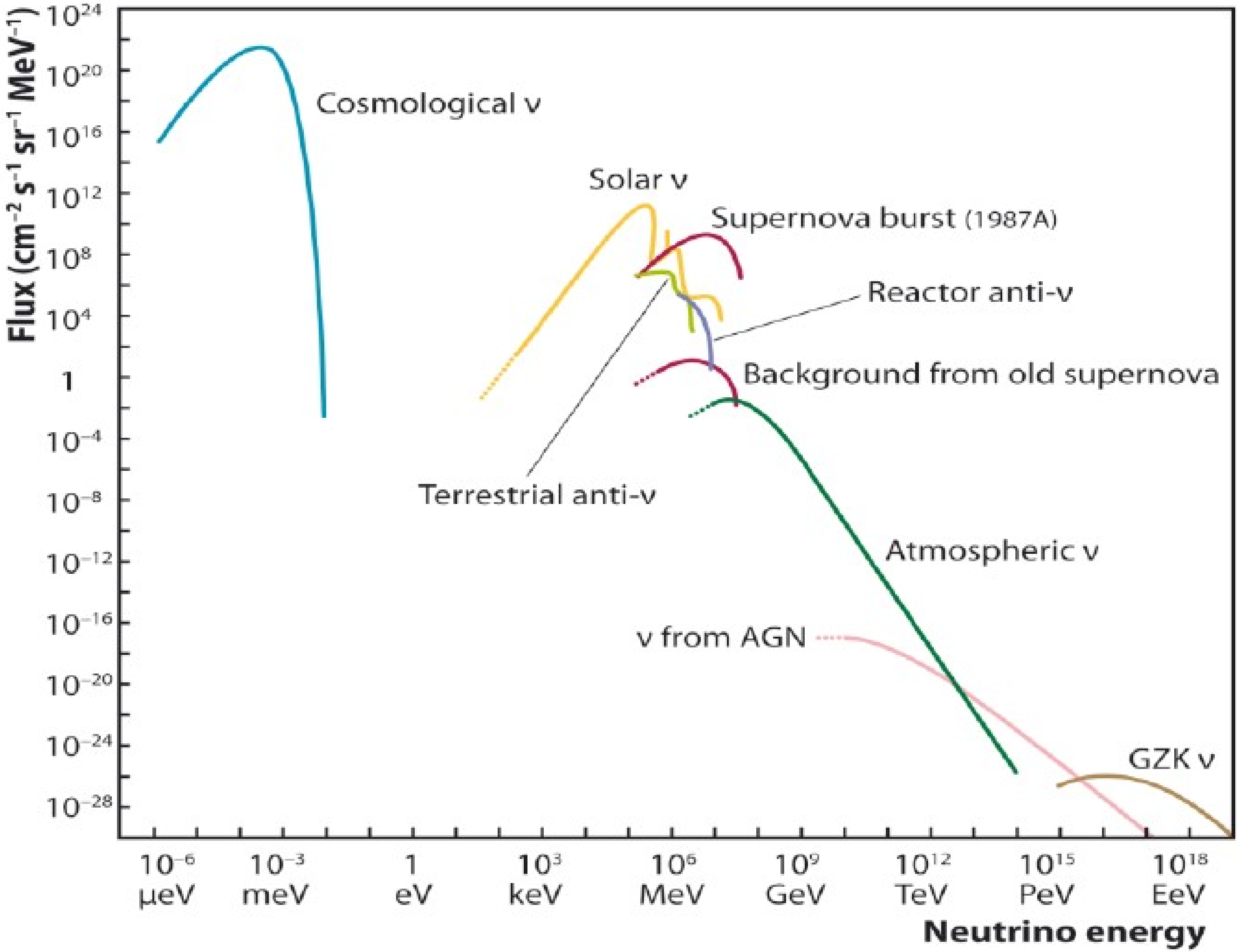
High energy neutrino astronomy

Status - perspectives

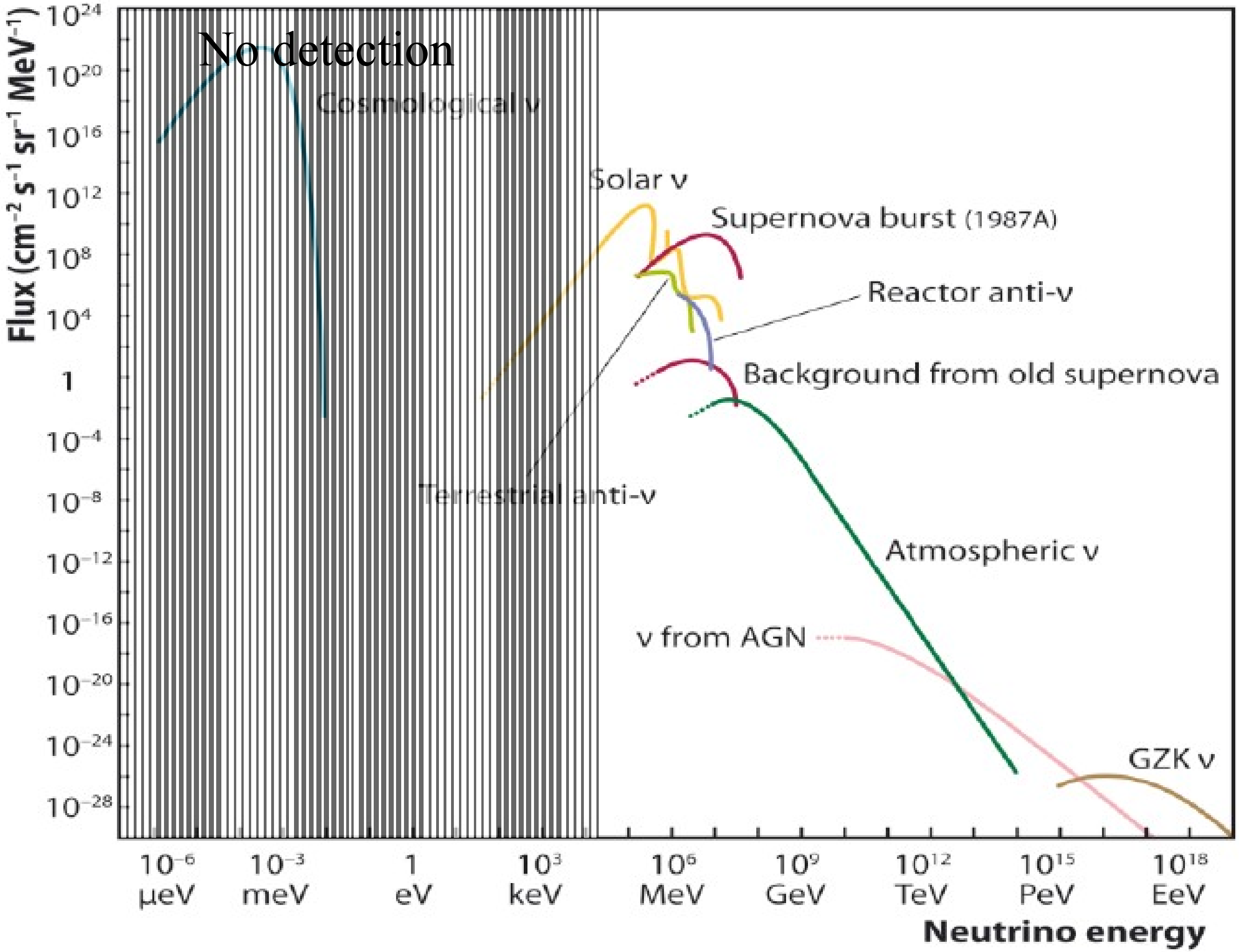
D. Dornic (CPPM)

