High energy neutrino astronomy: towards a km3 neutrino telescope in the Mediterranean Sea

E. Migneco

INFN

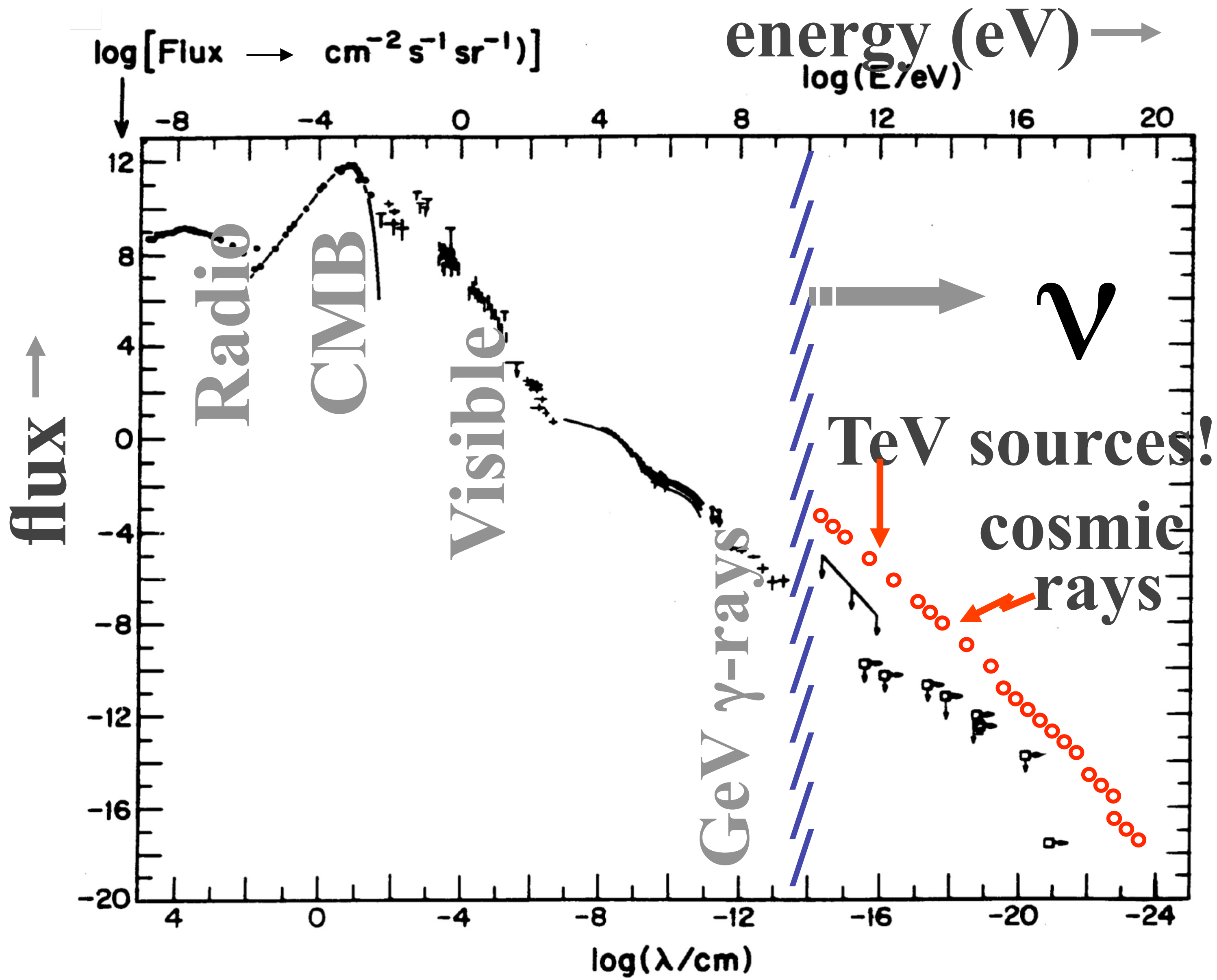
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

NEMO
NEUTRINO MEDITERRANEAN OBSERVATORY

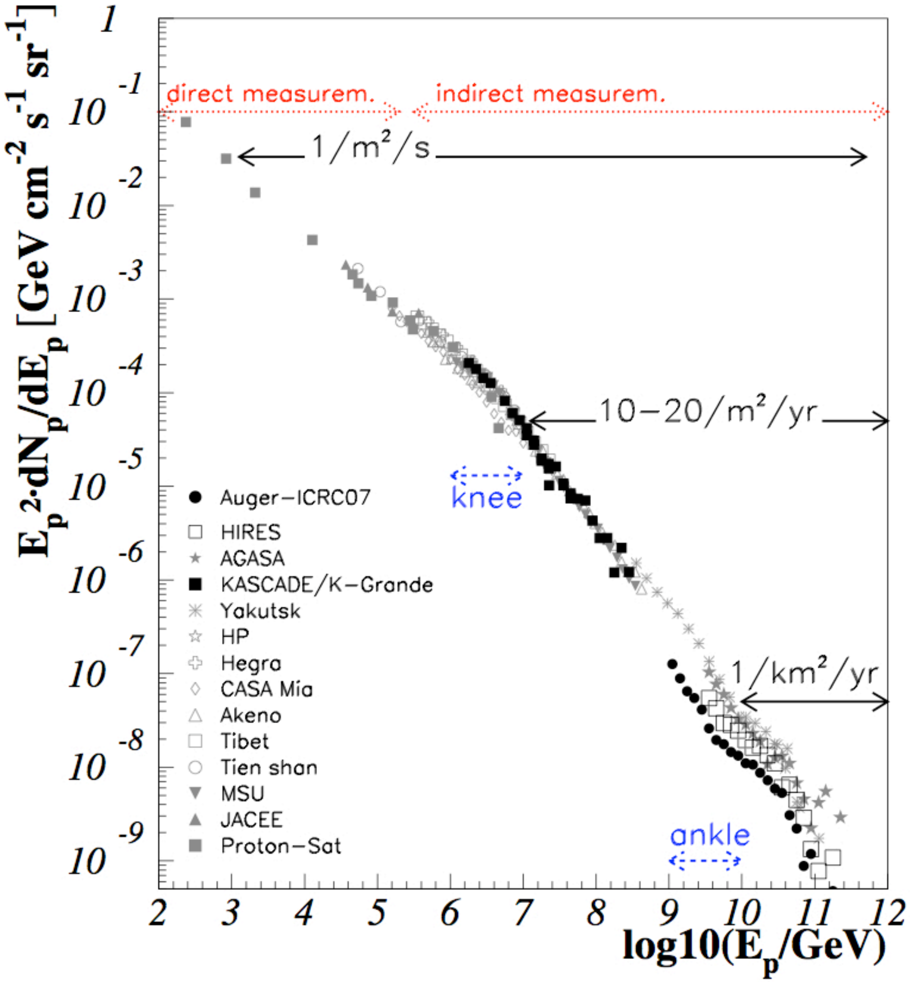
Talk outline

- A (short) introduction on HE neutrino astronomy
  - Cosmic-rays, gamma and neutrino connection
  - Expected neutrino fluxes
- HE neutrino detection
  - Underwater/ice Cherenkov detectors
- NEMO
- KM3NeT
- Summary and conclusions

The High Energy Universe



The High Energy Universe



Cosmic Rays with energies up to 3×10^{20} eV have been observed

Low energy region (up to 10^{15} eV) probably of galactic origin

The hardening of the spectrum in the high energy tail ($E > 10^{19}$ eV) may be an indication of an extragalactic component

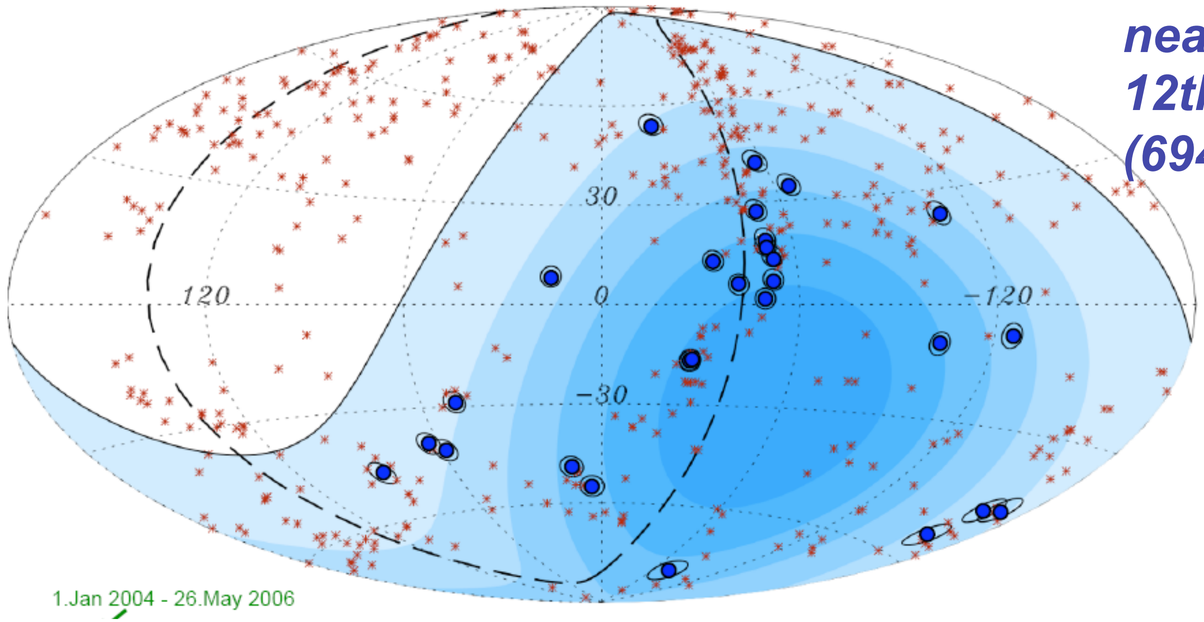
Evidence of GZK cut-off

Still some open problems:

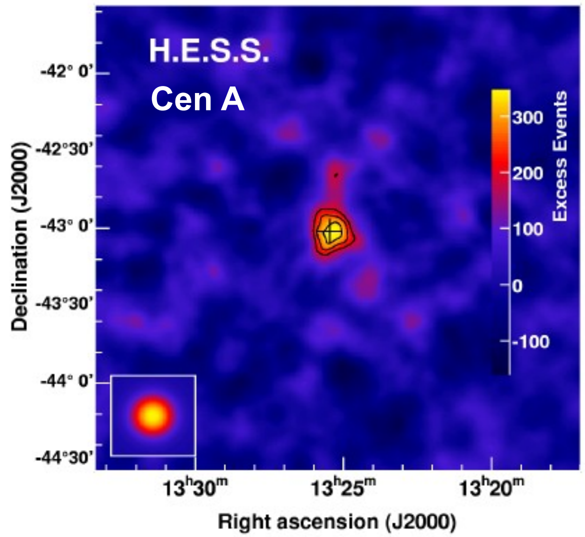
- Particle acceleration mechanisms
- Identification of the sources

AUGER data

27 Highest Energy Events > 57 EeV



Suitable source catalogue for nearby AGN:
12th Veron-Cetty catalogue
(694 AGN with z < 100 Mpc)



Combined-set analysis: R < 3.2°, z < 0.018, E > 57 EeV
27 evts, 20 correlate with AGN (5.6 exp.)
292 AGN in FoV

Correlation with Supergalactic plane ? Cluster from Cen A ?

In newer AUGER data correlation with AGN is NOT confirmed but anysotropy is there !

The Fermi acceleration mechanism

Observed $E^{-2.7}$ spectrum

Non-thermal spectrum. Statistical acceleration

Fermi's idea:

Particles gain energy hitting on clouds moving at V«c (inefficient)

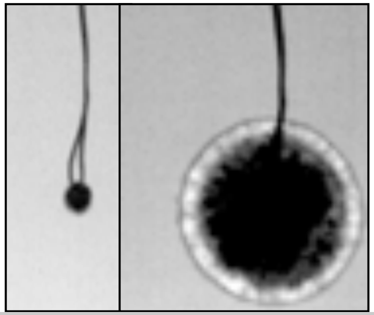
E^{-2} Spectrum

Bell's shock acceleration :

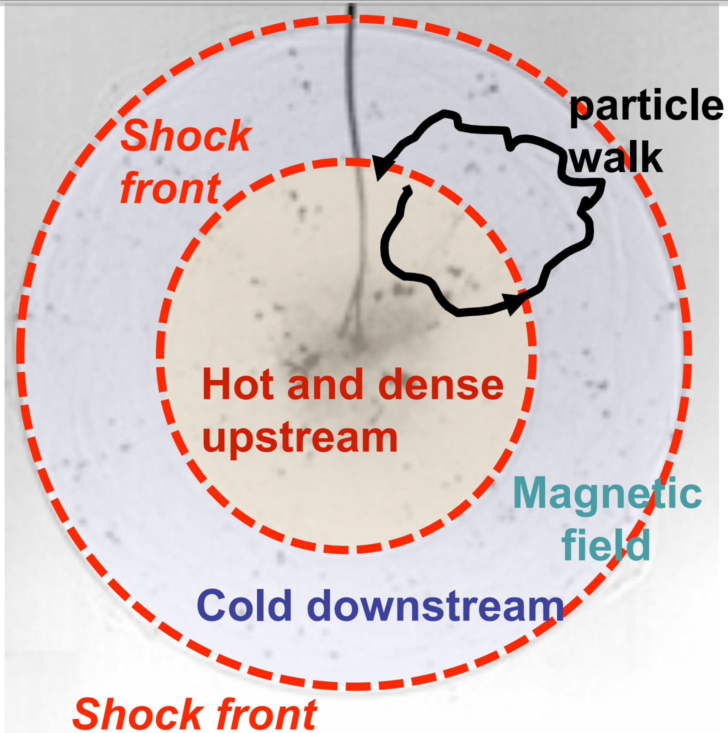
Each time a particle hit on the shock front it gains energy

