Neutrino Telescopes

Jürgen Brunner
CPPMarseille

Why neutrino telescopes ?
How do they work ?
Existing and Future projects -
Selected results and prospects

Why Neutrinotelescopes ?

Observation of universe with

New messenger:

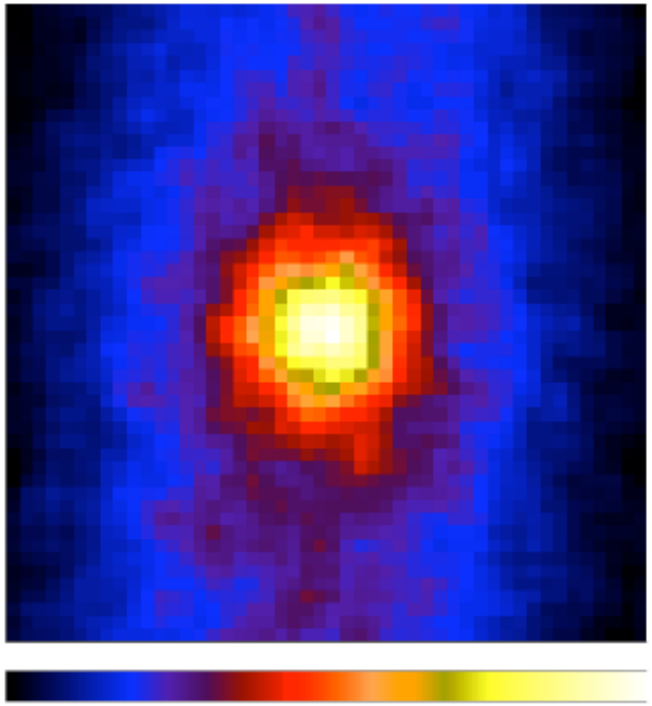
Neutrino ⟷ Photon ⟷ Proton

New wave length range (Energy): E > TeV

So far only 2 objects on MeV neutrino sky:

Sun !

SN1987A (few seconds)



Super- K (Japan) image of the sun using neutrinos

Production and transmission of neutrinos

Neutrinos produced in hadronic interactions of high energy protons or nuclei

$p/A + p/\gamma \rightarrow \pi^0 + \pi^\pm + \ldots$ at source

$\pi^0 \downarrow \gamma\,\gamma$

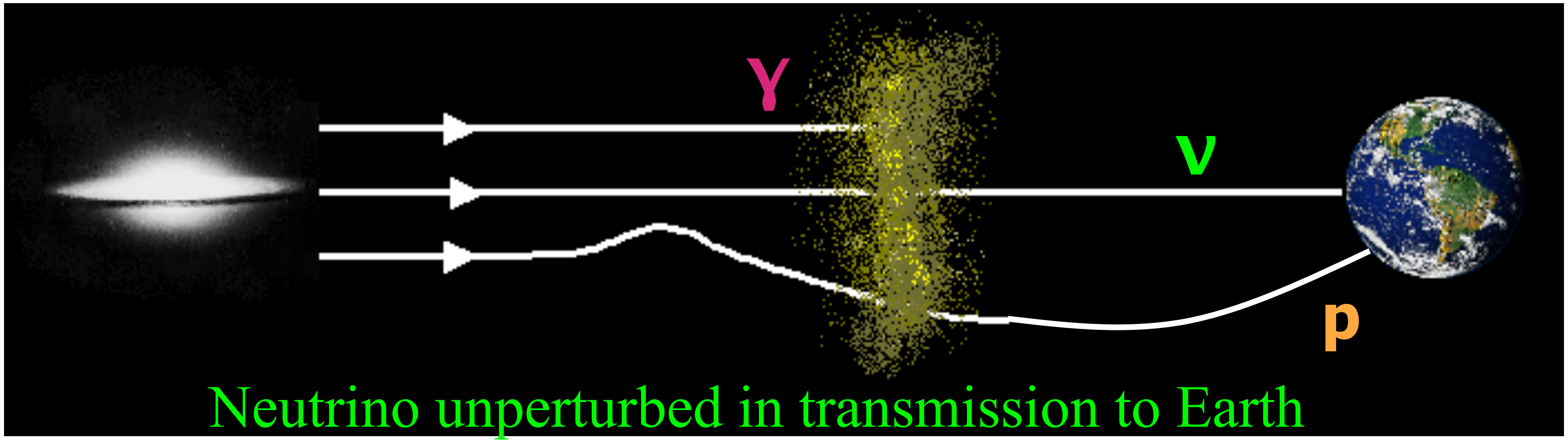
$\pi^\pm \downarrow \nu_\mu\,\mu$

$\mu \downarrow \nu_\mu\,\nu_e\,e$

$\nu_e : \nu_\mu : \nu_\tau$

$=$

$1 : 2 : 10^{-5}$



In transit : oscillations between flavours

at Earth

$\nu_e : \nu_\mu : \nu_\tau$

$=$

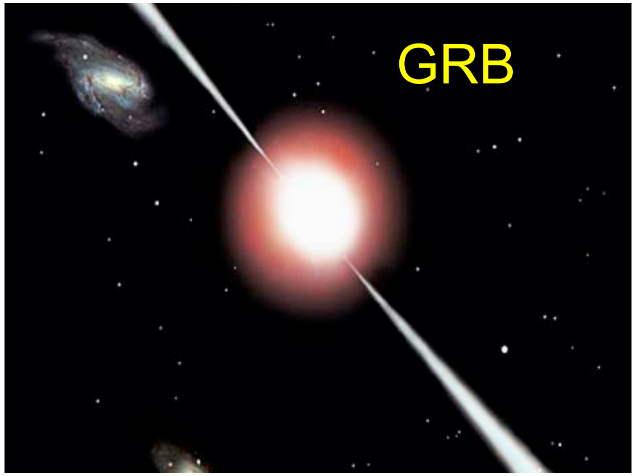
$1 : 1 : 1$

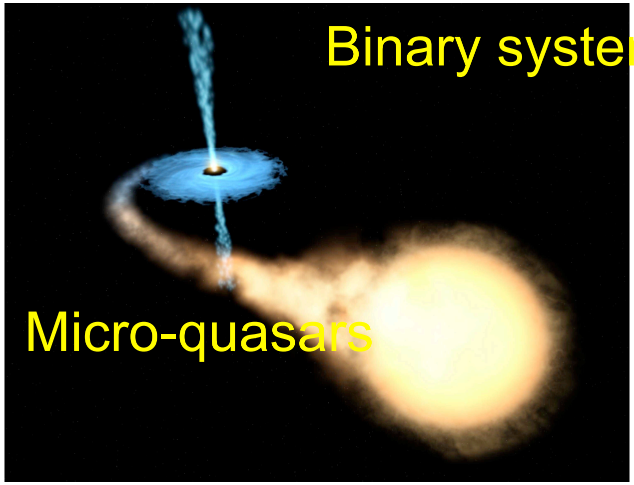
Potential neutrino sources

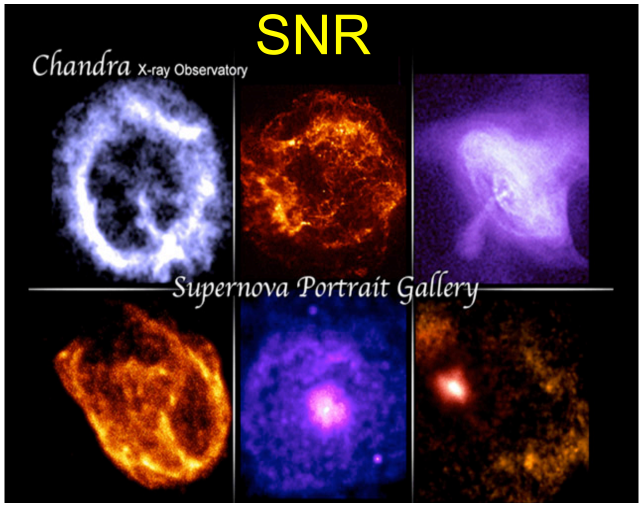
Search for galactic/extragalactic ν sources:

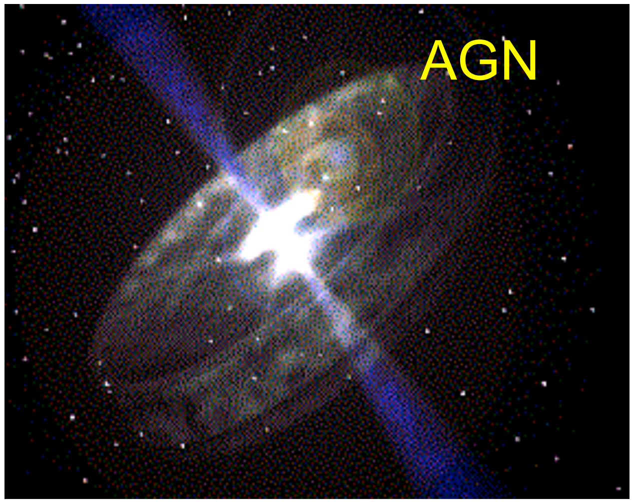
SN remnants, Galactic microquasars

AGN, GRB, …









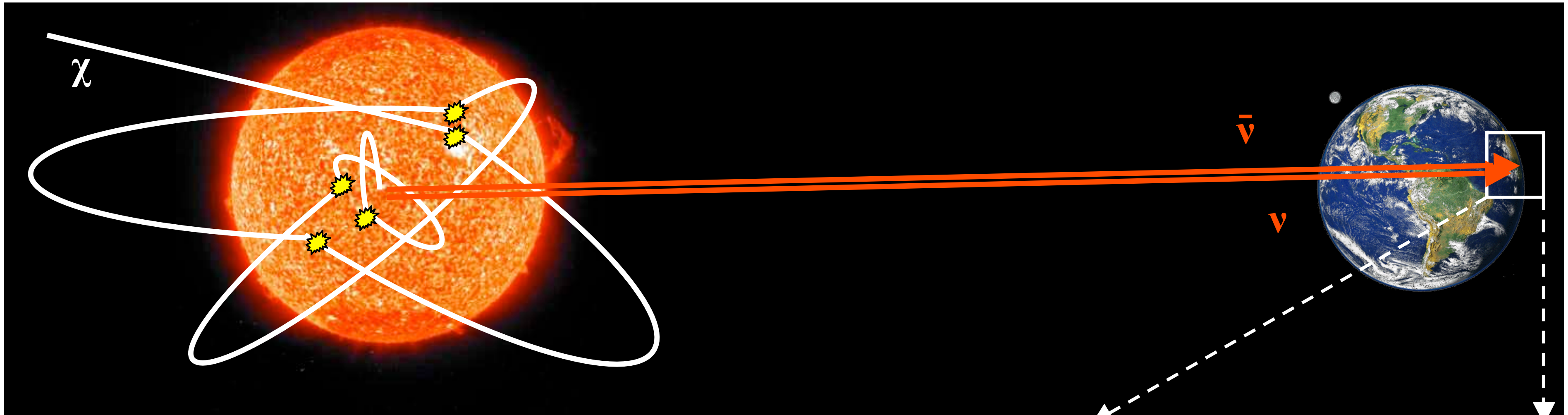
Common property of all potential sources:

Shock waves

Fermi acceleration

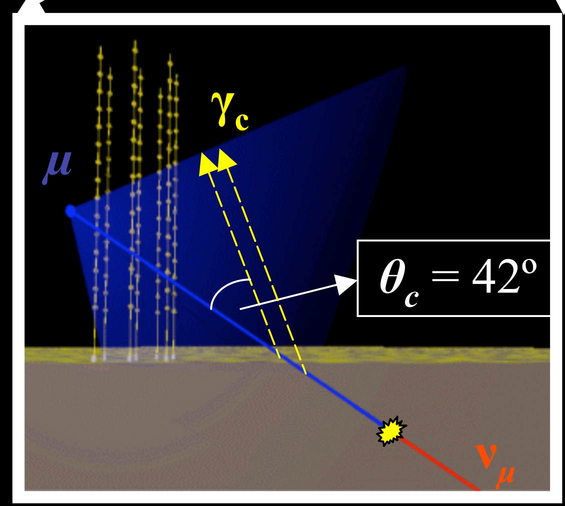
Possible sources of cosmic rays

Indirect detection of WIMPs with a neutrino telescope:

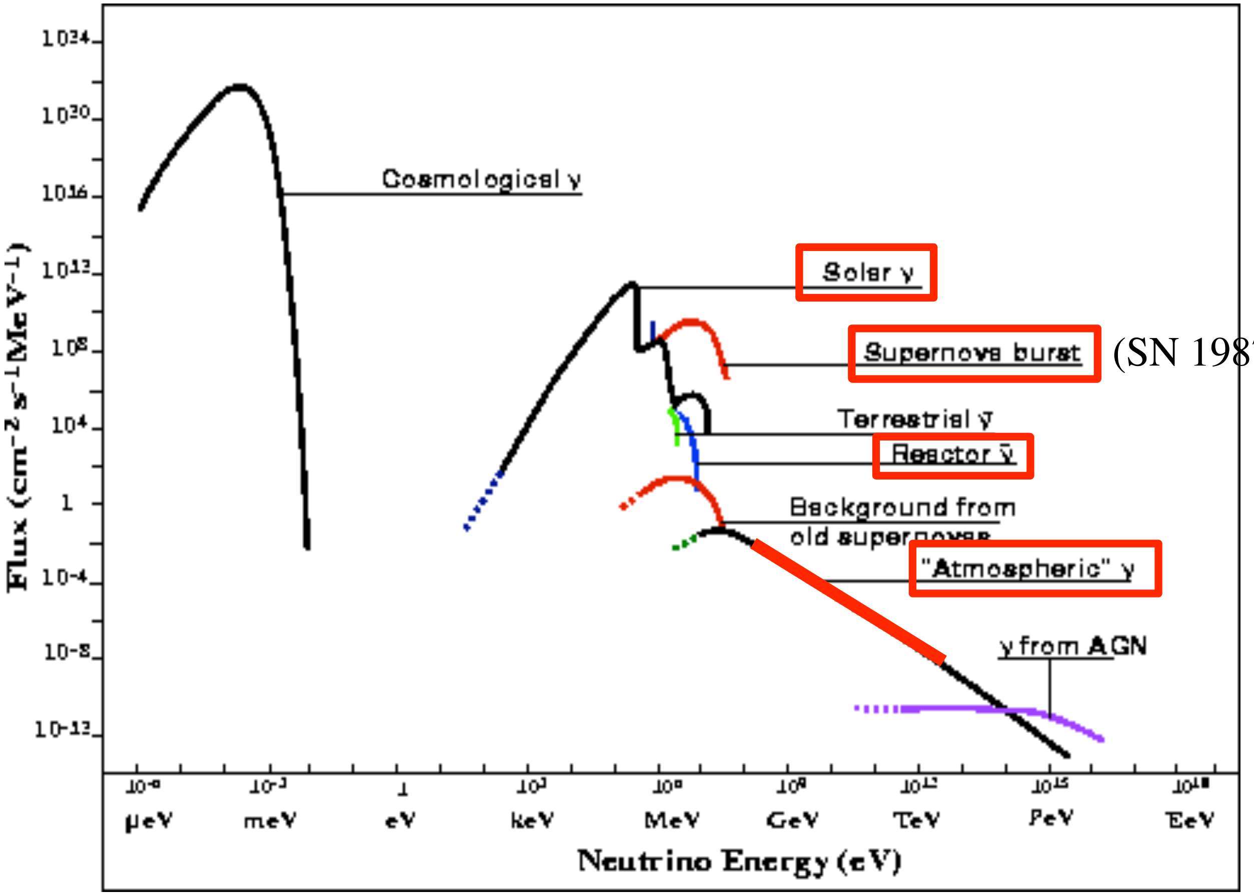


Indirect detection of WIMPs using neutrino telescopes:

- **Relic WIMPs from the Big Bang traversing the universe undergo multiple elastic interactions with inside a massive celestial object (Sun, Earth, center of our galaxy), lose kinetic energy and become gravitationally bound to the object.**
- **Over time, the WIMP density in the core of the object increases. This enhances the WIMP annihilation rate significantly, resulting in a neutrino flux with energies up to 400 GeV that will reach the Earth.**
- **These neutrinos can interact through a CC interaction in the vicinity of a neutrino telescope, producing an energetic muon. When traversing the transparent medium of the telescope, the muon will emit Cherenkov light. By measuring the time & position of the photons using a 3D grid of PMTs, the neutrino track can be reconstructed.**



Neutrino flux on Earth



(SN 1987A)

= measured

(other components are hypothetical)

