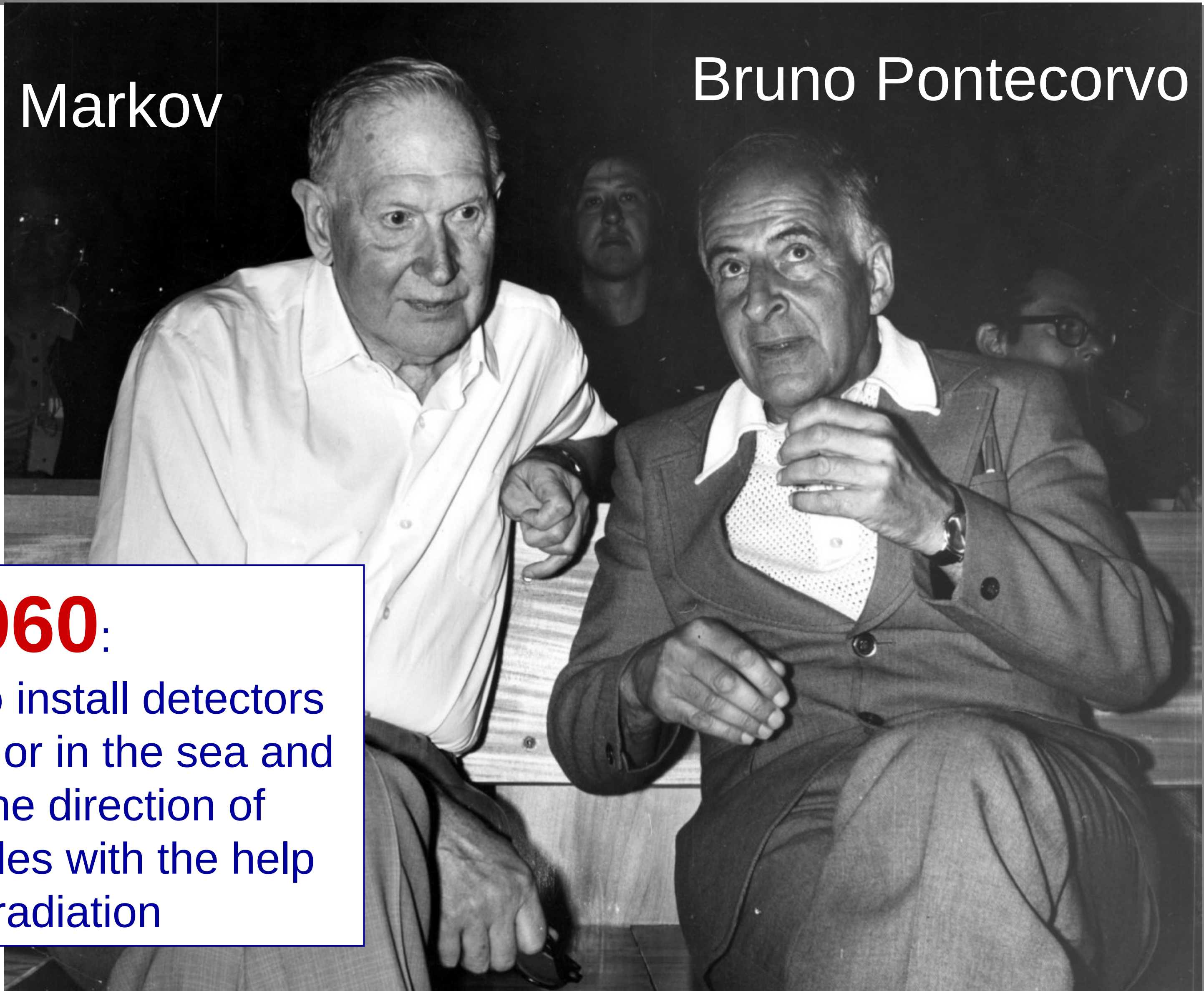
High Energy Neutrino Astronomy from infancy to maturity

LAUNCH Meeting
Heidelberg
Christian Spiering
DESY

High Energy Neutrino Astronomy from infancy to maturity

technological

The idea

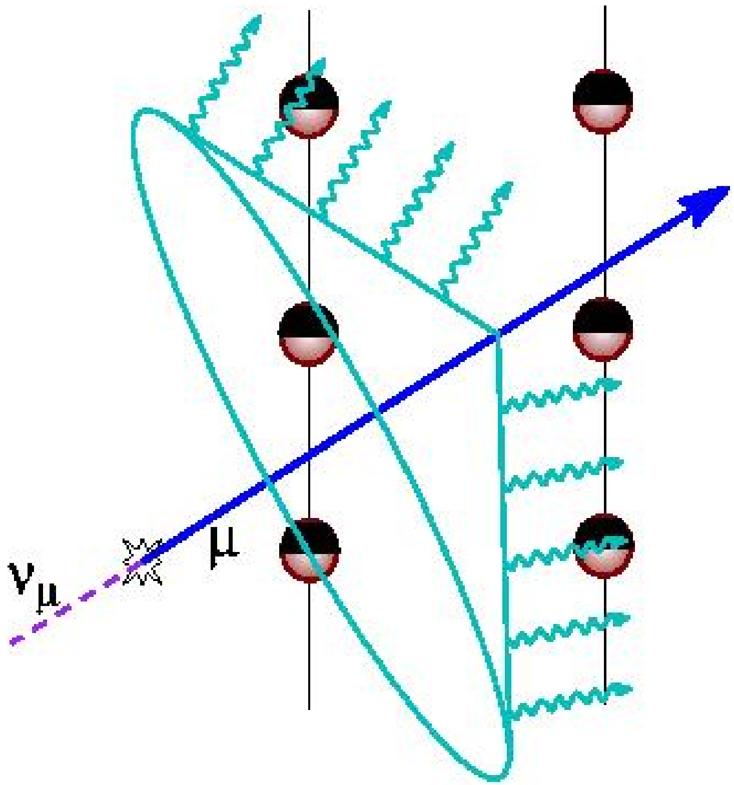


M.Markov, **1960**:

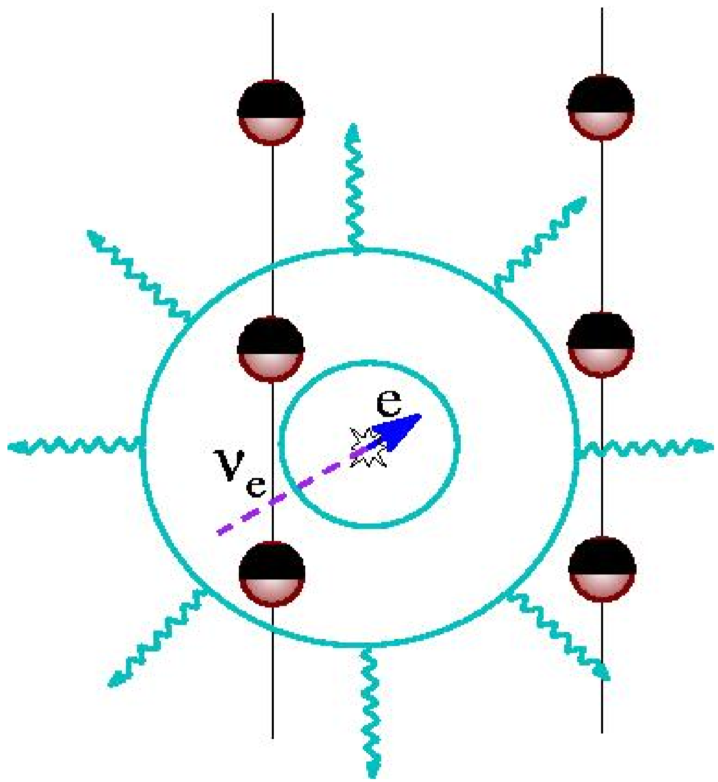
We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation

The detection principle

muon tracks



cascades



Why neutrinos ?

$$p + p \rightarrow \pi + \ldots.$$
$$\quad \hookrightarrow \mu + \nu_\mu$$
$$\qquad \hookrightarrow e + \nu_e + \nu_\mu$$

- **Travel straight** (in contrast to CR)
- **Are not absorbed by IR or CMB** (in contrast to gammas and CR)
- **Clear signature of hadronic nature**

$$p + \gamma \rightarrow n + \pi^+ \quad \textbf{or} \quad \rightarrow p + \pi^0$$
$$\hookrightarrow \mu + \nu \qquad\qquad \hookrightarrow \gamma + \gamma$$

$\nu_e : \nu_\mu : \nu_\tau$ ~ 1:2:0 changes to (typically) 1:1:1 at Earth

Challenges

- **Low interaction cross section**
- **Need huge detection volumes**
- **Actual neutrino flux depends on target thickness**
  - Predictions 25 years ago have been up to two orders of magnitude higher than today
  - 1990s: recognize need of cubic kilometer detectors
  - Now: cubic kilometer detectors will possibly just scratch the interesting range

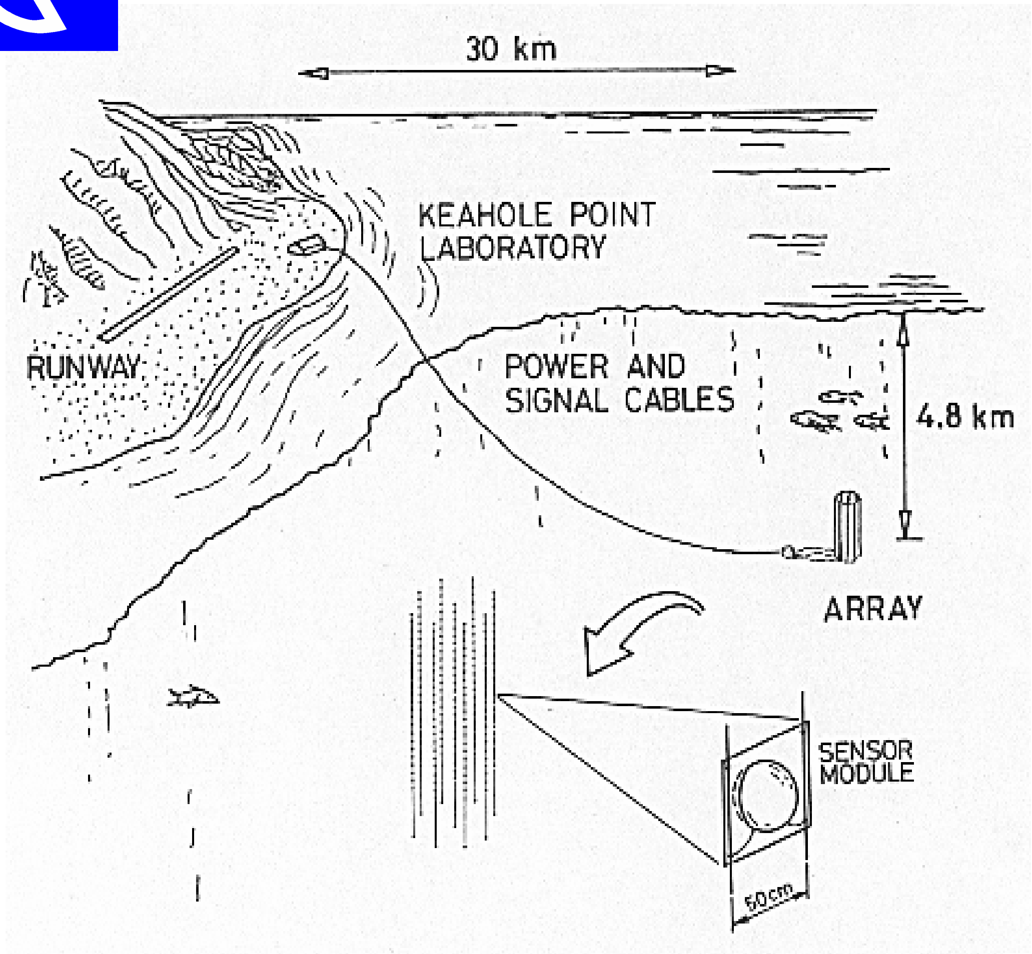
Challenges

- **Low interaction cross section**
- **Need huge detection volumes**
- **Actual neutrino flux depend… …et thickness**
  - Predictions 25… …up to two orders… …than today
  - …eed of cubic kilometer
  - …ow: cubic kilometer detectors will possibly just scratch the interesting range

Martin Harwitt: „Would one have believed the **timid predictions** of theoreticians, X-ray astronomy would likely have started only a decade later.“

Pioneering DUMAND

~ 1975: first meetings towards an underwater array close to Hawaii

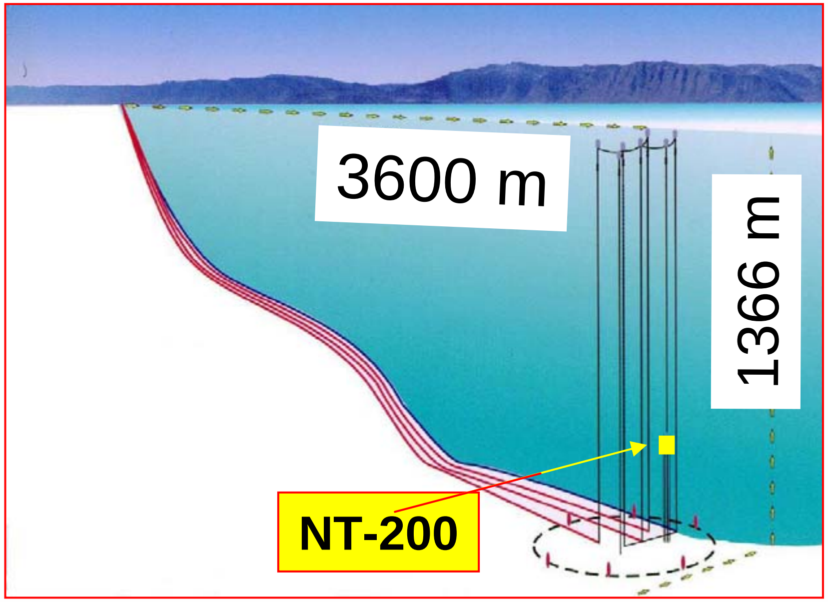


Test string 1987

Proposal 1988:
The „Octagon“
(~ 1/3 AMANDA)

