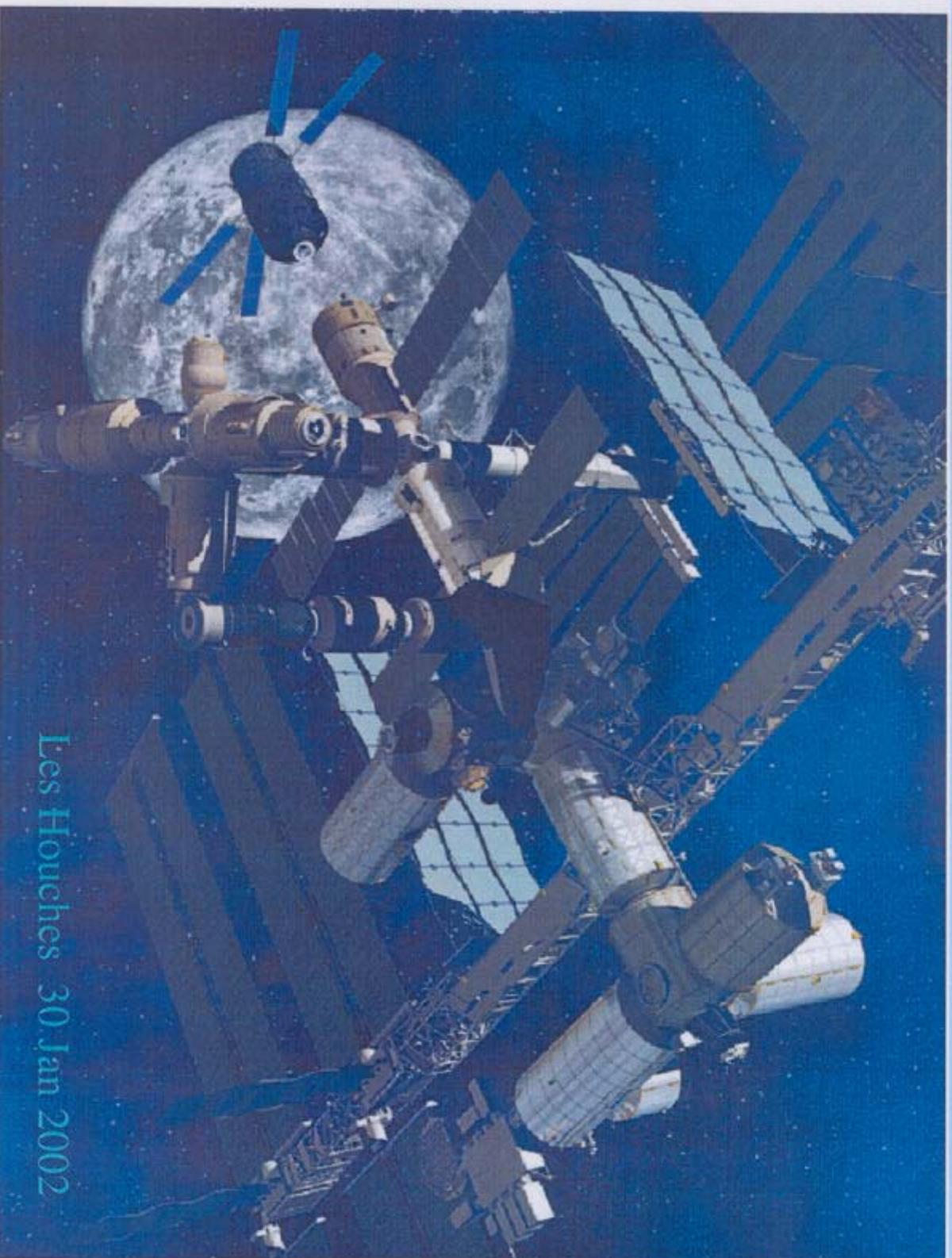




# THE EUSO PROJECT

SPACE OBSERVATORY FOR THE COSMIC RAYS AND NEUTRINOS



Les Houches 30 Jan 2002

S. Bottai INFN-Florence

EUSO *Extreme Universe Space Observatory*

# CONTENTS

- EUSO : description and status
- Detecting downwards going neutrinos with EUSO
- Calculation of upgoing  $\tau$ 's induced by  $\tau$  neutrinos in the Earth

# EUSSO

$E > 10^{19} \text{ eV}$  (EHECR) DETECTOR FROM SPACE (ISS)

• EUROPE

• USA

• JAPAN

- ITALY
- FRANCE
- PORTUGAL
- UK
- GERMANY

APPROVED BY ESA FOR "PHASE A" (FEB. 2002 - FEB. 2003)

2002 PHASE A

FEASIBILITY AND CONCEPTUAL DESIGN  
MEASUREMENT OF "NATURAL DETECTOR"

// B

// C

// D

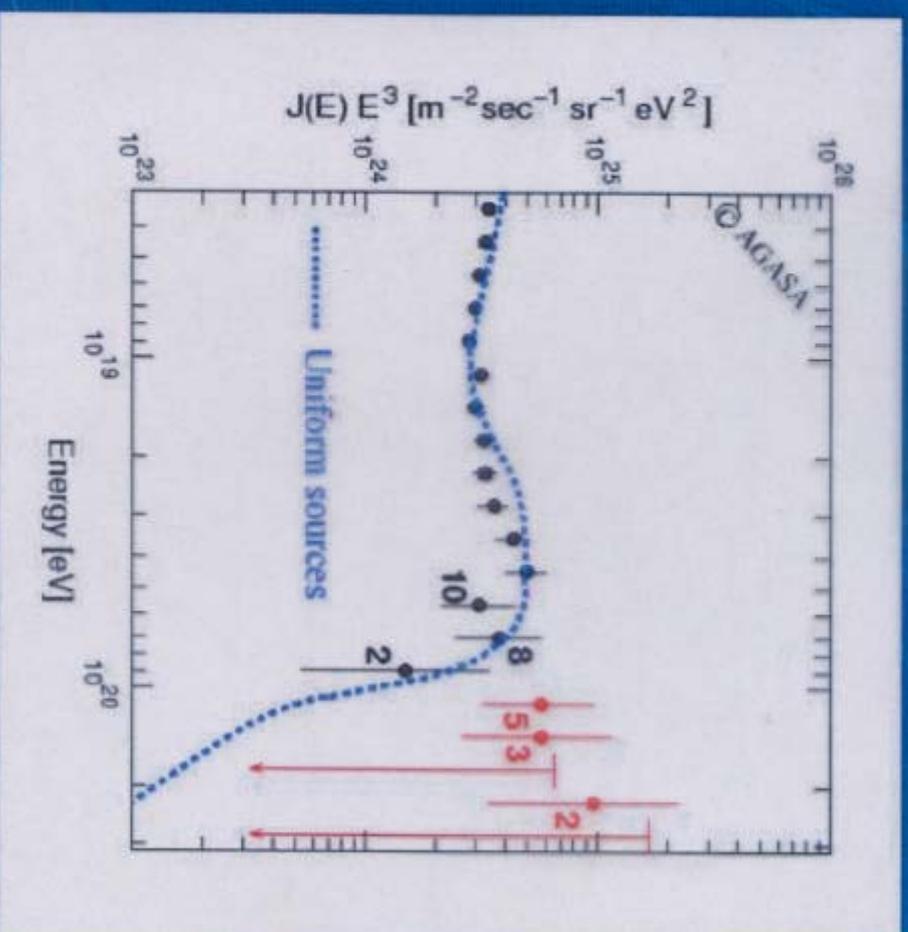
~ 2008

CONSTRUCTION - OPERATION

# The highest energy cosmic rays

Teshima at TAUP 2001

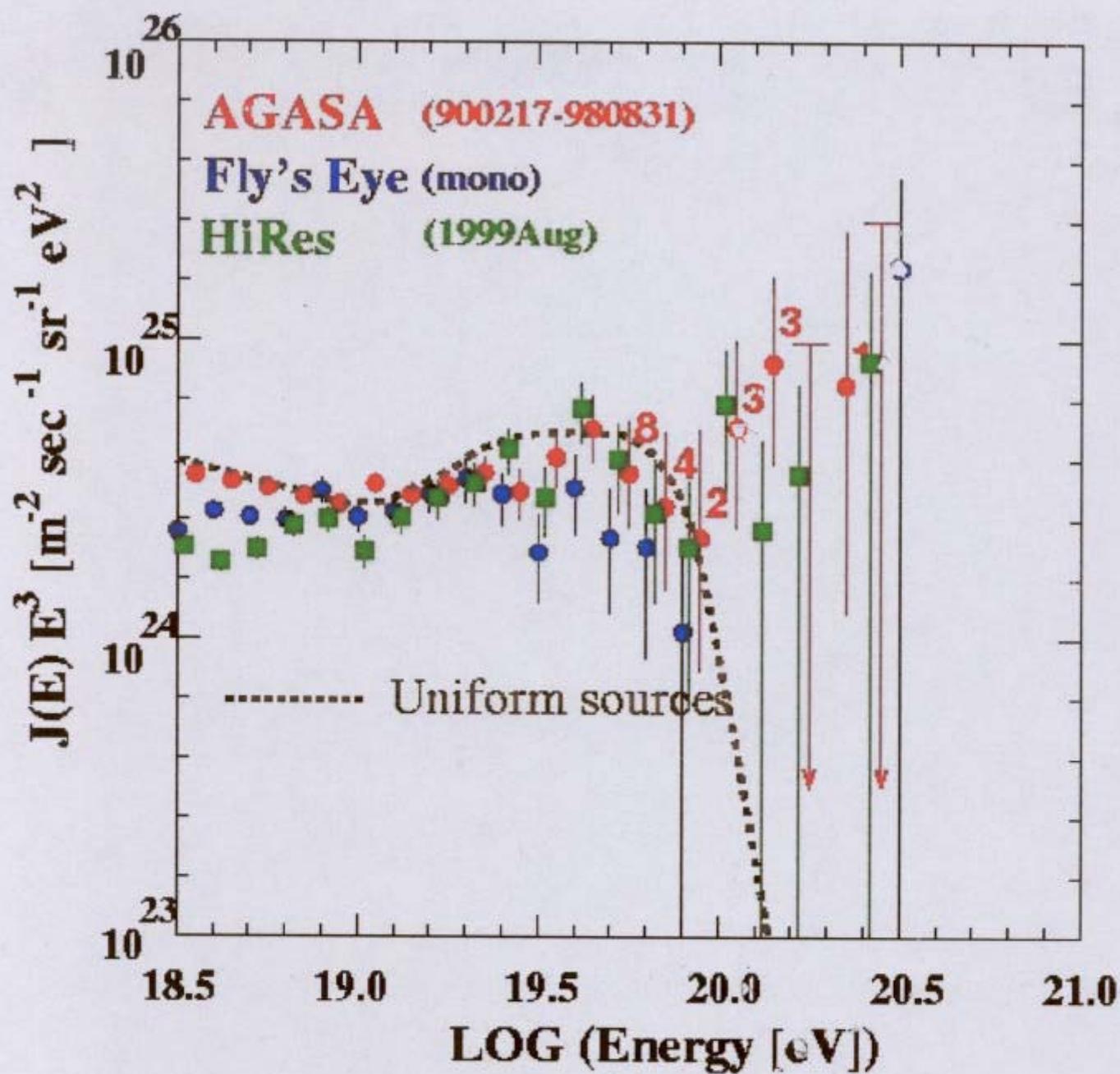
## Energy Spectrum by AGASA ( $\theta < 45^\circ$ )



GZK ??

SOURCES ??

P, FE,  $\gamma$ , ...??



