Neutrino 2002 Conference

Munich, may 25-30, 2002.

Auger
A Large Air Shower Array
and
Neutrino Telescope

- UHECR problematics, motivations for neutrino detection
- The Auger detector
- Neutrino identification and Acceptance
- Tau neutrino detection
- Alternative techniques and conclusions

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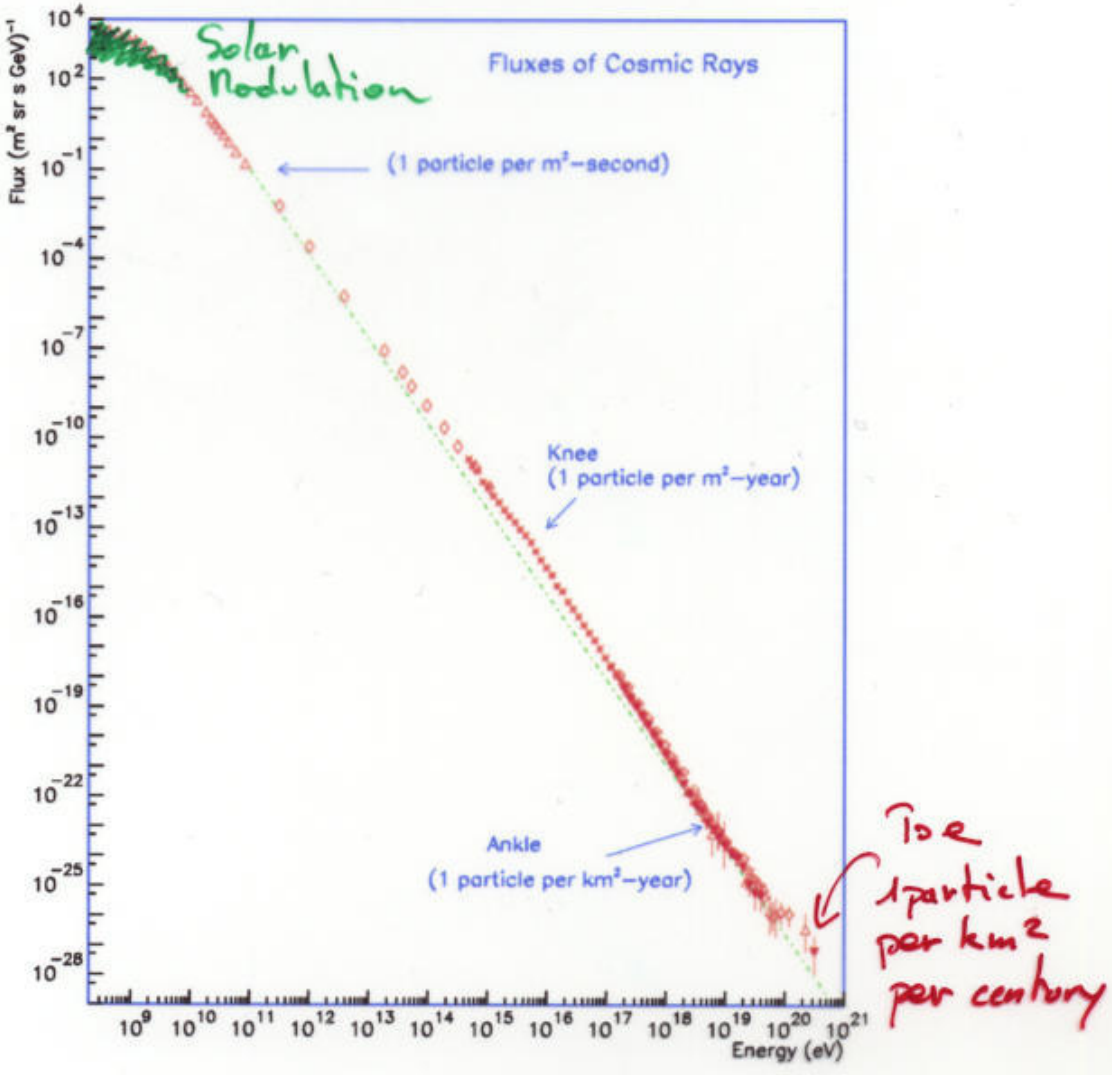
Universities of Paris VI and VII.

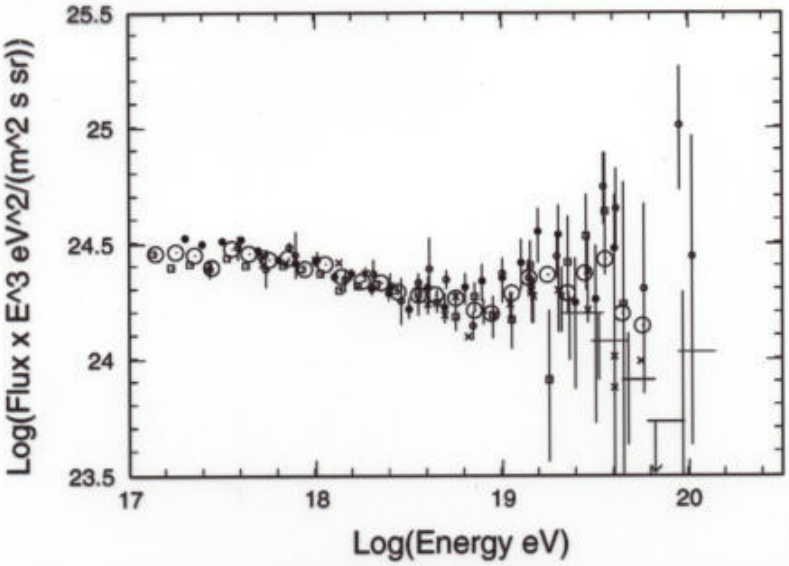
Observed (charged) spectra

- Victor Hess (1912)
- EAS: Pierre Auger (1938) Size $\Longrightarrow E > 10^{15} eV$
- Around 10^9eV : Galactic origin (strong Solar modulation)
- Between 10^9eV and 10^{15}eV : Galactic origin (SNR)
- Between 10^{15}eV and 10^{18}eV-10^{19}eV : Yet unclear, galactic.
- Above 10^{19}eV : Unknown but likely extra-galactique.



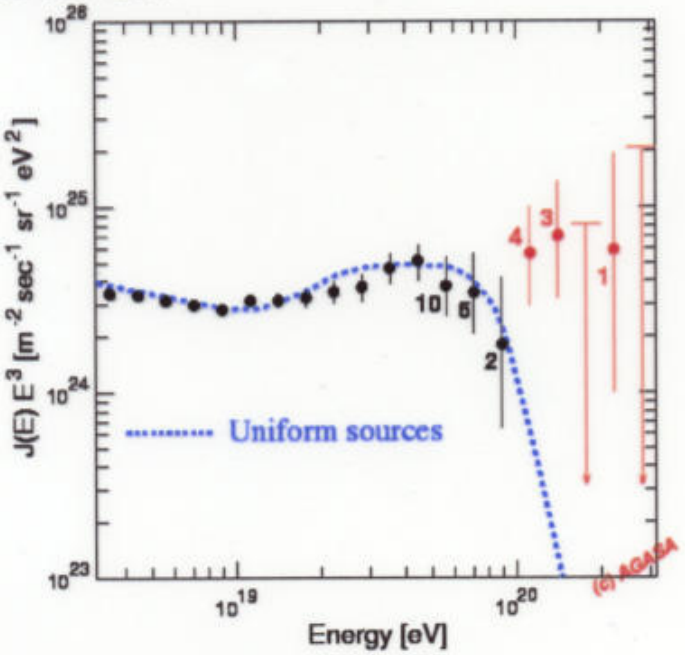
**** before July 2001 ****

Spectrum above 10^{17}eV : (remarkable agreement of experiments)



Composition (heavy ⟶ light); Origin (galactic ⟶ extra galactic)

Spectrum Above 10^{19}eV :



Production mechanisms ? How to reach this energy ?

Primary mass (Composition) ?

Source distribution and nature? Can those CR reach us ?

Where does the spectrum ends ?

Above 10^{20}eV

- Production mechanisms? How to obtain such a high energy ?
- Primary nature (Composition) ?
- Sources distribution ? Where do they come from and how do they reach us ?
- Where does the spectrum ends ?
- What else is there to see?

The very existence of cosmic rays above 10^{20}eV is a mystery... which we want to solve.

Orders of magnitude (at 10^{20}eV)

- Energy : 10^{20}eV $\approx$ 16 Joules $\approx$ 2g of lead out of a hunt gun (450 km/h).
- Flux : One event per km^2 and per century $\Longrightarrow$ detection surface $\approx$ 1000km^2
- Density : At ground level $\approx 10^{11}$ - 10^{12} particles, >99% EM (10 MeV) <1% muons (1GeV)
- Size : 20 km^2 foot print (1 part/m^2 at 1.5 km from the axis)
- Opacity : MFP $\approx$ 10-20Mpc i.e. a tiny fraction (10^{-9}) of the Universe (10 Gpc)

World record: E = 3×10^{20}eV 50 Joule (tennis ball above 100 km/h, 100 millions times a LHC beam)

Sources @ $\gg 10^{18}$ eV (10^{18} eV = 1 EeV)

- "Classic " : Acceleration (Bottom-Up)
  - AGN's
  - Radio Galaxies (powerful ones!).
  - Young neutron stars.
  - GRB.