Termination 1996

Pioneering Baikal

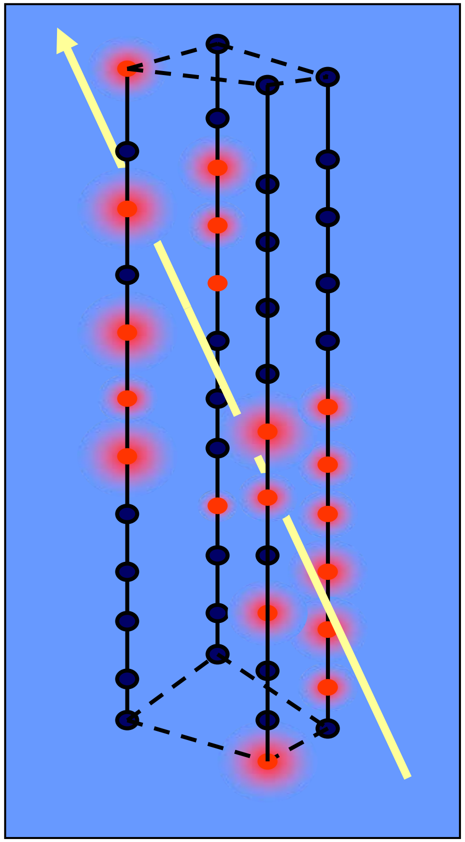


- 1981 first site explorations
- 1984 first stationary string
- 1993 first neutrino detector NT-36
- 1994 first atm. Neutrino separated
- 1998 NT-200 finished

Ice as natural deployment platform

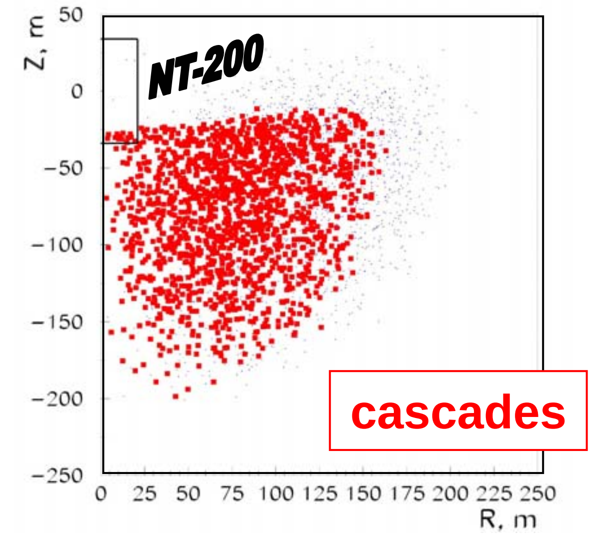

ОСТОРОЖНО СТЕКЛО

Pioneering Baikal



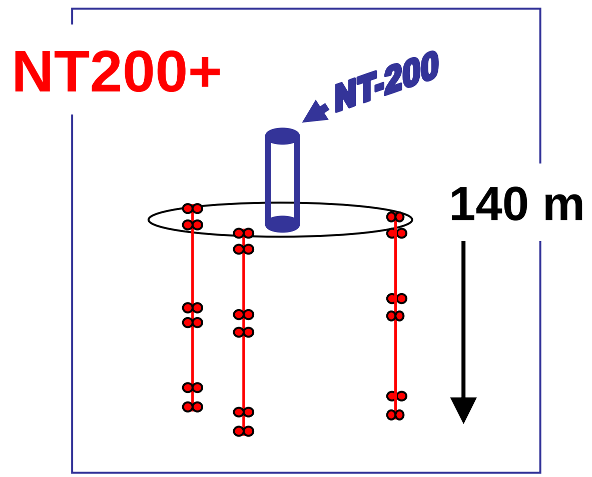
A textbook neutrino
4-string stage (1996)

Detection of high energy cascades outside the instrumented volume



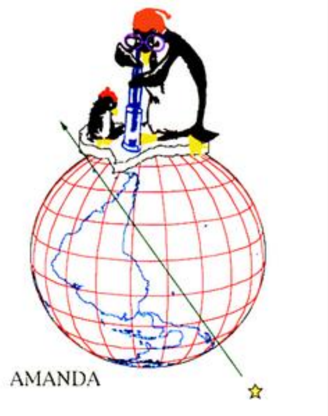
Fence the observation volume with a few PMTs

→ 4 times better sensitivity at high energies



NT200+ running since 2006

AMANDA

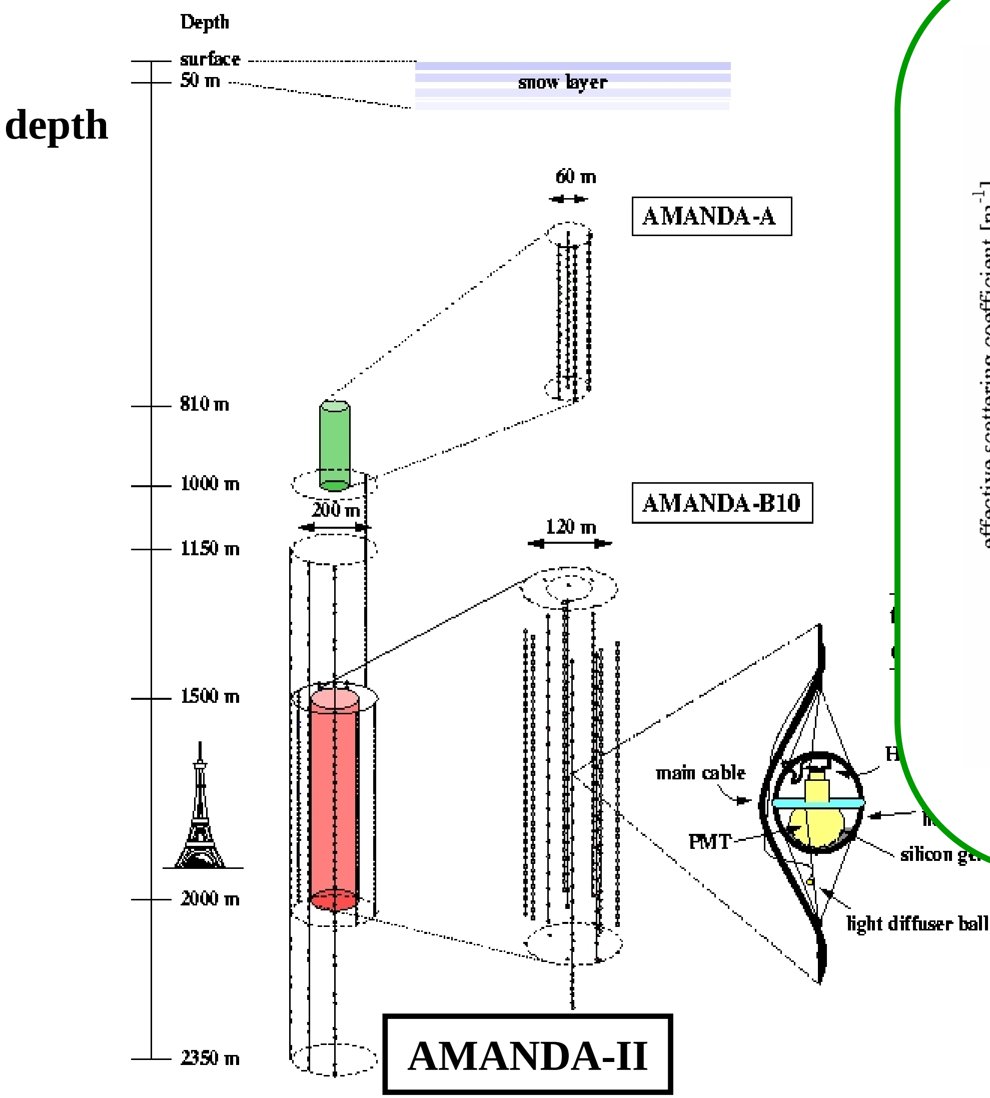


- 1990: first site studies at South Pole
- 1993/94 shallow detectors in bubbly ice
- 1997: 10 strings (AMANDA-B10)
- 2000: AMANDA-II

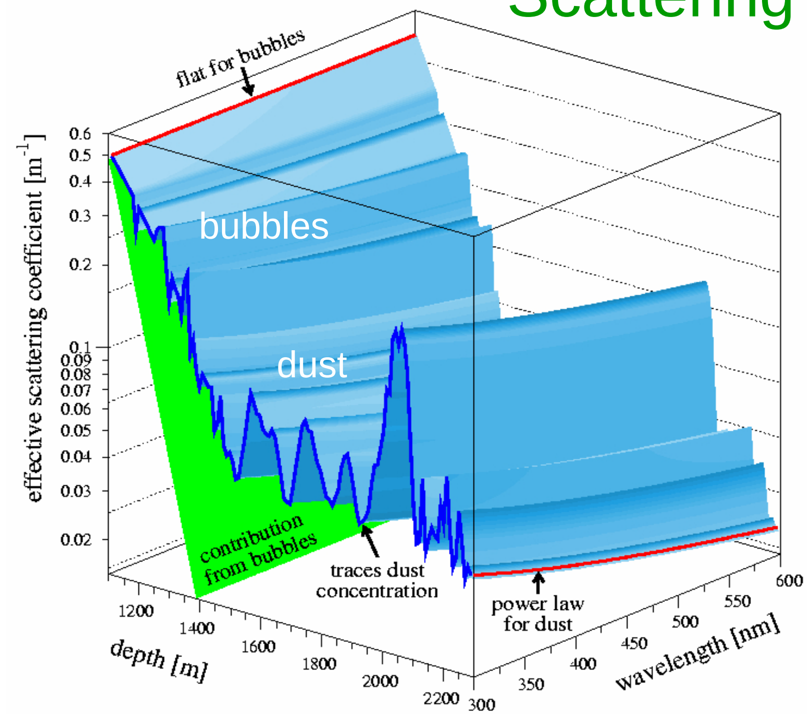
AMANDA

Hot water drilling

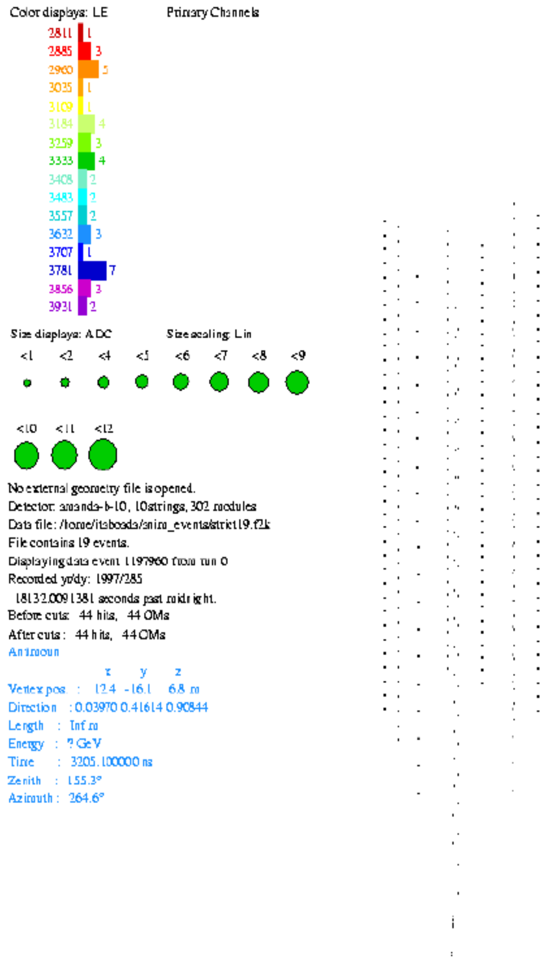
AMANDA



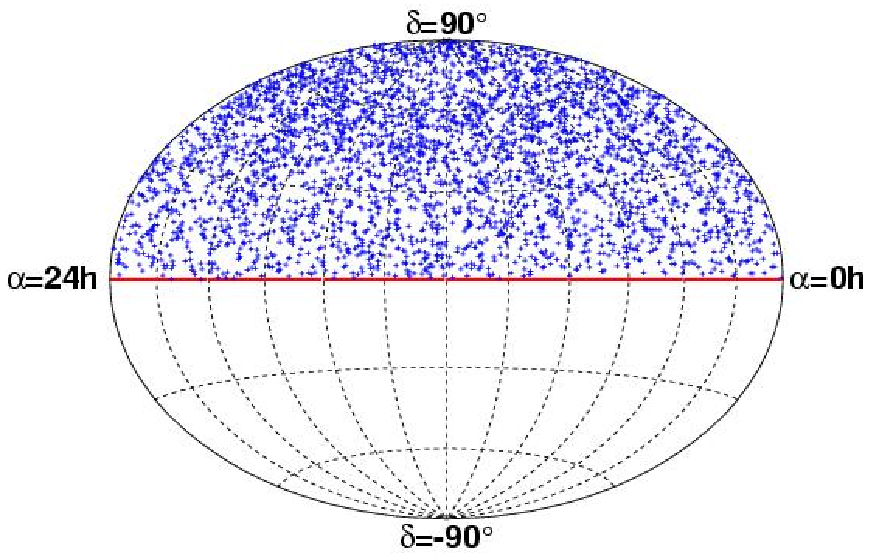
Scattering



AMANDA



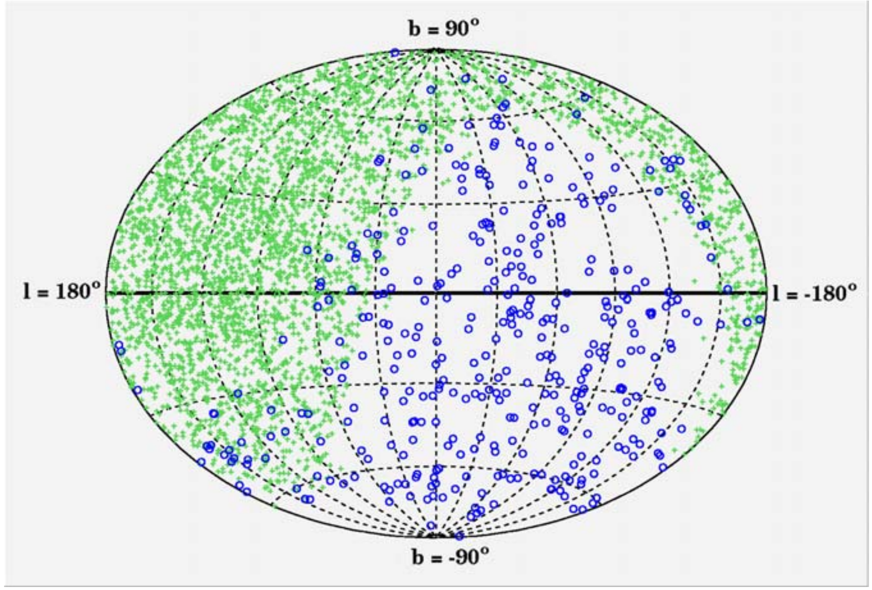
$$\nu_\mu + N \rightarrow \mu + X$$



AMANDA sykplot 2000-2003
3329 events below horizon

more on point sources
in the following talk

South and North



AMANDA & Baikal skyplot, galactic coordinates

Parameters of neutrino telescopes

Effective ν area:

- ~ 0.1 m² @ 10 TeV
- ~ 1 m² @ 100 TeV

} AMANDA, ANTARES

- ~ 100 m² @ 100 TeV — IceCube

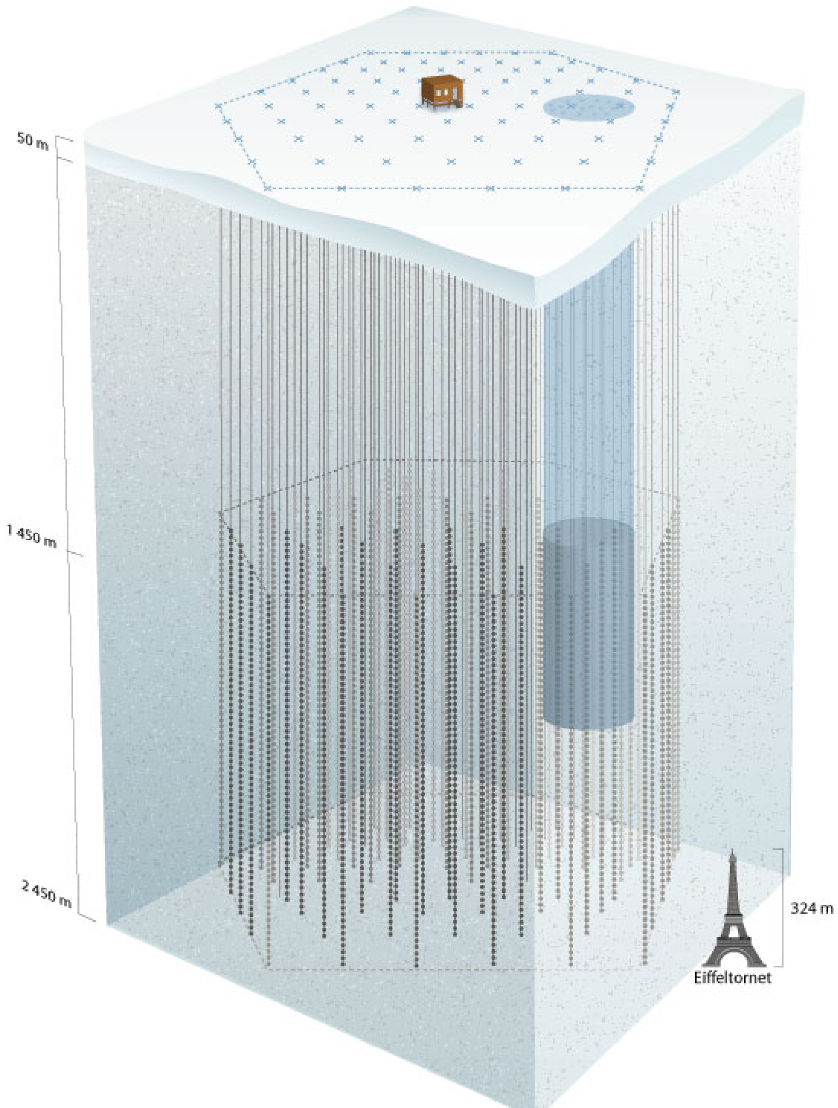
Point source sensitivity:

- AMANDA, ANTARES: ~ 10^{-10} ν / (cm² s) above 1 TeV
- IceCube: ~ 10^{-12} ν / (cm² s) above 1 TeV

IceCube

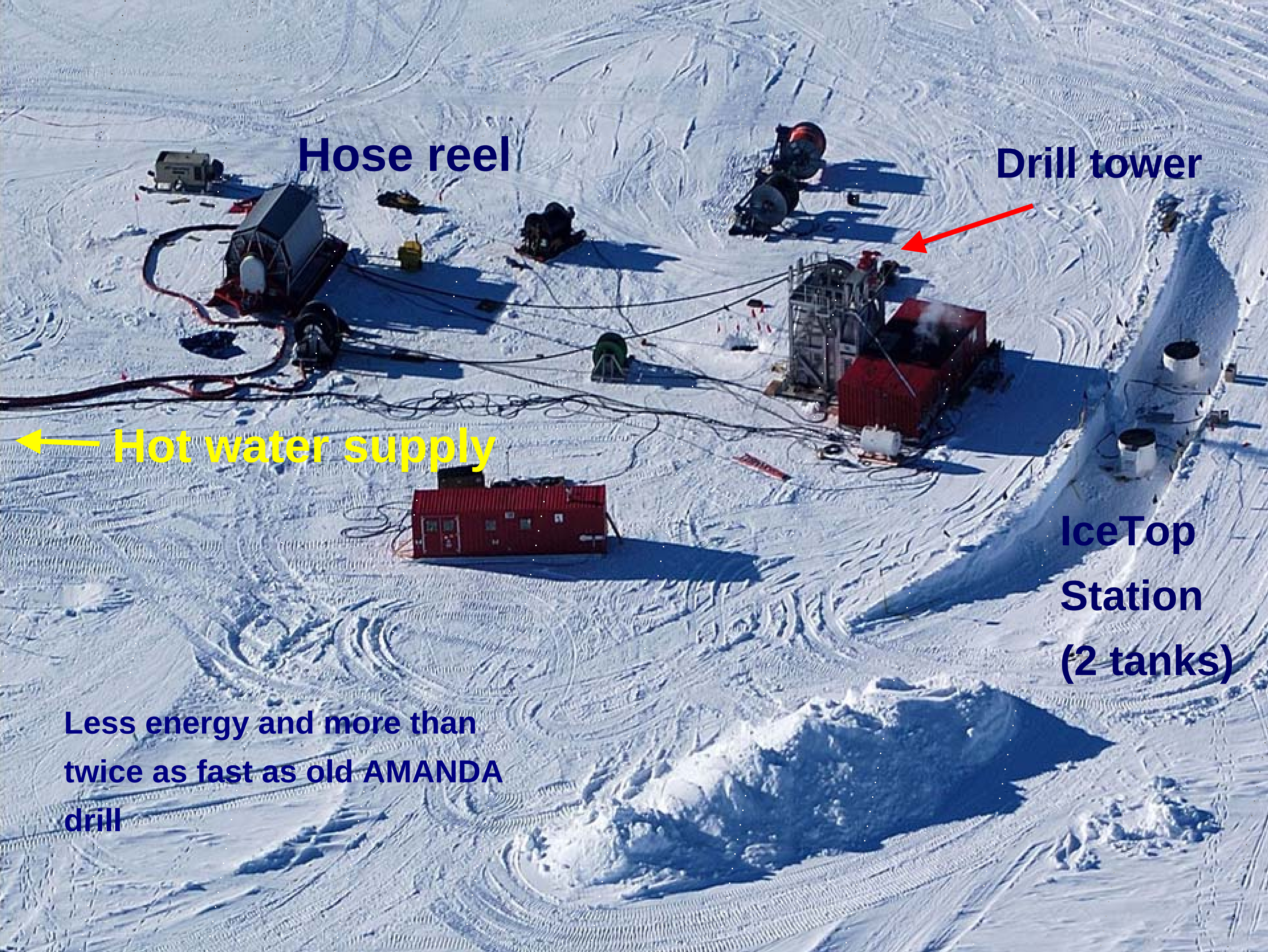

IceCube
South Pole Station
AMANDA
Skiway
Geographic South Pole
Dark sector

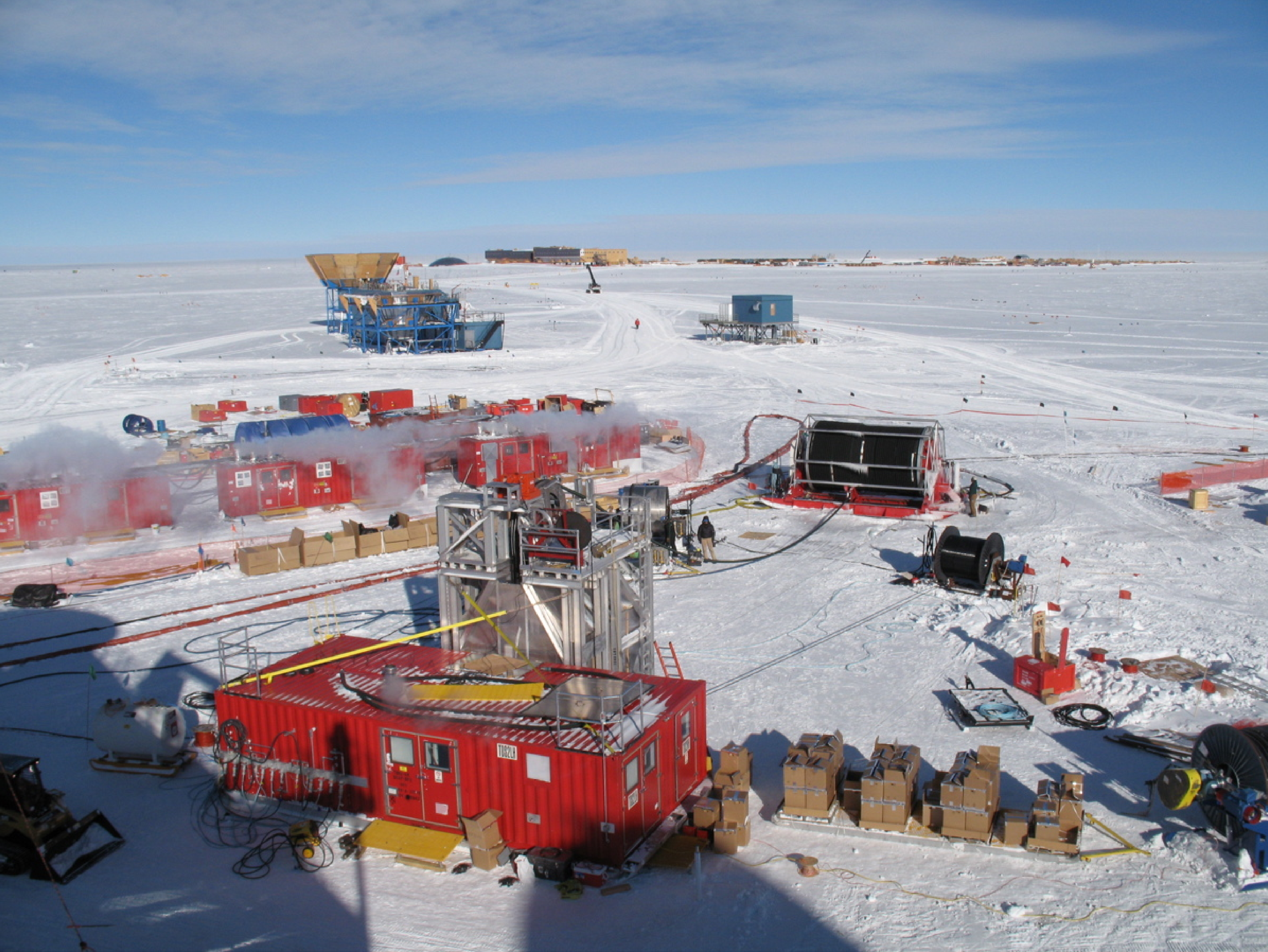
IceCube



- 4800 Digital Optical Modules on 80 strings

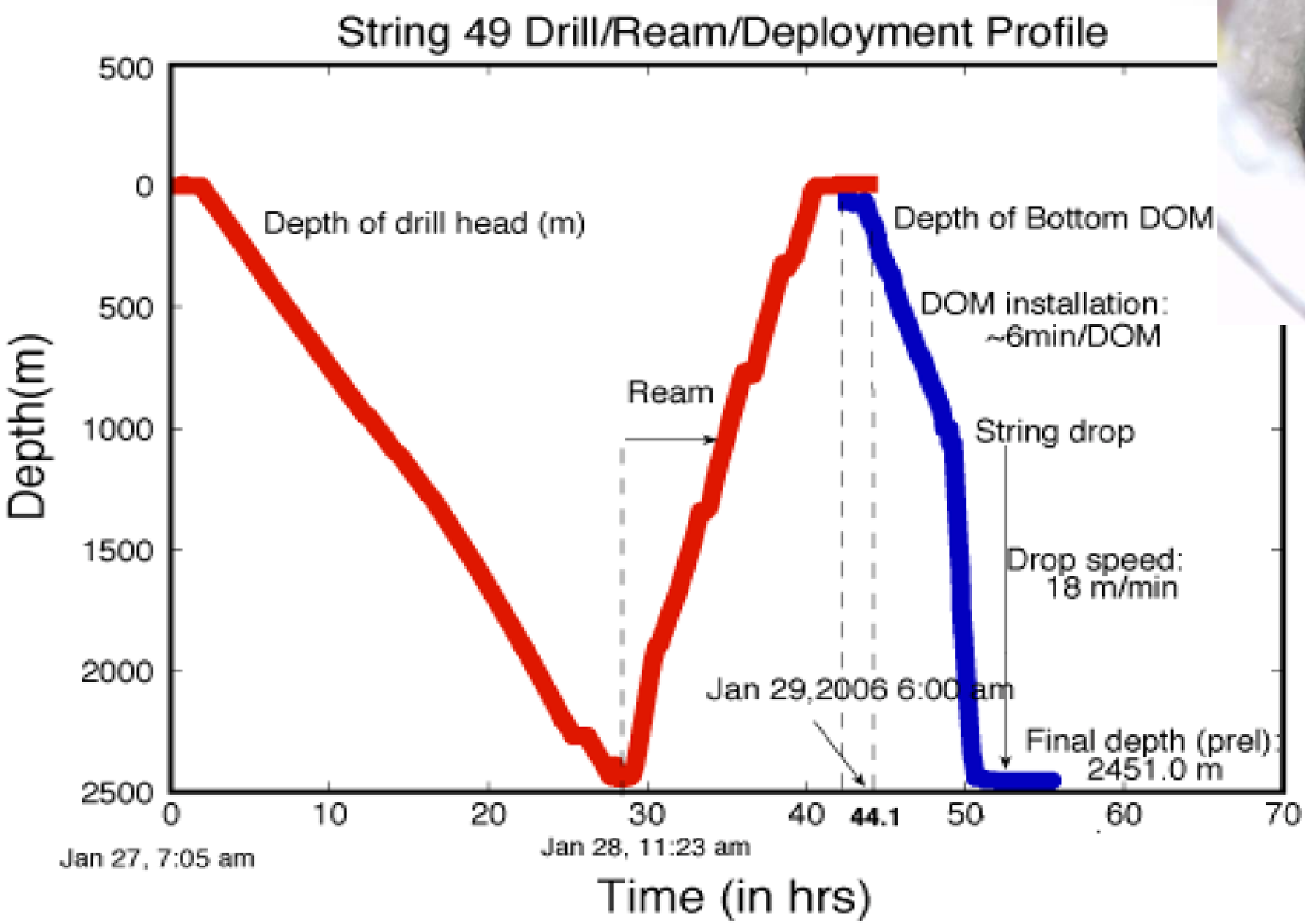
- 160 Ice-Cherenkov tank surface array (IceTop)
- 1 km^3 of instrumented Ice
- Surrounding existing AMANDA detector


