

High Energy Neutrino Telescopes

Paschal COYLE
CNRS/CPPM-Marseille

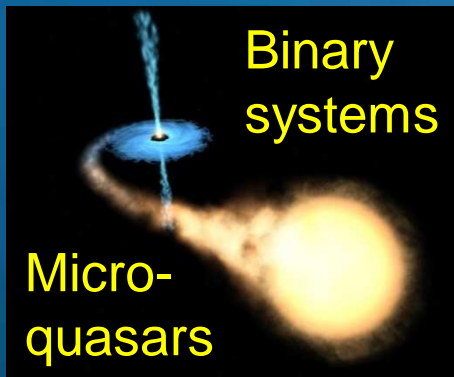
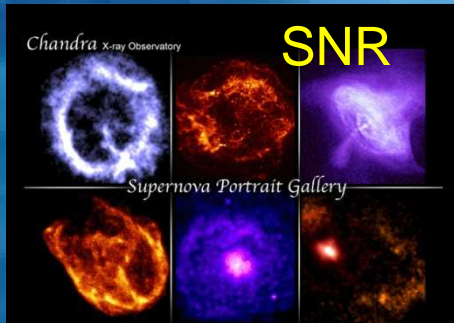


Ecole Astroparticules, OHP, 12 Sept, 2009

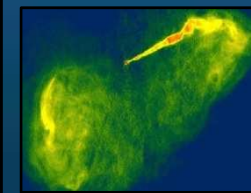
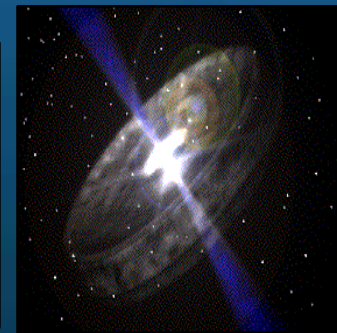
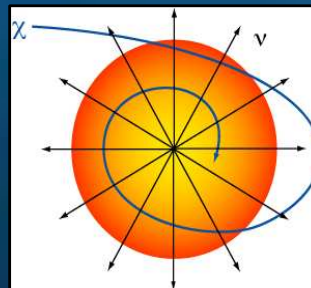
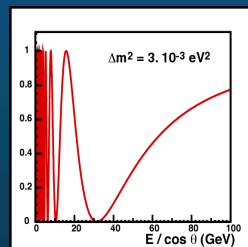
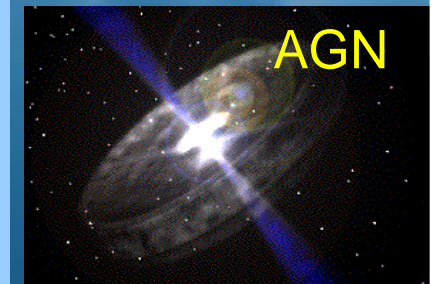




Science with High Energy Neutrinos



- **High energy neutrino astrophysics:**
galactic: SN, SNRs, μ -quasars...
extra-gal: AGNs, GRBs, GZK
- **Search for New Physics:**
Dark matter (sun, GC), Monopoles..
- **Earth-Sea Science:**
oceanography, sea biology, seismology, environment monitoring...



~MeV

GeV-100 GeV

GeV-TeV

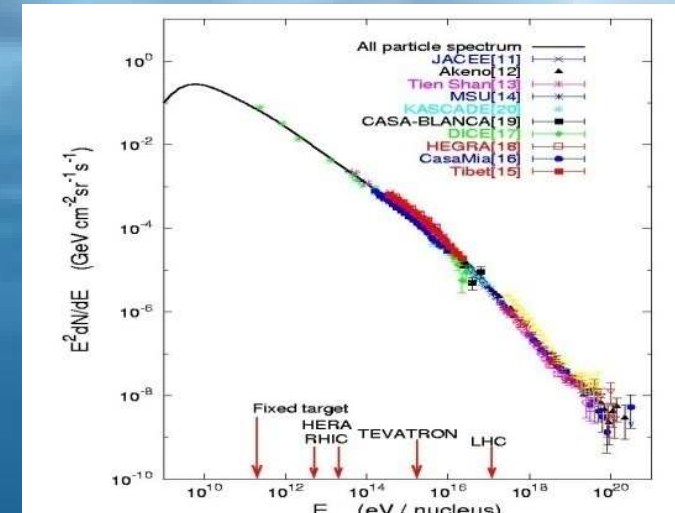
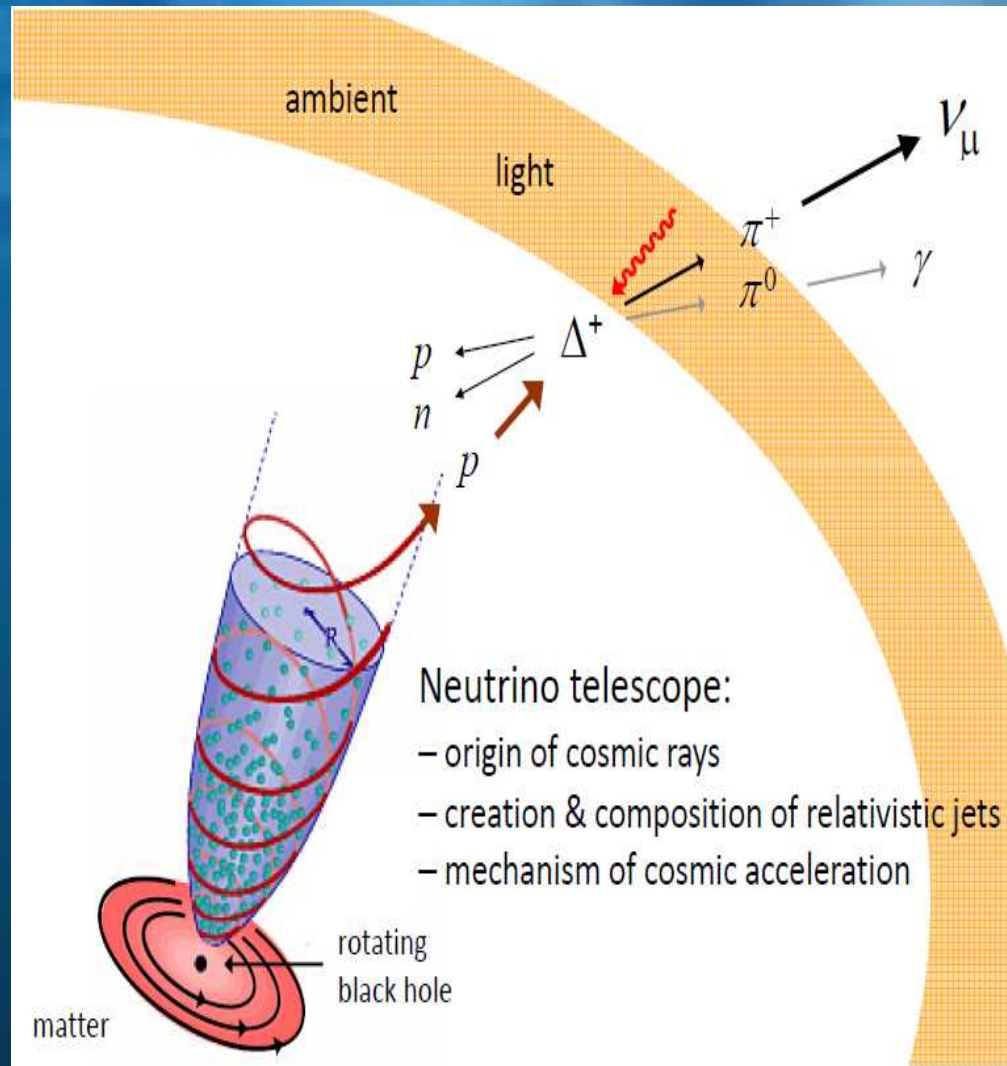
TeV-PeV

