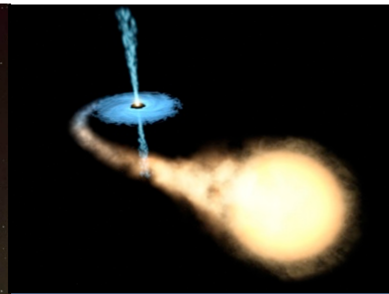
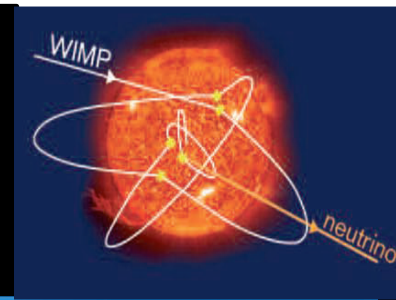
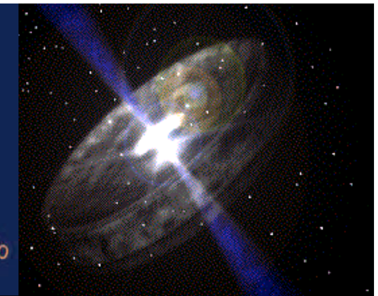
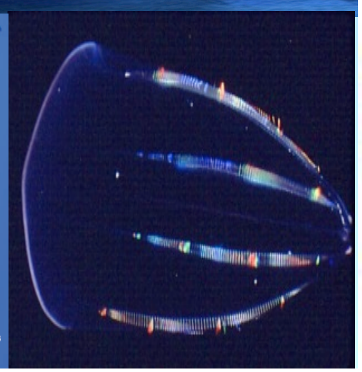
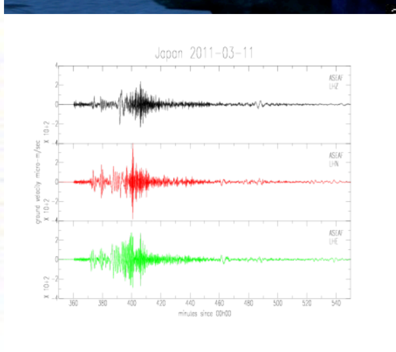




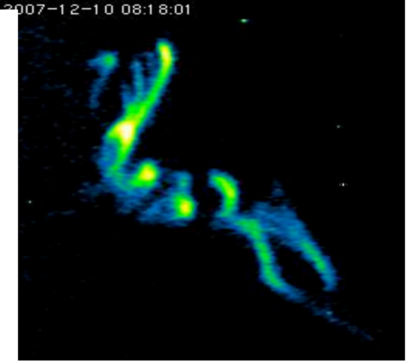


Mediterranean Neutrino Telescopes

IceCube Invites Astroparticle Physics
Madision, 28th April 2011

Paschal Coyle
Centre de Physique des Particules de Marseille



Science with Deep Sea Neutrino Telescopes

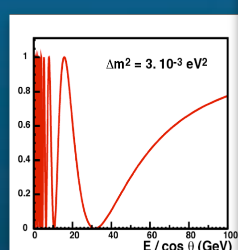
- **High energy neutrino astrophysics**:
  galactic: SN, SNRs, m-quasars, molecular clouds, etc...
  extra-gal: AGNs, GRBs, dark-GRBs, GZK, etc....

- **Search for New Physics**:
  Dark matter (Sun, GC), Monopoles, ??

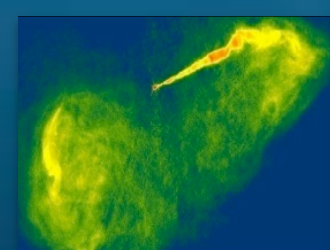
- **Earth-Sea Science:**
  oceanography, sea biology, seismology, environmental monitoring...

SN

oscillations

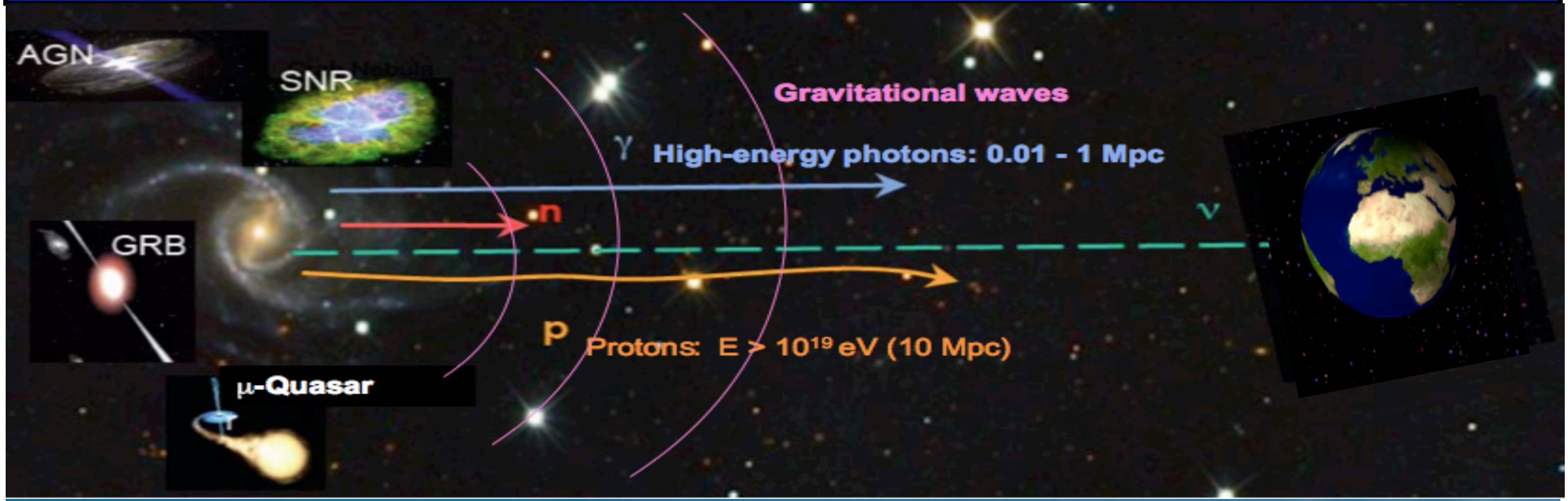


AGN/GRB



~MeV — GeV-100 GeV — GeV-TeV — TeV-PeV — PeV-EeV — > EeV

Neutrinos and Multimessenger Astronomy



Photons

- Ubiquitous tool for astronomy up to TeV energies (Hess, Magic, Veritas...)
- Absorbed by EBL at higher energies

Protons/Cosmic Rays

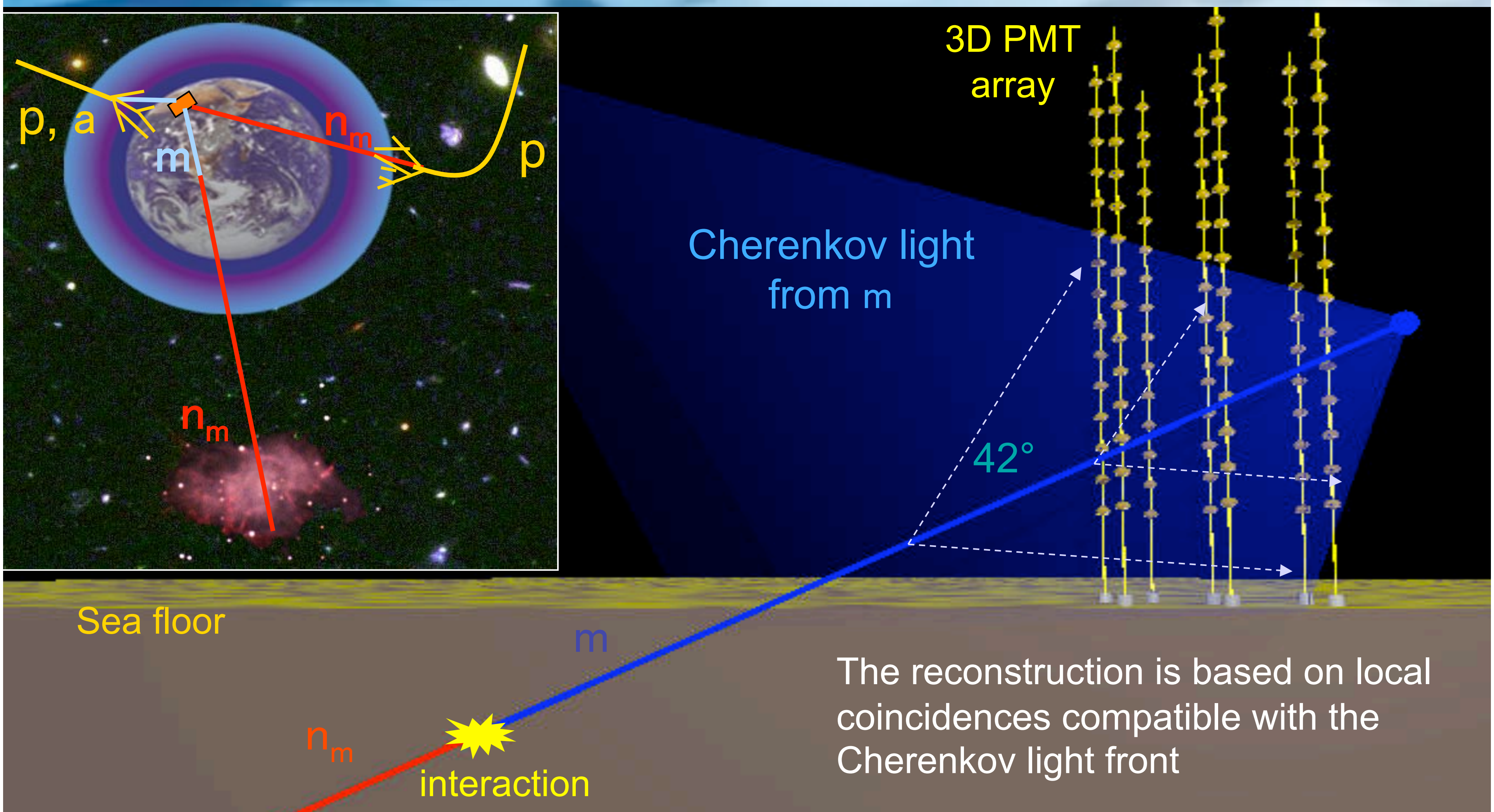
- Detected on Earth up to extreme energies 10^8 TeV
- Difficult to study sources due to deflection by magnetic fields

Neutrinos

- Unambigous probe of hadronic processes
- Not affected by B fields or dust
- Horizon not limited by interaction with CMB/IR
- Time correlated with transient photon signals

information on origin of CRs

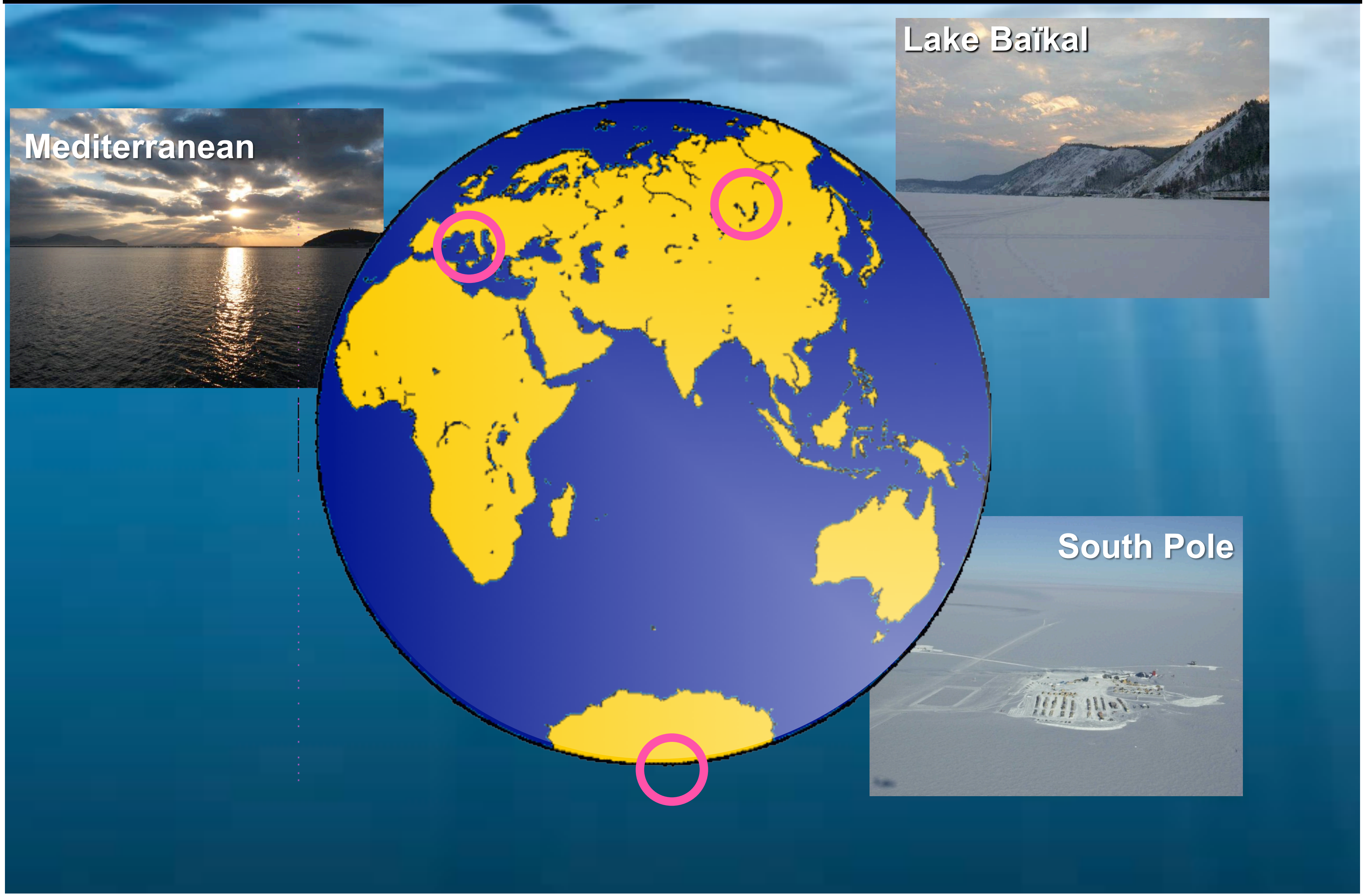
Detection Principle



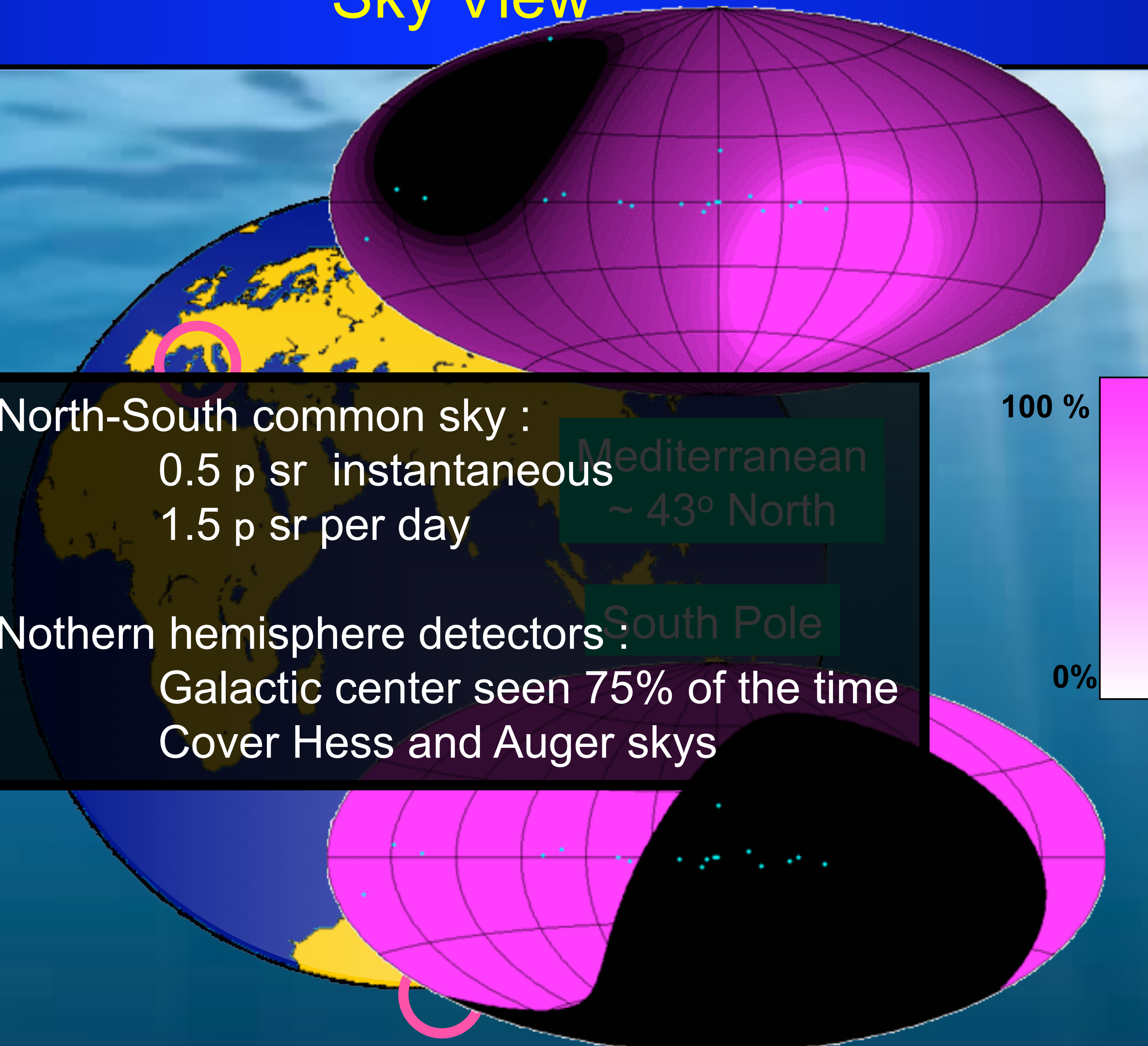
- Main detection channel: $□_{□}$ interaction giving an ultra-relativistic □ (□e and □tau also)

- Energy threshold ~ 10 GeV - 24hr operation, more than half sky coverage

High Energy Neutrino Telescopes



Sky View



North-South common sky :

0.5 p sr instantaneous

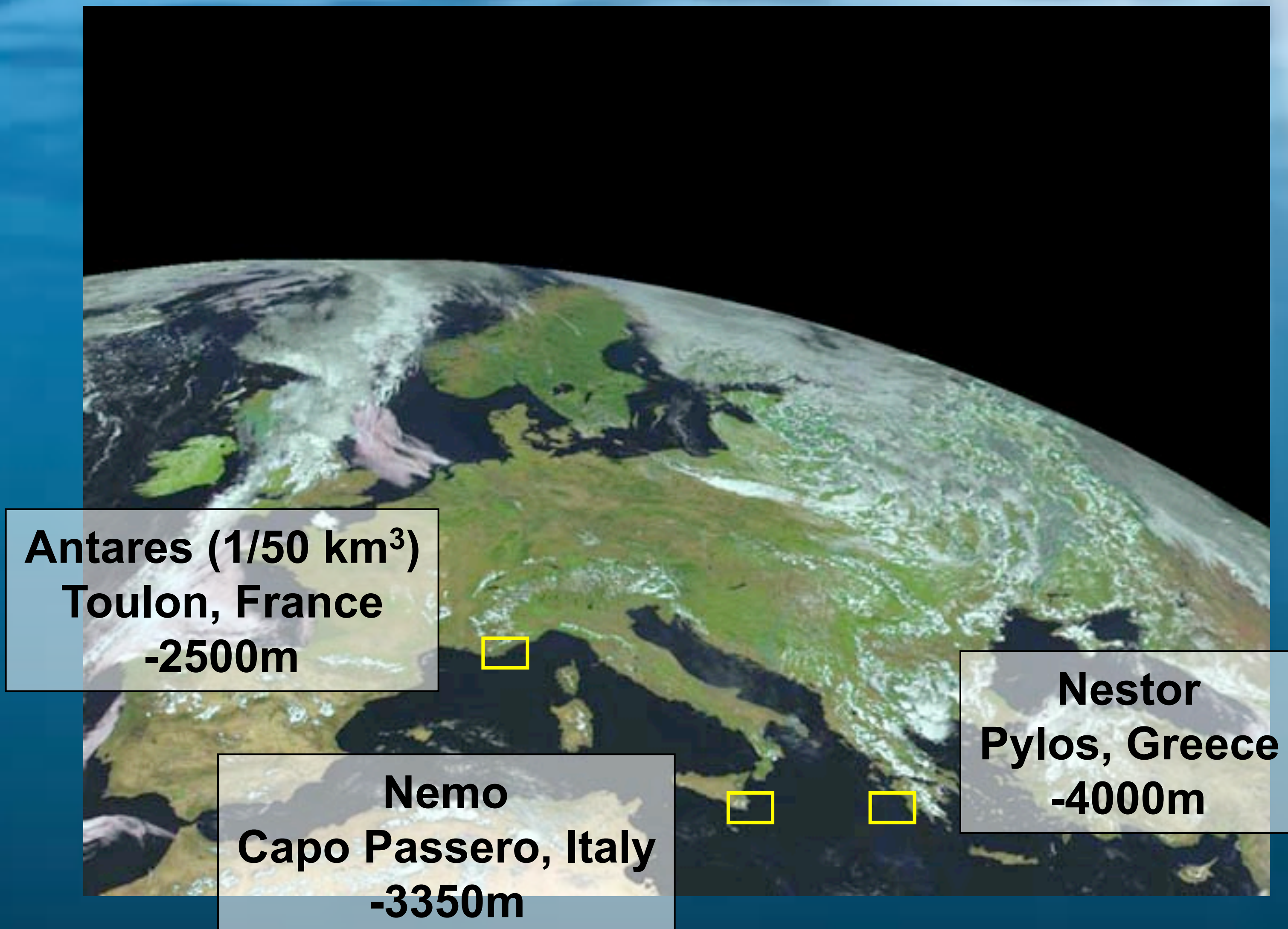
1.5 p sr per day

Nothern hemisphere detectors :