Hose reel
Drill tower
Hot water supply
IceTop
Station
(2 tanks)
Less energy and more than
twice as fast as old AMANDA
drill



... not always easy

IceCube Drilling & Deployment



Status 2007

IceCube Deployment

IceTop

Air shower detector

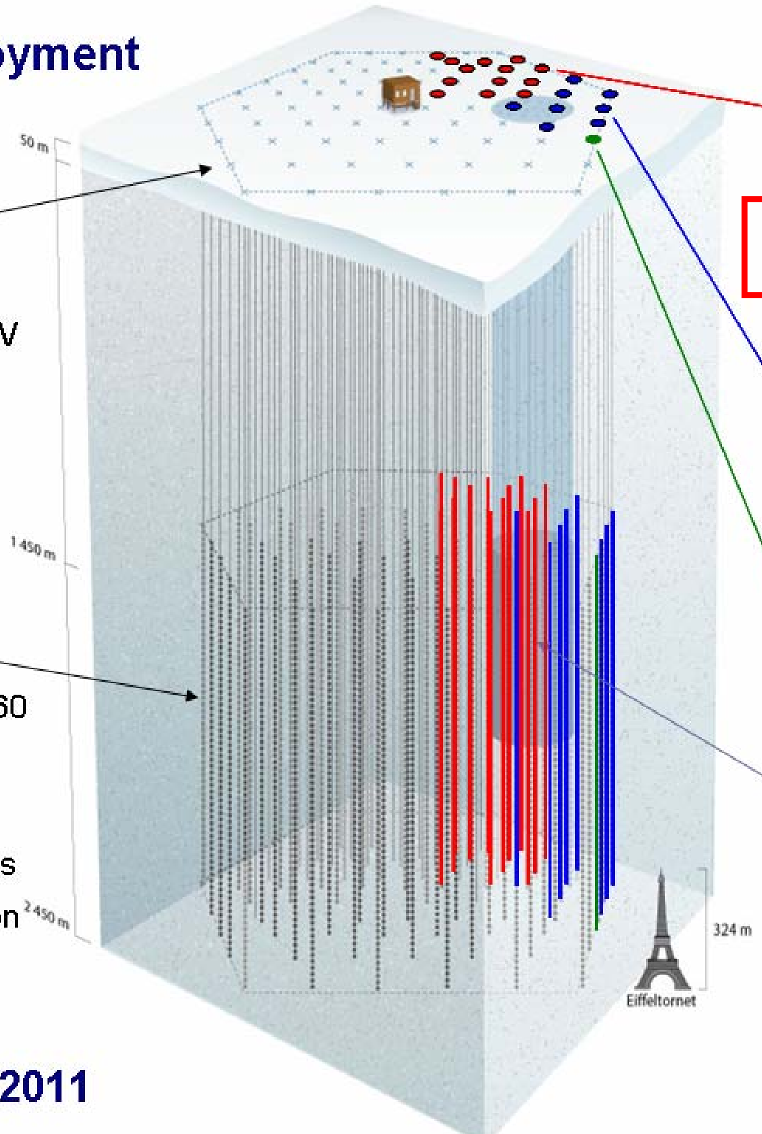
Threshold ~ 300 TeV

InIce

planned 80 strings of 60 optical modules each

17 m between modules

125 m string separation



2006-2007:
13 strings deployed

Altogether: 22 strings
52 surface tanks

2005-2006: 8 strings

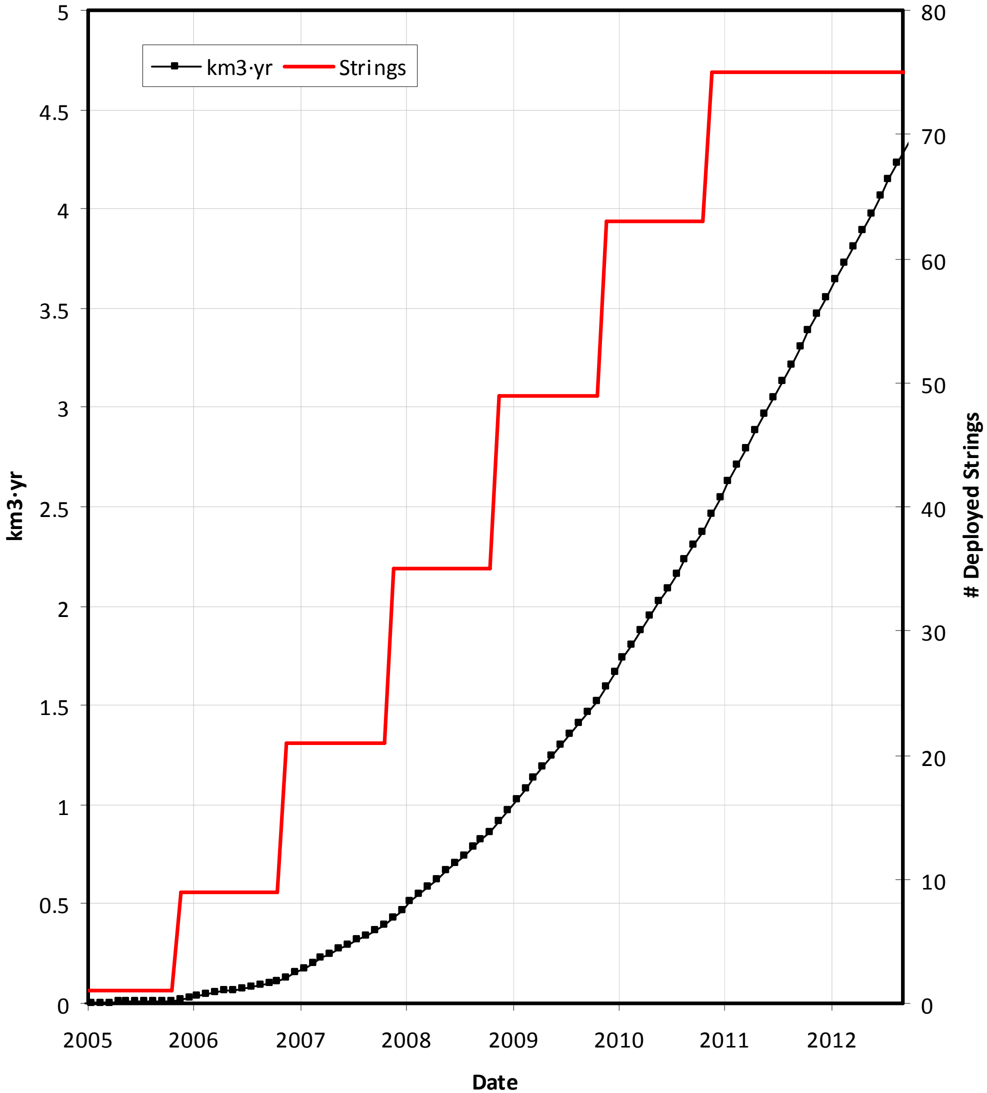
2004-2005 : 1 string

First data in 2005
first upgoing muon: July 18, 2005

AMANDA
19 strings
677 modules

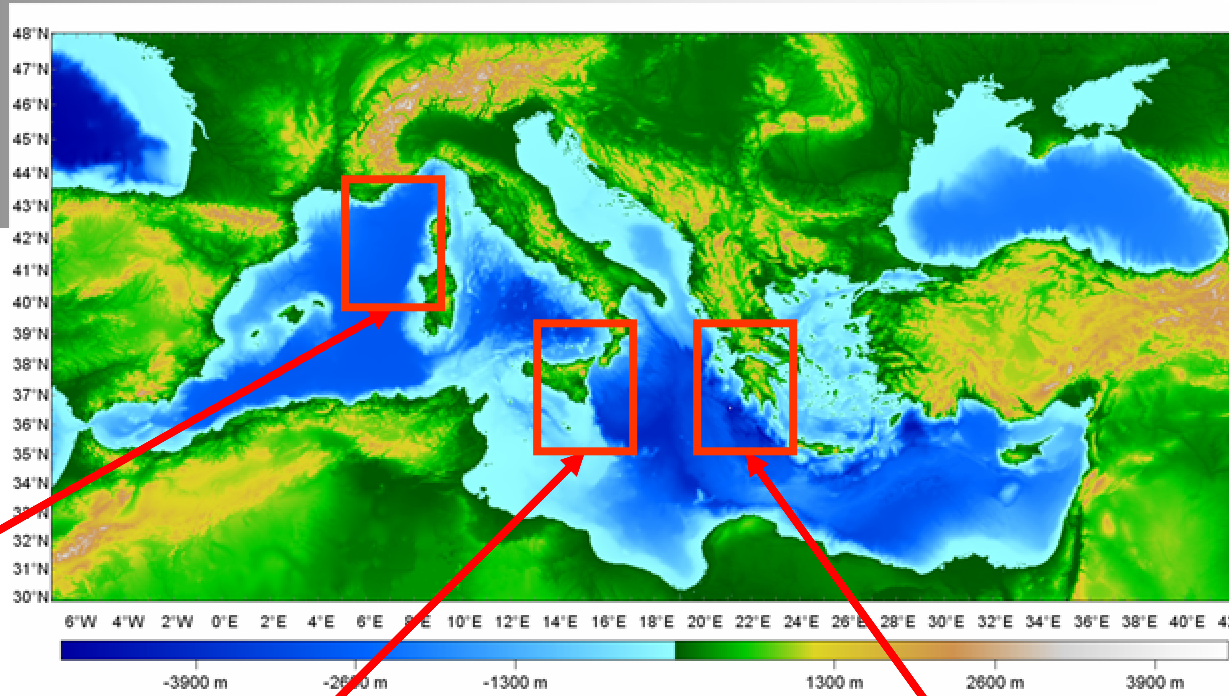
Completion by 2011

