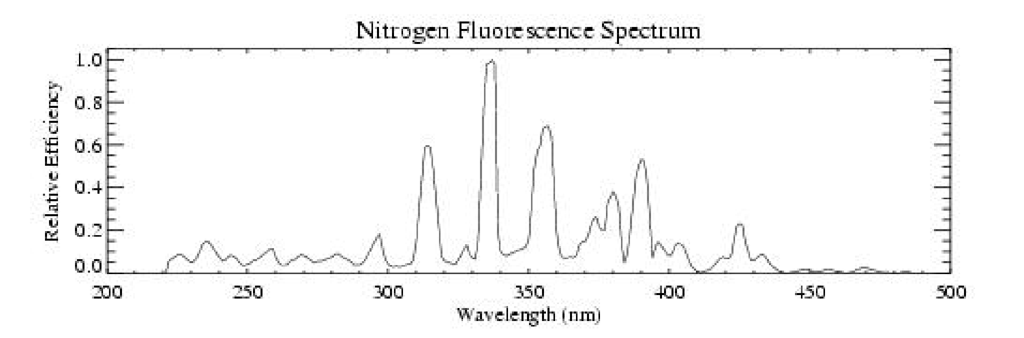


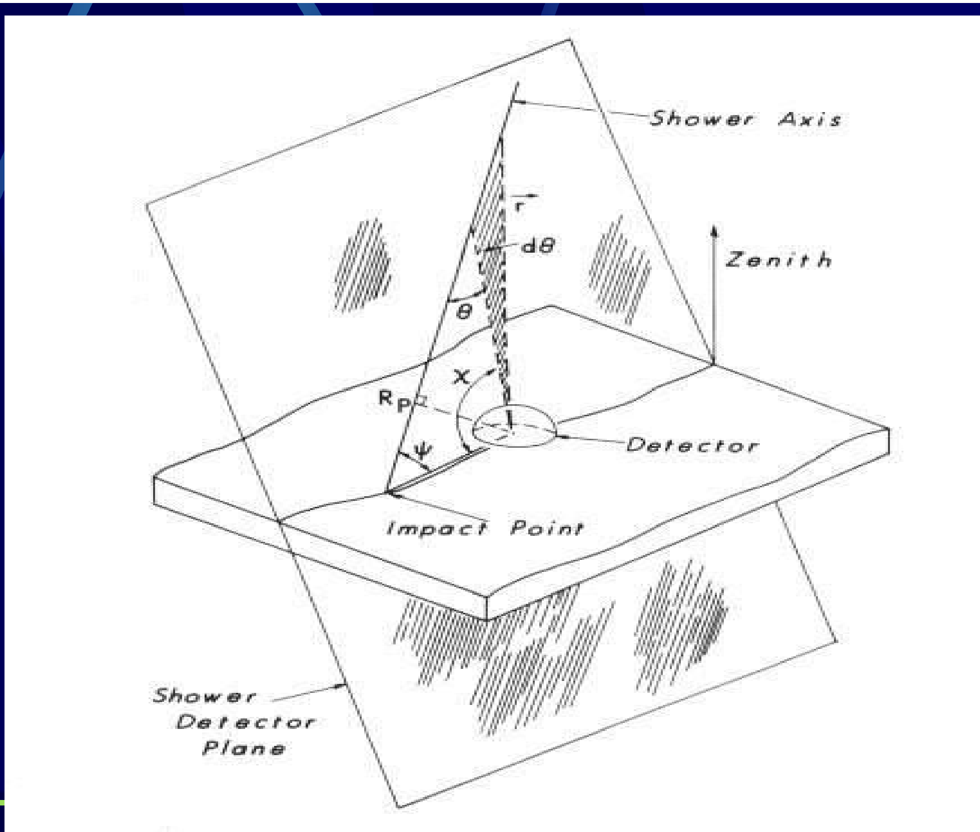
Third Highest event
97/03/30 150EeV



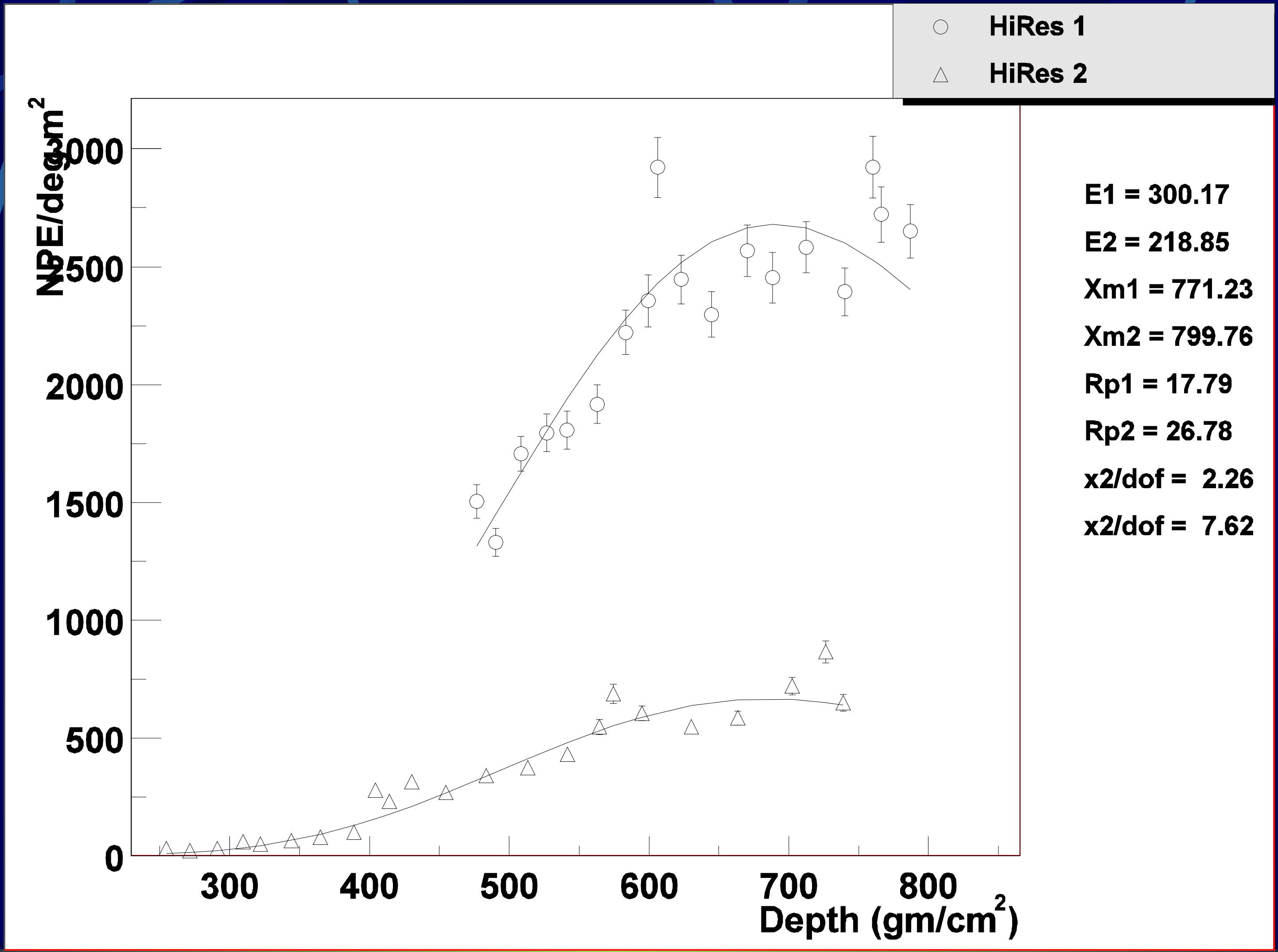
40 detecters were hit

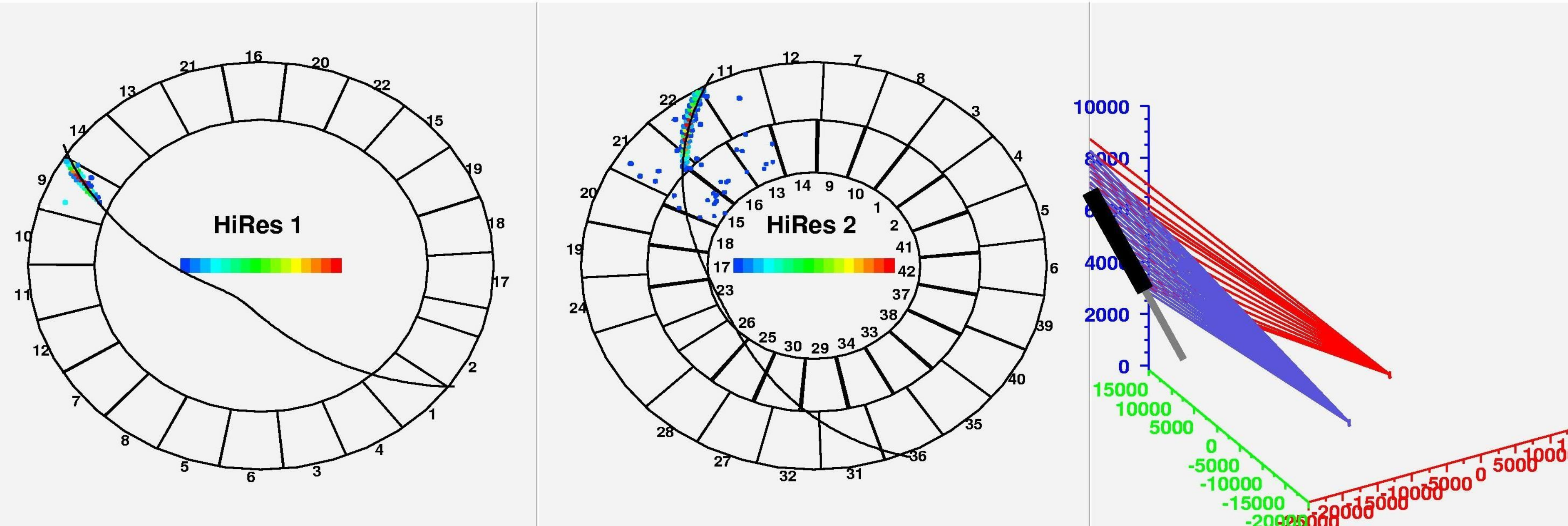
HiRes Experiment
Air Fluorescence detector

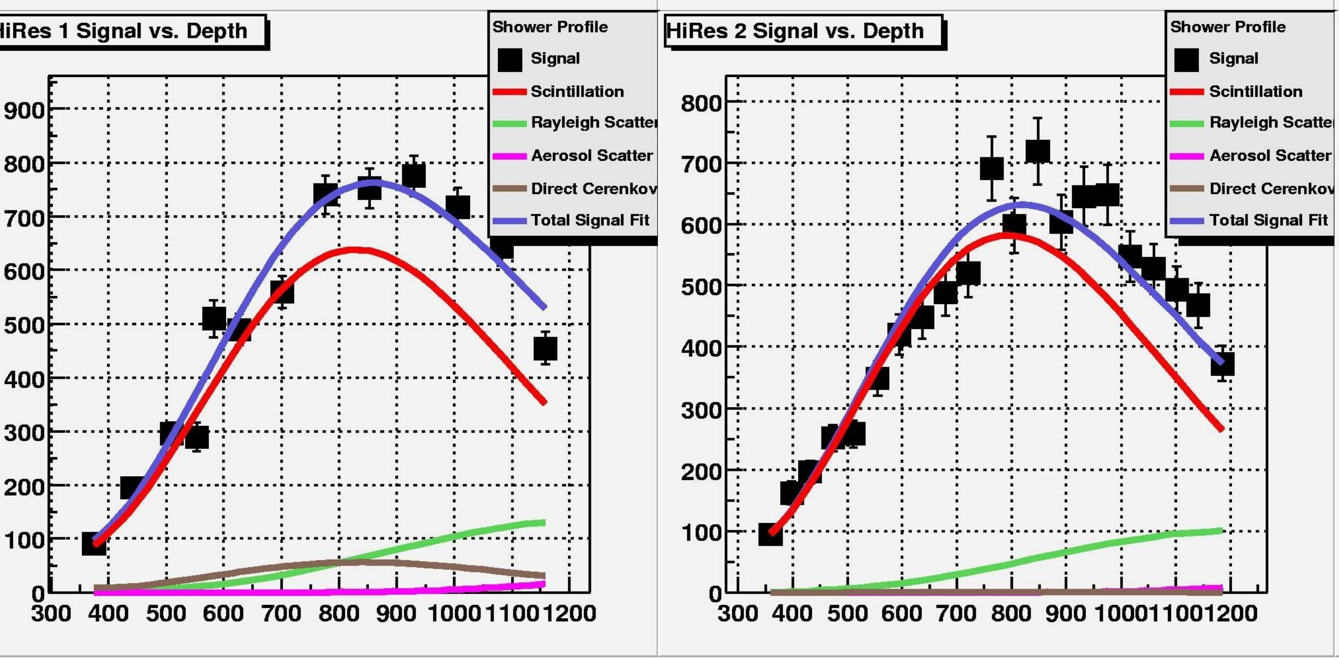




HiRes NSF events 200-300EeV







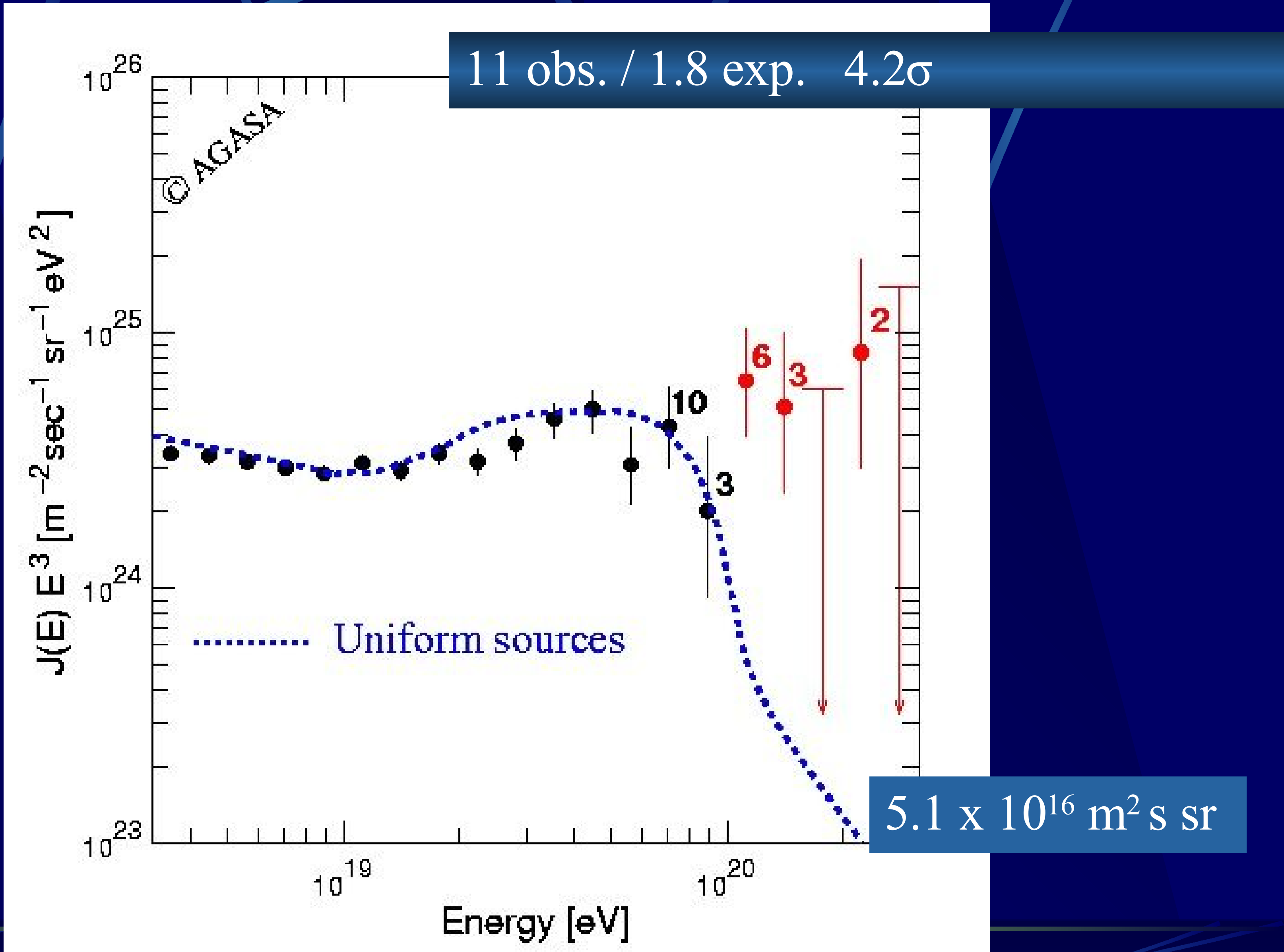
Event 1
19 Nov 2003

HiRes 1
Event Starting: 6:35:31.263281
Energy: 121.956 Eev
Distance to Core: 24949.022 m
Profile Fit χ^2: 6.1178
Shower max: 6.133e+10 particles
Depth at shower max: 865.069 g/cm^2

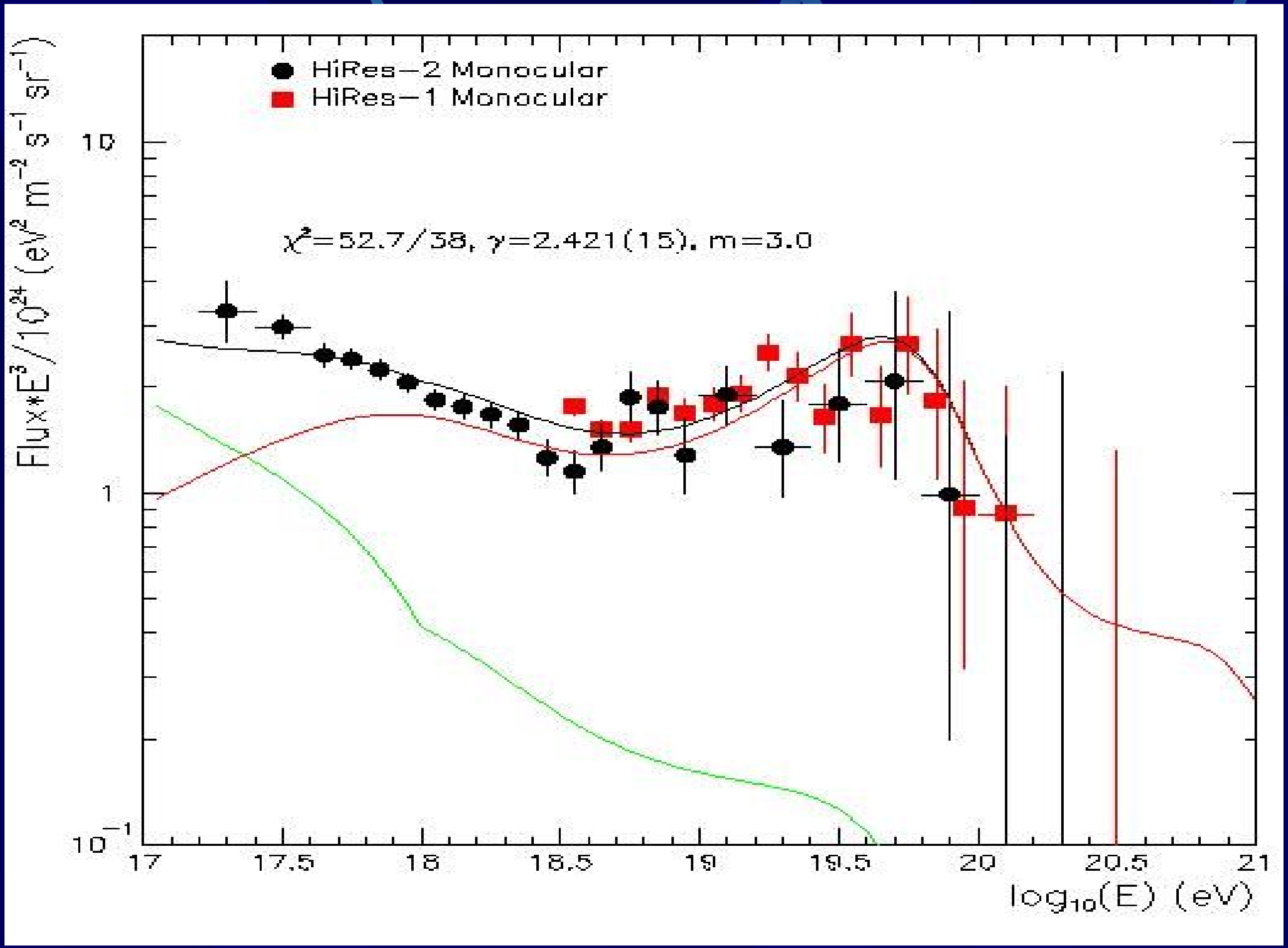
Shower azimuthal angle: 169.2 degrees
Shower zenith angle: 60.1 degrees

HiRes 2
Event Starting: 6:35:31.263180
Energy: 122.491 Eev
Distance to Core: 23533.923 m
Profile Fit χ^2: 1.8318
Shower max: 6.050e+10 particles
Depth at shower max: 830.569 g/cm^2

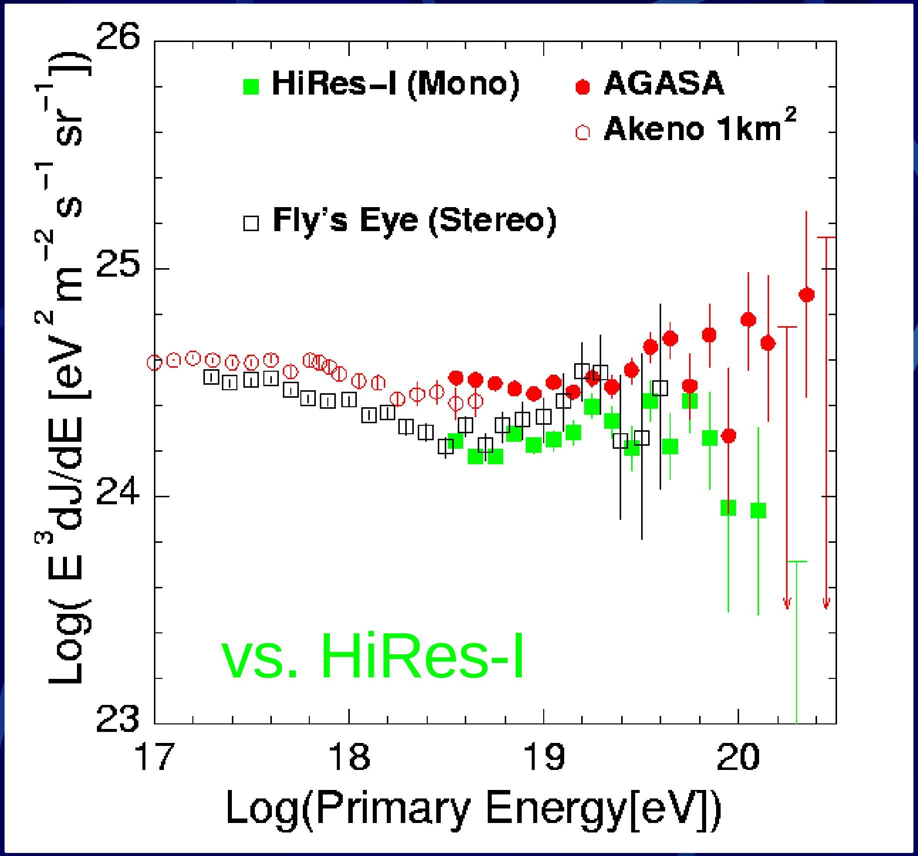
Energy Spectrum by AGASA (θ<45)

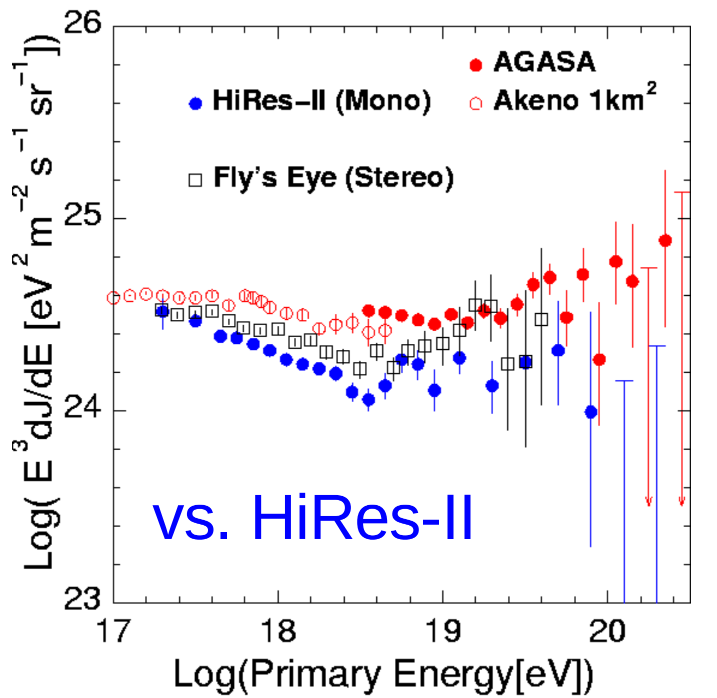


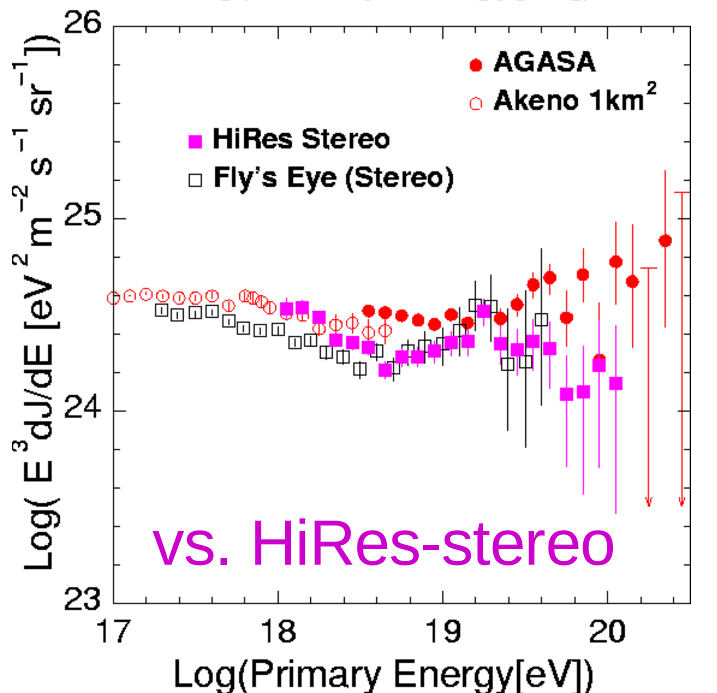
HiRes I, II mono spectrum



Recent spectra
(AGASA vs. HiRes@Tsukuba ICRC)

