The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2246-32

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

The JEM-EUSO mission

Gustavo MEDINA TANCO
Universidad Nacional Autonoma de Mexico
Mexico

The JEM-EUSO Mission

Gustavo Medina-Tanco
Instituto de Ciencias Nucleares, UNAM

UHECR field is at a critical point

Auger is at its peak of scientific output (and of cost-benefit ratio?)

From 2010 to 2011 (ICRC2011) it increased its exposure for most scientific output by ~60%

But:

2011: from 21,000 to 28,000 → 33%
2012: from 28,000 to 35,000 → 25%
2013: from 35,000 to 42,000 → 20%
2014: from 42,000 to 49,000 → 17%
2015: from 49,000 to 56,000 → 14%
2016: from 56,000 to 63,000 → 12%

+ aging

Auger North has been canceled

We need in the next few years a detector at least an order magnitude larger in exposure

What options for growth from $3x10^3$ to 10^5-10^6 km^2 ?

Ground detectors → Moderate technological challenge
Well known technique
Logistical nightmare → **Limited area**

Space detectors → New technological challenges
Known technique (FD)
Potentially huge area

JEM-EUSO mission

- First **space observatory** for extreme energy astroparticles
- Objectives: extreme energy cosmic rays, photons & neutrinos
    - CHARGED PARTICLE ASTRONOMY
- Instantaneous aperture: up to ~10^6 km^2
- Operational prototype of a new technique

JEM-EUSO instrument

HIGH COMPLEXITY SPACE MISION (TECHNICAL & LOGISTICAL)

- Refractor **telescope**
- Fresnel lenses (largest ever for space applications)
- Wide Field of View: ± 30 deg
- Active control of lenses due to temperature changes
- Spectral band: 200-400 nm
- Dimensions: 2.70 m diameter x 4 m length
- Mass: 2 tn
- Power consumption: 1 kW
- Atmospheric monitoring system: LIDAR + IR camera
- Focal surface: **5600 multi-anode PMT** (64 pix)
- Operation mode: nadir and/or inclined
- Expansible structure (telescopic masts)
- Deployment @ **ISS** (400 km of height)
- Launcher: **H2** + **HTV**
- Launching date: Dec 2016 / Jan 2017

JEM-EUSO Collaboration

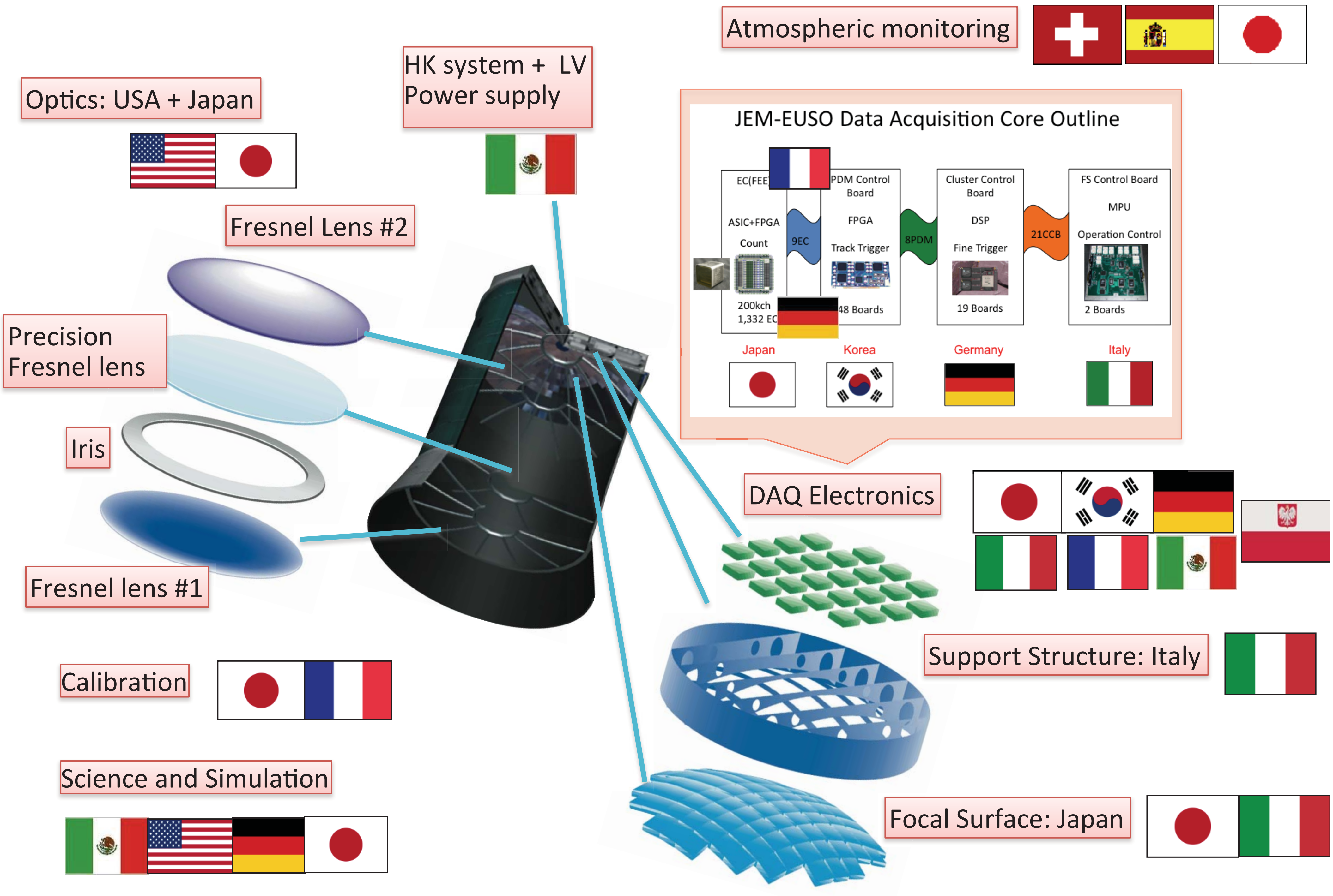
International effort

Japan, USA, Russia, France, Germany, Italy, **México**, Korea, Switzerland, Spain,
Slovakia, Poland, Bulgary

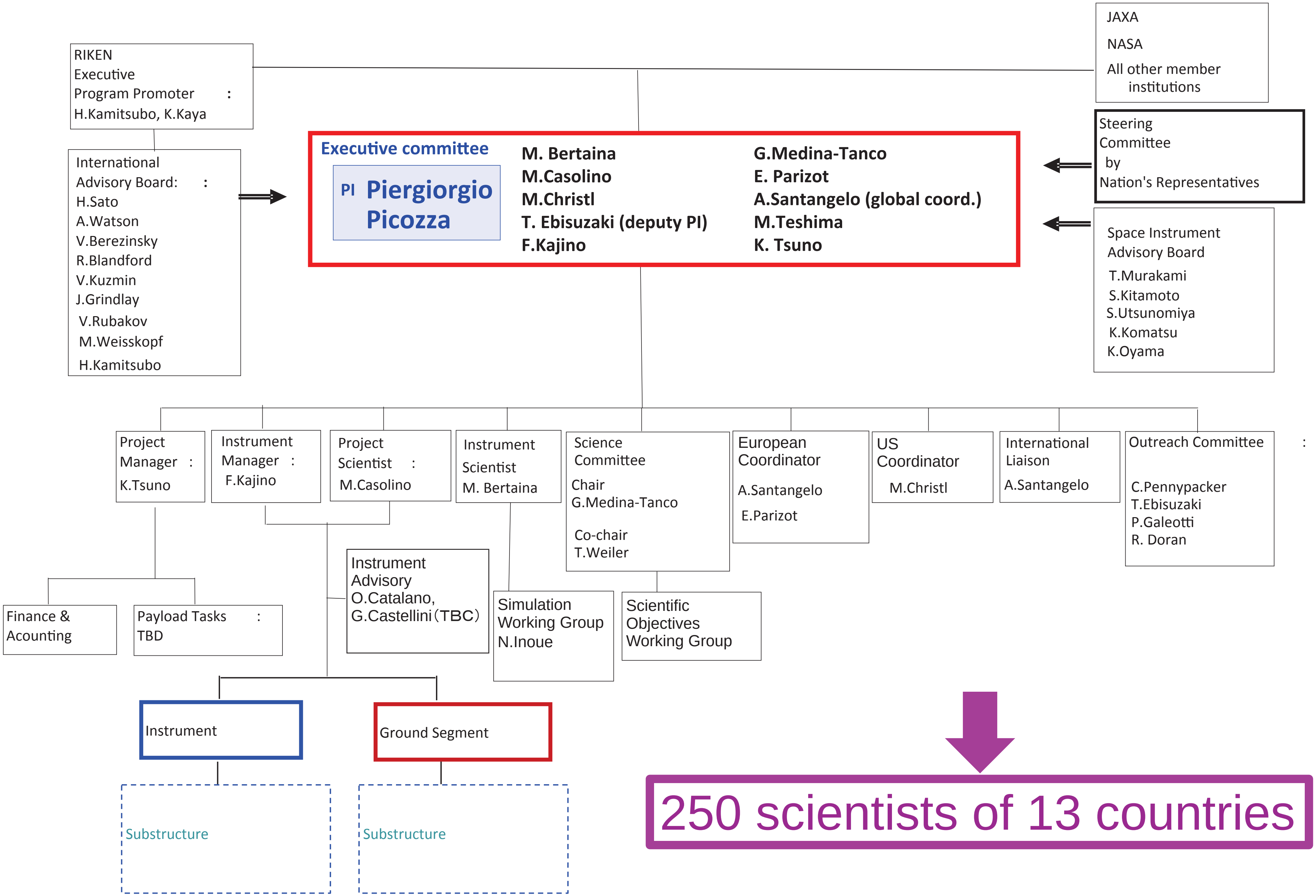
250+ scientists
80+ research institutions
13 countries

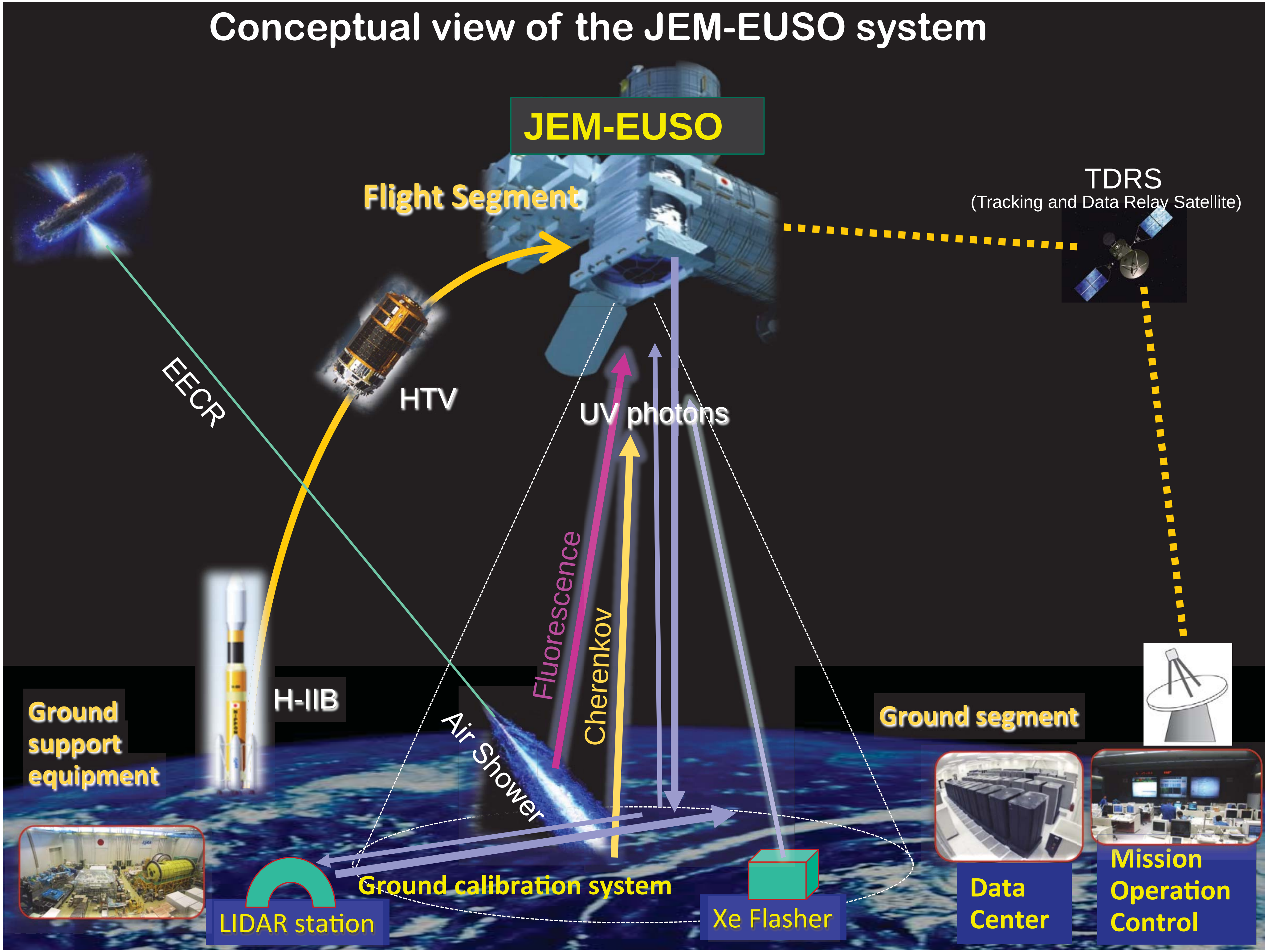
Space agencies involved: JAXA, NASA, ESA, DLR, ASI, CNES, AEM, etc…

International responsibility shearing

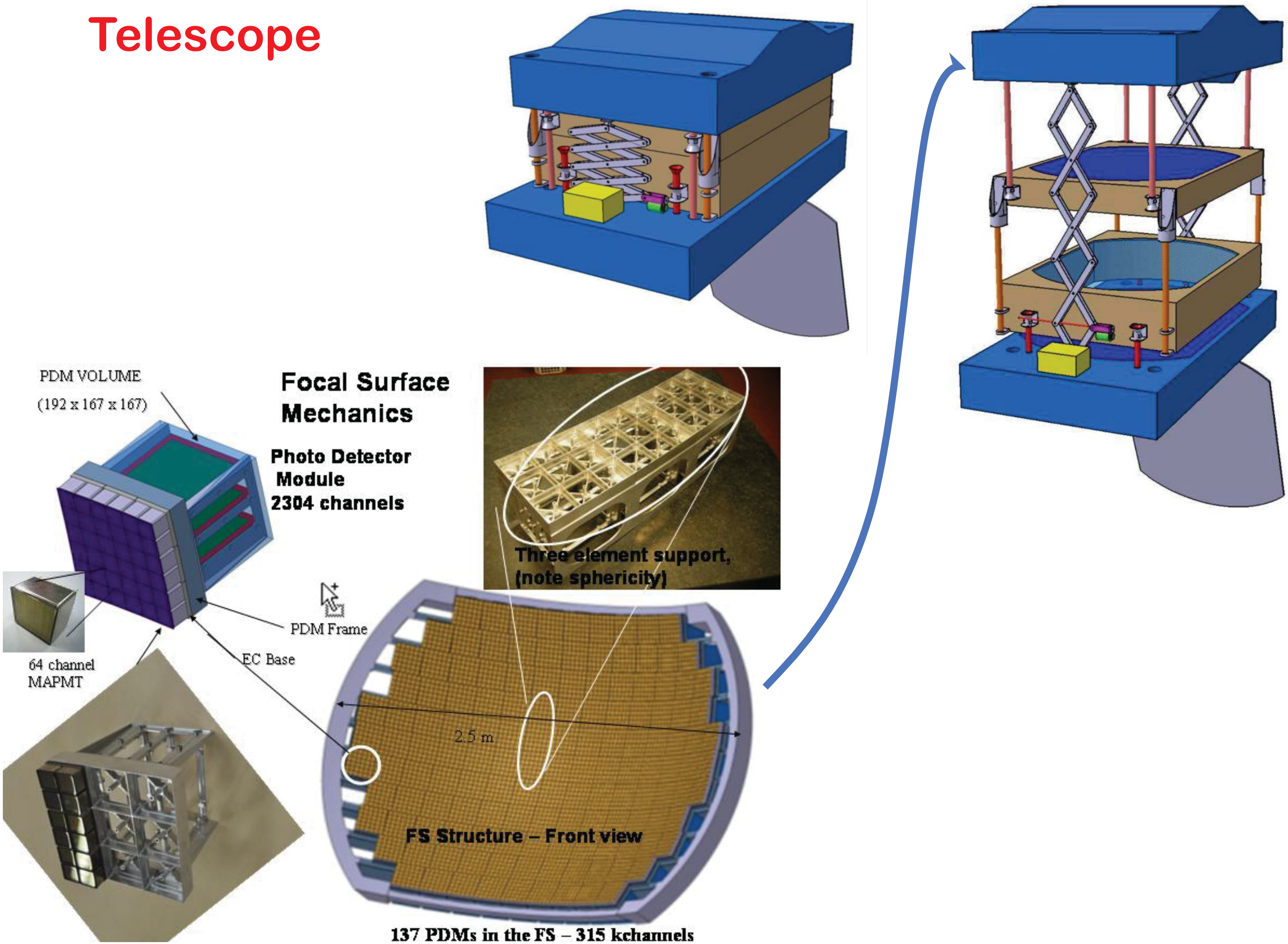


Management organization



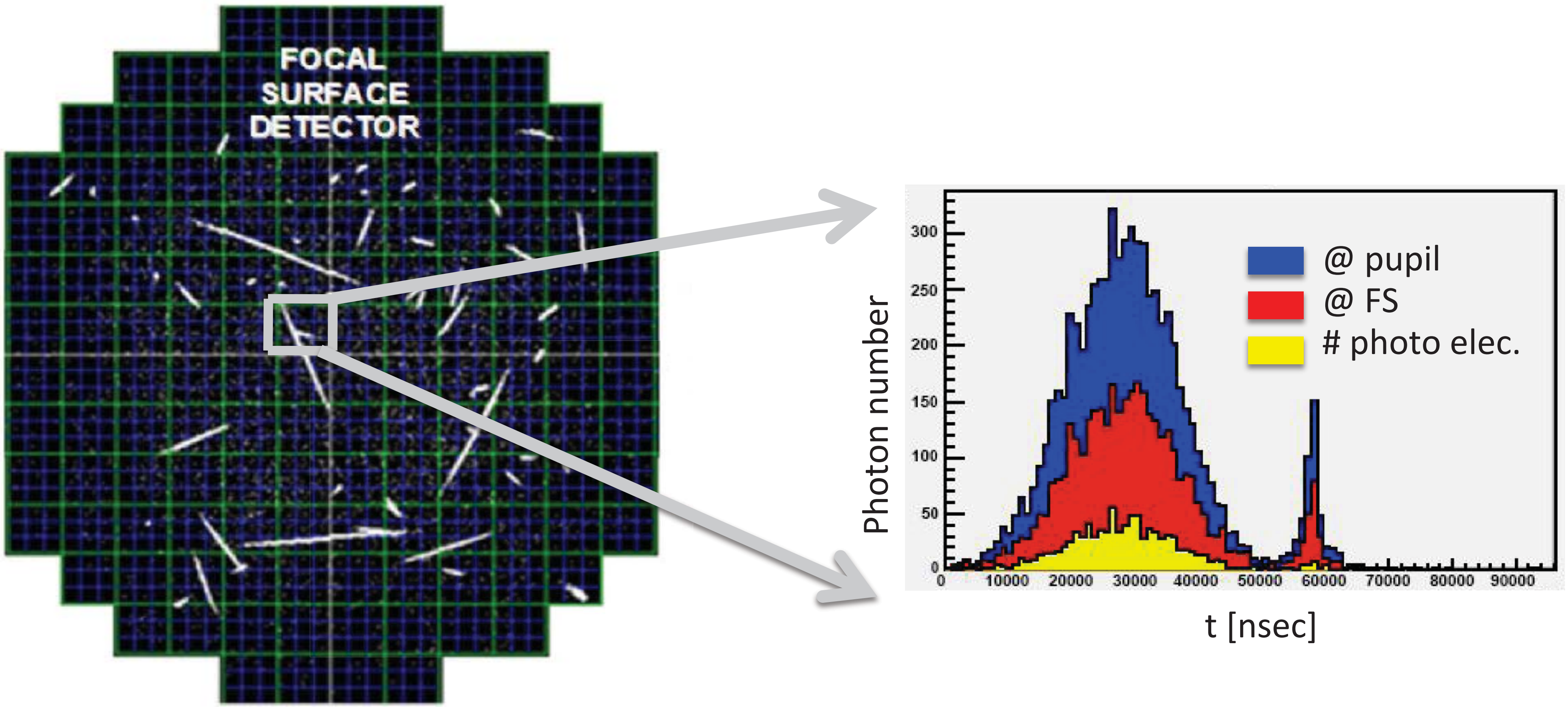

Conceptual view of the JEM-EUSO system
JEM-EUSO
Flight Segment
TDRS
(Tracking and Data Relay Satellite)
EECR
HTV
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground support equipment
Ground segment
Ground calibration system
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