AGASA  $E > 10^{20}$  eV

17



HIRES  $E > 10^{20}$  eV

~ 20

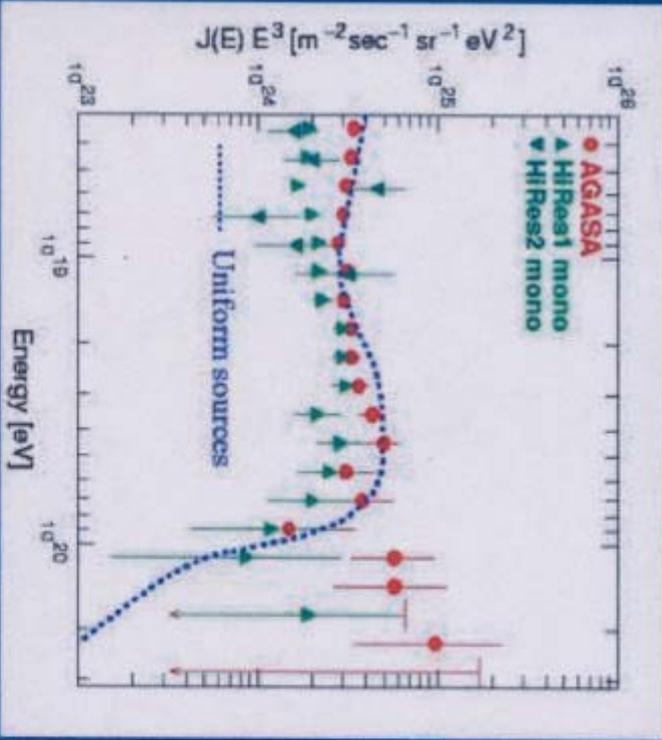
MEASURED

2

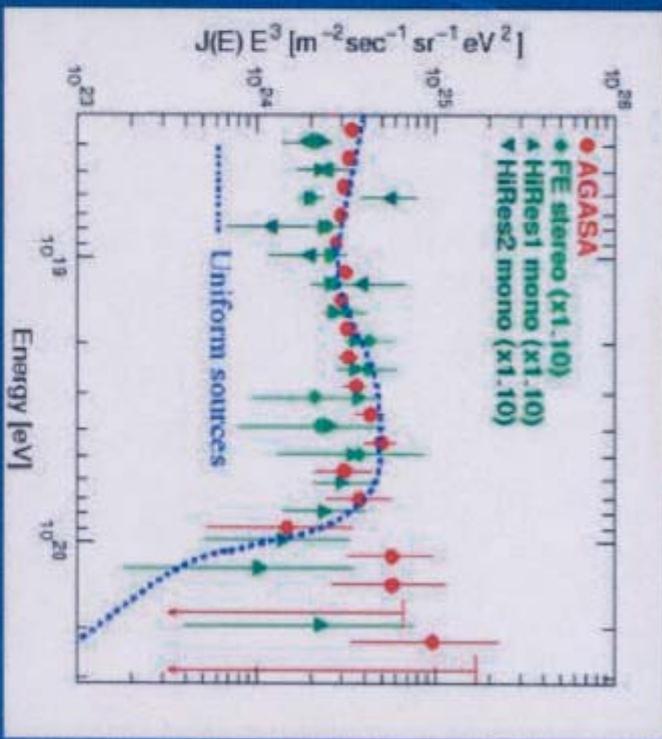
Teshima at TAUP 2001

# AGASA vs. HIRES I mono, HIRES II mono

Original AGASA + Original HIRES



Original AGASA + HIRES x 1.1



# NEUTRINOS AND EHECR

Possible sources of ehecr

BOTTOM - UP

TOP - DOWN

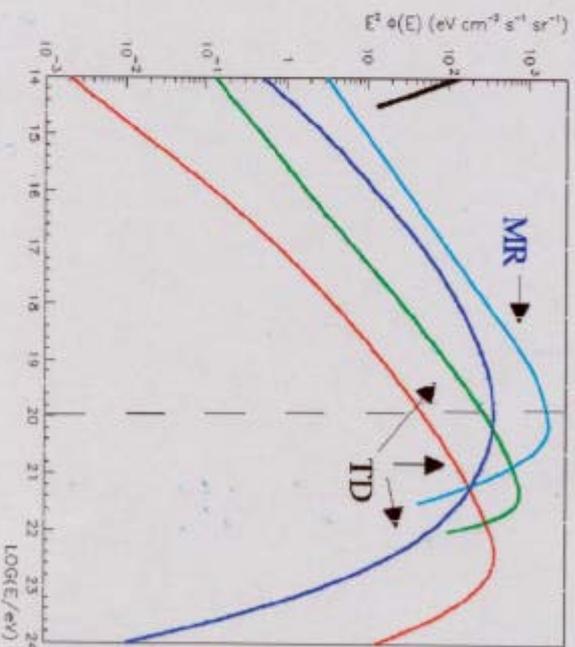
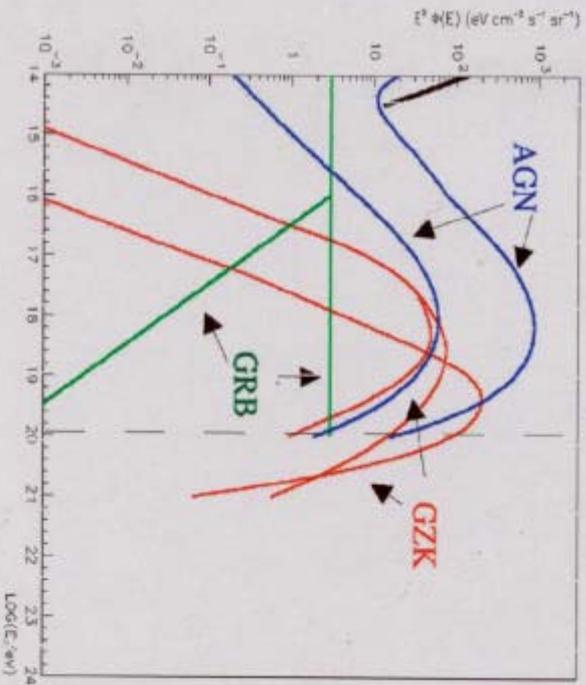
'SOFT'

'HARD'

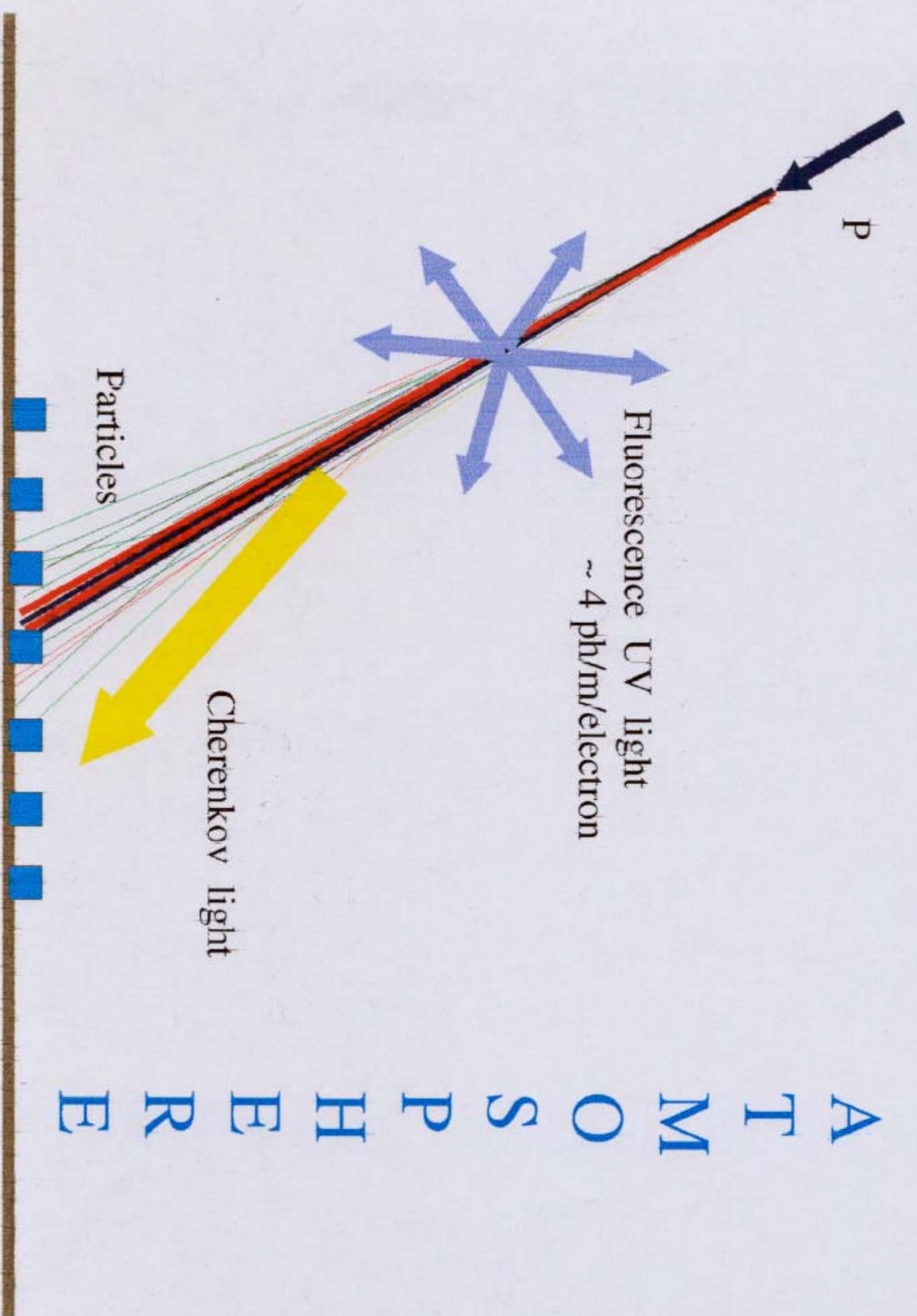
NEUTRINOS (No deviation)

