ANTARES and KM3NeT :
Deep Sea Telescopes to study the Universe

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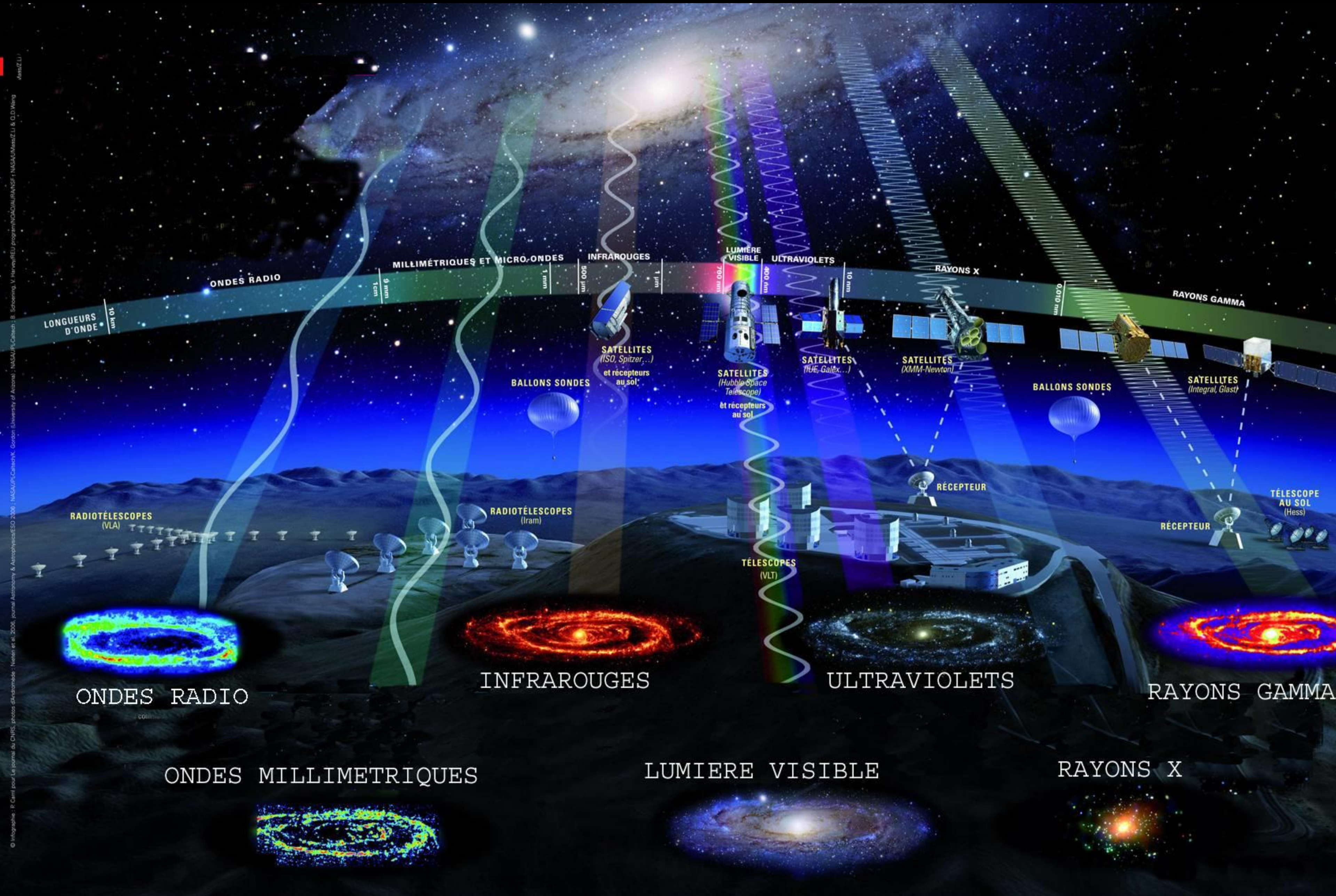
Centre de Physique des Particules de Marseille

Physics for both infinities @ CPPM - July 2017

Multi-Wavelengths Astronomy

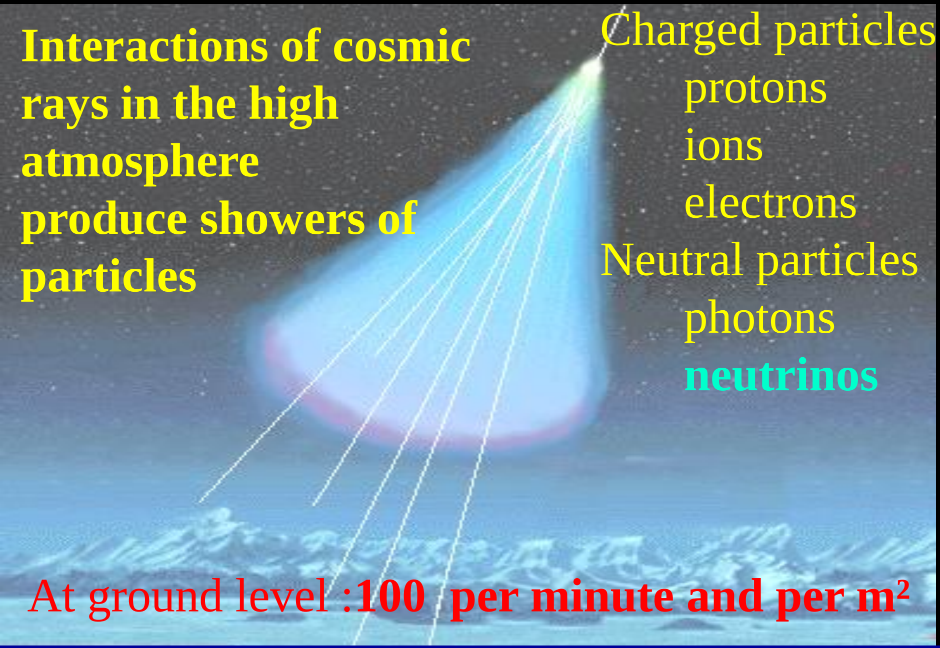


Cosmic Rays

Interactions of cosmic rays in the high atmosphere produce showers of particles

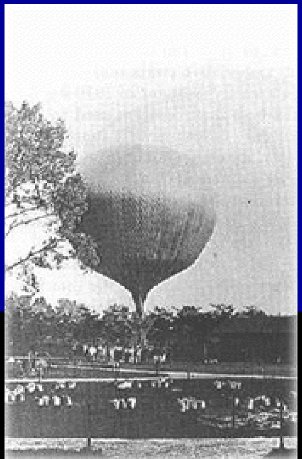
Charged particles
- protons
- ions
- electrons

Neutral particles
- photons
- **neutrinos**

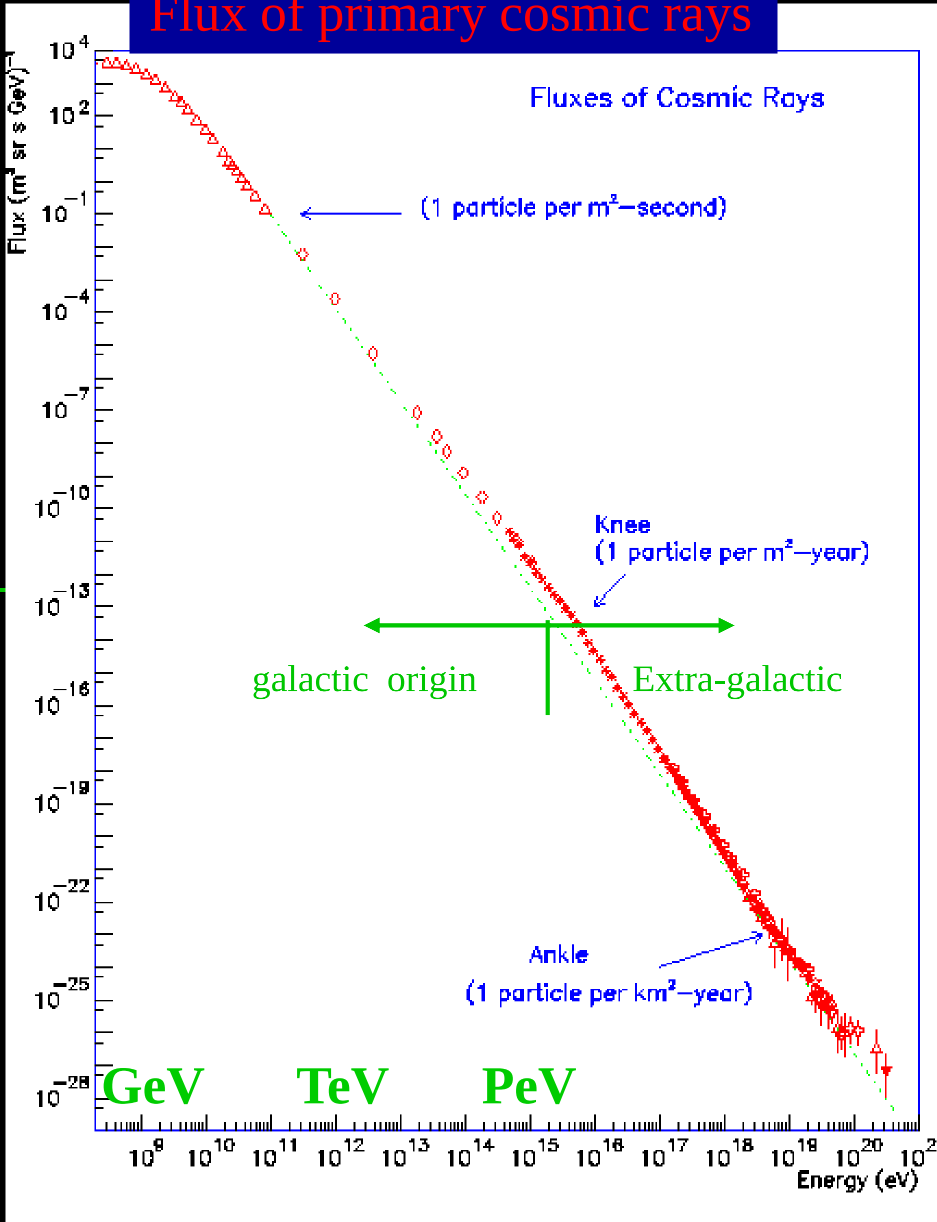


At ground level :**100 per minute and per m²**

100 years after their discovery, the origin of cosmic rays is still very unclear



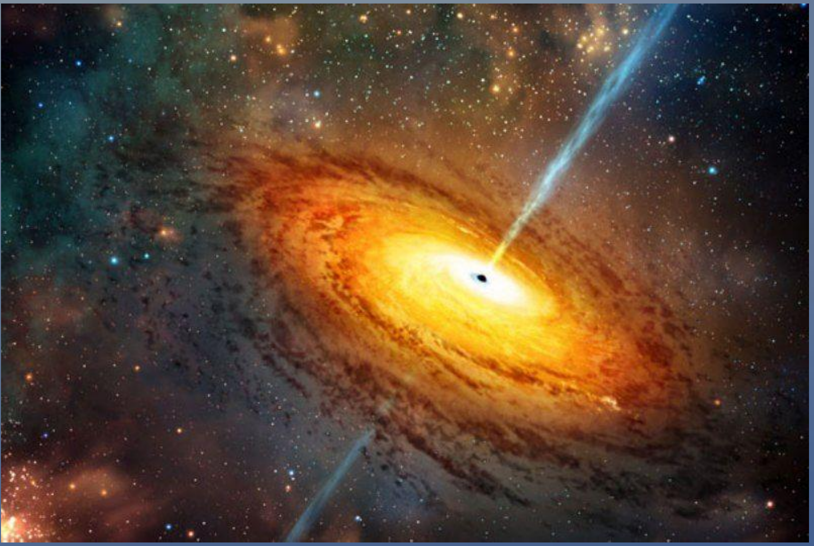
Flux of primary cosmic rays



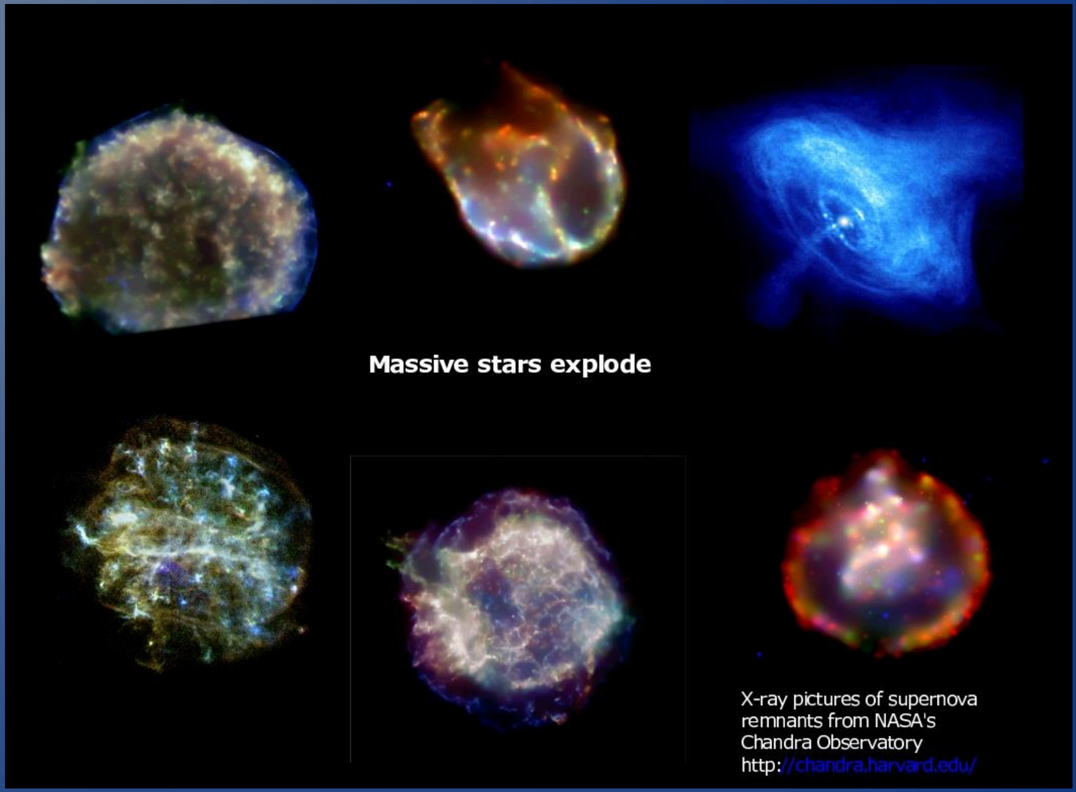
Potentiel Sources : Supernovae, Black Holes,…

High Energy Cosmic Rays come from the most violent phenomena of the Universe...

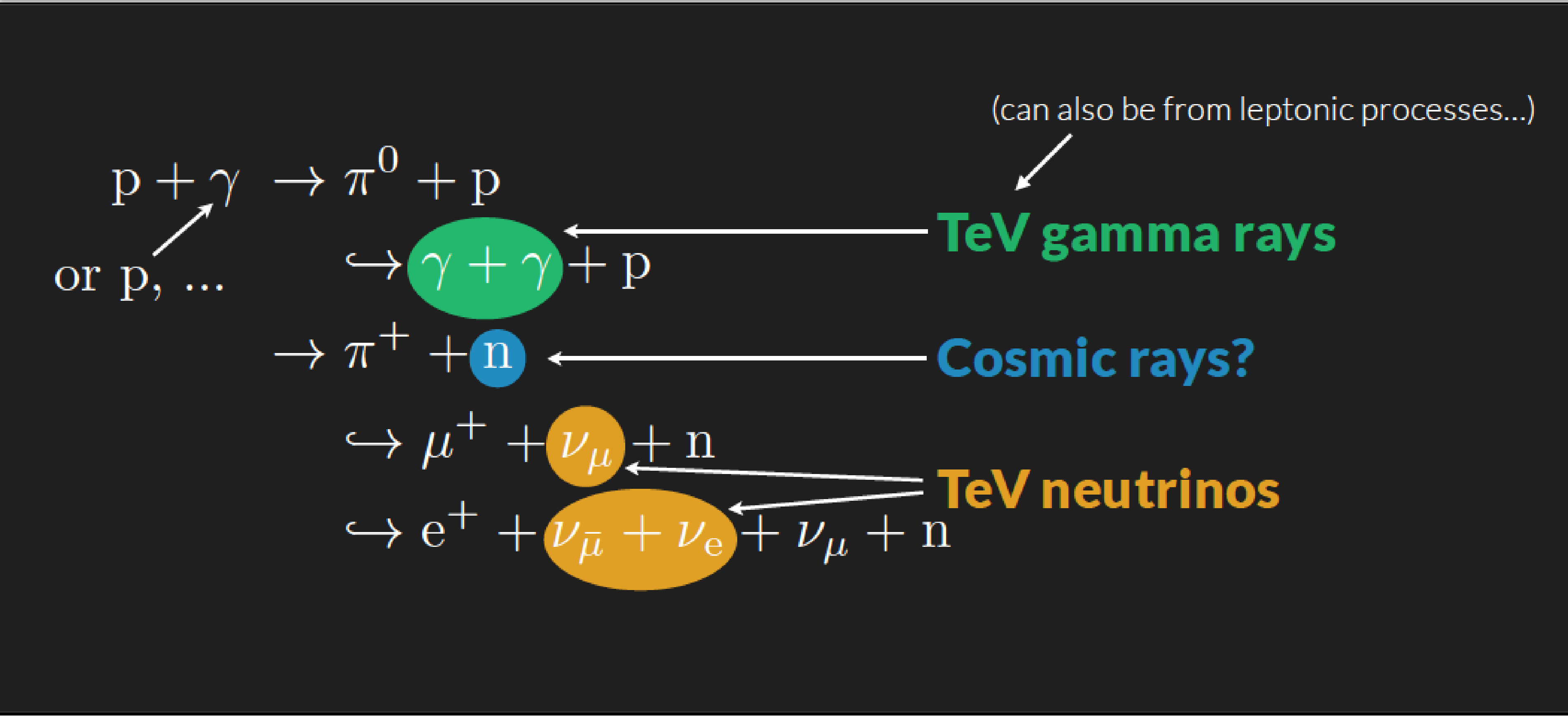
Massive star explosions (Supernovae)



Super-massive Black Holes (Active Galactic Nuclei)



The CR-Gamma-Neutrino Connection

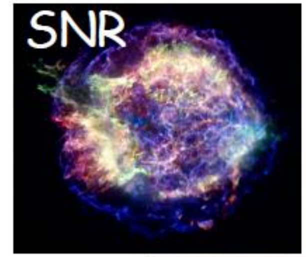


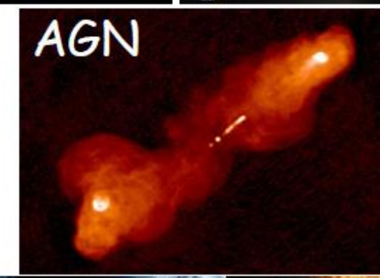
$\nu_e:\nu_\mu:\nu_\tau$ =1:2:0 source —oscillations→ $\nu_e:\nu_\mu:\nu_\tau$ =1:1:1 Earth

$$E_\nu \approx \frac{1}{20} E_P \approx \frac{1}{2} E_\gamma$$

High-energy neutrino astronomy?

High-energy neutrino production processes





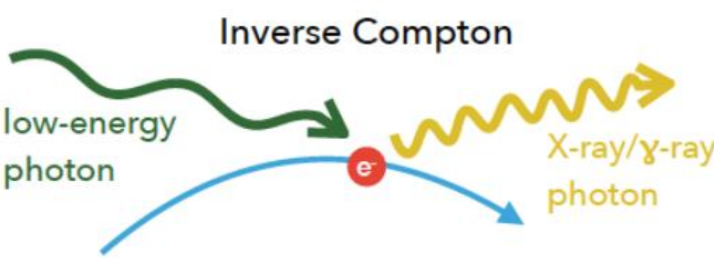
- **Hadronuclear** (e.g. galactic cosmic rays)

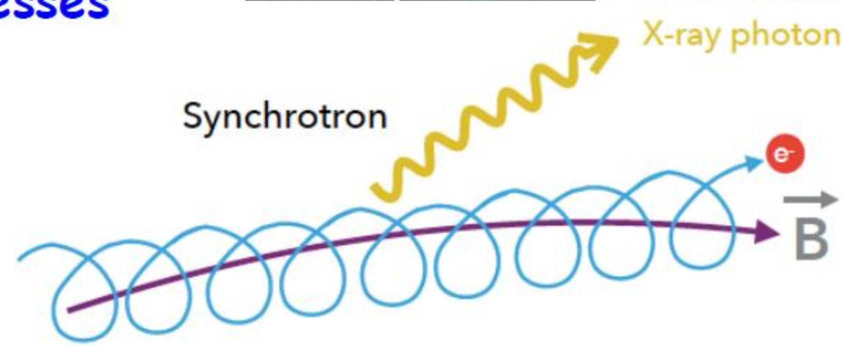
$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

- **Photohadronic** (e.g. gamma-ray bursts, AGNs)

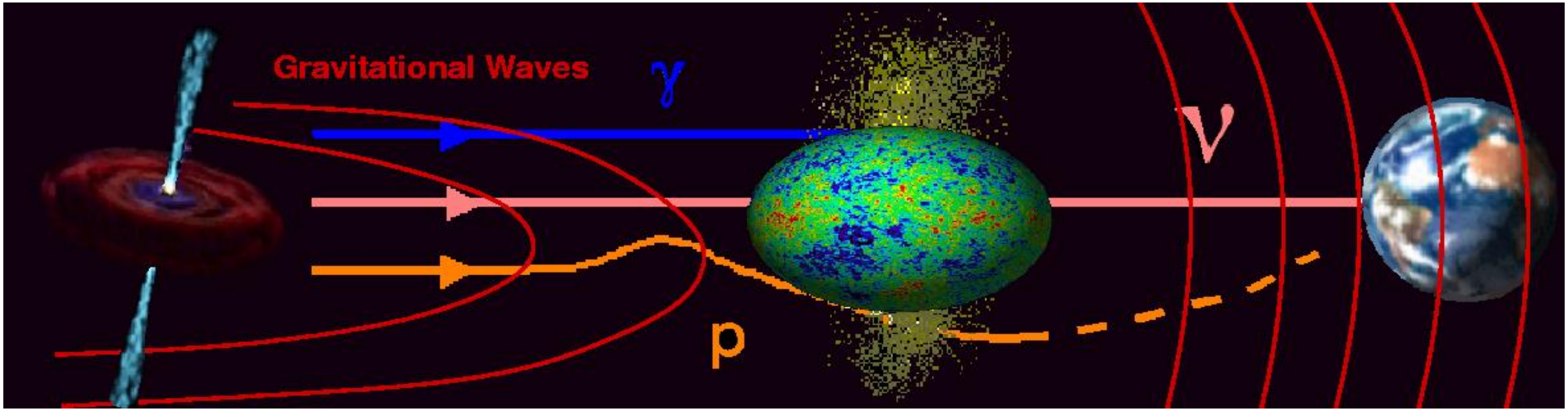
$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+ \nu_\mu \rightarrow n\,e^+ \nu_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

- But γ-rays also from **leptonic** processes





Neutrinos and Multi-Messenger Astronomy



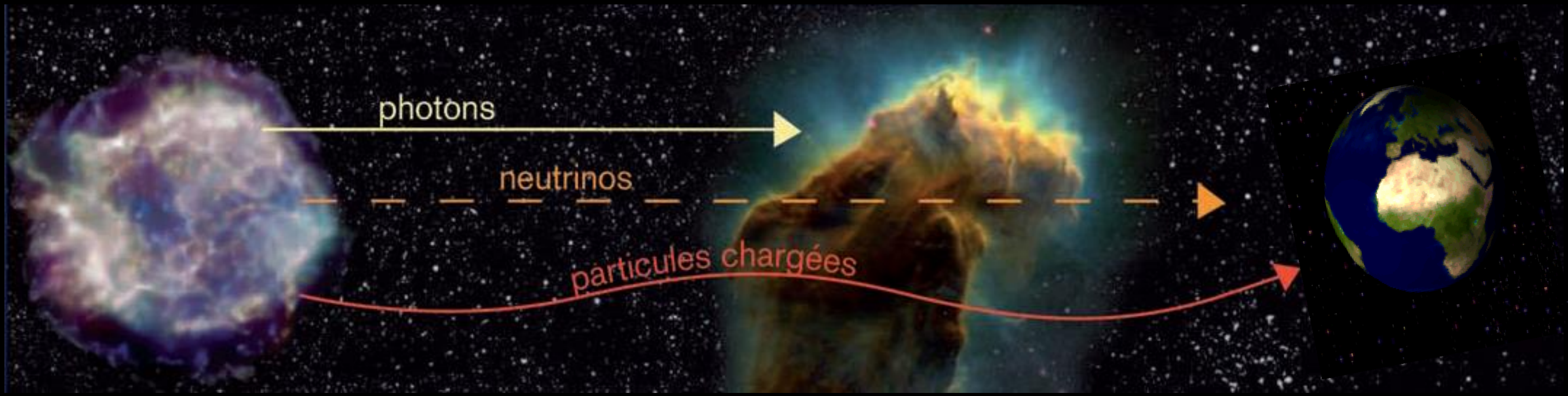
Cosmic Rays
Subject to deflection by magnetic fields
Horizon limited by GZK cutoff
Large time delay w.r.t. optical signals

Photons
leptonic and hadronic processes-> confusion
Absorbed at high energies and large distances

Neutrinos
Unambiguous signature of hadronic acceleration
Not deflected by magnetic fields or absorbed by dust
Horizon not limited by interaction with CMB/IR
Escape from region of high matter density
Time correlated with EM signals
Large sky survey
24/24, 7/7

-> identify the cosmic ray sources

Why looking for neutrinos ?



Pros for neutrino :

- Electricaly neutral, not deviated by magnetic fields ➔ astronomy
- No absorption ➔ observation over cosmological distances
- Interacts VERY weakly ➔ escapes from dense regions of the Universe

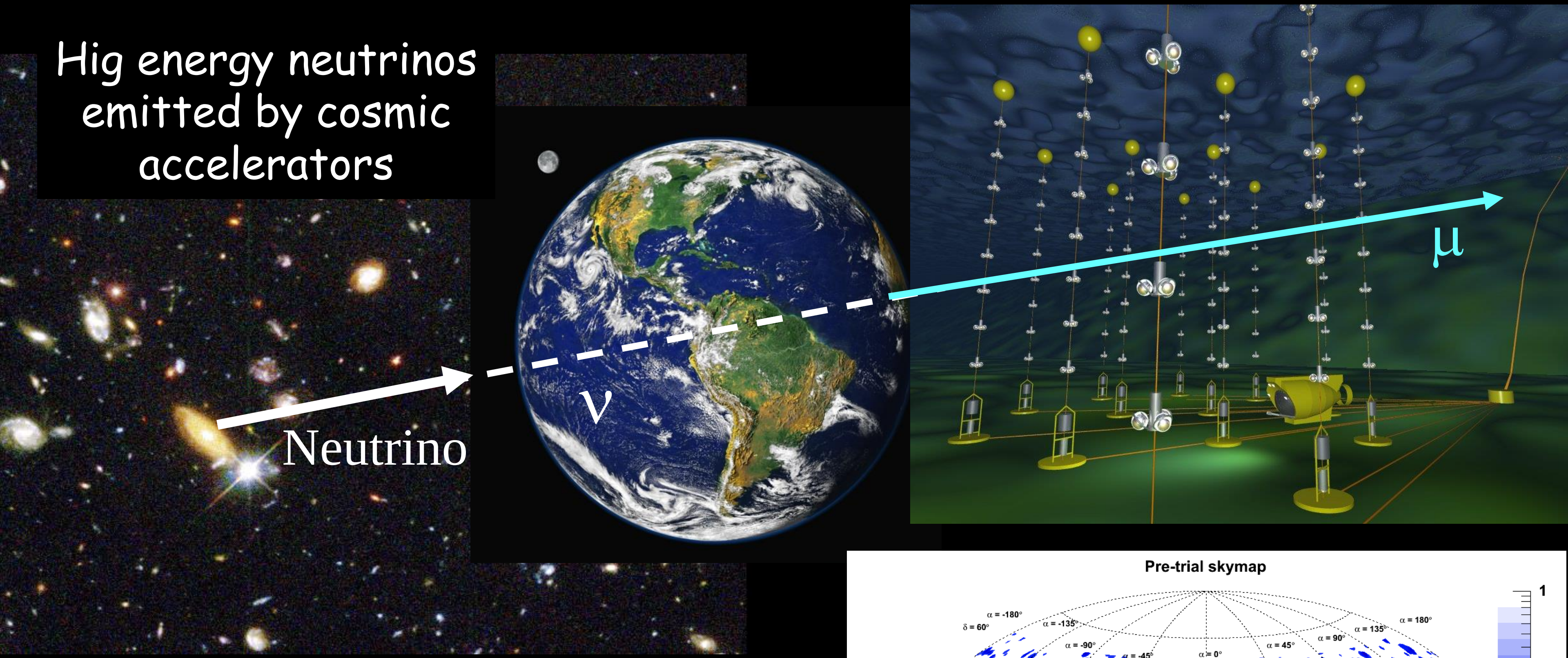
Cons :

Over 10 billions of neutrinos coming from the Sun and crossing the Earth, ONLY 1 will interact !!!

➔ Necessity of a HUGE detection volume

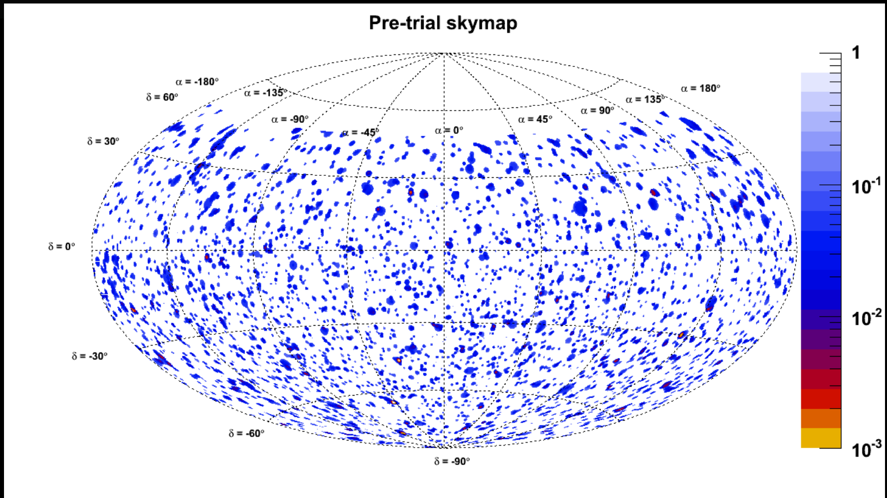
A new window over the Universe

Hig energy neutrinos emitted by cosmic accelerators

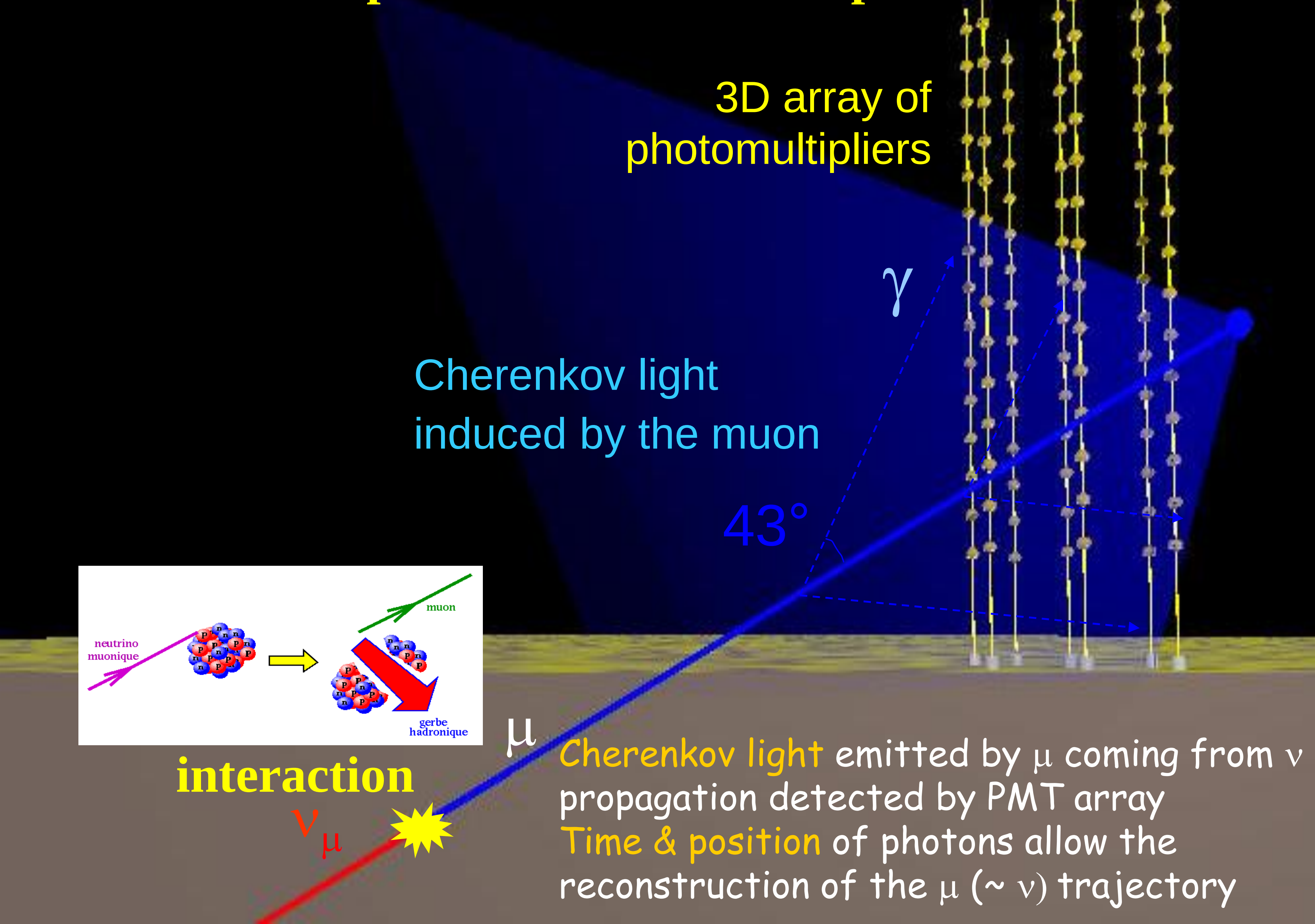


Neutrino Astronomy :

skymap of the most catastrophic events of the Universe



Detection Principe of Neutrino Telescopes



Cherenkov light emitted by μ coming from ν propagation detected by PMT array

Time & position of photons allow the reconstruction of the μ (~ ν) trajectory

Existing Neutrino Telescopes

ANTARES/KM3NeT

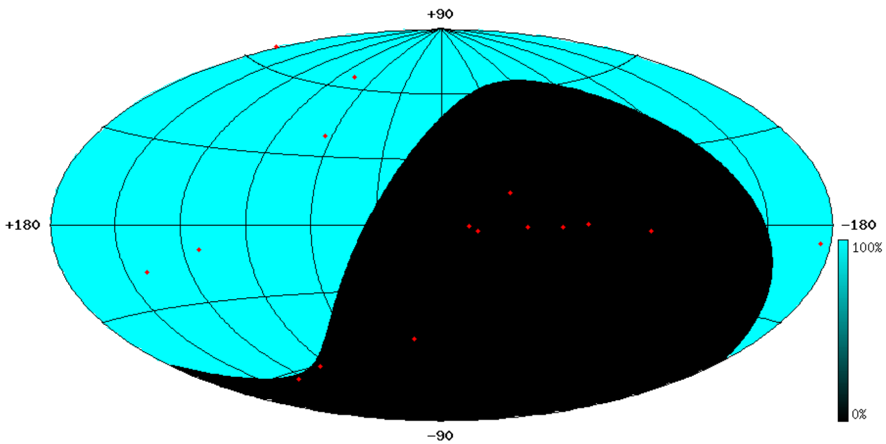
BAIKAL

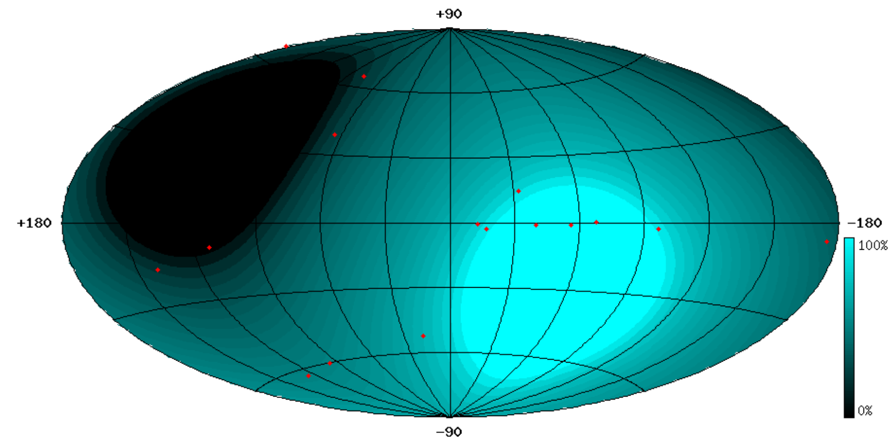
AMANDA/Ice Cube

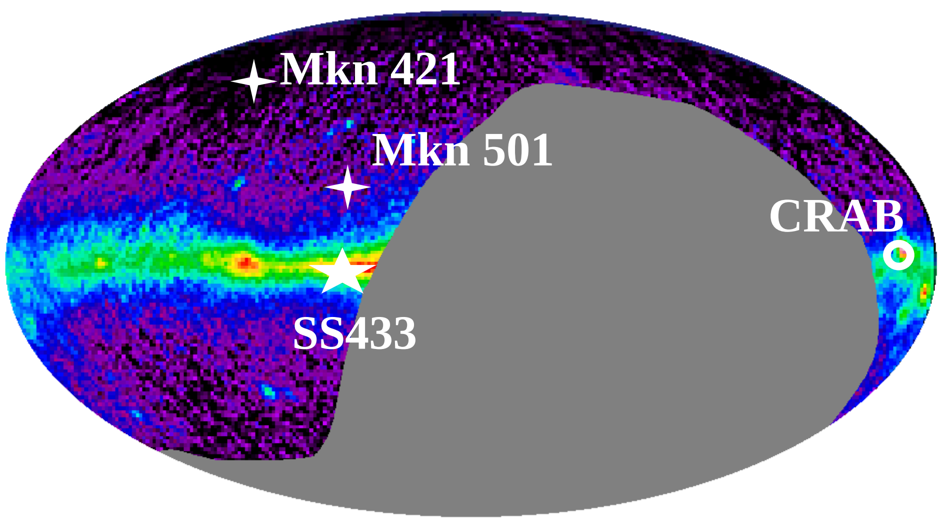
Region of Sky Observable by Neutrino Telescopes

