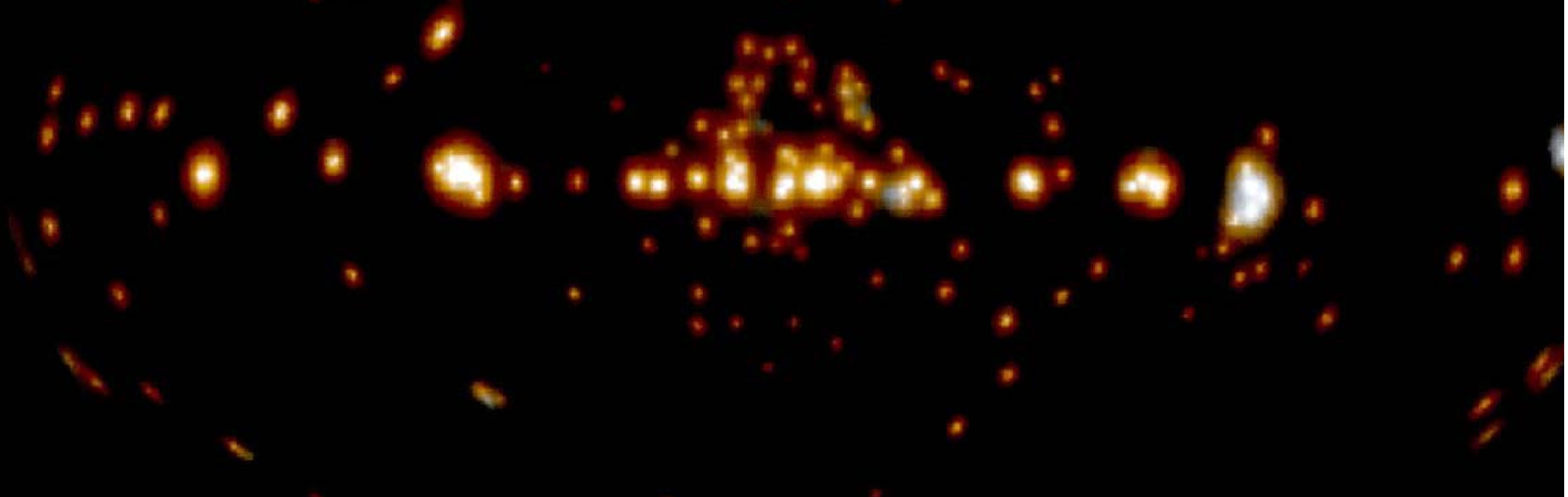
IFAE – Catania 30 Marzo – 2 Aprile 2005

Carla Distefano



Rivelazione di neutrini astrofisici di alta energia

Why neutrino astronomy?

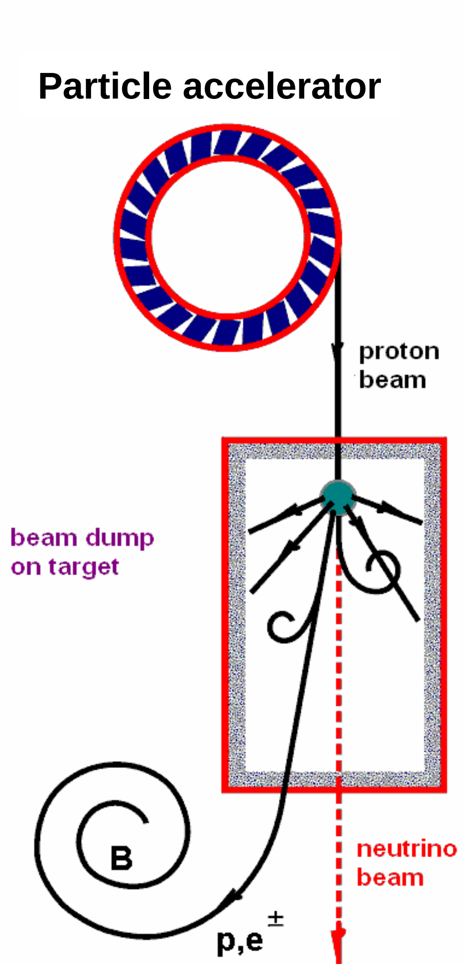
The detection of high energy gammas and CR are milestones in modern astrophysics but there are still open questions:

- Particle acceleration mechanism in astrophysical sources
- Identification of high energy CR sources
- Solution of UHECR puzzle
- Heavy dark matter content in the Universe

- Neutrinos traverse space without being deflected or attenuated
  - They point back to their sources
  - They allow to view into dense environments
- Neutrinos are produced in high energy hadronic processes
  - They can allow distinction between hadronic and leptonic acceleration mechanisms

Neutrino production in cosmic accelerators

Halzen



Proton acceleration

• Fermi mechanism

proton spectrum $dN_p/dE \sim E^{-2}$

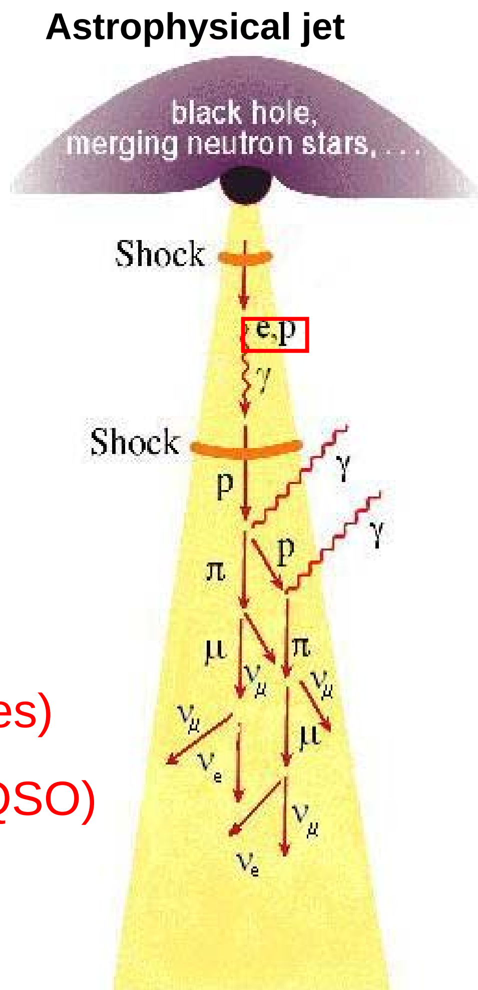
Neutrino production

• Proton interactions

p → p (SNR,X-Ray Binaries)

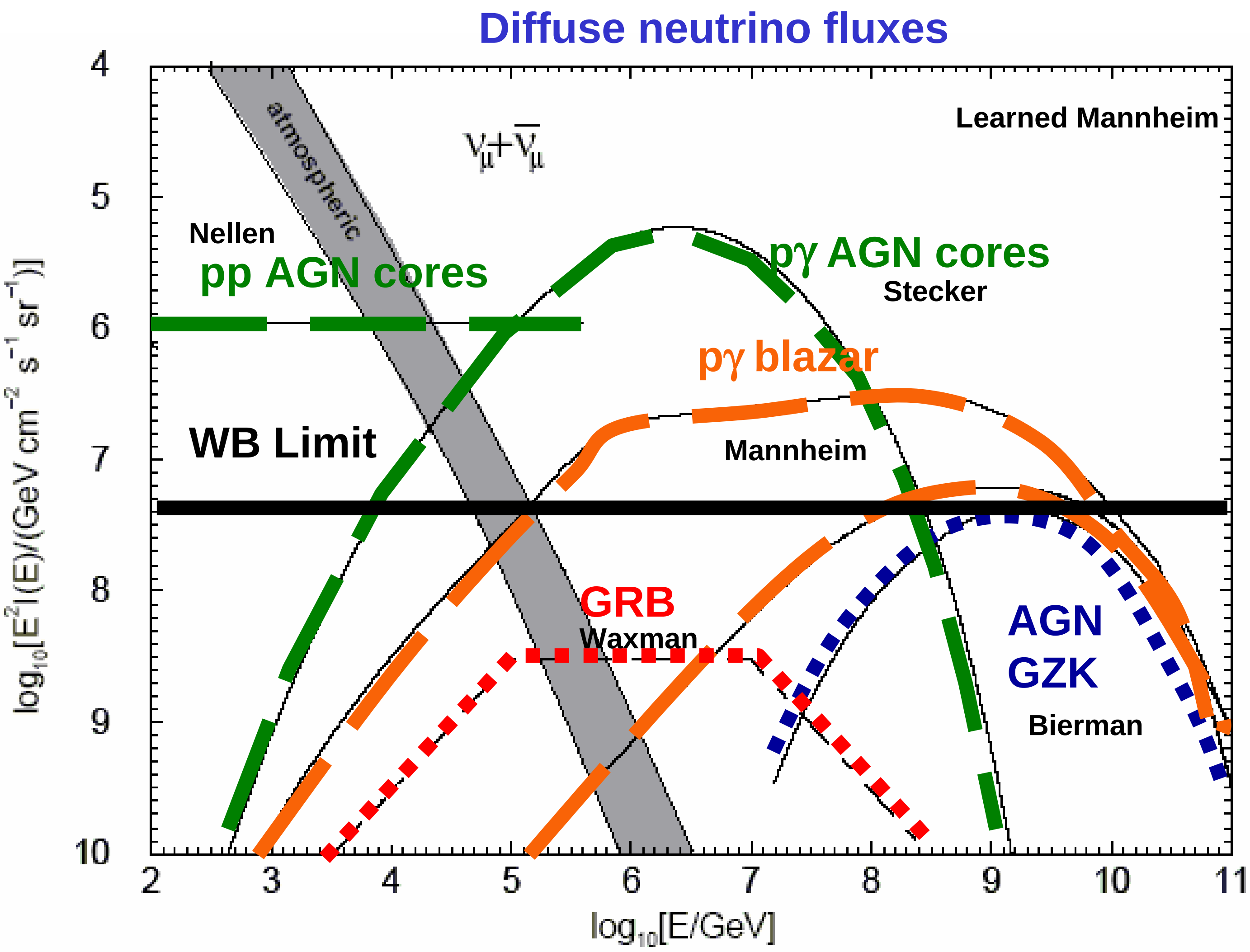
p → γ (AGN, GRB, microQSO)

• decay of pions and muons

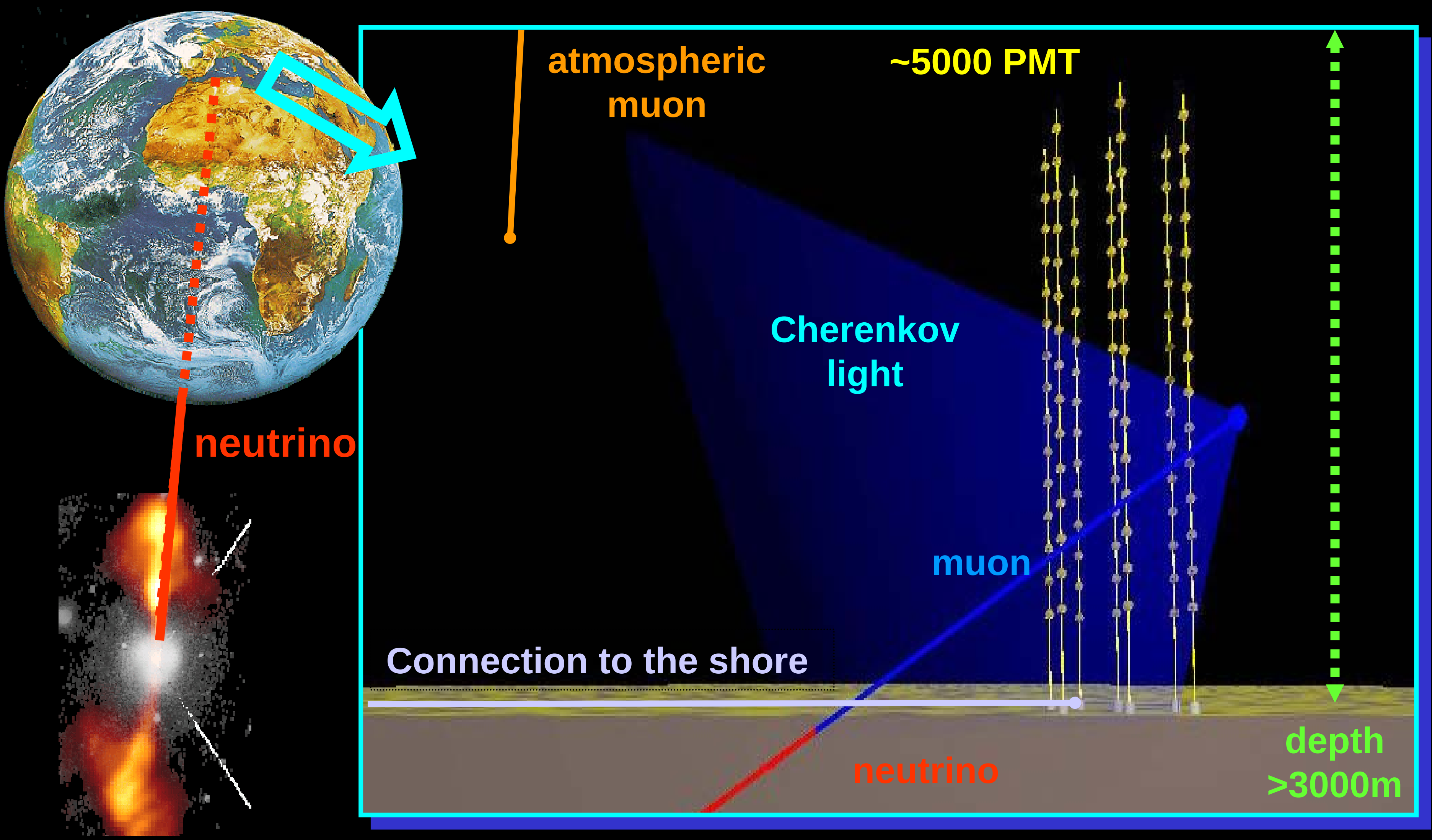


electrons are responsible for gamma fluxes (synchrotron, IC)