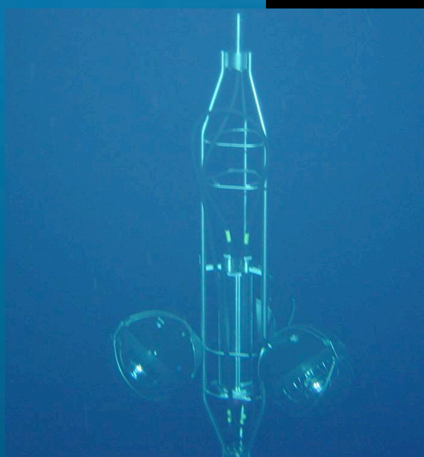
Galactic center seen 75% of the time

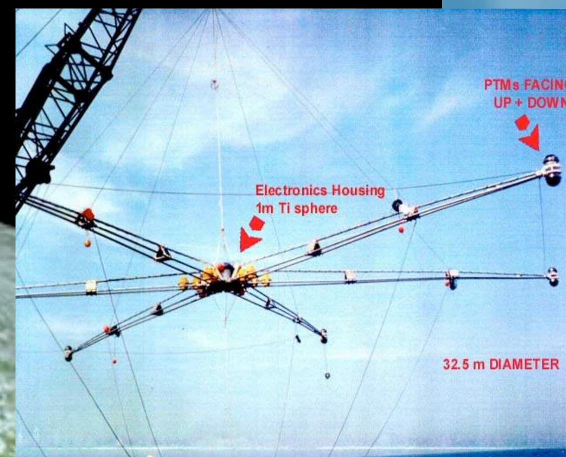
Cover Hess and Auger skys

Three Neutrino Telescope Sites



Efforts in the Mediterranean





(1/5
Fr
-2500m

Since 1996
Data taking
for science
150 members

Since 2000
R&D
80 members

Nemo
Capo Passero, Italy
-3500m

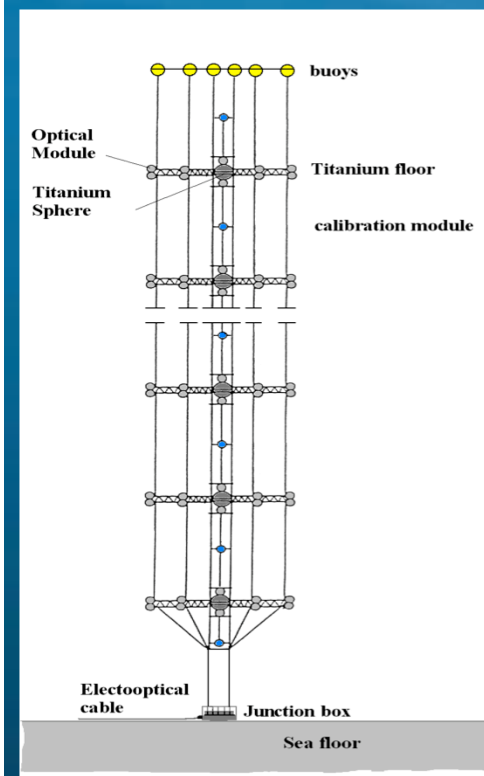
Nestor
Pylos, Greece
-4000m

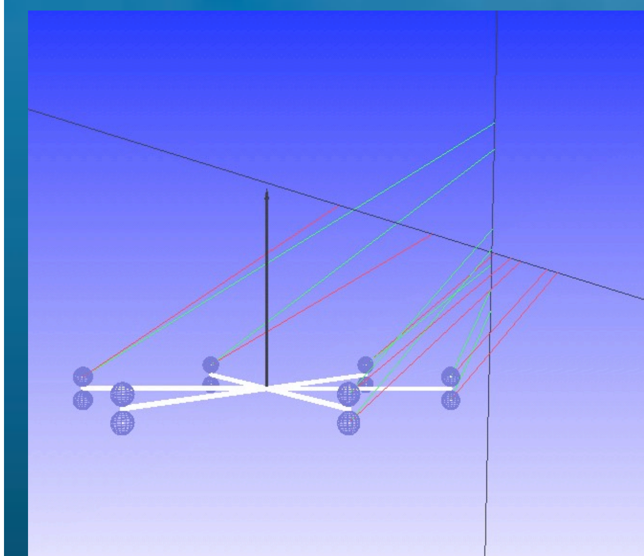
Since 1990
R&D
50 members

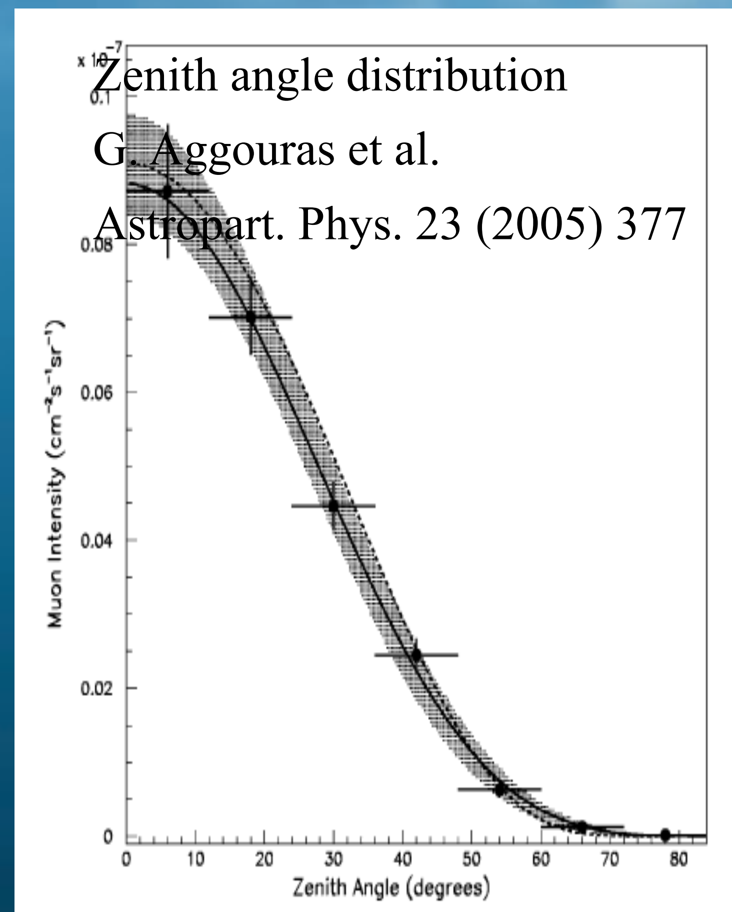
NESTOR R&D

Single floor deployed in 2003

Downward cosmic ray muons reconstructed







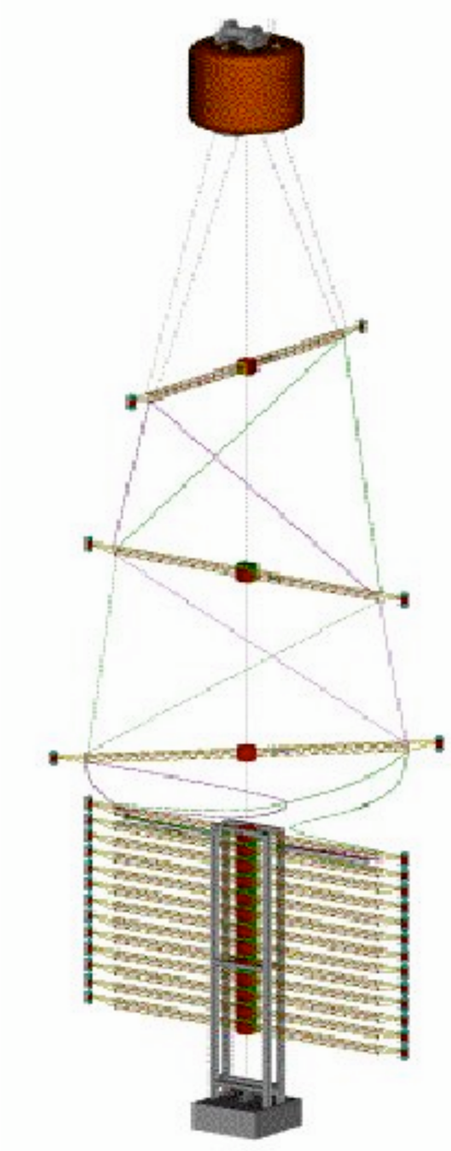
Zenith angle distribution

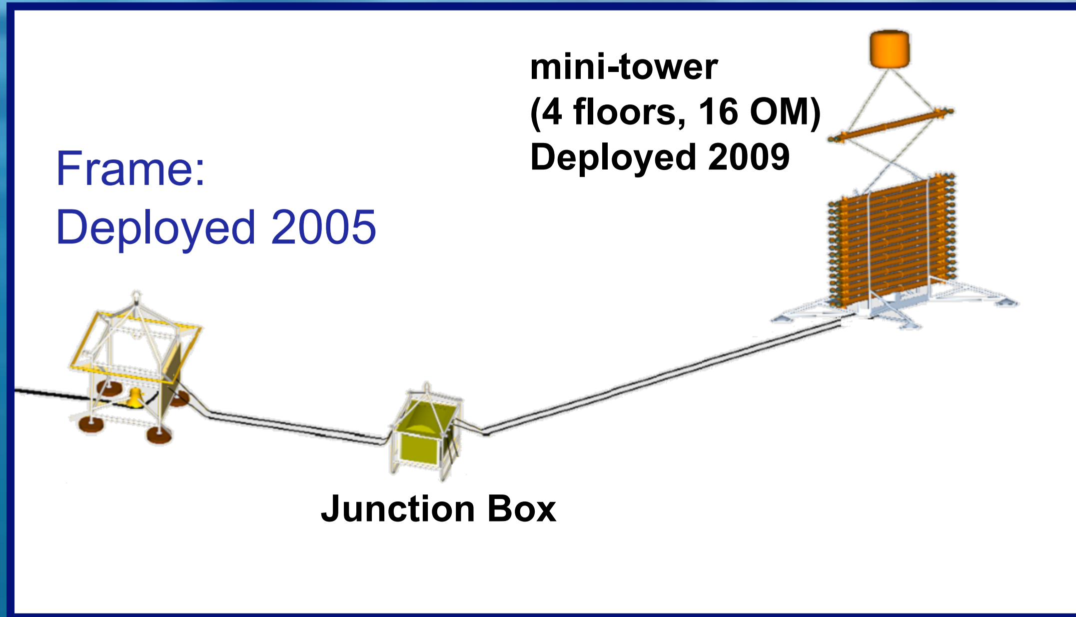
G. Aggouras et al.

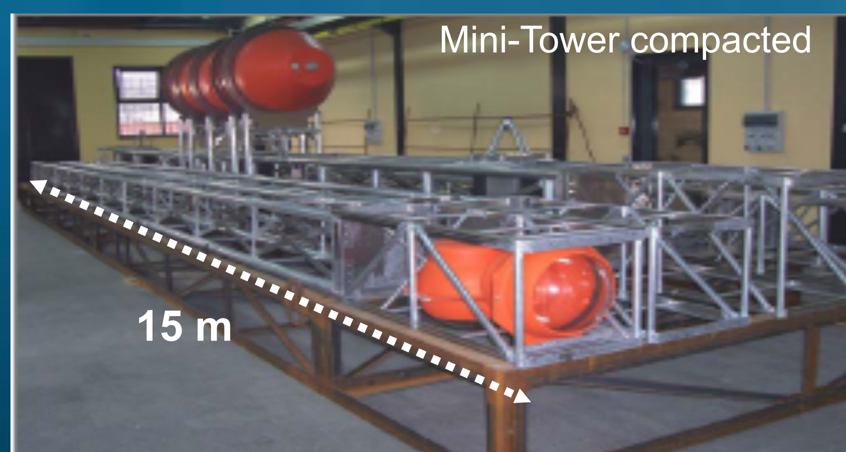
Astropart. Phys. 23 (2005) 377

NEMO R&D

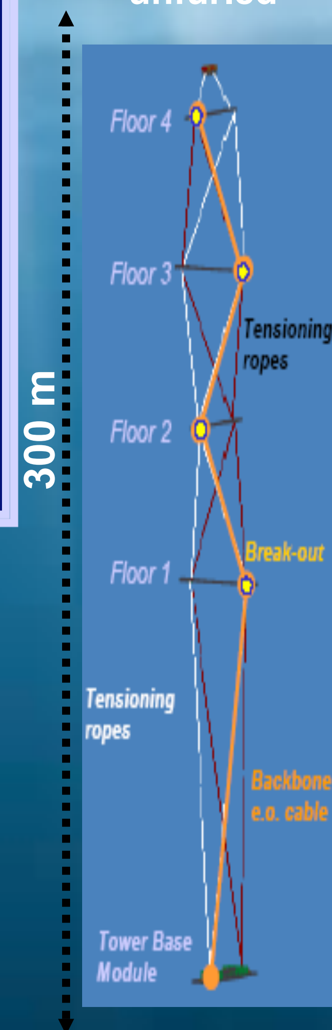
Underwater test site: 25km E of Catania, 2000m



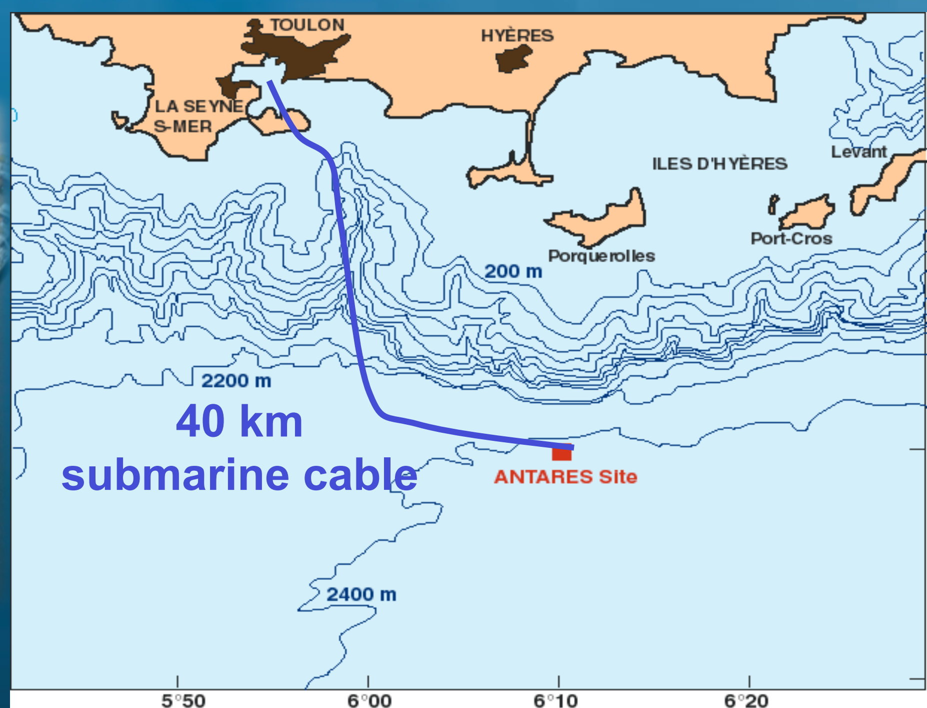




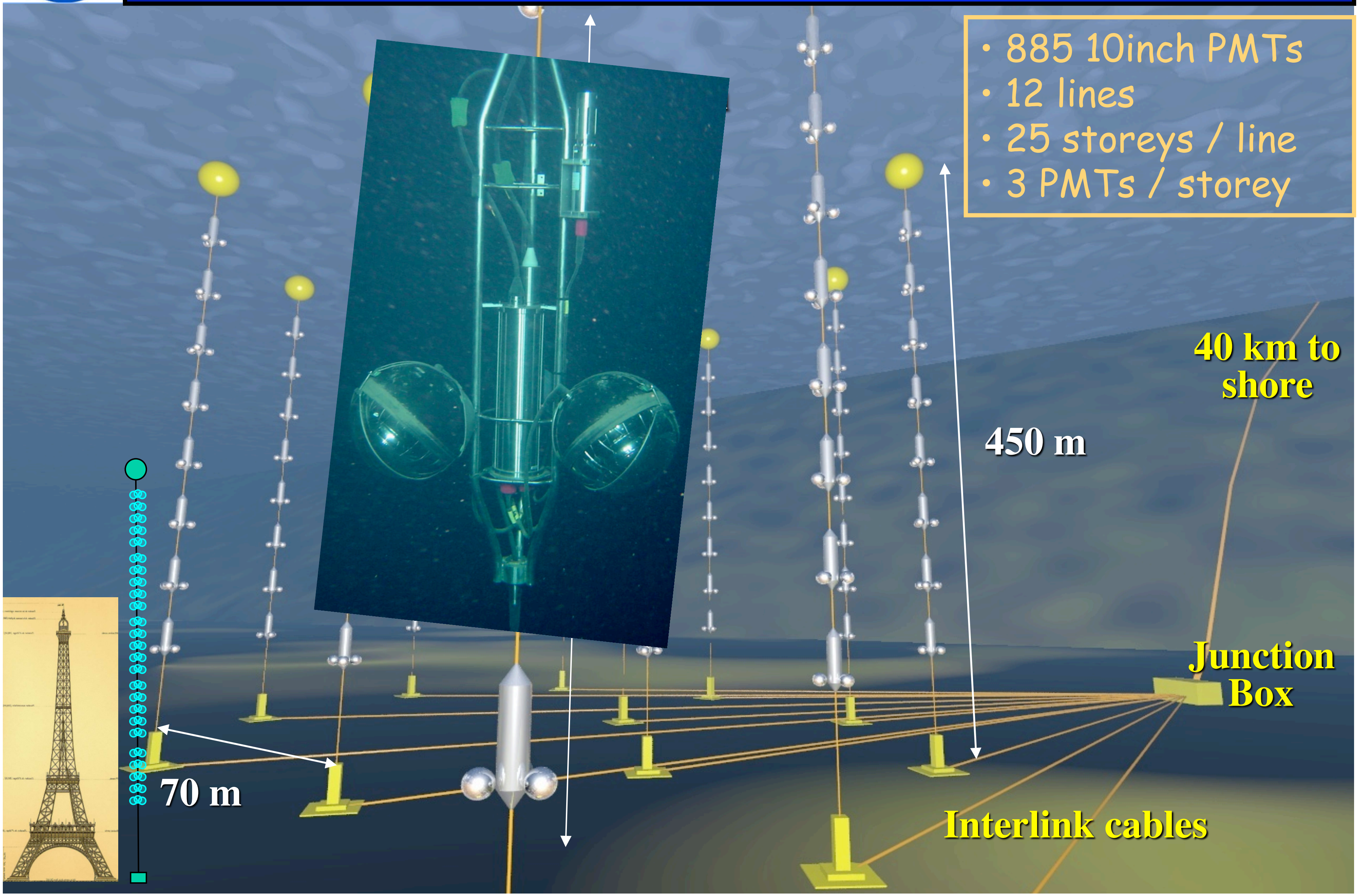
Mini-Tower unfurled



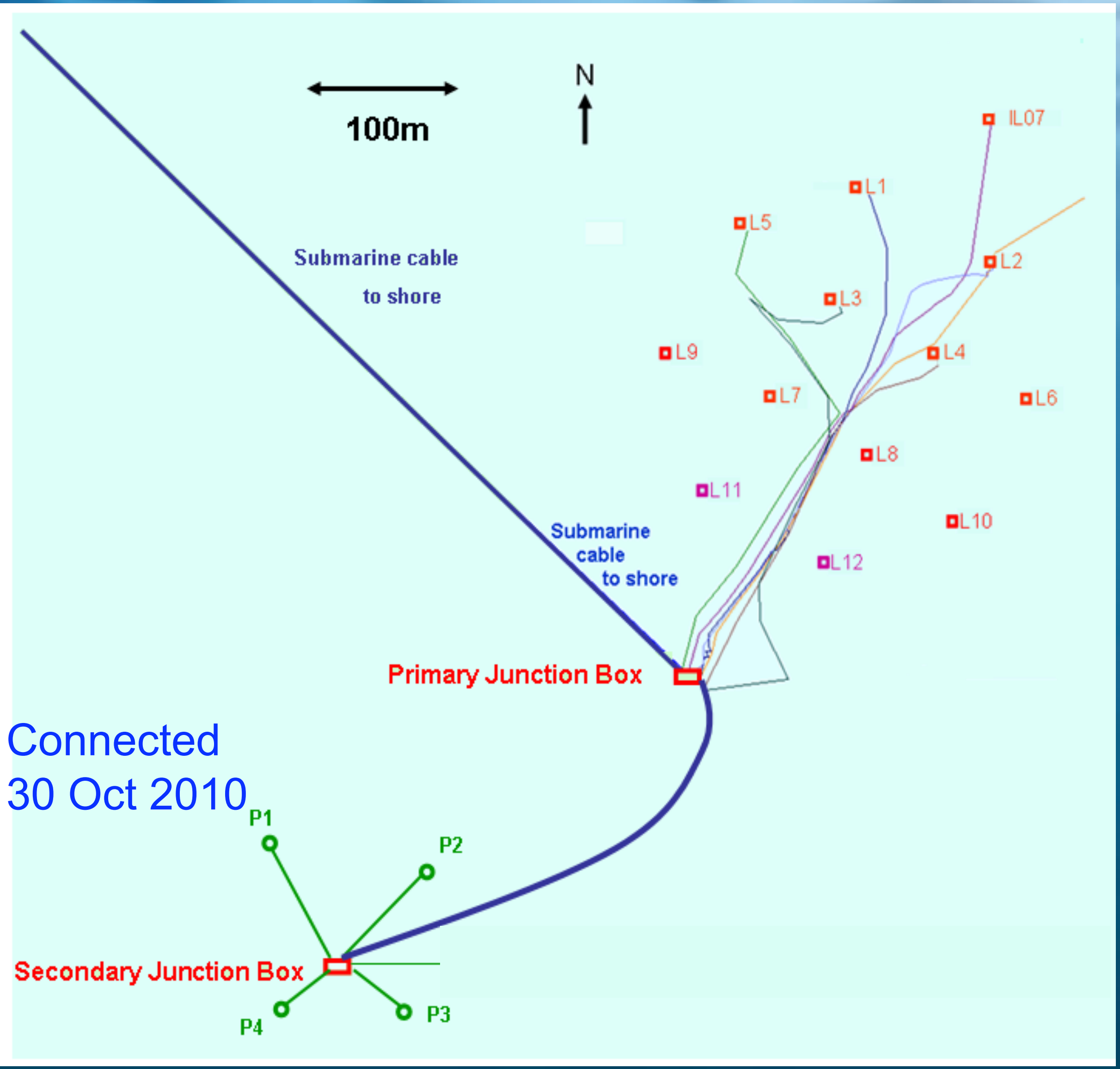
ANTARES Site



ANTARES Detector



ANTARES Infrastructure



Connected
30 Oct 2010

Junction box	2002
Line 1, 2	2006
Line 3, 4, 5:	01 / 2007
Line 6, 7, 8, 9, 10:	12 / 2007
Line 11, 12	05 / 2008

Deployment of Lines

Ready for deployment

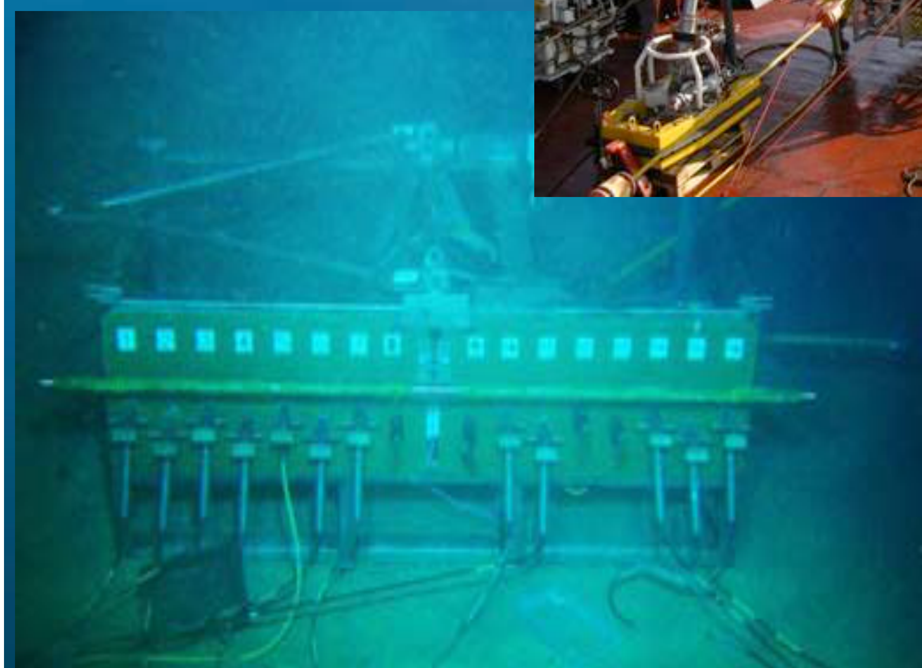
Loading line on boat

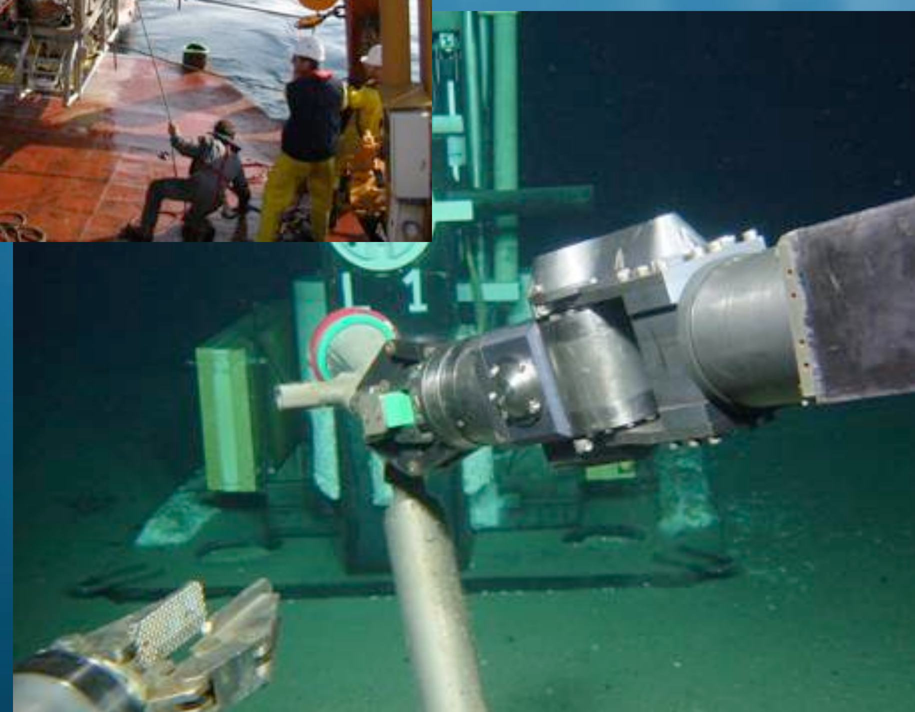
Installed within a few meters of the desired position

deployment

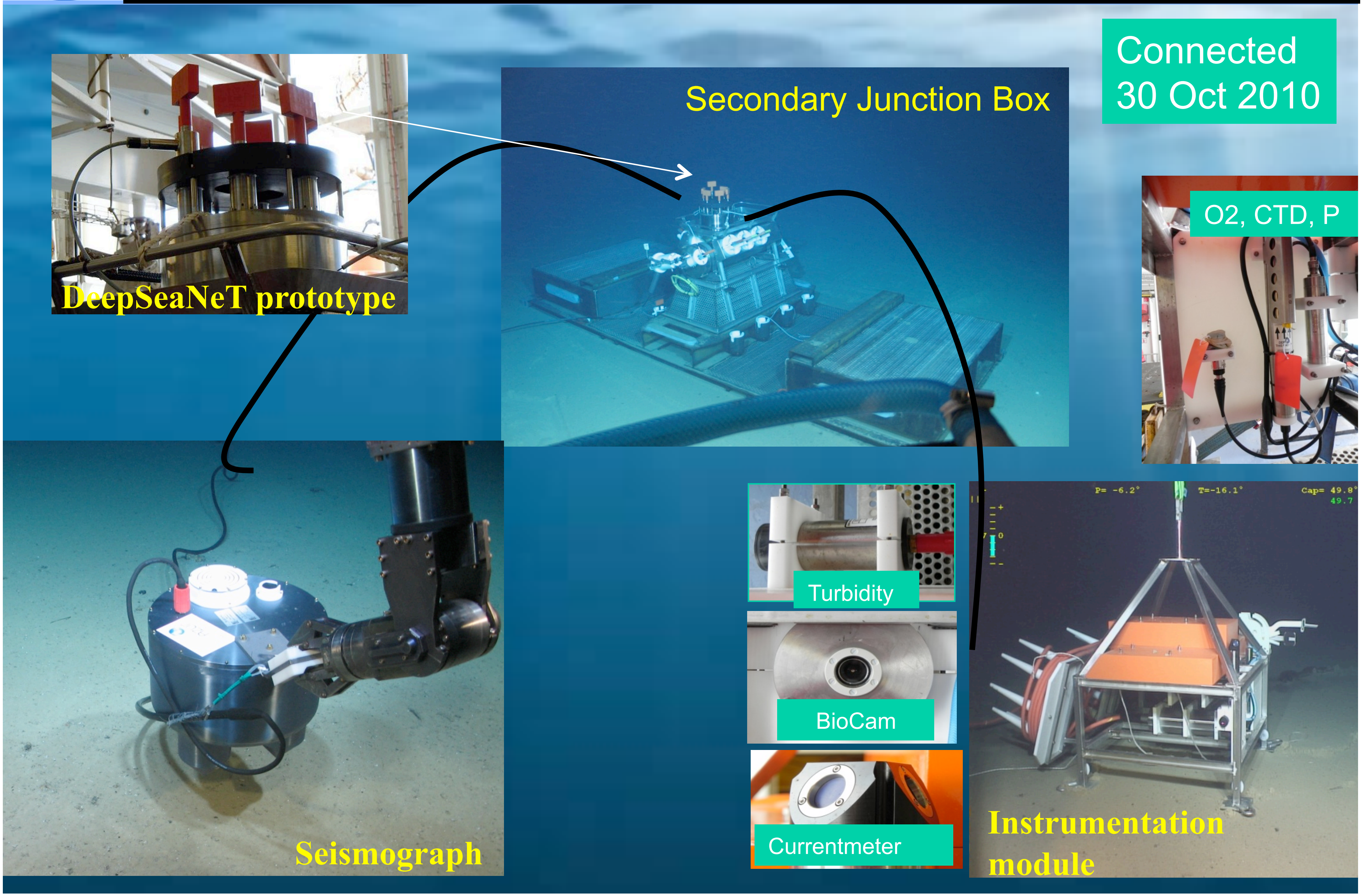
Line Connections

IFREMER ‘VICTOR6000’: Remotely Operated Vehicle (ROV)