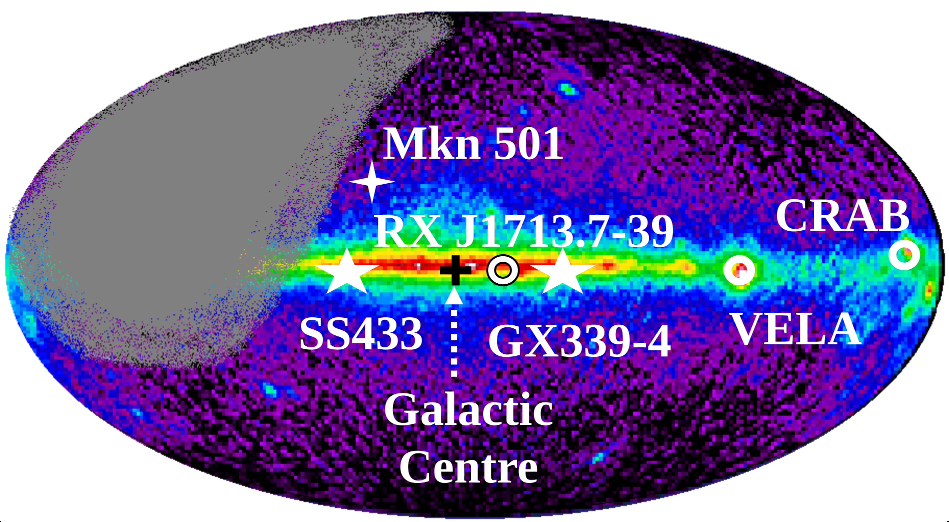
IceCube (South Pole) | **ANTARES (43° North)**

(ice: ~0.6°) Angular resolution (water: ~0.3°)

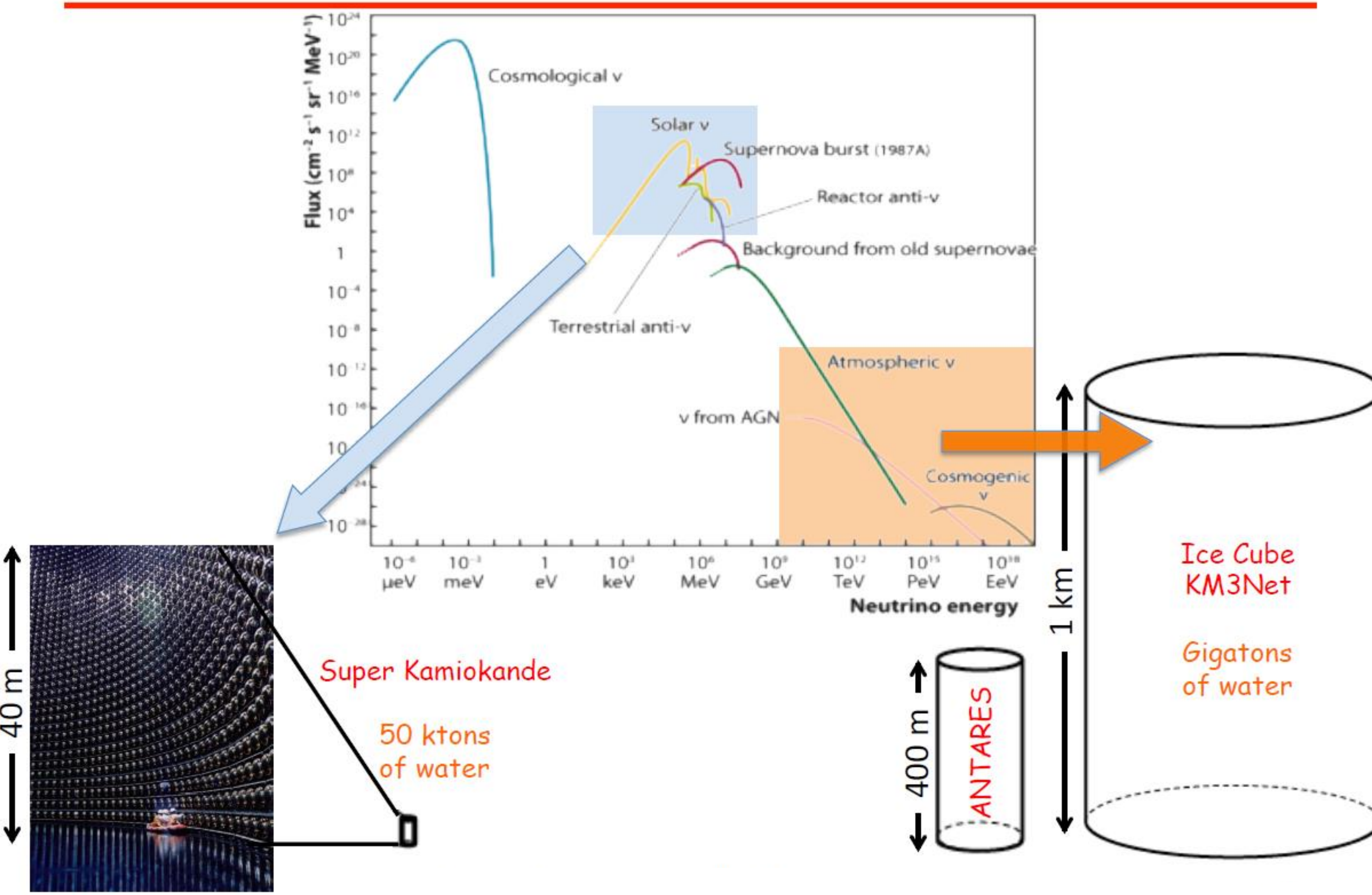


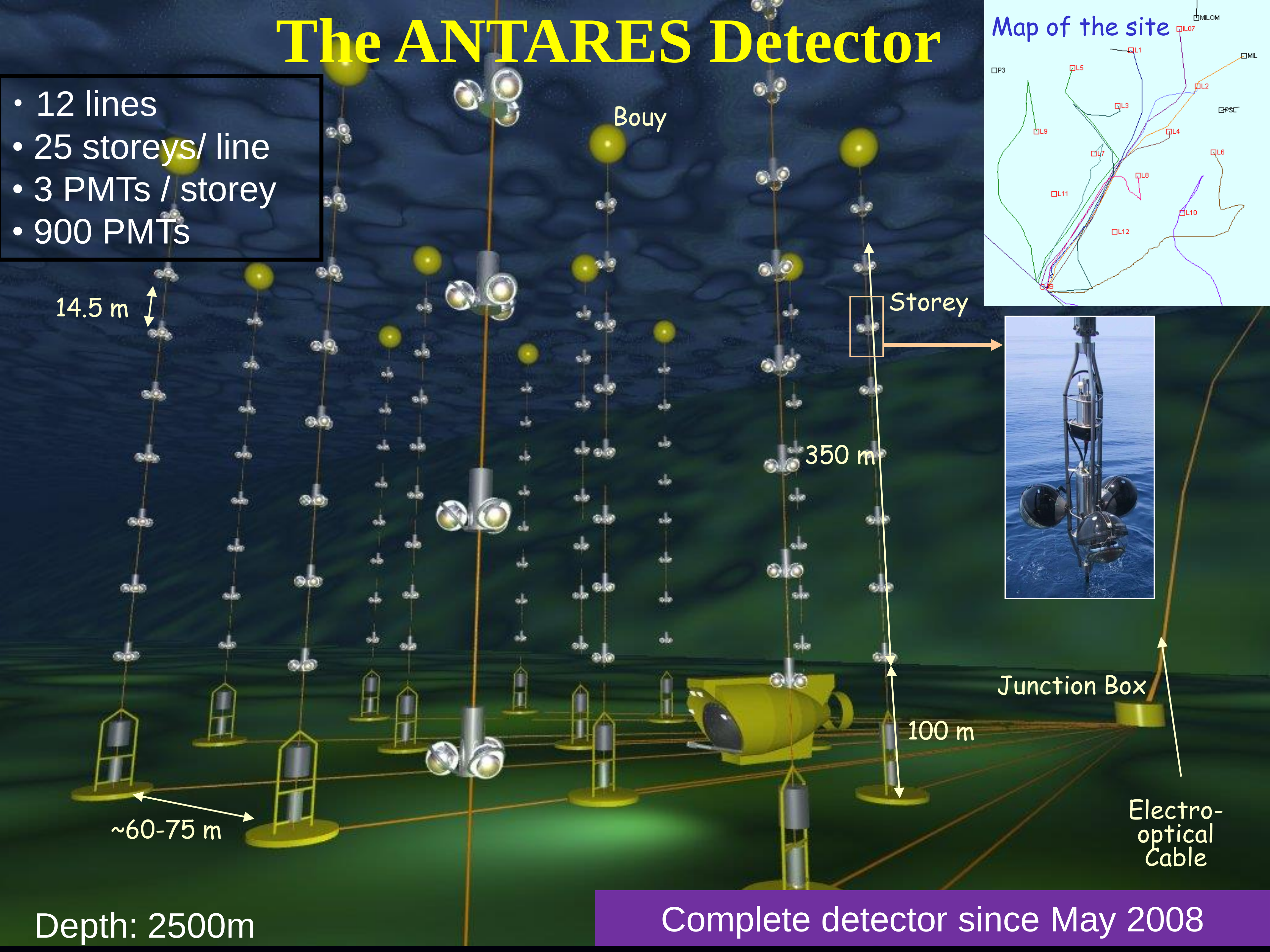






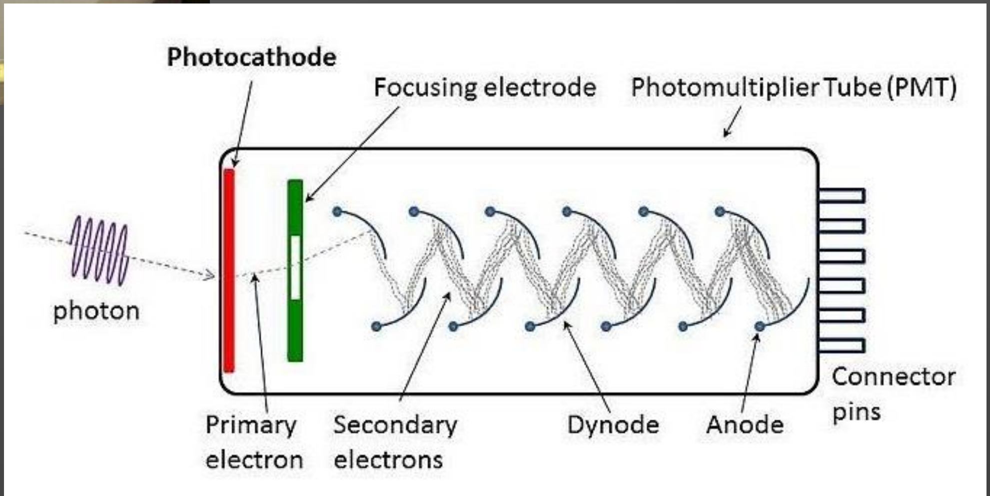
Neutrino spectrum



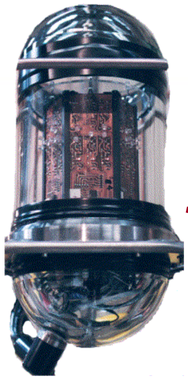

The ANTARES Detector
• 12 lines
• 25 storeys/ line
• 3 PMTs / storey
• 900 PMTs
Bouy
14.5 m
Storey
350 m
100 m
~60-75 m
Junction Box
Electro-optical Cable
Map of the site
Depth: 2500m
Complete detector since May 2008

The ANTARES site

The eyes of ANTARES : large photomultipliers

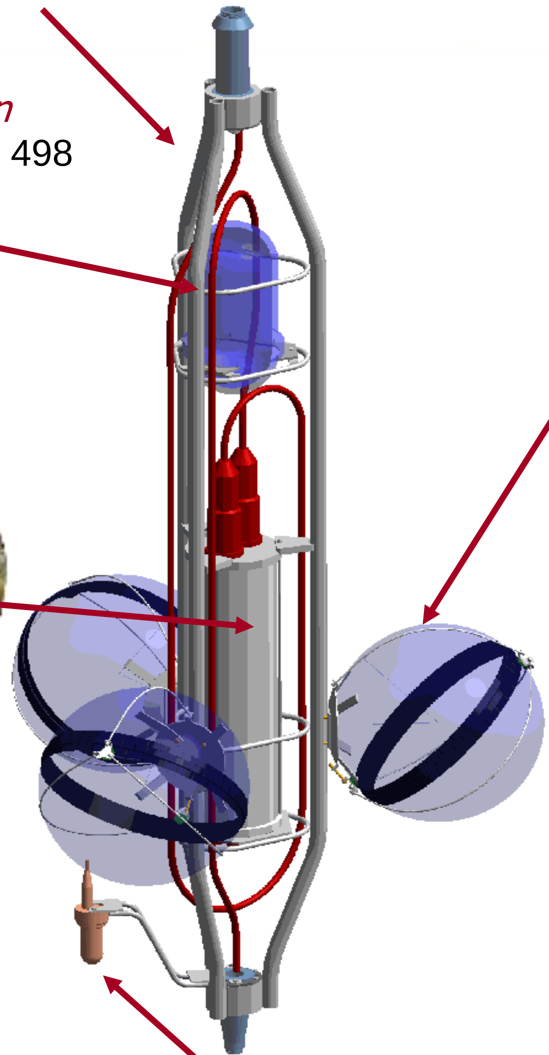


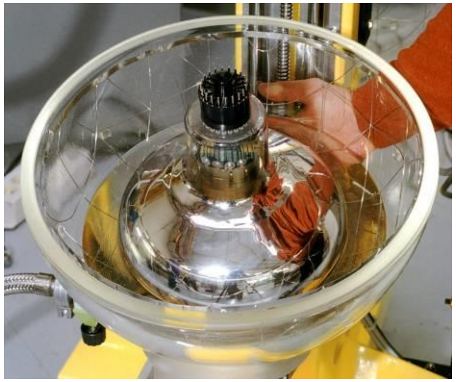
Basic neutrino detector element : Storey

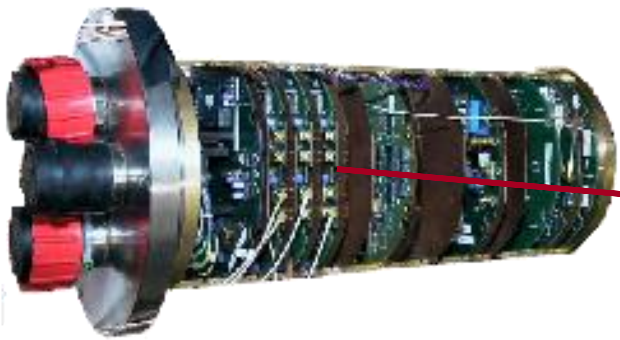


Titanium frame: *support structure*

Optical Beacon
with blue LEDs:
timing calibration
📖 NIM A578 (2007) 498





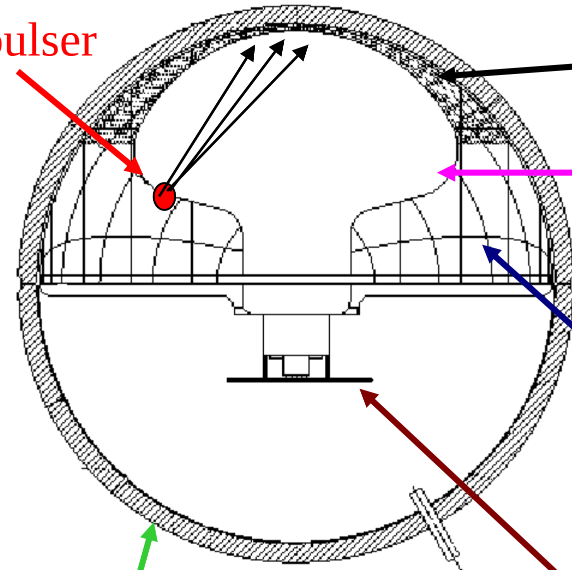


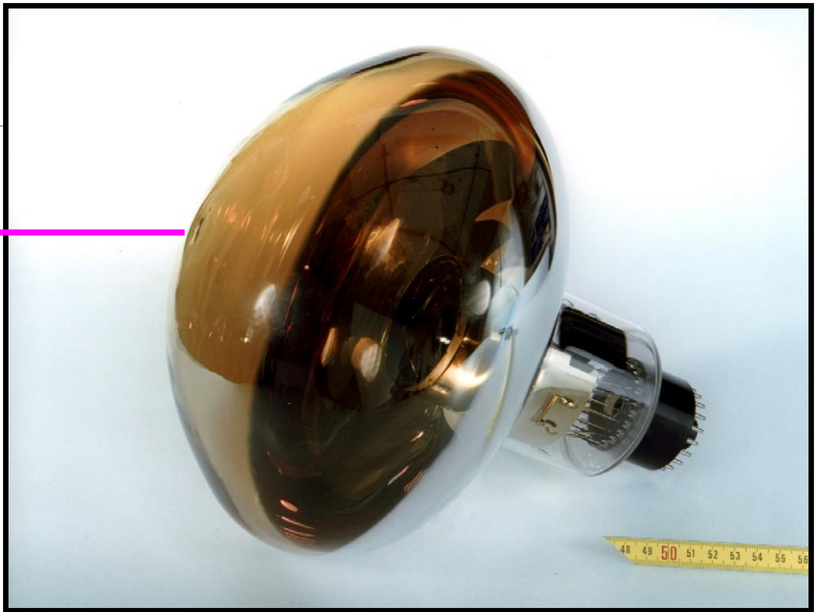
Optical Module:
10” Hamamatsu PMT in
17” glass sphere
photon detection
📖 NIM A484 (2002) 369
📖 NIM A555 (2005) 132

Local Control Module (Ti):
Front-end ASIC, DAQ/SC,
DWDM,
Clock, tilt/compass, power
distribution…
📖 NIMA 622 (2010) 59-73

Hydrophone:
acoustic positioning
📖 JINST 7 T08002

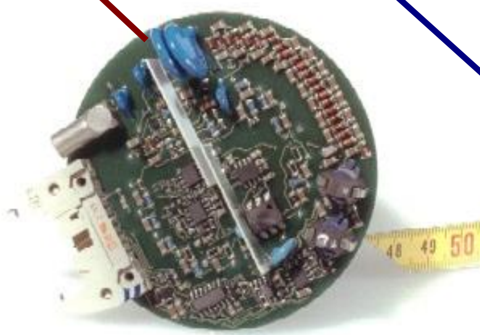
The Optical Module





Photomultipler: 10” Hamamatsu R7081-20

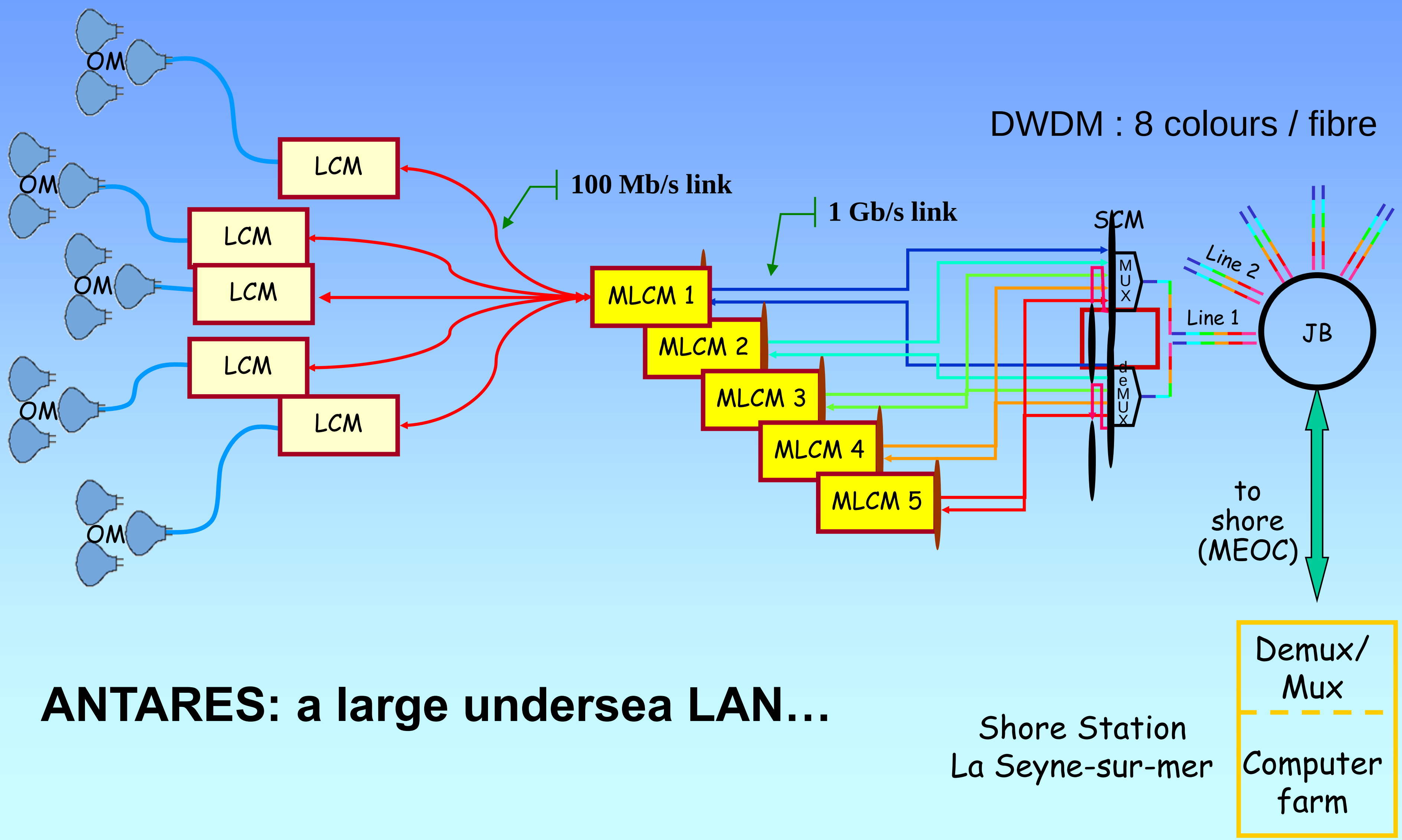
Glass sphere (Nautilus)



Active (C-W) PMT Base (ISEG)

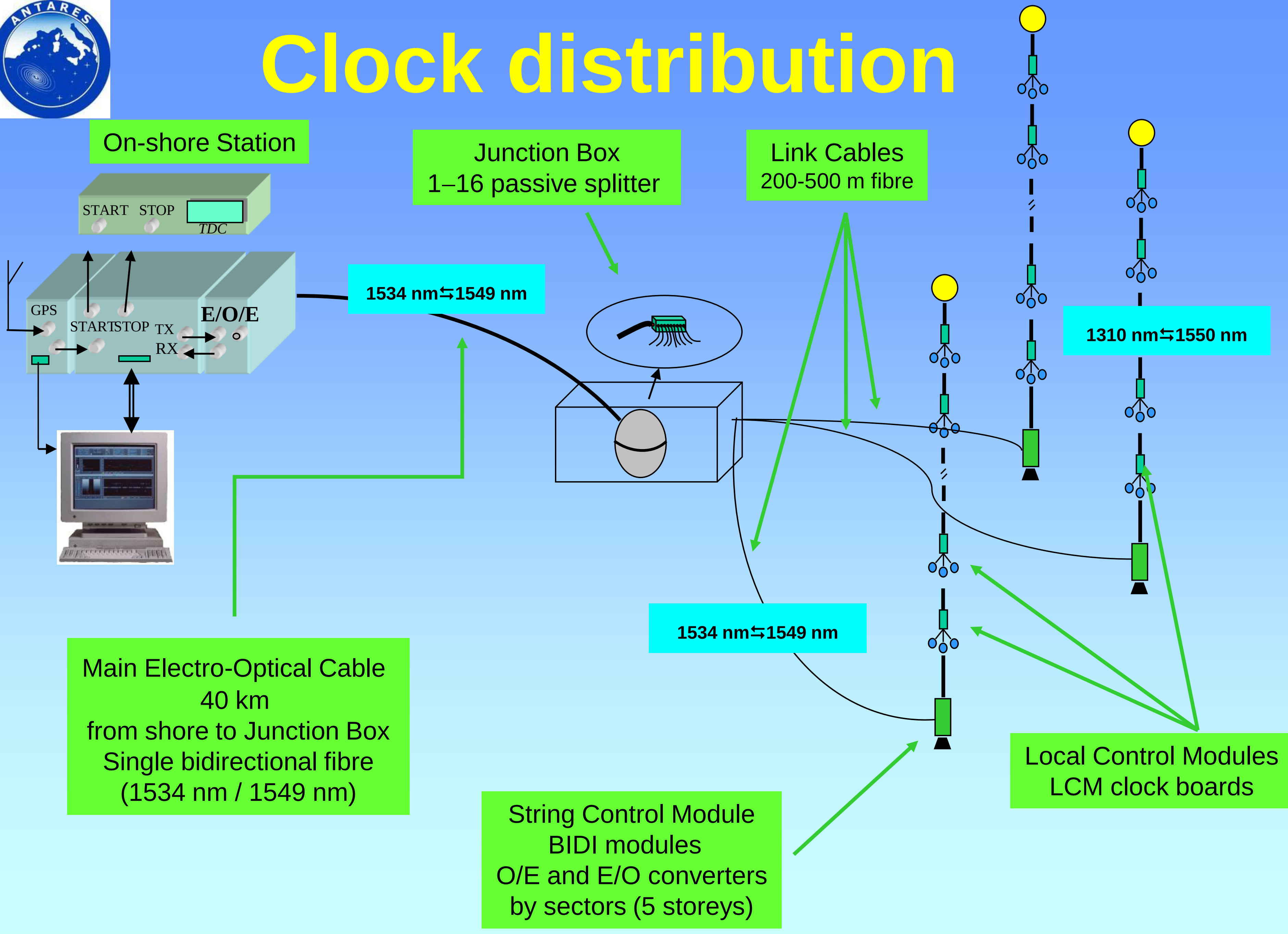
Mu metal magnetic shield

Data acquisition architecture



ANTARES: a large undersea LAN…

Clock distribution

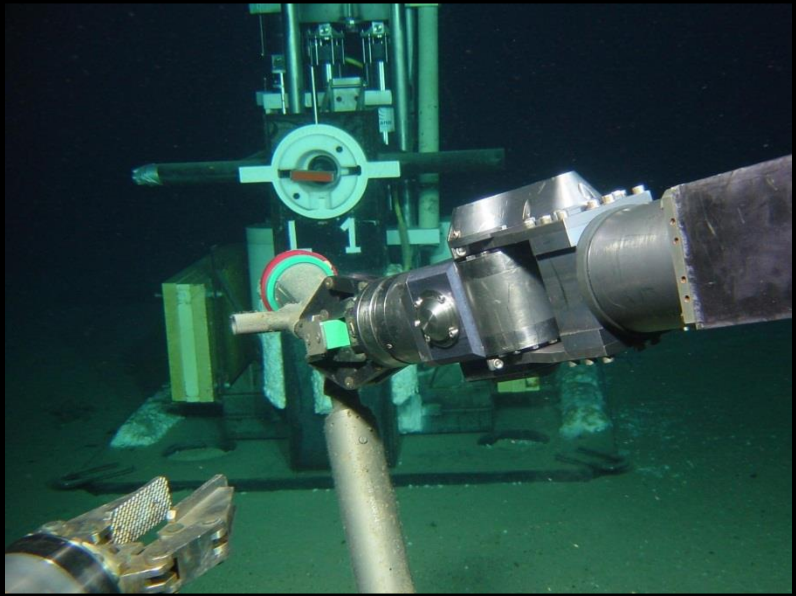


Line deployment operations

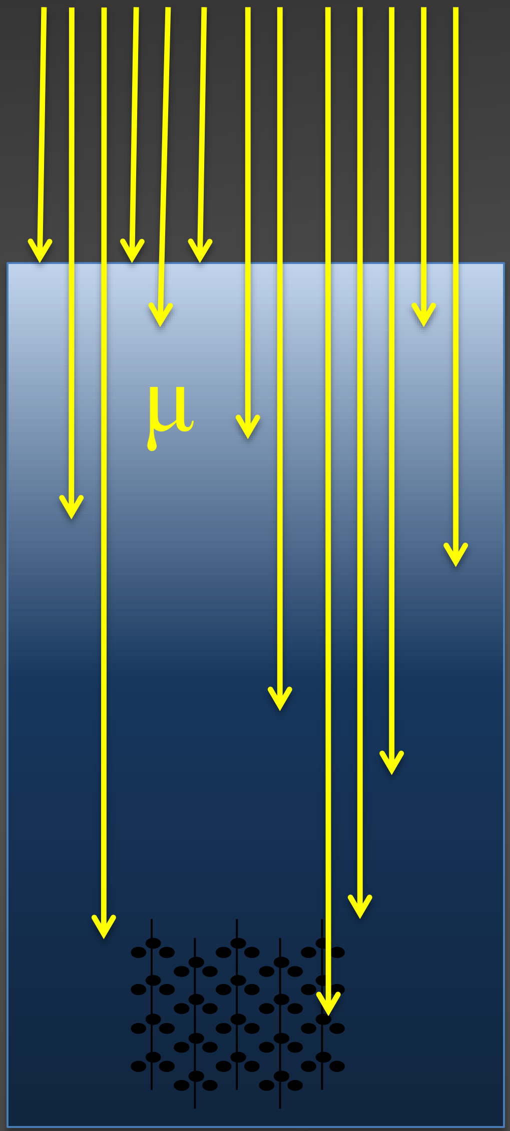
- DP Ship *Castor02*
- Precision of ~1m on the line position at sea bottom.
- ~7 hours operation

Undersea connection of lines with ROV

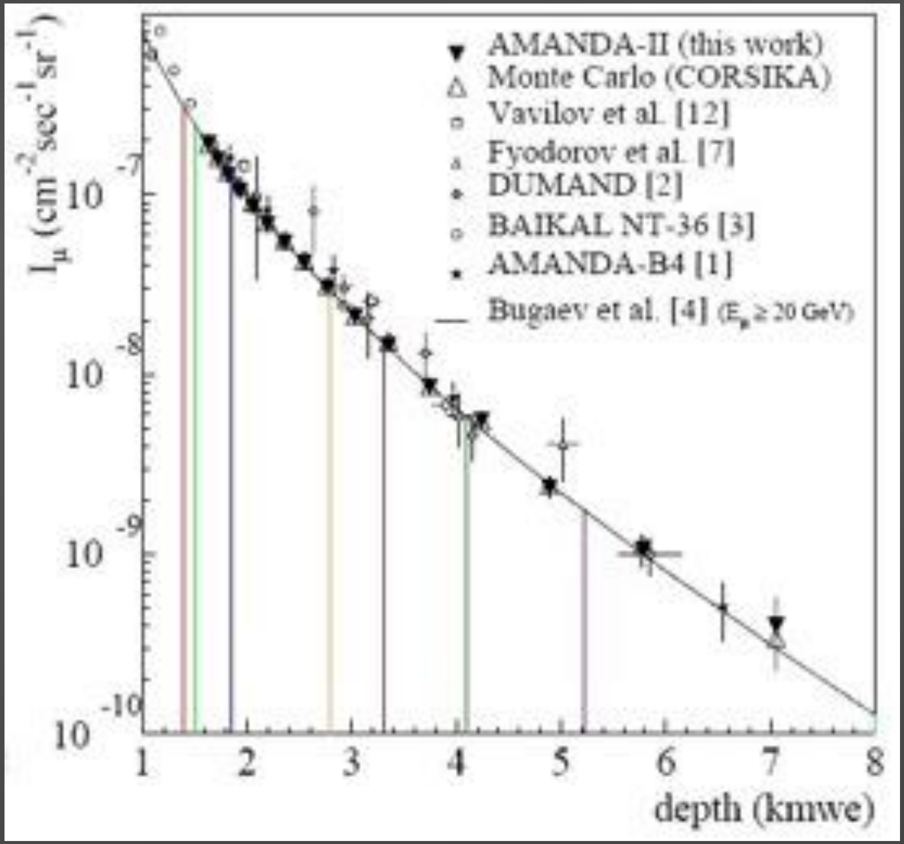
- Deep Sea ROV *VICTOR* of IFREMER
- ODI wate-metable connectors with:
  - 4 optical fibres
  - 2 electrical contacts



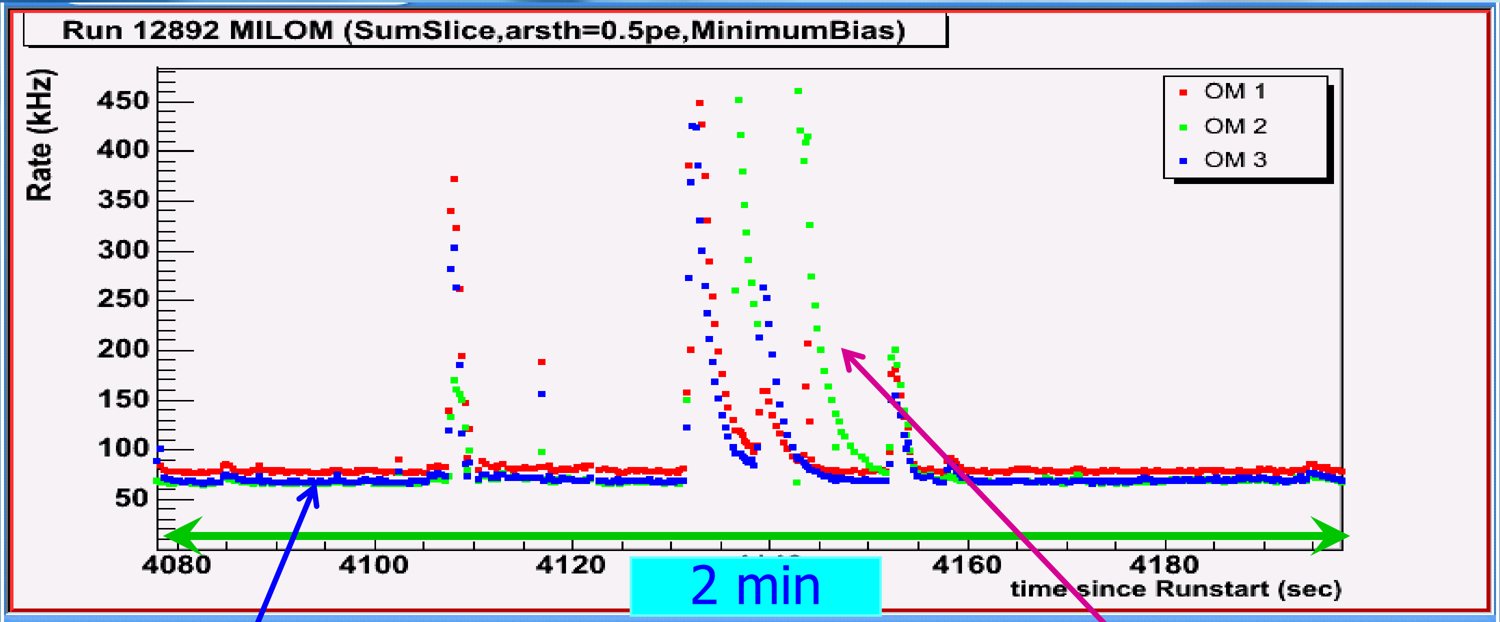
Why in the deep sea/ice ?