Telescope



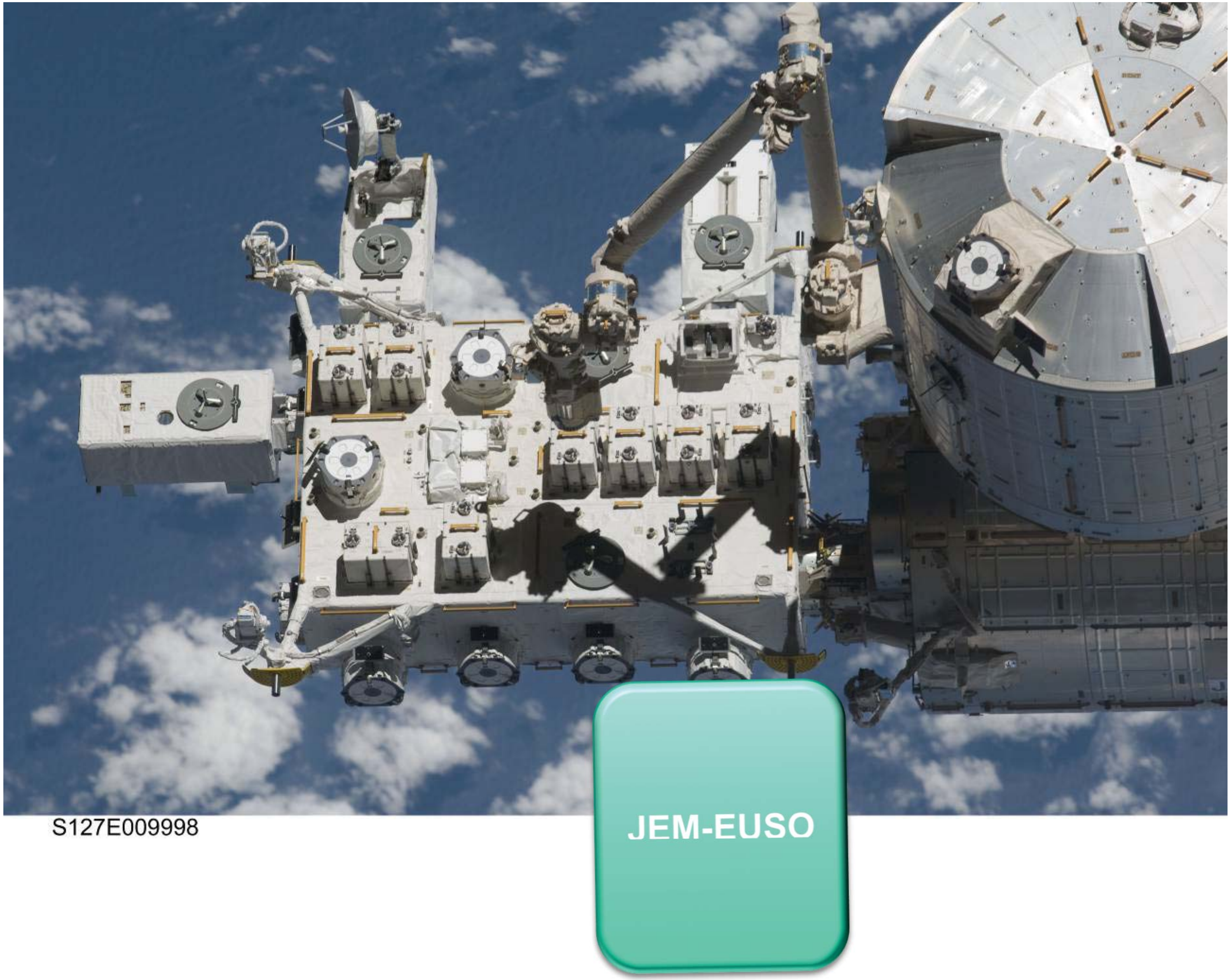
PDM VOLUME
(192 x 167 x 167)
Focal Surface
Mechanics
Photo Detector
Module
2304 channels
Three element support,
(note sphericity)
64 channel
MAPMT
PDM Frame
EC Base
2.5 m
FS Structure – Front view
137 PDMs in the FS – 315 kchannels

HE events



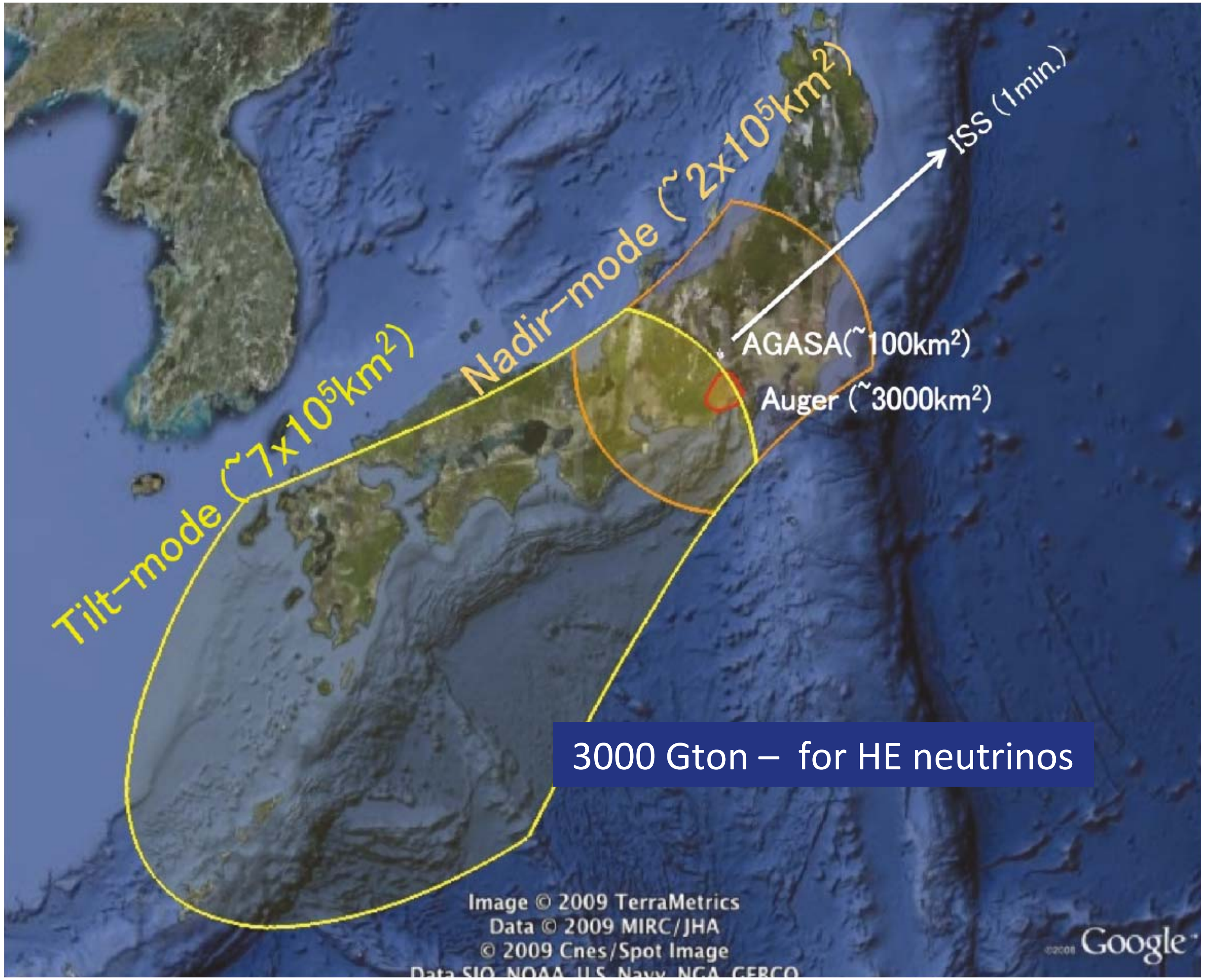
Hadron EAS @ 100 EeV

JEM-EF (Expose Facility)

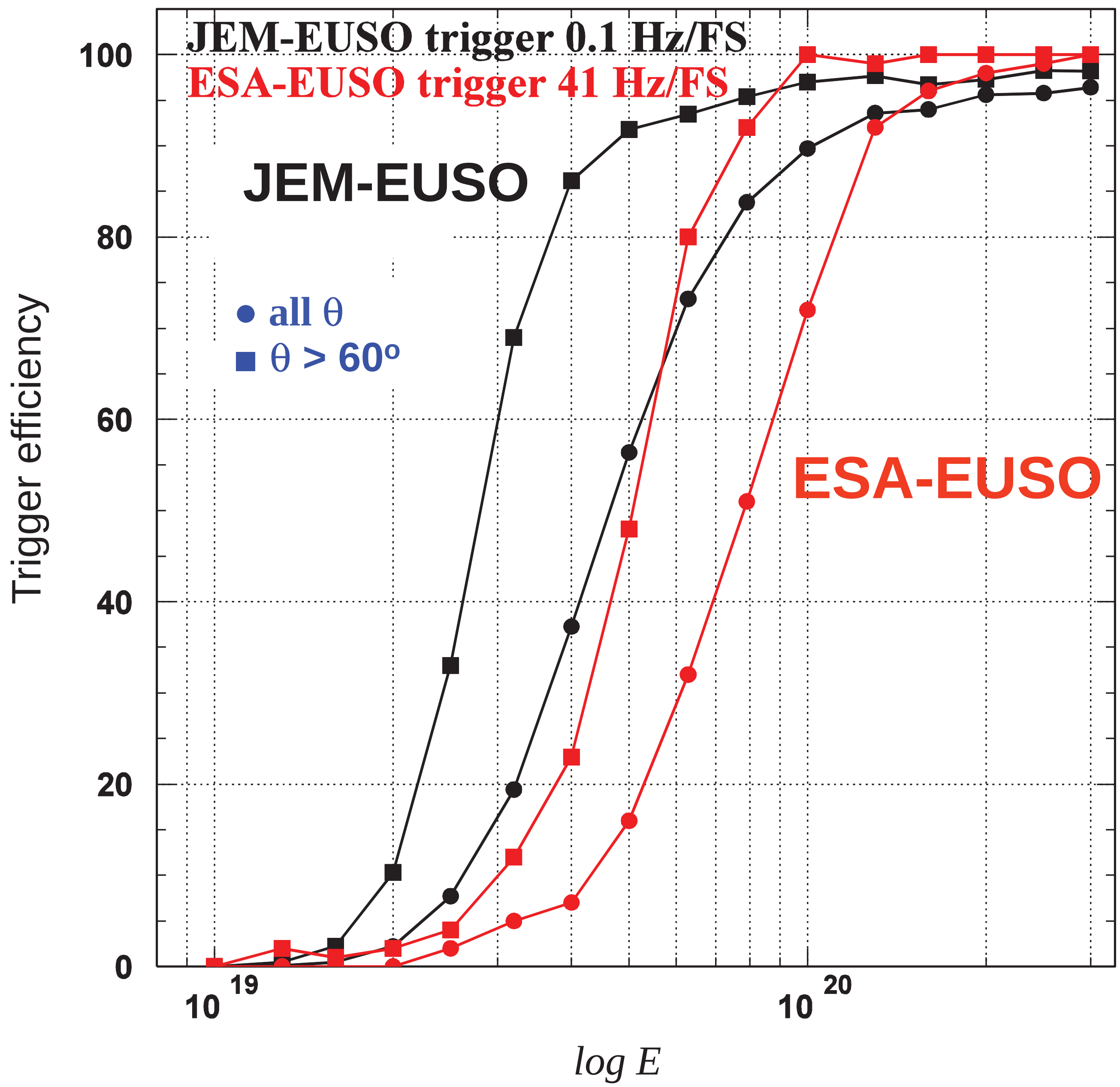


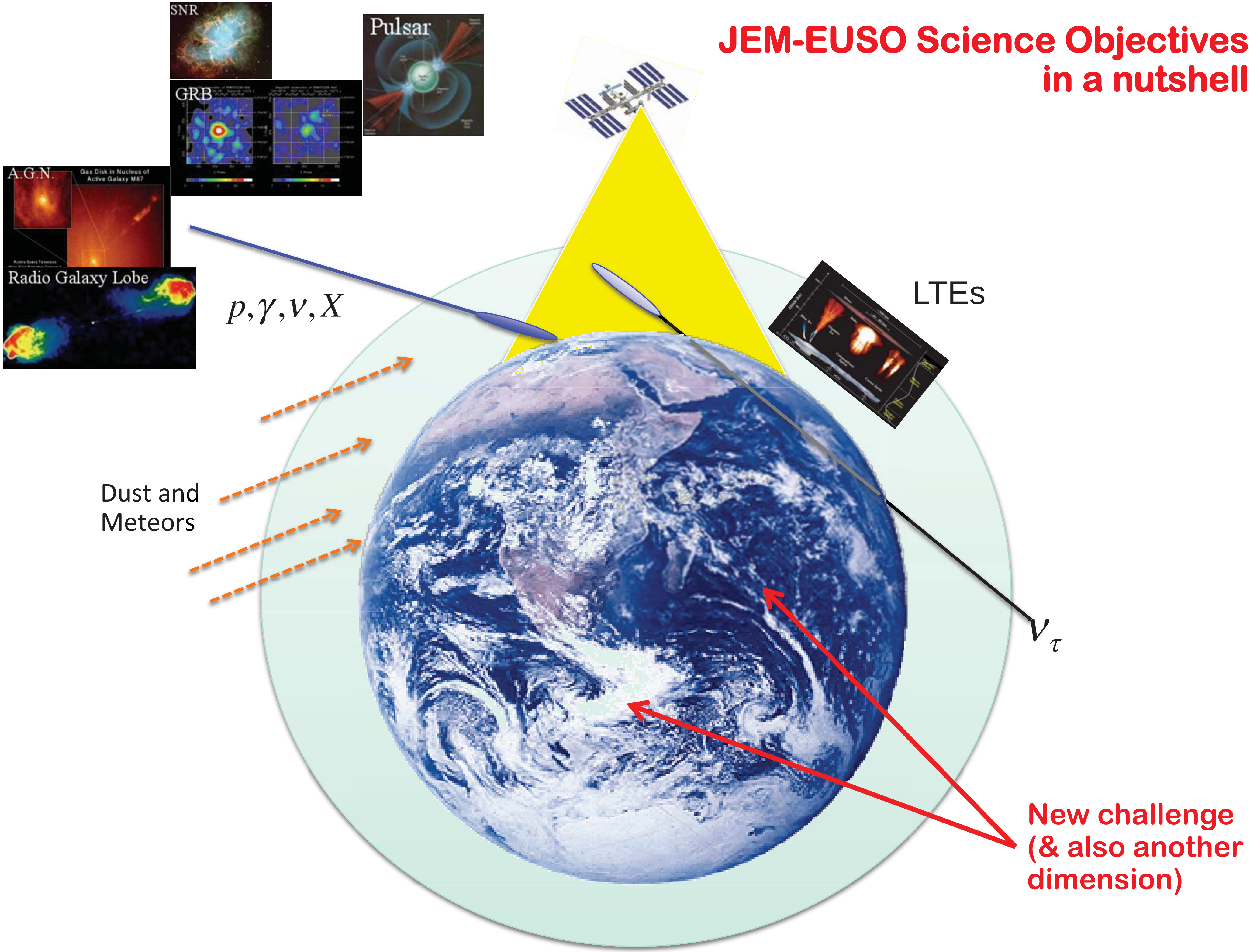
S127E009998

JEM-EUSO efective scale



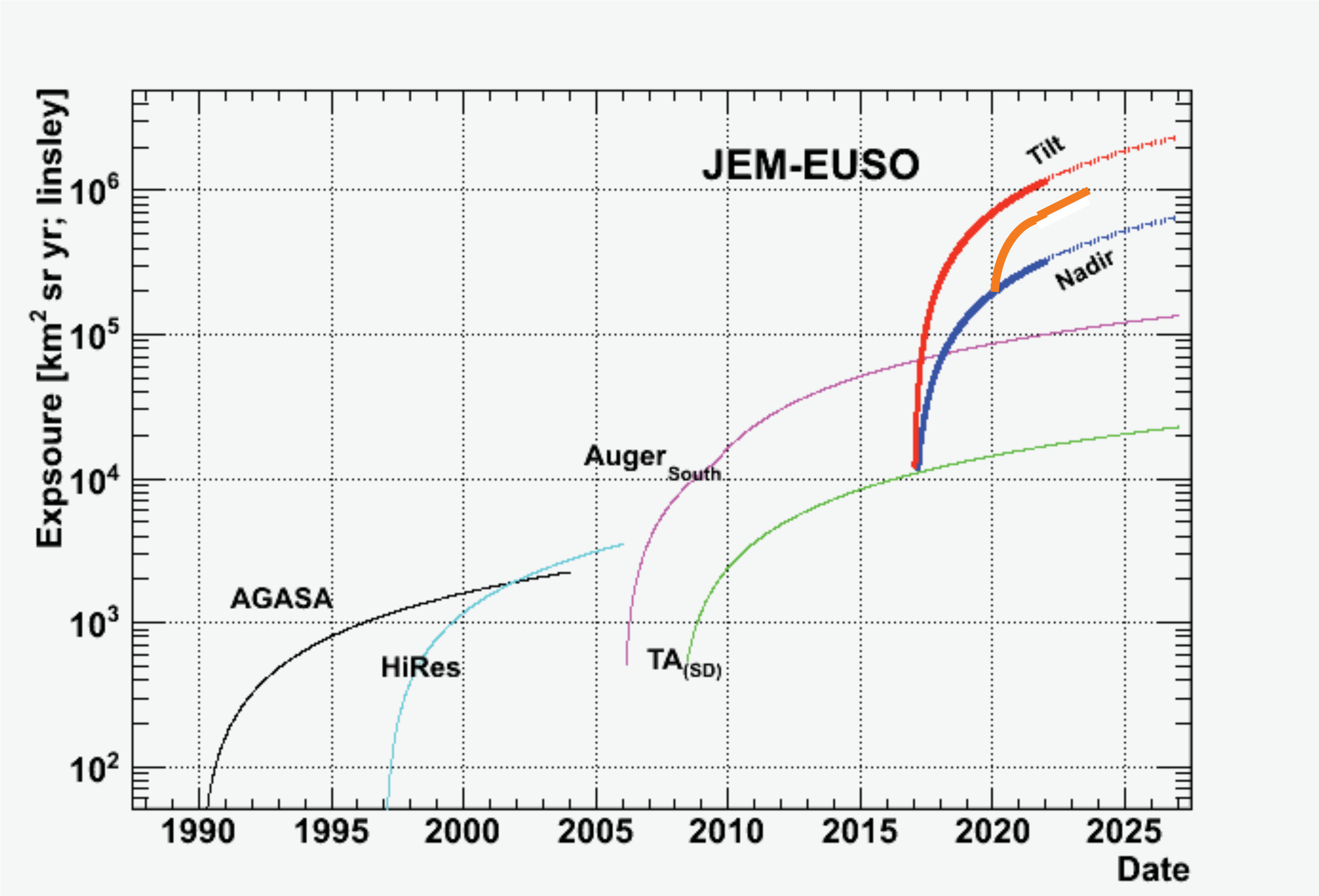
JEM-EUSO vs. old ESA-EUSO



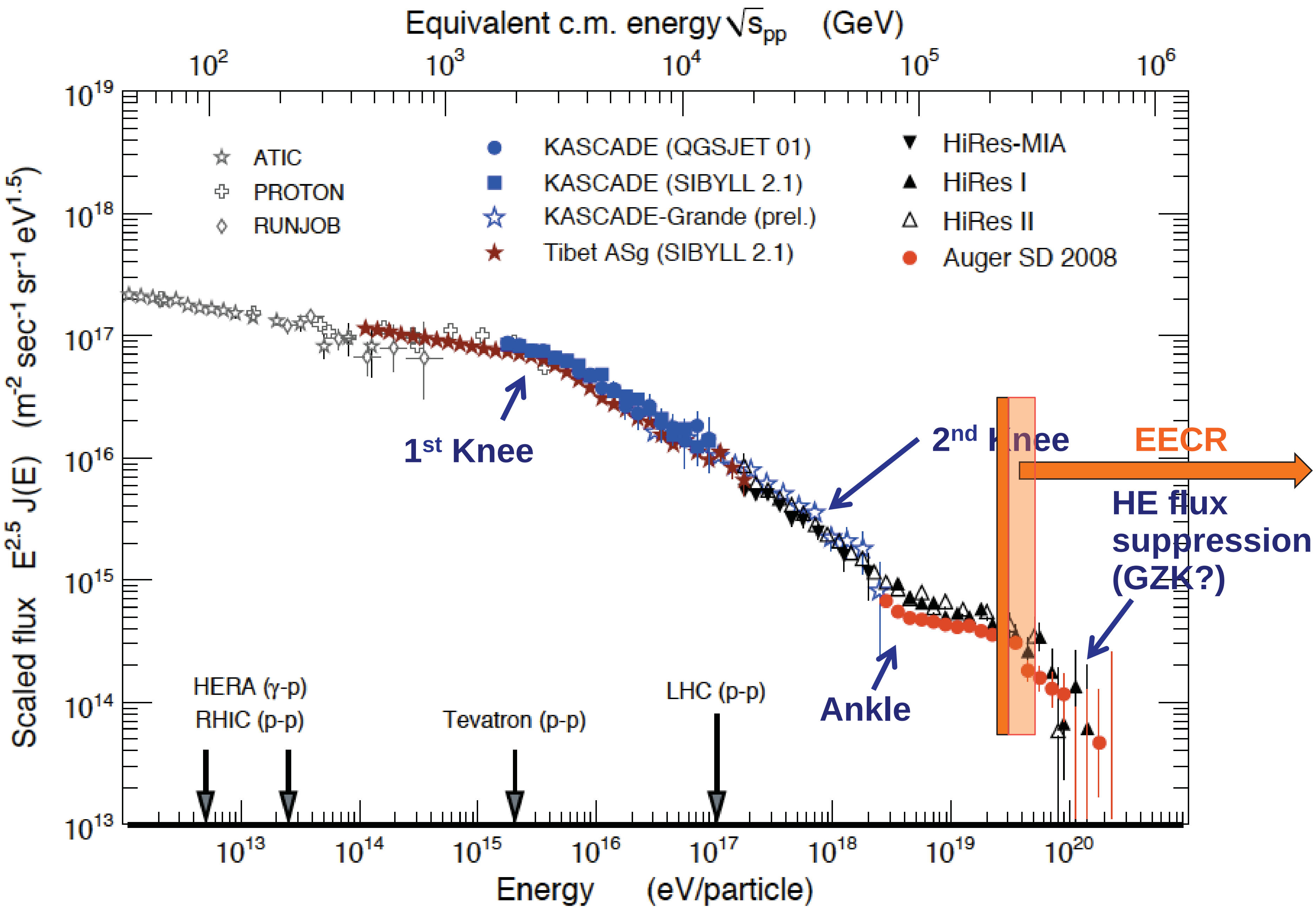

JEM-EUSO Science Objectives
in a nutshell
SNR
Pulsar
GRB
A.G.N.
Gas Disk in Nucleus of
Active Galaxy M87
Radio Galaxy Lobe
p, γ, ν, X
LTEs
Dust and
Meteors
ν_τ
New challenge
(& also another
dimension)

JEM-EUSO uniquenes

Large exposure + Full-sky coverage



JEM-EUSO EE target region



Main scientific objectives of the mission

Astronomy and astrophysics with particles of EHE

Objective #1

- **Identification of individual sources with high statistics**
- **Measurement of the energy spectrum of individual sources**
- **Understanding of the acceleration processes and source dynamics**

Objective #2

- High statistics measurement of the trans-GZK energy spectrum
- Exploration of the highest energy frontier

Objective #3

- Place limits on the *exoticons'* flux (topological defects, SHDM, etc.)

Exploratory objectives

1 . Detection of high energy **neutrinos** and interaction cross section measurement (new physics?)