Secondary Junction Box



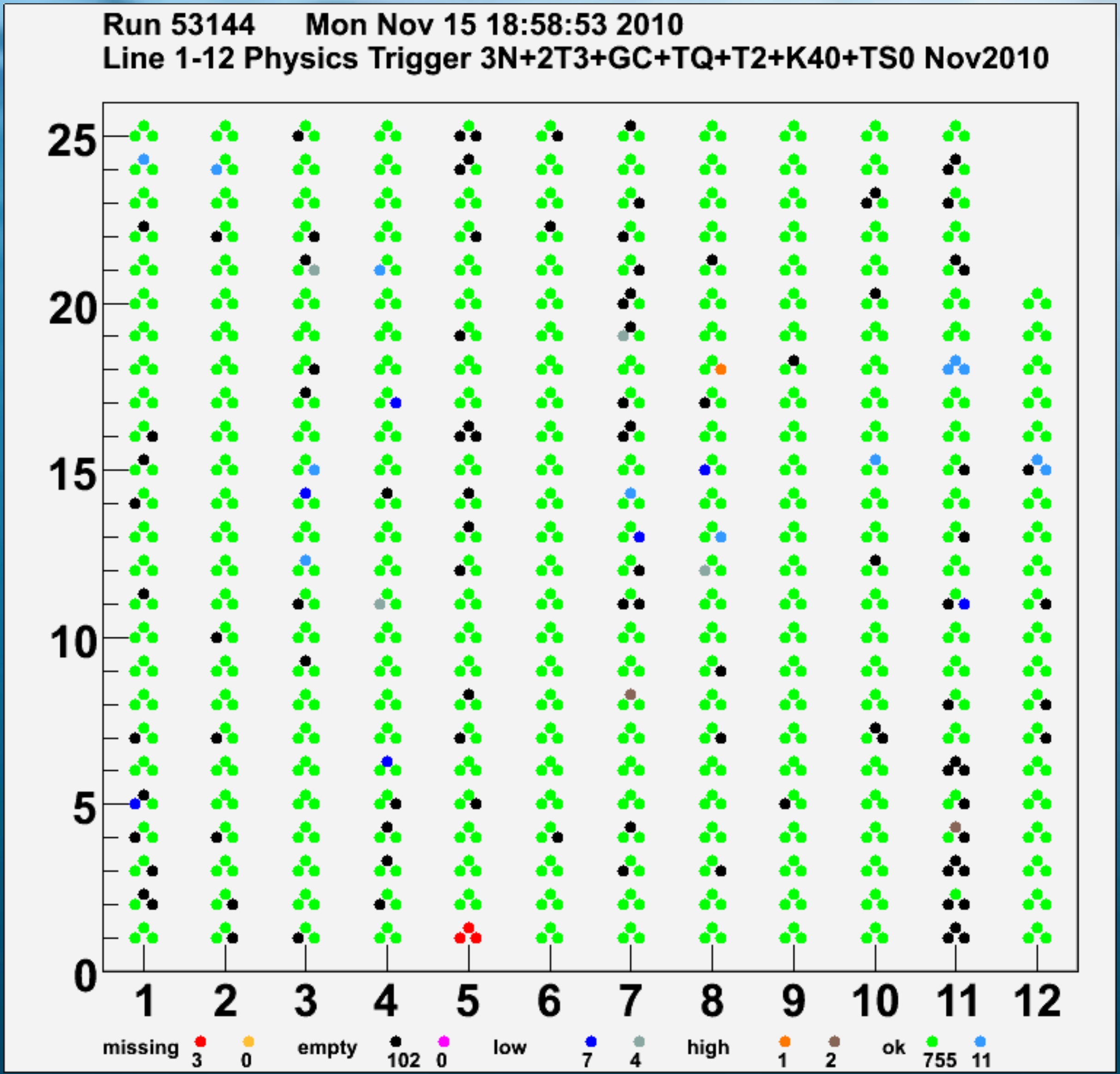
Detector Status

- Completion
  May 2008

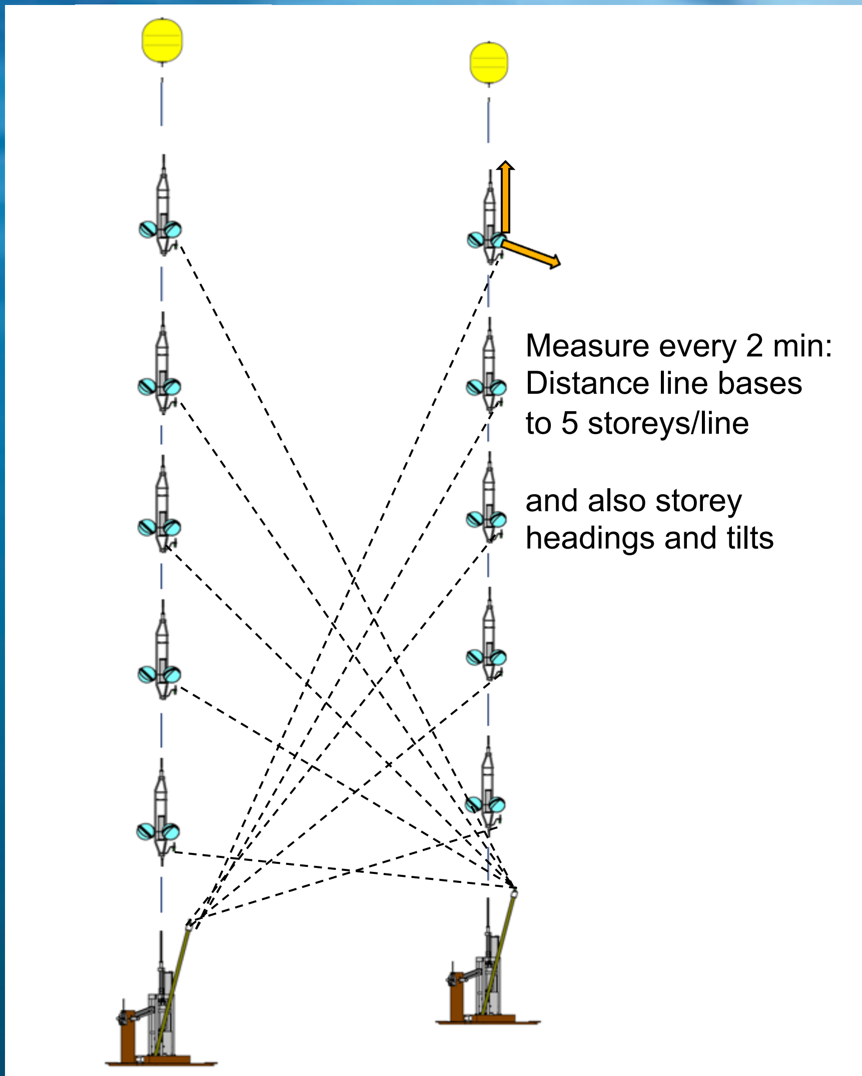
- 885 PMTs

- 88% giving data

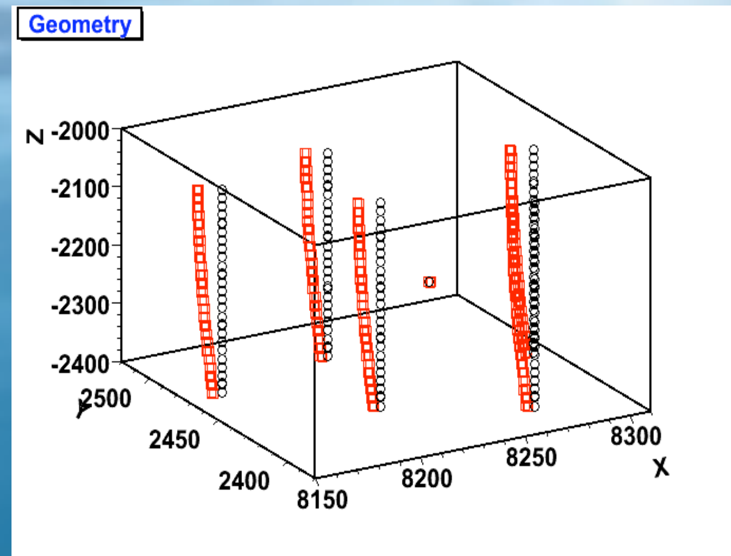
- Regular yearly maintenance

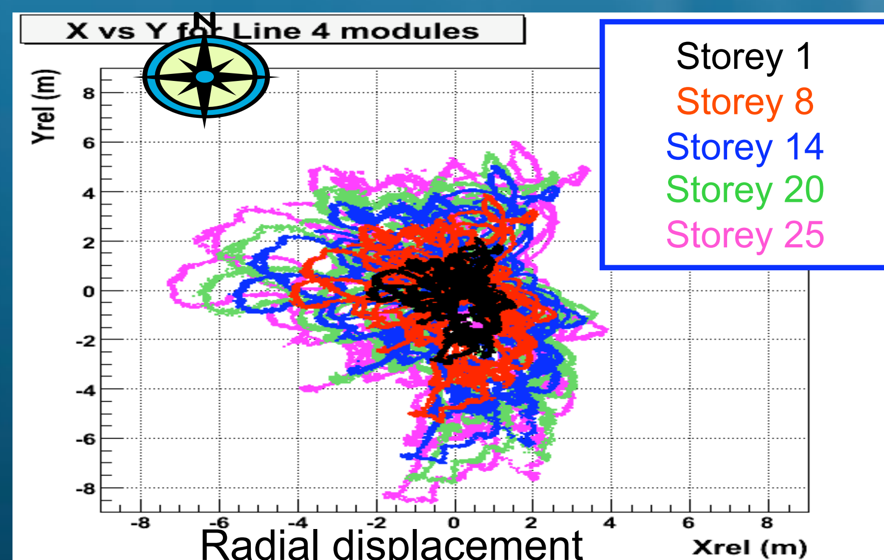


Acoustic Positioning

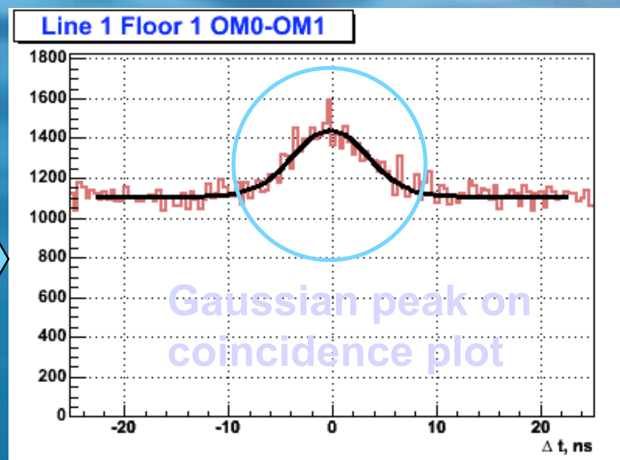


Precision ~ few cms

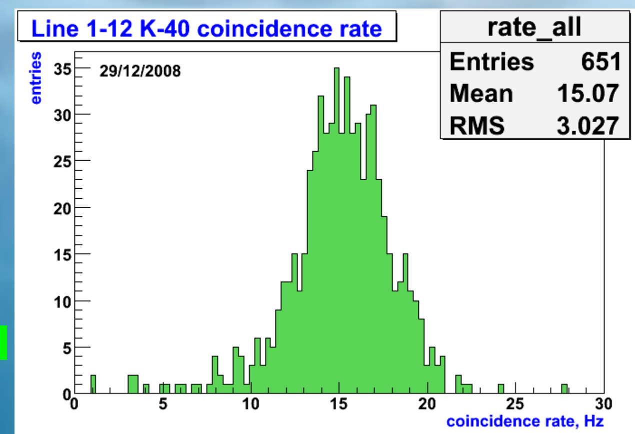




In-situ Calibration with Potassium-40

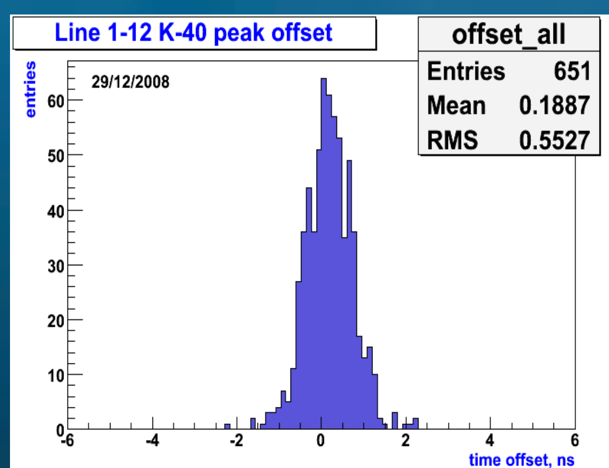


Integral under peak



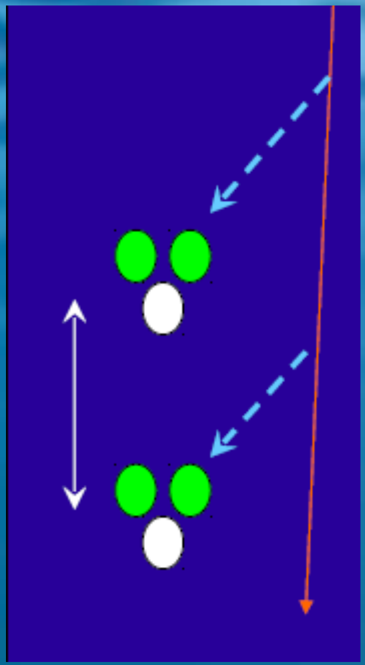
Precision (~5%) monitoring of OM efficiencies

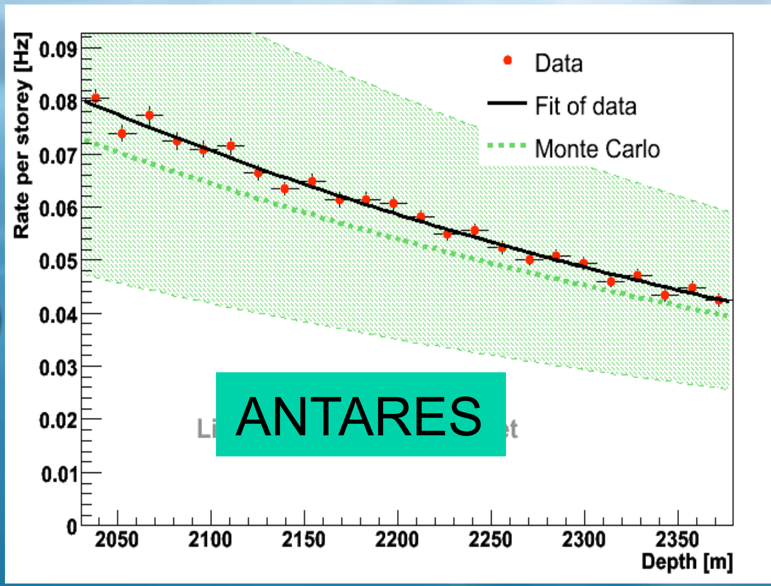
Peak offset



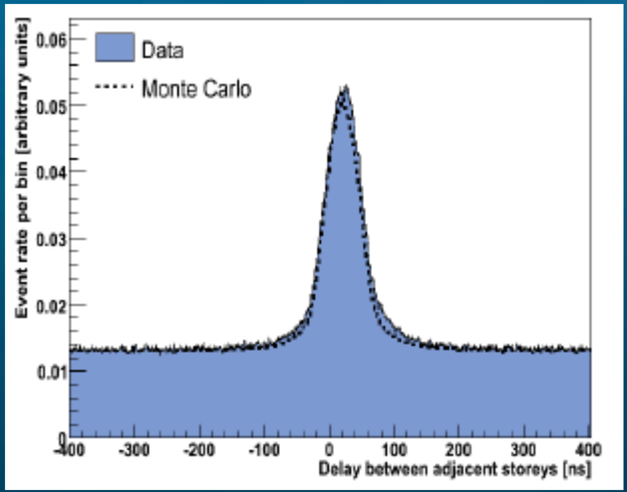
Cross check of time calibration

WATER Vs ICE: Uniformity/Resolution

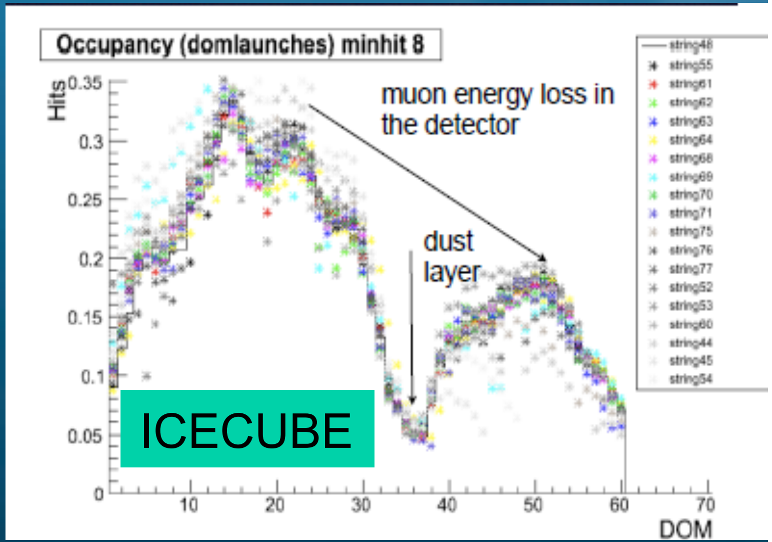




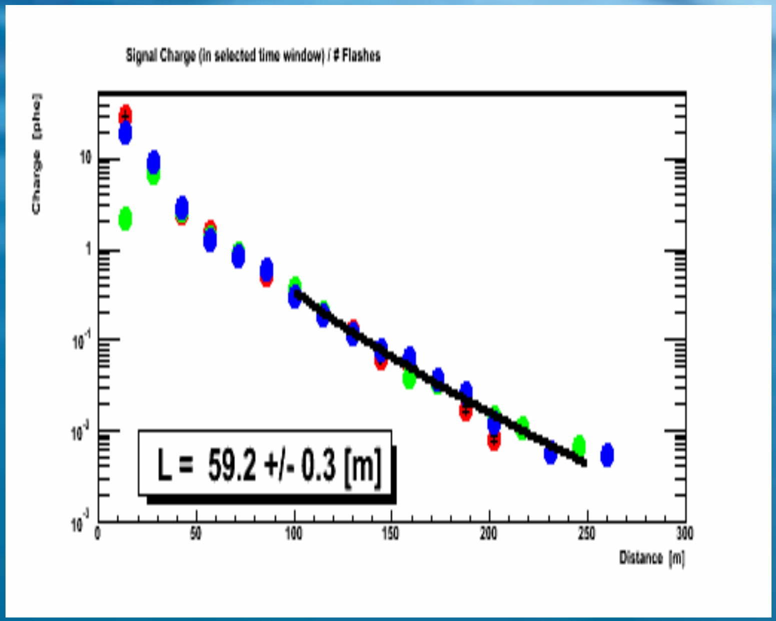
WATER:
Antares (~0.2°)
KM3NeT (~0.05°)

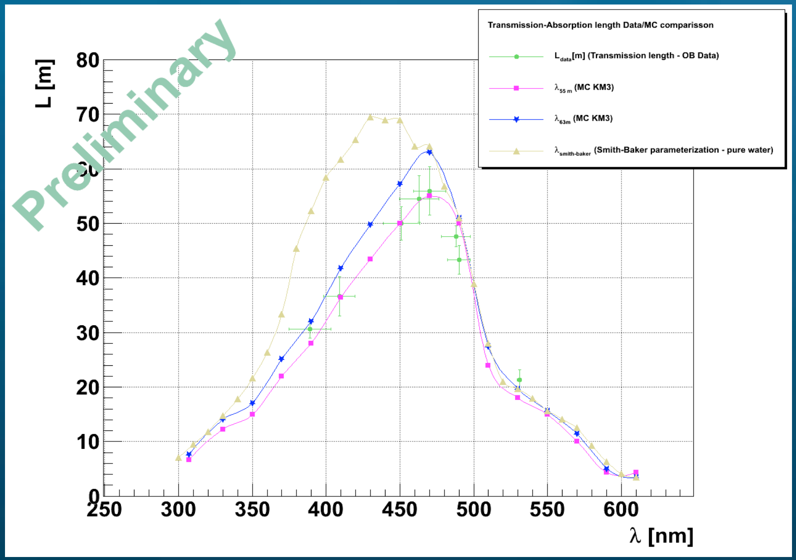


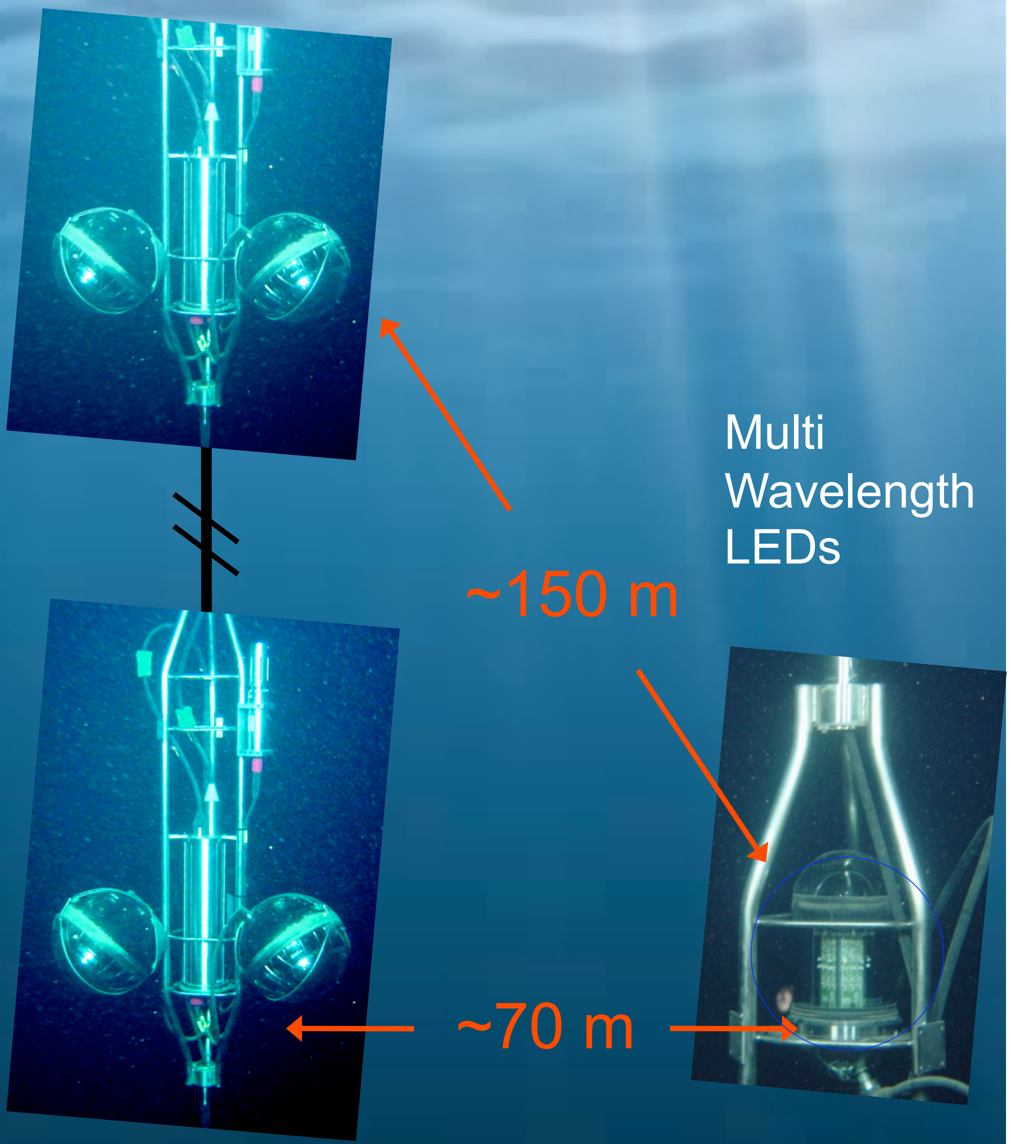
ICE:
Amanda (~2°)
IceCube (~0.7°)



