Last news from the deep

… where underwater/ice neutrino telescopes operate…

Chantal RACCA
IPHC Strasbourg

Today's menu

Fighting rumours, as an apetizer

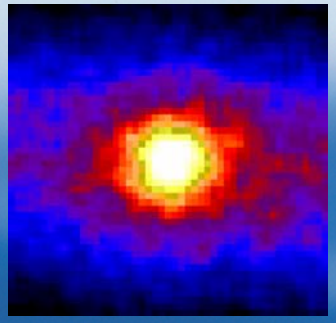
Flashback (on detection principle and physics case), as a starter

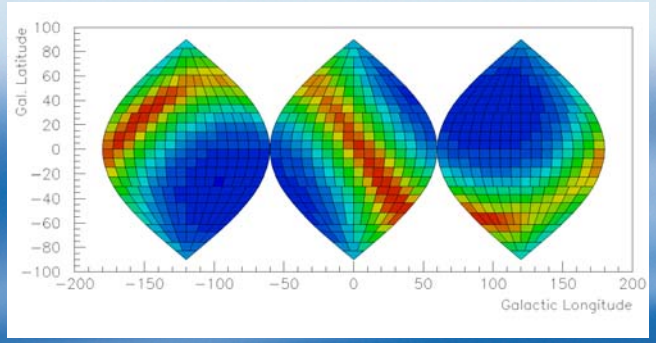
Snapshots on detectors and results, as main dish

Convinced for the dessert ?

Neutrino Telescopes do not operate yet…..

False! Kamiokande and Superkamiokande are ν–telescopes!

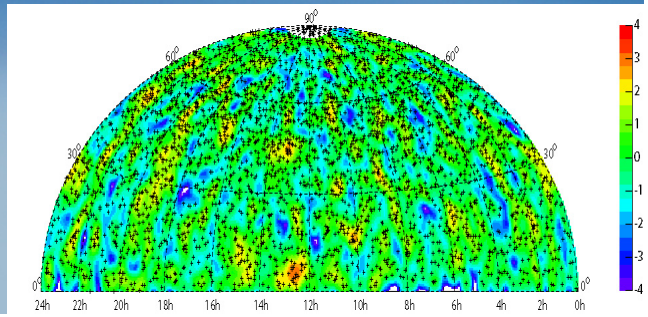




Well…

High energy Neutrino Telescopes do not operate yet….

False! AMANDA and BAIKAL are operating



Neutrino Telescopes sensitive enough will take years to be operational…

False! IceCube's schedule is awesome and KM3's is aggressive too

Neutrino Telescopes do not have a clear physics case…

False …(at least according to theorists!)…and see later…

and who knows, we are opening a new window to the Universe

(astrophysicists: "c'mmon, at most you'll just make a little hole in the wall")

Neutrino Telescopes are not experiments …

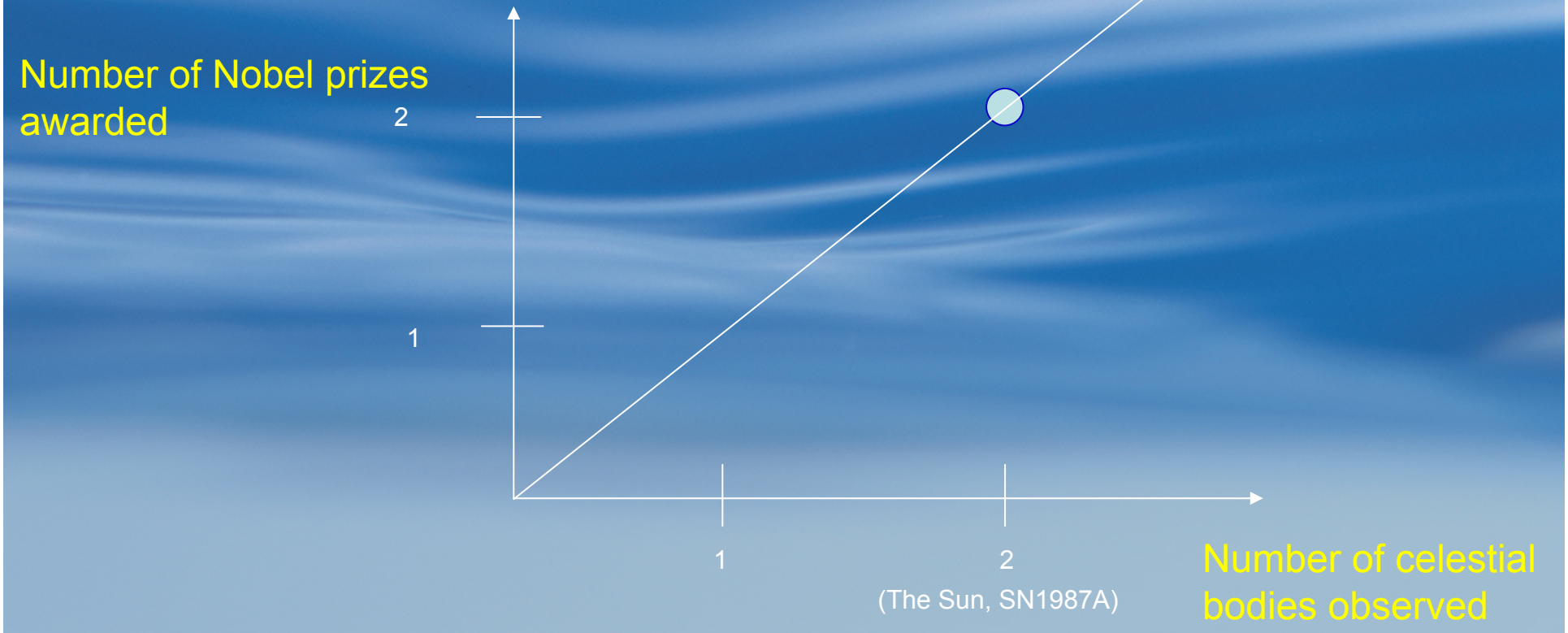
Yes!…they are “a way of life”!…

- Enter R&D phase as a graduate student
- Participate in the design of the detector as a PhD student
- During your first post-doc you help writing the TDR
- Start construction during your second post-doc
- Keep on building it during your third post-doc
- Come back home during the first data taking
- Try to understand the data as a Tenure Track-er
- Get permanent position (if you understand the data)
- Get promoted (if you beat the Waxman&Bahcall limit)
- Get full Professorship (if you find one single source)
- But most likely, retire during the construction phase of the mythical “kilometre cube”

…just like LHC experiments, isnt’ it ?

There are more profitable experiments than Neutrino Telescopes

….Really?

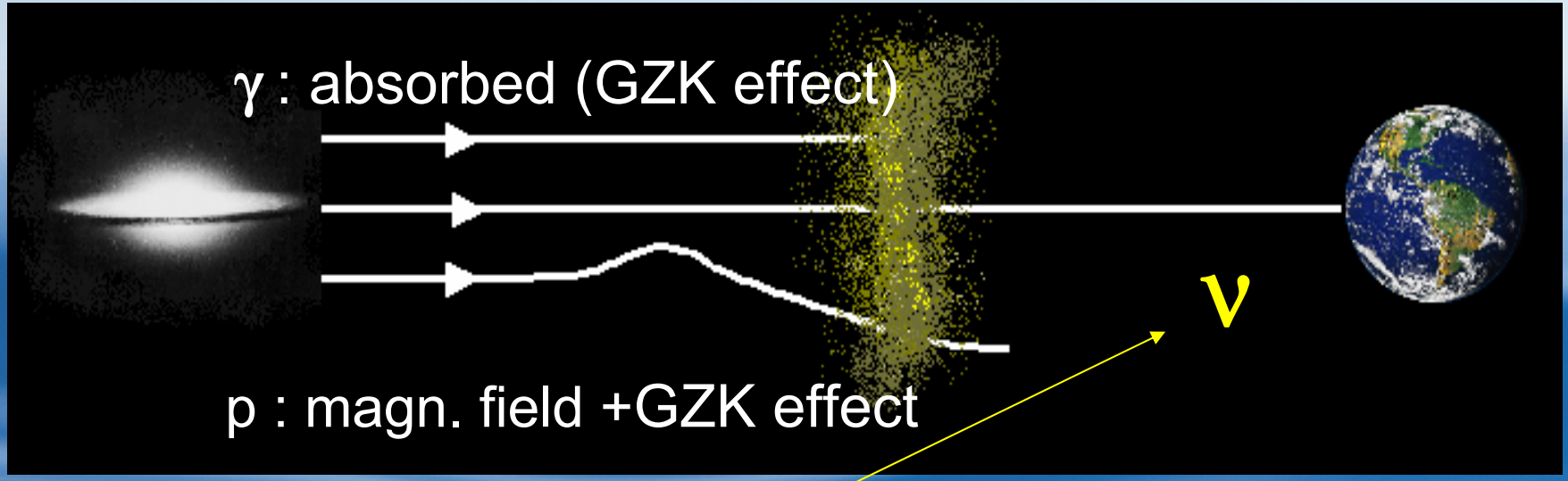


Flashback

ν : the cosmic messenger,

physics goals and detection principle

ν : the cosmic messenger



Neutrino

- Source exploration on cosmologic distances
- In the heart of sources…
- Weakly interacting → large detection volume

Scientific goals

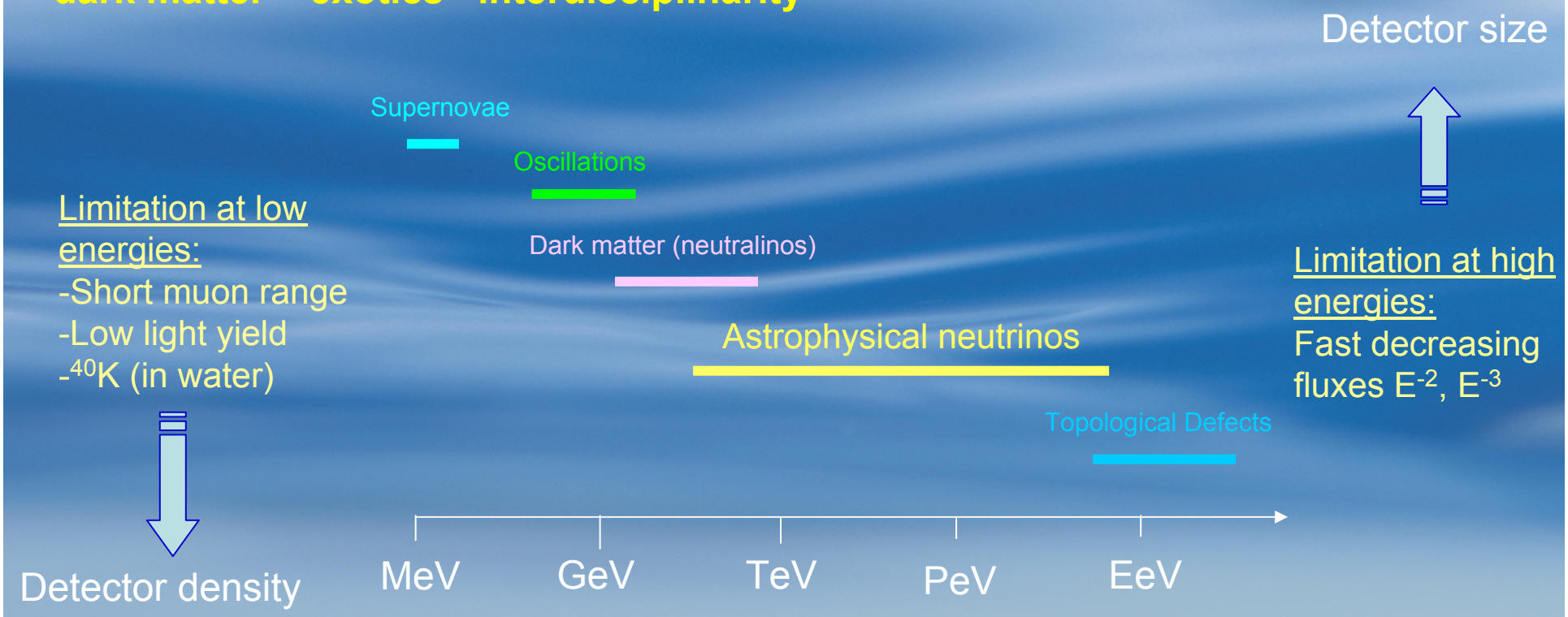
Neutrinos from galactic sources

- **–Pulsars**
- **–Young Supernova Remnants (up to 100 ev/year/km^2)**
- **–Micro quasars (SS433: up to 250 ev/year/km^2)**

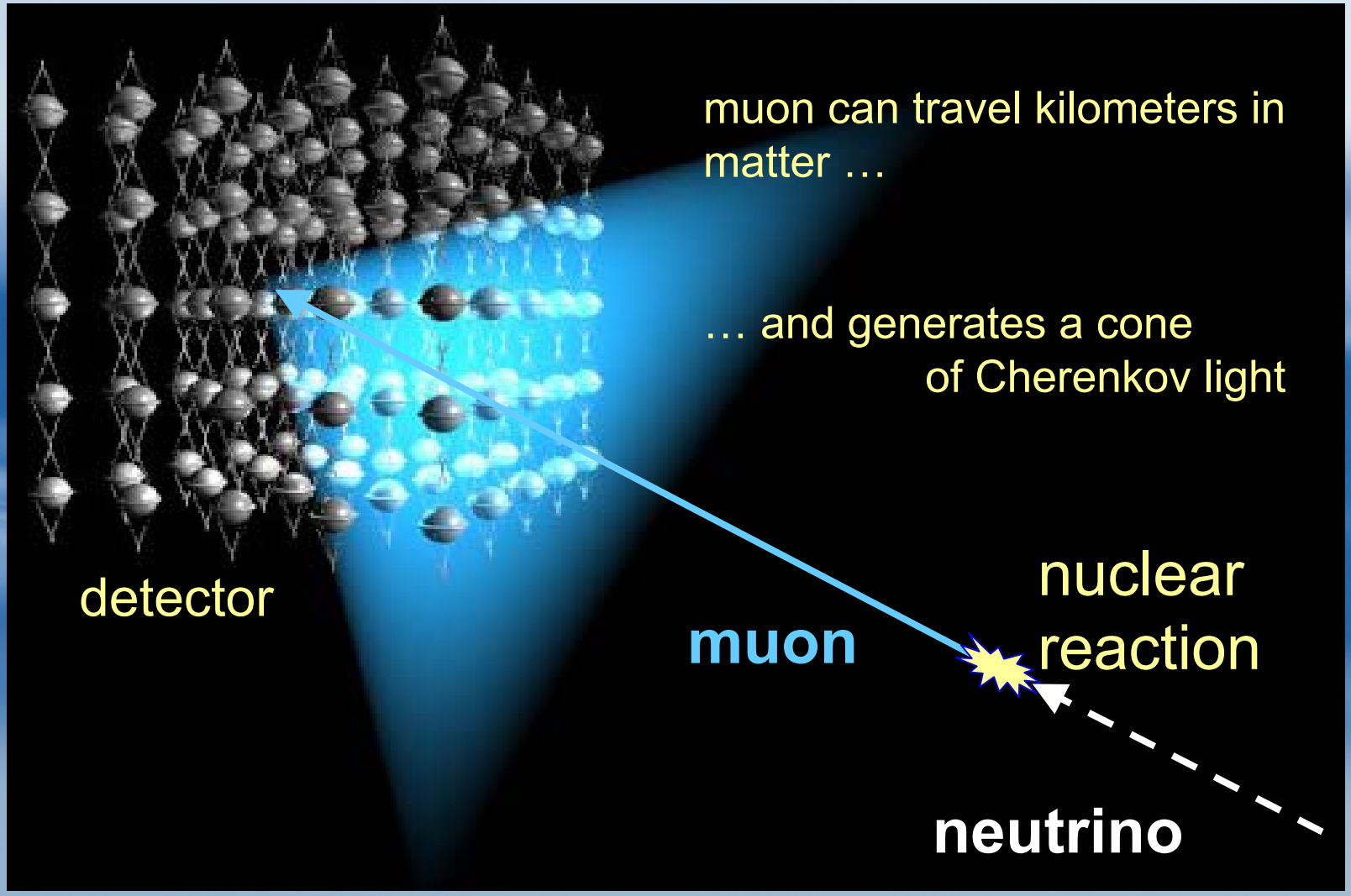
Neutrinos from extragalactic sources

- **–Active Galactic Nuclei (AGN) steady**
- **–Gamma Ray Bursts (GRBs) transient (1-100 s)**

+ dark matter + exotics +interdisciplinarity



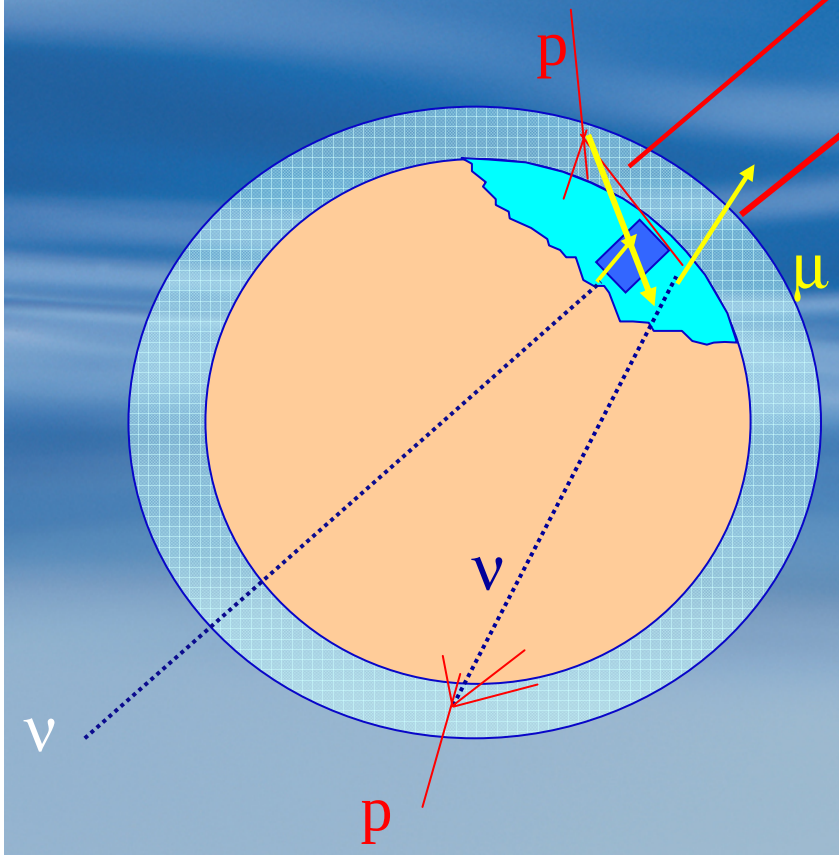
How can we do neutrino astronomy ?

