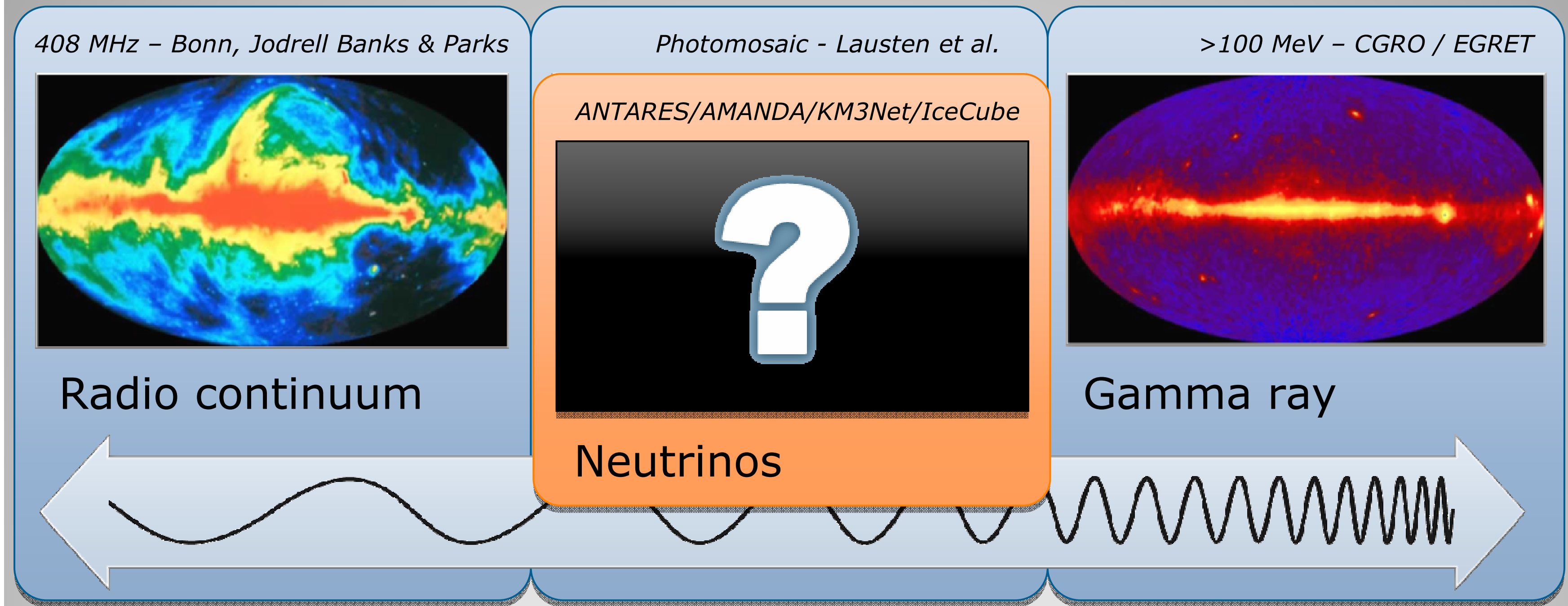
# Neutrino Telescopes

# IceCube,  ANTARES and KM3NeT

**J.J. Hernández-Rey**
**IFIC**

XXXVII  International Meeting on Fundamental Physics, Benasque, February 2009

# Motivations




If $E_\nu \approx 10$ GeV–$10^2$ EeV → 10 orders of magnitude range
(same span as radio to X-ray in EM radiation, but at $\lambda < 10^{-14}$ cm)

# Cosmic messengers

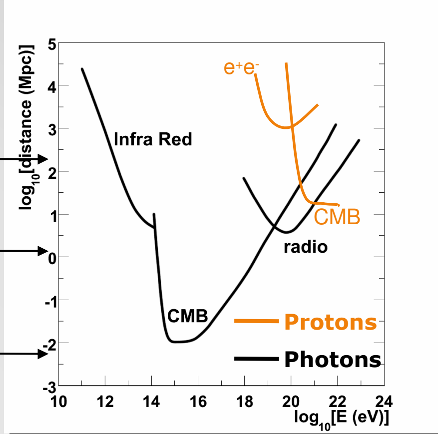
- Why neutrino astronomy?


- Protons are deflected by magnetic fields ($E_p < 10^{19}$ eV)
  UHE protons interact with the CMB ($E_p > 10^{19}$ eV → 30 Mpc)
- Neutrons decay (~10 kpc at E ~ EeV).
- Photons interact with the EBL (~100 Mpc) and CMB (~10 kpc).
- Neutrinos are neutral weakly interactive particles.

Mkn 421

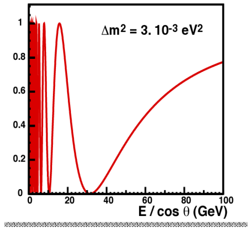
Local group

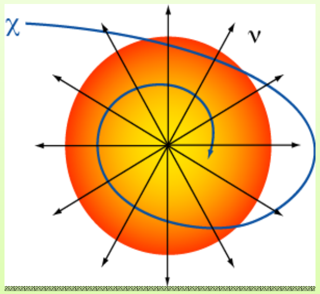
GC

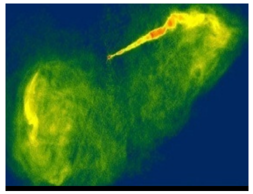


# Scientific scope

–Less amount of light
–Lower ranges
–$^{40}K$ background



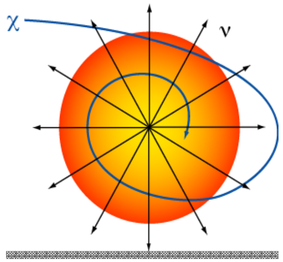




**~MeV** **GeV-100 GeV** **GeV-TeV** **TeV-PeV** **PeV-EeV** **➢EeV**

–Earth opacity
–Decreasing neutrino flux

# Where can neutrinos come from?

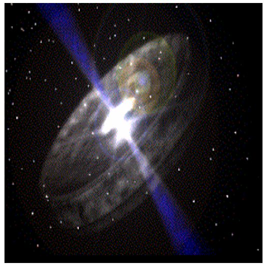
## WIMP decay products




HE neutrinos are the decay sub-products of the **annihilation** of **WIMPs** which may concentrate in astrophysical objects.

$$\chi + \chi \rightarrow q\bar{q}, \ldots \rightarrow X + \nu\bar{\nu}$$

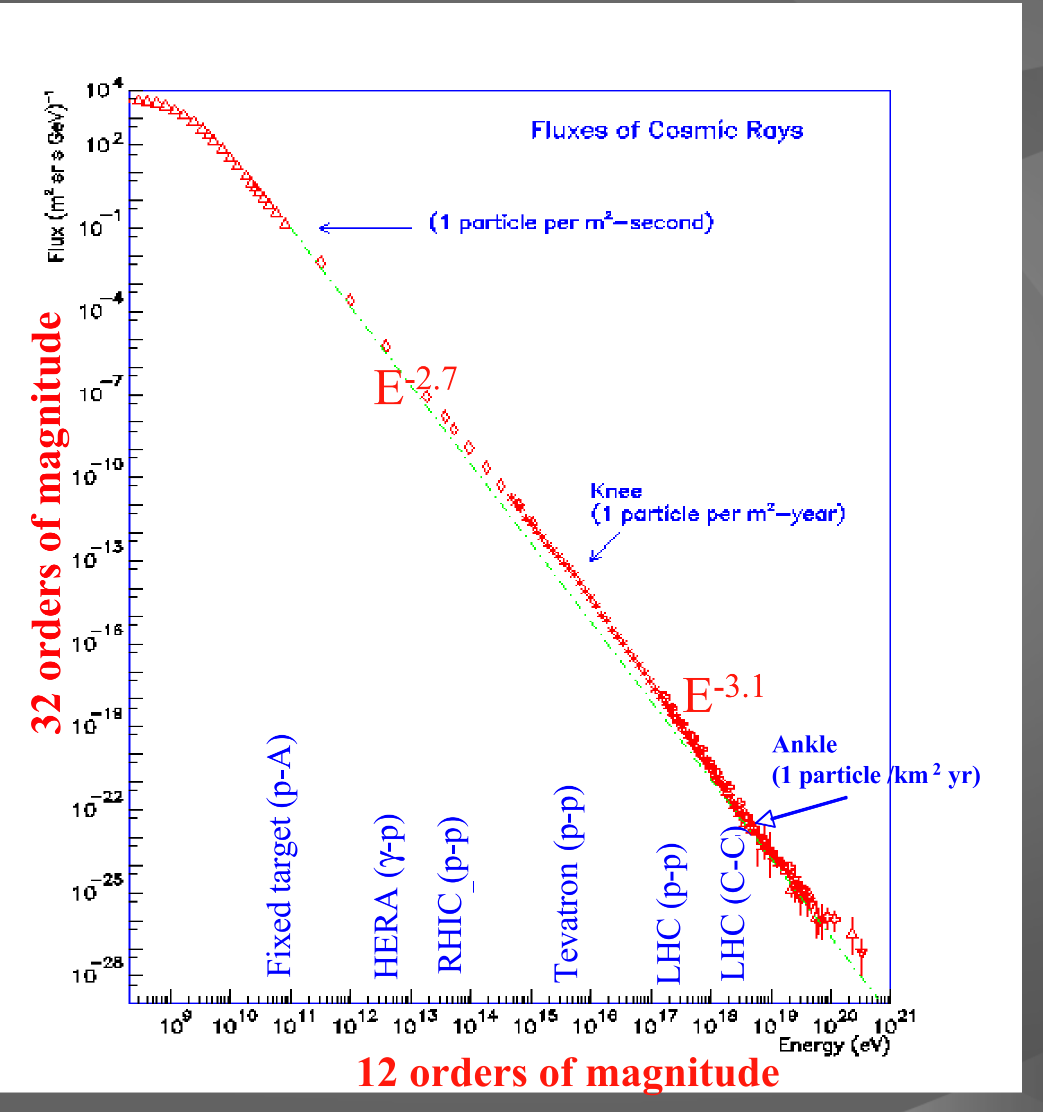
## Astrophysical objects

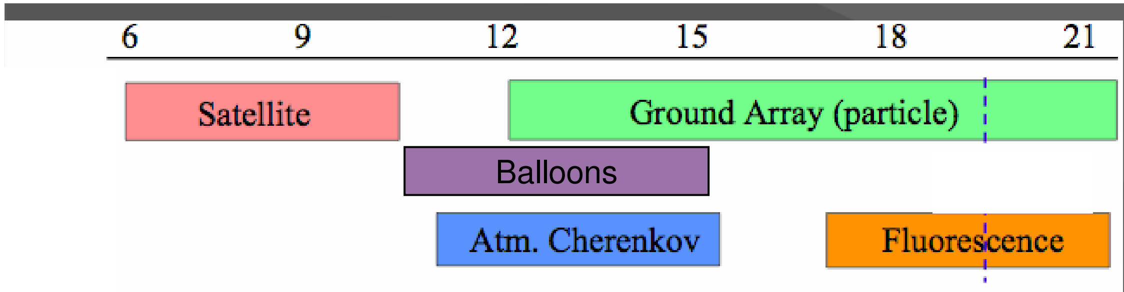


HE neutrinos appear as the sub-product of interactions of **accelerated protons** or nuclei with matter or radiation

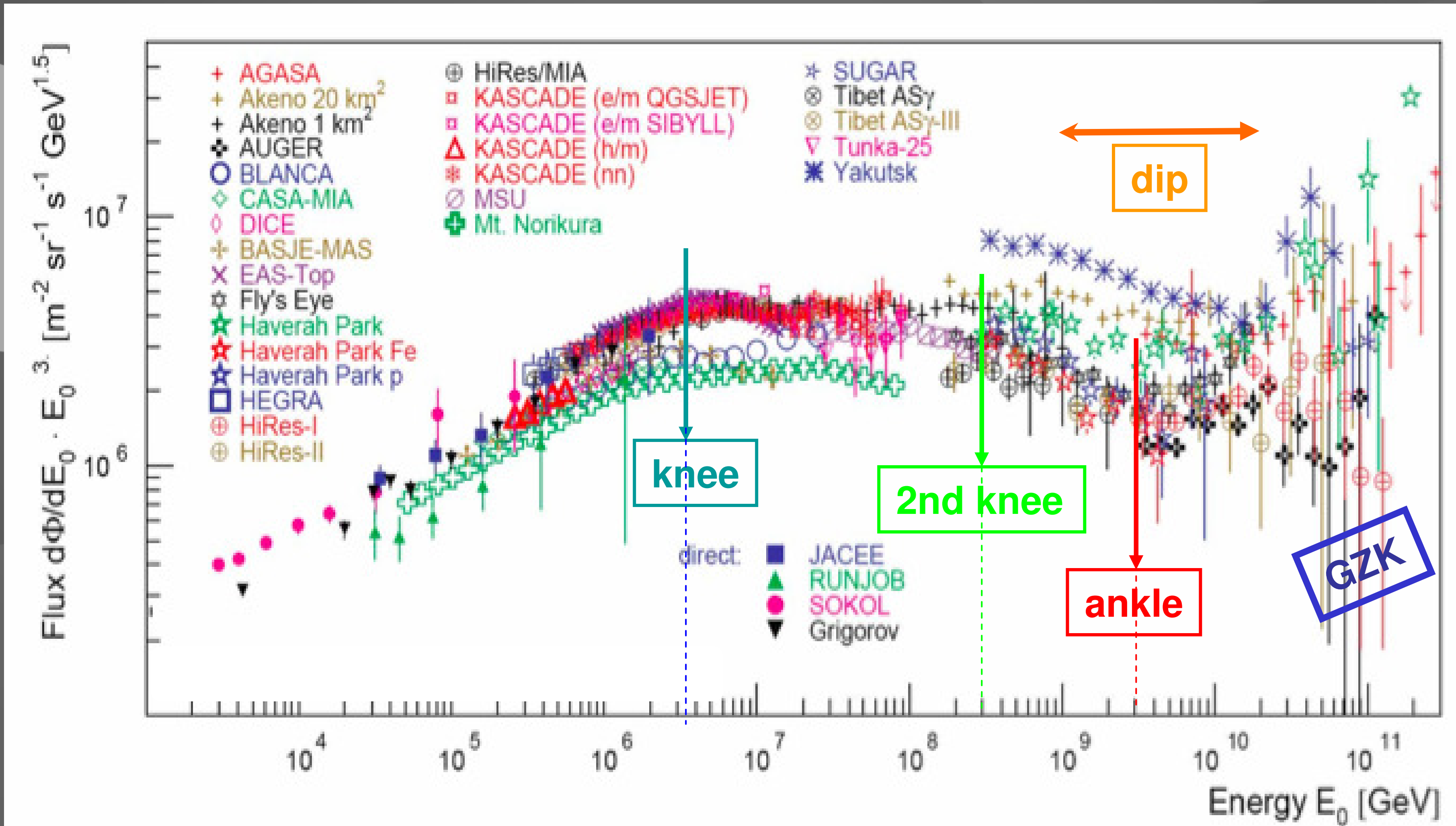
$$p + A/\gamma \rightarrow \pi^{\pm} + \ldots$$
$$\rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}) + \ldots$$
$$\rightarrow e^{\pm} + \nu_{e}(\bar{\nu}_{e}) + \nu_{\mu}(\bar{\nu}_{\mu}) + \ldots$$

# High energy cosmic rays






# A close-up of the CR spectrum




•From A. Castellina using J.R.Hoerandel

# Cosmic Rays, Gamma-rays and Neutrinos

### Leptonic acceleration

−Electrons are accelerated in cosmic environments via Fermi Mechanism.
−Gamma rays are produced in the interaction of multi-TeV electrons with ambient light (IC scattering).
− Neutrinos are not foreseen in this context.

### Hadronic acceleration

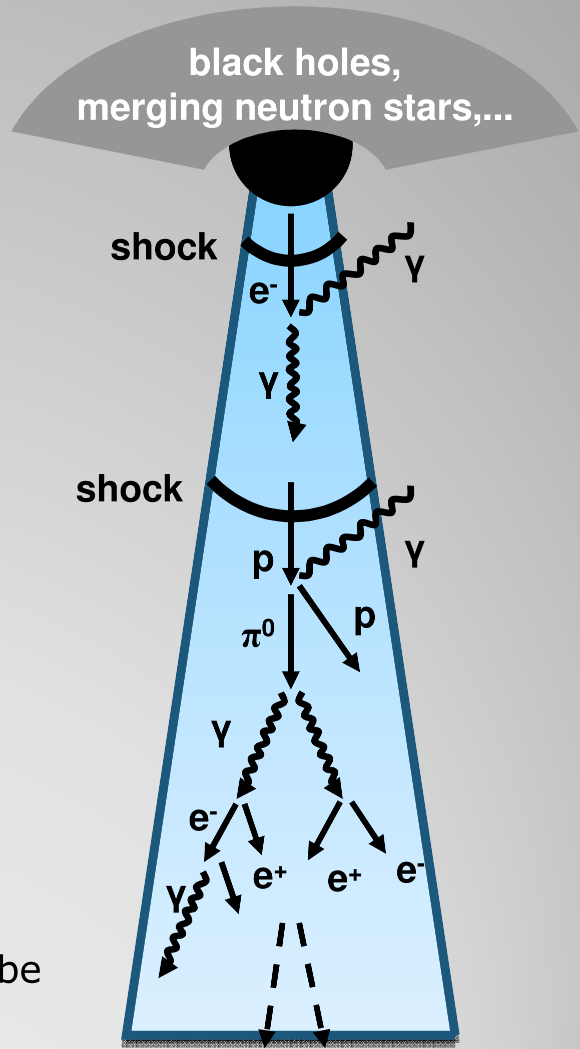
−Protons and heavy nuclei are accelerated via Fermi Mechanism and interact with ambient photons.

$$p + \gamma \rightarrow \Delta^{+} \rightarrow \pi^{0} + p$$

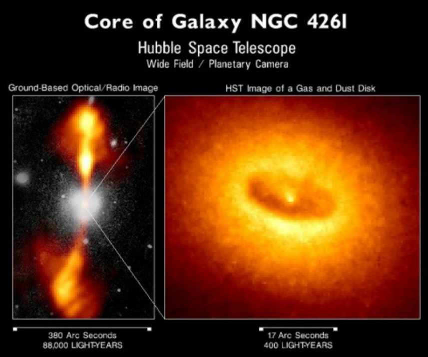
$$p + \gamma \rightarrow \Delta^{+} \rightarrow \pi^{+} + n$$

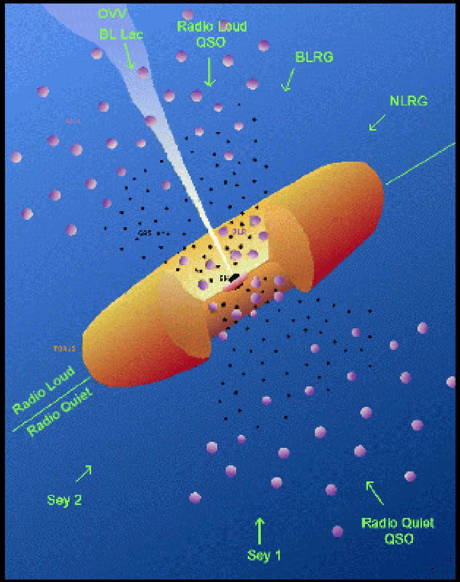
−Gamma rays are produced via $\pi^0$–meson decay.
−Neutrinos are also produced via $\pi^+$-meson decay.

X-ray observations indicate that leptonic acceleration exists. But we observe CR protons, hence there should be hadronic acceleration.



# Neutrinos sources



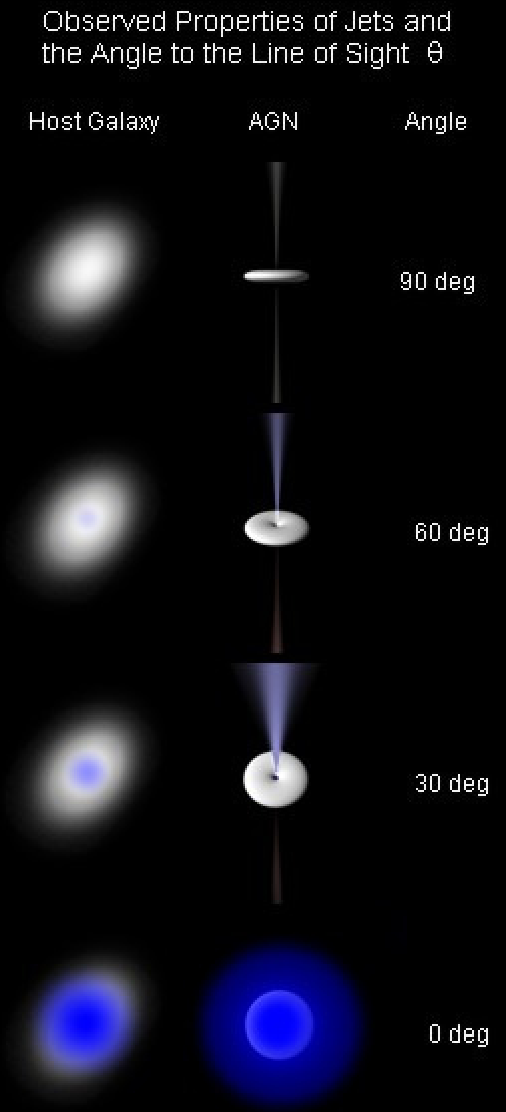




## Extra-Galactic sources

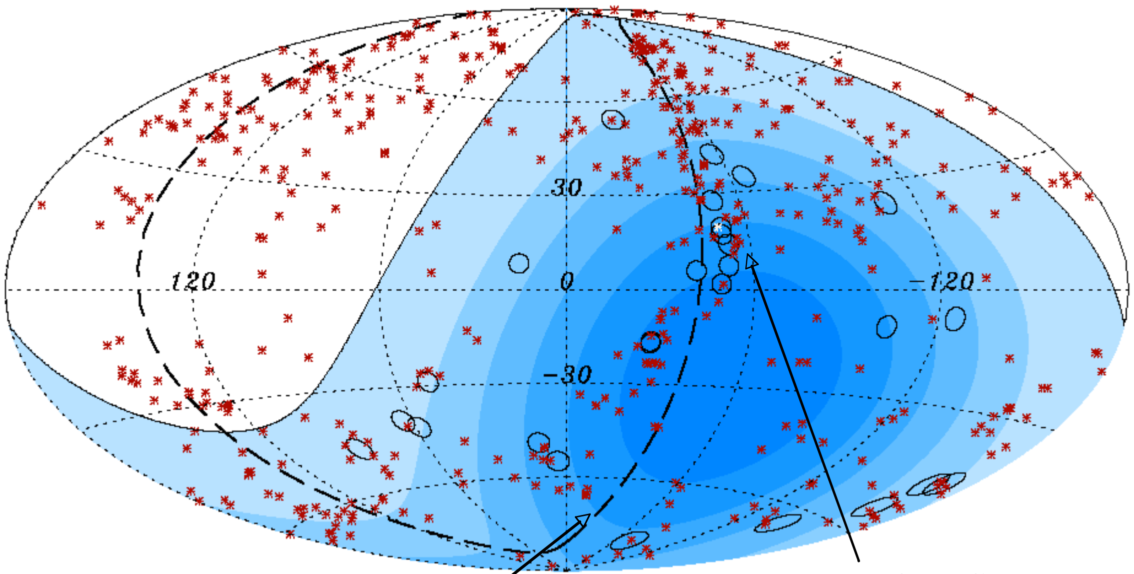
- The two most promising candidates are: Active Galactic Nuclei (AGN) and Gamma-ray Bursts (GRB)

- AGNs
  - A high luminosity compact region at the centre of some galaxies that are believed to be supermassive black holes that acrrete matter.
  - "Different objects" are just AGNs with different features: "Blazars" (BL Lac, FSRQs, etc.) are AGNs with jets pointing to Earth.

- The P.A. Observatory sees a Correlation between UHECR and nearby AGNs



# P.A.O results on UHECRs




**UHECRs and AGNs**

Correlation of UHECRs with AGNs positions: 20 out of 27 CRs with E>57 EeV correlate (within 3.2°) with nearby AGNs from the Véron-Cetty&Véron catalogue ( 292 AGNs with D < 75 Mpc).

**Some remarks**

- The observed pattern has a probability of $10^{-5}$ to come from isotropically distributed sources
- Correlation is not a proof of causality
- The VCV catalogue is known to be incomplete

# Extra-Galactic sources and the CR – Neutrino relationship

**Extra-Galactic sources**

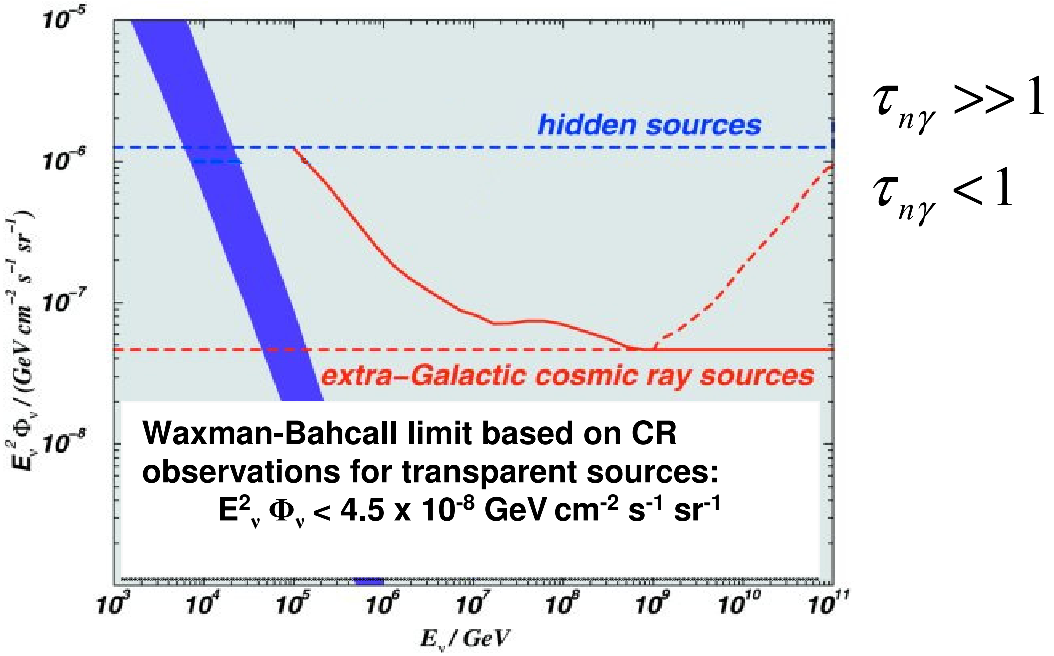
- Waxman & Bahcall limit

$E^2\, dN/dE \approx 10^{44}$ erg $Mpc^{-3}\, yr^{-1}$
(E ~ 100 PeV)
Estimate the relation between
$E^2\, dN/dE$ for CR and neutrinos
Assume optically thin sources
Assume some evolution with z
Take into account the effect of
oscillations:
$(\nu_e:\nu_\mu:\nu_\tau) \rightarrow (1:2:0) \rightarrow (1:1:1)$

- MPR

Possibility of some other effects
(different injection spectra, optically
thin sources, neutron escape)

- Some controversy



# SNRs - RX J1713.7–3946

**A special SNR**

• A clear shell-type SN discovered in soft X-rays by ROSAT. Bright X-ray emission by ASCA. In HE gamma by CANGAROO AND CANGAROO-II.

