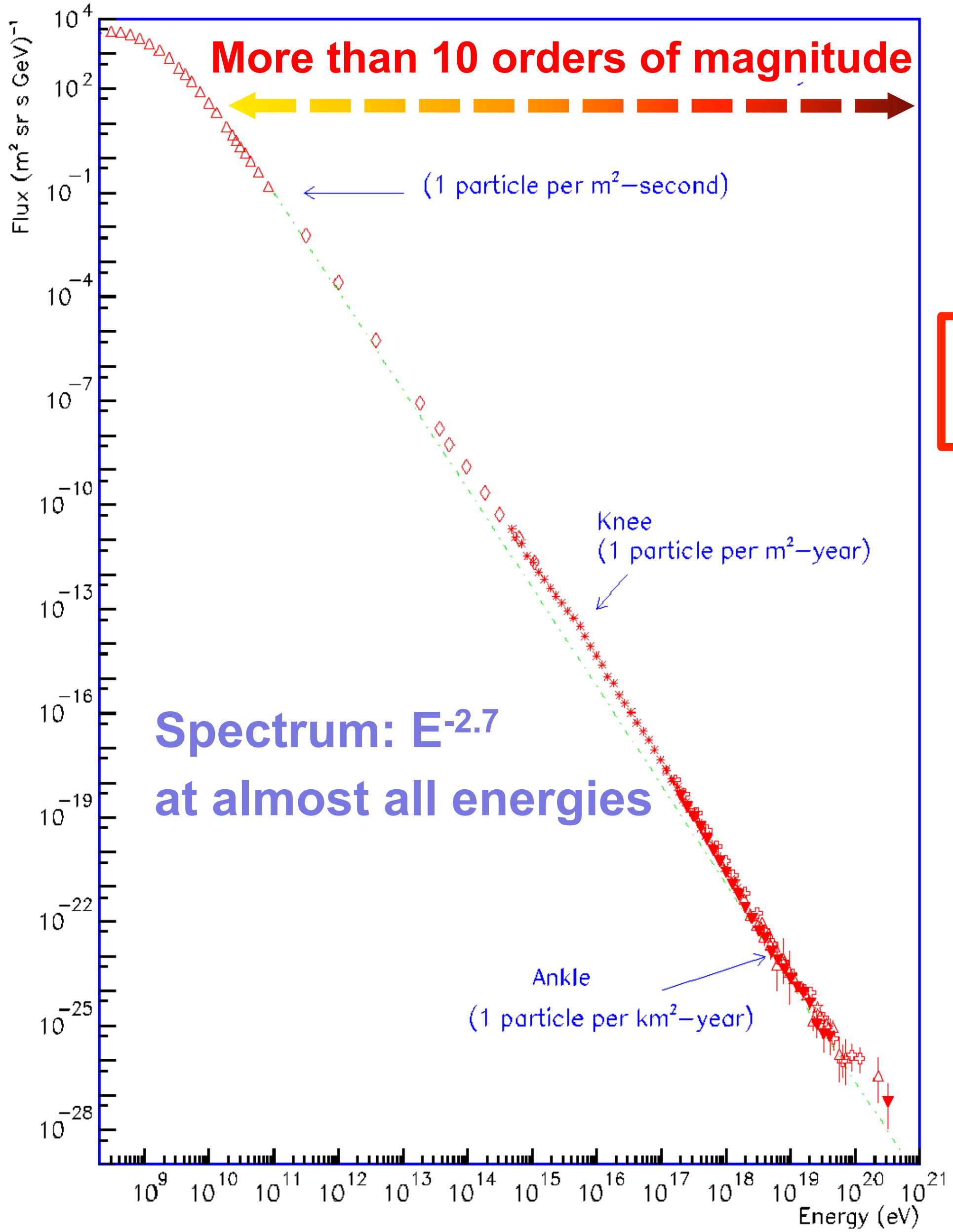
Neutrino Telescopes

Outlook

- Cosmic Ray
- Neutrino astronomy
- Detection techniques
- Projects
- Conclusion

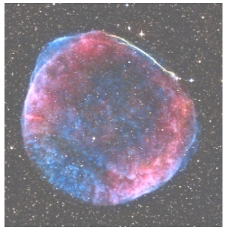
The Cosmic Ray (CR) Spectrum



The CR sources are still unkown

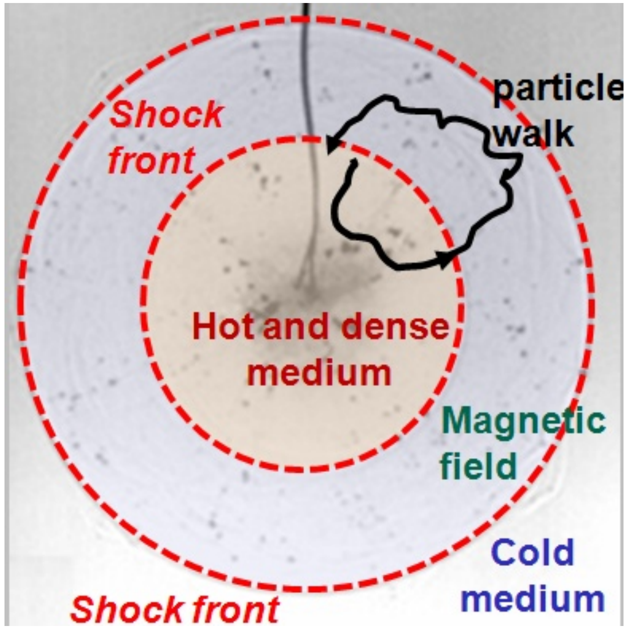
Fermi's Idea:
Statistical acceleration of particles
Bell's model:
Charged particle acceleration in shocks

$E_{max} \propto$ *time spent in the source (BxR)*
$dN/dE \propto E^{-2}$



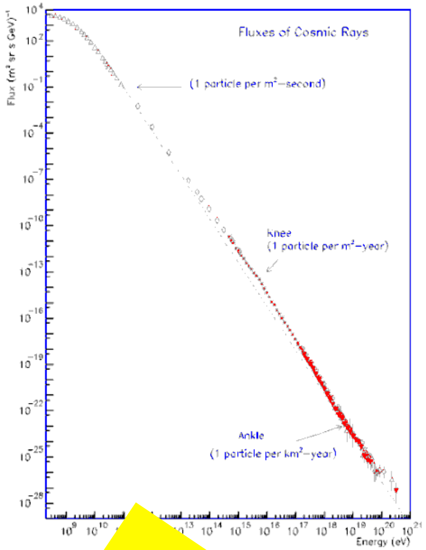
SN 1006

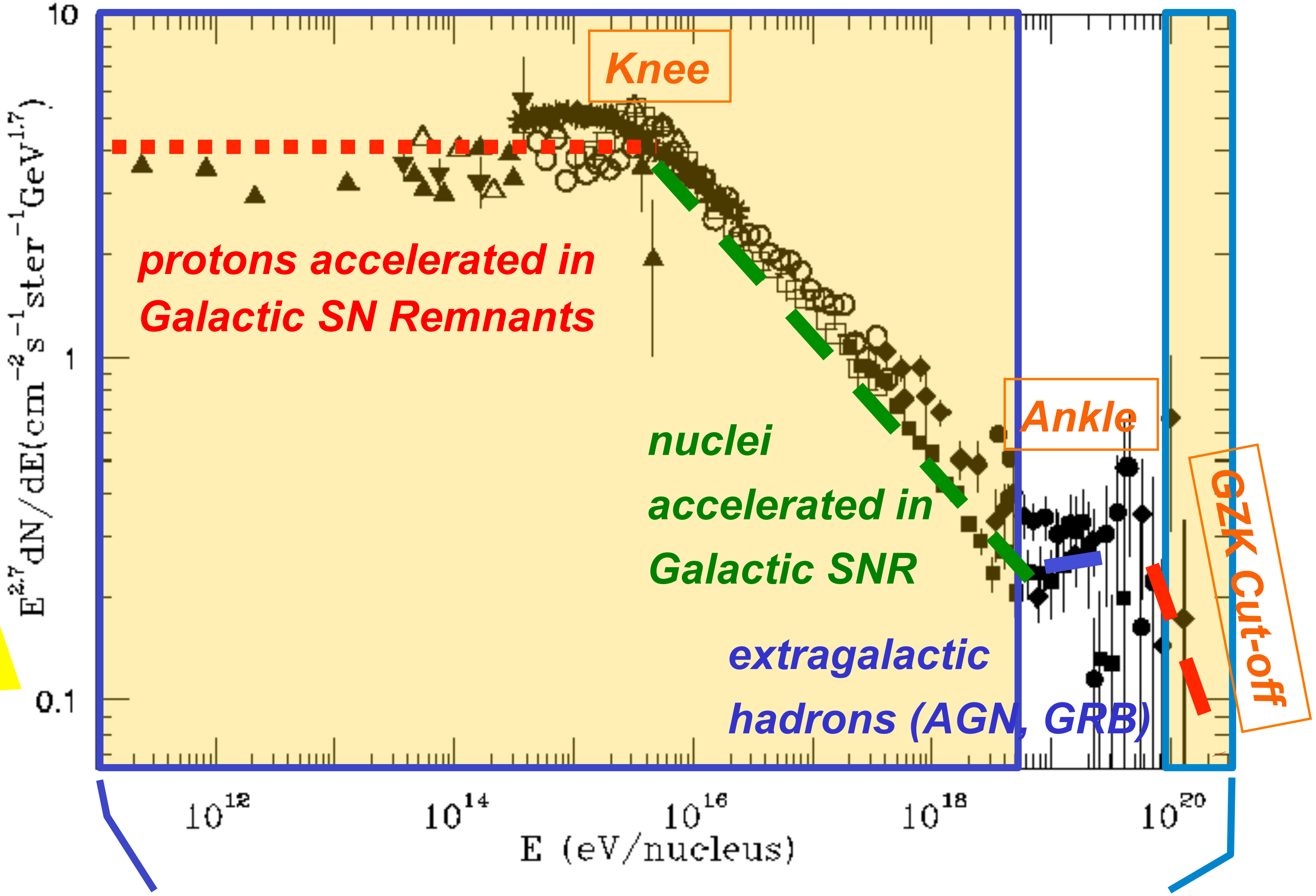
TNT detonation



E^{-2} (Fermi-Bell acceleration)
$E^{-0.6}$ (propagation in the Galaxy)

CR Origin: the standard scenario



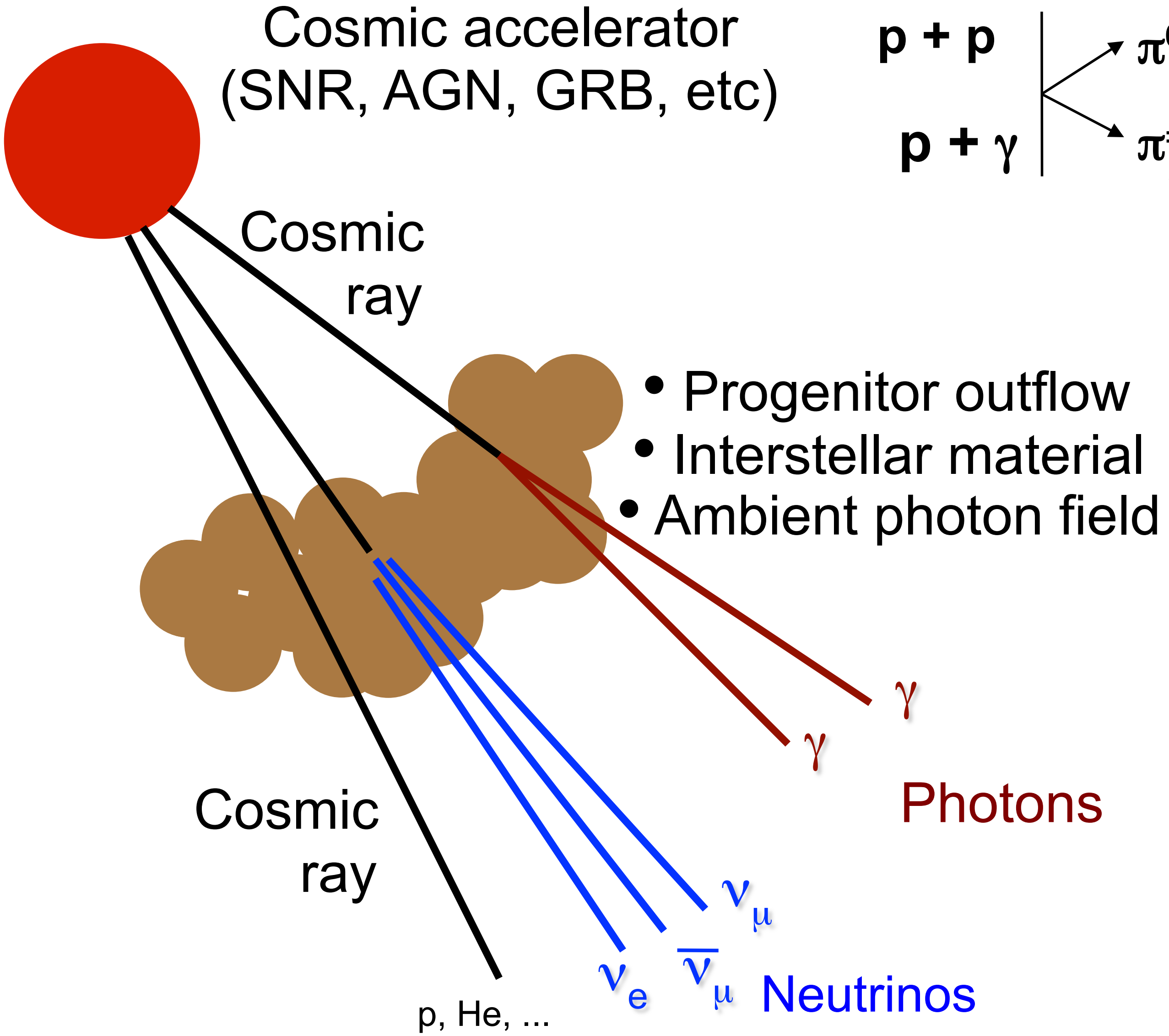


Hadrons deflected by the Galactic magnetic fields

Hadrons absorbed by the interaction with CMBR (GZK effect): p + CMBR → Δ^+ ($L^P_{attenuation}$ ~ 50 Mpc)

Astrophysical sources produce high energy hadrons

Cosmic Ray, Gamma Ray and Neutrinos

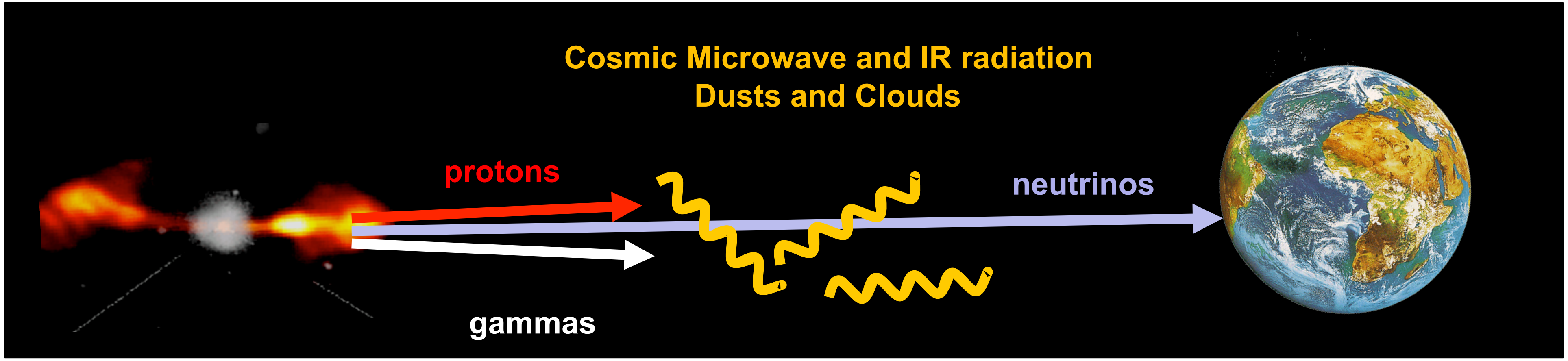


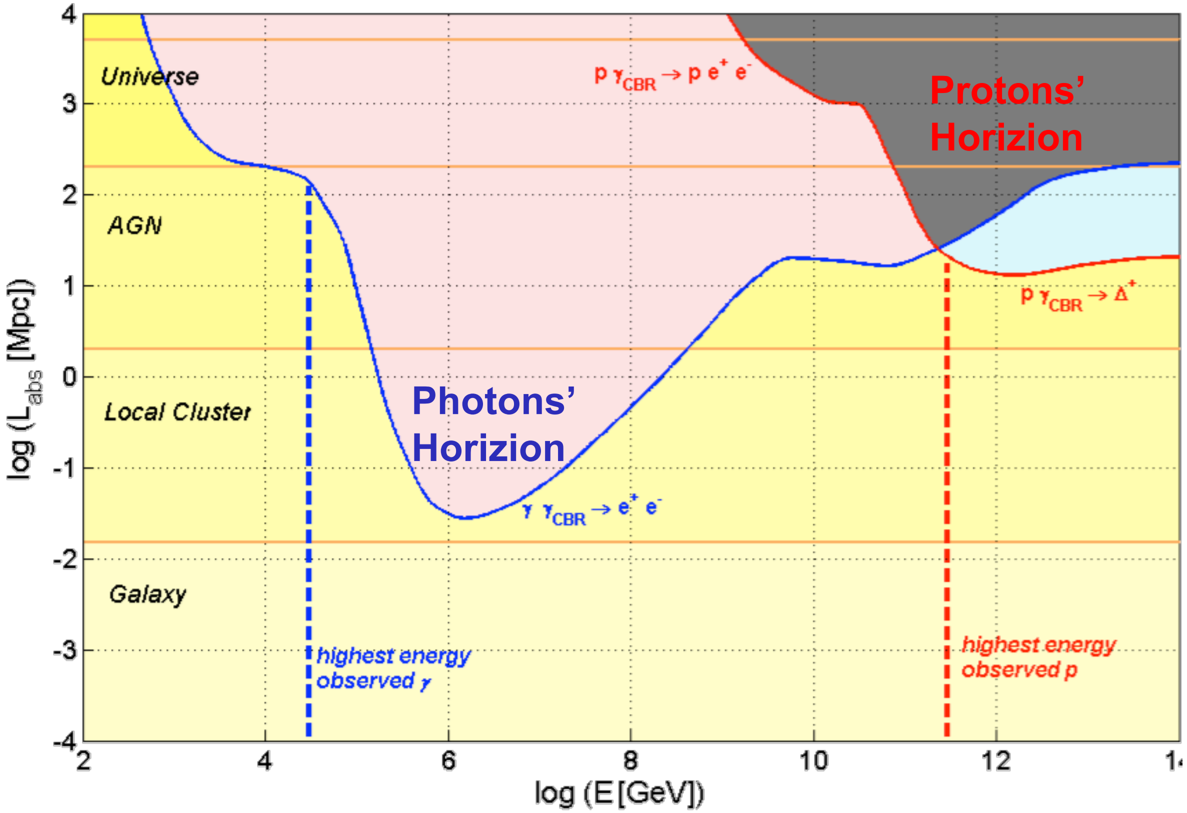
$$p + p,\; p + \gamma \rightarrow \pi^0 \rightarrow \gamma + \gamma$$

$$p + p,\; p + \gamma \rightarrow \pi^\pm \rightarrow \mu^\pm + \nu_\mu\, (\bar{\nu}_\mu)$$

$$\mu^\pm \rightarrow e^\pm + \nu_e\, (\bar{\nu}_e) + \bar{\nu}_\mu\, (\nu_\mu)$$

