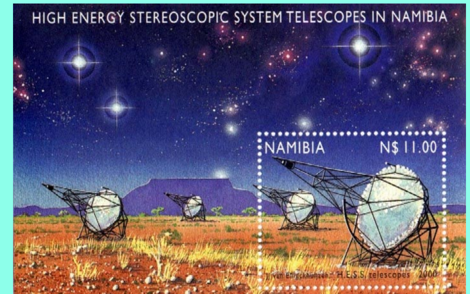
The EUSO project

JP Mendiburu- LAPP - Les Houches June 2001

Cosmic rays : 90 years of research

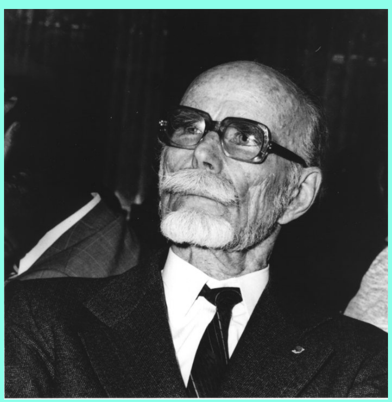
Discovery : V. Hess (1911)

- Ballon flight (5000m)
- Electrometers
- Non solar origin (eclipse)



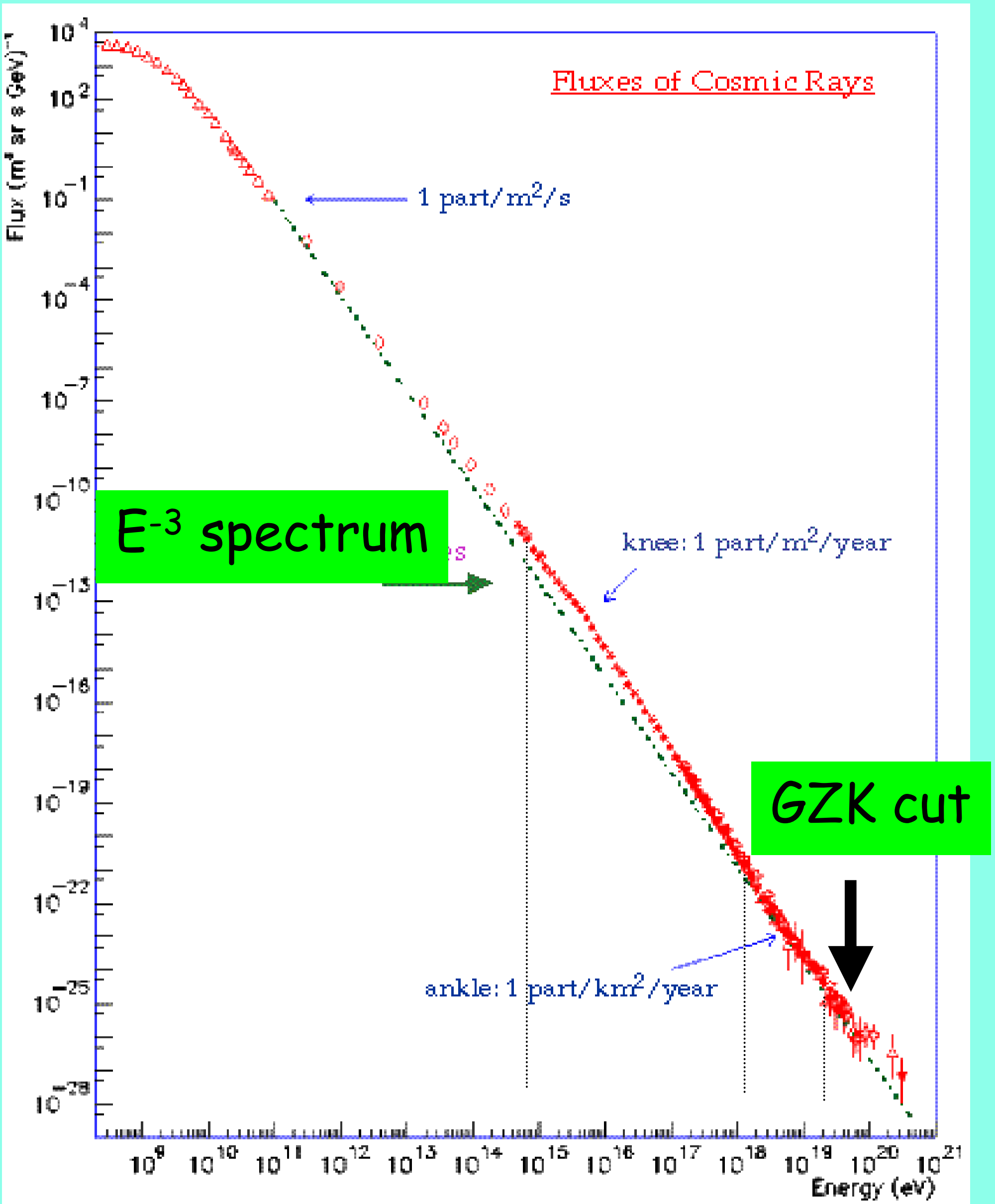
H.E.S.S project

- Understanding : P. Auger (1938)
  - Geiger counters coincidences
  - Mountain + sea level (Paris)
  - Extensive Air Shower (EAS)
    - E ~ 10^{15} eV(1 PeV)



PIERRE AUGER OBSERVATORY

Actual Knowledge



Possible Origins

$E < 10^{15}$ eV
Galactic

$5.\ 10^{19} < E < 3.\ 10^{20}$ eV

$10^{15} < E < 10^{18}$ eV
Extra-galactic ?

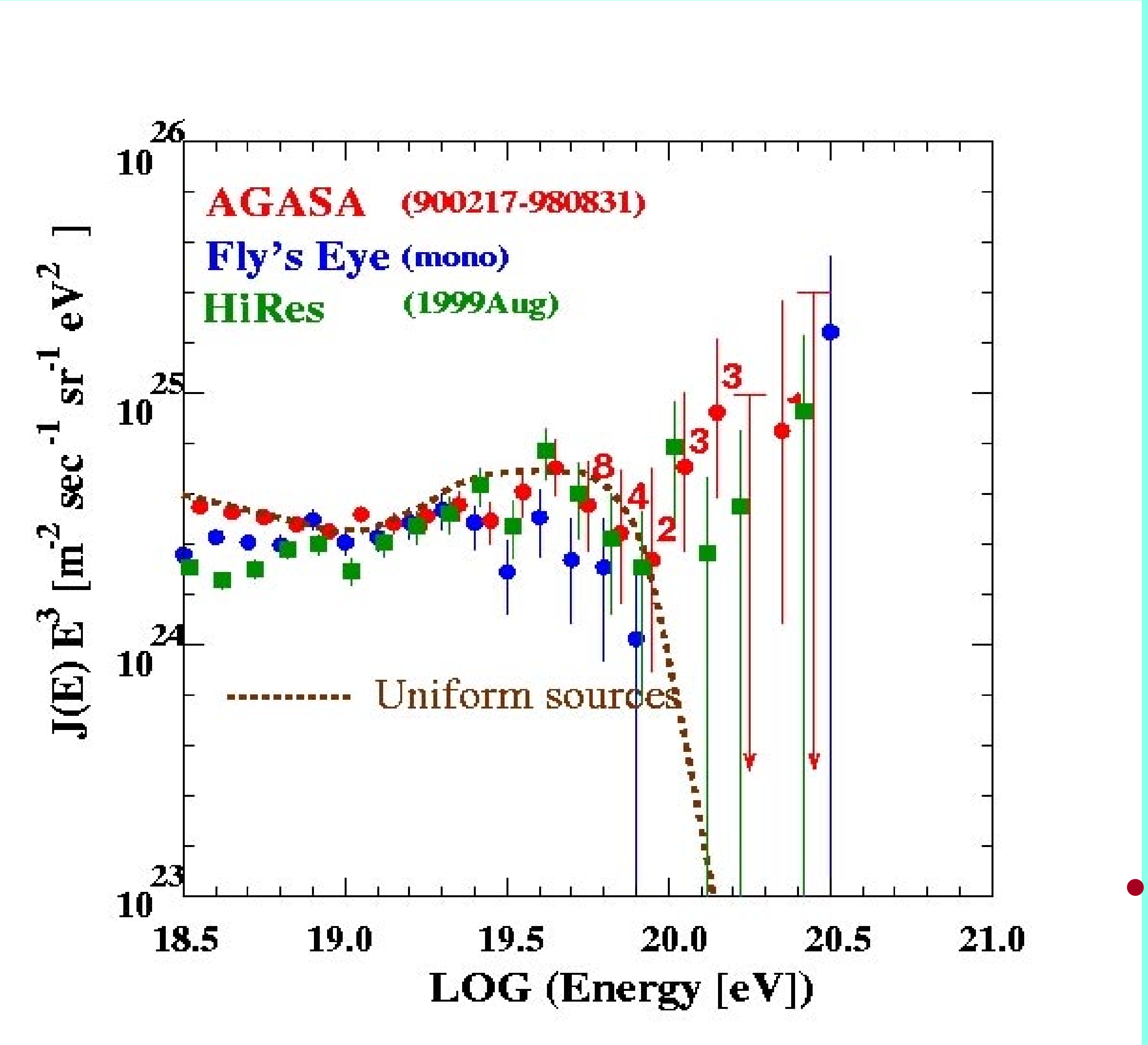
UHECR

$10^{18} < E < 5.\ 10^{19}$ eV
Unknown

EECR

$5.\ 10^{19} < E < 3.\ 10^{20}$ eV
Unexpected

THE ACTUAL MYSTERY OF E >10^{20} eV EVENTS



1962: First event (J. Linsley)

2001 : 40 years later

14 evts, 5 experiments

<u>Isotropy ?</u>

3 doublets, 1 triplet

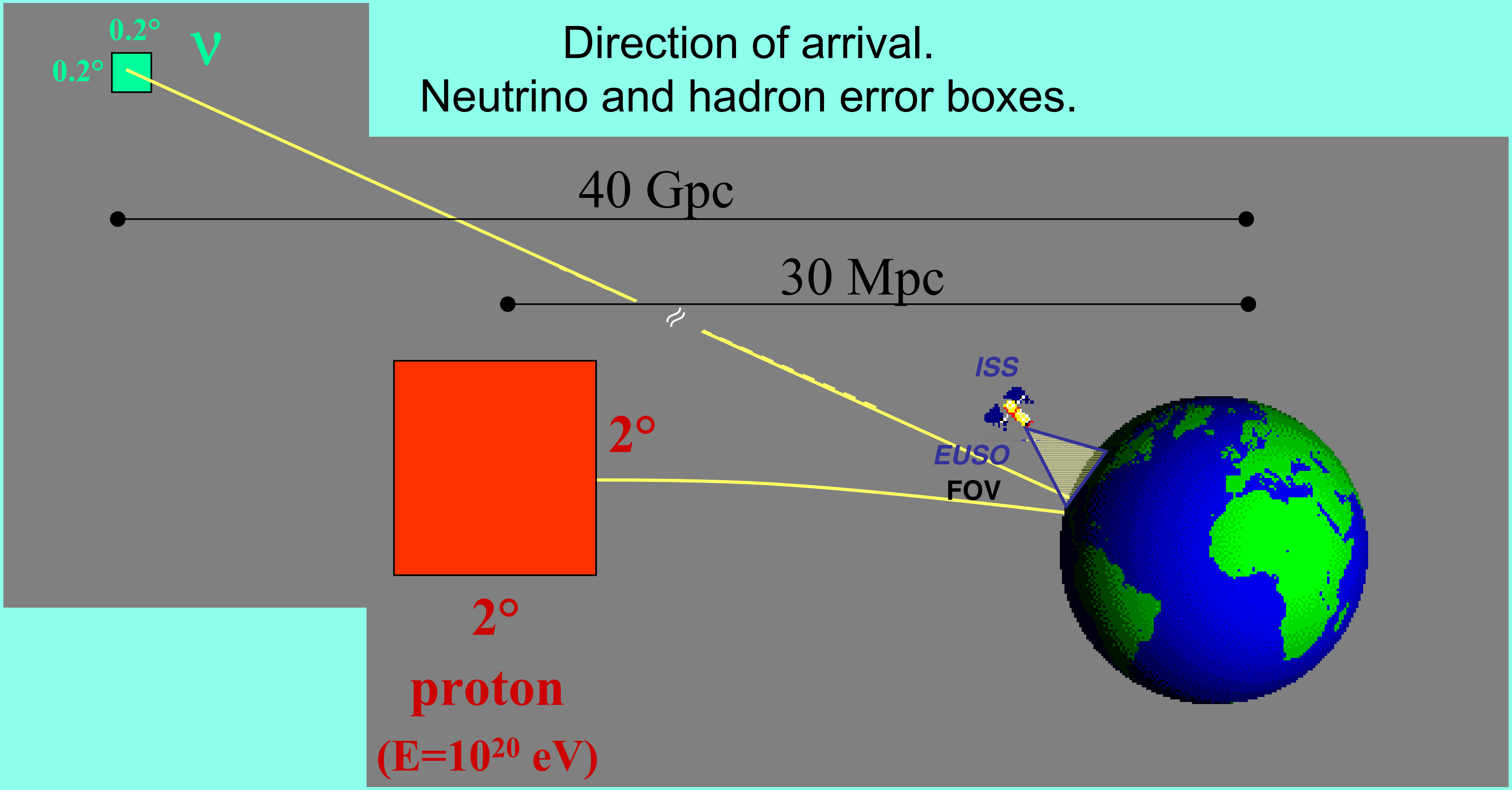
(P<1% … Importance to increase statistics)

<u>NO VISIBLE SOURCE</u>
< 50 Mpc

- <u>No clue of GZK cut</u>
  @ 5 10^{19} ?

