Incontri sulla Fisica delle Alte Energie

XVI Ciclo di Incontri

14-16 Aprile 2004

Torino

UHE & EHE Neutrino Astronomy

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Outline

Scientific motivations for neutrino astronomy

Why are we interested in UHE/EHE neutrinos?

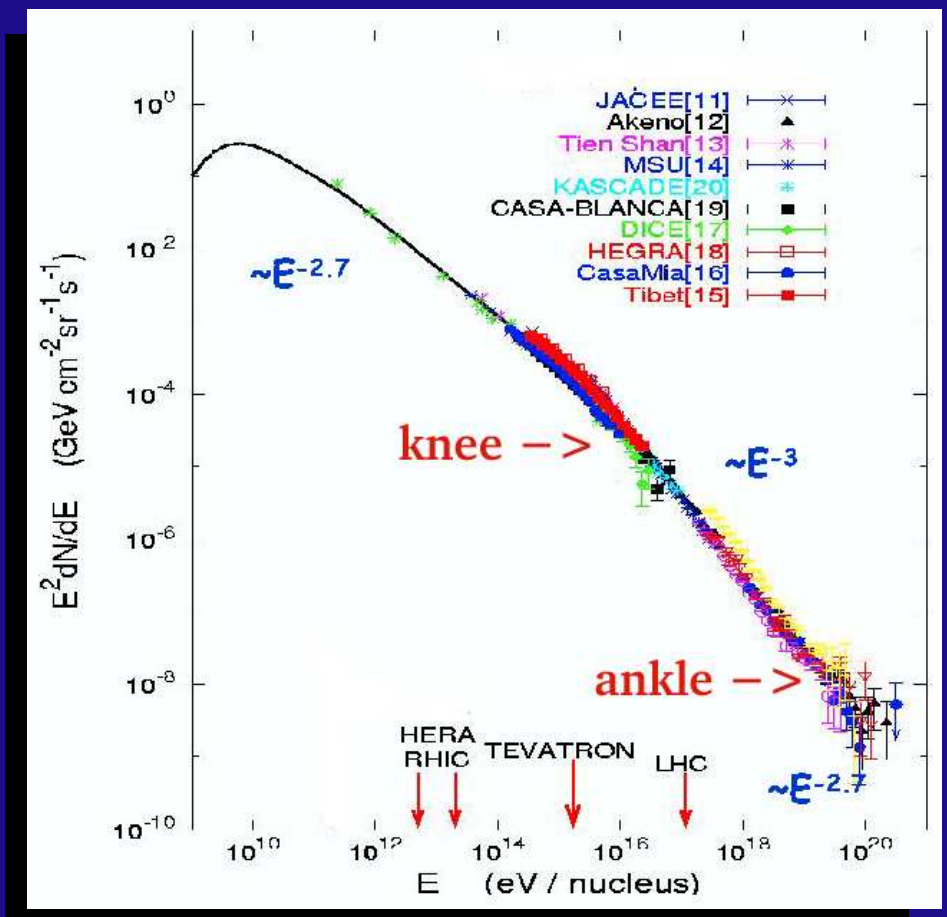
UHE/EHE neutrino sources and fluxes

UHE/EHE neutrino detection

Underwater/ice telescopes
Other technique

UHE/EHE Cosmic Rays

WE KNOW THAT THERE ARE SOURCES IN THE UNIVERSE THAT PRODUCE PARTICLES WITH ENERGIES UP TO $3 \cdot 10^{20}$ eV



BUT WE DO NOT KNOW WHAT ARE THESE SOURCES ?

CR data provide puzzles and questions rather than answers . . .

Why there is a 'knee'? Why there is an 'ankle'? Why there are CR with energies higher than GZK cutoff? What is chemical composition?

In the vicinity of GZK cutoff

GZK cutoff: interaction of primaries with γ_{CMB}

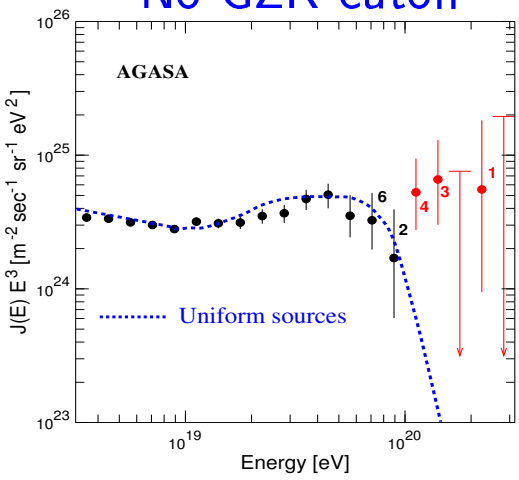
$$p + \gamma_{CMB} \rightarrow \Delta \rightarrow \pi + p$$

above $E_p = (m_\Delta^2 - m_p^2)/2E_{\gamma_{CMB}}$

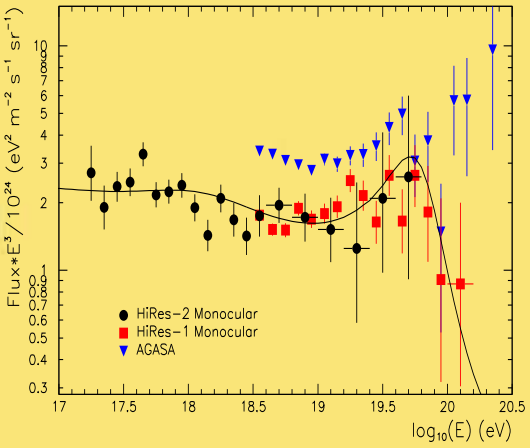
$\lambda_{\gamma p}(E_p > 5{\cdot}10^{19}\,\text{eV}) \approx 10\,\text{Mpc}$ (10^{-7} of the Universe)

AGASA: HiRes:

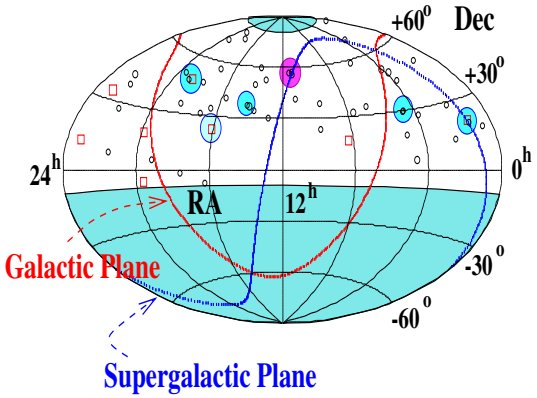
No GZK cutoff



Indication of cutoff



6 clusters

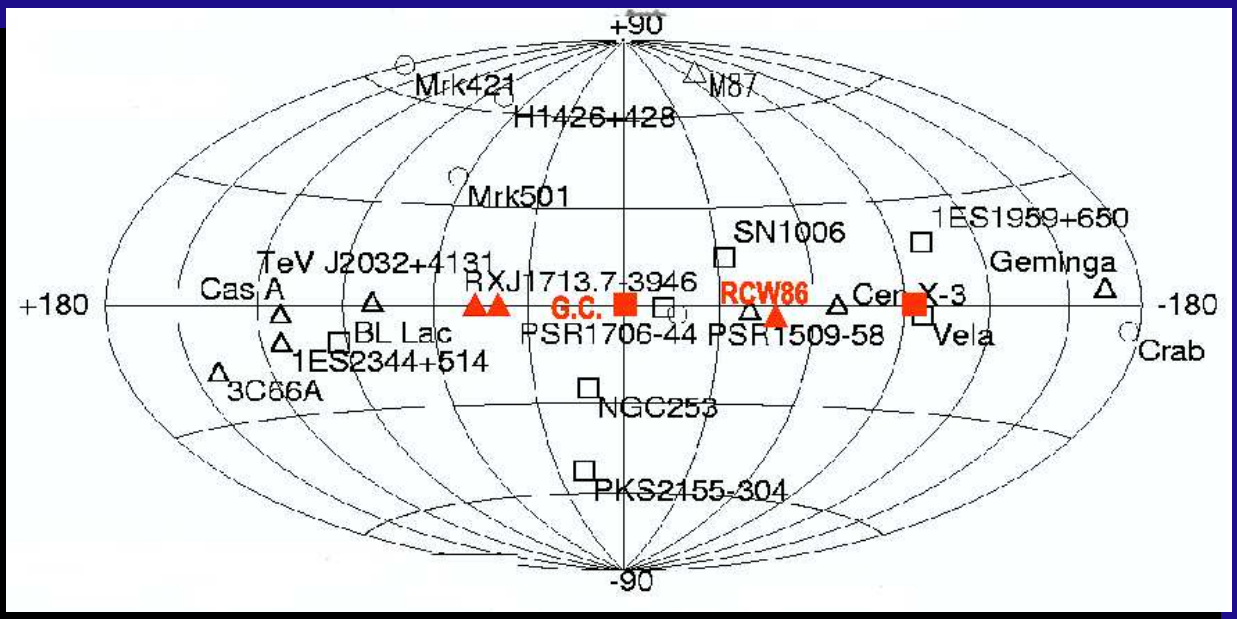


NO CLUSTERING

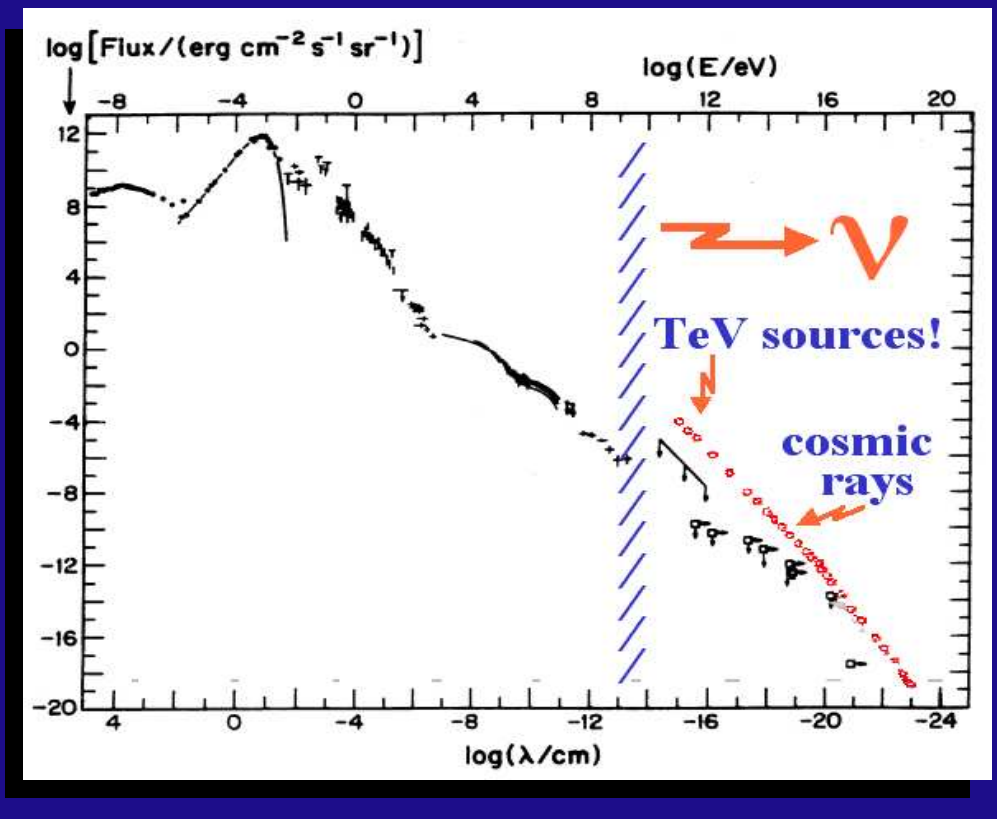
Mostly heavy nuclei

Mostly protons

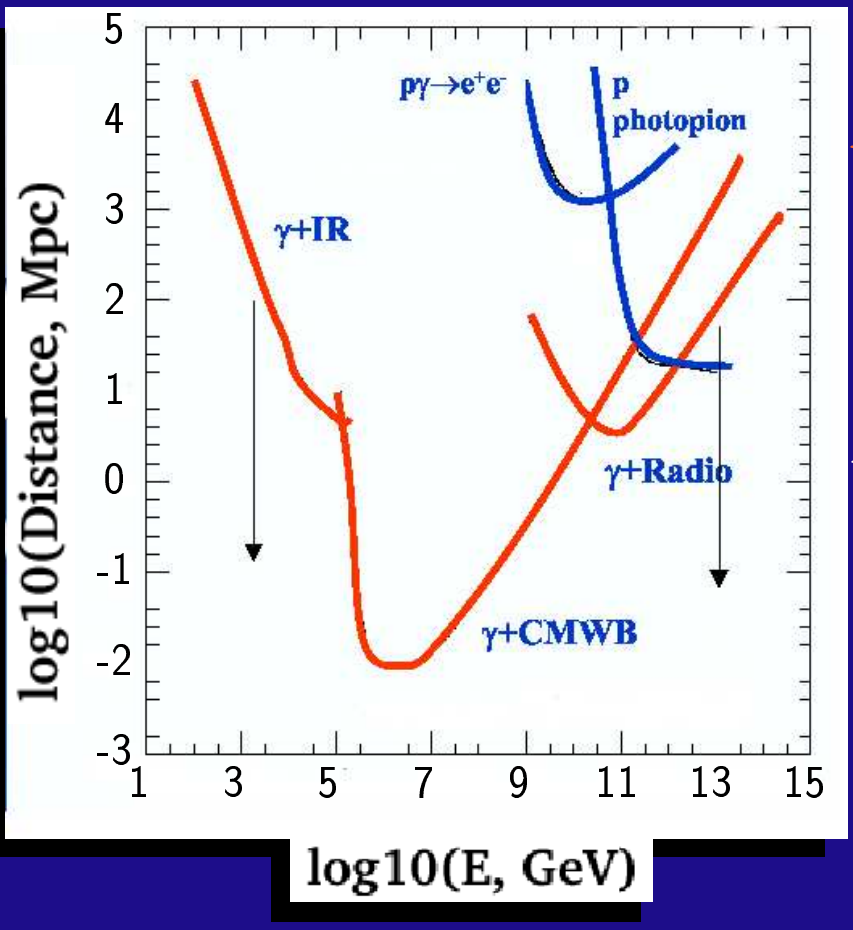
Gamma rays



Hundreds of sources (25 in TeV range) but cosmic γ-ray spectrum is cut above 1-10 TeV due to absorption by cosmic radiation background



Protons, photons, neutrons...



⟸ Visible Universe

⟸ Neighboring Superclusters

⟸ Virgo Supercluster

⟸ Local Cluster

⟸ Galaxy

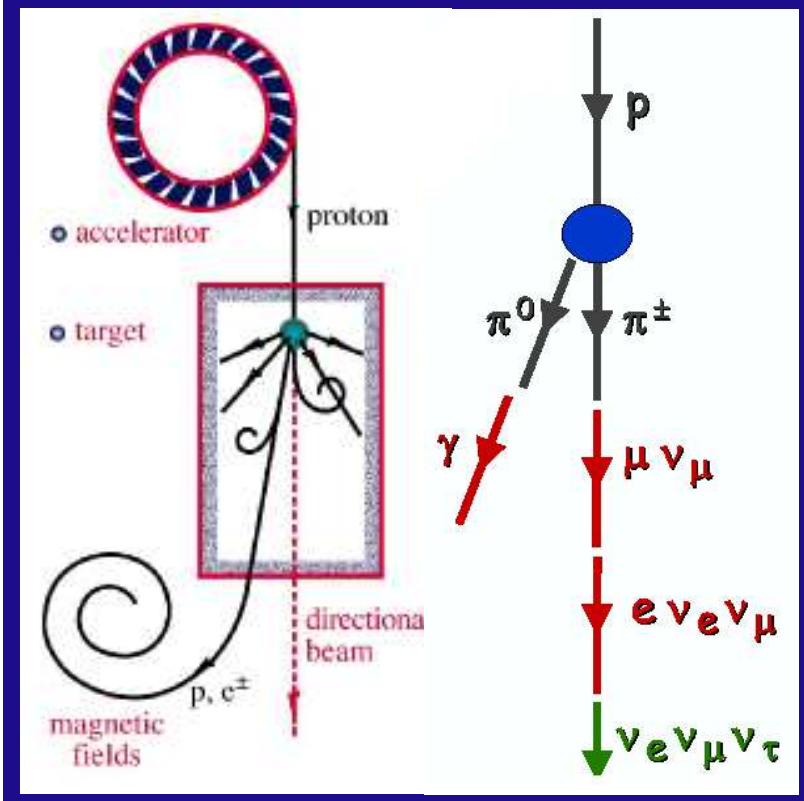
Protons: Direction scrambled by magnetic fields. At EeV range $\theta < 1^\circ$ for the Universe scale. Intergalactic magnetic fields: 10^{-7} to 10^{-12} Gauss (?). Above $\approx 5 \cdot 10^{19}$ eV – GZK cutoff.

Photons: Absorbed by extragalactic background $\gamma + \gamma_{bg} \rightarrow e^+ + e^-$. 1 PeV photon can not reach us from the Galaxy Center (10 kpc).

Neutrons: Too short life time. $\gamma\, c\, t = 50$ kpc for 10 EeV neutron.

The only weak interacting not deflected stable probe is neutrino!

Bottom-up models



Interaction of accelerated protons with matter and/or radiation surrounding the source or with cosmic radiation background

Initially:
$\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} = 1 : 2 : 0$

At the Earth:
$\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} = 1 : 1 : 1$
$(\nu_\mu \leftrightarrow \nu_\tau)$

$$p + p\,(\gamma) \rightarrow p\,(n) + \pi \rightarrow \mu + \nu_\mu \searrow e + \nu_\mu + \nu_e$$

Larmour radius must be less than acceleration volume size. Diffusive shock (1st order Fermi) acceleration (power-law spectrum $E^{-\gamma}$, γ =2–2.5)

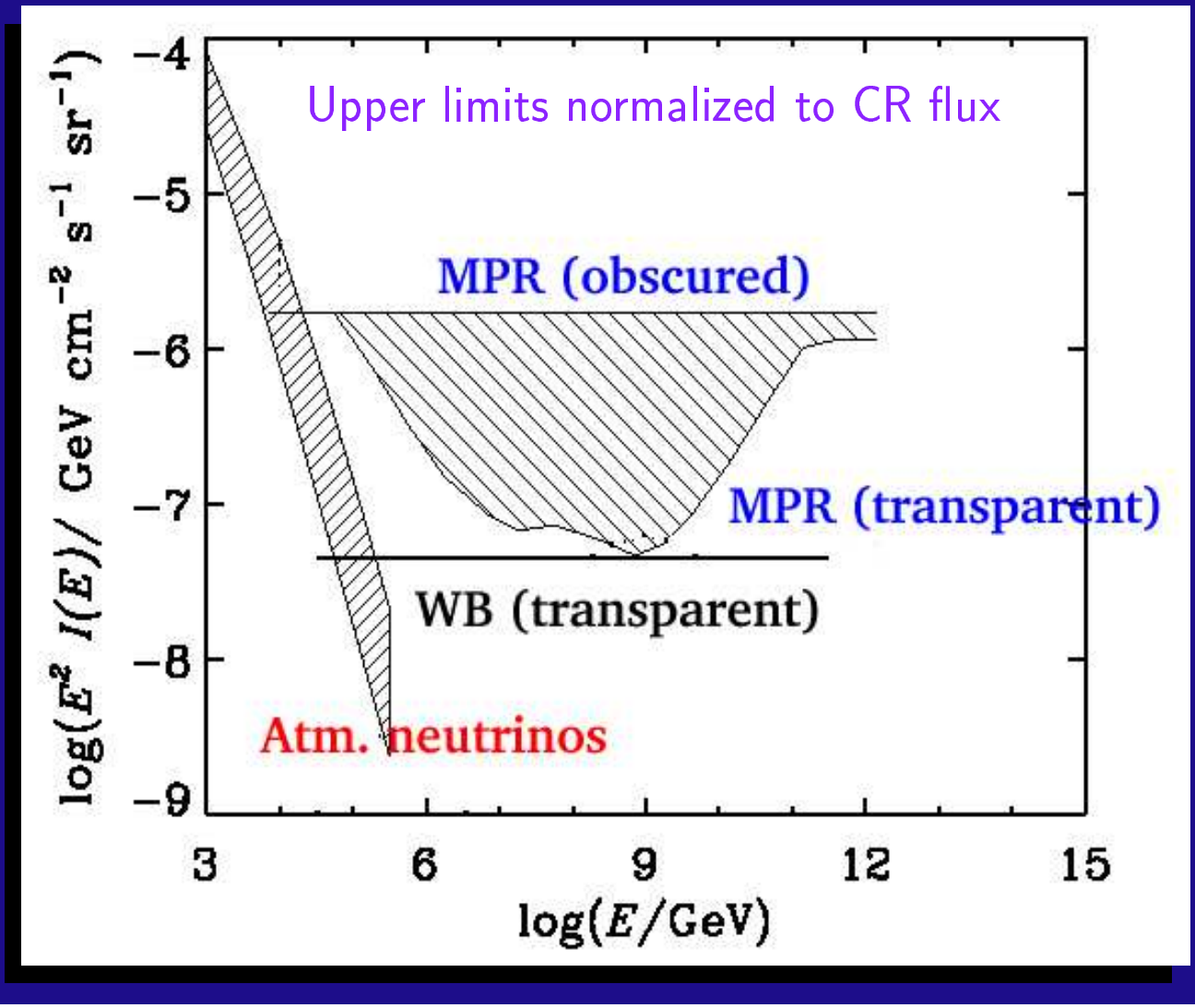
$$E_{max} \approx \beta Z \times \frac{B}{1\mu G} \times \frac{L}{1pc} \times 10^{15}\,\text{eV}$$

binary system with neutron star or black hole, supernovae explosion, AGN (black hole in a galaxy center), AGN + relativistic jet (blazar), GRB, ...