Absorption lenght of protons and gammas in the Universe





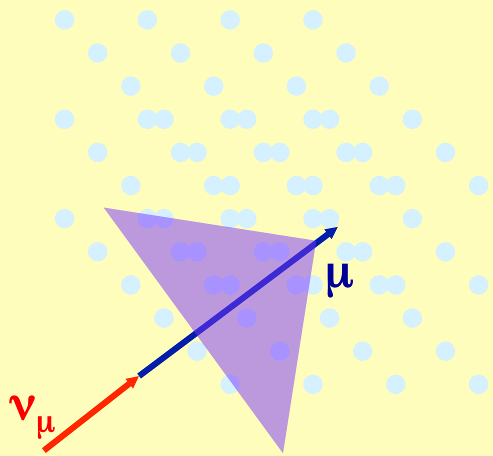
Neutrino astronomy can:

- ***probe the far and violent Universe***
- ***disentangle between pure leptonic and hadronic acceleration models***

Large Area Detectors for HE neutrinos

1 TeV — 100 PeV — 1000 ZeV

Optical Detection (ICECUBE-KM3NeT)



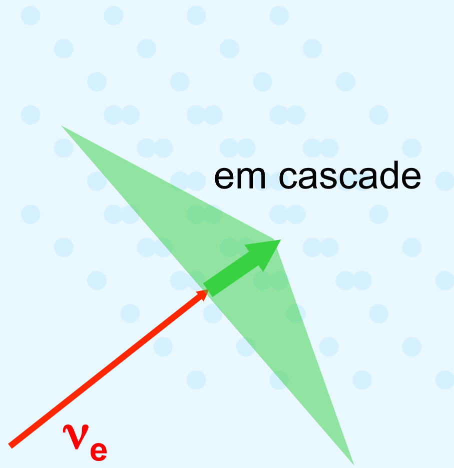
Medium: Seawater, Polar Ice

ν_μ (throughgoing and contained)
$\nu_{e,\tau}$ (contained cascades)

Carrier: Cherenkov Light (UV-visible)
Attenuation length: 100 m

Sensor: PMTs
Instrumented Volume: 1 km^3

Radio Detection (ANITA, RICE, ICERAY)



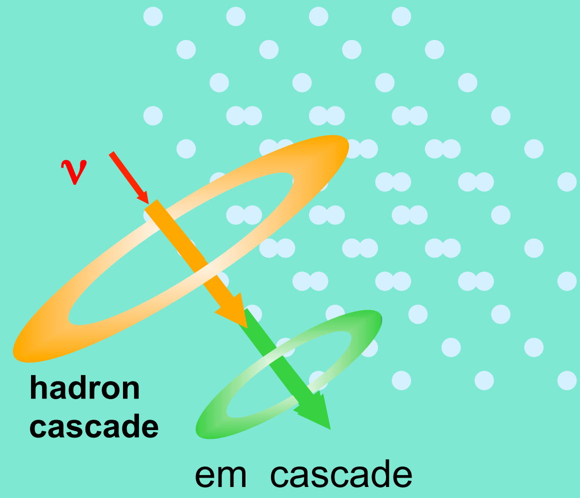
Medium: Salt domes, Polar Ice

ν (cascades)

Carrier: Cherenkov Radio
Attenuation length: 1 km

Sensors: RF-Antennas
Instrumented Volume: >>1 km^3

Acoustic Detection (SAUND, NEMO, AMADEUS)



Medium: Seawater (Salt)

ν (cascades)

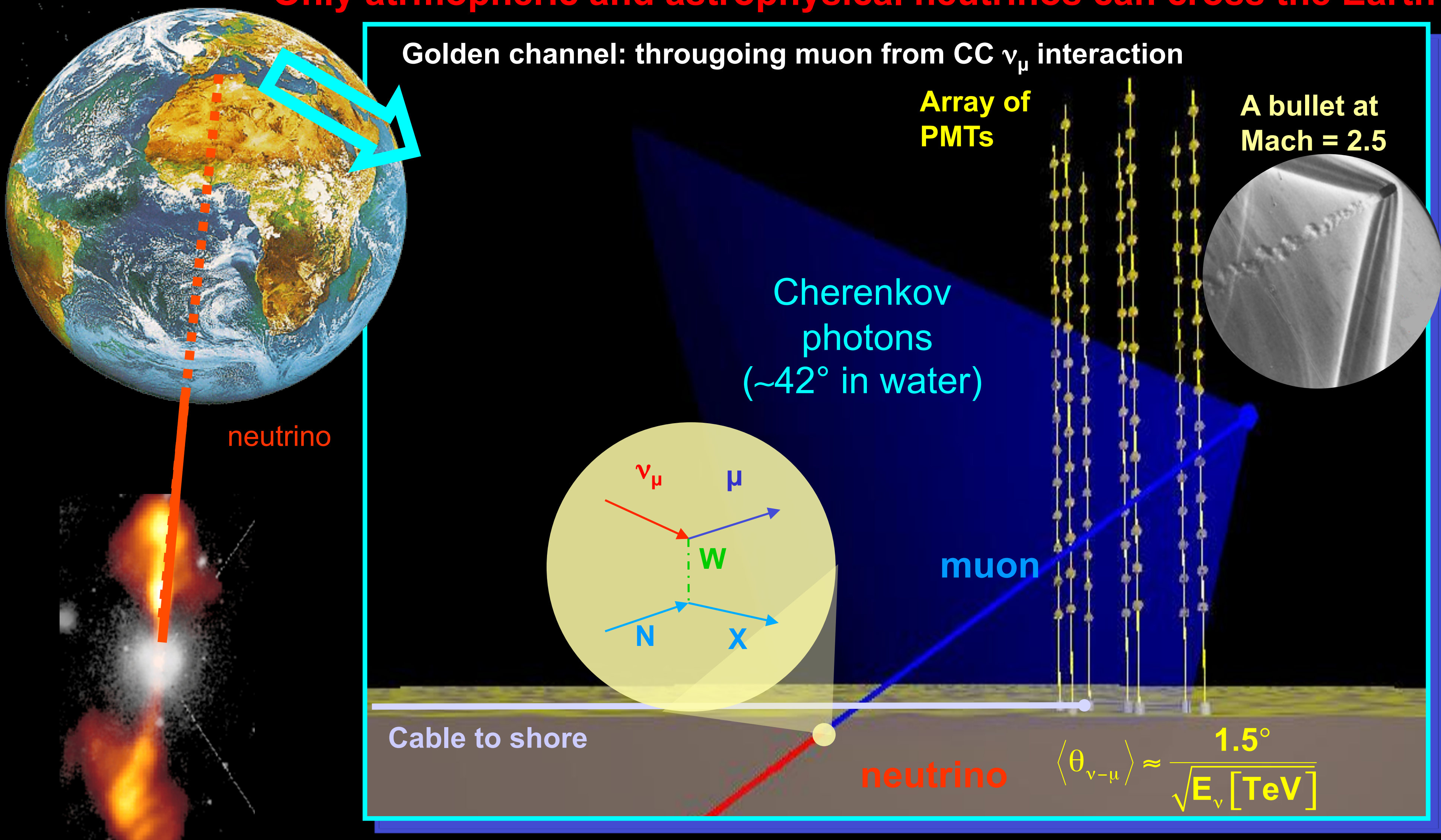
Carrier: Sound waves (tens kHz)
Attenuation length: ~ 1÷10 km

Hydro-phones
Instrumented Volume: >>1 km^3

Underwater(ice) Cherenkov neutrino detectors

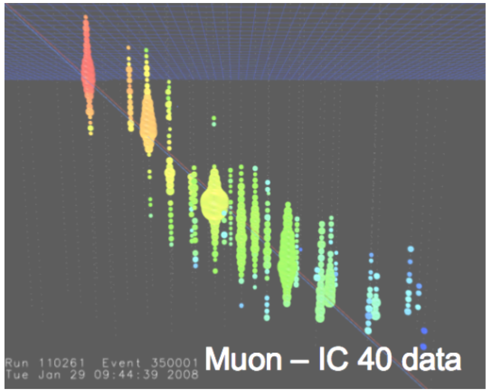
Look at upgoing muons: use the Earth as a filter

Only atrmopheric and astrophysical neutrinos can cross the Earth



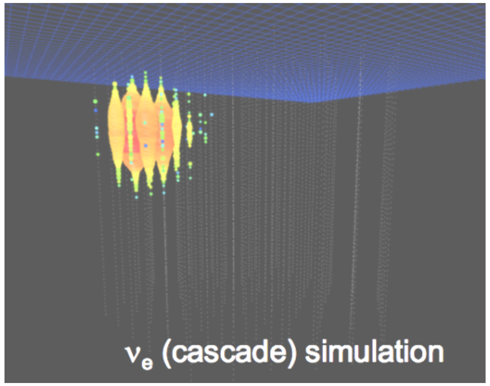
neutrino telescope !

Neutrino flavour identification



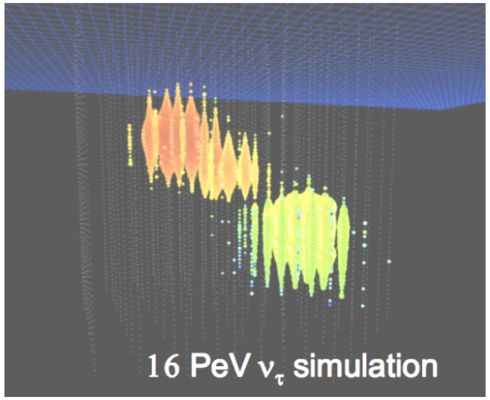
Tracks:
- **Golden channel for ν_μ (through-going muons)**

Best directional resolution, poor energy resolution (in case of not contained events).



Cascades:
- **All ν flavour (NC)**
- **ν_e and low-E ν_τ (CC)**

Good energy resolution

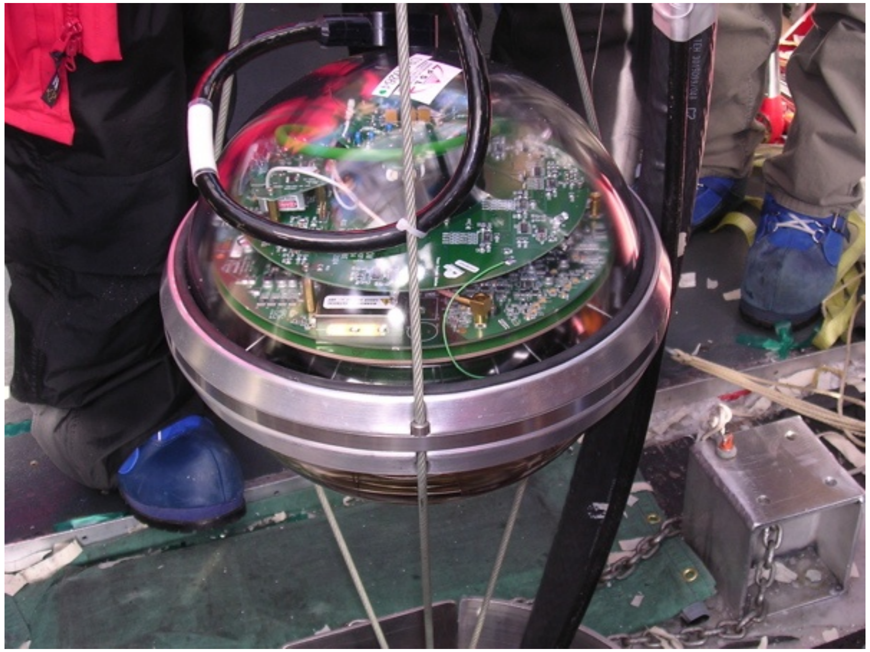


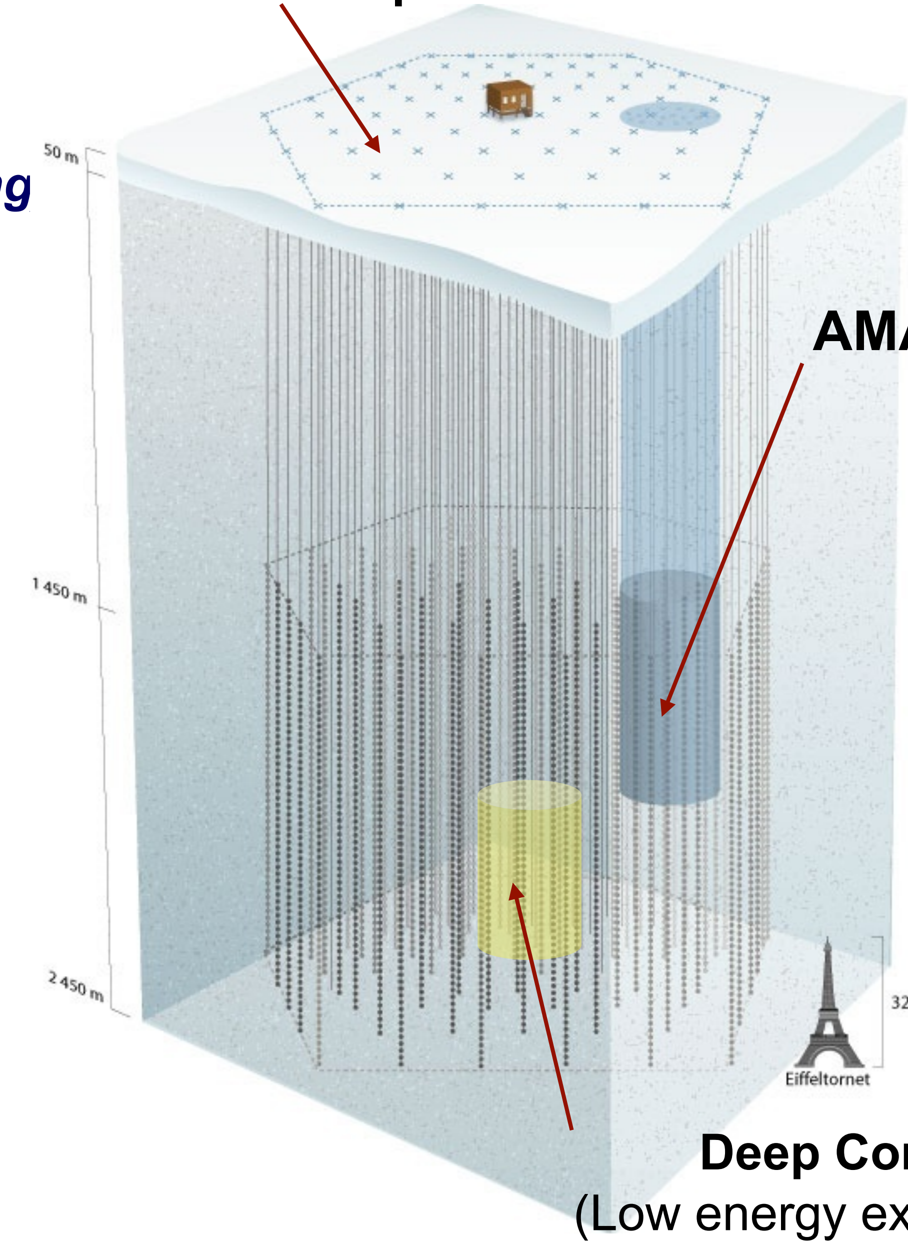
Composites:
- **High-E ν_τ (Double Bangs)**

Good directional and energy resolution

IceCube:The first km3-scale neutrino telescope

Location: Geographic South Pole
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
Status: completed

