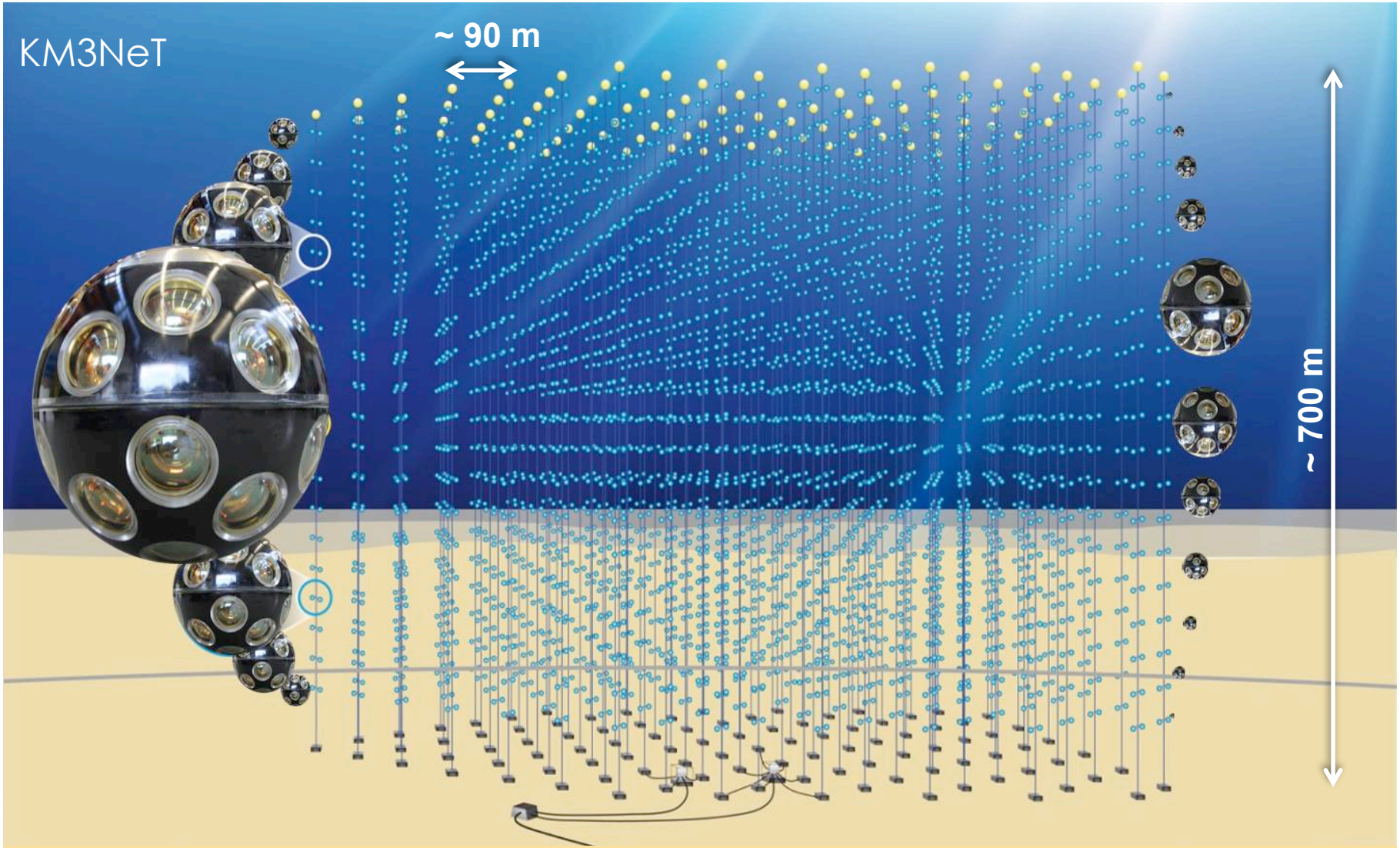
Il Progetto KM3: un telescopio di neutrini negli abissi del Mar Mediterraneo

F. Di Capua – Università di Napoli "Federico II"

IFAE 2015 - Roma

Il rivelatore KM3Net



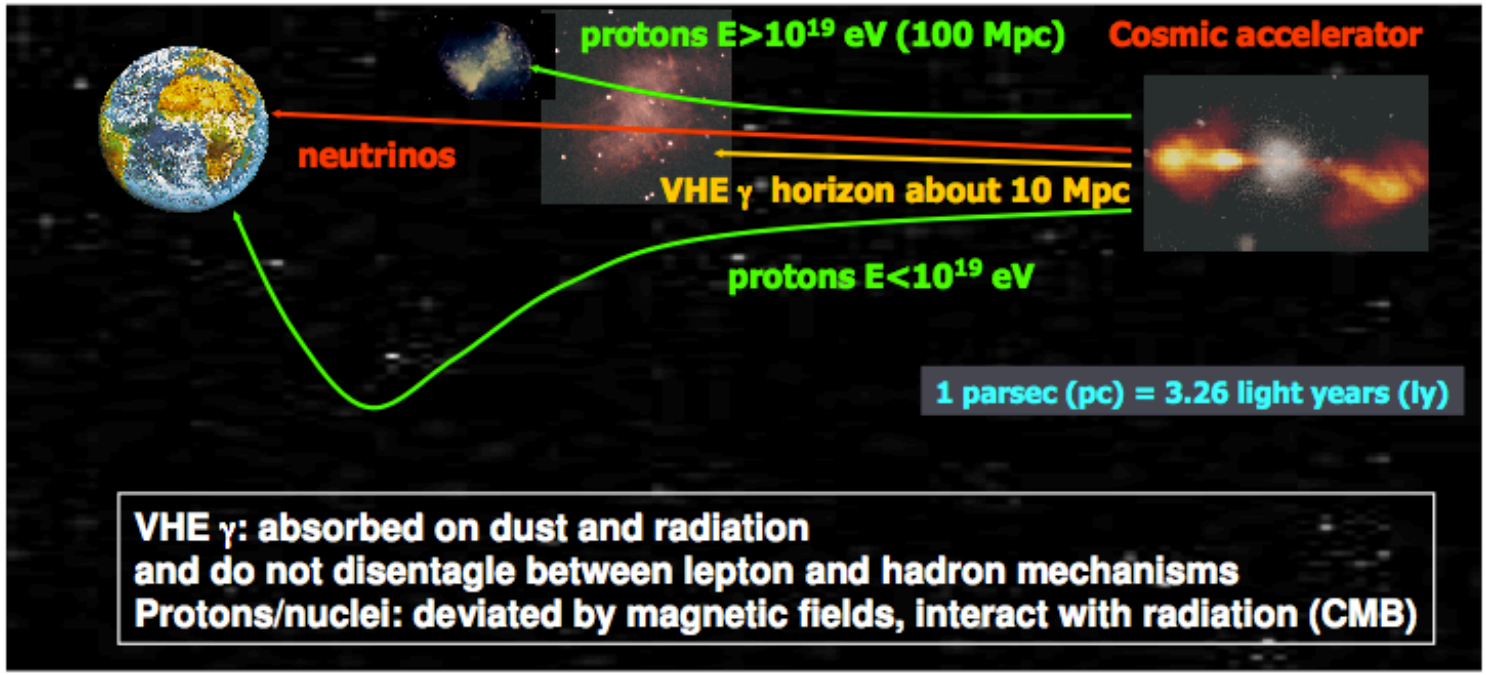
Circa 11000 KM3NeT-DOMs (Digital Optical Modules) montati su circa 600 KM3NeT DU (Detection Units)

Propriety KM3NeT Collaboration

18 moduli ottici per ogni unità di rivelazione (DU)
Distanza tra I moduli ottici ~ 36 m - Distanza tra le singole stringhe ~ 90 m
Distanza primo modulo ottico dal fondo marino ~ 100m

Motivazioni per la rivelazione di neutrino di alte energie

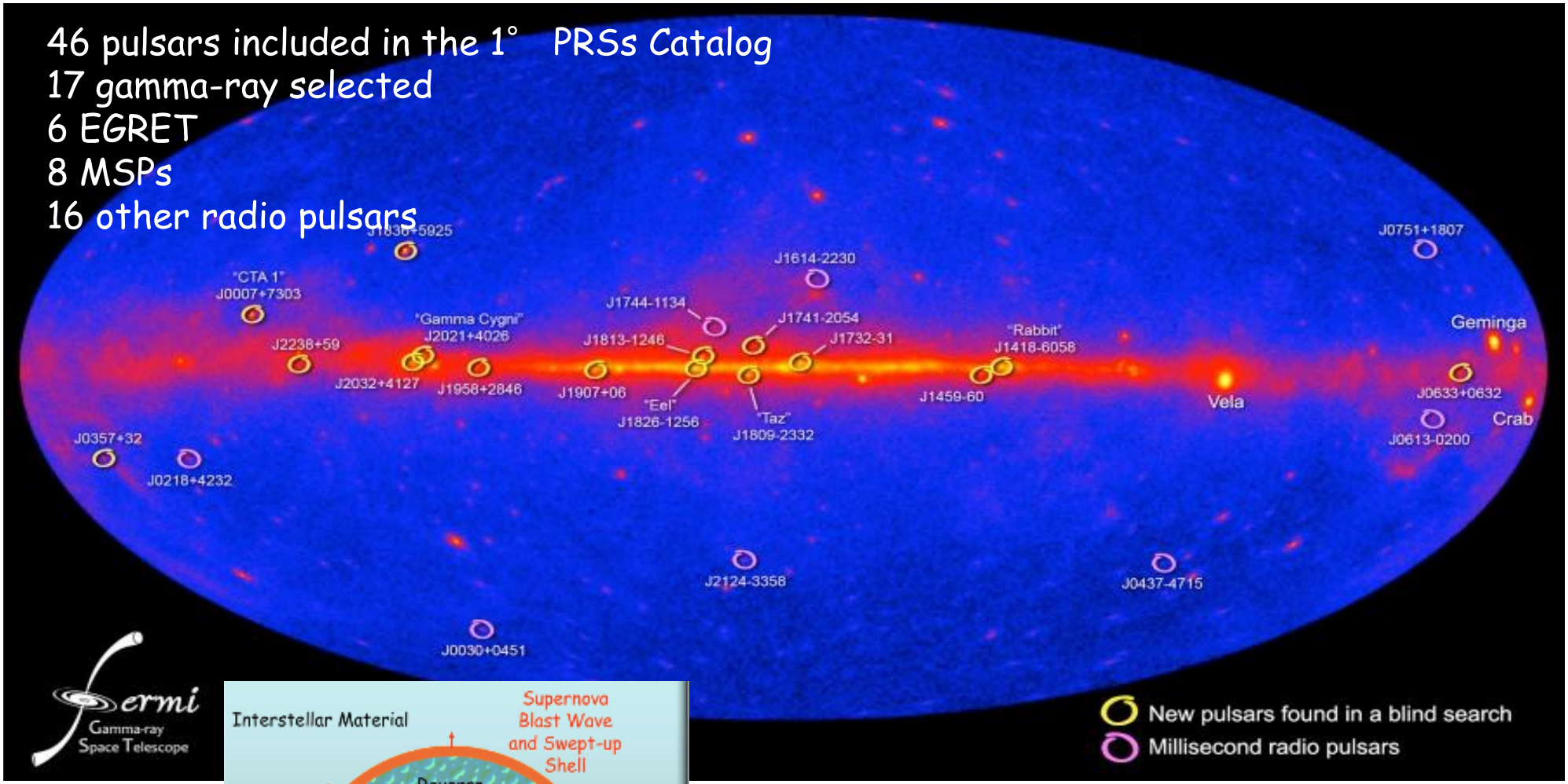
I neutrini portano al loro seguito un bagaglio unico di informazioni riguardo l'Universo di Alta energia



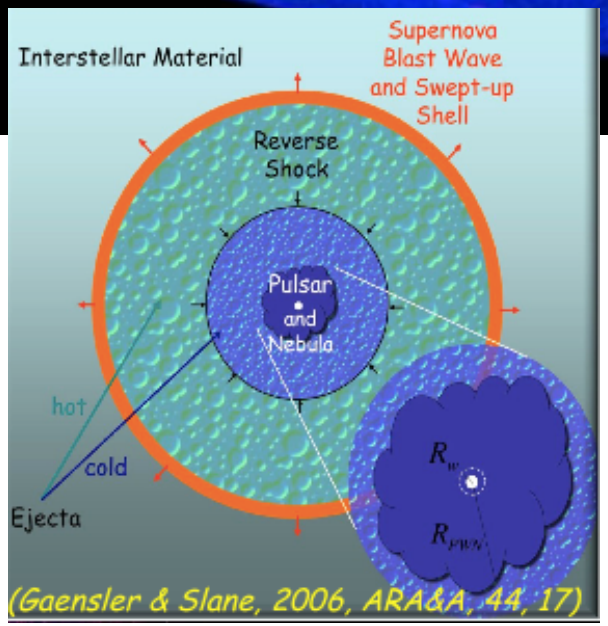
Motivazioni scientifiche

✓Sorgenti astrofisiche di neutrini di alta energia (SNR, microquasars, AGN, GRB)
✓Origine dei raggi cosmici
✓Sorgenti di neutrino sconosciute
✓Rivelazione indiretta di Materia Oscura
✓Oscillazioni di neutrino: gerarchia di massa

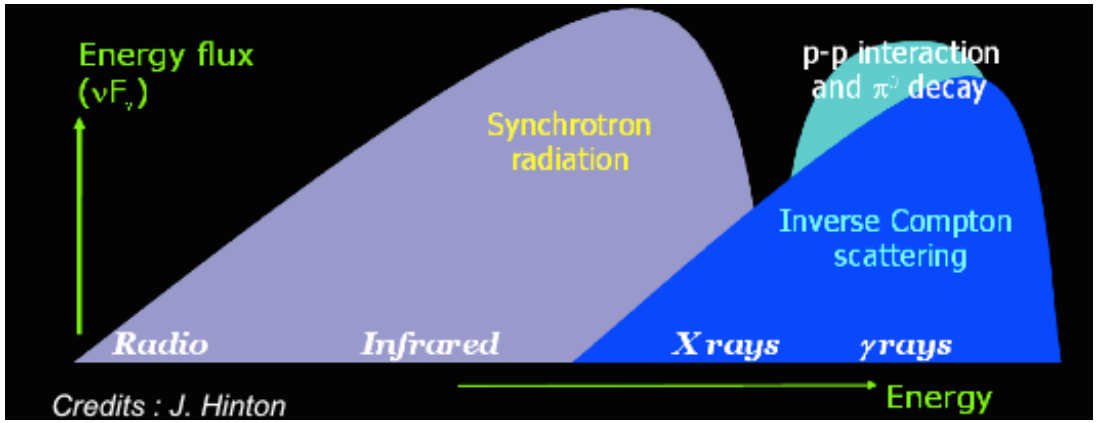
46 pulsars included in the 1° PRSs Catalog
17 gamma-ray selected
6 EGRET
8 MSPs
16 other radio pulsars



Pulsar
PWN
SNR
+
Black hole
AGN



(Gaensler & Slane, 2006, ARA&A, 44, 17)

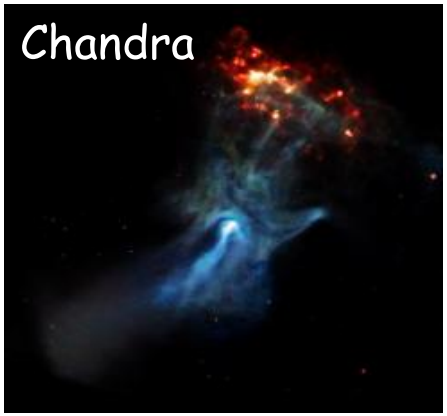


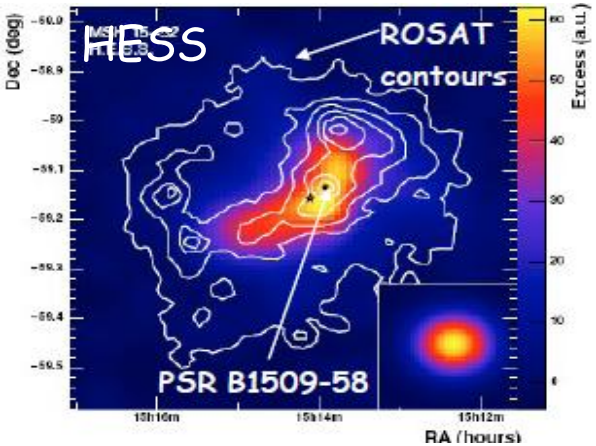
Credits : J. Hinton

Pulsar Wind Nebula with a Jet

Lastly the MSH15-52 and PSR B1509-58

(Abdo et al., 2010, ApJ, accepted, arXiv:1003.3833)

