Imaging the High-Energy Neutrino Universe from the South Pole

Results from AMANDA
and Status of IceCube

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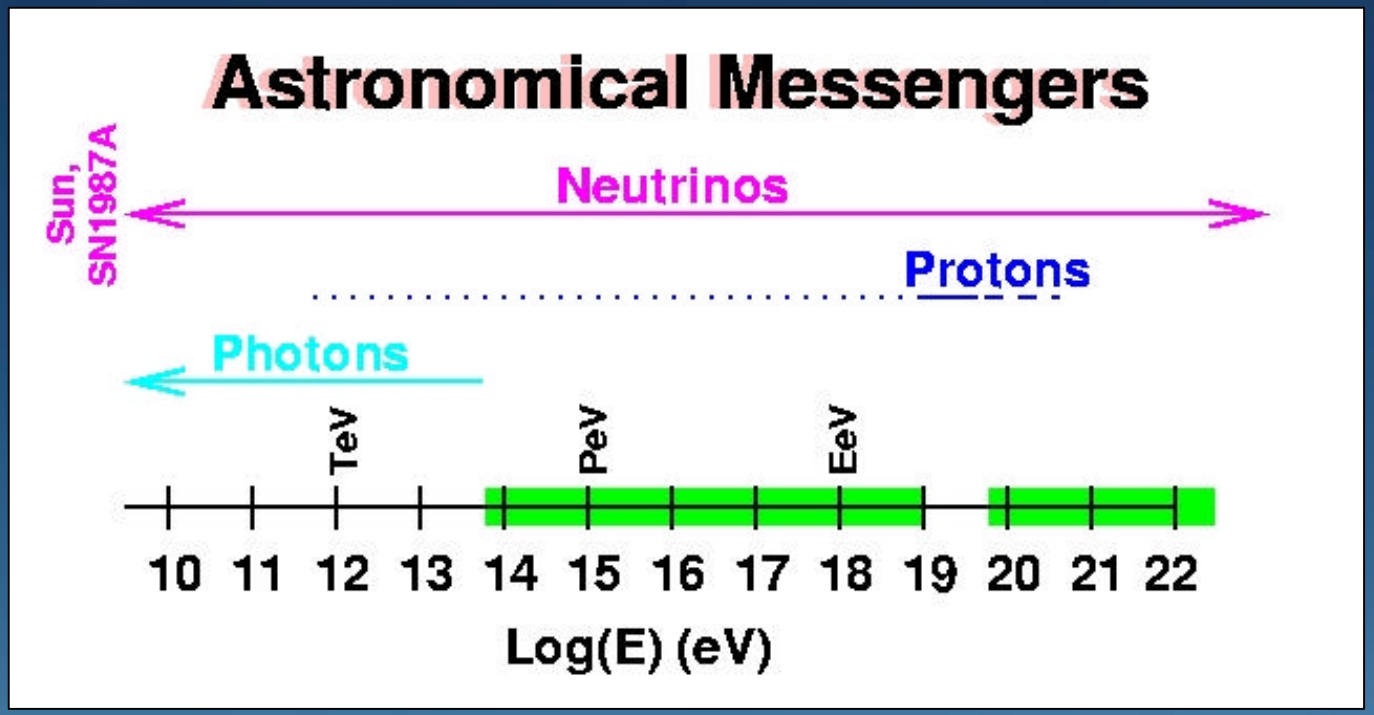
La Thuile, Feb 27 – Mar 5, 2005
Results and Perspectives in Particle Physics

http://amanda.uci.edu

http://icecube.wisc.edu

Neutrino Astronomy



Protons: directions scrambled by extragalactic magnetic fields

?-rays: straight-line propagation but reprocessed in sources; extragalactic backgrounds absorb E? > TeV

Neutrinos: straight-line propagation; not absorbed, but difficult to detect

High-Energy Neutrino Production and Detection

Candidate astrophysical accelerators for high energy cosmic rays:

- Active Galactic Nuclei
- Gamma-Ray Bursts
- Supernova Remnants
- …

Neutrino production at source:

p+γ or p+p collisions

? pion decay ? neutrinos

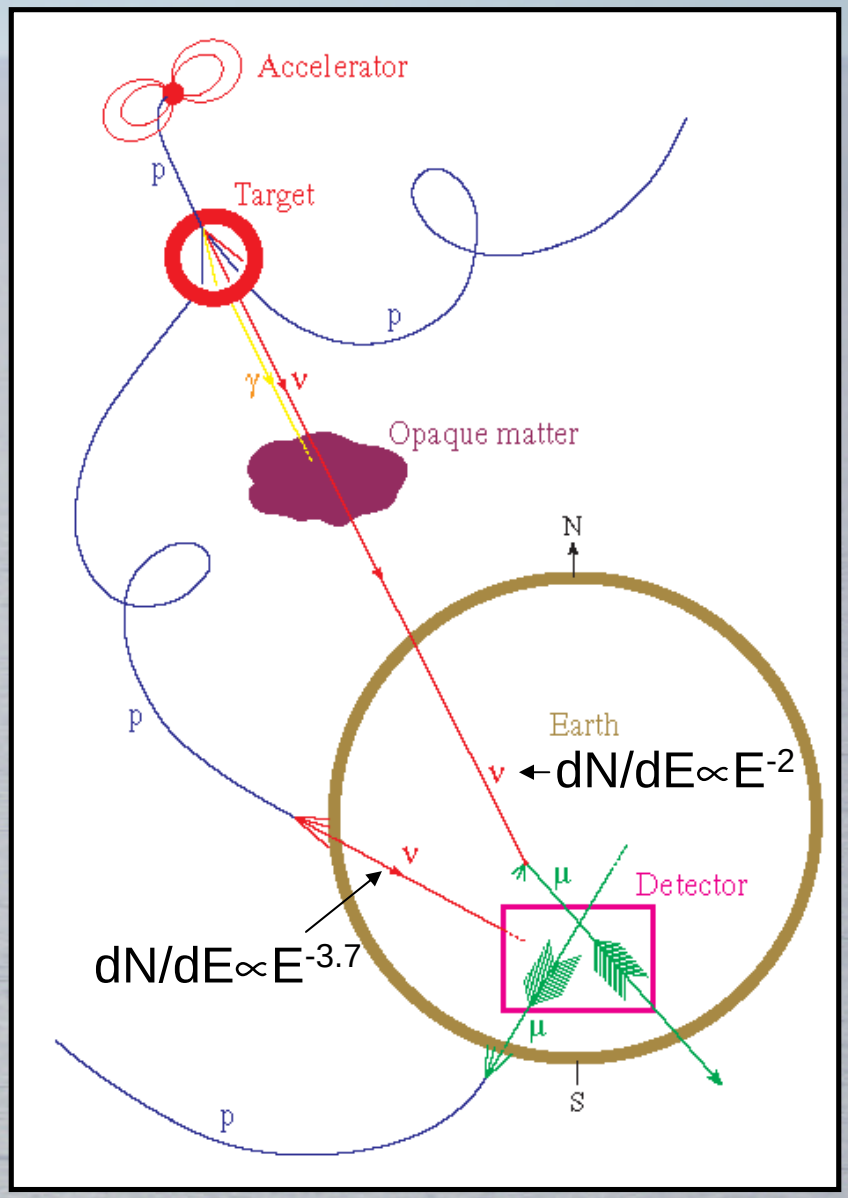
Neutrino flavors:

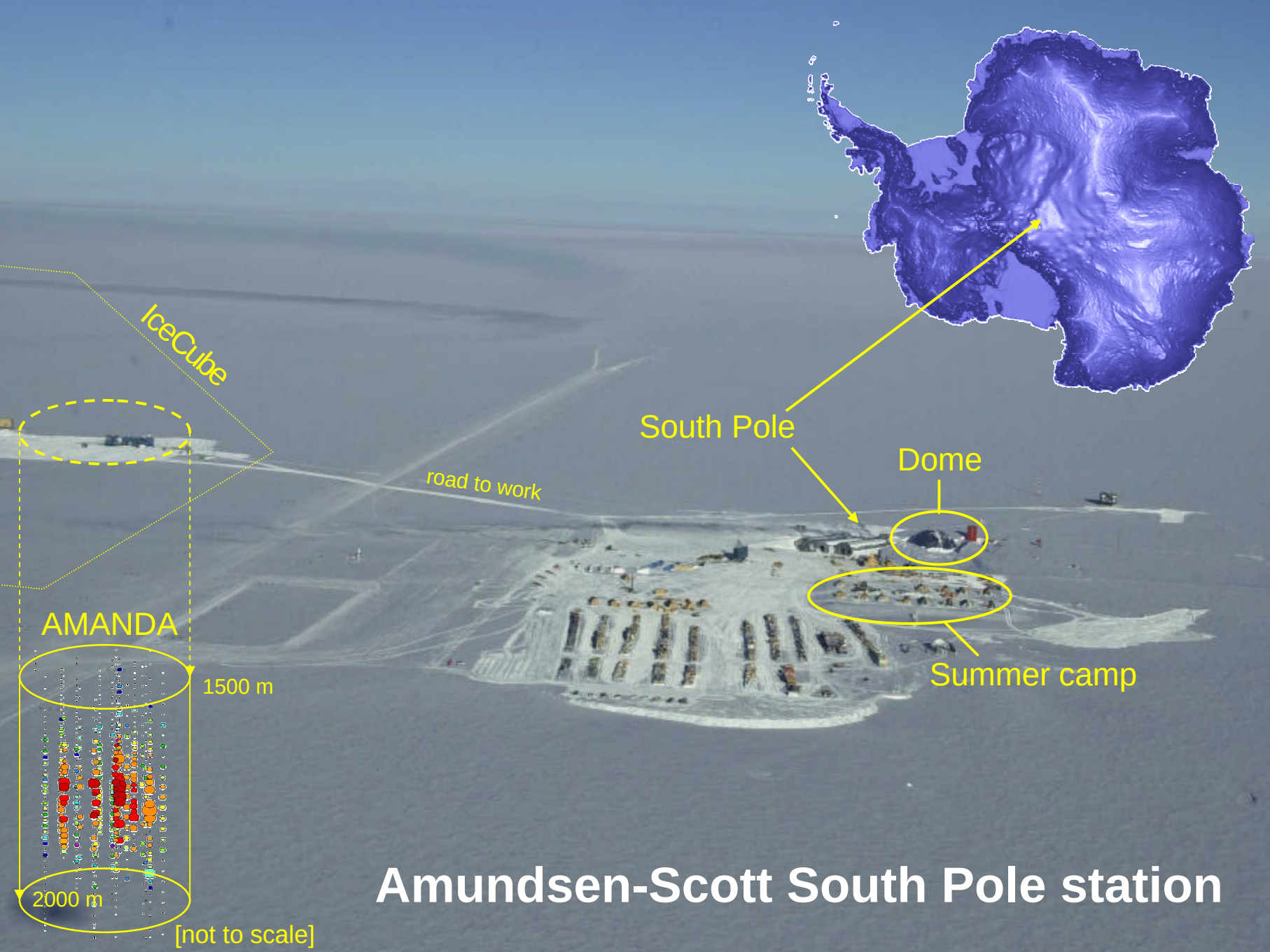
$n_e : n_m : n_t$ 1:2:~0 at source

1:1:1 at detector

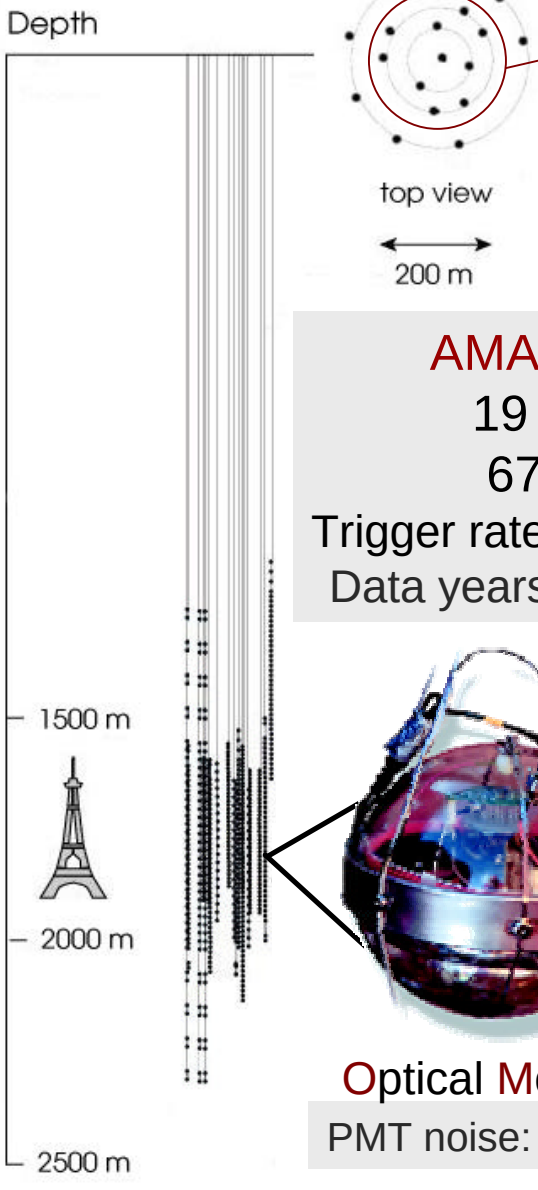
Neutrino astronomy requires large detectors

- Low extra-terrestrial neutrino fluxes
- Small cross-sections




IceCube
AMANDA
1500 m
2000 m
[not to scale]
road to work
South Pole
Dome
Summer camp
Amundsen-Scott South Pole station

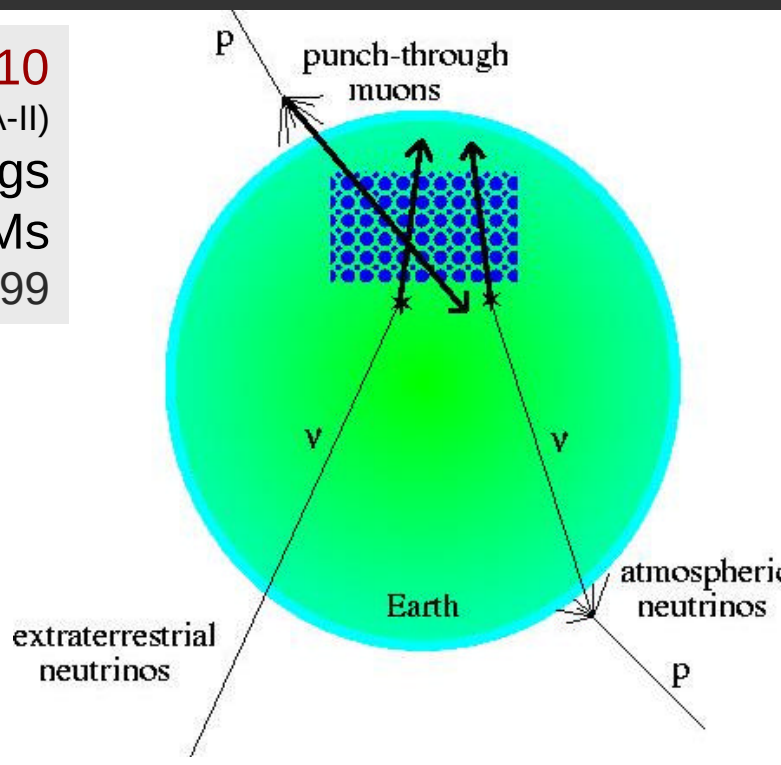
The Antarctic Muon and Neutrino Detector Array



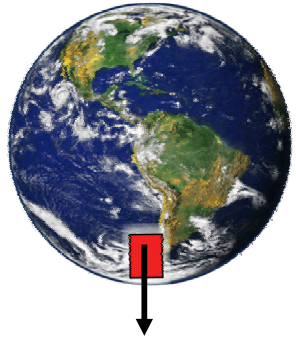
AMANDA-B10
(inner core of AMANDA-II)
10 strings
302 OMs
Data years: 1997-99

AMANDA-II
19 strings
677 OMs
Trigger rate: 80 Hz
Data years: 2000-

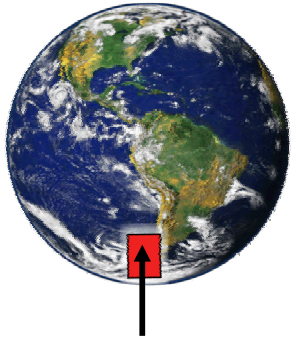
Optical Module
PMT noise: ~1 kHz



"Up-going"
(from Northern sky)



"Down-going"
(from Southern sky)

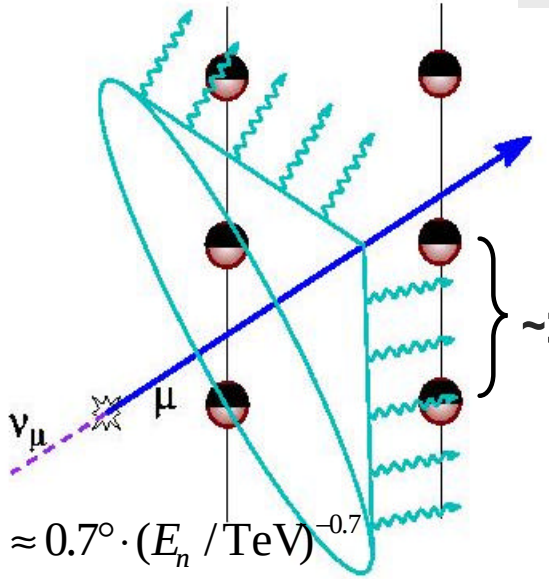


Neutrino Detection in Polar Ice

O(km) long muon tracks

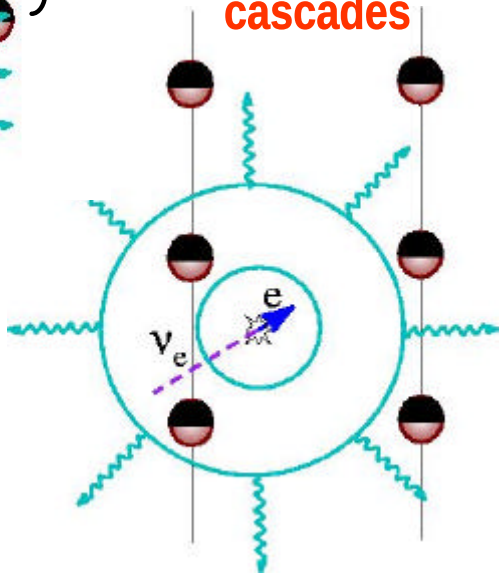
event reconstruction by Cherenkov light timing

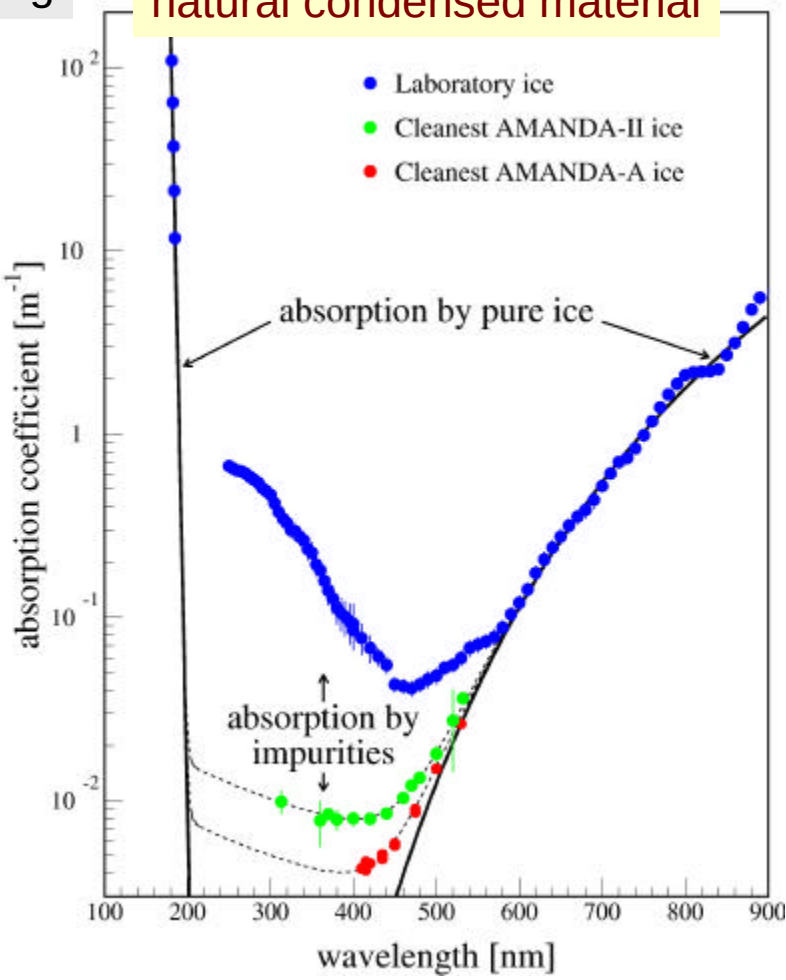
South Pole ice: (most?) transparent natural condensed material