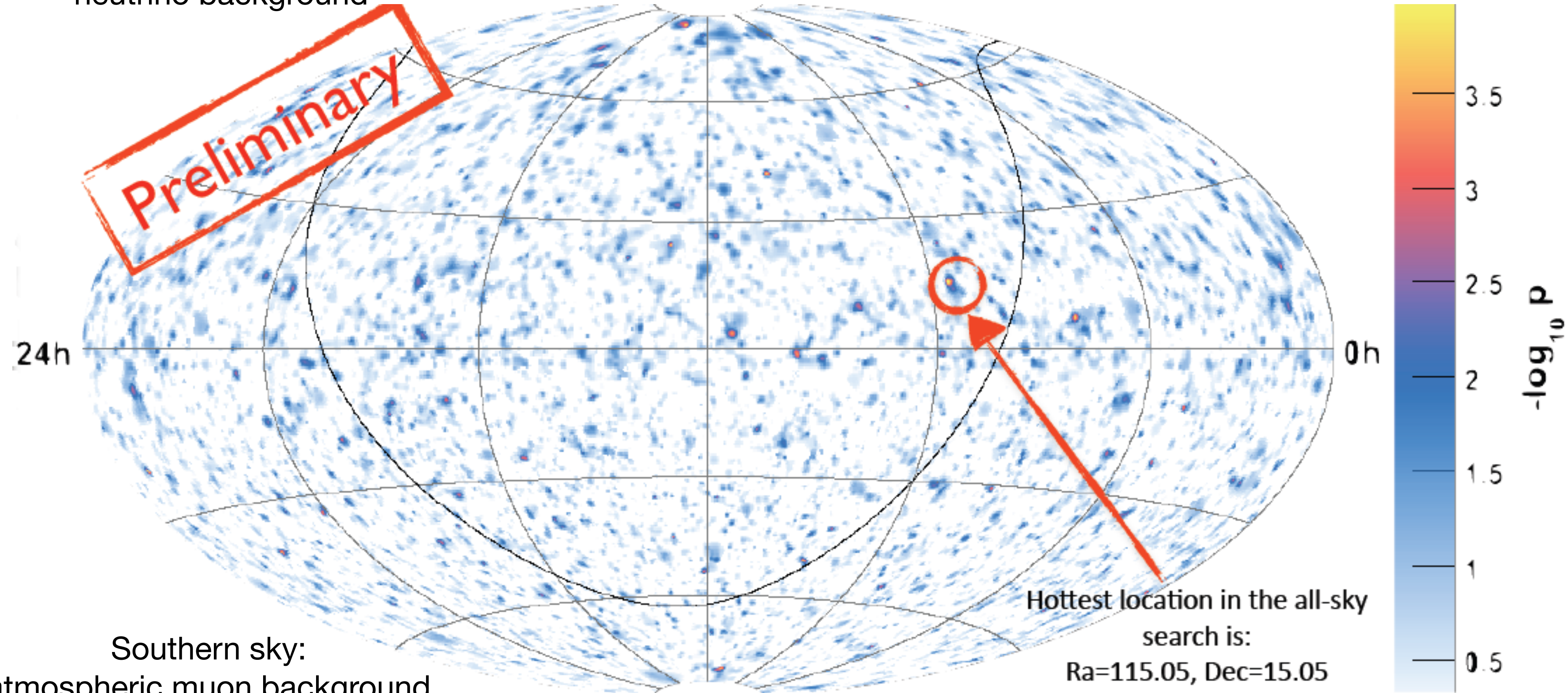




IceCube: Full sky point source search

J. Dumm ICRC 2009
J. Aguilar Vulcano 2010
Filimonov SCAR 2010

Northern sky: atmospheric neutrino background



Hottest location in the all-sky search is: Ra=115.05, Dec=15.05

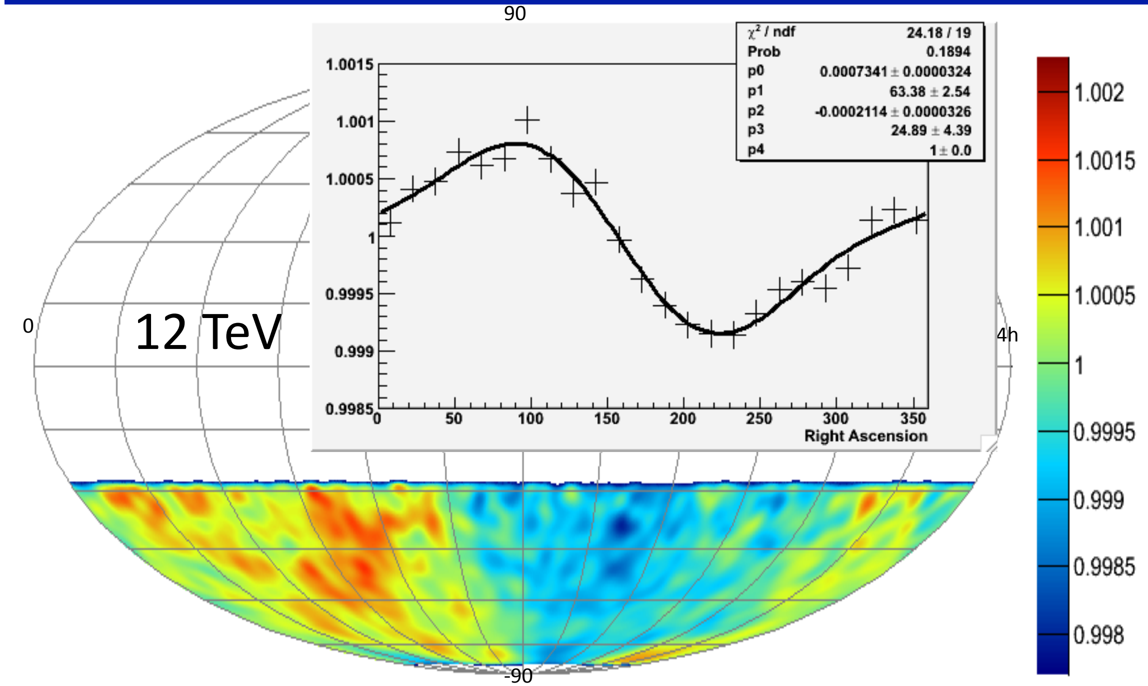
Southern sky: atmospheric muon background demand high energy events

Preliminary results from 375.5 days exposure

36,900 events: 14,121 upgoing and 22,779 downgoing

Maximum *p*-value 5.2 x 10^{-6}, seen in 18% of randomized sky maps

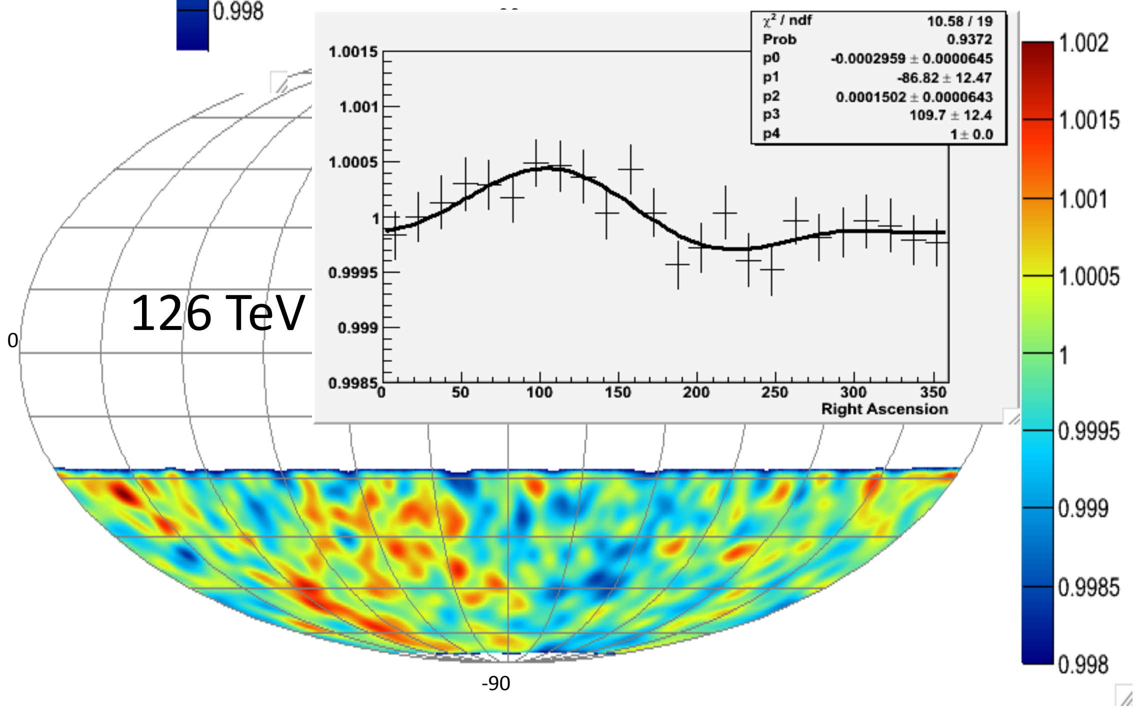
IceCube: Anisotropy



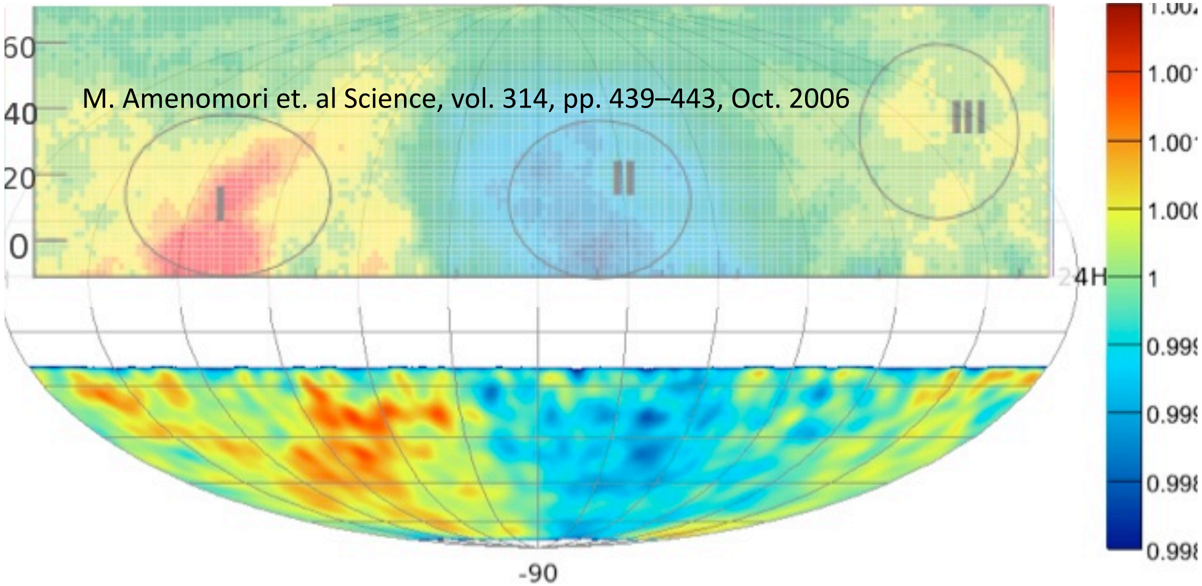
Anisotropies on the per-mille scale

(skymap in equatorial coordinates)

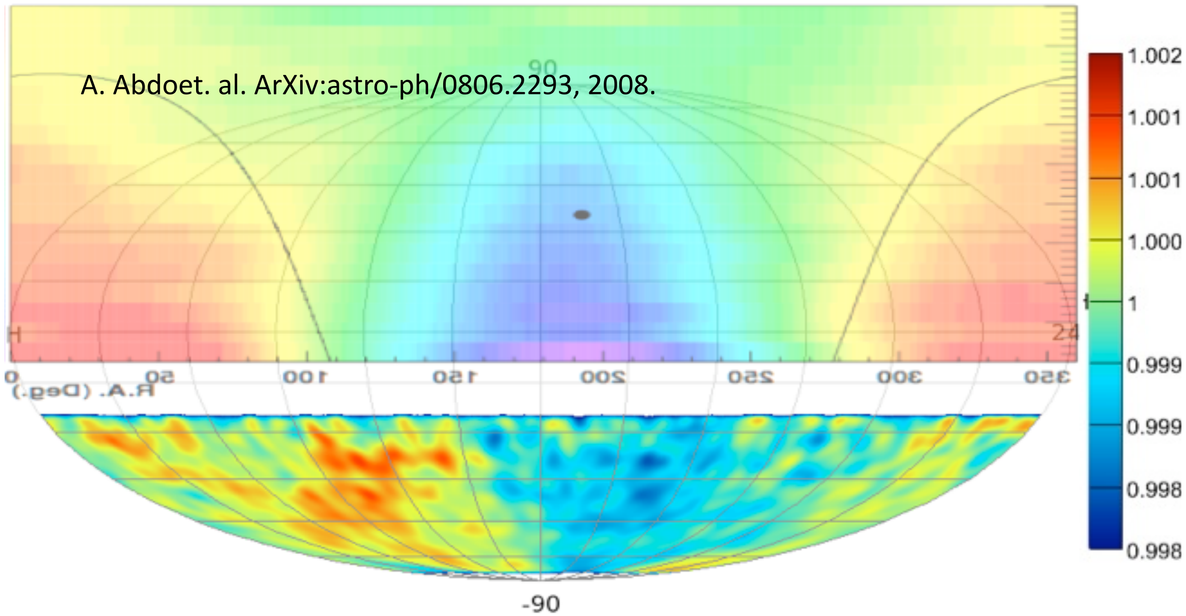
- Data: 22 strings, 4.3*10⁹ events.
- Median angular Resolution: 3° degrees.
- Median energy per cosmic ray particle: ~12 TeV.



IceCube: Anisotropy



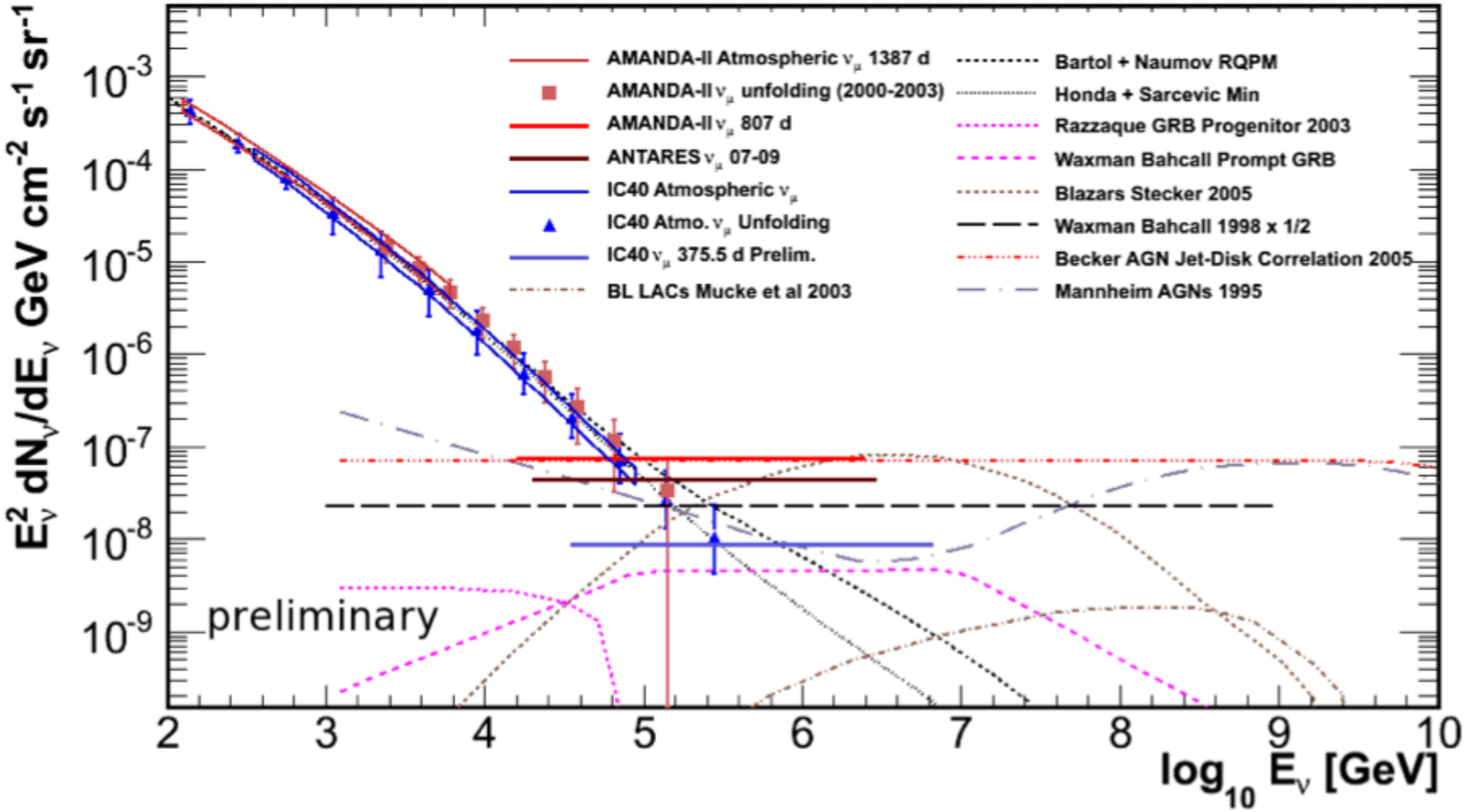
IceCube &Tibet Array



IceCube & Milagro

IceCube skymap is consistent with Large scale anisotropy results reported by previous experiments.