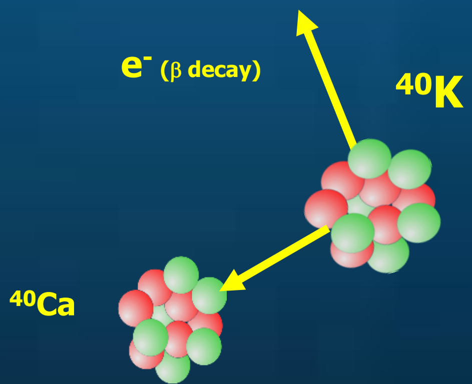
The 2000 m of water are used as shielding against downgoing muons produced by cosmic rays



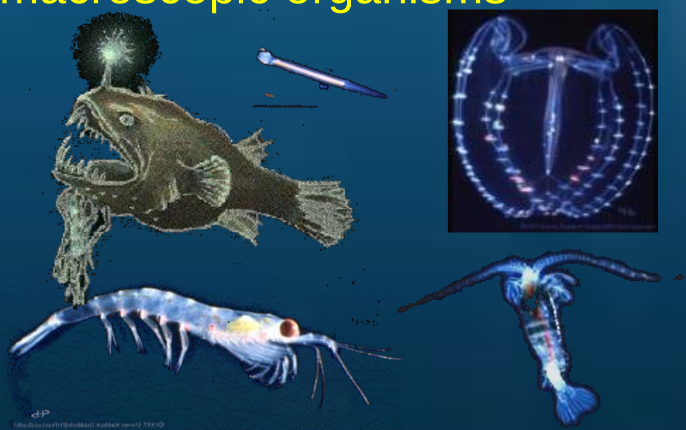
Counting Rate of an Optical Module



Baseline :
Sea salt radioactivity (^{40}K)
+ bioluminescent bacterias



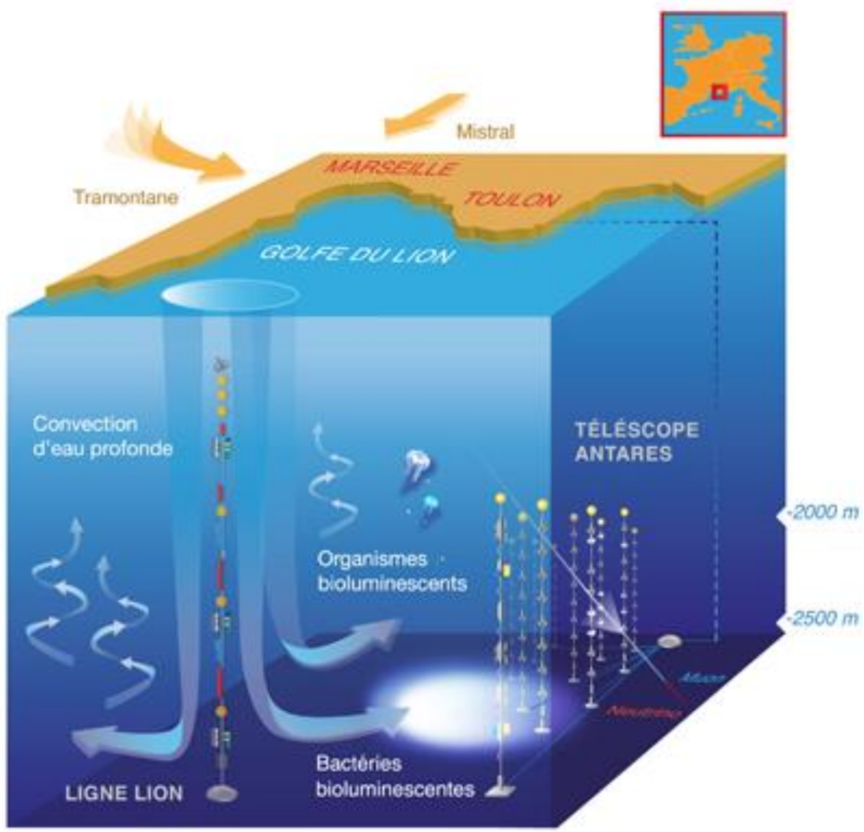
Bursts:
bioluminescence of
macroscopic organisms



Synergies with deep-sea science

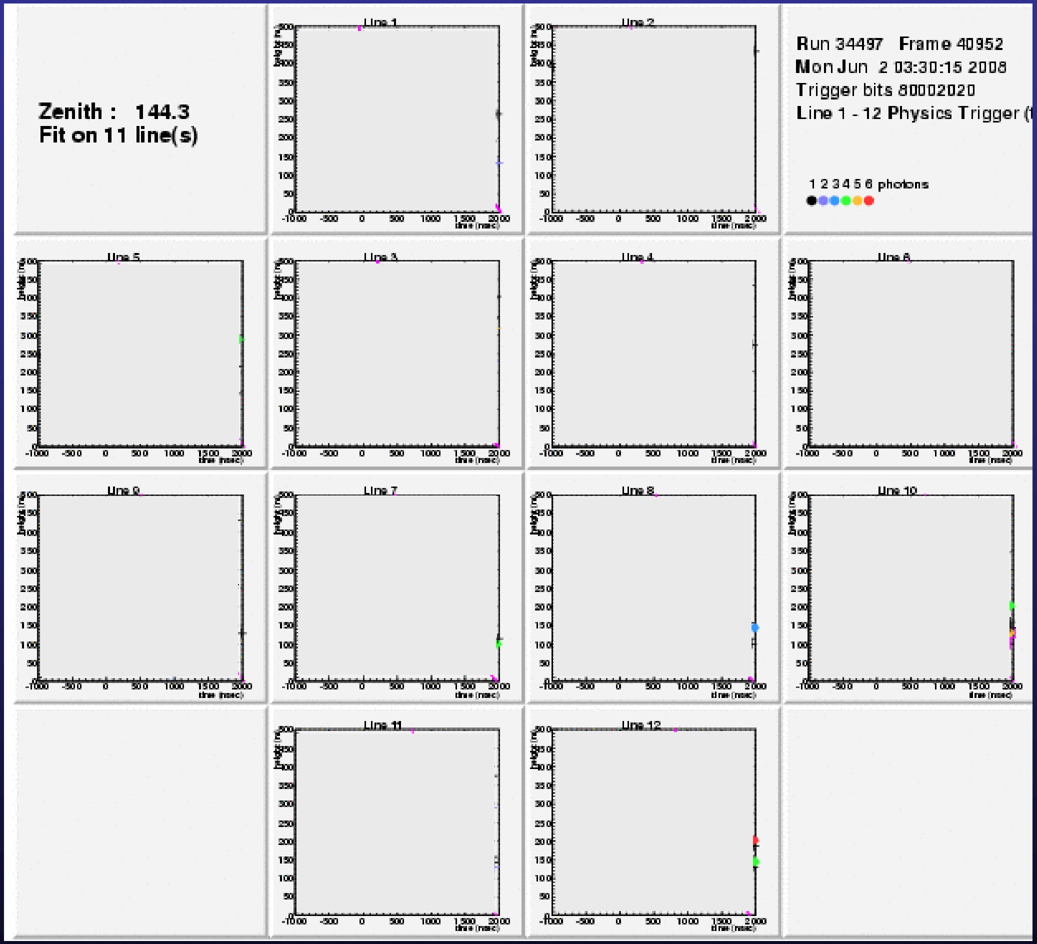
ANTARES awarded "La Recherche Prize" category "Coup de Coeur"

🕮 C. Tamburini, S. Escoffier et al., PLoS ONE 8(7) 2013
Deep-sea bioluminescence blooms after dense water formation at the ocean surface

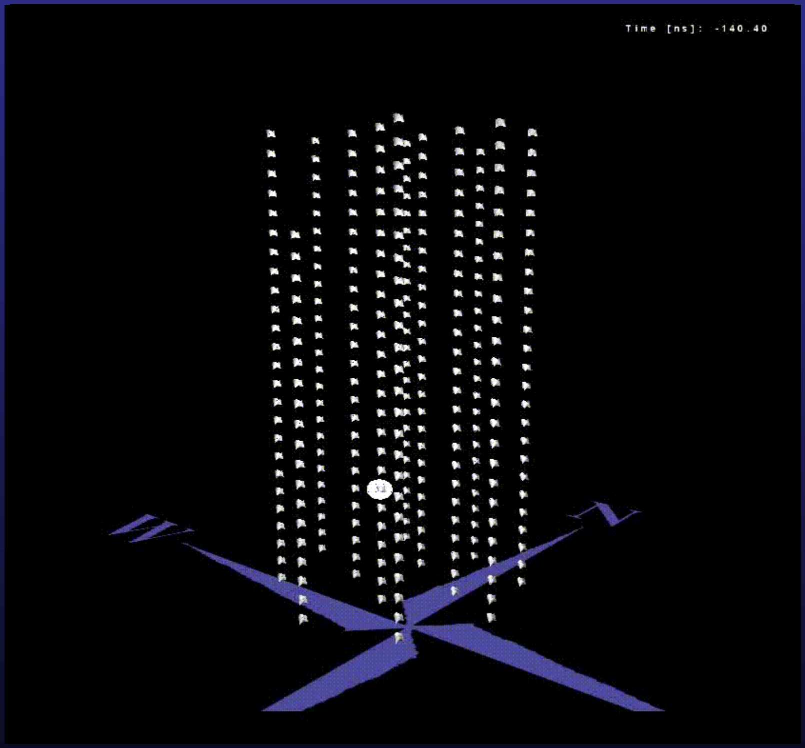


Example of a muon event

Few muons per second are detected

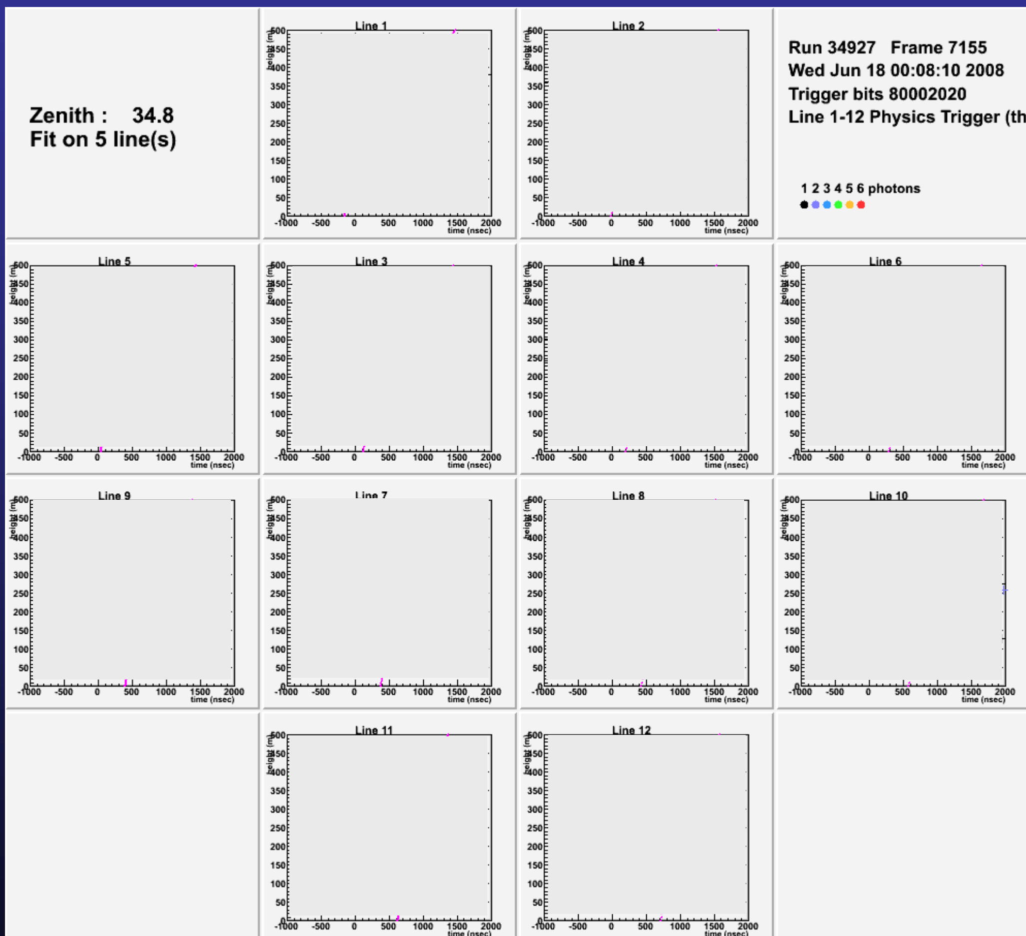


Example of a down-going muon event, détected over the 12 detector lines



Example of a neutrino event

Few neutrinos per day are detected

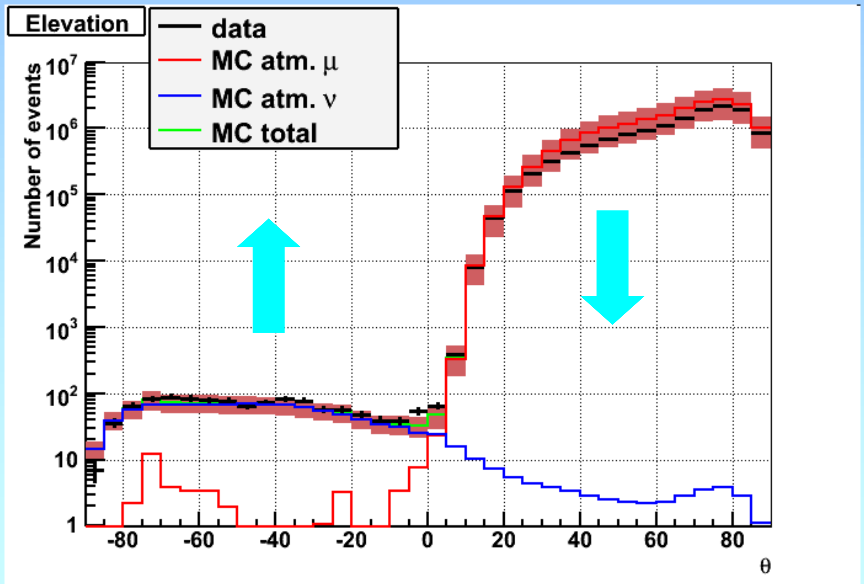


Example of an up-going muon event (i.e. a neutrino event) detected by 6/12 detector lines

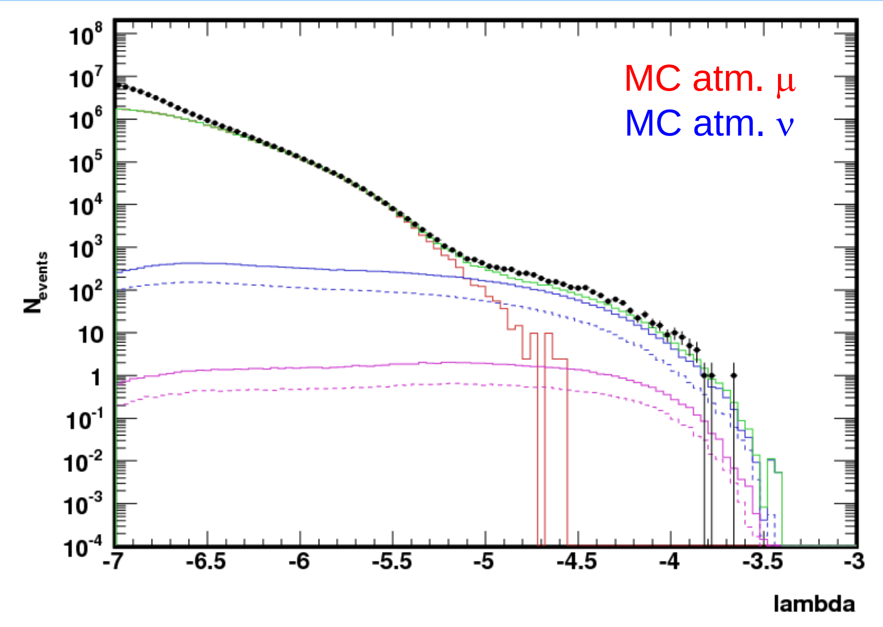
Event selection : background rejection

- Track reconstruction mainly based on minimization of hit time residuals using Chi2 or Likelihood method with PDF

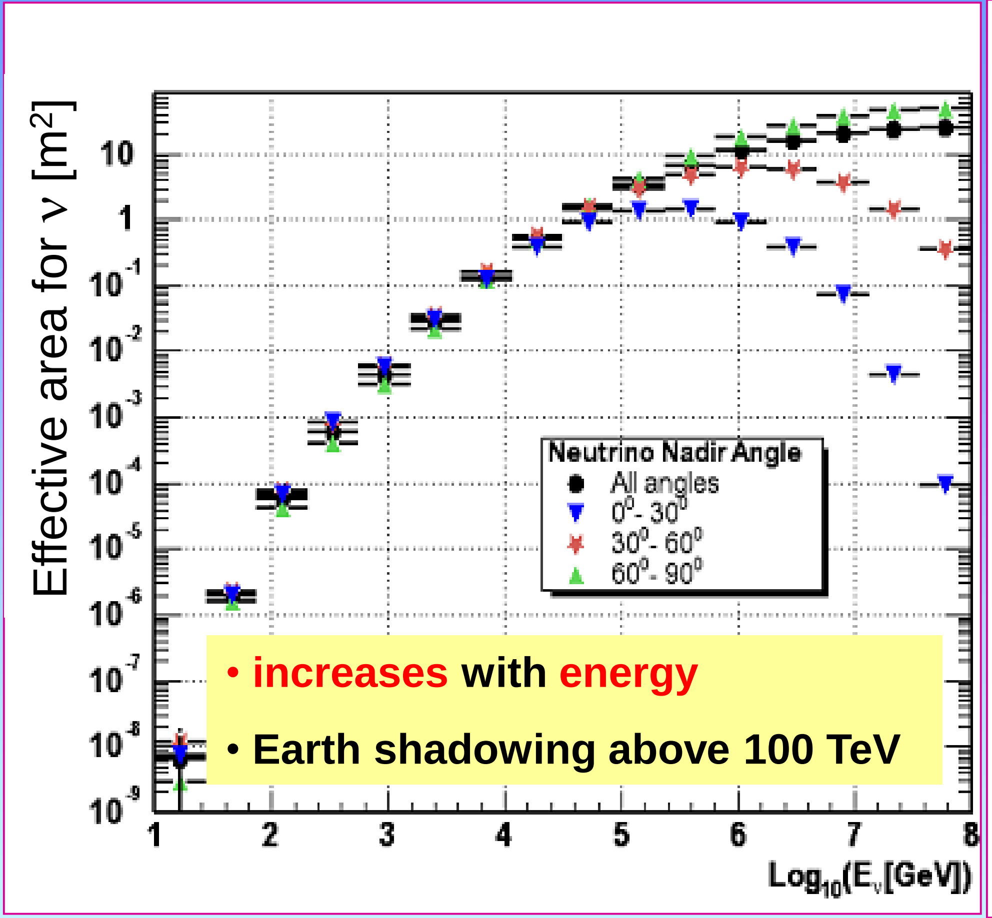
- Selection of neutrinos and rejection of atmospheric muons by selecting up-going tracks and cutting on track fit quality

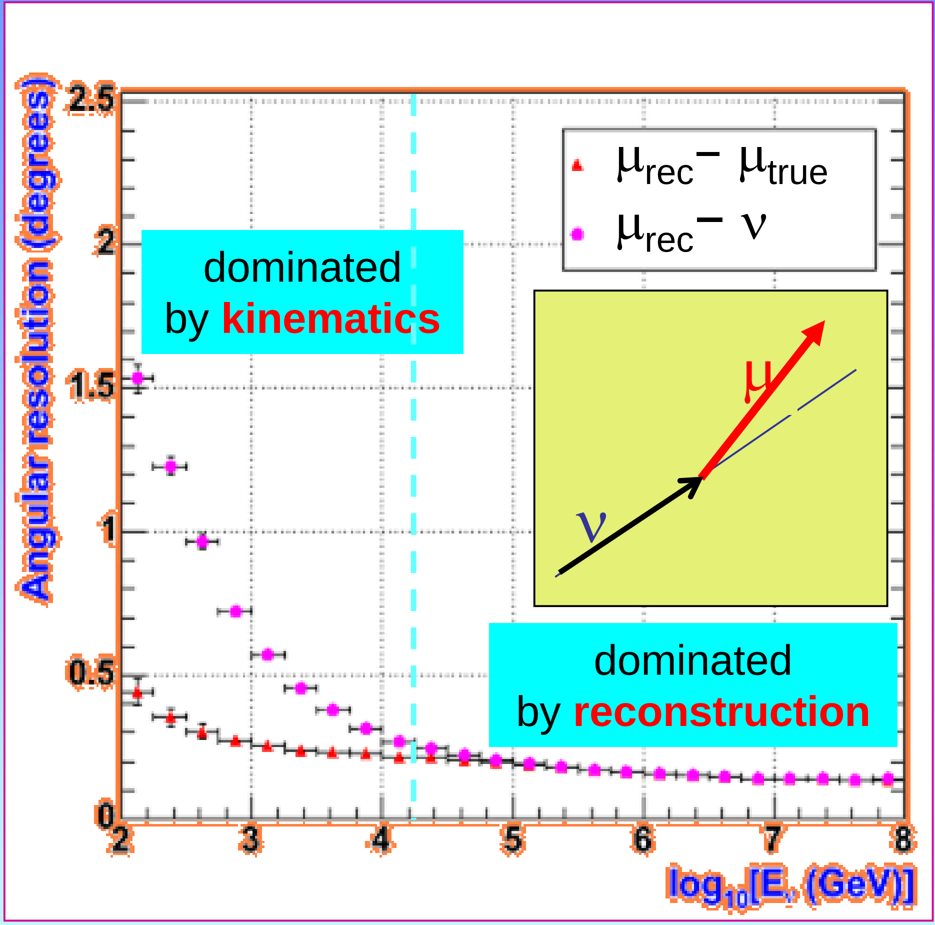


Elevation angle



ANTARES Detector Performances



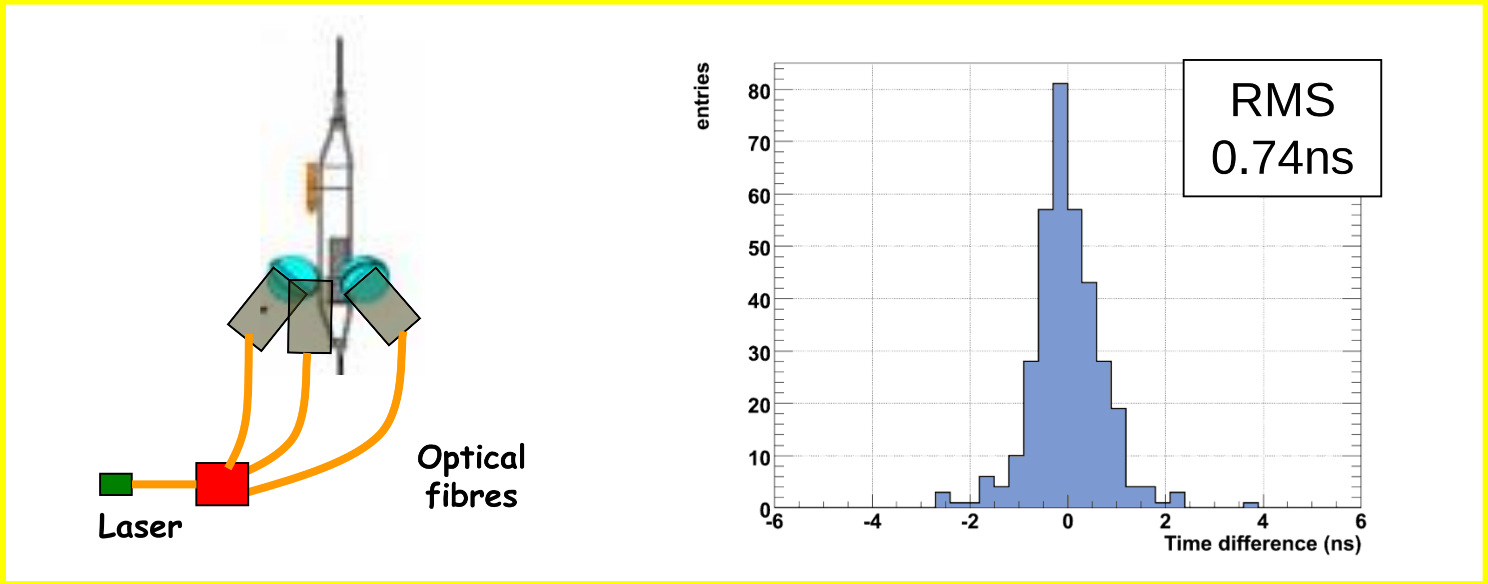


Angular resolution better than 0.3° above a few TeV, limited by:

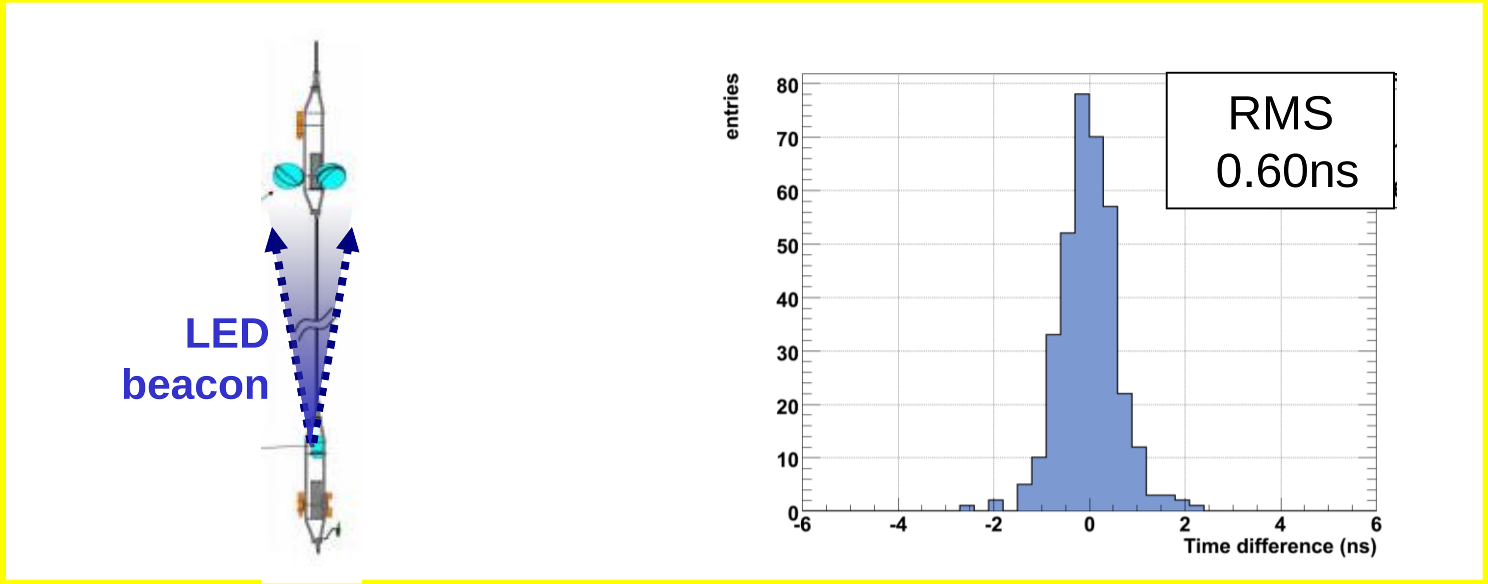
- Light scattering + chromatic dispersion in sea water: $\sigma \sim 1.0$ ns
- TTS in photomultipliers: $\sigma \sim 1.3$ ns
- Electronics + time calibration: $\sigma < 0.5$ ns
- OM position reconstruction: $\sigma < 10$ cm ($\leftrightarrow \sigma < 0.5$ ns)

Time Calibration

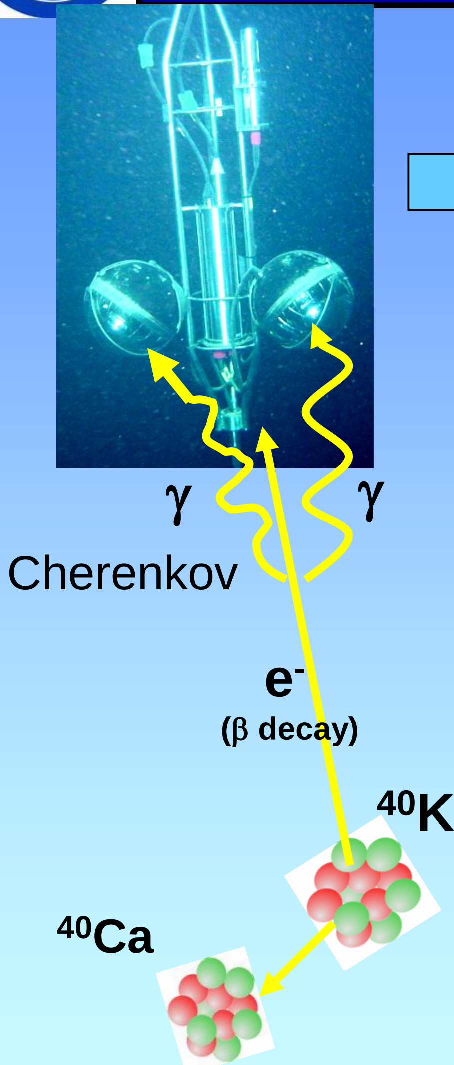
On shore laser system

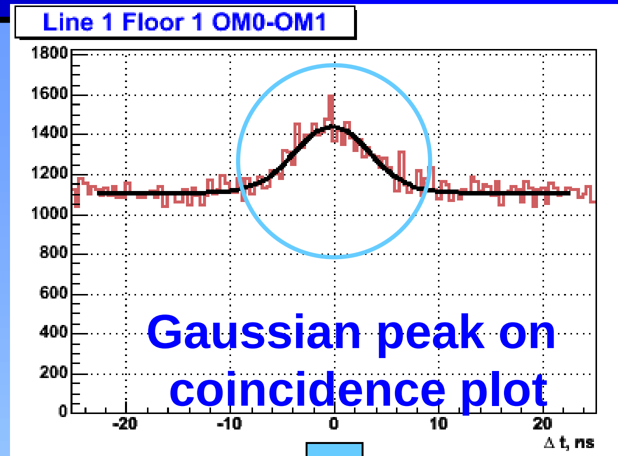


In sea LED beacon system



In situ calibration with Potassium-40



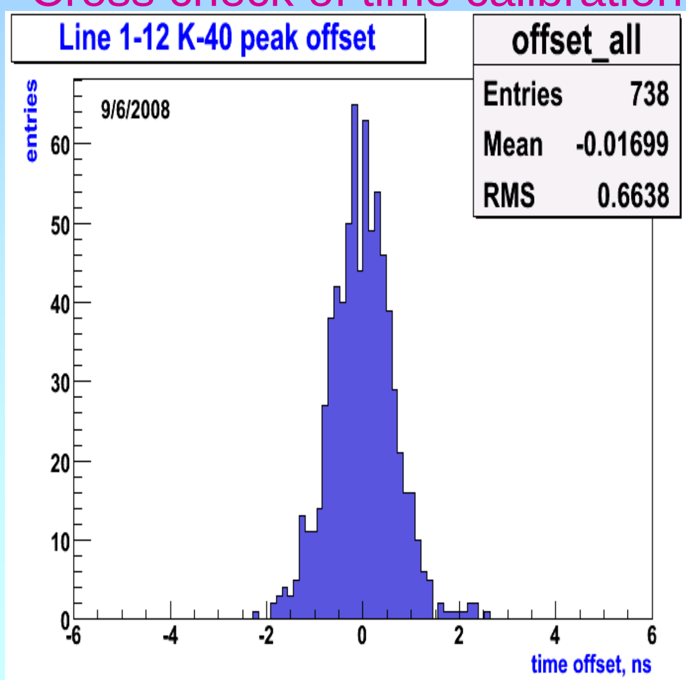


Integral under peak = rate of correlated coincidences

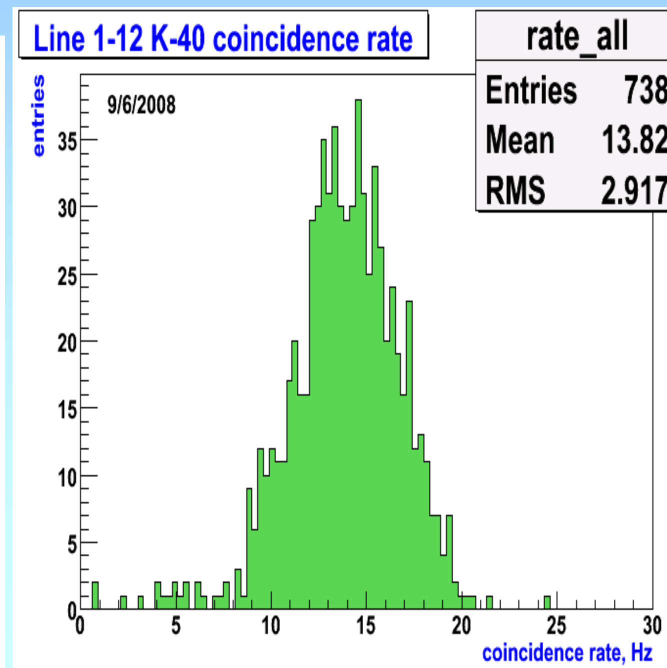
MC prediction =13 ± 4 Hz

Peak time offset :