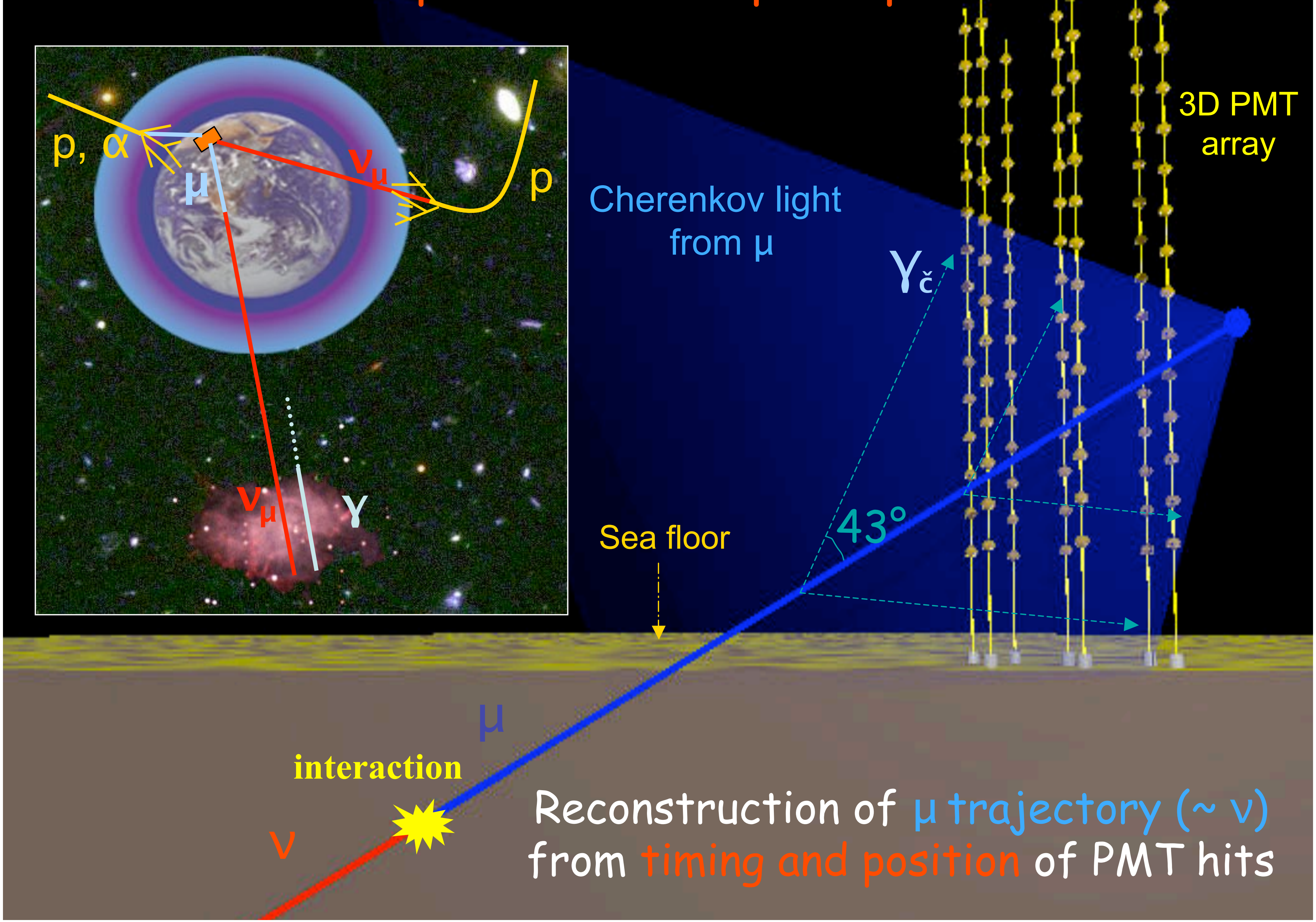
Solar neutrino experiments

Water-Cherenkov Detectors in natural environments

Alternative techniques

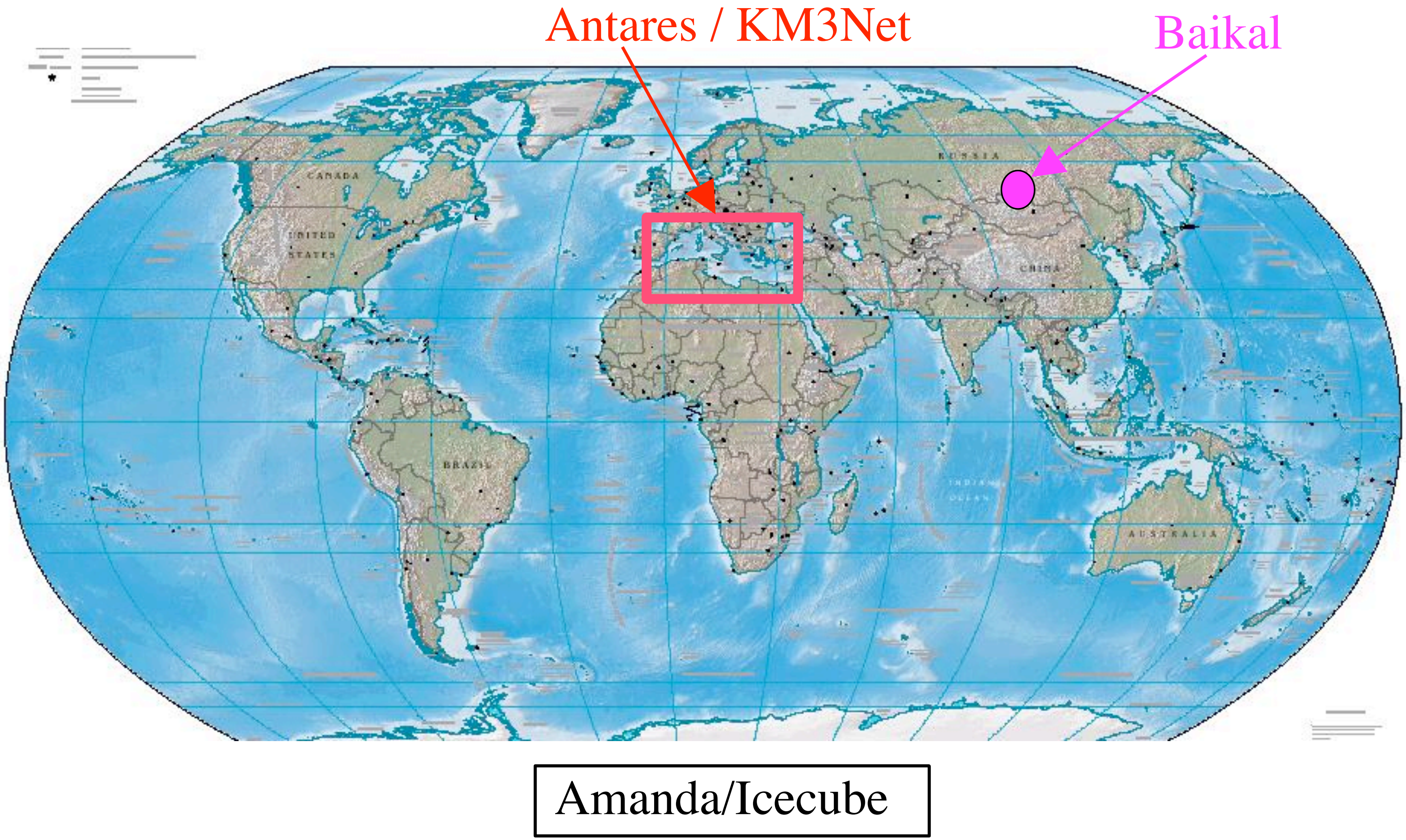
Energy range of Neutrino telescopes {

Neutrino telescope: Detection principle



Reconstruction of μ trajectory (~ ν)
from timing and position of PMT hits

Existing and future projects



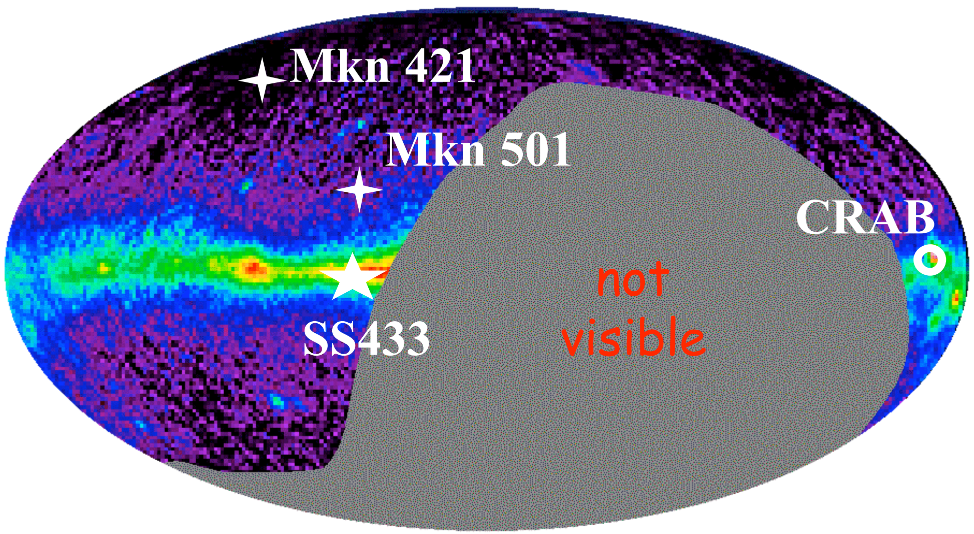
Region of sky observable by neutrino telescopes

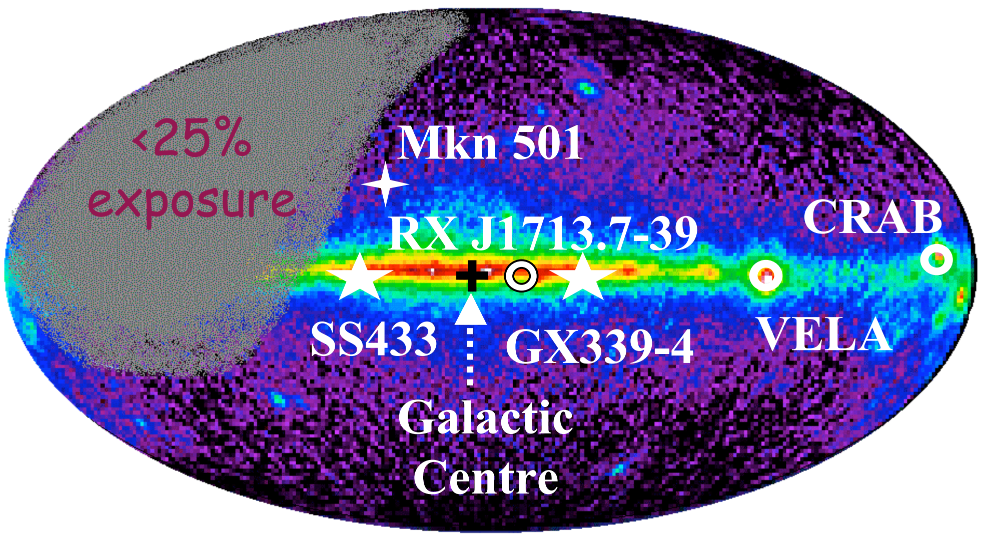
AMANDA (South Pole)

ANTARES (43° North)

under ice → less light background

under water → Less light diffusion → better angular resolution

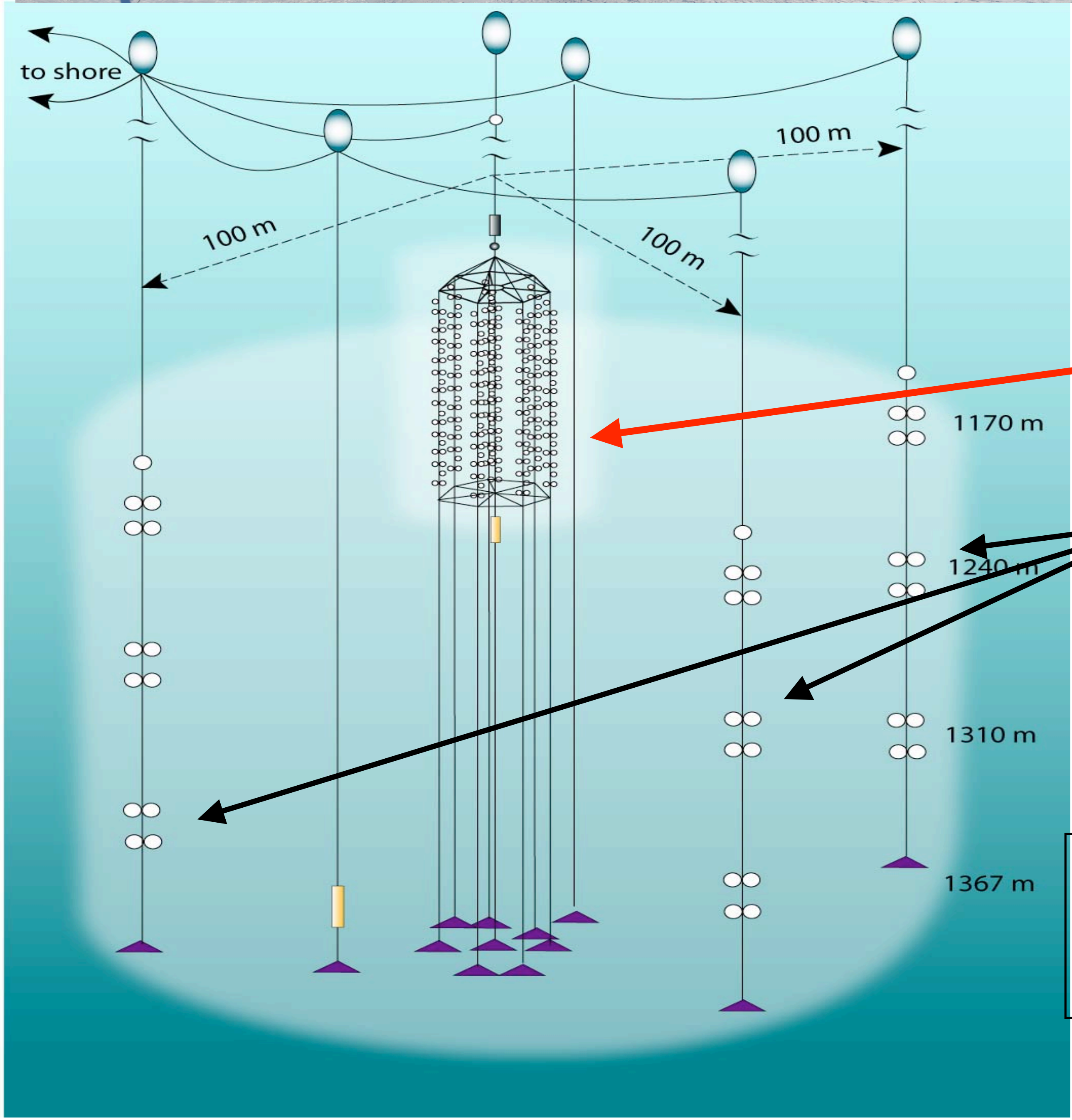




BAIKAL

Collaboration

- Institute for Nuclear Research, Moscow, Russia.
- Irkutsk State University, Russia.
- Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.
- DESY-Zeuthen, Zeuthen, Germany.
- Joint Institute for Nuclear Research, Dubna, Russia.
- Nizhny Novgorod State Technical University, Russia.
- St.Petersburg State Marine University, Russia.
- Kurchatov Institute, Moscow, Russia.



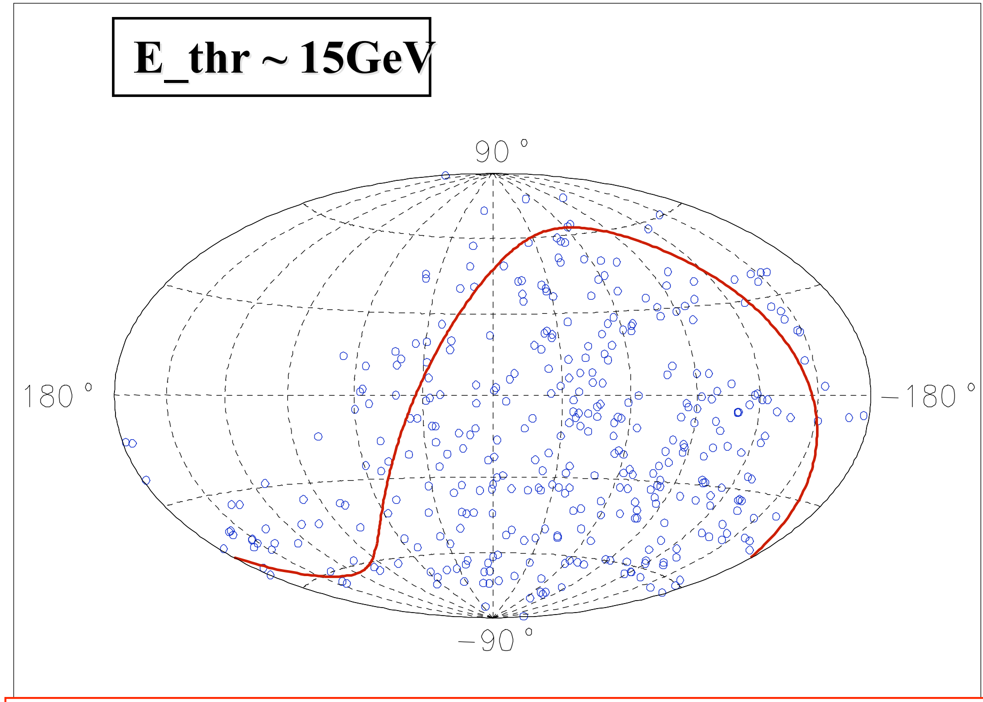
BAIKAL, Ralf Wischnewski

NT200+
=
NT200
+
3 long outer strings

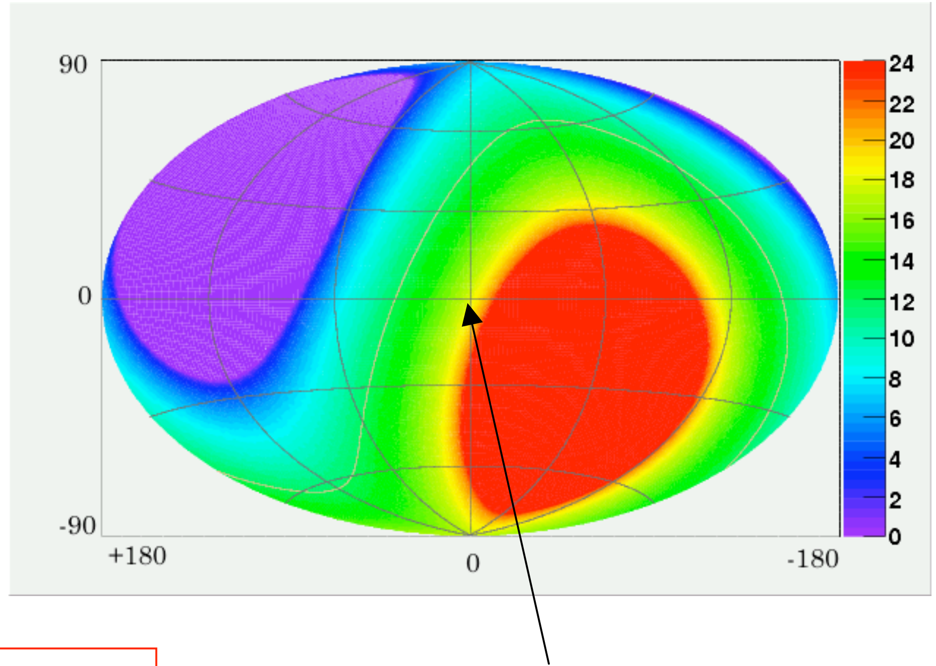
Km³ planned

- **Height = 210m**
- **∅= 200m**
- **Geom.Volume ~ 5 Mton**

Atmospheric Muon-Neutrinos



Skyplot of NT200 neutrino events / 5 years
(galactic coordinates)



Galactic center
visible 18 hours per day

- Data: <u>372 upward ν events</u> (1998-2002). (N_μ(>15GeV)/N_μ(>1GeV)~1/7)
- MC: 385 ev. expected (15%BG).

→ A high statistics neutrino sample for Point-Source Search, incl. GalCenter. **No evidence for non-atmosph. ν's.**

ICECUBE / AMANDA

IceCube

IceTop

Air shower detector

80 pairs of ice

Cherenkov tanks

Threshold ~ 300 TeV

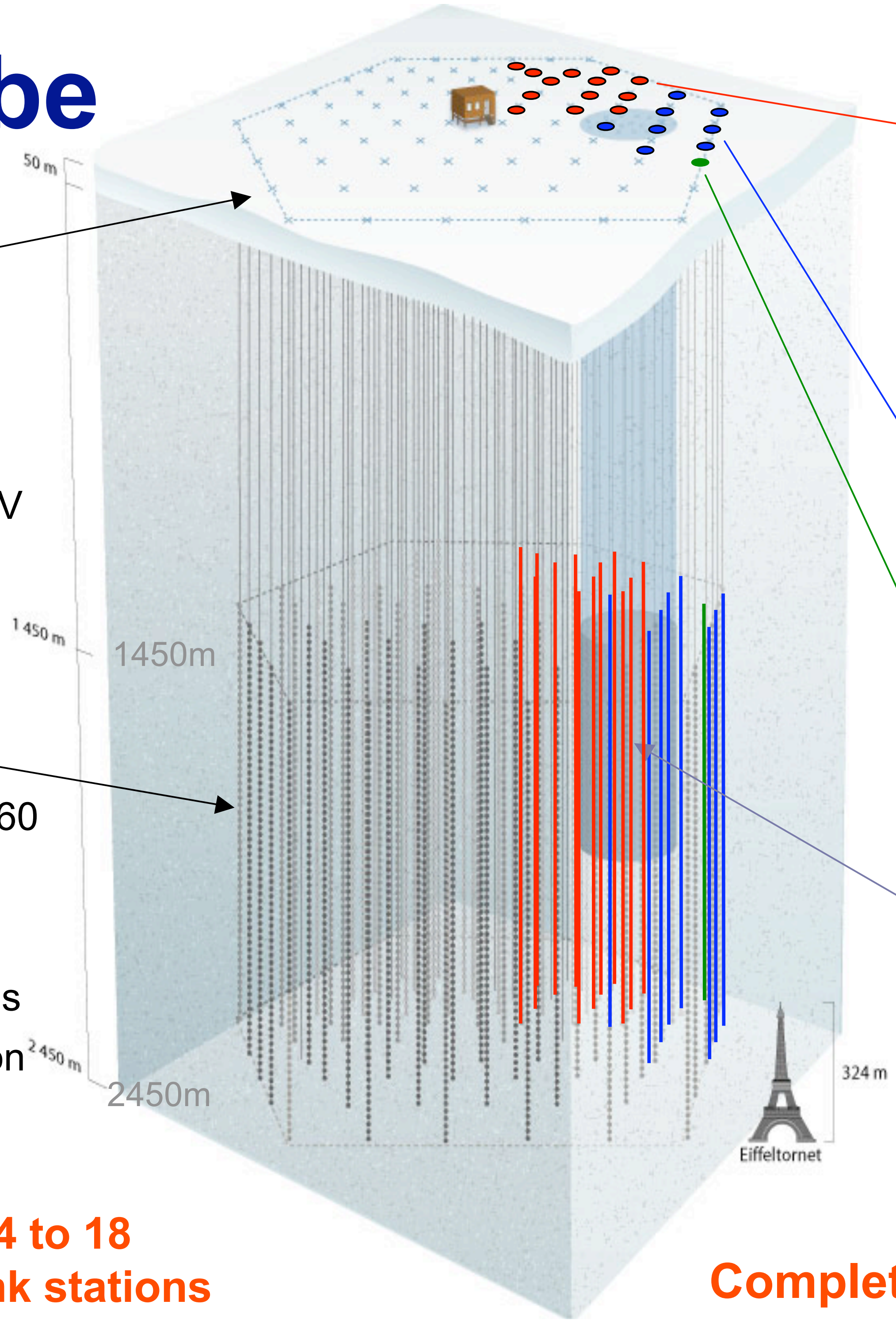
InIce

Planned 80 strings of 60

optical modules each

17 m between modules

125 m string separation



2006-2007:

13 strings deployed

Current configuration

- 22 strings
- 52 surface tanks

2005-2006: 8 strings

2004-2005 : 1 string

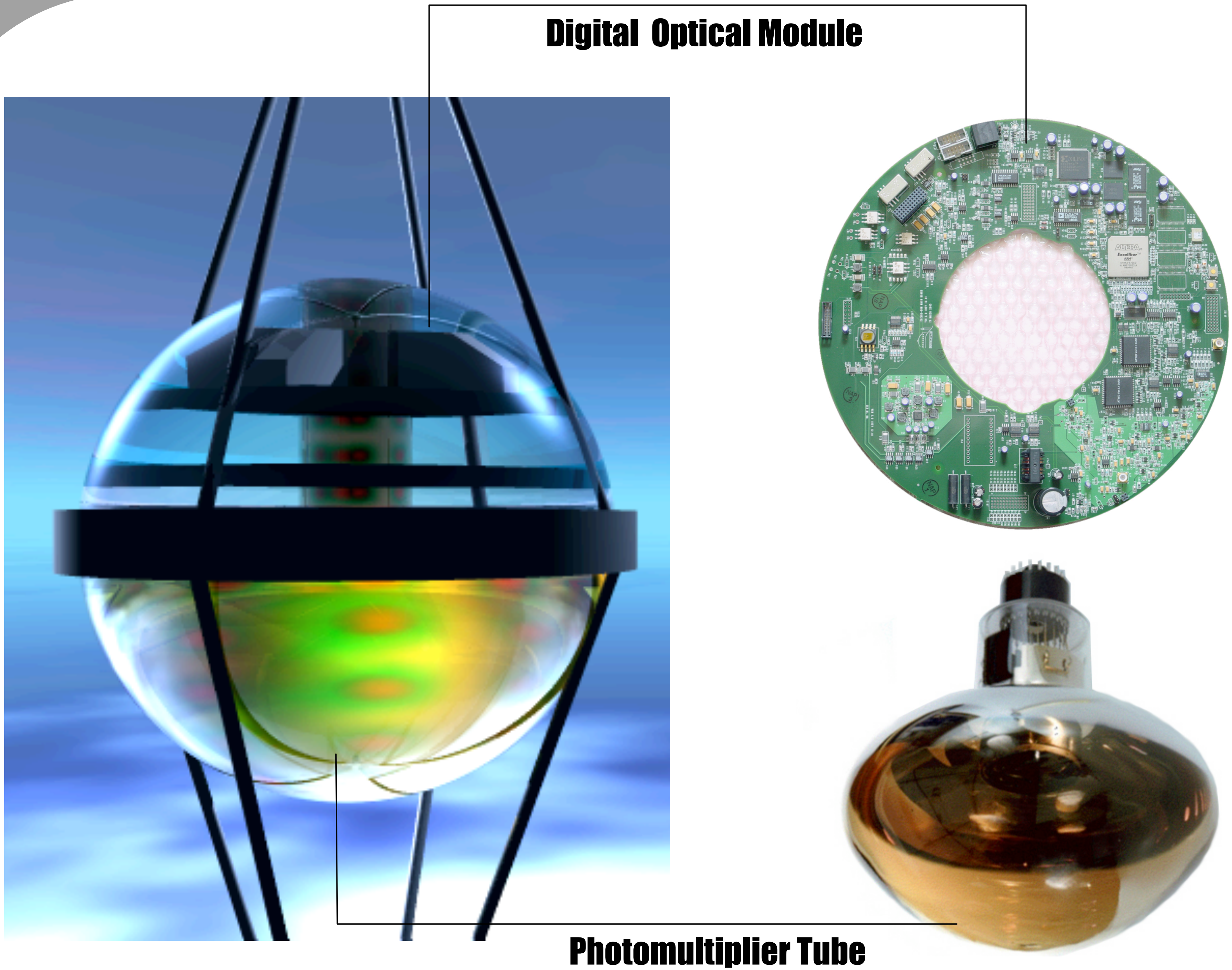
AMANDA-II

19 strings

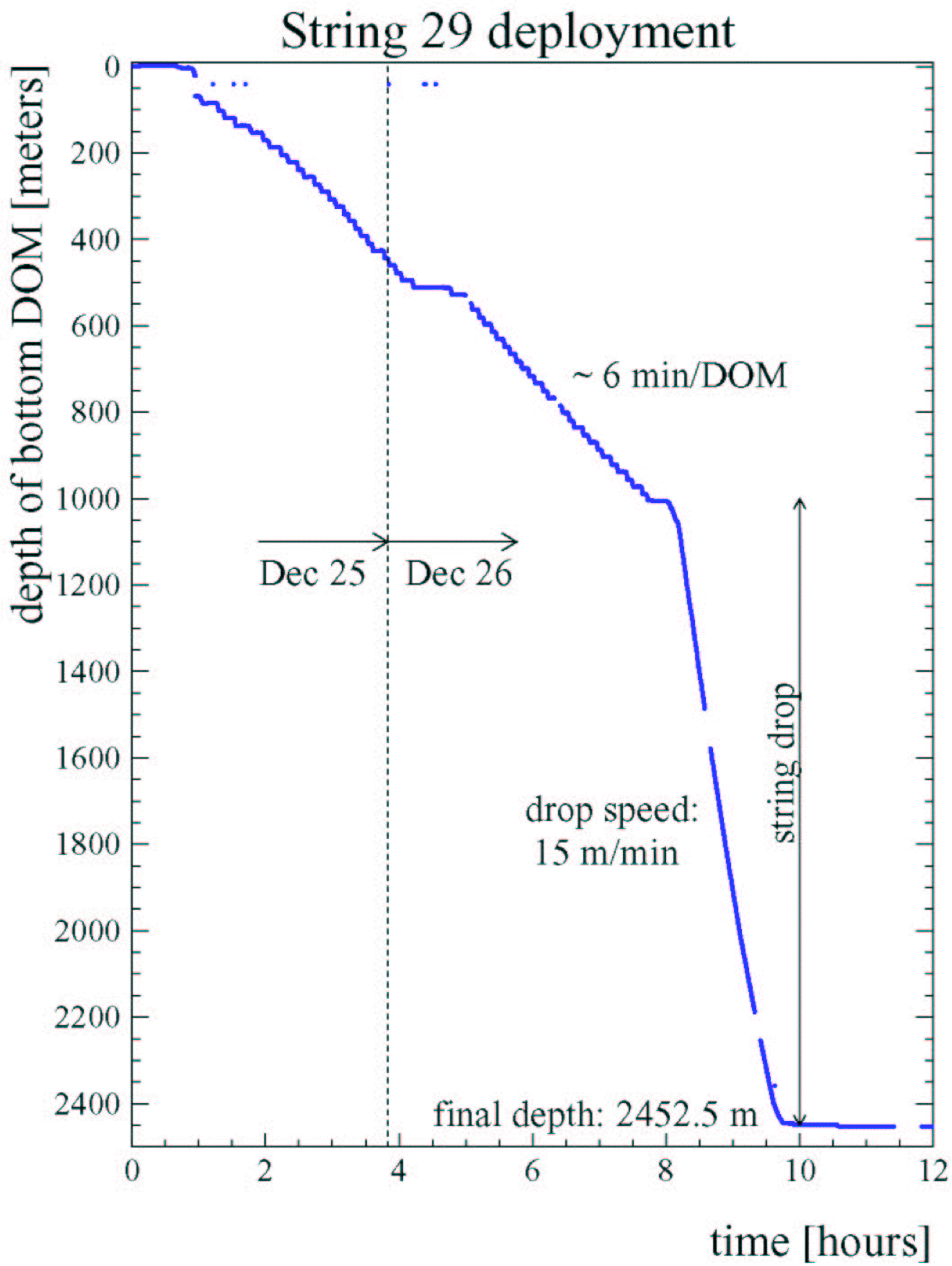
677 modules

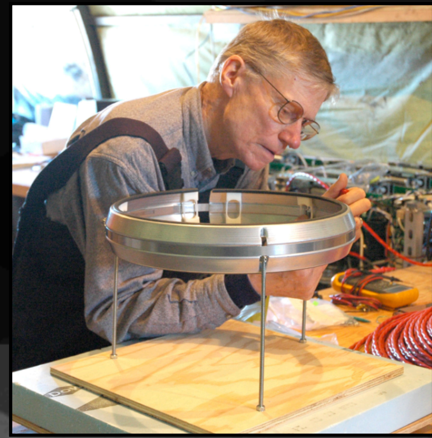
2007/08: add 14 to 18 strings and tank stations

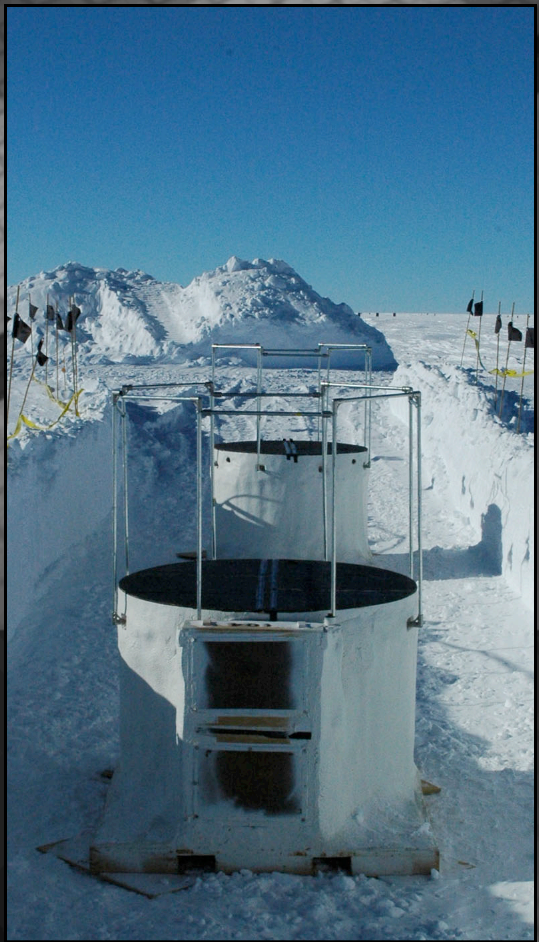
Completion by 2011.

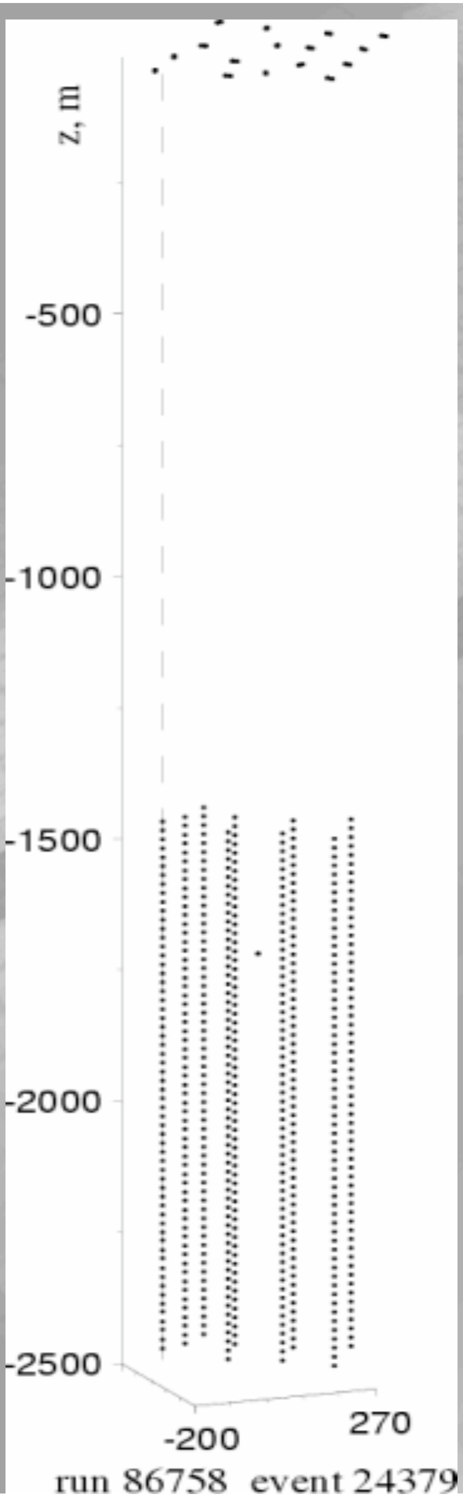

Digital Optical Module
Photomultiplier Tube


String cable 2500 m   Weight ~6 tons
11180 LBS


String 29 deployment
depth of bottom DOM [meters]
time [hours]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
0
2
4
6
8
10
12
~ 6 min/DOM
Dec 25
Dec 26
drop speed:
15 m/min
string drop
final depth: 2452.5 m