PeV-EeV

> EeV



Neutrino Production and Transport



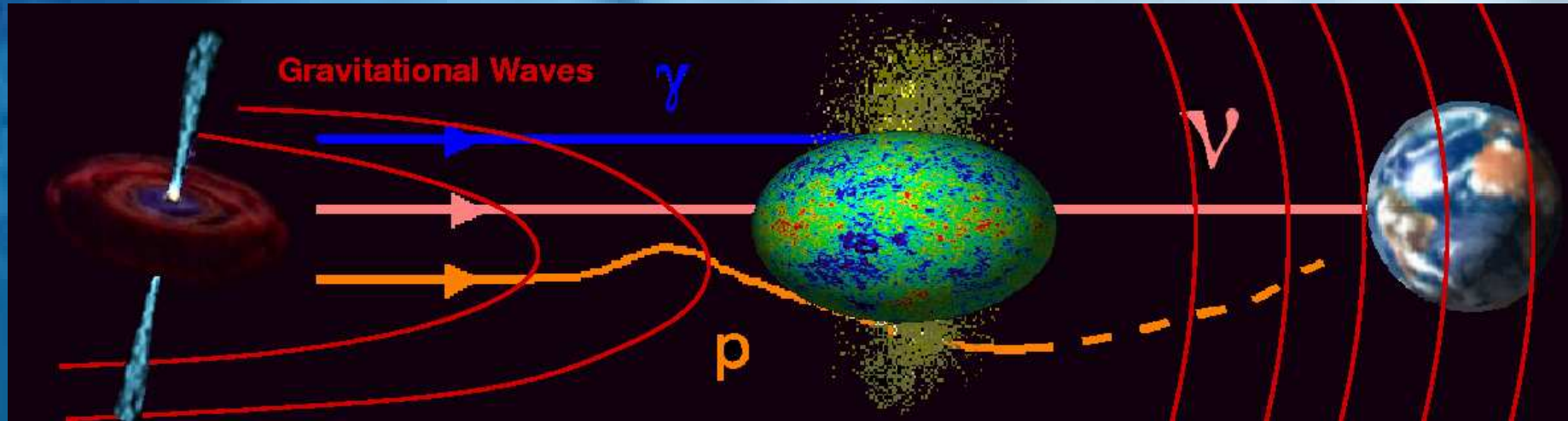
HE protons are accelerated
-but where?

Unambiguous probe of
hadronic processes

Oscillations during transit:
 $1\nu_e : 2\nu_\mu : 0\nu_\tau \rightarrow 1\nu_e : 1\nu_\mu : 1\nu_\tau$



Neutrinos and Multi-Messenger Astronomy



Neutrinos

- Not deflected by magnetic fields
- Not absorbed by dust
- Horizon not limited by interaction with CMB/IR
- Detectable over full energy range (GeV-→PeV)
- Can be correlated with optical signals

Unlike p^+

Unlike γ

Unlike p^+ and γ

Unlike p^+ and γ

Unlike p^+

absorption	cut-off	mean free path
γ -rays: $\gamma + \gamma_{2.7k} \rightarrow \pi^0 + X$	$> 10^{14} \text{ eV}$	10 Mpc
proton: $p + \gamma_{2.7k} \rightarrow \pi^0 + X$	$> 5 \cdot 10^{19} \text{ eV}$	50 Mpc
neutrinos: $\nu + \nu_{1.95k} \rightarrow Z + X$	$> 4 \cdot 10^{22} \text{ eV}$	(40 Gpc)
neutrons decay: $\Upsilon_{ct} = E/m_{ct} \sim 10 \text{ kpc}$ for $E \sim 10^{18} \text{ eV}$		



Universe is not transparent for HE photons or nuclei

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

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

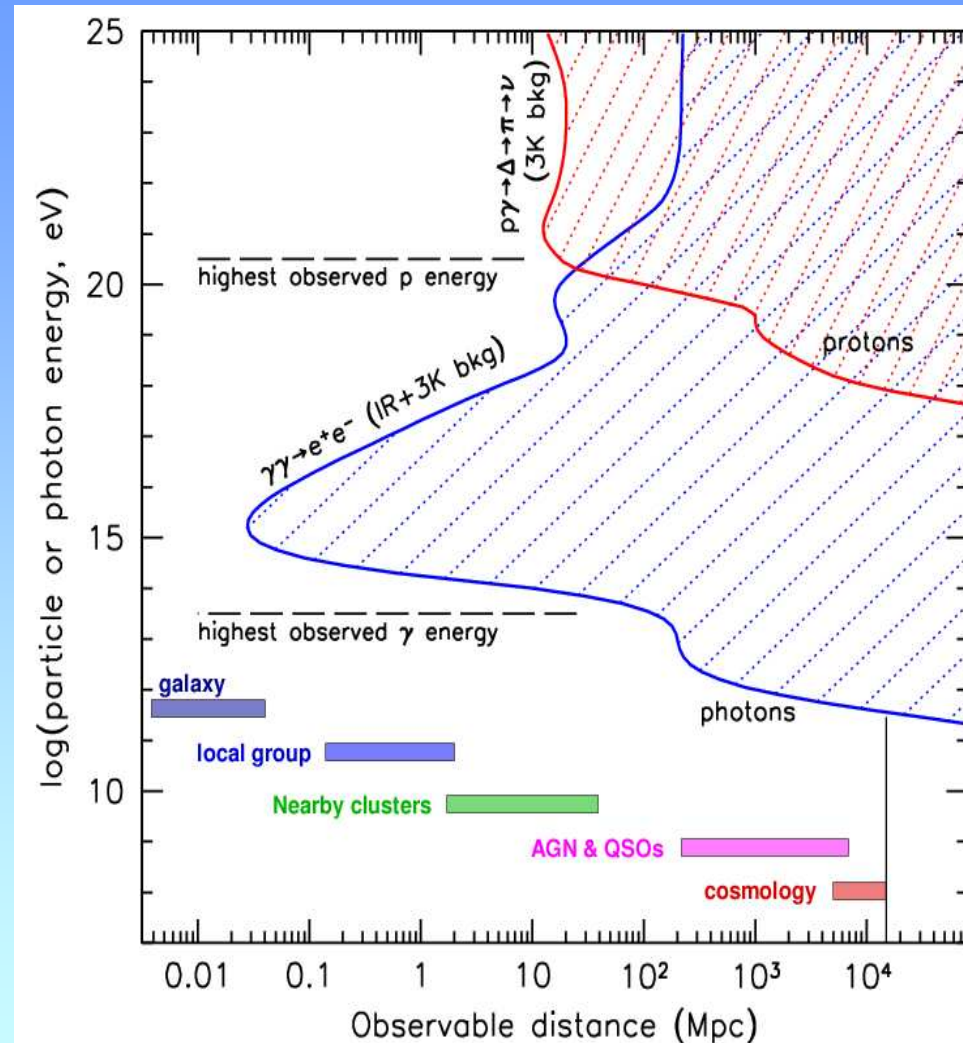
$$\downarrow$$
$$\mu^+ + \nu_\mu$$

GZK -neutrinos

Protons deflected by
magnetic field for

$$E < 10^{19} \text{ eV!}$$

Not pointing back to the
source!