$$\Theta_{mn} \approx 0.7^\circ \cdot (E_n / \mathrm{TeV})^{-0.7}$$

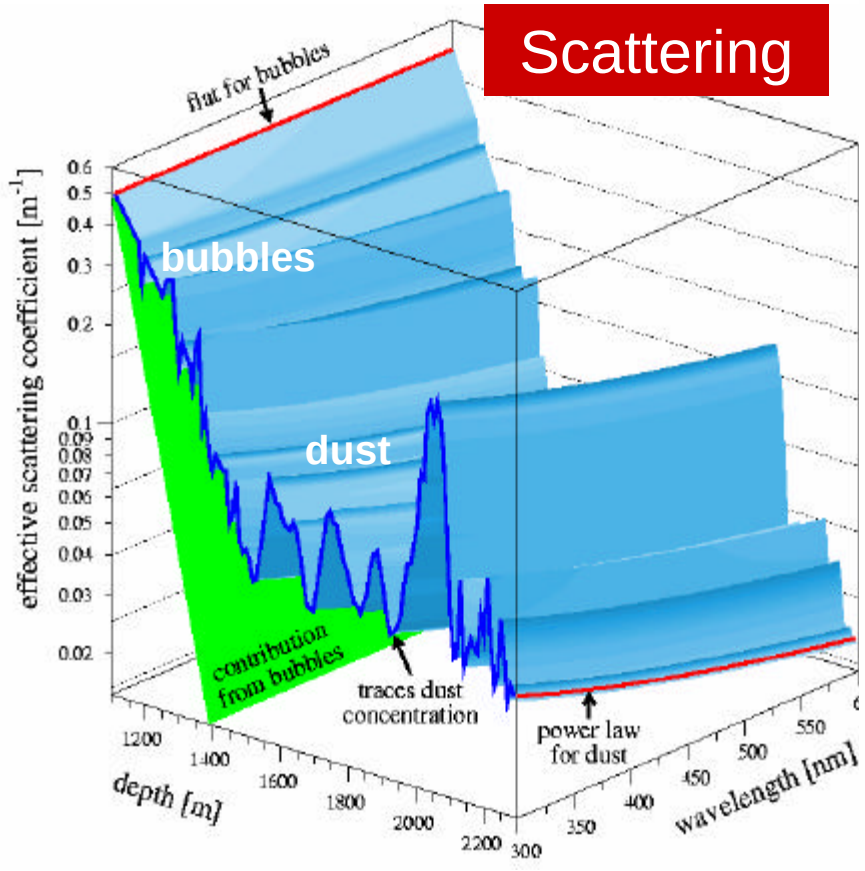
cascades

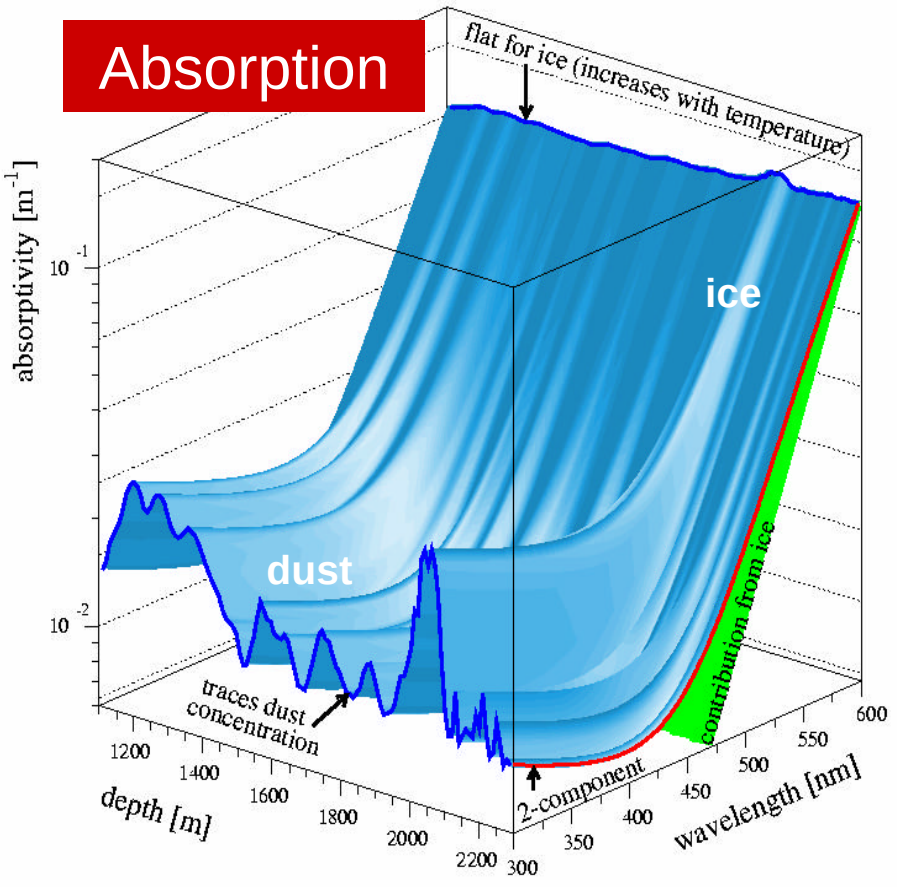




Longer absorption length ? larger effective volume

Detector medium: ice to meet you



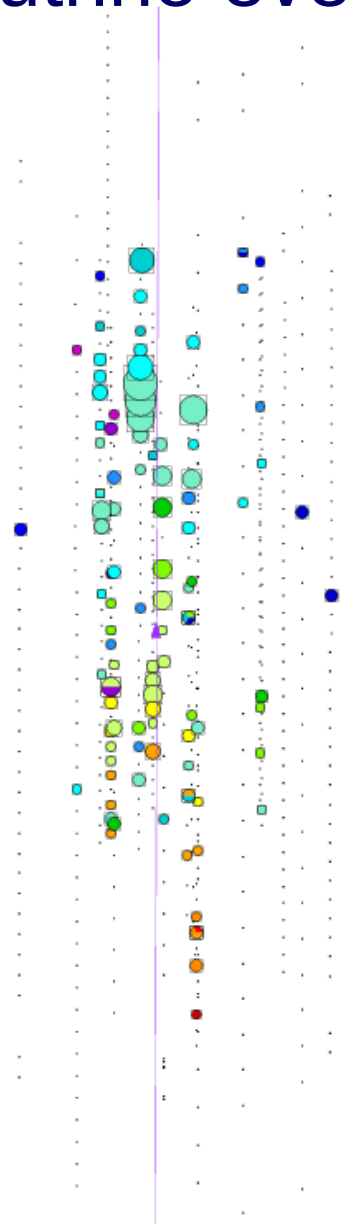


Ice properties not uniform:
vertical structure due to dust

Average optical ice parameters:

l_{abs} ~ 110 m @ 400 nm
l_{sca} ~ 20 m @ 400 nm

An up-going neutrino event in AMANDA



color = time
size = amplitude

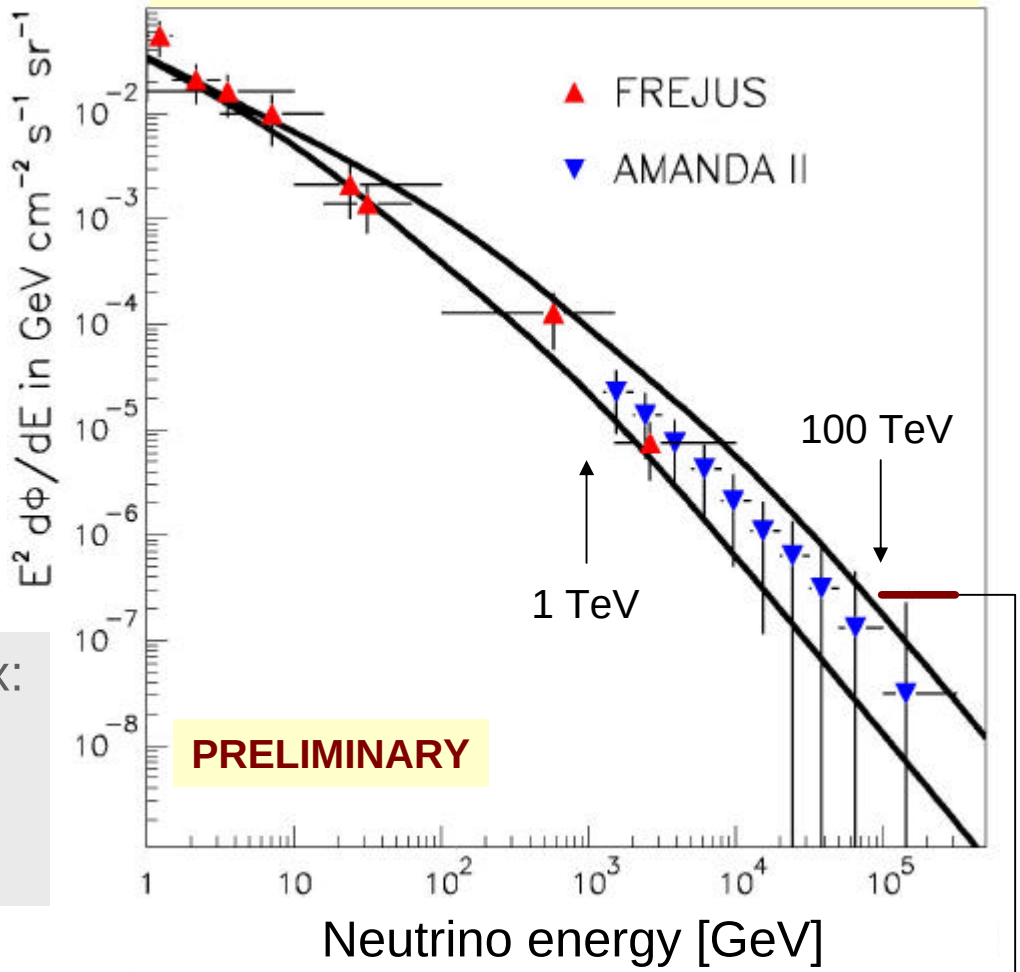
Atmospheric Neutrinos

AMANDA test beam(s): atmospheric ? (and μ)

- ? Neural Network energy reconstruction (up-going μ)
- ? Regularized unfolding
  - ? energy spectrum

Set limit on cosmic neutrino flux: How much E^{-2} cosmic ? signal allowed within uncertainty of highest energy bin?