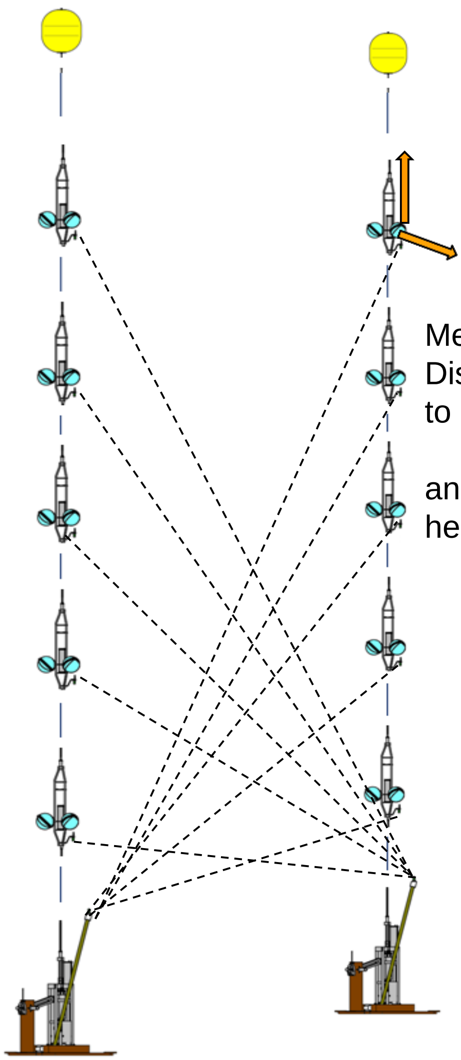
Cross check of time calibration



High precision (~5%) monitoring of OM efficiencies

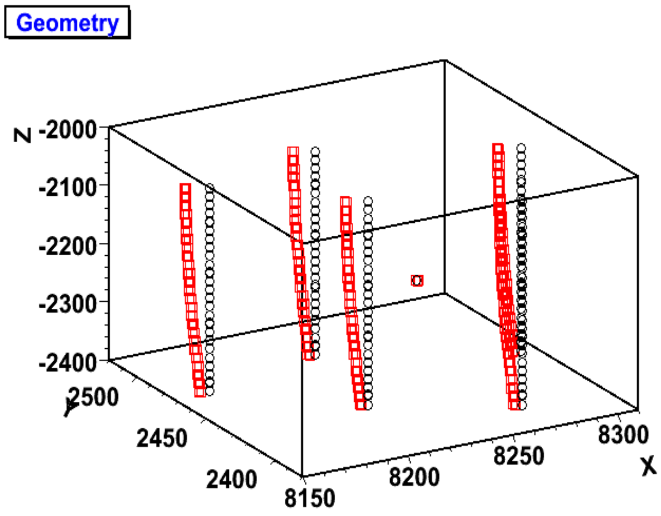


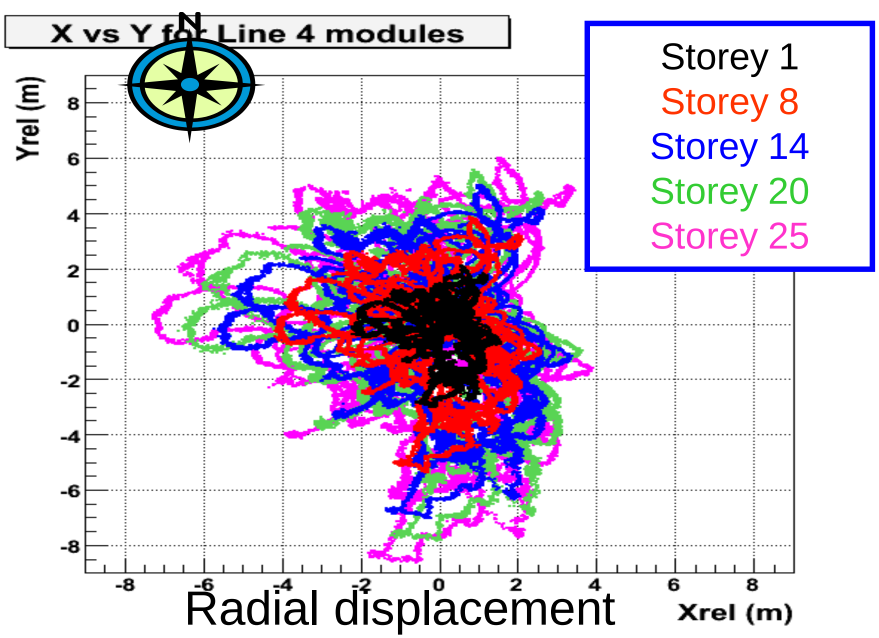
Acoustic Positioning



Measure every 2 min:
Distance line bases to 5 storeys/line

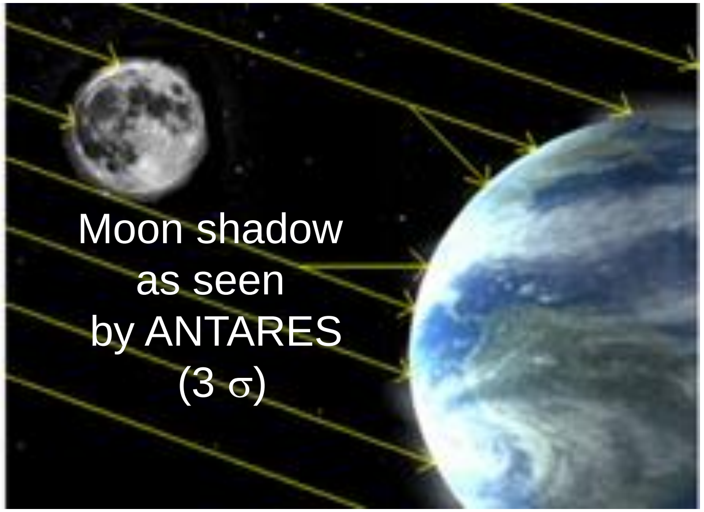
and also storey headings and tilts

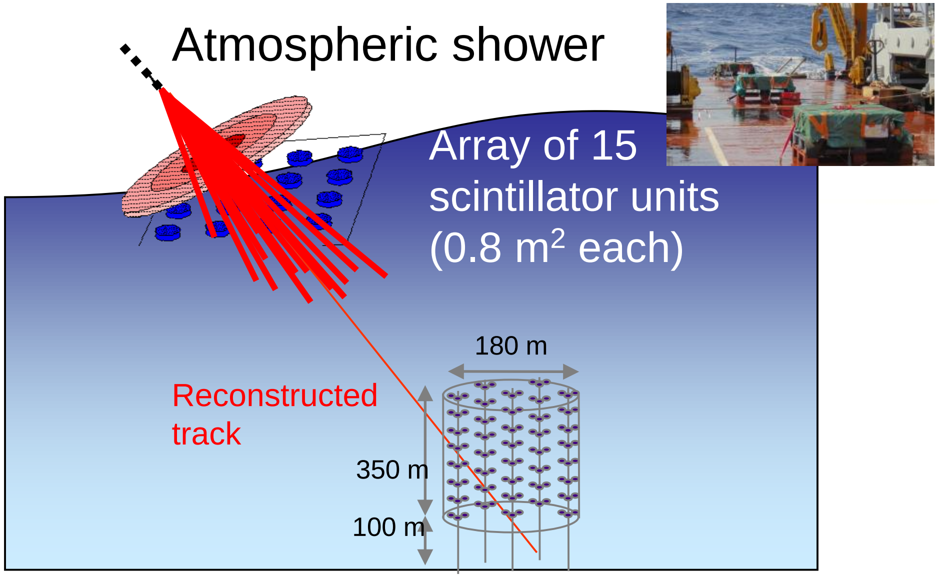


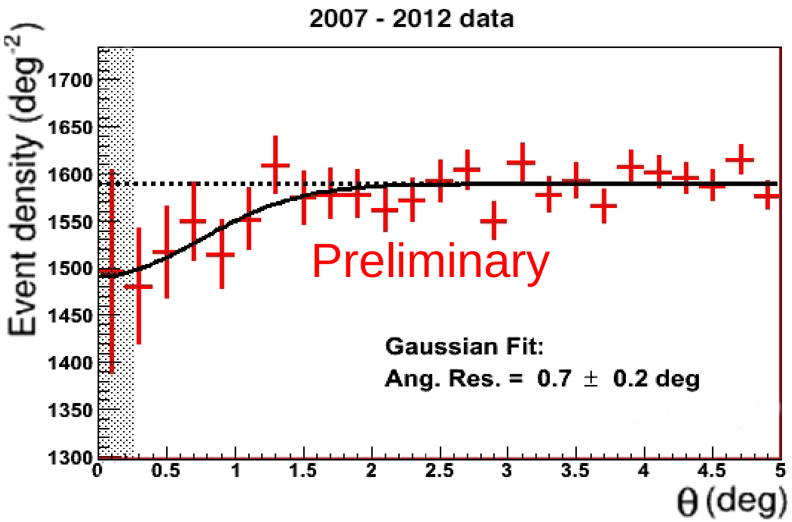


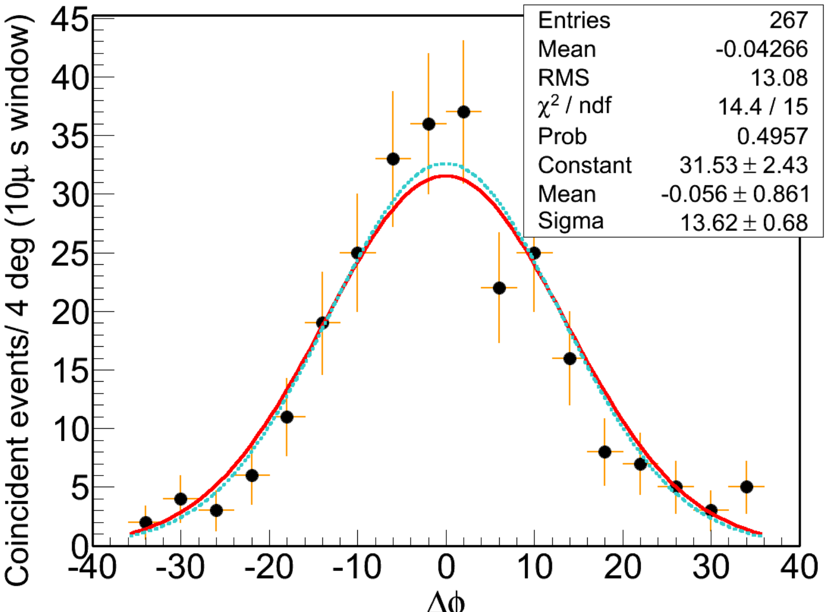
Radial displacement

Check of Detector Absolute Pointing

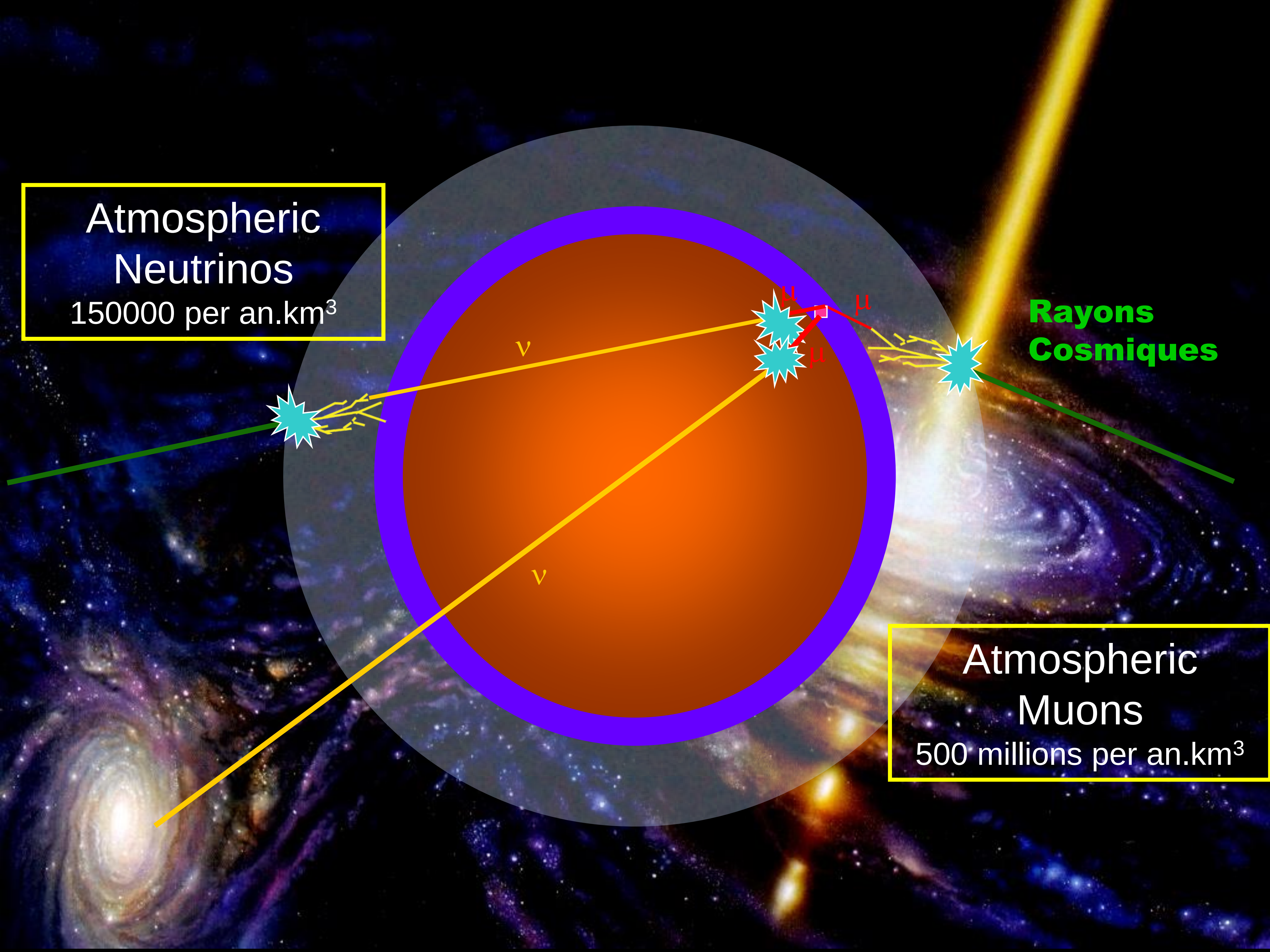






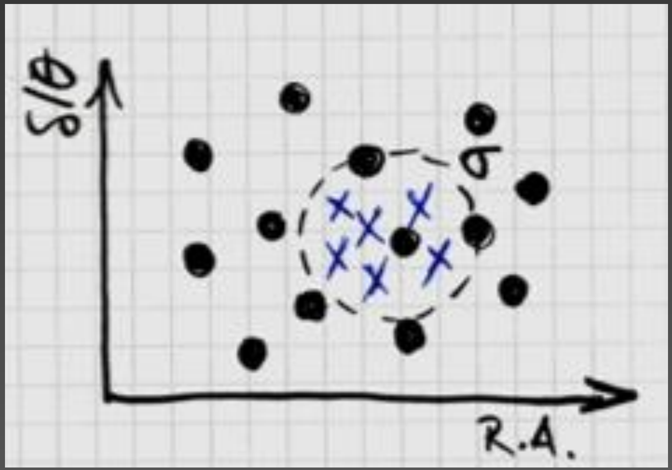


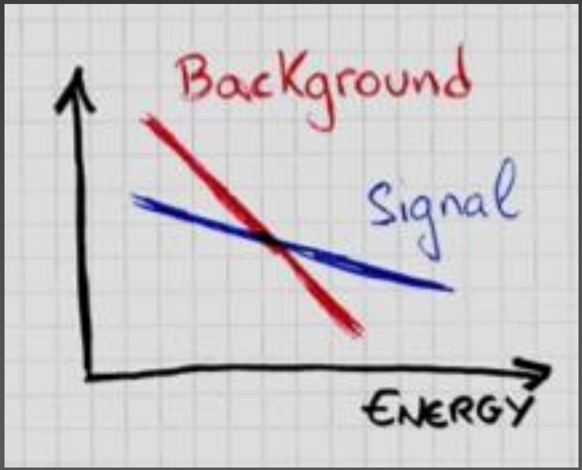
2 sea compains



Atmospheric Neutrinos
150000 per an.km³
ν
ν
μ
μ
μ
Rayons Cosmiques
Atmospheric Muons
500 millions per an.km³

Cosmic Signal vs atmospheric background





Background suppression :

- atmospheric muons : use reconstruction quality
- atmospheric neutrinos : isotrope + lower energy spectrum

Signal:

- distribution concentrated for point source + harder energy spectrum

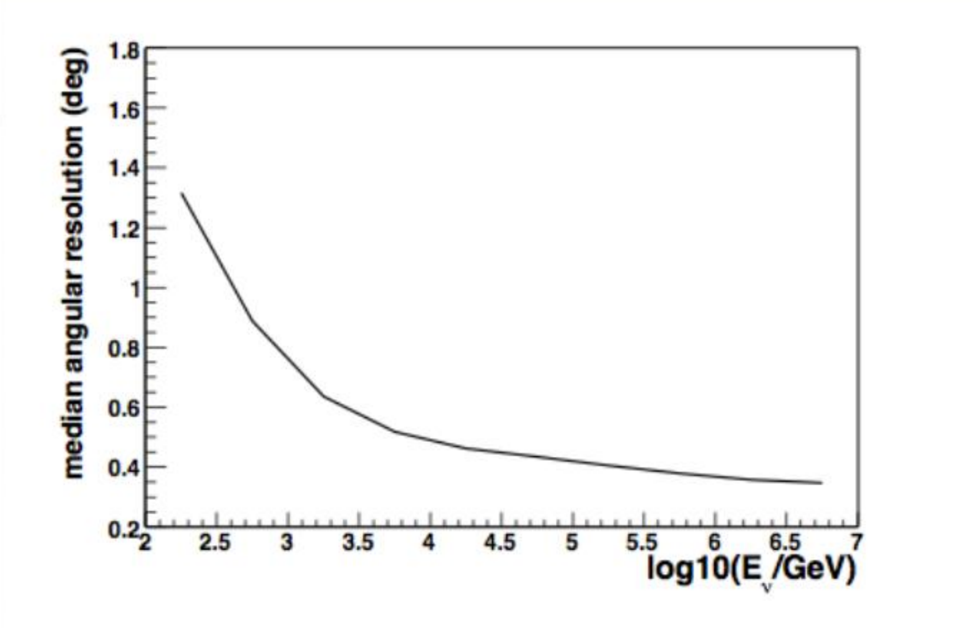
Point Source

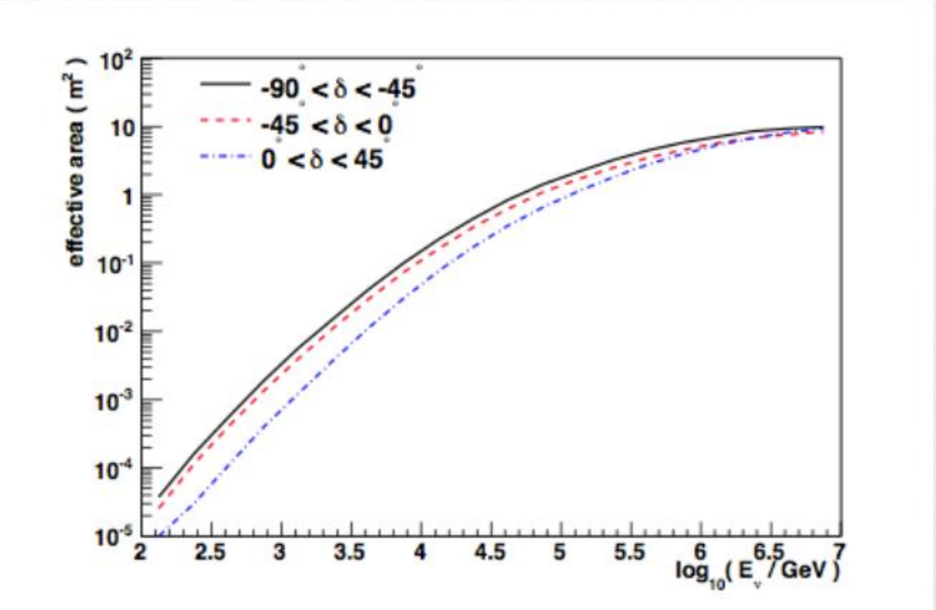
Diffuse Flux

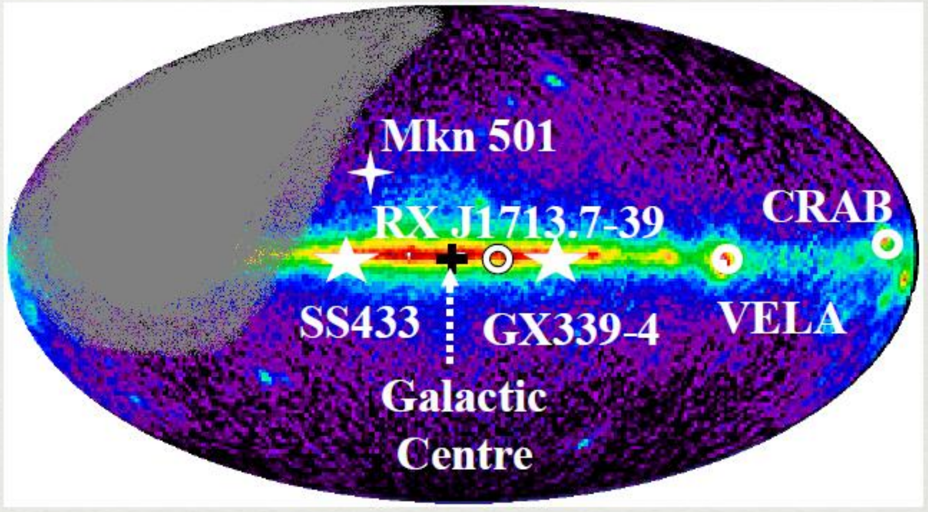
ANTARES in numbers

ANTARES in numbers:

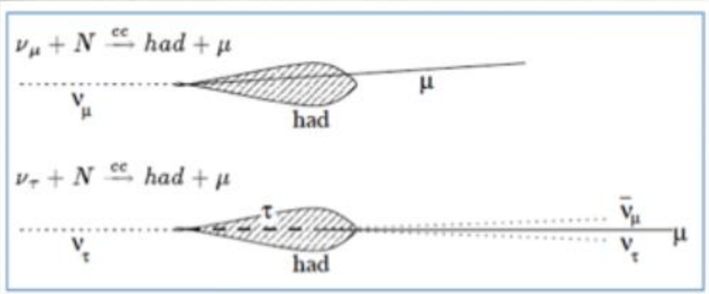
- 12-line data taking since 2008
- o(11000) detected neutrinos
- Angular resolution: 0.3-0.4° (median)
- Effective area: ≈1m² @ 30 TeV
- Visibility: ¾ of the sky, most of the galactic plane
- Real-time data processing

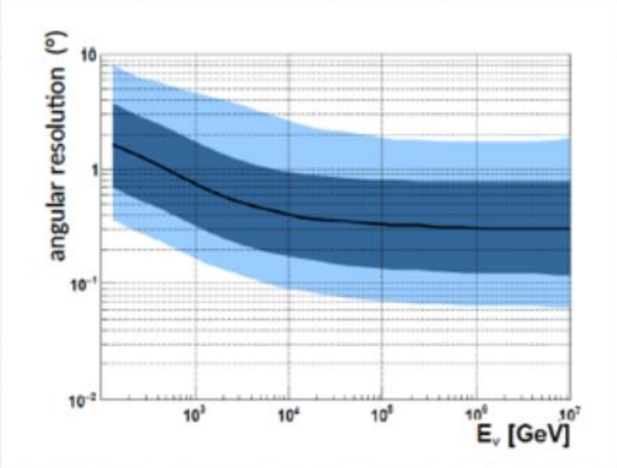




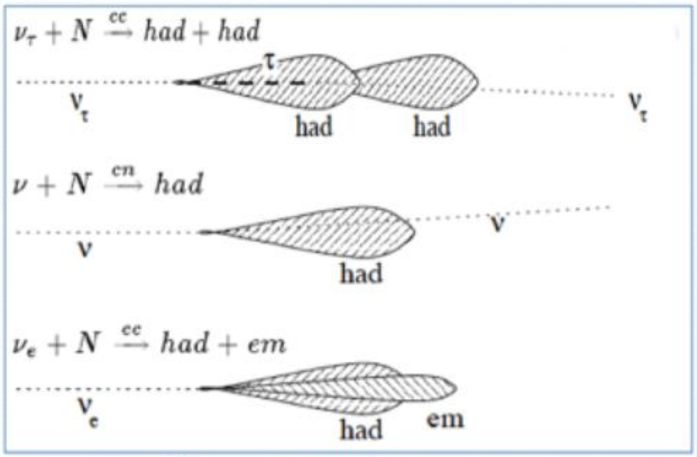


Neutrino event topologies

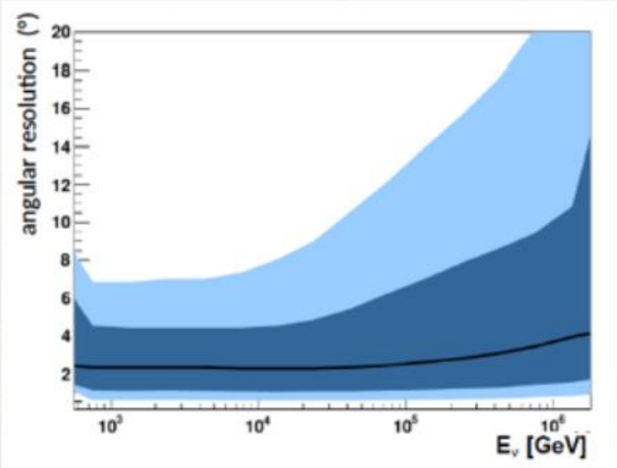




Tracks:
Angular resol: ~0.3°
Energy resol: factor 3
Large detection volume
=> Ideal for astronomy
=> but large atm bkg



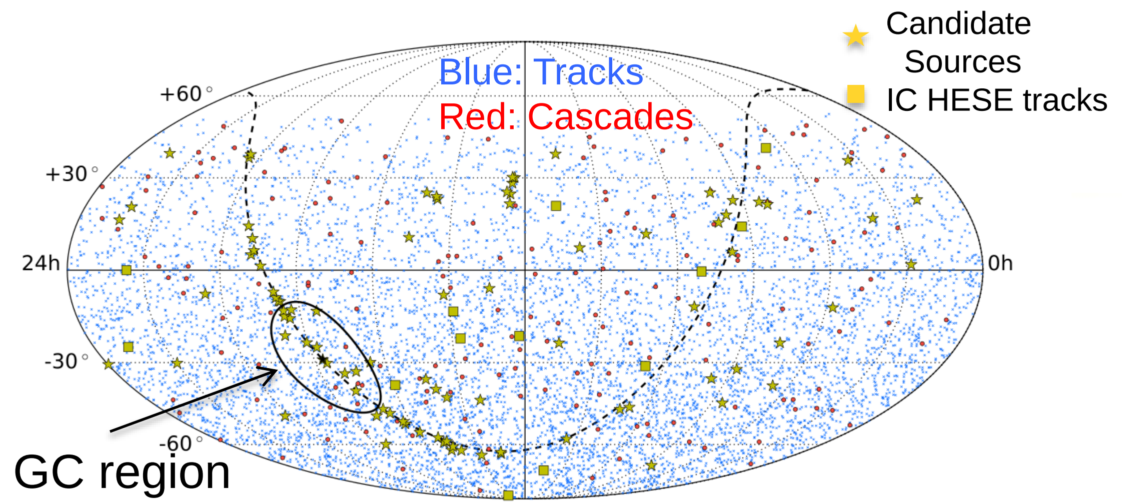
Not to scale



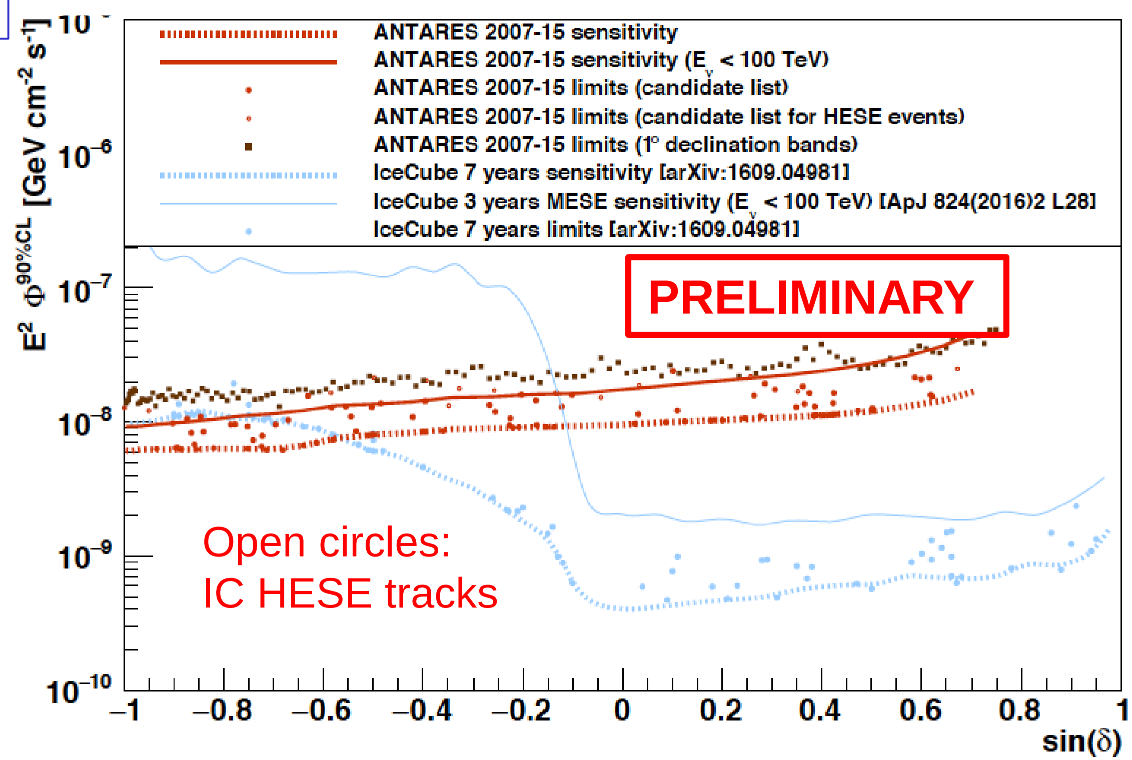
Cascades:
Angular resol: ~3°
Energy resol: 5-10%
Contained event
=> Almost no atm bkg

All flavor point source search with ANTARES

- 2007-2015 (2424 days):
  7629 tracks, 180 cascades
- Unbinned all-sky search
- 103 Candidate sources including 13 IceCube HESE tracks and HAWC sources

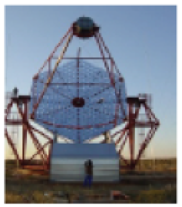


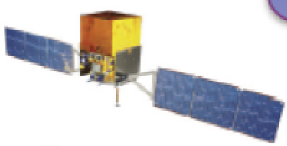
- No significant excess
- Best limits for part of Southern Hemisphere
- Excellent sensitivity for E_ν <100 TeV
- Results to be combined with latest IC search

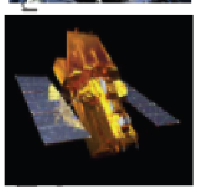


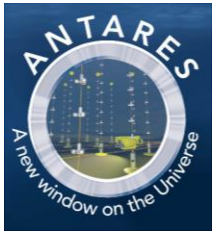
Towards a multi-messager astronomy…

→ Search for signals of transient catastrophic astrophysical events
(Gamma Ray Bursts, SuperNovae, flares of Active Galactic Nuclei,…)
with High Energy Neutrinos, Radio/Optical/X/γ Photons, Cosmic Rays, Gravitational Waves,…









GeV-TeV γ-rays
Fermi / HESS…

- JCAP 03(2013) 006
- A&A 559 (2013) A9
- JCAP 05 (2014) 001
- ❑ JCAP 12(2015)014

UHECR
Auger

- APJ 774 (2013) 19

HE neutrinos

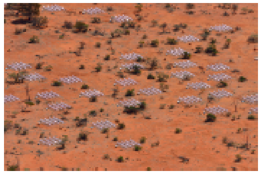
Optic / X-ray
TAROT,
ROTSE / Swift,
ZADKO

- APP 36 (2012) 204
- A&A 559 (2013) A9
- ❑ JCAP 02(2016)062A

Gravitational
Waves
Virgo / Ligo

- JCAP 06 (2013) 008
- ❑ PRD 93 (2016) 122010

Radio
MWA

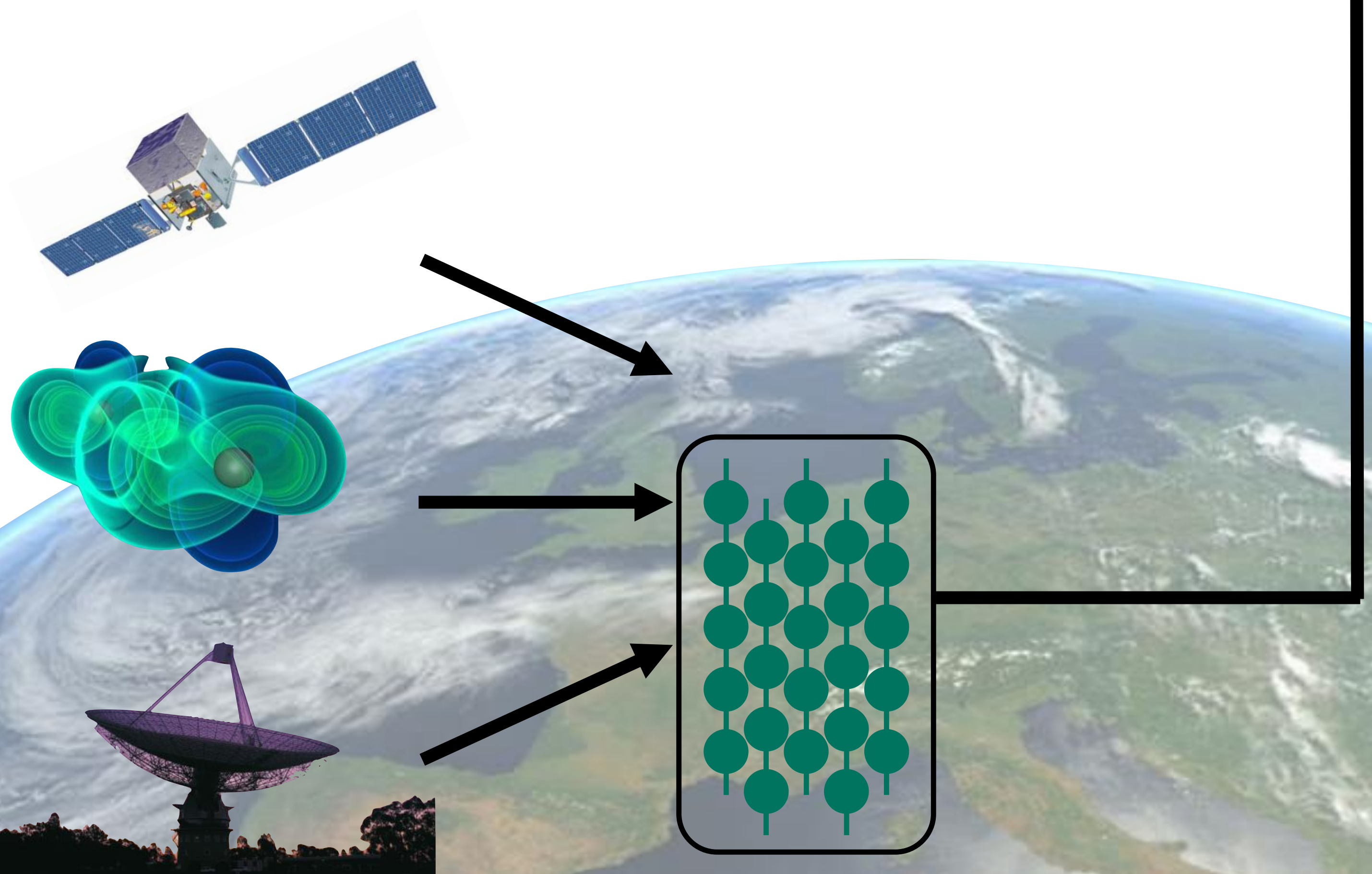


❑ APJ 820 (2016) L24

The multi-messenger program

1ST APPROACH:

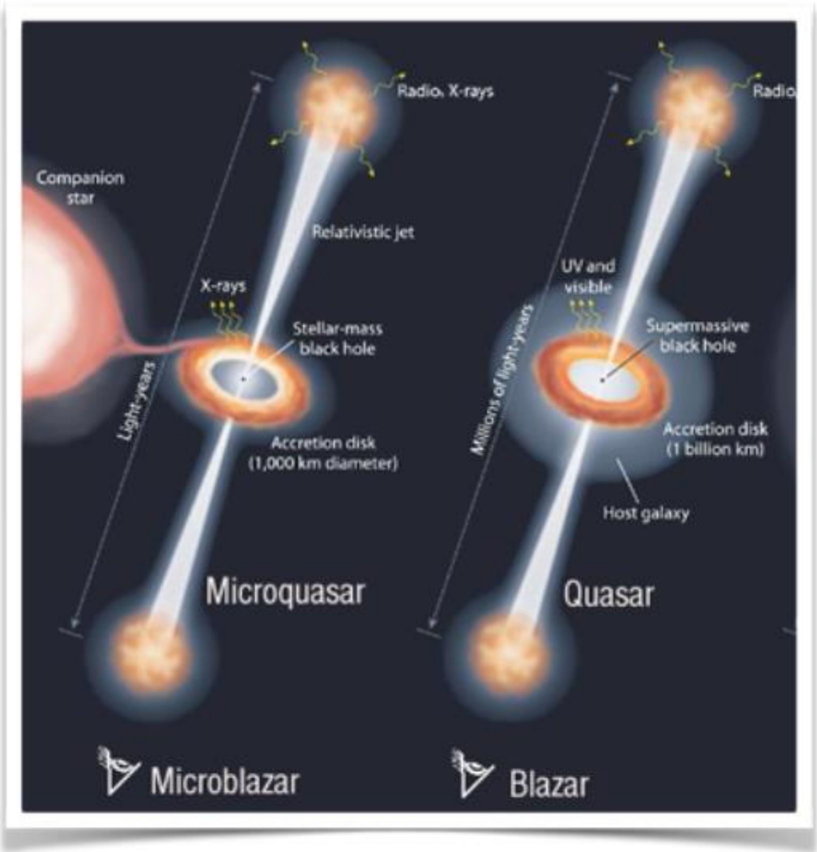
Time dependent searches

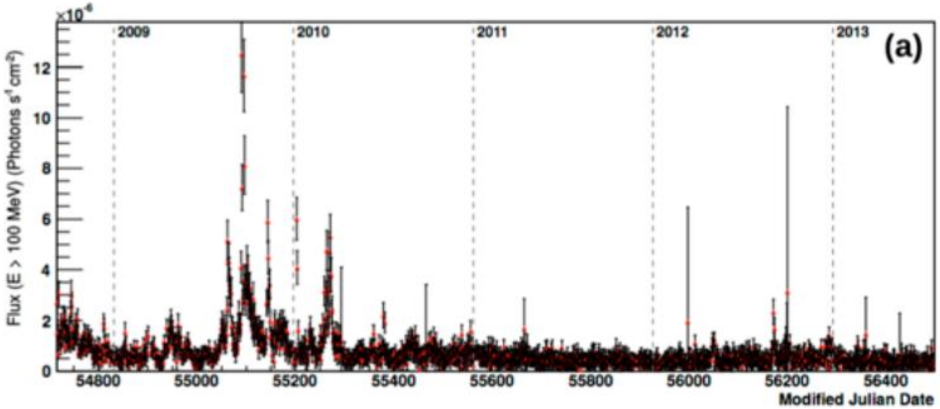


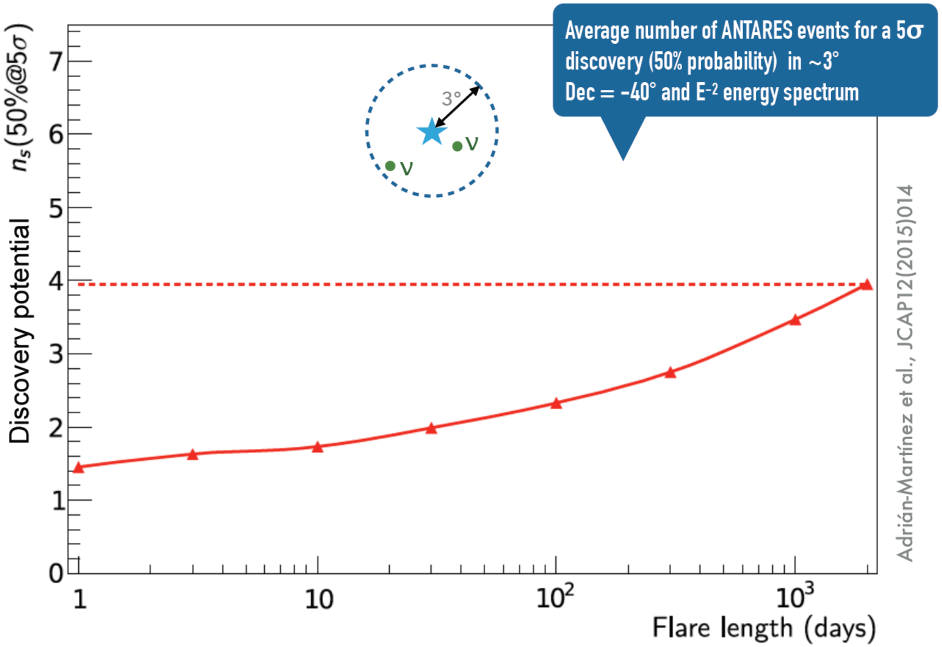
GRB
Microquasar
Gamma-ray binaries
Blazars
Supernovae Ib,c
Fast Radio Bursts

Search for flaring sources

- **Search for transient sources (GRBs, µQuasars, AGN flares...)** :
  → Search for time coincidences with γ or X observations





