Ultra-high Energy Neutrinos: Present and Future

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9th Workshop on High Energy Physics Phenomenology

Bhubaneswar, India

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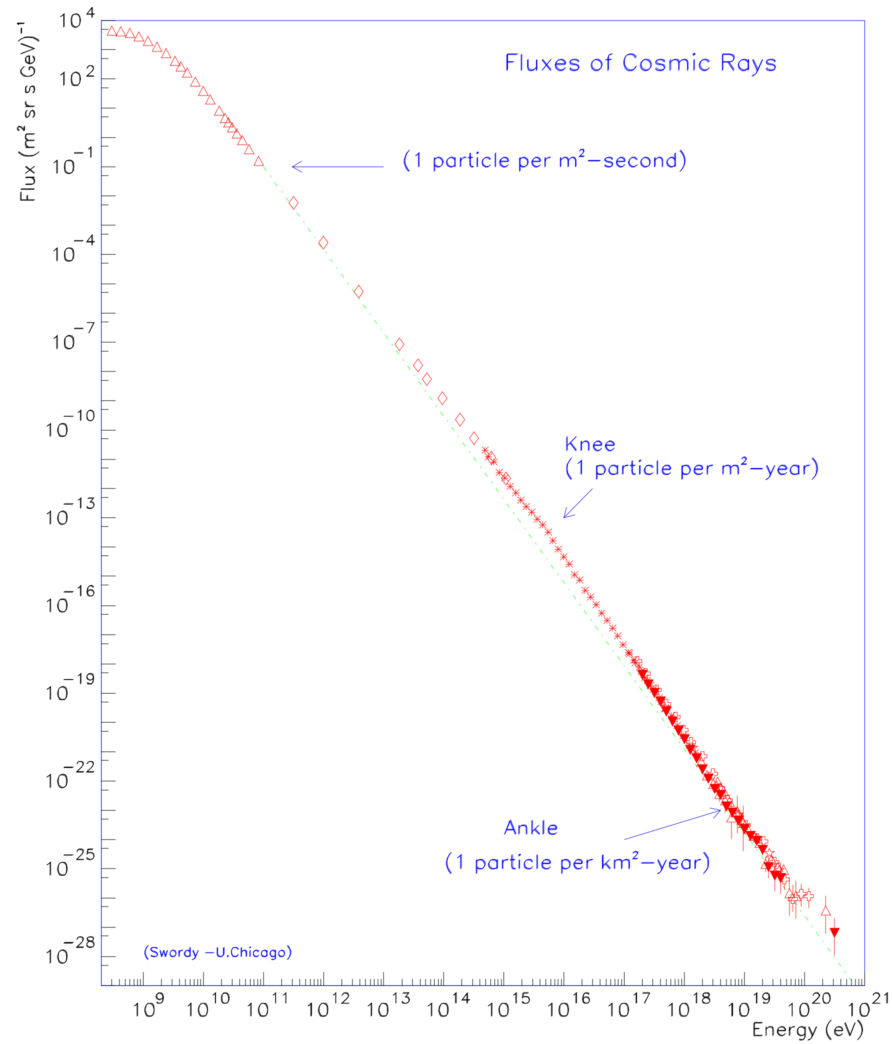
Outline

- Neutrinos: physics motivation
- Experimental detection (hot & cold neutrino telescopes
- Current experiments and results
- What's to be expected in the future

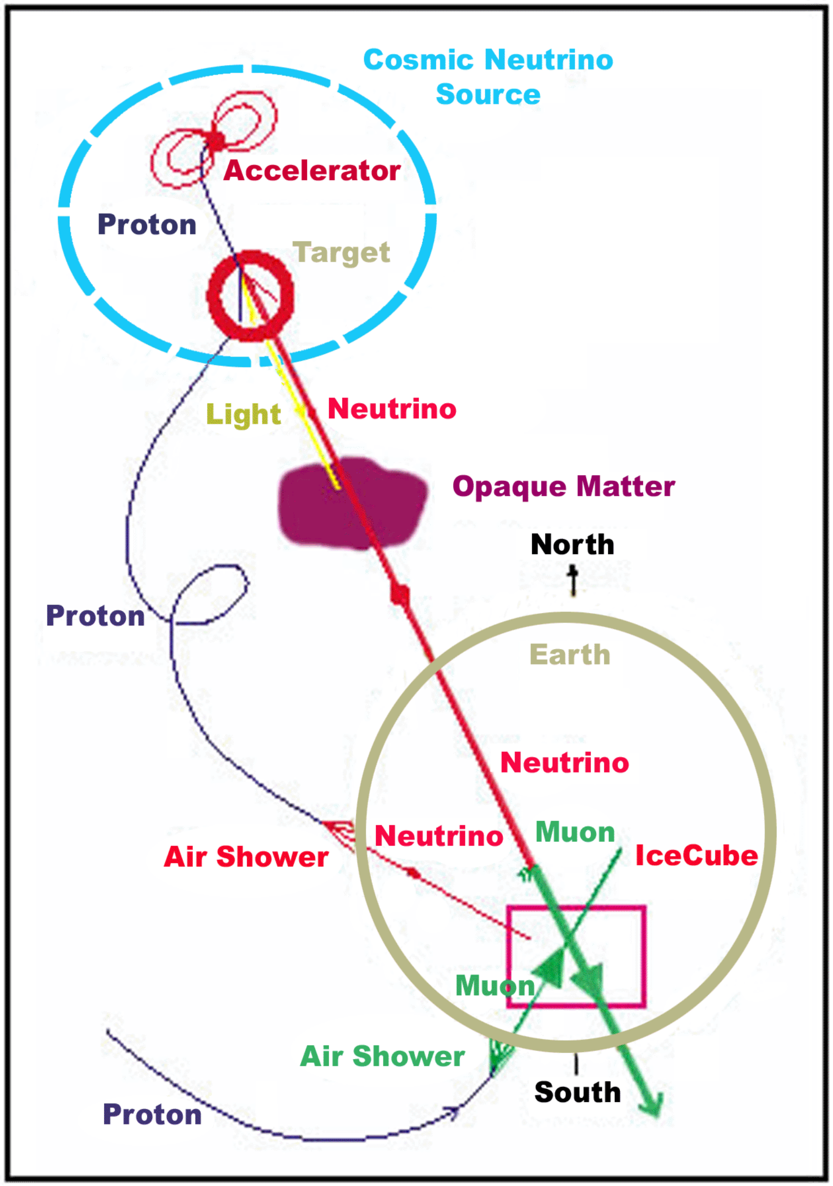
Neutrinos and cosmic accelerators

- Neutrinos open another window through which to view the universe
- Neutrinos traverse space unimpeded and are characteristic of HE hadronic processes
- Cosmic rays (protons?) with energies > 100 EeV and gammas with energies > 10 TeV have been observed
- The neutrino flux associated with possible cosmic accelerators (AGNs, SNRs, GRBs, ...) would reveal information about these sources



CR energy spectrum

Astrophysical neutrinos



- Consider a generic, "transparent" source of cosmic rays: protons accelerated (via Fermi mechanism) in a region of high magnetic field, interacting with protons/photons
- Neutrinos are produced via photopion production or through inelastic pp scattering
- Expected flavor ratio 1:2:0 at source becomes 1:1:1 at detection via oscillations
- "Guaranteed" flux of neutrinos associated with CR propagation: "GZK" neutrinos

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_\mu + \nu_e + \overline{\nu}_\mu$$

$$p\gamma \rightarrow \Delta^+ \rightarrow \pi^+ n$$

Particle physics with neutrinos

We may have "cosmic beams" of neutrinos which with to:

- **Search for non-SM interactions (e.g. TeV-scale gravity)**
- ***Study neutrino cross-sections***
- **Search for deviations from standard oscillatory behavior**

We may also search for:

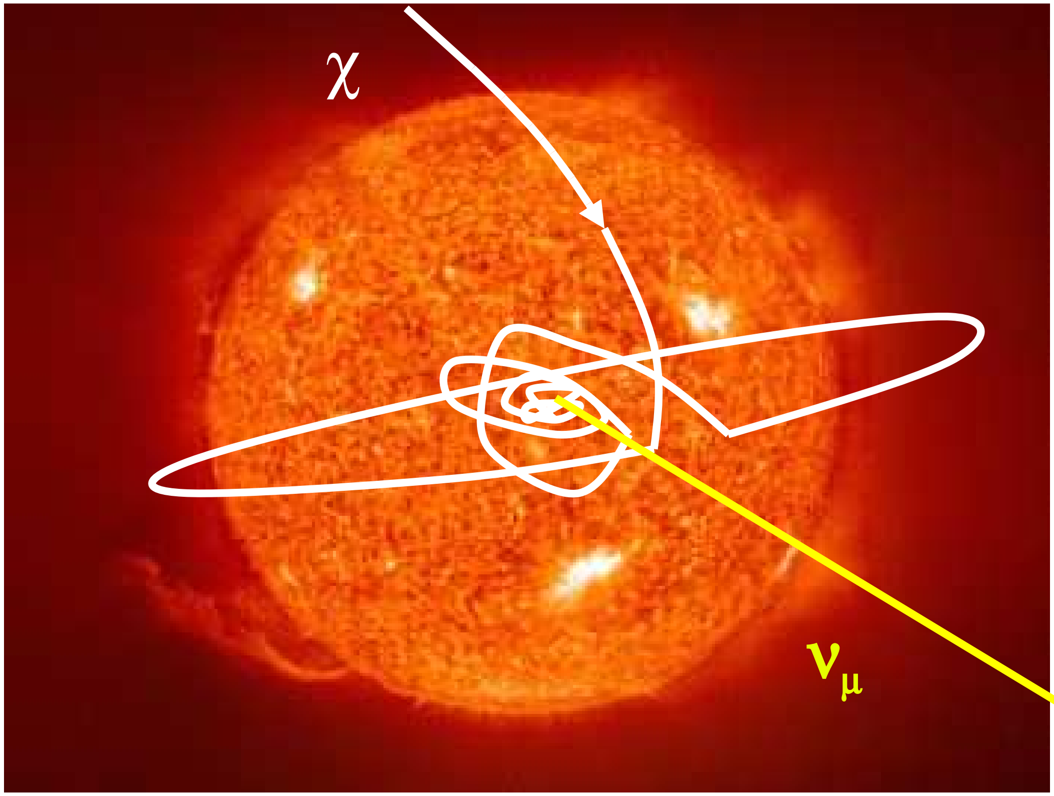
- **The exotic: magnetic monopoles, topological defects,...**
- ***Dark matter***