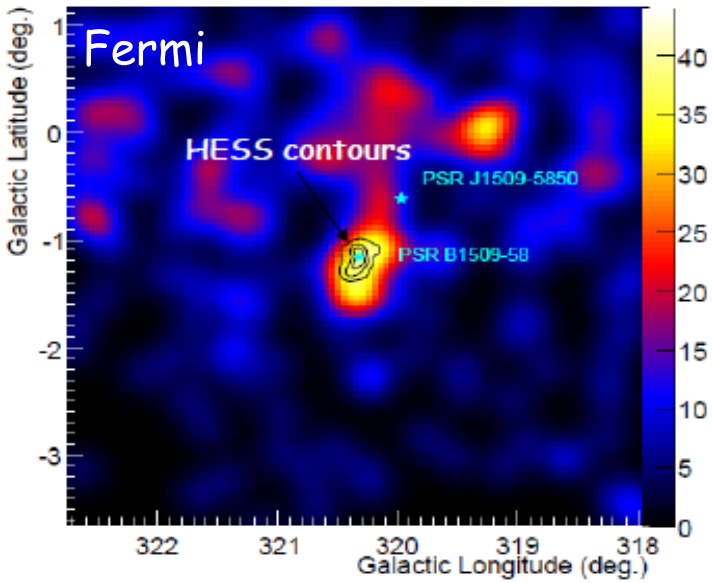


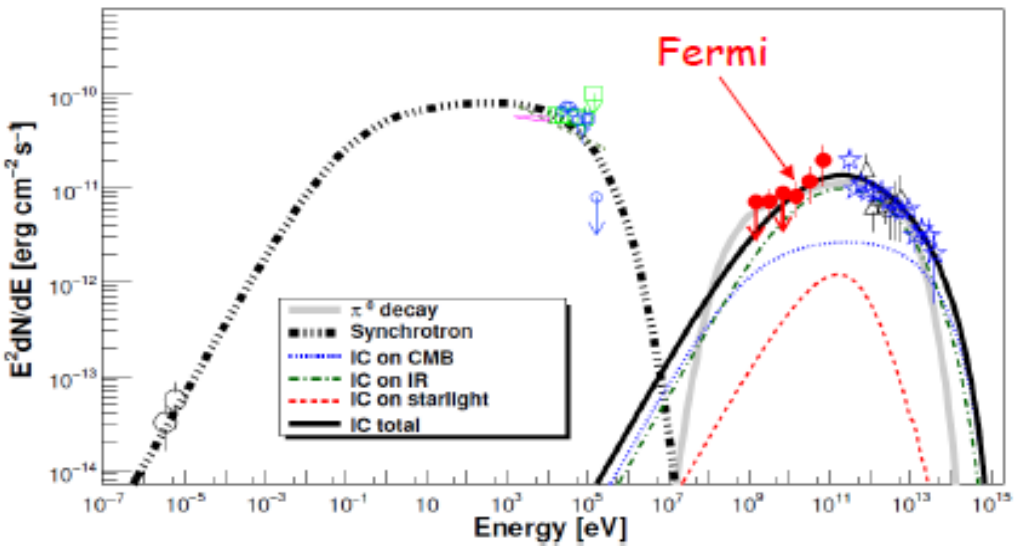


P=150 ms.

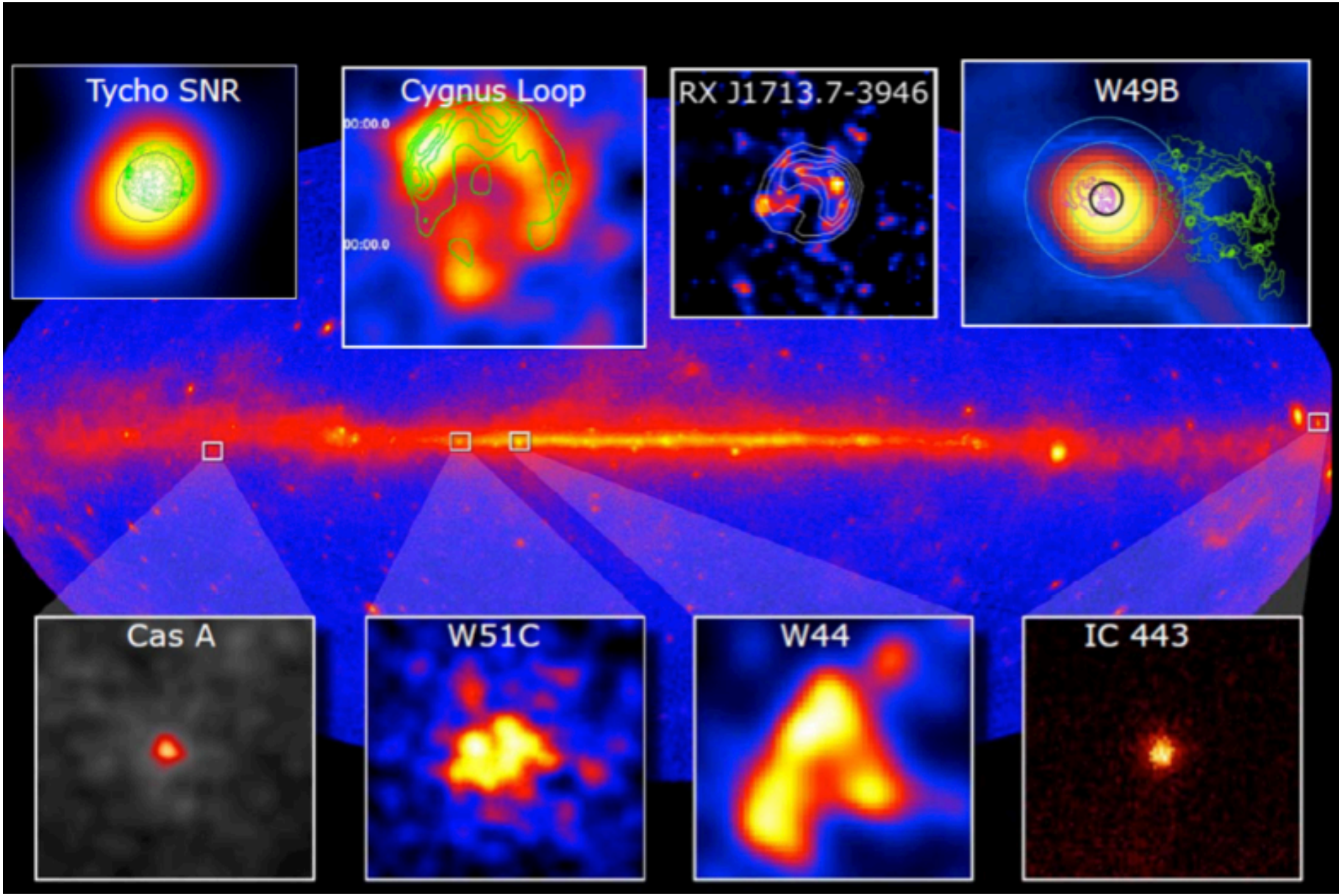
- Source extended : Rdisk = (0.25 ±0.05)°
- Flux (E>1 GeV) : ~ 3×10^{-9} cm^{-2} s^{-1}
- Spectral index : 1.6 ± 0.2

high energy emission can be explained by Inverse Compton scattering (mostly on FIR photon field)



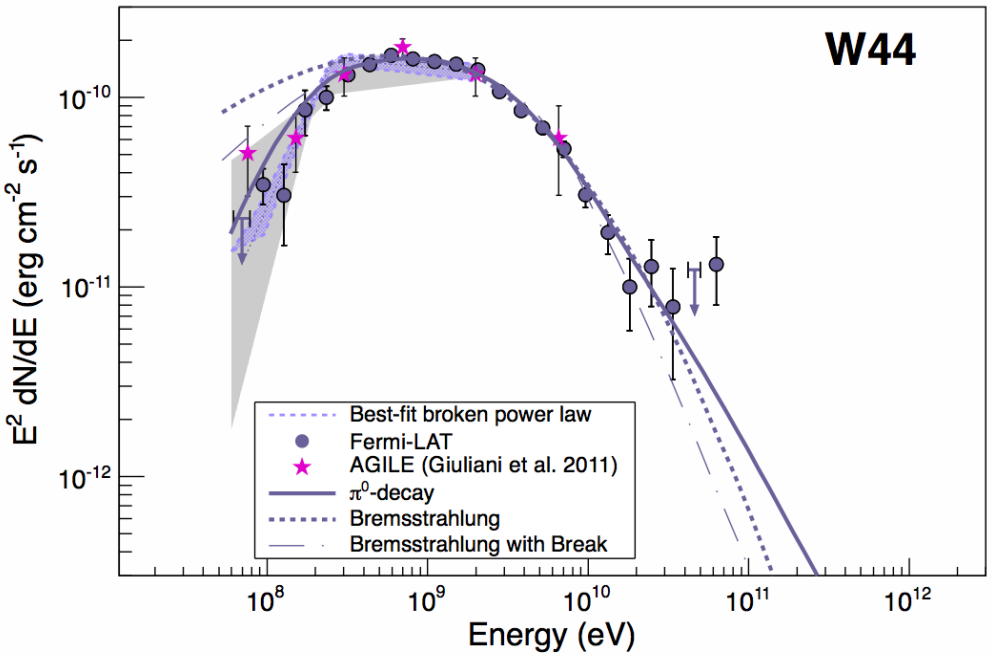


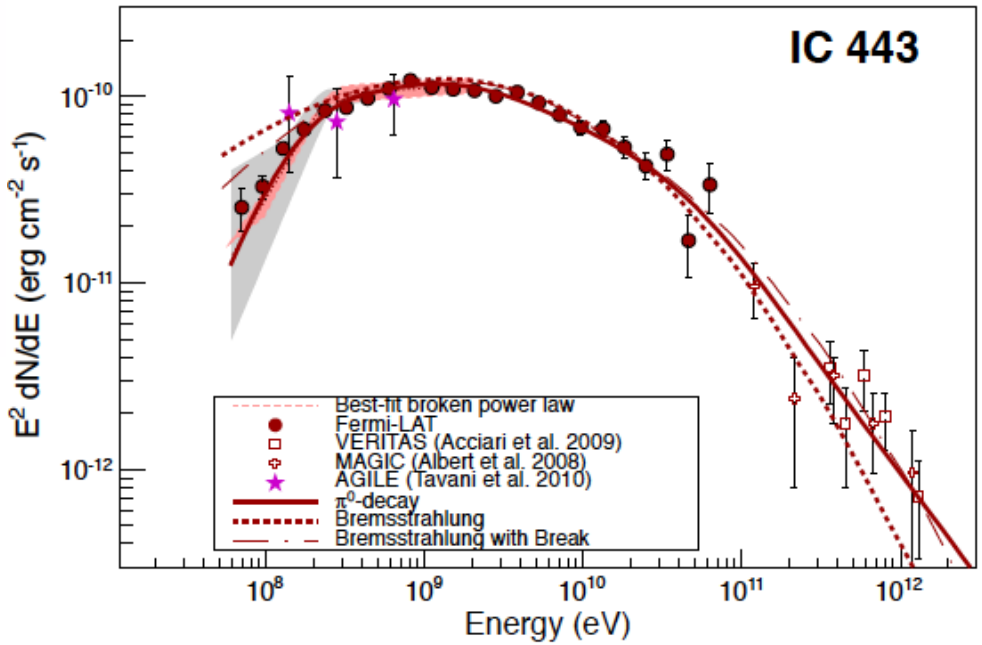
Verso un primo catalogo di SNR da Fermi LAT



Diverse classi di SNR – storiche e di media età, puntiformi, estese, shell-like

SNR W44 e IC443 - Rivelazione dello spettro caratteristico del decadimento del pione: diretta evidenza che i raggi cosmici primari vengono accelerati in SNR





Science 339 (2013) 807 [airXiv:1302.3307] 15 Feb. 2013

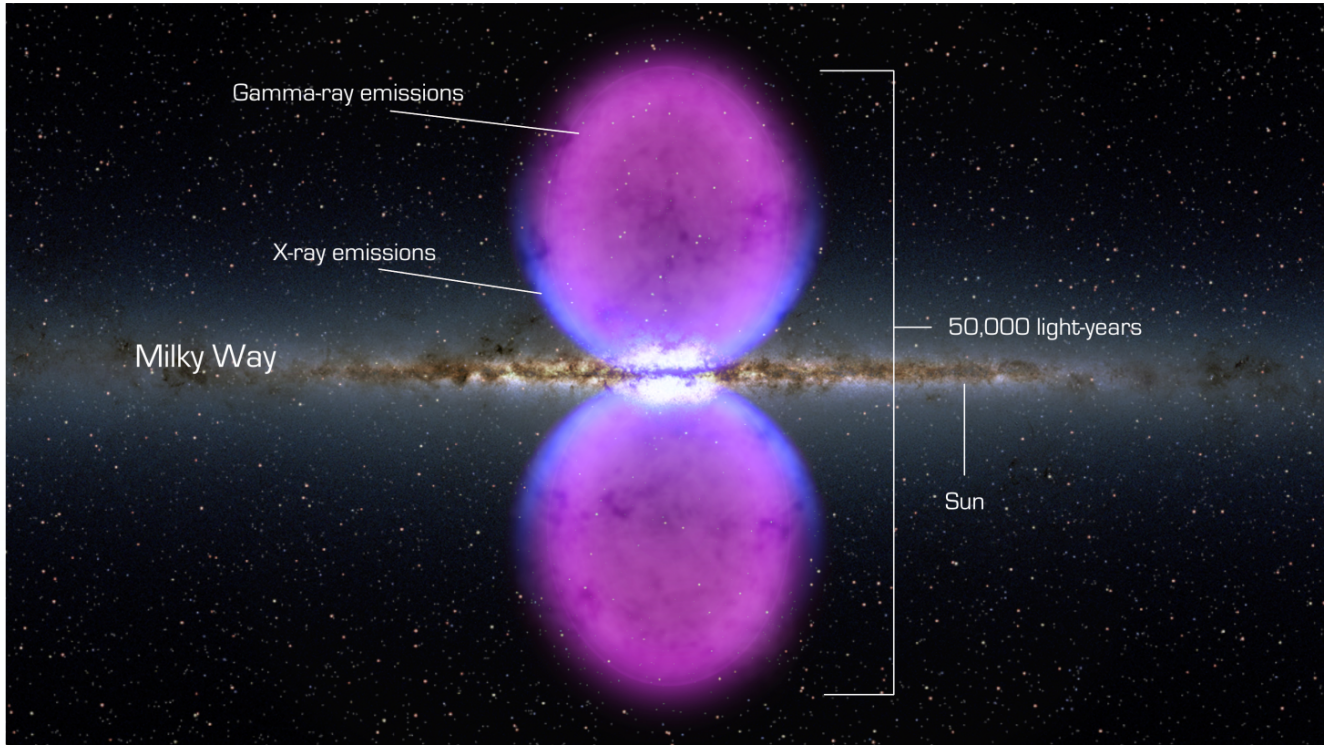
Neutrini dalle "FERMI Bubbles" ??