Supernovae

- When shock comes out of star it starts to accelerate protons.
- Up to 200 events with $E > 1$ TeV in KM3NET within few hours (E.Waxman and A.Loeb, astro-ph/0102317)
- Extra 1000-10000 events in first year (V.Berezinsky and V.Ptuskin, 1988)
- Can help to detect SN location up to 0.1 degree. (R.Tomas, D.S., G.Raffelt, M.Kachelriess and A.Dighe, hep-ph/0307050)



source	Distance (kpc)	E_ν (GeV)	$N_{\nu\mu}$ ($\text{km}^{-2} \text{yr}^{-1}$)	Reference
Supernovae	10	$< \sim 10^3$	~ 100	Waxman & Loeb 2001
Shocks		$\sim 10^2 - 10^6$	50 – 1000	Protheroe et al. 1998
pulsars		$\sim 10^5 - 10^8$	$\sim 100 - 1000$	Beall & Bednarek 2002
		$\sim 10 - 10^8$	$< \sim 1000$	Nagataki 2004



Interaction of CRs with Gas Clouds at GC

CR density much higher than local density in solar system
 \Rightarrow evidence for young source of high energy CRs near GC
 -SNR?

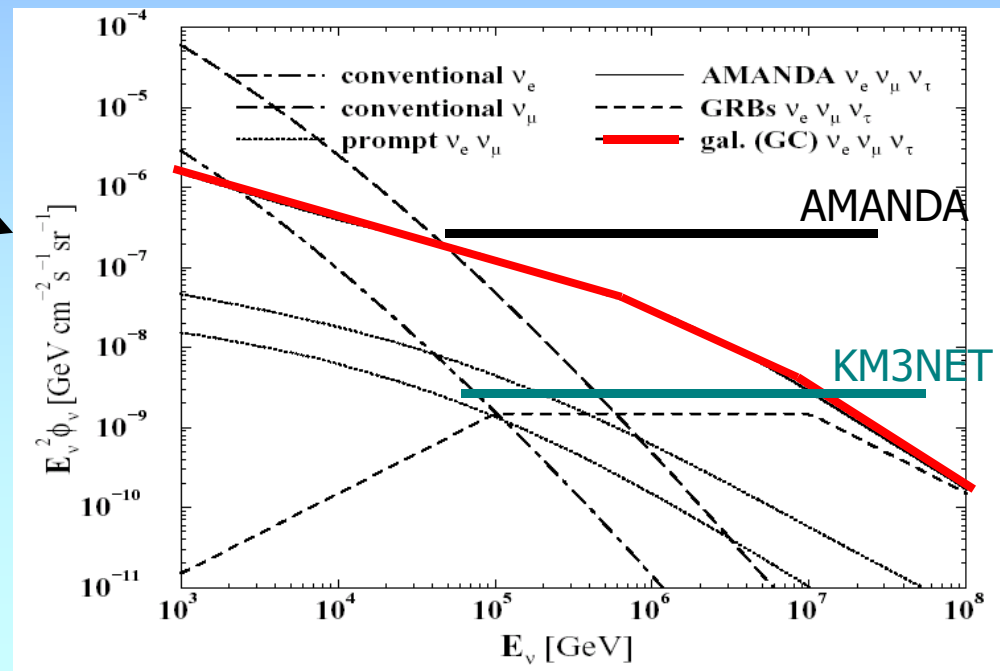
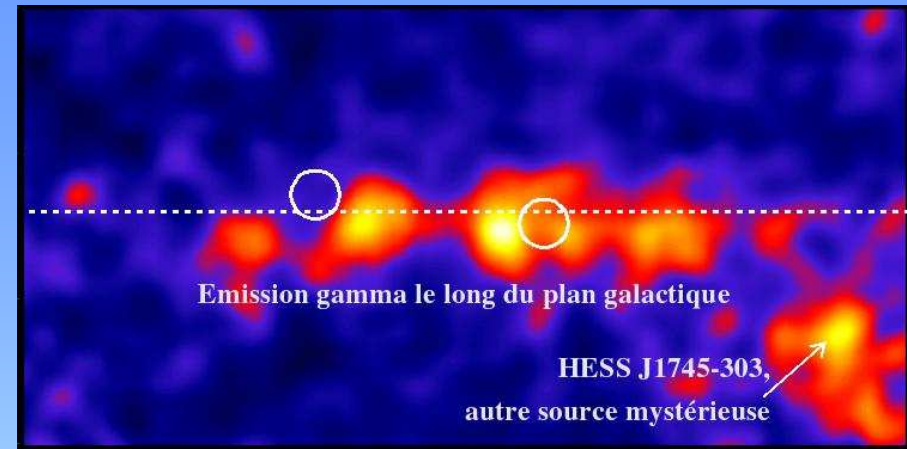
Arharonian et al, Nature 2006

neutrino signal from CR interactions detectable in KM3NET- enhancement in direction of GC

Candia, Astro-ph/0505346

CR interactions in clusters of galaxies with IR photons also detectable

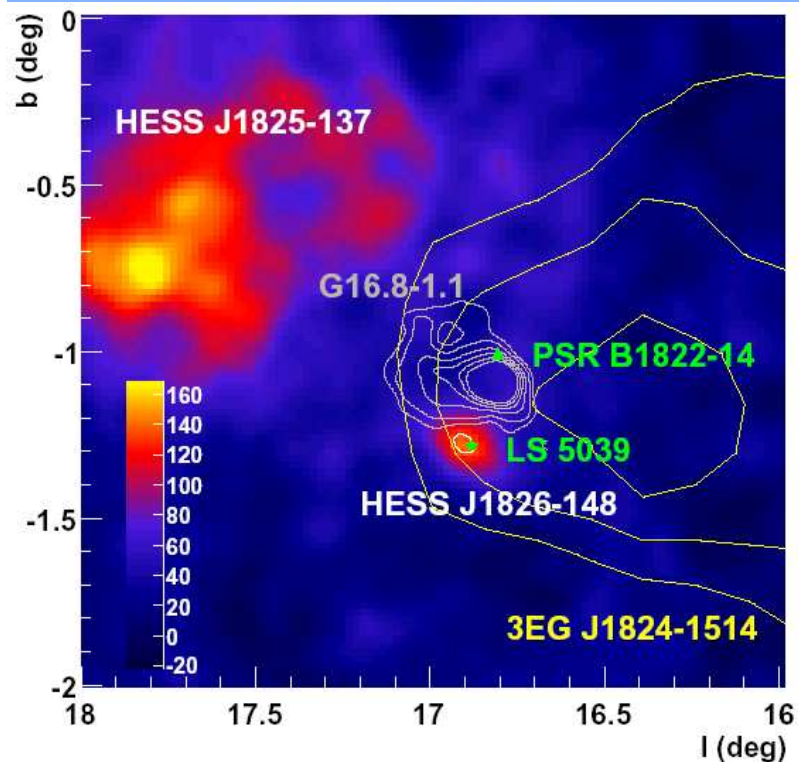
DeMarco et al,
 astro-ph/0511535





Compact Binary: LS5039

LS5039 observed by HESS
Index= 2.12 ± 0.15 , up to 4 TeV
Aharonian et al, astro-ph/0508298



severe absorption of >100 GeV gamma-rays
($\gamma + \text{starlight} \rightarrow e^+e^-$) \Rightarrow up to a factor 10 to 100
higher initial luminosity

severe radiative (synchrotron and Compton)
losses \Rightarrow difficult to accelerate electrons to
multi-TeV energies