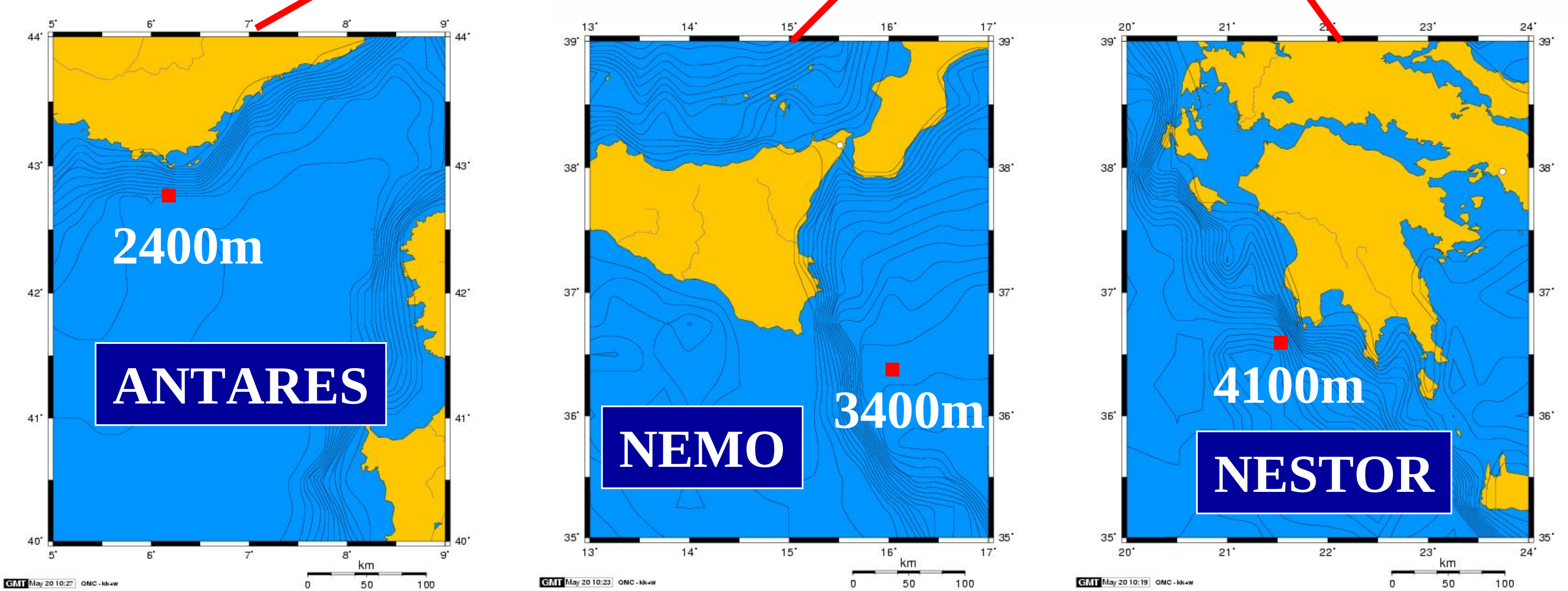
Cumulative Instrumented Volume



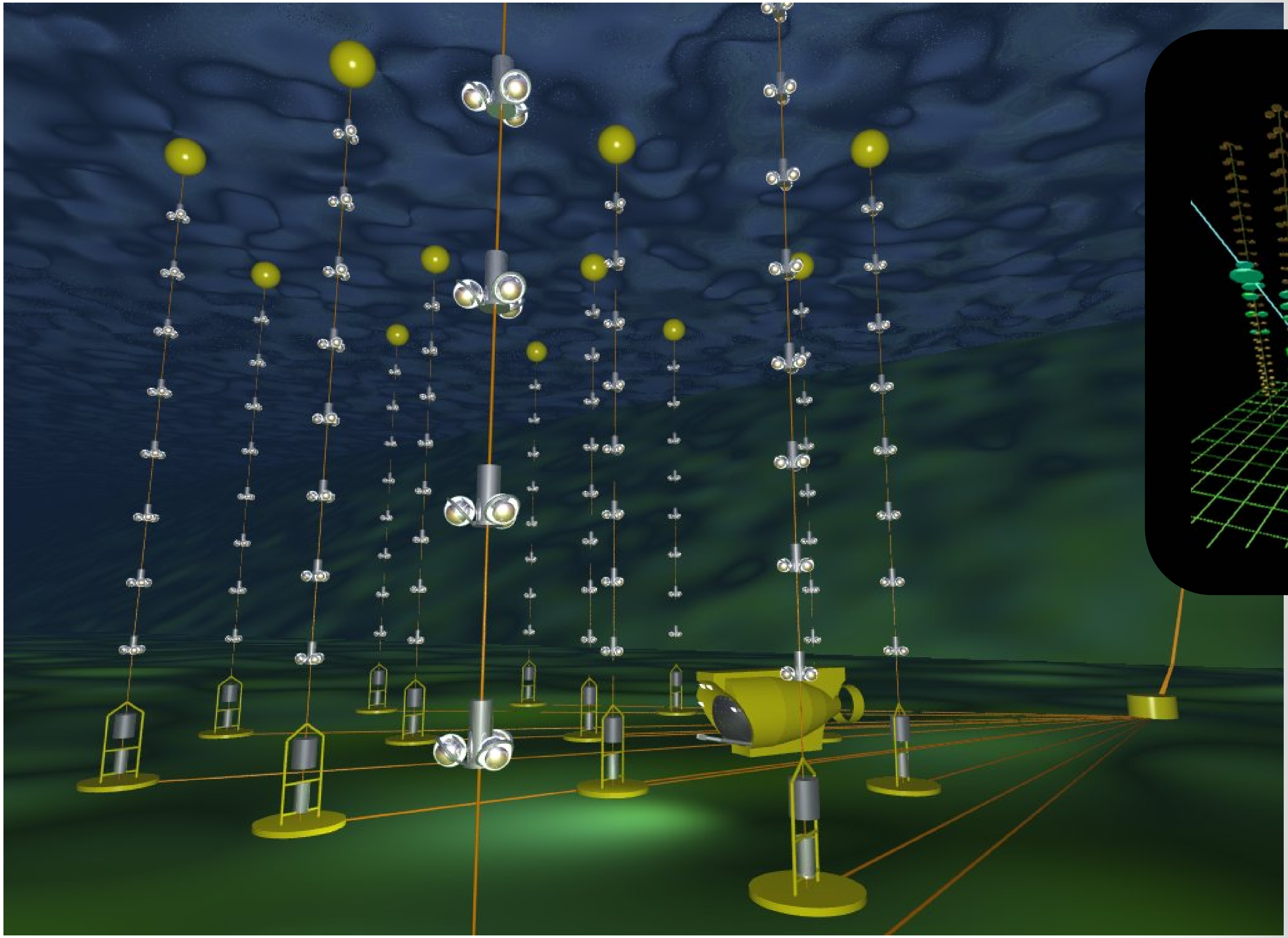
- Graph shows *cumulative* km^3·yr of exposure × volume
- 1 km^3·yr reached 2 years *before* detector is completed
- Close to 4 km^3·yr at the beginning of 2nd year of full array operation.

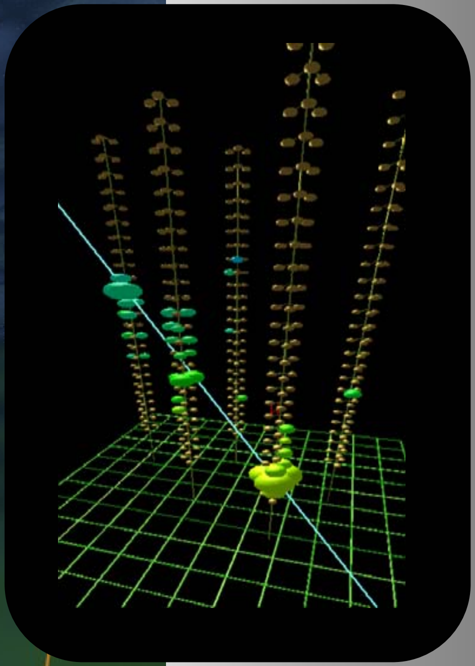
The Mediterranean approach





ANTARES



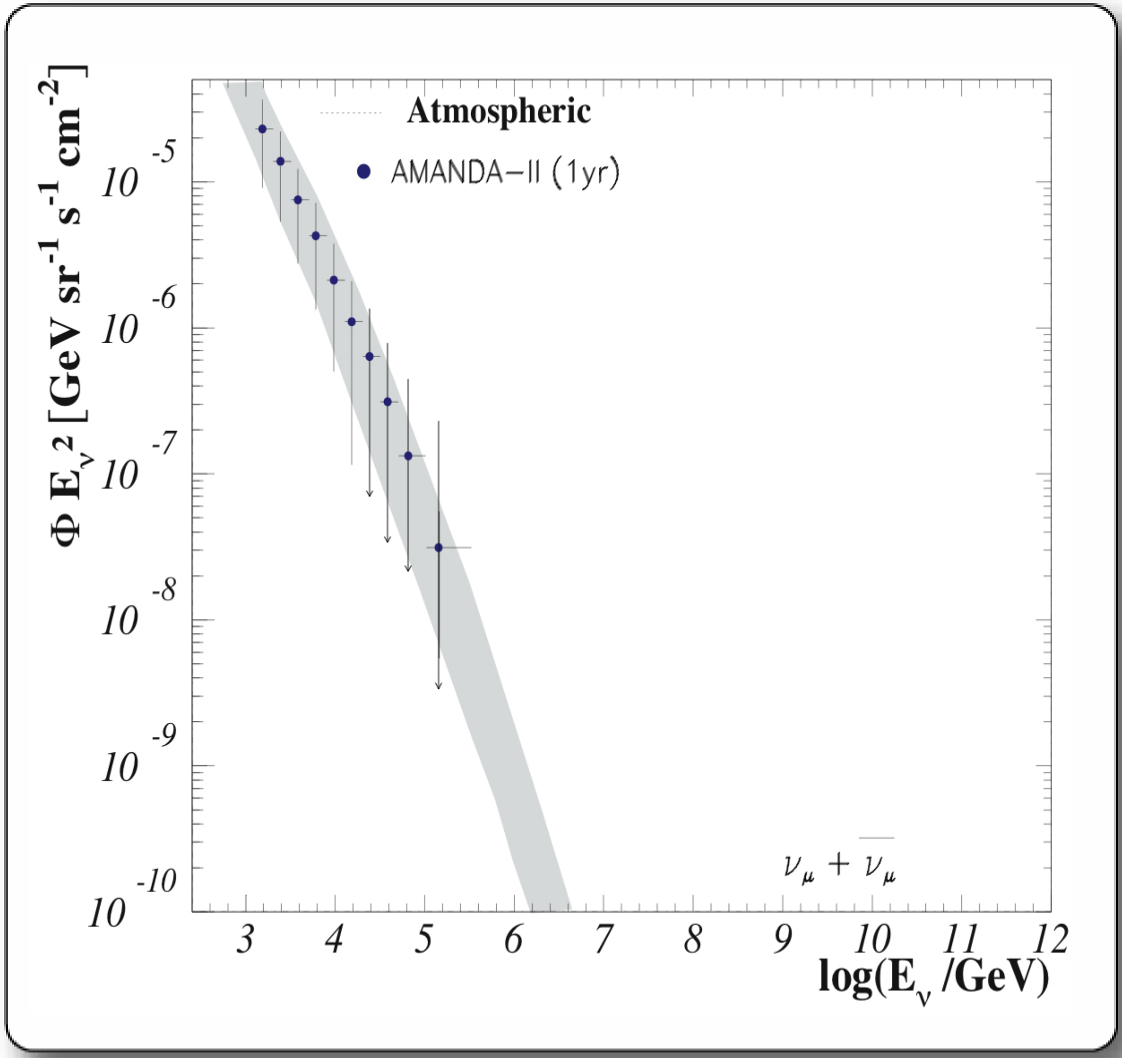


Neutrino candidate from 5-string detector

Physics from Baikal & AMANDA

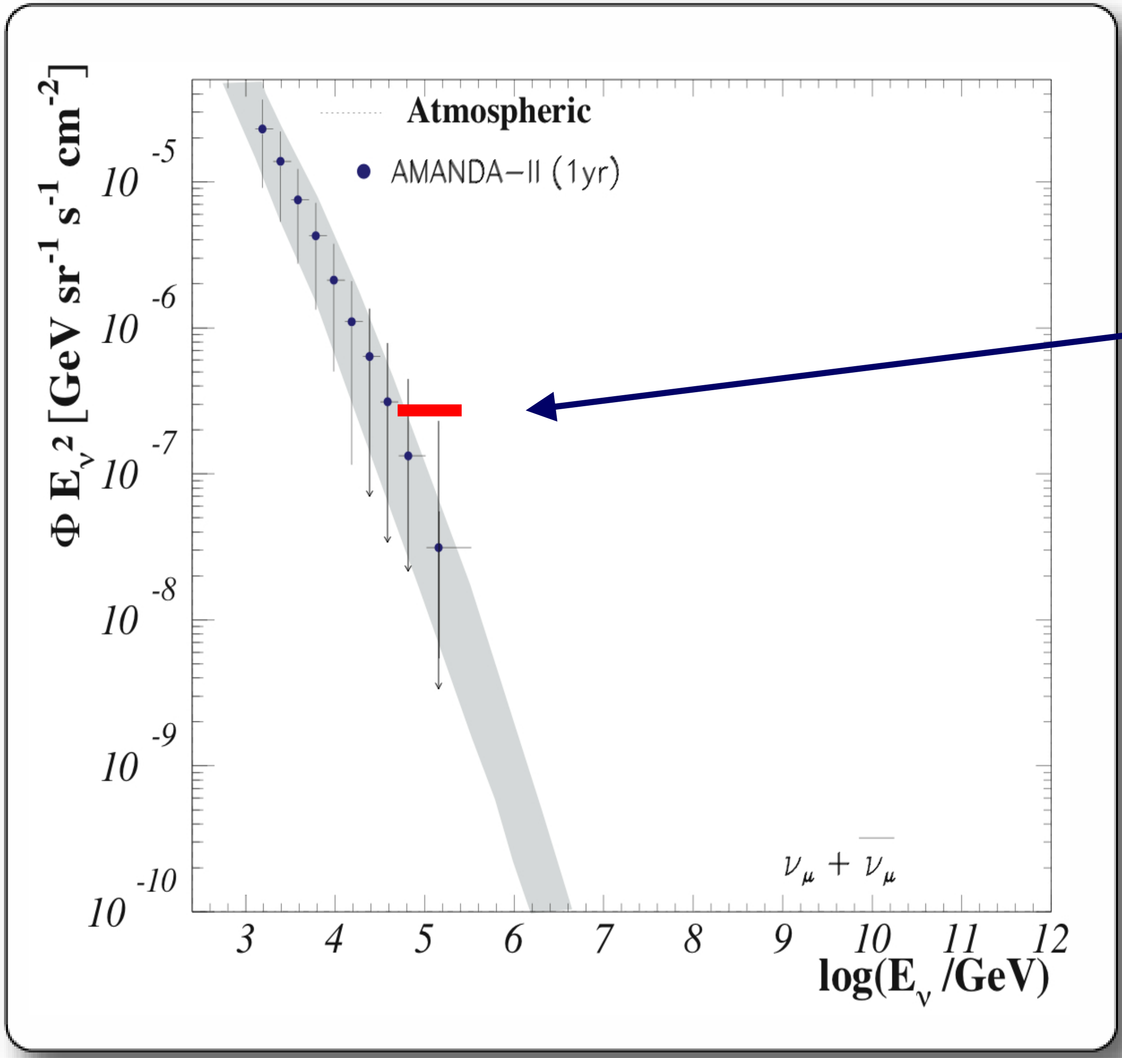
- Atmospheric neutrinos
- Diffuse fluxes
- Point sources → see talk of Elisa Resconi
- Coincidences with GRB
- Supernova Bursts & SNEWS
- WIMP indirect detection
- Magnetic monopoles
- ….
- ….