If those sources are to explain the observed UHECR spectra they will at least produce cosmogenic neutrino. (from the decay of pions photoproduced by GZK cutoff)

⇒ Lower bound on ν fluxes @ 10^{18} eV : 15 EeV km^{-2} yr^{-1} sr^{-1} (BW)

- "Exotic" : Decay (Top-Down) Massive particles or TD are the source of CR (no acceleration)
  - Topological defects collapses, intersections or interactions (strings, Monopoles, super-conducting strings, vortons...)
  - Massive (M>10^{20}eV) (meta) stable relic particles, (e.g. cryptons).

γ and ν In all cases are dominant at the source.

fluxes are always higher than BW bound above 10^{18} eV

Motivations

$\gamma, \nu_e \nu_\mu$

Primary and dominate at the source (TDs, Relic).

By products of pion photo-production

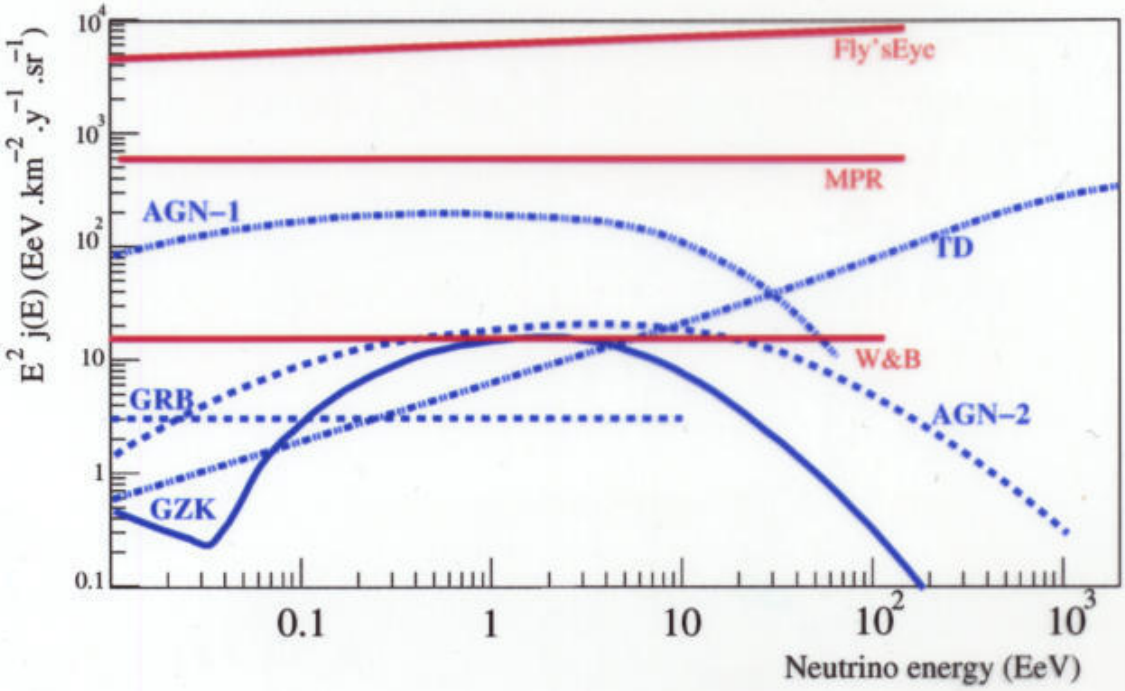
Undeflected by magnetic field.

Unaffected by energy losses.

⇒ Good signature/probe of standard and new physics

But : Cross section is still quite low ⇒ Need large fluxes.

Flux predictions (and upper limits):



Auger

- Large detection surface.

  6000 km^2 (2 sites), 1600 ground detector stations, 3 Fly's Eyes.

- Uniform sky coverage.

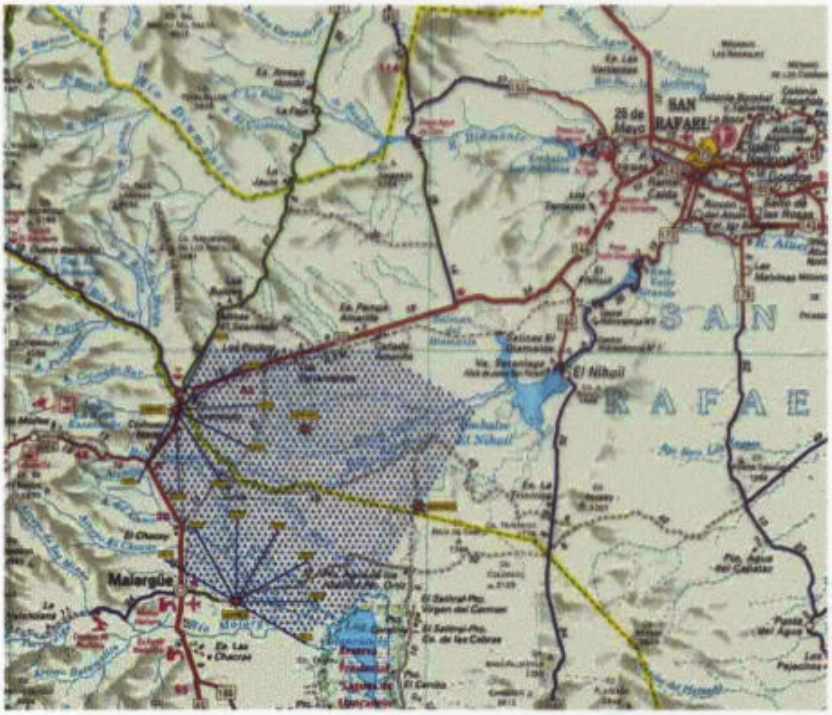
  Two sites, Argentina being installed, one foreseen in Utah, USA.

- Combined detector.

  Use two detection techniquess for cross calibrations, hybrid operation.

Performances

- Duty Cycle : 100 % Array, 10% Fluorescence
- Efficiency : > 90 % above 10^{19}eV
- Resolutions:
  - * Energy (array) : 15% (10^{20}eV) and 30% (10^{19}eV)
  - * Energy (hybrid) : 10% (10^{20}eV) and 20% (10^{19}eV)
  - * Angle (array) : 1^o (10^{20}eV) and 2^o (10^{19}eV)
  - * Angle (hybrid) : 0.2^o (10^{20}eV) and 0.35^o (10^{19}eV)
  - * Statistics : $30 >$ 10^{20}eV per year (today 20)
  - * Identification:
    - statistical for ^{56}Fe
    - shower by shower ID for neutrino and gamma.



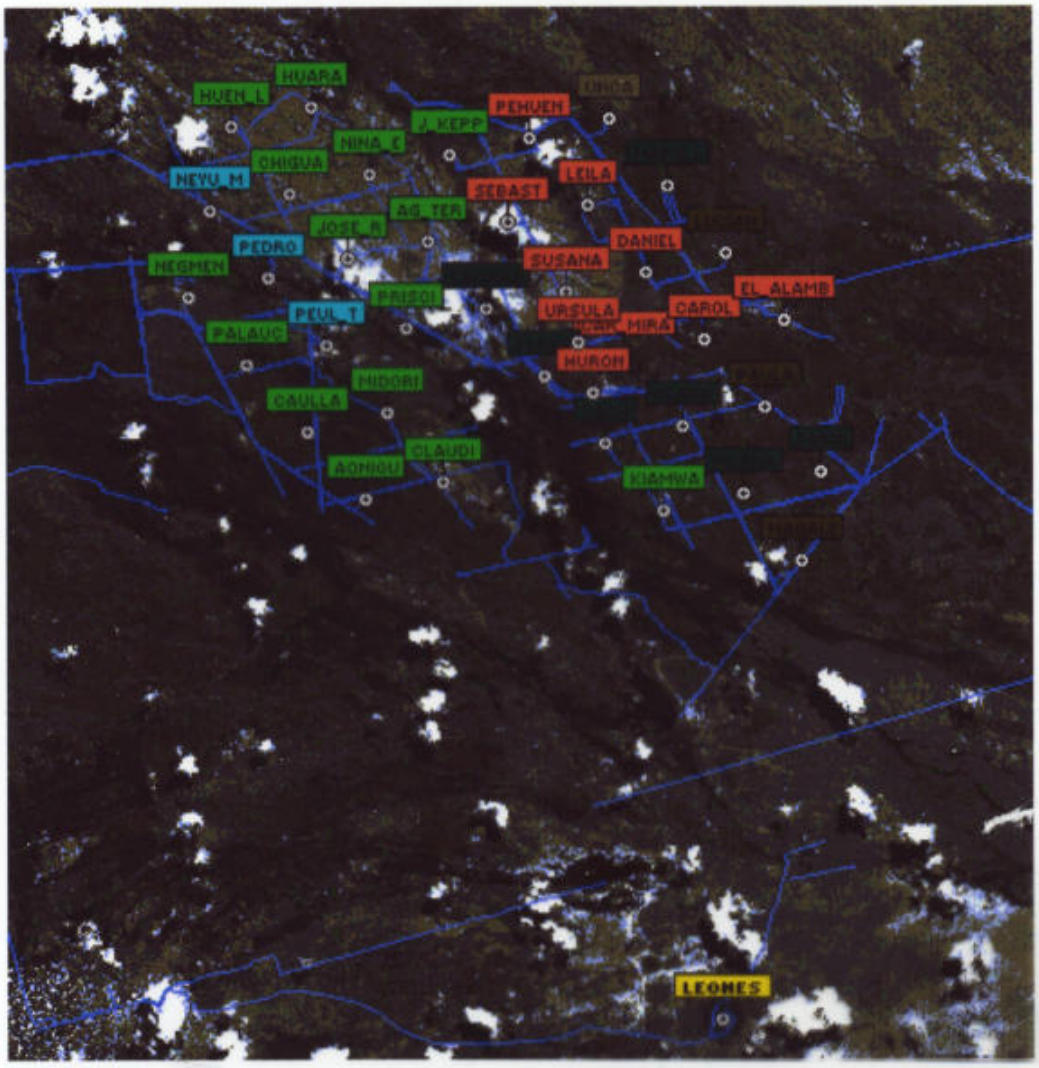
Situation

Objectives in 2001

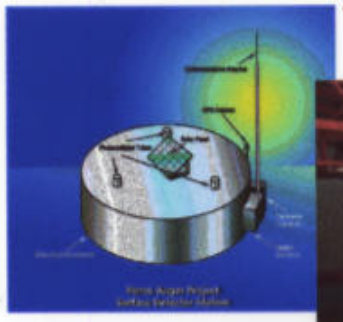
- 40 Cherenkov tanks
- 2 fluorescence cameras (2x30°)