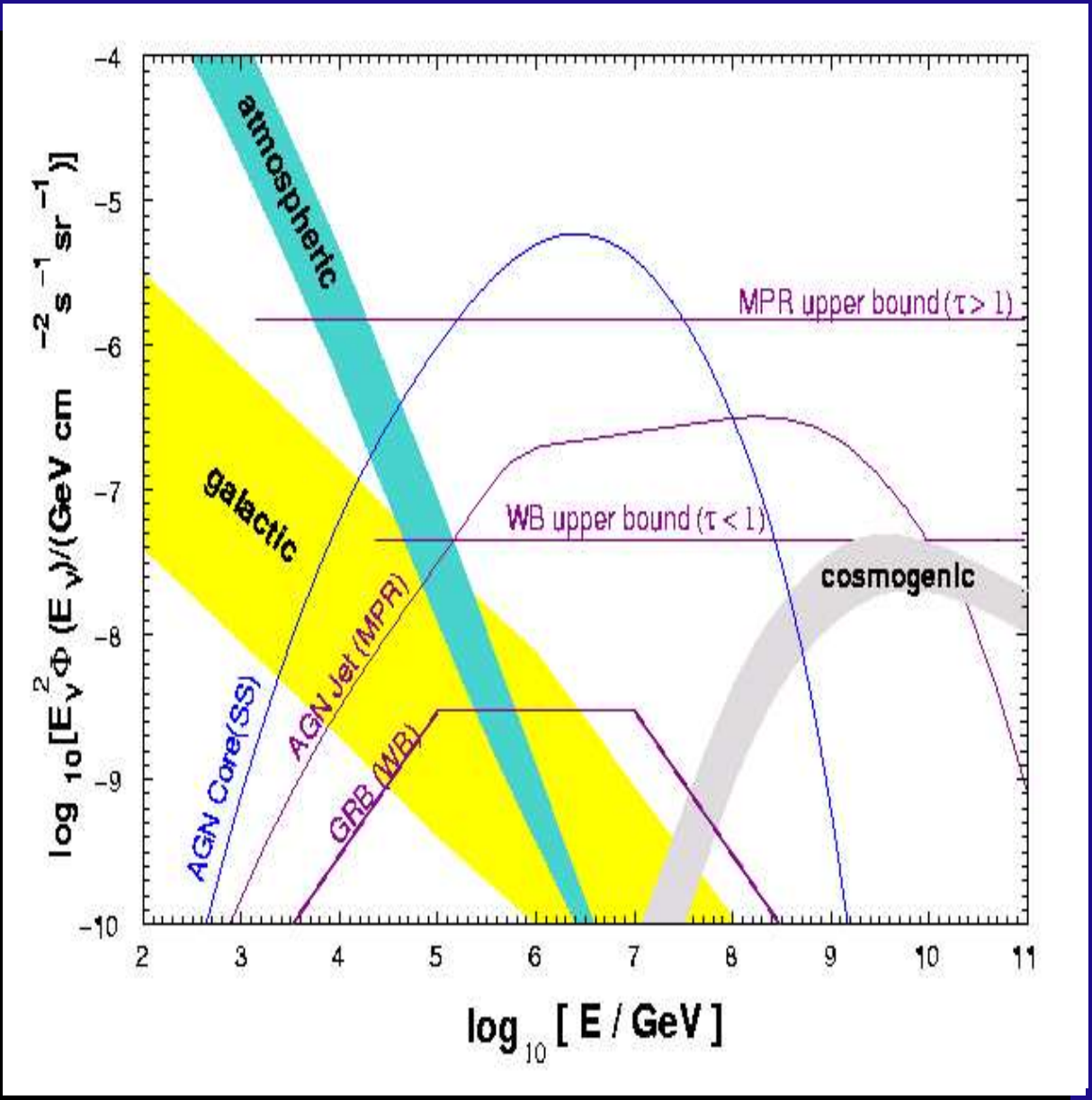
Top-down models

No acceleration but decays of massive "X-particles" with $m_X \geq 10^{21}$ eV produced by topological defects (cosmic strings, relic monopoles, ...) which generate UHE/EHE nucleons, γ-rays and neutrinos.

Predicted fluxes 1



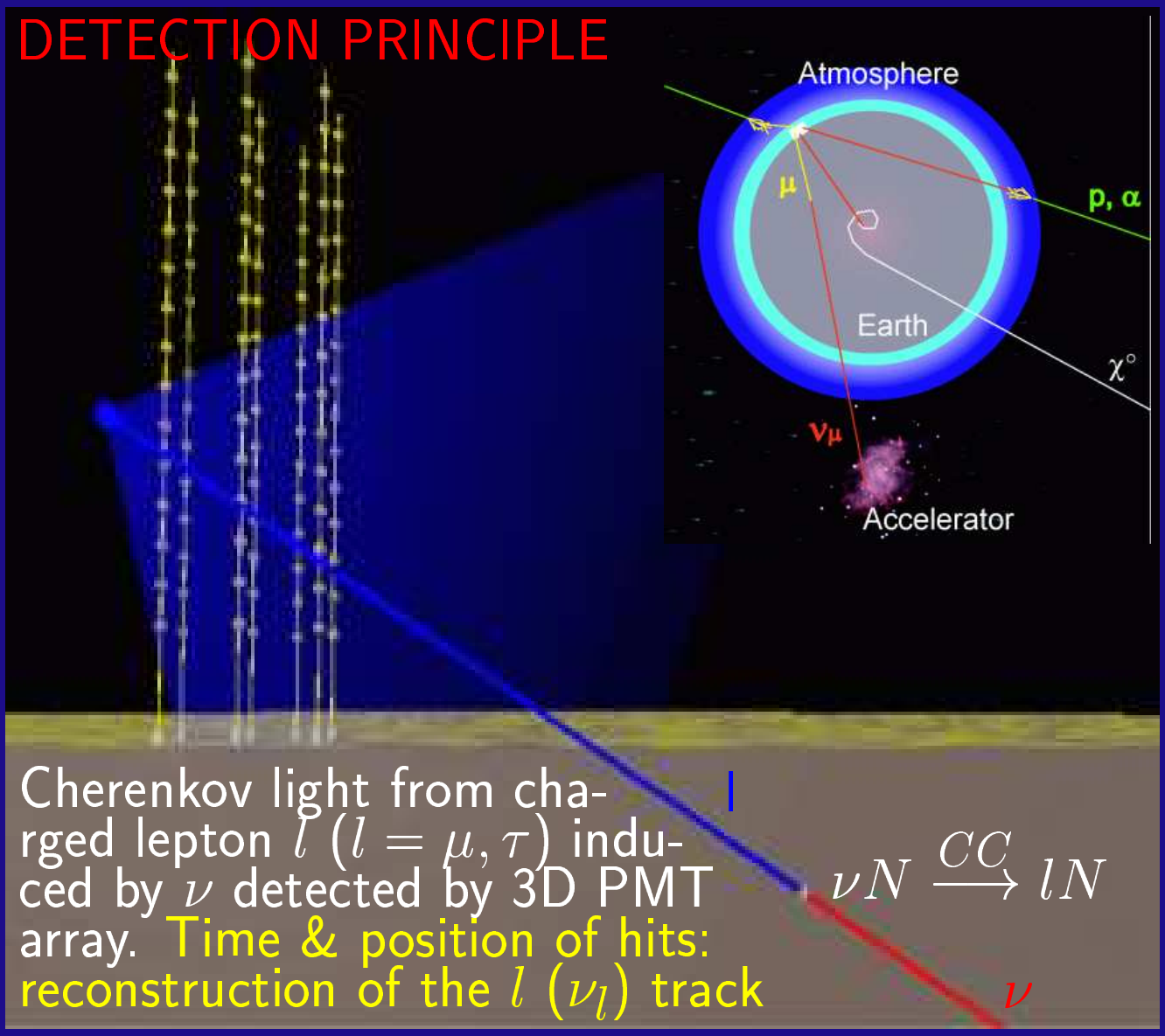
Predicted fluxes 2



Generally, predictions give
~100 events/year/sq.km
for E>10 TeV.

Deep Underwater Cherenkov Detectors

DETECTION PRINCIPLE



Cherenkov light from charged lepton l ($l = \mu, \tau$) induced by ν detected by 3D PMT array. Time & position of hits: reconstruction of the l (ν_l) track

$$\nu N \xrightarrow{CC} lN$$

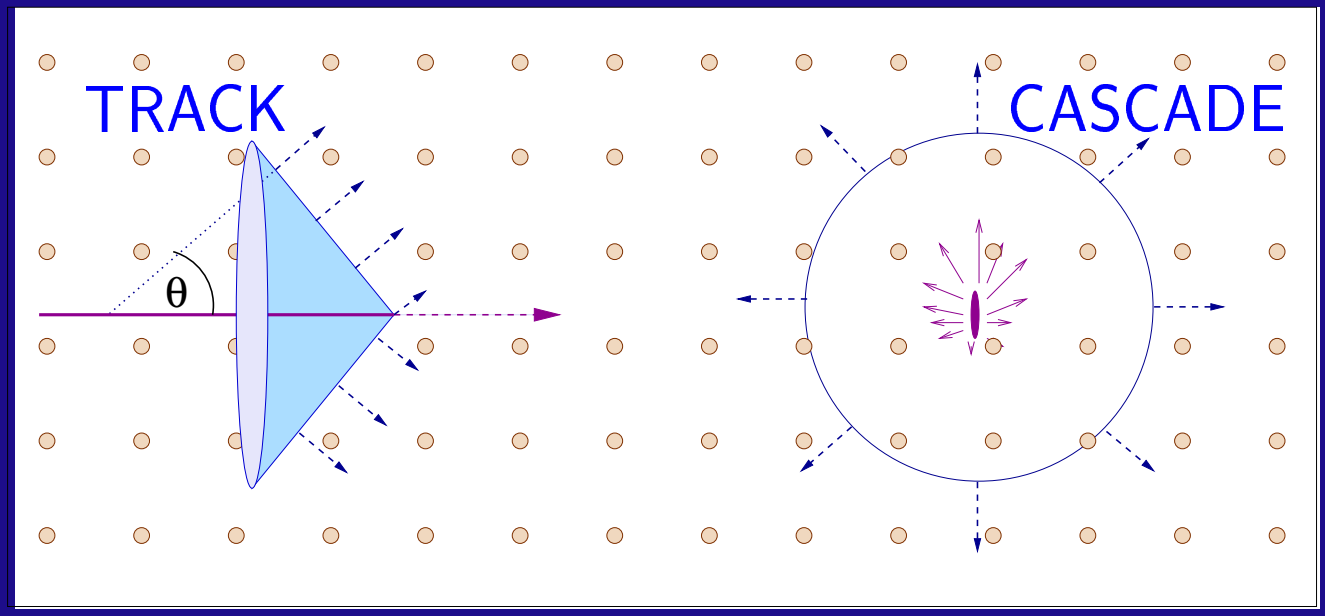
Background: μ_{atm} (downgoing), ν_{atm}