GDR PCHE Working group γ-cr-ν - 2008/12/09

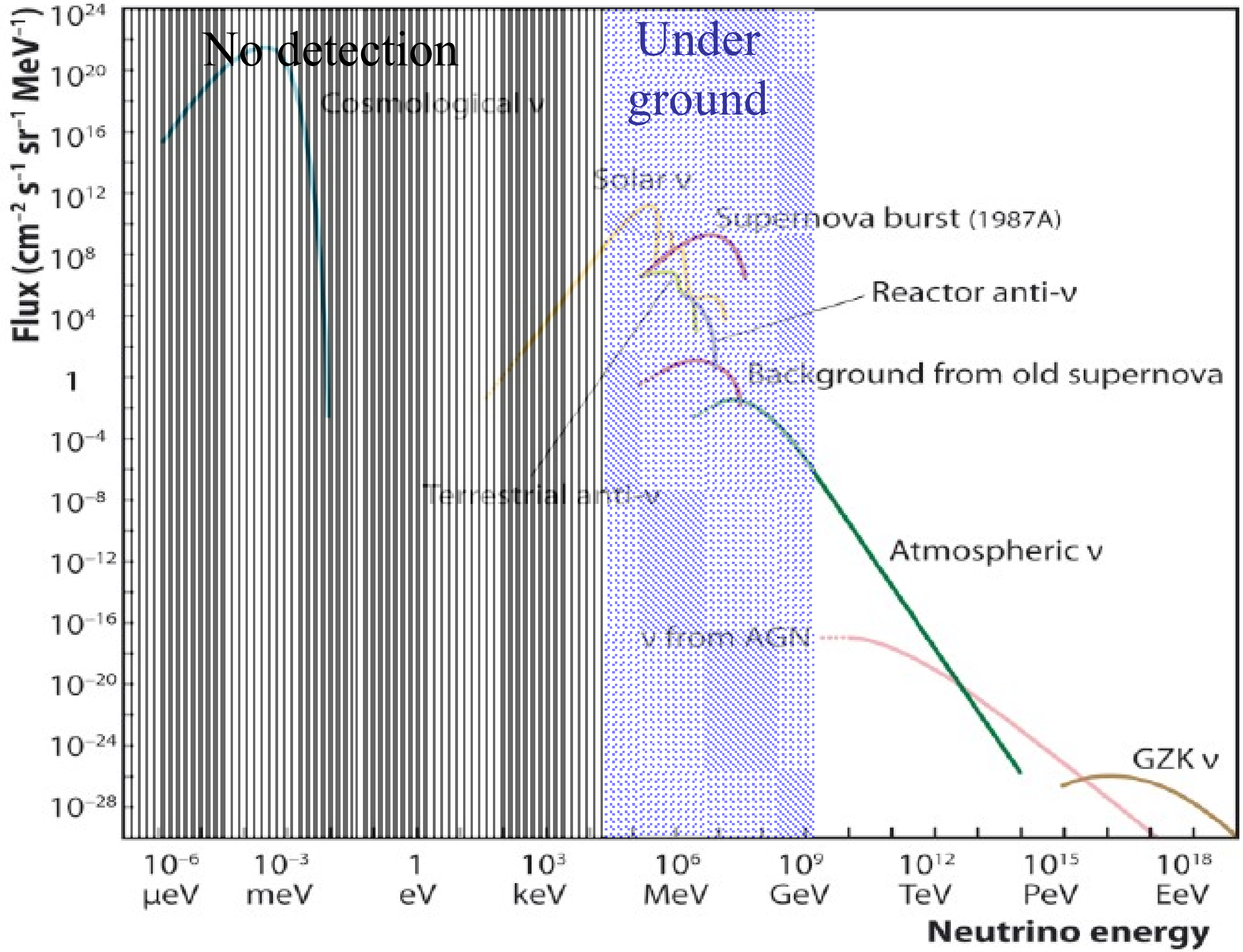
Neutrino - astronomy



Neutrino - astronomy

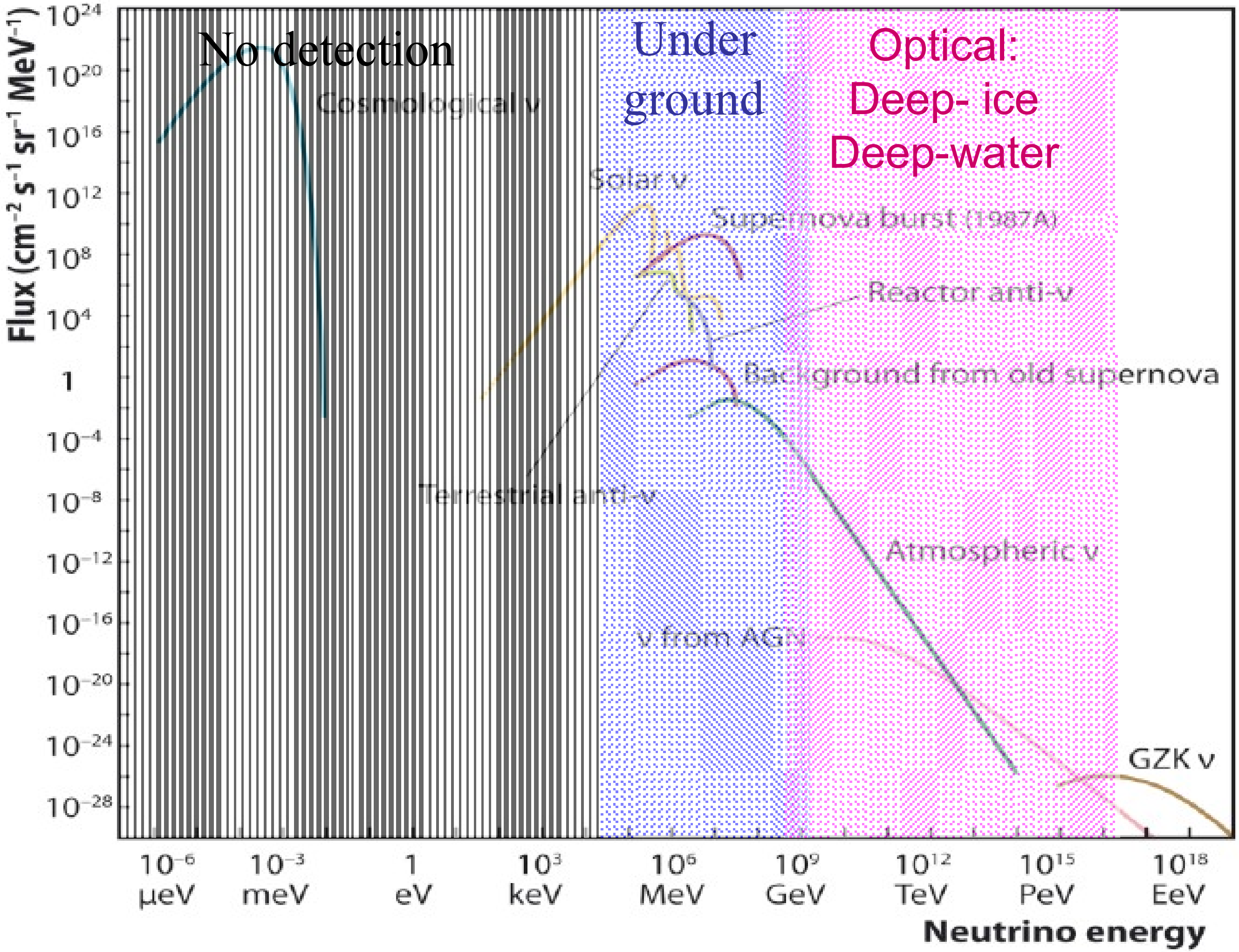


Neutrino - astronomy



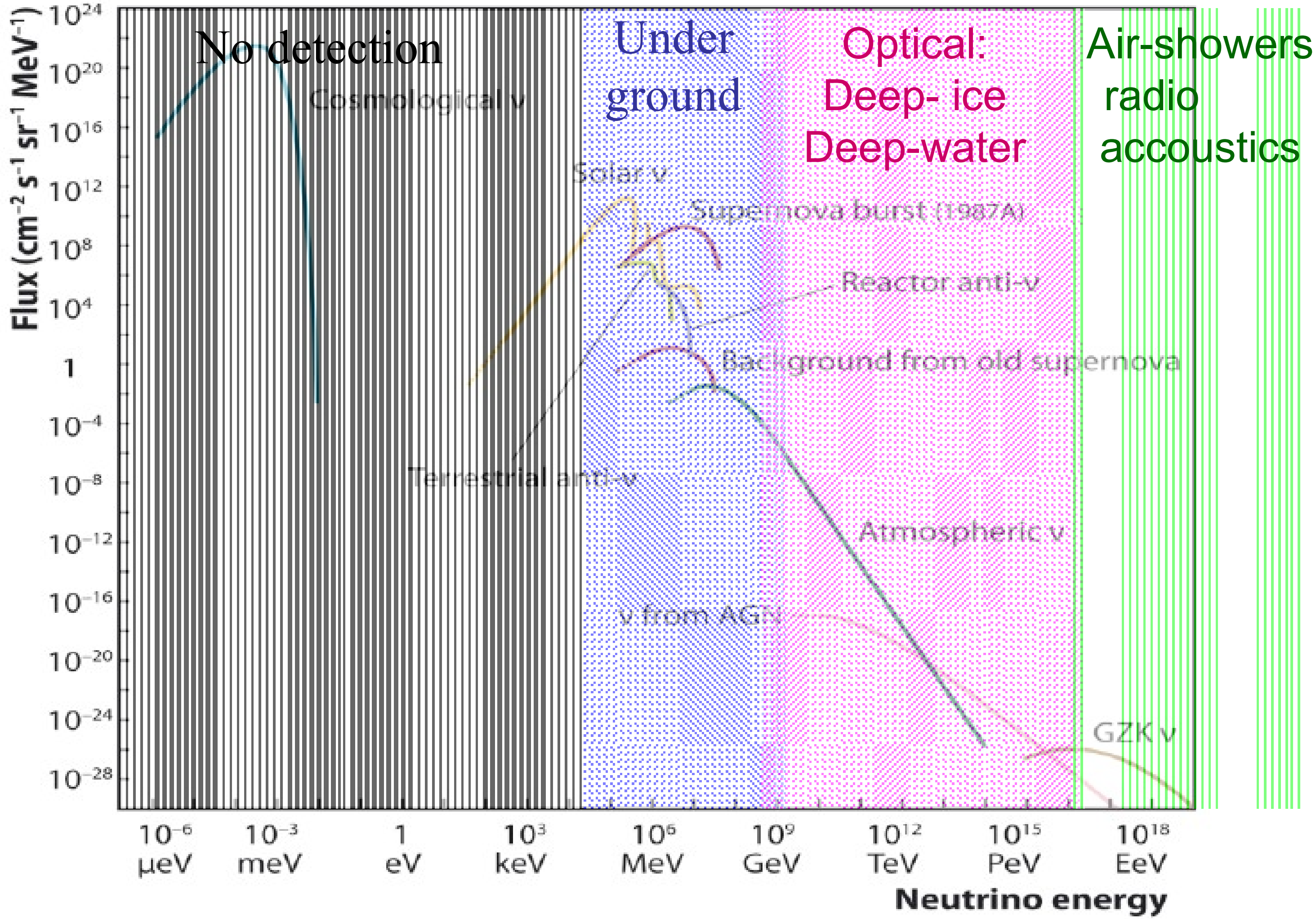
Detection volume (m^3) → 10^3 - 10^4 10^7 - 10^9 10^{11} →

Neutrino - astronomy



Detection volume (m^3) → 10^3 - 10^4 10^7 - 10^9 10^{11} →

Neutrino - astronomy



Detection volume (m^3) → 10^3 - 10^4 10^7 - 10^9 10^{11} →

HE neutrinos ?

HE neutrino : by-product of the interaction of HE cosmic rays

$$p + p(\gamma) \rightarrow \pi^{+\text{¿}-} + X$$

$$\pi \rightarrow \mu + \nu_\mu$$

$$\mu \rightarrow e + \nu_e + \nu_\mu$$

$$p + p(\gamma) \rightarrow \pi^0 + X$$

$$\pi^0 \rightarrow \gamma + \gamma$$

Hadronic models: strong link between CR, TeV and X-ray photons

HE neutrinos ?

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$$\pi^0 \rightarrow \gamma + \gamma$$

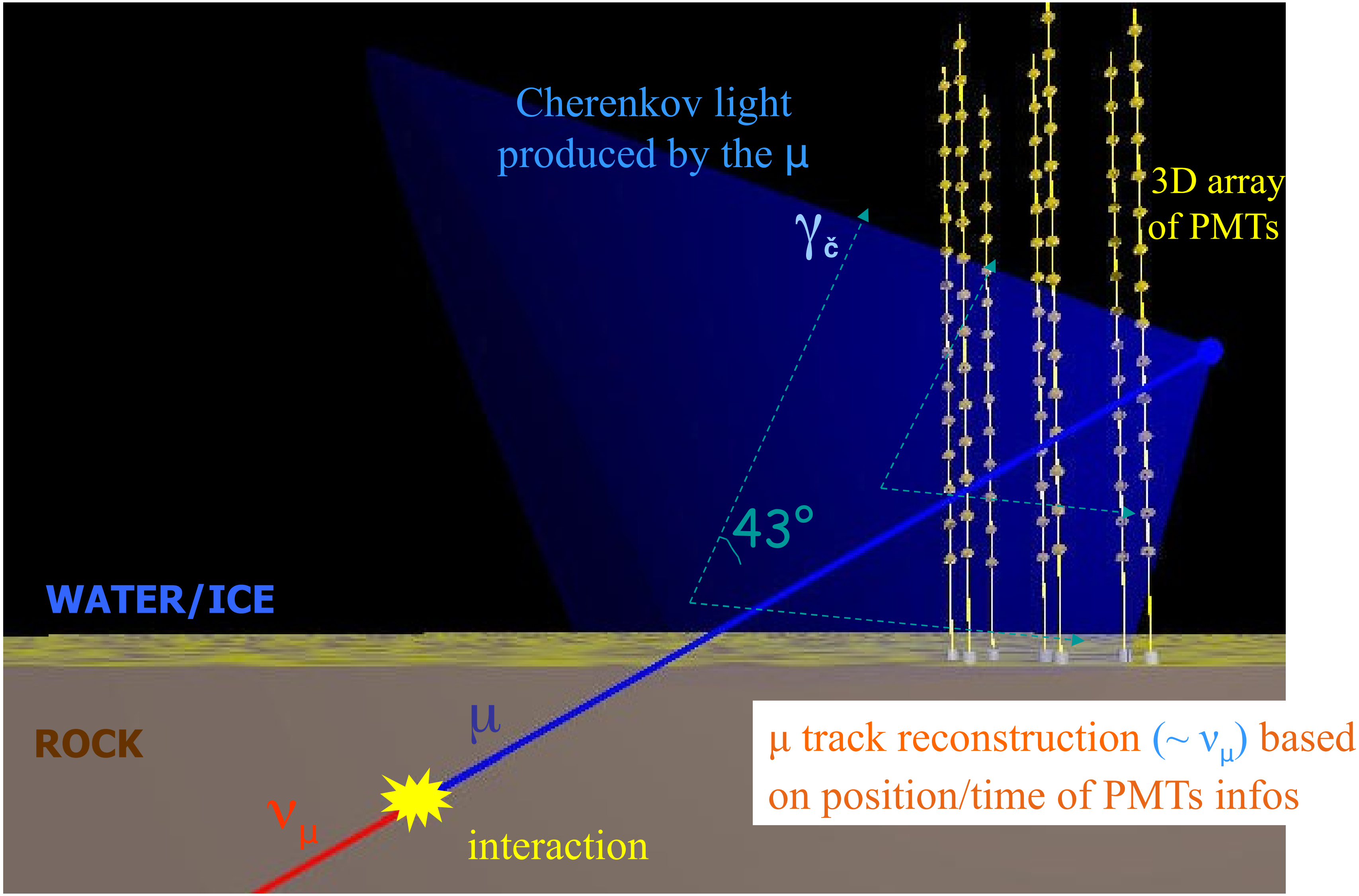
Hadronic models: strong link between CR, TeV and X-ray photons

Astronomy: neutrino perfect messenger (in theory):

- Neutral (perfect pointing)
- Low interaction (Tracer of processes hidden to traditional astronomy in dense region, large horizon…)

➔ Very difficult to detect (low reaction probability)

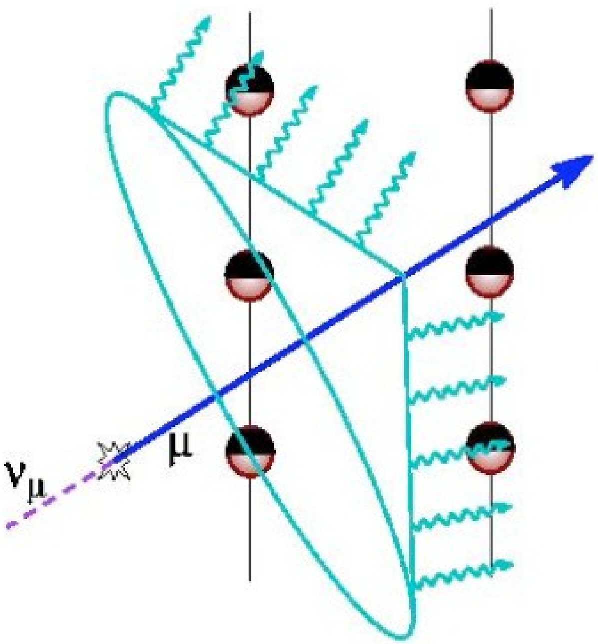
Detection principle



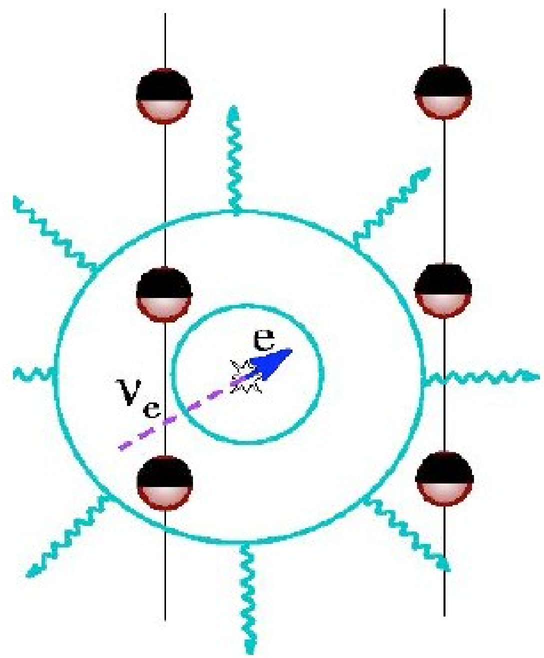
Neutrino signals

Detector sensible to the 3 neutrinos flavors

Muonic neutrino



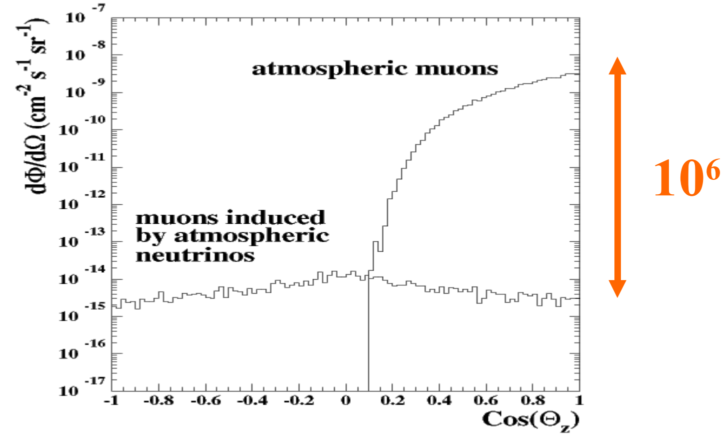
Electronic neutrino



Background rejection

Atmospheric down-going muons (CR interaction in the atmosphere)

Need very efficient track reconstruction (bad-reconstructed events)

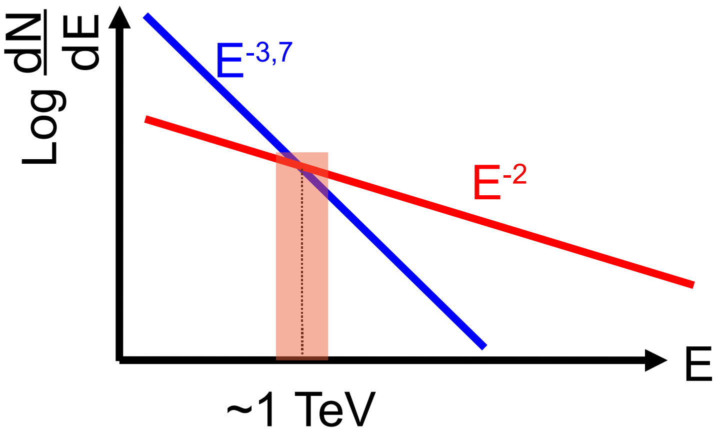


Atmospheric up-going neutrinos (CR interaction in the atmosphere)

Direction + Energy

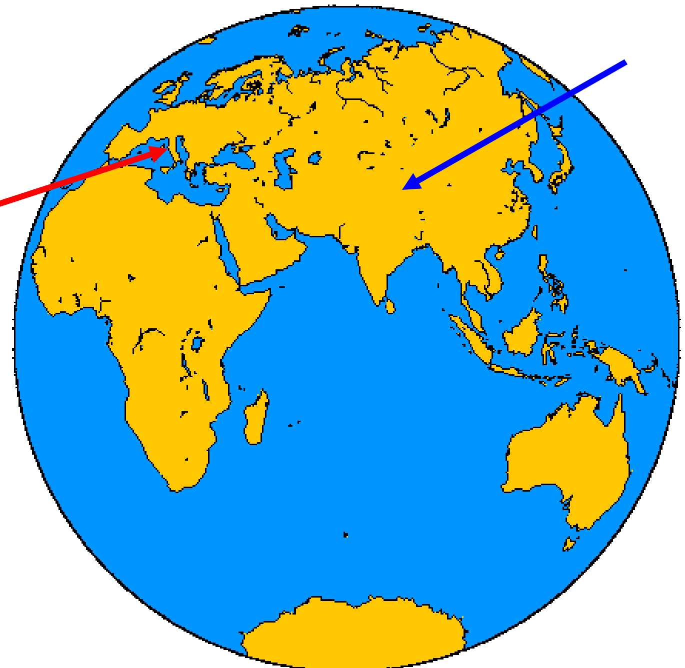
Background: isotropic locally
Signal: point like

Need very good angular resolution



HE neutrino detectors

BAIKAL: Lake Baikal, Siberia



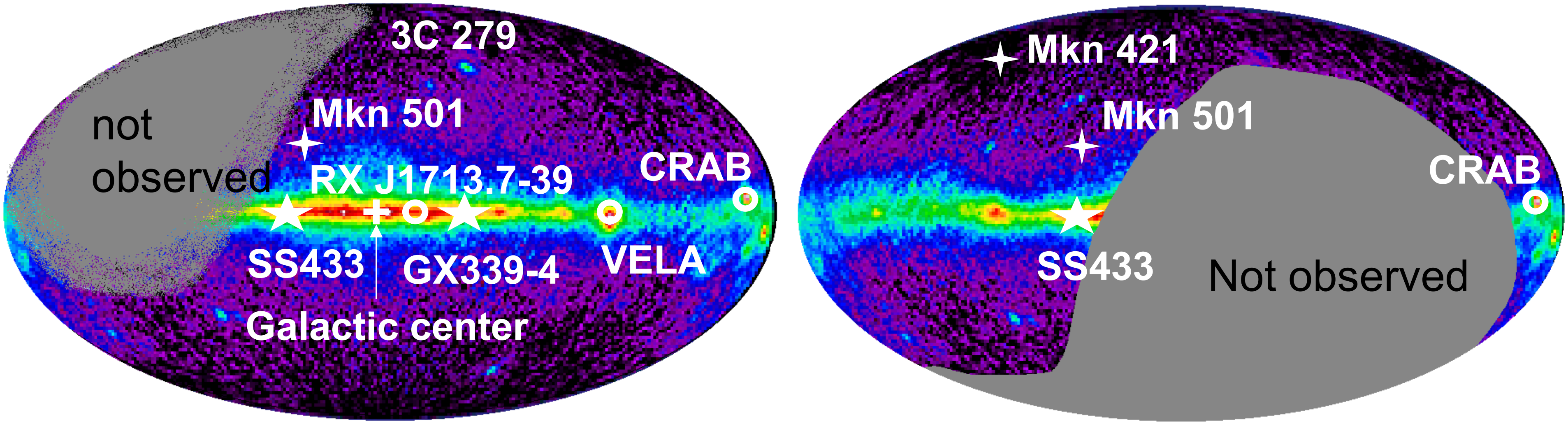
Mediterranean site
ANTARES: France
NEMO: Italy