Done:

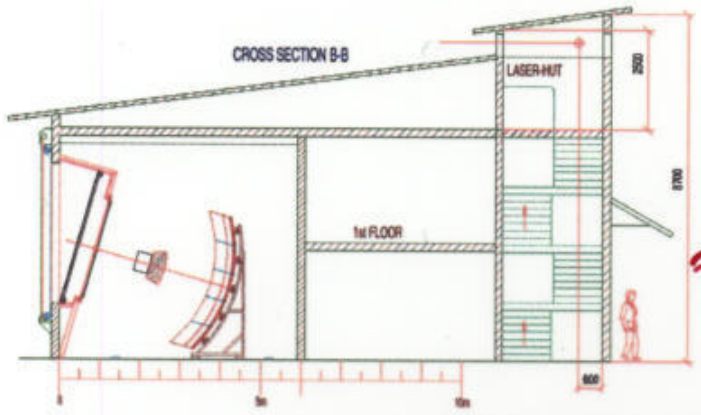
- 40 tank deployed (position and water)
- 30 equiped with electronics almost all runing.
- 2 caméras



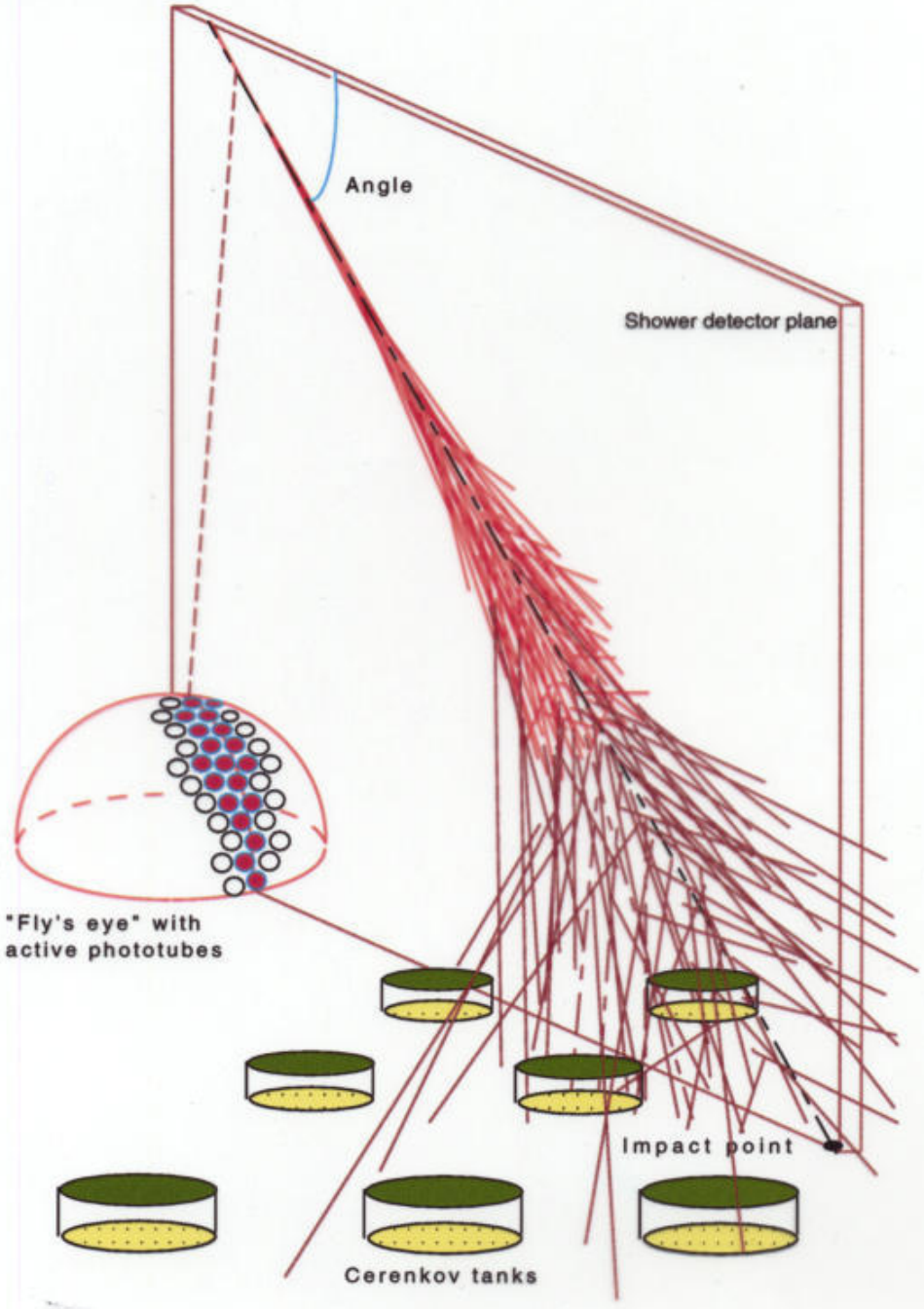
Auger Surface Detector



Auger Fluorescence Detector

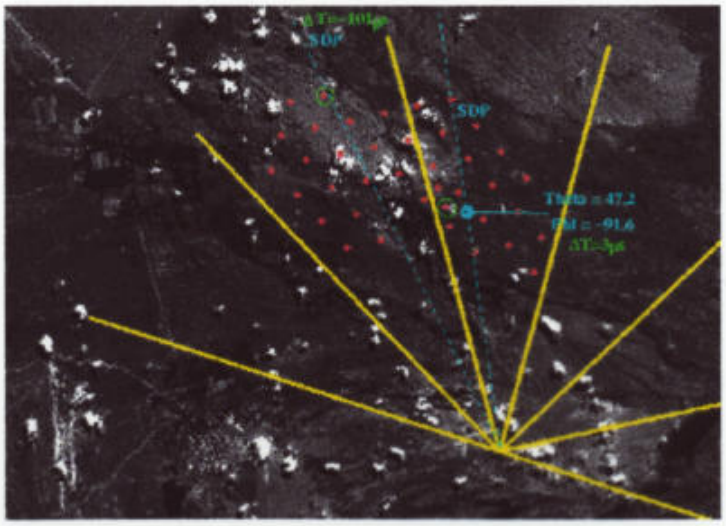


Hybrid operation mode :