For a recent review, see Anchordoqui and Halzen hep-ph/0510389

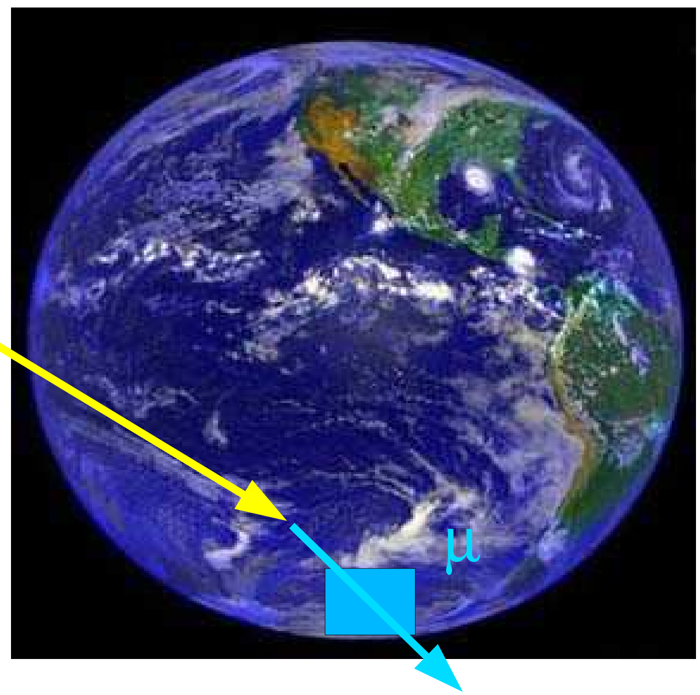
Neutrino cross sections

- Physics beyond the EW scale can enhance neutrino weak interaction cross sections beyond SM predictions
- Enhancements could in principle be seen from the event rates of up-coming and down-going neutrinos
- Probe the $\sigma_{\nu N}/\sigma_{SM}, \phi^{\nu}/\phi^{\nu}_{WB}$ parameter space (at CM energies up to $\sqrt{s} \sim 6\ TeV$)

Indirect dark matter searches



In MSSM the neutralino is the lightest stable particle and is a dark matter candidate



Sun and Earth WIMP searches: WIMPs scatter weakly on normal matter and lose energy, eventually becoming trapped in grav. field of heavy objects, annihilate pairwise

Neutrino detection

For a neutrino flux given by:

$$\frac{dF}{dE_\nu} \quad [neutrinos/GeV/cm^2/s]$$

The number of neutrinos seen in time T:

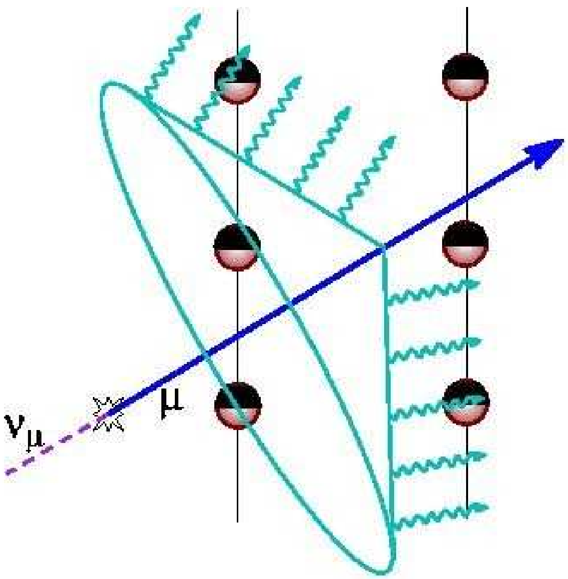
$$N = T \int_{E_\nu^{th}} A(E_\nu) P(E_\nu) \frac{dF}{dE_\nu} dE_\nu$$

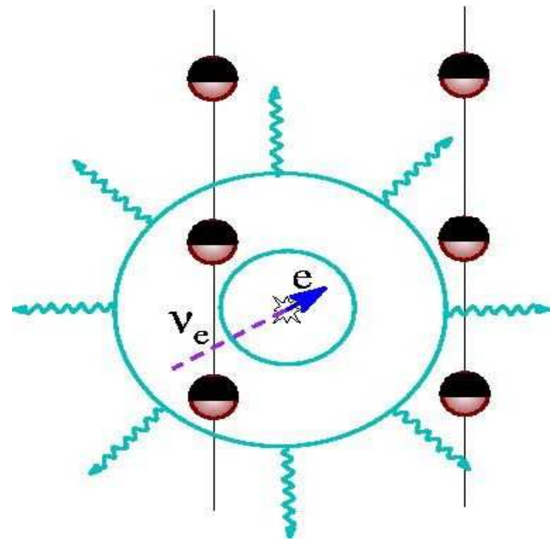
Energy threshold

Effective detector area > geometrical cross-sectional area

Probability of interaction within the detector volume

Neutrino detection





Tracks

- ν_μ CC interations
- Cosmic ray muons

Cascades

- ν_e CC interactions
- ν_τ CC interactions
- All NC interactions

Neutrino flavors

- $\nu_\mu \longrightarrow \mu$ **: Produce long muon tracks: Good directional resolution, poor energy resolution**
- $\nu_e \longrightarrow e$ **: Produce EM showers: Good energy resolution, poor directional resolution**
- ν_τ **: Can allow for interesting topologies**

Tau topologies

$$l_\tau \sim 50\ m \times (E_\tau / 10^6\ GeV)$$

- $E_\tau < 10^6\ GeV$:

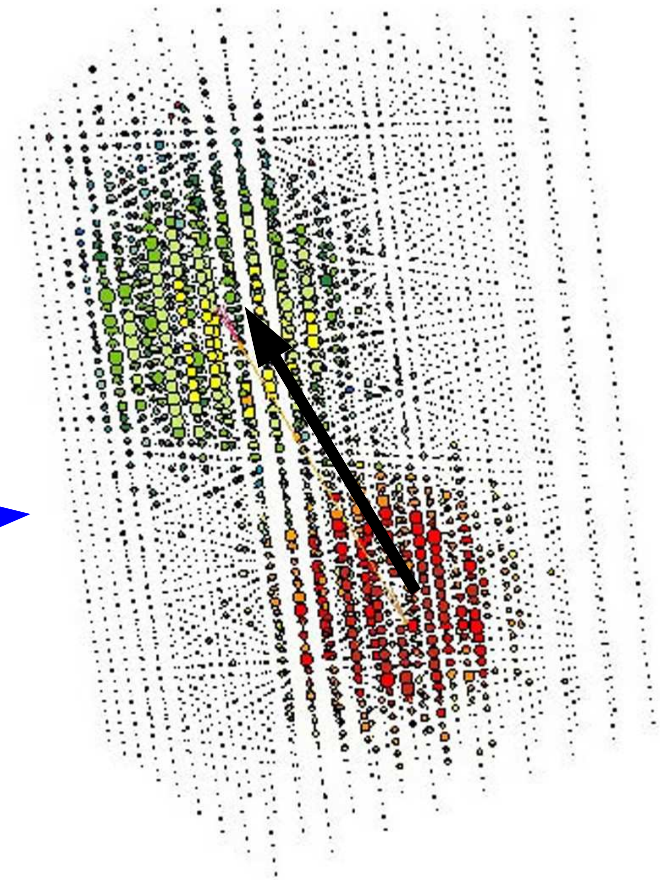
Shower can't be separated from hadronic shower of initial interaction

- $E_\tau > 10^6\ GeV$:

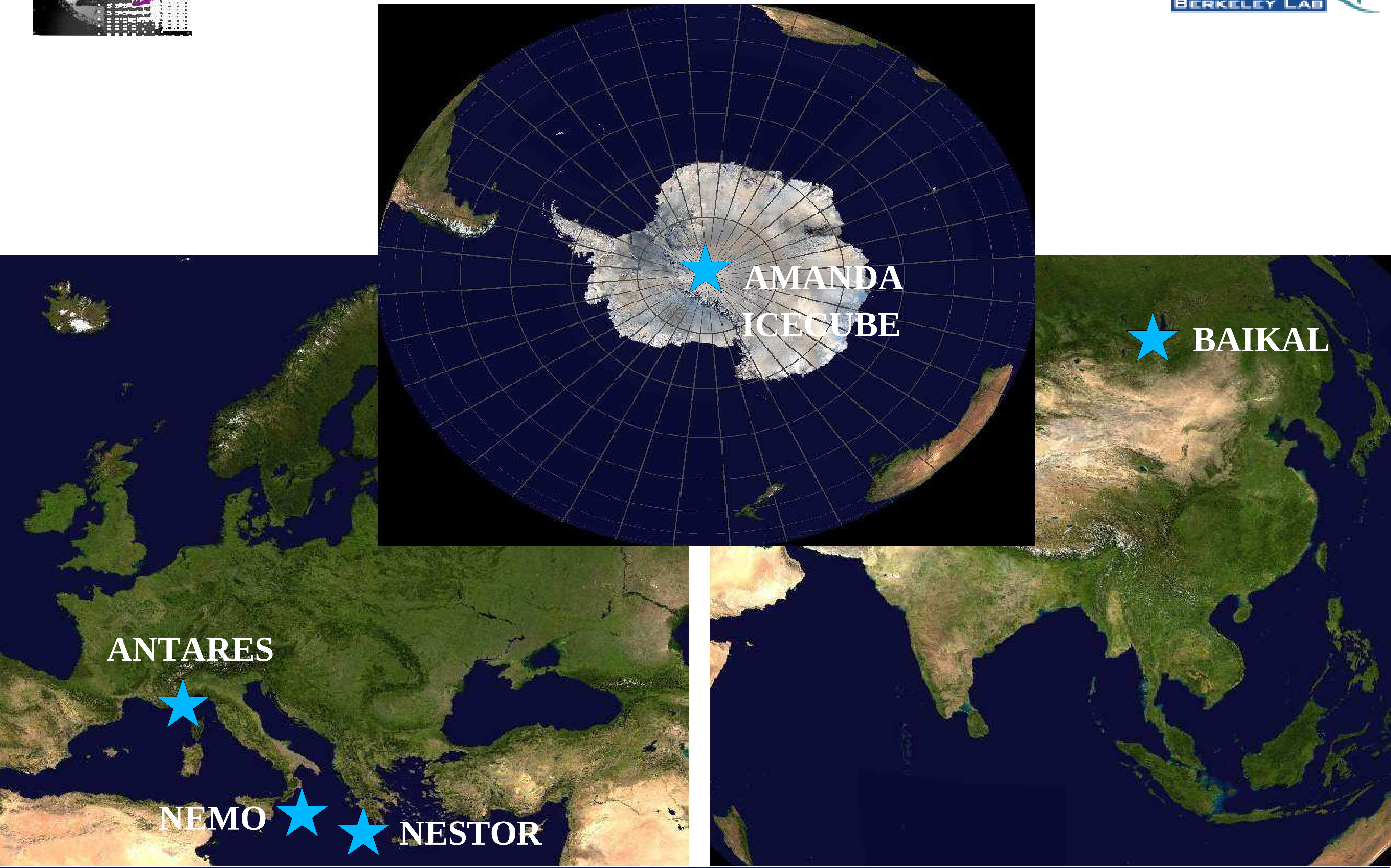
Range of τ ~ few hundred meters: allows for "double bang" topology

- $10^7 < E_\tau < 10^{7.5}\ GeV$:

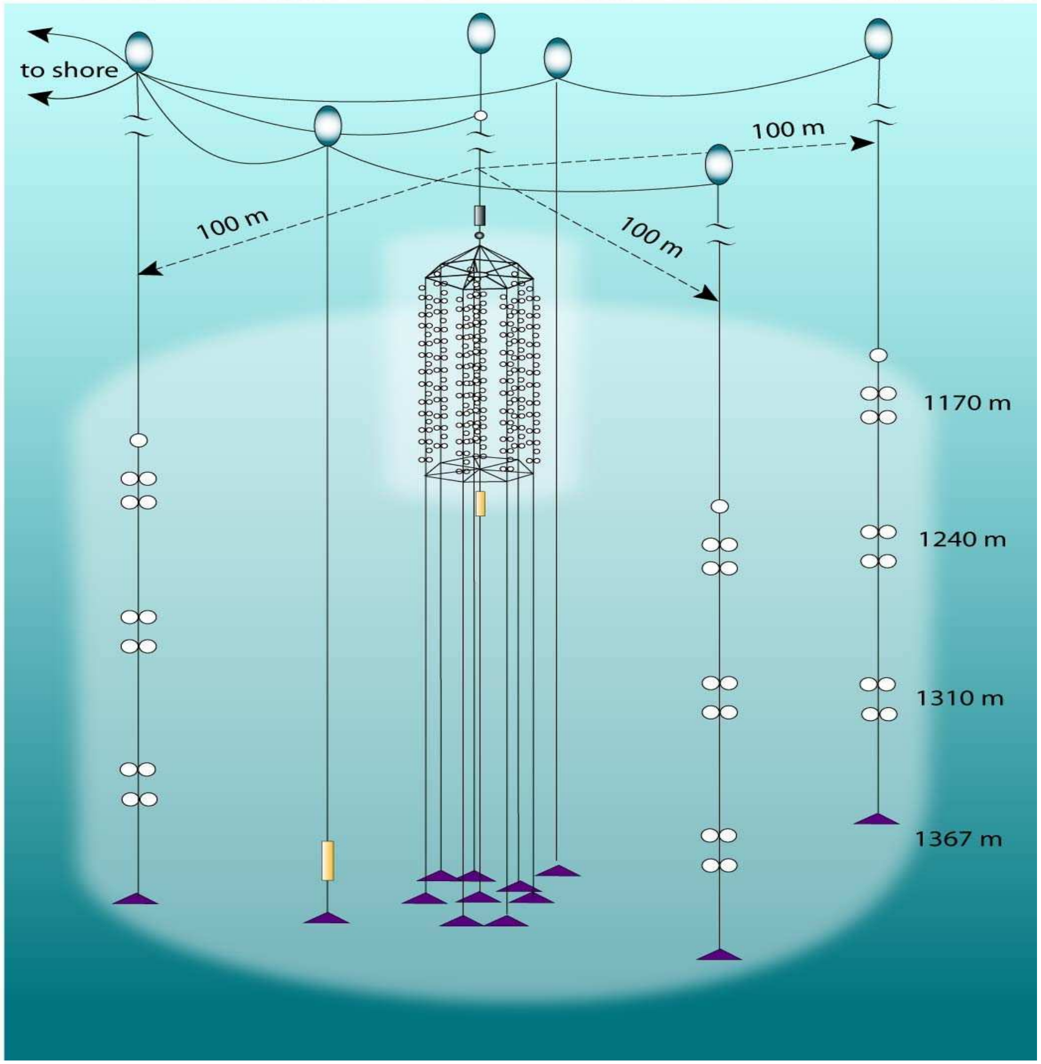
Decay length comparable to 1 km: "lollipop" topology



The World of Neutrino Telescopes



Baikal



Zh. Dzhilkibaev
(VLVnT Catania, 2005)

- Full NT-200 detector operating since 1998: 8 strings, 72 m long, with 192 OMs
- Since April 2005: NT-200+
- NT-200+ : 3 strings, 140 m long

Towards a cubic km GVD: R&D started, construction begins >= 2009

Baikal HE diffuse flux

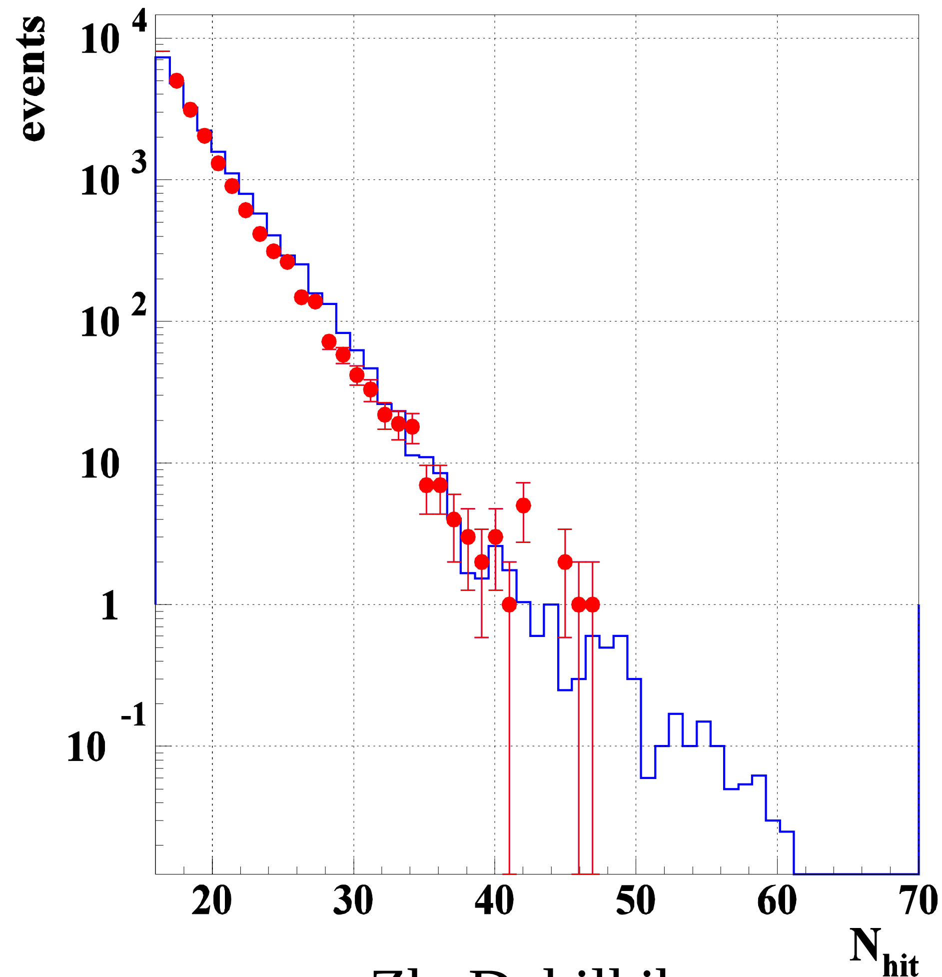
Limit HE casacades:

$$\Phi_\nu E^2 < 8.1 \times 10^{-7} GeV\, cm^{-2} s^{-1} sr^{-1}$$

$$22\ TeV < E < 50\ PeV$$

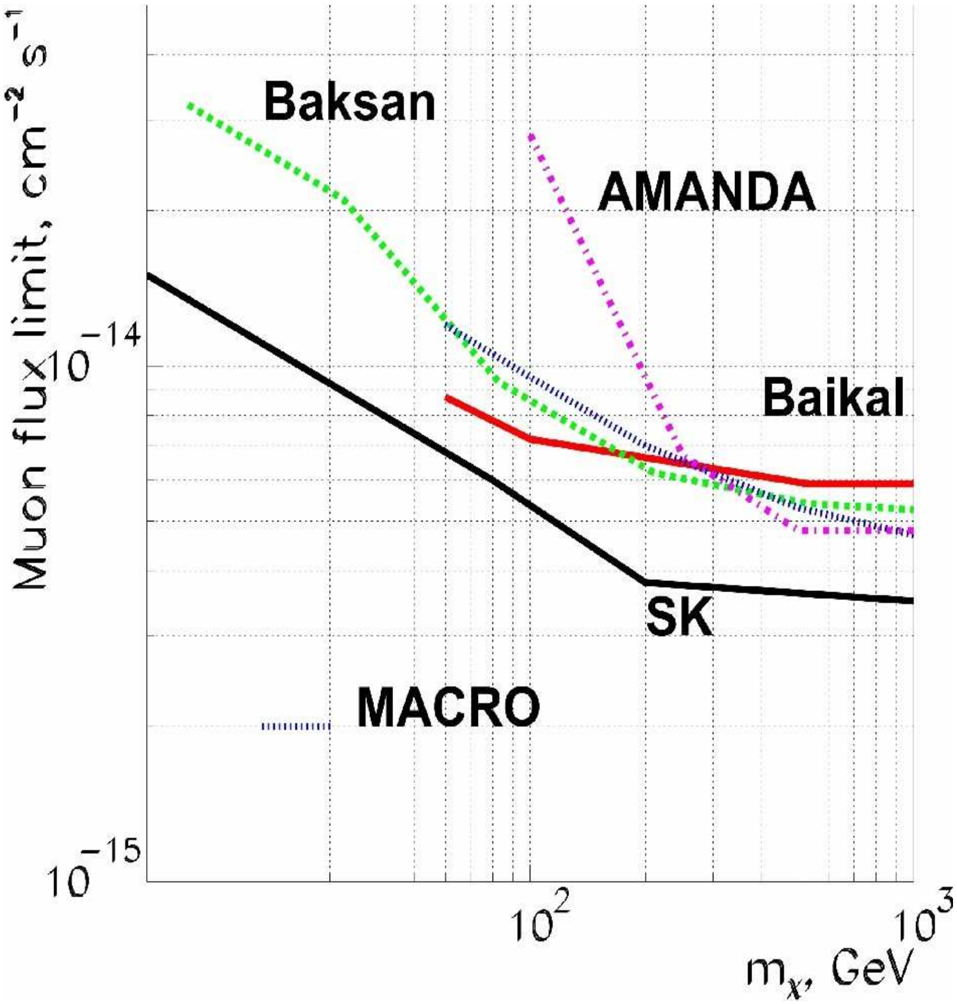
NT200 1998-2003 (1038 days)

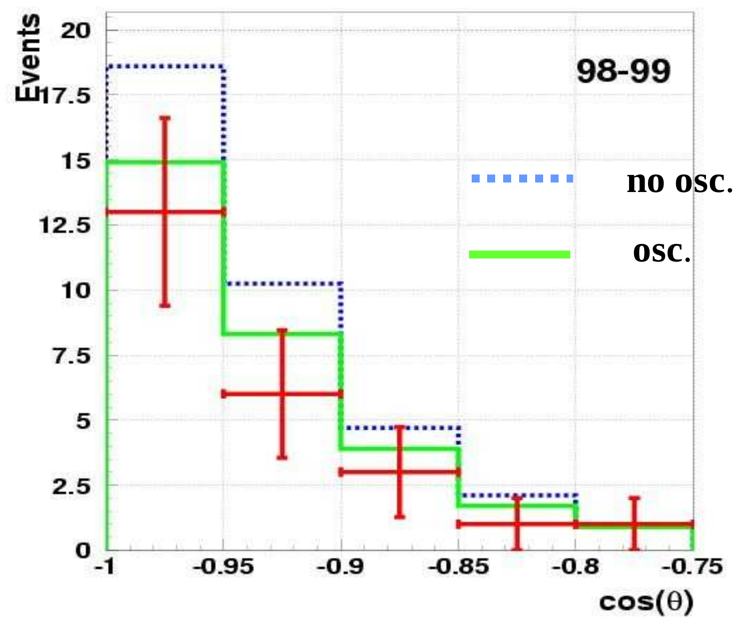
astro-ph/0508675 submitted to
Astropart. Phys.