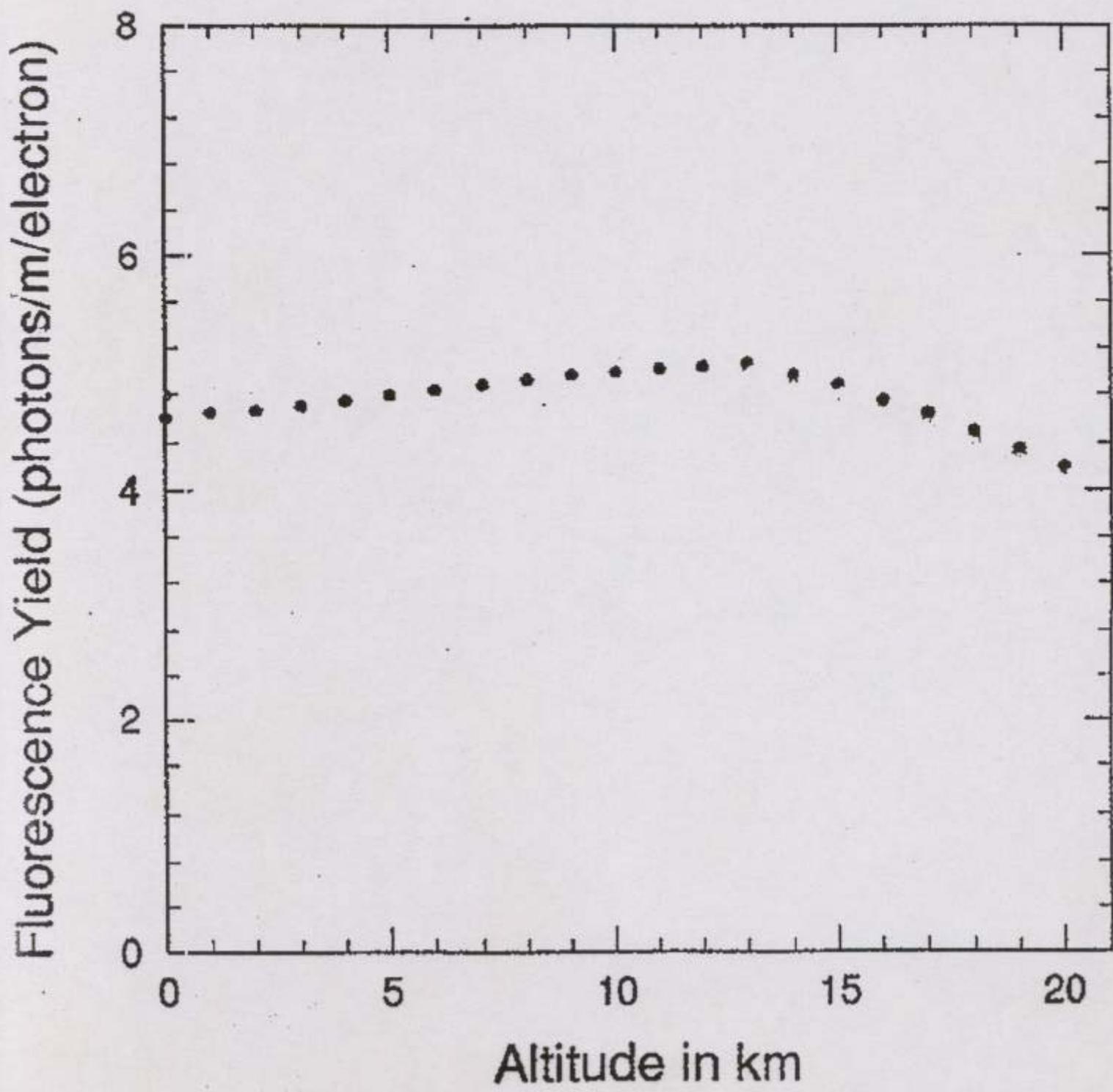
$10^{20}$  eV

$10^{20}$  eV



# ATMOSPHERE

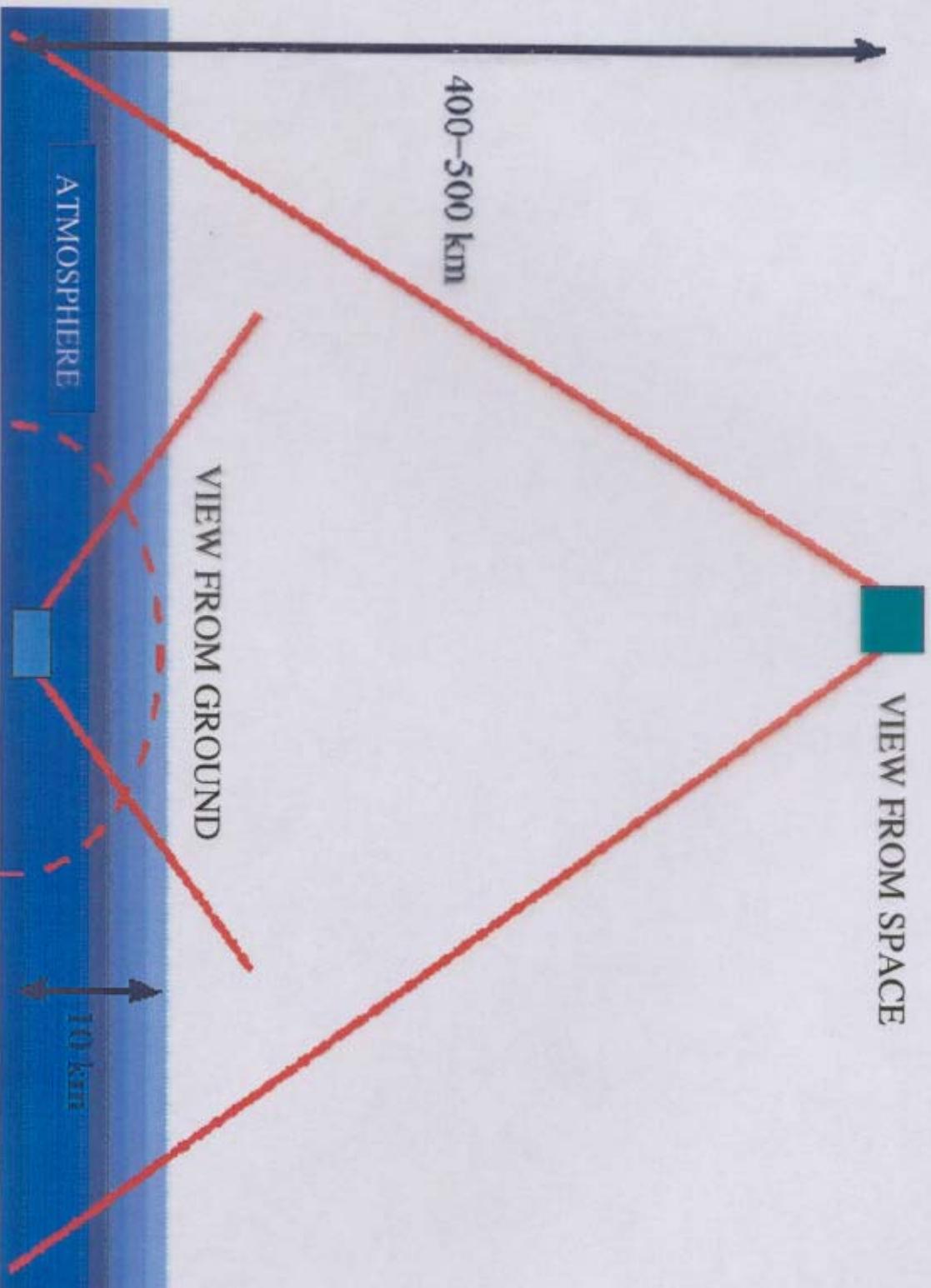




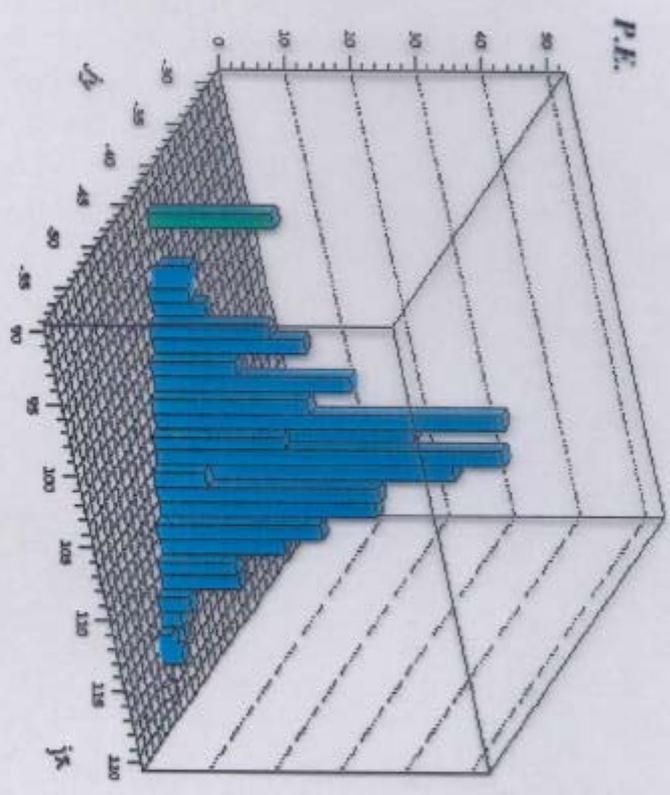


## EXPERIMENTAL APPROACHES

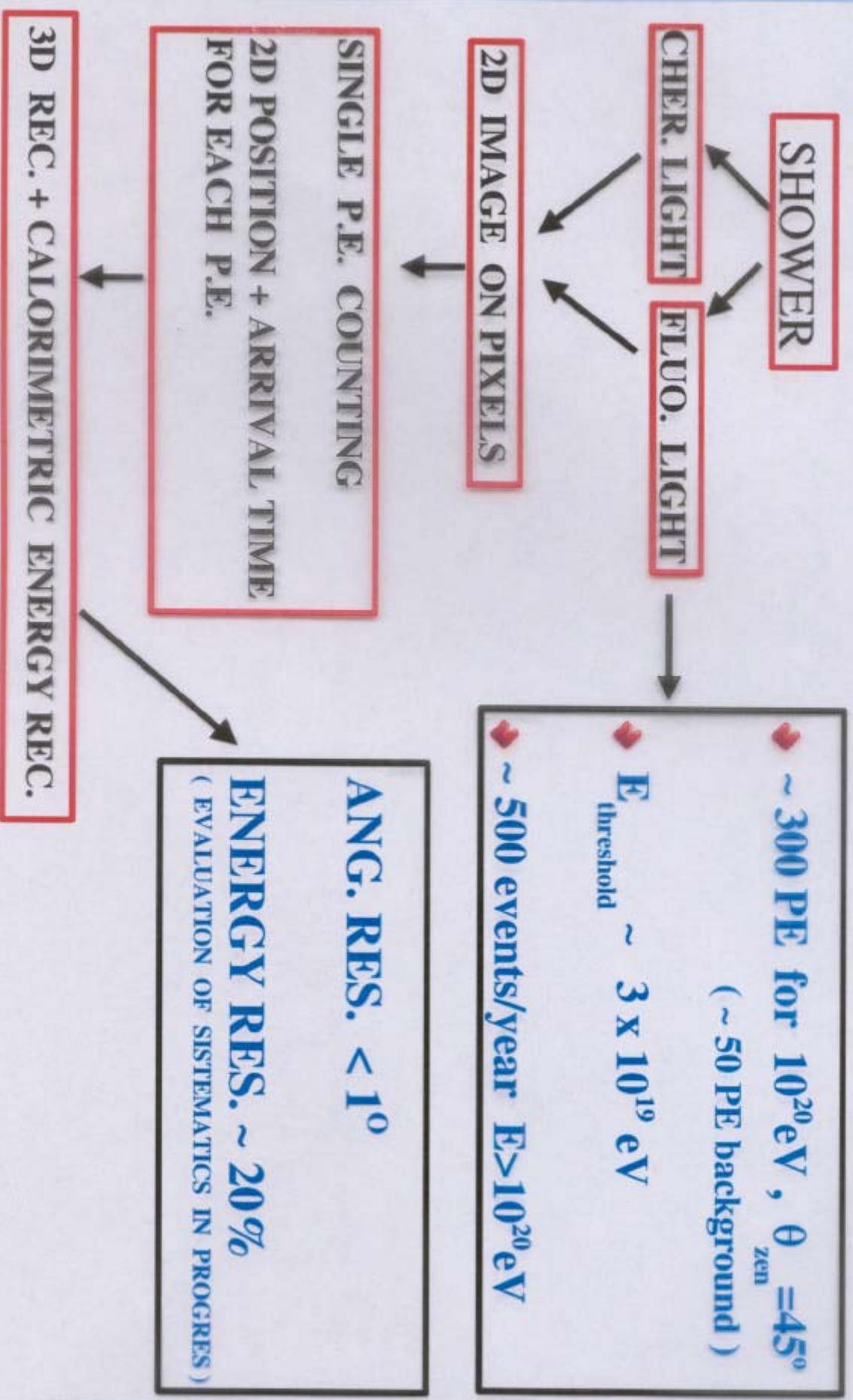
<b>DETECTOR</b>	<b>METHOD</b>	<b>ACCEPTANCE ( km<sup>2</sup> sr ) x duty cycle</b>
AGASA	'ground sampling'	200
HIRES	'fluorescence from ground'	10 <sup>3</sup> ( 0.1 )
————— FUTURE DETECTORS —————		
TA	'fluorescence from ground'	6 x 10 <sup>3</sup> (0.1)
AUGER	'hybrid from ground'	7x 10 <sup>3</sup>
EUSO	'fluorescence from space'	5 x 10 <sup>4</sup> (0.1)
KLYPVE – OWL	.....	.....



$$P^+ \quad E=10^{20} \text{ eV} \quad \theta_{zcn} = 60^\circ$$

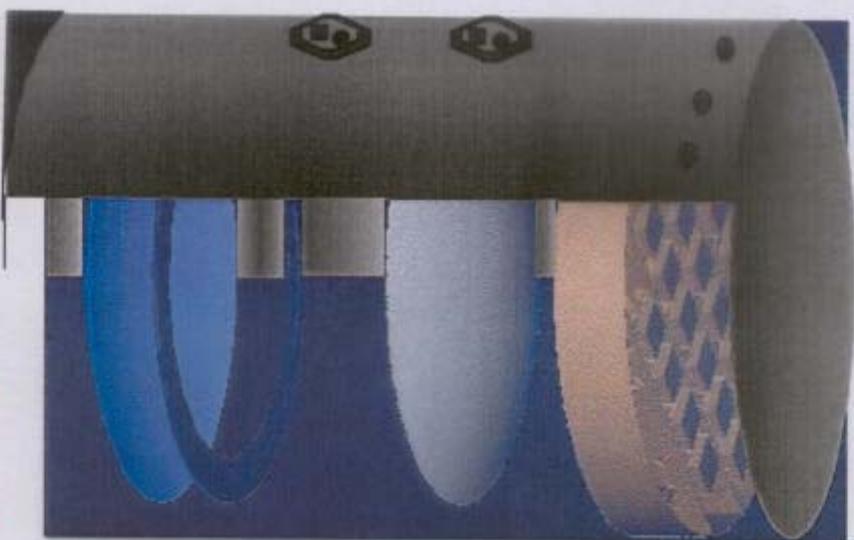


# BASIC OPERATIONAL SCHEME AND PERFORMANCE

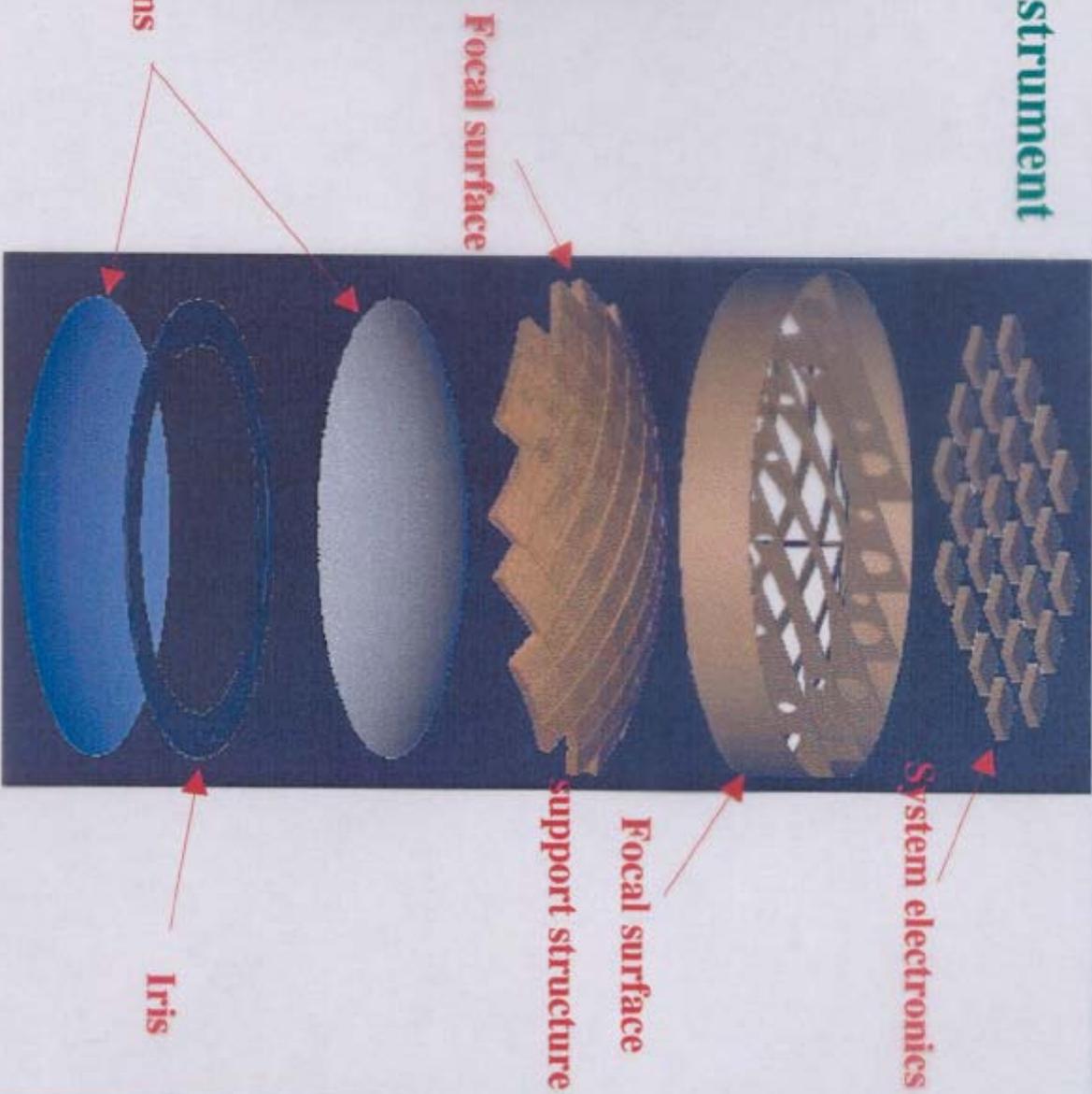


# THE INSTRUMENT

## A monocular compact instrument



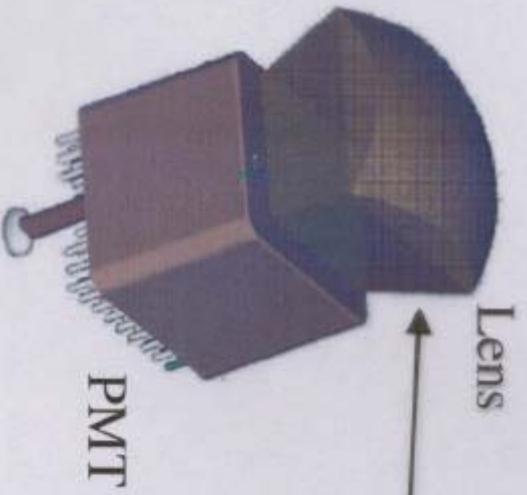
Fresnel lens



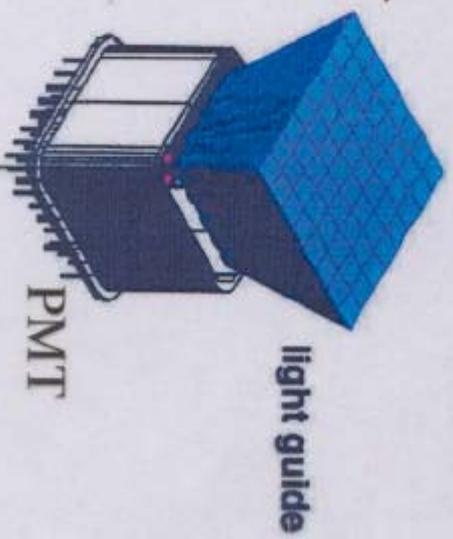
# THE LIGHT DETECTOR

16 or 64 pixels

dead area to be recovered



?