IceCube: limits to diffuse neutrino fluxes



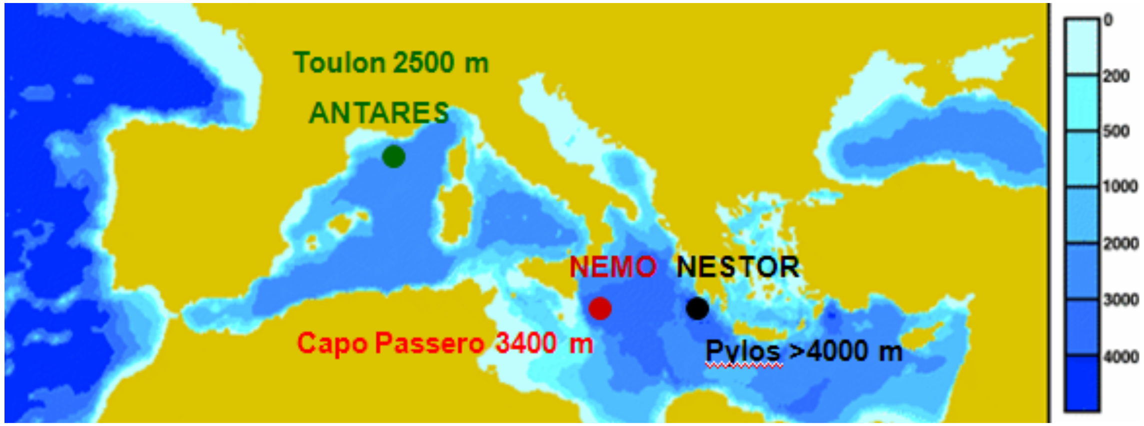
Towards the Mediterranean km^3

→ Need two telescopes (North and South Hemisphere) to cover the whole sky.
→ The Galactic Centre can be seen only from the Mediterranean telescope

KM3NeT

Born from the experience of the Mediterranean pilot projects:

ANTARES
NEMO
NESTOR



Intense technological R&D and coordination of Institutes

2006-2009 KM3NeT Design Study, Coordinated by Uni. Erlangen
2009-2012 Preparatory Phase, Coordinated by INFN

Goal: KM3NeT ~3 more sensitive than IceCube
- larger total photo-cathode area (larger detector)
- better direction resolution (sea water)

Towards the Mediterranean km^3: ANTARES

Location: Toulon

12 strings (75 PMT each)

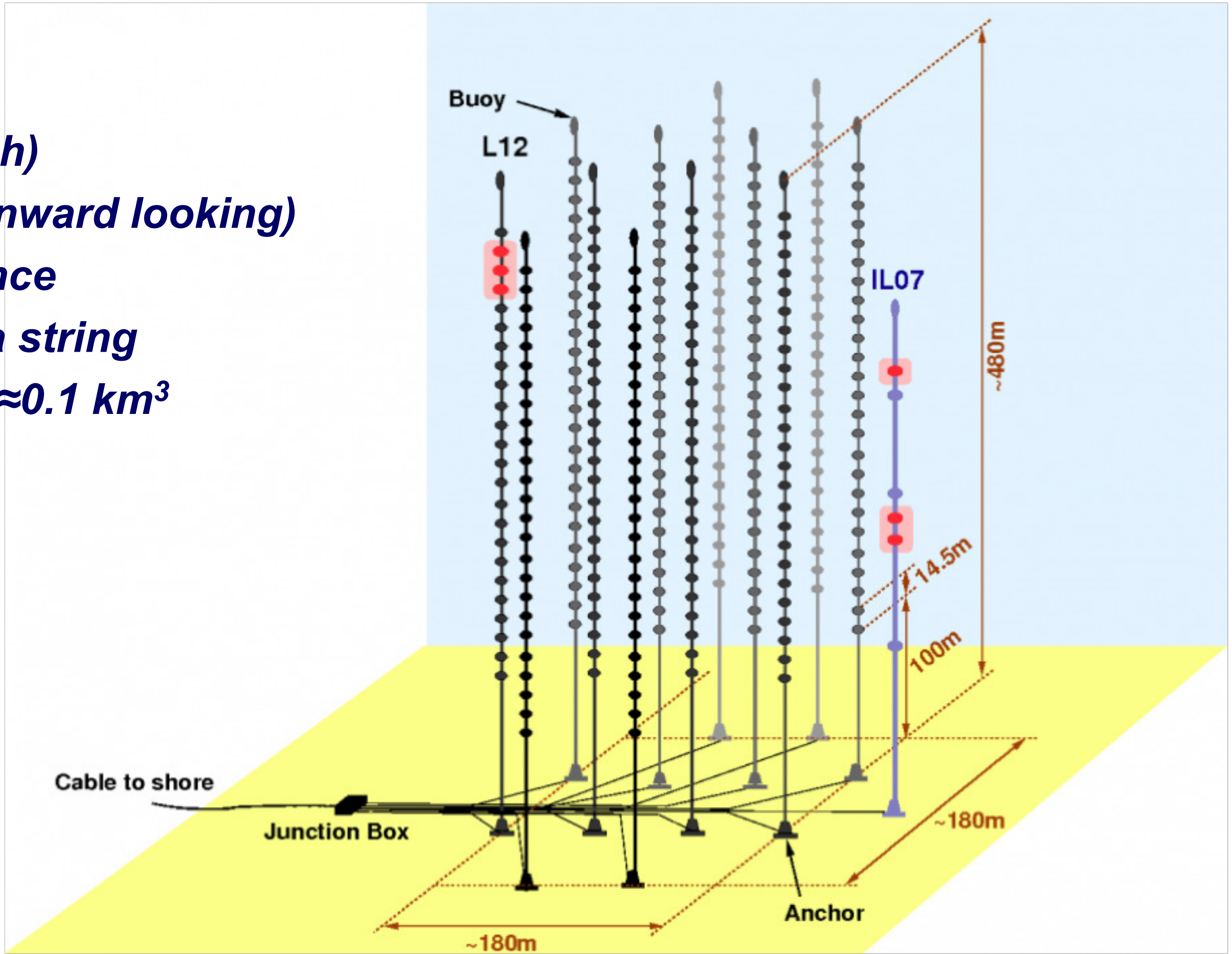
885 10"PMT (only downward looking)

65 m inter string distance

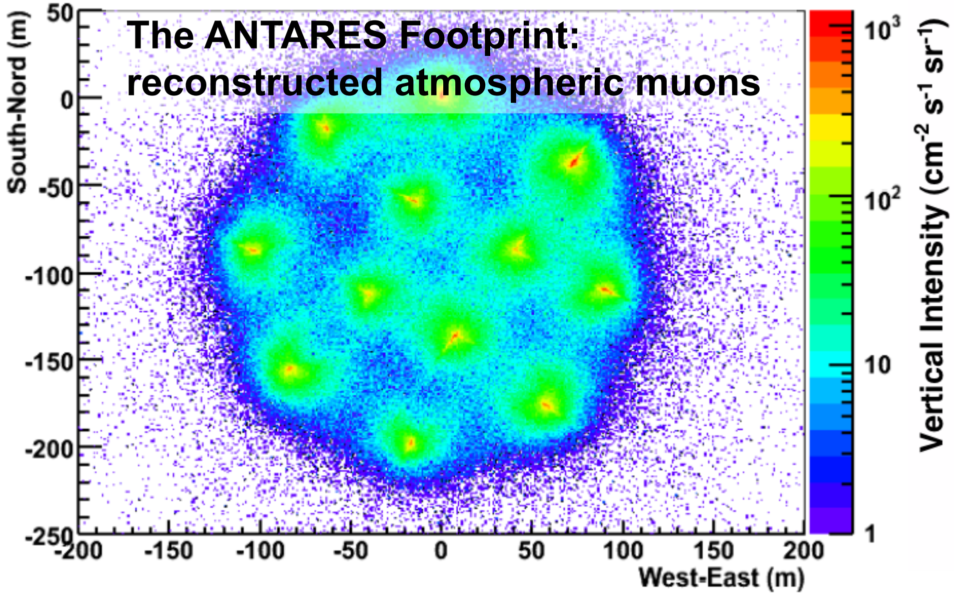
14.5 m spacing along a string

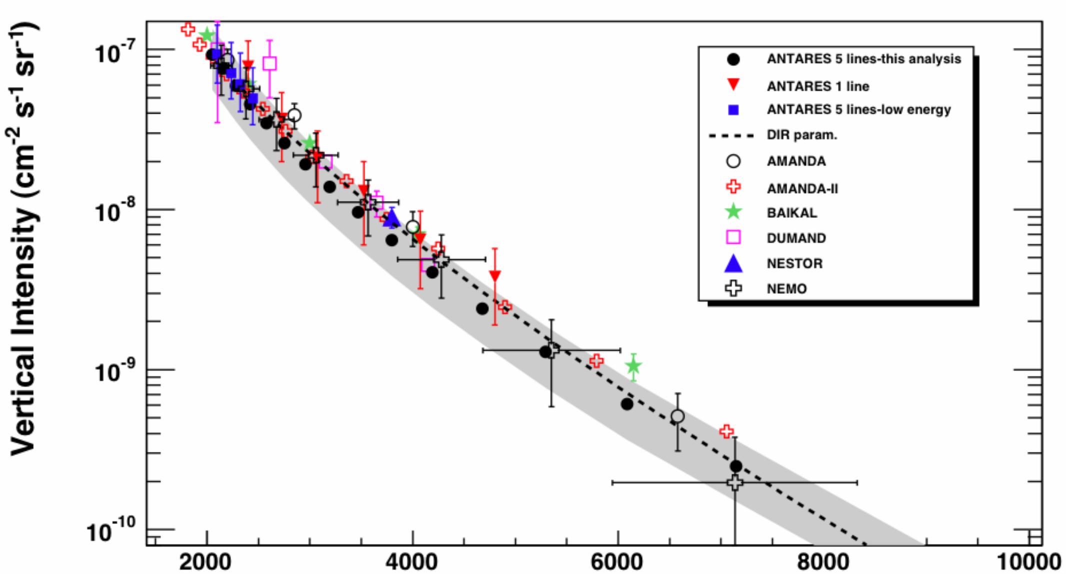
Instrumented volume: ≈0.1 km^3

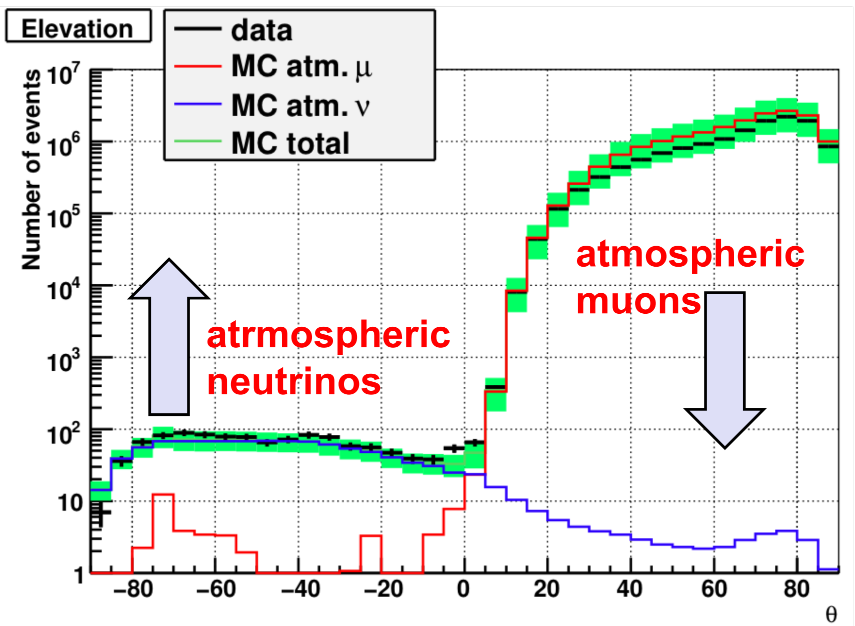
Status: completed

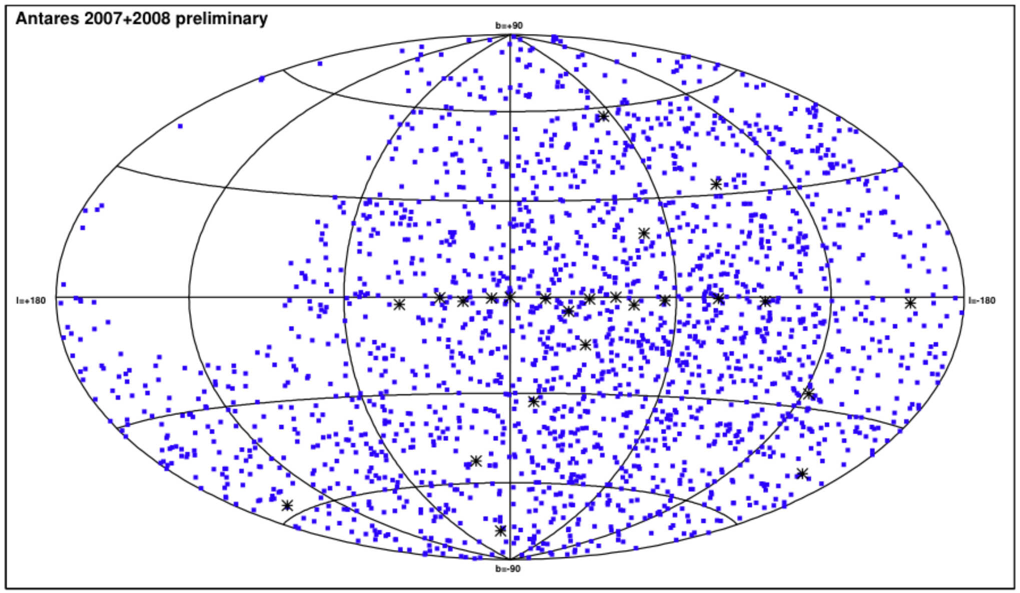


Towards the Mediterranean km^3: ANTARES





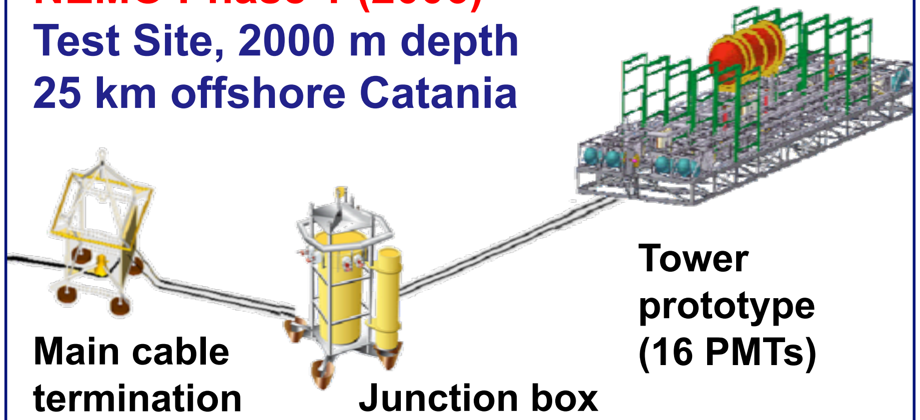


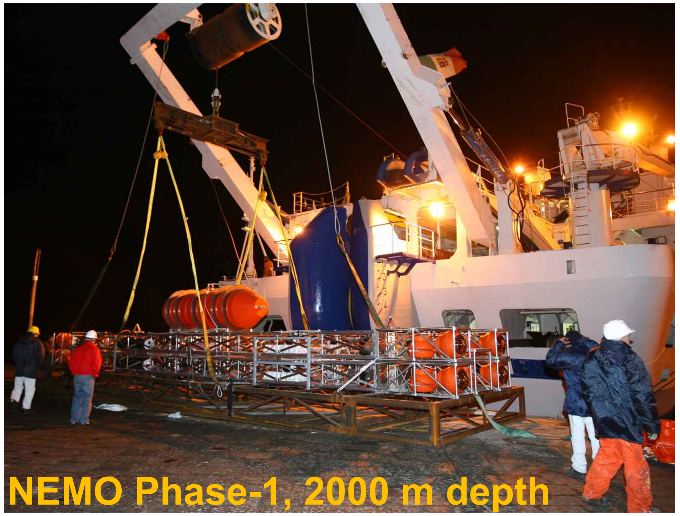


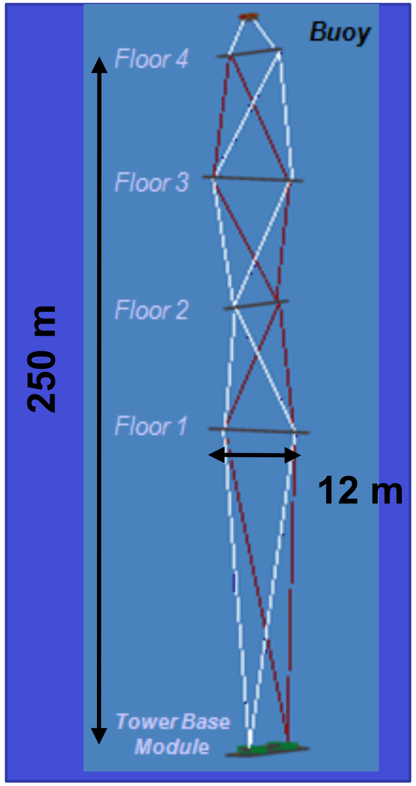
750 up-going neutrinos 2007+2008 data

Towards the Mediterranean km^3: NEMO

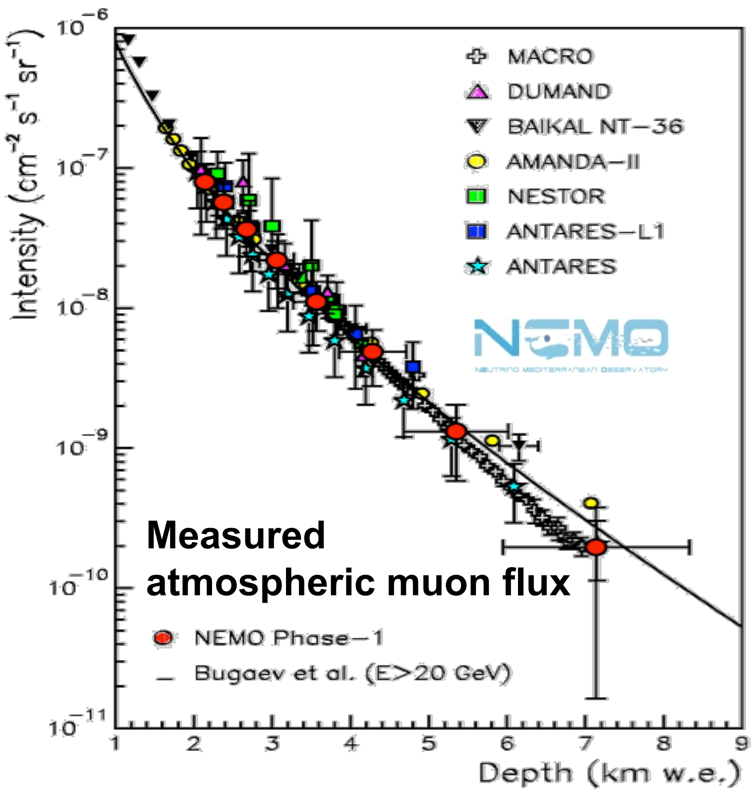
NEMO Phase 1 (2006)
Test Site, 2000 m depth
25 km offshore Catania



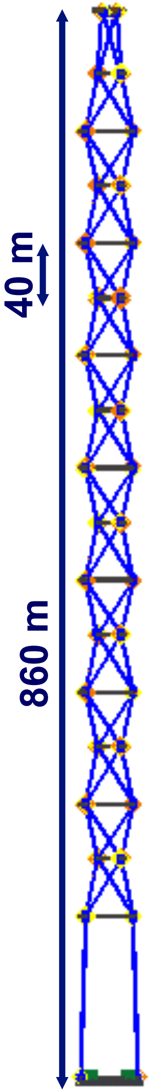




Location: Catania
1 tower (4 floors)
16 10"PMT
(downward and horizontal looking)
40 m spacing between floors
Successfully deployed and unfurled