2. Measurement of extreme energy **photons** (primaries from nearby sources, secondaries from propagation, super-heavy dark matter decay, Z-bursts)

3. Study the intensity and topology of Galactic and extragalactic **magnetic fields**.

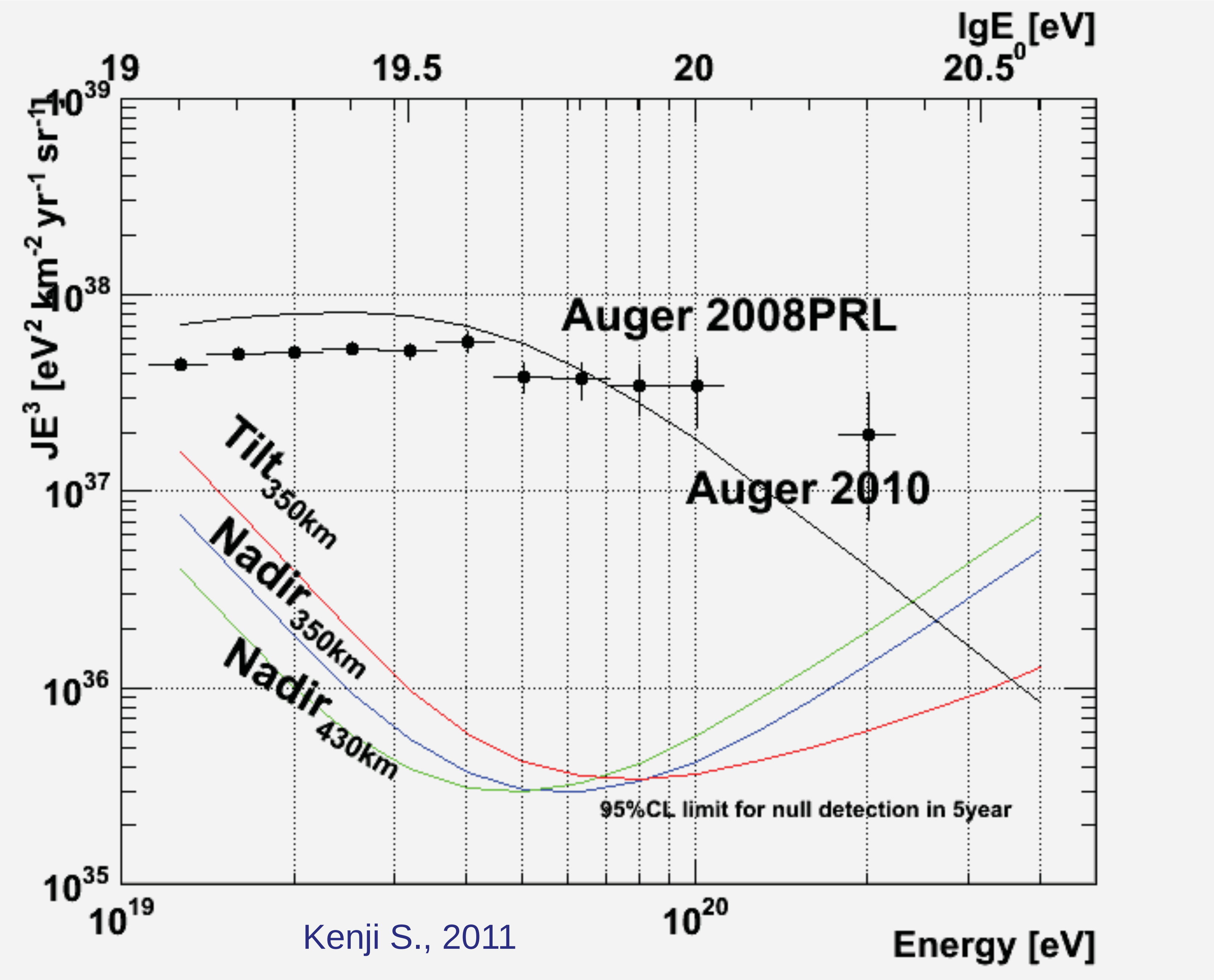
4. Test the effects of **quantum gravity** on the propagation of high energy particles through the universe.

5. Global observation of **atmospheric phenomena**: nightglows, lightening and plasma discharges.

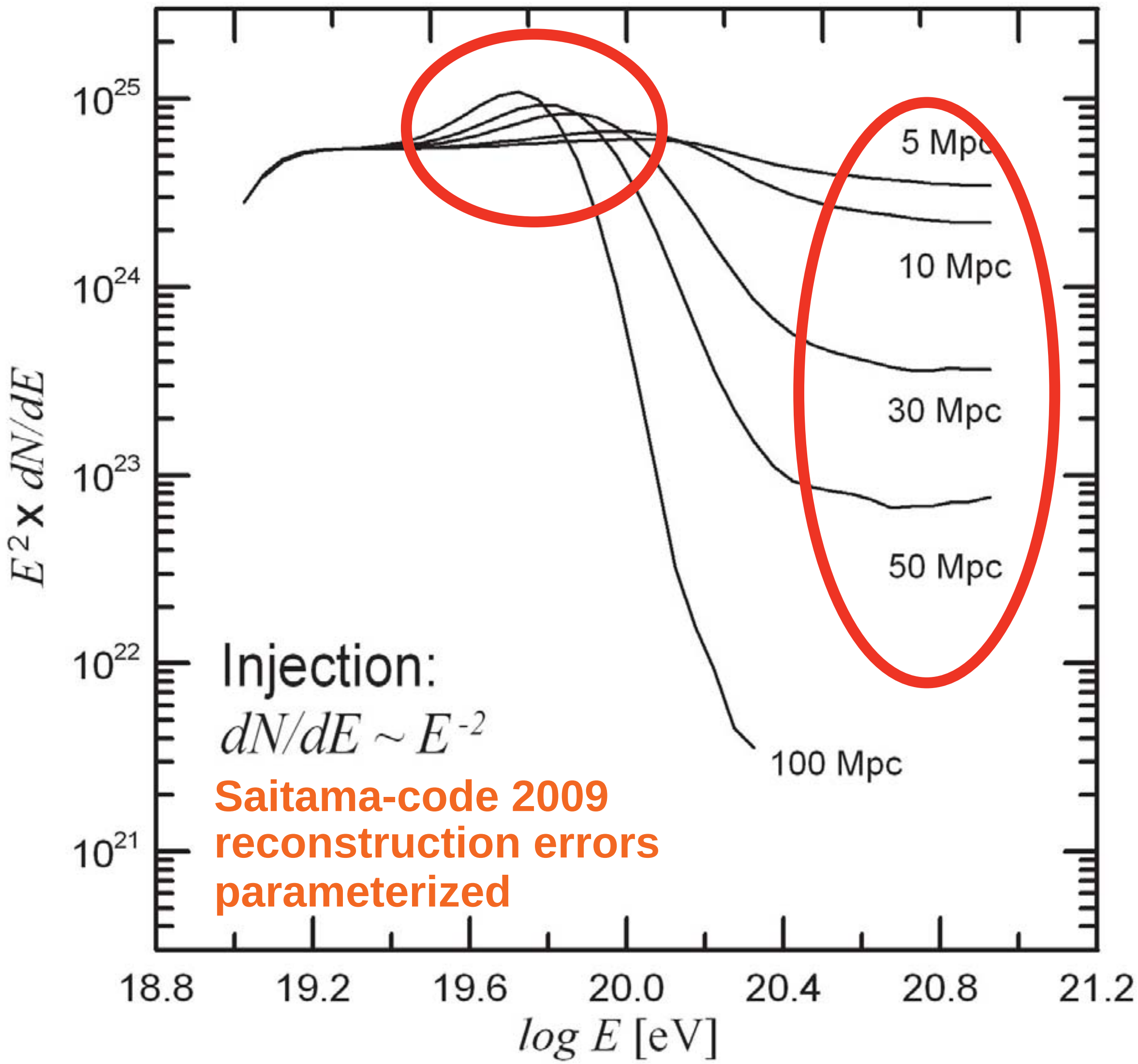
START TRECK objective: to explore the spectrum where no human being has gone before, i.e., the decade beyond 10^{20} eV

What can be achieved with these data?

Impact at the highest energies: the recovery



GZK flux-suppression – all sky spectrum



The flux-suppression may be a cut-off in acceleration rather than the result of propagation, either photo-pion production or photo-disintegration of heavy nuclei, or an acceleration limit.

In fact known astrophysical objects and bottom-up mechanisms apparently barely arrive at the maximum energies observed so far.

3D PROPAGATION SIMULATIONS

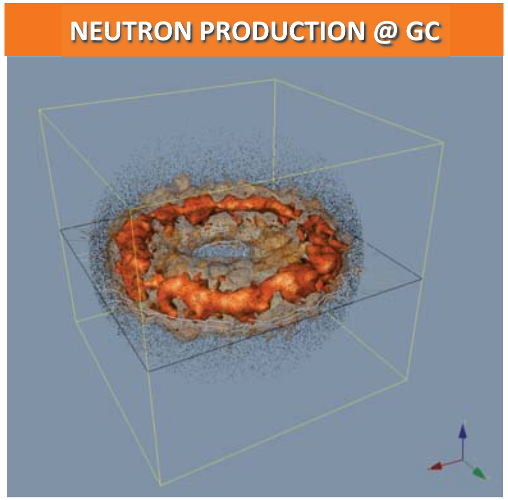
- Injection spectrum at the source is αE^{-2},

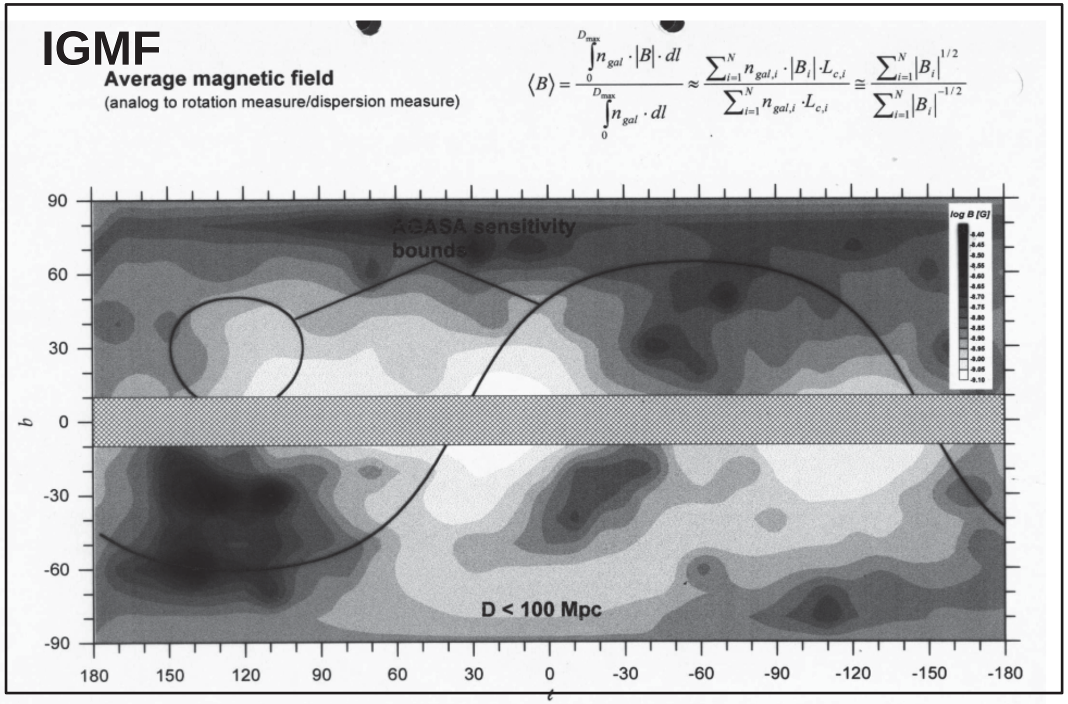
- Intergalactic magnetic field inhomogeneously distributed according to the IRAS LSS distribution of matter and to Faraday Rotation constraints, normalized to a filament in the Comma Cluster IGMF measurements.

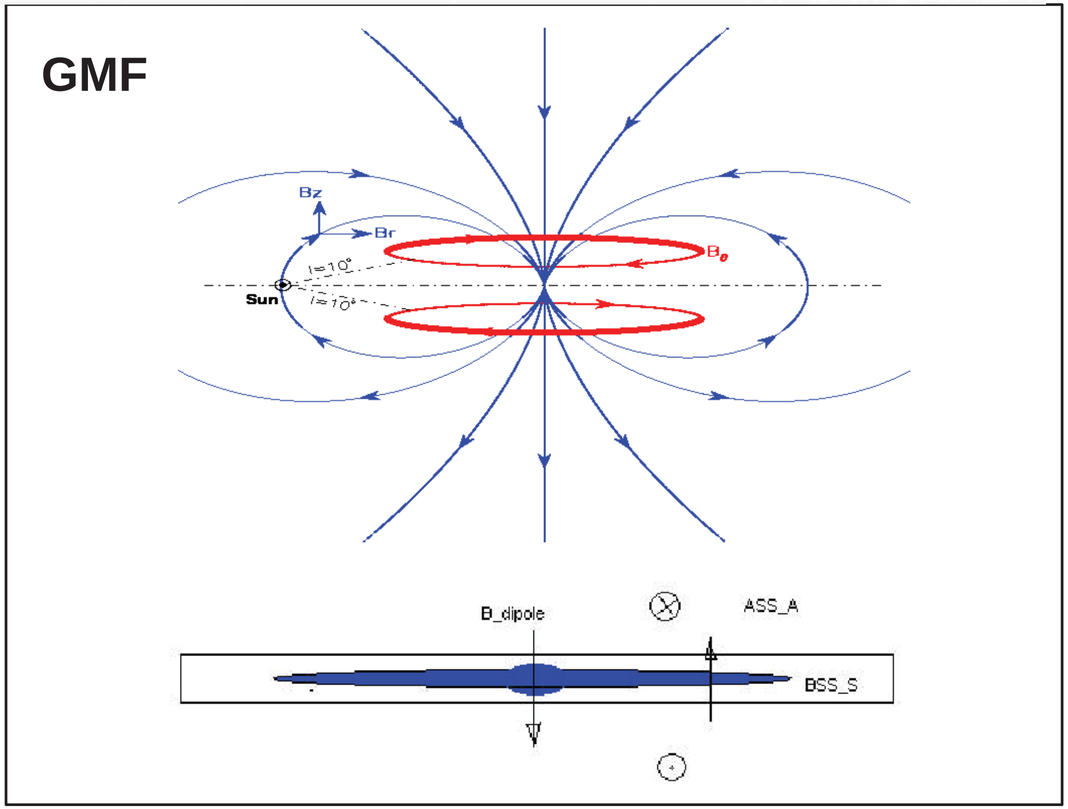
- Incoming events are selected with an appropriate trigger probability and their energies are convoluted with an energy and zenith angle dependent error.

- But NO reconstruction probability is applied, which would increasingly affect the lower energy portion (E<50 EeV) of all spectra.

G. Medina-Tanco – 1997… 2011

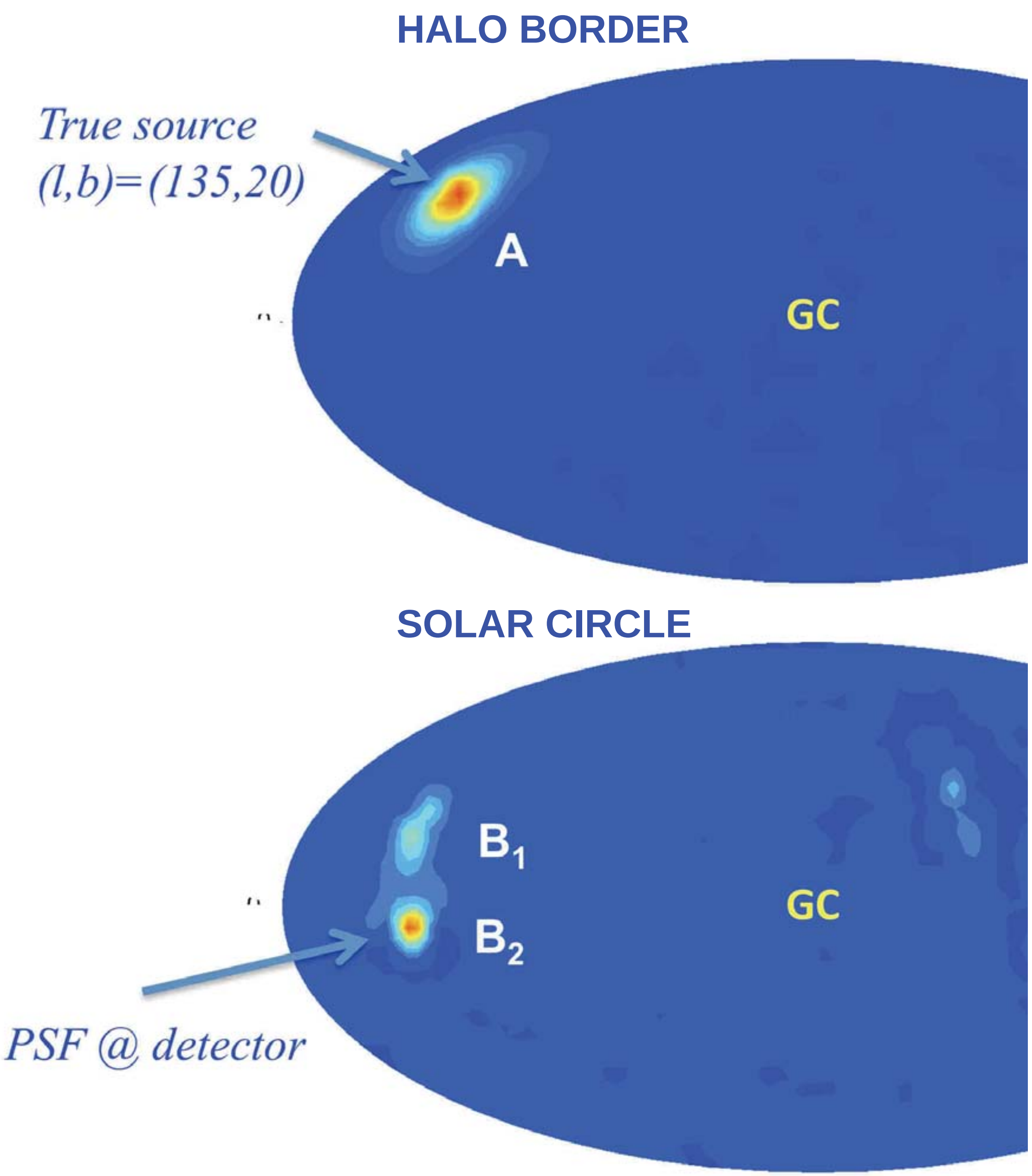






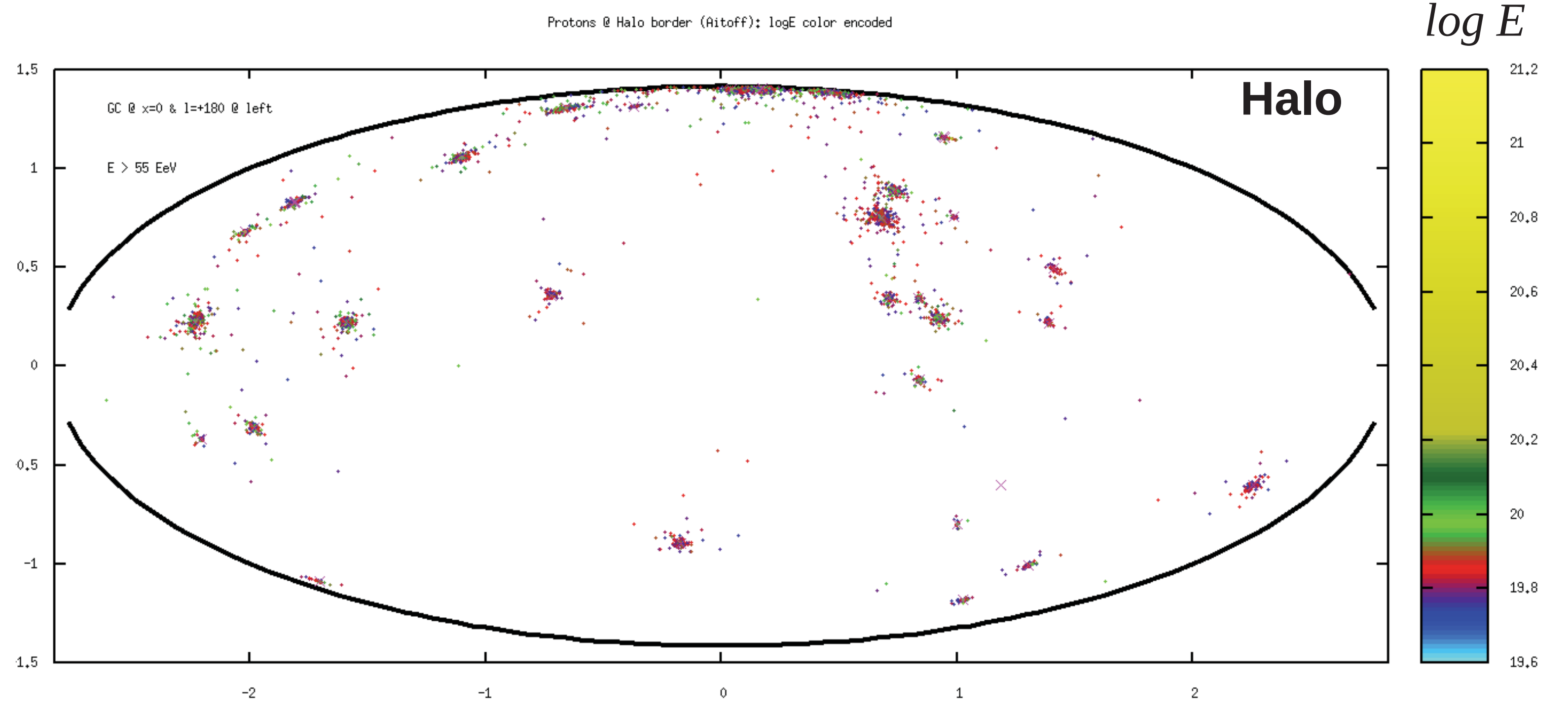
Individual source identification

G. Medina-Tanco – 2009 / ID0138

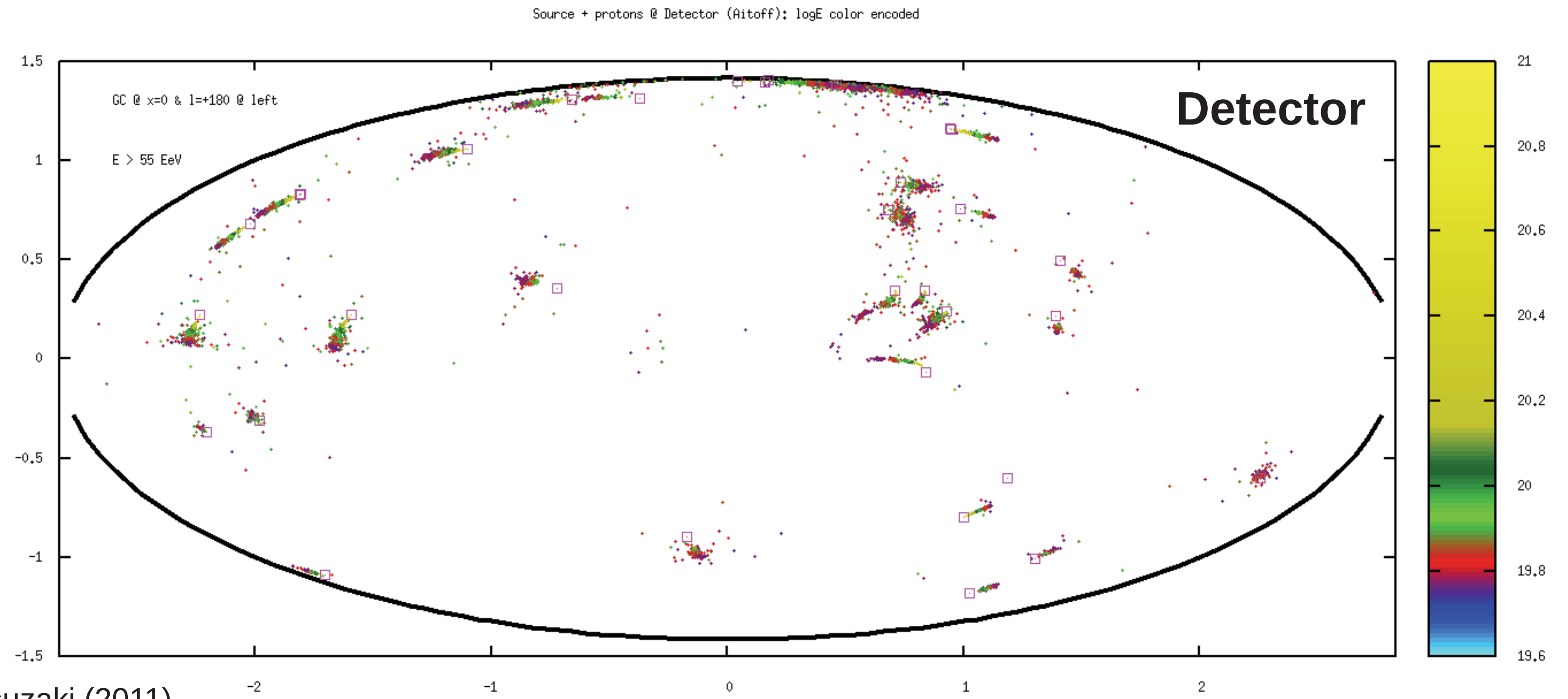


A magnetized Halo can affect individual p.s.f. which can also be used as a tool to understand the GMF