Possible extragalactic sources and fluxes



The observation of TeV neutrino fluxes requires km^2 scale detectors



Neutrino telescopes brief history

80's: DUMAND R&D

90's: BAIKAL, AMANDA, NESTOR

2k's: ANTARES, NEMO R&D

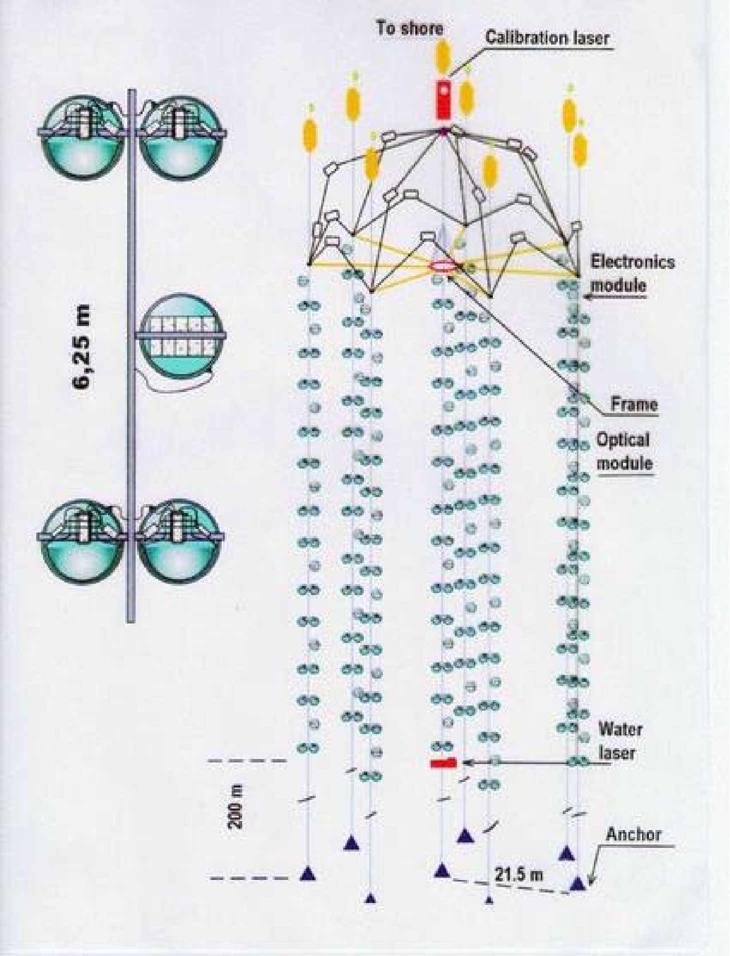
2010: ICECUBE

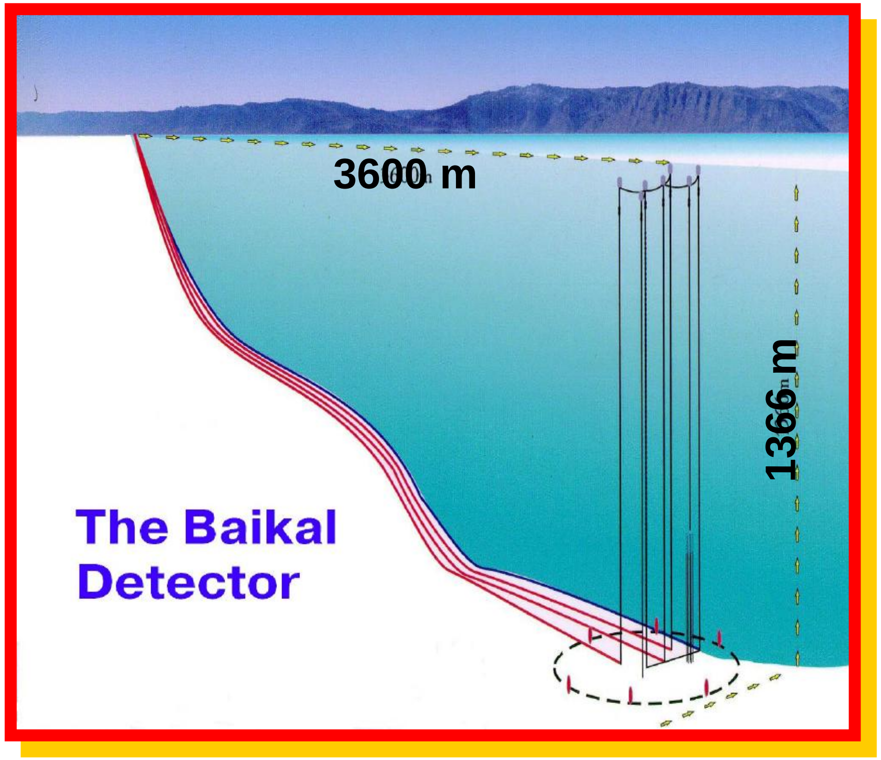
Mediterranean KM3 ...

The pioneer experiment: BAIKAL

Baikal-NT: 192 OM arranged in 8 strings, 72 m height

effective area >2000 m^2 (E_μ>10 GeV)





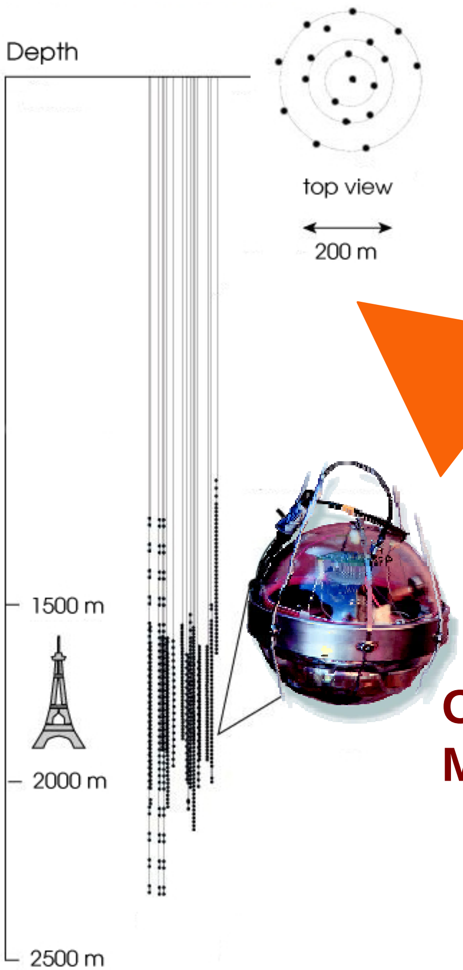
successfully running since 10 years
atmospheric neutrino flux measured

Depth max 1300m

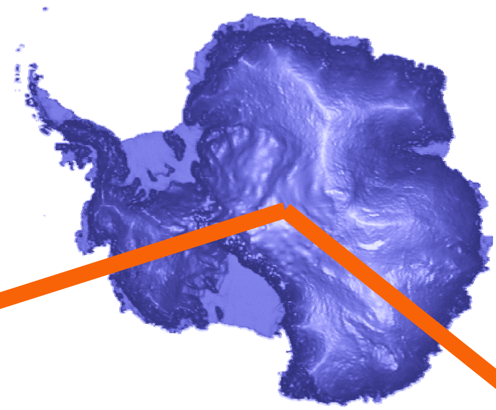
Blue light absorption length ~20 m

No ^{40}K but high bioluminescence rate

The largest detector up to date: AMANDA



AMANDA-II
19 strings
677 OMs
Depth 1500-2000m



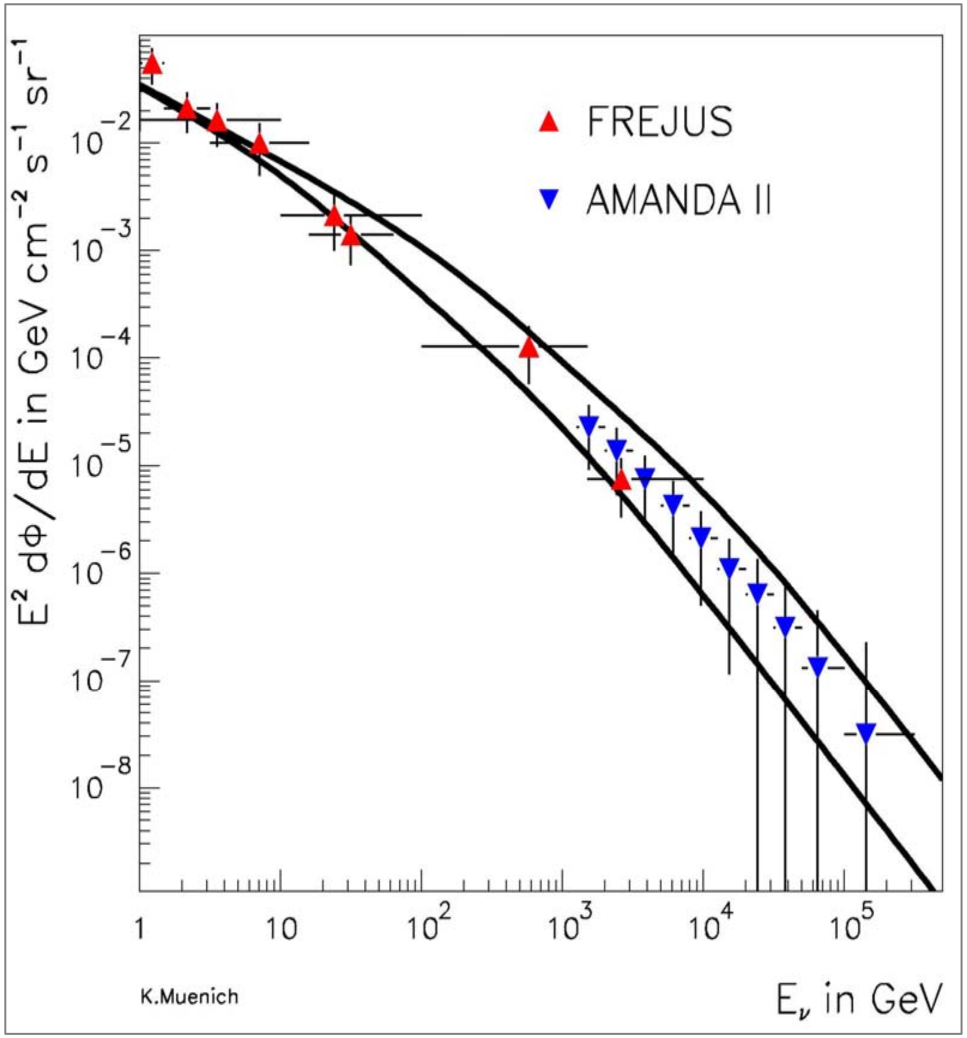
Optical Module

Effective Area ≈ 10^4 m^2 (E_μ ≈ TeV)

Angular resolution ≈ 2°

Results from AMANDA: atmospheric neutrino flux

Atmospheric neutrinos constitute the main background when searching for extraterrestrial neutrinos, but are also a natural calibration source.