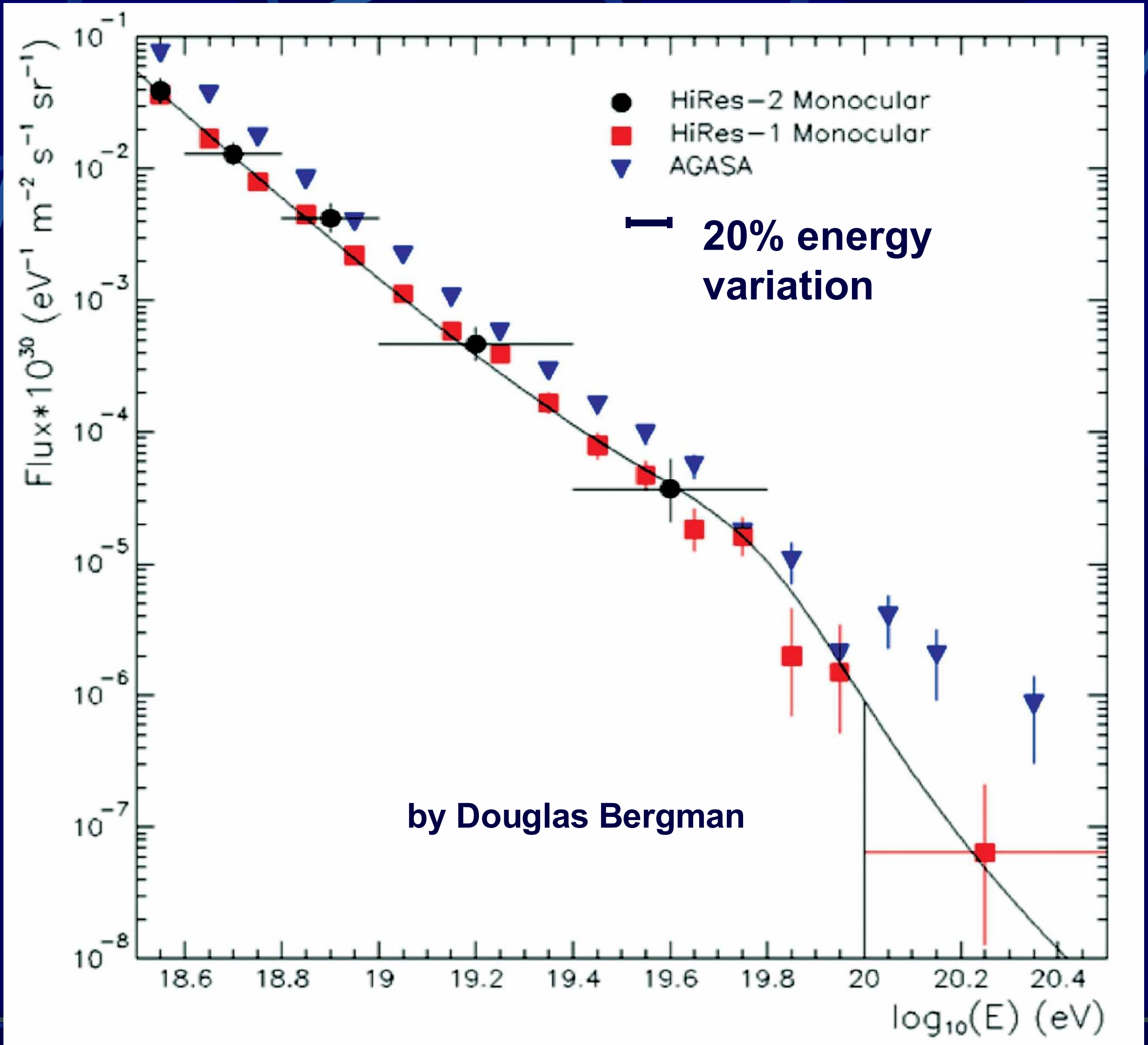




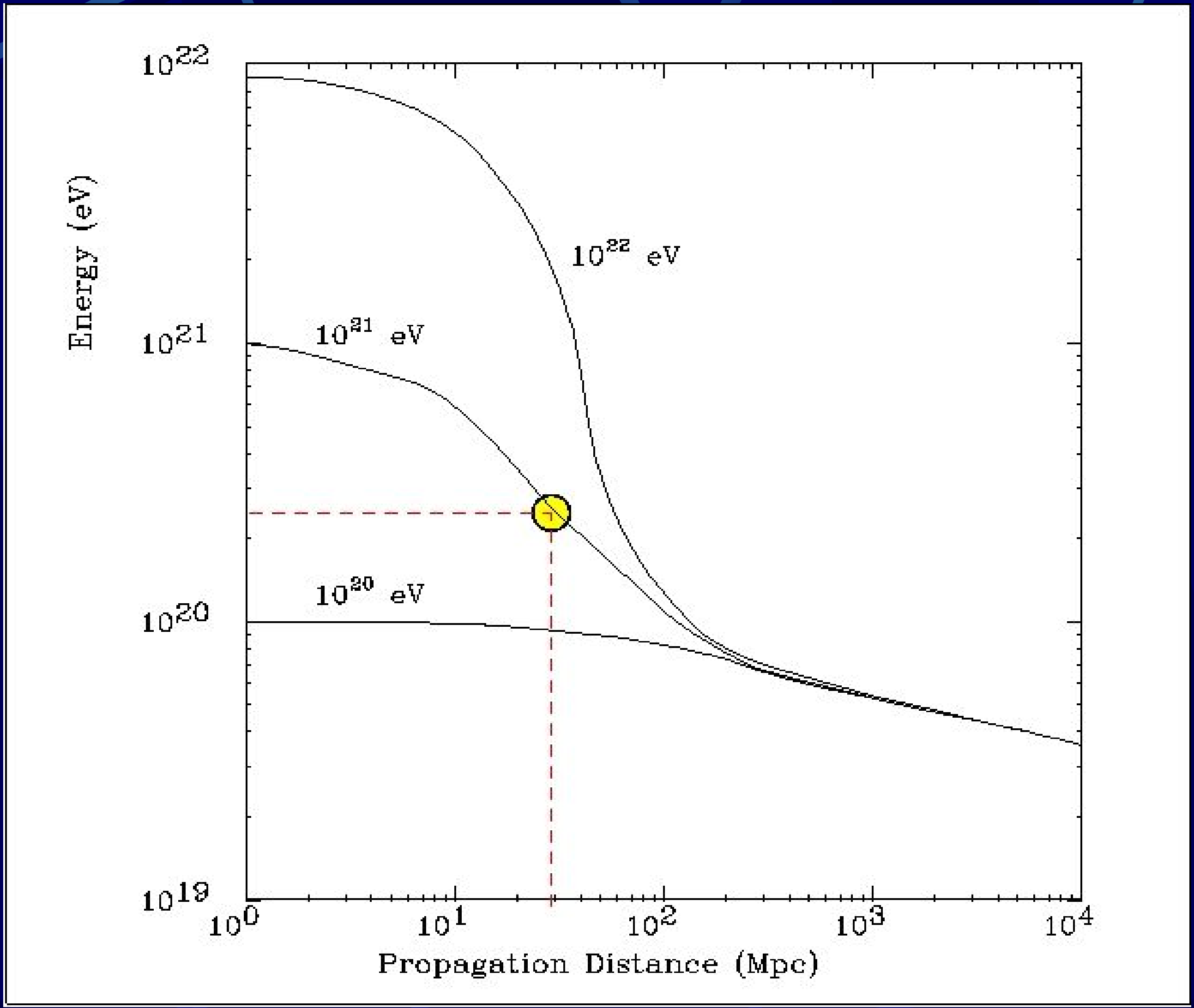


- ~2.5 sigma discrepancy between AGASA & HiRes
- Energy scale difference by 25%

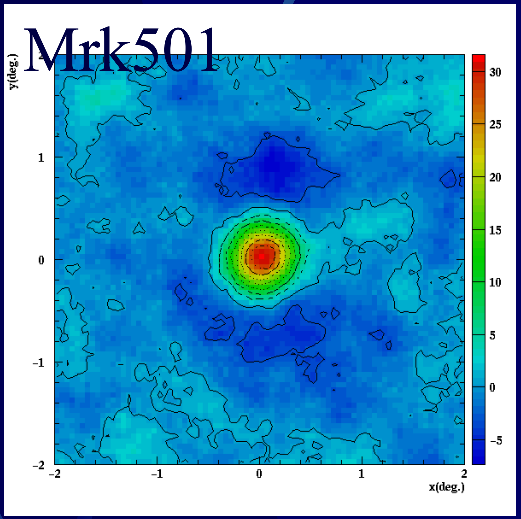
AGASA vs HiRes

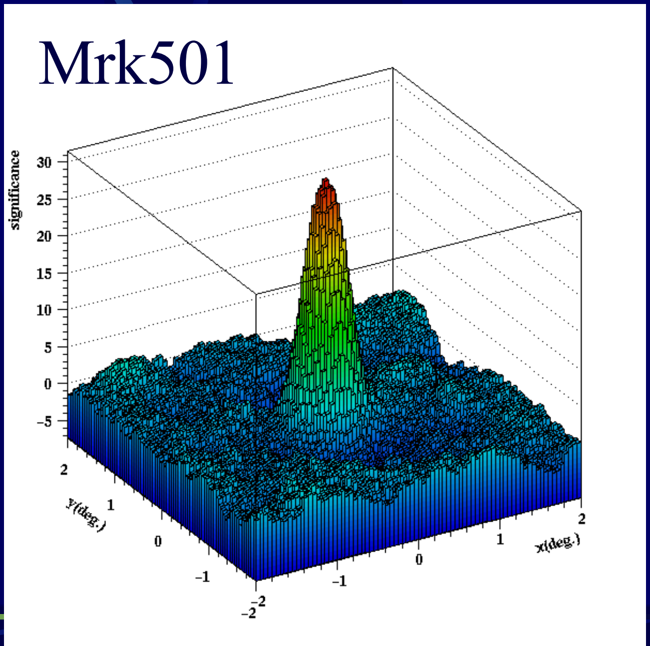


The history of the energy of C.R. traveling CMBR sea



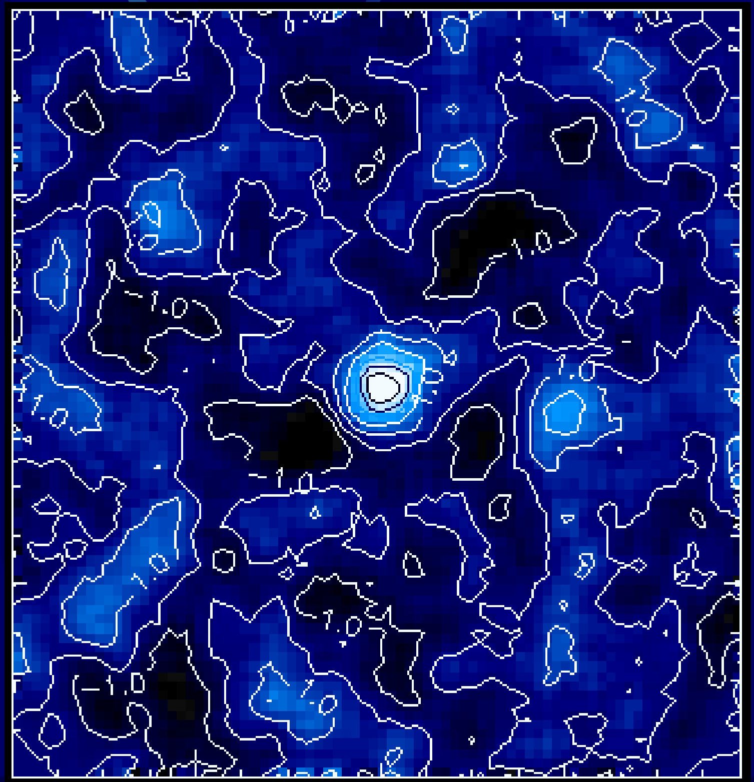
My short episode
IACT Telescope Array(95~97)



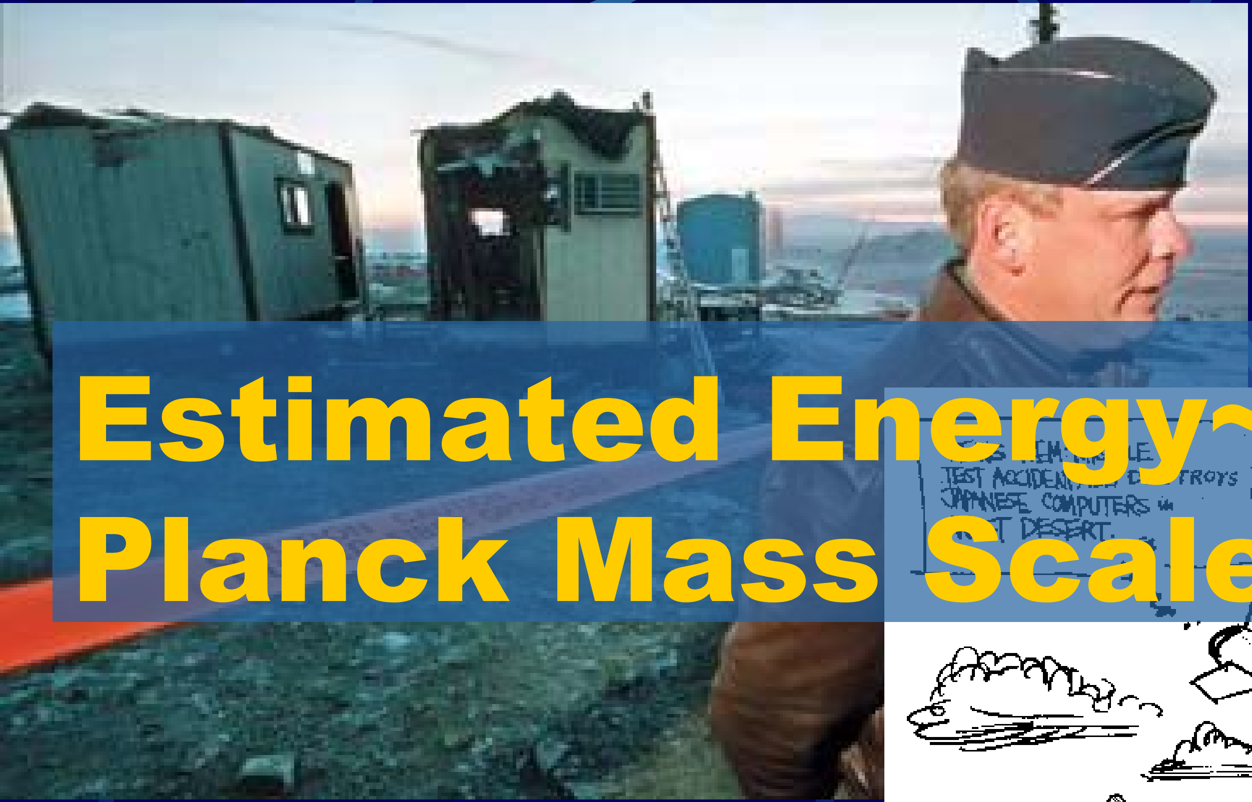


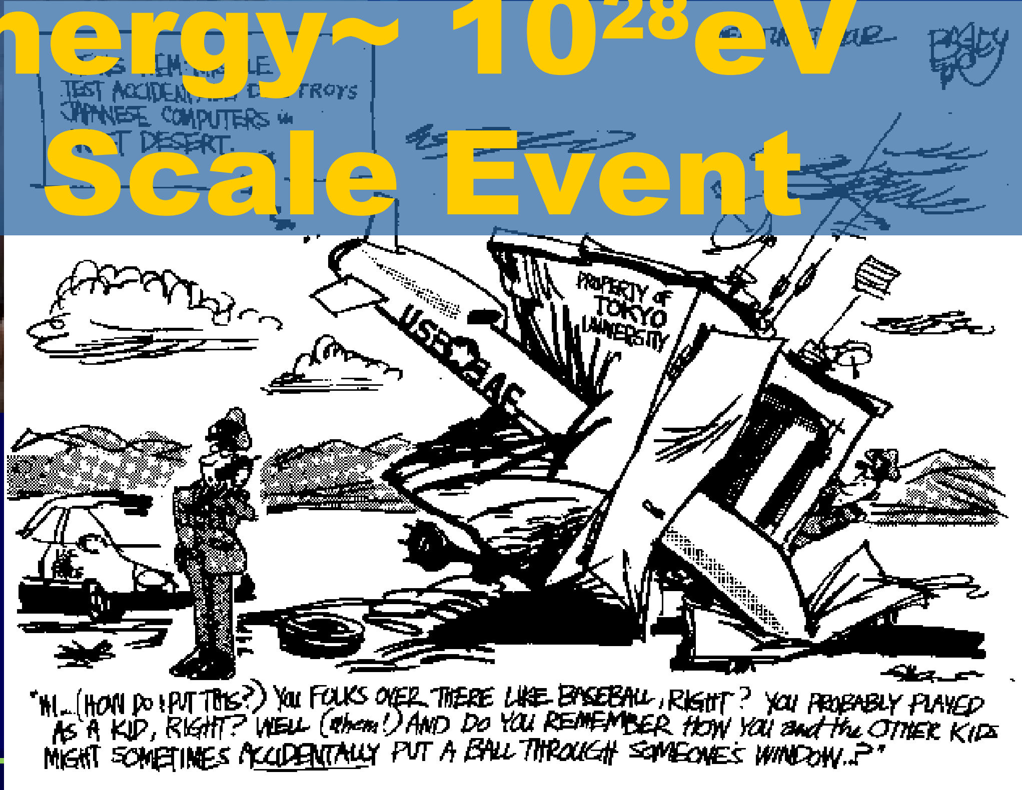
New TeV Gamma Ray Source 1ES1959+650

- Low Red shift X-BL Lac z=0.048
- Observation in 1998
  - MJD 50956-50965
    5.3 σ
  - MJD 50996-51023
    5.0 σ
- Significance Map
  4°x 4°FOV



Nightmare in Dec. 97 in Dugway Proving Ground

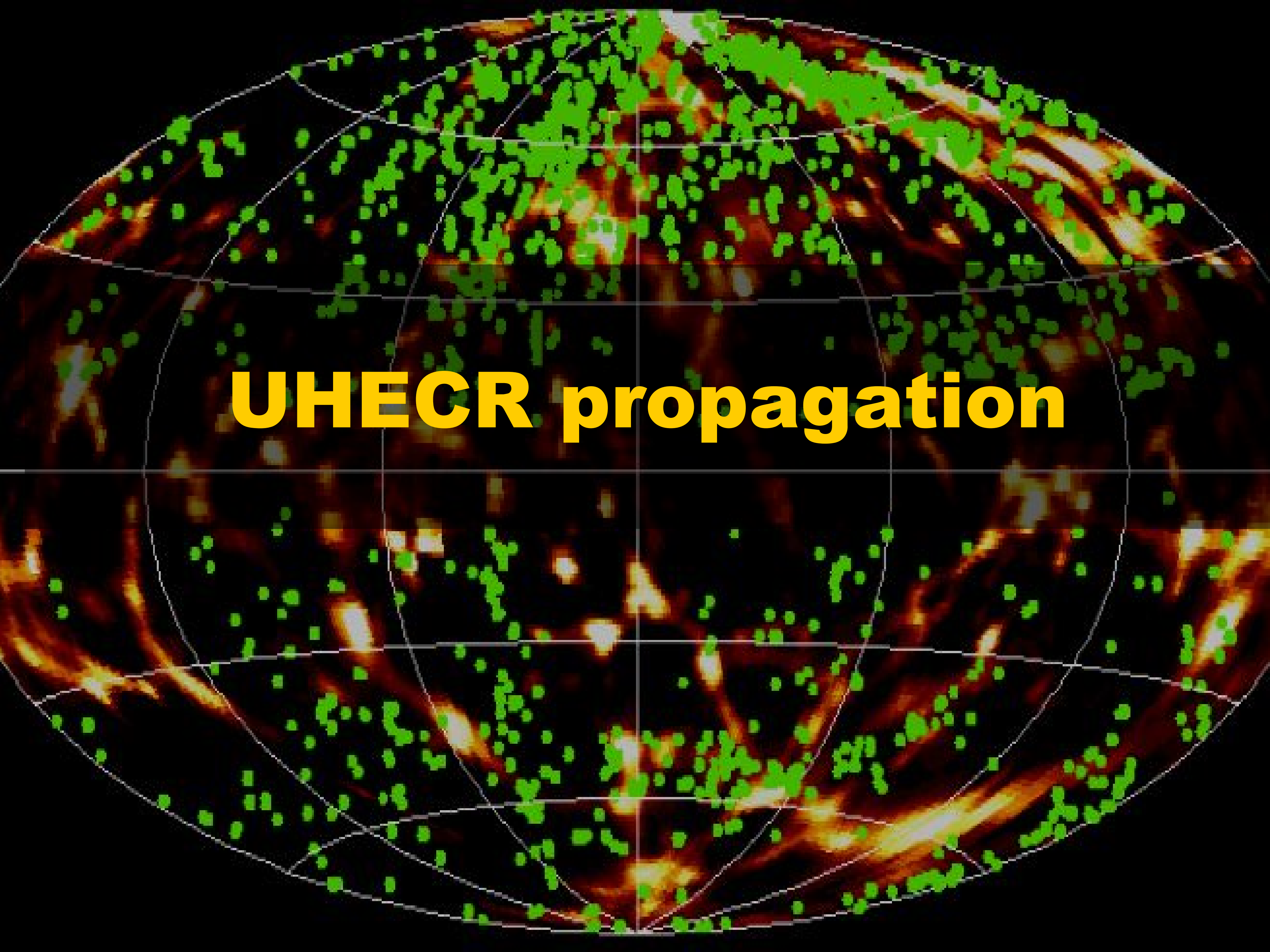




Estimated Energy~ 10^{28}eV

Planck Mass Scale Event

UHECR propagation



Background Radiations

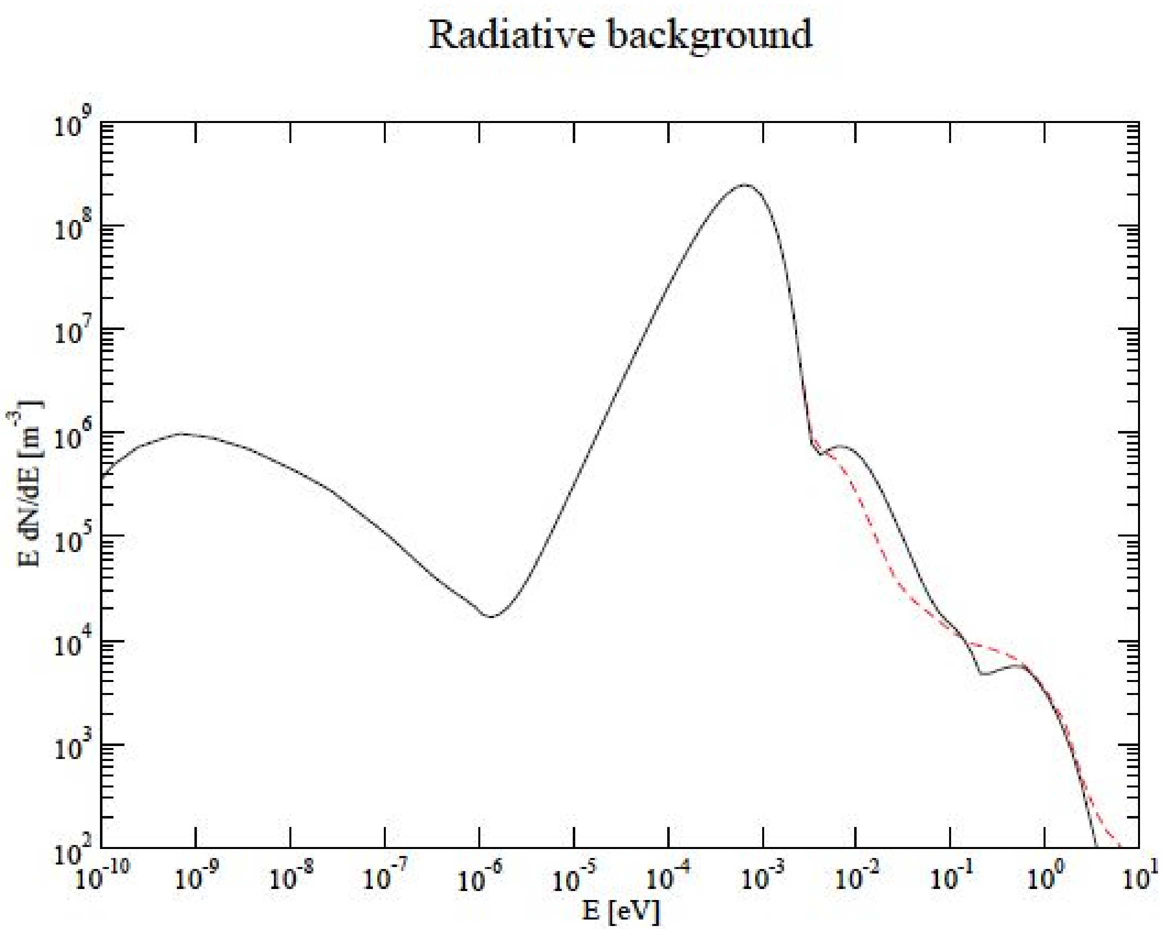
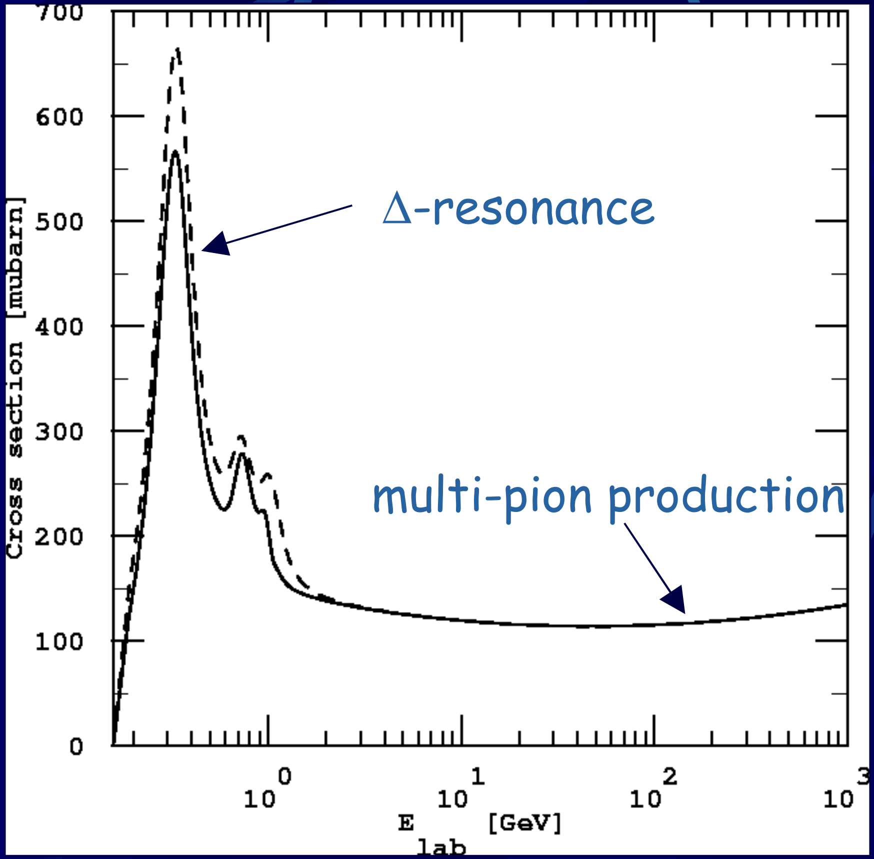
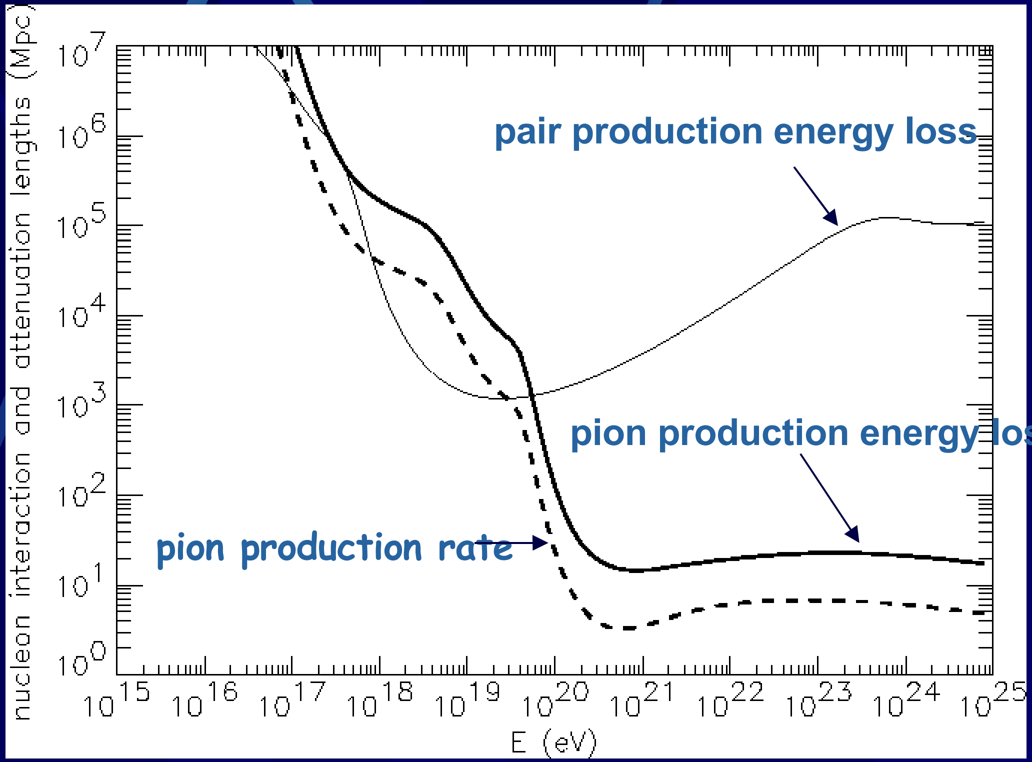


Figure 2. The local photon background we used. The main peak is due to the CMB, the radio background is taken from [33] in the hypothesis of red-shift evolving sources, the IR-UV background is taken from [24]. The dashed curve shows the result obtained in [30].