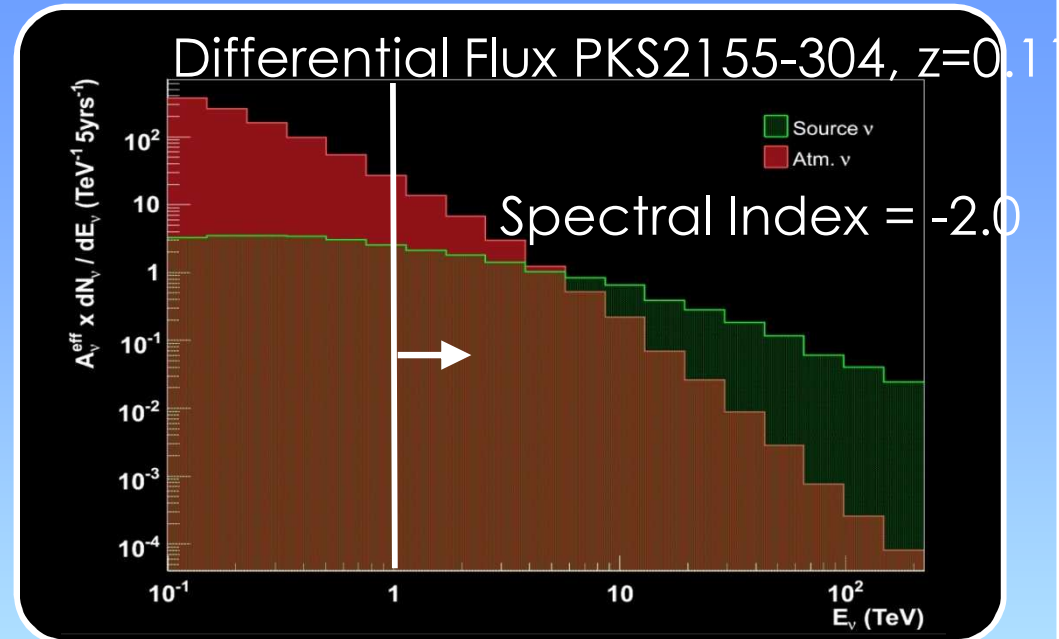
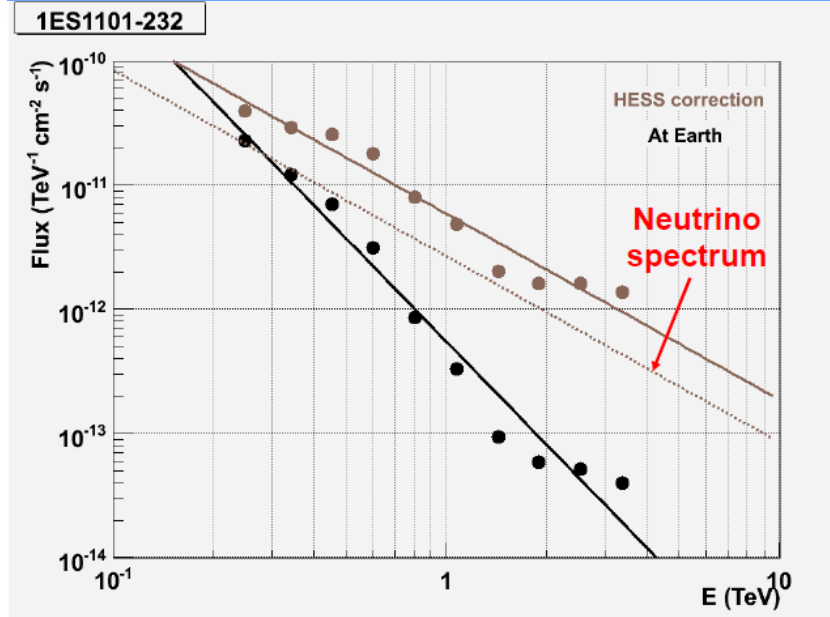
**Conclusion: TeV gamma-rays of
hadronic origin**

Extrapolation from HESS
observation: 3-6 neutrinos/yr/km²
Aharonian, Montaruli et al.,
Astro-ph/0508658

LS I+61 303
3-5 muon type/km²/yr
Christiansen et al., astro-ph/0509214



AGN ν Rates



Source	z	f_o	ν Param.		$> 1\text{TeV}$			$> 5\text{TeV}$		
			κ	Γ	N_ν^s	N_ν^{atm}	σ	N_ν^s	N_ν^{atm}	σ
1ES1101-232	0.186	63.21	4.91	1.11	599	53.5	39.9	586	8.08	48.7
H2356-309	0.165	68.47	2.47	1.34	126	62.2	12.0	121	9.7	18.3
PKS2155-304	0.0117	68.14	5.38	2.02	26.9	61.7	3.04	21.0	9.59	5.00
PK2005-489	0.0710	100.0	0.0930	3.30	0.0715	90.7	0	0.0145	14.4	0

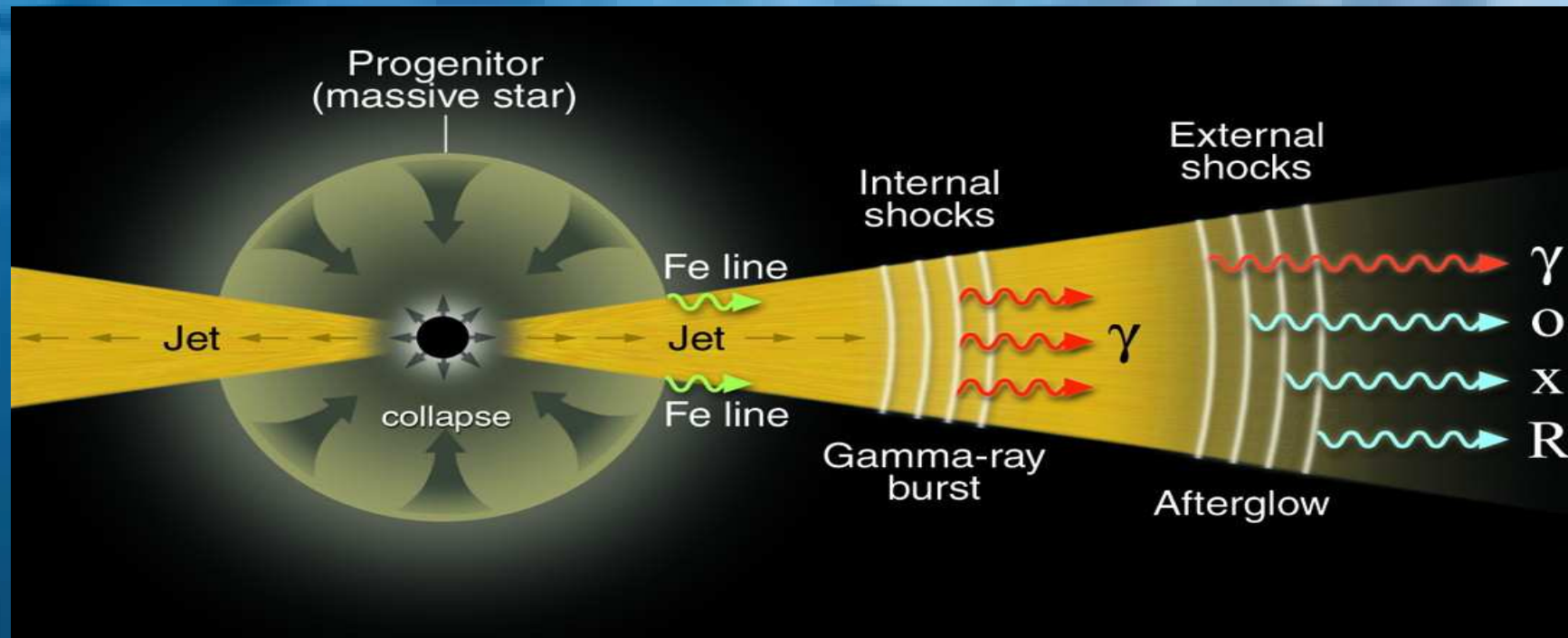
Table 1: Upper limits for the integral event rate from candidate Blazars above 1 TeV and 5 TeV including the expected atmospheric neutrino rate and the statistical significance of source over the background for 5 years of observing with the *standard* KM3NeT geometry.