KM3NeT: TDR Flexible Bar Structure

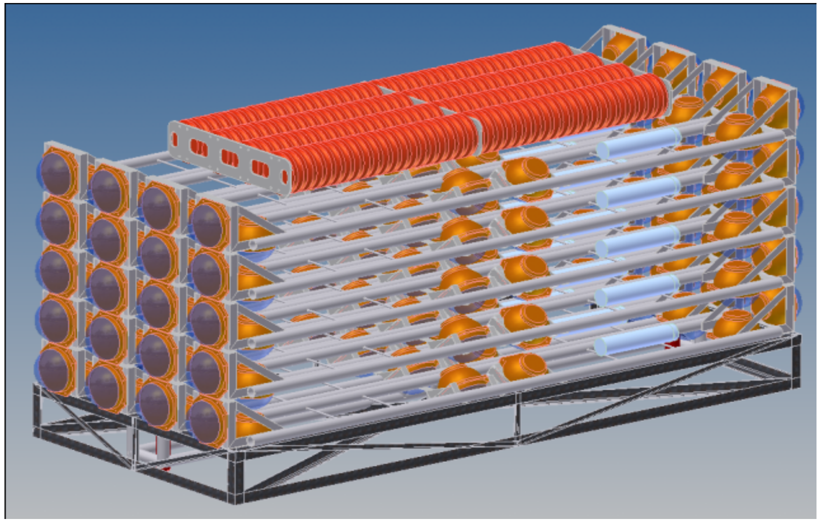


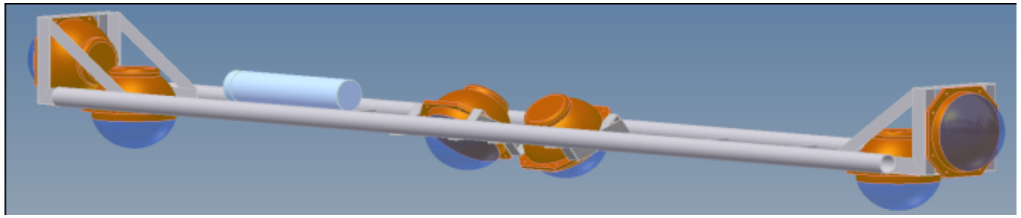
Bar Structure

Bar Structure (INFN / IN2P3 / CEA): Evolution from the NEMO tower

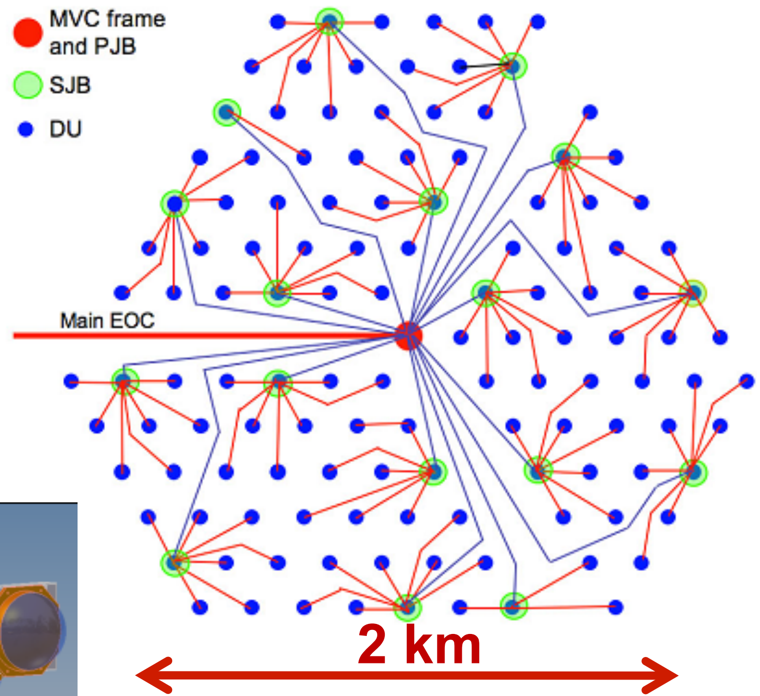
3D displacement of OMs : 6 m-long storey, 6 OM/storey, 20 storeys
- **Improve angular resolution at low energy**
- **Improve overall detector sensitivity**

Unfurling from Sea bed
- **Structure compact before sea operation**
- **Easier and faster deployment**

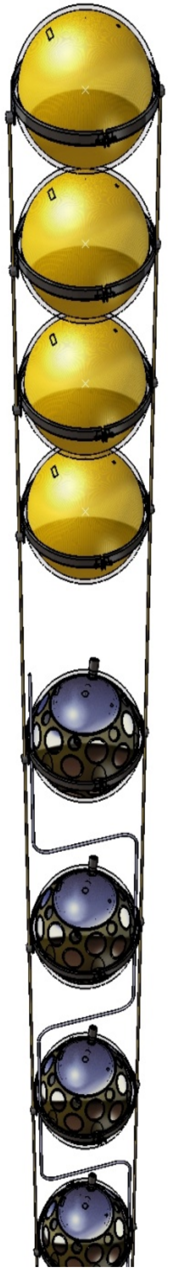




Detector Building Block
154 Detection Units @ 180 m



KM3NeT: TDR Slender String



Slender String (NIKHEF / NIOZ / NESTOR)

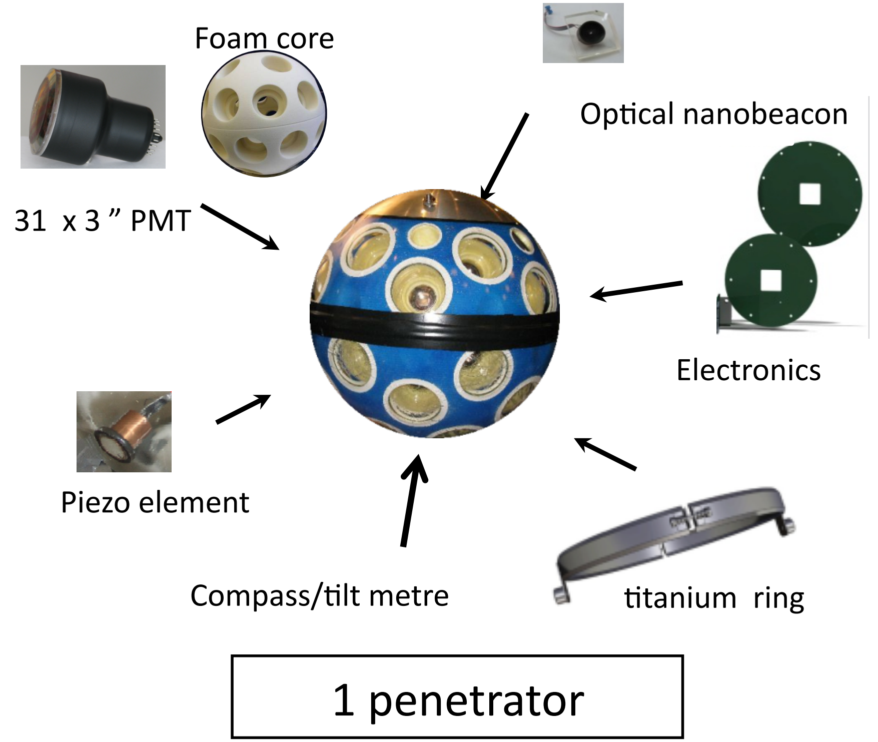
Evolution from the ANTARES string

1D displacement of OMs : 670 m, 20 storeys, 20 OM

Reduce connections (1 connector per OM)

Multi PMT optical module used

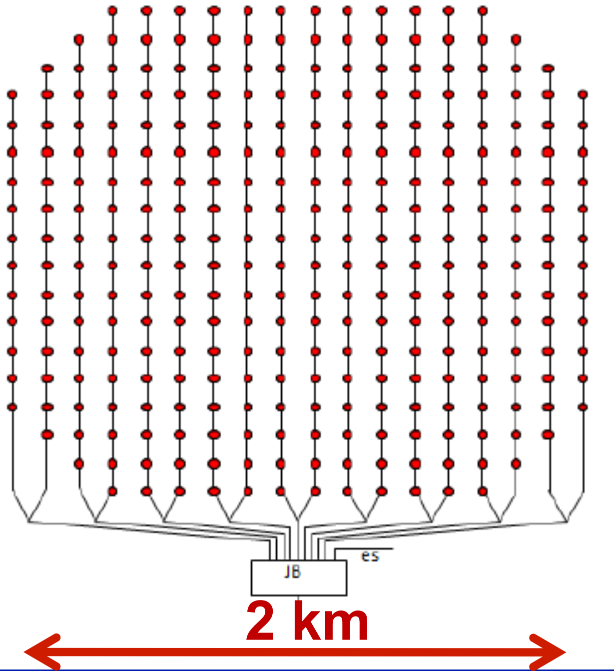
Unfurling from Sea bed



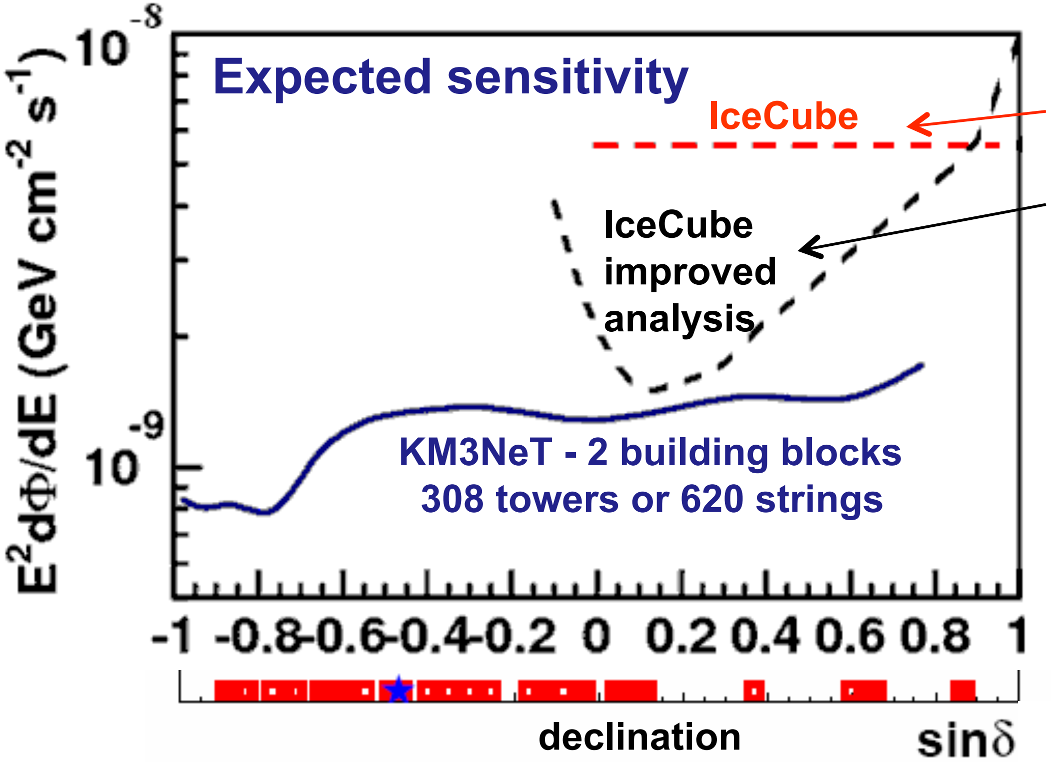
Multi PMT OM (31 x 4" PMTs)

Detector Building Block

310 Detection Units @ 130 m



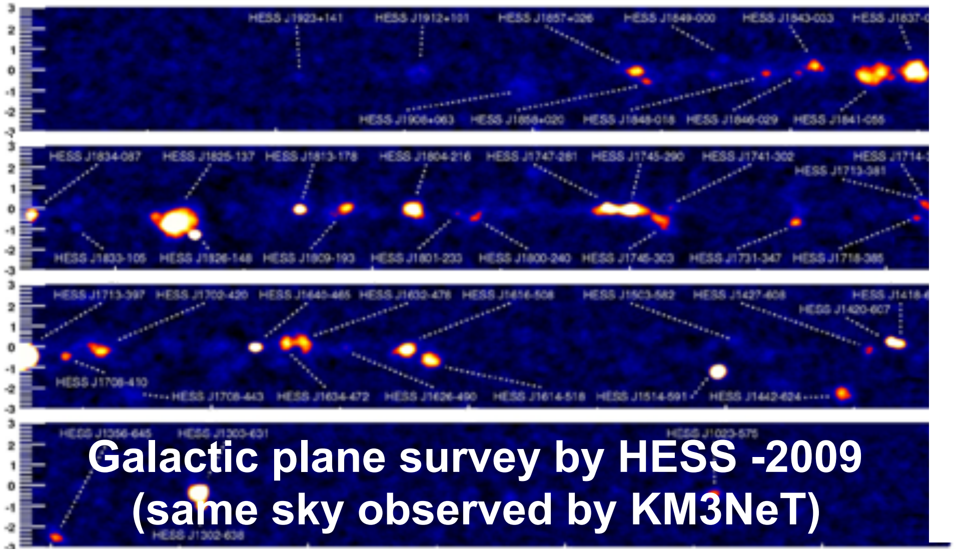
KM3NeT: Expected physics performances

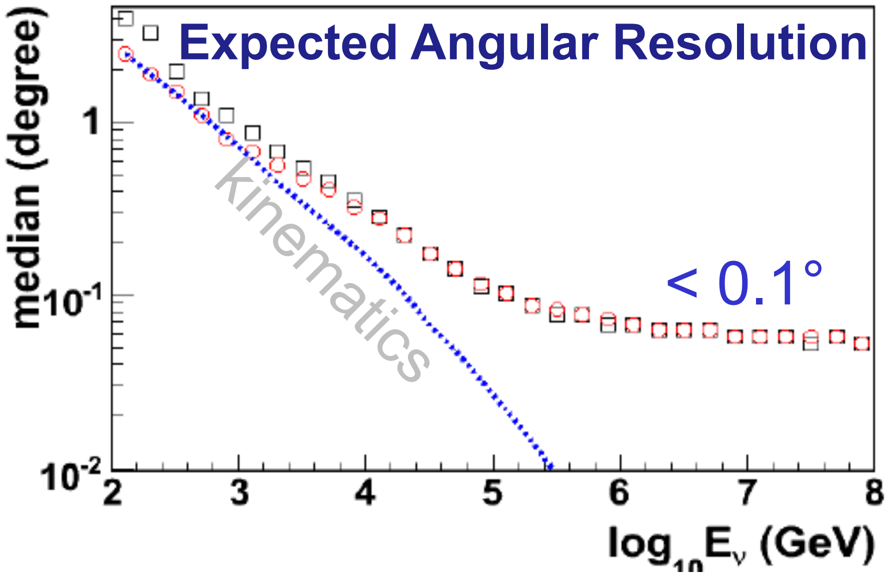


Aharens et al. AstroP. Phys.(2004)

Abbasi et al. Astro-ph (2009)

□ Observed Galactic sources
F. Aharonian et al. Rep. Prog. Phys. (2008) and
Abdo et al. Astrophys. Jour. 658 L33-L36 (2007)
★ Galactic center





Conclusions

Clear science goal

Neutrinos are optimal probes to study far and violent Universe and identify the CR sources

IceCube

- **IceCube completed, Deep Core (6 strings) installed**
- **First results from AMANDA, IC-22 and IC-40 published.**

ANTARES

- **Detector Completed and taking data, Maintenance (recovery, substitution) proven.**
- **Data analysis for the full detector is starting.**

NEMO

- **Phase 1 completed: Deep sea technology (mechanics, electronics, ...) fully tested**
- **Bar structure physics performances demonstrated by the results of Phase 1 and KM3NeT MC**

KM3NeT

- **Scientific objectives fully met with 2 Detector Building Blocks (either 610 string or 308 towers)**
- **TDR (April 2010): common technology platform**
- **Final Prototypes and tests (2010-2011). Site decision (end of 2011)**

Beyond the optical Cherenkov detectors

Novel techniques under test for GZK neutrino search: Radio-Cherenkov (ice) and Acoustic (water)

Backup slides

Event rates

- *Low noise rates: 280Hz (SPE/sec)*
– *Noise is dominated by glass (housing and PMT)*

Supernova explosion detection is possible
(Cherenkov light form intense MeV neutrino flux)

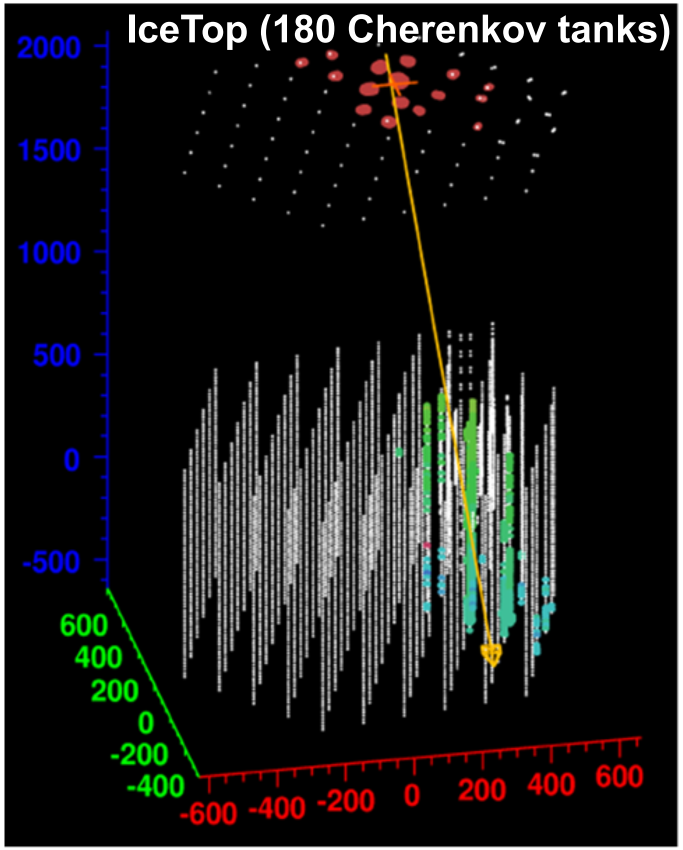
- *High duty cycle: >90%*
- *Event rates (40 strings)*
  - *Muons: ~1kHz*
  - *Neutrinos: ~100 / day*

