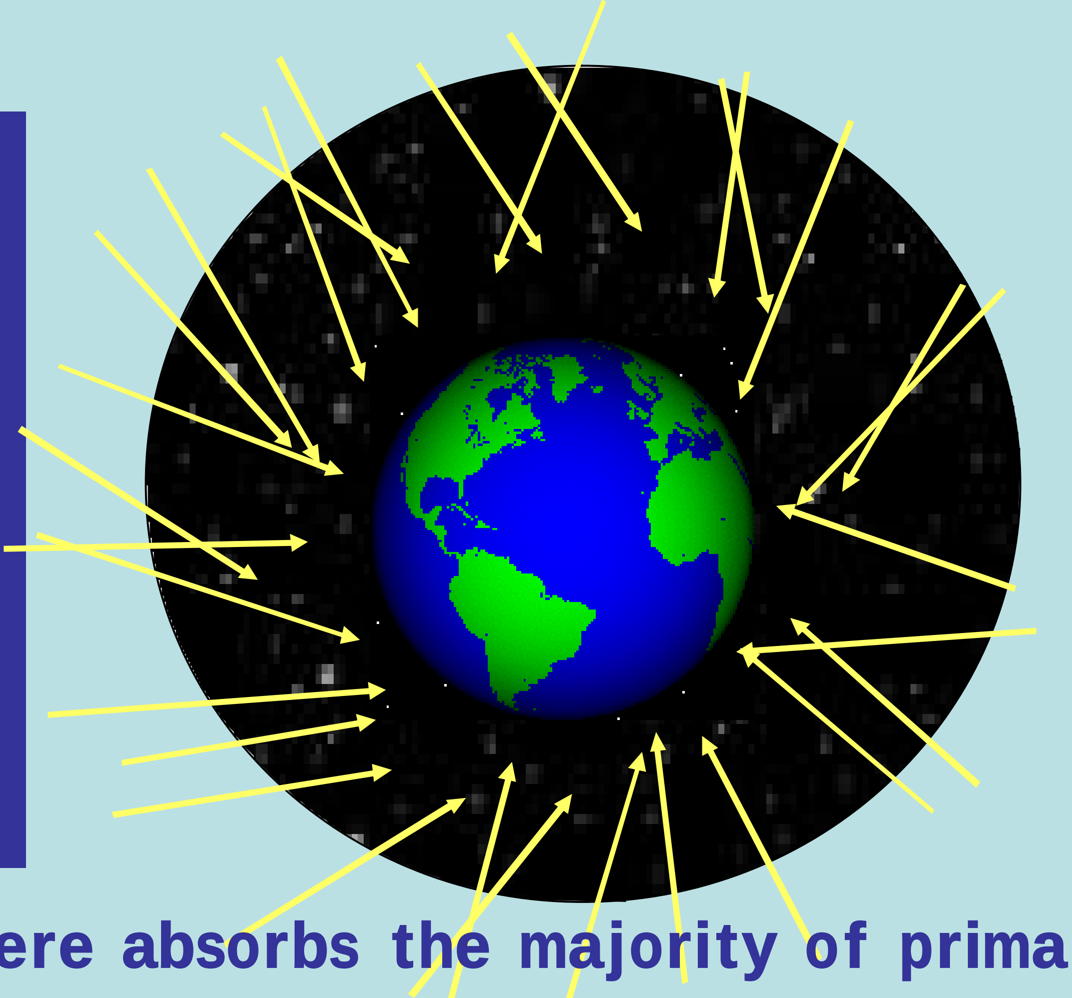
Extreme Energy Cosmic Rays: the EUSO Experiment

Cosmic Rays Connection with Cosmology and Particle Physics

What cosmic rays (CRs) are ?

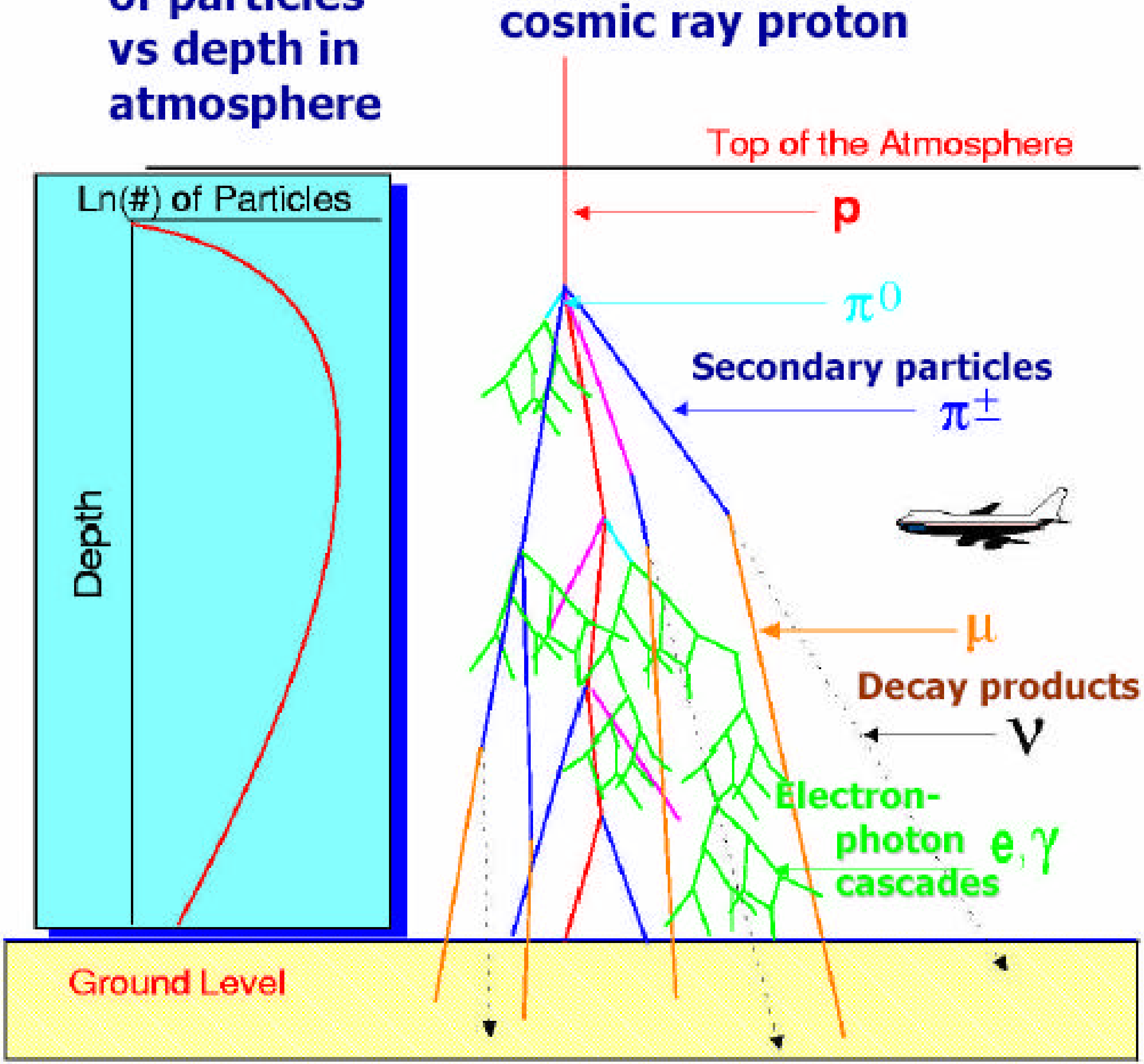
Primary CRs are very energetic (E > 10^9 eV) elementary particles (charged or neutral) that arrive continously onto the Earth.

Secondary CRs are the products of primary CRs after their interaction with C, N, O, ... nuclei in the Earth atmoshere.



The Earth atmosphere absorbs the majority of primary CR, depending on their interaction cross-section.

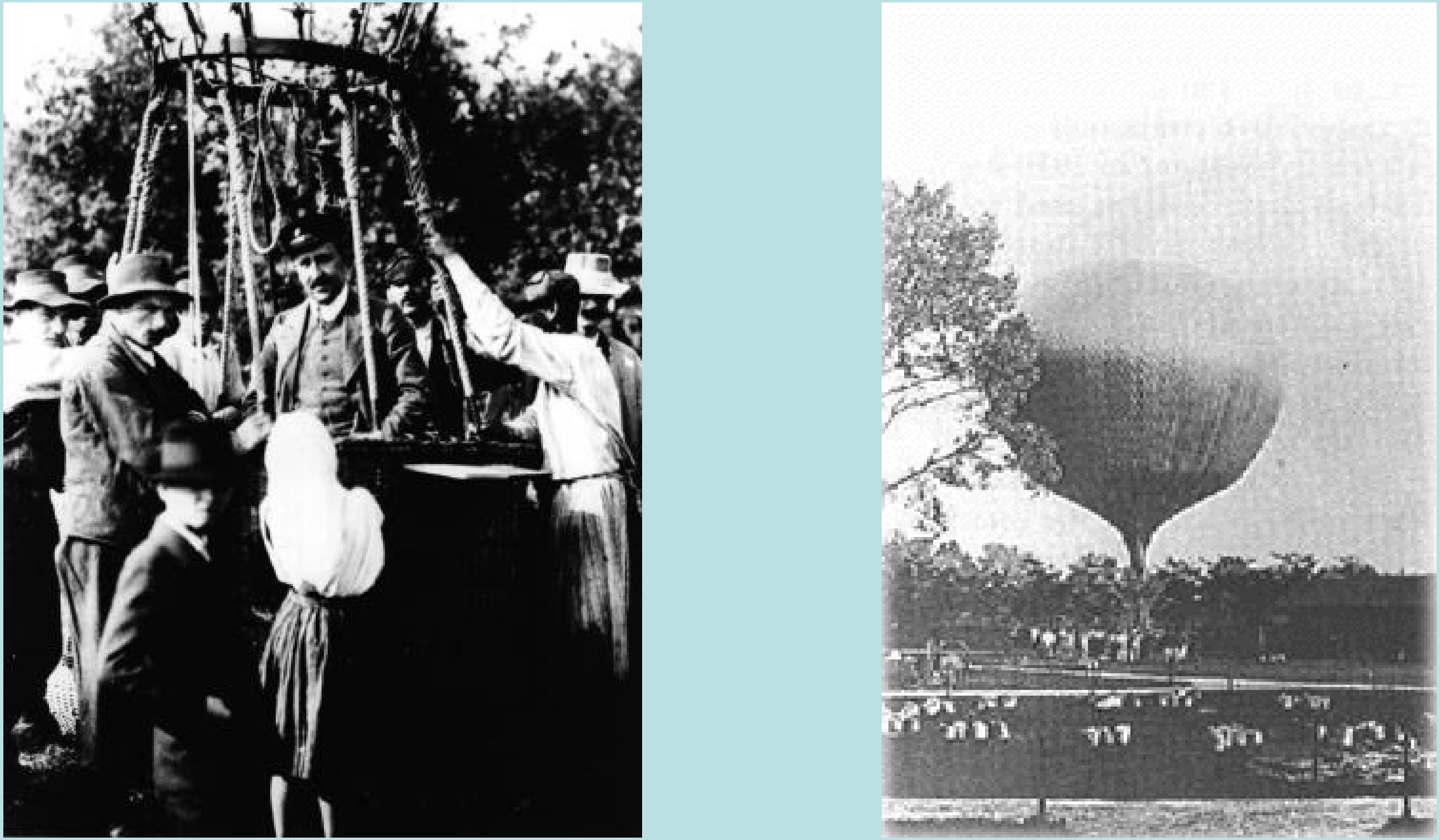
Total number of particles vs depth in atmosphere



(We can only detect and count charged particles)

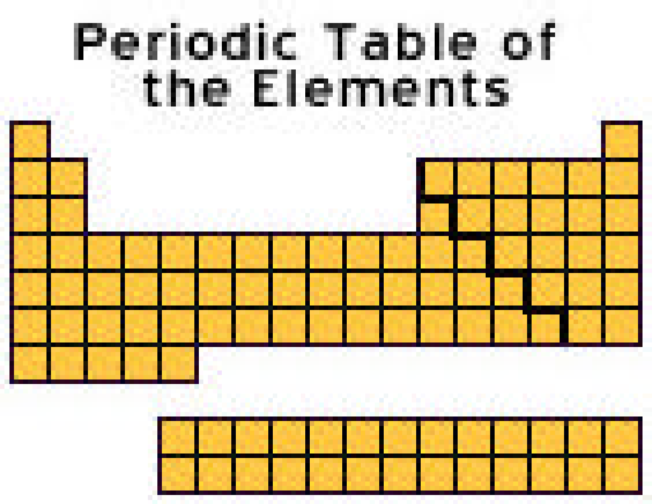
Hess discovery of cosmic rays	**1912**	
	1927	Cosmic Rays observed in bubble chambers
Anderson discovers antimatter	**1932**	
	1937	Discovery of muons
Auger discovers EAS	**1938**	
	1946	First experiments on EAS
Fermi theory on cosmic rays	**1949**	
	1962	Discovery of the first event a E = 10^{20} eV
GZK effect proposed	**1966**	
	1991	First event in Fly's Eye
Agasa detection of EECR	**1994**	
	1995	Project Auger starts
Project EUSO starts	**1997**	

In 1912, the austrian physicist Victor Hess discovered that the intensity of some misterious particles, detected on ground and of unknwn origin, increases with height (he went up to 5000 m)



… elementary particle physics was born …

Nell’ antichità



Nel XIX secolo

L’ atomo

Ma l’atomo è fondamentale?

No !!

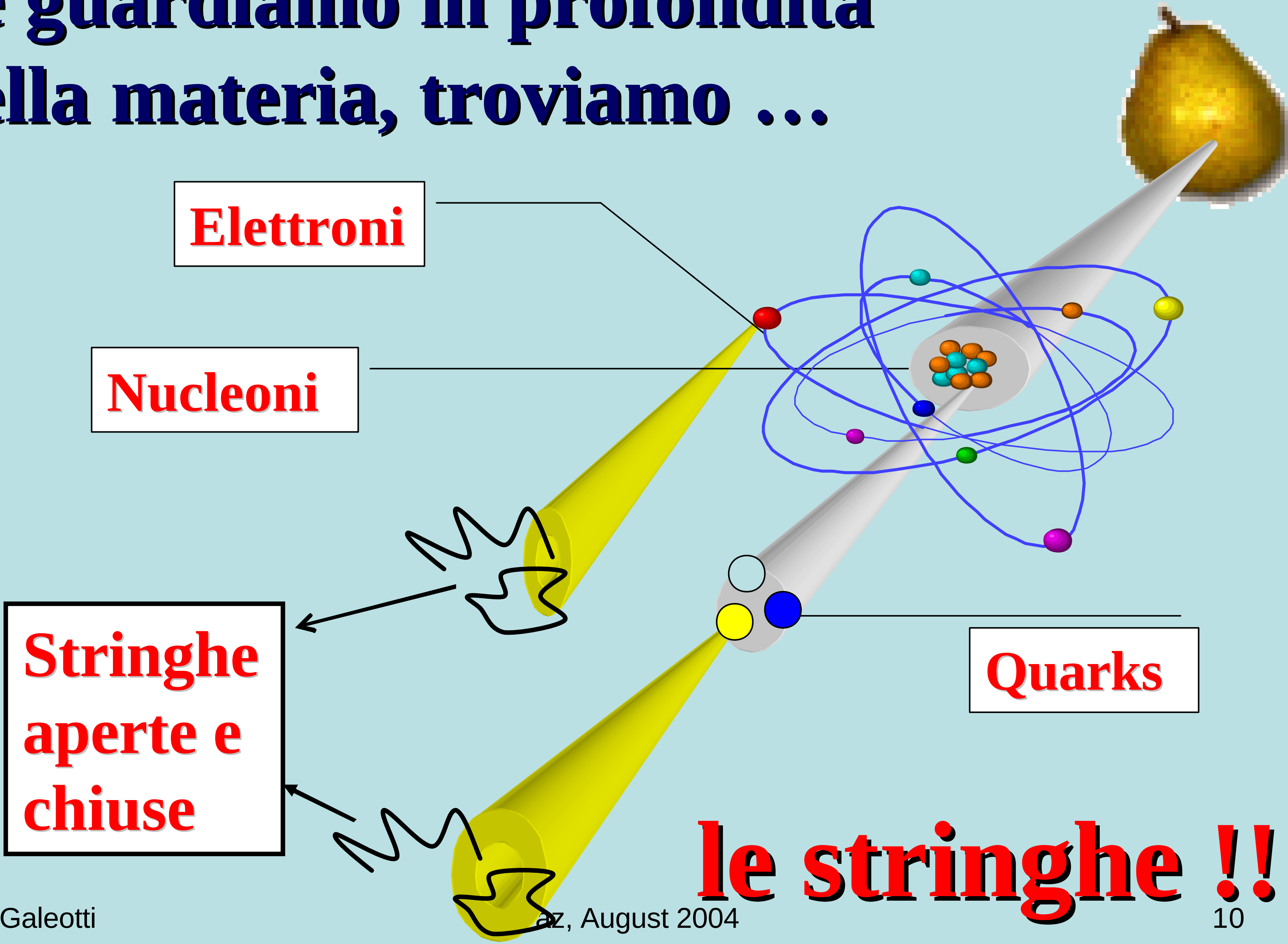
Il nucleo è fondamentale?

No !!

Esso è formato da protoni e neutroni

Protoni e neutroni sono a loro volta costituiti da **quarks**

Se guardiamo in profondità nella materia, troviamo …



Elettroni

Nucleoni

Quarks

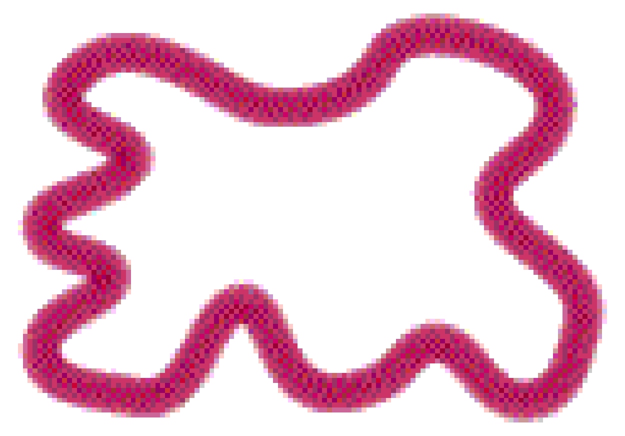
Stringhe aperte e chiuse

le stringhe !!

I costituenti ultimi della materia sarebbero delle minuscole cordicelle, dette STRINGHE

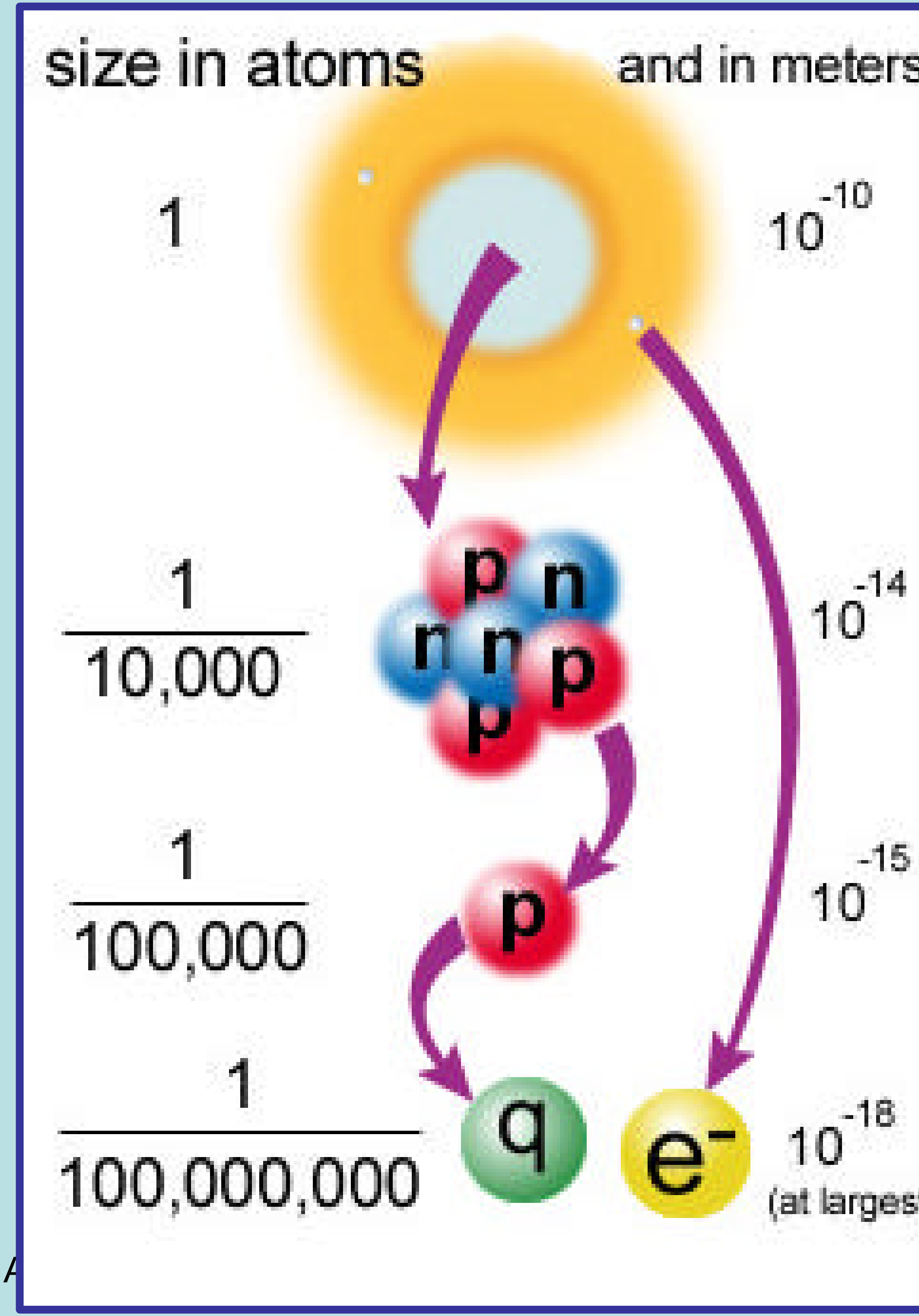
Lunghezza caratteristica 10^{-33} cm

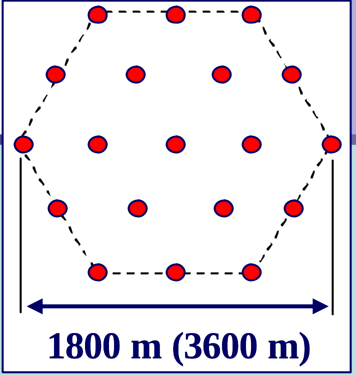
Stringa aperta



Stringa chiusa

Le dimensioni in gioco





Volcano Ranch - MIT “Desert Queen

1957-1963 Volcano Ranch, New Mexico, an array of 19 plastic scintillators was built.

1959 John Linsley and Livi Scarsi observed a shower made by $3 \cdot 10^{10}$ particles, produced by a primary CR whose energy was estimated as $E_0 = 6 \cdot 10^{19}$ eV.

1962 The array was extended to a diameter of 3.6 km, and J. Linsley observed the first CR with energy above 10^{20} eV; the detected EAS was made of ~ 50 billions particles. Note that 10^{20} eV corresponds to the energy required to move up a mass of 1.5 kg for 1 m.

Cosmic Rays

Many open questions:

- How/where are cosmic rays made?
- What process accelerates them to such enormous energies?
  - Supernova shocks?
  - Compact binary systems?
  - Active Galactic Nuclei?
- Why don't the highest energy cosmic rays point back to something interesting?
- Why are there kinks in the cosmic ray energy spectrum?
  - the knee at 10^{15} eV (1 PeV)
  - the ankle at 10^{19} eV (10 EeV)
  - the toe (?) at 10^{21} eV (1 XeV)
- How can the highest energy cosmic rays ($>10^{20}$ eV) ever reach us?
  - GZK cutoff should stop them

Charged particles from the cosmos

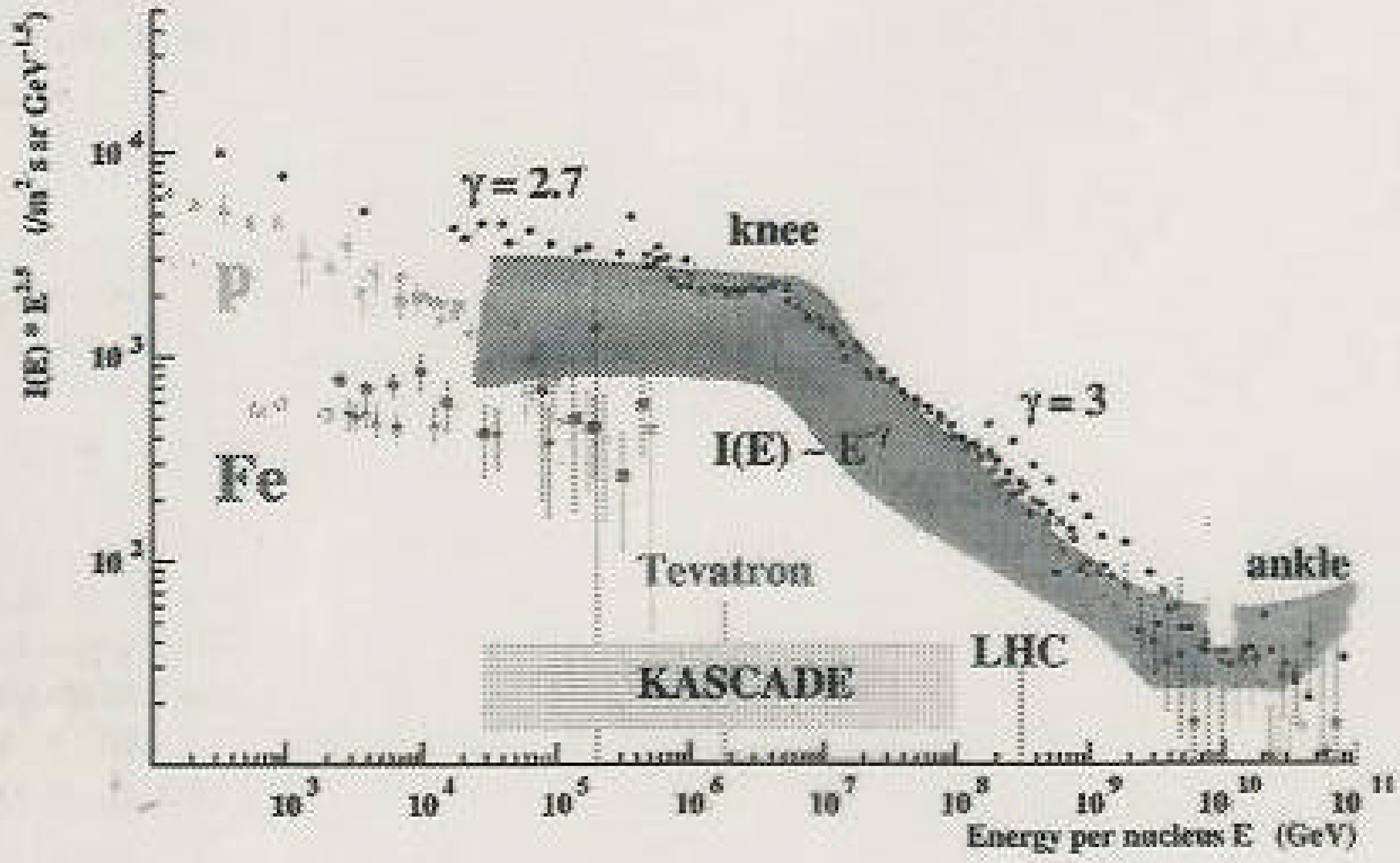
- Protons, α-particles, heavier nuclei
- No significant anisotropy seen
  ("well stirred" by Galactic magnetic field)
- Energies above 10^{10} eV are from our Galaxy

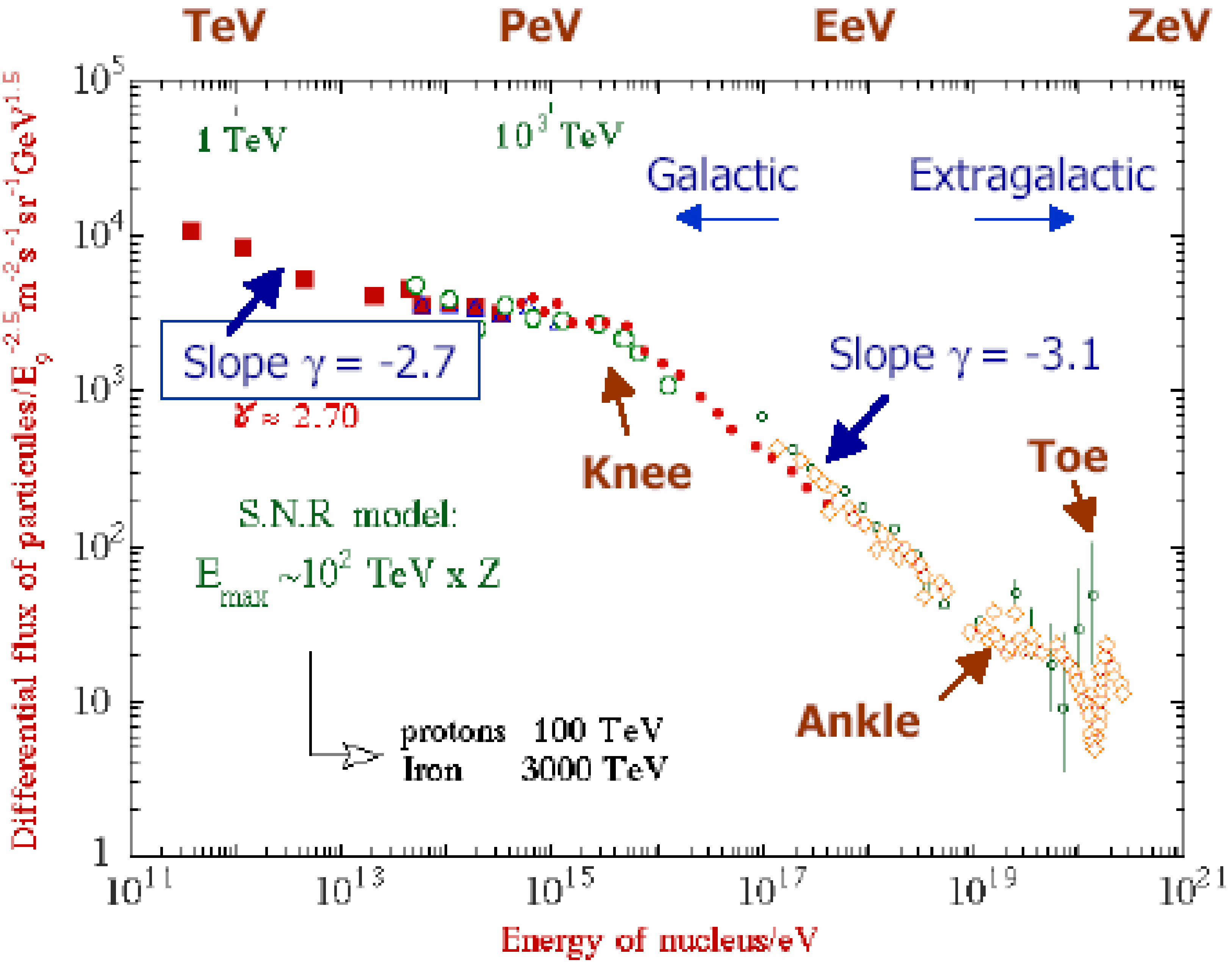
(note: TV or PC monitor uses 10^3 eV electron beam)

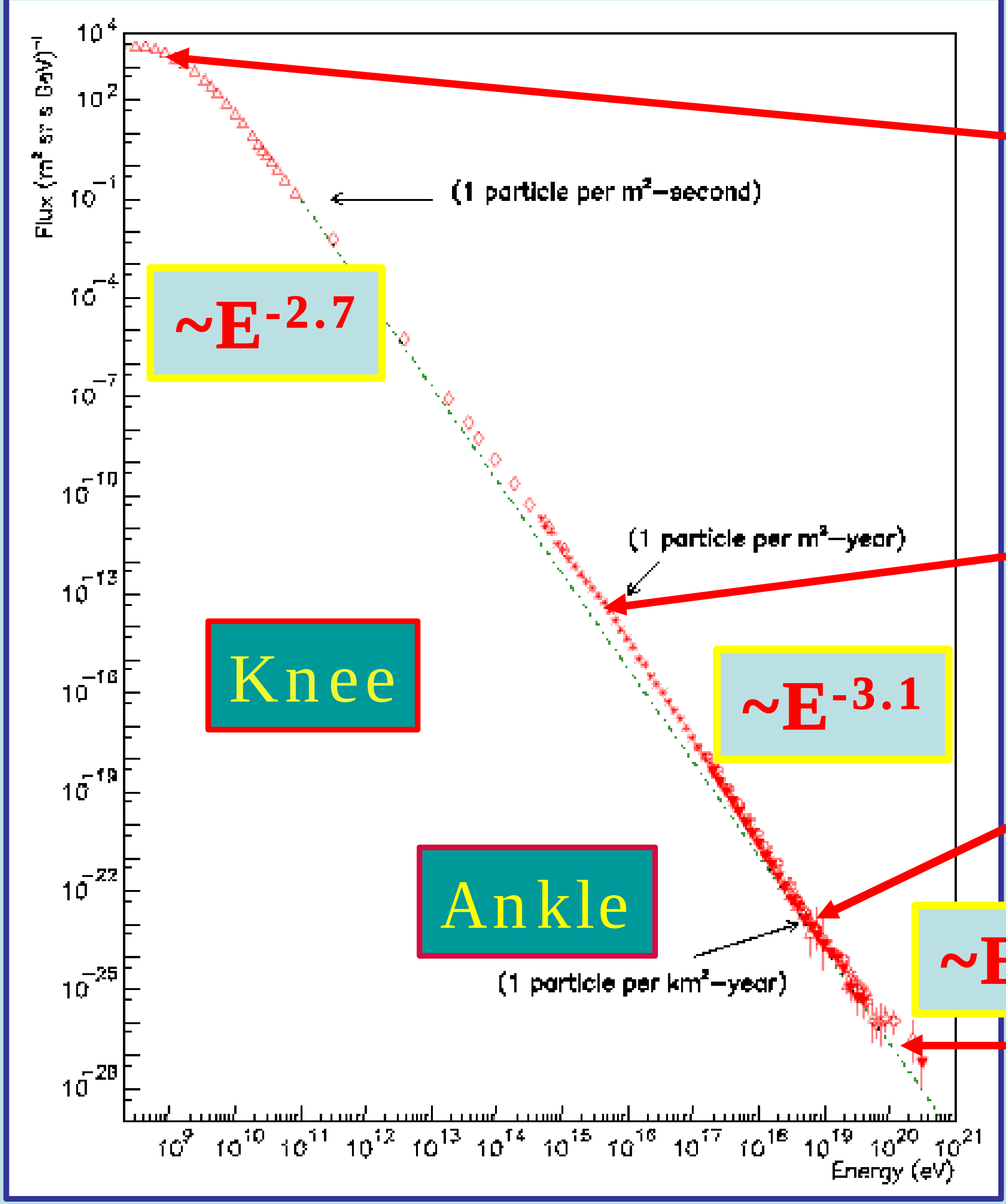
- Energies above 10^{18} eV are extra-galactic
- Intensity drops sharply with E (like $E^{-2.7}$):

Energy	**Rate of arrival**
10^{10} eV	1000 per m^2 per sec
10^{12} eV	1 per m^2 per sec
10^{15} eV	1000 per m^2 per year
10^{19} eV	1 per kilometer^2 per year

Highest energy seen is ~10^{20} eV, about 50 joules (energy of a 50 mph baseball in one proton!)