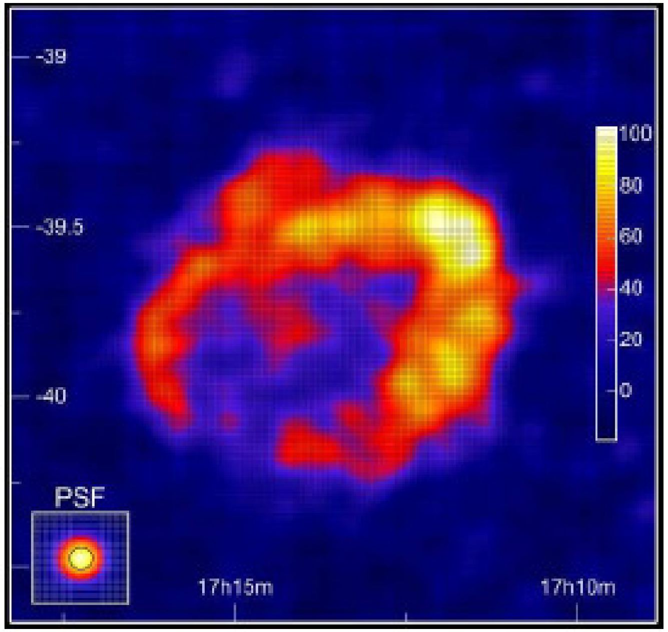
• CANGAROO-II hinted a possible hadronic origin. HESS (2003-2005) confirms the difficulty to explain it by leptonic acceleration.

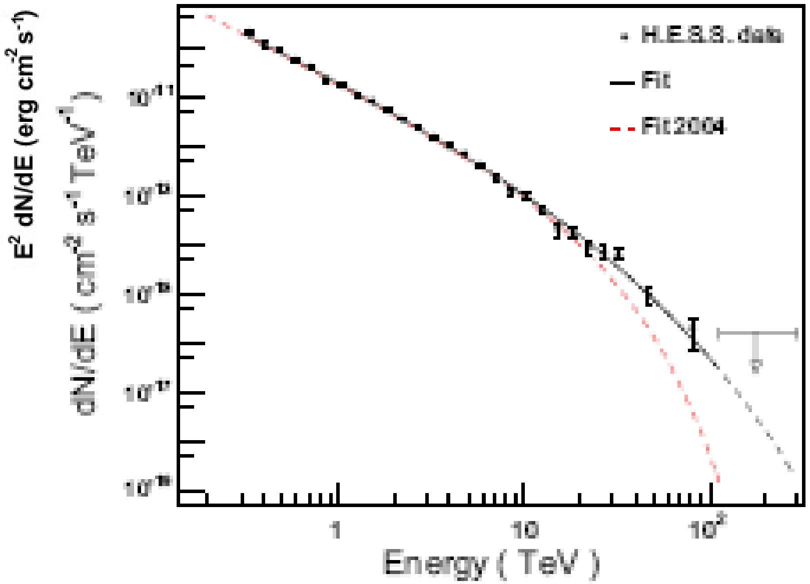
•Unnaturally low B fields have to be assumed to avoid too high synchroton radiation

(B ≤ 10 μG, even interestellar fields are higher and shocks are expected to amplify fields. Measurments in other SNRs indicate B ~ 100 μG)

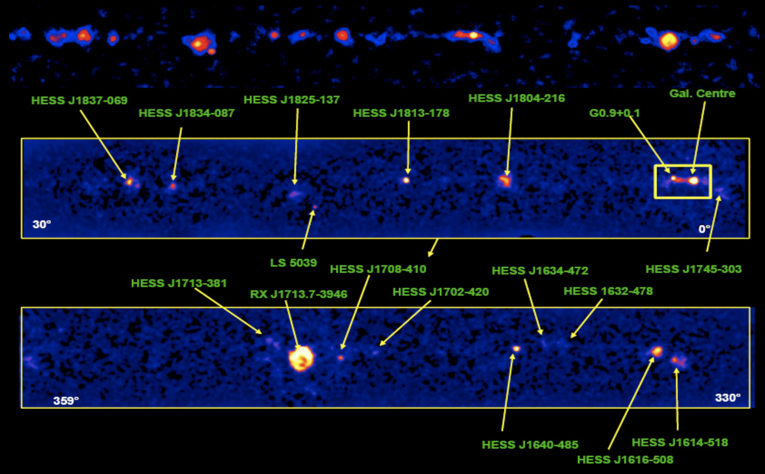
• Spectrum up to several tens of TeV. If gammas come from $\pi^0$, then protons are accelerated at E > several hundreds of TeV.

• Two other cases (RX J0852.0-4622 and RCW86, acceleration still unclear)

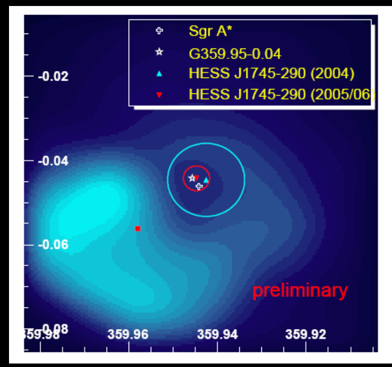


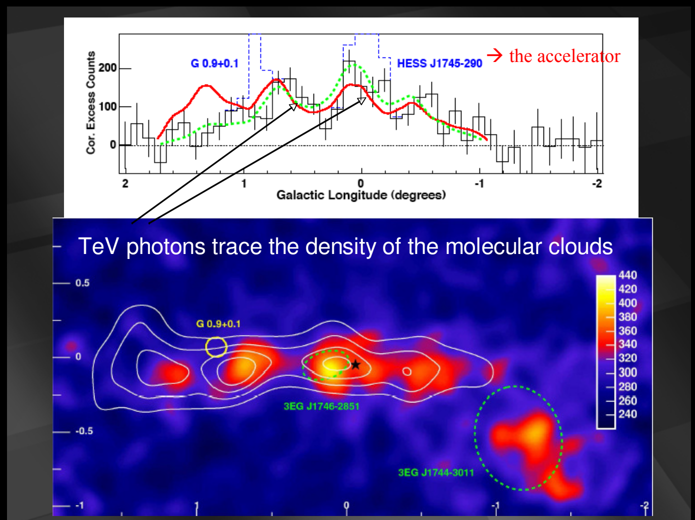
# The Galactic centre and plane by HESS

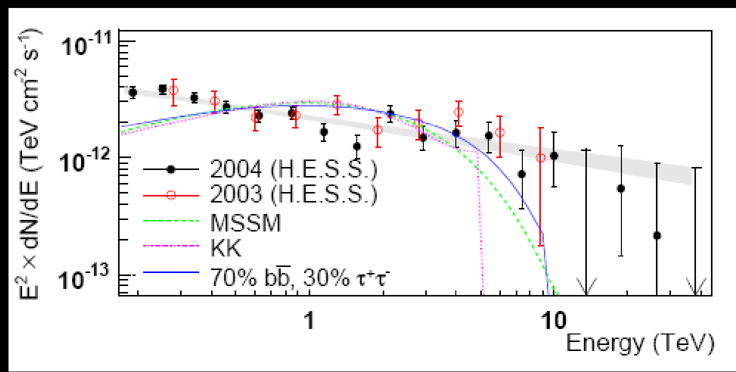



Several gamma-ray sources in the Galactic plane

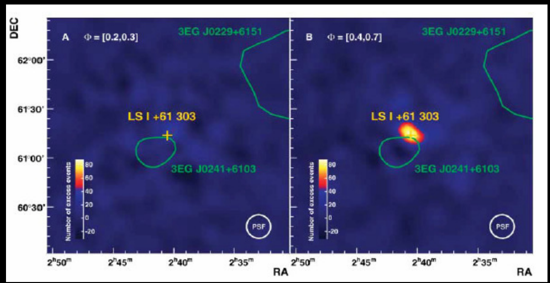


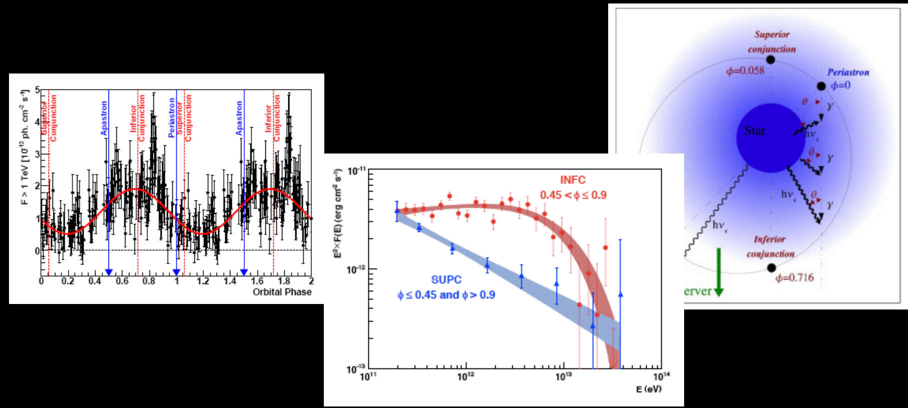

- Sgr A* (a radio source) lies on the position of a super-massive black hole (~ 3 x $10^6$ solar masses in 17 light-hours) in the Galaxy (according to star movements).
- Sgr A* emits X-rays (among others) HESS J1745-290 seems to be very near Sgr A*(excluded to come from Sgr A East, a SNR)
- No coincide of X-ray flares and γ-rays observed
- There is a PWN nearby (G259.95-0.04)



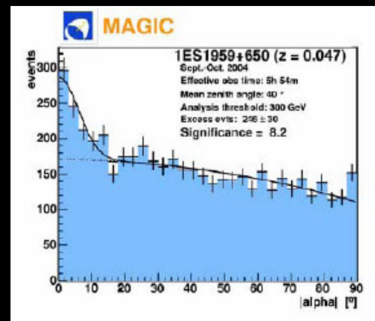
# A plethora of new γ sources



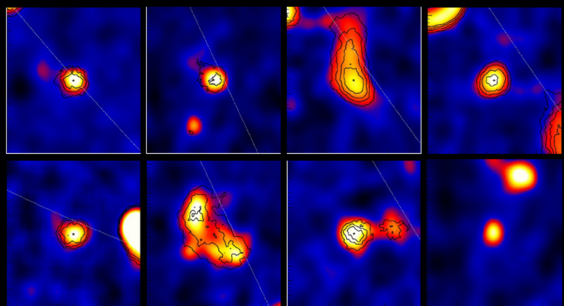




binary pulsars
galactic periodic sources

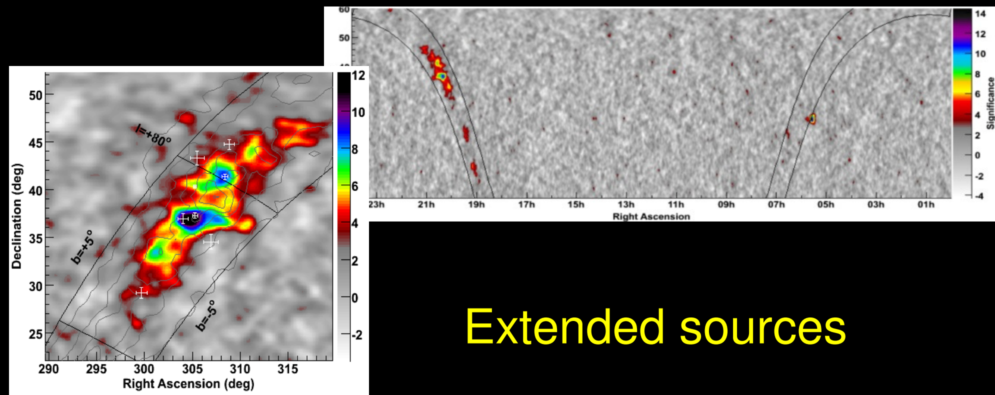
Micro-quasars




AGNs with “orphan” flares
1ES 1959+650

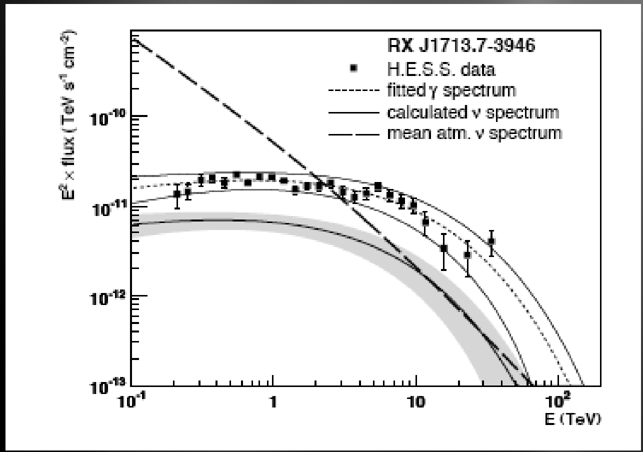


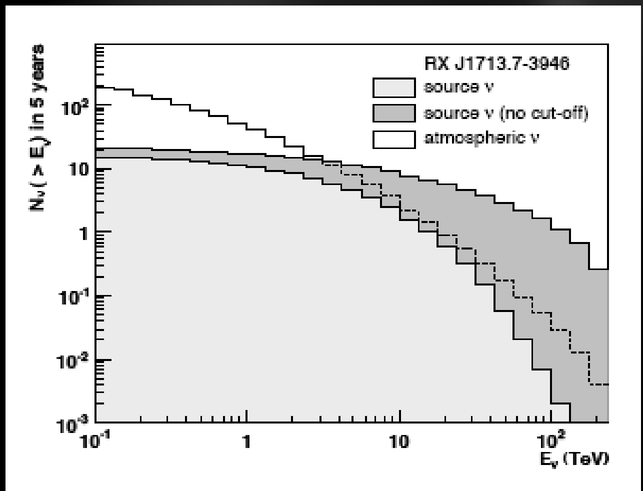
“Dark sources”
(not seen in X-rays or visible)




Extended sources

# Predictions




| Source Name | Ref. | ⌀ (°) | Vis. | Spec. parameters $k_\nu$ | $\Gamma_\nu$ | $\epsilon_\nu$ | $E_\nu > 1$ TeV $N_{src}$ | $N_{atm}$ | $E_\nu > 5$ TeV $N_{src}$ | $N_{atm}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Source class A (supernova remnants)** | | | | | | | | | | |
| RX J1713.7−3946 | 2006d | 1.3 | 0.74 | 15.52 | 1.72 | 1.35 | 7 − 14 (11) | 41 | 2.6 − 6.7 (4.6) | 8.2 |
| RX J0852.0−4622 | 2007 | 2.0 | 0.83 | 16.76 | 1.78 | 1.19 | 7 − 15 (11) | 104 | 1.9 − 6.5 (4.2) | 21 |
| HESS J1640−465 | 2006a | 0 | 0.83 | 0.93 | 2.41 | | 0.4 − 3.3 (2.2) | 8.7 | 0.0 − 2.1 (1.3) | 1.8 |
| HESS J1745−290 † | 2004a | < 0.1 | 0.65 | 0.85 | 2.29 | | 1.1 − 2.7 (2.0) | 6.4 | 0.5 − 1.8 (1.3) | 1.3 |
| HESS J1834−087 | 2006a | 0.2 | 0.54 | 0.80 | 2.45 | | 0.2 − 1.7 (1.1) | 6.0 | 0.0 − 1.1 (0.7) | 1.2 |
| HESS J1713−381 | 2006a | 0.1 | 0.73 | 0.23 | 2.28 | | 0.0 − 1.5 (0.6) | 7.2 | 0.0 − 1.1 (0.4) | 1.4 |
| Sums for source class A | | | | | | | ∼ 27 | 173 | ∼ 12 | 35 |
| **Source class B (binary systems)** | | | | | | | | | | |
| LS5039 (INFC) †† | 2006f | 0.1 | 0.57 | 2.50 | 1.61 | 1.01 | 0.3 − 0.7 (0.5) | 2.5 | 0.1 − 0.3 (0.2) | 0.5 |
| LS5039 (SUPC) †† | 2006f | 0.1 | 0.57 | 0.26 | 2.51 | | 0.1 − 0.3 (0.2) | 3.0 | 0.0 − 0.2 (0.1) | 0.6 |
| PSR B1259−63 | 2005h | < 0.1 | 1.00 | 0.34 | 2.72 | | 0.1 − 0.9 (0.6) | 9.1 | 0.0 − 0.4 (0.3) | 1.7 |
| **Source class C (no counterparts at other wavelengths)** | | | | | | | | | | |
| HESS J1303−631 | 2005g | 0.3 | 1.00 | 11.99 | 1.29 | 0.21 | 0.8 − 2.3 (1.6) | 11 | 0.1 − 0.5 (0.3) | 2.1 |
| HESS J1745−303 | 2006a | 0.4 | 0.66 | 1.01 | 1.79 | | 0 − 18 (9) | 9.0 | 0 − 16 (7) | 1.8 |
| HESS J1614−518 | 2006a | 0.5 | 1.00 | 2.41 | 2.44 | | 1 − 10 (6) | 19 | 0.0 − 6.7 (3.7) | 4.0 |
| HESS J1837−069 | 2006a | 0.2 | 0.53 | 1.65 | 2.27 | | 1.2 − 4.5 (3.3) | 5.9 | 0.4 − 3.2 (2.2) | 1.2 |
| HESS J1634−472 | 2006a | 0.2 | 0.85 | 0.64 | 2.36 | | 0.0 − 3.1 (1.7) | 9.8 | 0.0 − 2.2 (1.1) | 2.0 |
| HESS J1708−410 | 2006a | 0.1 | 0.76 | 0.44 | 2.33 | | 0.1 − 1.6 (1.1) | 7.6 | 0.0 − 1.1 (0.7) | 1.5 |
| Sums for source class C | | | | | | | ∼ 23 | 63 | ∼ 15 | 13 |
| **Source class D (pulsar wind nebula)** | | | | | | | | | | |
| Vela X | 2006c | 0.8 | 0.81 | 11.75 | 0.98 | 0.84 | 9 − 23 (16) | 23 | 5 − 15 (10) | 4.6 |
| HESS J1825−137 | 2006h | 0.5 | 0.57 | 10.73 | 2.08 | 4.24 | 5 − 10 (8) | 9.3 | 2.2 − 5.2 (3.7) | 1.8 |
| Crab Nebula | 2006g | < 0.1 | 0.39 | 22.38 | 2.15 | 1.72 | 4.0 − 7.6 (5.8) | 5.2 | 1.1 − 2.7 (1.9) | 1.1 |
| HESS J1632−478 | 2006a | 0.3 | 0.87 | 1.87 | 2.11 | | 0 − 18 (9) | 12 | 0 − 12 (7) | 2.4 |
| MSH 15 − 52 | 2005d | 0.2 | 1.00 | 1.89 | 2.27 | | 3.4 − 9.6 (7.1) | 10 | 1.5 − 6.6 (4.7) | 2.0 |
| HESS J1616−508 | 2006a | 0.3 | 1.00 | 2.11 | 2.36 | | 2.0 − 9.0 (6.6) | 14 | 0.3 − 5.9 (4.1) | 3.0 |
| HESS J1420−607 | 2006e | 0.1 | 1.00 | 1.16 | 2.25 | | 2.0 − 6.3 (4.6) | 9.6 | 0.7 − 4.4 (3.1) | 1.9 |
| HESS J1418−609 | 2006e | 0.1 | 1.00 | 0.94 | 2.19 | | 1.7 − 6.1 (4.2) | 9.6 | 0.8 − 4.5 (3.0) | 1.9 |
| HESS J1813−178 | 2006a | 0.1 | 0.59 | 0.96 | 2.09 | | 0.7 − 4.6 (3.2) | 5.8 | 0.2 − 3.6 (2.4) | 1.1 |
| HESS J1702−420 | 2006a | 0.2 | 0.77 | 0.82 | 2.32 | | 0.5 − 3.3 (2.1) | 8.4 | 0.0 − 2.3 (1.4) | 1.7 |
| HESS J1804−216 | 2006a | 0.4 | 0.61 | 1.49 | 2.73 | | 0.6 − 2.0 (1.5) | 8.4 | 0.1 − 1.0 (0.7) | 1.7 |
| G 0.9+0.1 | 2005a | < 0.1 | 0.65 | 0.27 | 2.31 | | 0.1 − 0.9 (0.6) | 6.2 | 0.0 − 0.6 (0.4) | 1.2 |
| Sums for source class D | | | | | | | ∼ 68 | 122 | ∼ 41 | 24 |
| **Diffuse emissions from CR interactions** | | | | | | | | | | |
| Gal. Centre Ridge | 2006b | 1.6 × 0.6 | 0.65 | 1.29 | 2.29 | | 1.0 − 4.2 (3.0) | 27 | 0.3 − 2.9 (2.0) | 5.3 |
| **Integrated emissions from the Galactic plane** | | | | | | | | | | |
| All known sources | | | | | | | ∼ 122 | 399 | ∼ 72 | 80 |
| Diffuse Plane Emission | | 60 × 2.0 | | | | | 24 | 1024 | 11 | 203 |

Within some natural assumptions a few neutrino events are predicted in a km3 detector

Kappes et al, astro-ph/0607286

# Required neutrino fluxes

**Powerful sources**

Required luminosity in neutrinos is:

$$L_\nu \approx N \left( \frac{D}{4\,Gpc} \right)^2 \left( \frac{AT}{1\,km^2\,yr} \right)^{-1} \times 10^{46}\, erg/s$$

N – Observed neutrinos ; D – Source distance
A – Effective area ; T – Data taking time

• For a few observed neutrinos in one year in a detector of A ~ 1 km$^2$ coming from 4 Gpc → $L_\nu \sim 10^{47}$ erg/s

• $10^{13}$ times the power of our Sun: Only AGNs ($10^{48}$ erg/s, continuous) and GRBs ($10^{52}$ erg/s, instantaneous) are known to deliver such power)

• In the Galaxy (D ~ few kpc) → $L_\nu \sim 10^{34}$ erg/s.
Only SNRs, PWN and micro-quasars could deliver such power.

**Some distances**

• The Milky Way
~ 30 kpc across

• Andromeda
D ~ 0.8 Mpc

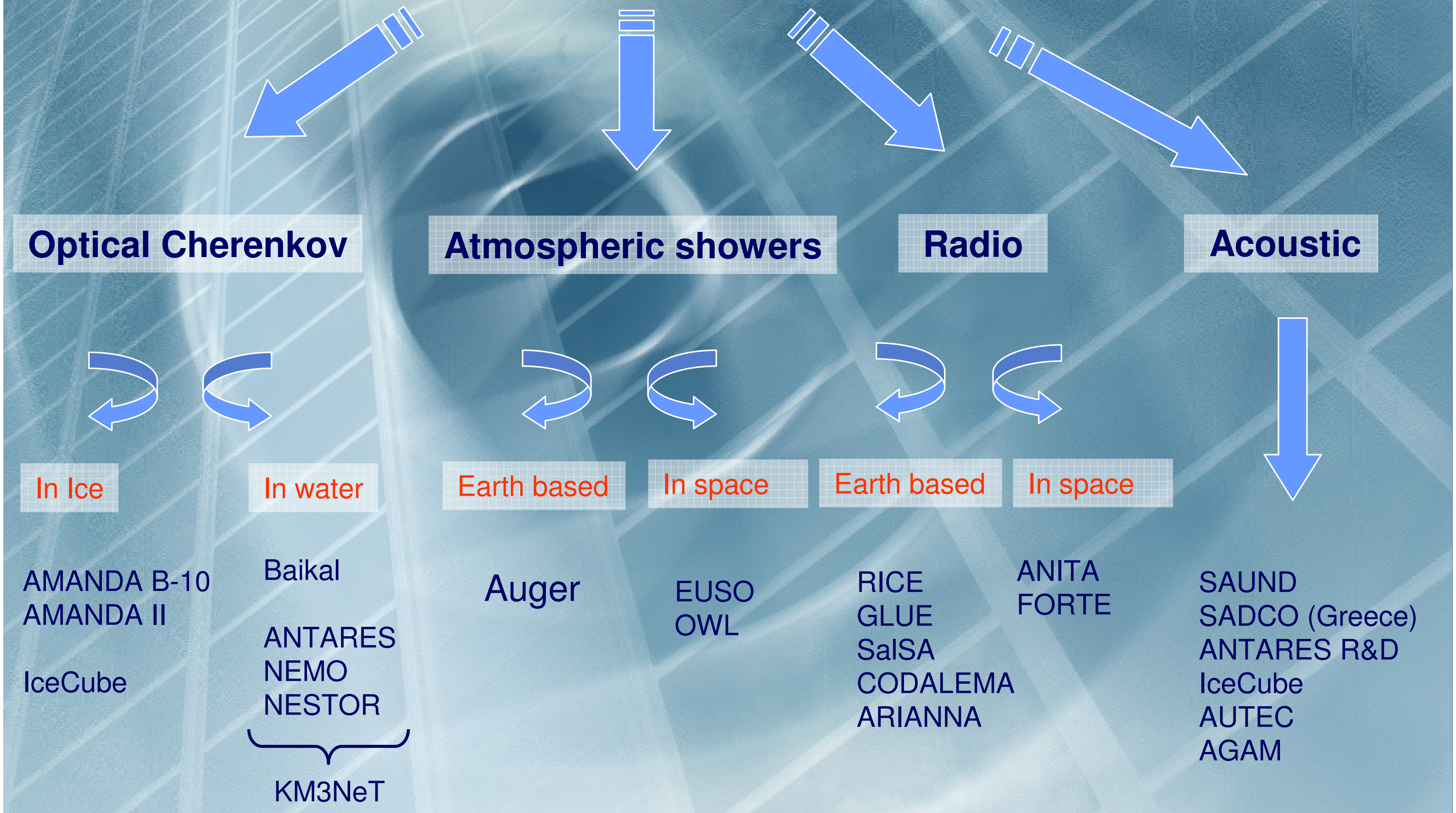
• Virgo Cluster
(the nearest large cluster)
D ~ 18 Mpc