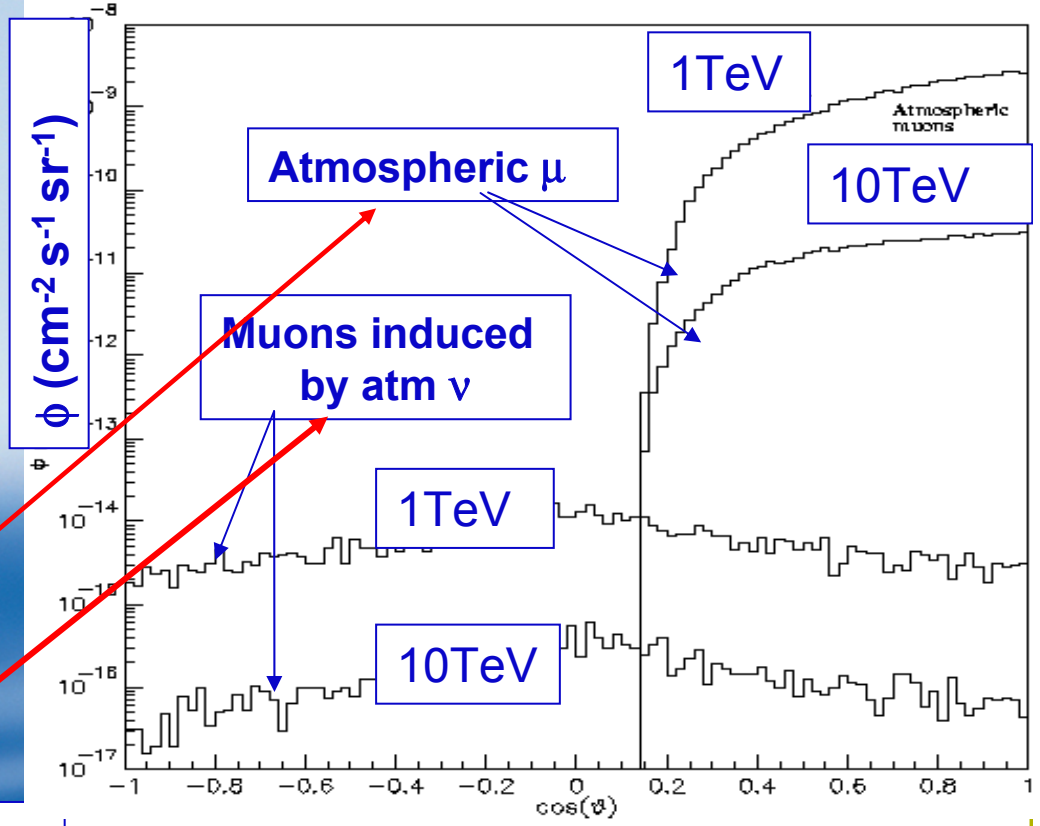


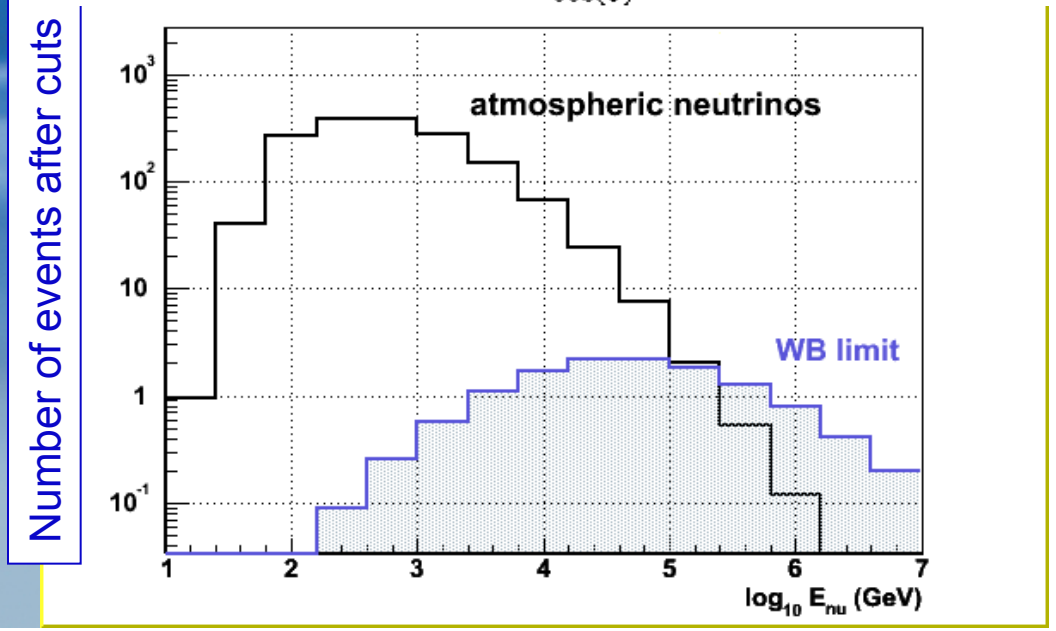
Physical background:

Muons produced by cosmic rays in the atmosphere (ν detector deep in the sea and selection of up-going events).

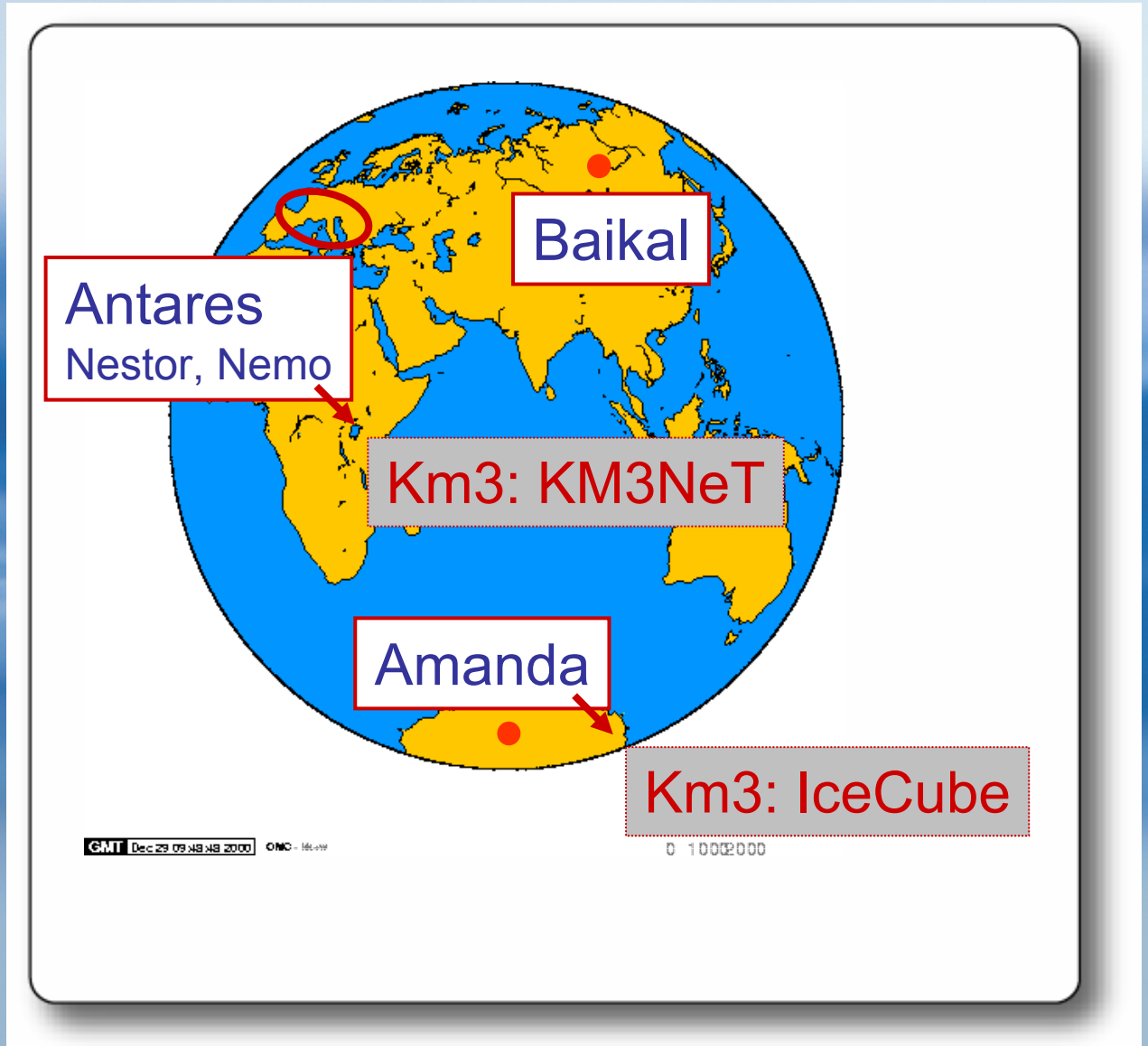
Atmospheric **neutrinos** (cut in energy).



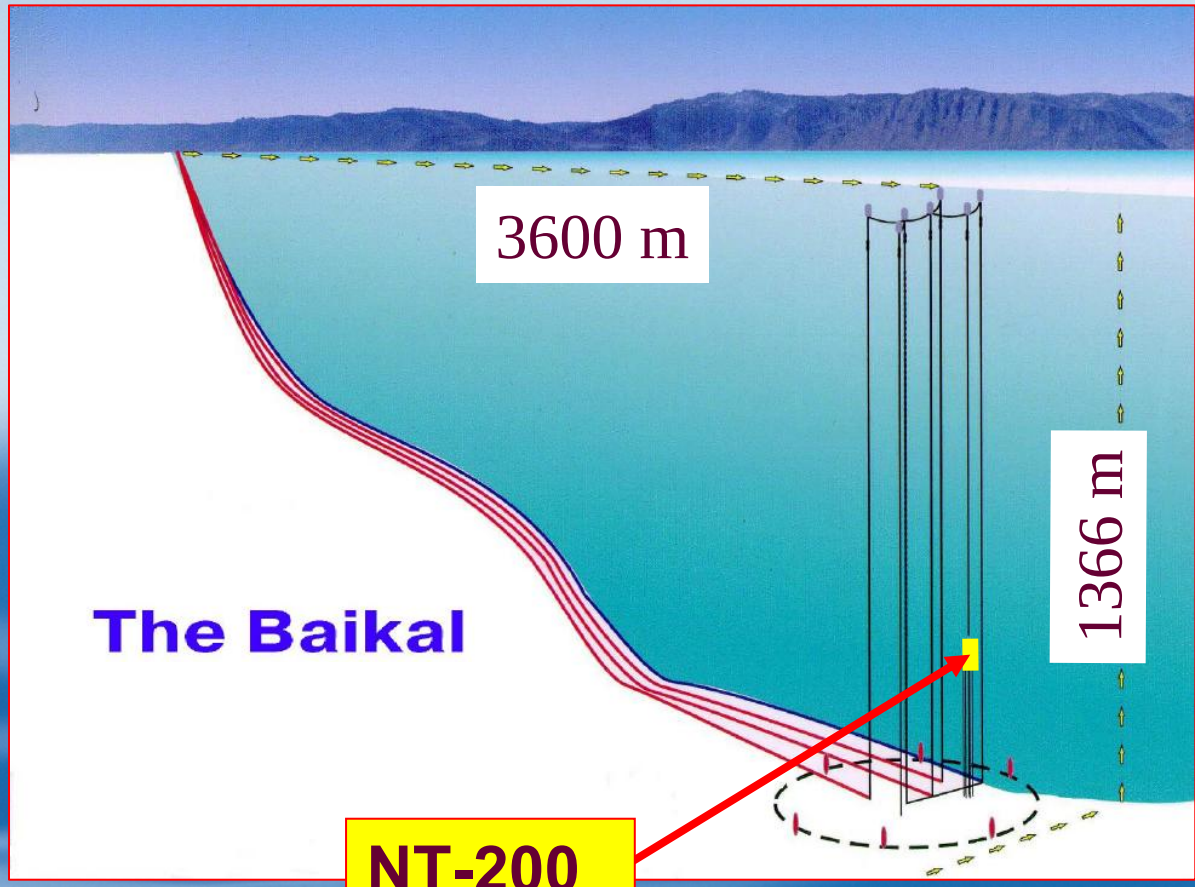


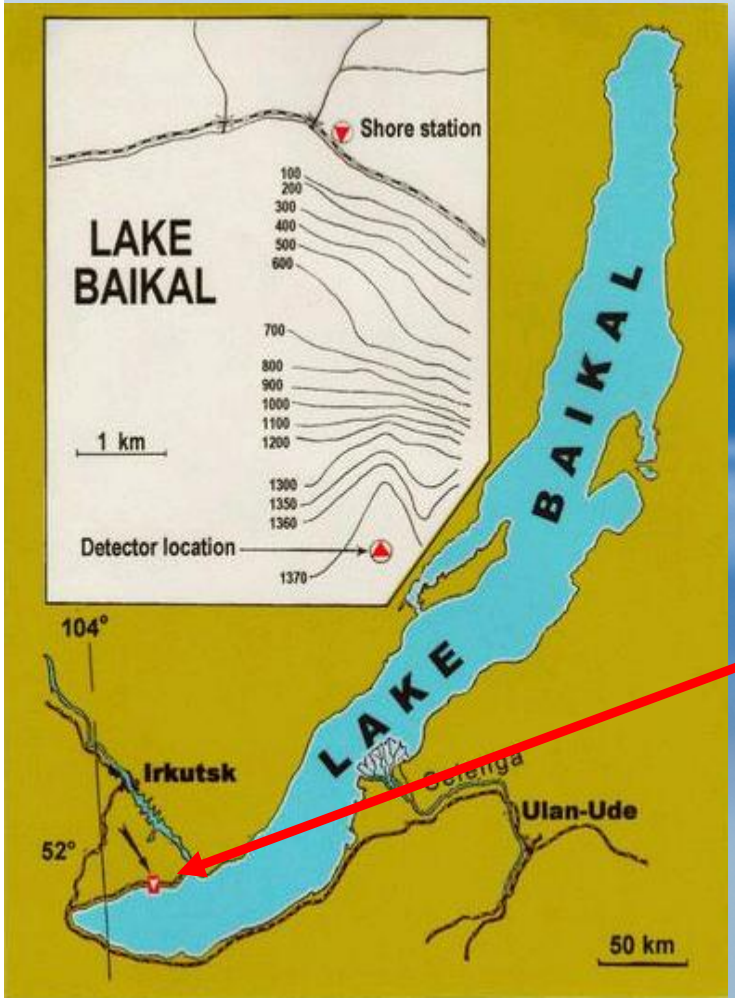


Snapshots



BAIKAL





NT-200

Absorption length: ~25m
Scattering length: 30-60 m

- 4 cables x 4km to shore.
- 1070m depth

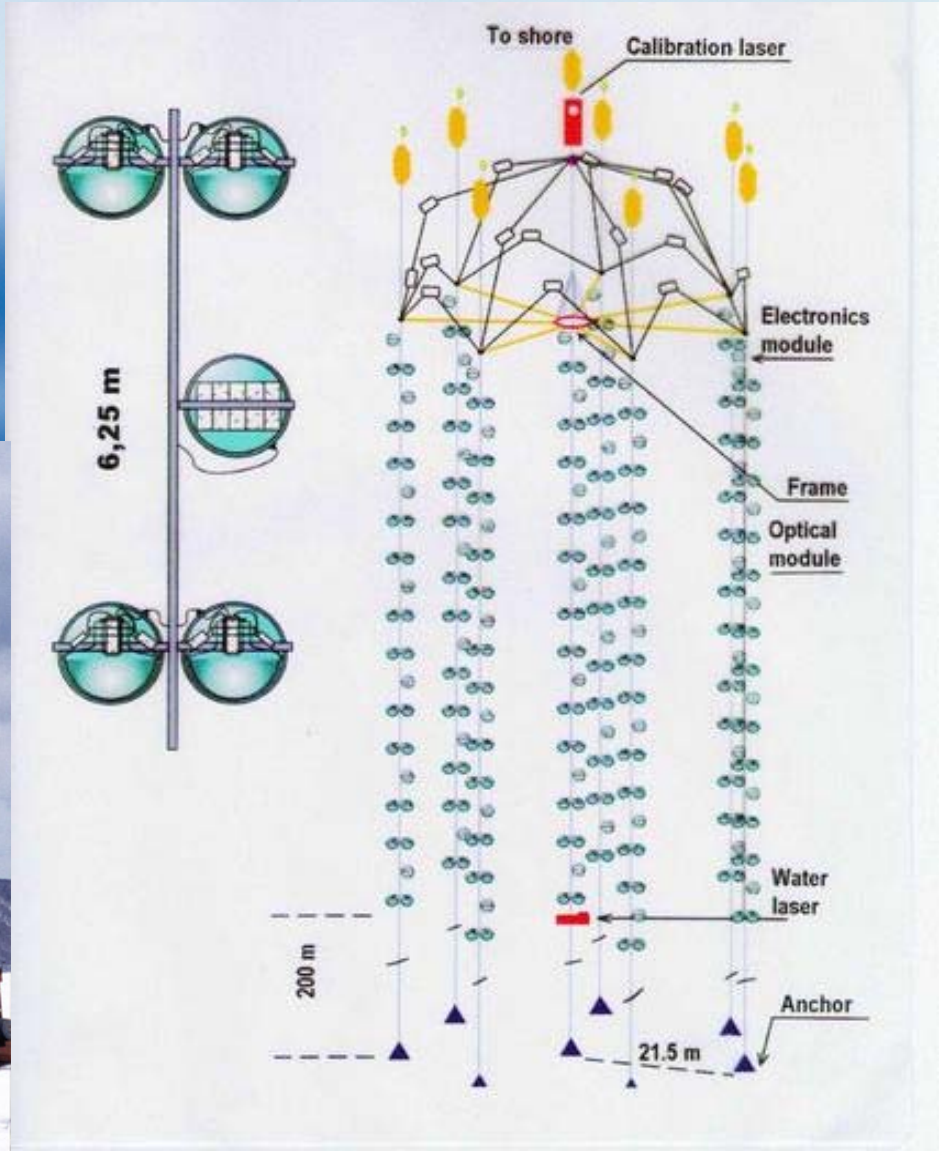
In operation since April 1998

BAIKAL NT-200

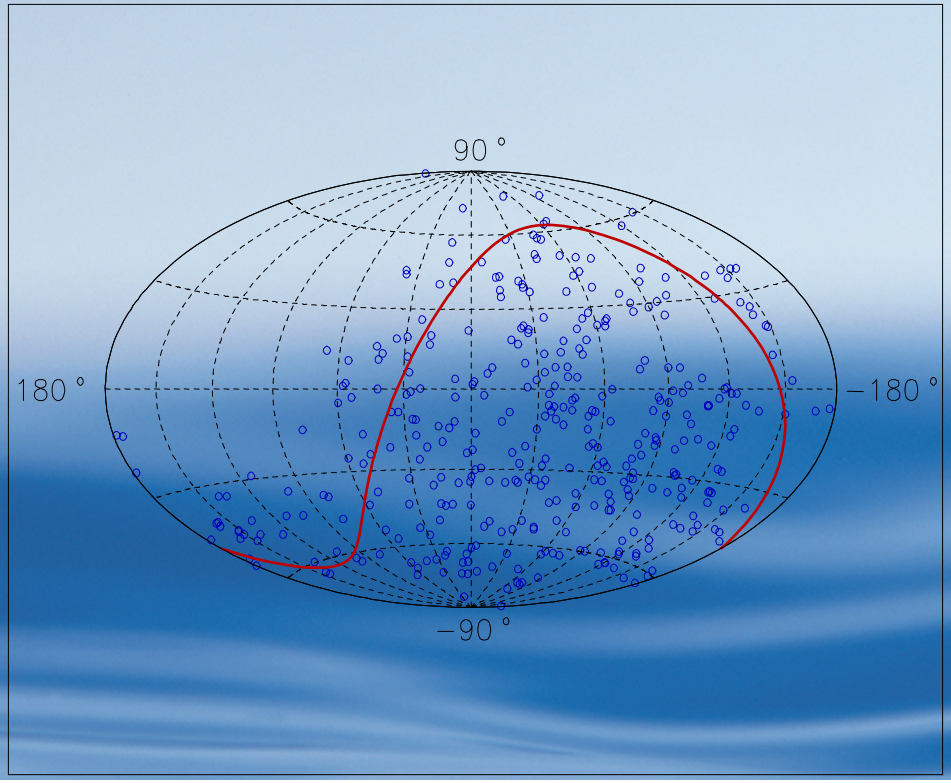
Location: Lake Baikal

Commissioned:	1997
No. of Strings:	8
Optical Sensors:	192
Depth:	1366m
Instrum. Volume/km3:	10^{-4}
μ-Effective area (1 TeV):	≈2000 m^2
Angular resolution (1 TeV):	3°

Deployment and maintenance:
From frozen surface in winter.