I(E) * E^2.5 (m^-2 s sr GeV^1.5)
10^4
10^3
10^2
p
Fe
γ = 2.7
knee
I(E) ~ E^-γ
γ = 3
Tevatron
KASCADE
LHC
ankle
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
Energy per nucleus E (GeV)


TeV
PeV
EeV
ZeV
1 TeV
10^3 TeV
Galactic
Extragalactic
Slope γ = -2.7
γ ≈ 2.70
Slope γ = -3.1
Knee
Toe
Ankle
S.N.R model:
E_{max} ~10^2 TeV x Z
protons 100 TeV
Iron 3000 TeV
Differential flux of particules/$E_9^{-2.5}$ $m^{-2}s^{-1}sr^{-1}GeV^{1.5}$
10^5
10^4
10^3
10^2
10
1
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
10^{21}
Energy of nucleus/eV



$\sim 10^2 / m^2 / s$

$\sim E^{-2.7}$

$\sim 1 / m^2 / year$

Knee

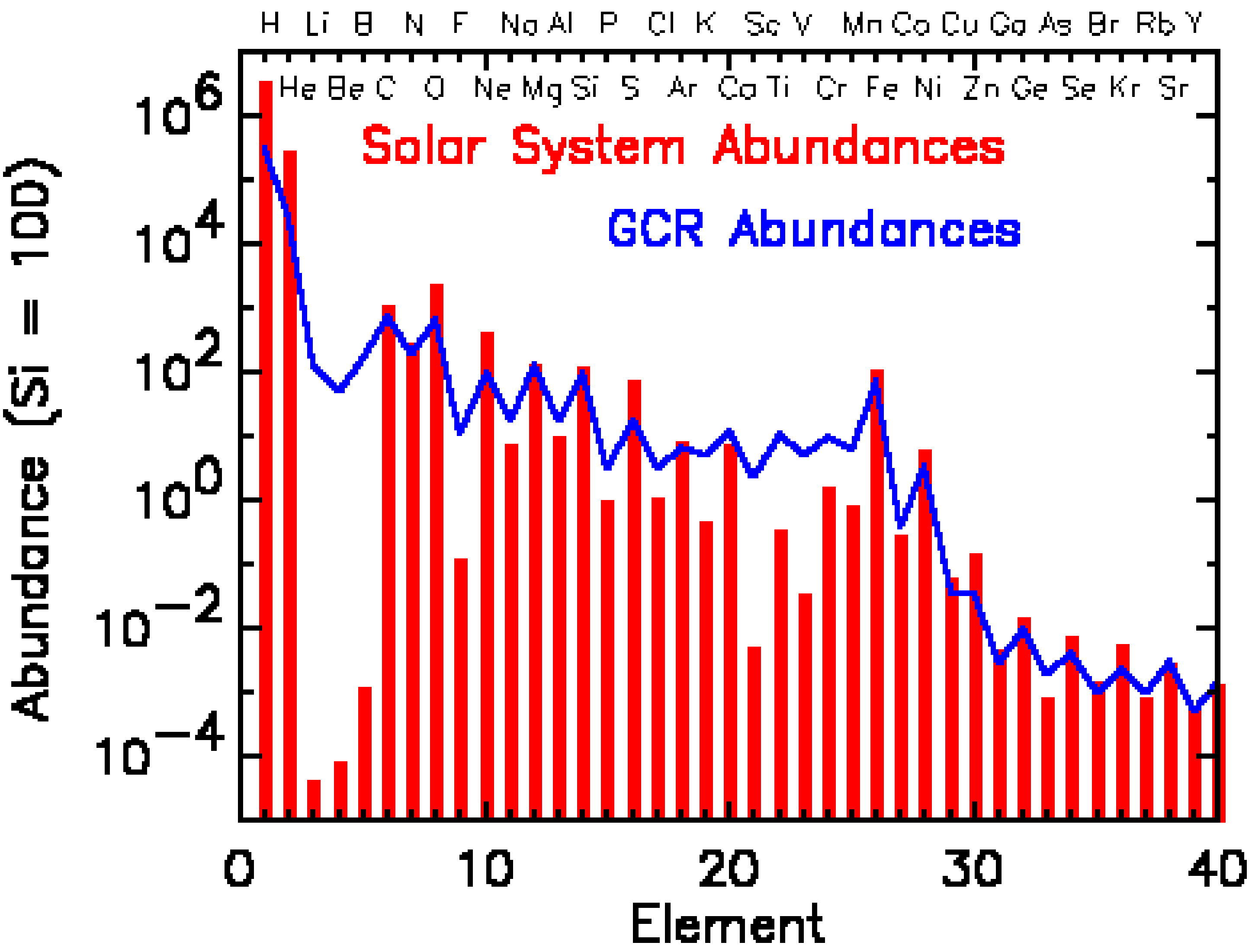
$\sim E^{-3.1}$

$\sim 1 / km^2 / year$

Ankle

$\sim E^{-2.7}$

$\sim 1 / km^2 / centur$


H Li B N F Na Al P Cl K Sc V Mn Co Cu Ga As Br Rb Y
He Be C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge Se Kr Sr
Solar System Abundances
GCR Abundances
Abundance (Si = 100)
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
0
10
20
30
40
Element

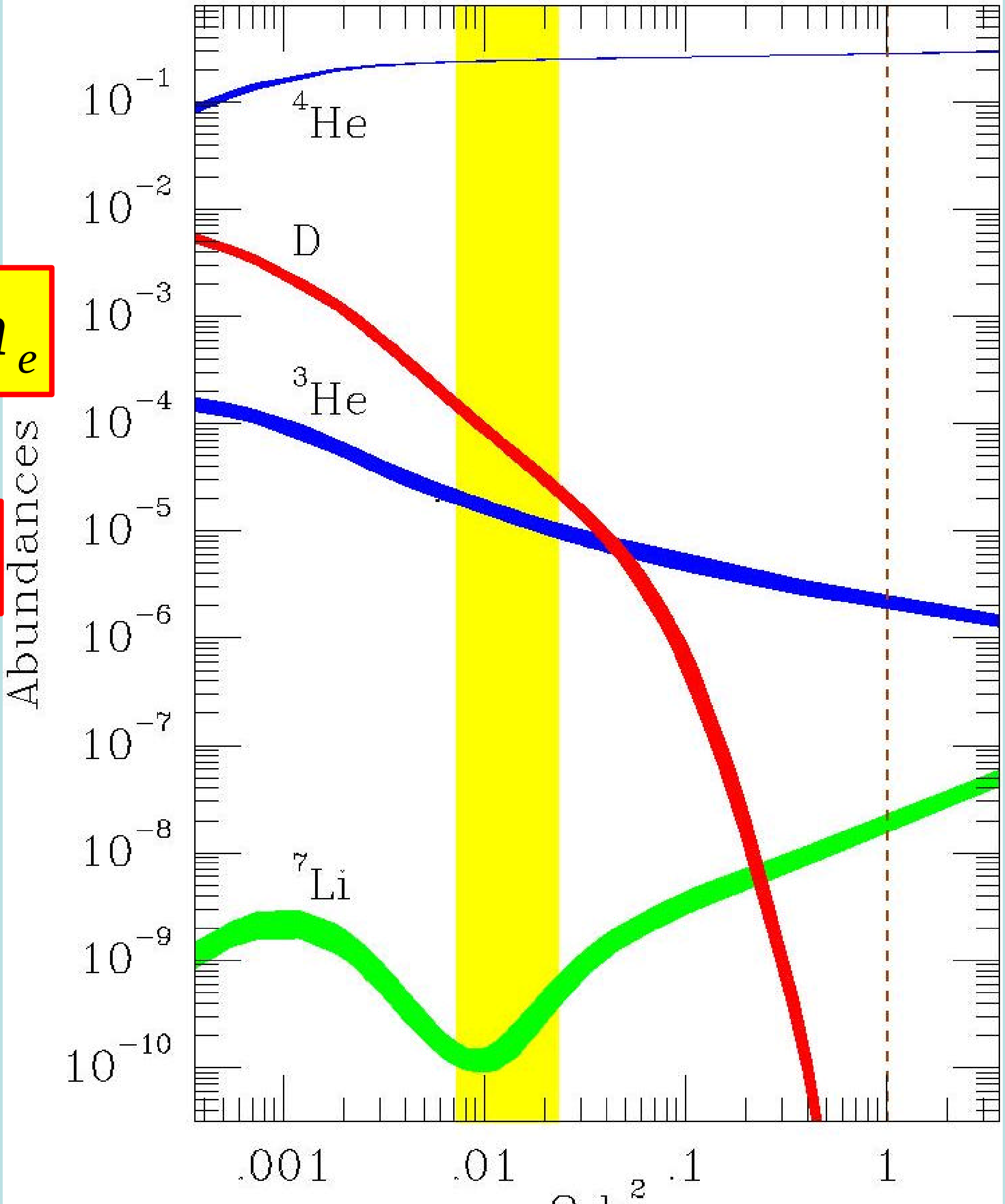
$$R = R_0 r^2 T^h$$

$$4\,{}^1H \rightarrow {}^4He + 2e^+ + 2n_e$$

$$2\,{}^4He \rightarrow {}^8Be \rightarrow 2\,{}^4He$$

$$\cancel{3\,{}^4He \rightarrow {}^{12}C}$$

A = 5 non esiste



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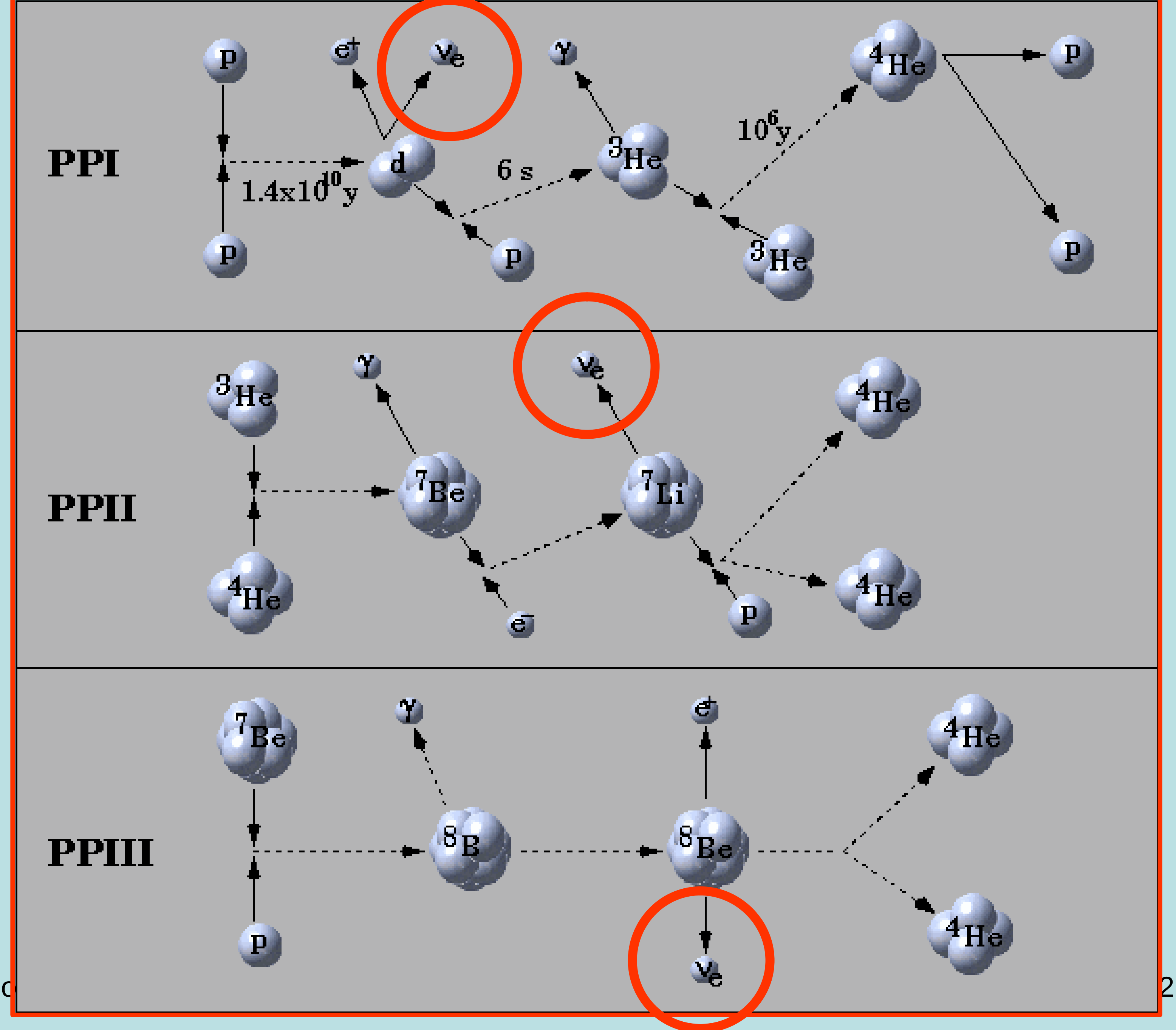
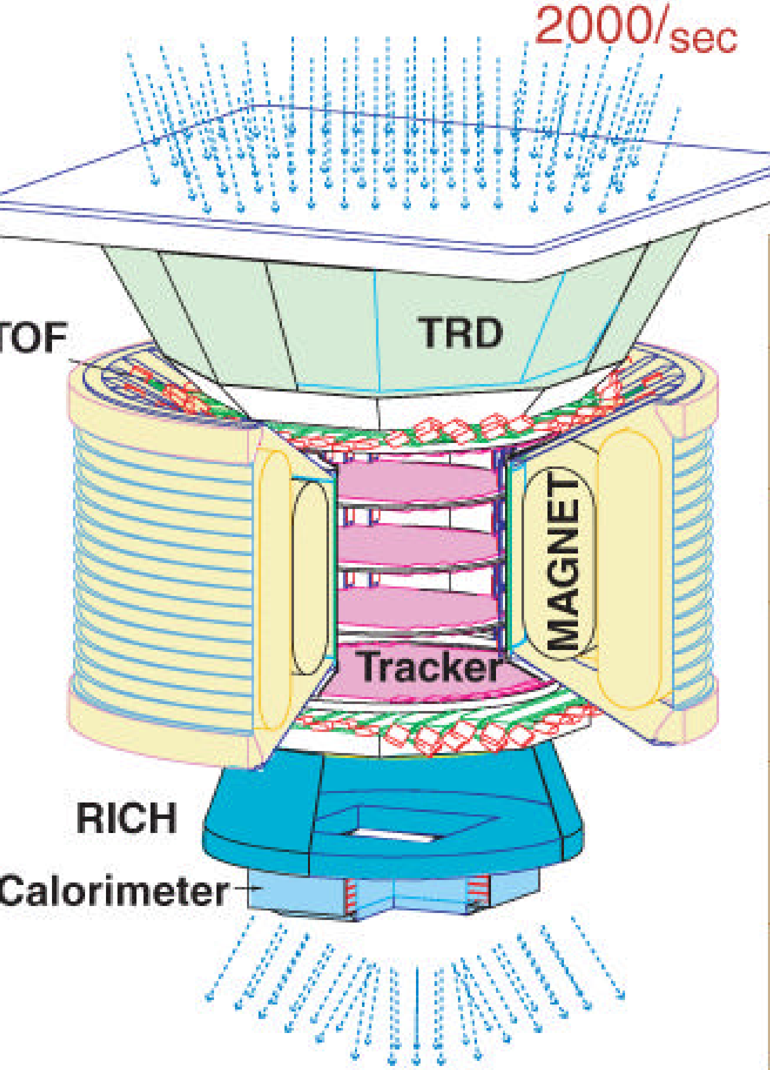

PPI
p
p
e+
νe
γ
d
1.4x10^10 y
6 s
3He
3He
10^6 y
4He
p
p
PPII
3He
4He
γ
7Be
e-
νe
7Li
p
4He
4He
PPIII
7Be
p
γ
8B
e+
8Be
νe
4He
4He

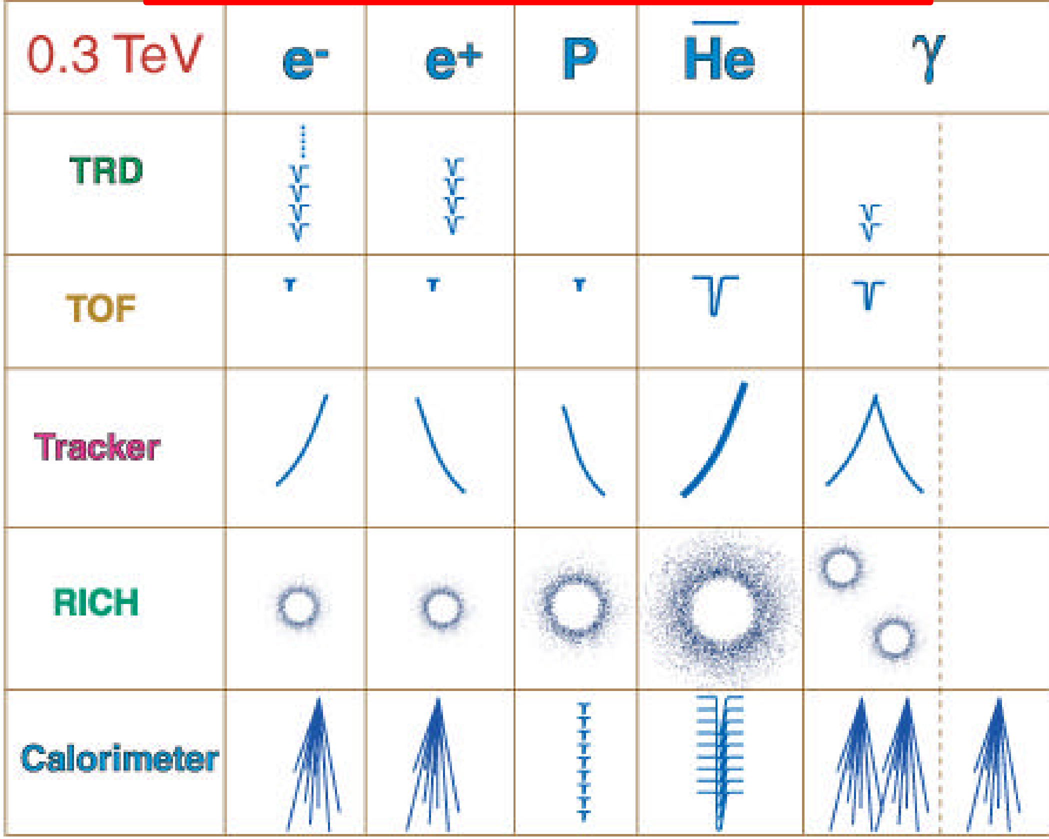
Only at low energies it is possible to measure primaries directly.

At high energies the flux is so low that only indirect measurements are possible.

AMS: A TeV Magnetic Spectrometer in Space

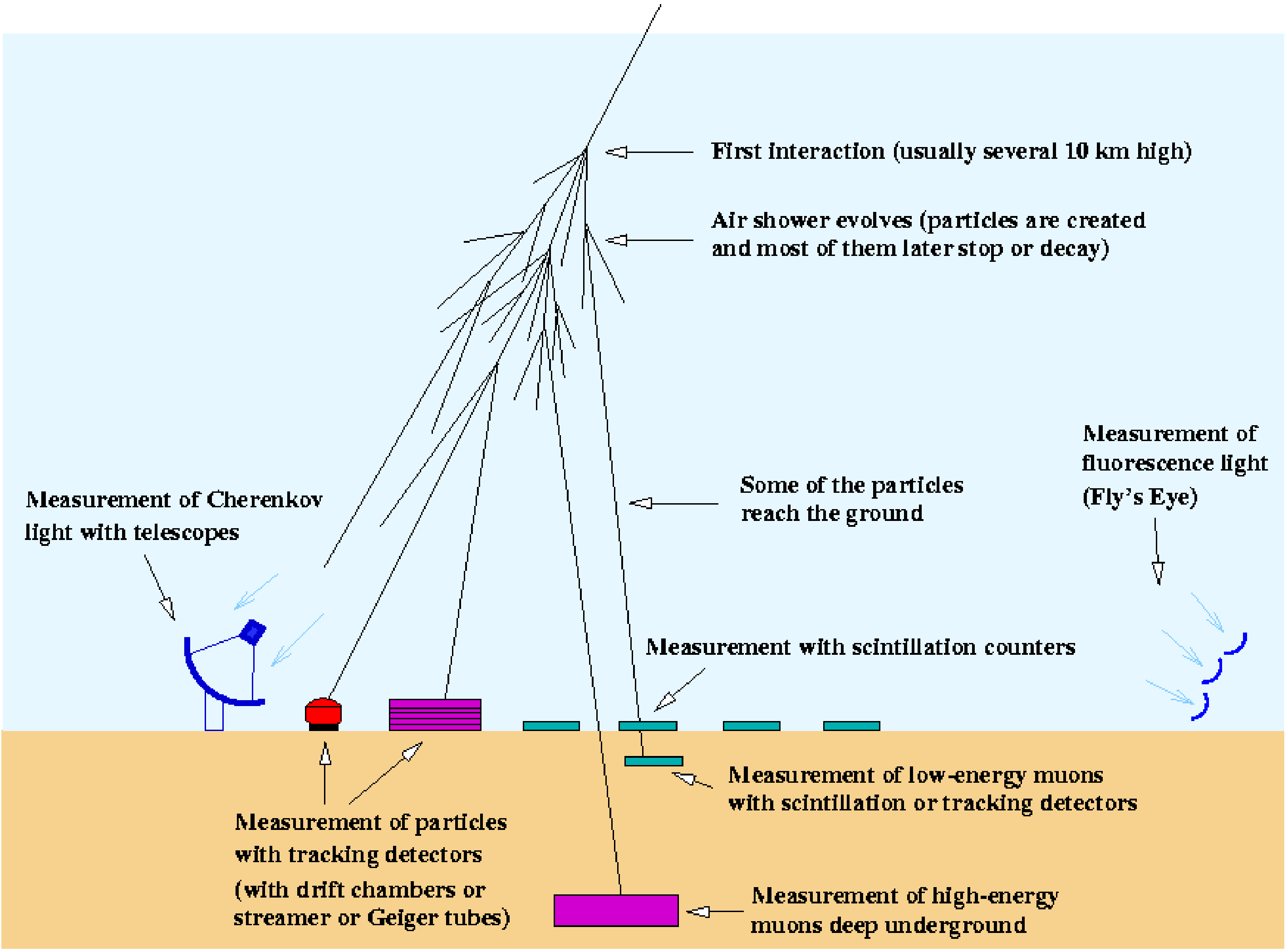


G.F. 5000 cm^2 sr
Exposure > 3 yrs



y2K025 _5 Gamma

Measuring cosmic-ray and gamma-ray air showers



First interaction (usually several 10 km high)

Air shower evolves (particles are created and most of them later stop or decay)

Some of the particles reach the ground

Measurement of fluorescence light (Fly's Eye)

Measurement of Cherenkov light with telescopes

Measurement with scintillation counters

Measurement of low-energy muons with scintillation or tracking detectors

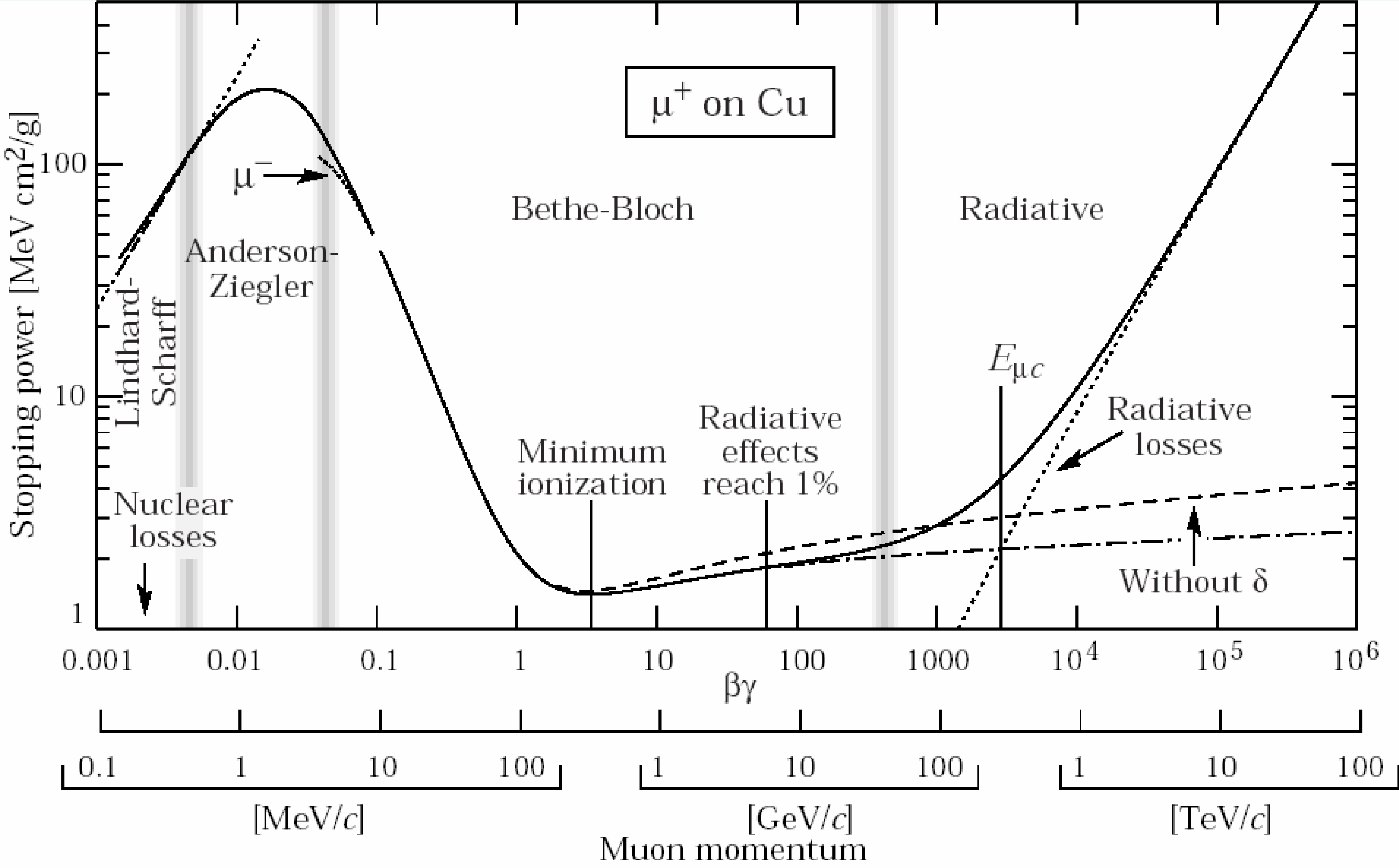
Measurement of particles with tracking detectors (with drift chambers or streamer or Geiger tubes)

Measurement of high-energy muons deep underground

(C) 1999 K. Bernlöhr

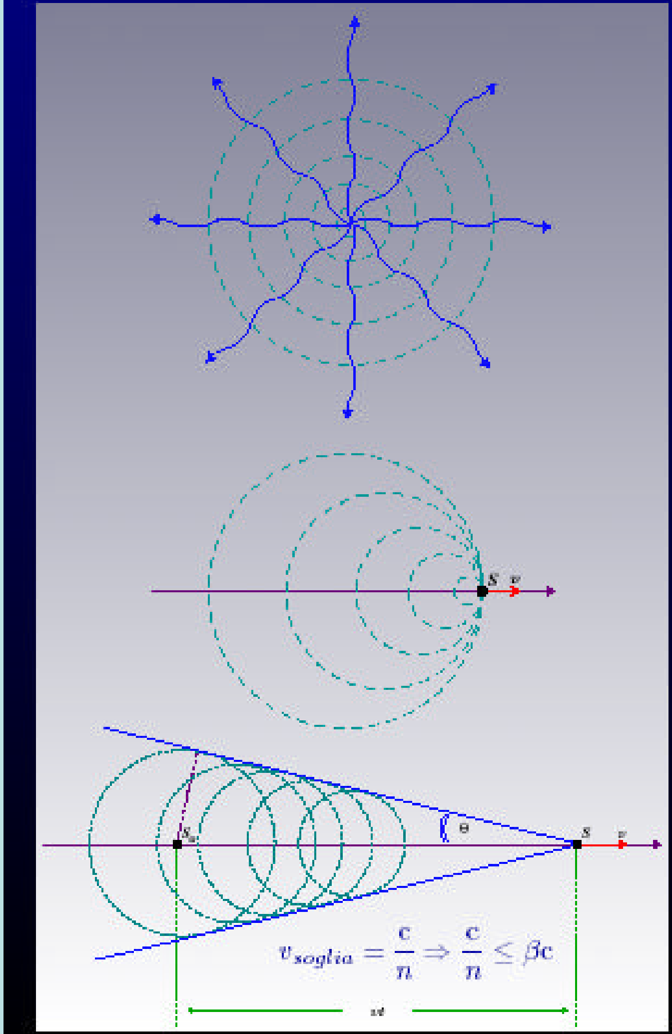
Only muons and neutrinos can penetrate large depths of rock.

Formula di Bethe e Bloch



Luce Čerenkov

Fronti d’onda

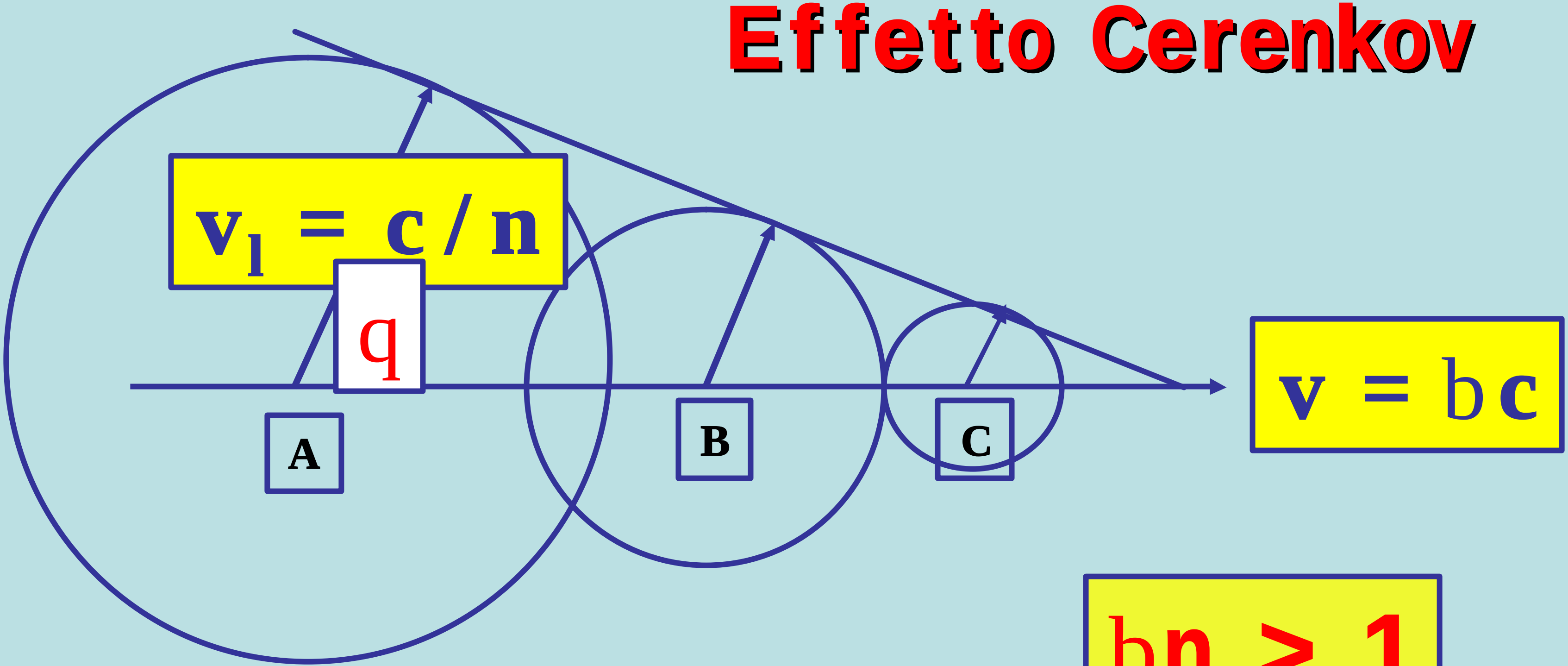


Fronte d’onda per una sorgente ferma

Fronte d’onda per una sorgente in moto a velocità *v*

Fronte d’onda per una sorgente in moto a velocità > v_c

Effetto Cerenkov



bn > 1

$$J = \arccos\frac{1}{bn}$$

$$J^{\max} = \arccos\frac{1}{n}$$

In water ($n = 1{,}33$, $v_l = 2{,}25 \cdot 10^8$ m/s) Cerenkov light is produces only if $\beta = 0{,}75$, and emitted with $\theta \sim 41$ degrees.

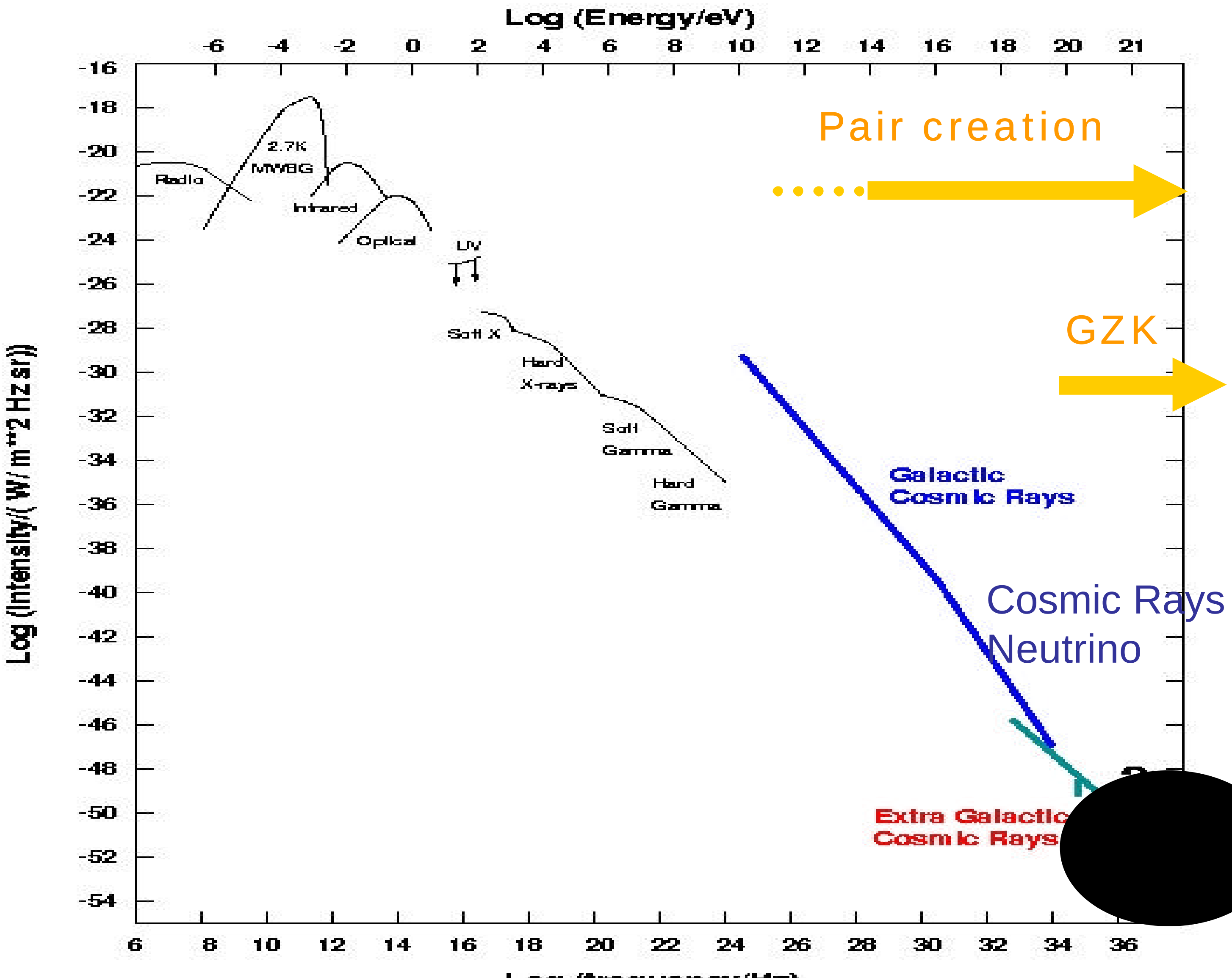
$$g = \frac{1}{\sqrt{1-b^2}} = 1{,}52$$

The table shows the minimum kinetic energies to produce Cerenkov ight in water.

particles	**e**	m	**k**	**p**	a
mc^2 (MeV)	0,51	106	493	938	3752
$(E_K)_{min}$ (MeV)	0,78	162	753	1432	5034

In air ($n = 1{,}0003$) only ultrarelativistic particles produce Cerenkov light along a very narrow cone with $\theta \sim 1{,}3$ degrees.

Cosmic Rays & Neutrinos
Messenger from Extreme Universe



Pair creation

GZK

Cosmic Rays and Neutrino

From Boltzmann ($k = 1.4 \cdot 10^{-23}$ J/K) one obtains the temperature corresponding to energy values

n (Hz)	~ 10^{10} radio	~ 10^{14} ottico	~ 10^{20} raggi X	~ 10^{25} raggi γ	**R.C.**
E (eV)	$\sim 10^{-4}$	~ 5	10^{5}	10^{10}	**10^{20}**
T (K)	1	10^{4}	10^{10}	10^{15}	**10^{25}**

CR particles (*p*, but also *n* and *g*) can have an energy so large that their origin could be only cosmological.