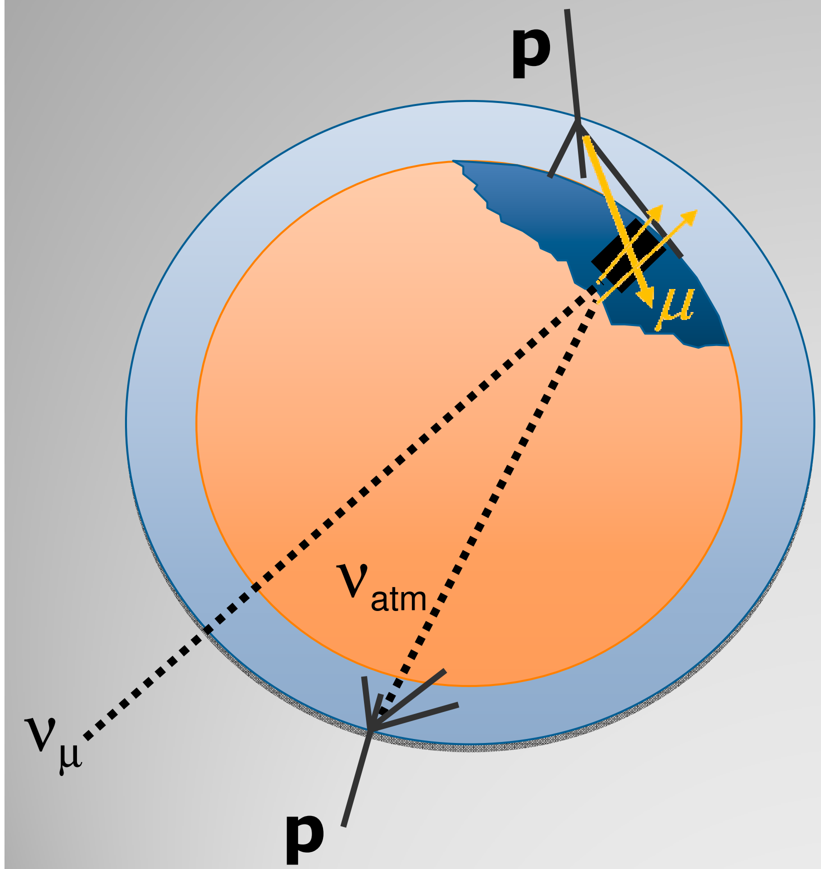
• Galaxy RXJ1242-11
(a supermassive black hole)
D ~ 200 Mpc

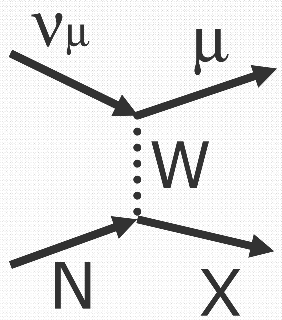
• The observable Universe
D ~ 14 Gpc

To give you an idea:
1 attoparsec ≈ 1 inch
(as useless for intuition as any other equivalence)

# Detection of extra-terrestrial neutrinos

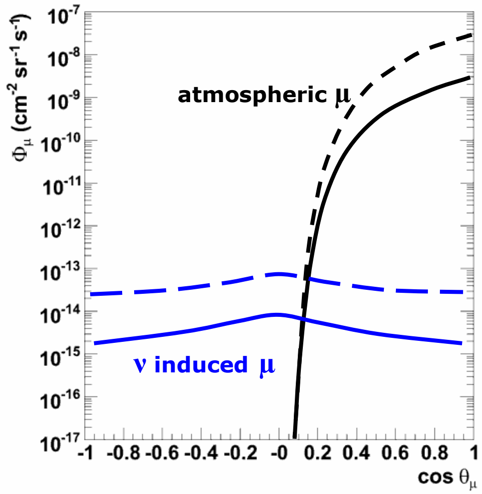




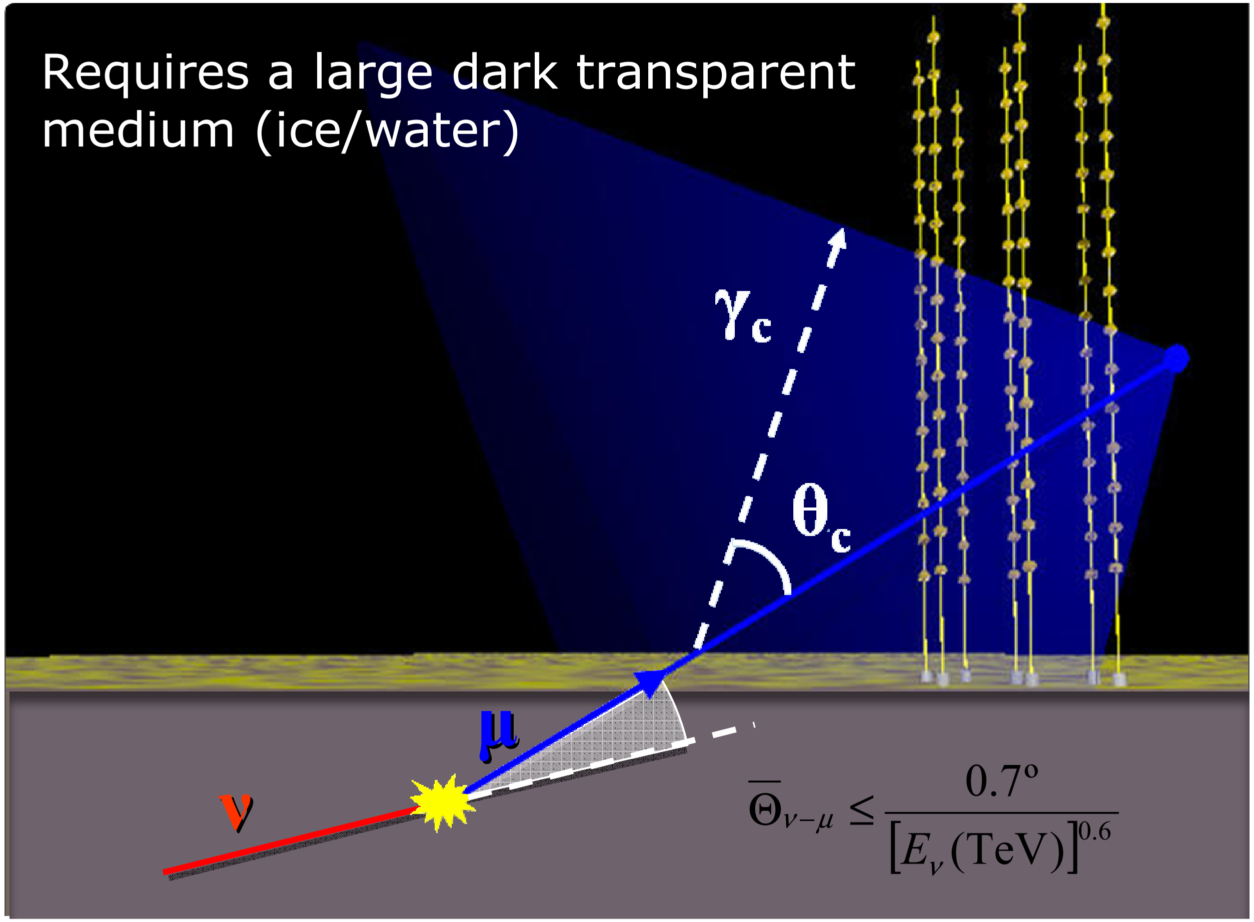

Cosmic neutrinos can interact in the Earth and release a muon

Atmospheric muons and neutrinos can also induce a signal at the detector




# Detection principle

# Cherenkov Neutrino detection

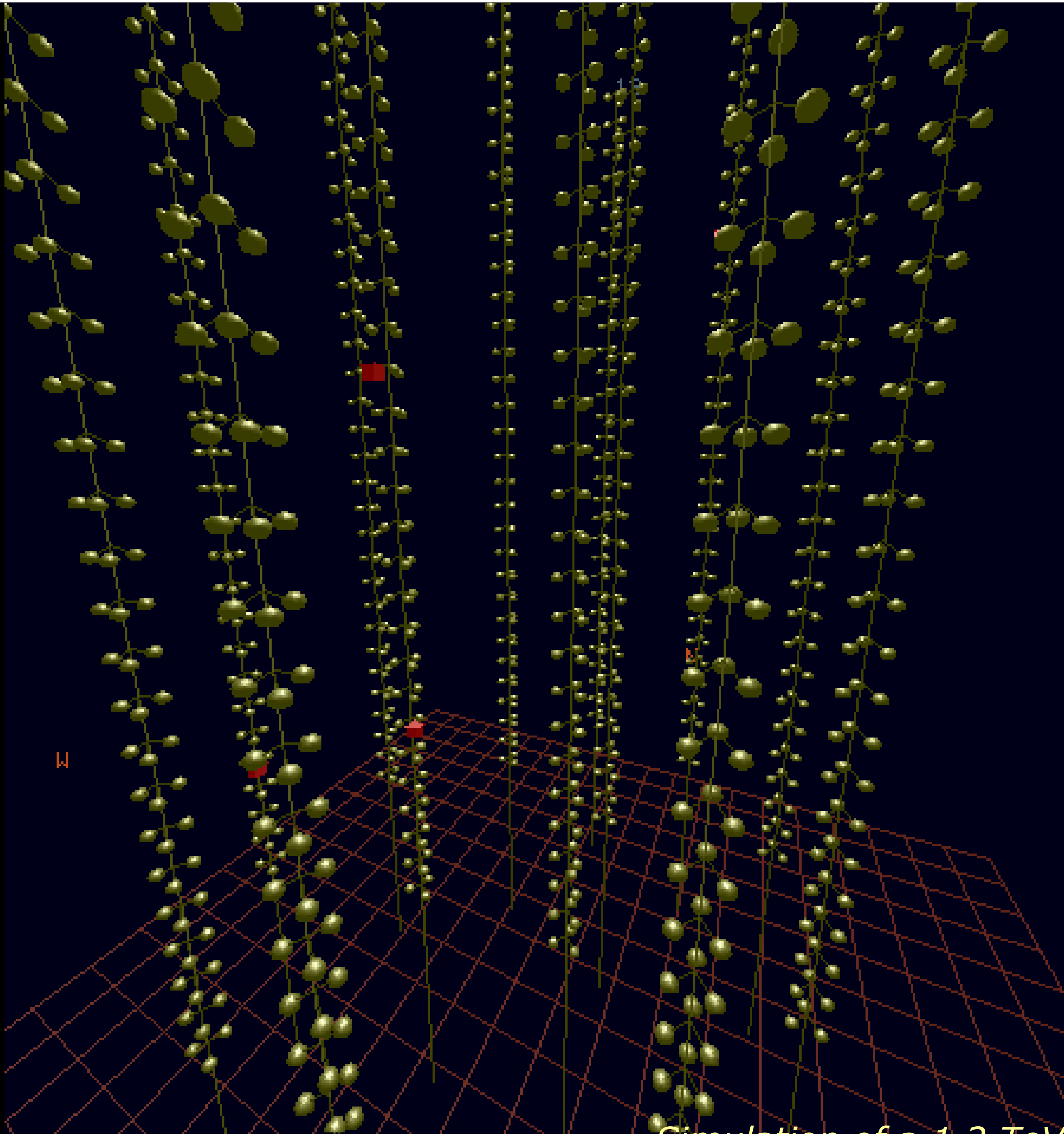



Muon neutrinos are well suited for HE detection (cross-section and muon range increase with energy)

Muons emit Cherenkov light collected by a lattice of PMTs.

Other signatures can also be detected.

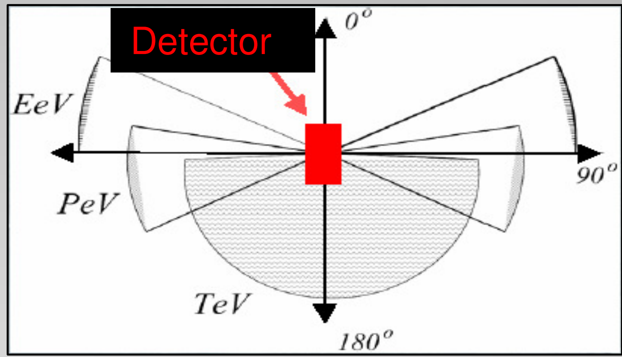
Long track ⟶ angular resolution



*Simulation of a 1.2 TeV muon*

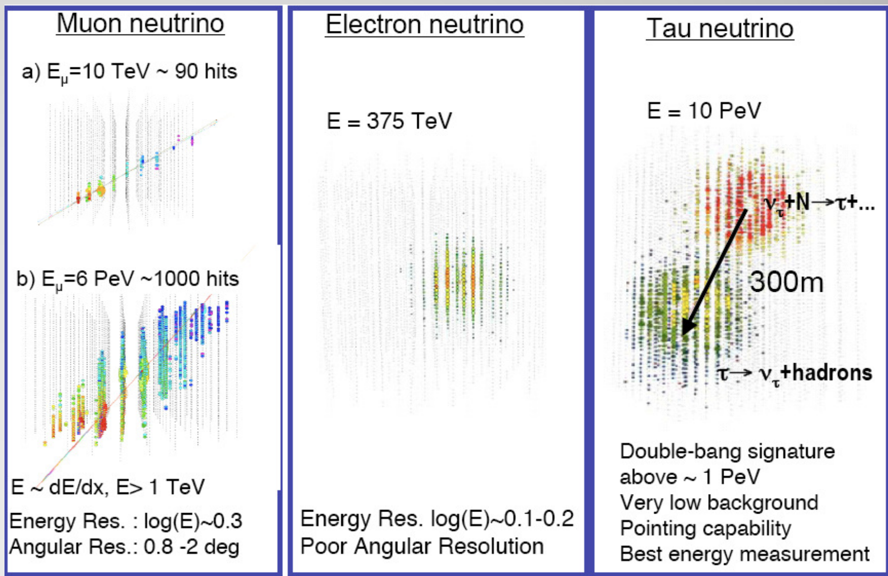
# Different channels, different energy regions

Earth starts to become opaque at E~1 PeV
Below the horizon PeV neutrinos can be detected
Downgoing tracks at high energies (EeV) can only come neutrinos

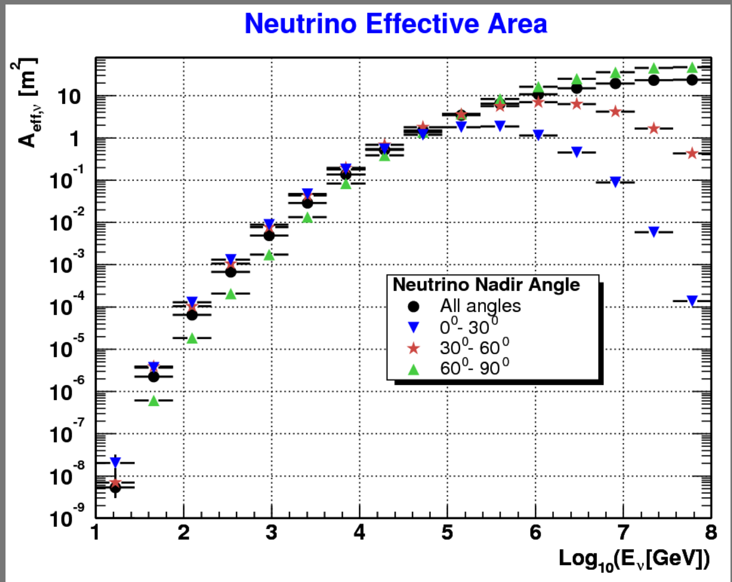


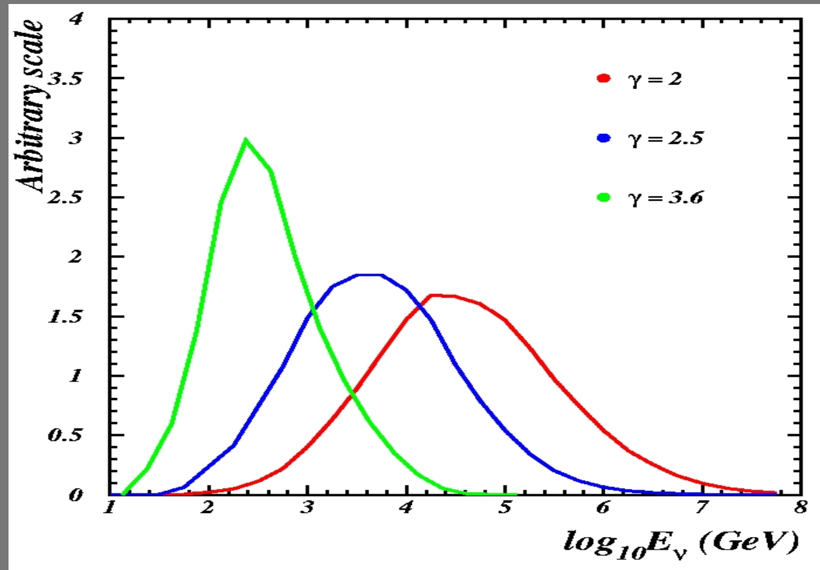

In addition to muons, EM showers can be identified.

Tau neutrinos can be identified by double bang events (production and decay).



# Effective Area and Energy response




Neutrino-nucleon cross-section

Neutrinos flux model

$$N_\mu = \int V_{eff}(E_\nu,\theta_\nu,\phi_\nu)\,(\rho\, N_A)\,\sigma(E_\nu)\,\frac{d\Phi_\nu}{dE_\nu d\Omega_\nu}\,dE_\nu\,d\Omega_\nu$$

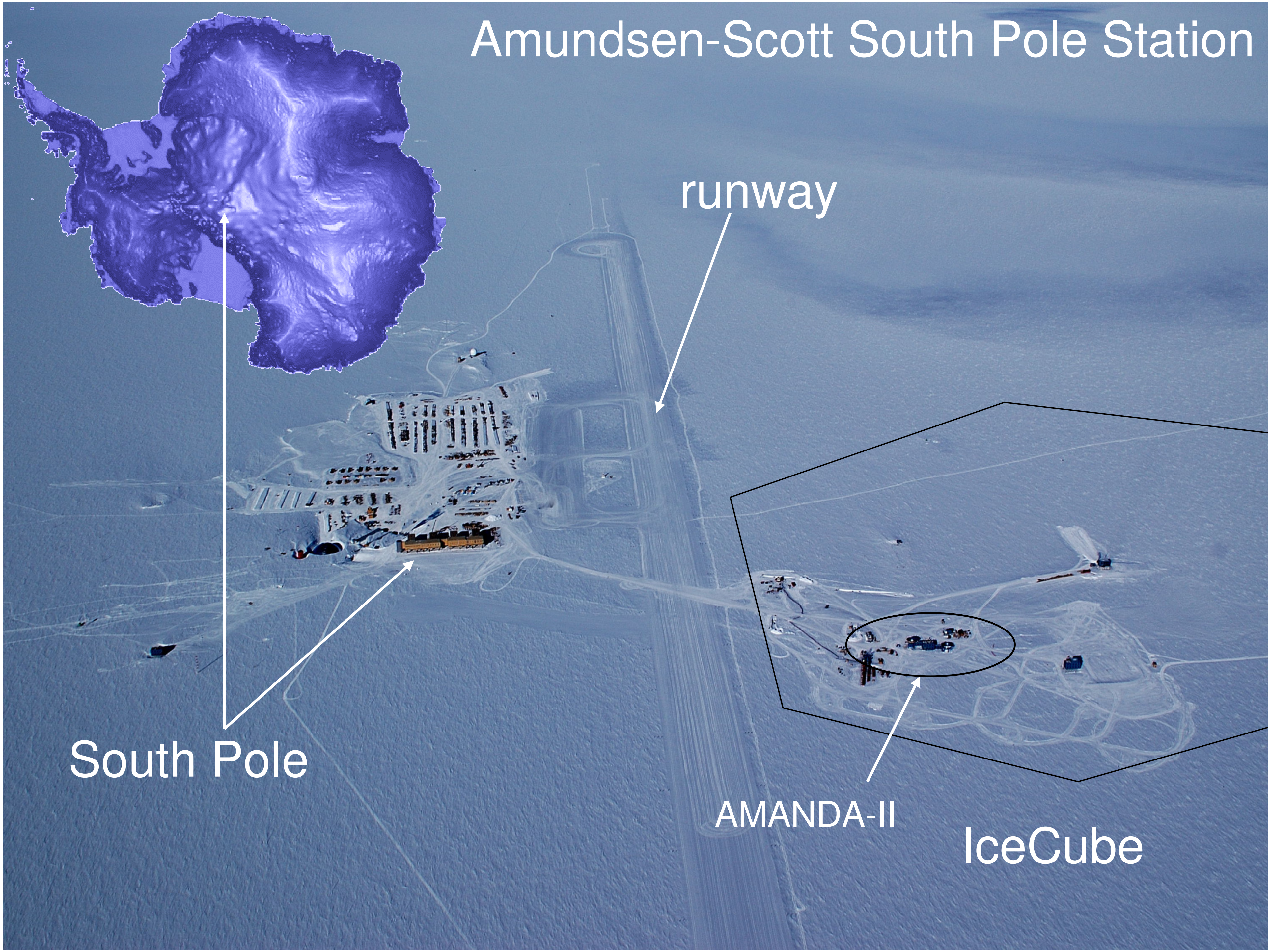
Target nucleon density

Shadowing effect

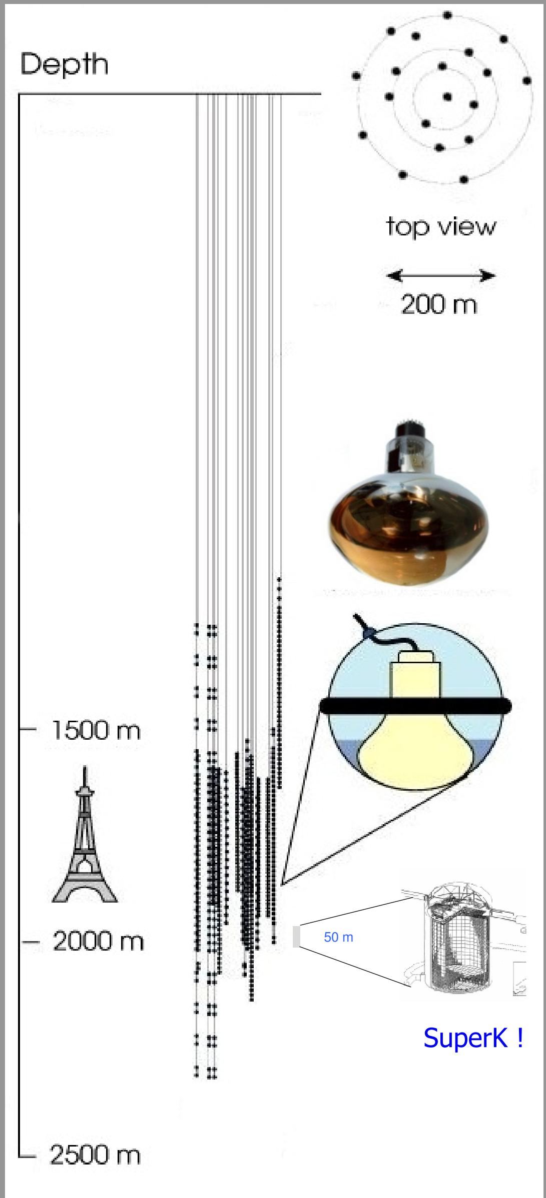
$$A^\nu_{eff} = V_{gen} \times \frac{N_{xxx}(E_\nu,\theta_\nu,\phi_\nu)}{N_{gen}(E_\nu,\theta_\nu,\phi_\nu)} \times (\rho\, N_A)\,\sigma(E_\nu) \times P_{earth}(E_\nu,\theta_\nu)$$

$$P_{earth}(E_\nu,\theta_\nu) = e^{-N_A\,\sigma(E_\nu)\int \rho\, dl}$$

$$N_\mu = \int A^\nu_{eff}(E_\nu,\theta_\nu,\phi_\nu)\,\frac{d\Phi_\nu}{dE_\nu d\Omega_\nu}\,dE_\nu\,d\Omega_\nu$$


Amundsen-Scott South Pole Station
runway
South Pole
AMANDA-II
IceCube

# AMANDA Detector




1997-99: **AMANDA-B10**
(inner lines of AMANDA-II)

- 10 strings
- 302 PMTs

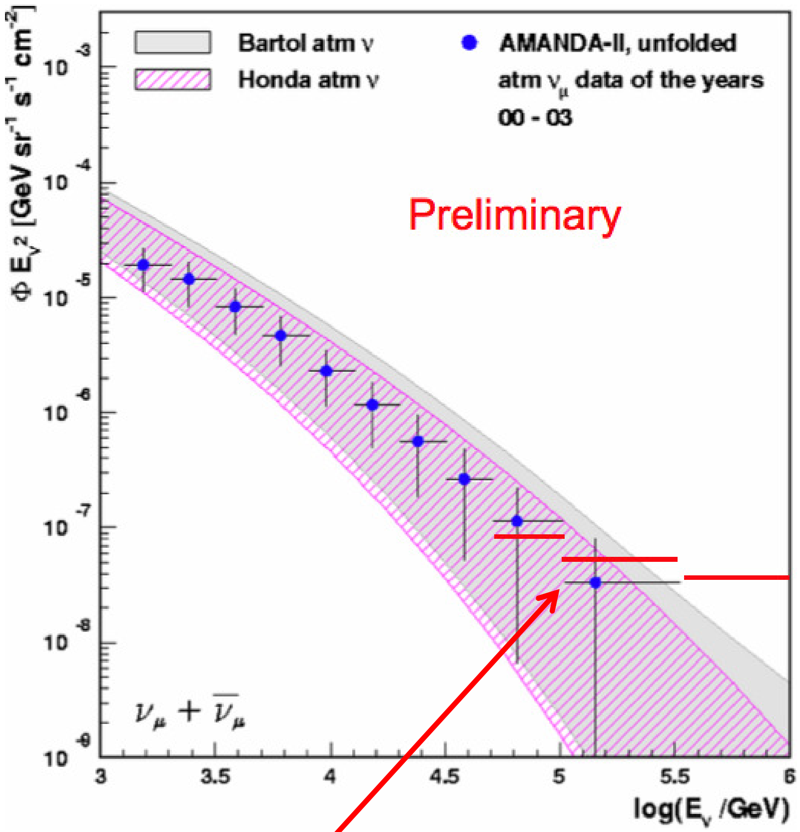
Since 2000: **AMANDA-II**

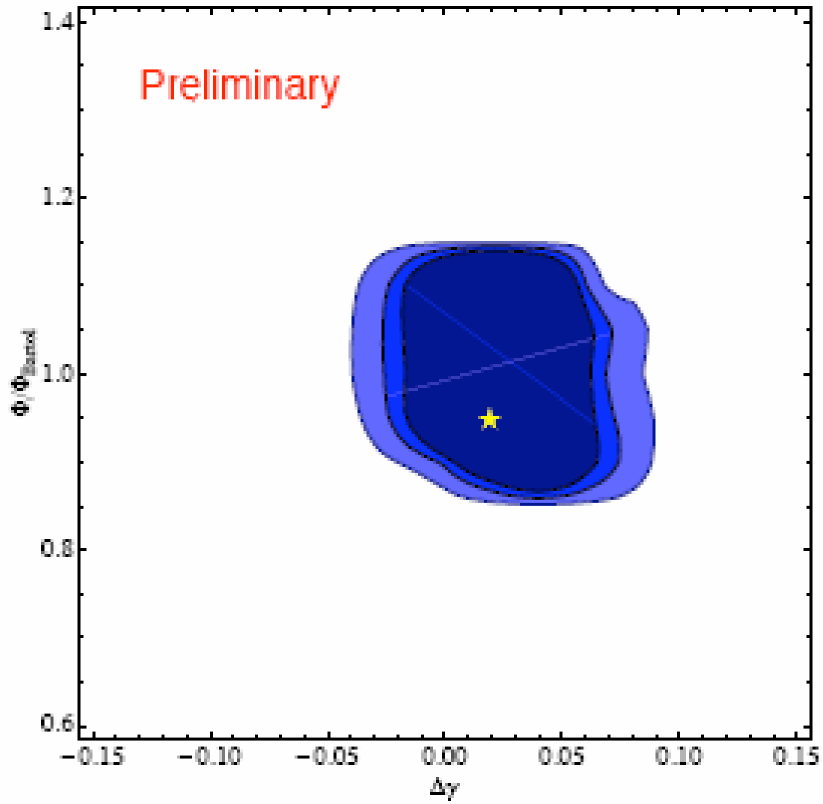
- 19 strings
- 677 OMs
- 20-40 PMTs / string

merged into IceCube

| Year | Livetime |
|---|---|
| 2000 | 197 d |
| 2001 | 193 d |
| 2002 | 204 d |
| 2003 | 213 d |
| 2004 | 194 d |
| 2005 | 199 d |
| 2006 | 187d |
| **Total** | **3.8 years** |