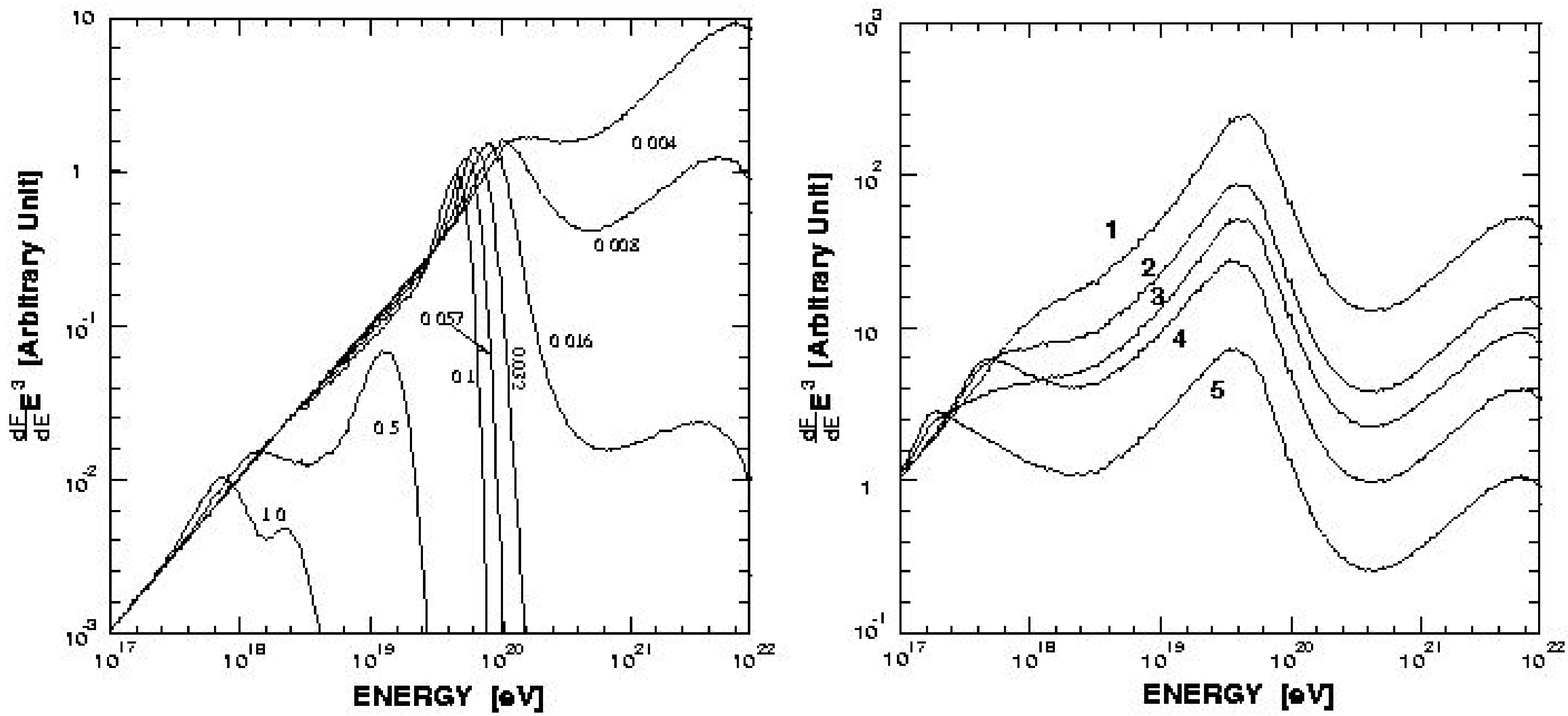
Greisen-Zatsepin-Kuzmin (GZK) effect





Energy Spectrum modification by the interaction with CMBR

by Yoshida and Teshima 1989



Berezinsky 2004

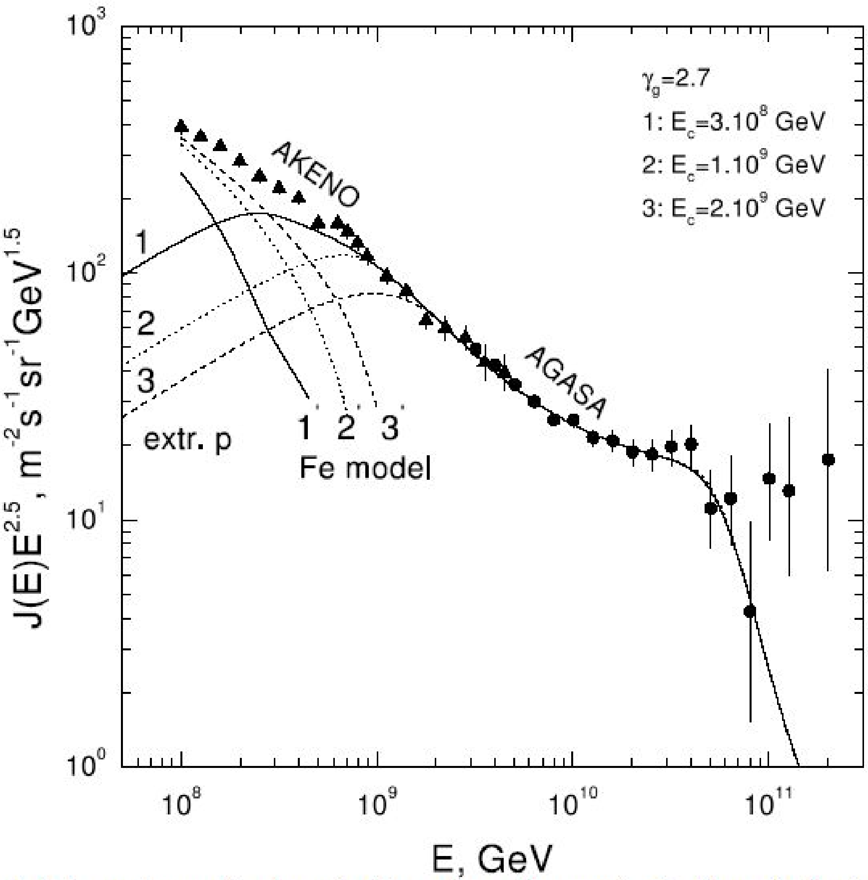


Figure 4: *Calculated spectrum of extragalactic protons (curves* 1, 2, 3*) and of galactic iron spectra (curves* $1', 2', 3'$*) compared with all-particle spectrum from Akeno and AGASA experiments. The galactic iron spectrum is obtained by subtraction of the calculated proton spectrum from the all-particle spectrum. The pairs of curves* 1 *and* $1'$, 2 *and* $2'$, 3 *and* $3'$ *correspond to* E_c *equal to* 3×10^8 *GeV,* 1×10^9 *GeV, and* 2×10^9 *GeV, respectively. The intersections of the curves* $1 - 1'$, $2 - 2'$ *and* $3 - 3'$ *give the transition from galactic (iron) to extragalactic (protons) components, which occurs at* 1.5×10^8 *GeV,* 3.6×10^8 *GeV and* 6.2×10^8 *GeV, respectively.*

Energy loss time of nuclei

Yamamoto et al. 2003

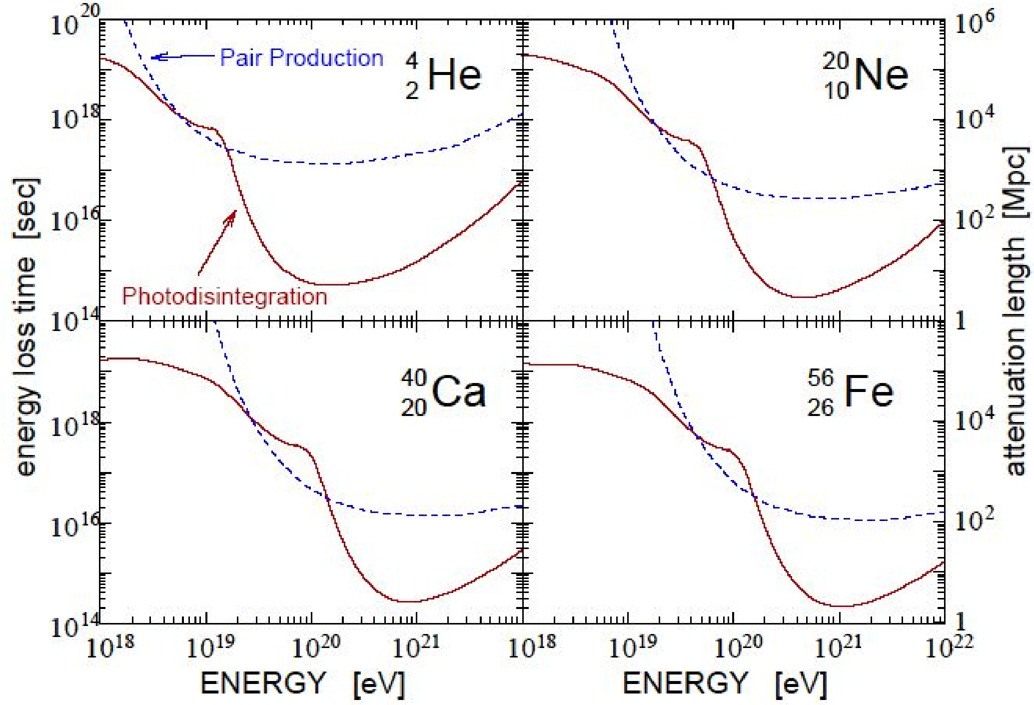
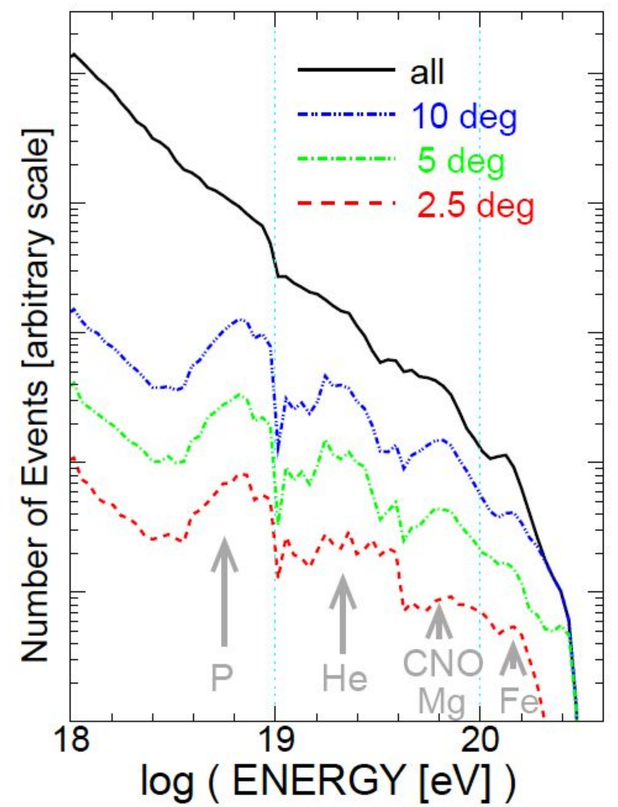


Fig. 1. Energy loss time of different mass nuclei as a function of energy. Solid line is that of single-nucleon emission by photo-disintegration and dashed line is pair production [17].



Energy spectrum of Nuclei by T.Wibig 2004

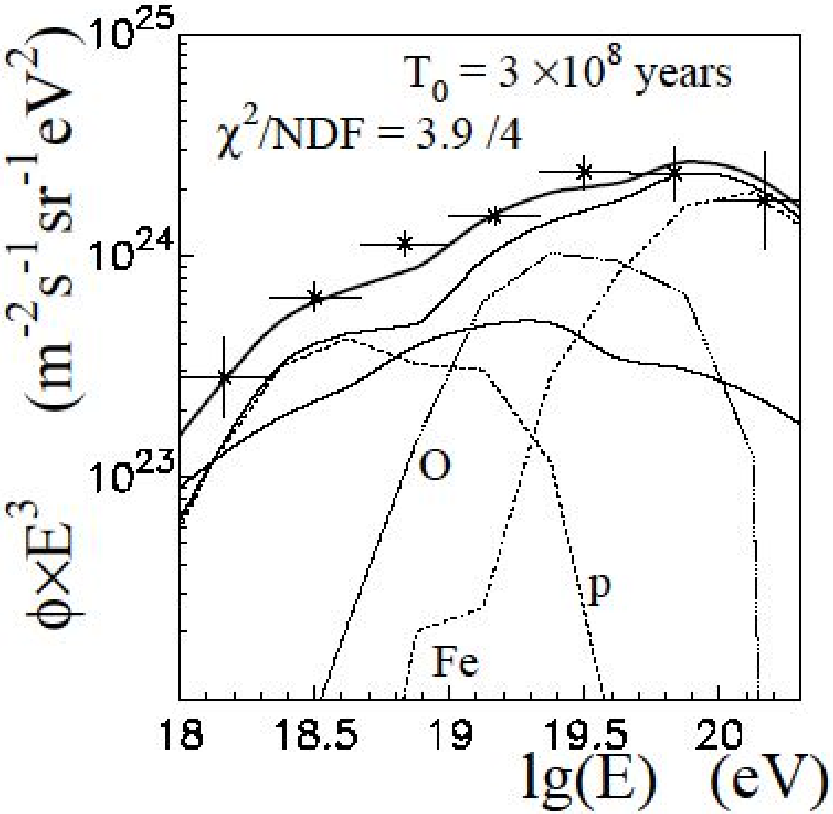


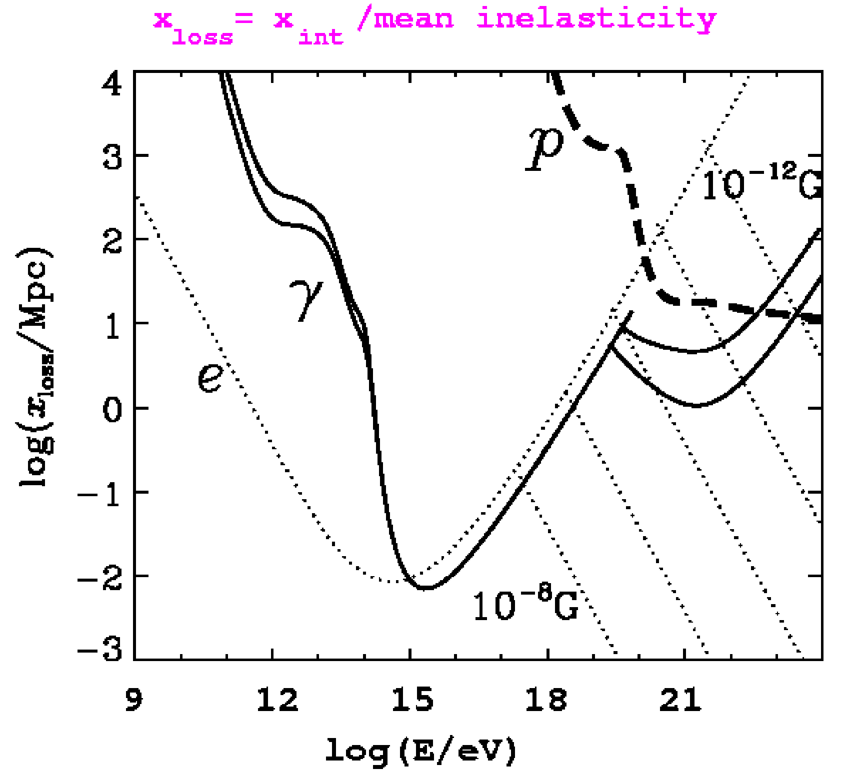
Fig. 12 UHECR flux for Single Source. Source is located at 15 Mpc and switched off at the time $T_0 = 3 \times 10^8$ years ago. The proton contribution is shown by dashed, iron by dot-dashed, and oxygen by dotted line. The source spectrum index is -2.1. The continuous background is shown by the thin solid line and was obtained assuming one random source per each 1000 Mpc^3 $\times$ 10^9 years.

GZK effect

- Energy Spectrum of cosmic rays are modified; suppression above $4x10^{19}$eV
- Secondary particles
  - π° 2γ cascade
    - γ; pair creation
    - e; Inverse compton, synchrotron
  - $\pi^\pm$ ν
- Generally, proton supply the energy to neutrino and gammas

$$p + \begin{matrix} N \\ \gamma \end{matrix} \rightarrow X + \left. \begin{matrix} \pi^{\pm} \rightarrow \text{neutrinos} \\ \pi^{\text{o}} \rightarrow \gamma - \text{rays} \end{matrix} \right\}$$

Attenuation length
p, γ, e



Included processes:

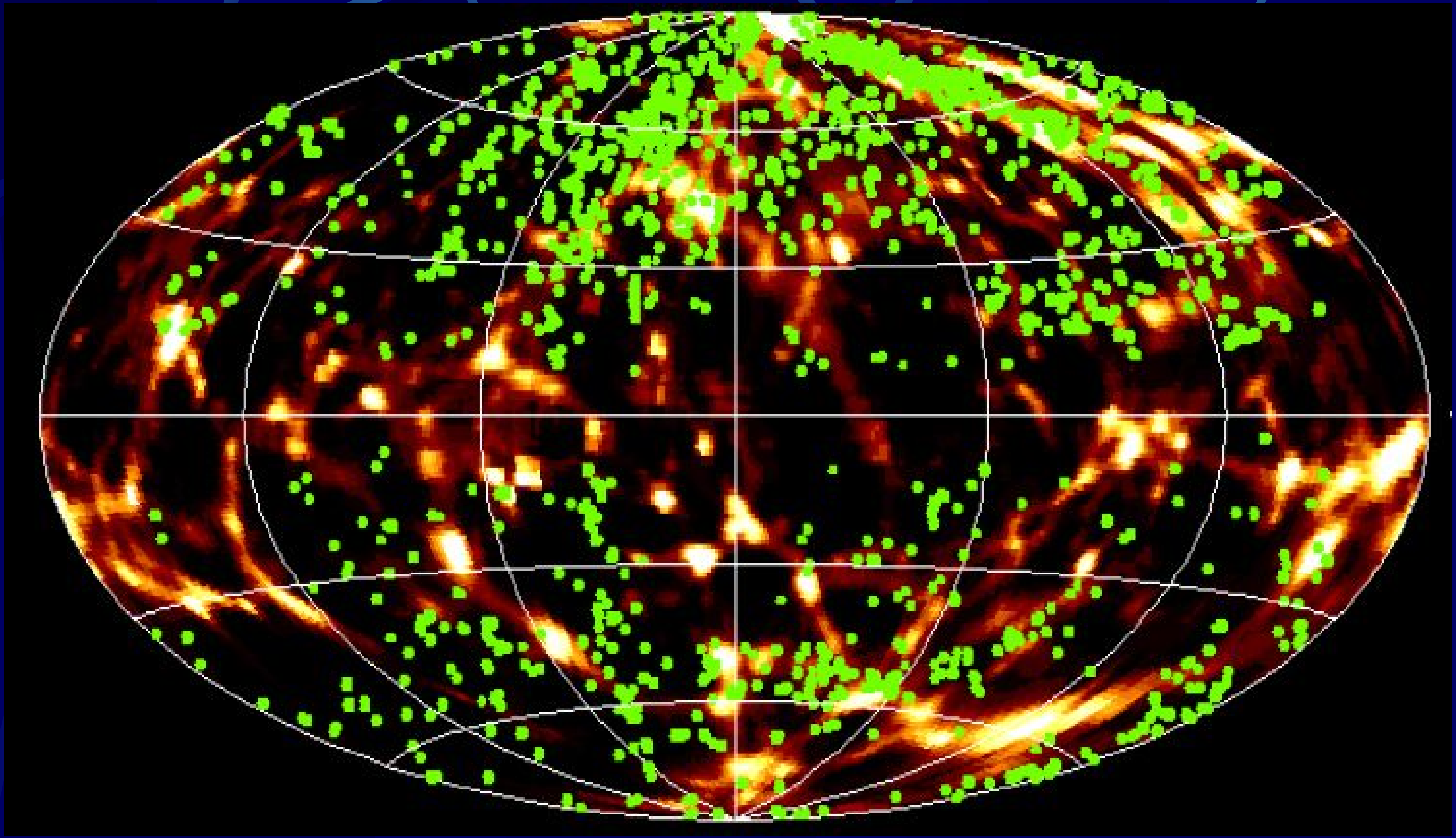
Electrons: inverse Compton; synchrotron rad (for fields from pG to 10 nG)

Gammas: pair-production through IR, CMB, and radio backgrounds

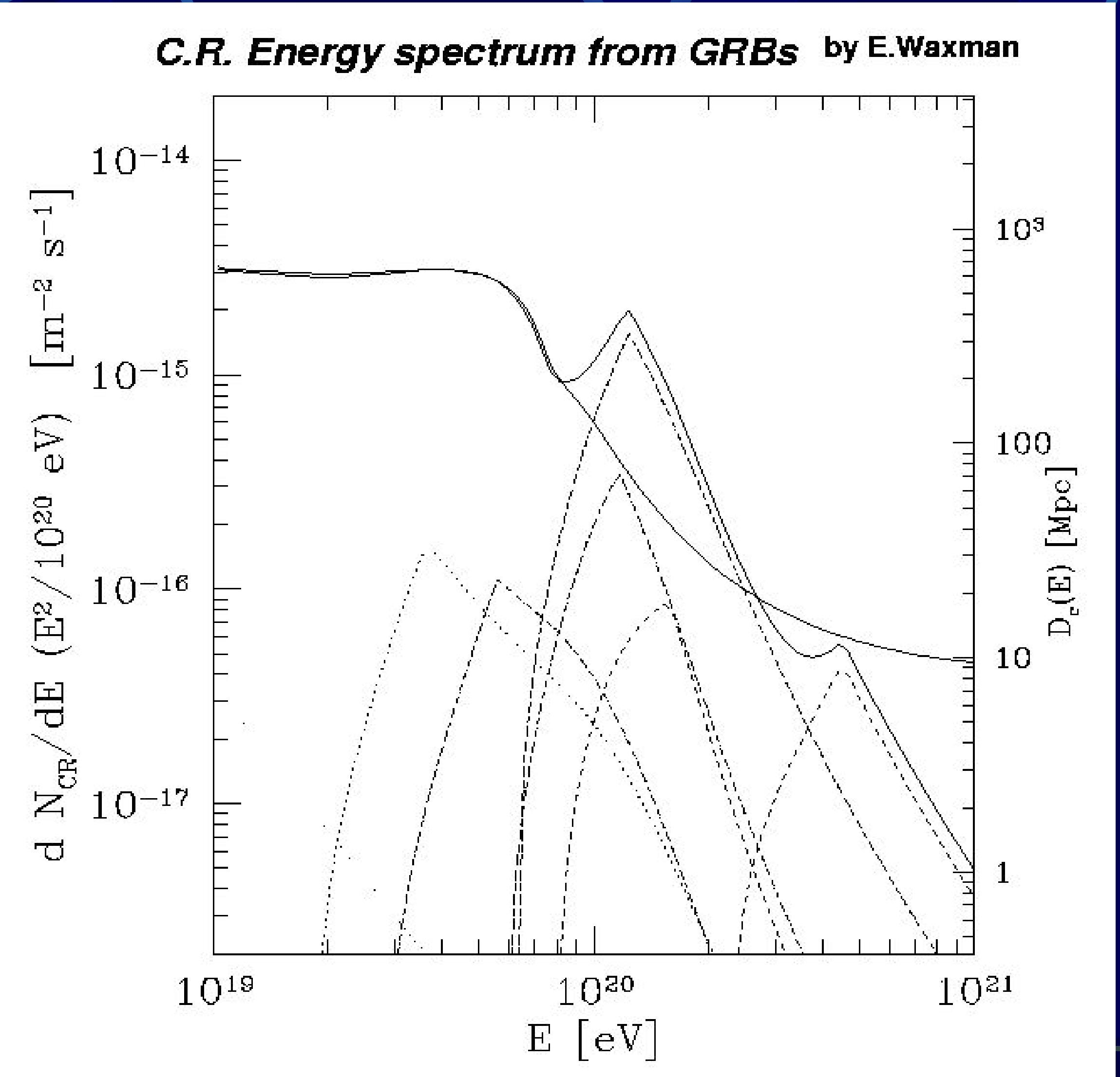
Protons: Bethe-Heitler pair production, pion photoproduction