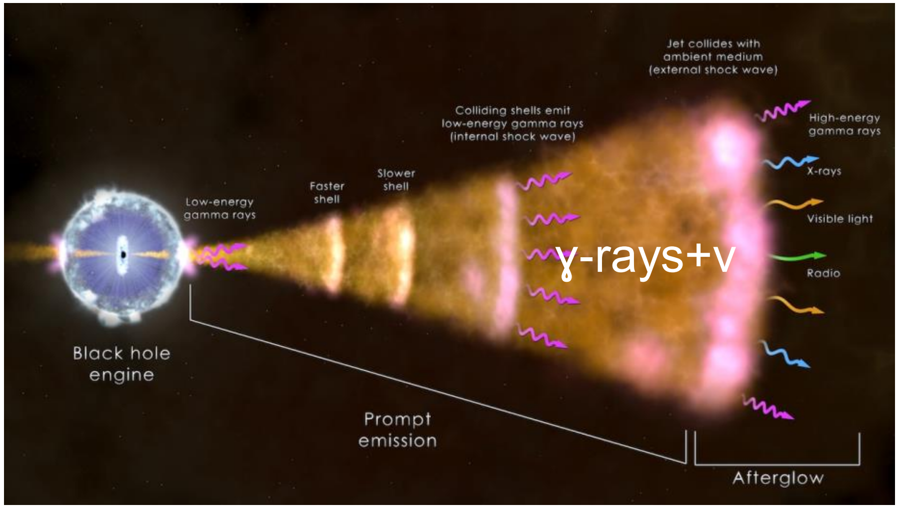


Gamma-ray bursts

- Search for muon neutrinos for 4 bright GRB observed between 2008 and 2013
- Two scenarios are investigated:
  - internal shocks
  - photospheric models

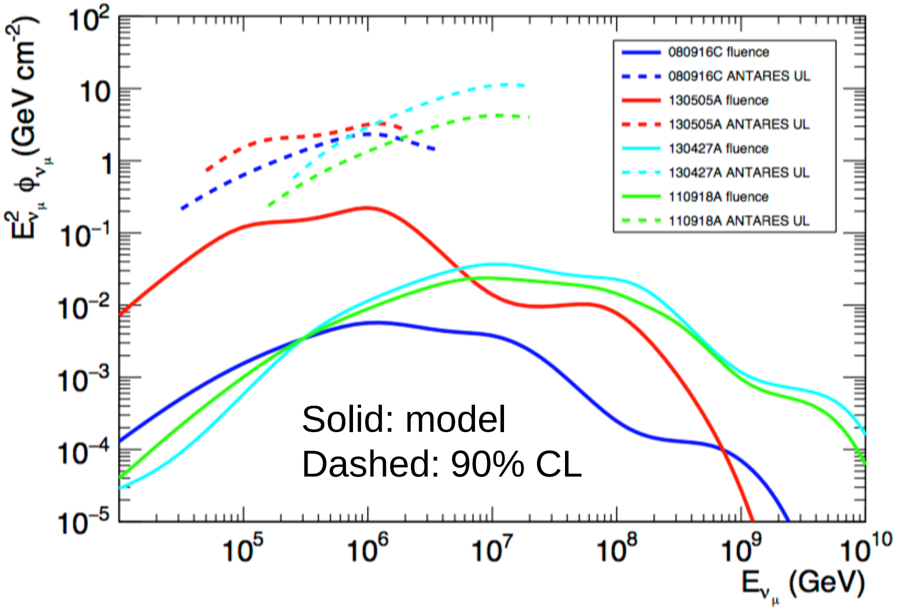
  → use of unfiltered data + special algorithm

📖 arXiv:1612.08589, MNRAS in press



- Stacked search for time shifted neutrinos (during 5 years of ANTARES data): probes wider time windows up to 40 days: no significant detection

📖 Eur.Phys.J. C77 (2017)



Search for Coincidences with Gravitational Waves

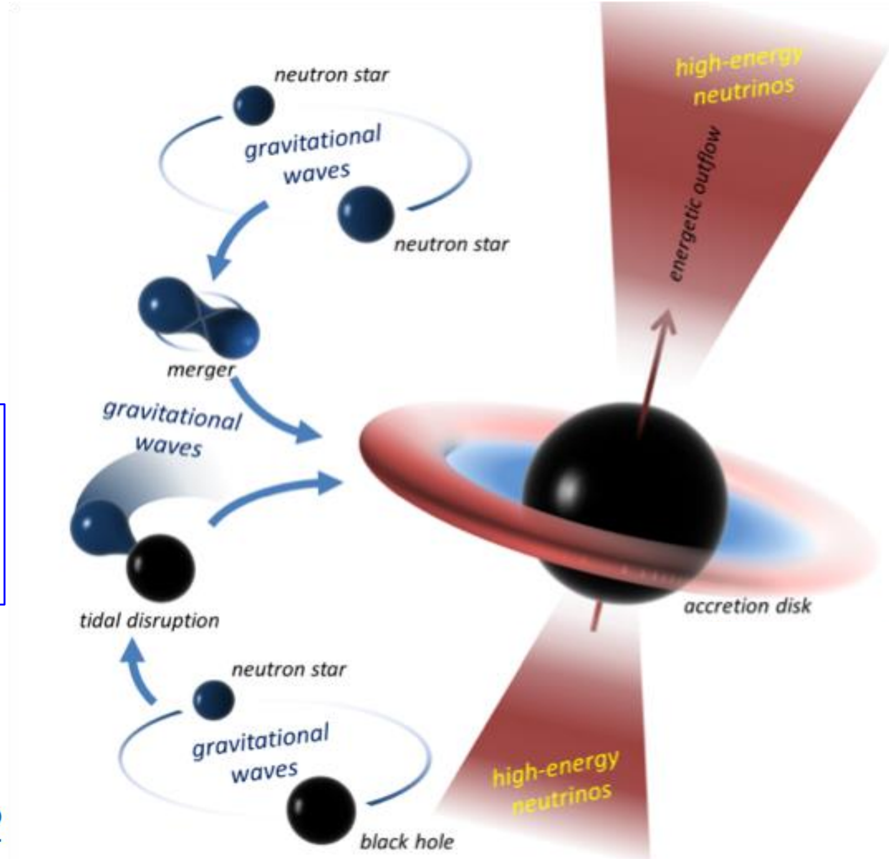
Mostly for BH/NS or NS/NS systems :

Gravitational waves
+ electromagnetic
+ neutrino emission (if baryonic ejecta)

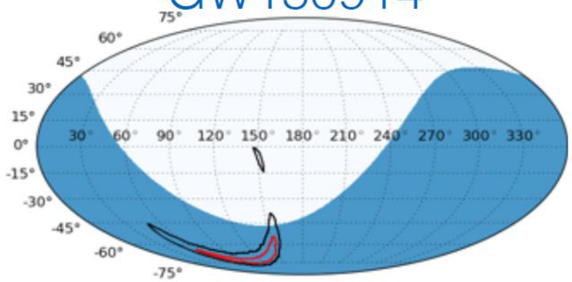
No counterpart observed so far

Limits from ANTARES dominate Eν < 100 TeV wrt IC

Limit on total energy radiated in neutrinos: <10% GW

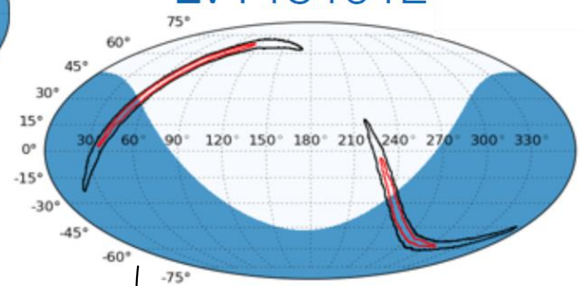


GW150914

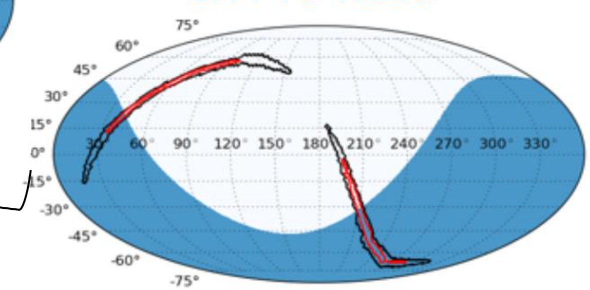


📖 PRD 93, 2016

LVT151012



GW151226



Now real time follow-up of ongoing science run

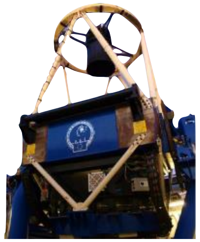
📖 arXiv:1703.06298

The multi-messenger program: TATOO

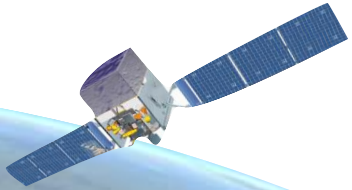
Telescope-Antares Target of Opportunity

2ND APPROACH:

Alert triggering

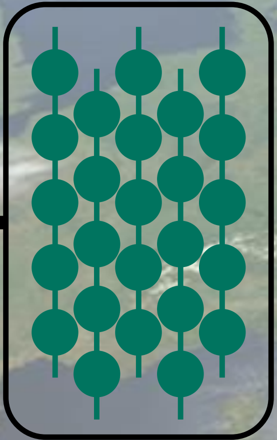


H.E.S.S.



\+ ...

Real-time analysis



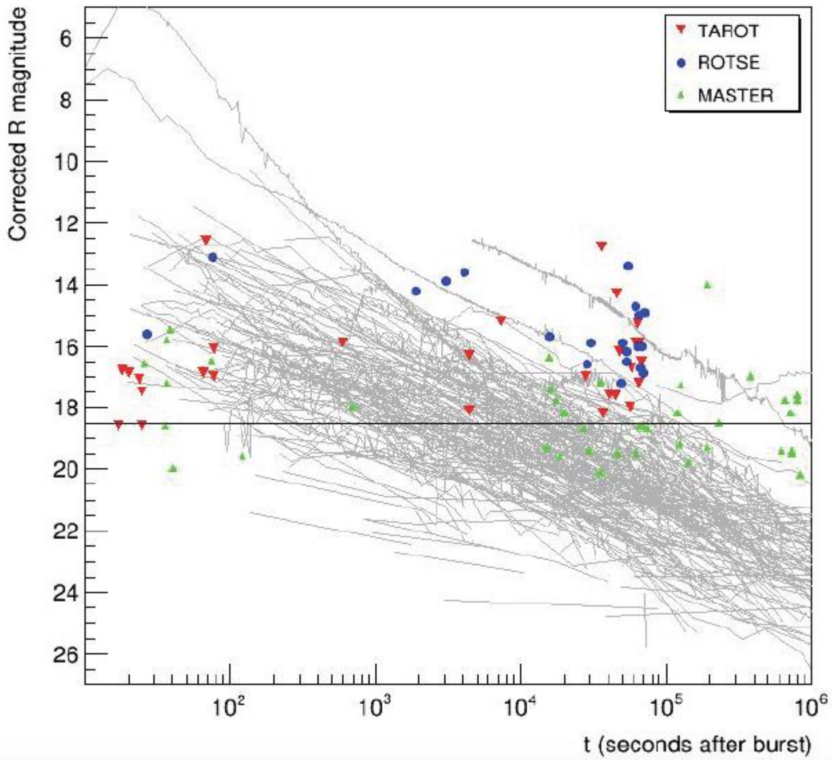
- Time to send an alert: ~5 s
- First optical image <20 s
- Median angular resolution: ~0.3°
- Triggers: single HE, preferred direction, multiplets

TATOO and the GRBs

Radio	Optical	X-ray	GeV γ-rays	TeV γ-rays
MWA (12/yr)	TAROT ZADKO MASTER (GWAC) (30/yr)	Swift (6/yr)	Fermi (offline)	HESS (2/yr) HAWC (offline)

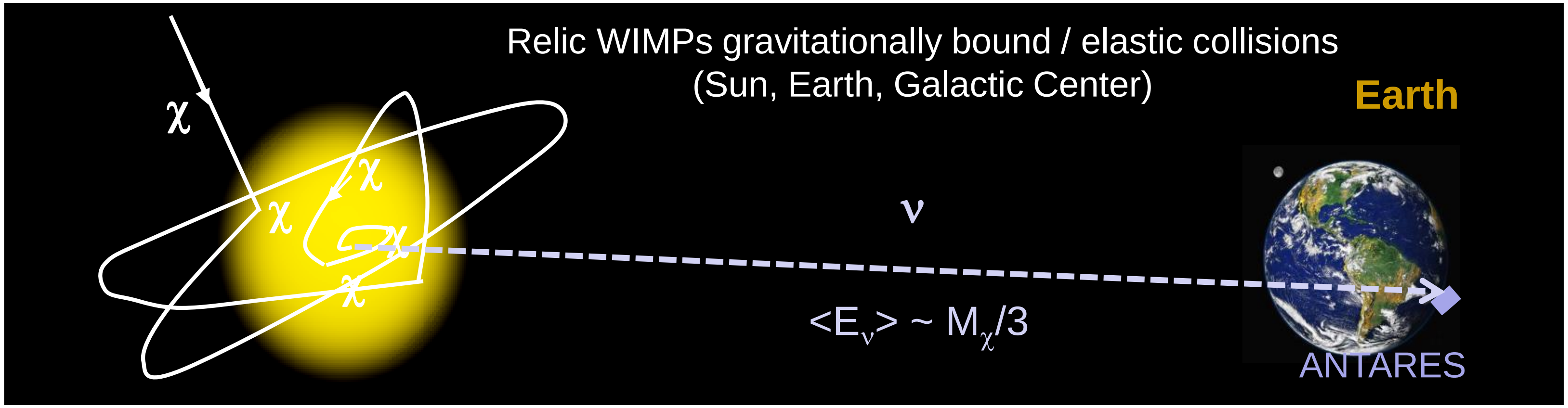
- 93 alerts with early (<24h) follow-up (01/2010- 01/2015)
- 13 follow-ups with delay < 1min (best 17s)
- 13 X-ray Swift follow-up (5-6hr delay)
- No transient candidate associated to neutrinos

GRB origin unlikely



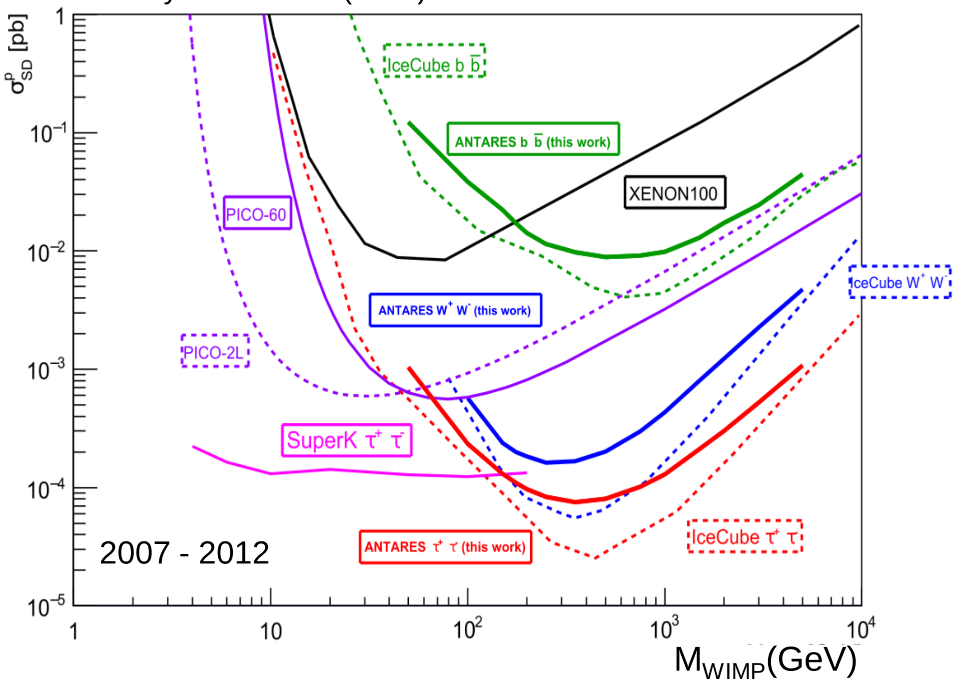
📖 JCAP 02:062, 2016

Indirect Search for Dark Matter

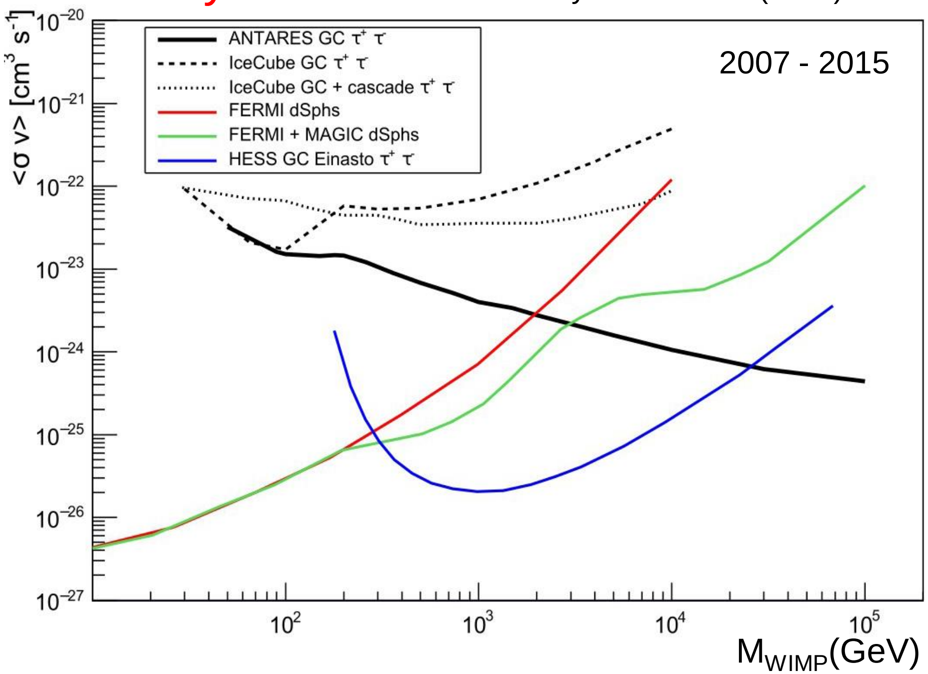


Track channel only

📖 Phys.Lett. B759 (2016) 69-74



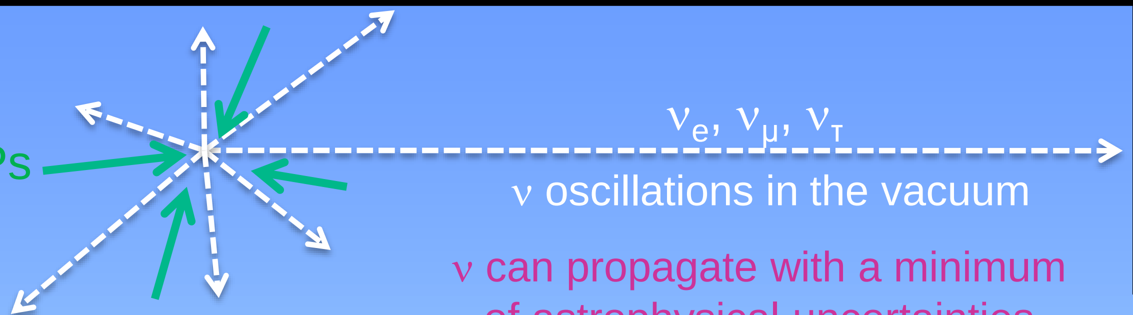
📖 Phys. Let. B 769 (2017) 249



Also DM from the Center of the Earth : 📖 Physics of the Dark Universe, 16 (2017) 41–48

Search for Dark Matter towards the Galactic Centre

WIMPs



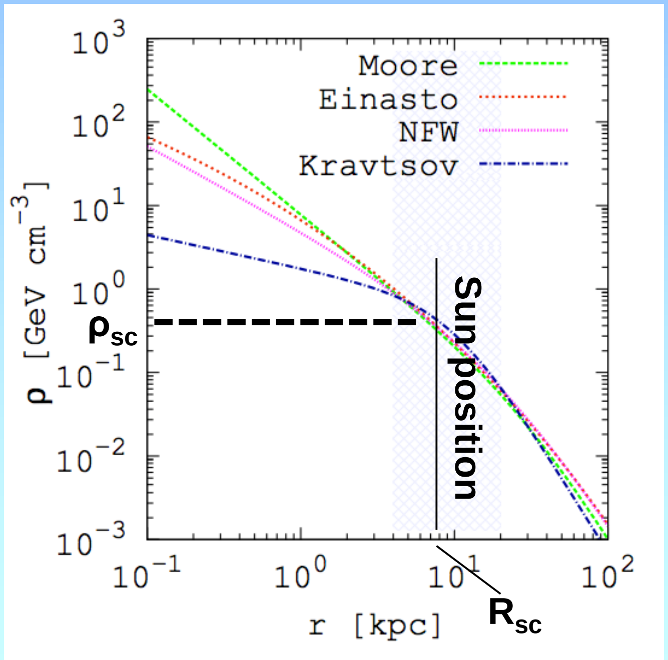
ν oscillations in the vacuum

ν can propagate with a minimum of astrophysical uncertainties

Galactic Centre

Earth

WIMPs self-annihilate according to $<\sigma_A v>$ (halo model-dependent)



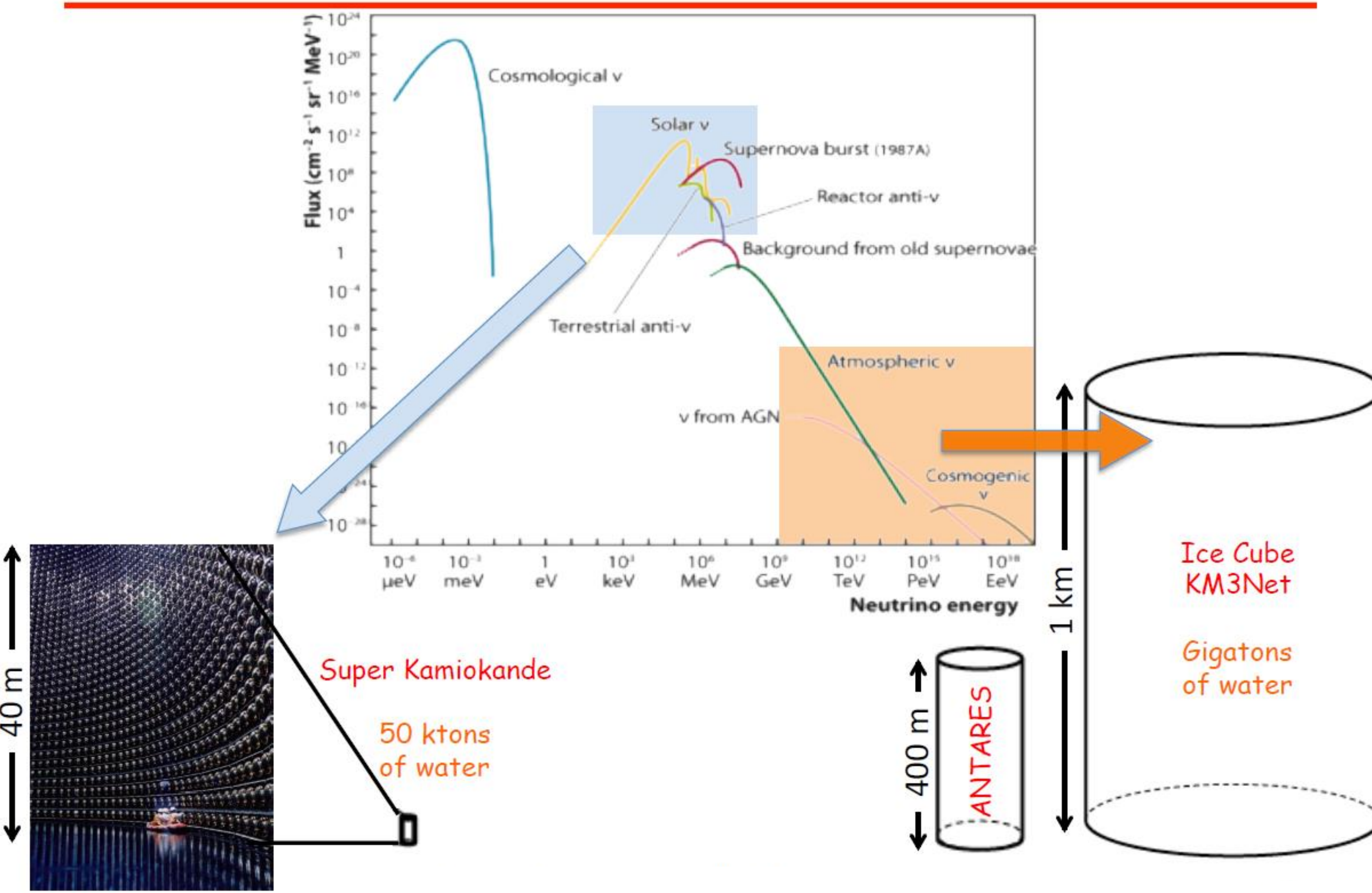
$$\frac{d\Phi_\nu}{dE_\nu}(E_\nu, \Delta\Psi) = \Phi^{PP}(E_\nu) \times J(\Delta\Psi)$$

where

$$\Phi^{PP} \equiv \frac{1}{4\pi} \frac{<\sigma v>}{2M^2_{WIMP}} \frac{dN_\nu}{dE_\nu}$$

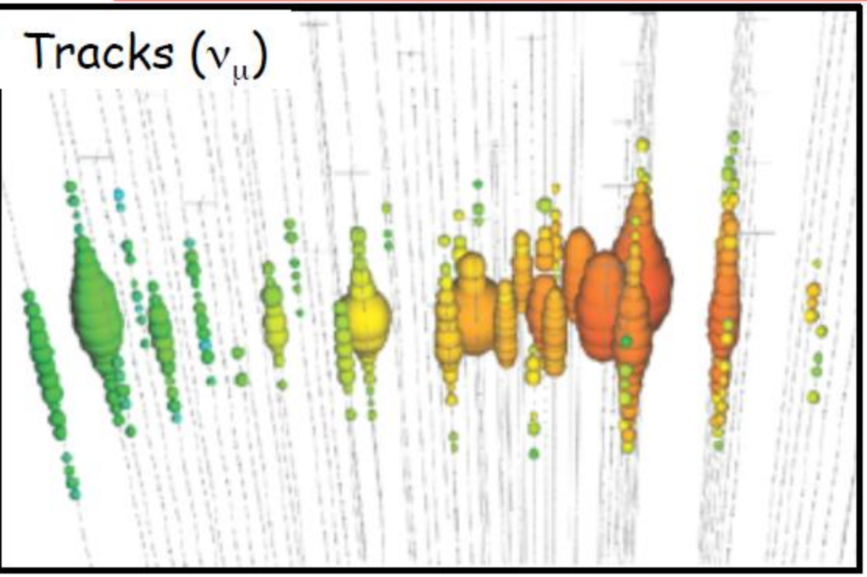
$$J(\Delta\Psi) = \int_{\Delta\Psi} \int \rho^2_{DM}(l, \Psi) \, dl \, d\Psi$$

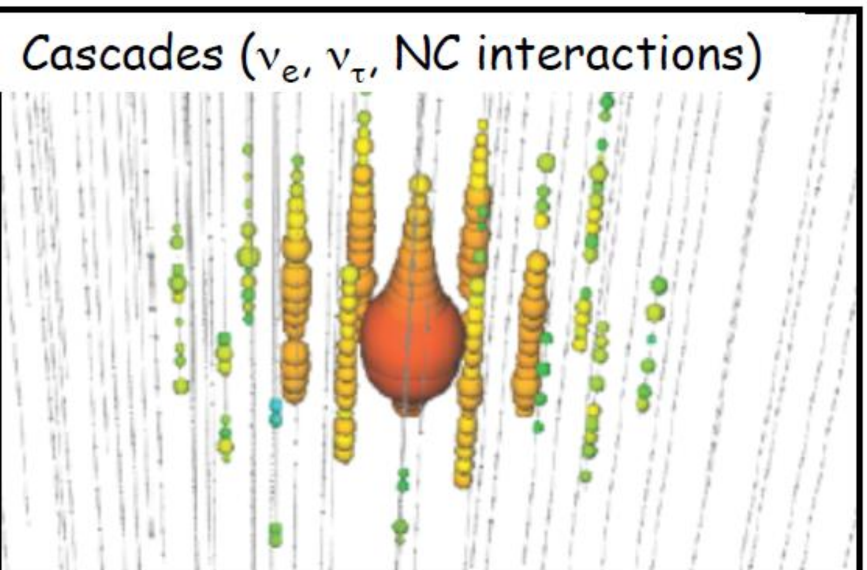
Neutrino spectrum



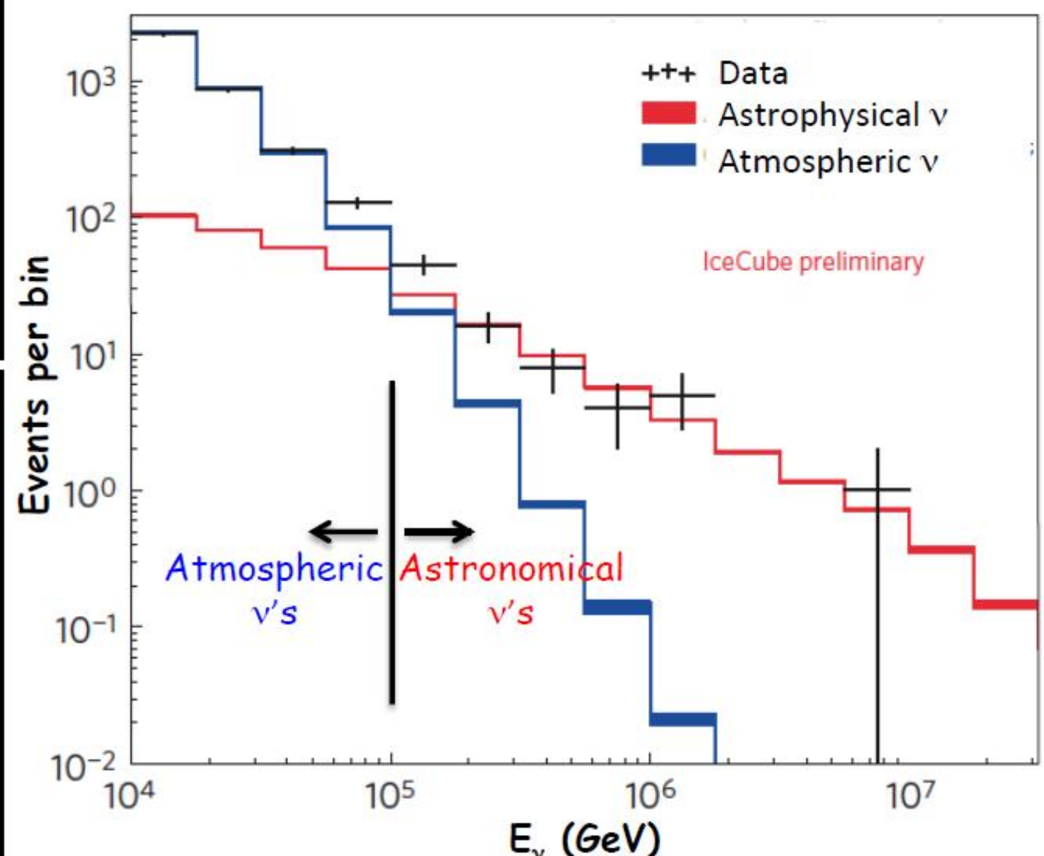
The IceCube Signal :

Birth of high-energy neutrino astronomy



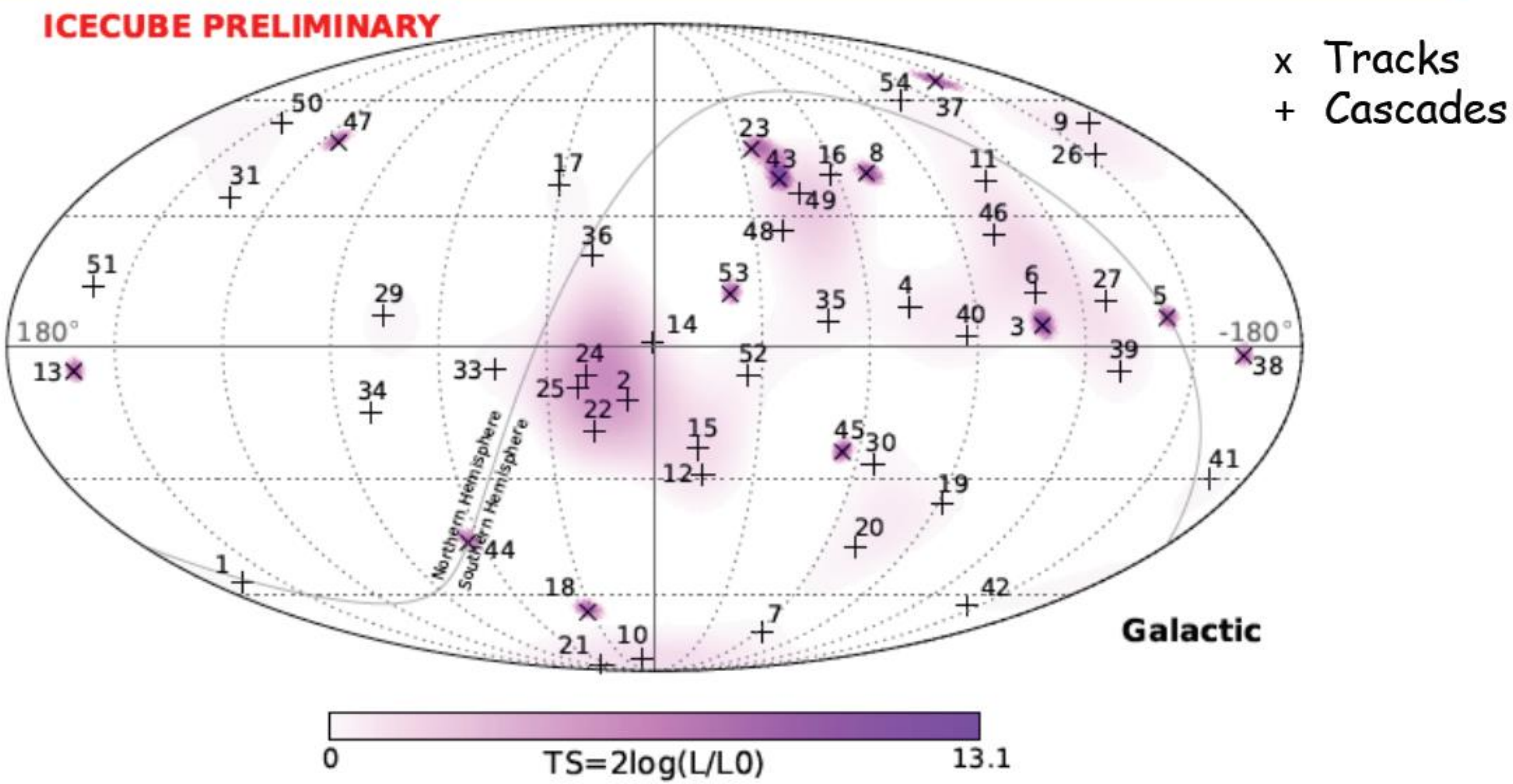


28 events (after 2 years)
Deposited energy from 30 TeV to 1 PeV



Halzen (2016) and refs. therein

The IceCube Signal :
Arrival direction



- Compatible with isotropy
- No source identified yet
- Subdominant Galactic component possible

→ Source identification?

