Ultra high energy neutrinos at the Pierre Auger Observatory

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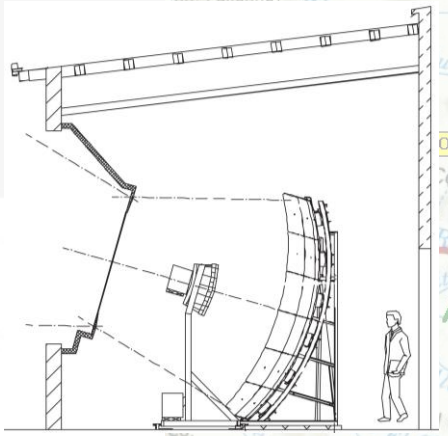
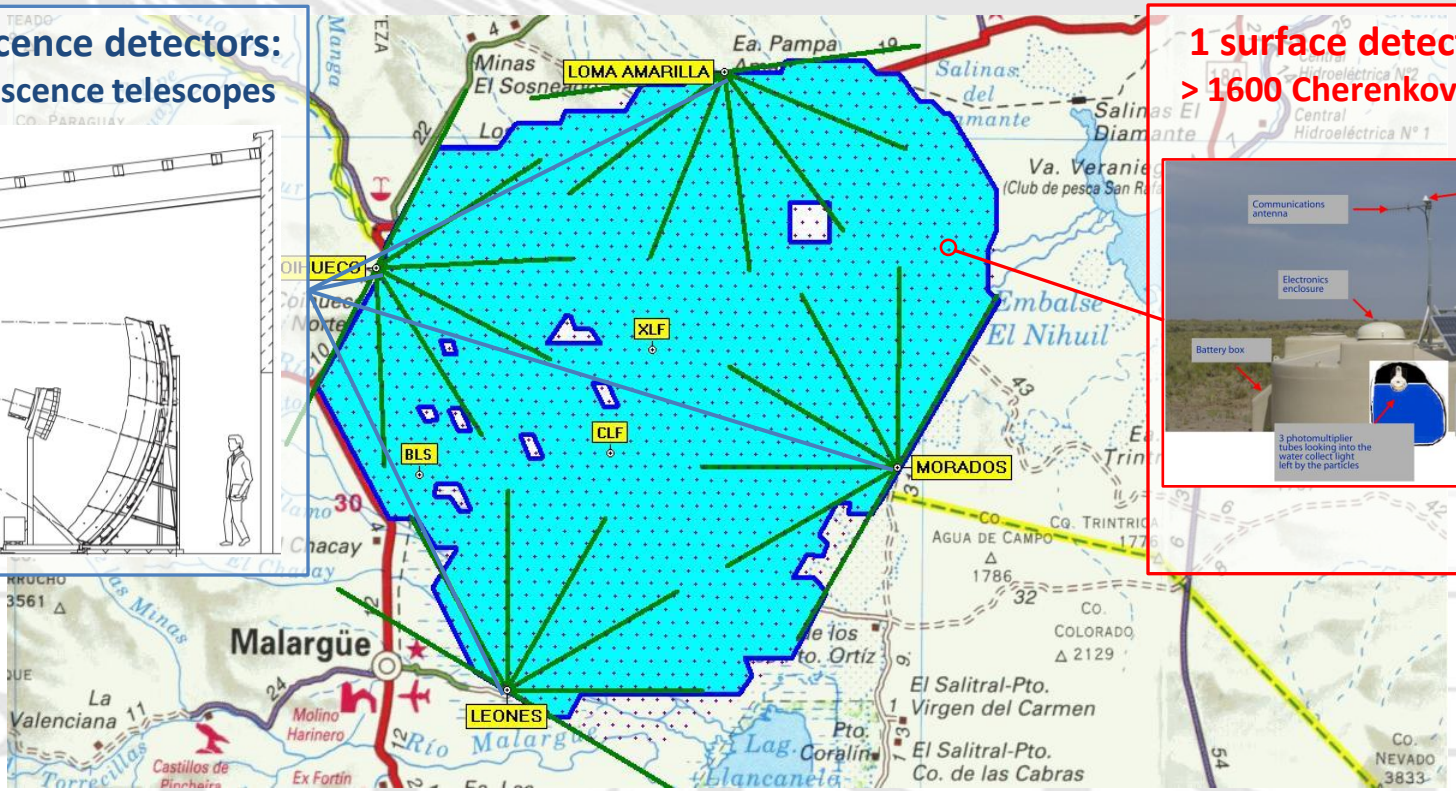
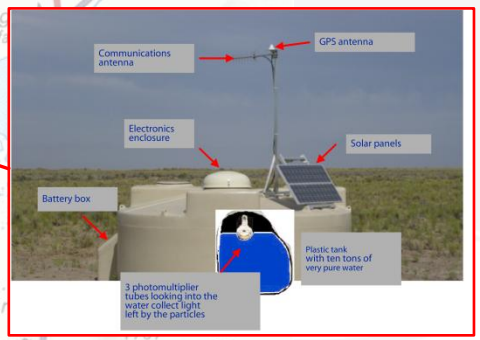
Pierre Auger Observatory (southern site)