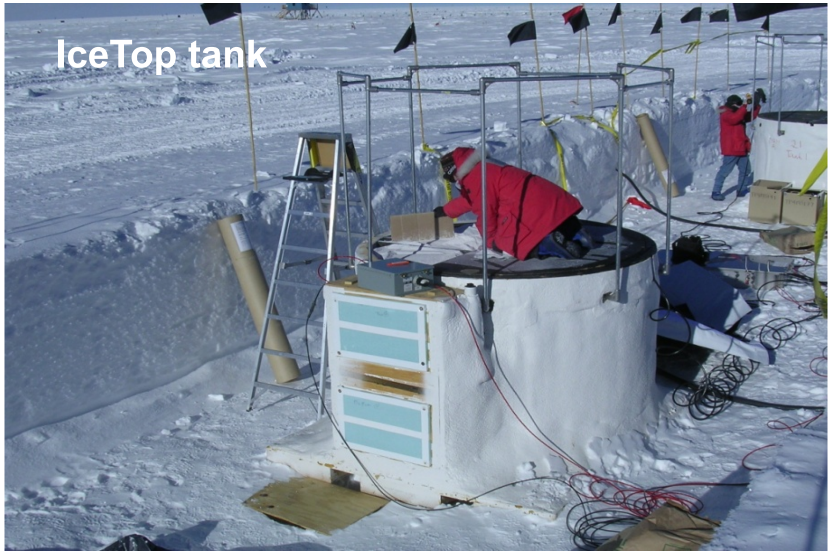
The DOM (Digital Optical Module)

Adapted from A.Karle, 2009

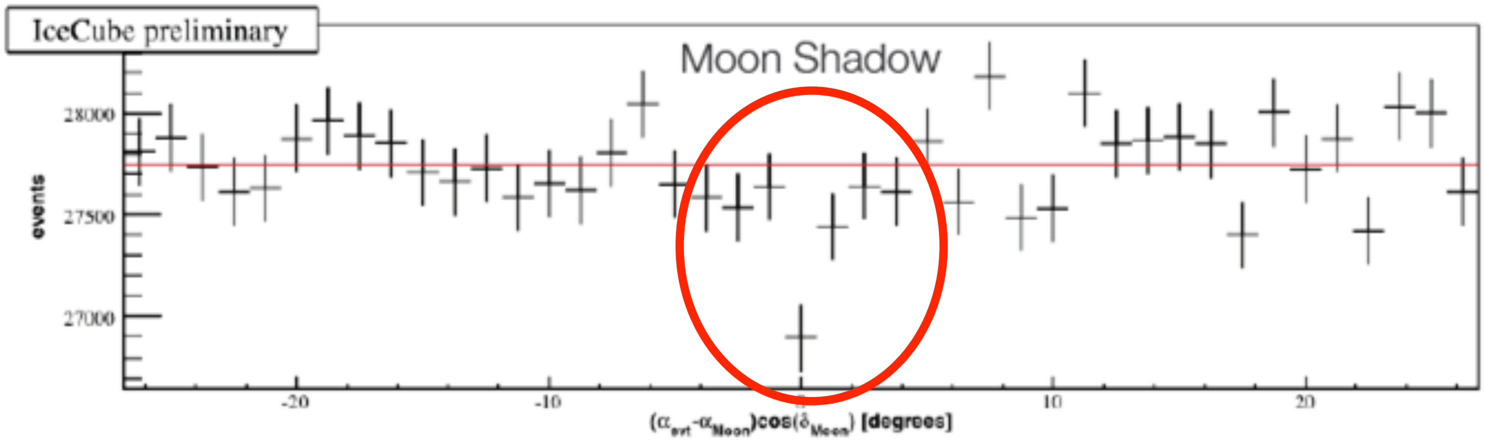
Strings	Year	Livetime	μ rate	ν rate
IC9	2006	137 days	80 Hz	1.7 / day
IC22	2007	275 days	550 Hz	28 / day
IC40	2008	~365 days	1000 Hz	110 / day
IC80*	2011	~365 days	1650 Hz	220 / day

IceCube: Angular Resolution

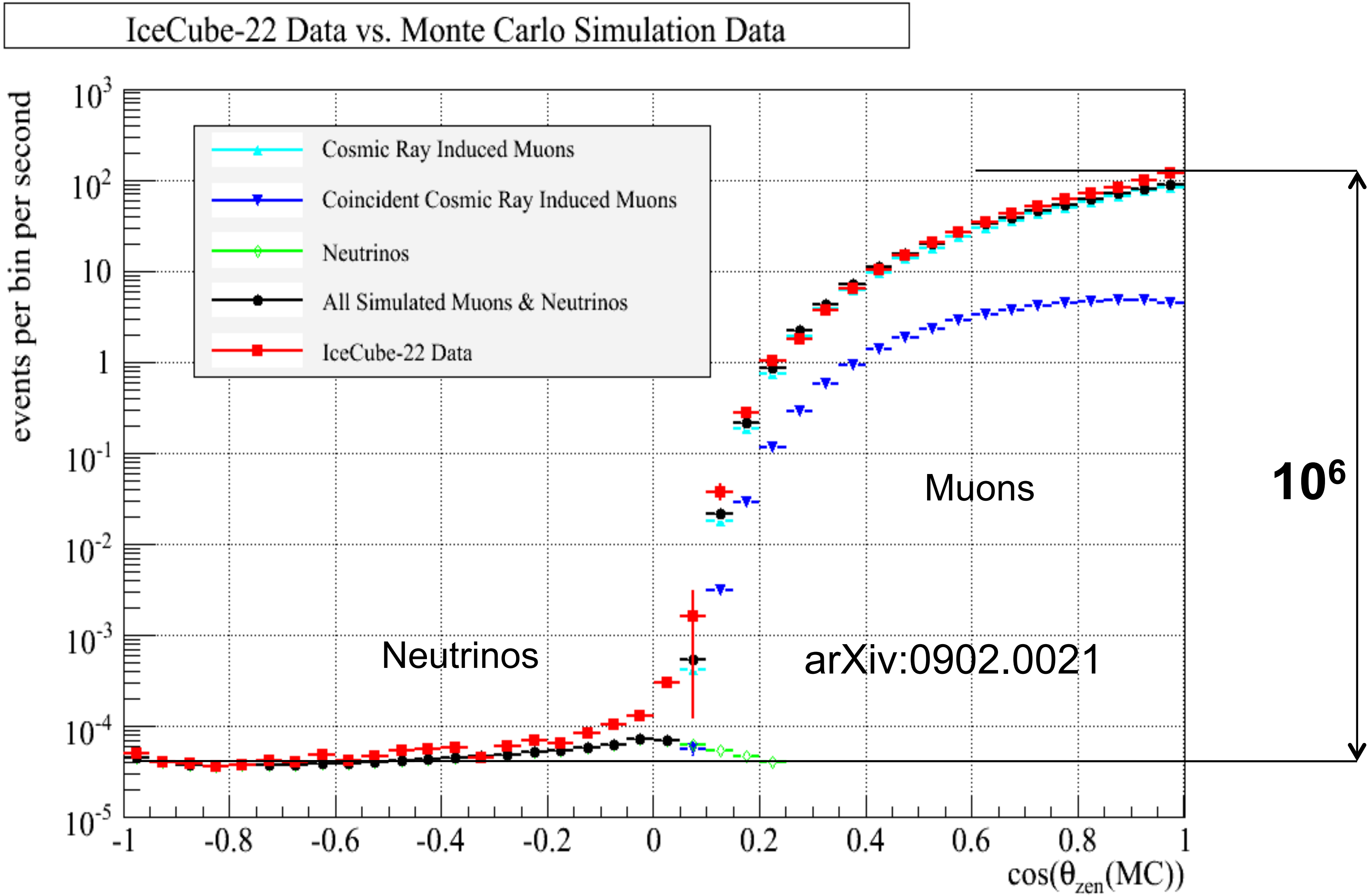




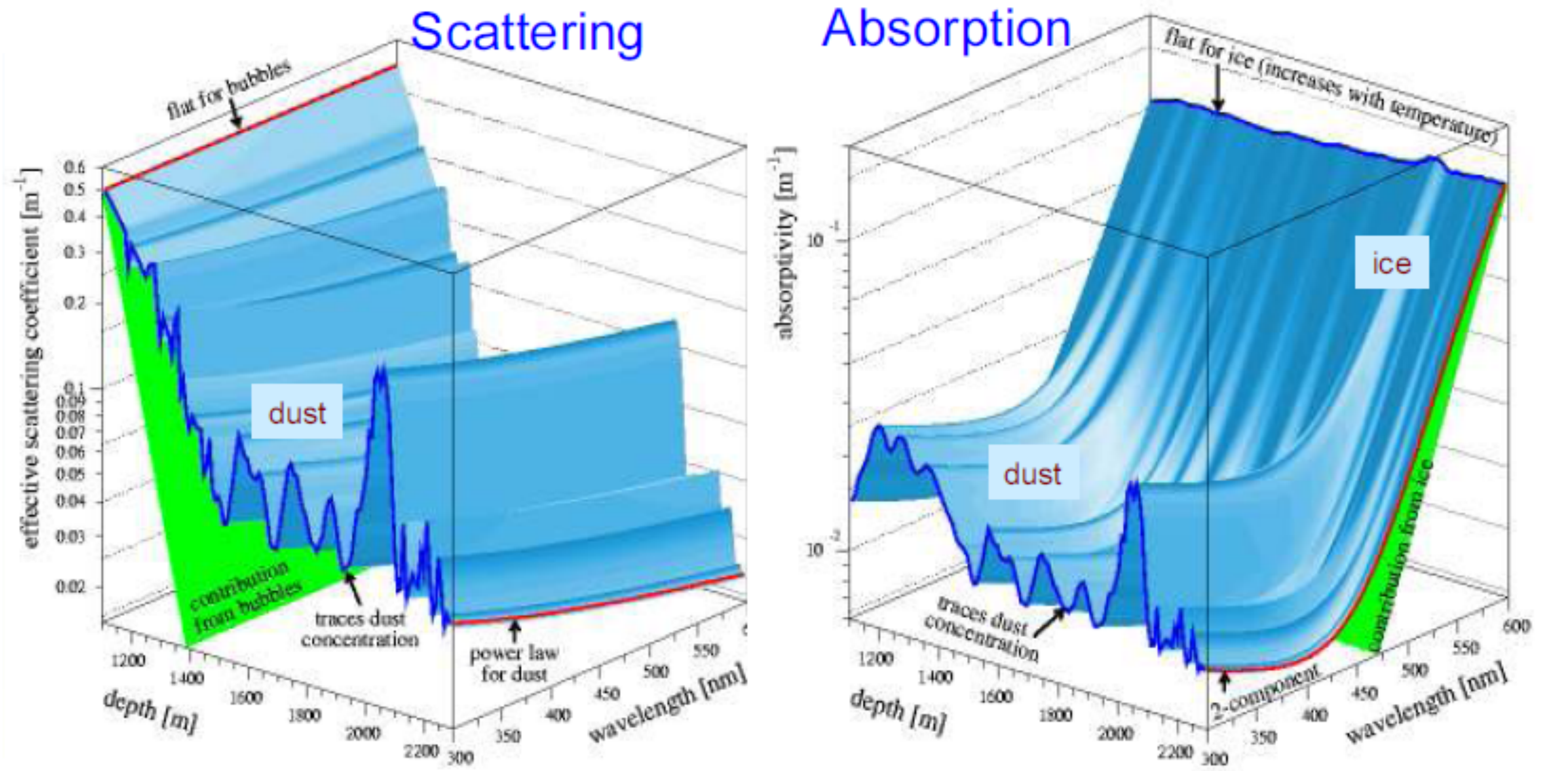
Icecube angular resolution evaluated with the surface shower array IceTop.
IC-22 : 1.5° | IC-40 : <1.0° | IC-80 : <0.5°



IceCube: All-sky muon flux (IC22,2009)

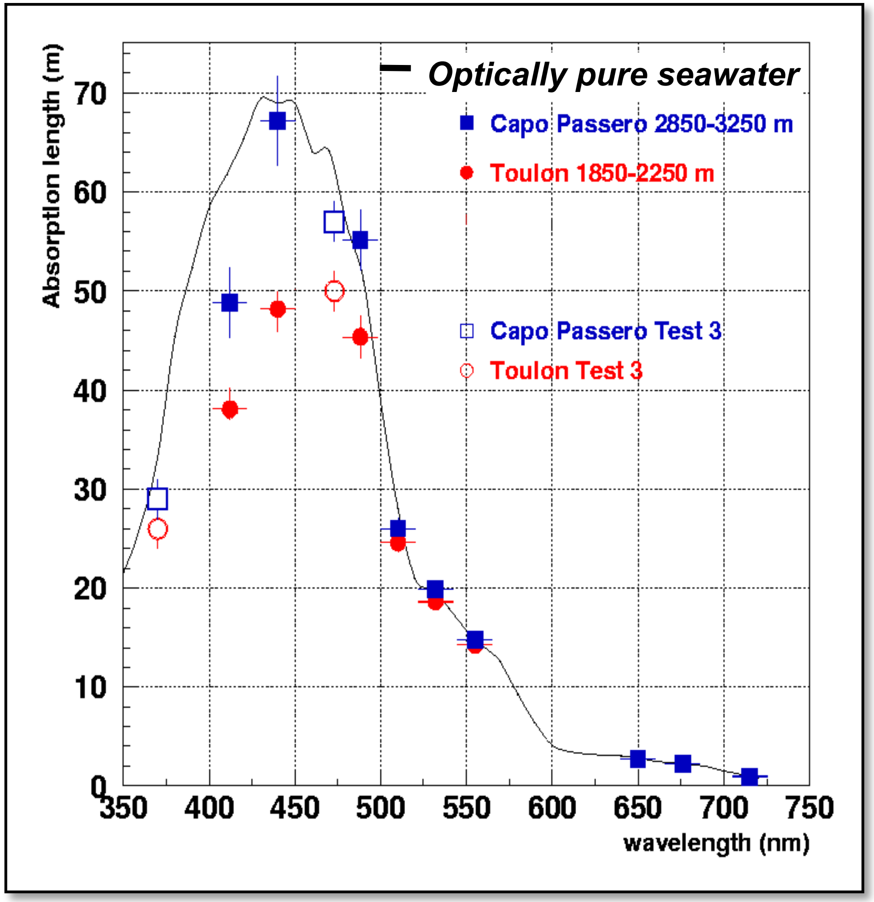


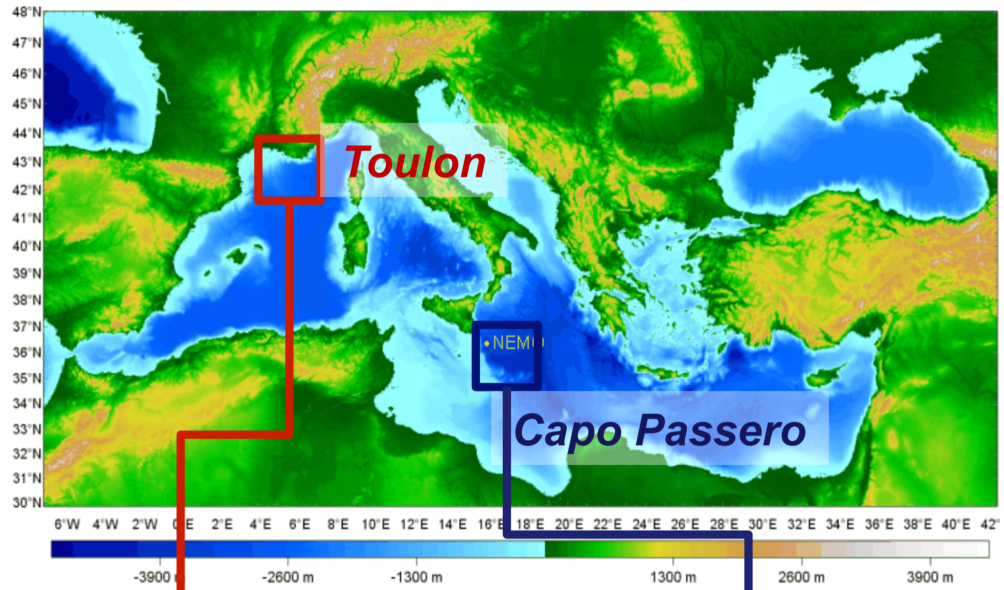
Ice optical properties

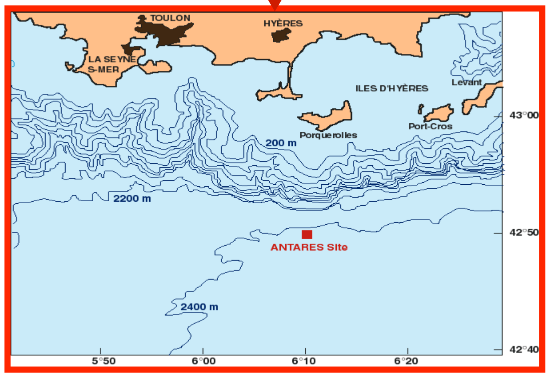


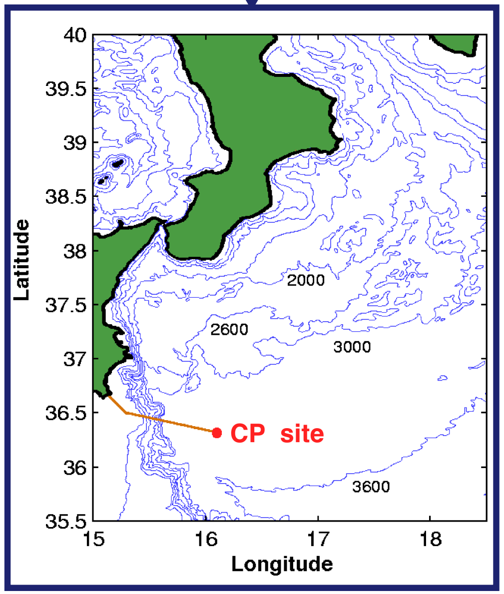
Absorption length is about 100 m
Scattering length is few cm (effective is few metres)