Matter (90Mpc) and Galaxy(45Mpc) distribution

By A.Kravtsov

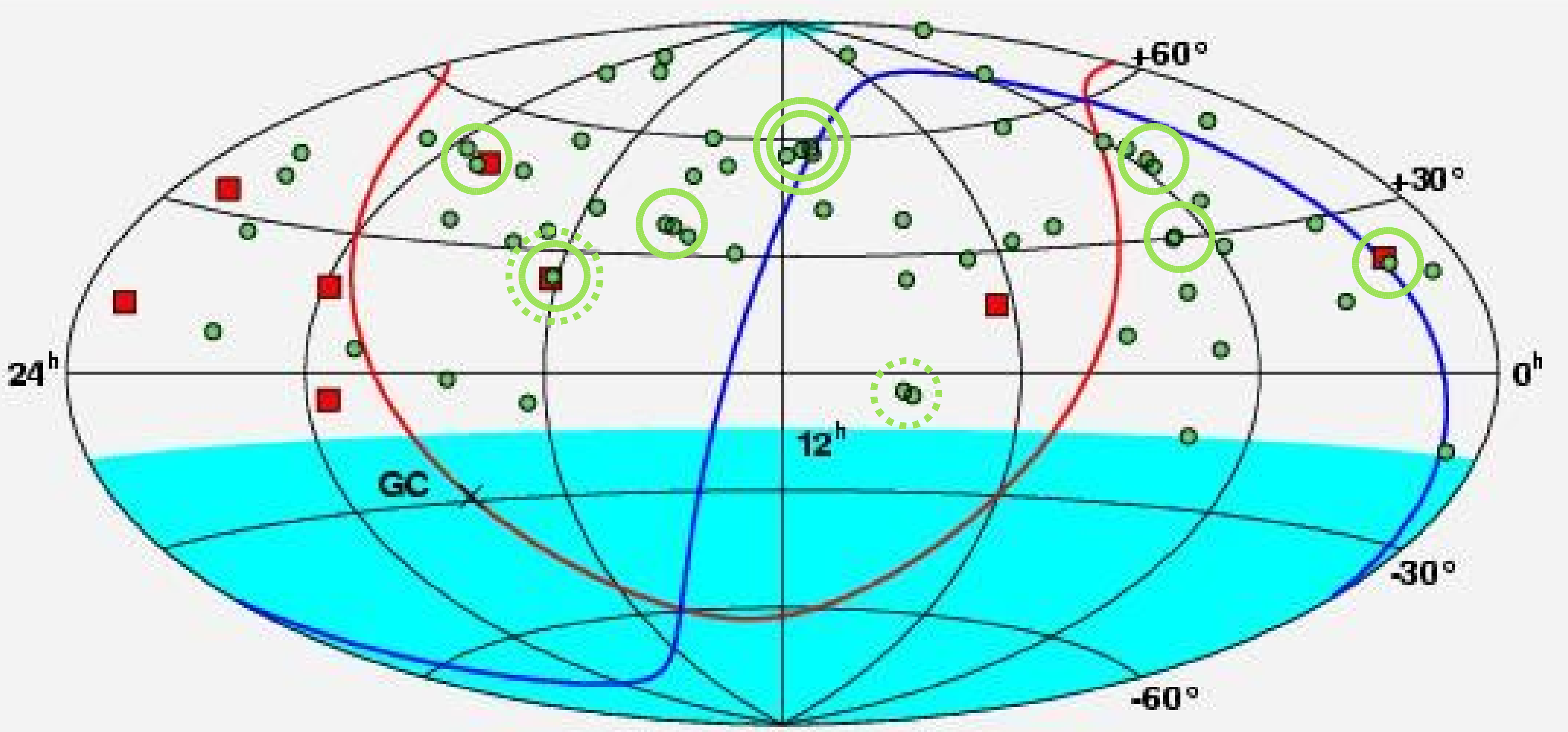


Cosmic Ray Energy Spectrum from GRBs(10~100) by E.Waxman

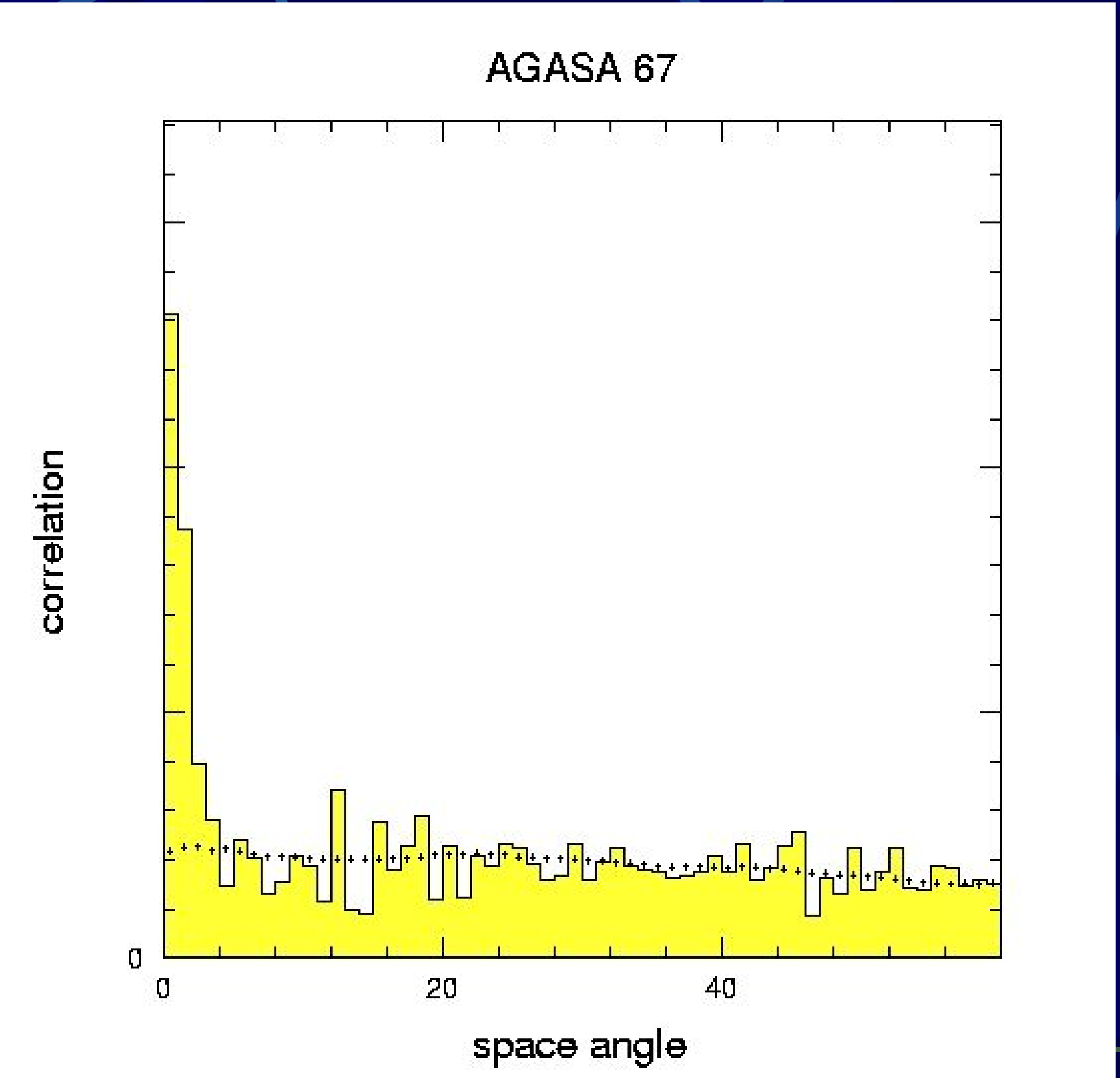


Arrival Direction Distribution >$4x10^{19}$eV zenith angle <50deg.

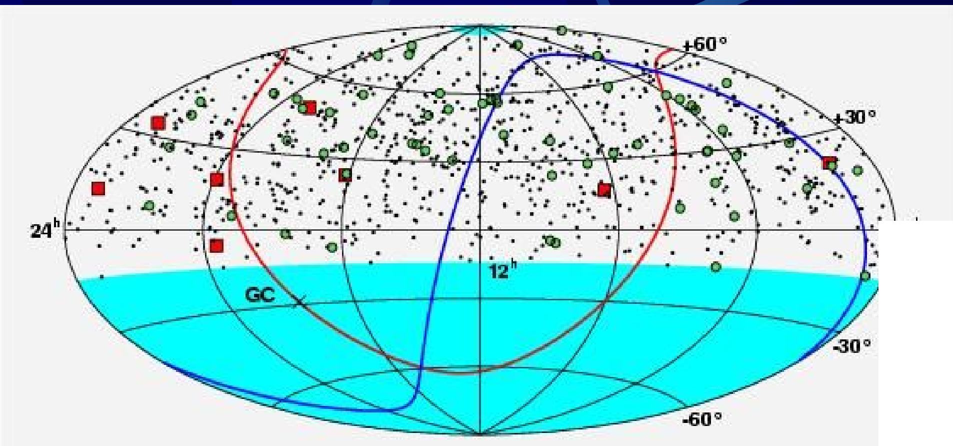
- Isotropic in large scale Extra-Galactic origin
- But, Clusters in small scale ($\Delta\theta$<2.5deg)
  - 1triplet and 6 doublets (2.0 doublets are expected from random)
  - One doublet triplet(>$3.9x10^{19}$eV) and a new doublet(<2.6deg)

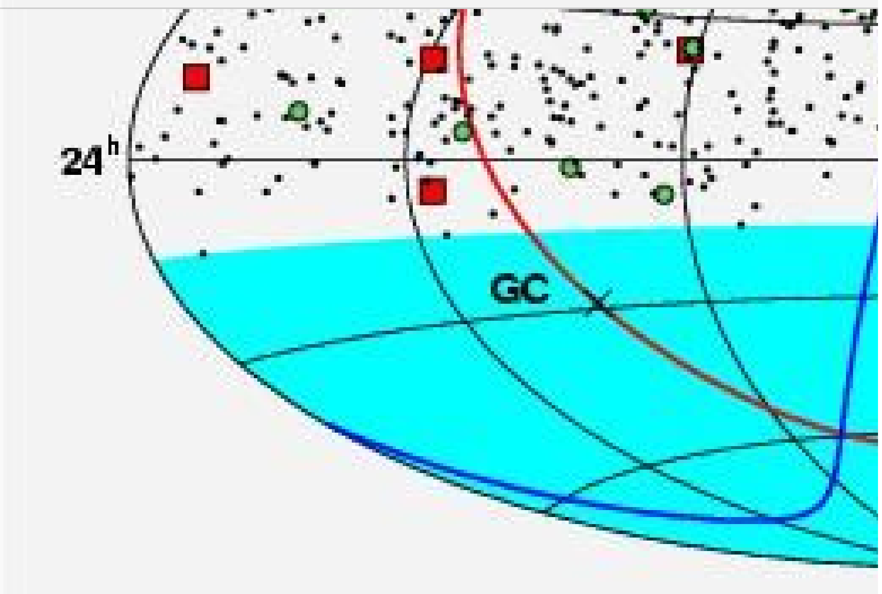


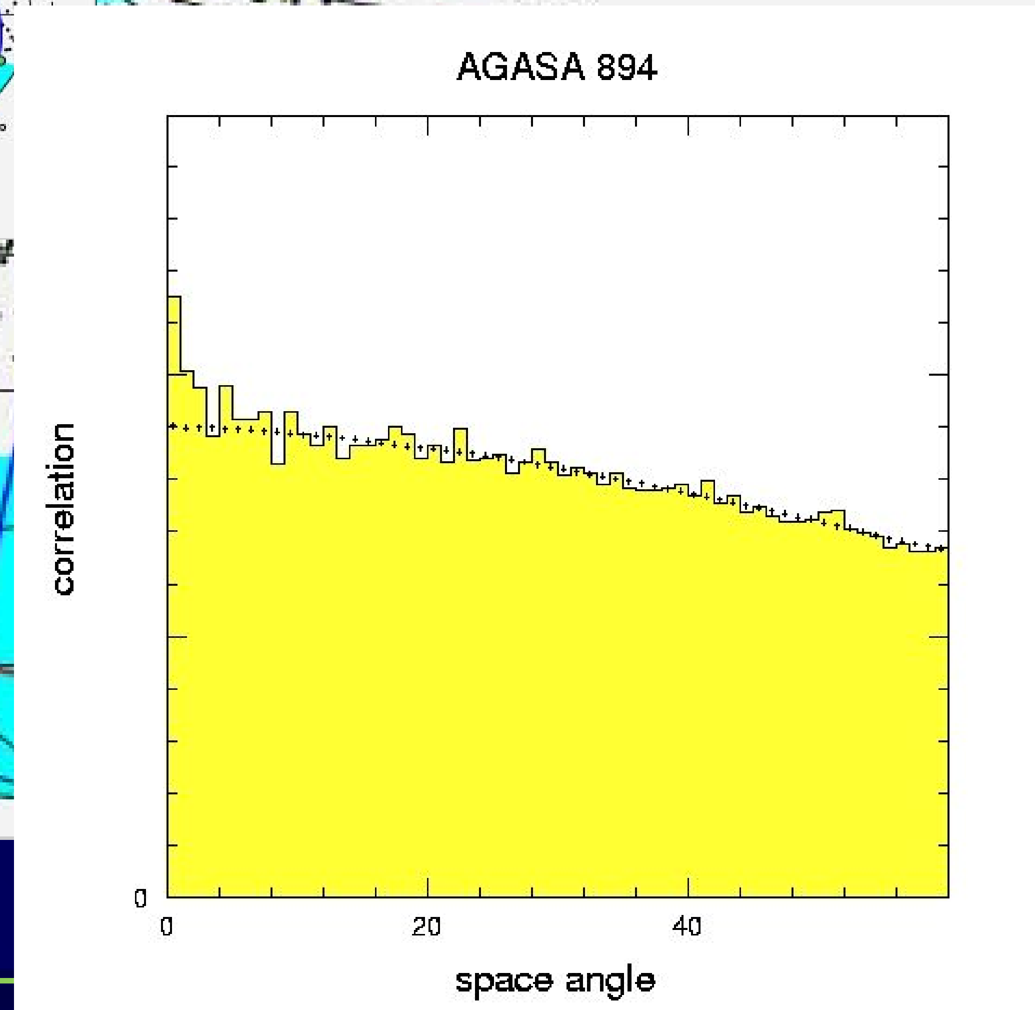
Space Angle Distribution of Arbitrary two events >$4x10^{19}$eV



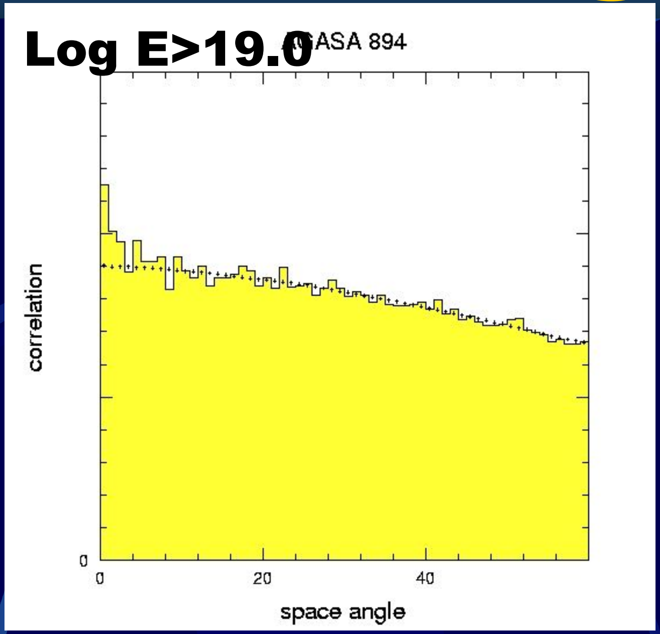
Arrival Direction Distribution >10^{19}eV

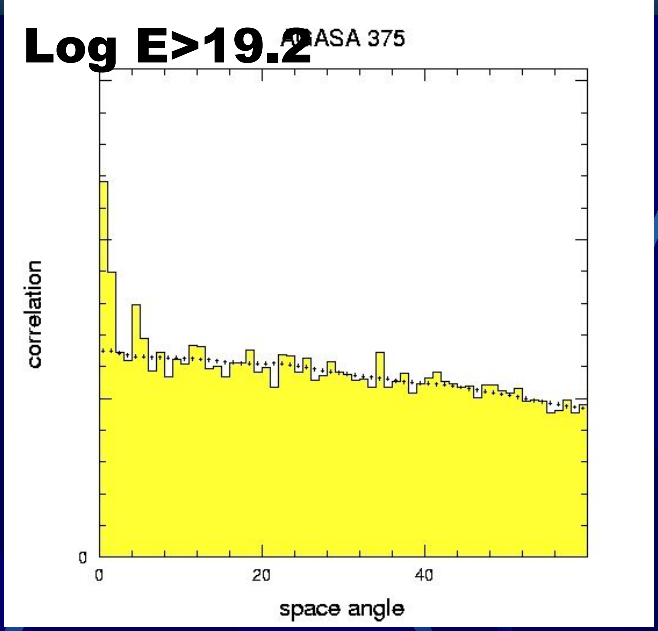


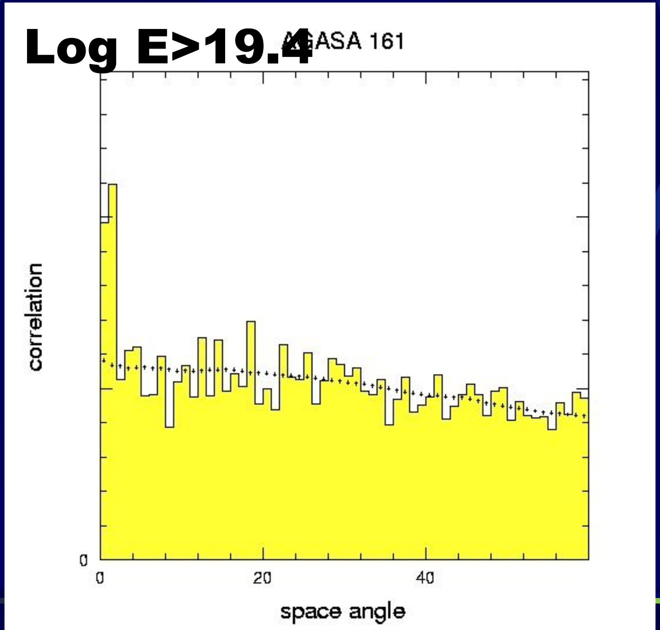


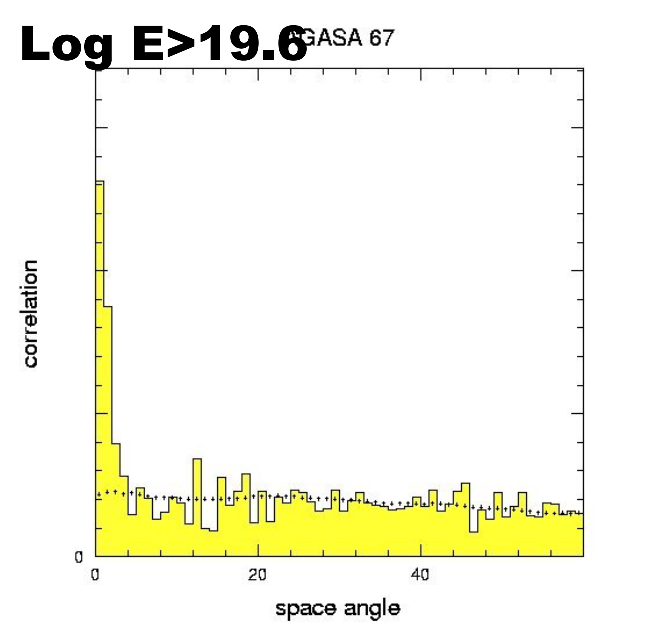


Space Angle Distribution

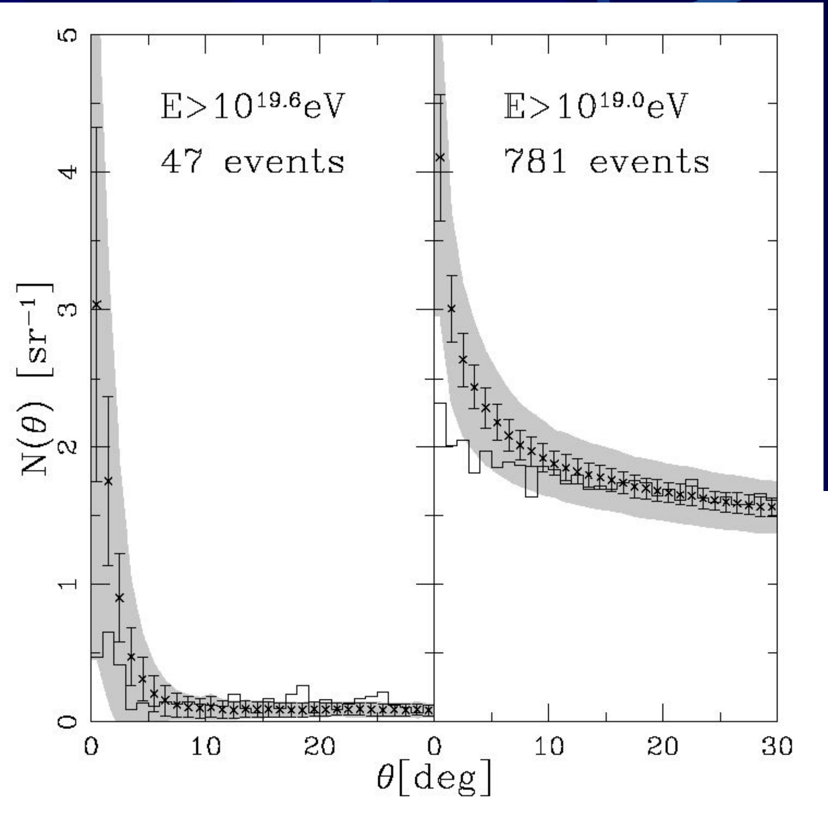




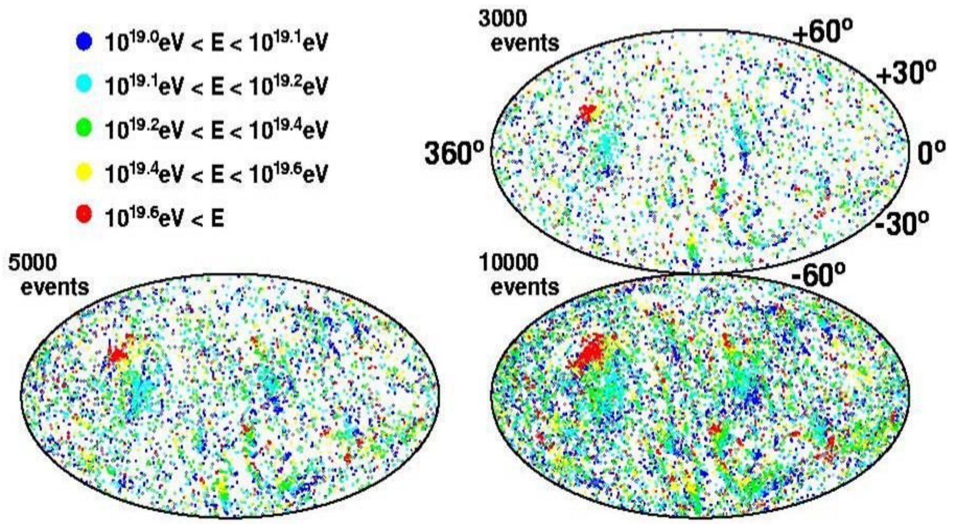




Expected Auto correlation Yoshiguchi et al. 2004



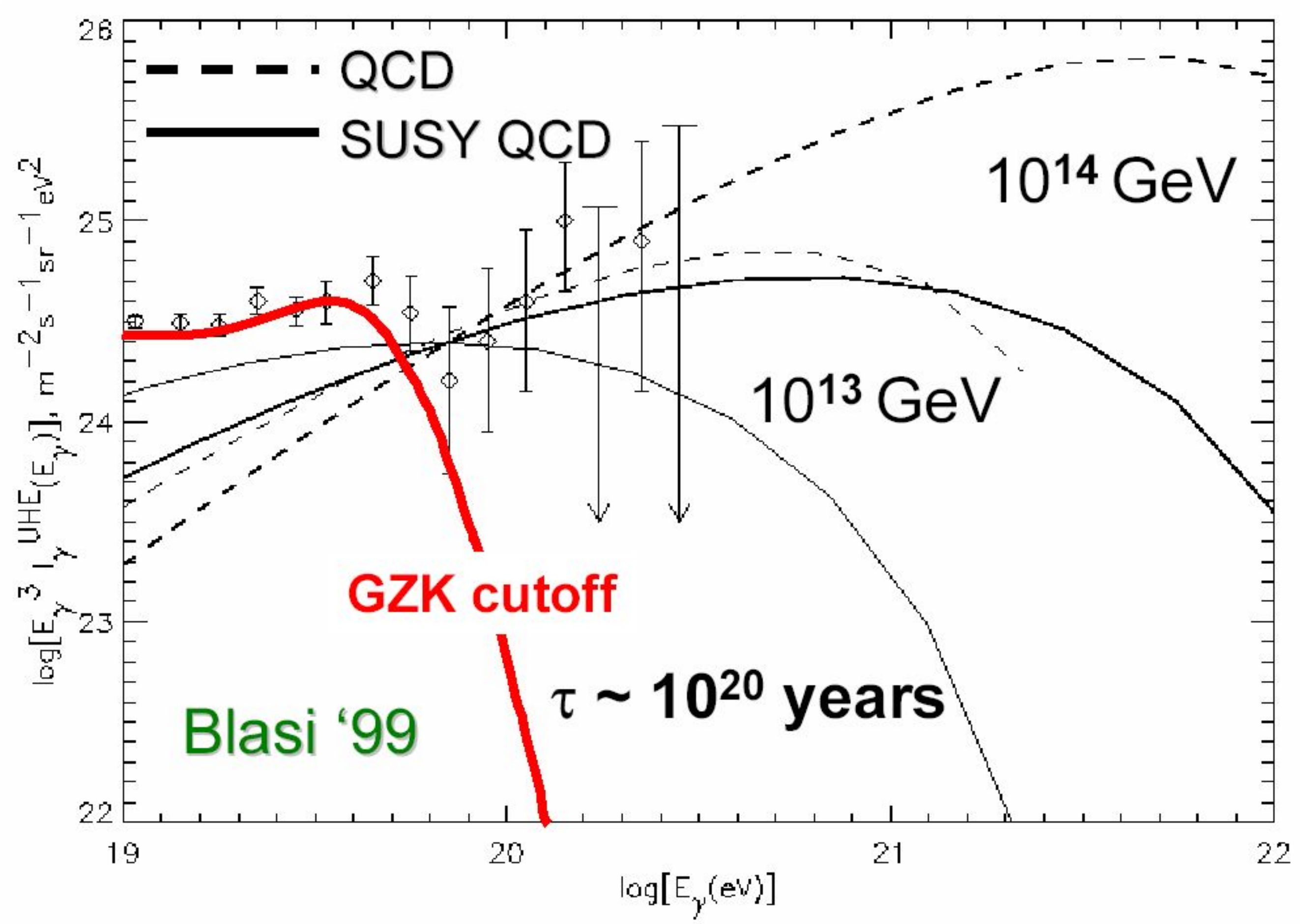
Number density of sources
~10^{-5} Mpc^{-3}