Atmospheric neutrinos



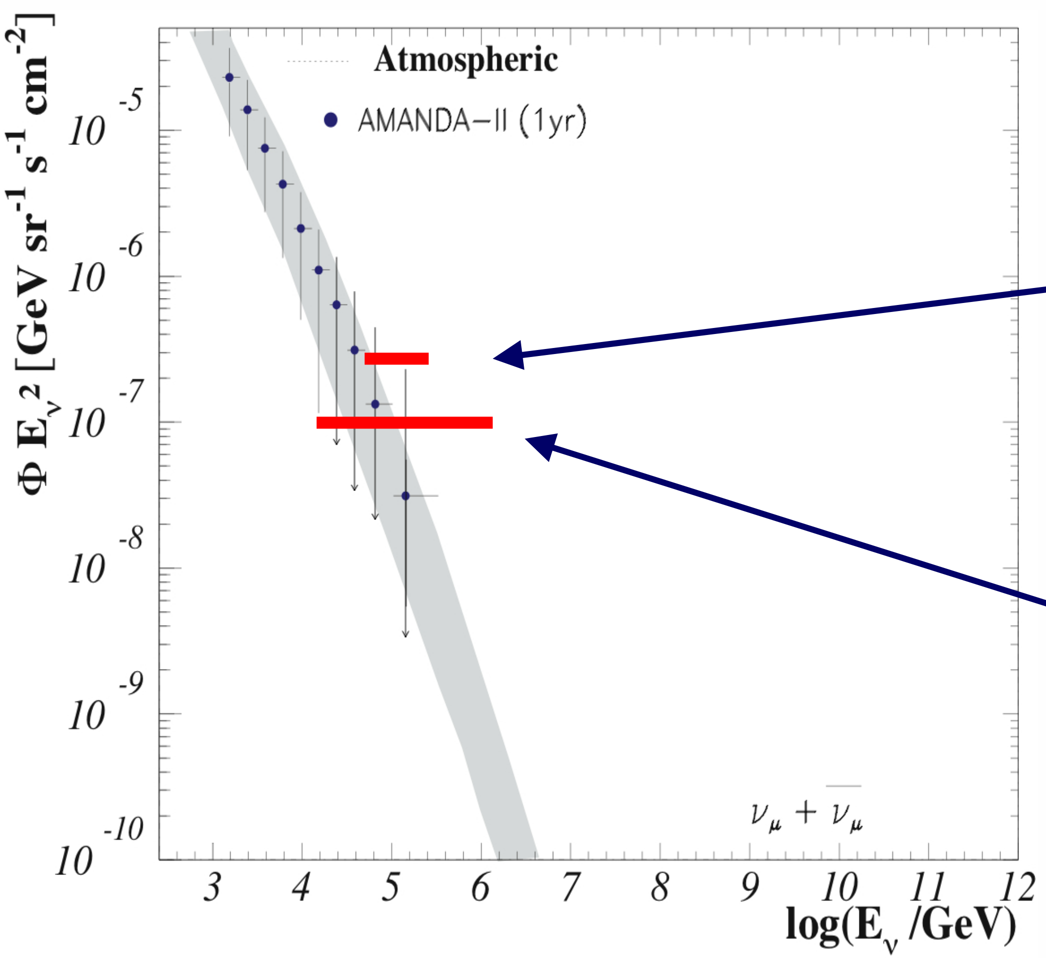
- Spectrum measured up to ~ 100 TeV

Limit on diffuse extraterrestrial fluxes



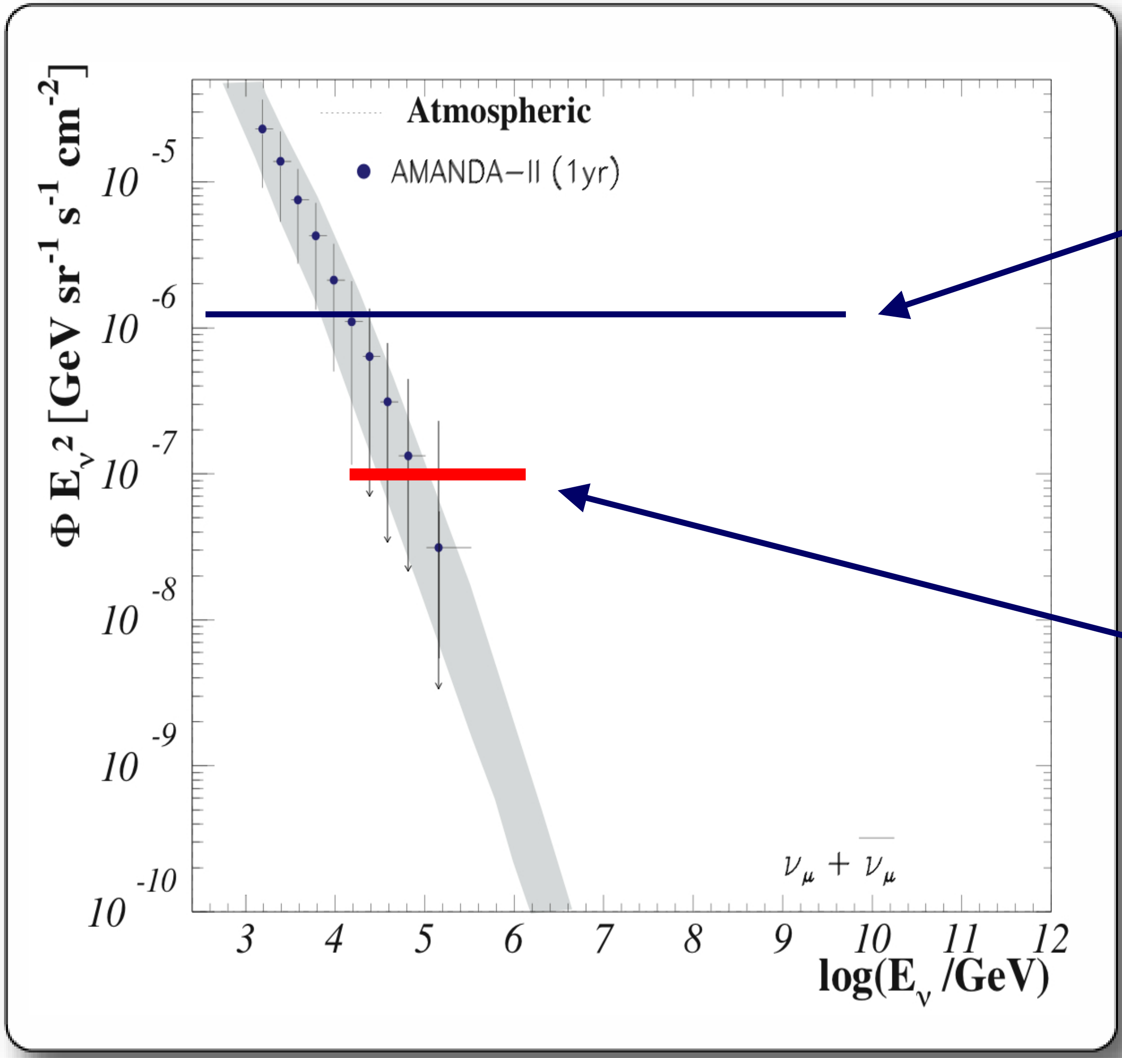
- Spectrum measured up to ~ 100 TeV
- From this method and one year data we exclude E^{-2} fluxes with $\Phi \cdot E^2 > 2.7 \cdot 10^{-7}$ GeV sr^{-1} s^{-1} cm^{-2}

Limit on diffuse extraterrestrial fluxes



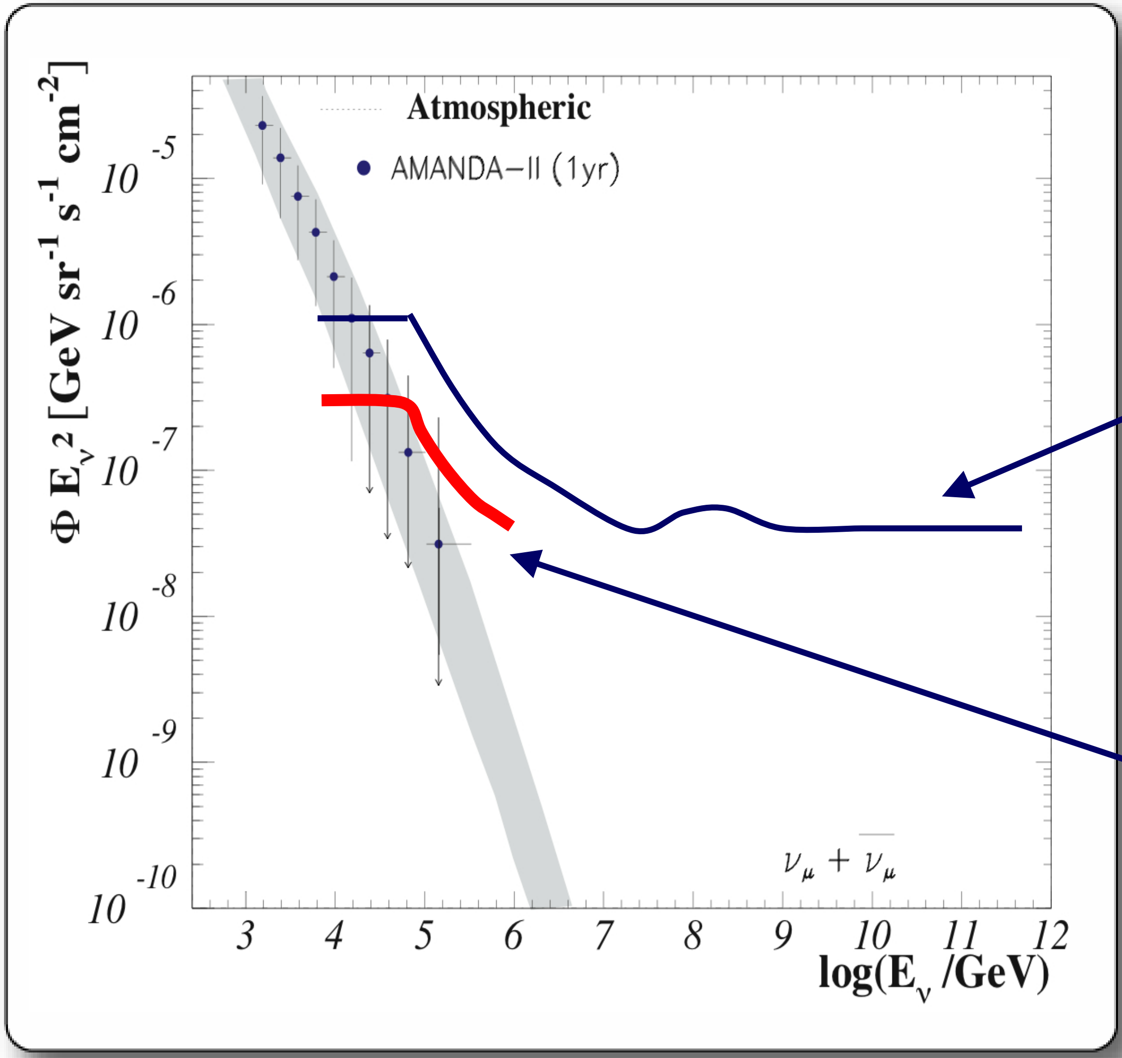
- Spectrum measured up to ~ 100 TeV
- From this method and one year data we exclude E^{-2} fluxes with $\Phi \cdot E^2 > 2.7 \cdot 10^{-7}$ GeV sr^{-1} s^{-1} cm^{-2}
- With 4 years and improved methods we are now at $\Phi \cdot E^2 > 8.8 \cdot 10^{-8}$ GeV sr^{-1} s^{-1} cm^{-2}

Experimental limits & theoretical bounds



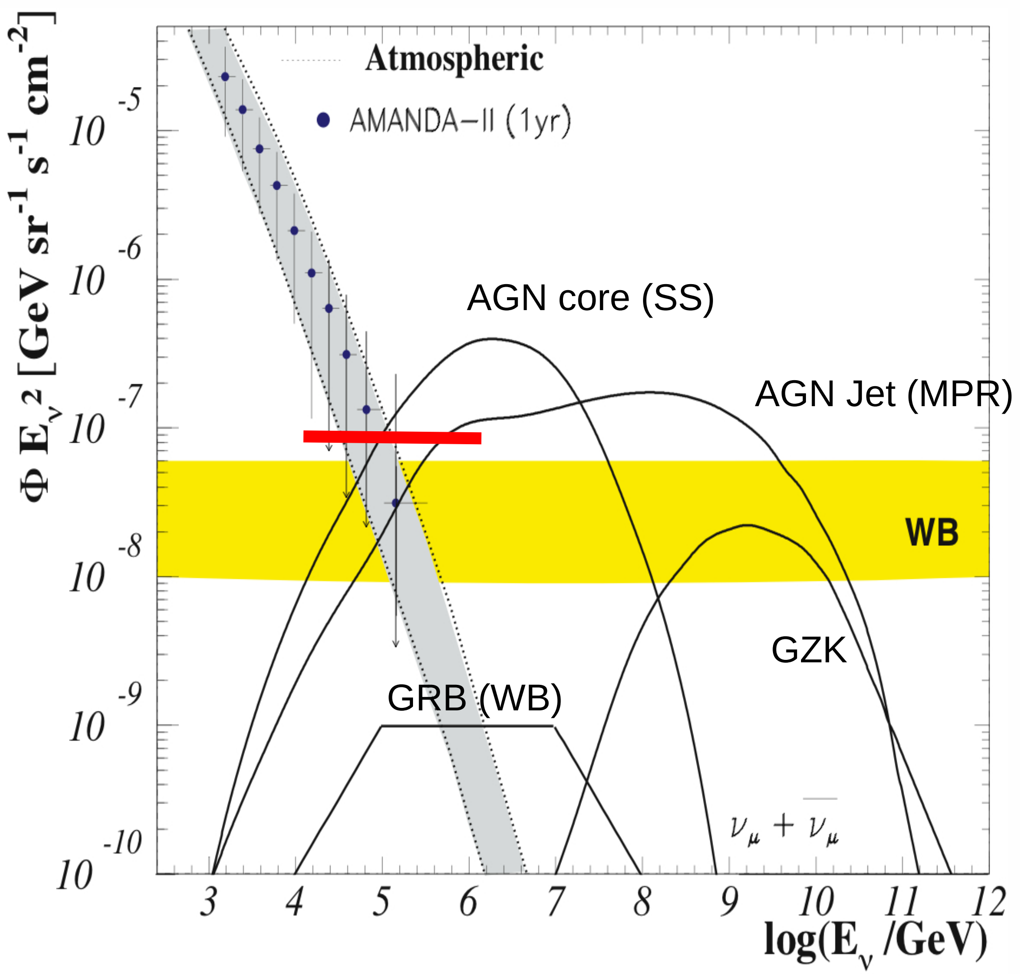
- MPR bound, no neutron escape (gamma bound)
- Factor 11 below MPR bound for sources opaque to neutrons

Experimental limits & theoretical bounds

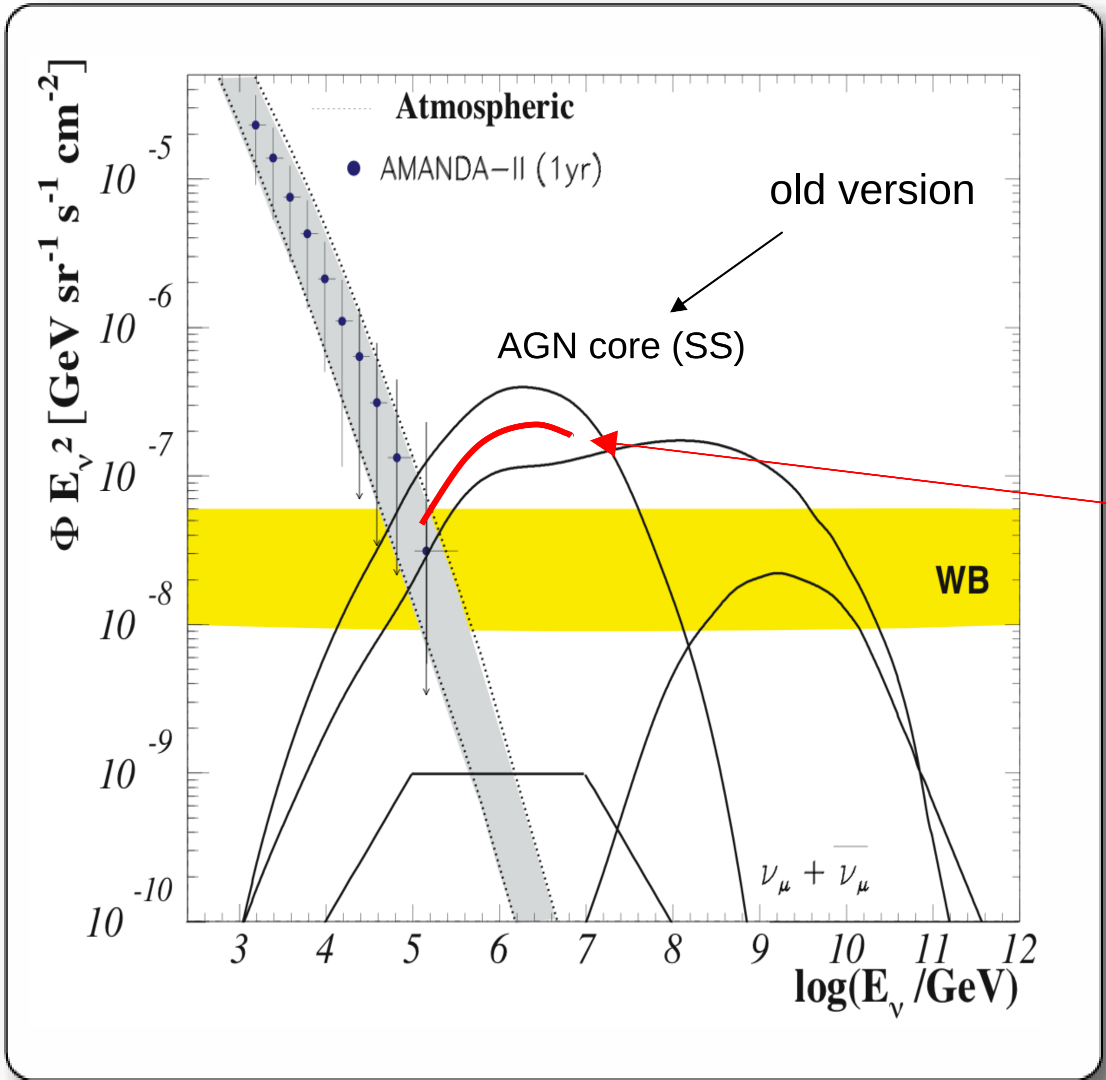


- MPR bound, neutrons escape (CR bound)
- Factor 4 below MPR bound for sources transparent to neutrons