# Diffuse flux limits



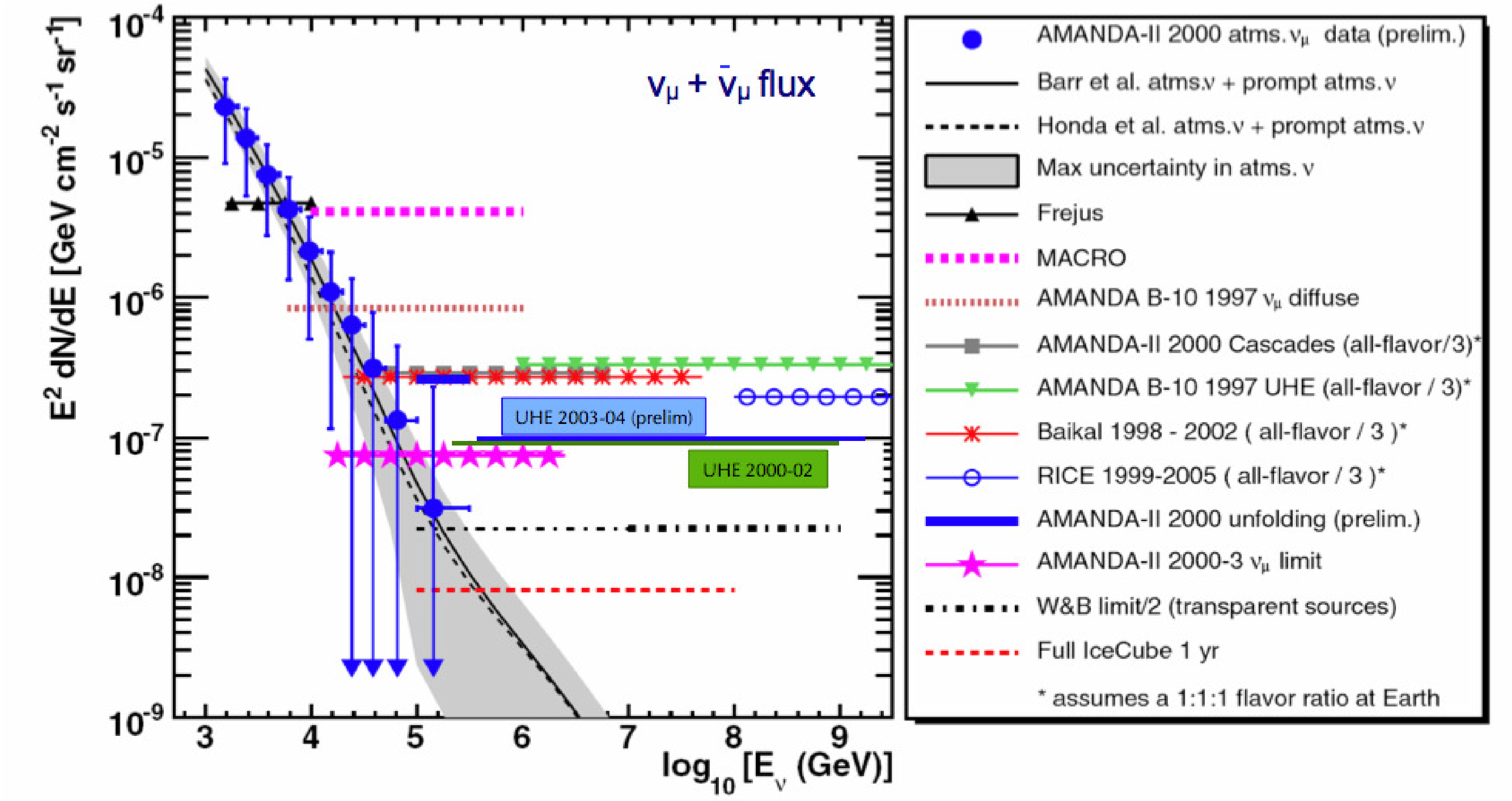




Limits on a possible $E^{-2}$ component

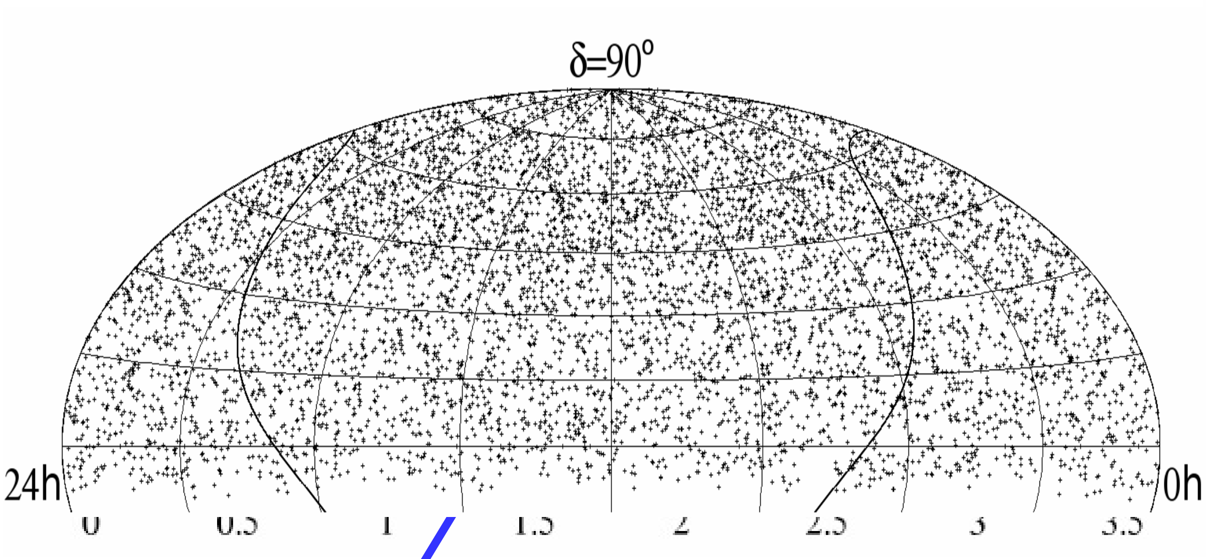
Expected precision (90%, 95% and 99% C.L.) in flux (wrt Bartol) and spectral index for the whole AMANDA data set.

# Diffuse fluxes

From the lack of excess wrt atmospheric limits can be set on neutrino diffuse fluxes assuming $E^{-2}$ spectrum



# AMANDA
# Point sources




Equatorial sky map of 6595 events recorded by AMANDA-II in 2000-2006

The most significant point has 3.4σ but this should happen 95% of the time with the present statistics.

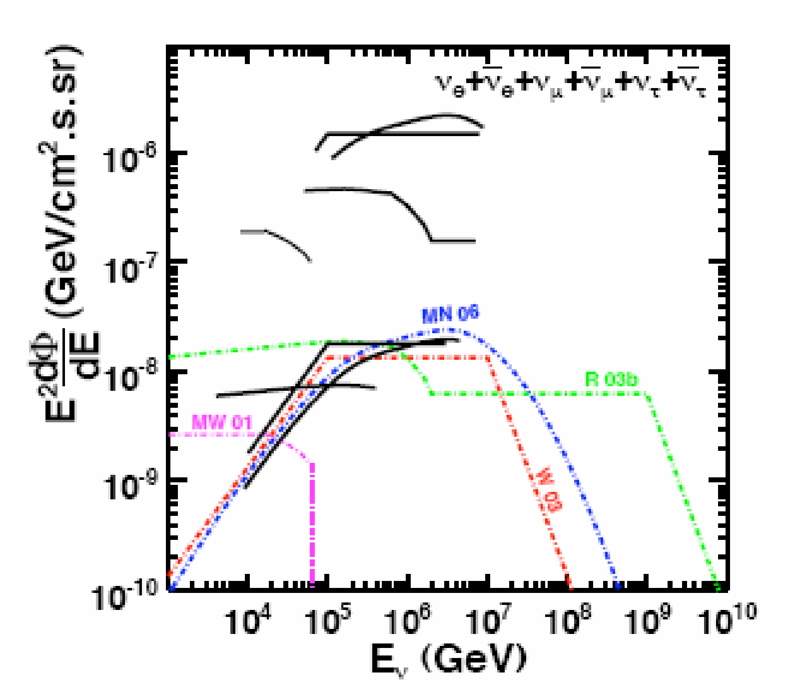
26 sources selected for search

| Source | $\Phi_{90}$ | $p$-value |
|---|---|---|
| Crab Nebula | 9.27 | 0.10 |
| MGRO J2019+37 | 9.67 | 0.077 |
| Mrk 421 | 2.54 | 0.82 |
| Mrk 501 | 7.28 | 0.22 |
| LS I +61 303 | 14.74 | 0.034 |
| Geminga | 12.77 | 0.0086 |
| 1ES 1959+650 | 6.76 | 0.44 |
| M87 | 4.49 | 0.43 |
| Cygnus X-1 | 4.00 | 0.57 |

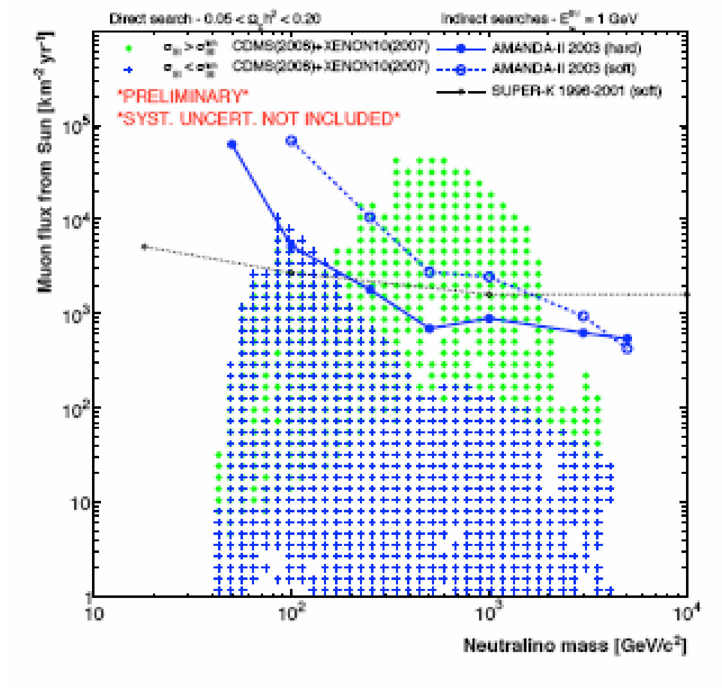
For 26 sources, $p \leq 0.0086$ occurs 20% of the time for at least one source.

$$E^2 \Phi_{\nu_\mu+\nu_\tau} < \Phi_{90} \times 10^{-11}\, TeV\, cm^{-2}\, s^{-1}$$

# Other searches




No coincidence of ν cascade events with 73 GRBs in all the sky. Limits on several GRB models.




Indirect limits on neutralino annihilation in the Sun (soft or hard annihilation)

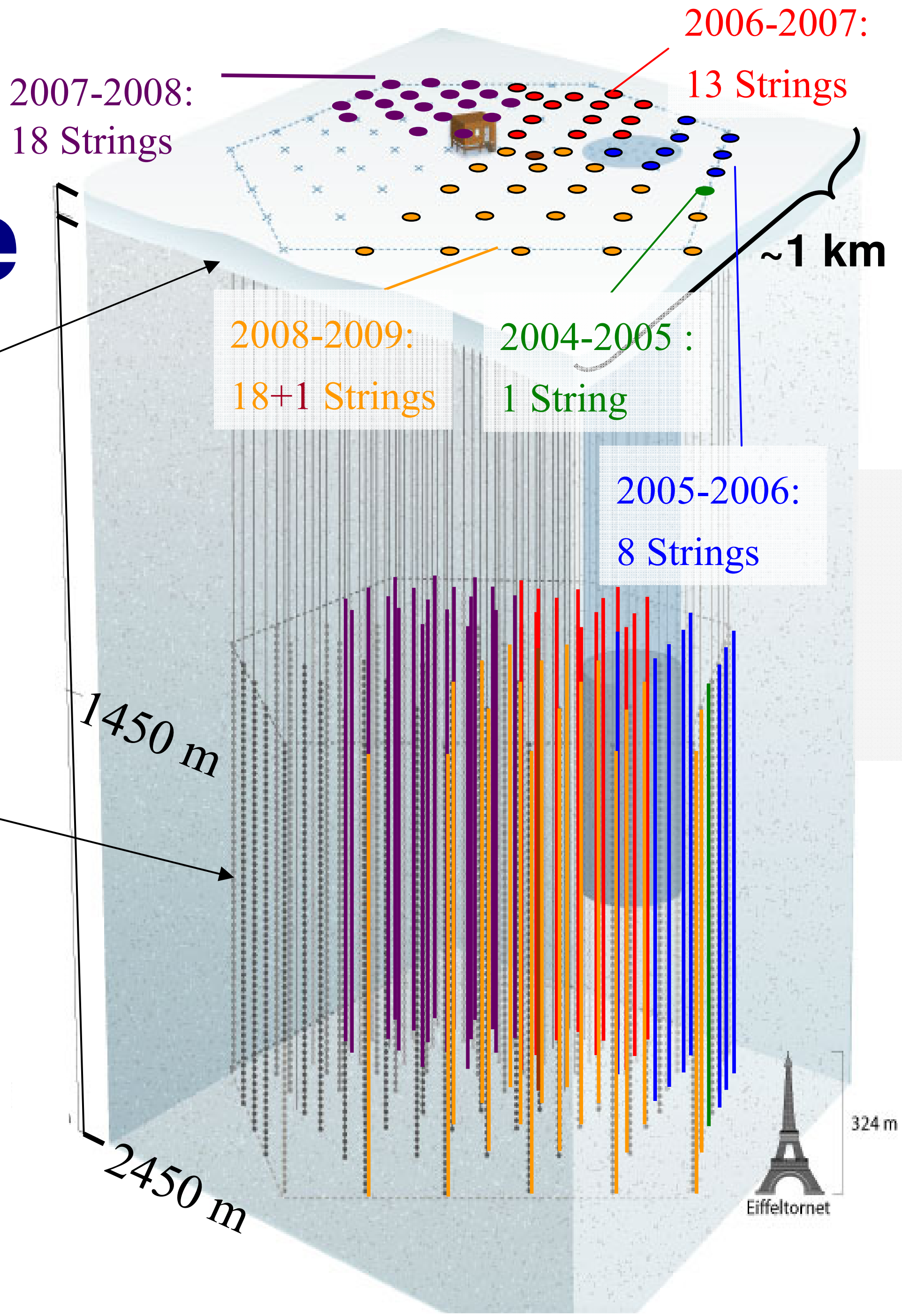
# IceCube

## IceTop

80 pairs of ice
Cherenkov tanks
Threshold ~300 TeV

## InIce

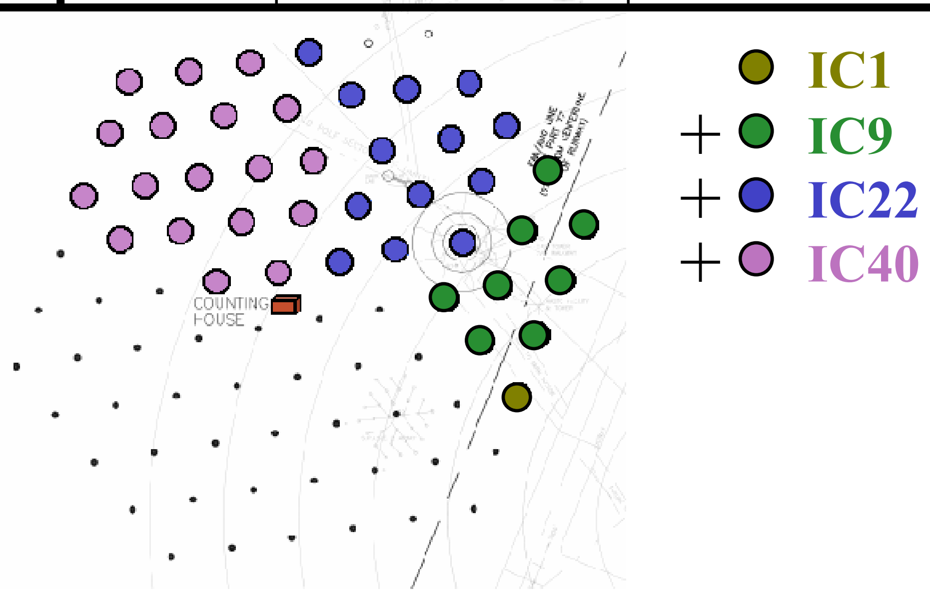
80 strings with 60 OMs
17 m between OMs
125 m between strings
1 km$^3$. A 1-Gton detector



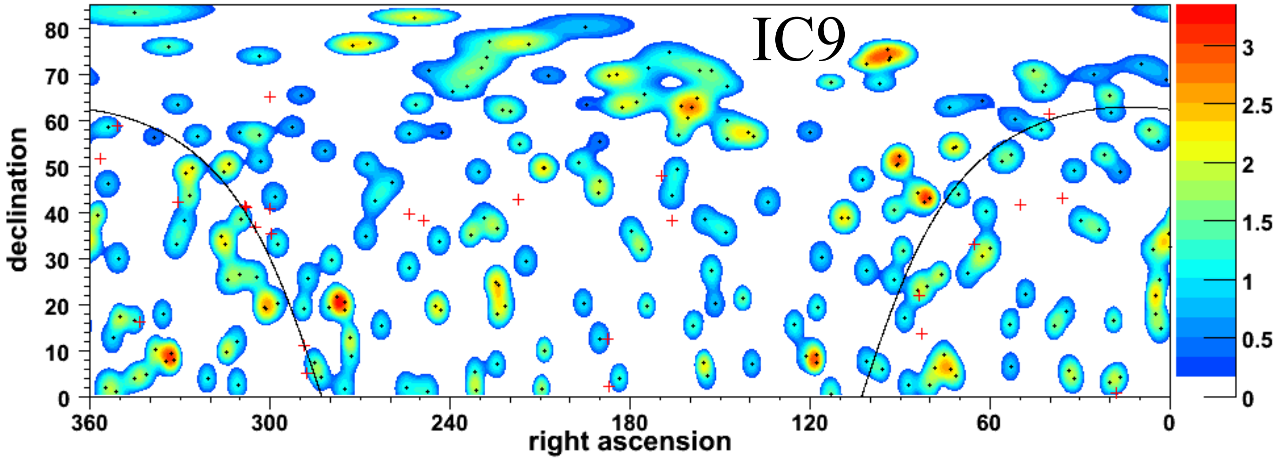

**At present a total of 59 strings (74% of detector) Full detector by 2011**

# IceCube Datasets

| #Strings | Year | Run Length | CR $\mu$ Rate | $\nu_\mu$ rate |
|---|---|---|---|---|
| IC1 | 2005 | 164 days | 5 Hz | ~0.01/day |
| IC9 | 2006 | 137 days | 80 Hz | ~ 1.5/day |
| IC22 | 2007 | 319 days | 550 Hz | ~ 20/day |
| IC40 | 2008 | ~ 1year | 1400 Hz | |
| IC%9 | 2009 | | | |
| IC80 | 2011 | 10 years | 1650 Hz | ~ 200/day |

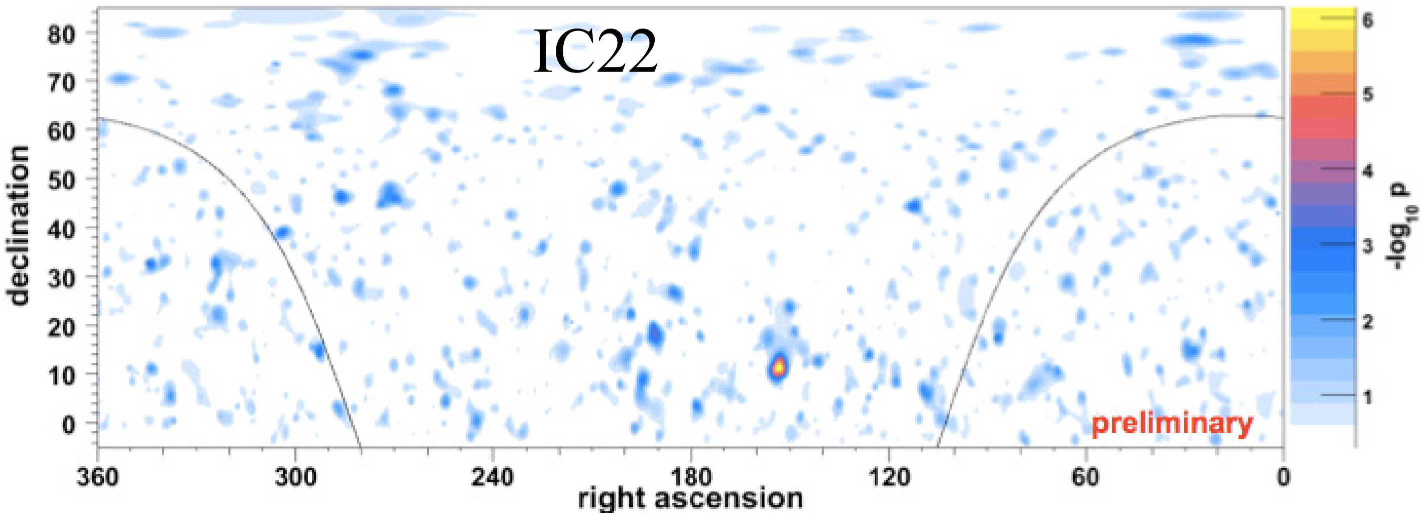


# IceCube Point Source Searches

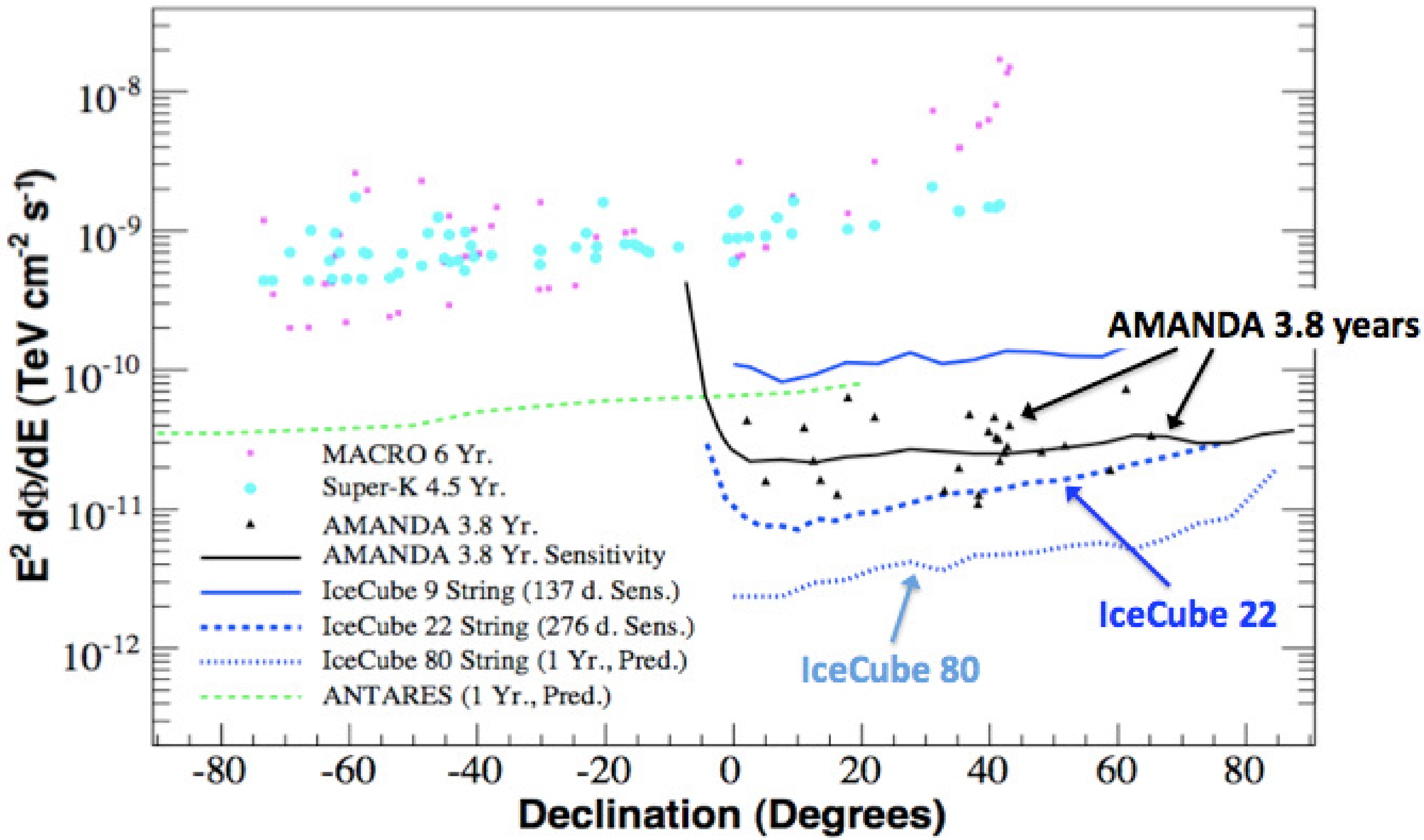


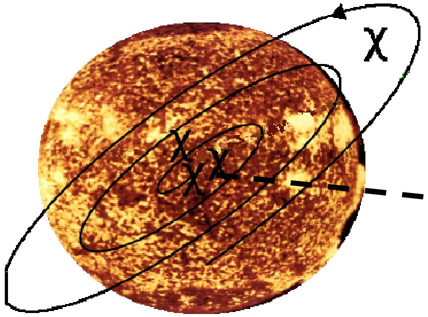

- 26 a priori source locations
- 60% of random datasets had a sigma higher than 3.35σ - no excess seen

- Unbinned likelihood + energy information
- Hottest spot at r.a.153º, dec.11º
- p-value (pre-trials): $7\times10^{-7}$ (4.8σ)
- p-value (post-trials) 1.34% (2.2σ)
- Consistent with background fluctuation