Isocurvature modes:	CMB, Large-scale structure
Decay:	Ultra High Energy Cosmic Rays
Annihilate:	Galactic Center, Sun
Direct Detection:	Bulk, Underground S

By Kolb, 2003

WIMPZILLA decay

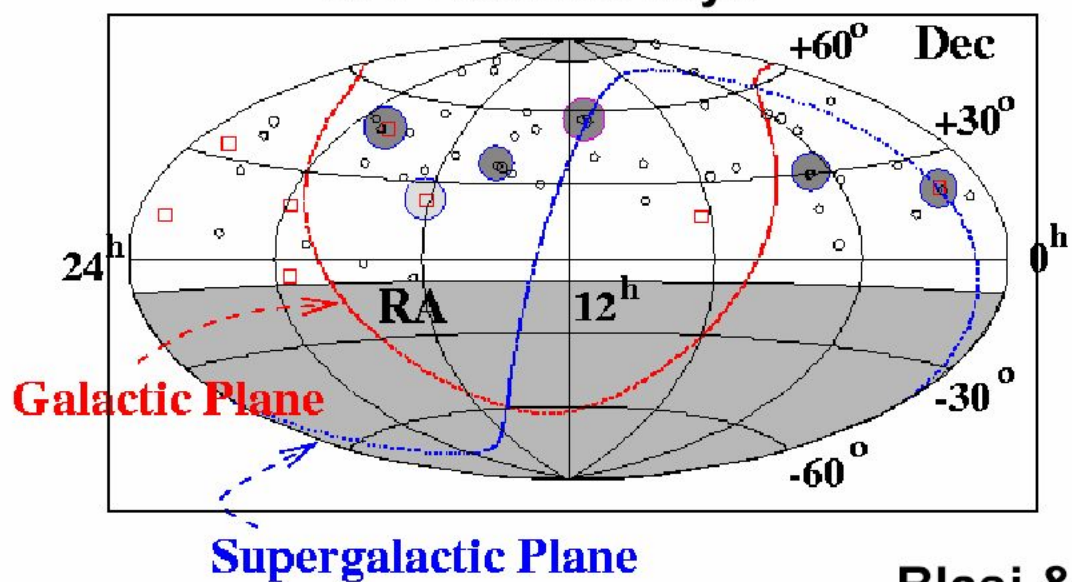


UHE cosmic rays mostly photons; characteristic spectrum;
UHE neutrinos; lower-energy crud;
clumping → anisotropies

By Kolb, 2003

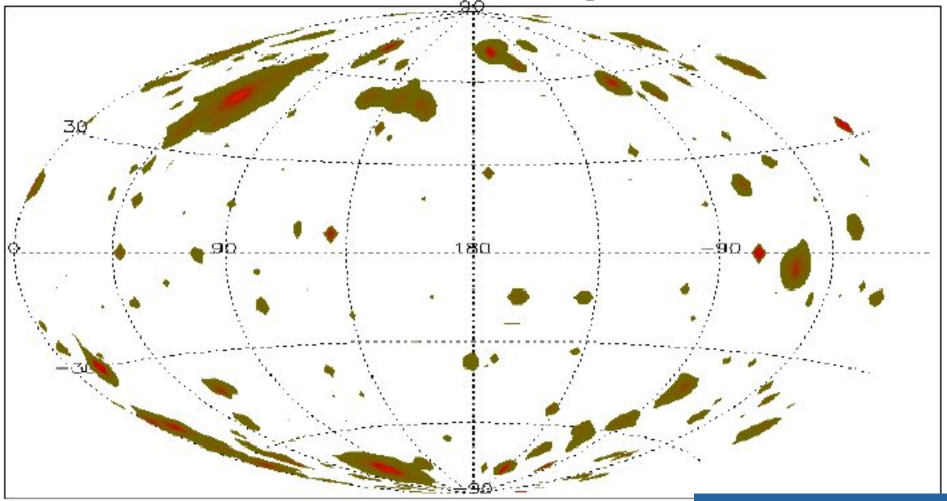
Clustering of UHE events

UHE cosmic rays



probability from isotropic distribution: <1%

Blasi & Sheth astro-ph/0006316



model follows Navarro, Frenk, White dark matter distribution

By Kolb, 2003

Summary; origin of UHECRs

- UHECRs   Diffuse γ, UHE neutrinos
- Fe; galactic origin or neaby galaxies
  - most economical
  - can not explain AGASA clusters
- P; Over density of nearby sources or very hard energy spectrum, GRBs, AGNs
- Super Heavy Relics in our Halo
  - we should see strong anisotropy
- Neutrino with large cross section

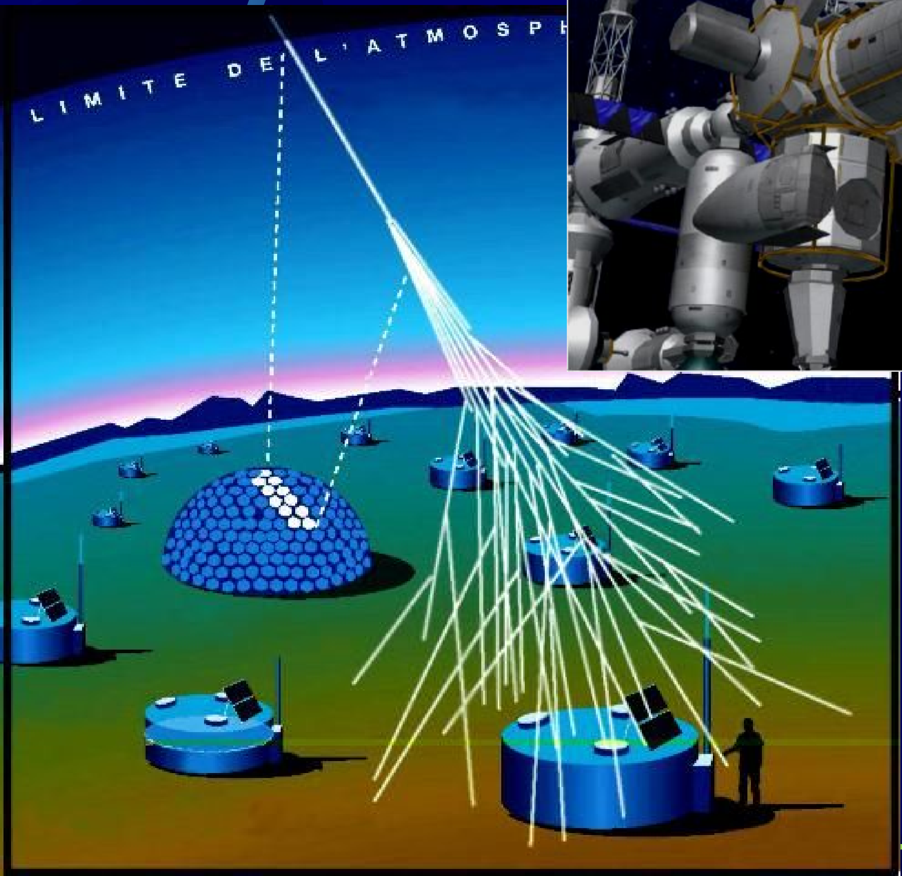
Ultra High Energy Cosmic Rays
-- Next generation experiments, mainly about EUSO --

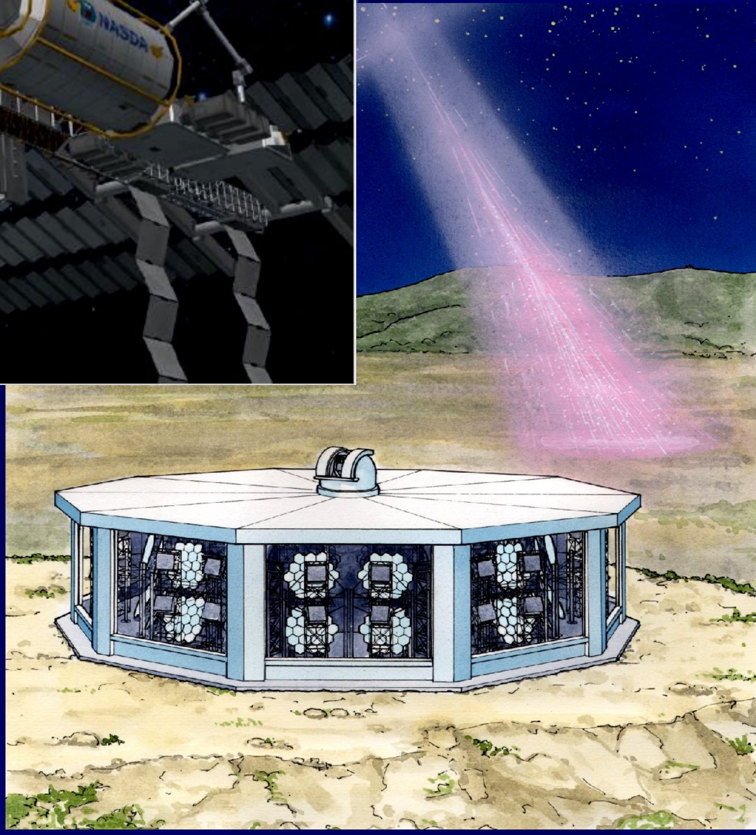
M.Teshima

Max-Planck-Institut für Physik, München

Schule für Astroteilchenphysik
Oct. 2004

New Projects for UHECRs

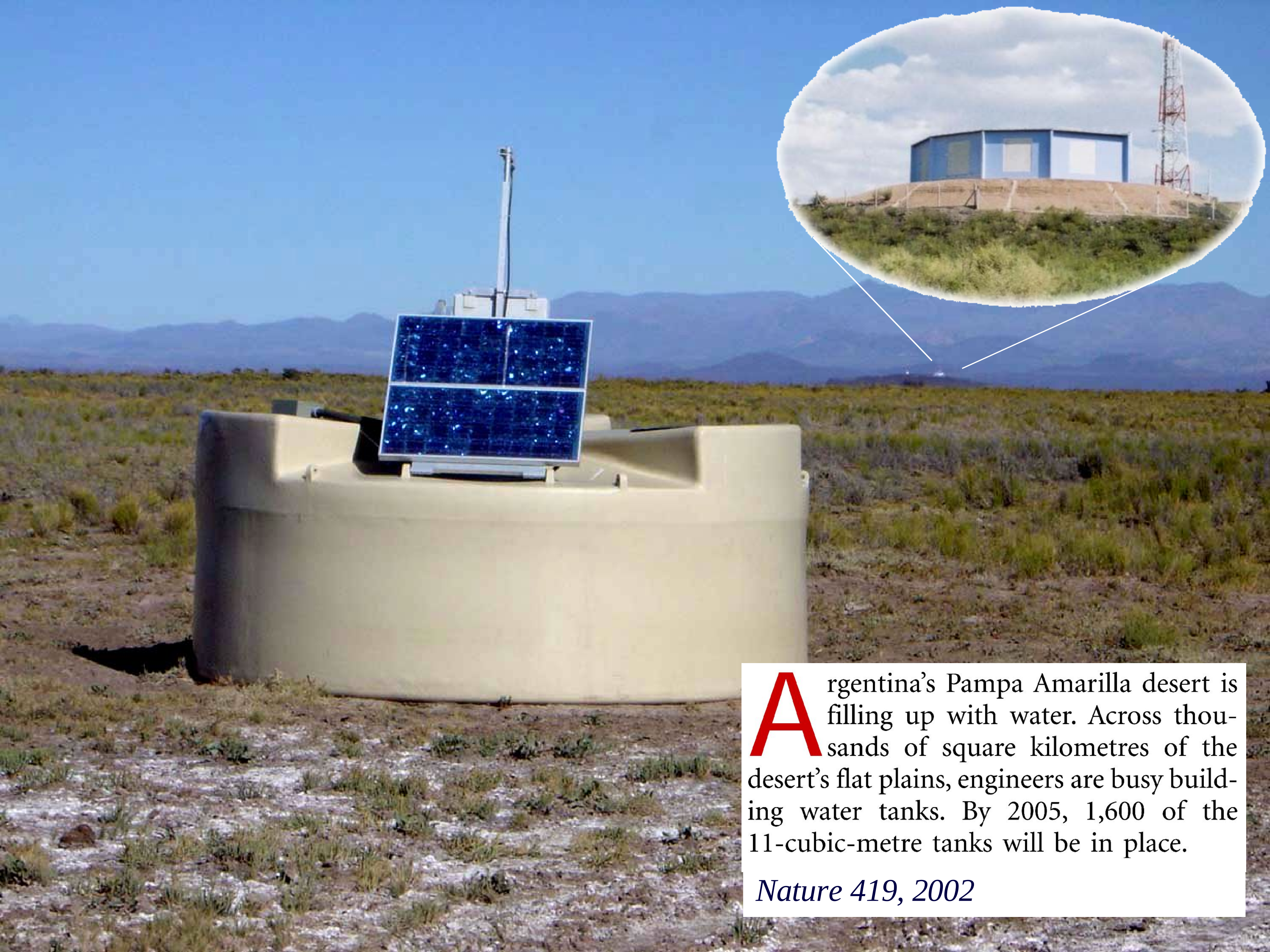




Auger Project

Hybrid measurement
1500 water tanks
3 Air fluorescence stations

Aperture ~ X30 AGASA

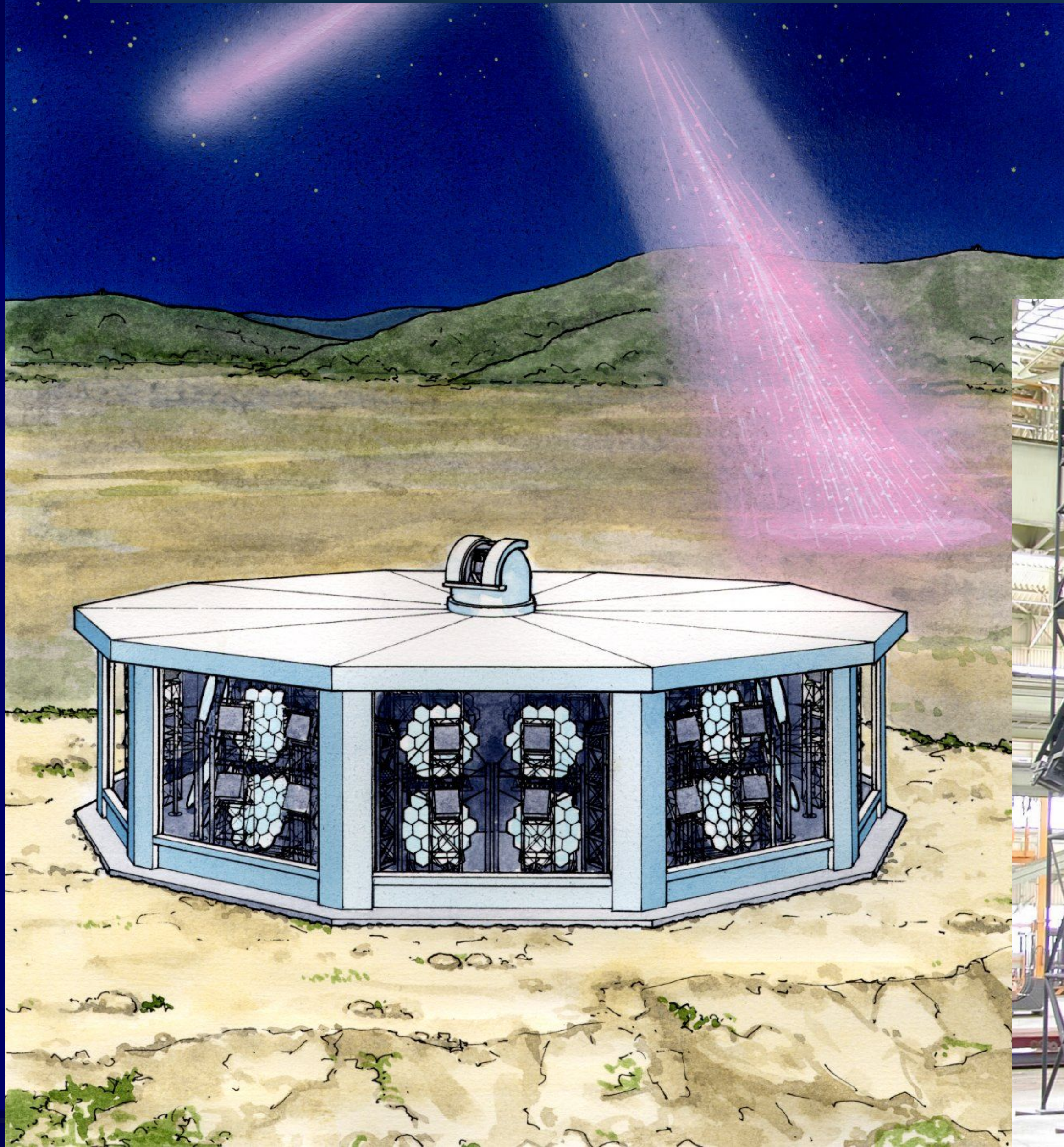


Argentina's Pampa Amarilla desert is filling up with water. Across thousands of square kilometres of the desert's flat plains, engineers are busy building water tanks. By 2005, 1,600 of the 11-cubic-metre tanks will be in place.

Nature 419, 2002

Telescope Array Project

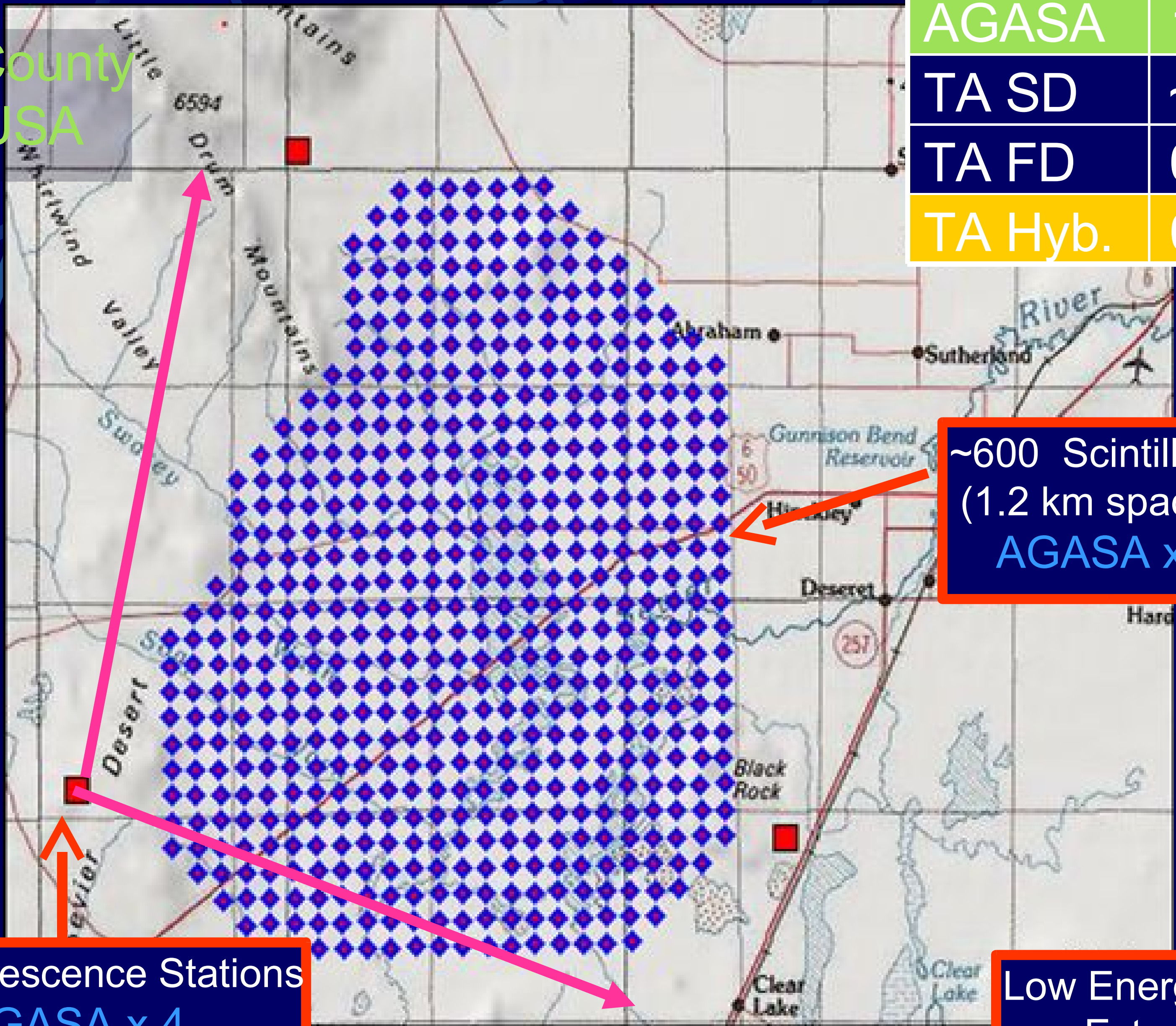
X10 AGASA



TA Detector Configuration

Exp	Res.
AGASA	1.6^0
TA SD	$\sim 1.0^0$
TA FD	0.6^0
TA Hyb.	0.4^0

Millard County
Utah/USA

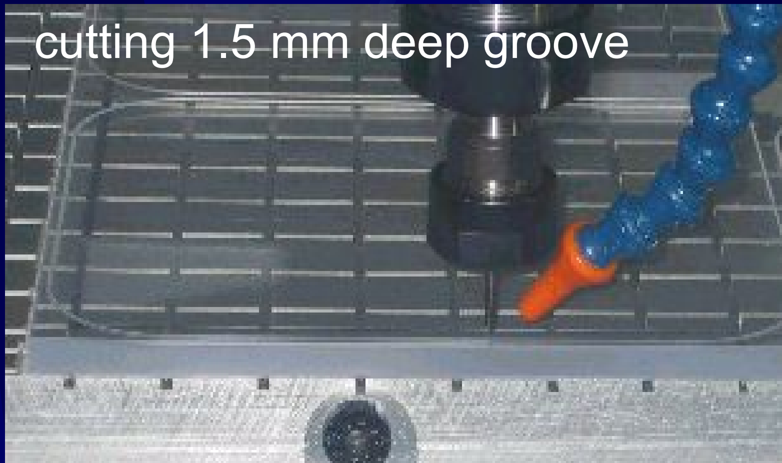


~600 Scintillators
(1.2 km spacing)
AGASA x 9

3 x Fluorescence Stations
AGASA x 4

Low Energy Hybrid
Extension

TA Scintillator Development



proto: 50 cm x 50 cm, 1cm thick
Wave Length Shifter Fiber readout
50 modules used in L3 for 2.5 yea

TA Telescope Development

Electronics
100 ns 14 bit AD conv.

