PIERRE AUGER OBSERVATORY

Update of the Auger limits on the diffuse flux of Neutrinos

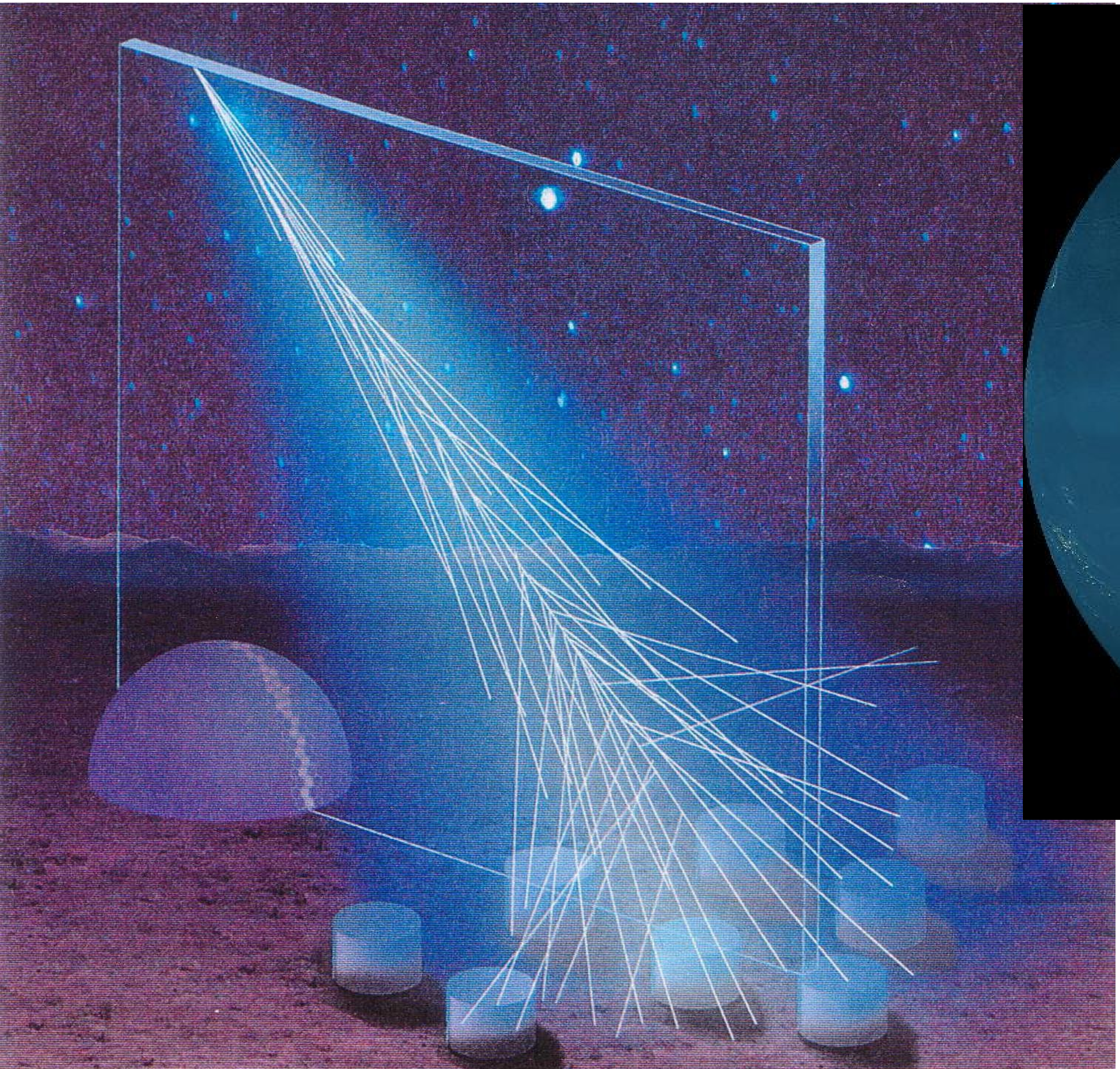
Pierre Auger Collaboration

March 12, 2009

XIII workshop on Neutrino Telescopes, Venezia

The PIERRE AUGER OBSERVATORY

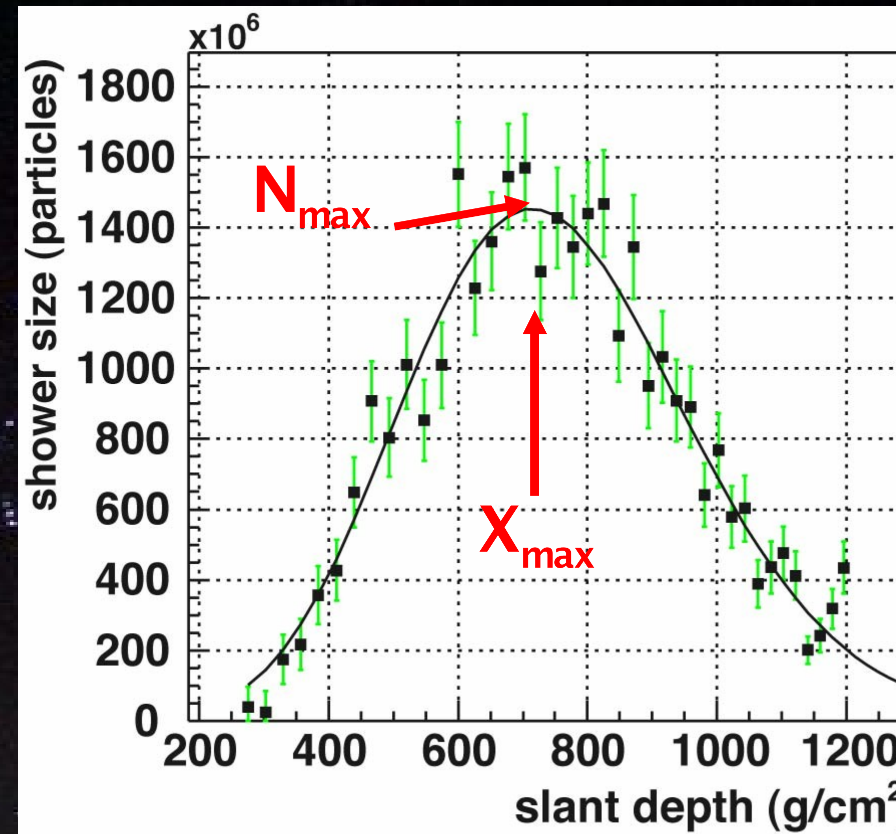
A huge (3000 km²) hybrid detector of Cosmic Rays above $10^{18.5}$ eV



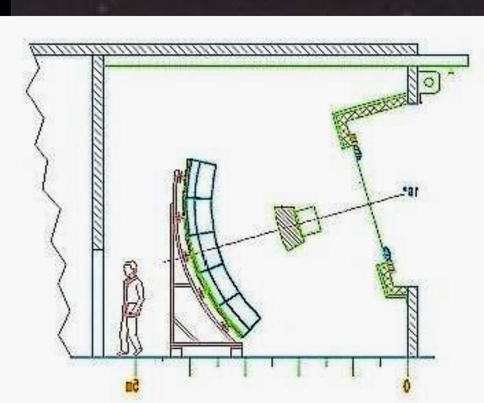
Malargüe @ 1400 m a.s.l.

Fluorescence Detector

Longitudinal profile :