Experimental limits & theoretical bounds

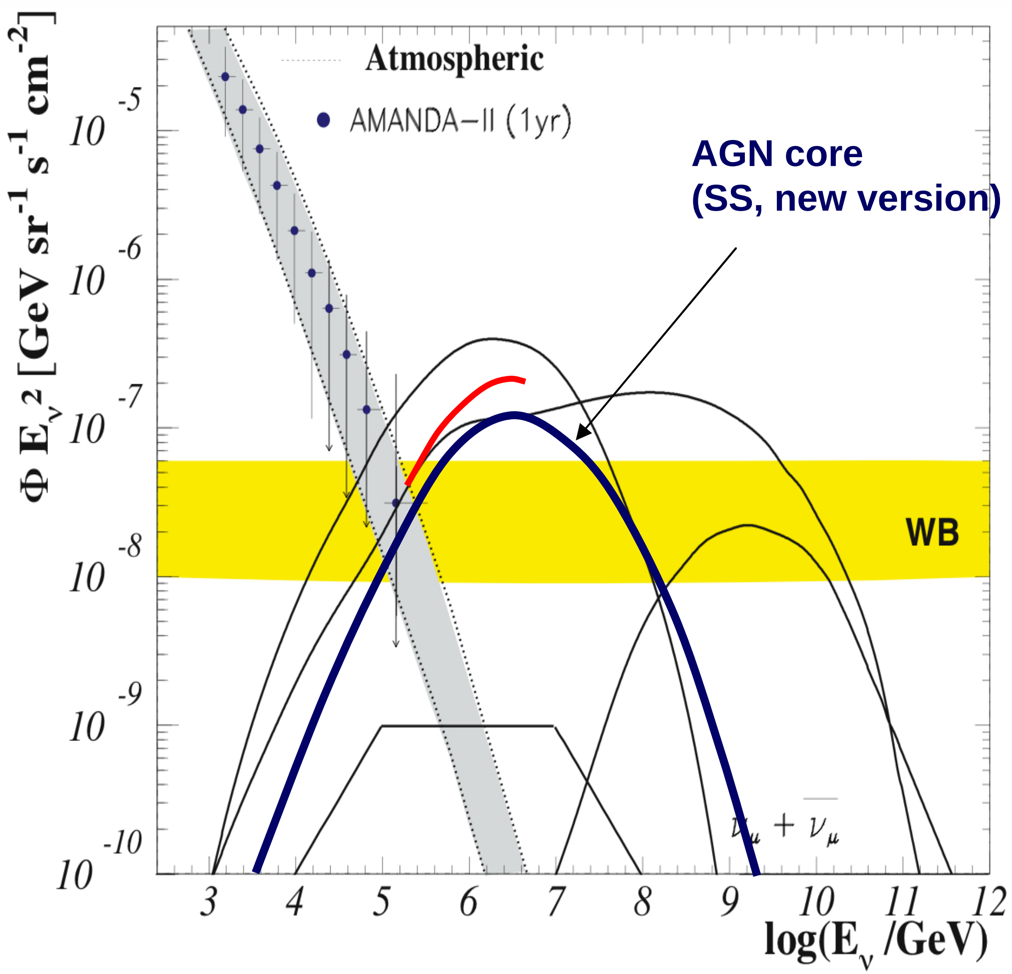


Experimental limits & theoretical bounds



„old“ Stecker model excluded

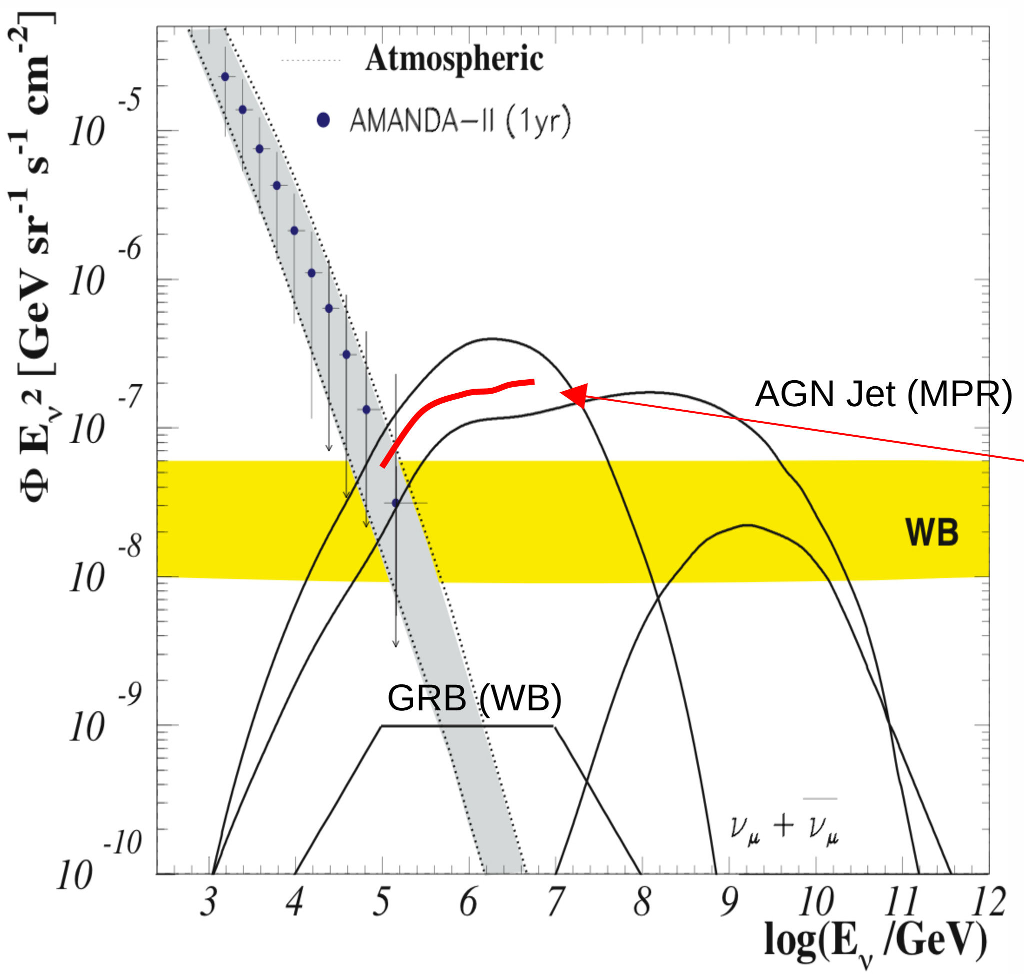
Experimental limits & theoretical bounds



„new“
Stecker model
not excluded

(MRF = 1.9)

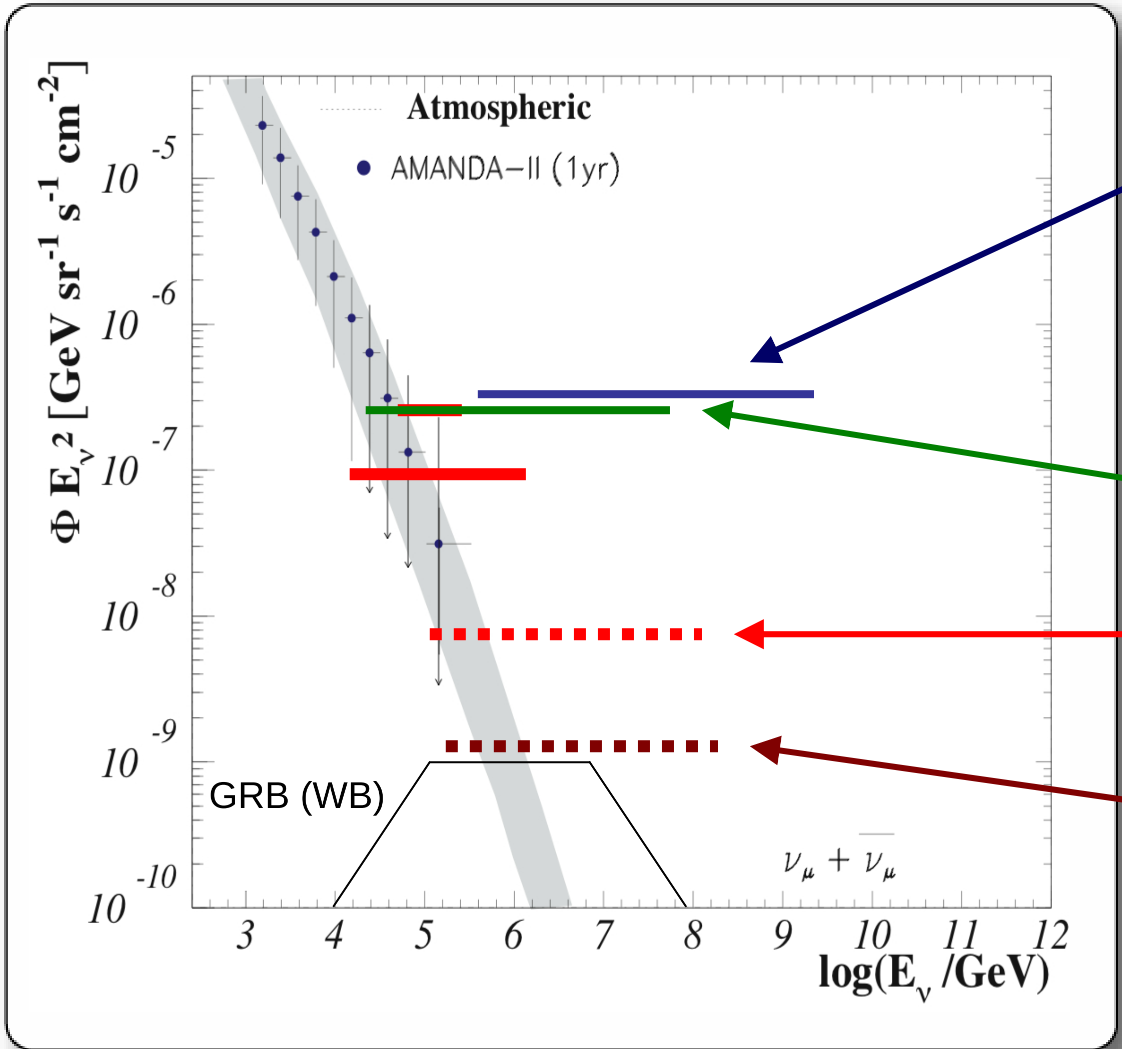
Experimental limits & theoretical bounds



still above AGN jet (MPR)

(MRF ~ 2.3)