First spectrum > 1 TeV (up to 300 TeV) - matches lower-energy Frejus data

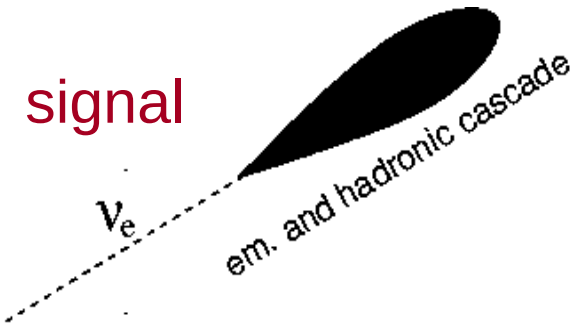


Limit on diffuse E^{-2} ?$_\mu$ flux (100-300 TeV): $\mathbf{E^2 F_{n_\mu}(E) < 2.6 \cdot 10^{-7}\ GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$

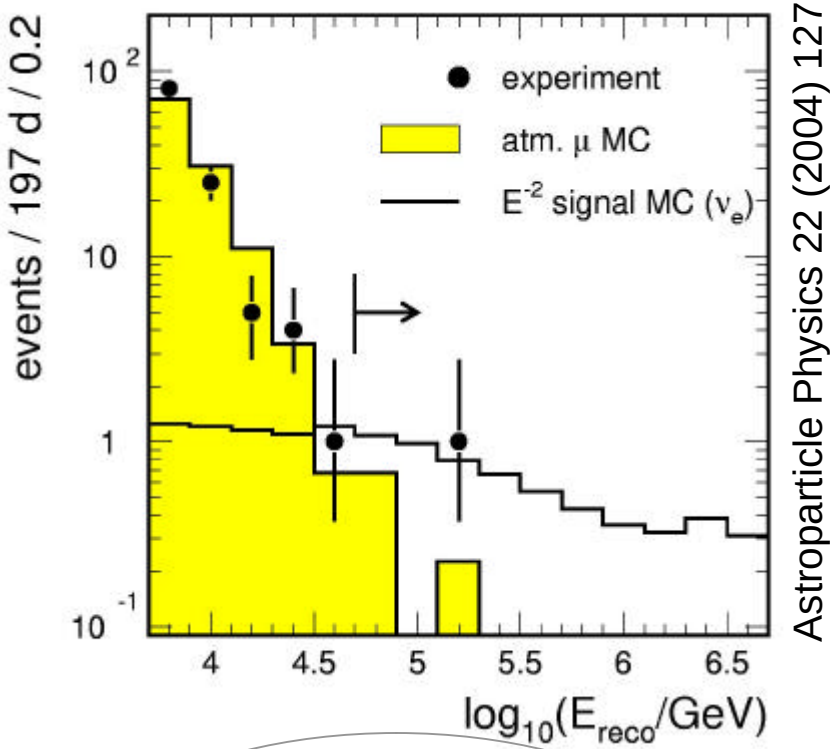
Diffuse ExtraTerrestrial Neutrino Search

Cascades: 4p coverage

signal



background

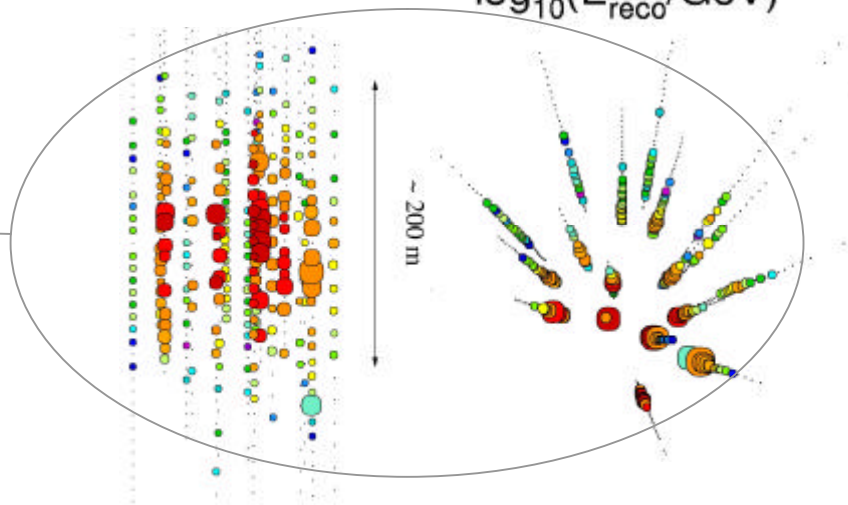


After optimized cuts:

N_{obs} = 1 event

$N_{atm\ \mu}$ = 0.90 $^{+0.69}_{-0.43}$

$N_{atm\ ?}$ = 0.06 $^{+0.09}_{-0.04}$ ± 25%$_{norm}$



Diffuse PeV-EeV Neutrino Search

Earth opaque to PeV neutrinos

? look up and close to horizon

Look for very bright events

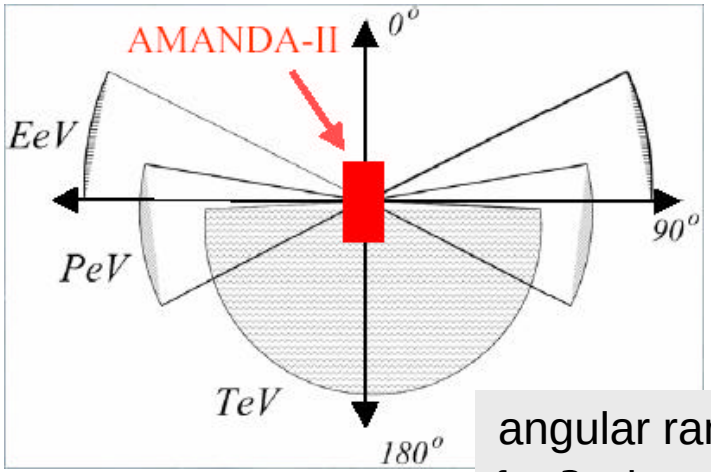
(large number of Optical Modules with hits)