## THE MACROCELL



The macrocell houses 9 microcells, each one has 4 MAPMTs on it.

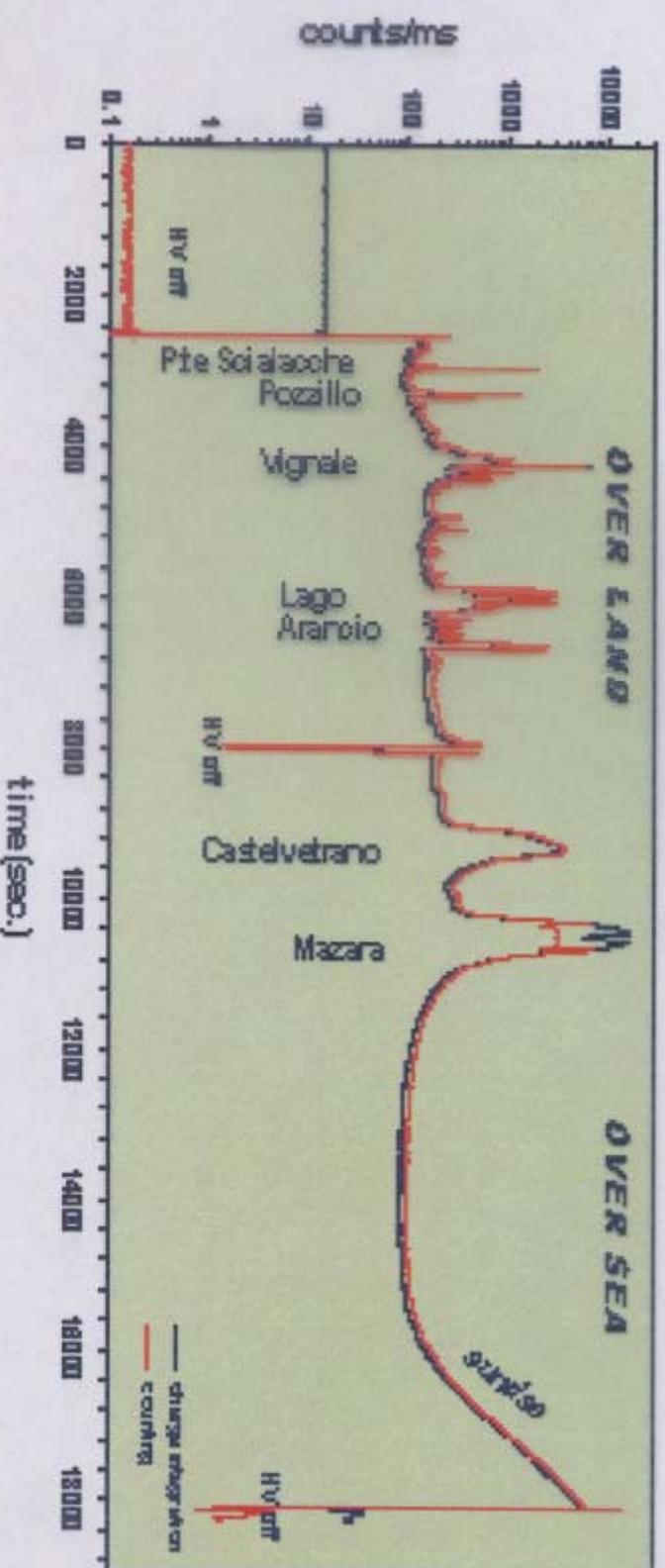
In the back side (not seen) there is the local read-out logic and power supply system. Each macrocell is independent from the others.

The macrocell mechanical structure also supports all the lenses used to focalize the image onto the photocathode sensitive area.

# BACKGROUND

Nightglow background measurement have been carried out using Balloon flight.

BABY data profile Mito-Trapani July 30 1998  
Ica'i - CNR, Palermo, Italy



$\text{background} = 4 \times 10^{11} \text{ ph/m}^2/\text{s}/\text{sr}$

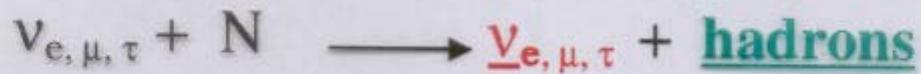
(PRELIMINARY RESULTS)

**DETECTING DOWNWARD GOING V  
WITH EUSO**

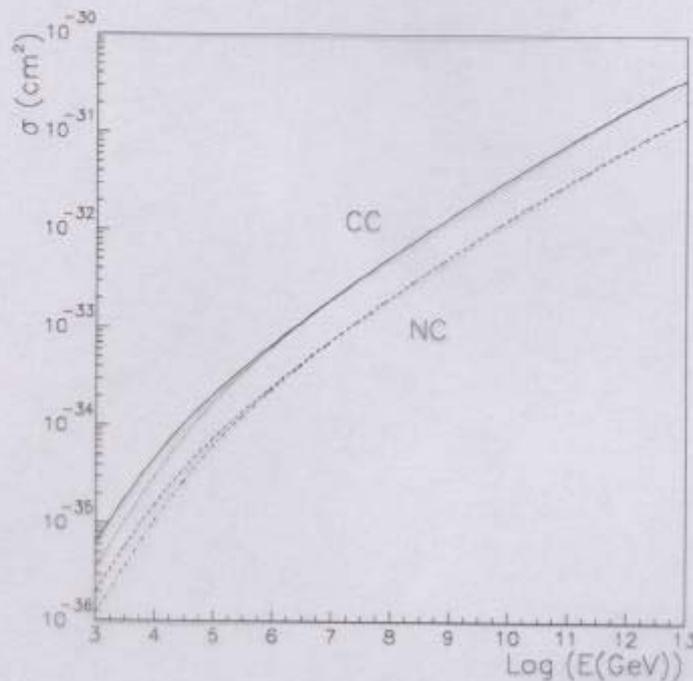
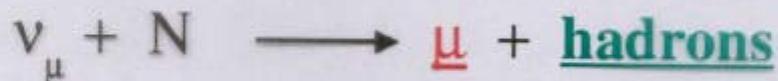
# NEUTRINO INTERACTIONS

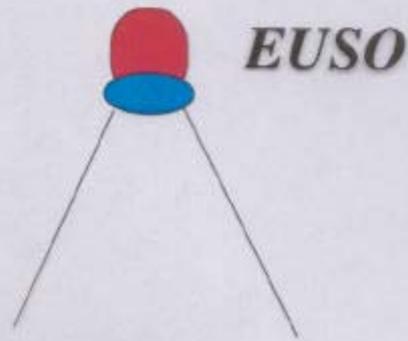
## ANELASTIC SCATTERING ON NUCLEONS

### NEUTRAL CURRENT (NC)

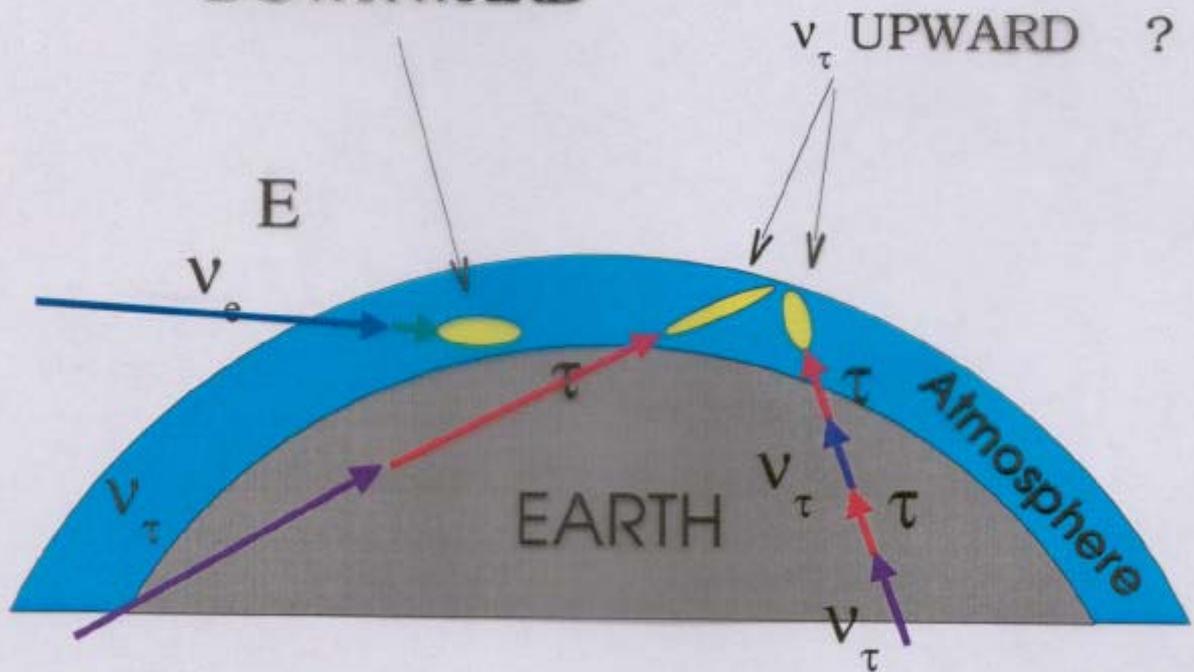


### CHARGED CURRENT (CC)





"standard" NEUTRINO  
 SIGNAL :  $\nu_e (\nu_\mu)$   
 DOWNWARD



TARGET MASS OF ATMOSPHERE  
 IN THE EUSO FIELD OF VIEW :