4 fluorescence detectors:
4x6 fluorescence telescopes





1 surface detector (SD):
> 1600 Cherenkov detectors



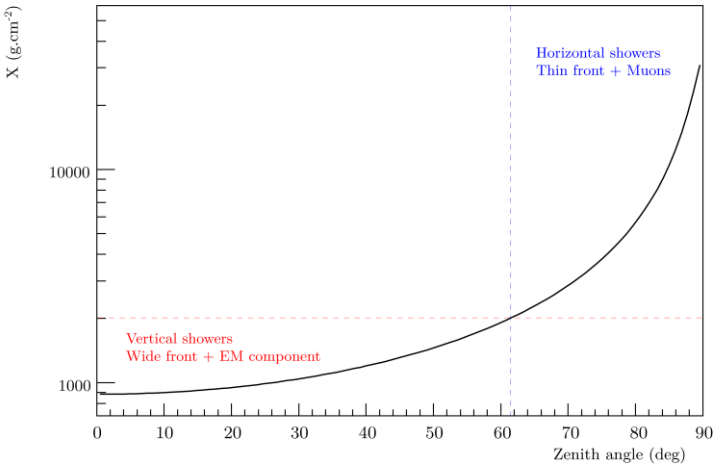
Completed in 2008 !!!

UHE Neutrinos detection with the SD

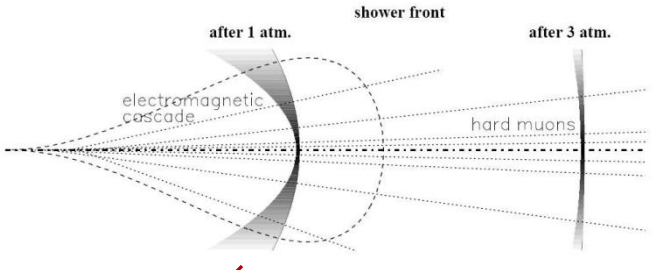
Detection = Discrimination from every other primaries

➔ Easy for very inclined showers

Amount of matter from top of atmosphere to ground as a function of zenith angle



Evolution of shower front with distance of propagation



Curved front EM + μ (wide signal) → Thin front μ (Narrow signal)

Young shower — **Old** shower

At large zenith angles (>75°):

Protons: High cross-section ➔ Interaction at top of the atmosphere ➔ Old shower

vs

Neutrinos: **Low cross-section** ➔ Interaction deep in the atmosphere possible ➔ Young shower

Look for very inclined events with the properties of young showers

UHE Neutrinos detection with the SD (2)