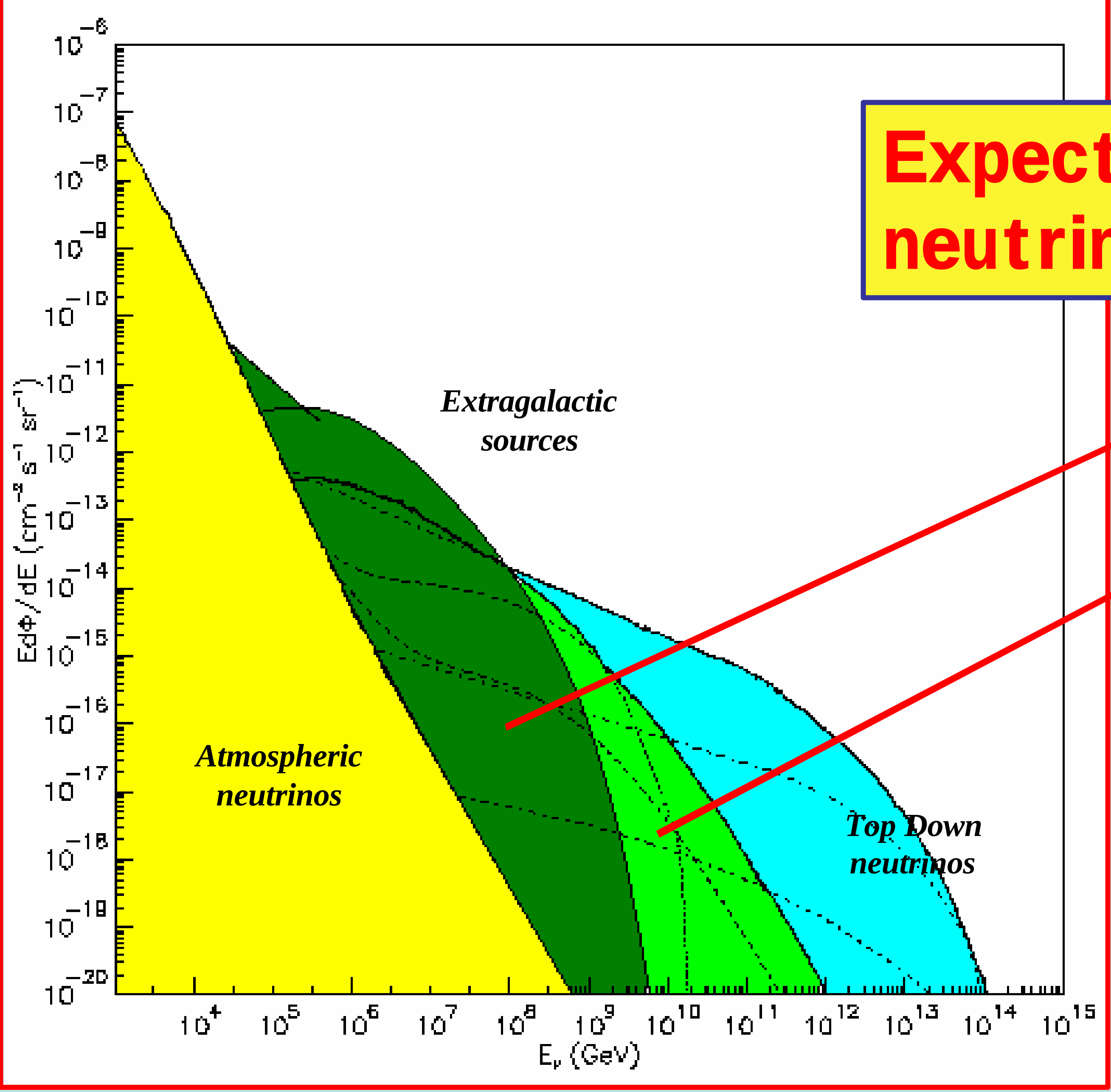
$$p+p \rightarrow p^{\pm}(K^{\pm})+X$$

$$|\rightarrow \quad m^{\pm}+n_{m}(\bar{n}_{m})$$

$$|\rightarrow \quad e^{\pm}+\bar{n}_{m}(n_{m})+n_{e}(\bar{n}_{e})$$

$$p+p \rightarrow p^{0} \rightarrow g+g$$

Expected UHE neutrino fluxes



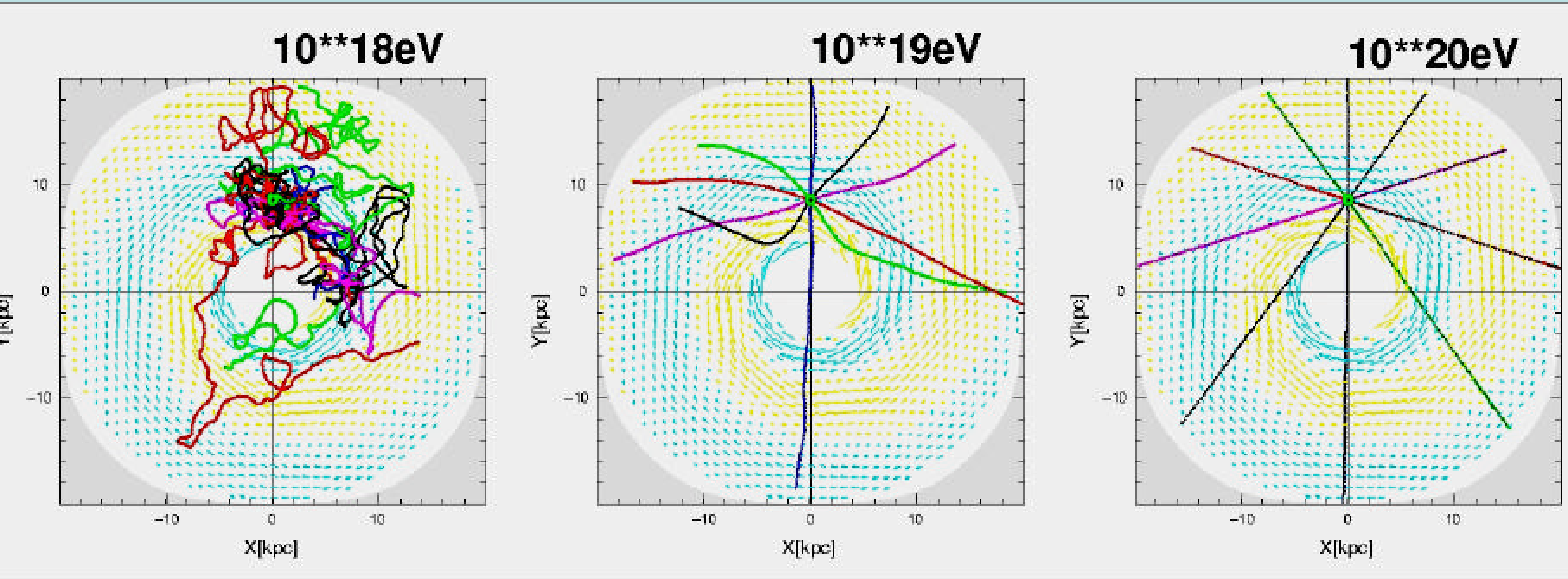
AGN Model
Stecker

AGN Models
Protheroe, Mannhein

GRB (fireball model) good candidates but big variability in flux calculations depending on GRB distance

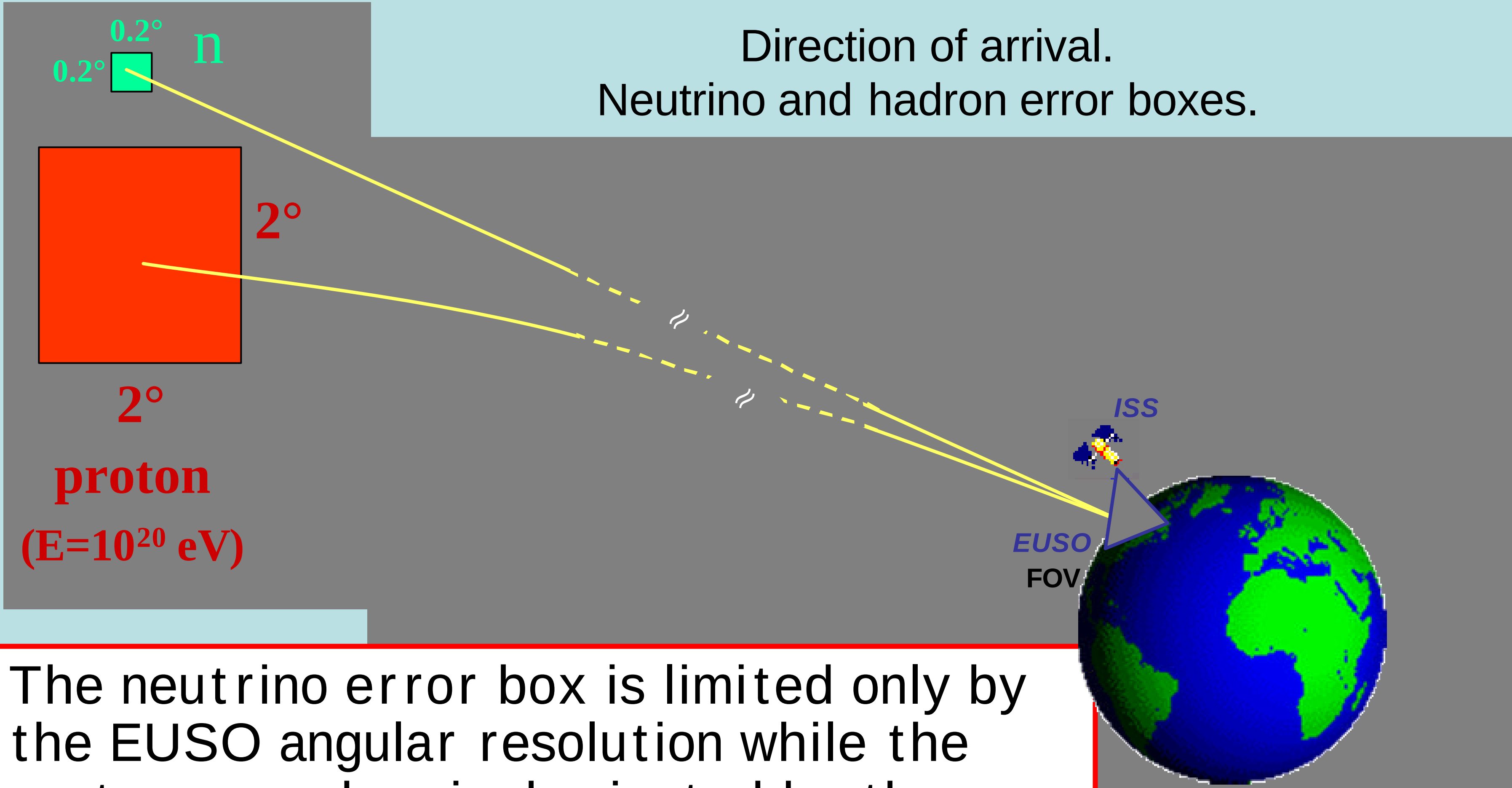
Cosmic Ray Propagation in our Galaxy

Deflection angle < 1 degree at 10^{20} eV



The Cosmic Radiation

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, <d> = 30 Mpc

Greisen, Zatsepin and Kuzmin (1960) pointed out that there ought to be a "cutoff" in the cosmic ray spectrum around 10^{20} eV:

- The universe is filled with Cosmic Background Radiation (CBR), relic photons from the Big Bang
- CBR photons have an energy spectrum characteristic of a blackbody at ~3K, so they are in the ~0.001 eV (microwave) energy range
- But in the rest frame of a 10^{20} eV proton, they look like high energy (10^9 eV) gamma rays!
- Protons and nuclei have a high probability (cross section) for interacting with GeV gamma rays and getting smashed into other (lower energy) particles

GZK Effect

$$\mathbf{p + h}n \circledR D^{+} \circledR \mathbf{N} + p$$

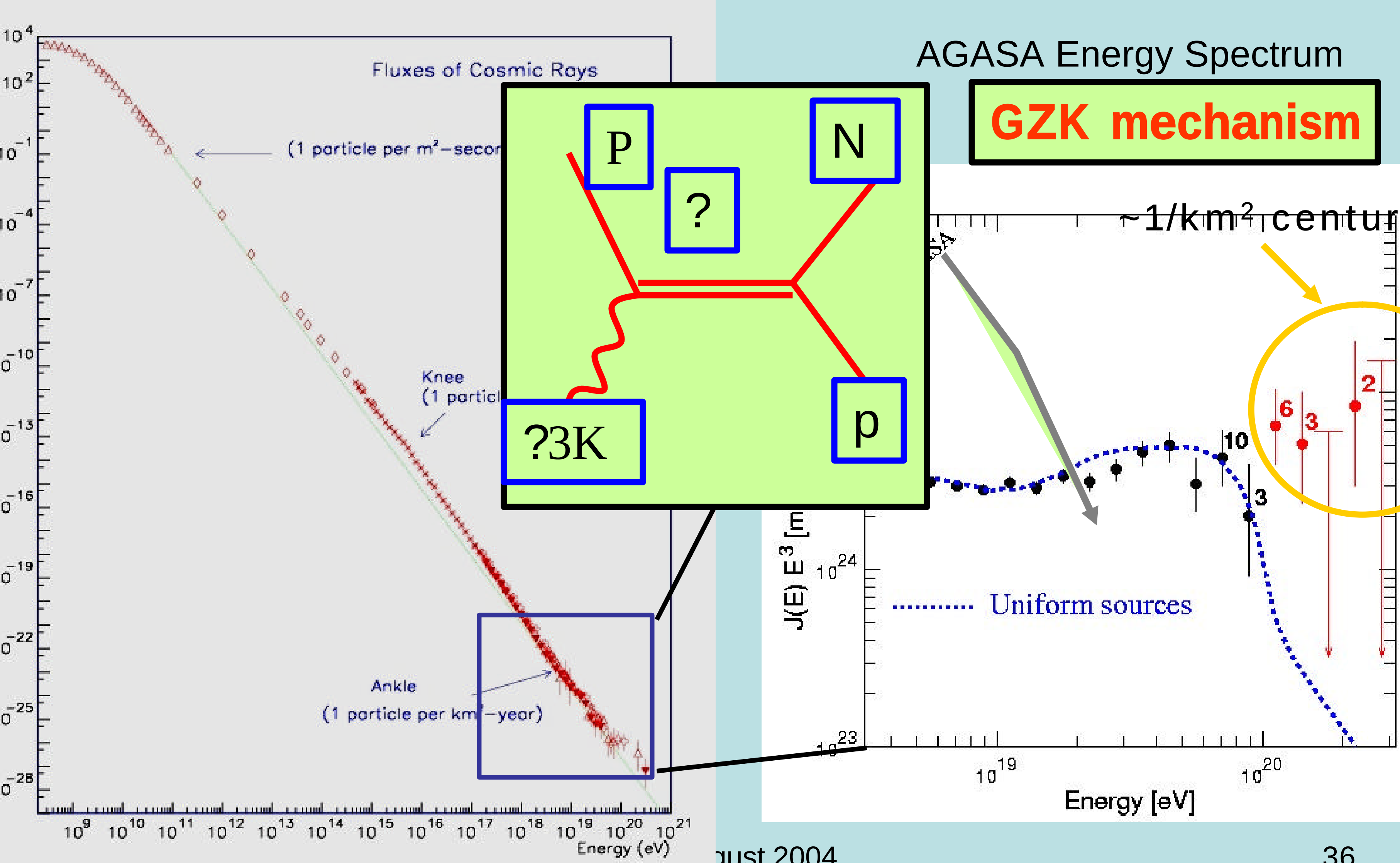
Energy and attenuation factor ($e^{-x/\lambda}_{GZK}$) are:

$$\mathbf{E_{GZK} \sim 5 \bullet 10^{19}\ eV}$$

$$l_{\mathbf{GZK}} \sim \mathbf{30\ Mpc}$$

- Super-GZK hadrons from distant sources will lose energy and pile-up at sub-GZK energies.
- If UHE CR are protons, they show the highest value for the Lorentz factor ($g \sim \mathbf{10^{11}}$) observed in nature.

Cosmic Ray Energy Spectrum



UHE CR PRODUCTION MECHANISMS

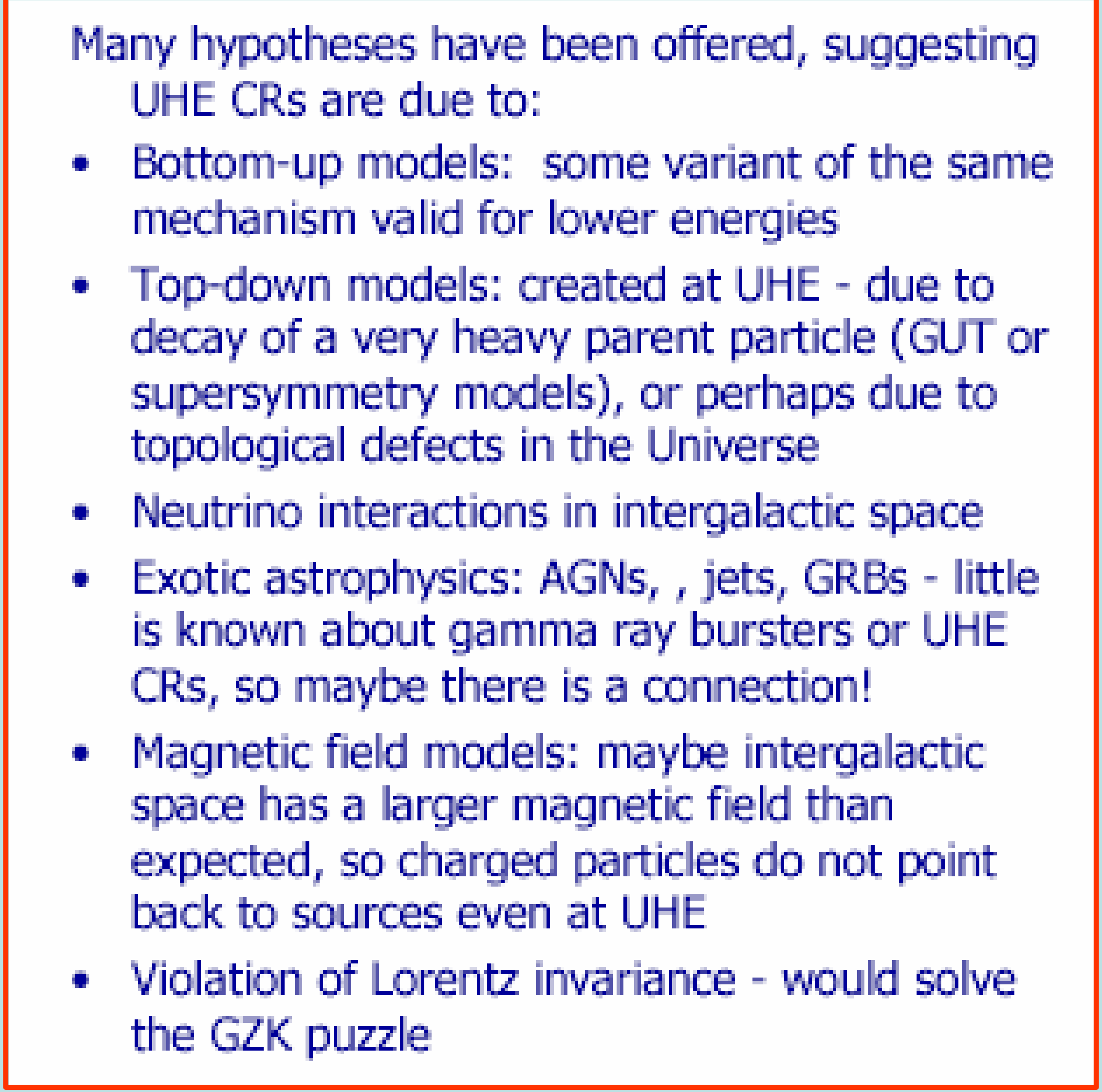
Observations and Experiments are needed to answer to the questions remaining open

Bottom – up signatures

- Protons/nuclei
- Power law spectrum
- counterparts

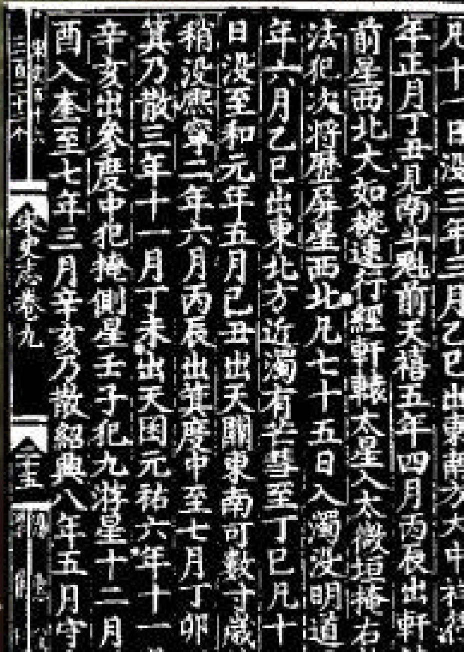
Top – down signatures

- Photons/neutrinos
- Non-power law spectrum
- No counterparts/repeats
- Halo distribution



Many hypotheses have been offered, suggesting UHE CRs are due to:

- Bottom-up models: some variant of the same mechanism valid for lower energies
- Top-down models: created at UHE - due to decay of a very heavy parent particle (GUT or supersymmetry models), or perhaps due to topological defects in the Universe
- Neutrino interactions in intergalactic space
- Exotic astrophysics: AGNs, , jets, GRBs - little is known about gamma ray bursters or UHE CRs, so maybe there is a connection!
- Magnetic field models: maybe intergalactic space has a larger magnetic field than expected, so charged particles do not point back to sources even at UHE
- Violation of Lorentz invariance - would solve the GZK puzzle



見十一日沒三年三月乙巳出東南方大中祥

年正月丁丑見南斗魁前天禧五年四月丙辰出軒

前星西北大如桃速行經軒轅大星入太微垣掩右

法犯次將歷屏星西北凡七十五日入濁沒明道

年六月乙巳出東北方近濁有芒彗至丁巳凡十

日沒至和元年五月己丑出天關東南可數寸歲

稍沒熙寧二年六月丙辰出箕度中至七月丁卯

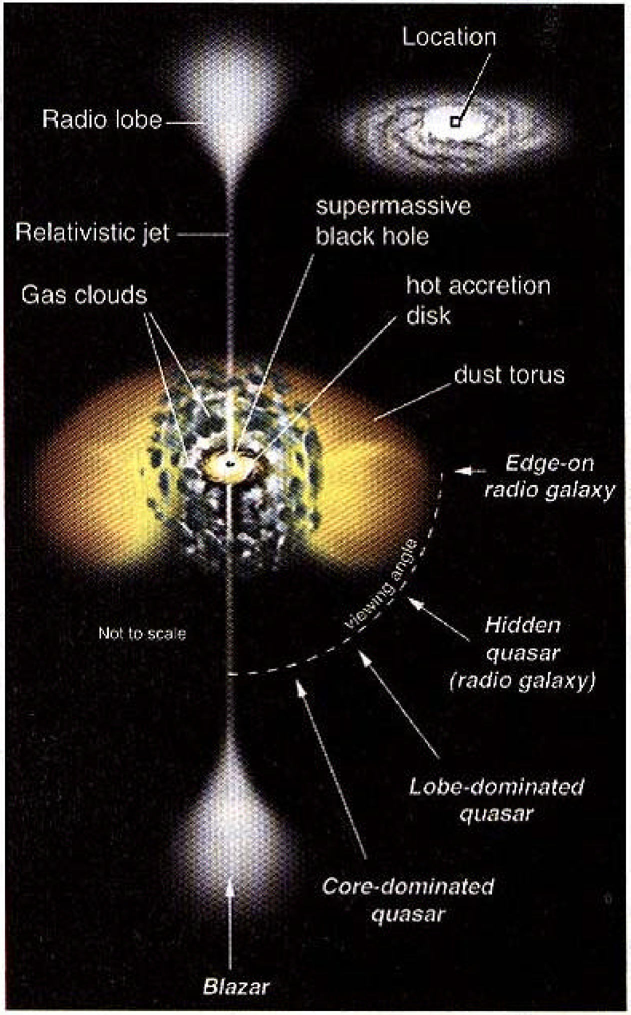
箕乃散三年十一月丁未出天囷元祐六年十一

辛亥出參度中犯掩側星壬子犯九游星十二月

酉入奎至七年三月辛亥乃散紹興八年五月守

宋史志卷九

THE UNIFIED MODEL



Slanted story. Seemingly diverse astronomical objects may be different views of galactic cores.

Low-luminosity sources

Increasing ?

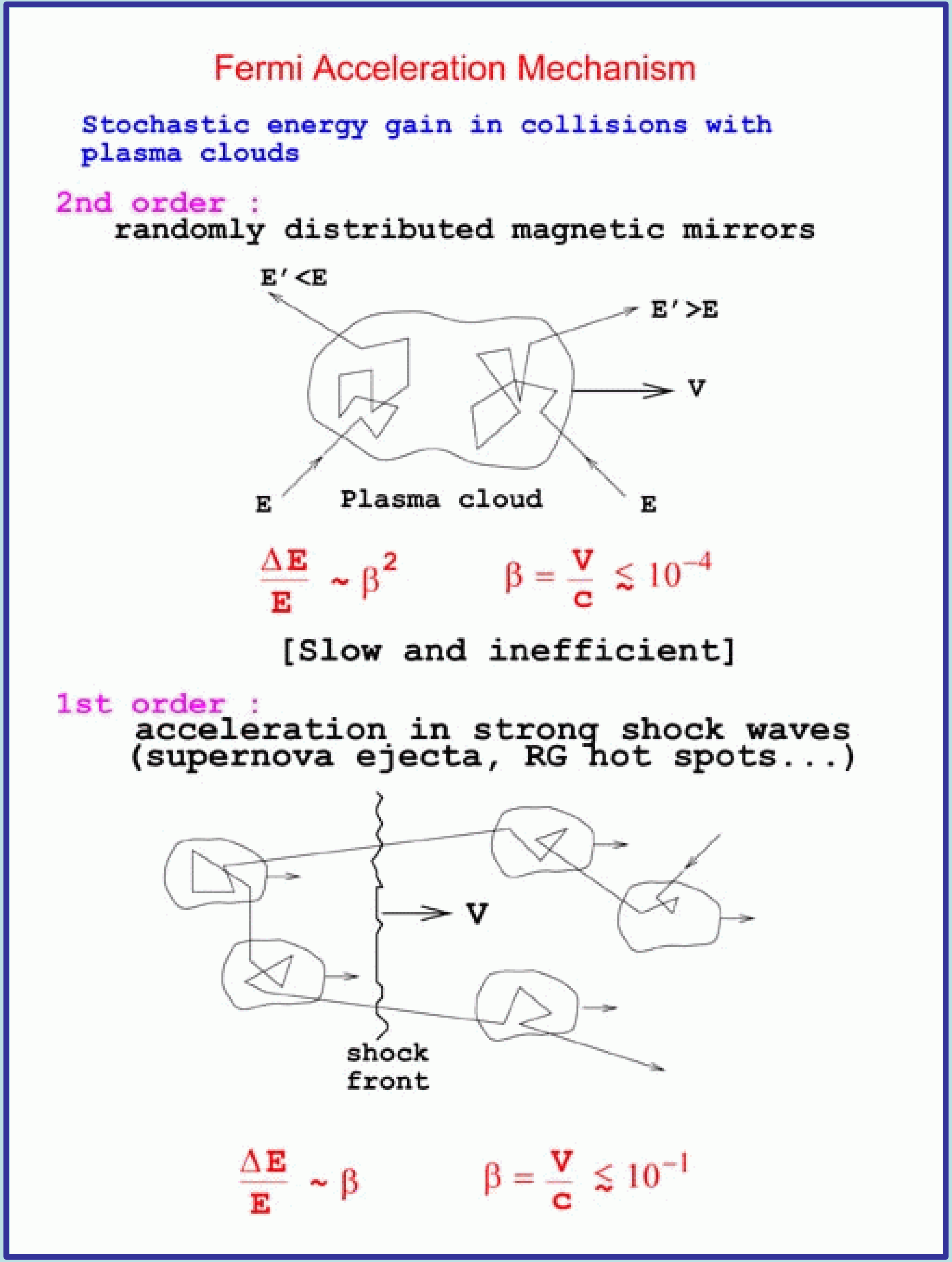
BL Lacs **FR I**

High-luminosity sources

Increasing ?

Radio-loud quasars **FR II**

(Antonucci 1993, Urry & Padovani 1995)



Fermi Acceleration Mechanism

Stochastic energy gain in collisions with plasma clouds

2nd order :
randomly distributed magnetic mirrors

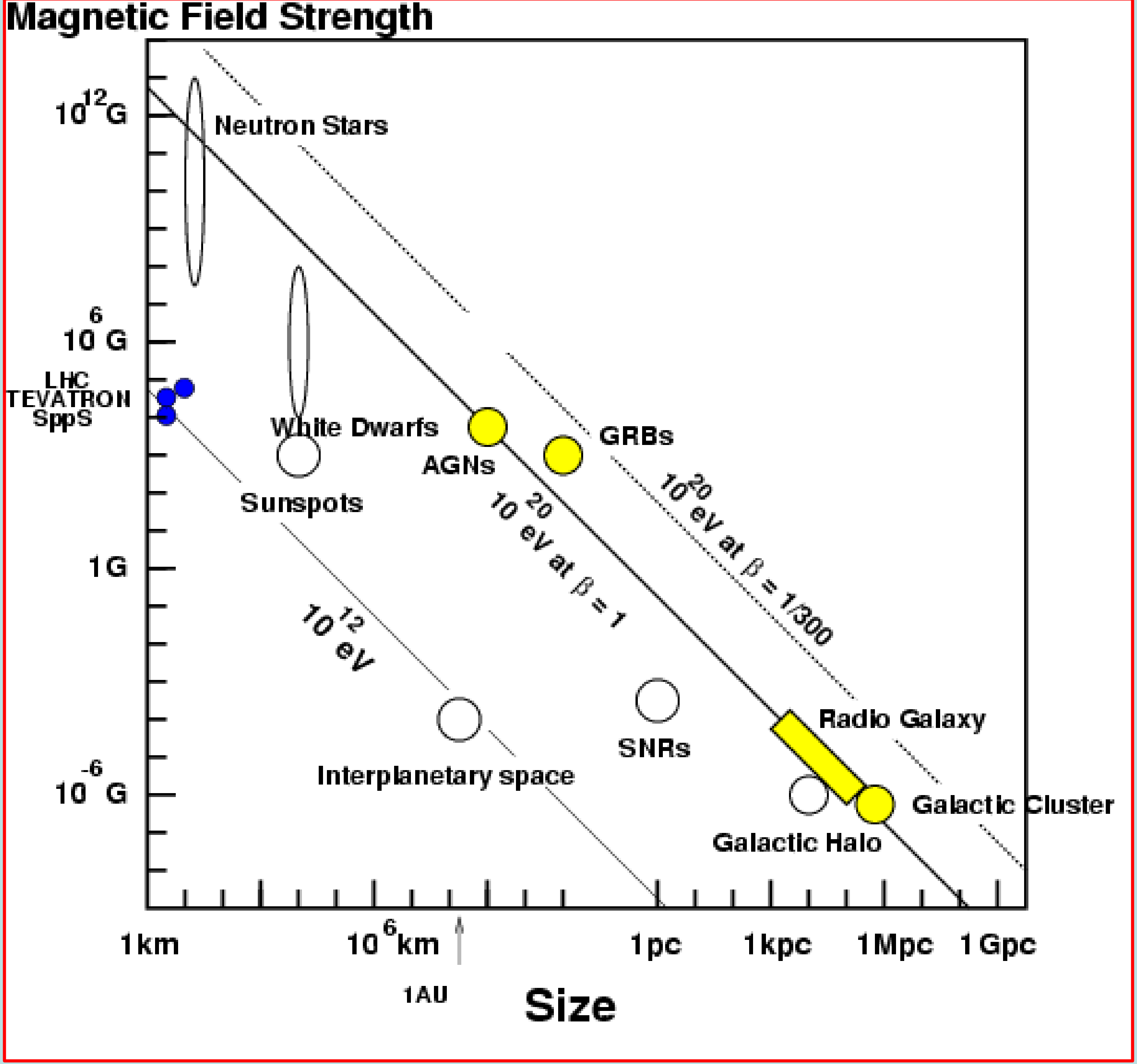
$$\frac{\Delta E}{E} \sim \beta^2 \qquad \beta = \frac{V}{c} \lesssim 10^{-4}$$

[Slow and inefficient]

1st order :
acceleration in strong shock waves
(supernova ejecta, RG hot spots...)

$$\frac{\Delta E}{E} \sim \beta \qquad \beta = \frac{V}{c} \lesssim 10^{-1}$$

Hillas plot



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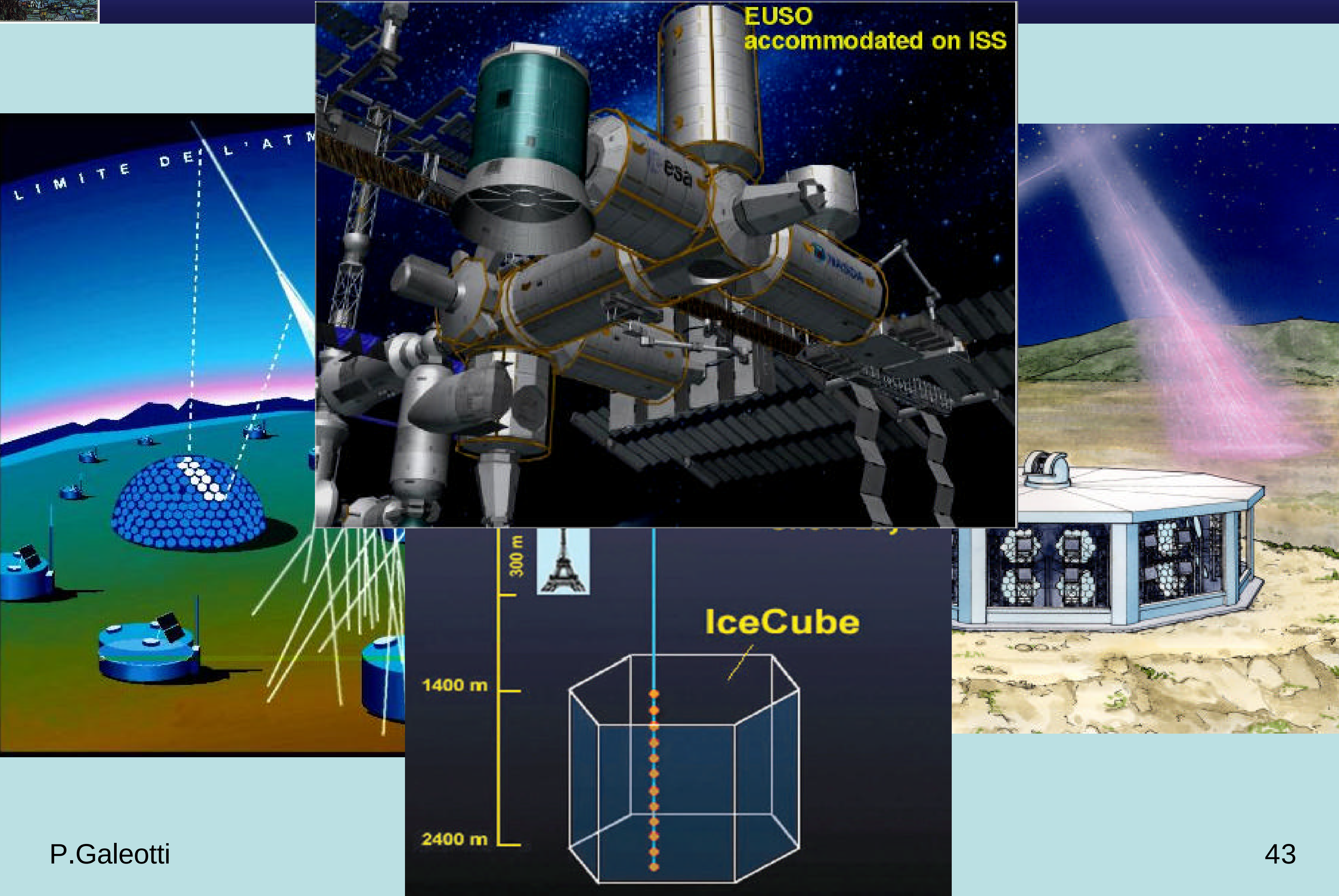
New Projects for UHECRs



EUSO: AN EXPERIMENT TO STUDY EECRs FROM SPACE

EUSO Concept

Large Distance and Large F.O.V.
→ Large Aperture

- ~6×10^5 km^2 sr
  - Good Cosmic Ray detector
- ~2000 Giga-ton atmosphere
  - Good neutrino detector

All Sky coverage

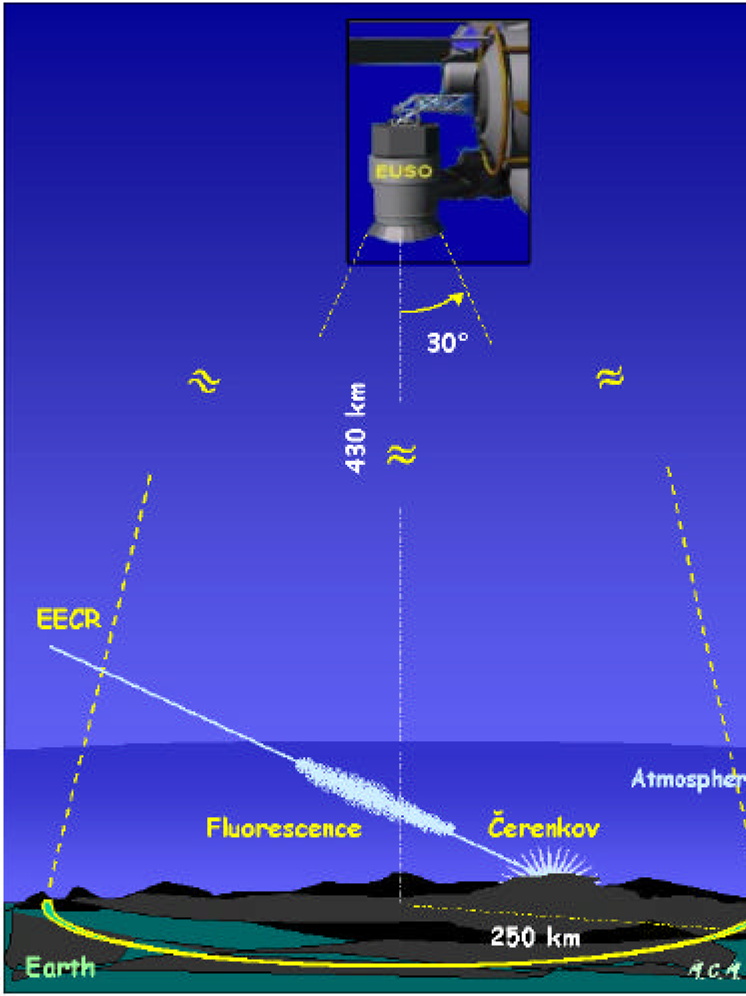
- North and south sky covered uniformly. ISS orbit: ~50°inclination.