charged particles are confined by the object magnetic field

maximum energy ∝ number of hits ∝ (confinement) B x R



Shock wave produced by the detonation of a TNT charge



Cosmic sources of HE particles

$$E_{max} \approx \beta_{shock} Z \cdot B[\mu G] \cdot L[kpc] \cdot 10^{18} eV$$

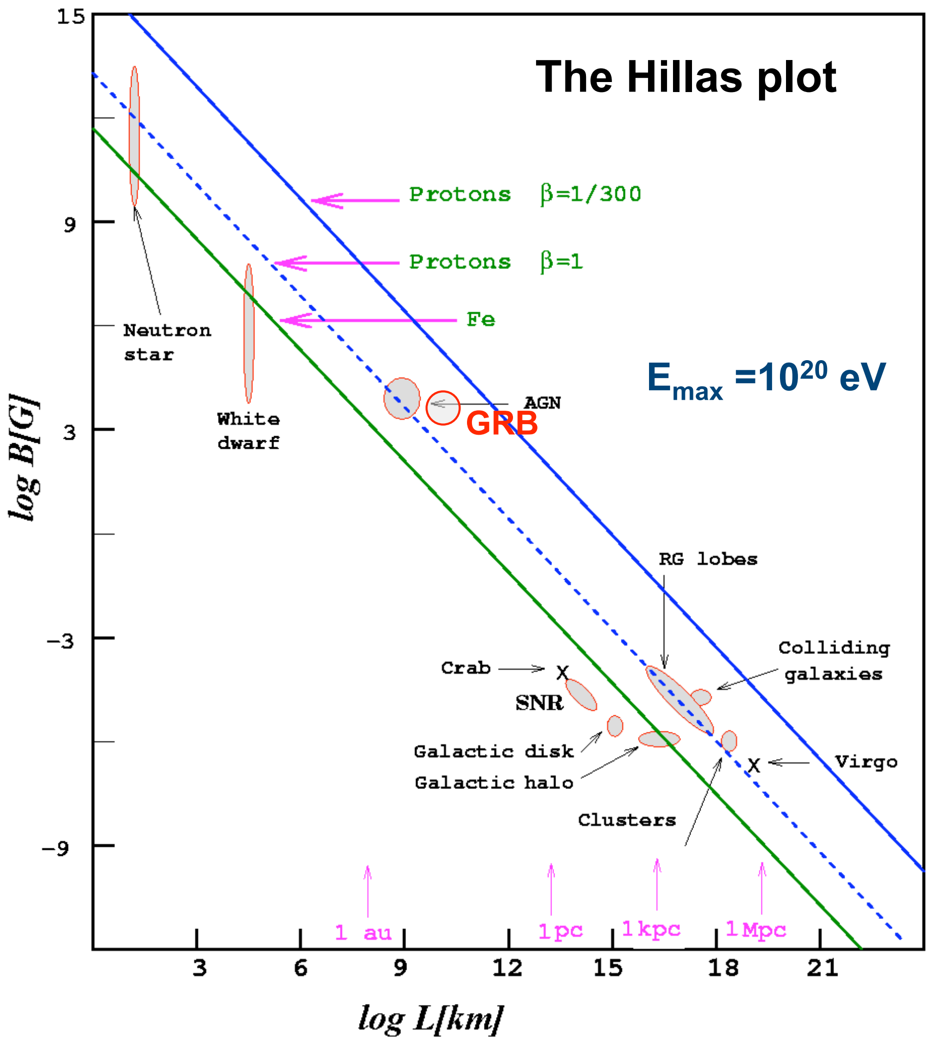
Fermi acceleration to high energies requires

- **Large cosmic objects**
- **Intense magnetic field**
- **High shockwave velocity**

These values are typical for very bright sources

Bright AGN
$L_\gamma \sim 10^{47}$ erg/sec

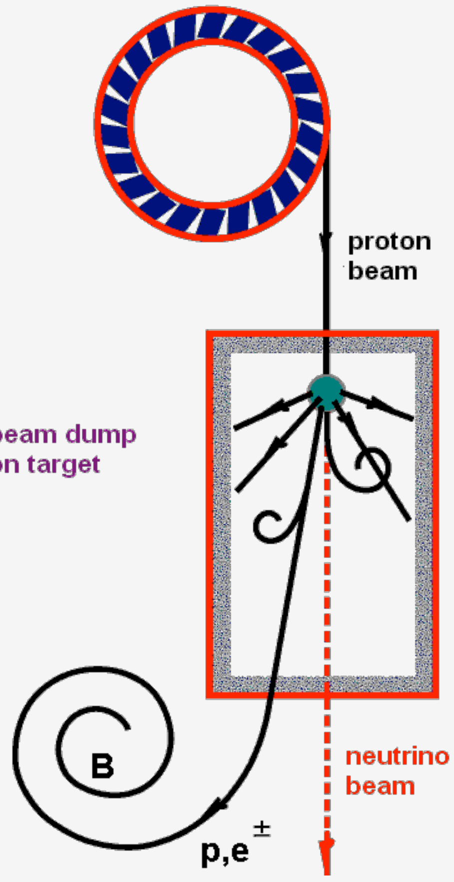
GRB
$L_\gamma \sim 10^{52}$ erg/sec



Cosmic accelerators

Fermi acceleration of protons and electrons in astrophysical sources

Particle accelerator



Spectrum $dN_{p,e}/dE \propto E^{-2}$

Leptonic HE γ production

synchrotron radiation followed by IC

$e + \gamma_{Synchrotron} \rightarrow e' + \gamma'_{HE}$

Hadronic HE ν and γ production

Fermi mechanism

p + p (SNR,X-Ray Binaries)→ X,π

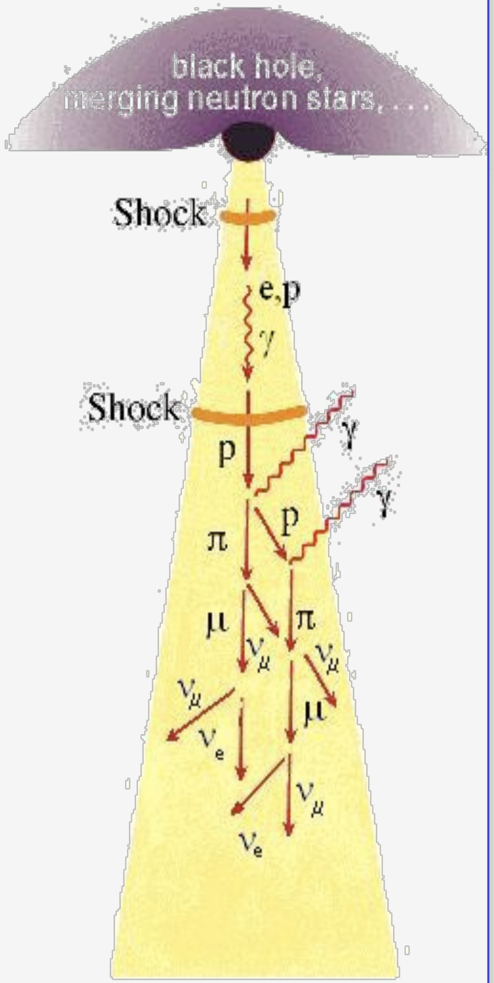
p + γ (AGN, GRB, μQSO) →Nπ

Decay of pions and muons

neutral pions → HE gammas

charged pions → HE ν_μ ν_e

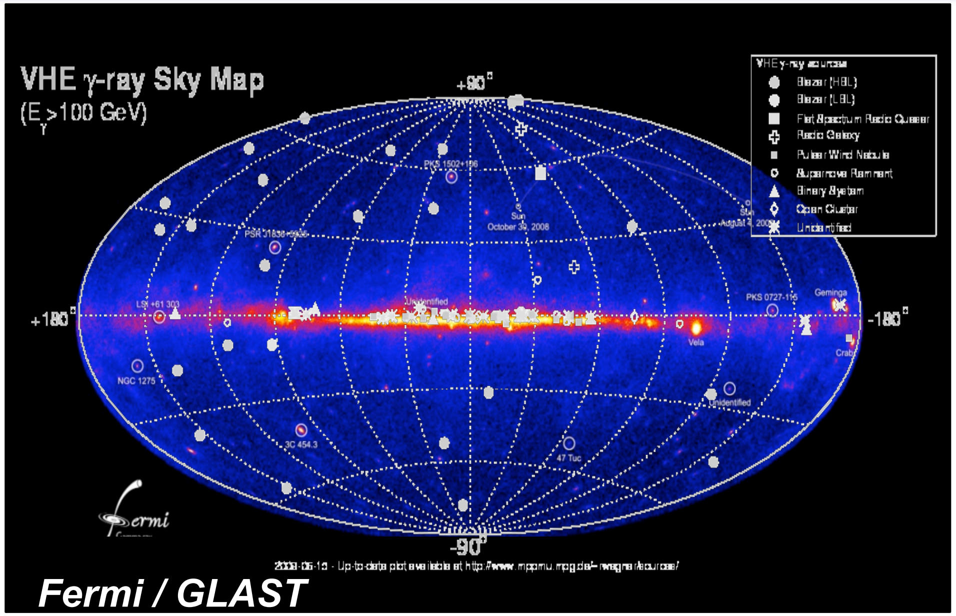
Astrophysical jet



The High Energy gamma-ray sky

The operation of HESS, Magic, Milagro and ARGO-YBJ revealed many Gamma Sources in the Galaxy (54 sources) and in the close Universe (28 extragalactic sources):

- ***The Galactic Centre***
- ***Galactic SNR (Supernova Remnants), PWN (Pulsar Wind Nebulas), microQuasars***
- ***Close AGN (Active Galactic Nuclei)***
- ***"Unidentified" sources (no low energy counterpart)***
- ***Leptonic processeses: synchrotron emission followed by Inverse Compton scattering***
- ***Hadronic processes***

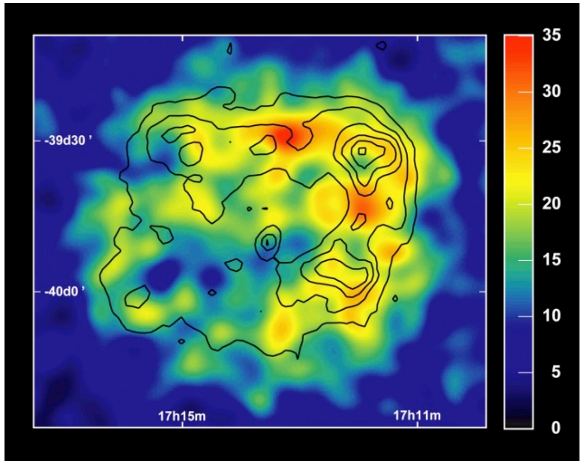


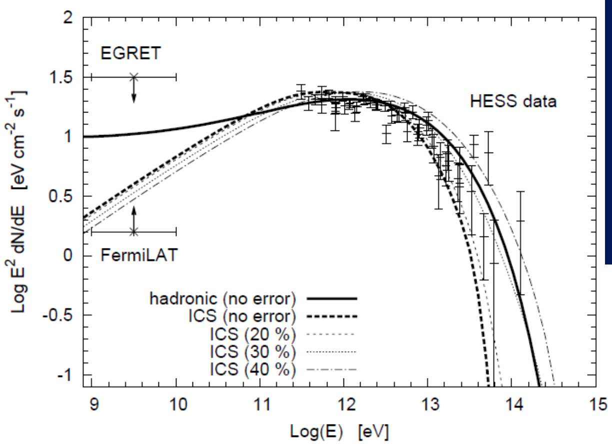
Disentangling between processes based on gamma ray spectrum and combined multi-wavelength observation… Waiting for HE neutrino detectors

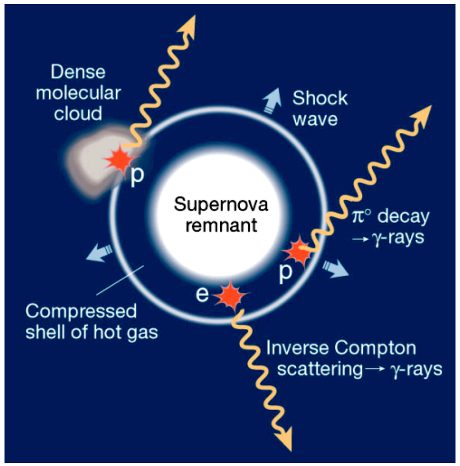
First adronic gamma-ray sources?

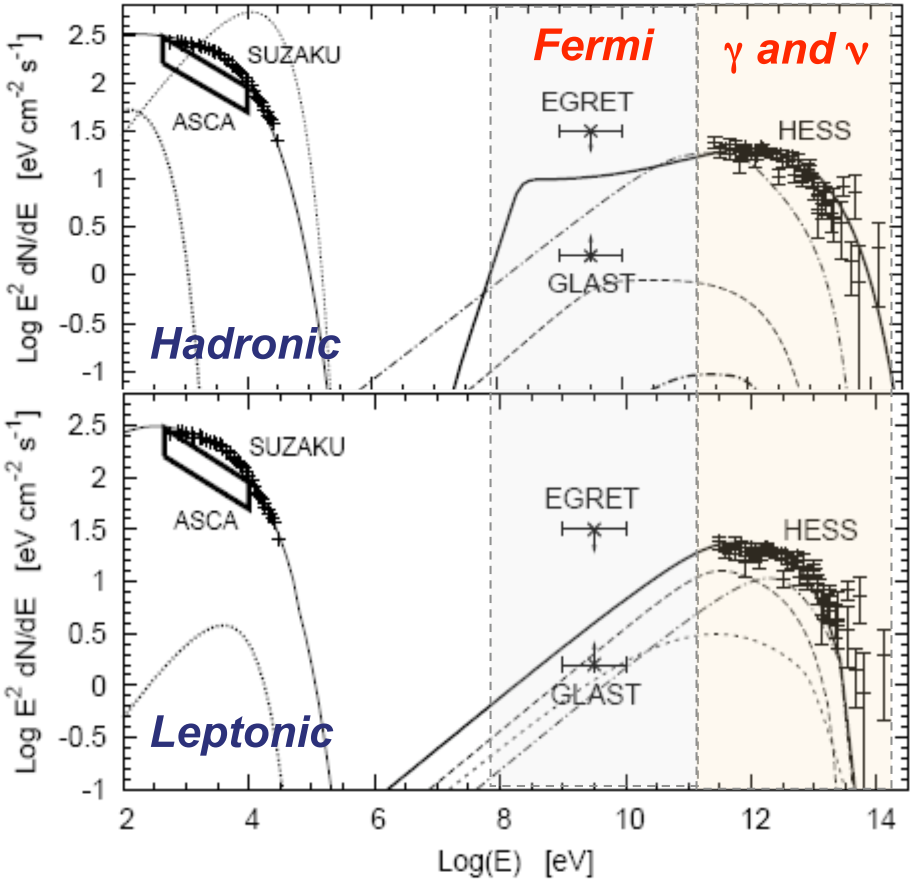
The Galactic SNR RXJ1713.7-3946:
proton acceleration + beam dump on nearby molecular clouds

- ***Power law spectrum $E^{-\gamma}$ observed up to 30 TeV***
- ***Spectral index $\gamma \approx 2$ implies acceleration of primaries up to 1000 TeV***
- ***Spectrum hardly explainable with IC mechanisms***