Optical Beacons: time calibration, absorption length

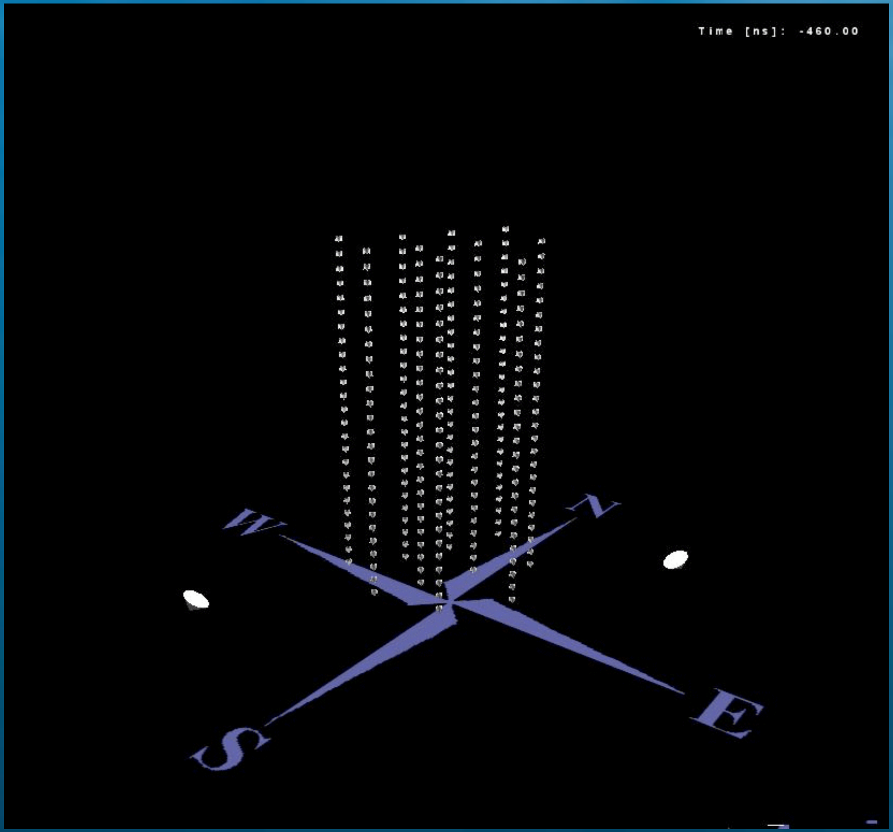




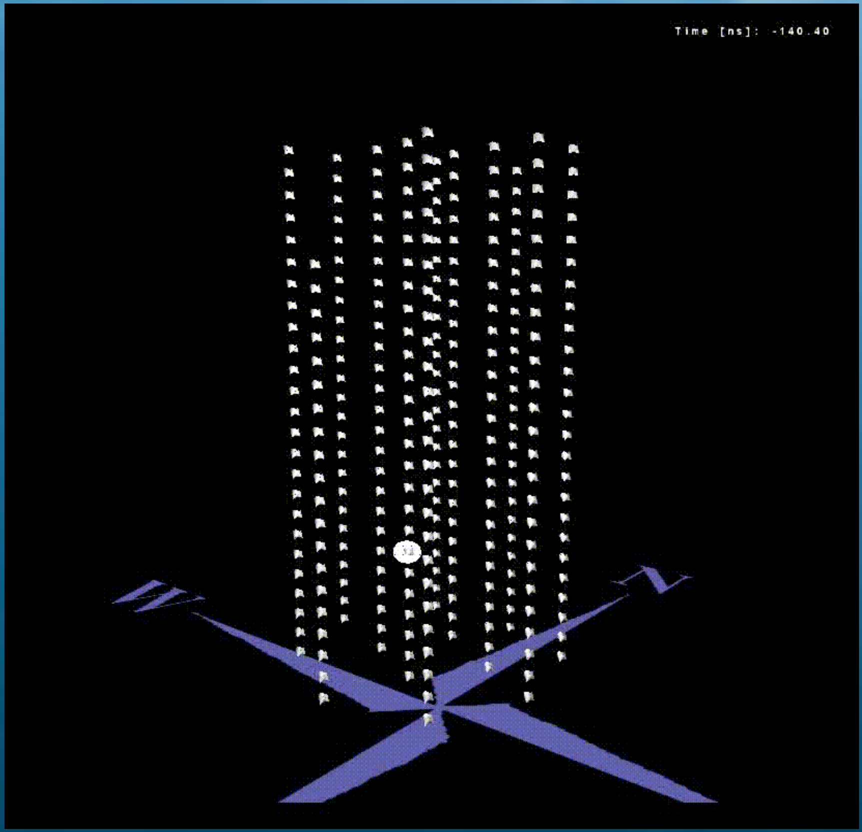


Example Data Events

reconstructed up-going neutrino
detected in 6/12 detector lines:

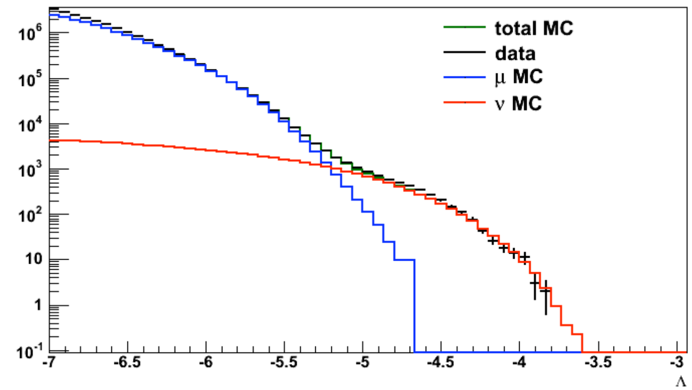


reconstructed down-going muon bundle
detected in all 12 detector lines:

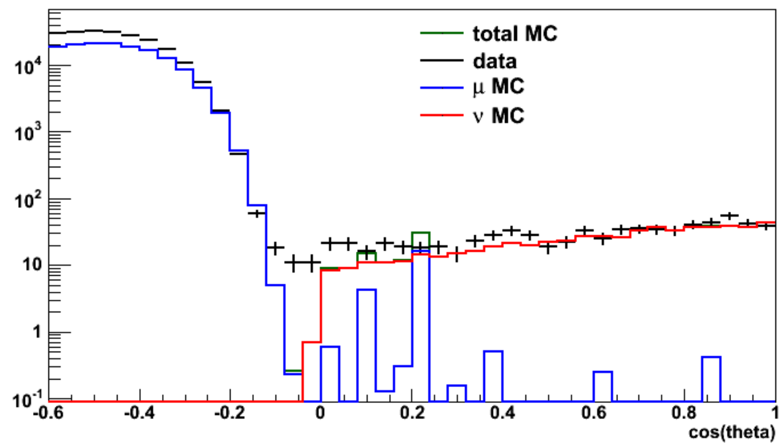


Track Reconstruction

- Maximum likelihood track fit to muon hypothesis (beta=1)
  - Pdfs for Cherenkov & ^{40}K bkgds
  - mulitple starting directions
  - Estimation of uncertainty on track direction
- Reasonable agreement data vs MC

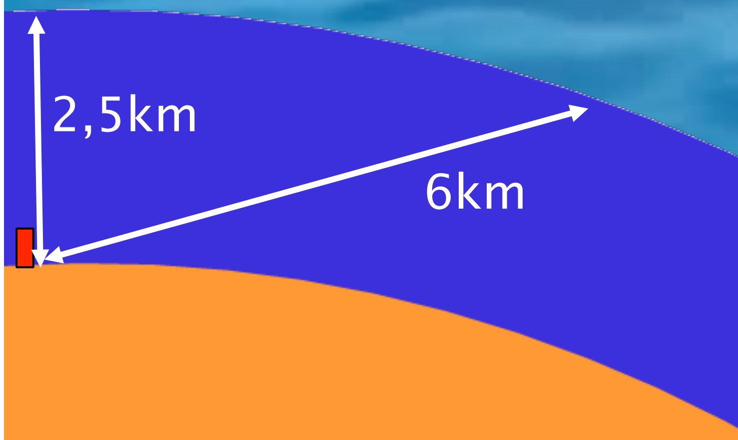


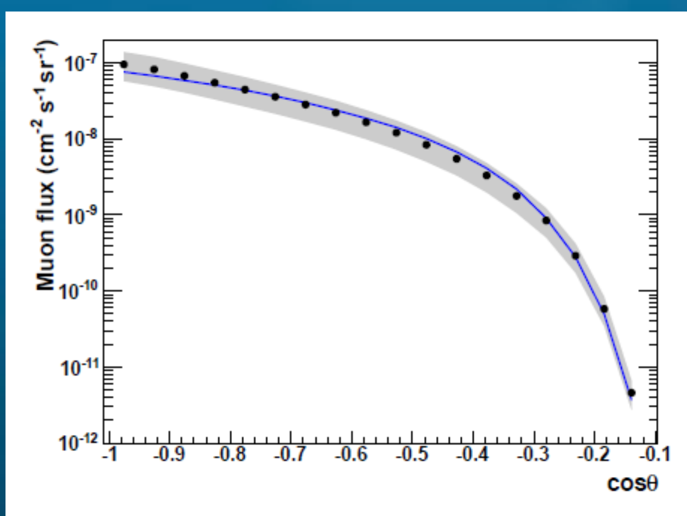
Distribution of quality parameter Λ for upgoing reconstructed tracks (2007-2008 data)



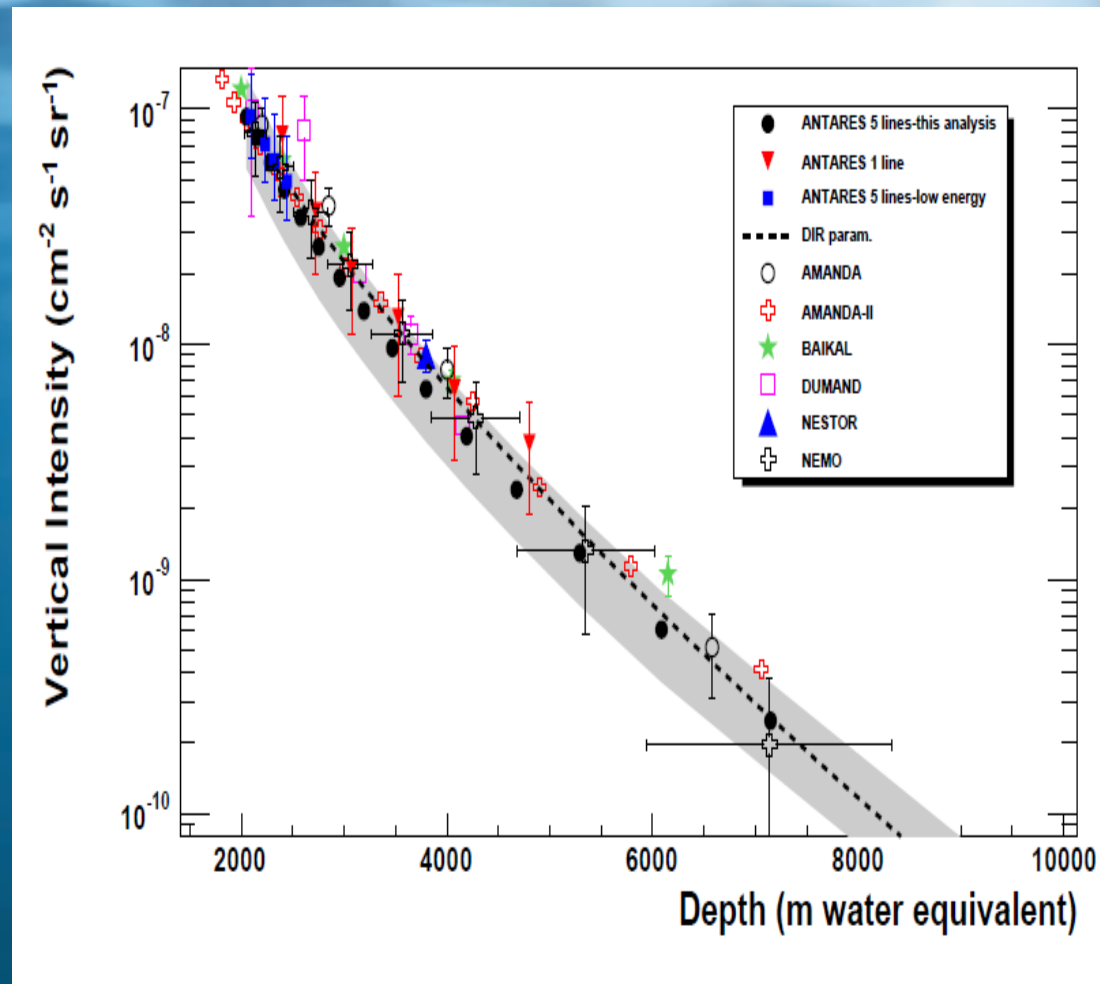
Distribution of zenith angle for all tracks with Λ > -5 (2007-2008 data)

Depth Intensity Relation from Zenith Distribution





Zenith angle distribution of muon flux at 2000 m



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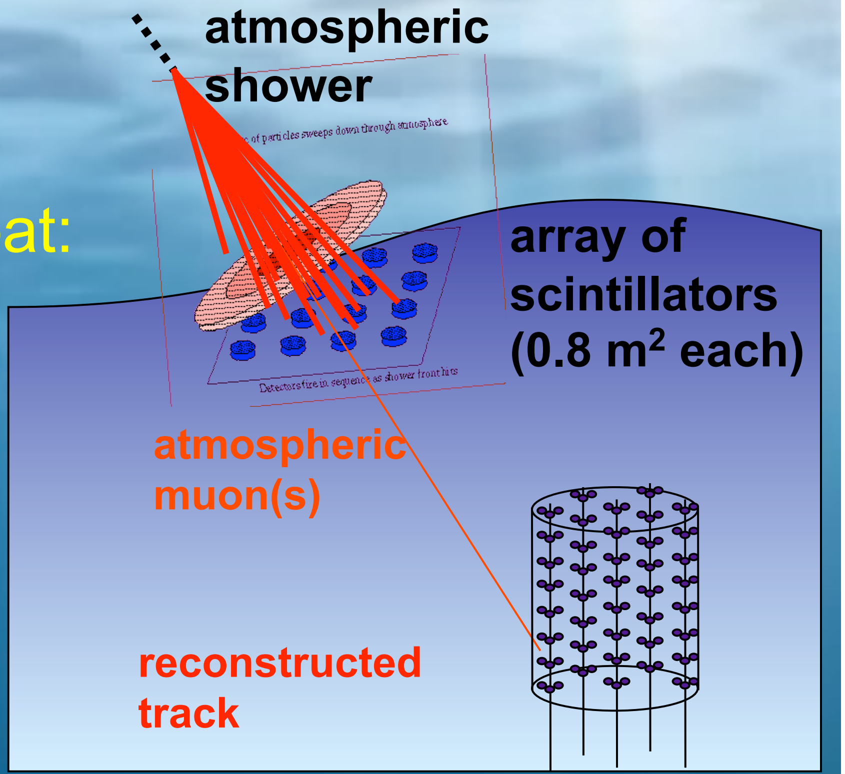
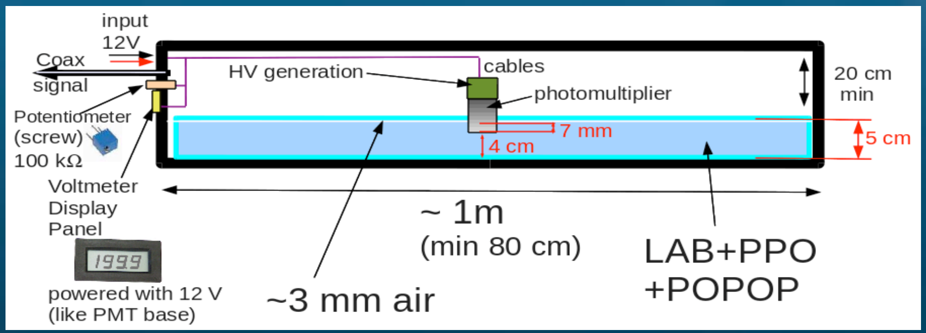
Surface Array Project

Liquid scintillator/PMT modules on boat:
Independent and rapid verification
of the absolute pointing

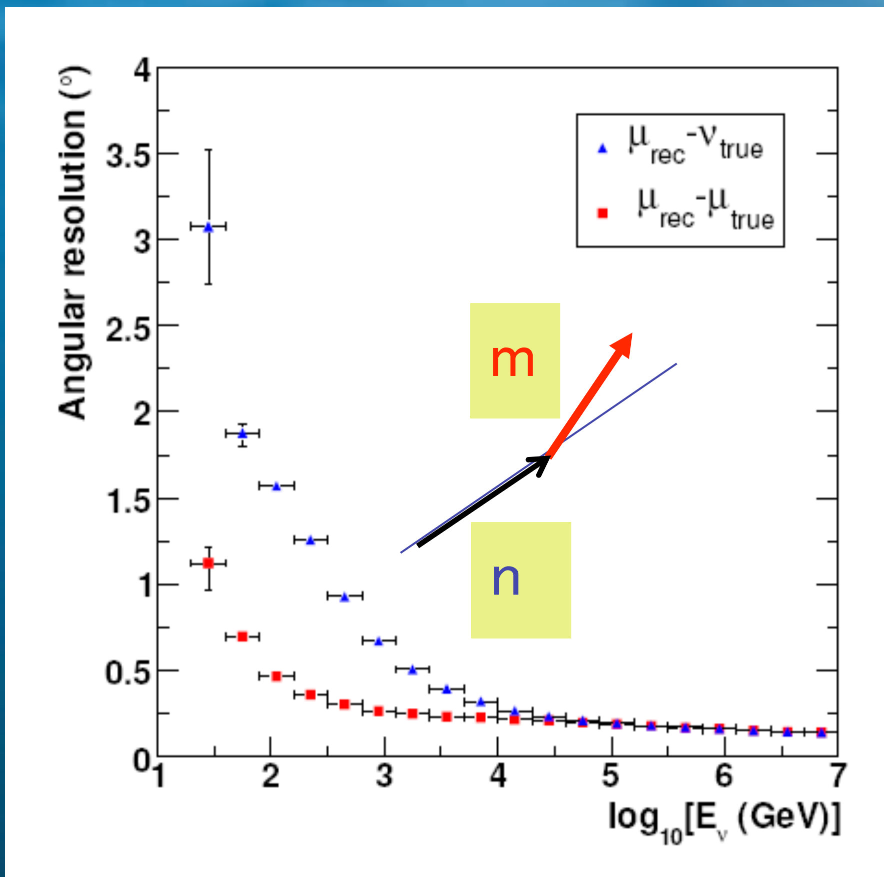


-16 units, 10 days: □□~0.25°, □□~0.7°
- 4 prototype modules tested at sea
- Performance as expected
-16 modules to be deployed this year



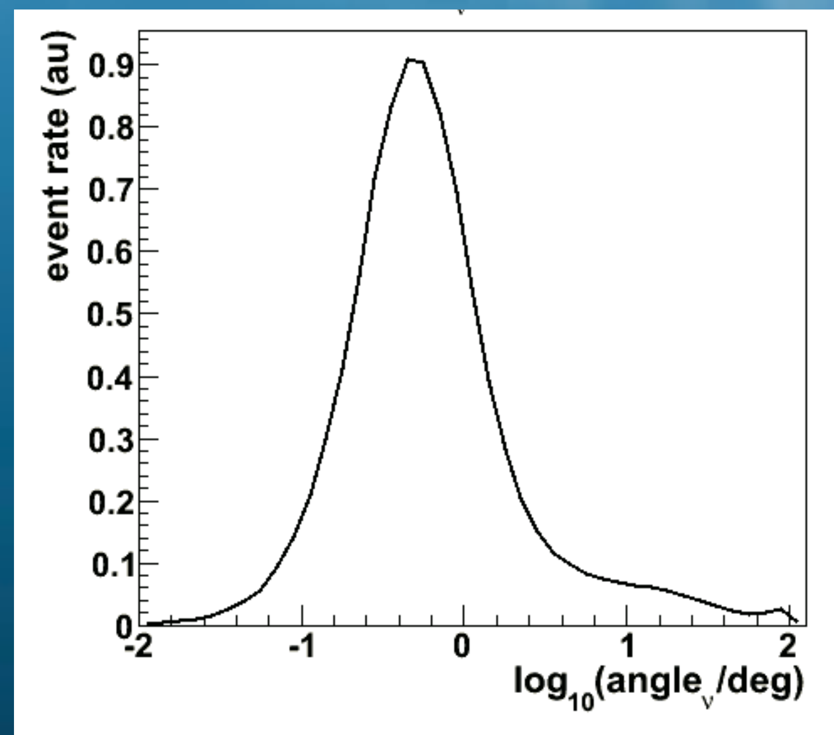
Angular Resolution for Upgoing Neutrinos