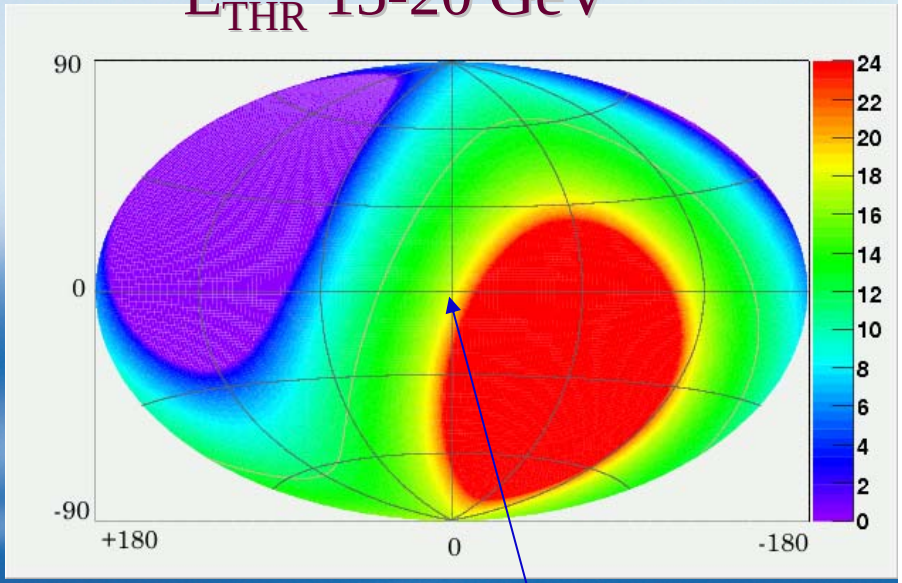
Atmospheric Muon-Neutrinos



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

372 Neutrinos in 1038 Days (1998-2003)
385 events from Monte-Carlo

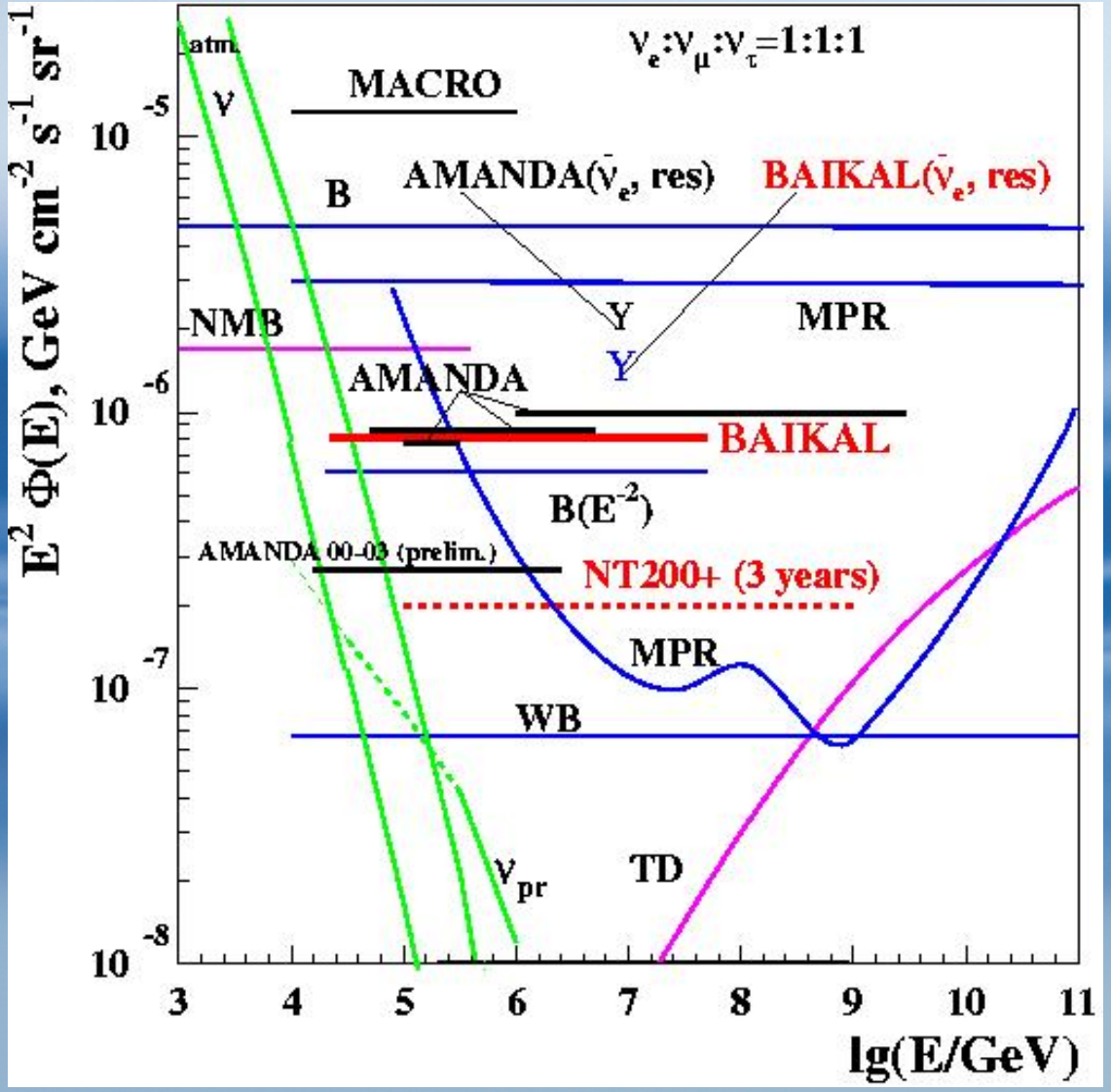
E_{THR} 15-20 GeV



18 hours per day for the Center of Galaxy

(Low energy phenomena)

Diffuse Neutrino Flux Limits + Models



For spectrum E^{-2}

$E^2\,\Phi\,(\nu_e + \nu_\mu + \nu_\tau) <$

$8.1\ 10^{-7}$ Gev cm^{-2} s^{-1} sr^{-1}

(90% confidence level)

20 TeV < E_ν <50 PeV

BAIKAL Upgrade NT200+

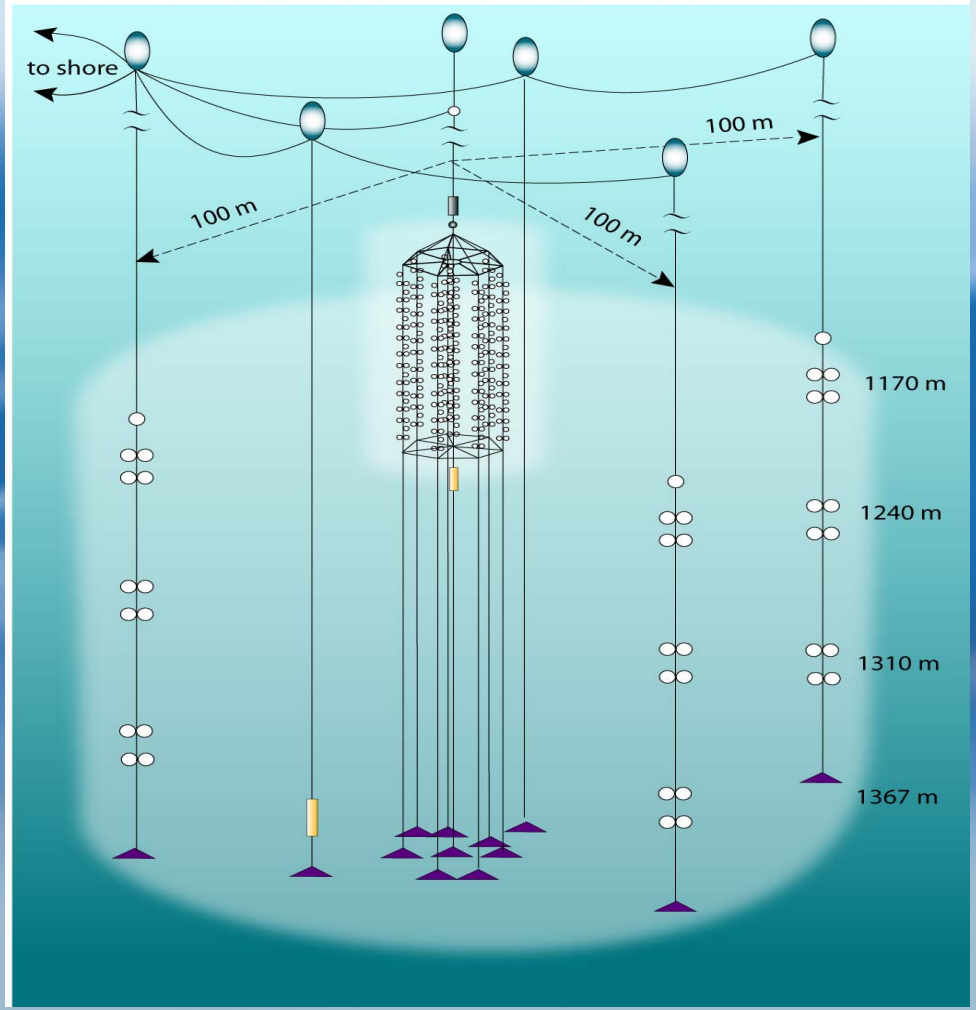
Commissioned: April 2005

Addition of
3 outer strings 12 PMT each
Other improvements: DAQ, new cable to shore,…

Increase in sensitivity by factor 3-4.

Preparing a design for: Giant Volume Detector, km scale

Height = 210m
∅ = 200m
Volume ~ 4 Mton



A Gigaton (km3) Detector in Lake Baikal

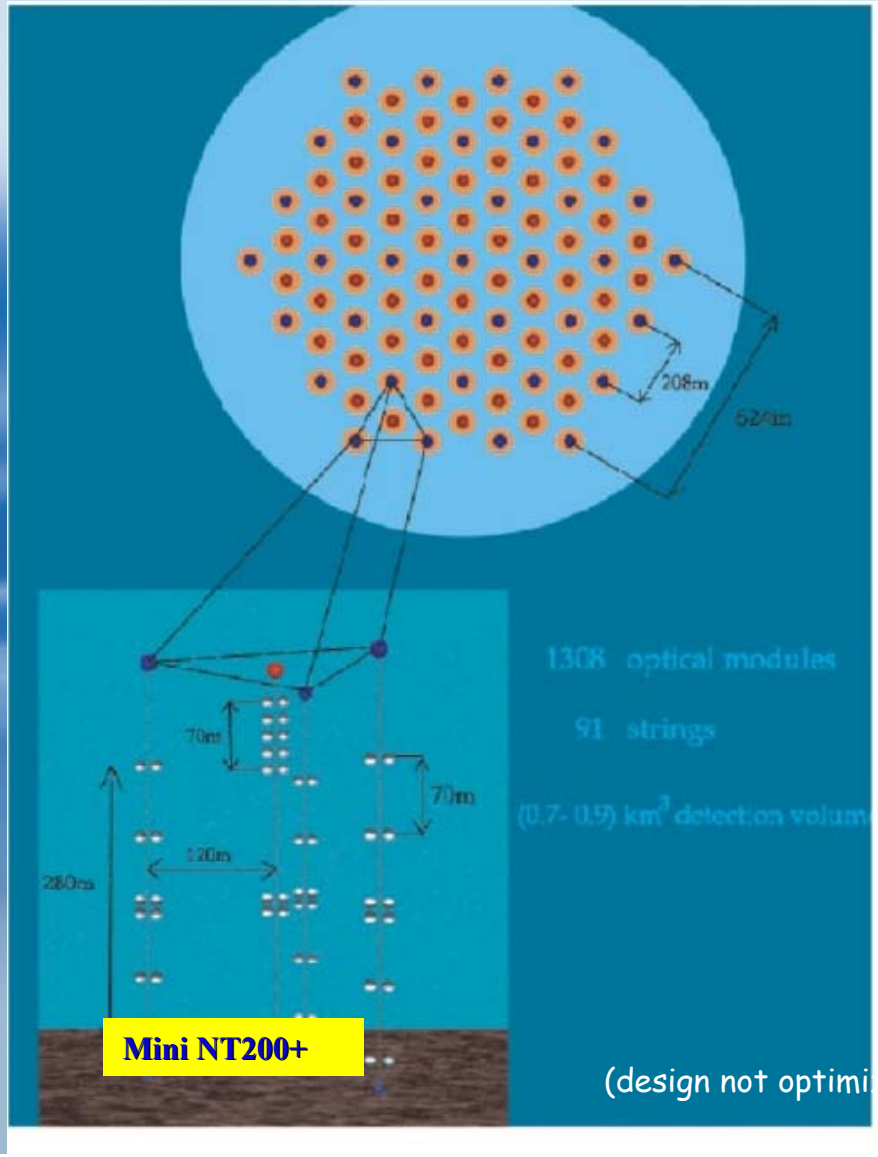
Sparse instrumentation:
91 strings with 12/16 OM = 1308 Oms

→ Cascade effective volume for 100 TeV: ~ 0.5 -1.0 km2

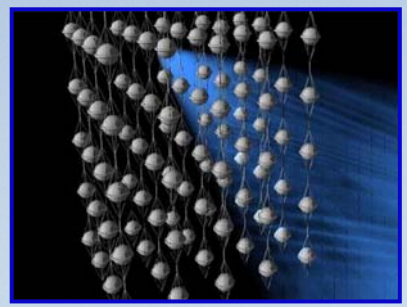
→ Muon threshold between 10 and 100 TeV

Baseline schedule:

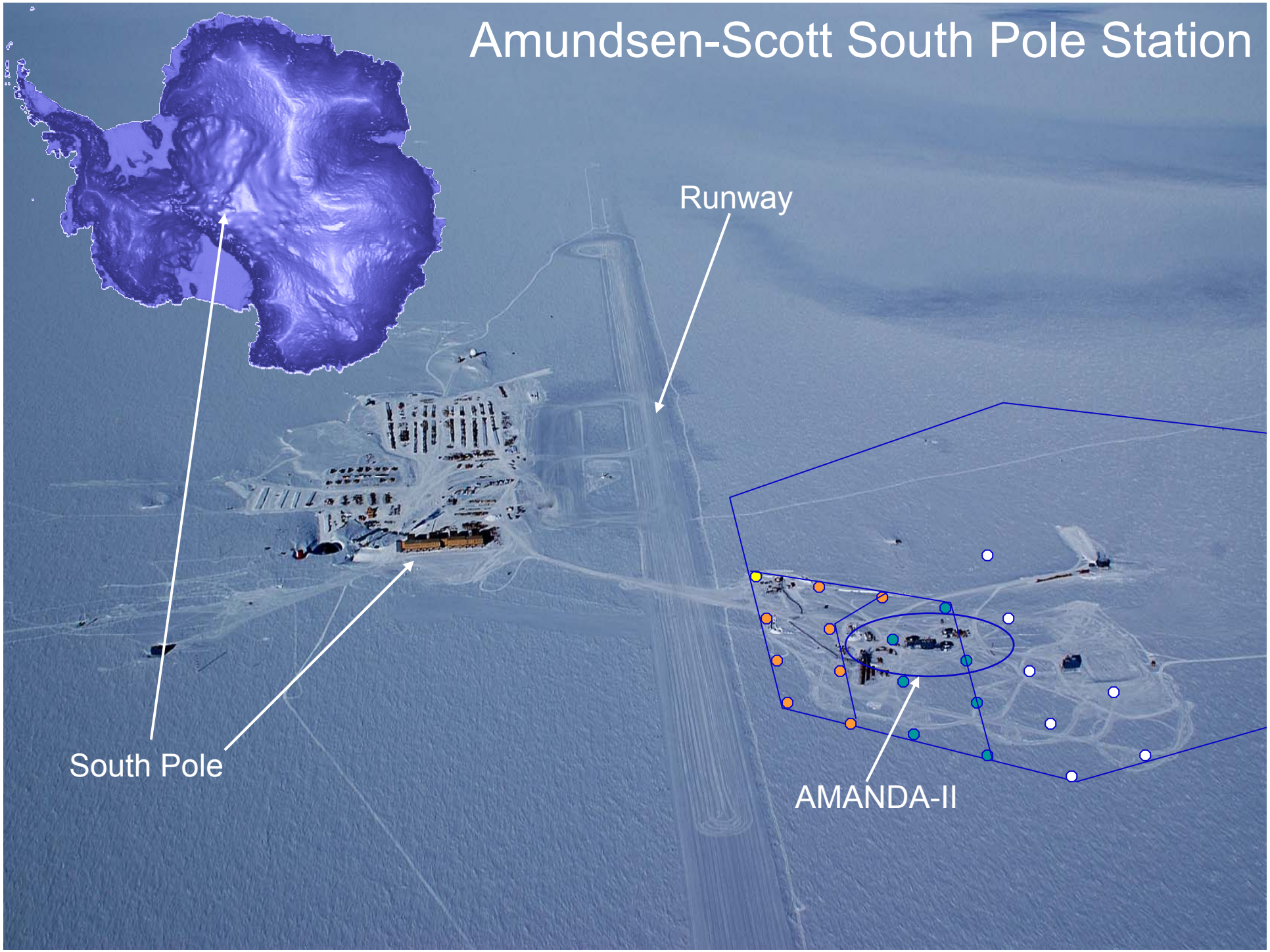
- R&D +TDR 2006-08. Funded.
- Construction ≥ 2009.



(design not optimized)