The Cosmic Radiation: source pointing

Direction of arrival.
Neutrino and hadron error boxes.



The neutrino error box is limited only by the EUSO angular resolution while the proton error box is dominated by the intergalactic magnetic fields.

Assumptions: <B> = 1 nGauss

The GKZ cut-off

The existence of Cosmic Rays with energies in excess of 10^{20} eV is of particular interest because of the "GZK cut-off" (Greisen, 1966; Zatsepin and Kuz'min, 1966).

$p + \gamma\,(2.7^o)$ ---> $n + \pi^+$, $p + \pi^0$, $p + e^+ + e^-$

ˡ**--->** $\mu\ \nu$

$\lambda = 6 \quad , \ 6 \quad , 1$ Mpc at 10^{20} eV

$A + \gamma\,(2.7^o)$ ---> $(A\text{-}1) + N$, $(A\text{-}2) + 2N$, $A + e^+ + e^-$

$\lambda = 1$ Mpc at 10^{20} eV

Protons with energy in excess of ~ $4 10^{19}$ eV would be constrained to have travelled less than ~ 50 Mpc through the intergalactic medium, i.e. very close (1% of universe).

Particles Interaction point of vue

- The EECRs have energies only a few decades below the Grand Unification Energy (10^{24} - 10^{25} eV), although still rather far from the Planck Mass of 10^{28} eV.
- If protons, they show the highest value for the Lorentz factor observed in nature ($\gamma \sim 10^{11}$).
- What is the limit in Cosmic Ray energies (if any) ?

Actual record : 3 10^{20} eV = 50 joules = 1 car at 1km/h !

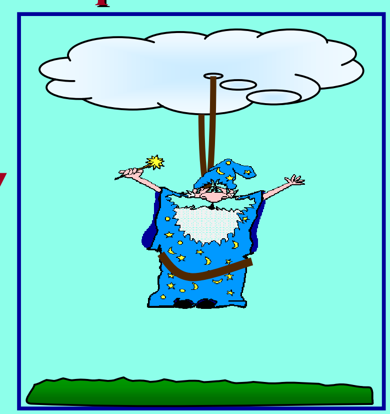
EECR production hypothesis

Two general production mechanisms proposed for the EECR:

"Bottom-up": with acceleration in rapidly evolving processes occurring in Astrophysical Objects with an extreme case in this class being represented by the Gamma Ray Bursts (GRBs). The observation of "direction of arrival and time coincidences" between the optical-radio transient and Extreme Energy Neutrinos could provide a crucial identification of the EECR sources.

Bottom - up

Top - down



"Top-down" processes with the cascading of ultrahigh energy particles from the decay of Topological Defects; these are predicted to be the fossil remnants of the Grand Unification phase in the vacuum of space. They go by designations, such as cosmic strings, monopoles, walls, necklaces and textures. Inside a topological defect the vestiges of the early Universe may be preserved to the present day.

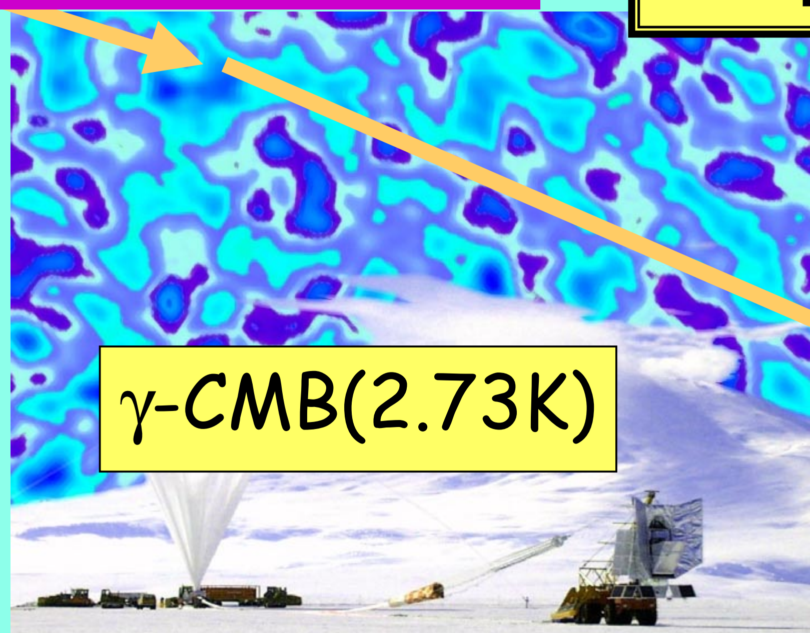
The Bottom-Up models

γ,p,n, N

λ_p < 50 Mpc @ 10^{20}eV

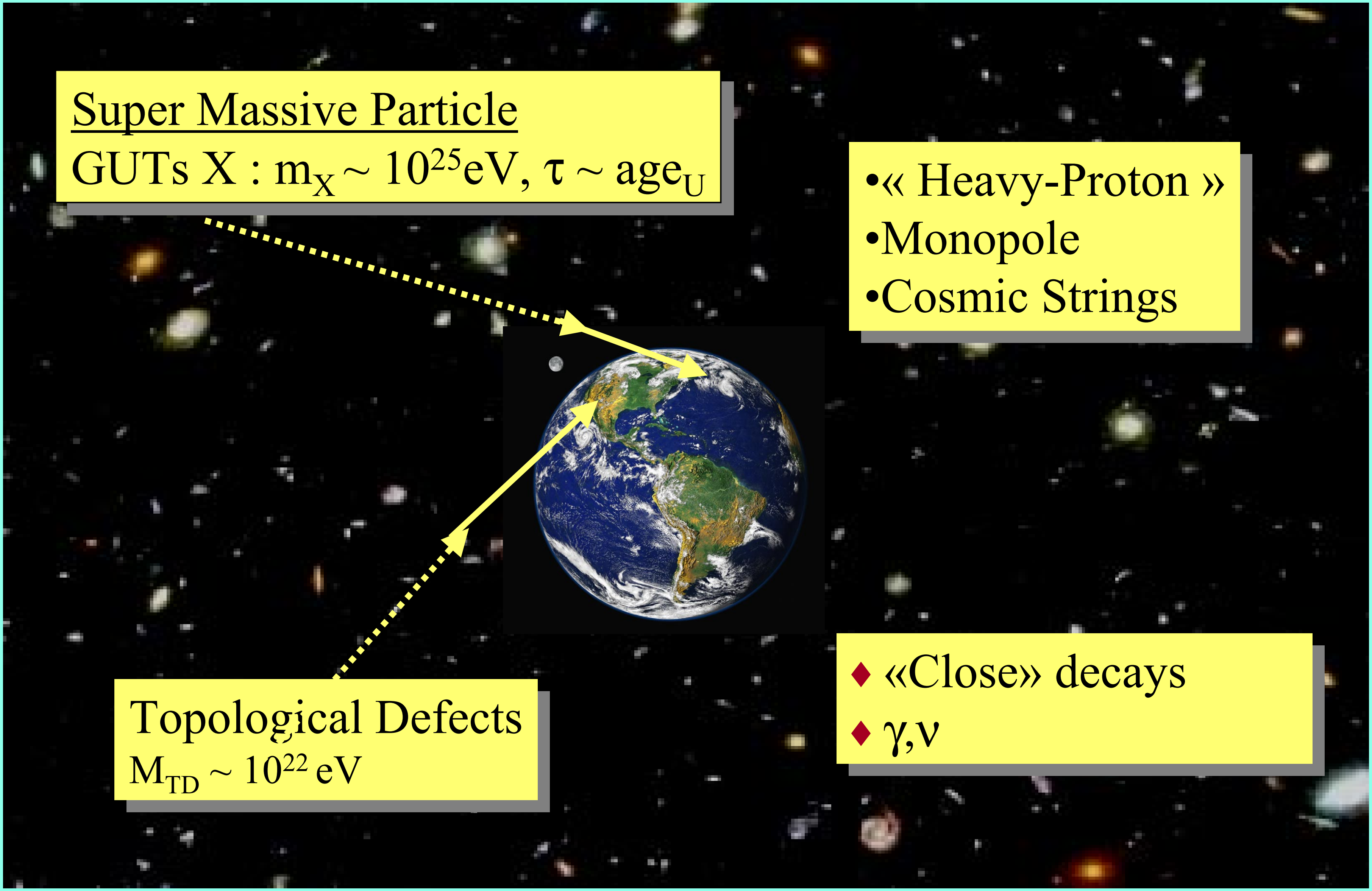
GZK cut
(Greisen Zatsepin Kuzmin)
E_{GZK} ~ 4 10^{19} eV

Accelerators
AGN
GRB
BH



γ-CMB(2.73K)

Top-Down models



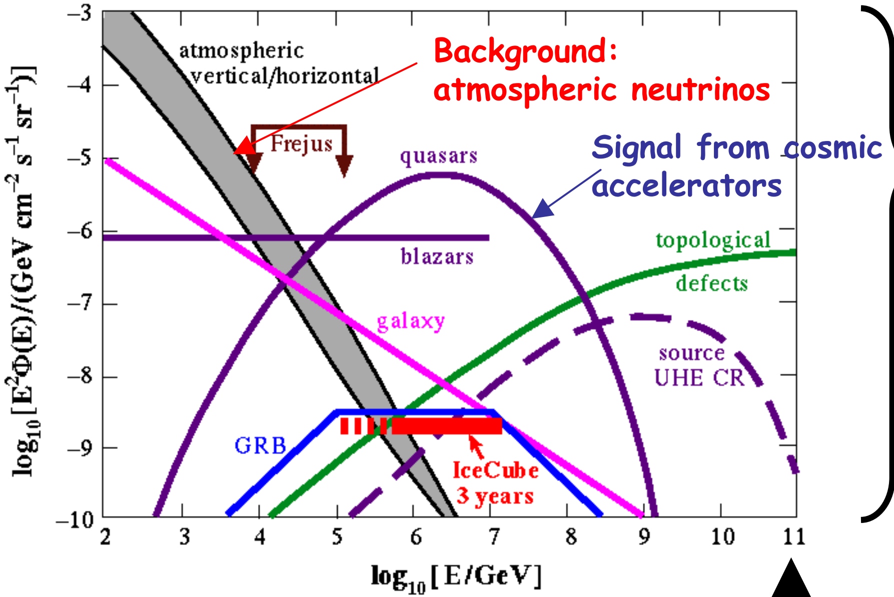
UHE neutrinos : ν's from TD's

<u>Topological defects</u> are expected to produce very heavy particles (X-particles).

As relics of an early inflationary phase in the history of the Universe, these particles may survive to the present as a part of dark matter. Their decay can give origin to the highest-energy cosmic rays, either by emission of hadrons and photons, or through production of <u>Extreme Energy neutrinos</u>.