$$1.5 \times 10^{18} \text{ g} \longrightarrow 1500 \text{ km}^3 \text{ w.e.}$$

$P_+$

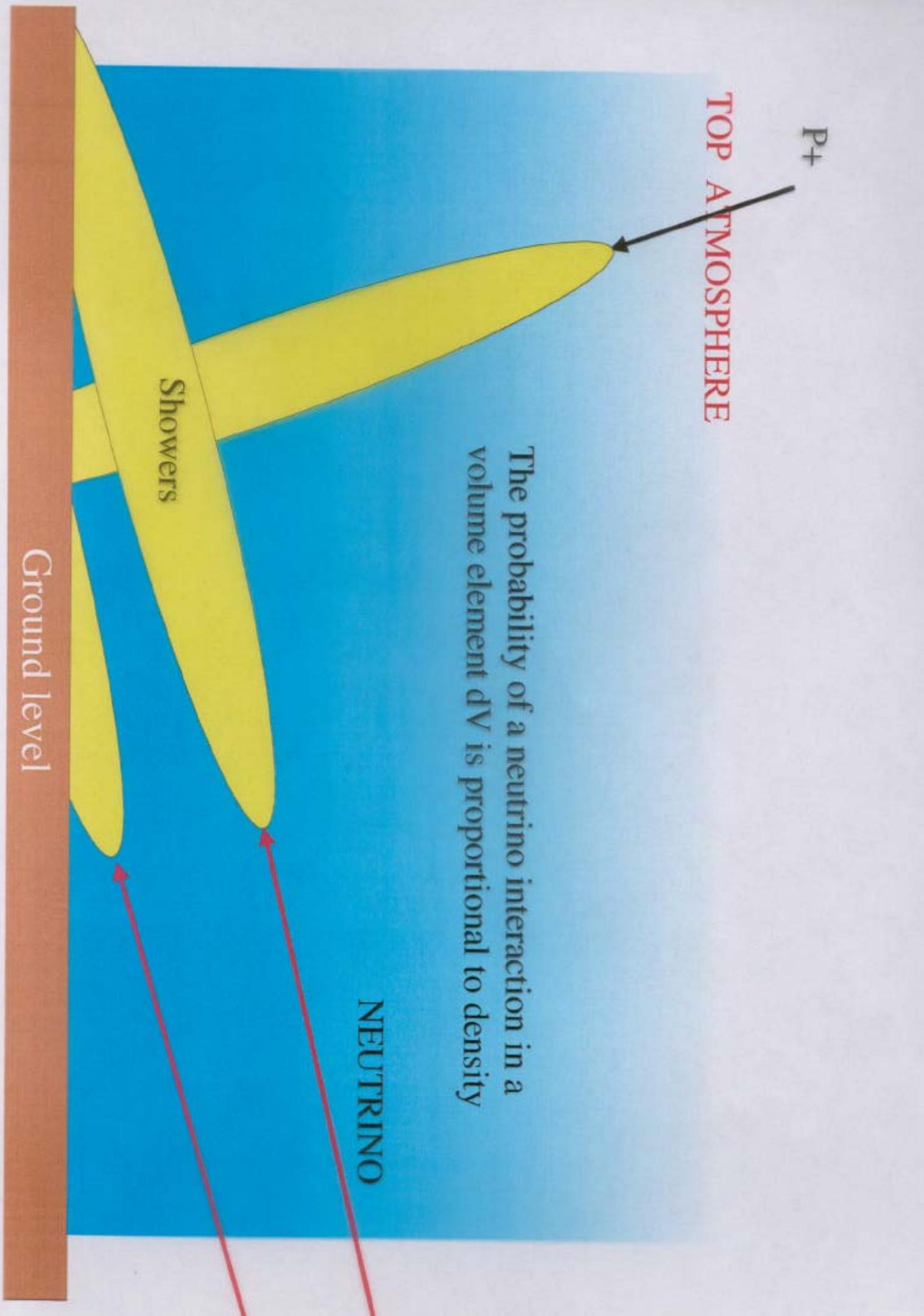
TOP ATMOSPHERE

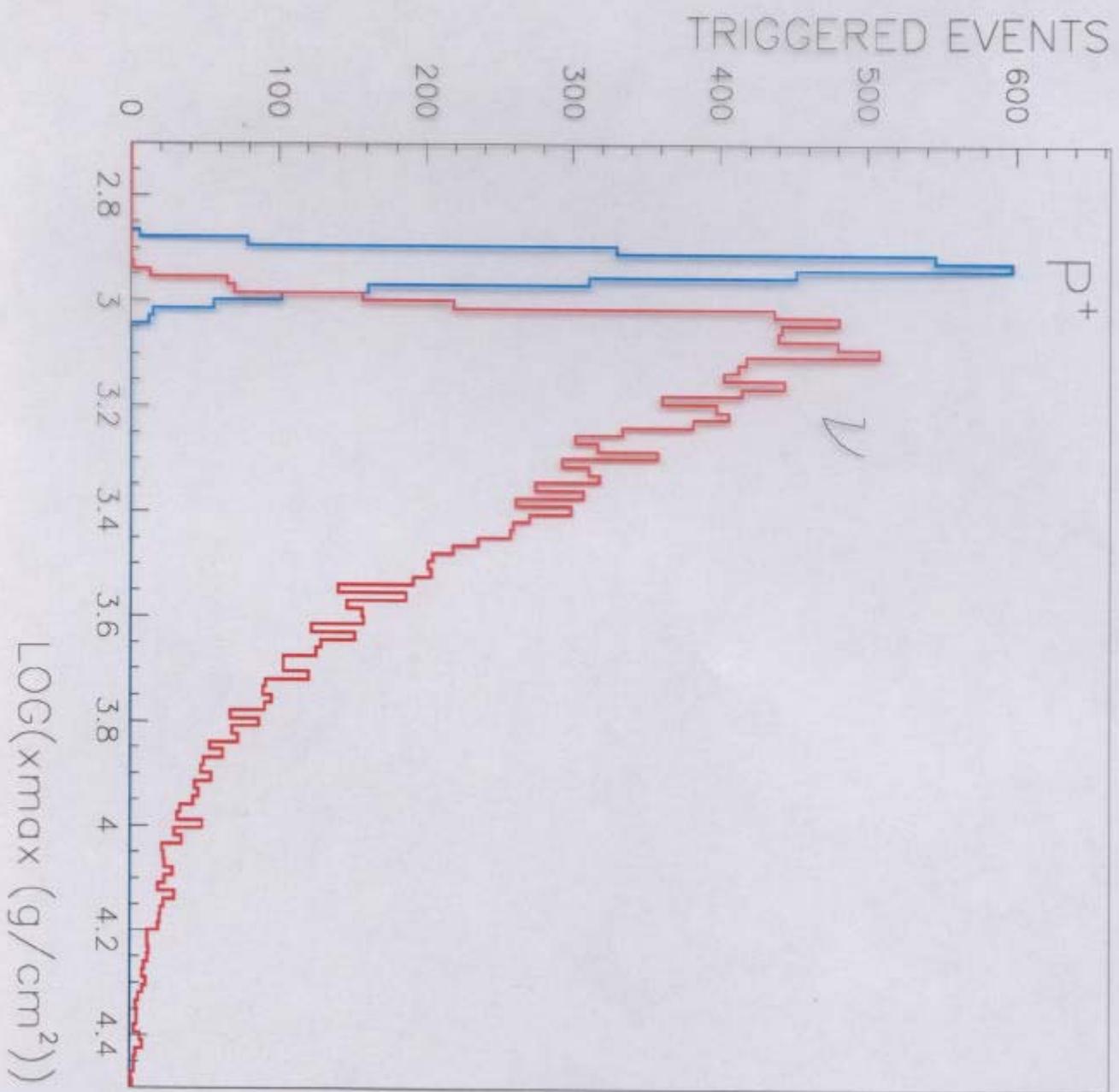
The probability of a neutrino interaction in a volume element  $dV$  is proportional to density

