Extreme Energy Universe

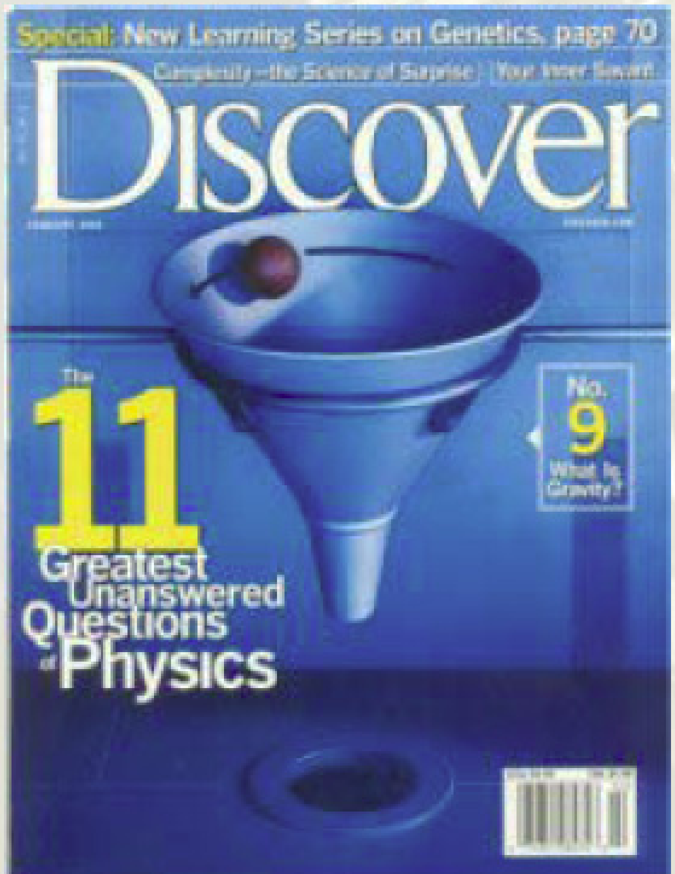
Yoshiyuki Takahashi

The University of Alabama in Huntsville, USA;

NASA MIDEX EUSO, Instrument Scientist

Scientific Motivation

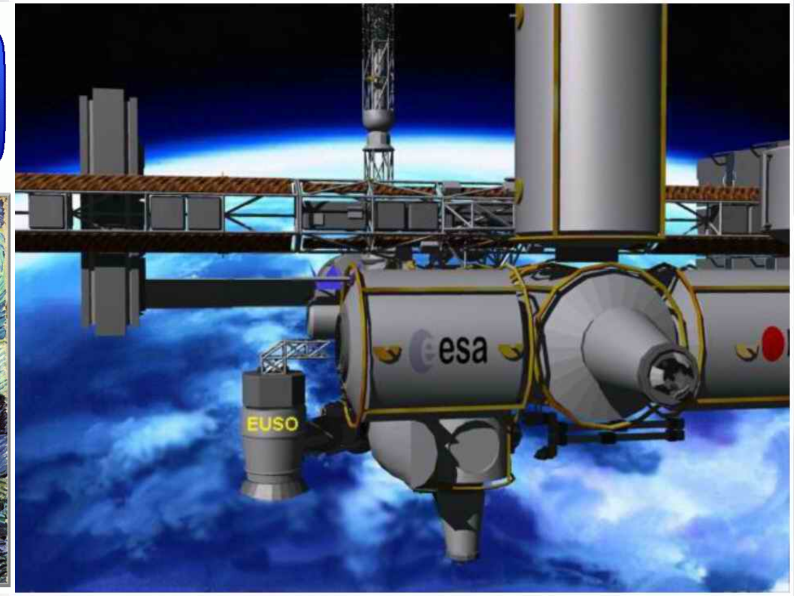
The Discover cover story is based on the 105-page National Research Council Committee on Physics of the Universe report Connecting Quarks with the Cosmos: 11 Science Questions for the New Century.



(Discover Magazine's Cover Story For February 2002)

1. What is dark matter?
2. What is dark energy?
3. How were the heavy elements from iron to uranium made?
4. Do neutrinos have mass?
5. Where do ultra-energy particles come from?
6. ~~Is a new theory of light and matter needed to explain what happens at very high energies and temperatures?~~
7. ~~Are there new states of matter at ultrahigh temperatures and densities?~~
8. Are protons stable?
9. What is gravity?
10. Are there additional dimensions?
11. How did the universe begin?

EUSO



Extreme Universe Space Observatory

The First Space Mission
To Explore the Extremes of the Universe
Using the Highest Energy Cosmic Rays and Neutrinos
...doing Astronomy looking downwards the Earth Atmosphere ...

EUSO Consortium - Institutes

The EUSO instrument consortium is truly global in nature with >150 researchers in 50 institutions in 6 countries in Europe, the USA, Japan and Brazil.

Participant Nations and Institutions

- **Brazil**
  - IAG, Univ Sao Paulo
- **France**
  - APC, Paris
  - CdF, Paris
  - IAP, Paris
  - LPSC, Grenoble
  - LPTHE, Paris
  - OdP, Paris
- **Italy**
  - IASF, Palermo
  - ISAC-CNR, Bologna
  - INFN & Univ. Genova
  - INFN & Univ. Firenze
  - INFN & Univ. Torino
  - INFN & Univ. Trieste
  - INFN Catania & Univ. Palermo
  - Univ. Roma “La Sapienza”
  - Scuola Normale Sup. Pisa
  - Oss. Astrofisico Arcetri
  - Oss. Astrofisico Catania
  - CARSO
  - INOA
- **Germany**
  - MPIfP, Munich
  - MPIHLL, Munich
  - MPIfRA, Bonn
  - Univ. Wuerzburg
- **Portugal**
  - LIP, Lisbon
- **Spain**
  - IAA-CSIC, Granada
  - Dpt.FTC & CAFPE, Univ. Granada
- **Switzerland**
  - Obs. Neuchatel
- **USA**
  - MSFC & NSSTC, Huntsville
  - UAH, Huntsville
  - UCB, Berkeley
  - UCLA, Los Angeles
  - Vanderbilt Univ.
- **Japan**
  - RIKEN
  - ICRR
  - Konan Univ.
  - ISAS
  - Rikkyo
  - KEK
  - NAO
  - Tokyo Univ.
  - Saytama
  - Aoyama
  - Kinki
  - Seikei
  - Kanazawa

Foreword - Essentials about EUSO .

Proposal :

On October 1999 the mission “Extreme Universe Space Observatory – EUSO” was proposed by a Consortium of Institutes to ESA as a “Free Flyer“ in response to an A.O. issued by the Science Directorate for “2 Flexi Missions (F2 / F3)“ to complement the “Science Mandatory Program“ in the time span up to 2010.
The A.O. was extended to exploit the Space Station facilities .

Science Objectives :

High Energy Cosmic Rays and Neutrino Astronomy .

Project Consortium :

Members from Europe (Italy, France, Germany, Portugal, Switzerland, Spain), USA, Japan and Brazil .
International Space Agencies involved : ESA , NASA and JAXA.

The Beginning: from “Free Flyer” to “Space Station”

In June 2000 , EUSO has been selected by the “Science Program Committee SPC” of ESA, together with a Proposal for an X-Ray Sky survey mission (“Lobster”), for implementation as “External Payload” for the Columbus Module contributed by ESA as a segment of the International Space Station.

To evaluate the feasibility of the conversion from Free Flyer to the Space Station platform , ESA carried out in 2000 for EUSO an “Accommodation Study” on shared responsibility between the Directorates for “Science” and “Manned Space Flight and Microgravity, MSM”. The Study was successfully concluded with the recommendation to proceed to a normal Phase A Study .

The recommendation was endorsed by both the “ Science Program Committee–SPC” and the “Manned Space Program Board” in their meetings in February 2001.

The EUSO Phase A Study.

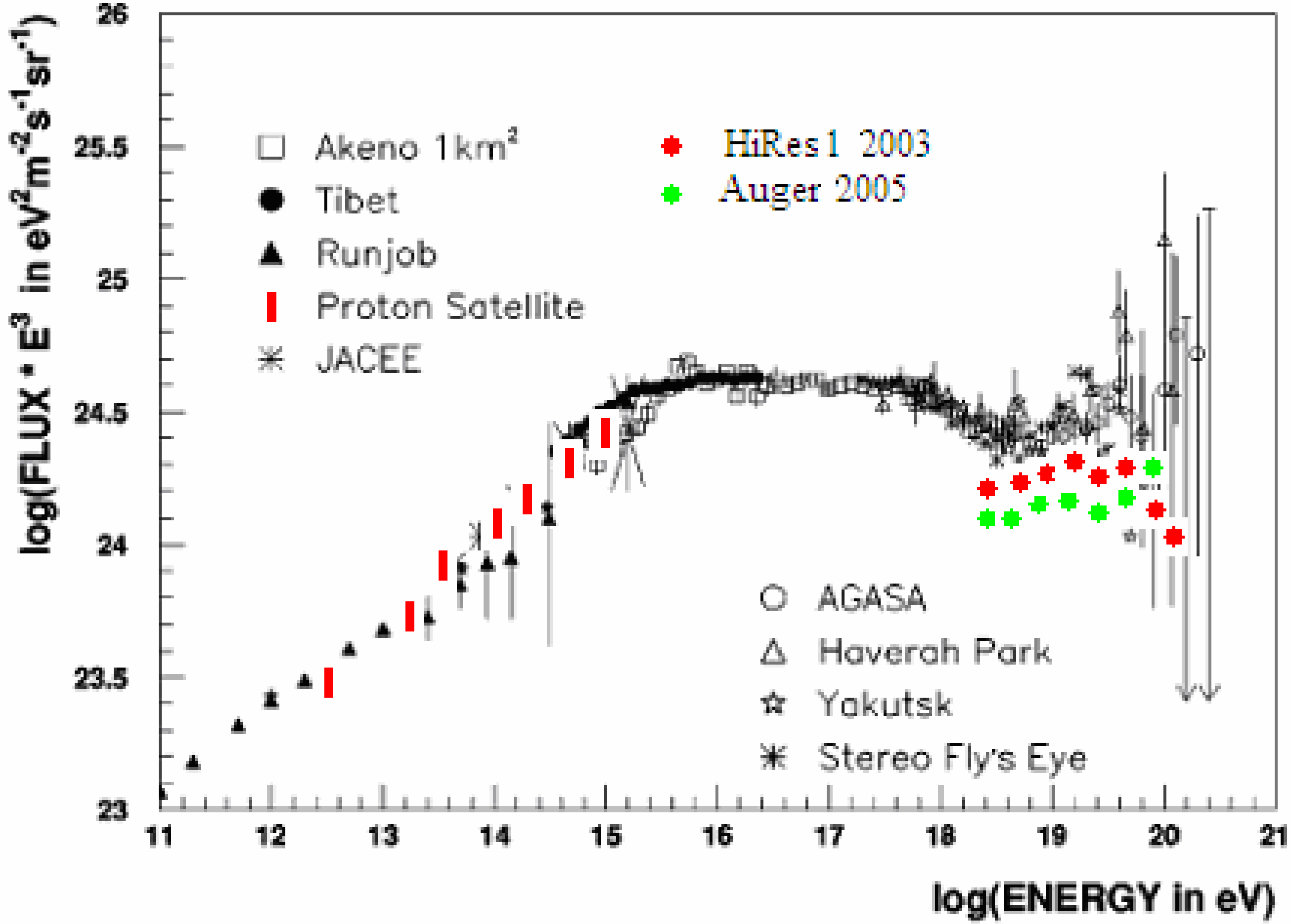
“Payload” defined as the activity concerning the robotically handled transportation , accommodation on the CEPF) and operation in orbit .
The Study , contracted by ESA to “Alenia Spazio” started in 2002 and ended in June 2004 : an extension from October 2003 considers transportation systems alternative to the Shuttle .
“Instrument” defined as the Hardware and the Scientific Ground Segment (Simulations , Science Data Analysis and Science Operation Centre), under the responsibility of the Consortium and funded by the National Space Agencies or Institutions, started in 2001 and ended in March 2004
.
The two Studies were jointly reviewed by an ESA appointed Panel:

In their meeting at ESTeC on 15 July 2004 the Panel considered successfully completion of the EUSO Phase A Study and concluded :

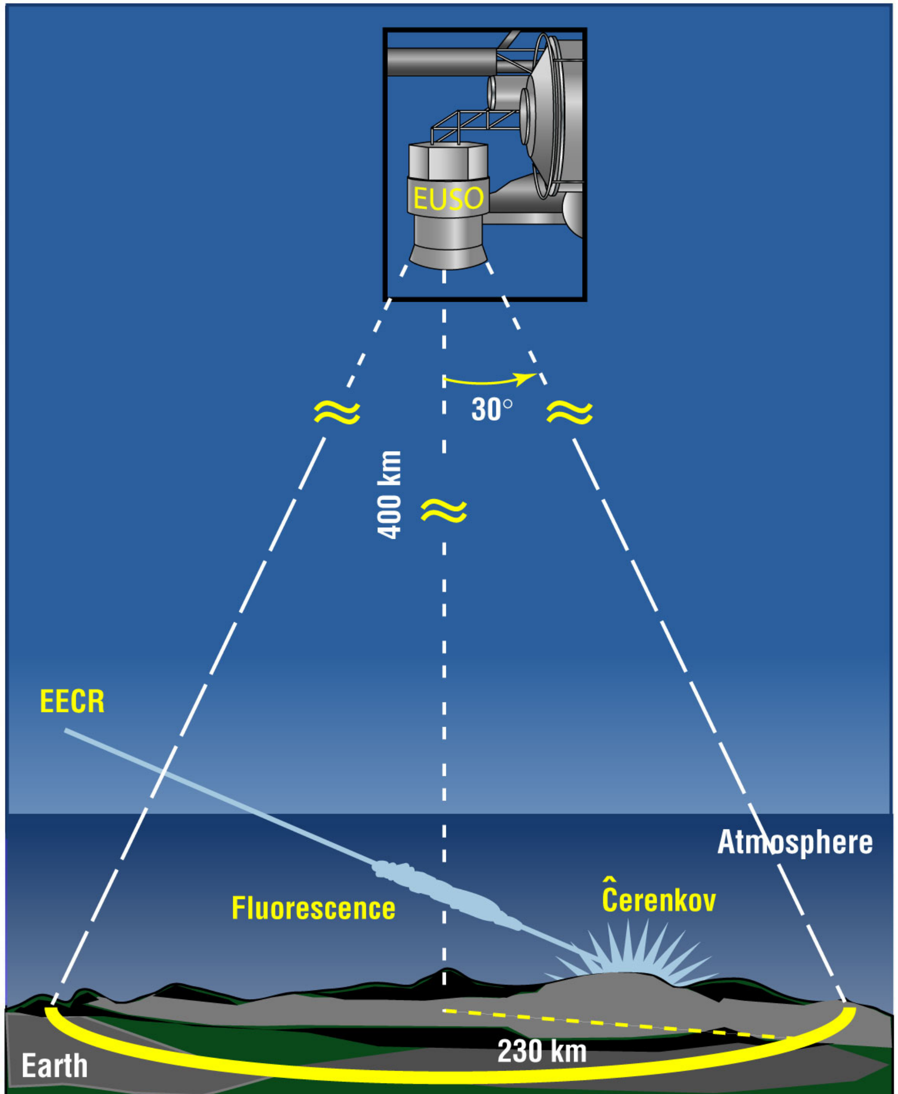
With the completion of the “Mission (Payload + Instrument) Phase A Extension Study”, the EUSO Project can technically proceed to Phase B.

Study of Extensive Air Showers has lead to the following main results:

1. Discovery of the “knee” in the CR energy spectrum at 3×10^{15} eV (G.B. Khristiansen, Moscow EAS array).
2. The “ankle” at the $3\text{-}10\times10^{18}$ eV (Yakutsk, Haverah Park, AGASA, Fly’s Eye).
3. Problem of CR cut off at 5×10^{19} eV.



EUSO Operation

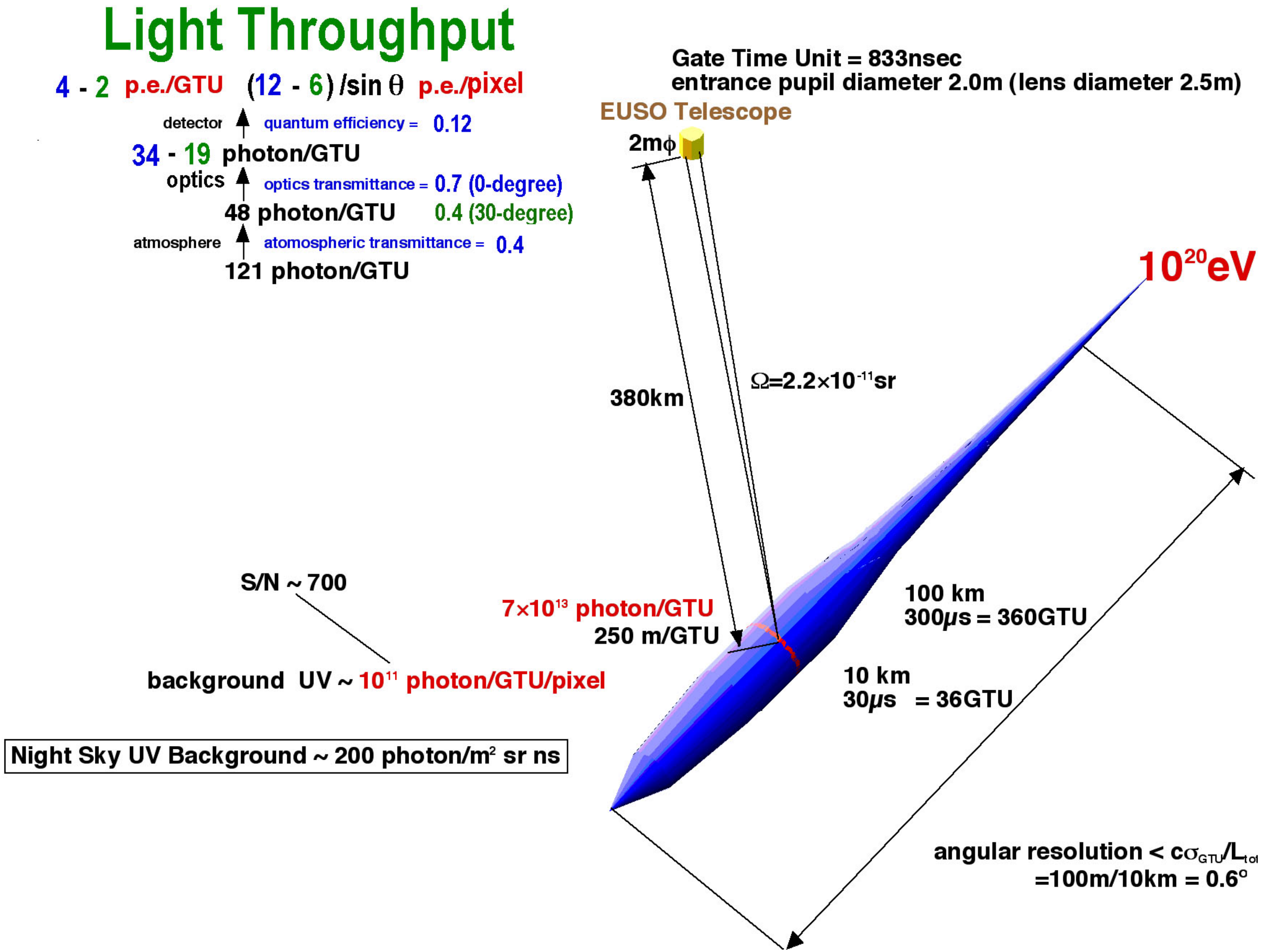


EUSO is a large wide angle UV camera on the Columbus module of the International Space Station. The focal surface is pixilated with multi-anode photo-multiplier tubes that operate in single photon counting mode.

From its berth on the ISS, EUSO views a large area in the atmosphere below. An EAS initiated by an EECR appears as a thin luminous disk streaking down though the atmosphere at the speed of light. Operating as a high-speed movie camera, EUSO records a video clip of the progress of the EAS shower front and the reflected Cherenkov flash from its footprint at the earth.

EUSO is equipped with a Lidar sounding system to measure the atmospheric conditions both along the path of the EAS and within the column of atmosphere through which that path was viewed so that the measurements can be corrected for losses due to scattering and absorption.