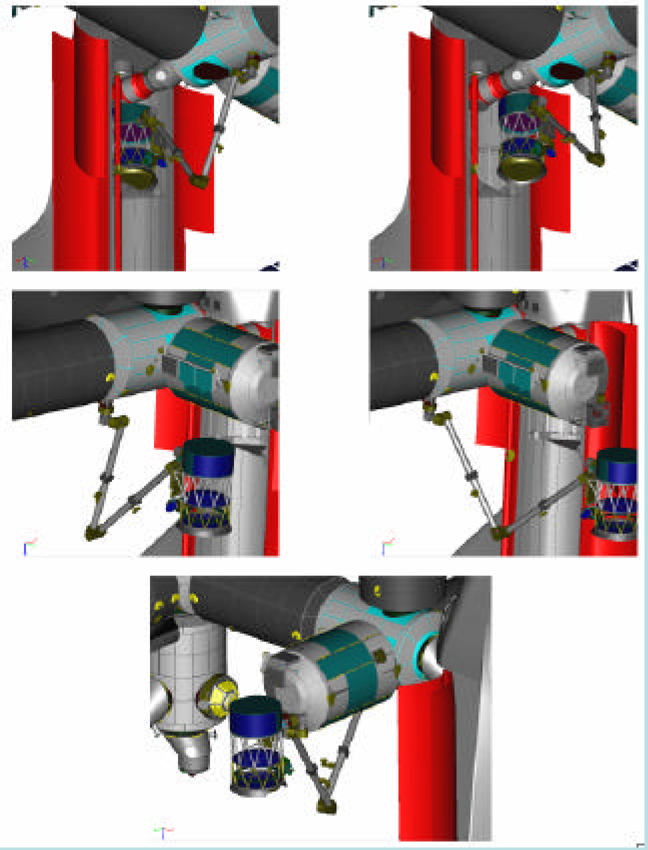
Complementary to the observation from the ground

- Different energy scale
- Different systematic errors

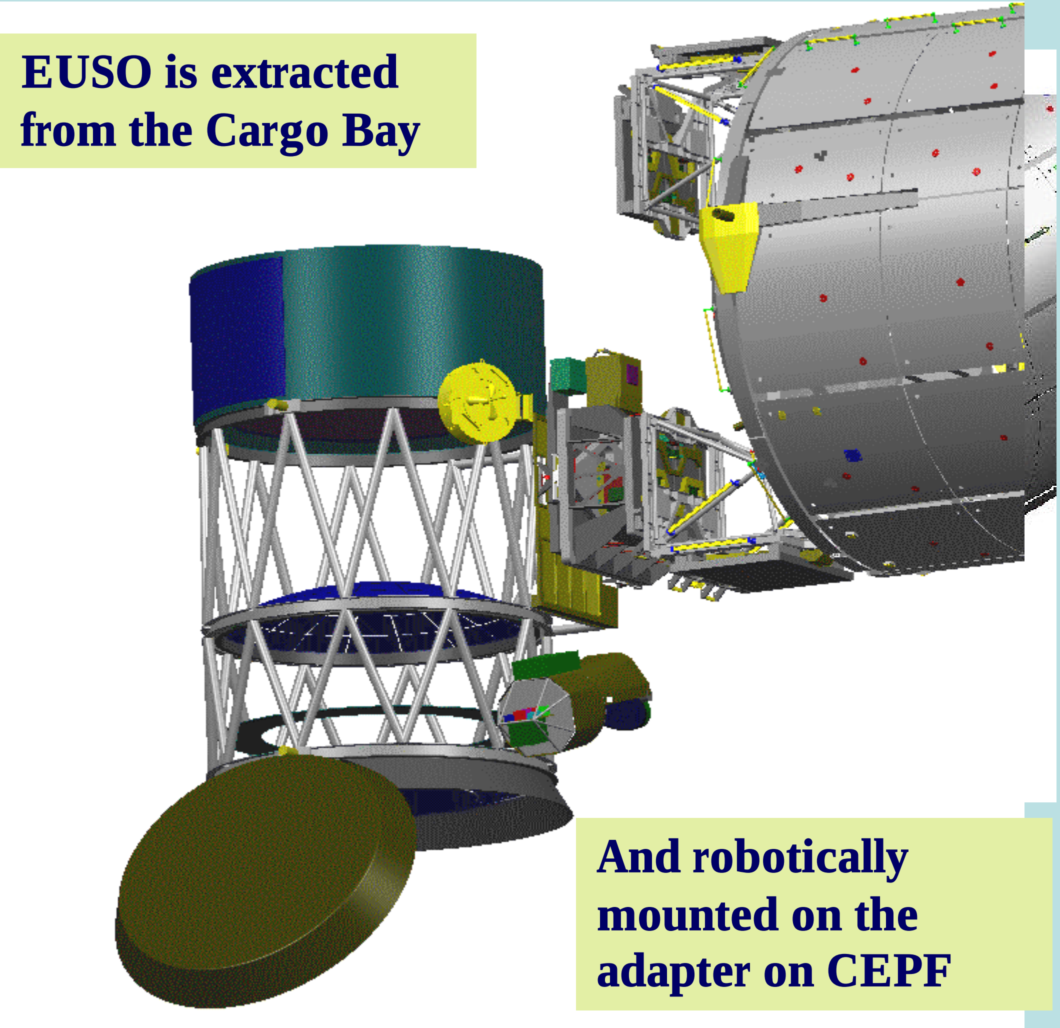
Shower Geometry is well defined

- Constant distance from detector





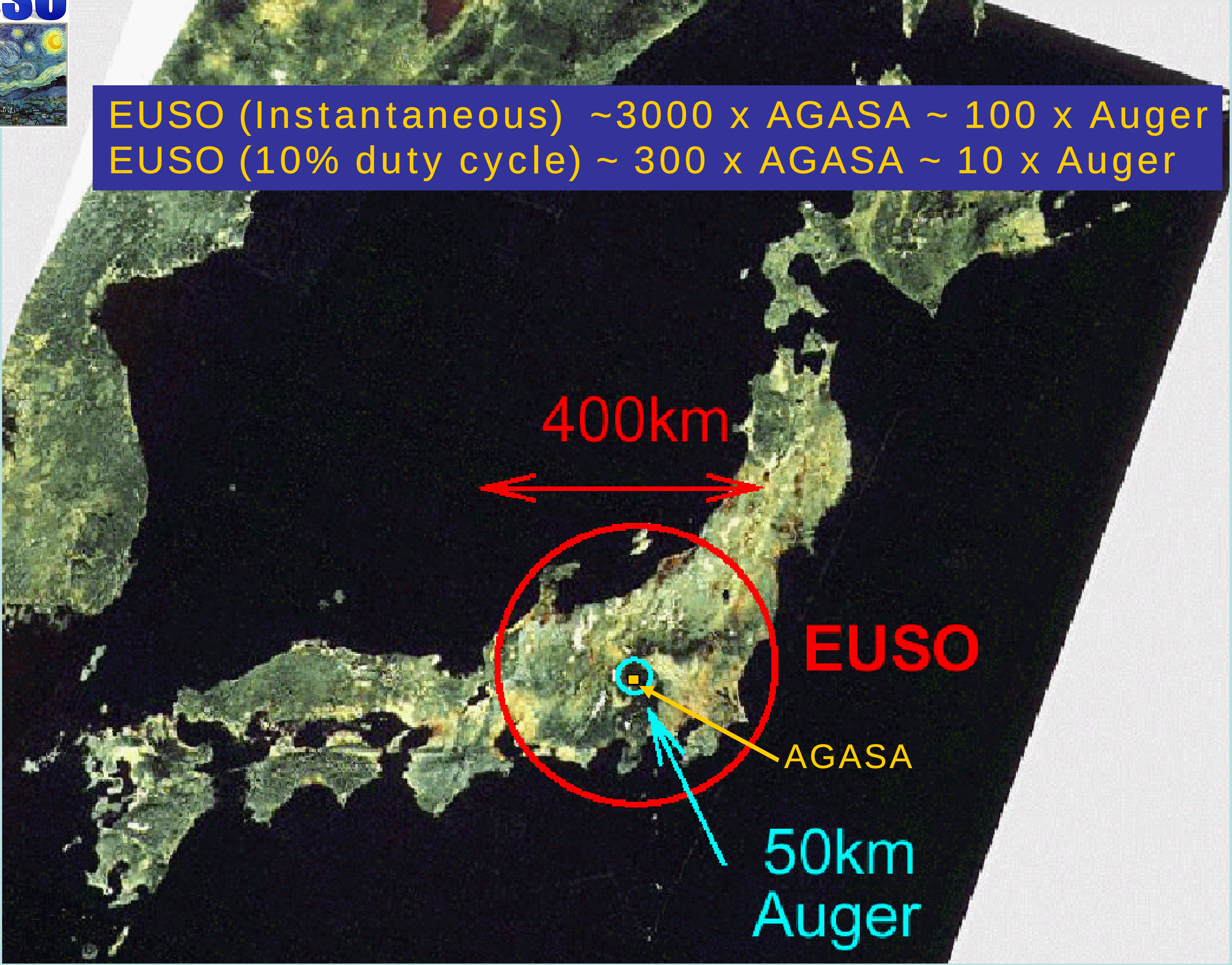
The P/L adapter assy is robotically unlocked and installed at CEPF



EUSO is extracted from the Cargo Bay

And robotically mounted on the adapter on CEPF

EUSO (Instantaneous) ~3000 x AGASA ~ 100 x Auger
EUSO (10% duty cycle) ~ 300 x AGASA ~ 10 x Auger



EUSO: Extreme Universe Space Observatory

An Innovative Space Mission doing astronomy by looking downward from the Space Station at the Earth Atmosphere.

EUSO **is devoted to the exploration from space of the highest energy processes present and accessible in the Universe. They are directly related to the extreme boundaries of the physical world.**

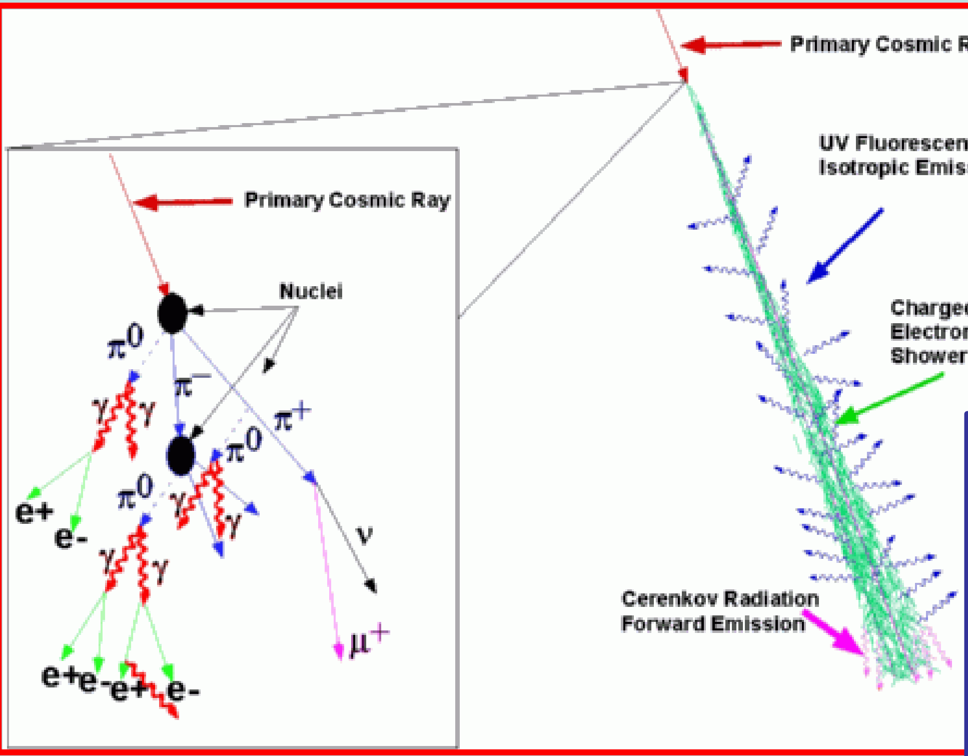
EAS DETECTOR
EUSO APPROACH

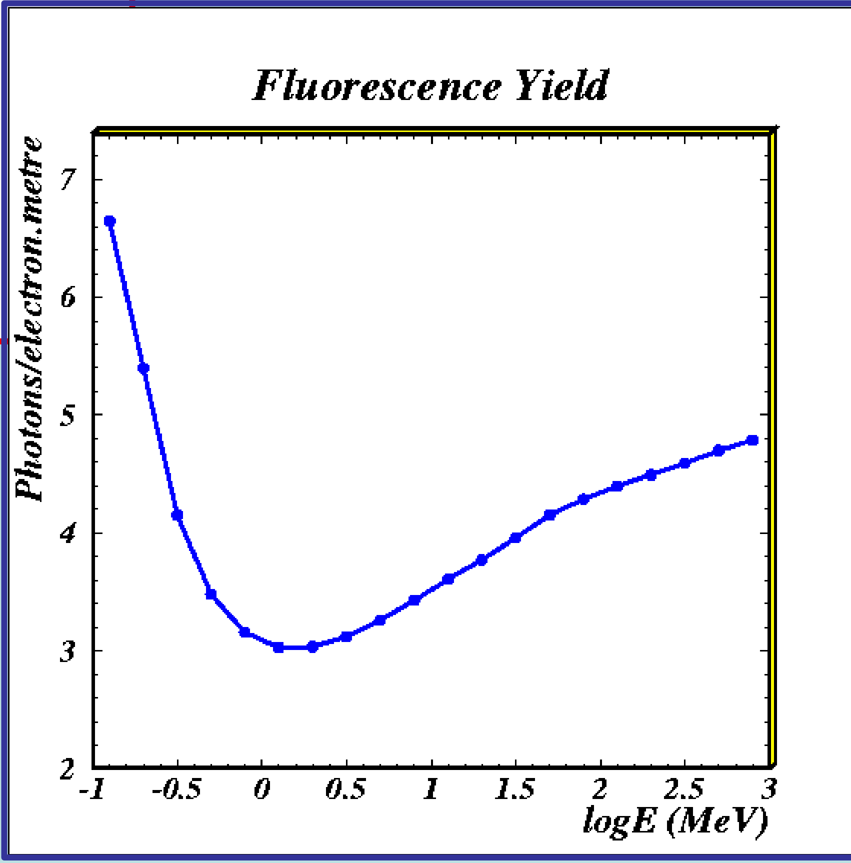
To obtain a statistical significant sample of EECR events at E > 10^{20} eV, with flux value at the level of:

1 particle / year / 100 $\mathbf{km^2}$

or with very low interaction cross section (neutrinos), a giant detector is required.

The earth atmosphere, viewed from space with an acceptance area of the order of **$\mathbf{6 \cdot 10^5\ km^2\ sr}$**, and a target mass of the order of **$\mathbf{2 \cdot 10^{12}}$ tons** constitutes an ideal target to UHE CR and cosmic neutrinos.





Fluorescence is isotropic

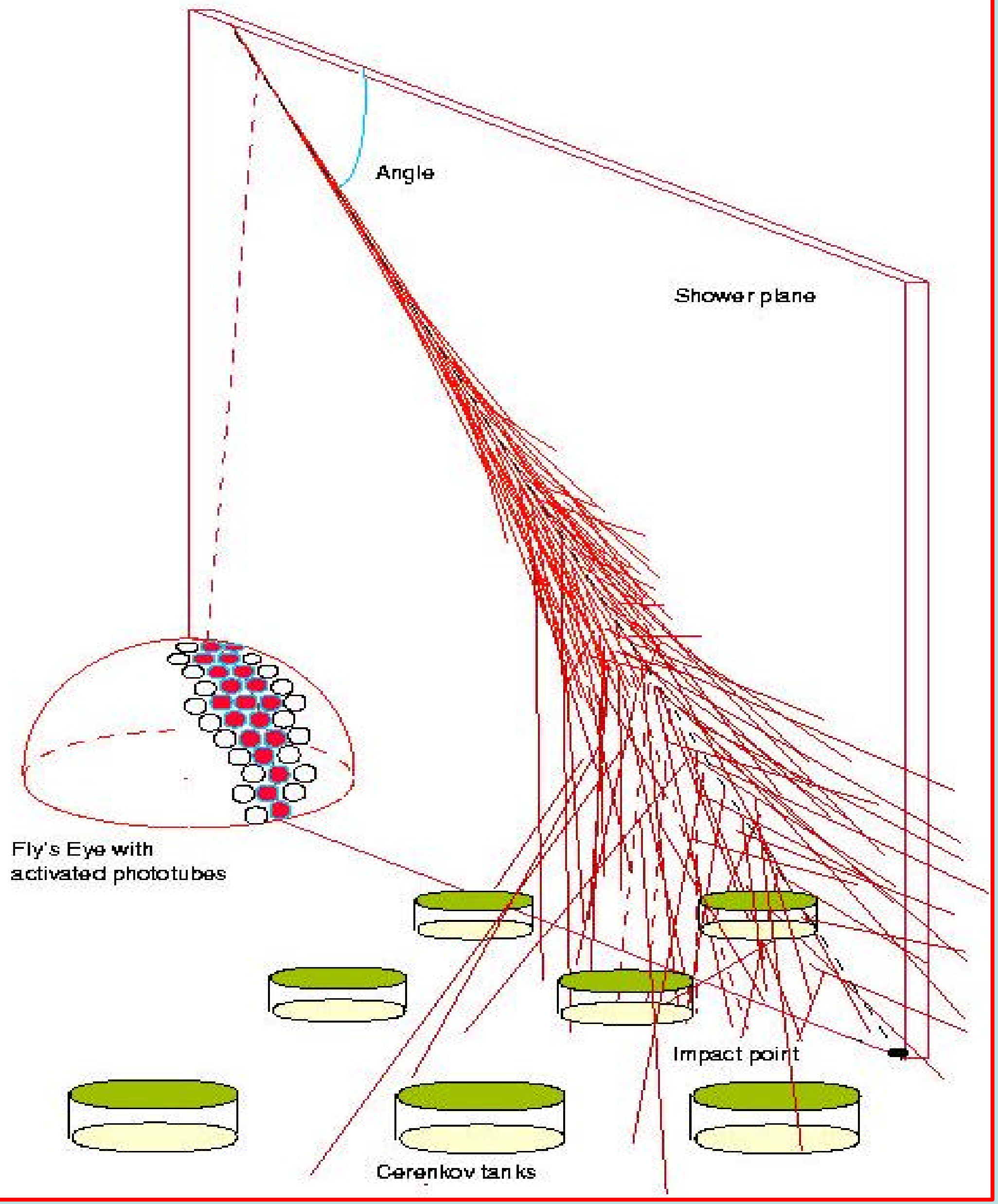
NATURAL DETECTOR:

THE EARTH ATMOSPHERE

- Atmosphere is required for the primary particle to interact and develop **shower** with a production of :
  - Cherenkov light
  - fluorescence light
- Details of the **UV light** production yield details of the primary particle :
  - the amount of UV light produced is proportional to the particle's energy
  - the shape of the shower profile and the atmospheric depth of the shower maximum contain information about particle mass composition

Detection techniques of ground based experiments

Detection method



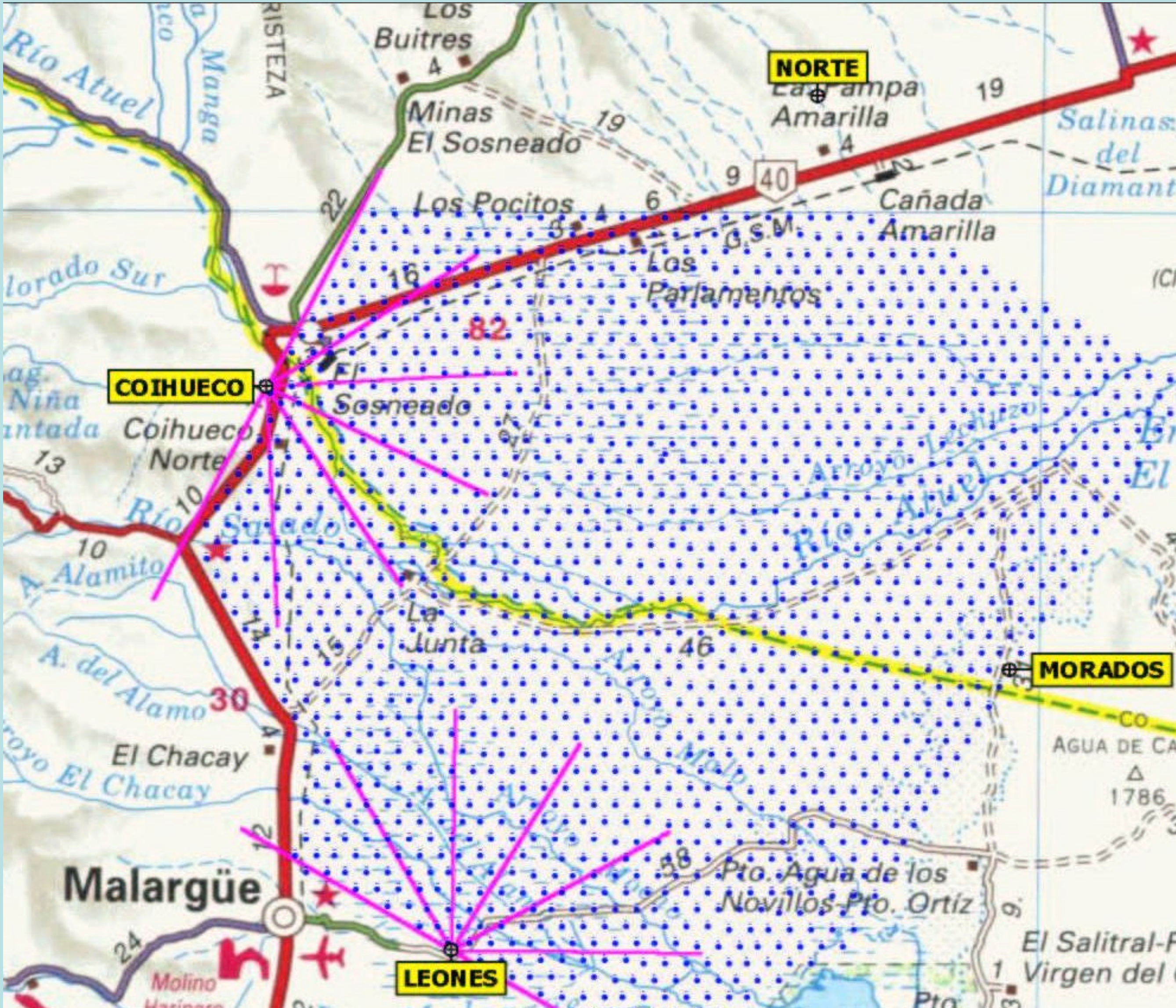
P.Galeotti

The Auger Observatory

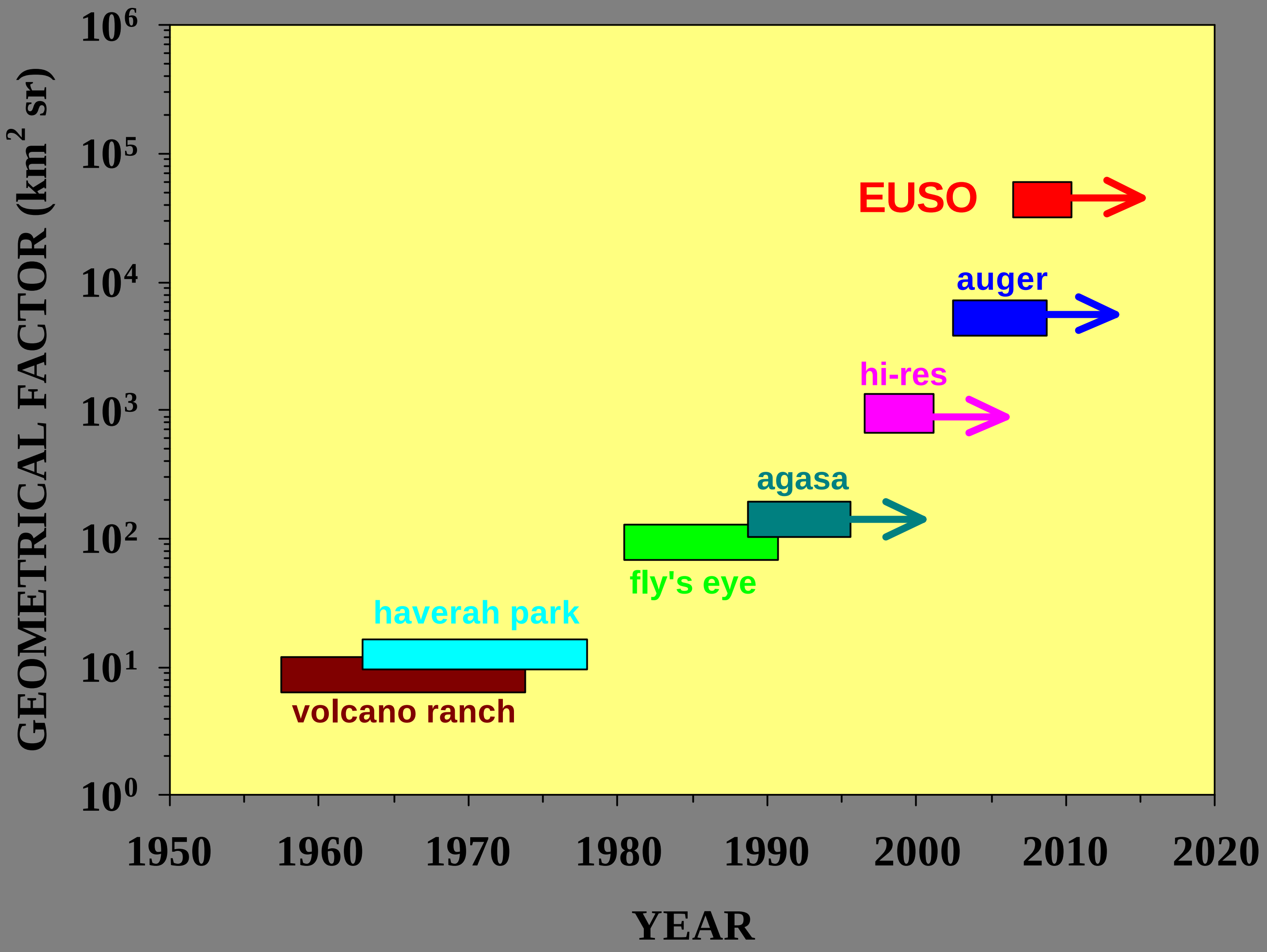
Area ˜ 3000 km^2 Aperture ˜ 7400 km^2 sr

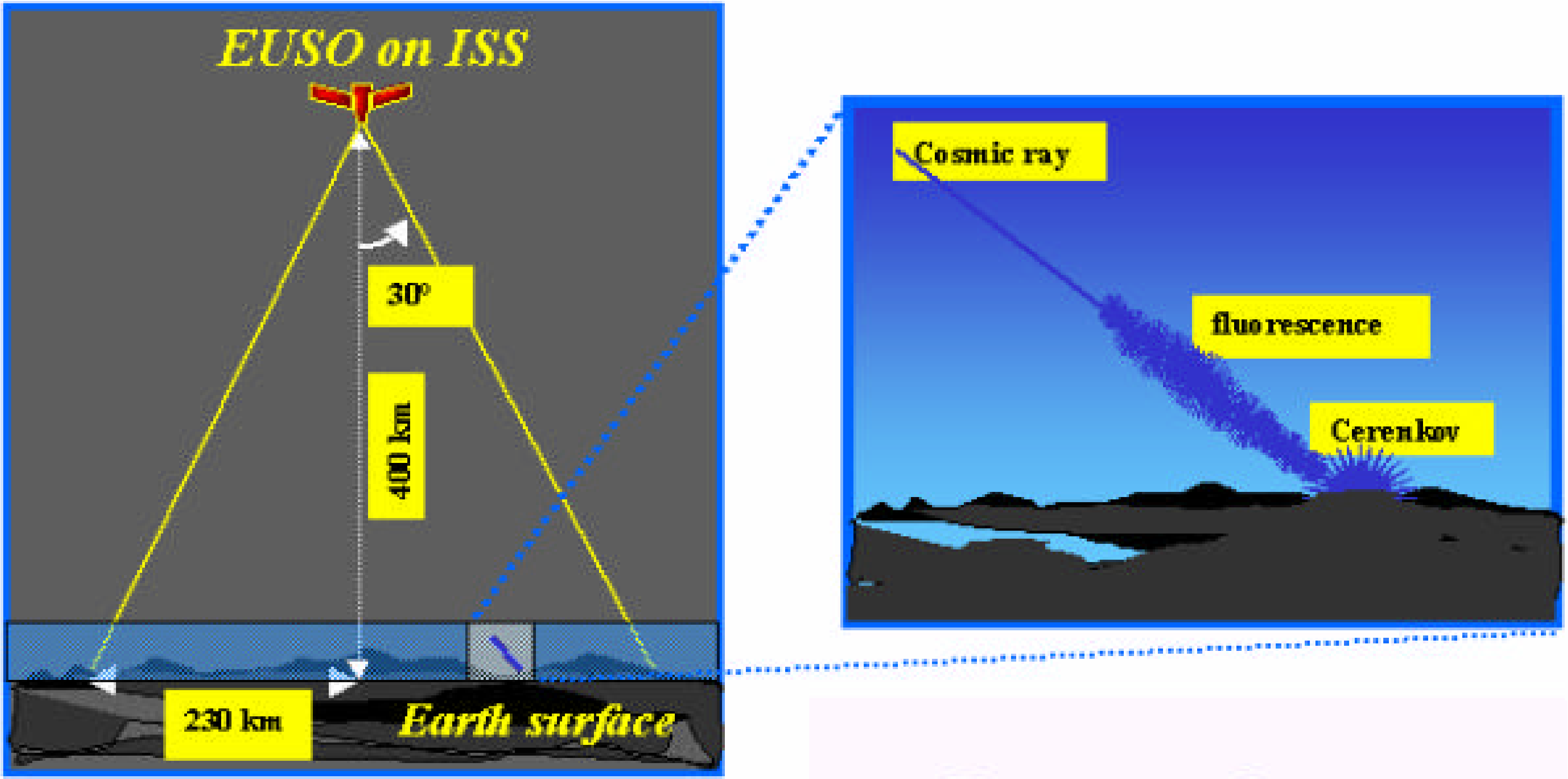
SD Array 1600
Cherenkov tanks
1.5 km spacing

FD 24
luorescence
elescopes
n 4 buildings



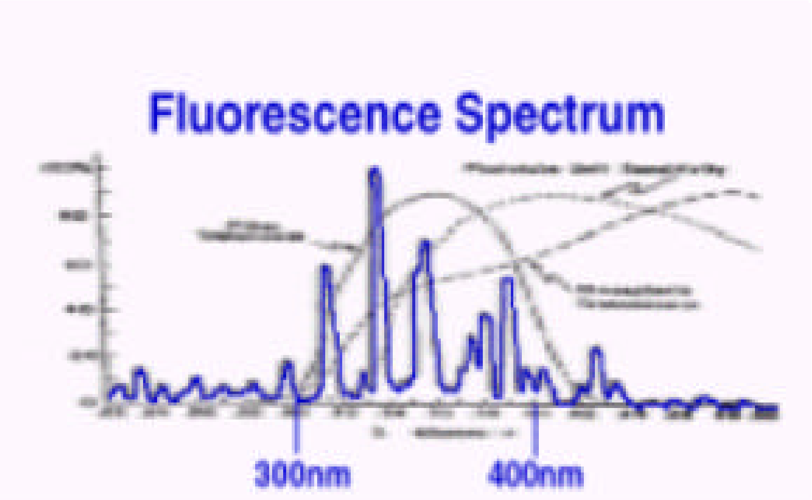
P.Galeotti


GEOMETRICAL FACTOR (km^2 sr)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
EUSO
auger
hi-res
agasa
fly's eye
haverah park
volcano ranch
1950
1960
1970
1980
1990
2000
2010
2020
YEAR



EUSO on ISS

Image and Time Structure

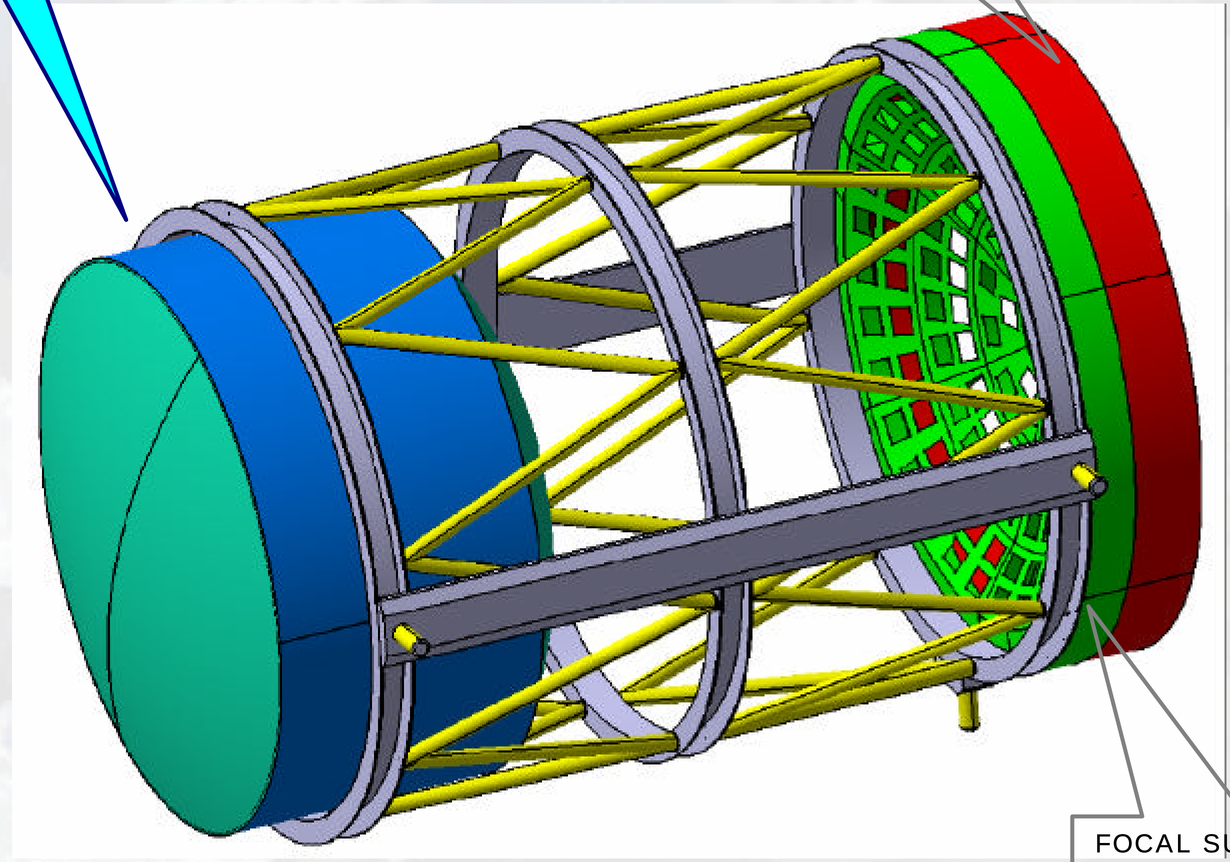


Fluorescence Spectrum

EUSO OBSERVATIONAL OBJECTIVES

- Extension of the measurements of the energy spectrum of UHE CR beyond the GZK limit
- Is there a maximum energy?
- How does the spectrum continues beyond the existing data?
- All sky survey of the arrival direction of UHE CR.
- Observation of a possible flux of UHE Cosmic Neutrinos.
- Systematic sounding of the atmosphere with respect to cloud distribution and UV light absorption and emission characteristics.
- Investigation of atmospheric phenomena such as meteors and electrical discharges.