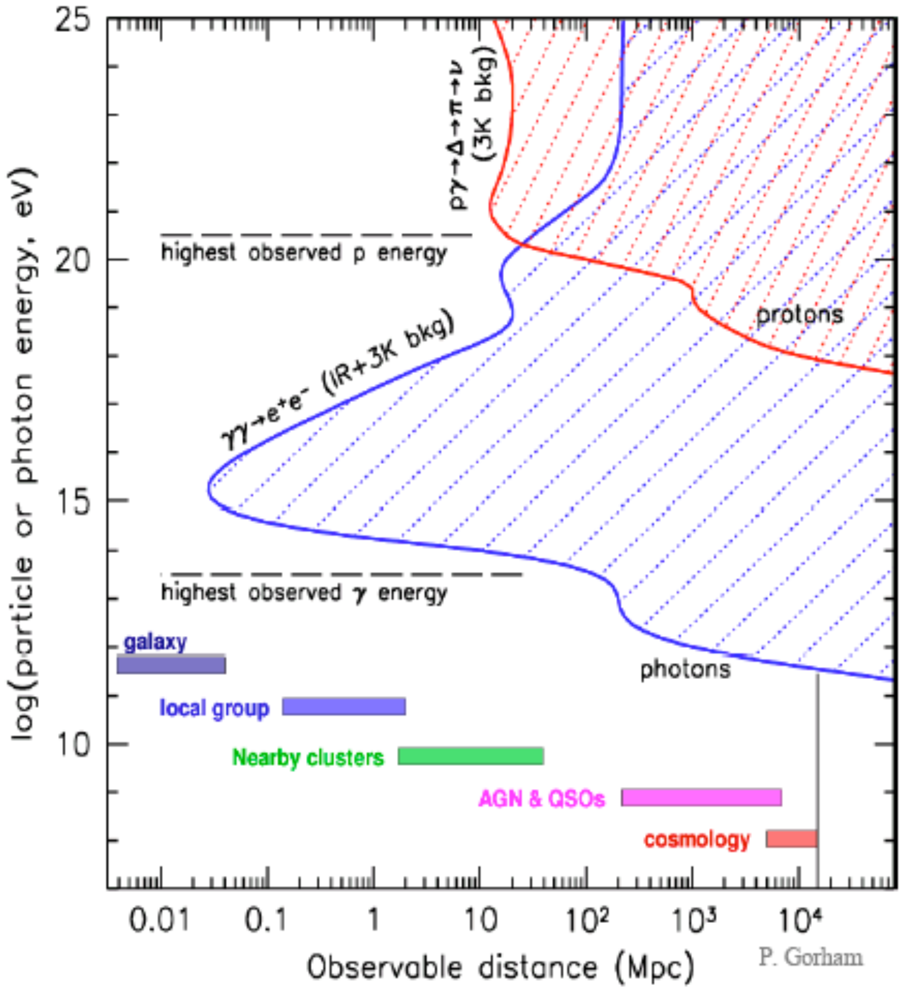
Neutrinos are the ultimate smoking gun for hadronic processes

The Universe is opaque to high energy gamma-rays and protons

$\gamma + \gamma_{CMB} \rightarrow e^+ + e^-$

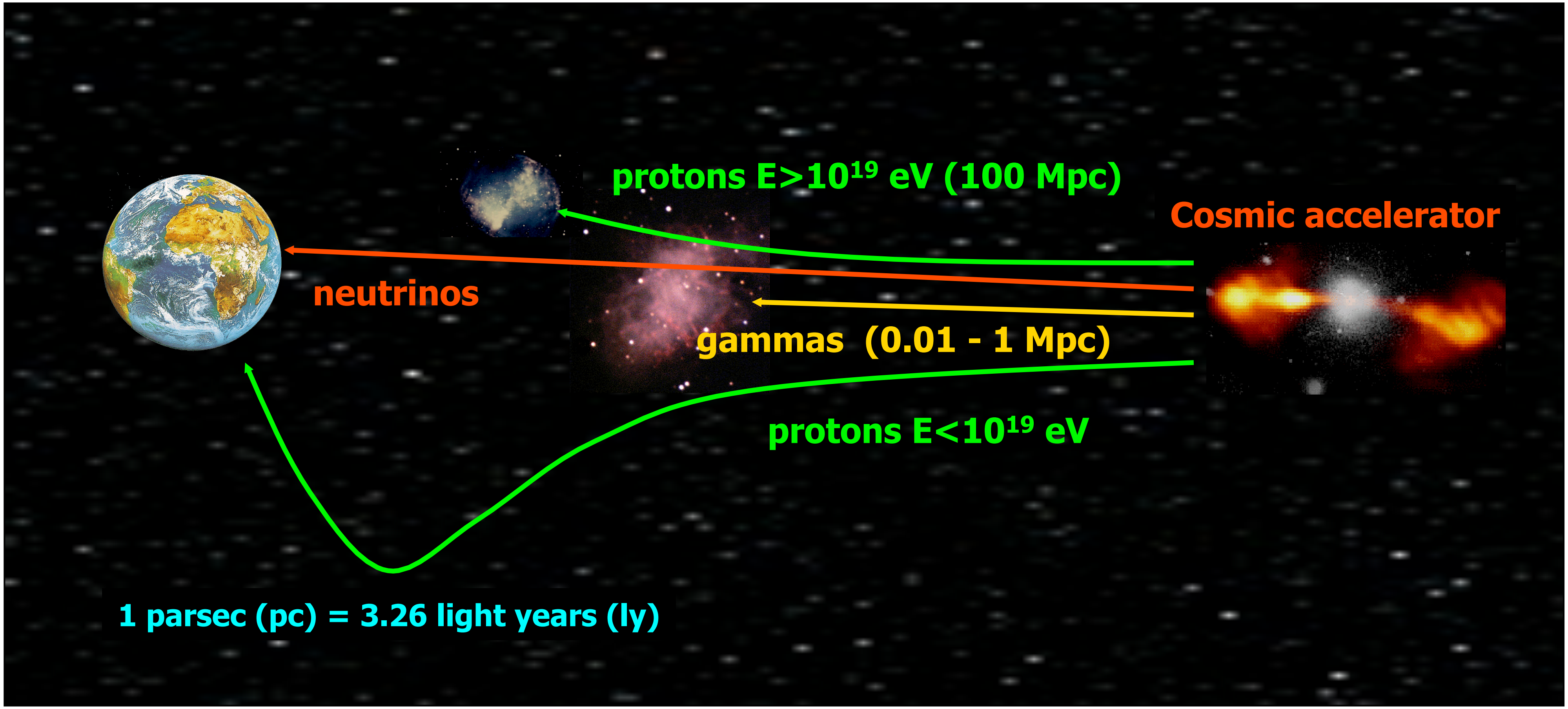
$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+ \rightarrow \mu^+ + \nu_\mu$

GZK effect



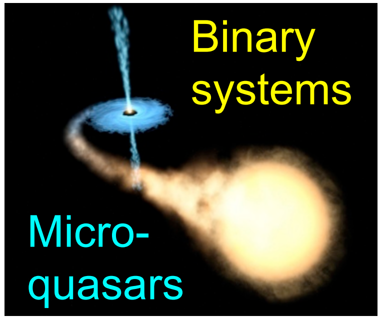
Protons with E < 10^{19} eV are deflected by magnetic field

At high energy only neutrinos can allow to observe the most distant sources



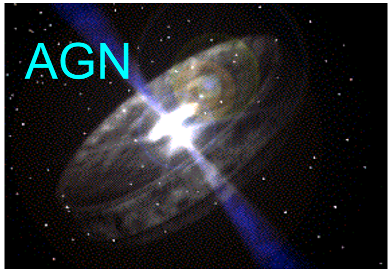
Photons: absorbed on dust and radiation;
Protons/nuclei: deviated by magnetic fields, reactions with radiation (CMB)

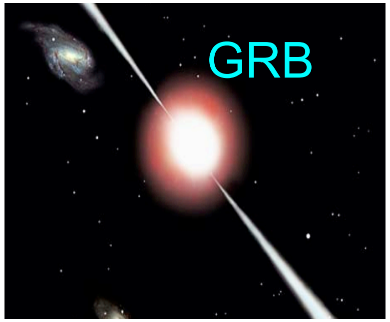
Potential Galactic sources



- The accelerators of cosmic rays
  - Supernova remnants
  - Pulsar wind nebulae
  - Micro-quasars
  - …
- Interaction of cosmic rays with interstellar matter
  - Possibly strong ν signal if CR spectrum harder in Galactic Centre than on Earth (supported by recent MILAGRO results)
- Unknown sources – what are the H.E.S.S. ”TeV gamma only” objects?

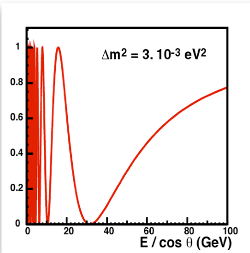
Potential extragalactic sources

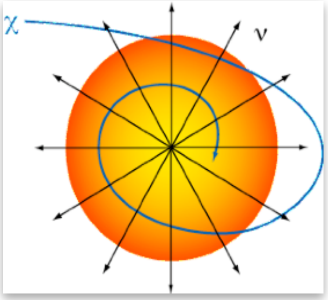


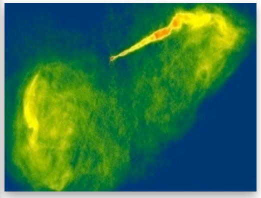


- AGNs
  - Models are rather diverse and uncertain
  - The recent Auger results may provide an upper limit / a normalisation point a UHE
  - Note : At some 100 TeV the neutrino telescope field of view is restricted downwards (ν absorption), but starts to be significant upwards.
- Gamma ray bursts
  - Unique signature: Coincidence with gamma observation in time and direction
  - Source stacking possible

Supernova neutrinos | Neutrino oscillations | Dark Matter searches | Astrophysical sources







~MeV | **GeV – 100 GeV** | **GeV - TeV** | **TeV - PeV** | **PeV - EeV** | **> EeV**

Candidate sources and events expected

$$\frac{N_\mu(E_{\mu,min},\vartheta)}{AT} = \int_{E_{\mu,min}}^{E_\nu} dE_\nu \, \Phi_\nu(E_\nu,\vartheta) \cdot P_{\nu\mu}(E_\nu,E_{\mu,min}) \cdot e^{-\sigma_{tot}(E_\nu) N_A Z(\vartheta)}$$

Neutrino flux	Probability to produce a detectable muon ($E_\mu > E_{min}$)	Earth transparency

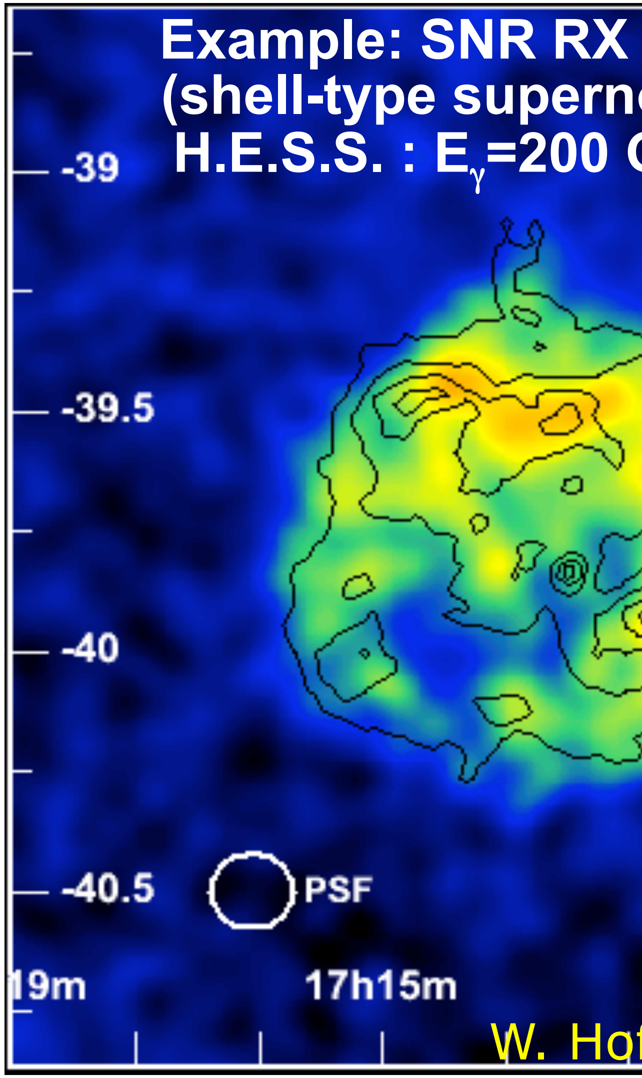
Diffuse fluxes

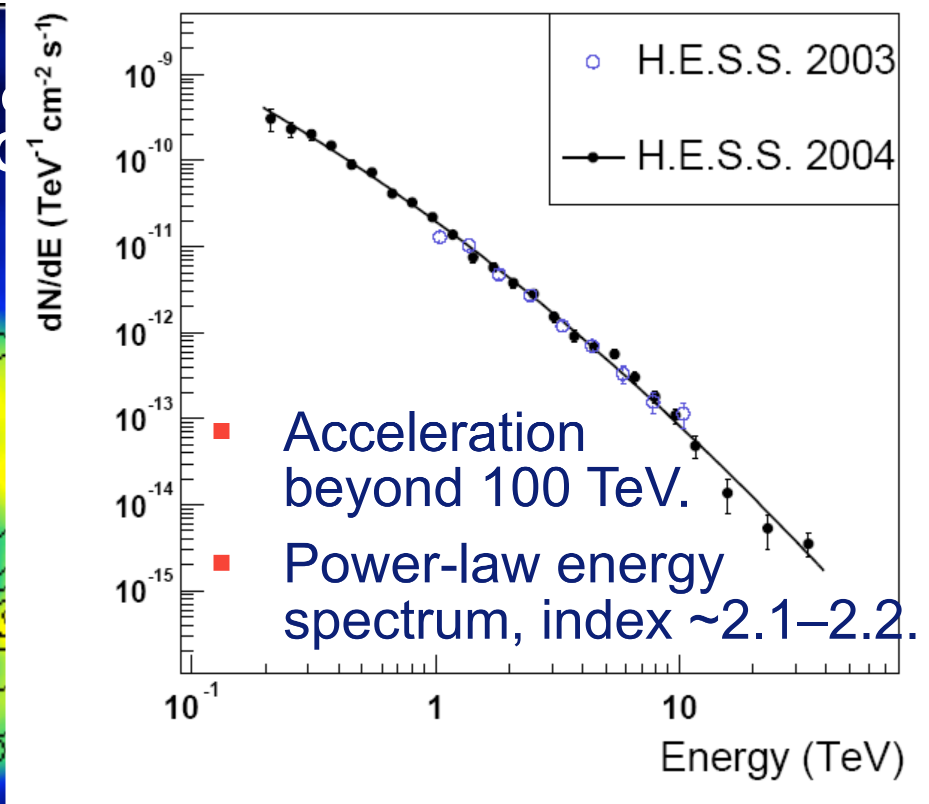
Neutrini da GZK	0.5 / year
GRB *(Waxman)*	50 / year
AGN (thin) *(Mannheim)*	few / year
(thick)	>10 / year ?