AMANDA/ICECUBE, Antarctica

Visible sky

Complementarity between Northern detectors and the South Pole ones

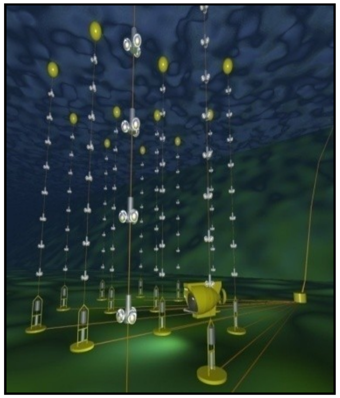
Northern site (43° North) South Pole site



Instantaneous common view: 0.5 π sr
Averaged common view : 1.5 π sr

1st generation detector

ANTARES



Complete June 2008

<u>Characteristics</u>

Depth: 2000 – 2500m

12 strings separated by ~60m

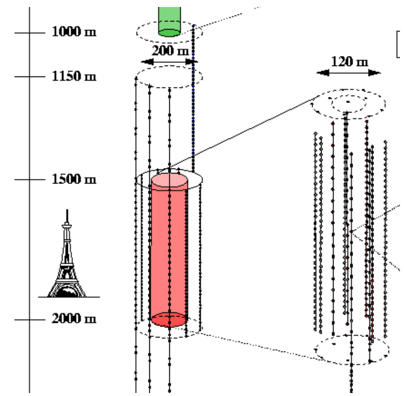
900 optical modules

<u>Performances</u>

Angular resolution ~0.3° (E > 10 TeV)

Seff ~ 0.1 m² (10 TeV) ~10 m² (10 PeV)

AMANDA



2000- 2007

<u>Characteristics</u>

Depth: 1500 – 2000m

19 strings

677 optical modules

<u>Performances</u>

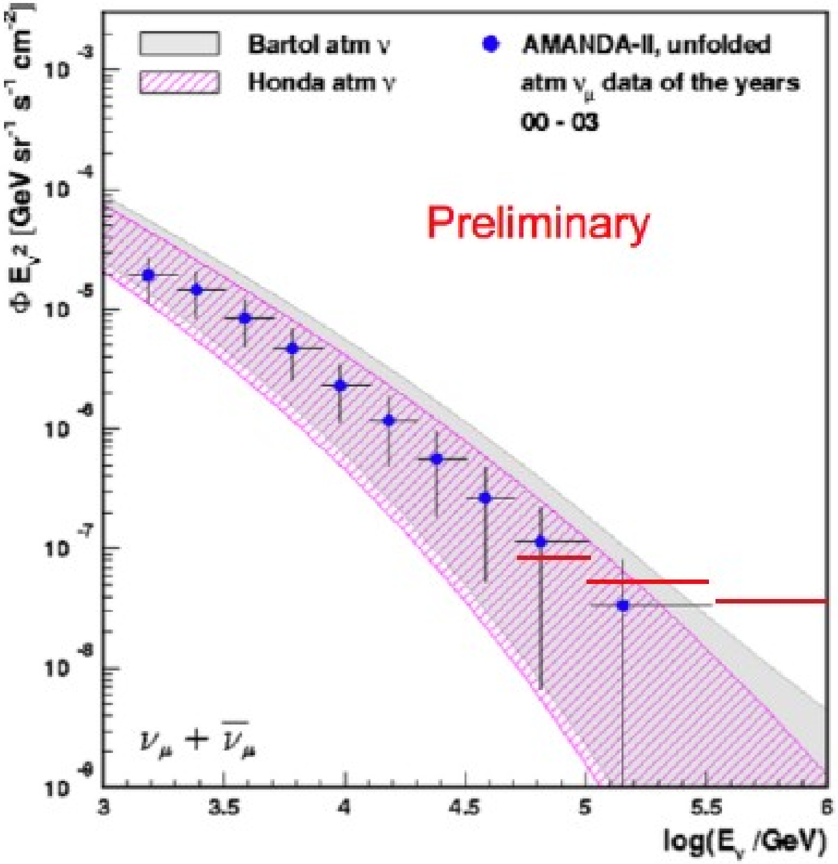
Angular resolution ~2.5° (E > 10 TeV)

AMANDA Results

AMANDA: 7 years data taking (2000-2007) → 3.8 yr lifetime

6595 neutrinos

Atmospheric neutrino spectrum up to 100 TeV



Limit on a possible E^{-2} component

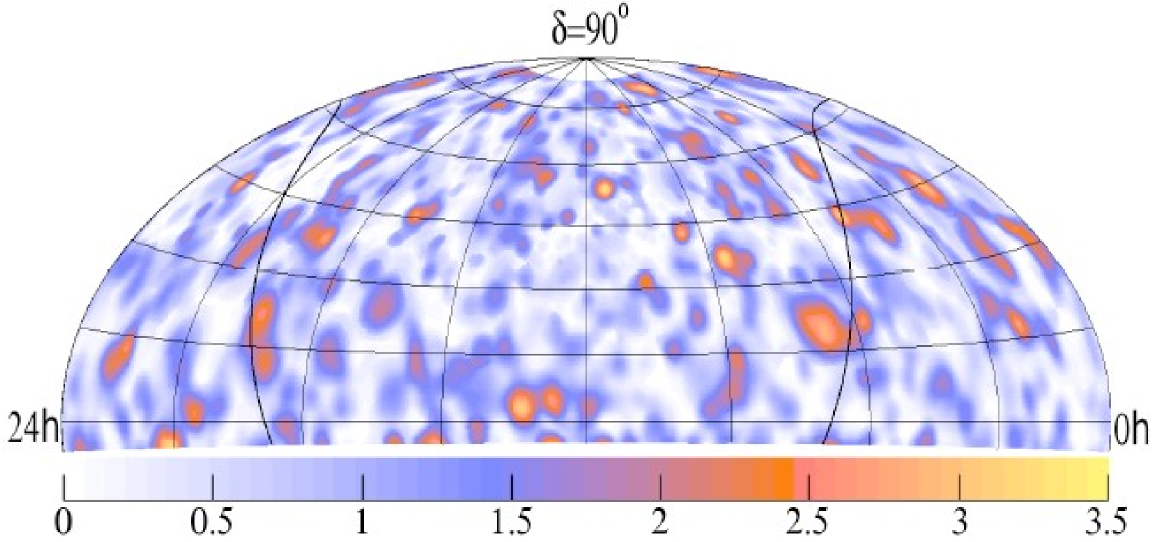
AMANDA Results

Point-source study

Upper limit: $5\times10^{-11}\,E_{\nu}^{-2}\,TeV^{-1}.cm^{-2}.s^{-1}.sr^{-1}$

(Average over the Northern hemisphere)

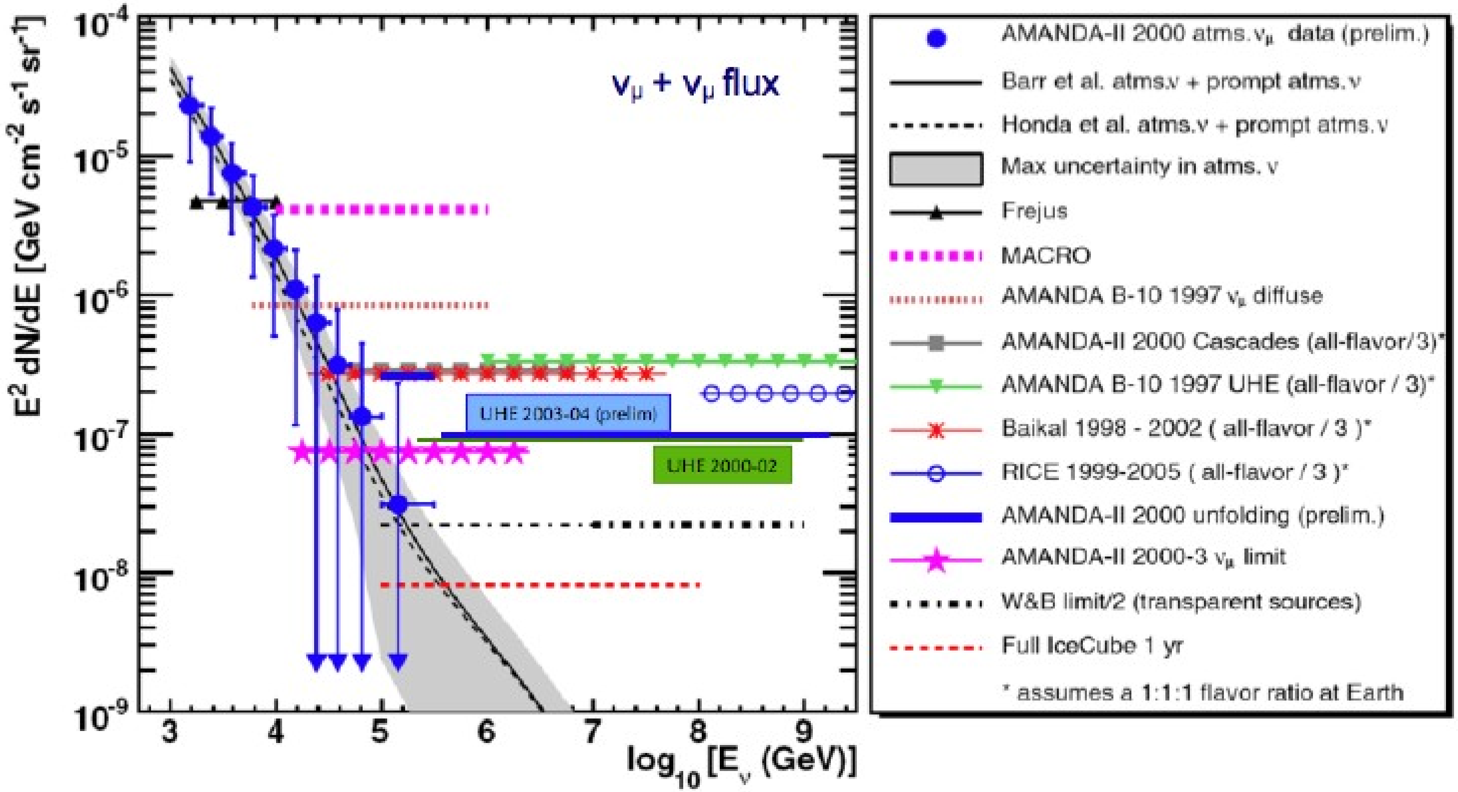
Sky map:



95% of RA-randomized sky-maps have maximum significance > 3.38σ

AMANDA Results

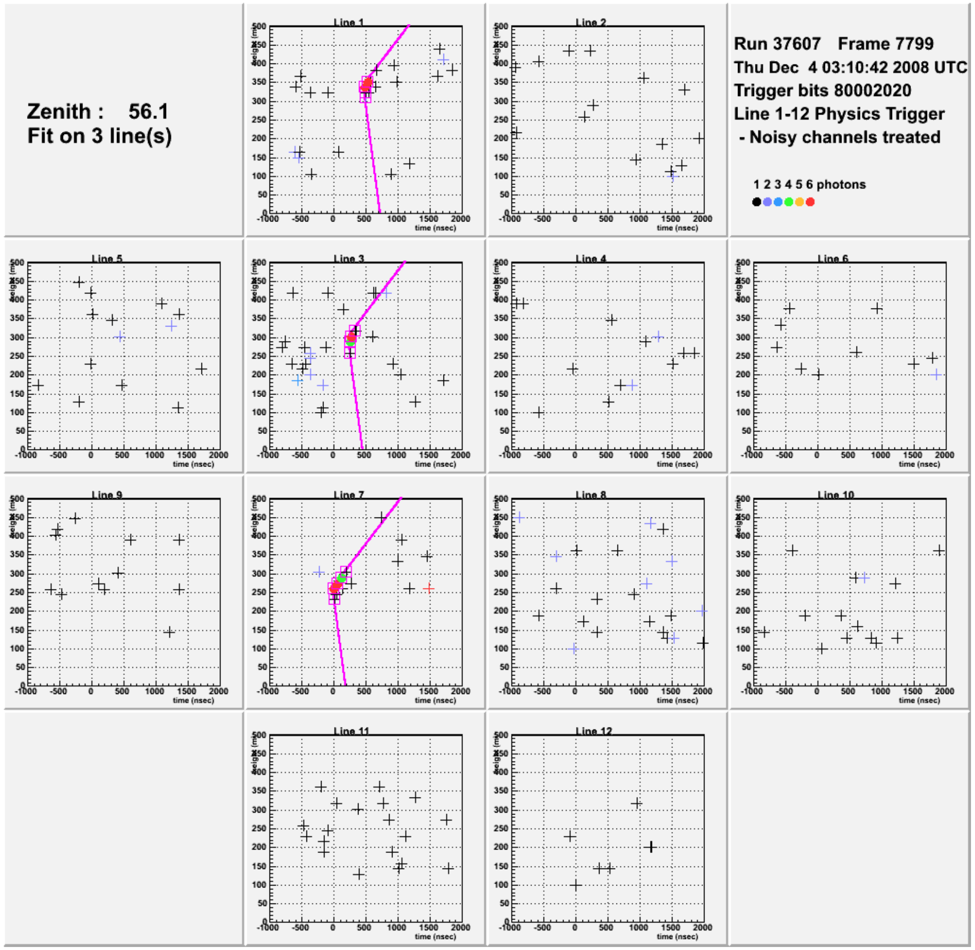
Integral limits on a possible E^{-2} diffuse flux



The energy ranges shown are those which produce the central 90% of events in each analysis.