Limit on diffuse extraterrestrial fluxes



AMANDA HE analysis

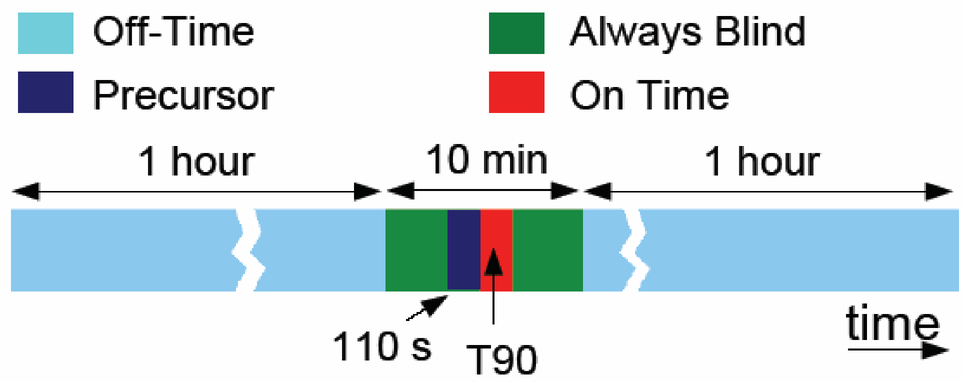
Baikal

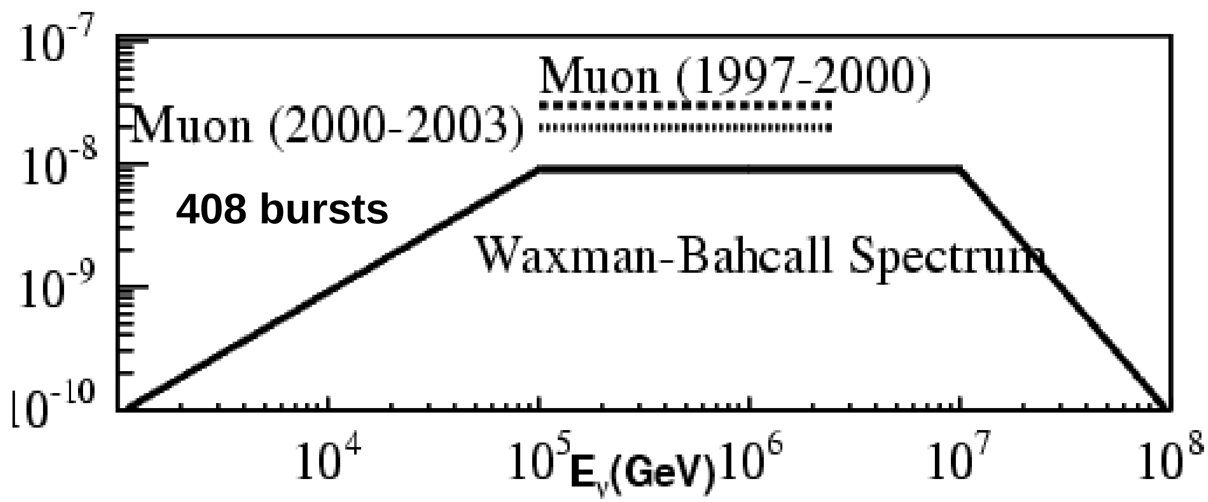
IceCube muons, 1 year

Icecube, muons & cascades 4 years

Coincidences with GRB

Check for coincidences with
- BATSE
- IPN
- SWIFT

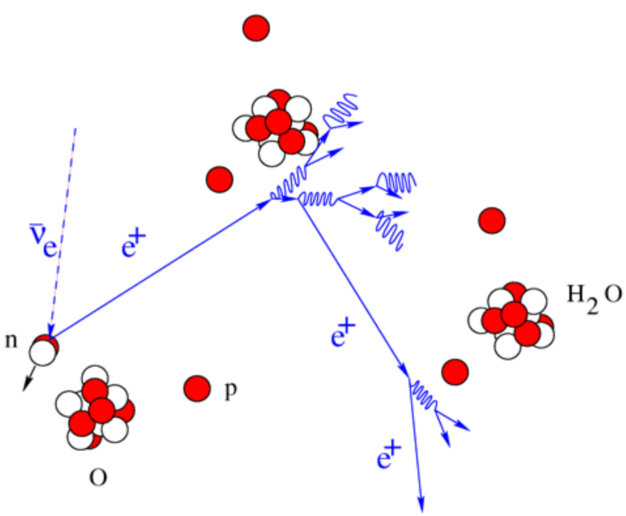




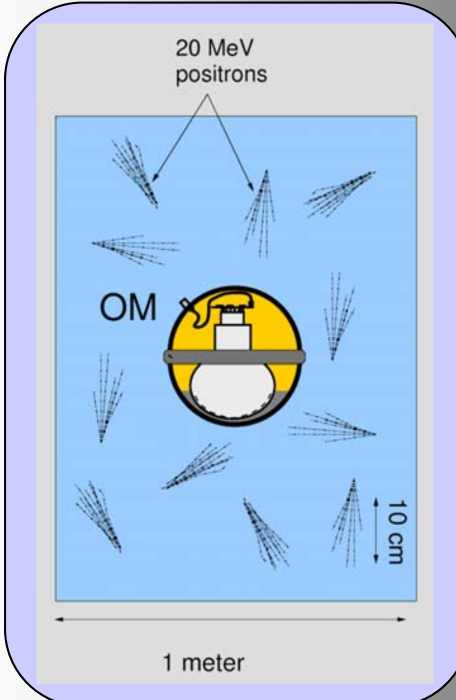
With IceCube: test WB within a few months

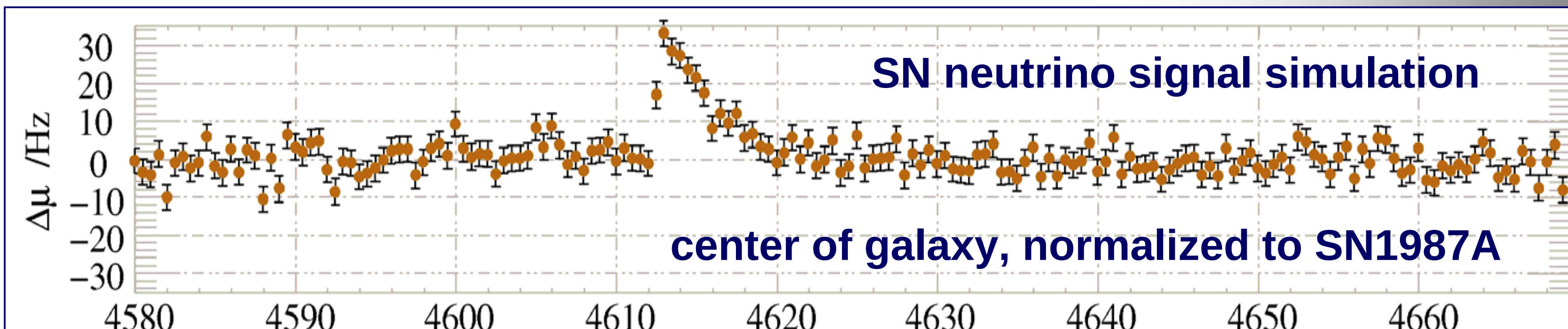
Detection of Supernova Bursts

- ice uniformly illuminated
- detect correlated rate increase on top of PMT noise



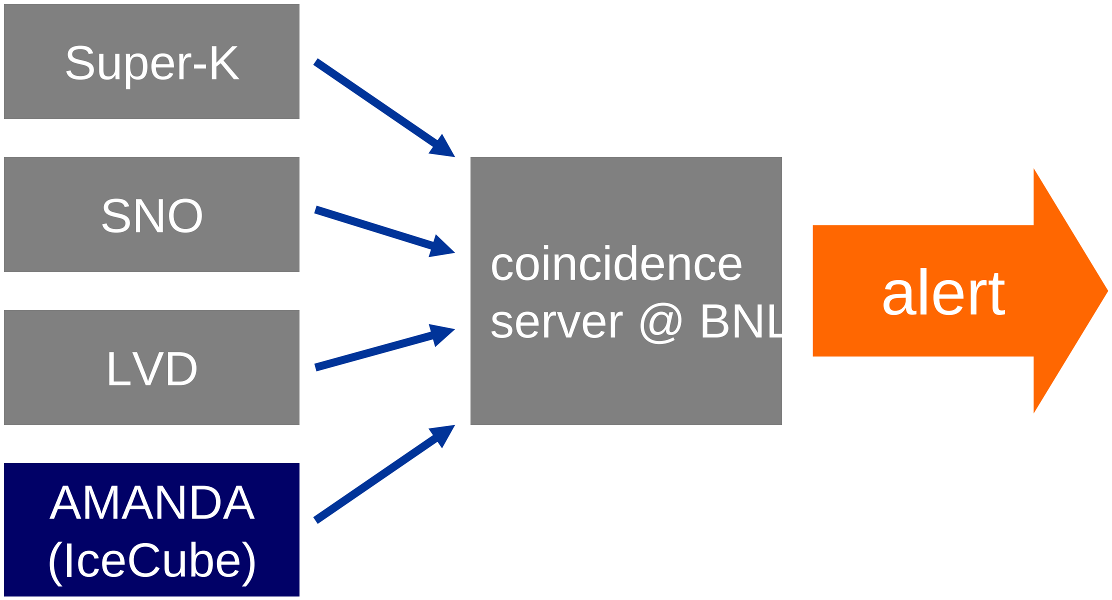
Dark noise in AMANDA only ~ 500 Hz !





Participation in SNEWS

…several hours advanced notice to astronomers



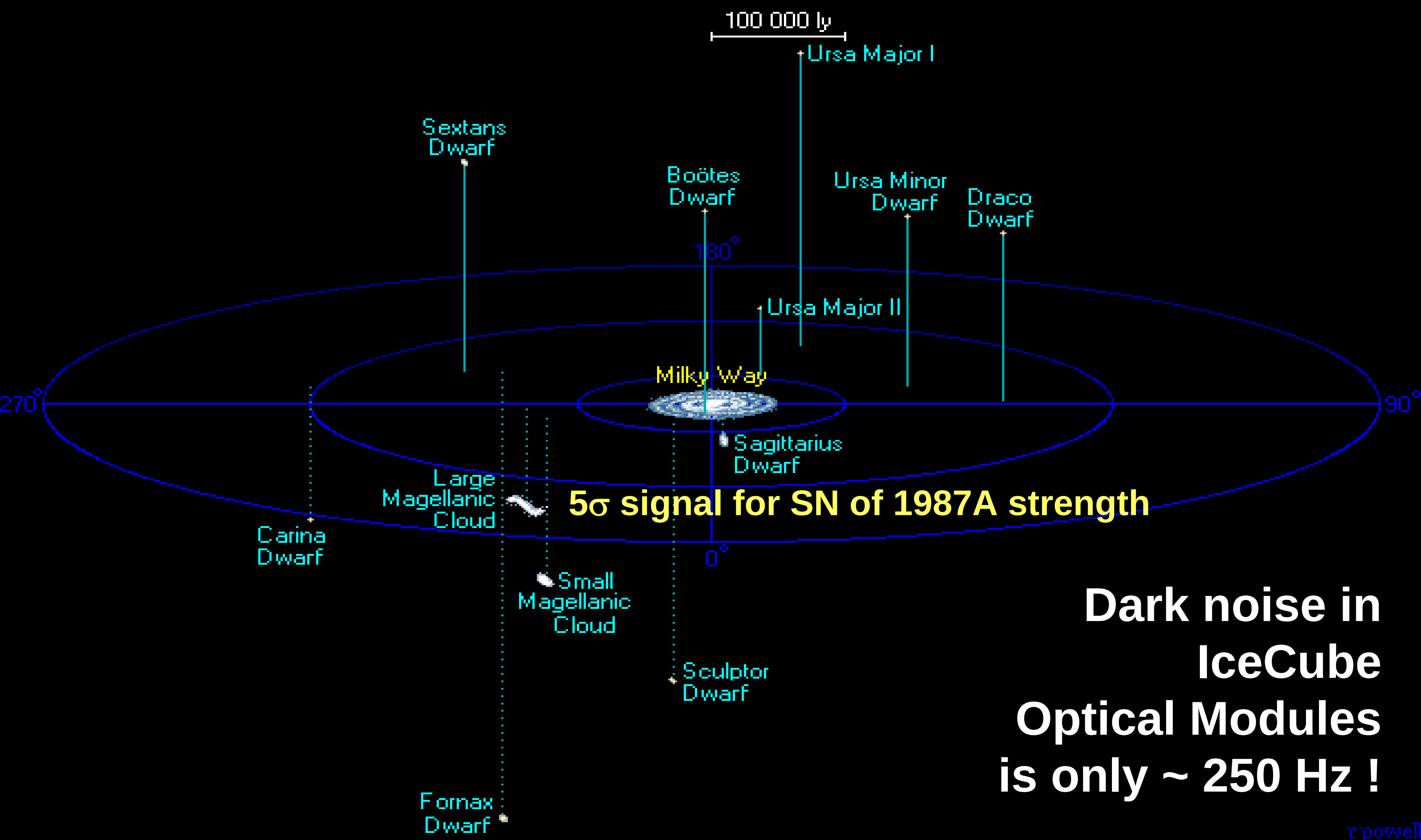
IceCube will follow this year

http://snews.bnl.gov and astro-ph/0406214

received iridium messages (last 4 weeks)

message type	time (UTC)	time delay to reception (seconds)	needed modem dial attempts
missing test message(s)			
test	Mon Jul 10 08:19:38 2006	224	1
test	Sun Jul 9 11:15:12 2006	218	1
test	Sat Jul 8 11:15:12 2006	208	1
test	Fri Jul 7 11:15:12 2006	208	1
test	Thu Jul 6 11:15:11 2006	214	1
test	Thu Jul 6 11:09:05 2006	205	1
missing test message(s)			
test	Mon Jul 3 09:45:12 2006	195	1
sn	Sun Jul 2 11:17:12 2006	445	1
	signal strength is [8.716532e+00 ± 1.325448e+00] Hz analysis timebase is [4] sec, active channels are [476], χ^2 is [5.421858e+02]		
test	Sun Jul 2 09:45:11 2006	196	1
test	Sat Jul 1 09:45:12 2006	195	1
test	Fri Jun 30 09:45:12 2006	185	1
test	Thu Jun 29 09:45:12 2006	181	1
sn	Wed Jun 28 11:20:29 2006	448	1
	signal strength is [7.296678e+00 ± 8.447978e-01] Hz analysis timebase is [10] sec, active channels are [474], χ^2 is [5.770201e+02]		
test	Wed Jun 28 09:45:12 2006	185	1
test	Tue Jun 27 09:45:12 2006	175	1
test	Mon Jun 26 09:45:12 2006	175	1
test	Sun Jun 25 09:45:12 2006	176	1
sn	Sun Jun 25 02:15:47 2006	571	2
	signal strength is [9.946102e+00 ± 1.333087e+00] Hz analysis timebase is [4] sec, active channels are [475], χ^2 is [5.061309e+02]		
test	Sat Jun 24 09:45:12 2006	165	1
test	Fri Jun 23 09:45:12 2006	165	1
test	Fri Jun 23 09:26:21 2006	170	1
test	Fri Jun 23 08:59:13 2006	732	10
test	Thu Jun 22 10:33:23 2006	162	1
test	Thu Jun 22 09:45:12 2006	160	1
test	Thu Jun 22 09:38:29 2006	163	1
test	Thu Jun 22 09:27:30 2006	167	1
test	Thu Jun 22 08:45:12 2006	173	1
missing test message(s)			
test	Tue Jun 20 09:30:12 2006	154	1

Supernova in IceCube



5σ signal for SN of 1987A strength

Dark noise in IceCube Optical Modules is only ~ 250 Hz !

Methods for > 100 PeV

- Radio detection of showers at the moon
  - GLUE, Kalyazhin
  - in future: LOFAR, SKA
- Radio detection of neutrinos in ice or salt
  - RICE, ANITA, Test array AURA (IceCube)
  - future: ARIANNA, SALSA
- Acoustic detection of neutrinos in water and ice
  - test arrays SPATS (IceCube) and AMADEUS (ANTARES)
- Detection of fluorescence signals in air
  - from ground: AGASA, Auger
  - from space: FORTE, in future – EUSO, OWL

Summary

- **tremendous technological progress over last decade** (Baikal, South Pole, now also Mediterrannean)
- **no positive detection yet, but already testing realistic models/bounds**
- **IceCube reaches 1 km^3 $\times$ year by the end of 2008**
- **entering region with realistic discovery potential**
- **IceCube discoveries/non-discoveries will influence design of KM3NeT**