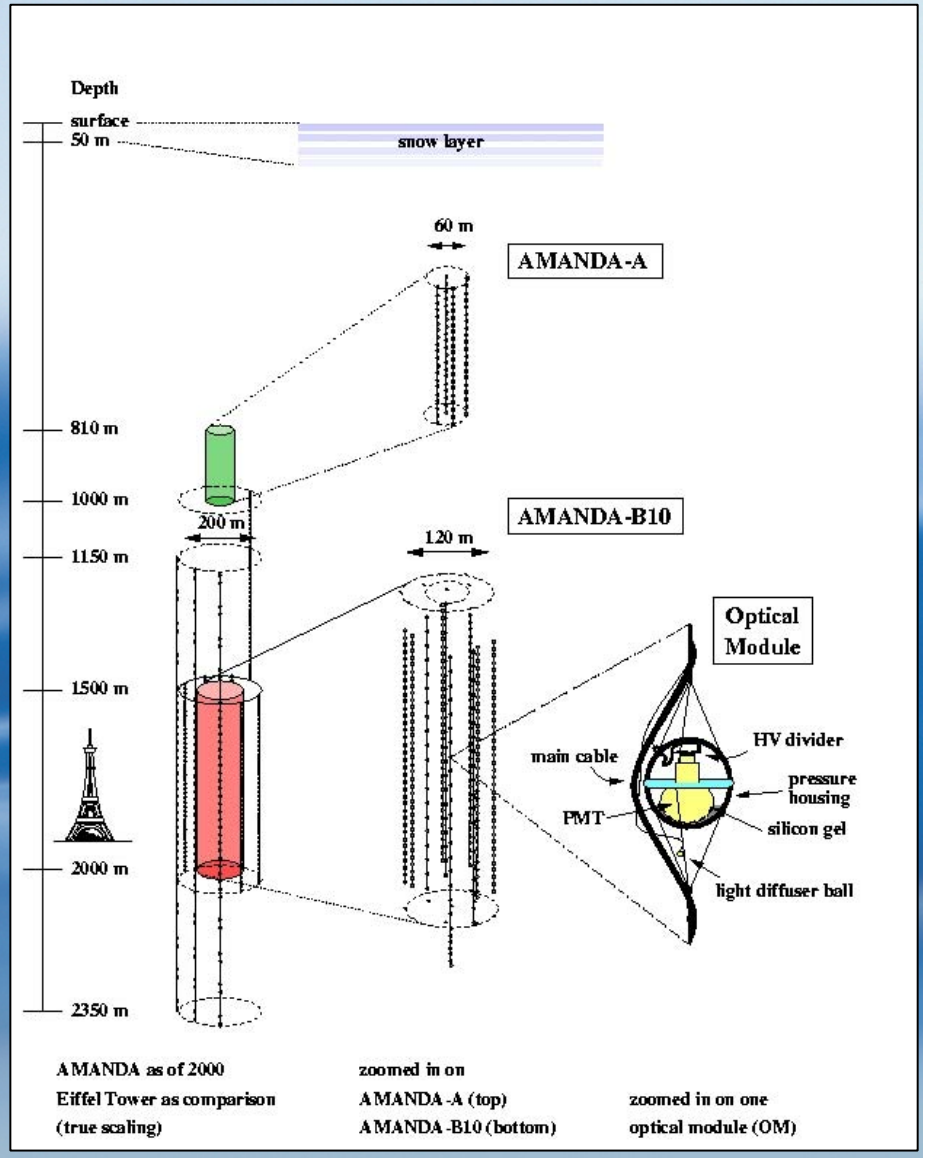



AMANDA / ICECUBE

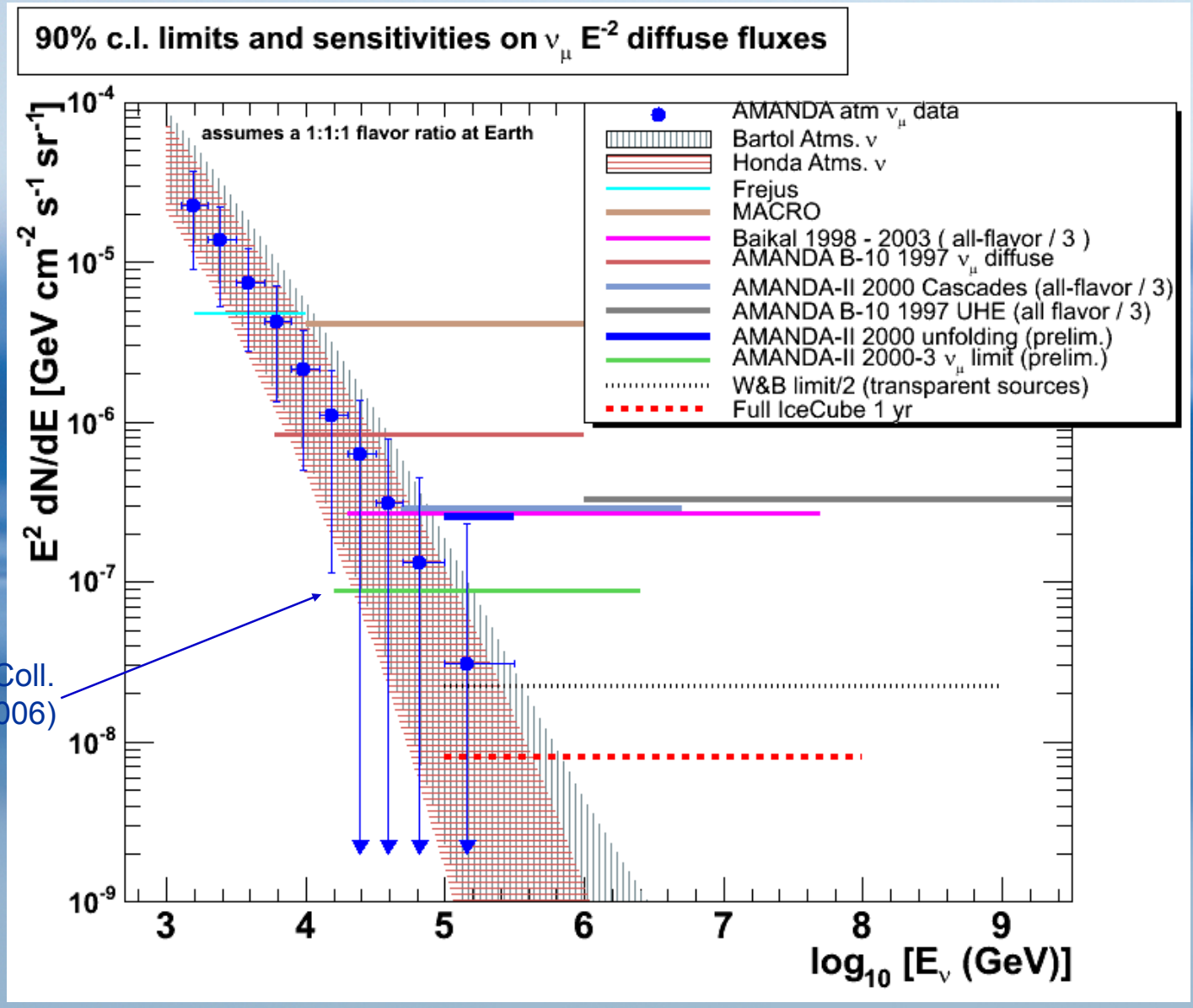

Amundsen-Scott South Pole Station
Runway
South Pole
AMANDA-II

AMANDA

- 677 analog OMs deployed along 19 strings
  - 10 strings 1997 (AMANDA B10)
  - 3 strings 1998 (AMANDA B13)
  - 6 strings 2000 (AMANDA II)
- Analog PMT signals using electrical and optical transmission lines.
- 200 m diameter, 500 meters height; AMANDA II encompasses 20 Mton instrumented ice volume.
- AMANDA will remain operational and form IceCube *Inner Core Detector* for low E physics (~ 100 GeV)
- IceCube surrounding strings provide effective veto – lower background and can push AMANDA energy threshold down.
- Conventional TDC / ADC technology for AMANDA has been entirely replaced by TWR system.
- Beginning 2007 season, AMANDA / IceCube data streams will be conjoined; detector subsystems will share trigger information.

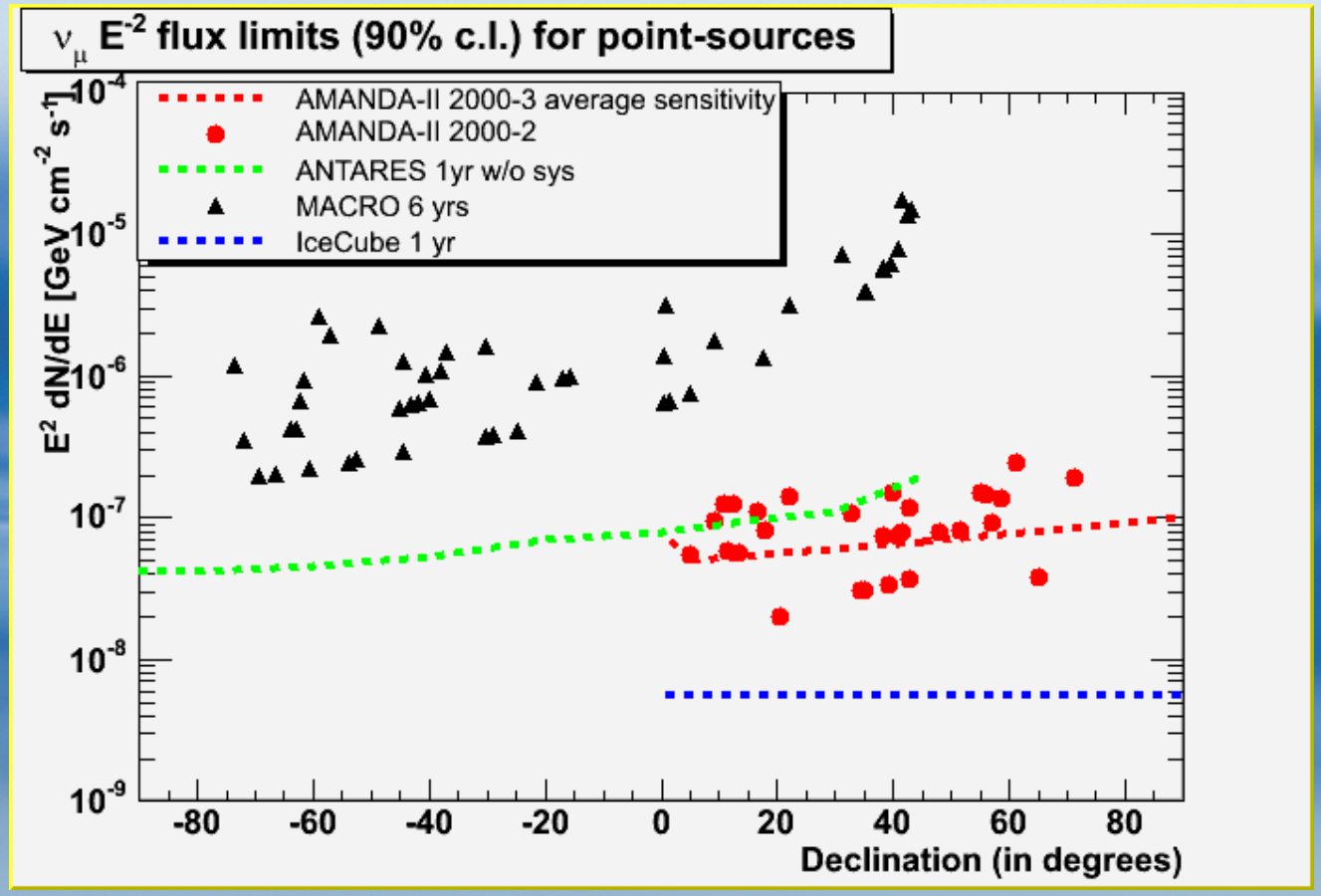


Limits to diffuse fluxes

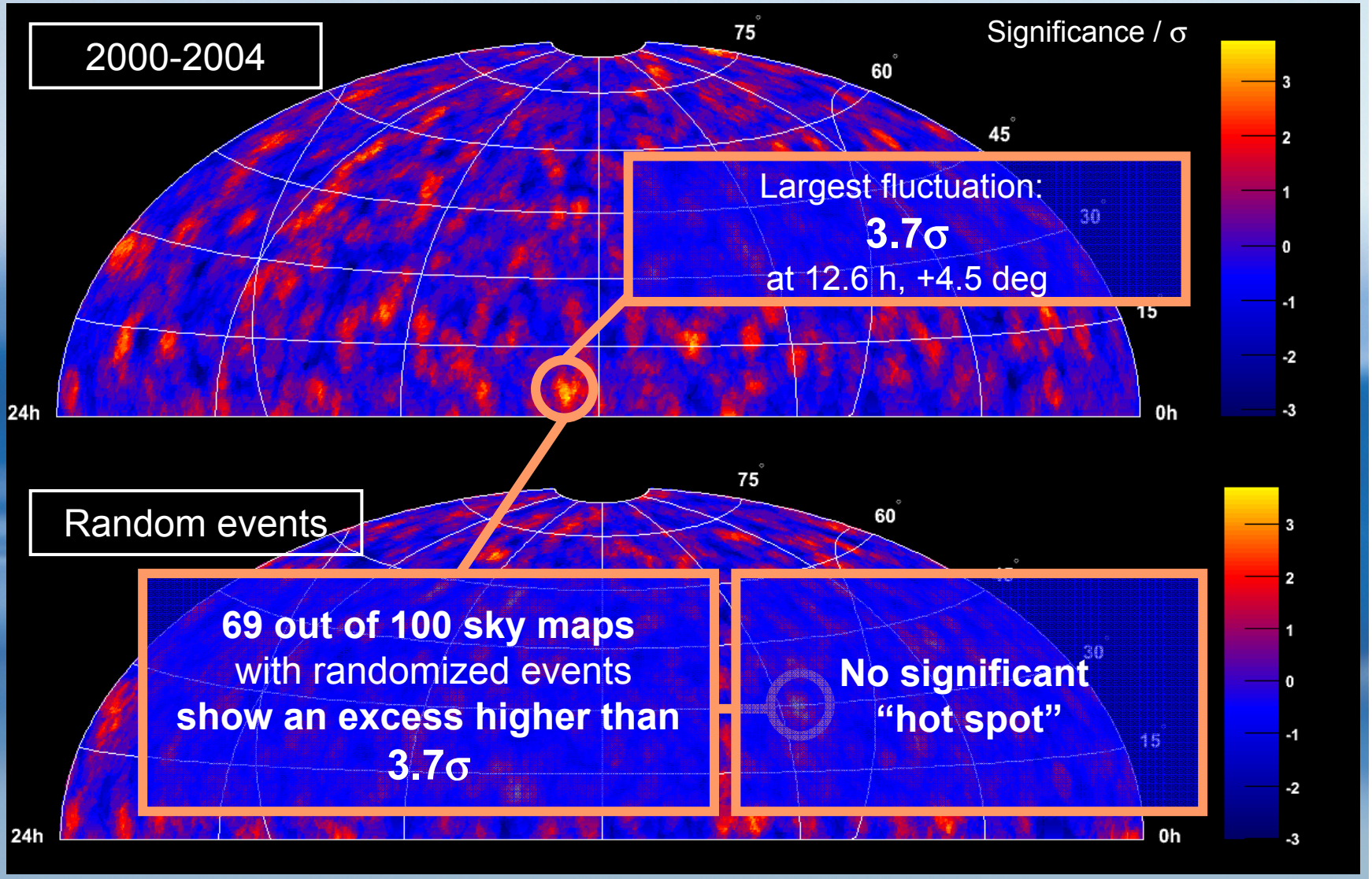


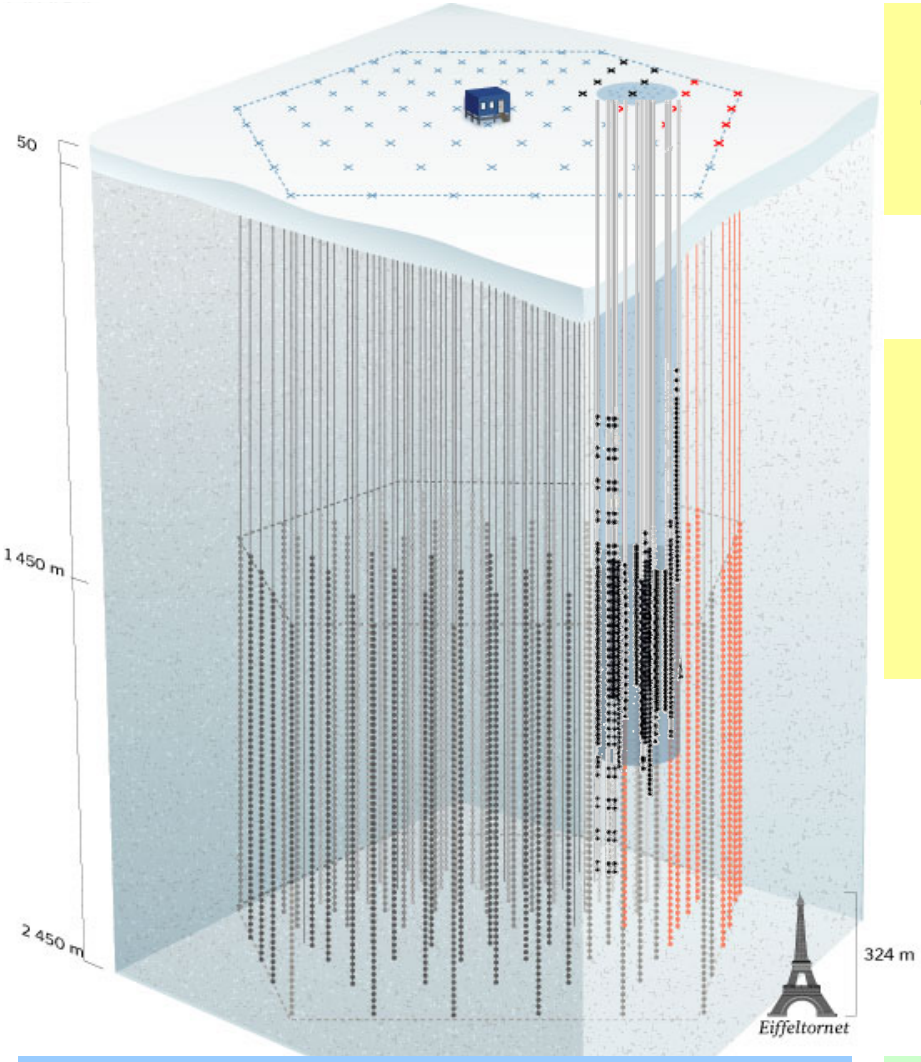
Hill, IceCube Coll. at Neutrino 2006)

Limits on point sources



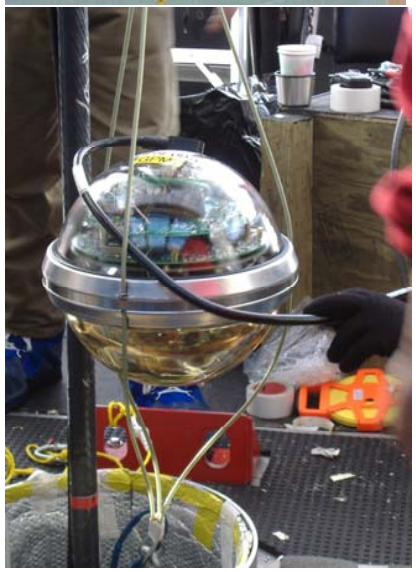
AMANDA Skymap



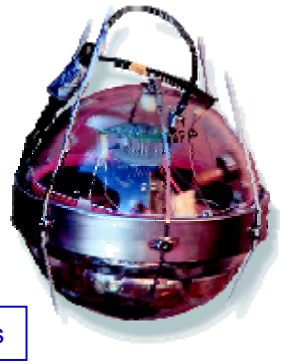


IceTop
160 frozen-water tanks
2 DOMs / tank

IceCube
80 strings
60 DOMs/string
17 m vertical spacing
125 m between strings



digital sensors (Digital Optical Modules)

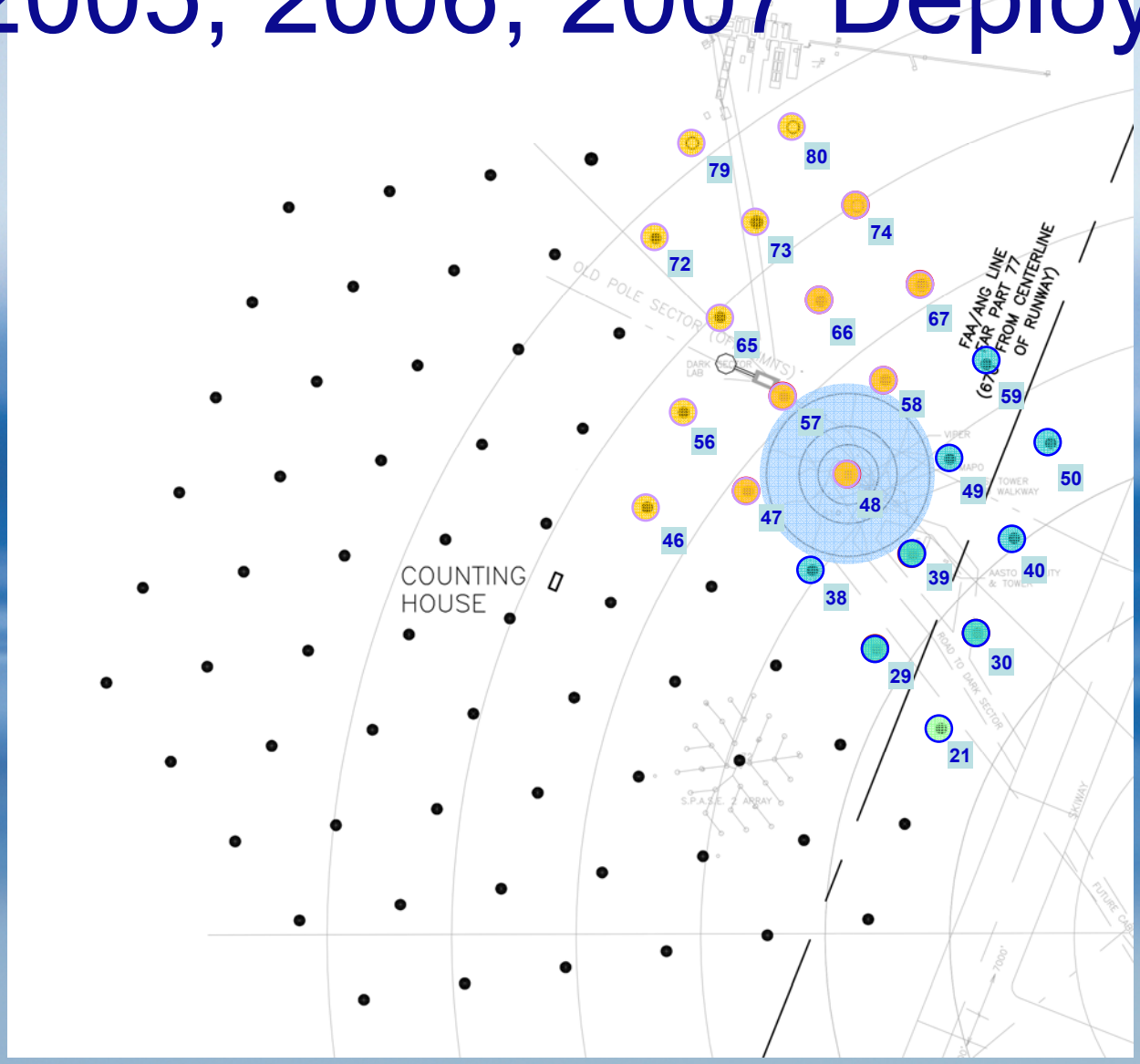


analog sensors

<u>instrument deployed (Jan 2006)</u>
9 IceCube strings (540 DOMs)
32 IceTop Tanks (64 DOMs)

AMANDA-II
19 strings
677 OMs

2005, 2006, 2007 Deployments



AMANDA

IceCube string and IceTop station deployed 01/05

IceCube string and IceTop station deployed 12/05 – 01/06

IceTop station only 2006

IceCube string and IceTop station to be deployed 12/06 – 01/07

604 DOMs deployed to date

Next year looking for ≥ 12 strings. IceTop will be backed off to remain in line with hole deployment

Want to achieve steady state of 14 strings / season.