ANTARES Results

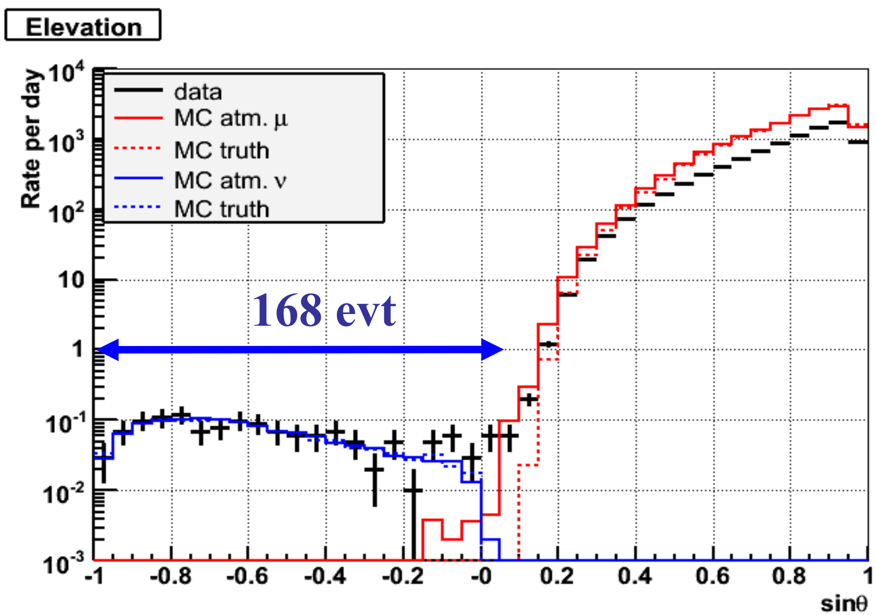
ANTARES: ~ 750 neutrino candidates (A5 and A10)



ANTARES Results

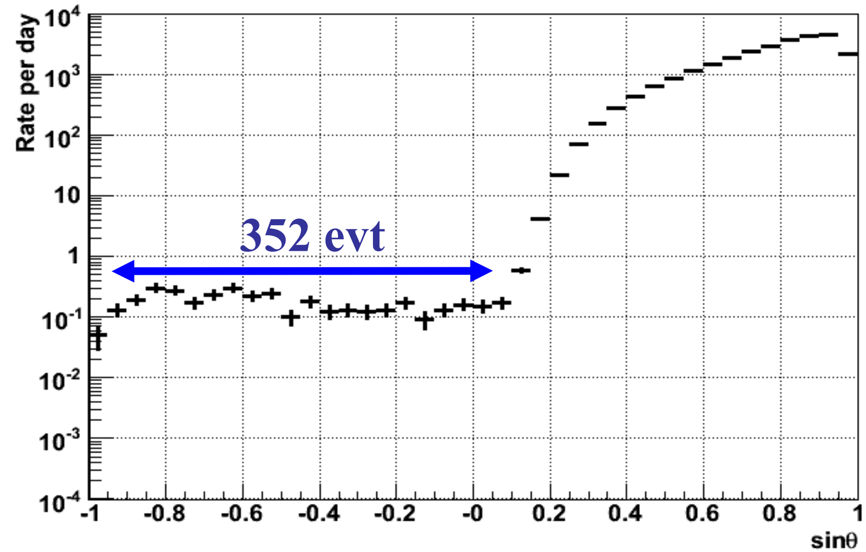
ANTARES: 5 lines 06/07 → 12/07 → Analyzed
10 lines 12/07 → 04/08
12 lines 05/08 →

5 lines (139 active days)



+75 single line events

10 lines (109 active days)

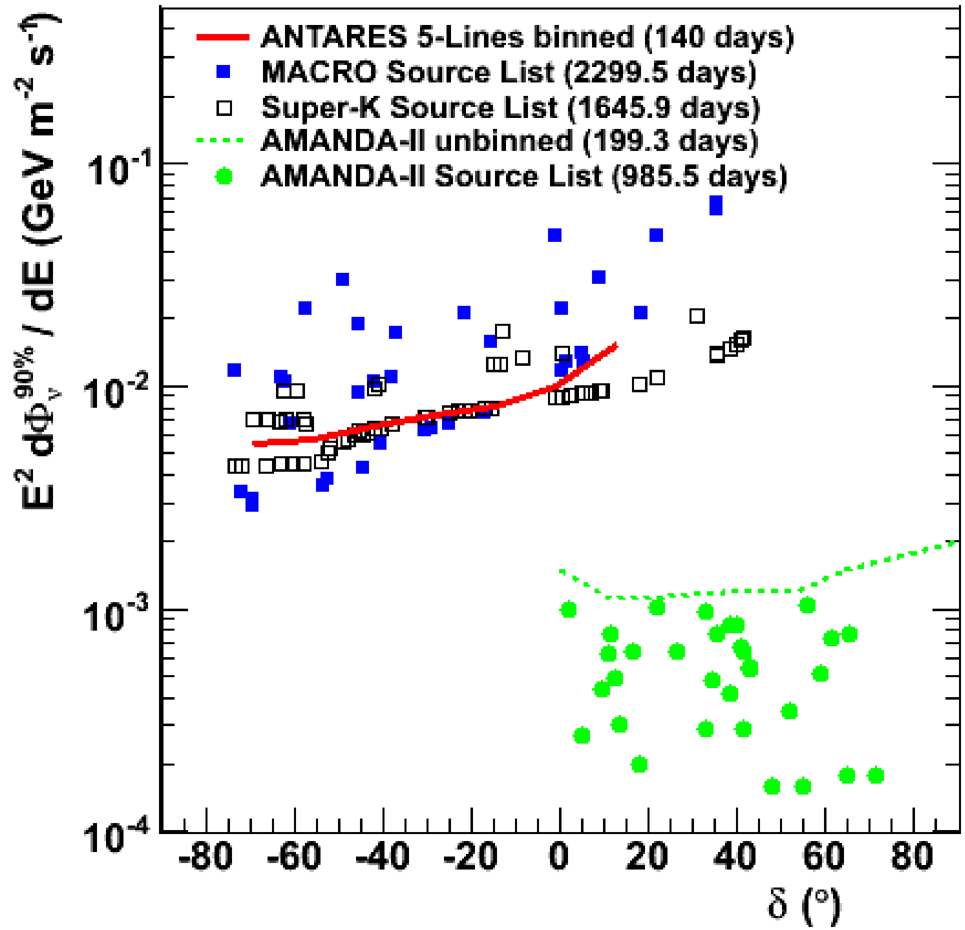


+143 single line events

ANTARES Results

Point-source study

Sensitivity (5 lines)



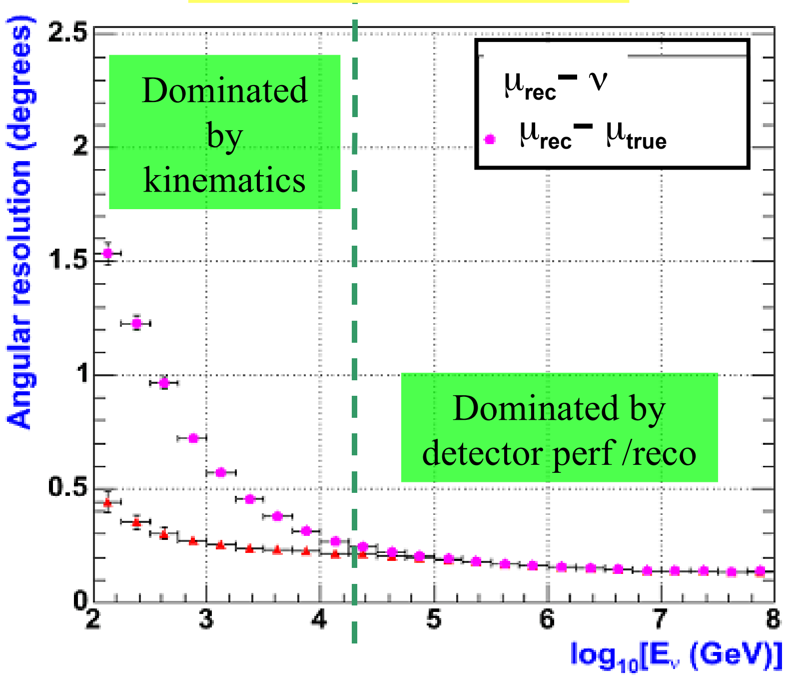
5 line data already analyzed:

→ Result on data will be available soon

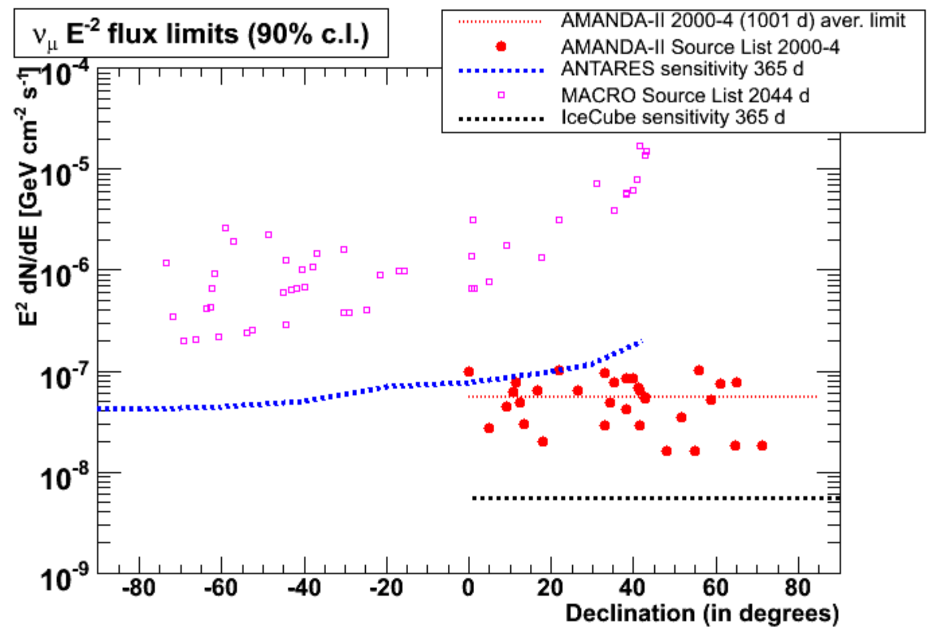
ANTARES Results

Expected performances for the 12 line detector

Angular resolution



Expected sensitivity

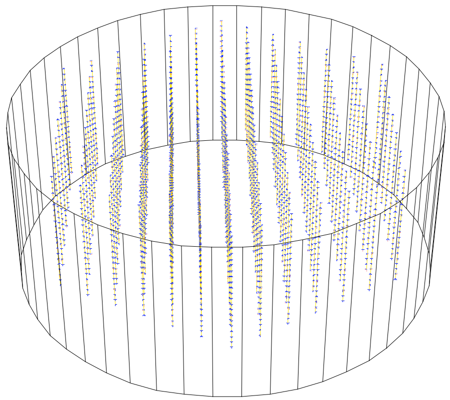


➡ Expected angular resolution better than 0.3° above a few TeV

~ 8 better resolution (~ 60 better sensitivity)

2nd generation detector ~1 km^3

KM3NeT



Characteristics

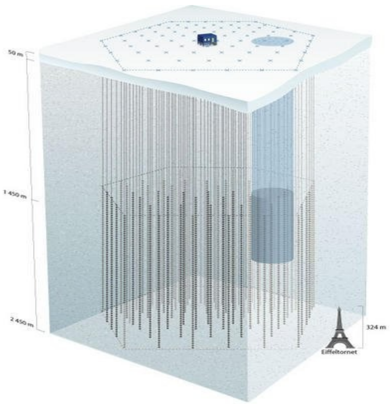
Not really defined

Performances

Angular resolution ~0.2° (E > 10 TeV)

Seff ~ 5 m^2 (10 TeV) ~200 m^2 (10 PeV)

IceCube



Characteristics

Depth: 1450 – 2450m

80 strings separated by 125m

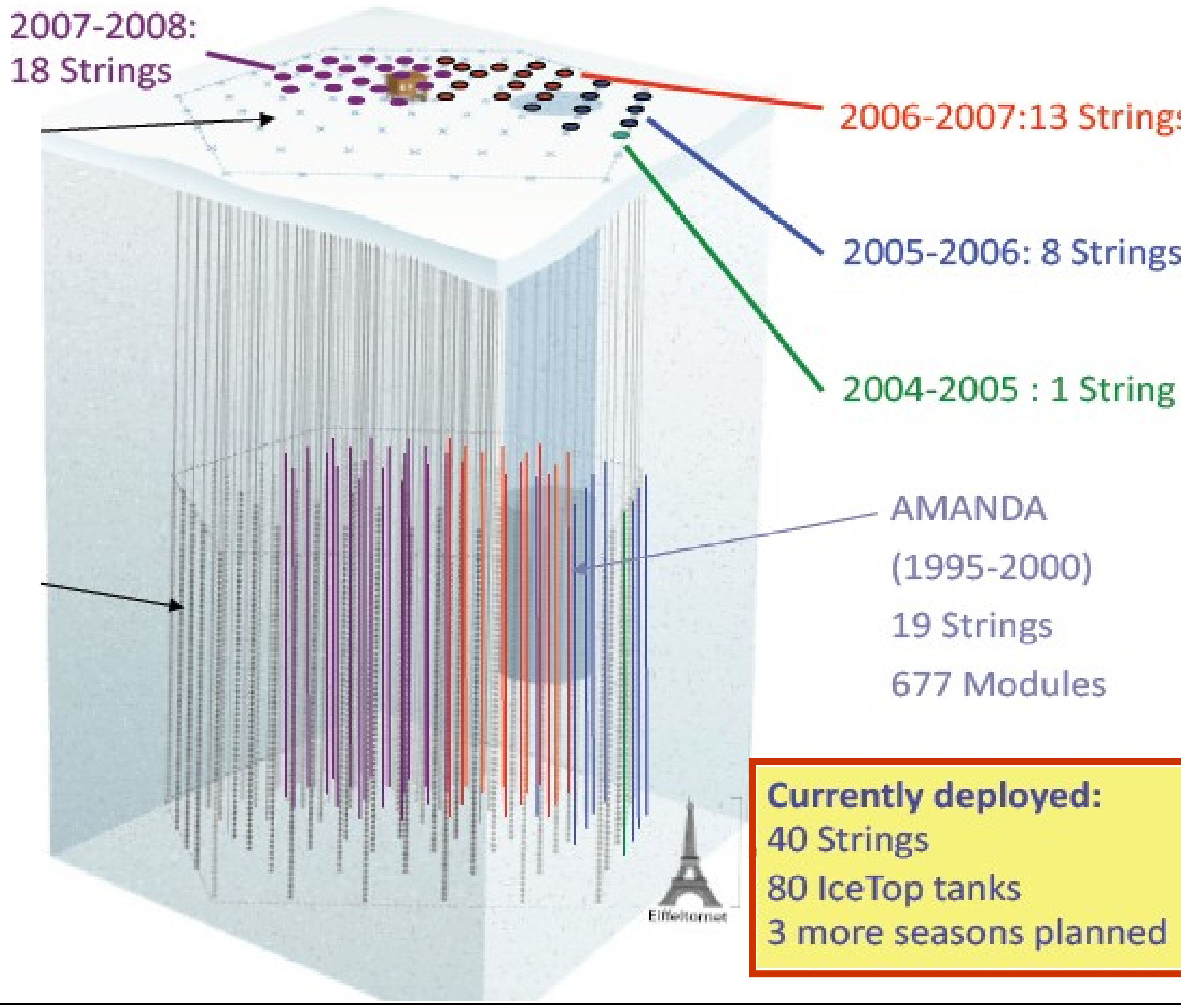
4800 optical modules

Performances

Angular resolution ~0.8° (E > 10 TeV)

Seff ~ 10 m^2 (10 TeV) ~300 m^2 (10 PeV)