Point-like sorces

GRB (030329) *(Waxman)*	1-10 / burst
AGN (3C279) *(Dermer)*	few / year
Galactic SNR *(Vissani)*	few / year
Galactic MicroQuasar *(Distefano)*	1-10 / year

Expected events in a 1 km^2 detector



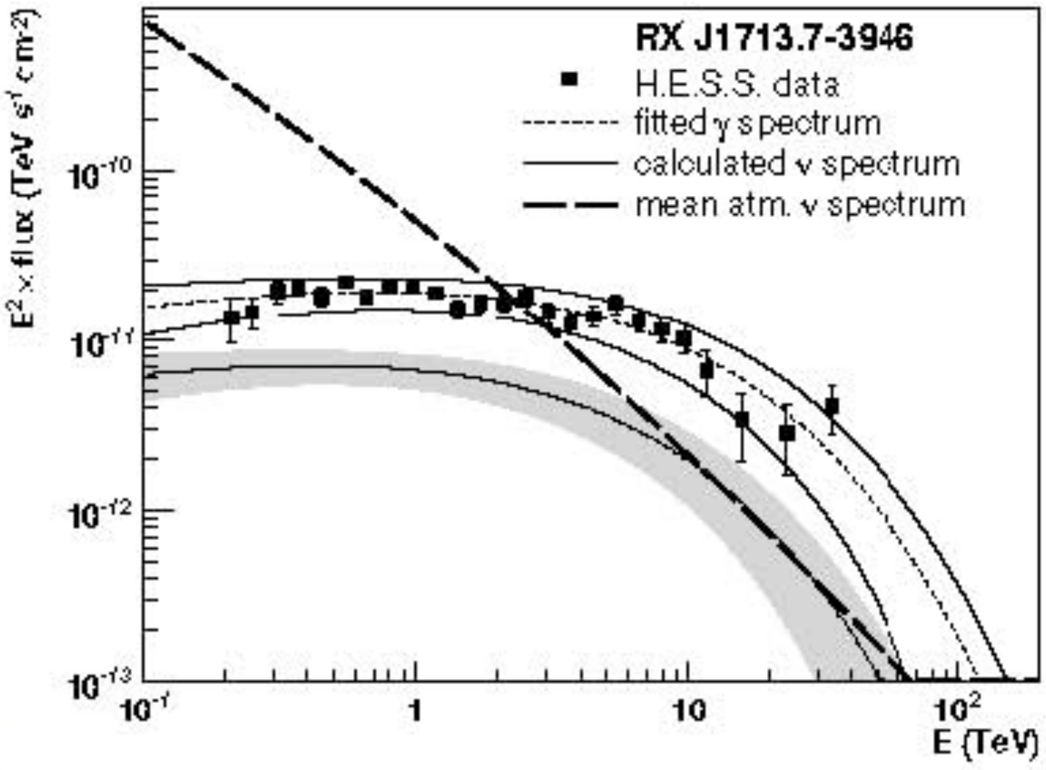


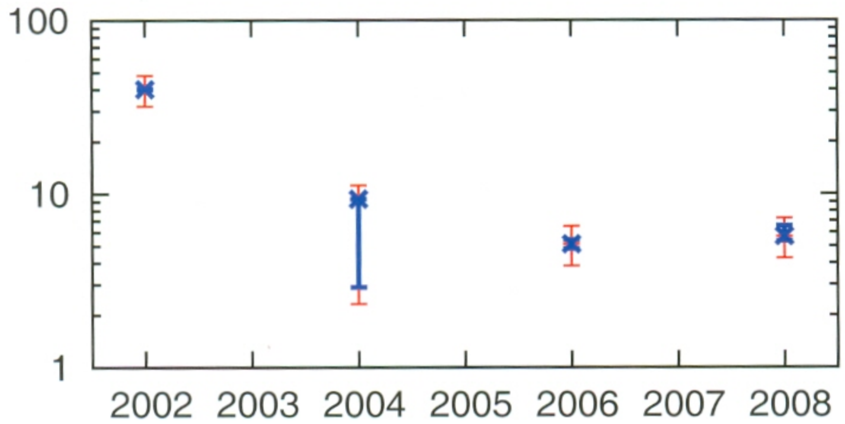
- Acceleration beyond 100 TeV.
- Power-law energy spectrum, index ~2.1–2.2.

- Spectrum points to hadron acceleration → ν flux ~ γ flux
- Typical ν energies: few TeV

- Good candidate
  for hadronic acceleration.
- Expected signal
  well related to measured γ flux,
  but depends on energy cutoff.
- Few events/year
  over similar background (1km^2).

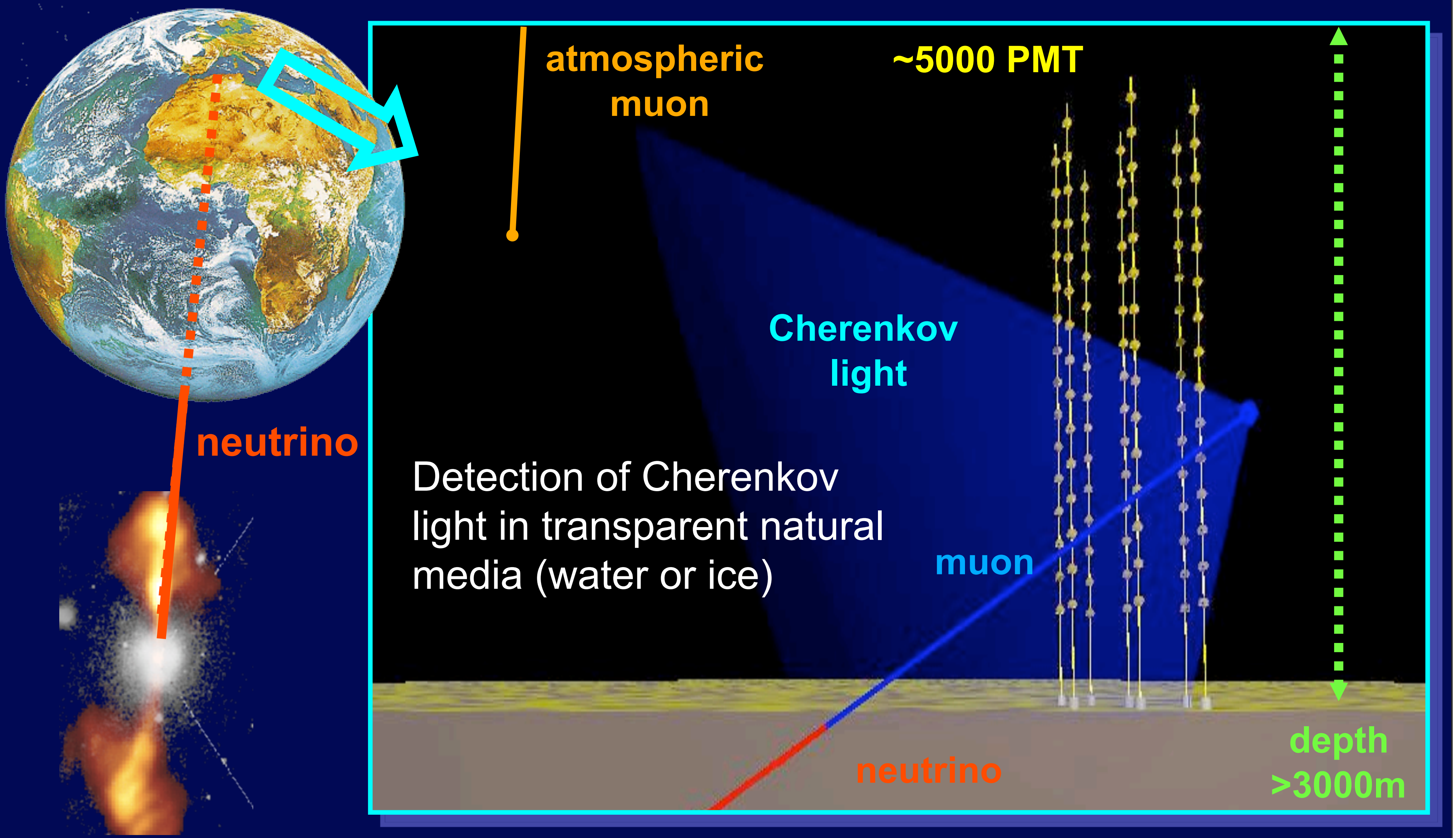
A. Kappes et al., 2007



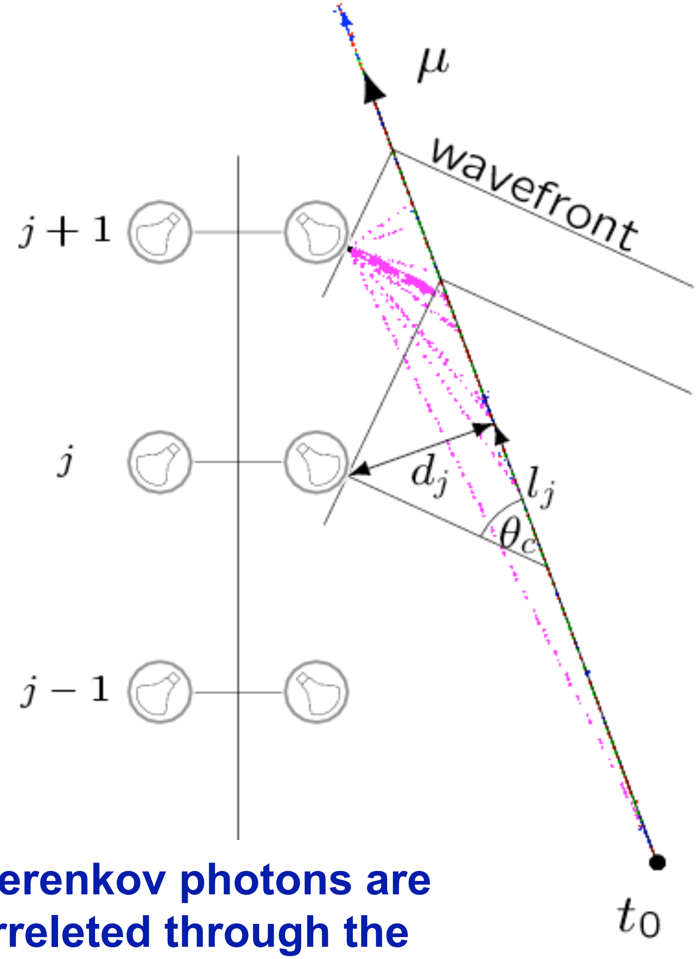


Predictions of neutrino fluxes have stabilized to a value of few per year per km^2
(F. Vissani et al., 2009)

High energy neutrino detection principle

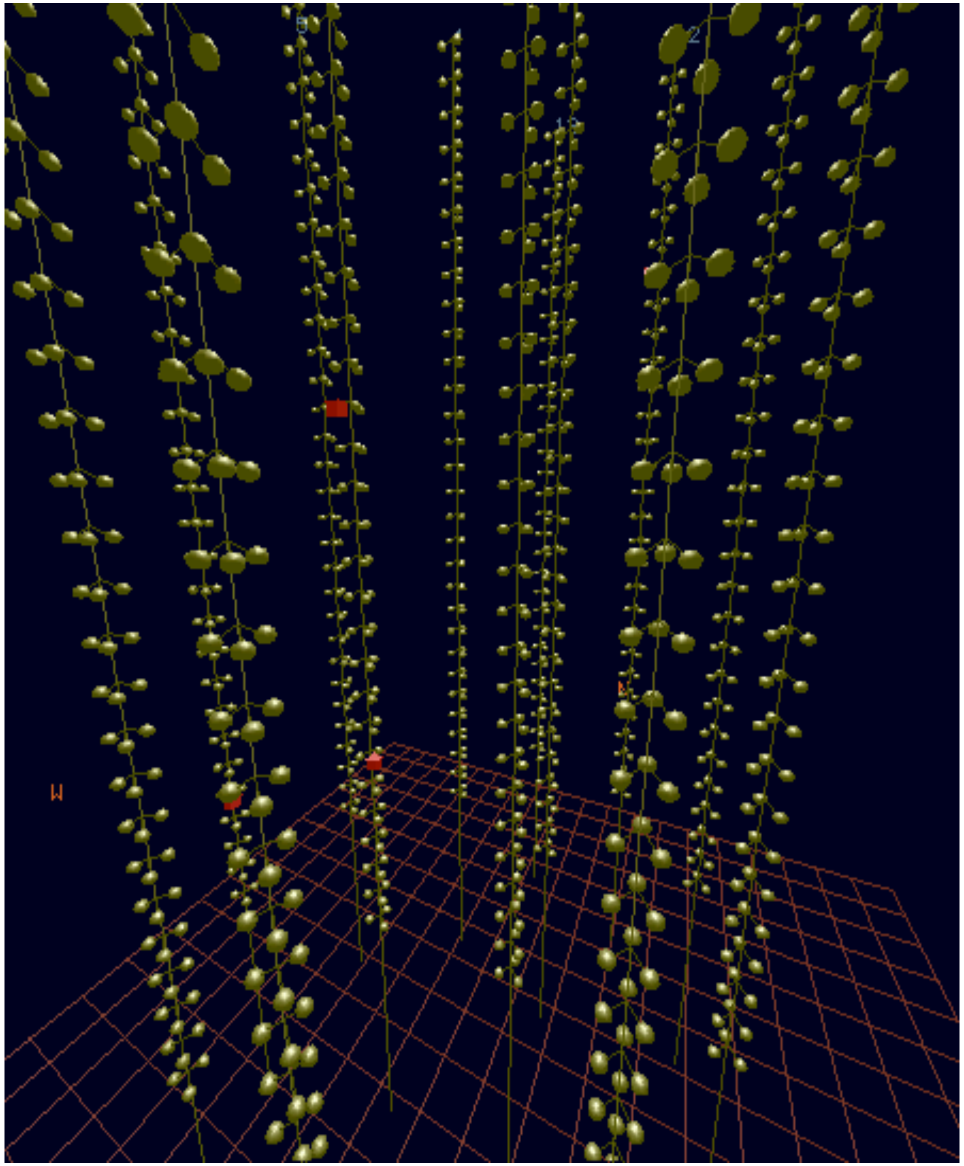


Detection technique



Cherenkov photons are correleted through the causality relation:

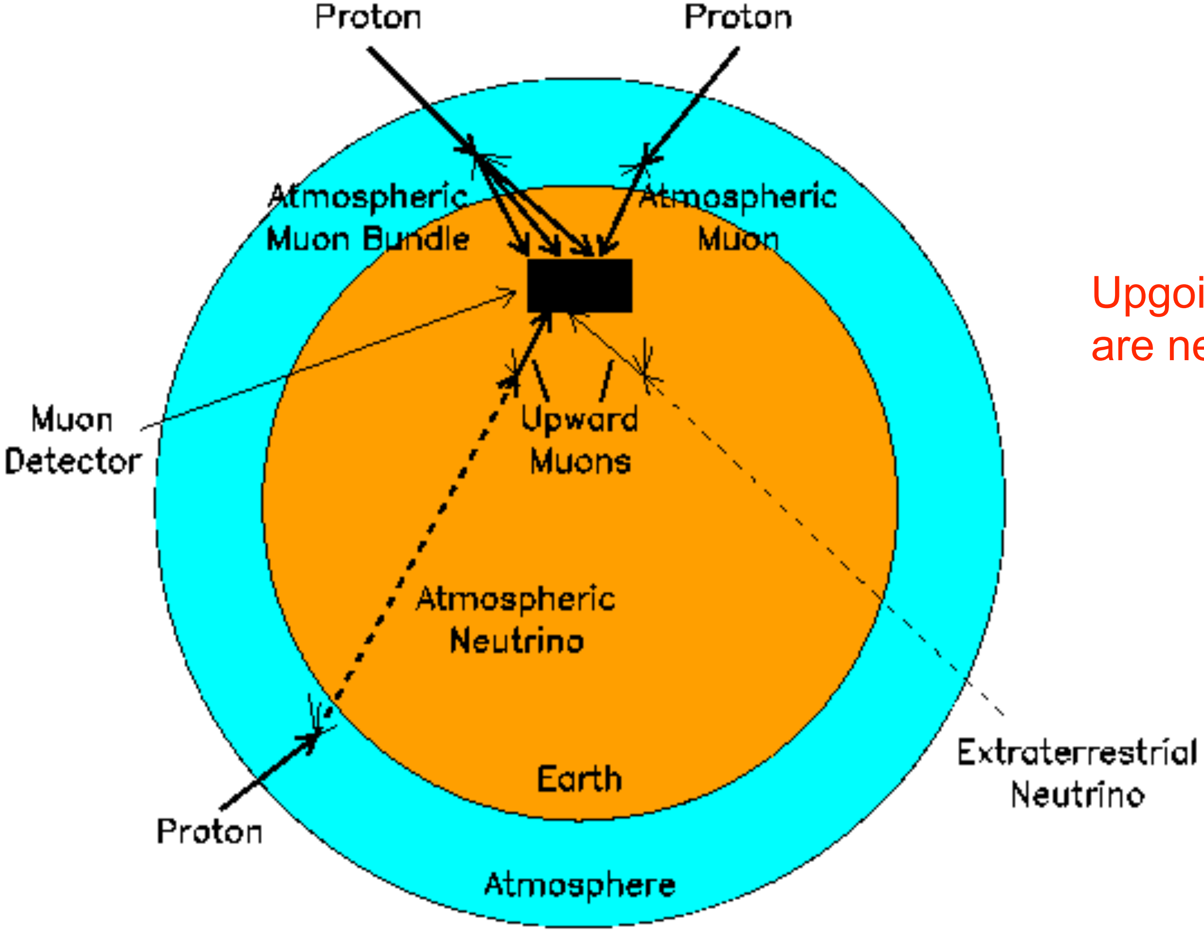
$$c(t_j - t_0) = l_j + d_j \, ctg(\vartheta_c)$$



The km3 telescope: a downward looking detector

Neutrino telescopes search for muon tracks induced by neutrino interactions

The downgoing atmospheric μ flux overcomes by several orders of magnitude the expected μ fluxes induced by ν interactions.



Upgoing and horizontal muon tracks are neutrino signatures

The international context

BAIKAL, AMANDA, ANTARES: data taking

NESTOR, NEMO: R&D

ICECUBE: construction, completion in 2011

KM3NeT in the Mediterranean Sea

The IceCube detector at the South Pole

Adapted from A.Karle, 2009

Completion January 2011:

86 strings (60 PMT each)

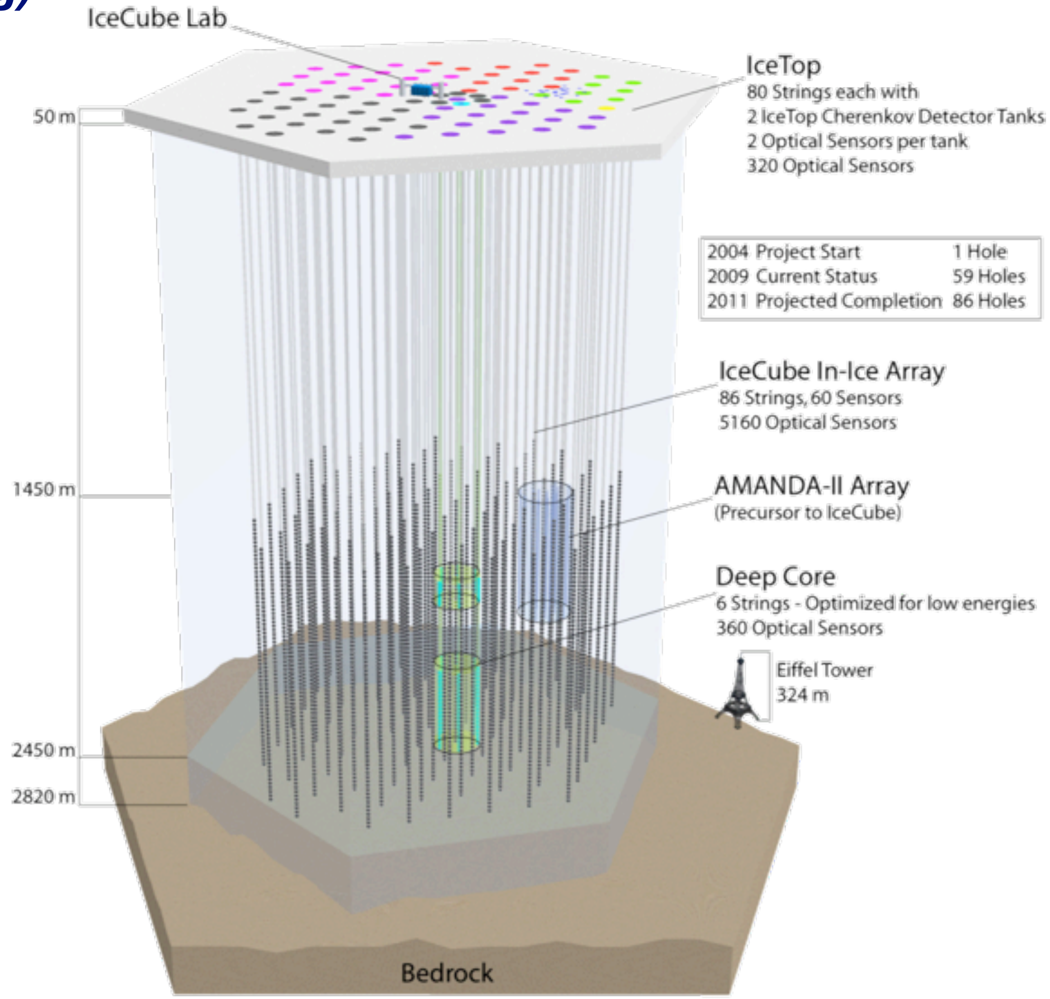
4800 10" PMT (only downward looking)

125 m inter string distance

16 m spacing along a string

Instrumented volume: 1 km^3 (1 Gton)

180 surface tanks for IceTop



Present Status

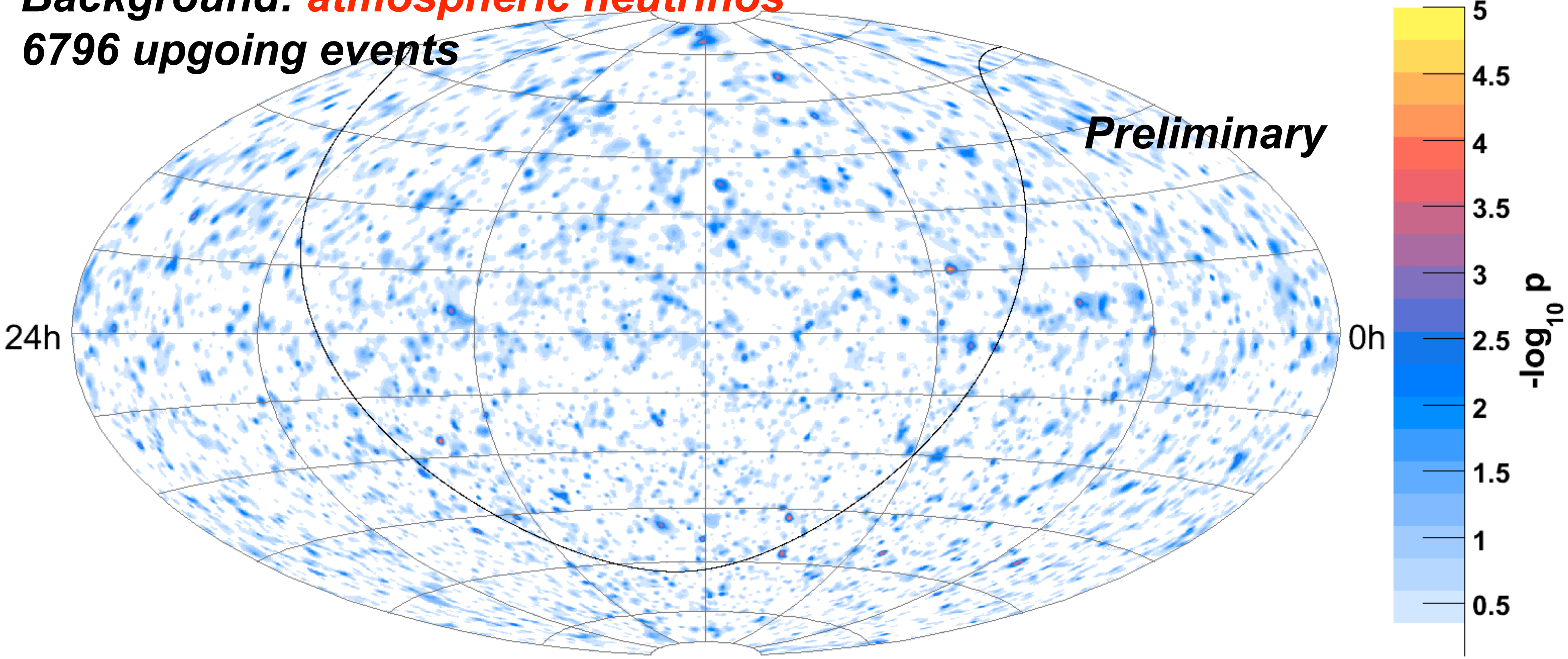
- ***59 strings***
- ***118 IceTop tanks***

The Detector is taking data during the construction phase.

Search for point sources: IceCube

Northern hemisphere
Background: atmospheric neutrinos
6796 upgoing events

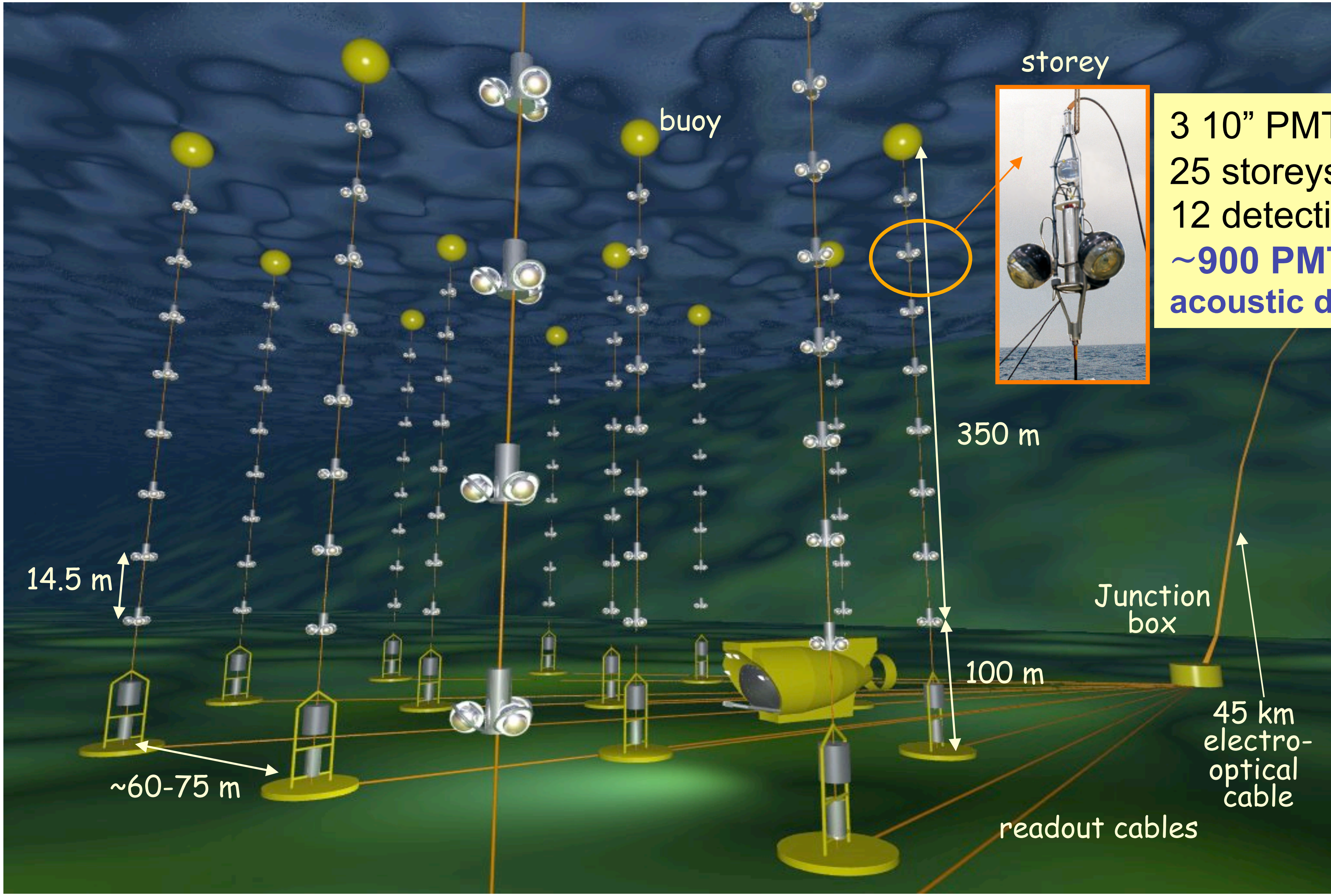
Adapted from A.Karle, 2009



Southern hemisphere
Background: atmospheric muons
Reduced by 10^{-5} using energy cut
10981 downgoing (high energy) muon events

175.5 days livetime,
17777 events:
6796 up-going,
10981 down-going

ANTARES: the first undersea neutrino telescope



3 10” PMT/storey
25 storeys/line
12 detection lines:
~900 PMT + acoustic detection

See A. Margiotta talk for a full report on Antares

NEMO

- R&D activity towards the km^3 started in 1998
- Search and characterization of an optimal deep-sea site
- Feasibility study and definition of a preliminary project of the km^3
- Development of innovative technological solutions for the km^3
  - Detector architecture
  - Deployment techniques
  - Power distribution
  - Data readout and transmission
- Advanced R&D activities to validate the proposed technologies