Zh. Dzhilkibaev
(VLVnT Catania, 2005)

Baikal indirect DM search





NT-200 livetime (502 days) E > 10 GeV

Muon flux limits from center of Earth

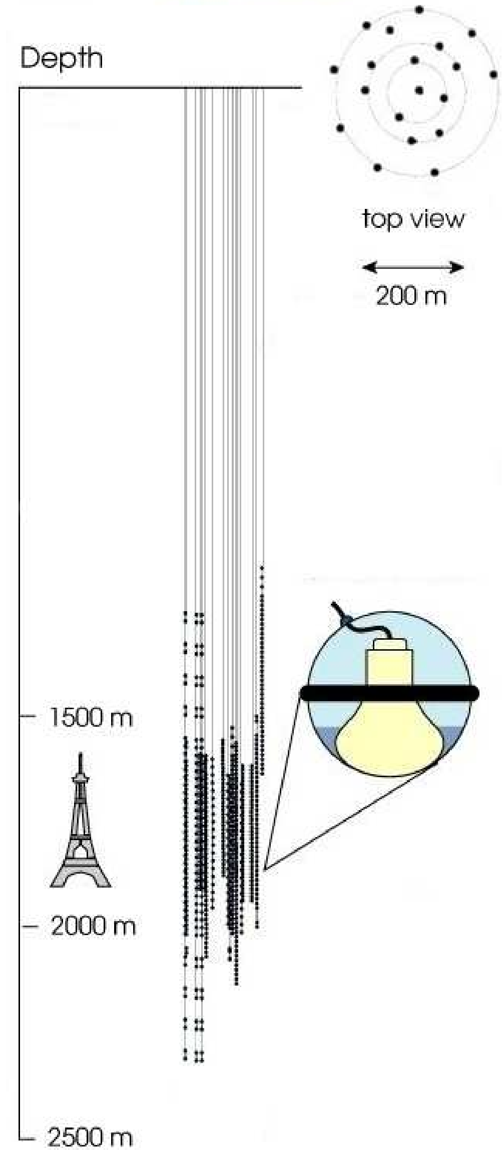
Nucl. Phys. B (Proc. Suppl.) **143** (2005) 335

R. Wischnewski C2CR 2005

AMANDA

- **A**ntarctic **M**uon and **N**eutrino **D**etector **A**rray
- AMANDA-II: 19 strings; 677 OMs; 2000-
- AMANDA-B10: Inner core of AMANDA-II; 10 strings; 302 OMs; 1997-1999

Channel	Angular resolution [deg]	$\sigma[\log_{10}(E/TeV)]$
Tracks	1.5 -2.5	0.3 - 0.4
Cascades	30 - 40	0.1 - 0.2



Nucl. Intr. Meth. A **524** (2004) 169

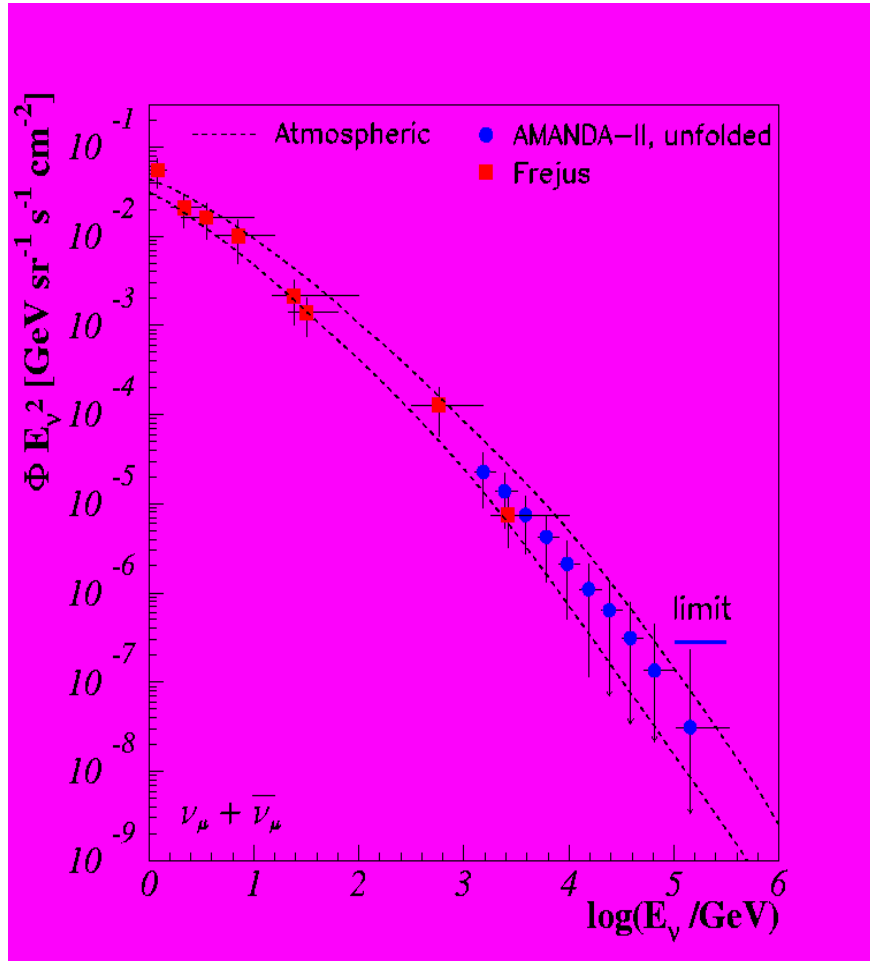
AMANDA diffuse flux: HE tracks

$$\Phi_\nu E^2 < 2.6 \times 10^{-7} GeV\,cm^{-2} s^{-1} sr^{-1}$$

$$100\ TeV < E < 300\ TeV$$

AMANDA-II 2000 (197 days)

ICRC 2005, Pune astro-ph/0509330



$$\Phi_\nu E^2 < 9.5 \times 10^{-8} GeV\,cm^{-2} s^{-1} sr^{-1}$$

$$13\ TeV < E < 3.2\ PeV$$

AMANDA-II 2000-2003 (807 days) **PRELIMINARY**

AMANDA diffuse flux: HE cascades

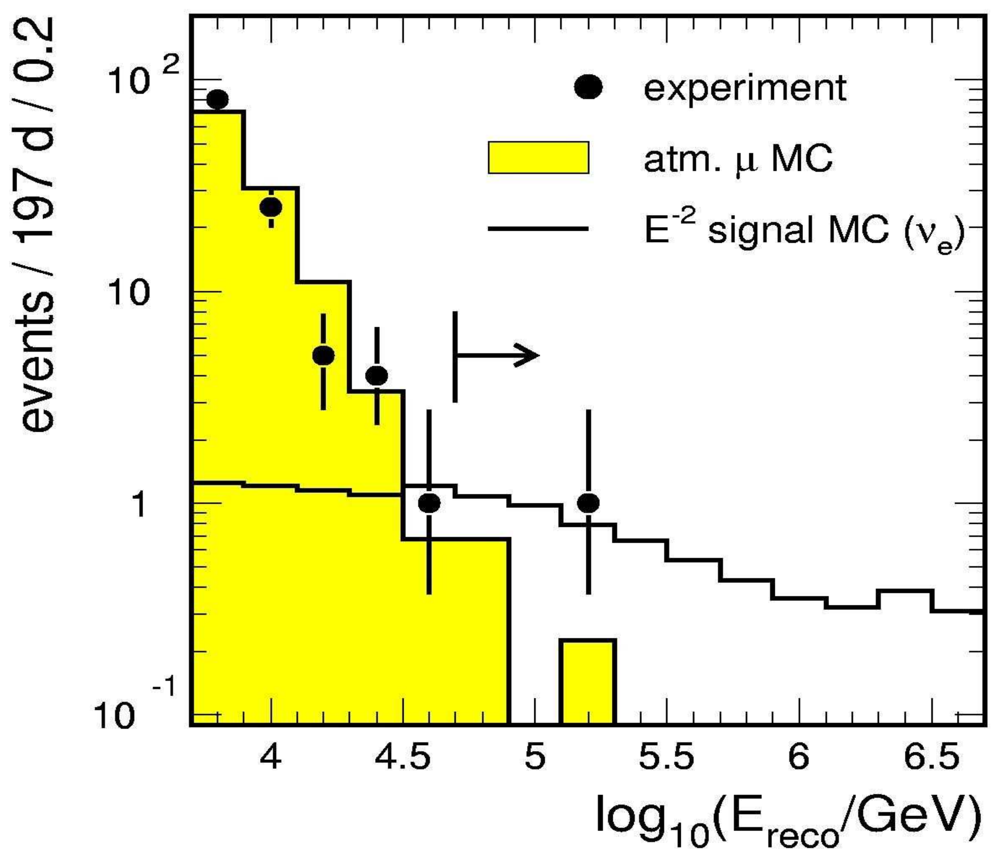
Limit: HE cascades

$$\Phi_\nu E^2 < 8.6 \times 10^{-7} GeV\, cm^{-2} s^{-1} sr^{-1}$$

$$50\ TeV < E < 5\ PeV$$

Astropart. Phys **22** (2004) 127

AMANDA-II 2000 (174 days)