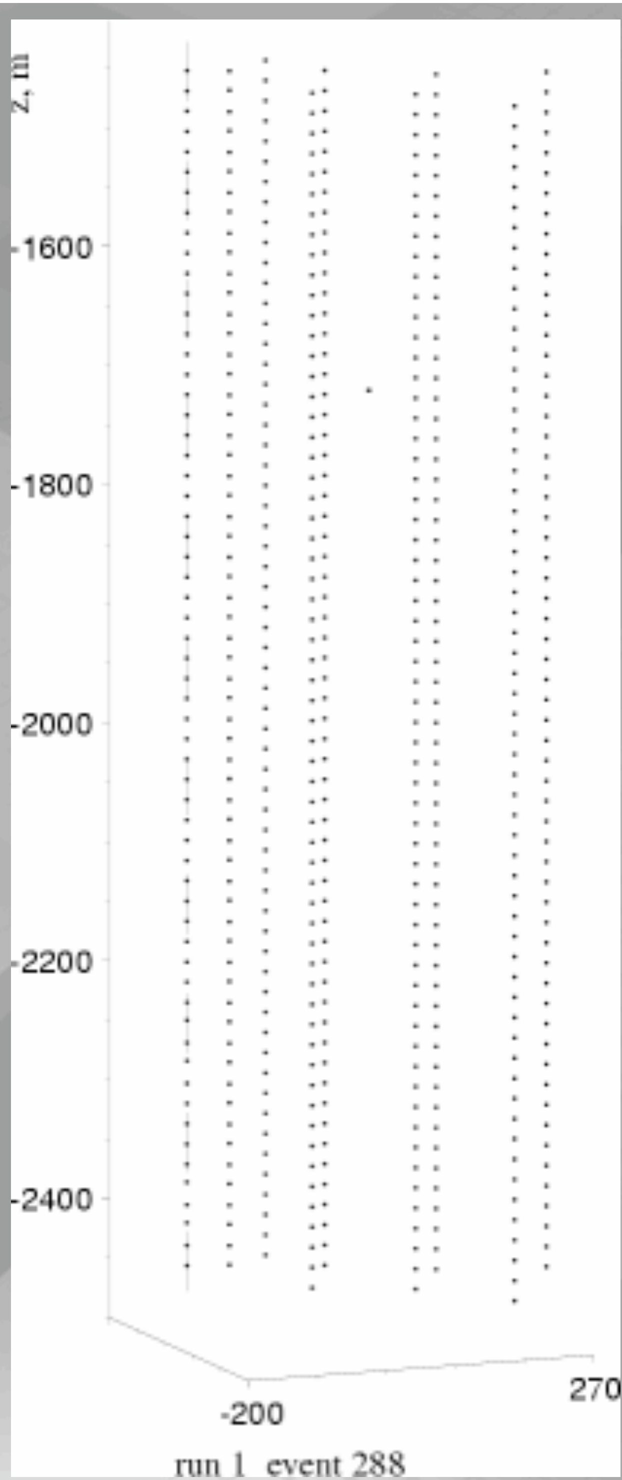




IceCube/IceTop coincident event

sample of events

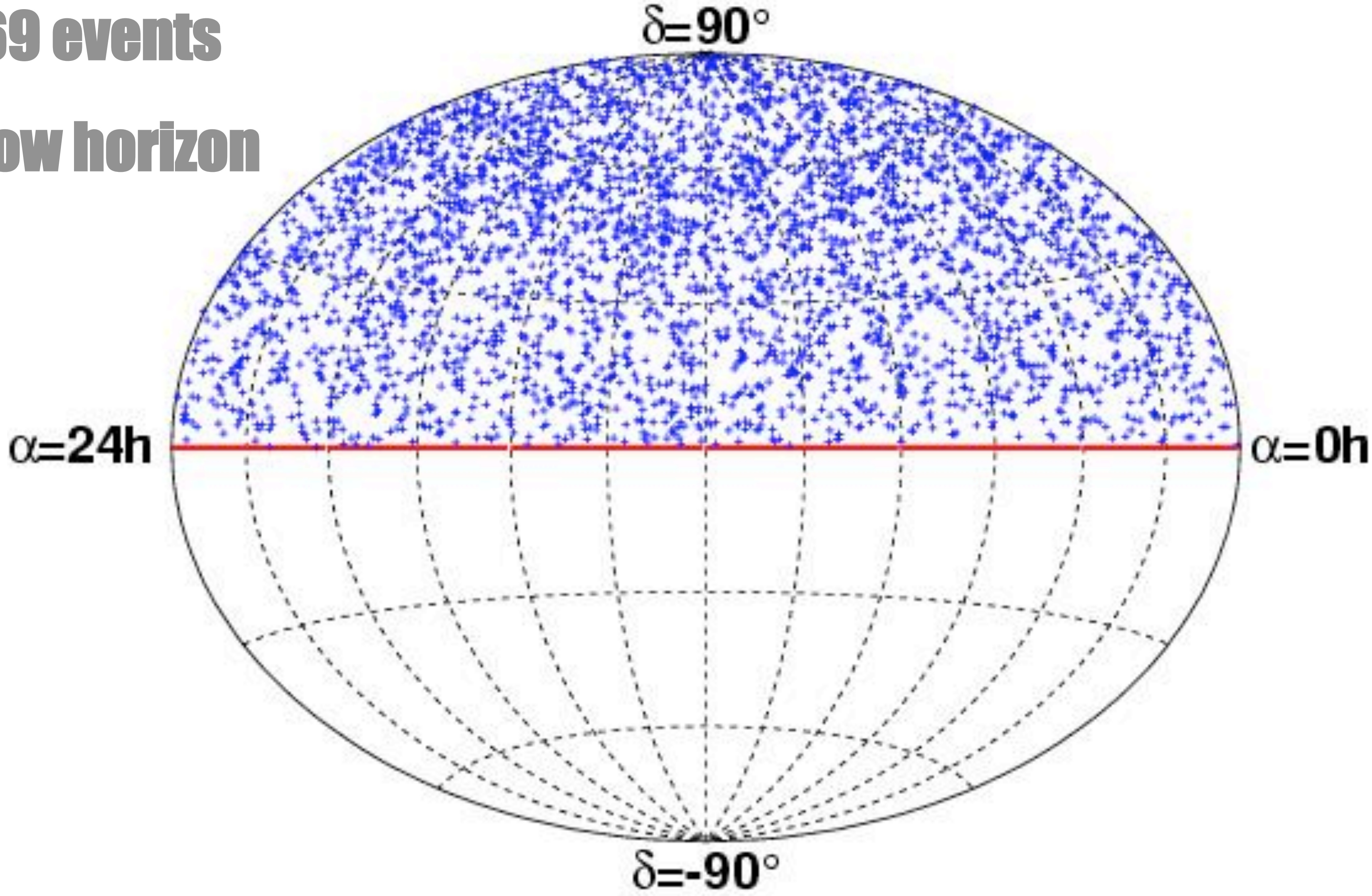
first IceCube neutrino

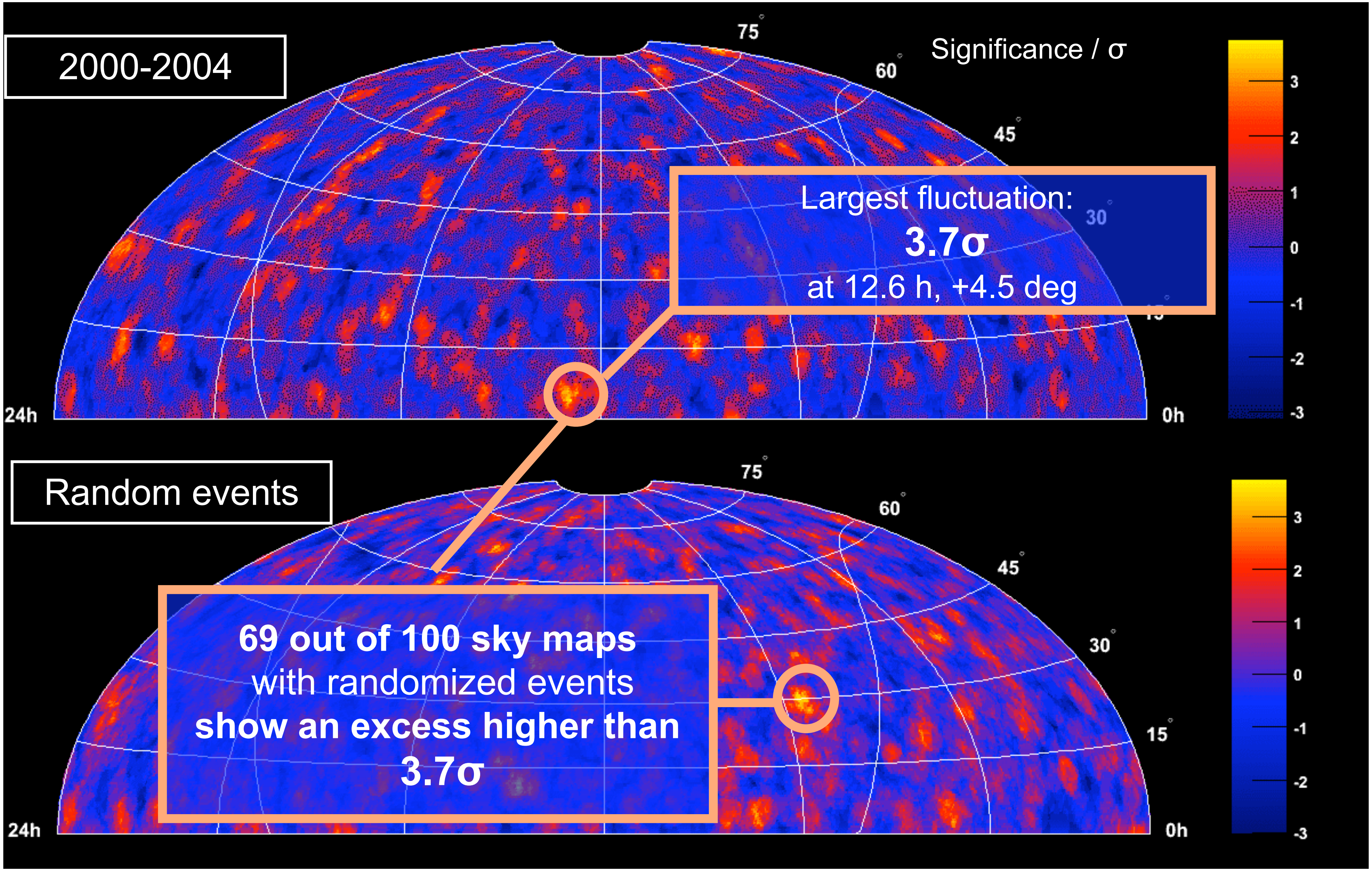


AMANDA skyplot 2000-2003

3369 events

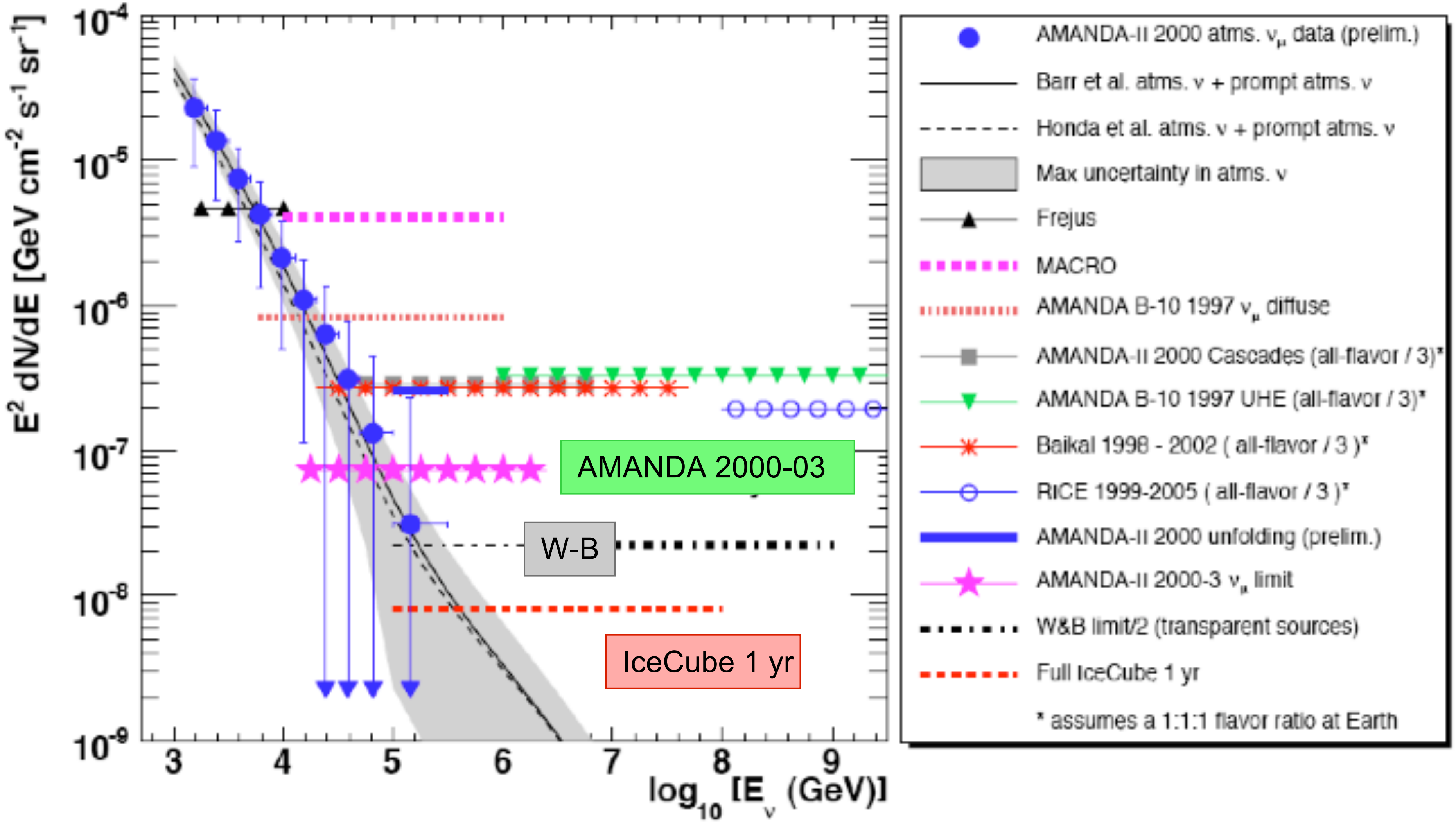
below horizon




2000-2004
Significance / σ
75°
60°
45°
30°
15°
24h
0h
3
2
1
0
-1
-2
-3
Largest fluctuation:
3.7σ
at 12.6 h, +4.5 deg
Random events
69 out of 100 sky maps
with randomized events
show an excess higher than
3.7σ