Full 12 line detector



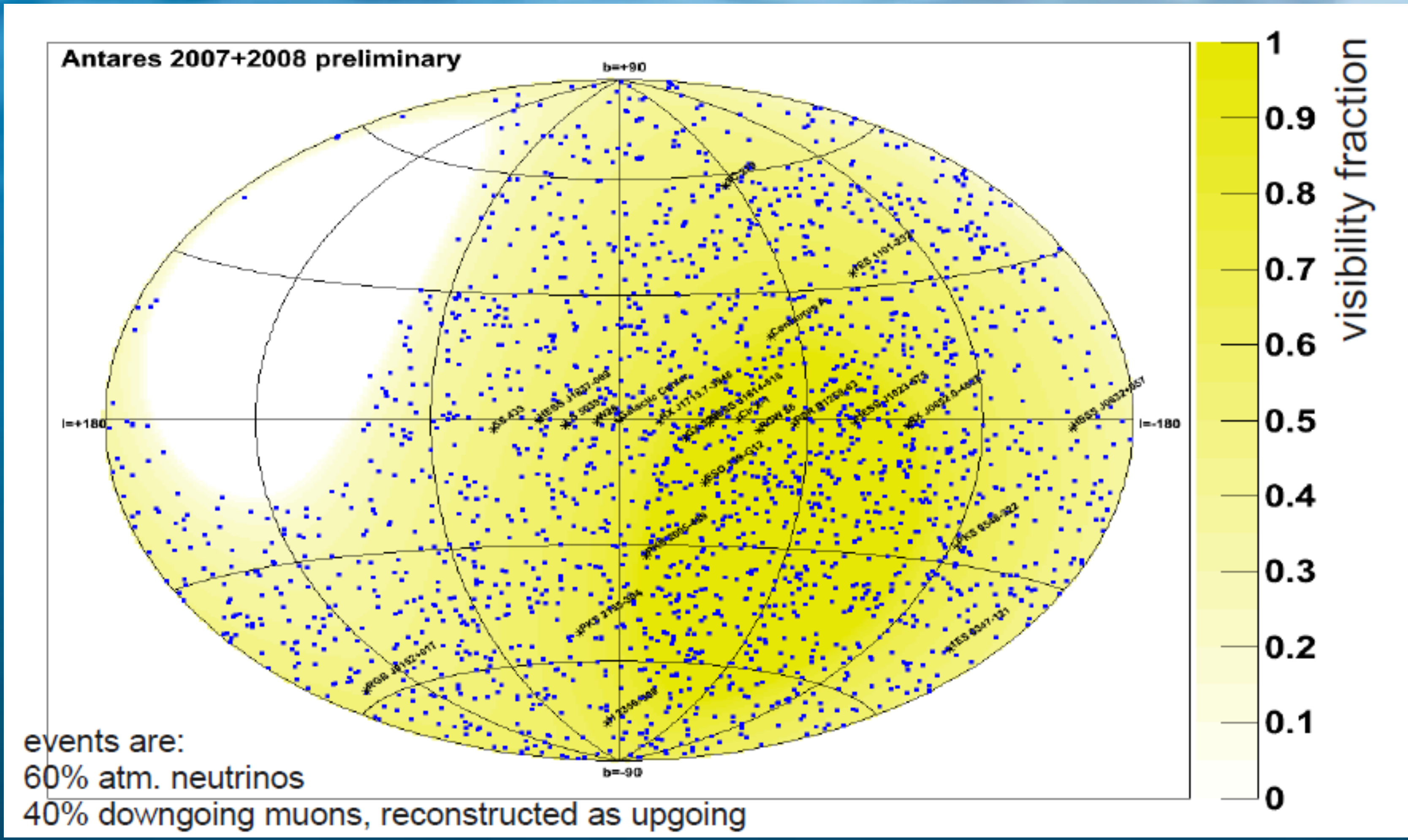
2007+2008 analyses:
Angular resolution ~ 0.5°
(ΔΘ < 1° , in 75% of cases)

- Integrated over all energies (E^{-2} flux)
- Half of data only 5 lines



Sky Map

Selection optimized for Model Discover Potential (Λ > 5.4):
(Live time 295 days)



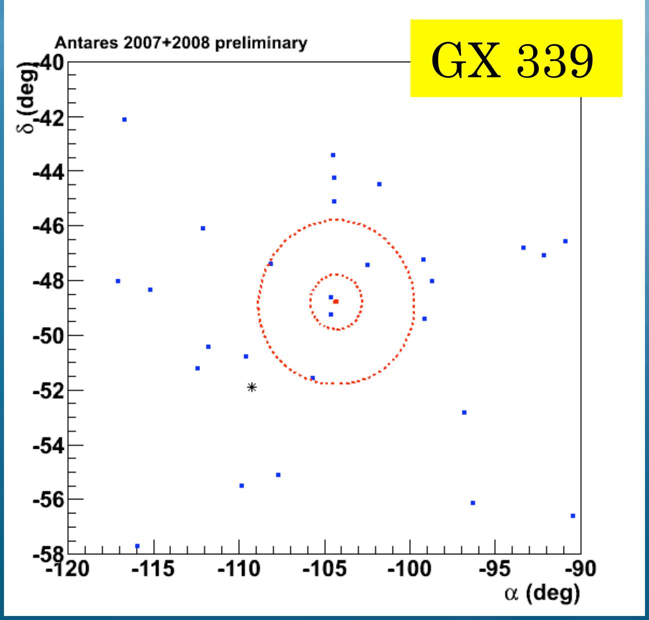
Most significant cluster located at: ra=134.6°, δ=13.4°
(post-trial probability to be background 2.4%)

Candidate List Search

List of 24 candidate sources

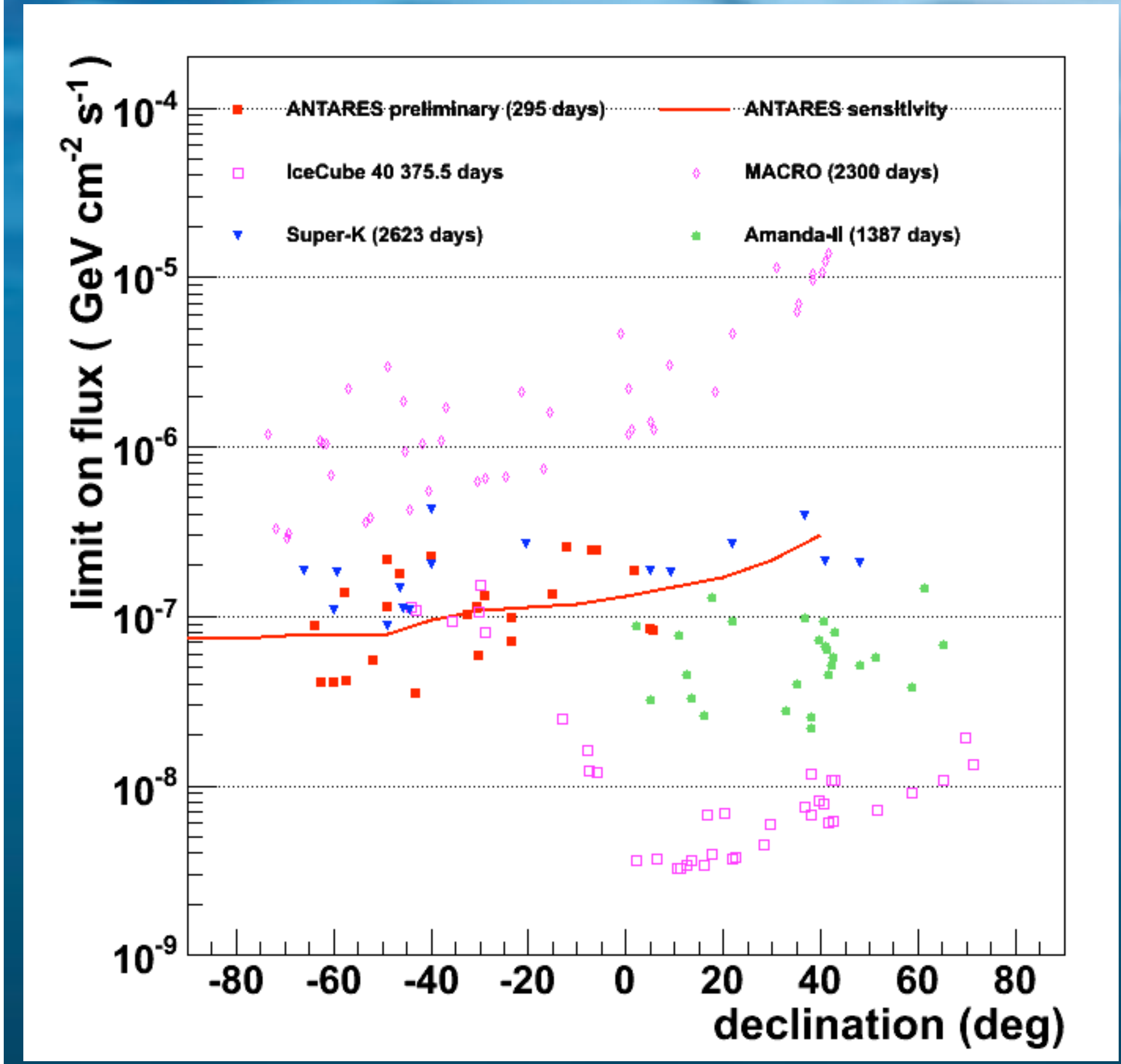
Source	ra,decl	fit Nsig	Q	Limit Nsig	Limit ϕ	p-value
GX 339	-104.3, -48.79	2.24	3.41	6.590	2.13e-07	0.068
RX J0852.0-4622	133.0, -46.37	1.24	1.81	5.510	1.78e-07	0.397
RX J1713.7-3946	-101.75, -39.75	1.07	1.80	5.540	2.25e-07	0.399
1ES 0347-121	57.35, -11.99	1.49	1.43	4.840	2.57e-07	0.574
HESS J1837-069	-80.59, -6.95	1.04	1.11	4.620	2.45e-07	0.705
3C 279	-165.95, -5.79	1.01	1.00	4.600	2.44e-07	0.743
PSR B1259-63	-164.3, -63.83	1.03	0.56	4.520	1.45e-07	0.879
HESS J1023-575	155.83, -57.76	1.05	0.24	4.220	1.36e-07	0.952
PKS 2005-489	-57.63, -48.82	0.00	0.00	3.530	1.14e-07	~ 1
RGB J0152+017	28.17, 1.79	0.00	0.00	3.110	1.87e-07	~ 1
Galactic Center	-93.58, -29.01	0.00	0.00	2.790	1.3e-07	~ 1
LS 5039	-83.44, -14.83	0.00	0.00	2.520	1.34e-07	~ 1
H 2356-309	-0.22, -30.63	0.00	0.00	2.430	1.13e-07	~ 1
PKS 0548-322	87.67, -32.27	0.00	0.00	2.160	1.01e-07	~ 1
W28	-89.57, -23.34	0.00	0.00	1.940	9.71e-08	~ 1
HESS J1614-518	-116.42, -51.82	0.00	0.00	1.690	5.46e-08	~ 1
1ES 1101-232	165.91, -23.49	0.00	0.00	1.400	7e-08	~ 1
Cir X-1	-129.83, -57.17	0.00	0.00	1.280	4.12e-08	~ 1
RCW 86	-139.32, -62.48	0.00	0.00	1.270	4.09e-08	~ 1
ESO 139-G12	-95.59, -59.94	0.00	0.00	1.270	4.09e-08	~ 1
PKS 2155-304	-30.28, -30.22	0.00	0.00	1.240	5.78e-08	~ 1
HESS J0632+057	98.24, 5.81	0.00	0.00	1.220	8.2e-08	~ 1
Centaurus A	-158.64, -43.02	0.00	0.00	0.860	3.5e-08	~ 1
SS 433	-72.04, 4.98	0.00	0.00	1.390	8.34e-08	~ 1

Most significant candidate
GX 339-galactic micro-quasar



Post trail probabilty to be background fluctuation= 6.8%
not significant

Point Source Limits



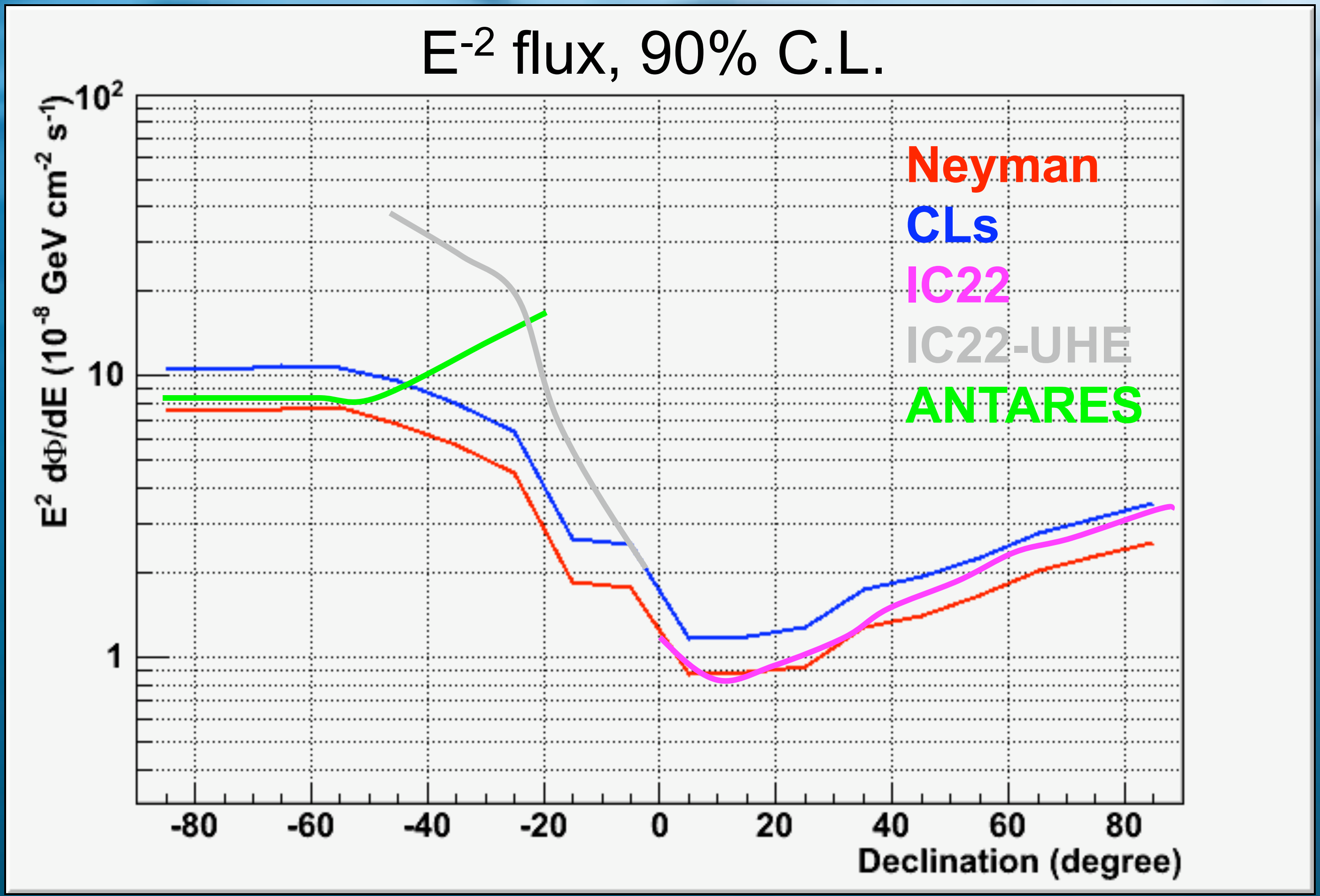
Quoted for E^{-2} flux

ANTARES- some of best limits in the Southern sky

much more data (2009-2011) on tape

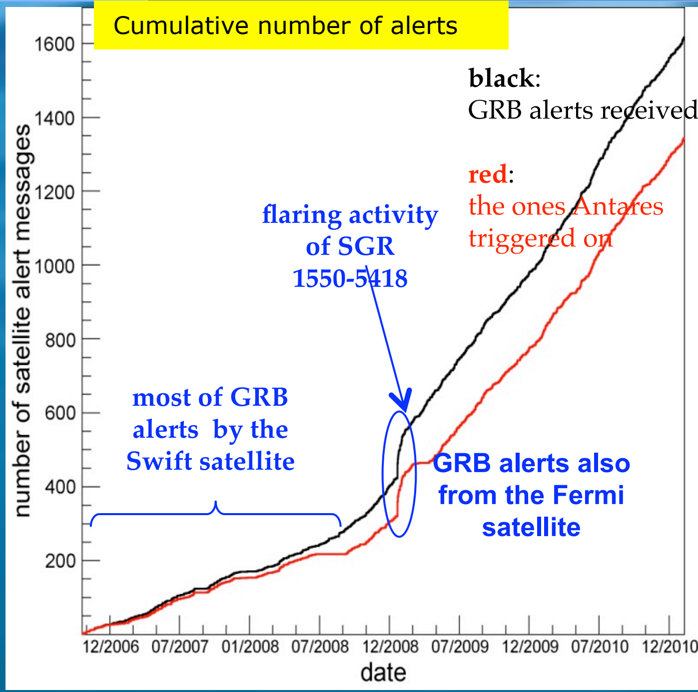
Expect further improvement once energy estimator included

Combining ANTARES & IceCube



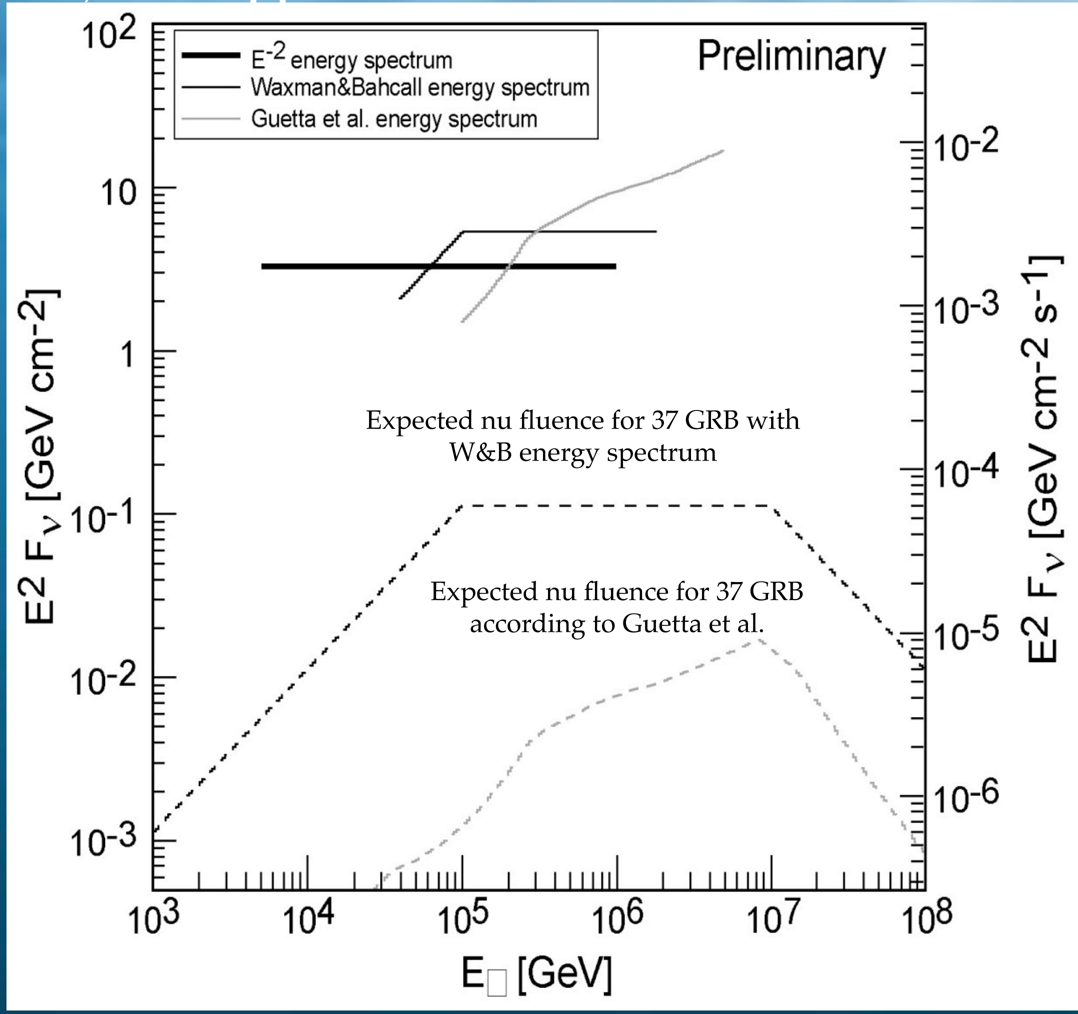
Improved sensitivity, especially in overlap region

GRB Triggered Searches



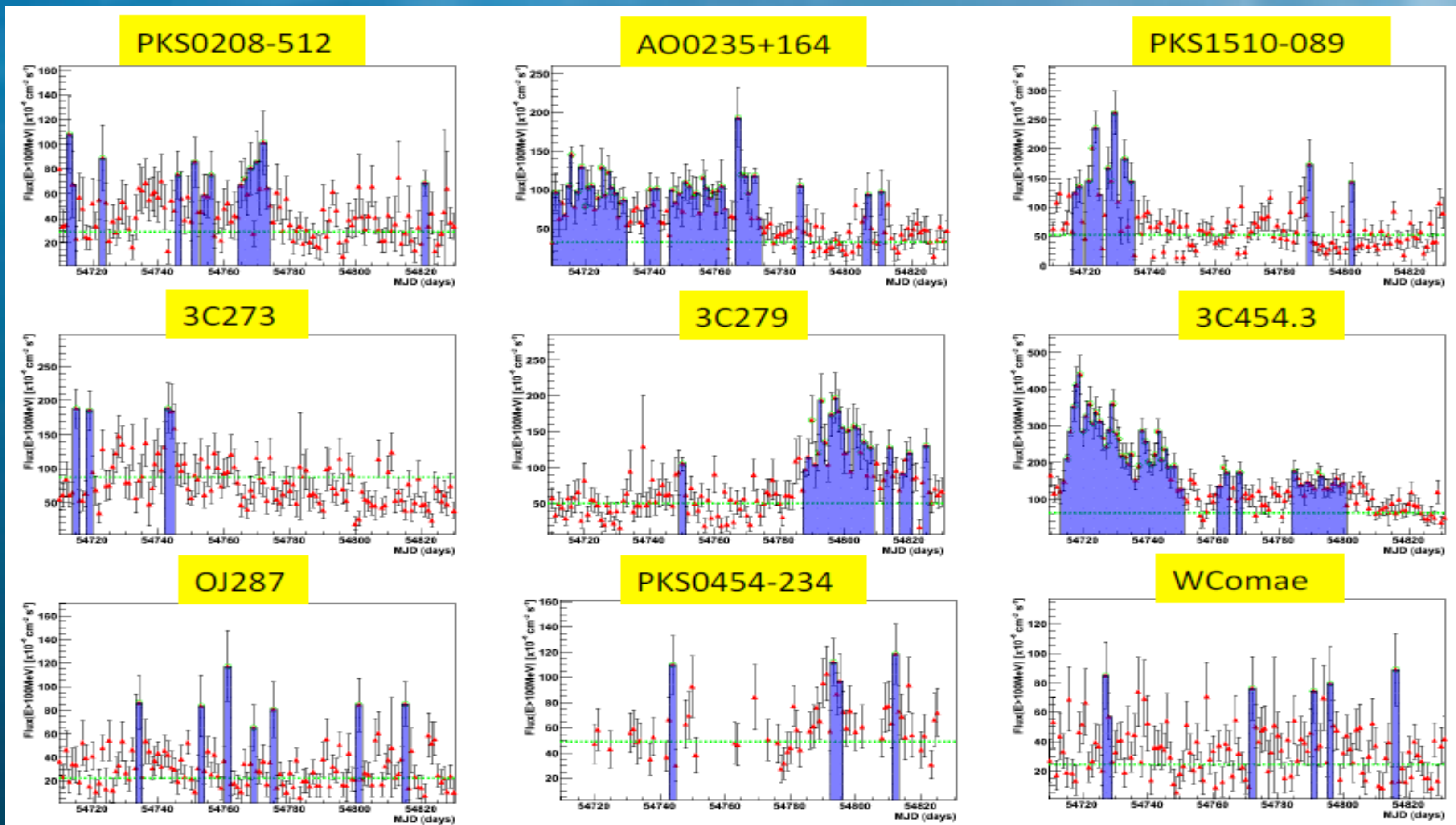
- > 1300 alerts from GCN have been recorded (Jan 2011)
- Lines 1-5 data unblinded: 37 GRB alerts
- The total prompt emission duration of the 37 GRBs is 1882 s

90% CL Upper limits on fluxes from 37 GRBs



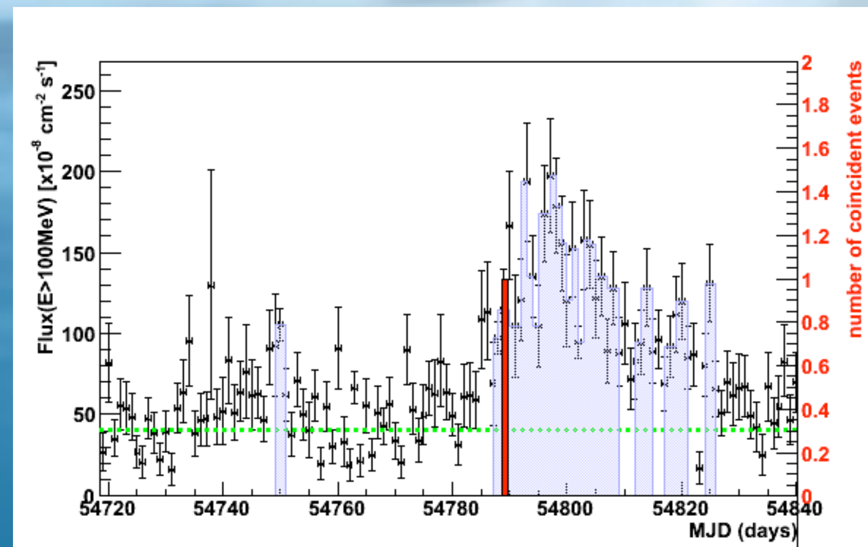
Search for neutrino emission from gamma-ray flaring blazars

1st year Fermi LBAS catalogue (LAT Bright AGN Sample):
10 sources with flares in 2008