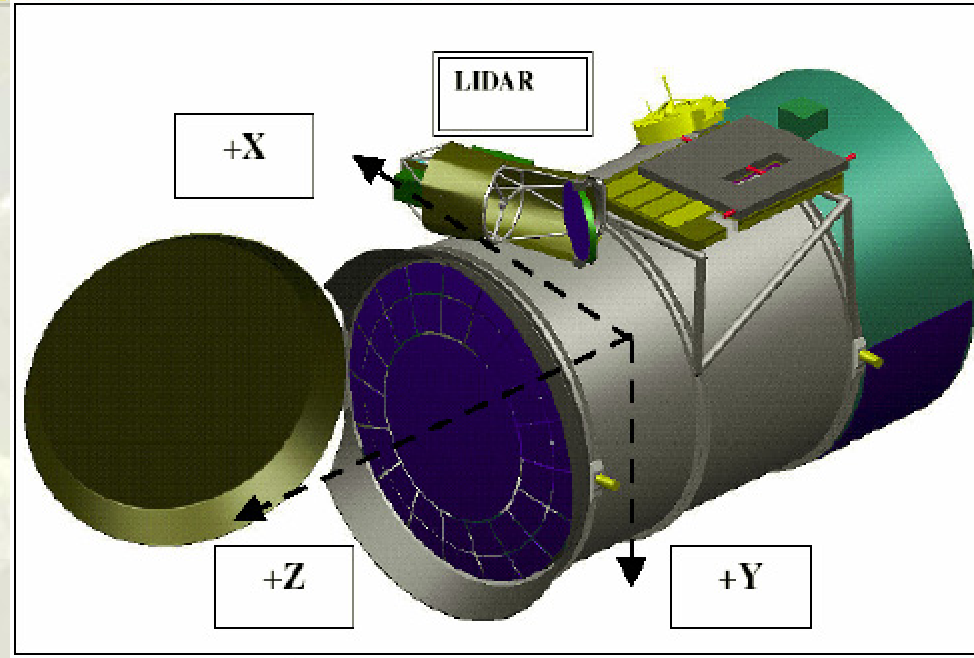
10^{19} eV Track volume has S/N ~ 70

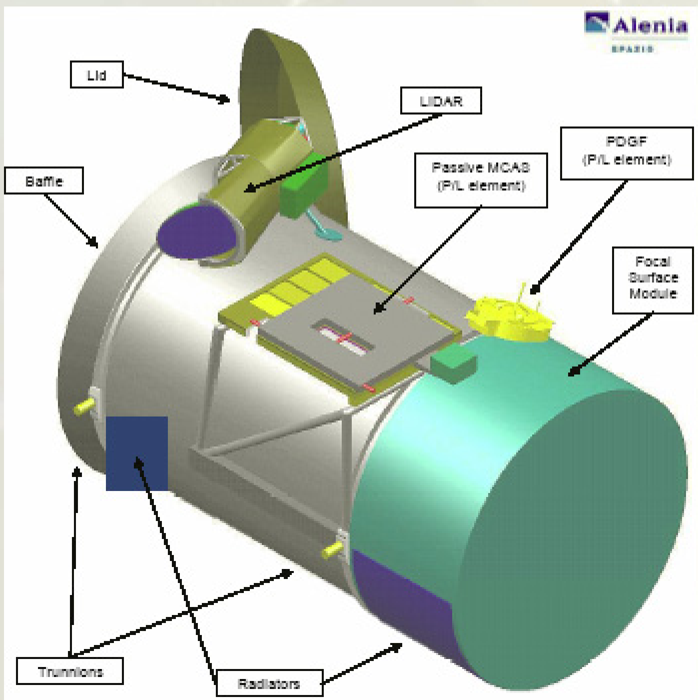


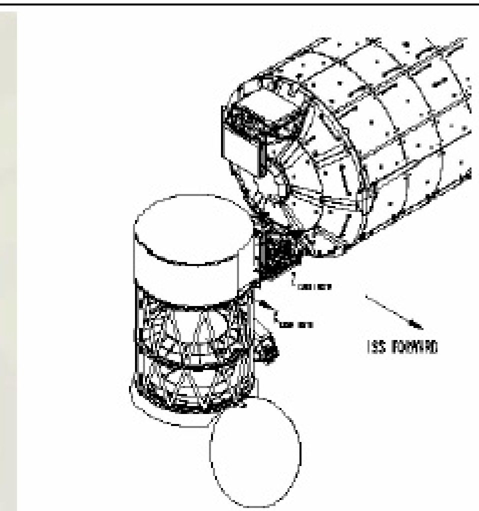
The Instrument: size

Length = 4.5 m

Width = 2.7 m



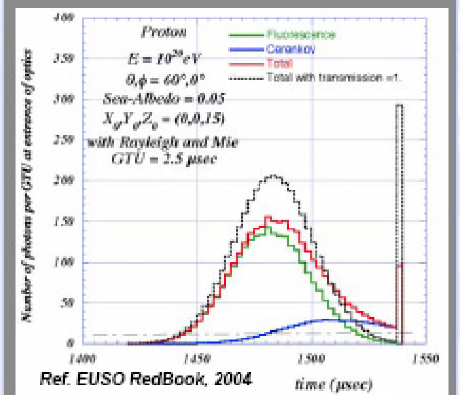




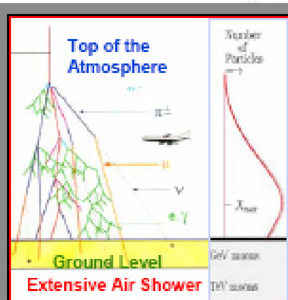
EUSO : Extreme Universe Space Observatory

EUSO Operation

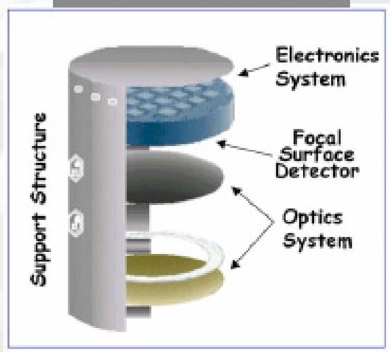
The signal arriving on EUSO



Ref. EUSO RedBook, 2004

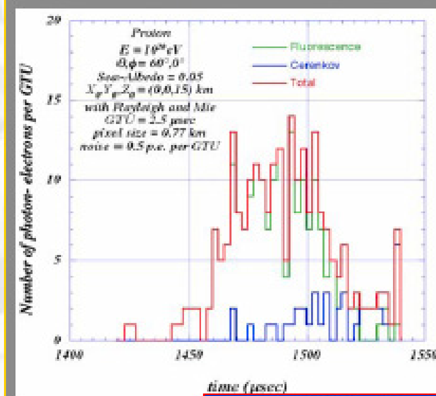


The EUSO telescope

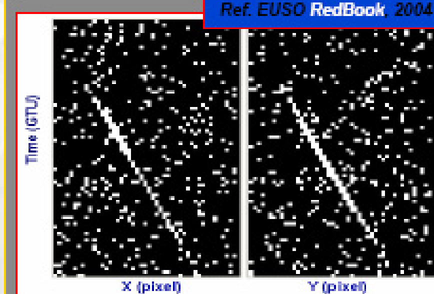


The shower will appear as a single track event (embedded in the background) whose duration, position and intensity are related to the arrival direction, energy and nature of the Primary EECR/ν.

The signal registered by EUSO

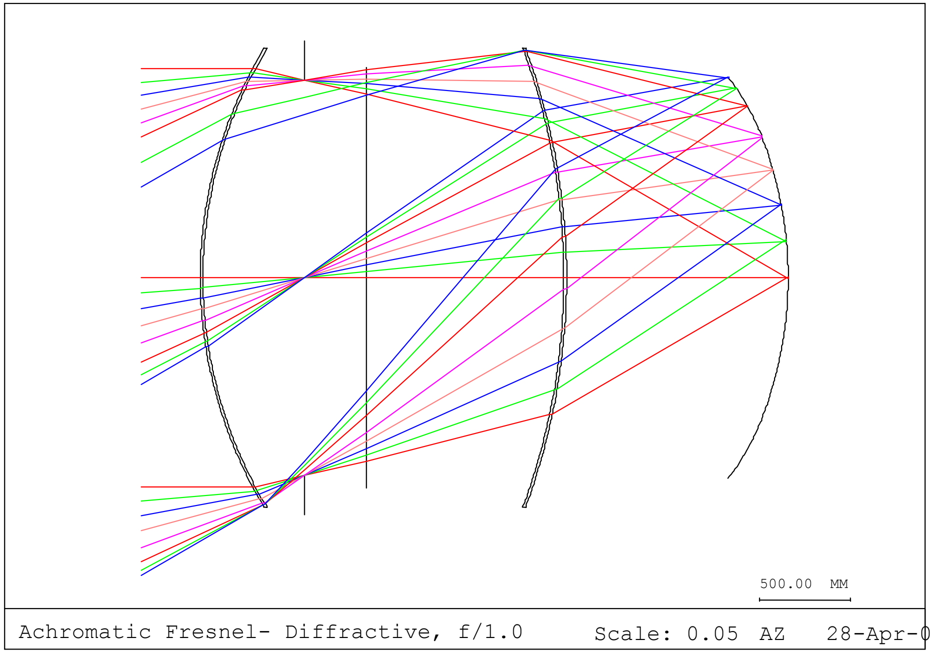


Ref. EUSO RedBook 2004



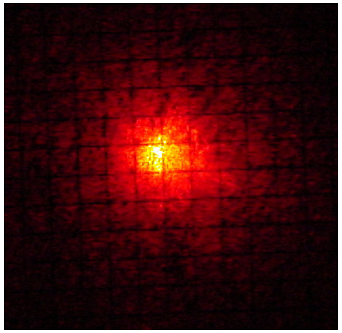
The space-time image is given in terms of X-T and Y-T projections of the collected photoelectrons, X and Y being the coordinates inside the field-of-view; the time coordinate T measures the shower development in depth, providing info about the shower length in the third direction, the height in the atmosphere.

Optics (USA, Huntsville)

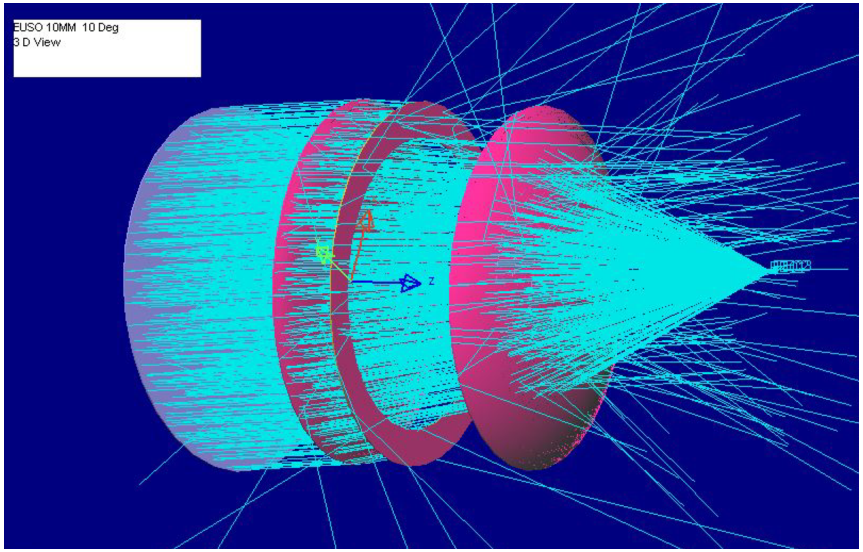


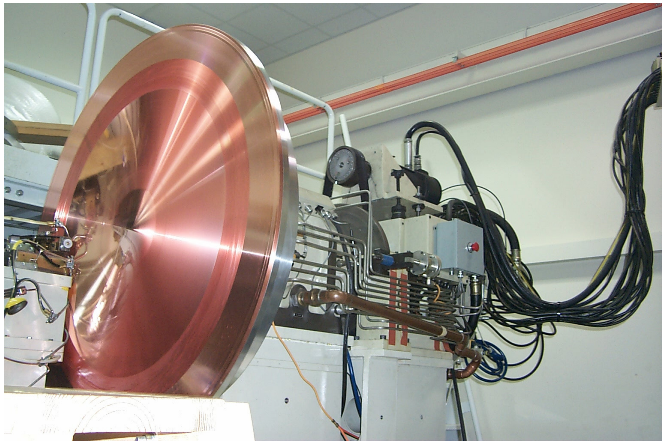
Optics Requirements

- FoV $\pm 30°$
- Pupil entrance pupil $\geq$ 1.9 m
- F/# $\leq$ 1.15
- Spot dimension ~ 0.1°
- Spectral range 300-400 nm



Spot of a prototype (plano-convex) Fresnel of 1 m diameter.

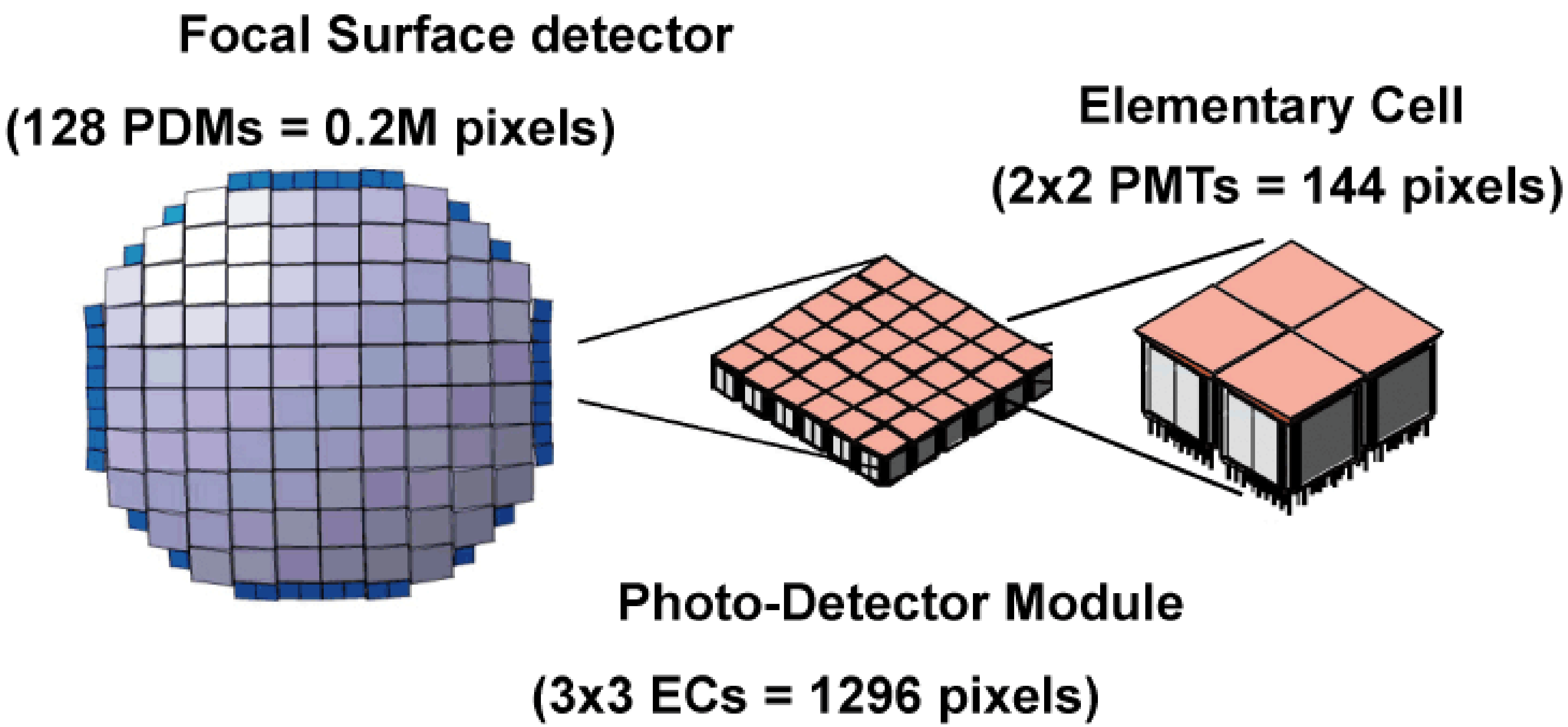




Fresnel lens

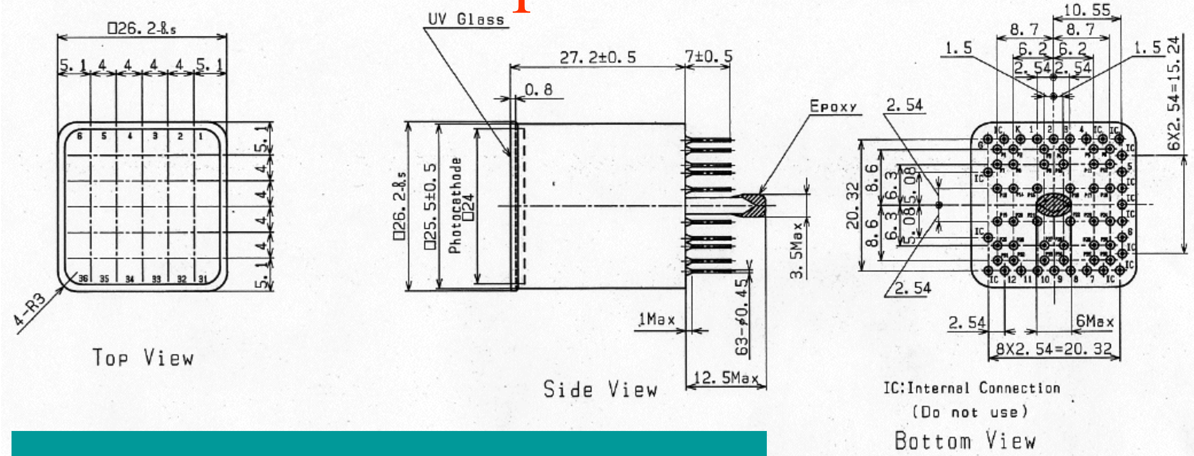
1.5 m diameter.

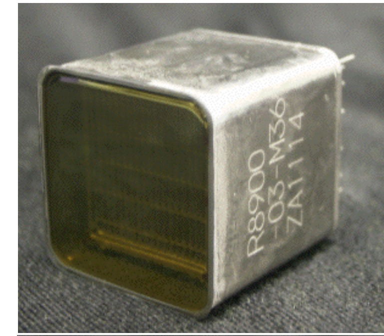
EUSO Focal Surface Detectors

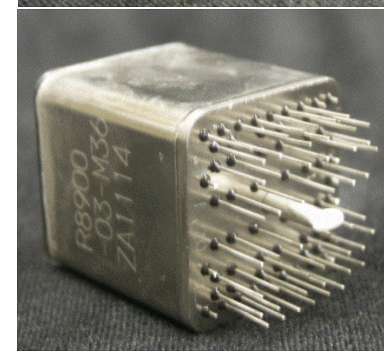


MAPMT Tests and Verification of the specs

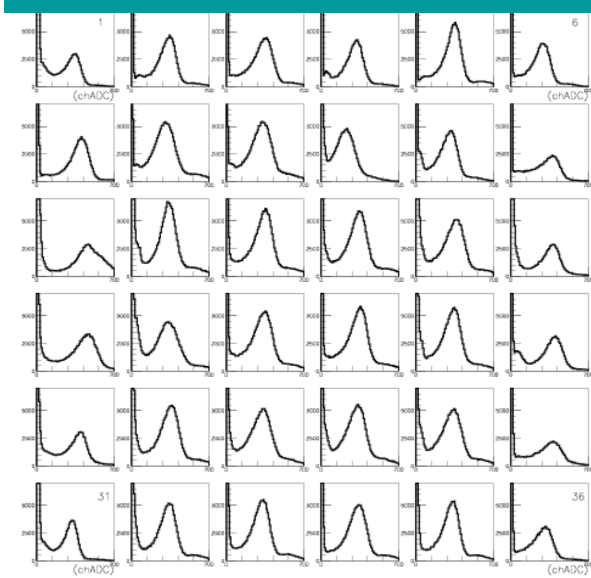
Phase A developed R8900-03-M36



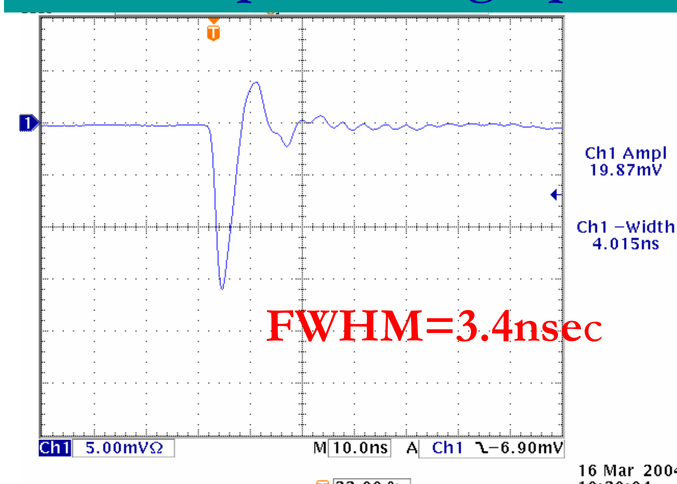




Pulse Height of a single photon (36 Channels)



Pulse shape of a single photon



FWHM=3.4nsec

Required spec and readiness of EUSO MAPMT

- Single-photon counting ⇒ Sufficiently high S/N
- Response faster than 10nsec ⇒ 3.4 nsec FWHM
- QE x e-collection rate x sensitive area ratio of NUV photons 330-400nm has to be 12% or large

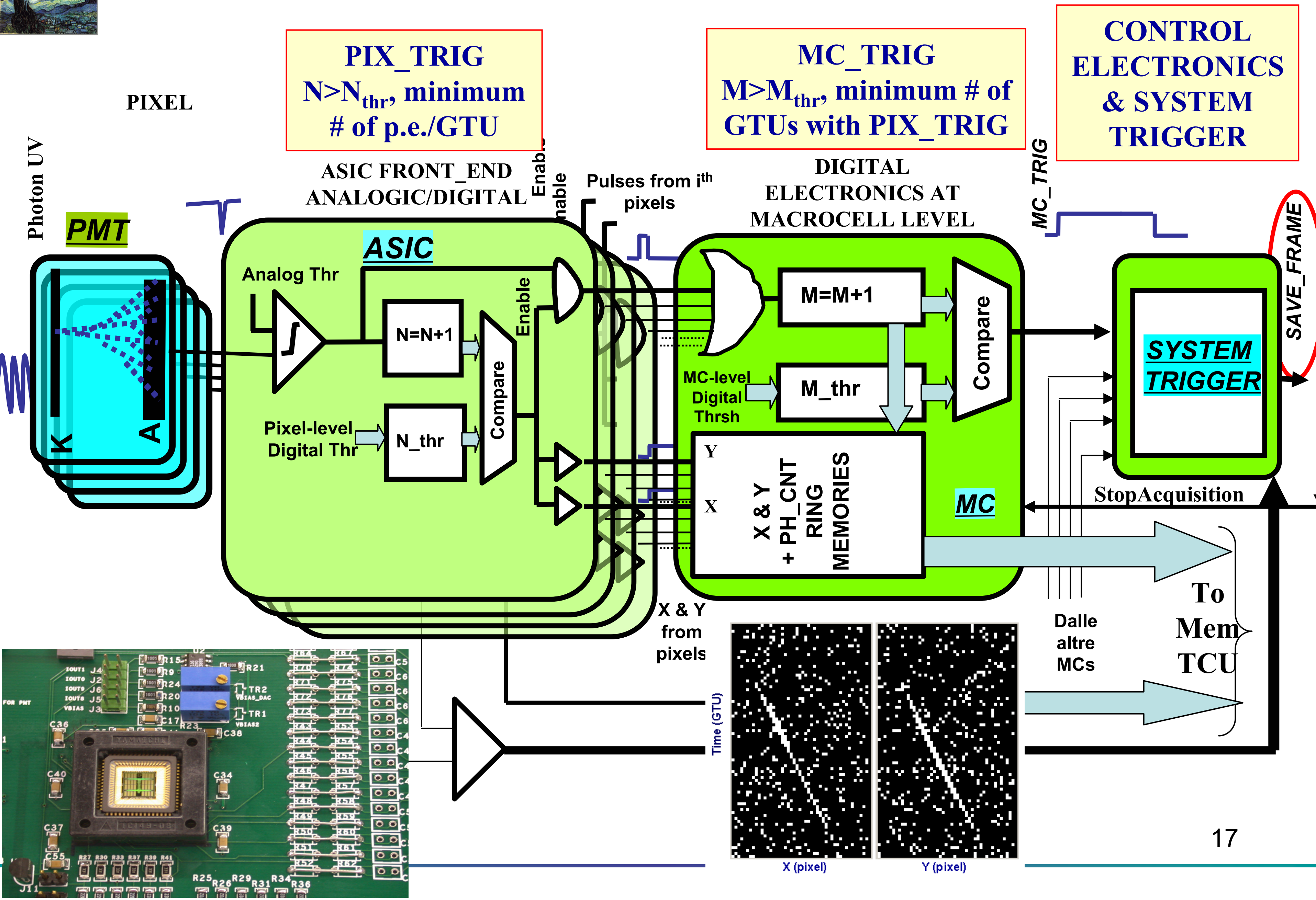
  ⇒ $0.25 \times 0.70 \times 0.85 = 0.15 \rightarrow 0.22$
- Stability of the anode sensitivity at 400 Km for 5 years ops.