Water Optical properties

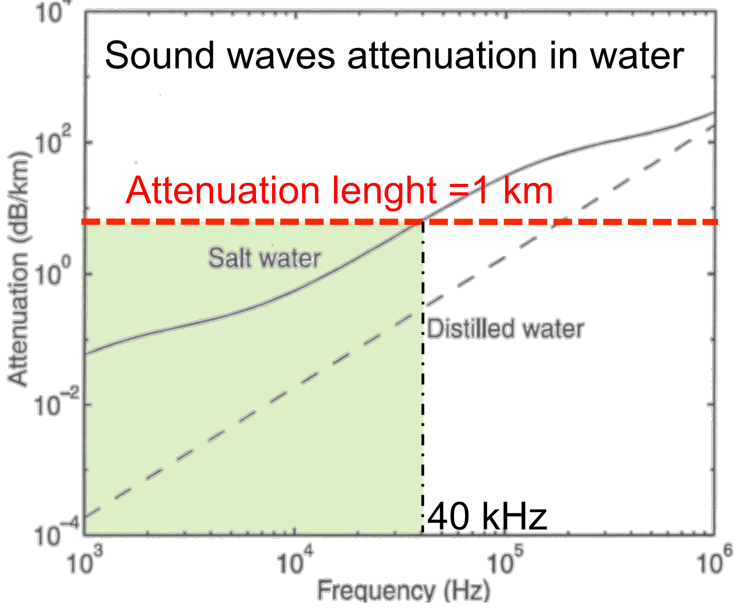


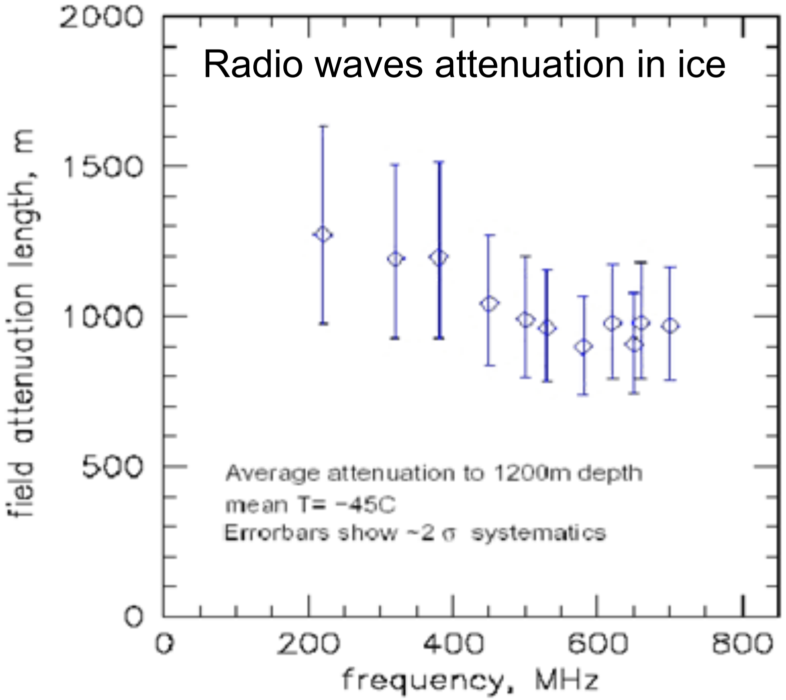


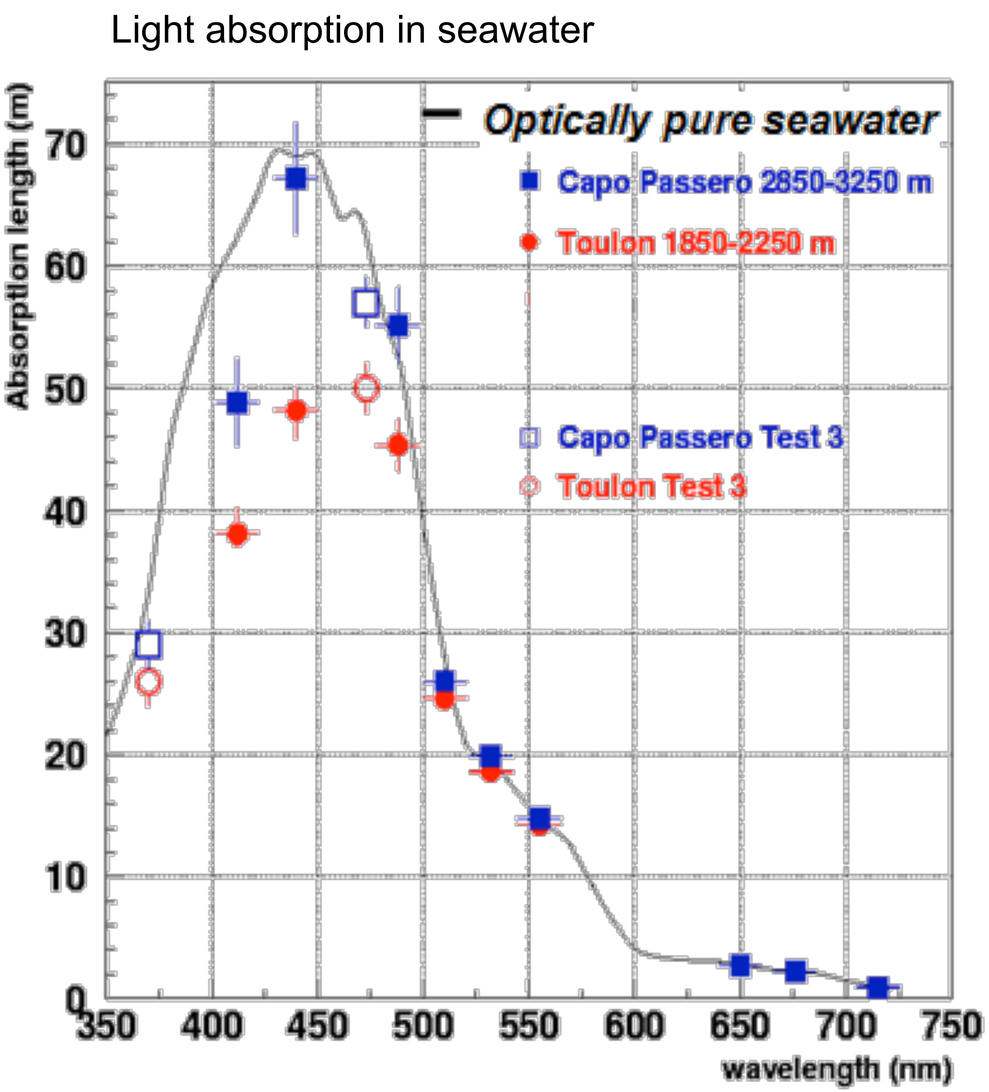




Acoustic and e.m. waves paropagation in water and ice



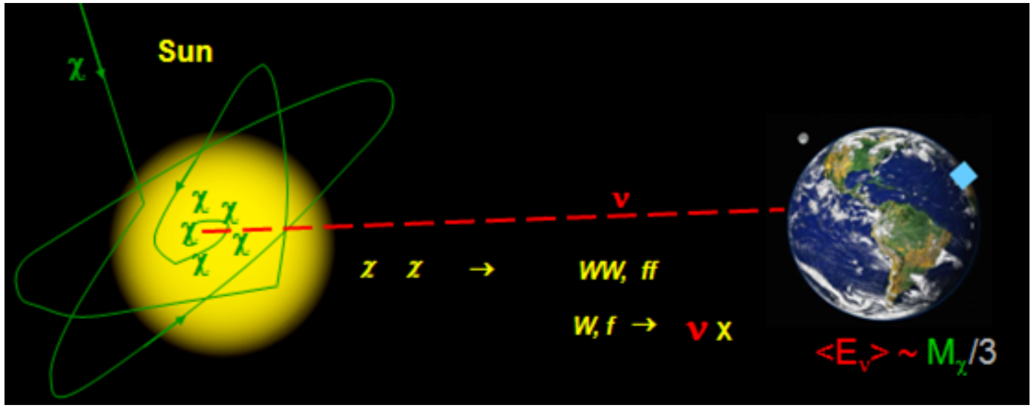




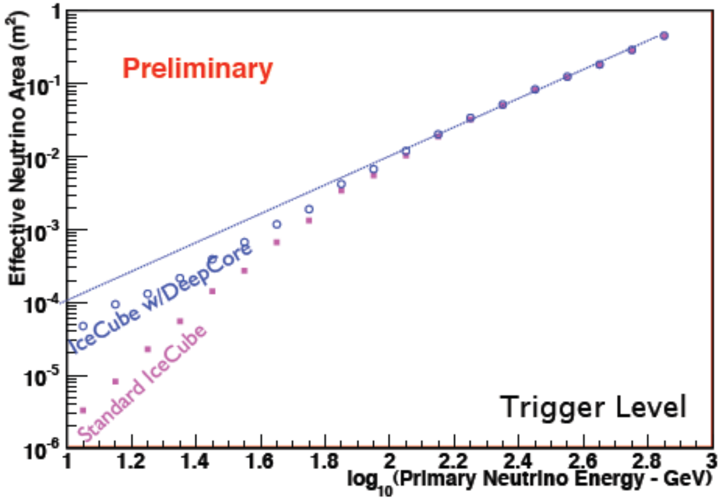
IceCube: WIMPs Detection

WIMPs gravitationally trapped via elastic collisions in the Sun.

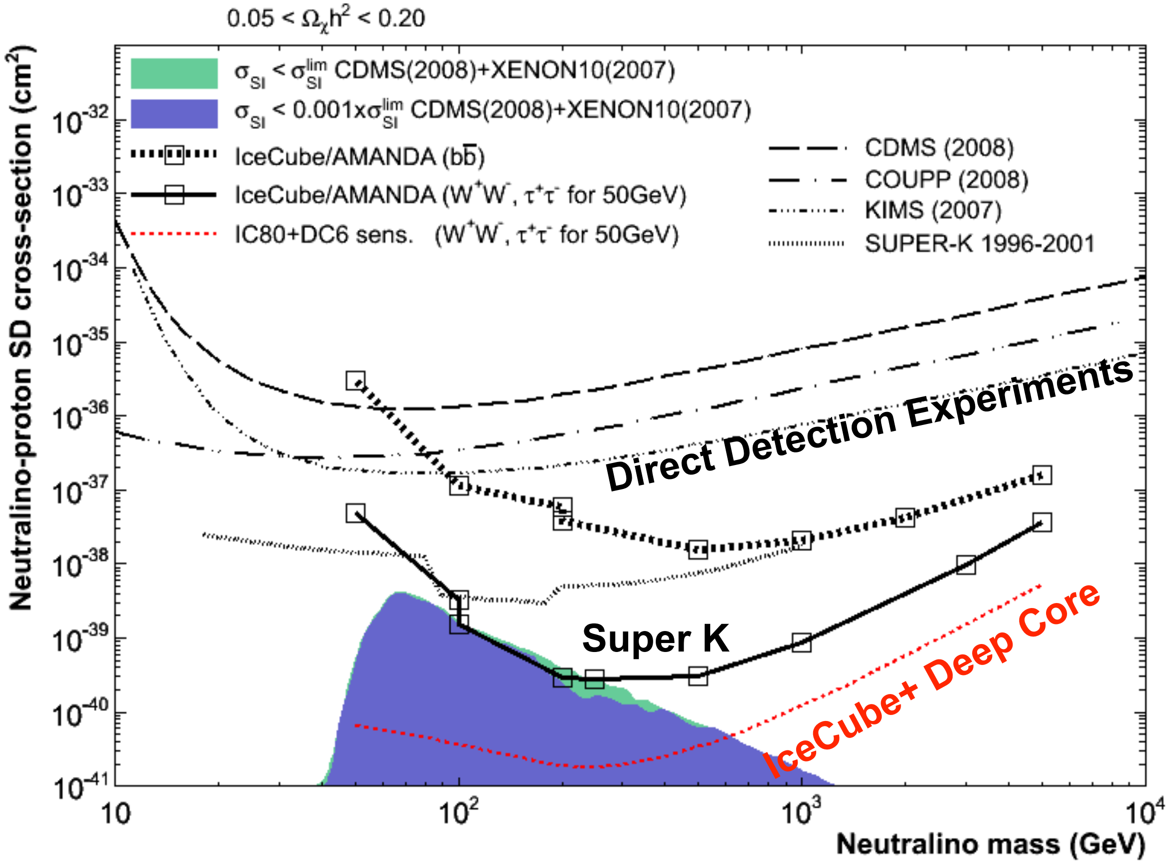
Expected # of events: few to O(1000) per year



Deep Core will implement IceCube capabilities at low E

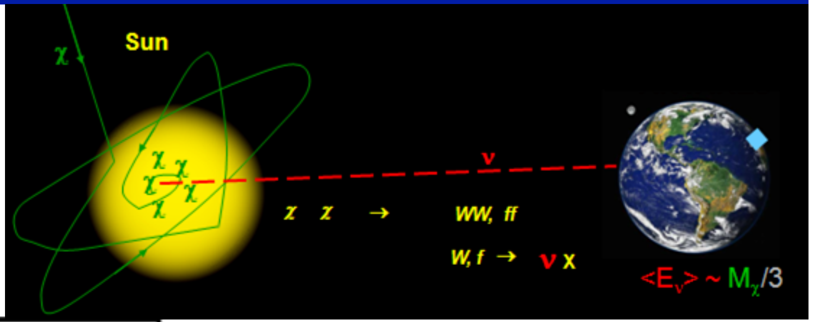


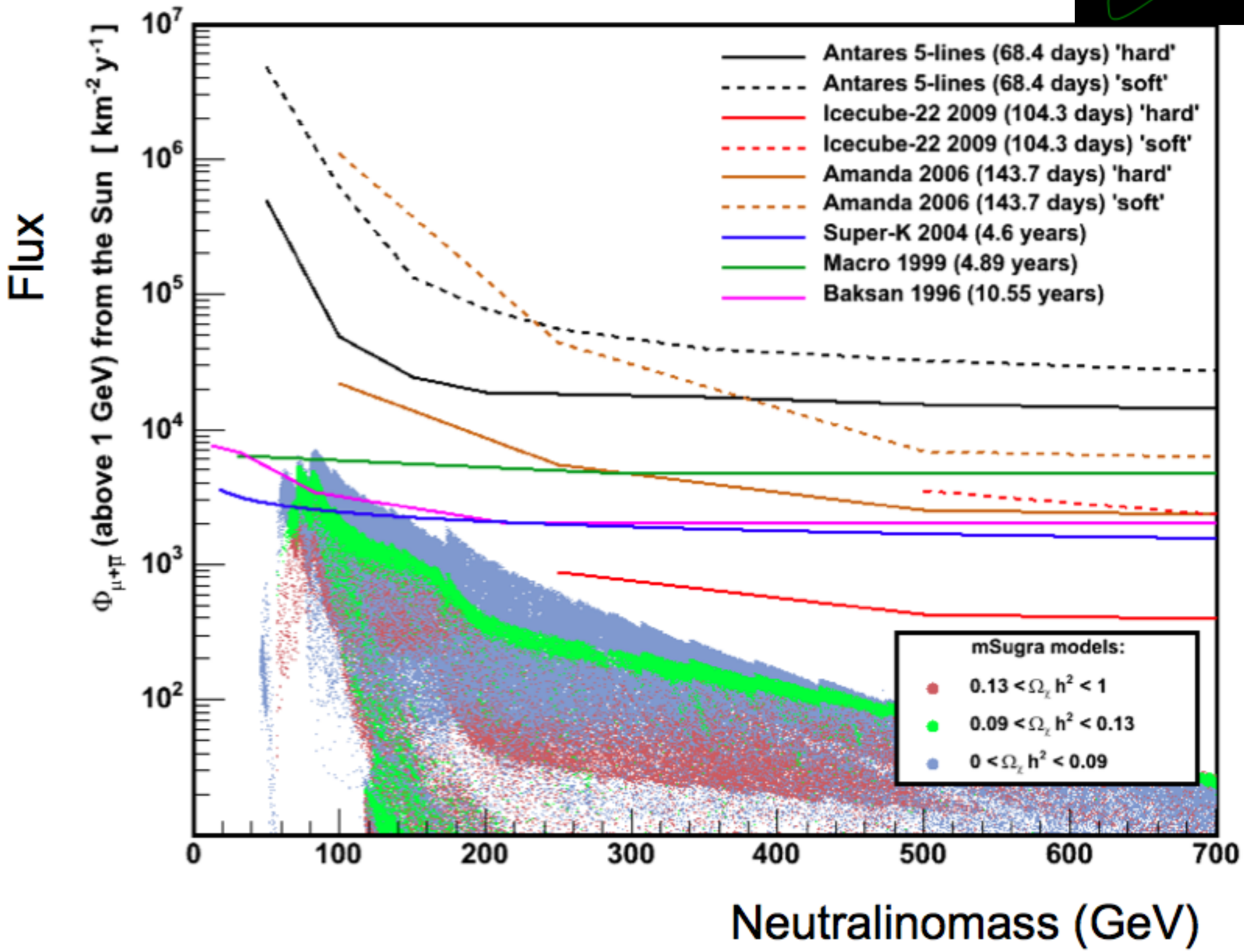
Deep Core + IceCube: veto for dowgoing muons (continuous Sun observation)



ANTARES: WIMPs detection

WIMPs gravitationally trapped via elastic collisions in the Sun.