AMANDA UHE neutrinos

UHE neutrinos AMANDA-II

$$\Phi_\nu E^2 < 3.8 \times 10^{-7} GeV cm^{-2} s^{-1} sr^{-1}$$

$$0.18\ PeV < E < 1.8\ EeV$$

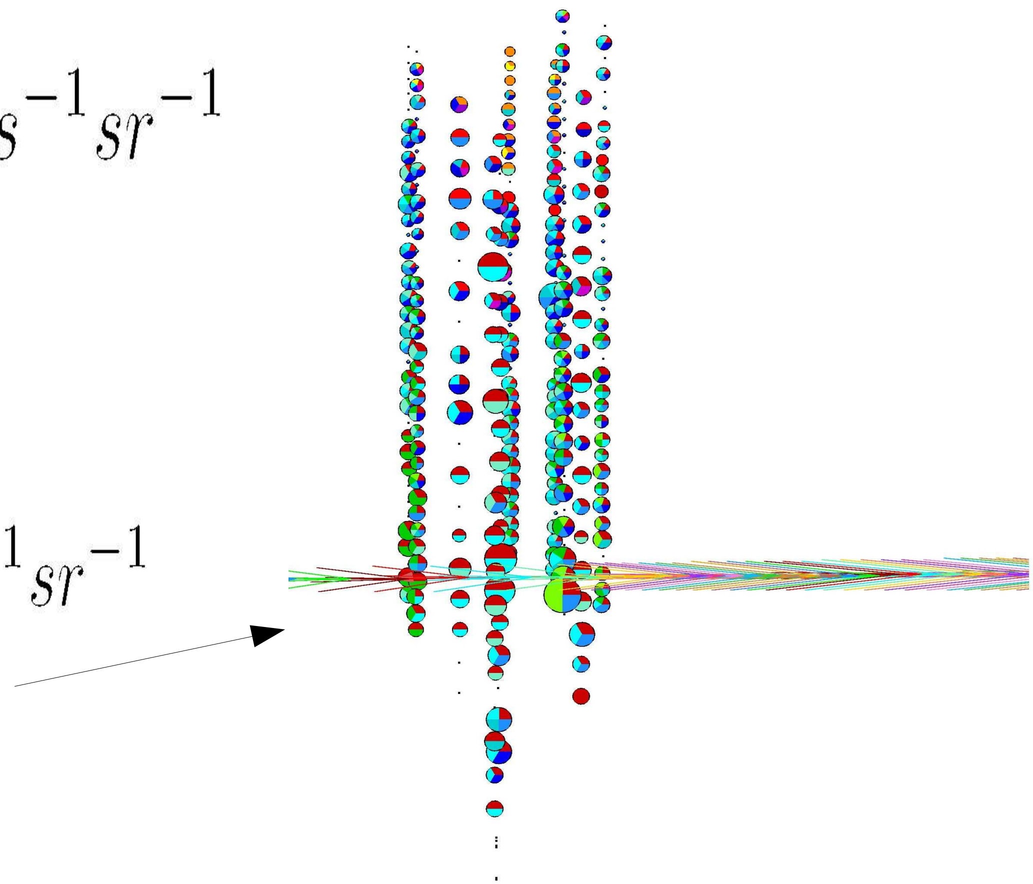
ICRC 2005, Pune astro-ph/0509330

UHE neutrinos AMANDA-B10

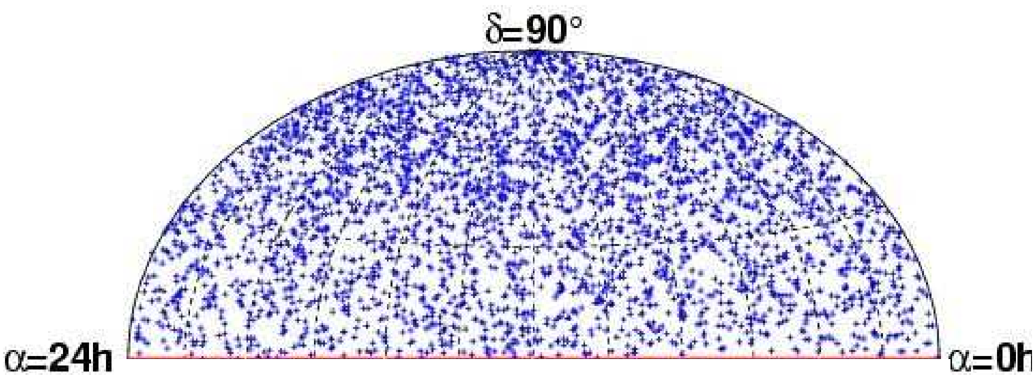
$$\Phi_\nu E^2 < 9.9 \times 10^{-7} GeV cm^{-2} s^{-1} sr^{-1}$$

$$1\ PeV < E < 3\ EeV$$

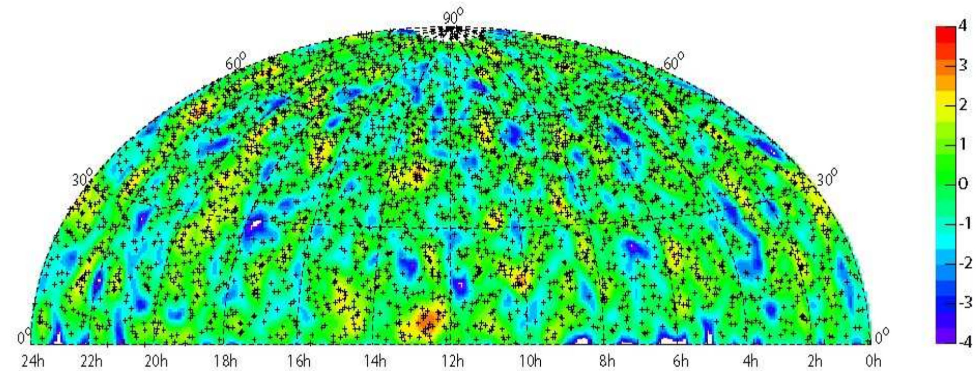
Astropart. Phys. **22** (2005) 339



AMANDA point source search



Event map



Significance map

ICRC 2005, Pune astro-ph/0509330

- **3329 neutrino candidates from the northern sky (2000-2003)**
- **Cluster search in northern sky: unbinned statistical analysis**
- **Comparison with expected atmospheric background**
- **No significant excess found**

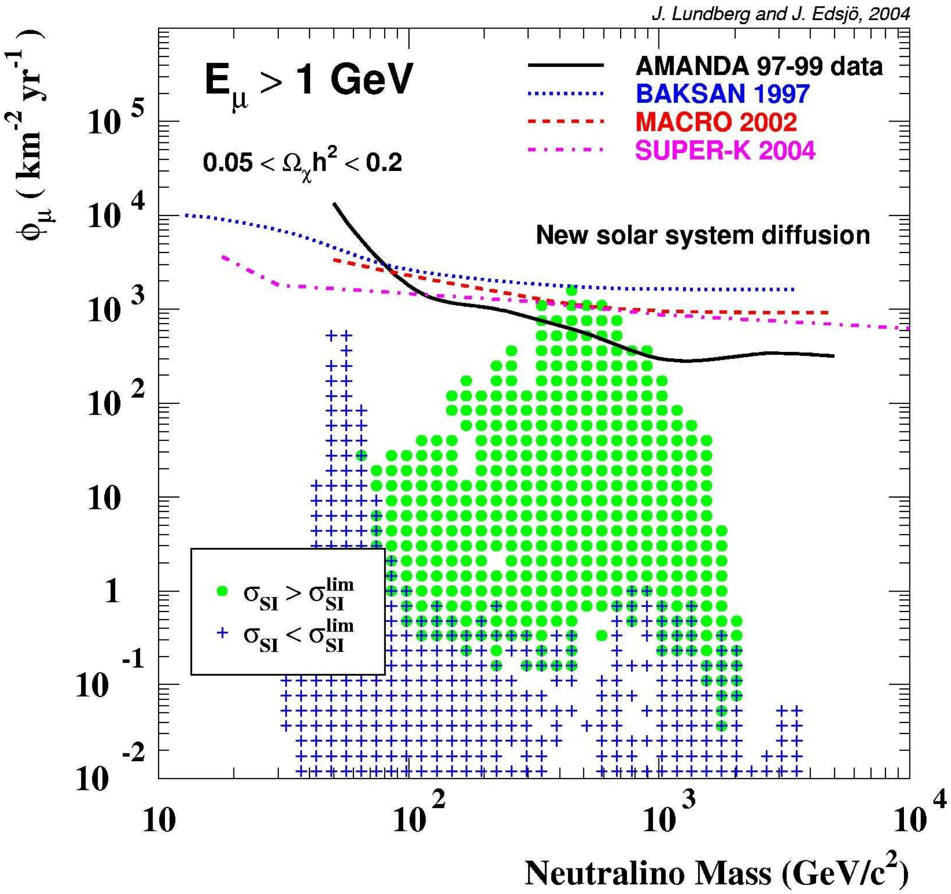
AMANDA point source searches

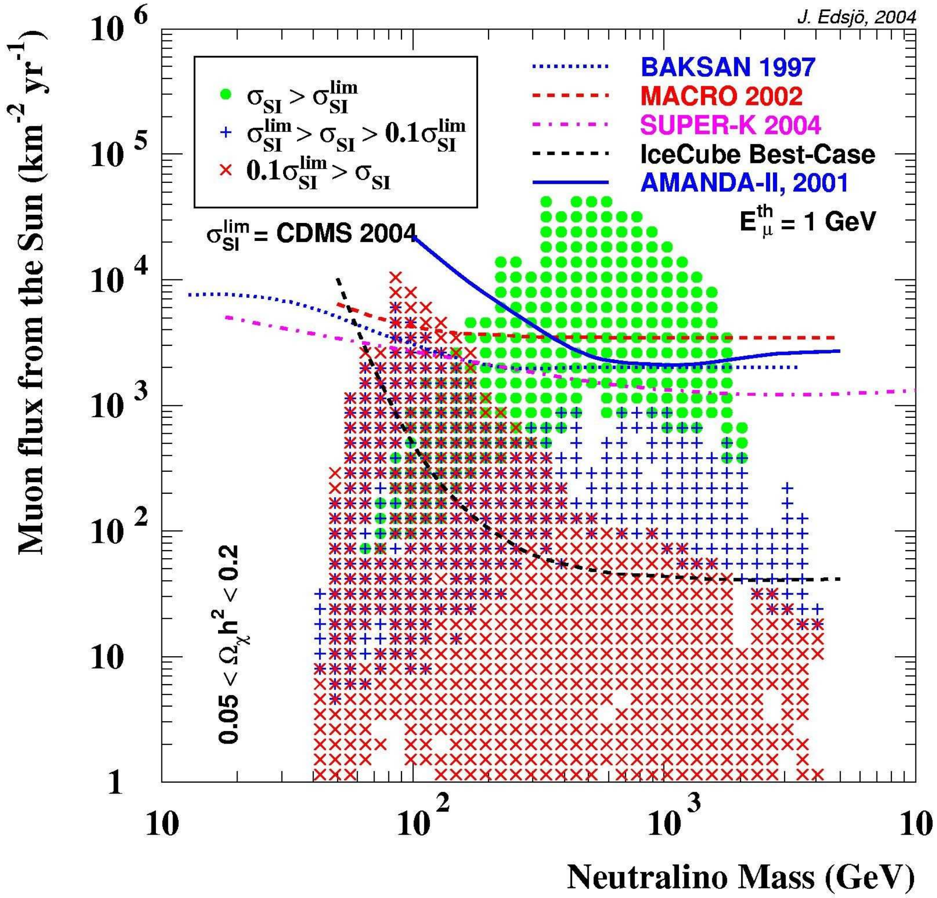
- Time-rolling search over 2000- 2003 (angular search bin: 2.25 – 3.75 deg.) for clustering with supernova remnants, microquasars, TeV and GeV blazars
- Stacking source analysis (2000)
- Time-correlation with transient phenomena: TeV gamma ray sources(2000-2003)
- Time-space coincidence with GRBs