  Required stability (< 25%) ⇒ below 20 %
- Less than 10% variation after the launch shake (12.7G, 120s)

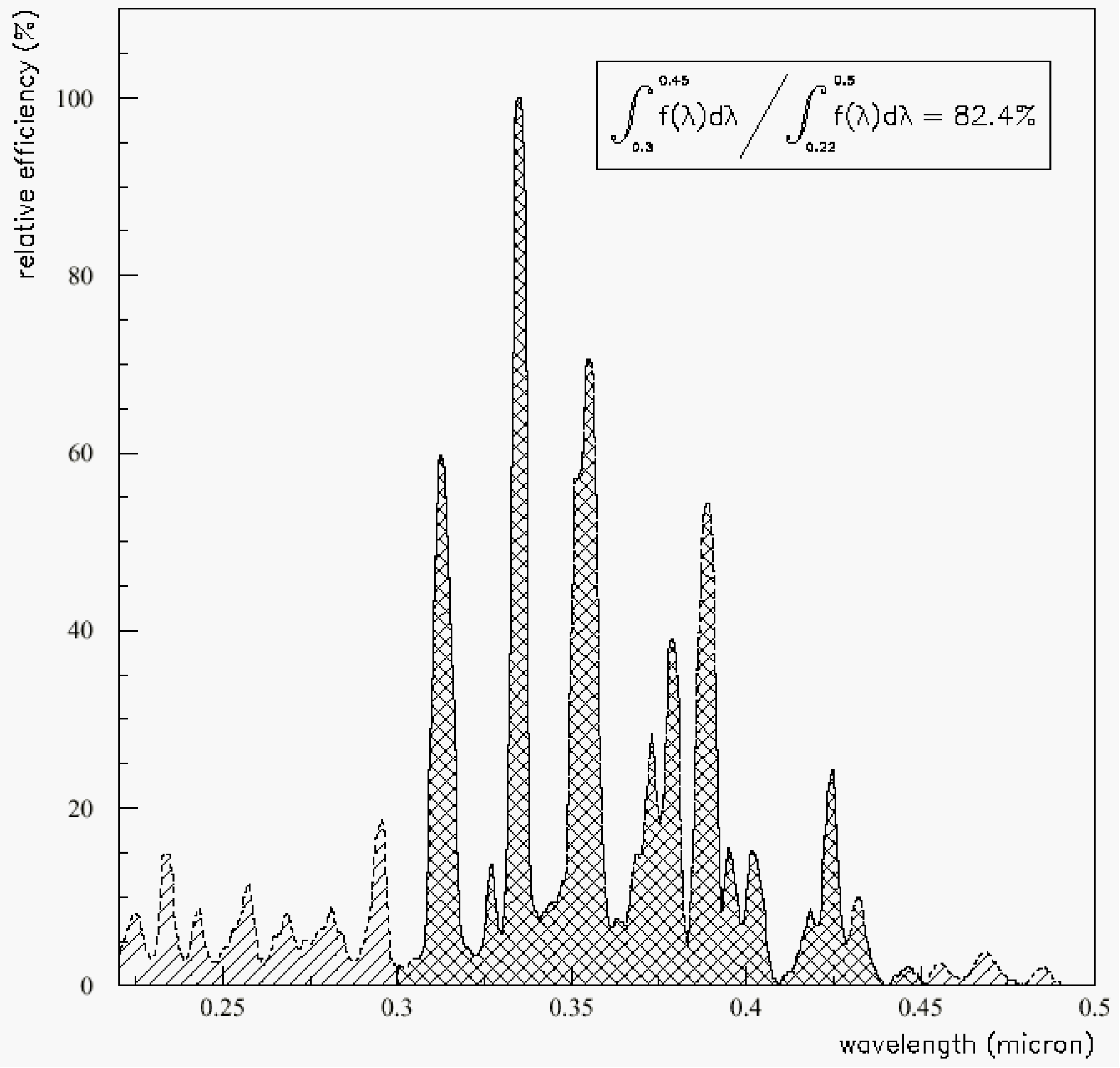
  Stability of the sensitivity ⇒ below 5%
- Fluctuation of the on-orbit sensitivity in Geomagnetic field

  ⇒ below 5% 以下
- Low cost per unit area size ⇒ flat panel (1/2 mass)

Electronics (Europe)

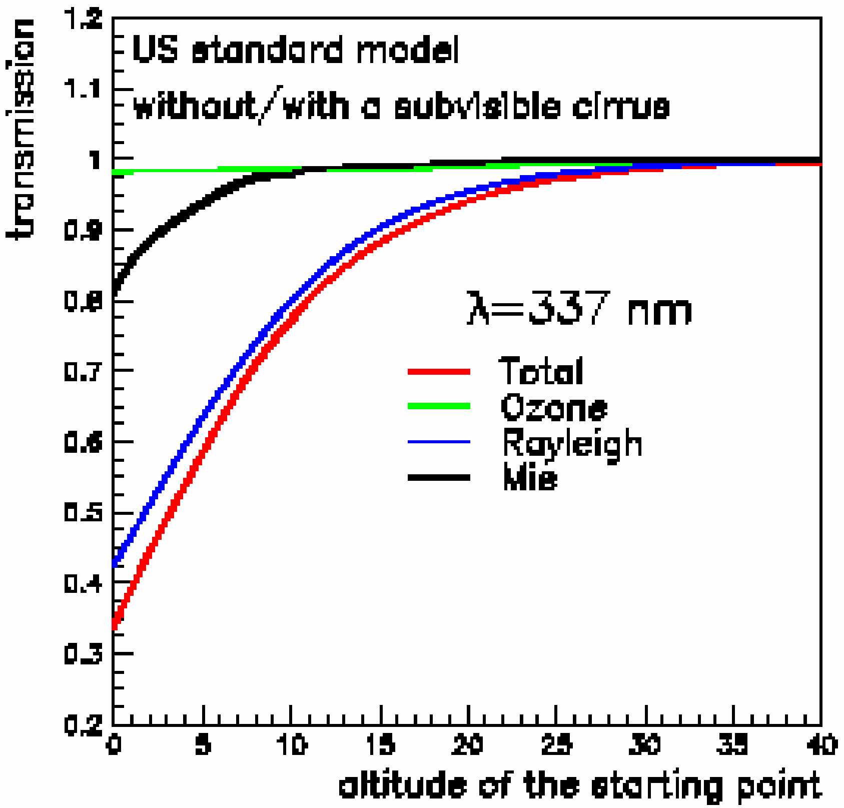


Fluorescence yields



Small uncertainties of atmospheric effects

- Mie scattering minimal
  - Worst case ~20%
  - clouds 2~3km （night）
- Total transmission
  - ~ 0.7 (7km)
  - Ground-based：0.1~0.01

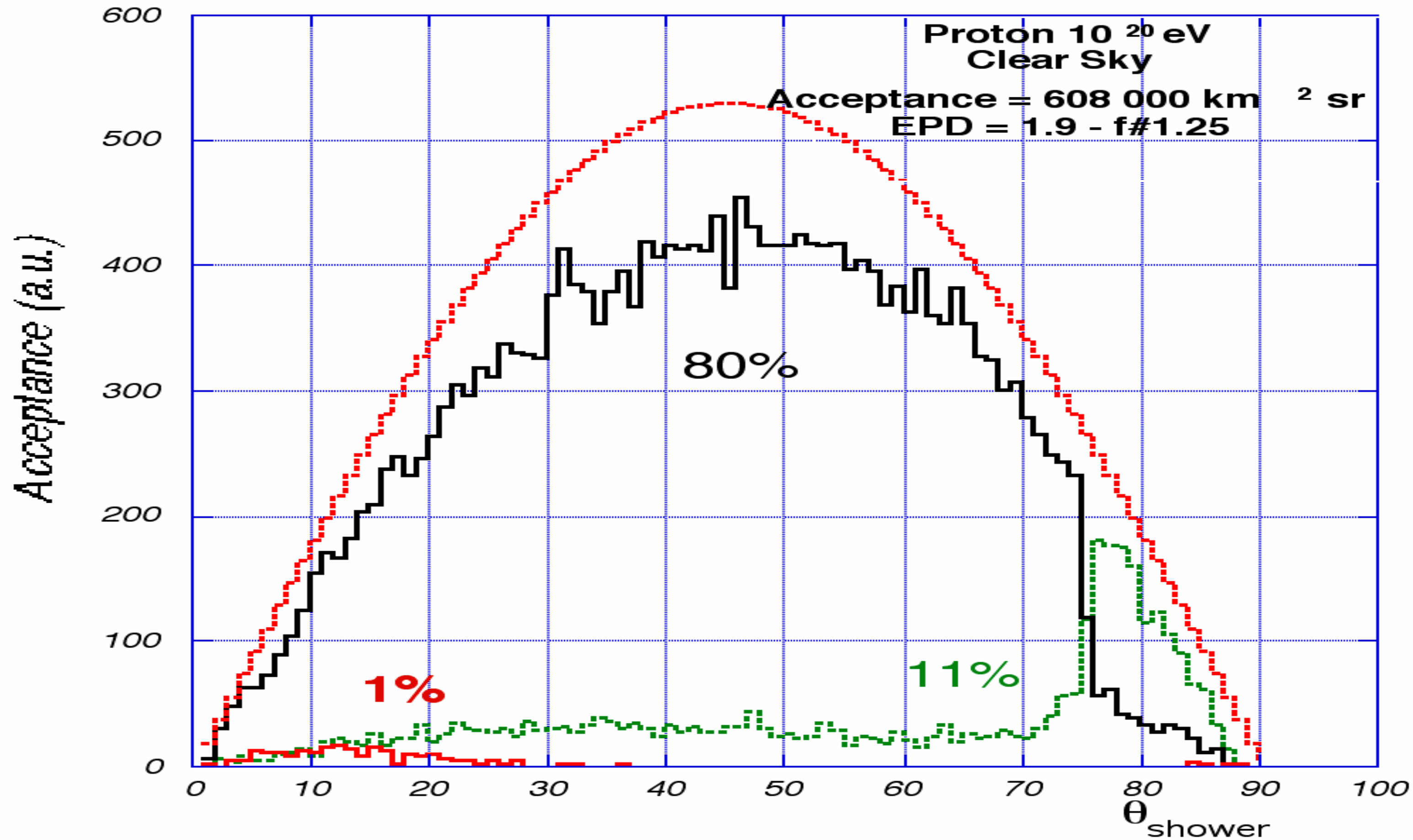


Duty cycle

EUSO Concept Study Report

No Sun Interf.	0.34		
No Moon Interf.	0.5	→	0.7
No Citylight Interf.	0.97		
Small Cloud Interf. (<15%: ISCCP)	0.52	→	1.00
Trigger Efficiency	0.8		
No Interef. From Aurola, Strom, etc.	0.8		
Product	**0.05**	→	0.14

EUSO Operation



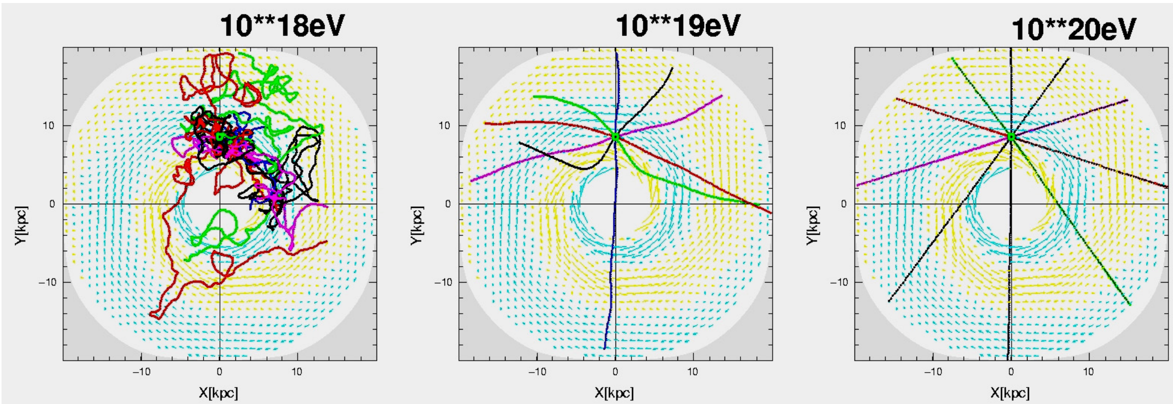
Differential acceptance of EUSO (arbitrary units) versus the zenith angle of the EECR. The top curve is the geometrical acceptance. Also shown are numerical simulations showing the acceptance for those events in which only the fluorescent signal was observed (11%), only the Čerenkov signal (1%) and both were observed (80%).

EUSO – Relevant characteristics and features.

Particle Channel of Astronomy

- Instantaneous aperture of $6\times10^5 km^2 sr$.
- Duty cycle ~20%
- “Atmosphere Detector” sounded by an autonomous Lidar = AS + EUSO.
- Dynamic range operating at $E>5\times10^{19}eV$).
- For $E>10^{20}eV$: ~10^3 events/year expected according to AGASA ;
  ~10^2 events/year expected if GZK is present.
  Critical Exposure Factor for observing all the individual R_{GZK} sources
- Uniform all sky coverage.
- Up to 10^{13} tons of active target mass for neutrino interaction.
- Eligible for neutrino astronomy
- Potentially open to investigate “New Physics” in the Extreme Energy domain.
- Atmospheric Physics . Meteors. Blue-jets and upward tau.

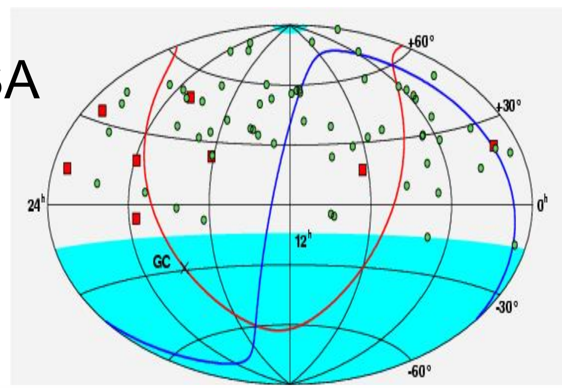
Particle Astronomy becomes real

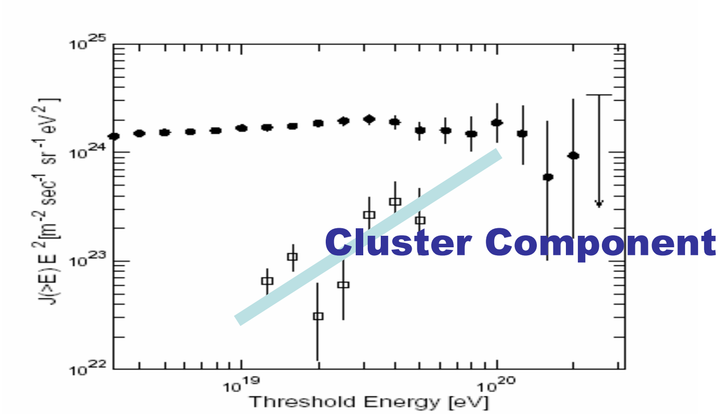


Protons barely deflected in galactic magnetic fields at above 10^{20}eV

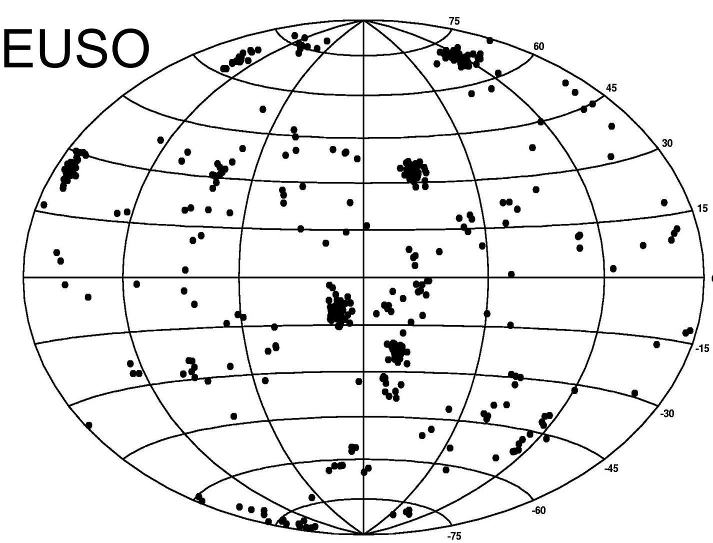
Particle Astronomy!

AGASA



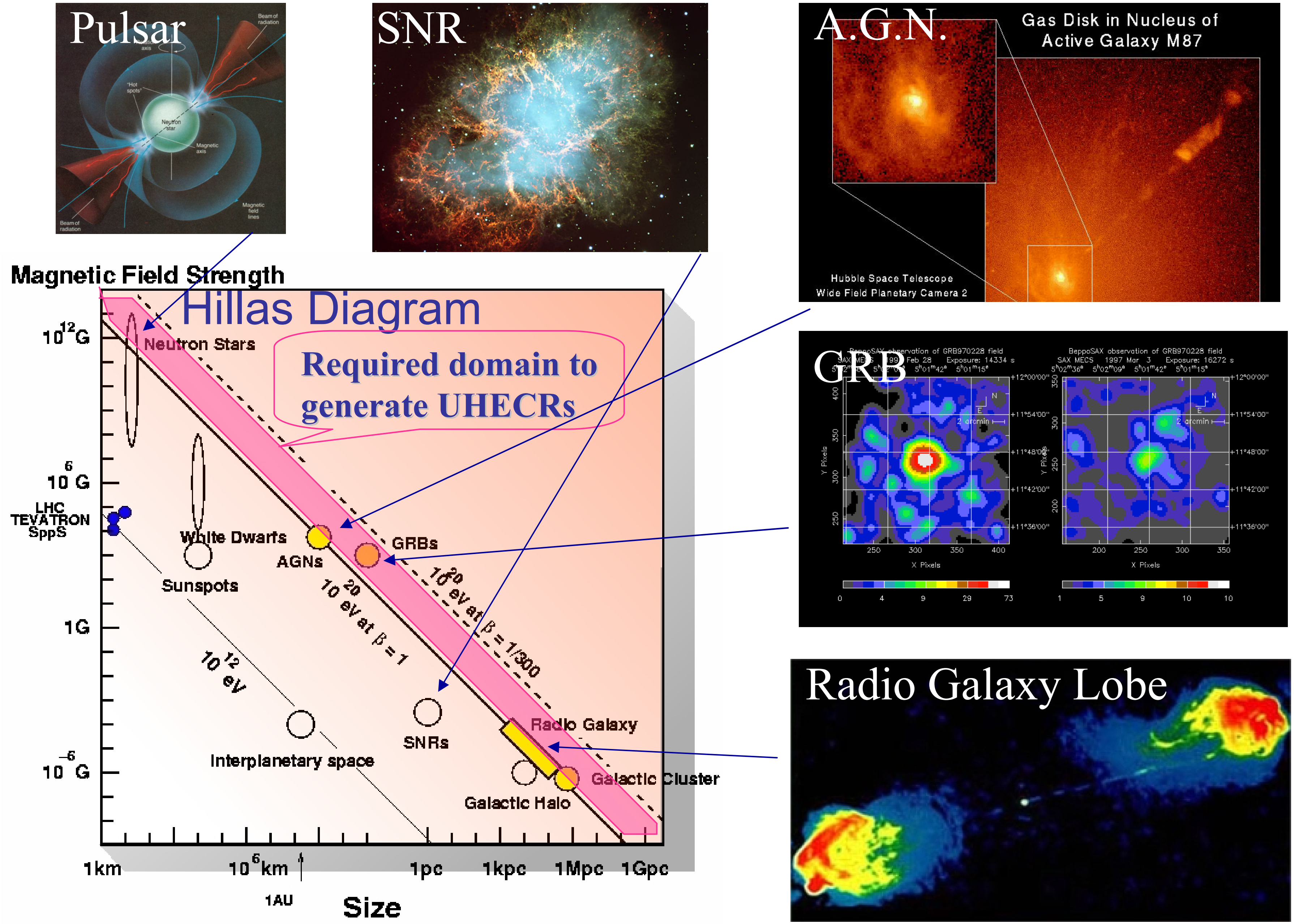


EUSO



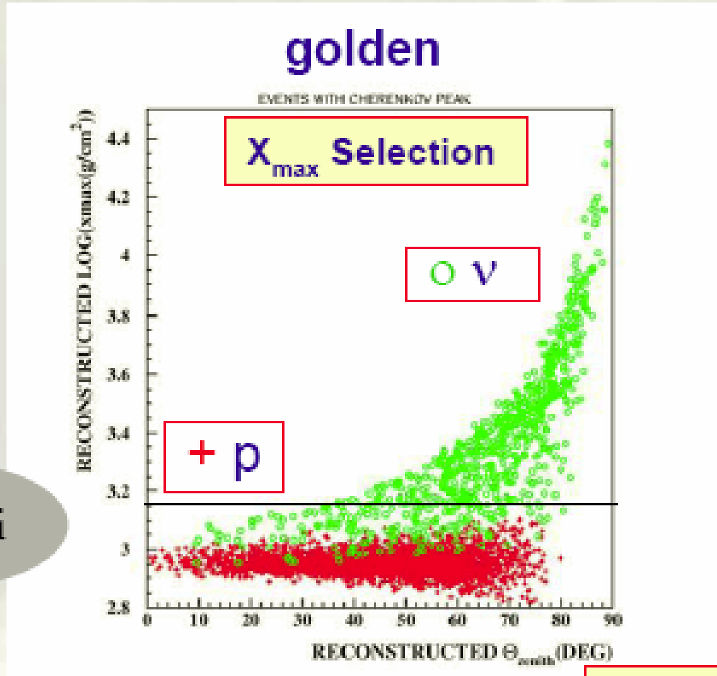
- **more than 2,000 events : $E>4x10^{19}$eV**
- **up to 60~70 clusters expected from AGASA**
- **All-sky monitor**