The NEMO collaboration

INFN

Bari, Bologna, Catania, Genova, LNF, LNS, Napoli, Pisa, Roma

Università

Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma *“La Sapienza”*

CNR

Istituto di Oceanografia Fisica, La Spezia
Istituto di Biologia del Mare, Venezia
Istituto Sperimentale Talassografico, Messina

Istituto Nazionale di Geofisica e Vulcanologia (INGV)

Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS)

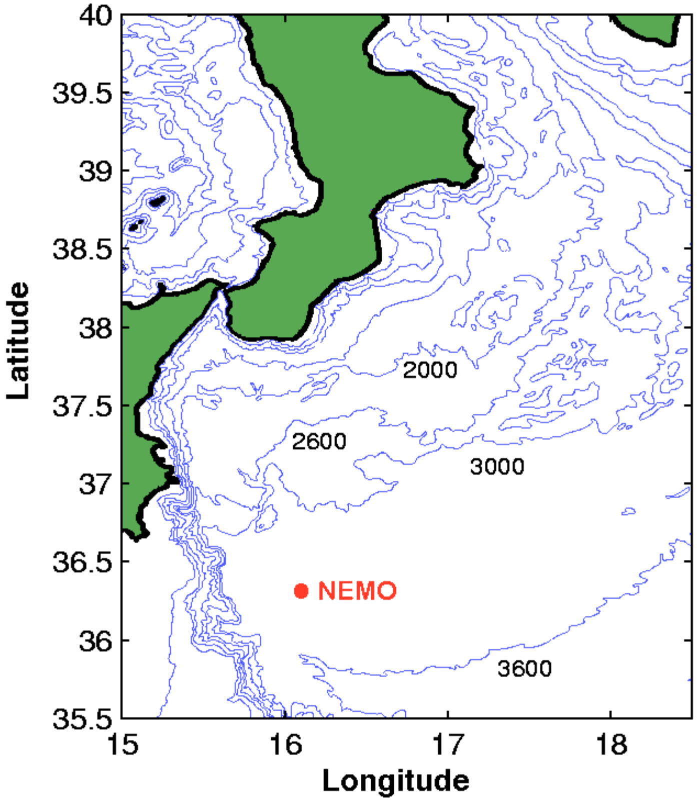
Istituto Superiore delle Comunicazioni e delle Tecnologie dell’Informazione (ISCTI)

More than 80 researchers from INFN and other italian institutes

The Capo Passero site

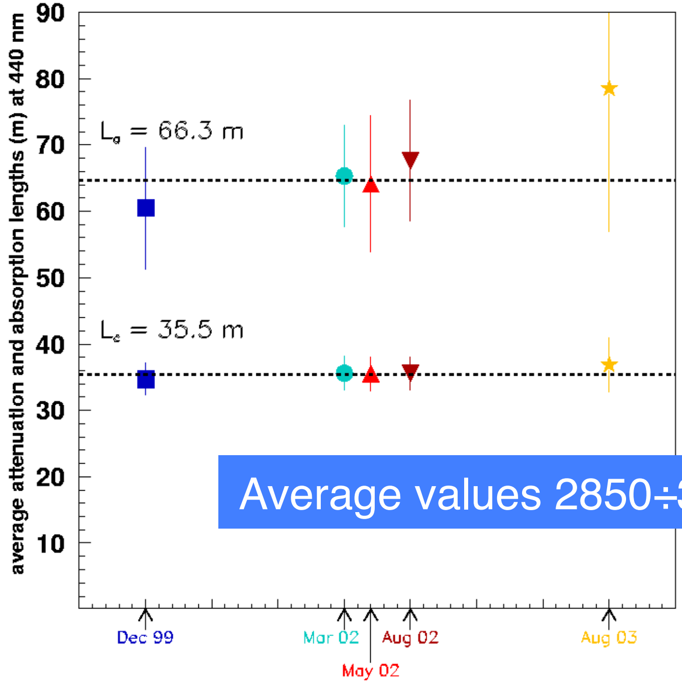
The site has been proposed in january 2003 to ApPEC as a candidate for the km3 intallation

- Depths of more than 3500 m are reached at about 100 km distance from the shore
- Water optical properties are the best observed in the studied sites ($L_a \approx 70$ m @ $\lambda = 440$ nm)
- Optical backgroung from bioluminescence is extremely low
- Stable water characteristics
- Deep sea water currents are low and stable (3 cm/s avg., 10 cm/s peak)
- Wide abyssal plain, far from the shelf break, allows for possible reconfigurations of the detector layout

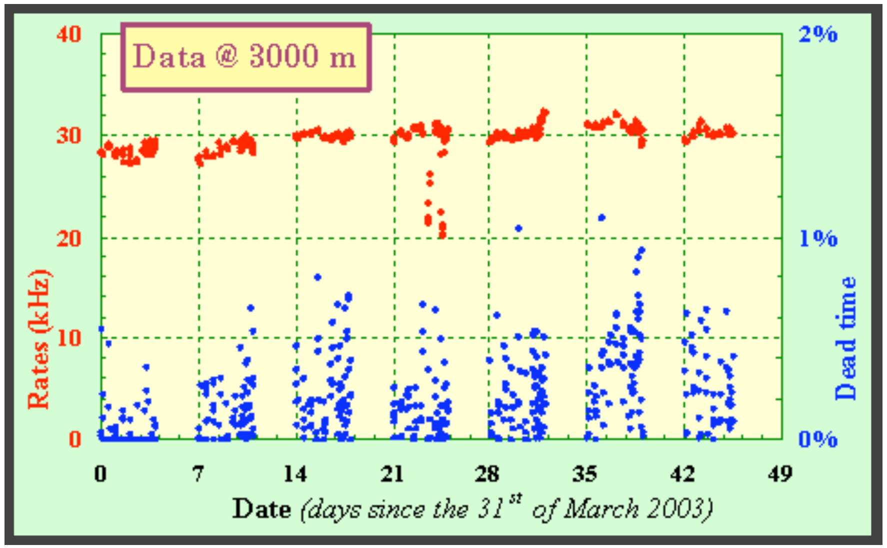


Seasonal dependence of optical properties

Absorption and attenuation lengths (for λ=440 nm)



Optical background



Data taken in collaboration with ANTARES

- PMT: 10"
- Thres: ~.5 SPE

Dead time:

Fraction of time with rate > 200 kHz

Absorption lenght values are compatible with optically pure sea water

The measured value of 30 kHz is compatible with pure ^{40}K background

No seasonal dependence observed

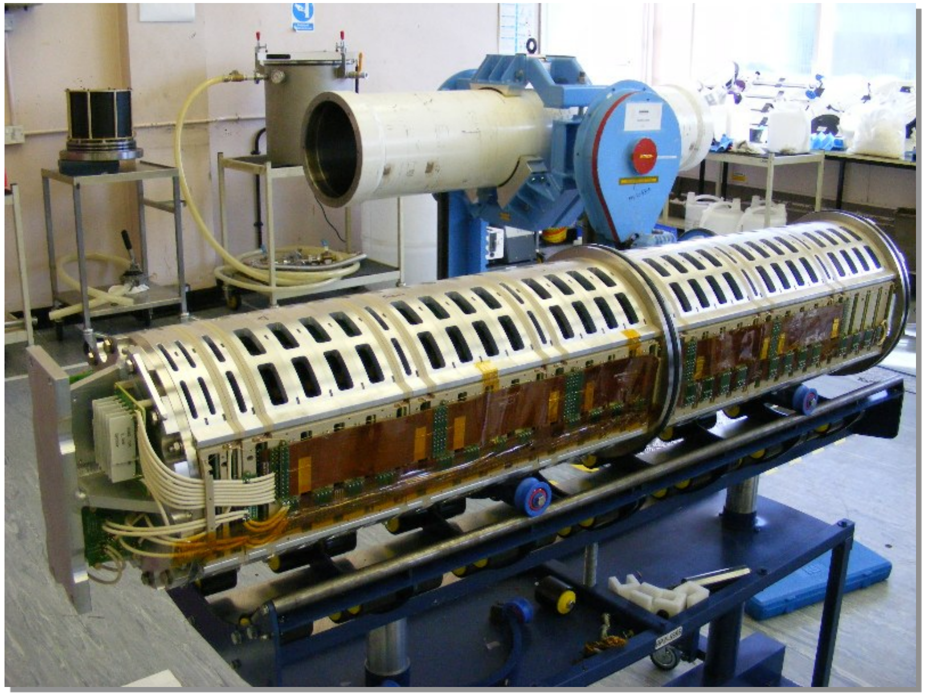
Infrastructures on the Capo Passero site

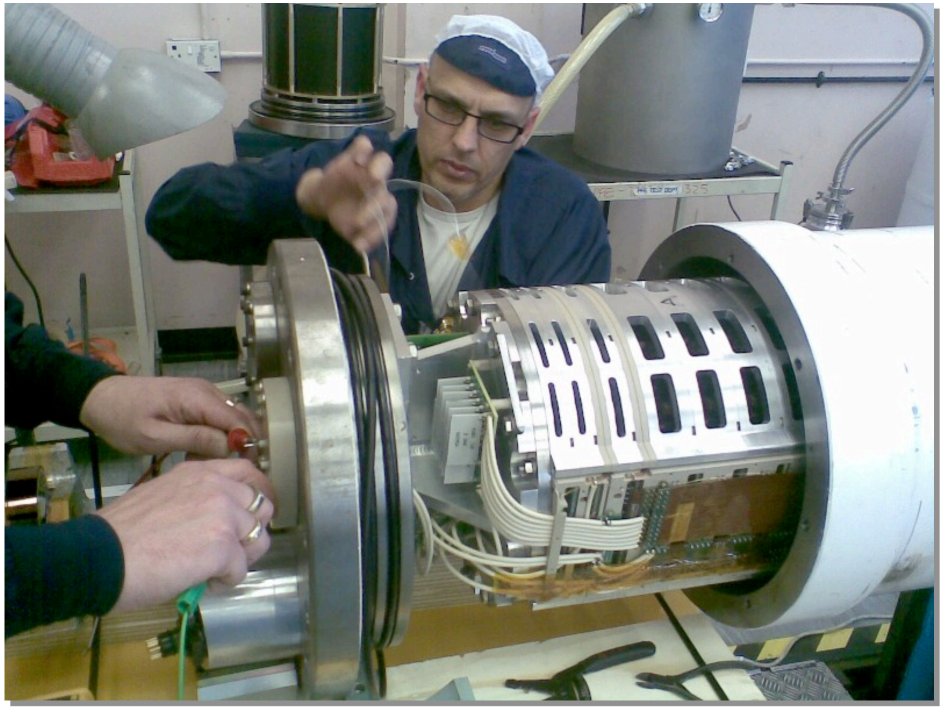
- 100 km electro-optical cable (>50 kW, 20 fibres) deployed in July 2007
- Innovative DC/DC power system esigned and built by Alcatel tested and working; installation in october 2009
- On-shore laboratory (1000 m^2) inside the harbour area of Portopalo completed

The Alcatel DC/DC system

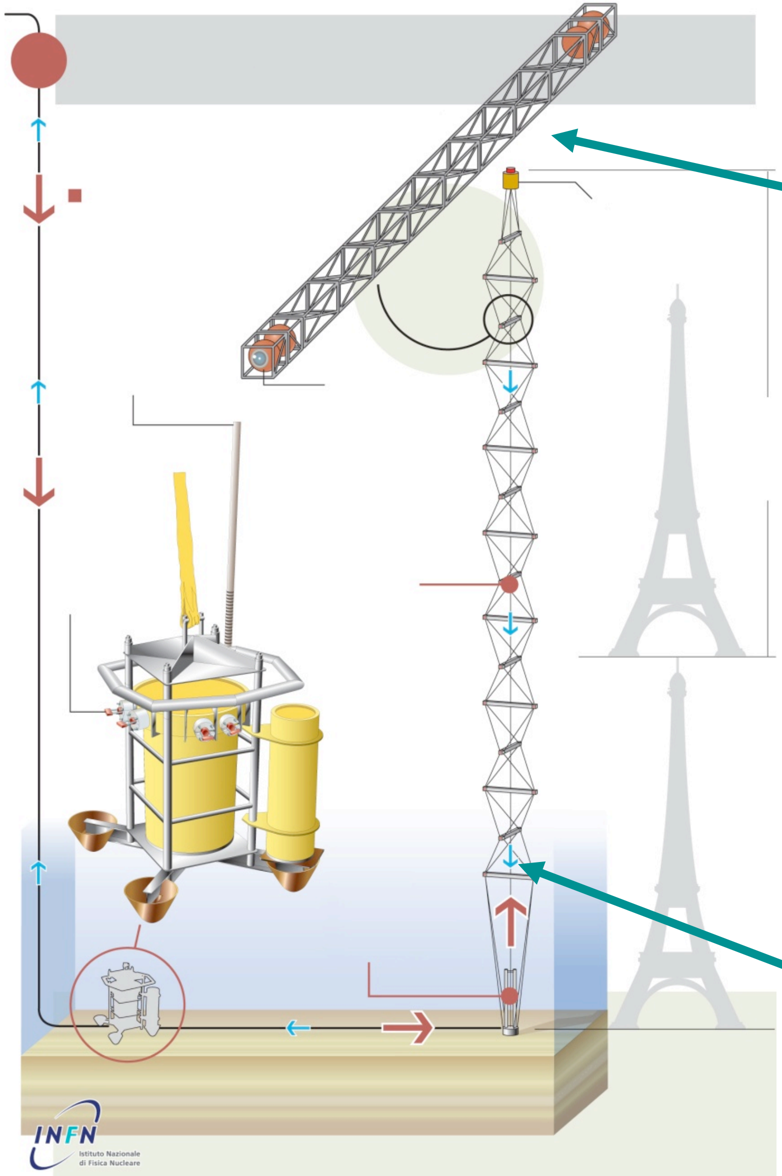
System based on an innovative 10 kW DC/DC converter specifically designed by Alcatel for deep-sea applications

Tested in laboratory at full load in realistic conditions and ready for installation



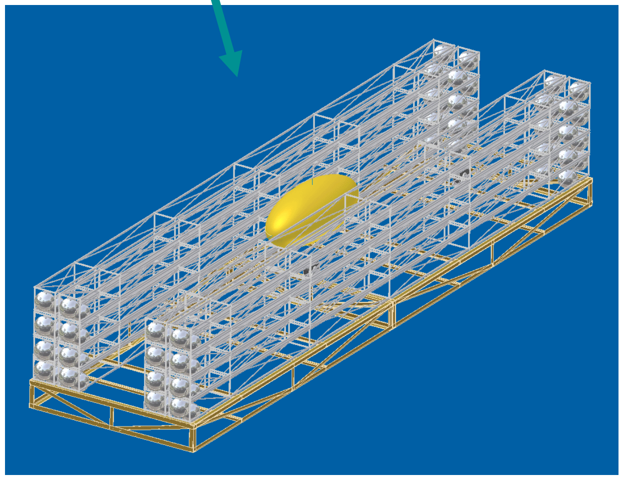


km3 architecture: the NEMO proposal



Vertical sequence of "storeys"