The Enhanced Hot Water Drill

EHWD designed to drill a 2450 m × 60 cm hole in ~30 hr. Fuel budget is 7200 gal per hole. Shown above is drill camp and tower site (inset), both mobile field arrays. Everything must fit into LC-130 for transport to Pole.

Supply: 200 GPM @ 1000 psi, 190 °F
Return: 192 GPM @ 33 °F **Make-Up:** 8 GPM @ 33 °F

Thermal Power: 4.5 Megawatt

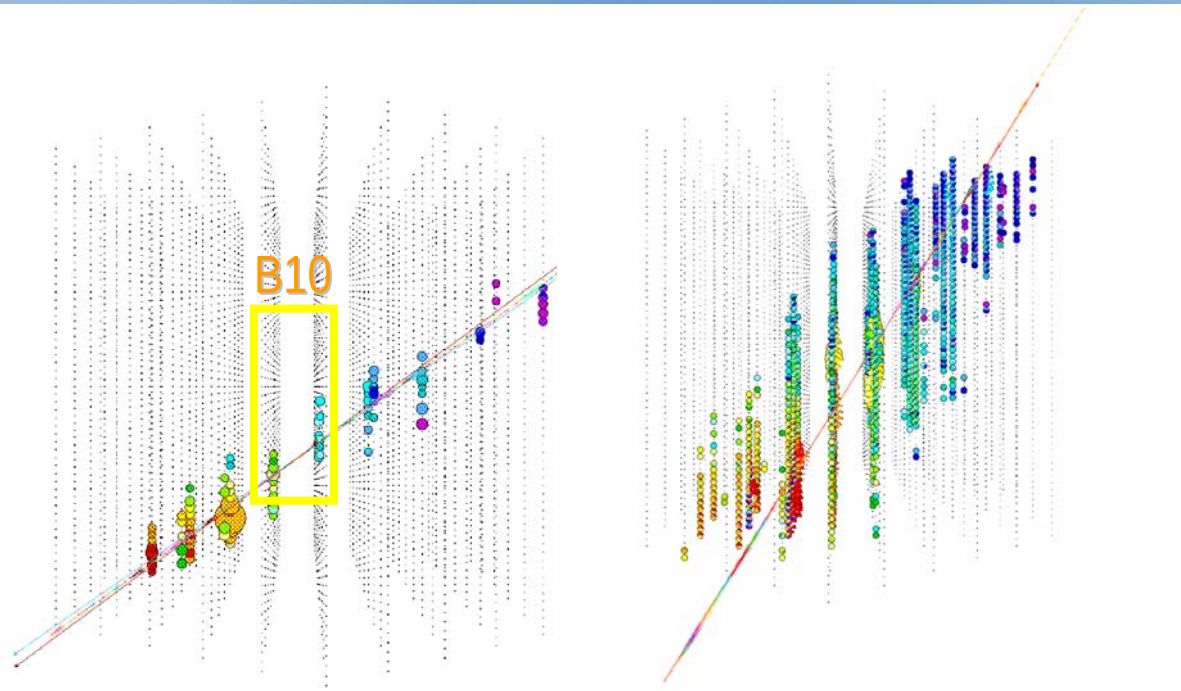
IceTop – the Surface Airshower

Event Signatures in IceCube …

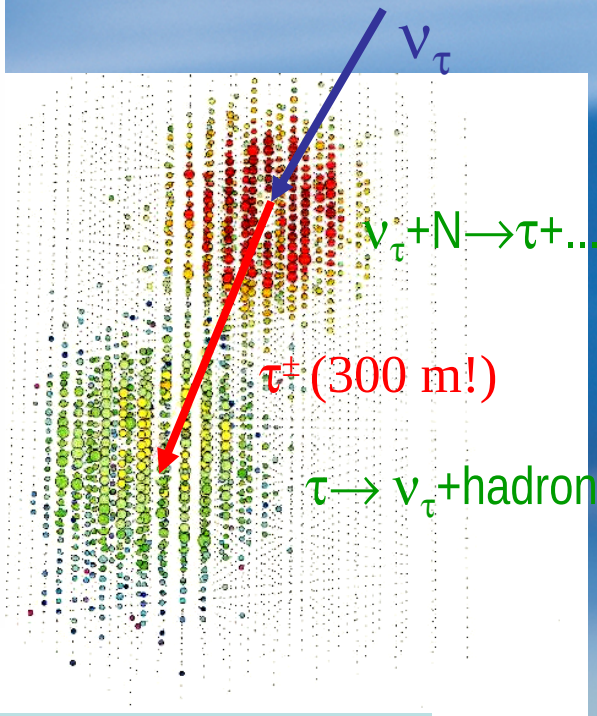
10^{13} eV (10 TeV)

$6x10^{15}$ eV (6 PeV)

Multi-PeV



signature of ν_μ



signature of ν_τ

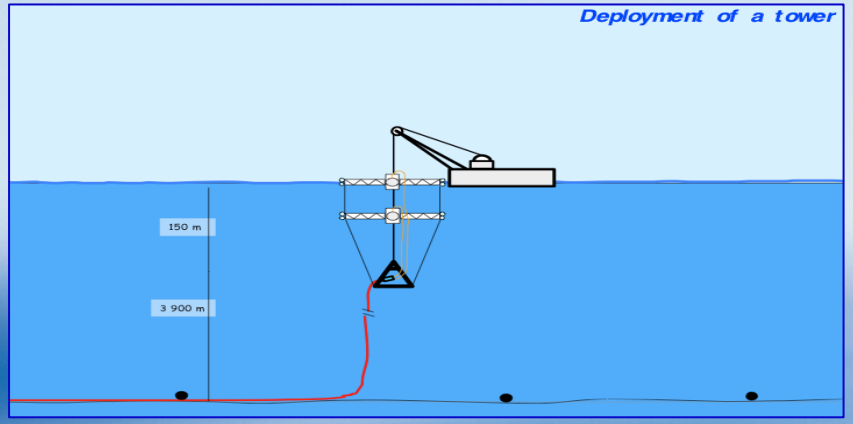
"The ν" @ South Pole

- IceCube is a km^3 detector that improves sensitivity and extends neutrino energy range detection with respect to AMANDA-II
- AMANDA-II upper limits on cosmic neutrino searches getting tighter and closer to WB limit
- IceTop/IceCube cosmic ray composition measurement up to ~10^{18} eV with x100 higher sensitivity than SPASE/AMANDA
- construction of IceTop and IceCube is proceeding at pace and every year the array increases size significantly
- IceCube and AMANDA overlap sensitivity in energy

NESTOR: Rigid Structures Forming Towers

- Tower based detector (titanium structures).
- Dry connections (recover−connect−redeploy).
- Up- and downward looking PMs.
- 3800 m deep.
- Electro-optical cable deployed June 2000, but damaged
- Cable recovered, repaired & redeployed (Jan 2002)
- 1 Floor deployed in 2003. downward cosmic ray muons reconstructed

After few weeks-fault developed in the submarine cable, awaiting repair

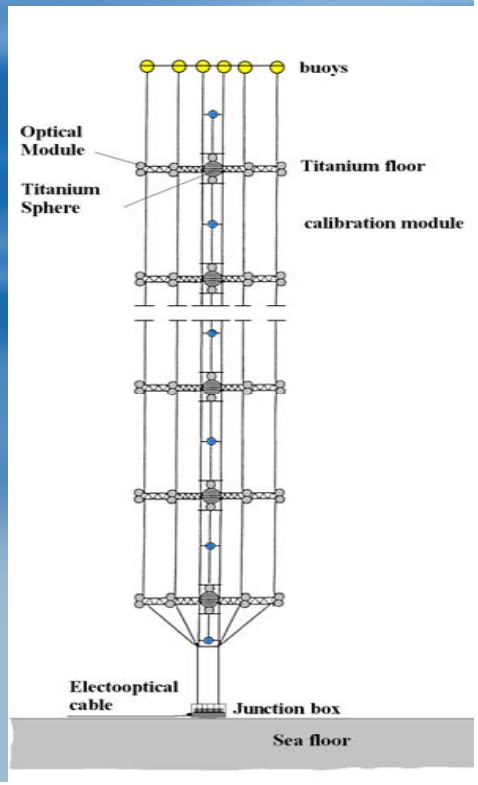


Tower(s) with12 floors

→ 32 m diameter

→ 30 m between floors

→ 144 PMs per tower



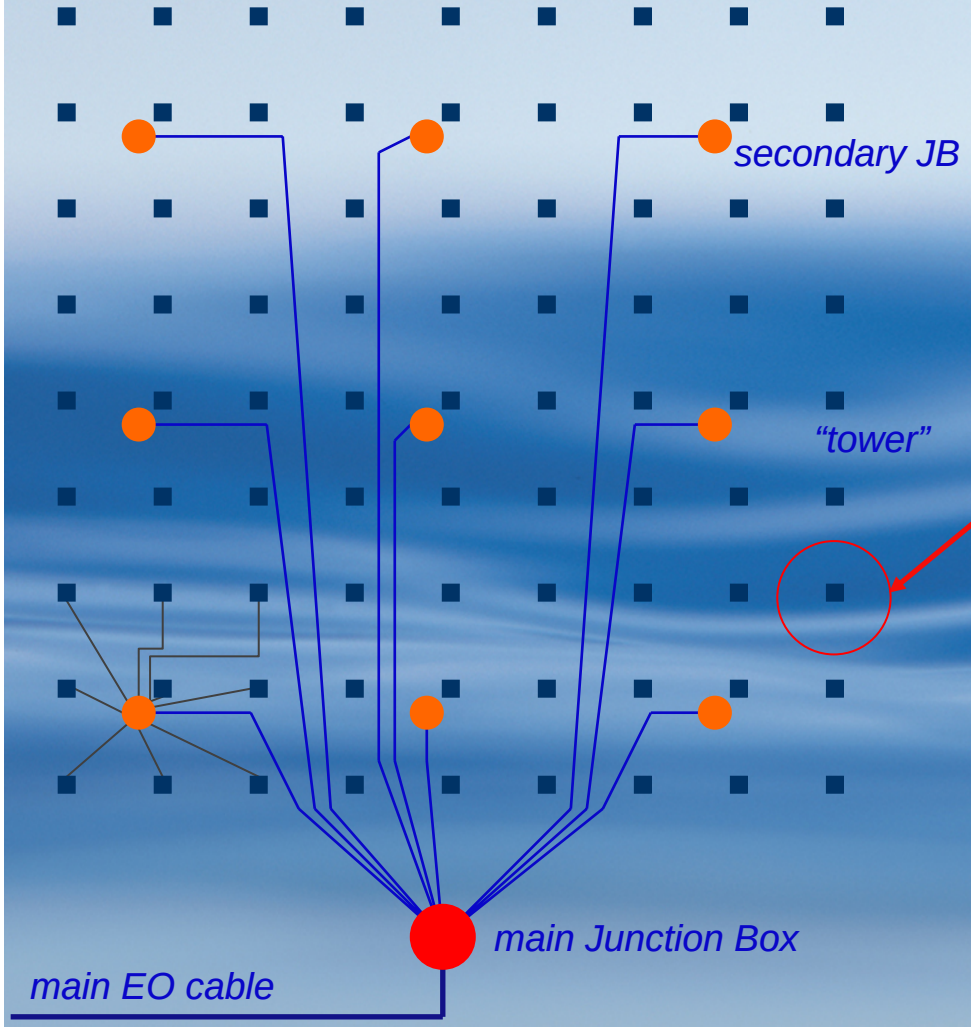
NEMO

95 Physicists from 12 Institutions

Phase1 → **Test of prototypes in deep sea**
Near Catania at 2000 m depth

Phase2 → **Construction of an infrastructure for km3**
Off Capo Passero at 3500 m depth

NEMO architecture

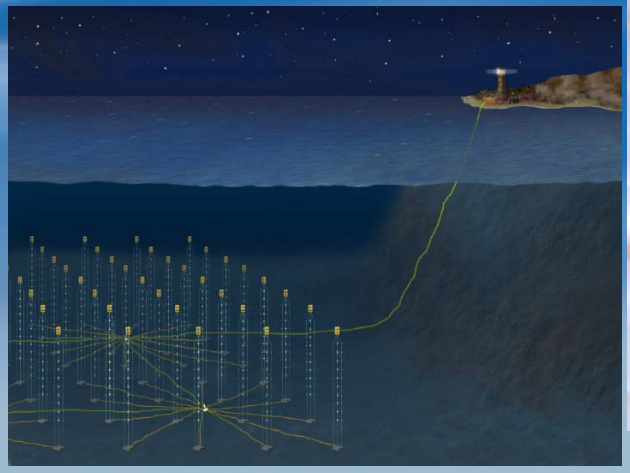


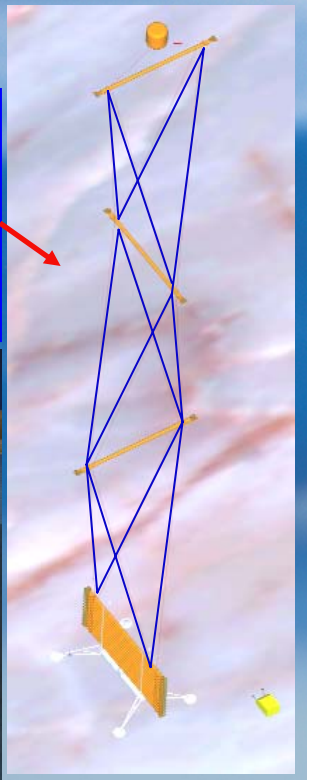
Detector architecture issues

Reduce the number of structures to reduce the number of underwater connections and allow operation with a ROV

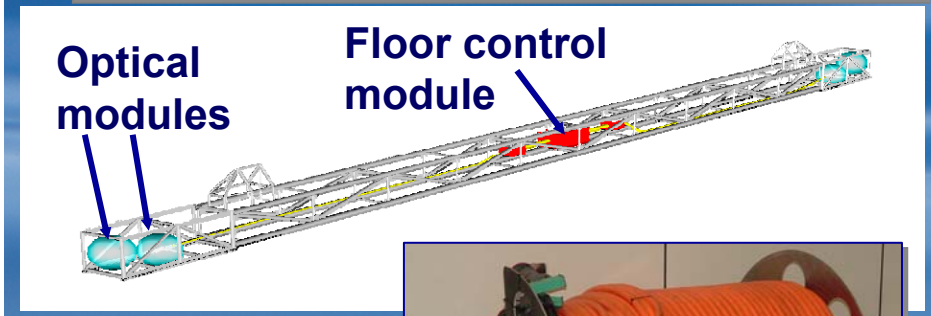
Detector modularity

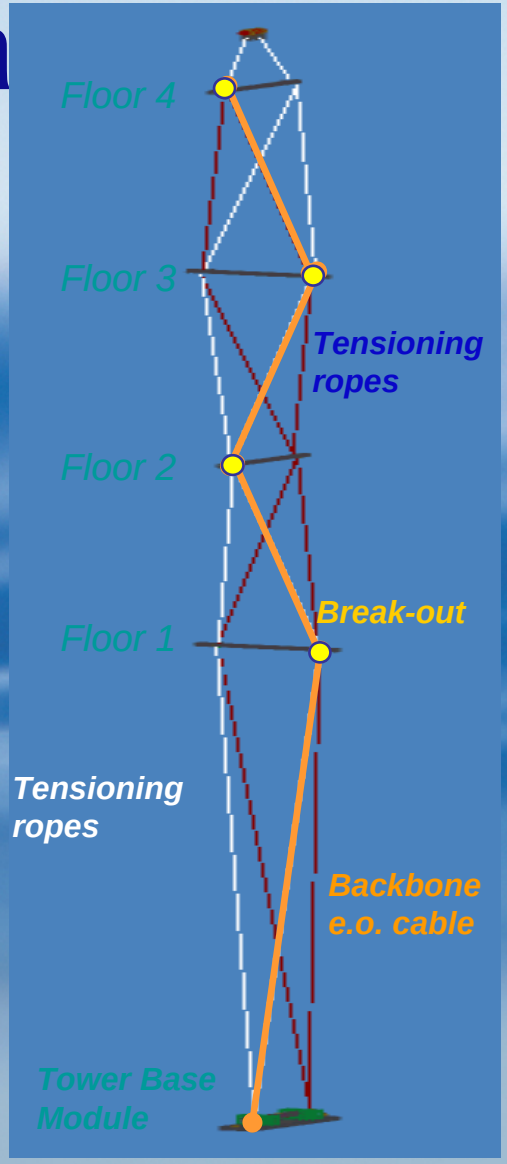
9 x 9 = 81 "Towers" with 3 dimensional and non homogeneous distribution of sensors





The Mini Tower for NEMO





Mechanical stresses are applied only to the tensioning ropes

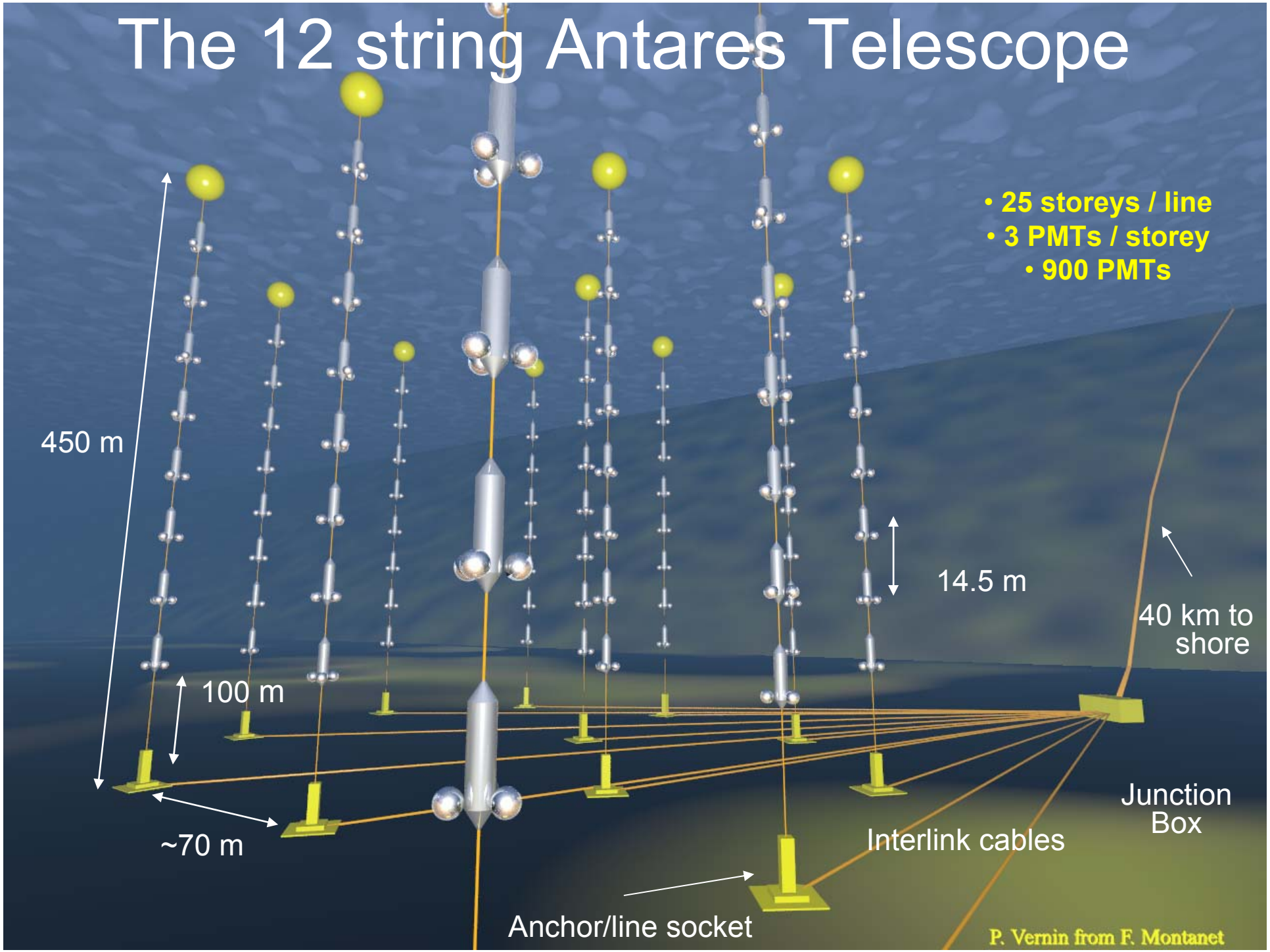
NEMO status

- Installation of the Catania Test Site at 2000m depth:

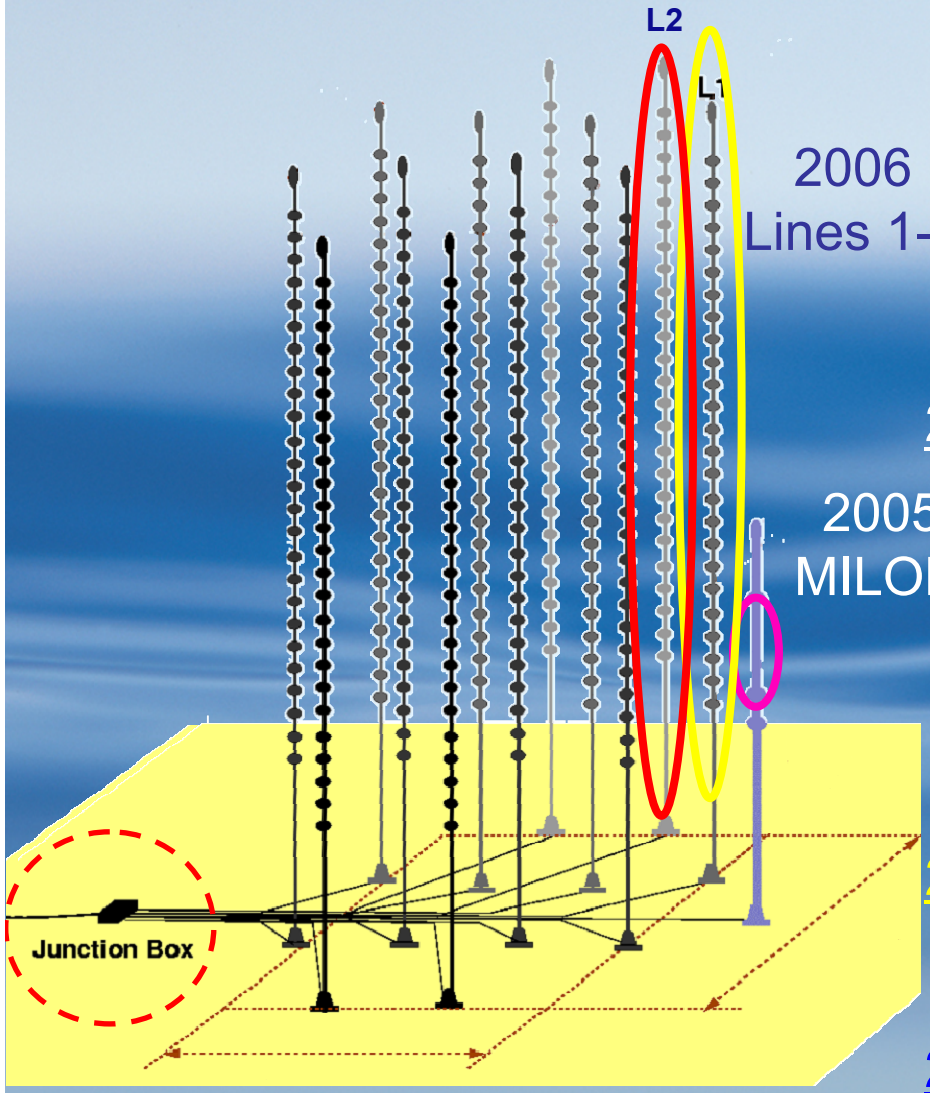
- Two underwater stations transmitting data since January 2005
- NEMO Phase-1 now under assembly →
- to be deployed in October

- Construction of the km3-infrastructure offshore Capo Passero:

- shore laboratory acquired → currently under restoration
- E.O. cable acquired → to be installed by Nexans-Alcatel within 2007
- a mini tower with 4 OM will be deployed together with the cable
- a fully equipped tower will be deployed within 2007


The 12 string Antares Telescope
• 25 storeys / line
• 3 PMTs / storey
• 900 PMTs
450 m
100 m
~70 m
14.5 m
40 km to shore
Junction Box
Interlink cables
Anchor/line socket
P. Vernin from F. Montanet

ANTARES Construction Milestones



2001 – 2003:

- *Main Electro-optical cable* in 2001
- *Junction Box* in 2002
- *Prototype Sector Line (PSL)* & *Mini Instrumentation Line (MIL)* in 2003

2005 – Now:

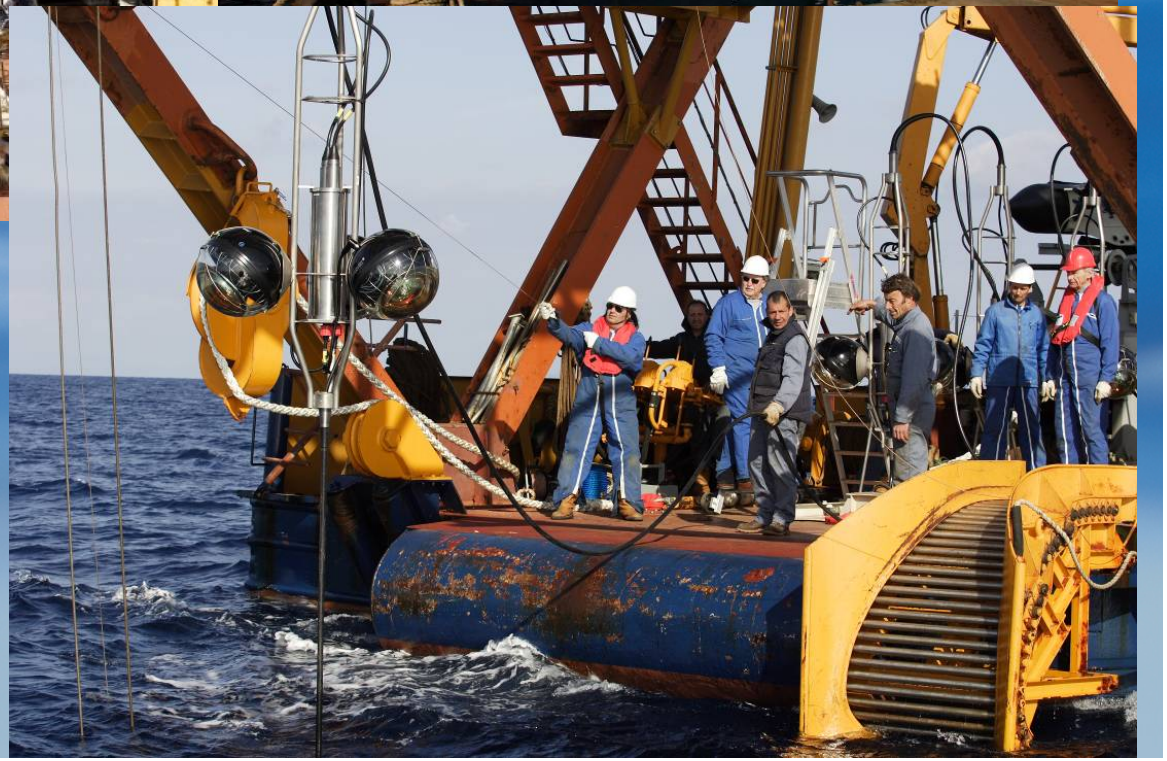
- *Mini Instrumentation Line with OMs (MILOM)* running since 12 April 2005
- *Line 1* running since 2 March 2006, first complete detector line
- *Line 2* running since 21 September 2006

2006 – 2007:

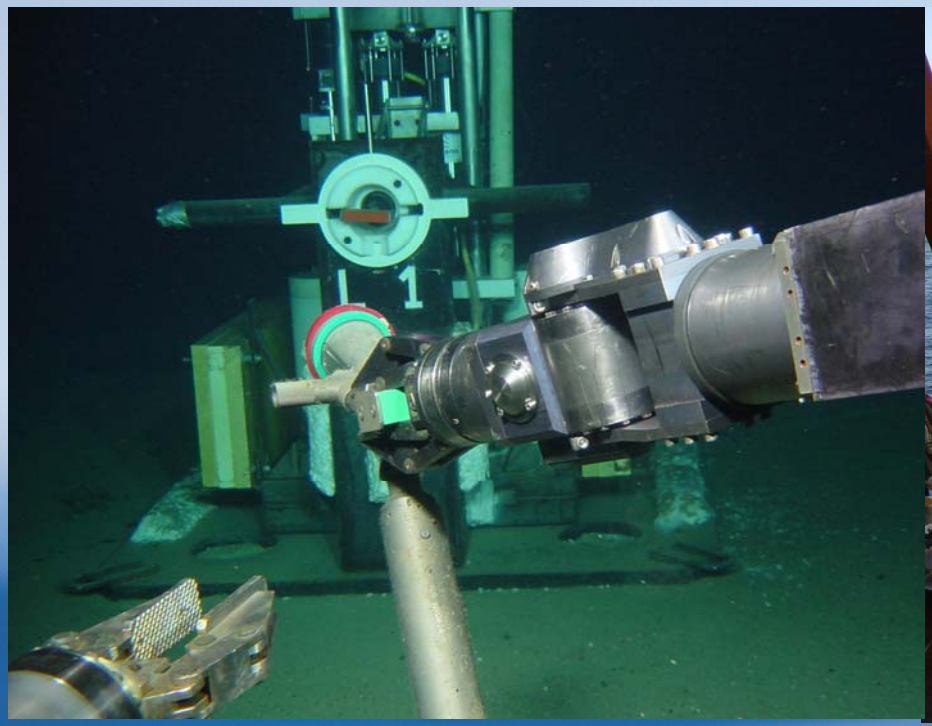
- Installation of *remaining 10 lines*

2007+: Physics with full detector !

First complete detector Lines installed in 2006

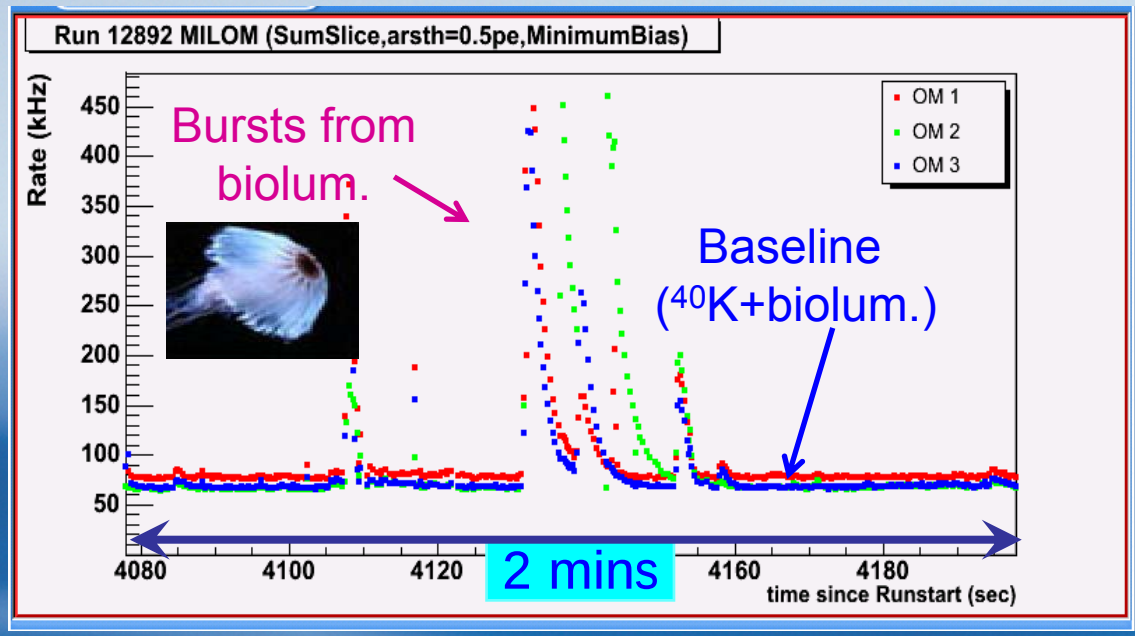


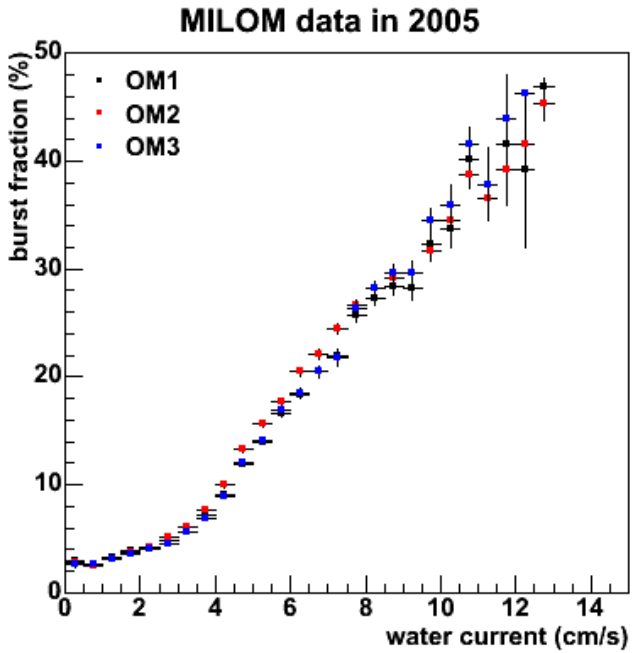
Line 1 deployed on Feb 14th…

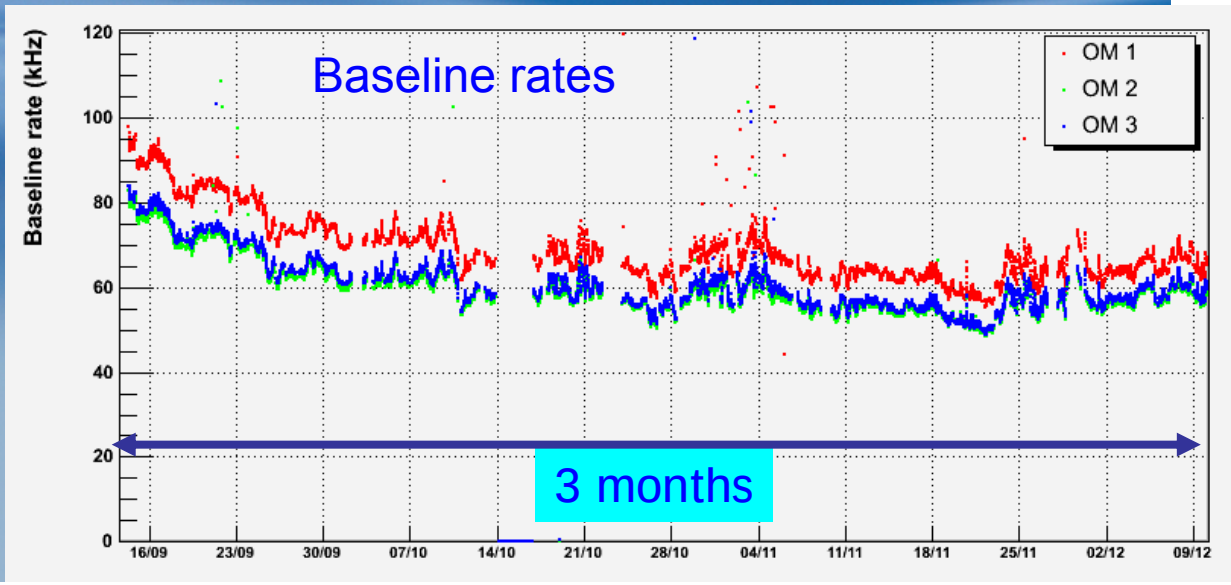


…and connected by submersible ROV Victor from Ifremer on March 2nd

Singles Counting Rates





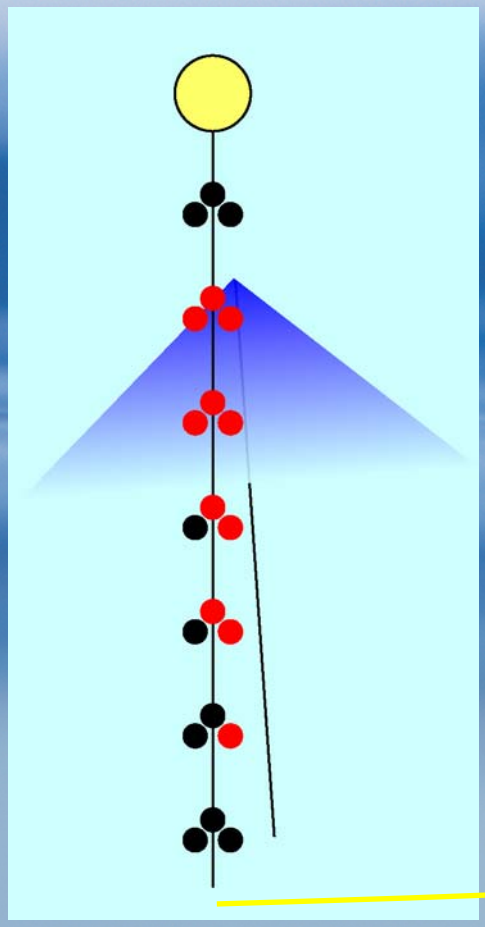


Burst-fraction:
fraction of time when rate > baseline + 20%

seasonal variations

Data taking & data processing

Line 1
operational since
March 2nd, 2006



Offline track reconstruction

Physics events

when enough correlated hits
are found

online data processing farm

DataFilter PC

ter PC

lter PC

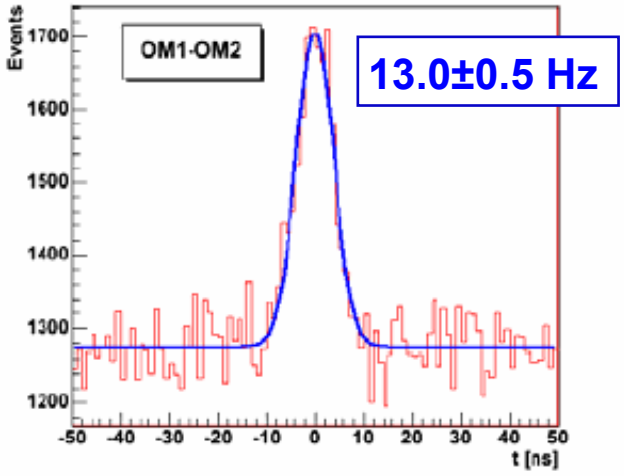
lter PC

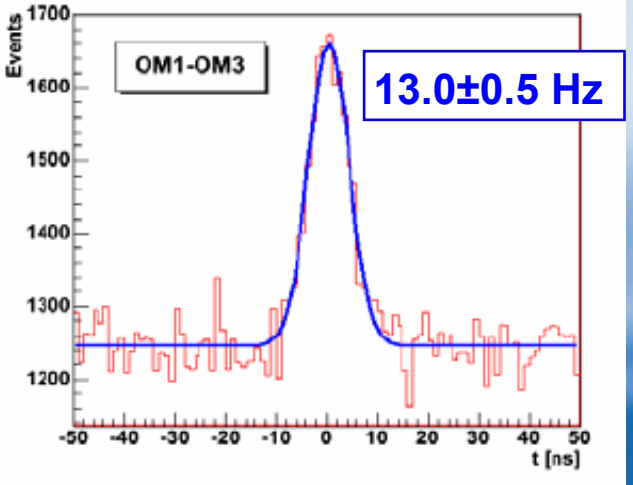
all data

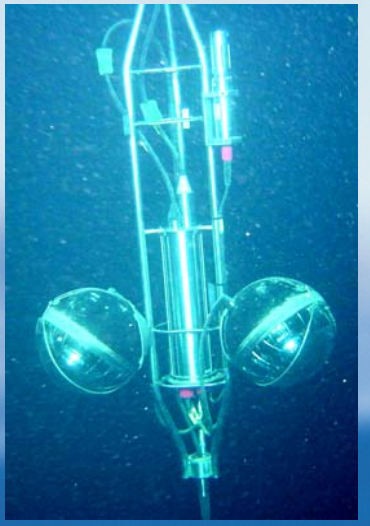
look for a muon-like
signal using
all registered hits