Proposed first by M. A. Markov (1960)

Pioneering experiments: DUMAND (since 70th to 1996), Baikal (1981 up to now)

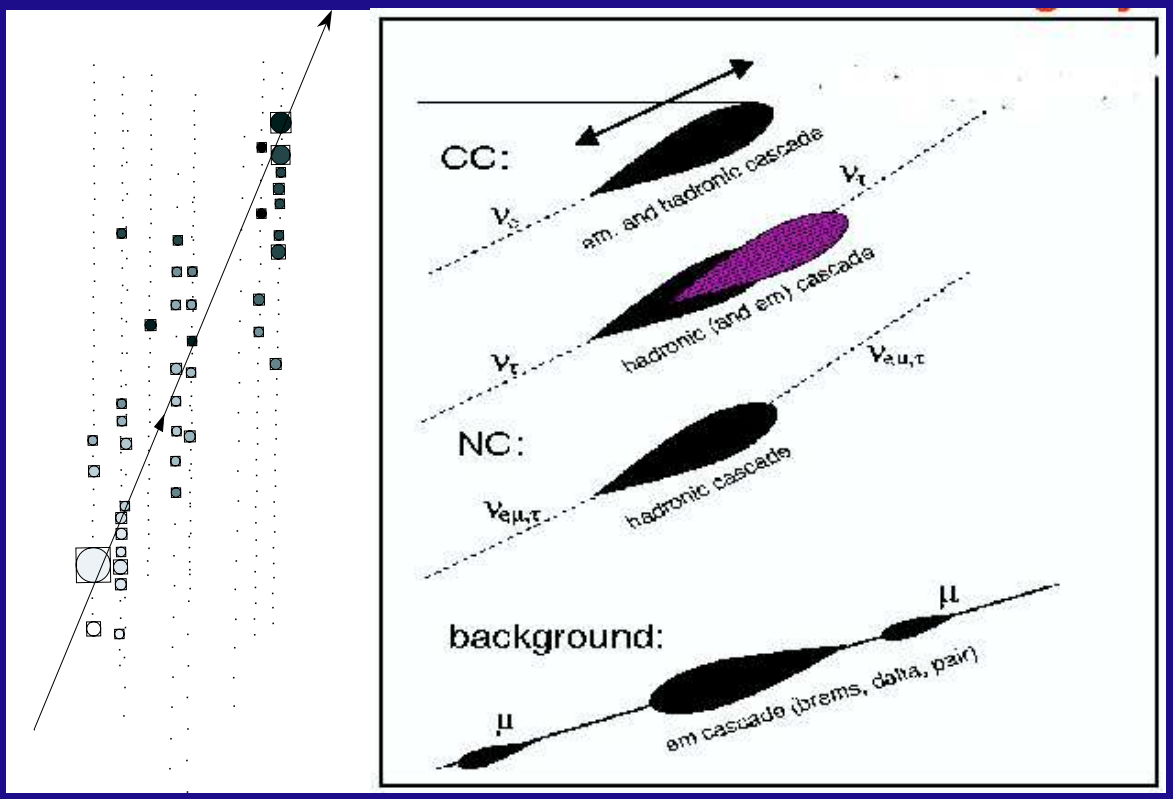
First detected neutrino (atm.): Baikal, 1995

Two event topologies

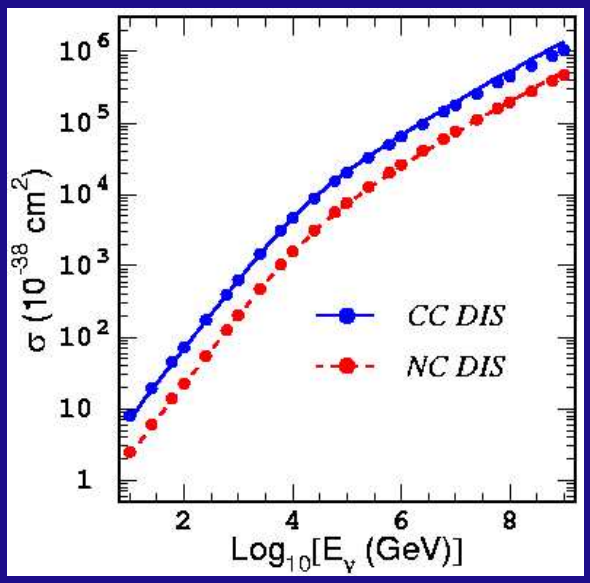


Muons and τ-leptons ($E_\tau > 2{\cdot}10^{15}$ eV)

Electrons and τ-leptons ($E_\tau < 2{\cdot}10^{15}$ eV), ν_e, ν_μ, ν_τ NC interactions



Tau neutrinos

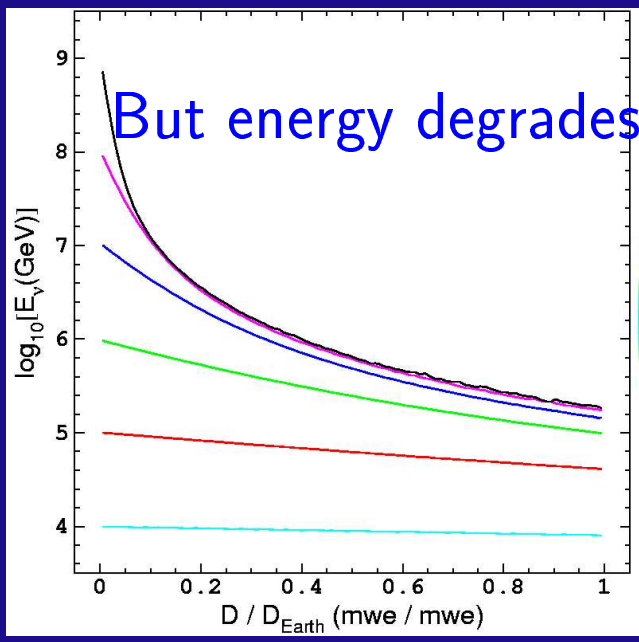


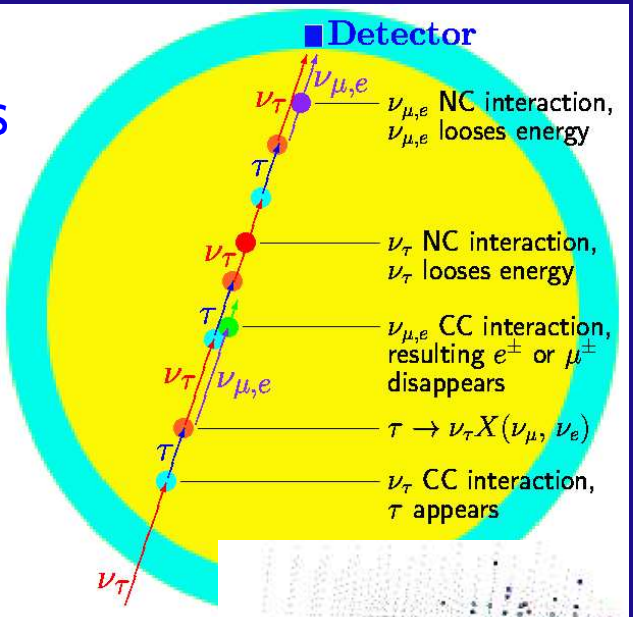
$\sigma_{\nu N}$ grows with energy $\Rightarrow$ above $\sim$100 TeV Earth becomes opaque for neutrinos. But not for ν_τ because of regeneration chain

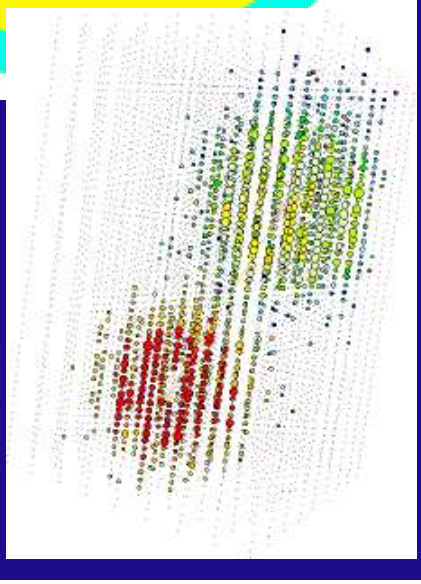
$$\nu_\tau \rightarrow \tau \rightarrow \nu_\tau \ldots$$

Moreover, some amount of $\nu_{e,\mu}$ is generated due to

$$\tau \rightarrow e(\mu)\nu\nu$$





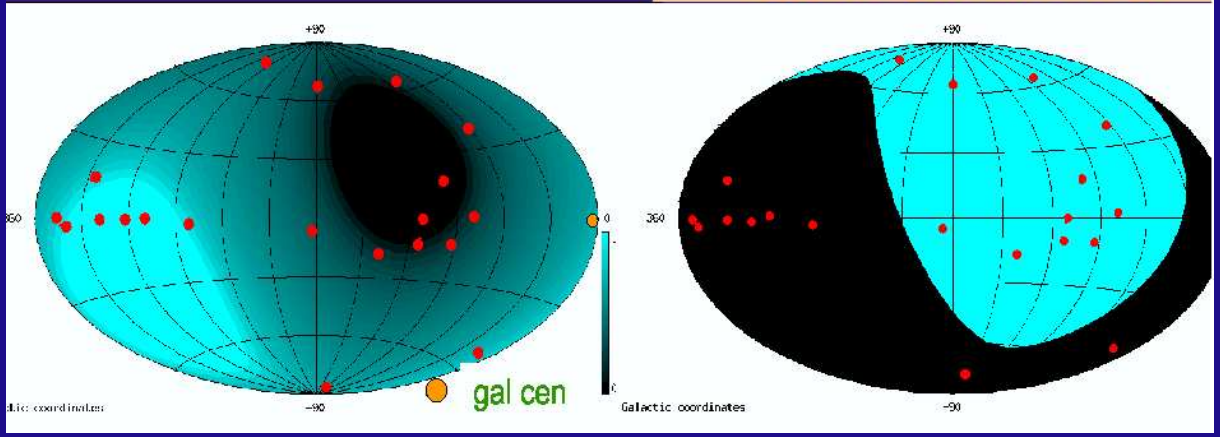


Specific background free Pev range ν_τ signature: 'double bang' (two cascades separated by track): 1-5 ev/yr/km^3