2 channels

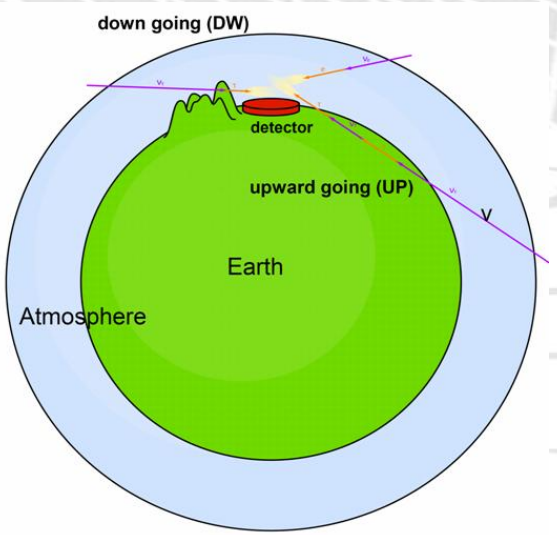
Downgoing neutrinos

Classical method:
Interaction ν – Atmosphere

↓

Development of a downgoing shower

Sensitive to:
ν_e, ν_μ, ν_τ



Skimming neutrinos

Interaction ν – Earth

↓

Lepton creation

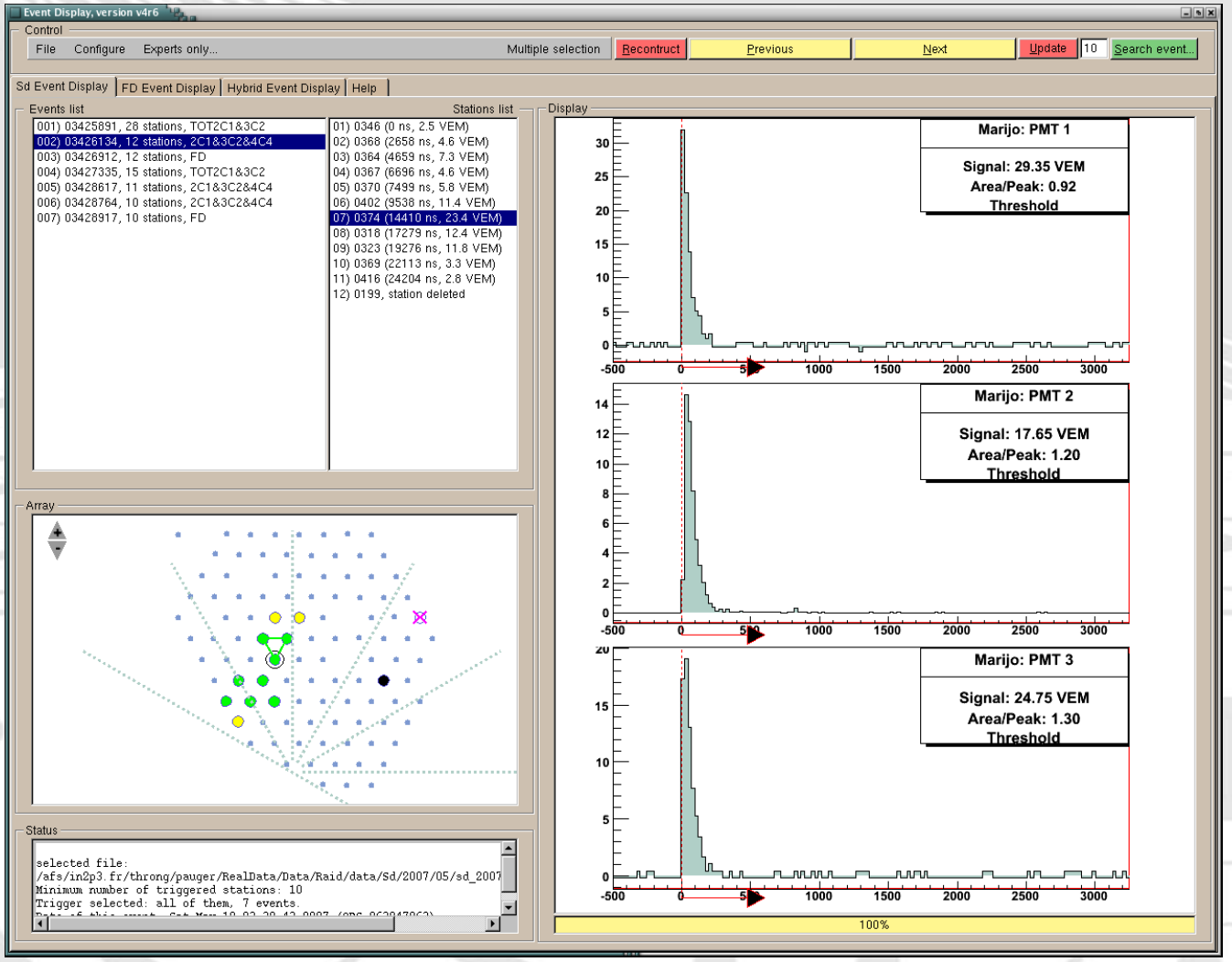
If decay outside of the Earth

↓

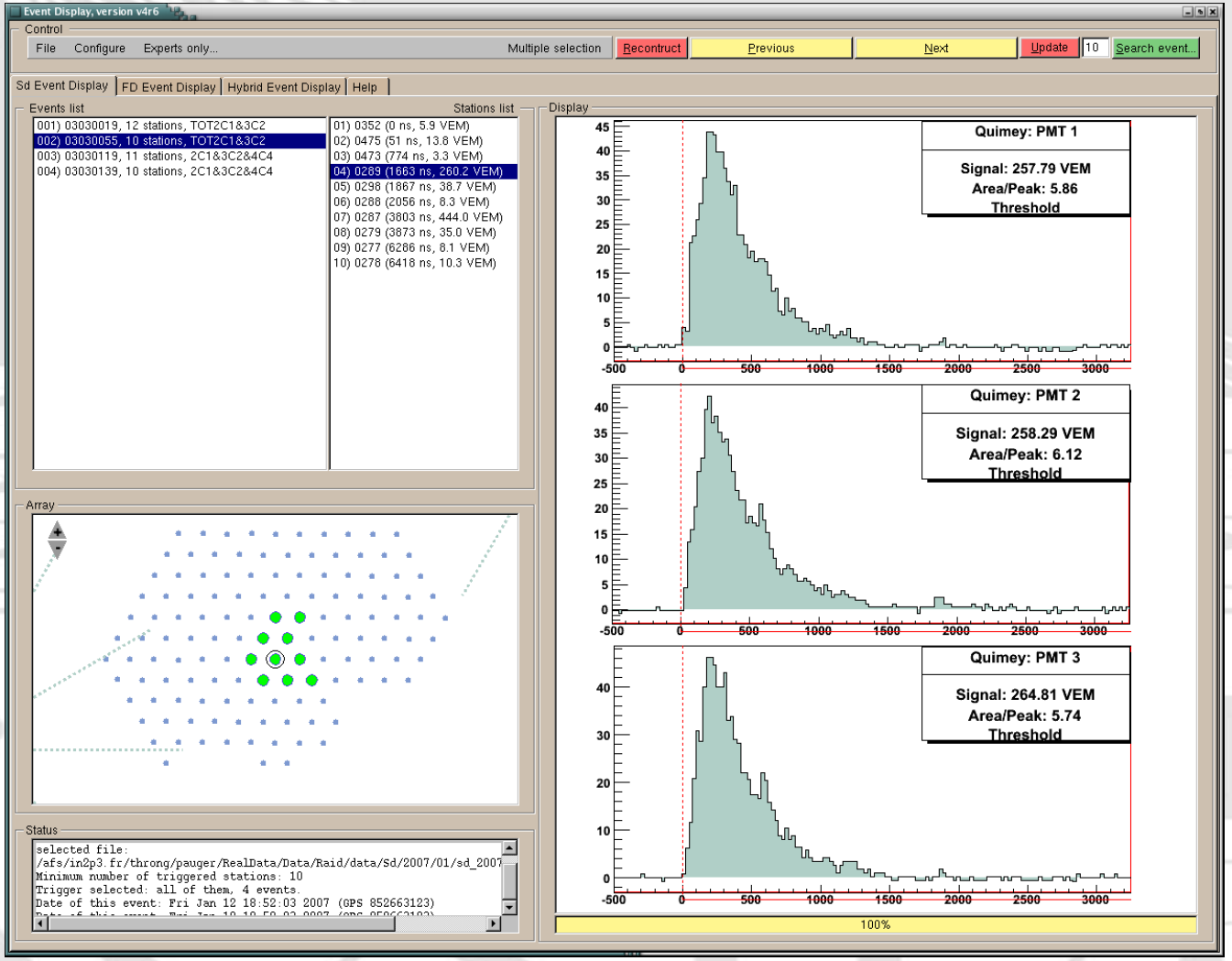
Shower development

Sensitive to:
ν_τ

Selection of UHE neutrinos (1)