NEUTRINO

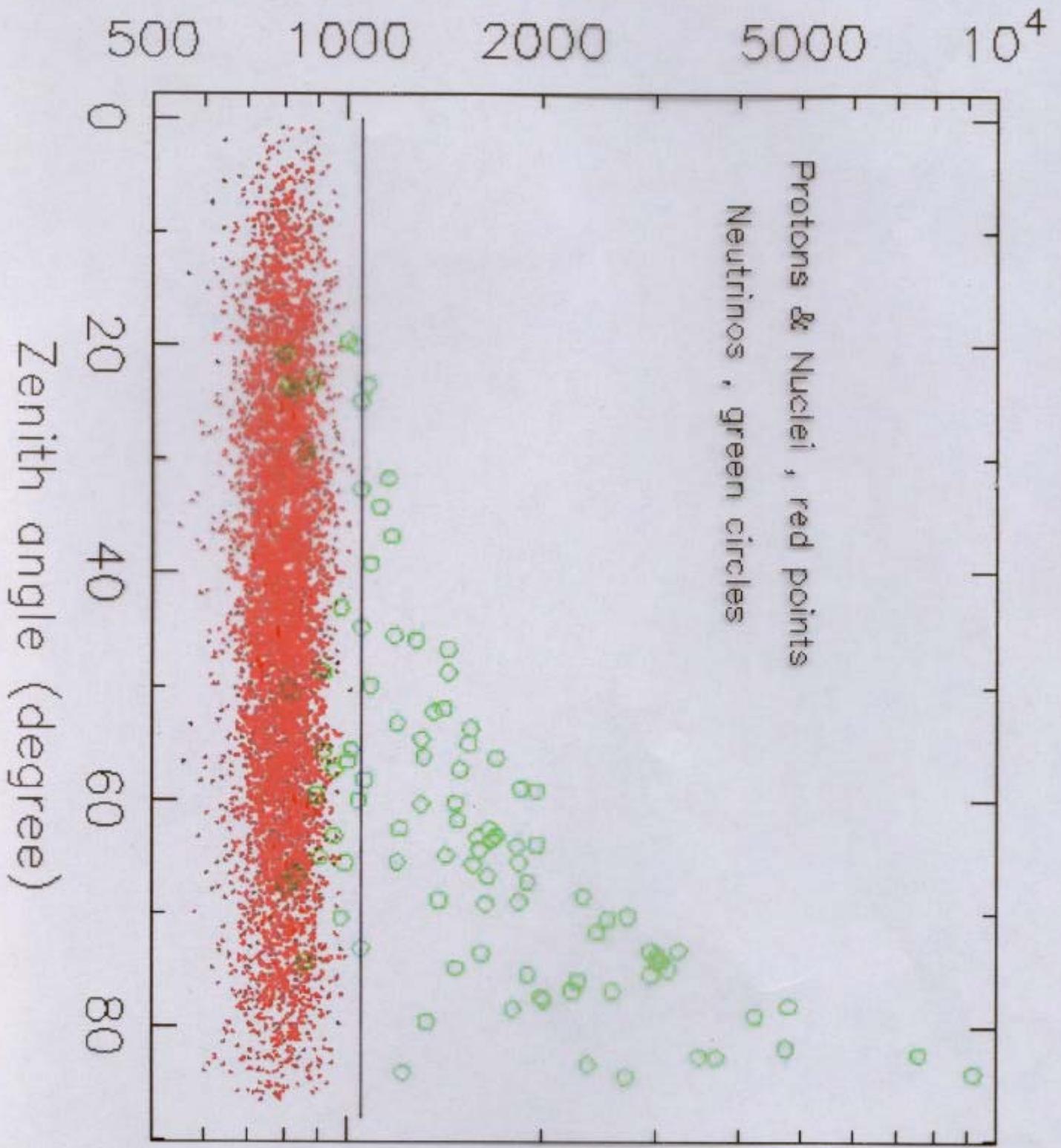
Showers

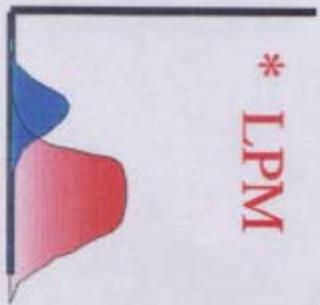
Ground level



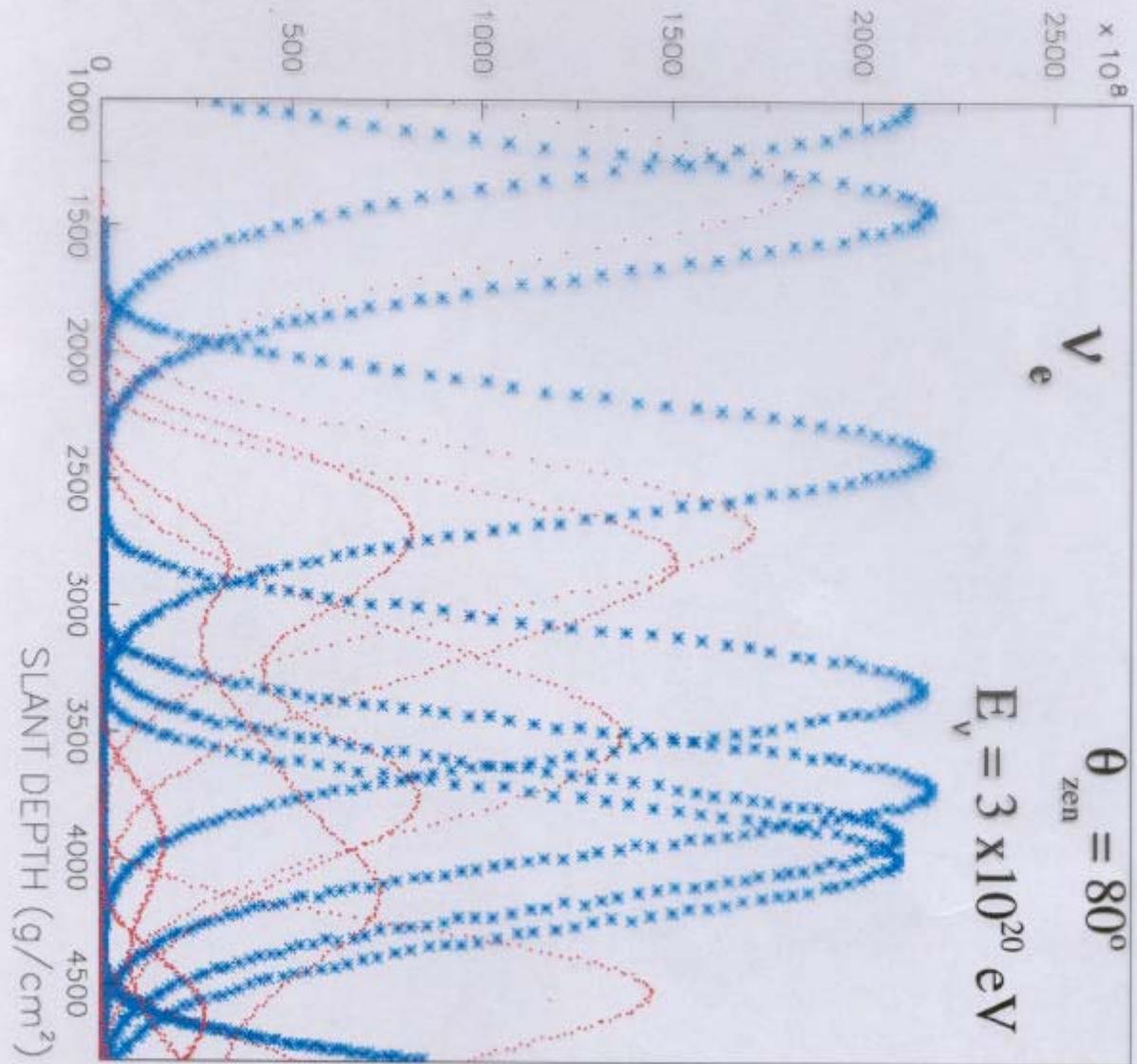


# Xmax (g/cm<sup>2</sup>) – Slant depth

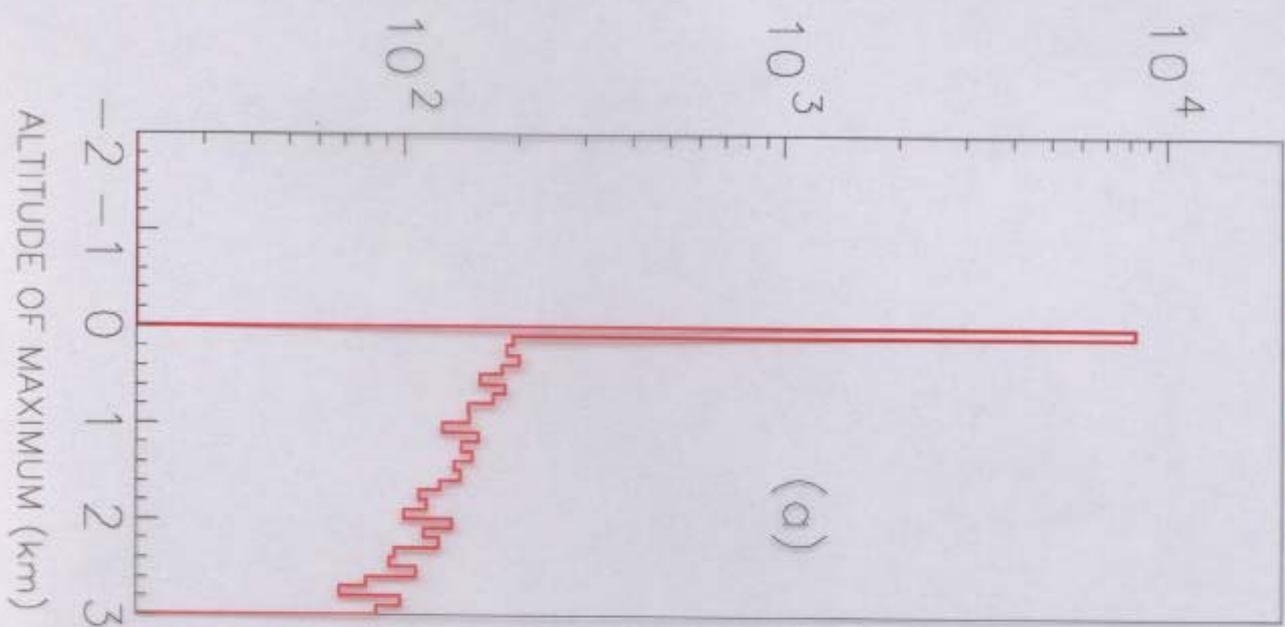




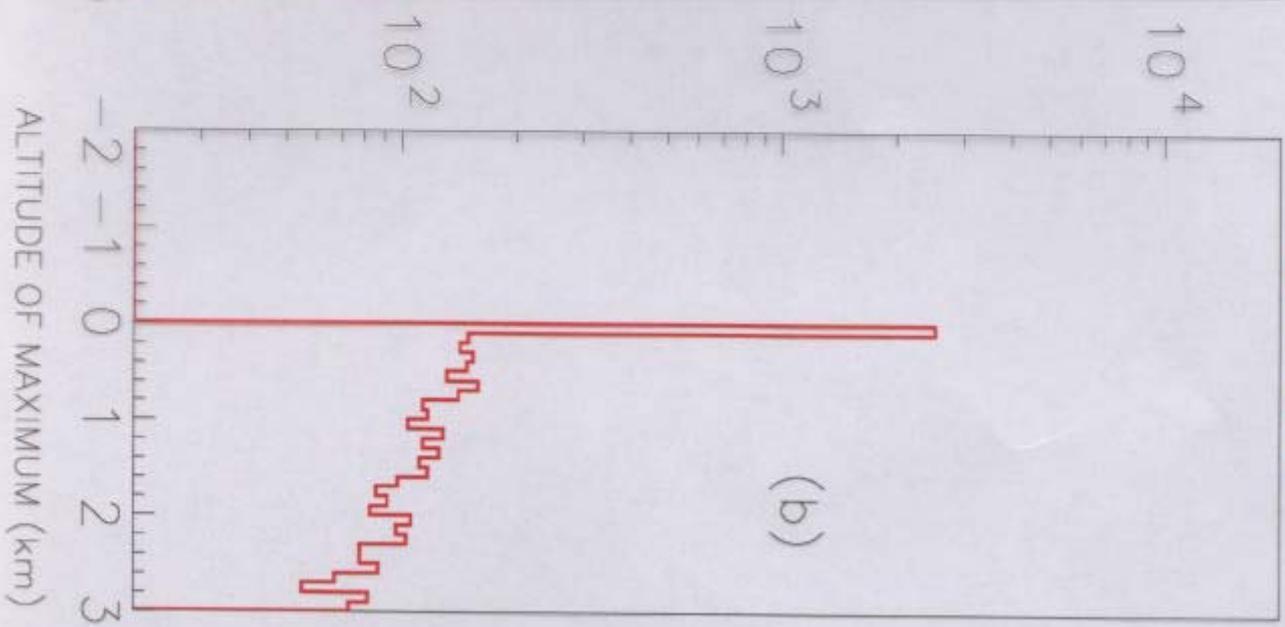
CHARGED PARTICLES



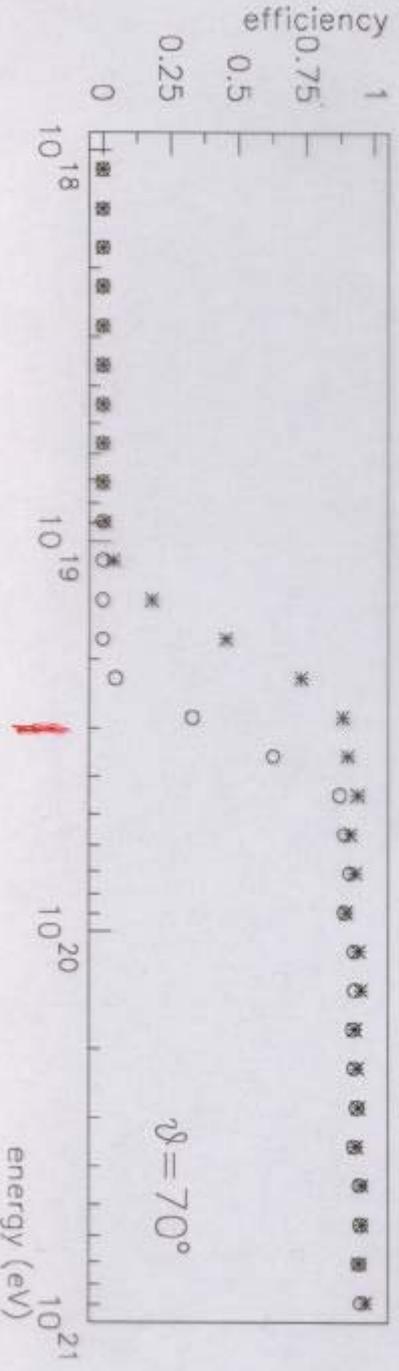
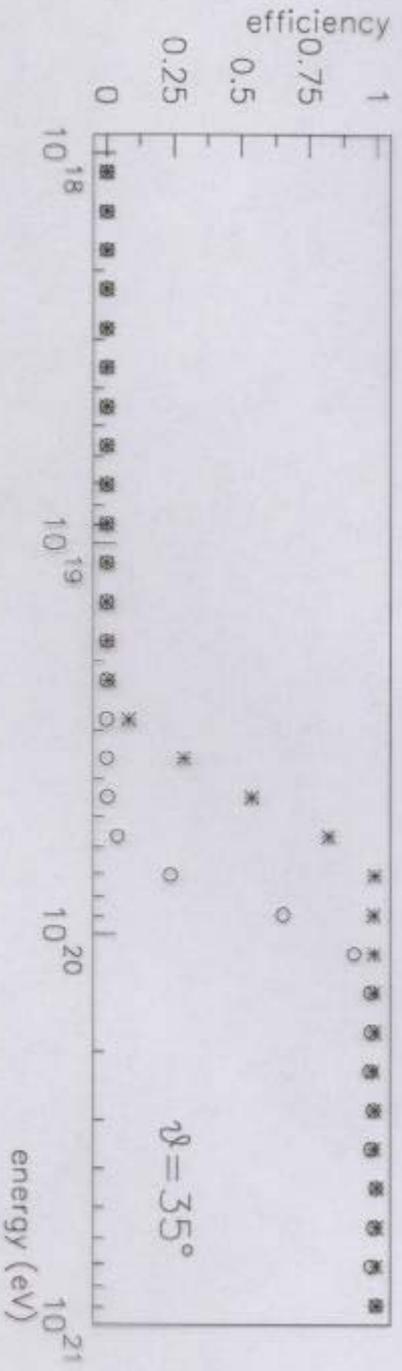
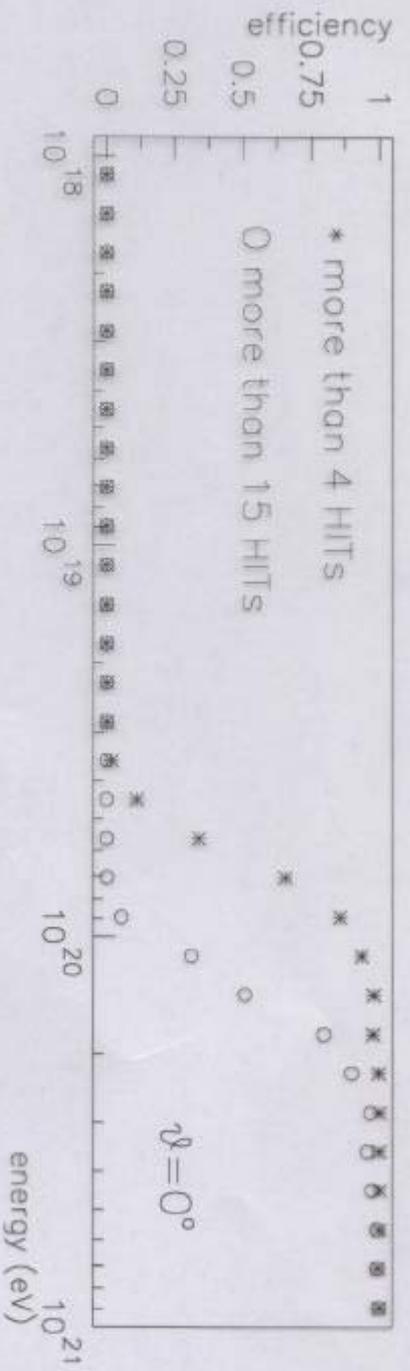
**generated**