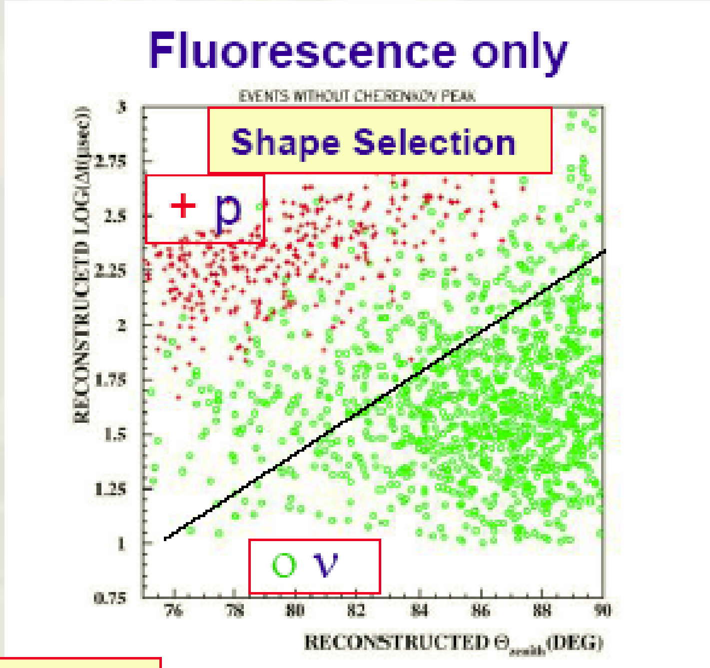
Astronomical objects that can deliver EECRs



Downward neutrino acceptance for EUSO

S. Bottai

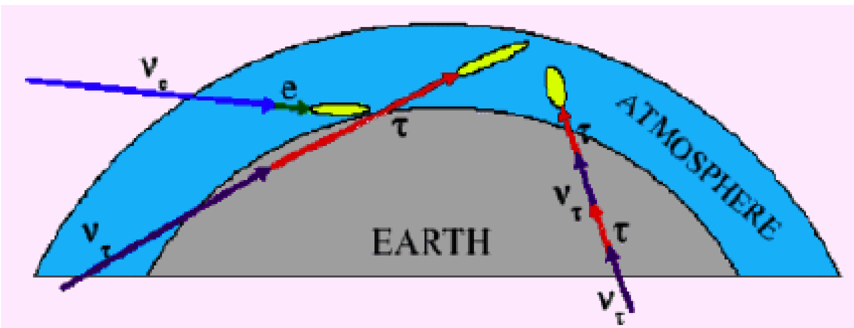




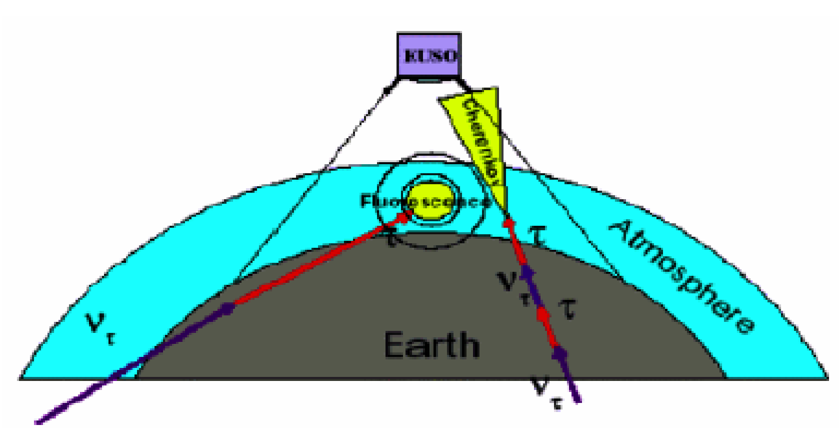
Rejection > 10^{-4}

- ✓ $2 * 10^{18}$ g is the total target mass under the FOV
- ✓ reduction due to trigger efficiency is calculated by full simulation. Clouds distribution is considered
- ✓ reduction due to selection efficiency needed for 10^{-4} proton rejection has been calculated from full simulation
- ✓ results show a sensitivity around 10 times AUGER for neutrino in the10^{20}eV energy region

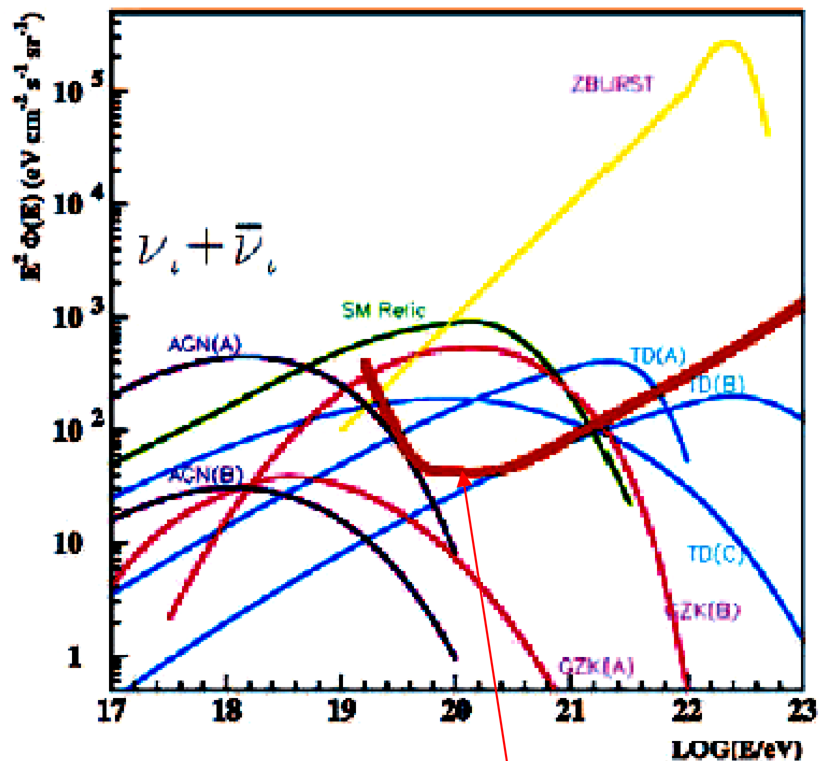
Neutrino Astronomy at Extreme Energies



ID of neutrinos

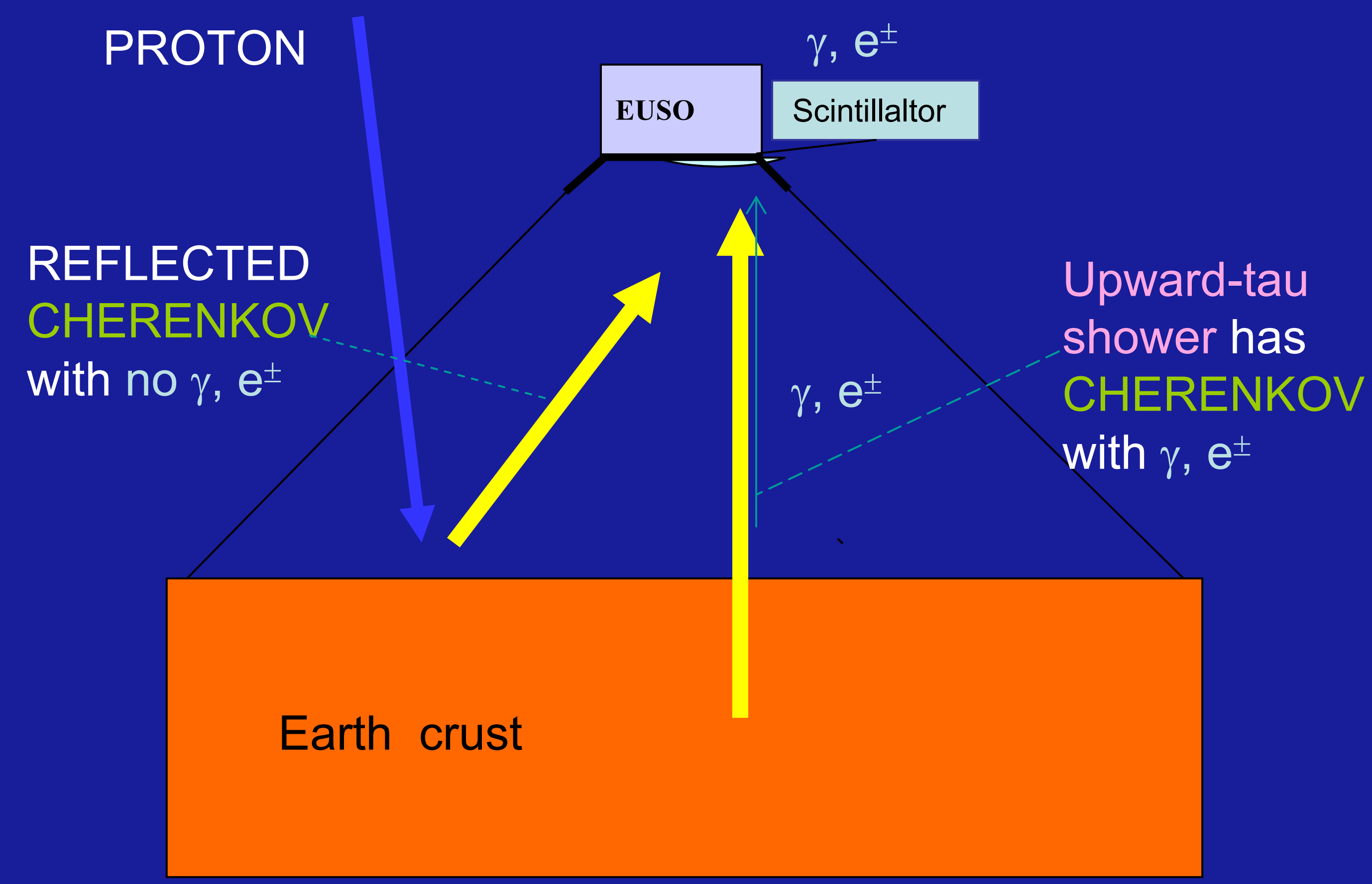


Upward neutrinos



EUSO Yield line
1 Event / flavor/ year

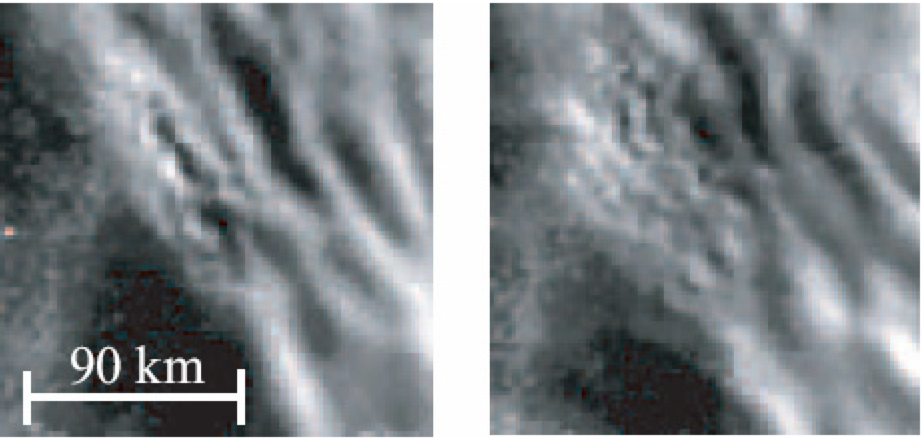
Events that Mimic Direct Cherenkov Light From Neutrinos



In case fluorescence is not detected for an AS event, Cherenkov lights reflected on ground-clouds can well mimic the neutrino direct Cherenkov signal. But,

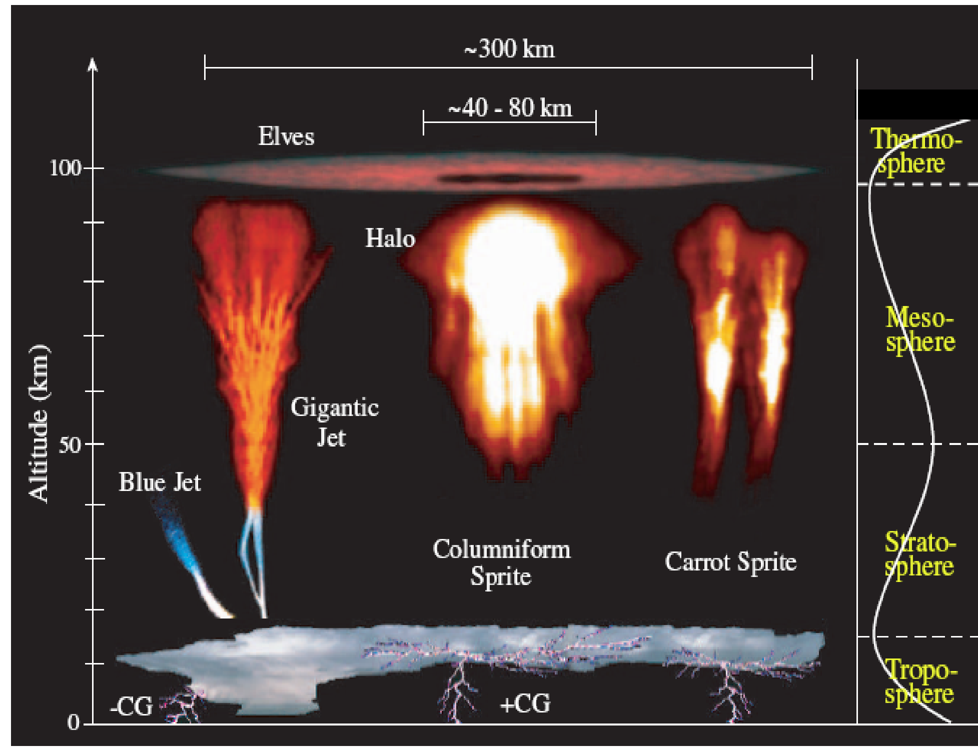
SCINTILLATOR on board can DISCRIMATE TRUE FROM FALSE.

Extreme Atmospheric Science



OH night glow observed from ground

High-vision camera
Meteor showers 2001

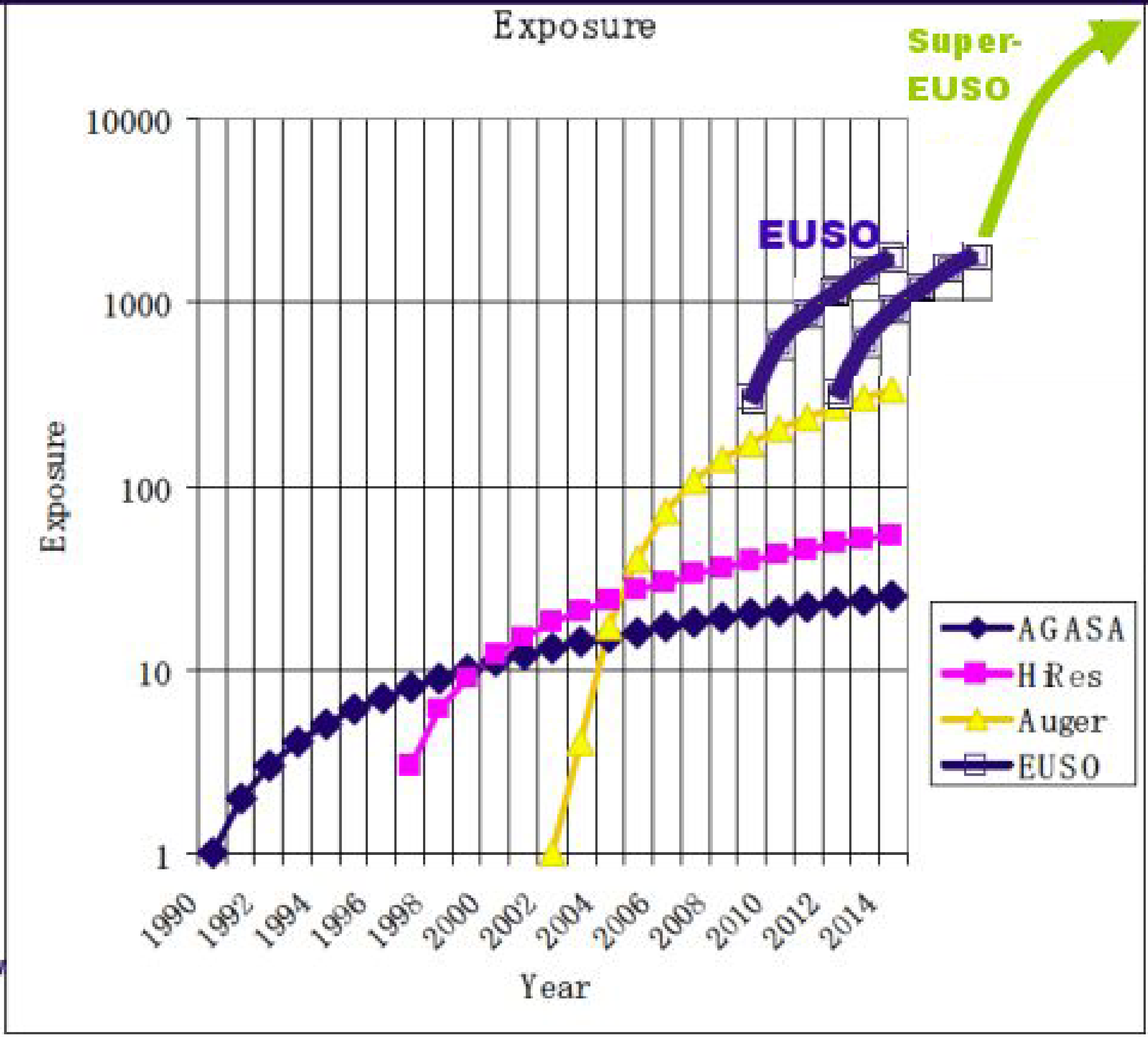


Extremely LargeTransient Sparks in the stratosphere when thunder clouds exist at lower atmosphere

Comparison of expected Exposures for various Experiments.

Experiment	Acceptance (Km^2 sr)	Assumed operational	Operation (N years)	Duty cycle(%)	Exposure (Km^2 sr year)	Units AGASA
AGASA	160	Completed	10.2	100	1.6 $x10^3$	1
Auger South	7.000	2006-2015	10	100	7.0 $x10^4$	45
Auger South + (Auger North) ---------------- Total Max	7.000 (7.000) ---------------	2006-2015 (2009-2015) ---------------	10 (7) -------------	100 (100) ----------	7.0 $x10^4$ + (5.0 $x10^4$) --------------- (12.0 $x10^4$)	44 + (31) ----------- (75)
EUSO (Super-EUSO)	600.000 (3,750,000)	2012-2016 (2020s)	5 (5 - 10 yrs)	20 (20)	6.0 $x10^5$ (75 $x10^6$)	375 (5000)

Exposure (AGASA unit)



Andrea

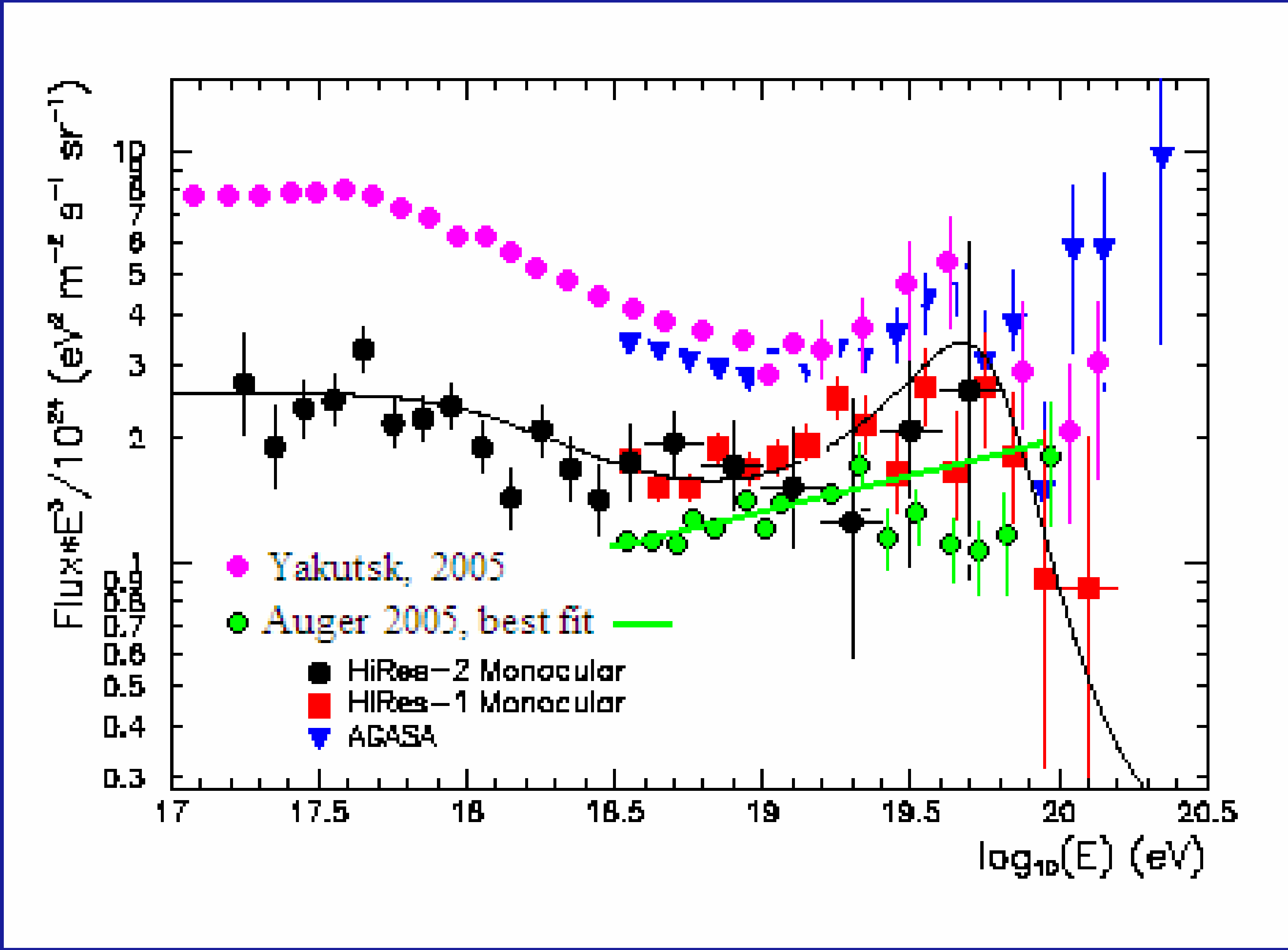
I. Detailed observations of the spectral changes is essential

- Steepening of spectrum at extreme energies is generally expected to a high confidence level due to several physics mechanisms. Details of the spectrum is essential to diagnose what mechanisms are actually acting to what extent. These mechanisms that have been predicted in the past are:

  - (1) Propagation cutoff by CMB photo-pion production on proton (GZK).
  - (2) Interaction cutoff by the high-energy multiple-scattering interference for EM-processes (LPM).
  - **(3) Zero-point momentum cutoff of the cosmological rest-system** (YY; Prog. Theor. Phys. 11, 611, 2003; 111, 545, 2004).
  - (4) Acceleration-limit in shock mechanisms.