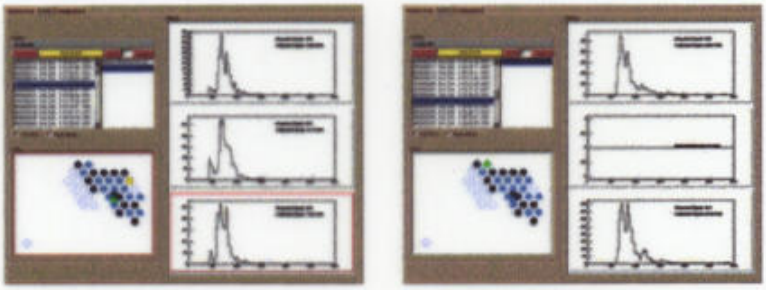


Sun 9 Dec. 02:56:45 2001, first hybrid event

Sun 9 Dec. 05:37:25 2001, second hybrid event

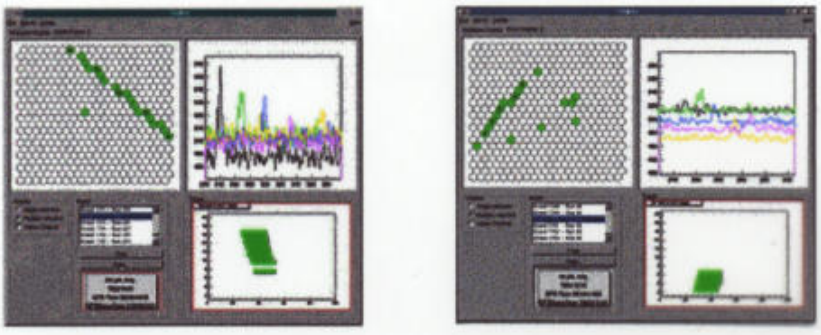


SD Data



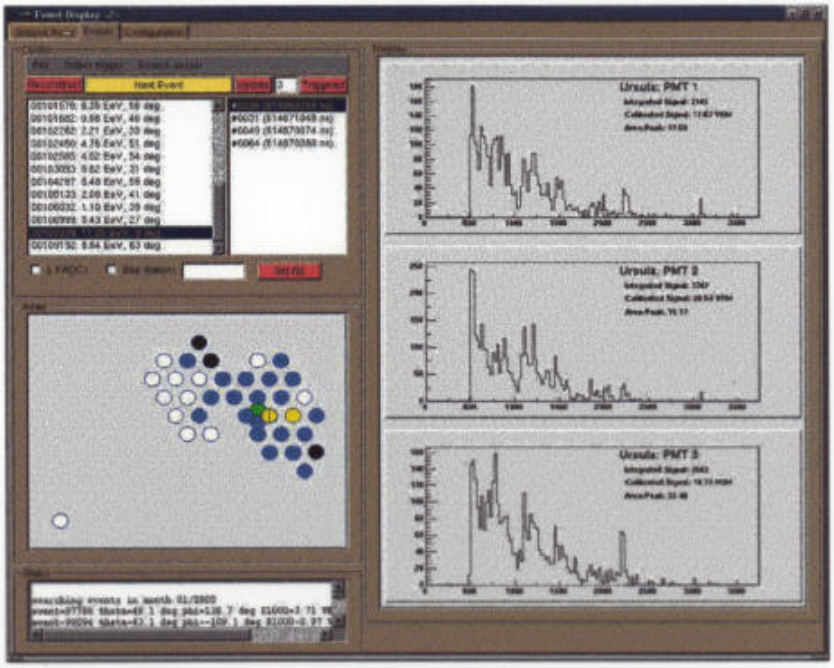
First hybrid, SD tank HURON Second hybrid, SD tank HUARA

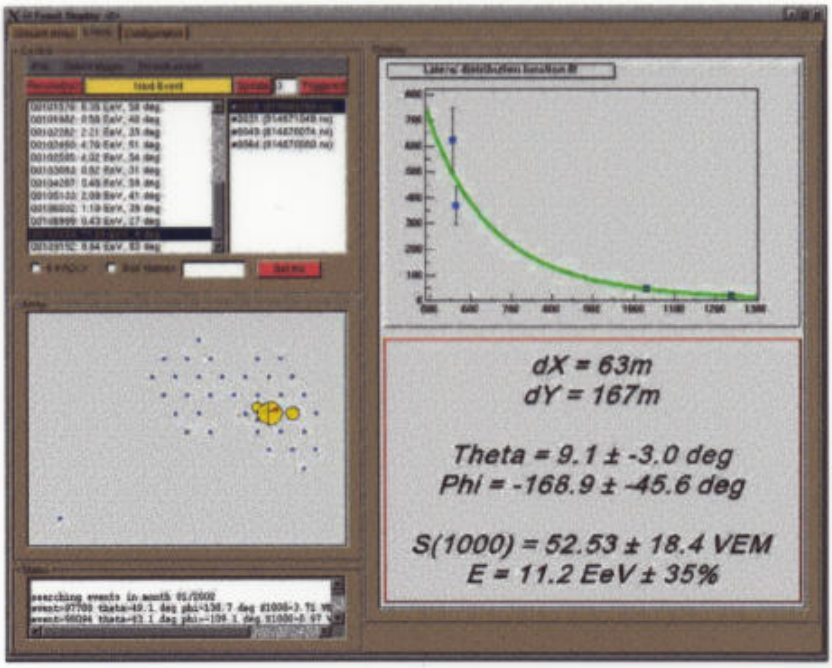
FD Events



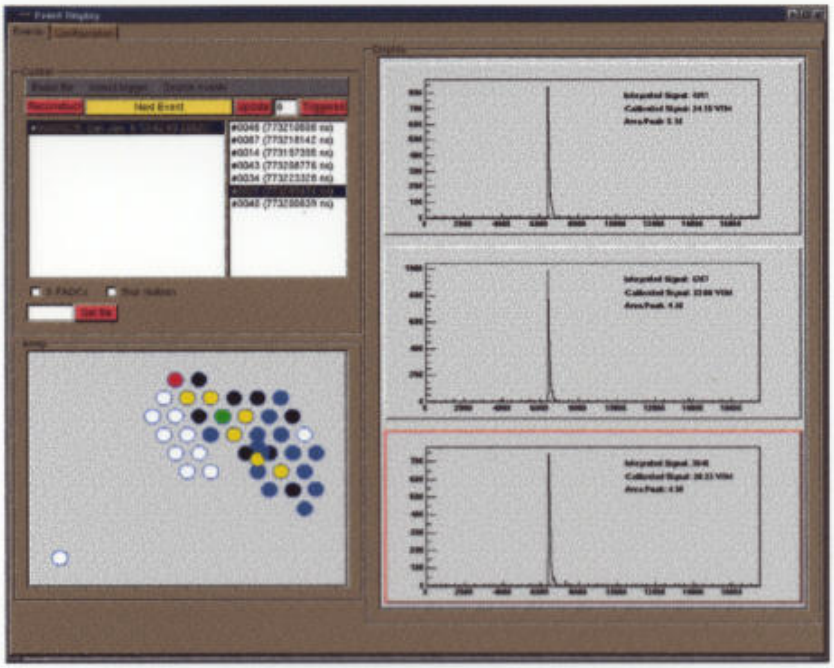
First hybrid, FD Los Leones bay 4 Second hybrid, FD Los Leones bay 5

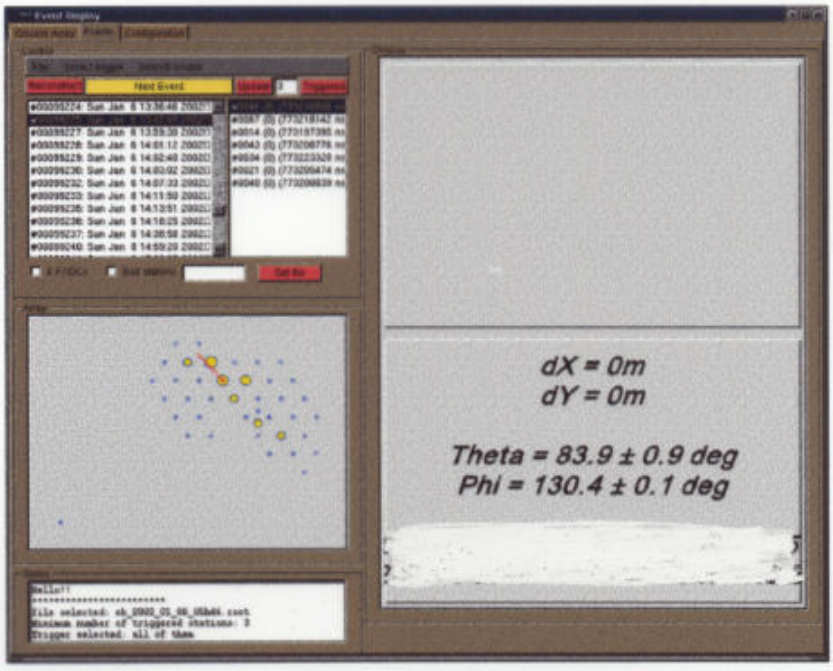
A shower event from January :





A horizontal event :