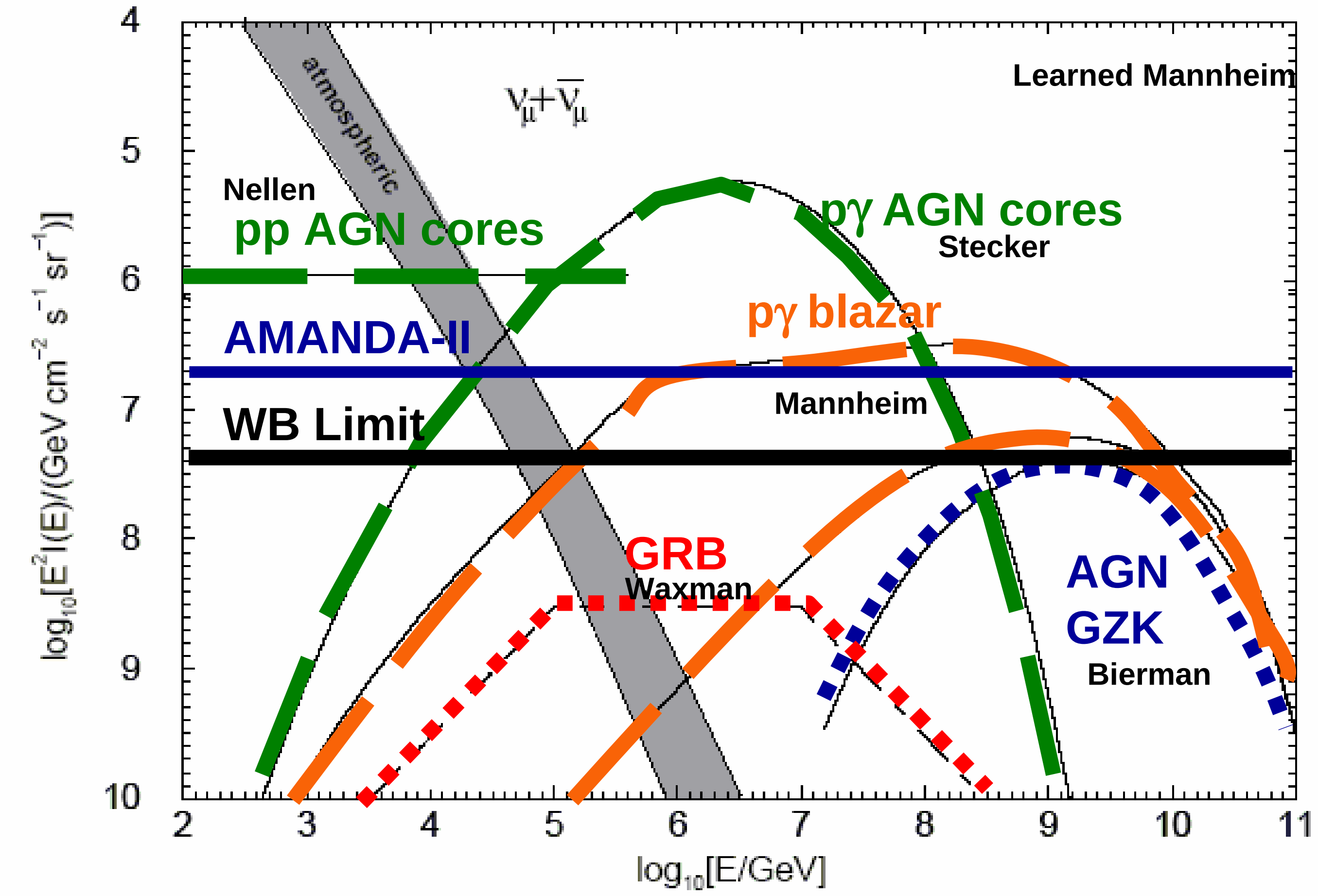


Spiering, astro-ph/0503122

Results from AMANDA: diffuse flux

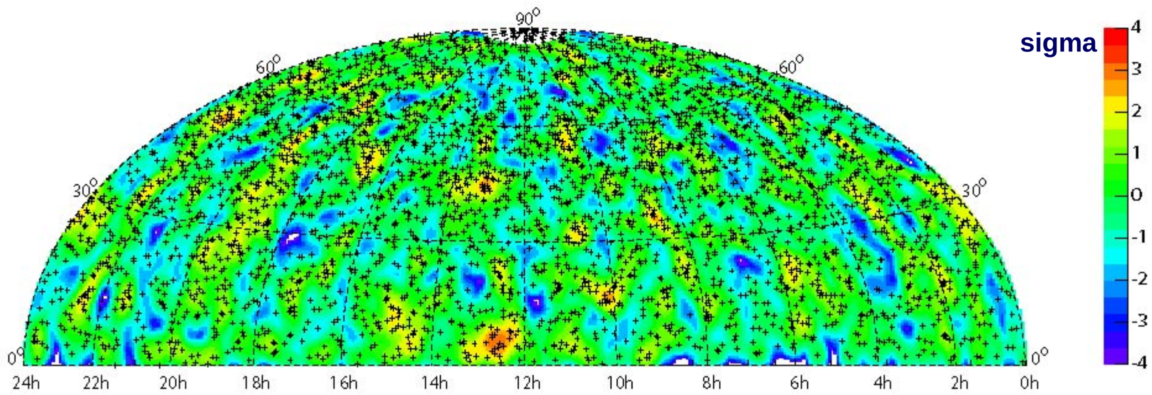
Up-going ν_μ :	$E_\nu^2\varphi_\nu(E_\nu)<2.6\cdot10^{-7}$ GeV/cm² s sr	100 TeV< E_ν<300 TeV
Cascades $\nu_e+\nu_\mu+\nu_\tau$:	$E_\nu^2\varphi_\nu(E_\nu)<8.6\cdot10^{-7}$ GeV/cm² s sr	50 TeV< E_ν<5 PeV
Horizontal UHE $\nu_e+\nu_\mu+\nu_\tau$:	$E_\nu^2\varphi_\nu(E_\nu)<9.9\cdot10^{-7}$ GeV/cm² s sr	1 PeV< E_ν<3 EeV

Spiering, astro-ph/0503122



Results from AMANDA: point-like sources

2000-2003 AMANDA sky plot: 3369 events



No evidence for point-like sources with an E_ν^{-2} energy spectrum based on the first four years of AMANDA-II.

The strongest excess was observed from the direction of the Crab nebula, with 10 events where 5 are expected.

A much larger array like IceCube is necessary.

Spiering, astro-ph/0503122

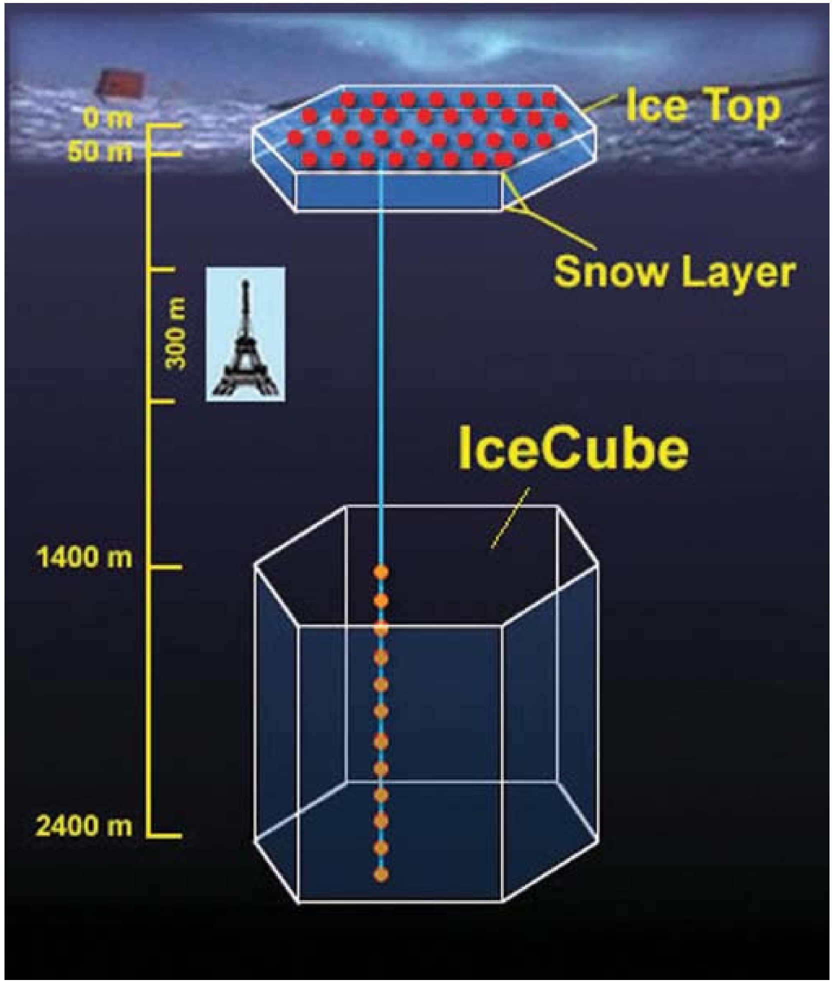
M. Ackermann, et al, 2004, submitted to PRD

Candidate	$\delta(°)$	$\alpha(h)$	n_{obs}	n_b	Φ_ν^{lim}
TeV Blazars					
Markarian 421	38.2	11.07	0	1.35	0.34
Markarian 501	39.8	16.90	3	1.31	1.49
1ES 1426+428	42.7	14.48	2	1.13	1.16
1ES 2344+514	51.7	23.78	1	1.25	0.82
1ES 1959+650	65.1	20.00	0	1.59	0.38
GeV Blazars					
QSO 0528+134	13.4	5.52	1	1.88	0.57
QSO 0235+164	16.6	2.62	3	2.15	1.12
QSO 1611+343	34.4	16.24	0	1.66	0.31
QSO 1633+382	38.2	16.59	1	1.33	0.75
QSO 0219+428	42.9	2.38	0	1.15	0.37
QSO 0954+556	55.0	9.87	2	1.04	1.50
QSO 0716+714	71.3	7.36	3	0.93	1.91
Microquasars					
SS433	5.0	19.20	1	2.21	0.55
GRS 1915+105	10.9	19.25	3	1.84	1.26
GRO J0422+32	32.9	4.36	2	1.49	1.08
Cygnus X1	35.2	19.97	0	1.59	0.31
Cygnus X3	41.0	20.54	1	1.26	0.75
XTE J1118+480	48.0	11.30	1	1.12	0.80
CI Cam	56.0	4.33	2	1.05	1.44
LS I +61 303	61.2	2.68	5	1.67	2.43
SNR, magnetars & miscellaneous					
SGR 1900+14	9.3	19.12	2	1.78	0.94
Crab Nebula	22.0	5.58	4	1.86	1.43
Cassiopeia A	58.8	23.39	2	1.12	1.38
3EG J0450+1105	11.4	4.82	1	1.83	0.59
M 87	12.4	12.51	3	1.83	1.24
Geminga	17.9	6.57	2	2.06	0.81
UHE CR Triplet	20.4	1.28	0	2.15	0.20
NGC 1275	41.5	3.33	1	1.14	0.78
Cyg. OB2 region.	41.5	20.54	1	1.14	0.78
UHE CR Triplet	56.9	12.32	1	1.17	0.93

ϕ_γ^{lim} in 10^{-8} cm^{-2} s^{-1}, E_ν>10 GeV, α=2

The future of underice neutrino telescope: ICECUBE

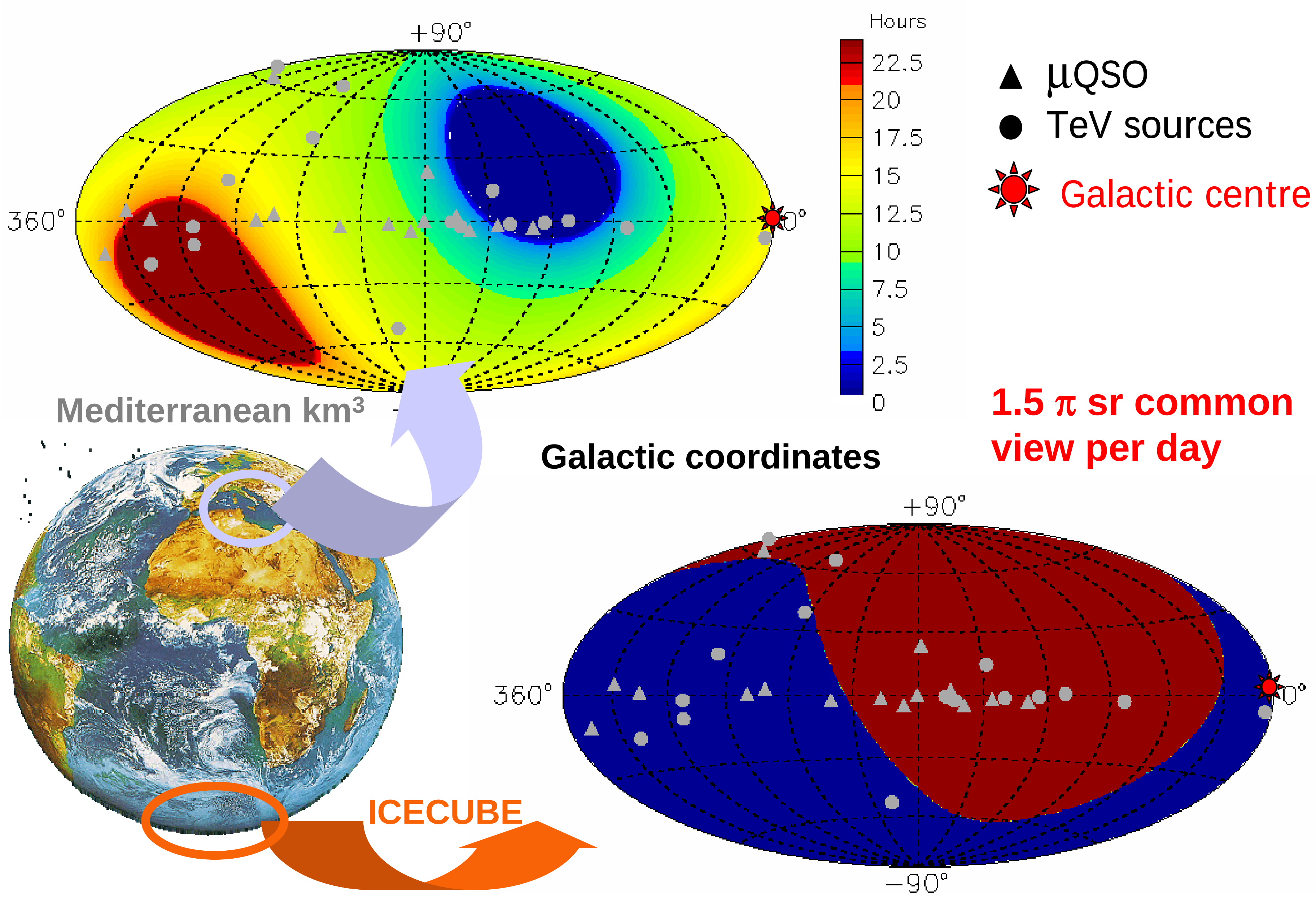
The technology for underice detectors is well established.
The next step is the construction of the km3 detector ICECUBE.