Very much details of the spectral transition are mandatory to diagnose any of these mechanisms as reflected in the actual observations. Furthermore, the spectral shape beyond any cutoff is decisive for complex nature of cutoffs; where statistics can become much reduced than otherwise and hard to observe unless extending the observational aperture to the size of EUSO and beyond. They are all coupled with the test of relativity.

Recent data on the Ultra High Energy Cosmic Rays



Energy calibration is missing, and the systematics differ each other.

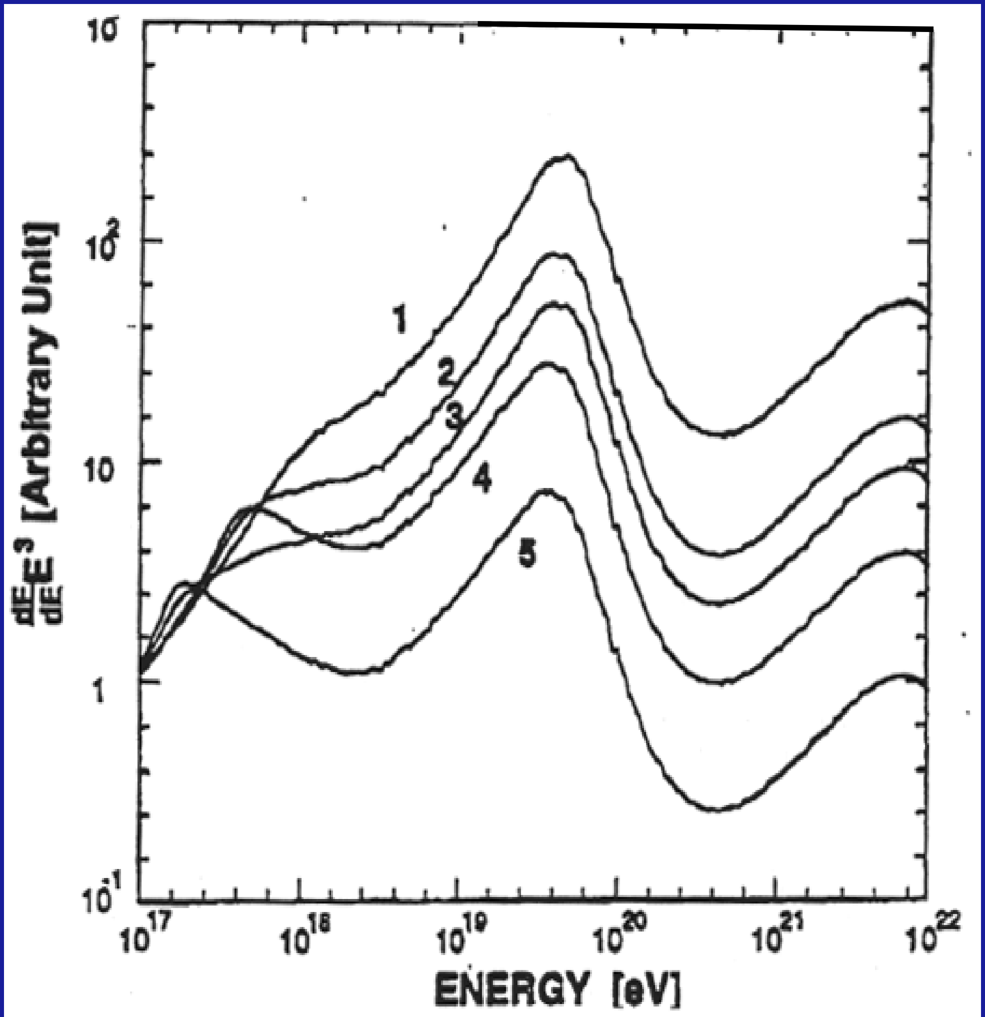
Absolute Energy Calibration !!!

Air showers induced by cosmic rays have such high energies as over 100 million times the highest energy proton synchrotron accelerator (10^{12} eV, Fermilab Tevatron). Because of the lack of artificial accelerators that permit the detector calibration, most of the air shower work have often been criticized or subjected to skepticism and great confusion. It is particularly so, when air shower data try to say with small statistics that GZK-cut-off is seen or surpassed. Great uncertainty of assumed hadronic interactions exists in the energy determination of air shower events.

EUSO is designed to be capable to collect cosmic rays with overwhelming statistics of 1000 events per year above 10^{20} eV. It is obvious that this data set would allow detailed characterization of the trans-GZK cut-off energies. There are certainly cosmic ray sources in universe at a distance beyond 50 Mpc. Therefore, there must be a bump at around 5 x 10^{19} eV – 10^{20} eV due to the very GZK propagation effect of trans-GZK particles in our microwave-filled universe. The expected OWL data should be able to clearly identify this bump. Identification of GZK cut-off energy is the best energy calibration of the cosmic ray data. EUSO could provide the absolute calibration for all the EHE cosmic ray energy spectra, using the cosmic accelerators, whatever they are, or whatever the uncertainty of hadronic interactions is.

The universal microwave background temperature of 2.7 °K provides us an absolute "calibration" of energy.

Absolute Energy Calibration and Evolution of Universe



The energy spectrum in the trans-GZK energy regime ($5 \times 10^{19} - 2 \times 10^{20}$ eV) is dependent on the evolution of universe since about 10 billion years ago, or the redshift z ~ 5 (Fig).

The overwhelming statistics of the EUSO data is expected to provide the information on the evolution of universe, whether it was homogeneous, or what was the degree of inhomogeneity in temporal-evolution.

Homogeneity of galaxy formation can be analyzed by an extensive all-sky survey by Sloan Digital Sky Survey being under construction, which would tell the evolution of baryonic matter density. The trans-GZK data by OWL-Airwatch would observe a different dimension of this evolving universe. It would provide information on the evolution of the origin of extremely high energies, including that of Dark Matter.

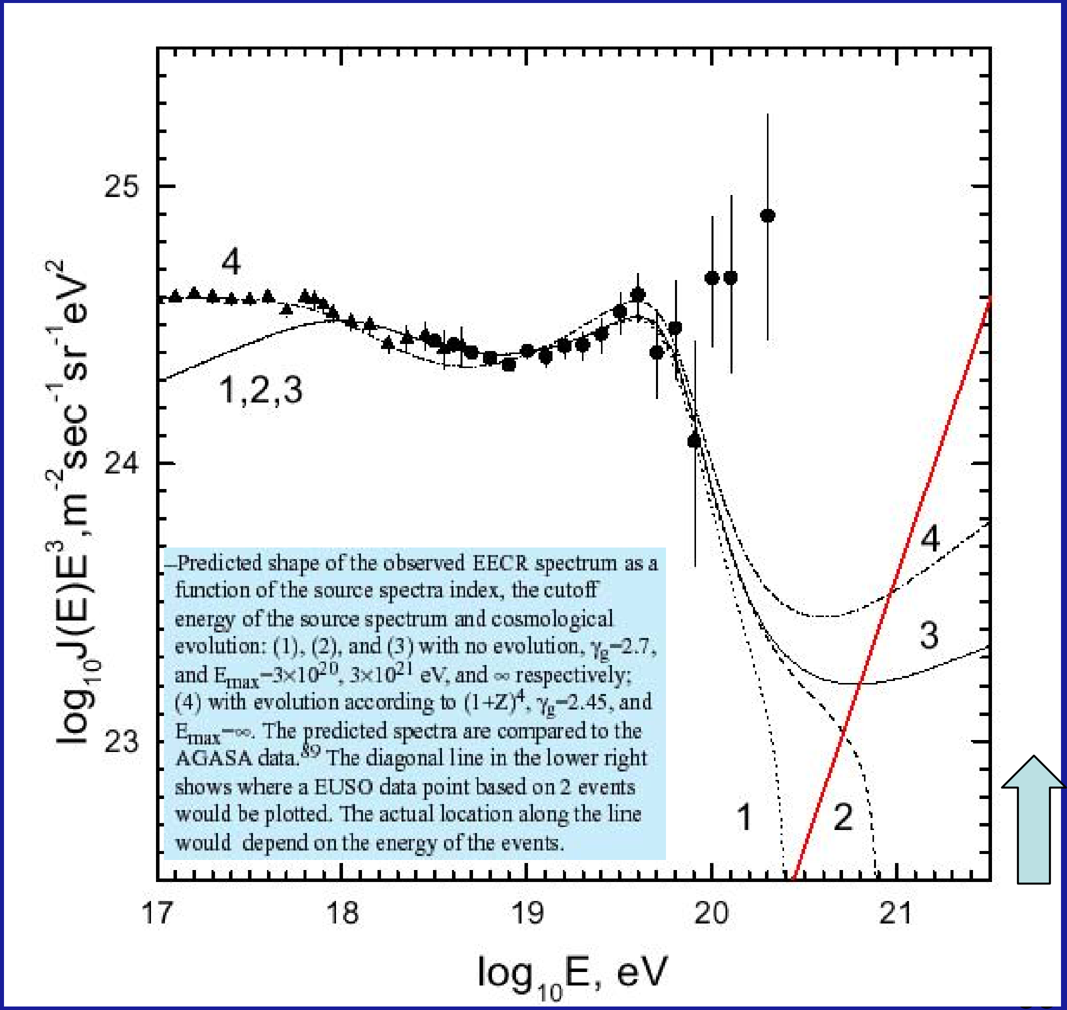
EECR Sources

Deep Survey Required Beyond 10^{20} eV

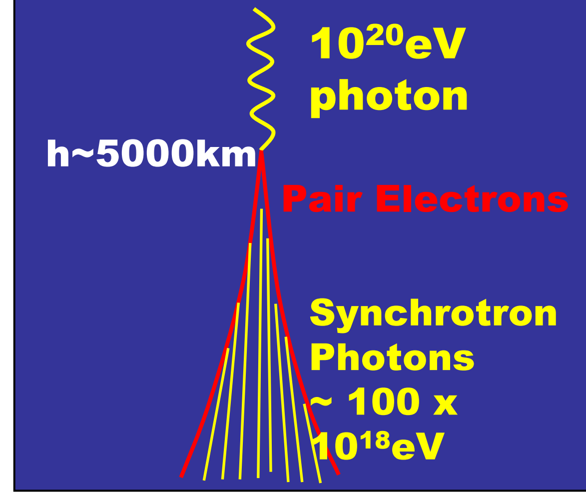
Figure shows the four predictions for the EECR trans-GZK spectrum beyond 10^{20} eV taken from Berezinsky et al, 2002, indicating GZK recovery by nearby sources.

Individual super-GZK sources can be identified by EUSO.

Red line shows the level of 10-events/yr by EUSO, which is also the critical exposure required for source observations beyond GZK (Stanev 2003).

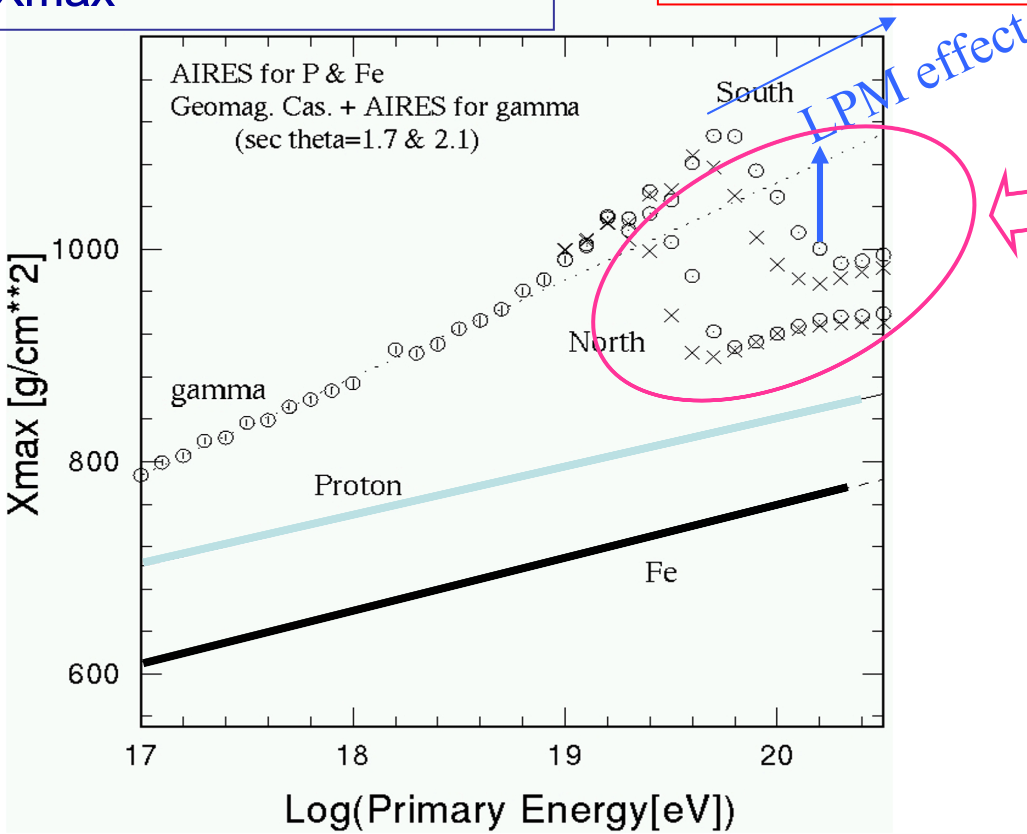


Particle Identification

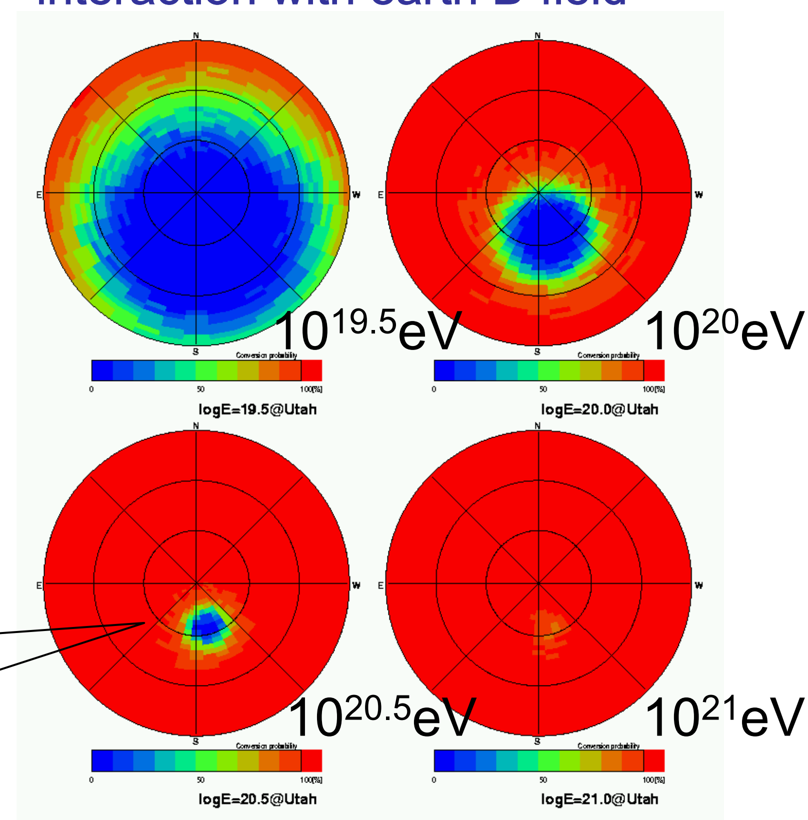


ID possible by the height of the shower maximum Xmax

⇒ γ-rays are essential to diagnose topological defects and Z-bursts



⇐ γ-rays begin early cascades by interaction with earth B-field



Probability of Early-Pair cascading is smaller for incidence from the direction of the north pole

Enemy No. 1 for GZK to Super-GZK:

LPM effect can **Kill** *almost all Air Shower experiments;*
Ground-arrays (AGASA, AUGER etc) cannot measure energy:

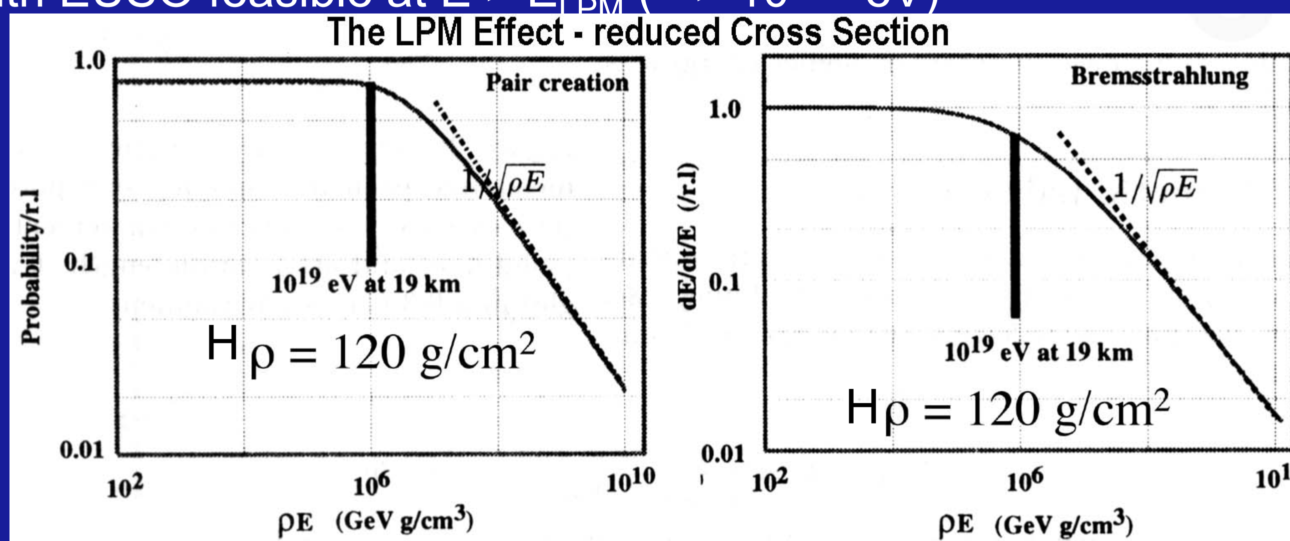
LPM delays and complicates the shower curves and lateral spread for
E > 5 x 10^{19} eV (γ); 5 x 10^{20} eV (p); 2 x 10^{22} eV (Fe).
- Lateral distribution severely distorted: S(600) invalid (AGASA & Auger)
- Side-way observations (Hi-Res/TA) miss almost all the good events.

•***EUSO***? - It is robust and powerful even with the LPM effects: LPM is much less troubling for upper-atmospheric shower developments;

OK for large angle proton events (at H_S > 20 km) to ~ 10^{21} eV …and
OK to 10^{22} eV for large-angle events with H_s > 30 km.

* EHECR observation with EUSO feasible at E > E_{LPM} (~ > $10^{20.5}$ eV)

E > $10^{20.5}$ eV events are OK for only upper atmospheric shower events,
but only with EUSO.
LPM, however, will help EUSO for Fe detection by H_{max} .