Observation of these neutrinos may teach us about the dark matter of the Universe as well as its inflationary history.

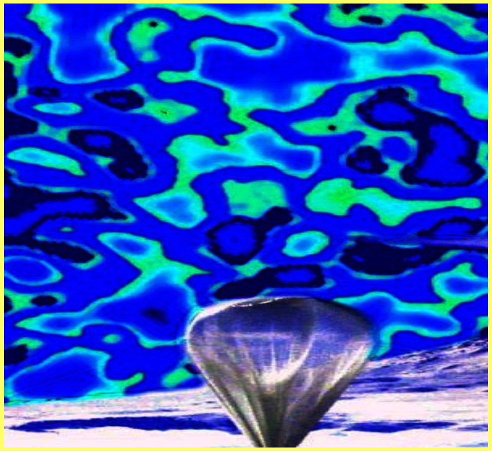
UHE neutrinos : ν's from Big Bang



GZK cut

«GZK effect» for ν's

$\nu + \nu_{CMB}(1.9K)$ -> $Z0, W^+W^-$



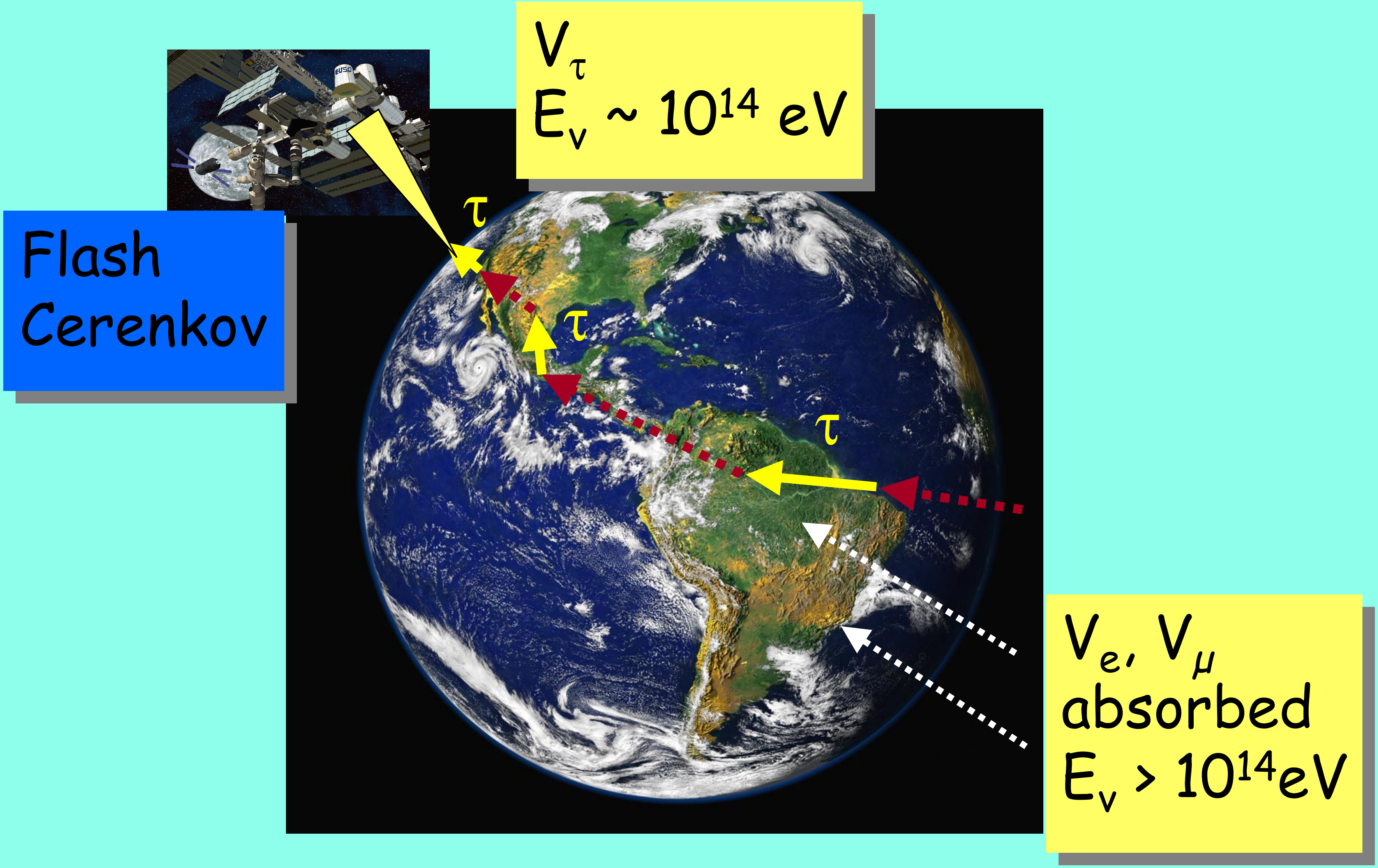
$E(\nu) \sim 10^{21}$ eV/m_ν(eV)

of m_ν !

Neutrinos are not absorbed in sources; they escape even from strong sources.

- λ_ν > 40 000 Mpc

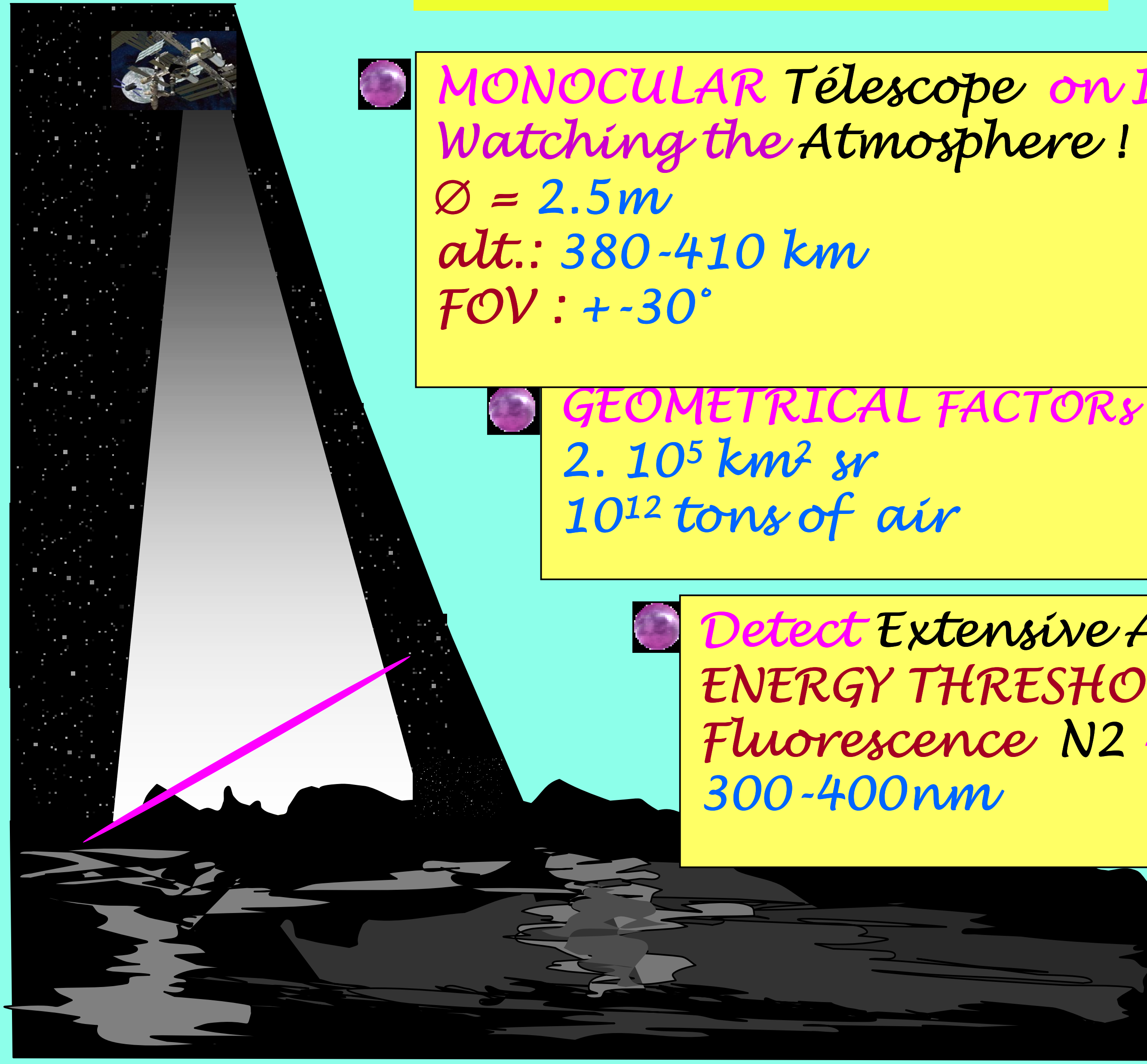
UHE neutrinos : going through the Earth



INTERACTION WITH CB : Summary

	Process	Cutoff Energy	Mean free path
Protons	$p + \gamma_{2.7K} \rightarrow \pi^{\circ} + X$	$\geq 5 \times 10^{19}$ eV	50 Mpc
Nuclei	$A + \gamma_{2.7K} \rightarrow \Delta^{+} + X$	$\geq 5 \times 10^{18}$ eV/n	100 Mpc
γ-rays	$\gamma + \gamma_{2.7K}$	$\geq 10^{14}$ eV (at 10^{20} eV)	10 Mpc (at 10^{20} eV)
ν	$\nu + \nu_{1.95K} \rightarrow (W/Z_0) + X$	$\geq 4 \times 10^{22}$ eV	40 Gpc

EUSO : THE APPROACH



- MONOCULAR Télescope on ISS/Colombus
  Watching the Atmosphere !
  ∅ = 2.5m
  alt.: 380-410 km
  FOV : +-30°

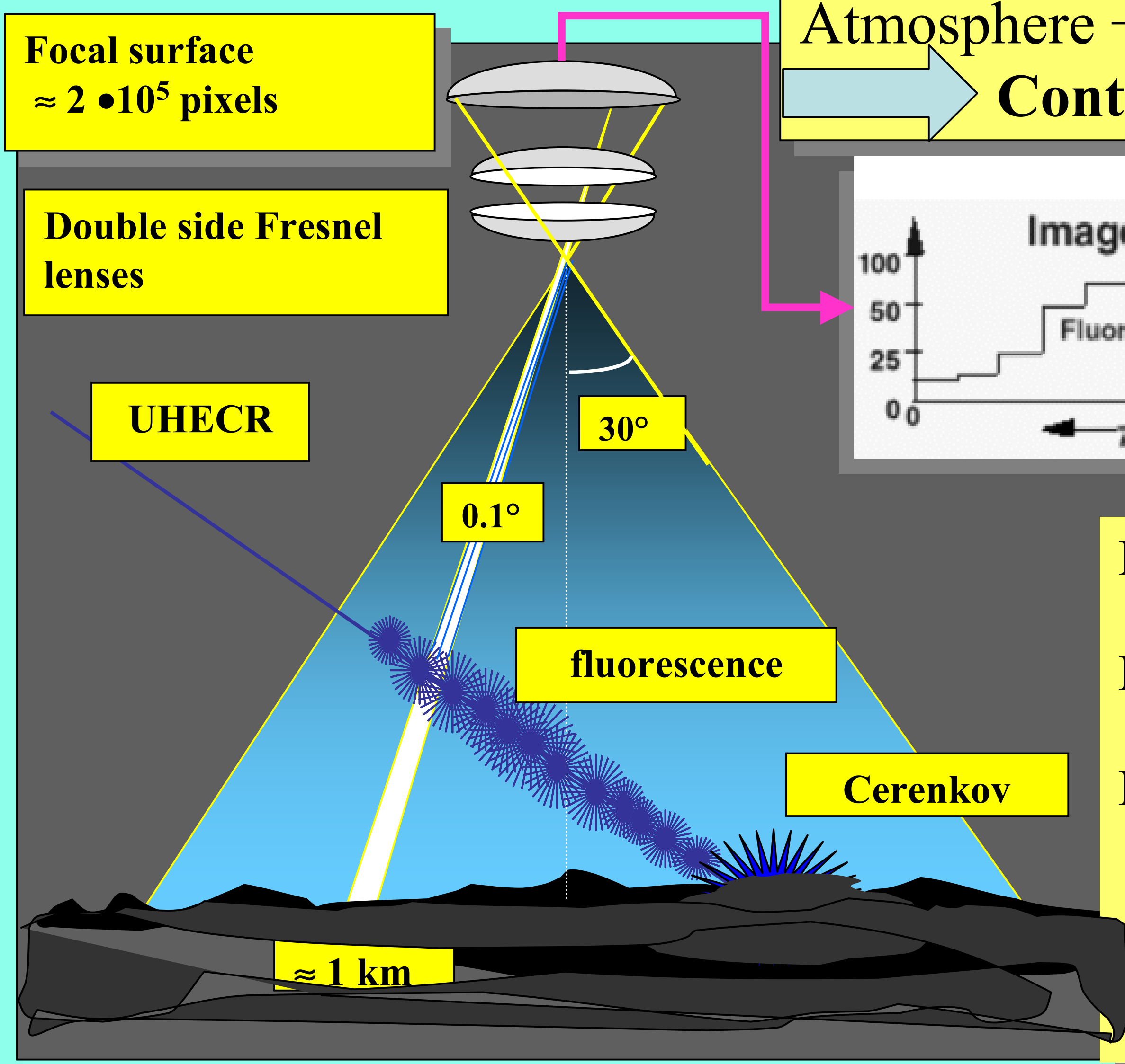
- GEOMETRICAL FACTORs
  2. 10^5 km^2 sr
  10^{12} tons of air