ICRC 2005, Pune astro-ph/0509330

No statistically significant excess seen

Indirect WIMP detection





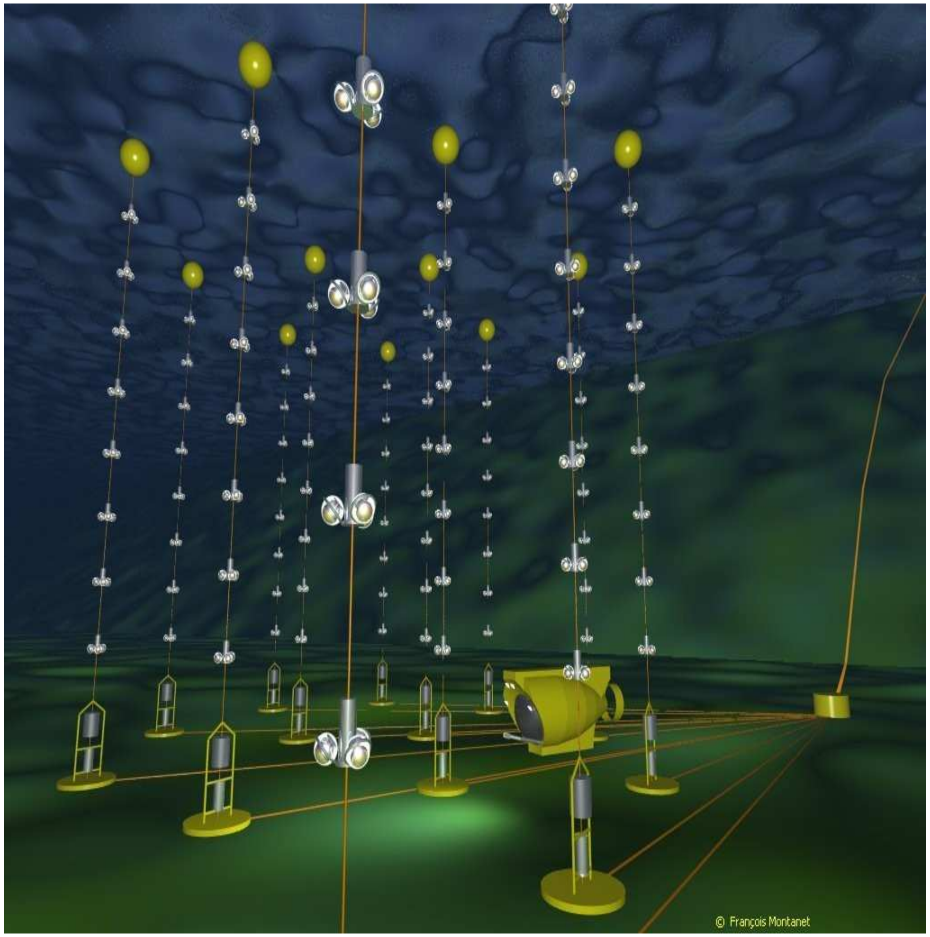
Earth center: muon flux limits

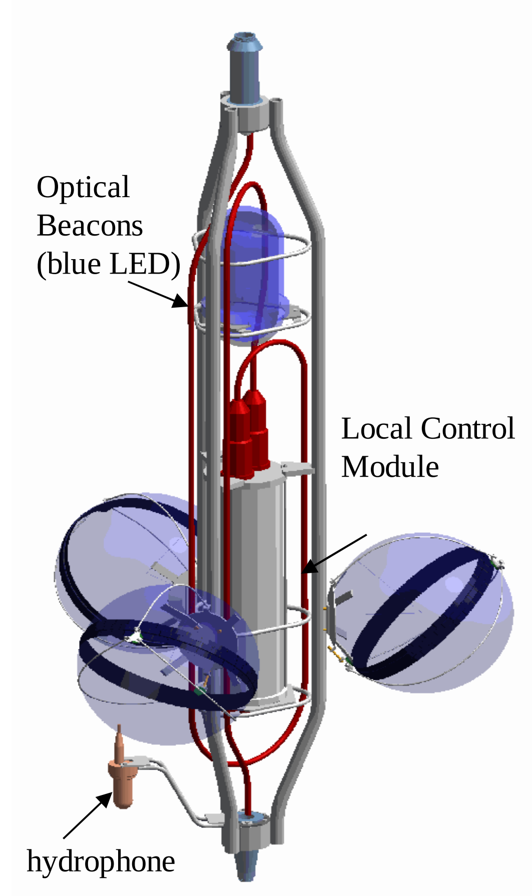
Sun center: muon flux limits

ICRC 2005, Pune astro-ph/0509330

ANTARES

ANTARES – F. Montanet CPPM/IN2P3/CNRS – Univ. Mediterranee



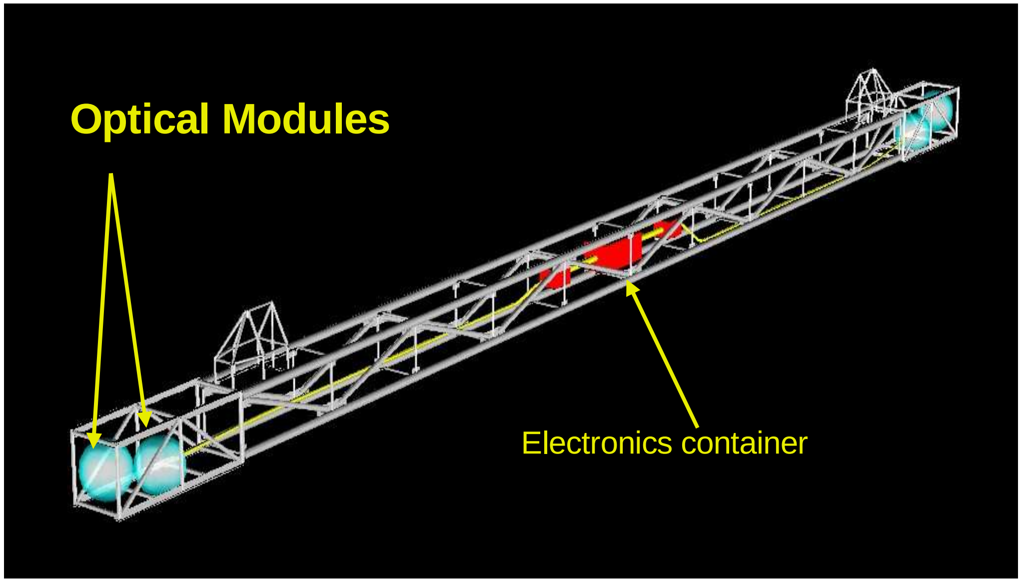


Proposed:
12 strings
25 stores / string
3 PMTs / story

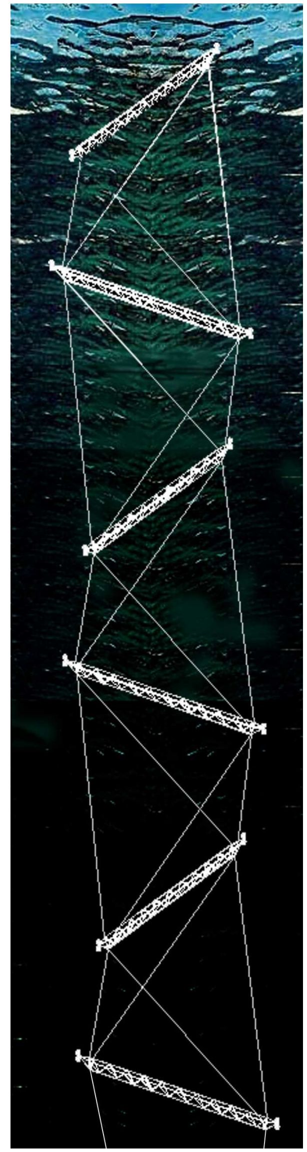
3.5π **sr coverage**

2/3 of the time: observation of Galactic Center

NEMO



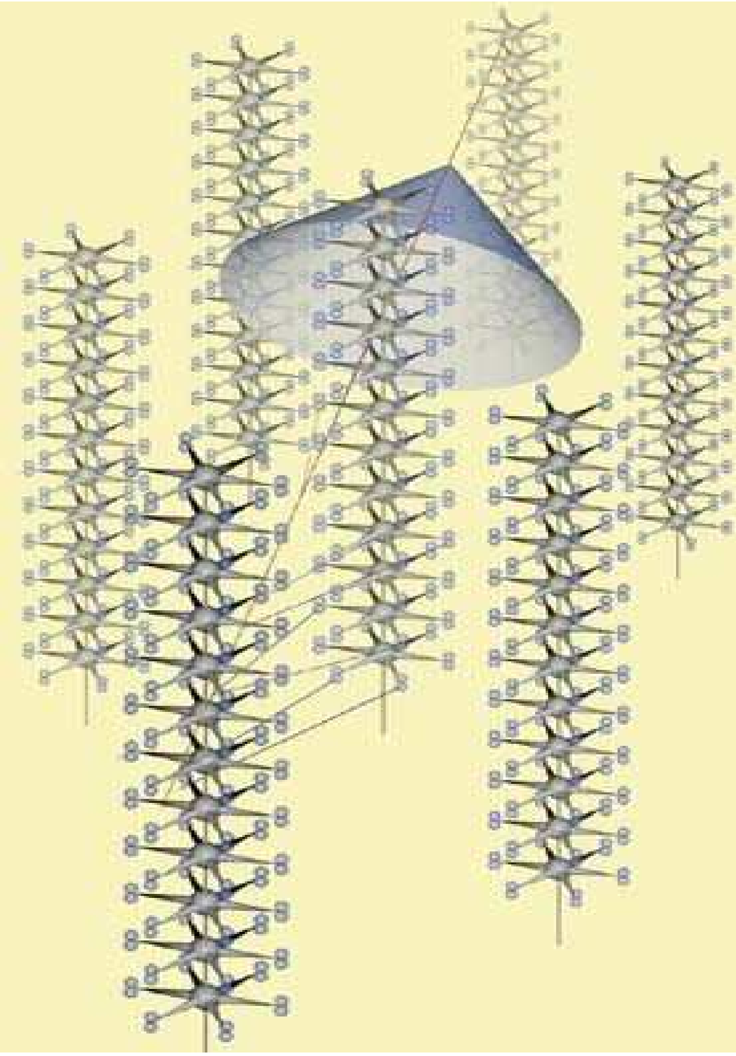
E. Migneco, VLVnT2 Catania 2005



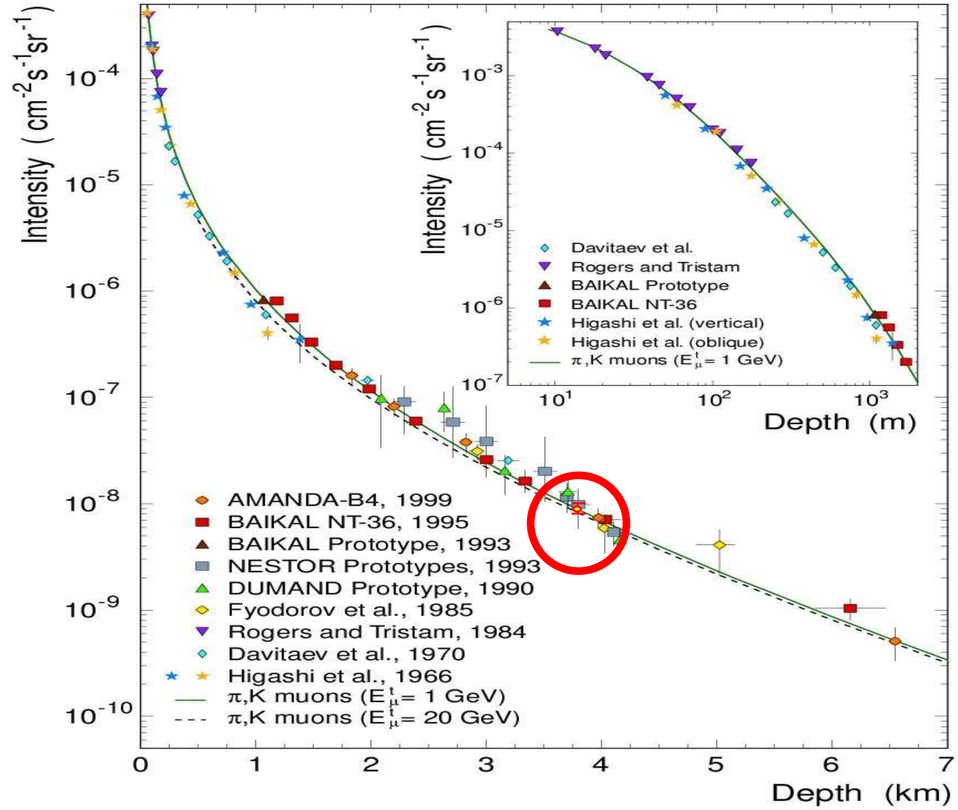
- Modular structure of towers consisting of 16 floors (spaced 40 m apart)
- Floor length: 15 m
- Tower height: 750 m
- R&D phase