The instrument

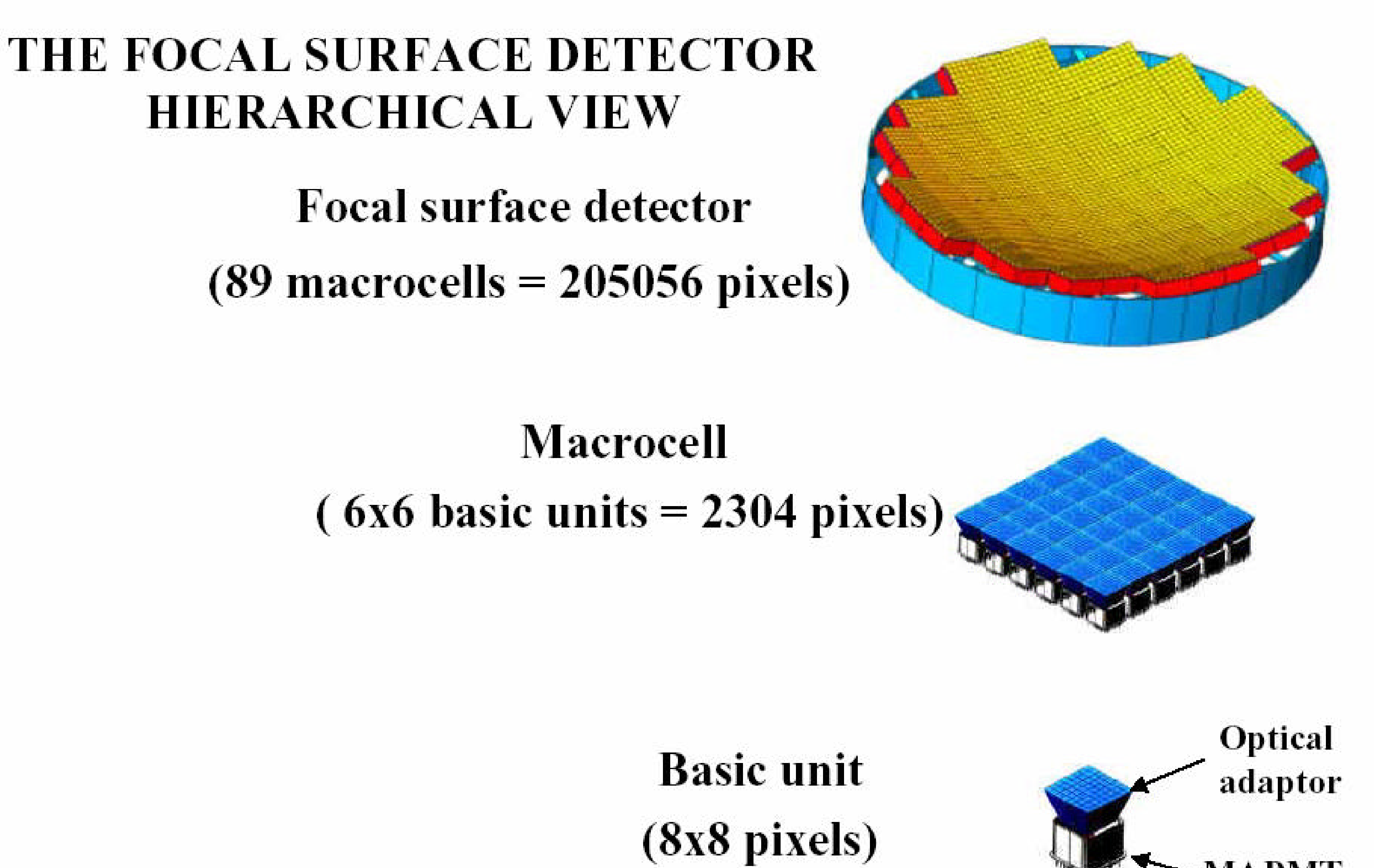


LENSES

ELECTRONICS :
PHOTON COUNTING
TIME INFORMATION

FOCAL SURFACE
LIGHT SENSORS

Focal Surface Detector Baseline design



THE FOCAL SURFACE DETECTOR HIERARCHICAL VIEW

Focal surface detector

(89 macrocells = 205056 pixels)

Macrocell

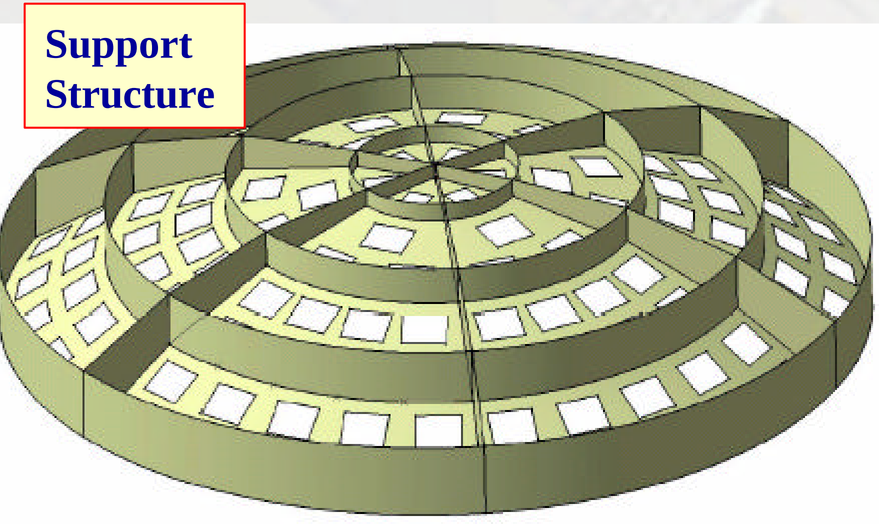
(6x6 basic units = 2304 pixels)

Basic unit

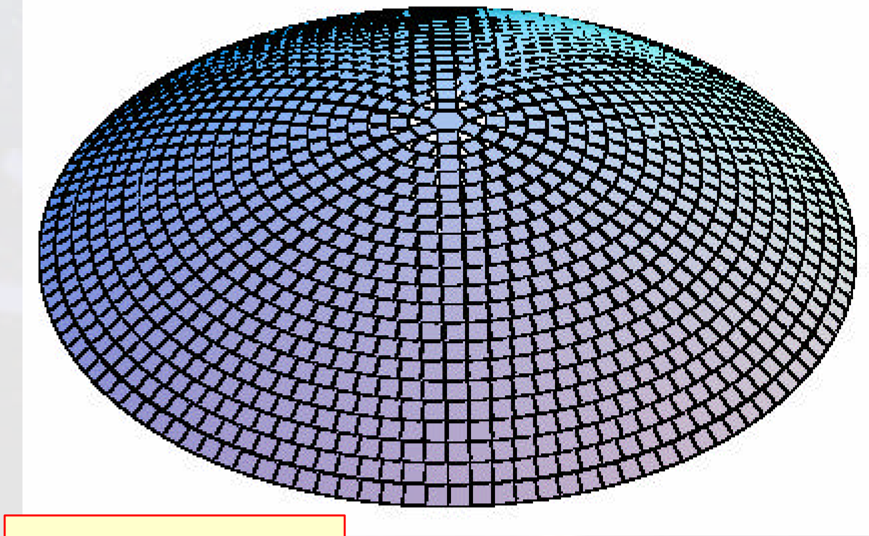
(8x8 pixels)

EUSO – The Focal Surface 200.000 pixels at single PE

Support Structure



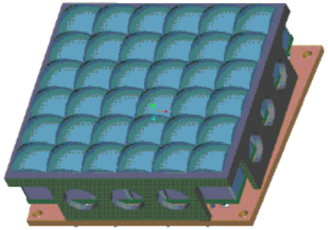

MAPMT R8900 – M36

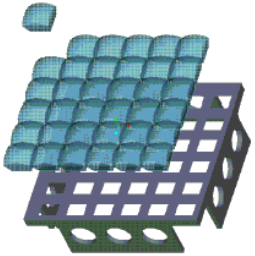


Focal Surface assembly

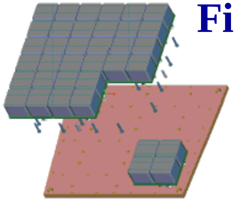
FILLING>0.9

Macrocell



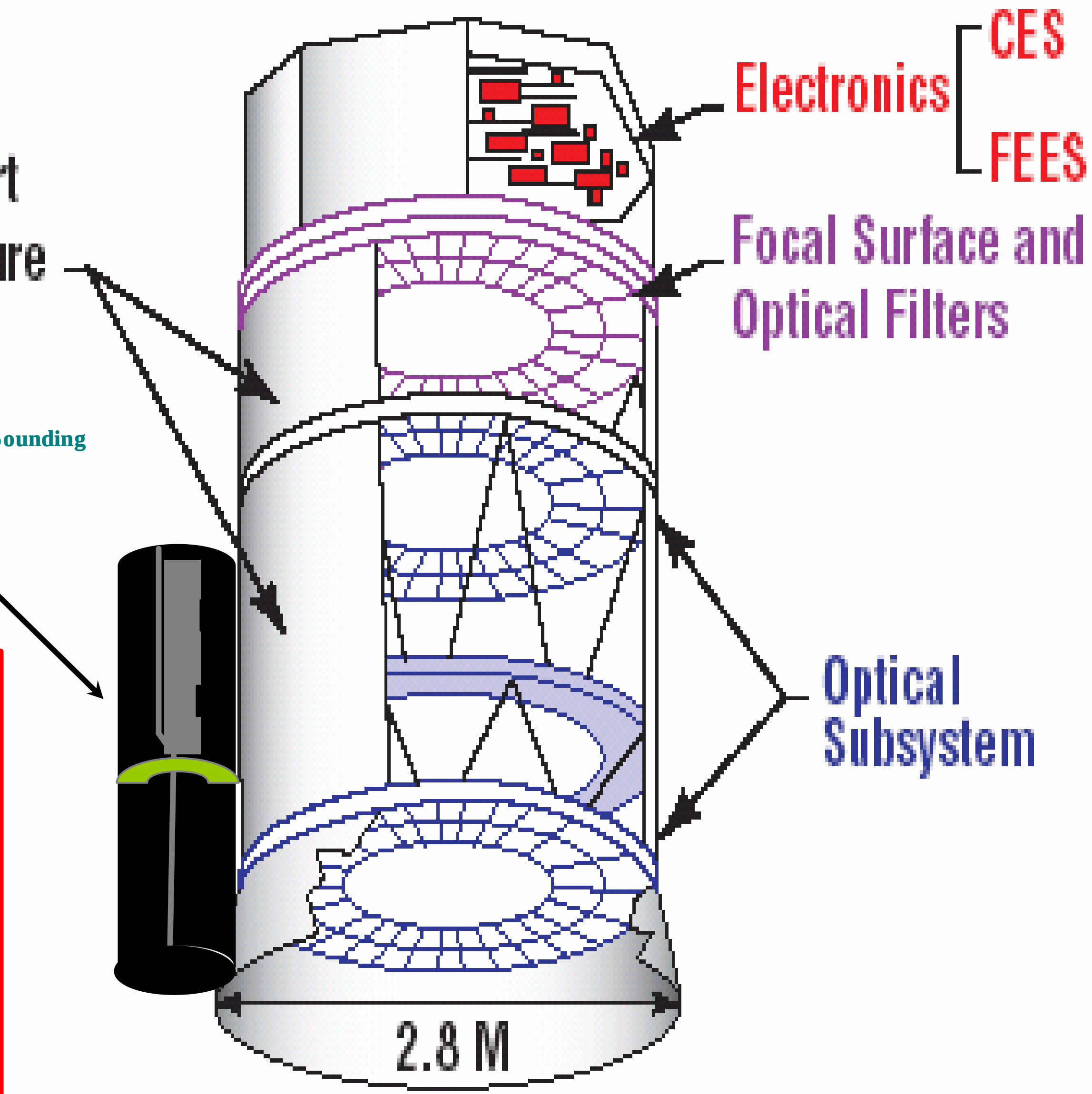


R8900 – M36



Filters

Microcell



Support Structure

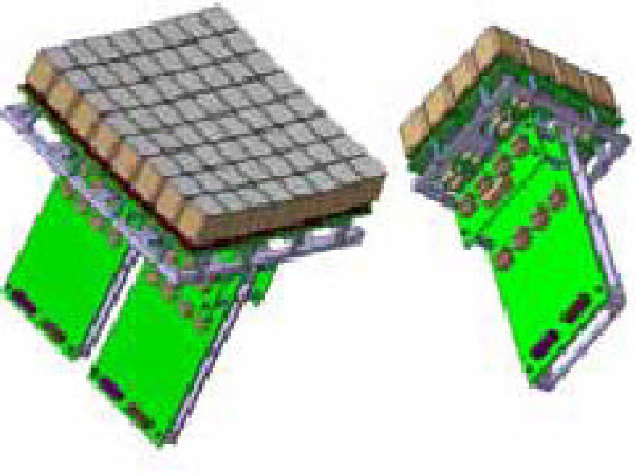
Electronics
CES
FEES

Focal Surface and Optical Filters

Atmospheric Sounding

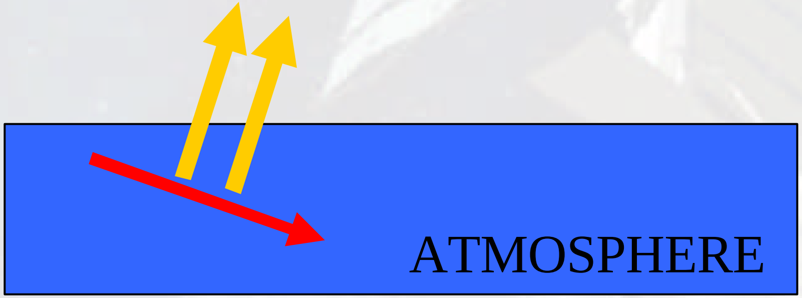
Optical Subsystem

2.8 M



Advantage of a space-based fluorescence detector for EECR

Geometrical Factor (A · W) » 6 · 10^5 km^2 sr (FoV=±30° at ISS mean distance h_{ISS}@430km



rather constant signal attenuation ~0.5

Negligible Proximity Effect

($\Delta D_{ist.}/D_{ist.} < 1\%$)

acceptance not depending on energy)

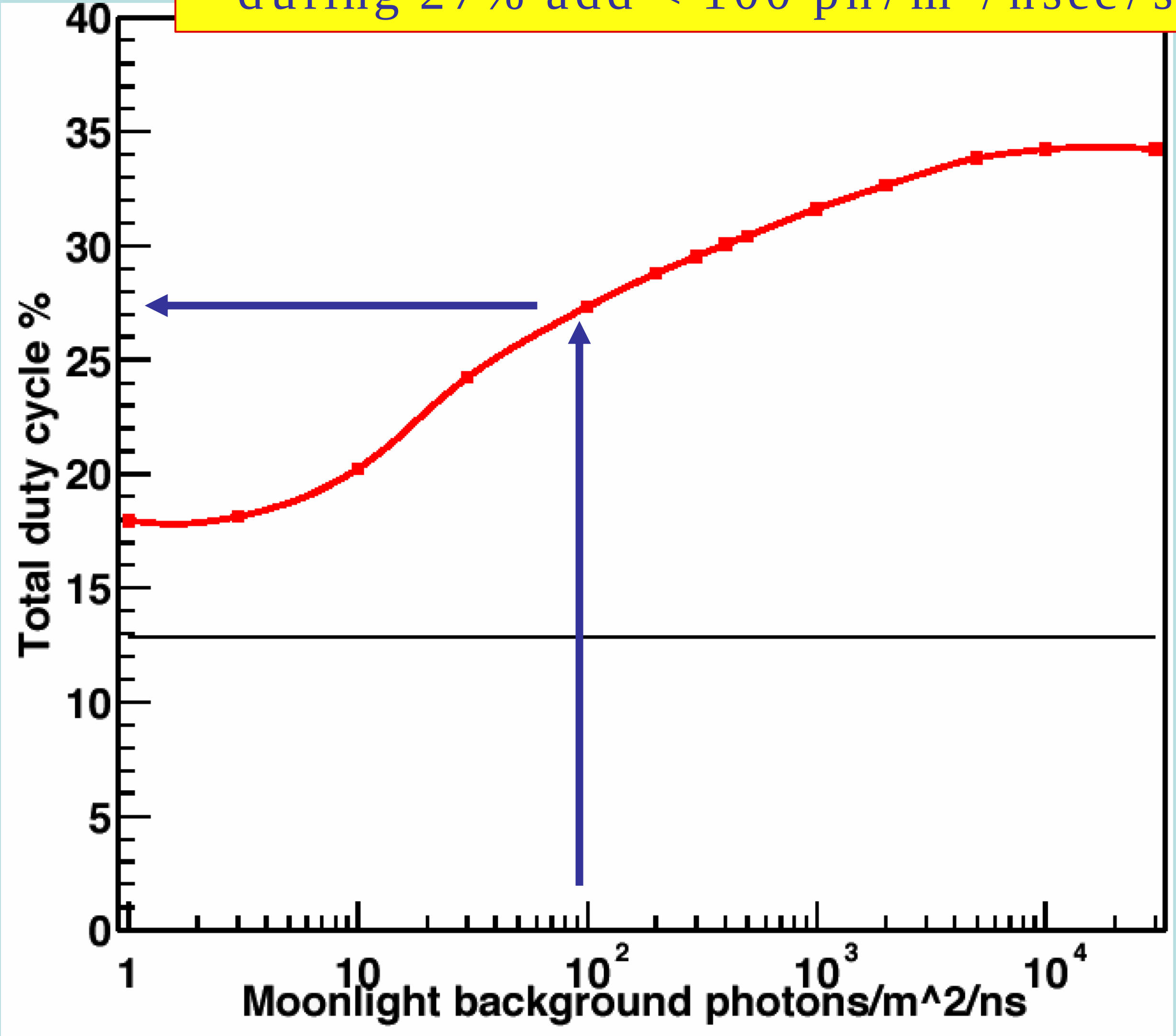
Full Sky Coverage

Cerenkov "footprint" of shower

Comparison of UHECR Experiments.
Large encircled area: EUSO, small encircled area: AUGER. No duty cycle included.
Ratio of effective geometrical factor (EUSO/AUGER):
- including duty cycle (10% for both arrays): ~ 70
- with duty cycle (10%) only for EUSO: ~ 7

In absence of moon, the background is estimated 300 ph/m²/nsec/sr mainly due to starlight and "l'Airglow"

- during 12.8% moon is below the horizon,
- during 18% (new moon) less than +1,
- during 27% add < 100 ph/m²/nsec/sr.



DETECTION TECHNIQUE

Euso will observe the **fluorescence signal** looking to Nadir at the dark Earth atmosphere from its location on the CEPF under a 60° full field of view. Fluorescence light will be imaged by a large Fresnel lens onto a **finely segmented focal surface**. A Cerenkov signal will be detected in a delayed coincidence with the fluorescence signal.

The segmentation and the time resolution adopted will enable the reconstruction of the EAS energy with an accuracy of order D**E/E ~ 30%**, and of the arrival direction **from a fraction of a degree to a few degrees** depending on energy and zenith angle of the primary particle.

Main characteristics of EUSO, a collaborative effort of research groups from Europe, USA and Japan

Field of view	+ 30 around nadir
Lens diameter	$\geq$ 2.5 m
Entrance pupil diameter	$\geq$ 2.0 m
F/#	$\leq$ 1.25
Operating wavelengths	330 – 400 nm
Angular resolution	~ 1^{O}
Pixel diameter	~ 5 mm
Pixel size on ground	~ 0.8 x 0.8 km^2
Number of pixels	~ 2.5 10^5
Operational lifetime	3 years

Baseline configuration of the EUSO instrument to be located on the CEPF of the ISS.

Item Description	Characteristic Value
EECR - Telescope	
Mass	1200 kg
Power	750 Watt
External Geometry	Cylindrical (pointing to Nadir)
Dimension	∅ 2.8 m ´ 4.2 m
Telemetry	2 kbit/s continuous
LIDAR for Atmosphere characterization	
Mass	200 kg
Power	300 Watt
External Geometry	Cylindrical (co-axial to Main Telescope)
Dimension	∅ 1 m ´ 3 m
Telemetry	25 kbit/s (per event)

SYSTEM ELECTRONICS

Multi-level trigger implementation

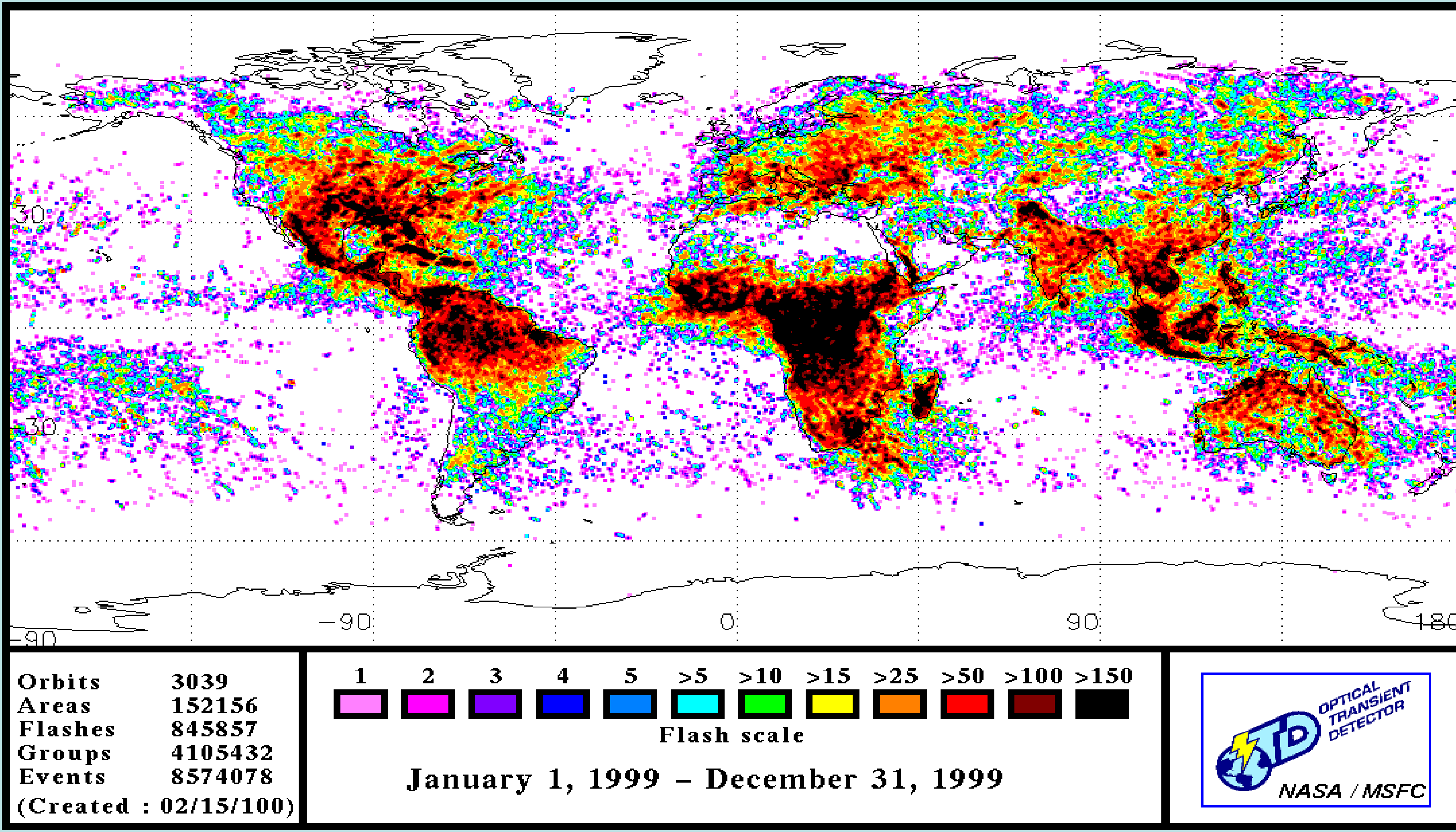
- **Trigger Mode 1 or *normal mode***

  (EECRs up to 300μs, GTU=833ns)
- **Trigger Mode 2 or *slow mode***

  (ex. Meteors up to 2 sec, GTU = 833ns ? 1ms)
- **Trigger Mode 3 or *fast mode***

  (ex. Calibration, GTU=200ns)
- …

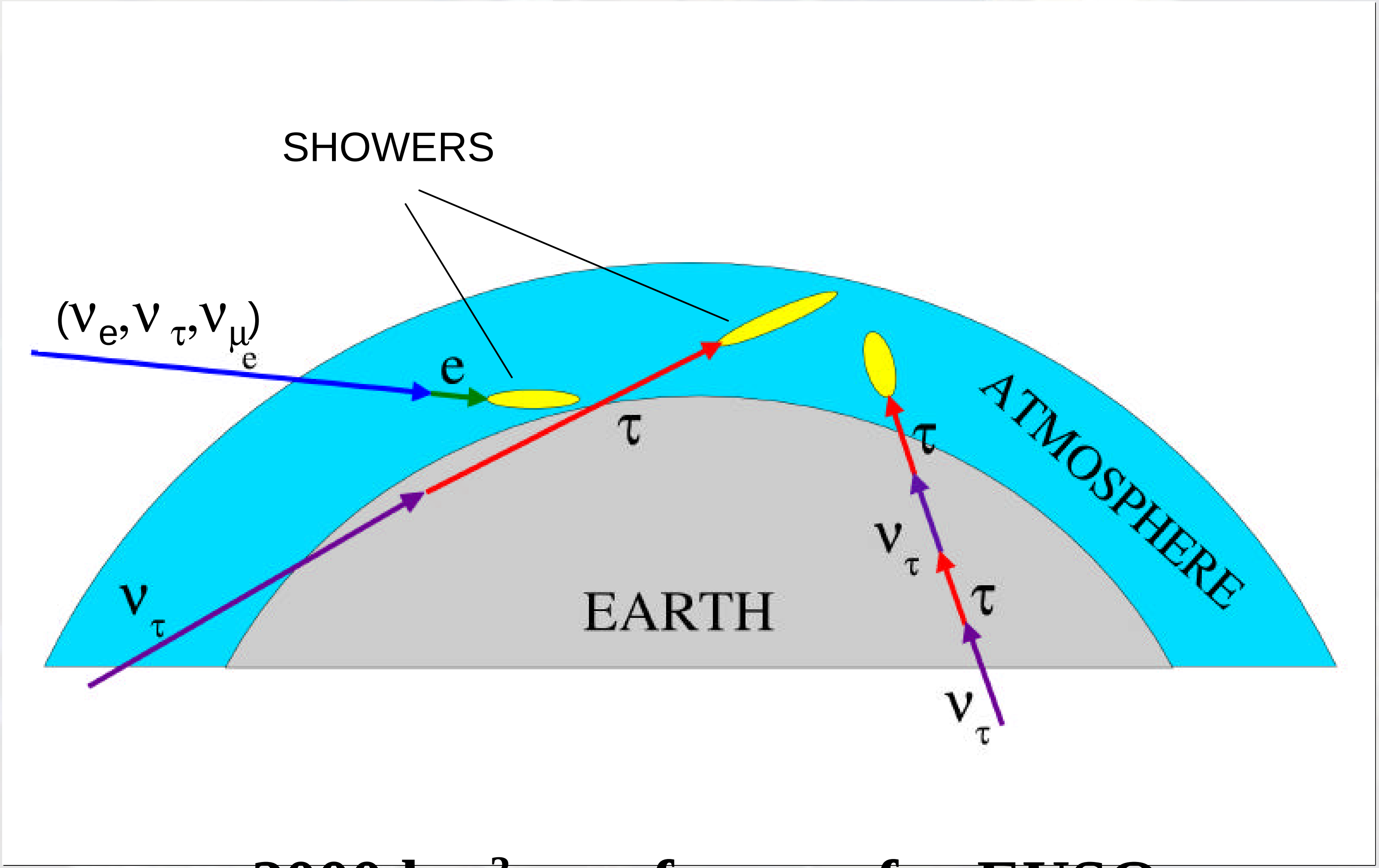
Lightnings



Orbits	3039
Areas	152156
Flashes	845857
Groups	4105432
Events	8574078

(Created : 02/15/100)

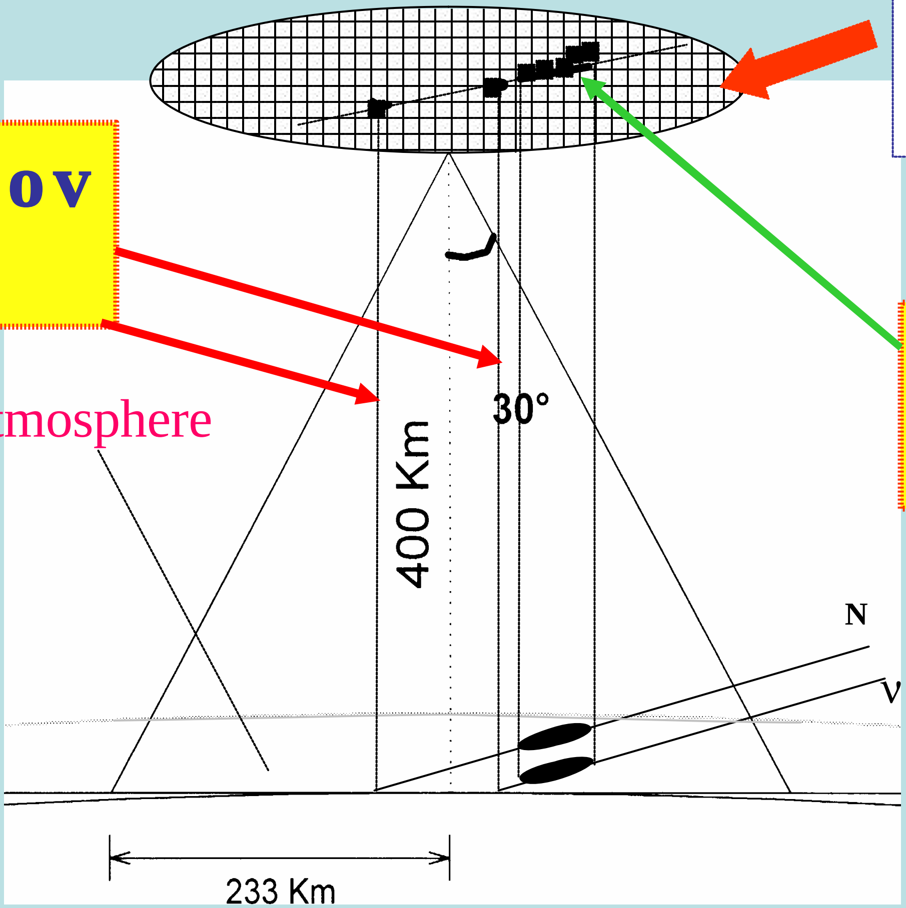
NEUTRINO EVENTS IN ATMOSPHERE



2000 km^3 we of target for EUSO

But : duty cycle, efficiency, very high energy threshold

The Cerenkov signal gives a unique signature to discriminate between high penetrating neutrinos and quick interacting hadrons

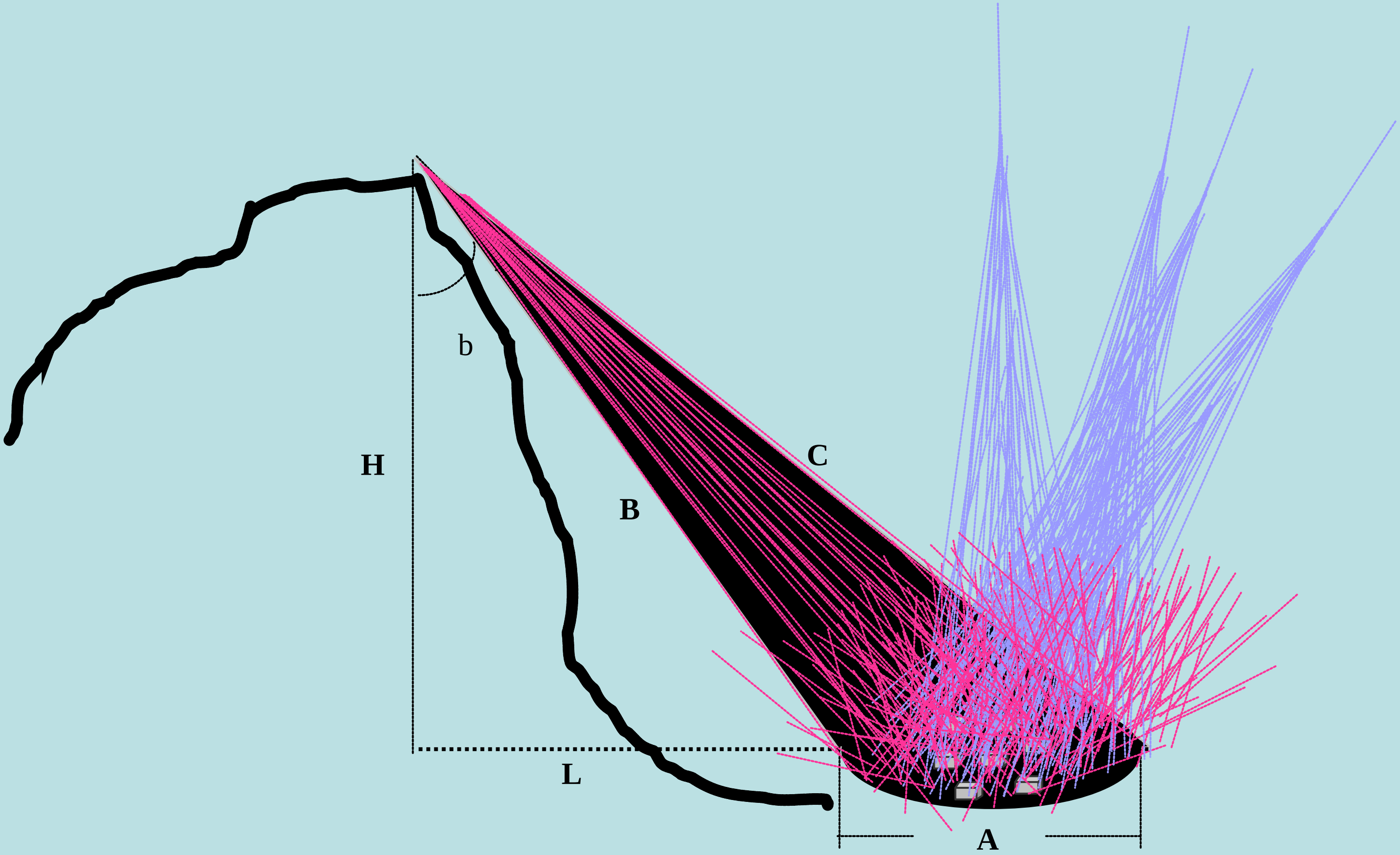


EUSO Focal Surface

Cerenkov signal

Fluorescence signal

ULTRA measurements



This kind of measurements are also very interesting by themselves since very few experimental data are available

Plateau Rosa (Italy) *Nuovo Cimento 6C, 2(1983) 202*
SPHERA (Kazakhstan) *Nuclear Physics , 52B (1997) 182*
Lake-p. Mussala (Bulgaria) *Proc. ICRC 2001, 900*

All these experiments have measured the Cerenkov light reflected by snow with no information about the associated EAS.

Other goals of the ULTRA experiment are:

- Study of the atmospheric radiative transfer (LIDAR)
- Measure the UV background at different Moon phases
- Meteor observations

What do we measure with ULTRA?

Cerenkov light diffused by:

-Desert land

-Grass-covered land

-Ocean (water) Surface

-Trees-covered land

-Iced (snow) Land

as a function of the shower size and axis inclination.