Possibile ricerca per un telescopio Cherenkov di neutrini nel Mediterraneo

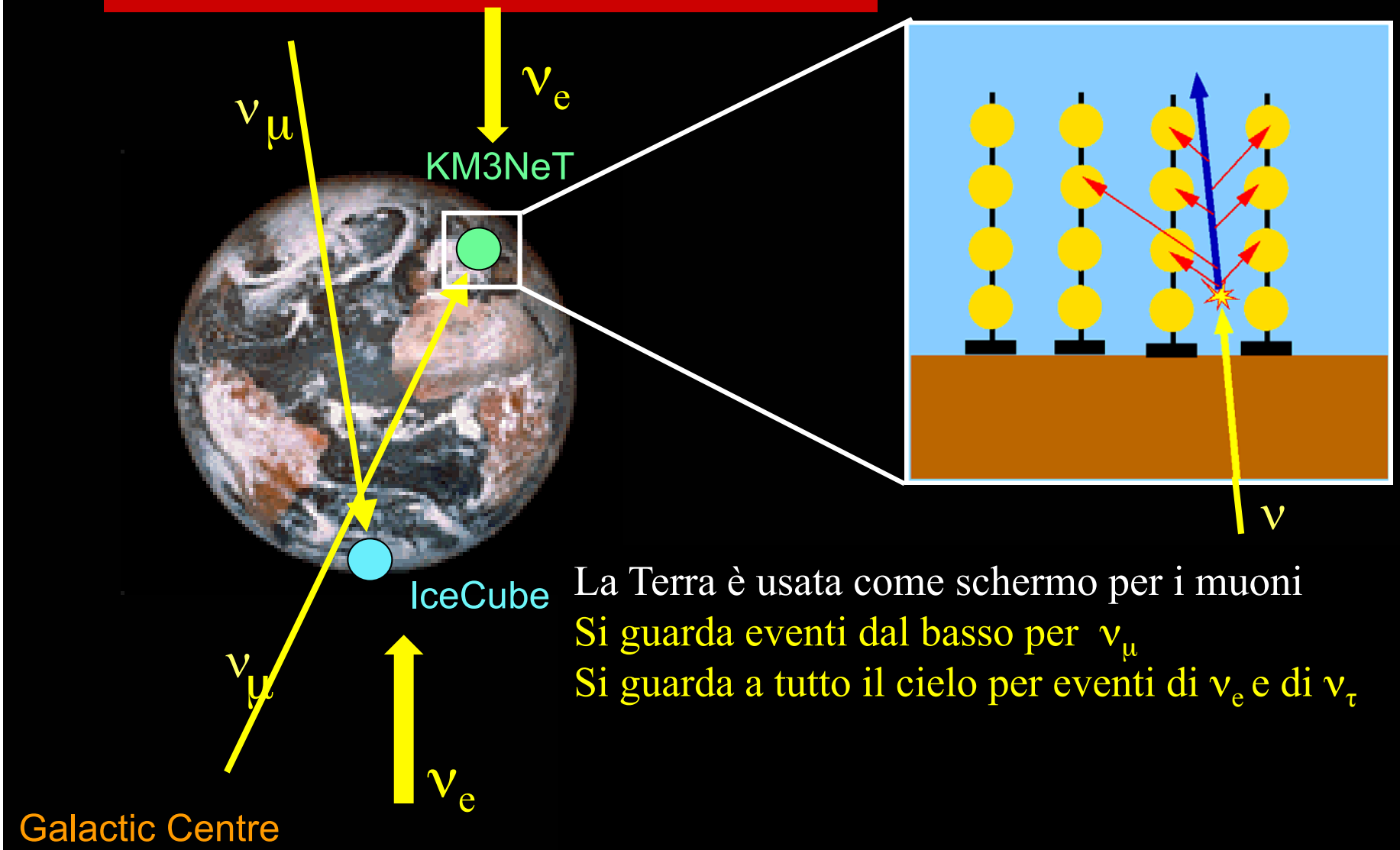
- FERMI ha rivelato emissioni di γ (spettro E^{-2}) fino a 100 GeV in una estesa "bubbles" attorno al Centro Galattico, lo spettro osservato non è compatibile con un meccanismo di Compton inverso - M.Su et al., Ap.J.724 (2010).

- Modelli basati su processi adronici (e.g. Crocker & Aharonian, PRL 2011) predicono significativi flussi di neutrini.

- Questa potrebbe essere una delle prime sorgenti di neutrino per un telescopio di neutrini nel Mediterraneo



Come funziona un Telescopio di Neutrini



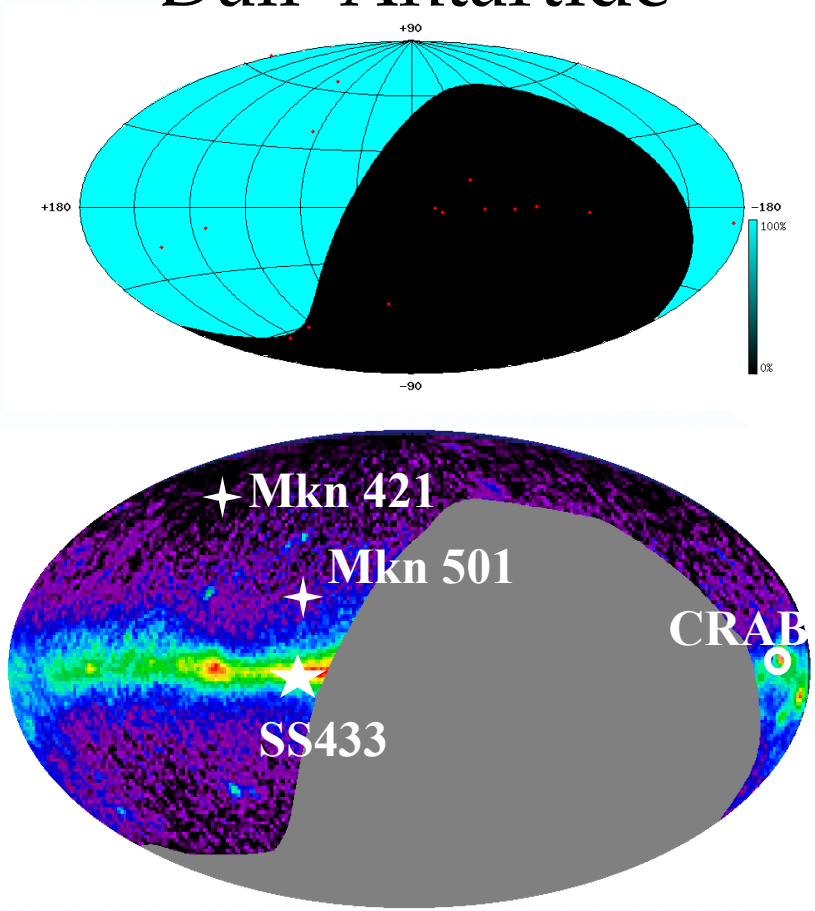
La Terra è usata come schermo per i muoni

Si guarda eventi dal basso per ν_μ

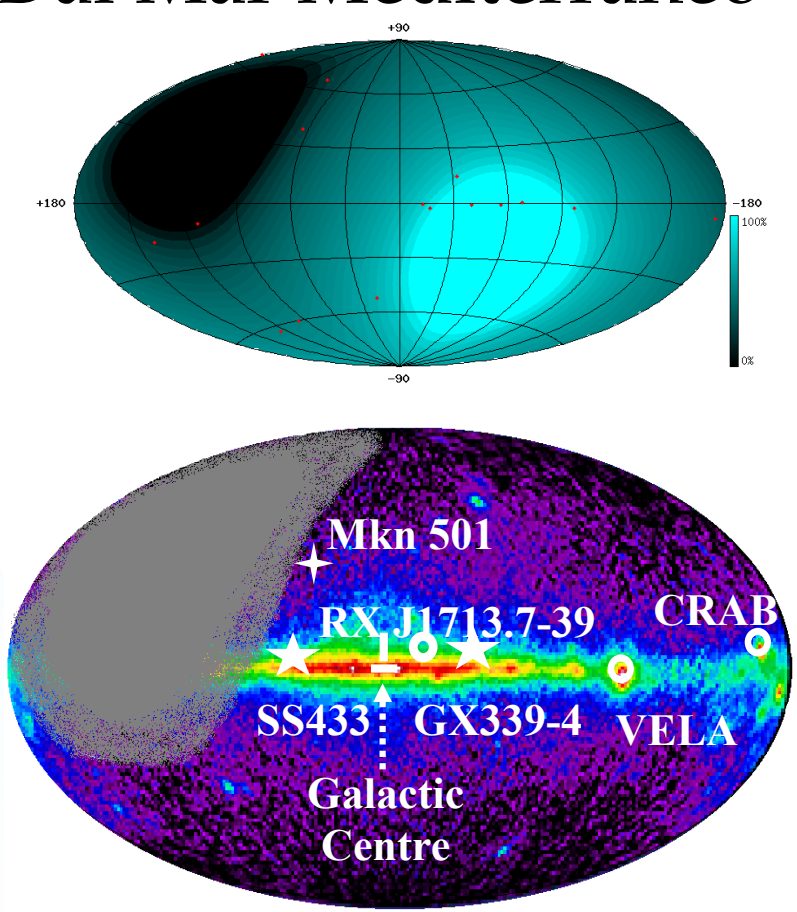
Si guarda a tutto il cielo per eventi di ν_e e di ν_τ

Viste per Astronomia dei Neutrini

Dall' Antartide



Dal Mar Mediterraneo

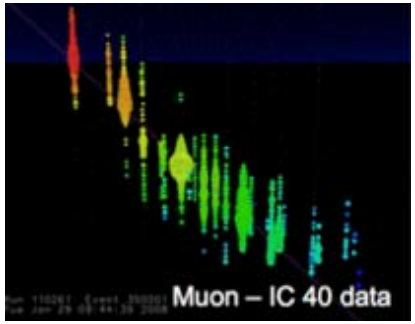


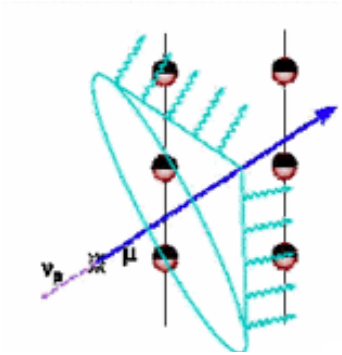
Dal Mediterraneo viene assicurata:

- **una copertura celeste a 3 π**
- **0.5 π sr di istantanea vista comune con IC**
- **circa 1.5 π sr di vista comune**
- **Centro Galattico è visibile per 2/3 del tempo.**

Un telescopio di neutrini (dimens. Km^3) nel mar Mediterraneo sarà complementare ad IceCube e … cercherà sorgenti di neutrino nel centro Galattico

Caratteristiche dei diversi sapori di neutrino

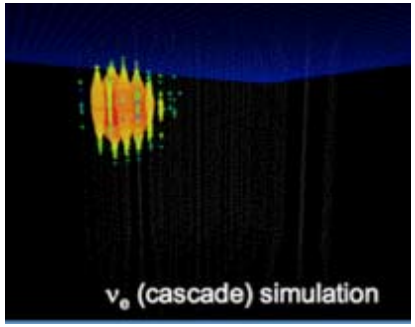


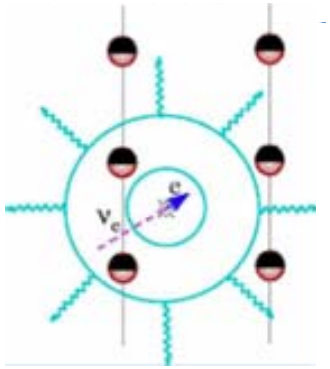


Tracce

$$\nu_{\mu} + N \rightarrow \mu + X$$

Risoluzione angolare <1°

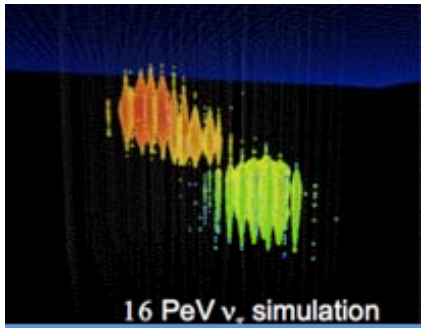




Cascata elettromagnetica ed adronica

$$\nu_{e(\tau)} + N \rightarrow e(\tau) + X$$
$$\nu_f + N \rightarrow \nu_f + X \quad f = e, \mu, \tau$$