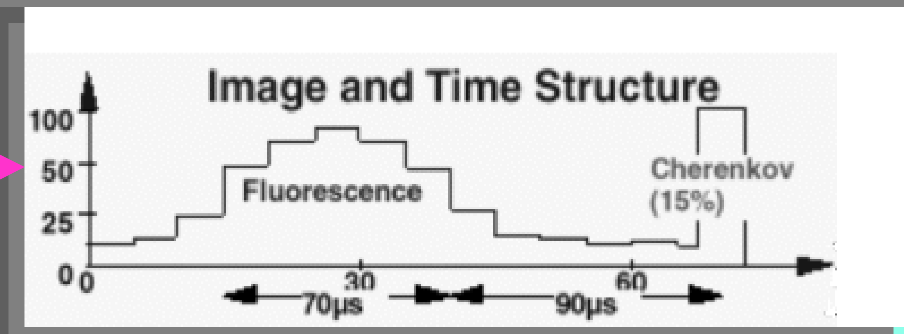
- Detect Extensive Air Showers
  ENERGY THRESHOLD $\geq 3\ 10^{19}$ eV
  Fluorescence N2 + Cerenkov
  300-400nm

EUSO concept: a space TPC

Atmosphere + EUSO = Calorimeter

⇒ **Contained EAS**





Energy
- Fluorescence + Cerenkov

Position
- X,Y,Z (t): 0.3 - 1 km

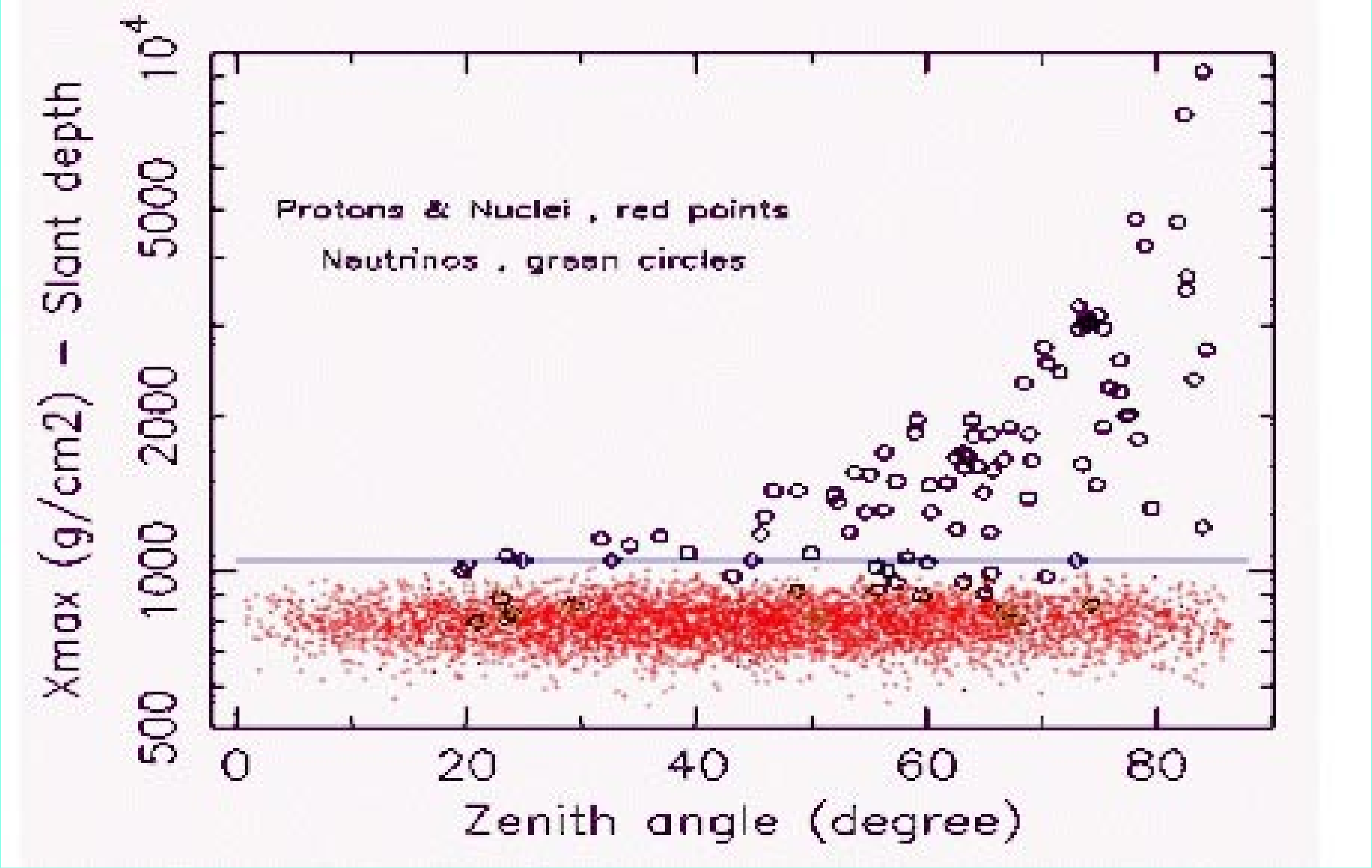
Direction
- Multi-hits tracks
- .σ_θ ~ 0.3°(h) - 3°(v)

EUSO : Field of View

FOV: ±30°
Ø: ~500km

Neutrinos versus Protons and Nuclei

Showers initiated very deep in the atmosphere indicate an origin by neutrinos because of neutrino-air nuclei interaction cross section hundreds times lower than the cross sections for protons, nuclei, or photons.

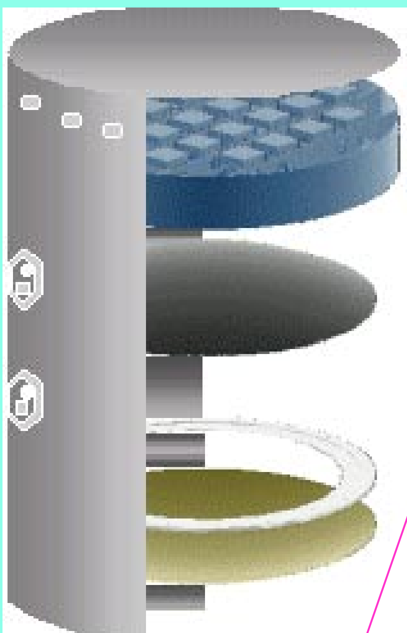


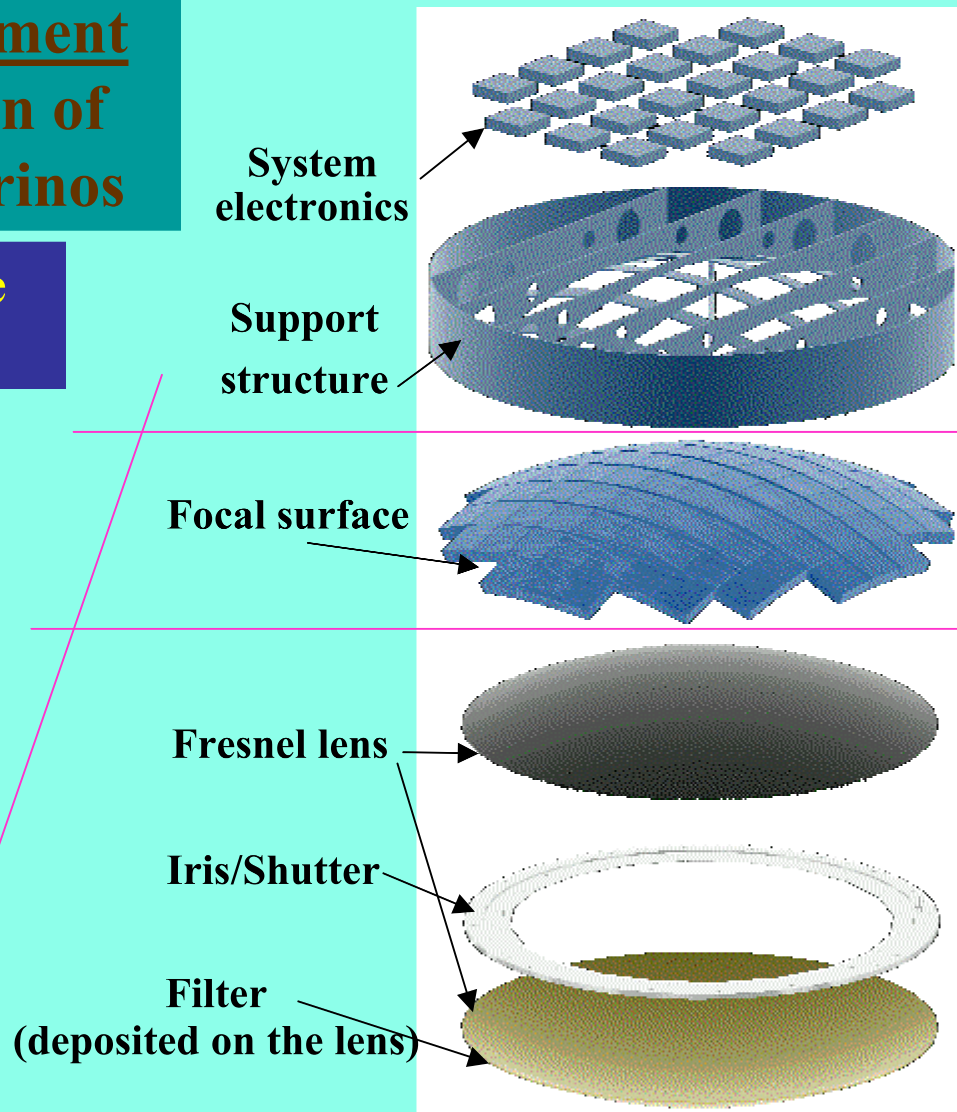
Shower depth distribution from Monte Carlo simulations: neutrino events can be distinguished from protons and nuclei.