Train neural network to distinguish

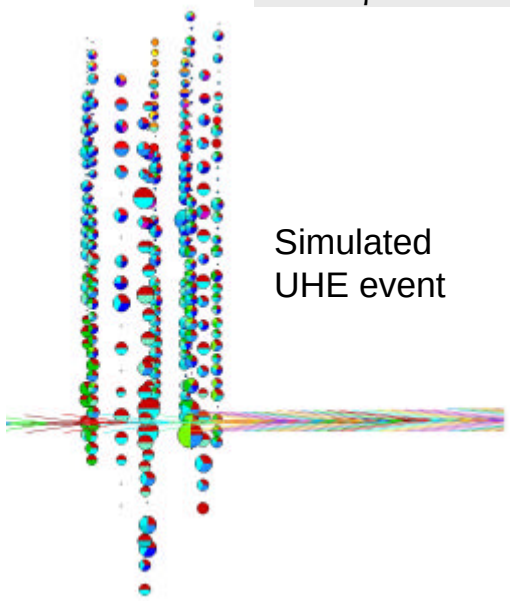
E^{-2} signal from background

N_{obs} = 5 events

N_{bgr} = 4.6 ± 36% events



angular range for $?_{\mu}$ detection

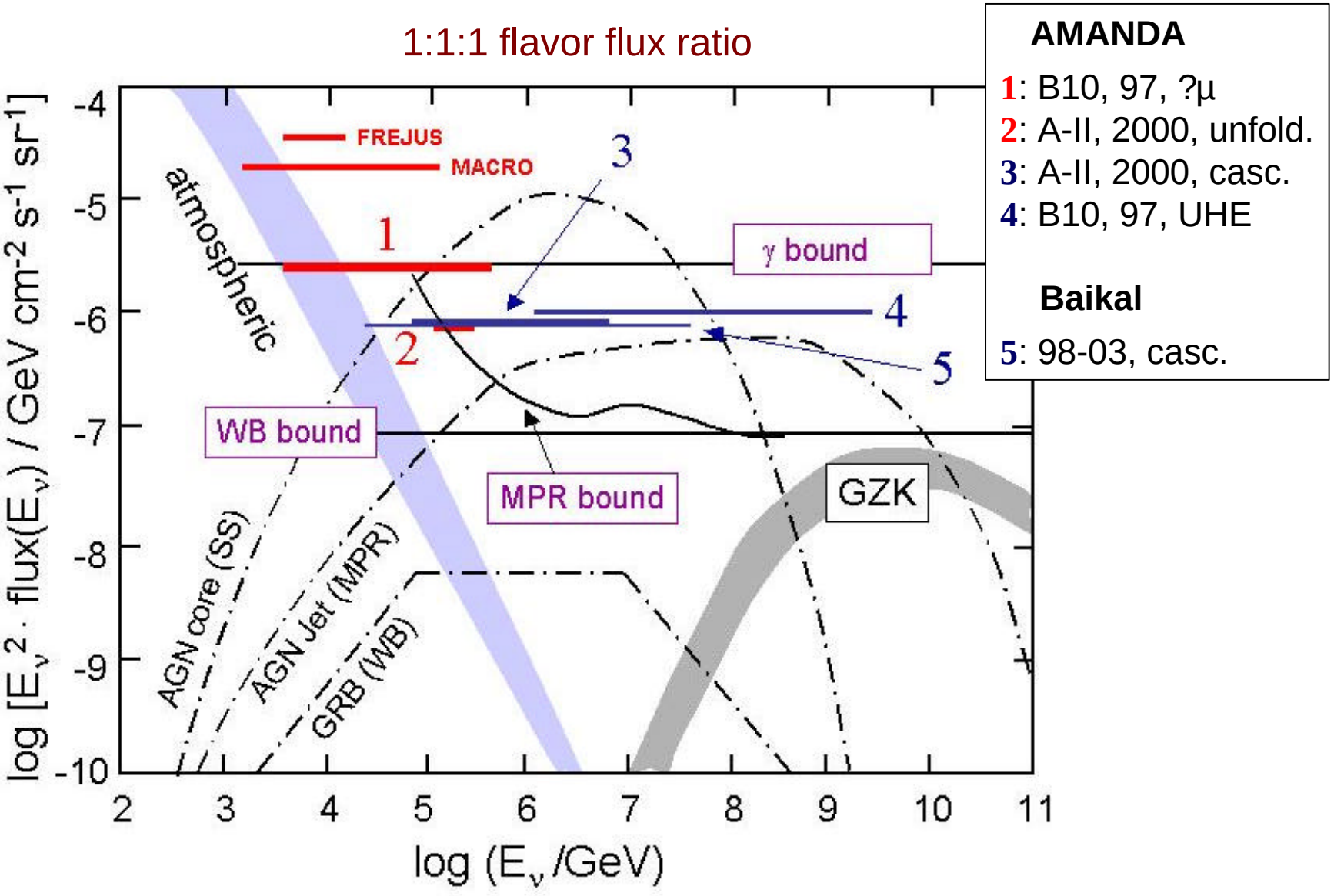


Simulated UHE event

Astroparticle Physics 22 (2005) 339

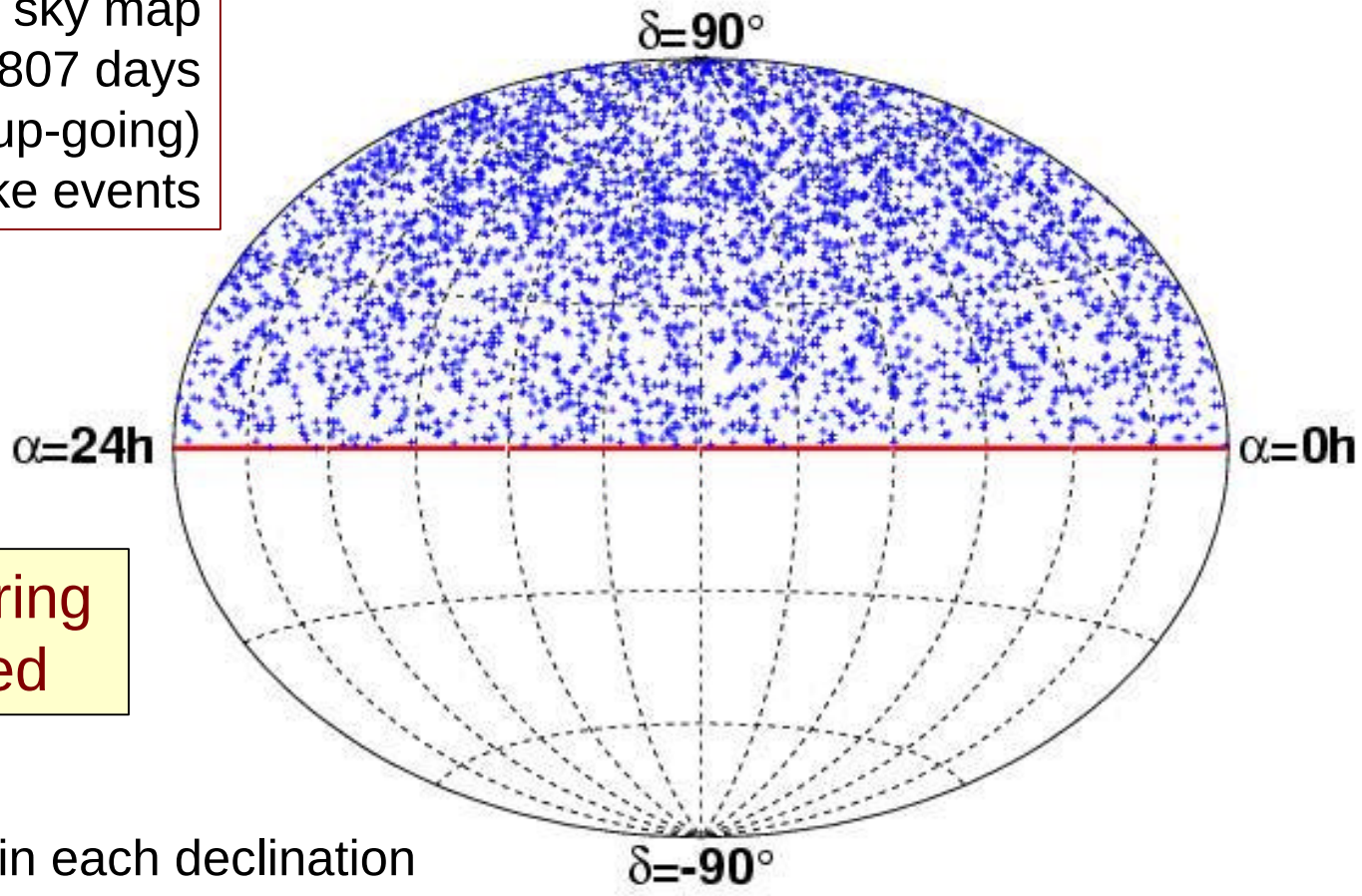
Limit on diffuse E^{-2} ? flux (1 PeV-3 EeV): **$E^2 F_{all\ n}(E) < 0.99 \cdot 10^{-6}$ GeV cm^{-2} s^{-1} sr^{-1}**

Diffuse All-Flavor Neutrino Flux Limits



Neutrino Point Source Search

2000-2003 sky map
Livetime: 807 days
3329 events (up-going)
<5% fake events



No clustering observed

Cuts optimized in each declination band assuming E^{-2} spectrum

No evidence for point sources with an E^{-2} energy spectrum

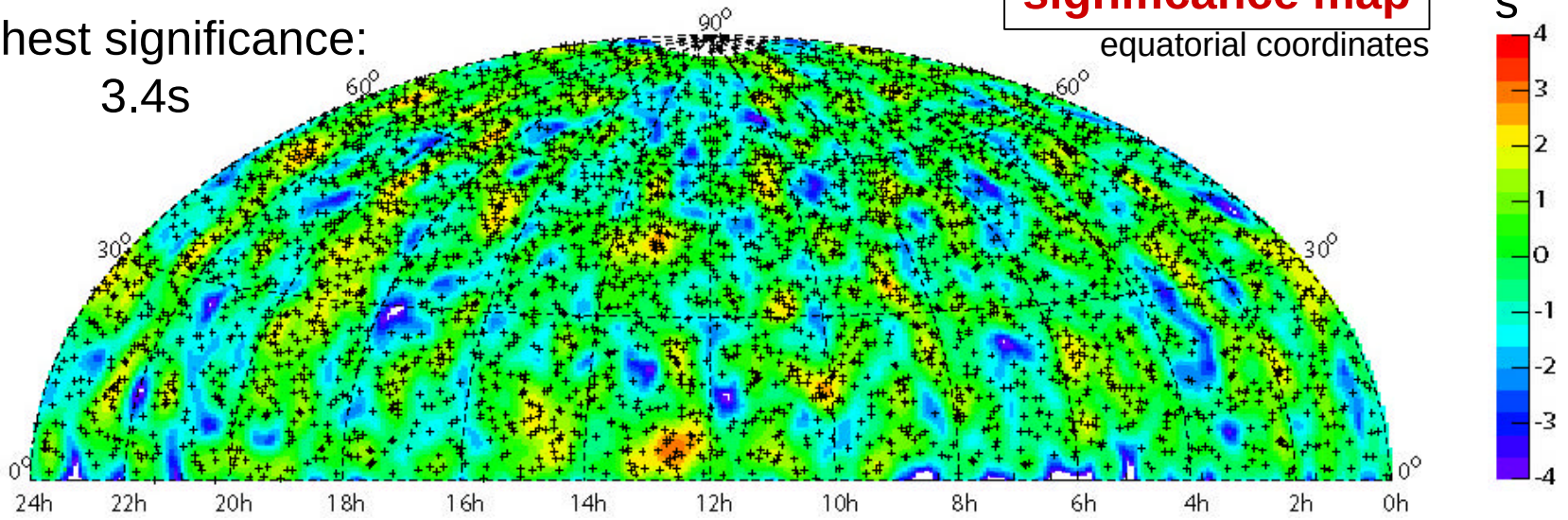
Consistent with atmospheric ?

“Hot Spot” Search

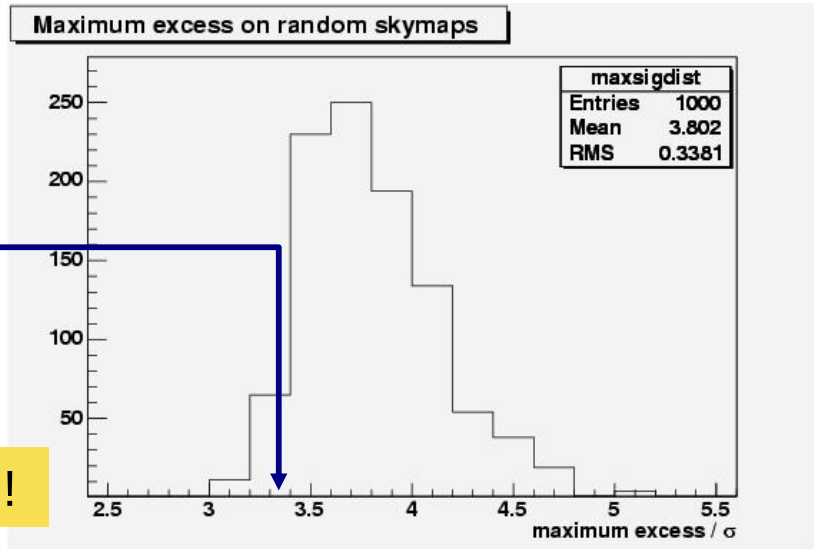
AMANDA 2000-2003

Highest significance:
3.4s

significance map
equatorial coordinates

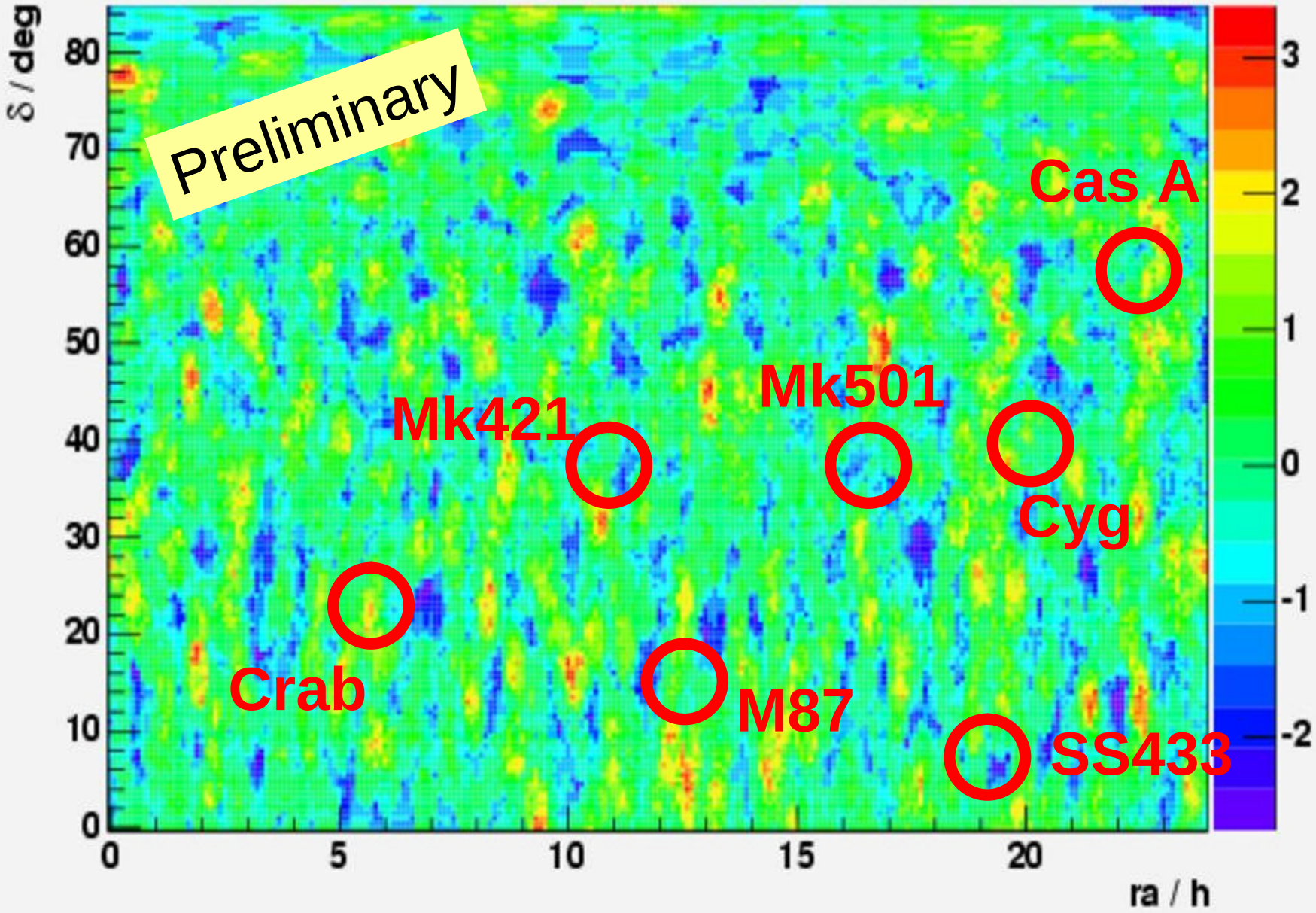


Assess statistical significance using random sky maps



No statistically significant hot spots !