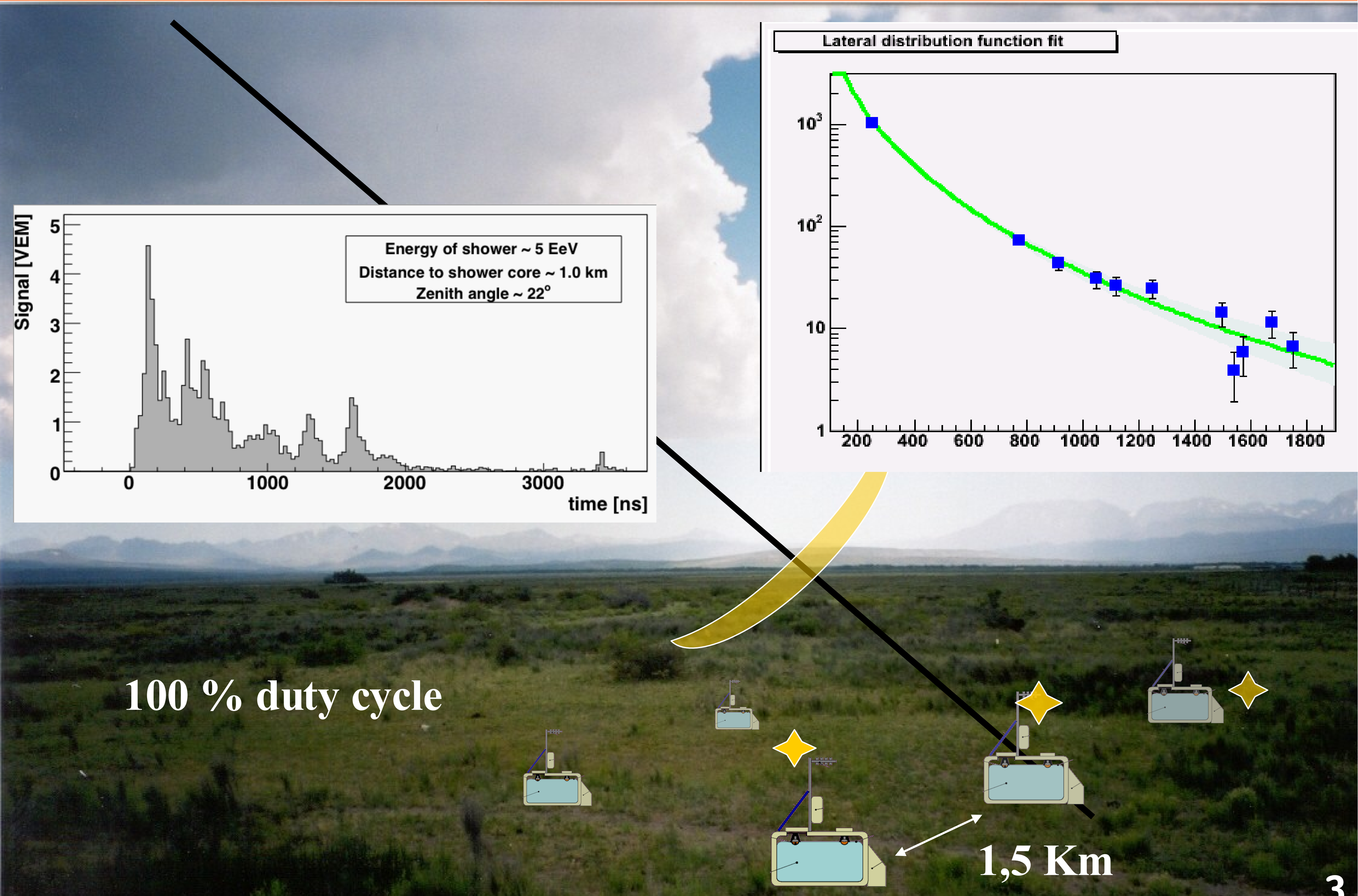


Fluorescence light

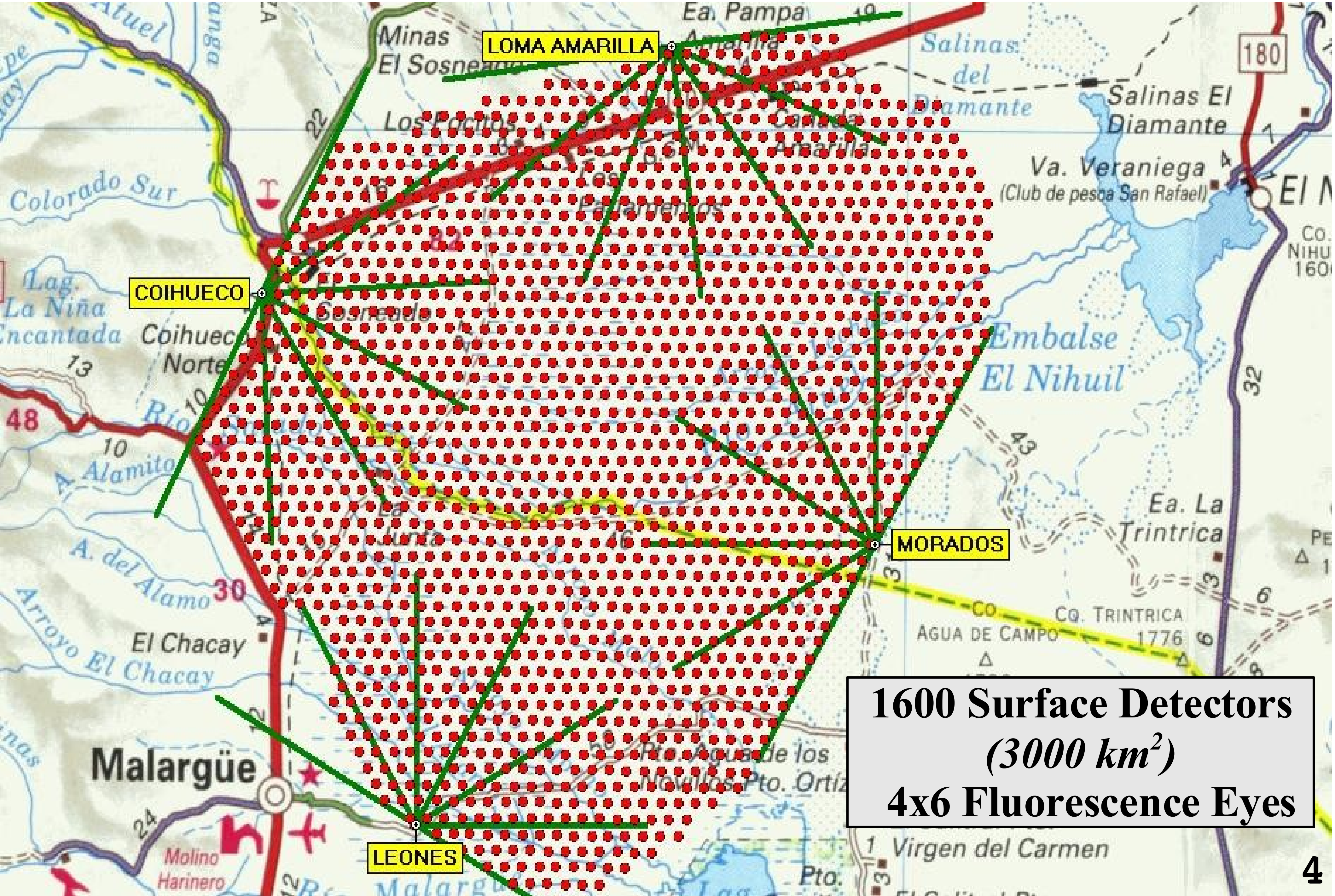


Statistically limited due to 10 % duty cycle

Surface Detector



The PIERRE AUGER OBSERVATORY

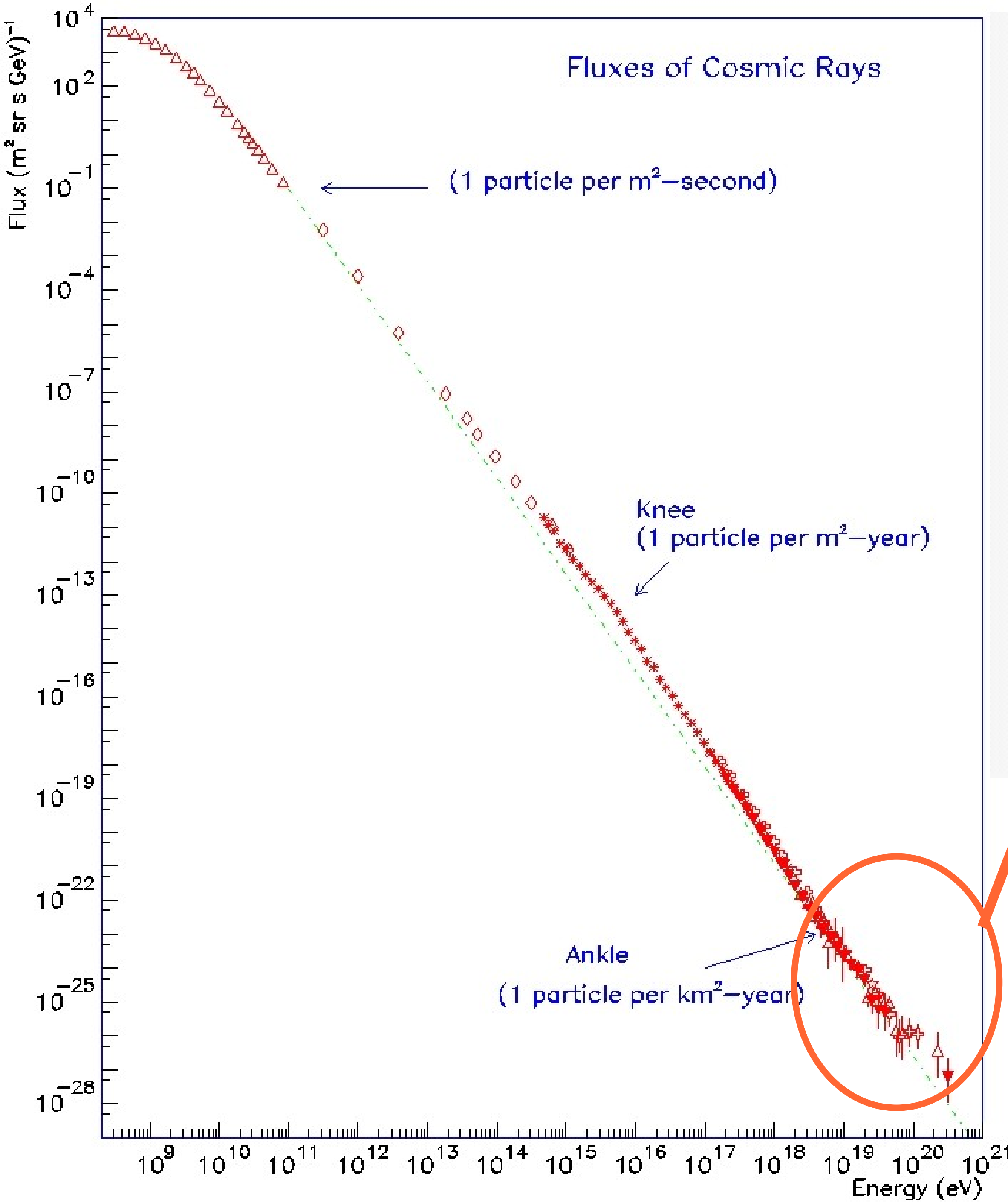


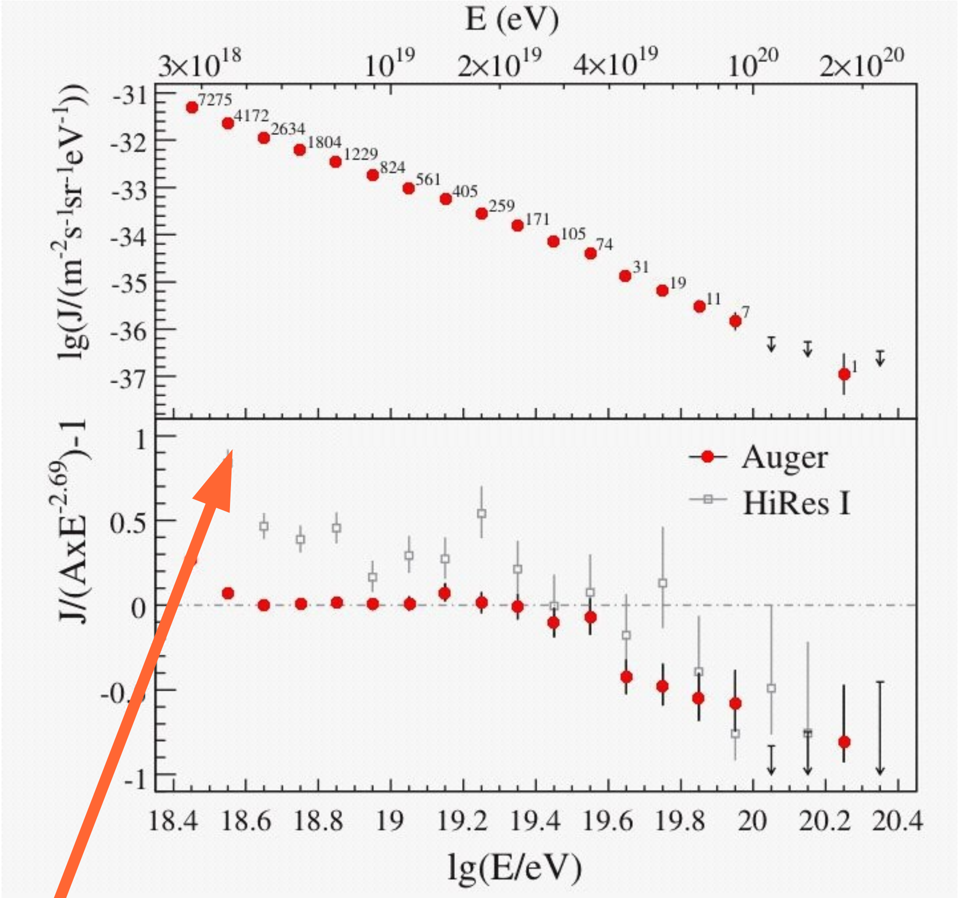
1600 Surface Detectors

(3000 km^2)

4x6 Fluorescence Eyes

Ultra High Energy COSMIC RAYS

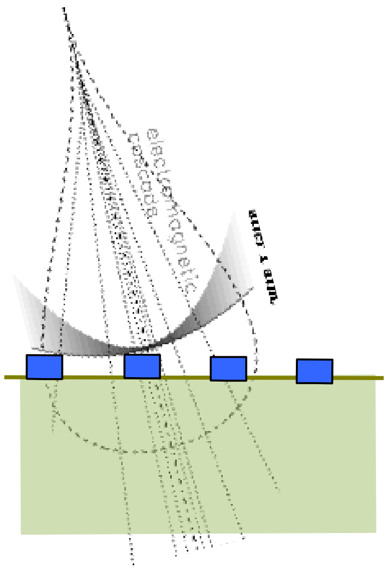


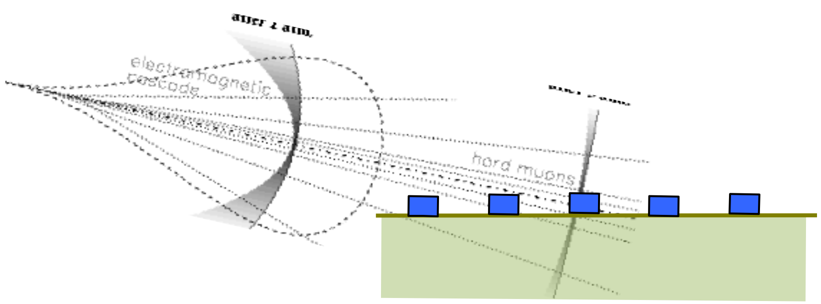


But the Pierre Auger Observatory also have the capability of detecting Ultra High Energy ν

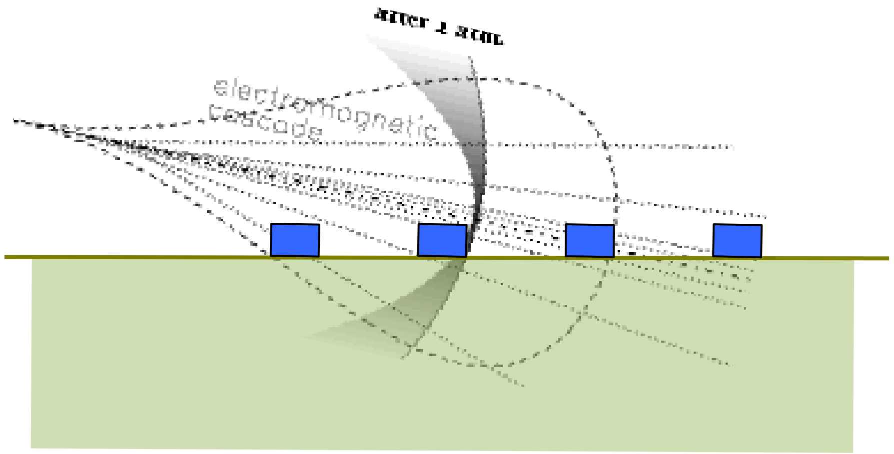
Neutrino Characteristics

"Standard" CR





Neutrino



For a very inclined shower (above 70 deg), the presence of ***electromagnetic*** component is a clear signature of a neutrino shower.