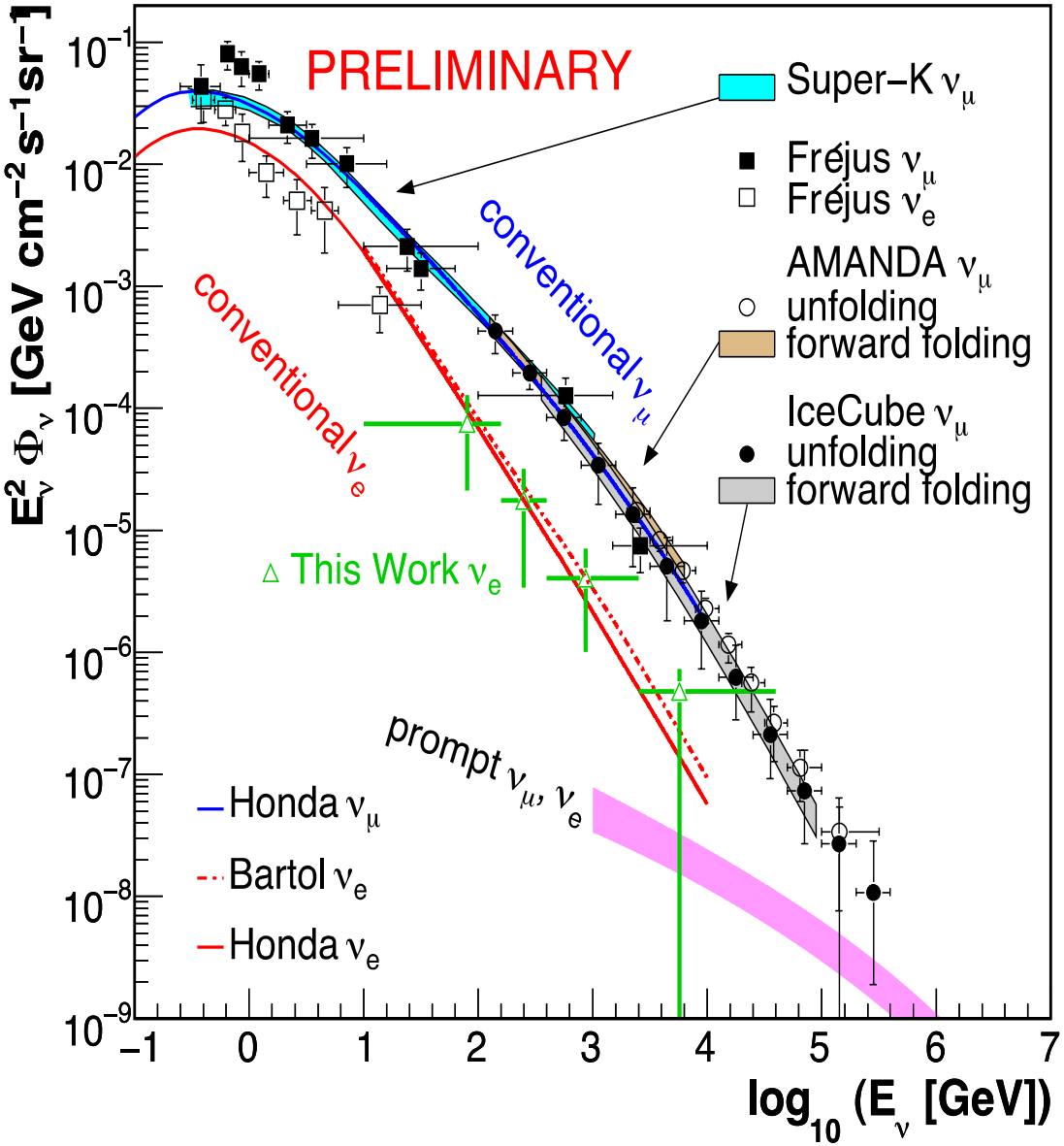
Risoluzione energetica 10%



Rivelazione di ν_T

Double Bang

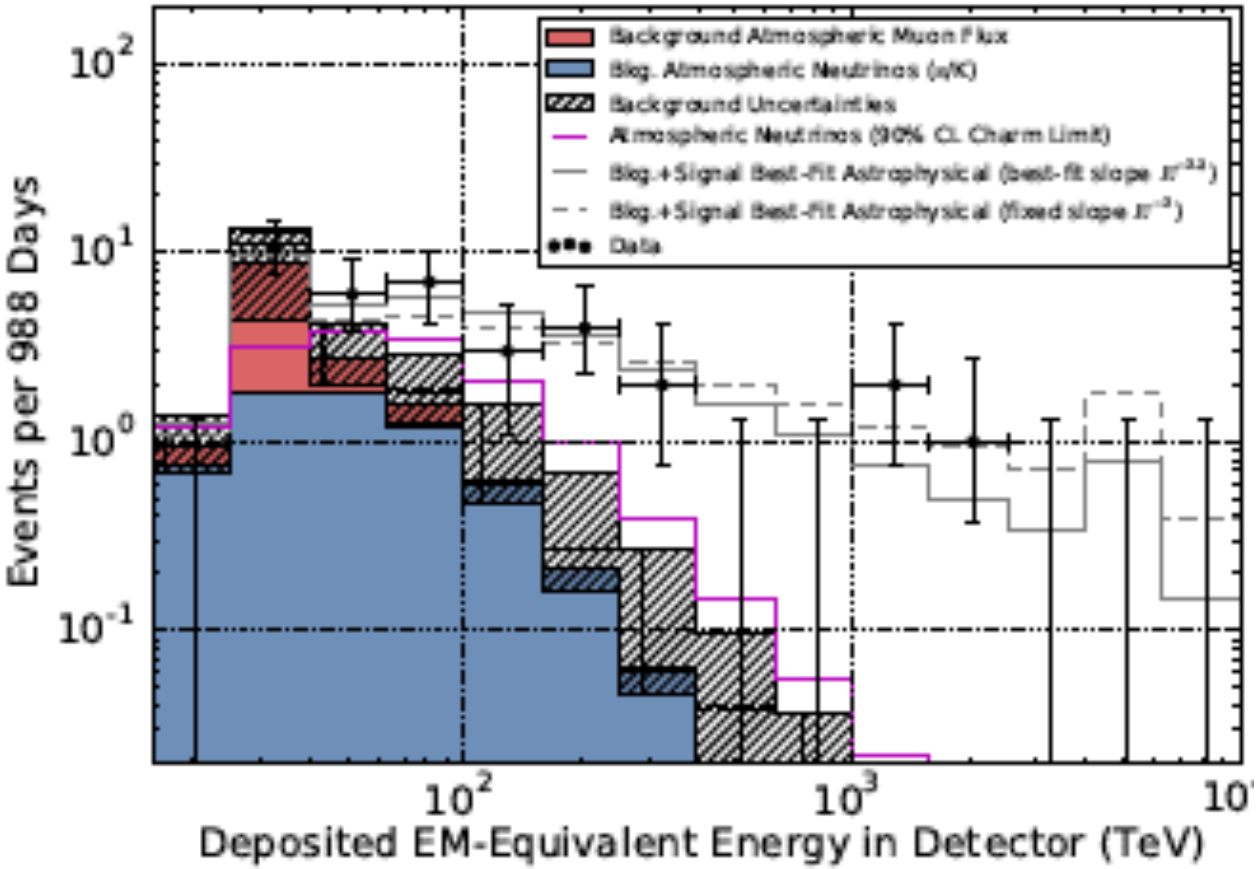
Principale fondo: neutrini atmosferici



PRL 110 (2013) 151105

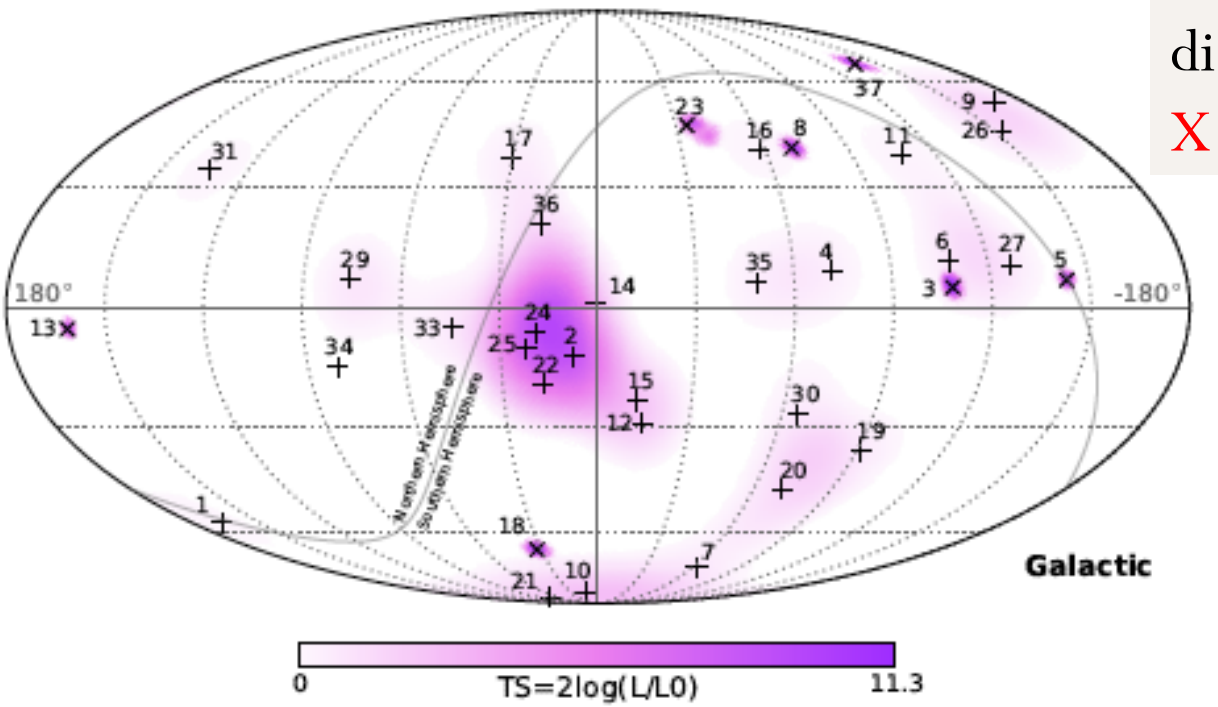
Segnale IceCube

Best fit per-flavor astrophysical (E^{-2}) flux
In the energy range of 60 TeV – 3 PeV
$E^2 \Phi(E) = 0.95 \pm 0.4 \times 10^{-8} \mathrm{GeV\ cm^{-2} s^{-1} sr^{-1}}$



- Totale di 37 eventi
- Spettro consistente con E^{-2}
- Indicazione della presenza di un cutoff attorno a 2 PeV
- Best fit della slope varia tra -2.0 e -2.3

Da dove proviene il segnale di IC?



+ Eventi di showers con 15° di incertezza

X Track events

In KM3NeT è attesa una migliore risoluzione per eventi di showers, 4° – 1.5° for 3TeV -1PeV (sistematiche non incluse)

KM3NeT stato attuale e futura strategia (2015)

Siti

Capo Passero
KM3NeT-ARCA
Astroparticle **R**esearch with **C**osmics in the **A**byss

Toulon
KM3NeT-ORCA
Oscillation **R**esearch with **C**osmics in the **A**byss

KM3NeT stato attuale e strategia (2015)

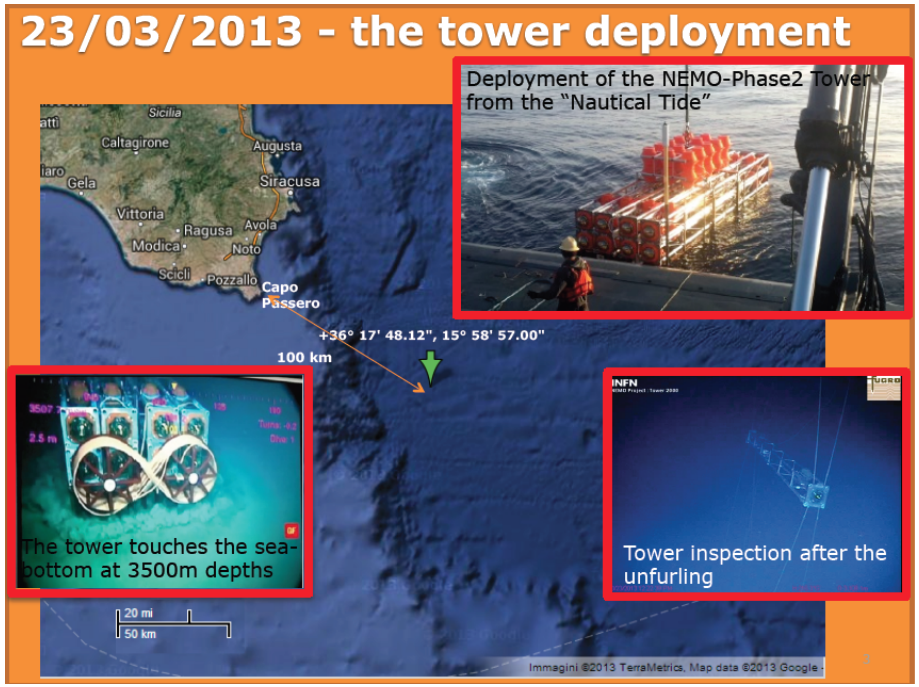
The Phase-1: investimento di **31 M€** coperto da fondi nazionali (NL 8.8 M€ and FR 3.5 M€) e regionali (FR 3.5 M€ and **IT 15 M€**). **(in construzione: previsto per fine 2016)**
24 stringhe (558 DOM) + 8 torri (Nemo)
Capo Passero (KM3NeT-ARCA neutrino astronomy)
= Antares x 3, Ice cube x 0,3.
7 stringhe Toulon (KM3NeT-ORCA neutrino oscillations)

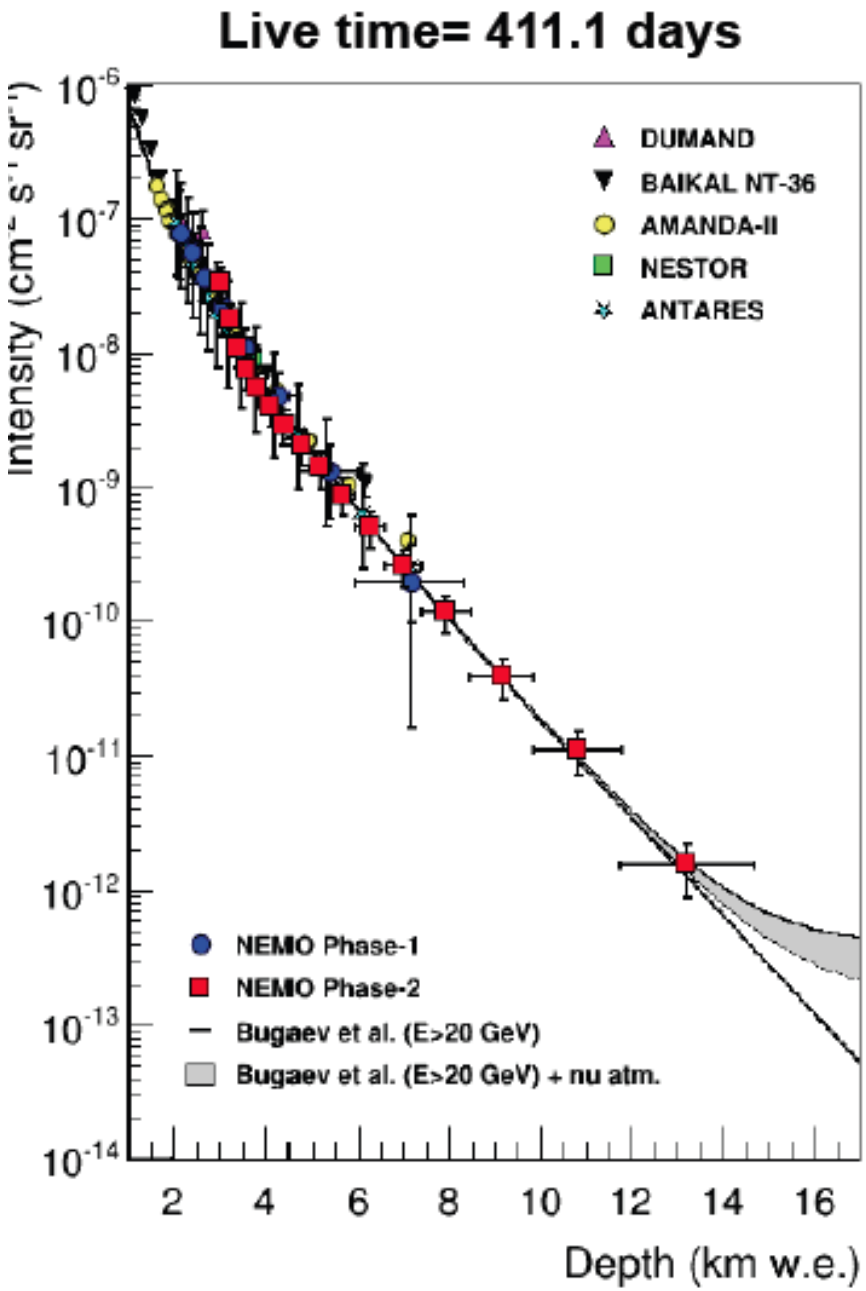
Phase-2.0: investimento di **95 M€.** (FR 12.4 M€, IT **70 M€,** NL 10 M€).
2 Blocchi di 115 stringhe ognuno
Capo Passero (KM3NeT-ARCA neutrino astronomia)
= Antares x 50, Ice cube x 2 : previsto fine 2020.
1 blocco of 115 strings Toulon (KM3NeT-ORCA neutrino oscillations)

KM3NeT 2.0 will appear on the ESFRI roadmap of 2016.

Versione finale KM3NeT: investimento per **130 - 170 M€.**
6 blocchi per un totale di 700 stringhe
= Ice cube x 6

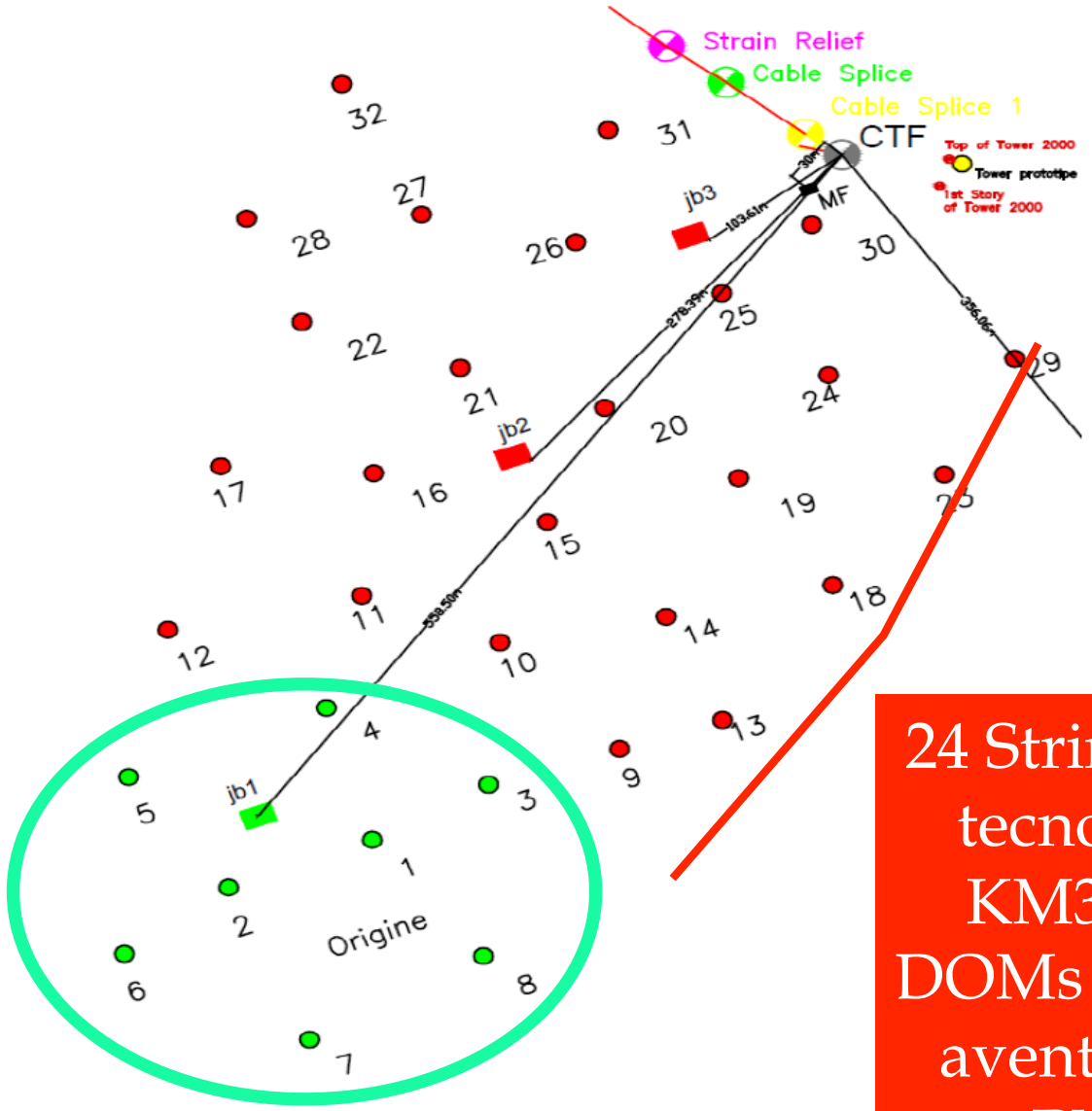
NEMO Tower

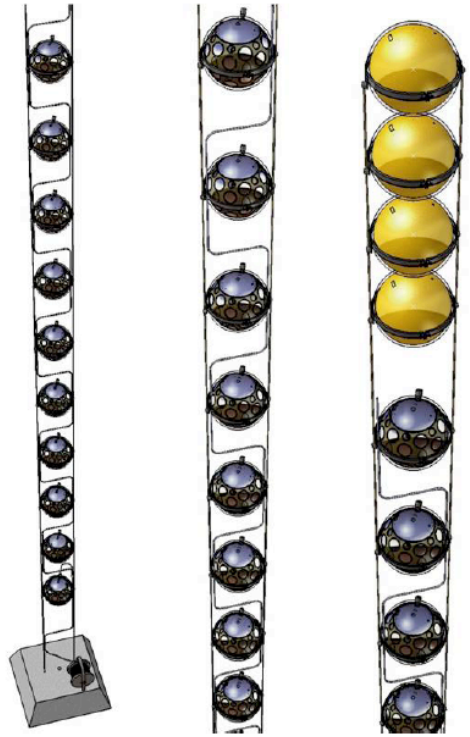

23/03/2013 - the tower deployment
Deployment of the NEMO-Phase2 Tower from the "Nautical Tide"
Sicilia
Caltagirone
Augusta
Gela
Siracusa
Vittoria
Ragusa
Avola
Modica
Noto
Scicli
Pozzallo
Capo Passero
+36° 17' 48.12", 15° 58' 57.00"
100 km
The tower touches the sea-bottom at 3500m depths
Tower inspection after the unfurling
20 mi
50 km
Immagini ©2013 TerraMetrics, Map data ©2013 Google


Live time= 411.1 days
Intensity (cm⁻² s⁻¹ sr⁻¹)
DUMAND
BAIKAL NT-36
AMANDA-II
NESTOR
ANTARES
NEMO Phase-1
NEMO Phase-2
Bugaev et al. (E>20 GeV)
Bugaev et al. (E>20 GeV) + nu atm.
Depth (km w.e.)