http://nemoweb.lns.infn.it/

NESTOR



S.E. Tzamarias Neutrino 2004



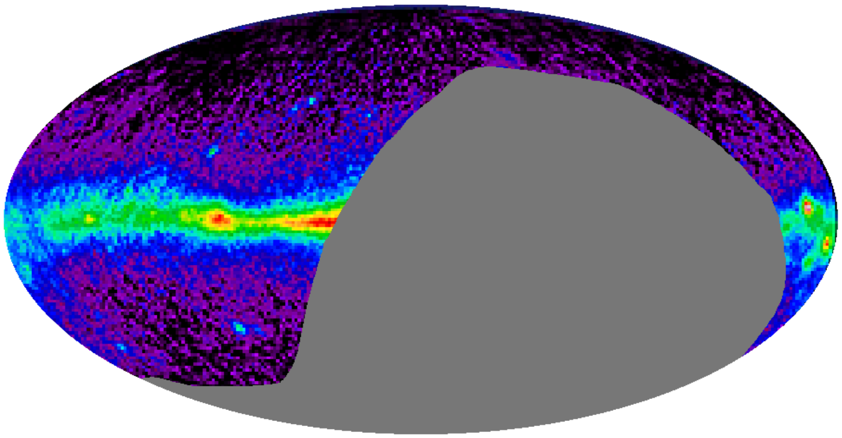
Muon flux measurement:
one floor @ 3500 m depth

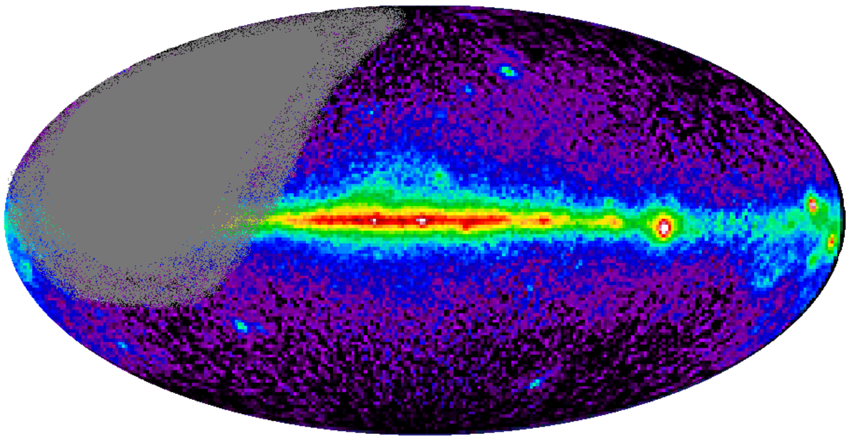
Astropart. Phys. **23** (2005) 377

http://www.nestor.org.gr

KM 3NeT

South Pole | **Mediterranean**



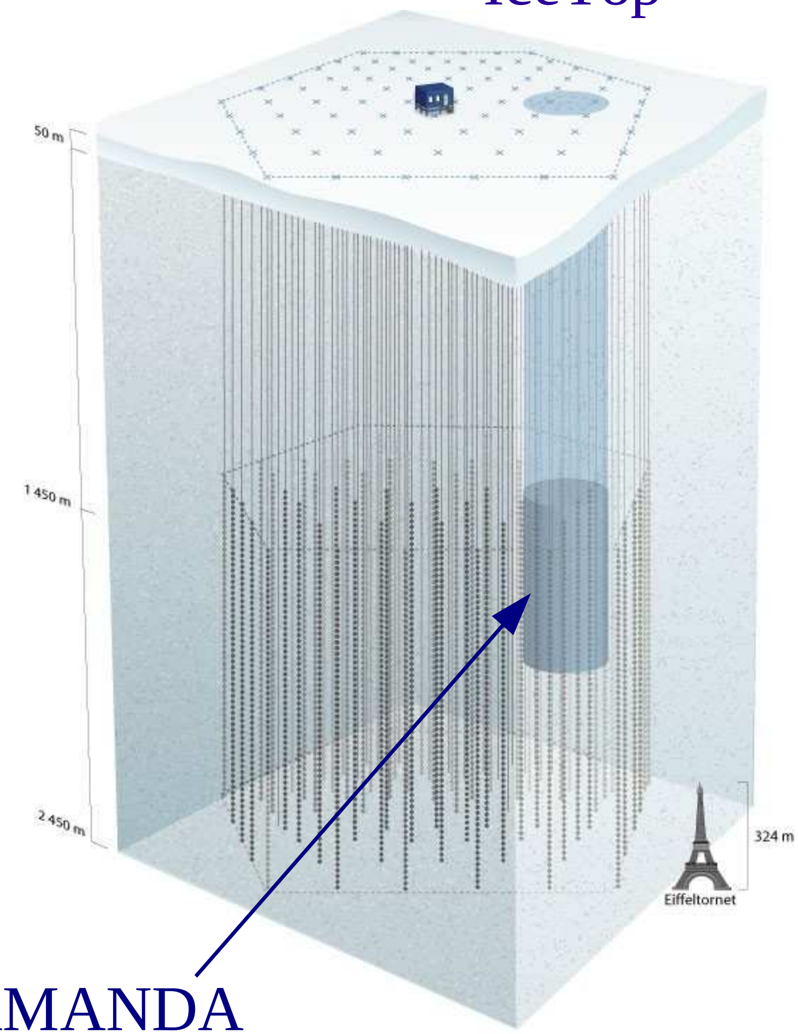


- **A cubic km telescope in the north in conjunction with IceCube would allow for full-sky coverage**
- **KM3NeT: a proposed effort utilizing the expertise of the 3 Mediterranean efforts**
- **EU-funded design program: begins Feb. 2006 → 3 yr. R&D phase**

http://www.km3net.org

IceCube

IceTop



AMANDA

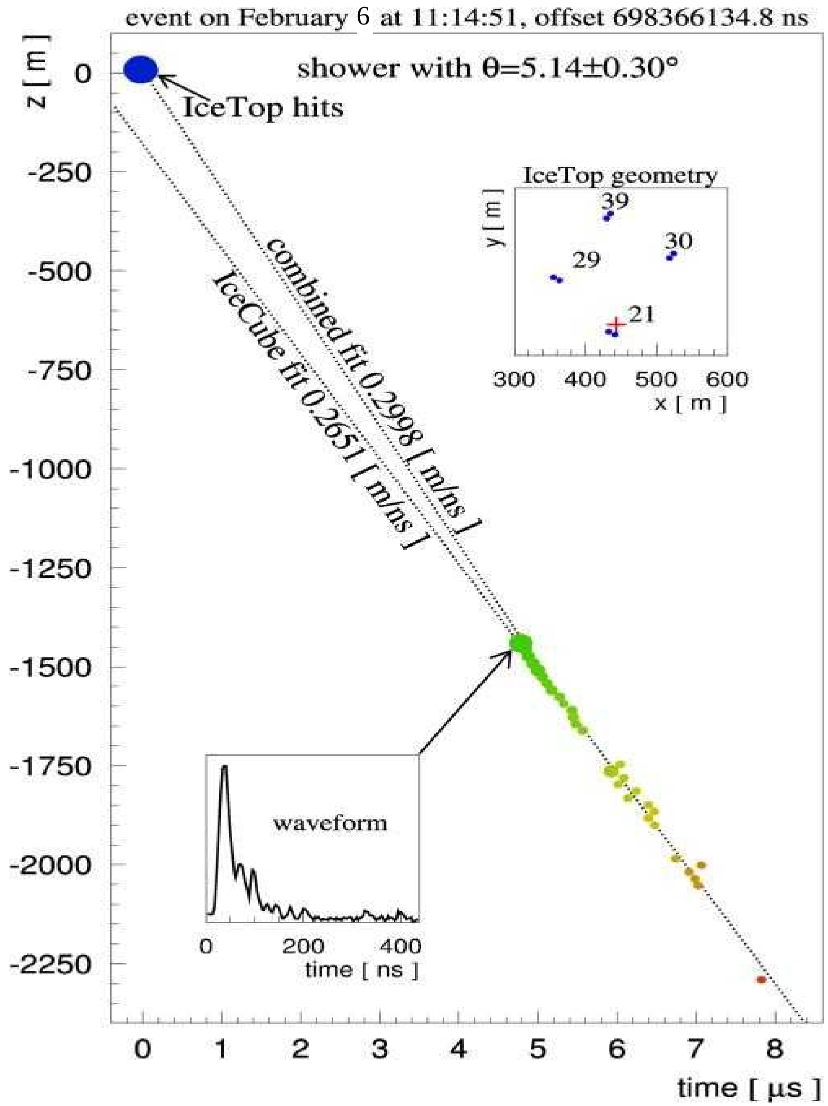
- **1 Gton instrumented volume**
- **1450 – 2450 m depth**
- **80 strings with 60 DOMs each, separated by 17 m**
- **125 m hexagonal grid**
- **IceTop air shower array: 160 water Cherenkov tanks, each with 2 DOMs**

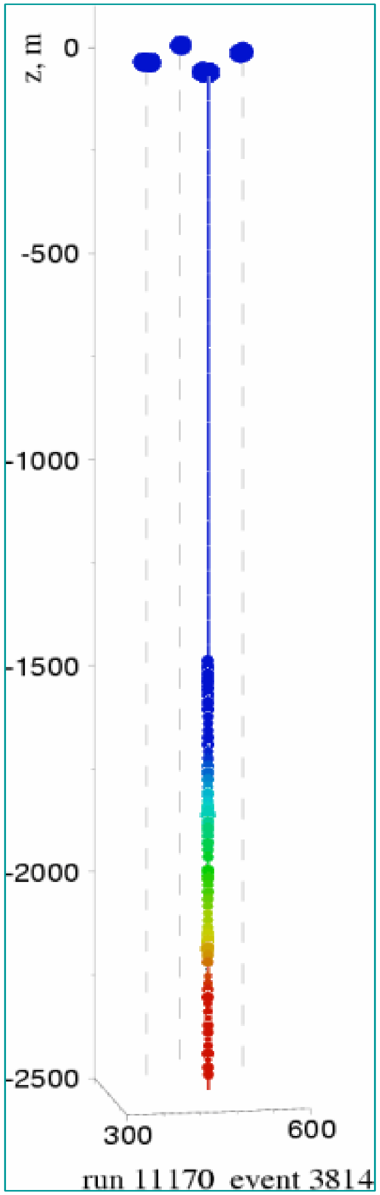
2004-2005 season: 1 string, 8 tanks deployed