Search for diffuse ν with hard spectrum

New results from 4 years Amanda

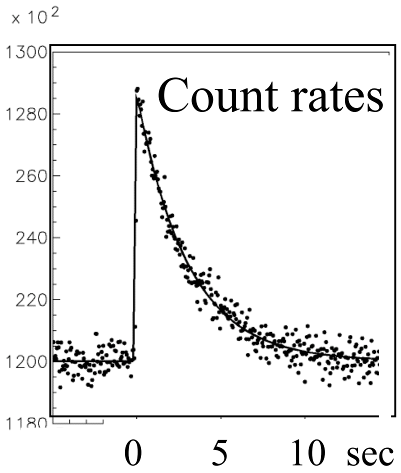


Achterberg et al., astro-ph/0705.1315

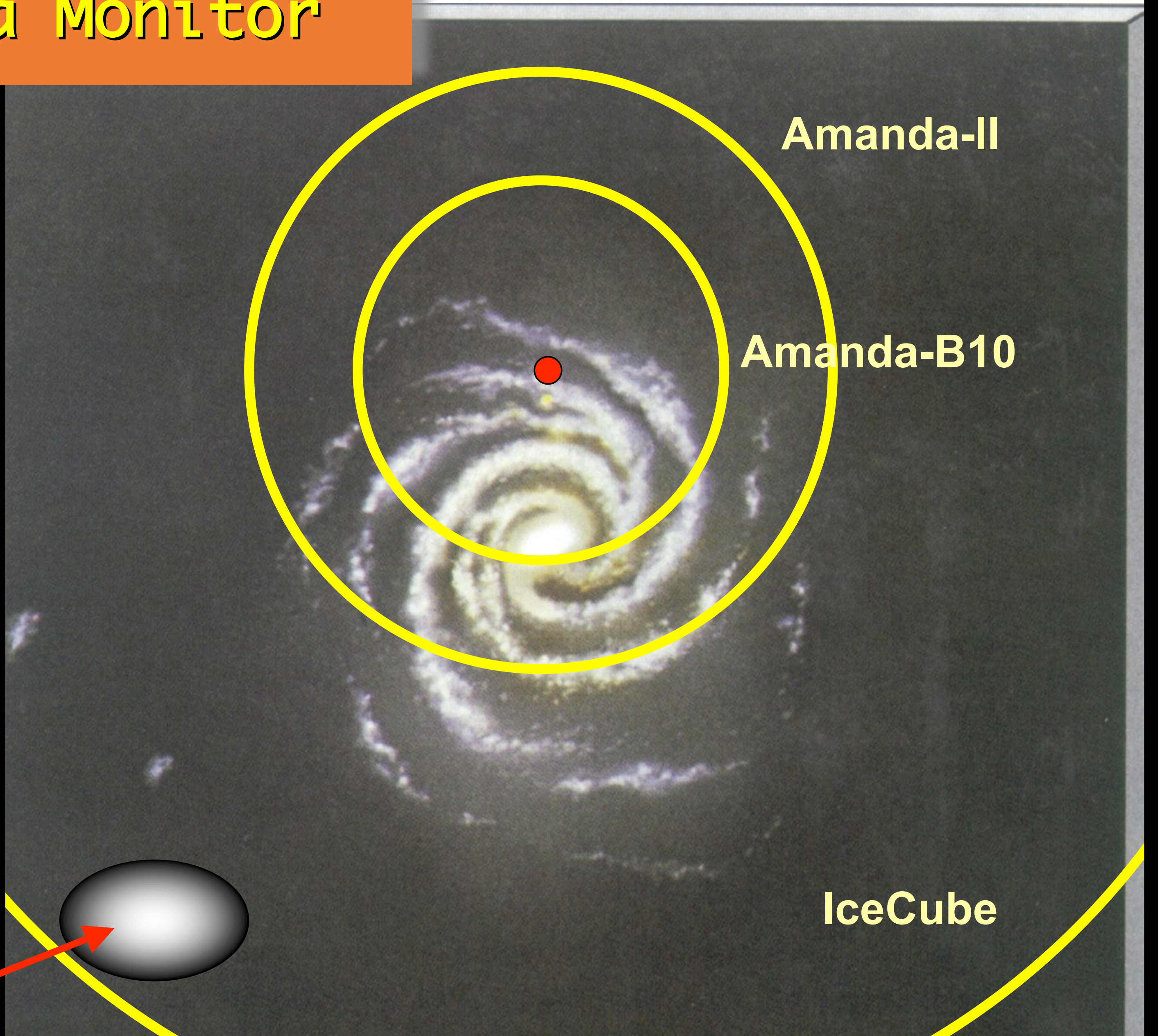
Supernova Monitor

B10:
60% of Galaxy

A-II:
95% of Galaxy

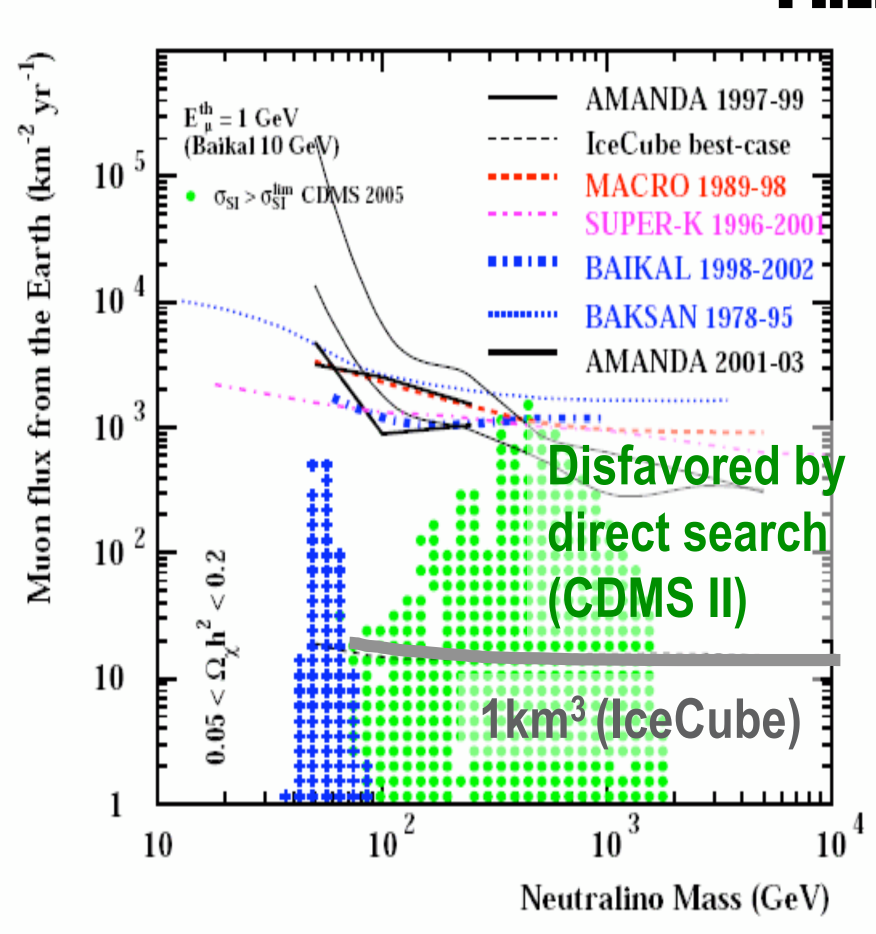


IceCube:
up to LMC

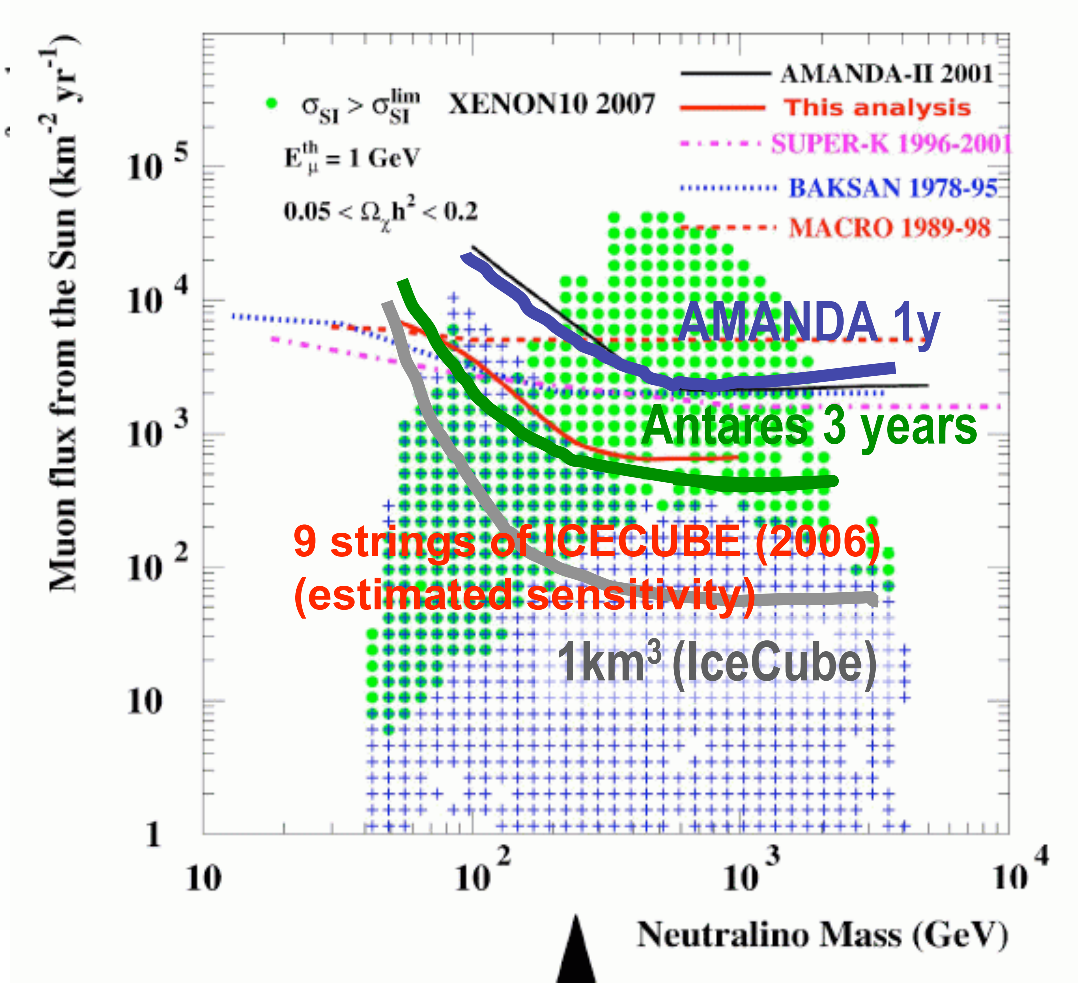


WIMP search --- new results

PRELIMINARY



Limits on muon flux from Earth



Limits on muon flux from Sun

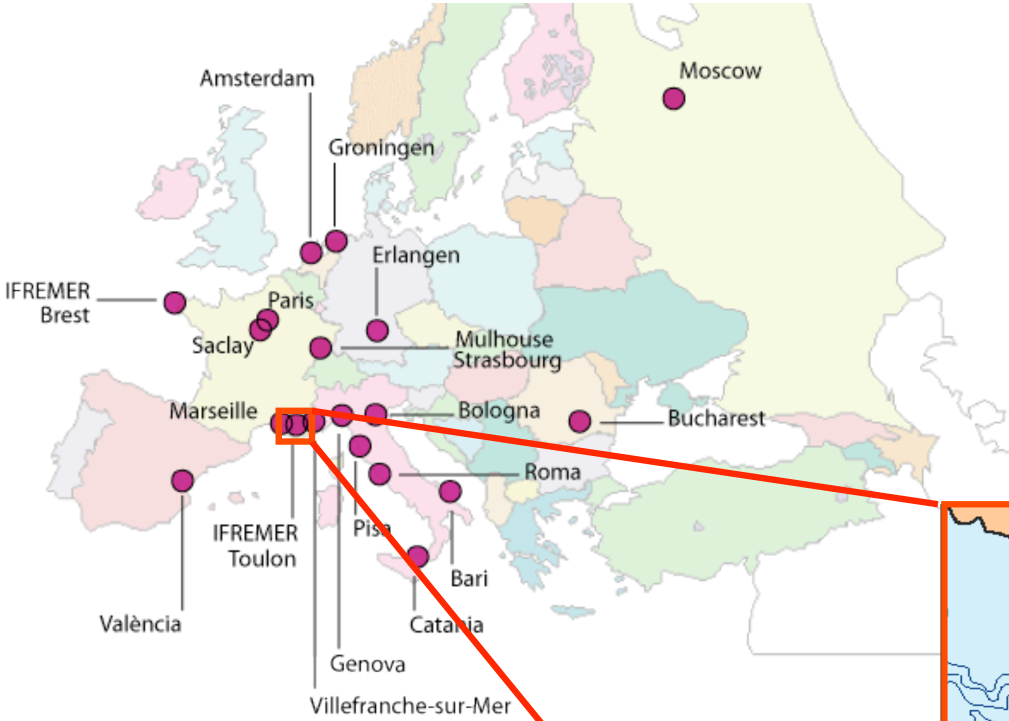
ANTARES

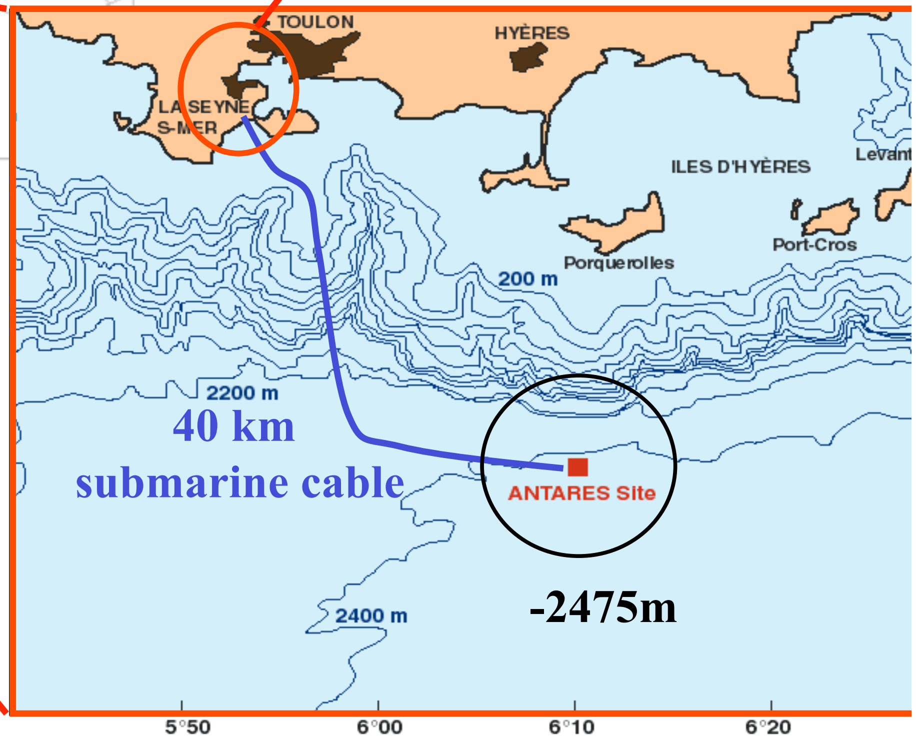
- 1996-2002
  Site exploration and R&D

- 2002-2008
  Construction of 12 lines

- 2008-2013…
  Operation for science

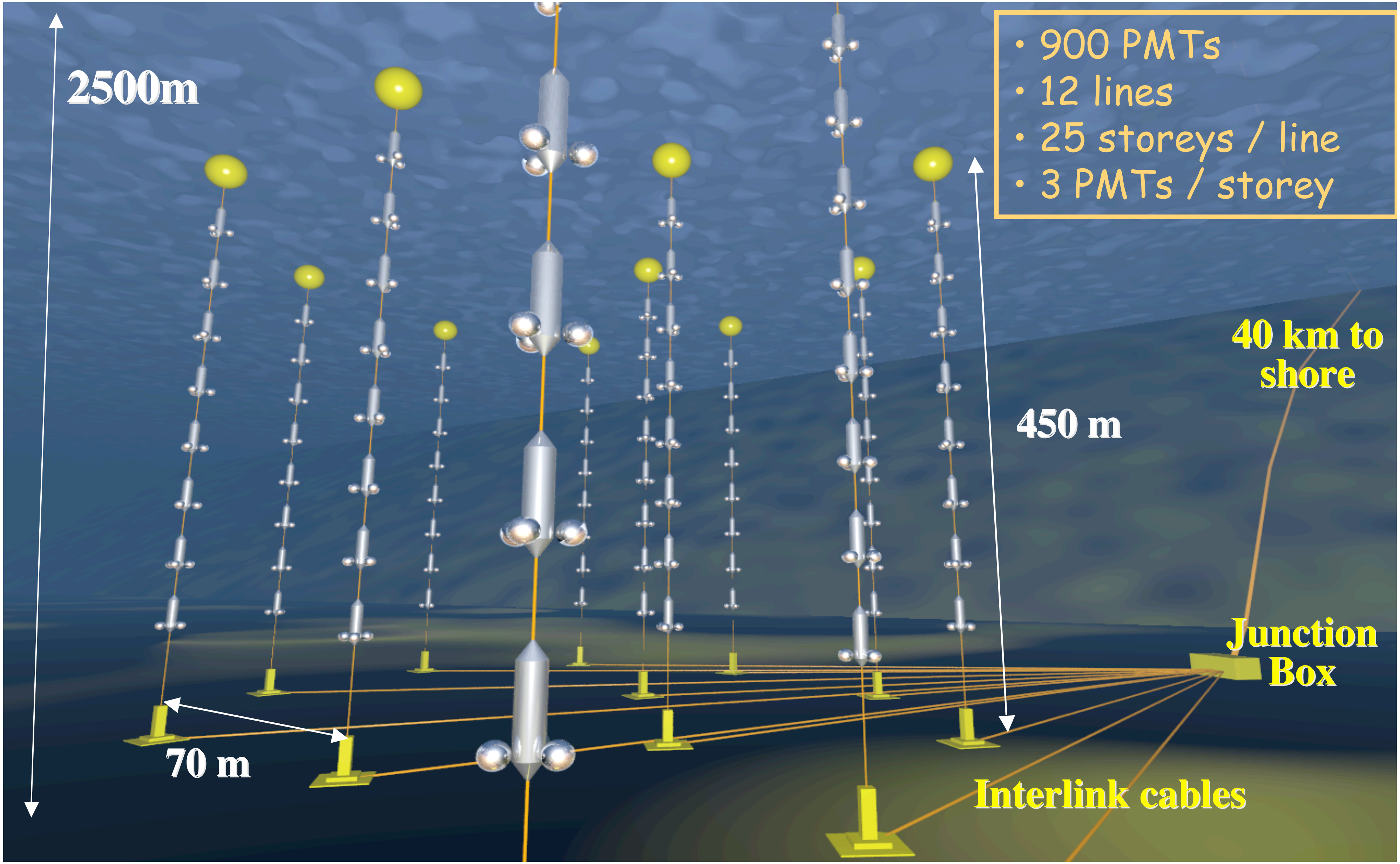
ANTARES Collaboration & detector site





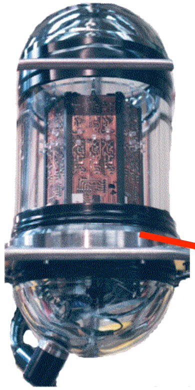
23 Institutes from
7 European countries

The ANTARES detector

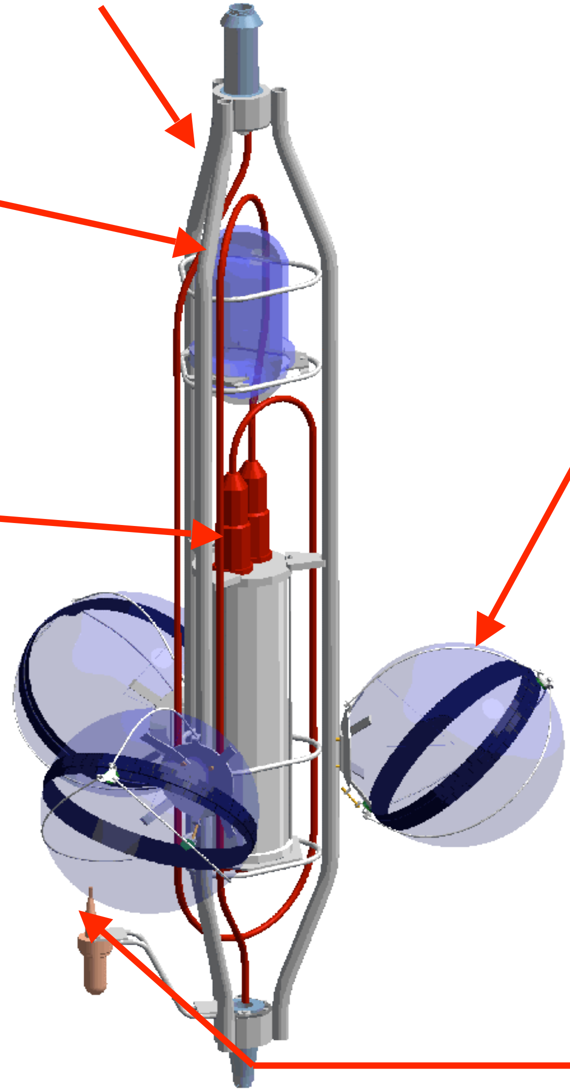


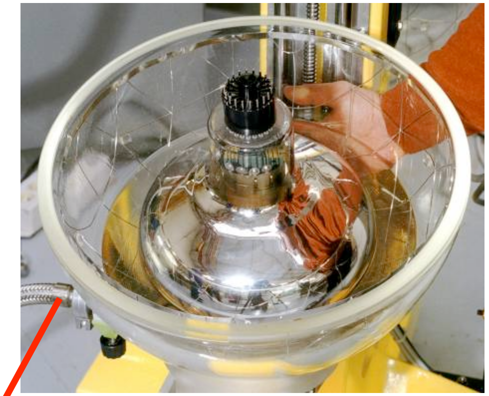
Basic detector element: storey

Optical Beacon
with blue LEDs:
timing calibration

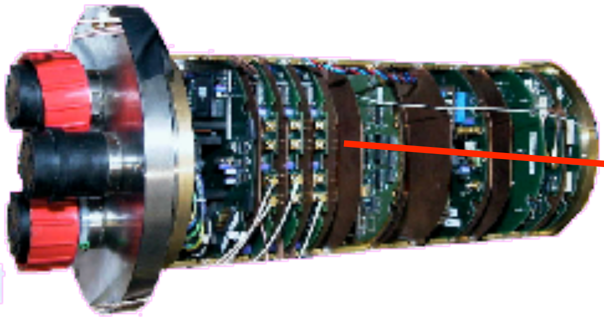


titanium frame: *support structure*



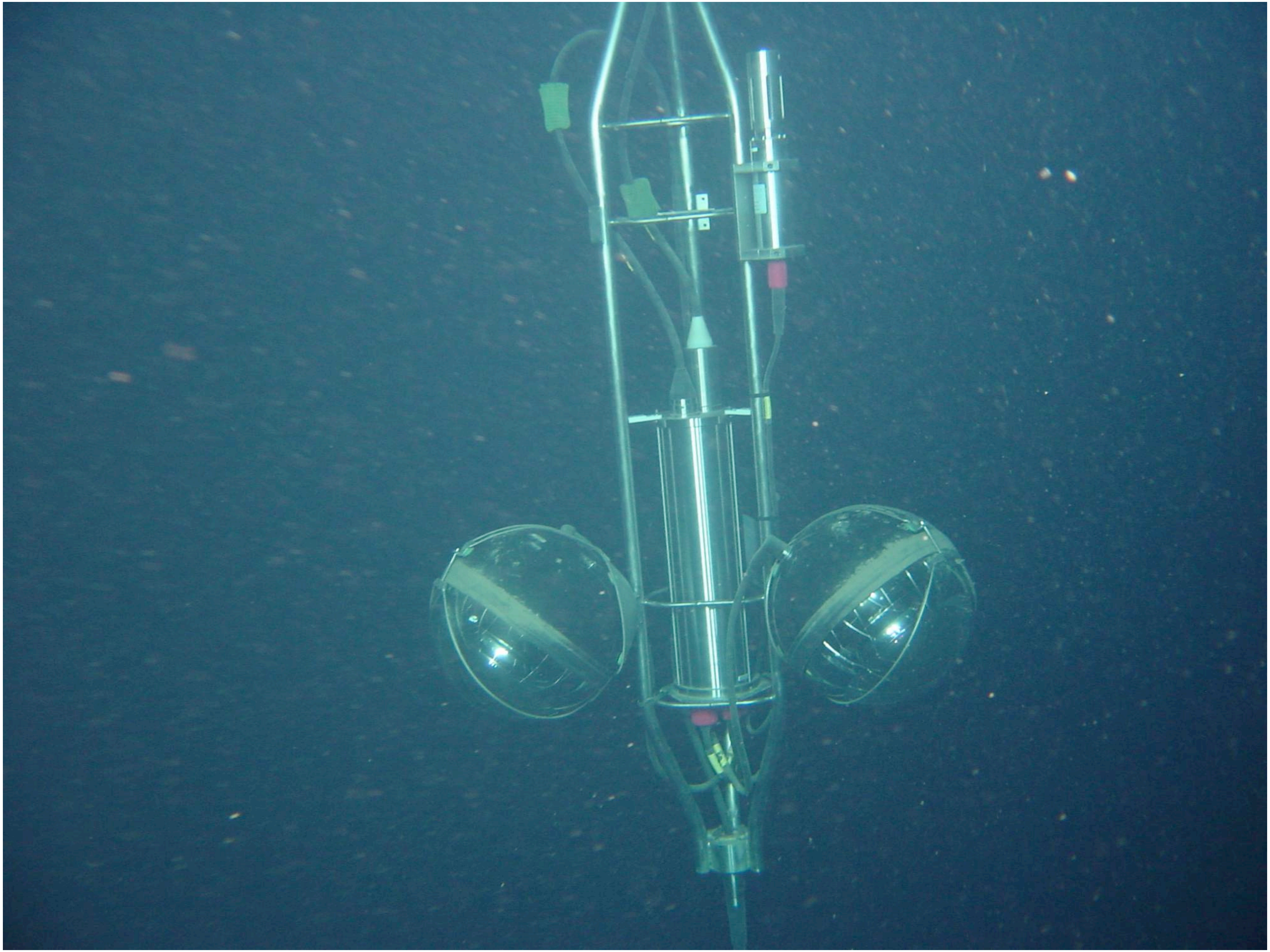


Optical Module:
10″ Hamamatsu PMT
in 17″ glass sphere
(σ_{TTS} ≈1.3 ns)
photon detection

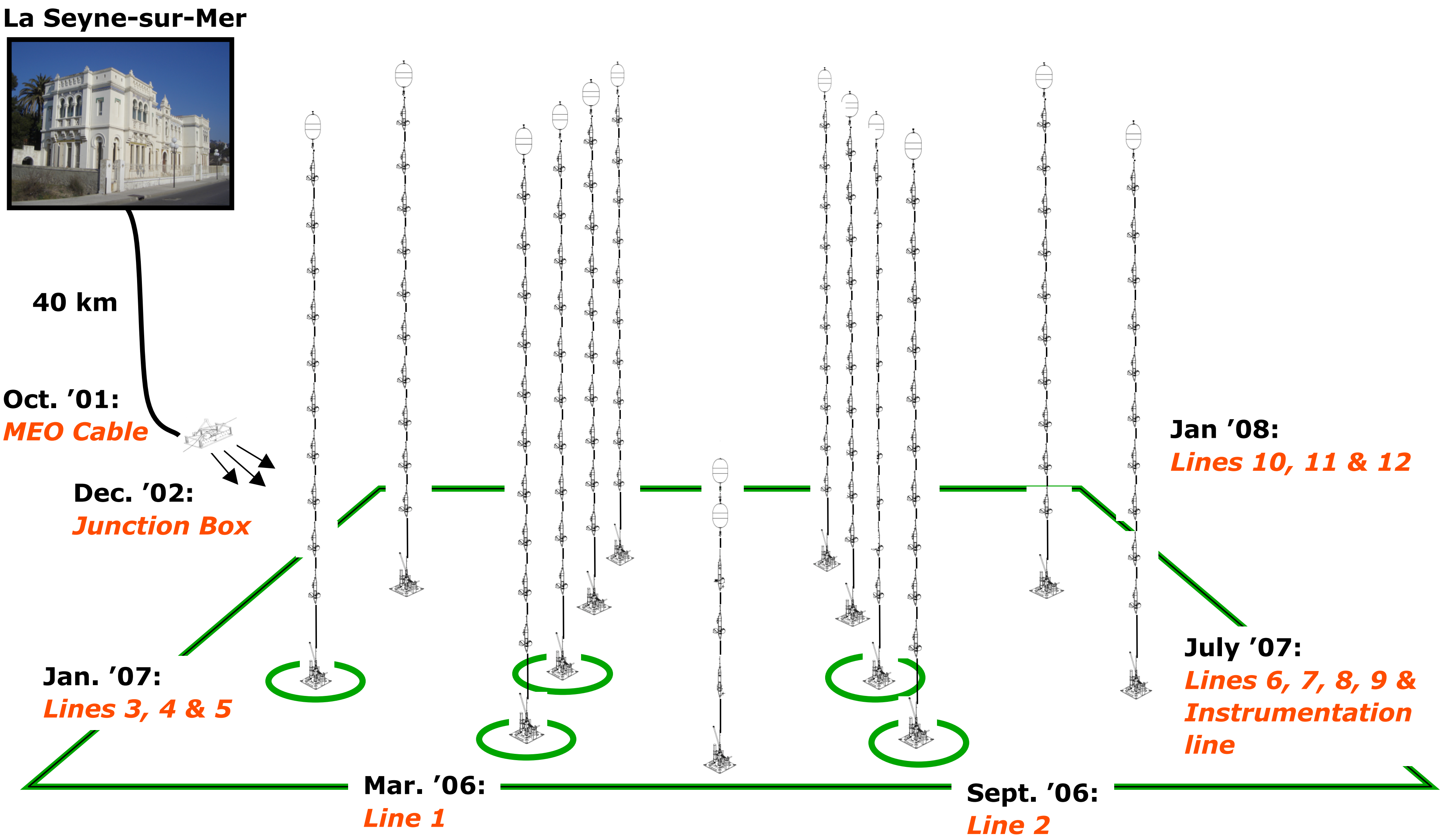


Local Control Module
(in Ti cylinder):
Front-end ASIC,
DAQ/SC, DWDM,
Clock, tilt/compass,
power distribution…