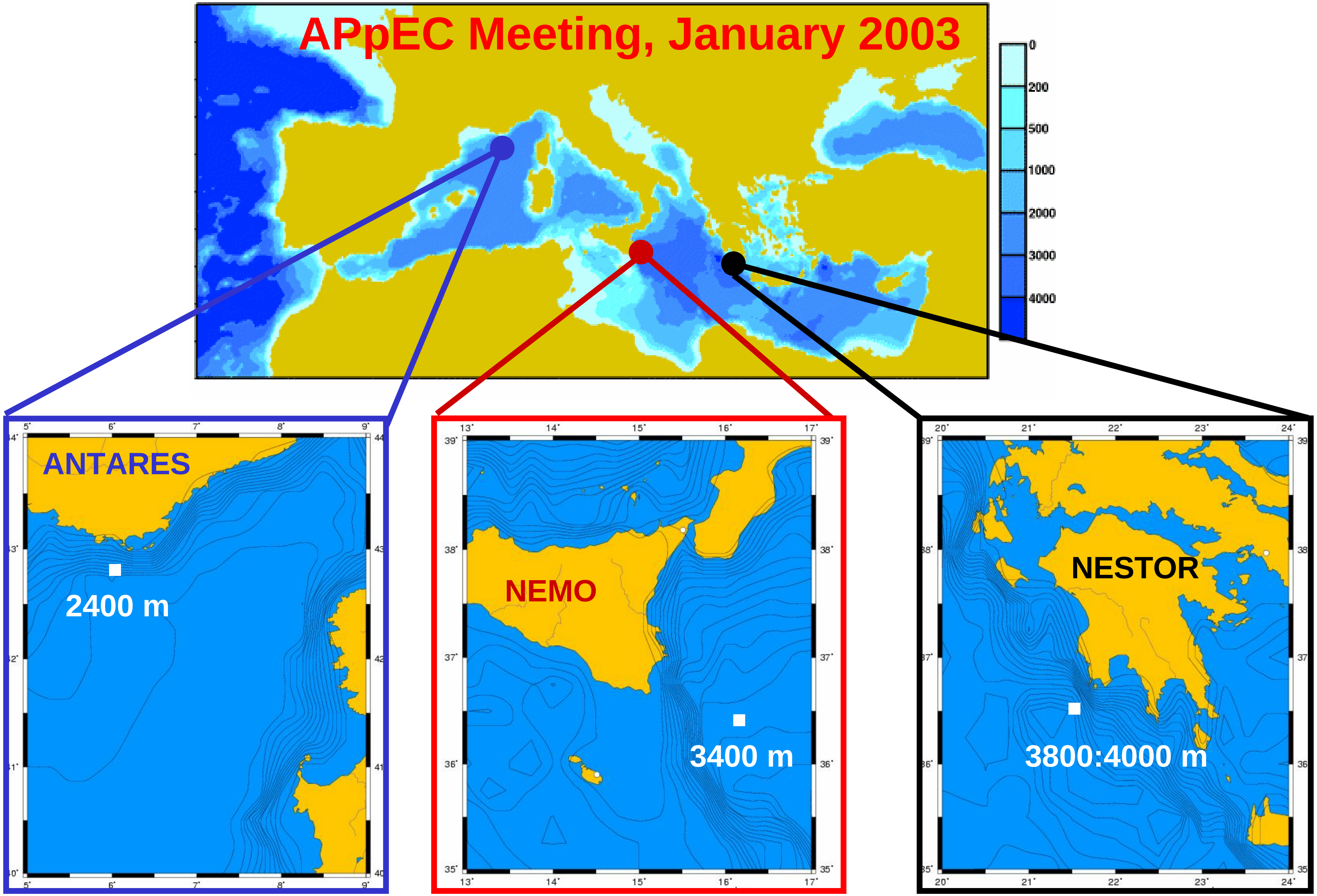
80 strings (60 PMT each)
4800 10" PMT (only downward looking)
125 m inter string distance
16 m spacing along a string
Instrumented volume: 1 km^3 (1 Gton)
First string deployed Jan 2005

IceCube will be able to identify
μ tracks from ν_μ for $E_\nu > 10^{11}$ eV
cascades from ν_e for $E_\nu > 10^{13}$ eV
ν_τ for $E_\nu > 10^{15}$ eV

Observation time for up-going neutrino events

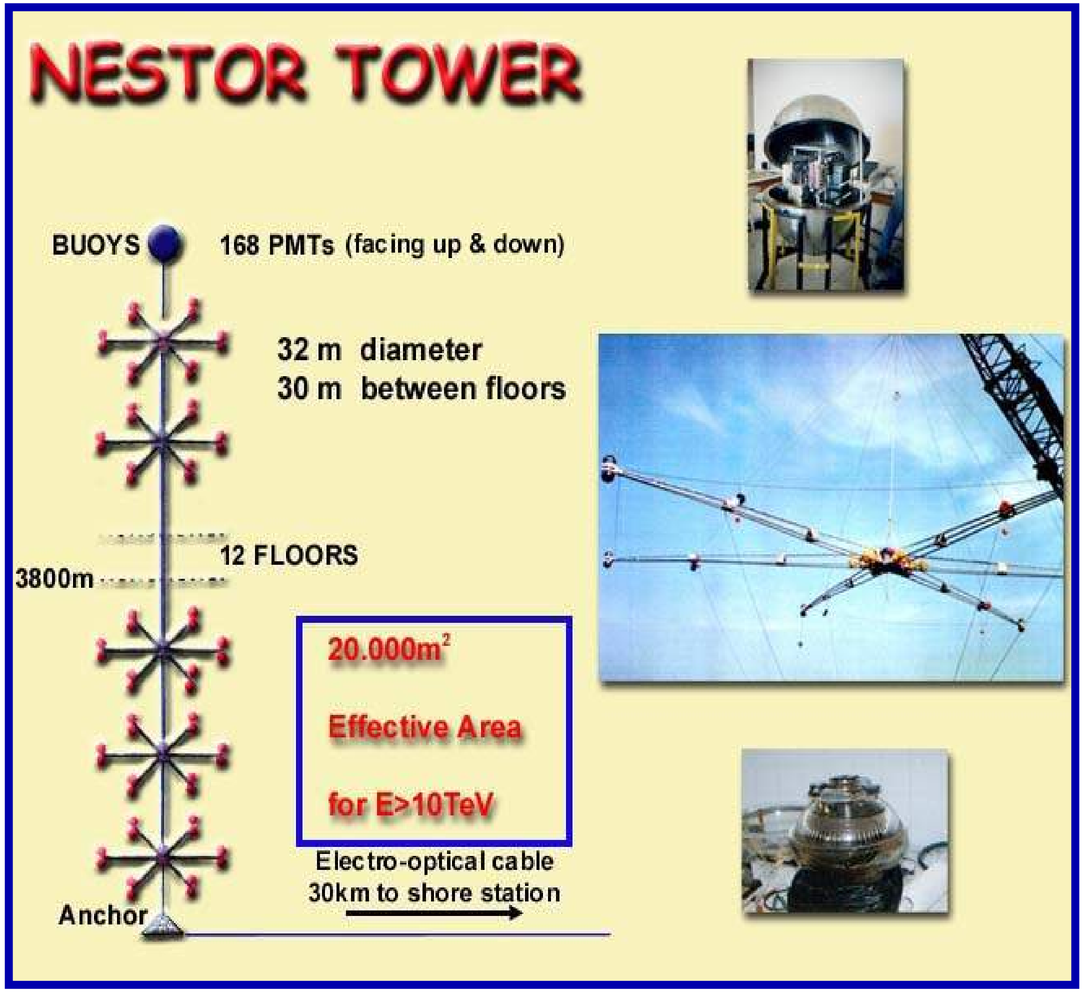


Candidate sites for the km^3

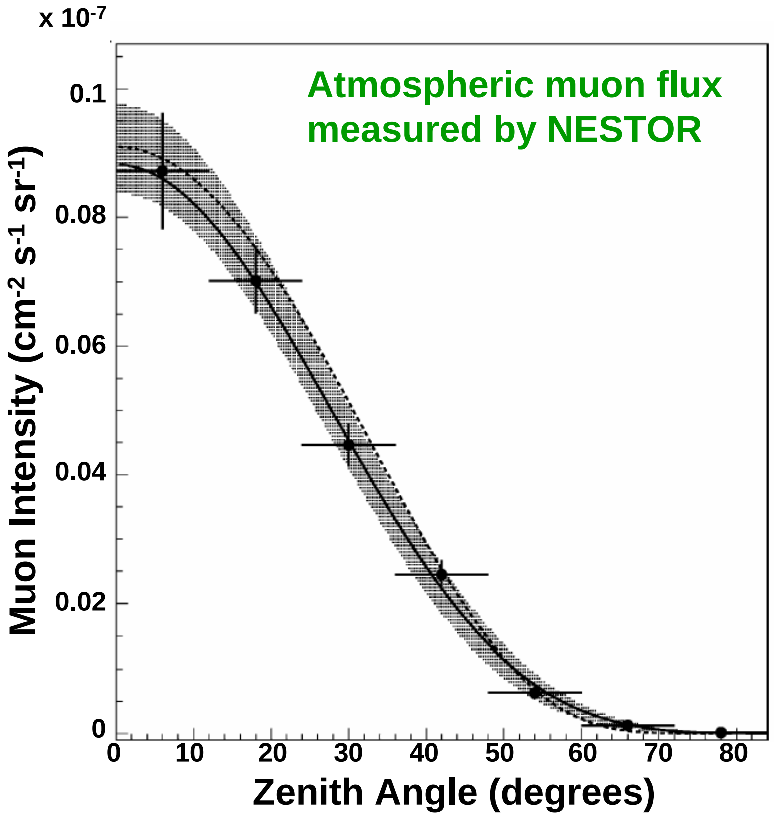


NESTOR

NESTOR aims at installing a "tower" equipped with optical modules of ≈ 20.000 m² detection area.

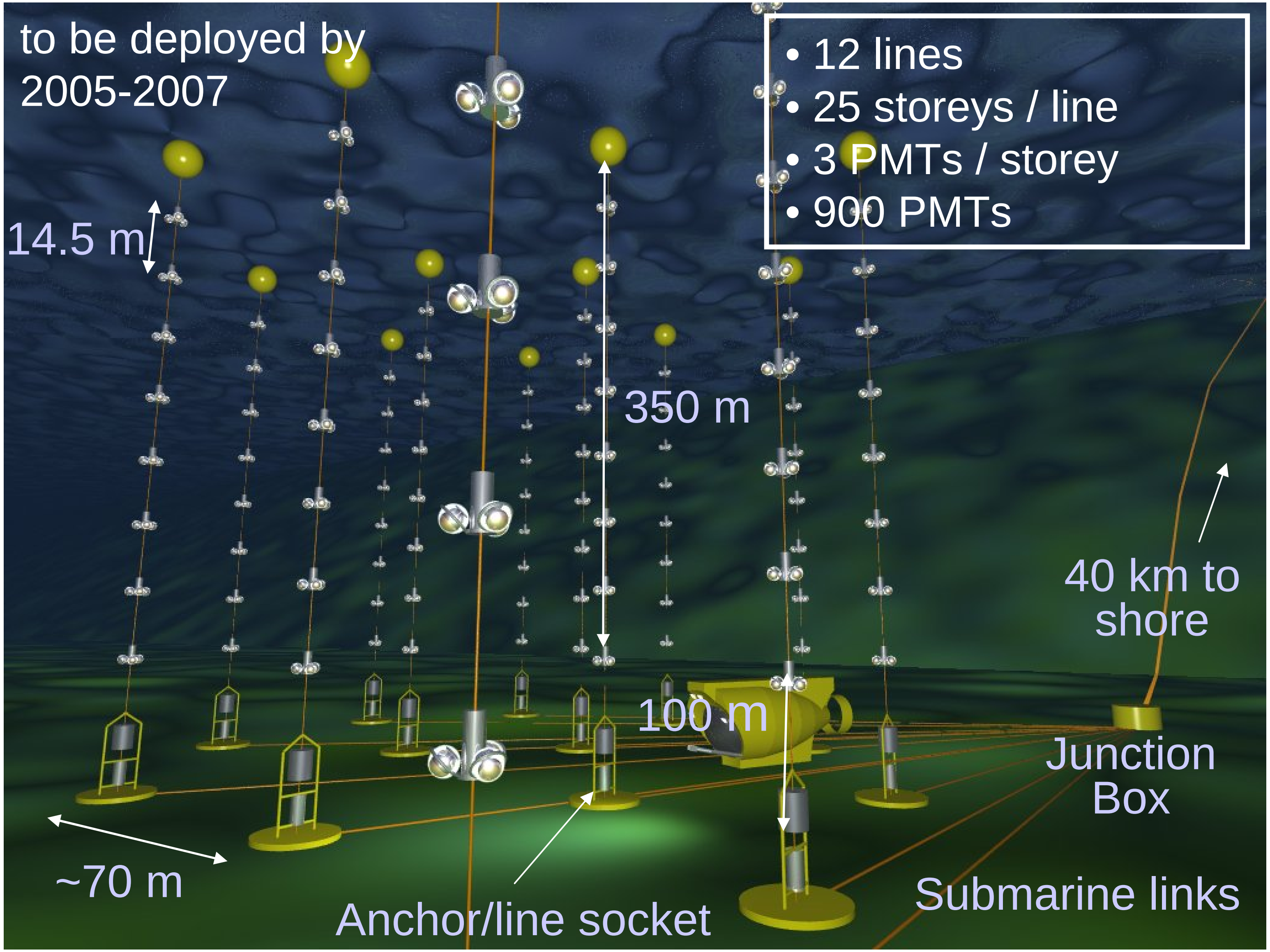


1 floor of 12 m diameter equipped with 12 PMTs deployed at 3800 m depth in March 2003