2005-2006 season goal: 8-12 strings

Cubic km instrumented: 2010

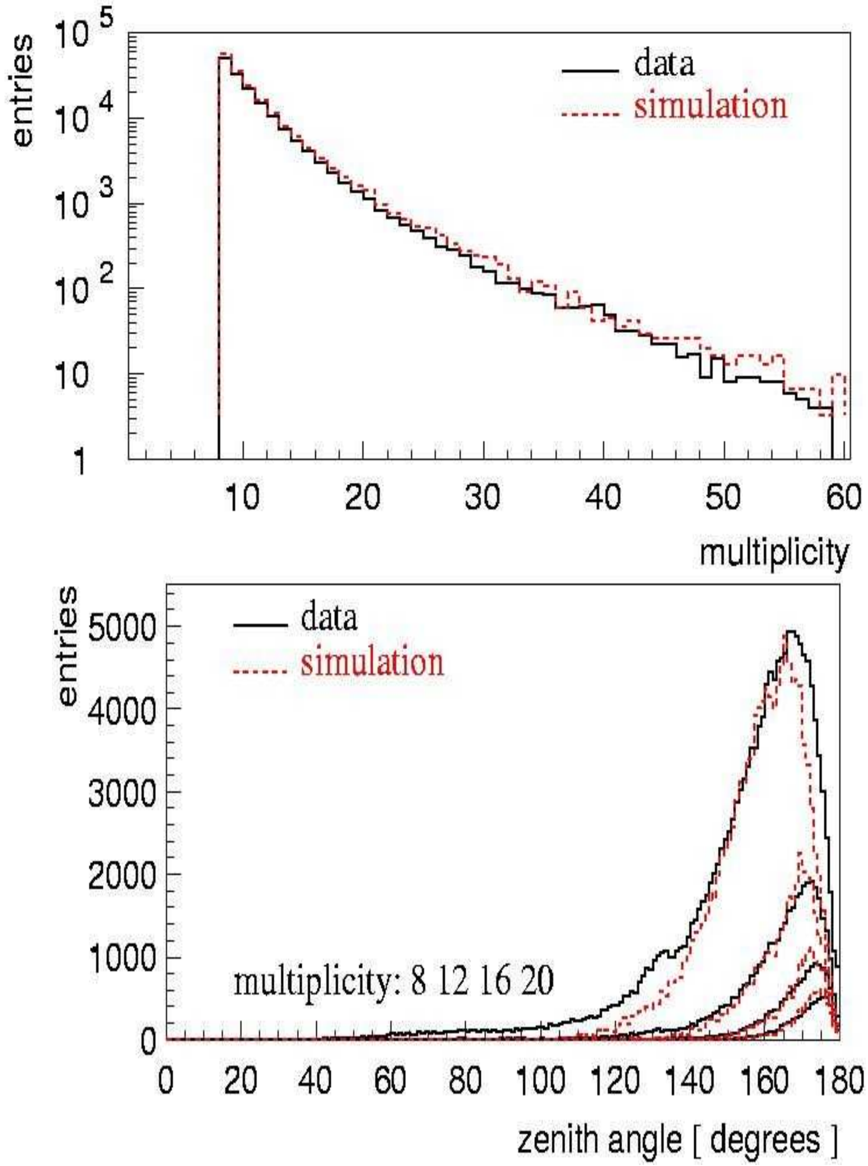
IceCube performance: "String 21"



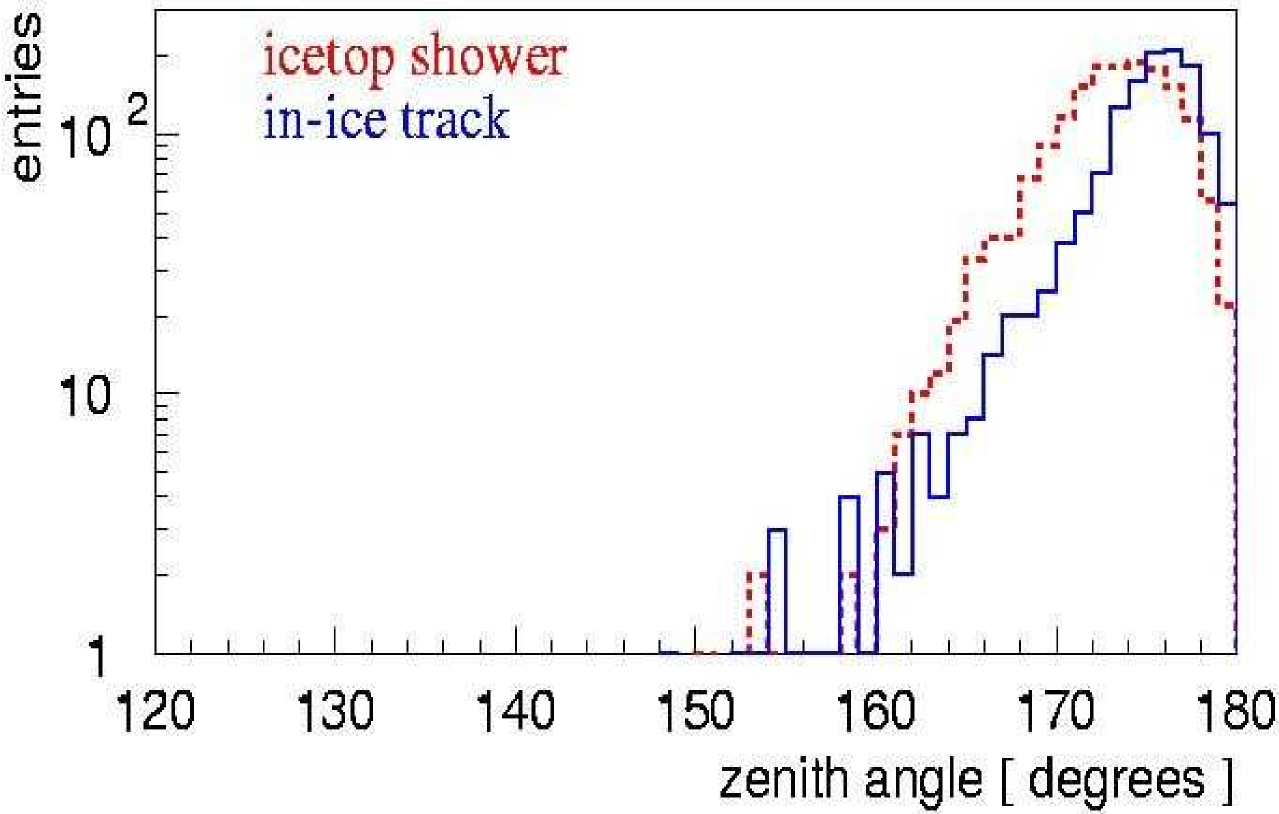


D. Chirkin ICRC 2005 Pune

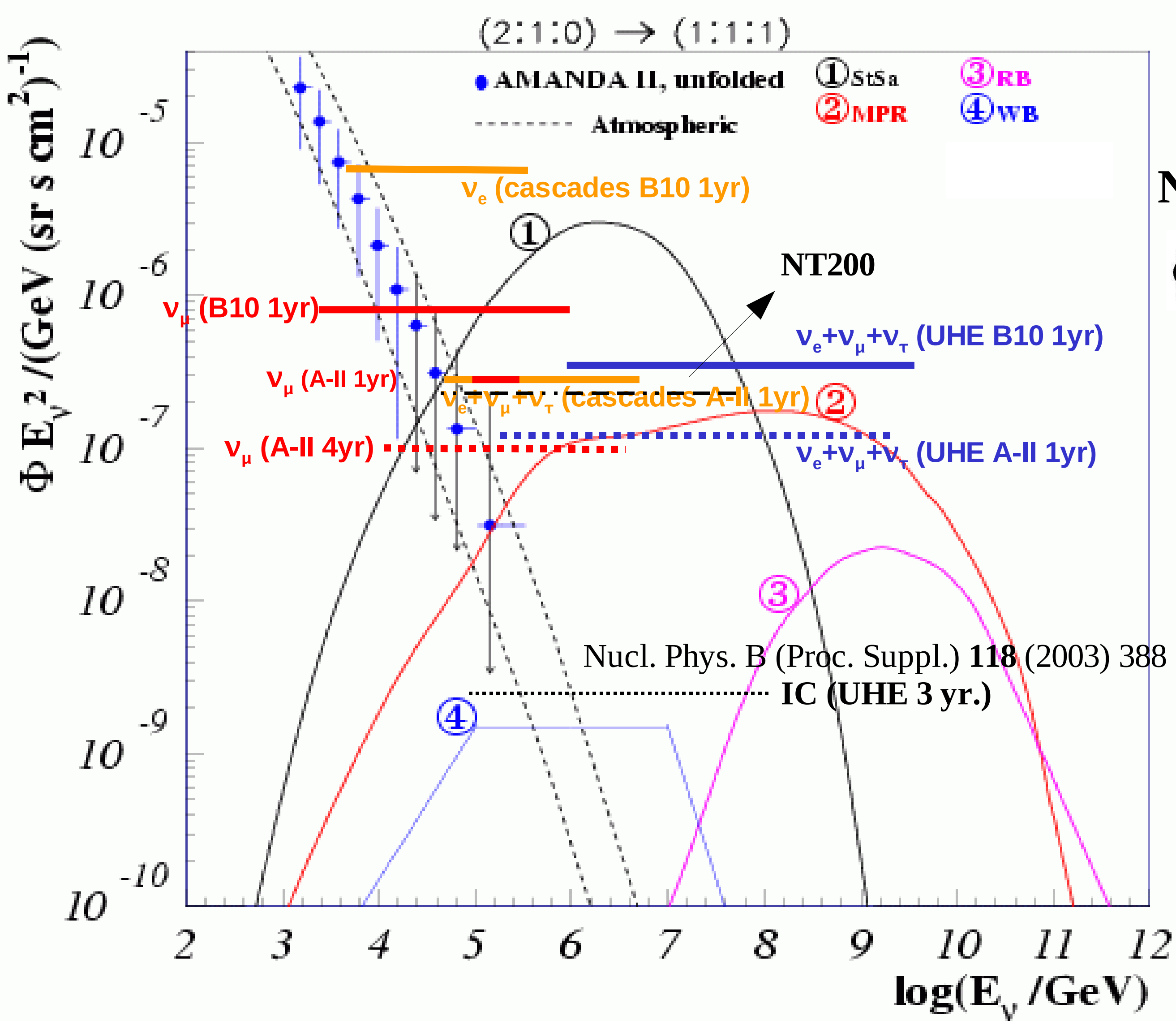
IceCube performance: muon zenith angle



IceTop/IceCube coincidences



Diffuse neutrino flux: summary



NT200+ expected sensitivity (3 yr.)

$$\Phi_\nu E^2 \sim 2 \times 10^{-7} GeV\, cm^{-2} s^{-1} sr^{-1}$$

astro-ph/0508675

Present and Future Summary

- No extra- terrestrial neutrinos detected as yet
- However, Baikal and AMANDA have placed limits on fluxes and constraints on models
- Extensions to Baikal detector will further this work
- 3 efforts in the Mediterranean have developed new technologies towards a cubic km telescope in the northern hemisphere
- IceCube: as of today (Jan. 6), 2 strings deployed this season with 3rd deployment beginning this morning


Thanks very much to the organizers!