Significance Map for 2000-2003



Round Up the Usual Suspects

Search for high energy neutrino excess from known gamma emitting sources

Usual suspect	z	Luminosity distance	$N_{observed}$	N_{back}
1ES 1959+650	0.047	219 Mpc	5	3.71
Markarian 421	0.03	140 Mpc	6	5.58
QSO 1633+382	1.8	14000 Mpc	4	5.58
QSO 0219+428	0.44	2600 Mpc	4	4.31
CRAB		1.9 kpc	10	5.36

TeV Blazars

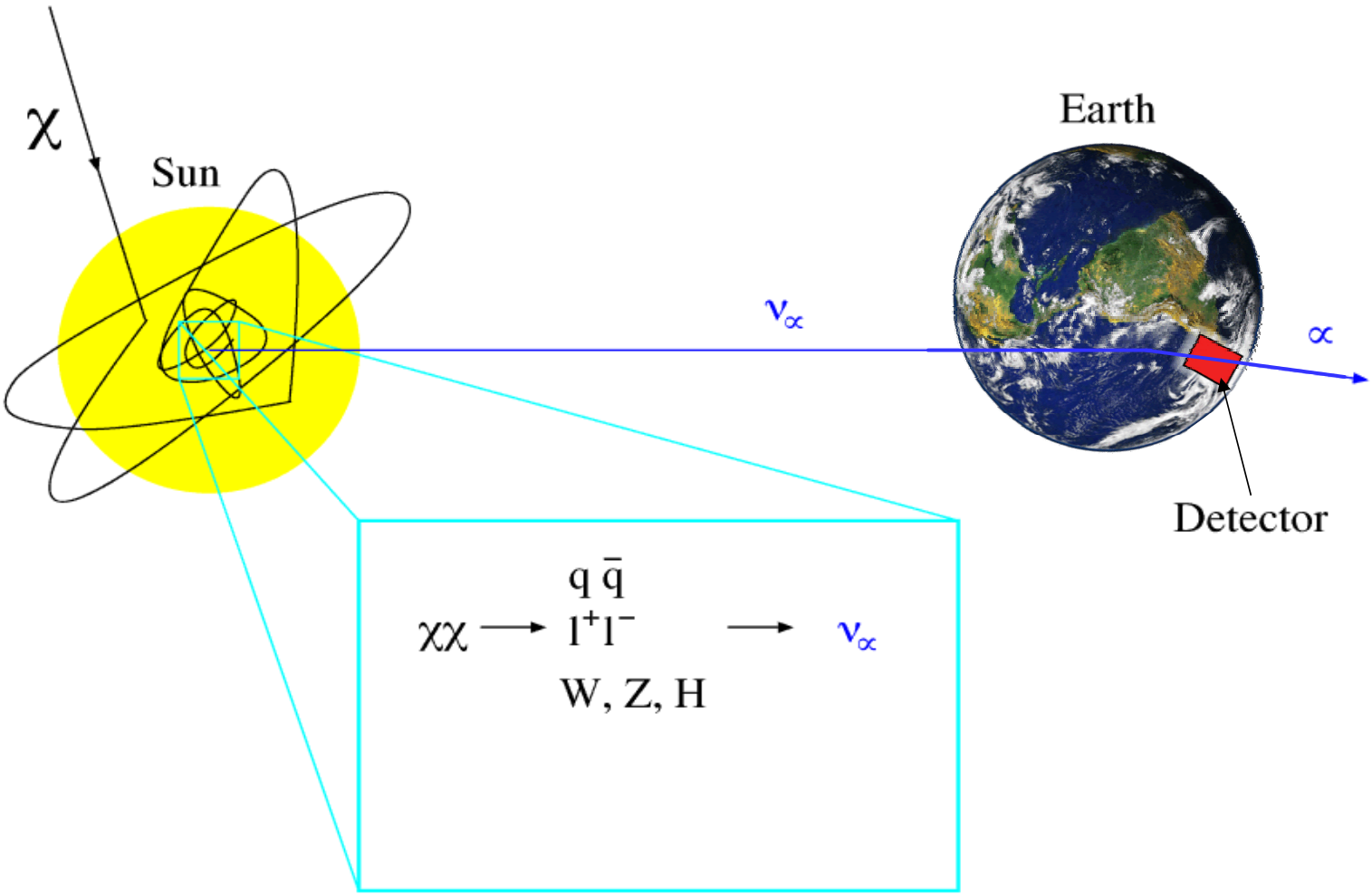
GeV Blazars

Supernova Remnant

No Statistically Significant Excess from 33 Targeted Objects

Indirect Dark Matter Search

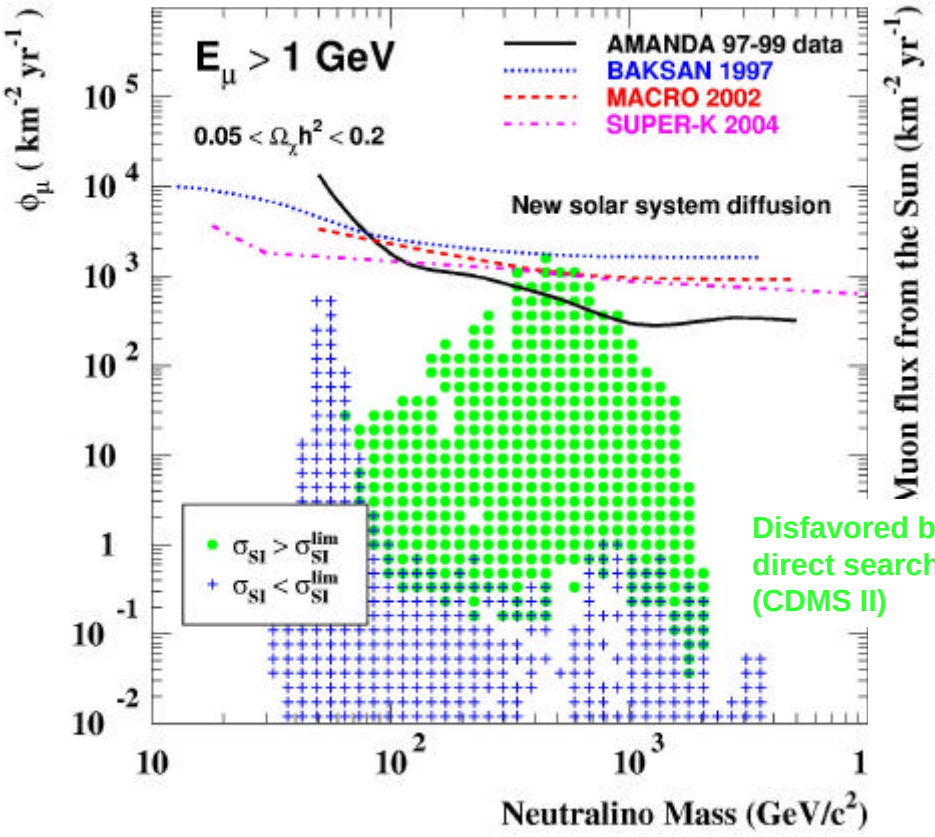
Sensitivity to muon flux from neutralino annihilations in the Sun or the center of the Earth