⟺ ***UV scope***

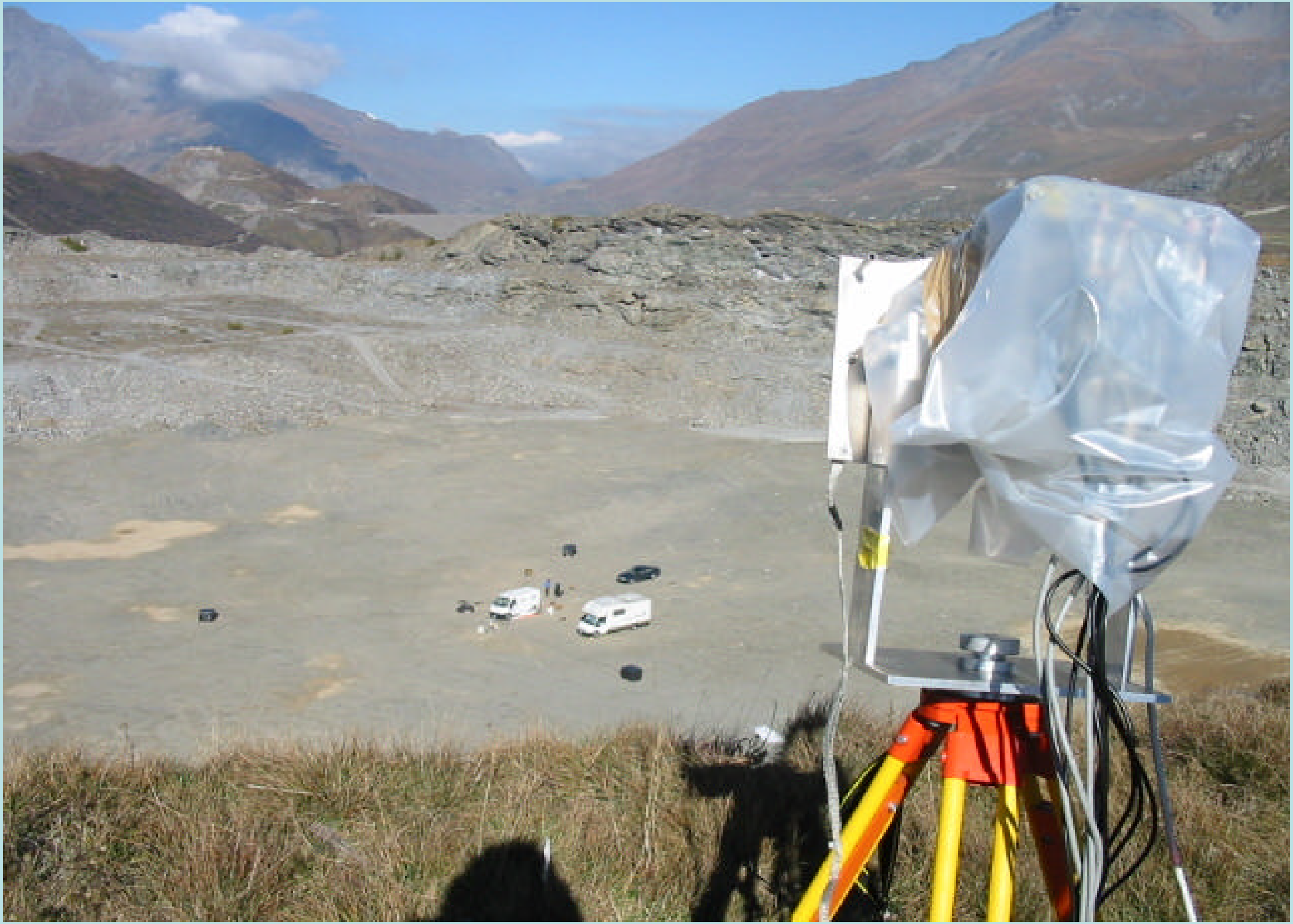
ET scope ⟺

Associated EAS parameters for each event:

- e.m. Size N_e

-Arrival Direction (q, f)

Experimental setup



RESULTS

Mont-Cénis:

2401 events in 17848 s, with a frequency of 0.1345 Hz,

2382 events with arrival direction reconstructed,

$Q < 10°$ → **261 events, with a frequency 0.0147 Hz**

$10° < q < 30°$ → **1333 events, with a frequency 0.0753 Hz**

From simulation

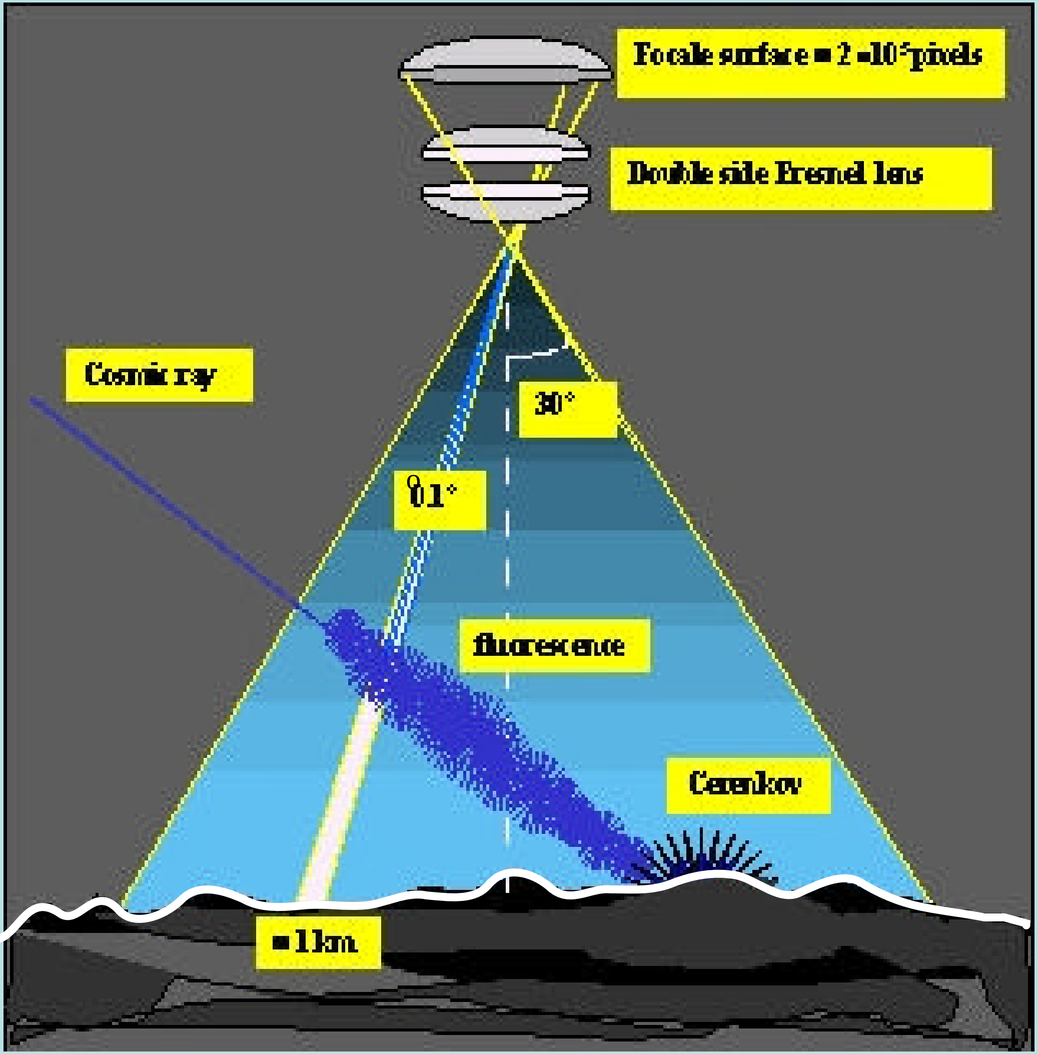
$Q < 10°$

$$\frac{n_{ev}}{\Delta T} = (0.011 \pm 0.003)s^{-1}$$

$10° < q < 30°$

$$\frac{n_{ev}}{\Delta T} = (0.058 \pm 0.005)s^{-1}$$

EUSO basic concepts and parameters



Target mass:

$2 \cdot 10^{12}$ tons

(2000 km^3 we)

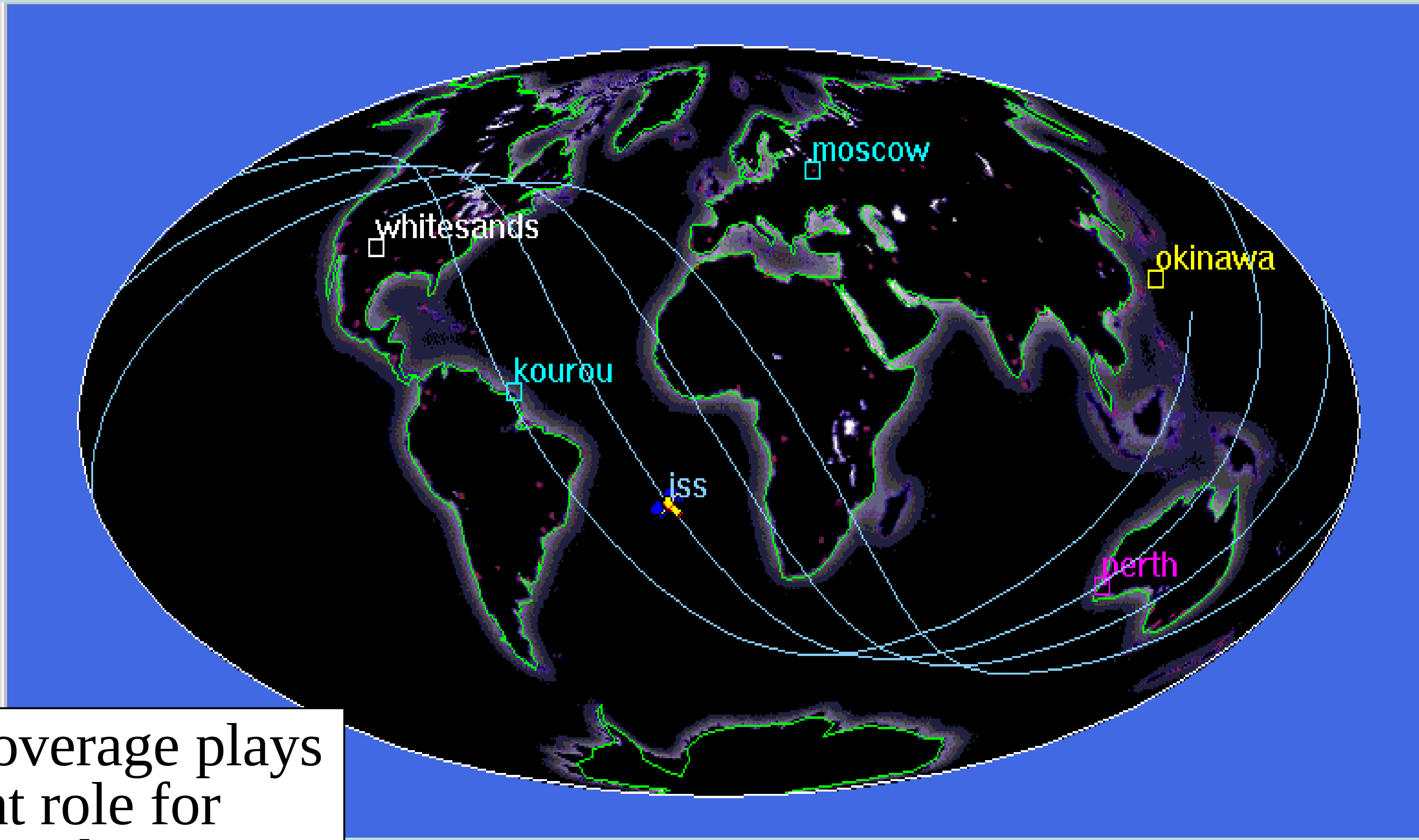
Aperture:

$6x10^5$ km^2sr

Threshold:

$E > 3 \cdot 10^{19} eV$

EUSO PERFORMANCE

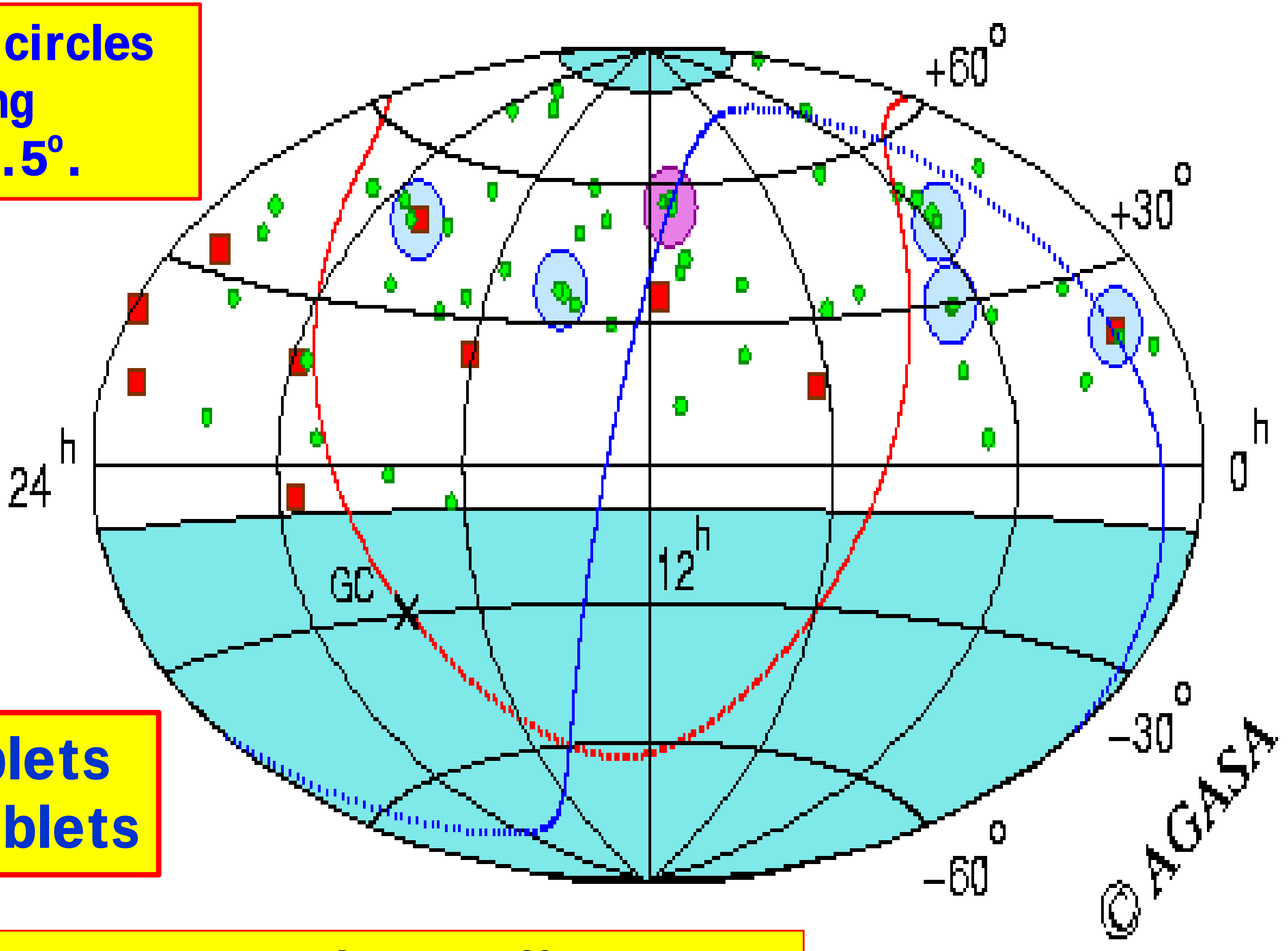


Total sky coverage plays an important role for anisotropy study

EUSO in a year operation will cover all sky directions

Arrival direction of 59 events (E > 4 10^{19} eV)

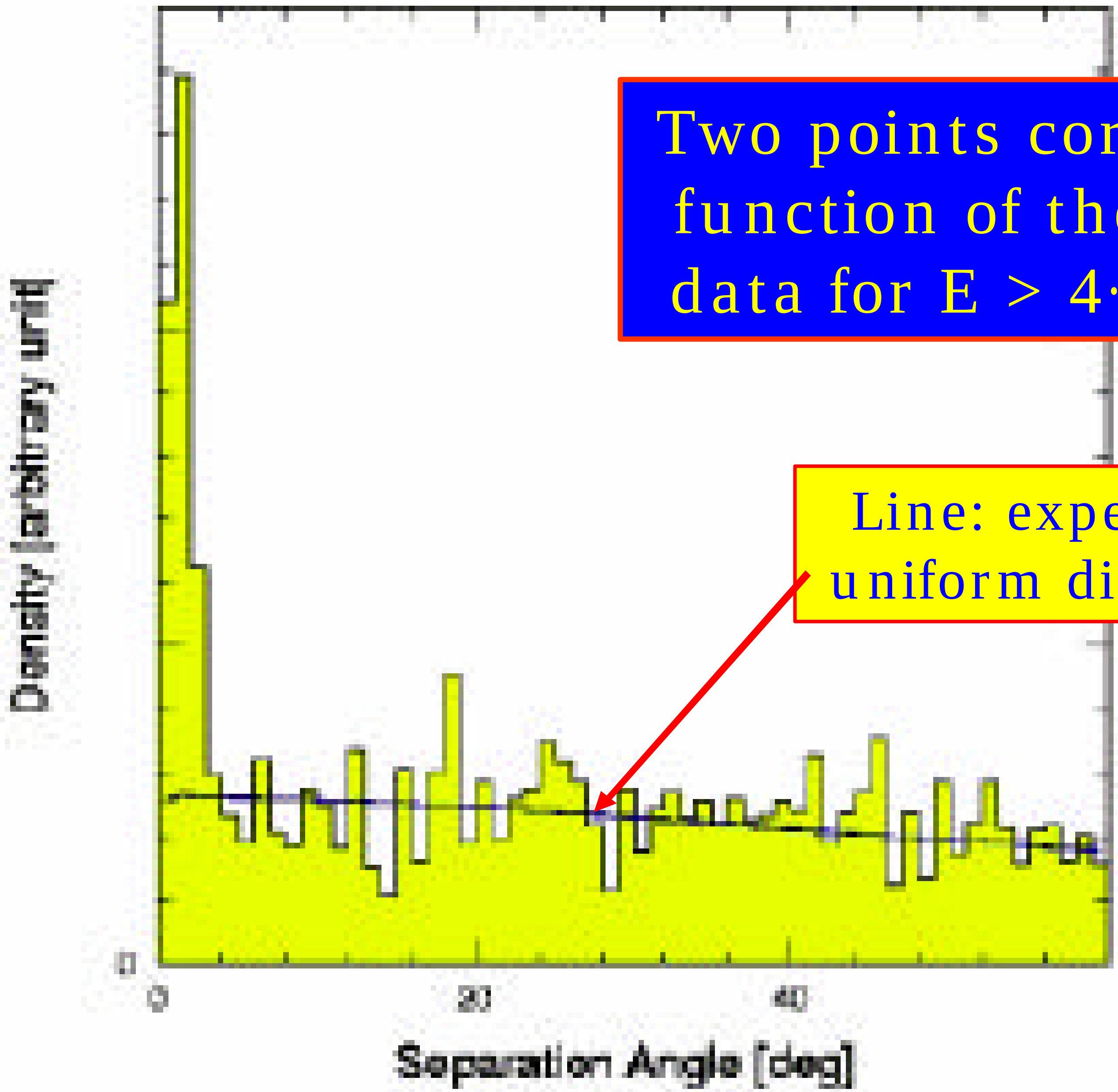
Shaded circles clustering within 2.5°.



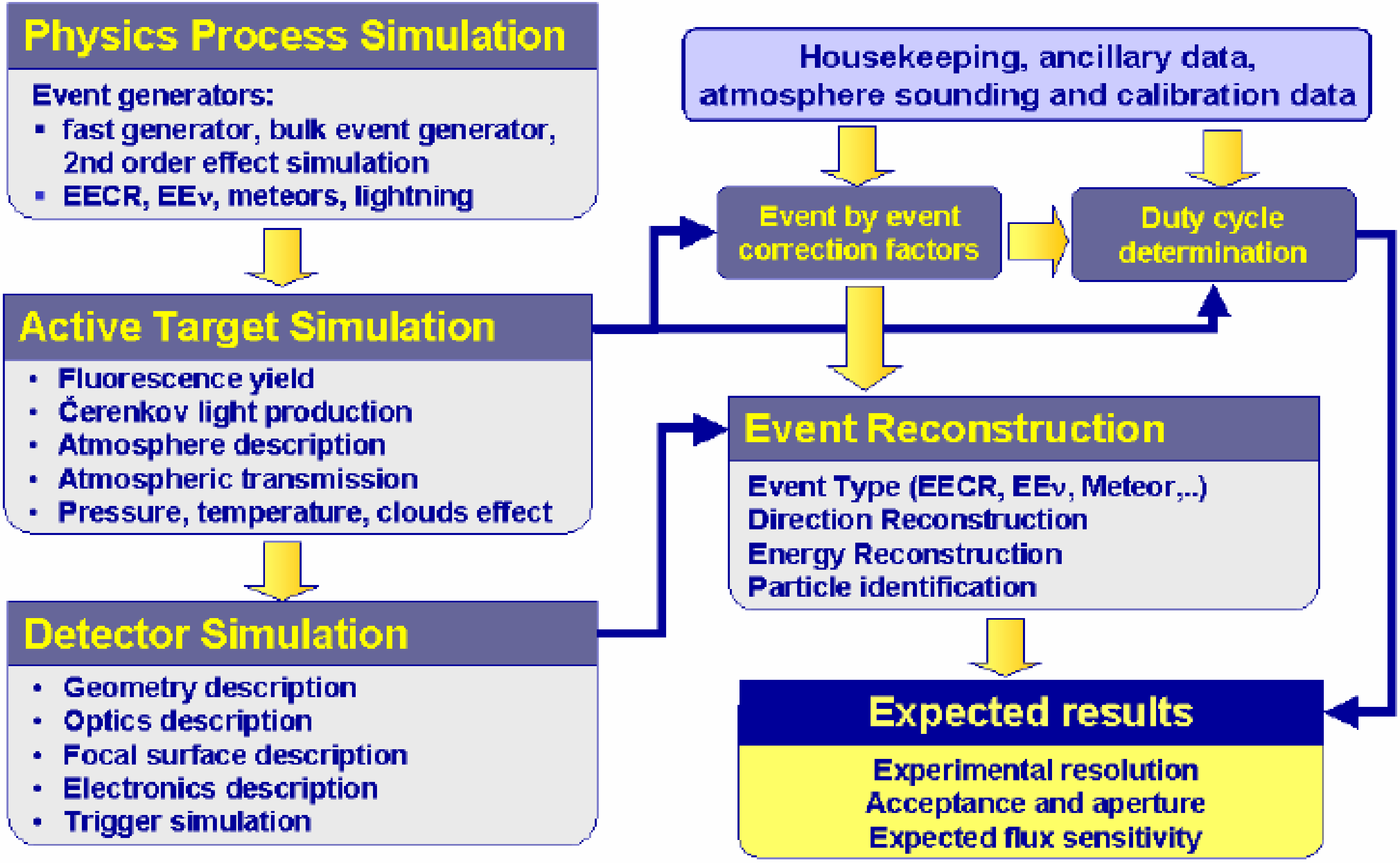
2 triplets
13 doublets

Red squares : events above 10^{20} eV
green circles : events of (4 – 10)x10^{19} eV

Two points correlation function of the Agasa data for $E > 4 \cdot 10^{19}$ eV



Line: expected from uniform distribution



Physics Process Simulation

Event generators:
- fast generator, bulk event generator, 2nd order effect simulation
- EECR, EEν, meteors, lightning

Active Target Simulation
- Fluorescence yield
- Čerenkov light production
- Atmosphere description
- Atmospheric transmission
- Pressure, temperature, clouds effect

Detector Simulation
- Geometry description
- Optics description
- Focal surface description
- Electronics description
- Trigger simulation

Housekeeping, ancillary data, atmosphere sounding and calibration data

Event by event correction factors

Duty cycle determination

Event Reconstruction

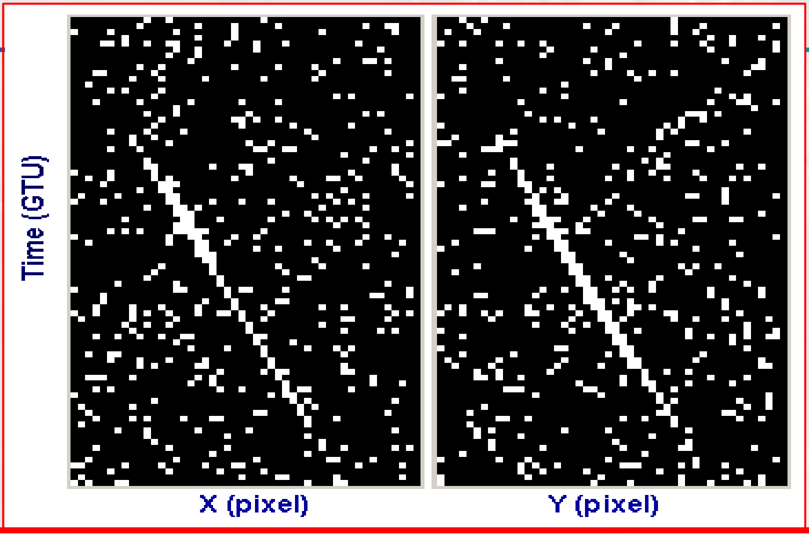
Event Type (EECR, EEν, Meteor,..)
Direction Reconstruction
Energy Reconstruction
Particle identification

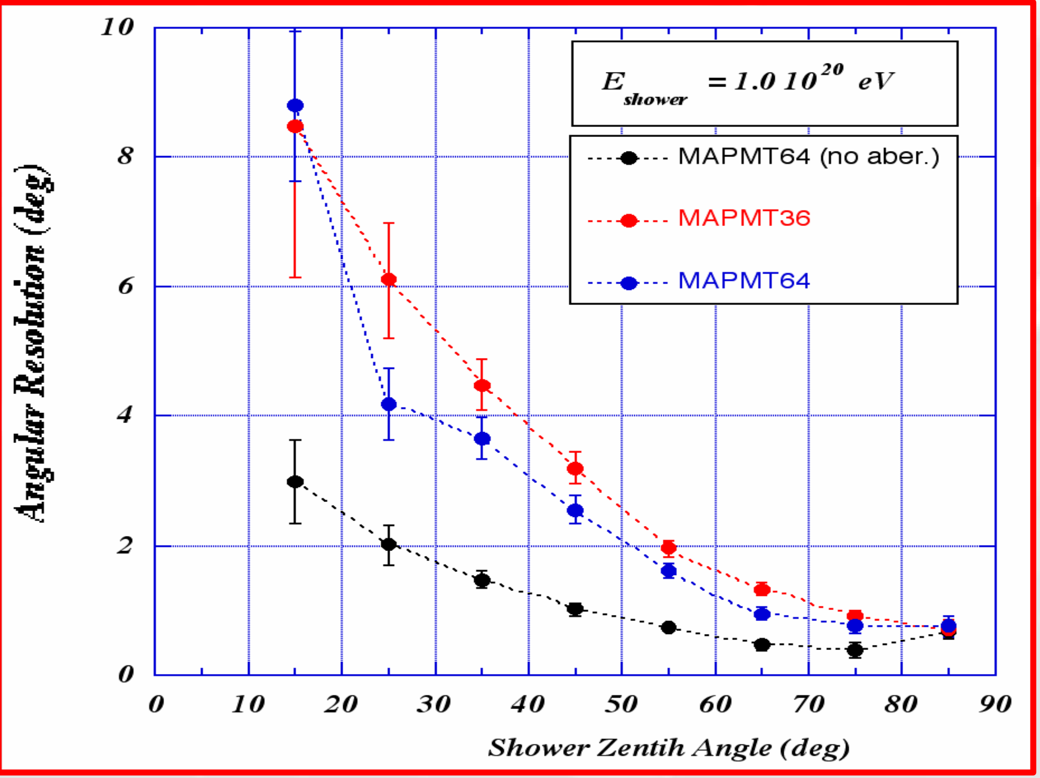
Expected results

Experimental resolution
Acceptance and aperture
Expected flux sensitivity

Figure 4.1-1 *The EUSO End-to-End simulation and event reconstruction flow-chart.*

EUSO resolution



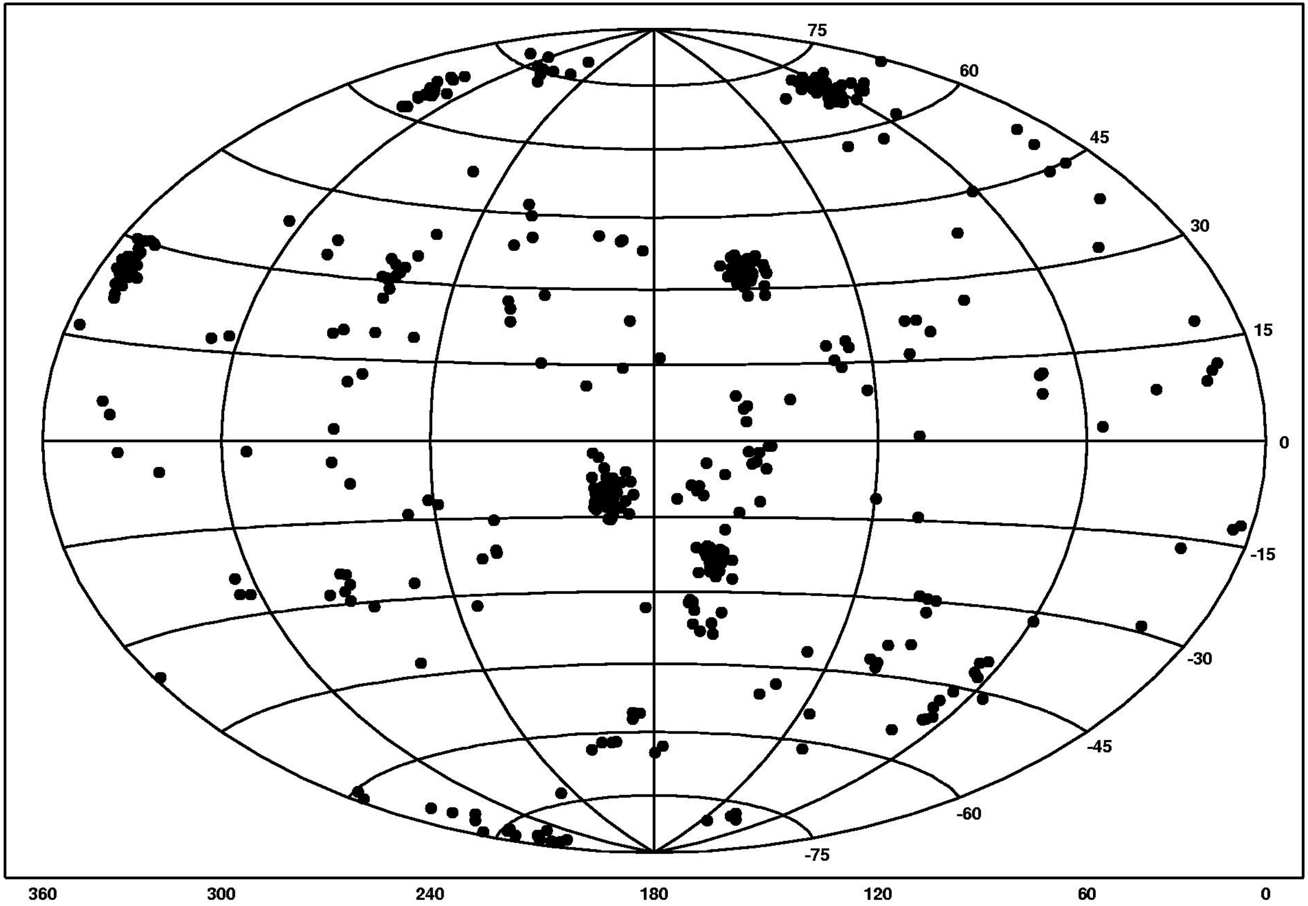


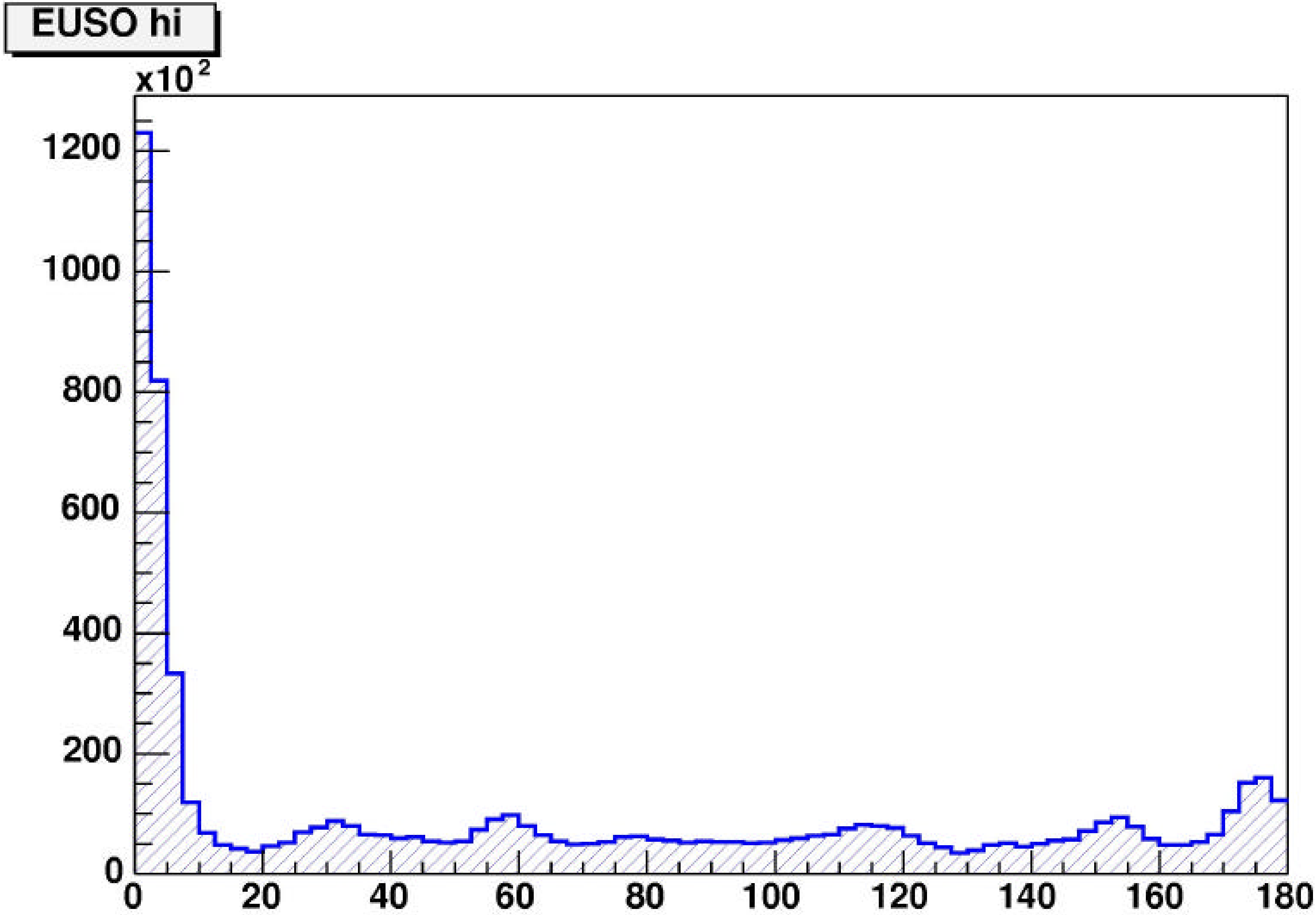
Angular res = 1^{o} – 4^{o}

Energy res = 20% (RMS)+..
(with Lidar info)

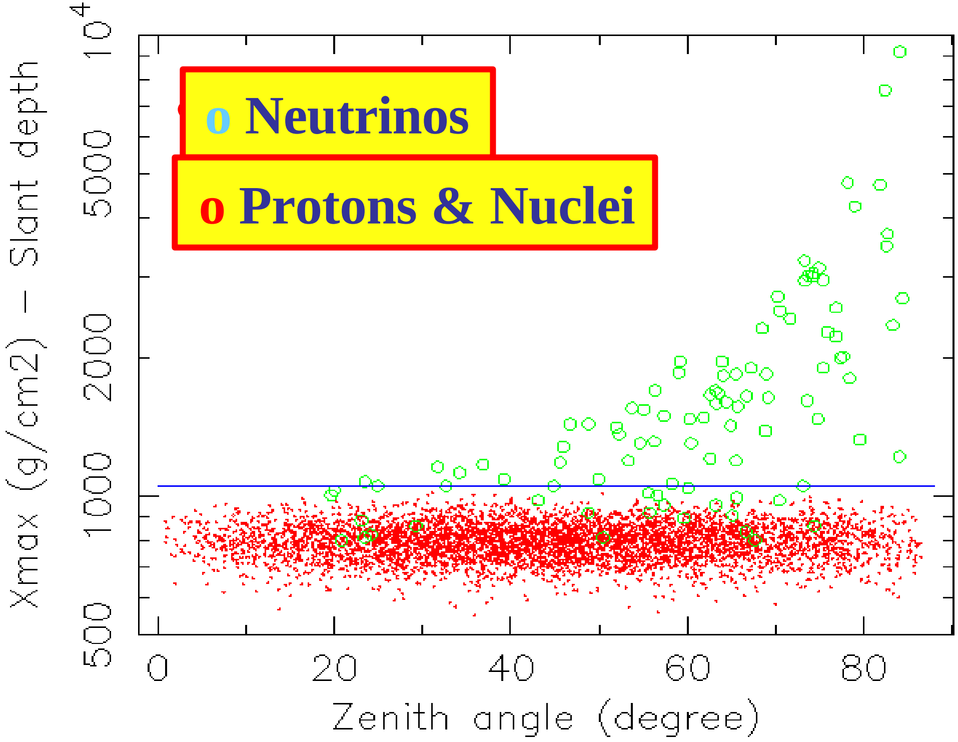
Xmax res = 50 g/cm^2
(with Lidar info)

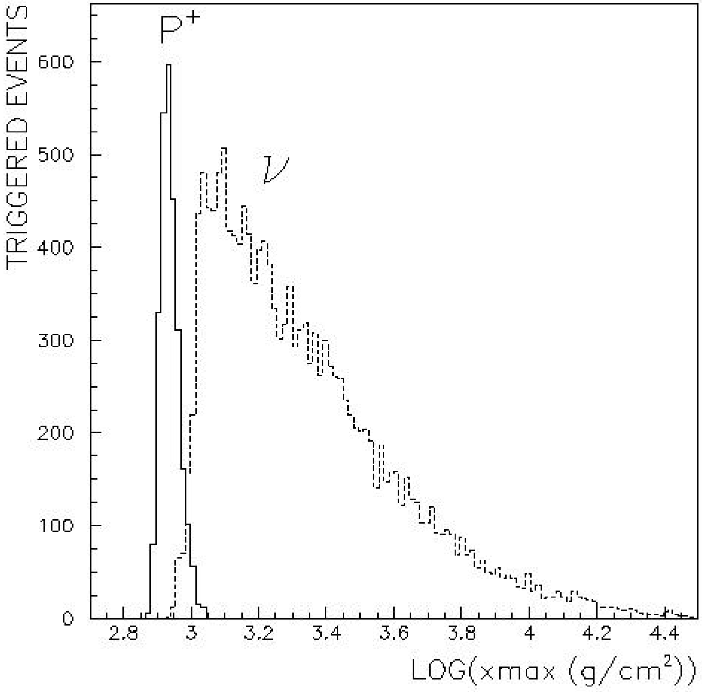
EUSO skymap > 10^{20}eV
maximum cluster 60~70




EUSO hi
x10²
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180

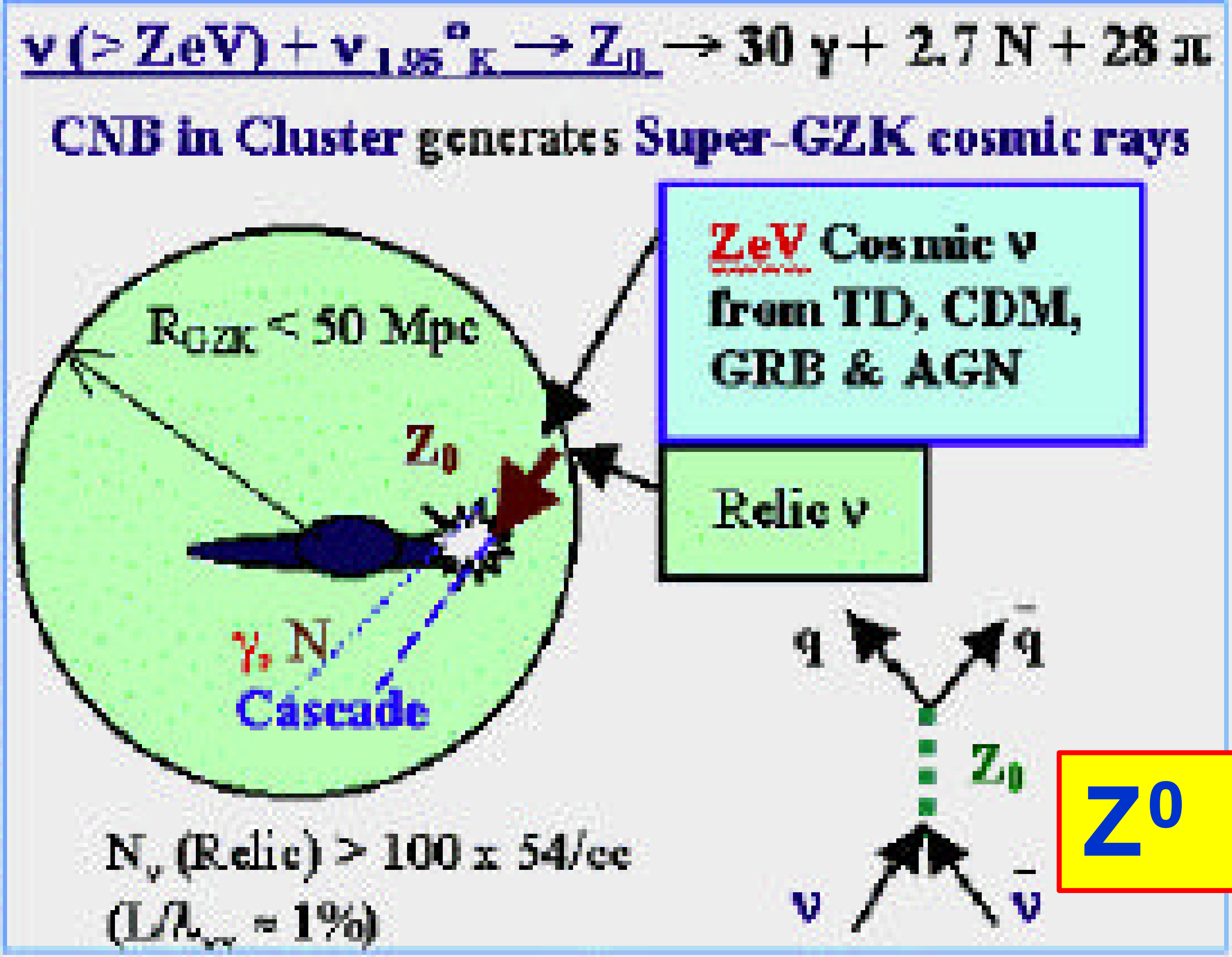
Shower X_{max} distribution from Monte Carlo simulations: neutrino events can be distinguished from proton and nuclei.