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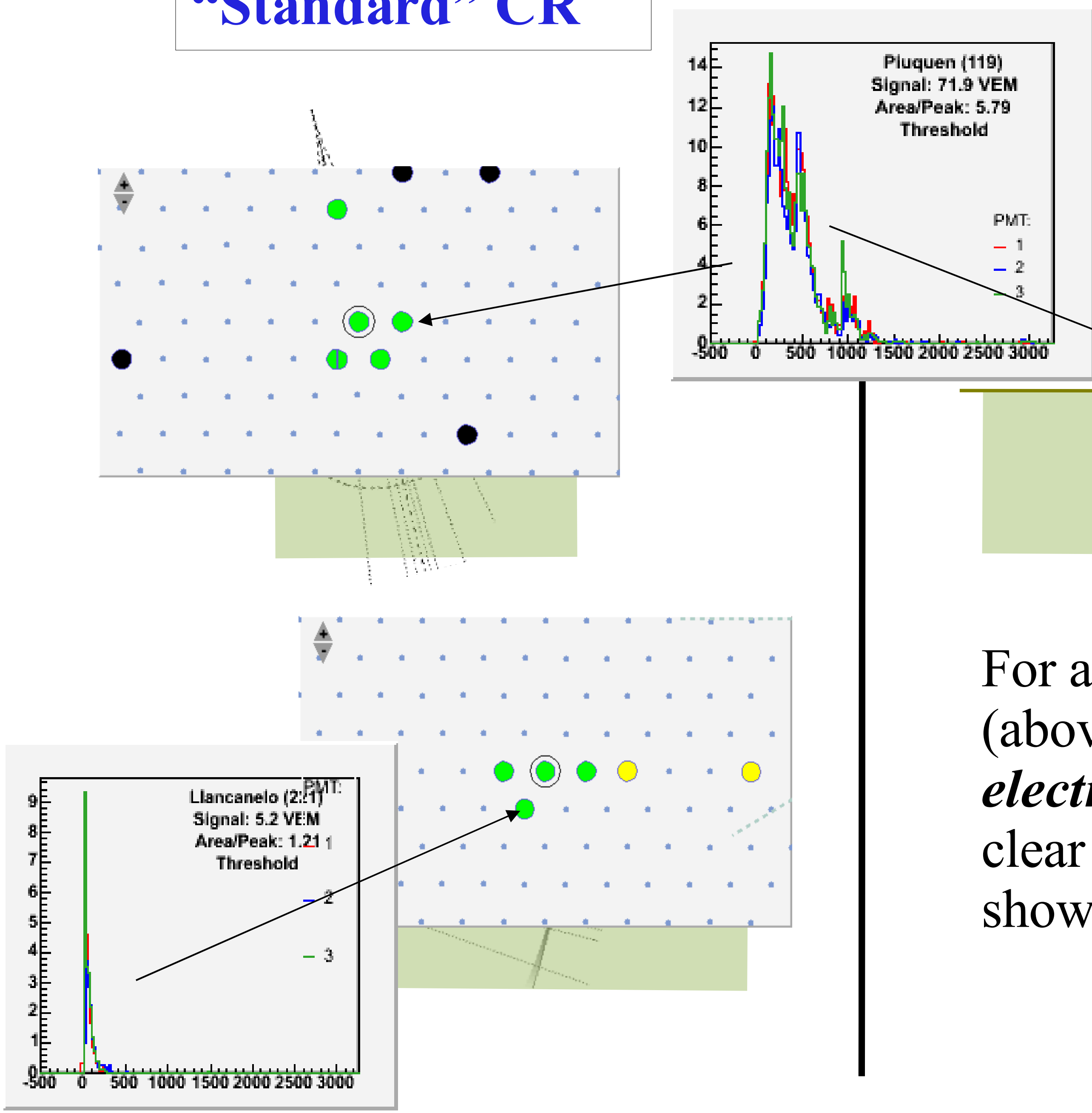
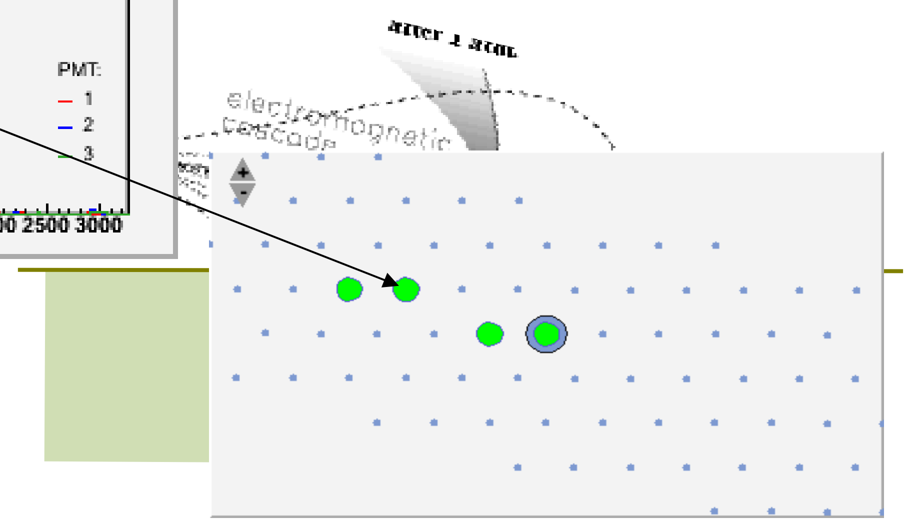
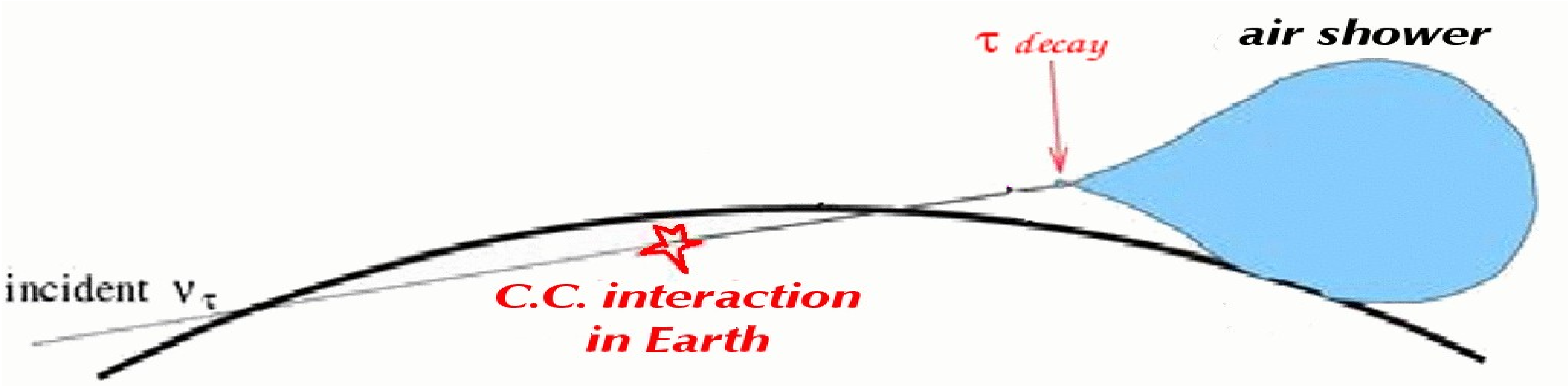




For a very inclined shower (above 70 deg), the presence of ***electromagnetic*** component is a clear signature of a neutrino shower.

SKIMMING NEUTRINOS (1)

All ν flavours can interact in the atmosphere and produce an EAS, but the earth-skimming mechanism can be used for ν_τ :



L_{int} (ν) ~ 500 km — θ>95, Earth opaque

L_{decay} (τ) ~ 50 km — (μ), much larger

L_{Eloss} ~ 10 km — (e), much smaller

(at 1 EeV)

Pierre Auger Observatory: 50 x 50 km^2

This channel has better sensitivity than neutrinos interacting in the atmosphere

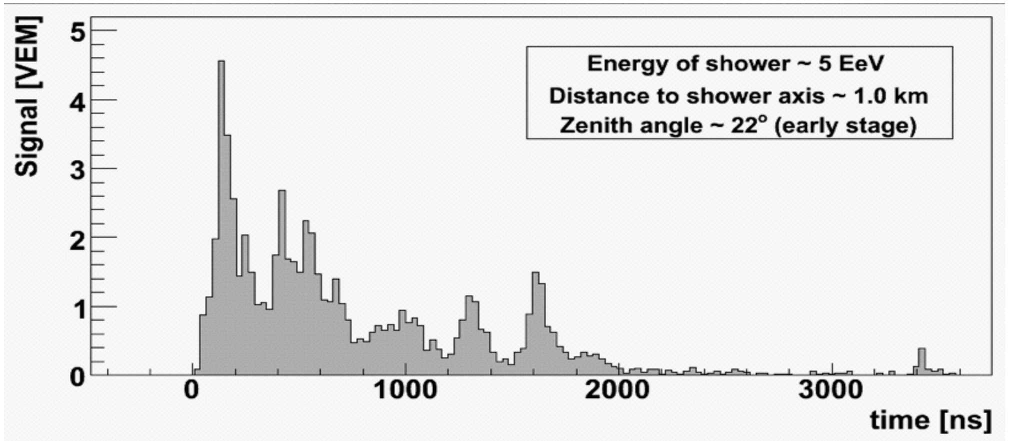
At source : very few ν_τ $\Rightarrow$ $\nu_e:\nu_\mu:\nu_\tau \simeq 1:2:0$, but ...

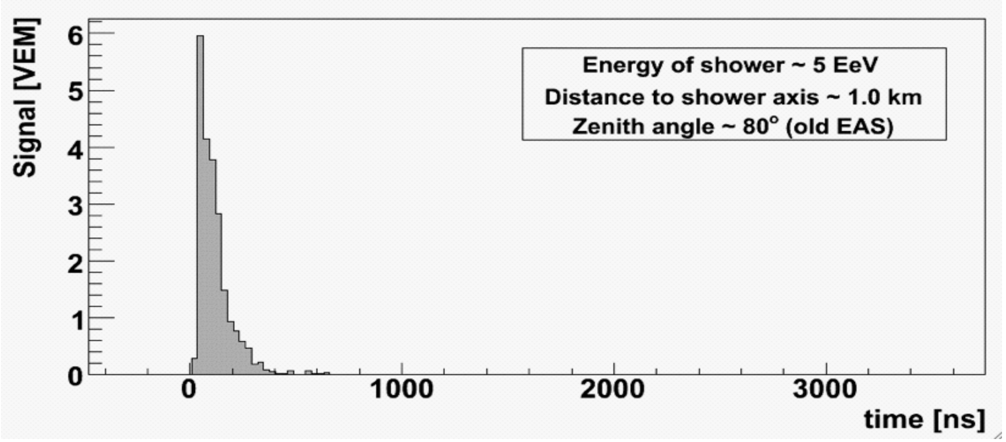
Oscillations with maximal mixing $\Rightarrow$ $\nu_e:\nu_\mu:\nu_\tau \simeq 1:1:1$ at Earth

SKIMMING NEUTRINOS (2)

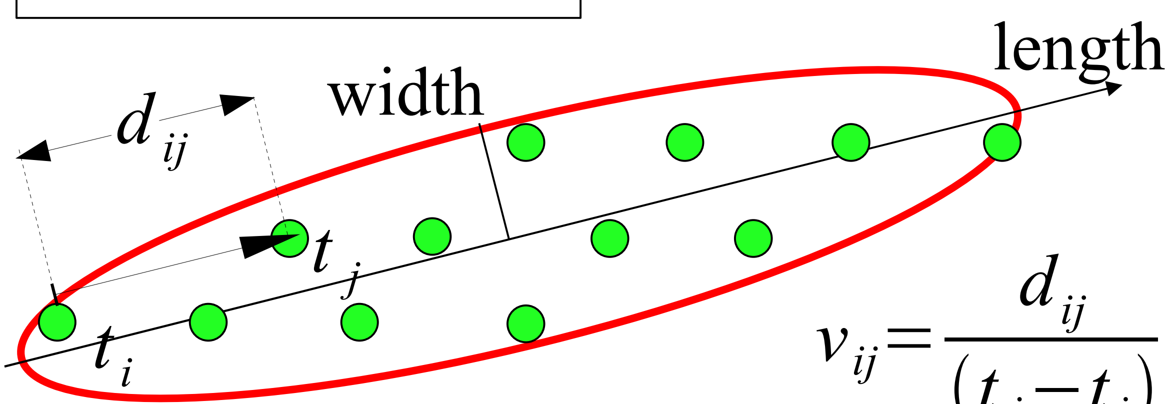
Shower induced by emerging τ : starts close to the detector (young) and is very inclined (90°< ϑ <95°)