IceCube status

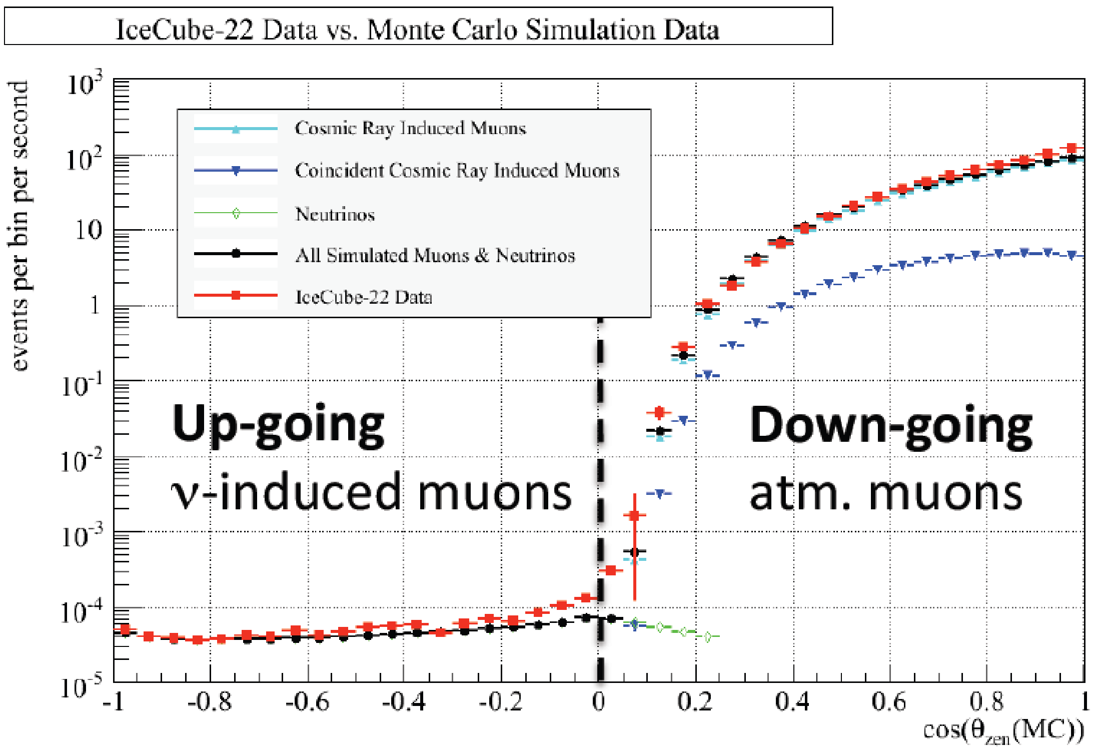


Currently deployed:
40 Strings
80 IceTop tanks
3 more seasons planned

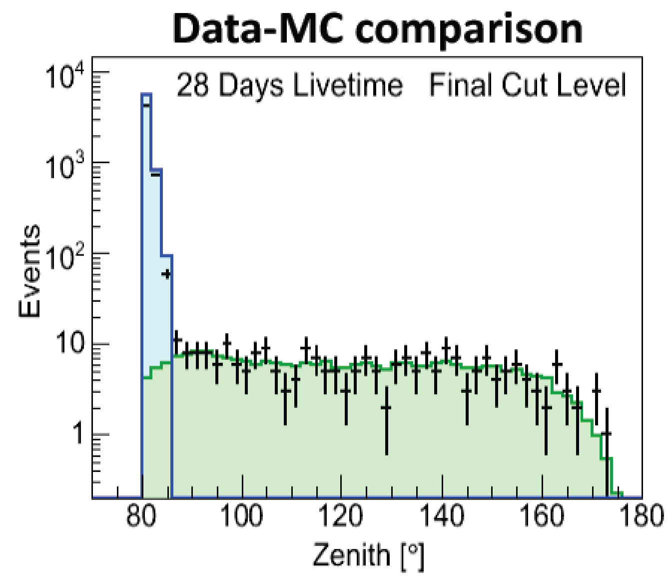
IceCube results (IC22)

Zenith distribution and data-MC comparison

5114 neutrino candidates in 276 days lifetime



After the final cut:

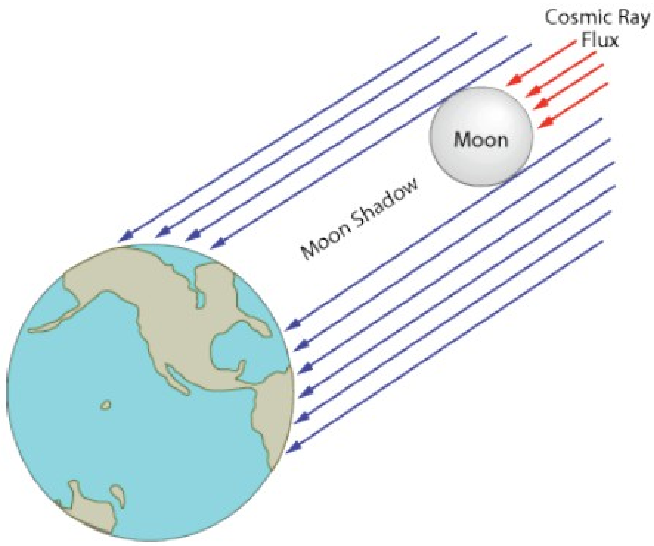


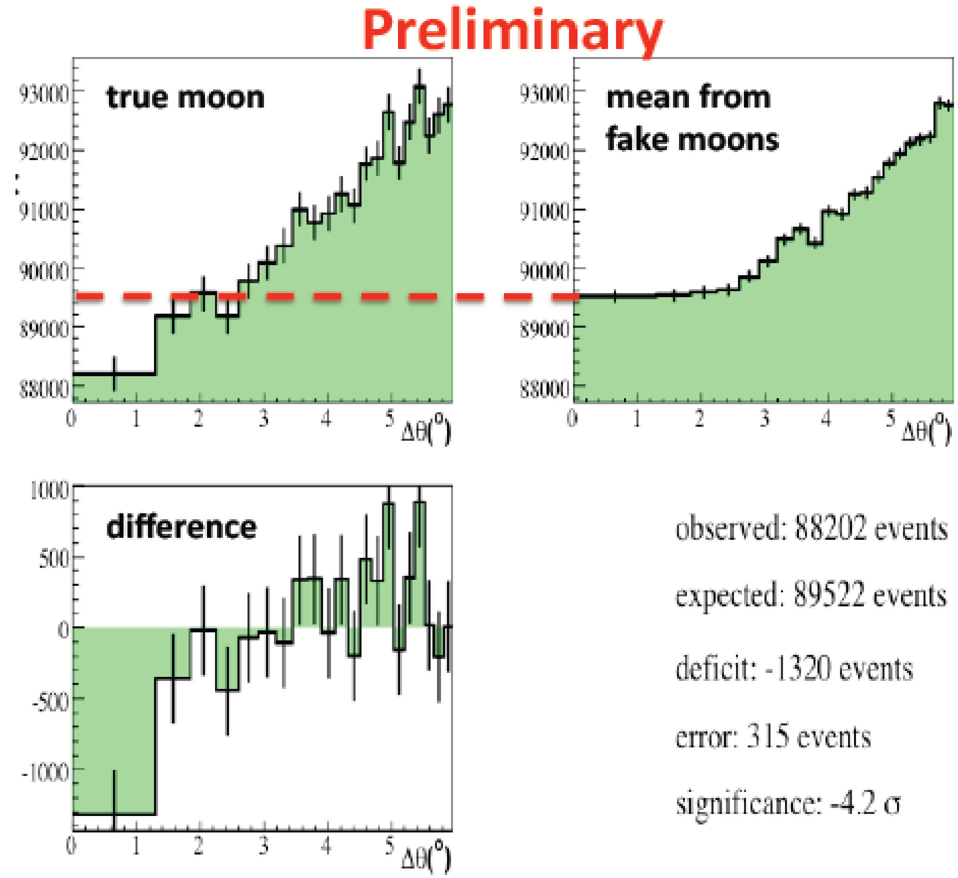
Backgrounds:

- Downgoing μ
- Atmospheric ν

IceCube results (IC40)

Pointing accuracy → Moon shadow detection





observed: 88202 events

expected: 89522 events

deficit: -1320 events

error: 315 events

significance: -4.2 σ

Angular resolution

- IceCube 22 < 1.5°
- IceCube 80 < 1°

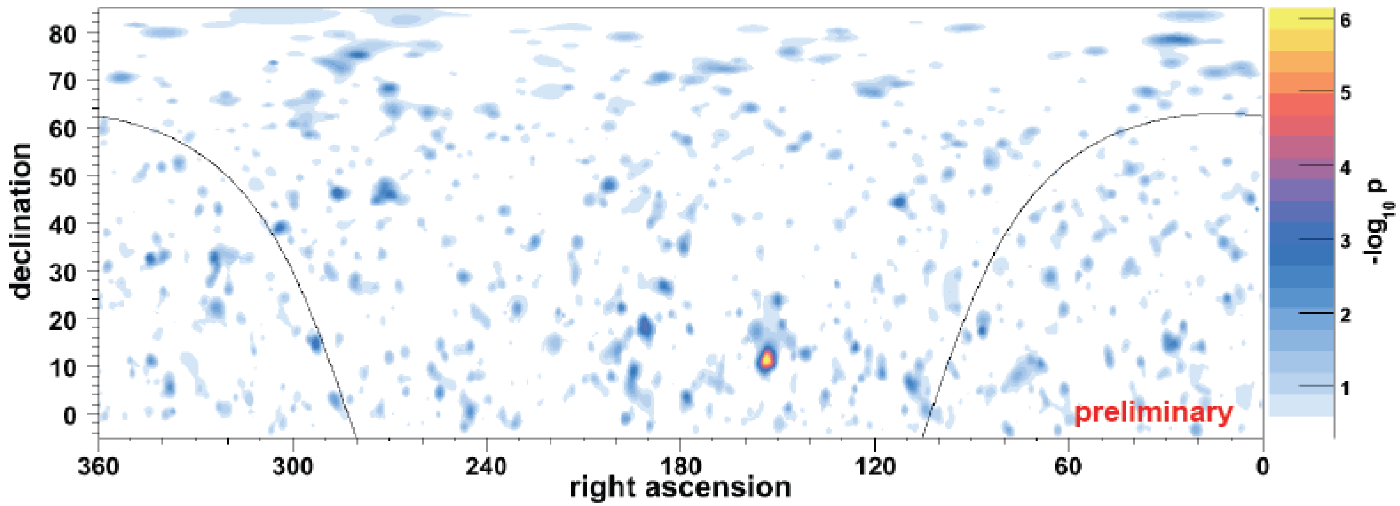
(3 month of IC40 data)

IceCube results (IC22)

Point-source study

Upper limit: $1.3\times10^{-11}\,E_\nu^{-2}\,TeV^{-1}.cm^{-2}.s^{-1}.sr^{-1}$ — > Factor 2 improvement compared to AMANDA

Sky map:



- Unbinned likelihood method using energy information
- Hottest spot found at r.a. 153º , dec. 11º
- pre-trial p-value: 7×10^{-7} (4.8 sigma)
- Accounting for all trials, p-value for analysis is 1.34% (2.2 sigma).
- At this significance level, consistent with fluctuation of background.

KM3NeT design study

FP6 design study 2006-09 – FP7 preparatory phase 2008-11

3 possible sites

- ANTARES: 2400m
- NEMO: 3500m
- NESTOR: 3700-5200m

3 structures tested in the design study:

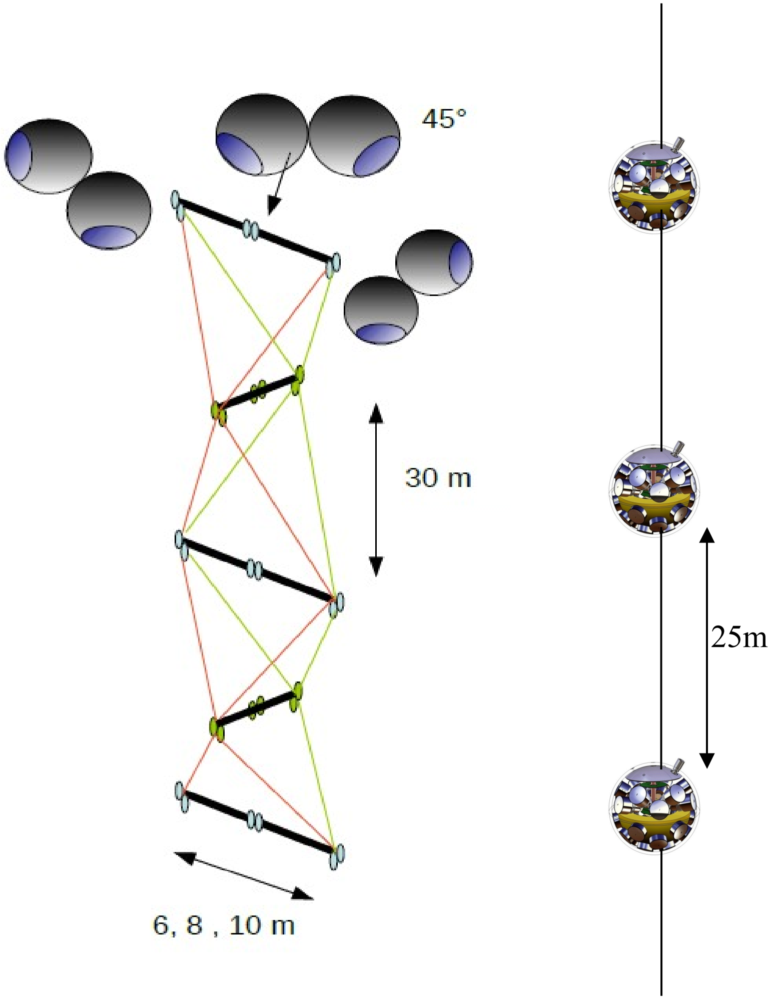
- Improved ANTARES line
- Improved NEMO tower
- "IceCube" string with Multi-PMTs

2 optical modules:

- Standard 8" PMT
- Multi-PMTs (31*3" per storey)

2 transmission systems:

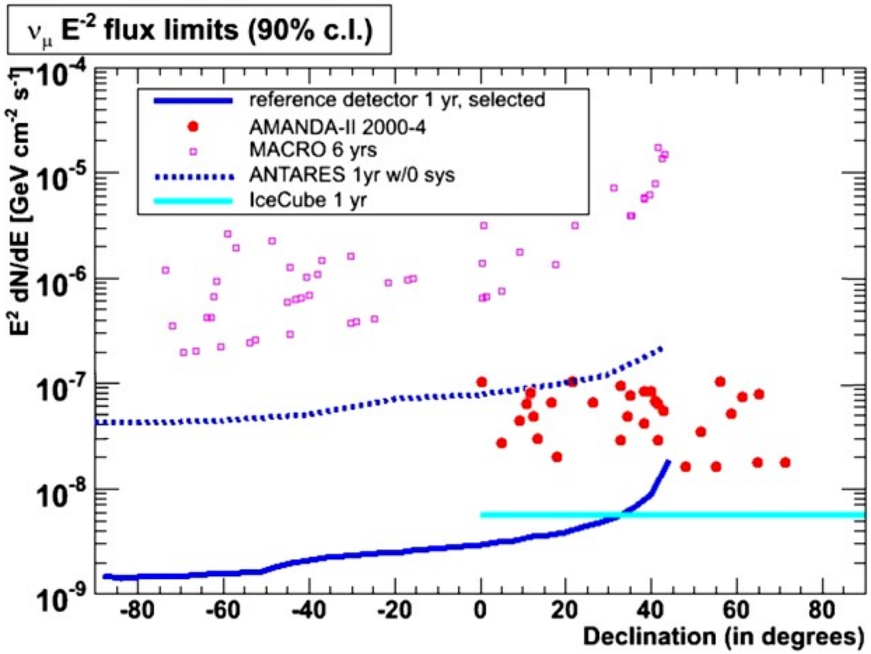
- Hybrid copper / optic
- All optic



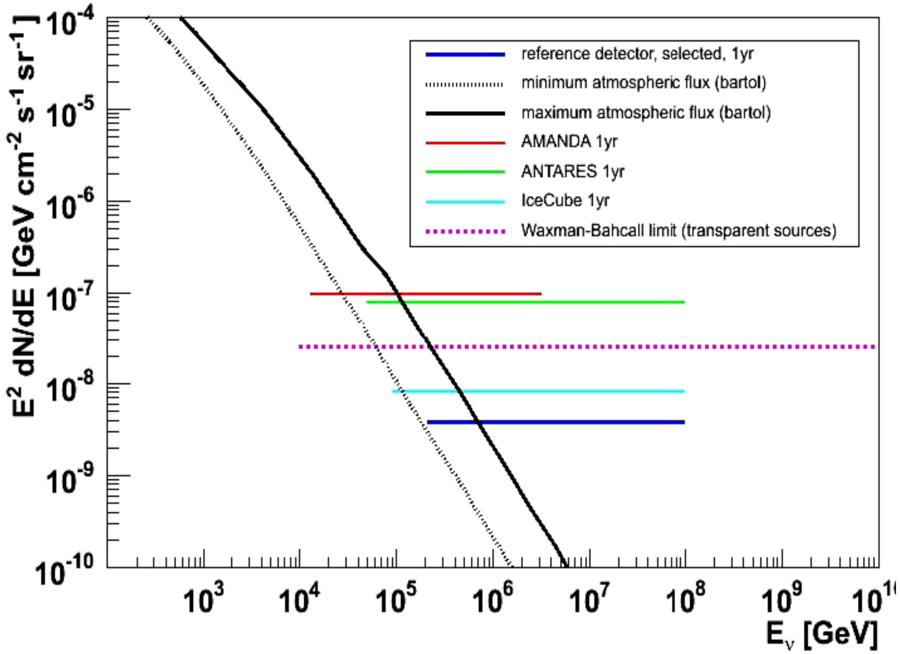
KM3NeT: expected performances

Based only on muon neutrino ν_μ detection generated with a E^{-2} spectrum

Point source



Diffuse



8.1×10^{-9} E^2 GeV cm^{-2} s^{-1} sr^{-1}

3.8×10^{-9} E^2 GeV cm^{-2} s^{-1} sr^{-1}

~ 50 more sensitive than ANTARES

~ 3 more sensitive than IceCube (better photocathode area and better angular resolution)