Neutrino telescopes

1 km^3 Mediterranean Sea?
ANTARES, NESTOR, NEMO-RD
11 sources observed >50% of day

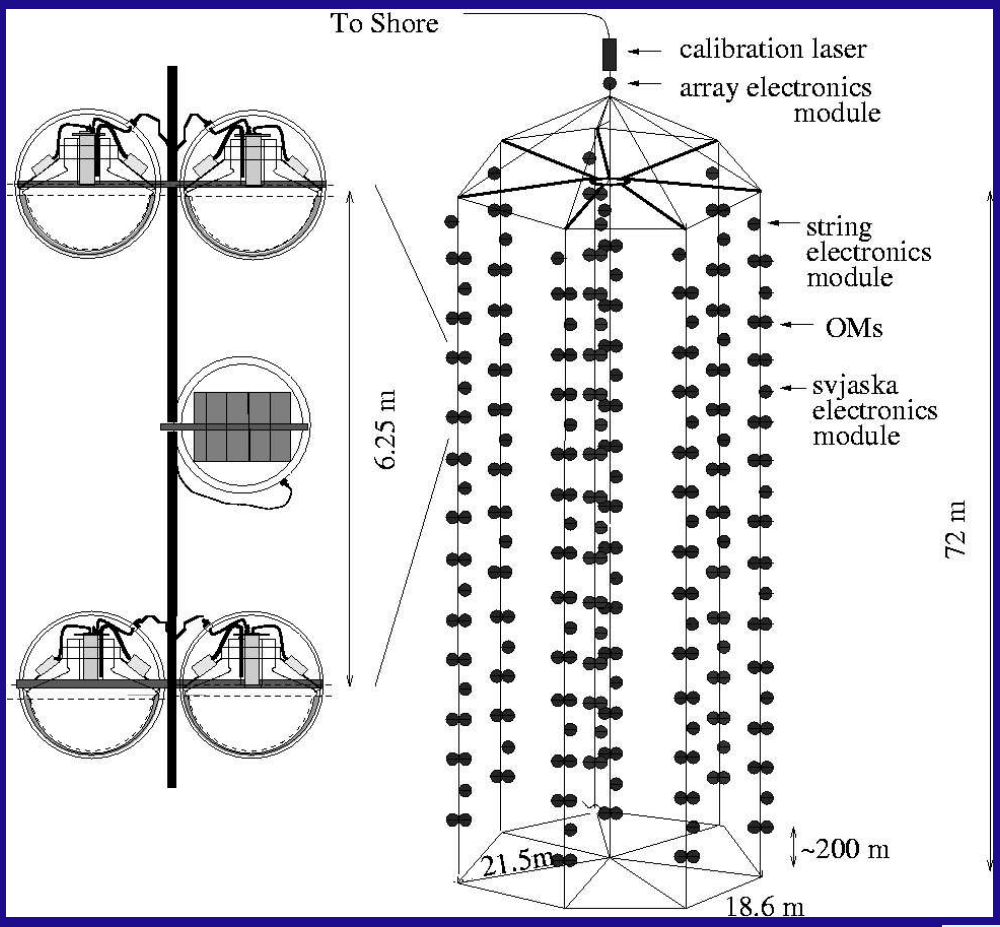
South Pole ice
AMANDA, ICECUBE (1 km^3)
11 sources always observed
9 never
Galactic Center never seen



Baikal	AMANDA-II	ANTARES	IceCube, NEMO
>0.0045 km^2	>0.03 km^2	>0.05 km^2	>1 km^2

E_μ >10-100 GeV

Baikal Neutrino Telescope NT-200



Siberian lake

4 km off-shore

1.1 km depth

192 15' PMTs

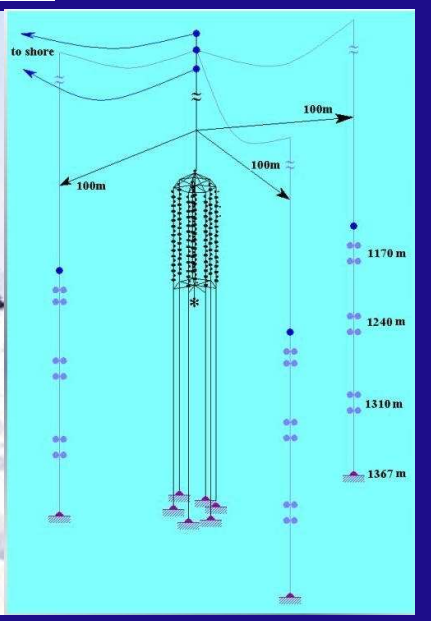
8 strings

Put into operation in 1998

Deployment from ice-platform

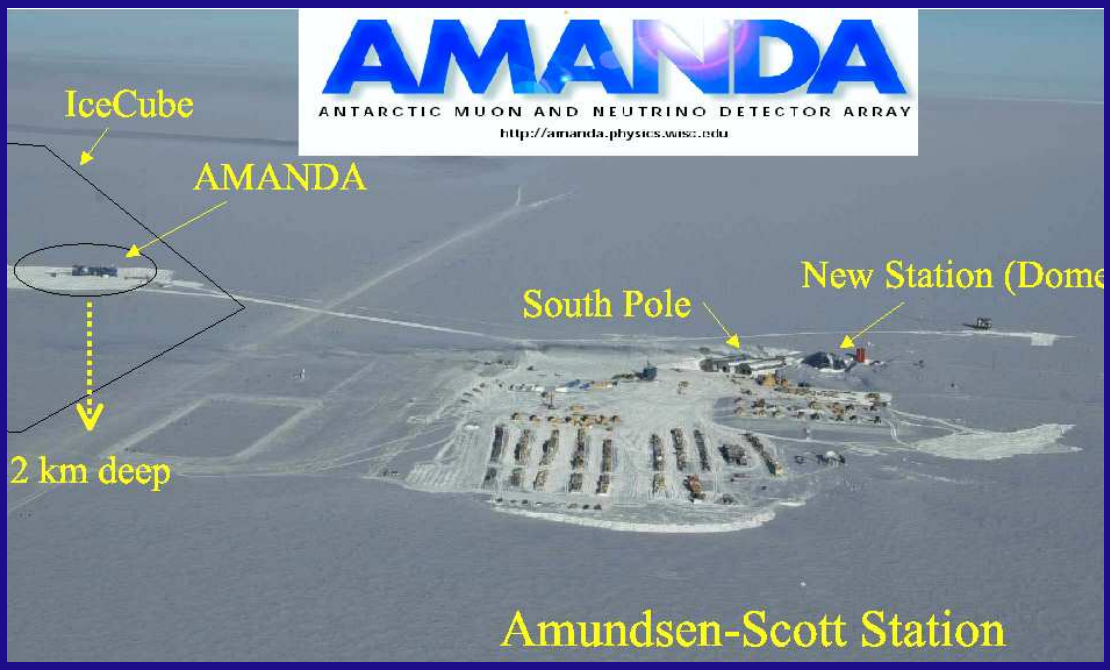
84 ν_{atm}'s reported (572 days)

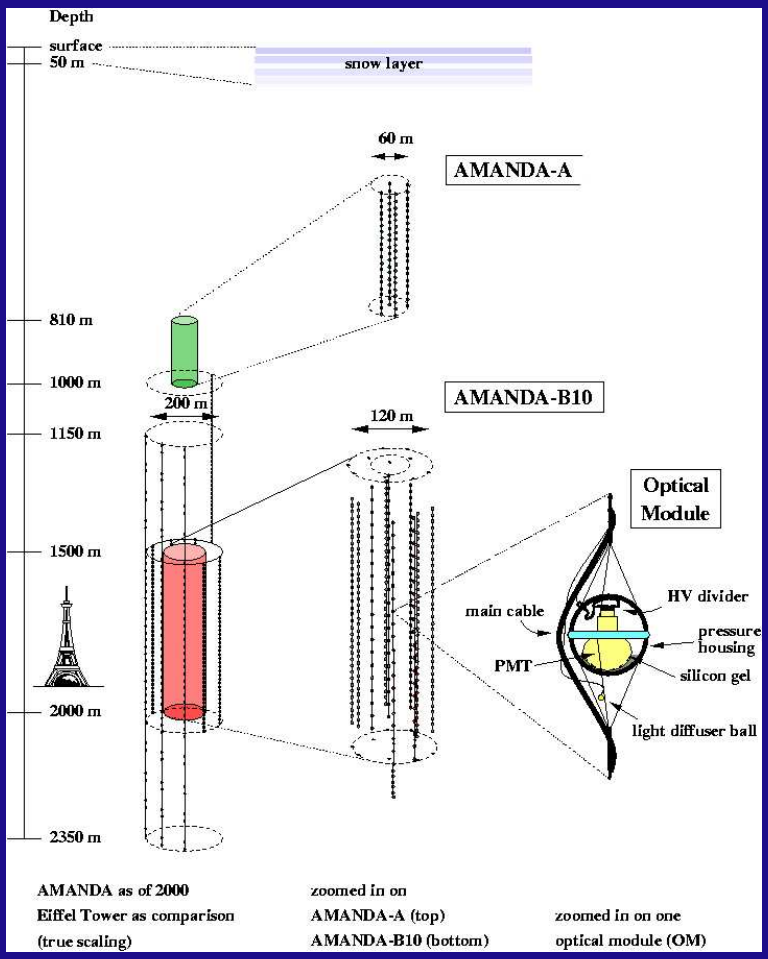
Upgrade to increase the area for UHE/EHE neutrinos: NT-200+ 3 additional strings 100 m apart. At the moment 2 of them are under deployment (winter campaign 2004)



Published results: atm. muons, atm. neutrinos, WIMPs, diffuse neutrino flux, magnetic monopoles