Young Showers





Inclined Showers



$$v_{ij} = \frac{d_{ij}}{(t_j - t_i)}$$

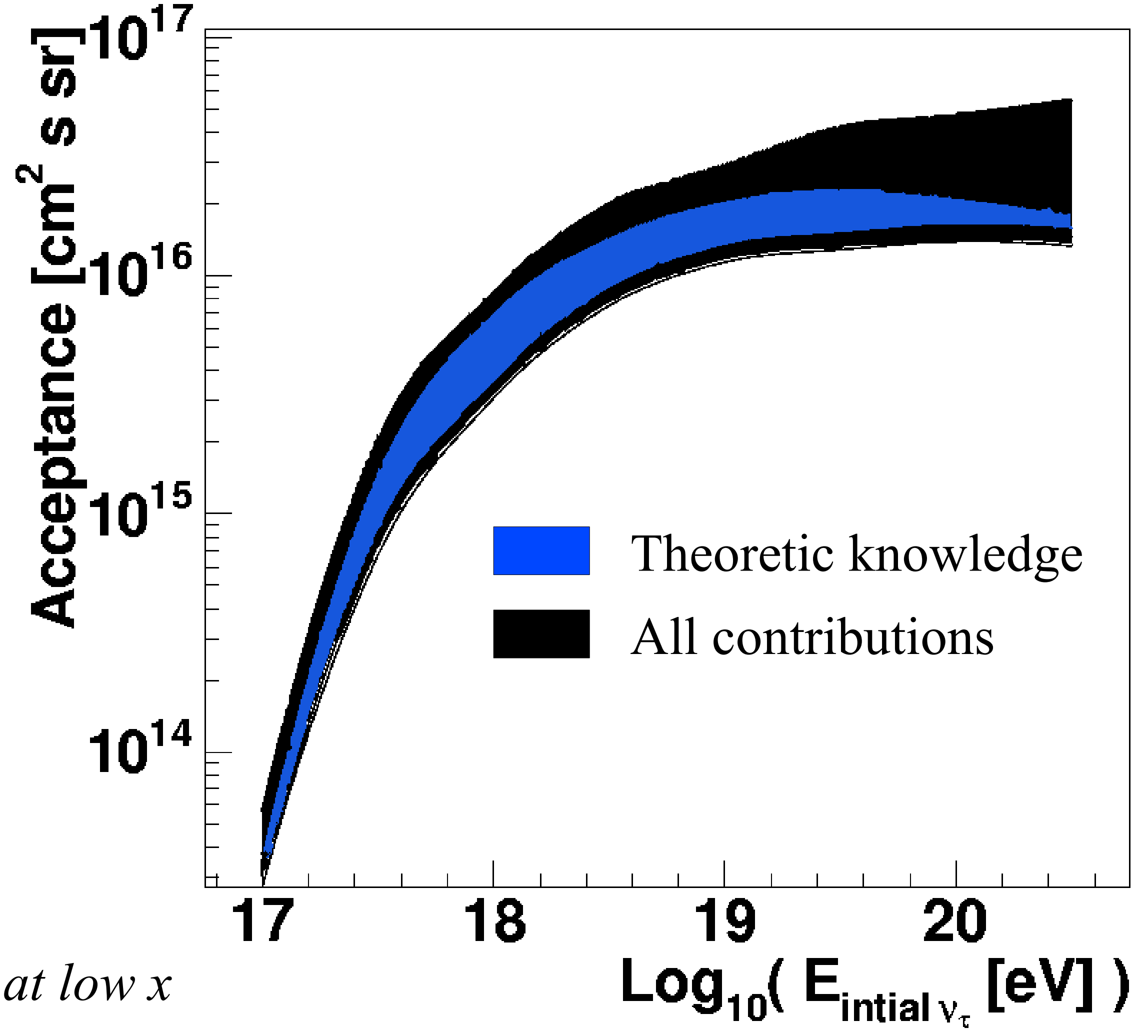
length/width > 5
<v> ∈ (0.29,0.31) m/ns
RMS(v) < 0.08 m/ns

~80% identification efficiency; < 1 event / 10 years of background

SKIMMING NEUTRIONS (3)

The most important drawback of the Earth-skimming channel are the large systematic uncertainties:

Source	Uncertainty
MC Simulations	
Interactions in Earth	±5%
Extensive Air Shower	+20%, -5%
Pierre Auger Observatory	
Acceptance	±2%
Topography	+18%
Theoretic knowledge	
Tau Polarisation	+17%, -10%
Cross Section	+5, -9%
Energy Losses	+25%, -10%
Total	+132%, -45%

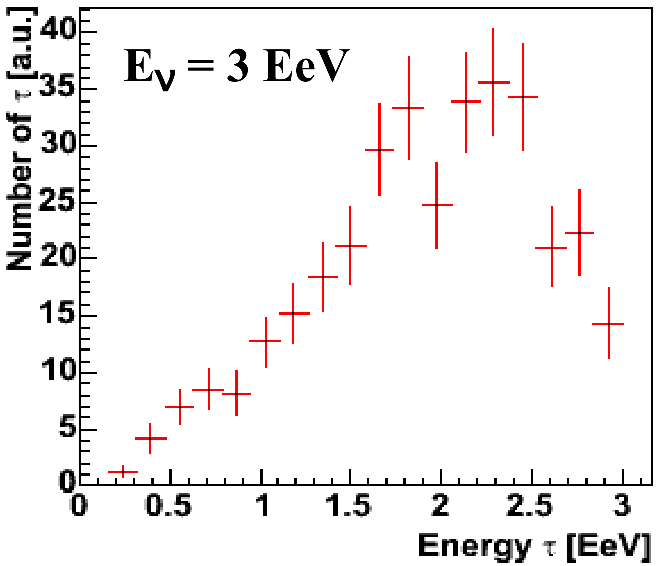


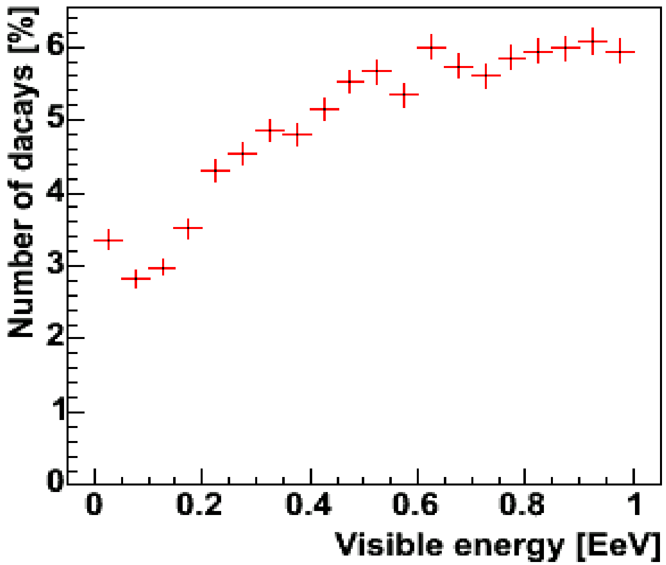
Extrapolated Parton Distribution Function at low x and high Q^2 are supposed to follow the trend

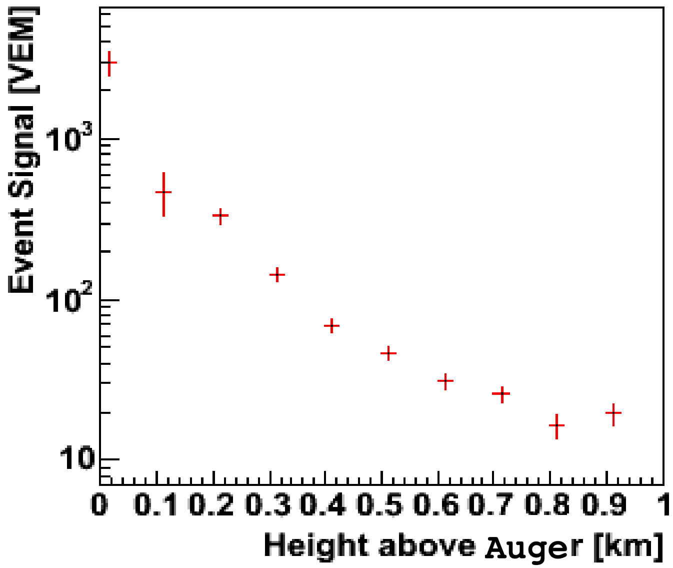
SKIMMING NEUTRIONS (4)

Energy reconstruction

Ideally, we would like to produce a ν spectrum or an energy dependent limit, but ...







No Energy Reconstruction Available

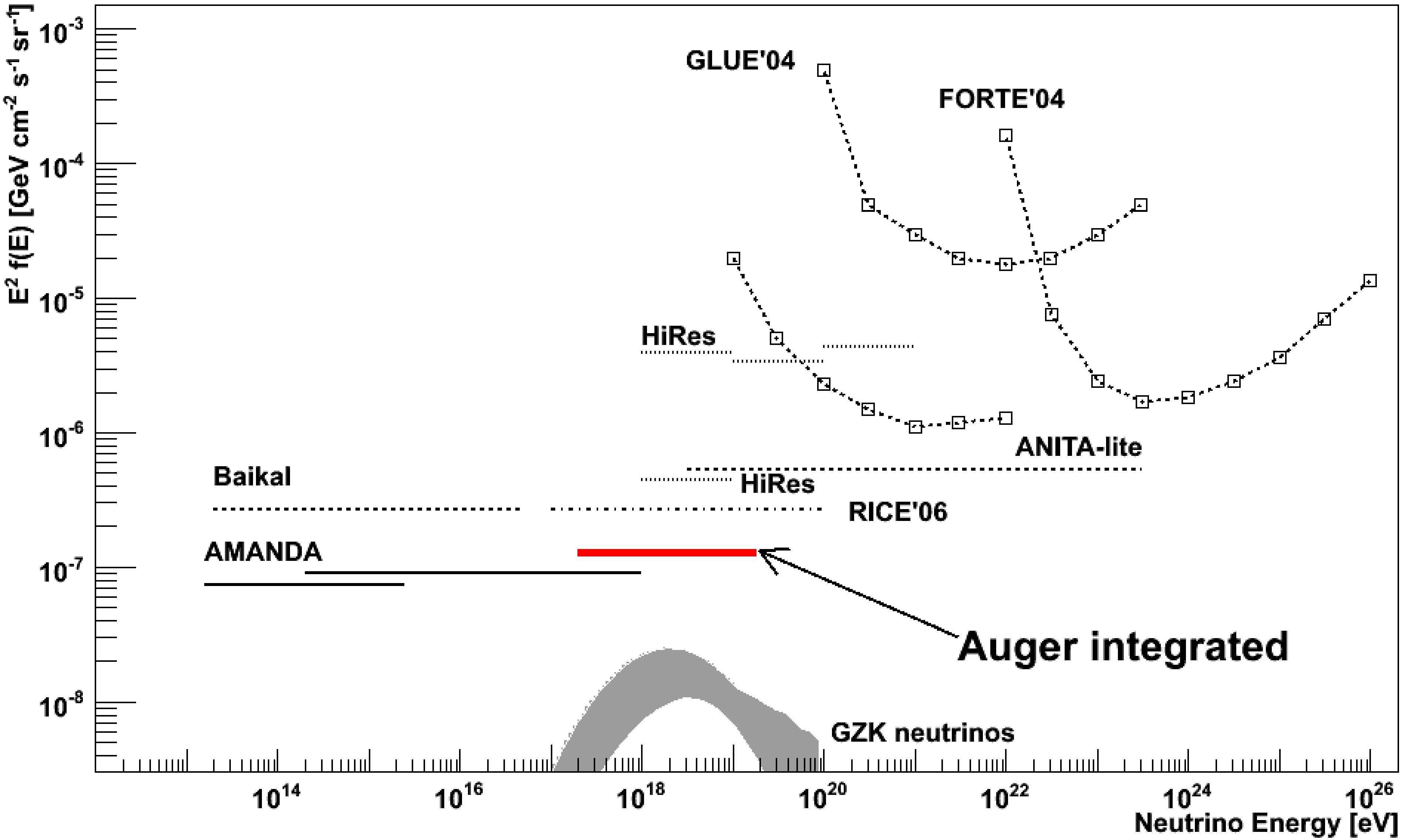
We can only give the flux limit for a given shape of the incident ν flux

Flux limit

$$K_{90} = \frac{2.44}{\int \Phi(E) \cdot Acc(E) dE}$$

SKIMMING NEUTRIONS (5)

90 % CL for each flavour with the worst systematic scenario and assuming: $\frac{dN_{\nu_\tau}}{dE} = f_0 E^{-2}$