Selection of UHE neutrinos (2)



Selection of UHE neutrinos (3)

Discriminating variables

Useful informations to test if a shower is inclined:

Arrival times, coordinates of triggered stations

Variables ?

i) **Reconstructed zenith angle**

But not only:

Footprint of the shower

Very inclined showers

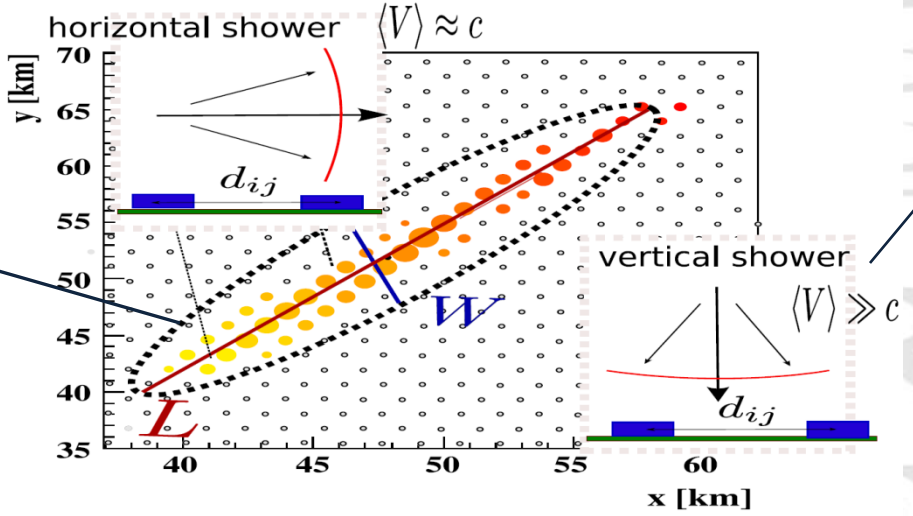
=

Elongated footprint

➔Use of the **ratio L/W**

L: length of the footprint

W: Width



Apparent velocity

Vertical showers: **<V> >> c**

vs

Horizontal showers: **<V>≈ c**

+

RMS scatter of V small

➔ Use of **<V>** and **σ_v**

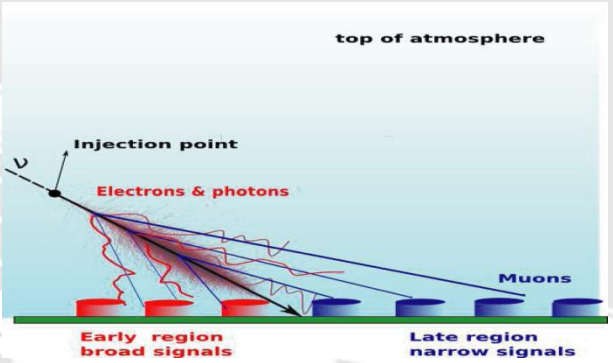
Selection of UHE neutrinos (4)

Discriminating variables

Useful informations to test if a shower is young:

- Number of TOT triggers (Time Over Threshold)

- Signals of the **first triggered stations:**

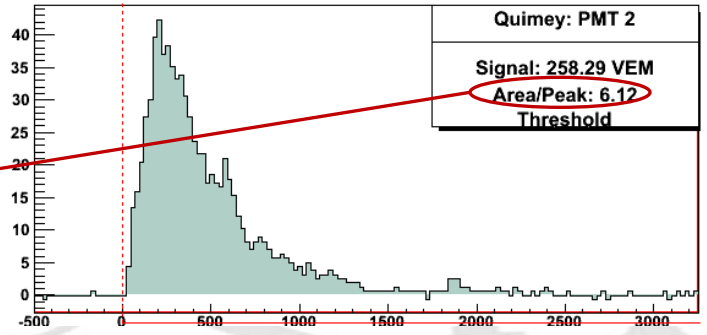


Variables:

- RiseTime of the Signal (ex: Time to reach 50% of the total signal)