II. Monitoring Neutrinos of Different Origins that could be an Important Final Cosmological and Fundamental Frontier

- Those conventionally asserted sources of neutrinos are
  - (1) Photo-pion propagation source)GZK-neutrinos),
  - (2) MHD acceleration from supermassive black holes (Blazars etc.),
  - (3) Decay of Topological Defects and Super-massive Super-symmetric Particles,
  - (4) Secondaries from Z-bursts.
- Less popular but fundamentally highly important components include:
  - **(5) Secondaries from Wakefield acceleration from GRBs and AGN MHD-jets.**
  - **(6) Direct emission from the bare singularities (they are effectively, quantum non-singularities) of Kerr-black holes and Sakharov-Tomozawa quantum effects,** including Nordstrom-Reissner-type repulsions (Schwarzschild Lapse function: $1 - R_s/r + q/r^2$).
  - **(7) Oscillation of mirror (right-handed) neutrinos** (Landau, Belenky, O'Kun, Berezinsky). The mirror matter is suspected as symmetry-broken much earlier than other spontaneous symmetry breaking in big-bang scenario, keeping far greater energy in dark (invisible) mirror neutrinos with higher mass than ordinary neutrinos. Ordinary left-handed neutrinos at Extreme Energies can be produced by mirror matter whose interaction is extremely rare ($W_R >> 6\ W_L$) but can oscillate into left-handed component in cosmic time.
  - (8) **Direct detection of degenerate neutrino sea** by $p + \nu \rightarrow \nu + p$ backscattered neutrino flux at Extreme Energies. This would constitute an ultimate verification of big-bang model, for which 1.95K neutrino backgrounds must be observationally proven. Much more than 100 Auger is required to ever detect this neutrino component. ("Neutrino Universe", in "Space Factory on International Space Station," Universal Academy Press, 2000).
- **These explorations demand > 100 Auger exposures, which is only possible by observatories from space.**

EXTREMELY-HIGH ENERGY NEUTRINO ASTROPHYSICS

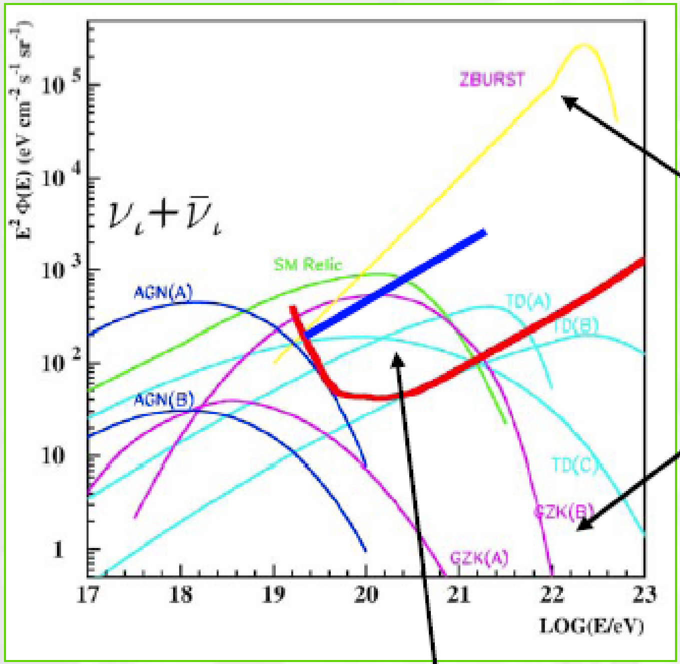
1. QCD Parton Densities at highest energies
2. Tomography of Dark-Matter Neutrinos in Cluster of Galaxies
   – by Cosmological Neutrinos
3 Testing the fundamentals of Relativity Principle - find γ-rays!
4 Oscillating tau-neutrinos can appear as upward showers at 10^{16-18} eV
5 "Sterile" or Right-handed neutrinos may appear for EUSO as
   – upward showers above 10^{18} eV
6 Greisen neutrinos (the most conventional source)
7 Testing the Topological Defects of very early Universe at 10^{-34} s
8. Probing Blazars and Gamma Ray Burst sources
9. Relic Neutrinos
10 Absolute energy calibration
11. Evolution of Universe

NEUTRINOS

EUSO sensitivity

Red line is the flux resulting in 1 event/year/decade in energy

Blu line ' the same ' for Auger



[1] Oleg E. Kalashev, Vadim A. Kuzmin, Dmitry V. Semikoz, Gunter Sigl. "ULTRAHIGH-ENERGY NEUTRINO FLUXES AND THEIR CONSTRAINTS" Phys.Rev.D66:063004,2002

ZBURST (>100 events/year in EUSO)

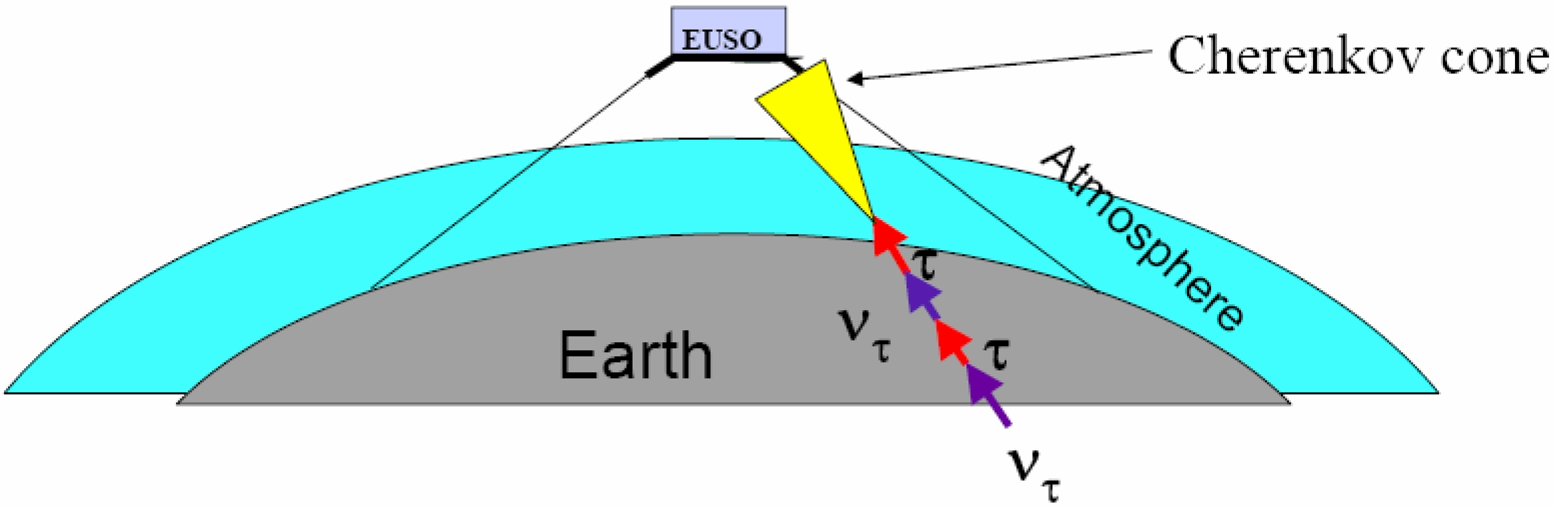
GZK(B) (~10 events/year in EUSO)

(both GZK and ZBURST here are the most intense of their category allowed in ref [1])

TD (A,B,C) (~ 5 events/year) ; MR (~ 10 events/year) are topological defect and massive relic fluxes of typical intensity !

S. Bottai

DIRECT CHERENKOV LIGHT DETECTION ?



DIRECT CHERENKOV LIGHT :

Most of light emission within $\theta_{cher} = 1.3^o$
around shower axis

DETECTION IN ONE OR FEW PIXEL-10^2ns
threshold energy (10 pe): ~ 10^{16} eV

EFFECTIVE AREA ~ AREA OF CHERENKOV CONE

MORE SCIENCE SUMMARIZED

(Takahashi 2/15/2005)

* Newer and fundamentally significant objects for observations at Extremely High Energies are revisited.

**This is an additional summary to be supplemented to the EUSO Science Case document (3-page main body) that we summarized and wrote in June, 2004.

II. Monitor different origins of neutrinos.

1. Secondary of MHD Black hole jets and GRB wakefields
2. Bare singularity quantum repulsions from Kerr BHs (Sakharov-Tomozawa, Reissner-Nordstrom type) - * singularity issue (see below)
3. Right-handed (Mirror) neutrinos
4. Relic neutrinos by $p+\nu \rightarrow \nu+p$

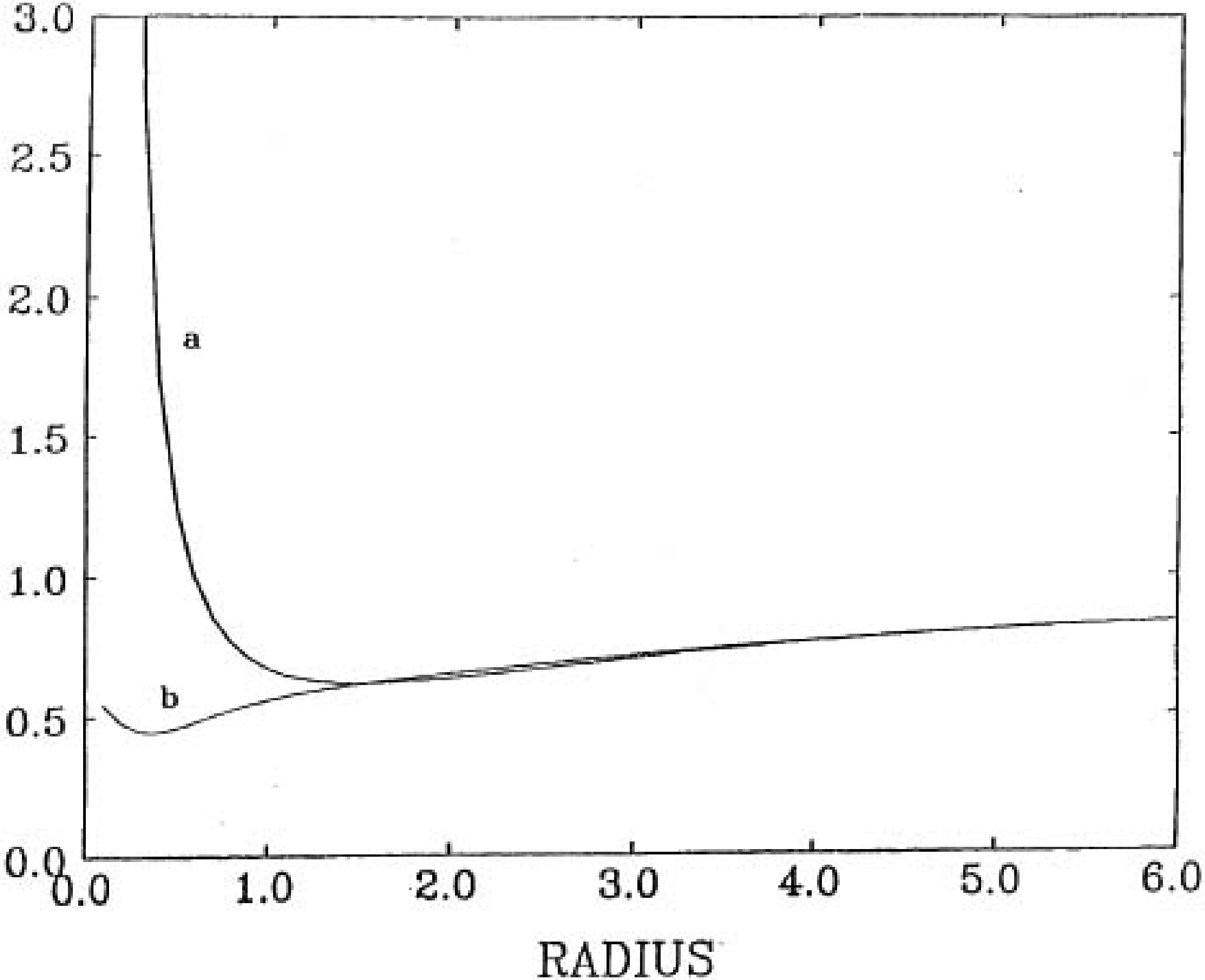


Fig. 2 A numerical solution for the Einstein equation with quantum corrections in the spherically symmetric static metric (the values of the parameters are $K = 1$, $\ell^2\alpha = 3$, $\ell^2\beta = 1$, $\gamma = \delta = 0$) : The curve a is for g_{00} and the curve b for g_{11}^{-1}.

Non-Singularity issue

Sakharov, Tomozawa, Nordstrom-Reissner, Feynman

Repulsive explosion of black holes in stellar collapse

Quantum Field Momentum Cutoff Issue

Y. Yamaguchi, Prog. Theor. Phys. 110, 611 (2003)

- Cutoff momentum of canonical commutation relations (CR) in Riemannian momentum space is due
- $[x_i, p^j] = i\{\delta_{ij} + (1/4K^2)(2p^i p^j - p^2\delta_{ij})\}$, hence,

$$v = \frac{p}{\sqrt{m^2 + p^2}}\left\{1 - \frac{p^2}{4K^2} + O(1/K^4)\right\},$$

when

$p^2 << K^2$

- A high-energy particle with momentum p runs at a velocity v slower than light velocity c by
- $p^2/4K^2$. or ($\Delta v \sim p^2/4K^2 \sim 10^{-5} - 10^{-13}$)

Quantum Field Momentum Cutoff Issue

Y. Yamaguchi, Prog. Theor. Phys. 110, 611 (2003)

- Cutoff momentum of canonical commutation relations (CR) in Riemannian momentum space is due

  $[x_i, p^j] = i\{\delta_{ij} + (1/4K^2)(2p^i p^j - p^2\delta_{ij})\}$, hence,

$$v = \frac{p}{\sqrt{m^2 + p^2}}\left\{1 - \frac{p^2}{4K^2} + O(1/K^4)\right\},$$

$$when$$

$$p^2 << K^2.$$

- A high-energy particle with momentum p runs at a velocity v slower than light velocity c by

  $p^2/4K^2$. or ($\Delta v \sim p^2/4K^2 \sim 10^{-5} - 10^{-13}$)

Lower limit of K ~ 10 TeV/c, from QED higher order correction.
Not m_X(GUT, 10^{22-25} eV/c), or m_P (10^{28} eV/c).

- Phase-space volume element at p > K in Robertson-Walker momentum metric gives,

$$\frac{d^3 p}{(1+\frac{p^2}{4K^2})^3} = \frac{4\pi p^2 dp}{(1+\frac{p^2}{4K^2})^3} \approx 4\pi \frac{dp}{p^4} \approx 4\pi E^{-4} dE.$$

- K might be as low as $10^{15} - 10^{19}$ eV/c, which can have 10^{3-4} boost if originating from line-of-sight jets in a cosmological rest frame.

- Cutoff energy point of the primary spectrum decides K.

Mirror neutrinos - Okun, Berezinsky

HE NEUTRINO ASTRONOMY AT $10^3 - 10^{10}$ GeV

V. Berezinsky

LNGS, Laboratori Nazionali del Gran Sasso, Italy

VHE : $E_\nu \geq 1$ TeV

UHE : $E_\nu > m_W^2/2m_e = 6.3 \times 10^6$ GeV

SuperGZK: $E_\nu \geq 1 \times 10^{10}$ GeV

HE NEUTRINO PRODUCTION

- PP AND Pγ INTERACTION OF ACCELERATED PROTONS

$p+p \to \pi^\pm(K^\pm) + all$, $\hookrightarrow \nu$ — HE NEUTRINO ASTRONOMY $E_\nu \gtrsim 1$ TeV

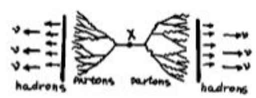
$p+\gamma \to \pi^\pm(K^\pm) + all$, $\hookrightarrow \nu$ — VHE NEUTRINO ASTRONOMY $E_\nu \gtrsim 0.05 \frac{m_\pi m_p}{\epsilon_{\gamma,mar}} \sim 10^7 - 10^8 \frac{1 eV}{\epsilon_{\gamma,mar}}$ GeV

- ANNIHILATION OF DM PARTICLES

$\chi+\chi \to \pi^\pm(K^\pm) + all$, $\hookrightarrow \nu$ — $E_\nu \lesssim m_\chi \lesssim 1$ TeV

- DECAY OF SUPERHEAVY PARTICLES

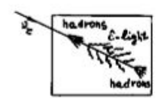
$X \to \pi^\pm(K^\pm) + all$ — UHE NEUTRINO ASTRONOMY $E_\nu^{max} \sim 5 \cdot 10^{-2} m_X$



NEUTRINO DETECTION

FOUR REMARKABLE REACTIONS

- $\nu_\mu + N \to \mu + all$ — SEARCH FOR DISCRETE SOURCES
- $\bar{\nu}_e + e \to W^- \to hadrons$ — MONOENERGETIC SHOWERS $E_0 = \frac{m_W^2}{2m_e} = 6.3 \cdot 10^6$ GeV, LARGE CROSS-SECTION
- $\nu_\tau + N \to \tau + hadrons$ — THREE SIGNALS:



PROMPT HADRONS,
CHERENKOV LIGHT FROM τ
HADRONS FROM τ-DECAY

- Z-BURSTS — SIGNAL FROM SPACE

$\nu + \bar{\nu}_{DM} \to Z^0 \to hadrons$ $\quad E_0 = \frac{m_Z^2}{2m_\nu} = 4 \cdot 10^{12} \left(\frac{1 eV}{m_\nu}\right)$ GeV

ROLE OF NEUTRINO OSCILLATIONS

OSCILLATION IS EFFECTIVE

$$P_{\nu_\mu \to \nu_\mu} = \frac{1}{2} \sin^2 2\theta \sin^2 \frac{r}{L(E)}$$

$$L(E) = \frac{4E}{\Delta m^2} = 25 \left(\frac{E}{10^6 GeV}\right)\left(\frac{10^{-10} eV^2}{\Delta m^2}\right) Mpc$$

$\bar{\nu}_e$ AND ν_τ ARE INEFFICIENTLY PRODECED IN ACCELERATOR SOURCES

$$p+\gamma \to \Delta^+ \to p+\pi^0;\ n+\pi^+,\ \pi^+ \to \mu^+ + \nu_\mu,\ \mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e$$

OSCILLATIONS:

$\bar{\nu}_\mu \to \bar{\nu}_e$ SNO

MSW: $\Delta m^2 \approx 4 \cdot 10^{-5} eV^2$ $\quad L(E) \approx 70 pc \left(\frac{E}{10^{10} GeV}\right)$

$\nu_\mu \to \nu_\tau$ ATM

VACUUM: $\Delta m^2 = 3 \cdot 10^{-3} eV^2$ $\quad L(E) = 1 pc \left(\frac{E}{10^{11} GeV}\right)$

HE NEUTRINOS FROM EPOCHS WITH LARGE z

(TD AND DECAY OF SUPERHEAVY PARTICLES)

- ABSORPTION OF HE NEUTRINOS

$\nu + \bar{\nu} \to f + \bar{f}$ $\quad f = e, \mu, \tau, u, d, s \ldots$

$z_{abs} = 7.9 \cdot 10^4 (E_{\nu 0}/1 TeV)^{-1/3}$

$E_{\nu 0}$ IS ENERGY AT $z = 0$

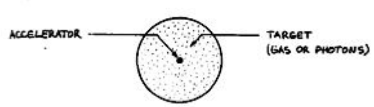
- NUCLEOSYNTHESIS BOUND

NEUTRINO FLUXES ARE STRONGLY RESTRICTED BY PRODUCTION OF D/^{3}He AFTER BBN ($z > 1 - 100 s$)

$\nu + \bar{\nu}_{DM} \to \pi^0 \to \gamma \to$ cascade — MeV photons $\gamma + {}^4He \to D, {}^3He$

NEUTRINO SOURCES

- ACCELERATOR SOURCES



- NON-ACCELERATOR SOURCES

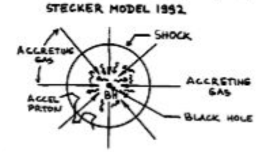
ANNIHILATION $X + \bar{X} \to (\pi^\pm, K^\pm) \to \nu$

DECAY $X \to$ PARTON CASCADE $\to \pi^\pm, K^\pm \to \nu$

- HIDDEN SOURCES

HE ν's FROM RADIO-QUIET AGN

STECKER MODEL 1992



- STANDING SHOCK AT $R_{sh} \sim 20\, r_g$
- PROTONS ARE ACCELERATED AND DRAGGED DOWNSTREAM

$Q_{prod}(E) \sim E^{-2}$, $\int_0^{E_m} Q_{prod}(E) E dE = \eta\, G M_{bh} \dot{M} / R_{sh}$

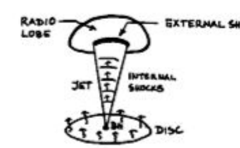
- DENSITY OF X-RAY PHOTONS, $n_X(E)$, - OBSERVATIONS
- NEUTRINO PRODUCTION: $p + \gamma_X \to \pi + all$
- NON-TRANSPARENCY FOR γ WITH $E_\gamma \gtrsim 1$ MeV

$\gamma + \gamma_X \to e^+ + e^-$

HE ν's FROM RADIO-LOUD (JET) AGN

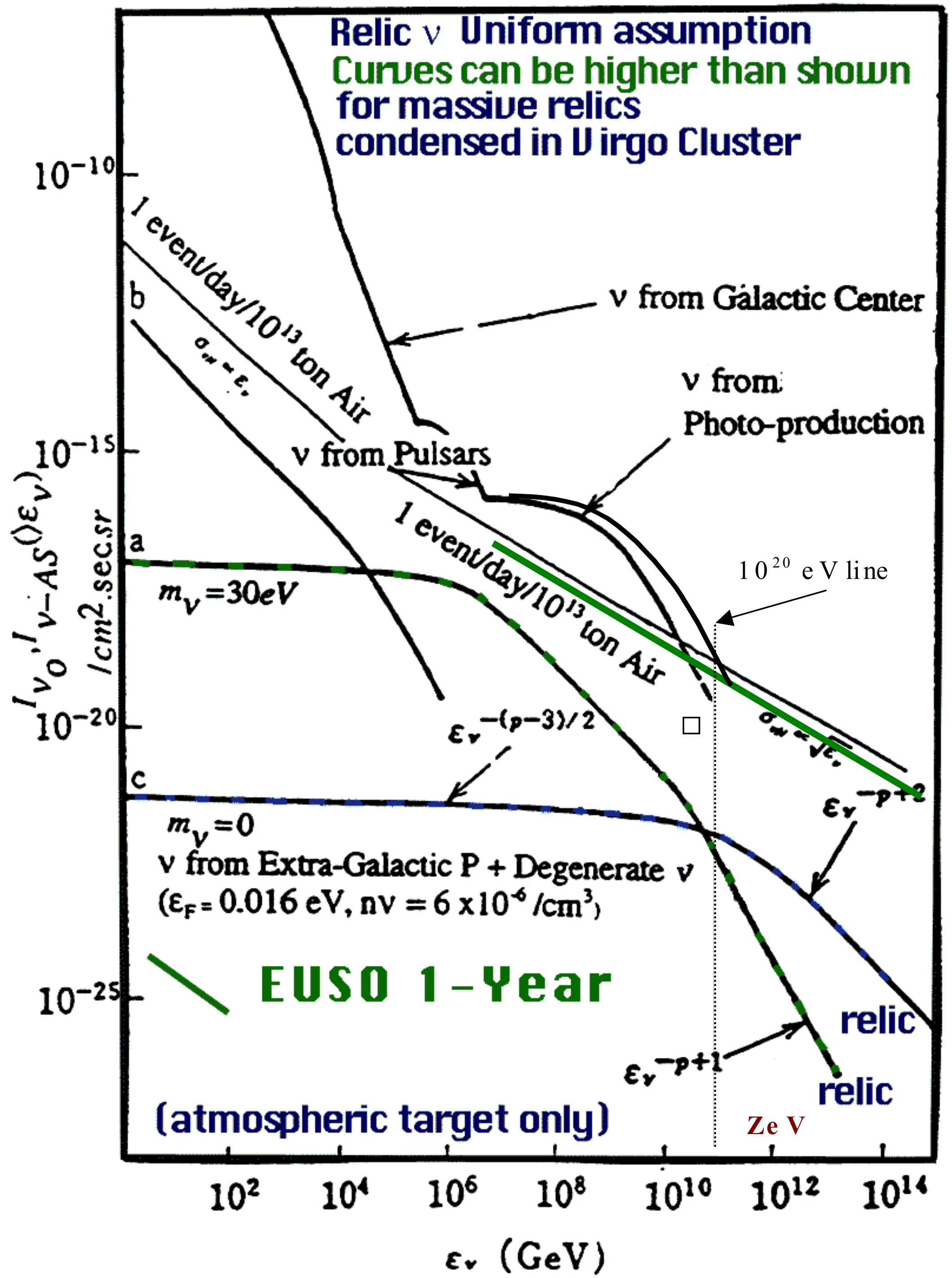
Mannheim 1995

Atoyan, Dermer 2001



TRANSPARENT FOR HE γ's

- NEUTRINO PRODUCTION: $p + \gamma_{tar} \to \pi^\pm + all$
- TARGET PHOTONS: SYNCHROTRON AND IC
- WITH PROTON LUMINOSITY $L_p = 2 \cdot 10^{48}$ erg/s 3C 279 CAN BE DETECTED BY $1 km^3$ DETECTOR AT RATE $\sim 1 yr^{-1}$ (Atoyan, Dermer)
- DIFFUSE FLUX CAN BE DETECTABLE



Relic Neutrinos

The position of the "Directorate for Science" and of the "Science Program Committee".