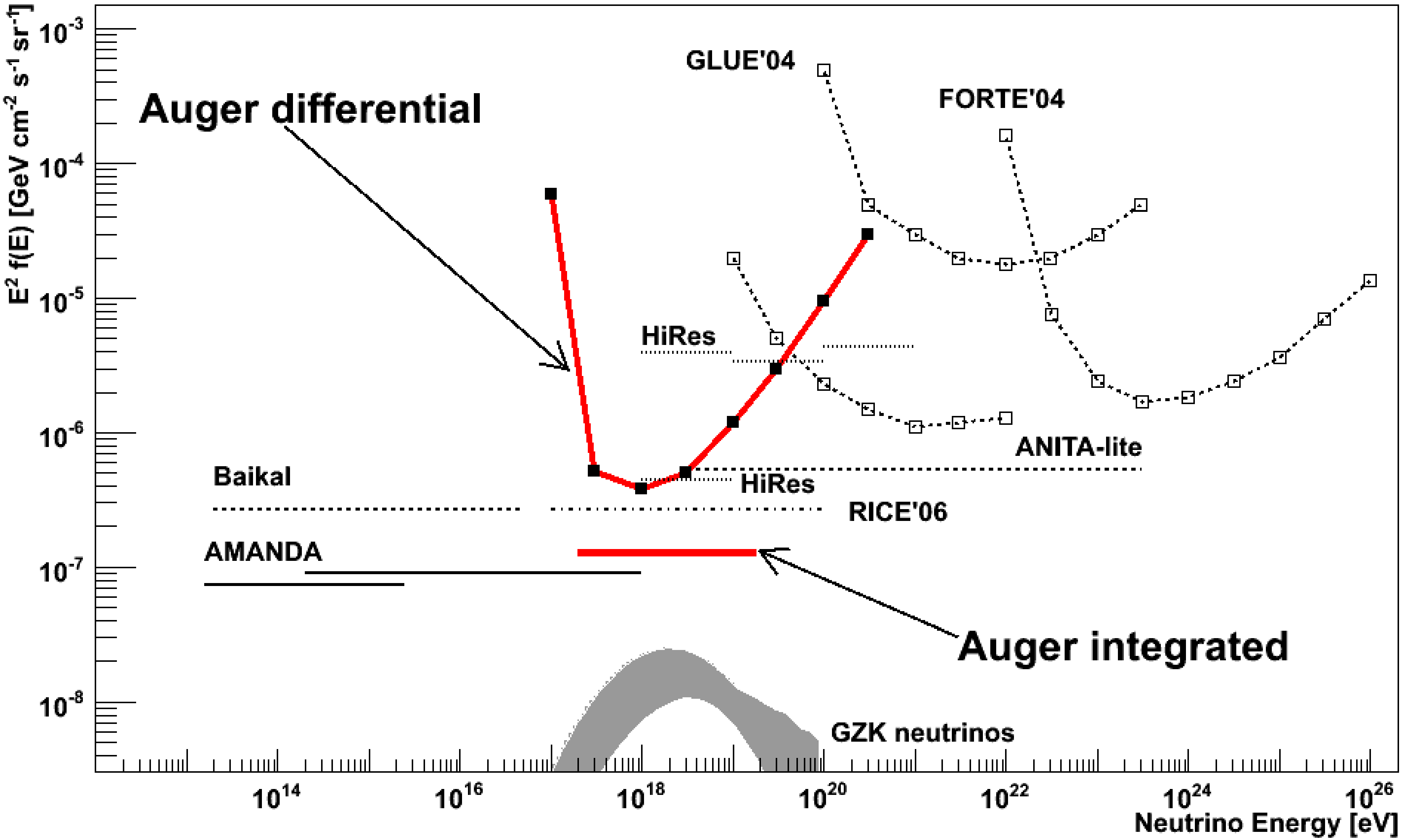


Pierre Auger Collaboration, Phys. Rev. Letters 100 (2008) 211101

SKIMMING NEUTRIONS (5)

Differential format at **90 % CL** for each flavour, worst systematic scenario

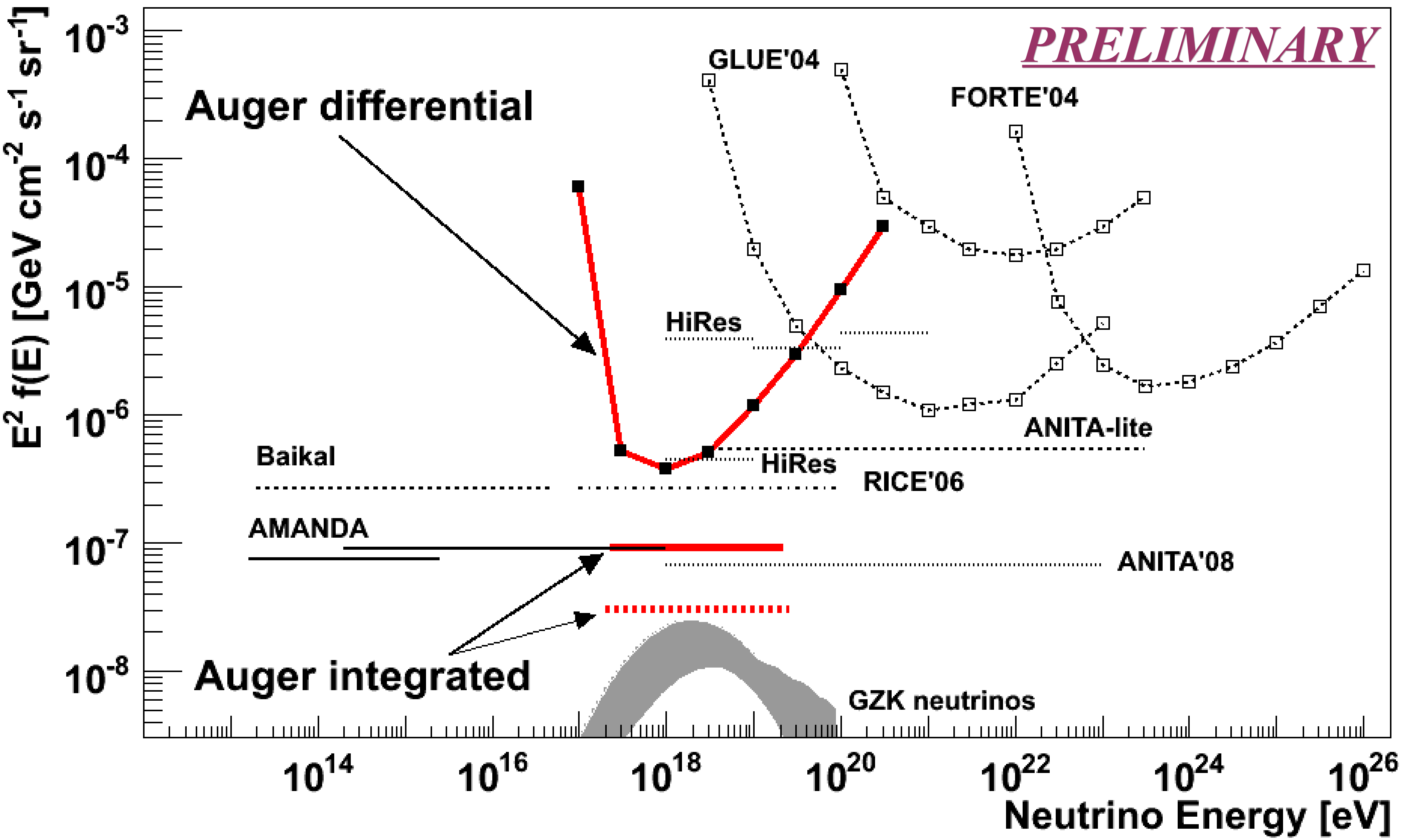
$$2.3/\text{Exp} \times E_{\nu}$$



Pierre Auger Collaboration, Phys. Rev. Letters 100 (2008) 211101

SKIMMING NEUTRIONS (6)

90 % CL for each flavour with data from Jan'04 until April'08

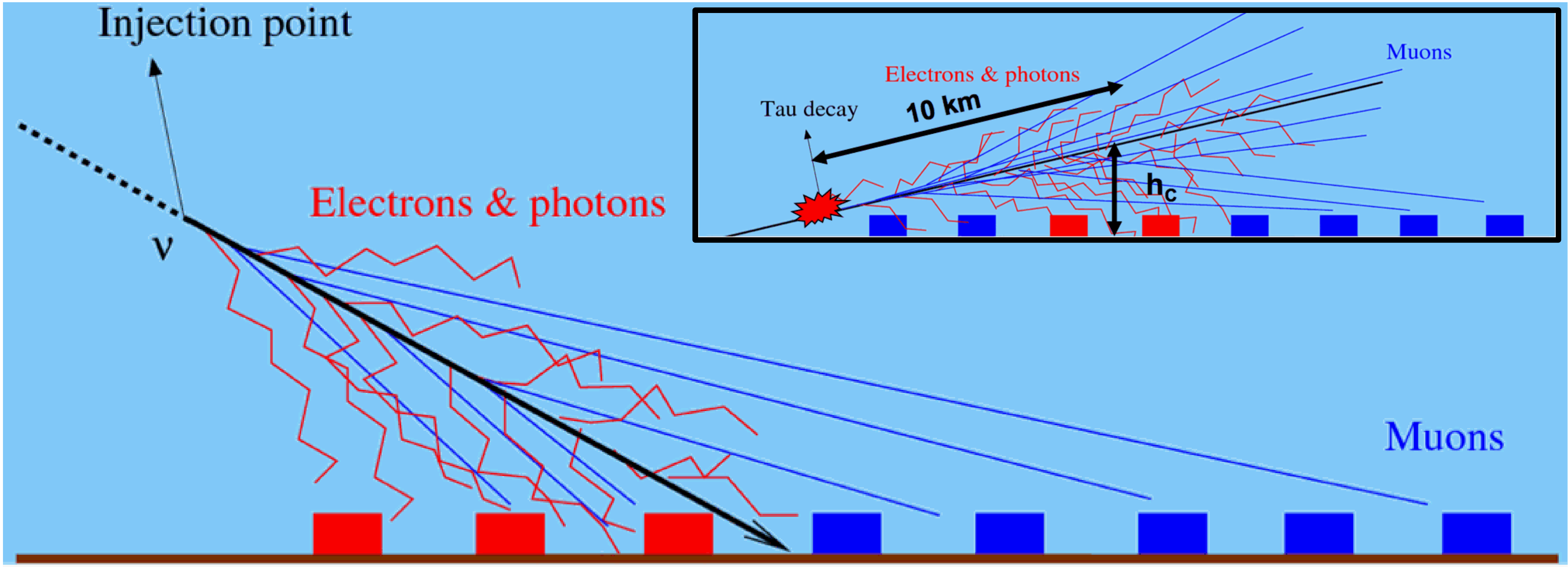


DOWN-GOING NEUTRINOS (1)

All ν flavours can interact in the atmosphere and produce an EAS:

A very inclined neutrino (θ>75º) that interacts deep in the atmosphere can also be identify in the huge "background" of nucleonic showers.

Worst sensitivity but less systematic uncertainties



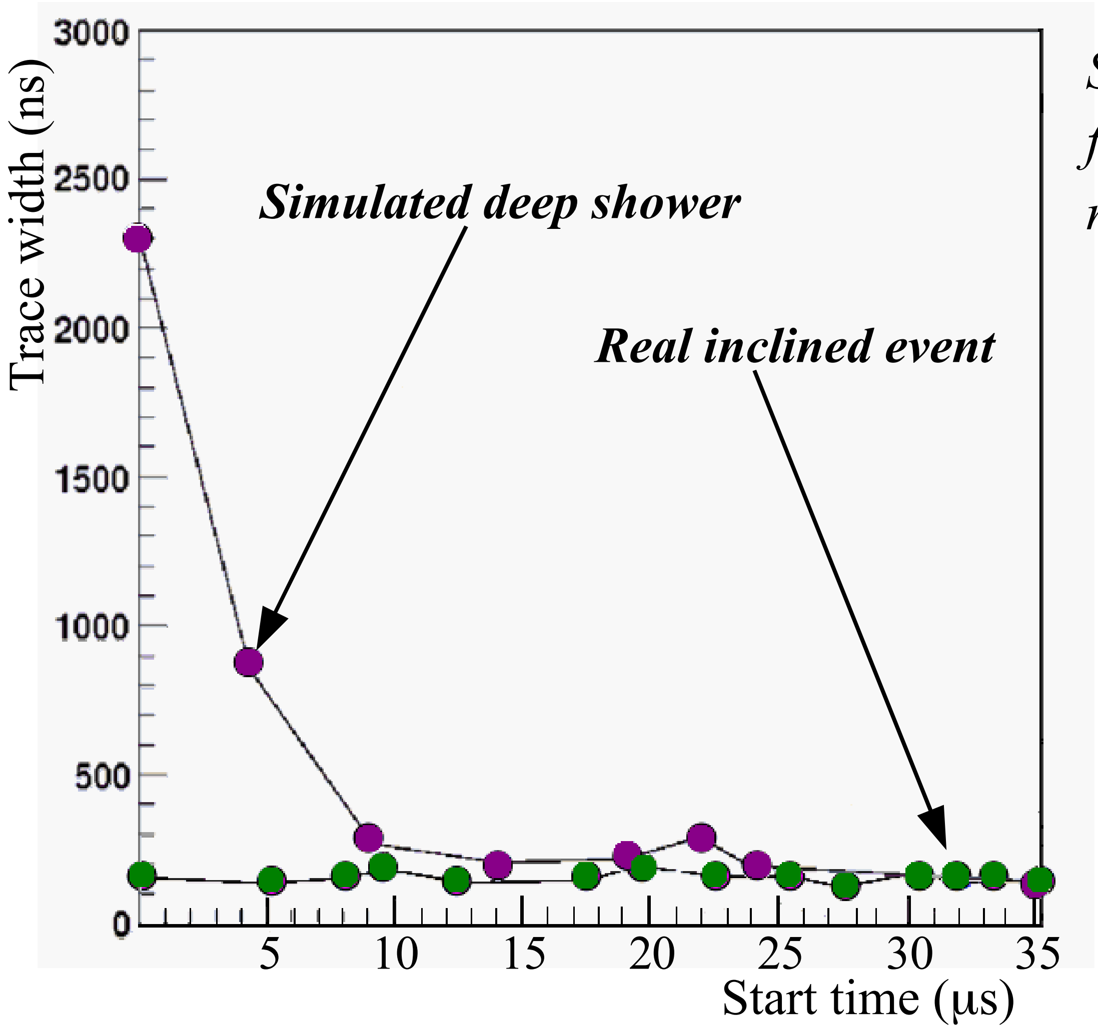
Early region – broad signals **Late region – narrow signals**