AMANDA



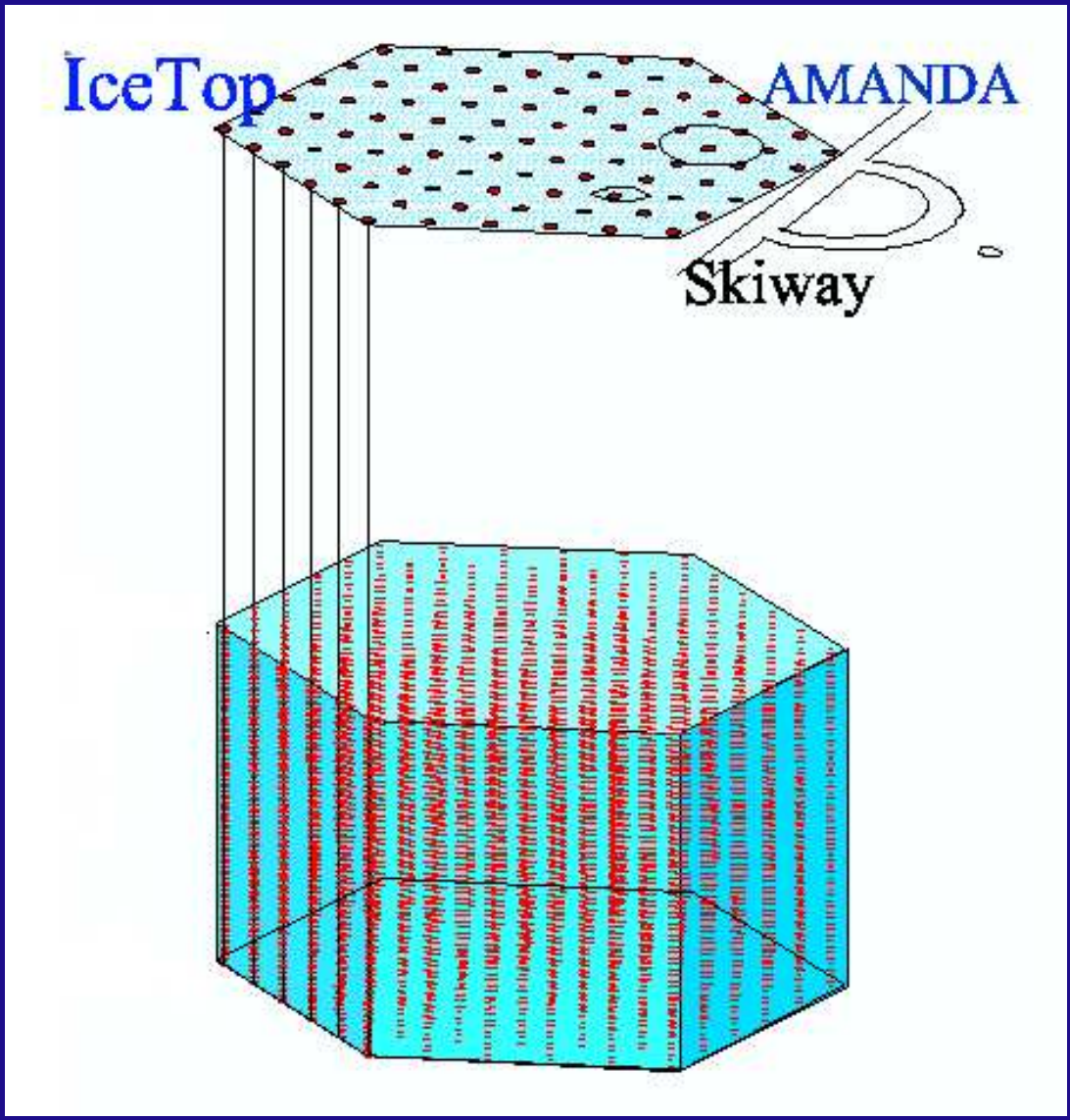


AMANDA B10 (1995-97):
302 PMTs/10 strings
1.5-2 km depth

AMANDA-II (by 2000):
667 PMTs/19 strings
A_{eff} >0.03 km
for E_μ >100 GeV

Published results:
atm. ν's, diffuse ν's,
point like sources,
cascades, WIMPs, SNs

Next future: IceCube

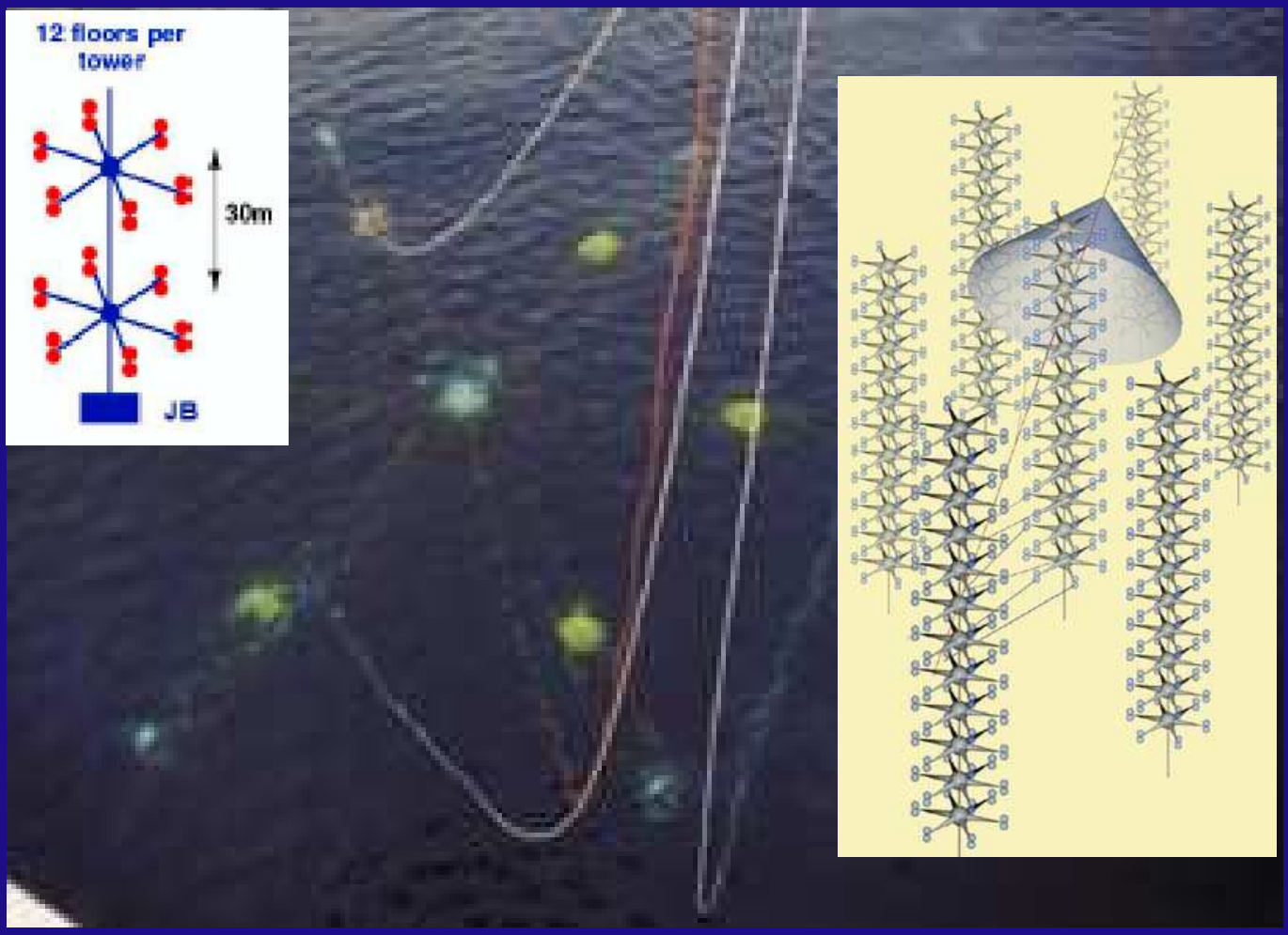


IceCube: 4800 PMTs/80 strings, 60 PMT/string spaced by 17 m. Each string from 1400m to 2400m. Instrumented volume 1 km^3. Construction will start austral summer 2004/2005. 16 strings/season.

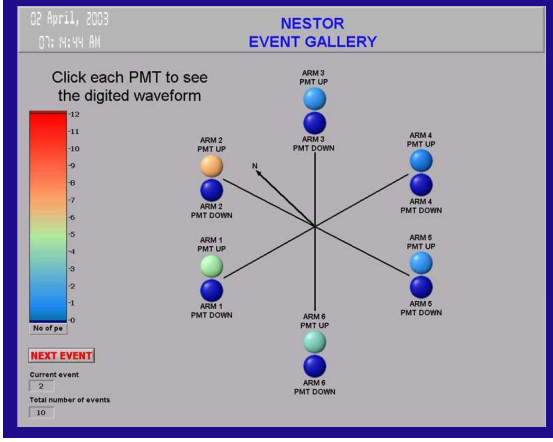
IceTop: EAS for calibration, veto and CR composition. 80 pair of 2m diameter ice tanks instrumented with 2 PMTs. E_{th} =300 TeV

NESTOR

Neutrino Extended Submarine Telescope with Oceanographic Research



Tower based detector with 12 hexagonal floors spaced by 30m with 6 pairs of up-down looking 15' PMTs each. 4 km depth. Near Pylos (Greece). $A_{tower} > 0.02\,\mathrm{km}^2$ for $E_\mu > 10\,\mathrm{TeV}$.
28km electro-optical cable put in 2000 and repaired in 2002.



March 29, 2003: prototype floor with 6m arms deployed (in final design 16m arms). >5 millions triggers recorded.