KM3NeT-It: **Fase-1** @ Capo-Passero: 2014-16

Antares x 3, Ice cube x 0,3

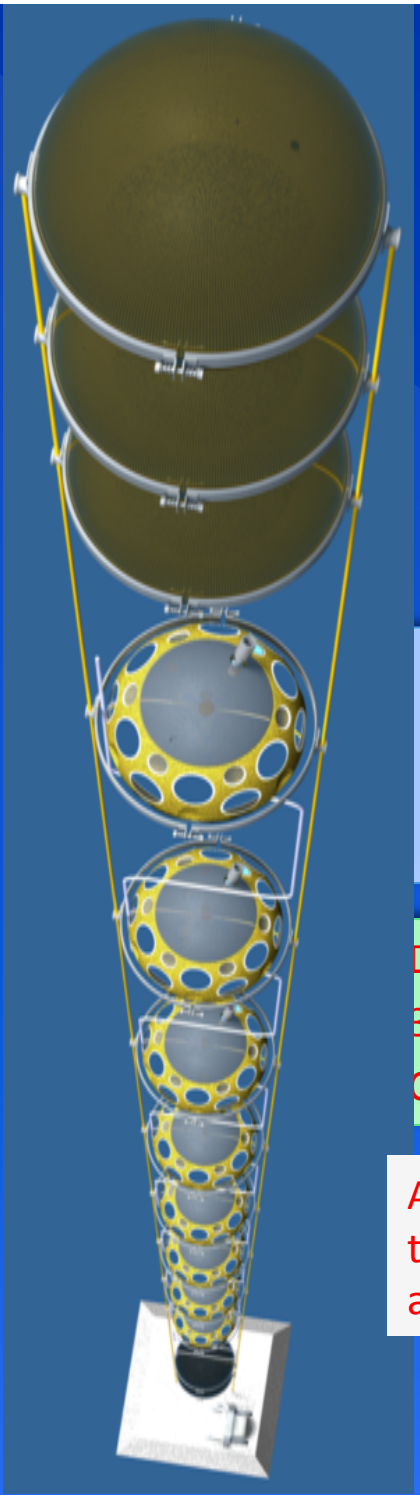




8 Torri NEMO-Fase 2

24 Strings con tecnologia KM3NeT: DOMs ognuno aventi 31 3" PMTs

The String Technology



Digital Optical Module

31 small, 3”, PMTs in one glass sphere

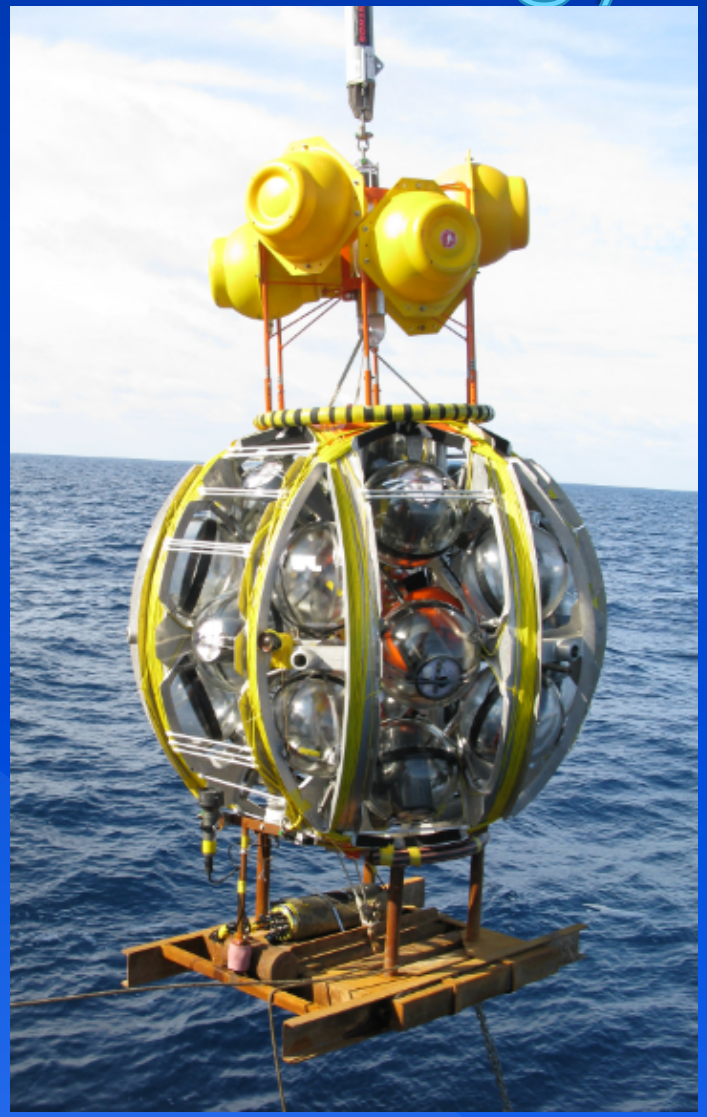
Photon counting

Detection Unit with 18 storeys

36 m inter-storey distance

Compact deployment

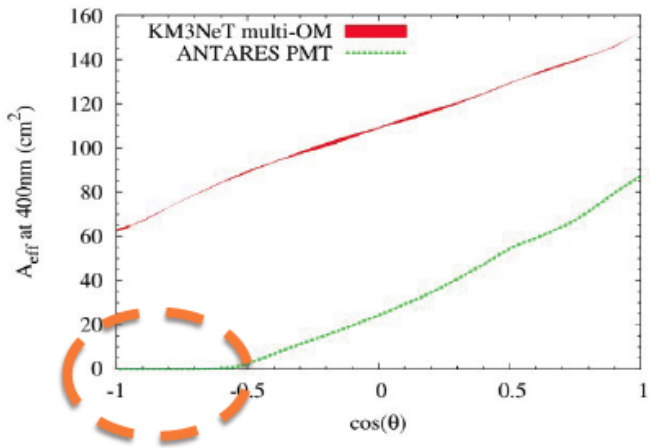
A multi-PMT OM mounted on the ANTARES Instrumented line allowed to study its behaviour



Modulo Ottico - Multi-PMT Vs Singolo PMT

The ANTARES optical module
(single 10" PMT in a 17" sphere)

The KM3NeT DOM
(31 3" PMTs in a 17" sphere)



- La segmentazione del fotocatodo consente un conteggio dei fotoni con maggiore capacità di rigettare il background
- Area massimizzata, rapporto aree fotocatodi $31 \times \pi \times 1.5^2 / (\pi \times 5^2) = \mathbf{2.8}$
- Trigger locali possono essere studiati
- La sensitività viene estesa ad una grande frazione di angolo solido
- Prezzo per unità di area del fotocatodo è più conveniente

Prestazioni 3″ PMT

– timing	≤ 4.5 ns (FWHM)
– Q.E.	~30%
– collection efficiency	≥ 90%
– photon counting purity	100% (by hits, up to 7)
– 3 serious suppliers	

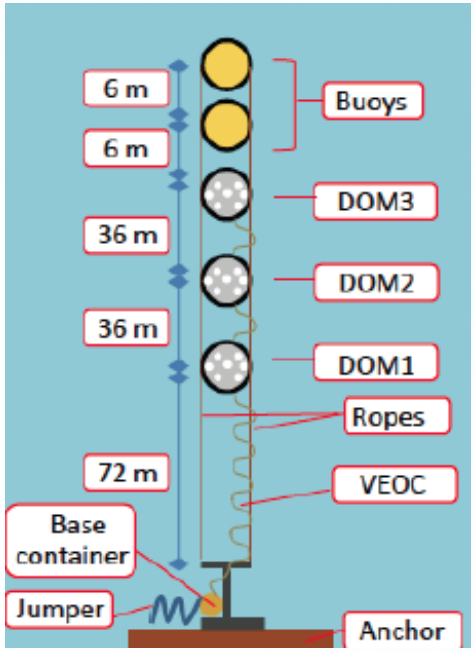
ETEL D792

Hamamatsu R12199

HZC XP53B20

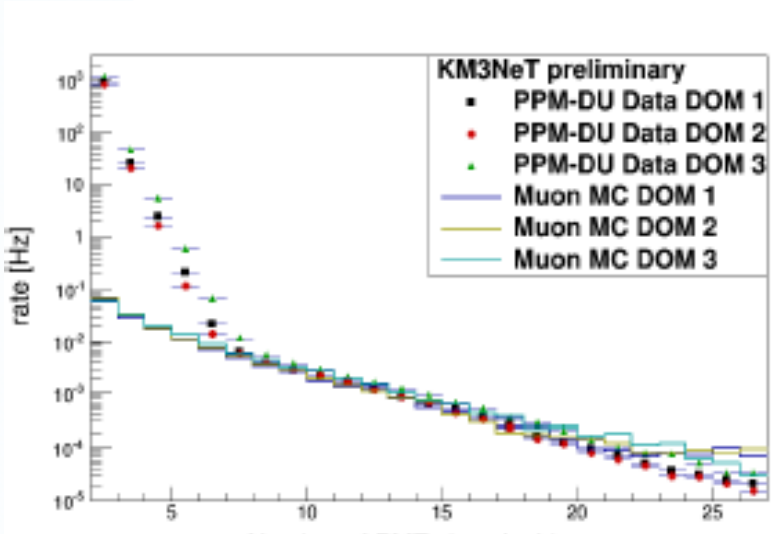
Prototipo PPM-DU (3 Moduli Ottici)

Deployment time!

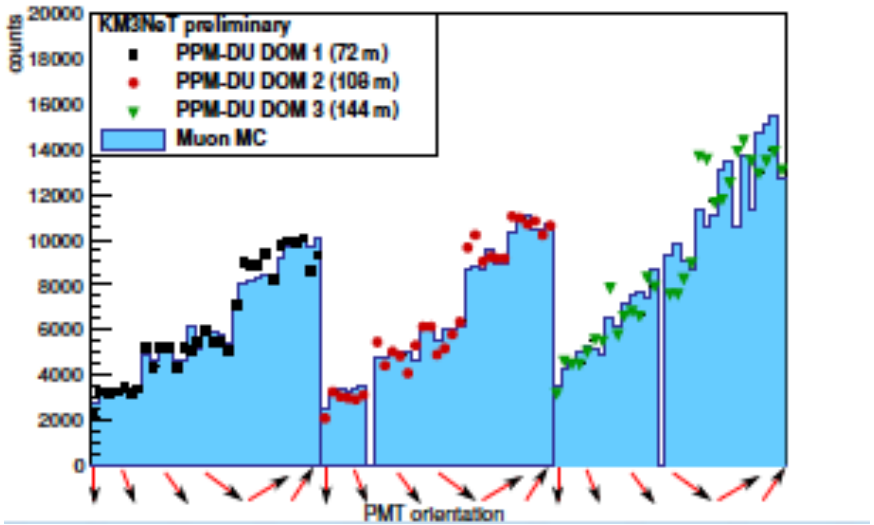


- Tre Moduli Ottici (31 x 3″ PMT)
- Assemblati in una piccola linea
- Connessione alla Junction Box attraverso in cavo elettro-ottico
- Ogni DOM contiene un LED beacon per calibrazione

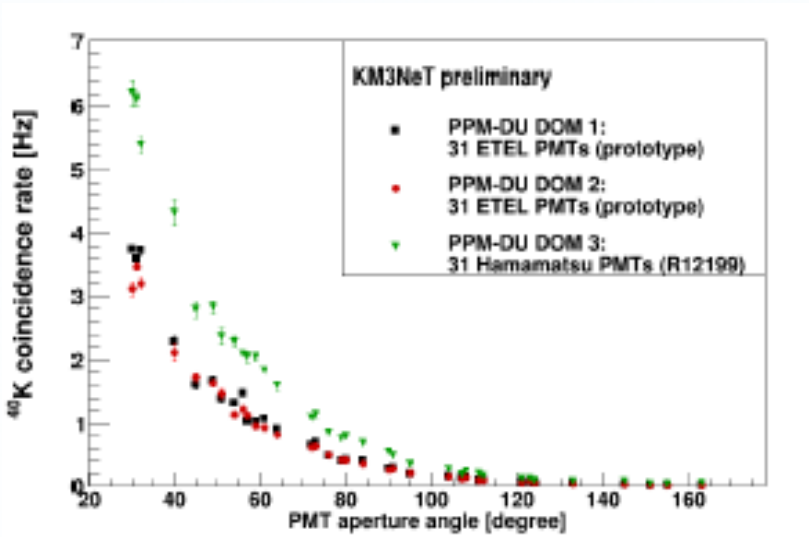
Prototipo PPM-DU - Risultati



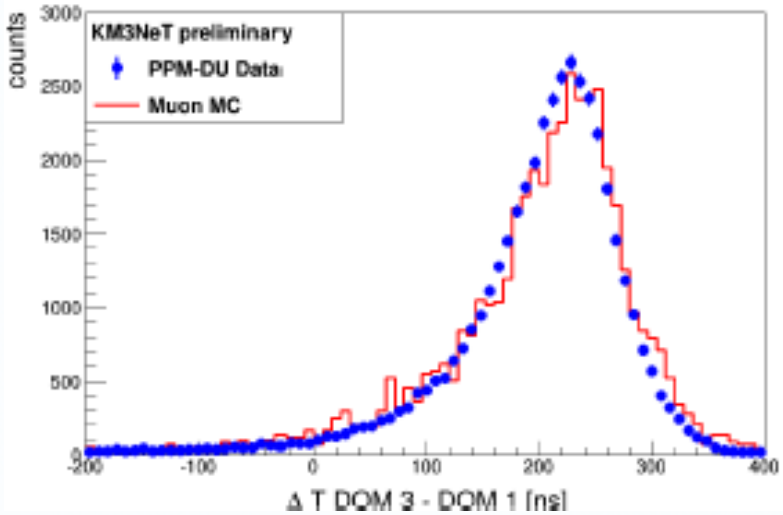
Numero di PMT in coincidenza



Distribuzione di hits in funzione dell'orientazione dei PMT (Nhit>8)



Coincidenze in funzione dell'apertura angolare dei PMT



Offset temporale DOM1-DOM3 (Tracce di muoni)

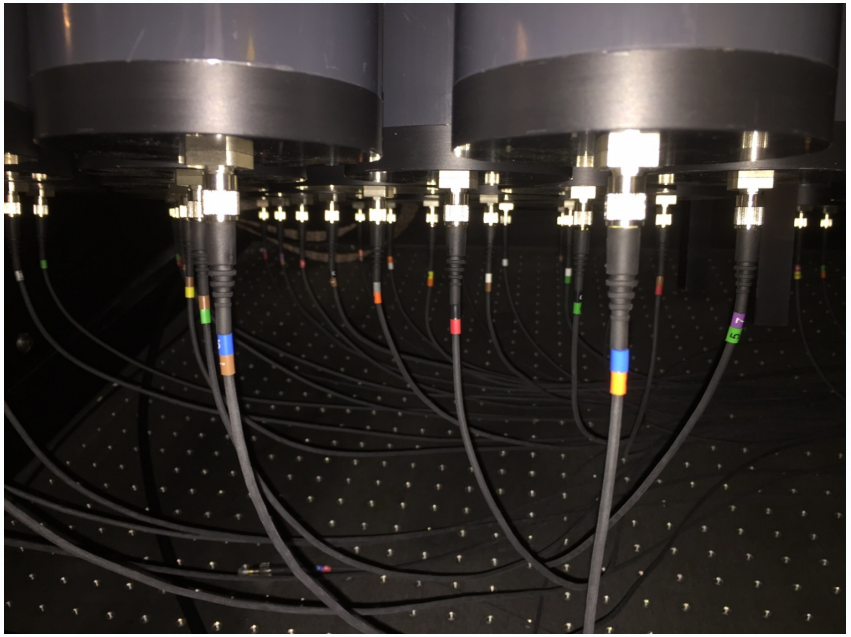
PMT Test Site: Napoli INFN laboratory

- Load PMTs on the trays
- Set Nominal HV
- HV tuning (including HV tuning analysis)
- Darkening
- LASER tests (TTS, prepulses, afterpulses and Delayed pulses)
- PMT selection after test results and packaging