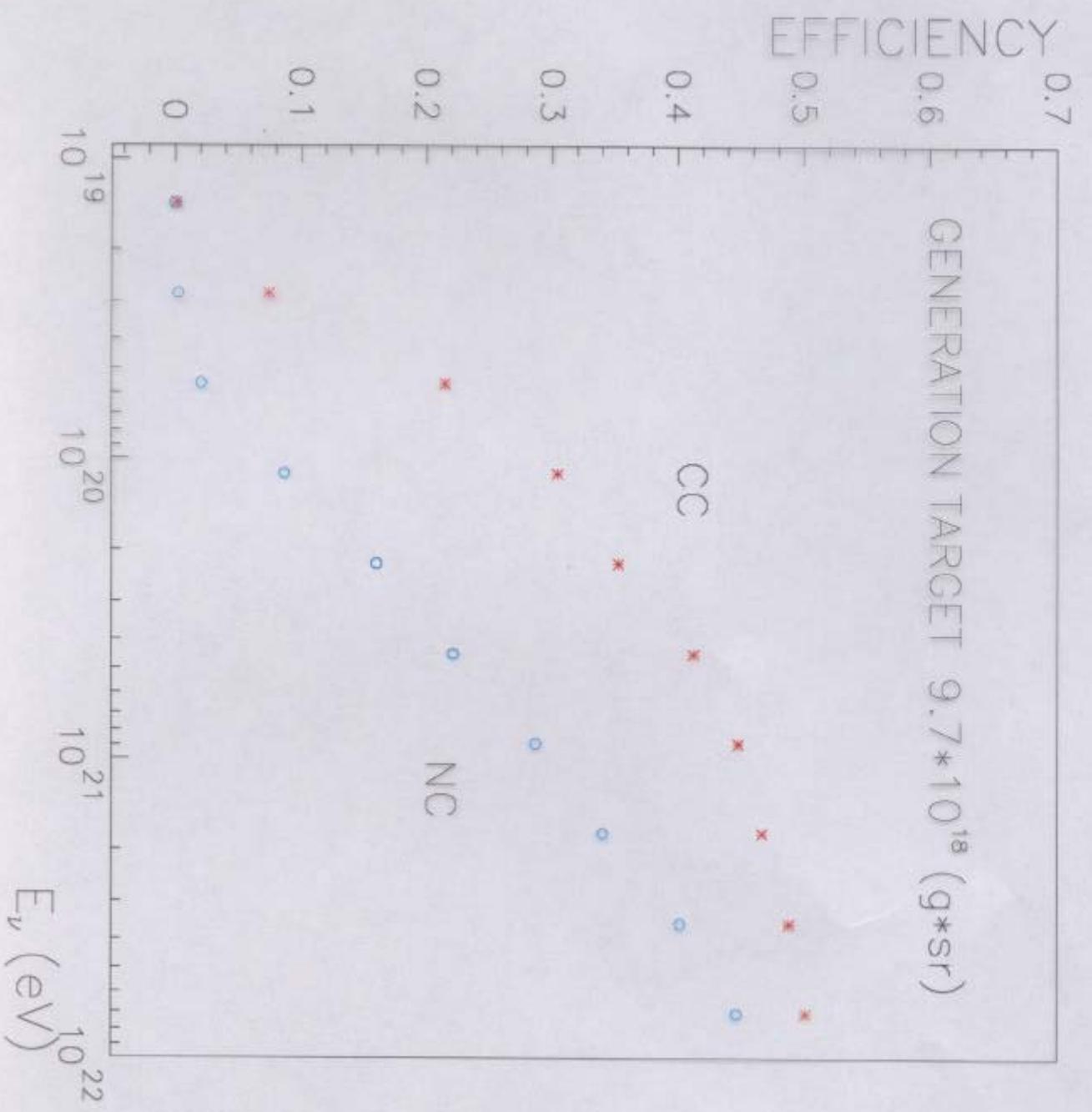
**detected**



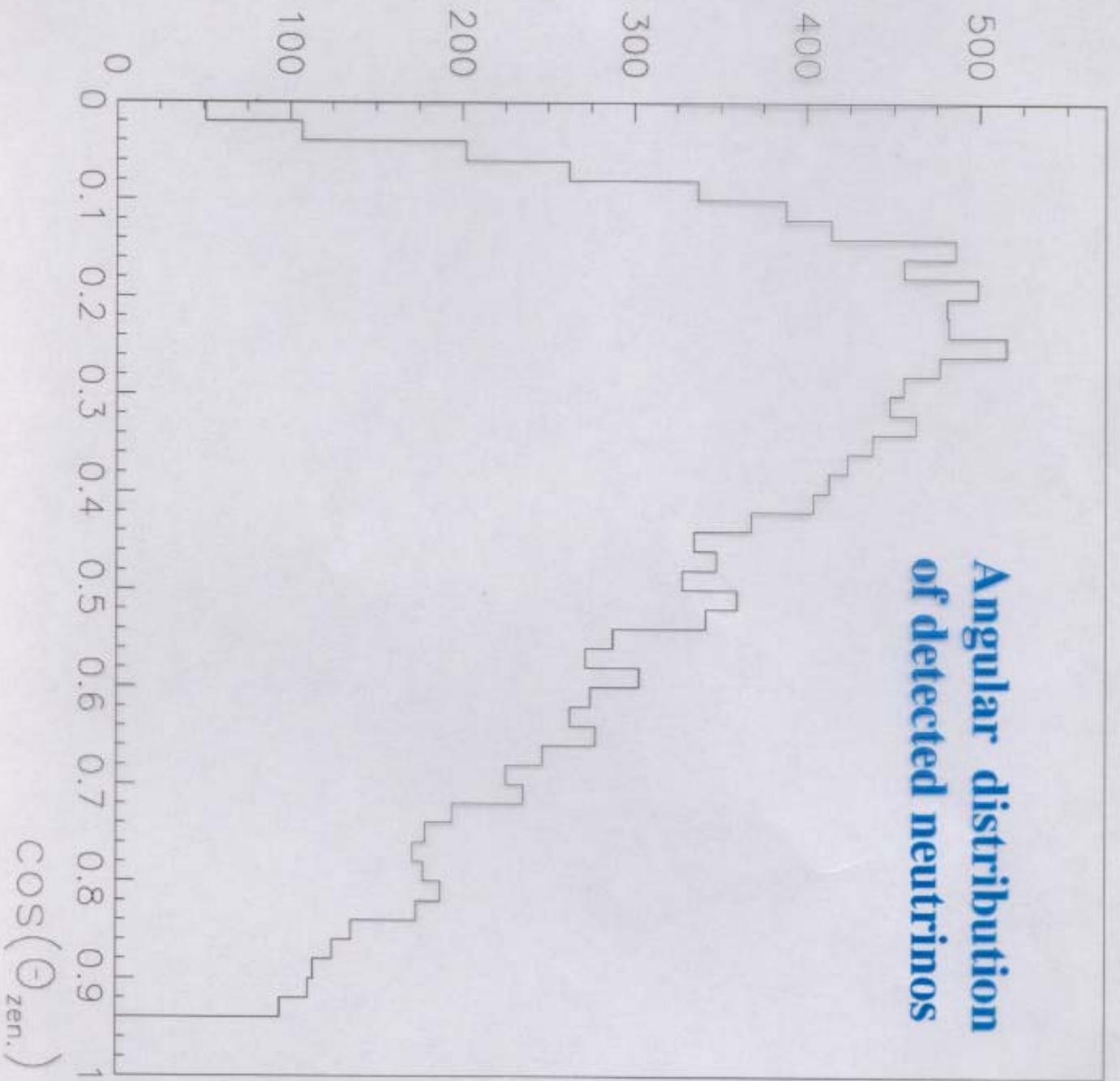
# protons



( selection : trigger + cherenkov + xmax selection )



# Angular distribution of detected neutrinos



## NEUTRINOS FROM TOP DOWN MODELS

3 years	TD1	TD2	TD3	<del>TD4</del>	MR
INTERACTIONS INSIDE TARGET *0.1	98	94	22	816	396
EVENTS DETECTED	21	15	6	188	61

## NEUTRINOS FROM GZK AND AGN

3 years	GZK1	GZK2	GZK3	AGN1	<del>AGN2</del>
INTERACTIONS INSIDE TARGET *0.1	0.5	4.6	26	1	11
EVENTS DETECTED	0.1	0.7	3.4	0.16	2

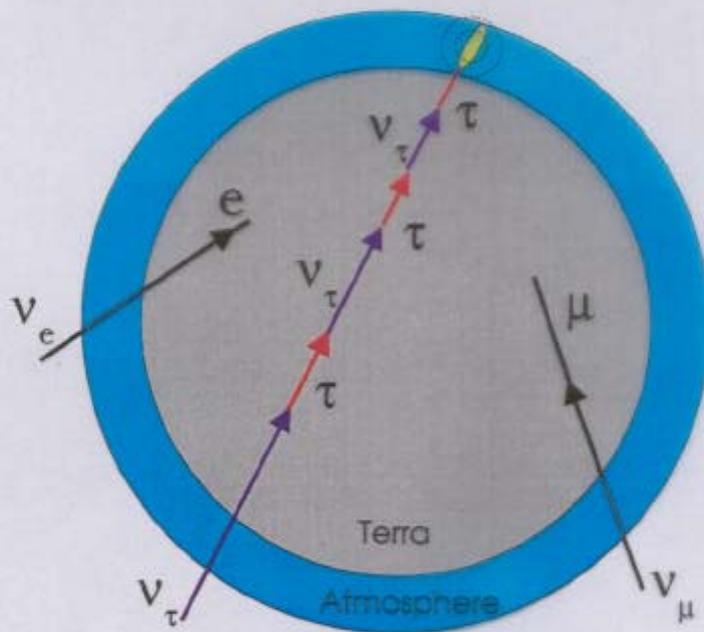
**EAS INDUCED BY UPWARD GOING  
TAU EMERGING FROM THE EARTH**

(BOTAI, GURGOLOA)  
SUBMITTED TO  
ASTR. PHYS.

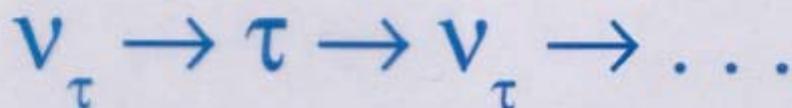
$\tau$  INDUCED BY  $\nu_\tau$  IN THE EARTH:  
NEW OBSERVATIVE CHANNEL FOR COSMIC  
NEUTRINOS ?

$$E_\nu = 10^{15} \text{ eV} \quad \mathcal{L}_{\text{intCC}} \sim R_T$$

$\nu_e$   $e$   $\nu_\mu$  ARE PRACTICALLY ABSORBED AFTER ONE CC



regeneration mechanism due to  $\tau$   
decay in flight



# $\tau$ energy loss

## Radiative processes

- Bremsstrahlung  $\tau + Z \rightarrow \tau + Z + \gamma$
- direct pair production  $\tau + Z \rightarrow \tau + Z + e^+e^-$
- photonuclear interaction  $\tau + Z \rightarrow \tau + \text{hadrons}$

Bremsstrahlung

$$\sigma_{\text{brems}} \sim \left(\frac{m_e}{m_\tau}\right)^2$$

direct pair production

$$\sigma_{\text{dpp}} \sim \frac{m_e}{m_\tau}$$

photonuclear

$$\sigma_{\text{phnuc}} \sim \frac{1}{m_\tau}$$

radiation length for  $\tau$ :

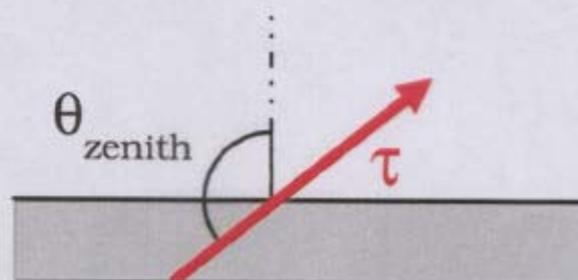
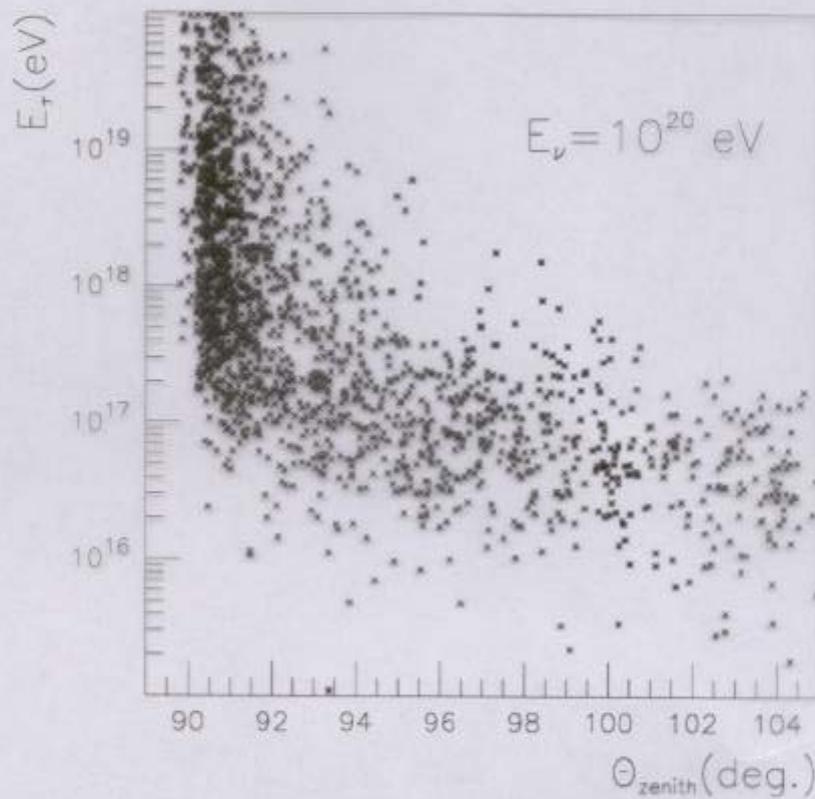
$$R_{\text{nuc}} \sim R_{\text{pair}} \ll R_{\text{brems}}$$

## DECAY

$$\tau \rightarrow \nu_\tau + \dots \quad \text{TAUOLA library}$$

# SIMULATION OF PROPAGATION THROUGH THE EARTH

$$10^{14}\text{eV} \leq E_\nu \leq 10^{22}\text{eV}$$



# DEFINITION OF EFFECTIVE APERTURE

IT CONTAINS ONLY AND COMPLETELY  
THE PHYSICS OF PROPAGATION  
THROUGH THE EARTH

**FOR ISOTROPIC FLUXES:**

**EFFECTIVE  
APERTURE**  
(sr)

$A_{\text{eff}}(E_v, E_{\text{thr}})$

$$A_{\text{eff}}(E_v, E_{\text{thr}}) = \int_{\Omega} P_{\nu, \rightarrow \tau}(\vartheta_{\text{zenith}}, E_v, E_{\text{thr}}) |\cos(\vartheta_{\text{zenith}})| d\Omega$$

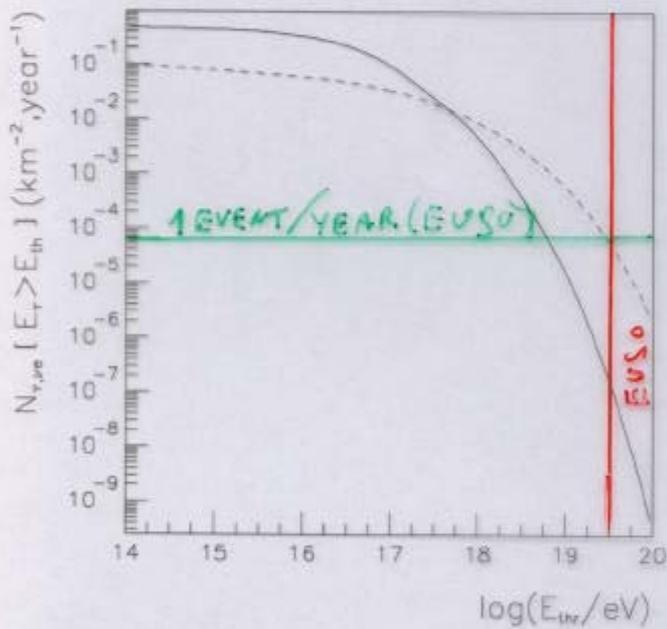
**NUMBER OF EMERGING  $\tau$  FOR UNIT EARTH SURFACE :**

$$N_{\tau}(E_{\tau} > E_{\text{thr}}) = \int_{E_v} A_{\text{eff}}(E_v, E_{\text{thr}}) \frac{d^2 N_{\nu}}{dE_v d\Omega} dE_v$$