ULX

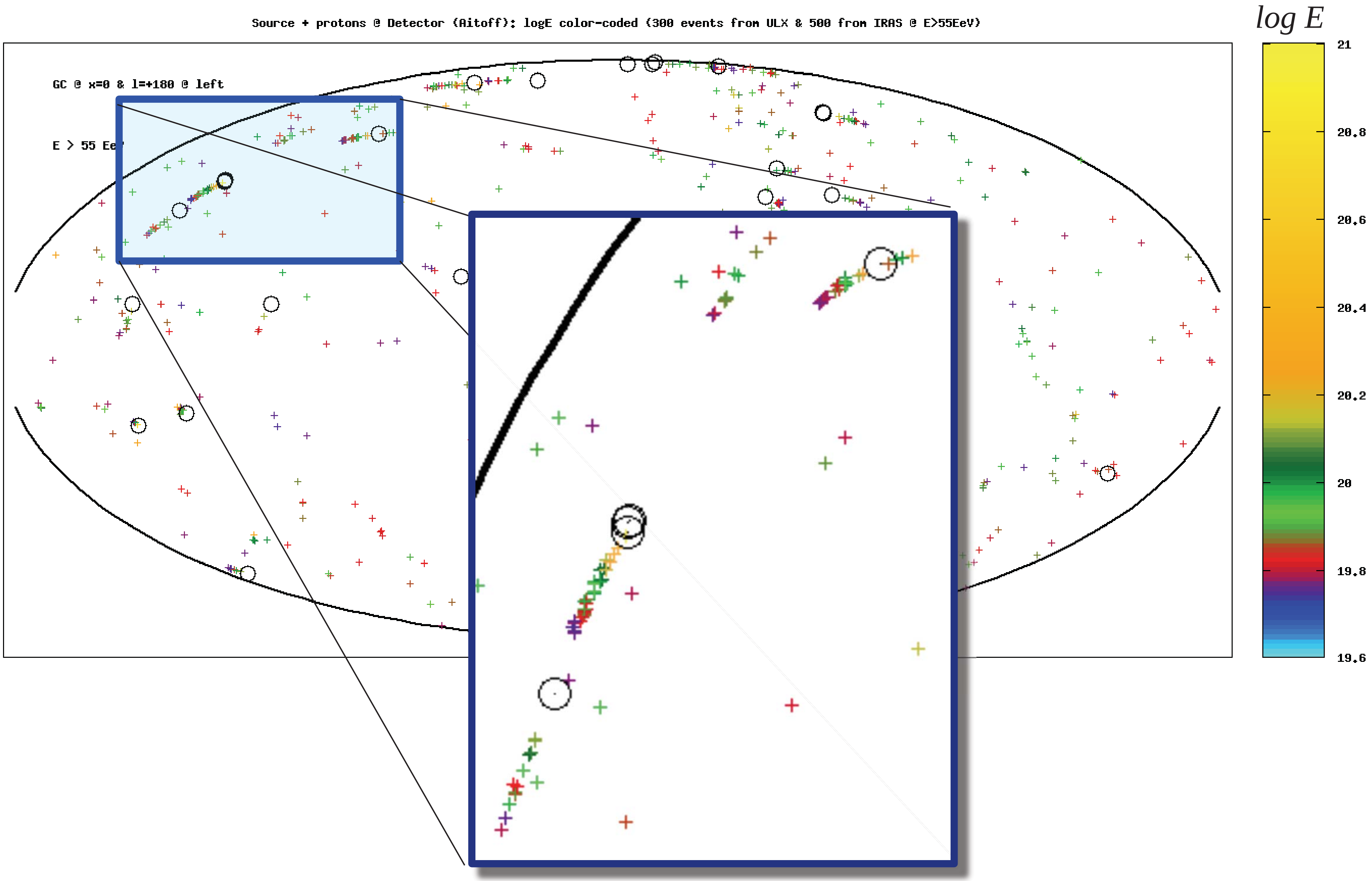


55 EeV



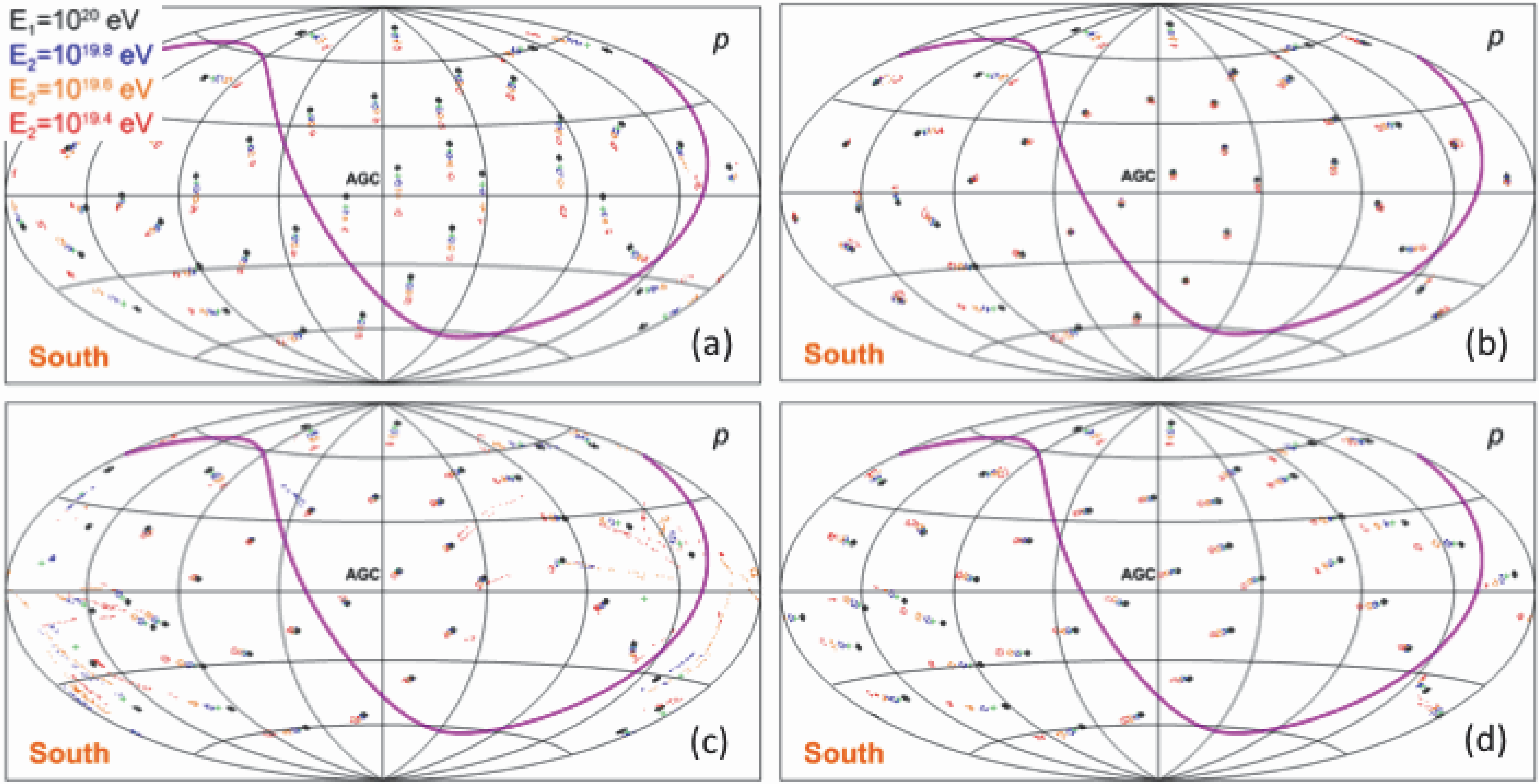
Medina-Tanco & Ebisuzaki (2011)

Protons: E>55 EeV - 300ev from ULX + 500ev from IRAS



GMF assesment

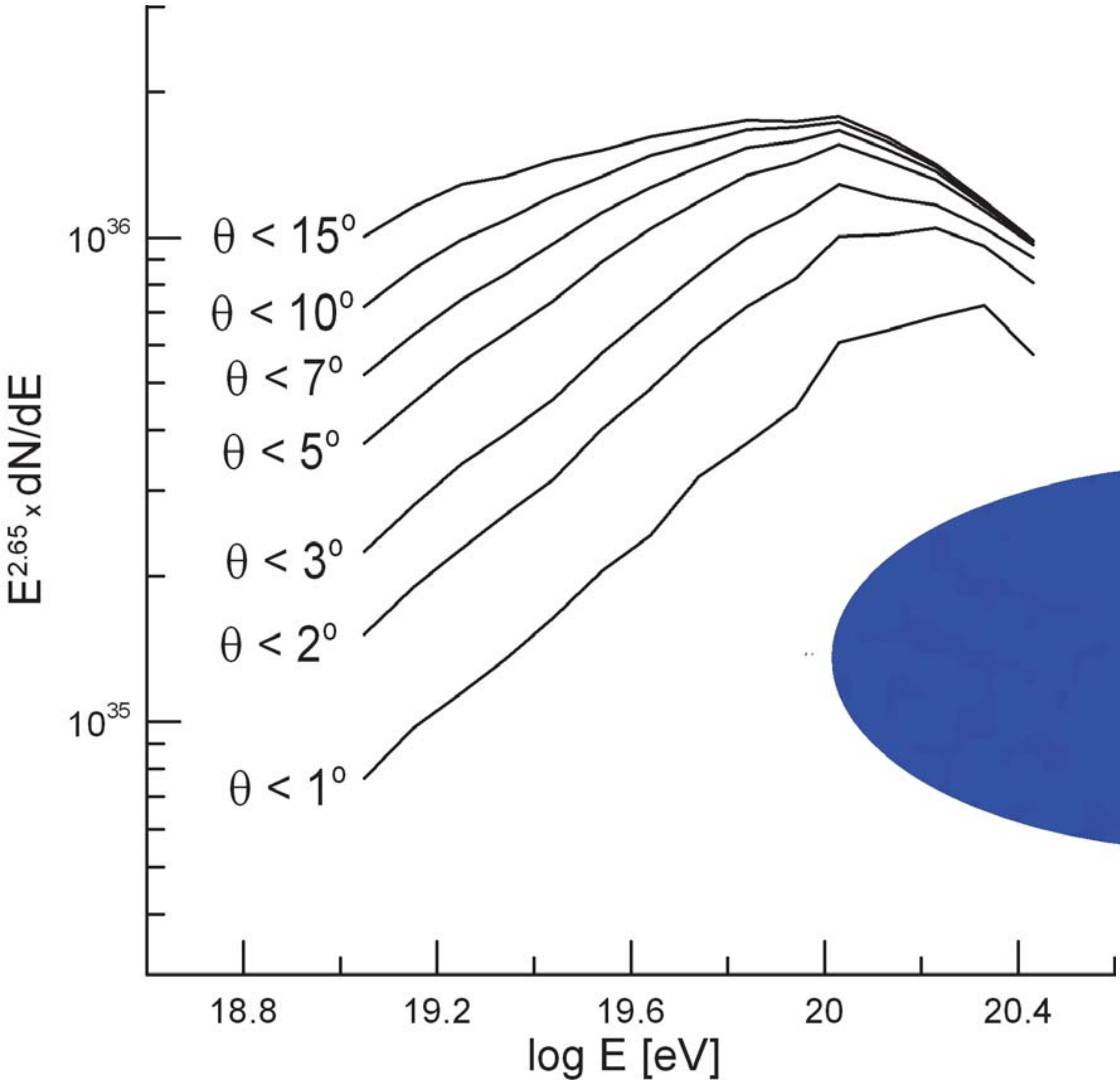
Medina-Tanco & Teshima (2003)



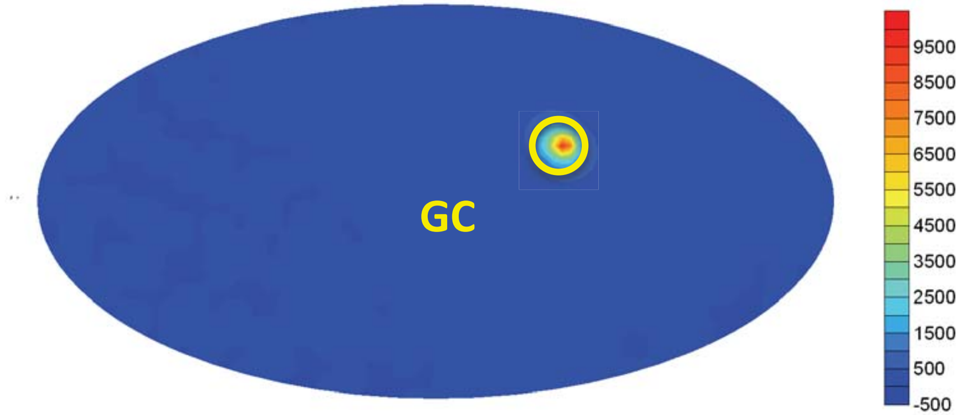
Point source image distortions as a function of energy for different GMF configurations: (a) ASS-S B_z=0; (b) BSS-S B_z=0; (c) BSS-S B_z dipolar; (d) BSS-S B_z=0.3 mG (uniform inside Disk). Particles with log E(eV) = 19.4, 19.6, 19.8 and 20.0 are shown. It can be seen that different topologies produce very different patterns of distotion over the celestial sphere. JEM-EUSO, with is high statistics and its 4p sr coverage is ideally suited to perform this measurement [947].

IGMF: spectra and assumed PSF

D ~ 5 Mpc
(~ Cen A)

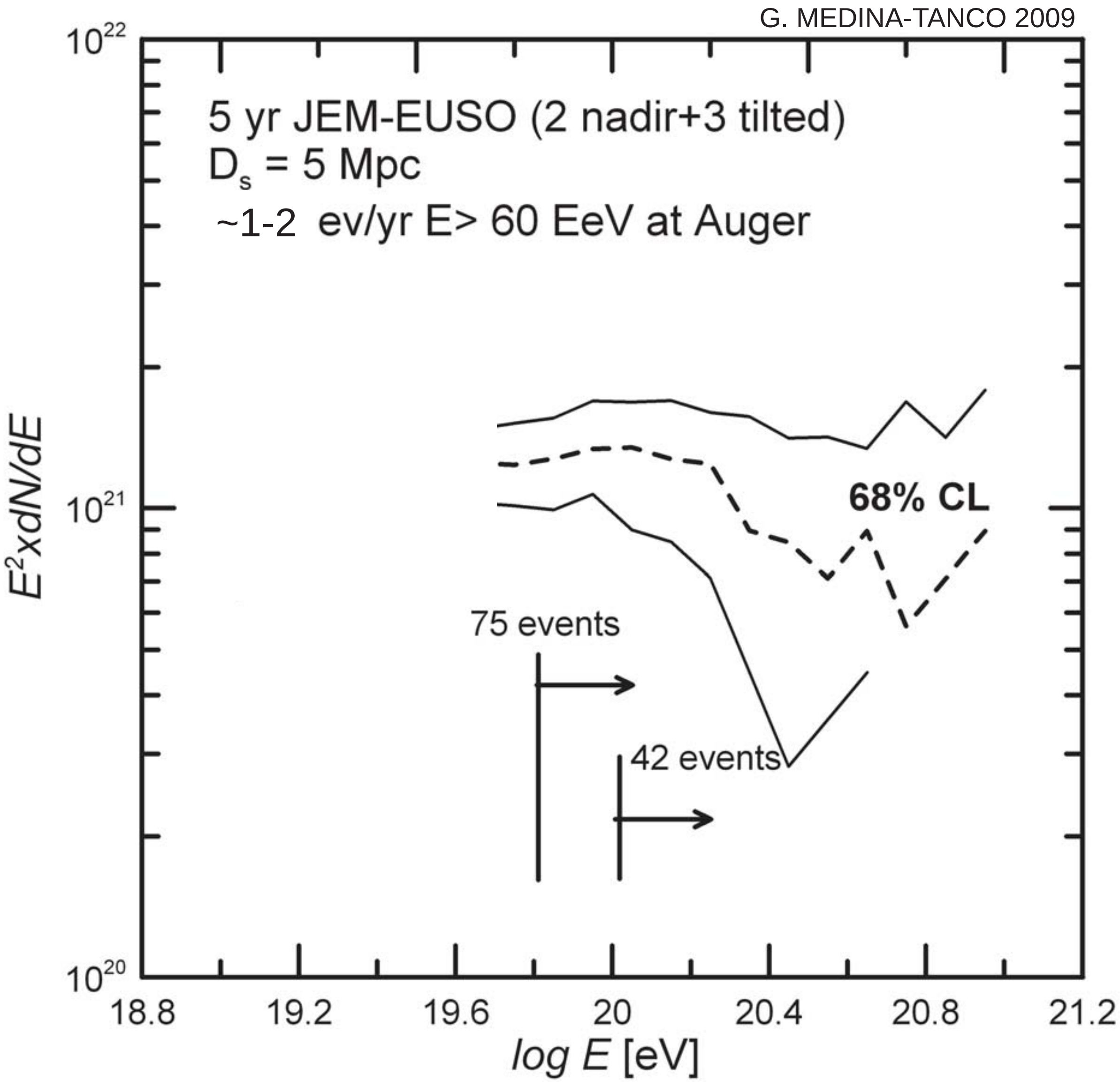


Circles of varying radius centered at true source position on the sky



The hardness of the spectrum strongly depends on the radius of the PSF

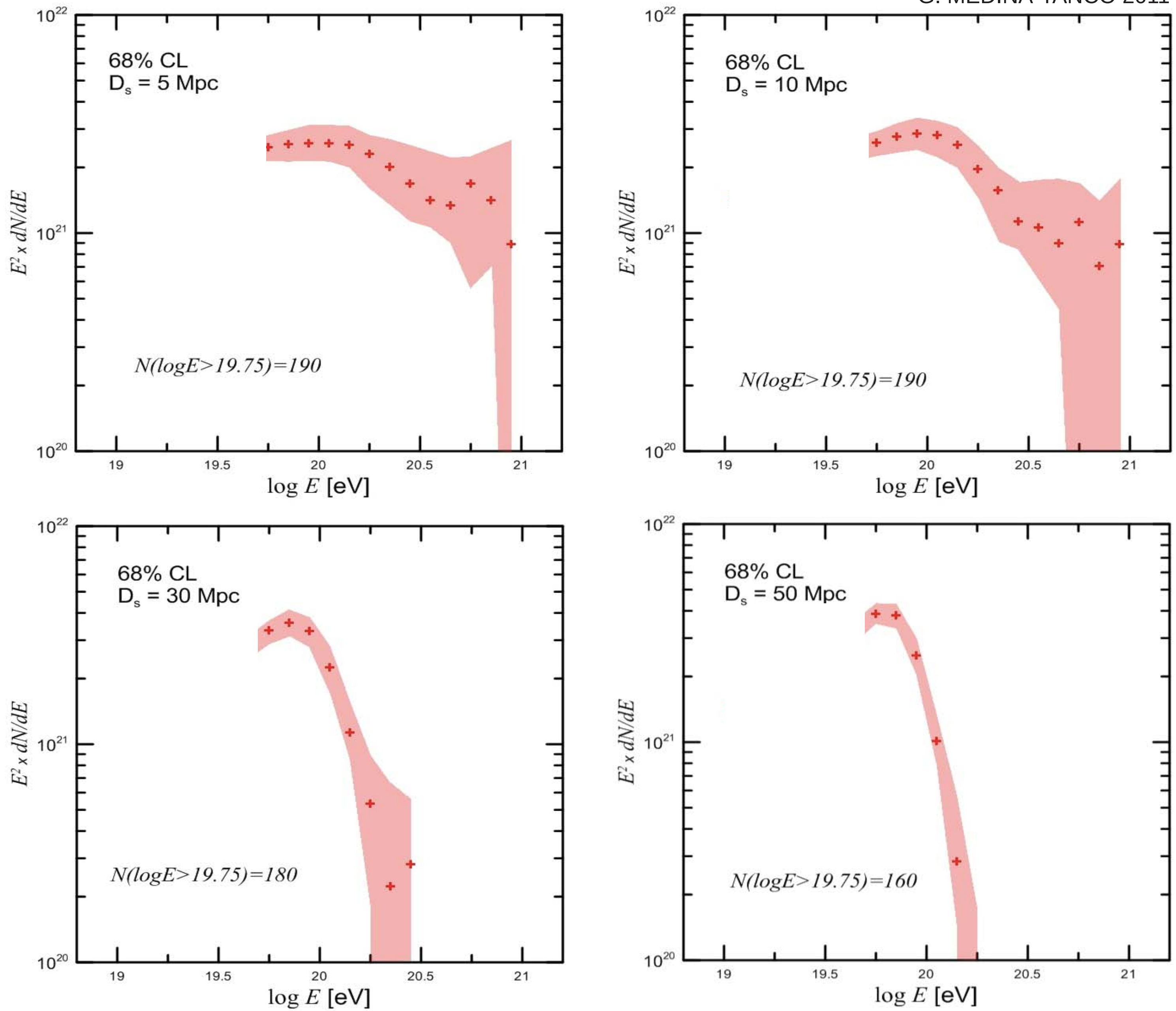
Individual source spectra



Spectra of individual sources (or unresolved source-regions)