Search for neutrino emission from gamma-ray flaring blazars

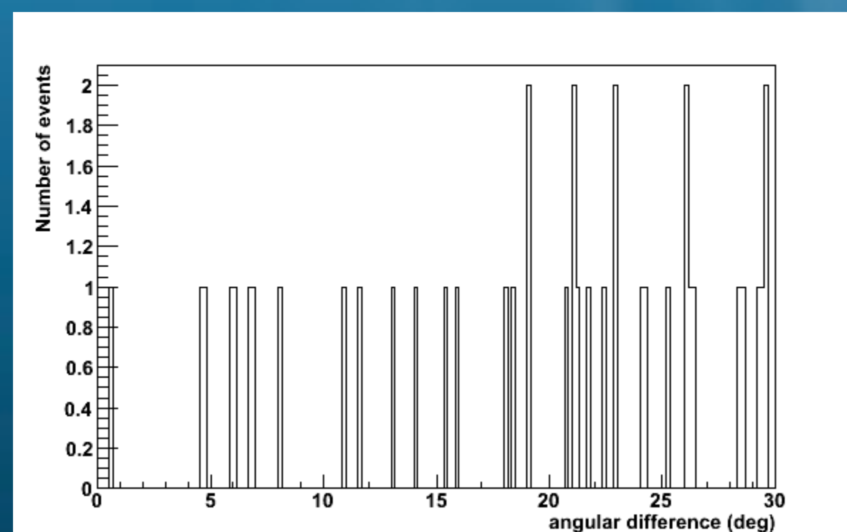
9 sources: 0 events upper-limit on the neutrino fluence



3C279: 1 event compatible with the source direction (Δα=0.56º) and time distribution

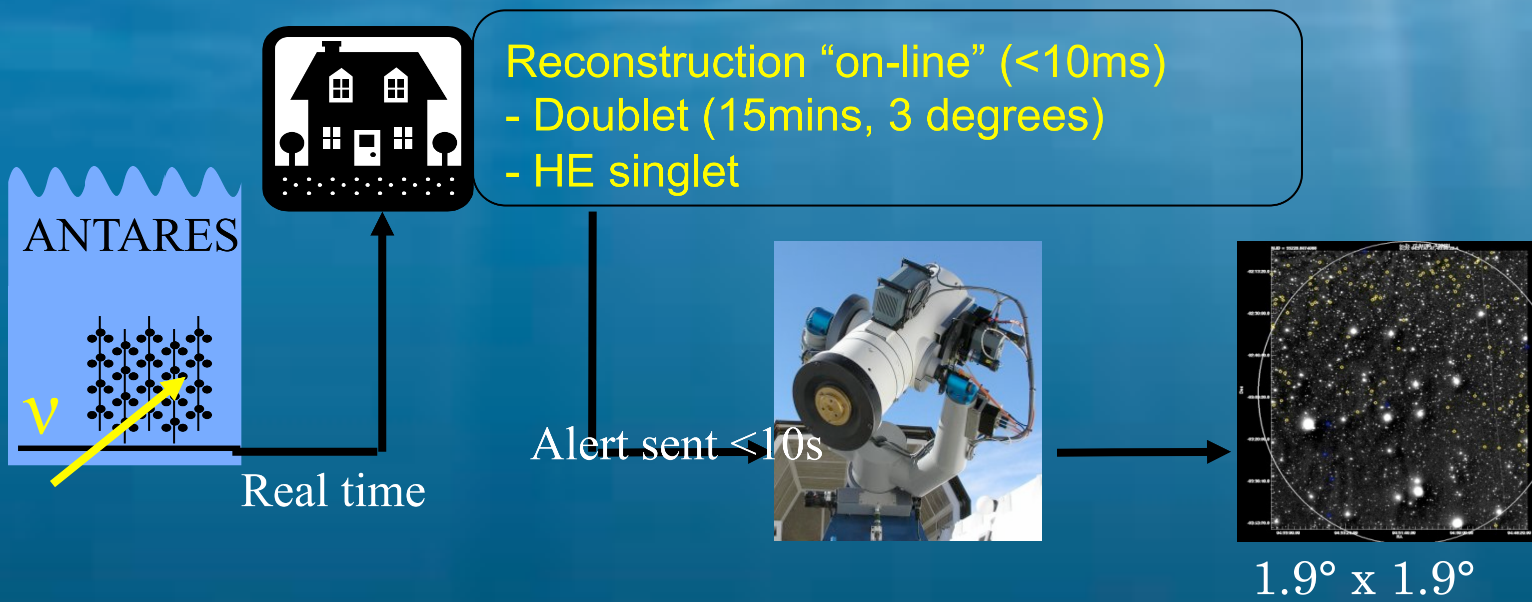
Þ pre trial p-value = 1.1%
post trial p-value ~10%

not significant



TaToO:
Telescopes and ANTARES Target of Opportunity

TAToO: optical follow-up of neutrino alerts in order to search for transient sources (GRB, choked GRB, AGN flare…)



Large sky coverage (>2π sr) + high duty cycle
Improved sensitivity (1 neutrino → 3 sigma discovery)
No hypothesis on the nature of the source
Independent of availability of external triggers

Optical Follow-Up

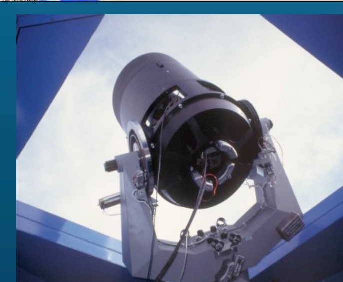
27 alerts sent in 2010: all followed by optical telescopes

TAROT: two 25 cm telescopes

- fov 1.86° x 1.86°
- Magnitude V<17 (10s), V<19 (100s)
- slewing time ~ 10s

ROTSE: four 45 cm telescopes

- fov 1.85° x 1.85°
- Magnitude V~19 (60s)
- slewing time < 6-8s



Analyses ongoing….

Diffuse n$_m$ flux analysis

Data: 2008-2009

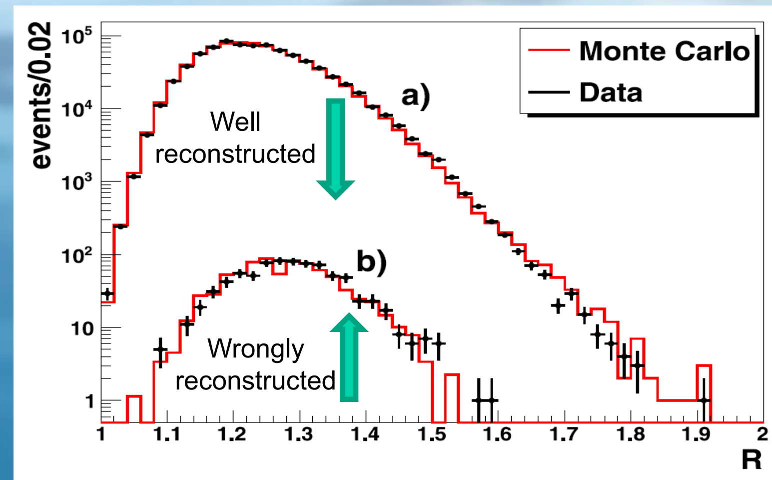
First level: good quality upgoing tracks

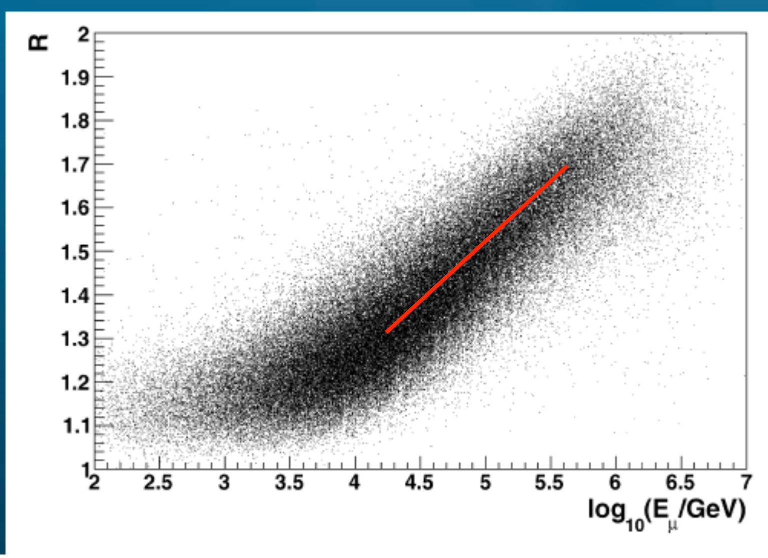
Cuts on zenith angle, Λ , n_{lines} in prefit, N_{hit}

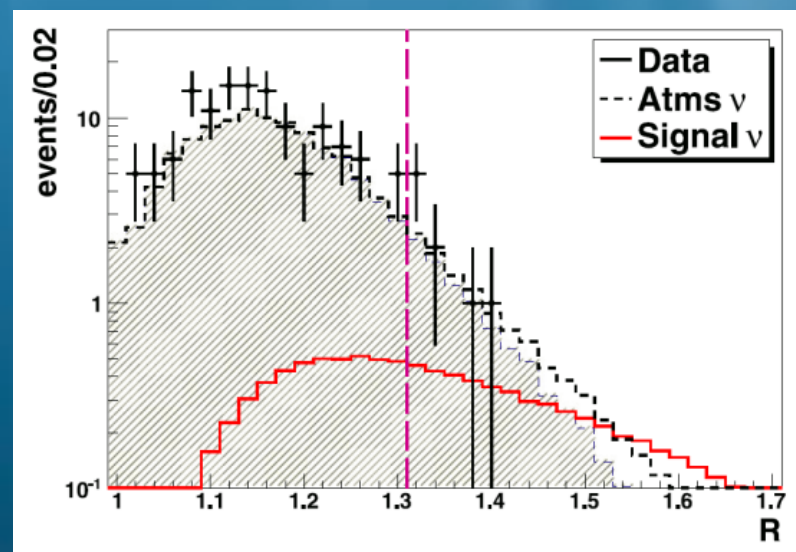
Second level: Λ vs N_{hit}

Energy estimator:

Repetition (R) of hits on the same optical module

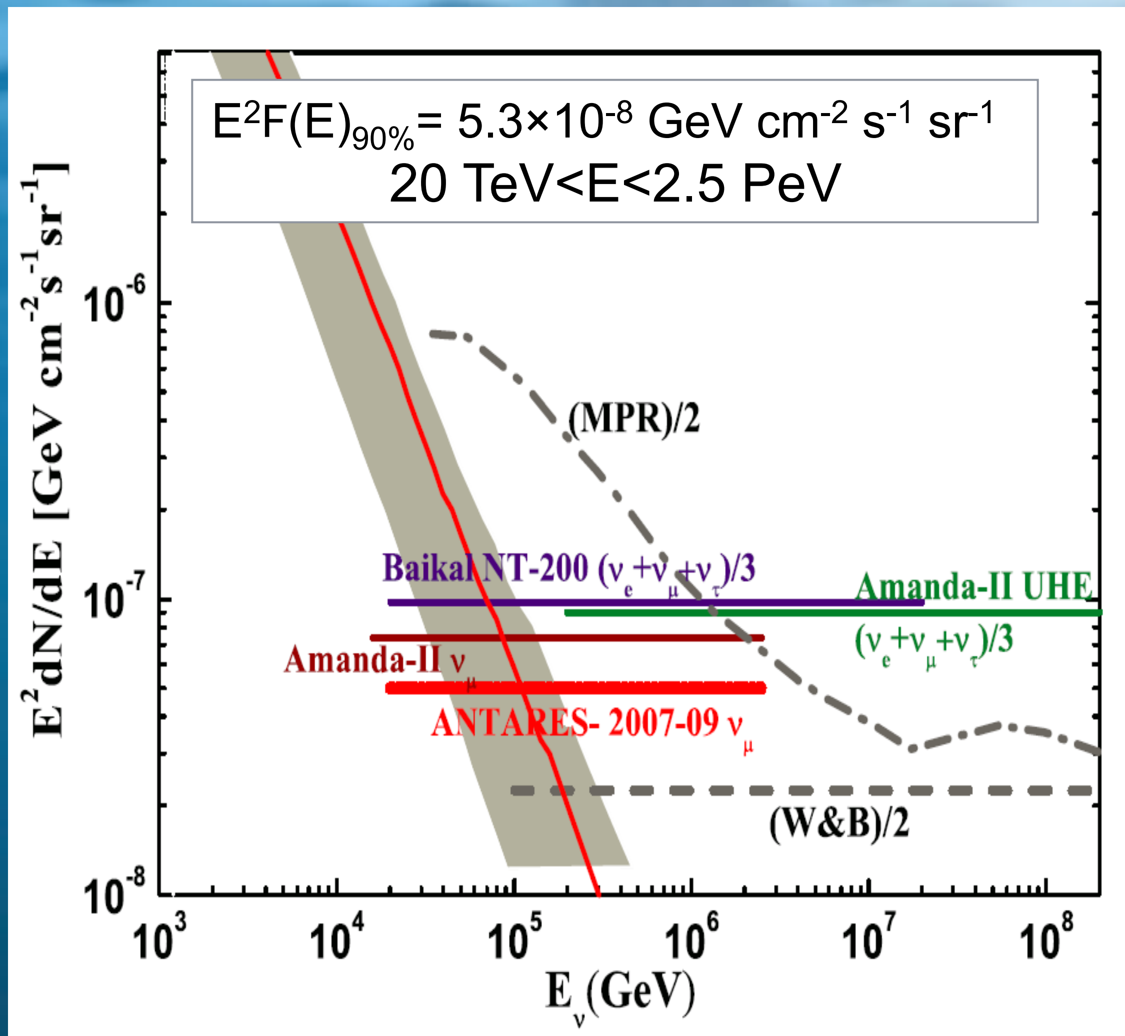






Distribution of the *R* parameter for the 134 neutrino candidates

Diffuse ν_μ flux



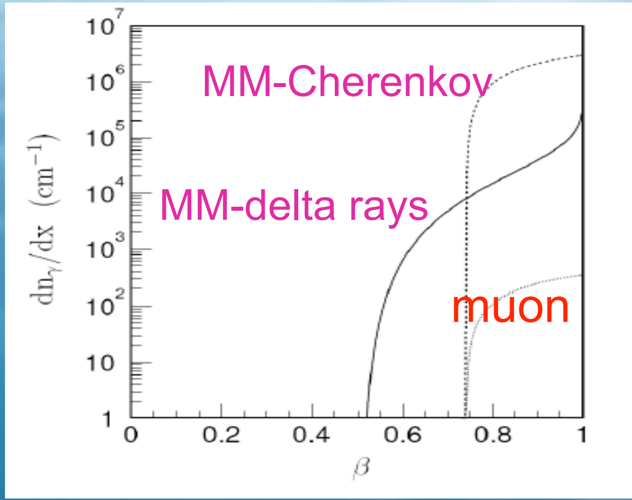
"Search for a diffuse flux of high-energy ν_μ with the ANTARES neutrino telescope"
Physics Letters **B696** (2011) 16-22.

Magnetic Monopoles

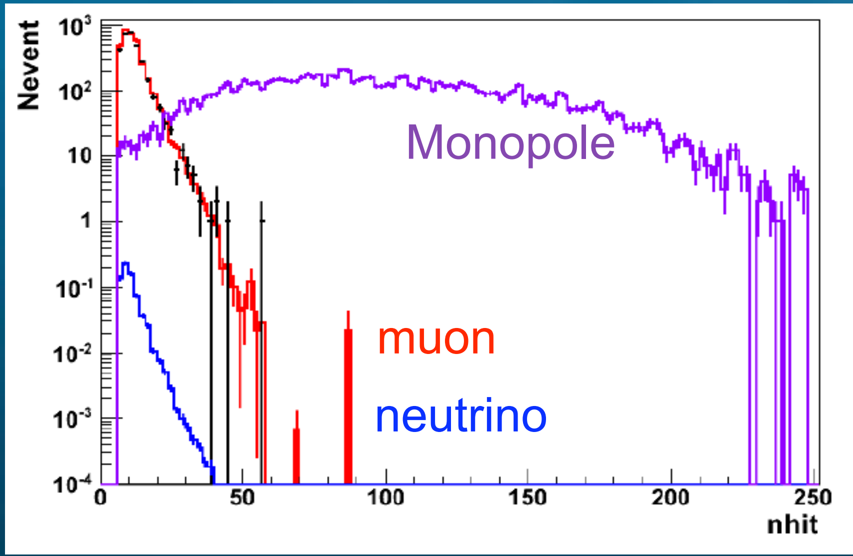
- Required in many models of spontaneous symmetry breaking ('t Hooft, Polyakov)

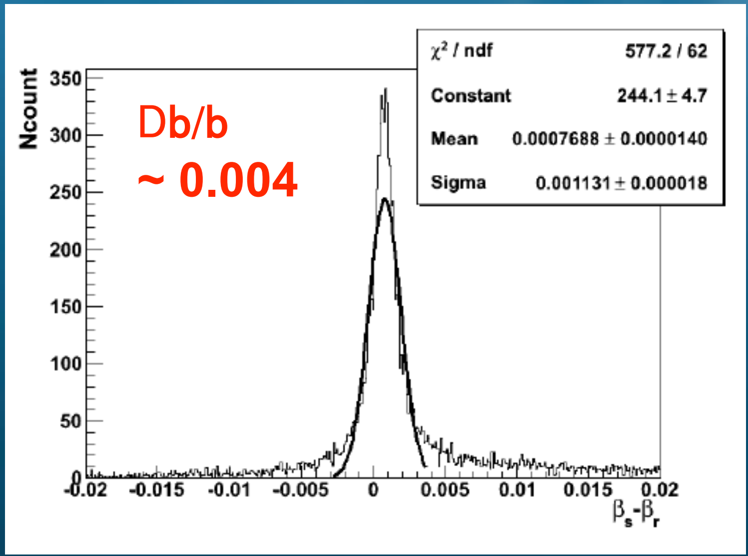
  upgoing [?] masses less than ~10^{14} GeV

- High photon yield (8.5×10^3 times μ)
  Cherenkov threshold $\beta > 0.74$
  secondary δ-rays $\beta \geq 0.5$



- Modified track reconstruction with b free





Magnetic Monopoles (cont)

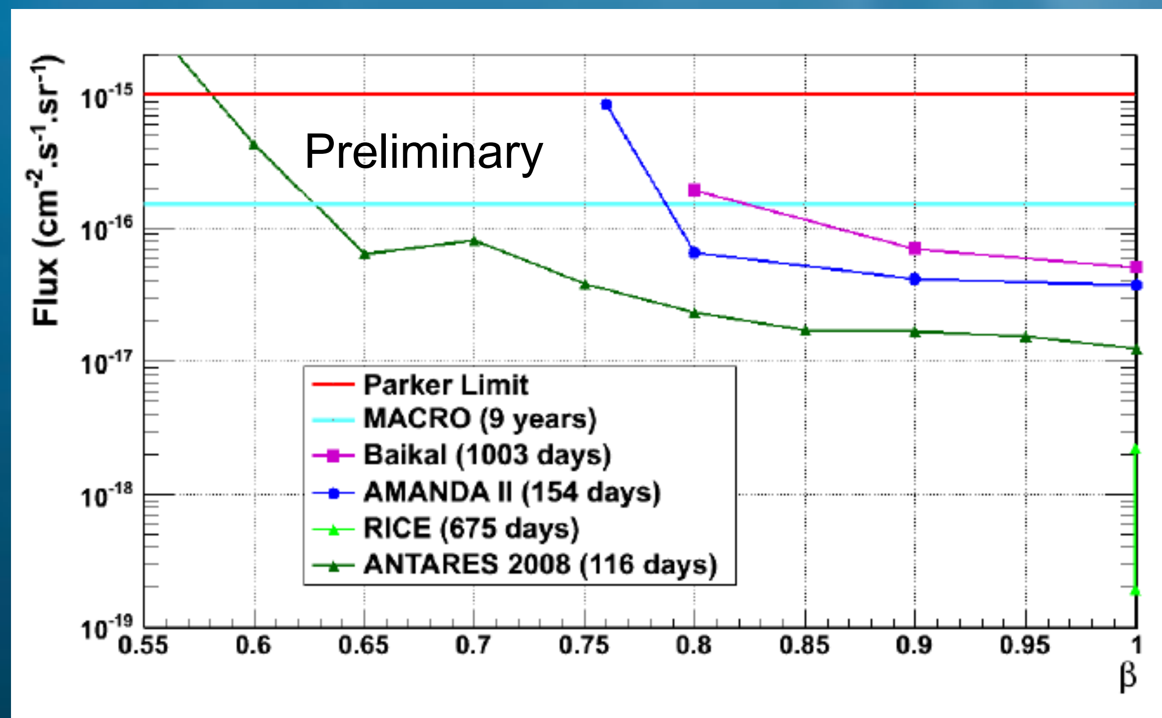
- Selection criteria based on:
  - upward going direction
  - reconstructed beta
  - λ = log(chi2 b=1/chi2 b=free)
  - number of hits

- Optimised for model discovery potential

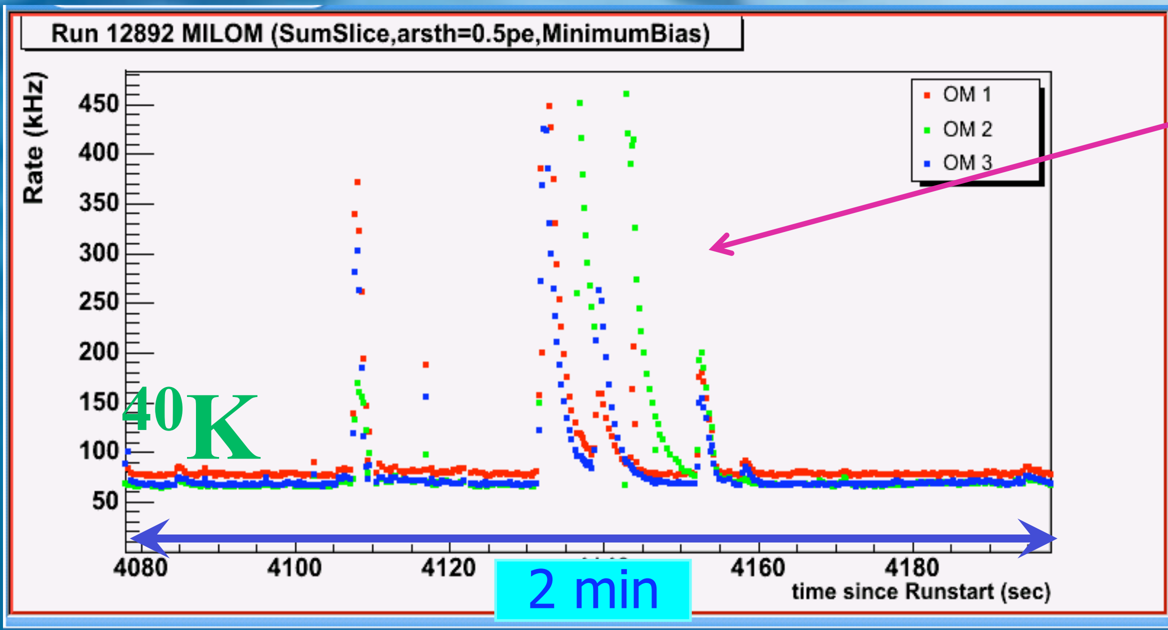
β	Number of observed events	90% C.L. upper flux limit ($cm^{-2}s^{-1}sr^{-1}$)
0.55	12	3.97×10^{-15}
0.60	3	4.29×10^{-16}
0.65	0	6.45×10^{-17}
0.70	1	8.20×10^{-17}
0.75	0	3.79×10^{-17}
0.80	0	2.33×10^{-17}
0.85	0	1.70×10^{-17}
0.90	0	1.68×10^{-17}
0.95	0	1.54×10^{-17}
0.99	0	1.24×10^{-17}