# FLUXES OF EMERGING $\tau$

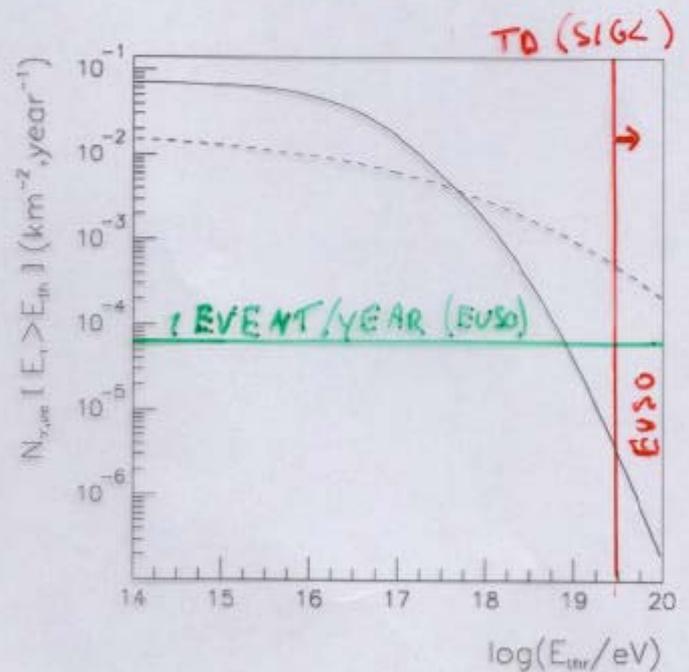
**BOTTOM-UP**

AGN



**TOP-DOWN**

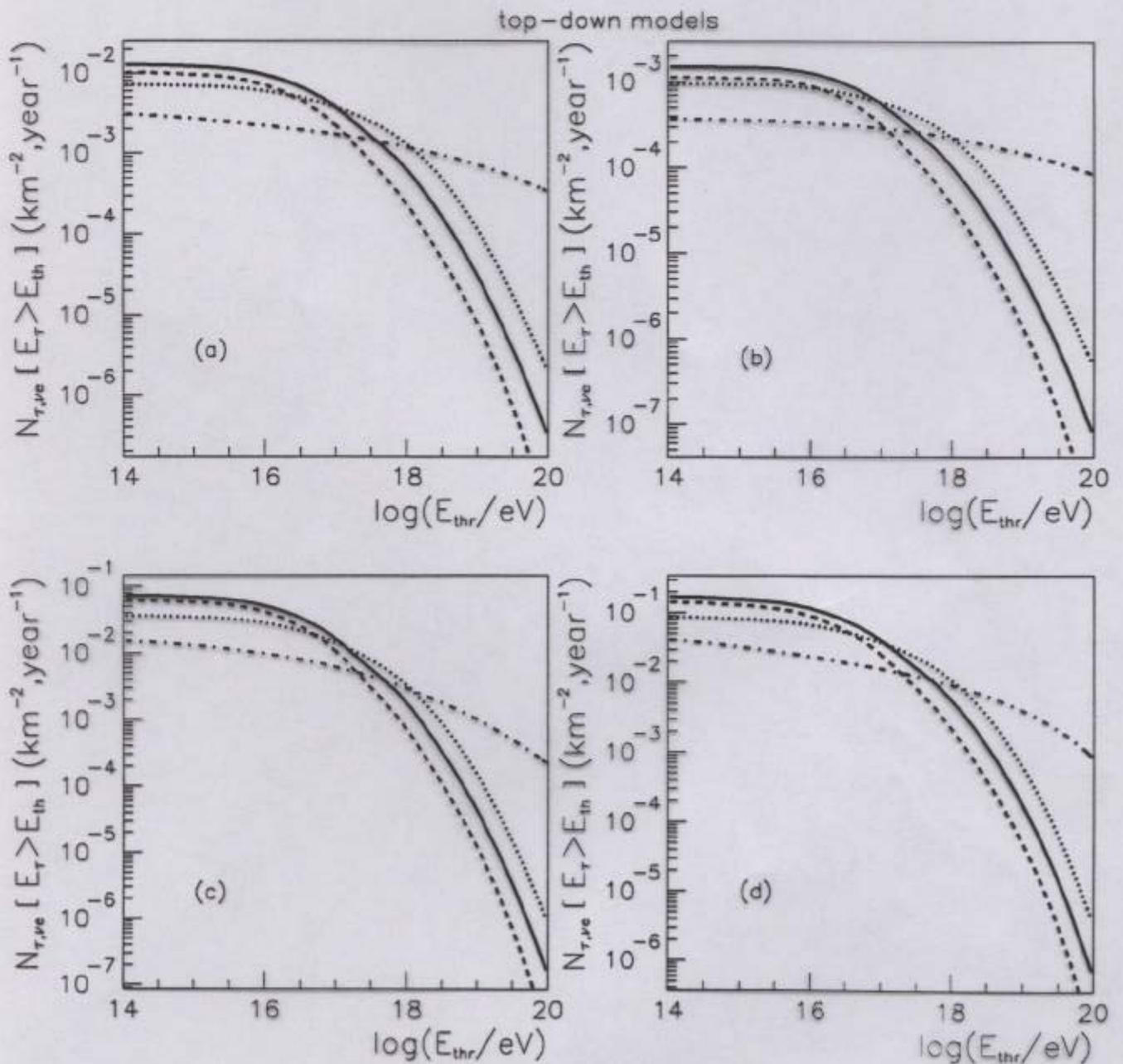
TOP. DEF.



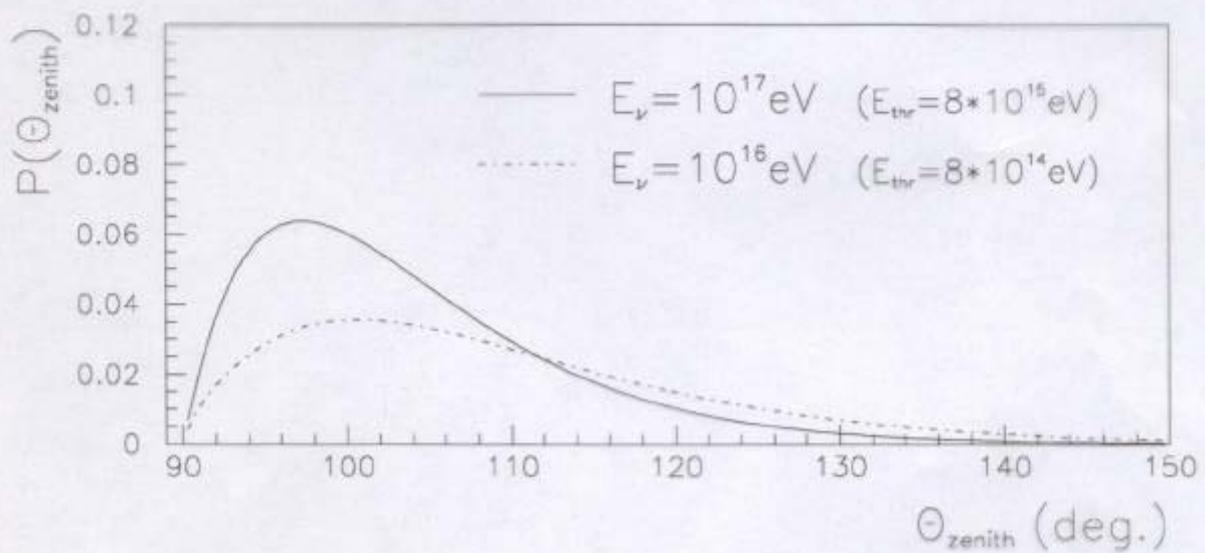
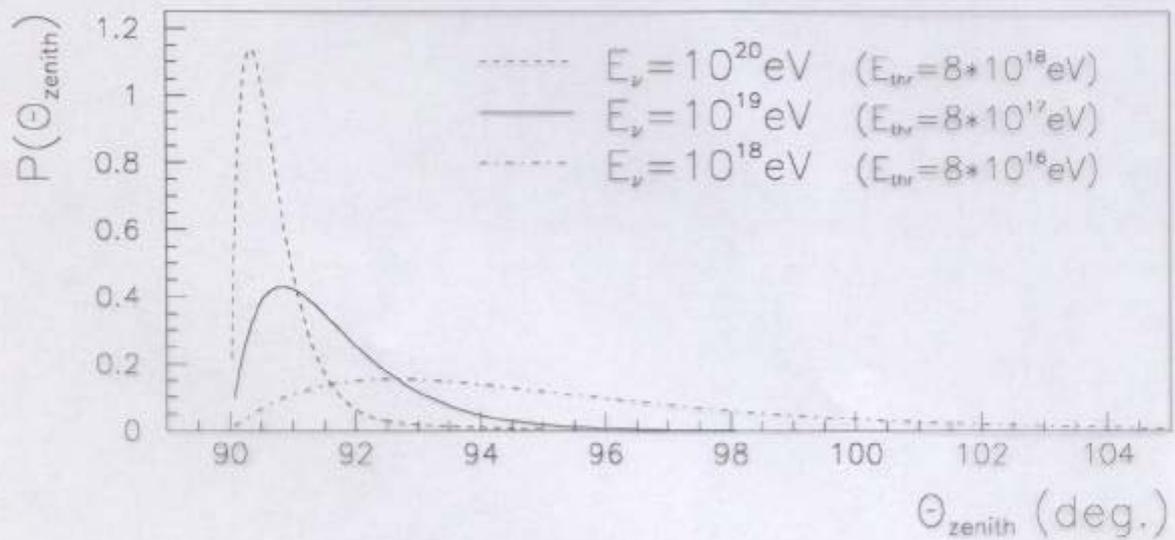
CONDITION FOR DETECTION :

$$E_{thr} < 10^{18} \text{ eV} \quad S > 10^3 \text{ km}^2$$

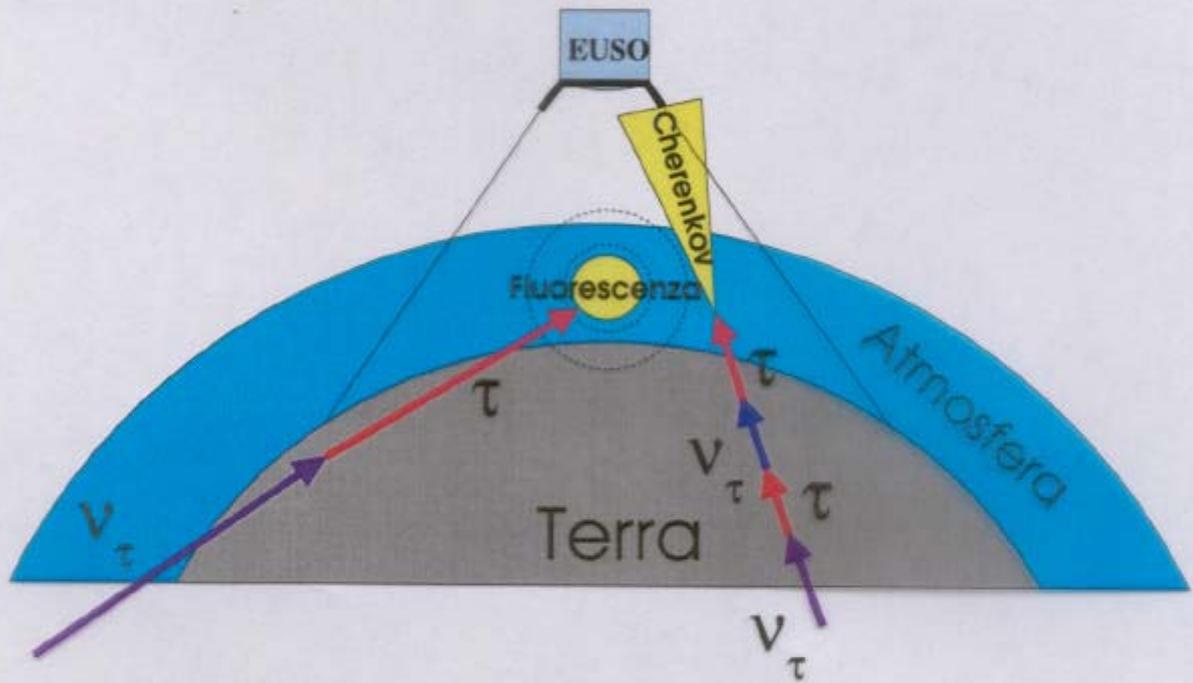
- a) TD → Protheroe and Stanev, Phys. Rev. Lett. 77 (1996)
- b) TD → Sigl, Phys. Lett. B 392 (1997)
- c) TD → Sigl, Lect. Notes Phys. 556, 2000
- d) MR → O. E. Kalashev et al. astro-ph/9911035, 1999



# ANGULAR DISTRIBUTION FOR EMERGING $\tau$



## DIRECT CHERENKOV LIGHT DETECTION ?



### DIRECT CHERENKOV LIGHT (very preliminary) :

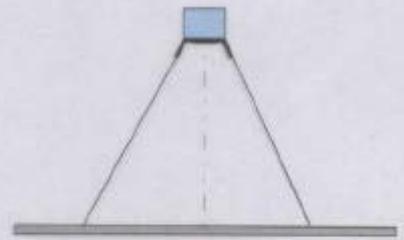
$$\theta_{\text{cher}} = 1.3^\circ$$

DETECTION IN ONE PIXEL

threshold energy (4 pe):  $\sim 2 \cdot 10^{15}$  eV

EFFECTIVE AREA  $\sim$  AREA OF CHERENKOV CONE  
 $\sim 250$  km<sup>2</sup>

standard configuration



events selected only near the vertical



no detection

inclined configuration  $\sim 40^\circ$



from optimistic AGN flux  $\sim 10$  events/year

## CONCLUSIONS

- EUSO is a candidate for EHE neutrino astronomy ( $E \sim 10^{20}$  eV)
- Good P- $\nu$  discrimination
- Detection efficiency for neutrinos is lower than for protons
- Some tens of events expected from top-down models
- Detection of upward  $\tau$  neutrinos require lower energy thresholds