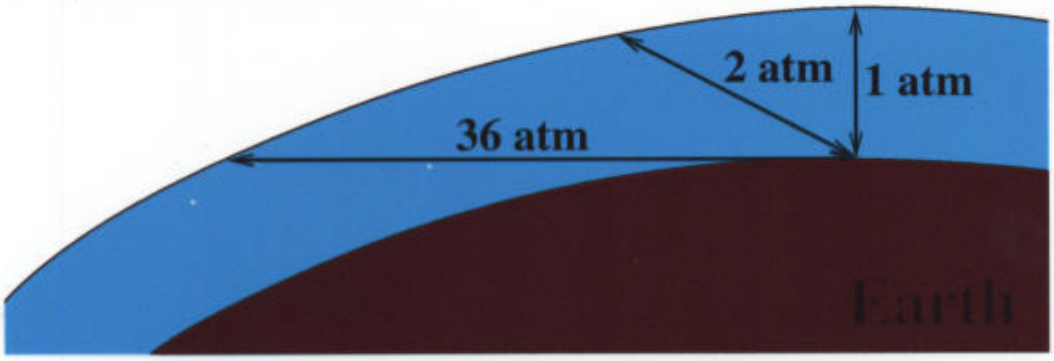




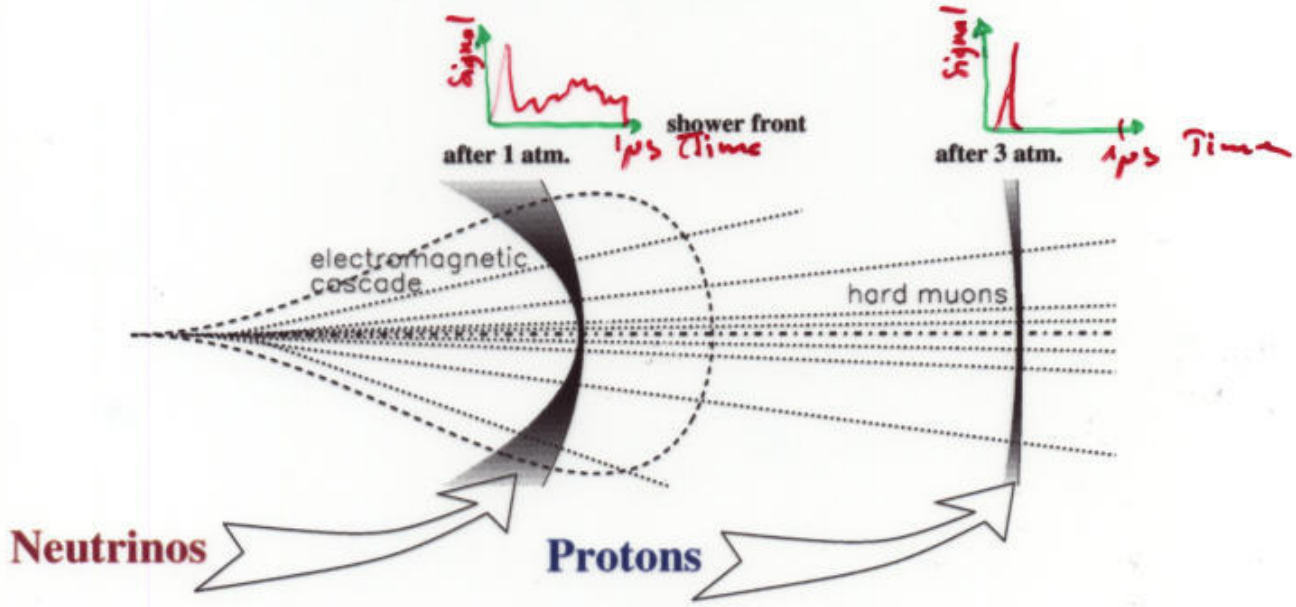
Neutrino Detection

Properties of neutrino induces air showers : HAS

Horizontal Showers



Thickness depending on zenith angle θ



Shower aspect at various depths

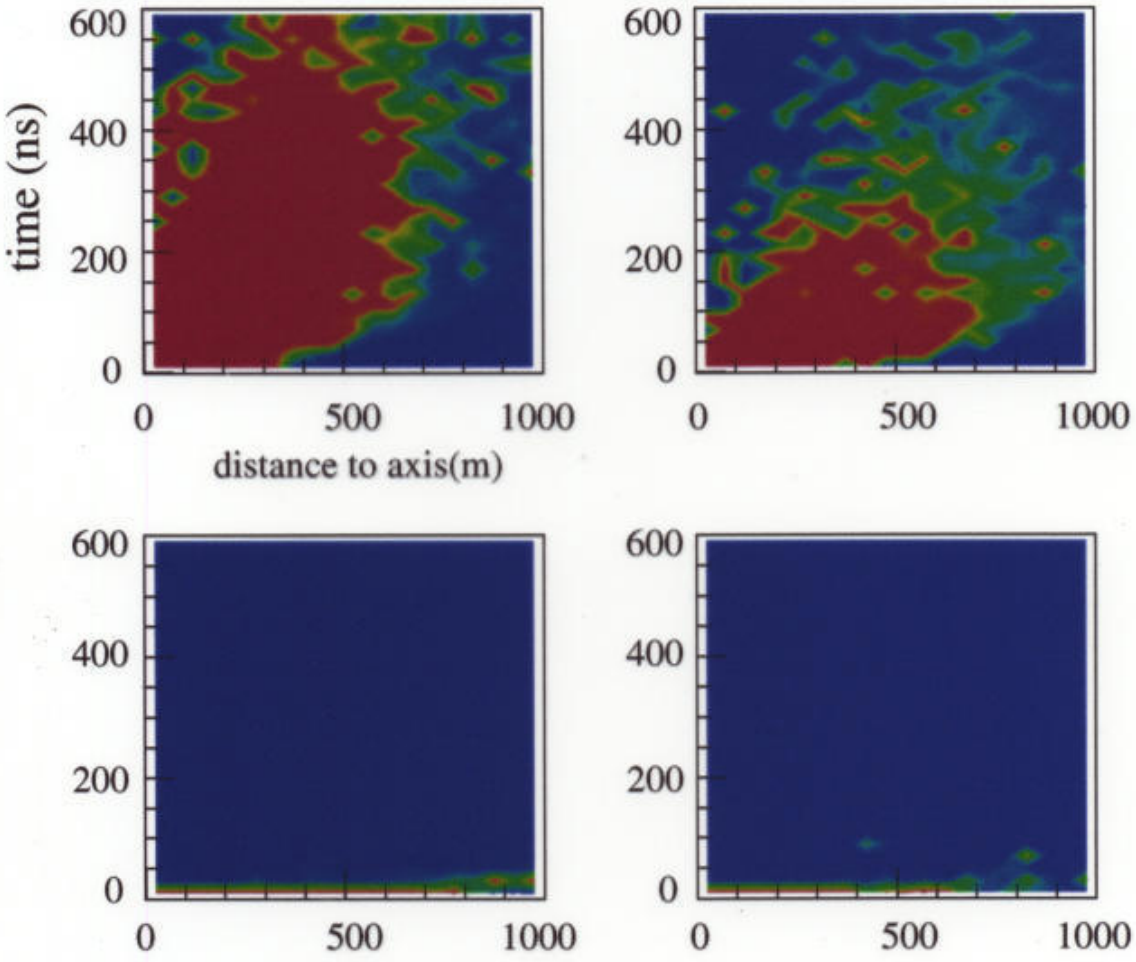
Horizontal showers (above 70°) will show large differences between protons and neutrino

Neutrinos

Background rejection

Studies from ground signal of 10^{19}eV protons at 80 deg and various injection altitude.

altitude = 2 km "Neutrino like" Altitude = 3 km

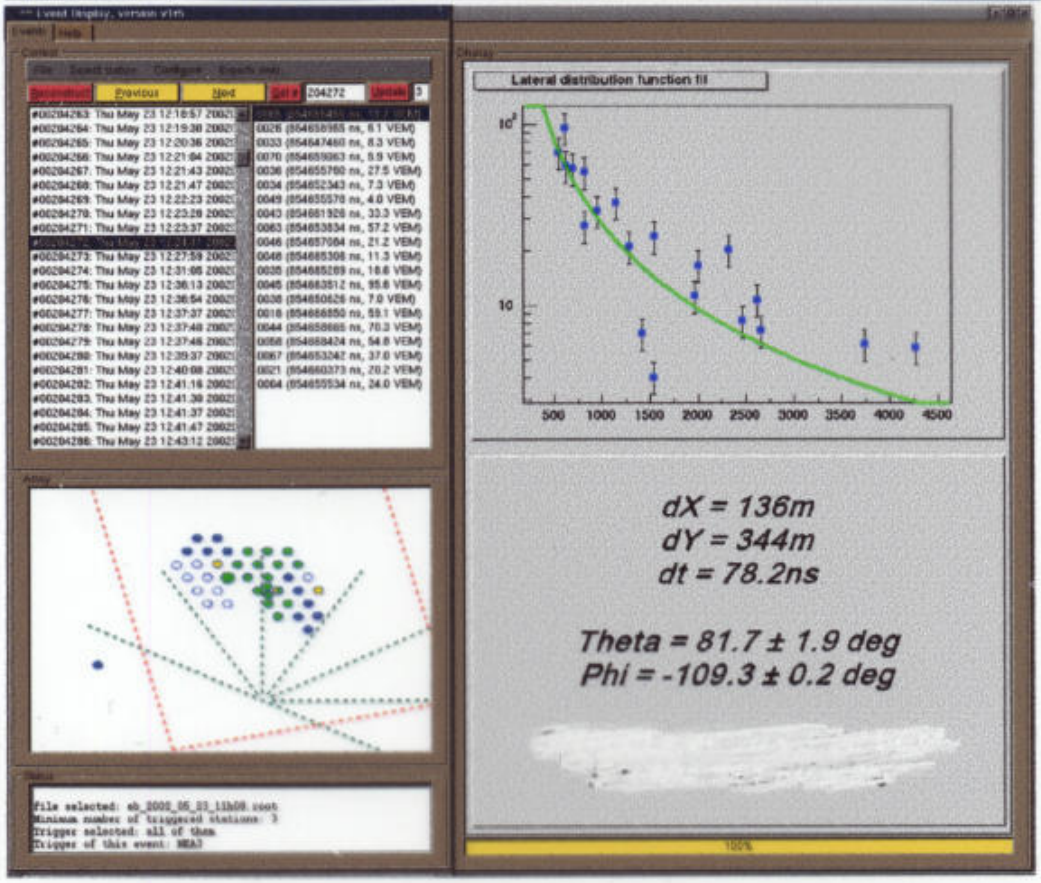


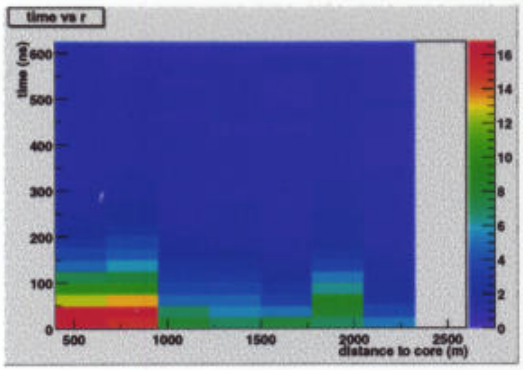
altitude = 20 km "Protons like" Altitude = 100 km

Cosmic background $\simeq$ 1 per day

Rejection power lager than $10^4 \Rightarrow$ OK

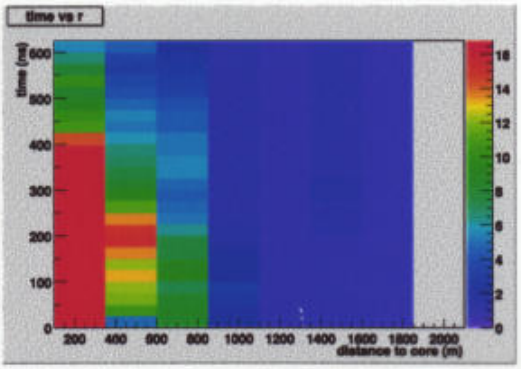
A VERY large REAL horizontal event (May 23rd)