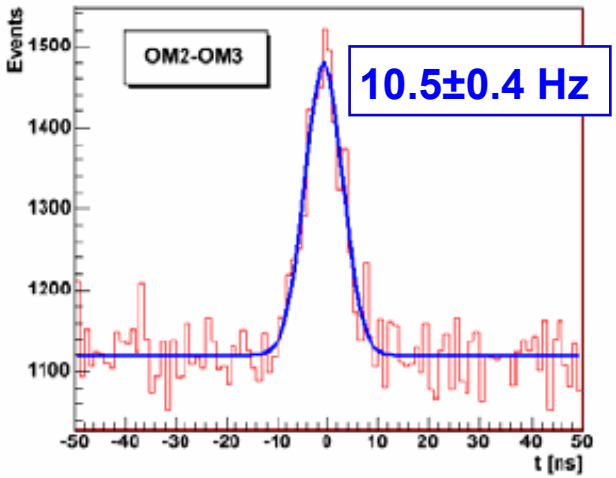
Coincidence rates from ^{40}K decays

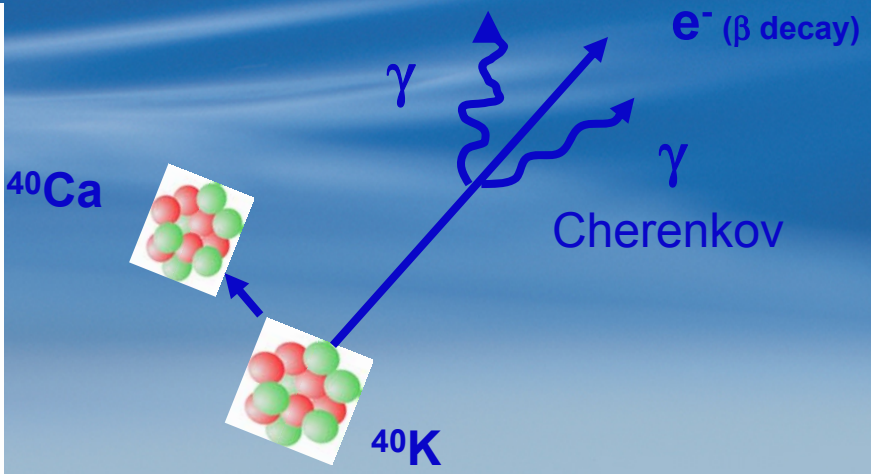
^{40}K coincidence rate from Gauss fit:





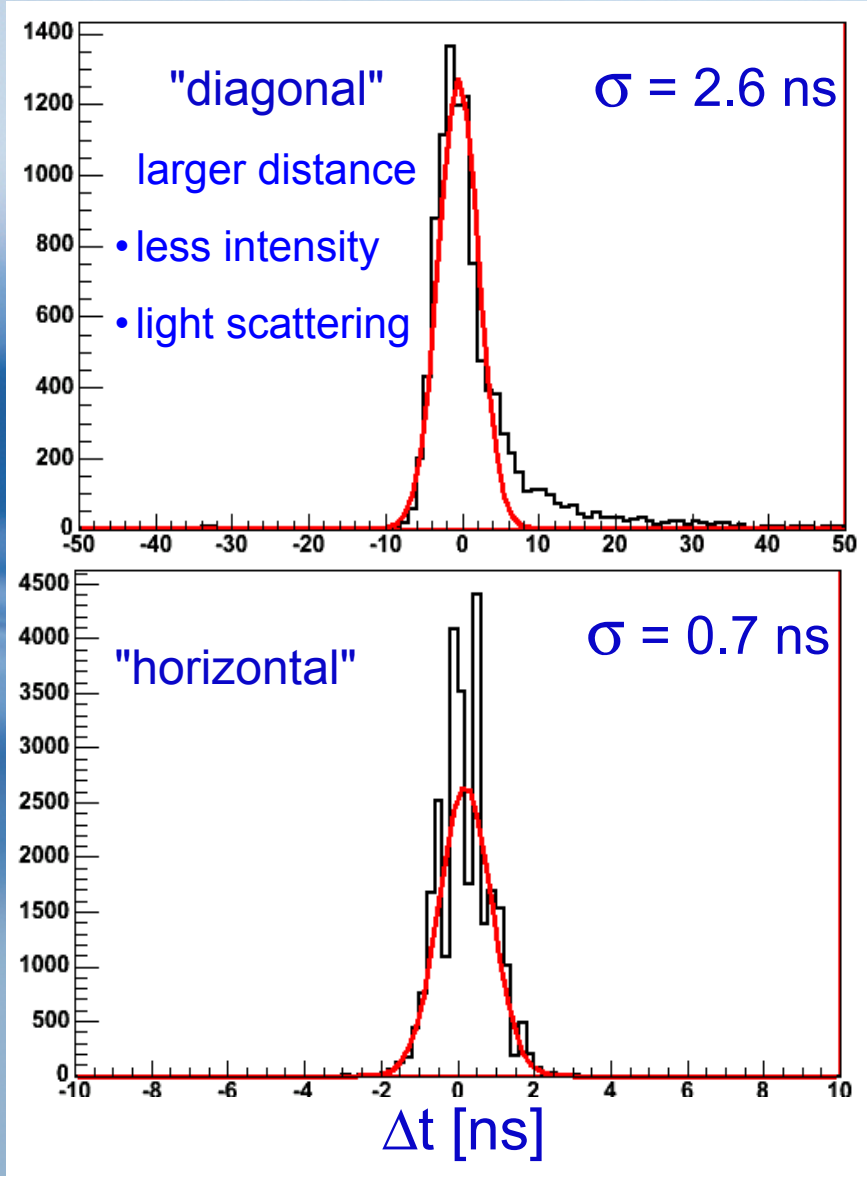


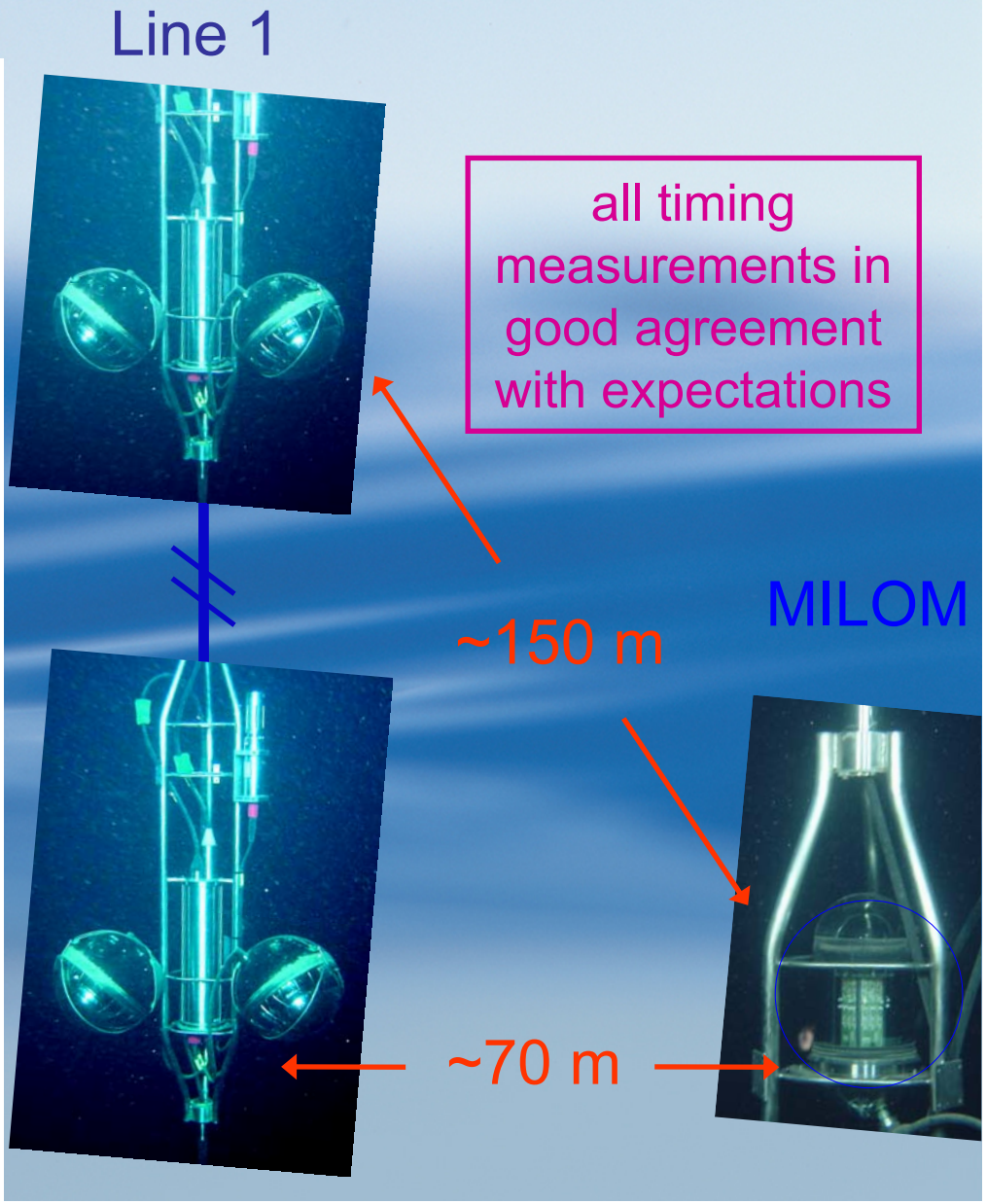




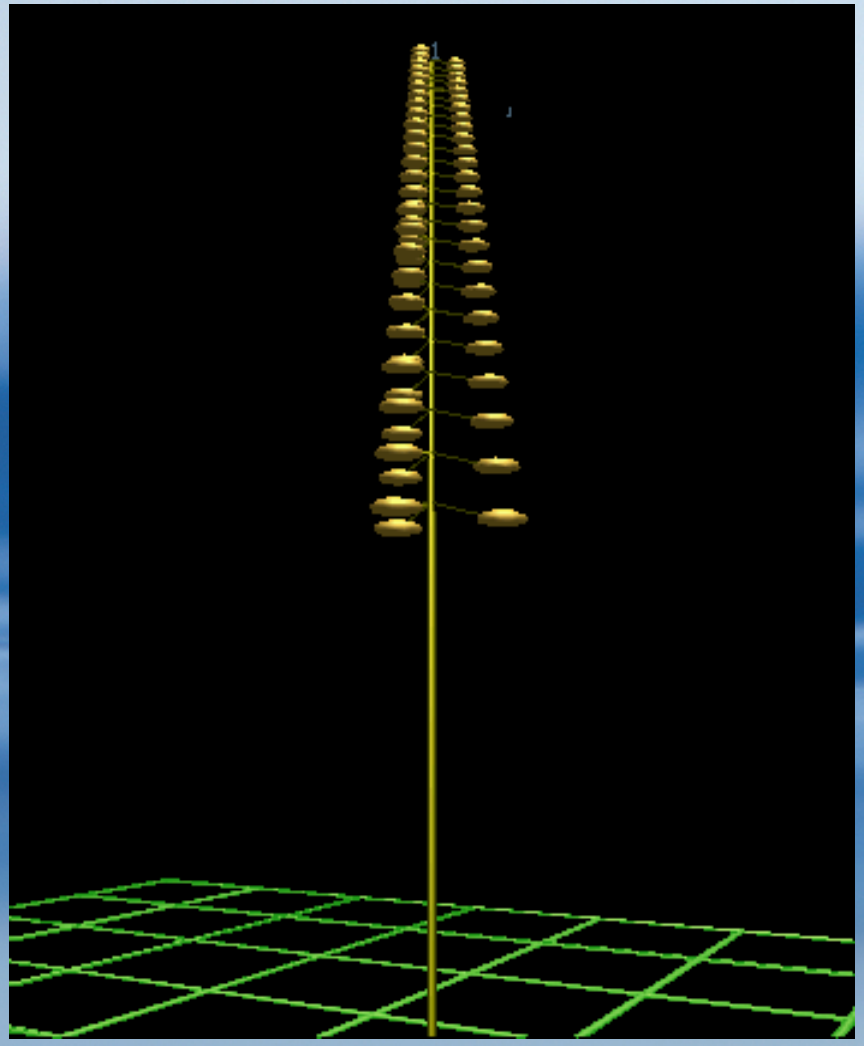
Simulation: 12 Hz ± 4 Hz (sys)

Line 1 time calibration with MILOM LED beacon





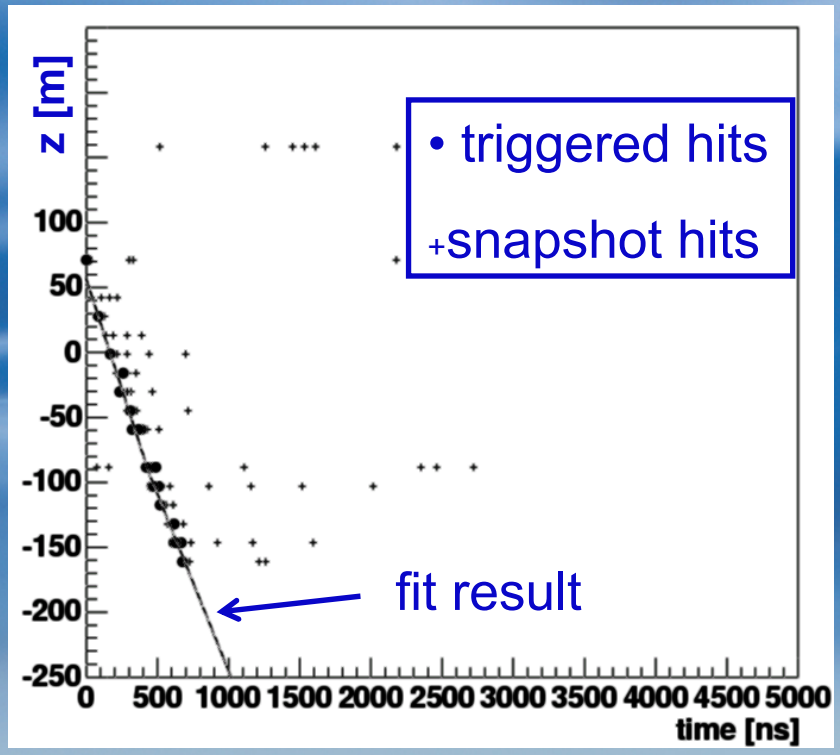
The first muon found with Line 1



Event Display by Aart Heijboer

Recorded on March 4th:
2 days after Line 1 connection !

single string muon reconstruction

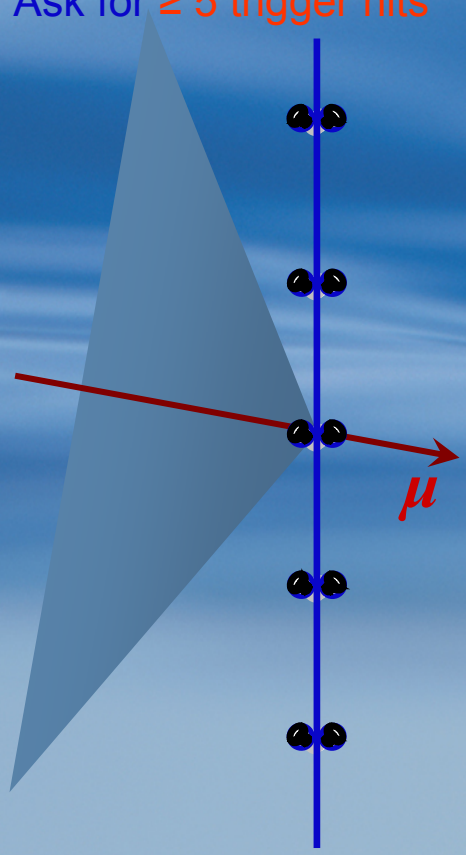


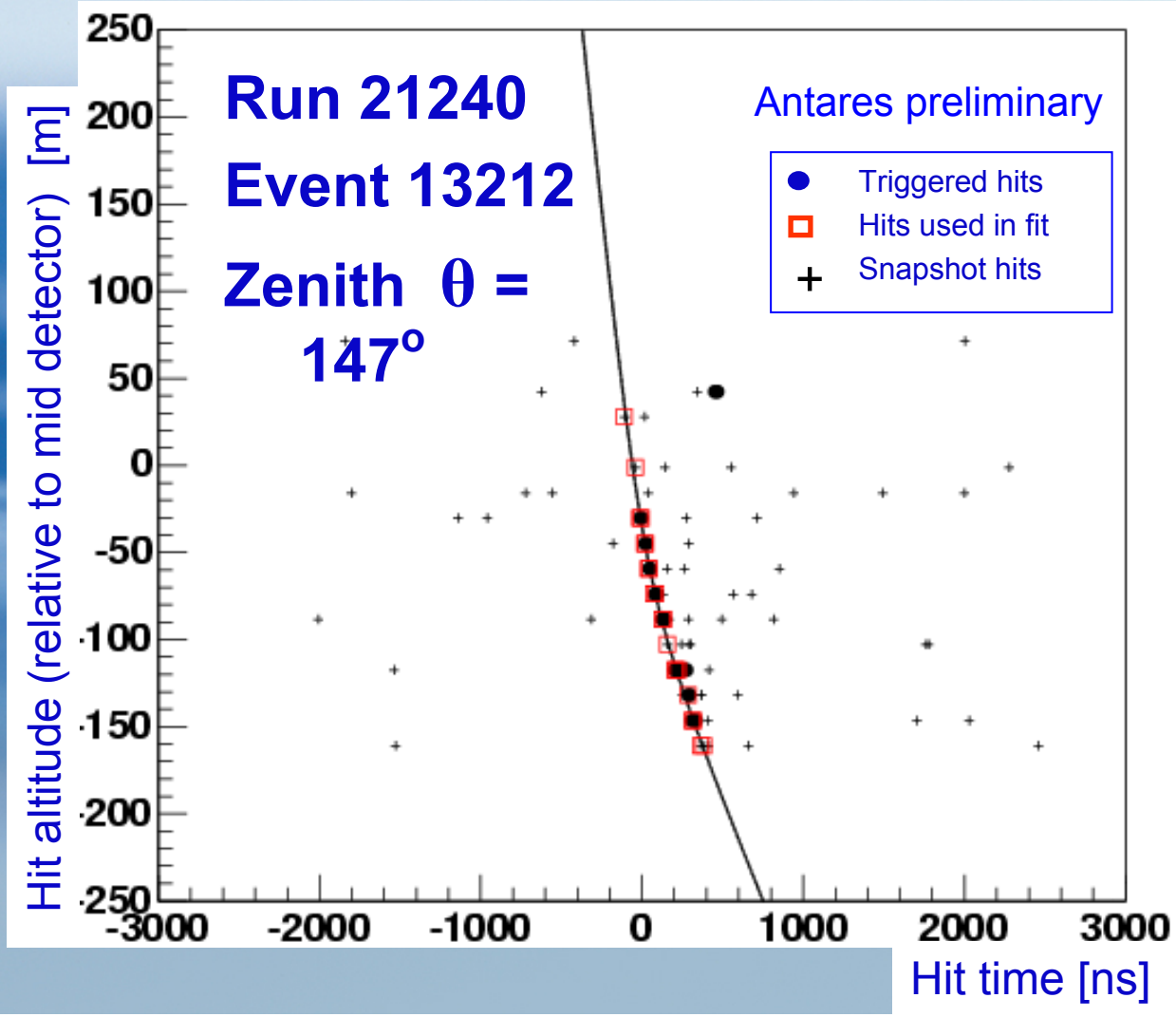
Reconstruction of atmospheric muon tracks

Reconstruction with Line1: Algorithm minimizes $\chi 2$
of PMT hit time vs altitude to find zenith angle of μ track

Online Data filter :