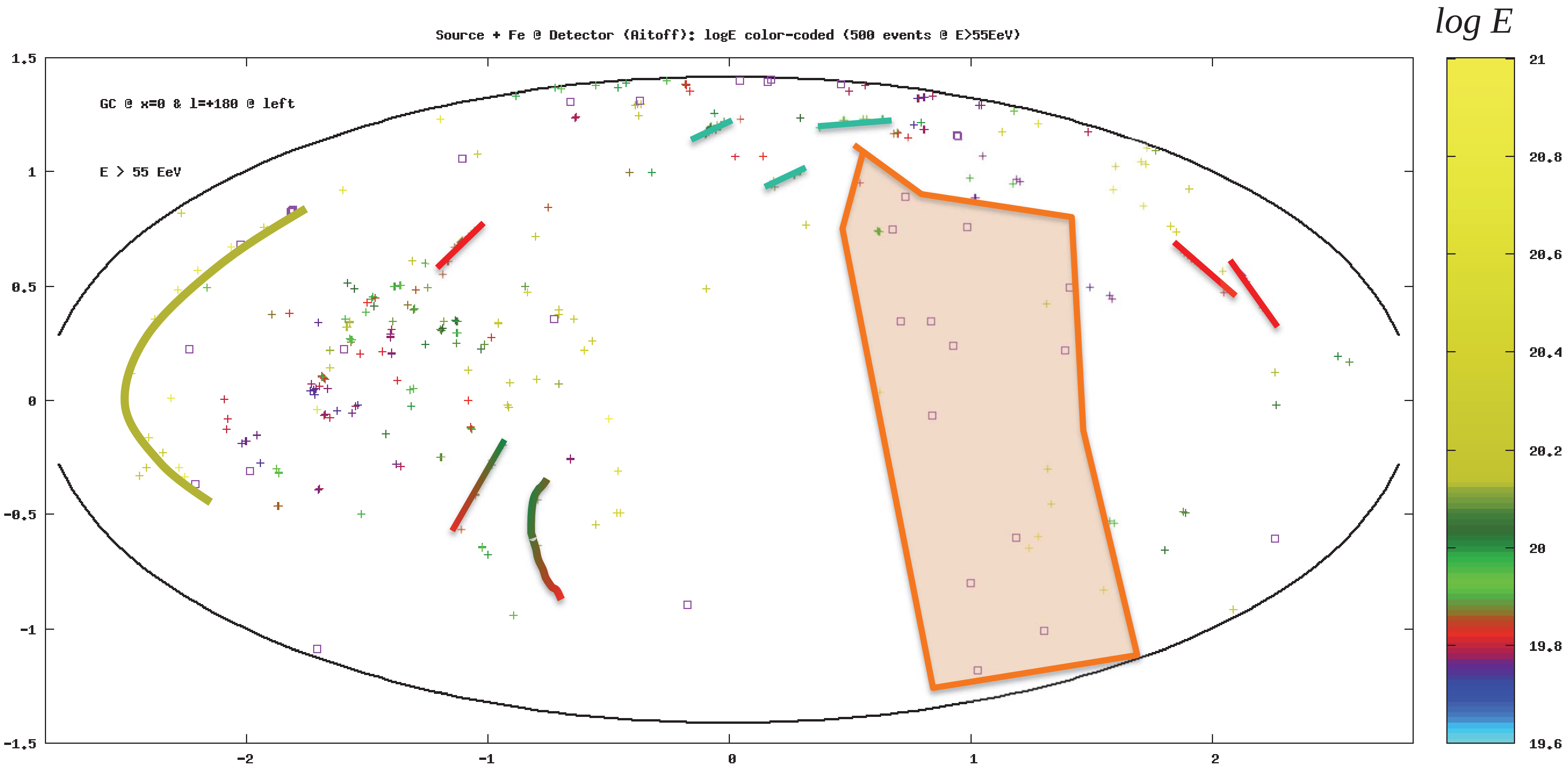
G. MEDINA-TANCO 2011

Simulated observed spectra of a point sources as a function of distance. The median and the upper and lower 68% CL are shown for each spectrum. All the hypothetical sources have approximately the same flux at Earth, which amounts to ***~ 160 to 190 events above 55 EeV****. If achieved in 5 yrs of operation of JEM-EUSO, such a flux would correspond to a collection rate at Auger of less than 4 events per year associated with each source. The injection spectrum at he source is* αE^{-2}*, an intergalactic magnetic field of 1 nG intensity and correlation length of ~1 Mpc is assumed, and the incoming events are selected with an appropriate trigger probability and their energies are convoluted with an energy and zenith dependent error. No reconstruction probability is applied, which would increasingly and considerably affect the lower energy portion (E<50 EeV) of all spectra.*



Based on Auger results, assume that correlation with source is traceable down to 55 EeV

Fe: 500ev from ULX & no background events



Source identification

The identification of the sources can follow different paths:

- Individual source identification

- Statistical identification ⟷ Catalogues →
  - High statistics
  - Uniform exposure in DEC

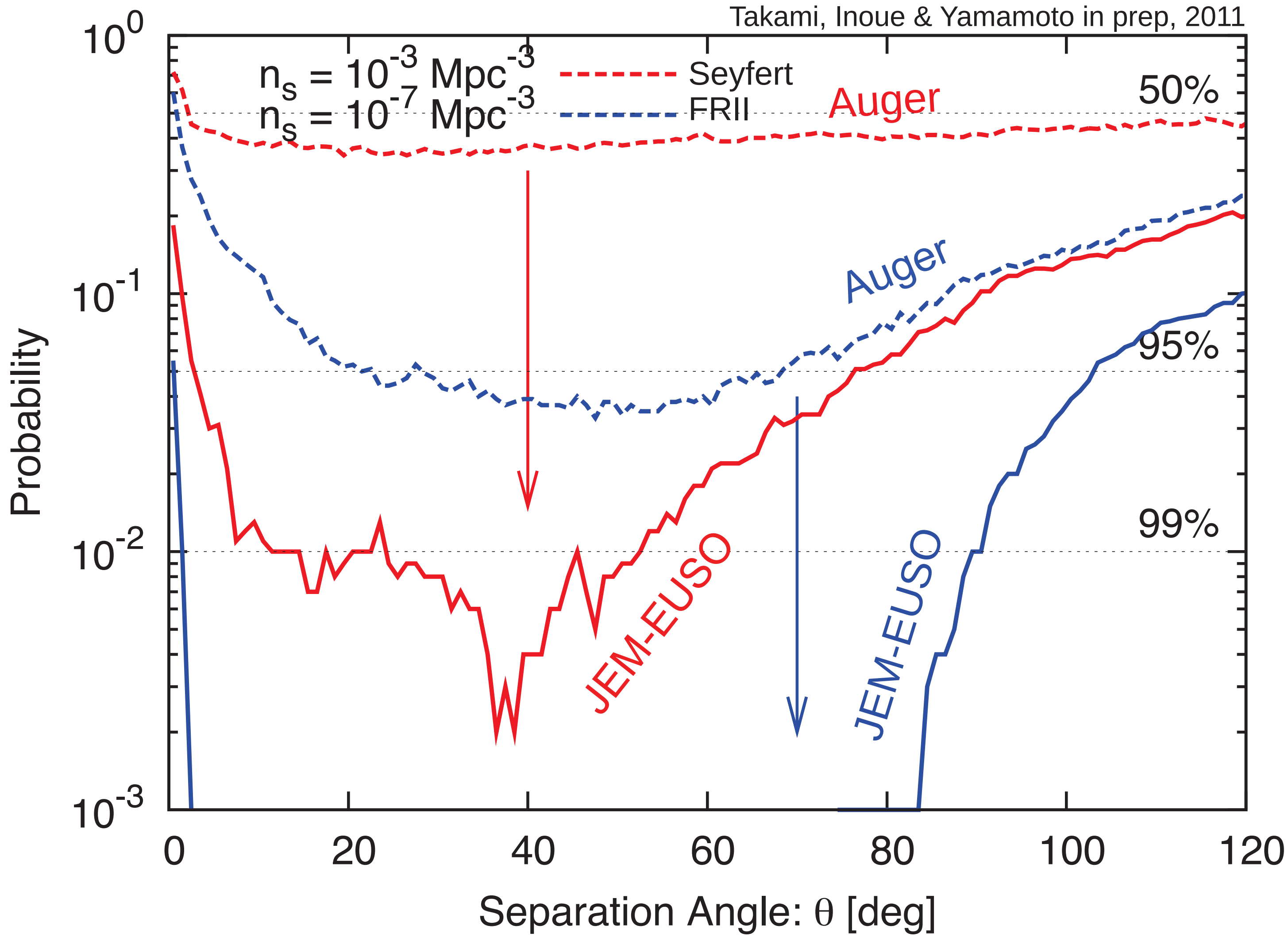
  ⟷ Source density

Source density

For a given N_{ev}: n_s ↓ → $N_{multipletes}$ ↓ → L_s ↑ → *Multiplicity per multiplet* ↑

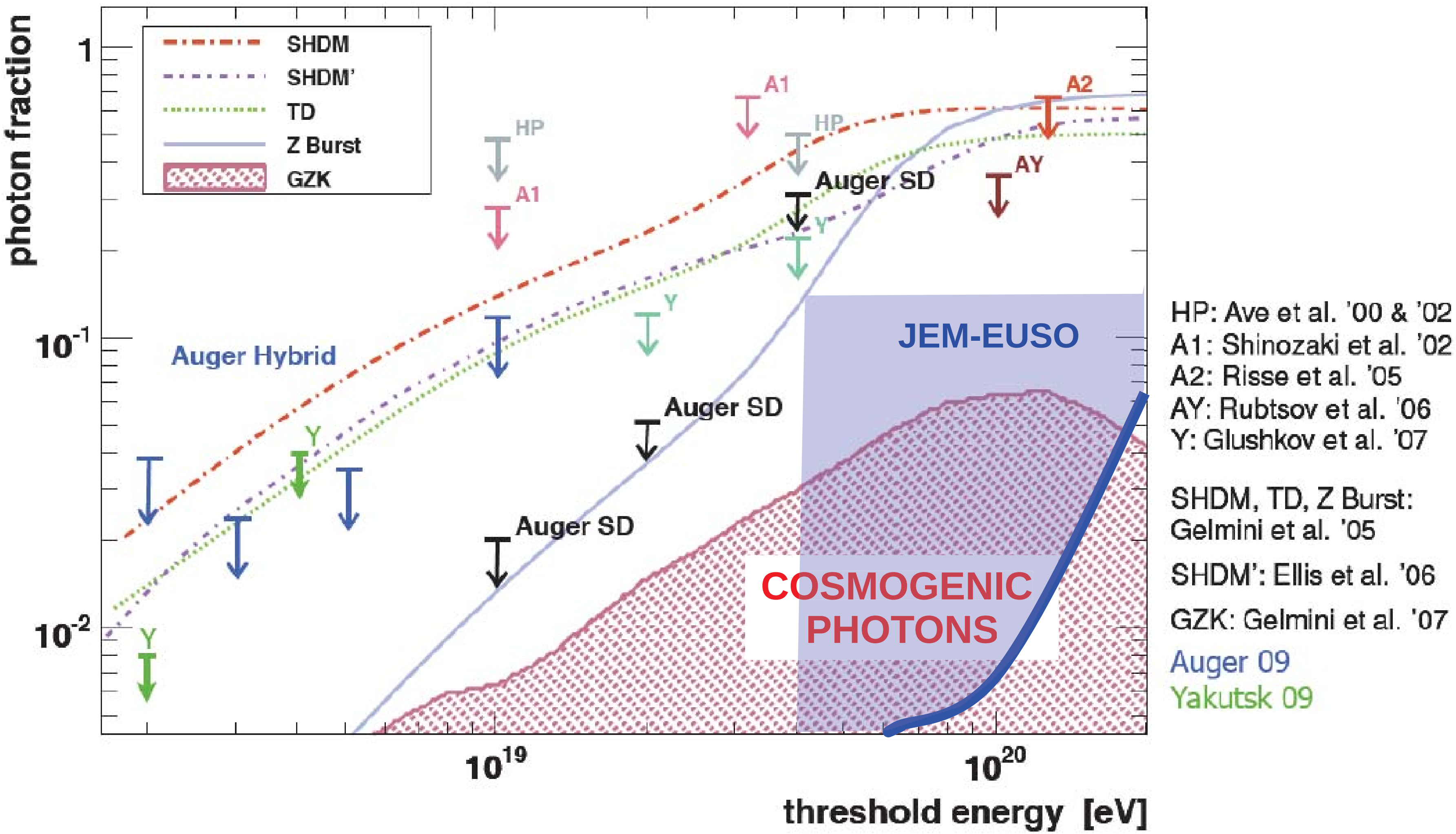
If magnetic deflections are not too large, a low density of sources implies a relatively high EECR luminosity per source and, therefore, a smaller number of larger multiplicity clusters of events is expected, while the opposite should occur in a large density scenario. The degree of clustering over the celestial sphere should also be dependent on the large scale spacial distribution of the sources.

Probability that positive excess in the arrival distribution of EECRs (for Fe injection at LSMD from IRAS PSCz), compared to an isotropic distribution, is NOT realized (p). The probability that positive excess is realized (1-p) is indicated by numbers in the figure



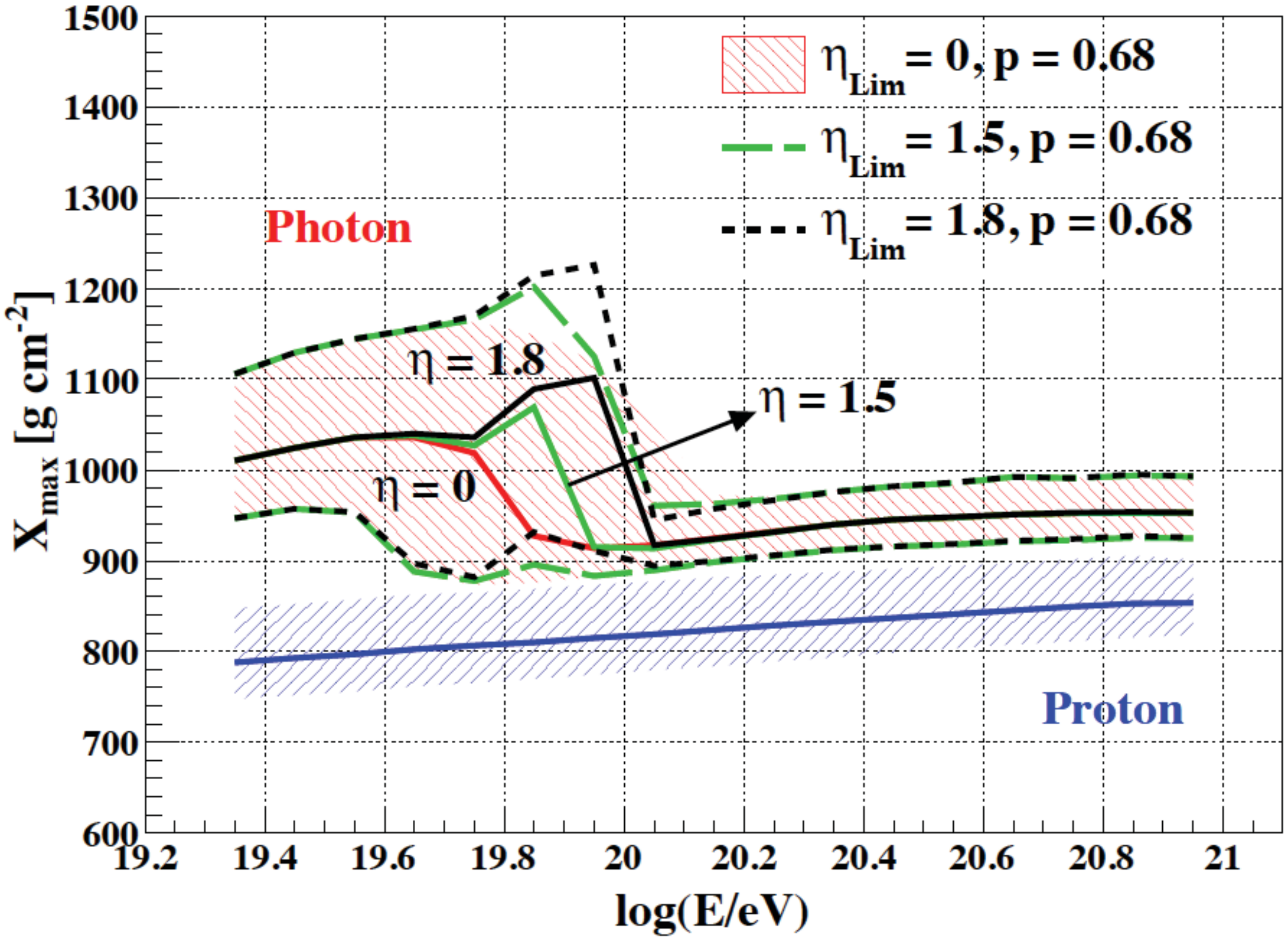
Upper limits on the photon-abundance – simple approach

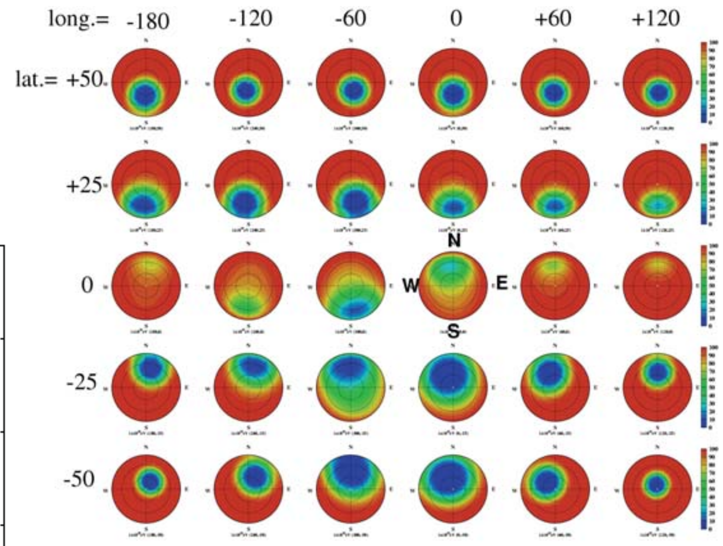
Adapted fromAuger Collaboration, Astroparticle Phys. 31 (2009) 399–406



For a sample of size N, a rejection level α, and the ad hoc assumption that there are no γ events in the sample → $\mathcal{F}_{\gamma}^{min} = 1 - (1-\alpha)^{1/N}$

X_{max}: protons vs. photons



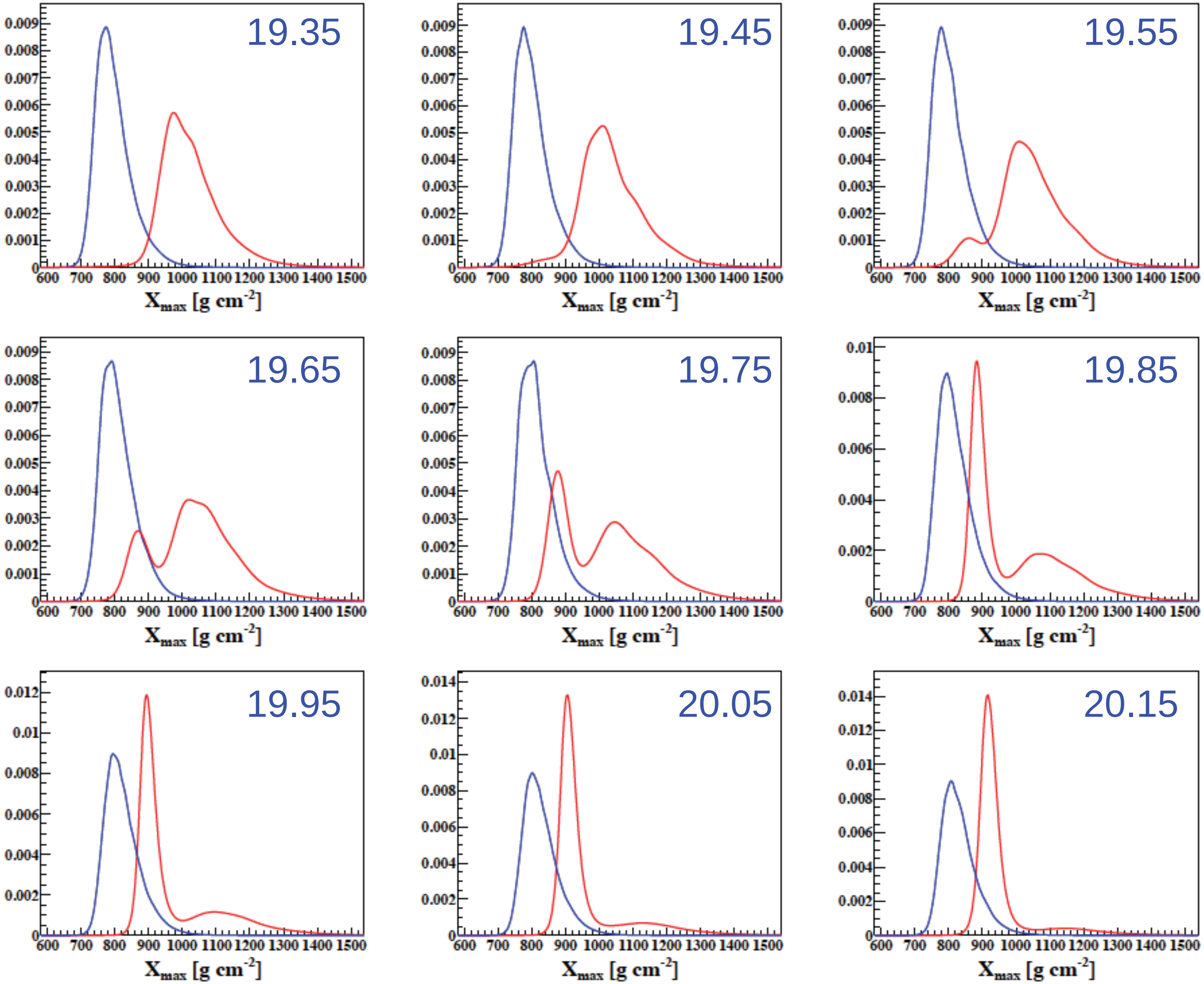


Angular dependence of the probability of the extreme energy gamma rays interacting with the geomagnetic field.