EUSO Collaboration

A compact instrument for the observation of EECRs and Neutrinos

Europe
ESA





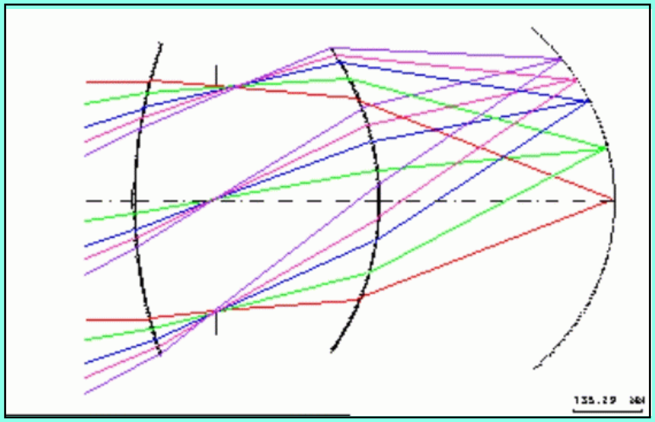
France
(IN2P3/CNES)
Italy:
(INFN/ASI)
Portugal:
(ICCT/FCT)
D/UK/CH

Japon
RIKEN
NASDA

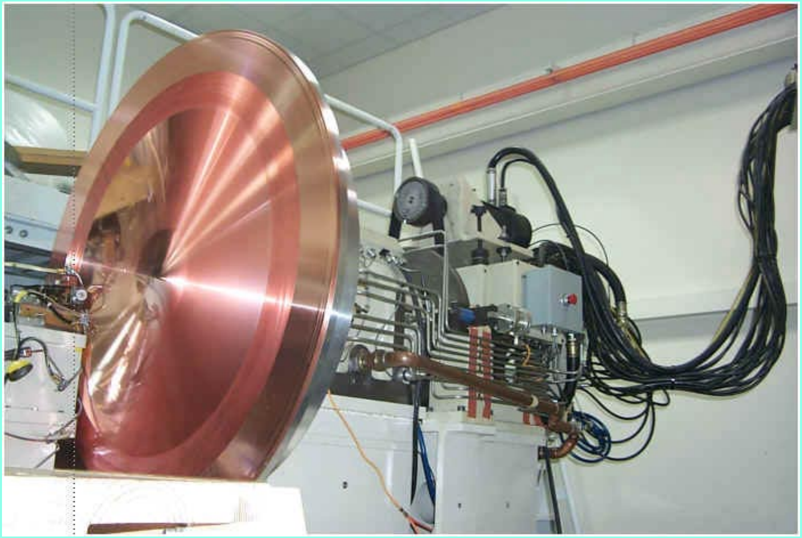
USA
OWL
NASA

OPTICS DESIGN

- 2 meter entrance pupil diameter (EPD)
- f number ratio close to 1 (f/1.1 ~ 1.3)
- 0.1° angular resolution
- total field of view of 60°
- radiation-hard plastics
- filters like BG-3 or custom made deposited on the plastics



Double lens double sided Fresnel configuration

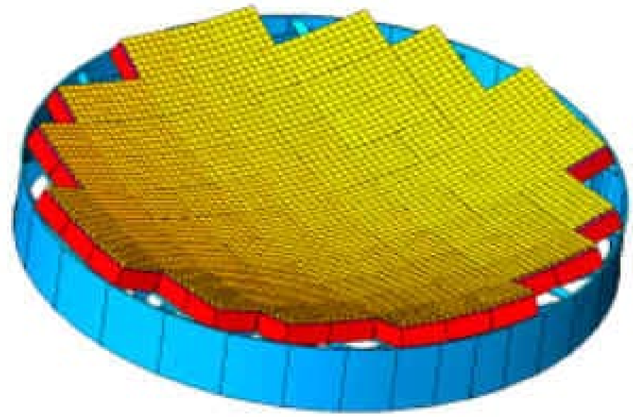


Diamond turning of 1.3 m Fresnel mandrel at NASA/MSFC

FOCAL SURFACE DETECTOR HIERARCHICAL VIEW

Focal surface detector

(89 macrocells = 205056 pixels)

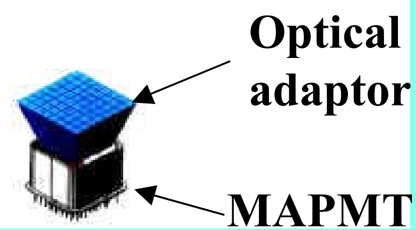


Macrocell

(6x6 basic units = 2304 pixels)

Basic unit

(8x8 pixels)

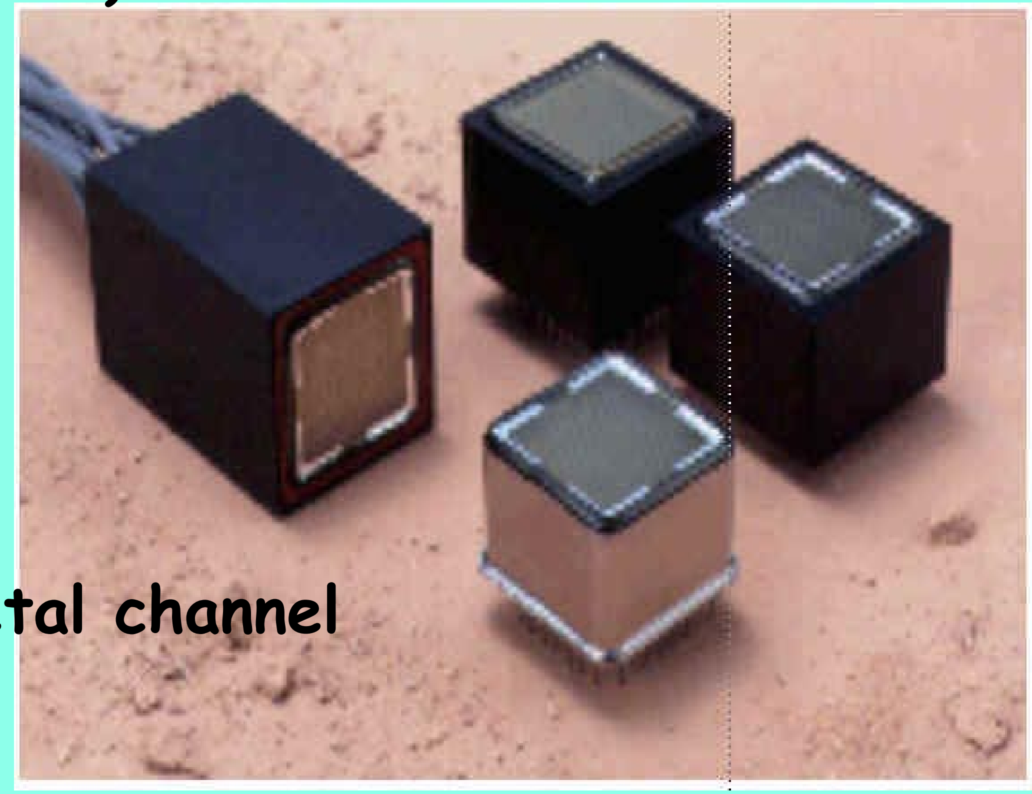


THE PHOTODETECTORS

MultiAnodes PMTs

Developped @INP/LAPP(1980)
M4,M16 used by AMS

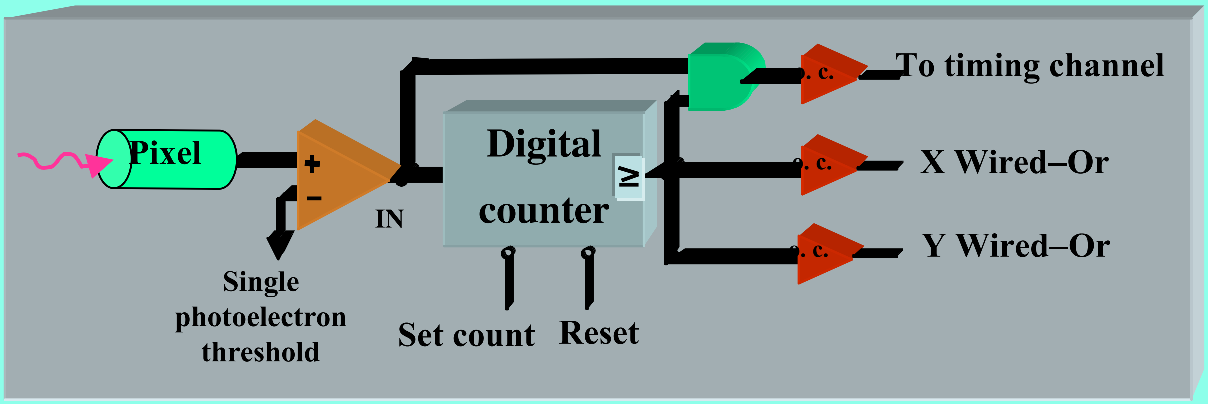
Hamamatsu
R5900-M64



FEATURES

8 x 8 Multianode
High Speed Response
Low cross-talk
Newly Developed "metal channel dynode"

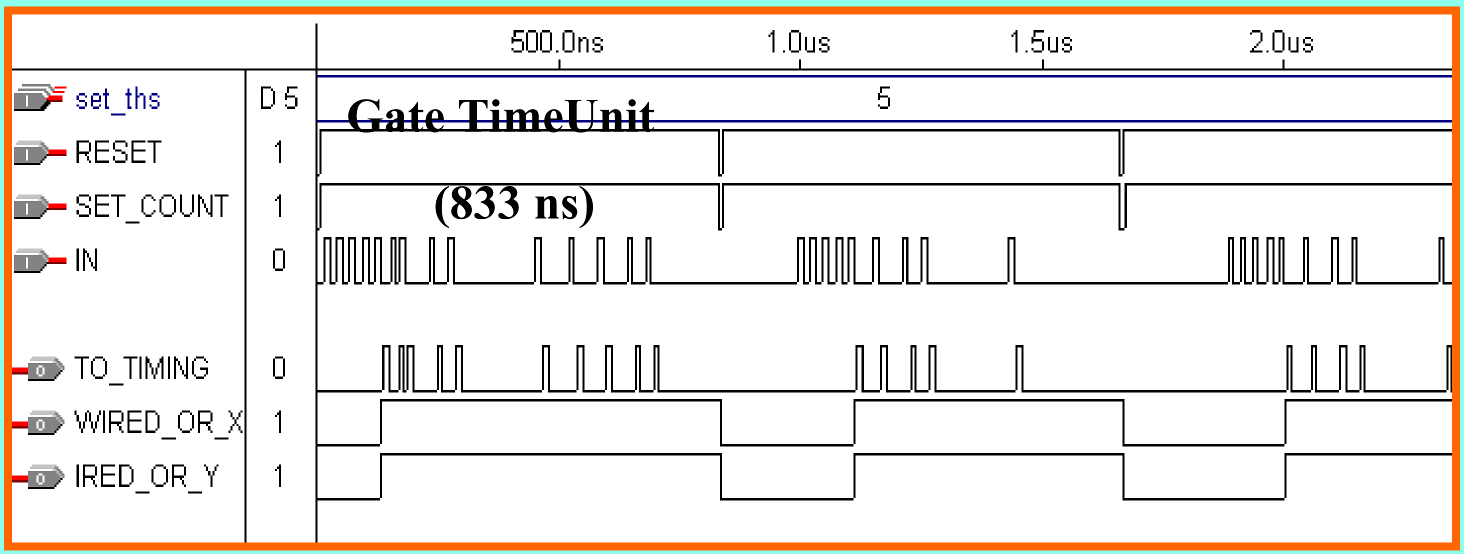
THE PRINCIPLE OF TRIGGER



@ Low Comsumption
PM+FFE~600W

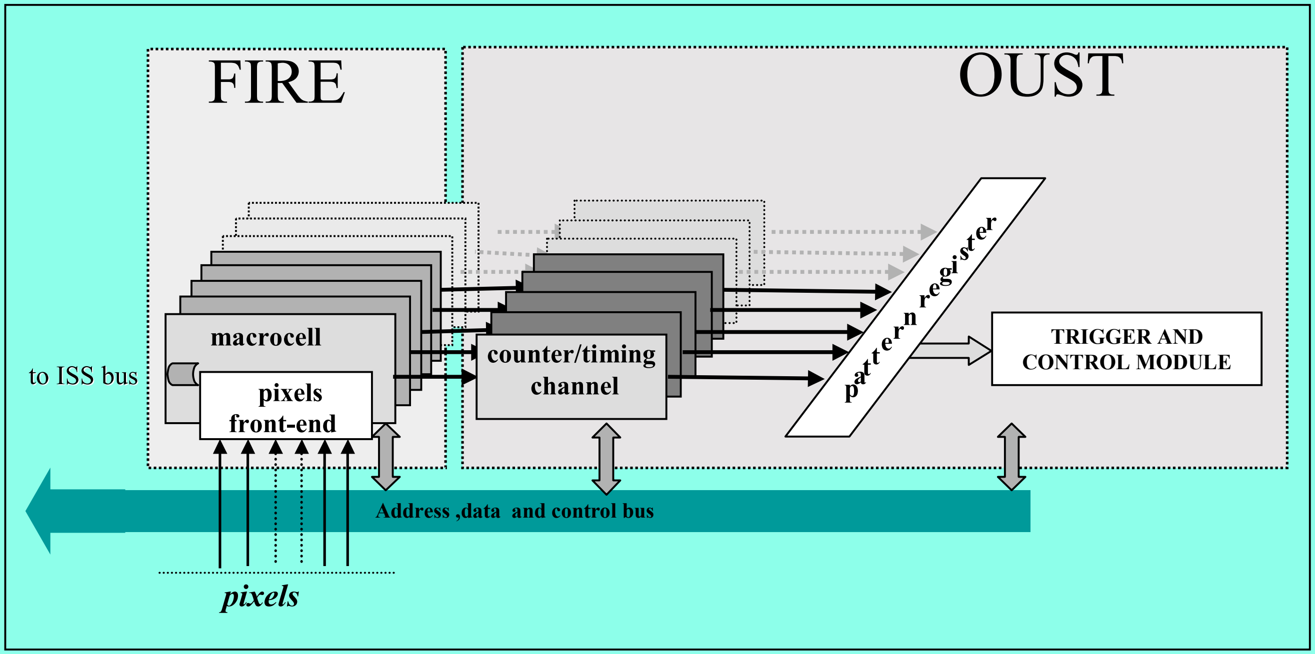
@ 3D
x,y -> pixel (~1km)
z -> timing (~1μs)