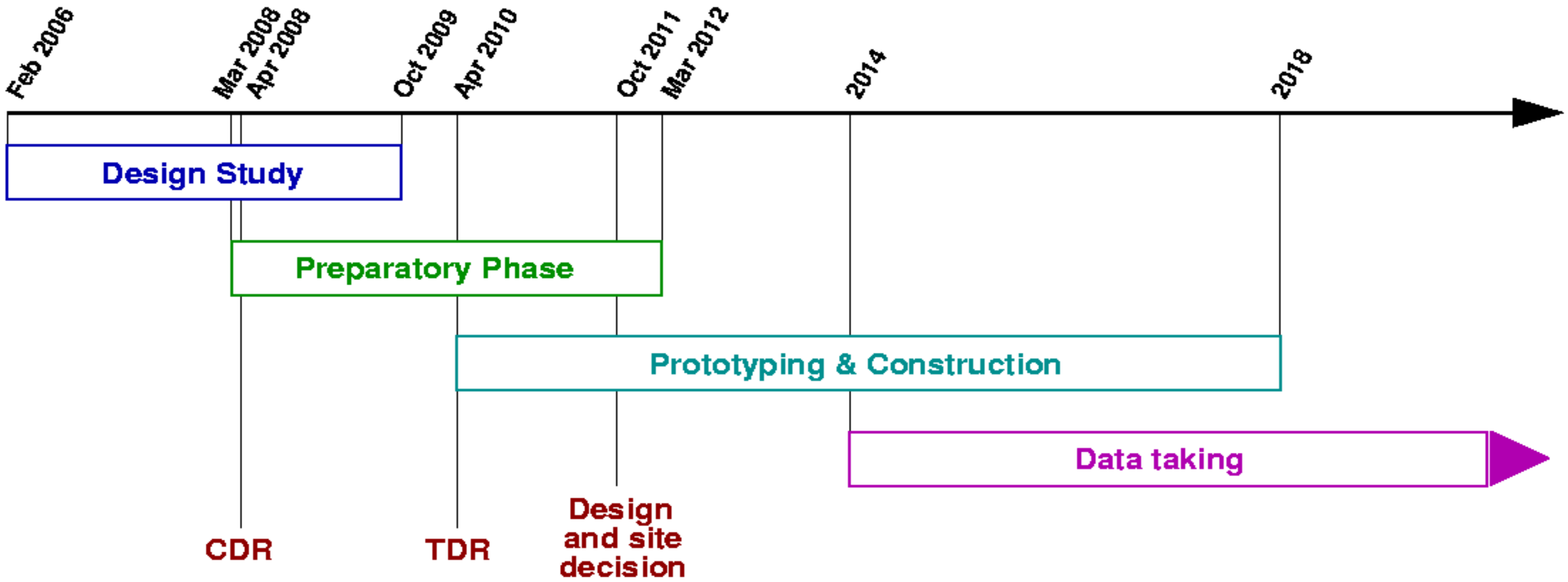




5-line data 2007

68 days detector live

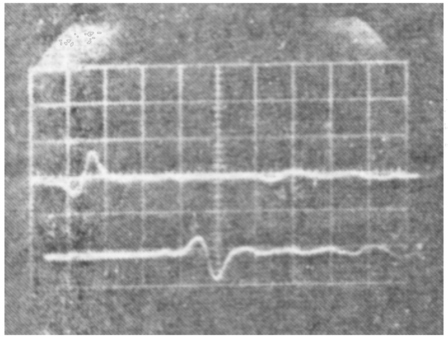
KM3NeT: Time schedule

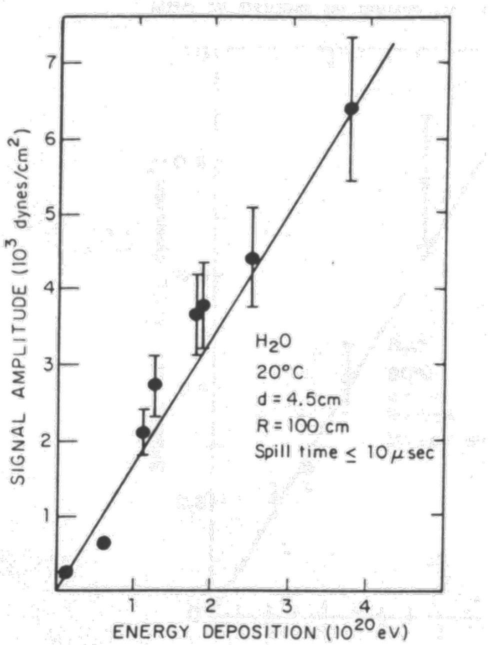


Accelerator experiments: results and open questions

Brookhaven NL (Harvard, SLAC) 1979

200 MeV proton beam (LINAC)
Spill time 3 to 20 μs
Beam diameter 4.5 cm
Energy deposited in water $10^{19} \rightarrow 10^{21}$ eV
Bipolar pulses observed
Dependency on C_p, T and on beam diameter confirmed (10% uncertainty)





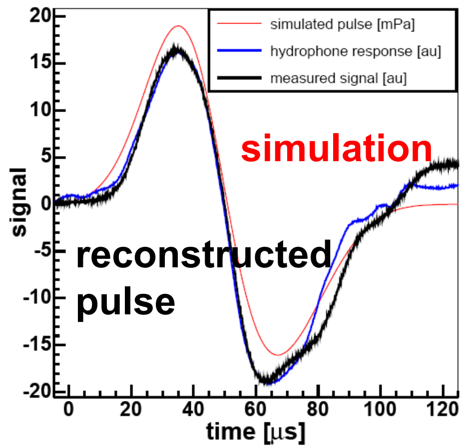
Recent measurements (2000's)

Uppsala: 177 MeV p
E= 10^{16} – $10^{17.5}$ eV
Bipolar pulse observed
Unclear dependence on temperature
Other contibution to observed pulses ?

ITEP Synchrotron: 100, 200 MeV p
E= 10^{15} – 10^{20} eV
Measured pressure increses linearly with E

Erlangen Laser Nd-YaG
E= 10^{17} – 10^{19} eV
Dependence on C_p confirmed

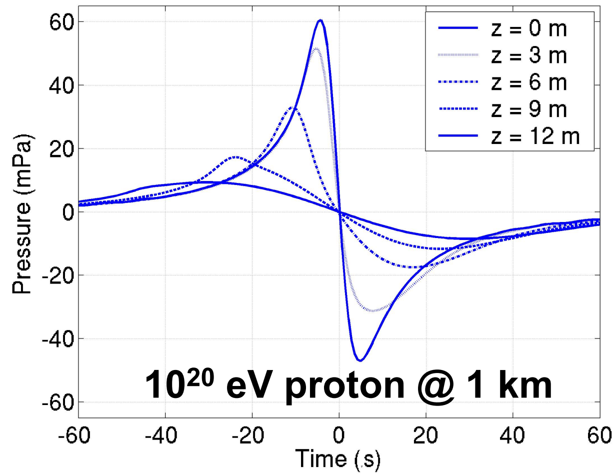
A well calibrated shower energy vs. acoustic amplitude relation is still missing

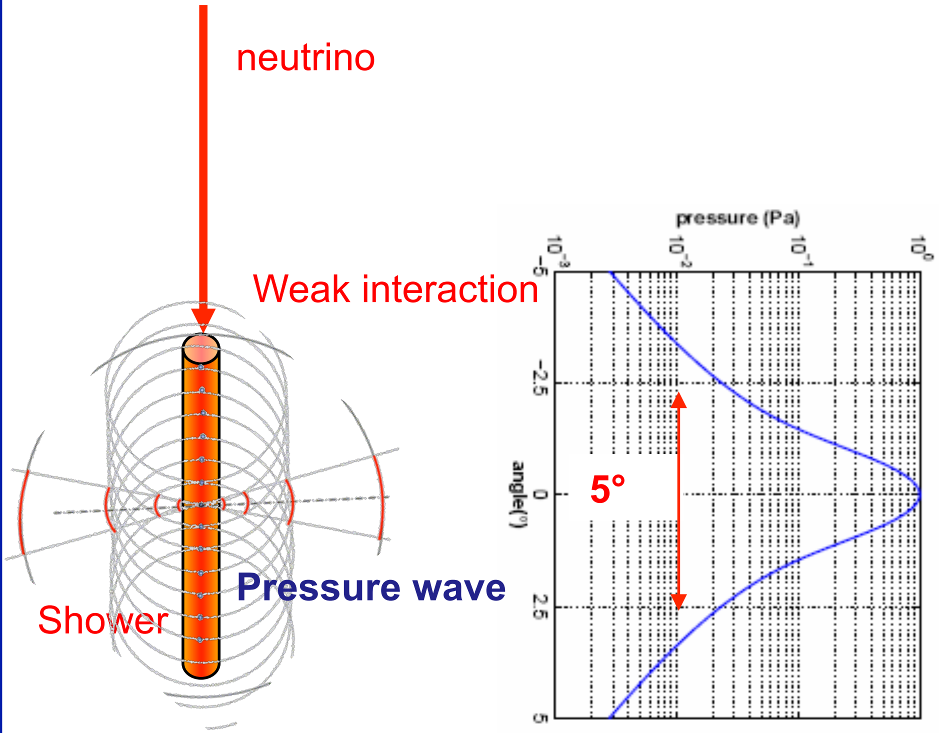


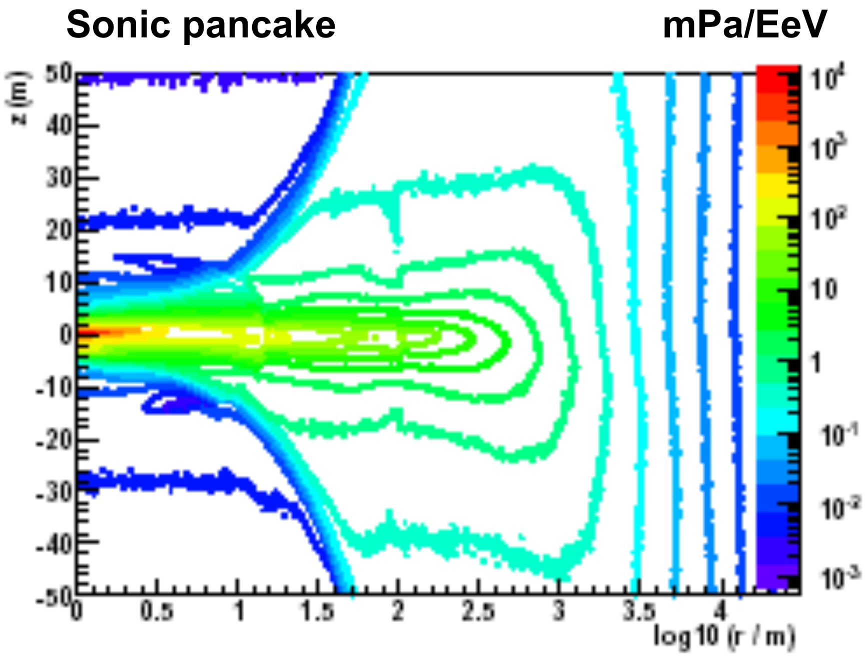
Coherent sound emission: angular dependency

Based on the Learned paper 1979

The simultaneous sound production along the shower results in a coherent emission in the plane perpendicular to the shower axis. The "pancake" is very collimated and the pulse changes as a function of angle both in amplitude and shape.

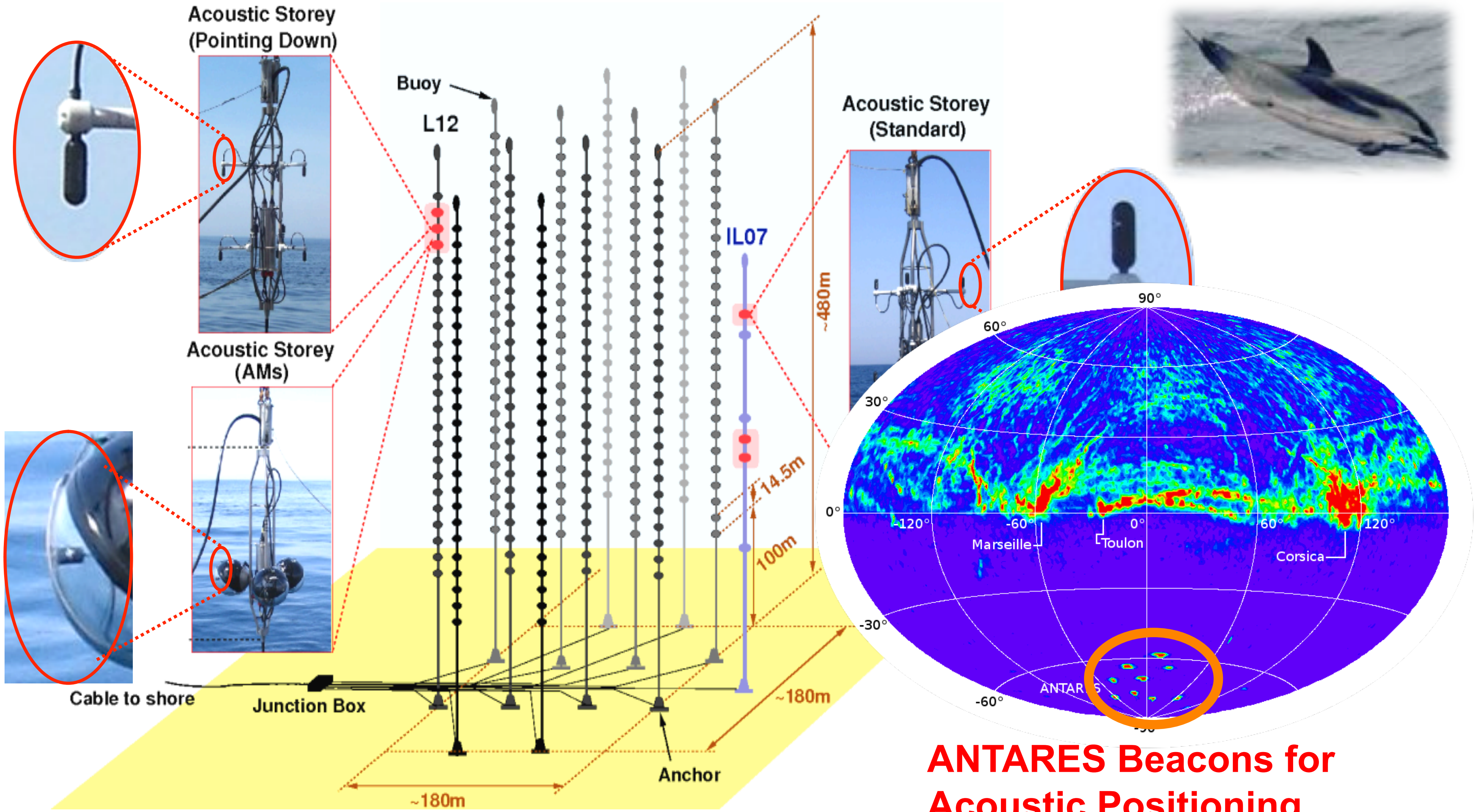






Acoustic detection in ANTARES: AMADEUS

AMADEUS comprises a series of hydrophones on two ANTARES lines
A test bench to study the feasibility of a large acoustic UHE neutrino detector
Study of acoustic environment and backgrounds
Study of methods to reconstruct event direction

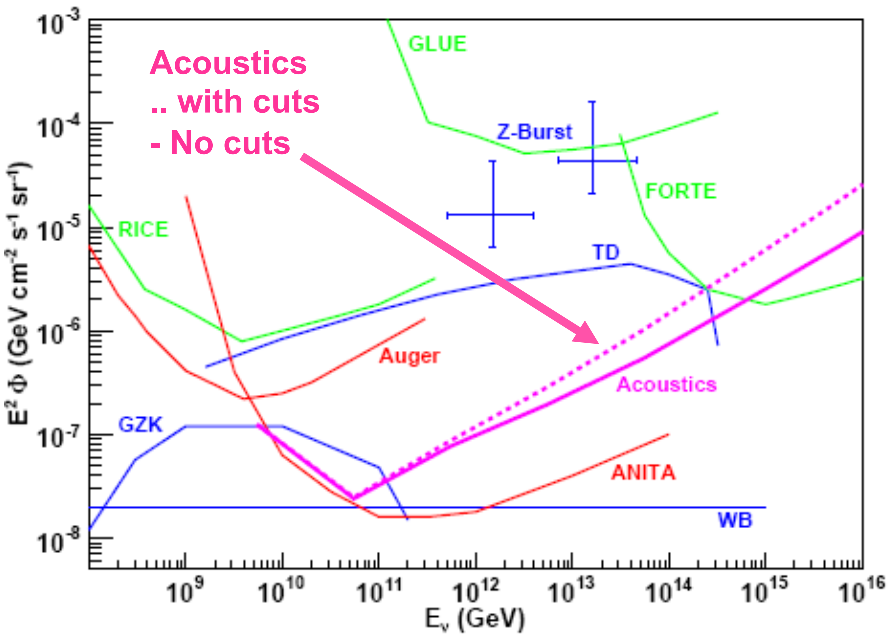


ANTARES Beacons for Acoustic Positioning

Acoustic detectors expected sensitivity

Standard approach

Largely spaced detectors for GZK neutrino detection

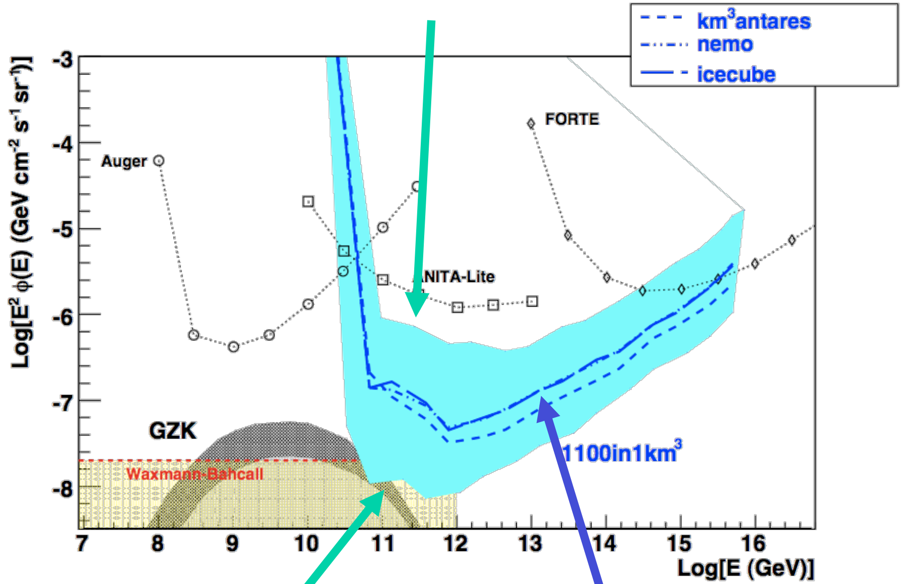


1500 km^3, 200 hydros per km^3
5 years
threshold 5 mPa

Calculation from ACORNE (Sheffield)

1100 hydros in 1 km^3

1 year, threshold 35 mPa



km^3 regular geometries
5 years, 15 mPa, 95% CL

10 years, threshold 5 mPa

A “complementary” km^3-scale detector ?

Just a raw idea: possible neutrino event calorimetry ?

Acoustic system triggered by KM3NeT to reduce acoustic background (time and direction)