Each panel shows horizontal coordinates at the different longitude and latitude on the Earth. From the bluer patches of the sky, extreme energy gamma rays are more likely to initiate an EAS with large X_{max} due to the LPM effect

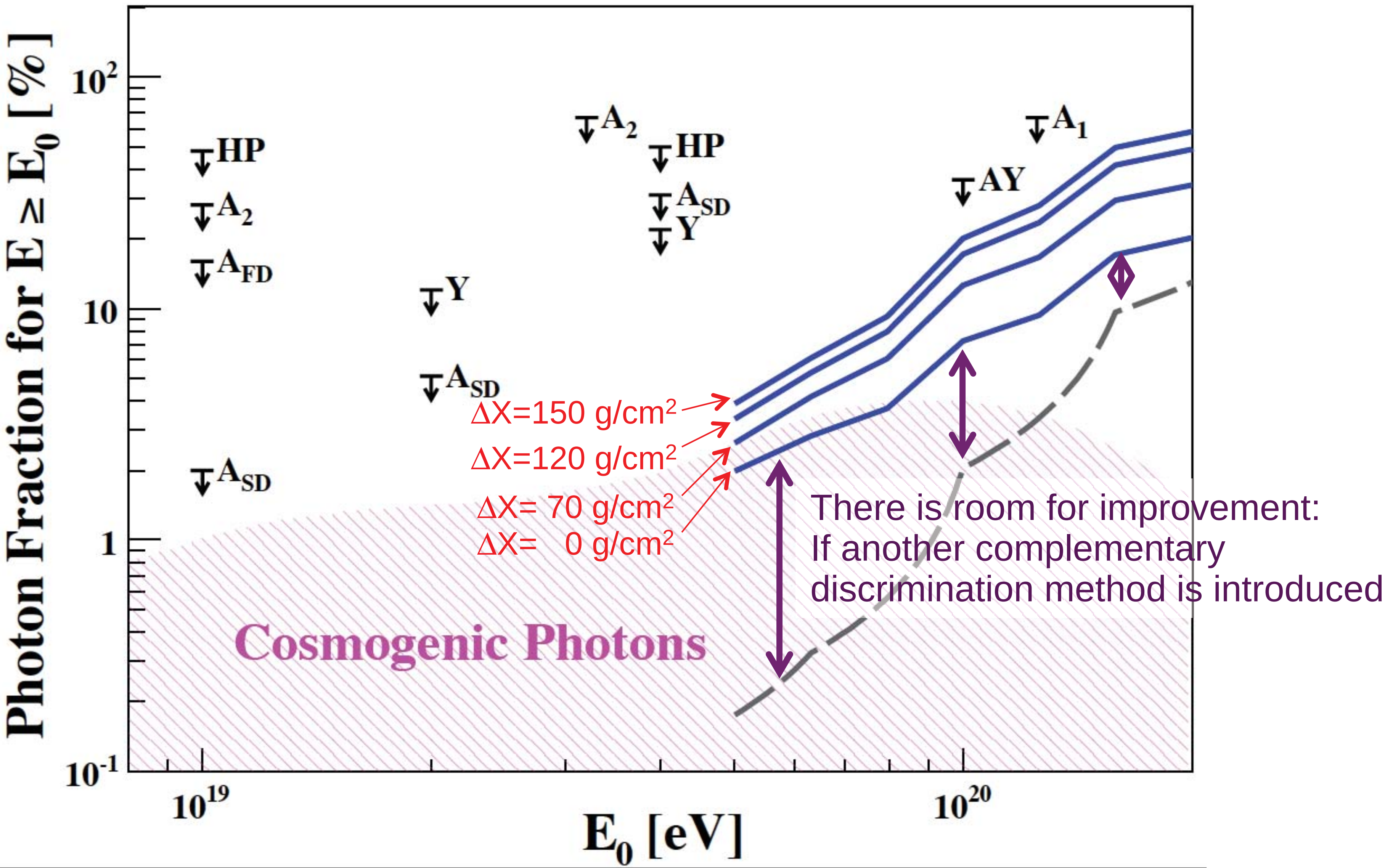
X_{max}: protons vs. photons

log(E) = 19.35 -- 20.15, Δlog(E) = 0.1



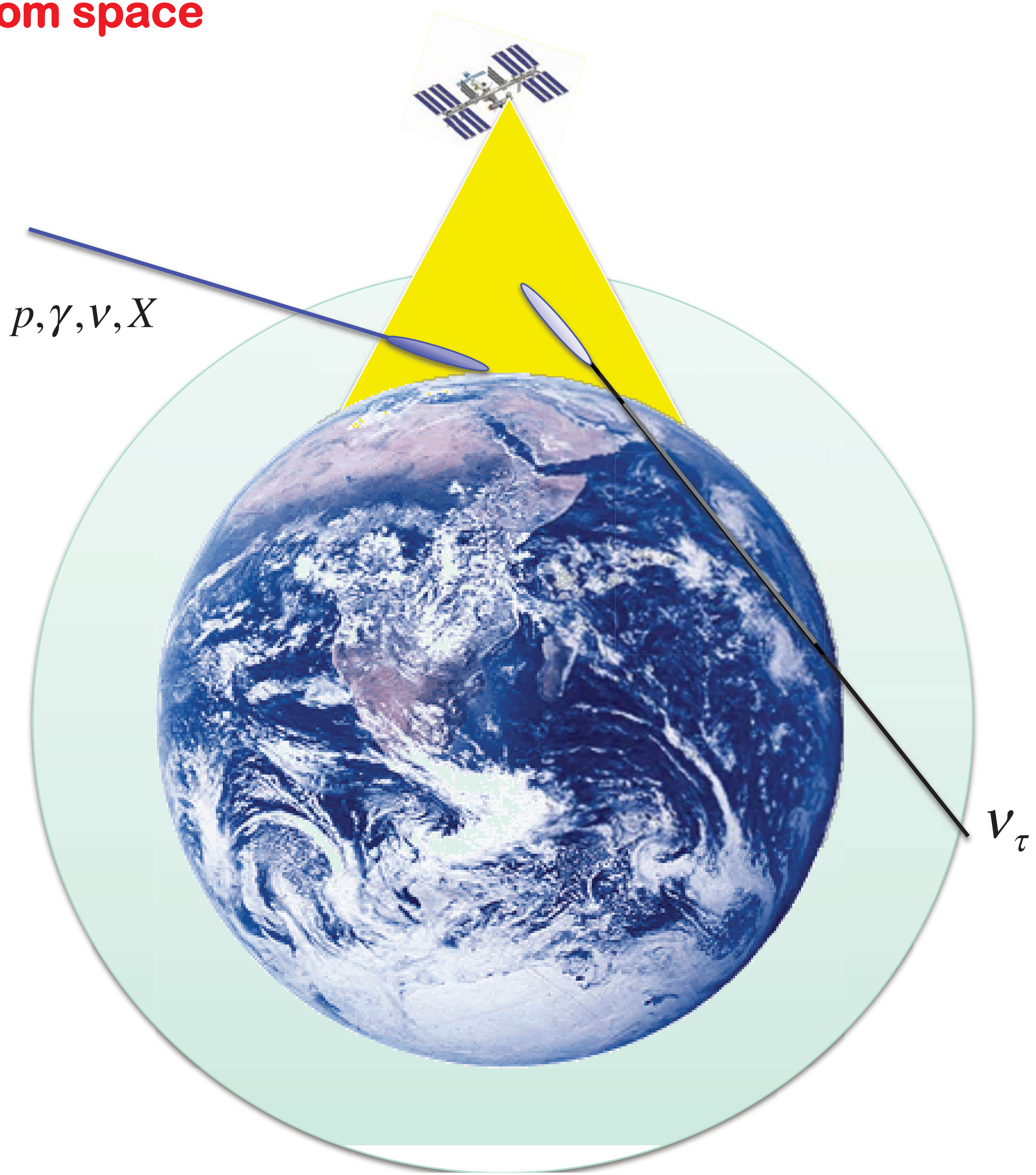
Upper limits on the photon-abundance

Supanitsky & Medina-Tanco, Astropart. Phys. 2011



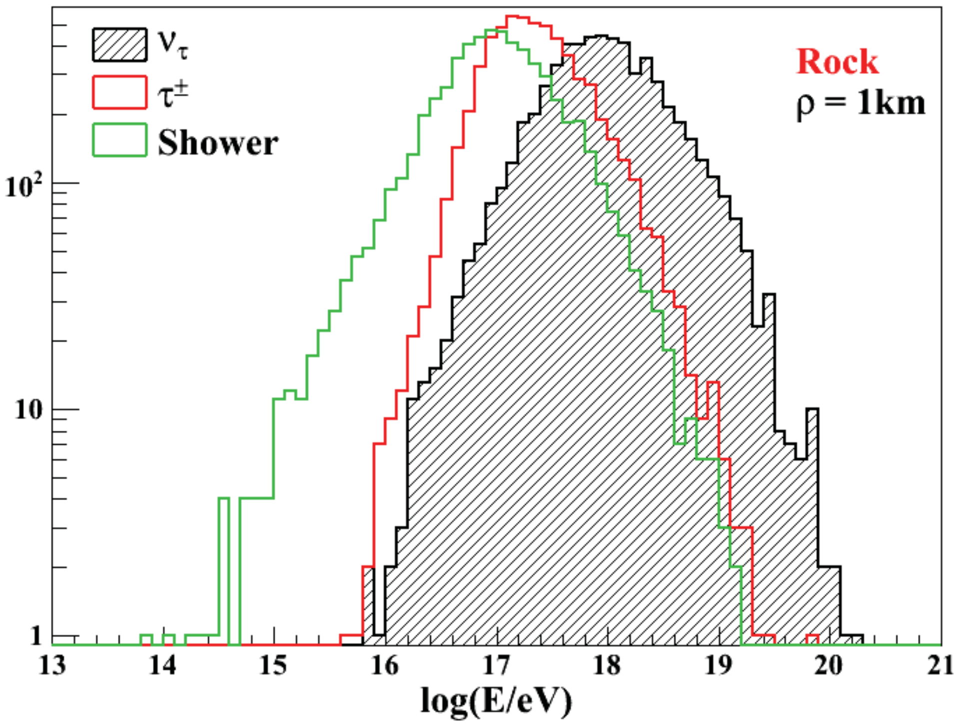
The upper limits on the fraction of photons in the integral cosmic ray flux at 95% of confidence level. Dashed line corresponds to the ideal case in which it is known that there is no photon in the data. Solid red lines are the upper limits obtained by using the optimized cut method. Dash-dot-dash blue lines are the upper limits obtained by using ξX_{max} method. For each method, the lines from bottom to top correspond to a Gaussian uncertainty of 0, 70, 120 and 150 g cm^2. Shadow region is the prediction for the GZK photons [1]. Black arrows are experimental limits, HP: Haverah Park [20]; A1, A2: AGASA [21,22]; AFD, ASD: Auger [23,24]; AY: AGASA-Yakutsk [25]; Y: Yakutsk [26].

Neutrinos from space



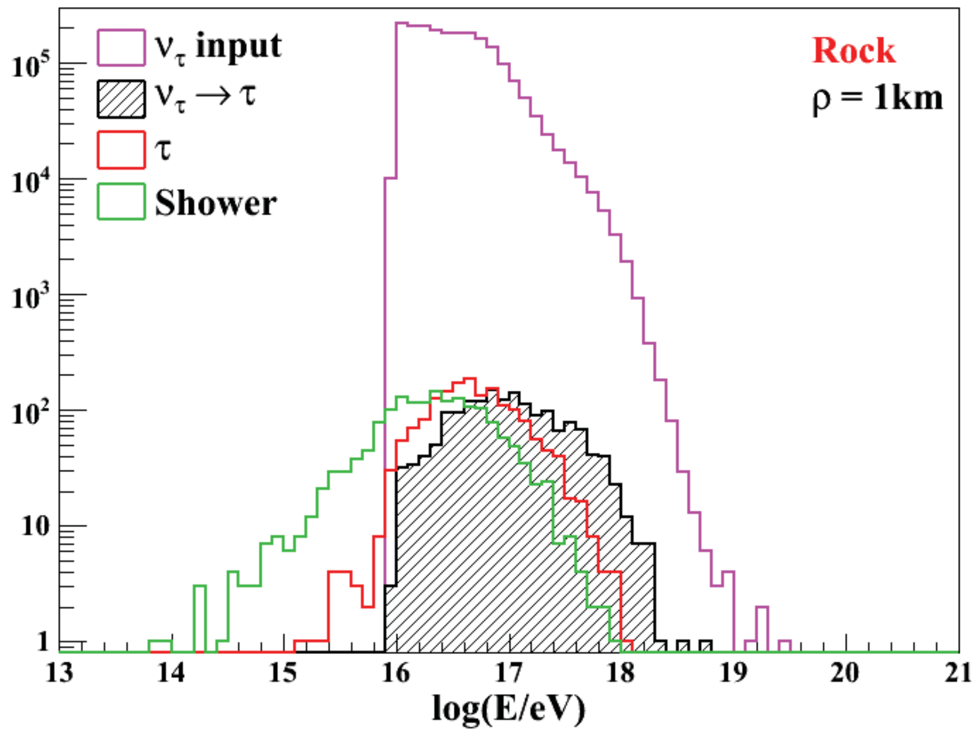
Neutrino discrimination: up-going tau neutrino

COSMOGENIC



GRB

Supanitsky & Medina-Tanco, 2011

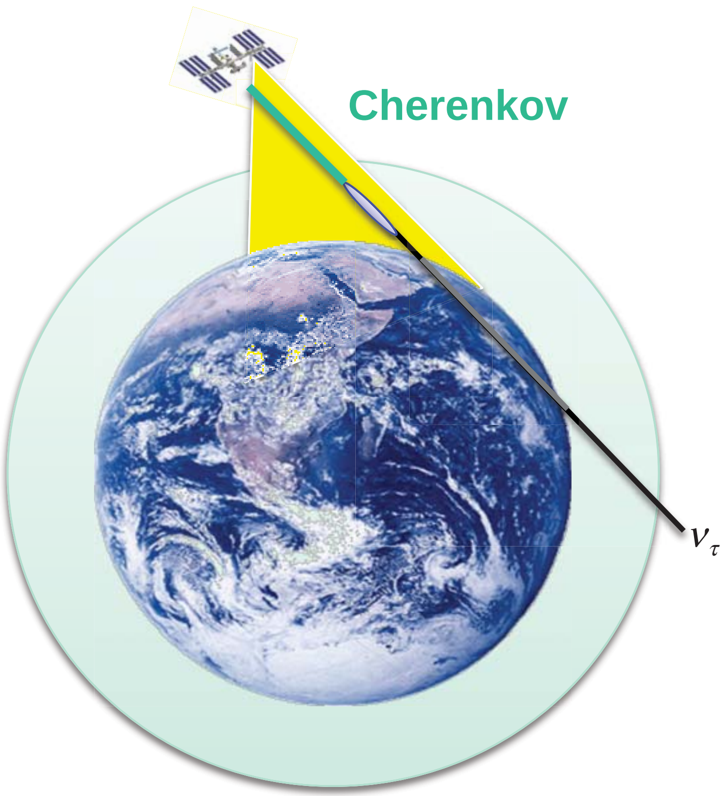


Neutrino discrimination: up-going tau neutrino

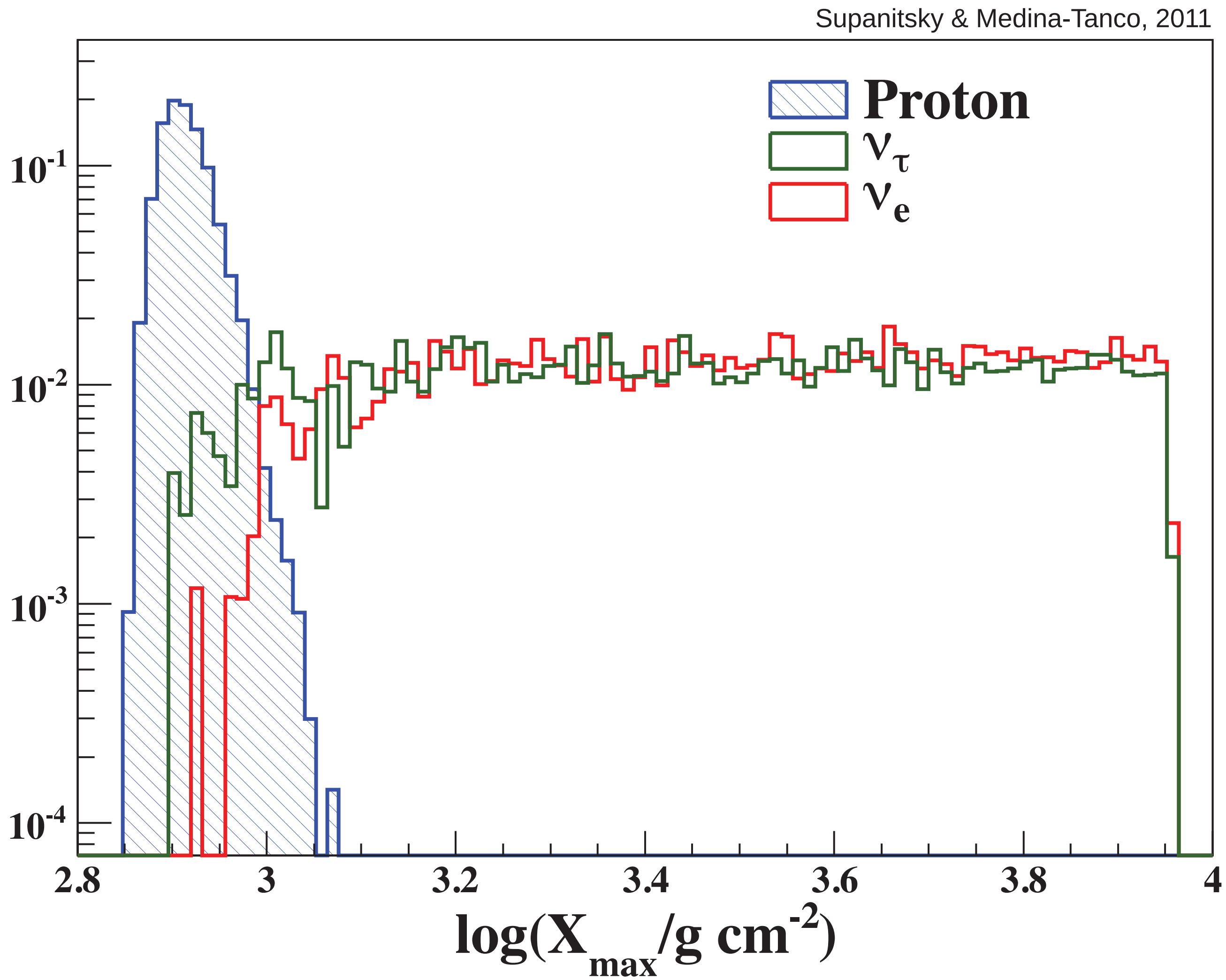
Trivial discrimination … but only if it is realistically observable:

-- Background due to environmental radiation should be low enough

-- Trigger must be adequately configured:
which probably renders useless the detector for regular EECR showers unless it is only used in coincidence



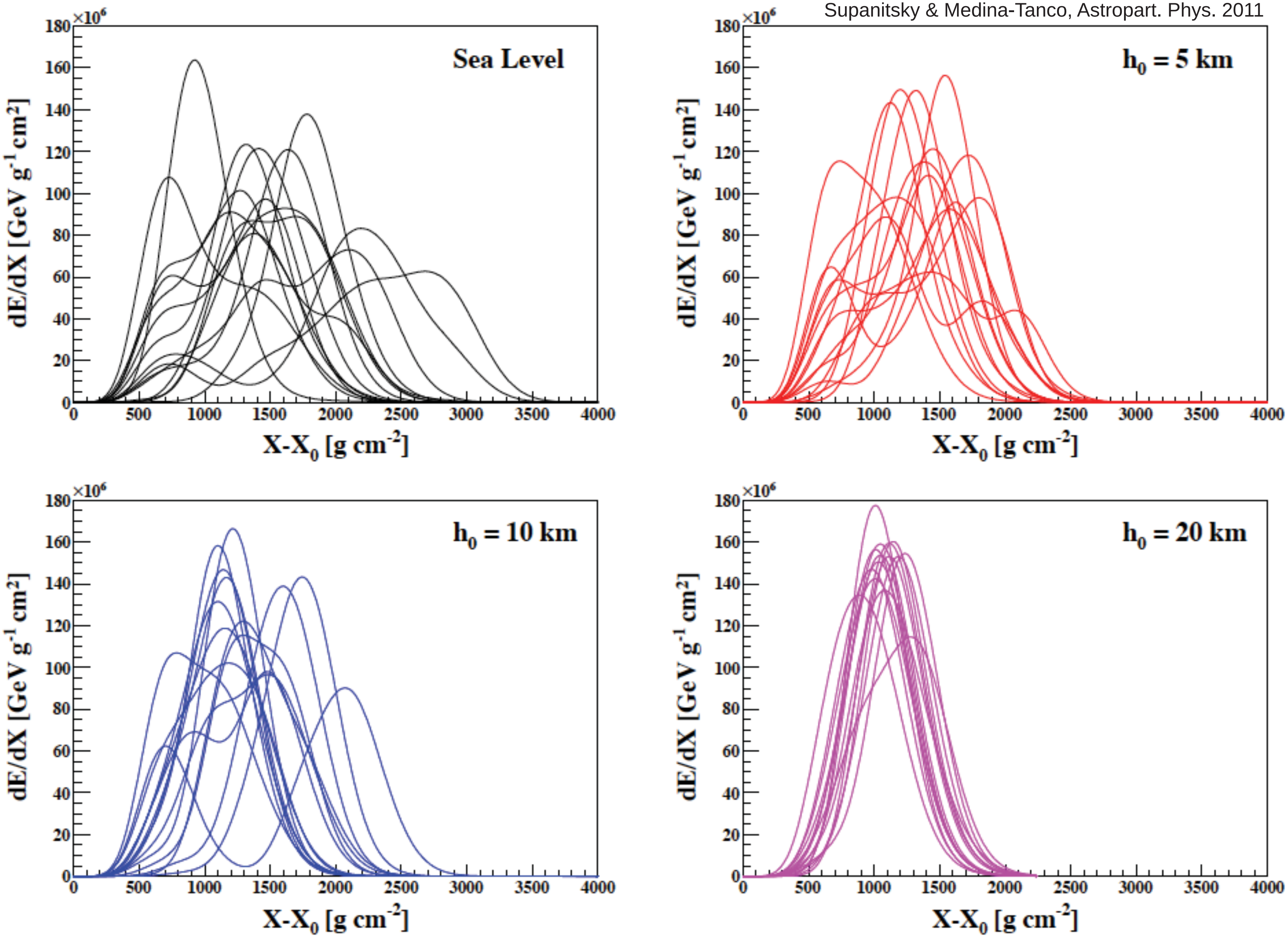
Neutrino discrimination: down-going neutrinos