745 atmospheric muon events reconstructed

ANTARES is installing a 0.1 km^2 demonstrator detector close to Toulon

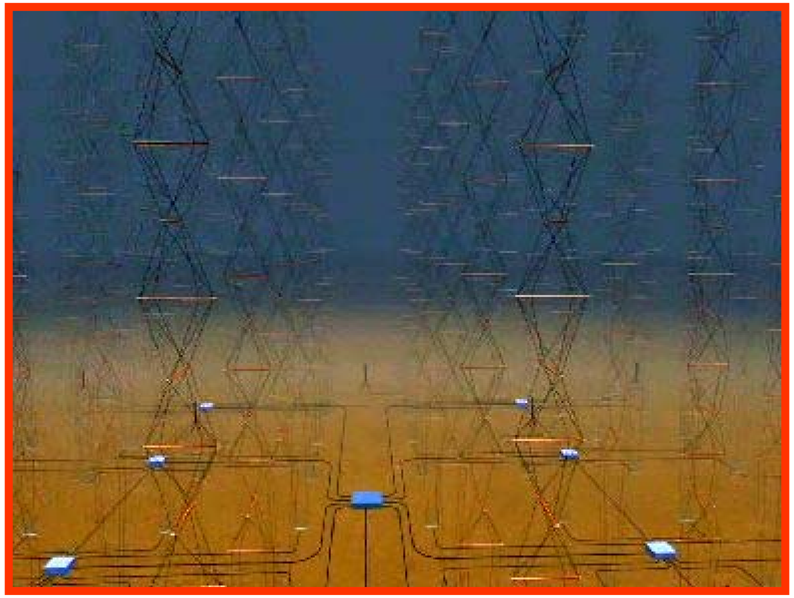


ANTARES deployed Line0 and Milom, underwater connection Apr. 2005.

NEMO

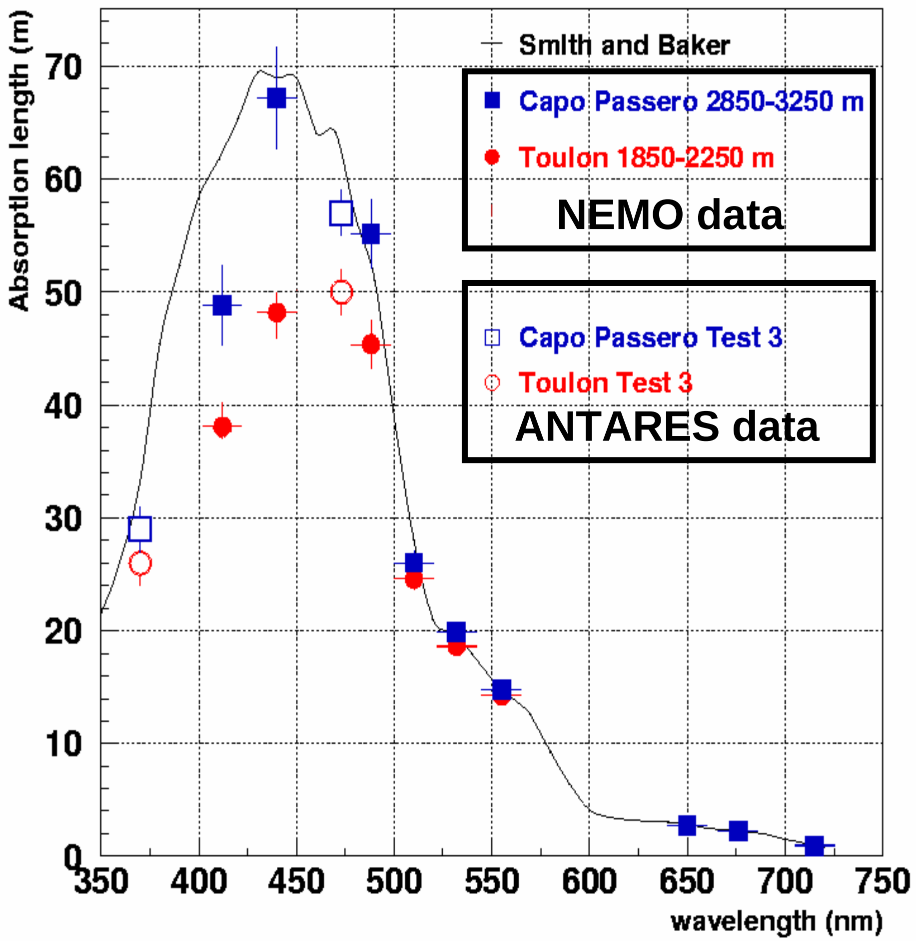
The NEMO Collaboration is dedicating a special effort in:

- **search, characterization and monitoring of a deep sea site adequate for the installation of the Mediterranean km^3;**
- **development of technologies for the km^3 (technical solutions chosen by small scale demonstrators are not directly scalable to a km^3).**



Seawater optical properties in Toulon and Capo Passero

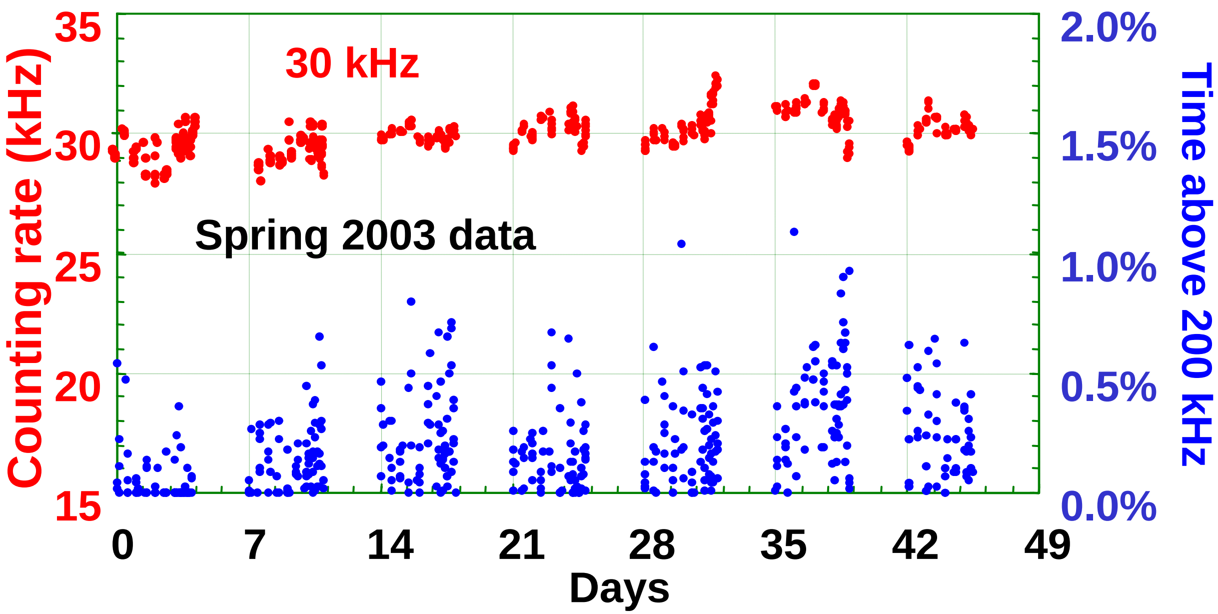
Optical properties have been measured in joint ANTARES-NEMO campaigns in Toulon and in Capo Passero (July-August 2002)

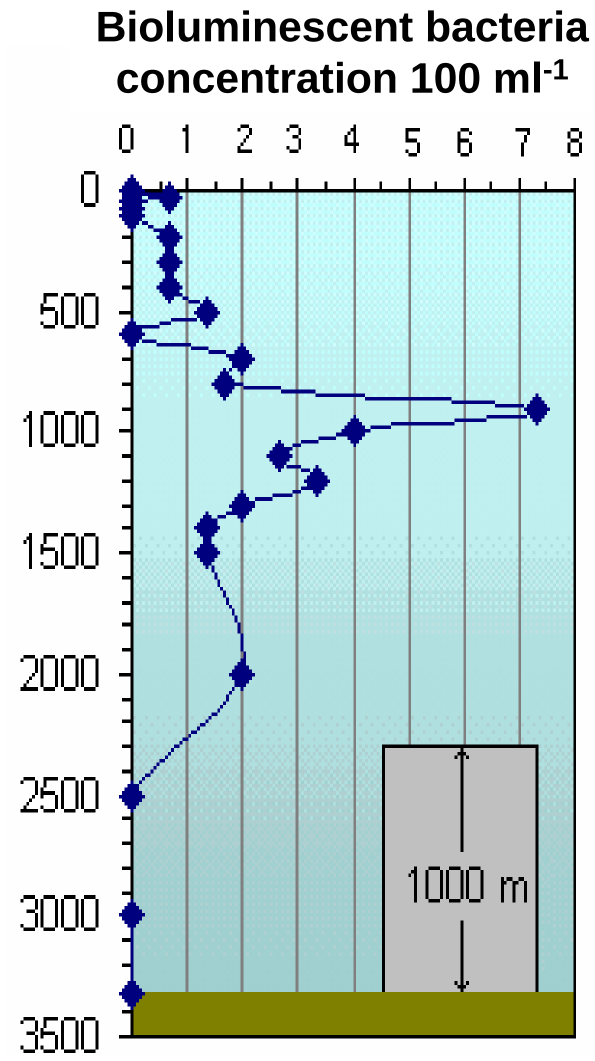


- **Absorption lengths measured in Capo Passero are close to the optically pure sea water data**
- **Differences between Toulon and Capo Passero are observed for the blue light absorption**

Capo Passero: Optical background

Optical background was measured in Capo Passero with different devices. Data are consistent with 30 kHz background on 10” PMT at 0.3 spe (mainly ^{40}K decay, very few bioluminescence).

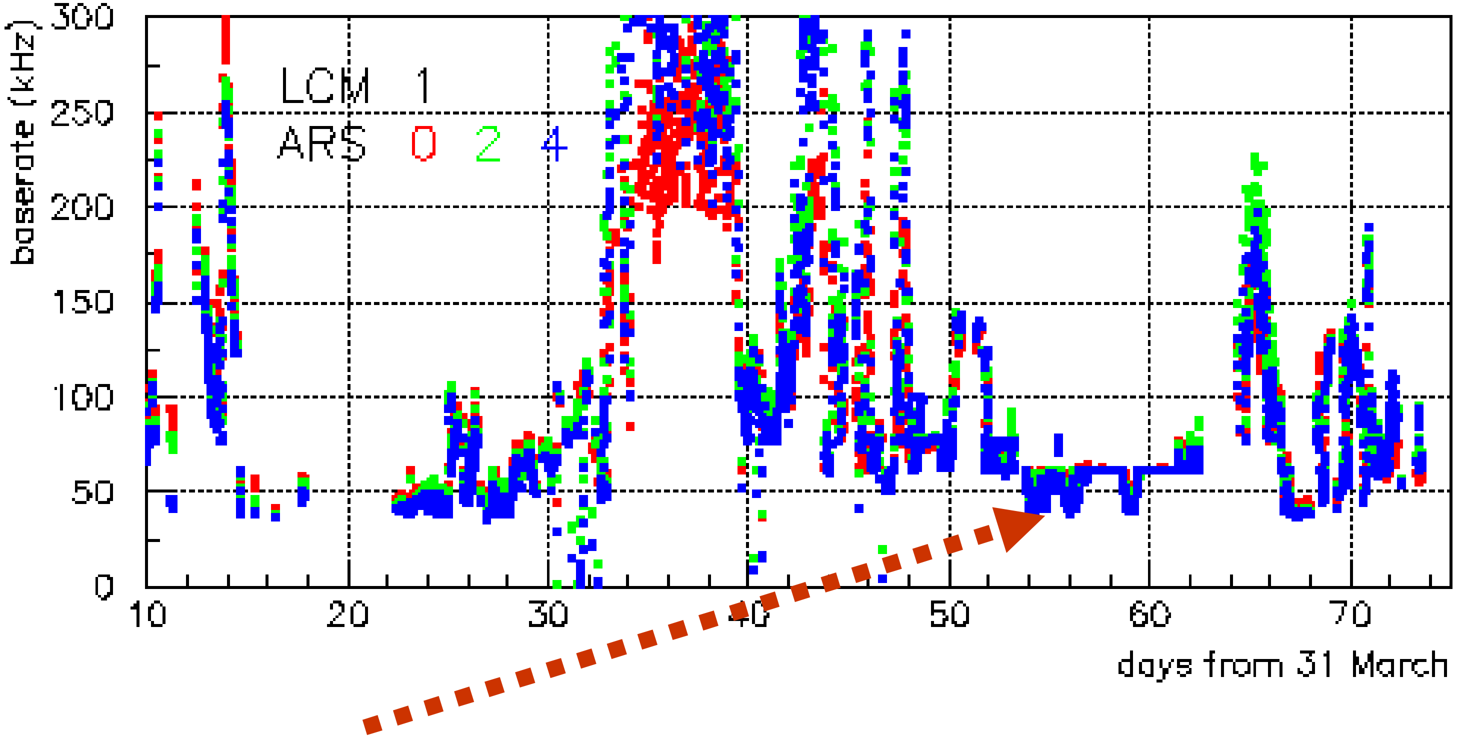




Optical data are consistent with biological measurements:
No luminescent bacteria have been observed in Capo Passero below 2500 m