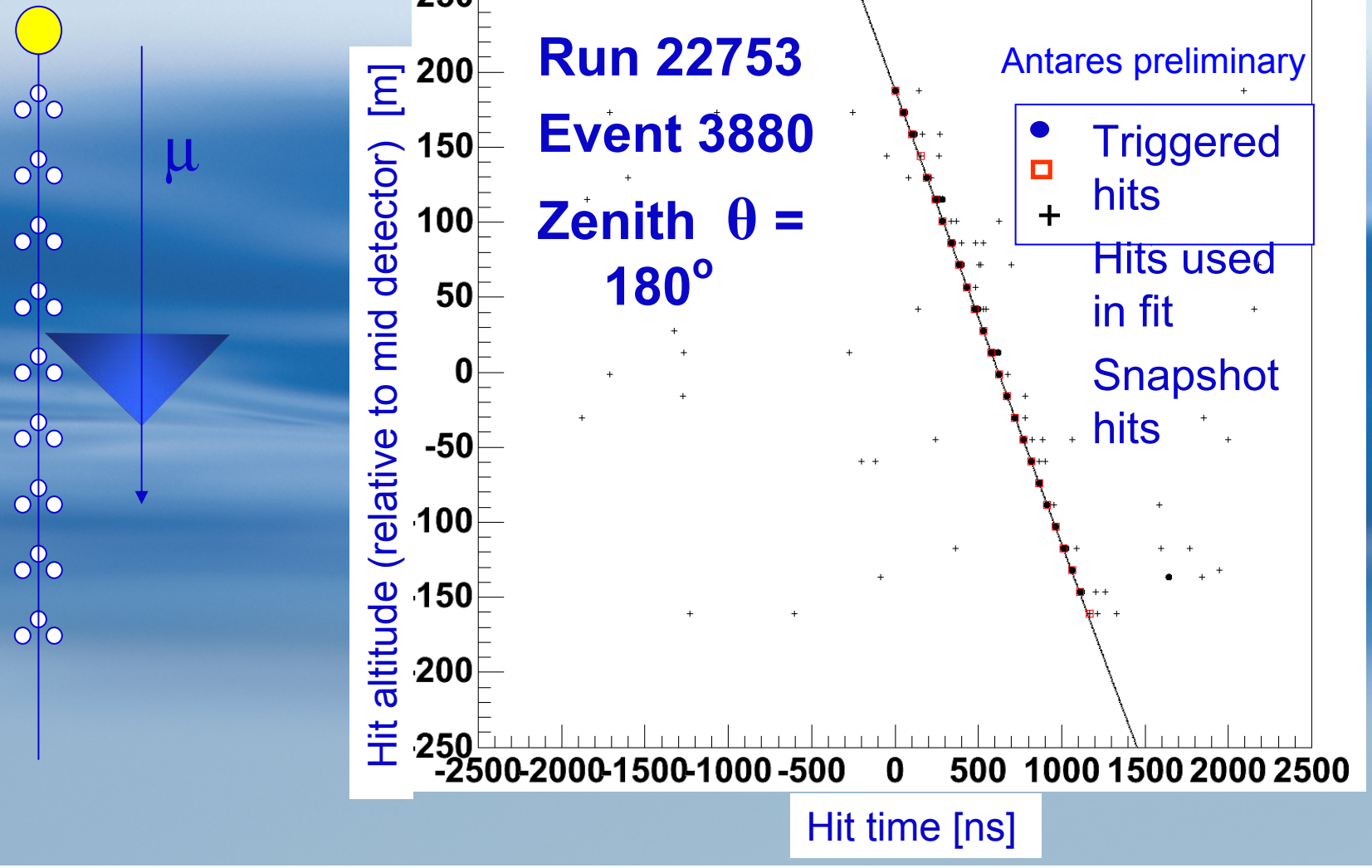
- Look for local coincidences (trigger hits) within 20ns
- Ask for ≥ 5 trigger hits



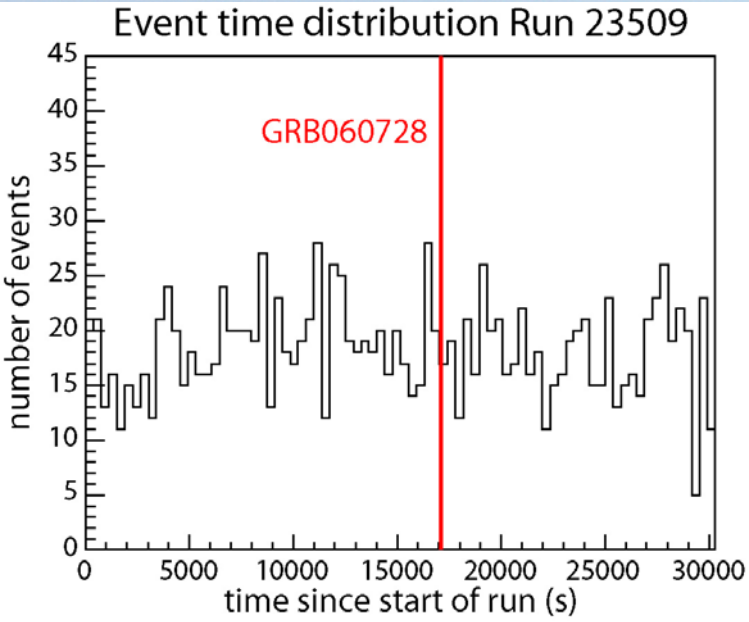


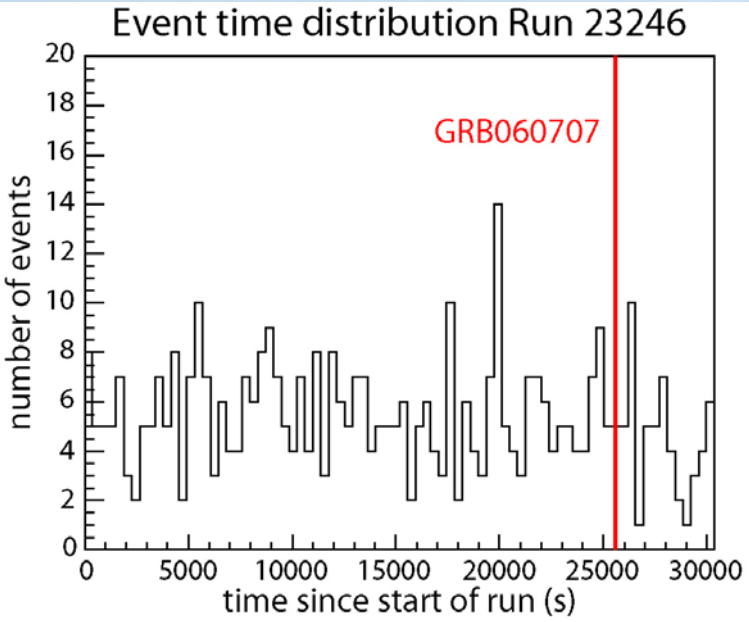
Reconstruction of atmospheric muon tracks

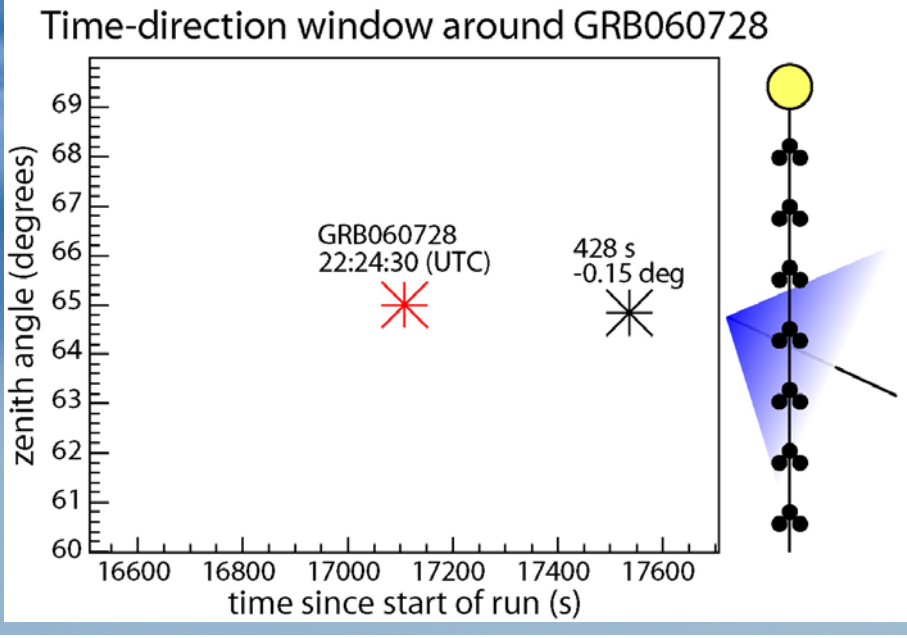
A nice, vertical track with hits in each storey of the line

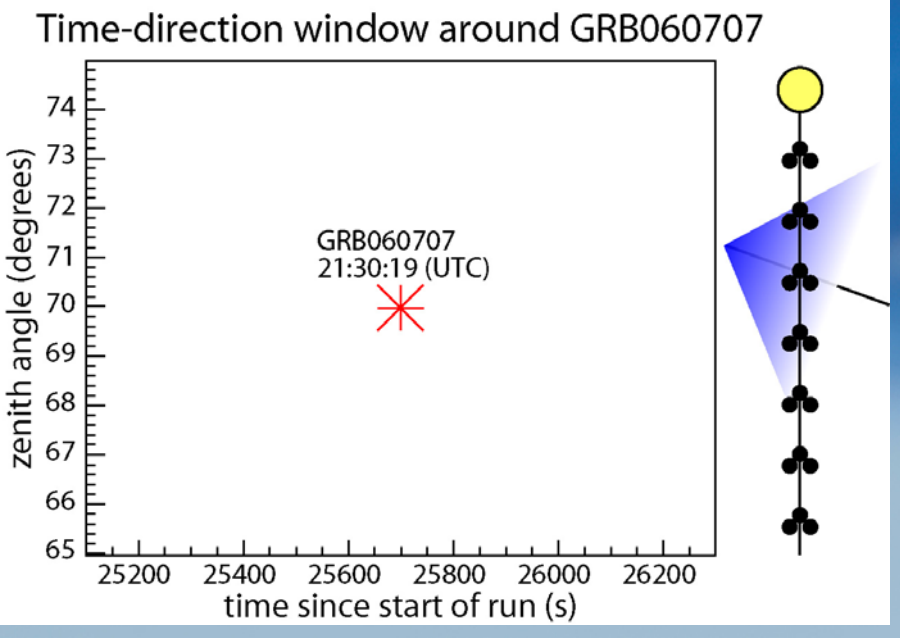


Event times

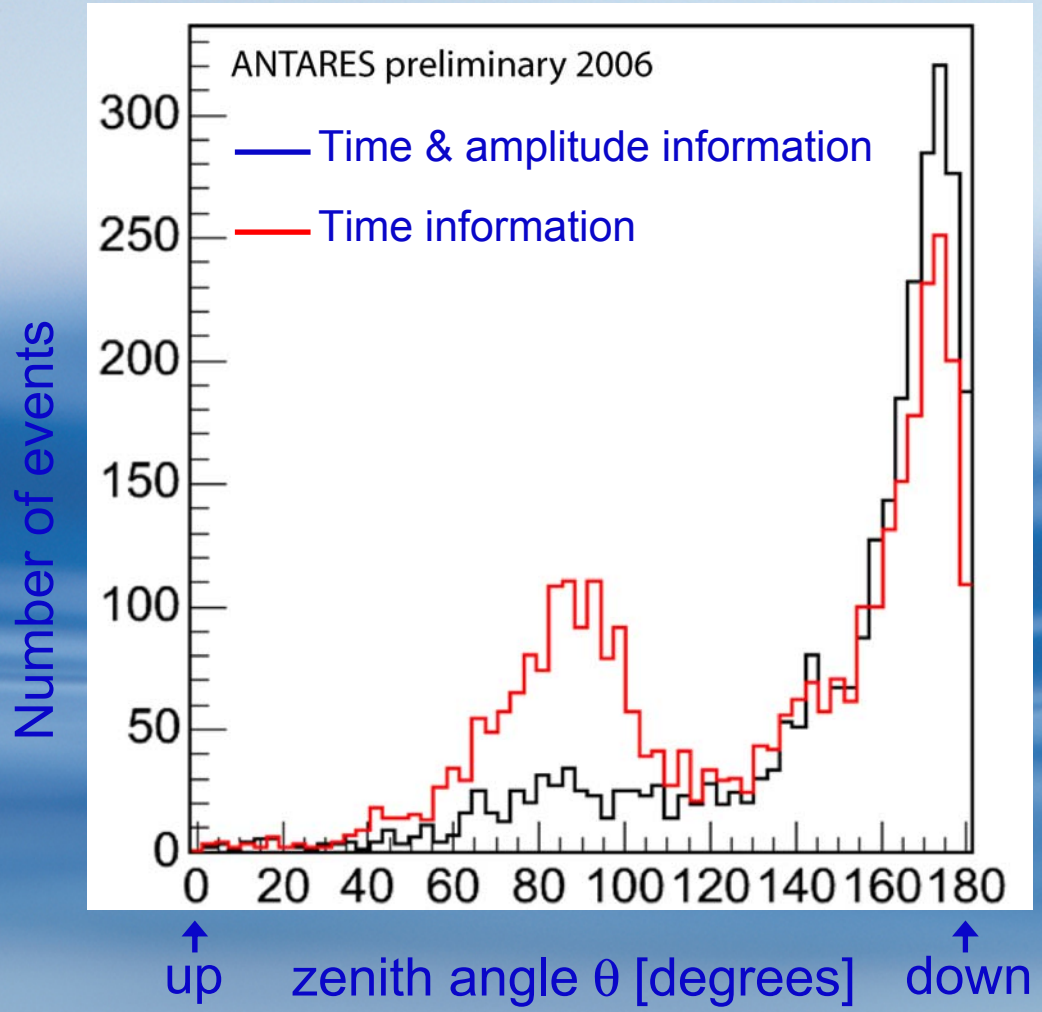

Event time distribution Run 23509
GRB060728
number of events
time since start of run (s)

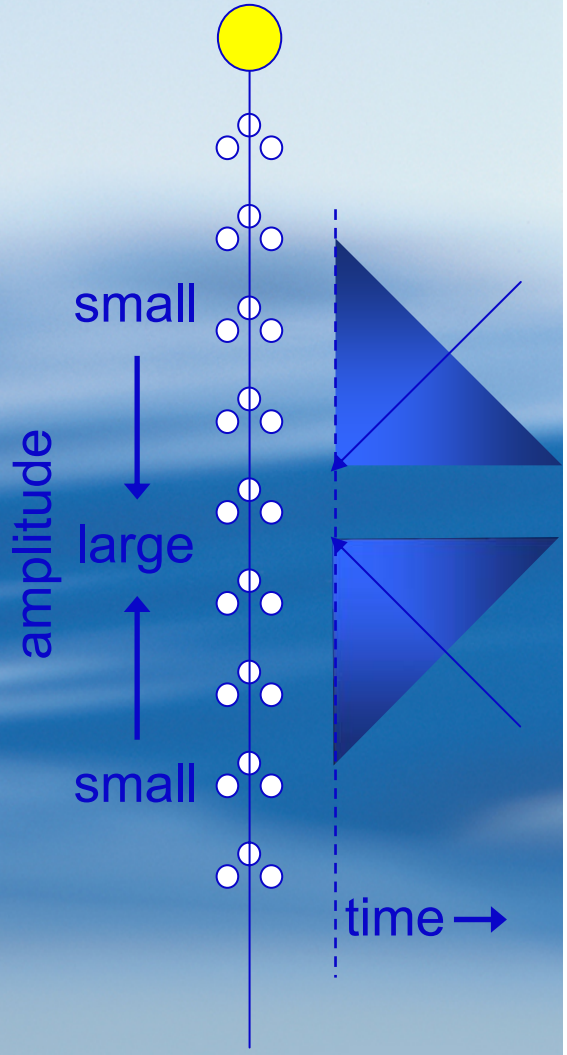

Event time distribution Run 23246
GRB060707
number of events
time since start of run (s)


Time-direction window around GRB060728
GRB060728
22:24:30 (UTC)
428 s
-0.15 deg
zenith angle (degrees)
time since start of run (s)


Time-direction window around GRB060707
GRB060707
21:30:19 (UTC)
zenith angle (degrees)
time since start of run (s)

Atmospheric muon zenithal angular distribution





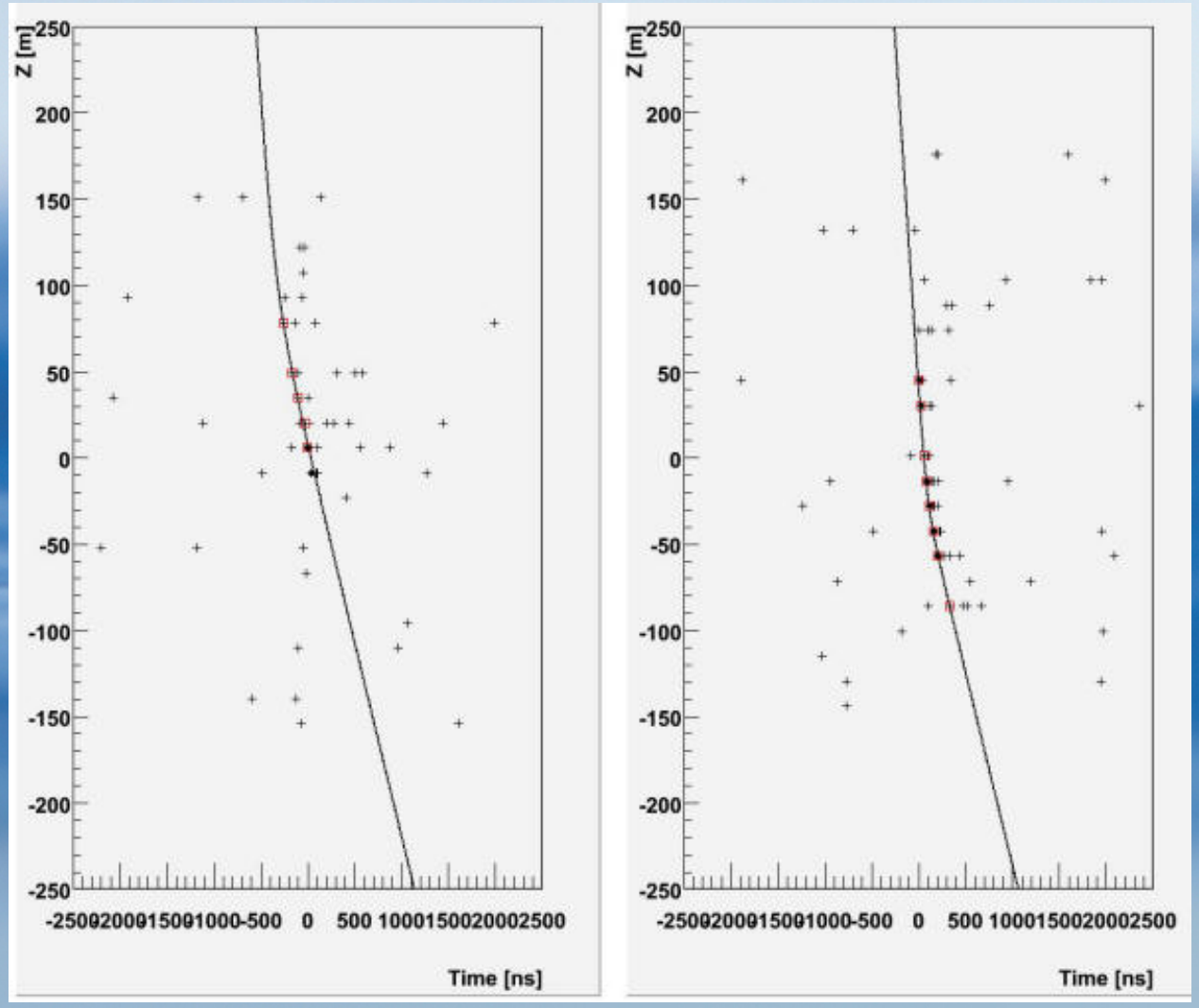
✓muon reconstruction is working well

✓ hunting for neutrinos…

Line 2 deployed Jul 27th

Connected with NAUTILE
Sept 21st

First muon seen by lines 1&2



KM3NET Design Study

The next step in the Mediterranean Sea is an EU funded 'Design Study':

- Participation: all current projects + "newcomers" + marine institutes
- EU Contribution : 9 M€
- Starting date : feb 1, 2006
- Duration : 3 years (TDR: feb 2009)
- Target Cost: ~200 M€ ?
- Size : minimum 1km3 and extendable

KM3NET is included in the *Astroparticle Physics European Coordination (ApPEC)* ROADMAP

KM3NET is selected by the *European Strategy Forum for Research Infrastructures (ESFRI)* 'List of Opportunities'

Conclusions

- The recent past of neutrino astrophysics is extremely bright
  (ν oscillations, confirmation of solar model, direct detection
  of supernova collapse)

- High energy Neutrino Telescopes are presently operating.
  The technique is proven and the limits obtained are meaningful

- New, bigger and more sensitive telescopes will soon operate

Surprises might be round the corner…