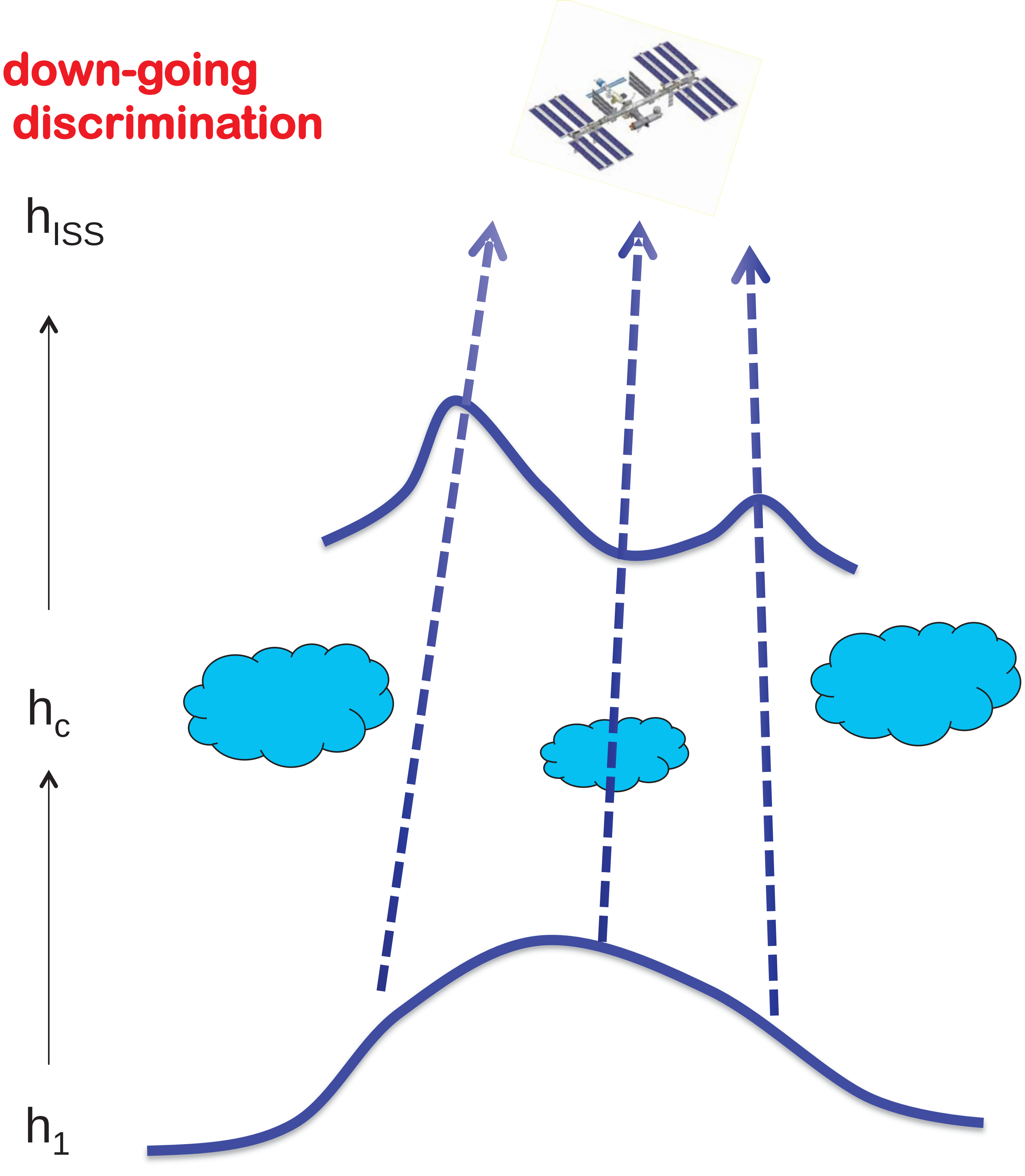
Distribution of the first peak of the profiles for proton and neutrinos of $E = 10^{20}$ eV and $\theta = 85^{o}$.

Inclined down-going neutrino discrimination

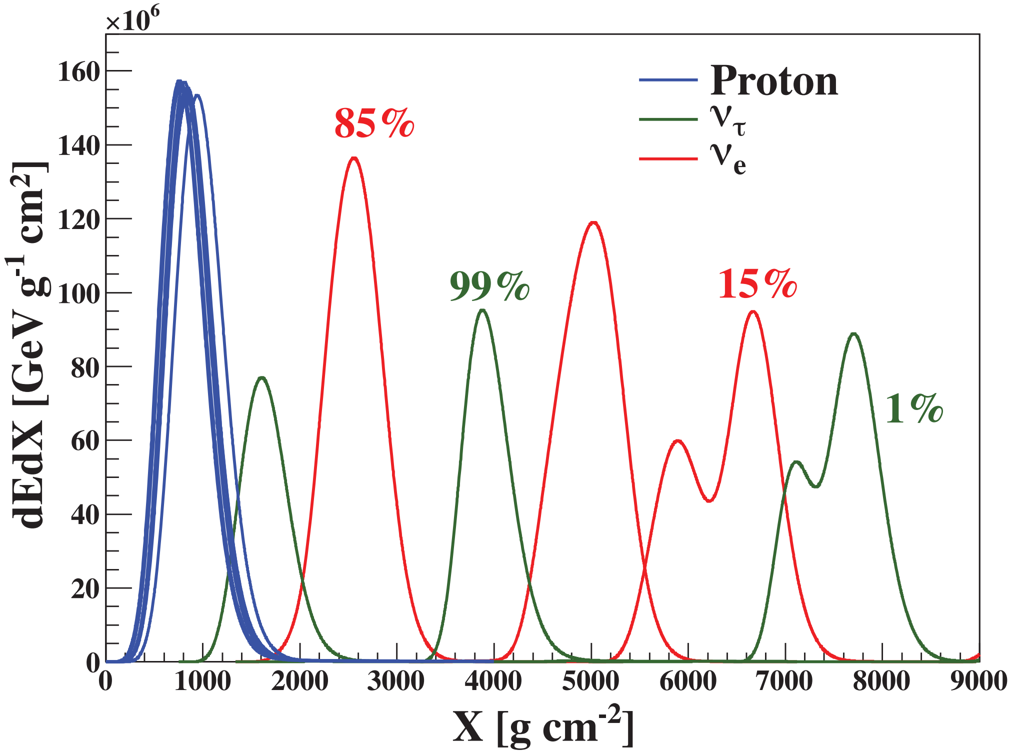
Supanitsky & Medina-Tanco, Astropart. Phys. 2011

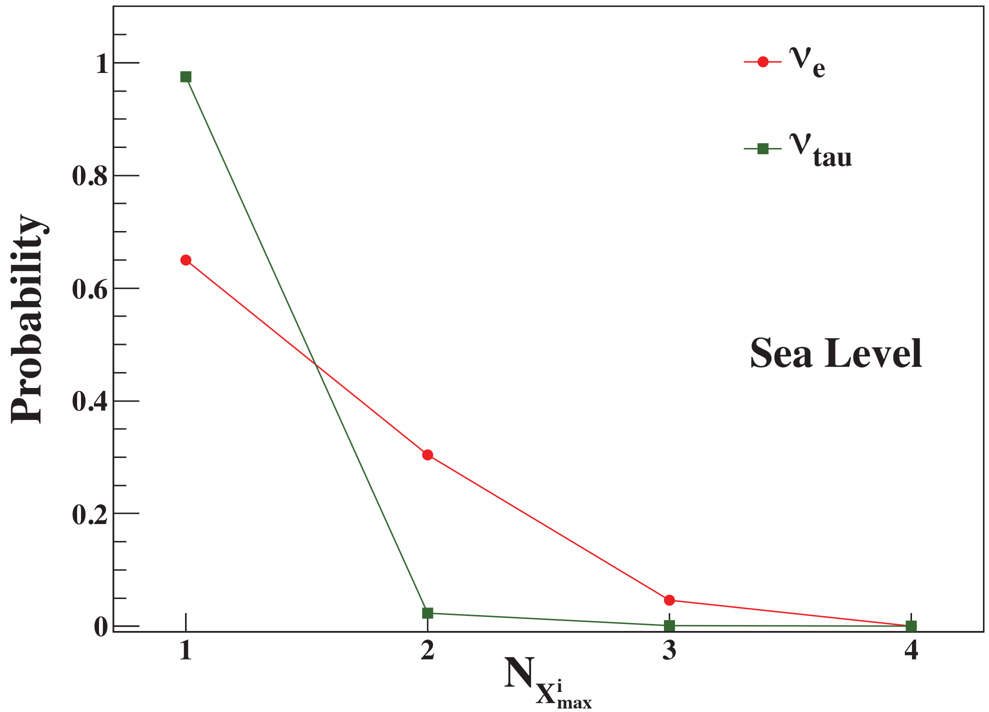


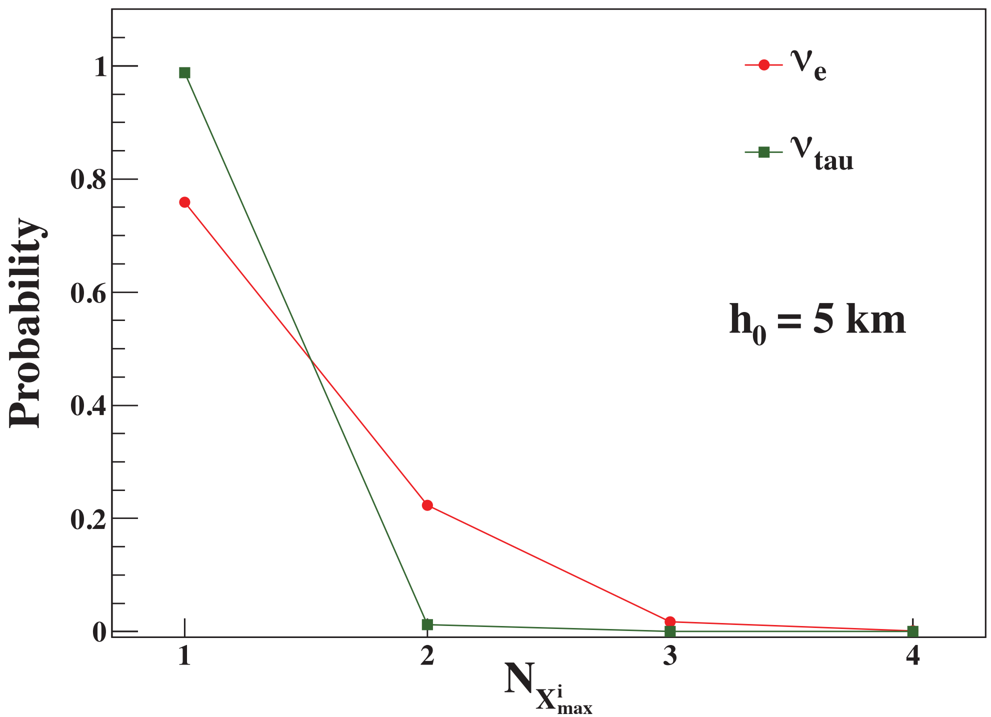
Inclined down-going neutrino discrimination



Inclined down-going $\nu_e - \nu_\tau$ discrimination

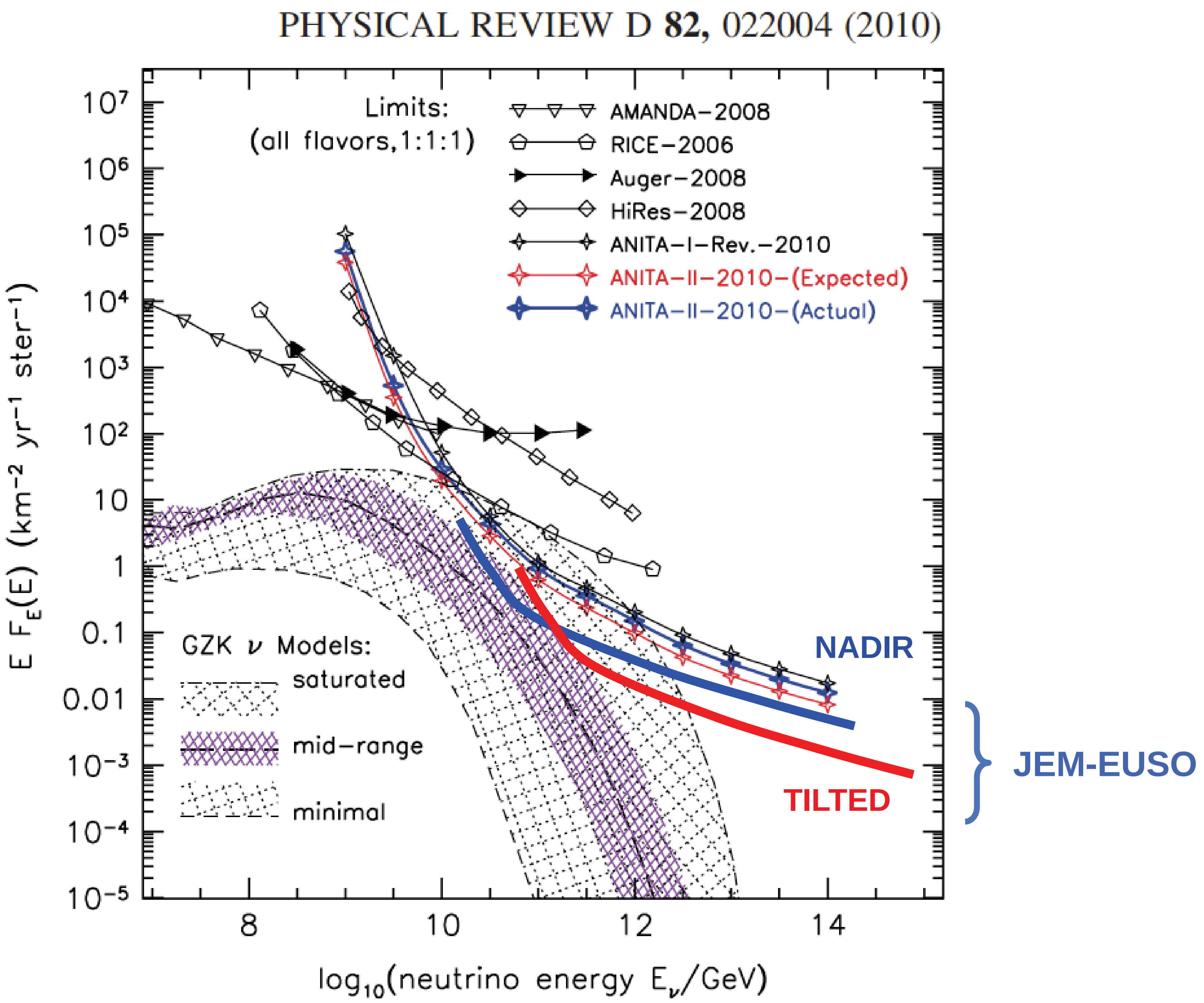




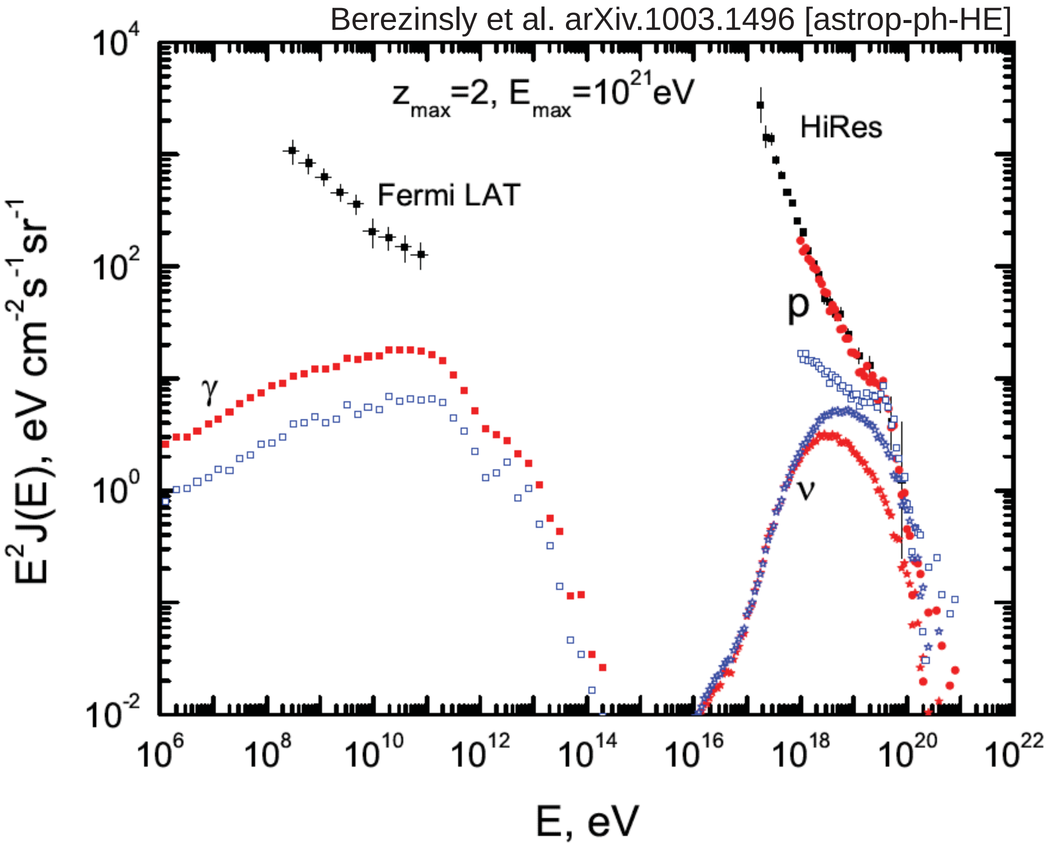


CC interactions considered
NC neglected

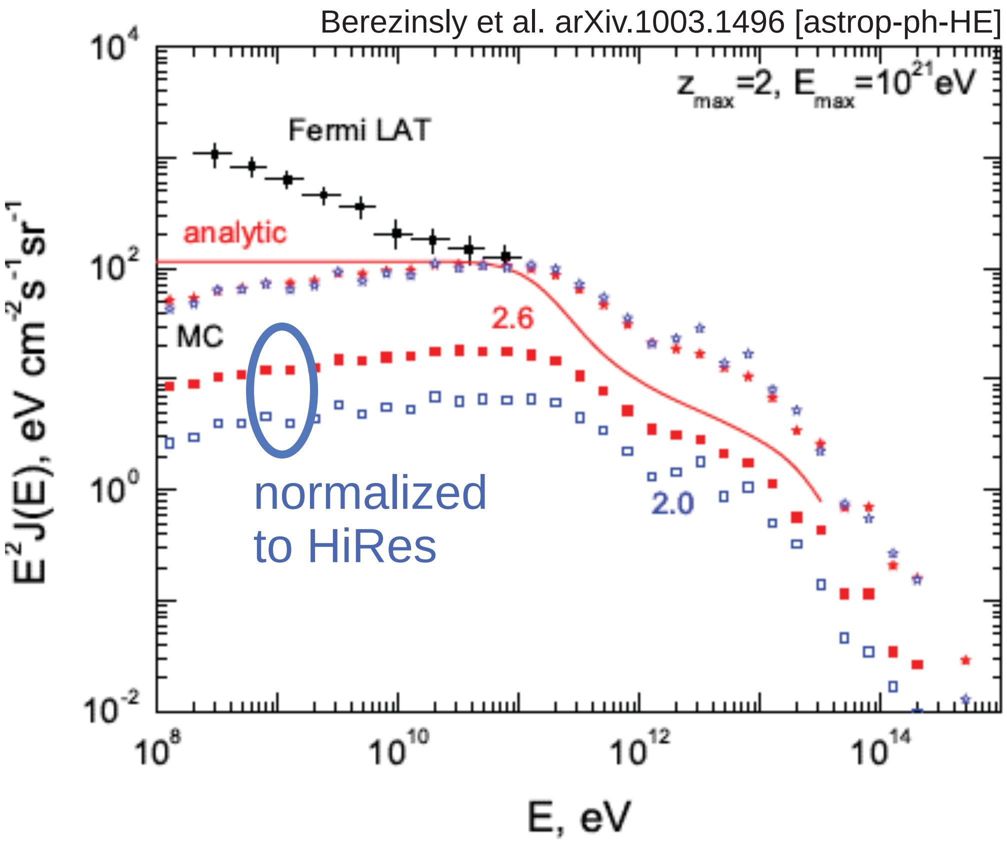
Upper limits on neutrino flux – ideal case