The Science Programme Committee (SPC), at their meeting on 7 and 8 June 2004, did not include Space Station based Missions in their priority list for a possible complement of the "ESA Science Mandatory Programme" considered up 2012 . However the SPC expressed the intention to continue supporting the "SPC/PB-HSR Joint Working Group" with the mandate to confirm and consolidate the role of ESA, the National Agencies and the International Partners in the development and financing of Space Science payloads for accommodation on the ISS .

For what EUSO is concerned Dr. D. Southwood , ESA Director for Science , in a letter to the EUSO P.I. ,dated 29 July 2004, stated :

…"although the ESA Science Programme Directorate at this moment in time does neither have the mandate nor the funds available to proceed to Phase B, it is my intention to monitor closely, to coordinate when necessary and to assist when possible, the further developments and deliberations regarding EUSO."

Under this profile the following actions need to be implemented :

A) By the EUSO Consortium :

- ***Confirm the commitments subscribed and ensure the "Instrument funding".***
- ***Identify a "National Agency" acting as support and sponsor for the "EUSO Instrument" vis-à-vis ESA for mission implementation.***

B) By ESA , NASA and JAXA :

- ***Establish a Tri-Agency MOU regulating the "Payload" side of the Mission.***

C) Provided the assurance of conditions A) and B) "ESA MSM" Directorate (now "D-HME": "Human flight Microgravity and Exploration Directorate") could start Phase B for the EUSO Payload . Duration is estimated at 18 months with cost between 3 and 5 MEuro

This process should be completed in time to assure the follow on of EUSO into an operational Phase B not later than December 2006

The proposed solution for EUSO

Taking into account :
- the outcome of the "ESA Review Board conclusions" on 15 July 2004,
- the "Wrap-up and conclusion" of the *EUSO Trilateral Agency (ESA, NASA, JAXA) meeting held at ESTEC on 15 July 04 ,*
-the position expressed by the ESA Director for Science on 27 July 2004:

the following strategy has been proposed by the PI on behalf of the EUSO Consortium to allow completion and launch of EUSO in orbit within a convenient time (2010), not later than 2012 :

1. Reconfiguration of EUSO in 2004-05 from a mission in the frame of the "ESA Special Project" coordinated and supported by ESA.

2. Refoundation in 2005-06 in ESA D/S and D/HME, as the "ESA Mandatory Science Program", to be re-proposed at the Cosmic Vision Slice-1, Spring of 2006.

- possibile cooperation with TUS/FSA on ISS can be included

B) - Tri-Agency (ESA , NASA, JAXA) M.O.U. regulating the “Payload” side.

Following the outcome of Action A , concerning the “Instrument”, the three Agencies involved in the “Payload” side (Transportation to the ISS ; Collocation on the Station ; Operation in orbit) will be briefed and negotiations started to reach a formal M.O.U. for the Mission.

In the short term plan the next interagency teleconference is planned on 27 January 2005 . Should it be necessary an additional oudating , it will be provided accordingly.

Main points on the table:

- ***Transportation.*** *NASA STS Shuttle is planned for decomissioning by 2010. As alternate the HTV of JAXA has been investigated: a study carried out by JAXA-ESA-Alenia has validated the compatibility with minor modifications, First launch date possible: starting 2009.*
- ***Collocation.*** *Columbus (Exp.Payl.Fac. , TAB), S-3 on Truss , JEM Exp.*
- ***Funding.*** *To be negotiated . NASA on the basis of the agreement presently existing with ESA is not included.*

ESA D/Science June 2004 and After

- ***No ESA missions up to 2012 were recommended / funded***
  Due to a severe deficit and lack of money in ESA D/S 2002-07
- EUSO was pointed out in 2004 to answer on 3-issues

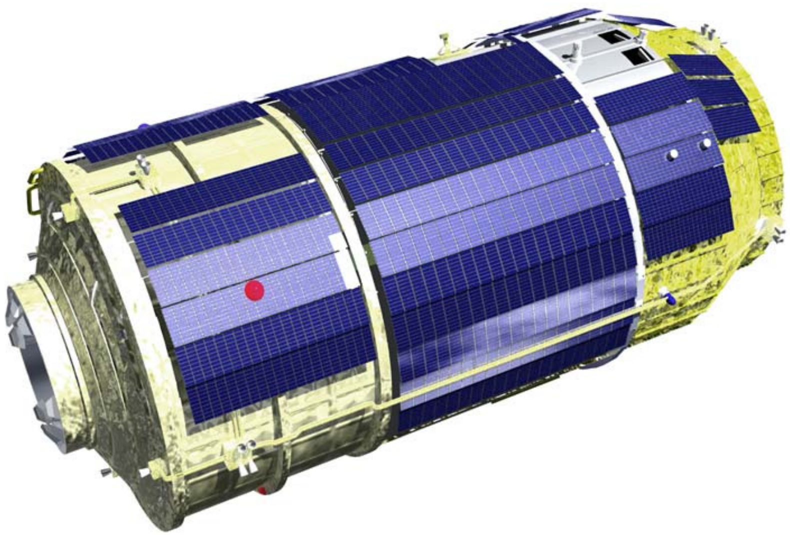
1. Launch opportunities if STS doesn't fly → **HTV of JAXA**
2. ESA Member sates must make budgetary commitment
   → **Re-work by getting Slice-1 of CV (2006)**
3. Watch Auger results and re-design if needed
   → Auger showed lower EHE intensity,
   hard to solve the Physics by Auger itself.
   → Auger confirmed the requirement of the Critical Exposure Factor
   that EUSO has been demonstrating as such.

➢ ***Propose in ESA D/S 2006 for new budgetary cycle***

Table 1 -EUSO Instrument cost end-to-end repartition (for Phase B, 10 to 15 % of total) .
(20 October 2004 Interagency Teleconference)

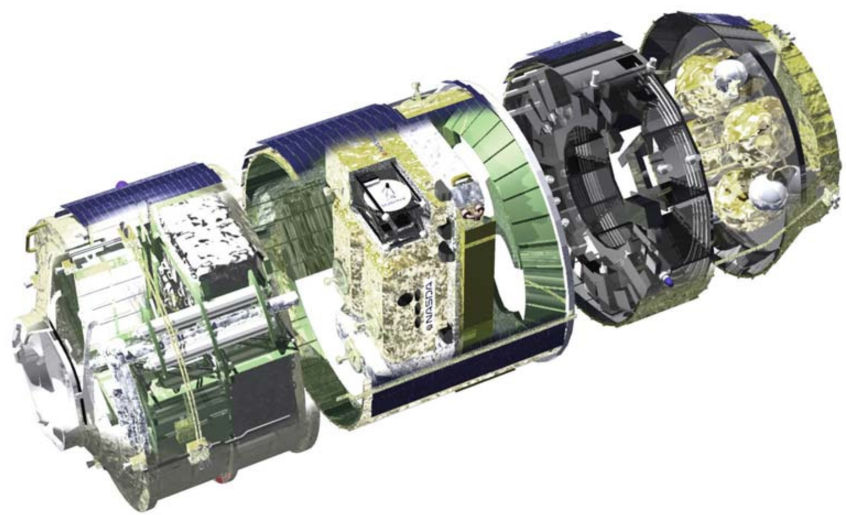
Nation	Direct Cost (MEuro)	Indirect Cost (MEuro)	Funding Agencies	Status
Italy	**40**	**16**	ASI ,INFN, University	Submitted to ASI
France	**10**	**8**	CNES,IN2P3, University	Submitted to CNES request for 5.2MEuro (negotiable to 10 MEuro)
Germany	**4.8**	**6**	DLR,MPI, University	Letter of intent of Director of MPI
Portugal	**4**	**2.6**	GRICES,LIP, University	Mission approved end-to-end , with allocation of funds confimed yearly
Switzerland	**5**	**2.4**	PRODEX, Observatoire de Neuchatel.	Negotiations with PRODEX under way.
Japan	**16**	**12**	RIKEN , JAXA	Phases A and B funded by Riken. Proposal to JAXA for C-D-E
USA	**23**	**-**	NASA	Mission approved end-to-end, conditioned to ESA confirmation
Spain	**3.8**	**TBD**	Ministry of Science &Tech. Prog.Nacional de Inv.Espacial	Letter of intent of Manager of Spanish National Space Program
Brazil	**3**	**TBD**	AEB	Letter of intent of President of Space Agency of Brazil
Total	**109,6**			