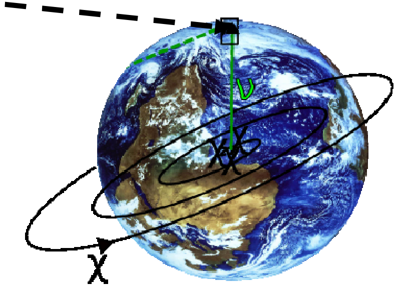


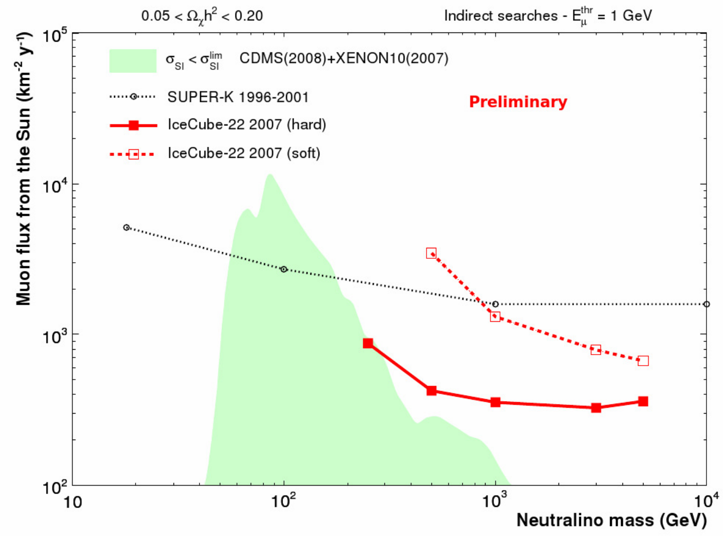
# Flux Limits for Point Sources



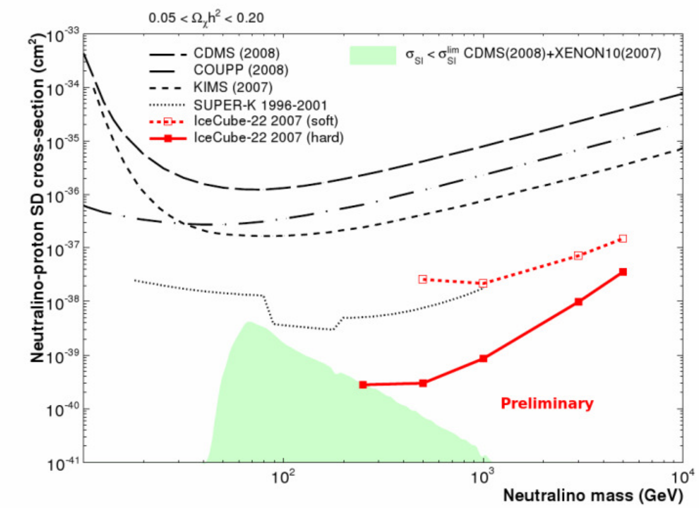



# Indirect search for WIMPs

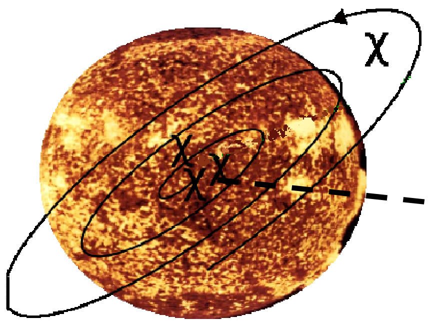


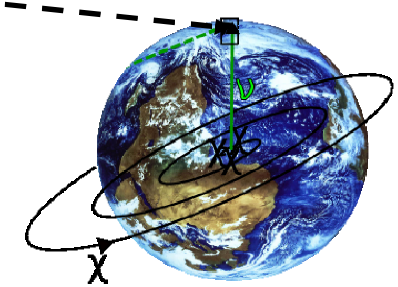

No excess with IC22
90% CL limit (from Sun)

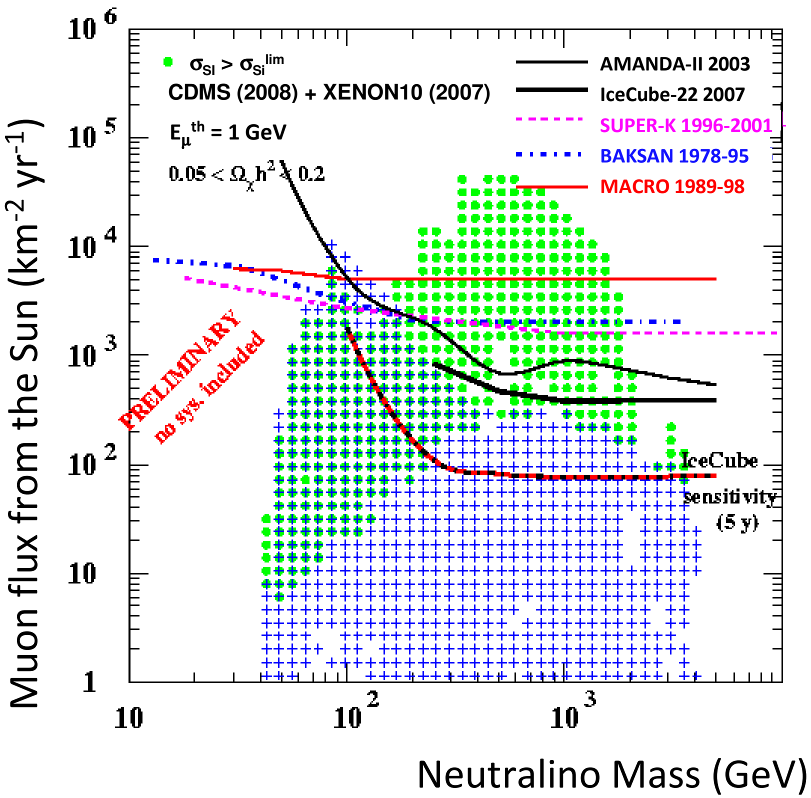



IC22: Best limit for
spin-dependent cross-section




# Indirect search for WIMPs



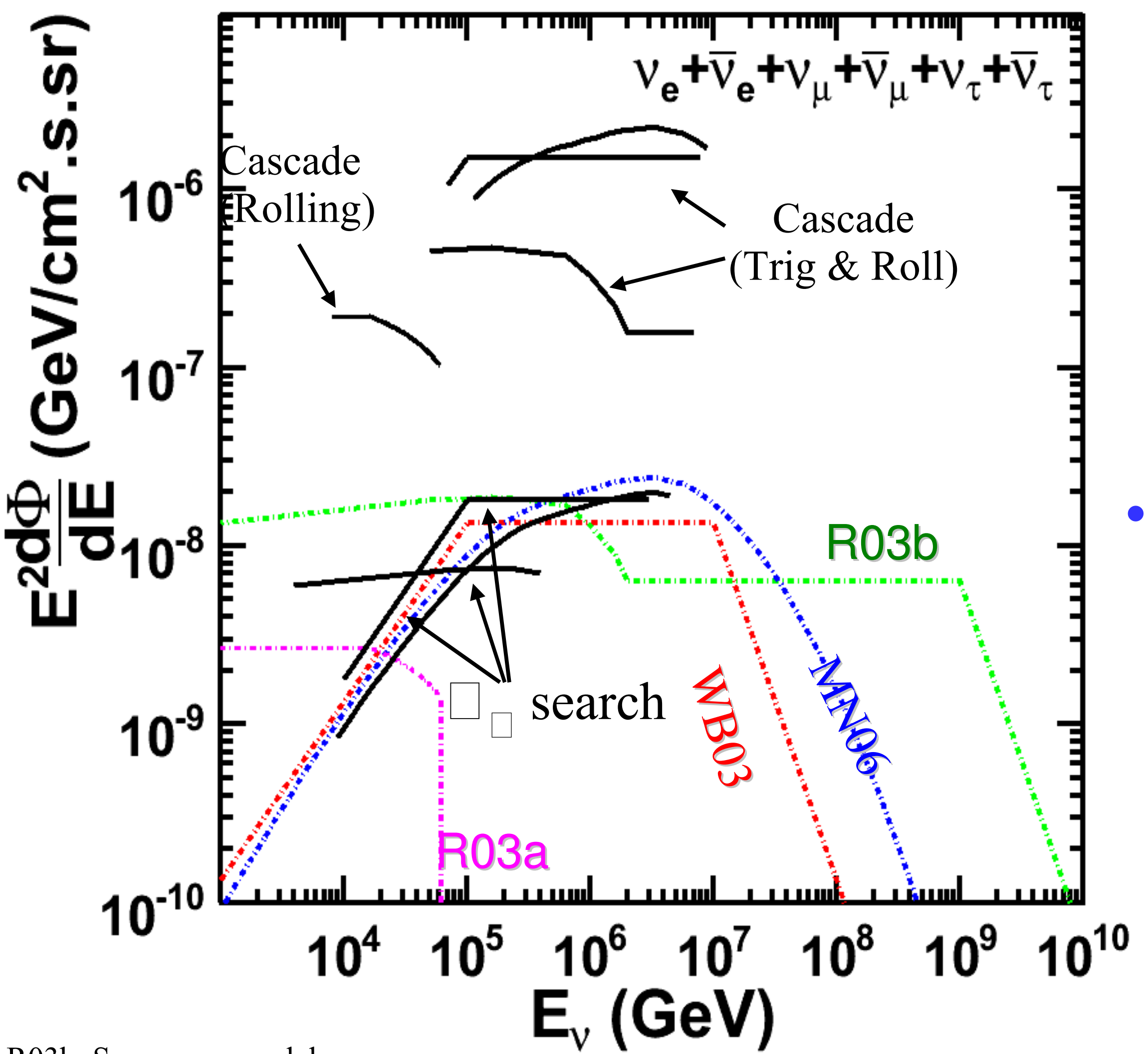




● models disfavoured by direct searches

+ models **not** disfavoured by direct searches

Full IceCube 5-years:

# GRBs in AMANDA & IceCube



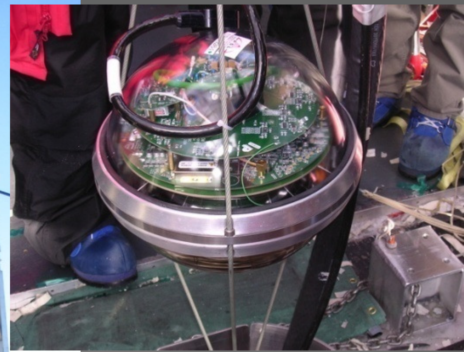

- **AMANDA**
  - $\nu_\mu$ search
    - Over 400 GRBs in Northern Hemisphere
  - Cascade search
    - Triggered search for 73 GRBs in both hemispheres
    - Rolling search for 2001-2003
- **IceCube**
  - 93 SWIFT bursts during IC22
  - GRB080319B: brightest (optical) burst ever
    - ~0.1 $\nu_\mu$ events predicted in IC22 using fireball model
    - ~1 $\nu_\mu$ event predicted for equivalent burst in IC80

R03b: Supranova model
WB03: Waxman-Bahcall model
R03a: Choked Burst model
MN06: Murase Nagataki model

IceCube will be able to detect Waxman-Bahcall or similar GRB fluxes within the next few years

# IceCube construction
# A logistic exploit

500 Tons of material
brought to South Pole

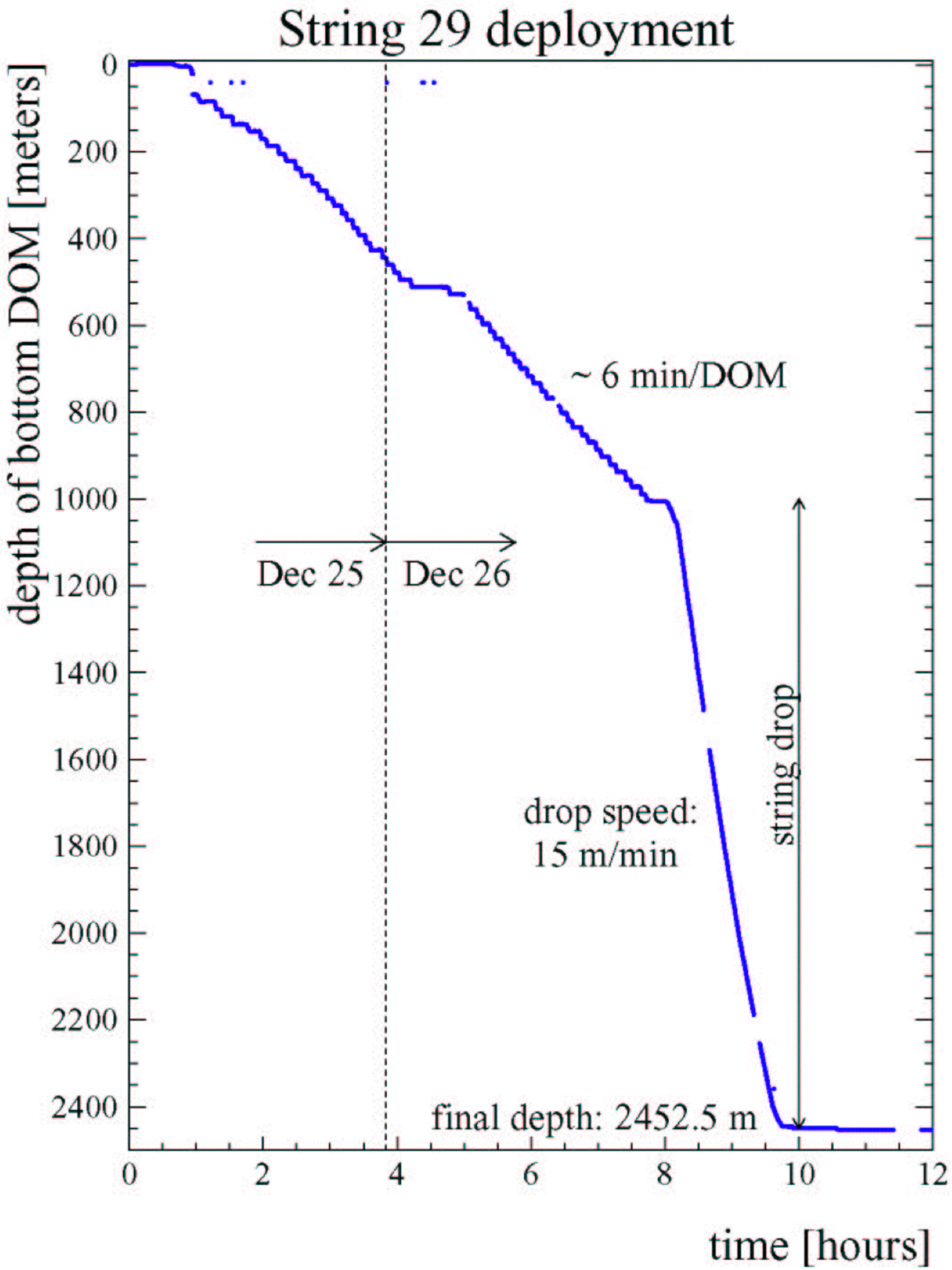


A 5 MW power plant

Unprecedented drilling
capabilities

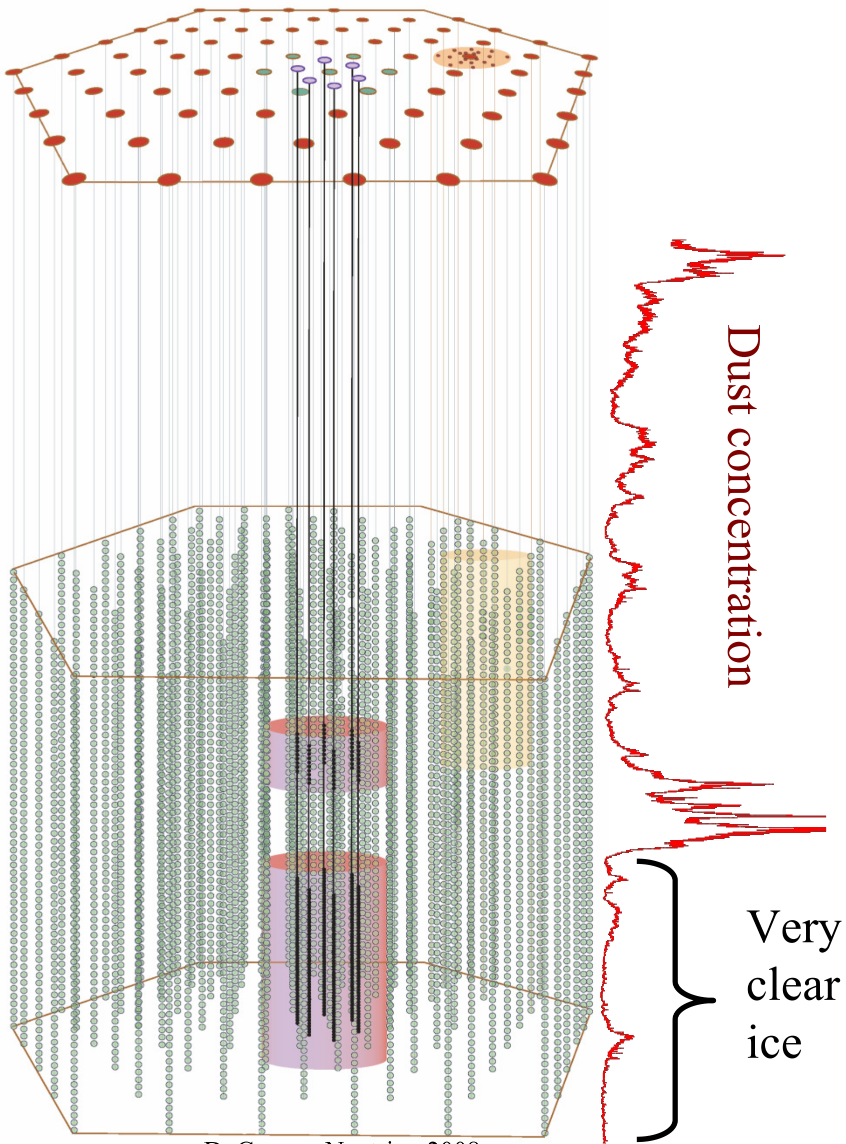
More than 50 flights

## String cable 2500 m   Weight ~6 tons

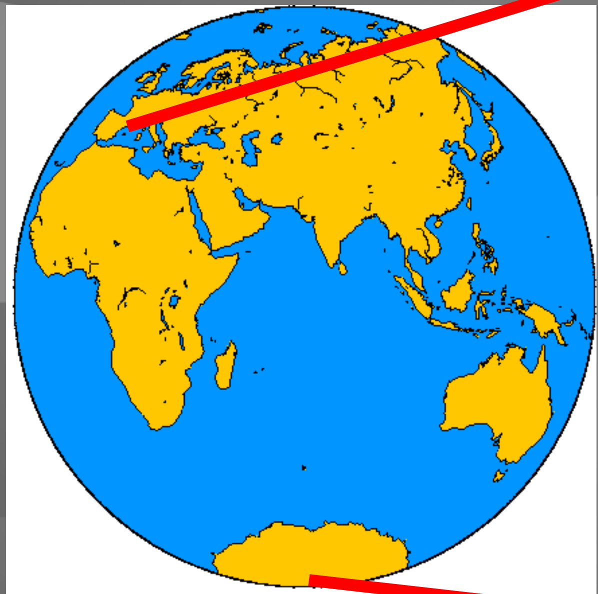
# Future Plans

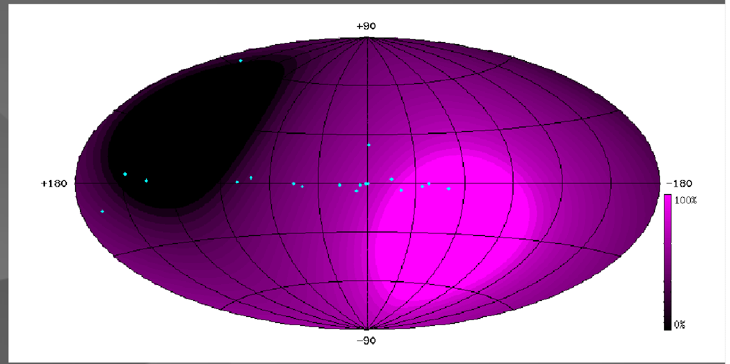
- Deep Core
  - Greatly enhances IceCube sensitivity to lower energy ν's
    - Lower mass solar WIMPs
    - Atmospheric neutrinos
  - Six new strings
    - 60 high QE DOMs in clear ice
    - First string deployed 08/09,
    - Remaining strings deployed 09/10
- Multi-messenger astronomy
  - Correlations with ROTSE, AGILE, MAGIC, and LIGO
- New Technologies
  - 3 Prototype digital radio strings deployed with IceCube strings
  - 4 Hydrophones deployed above IceCube



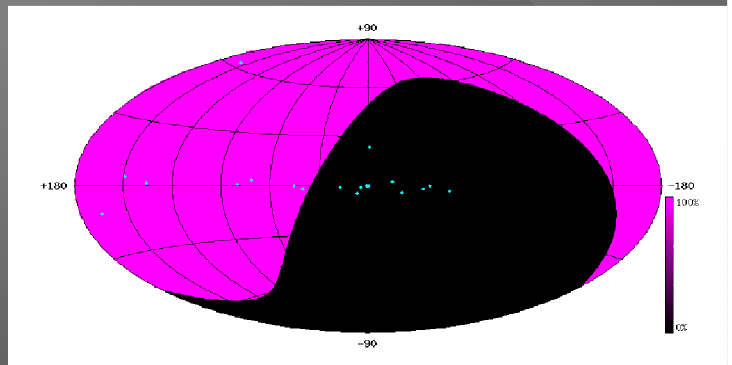

D. Cowen, Neutrino 2008

# Telescopes in the Northern Hemisphere






ANTARES
43$^{o}$ North
2/3 of time: Galactic Centre



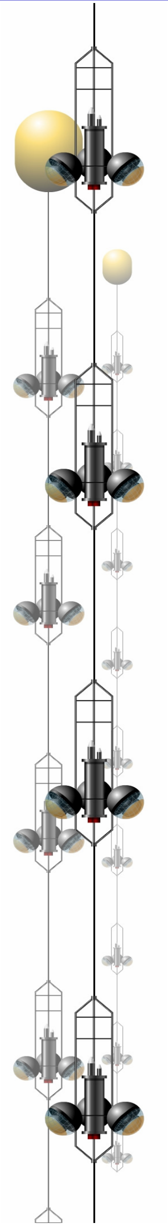

0.5 $\pi$ sr instantaneous common view
1.5 $\pi$ sr common view per day

AMANDA/IceCube
South Pole

> 25%

> 75%

# The Antares collaboration



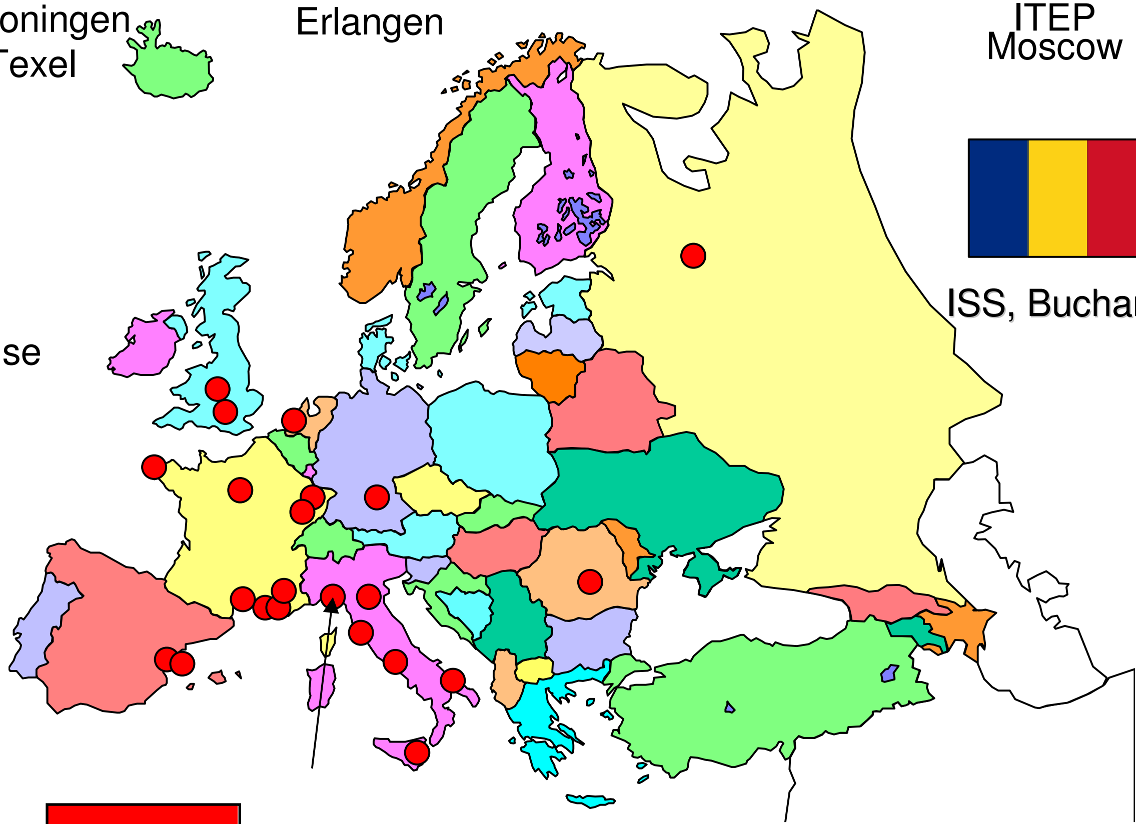
NIKHEF Amsterdam
KVI Groningen
NIOZ Texel

Erlangen

ITEP
Moscow

APC Paris
IFREMER, Brest
DAPNIA, Saclay
IReS, Strasbourg Mulhouse
CPPM Marseille
IFREMER,Toulon
COM, Marseille
OCA, Nice