Multi-messenger approaches

<u>Goal</u>: enhance the discovery chance for neutrinos in case of correlations (lower detection threshold, lower the background contamination…)
"Special" neutrinos: Target of opportunity for others telescopes

Perfectly target for transient sources detection:

GRB, SN, AGN flare, μ-quasar flares…

Use of multi-messenger method:

GRB studies: X-ray detection and neutrino

NToO MAGIC / IceCube (TeV gamma-ray)

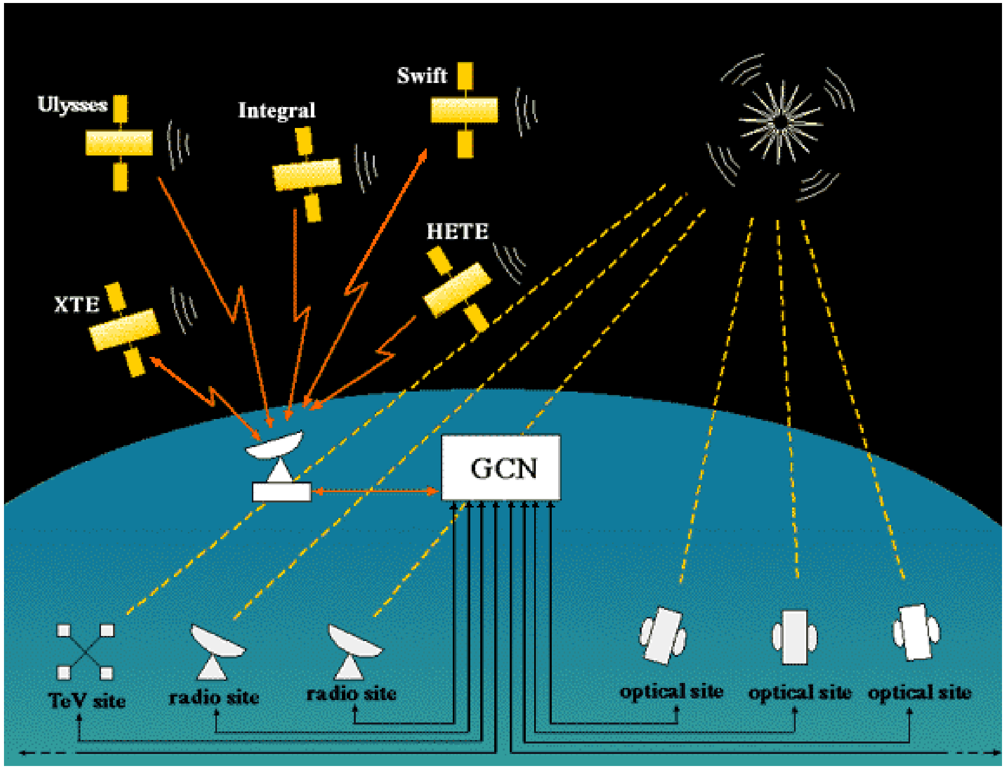
Transient sources (optical follow-up)

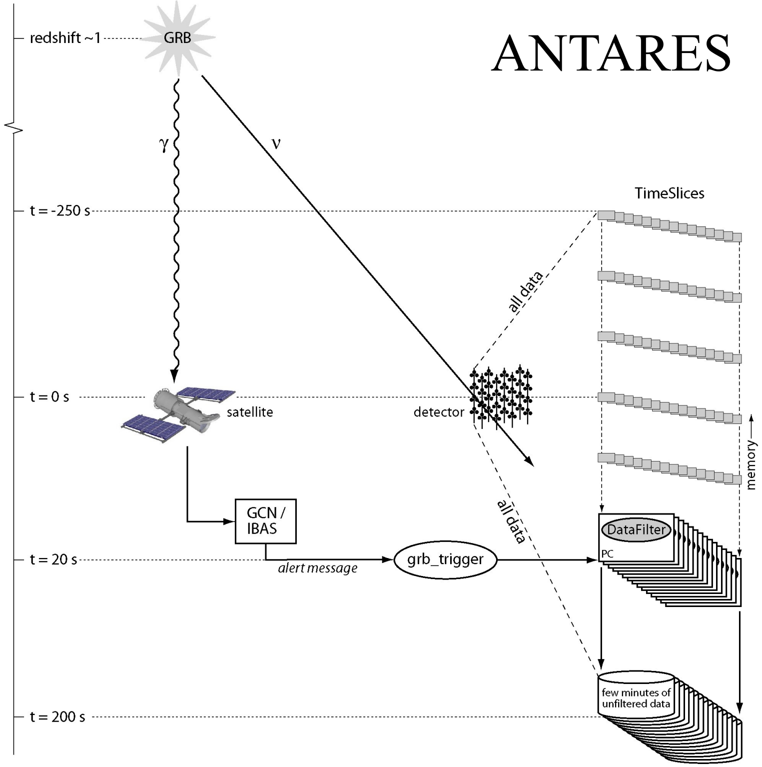
GW interferometers / Neutrino telescopes

Multi-messenger approaches

GRB studies

➡ Neutrino telescopes are client of the GCN



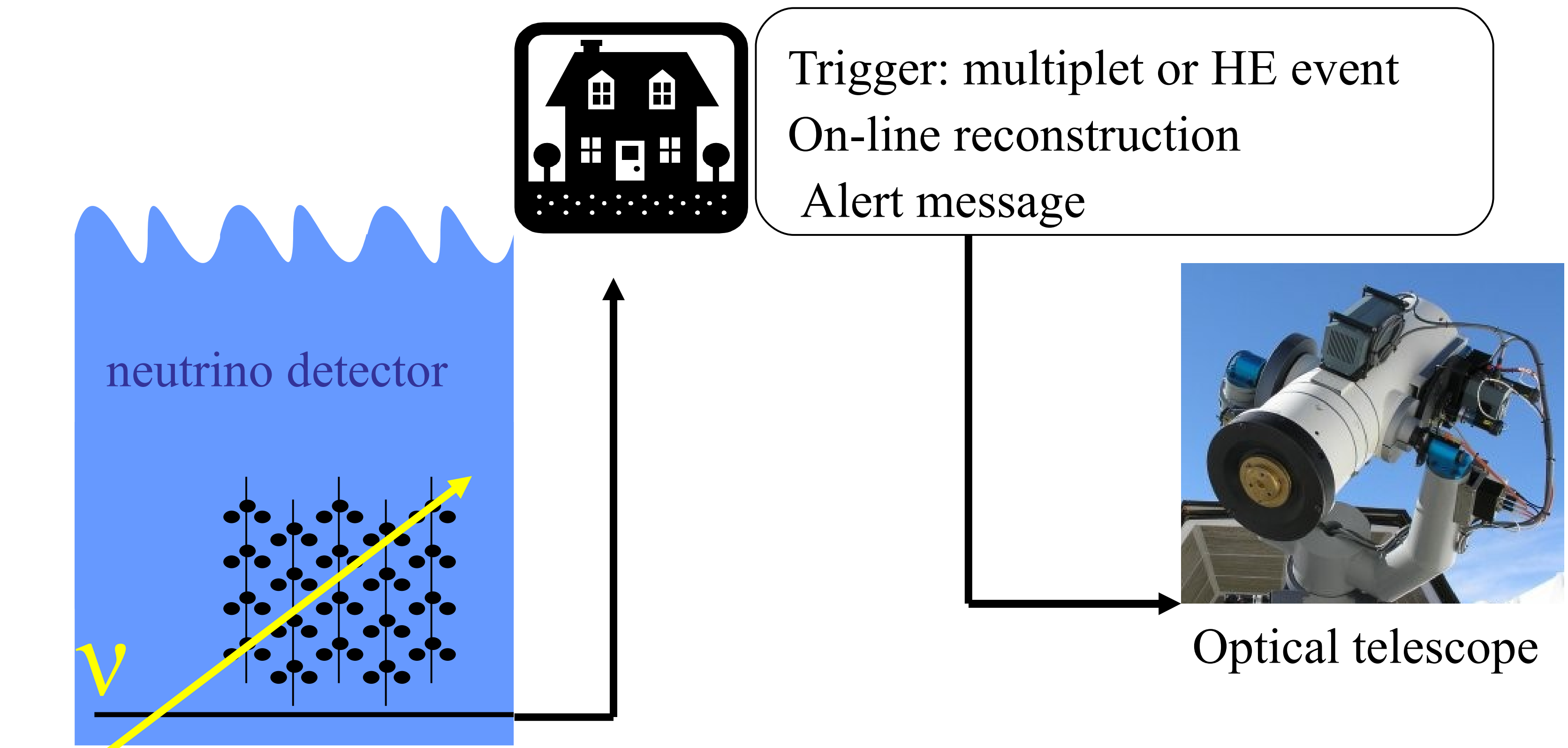


Special data taking (without filtering)

Multi-messengers approaches

Optical follow-up observations after a trigger on neutrino alerts

- IceCube / ROTSE
- ANTARES / TAROT (in preparation)



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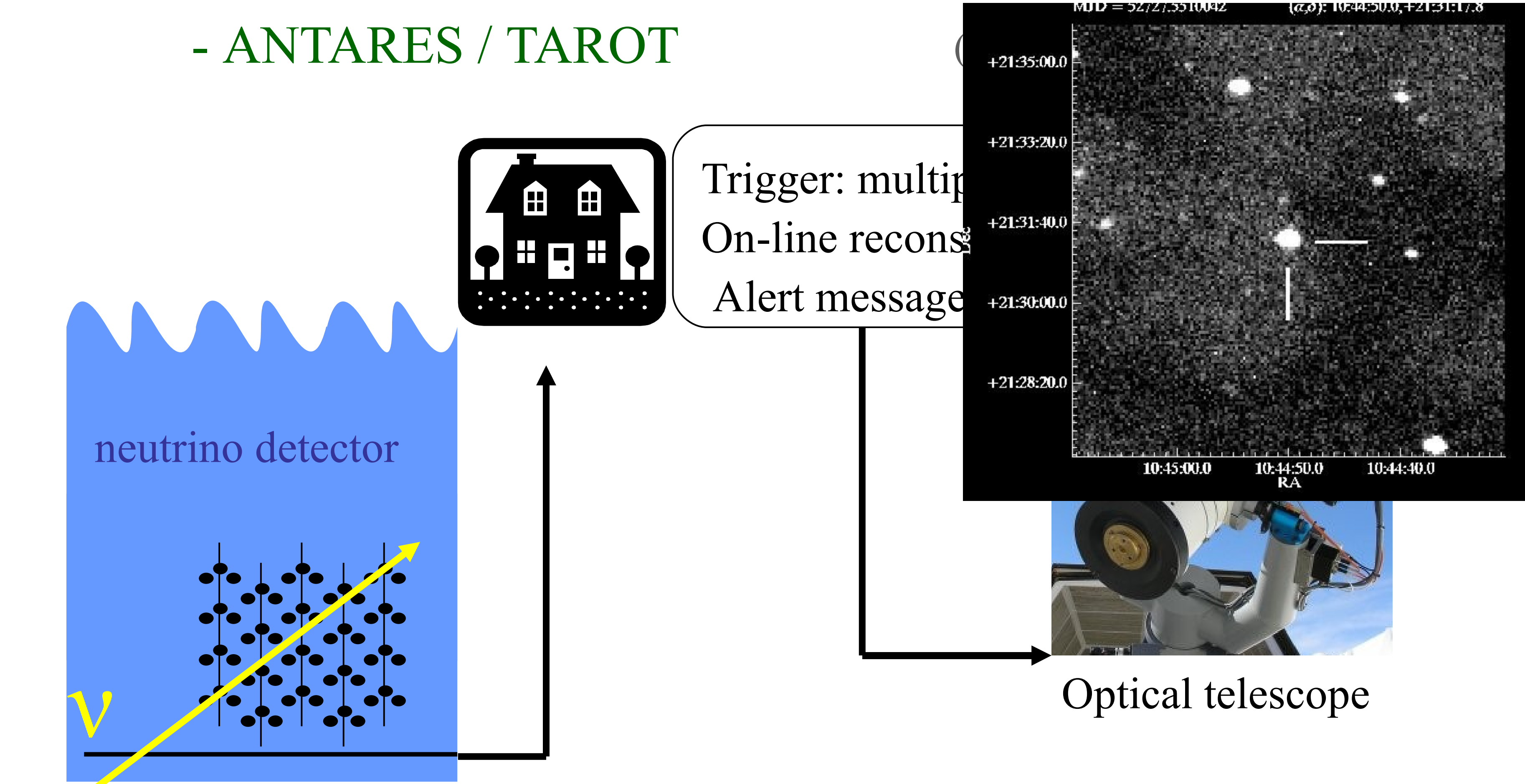
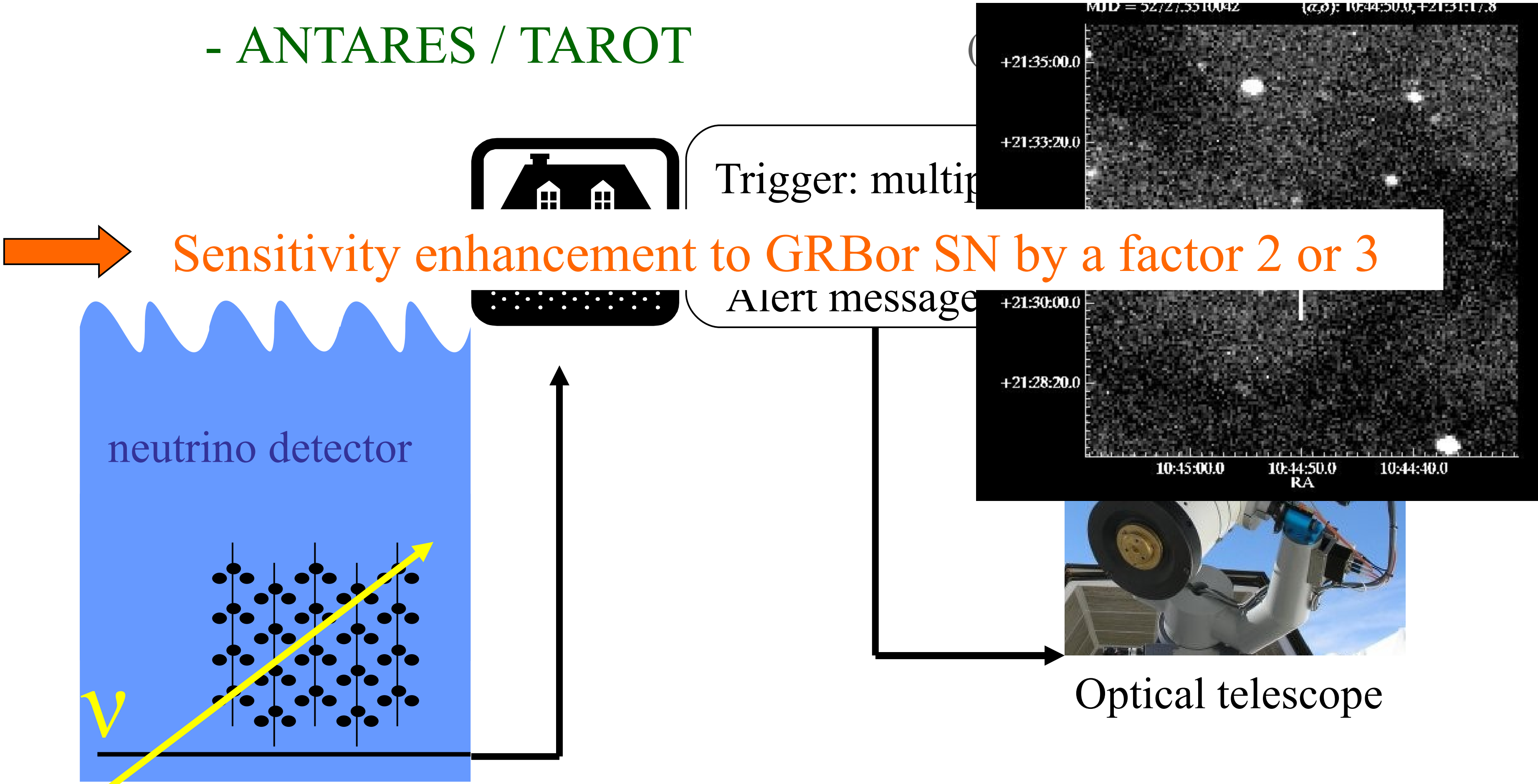