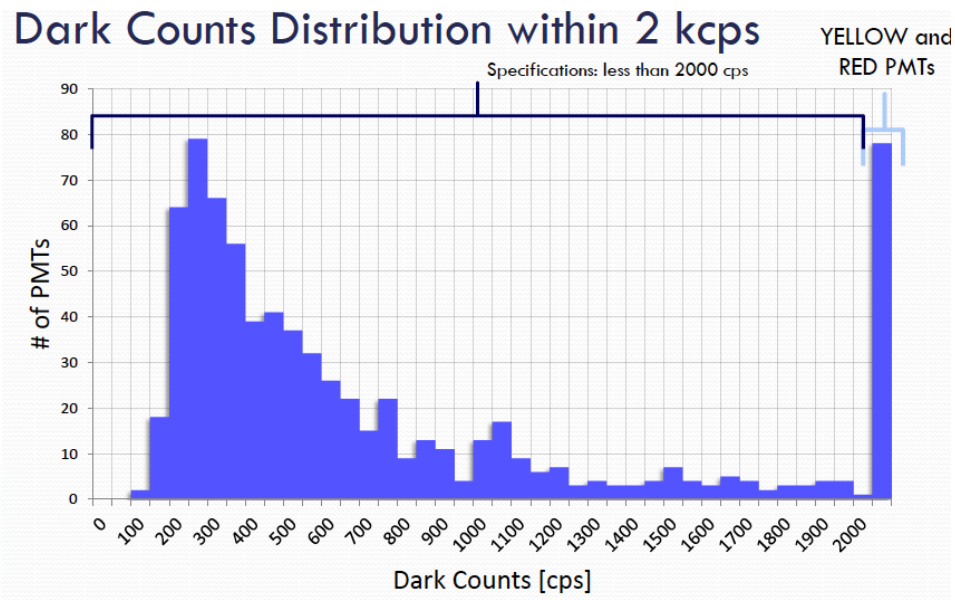
9 ore per ogni test

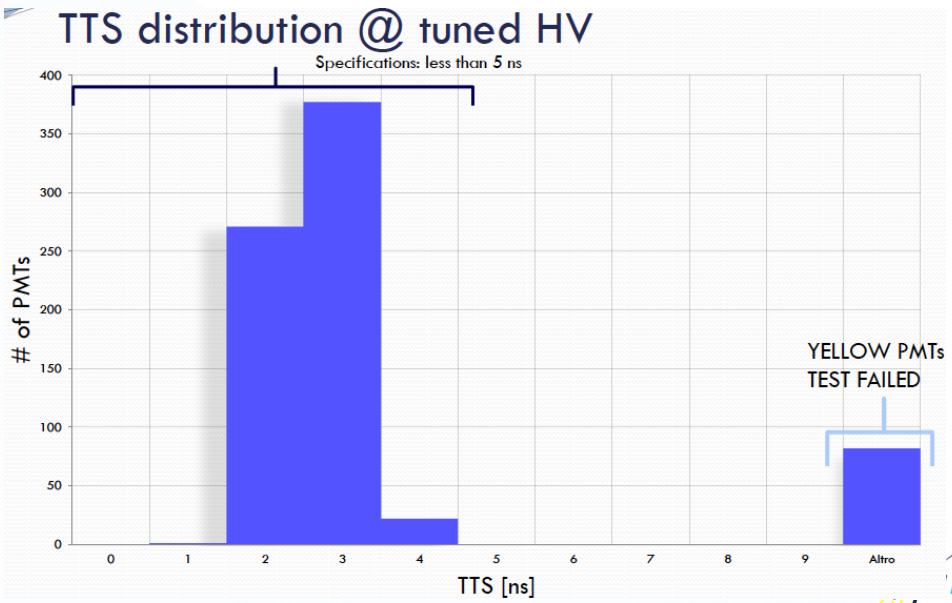
LASER controller modificato per controllare ogni componente in remoto.
62 PMT testati per ogni sessione
Al momento 2 sessioni/giorno vengono effettuate (124 PMT)
Fino ad ora testati oltre 2000 PMT rispetto al totale previsto da Fase1 (7500)

Test dei PMT

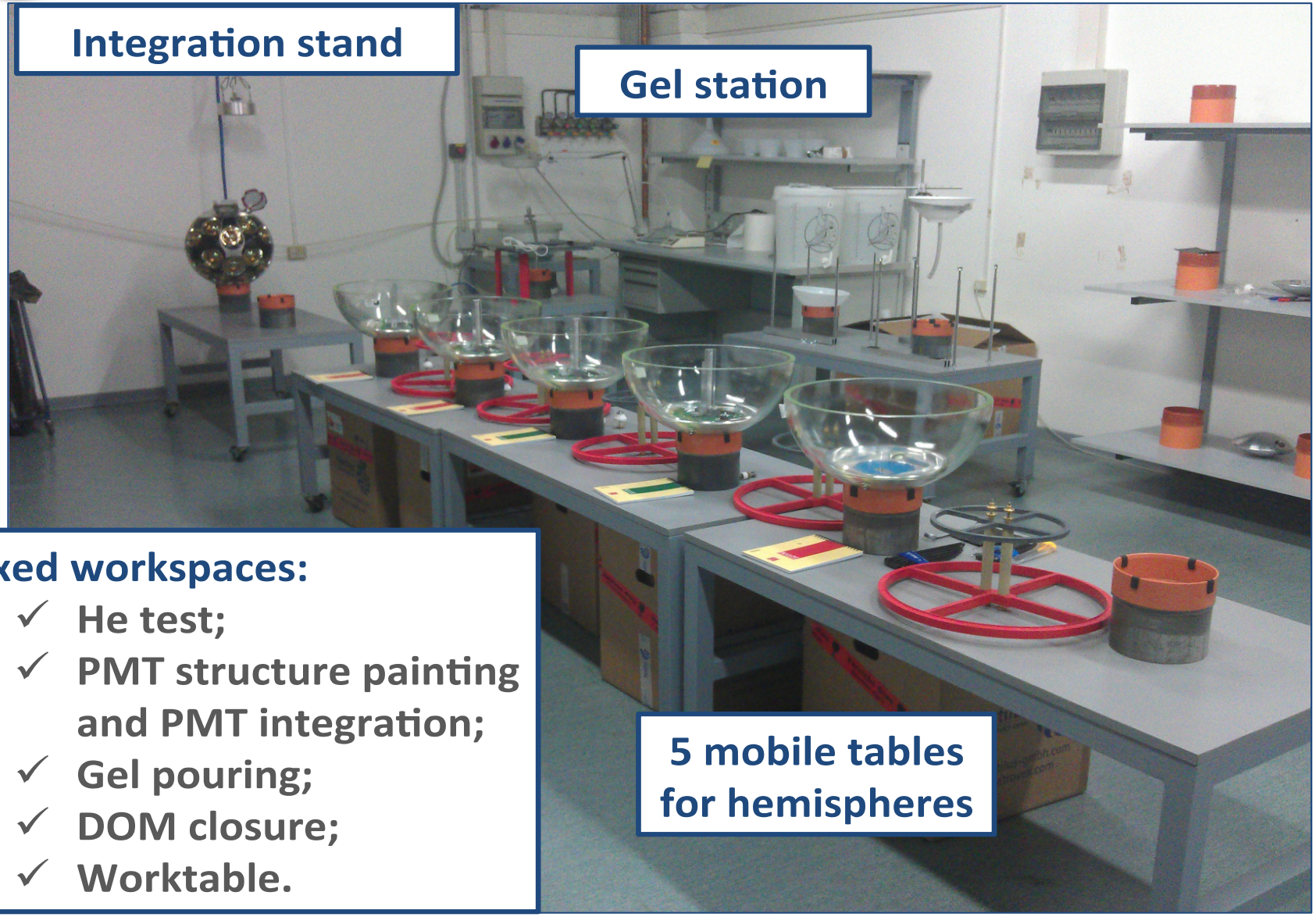


The optical splitter connected to the dark cylinders





The DOM integration site



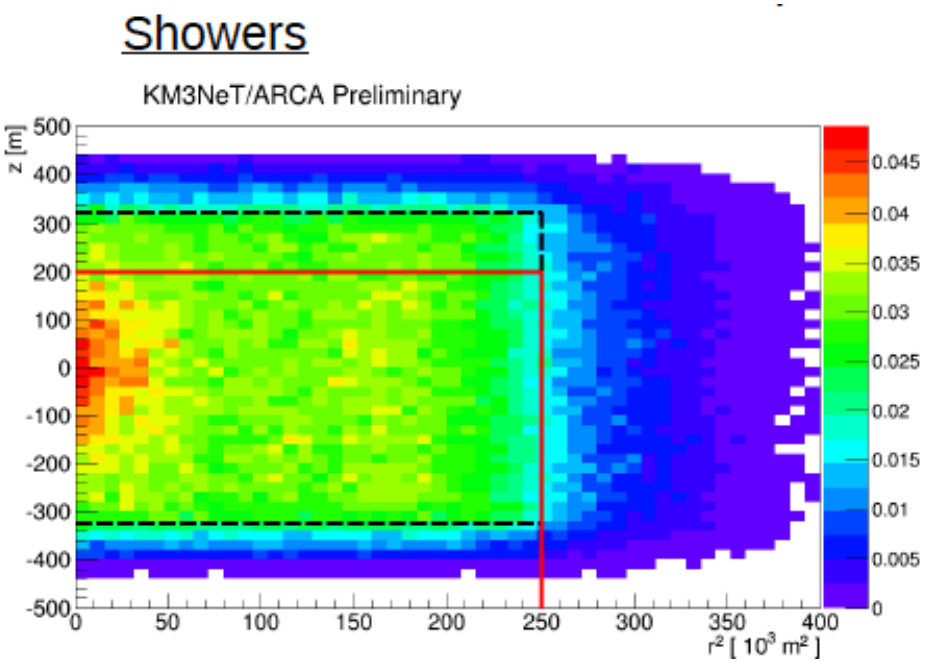
5 fixed workspaces:

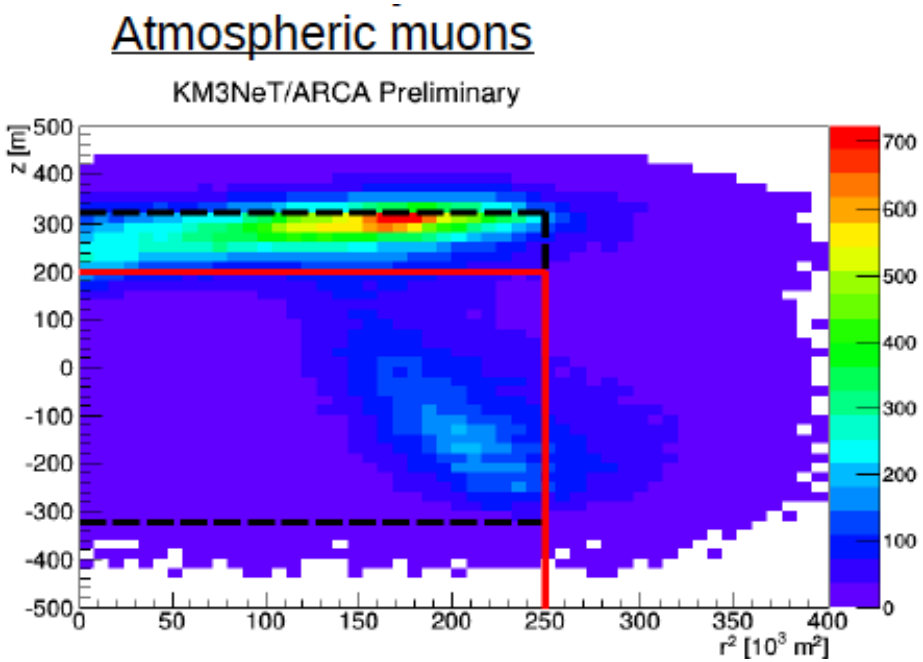
- ✓ He test;
- ✓ PMT structure painting and PMT integration;
- ✓ Gel pouring;
- ✓ DOM closure;
- ✓ Worktable.

Segnale IceCube: ricerca su tutto il cielo un eccesso di eventi di neutrino di alta energia

Analisi showers

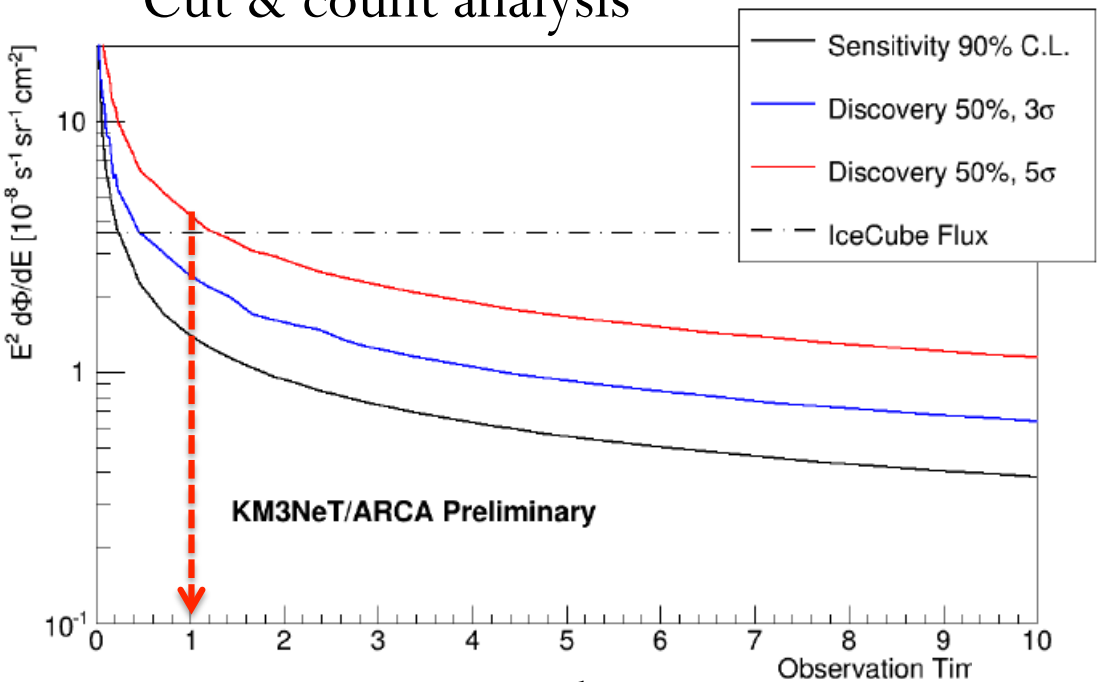
- Coincidenze 5 (o più) PMT nello stesso modulo ottico (ΔT=10ns)
- Numero totale di hits >2000
- Taglio sulla posizione del vertice (veto per i muoni)
- Taglio in energia (total ToT>12μs)





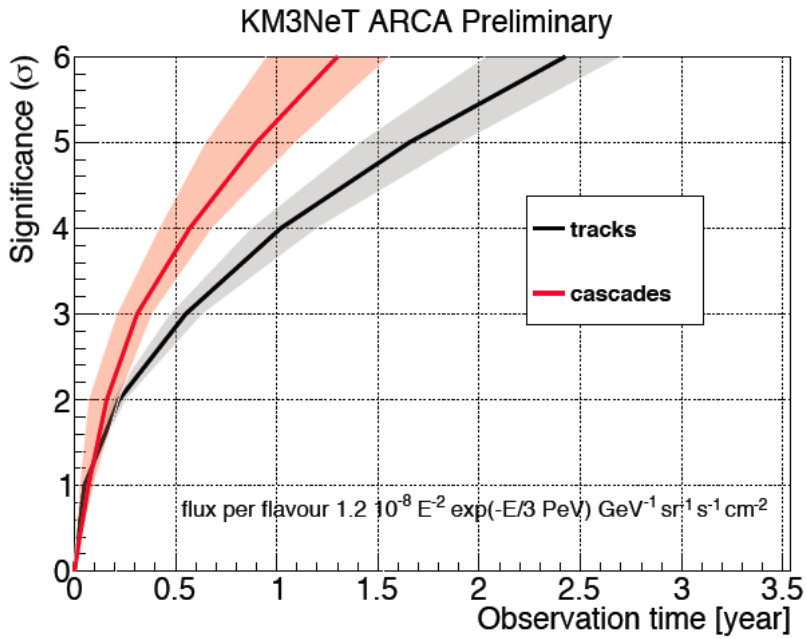
Segnale IceCube (KM3Net Fase 2)