@ Energy
~ #photons (10ns)



ELECTRONICS HIERARCHICAL ORGANIZATION

A "free running" method has been adopted to store temporarily the information coming from the detector in cyclic memory and recover it at the time that a trigger signal occurs.



EUSO

ELECTRONICS HIERARCHICAL ORGANIZATION

PFE
Pixel **F**ront **E**nd

In order to minimize the background "single photoelectron counting" techniques with a fast response detector (~10 ns) are used. Pixel Front End electronics to be integrated into a custom ASIC (Application Specific Integrated Circuit) device.

FIRE
Fluorescence **I**mage **R**ead-out **E**lectronics

The FIRE system has been designed to obtain an effective reduction of channels and data to read-out, developing a method that reduces the number of the channels without penalizing the performance of the detection system.

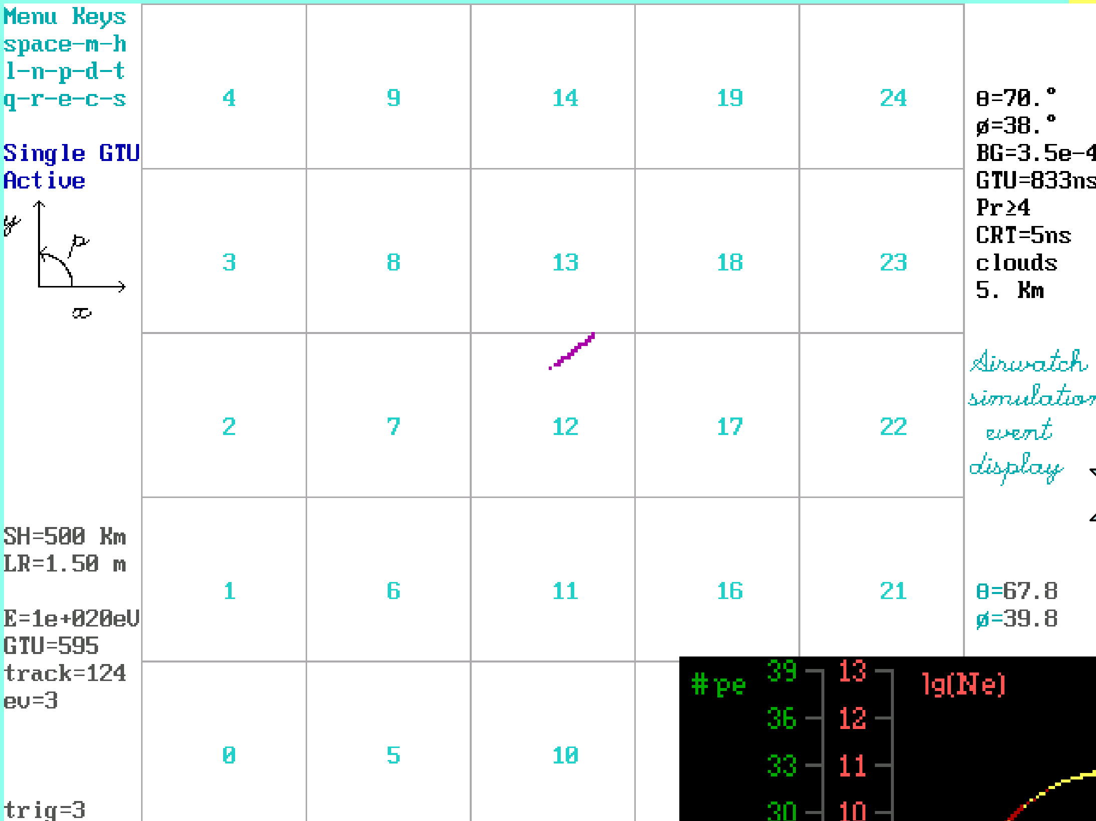
OUST
On-board **U**nit **S**ystem **T**rigger

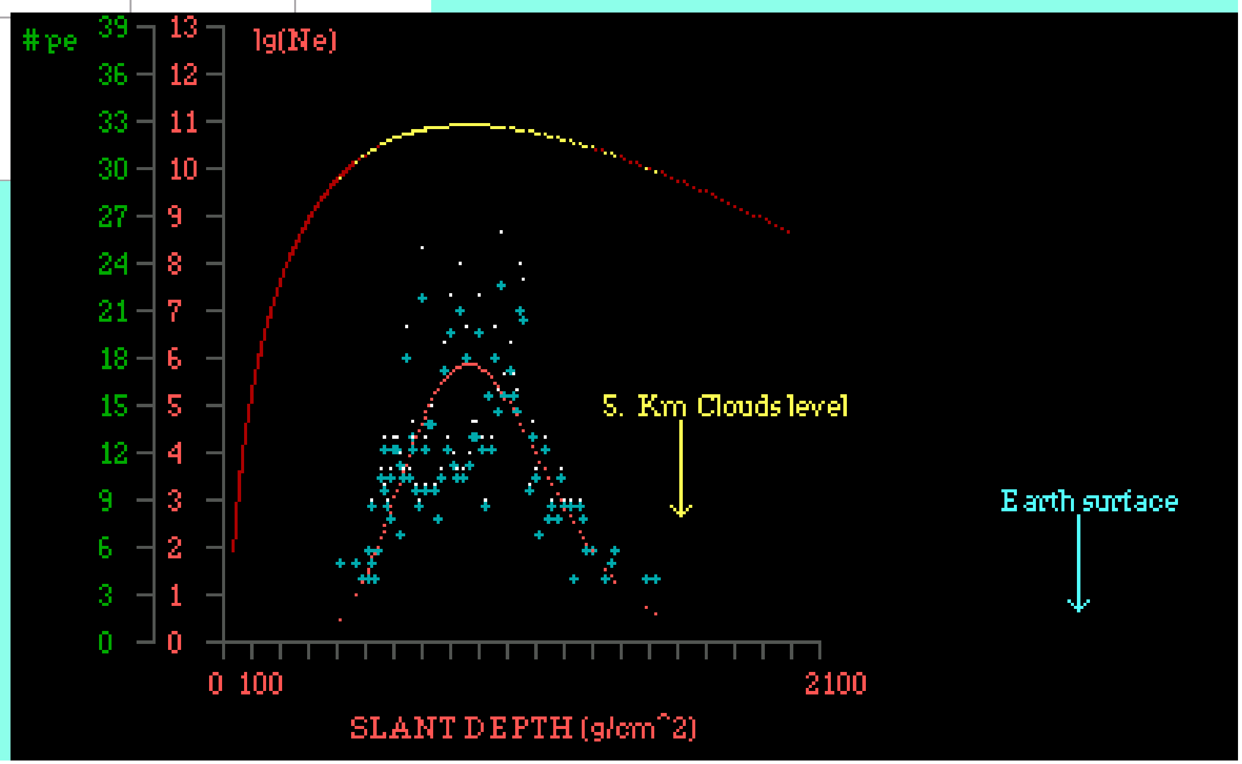
The trigger module OUST has been designed to provide different levels of triggers such that the physics Phenomena in terms of fast, normal and slow in time-scale events can be detected.

Simulations

@ Optimisation
FIRE + OUST

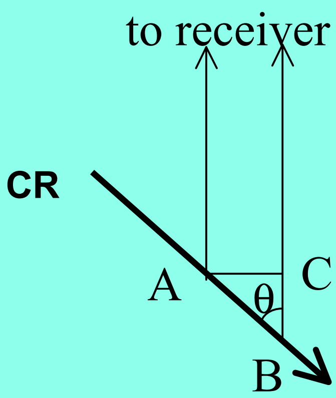
@ Background level
1/2 Moon



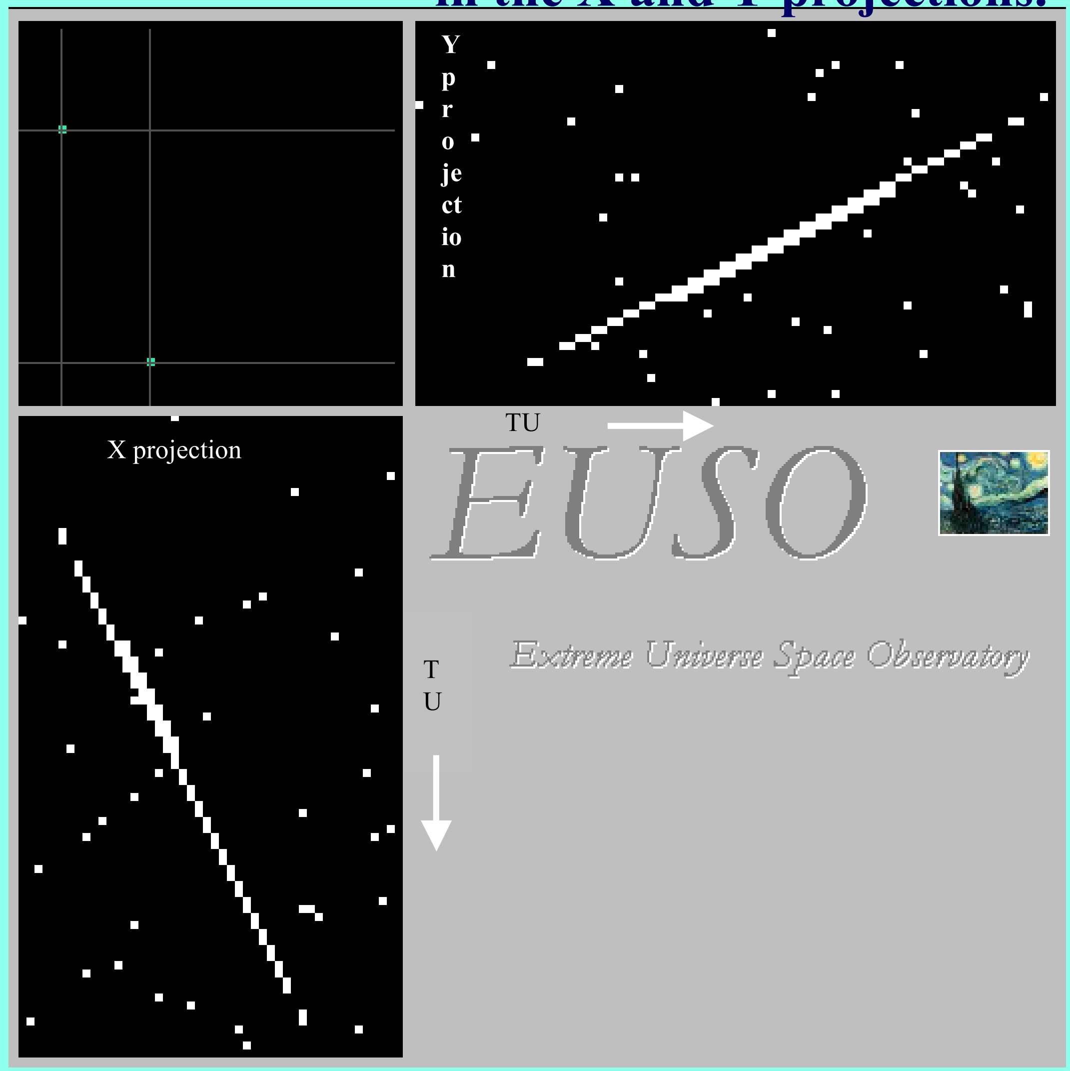


THE EUSO TELESCOPE

Direction and Energy reconstructions



Representation of a track in the X and Y projections.