Large uncertainties
On EBL correction



Gamma Ray Bursts

Fireball model (Meszaros, Rees 1994)



TeV neutrinos from inside the star

[Meszaros & Waxman, 2001]
[Razzaque et al. 2003]

PeV Neutrinos from internal Shocks

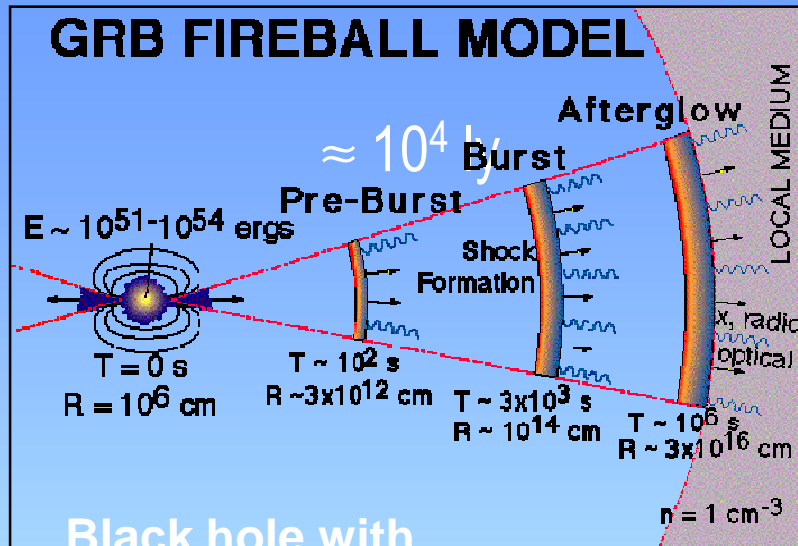
[Waxman & Bahcall 1997]
[Gupta & Zhang, 2006]
[Murase & Nagataki 2006]

EeV Neutrinos from external Shocks

[Dermer 2001]
[Waxman & Bahcall, 2000]



ExtraGalactic: Gamma Ray Bursts



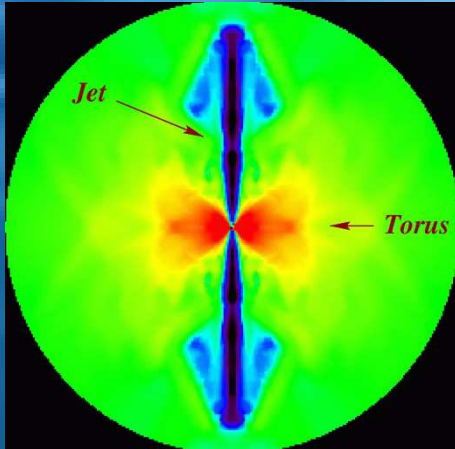
- energy of 1 solar mass over time 1-10secs
- possibly standard candles of energy $\sim 10^{52}$ ergs/s
- some associated to supernovae

source	Distance (kpc)	E_ν (GeV)	$N_{\nu\mu}$ ($\text{km}^{-2} \text{yr}^{-1}$)	Reference
GRB	z=1	100TeV-100PeV 10^{14}eV	several	Dermer astro-ph/0506385
GRB			~20	Waxman astro-ph/0502159
GRB			~25	Halzen astro-ph/0506248

time and location information \rightarrow background free (special triggers possible)



Choked/Dark Gamma Ray Bursts



$\Gamma=3$, $E_K \sim 3 \cdot 10^{51}$ ergs
 Baryon rich (dirty fireball)
 \Rightarrow enhanced neutrino signal