Toulon: Optical background measured by prototype line

Baseline rate: median of rate in 15 min for 65 days



Quiet phases (10 days): 60 kHz

Capo Passero site characteristics

- **Light absorption lengths (~70 m @ 440 nm) are compatible with optically pure sea water values. Measured values of optical properties are constant through the years (important: variations on L_a and L_c will directly change the detector effective area)**
- **Optical background is low (consistent with ^{40}K background with only rare occurrences of bioluminescence bursts)**
- **The site location is good (close to the coast, flat seabed for hundreds km^2, far from the shelf break and from canyons, far from important rivers)**
- **Measured currents are low and regular (2-3 cm/s average; peak value <12 cm/s)**
- **The Sedimentation rate is low (about 60 mg m^{-2} day^{-1})**
- **No evidence of recent violent events from core analysis (last 60000 years ago)**

Present proposal for Detector Layout

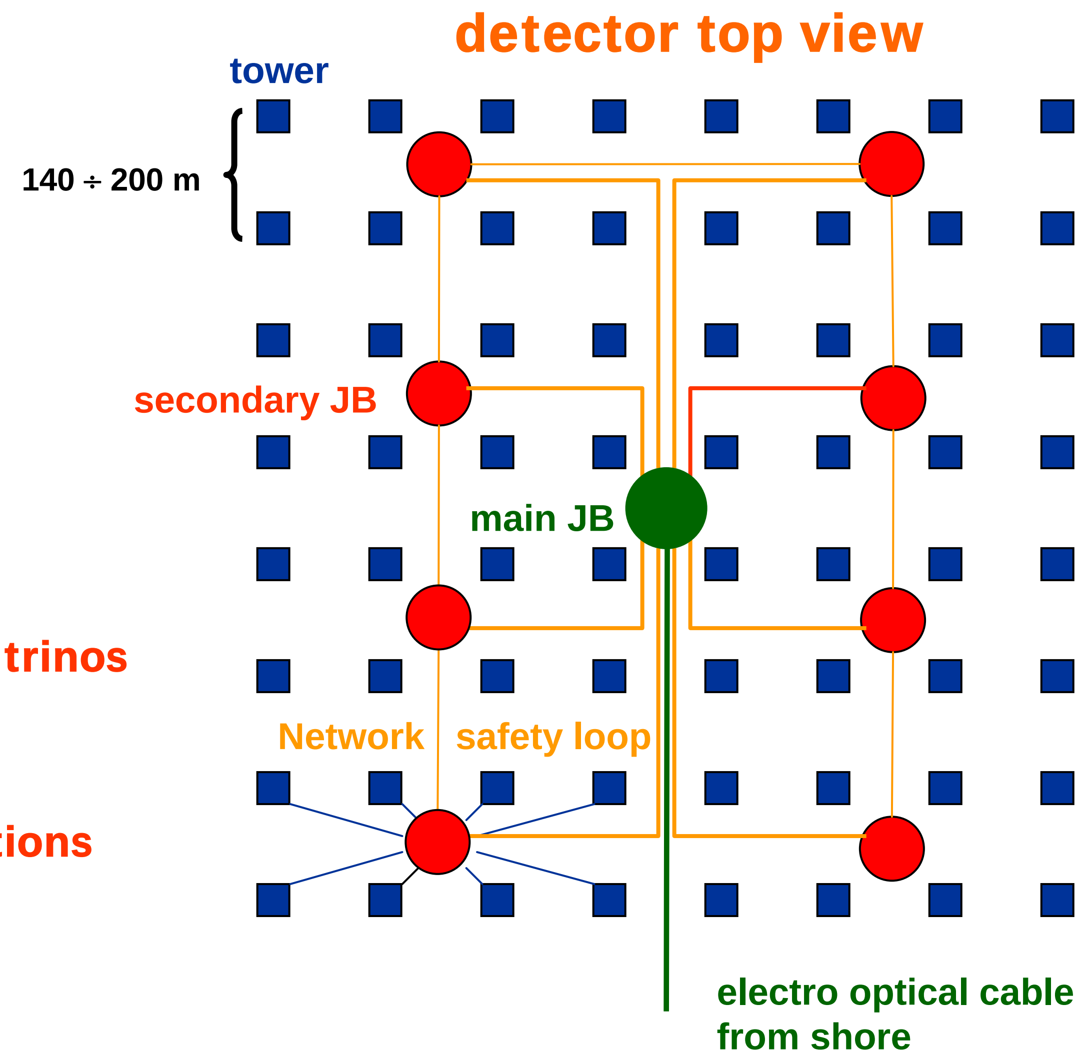
- 1 main Junction Box
- 8 ÷ 10 secondary Junction Boxes
- 60 ÷ 80 towers
- 140 ÷ 200 m between each tower
- 16 ÷ 18 floors for each tower
- 64 ÷ 72 PMT for each tower
- 4000 ÷ 6000 PMTs

The tower geometry allows:

good sensitivity to 100 GeV neutrinos

A_{eff} > 1 km^2 at E_ν ~10 TeV

feasibility of underwater operations



Several layouts under study

Changes: distances, number of towers, tower length, shape (hexagonal), ...

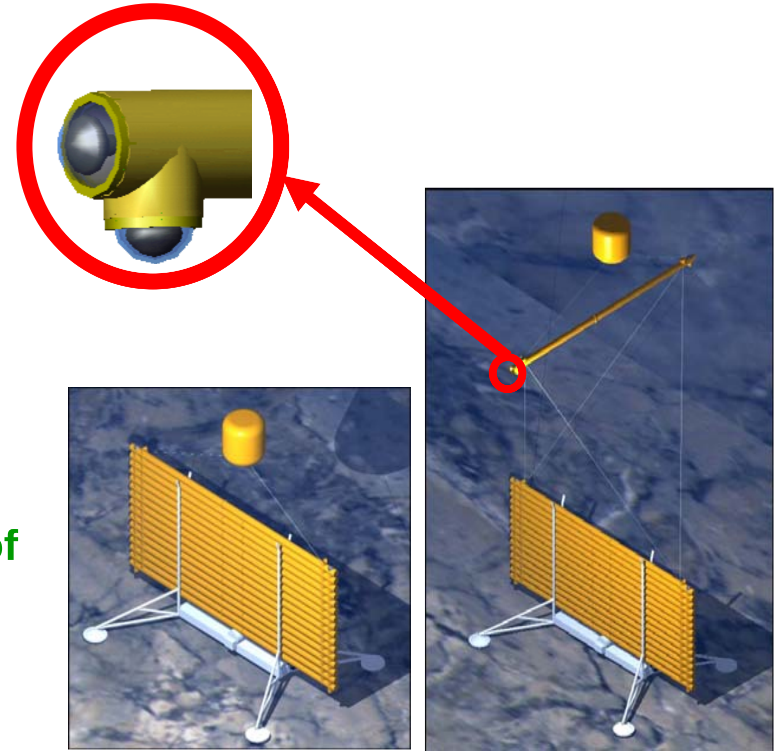
The NEMO tower

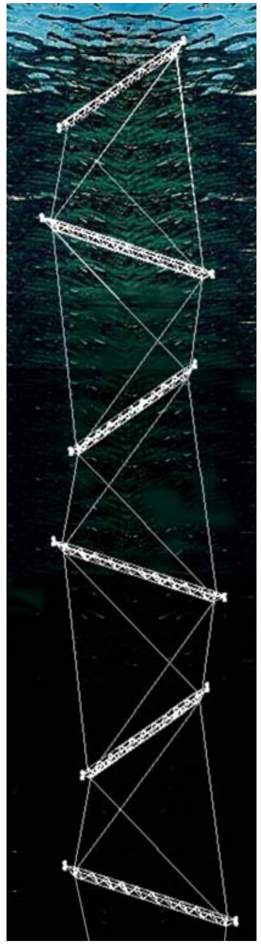
The NEMO tower is a semi-rigid 3D structure designed to allow easy deployment and recovery. High local PMT density is designed to perform local trigger.

Height:	
compacted	15:20 m
total	750 m
instrumented	600 m
n. beams	16 to 20
n. PMT	64 to 80

Beams:	
length	20m
spacing	40 m

A 1:5 scale model of the tower – 4 floors tested in shallow water (April 2004)

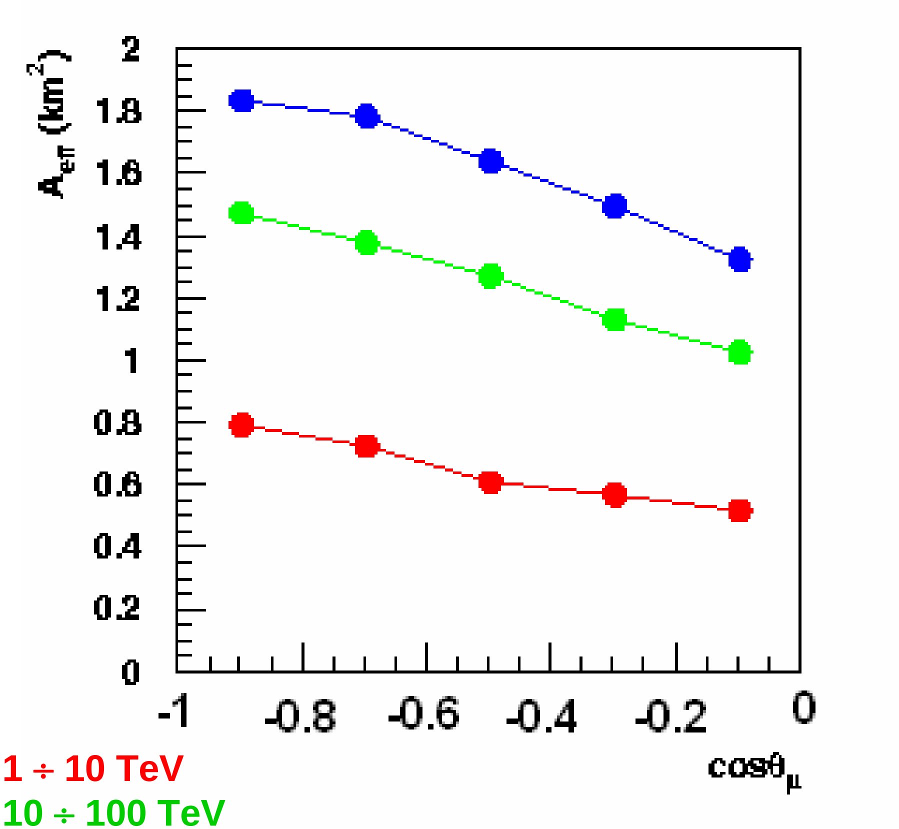


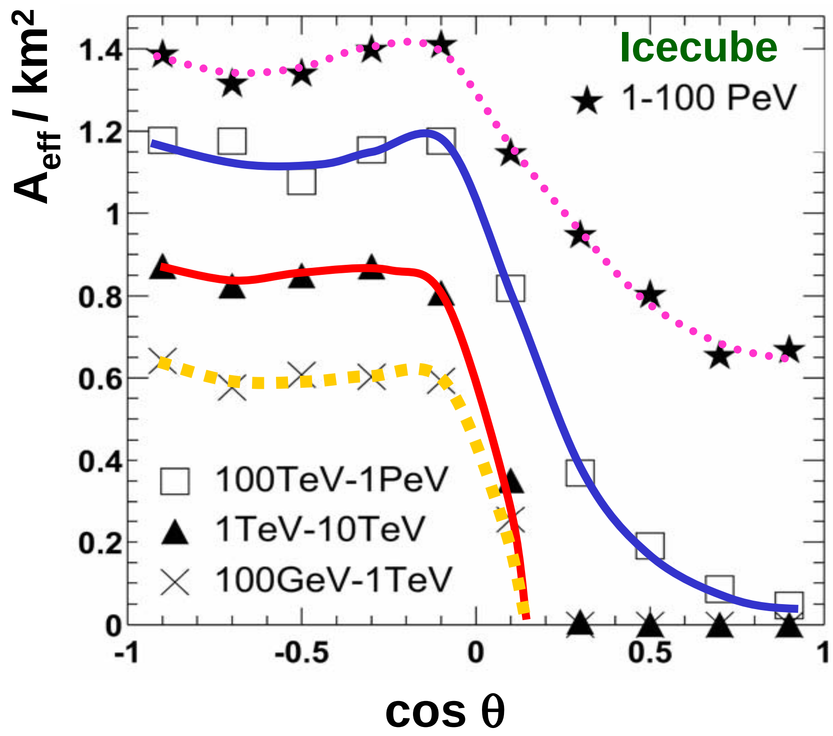


Comparison "tower detector" in Mediterranean vs IceCube

81 towers arranged in 9x9 lattice
140 m between towers
for a total of 5832 PMTs
optical background 30 kHz
optical properties of Capo Passero