Diffuse flux (all flavors) PRELIMINARY

Tracks

Data: 2007-2015 **(2451 livedays)**

Above E_{cut}: Bkg: 13.5 ± 3 evts, IC-like signal: 3 evts

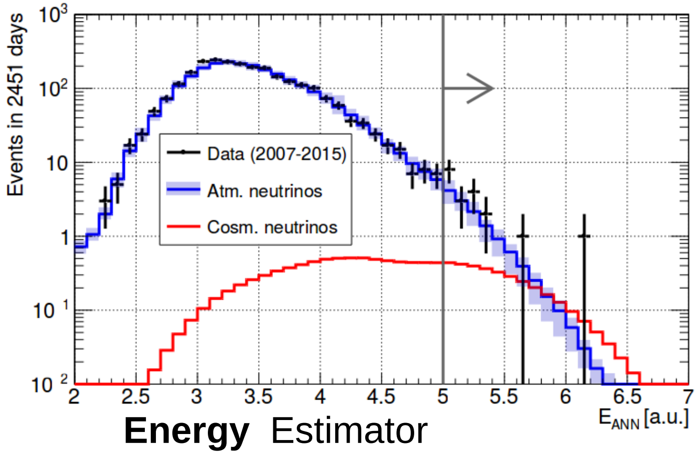
Observed: **19 evts**

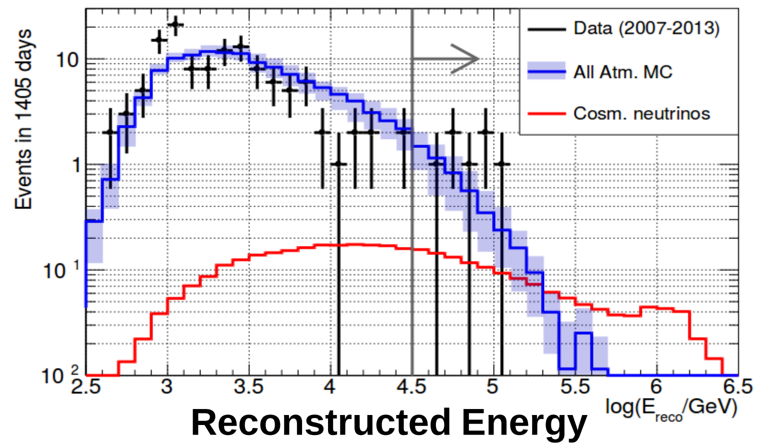
Cascades

Data: 2007-2013 **(1405 livedays)**

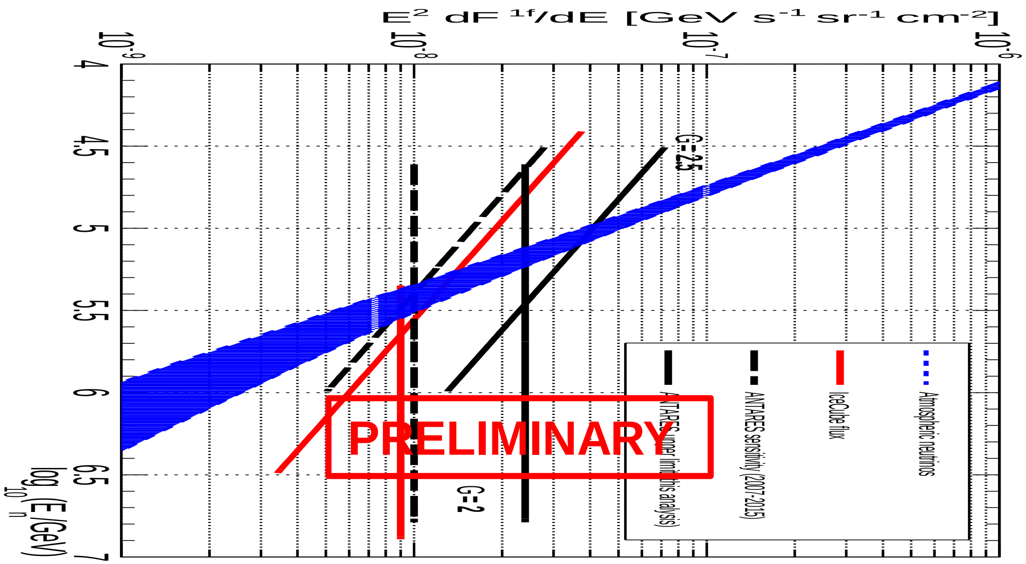
Above E_{cut}: Bkg: 5 ± 2 evts, IC-like signal: 1.5 evts

Observed: **7 evts**





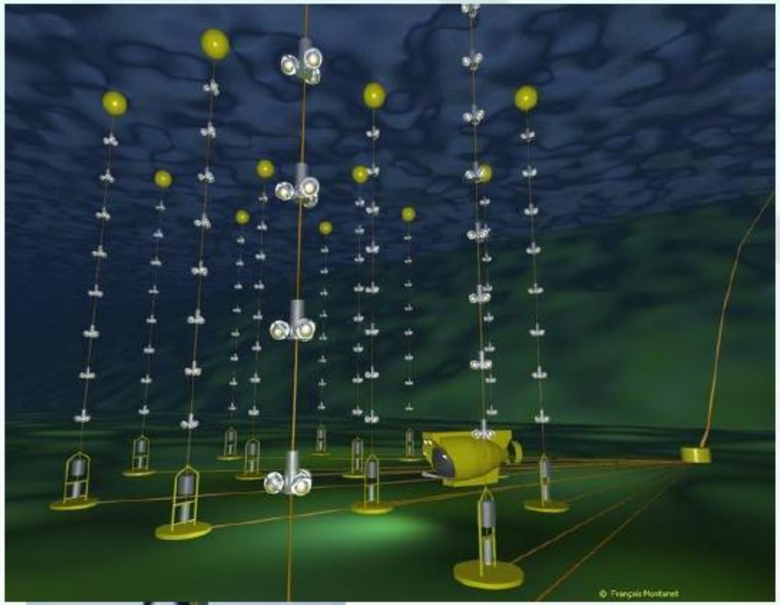
Compatible with both bkg and IC expectations



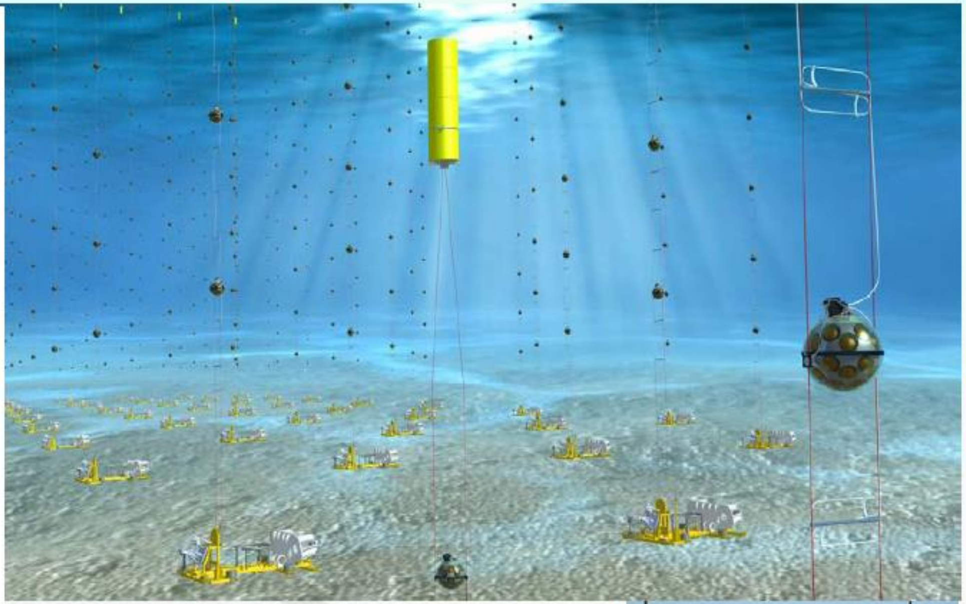
The future of Neutrino Astronomy in the Mediterranean Sea

ANTARES → KM3NeT

12 Lines, 885 OM



3 Building Blocks on 2 Sites
3*115 lines, ~6210 OMs, ~ 192510 PMTs



Basic active element:
Digital Optical Module
31 x 3" PMTs

18 OMs/line

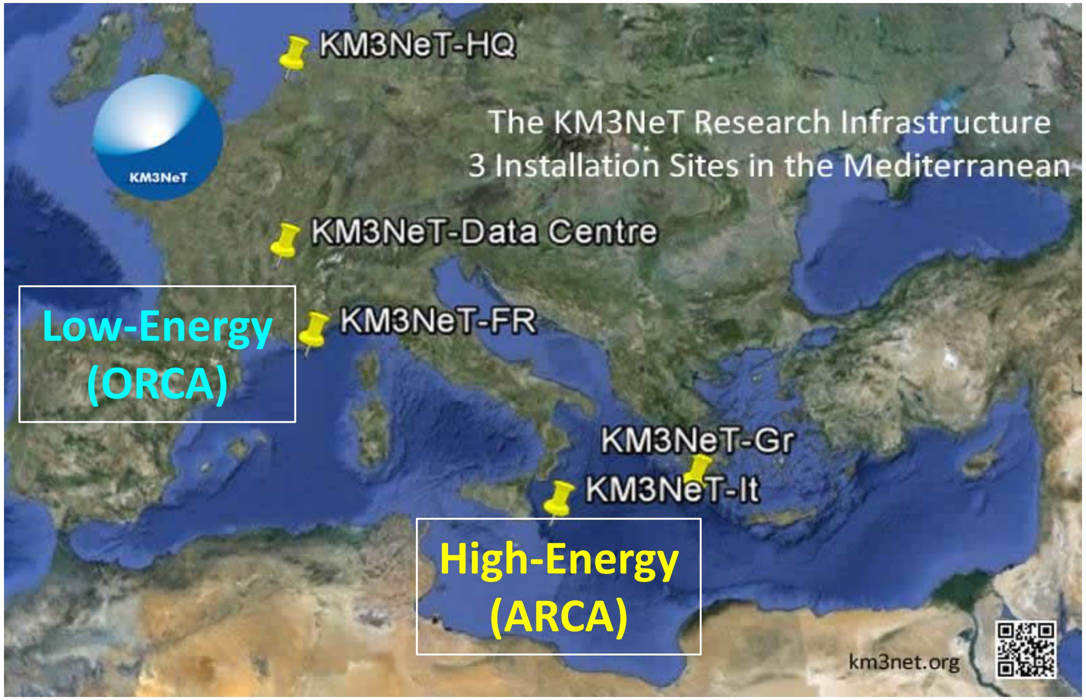
KM3NeT

KM3NeT is a distributed research infrastructure with 3 main science topics:

- The origin of cosmic neutrinos (high energy)
- Measurement of fundamental neutrino properties (low energy)
- Deep Sea Observatory - Oceanography, bioacoustics, bioluminescence, seismology

Single Collaboration

Single Technology



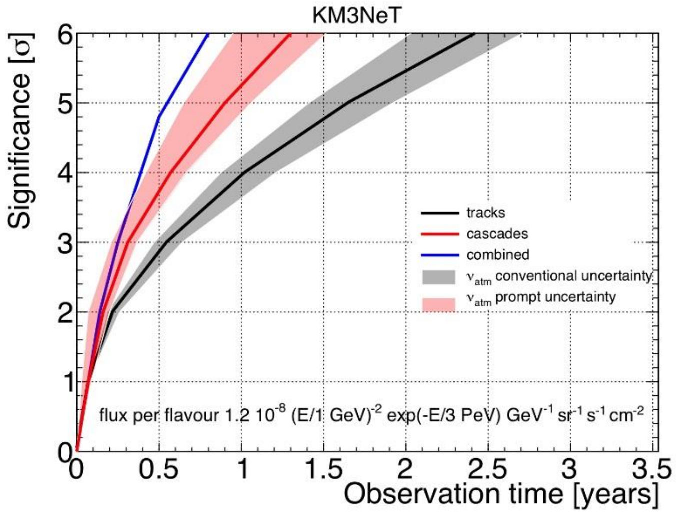
ARCA - Astroparticle Research with Cosmics in the Abyss

ORCA - Oscillation Research with Cosmics in the Abyss

KM3NeT Objectives

Astroparticle Research with Cosmics in the Abyss (ARCA):

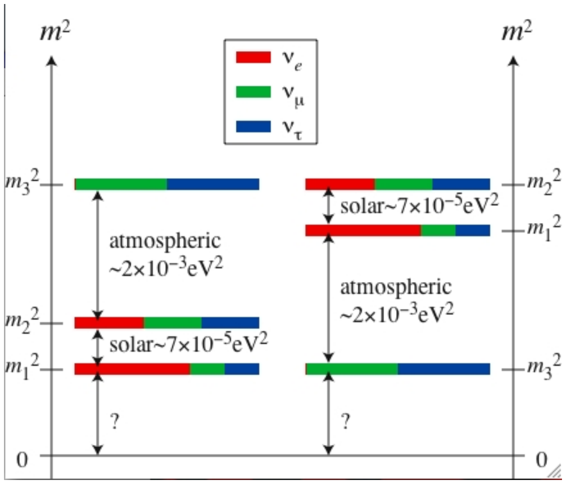
Sparse telescope optimised for TeV-PeV cosmic neutrinos



Discover/observe high-energy astrophysical neutrino sources

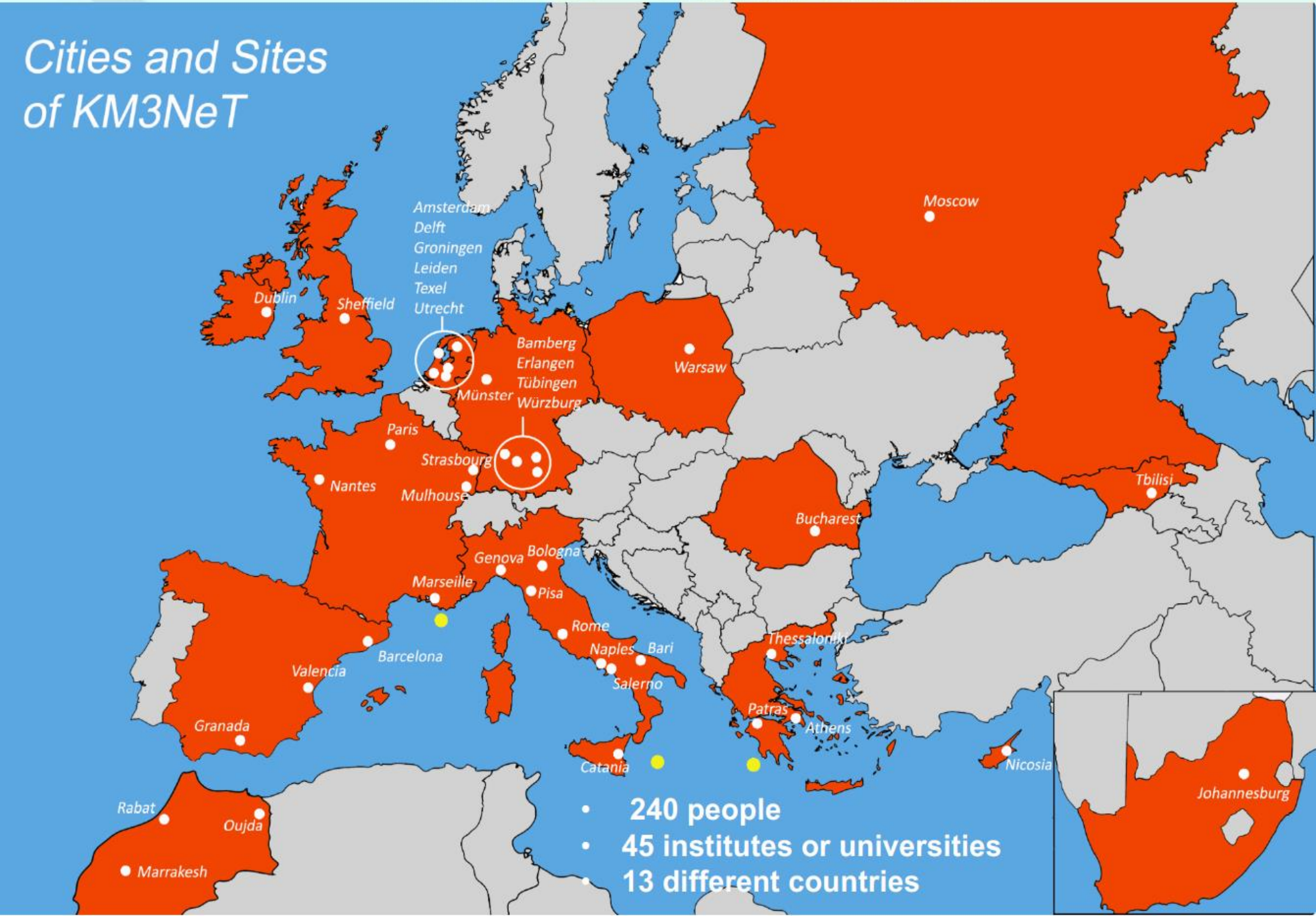
Oscillation Research with Cosmics in the Abyss (ORCA):

Dense detector optimised for GeV atmospheric neutrinos



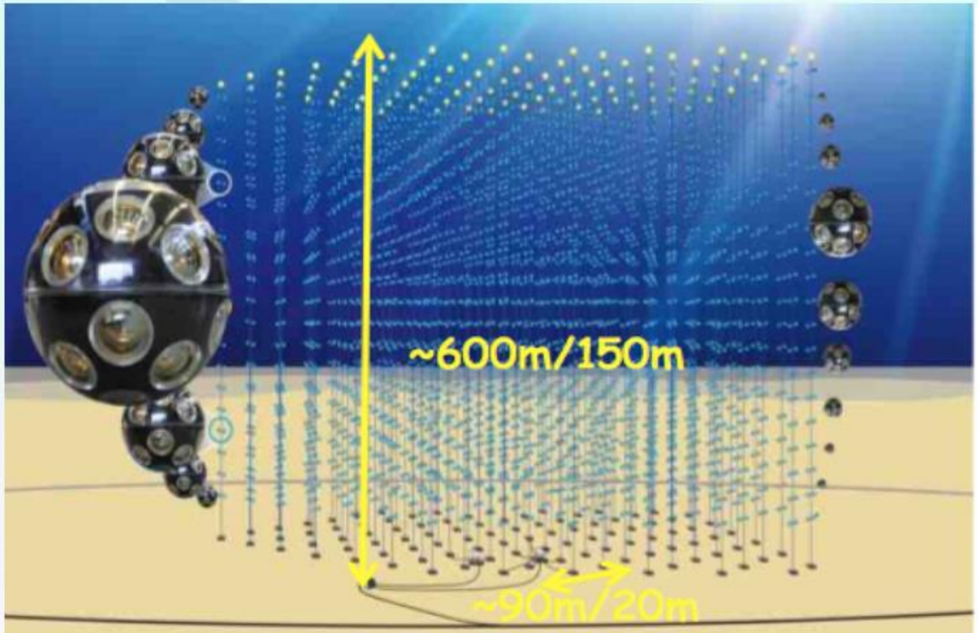
Determine the Neutrino Mass Hierarchy

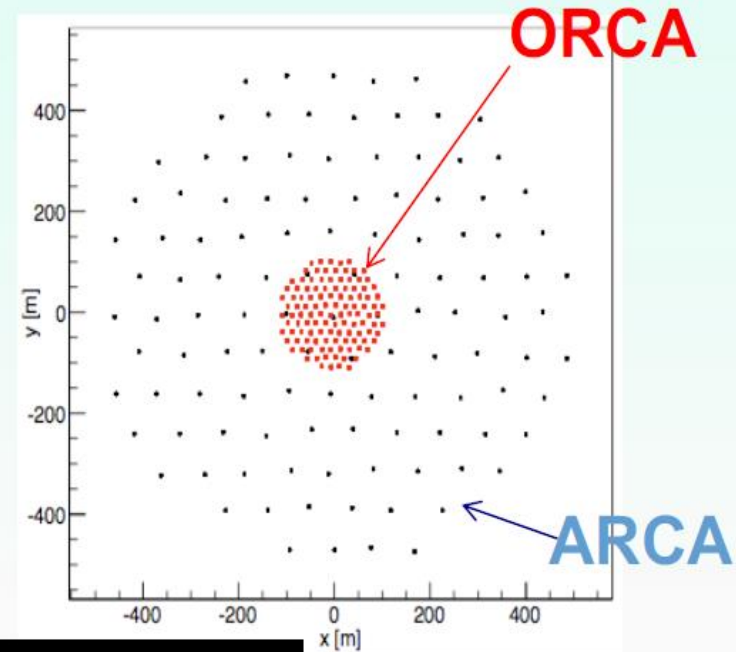
KM3NeT - Collaboration



- 240 people
- 45 institutes or universities
- 13 different countries

KM3NeT Building Blocks

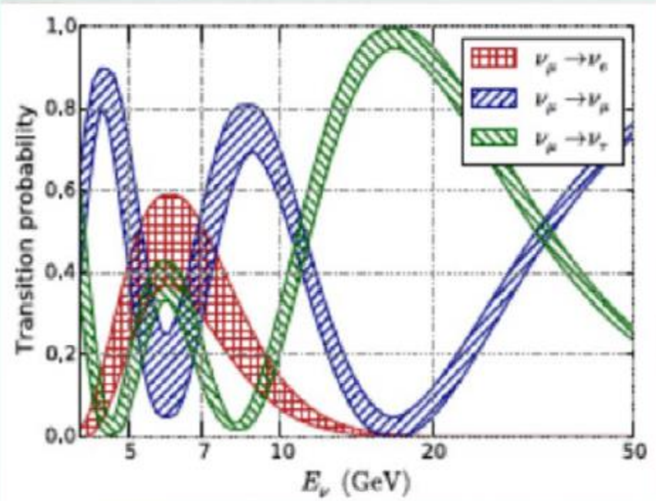


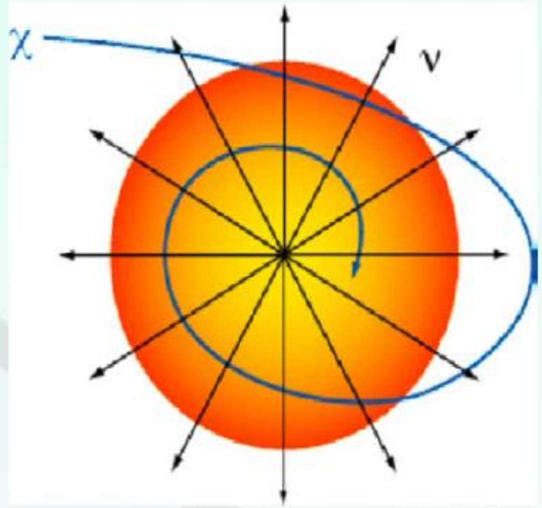


[redacted]

	ARCA	ORCA
Location	Italy – Capo Passero	France - Toulon
Detector Lines distance	90m	20m
DOM spacing	36m	9m
Instrumented mass	500Mton	5,7 Mton

KM3NeT Neutrino Telescope science scopes





Composite View of the Crab Nebula

Low Energy	Medium Energy	High Energy
MeV < E_ν < 100 GeV	M eV < E_ν < 100 GeV	E_ν > 1 TeV

Low Energy
- Neutrino Oscillations
- Neut. Mass Hierarchy
- Sterile neutrinos
- Neut. From Supernovae

Medium Energy
- Dark Matter search
- Monopoles
- Nuclearites

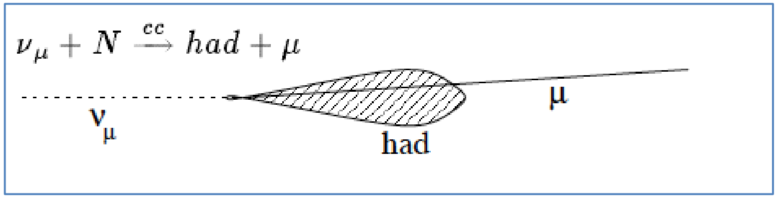
High Energy
- Neutrinos from extra-terrestrial sources
- Origin and production mechanism of HE CR

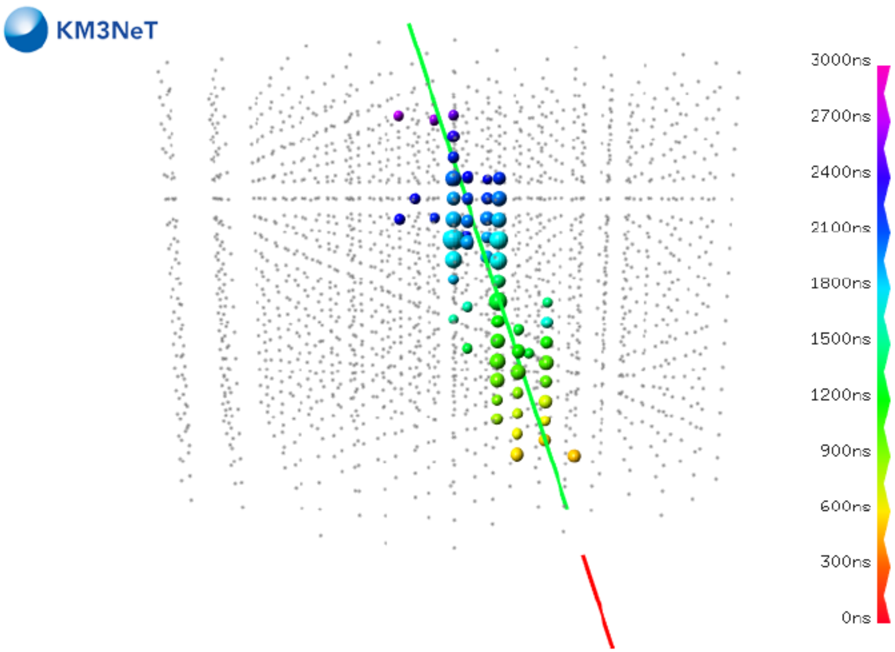
KM3NeT-ORCA ⟷ ANTARES ⟷ KM3NeT-ARCA

… and synergies with Sea-Sciences: oceanography, biology, seismology, …

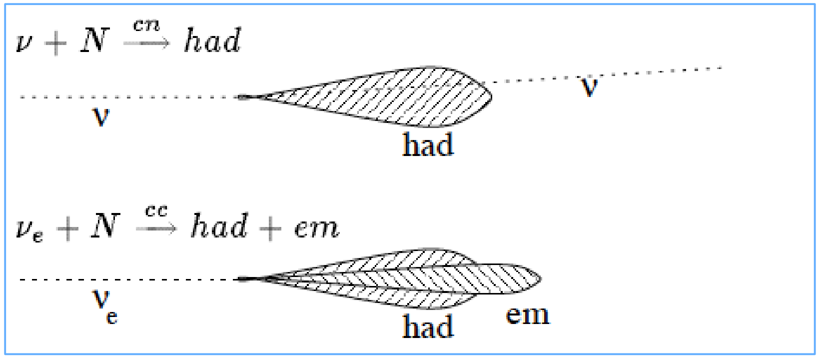
Event Topologies

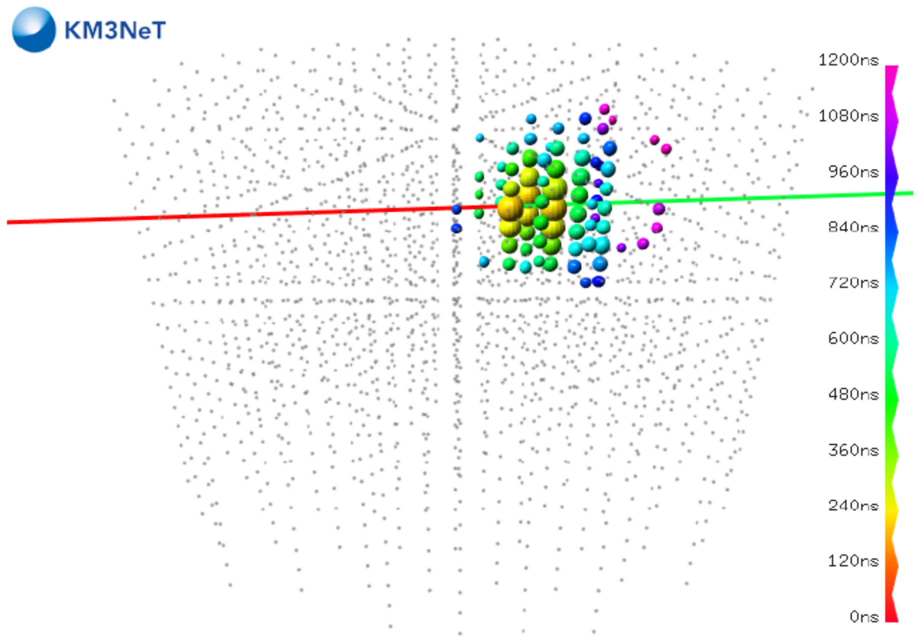
Track-like (ν_μ^{CC})





shower-like (ν^{NC}, ν_e^{CC})



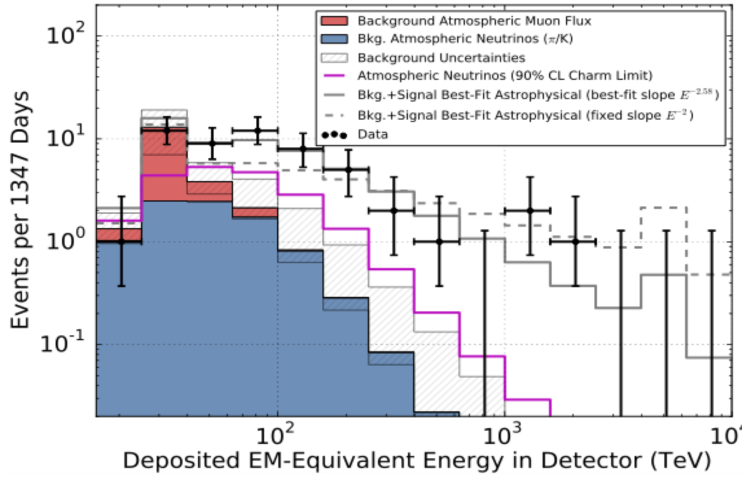


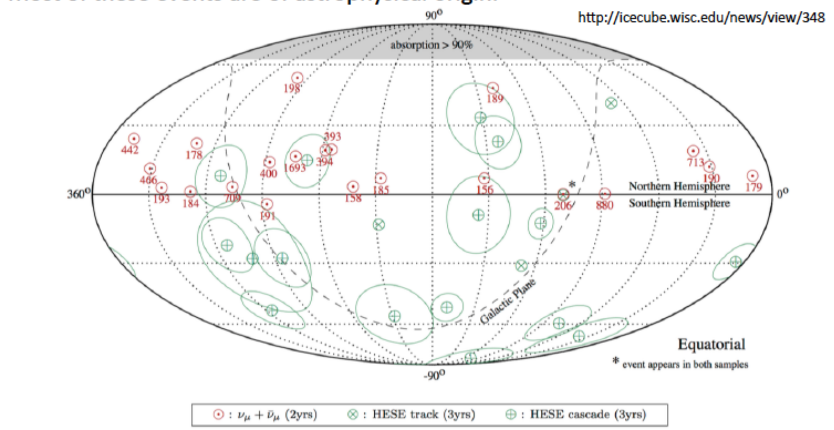
ARCA simulation, TeV neutrino energies

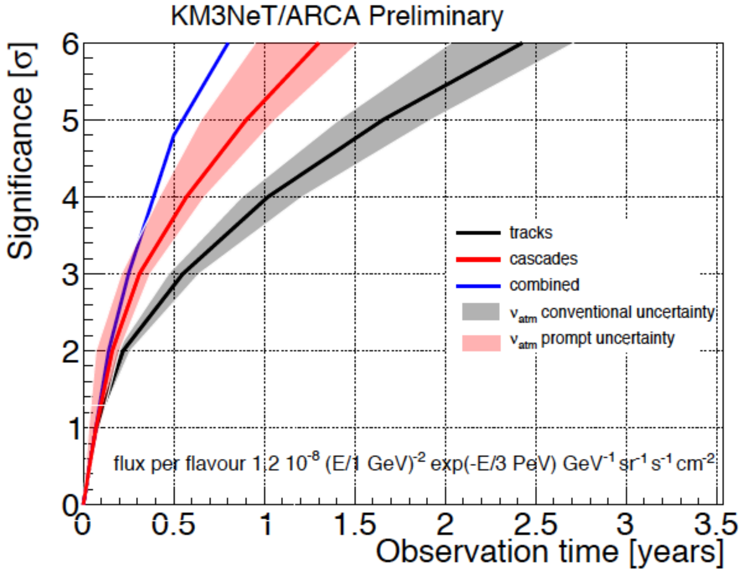
KM3NET: Diffuse Flux

IceCube: 4 year HESE analysis (ICRC 2015)
53 events (5.7 sigma), Ethreshold: 60 TeV

p=2.5% in gal. plane scan
within ± 7.5° gal. latitude

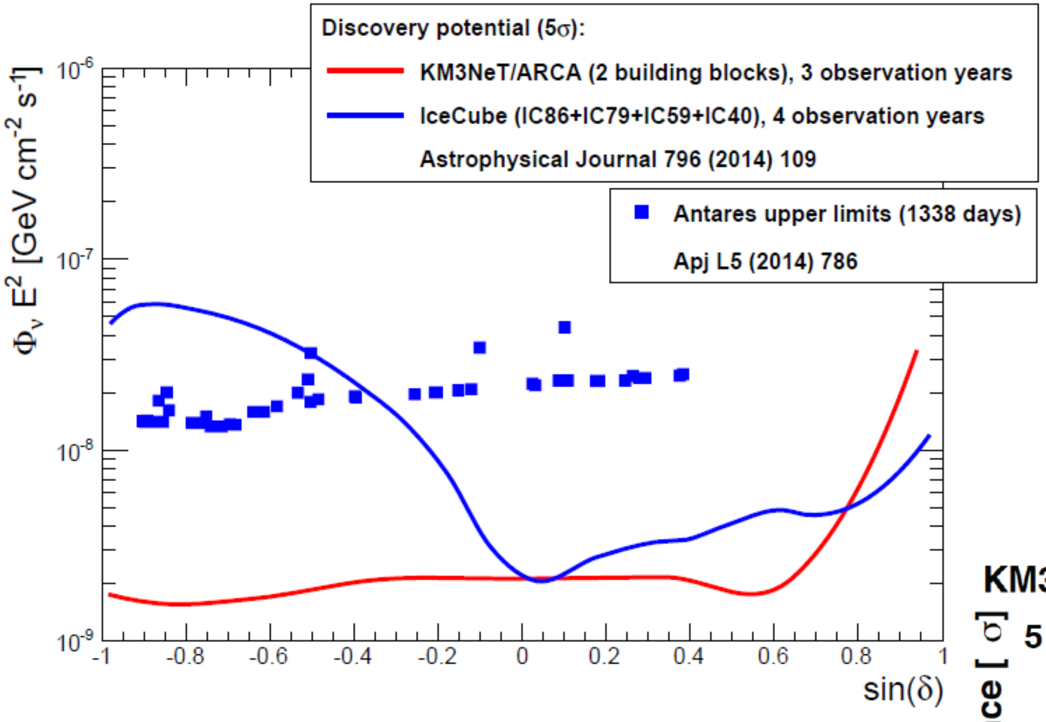






KM3NeT:
5 sigma in 1/2 year

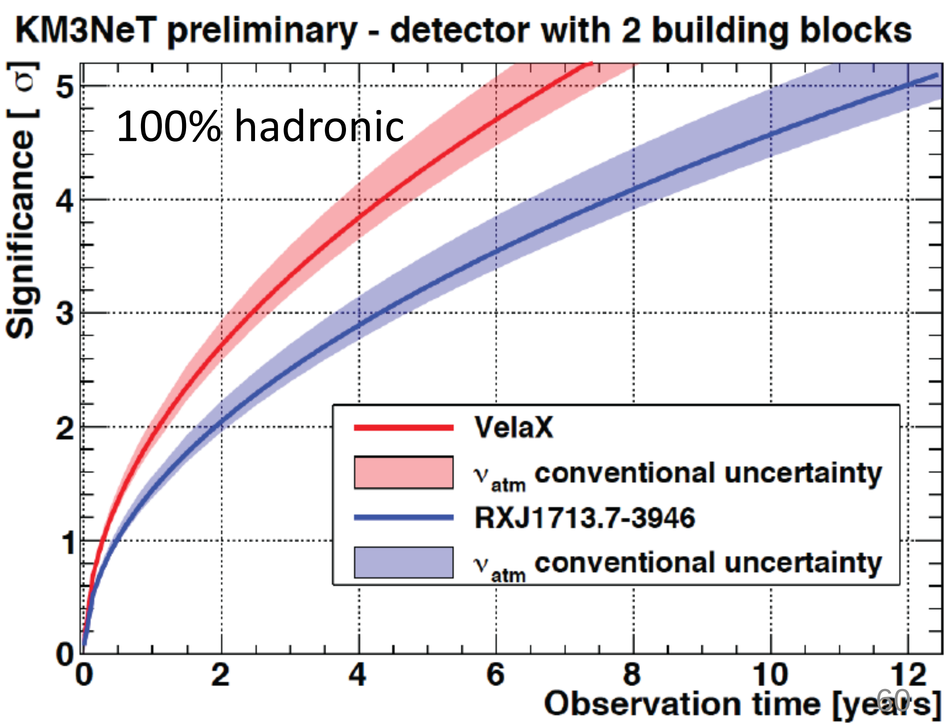
KM3NET: Point Sources

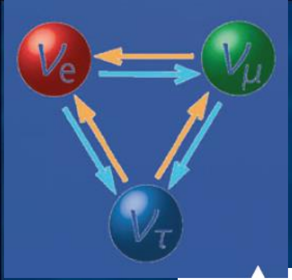


- Significant discovery potential for extragalactic sources
- Galactic sources in reach

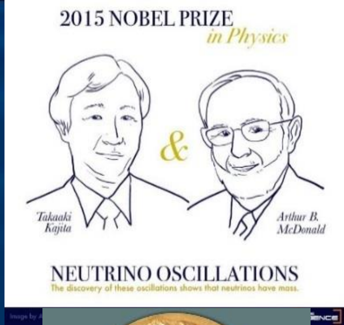
	muon	cascade
Angular resolution	0.1° (0.5°)	2° (15°)
Energy resolution	300%	5%

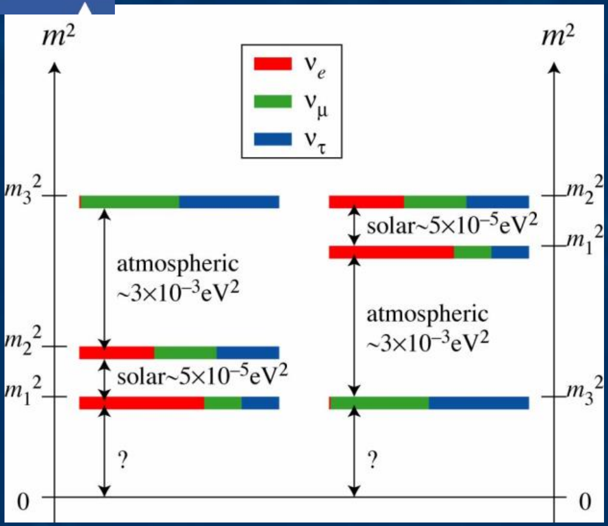
(IceCube performance)



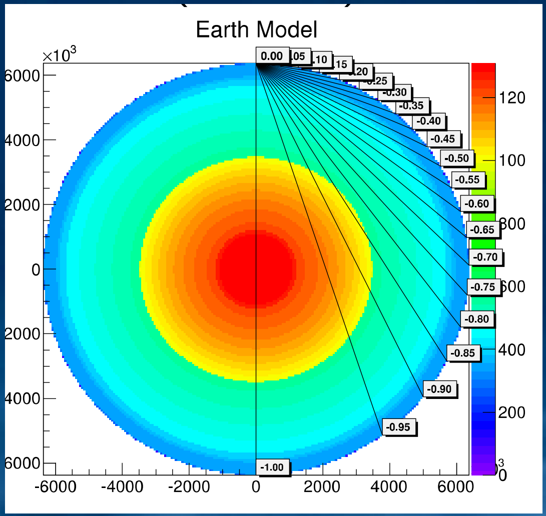


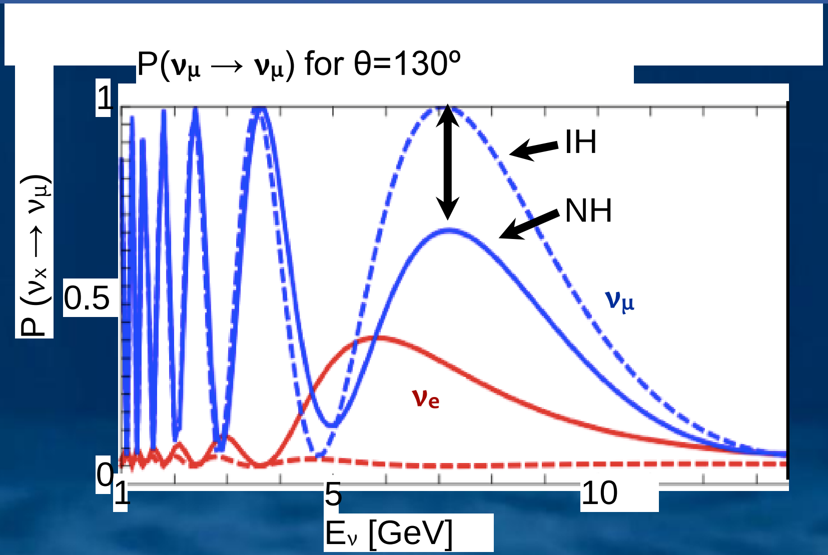
Determination of the **Neutrino Mass Hierarchy** using atmospheric neutrino oscillations





Fundamental parameter of the neutrino particles still unknown !!