Structure packable for integration and deployment

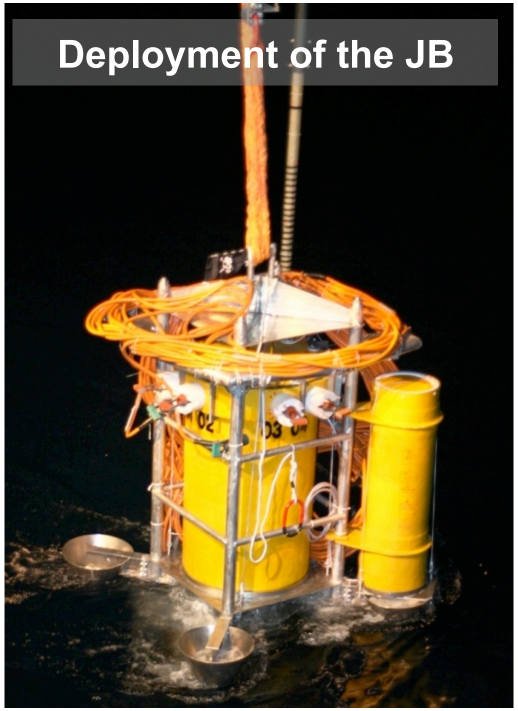


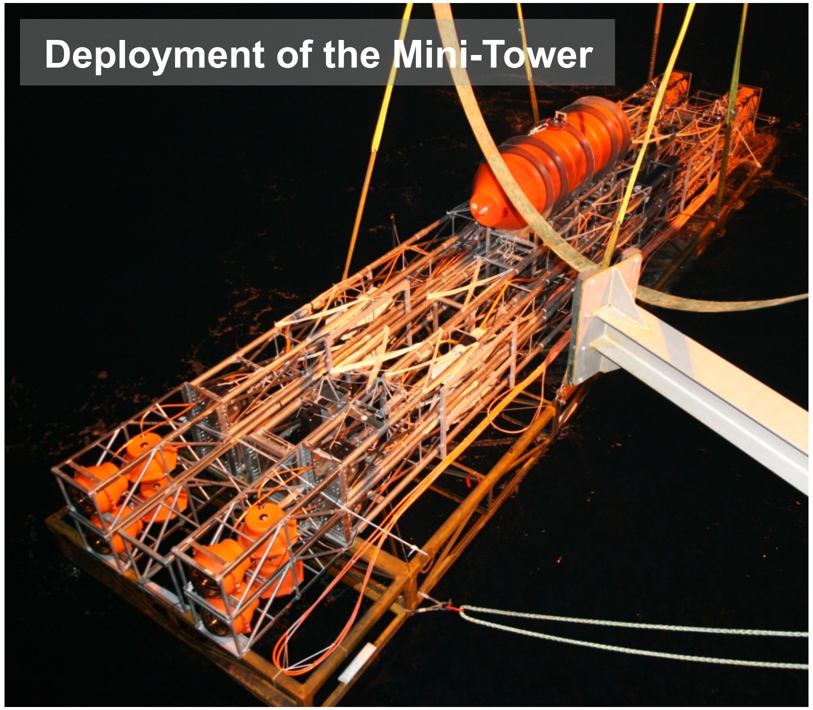
Detector based on tower-like structures with horizontal extent

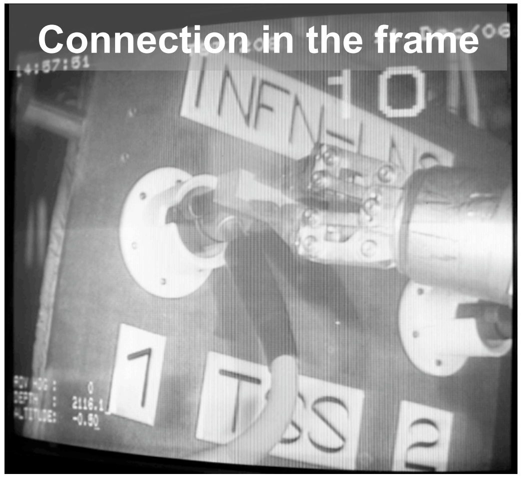
Non homogenus distribution of sensors

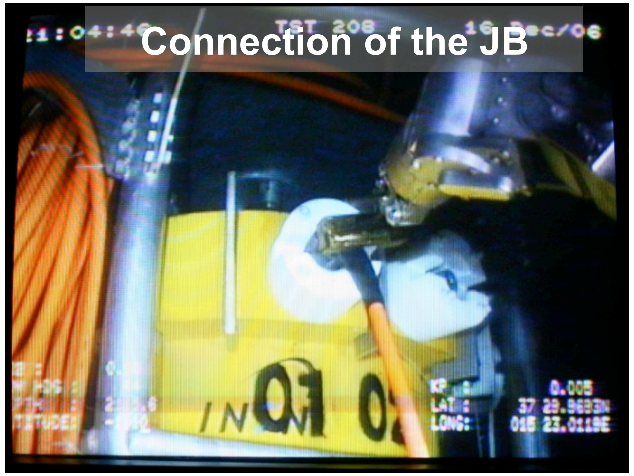
Technologies tested in NEMO Phase-1

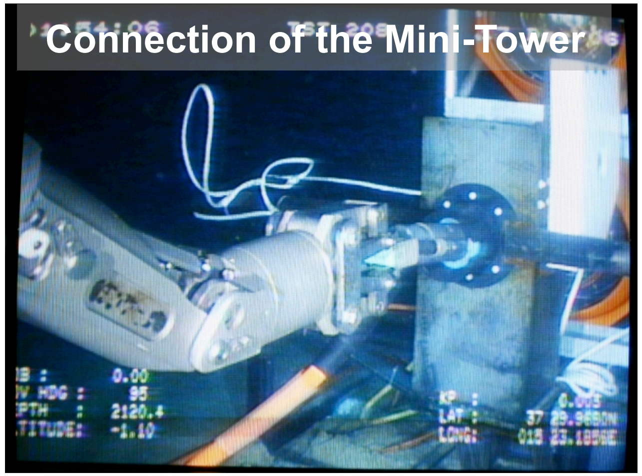
Phase-1 installed in december 2006 at the Catania Test Site (2000 m depth)


Deployment of the JB

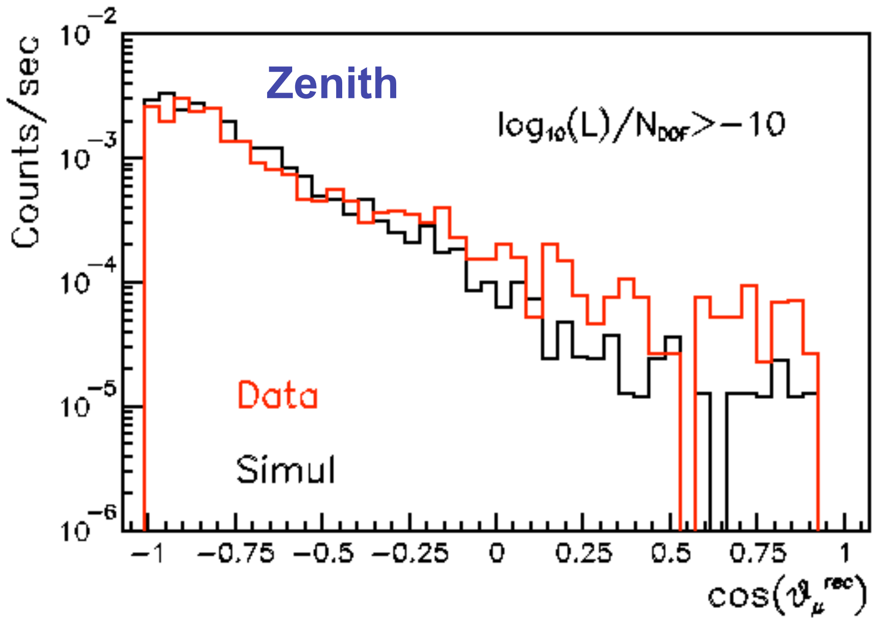

Deployment of the Mini-Tower

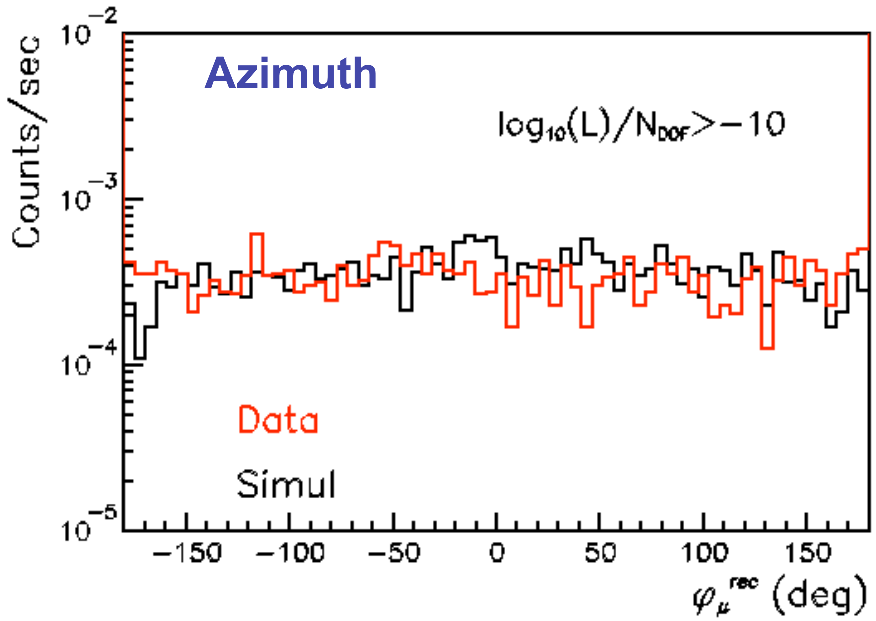

Connection in the frame

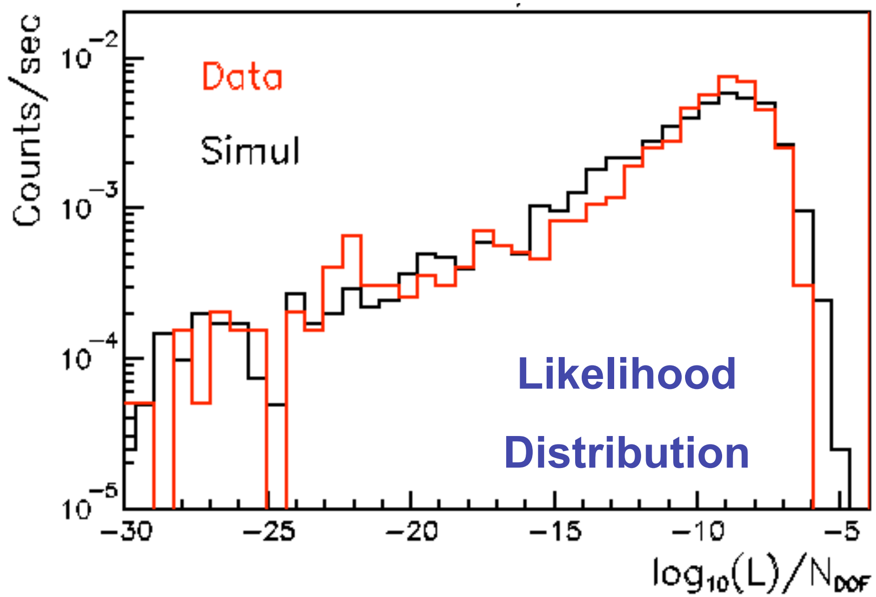

Connection of the JB


Connection of the Mini-Tower

Atmospheric muon angular distribution



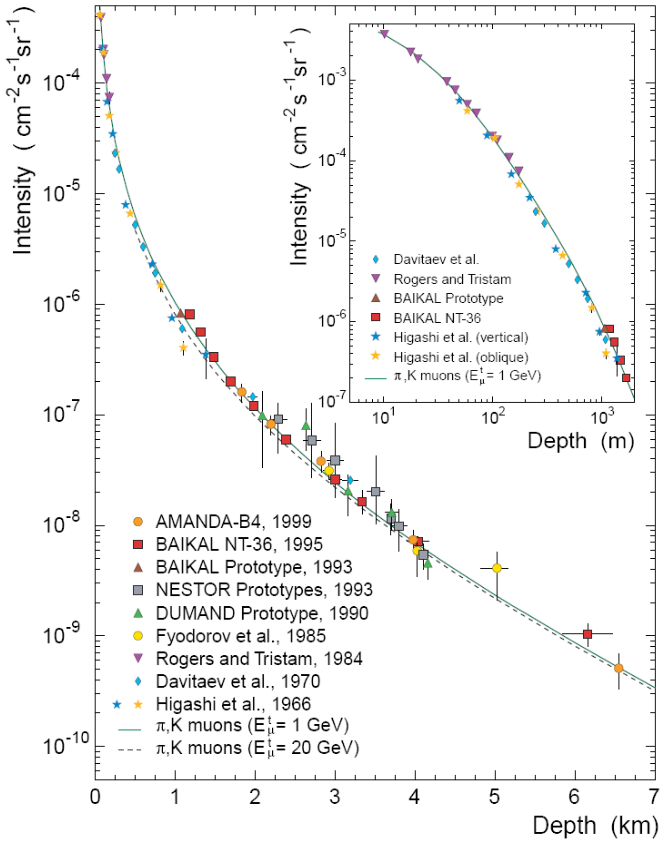


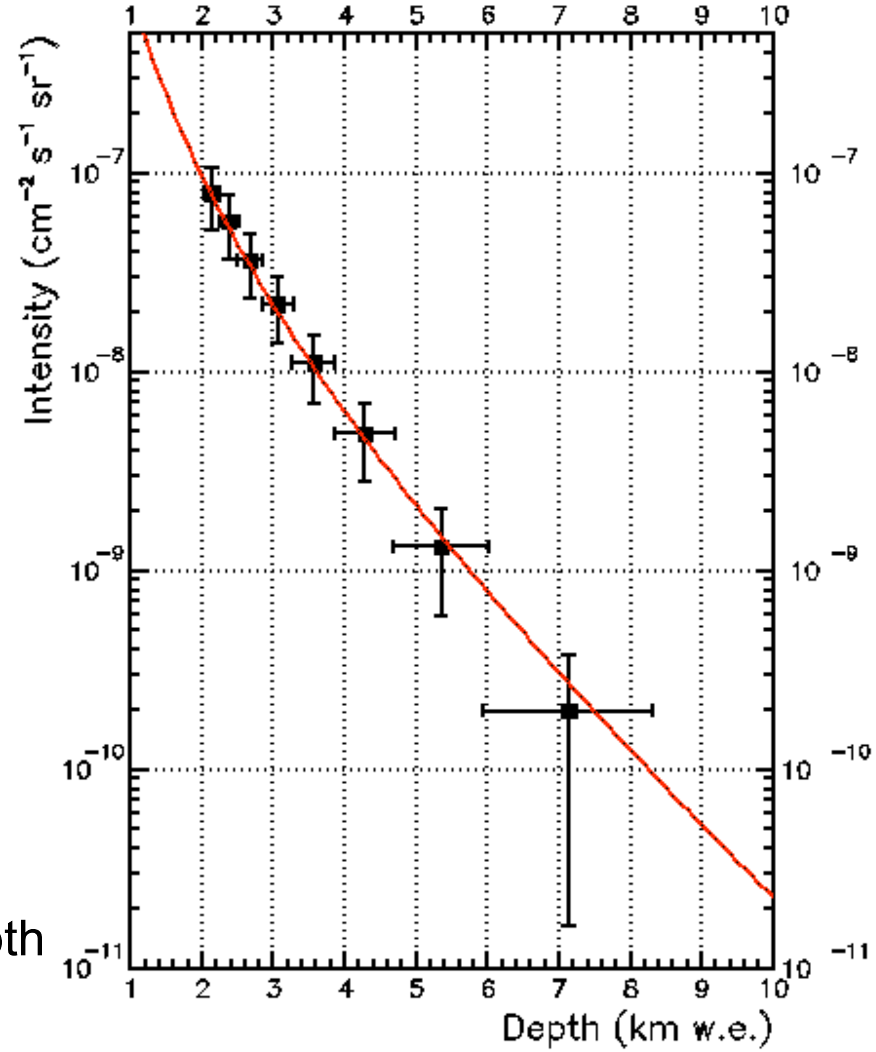


23-24 January, 2007:

LiveTime: 11.31 hours
OnLine Trigger: ~$6\cdot10^7$
OffLine Trigger (7 seeds): 184709
Reconstructed tracks: 2260
Selected tracks: 965

Vertical muon intensity





Vertical Muon intensity as a function of depth from data recorded on 23-24 Jan, 2007
Compared with the relation from
Bugaev et al, Phys. Rev. D58, 05401 (1998)

KM3NeT: towards a km3-scale neutrino telescope in the Mediterranean Sea

www.km3net.org

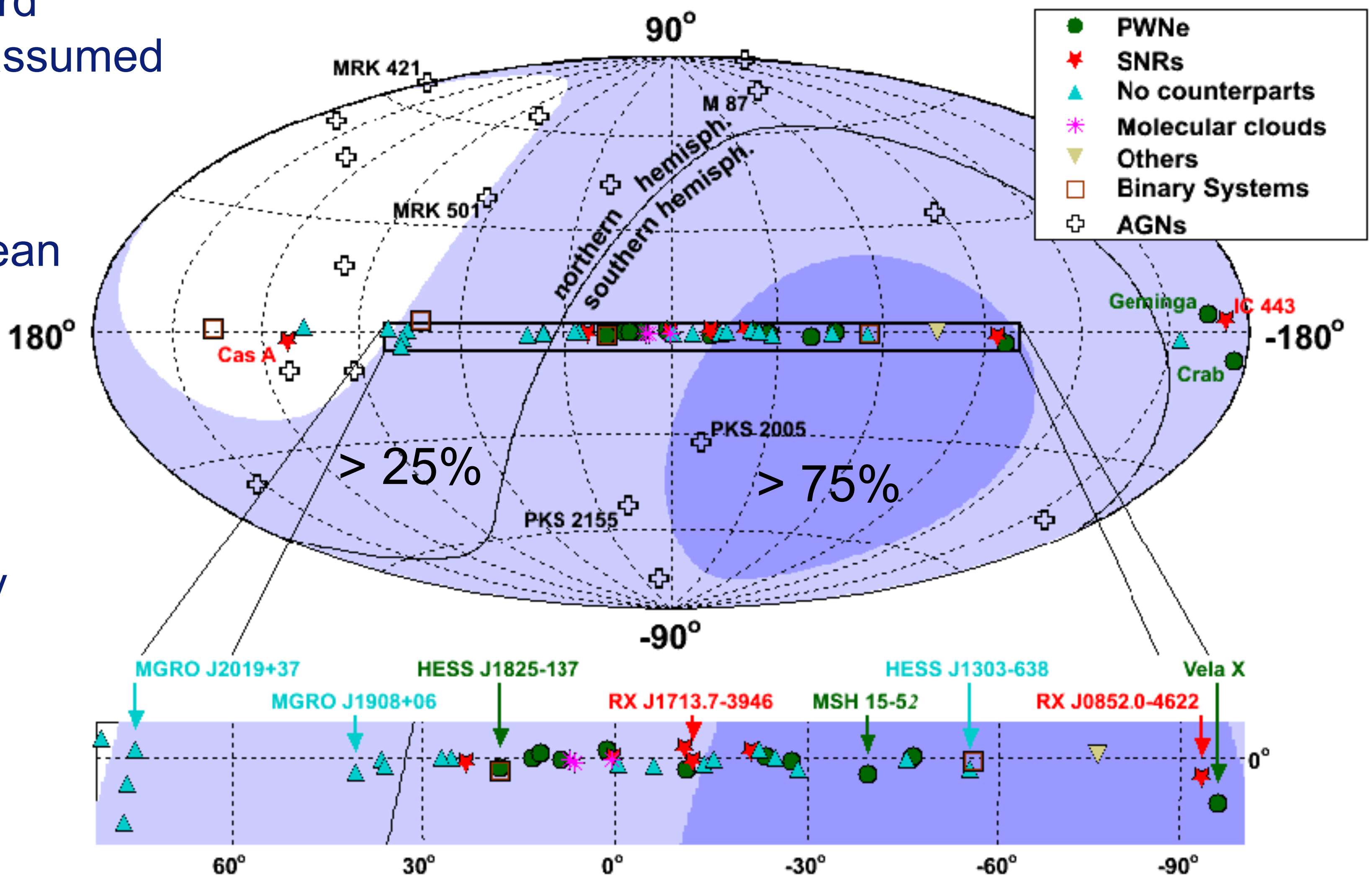
KM3NeT

- Consortium between the Institutes that developed and support the pilot projects in the Mediterranean
  - 40 Institutes from 10 European Countries (Cyprus, France, Germany, Greece, Ireland, Italy, The Netherlands, Rumania, Spain, U.K.)
- Large European Research Infrastructure
  - Included in the ESFRI roadmap for the European Research Infrastructures
- Design Study project
  - Approved under the 6th FP
  - Three year project started in 2006 funded by the EC for 9 M€
  - Conceptual Design Report Published in 2008
  - Will conclude in 2009 with publication of a Technical Design Report
- Preparatory Phase project
  - Approved under the 7th FP
  - Three year project started in 2008 funded by the EC for 5 M€
  - Coordinated by INFN

Mediterranean KM3 sky view

2π downward sensitivity assumed

Located in Mediterranean → visibility of given source can be limited to less than 24h per day

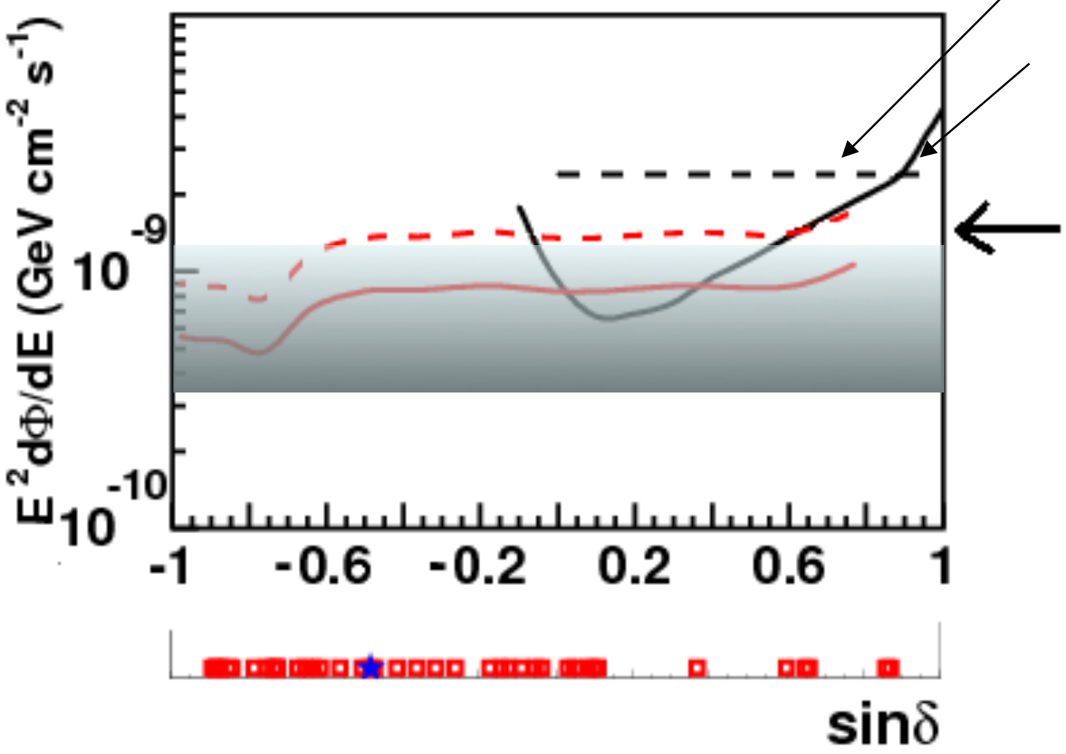


KM3NeT sensitivity

Sensitivity to point like source as a function of the source declination for three years of observation time

Black lines IceCube

Red lines KM3NeT (127 towers)



Aharens et al. Astr. Phys. (2004)

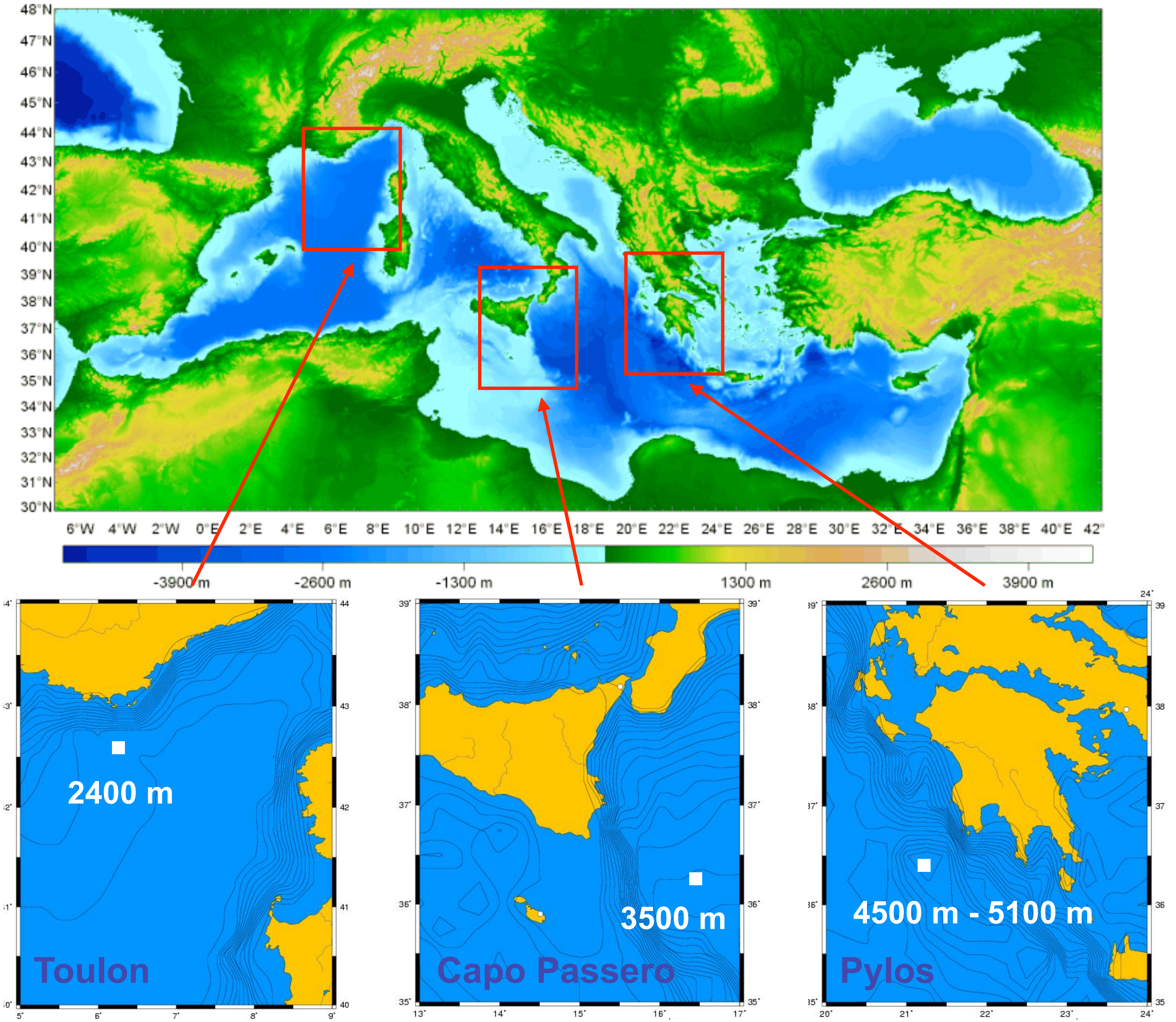
R. Abbasi et al. Astro-ph (2009) scaled

Average value of sensitivity from R. Abbasi et al. Astro-ph (2009)

□ Observed Galactic source (SNR, unidentified, microquasar) declination - From F. Aharonian et al. Rep. Prog. Phys. (2008) and MILAGRO sources from Abdo et al. Astrophys. Jour. 658 L33-L36 (2007)

★ Galactic center declination

KM3NeT candidate sites



Convergence towards a final KM3NeT detector design

- Main technical choices in the detector design have been made
- Full design will be described in a Technical Design Report to be published at the conclusion of the Design Study (november 2009)
- Some “preferred” innovative technical solution that will be considered for the construction are now under validation tests
- Backup solutions based on consolidated technologies have been identified
- Several concepts developed by the NEMO collaboration will be retained in the final design
    - Tower with horizontal extent
    - Packable structure for integration and deployment with unfurling on the seabed
    - DC power feeding system

Conclusions and outlook

- In the short term program validation tests of the technical solutions will be carried on by the KM3NeT collaboration
- Further development of the simulation and analysis tools is also under way
- Issues concerning legal, financial and governance are presently dealt with by the Preparatory Phase project
- The assessment of the single vs multi-site option will be done within the Preparatory Phase project, but preliminary results indicate that a multi-site telescope has at least the same sensitivity than a single one
- No technical "bottlenecks" are present, but improvement of overall reliability is needed
- Main issues for the construction phase appears now to be "financial"