Indirect Dark Matter Search

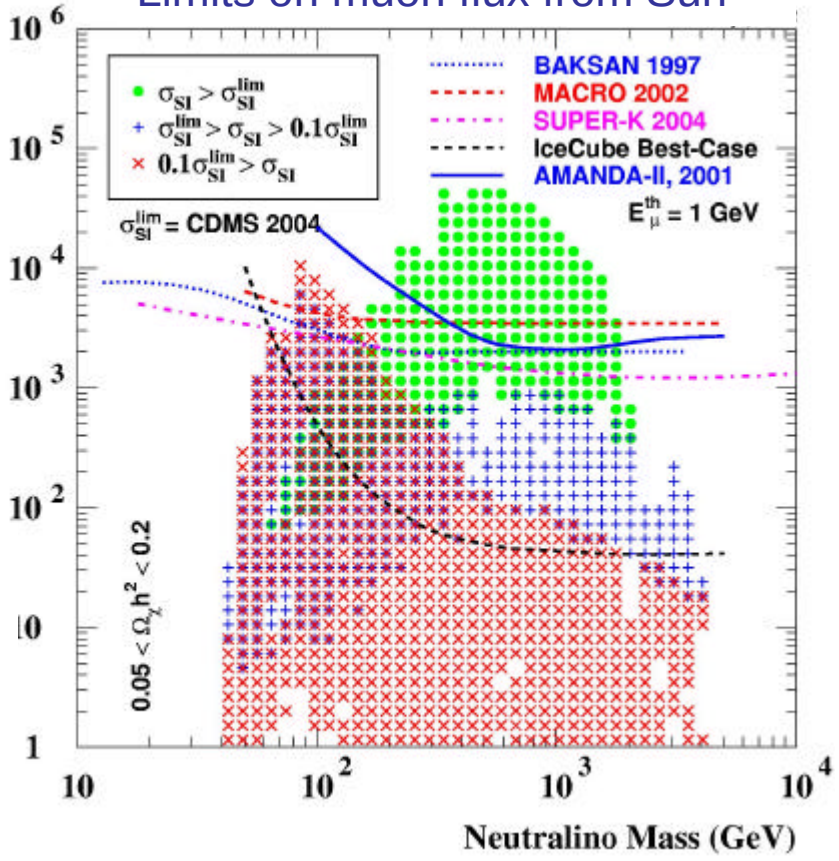
PRELIMINARY

Limits on muon flux from Earth center



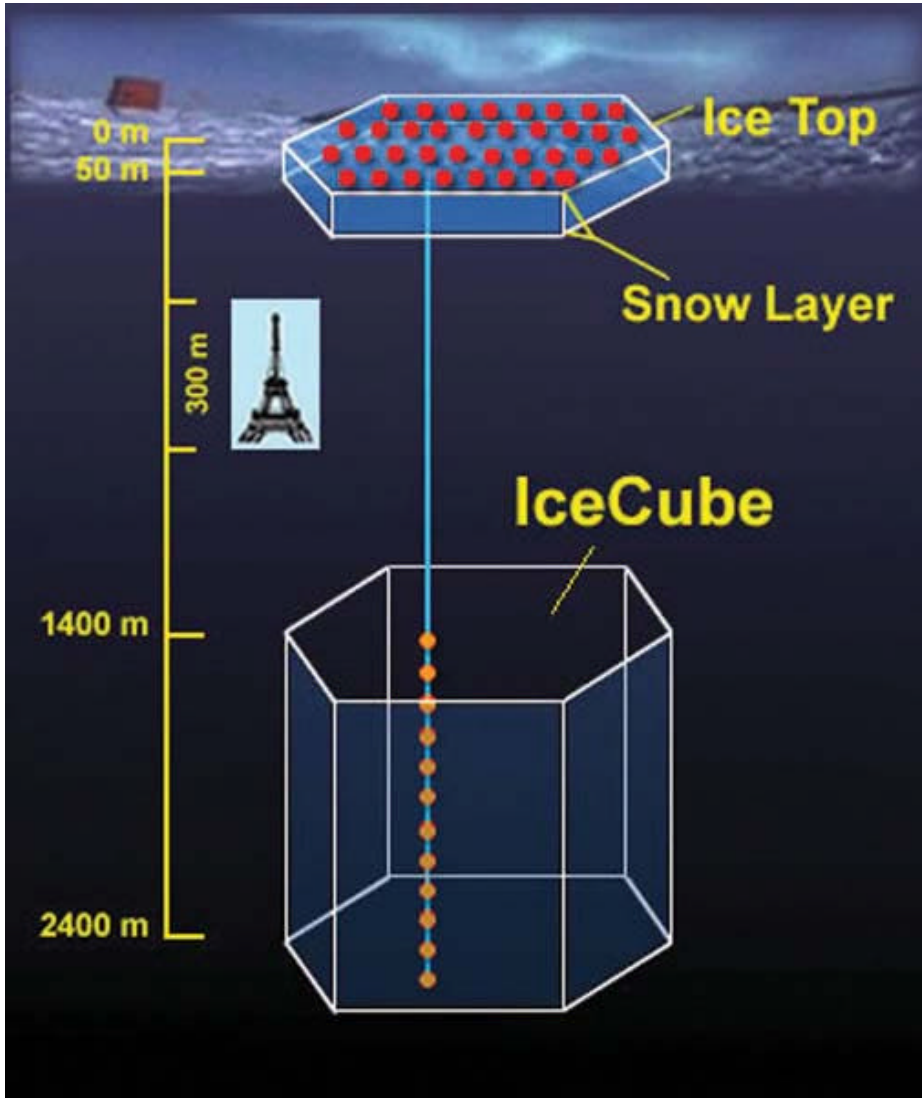
Disfavored by direct search (CDMS II)

Limits on muon flux from Sun



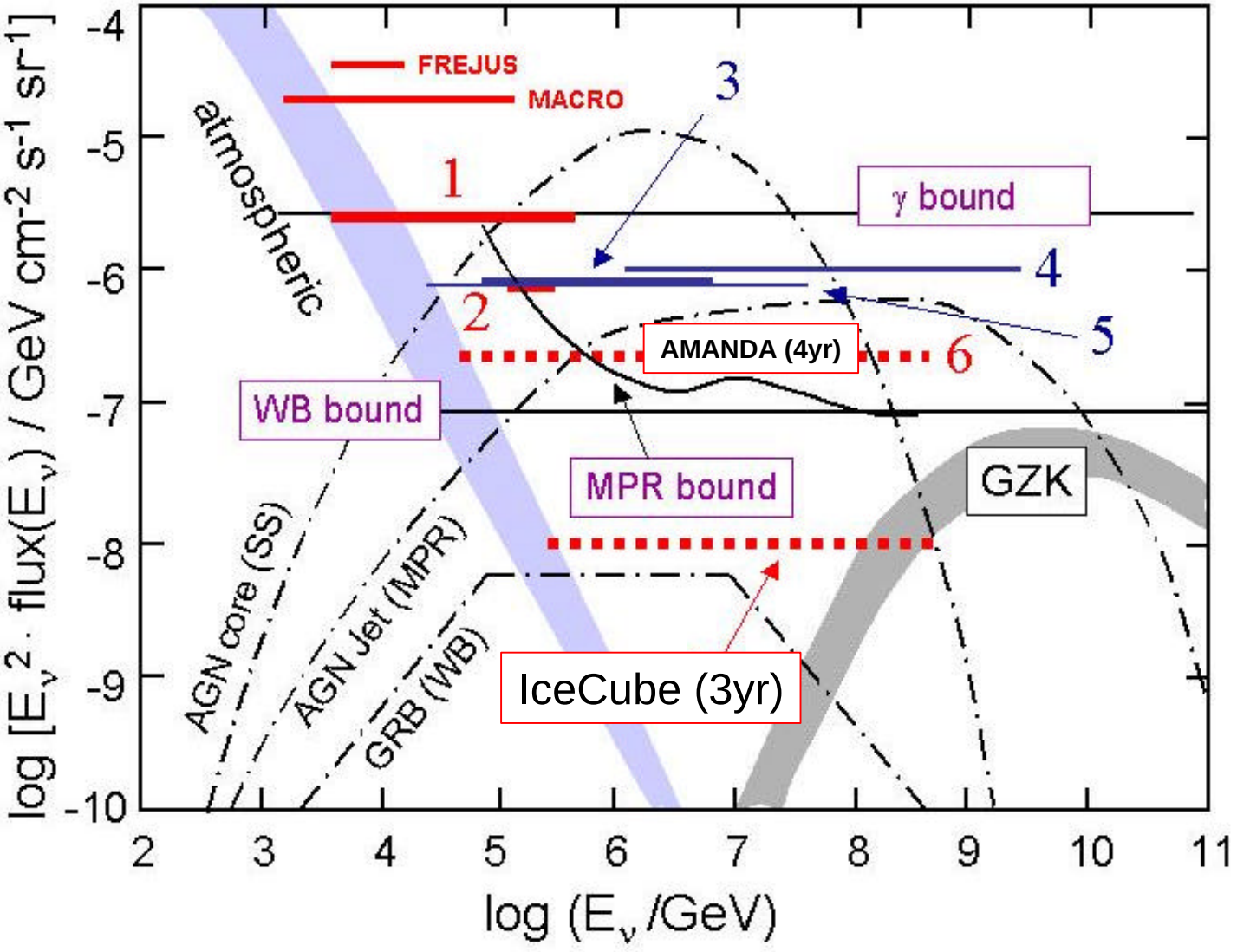
The Next Generation: IceCube

- 80 strings with 60 optical modules (OMs) on each
- Effective Volume ~ 1 km^3
  - Size required to see "guaranteed" neutrino sources
- Geometry optimized for TeV-PeV (EeV) neutrinos
  - 17 m OM spacing
  - 125 between strings
- Surface Array (IceTop)
- PMT signal digitization in ice