Zenith angle 82 degrees;

Energy around $\gtrsim$70 EeV



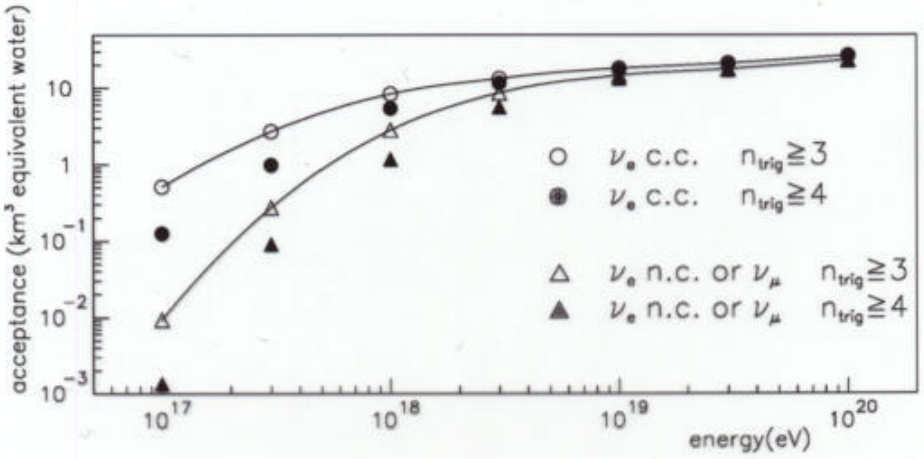
Zenith angle 45 degrees;

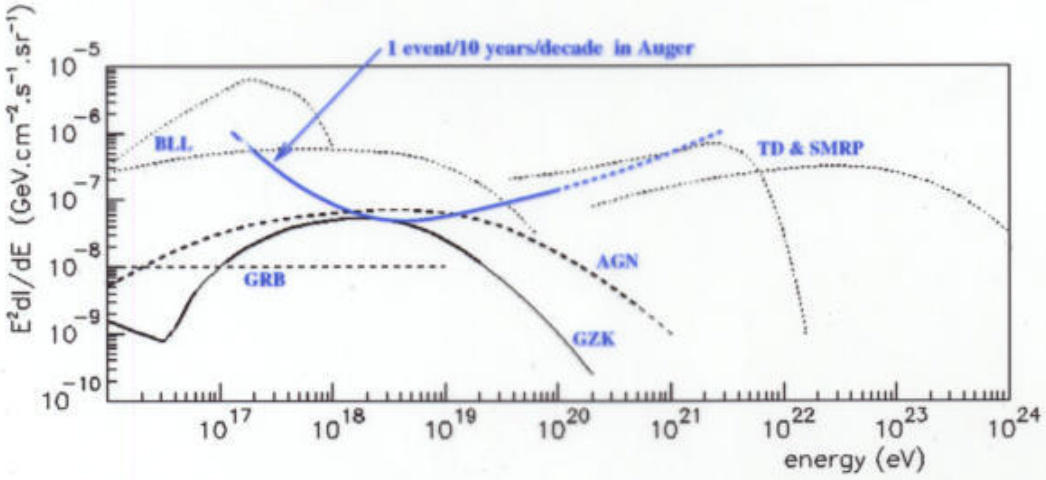
Energy around 20 EeV

Neutrinos

Atmospheric Showers ν selection :

- Local Tank Signal : $>$ 8 V.E.M. or $>$ 4 V.E.M. and $t_{90} - t_0 > 200$ ns
- more than 1/3rd of tanks (and at least 2) with $t_{90} - t_0 > 150$ ns





⇒ no signal unless speculative models

Tau Neutrinos detection

- A.L-S astro-ph 00 09 444
- Bertou, Billoir, Deligny, Lachaud, A.L-S astro-ph 01 04452
- published in Astroparticle Physics Vol 17 n°2 185-193 (2002)

If neutrino oscillate with max $\nu_\mu \leftrightarrow \nu_\tau$ mixing

on Earth :

$$\nu_e : \nu_\mu : \nu_\tau \simeq 1 : 1 : 1$$

Therefore we expect to see ν_τ and τ

Auger τ by numbers :

$\gamma c\tau$ = 50 E_{18} km

MFP $\simeq$ 300 $E_{18}^{-0.4}$ km ($\sigma_{cc} = E_{18}^{-0.4}\ 10^{-32}\text{cm}^2$)

Attenuation length at 1 EeV:

300 km bremsstrahlung,

30 km with pair production,

18 km downto 6 km if high Q^2 DIS contribution.

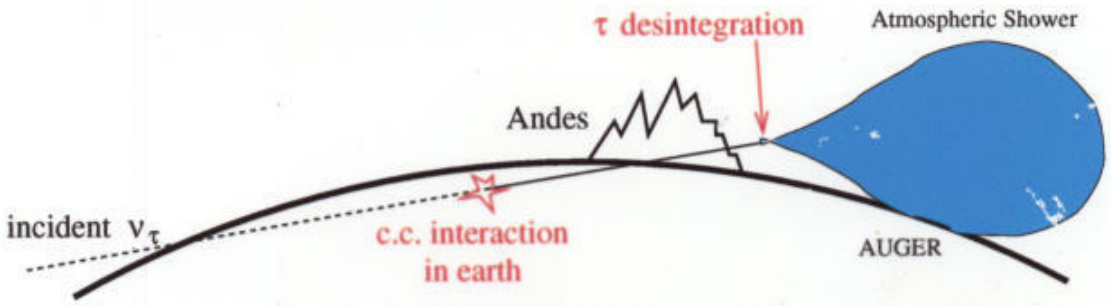
Remember :

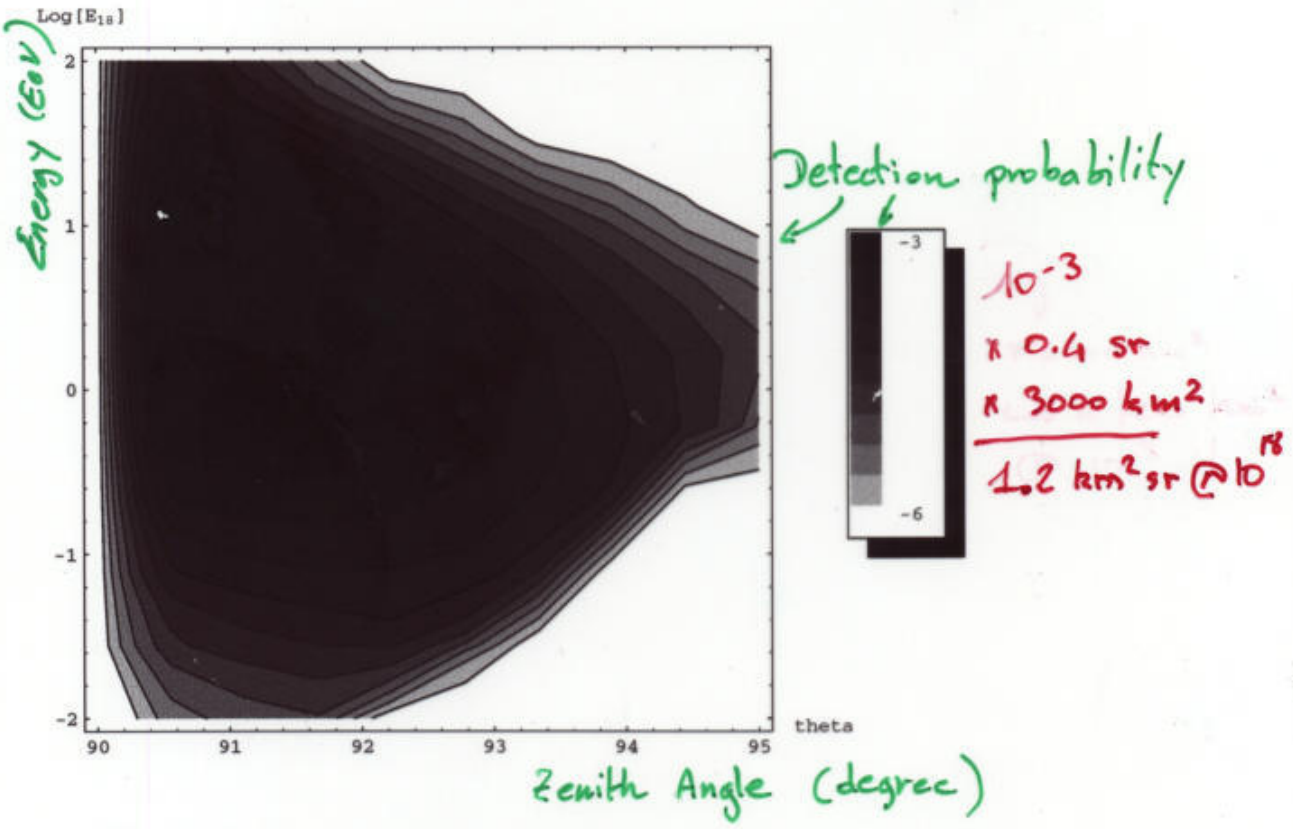
Auger $\simeq$ 40x60 km

Shower size $\simeq$ 15 km

Neutrinos

Underground Interaction (ν_τ)