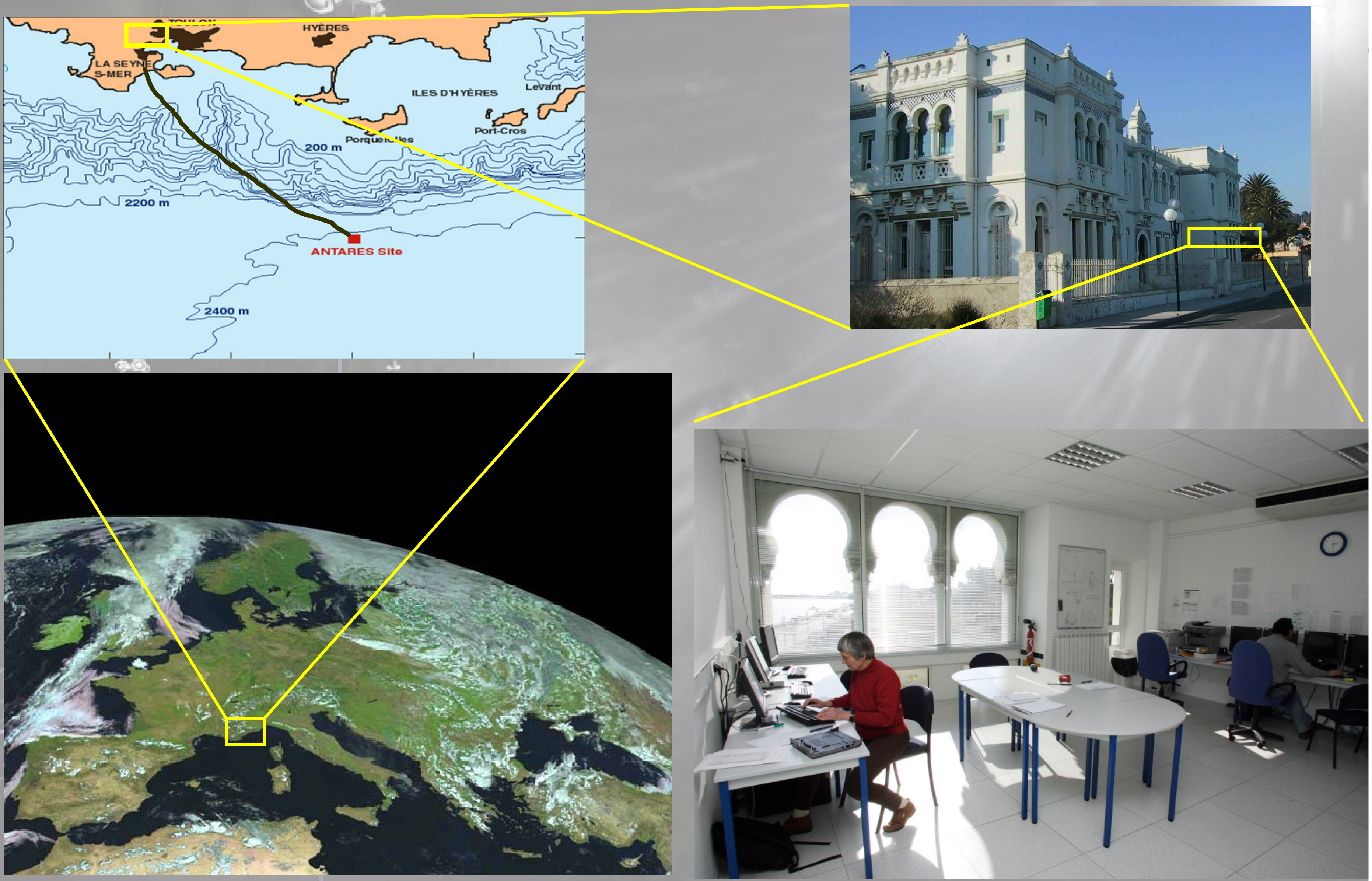
ISS, Bucharest



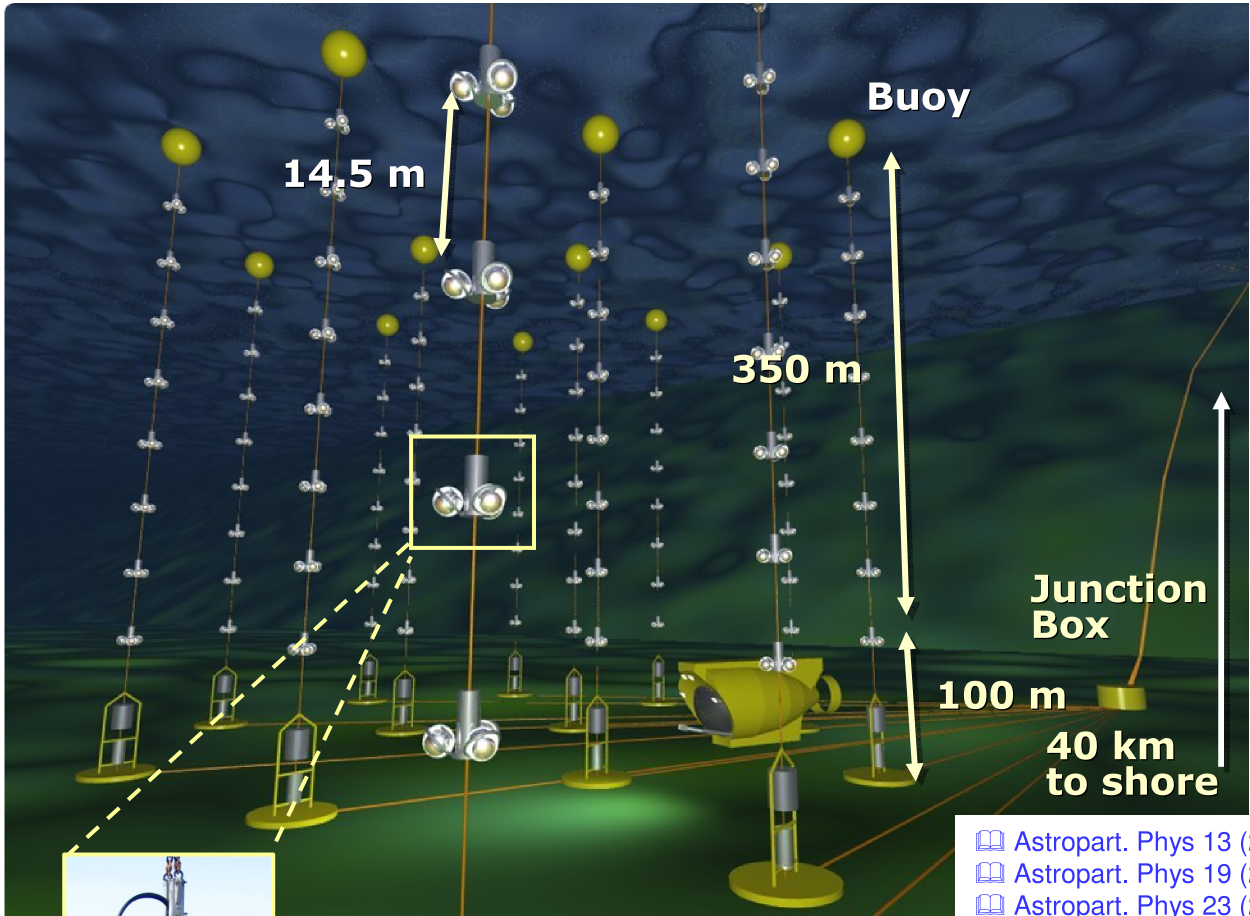
INFN Bari
INFN Bolgna
INFN Catania
INFN Genova
LNS
INFN Pisa
INFN Roma

IFIC Valencia
UPV

**7 countries, 25 institutes,**
**~150 engineers, sea scientists**
**& physicists**

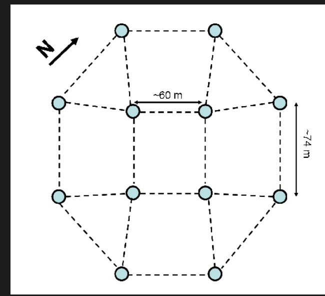

HYÈRES
LA SEYNE
S-MER
ILES D'HYÈRES
Levant
Port-Cros
200 m
2200 m
ANTARES Site
2400 m

# The Antares Telescope

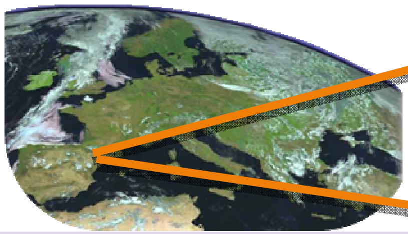



–12 lines (900 PMTs)
–25 storeys / line
–3 PMTs / storey

Horizontal layout

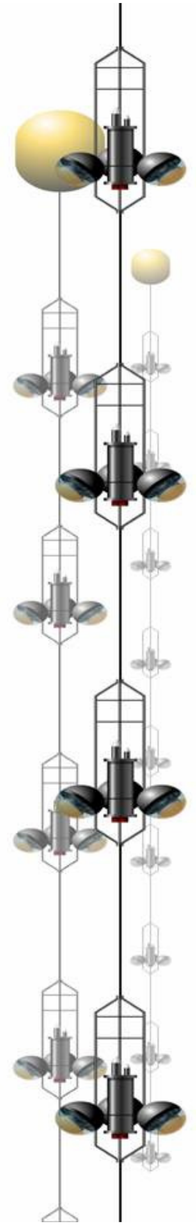


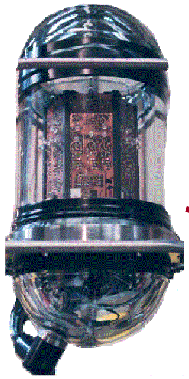

Astropart. Phys 13 (2000) 127-136 (Background light)
Astropart. Phys 19 (2003) 253-267 (Sedimentation & Fouling)
Astropart. Phys 23 (2005) 131-155 (Light transmission)



The detector is located in the Mediterranean Sea (42º50'N, 6º10'E) at **2500 m** depth, in the south coast of Toulon (France).

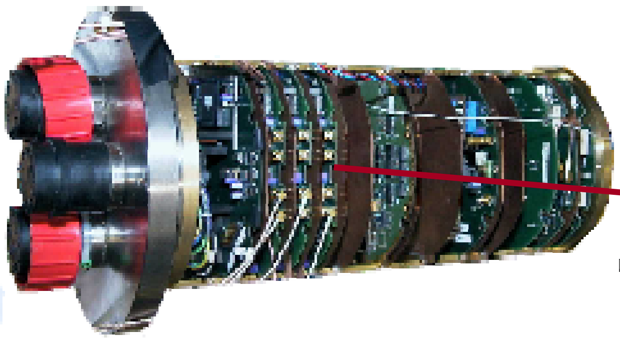
# Basic detector element: storey

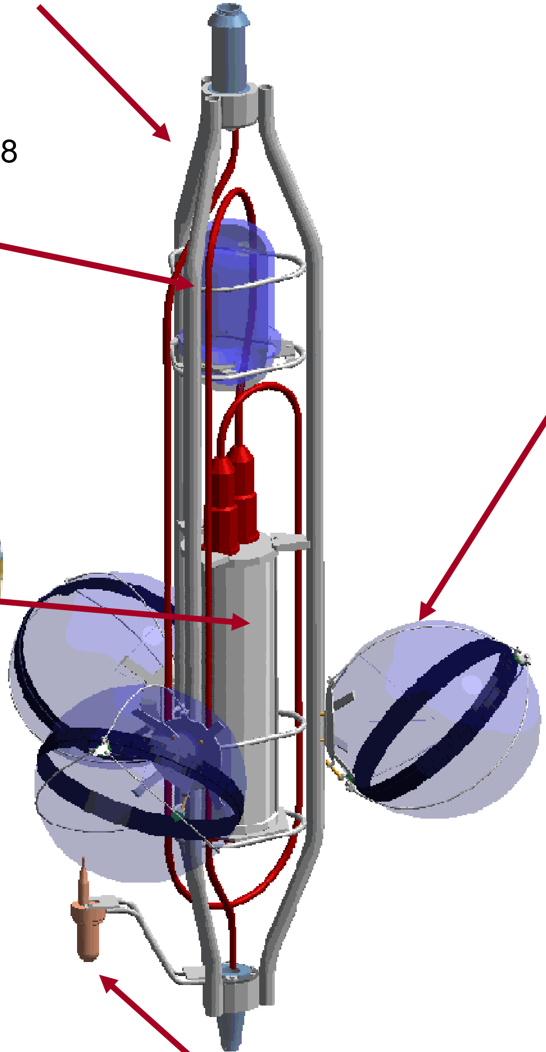


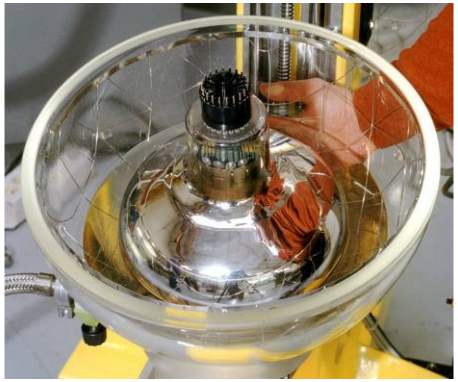


Titanium frame: *support structure*

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





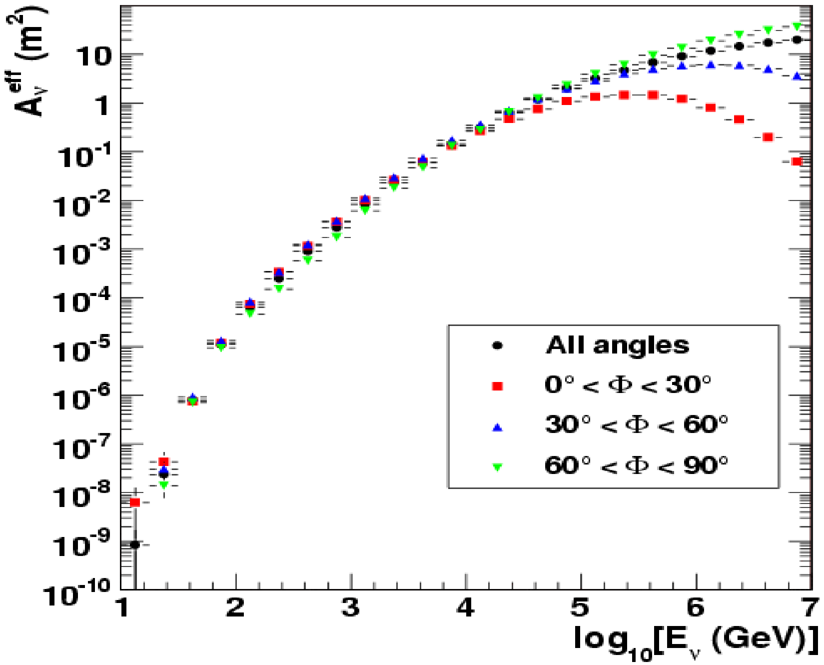


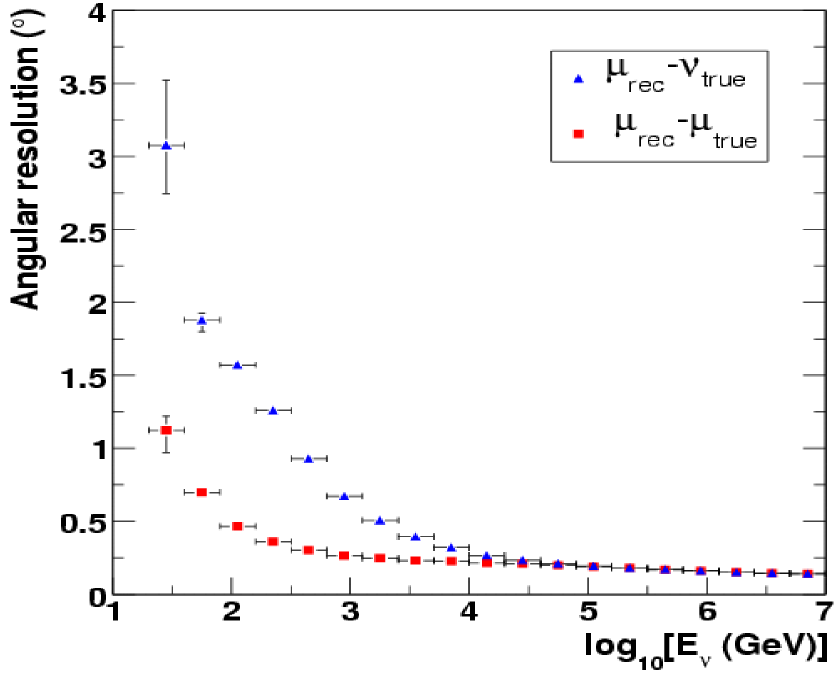
Optical Module:
10″ Hamamatsu PMT in
17″ glass sphere
*photon detection*
📖 NIM A484 (2002) 369
📖 NIM A555 (2005) 132

Local Control Module (Ti):
*Front-end ASIC, DAQ/SC, DWDM,*
*Clock, tilt/compass, power distribution…*

Hydrophone:
*acoustic positioning*

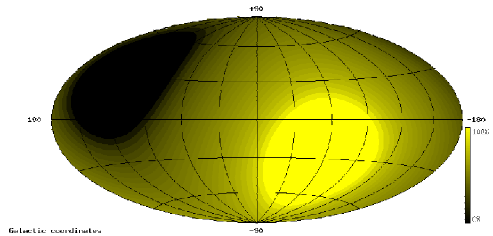
# Detector performance



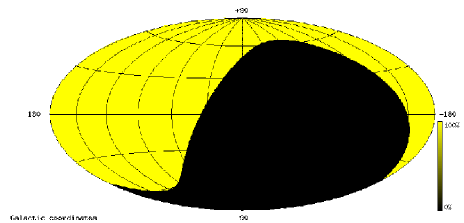




- **Neutrino effective area** is **> 1 m²** for energies > 100 TeV
- **Angular resolution** better than **0.3°** above a few TeV,.