Due to the different geometry, a different identification criterion is needed

DOWN GOING NEUTRINOS (2)

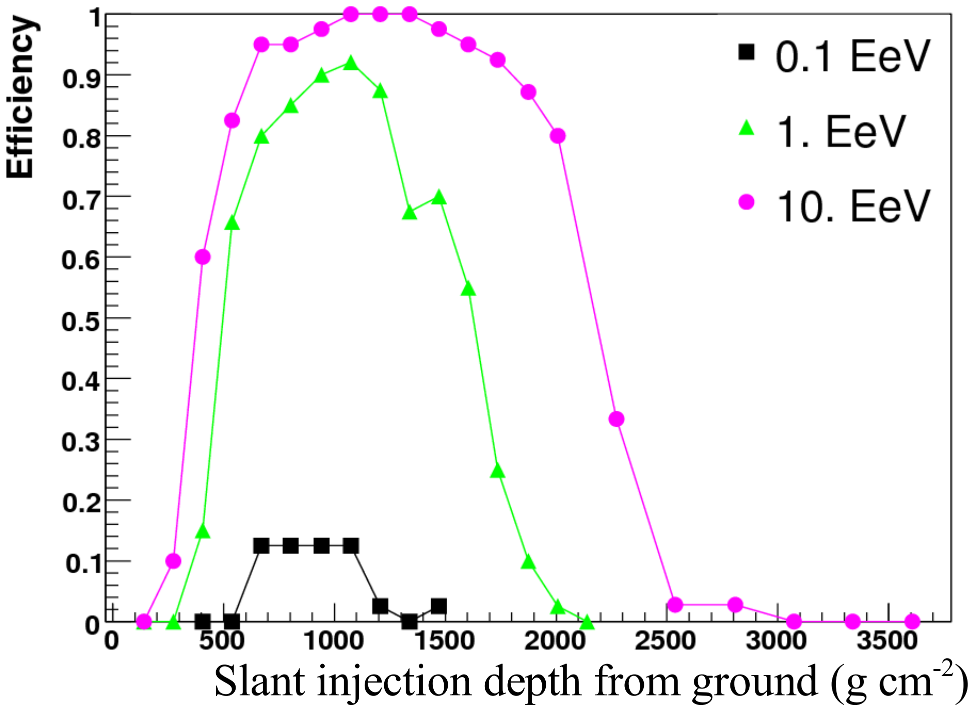
Showers induced by nucleons start shortly after entering the atmosphere: narrow signals for inclined showers (ϑ >75°)

Broad signal in earliest tanks



Efficiency

Showers induced by neutrinos that interact far from the ground can not be distinguished from nucleonic showers



High identification efficiency without background from nucleonic showers

SUMMARY AND PROSPECTS

- The Pierre Auger Observatory has a **large discriminant capacity** to distinguish earth-skimming neutrinos from standard Cosmic Rays.

- From Jan'04 till Aug'07 (about 1 year of a full Surface Detector), **ZERO ν_τ candidates** have been found, leading to spectra dependent limit to tau neutrinos of $E^2 dN/dE$ **$1.3 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}**.
  (*Preliminary: new data set* $\rightarrow$ ***$9 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}***)

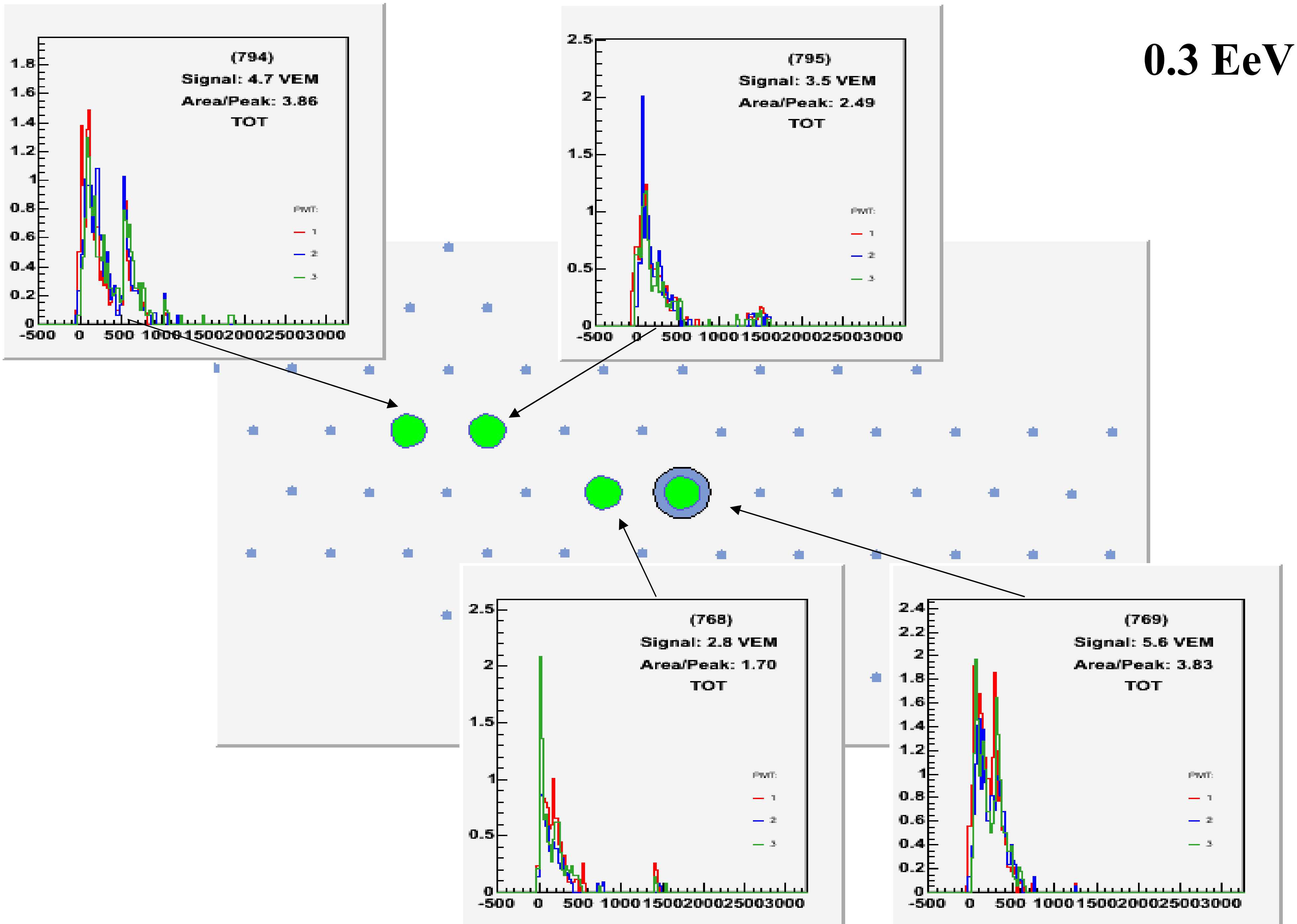
- The Pierre Auger Observatory has its maximum sensitivity at **the most relevant energy range (~ 1 EeV) for GZK** neutrinos, the expected level of which will be tested in about 10 years.

- The Pierre Auger Observatory is also sensitive to **neutrinos that interact in the atmosphere**. This channel has different systematics and depends differently on neutrino properties.

END OF TALK

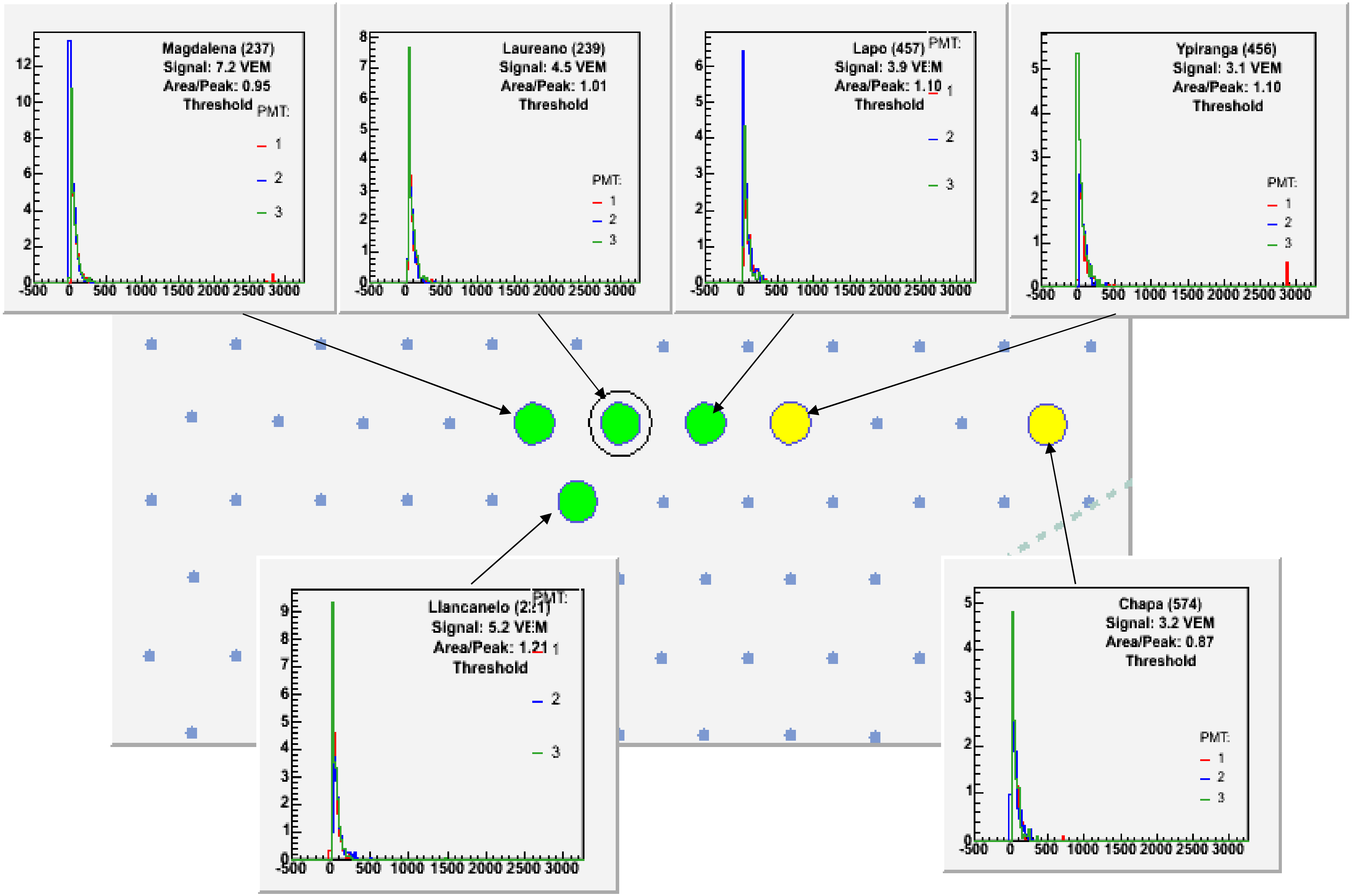
Tau Neutrino (Monte Carlo)