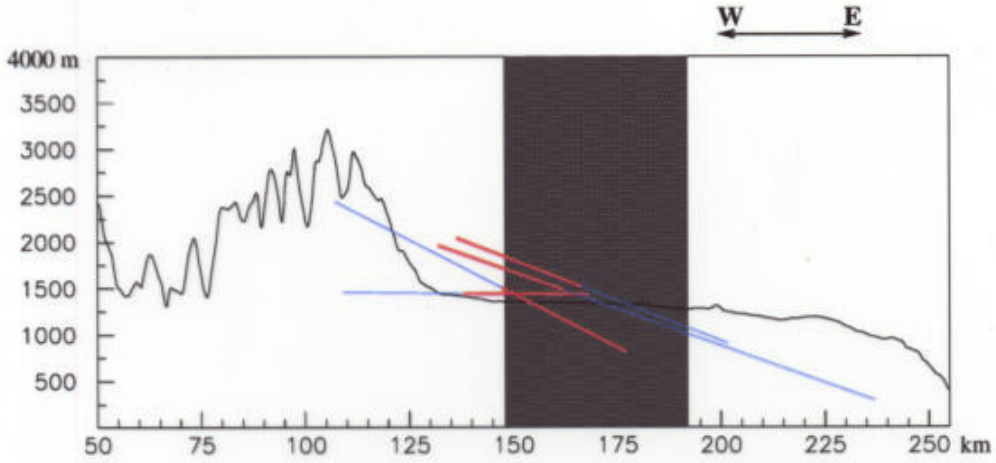
Maximum sensitivity:

$\simeq 91^\circ$

$\simeq 3 \times 10^{18}\,\mathrm{eV}$

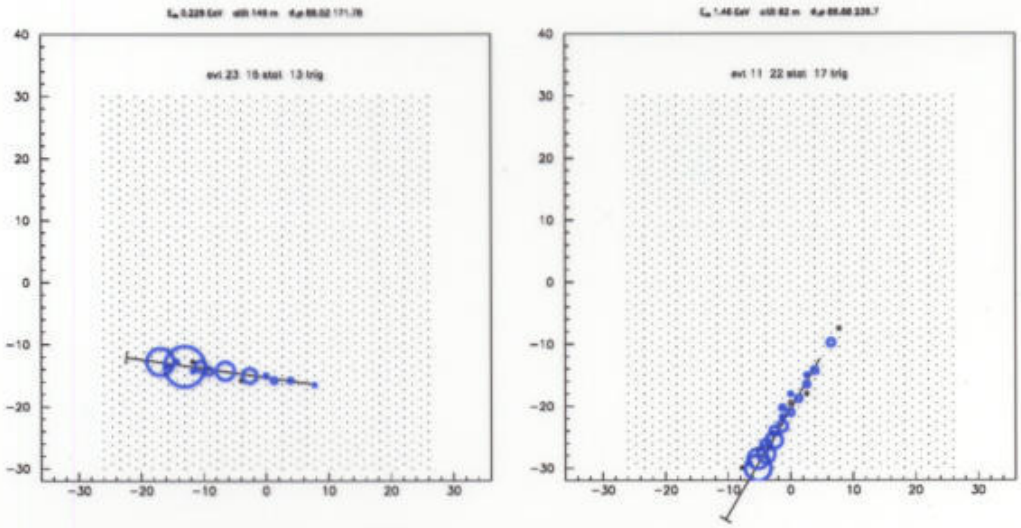
Neutrinos

Some ν_τ showers



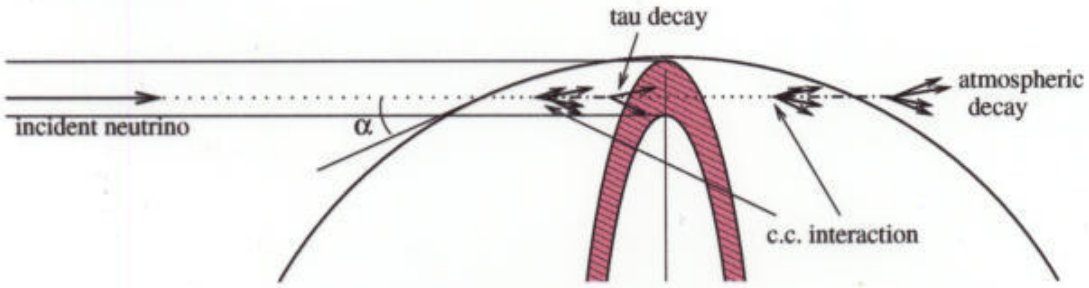
Examples of 10^{18}eV ν_τ

($10\times$ more upgoing τ than downgoing from Andes.)

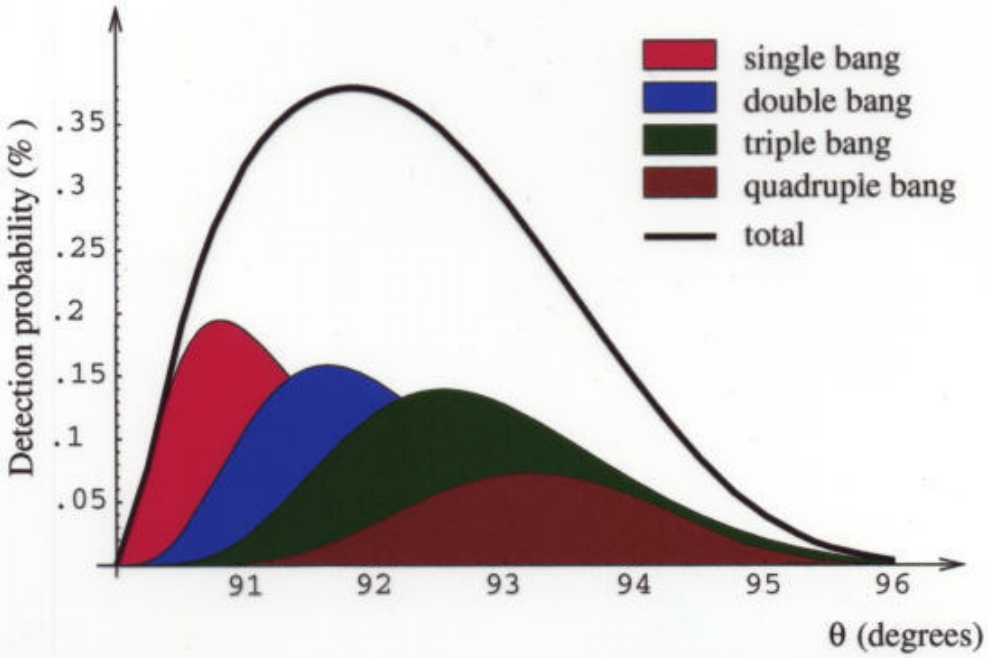


at 3×10^{17} eV at 3×10^{18} eV

Multi Bangs

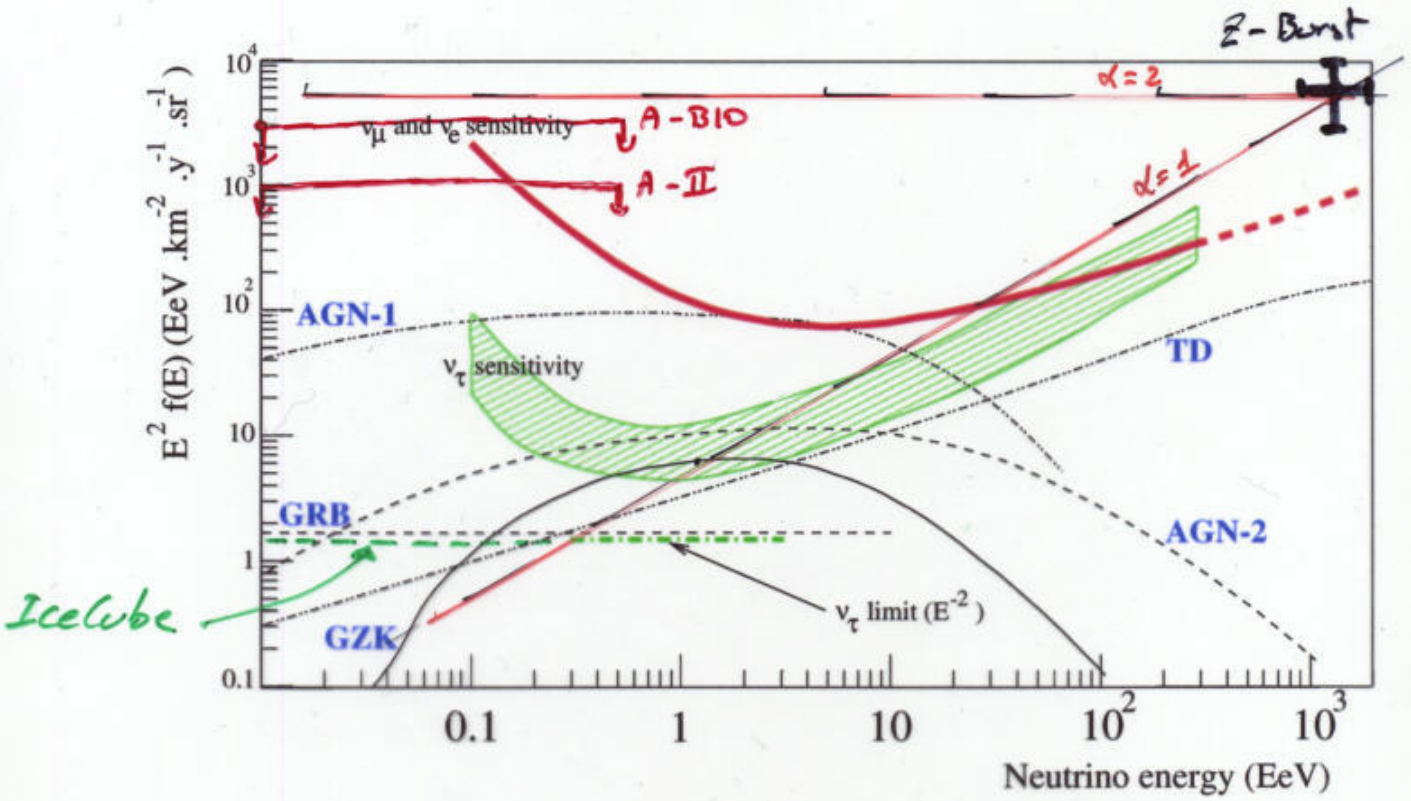


$$\nu_\tau \rightarrow \underbrace{\left[\nu_\tau \left\{ \begin{array}{ll} \xrightarrow{cc} & \tau \\ \xrightarrow{nc} & \nu_\tau \end{array} \right| \tau \left\{ \begin{array}{ll} \xrightarrow{cc/decay} & \nu_\tau \\ \xrightarrow{nc} & \tau \end{array} \right. \right]}_{n\ times} \rightarrow \tau$$