***Sky view***



***Antares/KM3NeT***



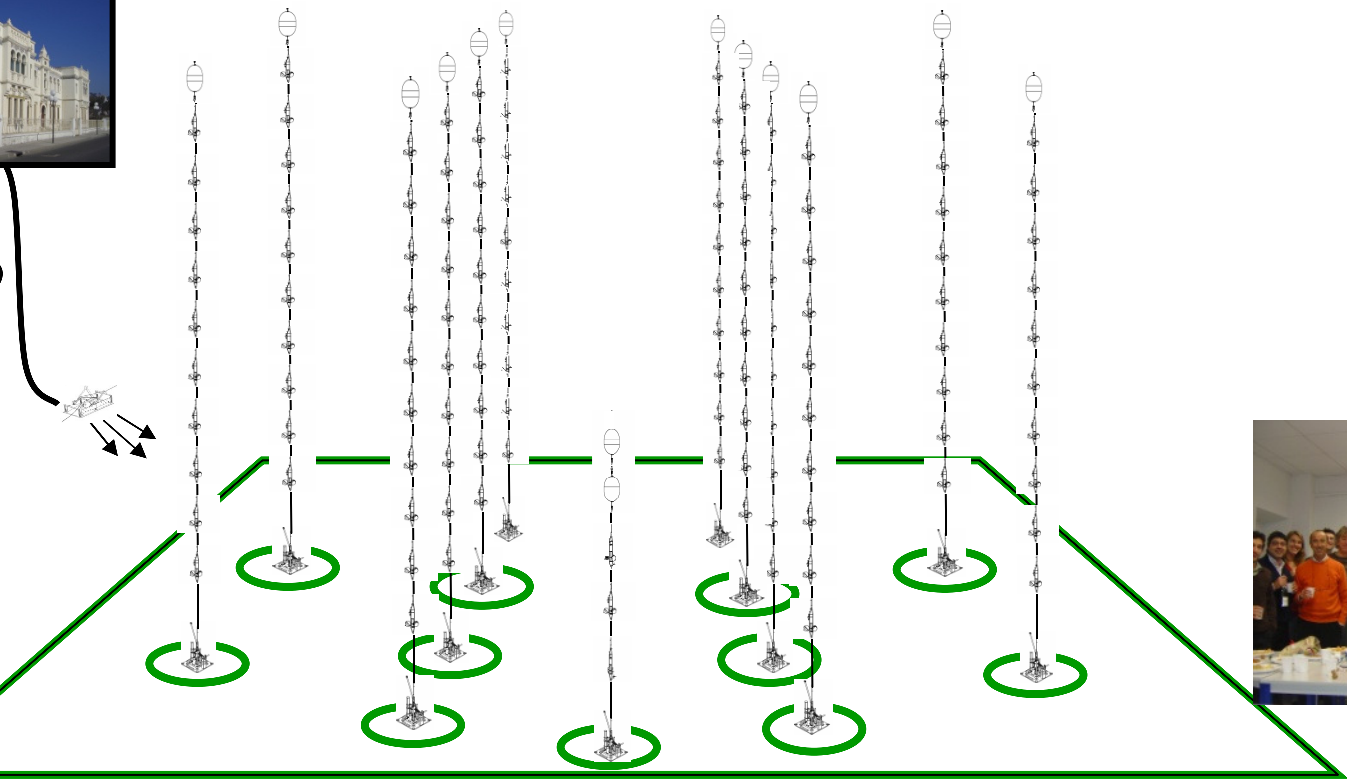
***Amanda/IceCube***

# Deployment

**Data taking periods:**

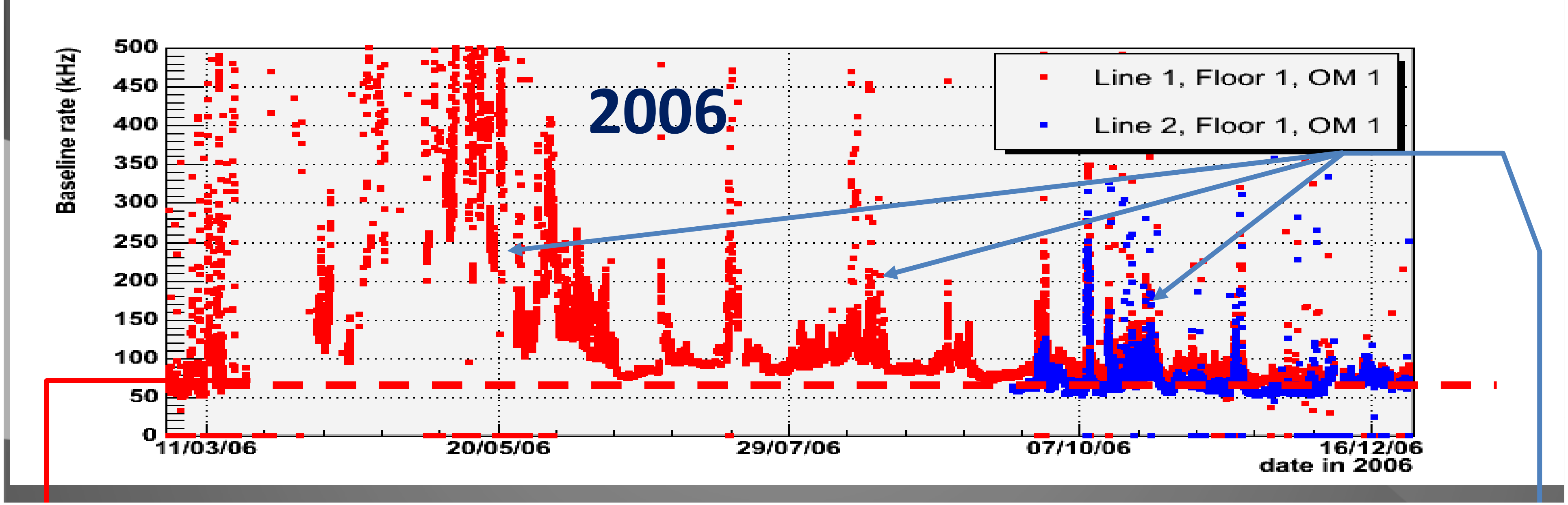
- ***MILOM : Mar ’05 – Mar ‘06***

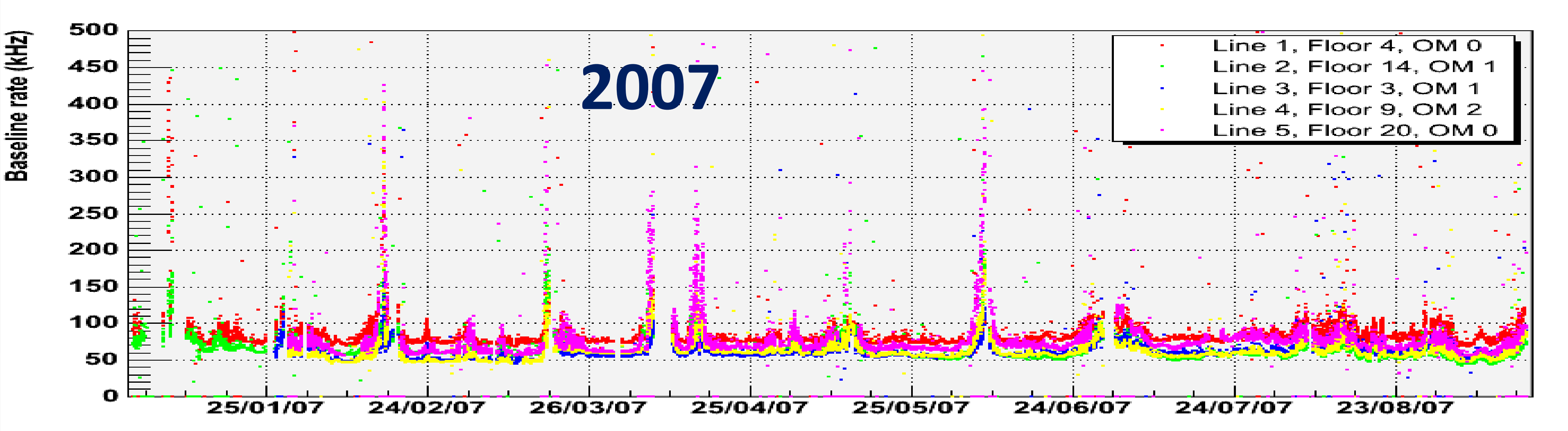
*La Seyne-sur-Mer*



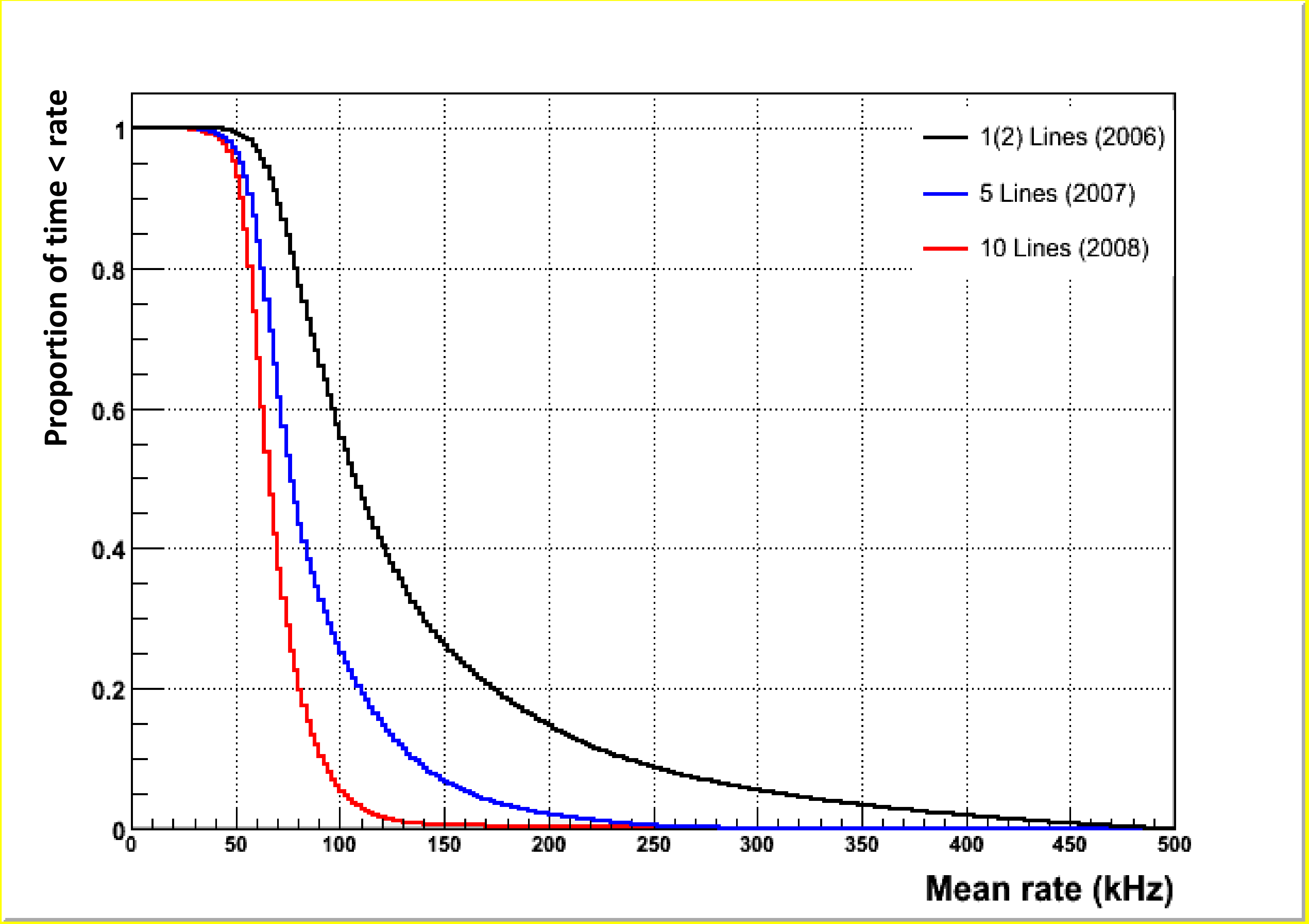

*(2.5 km depth)*

# Optical background

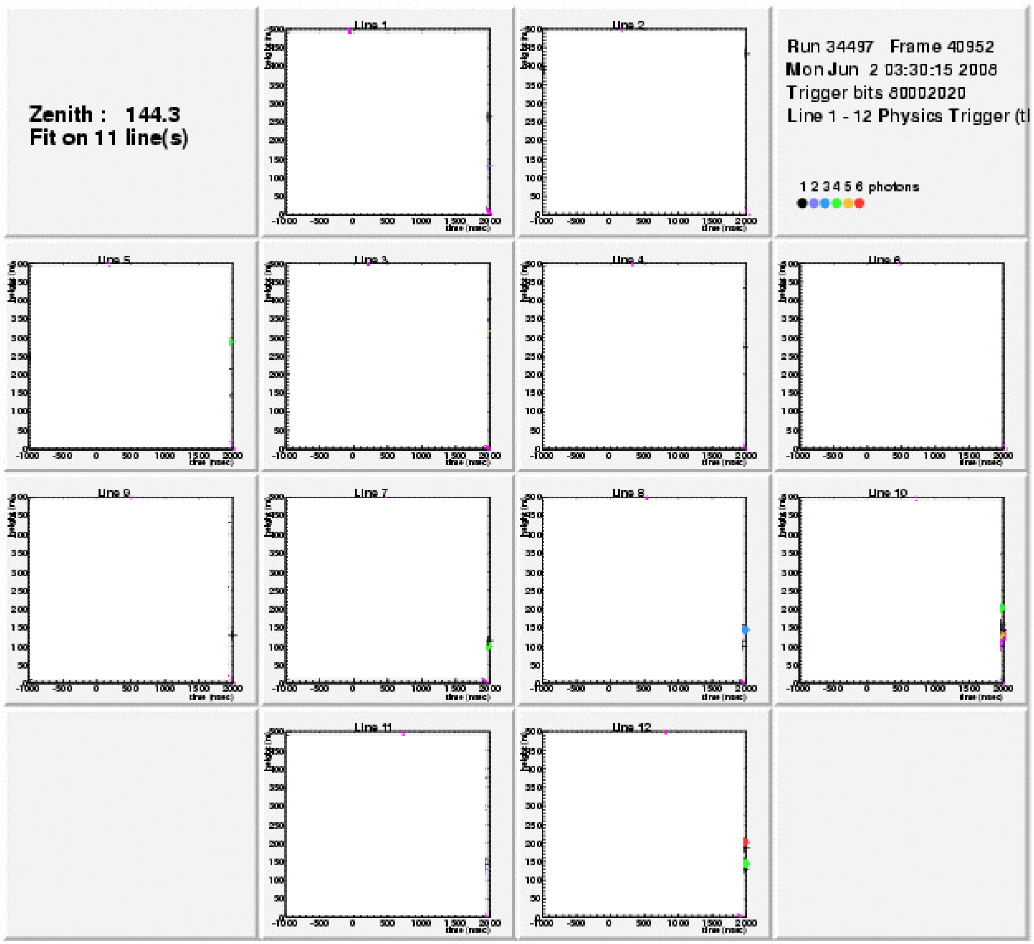


# Optical background

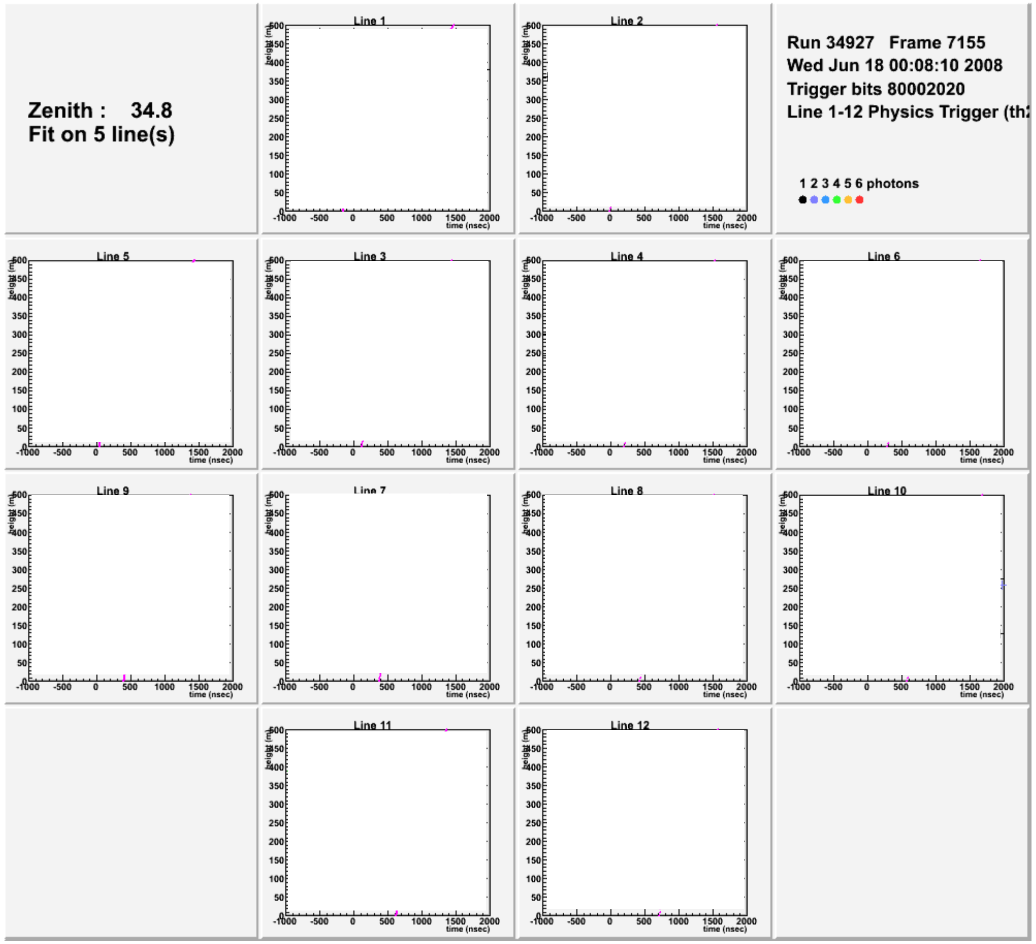


# (multi-) Muon Event

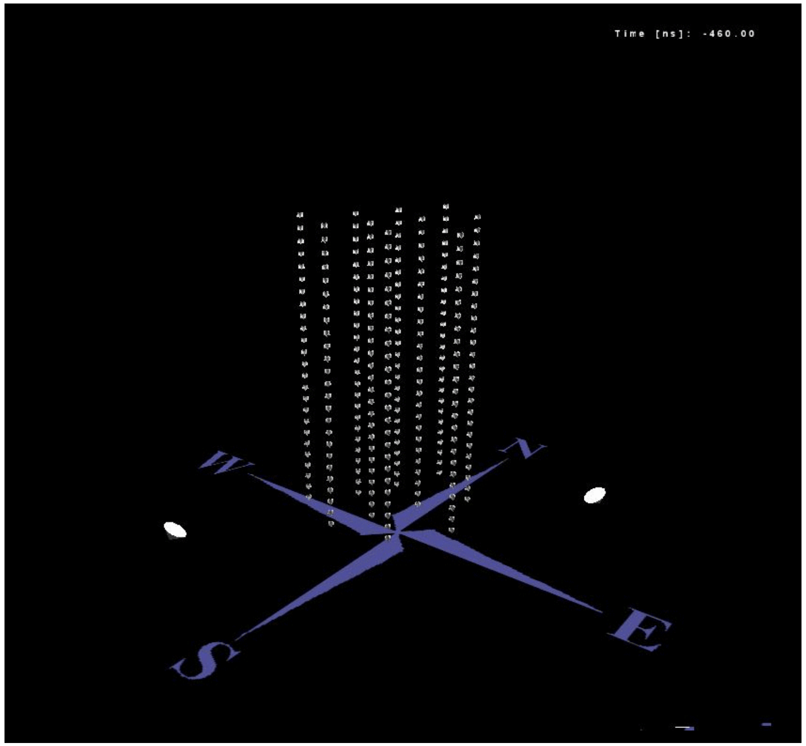



***Example of a reconstructed down-going muon, detected in all 12 detector lines:***

# Neutrino candidate

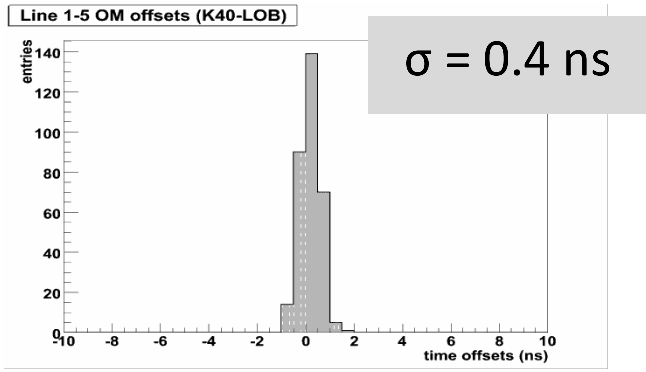


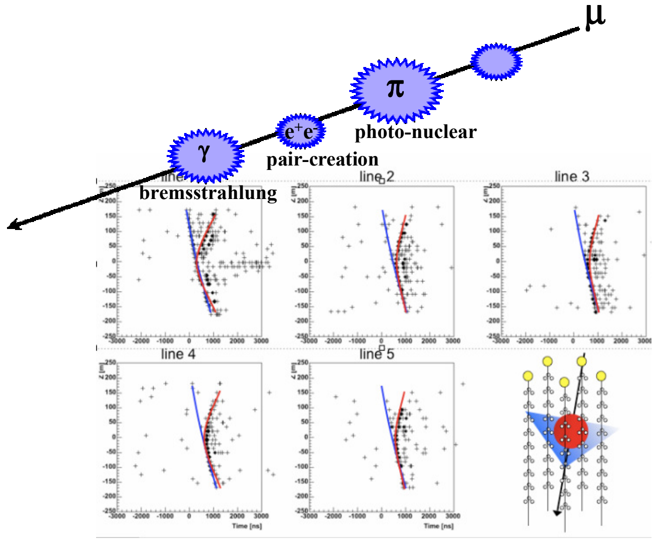

***Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:***

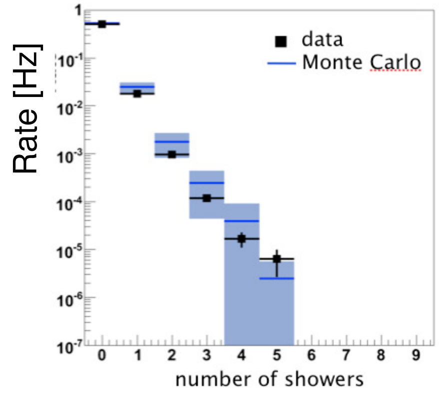


## Showers from μ's can be reconstructed

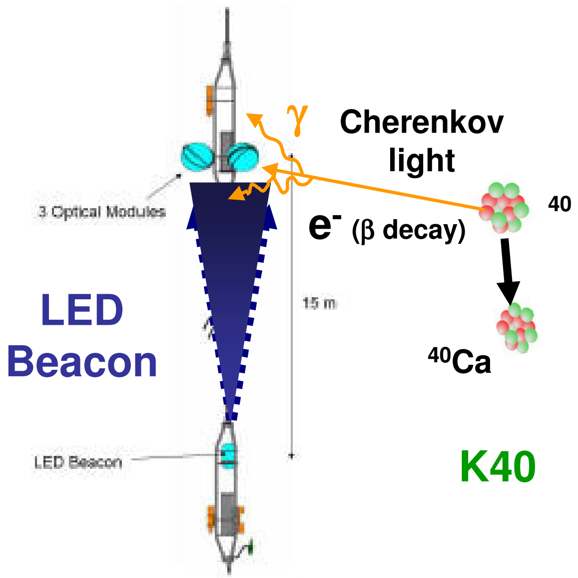
LED beacons – K40

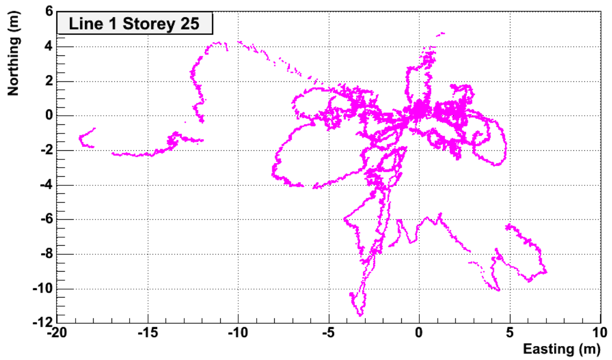


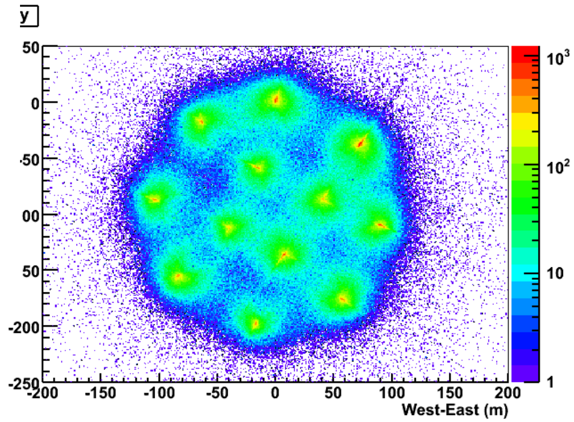

## Time calibrated to < 0.5 ns



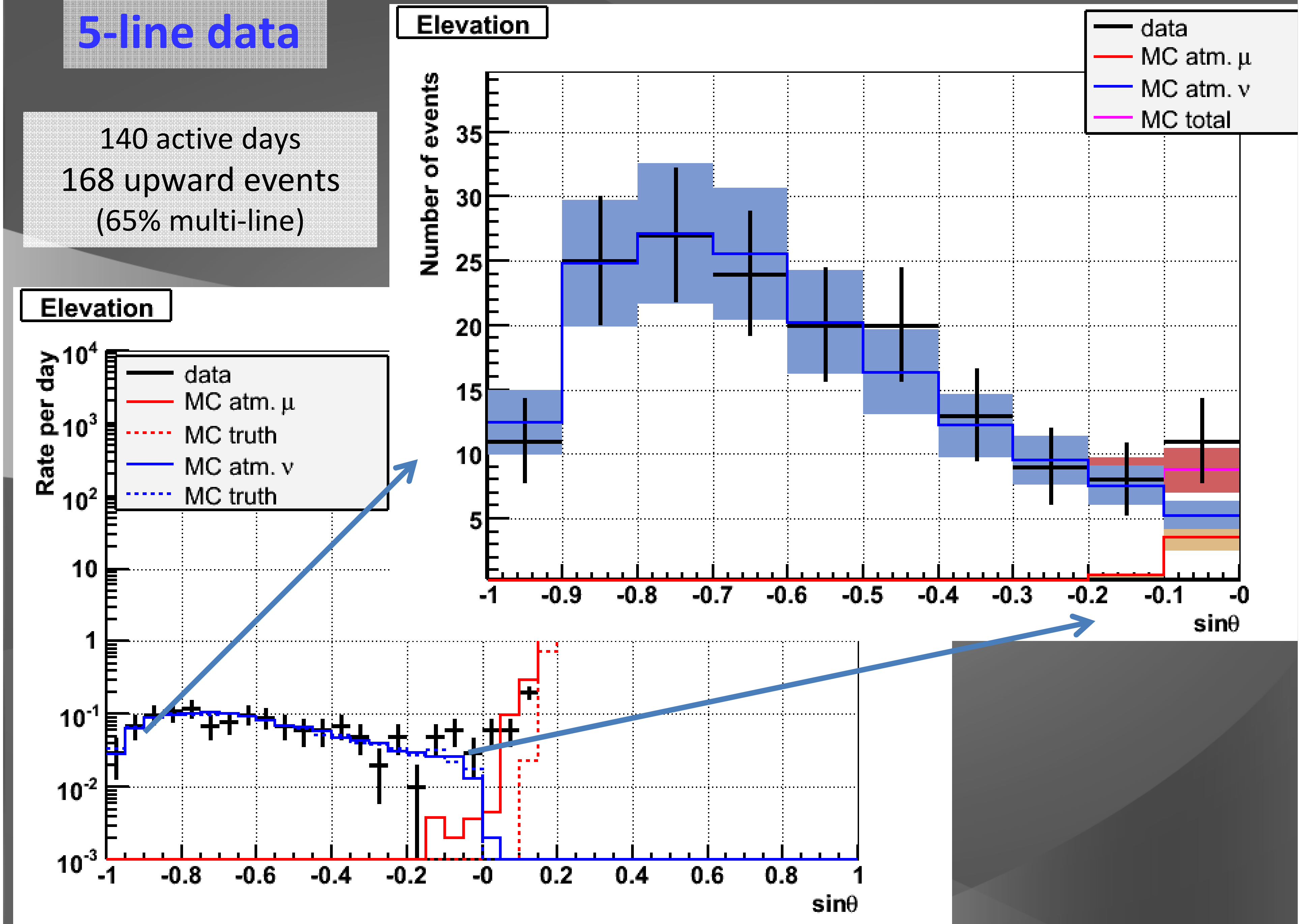

## Positioning ~ 10 cm

## ANTARES as seen by atmospheric muons



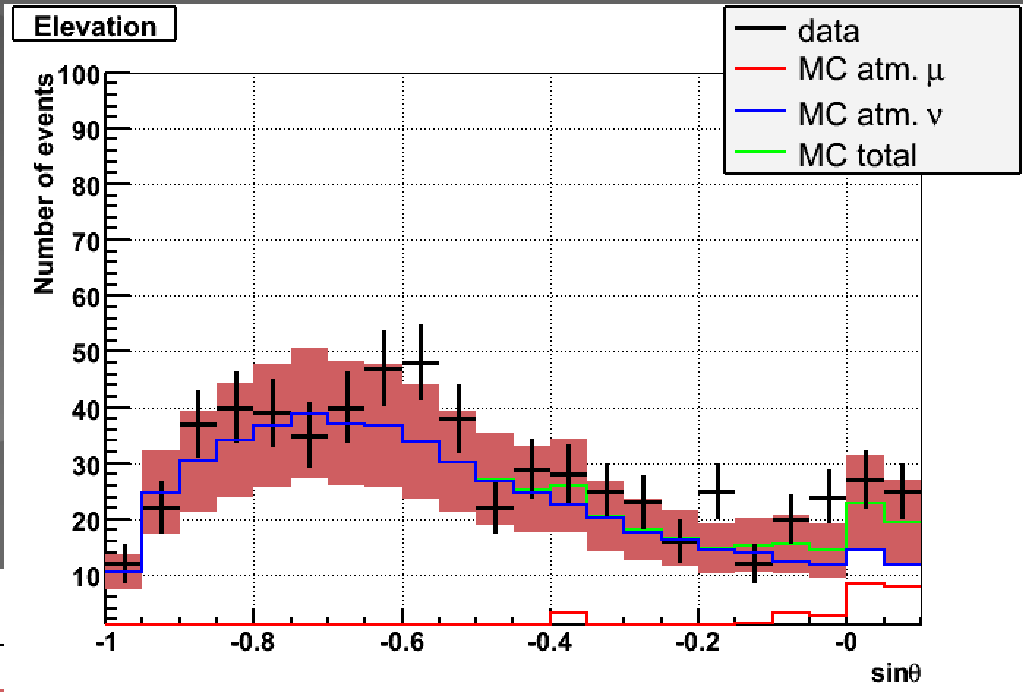
# 5-line data

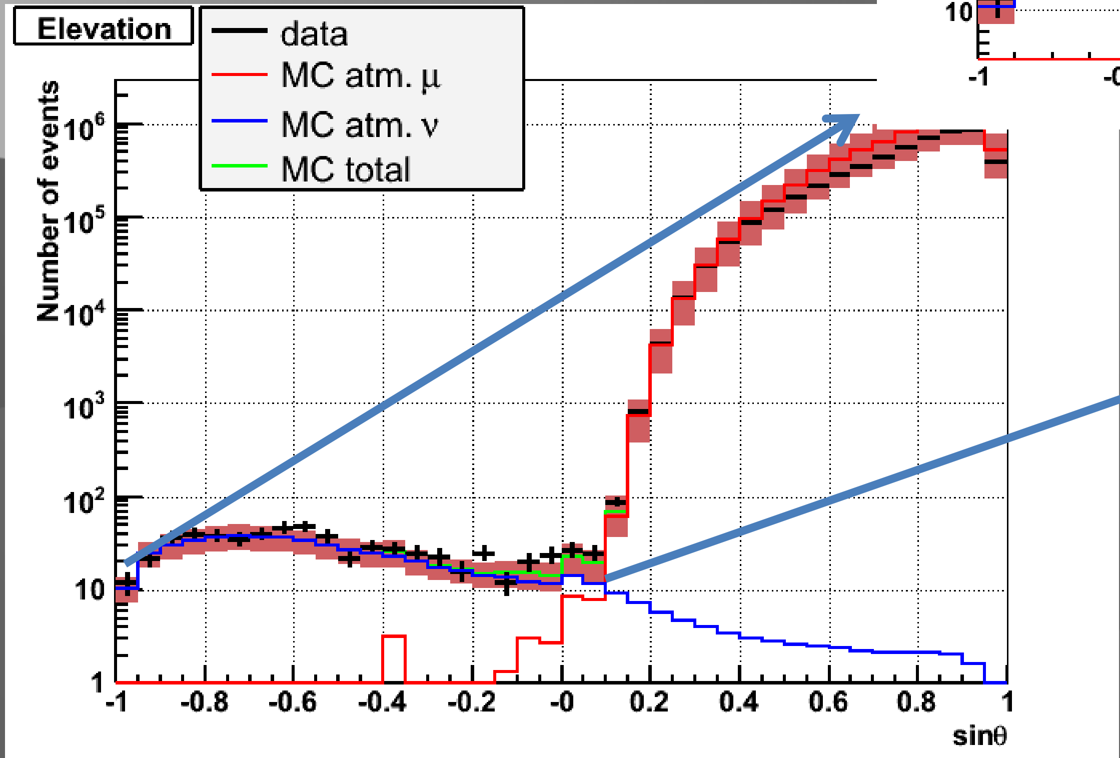
140 active days
168 upward events
(65% multi-line)



# 2008 data
# 10/9/12 lines

174 active days
819 upward events
(71% multi-line )