0.3 EeV

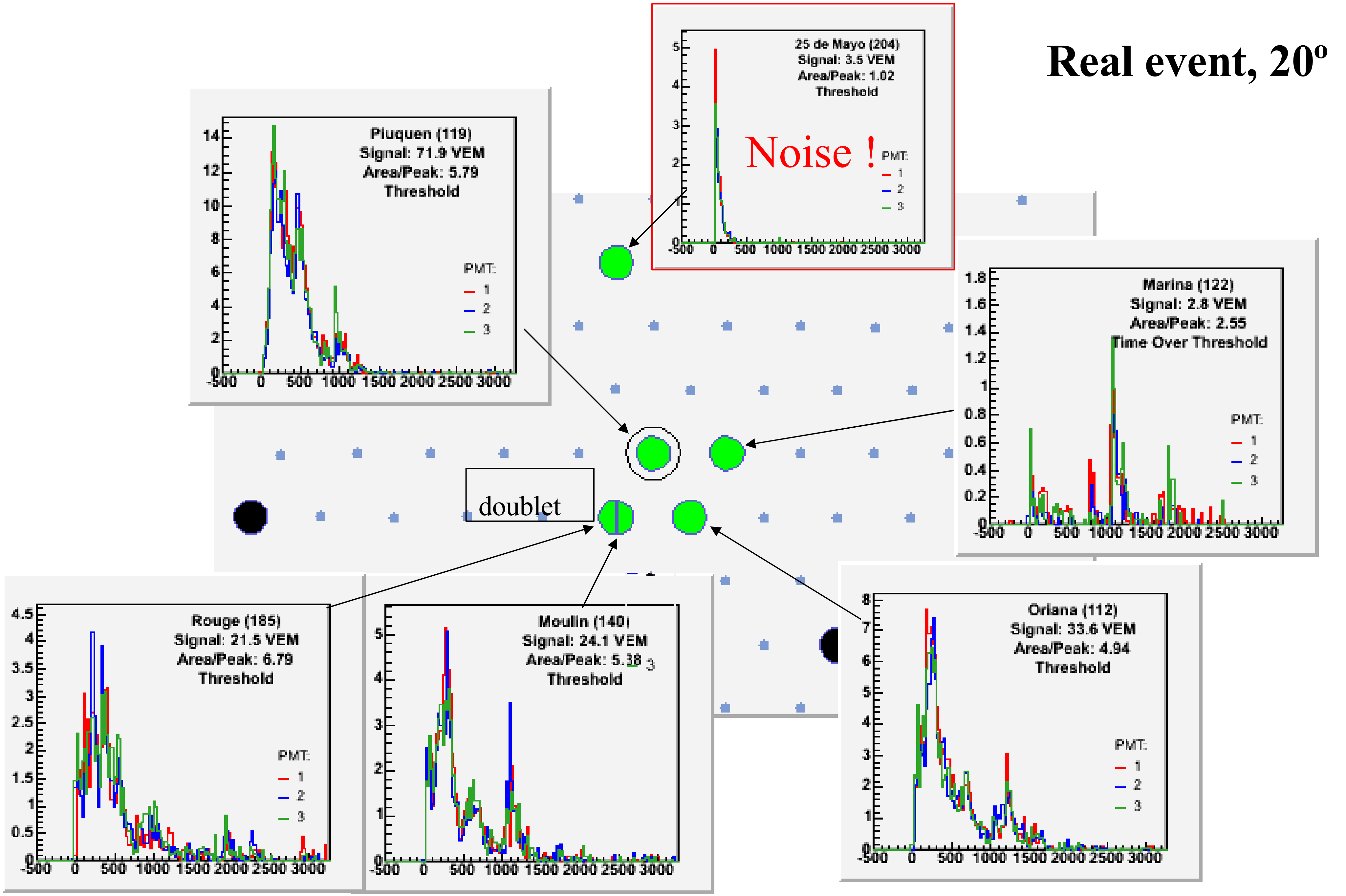


INCLINED EVENT

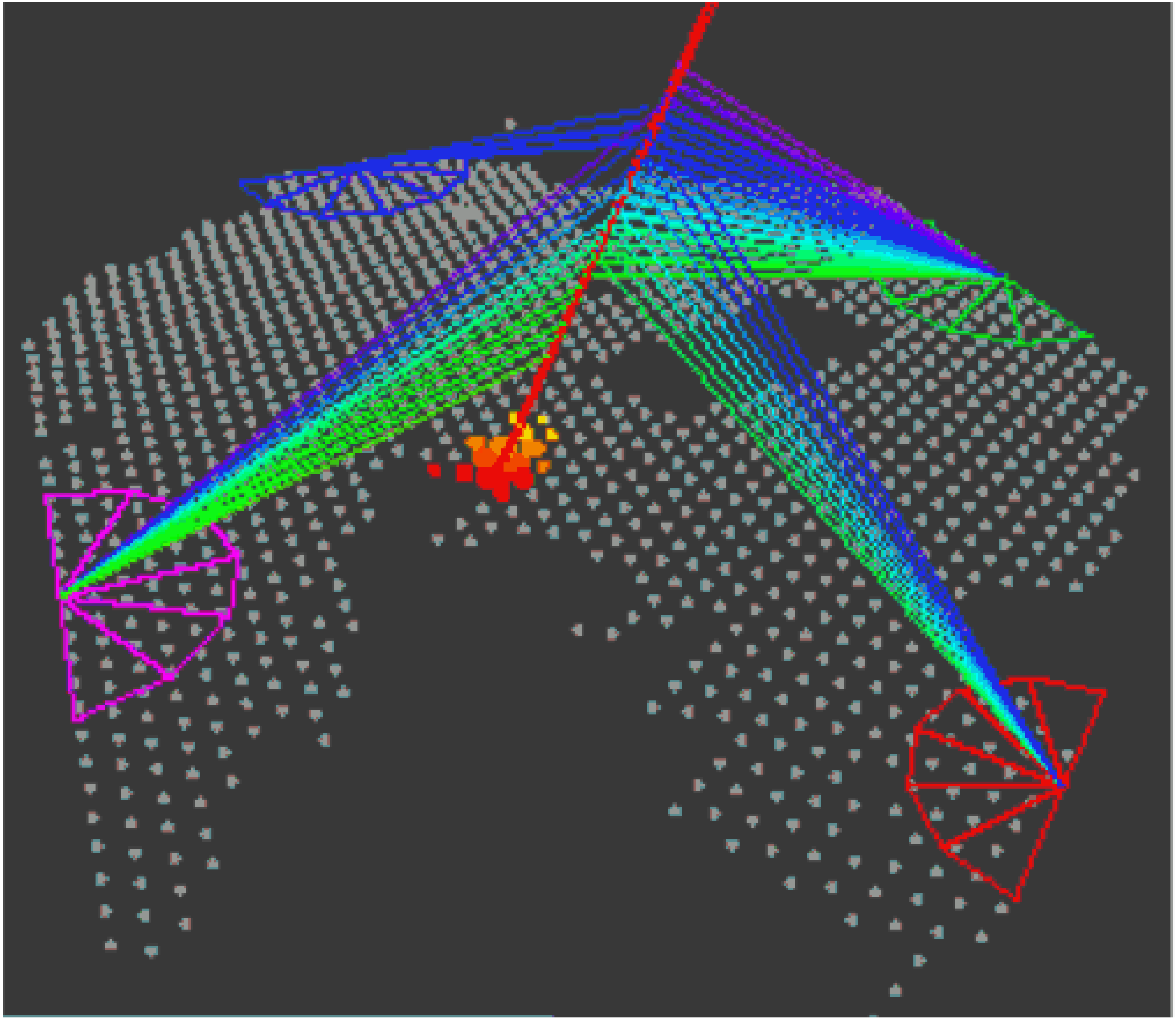
Real event, 80º



VERTICAL EVENT



Hybrid Detector



THE PIERRE AUGER OBSERVATORY

A huge detector to study the Cosmic Rays at the highest energies (EeV).

We also have the capability of detecting Ultra High Energy ν

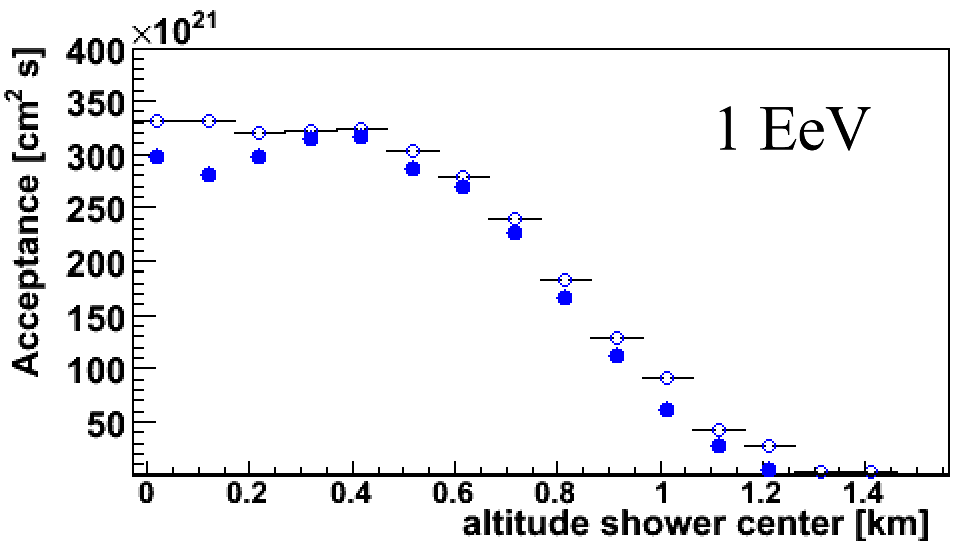
ACCEPTANCE

Atmosphere and detector

Acceptance for τ showers

- Depends on tau energy and altitude shower centre
- Growing detector

$$Acc_\tau(E_\tau, dh_c)$$



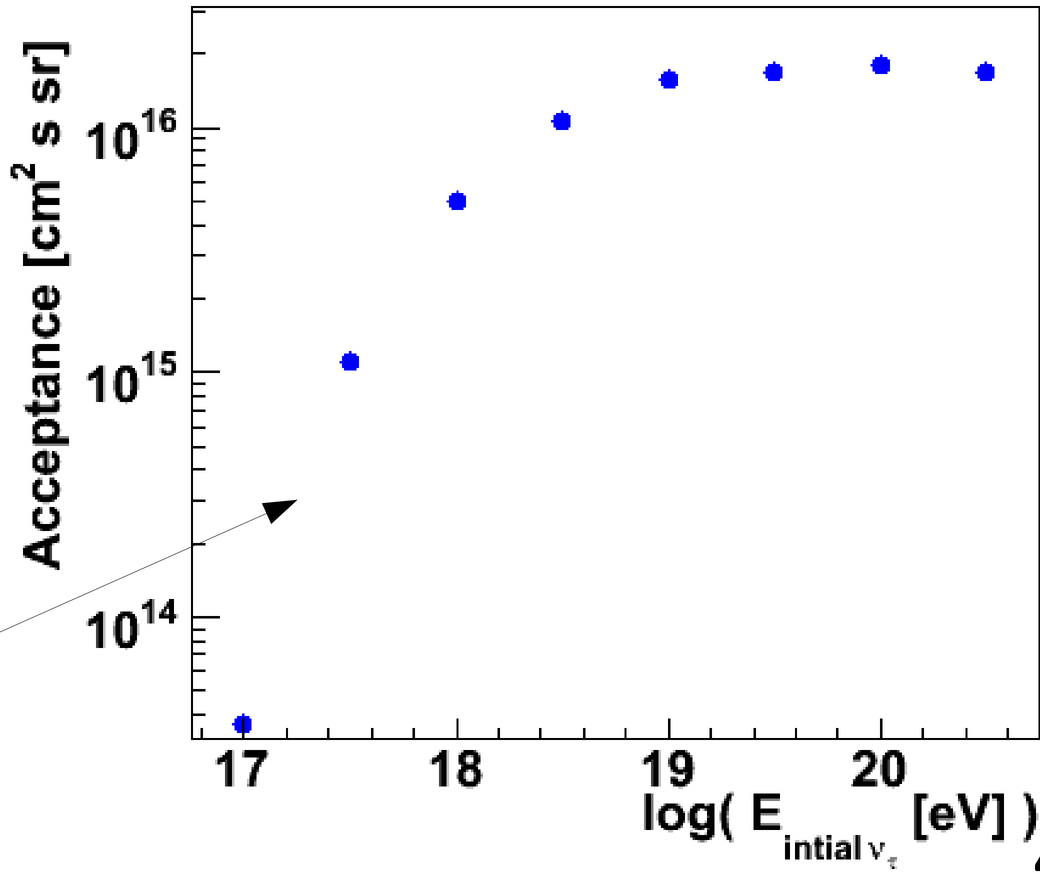
$$\int dh_c \frac{d^2N}{dE_\tau dh_c} Acc_\tau(E_\tau, dh_c)$$