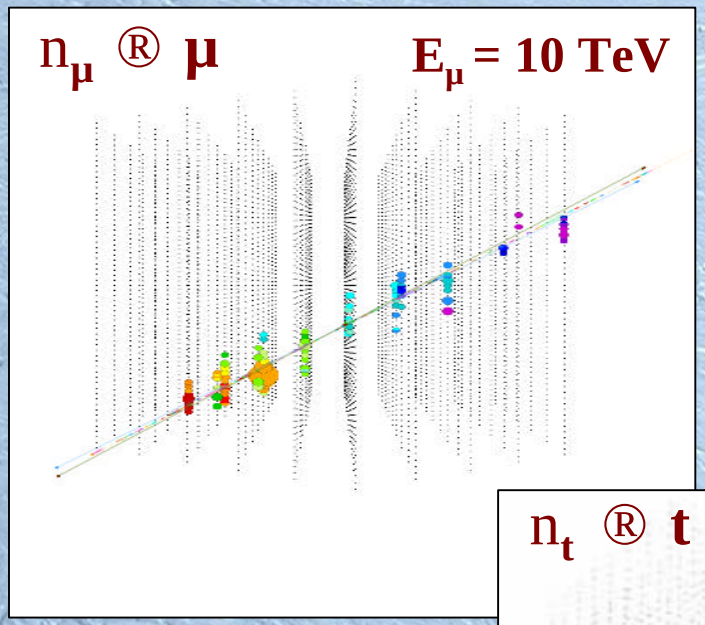


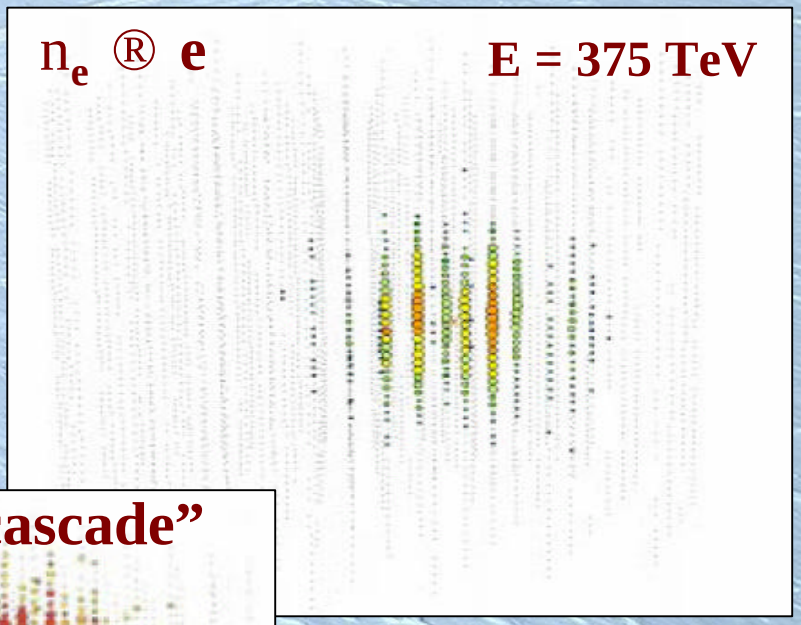
IceCube Sensitivity

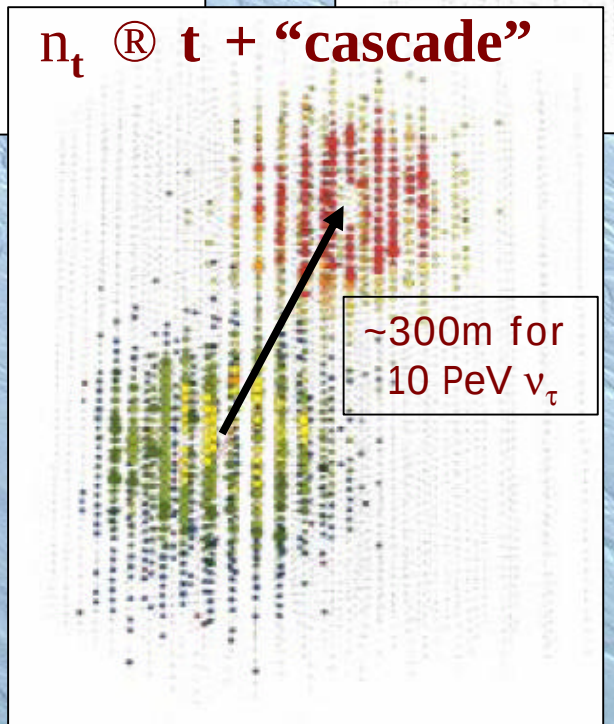
1:1:1 flavor flux ratio



IceCube All-Flavor Neutrino Detection



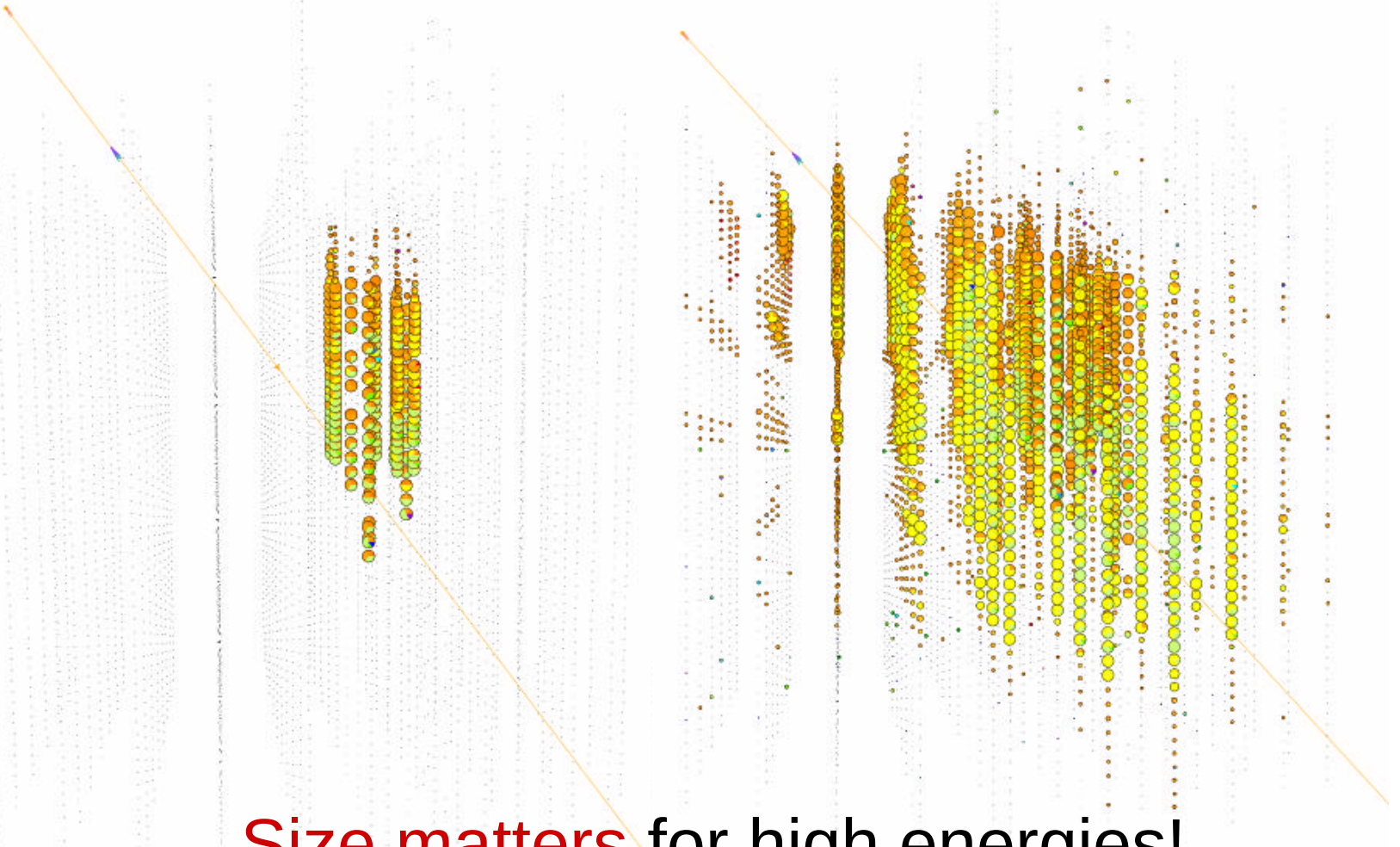




Simulated 2×10^{19} eV neutrino event

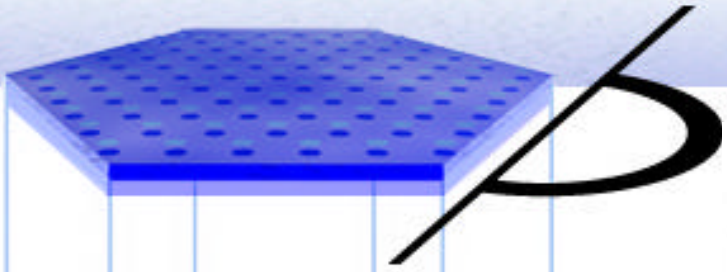
in AMANDA

in IceCube



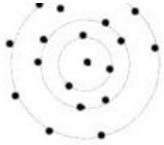
Size matters for high energies!

How large is IceCube?



AMANDA-II

Depth

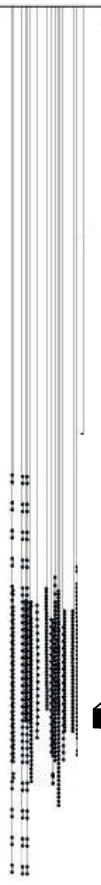


top view

200 m

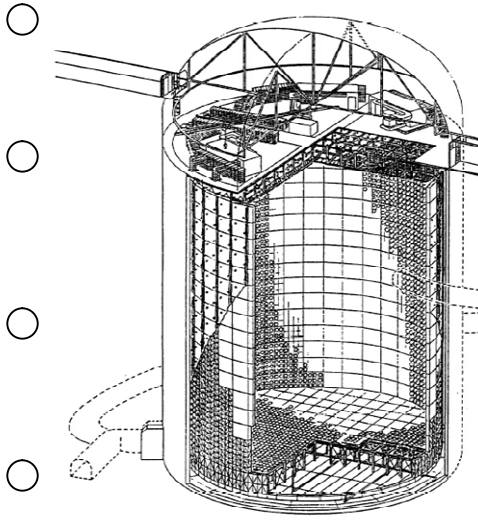
1450 m

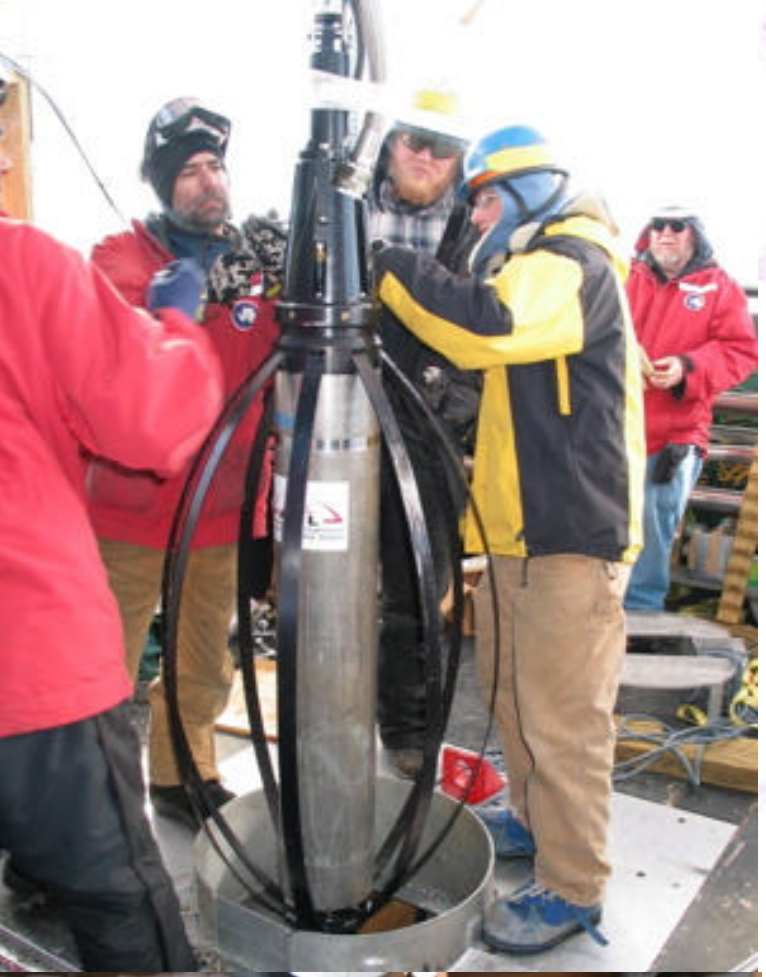
2450 m



50 m

Super K





January 2005:

First string deployed!

60 optical modules

Deepest module at 2450 m

Conclusions

No extraterrestrial ? signal observed…yet

- Limits (TeV-EeV) on diffuse ET neutrino flux
- Point source searches:
  - No statistically significant hot spots
  - No evidence for high-energy neutrino emission from gamma emitting objects

IceCube is under construction

- 2-3 orders of magnitude increase in sensitivity
- Higher energies
- All flavors

The AMANDA Collaboration

United States

Bartol Research Institute
UC Berkeley
UC Irvine
Pennsylvania State
UW Madison
UW River Falls
LBNL Berkeley

Europe

VUB-IIHE, Brussel
ULB-IIHE, Bruxelles
Université de Mons-Hainaut
Imperial College, London
DESY, Zeuthen

Mainz Universität
Wuppertal Universität
Universität Dortmund
Stockholms Universitet
Uppsala Universitet
Kalmar Universitet

Antarctica

South Pole Station

~150 members