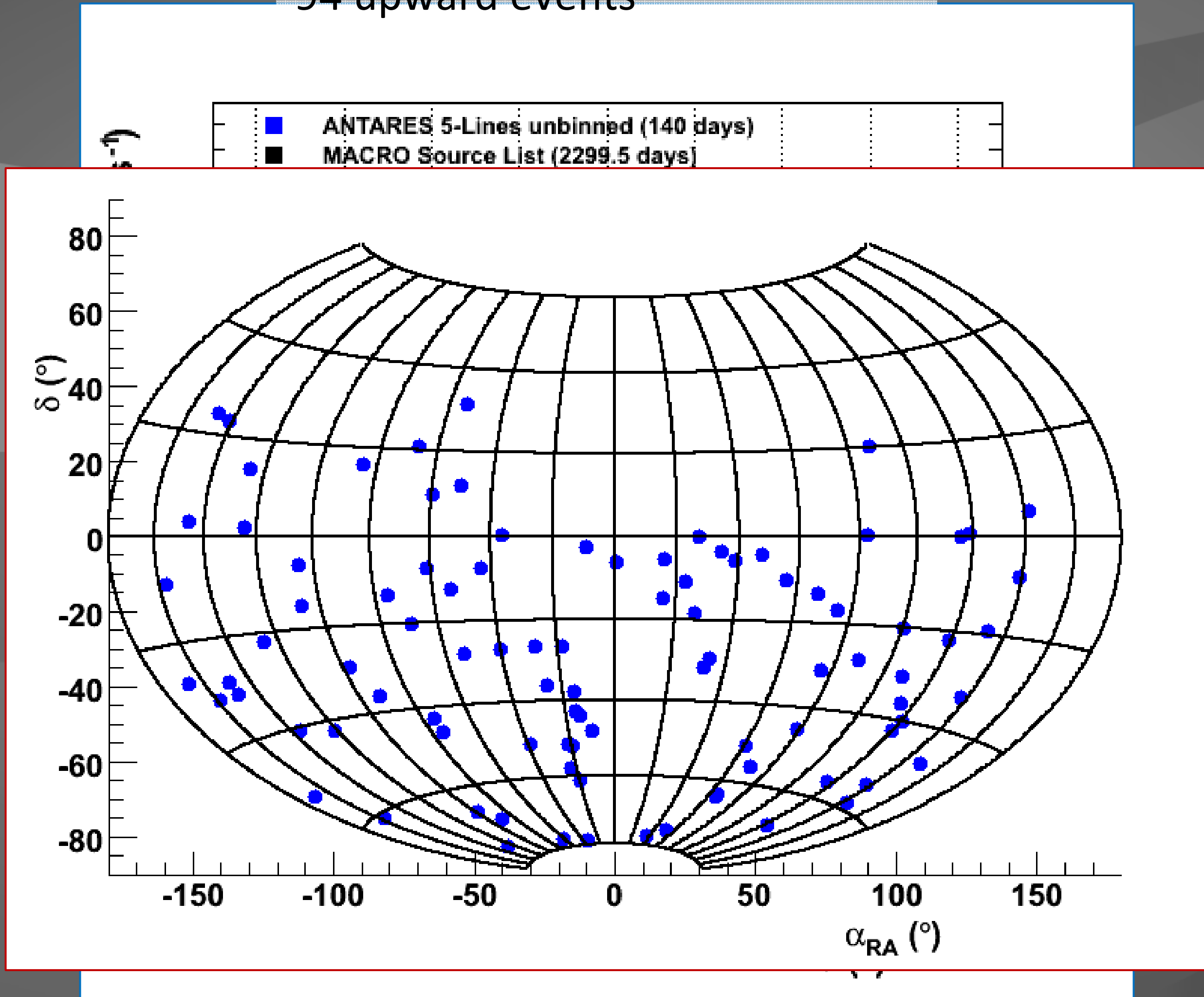


# Point source search

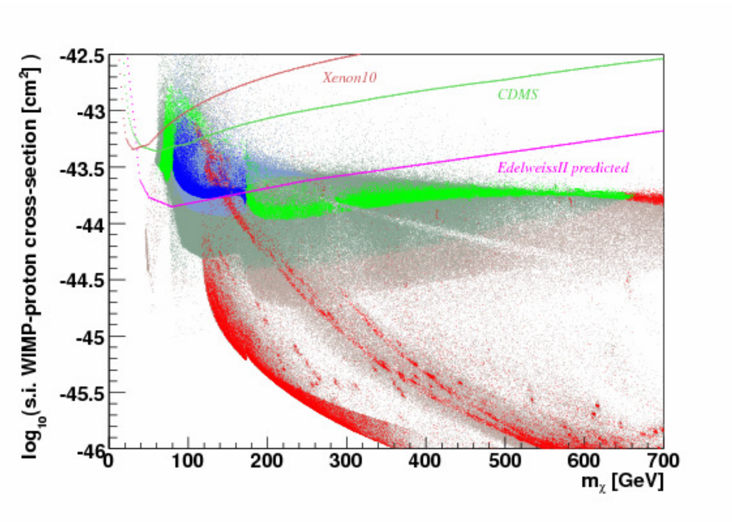
List of 25 sources
No excess found

**5-line data,** 140 active days,
94 upward events

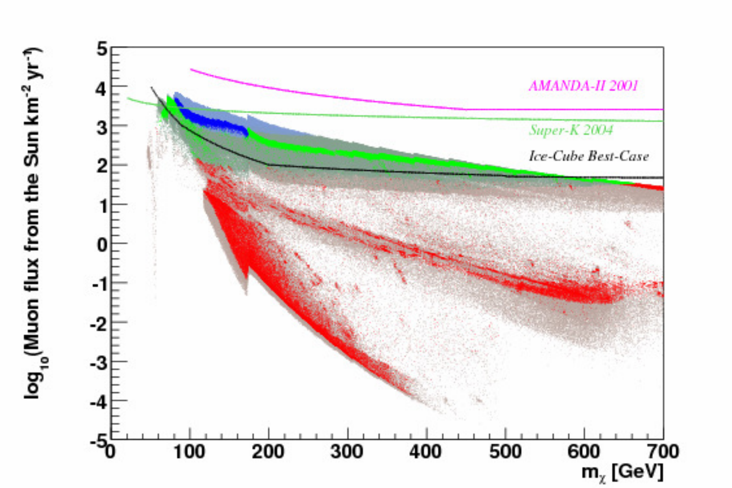


# Dark Matter Search

S.I. WIMP-proton x-section ($cm^2$)




Muon flux ($km^{-2}\ yr^{-1}$)




ANTARES and KM3NeT
3 year data taking
(From the Sun)

**mSugra models favoured by WMAP**

- 90% CL excudable by ANTARES
- 90% CL excludable by KM3NeT
- not excludable

**mSugra models disfavoured by WMAP**

- 90% CL excludable by ANTARES
- 90% CL excludable by KM3NeT
- not excludable

$0 < m_0 < 8$ TeV ; $0 < m_{1/2} < 2$ TeV
$0 < \tan\beta < 60$ ; $0 < A_0 < 3m_0$

**Upper branch**: Focus point region
$m_0 >$ 2TeV; $m_{1/2} >$200 GeV to right upper corner
**Middle branch**: A-annihilation
$\tan\beta$=50-60
**Lowest branch**: co-annihilation-region
Low $m_0$ ; $m_{1/2}$ <1.5 TeV

# NESTOR: Rigid Structures Forming Towers

- Tower based detector (titanium structures).
- Dry connections (recover – connect – redeploy).
- Up- and downward looking PMs (15’’).
- 4000-5200 m deep.
- Test floor (reduced size) deployed & operated in 2003.
- Deployment of 4 floors planned in 2009

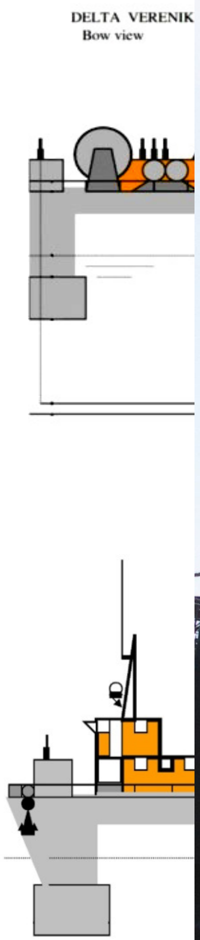
**Vision: Tower(s) with12 floors**

→ **32 m diameter**

→ **30 m between floors**

→ **144 PMs per tower**

# NESTOR: The Delta-Berenike Platform





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# The NEMO Project

- Exte
  (Cap
  dept
- R&D
  mec
  elect
- Simu

Example: Flexible tower

- 16 arms per tower,
  20 m arm length,
  arms 40 m apart;
- 64 PMs per tower;
- Underwater connections;
- Up- and downward-looking PMs.

# NEMO Phase I: First steps


- Test site at 2000 m depth operational.
- Funding ok.

Geoseismic station SN-1 (INGV)

5 km e.o. cable

21 km e.o. Cable with single steel shield

J

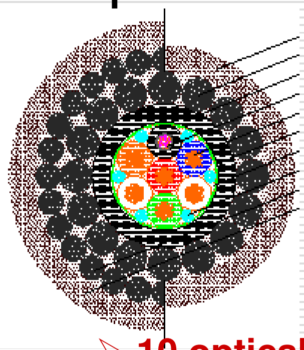
BU

J

J

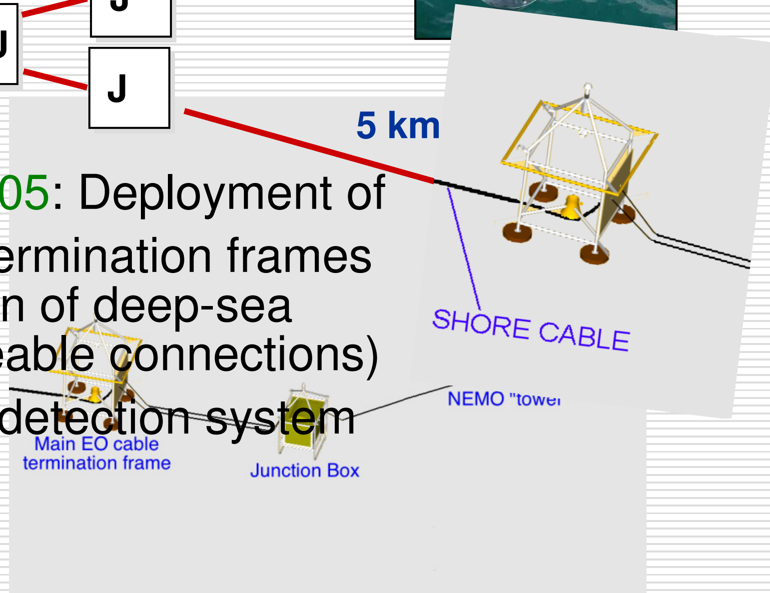
5 km

2.5 km e.o. Cable with double steel shield



January 2005: Deployment of

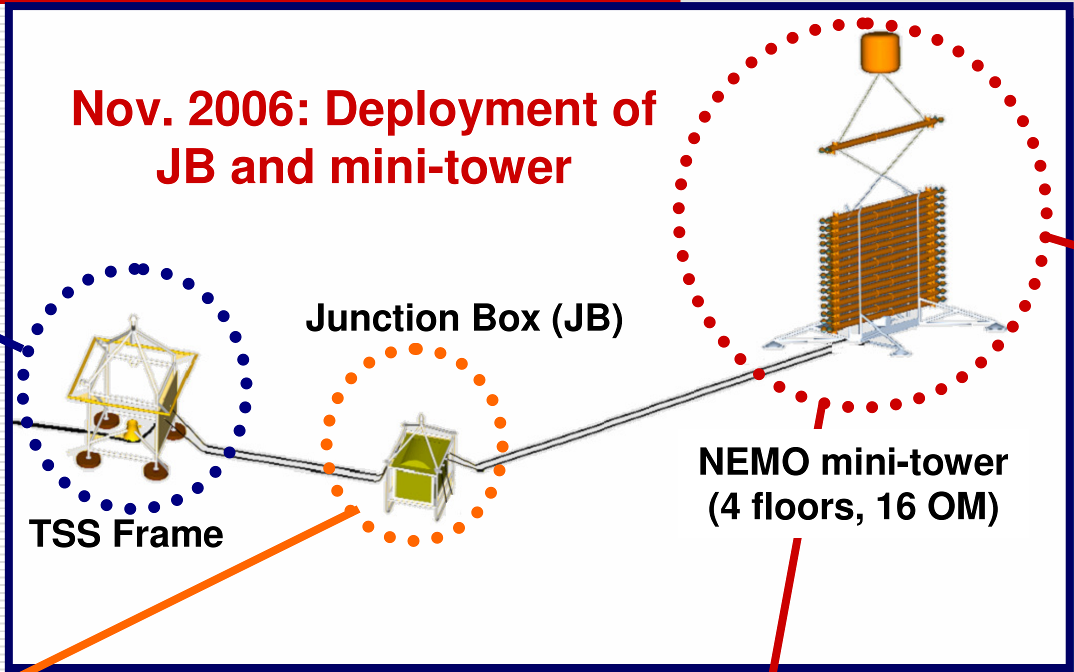
- 2 cable termination frames (validation of deep-sea wet-mateable connections)
- acoustic detection system (OνDE).

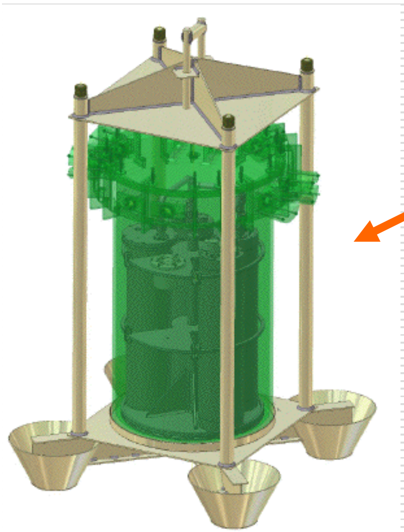


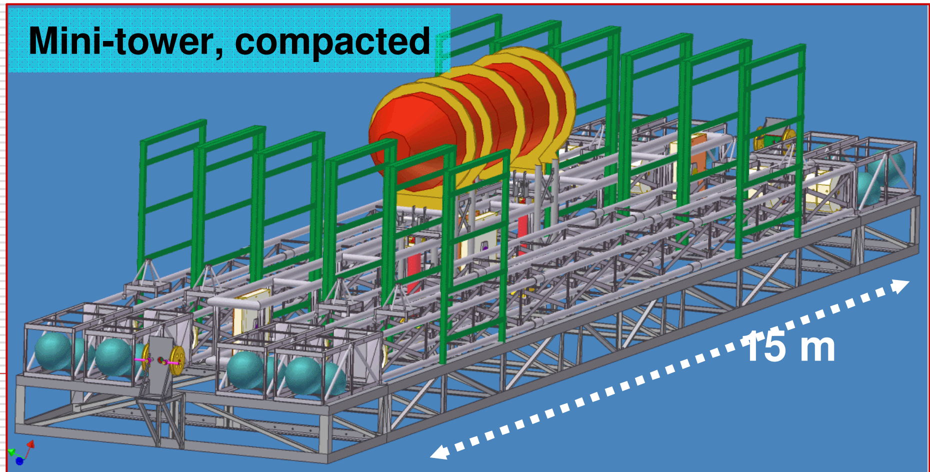

- 10 optical fibres standard ITU- T G-652
- 6 electrical conductors Φ 4 mm$^2$

# NEMO Phase-1: Current Status

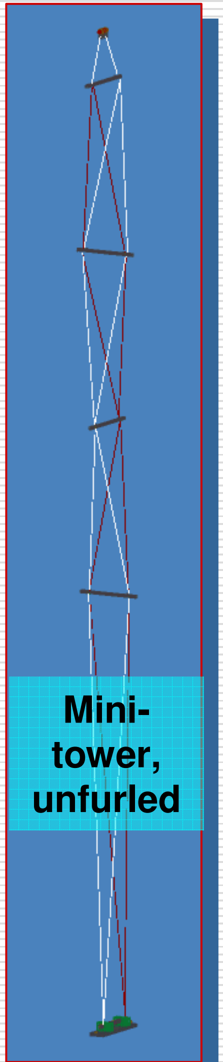
**Deployed January 2005**





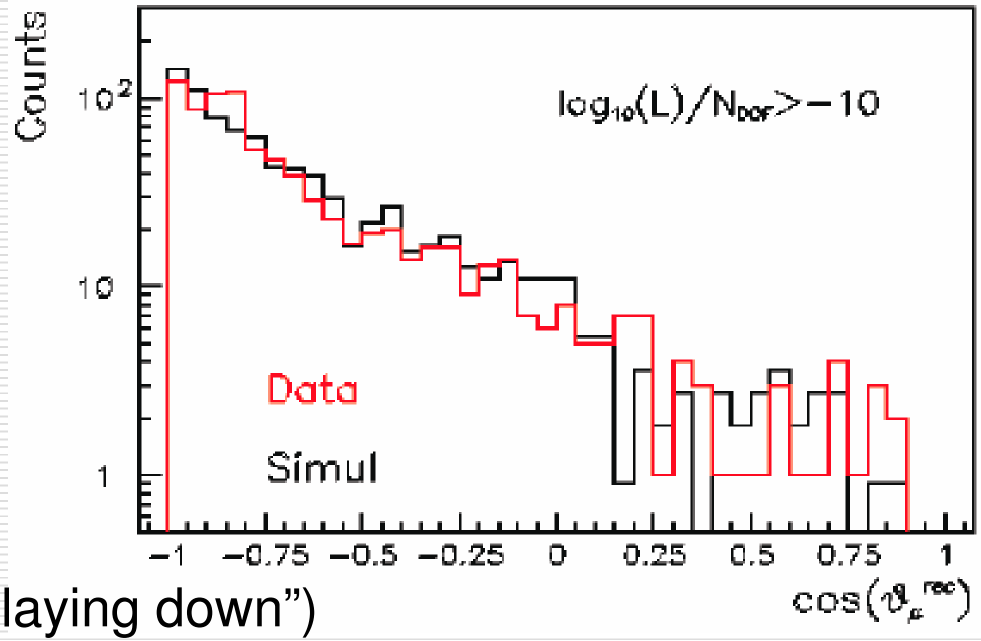

300 m



# NEMO: Phase-1 Results

- Successful deployment and system test, all components functional
- Data being analysed (example: muon angular distribution)
- Some problems:
  - Missing buoyancy (tower "laying down") traced back to buoy production error
  - Junction Box: Incident at deployment, data transmission problem after some weeks, short after ~5 months → recovery & analysis → some redesign for Phase-2

**Atmospheric muon angular distribution**



# NEMO: Phase-2

- Objective: Operation of full NEMO tower (16 floors) and Junction Box at 3400 m depth (Capo Passero site)
- Some design modifications (cabling, calibration, power system, bar length 15 m → 12 m, …)
- Infrastructure:
  - Shore station in **Portopalo di Capo Passero (→ under renovation)**
  - **Shore power system ( → under construction)**
  - **100 km main electro-optical cable (50 kW, 20 fibres) (→ laid)**
  - **cable termination frame with DC/DC converter (Alcatel)**

# KM3NeT

## A research facility in the Mediterranean Sea

- A next generation neutrino telescope
- Cabled observatory for Earth and Marine sciences

ANTARES + NESTOR + NEMO + …

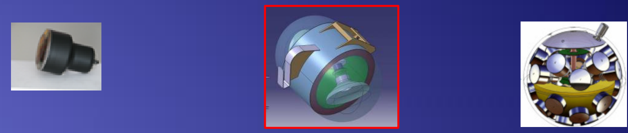
40 institutes from 10 European countries

# Design goals

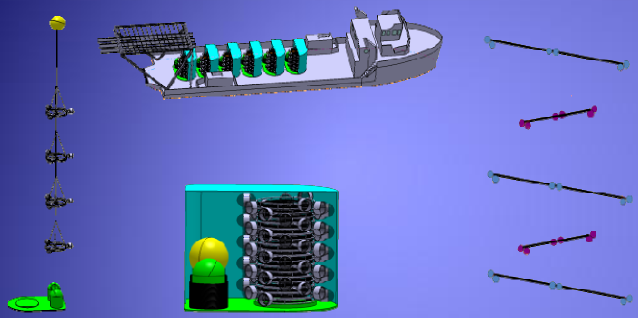
- Substantially better sensitivity than IceCube
- > 1 $km^3$
- Core process:
  $\nu_\mu$+N $\rightarrow$ $\mu$+X at neutrino energies above 100 GeV
- Construction and deployment < 4 years
- Data taking period > 10 year
- Optimized for energy range 1 TeV – 1 PeV
- Angular resolution < 0.1°
- Zenith angle:
  - Full acceptance for neutrinos originating from directions up to at least 10° above the horizon
  - For energies > 100 TeV angular acceptance limited only by the absorption of the Earth

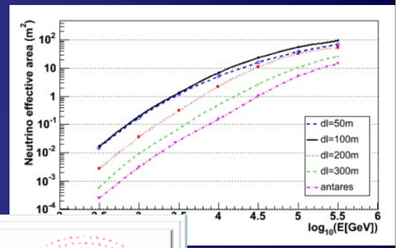
KM3NeT

# Design proceeding well…

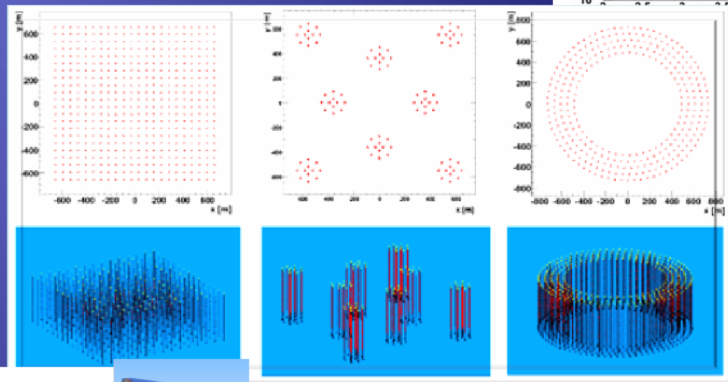


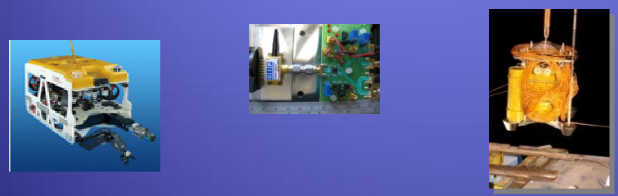
Several photo-sensors and optical module arrangements studied.



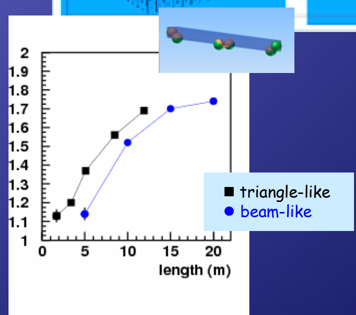



Self-unfolding structures for massive deployment





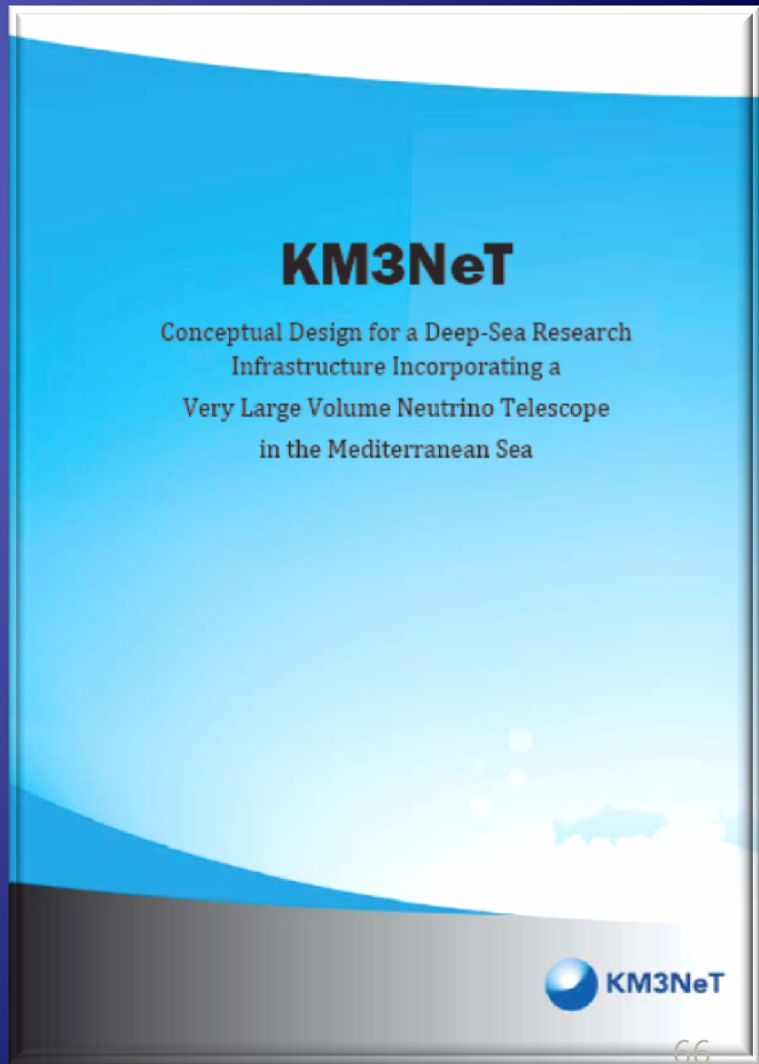
… + studies on data transmission, power distribution, time calibration and positioning, marine operations,



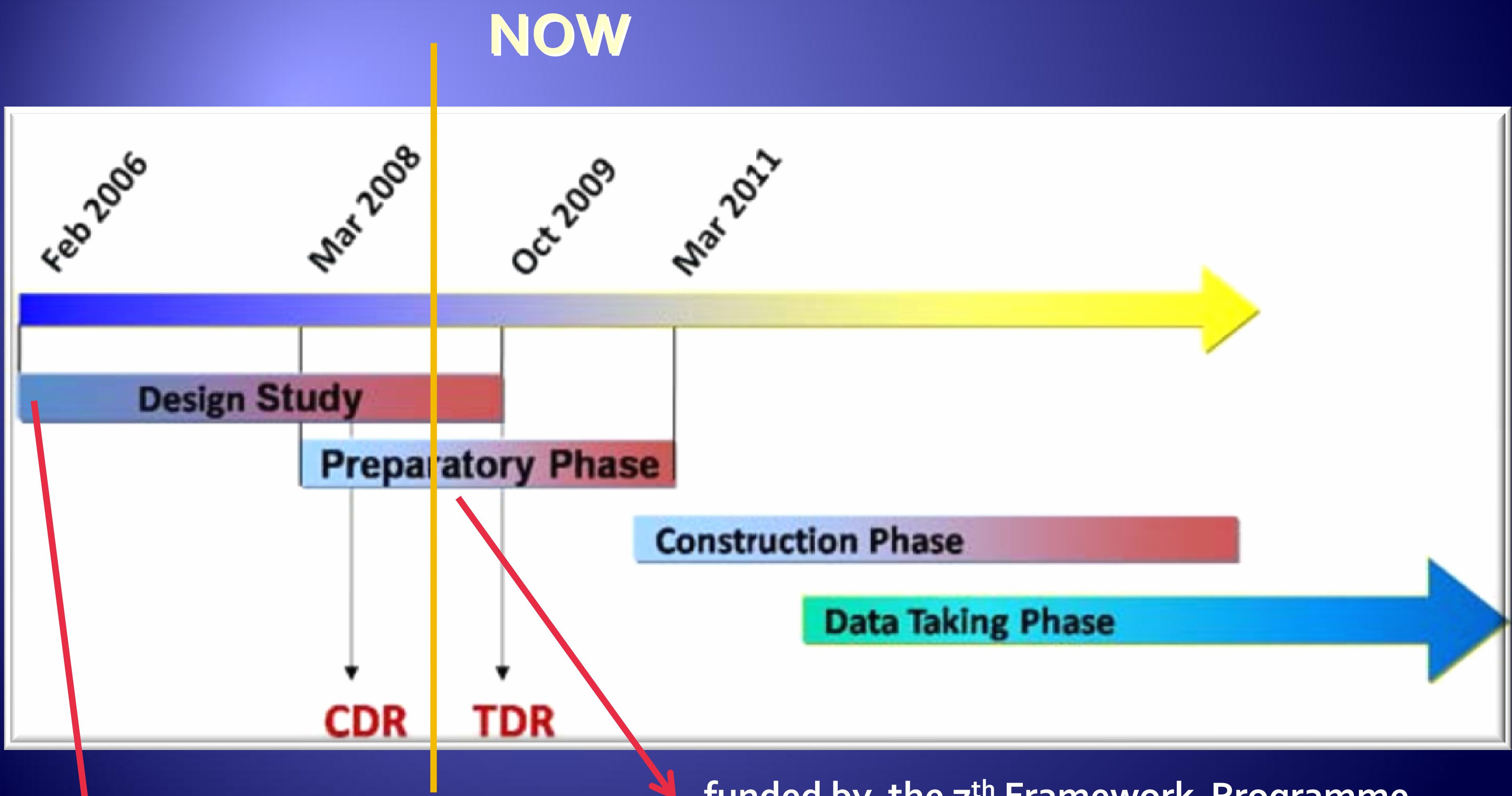

Performance in terms of effective area and resolution for different configurations have been studied

# Conceptual Design Report

- Released on April 2008
- Available at **www.km3net.org**
- Includes:
  - Science case
  - Site studies
  - Design goals
  - Technical implementation
- Design Study funded by the 6th Framework Programme of the European Commission



# KM3NeT project timeline




funded by the 7th Framework Programme

funded by the 6th Framework Programme

# Conclusions

• IceCube > 70% complete, finished by 2011. Approaching the km3 scale

• ANTARES completed. The largest neutrino telescope in the Northern Hemisphere. Competitive limits from 5-lines (140 days).

• KM3NeT Conceptual Design Report ready. Technical Design Report next year.

- – Supported by ESFRI, ASPERA and ASTRONET.
- – Design Study and Preparatory Phase funded respectively by the $6^{th}$ and $7^{th}$ Framework Programmes of the European Commission
- – Construction could start as early as 2011