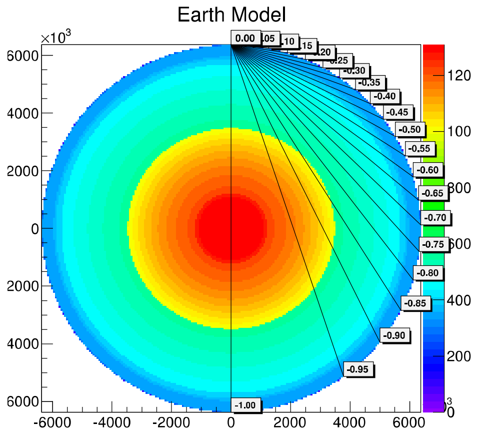


Precise study of the **flux of atmospheric neutrinos of few GeV** interacting in the Earth

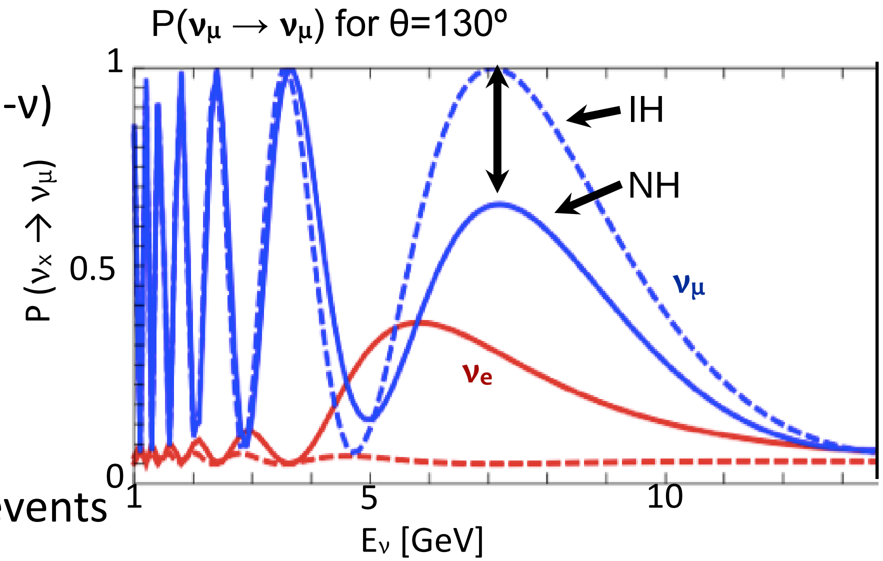
Measuring the neutrino mass hierarchy with atmospheric neutrinos

- a « free beam » of known composition (ν_e, ν_μ)
- wide range of baselines (50 → 12800 km) and energies (GeV → PeV)
- oscillation pattern distorted by Earth matter effects (hierarchy-dependent):

  maximum difference IH ↔ NH at
  $\theta=130°$ (7645 km) and E_ν = 7 GeV



- opposite effect on anti-neutrinos: IH(ν)≈NH(anti-ν)
  BUT differences in flux and cross-section:
  $\Phi_{atm}(\nu) \approx 1.3 \times \Phi_{atm}(\text{anti-}\nu)$
  $\sigma(\nu) \approx 2\sigma(\text{anti-}\nu)$ at low energies



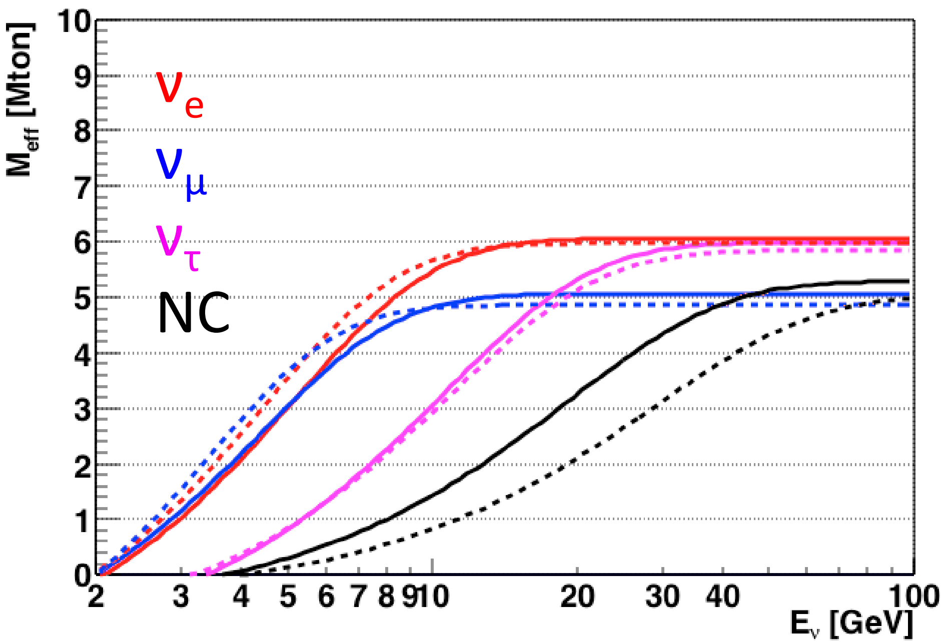
- measure zenith angle and energy of upgoing atmospheric GeV-scale neutrinos,
  identify and count muon and electron channel events

- feasible now that θ_{13} is measured to be large

📖 Akmedov, Razzaque & Smirnov, JHEP 02 (2013) 082

Effective Mass of ORCA

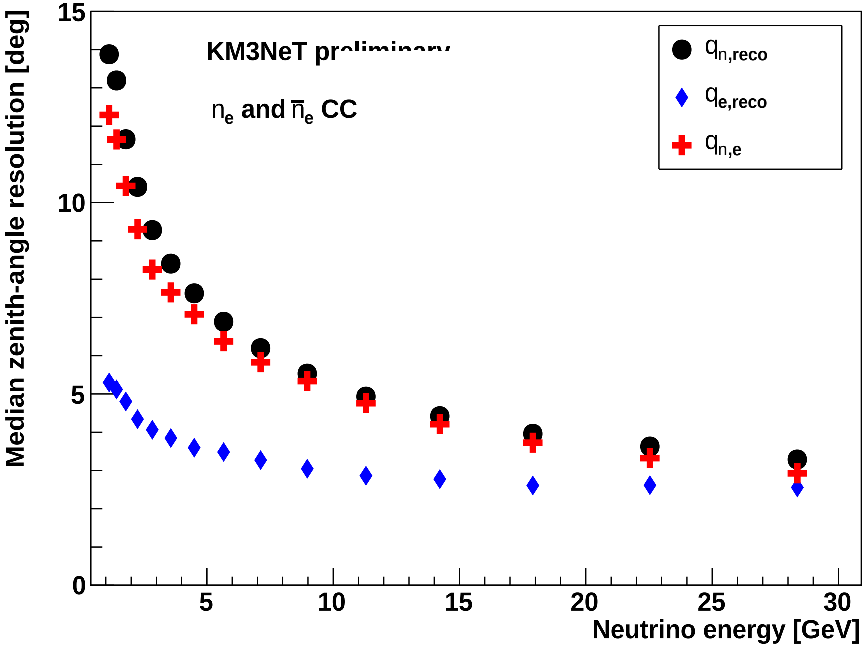
After triggering, atmospheric muon rejection and containment cuts:



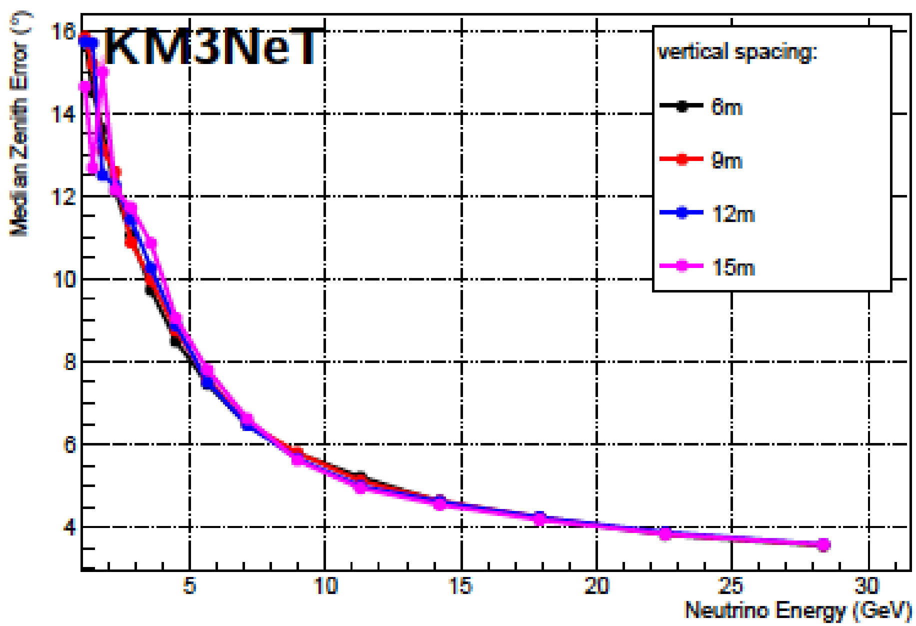
Events/yr:
ν_eCC: 17,300
ν_μCC: 24,800
ν_τCC: 3,100
NC: 5,300

- Energy threshold determined by DOM spacing
- 6 Mton@10 GeV
- 50% Efficiency at 5 GeV

Shower



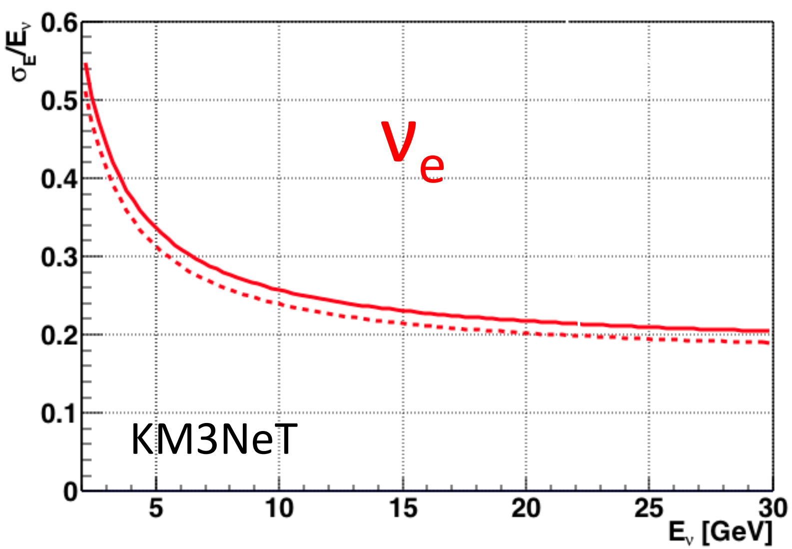
Track



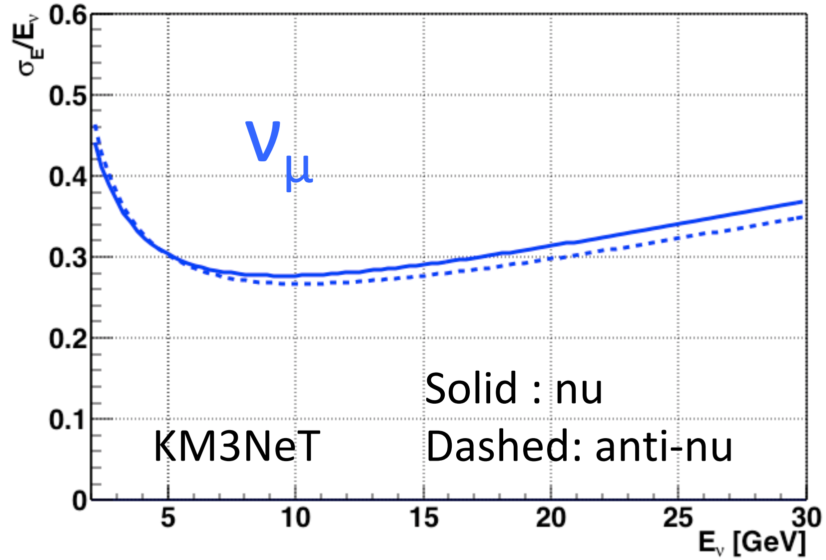
- 7°(5°) for 5(10) GeV for both channels
- Dominated by kinematic smearing

Energy Resolutions of ORCA

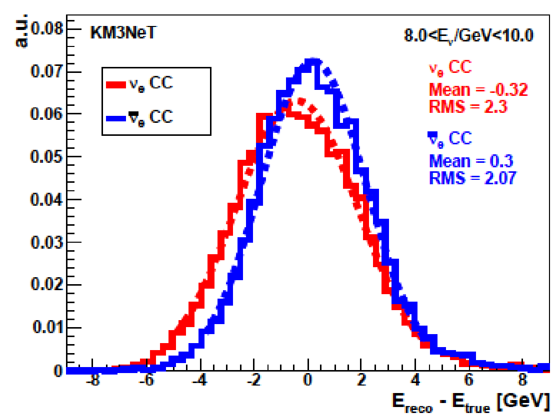
Shower



Track



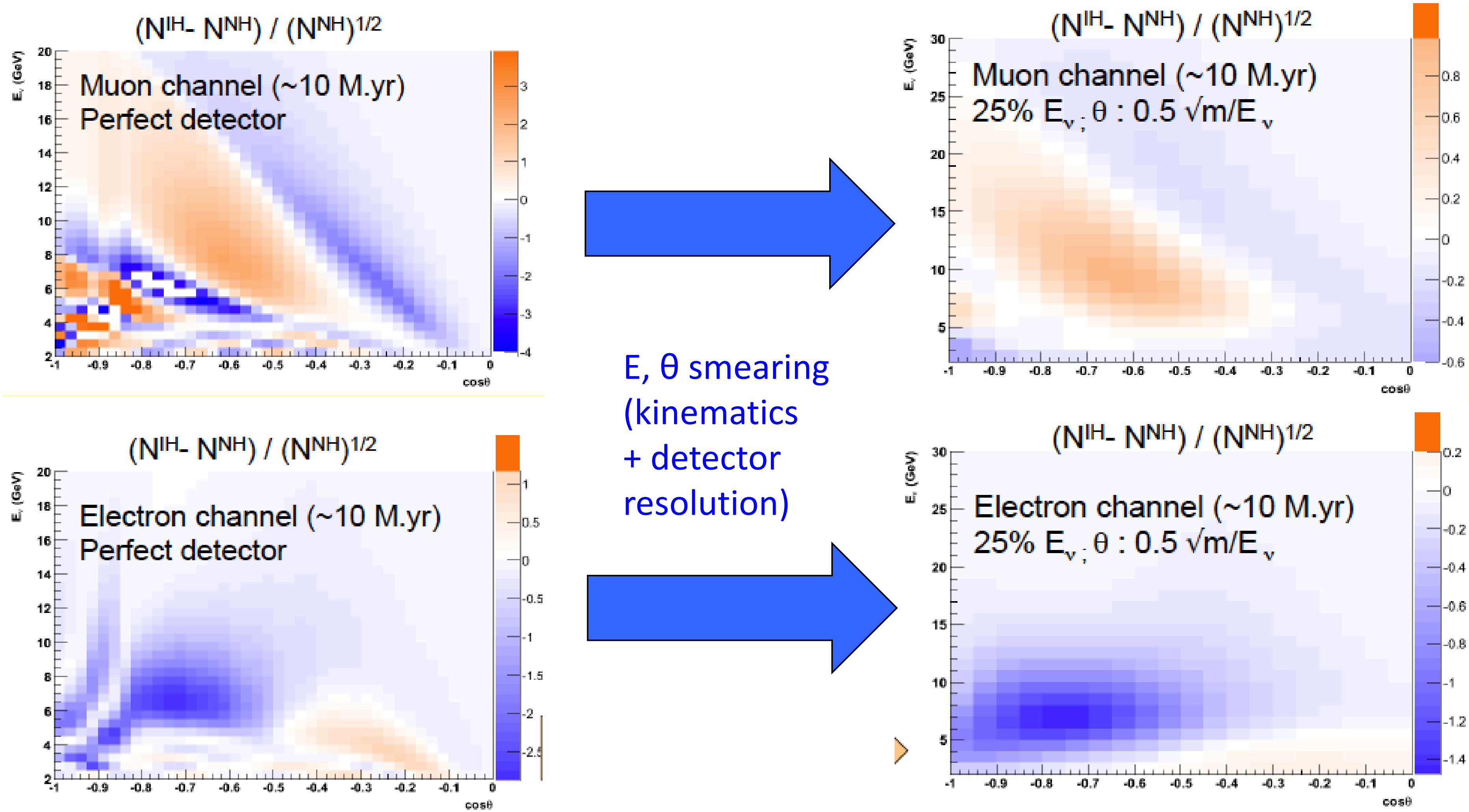
- Energy resolution better than 30% in relevant range
- Close to Gaussian



Experimental signature

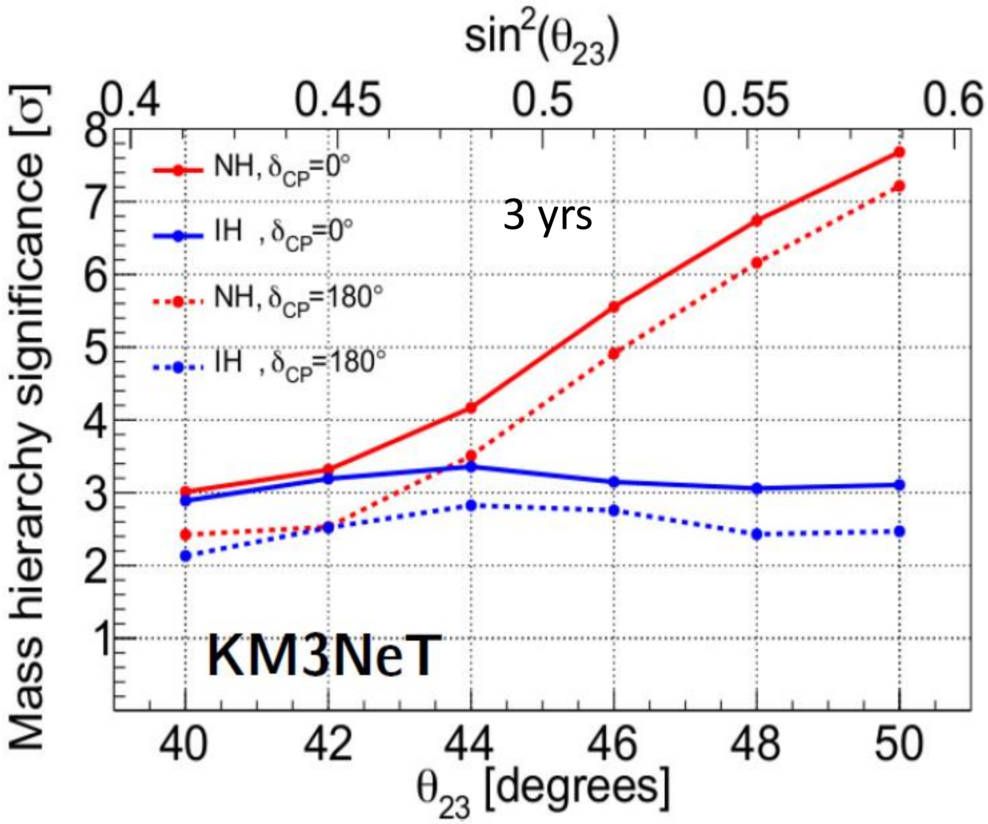
Both muon- and electron-channels contribute to net hierarchy asymmetry

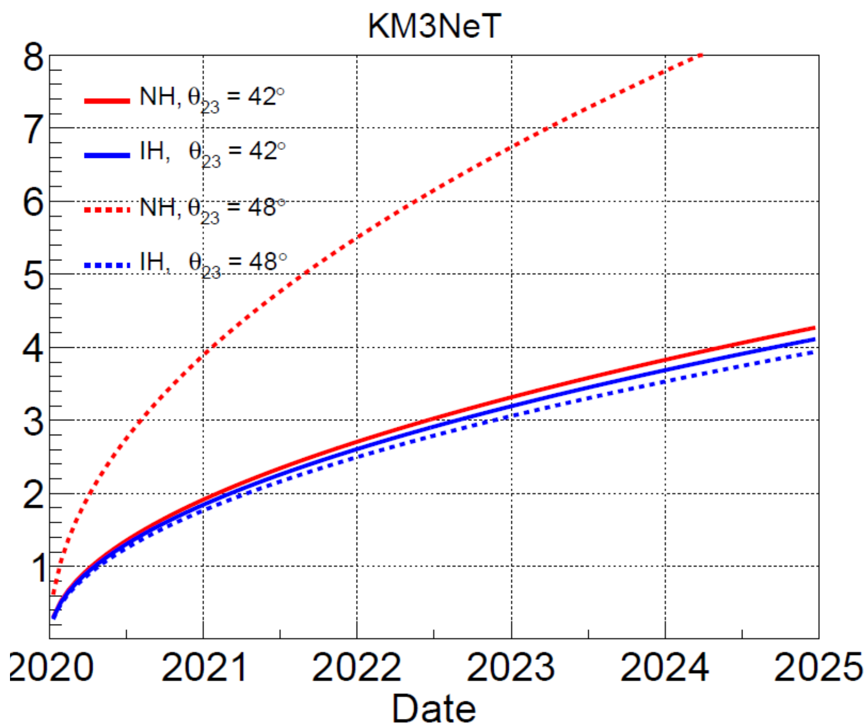
electron channel more robust against detector resolution effects:



Sensitivity to Mass Hierarchy of ORCA

- After 3 years 3σ for most of the parameter space
- NH and 2nd Octant of θ_{23} much better

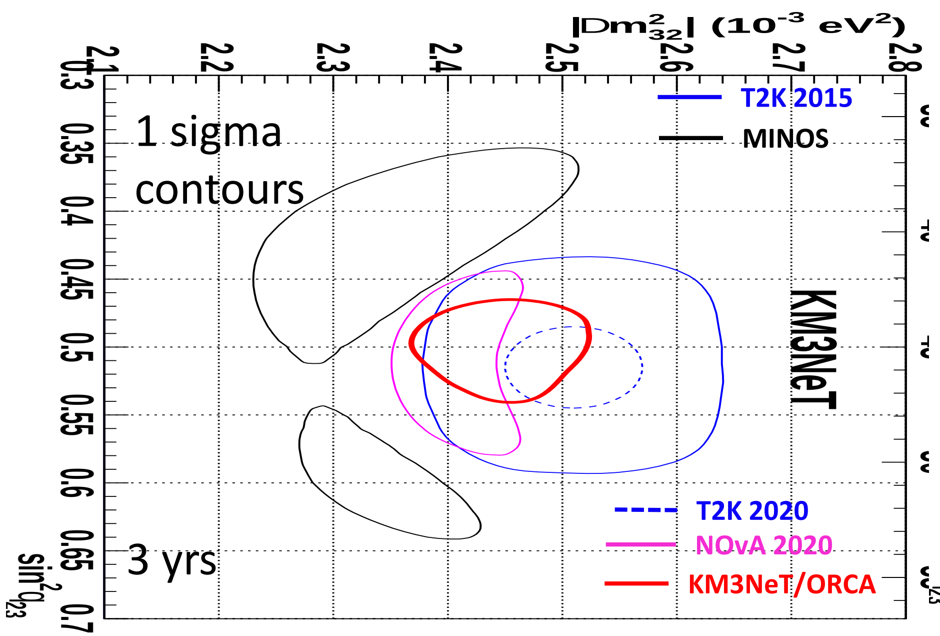




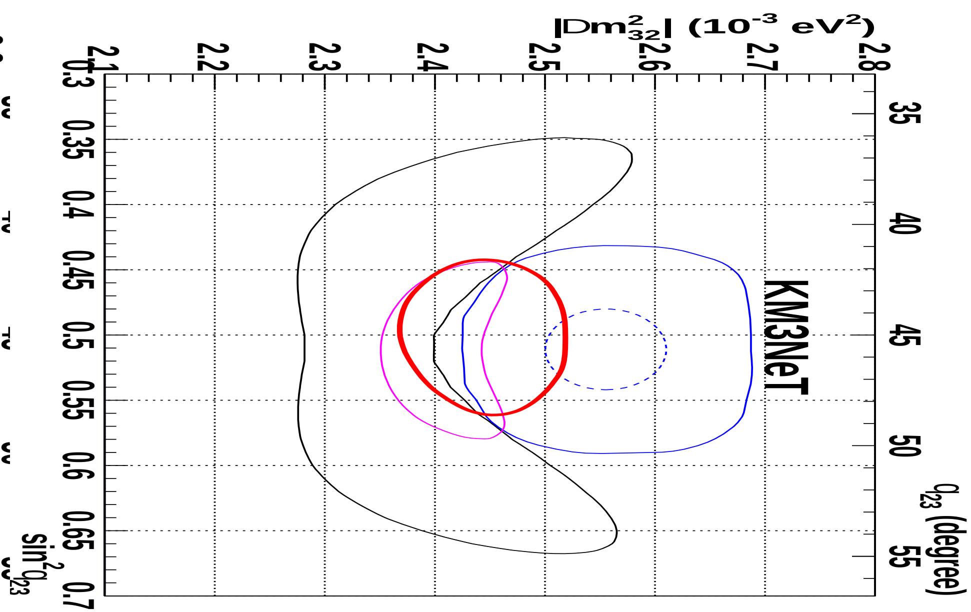
Measurement of Δm^2_{32} and $\sin^2\theta_{23}$

- Achieve 2-3% precision in Δm^2_{32} and 4-10% in $\sin^2\theta_{23}$
- Competitive with NOvA and T2K projected sensitivity in 2020

Normal Hierarchy



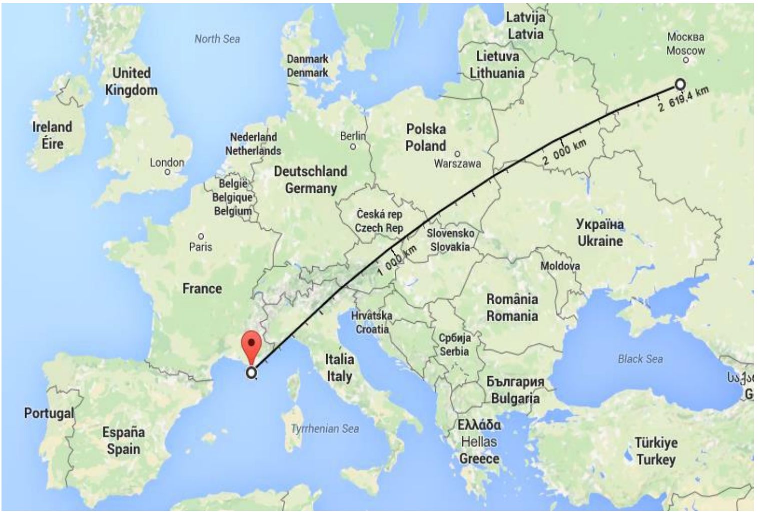
Inverted Hierarchy



Additional ORCA Physics Topics

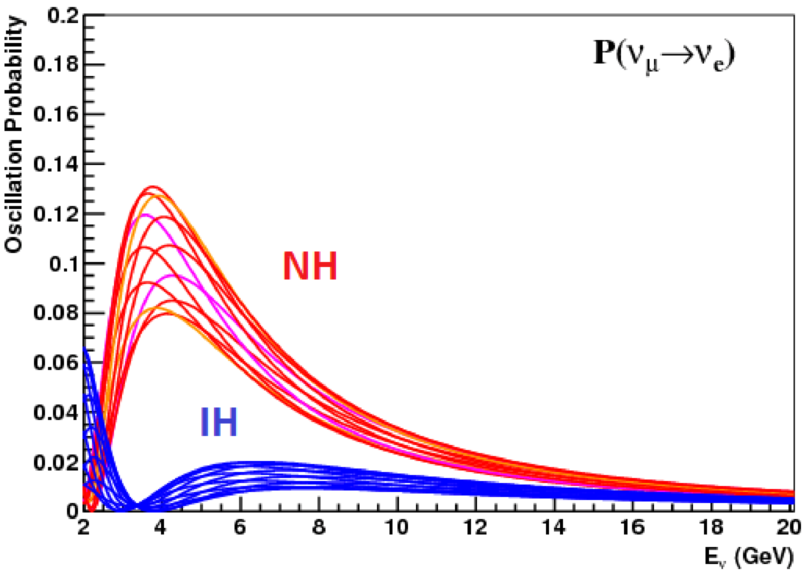
- Unitarity of PMNS matrix
- Exotic physics
  - sterile neutrino, Non-standard interactions
- Earth tomography
- Low energy neutrino astronomy
  - Transient phenomena
- Dark Matter indirect searches
- Supernovae monitoring
- Neutrino beam from Protvino
- Earth and Sea Science

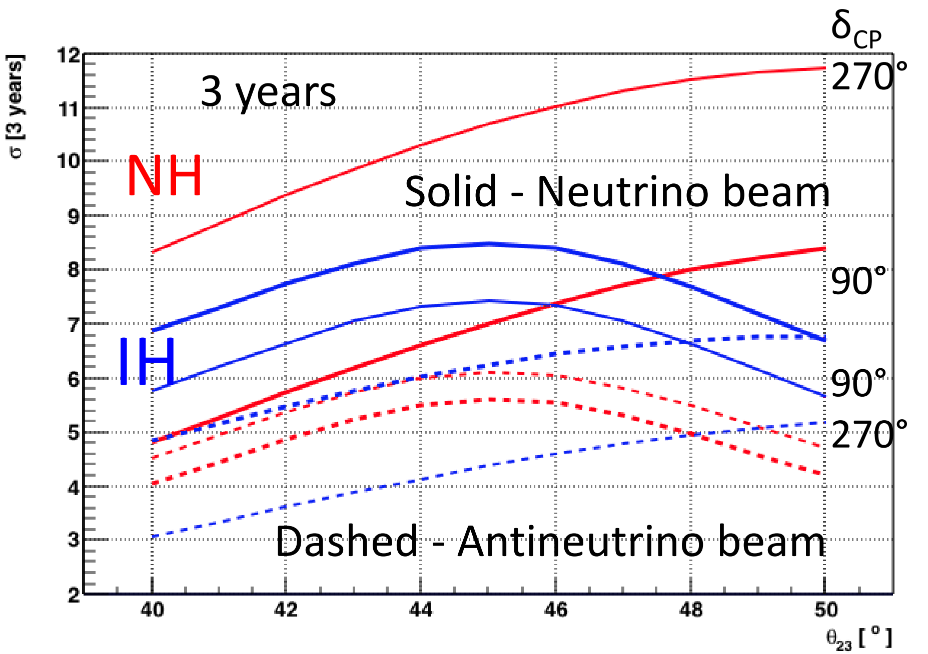
P20: Protvino to ORCA



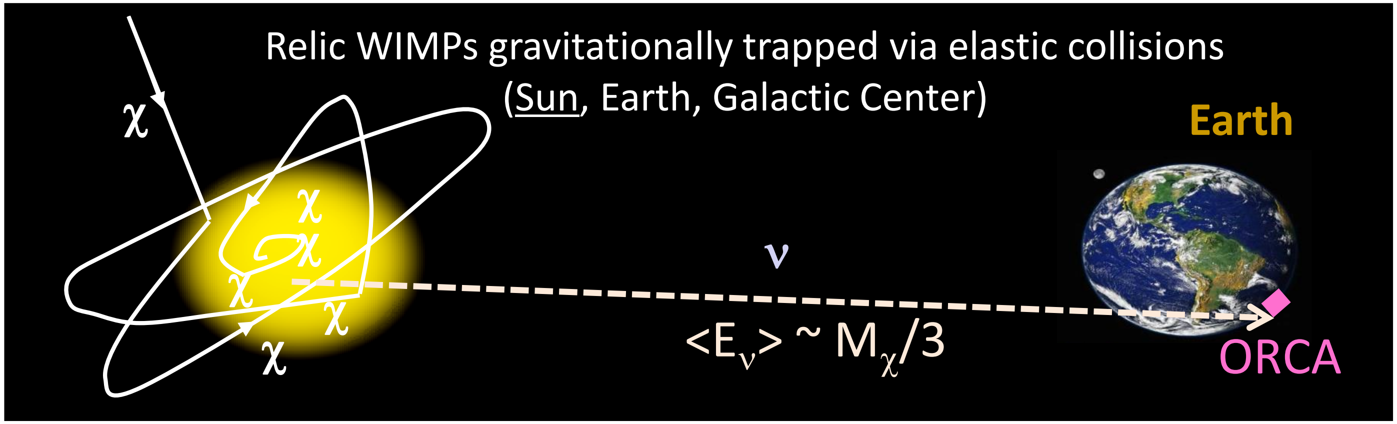
- U70 proton accelerator in Protvino
  E = 70 GeV
- Proposed intensity upgrade
  P = **450 kW**
  - ➢ Up to **4.10^{20} POT / year**

- ν_e appearance at **L = 2600 km**
- Target energy range : **3-8 GeV**
- Optimal baseline for separating NMH from δ_{CP}

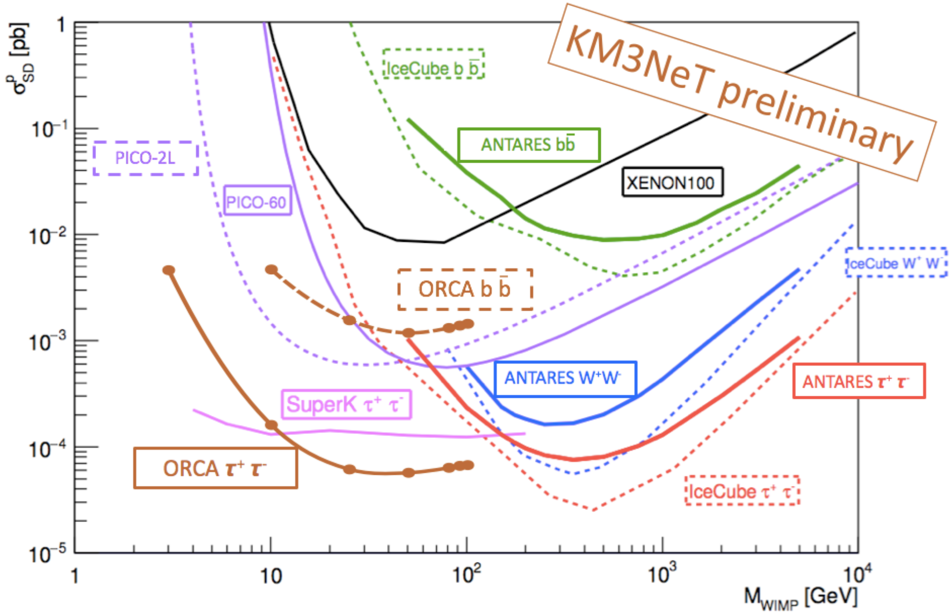




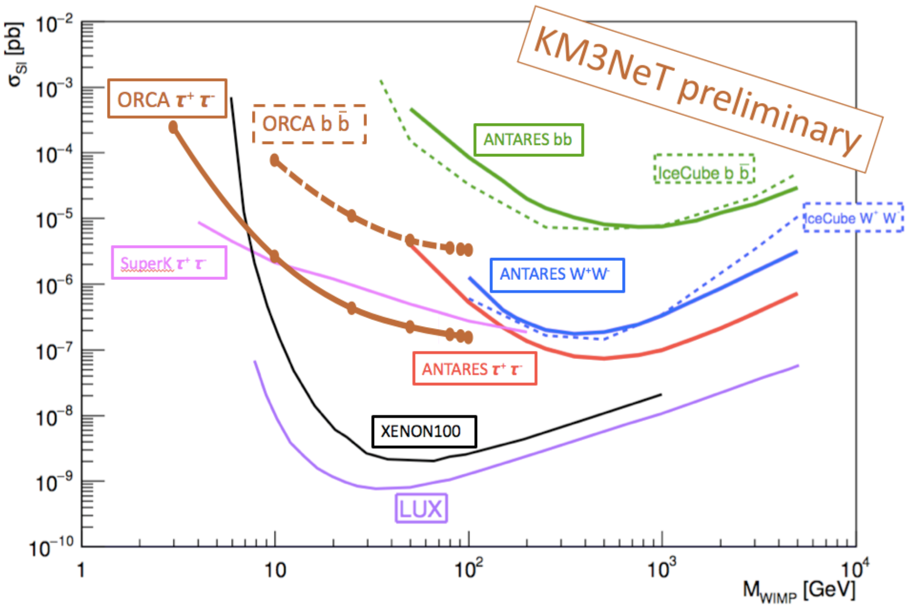
Indirect Detection of Dark Matter



Spin Dependent



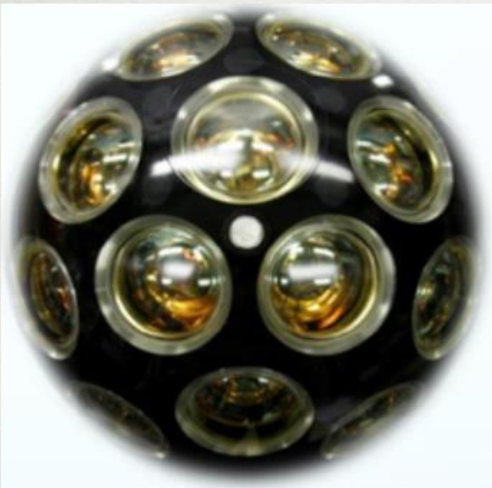
Spin Independent



ORCA 3 years - tracks+showers

KM3NeT technologies

DOM



-31 x 3" PMTs
Transmission Gbit/s on optical fibre
Synchro with Hybrid White Rabbit
Calib LED flasher & acoustic piezo
Position Tiltmeter/compass