- FallTime of the signal

-Area over Peak **(AoP)**
Ratio Signal/Peak



AoP:
Large for broad signals

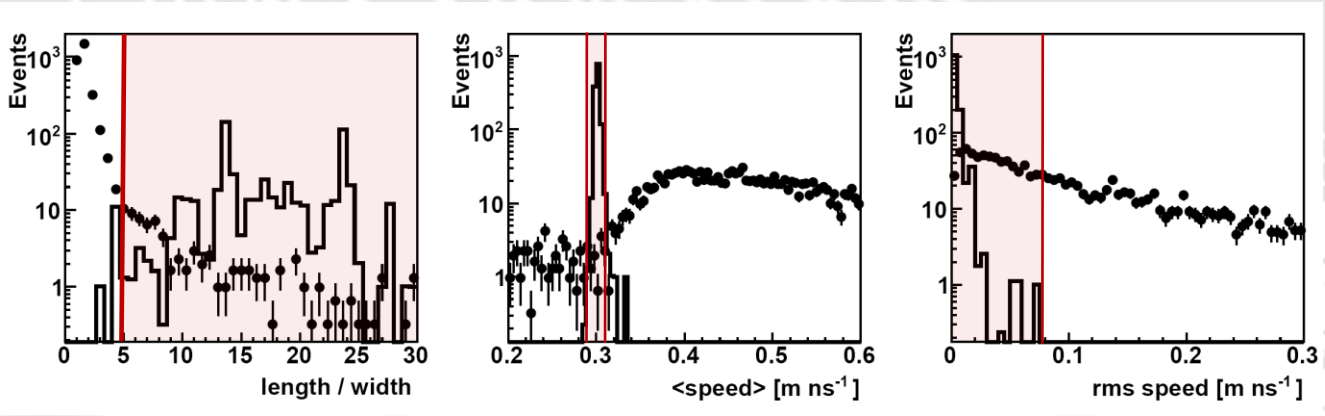
Single muons: AoP ≤ 1.4

Earth Skimming Neutrinos

Optimized cuts

Very inclined showers

L/W ≥ 5 **0.29 ≤ <V> ≤ 0.31 m ns^{-1}** **RMS V ≤ 0.08 m ns^{-1}**



Young showers

60% of triggered stations = « young shower » station: **≥ 13 bins (25 ns) with signal ≥ 0.2 VEM**

&&

Area over Peak ≥ 1.4

Earth Skimming Neutrinos (2)

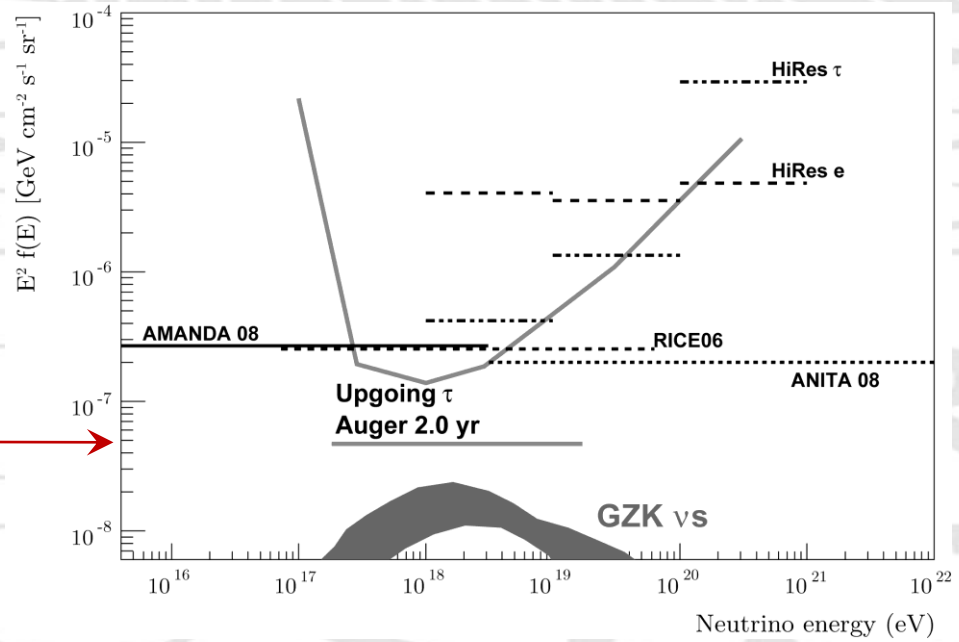
Results

Selection criteria + Data 01/2004-08/2007

➔ Upper limit on the diffuse flux of UHE tau neutrinos from the Pierre Auger Observatory

The Pierre Auger Collaboration, *Phys. Rev. Lett.* ***100****, 211101 (2008)*

Update: Selection criteria + Data 01/2004-02/2009 = **0 candidate again**

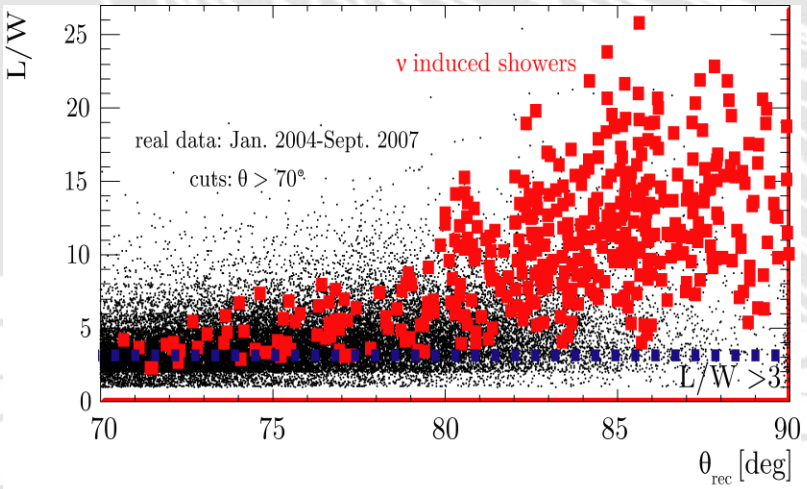


4.7×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}

Downgoing Neutrinos

Optimized cuts

Very inclined showers



L/W > 3

$\langle V \rangle \leq 0.313$ m ns^{-1}

$\theta_{rec} \geq 75°$

RMS ≤ 0.08 m ns^{-1}

Young showers

Broader angular range ➔ larger background contribution ➔ More demanding selection