H2A Transfer Vehicle

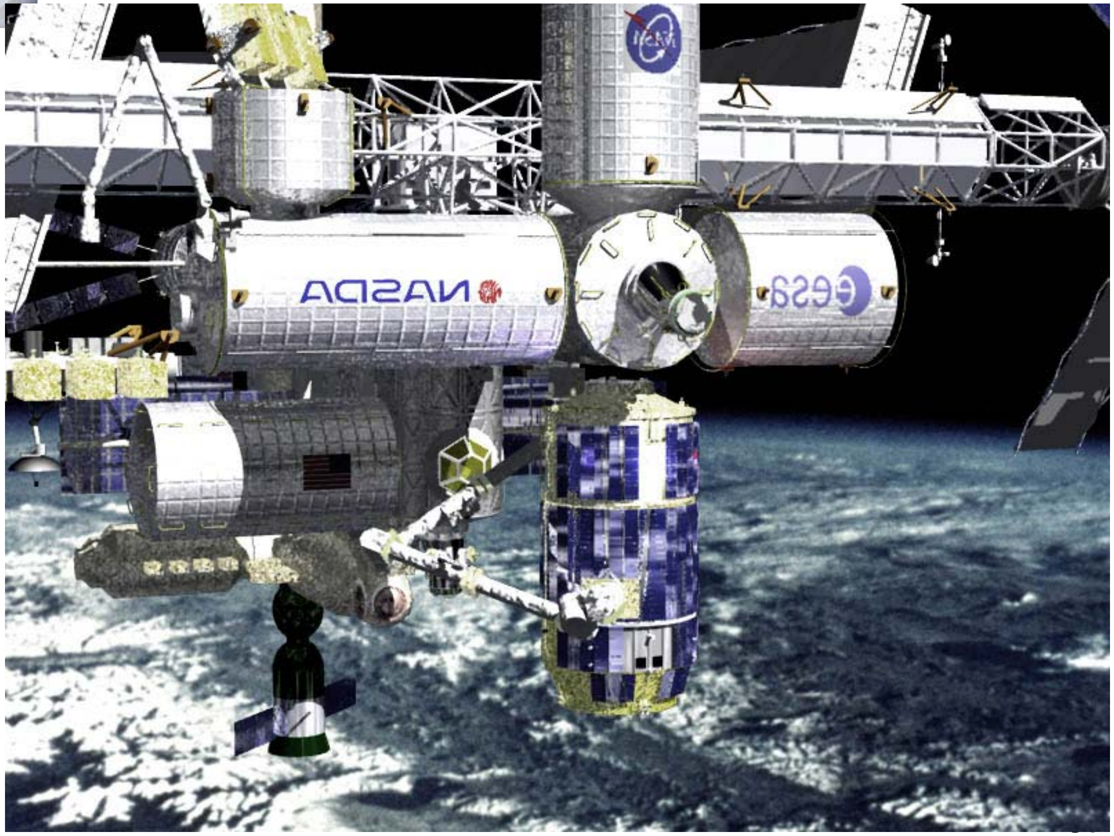


First Launch:2008

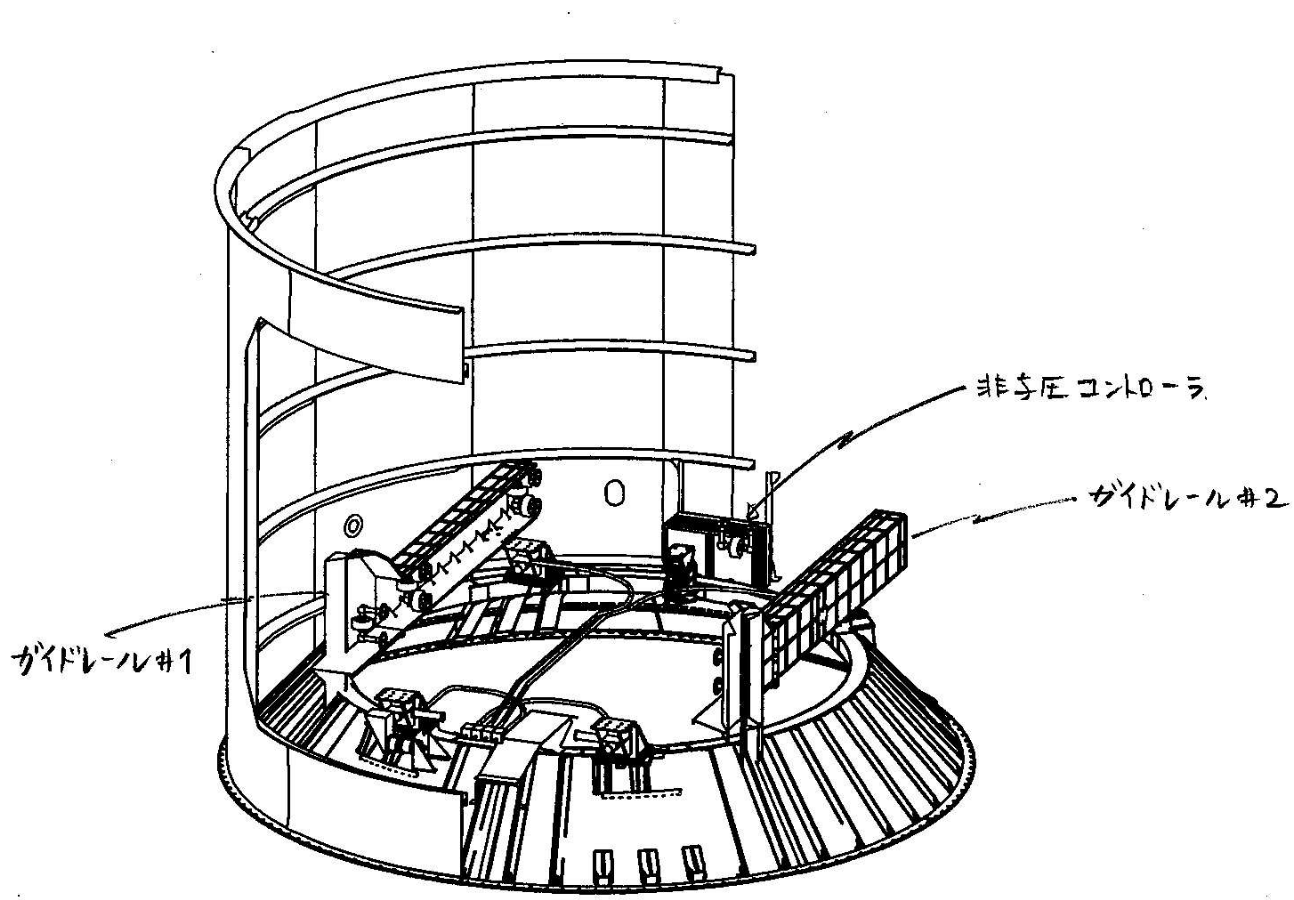
Launch Once a Year



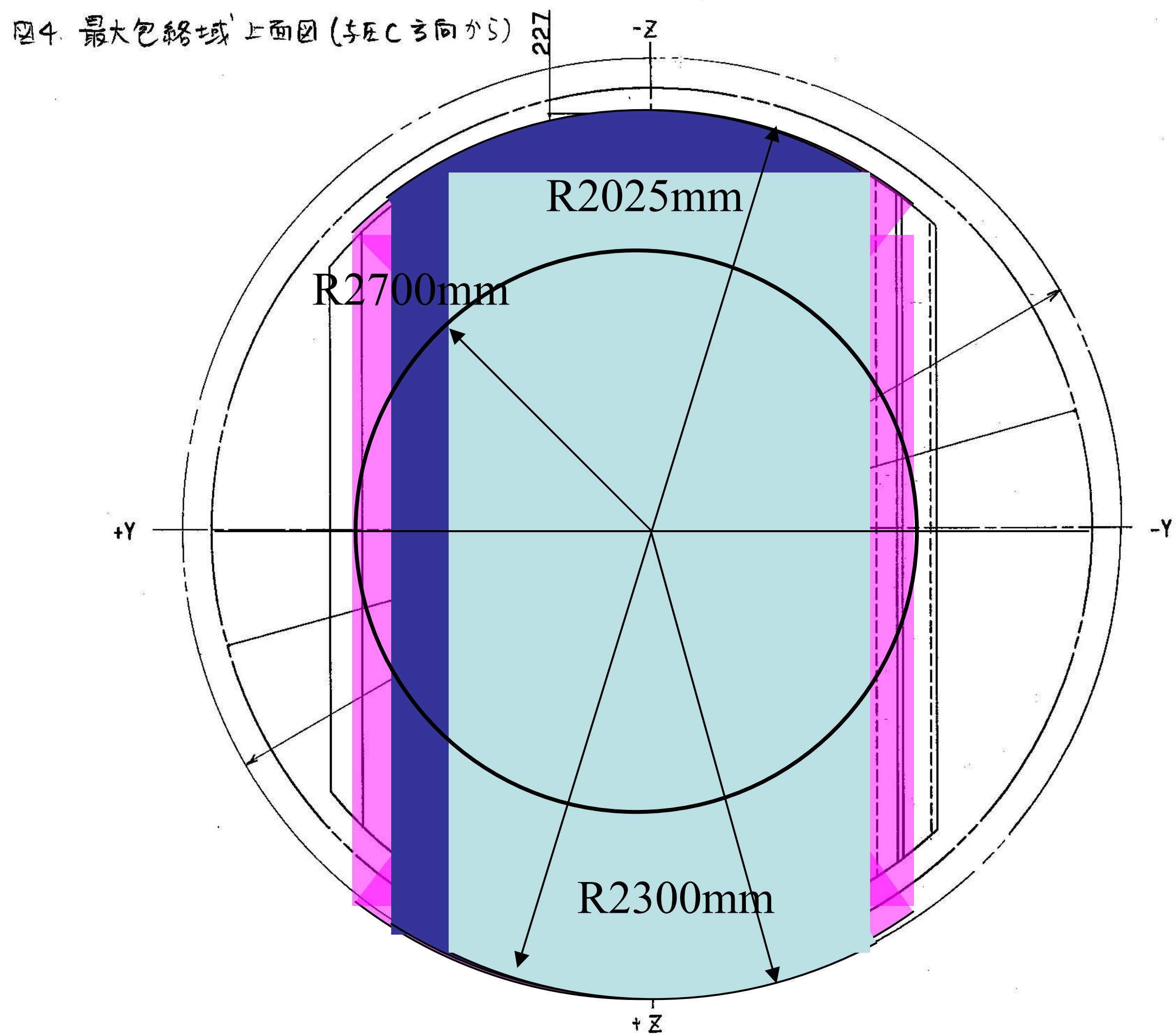
HTV



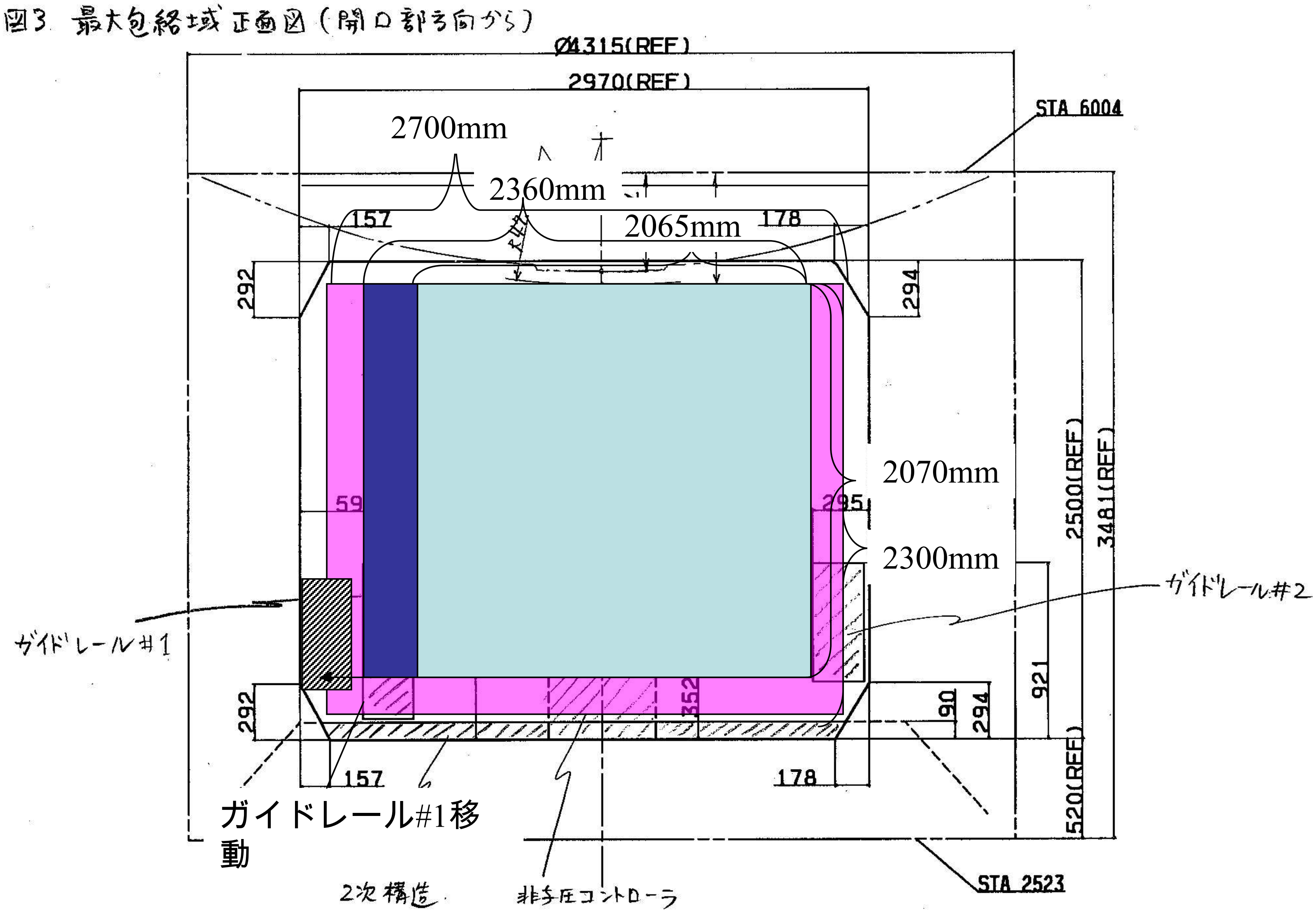
Inside of Unpressurised Module

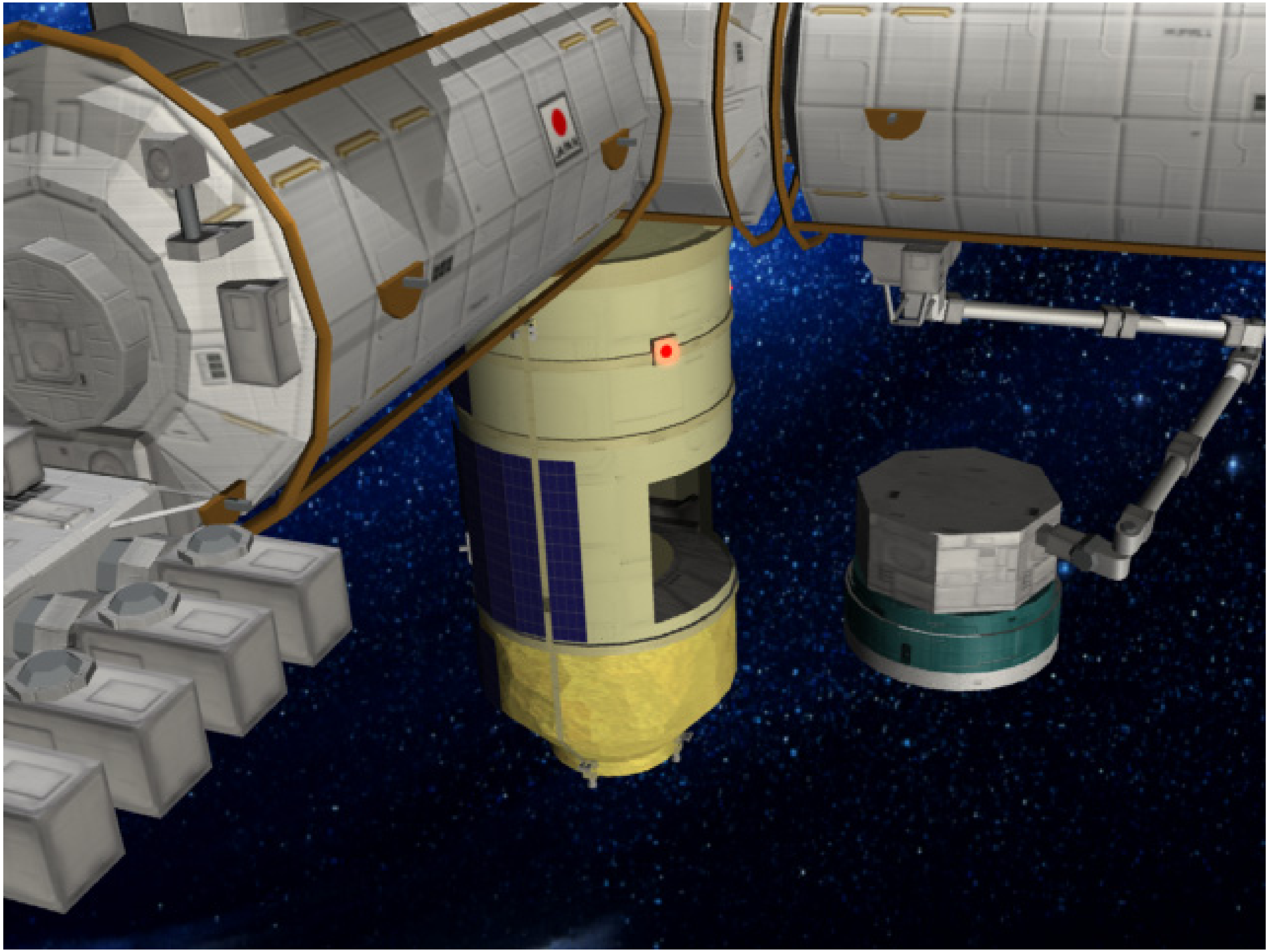


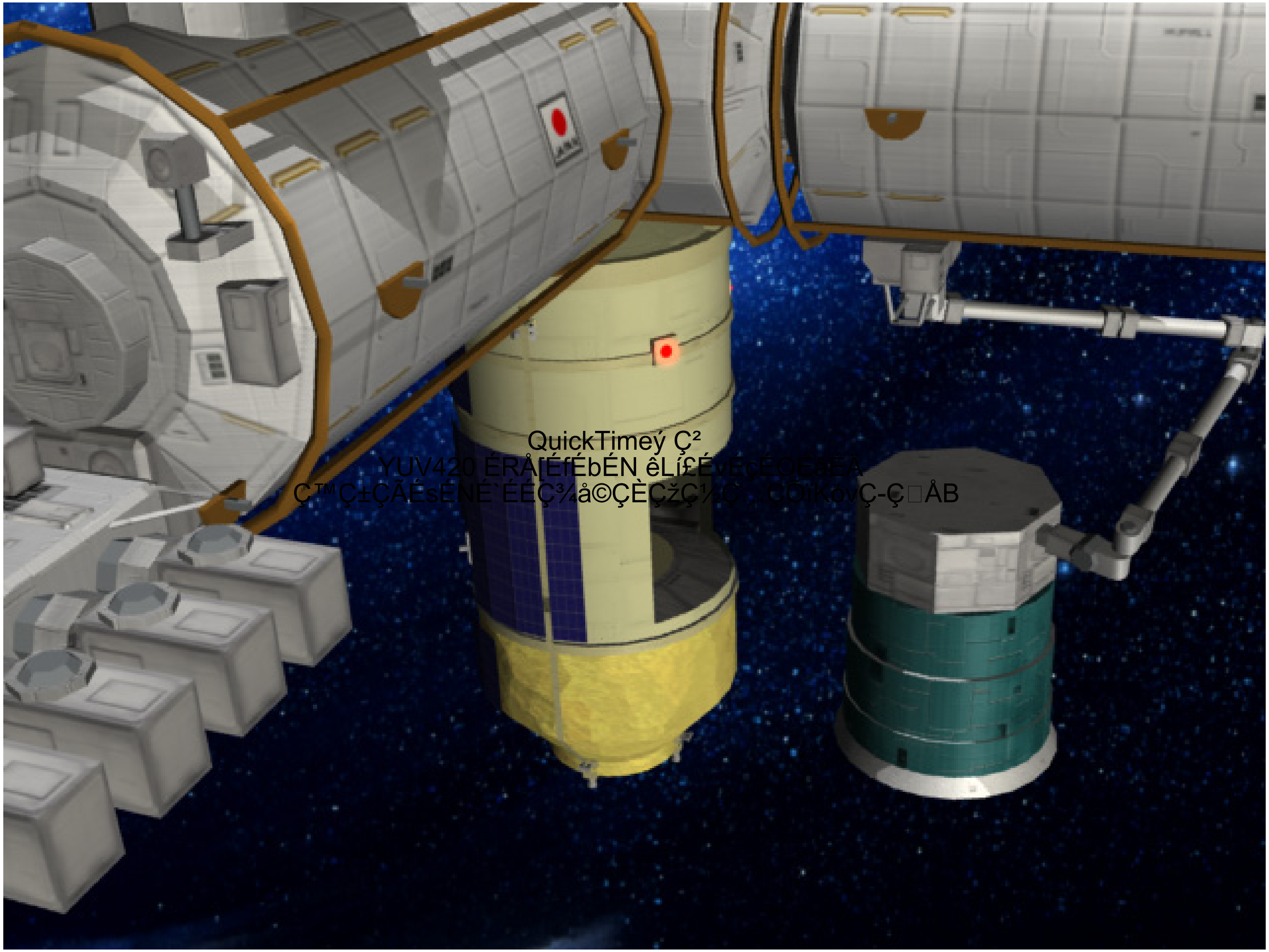
Envelope (upside view)



Envelope (front side view)






QuickTimeý Ç²

Beyond Auger is mandatory for EHE Sciences

- Two cases of the Auger results
  - No or Little GZK Cut-off
    - High statistics is essential to identify γ-ray observation is in order to identify Super-GZK sources such as Top-Down and/or Z-bursts.
    - N-S Hole-effect of Early Magnetic Cascading and LPM effects
  - Clear GZK Cut-off
    - Anisotropy would be imminent and Critical Exposure Factor by EUSO
    - Recovery from GZK for local sources (E> 3 x 10^{20} eV)
    - Absolute Energy Calibration by the details of the trans-GZK spectrum
- Essential standing of the EUSO for EHE Sciences
  - All-sky monitoring of the EHE sources
  - Overwhelming Statistics (>10^{20} eV)
    - 2876 (Super GZK)
    - 227 (GZK)
  - Observability of neutrinos

Phase-A Extension Final Review (July 2004)

- **Conclusion: EUSO is ready to move on to Phase-B**

  ESA - MSM (ISS Division) takes care of the Phase-B
  - Joint venture of D-MSM and D-SCI

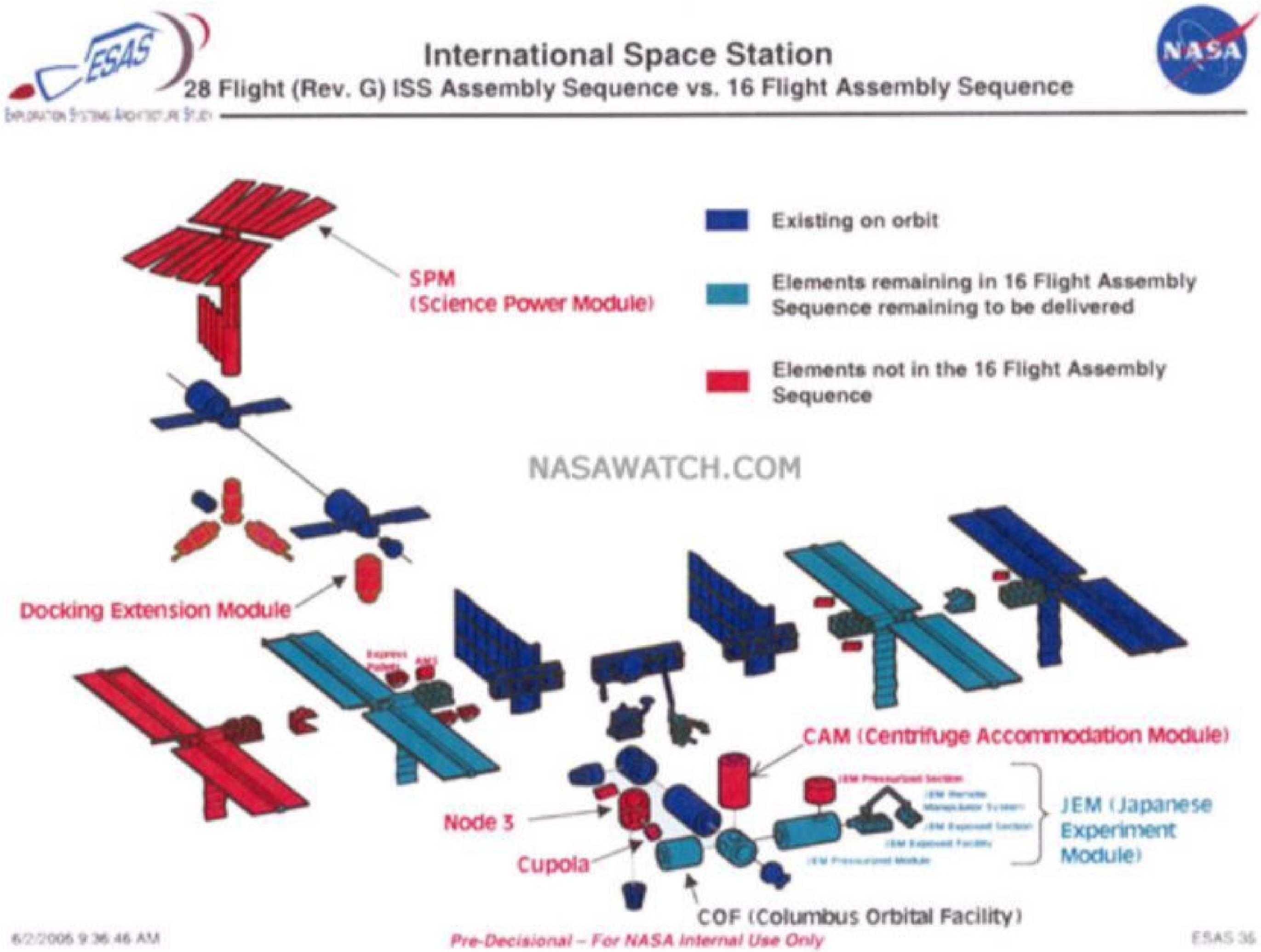
- EUSO's Science values would not change no matter what data come out from AUGER experiments.
  - Change of the design is not required.

- Launch opportunity would be available by JAXA's HTV

- ASI is maintaining the budget book of 40 M Euros for the EUSO Instrument, Italian contribution.

- NASA does not change its approved end-to-end financial commitment of $36M for U.S. contribution by MIDEX Explorer funds.

NASA ISS predecisional



EUSO from Space - Comparison with ground experiments.

a) Advantages :

- Large Acceptance up to 10^6 Km^2 sr : two orders of magnitude above ground limit for instantaneous value and one order considering duty cycle. Ultimate means of large-area research.
- All sky survey.
- Fluorescence observations from top of atmosphere avoiding absorption effects from lower layers.
- No "Proximity effects".
- Large "Active target mass" for "Low interaction particles": up to 10^{13} tons : four order of magnitude above one "Km cube" of water.
- Possibility of observing interaction paths larger than hundreds hadron interaction length in air.
- Possibility of observing all inclination up to "Upward moving" showers".
- Contextual observation of Atmospheric Physics and Meteor Phenomena.

EUSO from Space - Comparison with ground experiments.

b) Limitations:

- **For E.A.S. characterization only the atmospheric induced fluorescence emission is observable compared with contextual "Fluorescence–Direct particle detection in the landing shower front" for Ground based Experiments.**
- **Low level of signal because of distant observation.**
- **No choice for the observation site.**
- **Higher cost for Space operation compared to Ground based.**

Are the scientific topics addressed by EUSO likely to be still relevant at the time of a 2010/2012 launch?

a) From the comments of the "Science Study Team" Indipendent Scientists , with reference to UHECR and the "GZK vs no GZK" issue:

…in the assumption that Auger South will be completed at the end of 2005 and that showers can be reconstructed out to zenith angles of 80º… with the exposure reached by the end of 2009, some 600 events above 10^{20} eV are expected if the flux reported by the AGASA group (based on 11 events) is correct. Even with this number of events, the EUSO instrument will have statistical advantages over Auger and will be able to see the whole sky… Additionally, it must not be overlooked that the 'instantaneous' aperture of EUSO is potentially very large. If UHECR are emitted from sources in bursts for a short time, EUSO is a superior instrument to Auger for source detection.

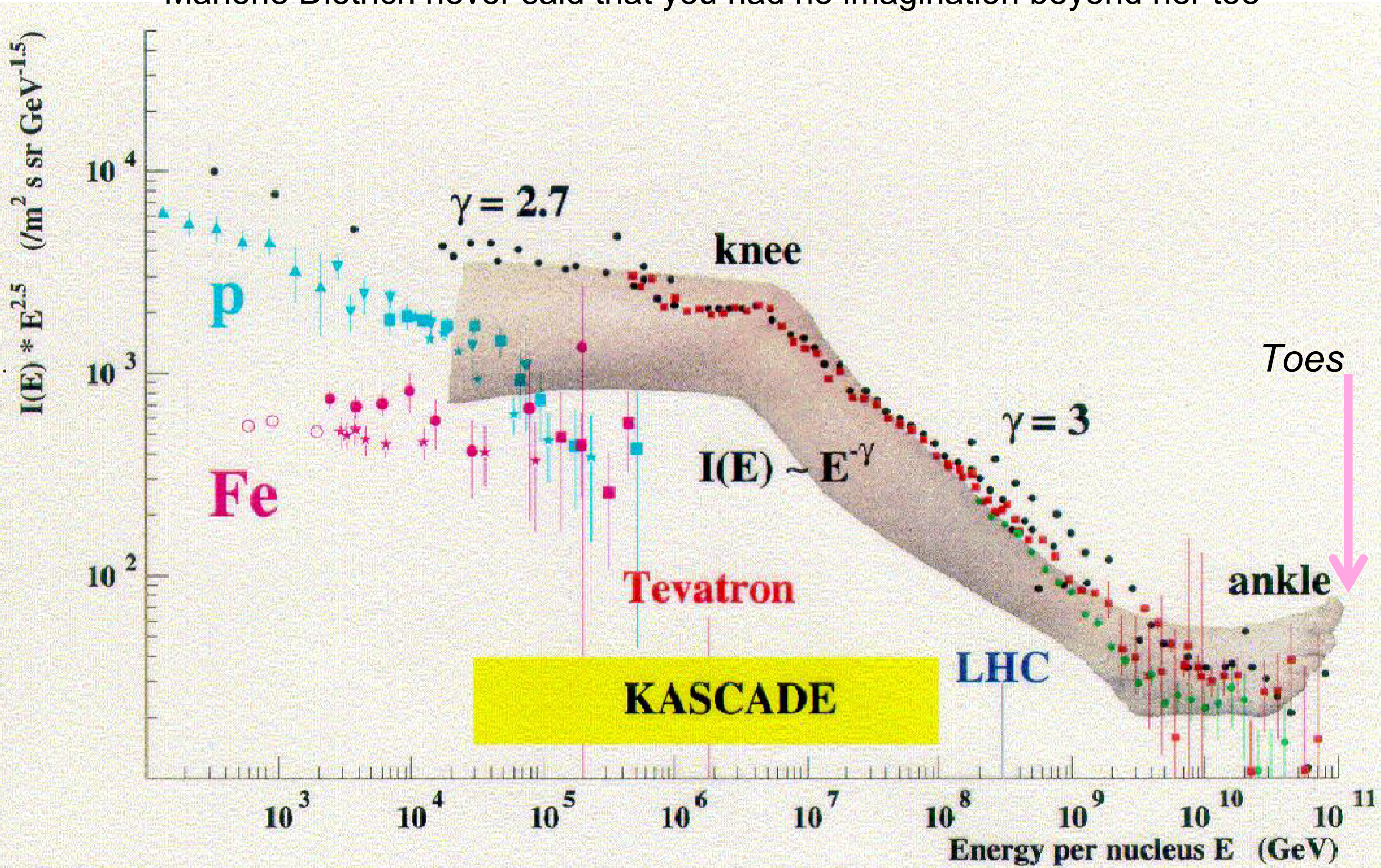
There are plans to complete the Auger Observatory by the addition of a Northern site … the time scale is uncertain …Construction is expected to be more rapid than it has been at the southern site but the start of exposure with the full aperture is likely to be late 2009/early 2010. The first phase of Auger-North will have similar functionality to Auger-South…

If the rate of events above 10^{20} eV is more like that found by the HiRes group, then the case for EUSO post-2010 is even stronger as the number of events observed by Auger will be correspondingly smaller…

b) Situation unchanged for all other scientific topics.

Cosmic Rays - still Mysterious.

- Marlene Dietrich never said that you had no imagination beyond her toe



Possible Cooperation of EUSO and TUS/KLYPVE

- Had a History of the First discussions in Albuquerque, February, 2000, and Metepac, Mexico, August, 2001
- Boris Khrenov letter for cooperation of TUS with EUSO on ISS (Sep 2005) suggesting TUS to EUSO deployments on ISS, & detector cooperation
- Livio Scarsi letter (Oct 205) to search for a possibility of cooperation
- We are meeting today for finding the possible ways of cooperation
  - ❑ Overall - Is time too short for major addition to TUS ? EUSO funds available for ?
    1. If ISS Logistics (TUS - Progress), (EUSO - HTV or Progress M?)
       Parts? or Joint operations?
    2. If free flyer
  - ❑ Parts
    1. Optics (Optic metrology - UAH + Florence?)
    2. Detector (RIKEN + Hamamatsu, Japan?)
    3. Electronics (Italian institutions)
    4. Others (Atmospheric monitoring, lightning protection, lidar ?)
- EUSO re-foundation can possibly include TUS participation.
- Is Joint planning and participation in EUSO possible from Russia?

Major Design Change and Improvements

- Use a Single Diffractive/Holographic Optical Element (HOE) located near the aperture top of the system.
  - Removes complexity of macro-grating structure on first and last surfaces.
  - Central HOE yields better chromatic correction with more flux within 5mm pixel.
  - Central HOE acts as field lens—significantly lowering off-axis vignetting with EPD=2.3m.