More frequent than 'standard' GRBs
 No optical counterpart

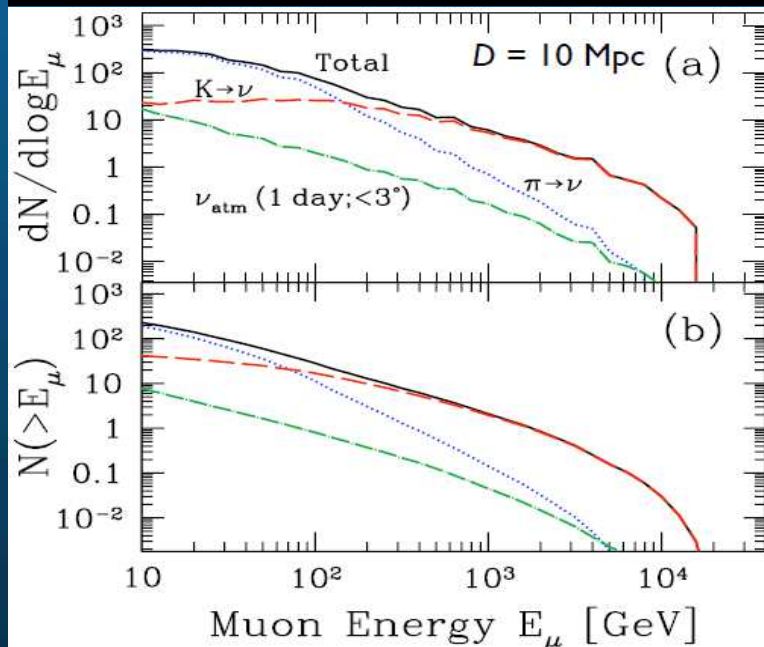
kaon decay contribution dominates

Detected neutrinos above 100 GeV
 ~ 30 per km³ @ 10 Mpc
 ~ 3 per km³ @ 30 Mpc

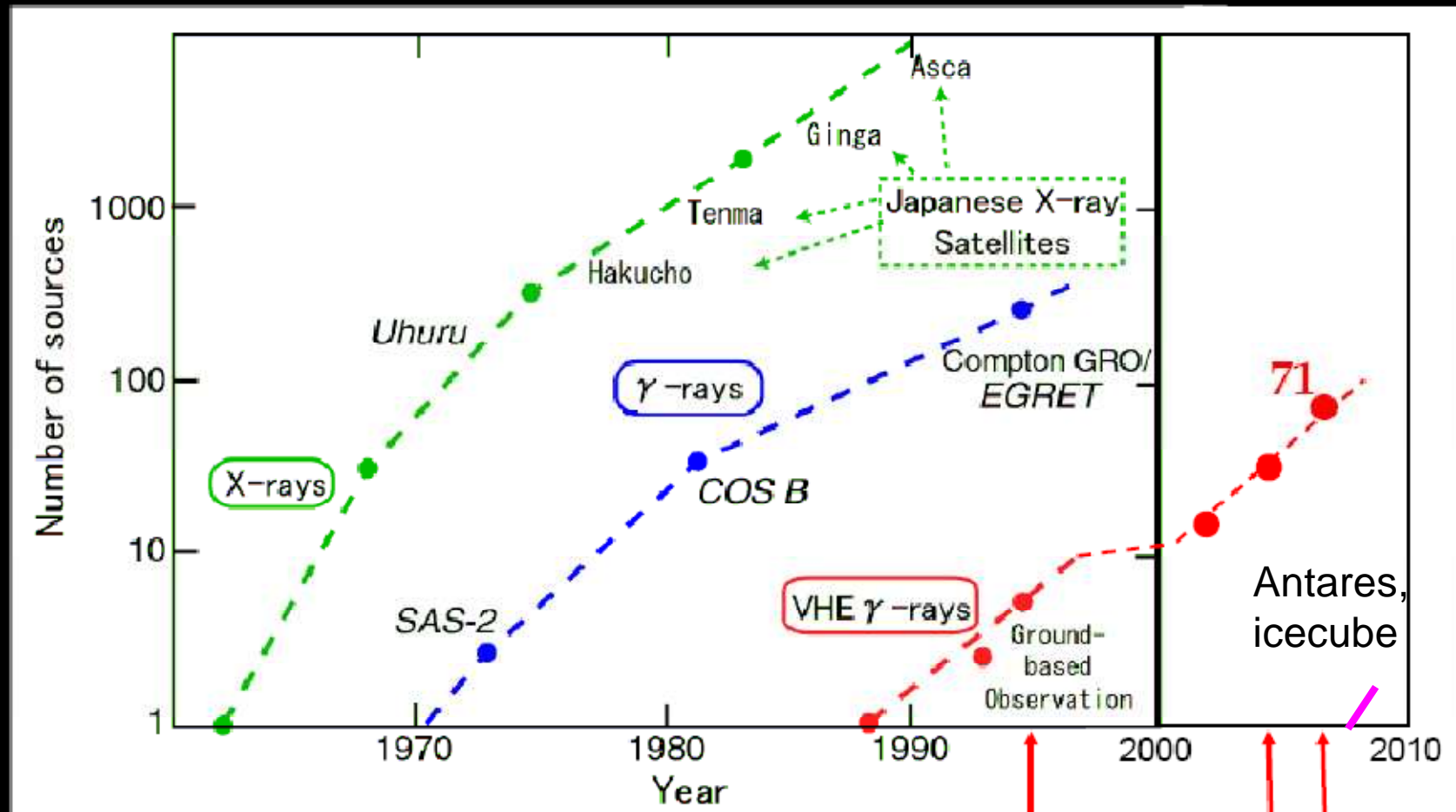
Neutrinos cluster within 10s
 and 3 degree angular bin
 \Rightarrow Extremely low background

$R_{SN}(< 10 \text{ Mpc}) \sim 3 \text{ yr}^{-1}$,
 $R_{SN}(< 30 \text{ Mpc}) \sim 90 \text{ yr}^{-1}$

Ando & Beacom, *Phys. Rev. Lett.* **95**, 061103 (2005)



KIFUNE PLOT



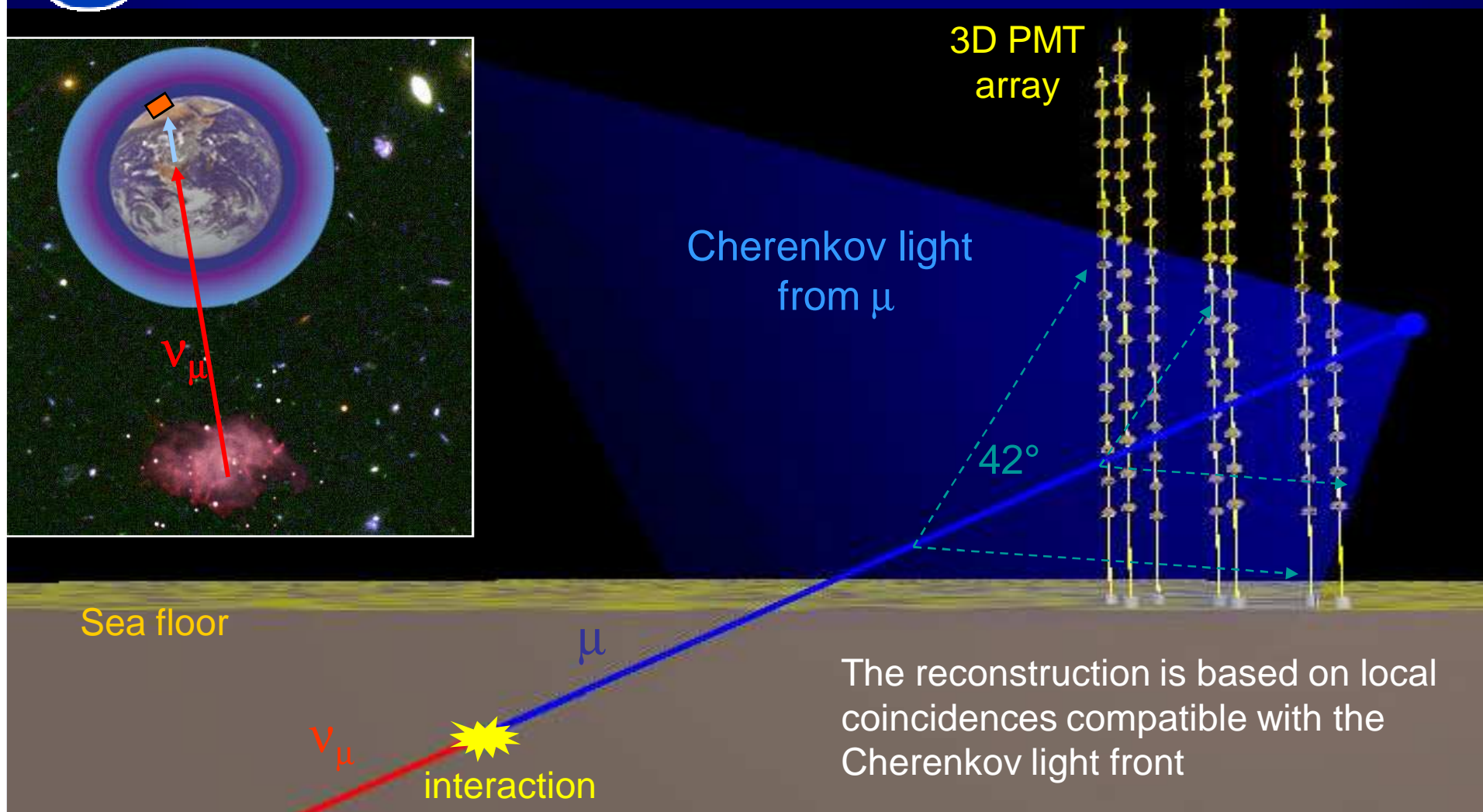
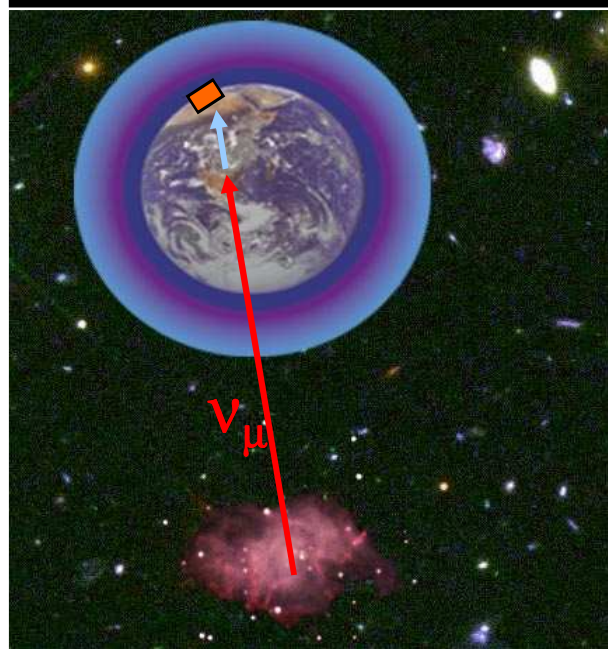
Source count vers us year
[T. Kifune]