80 strings (60 PMT each)
4800 10" PMT (only downward looking)
125 m inter string distance
16 m spacing along a string





1 ÷ 10 TeV
10 ÷ 100 TeV
100 ÷ 1000 TeV

Simulations of NEMO detector performed with the ANTARES simulation package

Comparison "tower detector" in Mediterranean vs IceCube

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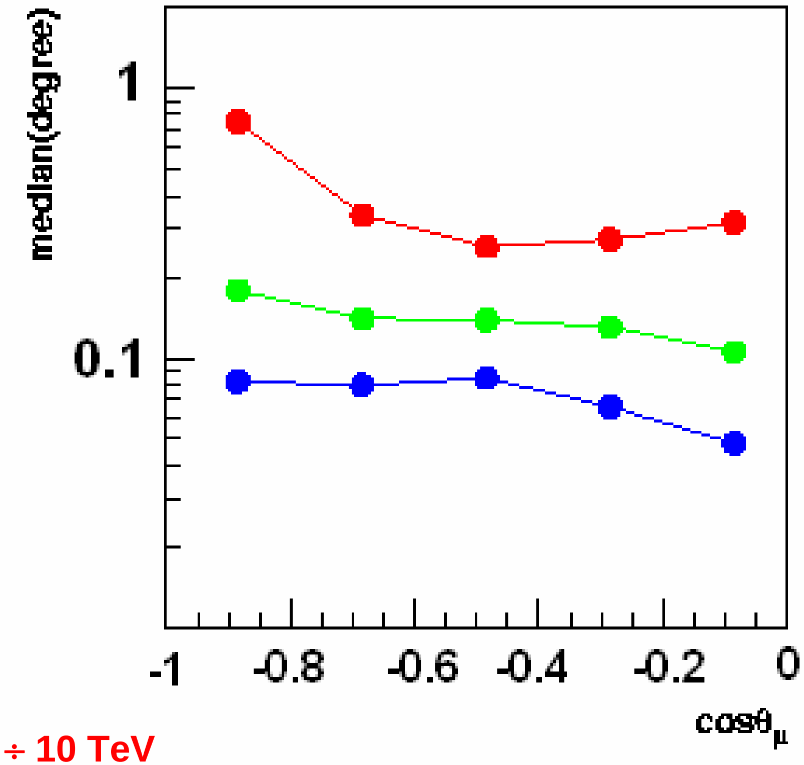
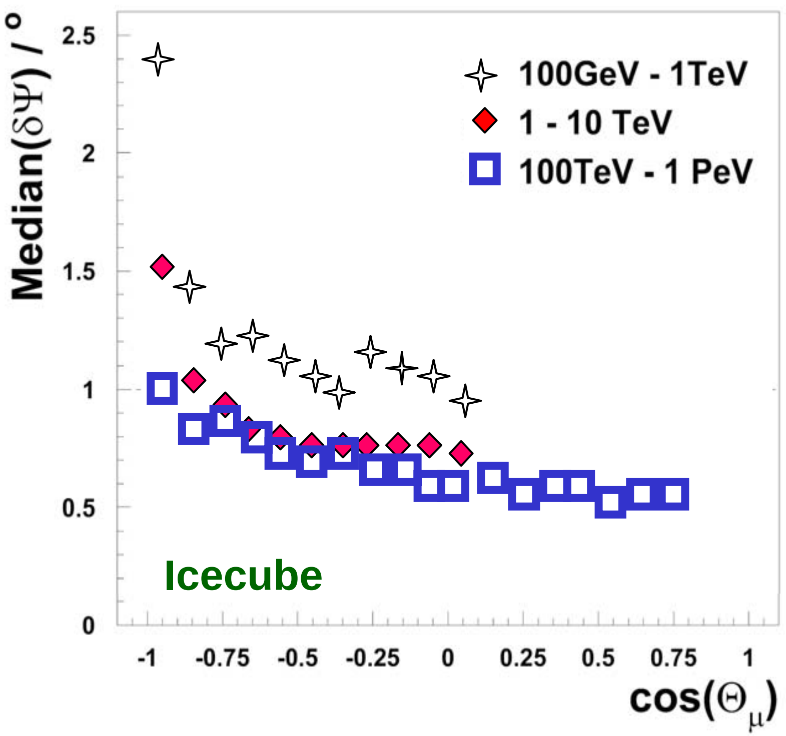


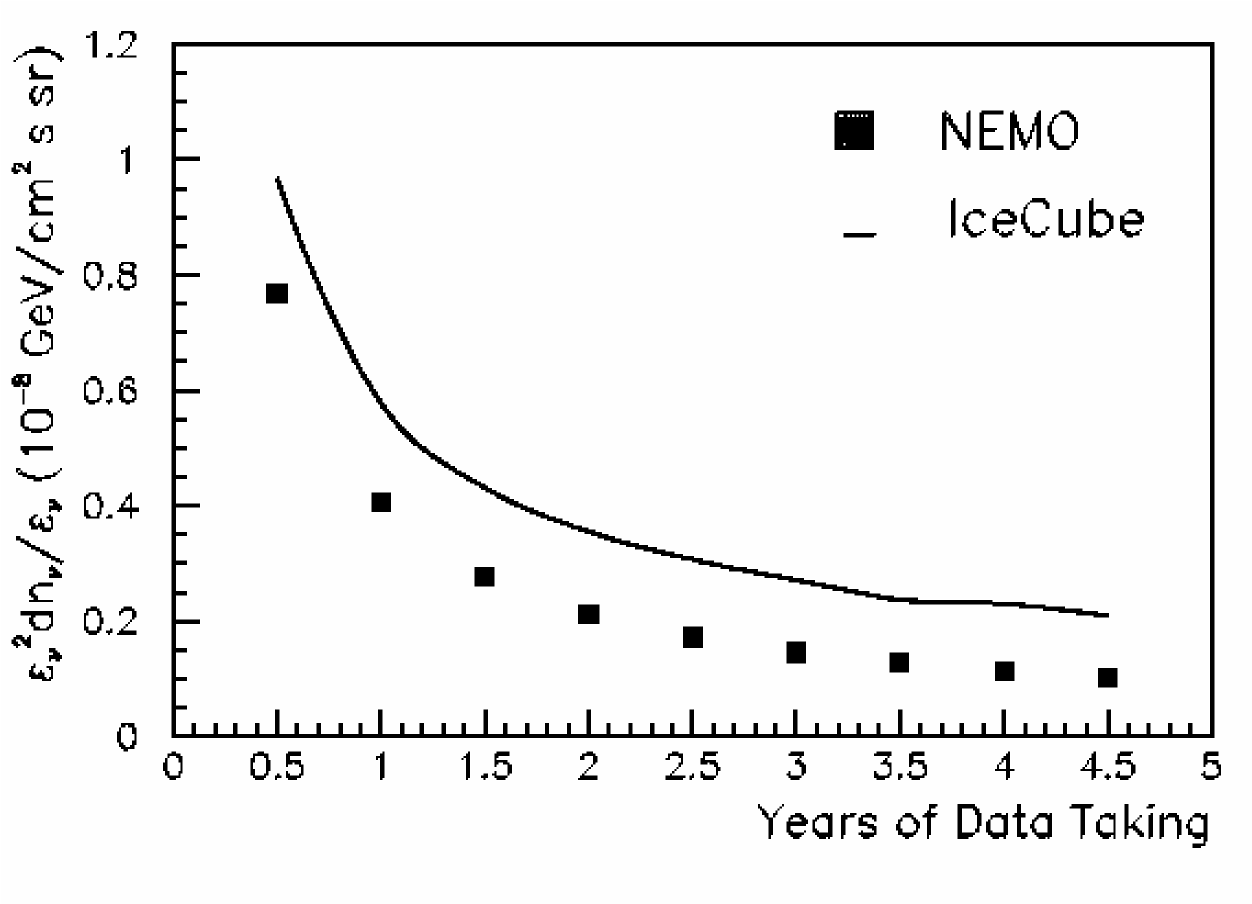
1 ÷ 10 TeV
10 ÷ 100 TeV
100 ÷ 1000 TeV



Simulations of NEMO detector performed with the ANTARES simulation package

Comparison "tower detector" in Mediterranean vs IceCube

Preliminary results for the NEMO sensitivity to a E_ν^{-2} neutrino spectrum from a point-like source.



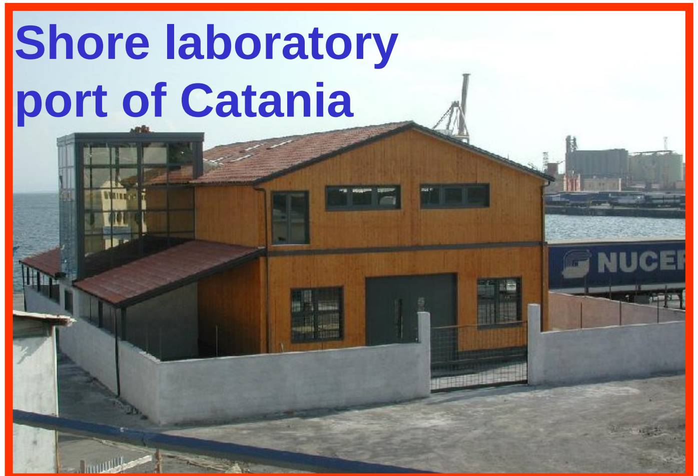
Search bin:

NEMO 0.3°

IceCube 1°

The NEMO test site in Catania

Shore laboratory
port of Catania

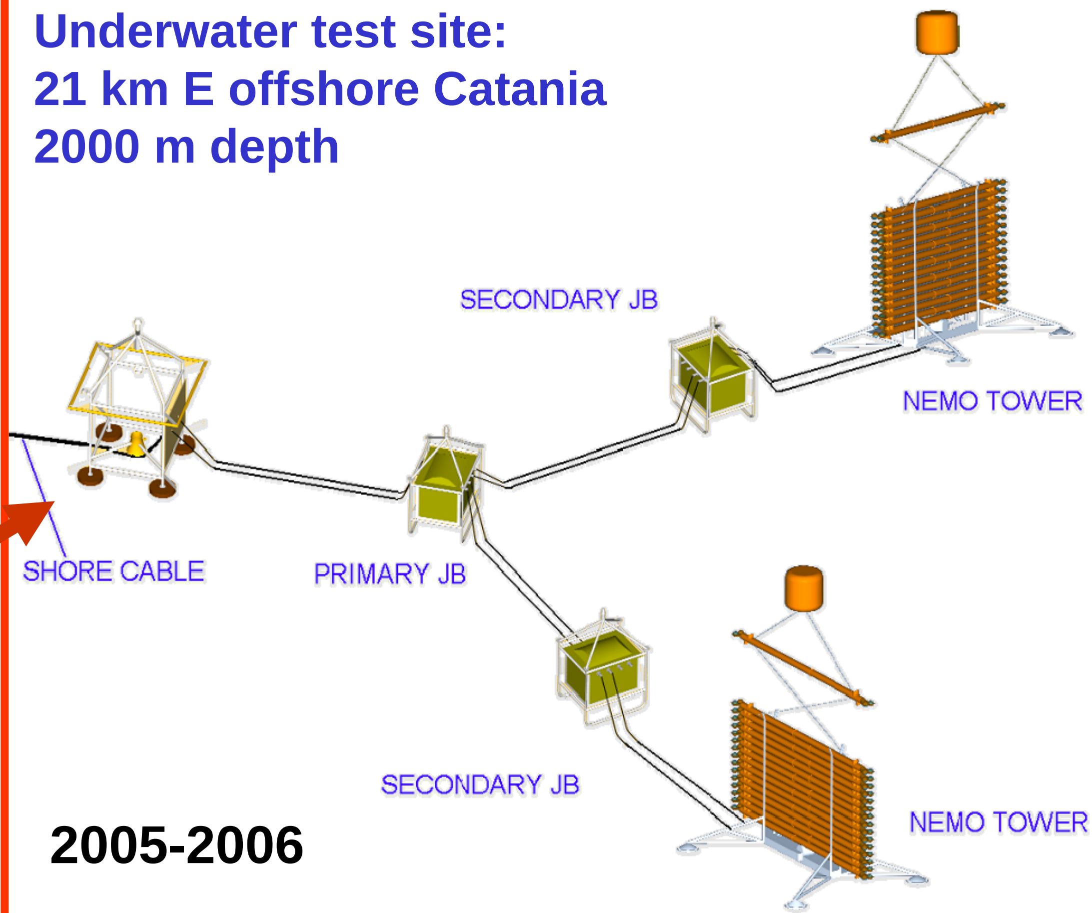


A fully equipped facility to test and develop technologies for the Mediterranean km^3

cable:
10 OF; 6 conductors

22 Jan 2005

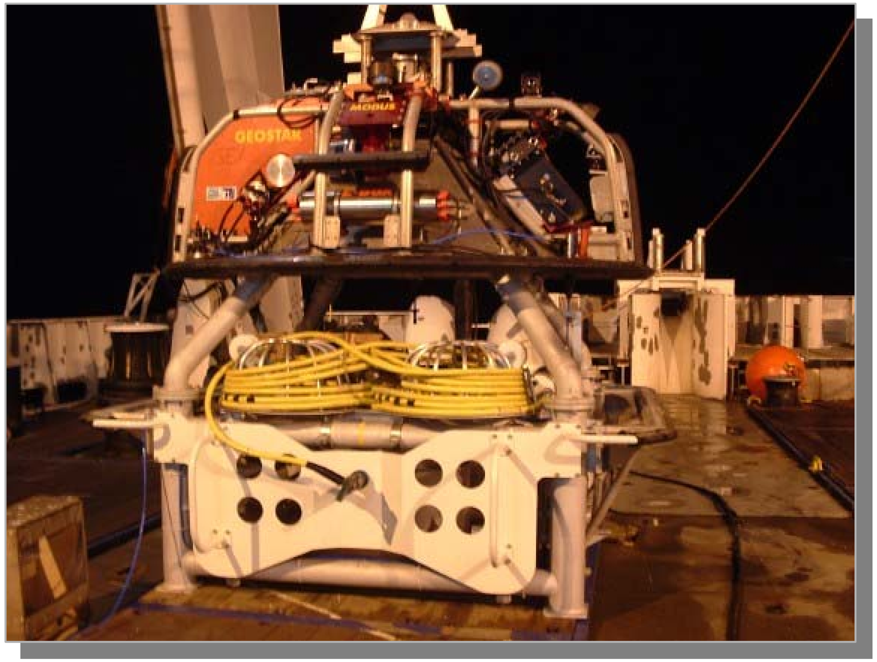
Underwater test site:
21 km E offshore Catania
2000 m depth