Neutrinos

A summary of Auger expected performances



Hatched area represents two extreem DIS energy loss models.

Flux divided by two (full mixing hypothesys $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$).

Dotted line speculative. Dahsed line probable. Solid line certain.

Limit is 90% C.L after 5 years.

Poster I.9

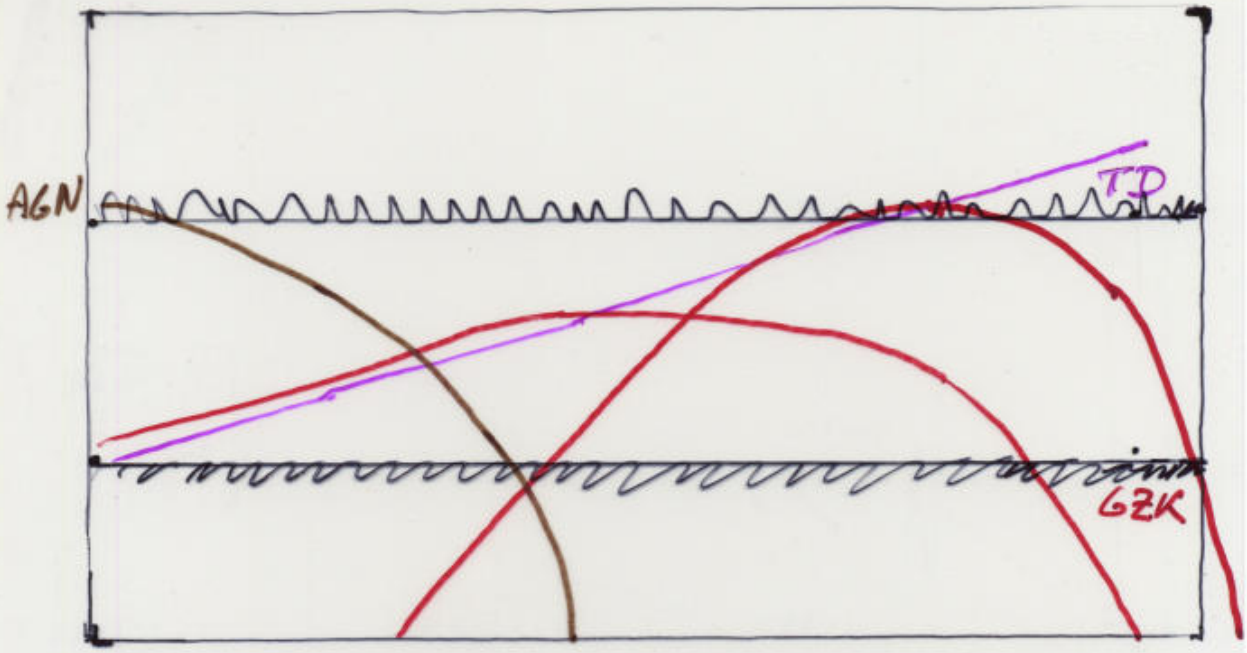
After only 1 year with new fluxes hep-ph 0205050

Expected number of events after 5 years.

E-loss	AGN-1	TD	GRB	GZK	AGN-2	Z-burst
BS+PP	135.0	11.5	2.5	8.5	14.5	>5000 (α=2)
BS+PP+DIS-high	50.0	4.0	1.0	3.0	5.5	~ 20 (α=1)

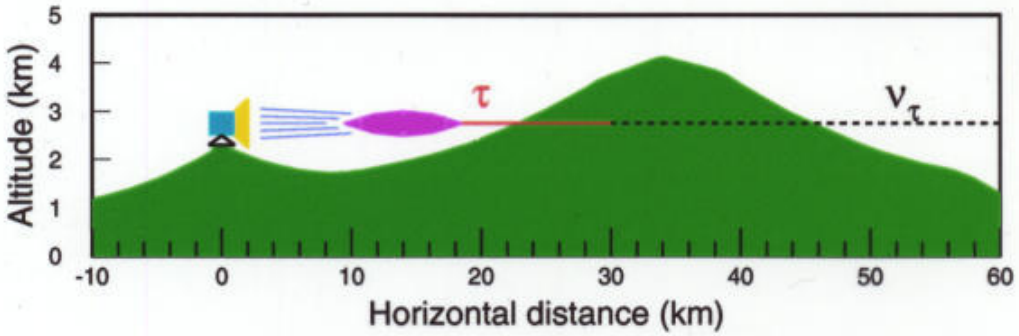
GZK + GRB/AGN-2 → At Least one ν_τ event per Year

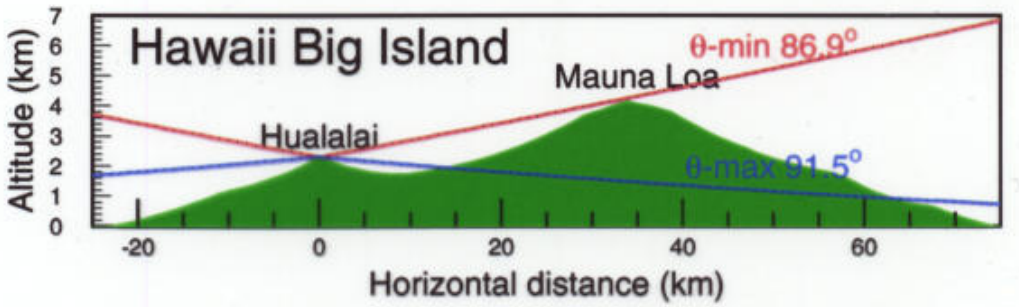
Ahronian et al. Foster I.S
hep-ph 0205050 [Semikov]

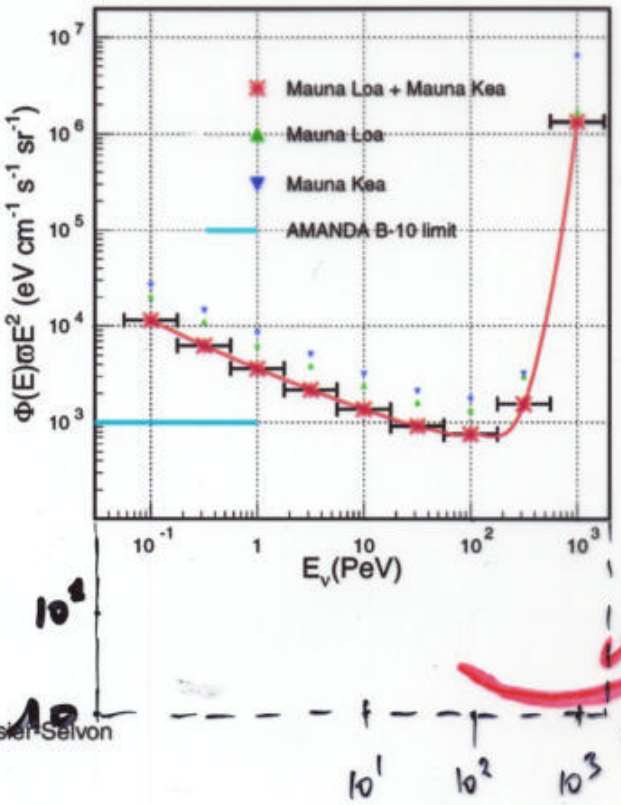


(3 years)

Alternative Ideas







See for details :

- Fargion (2000)
- Vannucci (2001)
- Hou & Huang (2002)

Auger ν_τ

Conclusions

- Detector is under construction and performing above specification [2005]
- Neutrino performance are expected to be very good especially for ν_τ detection
- Encouraging results fron Haverah Park HAS analysis (Energy reconstruction)
- Fluorescence detection with Auger telescope still to be explored

$\{ CR \in [10^{18}, 10^{20}]\ eV \} + \{ CMB \} + \{ \sin^2 2\theta_{\mu\tau} \sim 1 \}$

$\Downarrow$

Auger might very well be the first tau neutrino appearance experiment with positive results before 2006.

Please Use: $5\ 10^{-9}\ GeV\ cm^{-2}\ s^{-1}\ sr^{-1}$ (90% CL 5 years)
as Auger projected limit on ν fluxes