Rome

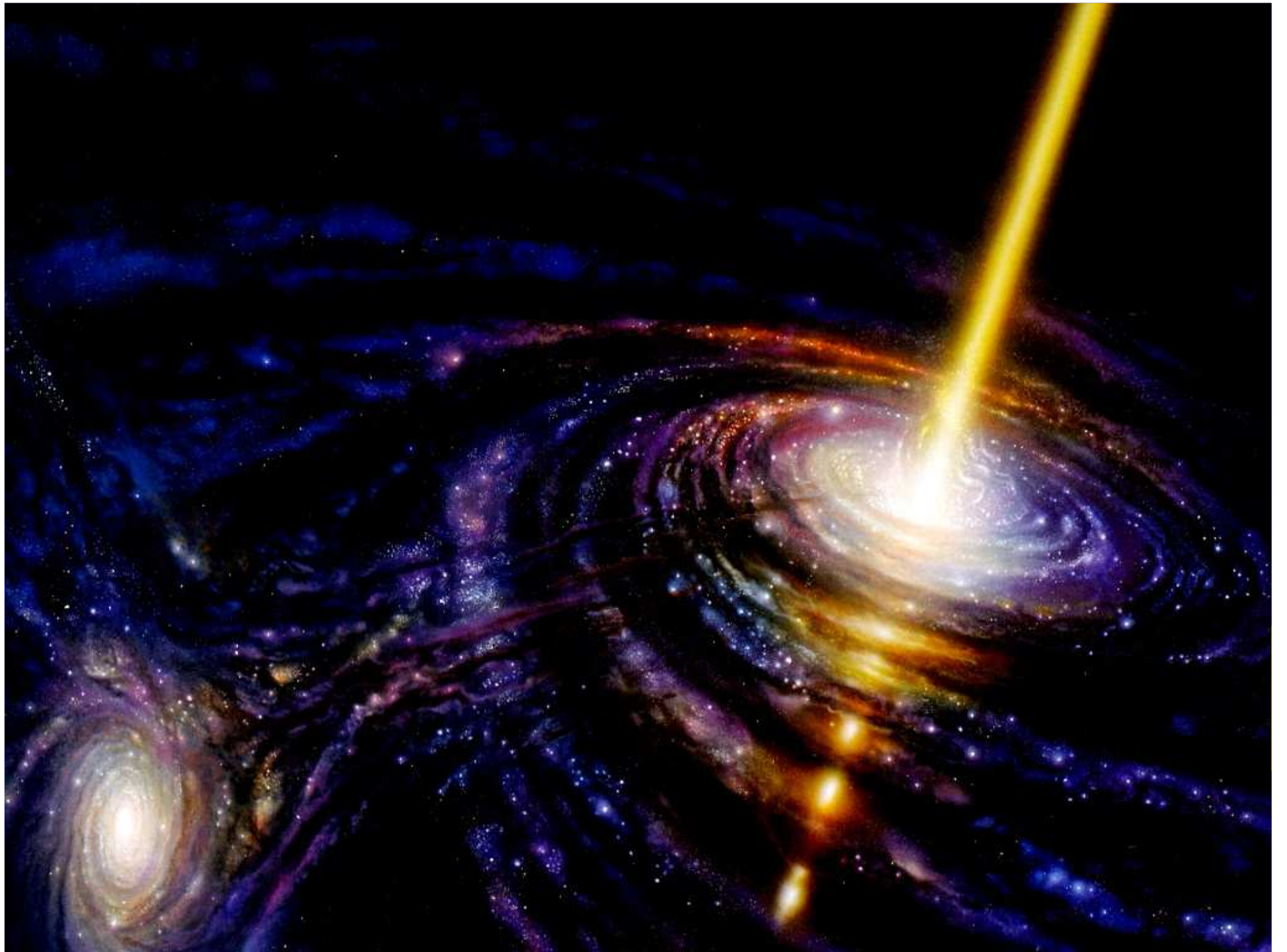
Pune Merida



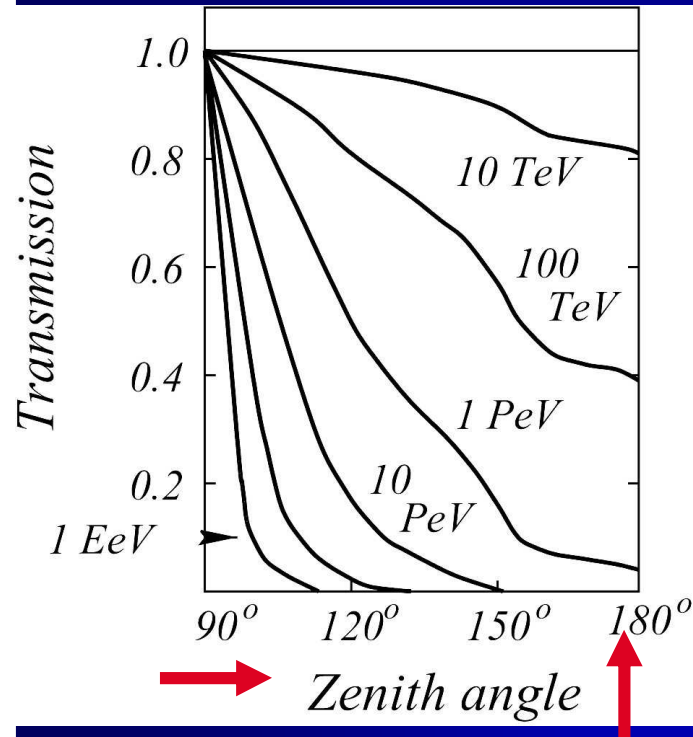
Detection Principle



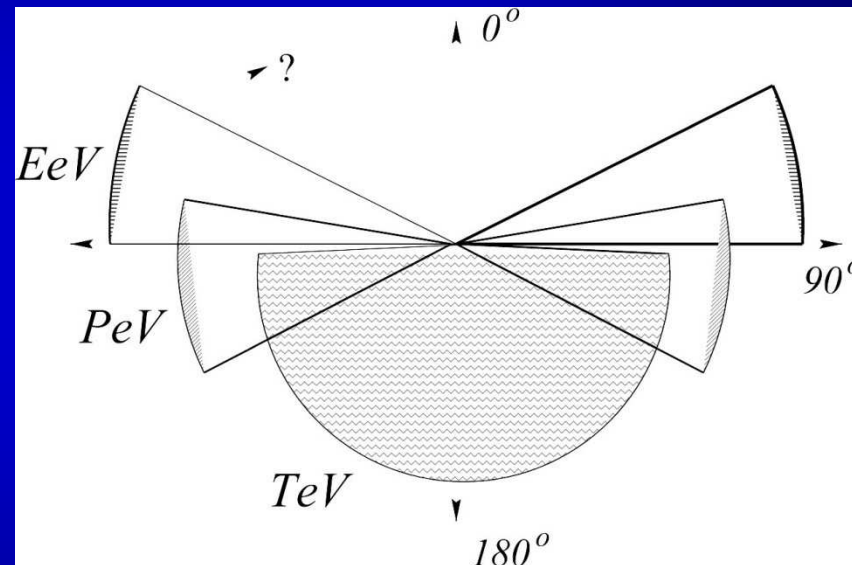
- Main detection channel: ν_μ interaction giving an ultra-relativistic μ (ν_e and ν_τ also)
- Energy threshold ~ 10 GeV
- 24hr operation, more than half sky coverage