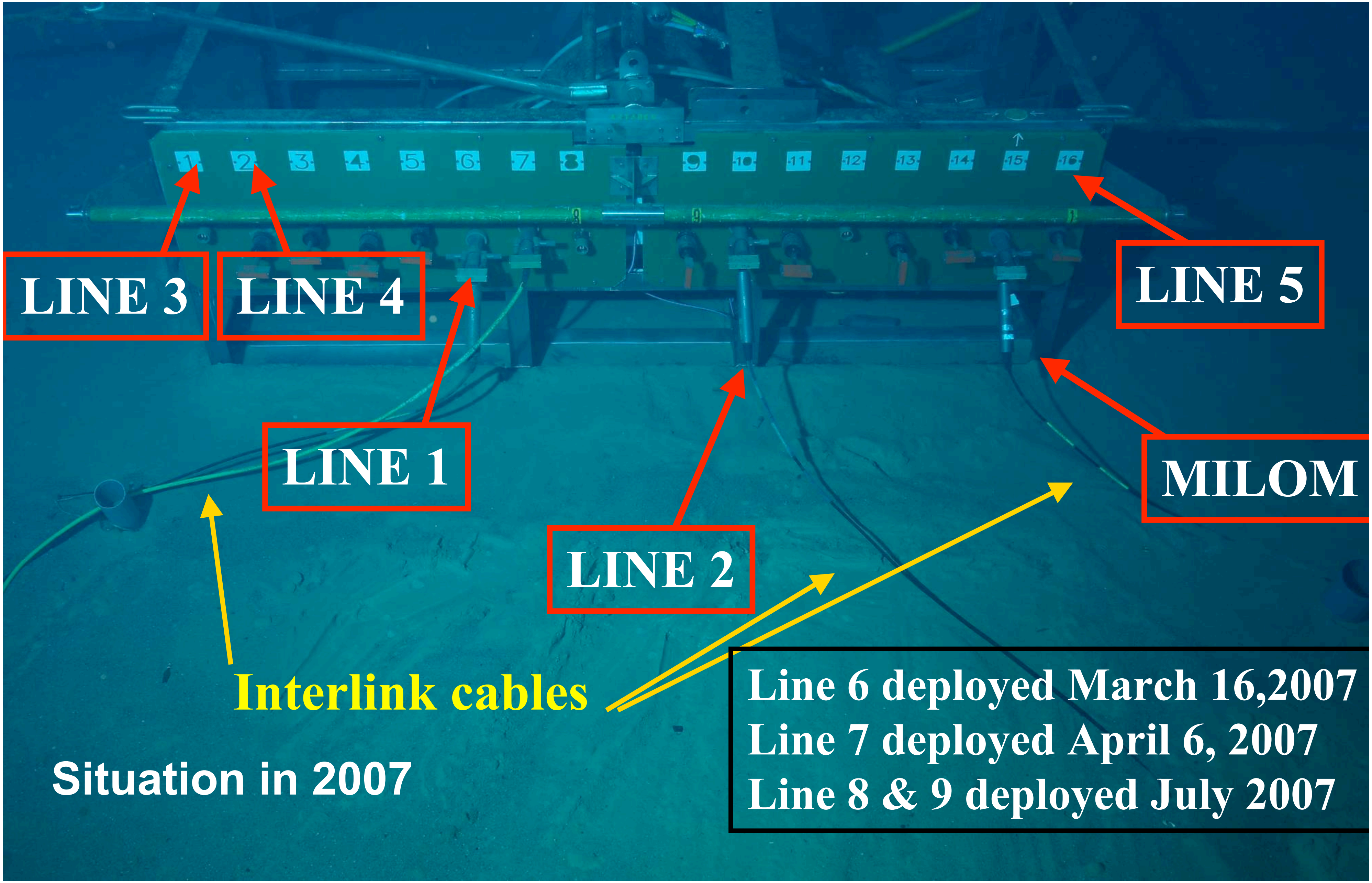
Hydrophone
acoustic positioning



Status of ANTARES



Junction Box at present time



Line 1

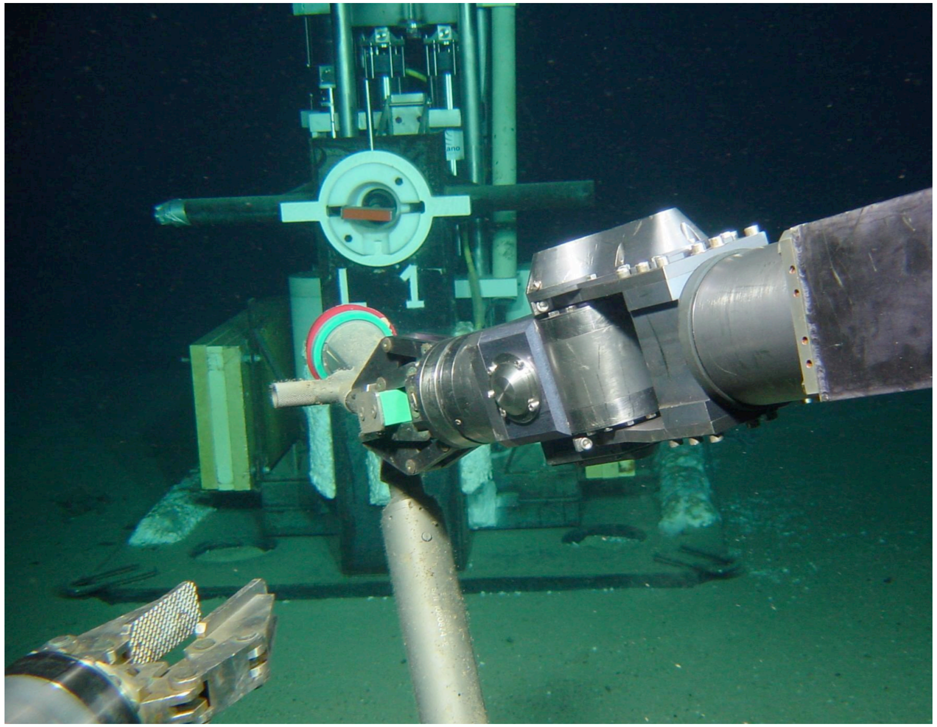
Operational since March 2006

Line deployment with CASTOR

Connections with IFREMER submersibles

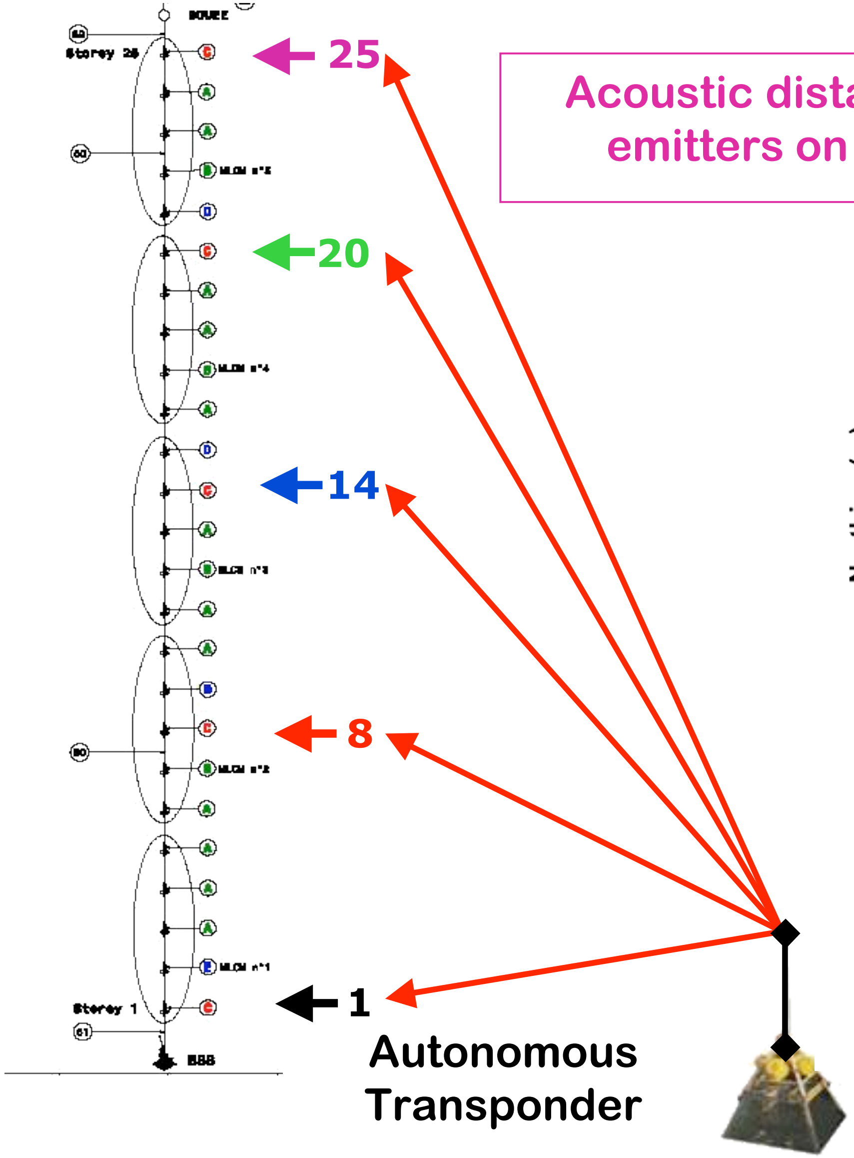
Connection of first line

ROV VICTOR

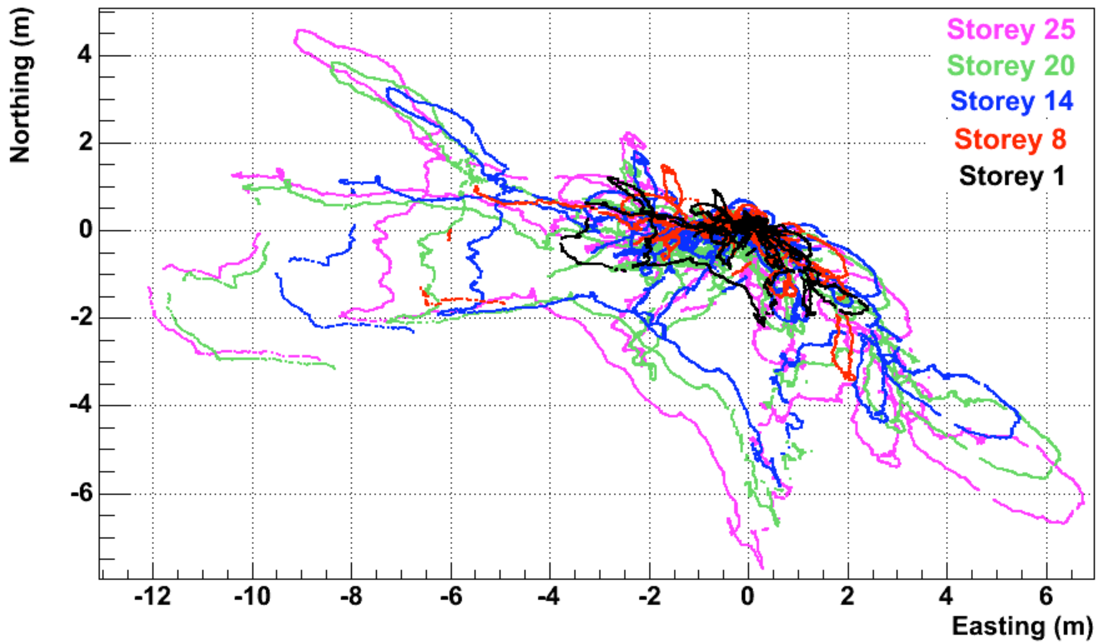


Data from acoustic positioning system

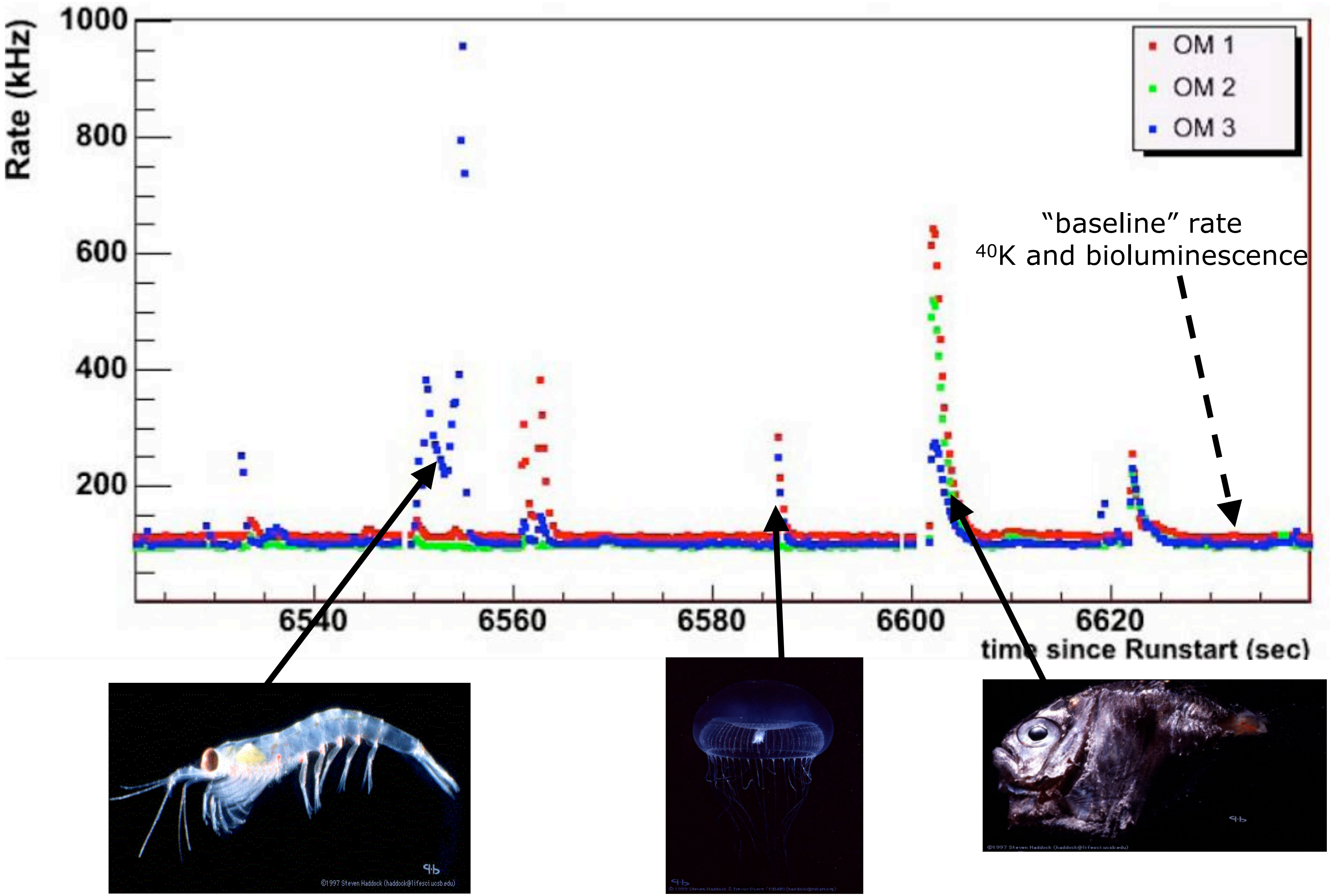
Acoustic distance measurement of hydrophones from fixed emitters on MILOM anchor + autonomous transponders



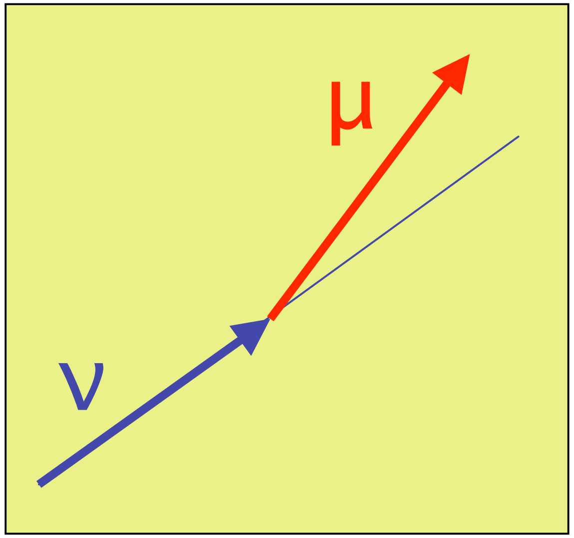
Position of hydrophone relative to line base location

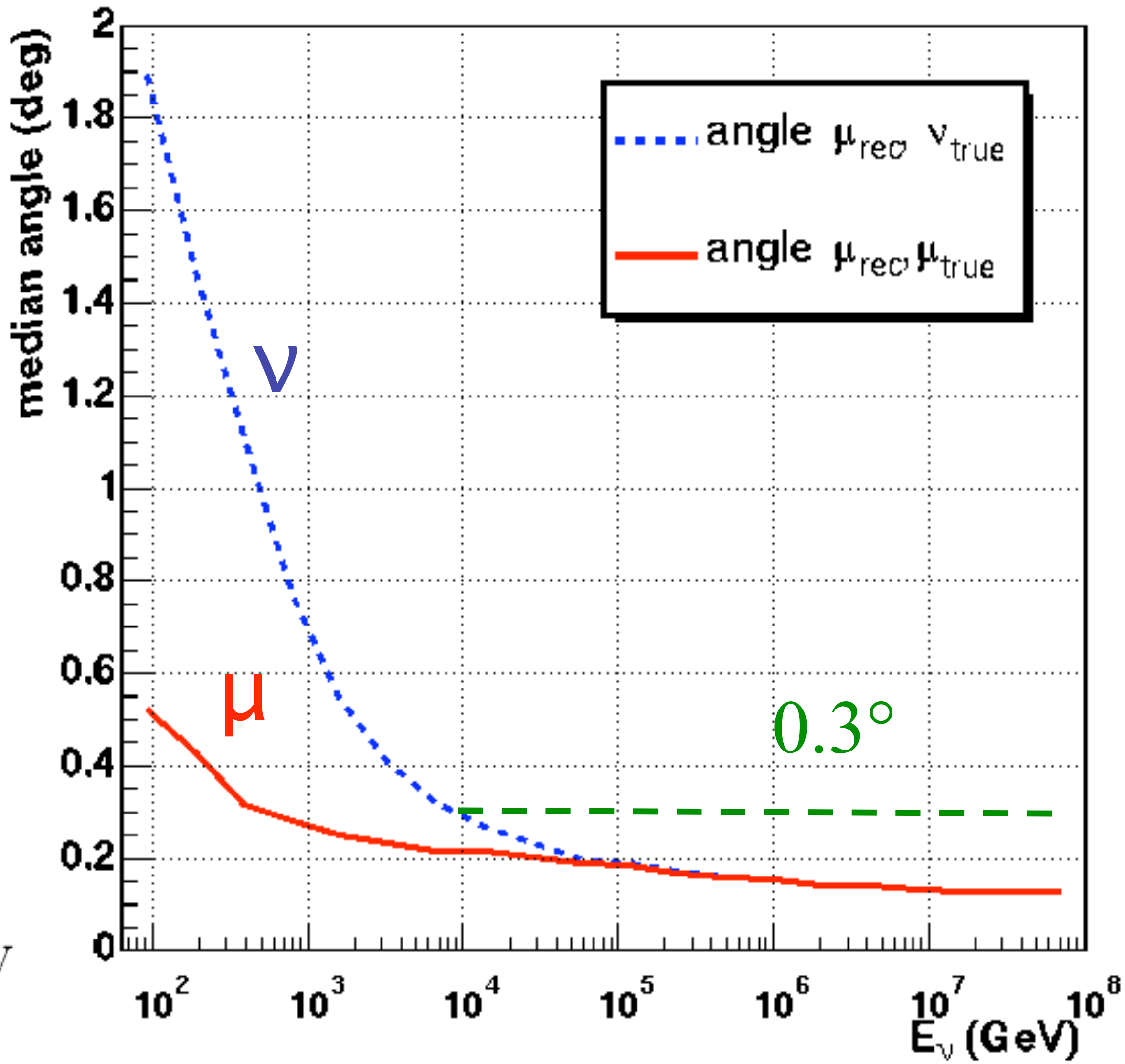


Counting rate in photomultipliers



Angular Resolution





Deep inelastic scattering :

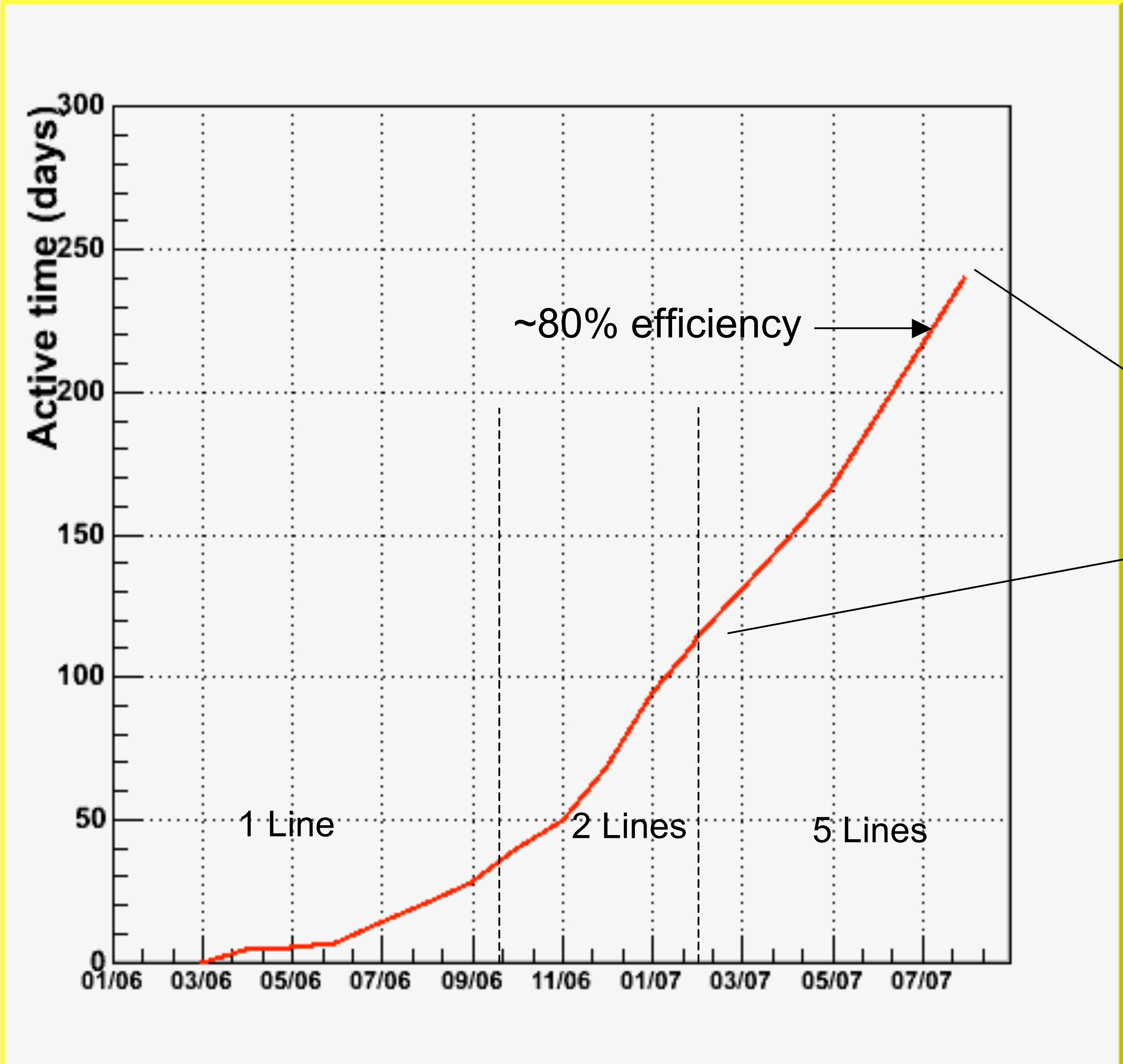
$$\sqrt{\langle \theta^2_{\mu\nu} \rangle} \approx \sqrt{\frac{m_N}{E_\nu}}$$

$$\langle \theta_{\mu\nu} \rangle = \frac{0,64^\circ}{(E_\nu/TeV)^{0,56}} \qquad E_\nu > 10\,\mathrm{TeV}$$