Cut & count analysis



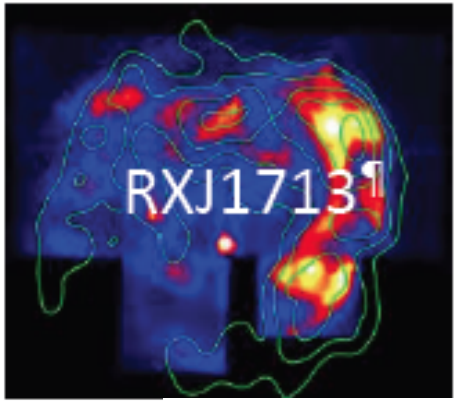
Circa un anno per evidenza a 5σ

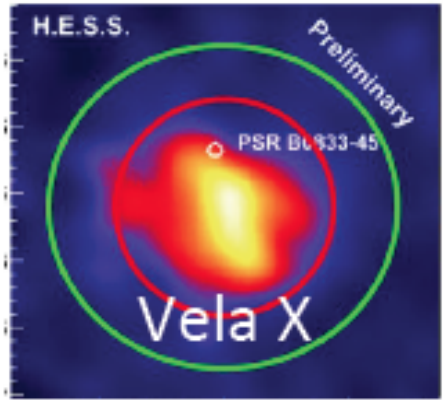
Poster
L. Fusco



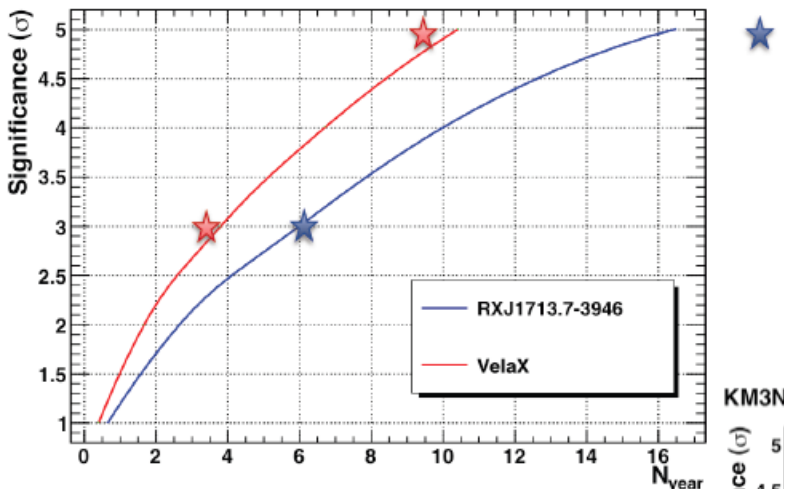
Showers ->full sky analysis
Tracks ->upgoing tracks

Sorgenti Puntiformi

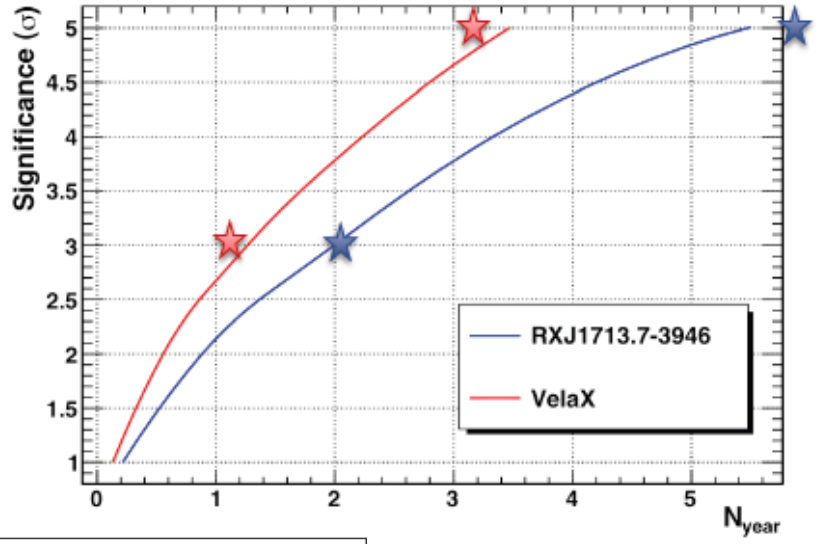




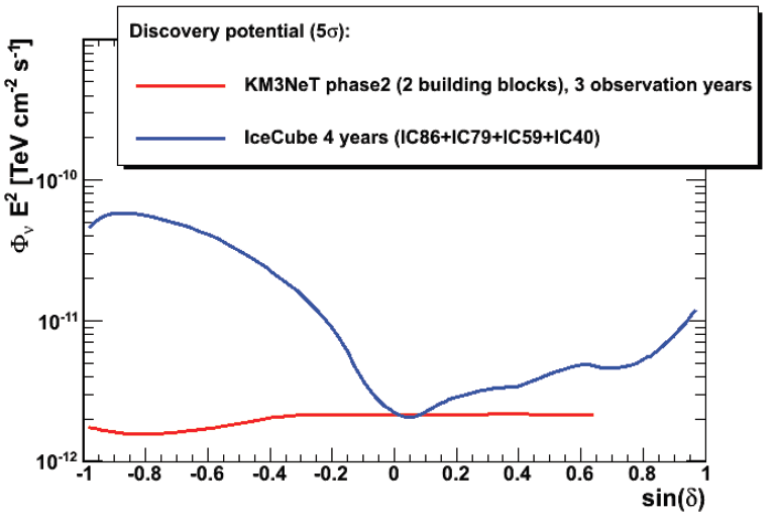
KM3Net Fase 2



KM3Net Fase 3



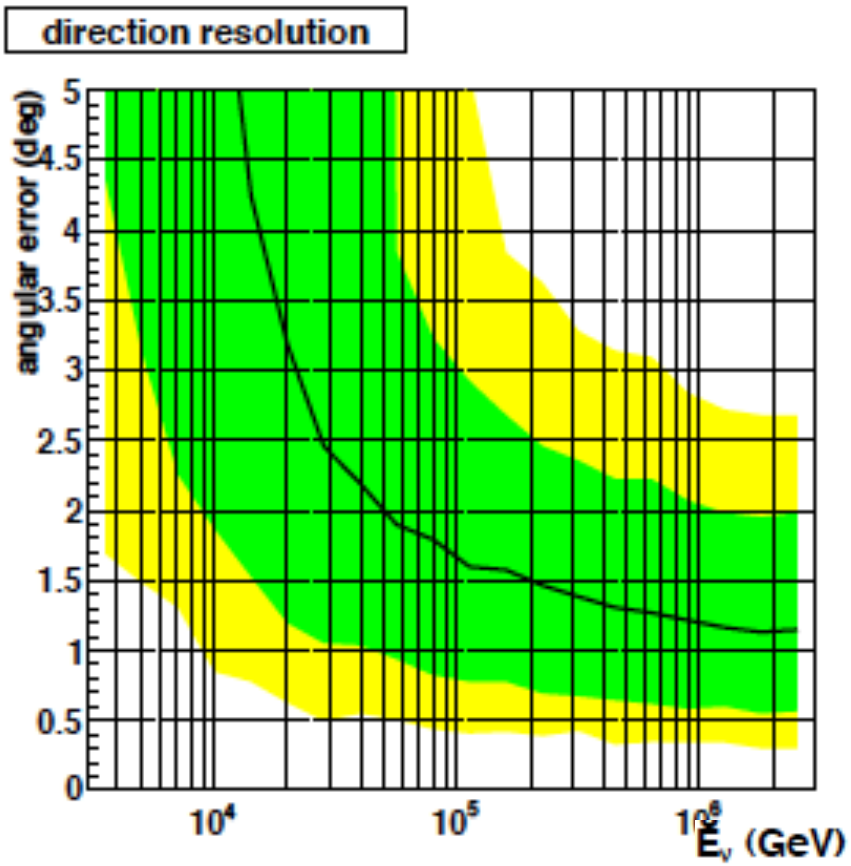
Potenziale di scoperta
Sorgente generica

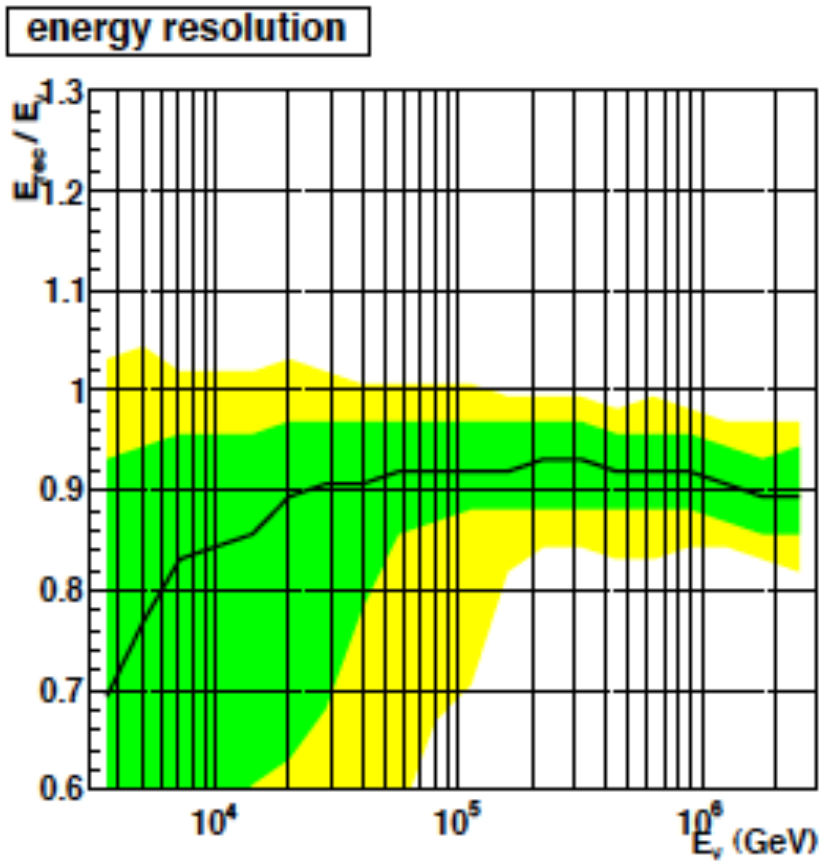


Sorgenti Puntiformi: prospettive future

- Altre sorgenti promettenti, stacking analisi
- Includere morfologia
- Analisi usando tutti i sapori di neutrino

Showers: risoluzione angolare ed in energia

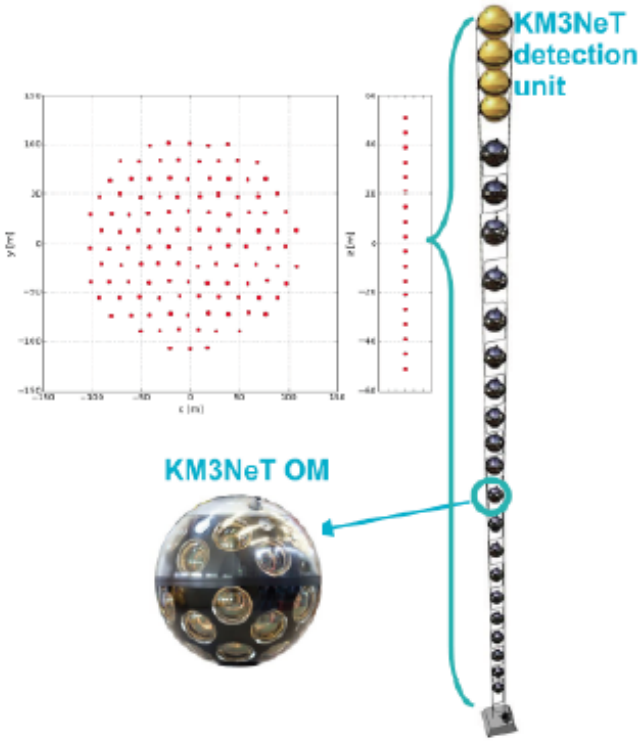




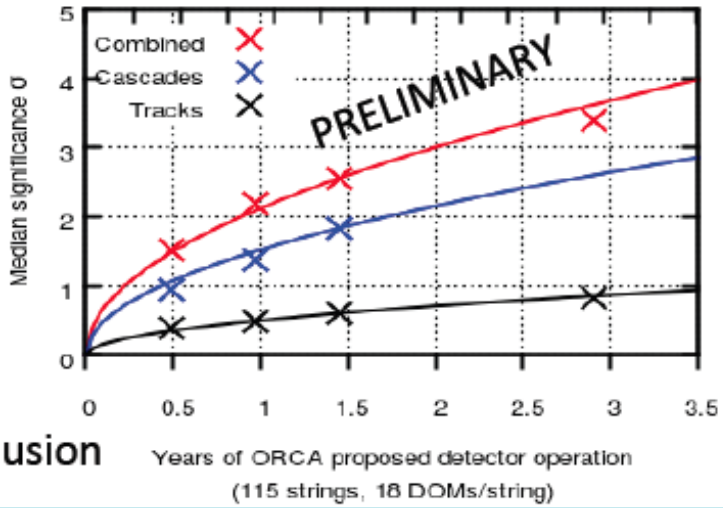
SPARES

ORCA is part of the KM3NeT research infrastructure. Different detector, same technology

- Few GeV signal => more compact detector (75 times denser!)
- Angular and energy resolution are very challenging



- 115 detection units, 20m spacing
- 18 Optical Modules (DOMs) per detection unit
- 6m vertical distance between DOMs
- 31 3" PMTs/DOM
- Instrumented volume about 3.75 Mtons
- Estimated cost 40 M€ (conservative)
- Geometry optimisation study ongoing