Ultrahigh-energy neutrinos arise from

- Decay of cosmic string or superheavy relic particles
- Decays of pions in the GZK process
- Z_0-burst mechanism

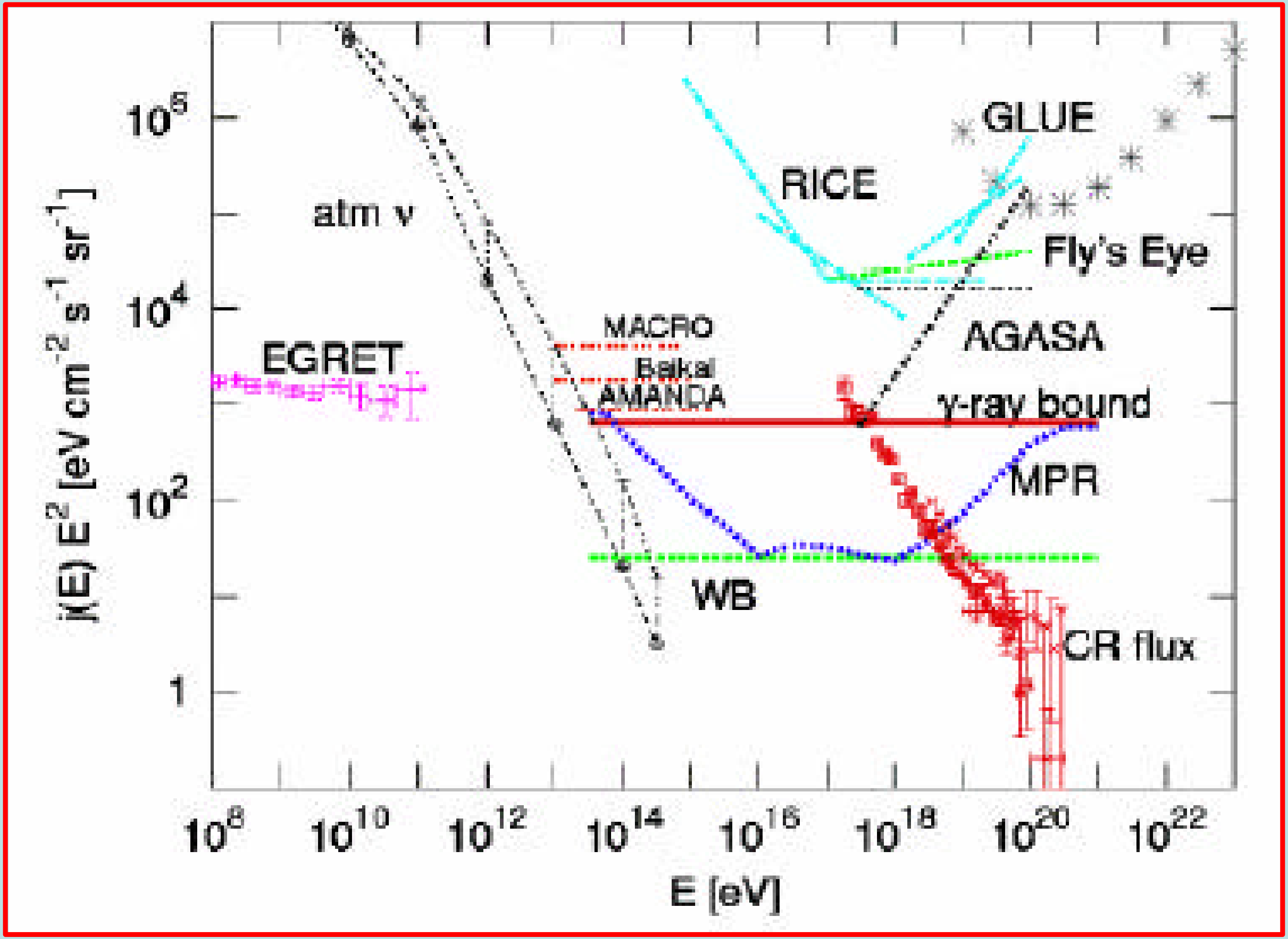


$\nu(> \mathrm{ZeV}) + \nu_{1.95\,{}^{\circ}\mathrm{K}} \to Z_0 \to 30\,\gamma + 2.7\,N + 28\,\pi$

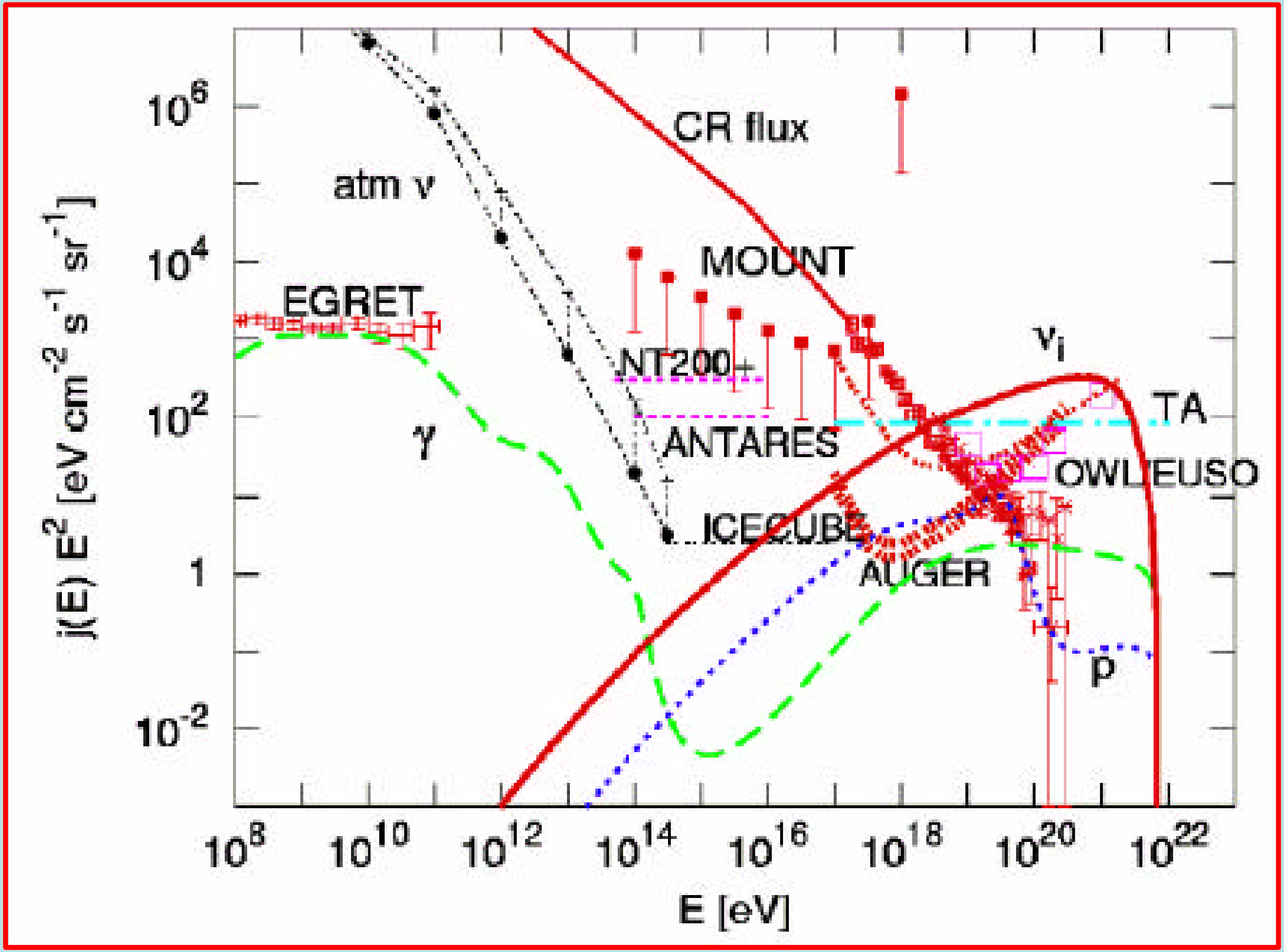
CNB in Cluster generates Super-GZK cosmic rays

Z^0 burst

Theoretical neutrino flux upper limits

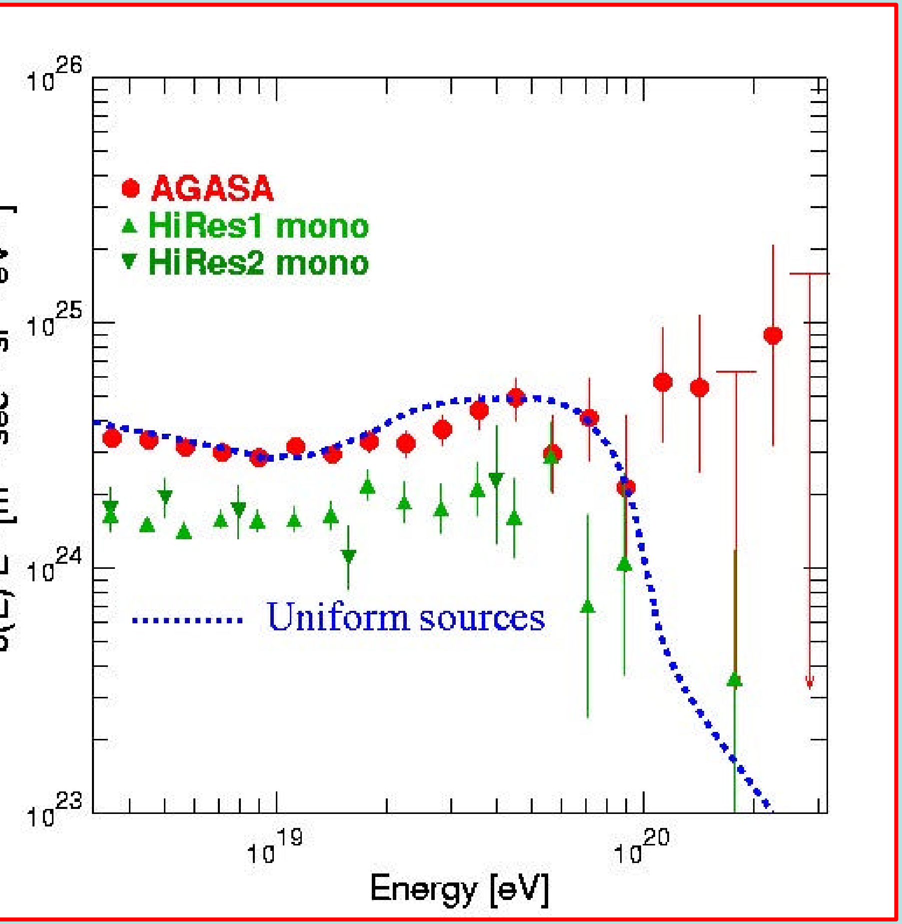


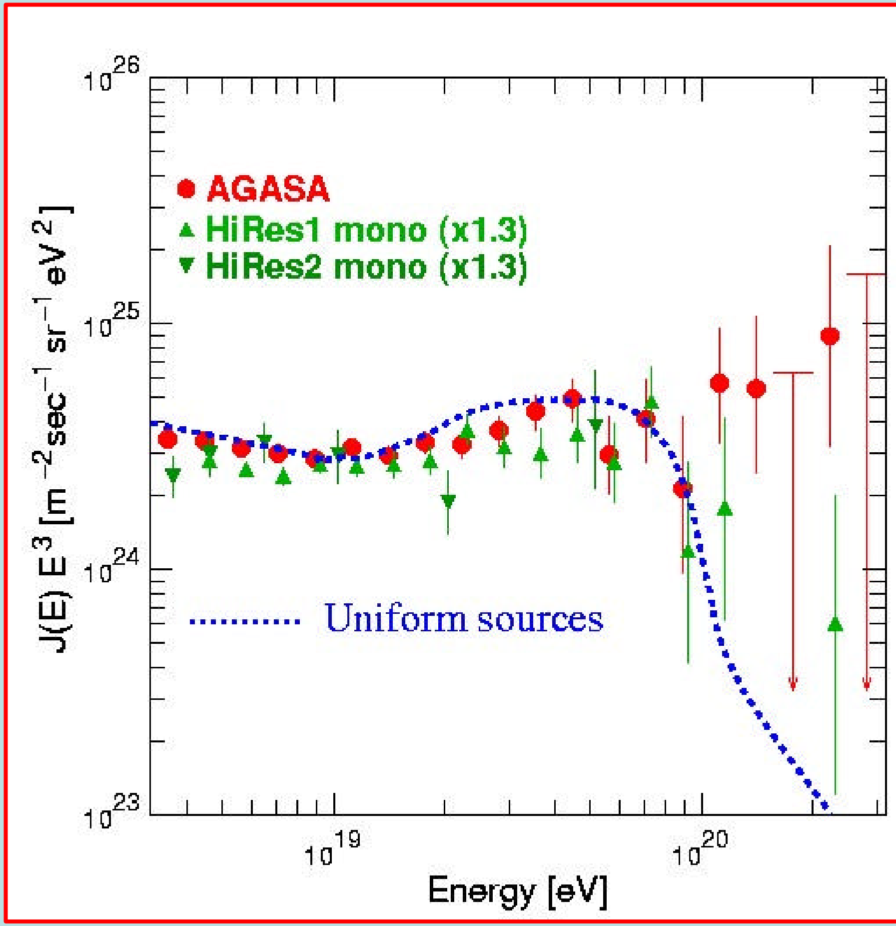
Predicted differential fluxes of g, n, and p

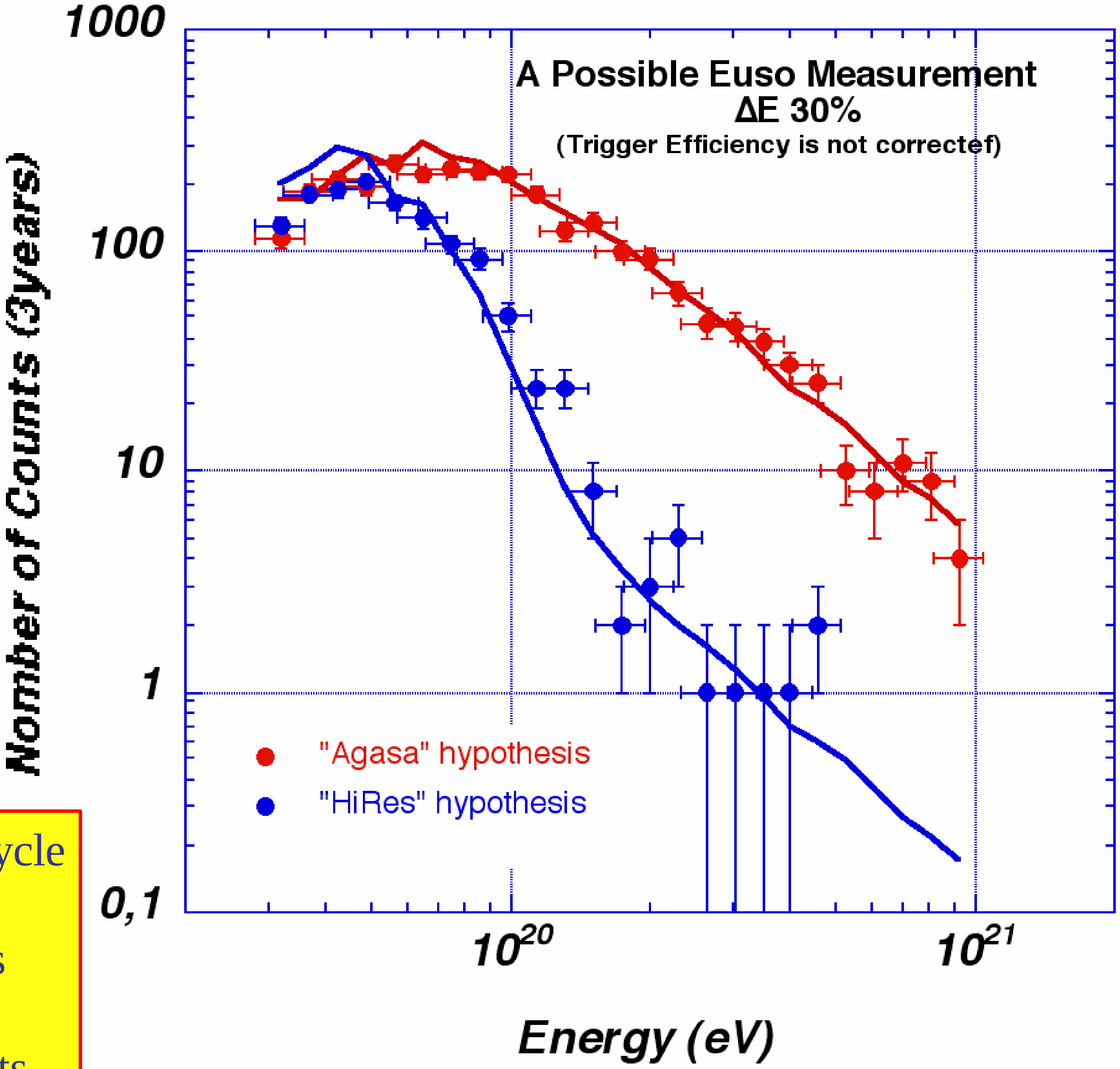


AGASA vs HiRes

(See Teshima Energy determination in AGASA)







- With a 12% Duty Cycle
- ? E of 30%
- Statistical error bars
- Above 10^{20}eV

  Agasa > 1000 events

  Hires > 78 events

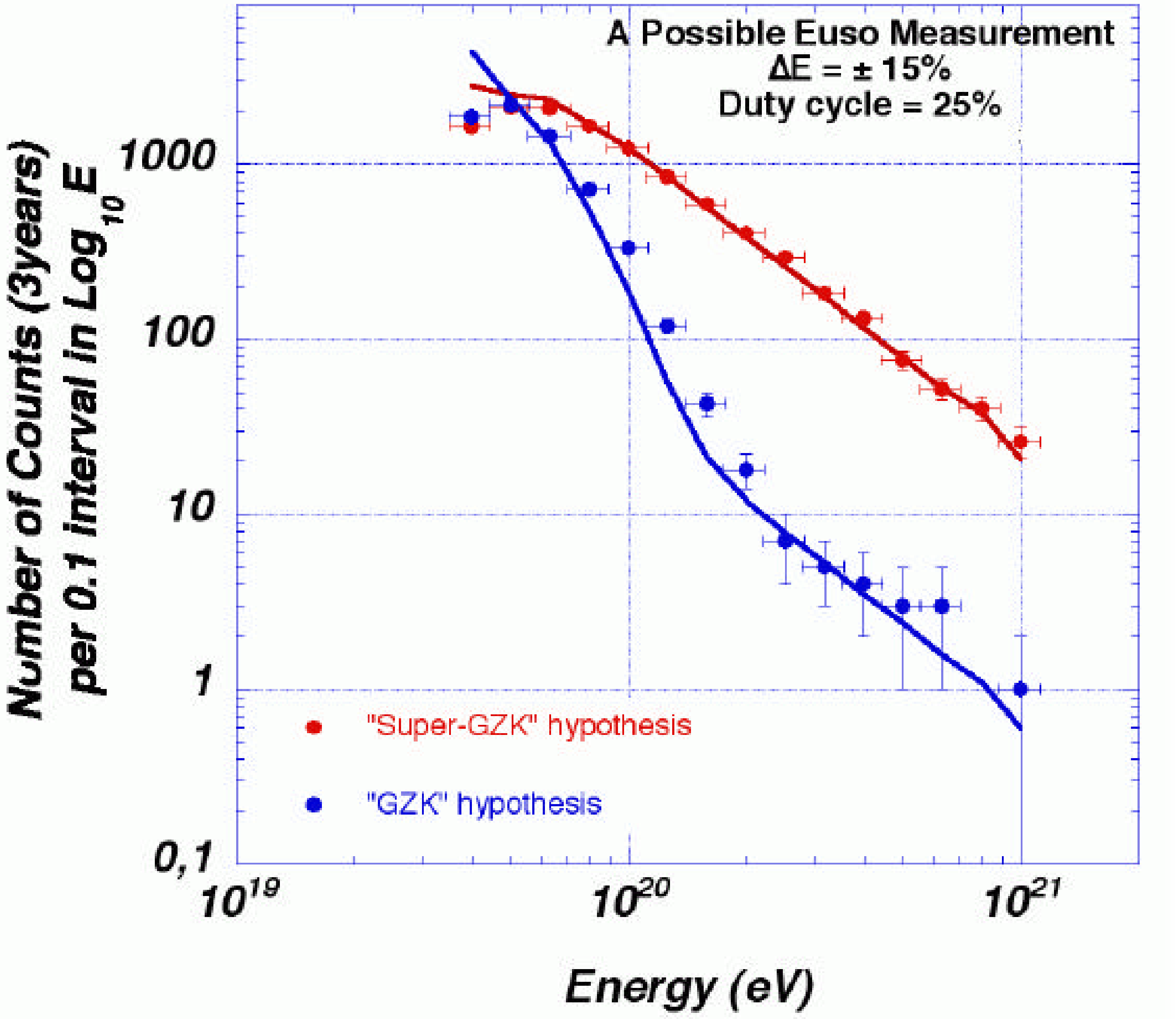
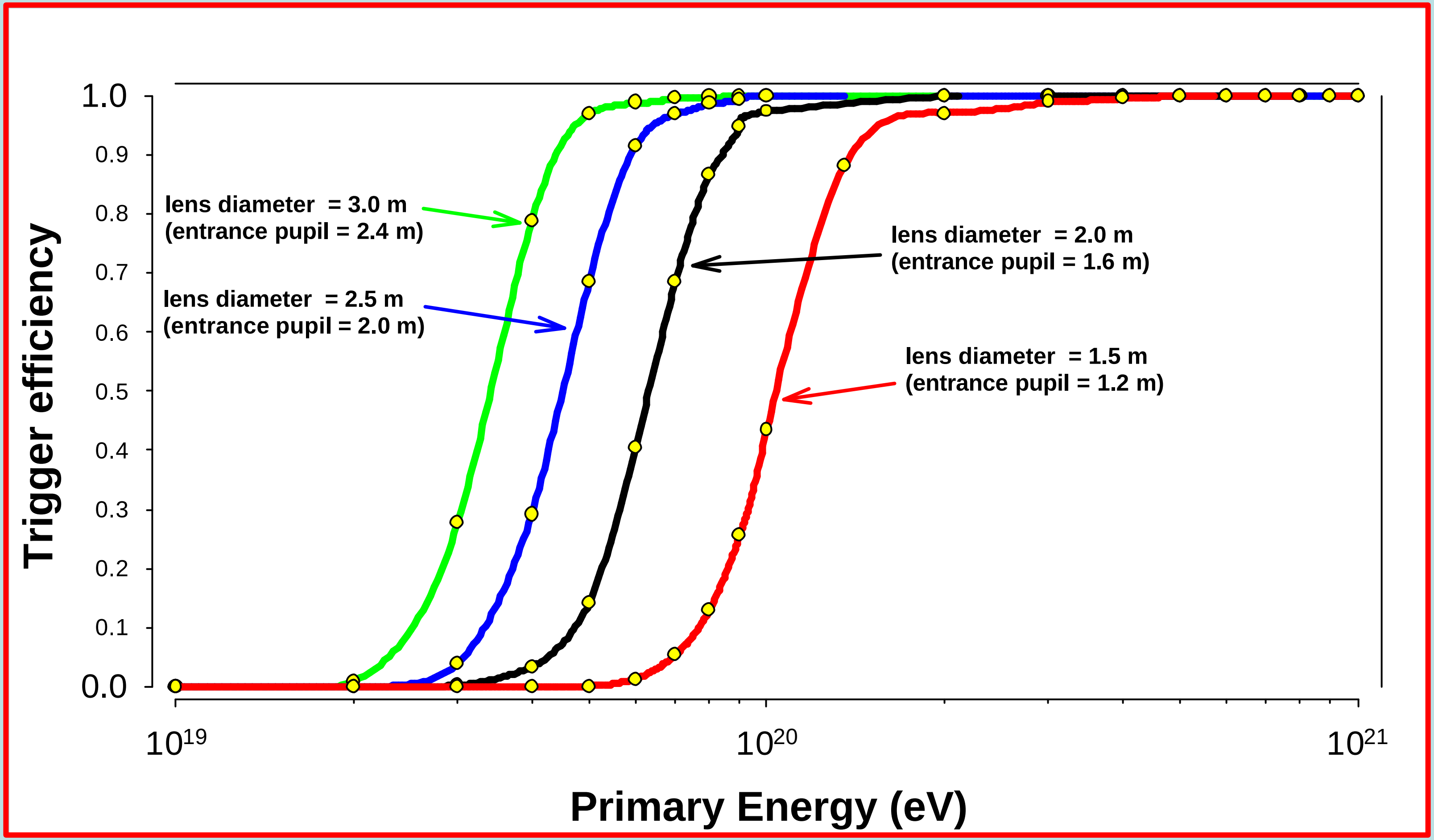


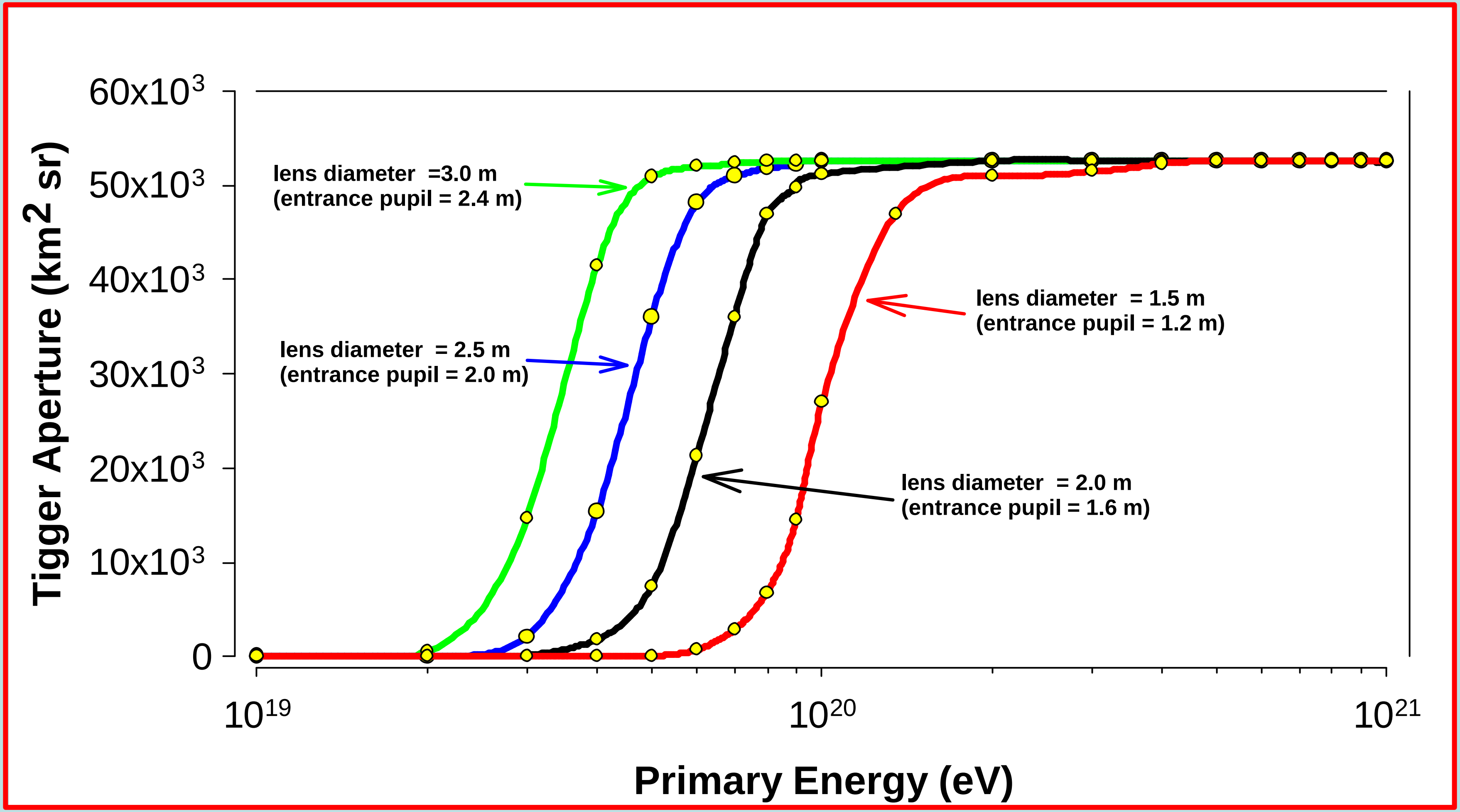
Figure 7.3-1 *EUSO counting rates expected after three years of operation (see text for details).*

EUSO PERFORMANCE



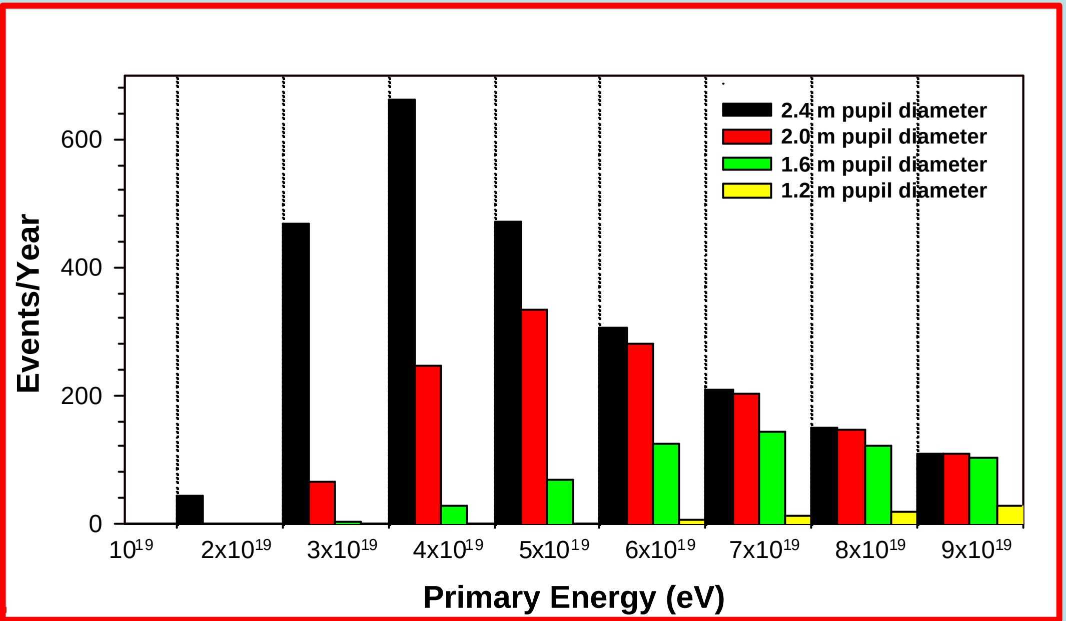
Triggered event is validated only if shower profile is identified (reconstruction criterium: $X_{max} \pm 100\ g/cm^2$)

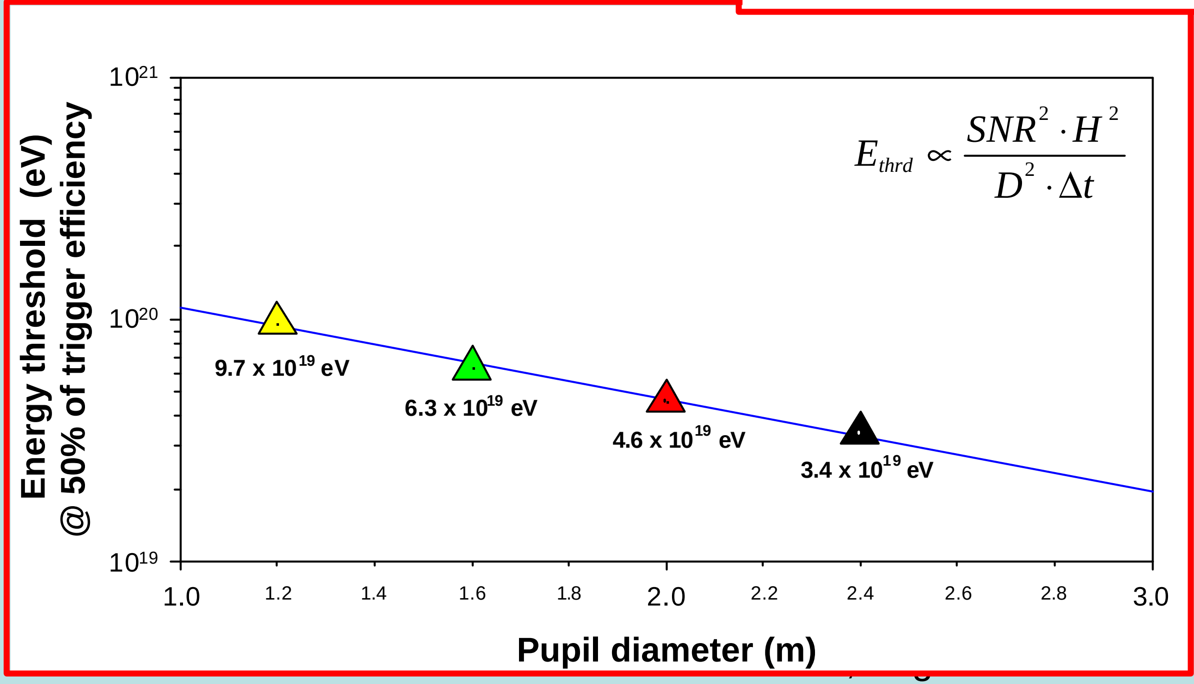
EUSO PERFORMANCE



The trigger aperture includes a 10% duty cycle

energy threshold and event statistics for various configurations.



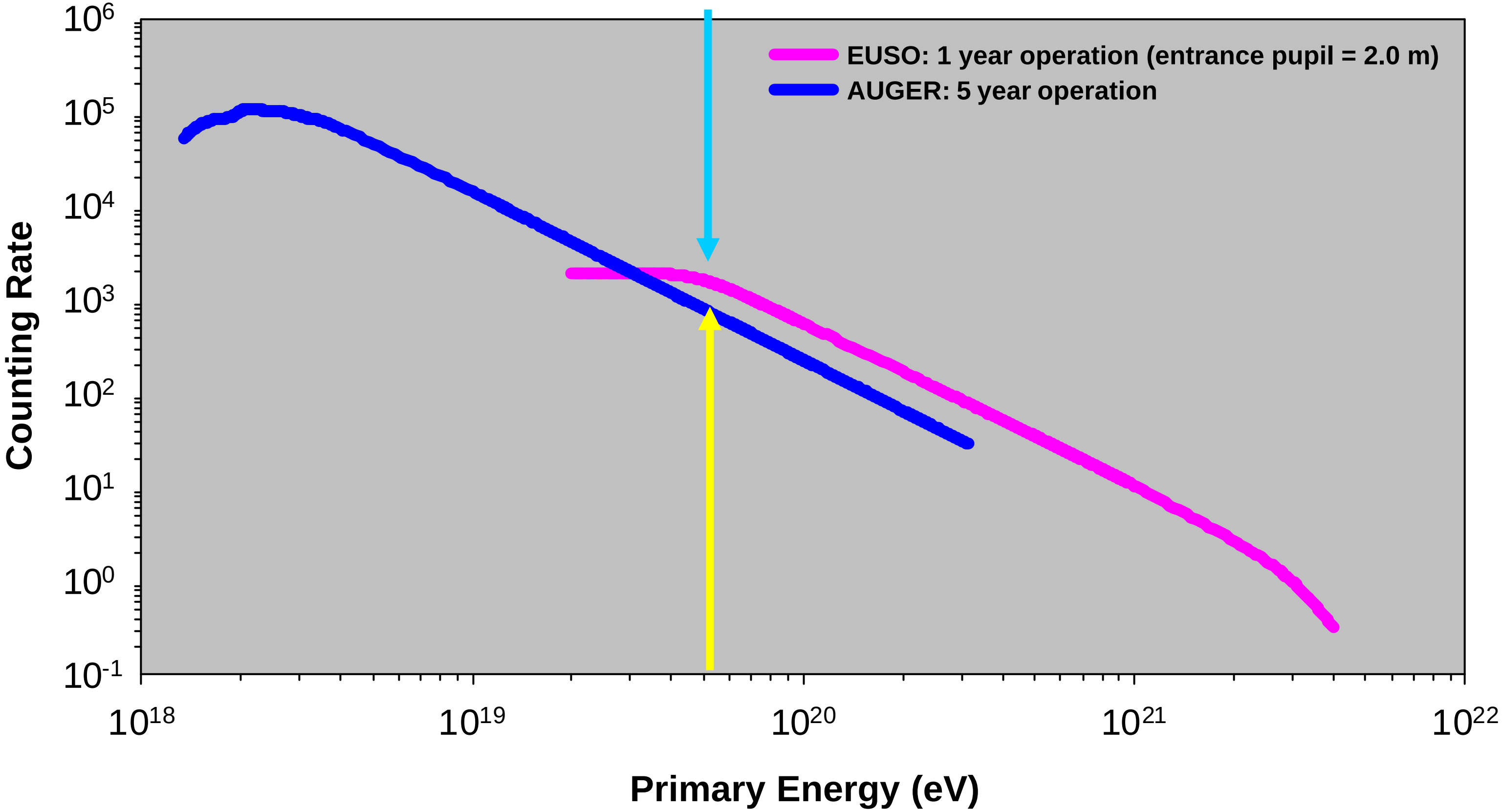


$$E_{thrd} \propto \frac{SNR^2 \cdot H^2}{D^2 \cdot \Delta t}$$

Model predictions for the energy at the GZK effect is around

$4 \sim 5 \cdot 10^{19}$ eV.