➔More variables:

AoP and AoP^2 for the 4 first triggered stations

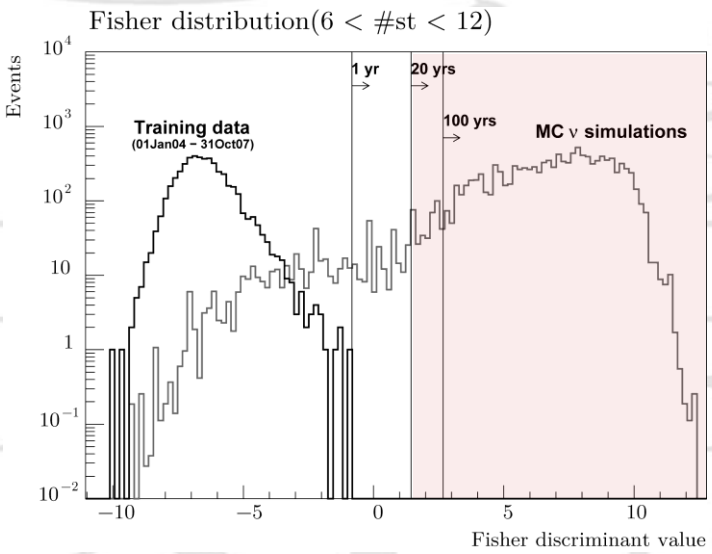
+ $AoP_1 \times AoP_2 \times AoP_3 \times AoP_4$ and $\langle AoP \rangle_{early} - \langle AoP \rangle_{late}$

Downgoing Neutrinos (2)
Fisher discriminant

Fisher discriminant f = linear combination of:

$AoP, AoP^2, AoP_1 \times AoP_2 \times AoP_3 \times AoP_4, \langle AoP \rangle_{early} - \langle AoP \rangle_{late}$)

f allows the **best separation possible** between two populations of events: Data vs Simulated neutrinos



Extrapolation of the exponential tail

➔ Number of Background events

➔ **f chosen for < 1 background event / 20 years**

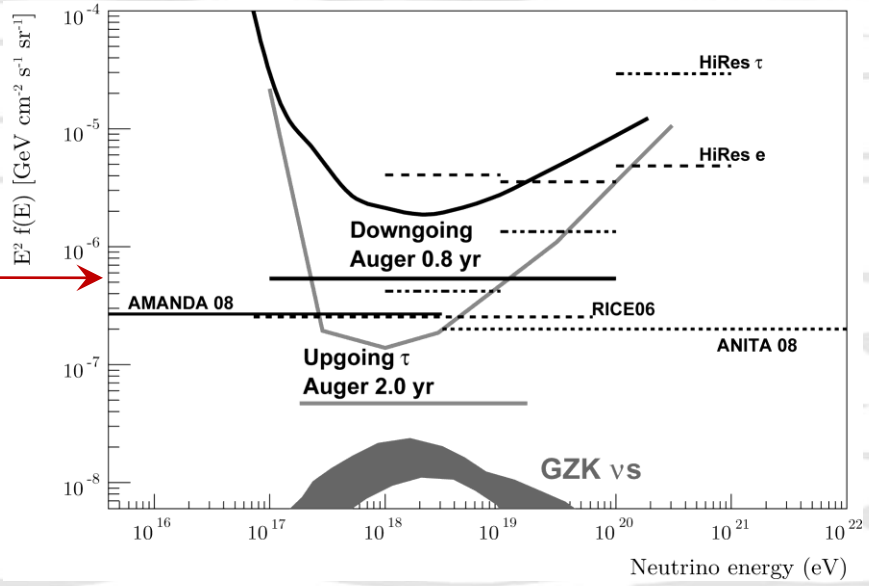
Downgoing Neutrinos (3)

Results

Selection criteria + Data 01/2004-02/2009 = **0 candidate**

Exposure of SD array to UHE neutrinos

5.2×10^{-7} GeV cm^{-2} s^{-1} sr^{-1}



Implication of Auger results on neutrino sources

Very large uncertainties remain in the expected UHE neutrino fluxes

How to gain a better insight ?