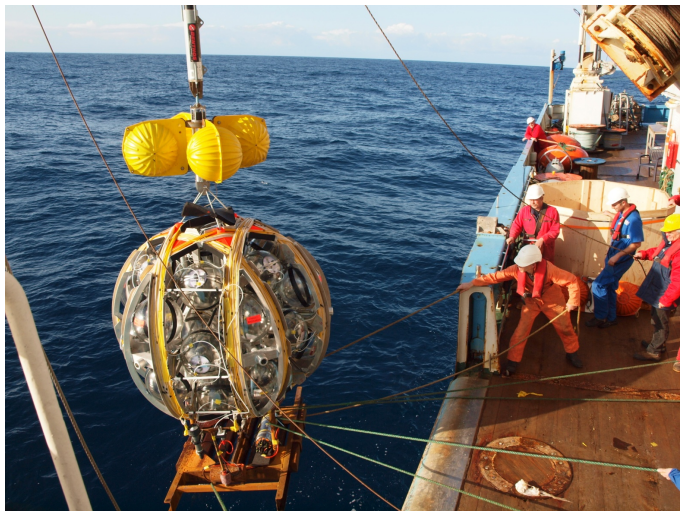


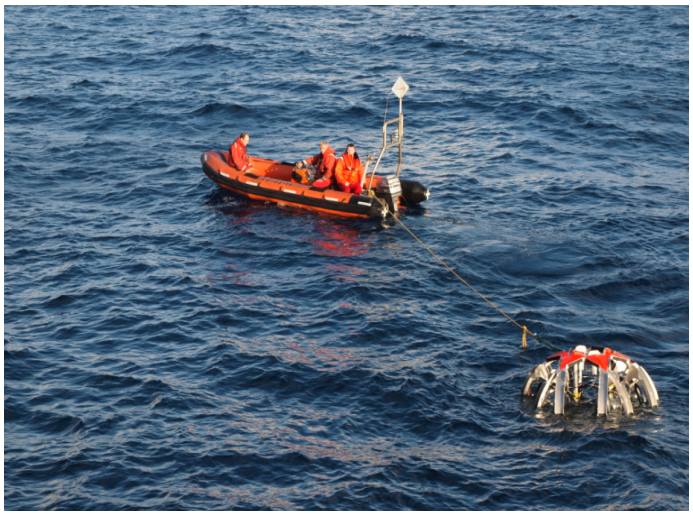
Inverted mass hierarchy exclusion

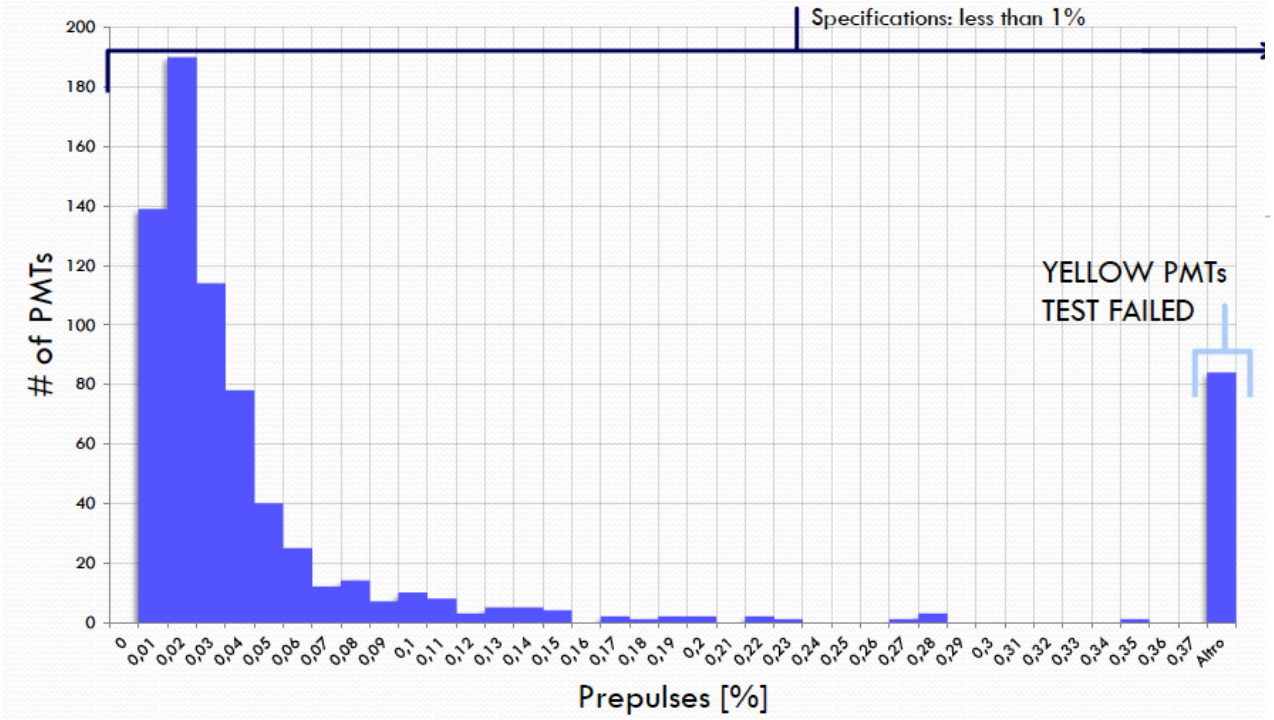
Test of the string prototype

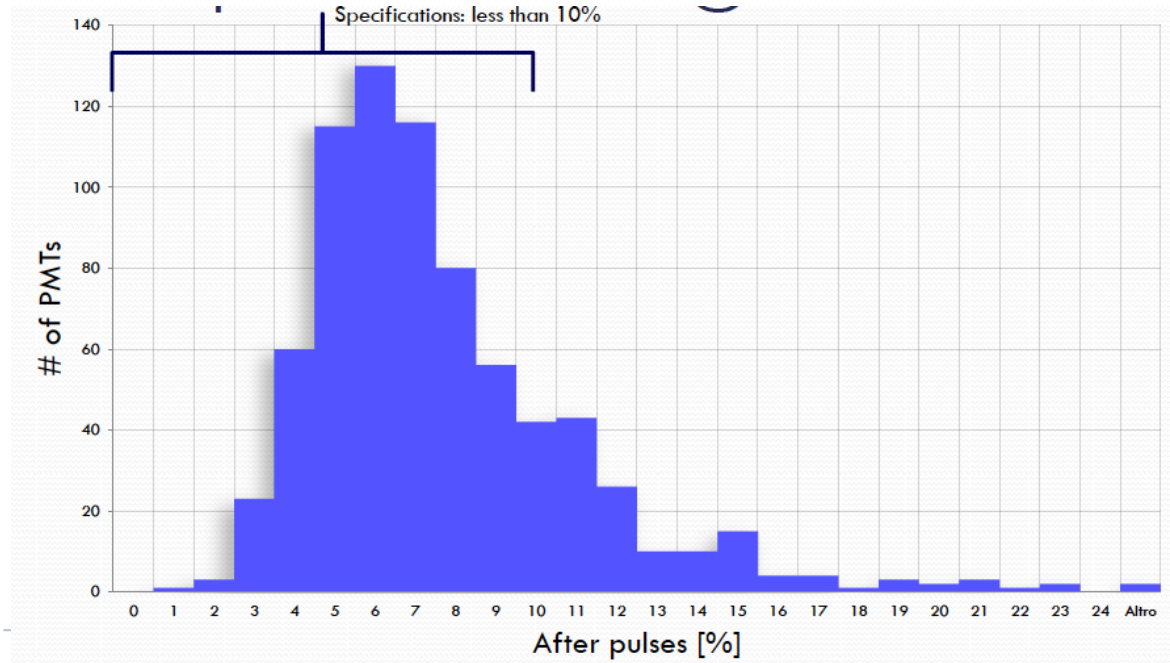
Storage on deck of the Pelagia

Deployment and recovery

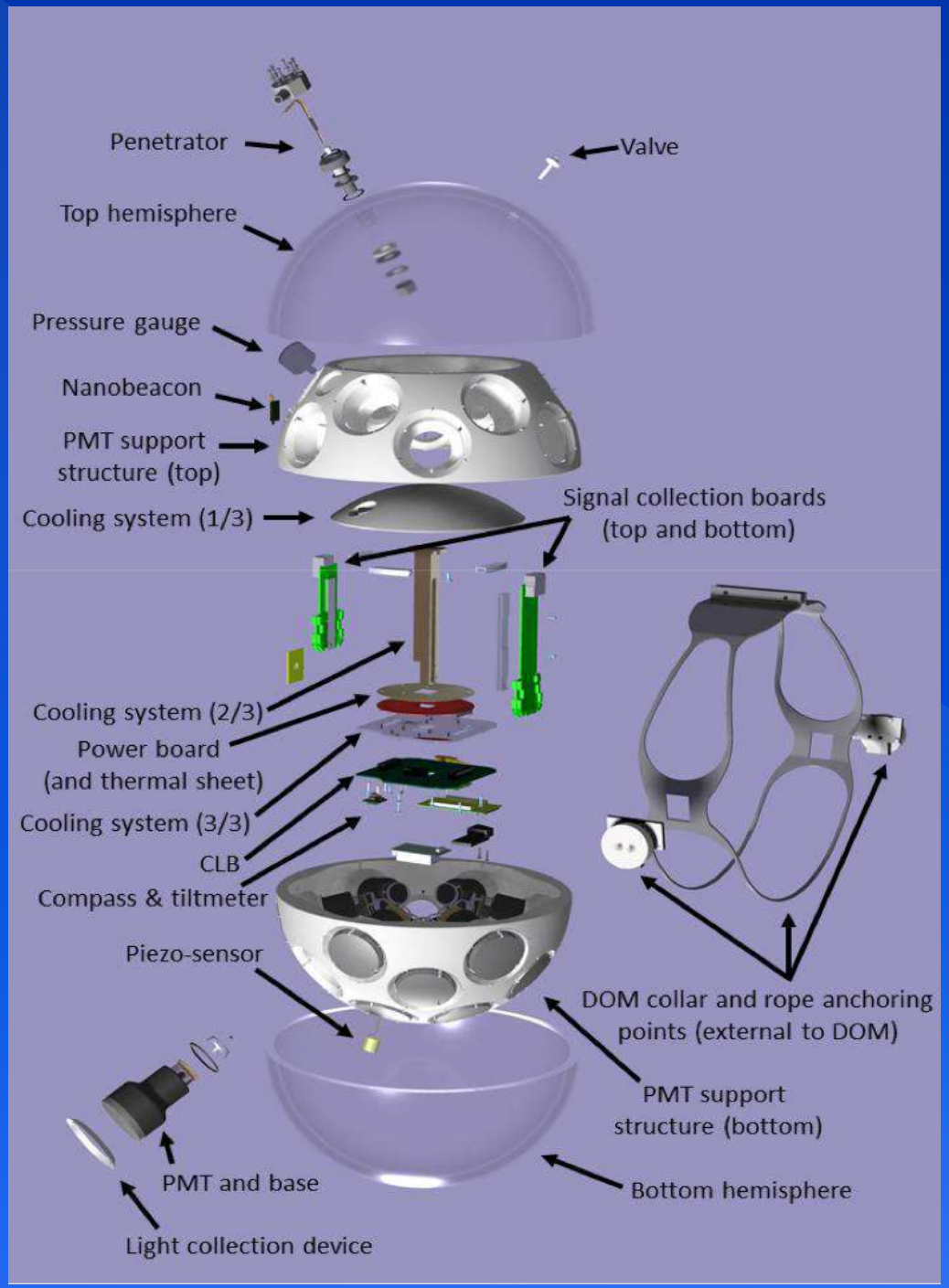





Specifications: less than 1%
YELLOW PMTs
TEST FAILED
# of PMTs
Prepulses [%]


Specifications: less than 10%
# of PMTs
After pulses [%]

Multi-PMT Digital Optical Module



31 x 3" PMTs
- Hamamatsu, ETL, HZC

Light collection ring
- 20-40% gain in photocathode

Low power
- < 10 W/DOM

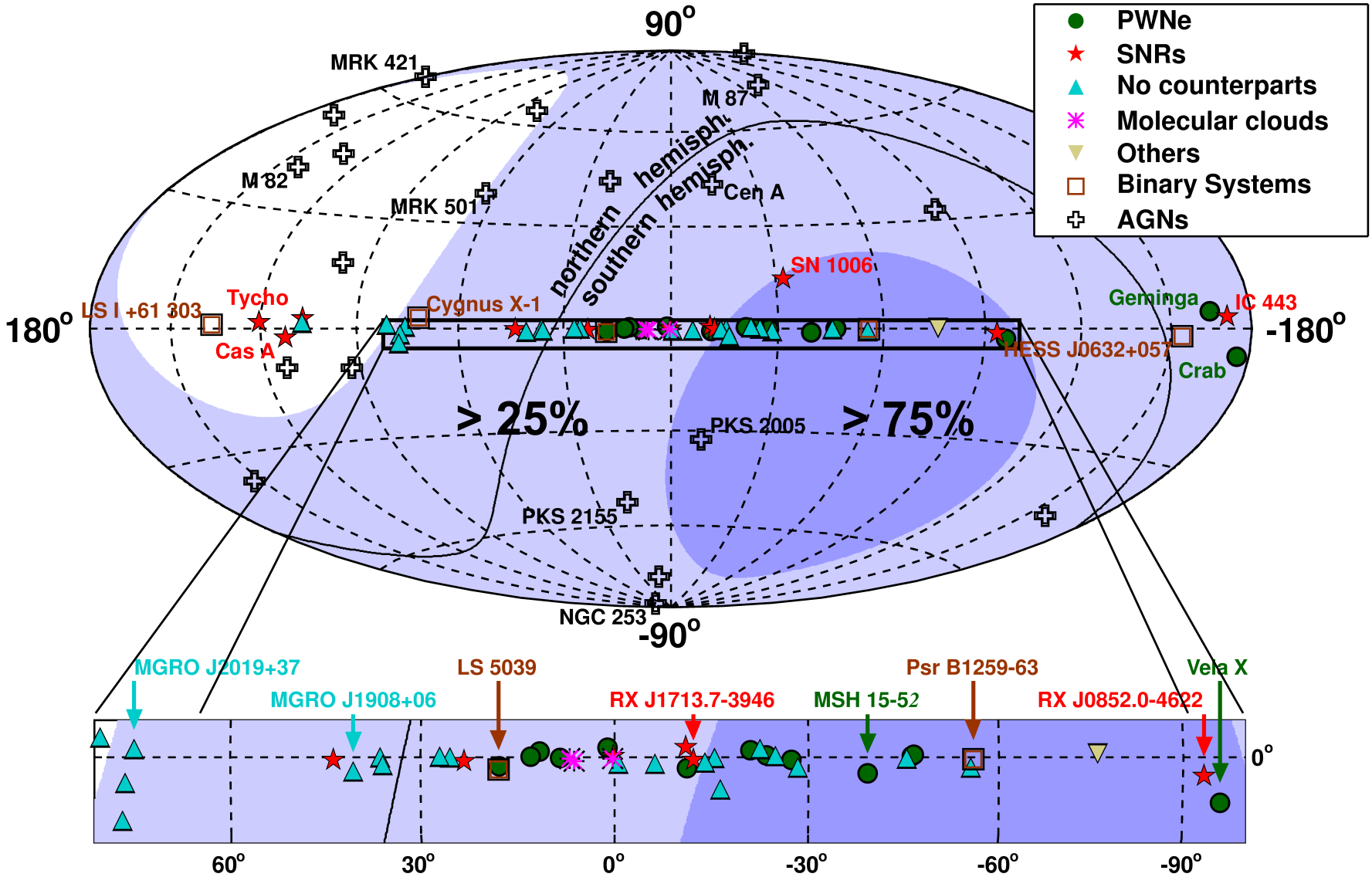
FPGA readout
- sub-ns time stamping
- time over threshold
- all data to shore
- White Rabbit synchronization

Calibration
- < LED & acoustic piezo in sphere

Optical fibre data transmission
- DWDM with 80 wavelengths
- Gb/s readout

Copertura celeste - Mar Mediterraneo

Cielo osservato, in coordinate galattiche da un rivelatore efficiente a tracce provenienti da sotto l'orizzonte



A Brief History of KM3NeT

NEMO – ANTARES – NESTOR pilot projects

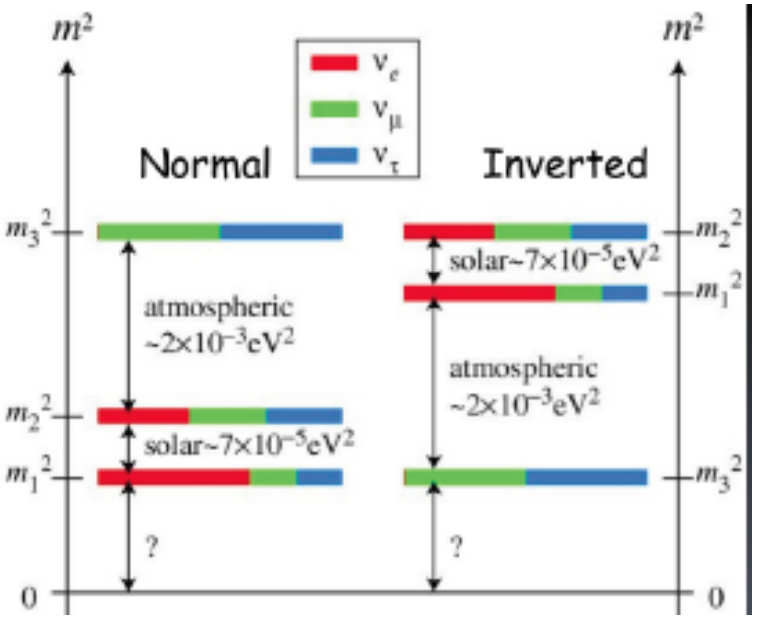
KM3NeT Design study project funded with 9 Meuro under 6th EC Framework Programme
Conceptual Design Report

KM3NeT Peparatory Phase funded with 5 Meuro under 7th EC Framework Programme
Technical Design Report
Concluded in February 2012

Memorandum of Understanding
185 Scientist, 40 Institutes (10 INFN)

Strong centralised management and introduced effective oversight mechanisms through a **Scientific and Technical Advisory Committee (STAC) and a Resources Review Board (RRB)** comprising eminent researchers and science managers.

The data is centrally processed in large facilities (CC-Lyon, CNAF, and computing centres of partner institutes) including GRID-facilities (**ReCaS**, HellasGRID) and high-level data is provided to all collaboration members.



$$P_{e\to\mu} \approx P_{\mu\to e} \approx \sin^2\theta_{23}\sin^2(2\theta_{13}^{\text{eff}})\sin^2\left(\frac{\Delta_{13}^{\text{eff}}L}{2}\right)$$

$$\Delta_{13} = \frac{\Delta m_{13}^2}{2E_\nu} \qquad \sin^2(2\theta_{13}^{\text{eff}}) = \frac{\Delta_{13}^2\sin^2(2\theta_{13})}{\Delta_{13}^{\text{eff}}L}$$

$$\Delta_{13}^{\text{eff}} = \sqrt{[\Delta_{13}\cos(2\theta_{13}) - A]^2 + \Delta_{13}^2\sin^2(2\theta_{13})}$$

$A = \sqrt{2}G_F N_e$ for ν and $A = -\sqrt{2}G_F N_e$ for $\bar{\nu}$