ANTARES

Astronomy with a Neutrino Telescope and Abyss environmental RESearch

Started in 1996

1996-99: R&D program, site evaluation

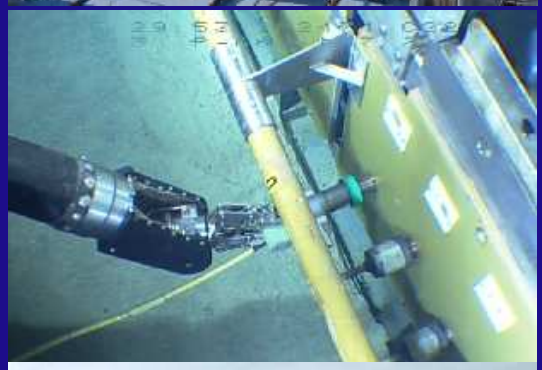
1999: 0.1km^2 detector Proposal

Nov 1999-Jun 2000: "Demonstrator string", 50,000 μ's detected

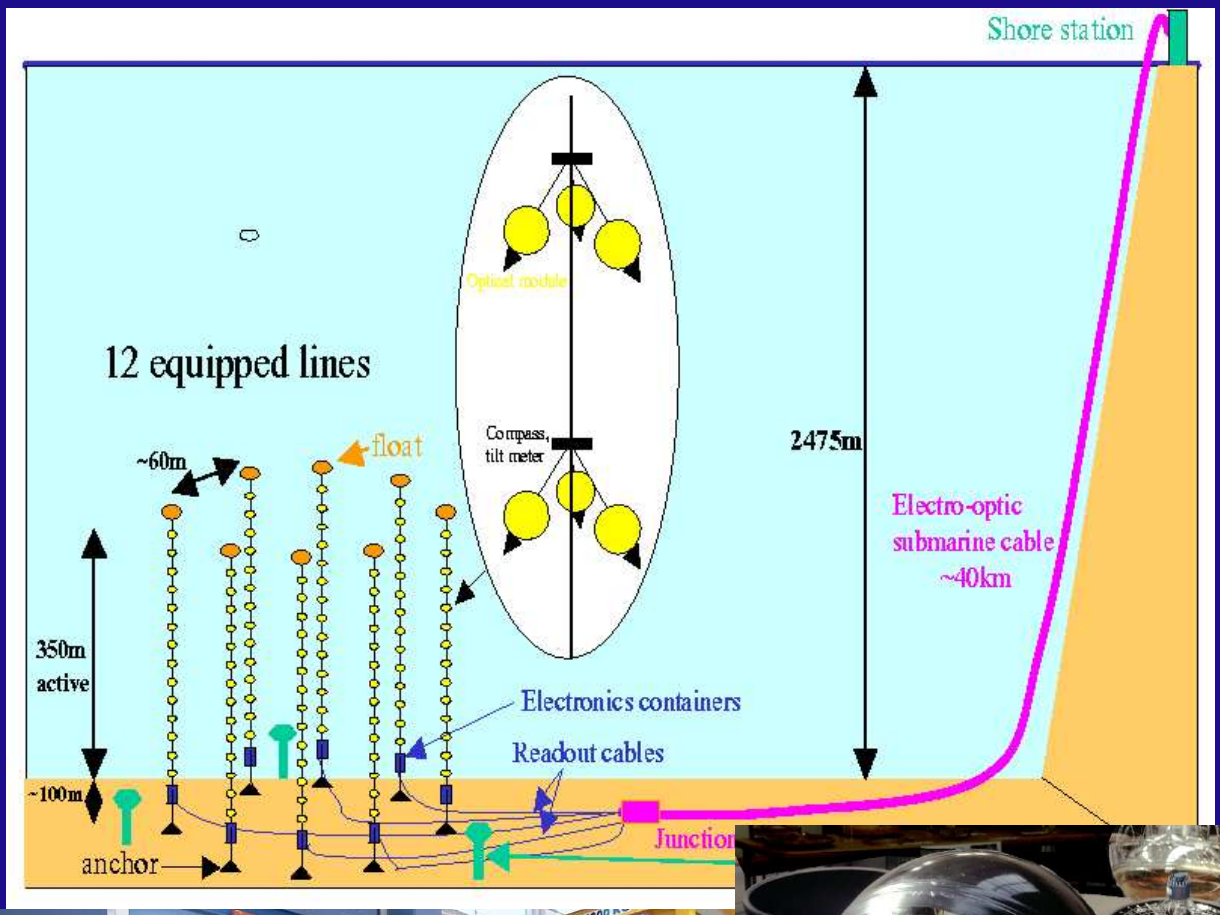
2001: MEO cable deployed

2002-2003: JB, final design prototype line and instrumentation line deployed, connected to MEOC by a manned submarine and put into operation

2004-2006: 12-string detector to be deployed



ANTARES: design



12 strings; 25 storeys/string;

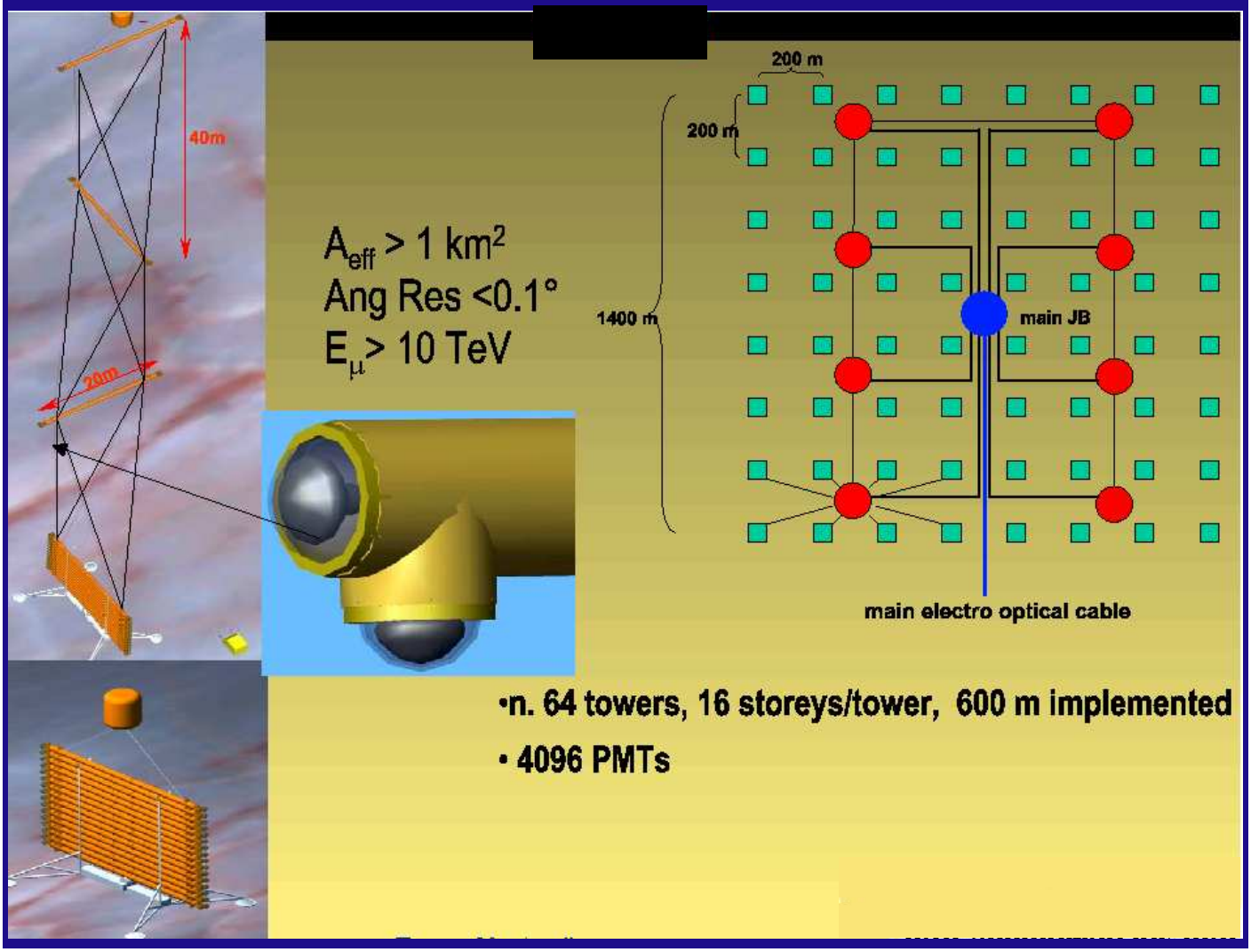
3 OM/storey; 14.5 m between storeys; ~60m between strings

NEMO

NEutrino Mediterranean Observatory
INFN (Bari, Bologna, Cagliari, Catania, Genova, LNS, Messina, Roma),
Oceanographic and geophysics Institutes

R&D phase (1999-2002): >20 sea campaigns to select optimal site (Capo Passero, 3500m depth). R&D on materials, PMTs and mechanics. Feasibility study and simulations.

Phase 1 (2002-2005): Advanced R&D and prototyping. Test site off-shore Catania: Lab connected to shore by already deployed 28km EOC.

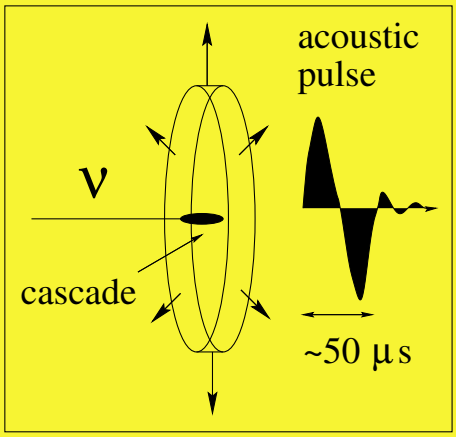


KM3NeT

KM3Net, a European neutrino telescope to be built at the bottom of the Mediterranean Sea, will open a new window on the Universe. The kilometre-sized KM3NeT will search for neutrinos from distant astrophysical sources like gamma ray bursters, supernovae or colliding stars and will be a powerful tool in the search for dark matter in the Universe. An array of thousands of optical sensors will detect the faint light in the deep sea fromcharged particles originating from collisions of the neutrinos and the Earth. The facility will also house instrumentation from other sciences like marine biology and geophysics for long term and on-line monitoring of the deep sea environment and the sea bottom at a depth of several kilometres.

http://www.km3.org

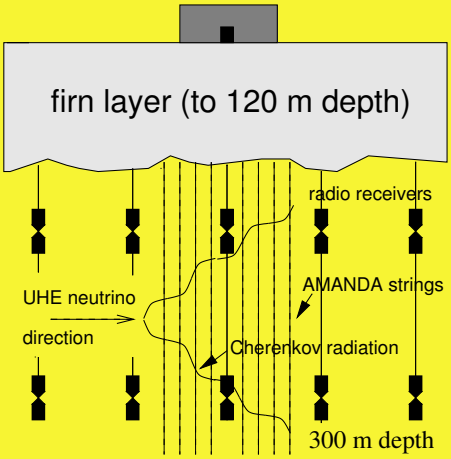
Acoustic and radio

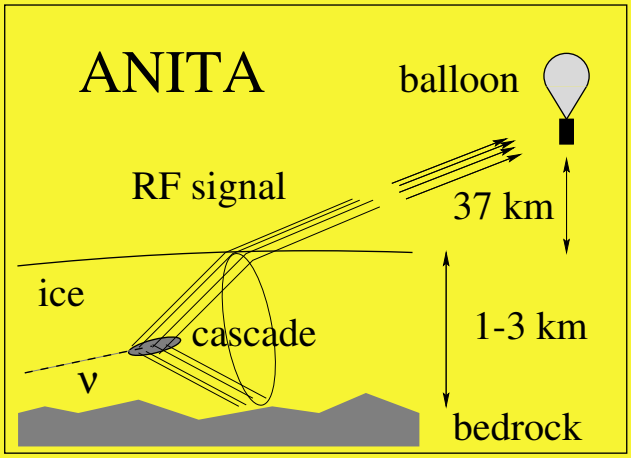


Acoustic detection. AUTEC project: usage US Navy hydrophone array close to the Bahamas. 52 hydrophones, 250 km^2, E_{th} $\sim 10^{20}$ eV.