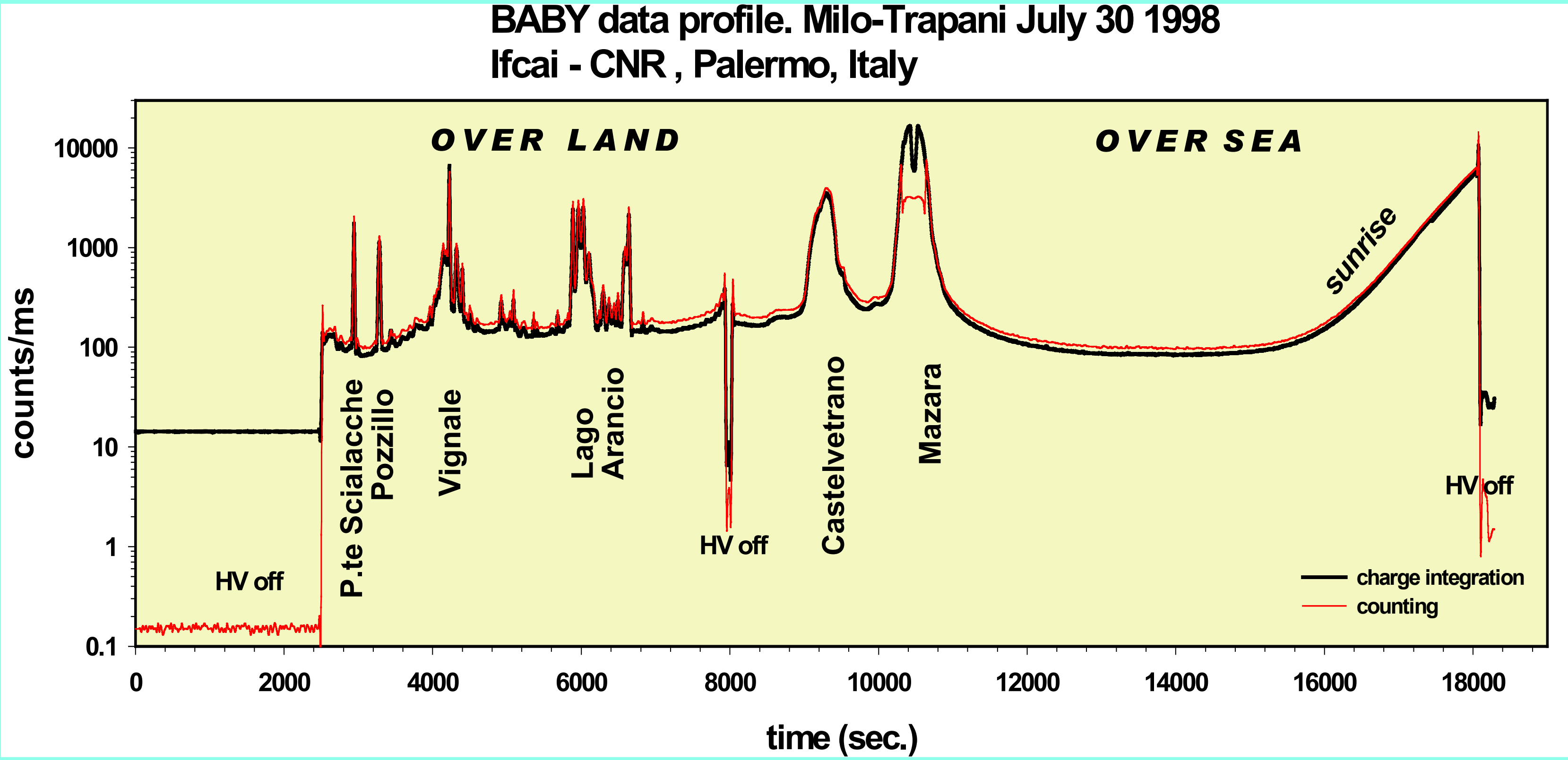


$$\varphi = \tan^{-1} \Delta Y / \Delta X$$

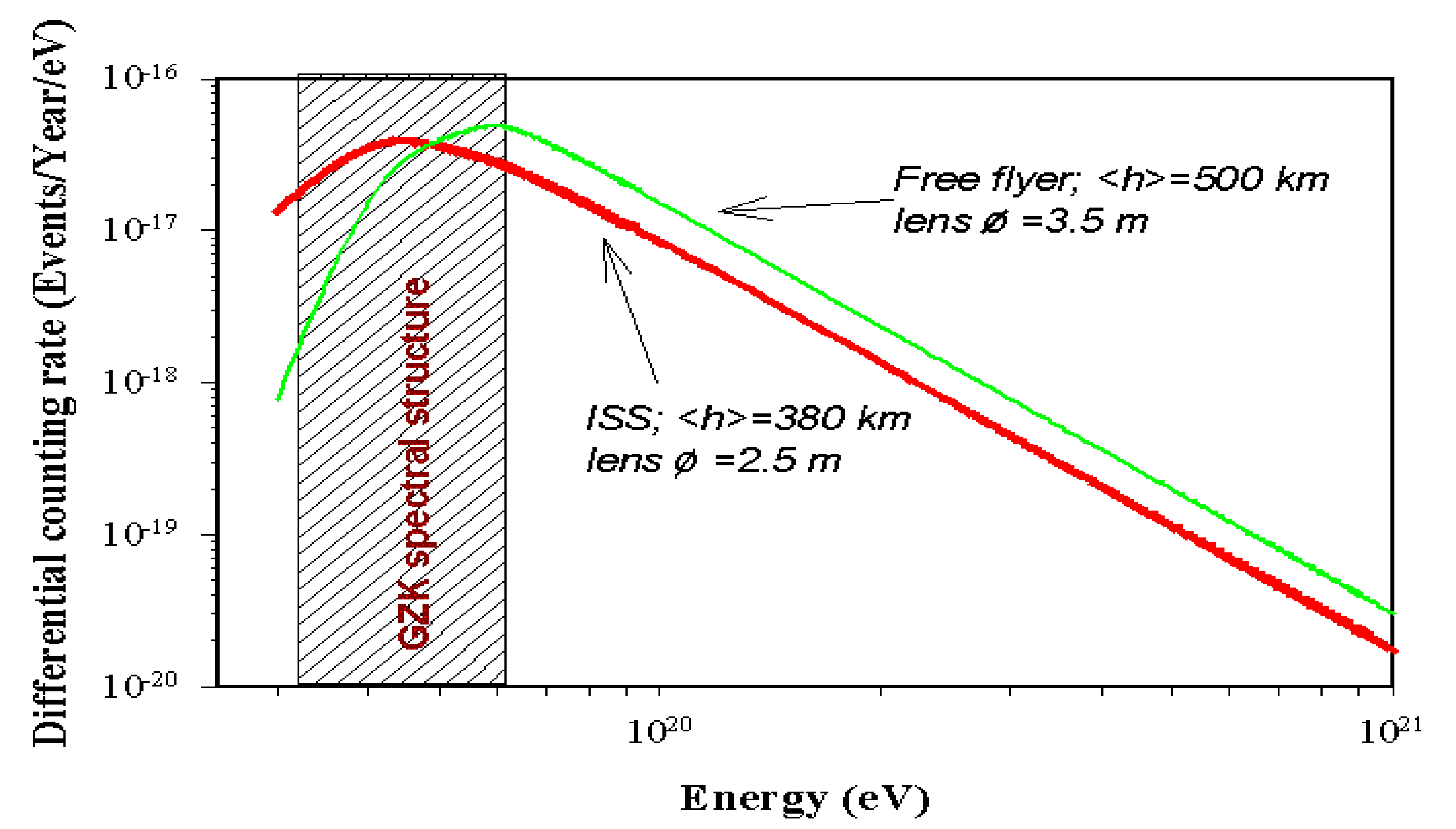
$$\theta = 2 \bullet \tan^{-1} \frac{(\Delta Y^2 + \Delta X^2)^{1/2}}{c \bullet \Delta t}$$

BACKGROUND

Nightglow background measurement have been carried out using Balloon flight : ~200 ph./m^2/sr/ns



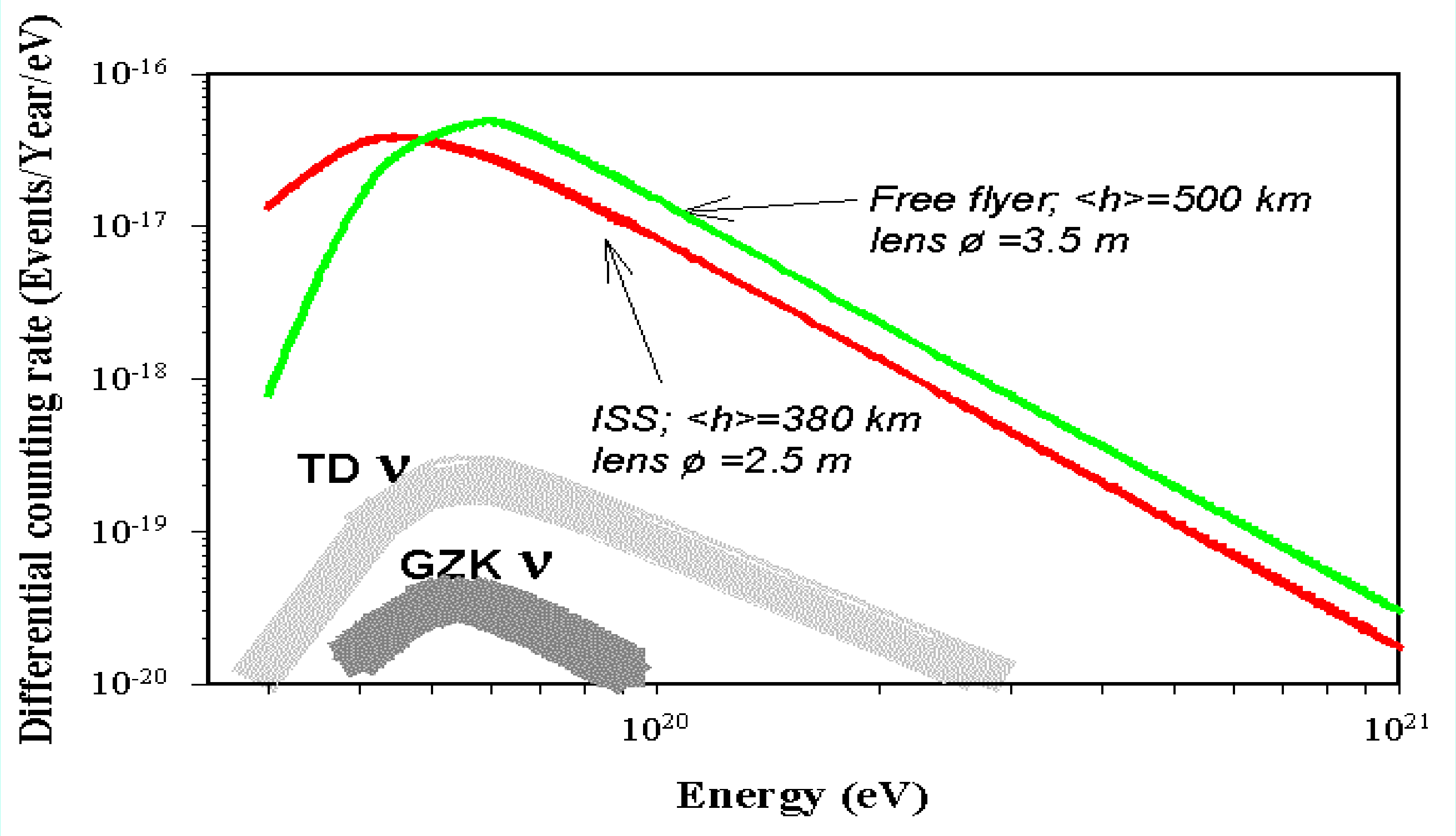
EUSO differential rate for UHECR



Differential EECR counting rate (spectral index assumed 2.7).