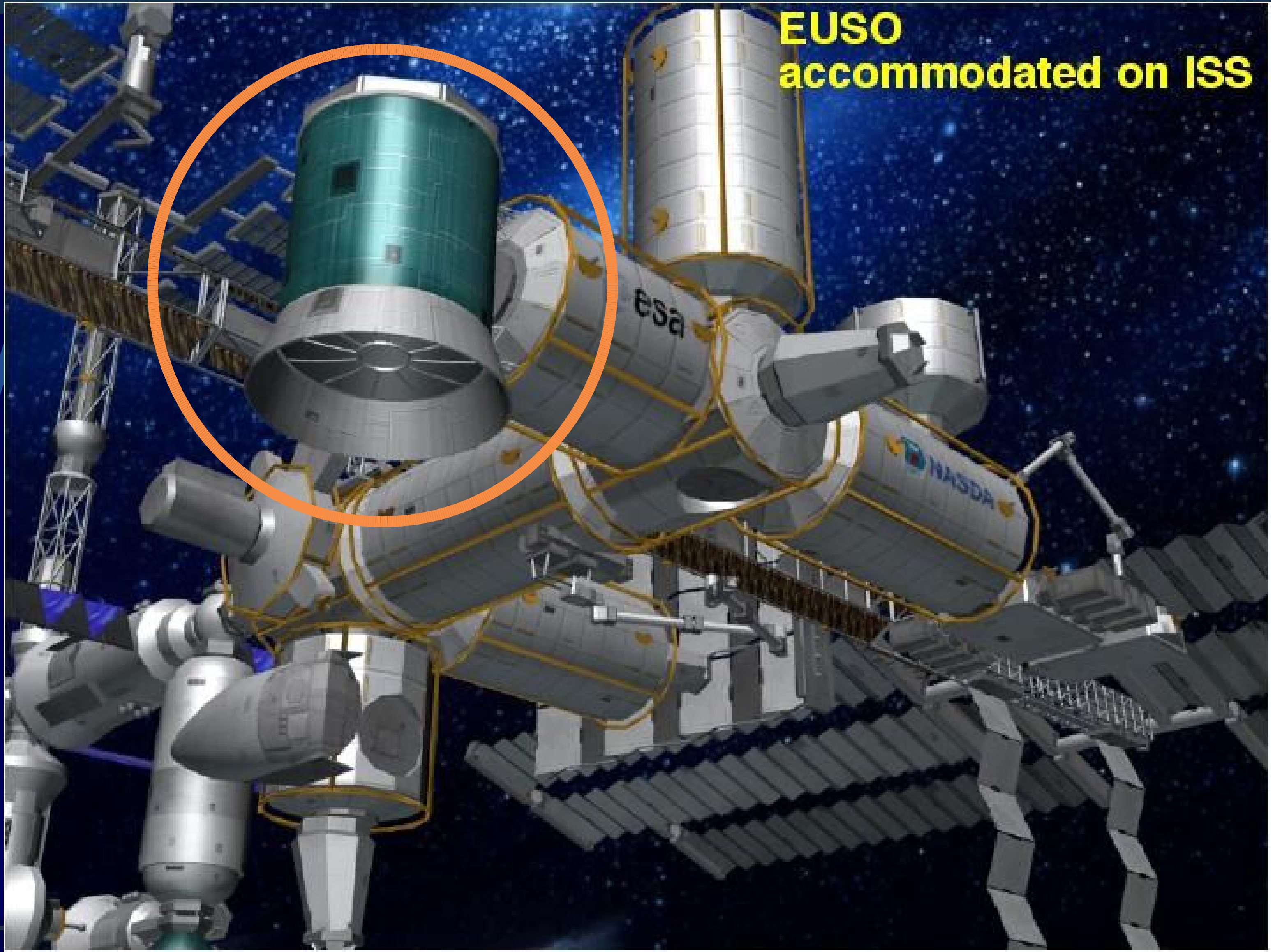
Signal recognition by FPGA

Imaging Camera *PMT Array*

Telescope *Φ Spherical Mirror*

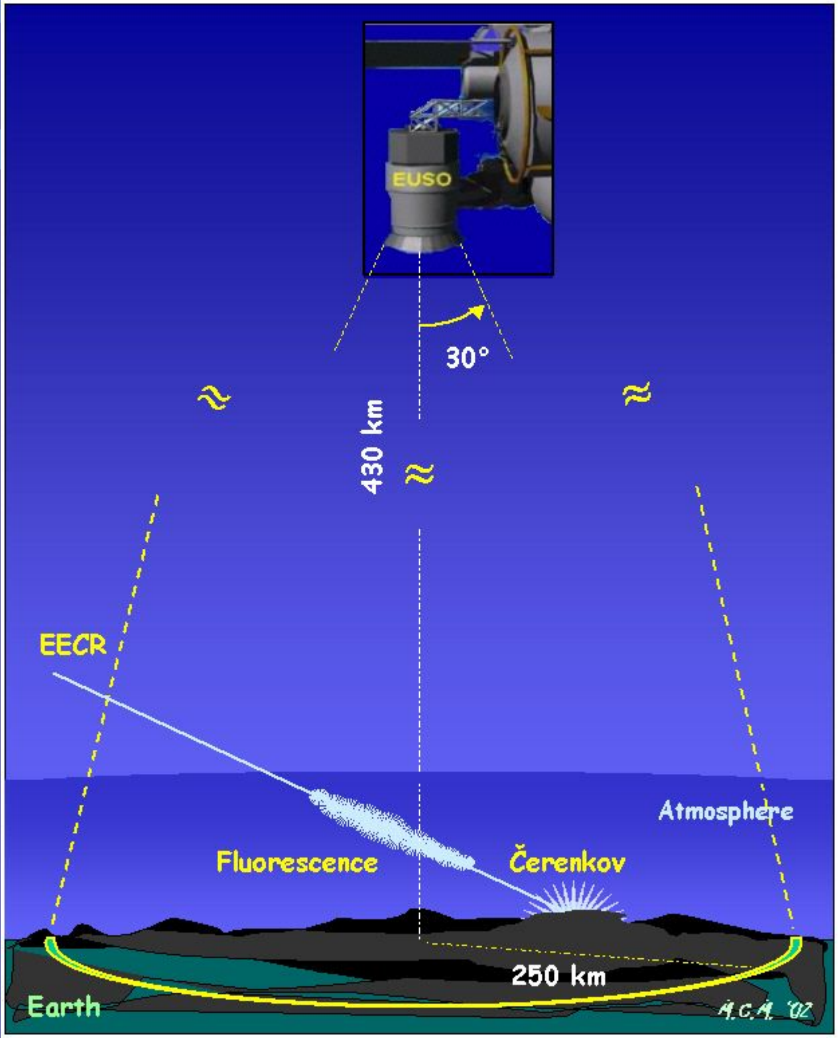
EUSO

Extreme Universe Space Observatory
x300, x3000 AGASA

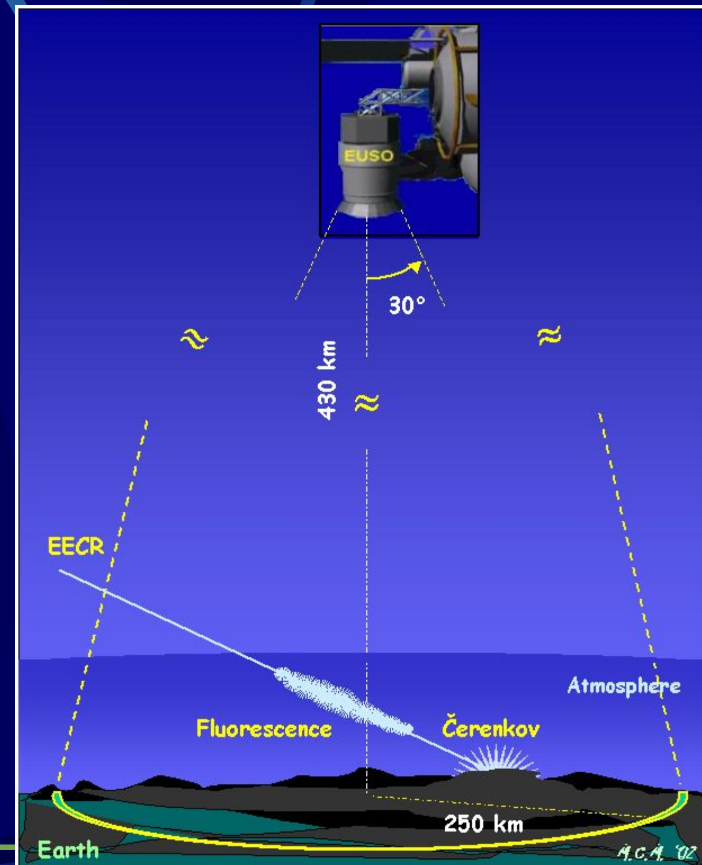


EUSO Concept

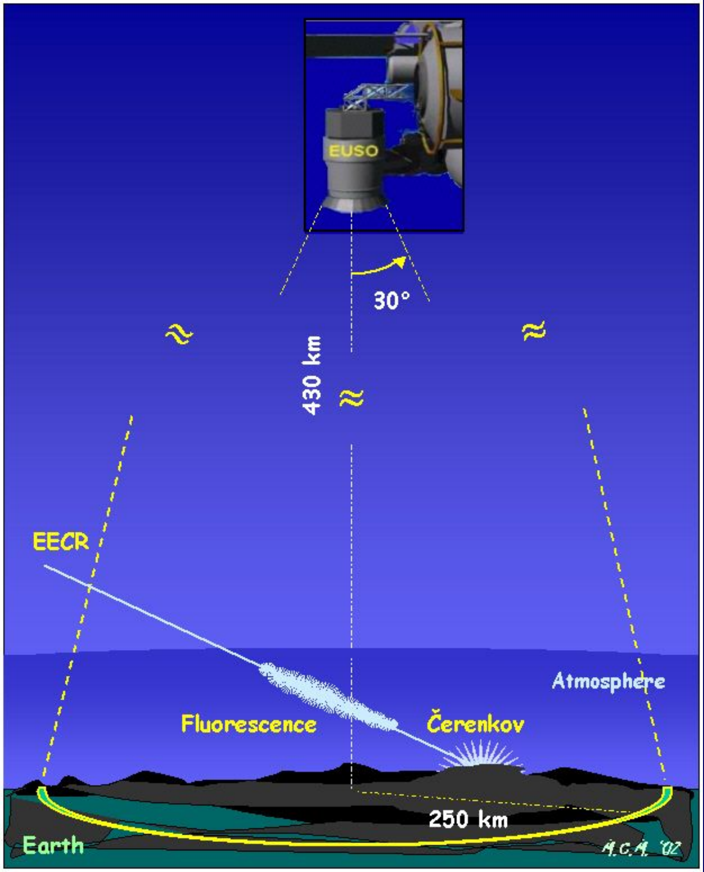
- Large Distance and Large F.O.V. Large Aperture
  - ~6x10^5 km^2 sr
    - Good Cosmic Ray detector
    - 3000 times sensitive to C.R. bursts
  - 1500 Giga-ton atmosphere
    - Good neutrino detector
- All Sky coverage
  - North and south skys are covered uniformly. sensitive to large scale anisotropy
- Complementary to the observation from the ground
  - Different energy scale and systematics
- Shower Geometry is well defined
  - Constant distance from detector

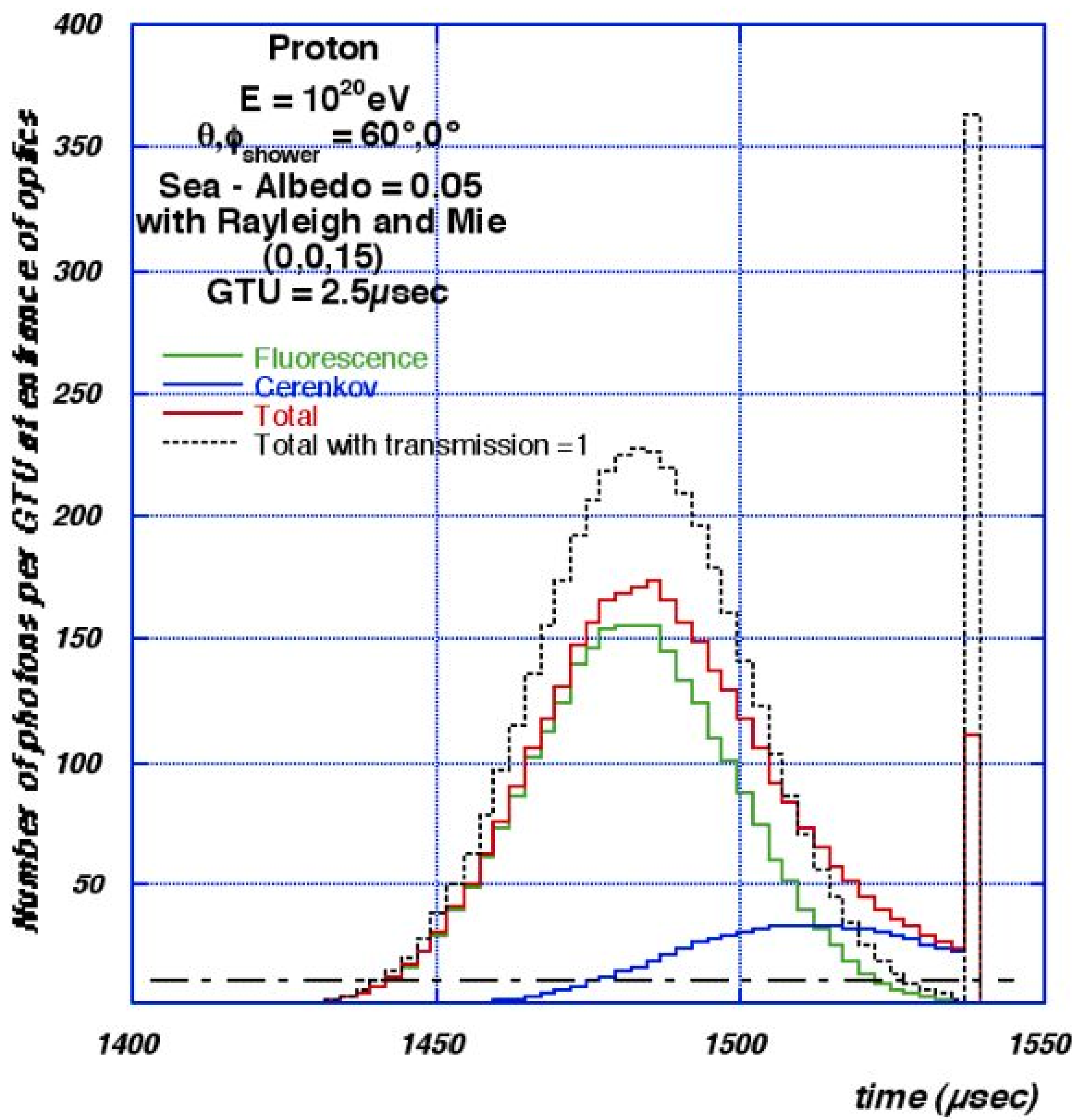


Effective Area ~200,000km^2 1/2 Deutschland (360,000km^2)

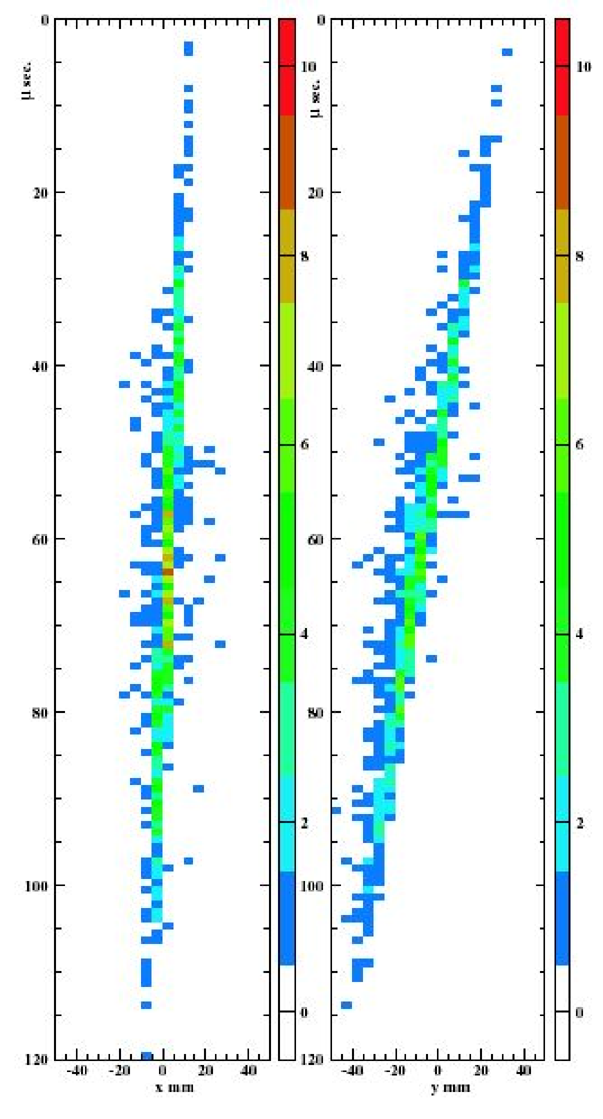


Signal of photons

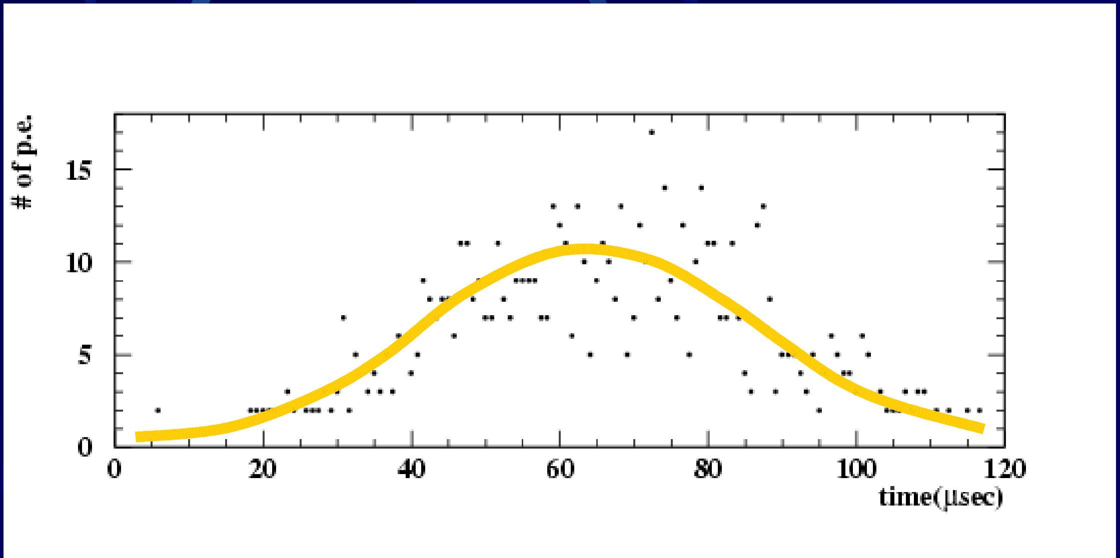




Shower Track Image (M.C. Simulation)

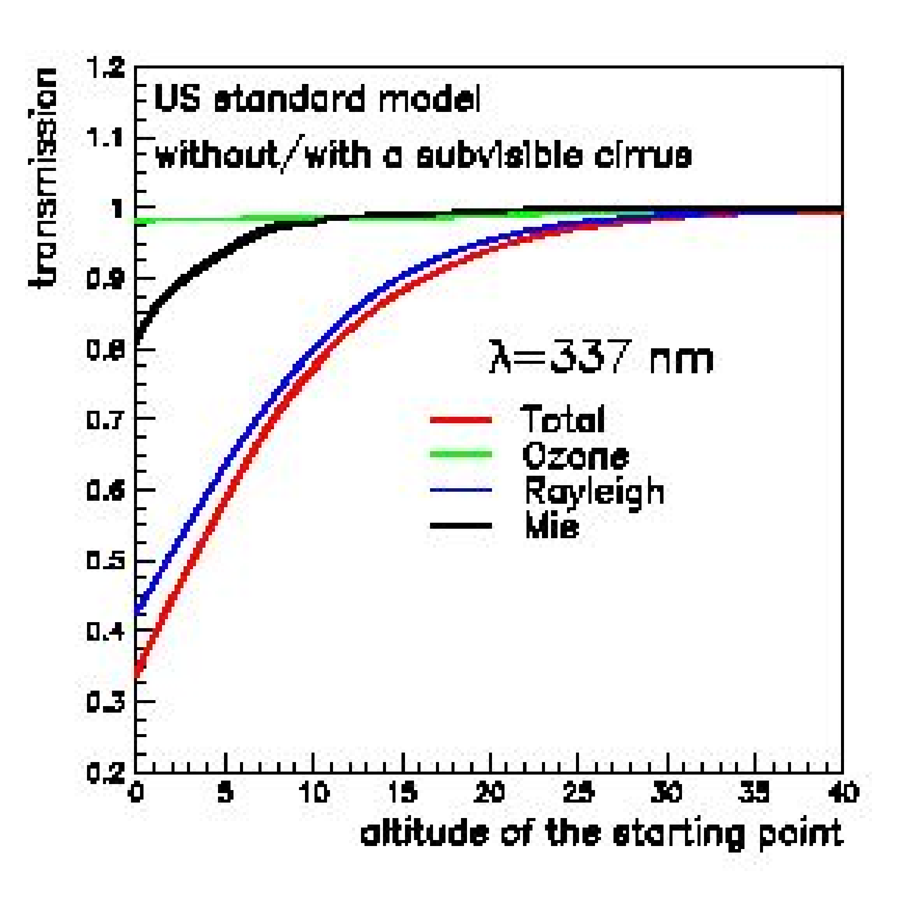


10^{20}eV shower
zenith angle =60 degree
Total signal ~ 700p.e.

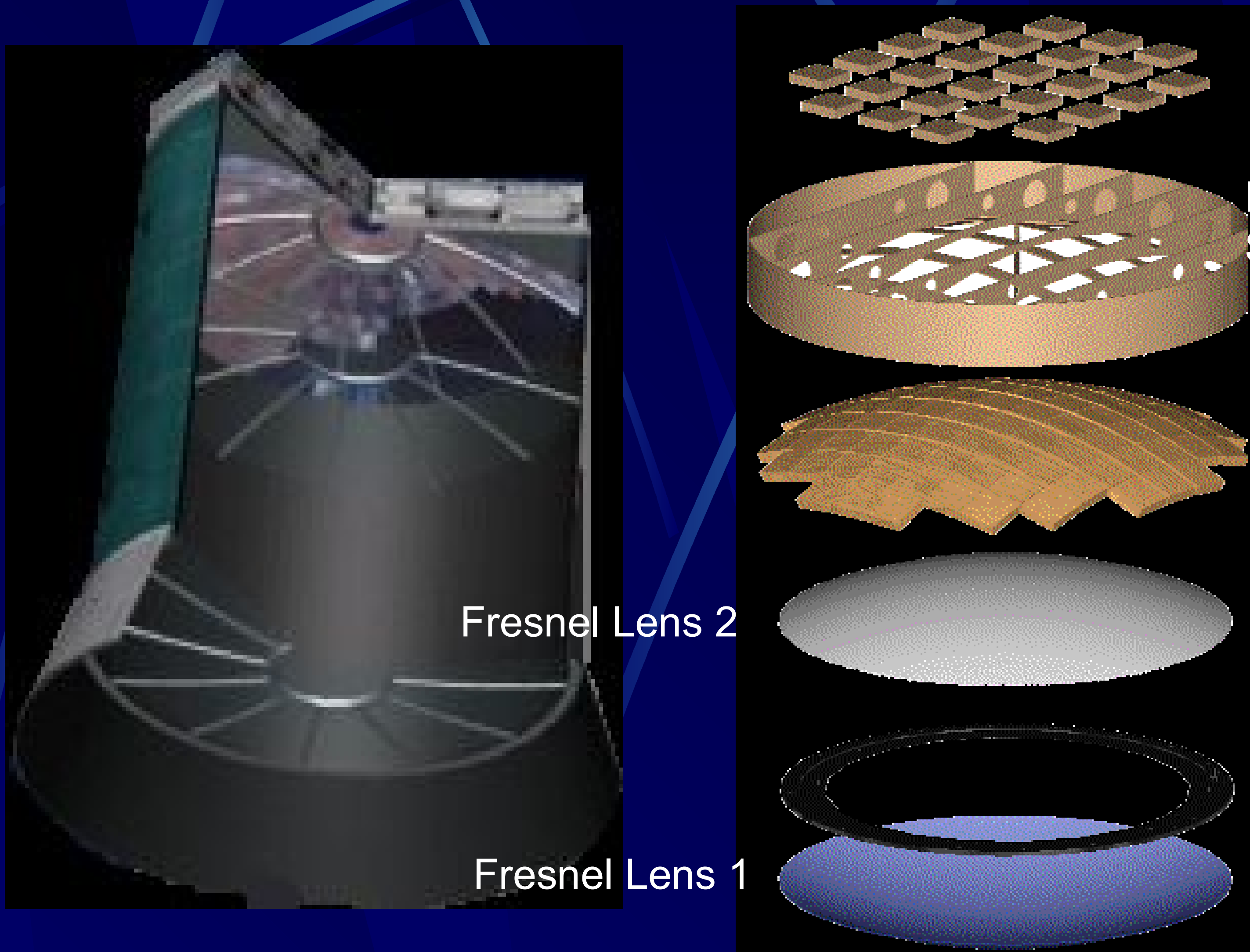


Atmospheric Transmission
better than ground based air fluorescence detector

- Small effect by Mie scattering
  - Worst ~20%
  - Cloud go down 2~3km altitude in the night
- Smaller Absorption in absolute value
  - ~ x0.3
  - Ground based x0.1~0.01

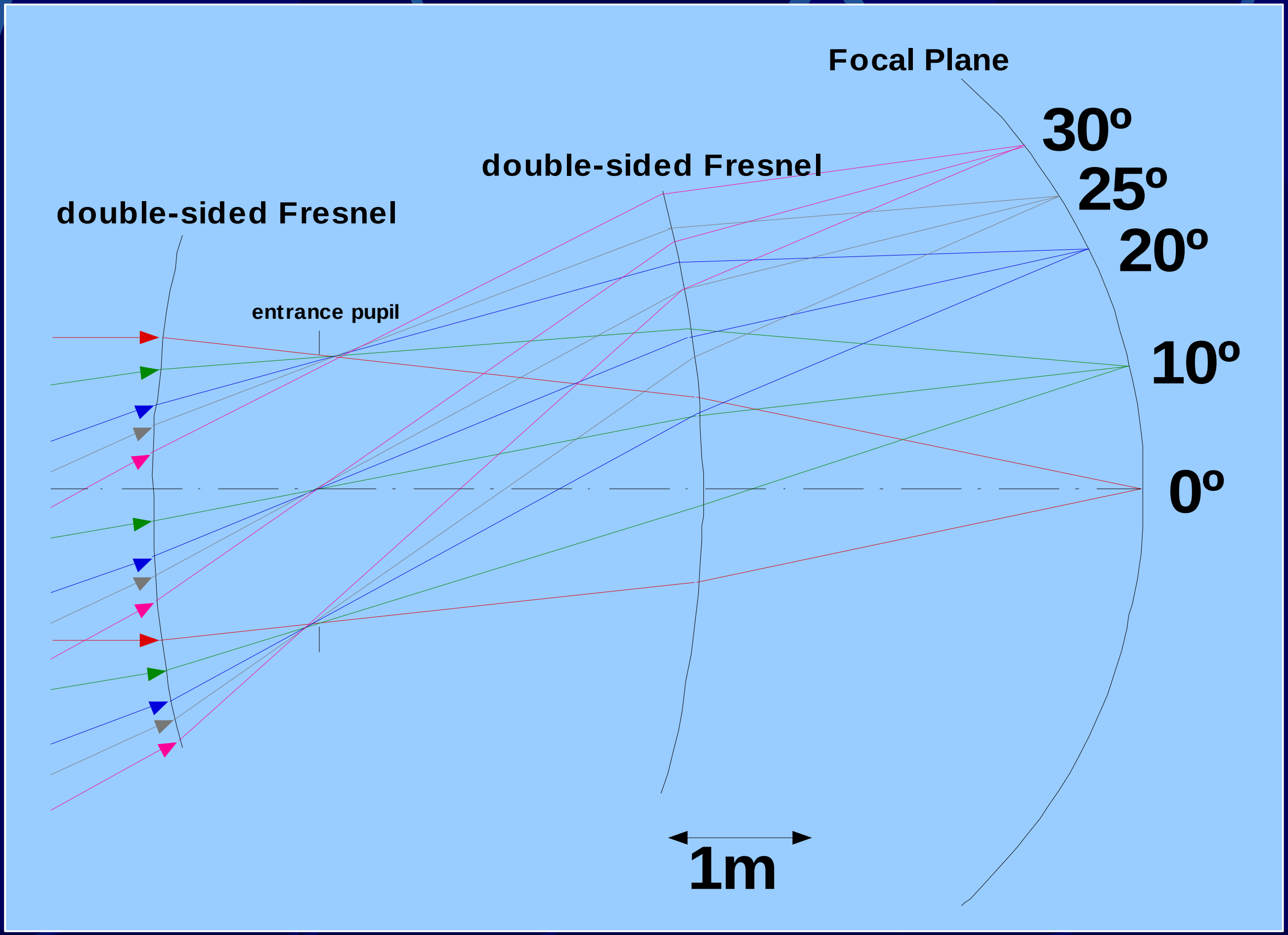


Detector Element

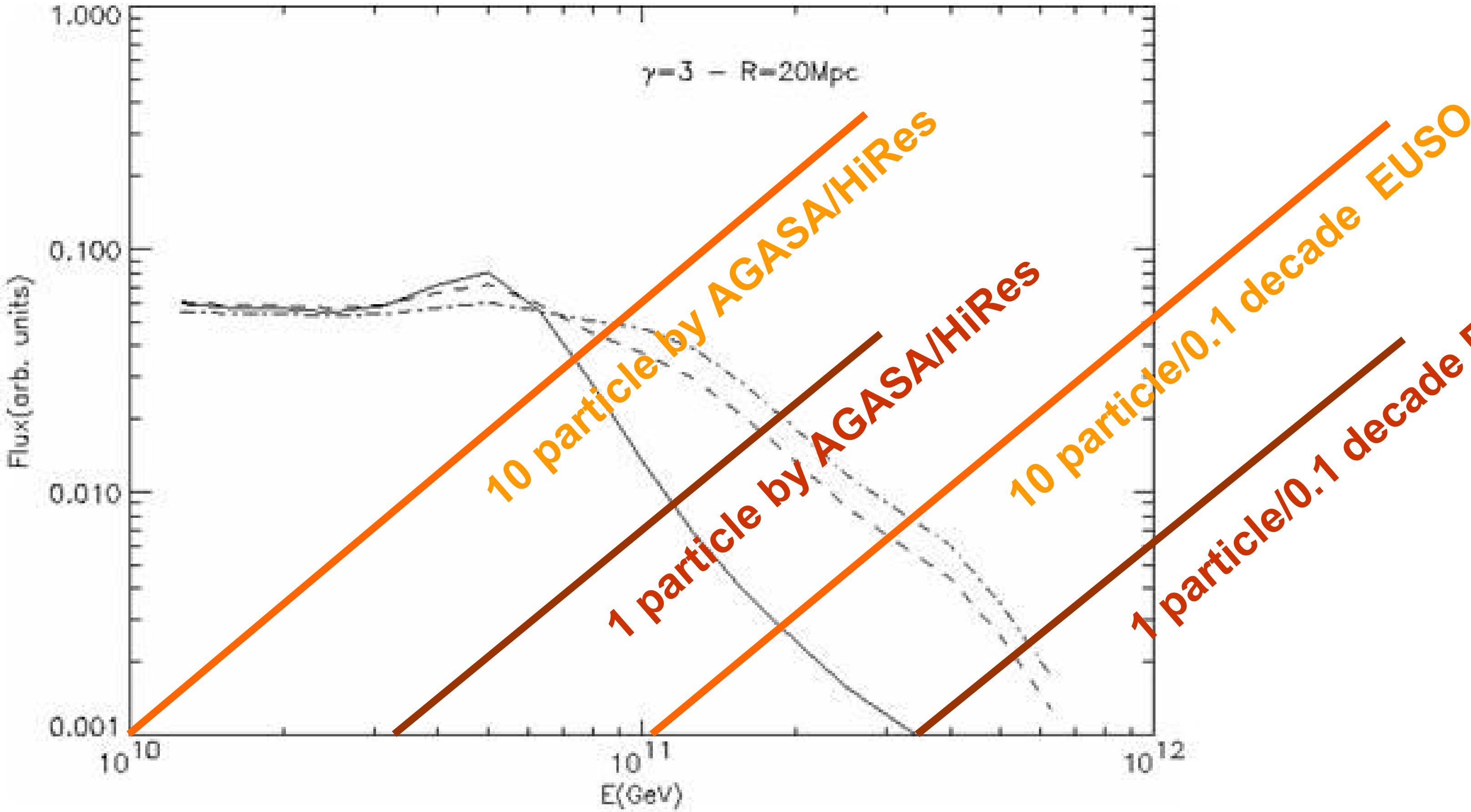


Euso Optics

Wide Angle and High Resolution
F.O.V. +-30° δθ 0.1°



What the GZK effect tells us about the source distribution (in the absence of strong magnetic deflection)



Observable spectrum for an E^{-3} injection spectrum for a distribution of sources with overdensities of 1, 10, 30 (bottom to top) within 20 Mpc, and otherwise homogeneous.