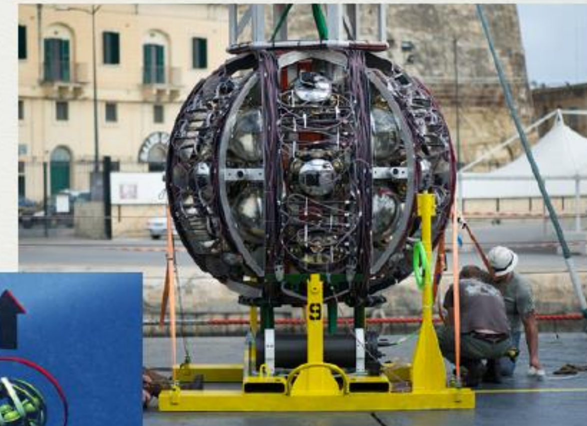
➡ Uniform angular coverage
➡ Directional information
➡ Digital photon counting
➡ Wide angle of view
➡ Background rejection
➡ All data to shore

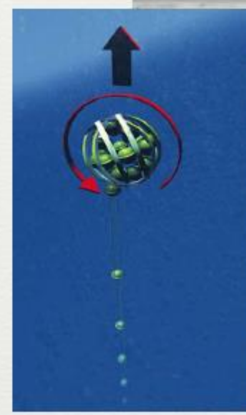
String

~ 700 or 200 m

- 2 Dyneema ropes
- VEOC: Oil filled PVC tube
- Low drag
- Low cost

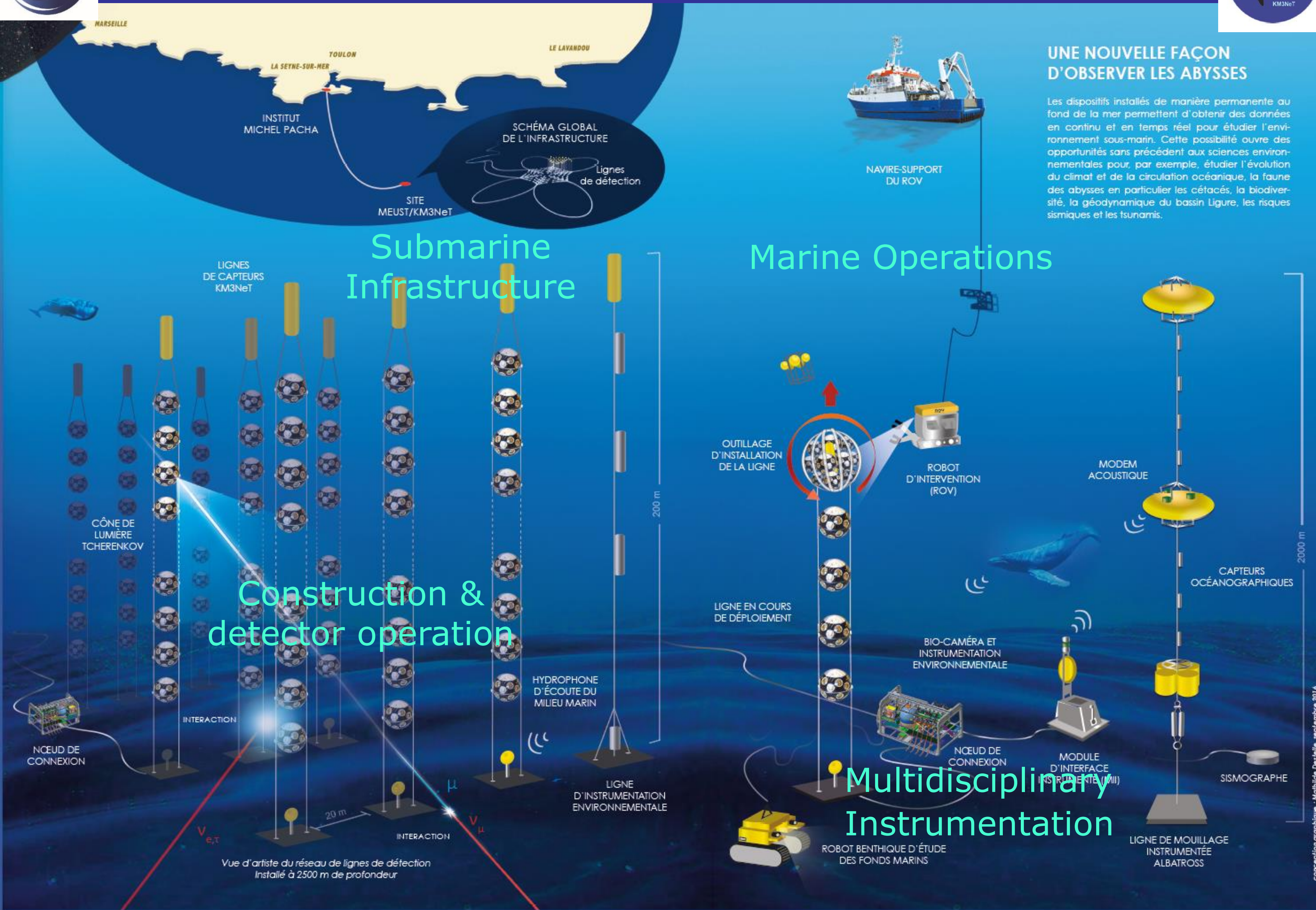
LOM





- Rapid / safe deployment
- Multiple strings / campaign
- Auto/ROV unfurling
- Re-useable

The KM3NeT/ORCA in Provence



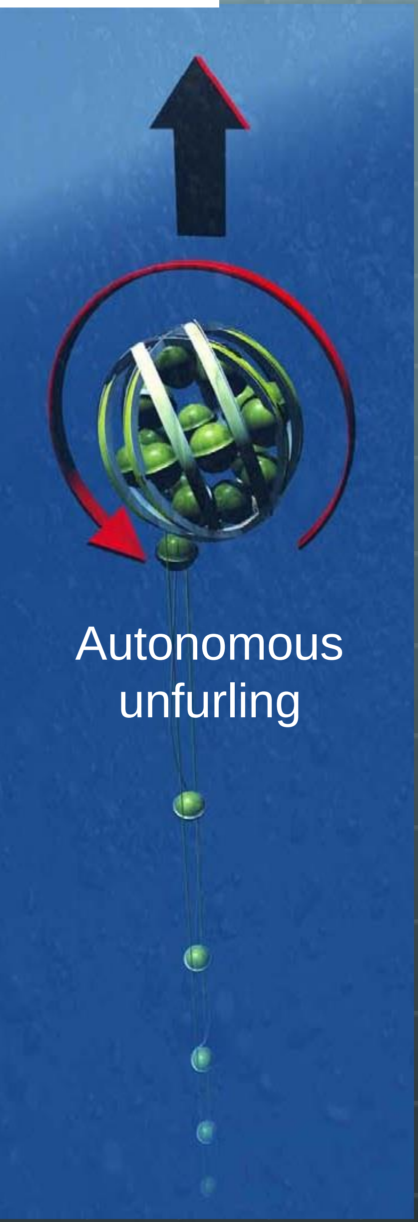
Submarine Infrastructure

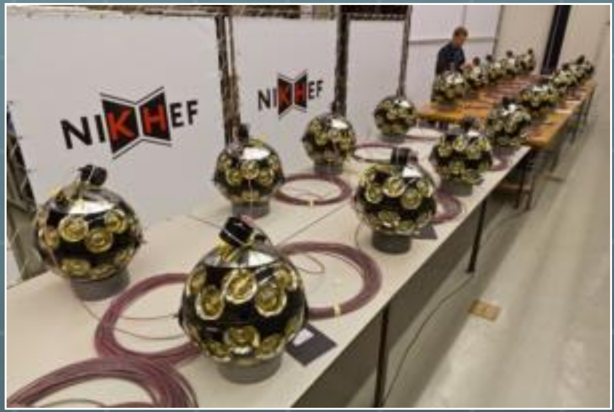
Marine Operations

Construction & detector operation

Multidisciplinary Instrumentation

Construction of the KM3NeT ORCA detector





CPPM is an integration site for the KM3NeT- ORCA detector lines.

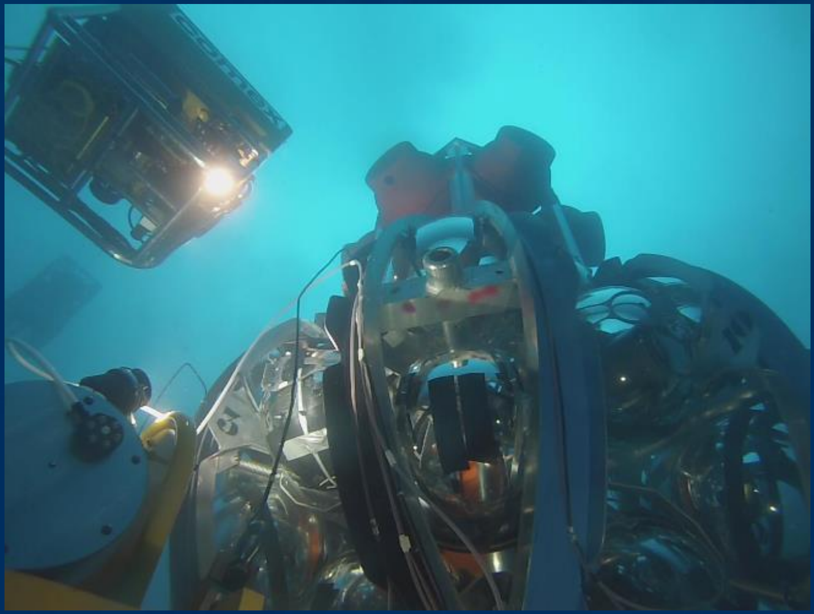
Line calibration in a dedicated Dark Room prior to deployment

Management of the Sea Operation for the detector installation on the Toulon site

Detector Unit : vertical lines equiped with 18 DOMs spaced by 9m

Construction of KM3NeT ORCA

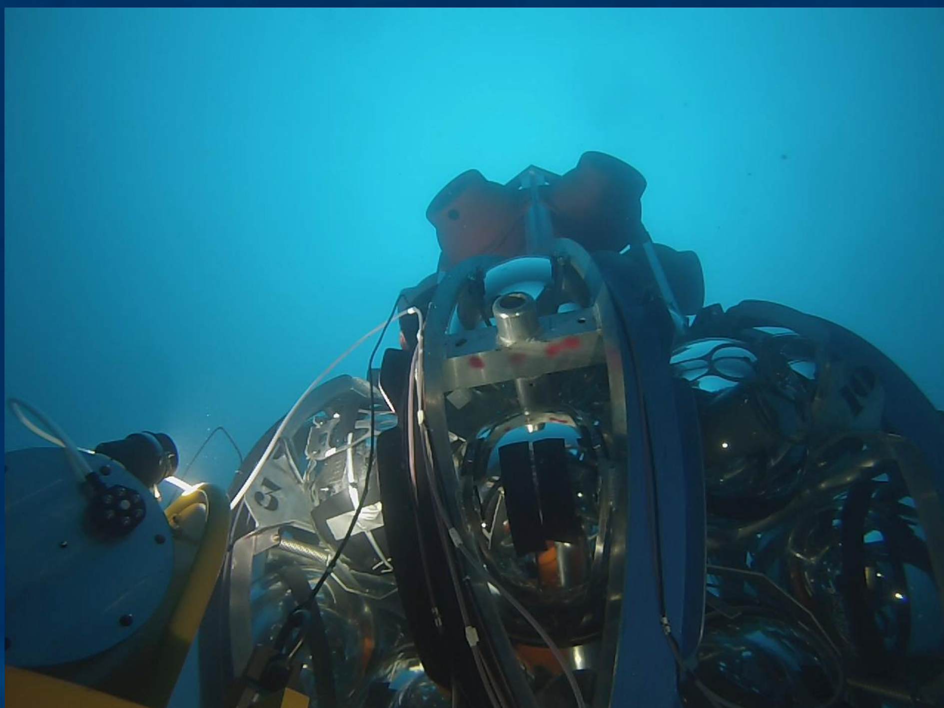
- Configuration ORCA line defined (9m between DOMs)
- Deployment with LOM validated by shallow water tests



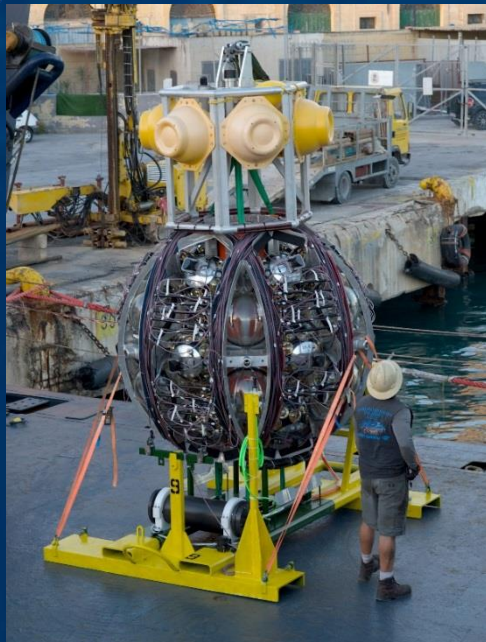
Preparation of 2 first ORCA lines under progress
→ Deep sea installation after Summer

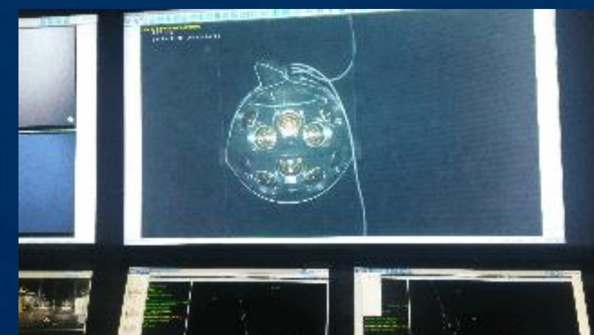
Construction of KM3NeT ORCA

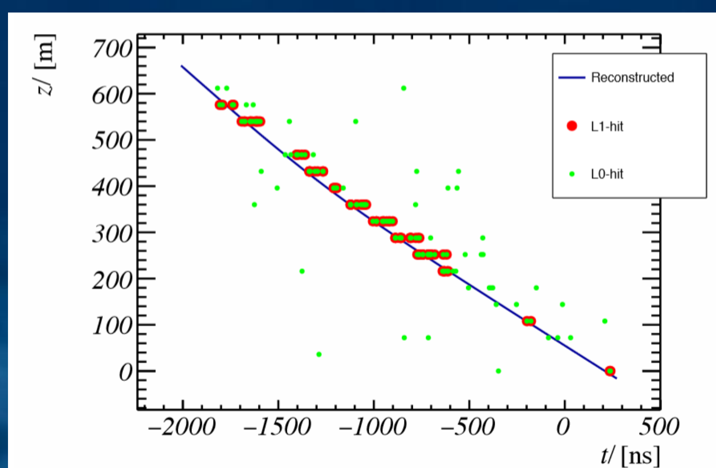
Deployment with LOM validated by shallow water tests



The first KM3NeT-ARCA detector lines

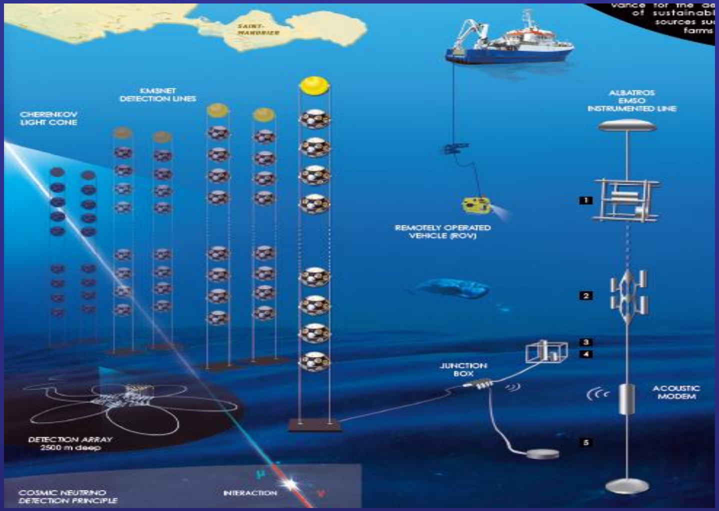


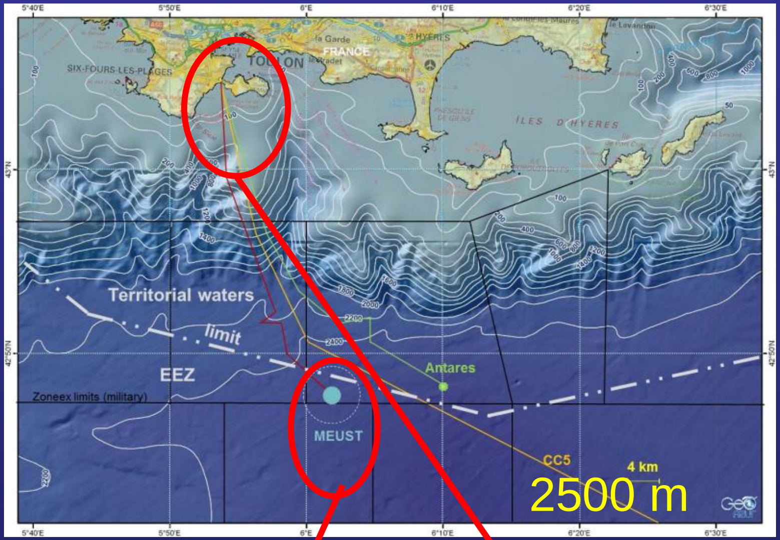


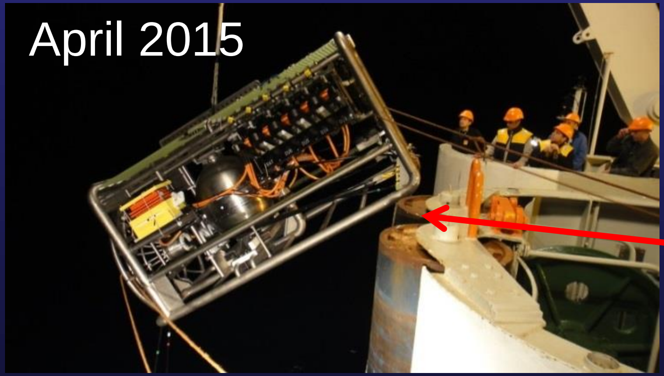


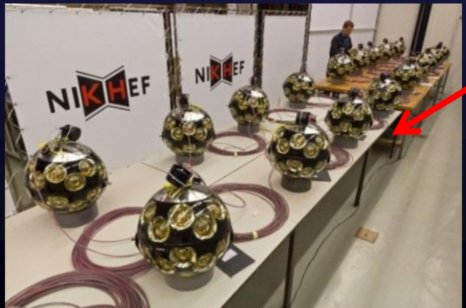
First line in operation since December 2015, 2nd since May 2016

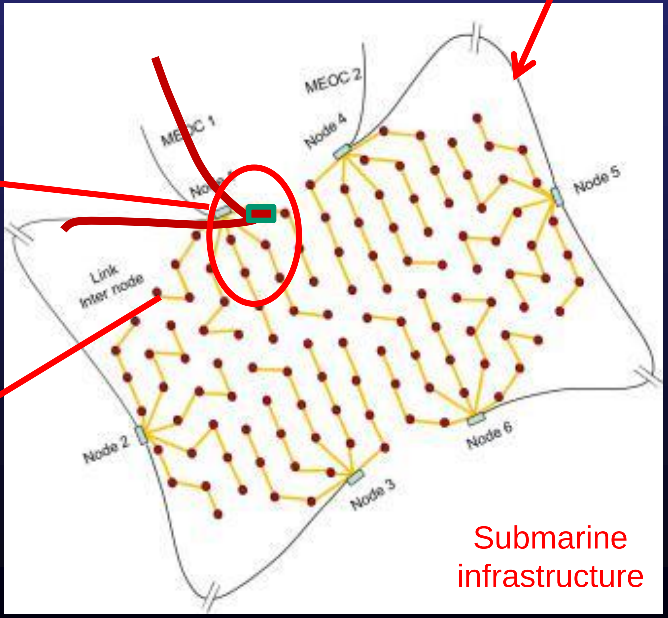
Construction of the Submarine Infrastructure for KM3NeT-ORCA





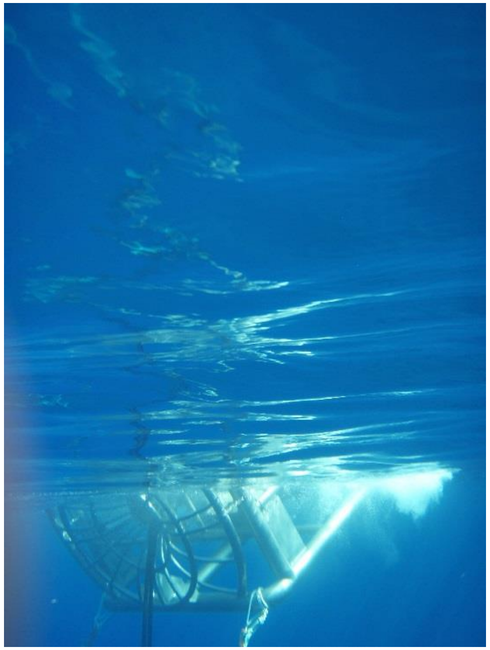


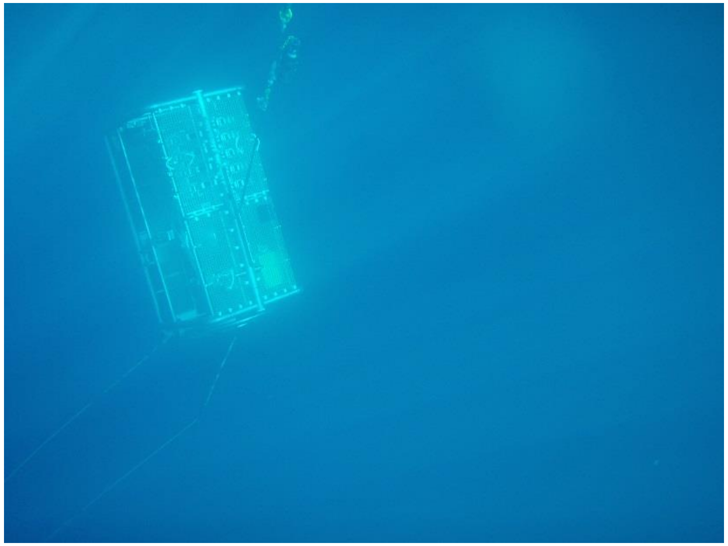


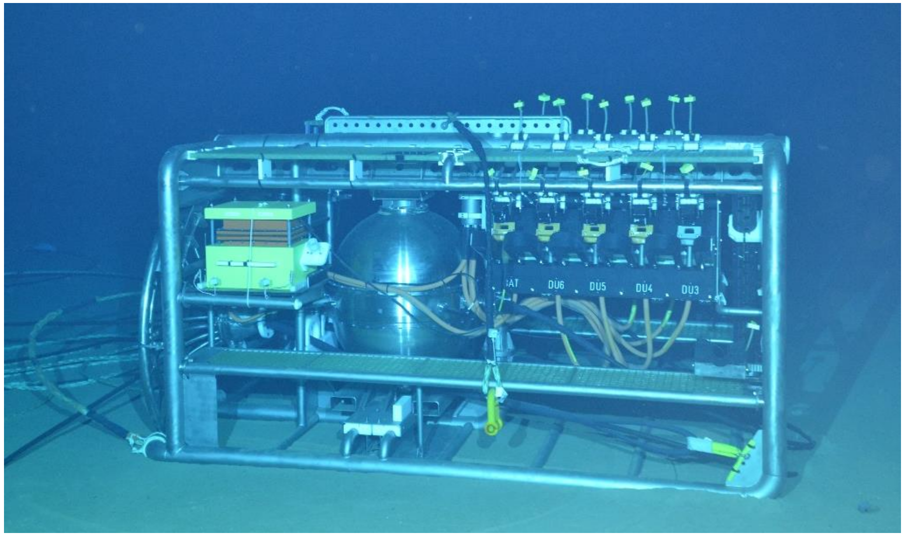


December 2014

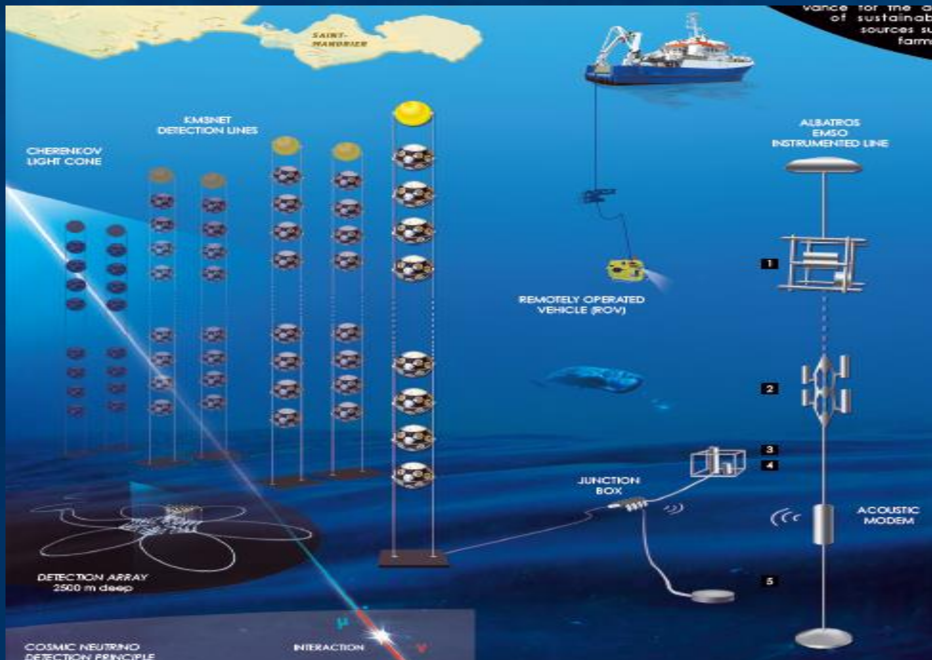
Node Deployment (29 Sept 2016)







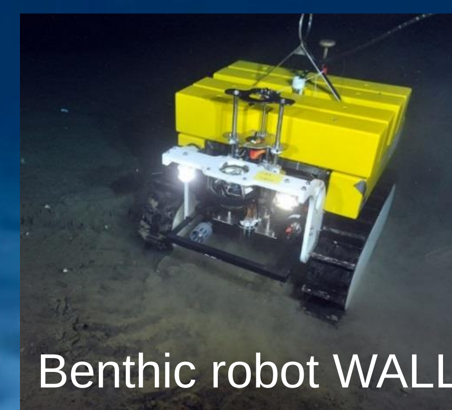
A Multidisciplinary Observatory in the Deep Sea



- Astronomy
- Neutrino physical properties
- Physico-chemical oceanography
- Marine Biology
- Bioacoustic
- Bioluminescence
- Microbiology
- Ecology, biogeochimie
- Sismology
- Environnement
- Renewable energies
- Underwater acoustic
- R&D marine technologies
- …

Dolphins (Pilot Whales) observed on ANTARES site

Deep sea sismometer

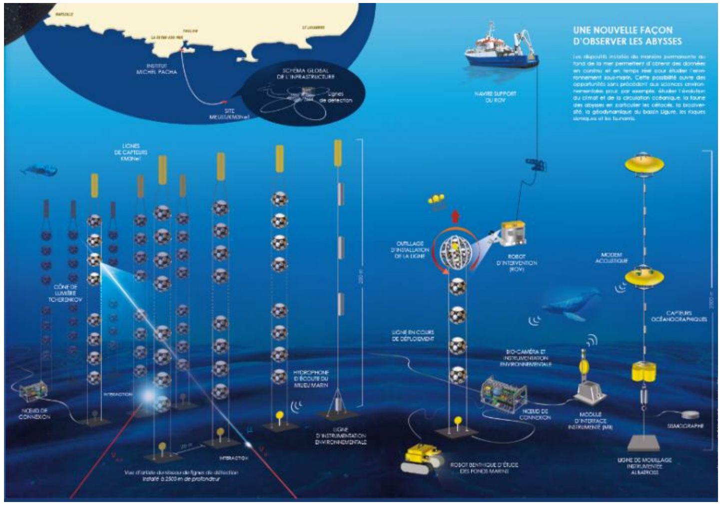


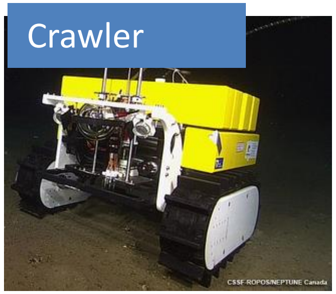
Benthic robot WALLY

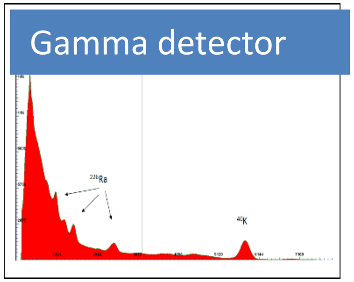
ANTARES/ORCA: Earth and Sea Sciences

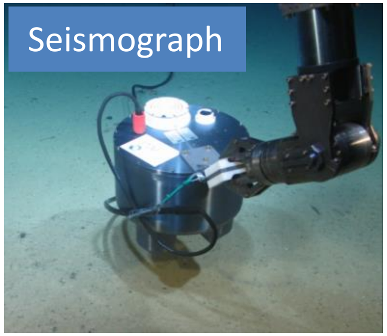
- Real-time
- Continuous
- High frequency
- High power
- Multiple sensors

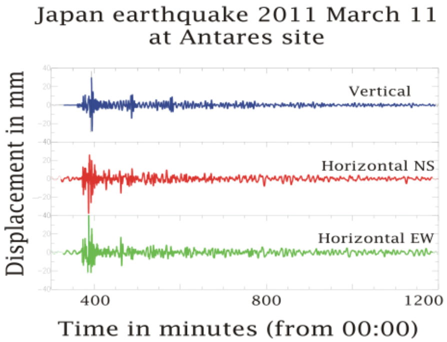
MIO, IPGP, GeoAzur,
DT-INSU, Univ. Toulon

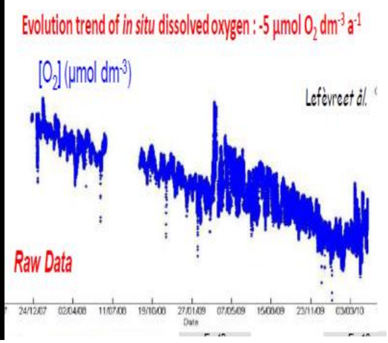


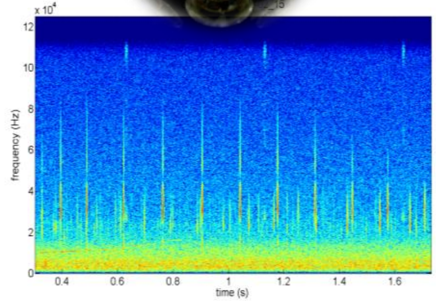




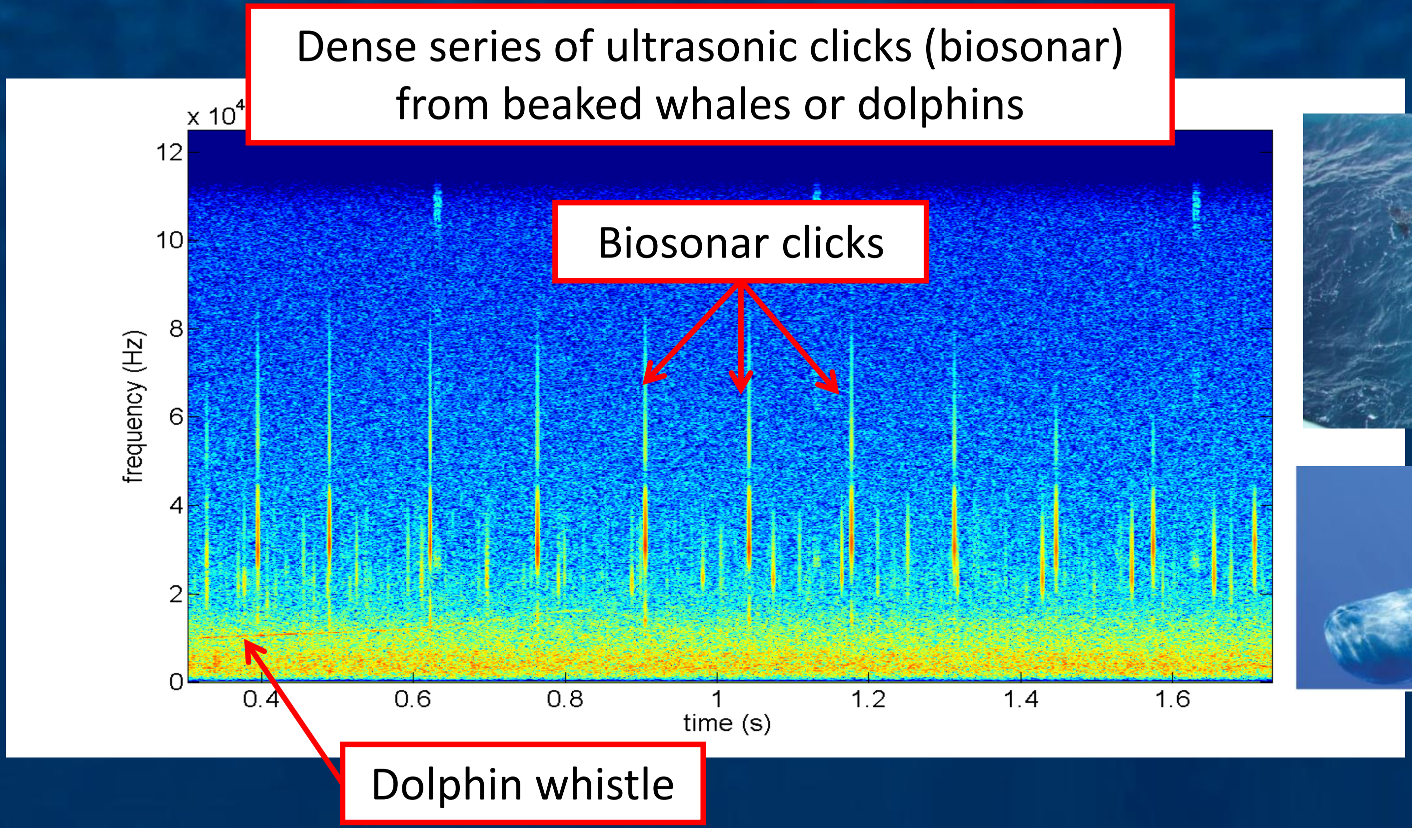








Bioacoustic studies of Whales and Dolphins



Detection and localisation of bioacoustic sources (cetaceans) using hydrophones integrated on ANTARES and KM3NeT detectors

Summary & Perspectives

- After decades of dream and intensive R&D, Neutrino Astronomy is finally opening **a new window over the Universe**
- ANTARES is recording new neutrino events every days
  → >10 000 neutrinos detected so far !
  → analyses are under progress looking for **the origine of HE Cosmic** and **discovering the nature of the mysterious Dark Matter**
- The building of the new generation neutrino telescope KM3NeT, based on an improved technology, **has started !**
  → it should lead to **fondamental results** during the next decade on :
  - **Neutrino Astronomy** (ARCA)
  - **Fundamental properties of neutrinos** (ORCA)
- The submarine infrastructure offers an unique potentiel of very rich **multidisciplinary researchs** in the deep sea

Lots of New, Rich and Great Physics !

→ Join us on this Adventure !!