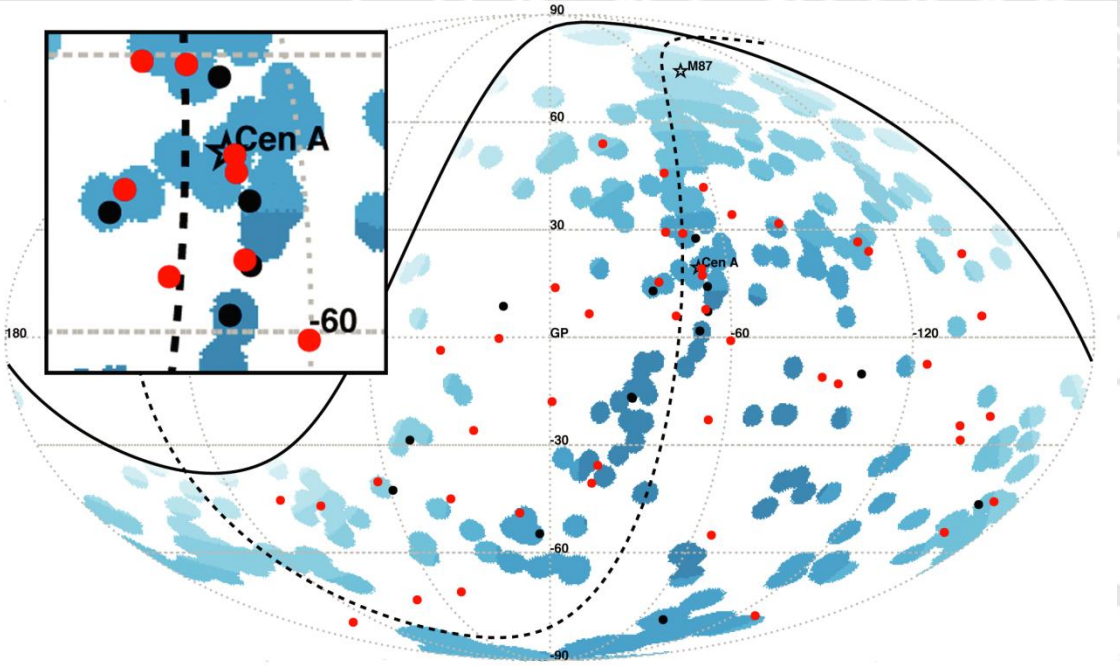
➔Ultra High Energy Cosmic Rays experiments

➔ **The Pierre Auger Observatory**

Implication of Auger results on neutrino sources (2)

Individual sources

Most interesting result: **Correlation of the highest energy cosmic rays with nearby AGNs**



Interesting features:

Sources correlated with the distribution of matter
➔Consistent with AGNs or GRBs

Accumulation around CenA ?

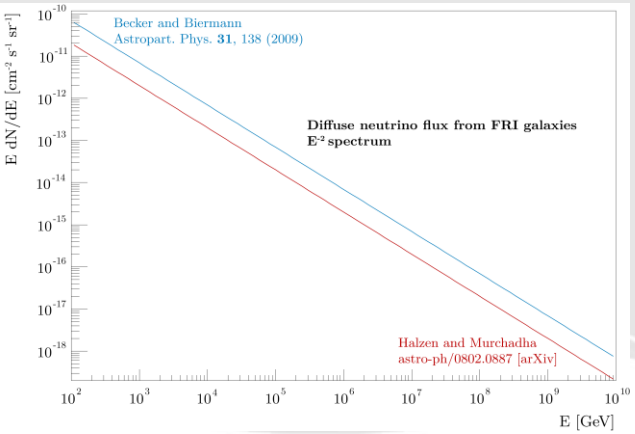
Implication of Auger results on neutrino sources (3)
Individual sources

Accumulation ➔ FRI galaxies as sources of UHECRs ?:

Lots of temptative calculations

But why no event detected from M87 (virgo cluster) ?

Border of Auger field of view ?
FRI not sources of UHECRs ?



Right now, we cannot state what the sources of UHECRs are.

Correlation compatible with many sites already in the short list for UHECR's sources

Implication of Auger results on neutrino sources (4)

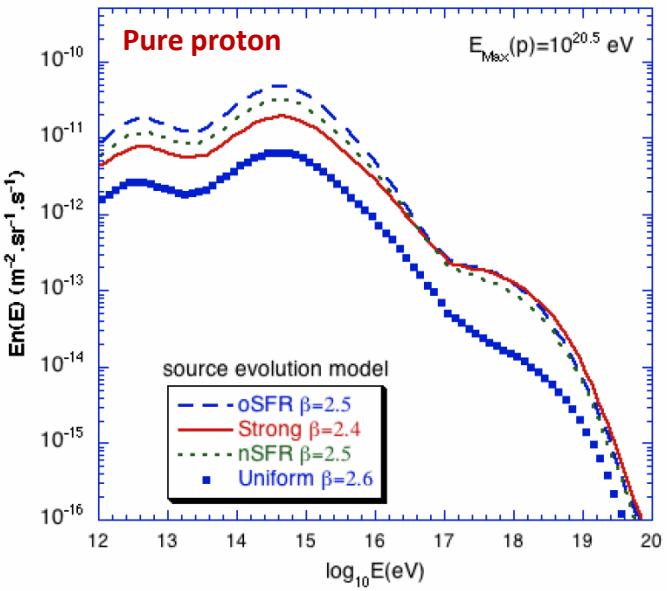
Cosmogenic Neutrinos

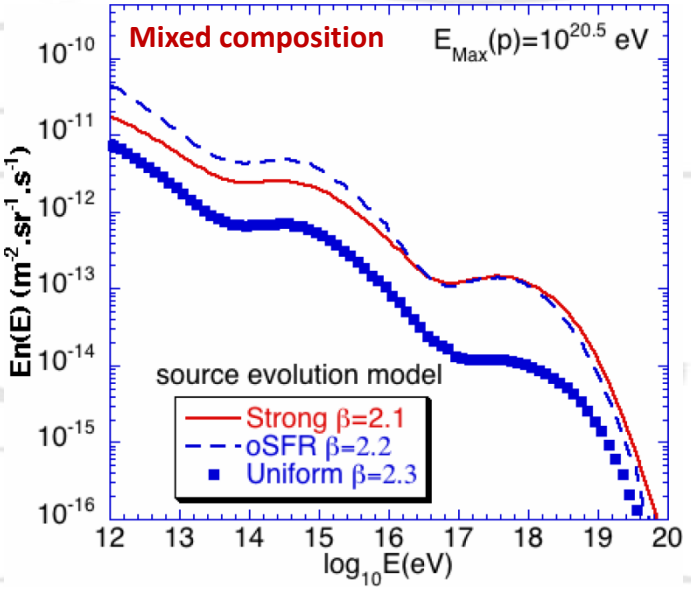
Cosmogenic neutrinos = neutrinos produced through interactions of UHECRs (p, …, Fe) with diffuse photons backgrounds (CMB, CIB …)