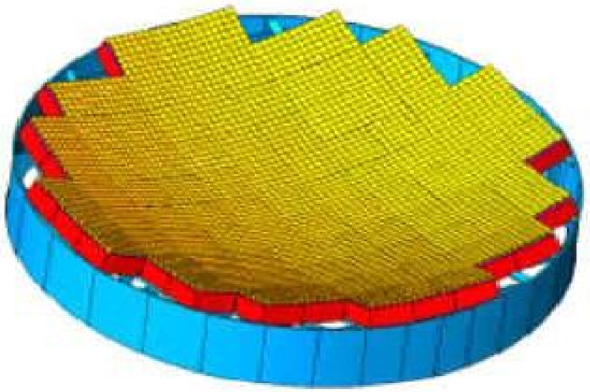
Blanton, Blasi, Olinto, Astropart.Phys. 15 (2001) 275

Focal Surface Detector Baseline design

THE FOCAL SURFACE DETECTOR HIERARCHICAL VIEW

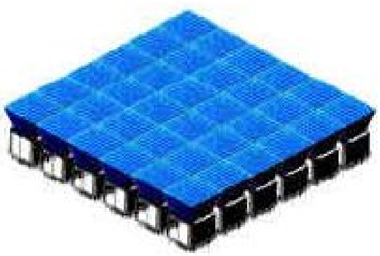
Focal surface detector

(89 macrocells = 205056 pixels)



Macrocell

(6x6 basic units = 2304 pixels)



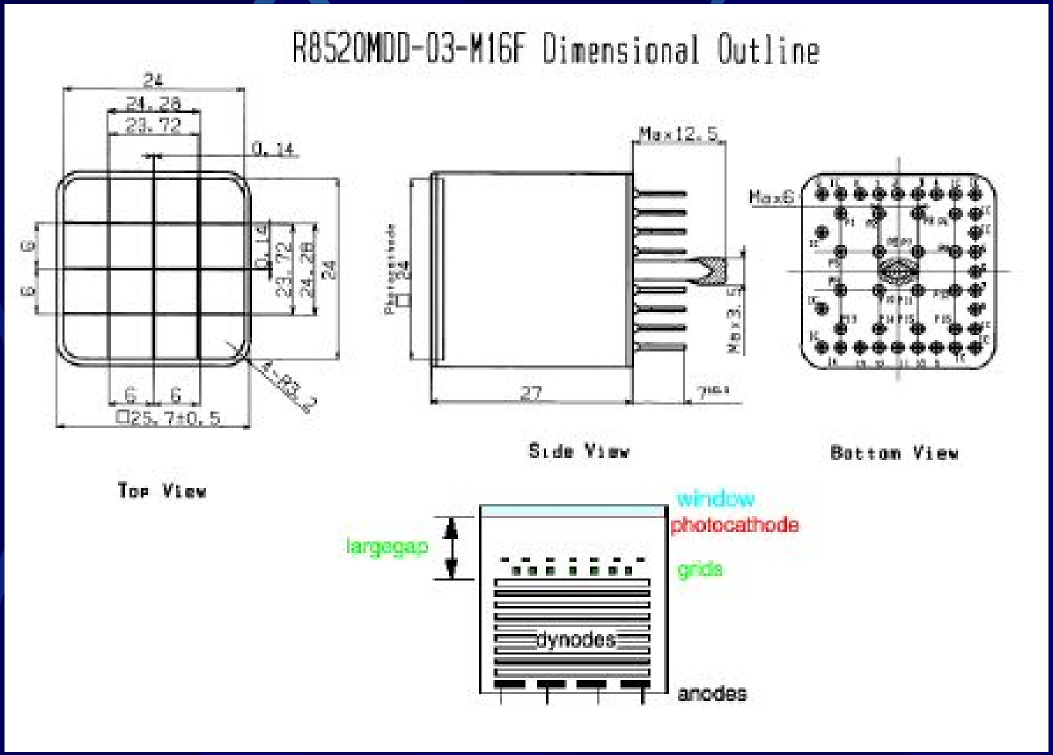
Basic unit

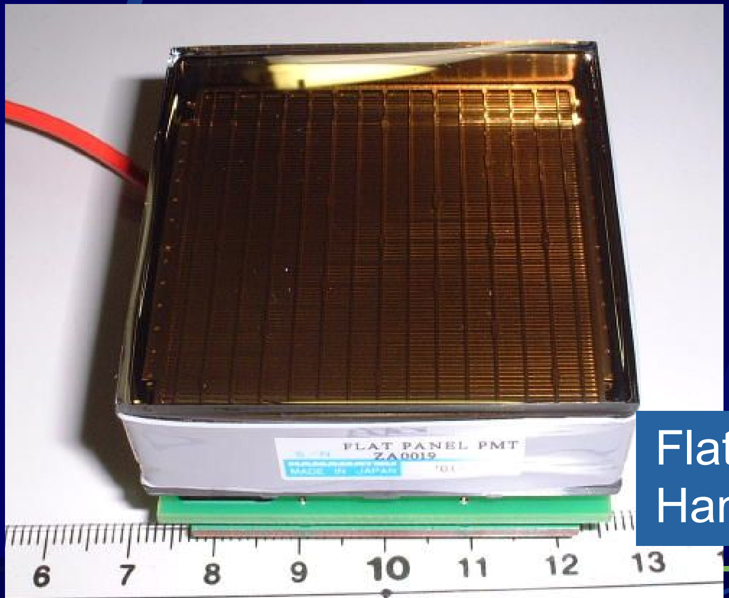
(8x8 pixels)

Hamamatsu MAPMT

New Development by Riken Group
Higher Photon Collection efficiency
R8900-M16/M25 (45% 85%)

R7600-M64

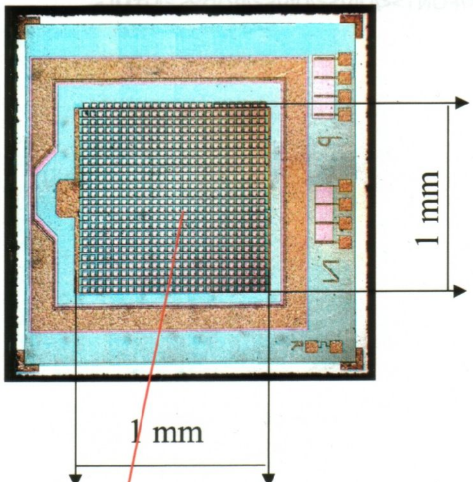




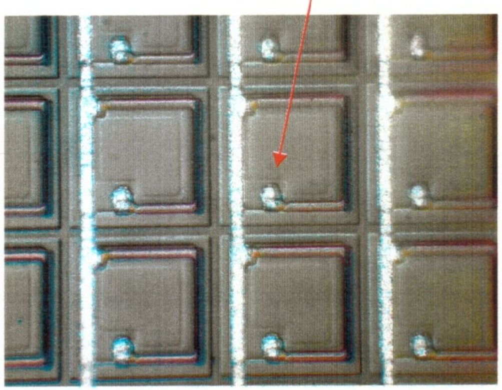
Flat Panel MAPMT
Hamamatsu H8500

EUSO

Microphotography of the SiPM

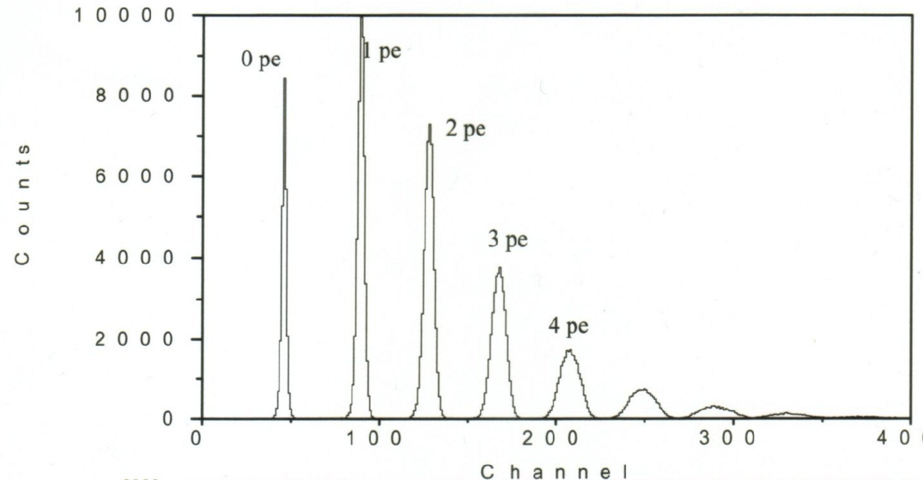


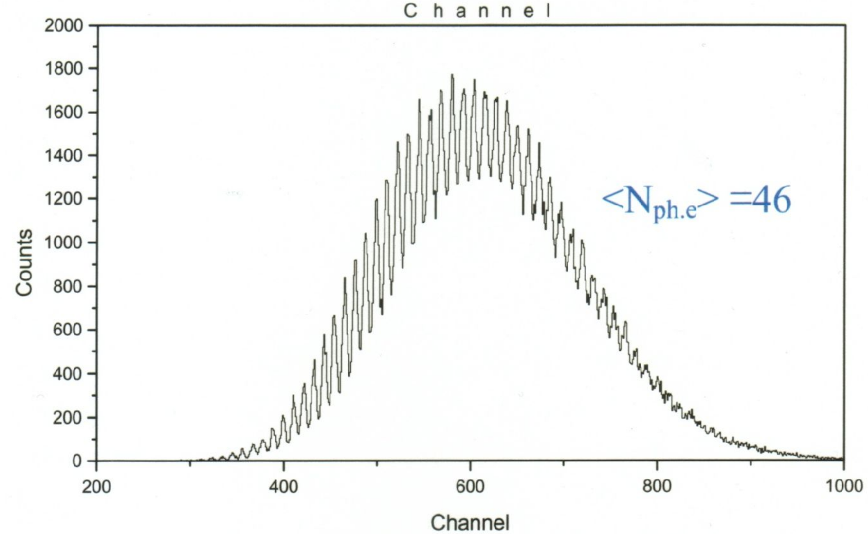
SiPM



Pixels of the SiPM

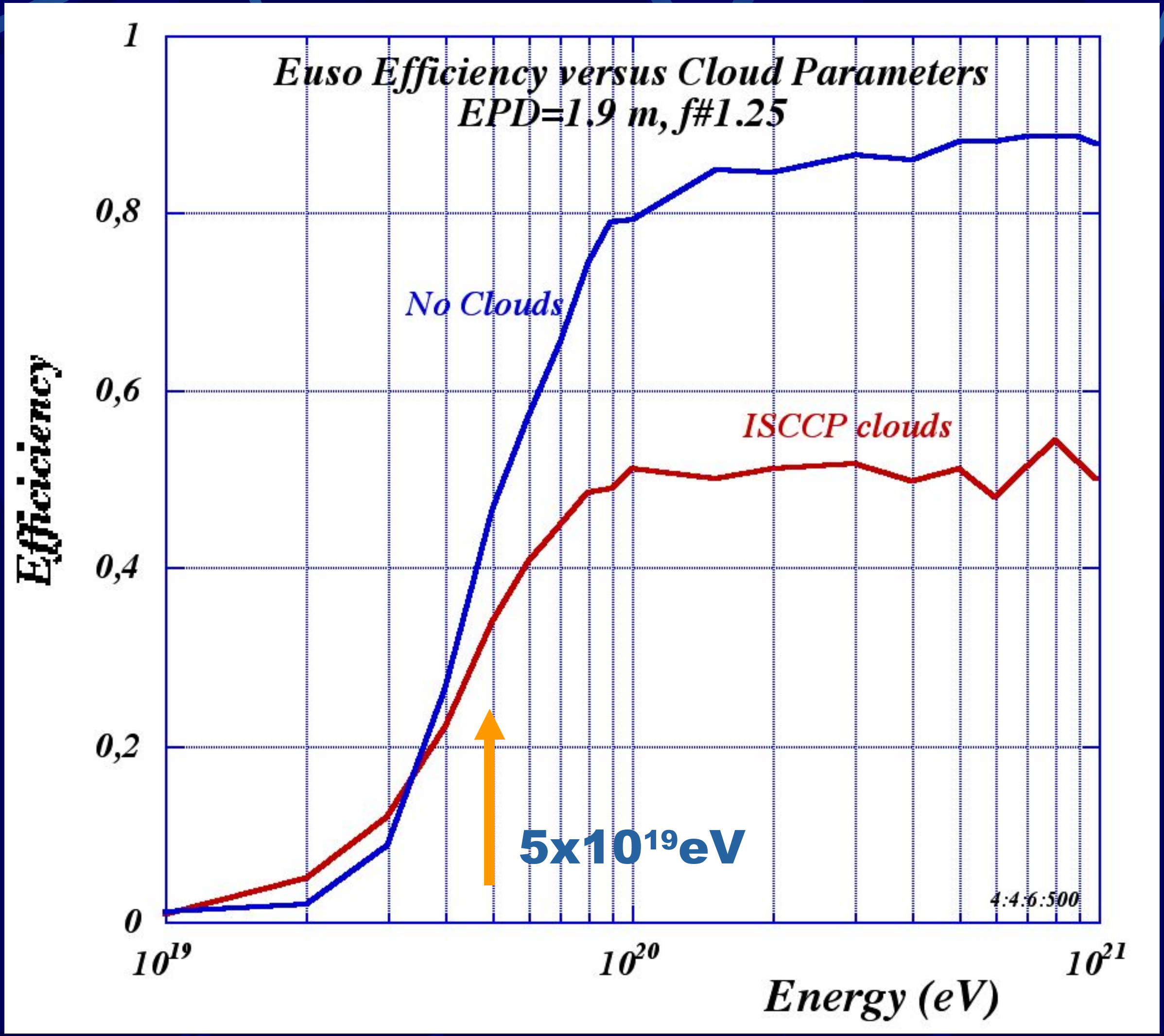
Single photoelectron (single pixel) spectra



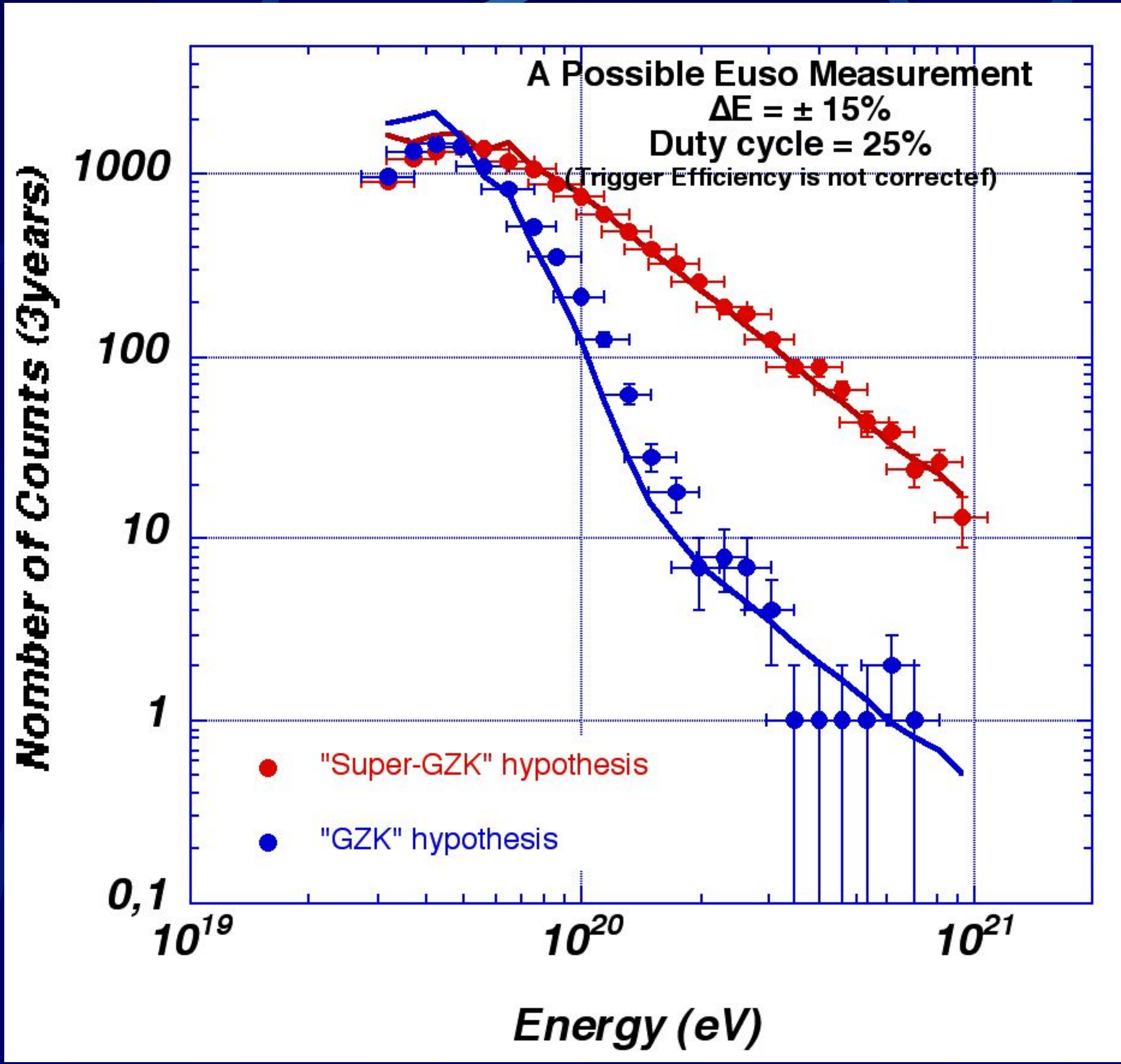


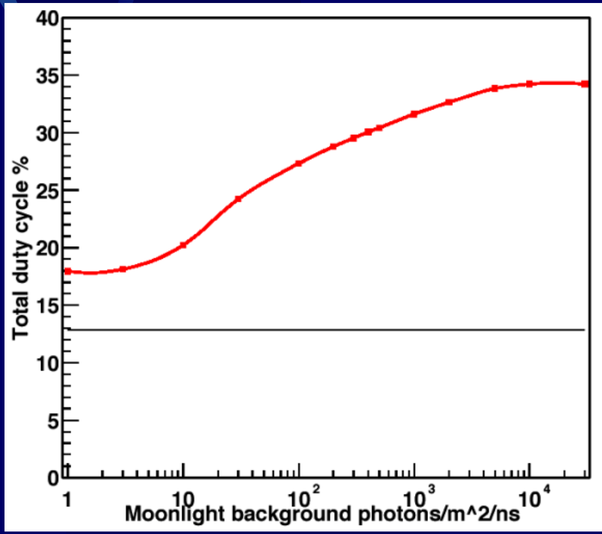
- SiPM consists of a large number of pixel photoelectron counters with binary readout for each pixel, working as analogue device
- signal uniformity from pixel to pixel is quite good

Energy Threshold

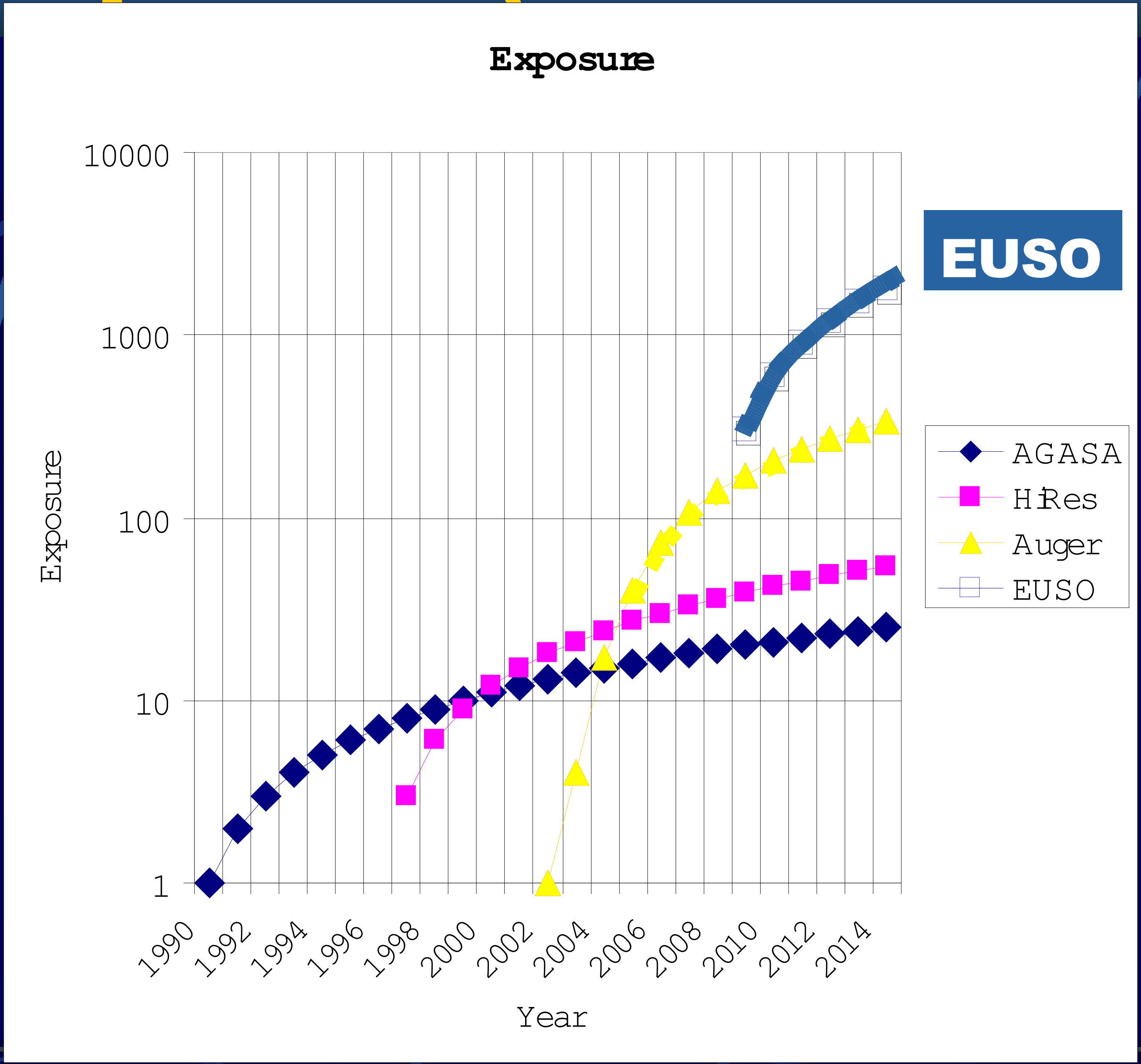


Possible EUSO measurement

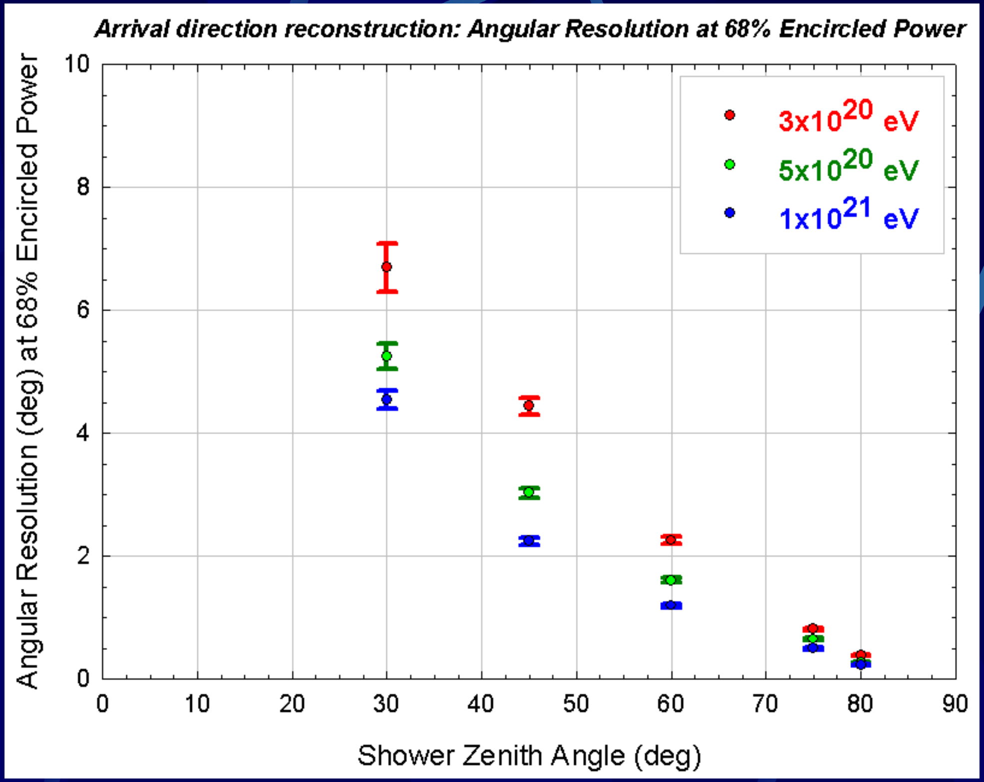


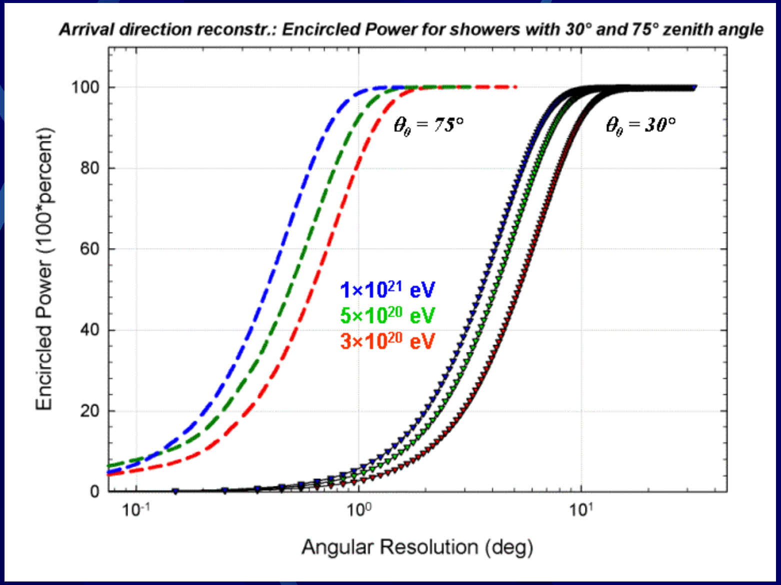


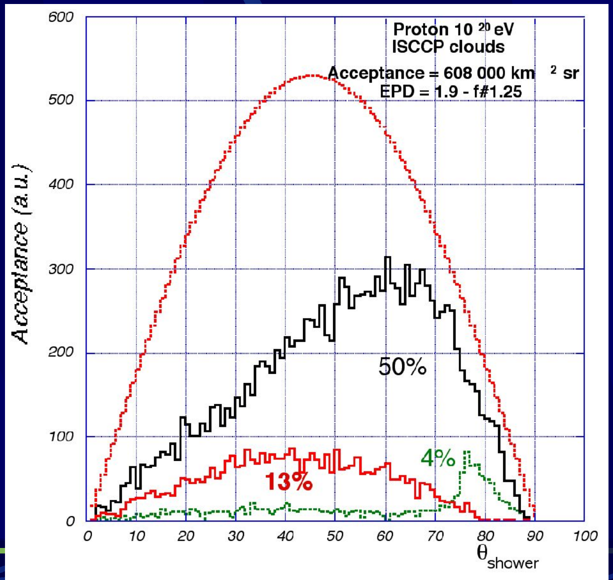
Exposure (AGASA unit)