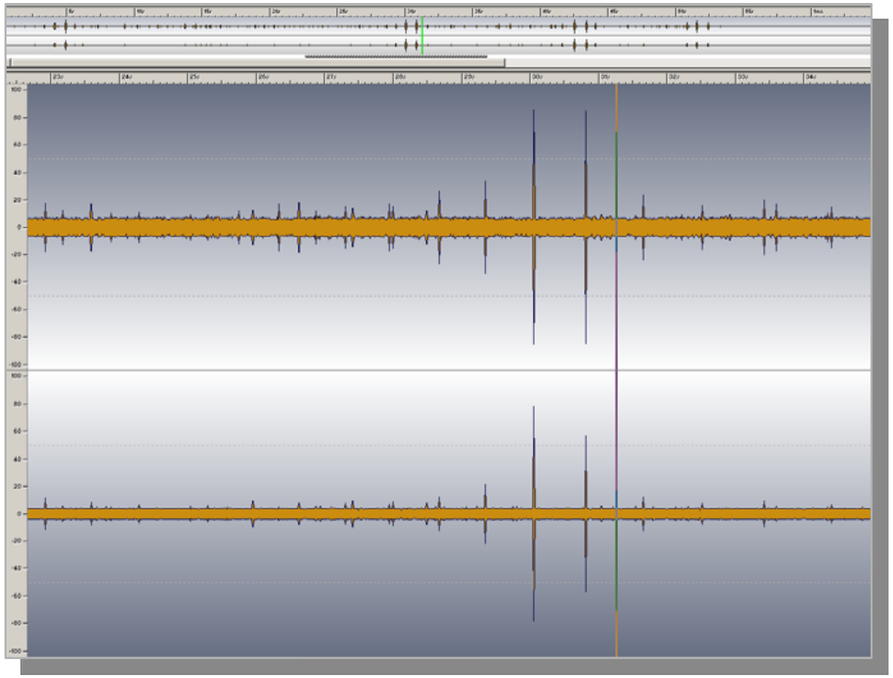
2005-2006

First data from 2000 m

- **GEOSTAR SN-1**, a deep sea station for on-line seismic and environmental monitoring by INGV. The NEMO test site is the Italian site for ESONET (European Seafloor Observatory NETwork);
- **OνDE**, for on-line deep sea acoustic background monitoring.



GEOSTAR SN-1 deep sea station



Sperm whale clicks (echo localization)

The NEMO Phase 2 project in Capo Passero

PROPOSED INFRASTRUCTURE

- Shore station at Portopalo di Capo Passero to host the power system the data acquisition and detector integration facilities
- 100 km electro optical cable
- Underwater infrastructures (main junction box)
- Two intermediate connection stations in shallow and medium deep waters for interdisciplinary activities (agreement with INGV and SACLANTCen)

STATUS

- Project already funded
- Procedures for the purchase of EO cable (≈48 optical fibres, 30÷40 kW) started
- Procedures for the acquisition of an already existing building, to be renovated and used as shore station, approved by INFN
- Project to be completed in two years

Summary

- **Baikal** and **AMANDA** have demonstrated the feasibility of the high energy neutrino detection;
- The forthcoming km^3 neutrino telescopes are "discovery" detectors with high potential to solve HE astrophysics basic questions:
  UHECR sources, HE hadronic mechanisms, Dark matter ...
- To fully exploit neutrino astronomy we need two km3 scale detectors, one for each hemisphere;
- The under-ice km^3 **ICECUBE** is under way, following the AMANDA experience;
- The Mediterranean km^3 neutrino telescope, when optimized, will be an powerful astronomical observatory thanks to its excellent angular resolution;
- The feasiblity of km^3 detectors at depth $\approx$ 3500 m is widely accepted;
- **ANTARES** deployed Line0 and Milom, underwater connection Apr. 2005;
- **NEMO** started Test Site installation.

The Mediterranean km^3 detector potentials and payoffs

Structures can be recovered:

• The detector can be maintained

• The detector geometry can be reconfigured

The underwater telescope can be installed at depth $\geq$ 3500 m

Muon background reduction

Light effective scattering length (>100 m) is much longer than in ice (20 m)

Cherenkov photons directionality preserved

Light absorption length in water (70 m) is smaller than in ice (100 m)

Less Cherenkov photons detected

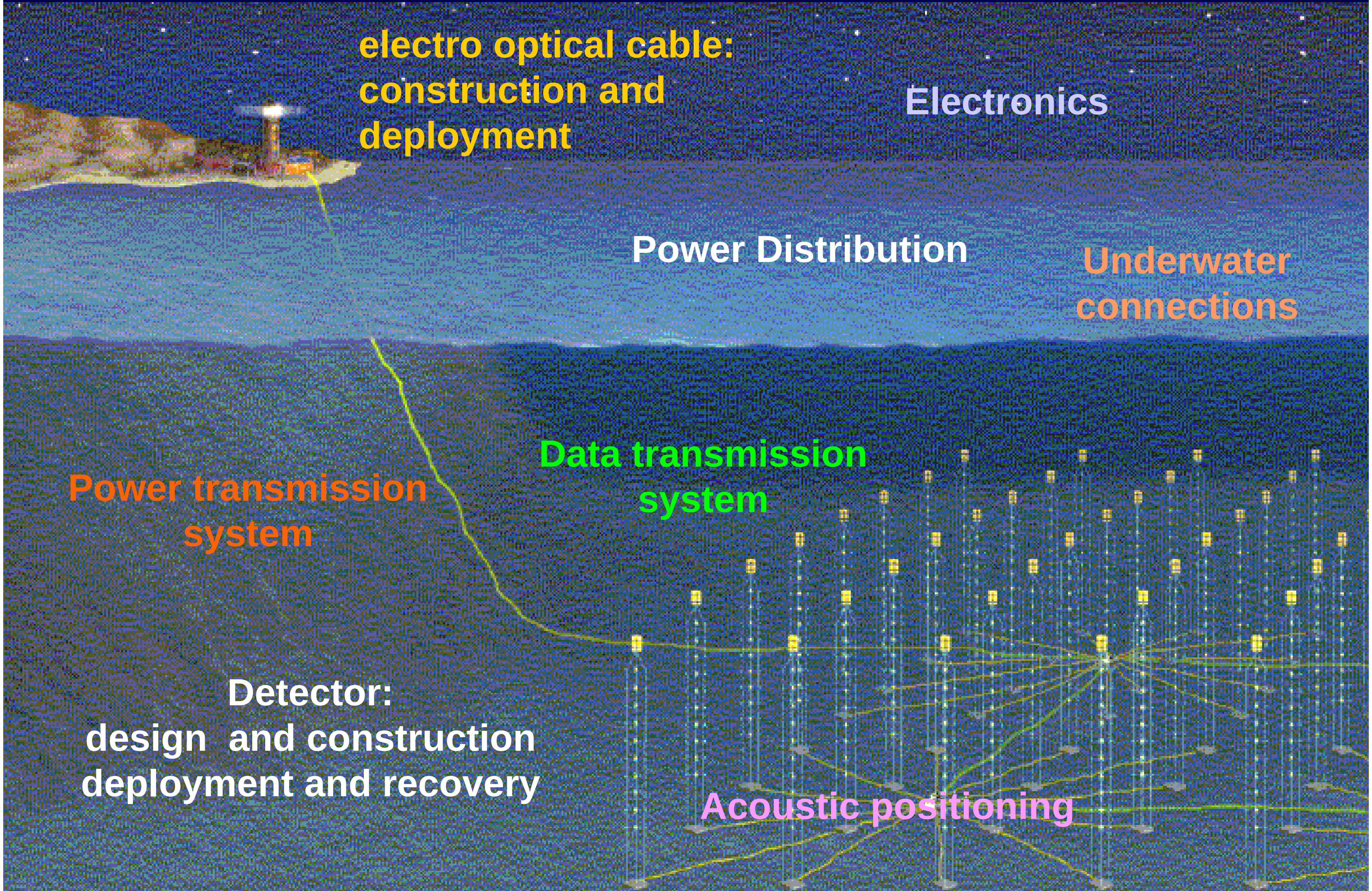
^{40}K decay in water + bioluminescence

Optical background and dead time increased

Sediments and fouling

Optical modules obscuration → maintenance

Towards the Mediterranean km^3: technological challenges



Data transmission goals

- Transmit the full data rate with minimum threshold
- Only signal digitization should be performed underwater
- All triggering should be performed on shore
- Reduce active components underwater

Assuming

- **An average rate of 50 kHz (40K background) on each OM**
- **Signal sampling (8 bits) at 200 MHz**
- **Signal length of 50 ns (true for 40K signals) ➔ 10 samples/signal**

➡ 5 Mbits/s rate from each OM ➔ **25 Gbits/s** for the whole telescope (5000 OM)

Rate affordable with development and integration of available devices for telecommunication systems

Possible architecture for the km3 detector

Based on DWDM and Interleaver techniques

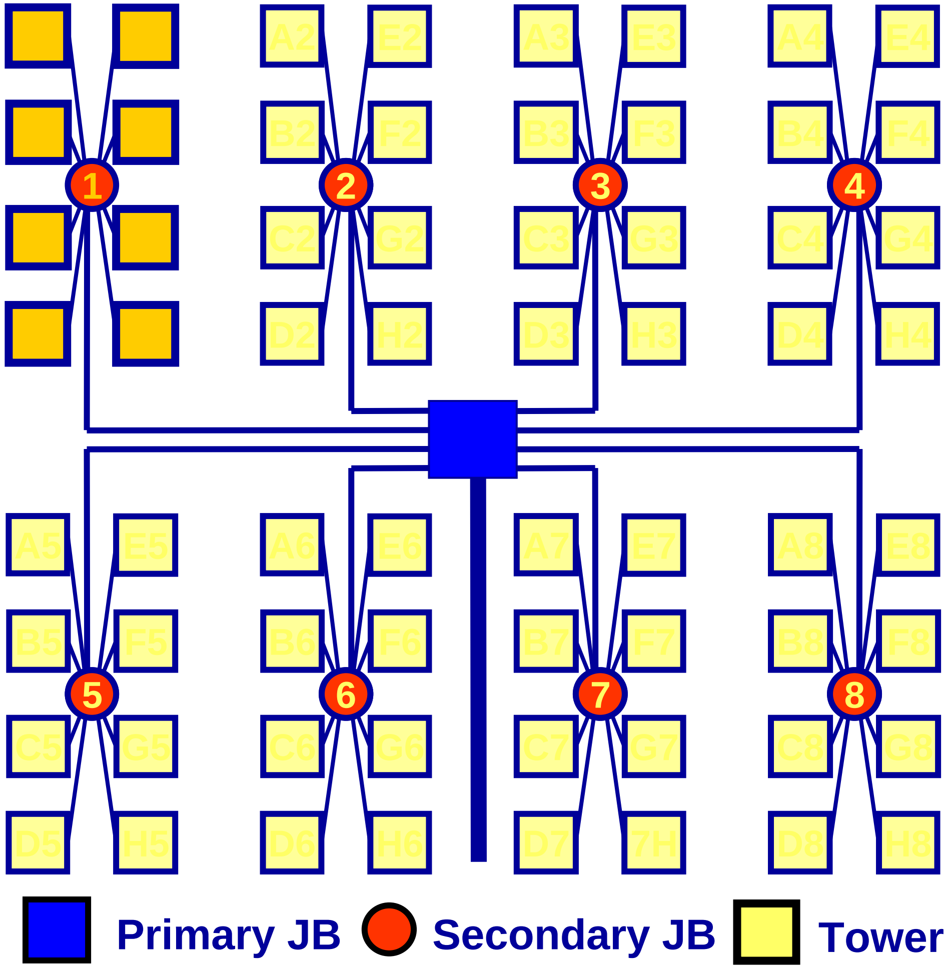
First Multiplation Stage (Tower base):

- **16 Channels coming from the 16 tower floors. The channels are multiplexed in one fibre at the base of each tower.**

Second multiplation stage (secondary JB):

- **32 channels coming from a couple of tower are multiplexed with an interleaver;**
- **The output is a single fibre for each of the four couples of towers.**

All the fibres coming from the secondary JB go directly to shore (connection to the main electro-optical cable inside the main JB)



Mostly passive components

Very low power consumption