Cherenkov radio emission from e/m showers generated by ν_e

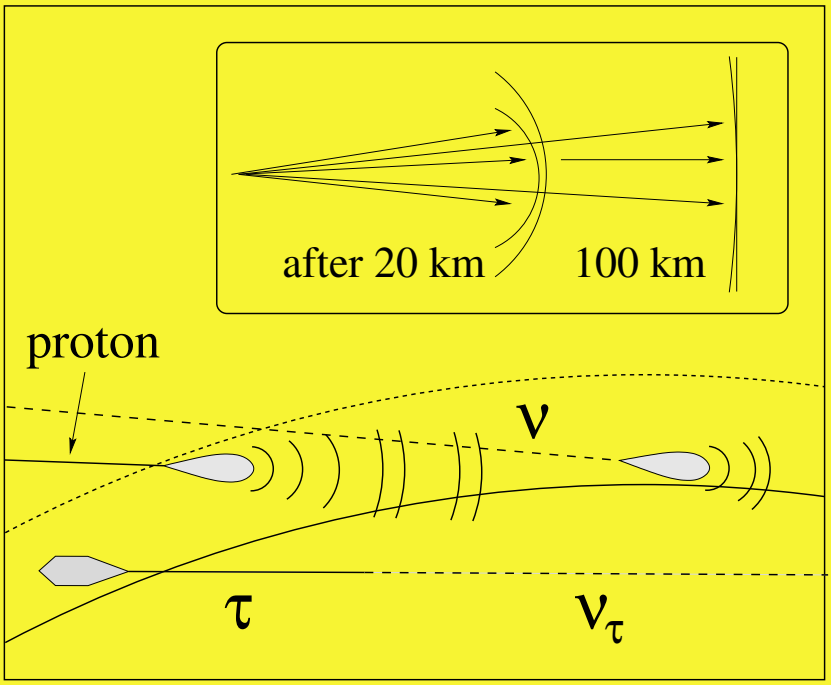
The RICE project (South Pole). Prototype detector, 20 radio receivers 120-300 m depth. E_{th} $\sim 10^{17}$ eV. Limit on diffuse ν_e flux $10^{-4} E_\nu^{-2}\, GeV^{-1} cm^{-2} s^{-1} sr^{-1}$ ($\sim$3 orders of magnitude above W&B).





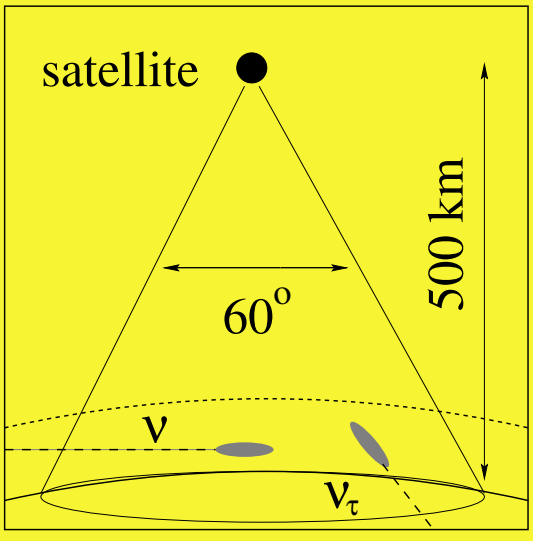
The ANITA balloon project: flight in 2006 on an Antarctic circumpolar path. Expected sensitivity from 30 day flight $10^{-4} E_\nu^{-2}\, GeV^{-1} cm^{-2} s^{-1} sr^{-1}$ above E_{th} $\sim 10^{19}$ eV

Air showers



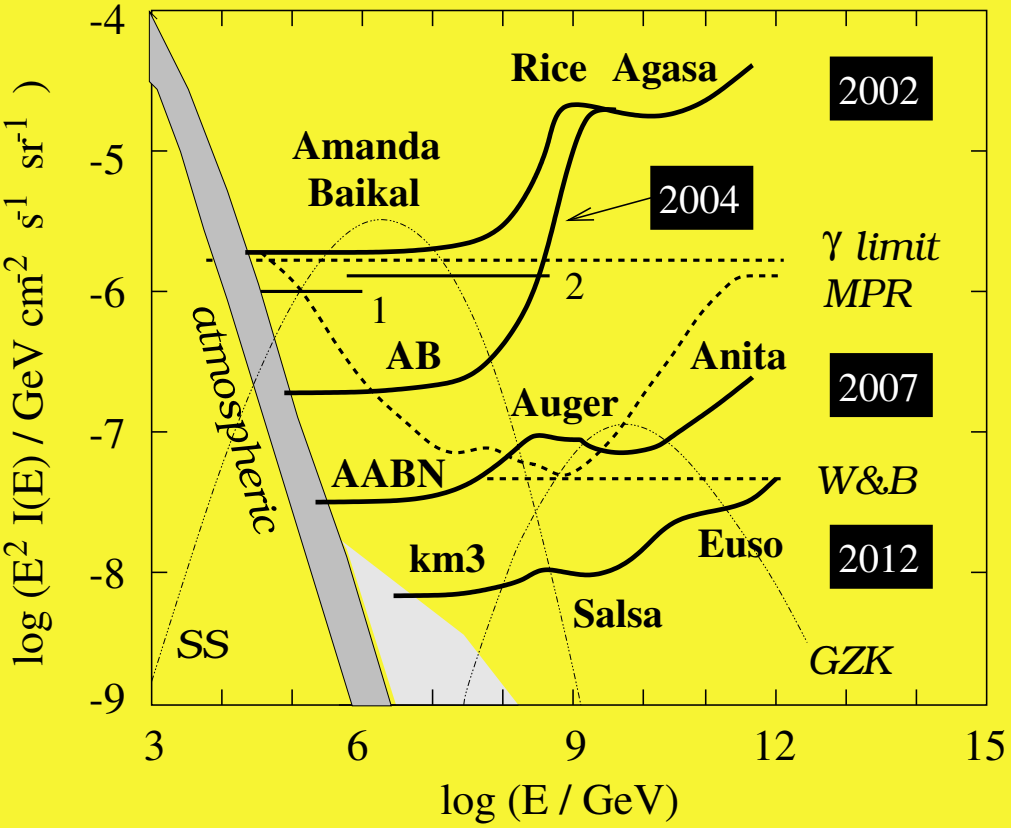
Nearly horizontal air showers ($\theta > 70^\circ$) are produced by neutrino, showers produced by primary CR are absorbed. Showers with $\theta < 0$: $\nu_\tau \rightarrow \tau$

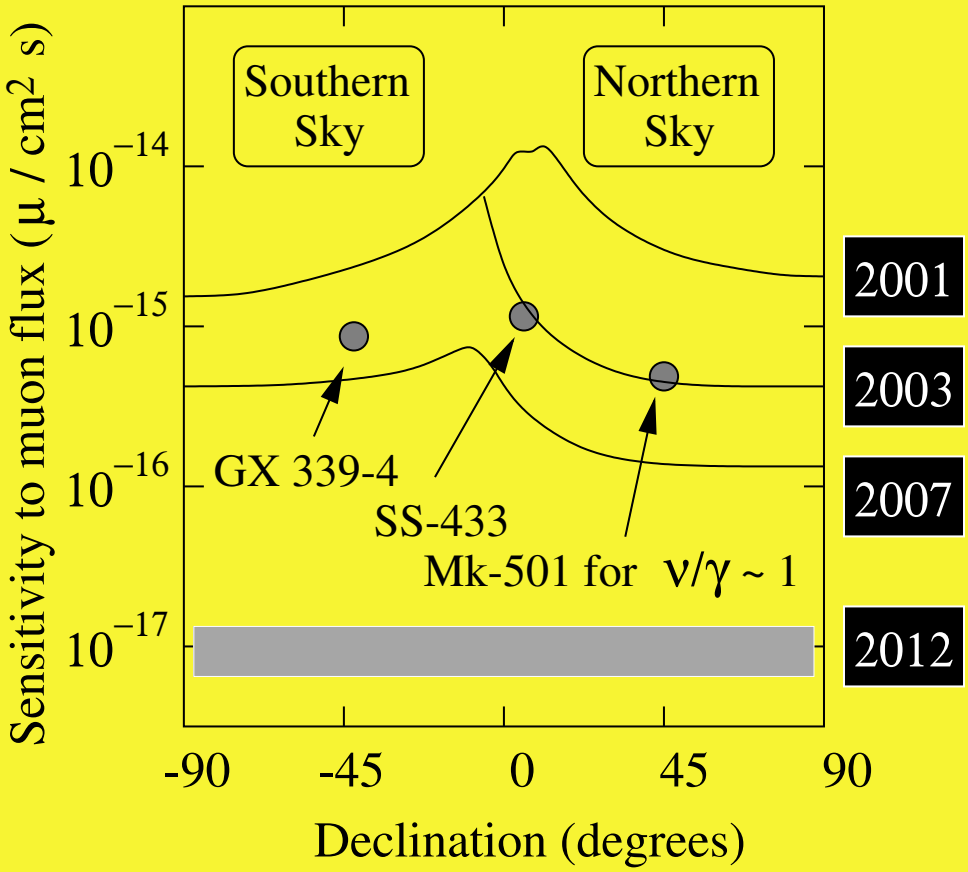
AGASA (100 km^2): $10^{-5} E_\nu^{-2}\, GeV^{-1} cm^{-2} s^{-1} sr^{-1}$ above E_{th} ~10^{18} eV. AUGER observatory (3000 km^2, completed in 2005) can reach W&B level for several years.



EUSO and OWL: satellite based experiments. Monitored mass ~10 Tera-tons, threshold energy E_{th} ~10^{18} eV

Results and plans





Ch.Spiering, astro-ph/0303068

Summary

The next 5 years several new detectors serving neutrino astronomy are expected to be completed: AUGER (2005), ANTARES (2006), IceCube(2010), ...

Underwater km3 neutrino telescope for southern hemisphere (NEMO, KM3NeT) will hopefully follow.

Observation of UHE neutrinos from astrophysical sources are expected. Limits $\rightarrow$ fluxes.

Guesses for CR puzzles.

"...because then we might find something that we weren't looking for, which might be just what we were looking for, really."

A. Miln, "Winnie-The-Pooh"