Earth Monte Carlo

Conversion $\nu_\tau \rightarrow \tau$

- Neutrino cross section
- Tau energy losses
- Tau decay

$$\frac{d^2N}{dE_\tau dh_c}$$



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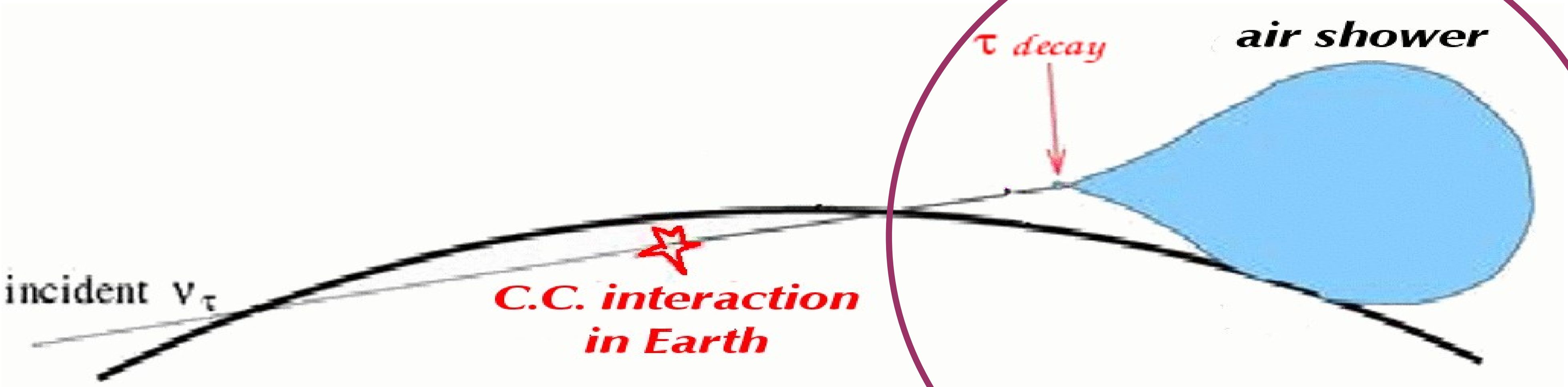

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(at 1 EeV)

Pierre Auger Observatory: 50 x 50 km^2

This channel is expected to produce more identified neutrinos.

At source : very few ν_τ ⇒ $\nu_e:\nu_\mu:\nu_\tau \simeq 1:2:0$, but ...
Oscillations with maximal mixing ⇒ $\nu_e:\nu_\mu:\nu_\tau \simeq 1:1:1$ at Earth

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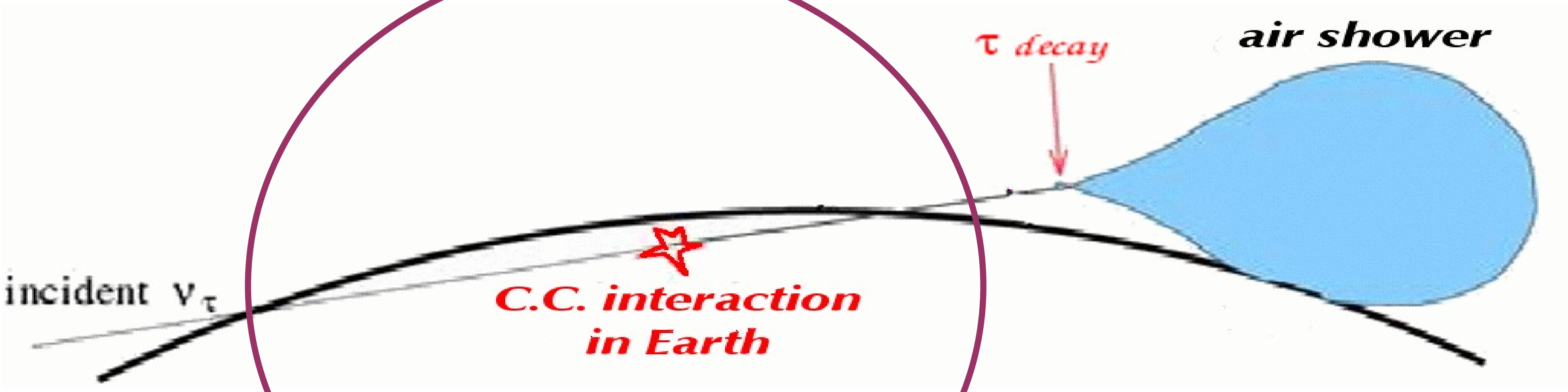

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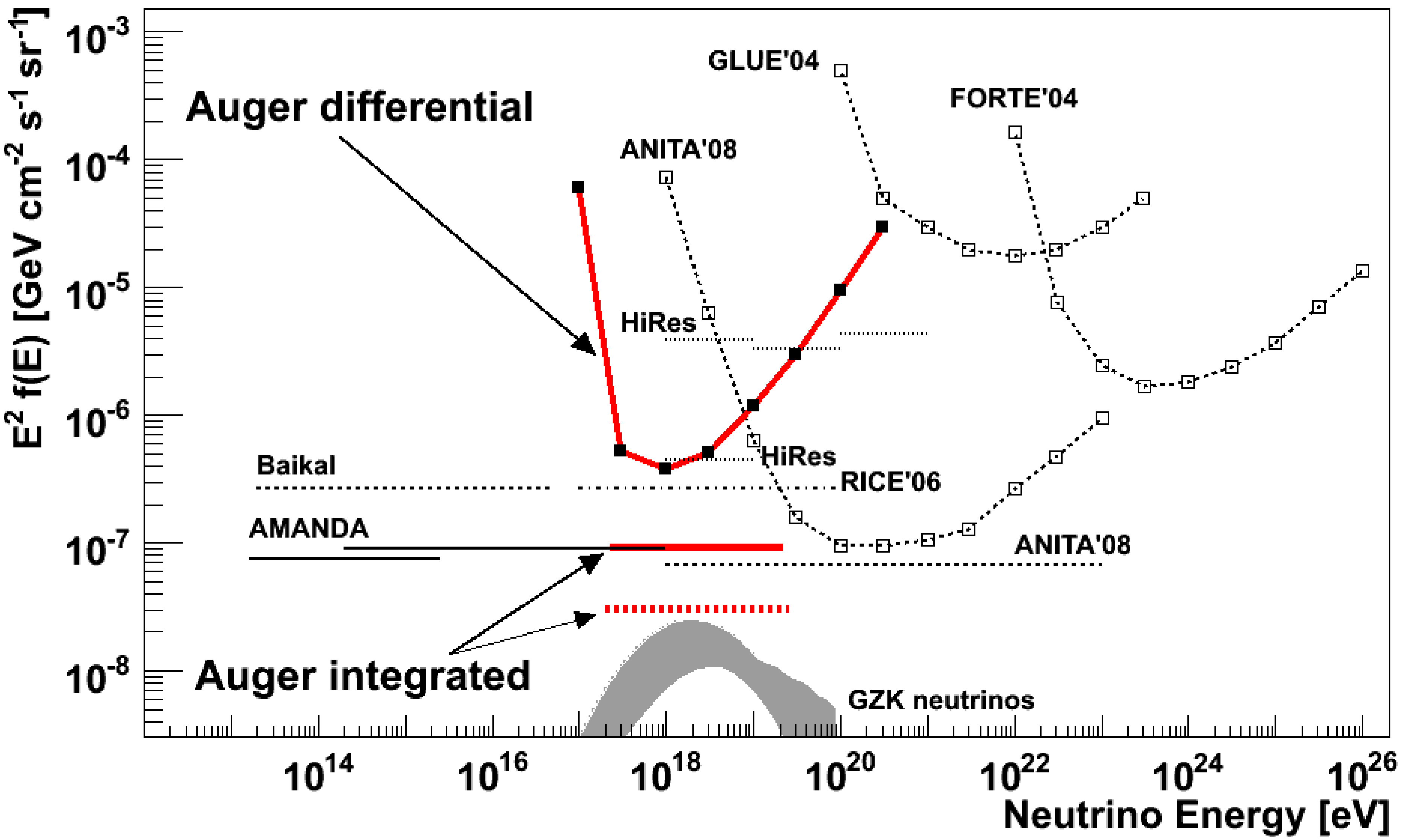
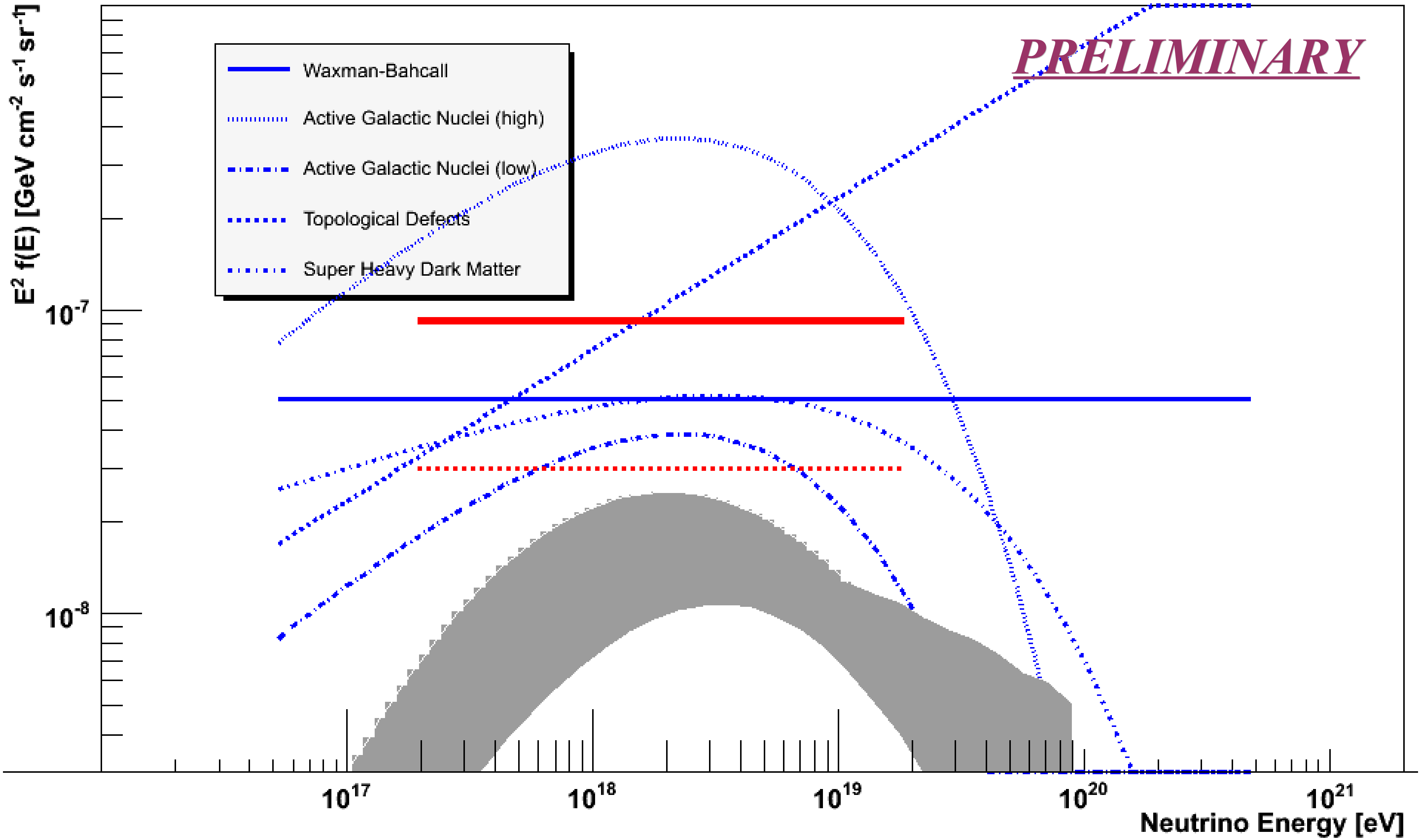
DIFFERENTIAL FORMAT



MODELS



Waxman-Bahcall
Active Galactic Nuclei (high)
Active Galactic Nuclei (low)
Topological Defects
Super Heavy Dark Matter
PRELIMINARY
E² f(E) [GeV cm⁻² s⁻¹ sr⁻¹]
10⁻⁷
10⁻⁸
10¹⁷
10¹⁸
10¹⁹
10²⁰
10²¹
Neutrino Energy [eV]