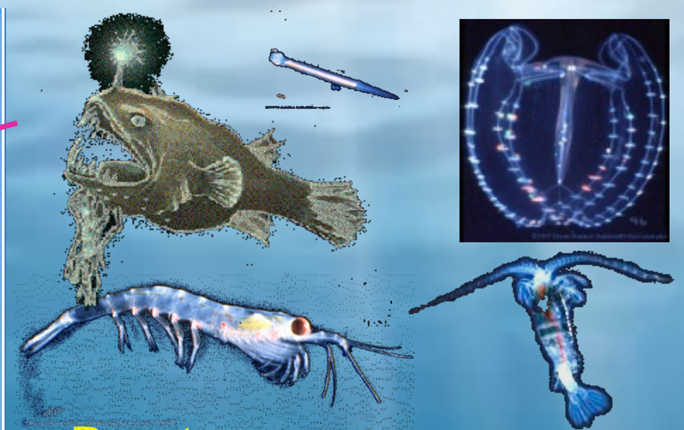
Best limits

currently available

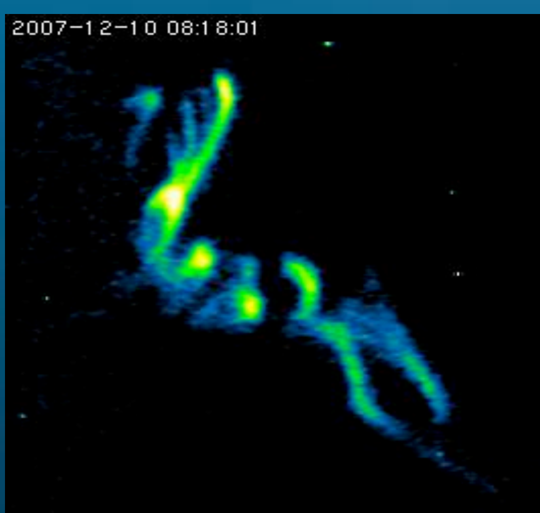


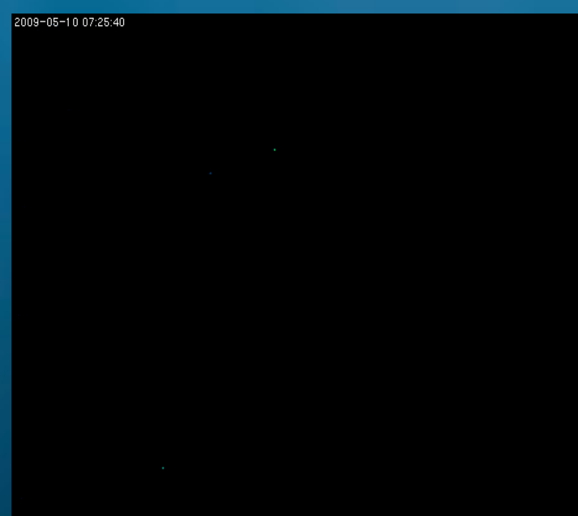
Real Time BioCameras



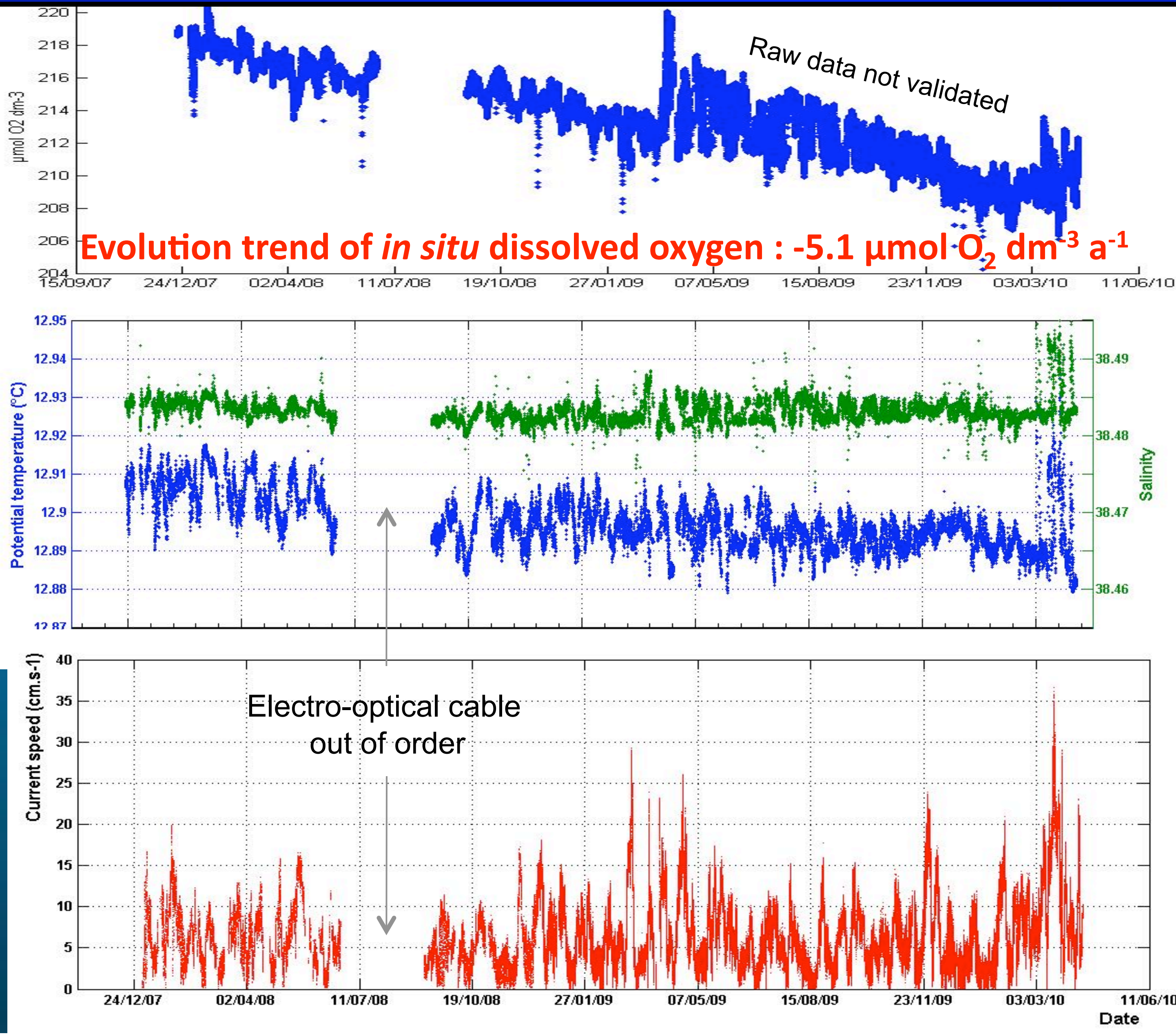


Bursts:
bioluminescence from Macroscopic organisms

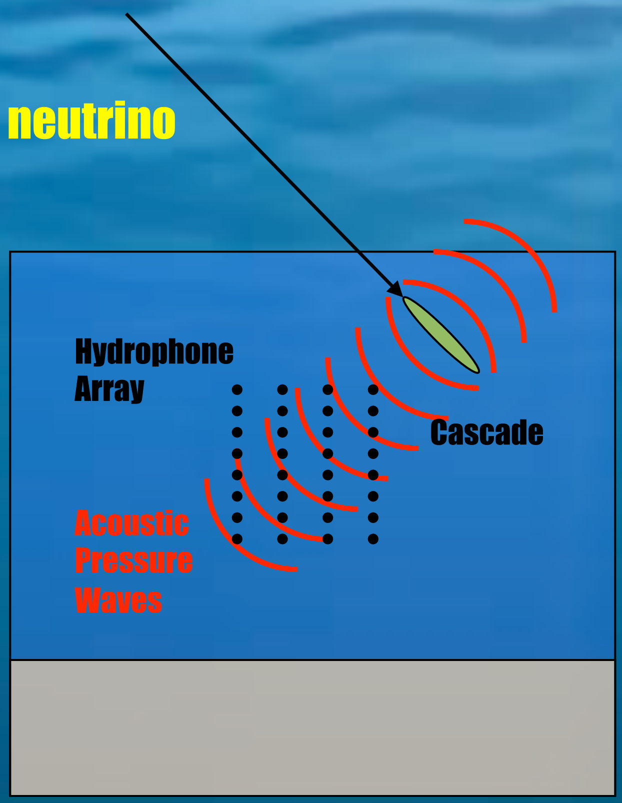


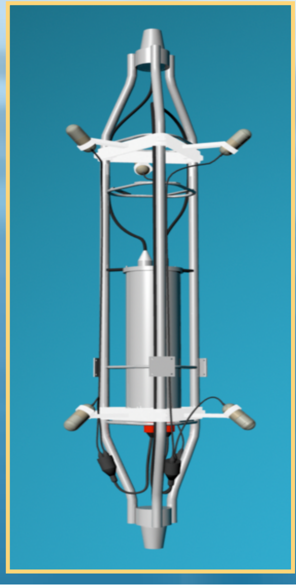


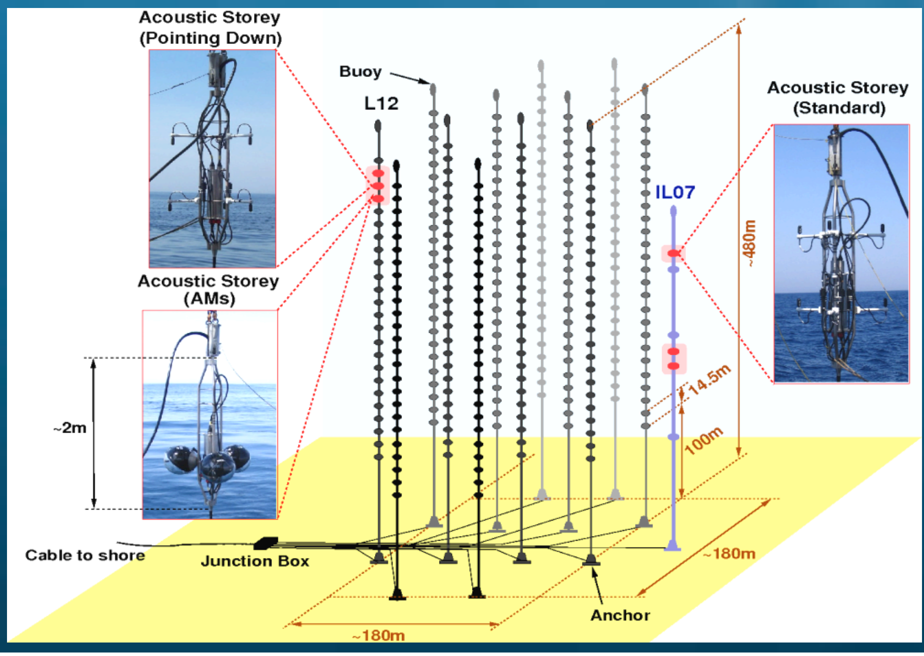
Temperature, Salinity, O_2 Time-Series (IL07)



AMADEUS: Acoustic Detection of Neutrinos



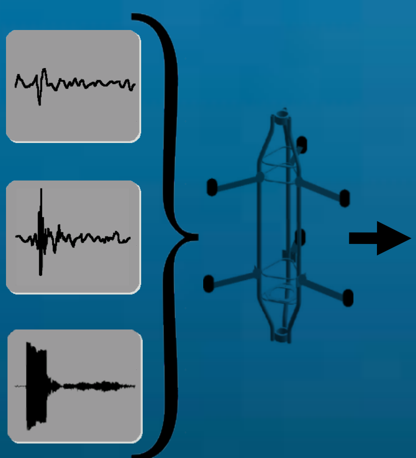


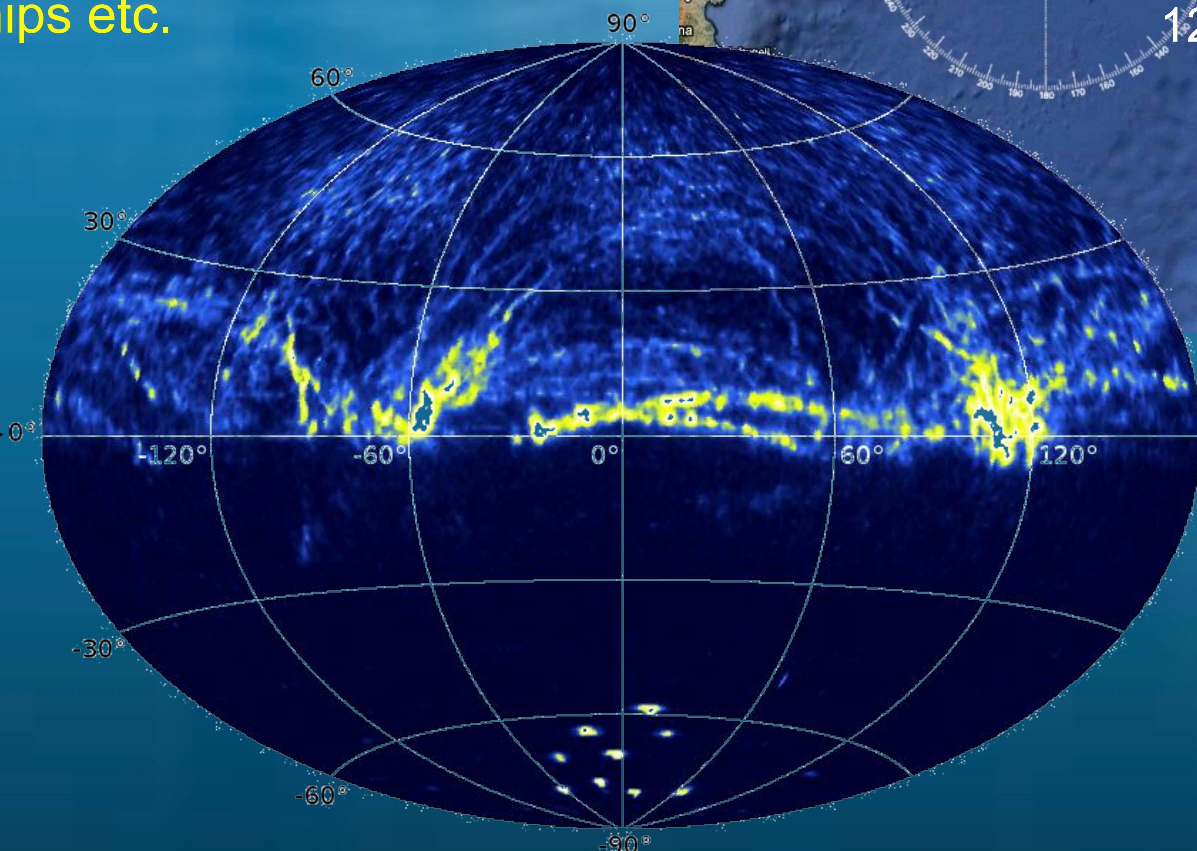


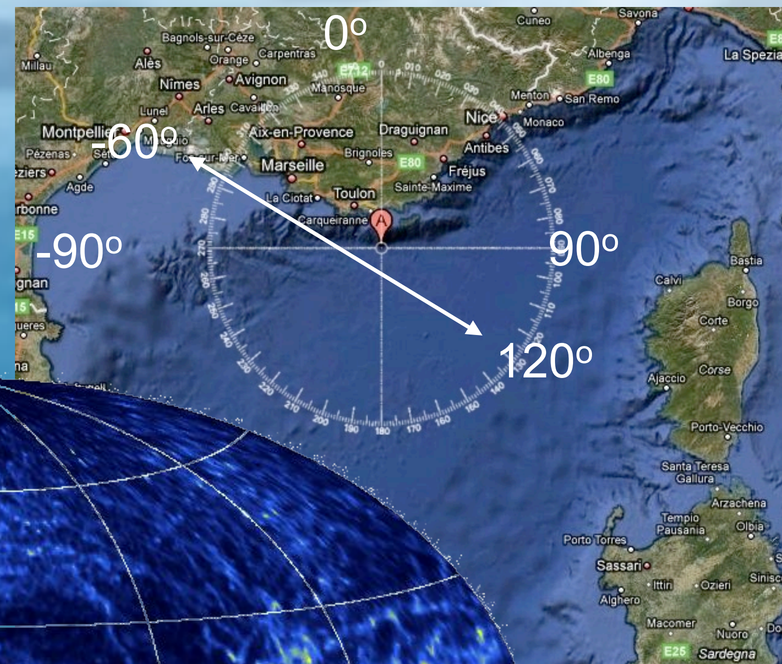
Acoustic Source Direction Distribution

Direction reconstruction from one storey on L12

All types of transient signals included, sea mammals, ships etc.



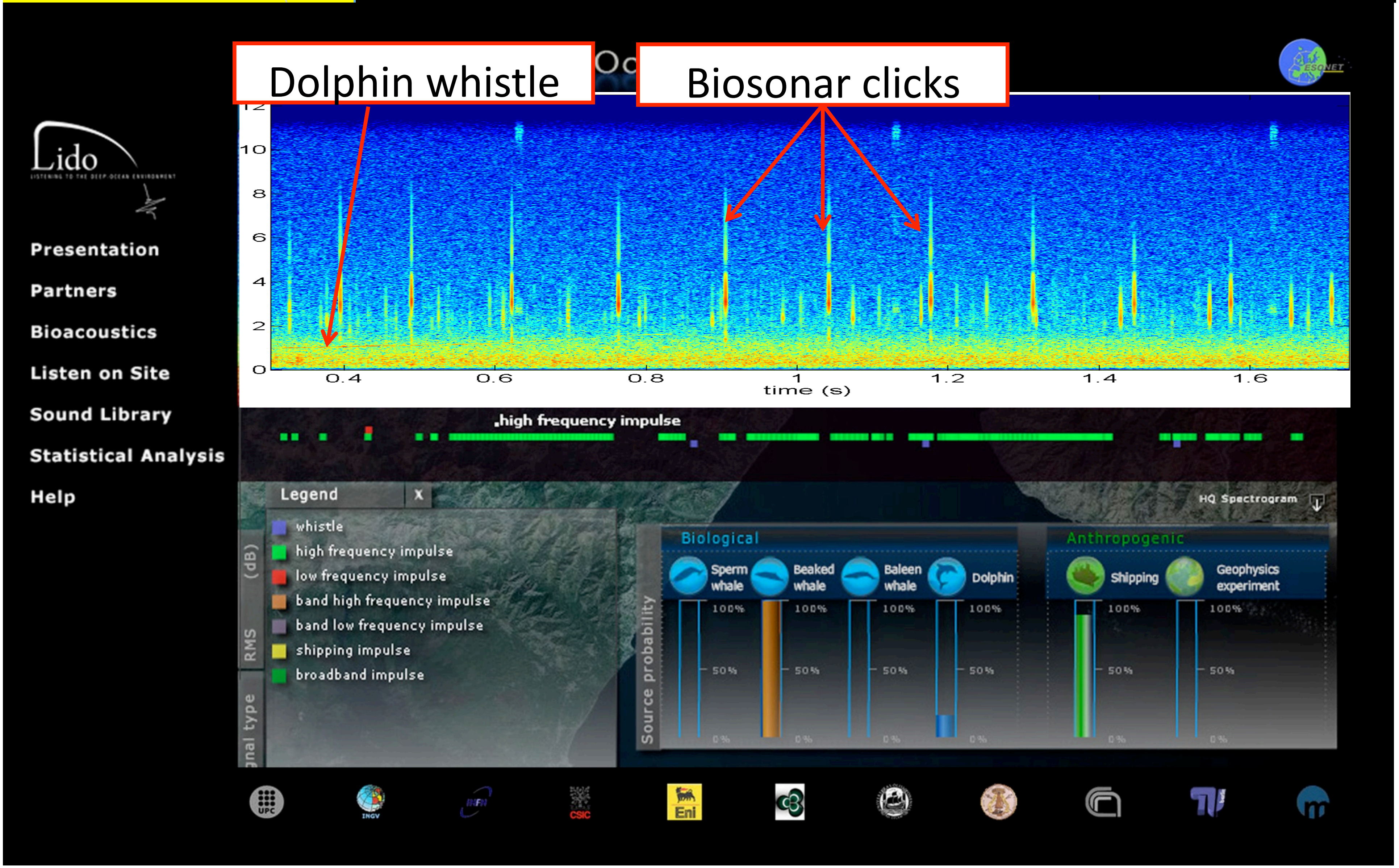




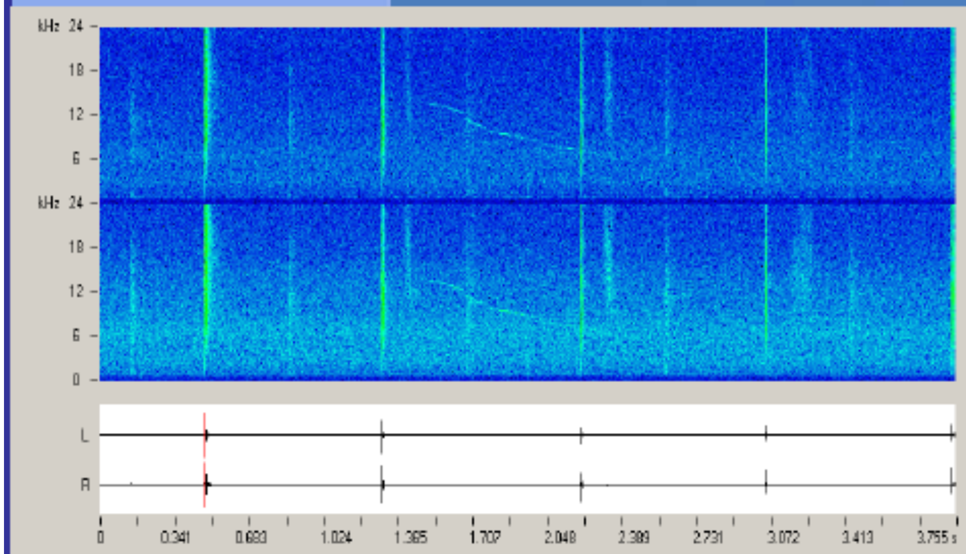
Lido

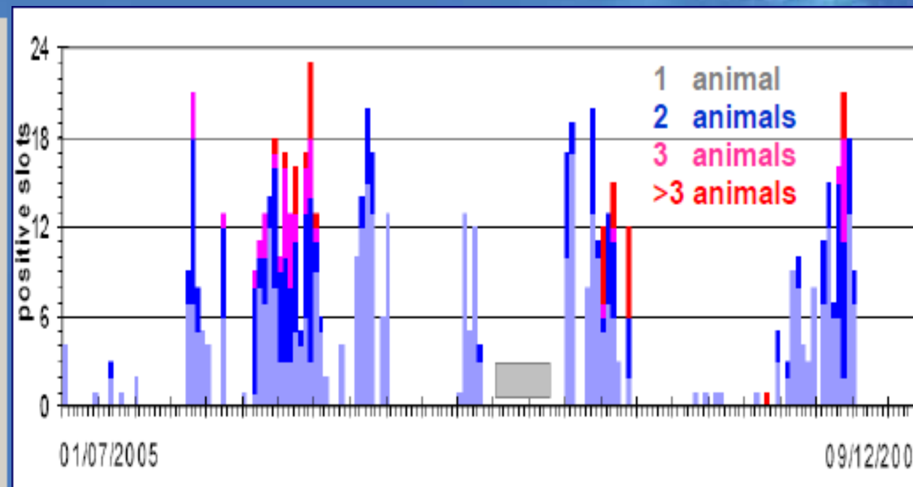
LISTENING TO THE DEEP-OCEAN ENVIRONMENT

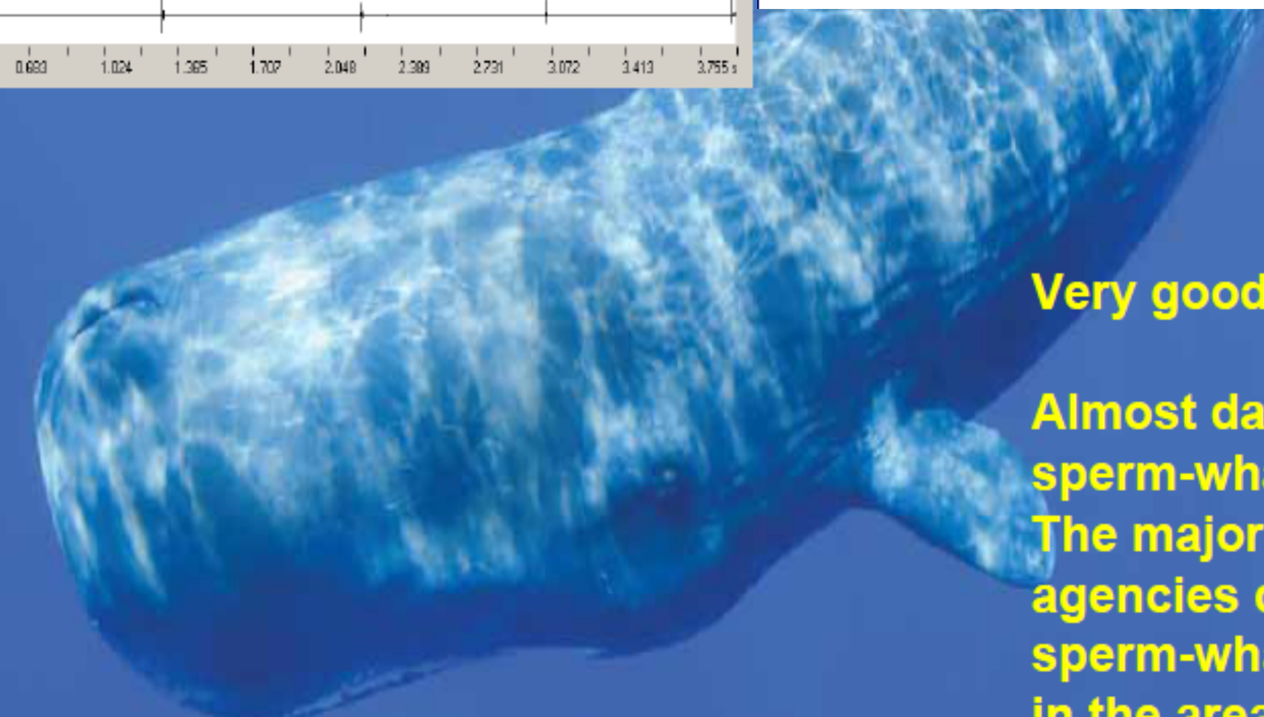
http://www.listentothedeep.org



...A lot of fun with dolphins and whales!