AUGER – EUSO BRIDGE



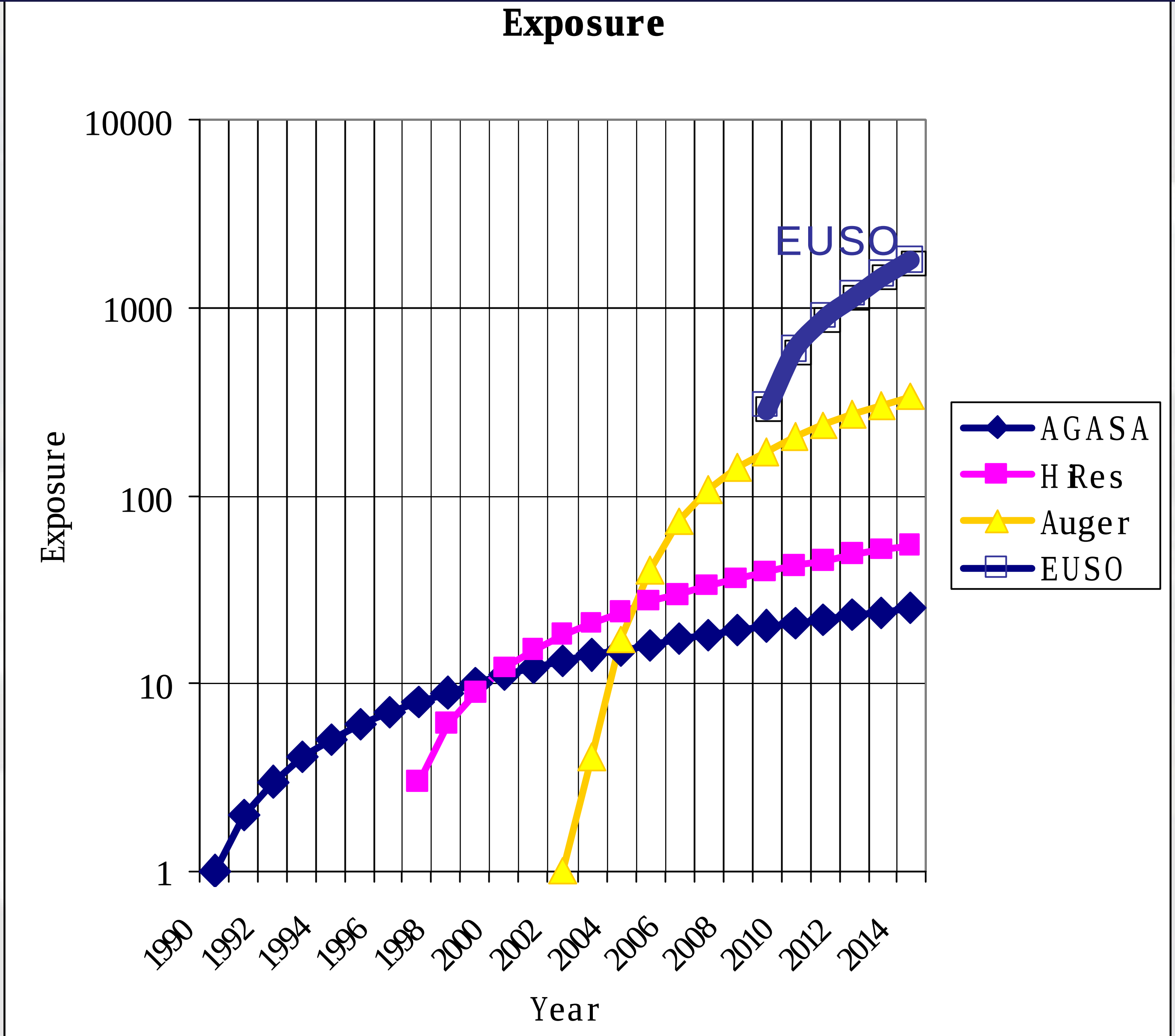
In 5 years operation @ $5 \cdot 10^{19}$ eV AUGER statistical errors within ~ 5 %

In 1 year operation @ $5 \cdot 10^{19}$ eV EUSO statistical errors within ~ 5 %

Study of EECR Energy Spectrum

	$>4\times10^{19}$	$>10^{20}$	$>3\times10^{20}$	$>10^{21}$
Extended spectrum	~4000	~1000	~100	~10
GZK spectrum	~3000	~150	~2	0

Exposure (AGASA unit)



BOTTOM - UP PROCESSES

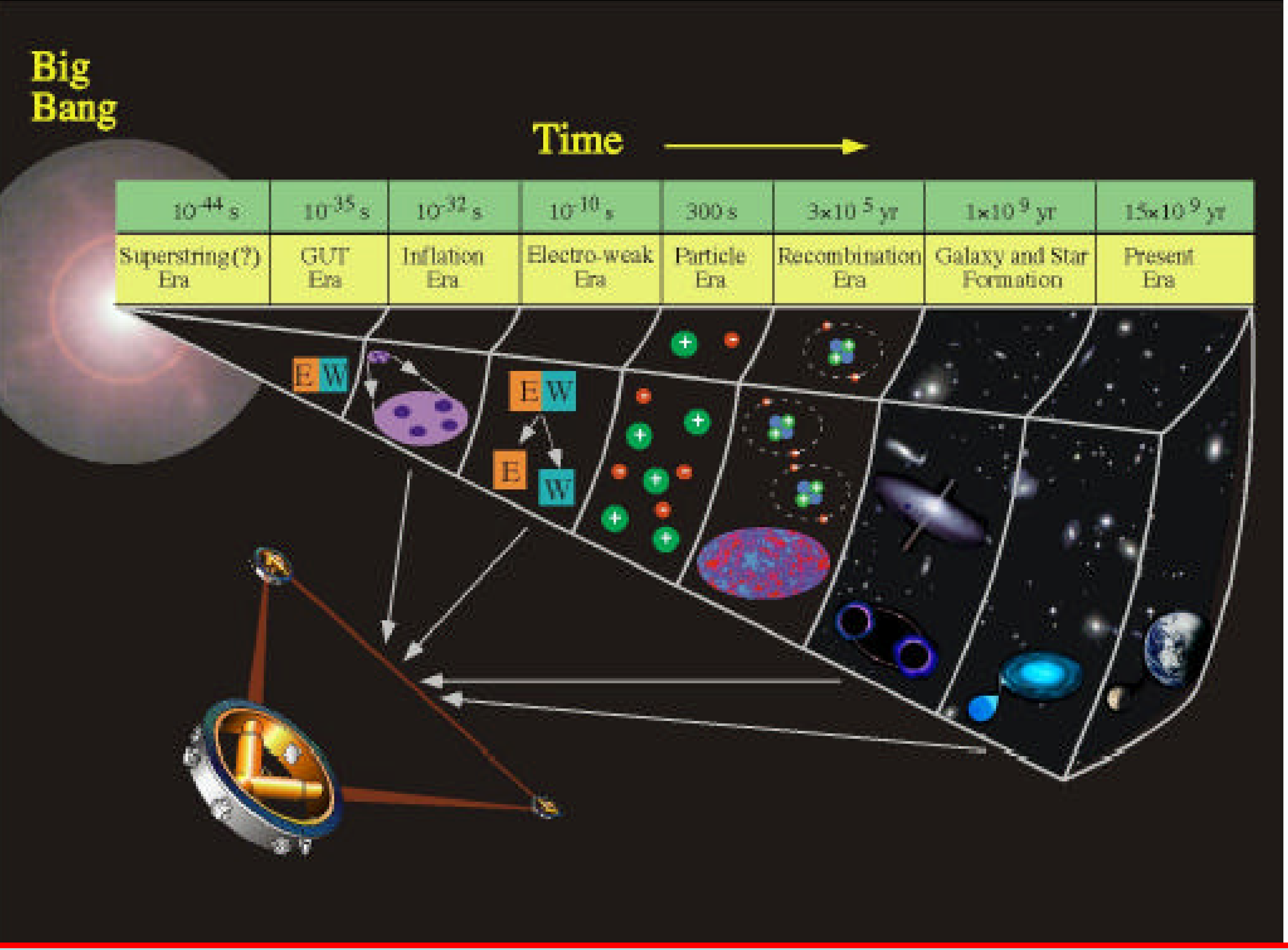
Here acceleration of low energy particles occurs in objects such as AGN and their radio lobes, interacting galaxies or highly magnetized neutron stars (an extreme case in this class are GRBs).

The observation of a direction of arrival and time coincidence of a GRB and an extreme energy neutrino ($E > 10^{19}$ eV) would provide a crucial test for the identification of GRBs as the UHE CR sources, in spite of their location at distances well beyond the GZK limit.

TOP - DOWN PROCESSES

One way to overcome the many difficulties with the acceleration of EECR is to introduce a new, unstable supermassive particle called the X-particle. The decay of these particles is thought to produce copious amounts of photons, neutrinos and leptons, and a smaller fraction of protons and neutrons which could be detected as UHE CR.

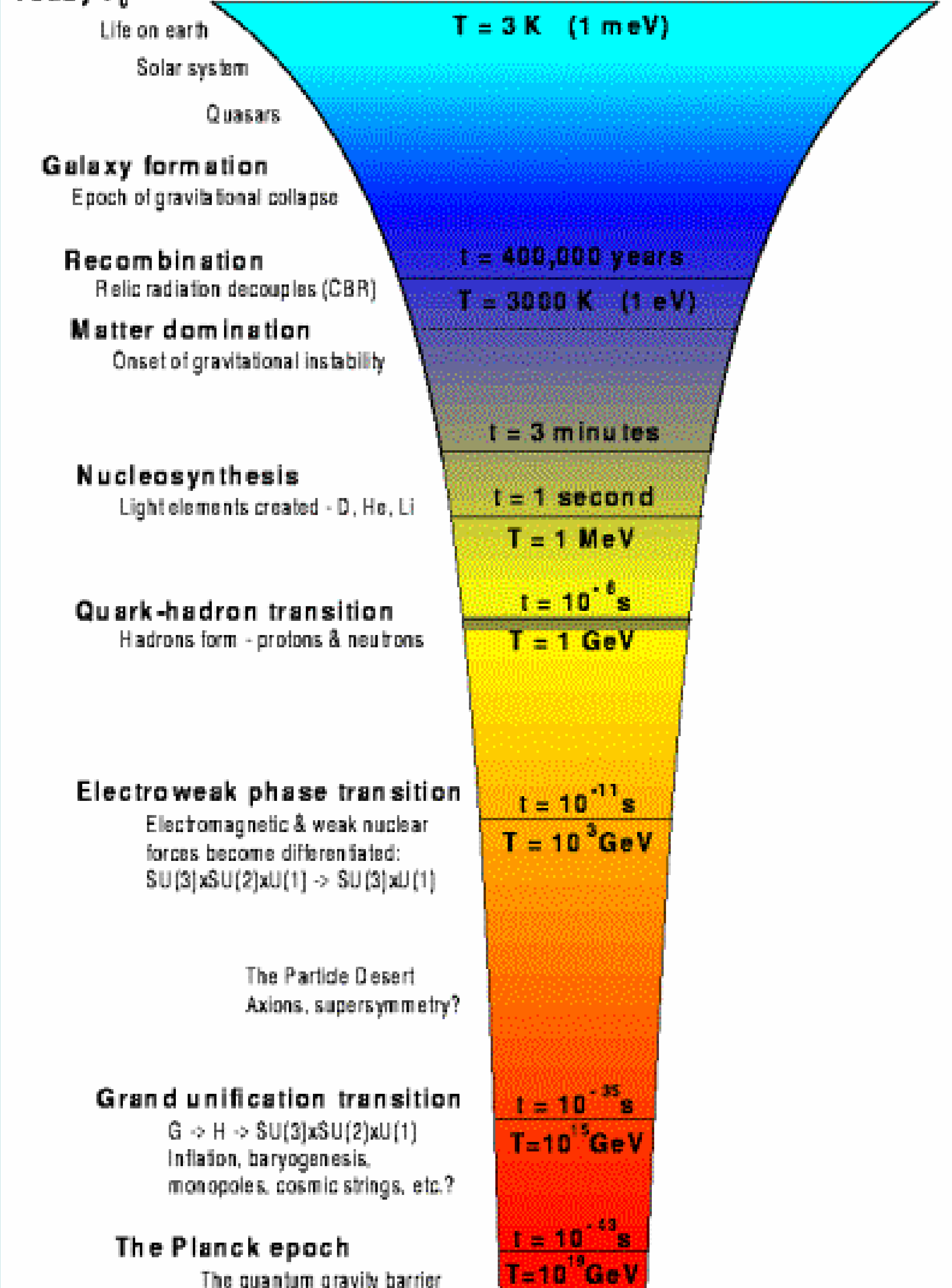
The X-particles themselves could be produced by the decay of topological defects or supermassive relic particles produced at the end of the GUT phase transition stage of the universe.



Big Bang

Time →

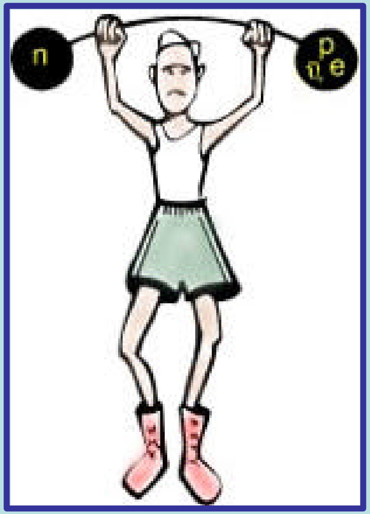
10^{-44} s	10^{-35} s	10^{-32} s	10^{-10} s	300 s	3×10^{5} yr	1×10^{9} yr	15×10^{9} yr
Superstring(?) Era	GUT Era	Inflation Era	Electro-weak Era	Particle Era	Recombination Era	Galaxy and Star Formation	Present Era


Life on earth
Solar system
Quasars
Galaxy formation
Epoch of gravitational collapse
Recombination
Relic radiation decouples (CBR)
Matter domination
Onset of gravitational instability
Nucleosynthesis
Light elements created - D, He, Li
Quark-hadron transition
Hadrons form - protons & neutrons
Electroweak phase transition
Electromagnetic & weak nuclear
forces become differentiated:
SU(3)xSU(2)xU(1) -> SU(3)xU(1)
The Particle Desert
Axions, supersymmetry?
Grand unification transition
G -> H -> SU(3)xSU(2)xU(1)
Inflation, baryogenesis,
monopoles, cosmic strings, etc.?
The Planck epoch
The quantum gravity barrier
T = 3 K (1 meV)
t = 400,000 years
T = 3000 K (1 eV)
t = 3 minutes
t = 1 second
T = 1 MeV
$t = 10^{-6}$ s
T = 1 GeV
$t = 10^{-11}$ s
$T = 10^{3}$ GeV
$t = 10^{-35}$ s
$T=10^{15}$ GeV
$t = 10^{-43}$ s
$T=10^{19}$ GeV

The fundamental interactions

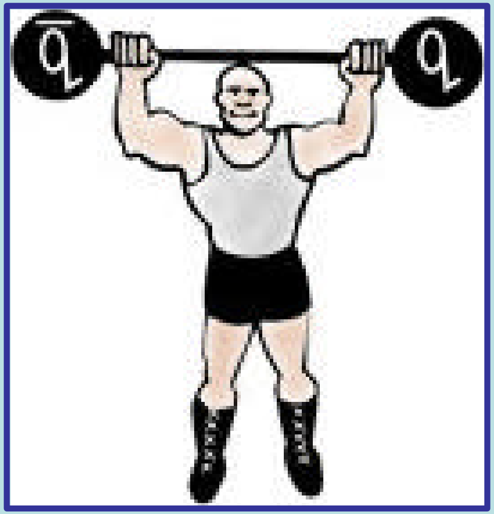
gravity

electromagnetism



week

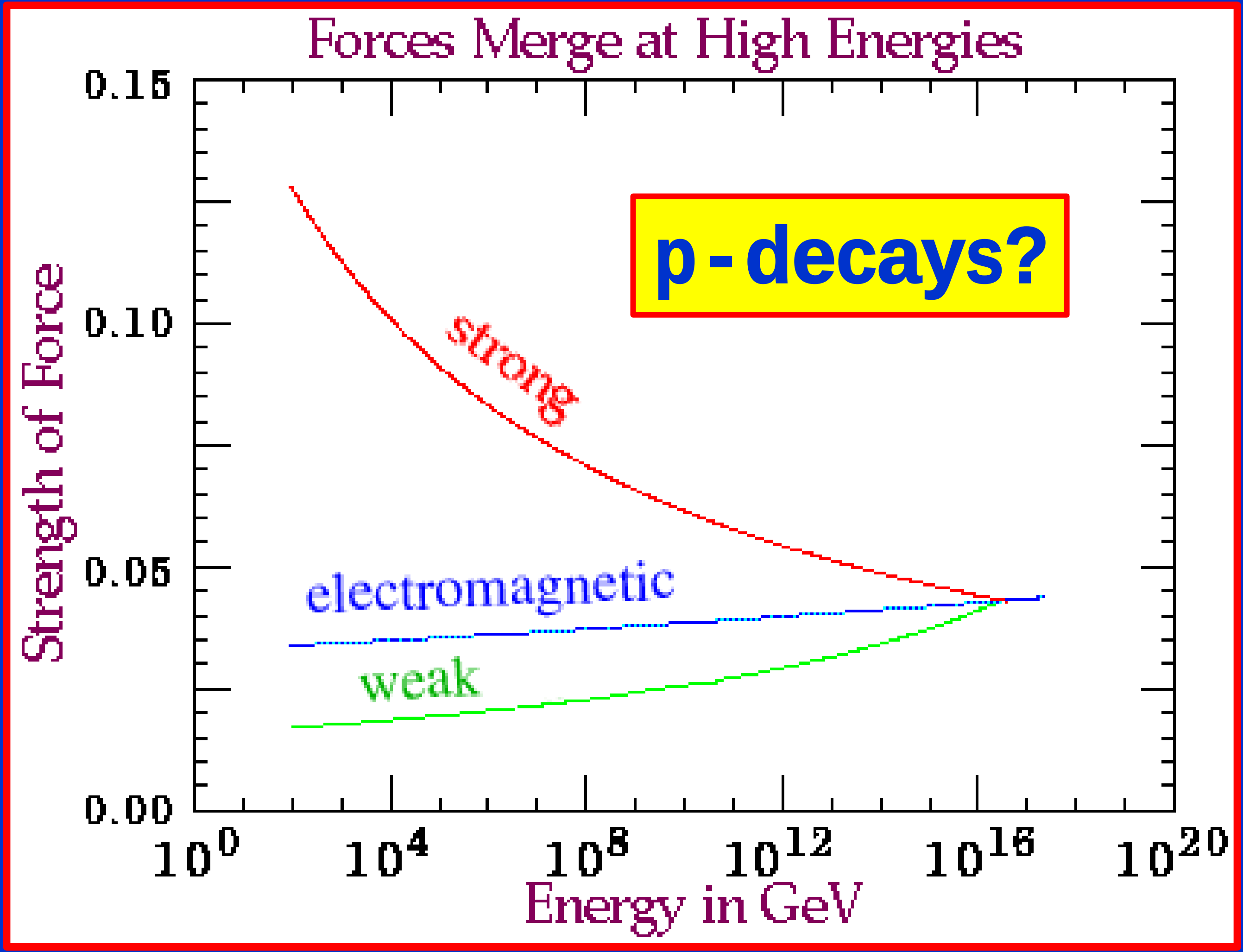
strong



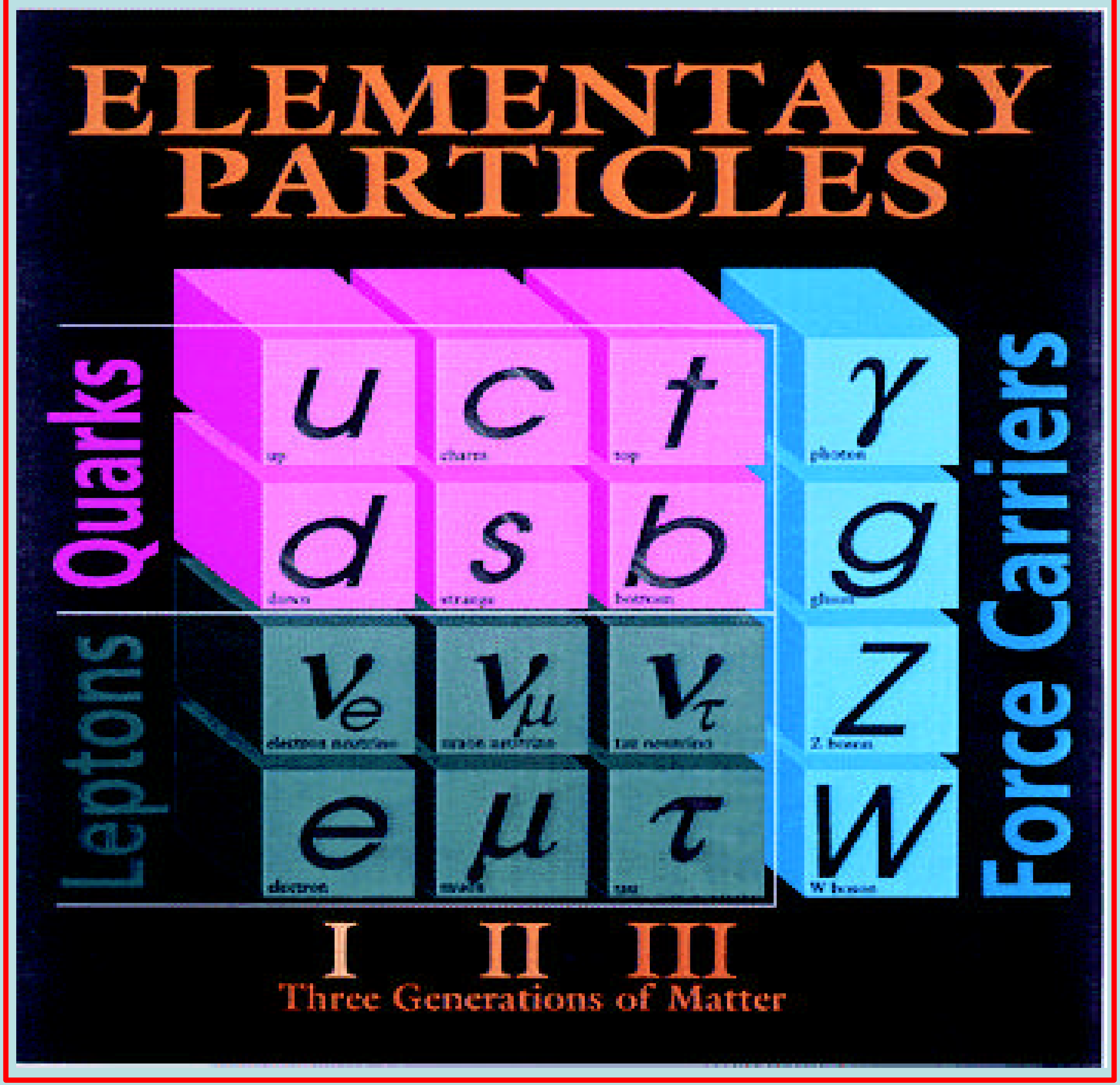
STANDARD MODEL (1970)

GUT SU(3)xSU(2)xU(1) gravity not include

~ 100 GeV
electroweak
unification



P.Galeotti


ELEMENTARY PARTICLES
Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Leptons
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
e
electron
μ
muon
τ
tau
Force Carriers
γ
photon
g
gluon
Z
Z boson
W
W boson
I II III
Three Generations of Matter

p? $e^+\pi^0$

p? $K^+\nu$

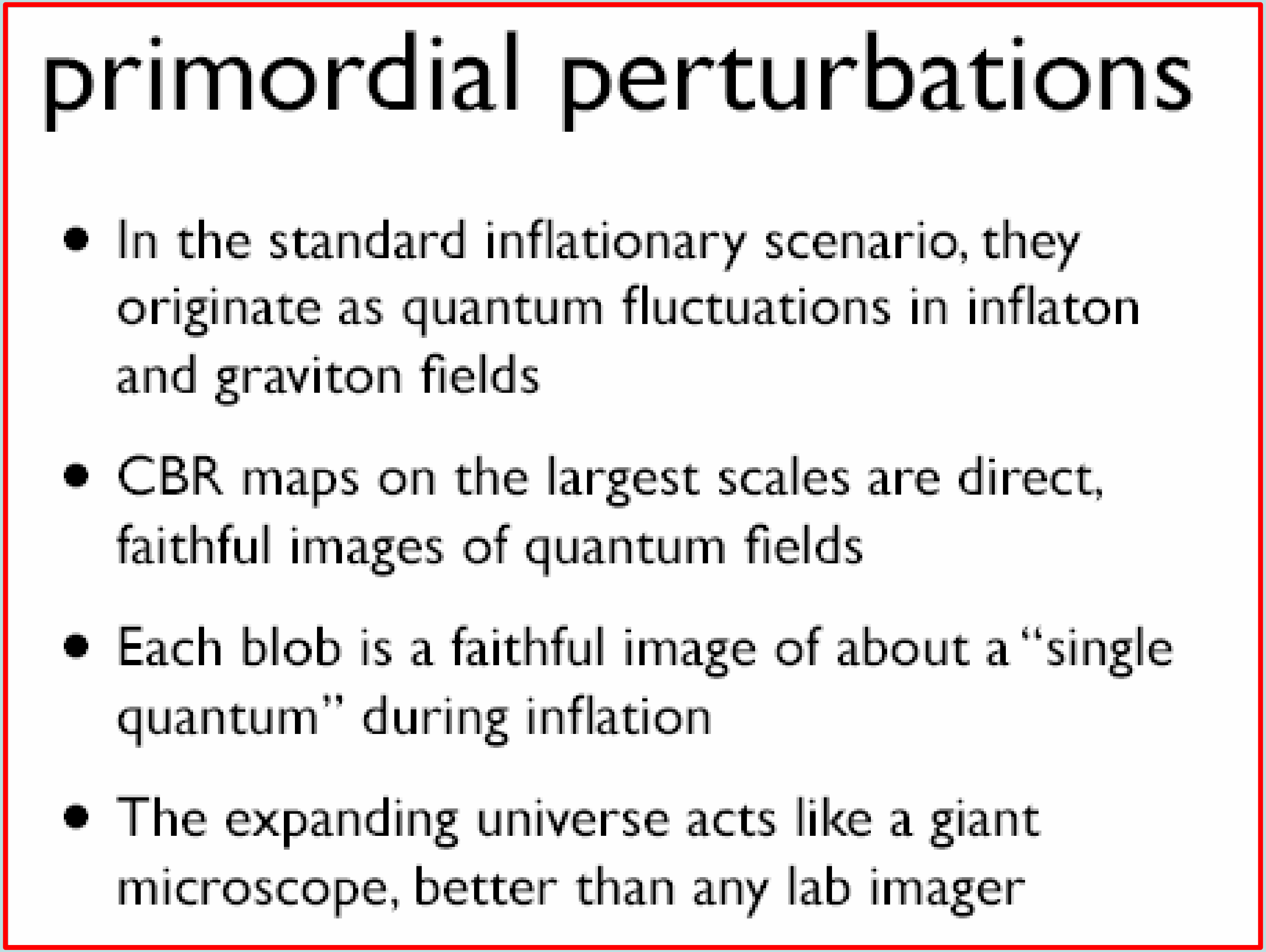
Models of inflation

old, new, used (pre-owned),
chaotic, quixotic, ergodic,
exotic, eckpryotic, autoerotic,
faith-based, free-based,
3-brane, D-brane, no-brain,
supersymmetric, superstitious, supercilious,
natural, supernatural, *au natural,*
hybrid, low-bred, white-bread,
one-field, two-field, left-field,
eternal, internal, infernal,
self-reproducing, self-promoting,
dilaton, dilettante, …….

R.Kolb

Superheavy relic (wimpzilla) characteristics:

- supermassive (~10^{12} GeV)
- abundance depends only on mass
- abundance independent of interactions
  - sterile?
  - electrically charged?
  - strong interactions?
  - weak interactions?
- unstable (lifetime > age of the universe)?



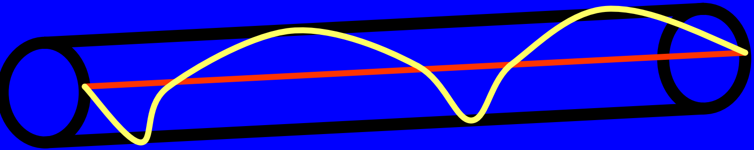
primordial perturbations

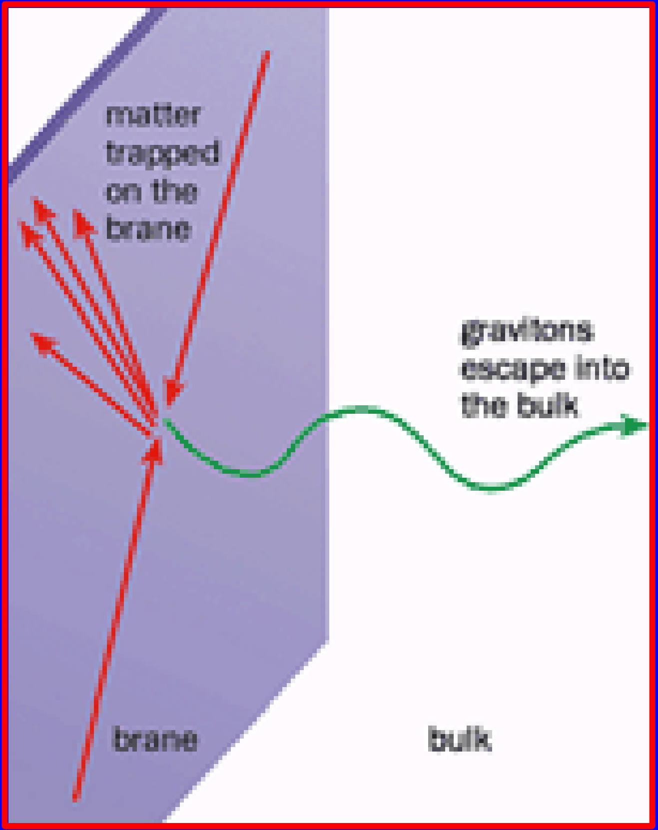
- In the standard inflationary scenario, they originate as quantum fluctuations in inflaton and graviton fields
- CBR maps on the largest scales are direct, faithful images of quantum fields
- Each blob is a faithful image of about a “single quantum” during inflation
- The expanding universe acts like a giant microscope, better than any lab imager

String theory requires 10 dimensions, but the universe has only 4 dimensions

COMPACTIFICATION 10 ? 4

6 dimensions are small and compact

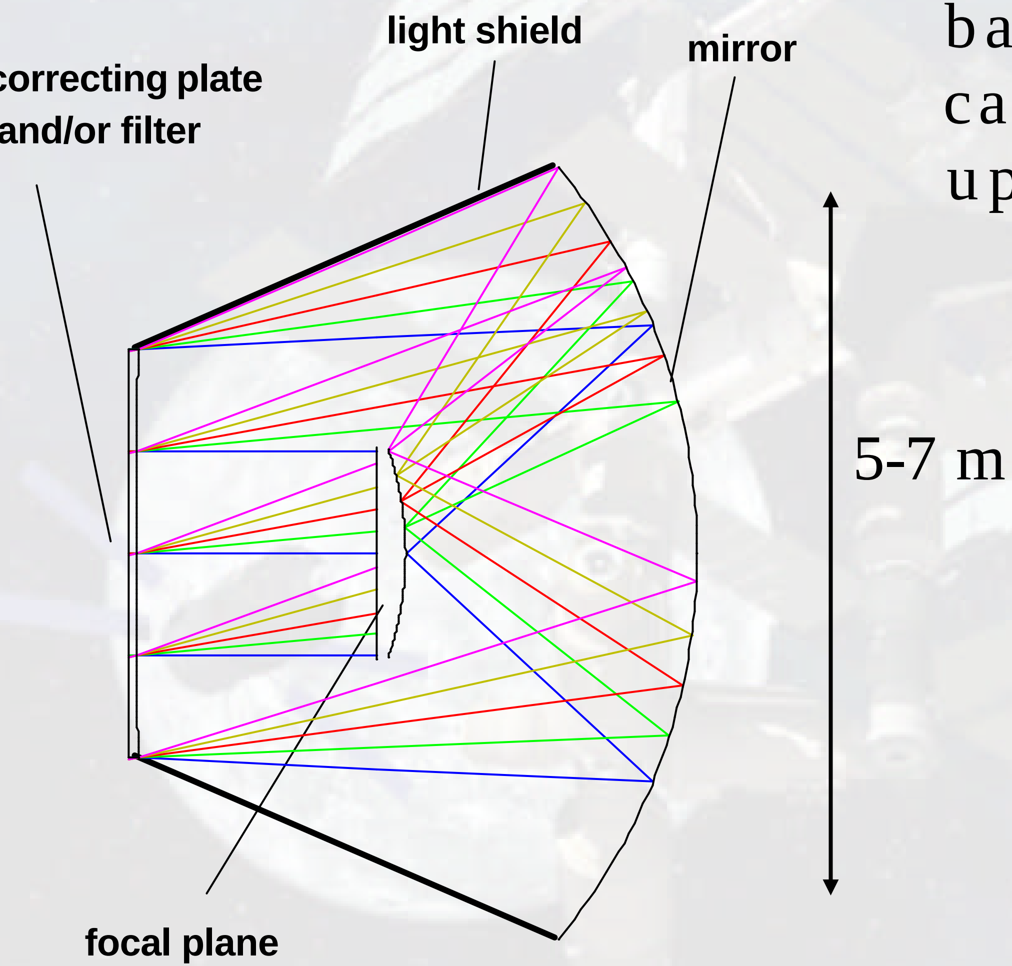




Will EECR solve the cosmology problem?

A proposed large mirror system

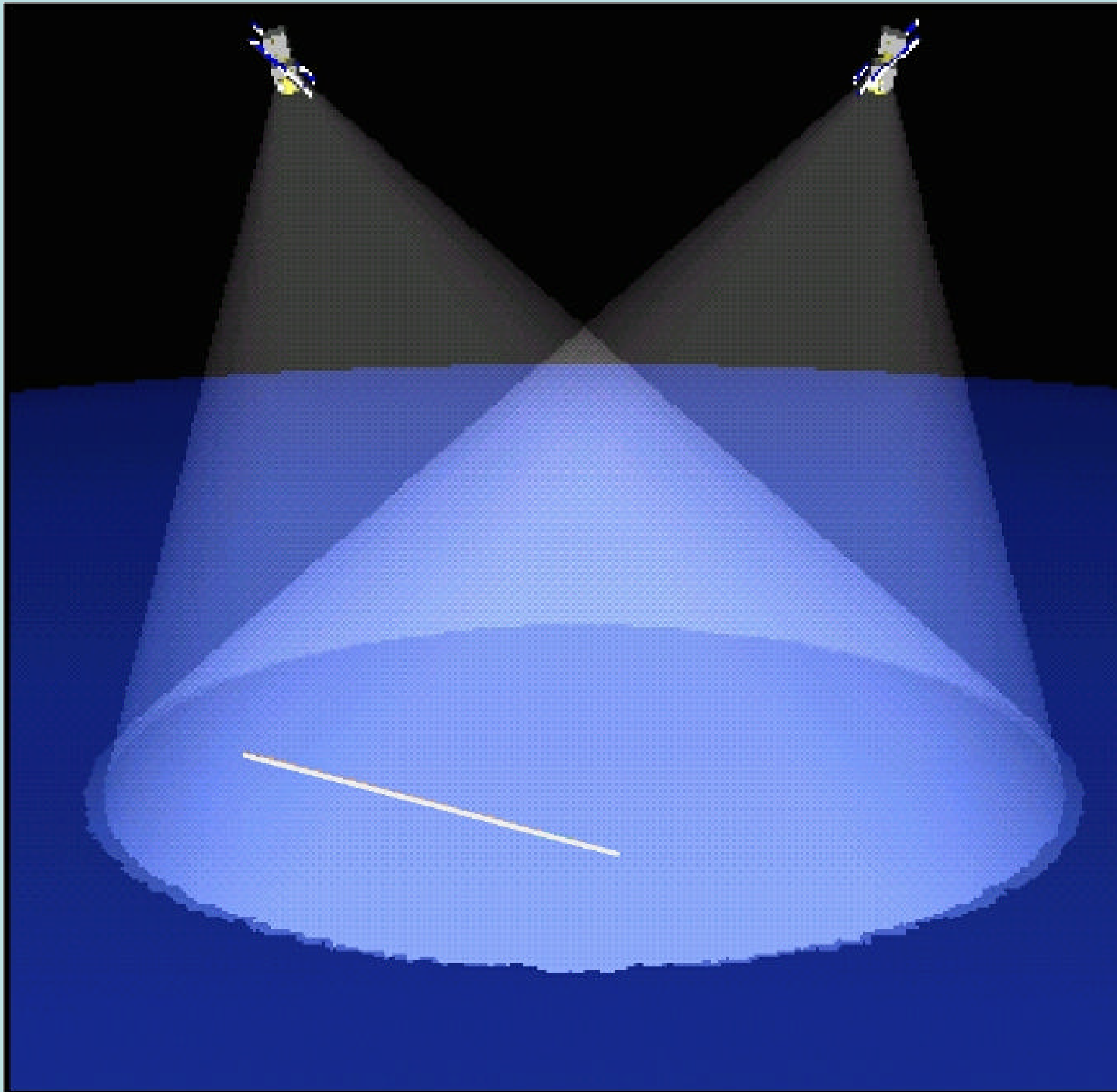
Design of a mirror optics, based on the Schmidt camera principle, with FOV up to 25°



3 identical DETECTORS ASSEMBLED INSIDE THE ISS ?

Solid state detectors ?

OWL



P.Galeotti