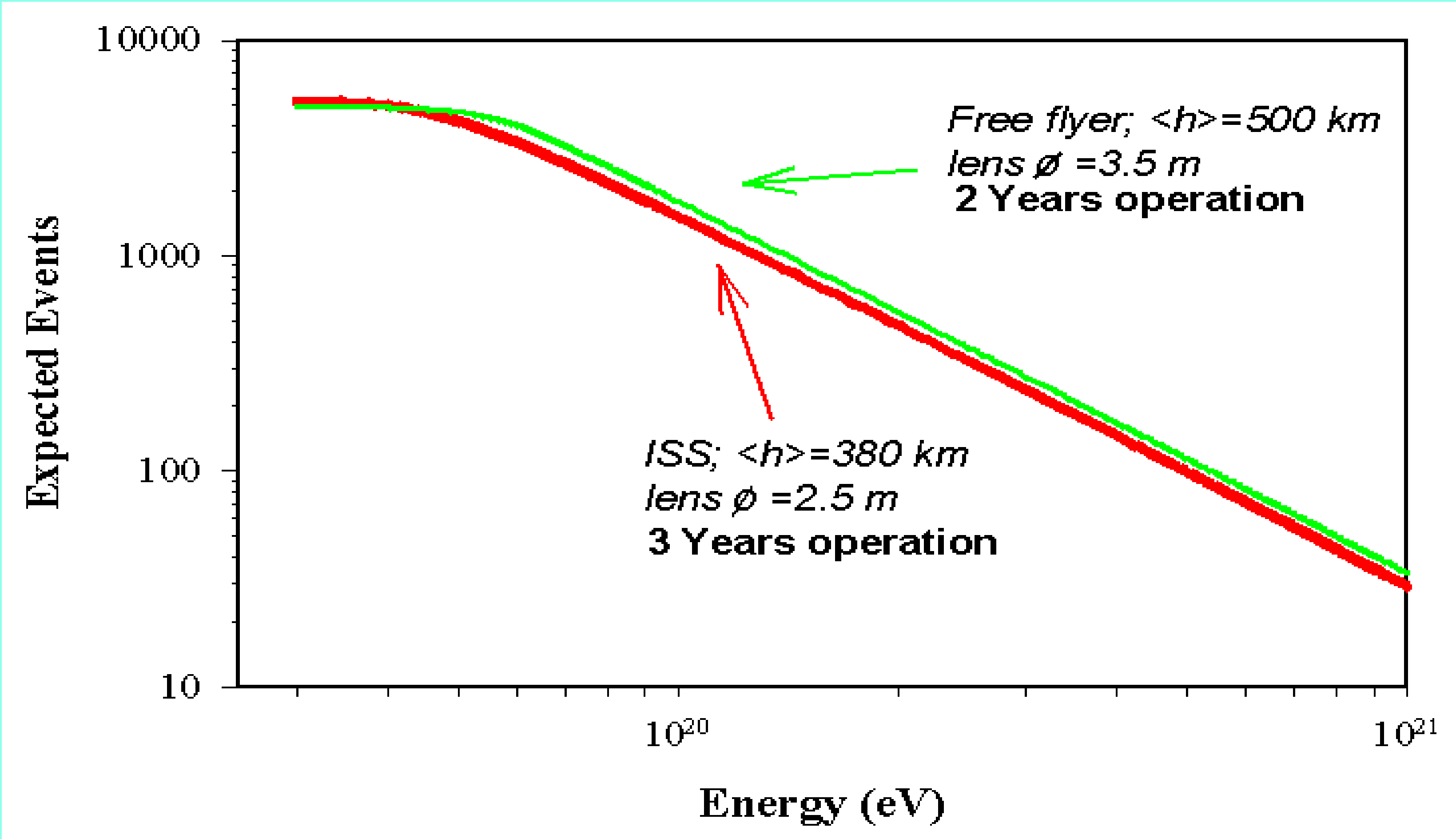
The dashed zone shows the spectral region where structure induced by the GZK cut-off is expected. The lens diameter is the maximum external diameter allowed in each configuration (Free flyer and ISS) .

EUSO differential rate for ν



The differential flux of neutrinos predicted using the Topological Defects model of Sigl et al. (1998) and the GZK model of Stecker et al. (1991).

EUSO integrated rate for UHECR

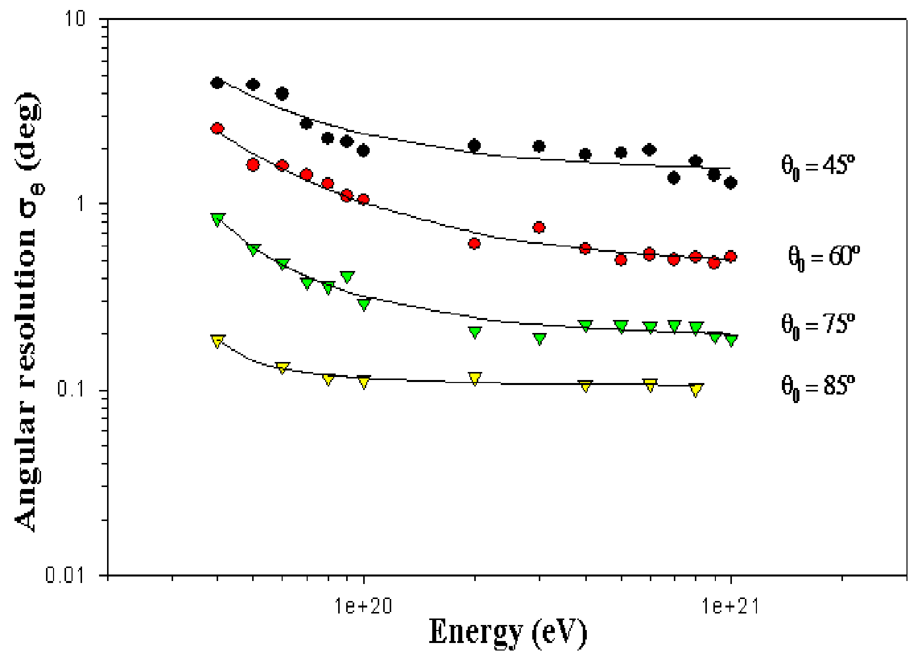


Expected number of events above an energy E for the original free flyer proposal with 2 years of operation and for the ISS configuration with 3 year operations.

SUMMARY OF TELESCOPE EXPECTED CHARACTERISTICS

- ***Energy resolution***
  - .ΔE~20% @ 10^{20} eV, fluorescence only
  - Cerenkov signal would help
- ***Position resolution***
  - ~0.8 x 0.8 km² x (0.3-1.0) km
- ***Angular resolution***
  - horizontal EAS favored

    σ ~ 0.2°

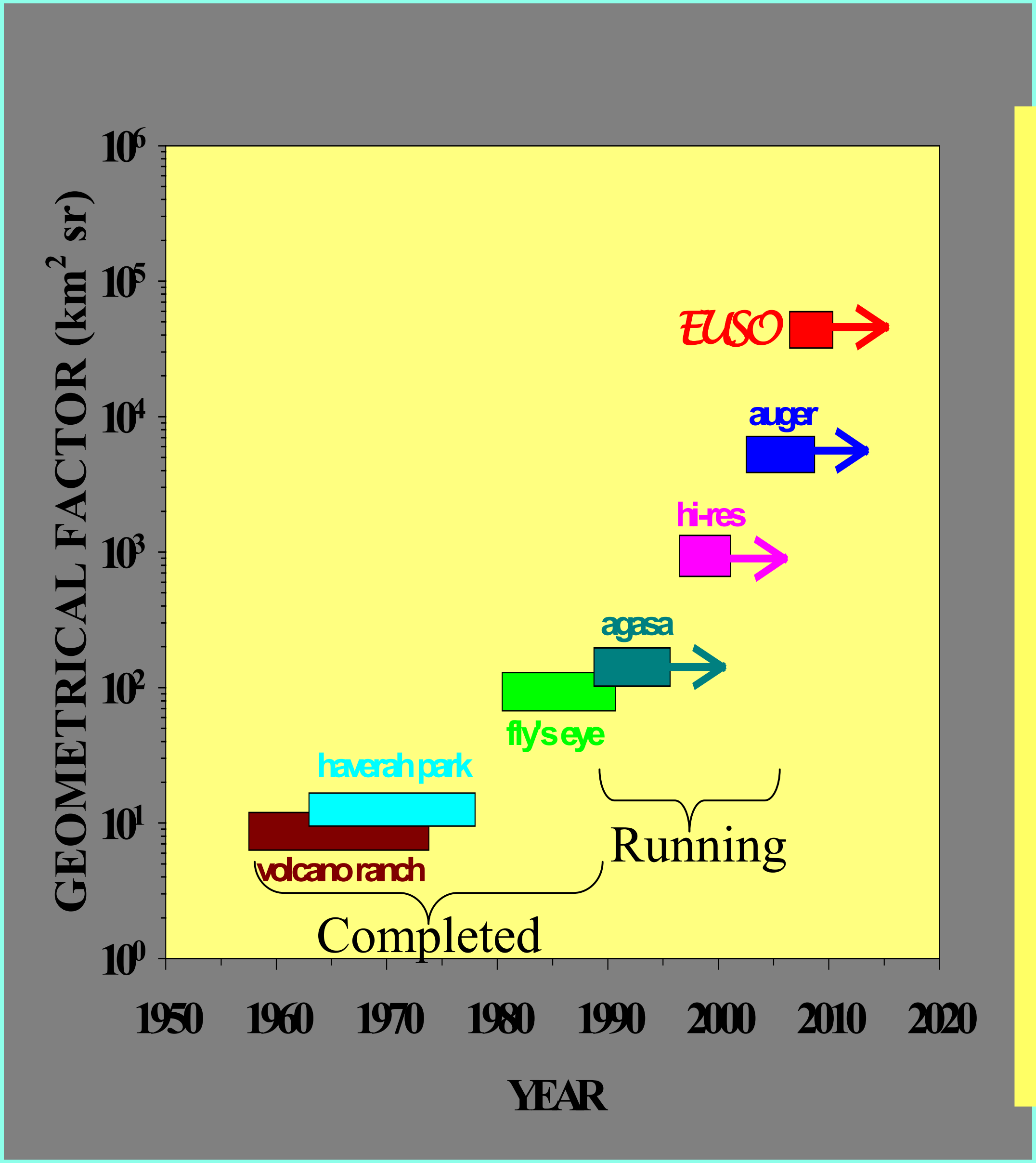


17 July '99

h=380 km, FoV = ±30°
S ~ 200 000 km²
.ε ~ 10% (d/n, albedo,...)
ISS : ±50°
Mission : 3 years

- Fully contained EAS (X_{max})
  - ~1000 evts/y (E>4.10^{19}eV)
    (7-70 x groud based exp.)
- Full sky coverture :
  - Super Galactic Plane

Comparison of UHECR Experiments



	Auger	EUSO
Status	Under construction	PhaseA
Energy (eV)	10^{19}-10^{21}	> $4x10^{19}$
θ resolution @10^{20}eV	1.3°	0.3° (θ>70°) 3° (θ<30°)
Energy resolution	25%	20%
Aperture (km² .str)	7000	10^6
Duty cycle	100%	10%
Effective Aperture	7000	100 000
Events/year E>10^{20}eV	70 none few TD ν	>500 few GZK ν 150TD ν

Conclusions

- EUSO is the first generation of EECR space Observatory:
  - Complement ground based exp.
  - Accepted in ESA Phase A
  - Data taking > 2007
- The Aims
  - ~500 evts/year ($E>10^{20}$eV)
  - few-150 ν's/y

➨ Understand the GZK **mystery**

➨ …