< 0.3° for >10 TeV :dominated by detector resolution

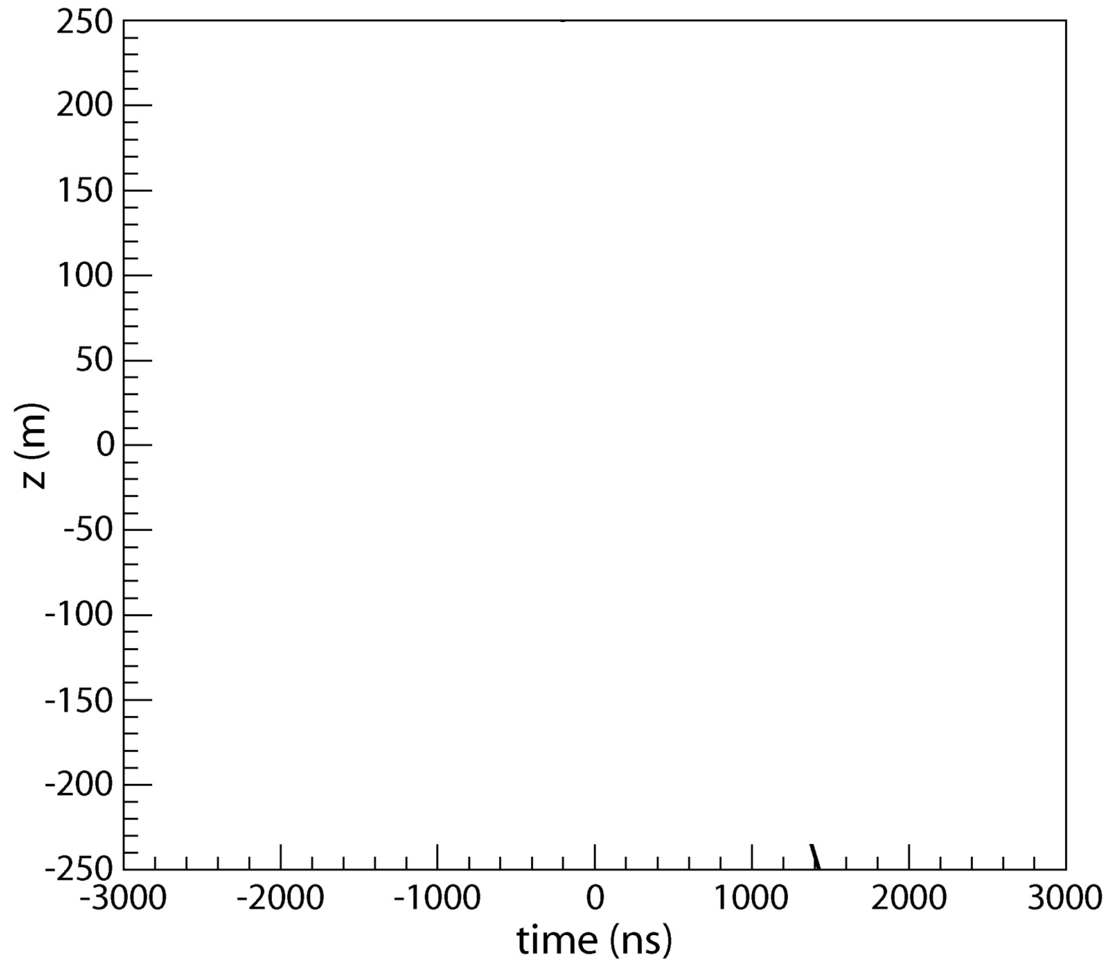
Accumulated data taking time

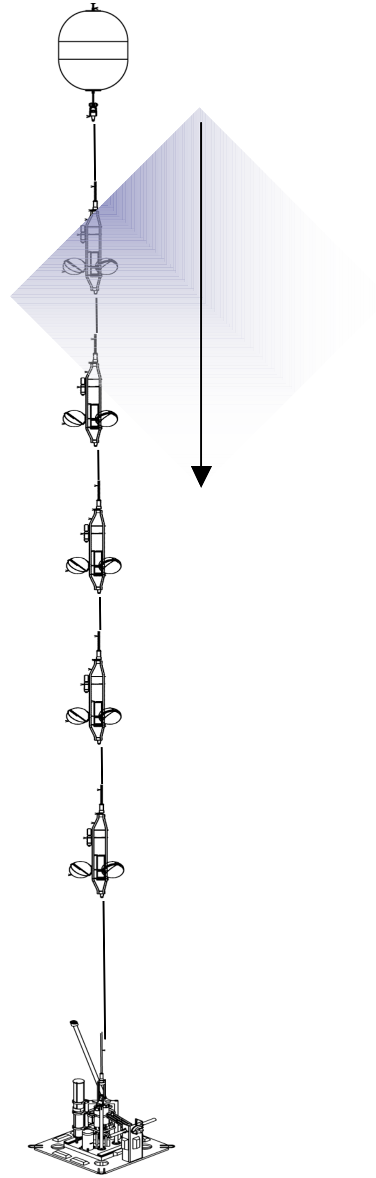
Effective number of days with all losses and inefficiencies included



130 active days with 5 lines

Vertical muon

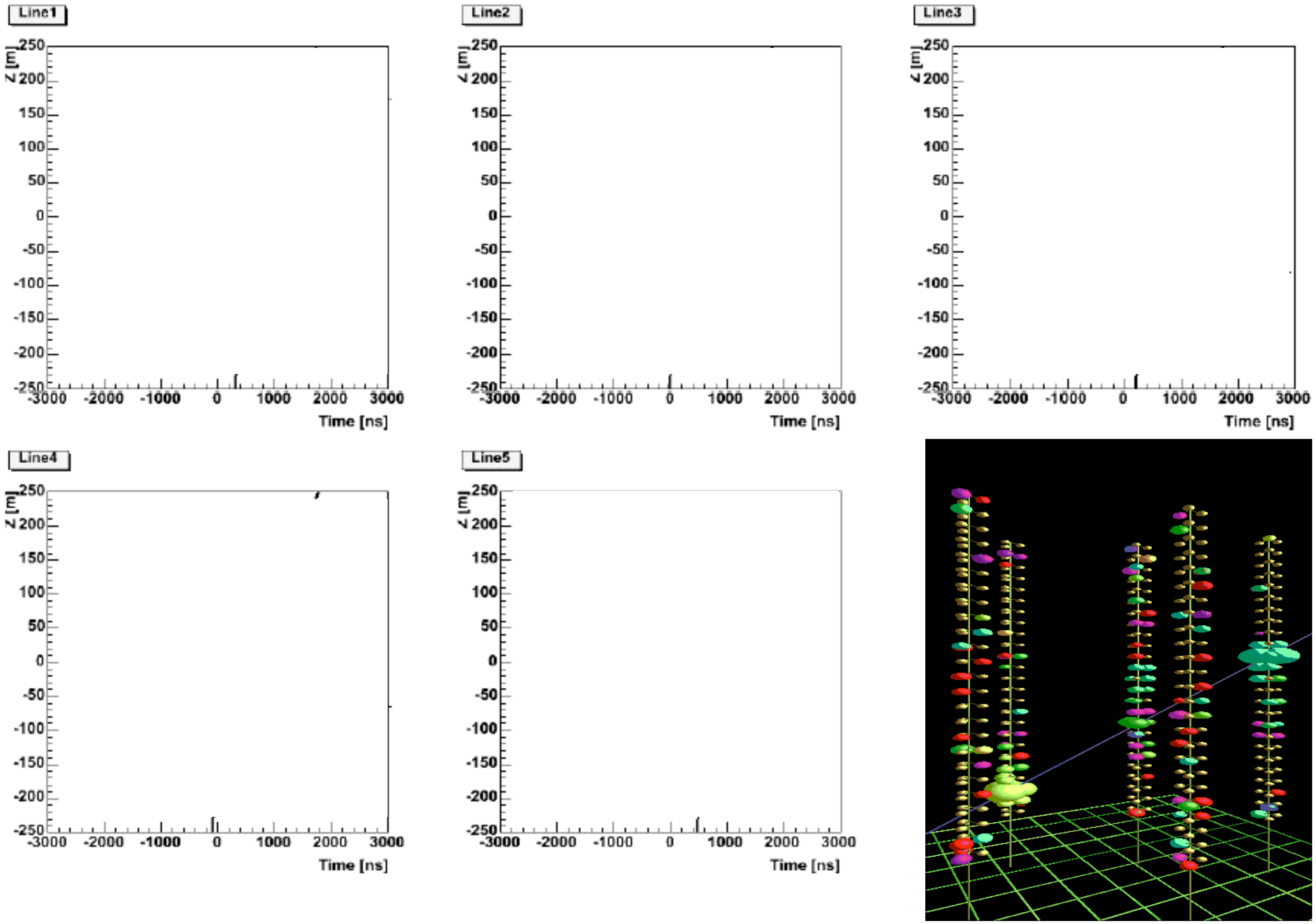




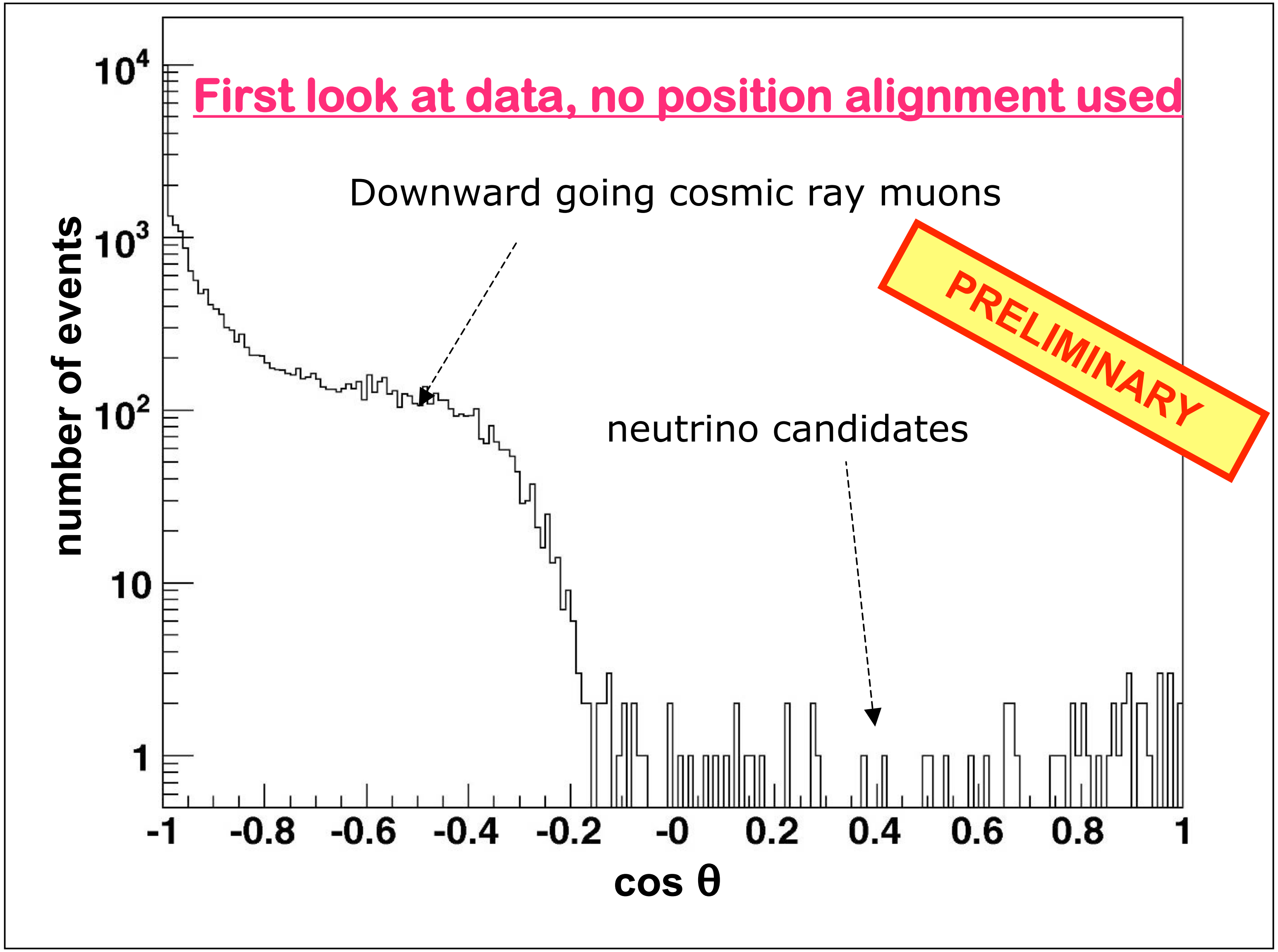
First confirmed neutrino

Θ=35°

Run : 25929 Event : 6742 FrameTarget : 18 FrameIndex : 61770
a: 37.1598 b: 22.0721 t0: 164892932.2 θ: 0.61779 ϕ: -3.7146 fit : 1/4



Zenith angle distribution

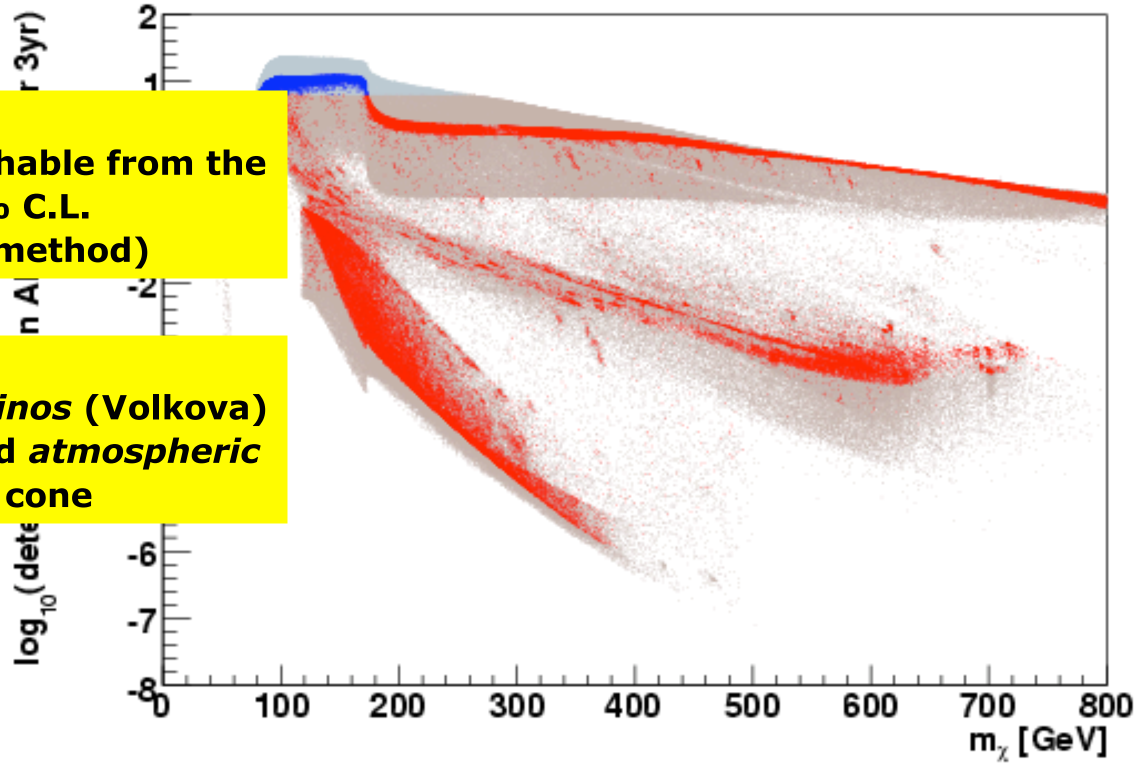


ANTARES WIMPS search from the sun

Excludable $\nu_\mu + \bar{\nu}_\mu$ detection rate in ANTARES per 3 years vs. m_χ:

“Excludable” =
Signal is distinguishable from the background at 90% C.L. (Feldman-Cousins method)

<u>Background:</u>
***atmospheric neutrinos* (Volkova) & misreconstructed *atmospheric muons* within a 3° cone**

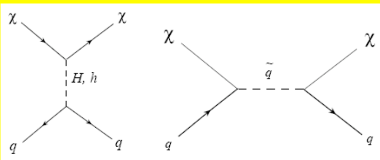


- **: Excludable models for which $0.094 < \Omega_\chi h^2 < 0.129$**
- **: Excludable models for which $\Omega_\chi h^2 < 1$**
- **: Non-excludable models for which $0.094 < \Omega_\chi h^2 < 0.129$**
- **: Non-excludable models for which $\Omega_\chi h^2 < 1$**

Comparison to direct detection experiments

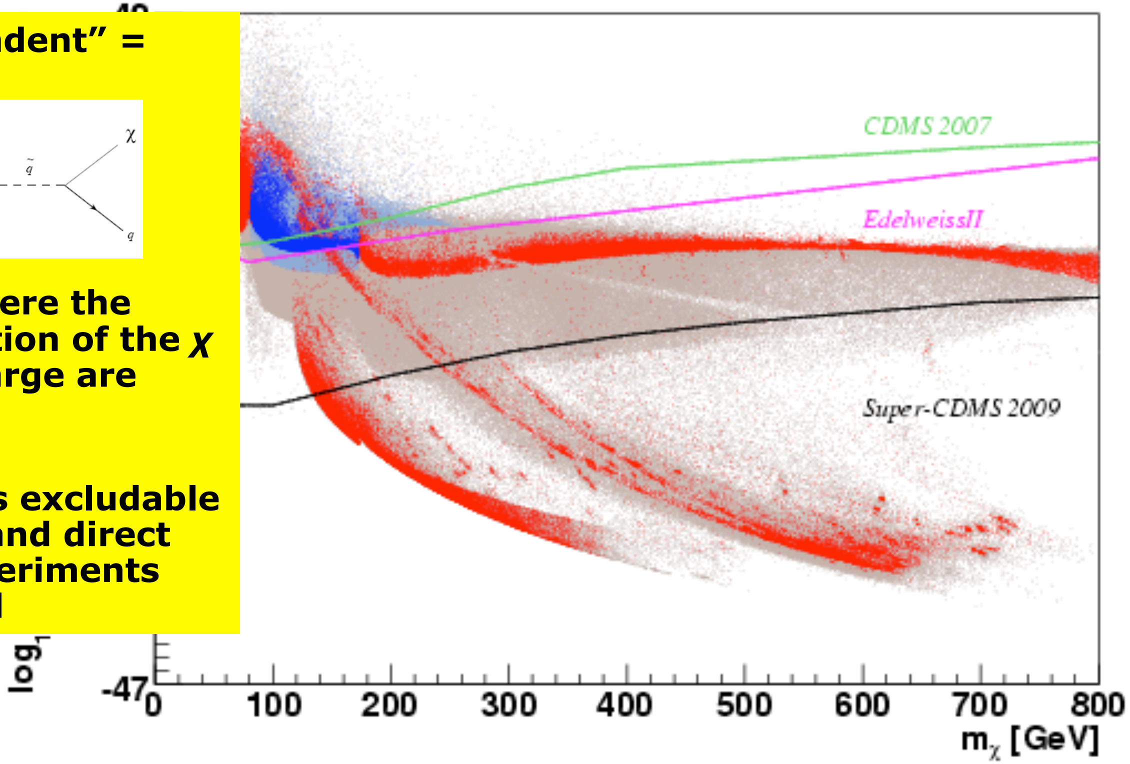
Spin independent *χp* -> *χp* cross section of (non-)excludable models in ANTARES per 3 years vs. m_χ:

"spin-independent" =



-> models where the Higgsino fraction of the χ is relatively large are dominant

-> the regions excludable by ANTARES and direct detection experiments are correlated



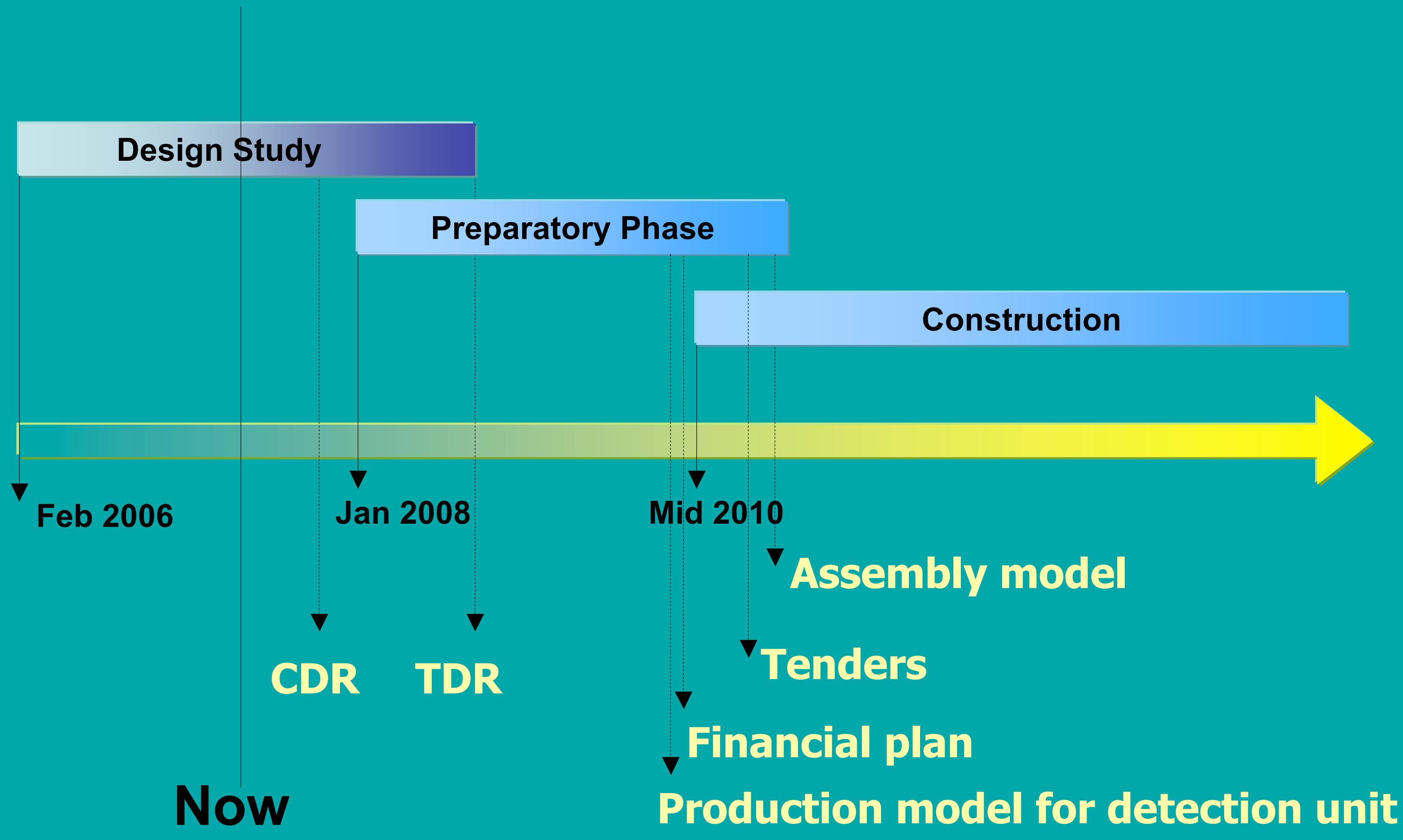
KM3NeT consortium

38 institutes from:

Cyprus, France, Germany, Greece, Ireland
Italy, Malta, The Netherlands, Spain, UK

ANTARES + ΝΕΣΤΩΡ + NEMO NEUTRINO MEDITERRANEAN OBSERVATORY +..

Foreseen KM3NeT profile

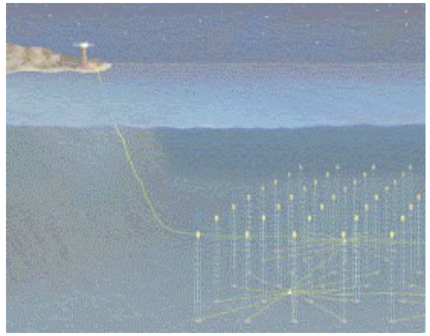


Neutrino skymap ?

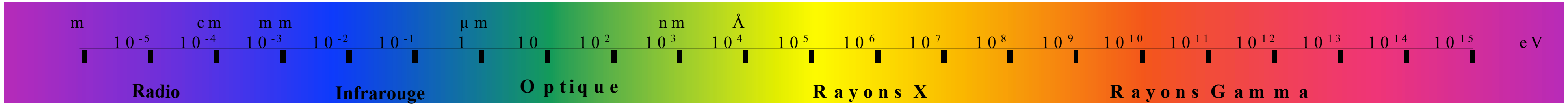
Radio Telescope
(Bonn)

Optical Telescope
(Palomar)

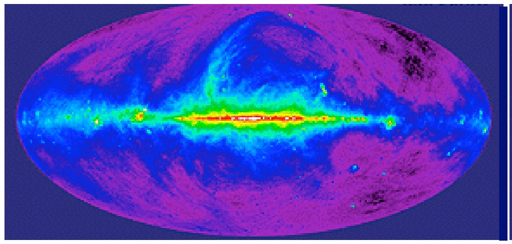
X - ray Satellite
(INTEGRAL/ESA)



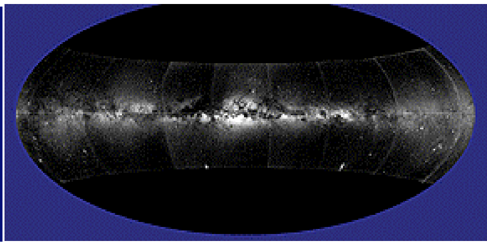
Neutrino Telescope



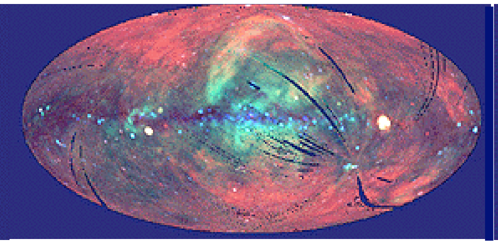
View of sky in Galactic Coordinates in four different photon wavelengths



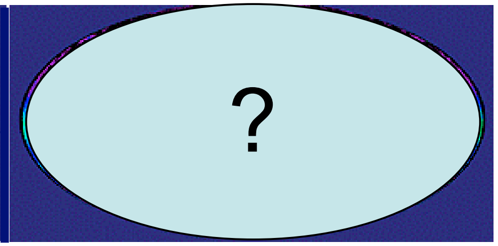
Radio



Visible light

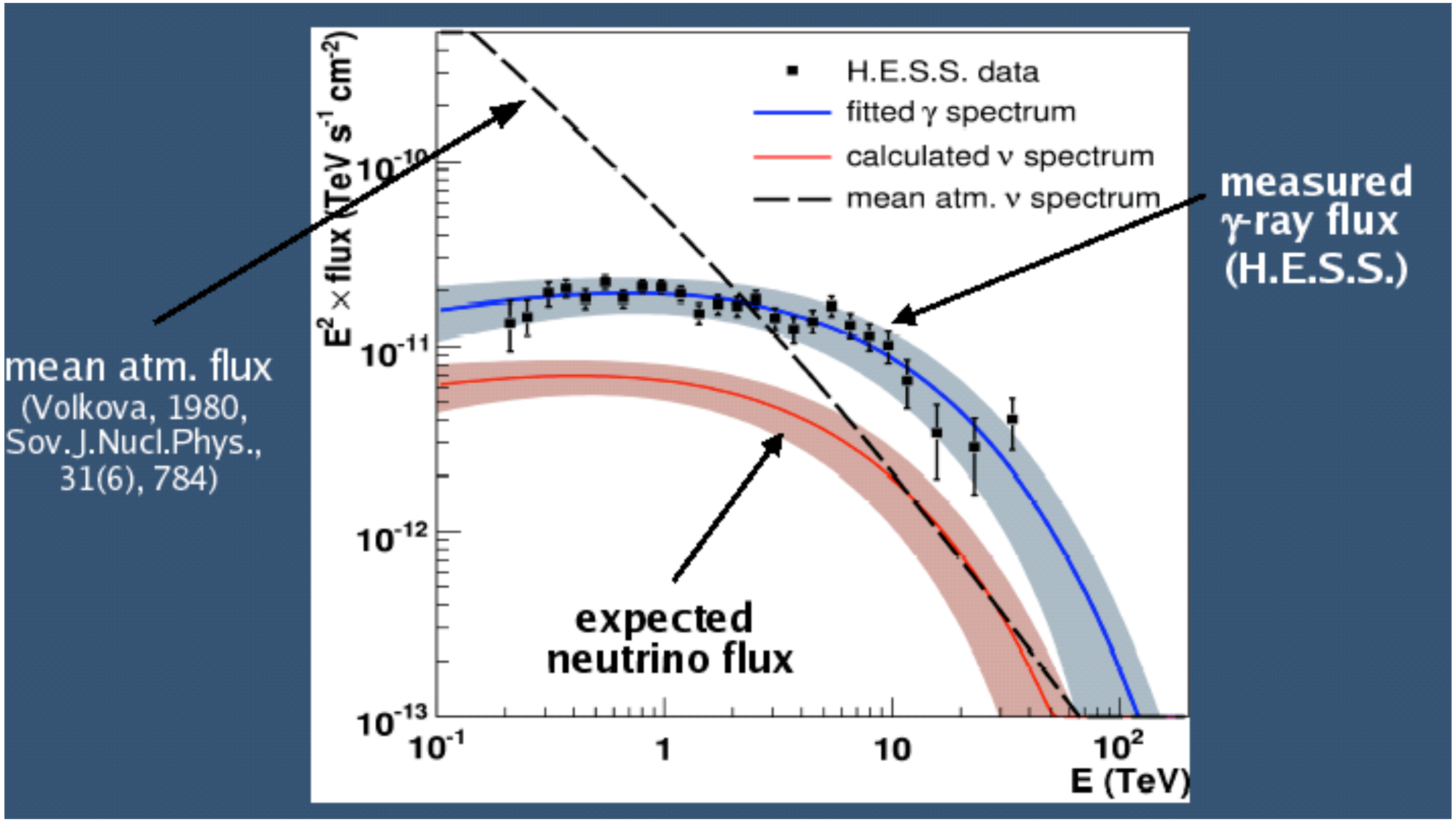


X - rays



Neutrinos

Expected ν flux from galactic point sources, example: RXJ 1713-3946



Christian Stegmann et al.

Note importance of background of atmospheric ν in a km^3 detector

Neutrino Event Rates (II)

- γ-ray sources with observed cut-off (KM3NeT, 5 years)

	Type	Dia. [º]	E > 1TeV src	bck	E > 5TeV src	bck
- Vela X	PWN	0.8	9 – 23	23	5 – 15	4.6
- RX J1713.7-3946	SNR	1.3	7 – 14	21	2.6 – 6.7	8.2
- RX J0852.0-4622	SNR	2.0	7 – 15	104	1.9 – 6.5	21
- HESS J1825–137	PWN	0.3	5 – 10	9.3	2.2 – 5.2	1.8
- Crab Nebula	PWN	<0.1	4.0 – 7.6	5.2	1.1 – 2.7	1.1
- HESS J1303–631	NCP	0.3	0.8 – 2.3	11	0.1 – 0.5	2.1
- LS 5039* (INFC)	Binary	<0.1	0.3 – 0.7	2.5	0.1 – 0.3	0.5

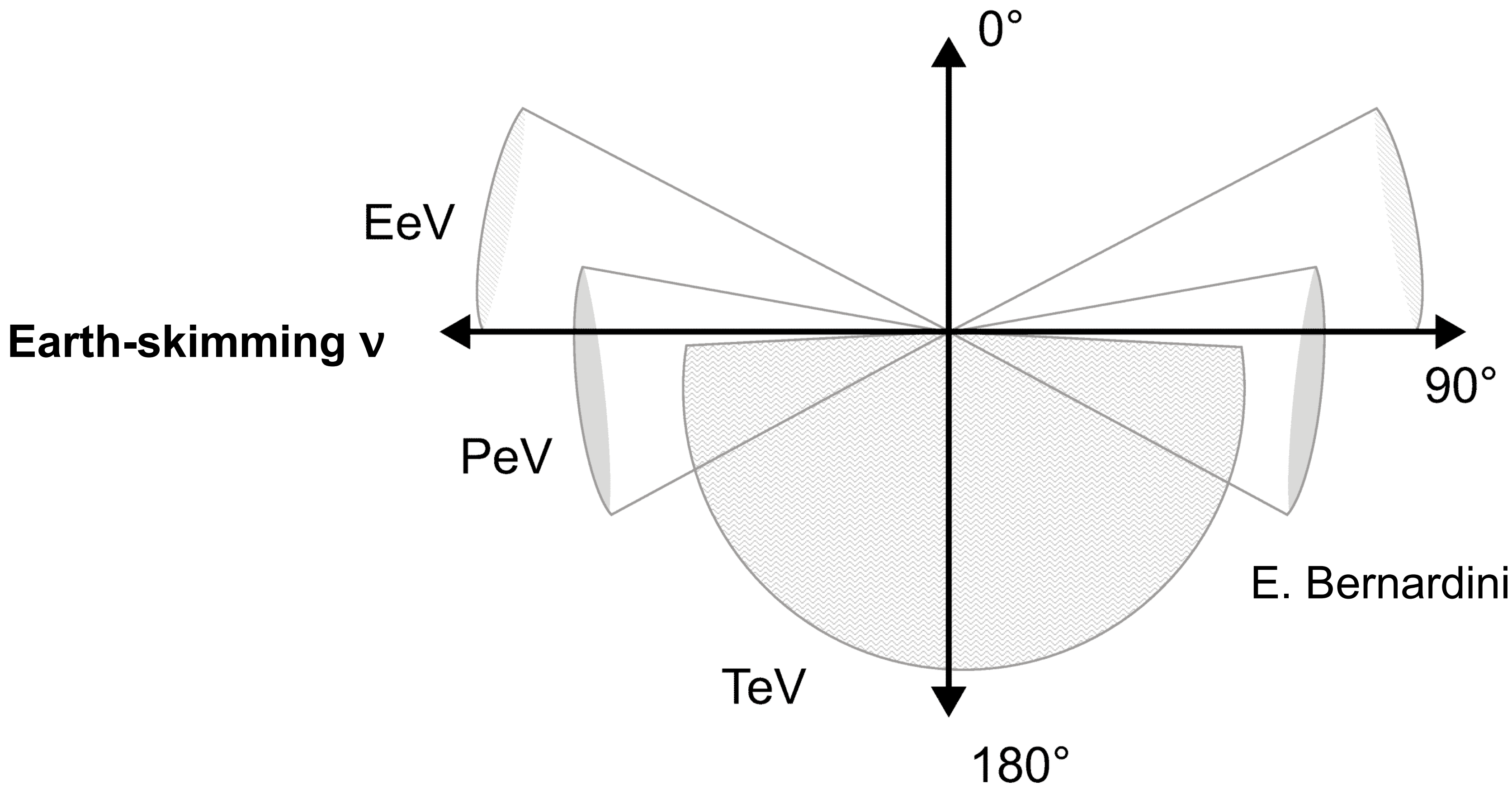
NCP: no counterparts at other wavelength

* no γ-ray absorption

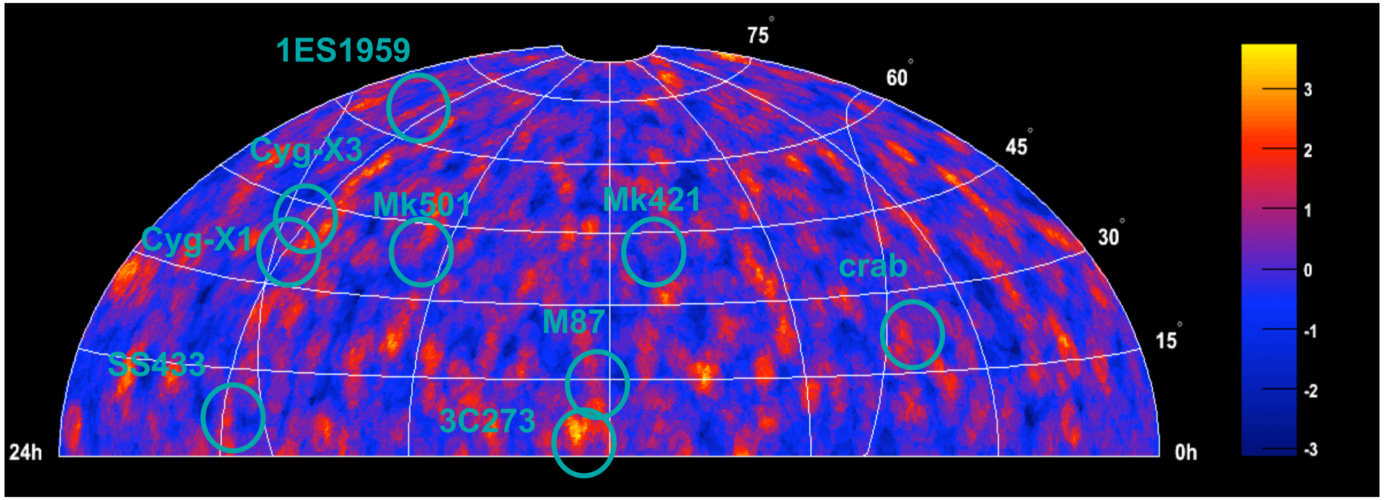
- 23 further γ-ray sources investigated:
  - All γ-ray spectra show no cut-offs (but limited statistics)
  - Event numbers mostly below 1 – 2 in 5 years

Christian Stegmann, Galactic Neutrinos, ICRC 2007

>PeV ν absorbed in the Earth



Search for neutrinos from 32 candidate sources



event selection optimized for both dN/dE ~E^{-2} and E^{-3} spectra

source	nr. of ν events **(5 years)**	expected background **(5 years)**	E^{-2} flux upper limit (90% c.l.) $\Phi_{\nu_\mu+\nu_\tau}$ [10^{-11} TeV^{-1} cm^{-2} s^{-1}]
Markarian 421	**6**	**7.4**	**7.4**
M87	**6**	**6.1**	**8.7**
1ES 1959+650	**5**	**4.8**	**13.5**
SS433	**4**	**6.1**	**4.8**
Cygnus X-3	**7**	**6.5**	**11.8**
Cygnus X-1	**8**	**7.0**	**13.2**
Crab Nebula	**10**	**6.7**	**17.8**
3C 273	**8**	**4.72**	**18.0**

No significant excess observed

1.2σ equiv. (random maps)

Achterberg et al. 2007, astro-ph/ 0611063