Angular Resolution



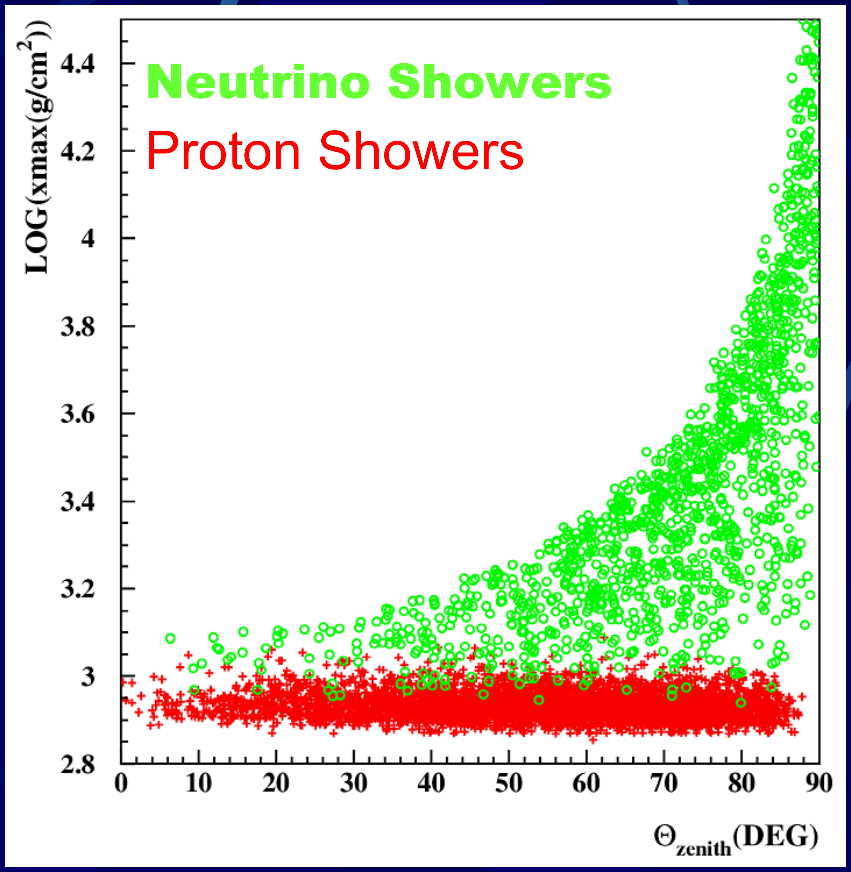




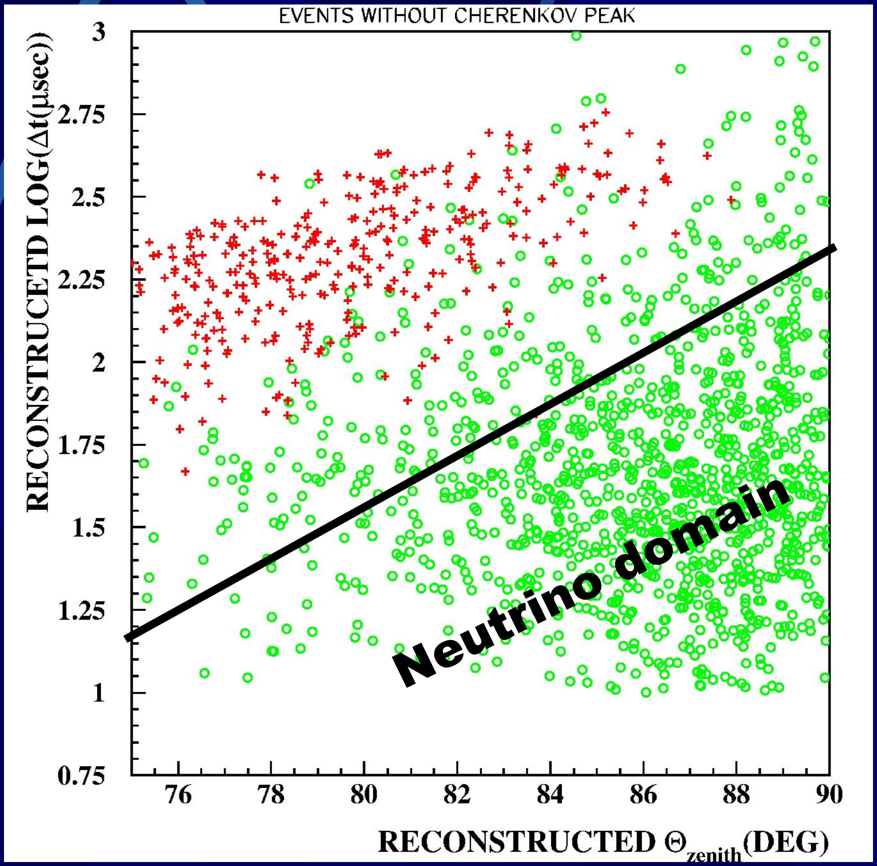
Neutrino Detection capability

Just using observables
No need for Cherenkov ref.

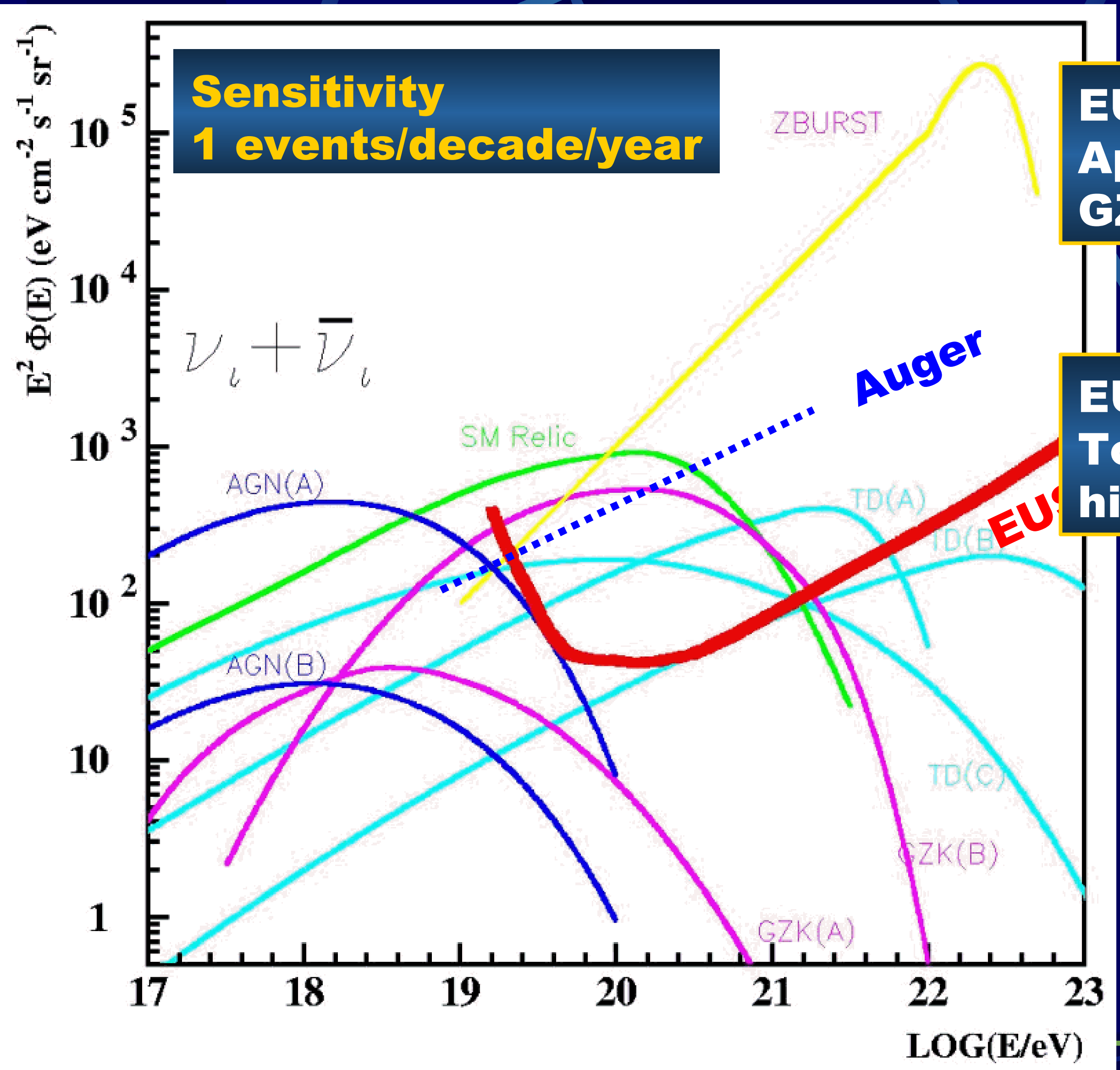
Zenith Angle vs. Xmax



Zenith Angle vs. Shower Time width



Neutrino sensitivity (downward neutrino)



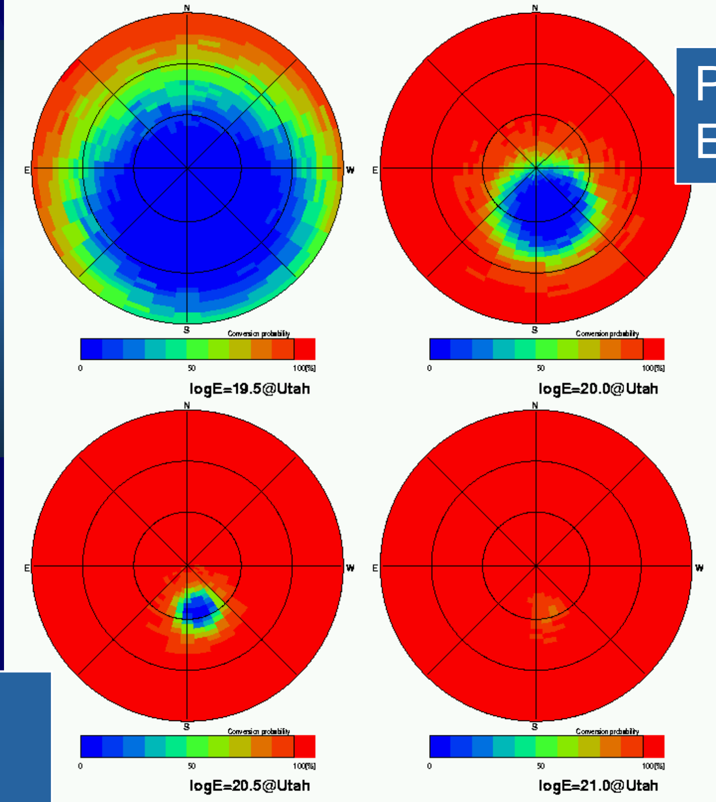
EUSO has 10 times larger Aperture than Auger above GZK energy

EUSO is sensitive Z-Burst, Top Down Models and highGZK flux.

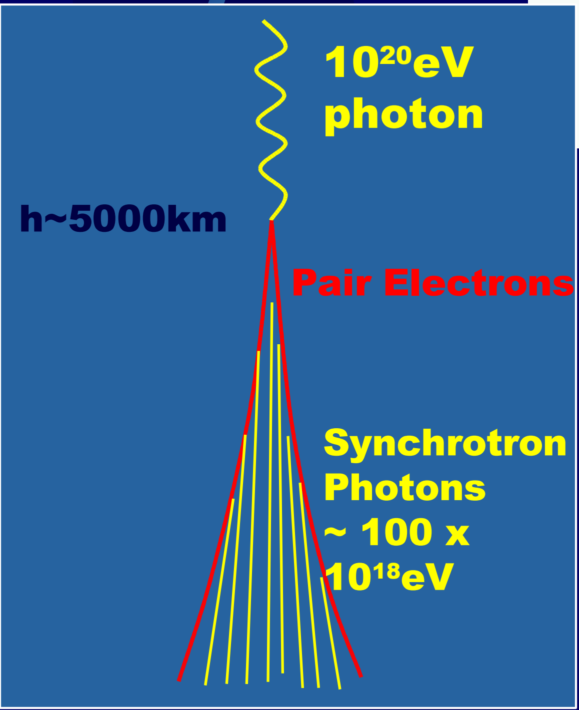
Gamma Ray Identification

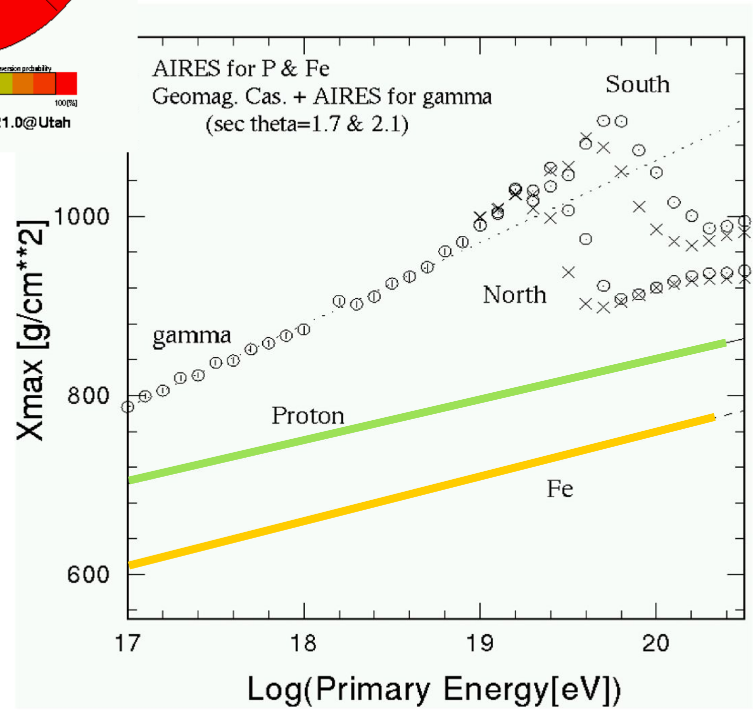
Geomagnetic Cascade

Pair Production prob.
Energy & Direction



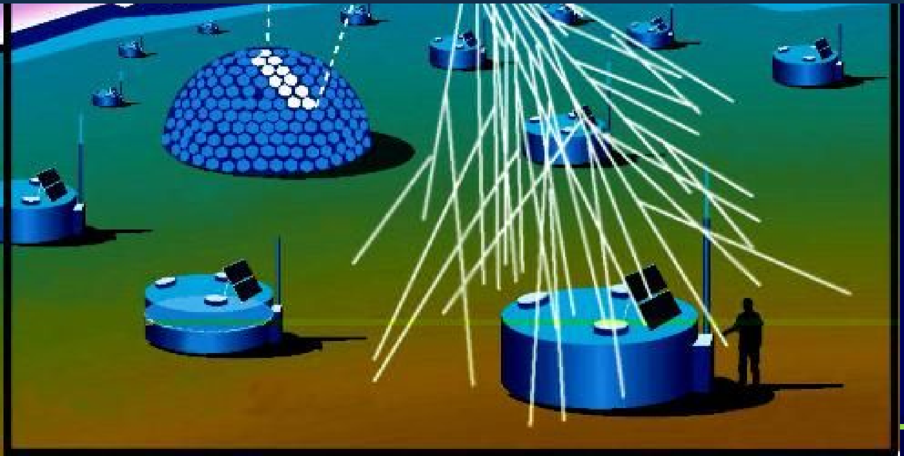
Xmax distribution

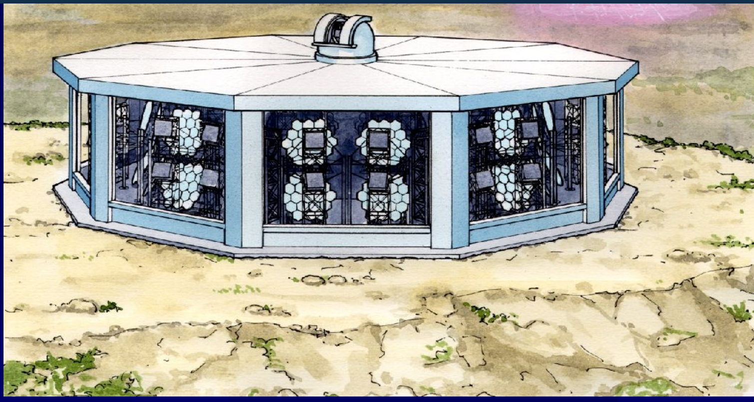




New Projects for UHECRs

Golden period of UHECR observation!!



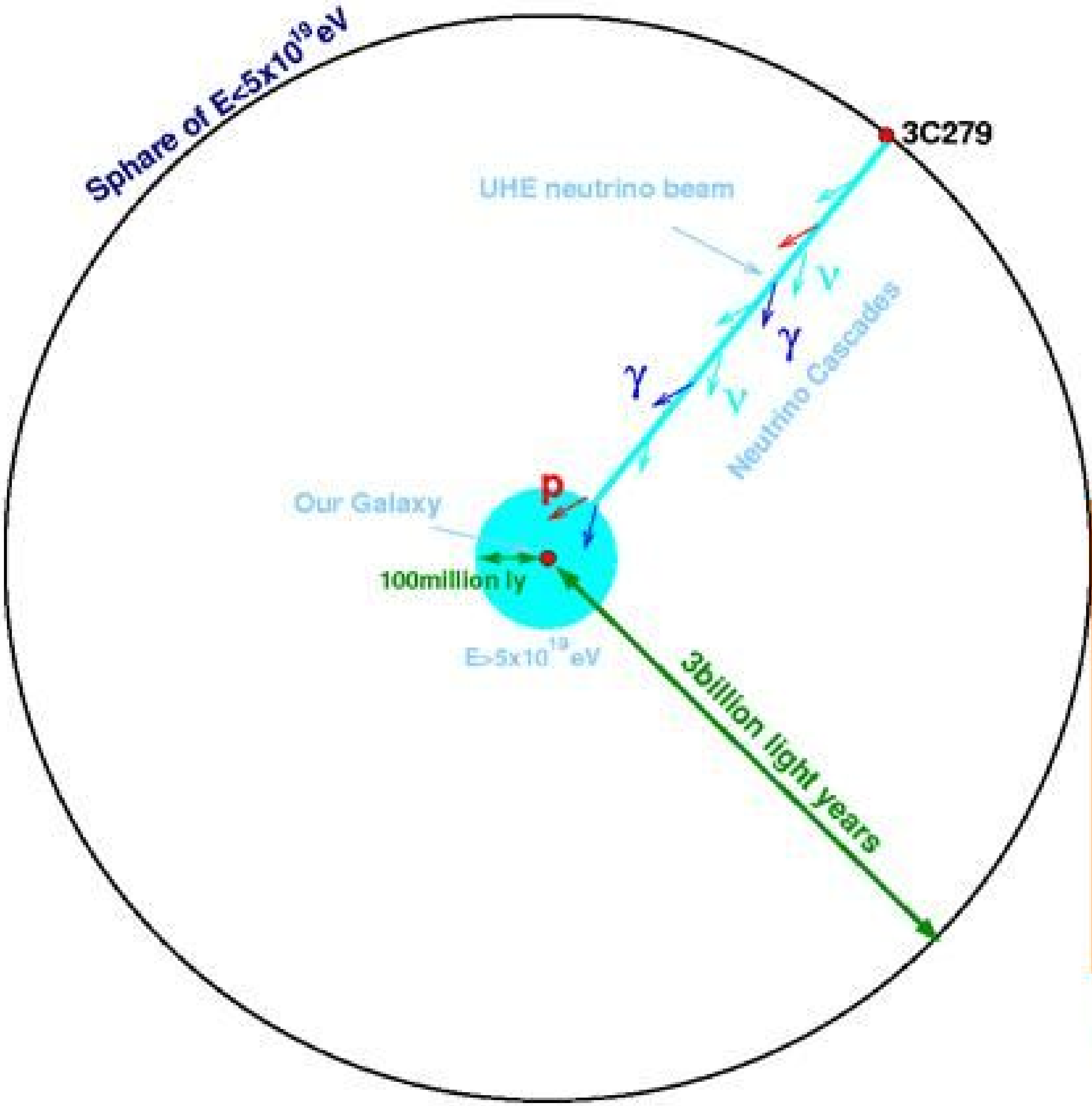


EUSO in ISS

Accommodation in ISS

Cosmic Ray observations

The Z-burst effect



A Z-boson is produced at the neutrino resonance energy

$$E_\nu^{res} = 4 \cdot 10^{21}\,\text{eV}\left(\frac{\text{eV}}{m_\nu}\right)$$

"Visible" decay products have energies 10-40 times smaller.

Main problems of this scenario:

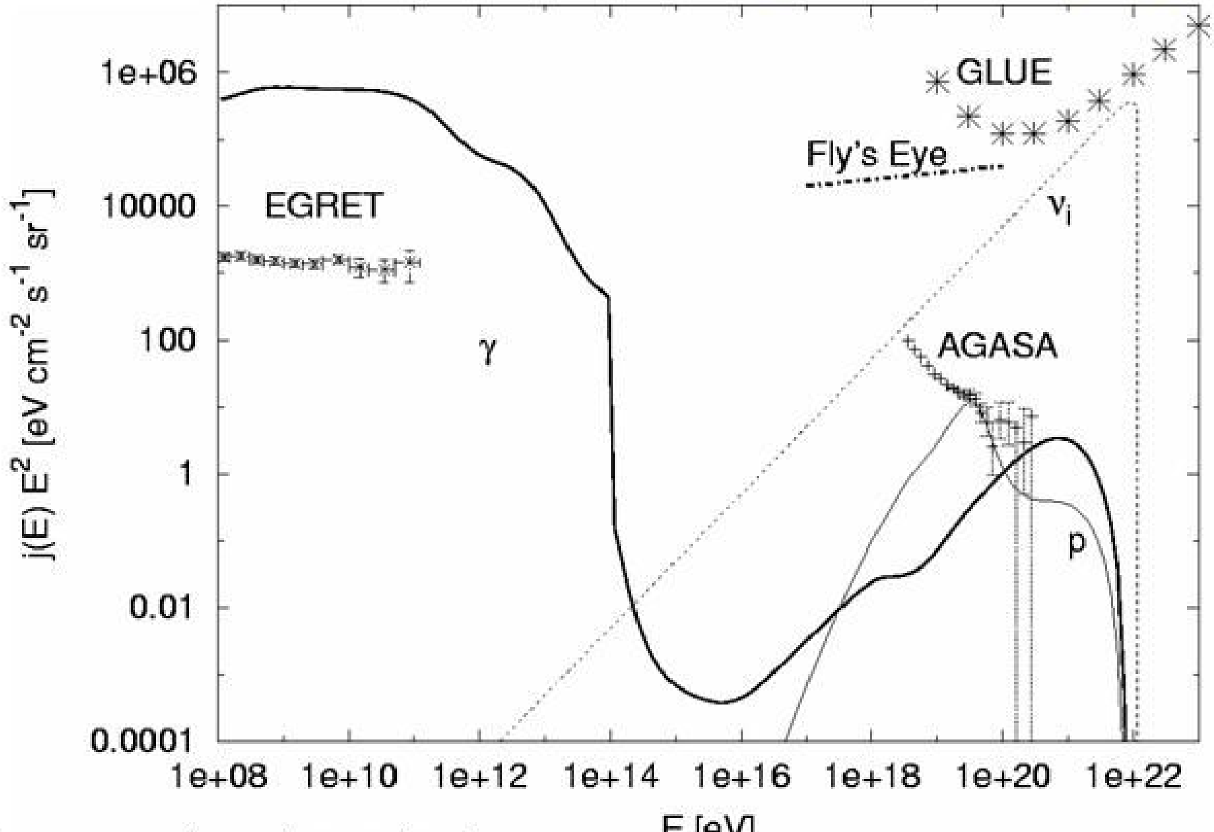
* sources have to accelerate up to ~10^{23}eV.
* γ-rays emitted from the sources and produced by neutrinos during propagation tend to over-produce diffuse background in GeV regime.

Fargion, Weiler, Yoshida

By G.Sigl

Z-burst model violates EGRET diffuse gamma flux (G.Sigl)

The Z-burst mechanism: Sources emitting neutrinos and γ-rays



Kalashev, Kuzmin, Semikoz, Sigl, PRD 65 (2002) 103003

Sources with constant comoving luminosity density up to z=3, with E^{-2} γ-ray injection up to 100 TeV of energy fluence equal to neutrinos, m_ν=0.5eV, B=10^{-9} G.

Optimistic Z-burst model

(Only neutrino produced at sources) by G.Sigl and D.Semikos