New FERMI-LAT constraints

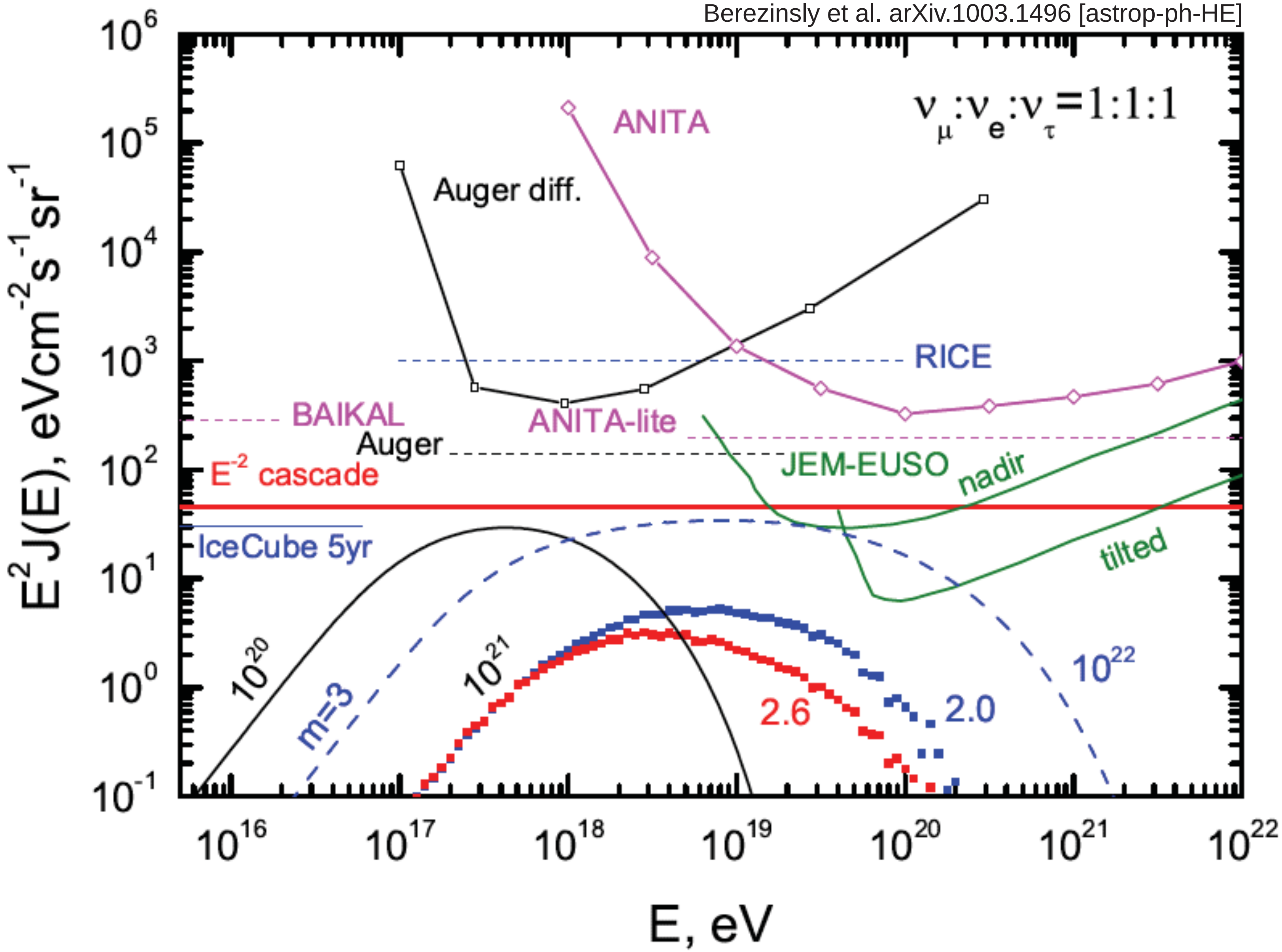


Fermi-LAT data (black circles) for the EGRB and UHECR data from HiRes (dots) together with UHE neutrino (stars) and photon (boxes) fluxes for $E_{\max} = 10^{21}$ eV, $z_{\max} = 2$, $m = 0$ and $\alpha_g = 2.0$ (blue, open) and $\alpha_g = 2.6$ (red, filled symbols).



Fermi-LAT EGRB spectrum (black circles with with error bars) in comparison with maximally allowed fluxes given by analytical (solid red line) and MC calculations (red stars for $\alpha_g = 2.6$, and blue stars $\alpha_g = 2.0$). All three curves are normalized by the highest energy point of the Fermi spectrum. The MC EGRB fluxes are calculated for the following values of the parameters: $E_{\max} = 10^{21}$ eV, $z_{\max} = 2$, $m = 0$ and $\alpha_g = 2.6$ or 2.0. Also shown two MC spectra with the same parameters as above, but normalized to the HiRes proton spectrum (red boxes for $\alpha_g = 2.6$ and blue boxes for $\alpha_g = 2.0$). The plot illustrates the universality of the cascade spectrum and reasonably good agreement between MC and analytical results.

New FERMI-LAT constraints

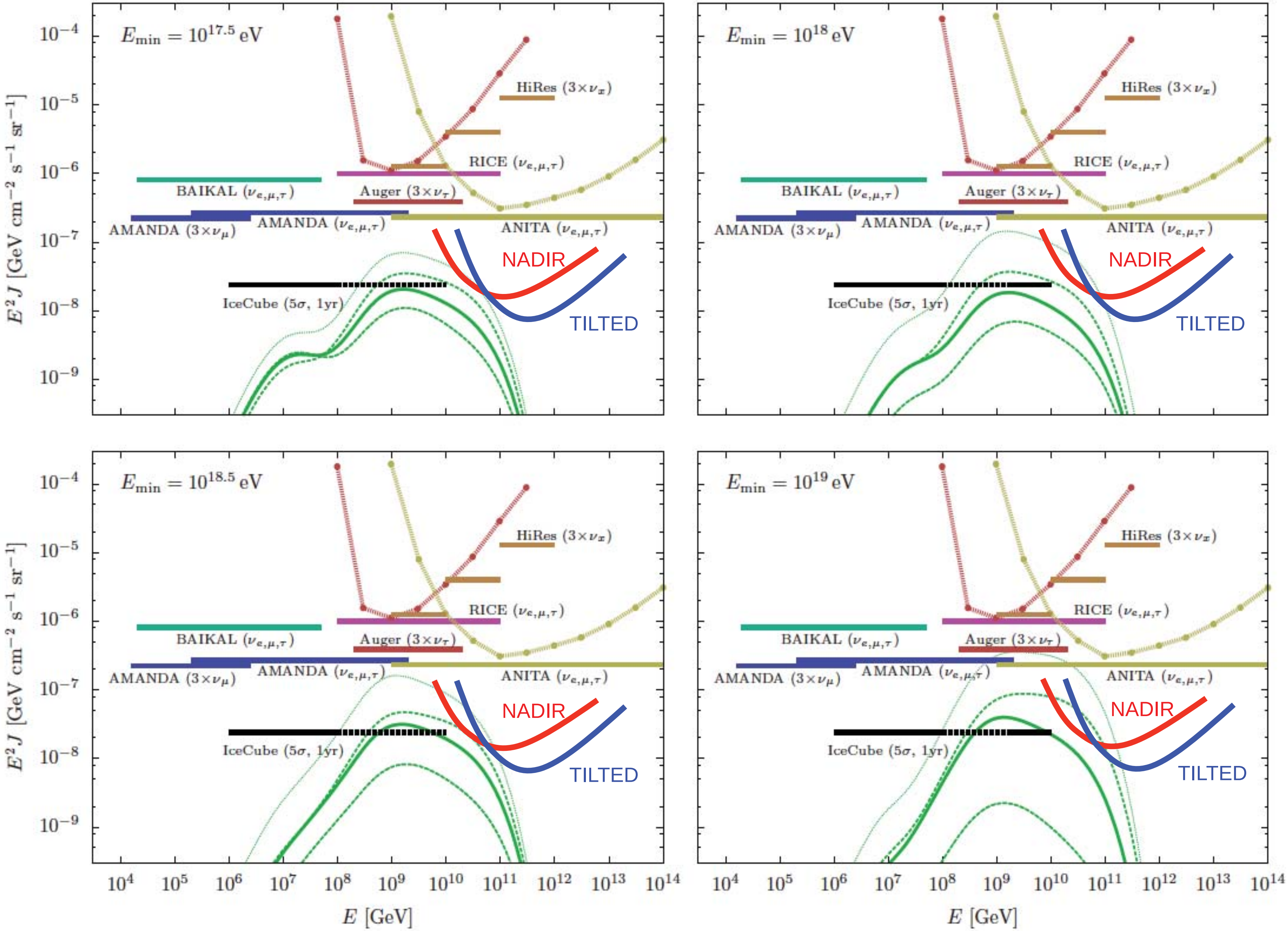


Only very extreme models can be constrained by JEM-EUSO

But …

Ahlers et al, arXiv:1005.2620v2 [astro-ph-HE]

The CNB is still constrained by JEM-EUSO for large corss-over energies (E_{cr}>$10^{18.5}$eV)



LIV for HE electrons and photons

The same argument of Glashow & Coleman can be applied to the decay of photons into e-pairs

$$\delta_{e\gamma} = c_e - c_\gamma$$

If $\delta \neq 0$ $\longrightarrow$ $\gamma \to e^+ + e^-$ is kinematically allowed for all photons with:

$$E > m_e \sqrt{\frac{2}{|\delta|}}$$

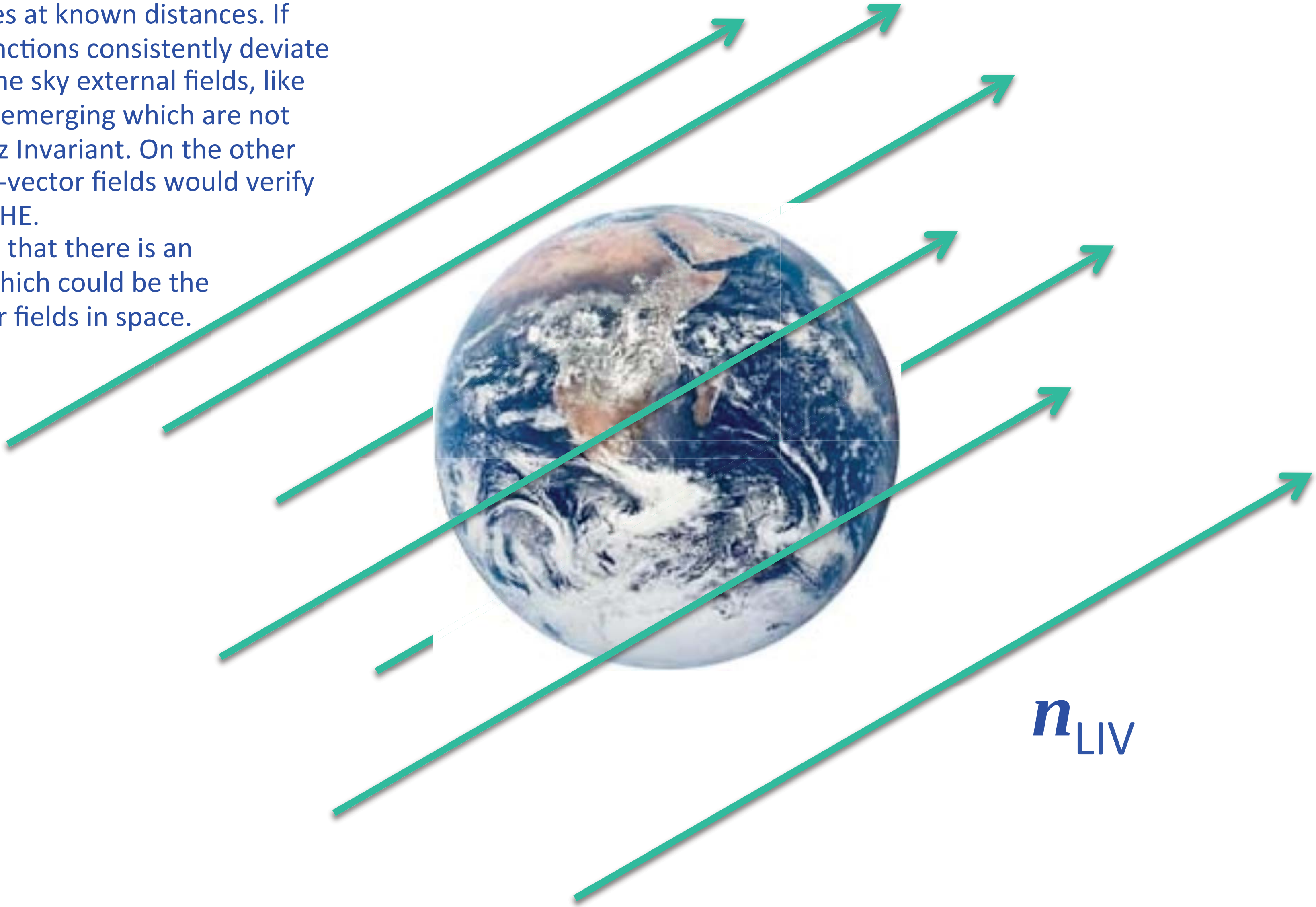
Thus even a trivial (but still restrictive) limit on δ comes from the mere eventual observation of HE photons by JEM-EUSO at ~ 10^{20} eV:

$$\delta_{e\gamma} < \frac{2m_e^2}{E_{\max}^2} \approx \frac{2 \times \left(5 \times 10^5\right)^2}{\left(10^{20}\right)^2} \sim 5 \times 10^{-29}$$

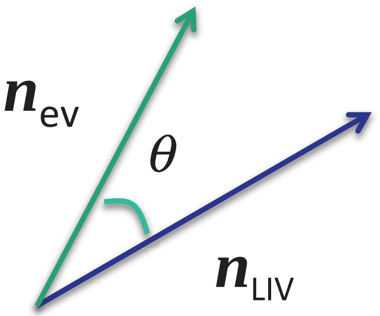
LI space symmetry violations

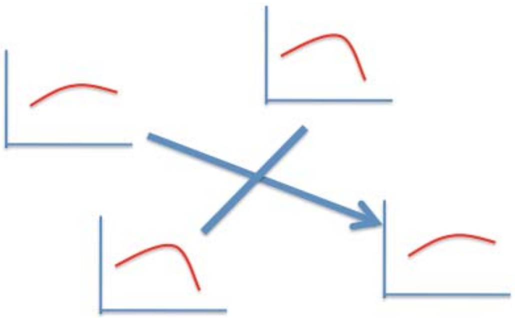
The possibility exists that there is an asymmetry in space, which could be the manifestation of vector fields in space.

A stringent test of relativity could be made from high multiplicity sources at known distances. If the GZK steepening functions consistently deviate at some directions in the sky external fields, like vector fields, might be emerging which are not unidirectionally Lorentz Invariant. On the other hand, the proof of non-vector fields would verify Lorentz Invariance at EHE.
The possibility remains that there is an asymmetry in space, which could be the manifestation of vector fields in space.

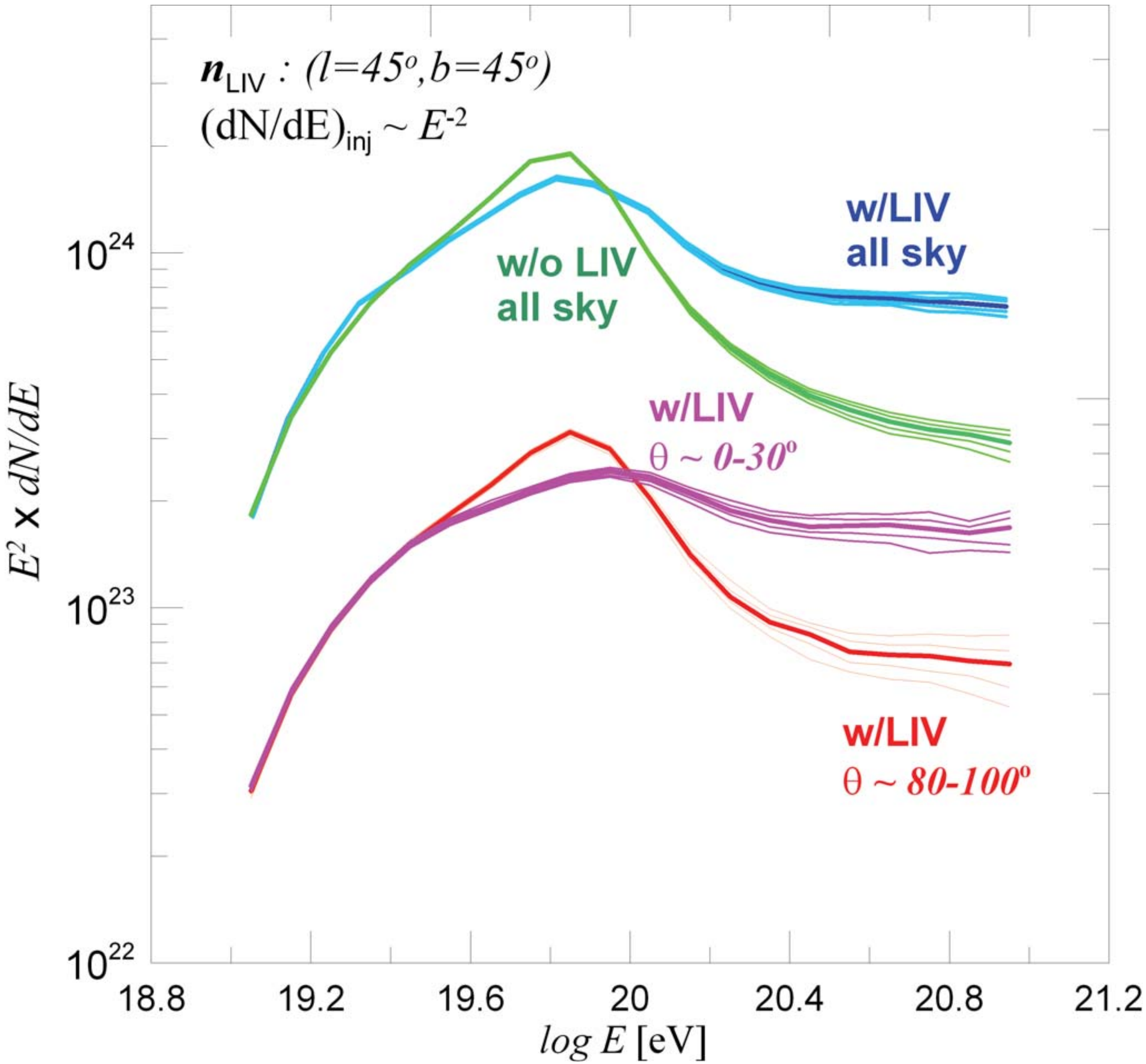


UHECR spectra at different region of the sky

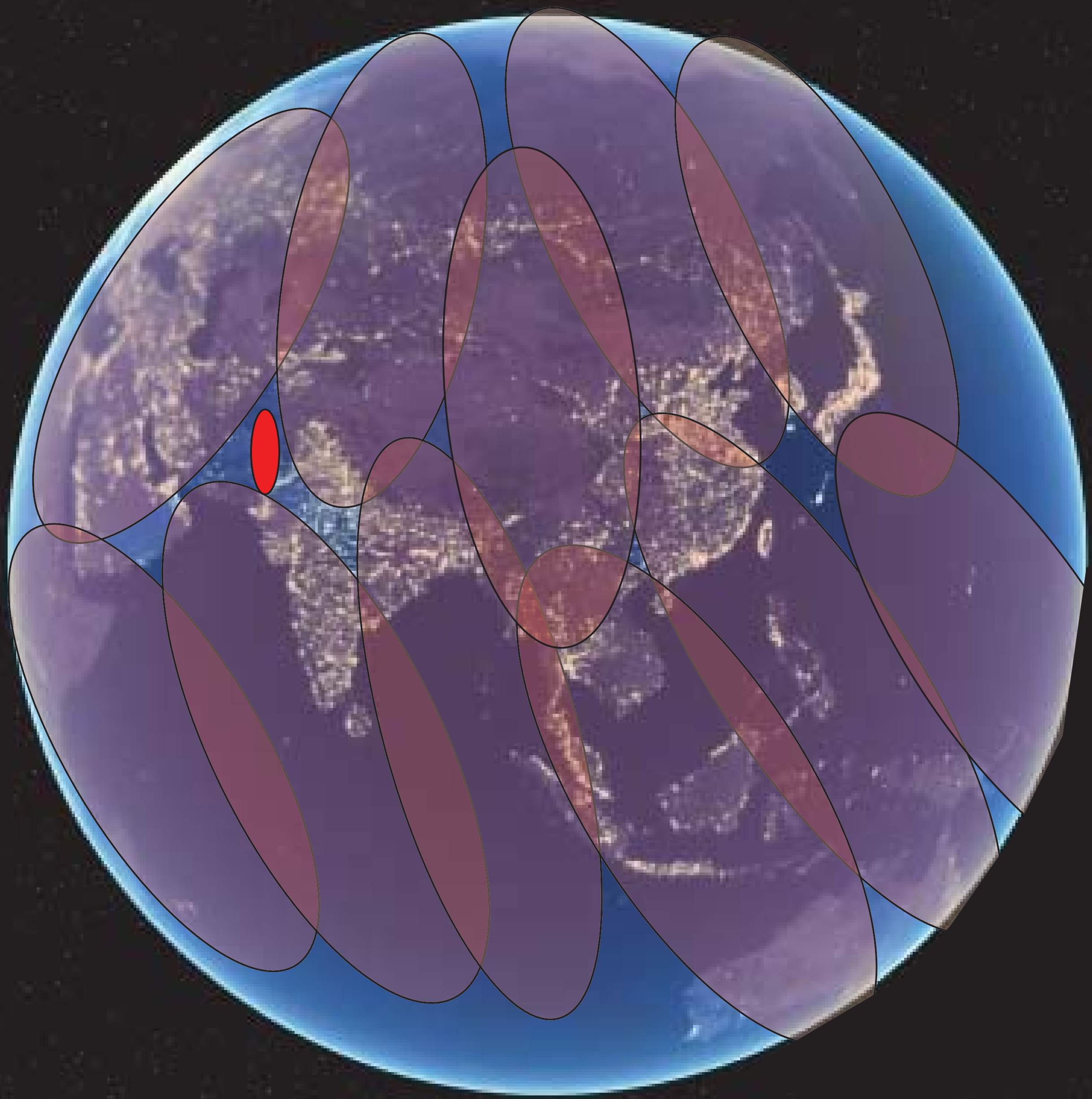




C.L.: 68% & 95%
ICRC 2009 exposure
& trigger efficiency



Maximal detector



Maximal detector

$$\zeta_{max} = f_C \times f_D \times A_{Earth}$$

$$\zeta_{max} \sim 71 \times 10^6 km^2$$

$$\zeta_{max} \sim 710 \times \zeta_{JEM-EUSO}$$

$$\Phi_{max}(> 55EeV) \sim 1.4 \times 10^5 \ yr^{-1}$$
$$\Phi_{max}(> 100EeV) \sim 4260 \ yr^{-1}$$

$$\Phi_{max}^{No \ Recovery}(> 1ZeV) \sim 0.05 - 0.5 \ yr^{-1}$$
$$\Phi_{max}^{Recovery}(> 1ZeV) < 5 \ yr^{-1}$$