Multi-messengers approaches

Optical follow-up observations after a trigger on neutrino alerts

- IceCube / ROTSE
- ANTARES / TAROT

→ Sensitivity enhancement to GRBor SN by a factor 2 or 3



Multi-messengers approaches

AMANDA II result: 2 neutrinos coincident with a flare of 1ES1959+650 (HEGRA & Whipple) (not significant)

↓

NToO between AMANDA II and MAGIC

Tested between 27th September to 27th November 2006

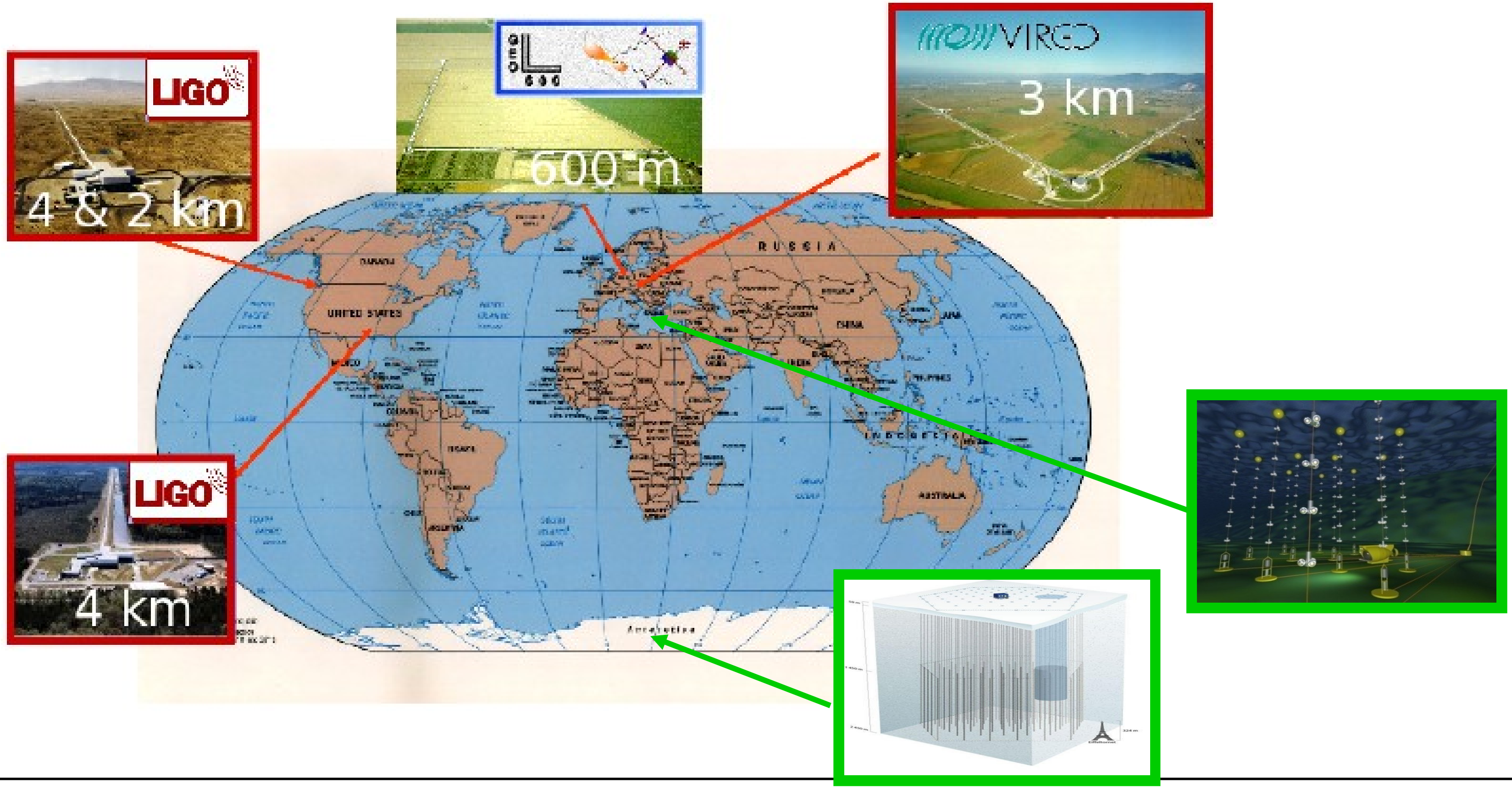
Search for flares of neutrinos in the sample of up-going events

If compatible the position with a given list of blazar or μ-quasar sources → Send an alert to the MAGIC

MAGIC will answered in the day (day/night)

Multi-messenger approaches

Coincidence between gravitational wave interferometers (VIRGO – LIGO) and neutrino telescopes (ANTARES – IceCube)



Outlook - conclusions

Detector status:

- *ANTARES*: complete June 2008, 500 neutrinos recorded (A5-10)
  Very good angular resolution (0.3° at HE)
- *IceCube*: 40 strings already deployed, IC22 data analysis
  Very large effective area (~ 5 m^2 at 10 TeV, ~200 m^2 at PeV)

Future:

- *IceCube improvements*: deep-core (LE) or superIC (UHE)
- *KM3NeT*: design study is on the way
  (may be it will evolve with the IC result)

Multi-messenger approaches are essential to the neutrino telescopes

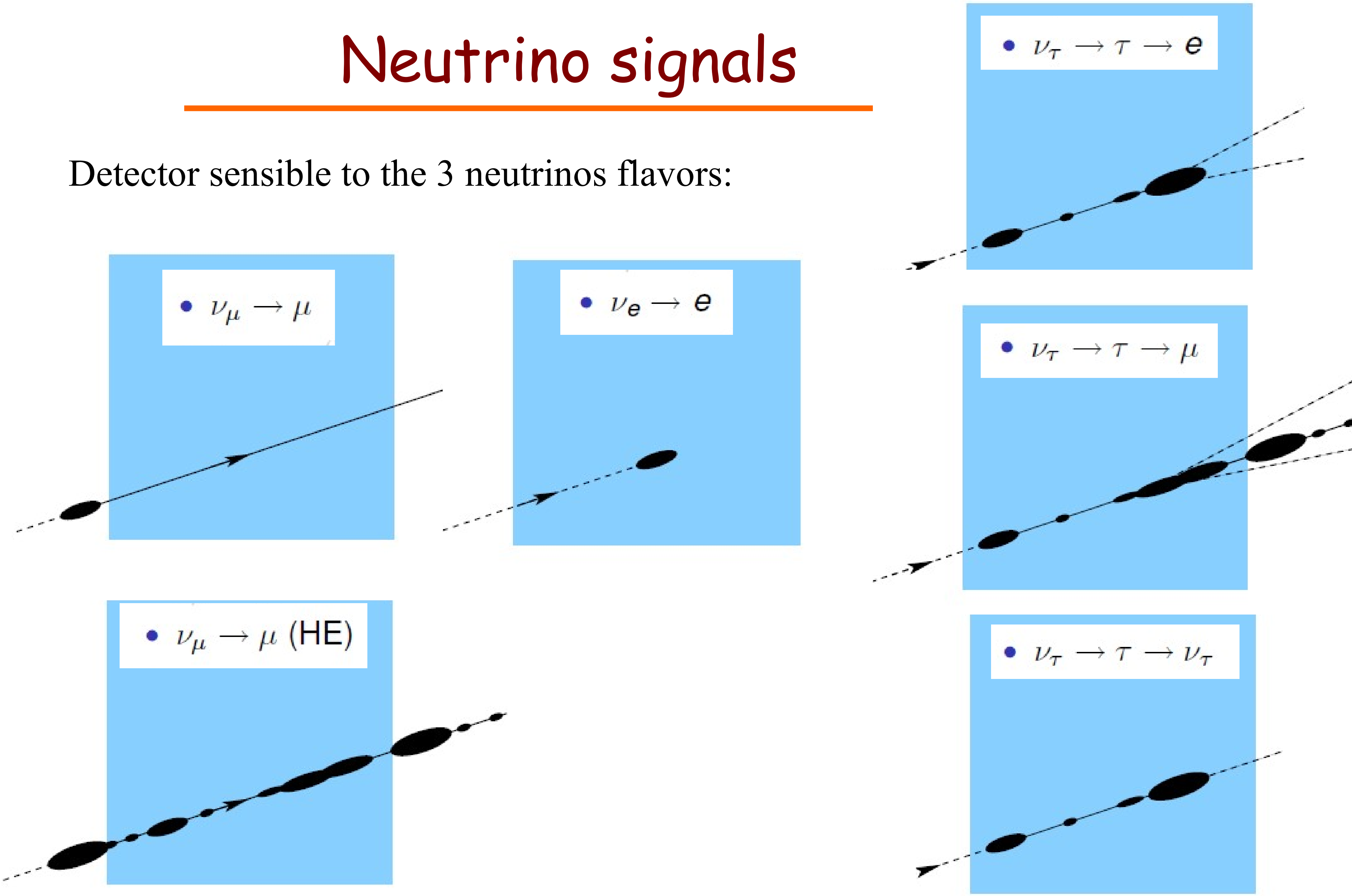
?

?

?

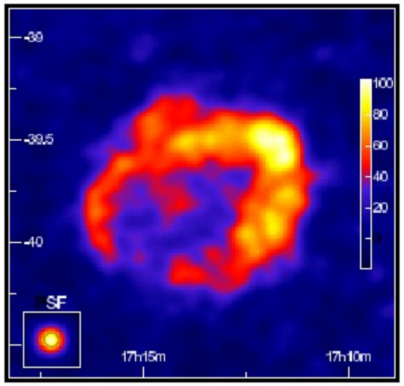
Neutrino signals

Detector sensible to the 3 neutrinos flavors:



SNRs

Cherenkov telescopes:

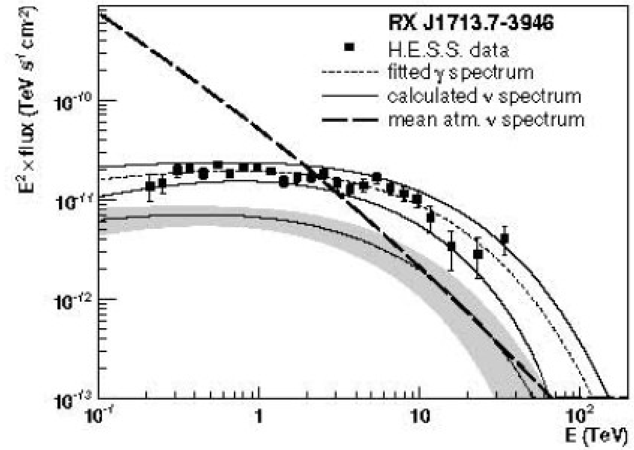


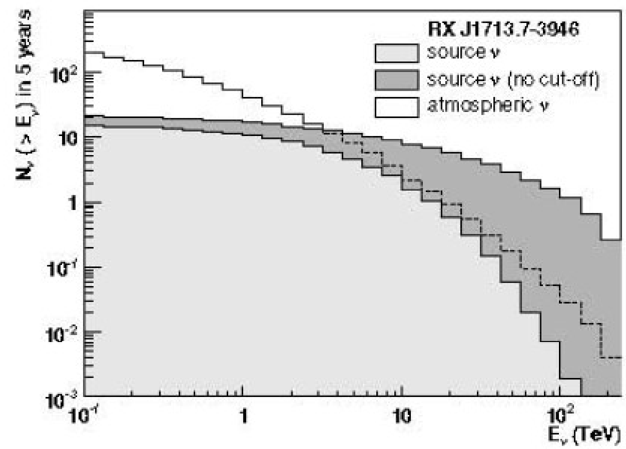
Suppose an hadronic model, HE neutrinos flux can be derived from HE gamma spectrum:

$$pp(p\gamma) \rightarrow \pi^{\pm}, \pi^{0}, \ldots$$

$$\pi^{\pm} \rightarrow \mu\nu_{\mu} \rightarrow e\nu_{\mu}\nu_{\mu}\nu_{e}$$

$$\pi^{0} \rightarrow \gamma\gamma$$





RXJ1713-3946: extended source (Φ ~ 1.3°) and ~75% of the time bellow the horizon

→ in 5 years: 5 neutrinos for 15 background events

(Possible background reduction by choosing only hot spots)

Dornic et al, astro-ph/0711.2145

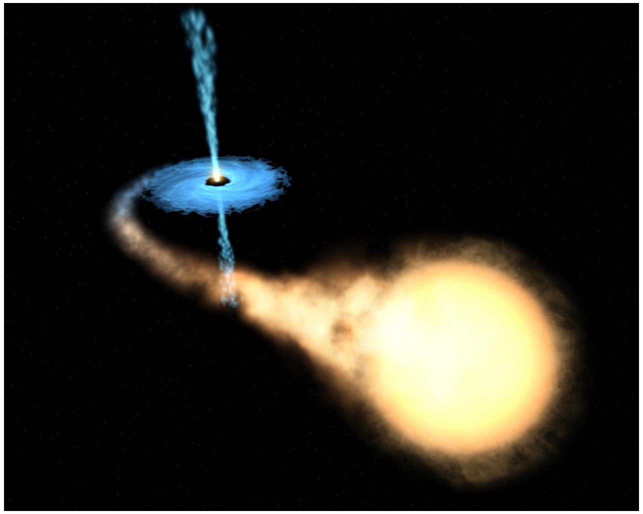
Kappes et al, astro-ph/0607286

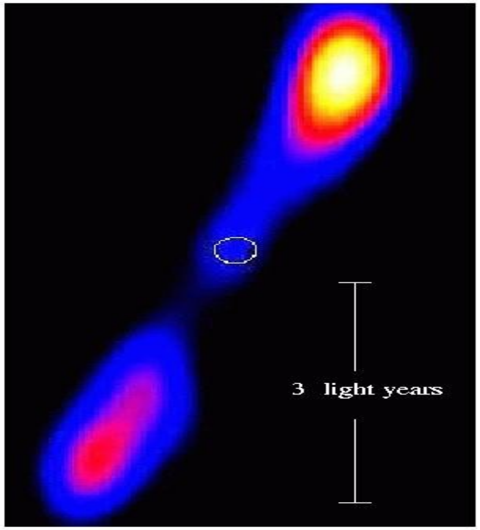
Microquasars

Prediction for a NEMO detector:

Source name	Δt (days)	f_ν^{th} (erg/cm^2 s)	N_μ^{m}	b
Steady Sources				
LS 5039	365	$1.69 \cdot 10^{-12}$	0.1	0.1
Scorpius X-1	365	$6.48 \cdot 10^{-12}$	0.2	0.1
SS433	365	$1.72 \cdot 10^{-9}$	76.0	0.1
GX 339-4	365	$1.26 \cdot 10^{-9}$	68.0	0.1
Cygnus X-1	365	$1.88 \cdot 10^{-11}$	0.5	0.1
Bursting Sources				
XTE J1748-288	20	$3.07 \cdot 10^{-10}$	0.8	0.3
Cygnus X-3	3	$4.02 \cdot 10^{-9}$	0.8	0.1
GRO J1655-40	6	$7.37 \cdot 10^{-10}$	0.6	0.1
GRS 1915+105	6	$2.10 \cdot 10^{-10}$	0.1	< 0.1
Circinus X-1	4	$1.22 \cdot 10^{-10}$	0.1	0.1
XTE J1550-564	5	$2.00 \cdot 10^{-11}$	< 0.1	< 0.1
V4641 Sgr	0.3	$2.25 \cdot 10^{-10} \div 3.25 \cdot 10^{-8}$	$< 0.1 \div 1.4$	0.1
GS 1354-64	2.8	$1.88 \cdot 10^{-11}$	< 0.1	0.1
GRO J0422+32	$1 \div 20$	$2.51 \cdot 10^{-10}$	$< 0.1 \div 0.4$	0.1
XTE J1118+480	$30 \div 150$	$5.02 \cdot 10^{-10}$	$1.0 \div 4.8$	0.2

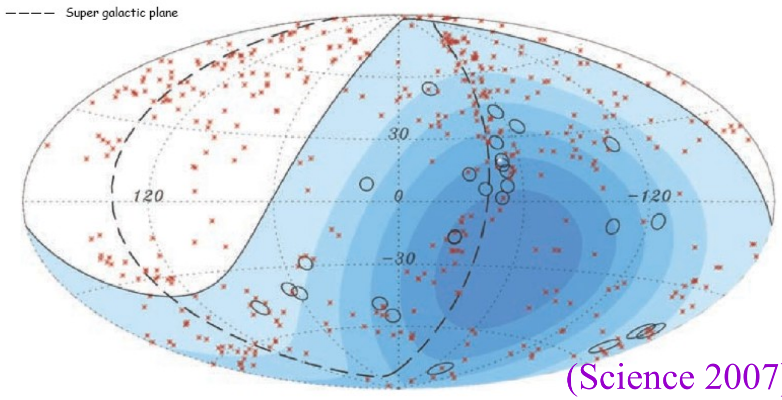
Distefano, astro-ph/07062993





AGNs

Recent Auger results on the correlation with nearby AGNs (z<0.018)



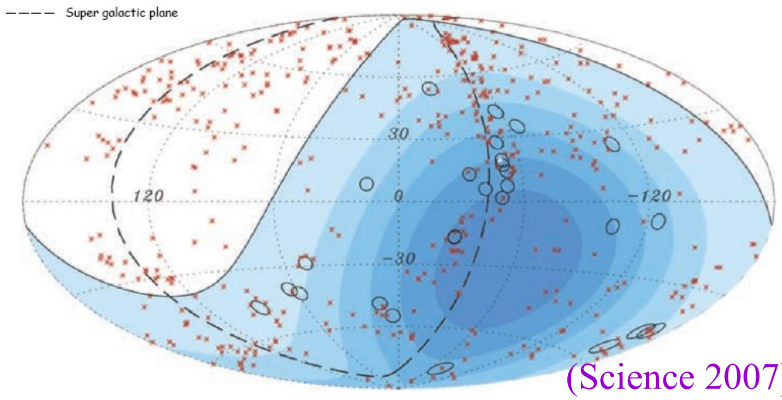
(Science 2007)

Neutrinos flux calculation from Cen A (4 Mpc):

Assuming that 2 CR detected in a window of 3.2° → Detected number of neutrinos: between 2 and several 10^{-3} event per year following different models

AGNs

Recent Auger results on the correlation with nearby AGNs ($z<0.018$)



(Science 2007)

Neutrinos flux calculation from Cen A (4 Mpc):

Assuming that 2 CR detected in a window of 3.2° → Detected number of neutrinos: between 2 and several 10^{-3} event per year following different models

Neutrinos flux calculation from few AGNs detected by HESS:

After correction of the ISM absorption (EBL), neutrino spectra calculation:

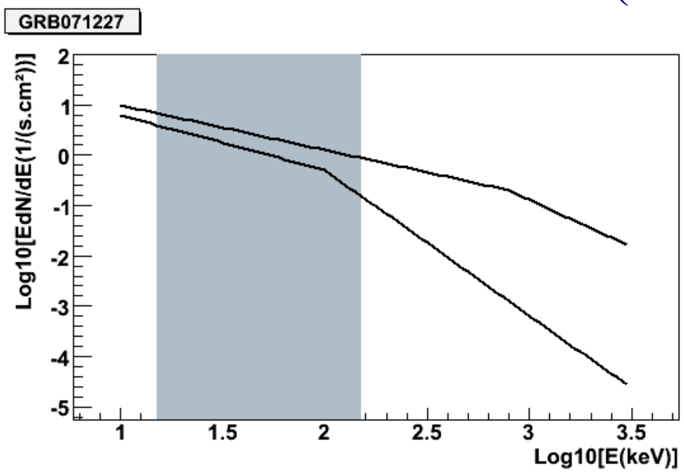
⇒ Very hard spectrum ($\Gamma<1.8$) ⇒ Optimistic prediction

GRBs

If we suppose that CR are accelerated in jets, then they can interact with the burst X-ray photon (synchrotron from accelerated electrons)

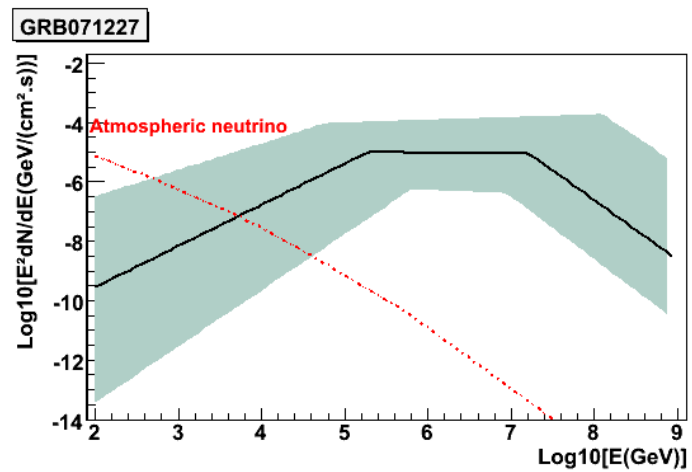
→ HE neutrinos production (> qq 10 TeV)

Prediction for GRB071227 (z ~ 0.38),



Interaction

($p\gamma$)



→ 0.5 events (± 1 order of magnitude)

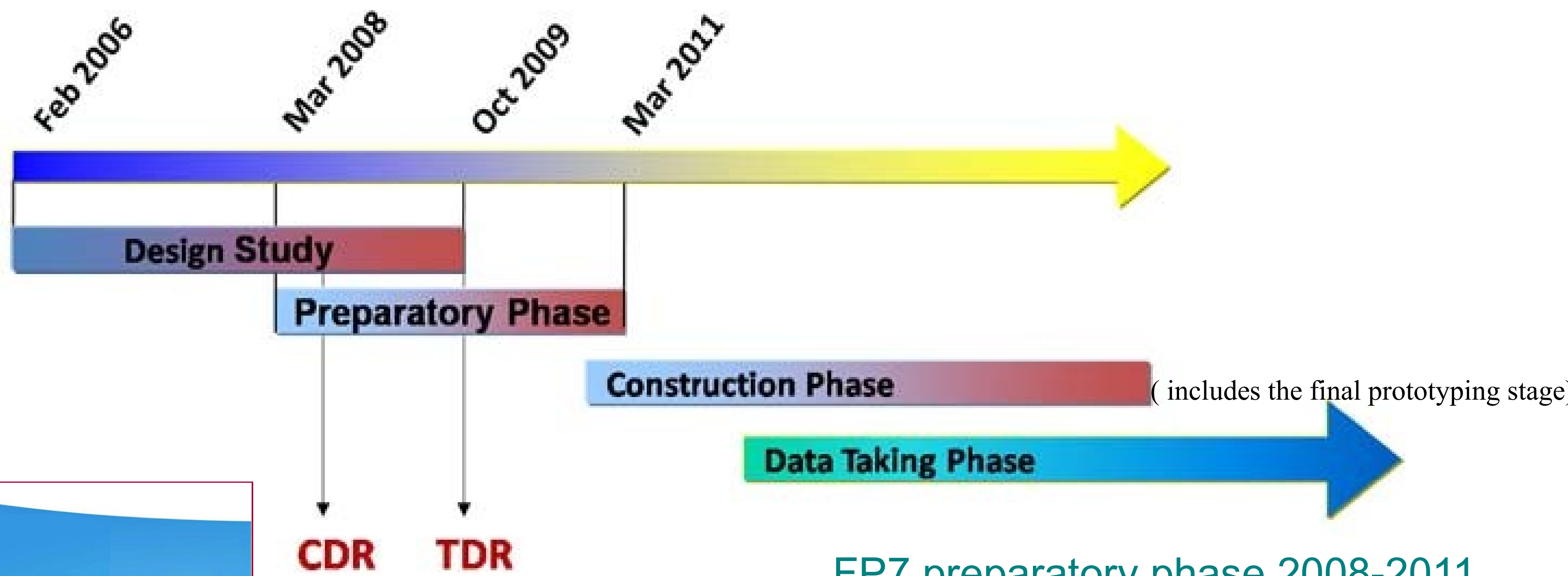
Dornic et al, NIM Physics A

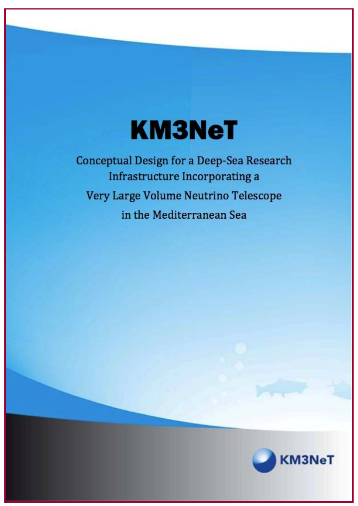
but very large incertitude on the model

→ Contribution for the diffuse flux: few 10 neutrinos per year

Slow jet model of core collapse SN seem very promising for neutrino detection

KM3NeT: from a concept to the realisation





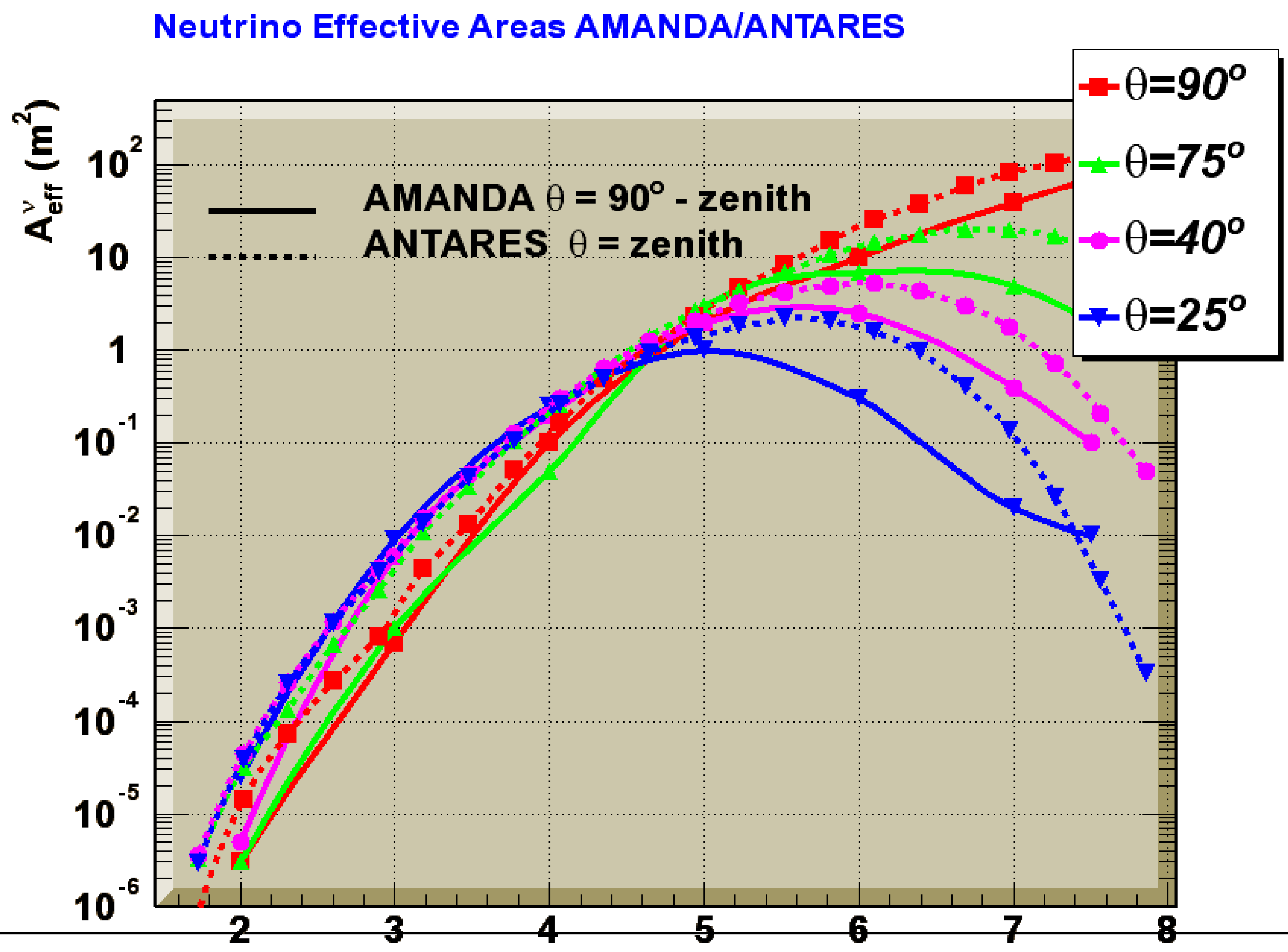
http://www.km3net.org/CDR/CDR-KM3NeT.pdf

FP7 preparatory phase 2008-2011

Goal: Preparation of the construction of the KM3NeT facility

- Legal, governance, siting issues
- System prototyping
- Industrialisation of production
- Mass production: assembly and integration process
- Public data procedures.

?



Neutrino Effective Areas AMANDA/ANTARES
AMANDA θ = 90° - zenith
ANTARES θ = zenith
θ=90°
θ=75°
θ=40°
θ=25°
A^{ν}_{eff} (m^2)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
2
3
4
5
6
7
8
$\log_{10}$ E (GeV)