Very good news from OνDE:

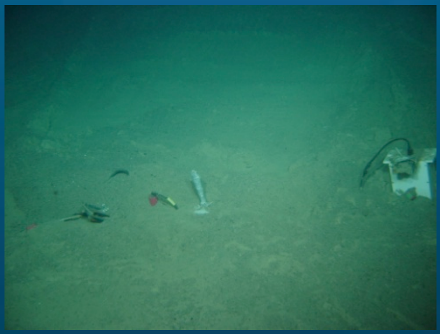
Almost daily detection of sperm-whales

The major environmental agencies declared that sperm-whales disappered in the area

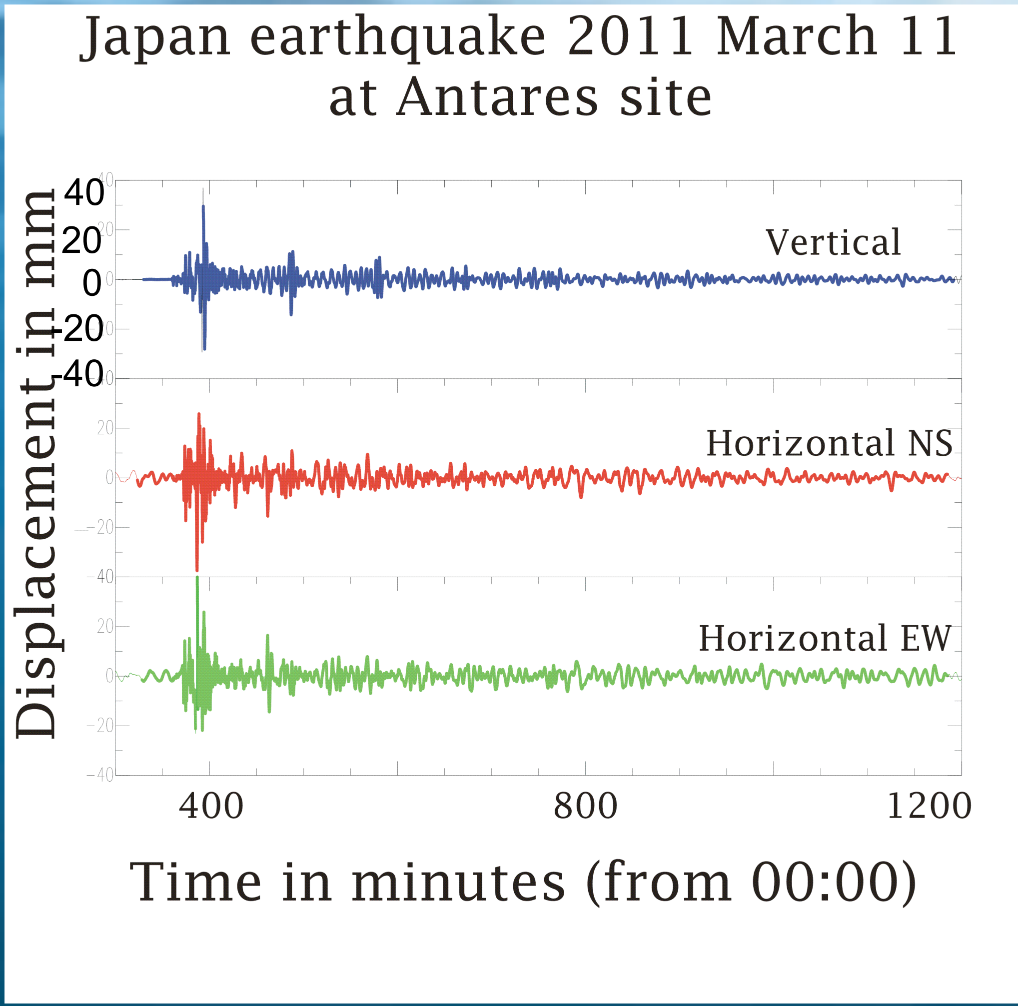
Seismograph: Japan Earthquake

In laboratory

Deployment

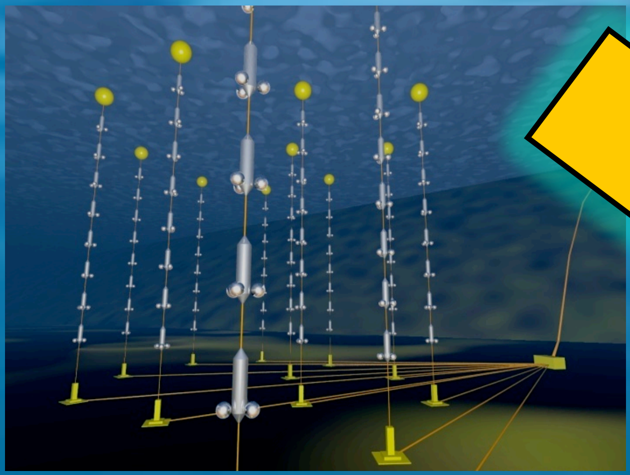


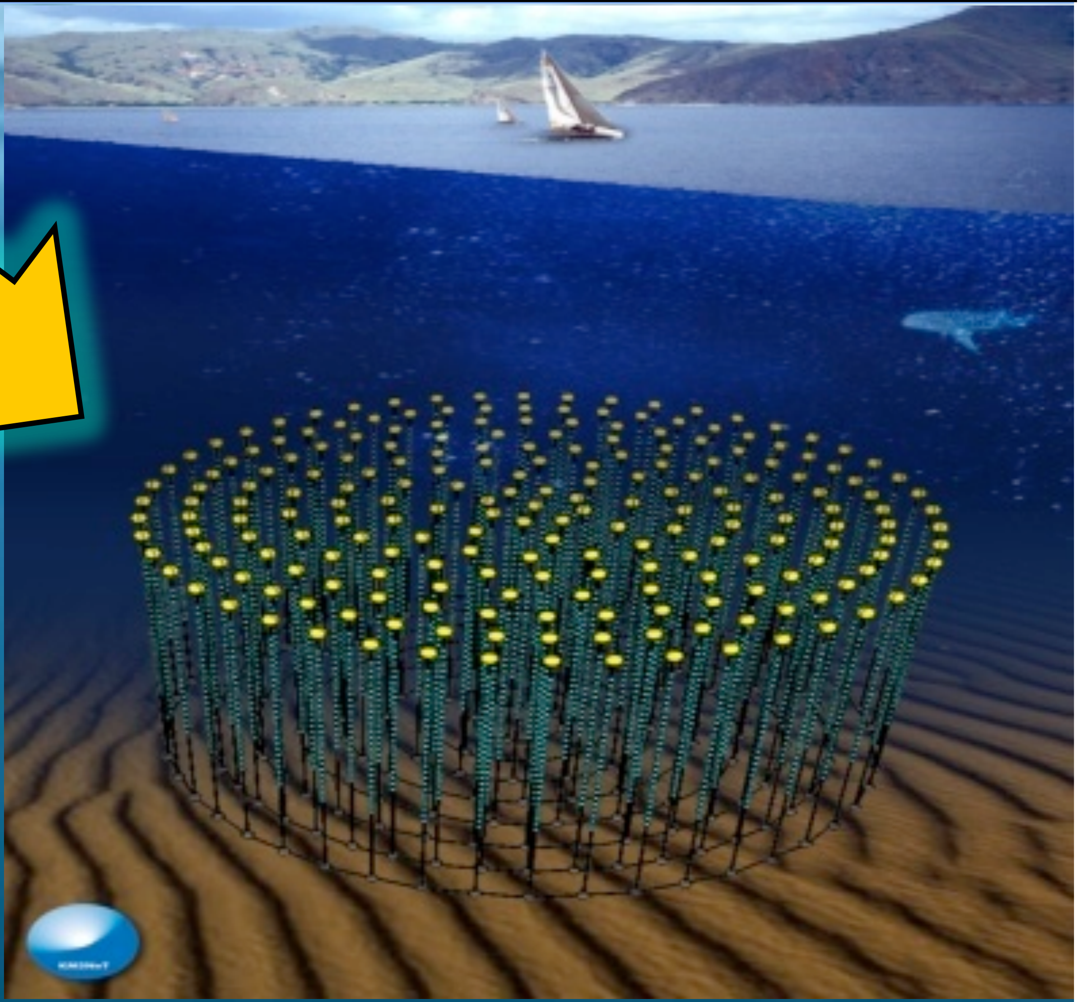
Buried at site

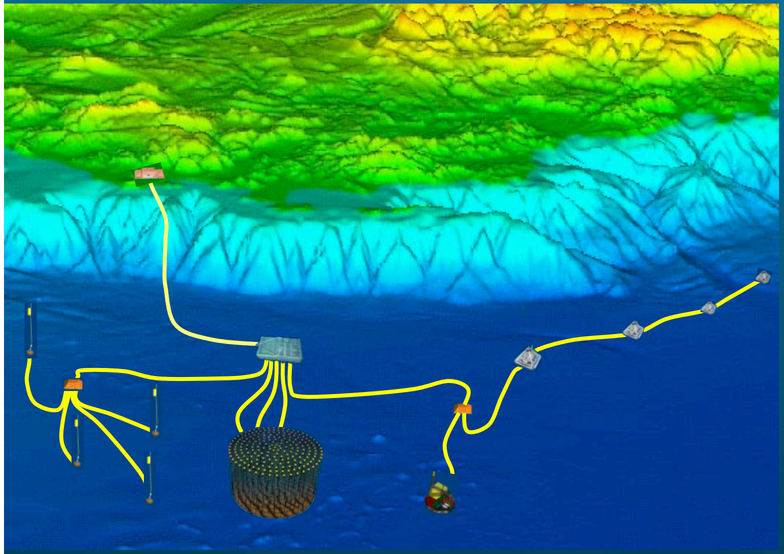


Seismic/Tsunami network to be extended towards Nice

KM3NeT



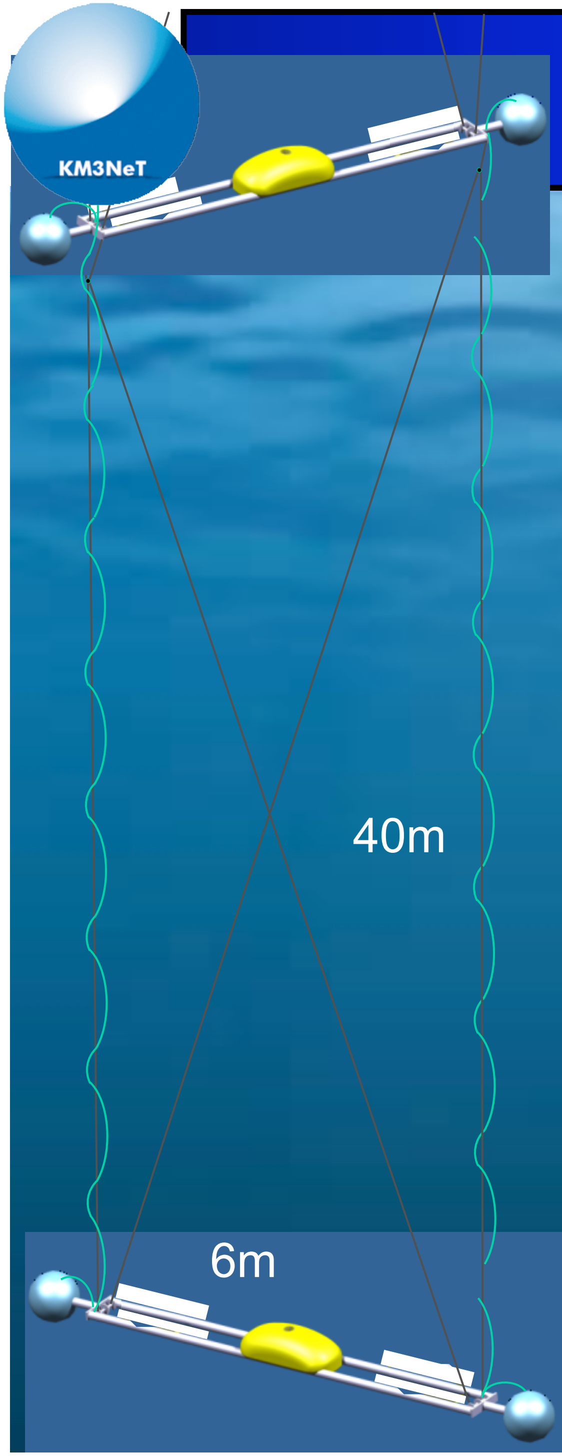


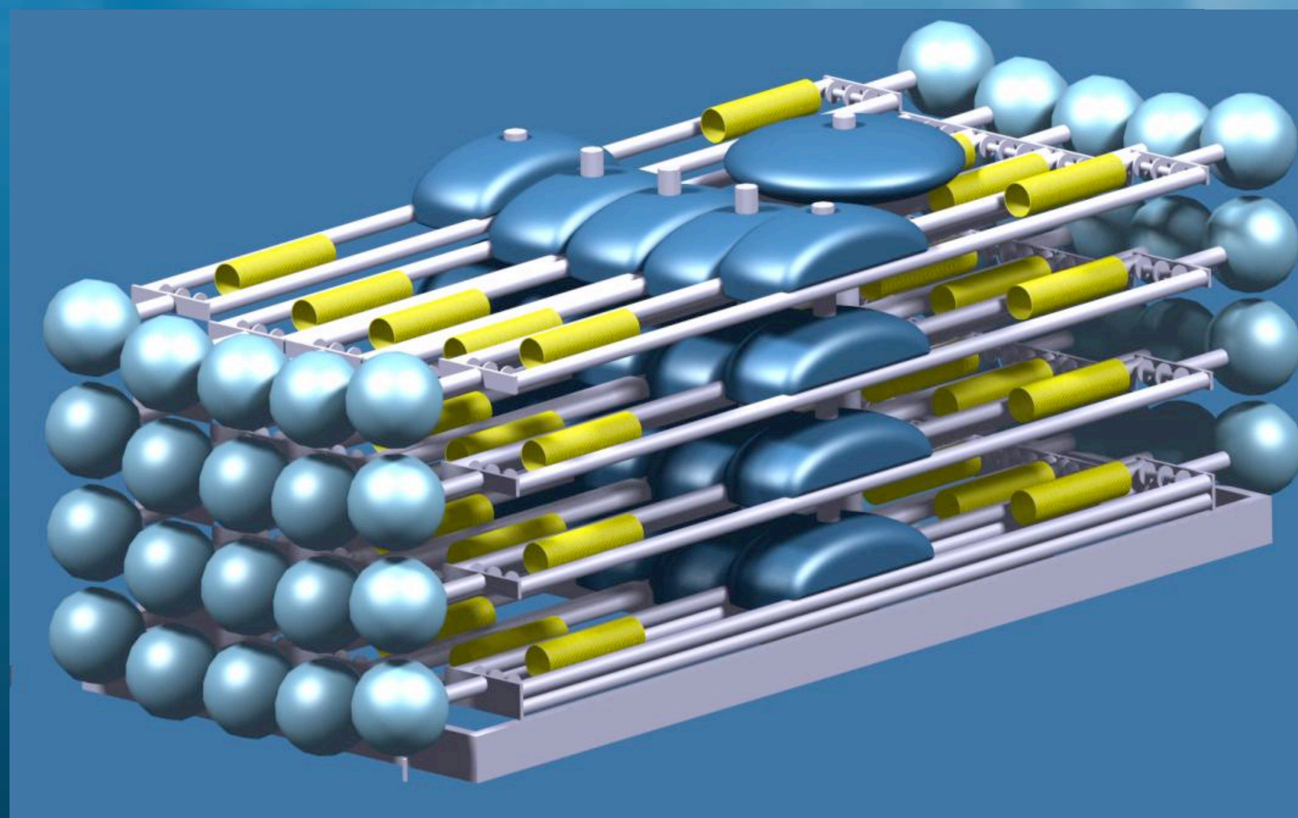


Design study FP6 last 4 years --- TDR published
Preparatory Phase FP7 ongoing
On ESFRI Roadmap

Mechanical Design

Storeys	20
Height	900m
Compact Package	6 x 2.5 x 2.5m
Top drift @ 30 cm/s	~120 m
Total buoyancy	~10 kN
EO Cable	2 x 6.35 mm OD





Multi-PMT Optical Module

Self-contained “plug-and-play” module (17”)

- Photo-sensors 31 (19+12) 3” PMTs
  - Equivalent of 4 x 8” PMTs
- Includes:
  - All read-out/control electronics
  - Calibration devices
- Single penetrator for connection to an e/o backbone cable

Distinguish single from multiple photon hits:

- Photon counting = PMT counting
- Background rejection – ^{40}K

Looking upward:

- Background rejection – atmospheric muons
- More uniform angular acceptance

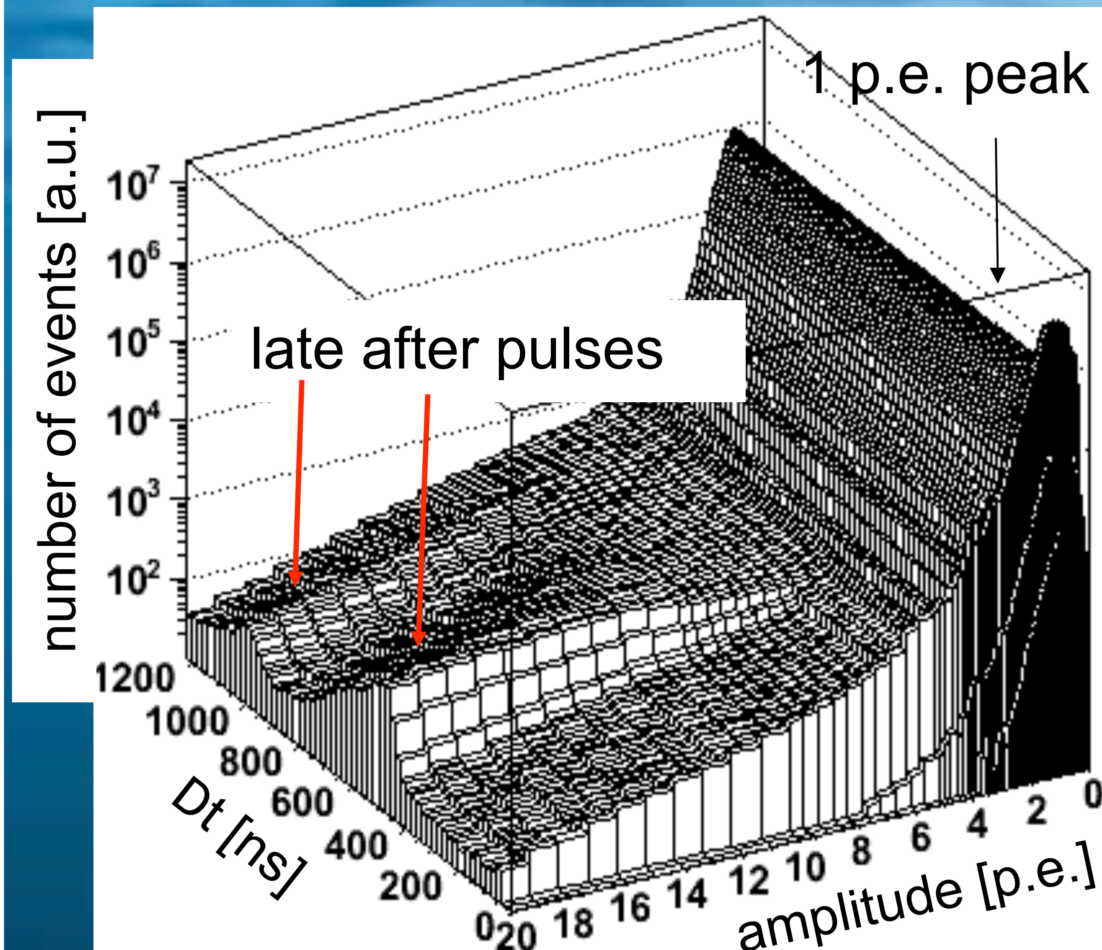
Directionality:

- Signal photons from one side

Ageing:

- lower gain ~10^6
- charge spread over multiple dynode chains

Large PMT -Afterpulses

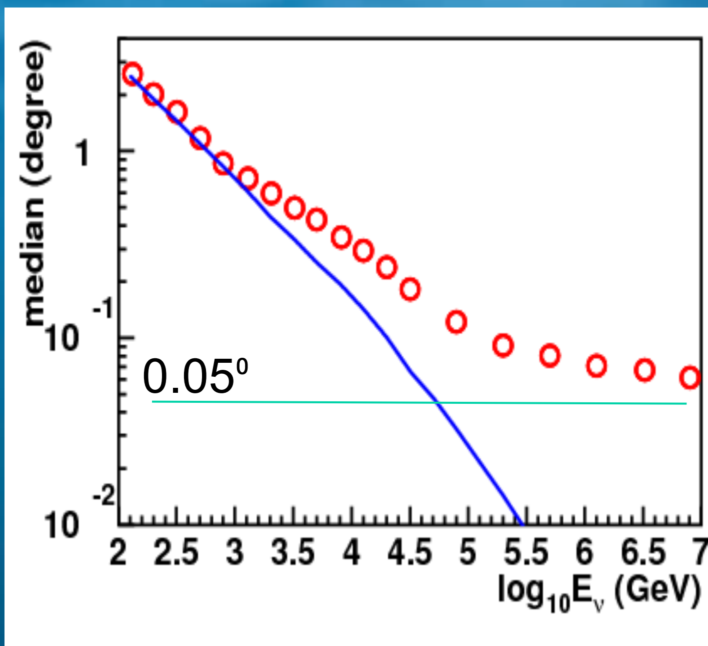


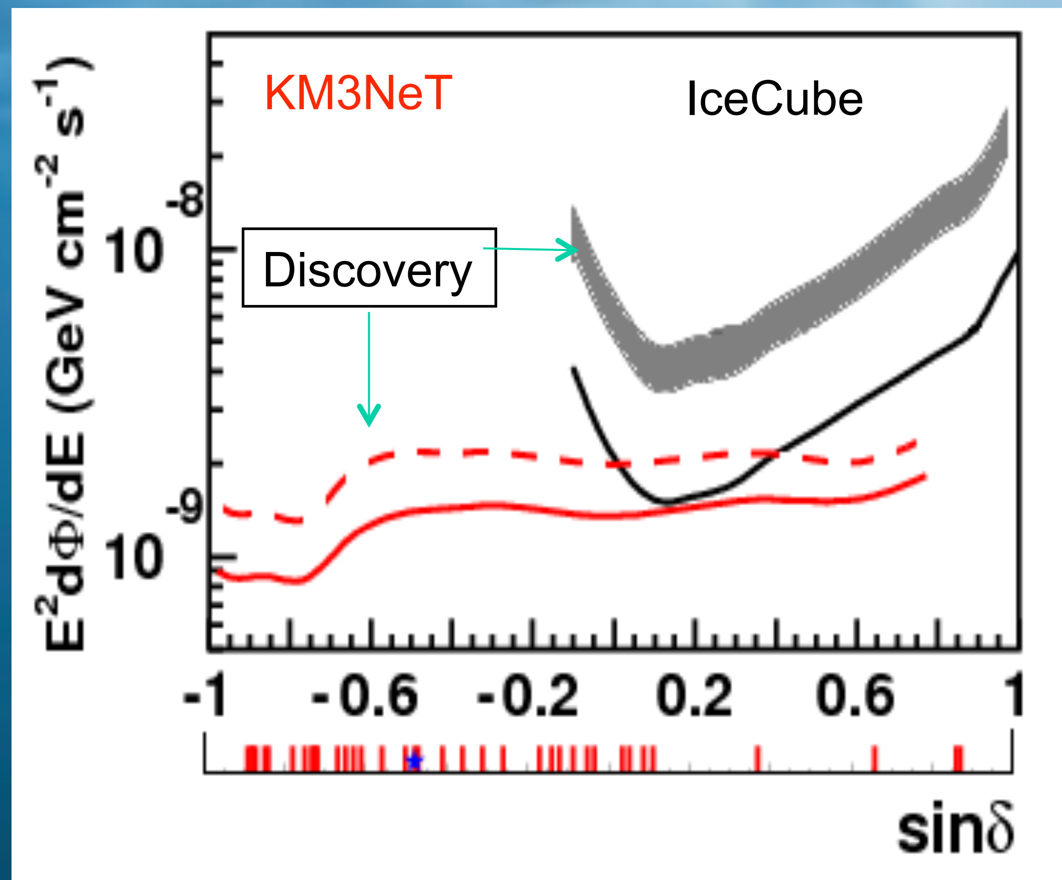
In multi-PMT DOM we see real large photon fluxes with more than one tube.

➢Less sensitive to single tube noise

Point Source Sensitivity

TDR layout: 2 building blocks (160 DUs each), 180m spacing





Further improvement expected from use of energy estimators and unbinned approach

Congratuations IceCube!