Inputs needed:
- Composition of UHECRs
- Injection spectrum (spectral index + maximum energy)
- Distribution of the sources + Evolution with the redshift

Right:
Exemples of UHE cosmogenic neutrino fluxes
*Allard et al., JCAP **0609**, 005 (2006)*

$E^{-\beta}$ spectrum, $E_{max} = 10^{20.5}$ eV
4 cosmological evolutions

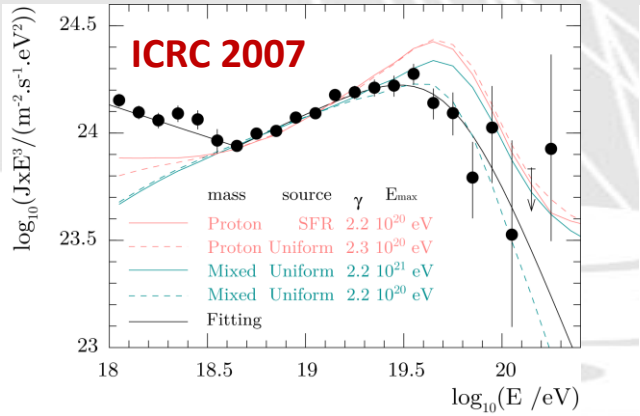


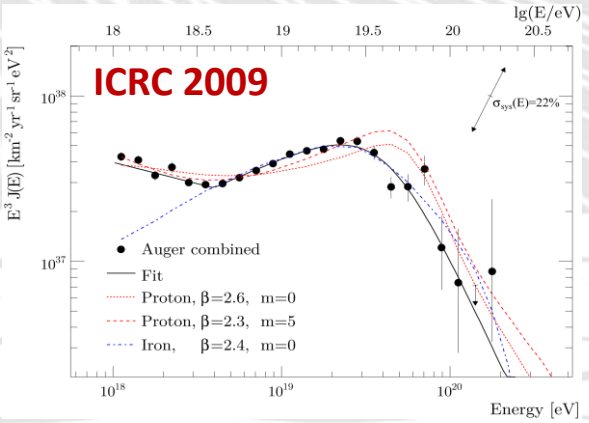


Implication of Auger results on neutrino sources (5)

GZK Neutrinos

AGN correlation + Energy spectrum above 10^{18} eV compatible with GZK effect





We cannot choose yet one model for the production of UHECRs

➔ Large uncertainties on UHE neutrino fluxes

But,

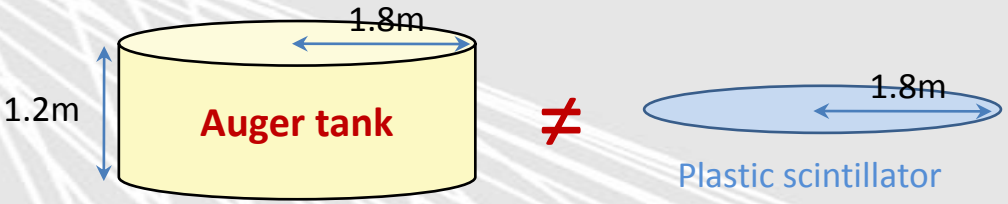
Auger can provide informations on:

- Injection spectrum
- Sources: distribution, nature ?
- Composition

All that we need !!!

Conclusion

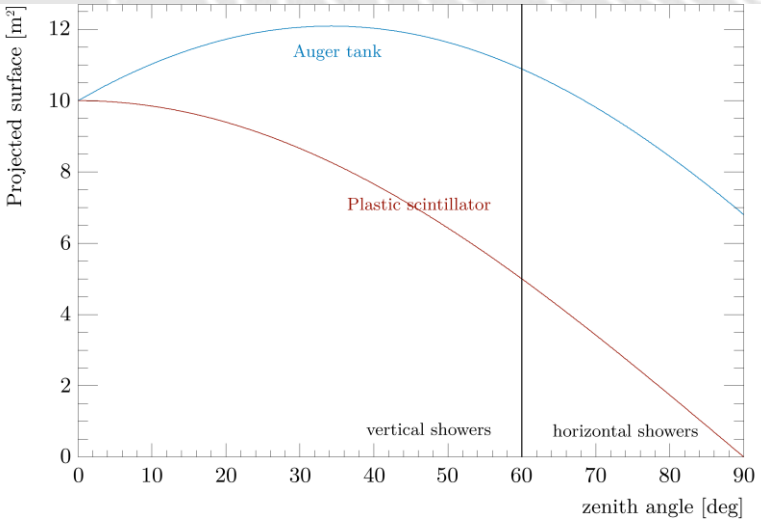
UHE Neutrinos detection with the SD (1)



➔ Sensitivity to very inclined showers

Why ?

➔



➔ **Possible detection of UHE neutrinos**