Transmission of Earth for Neutrinos



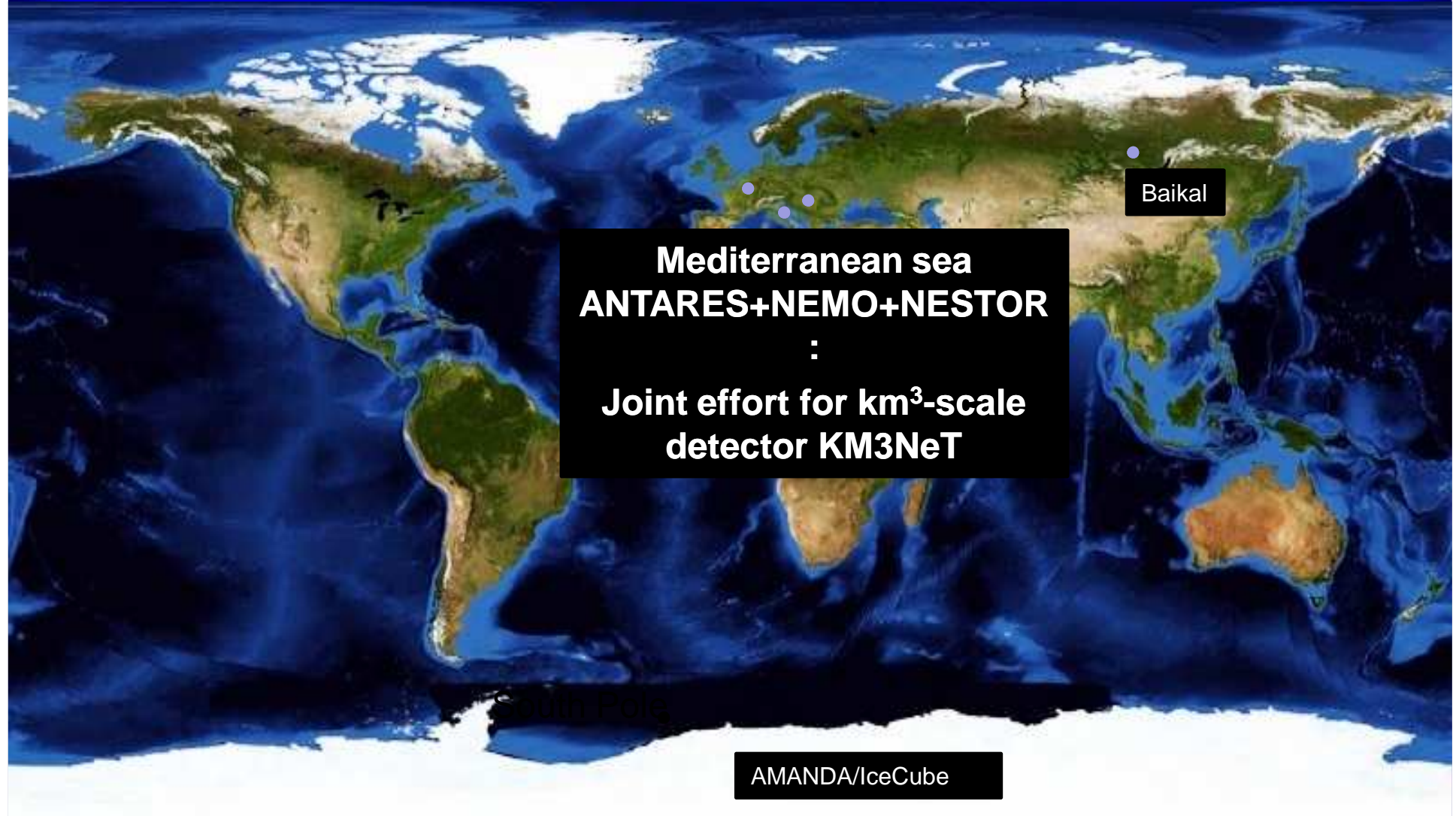
→ **Earth opaque above a few PeV**



Downward- background at high energies is small.

PeV acceptance around horizon
EeV acceptance above horizon

High Energy Neutrino telescopes



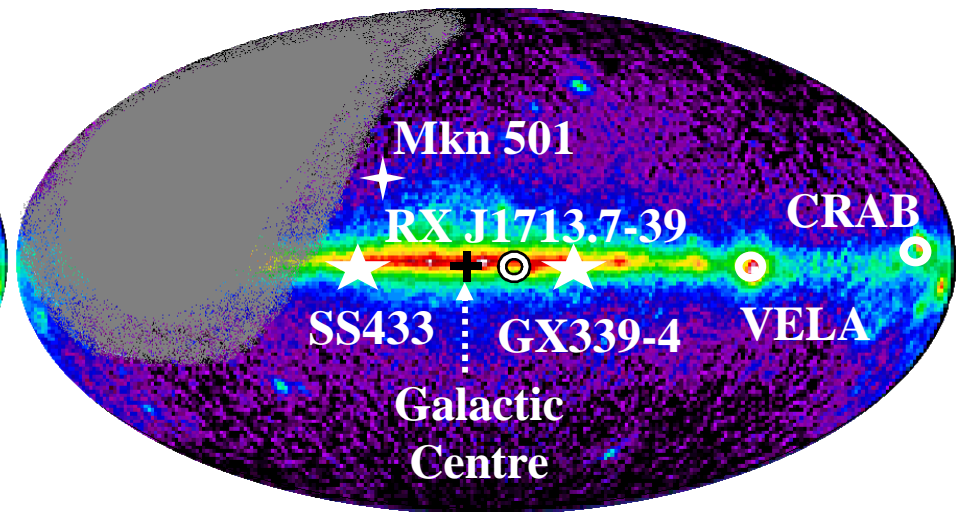
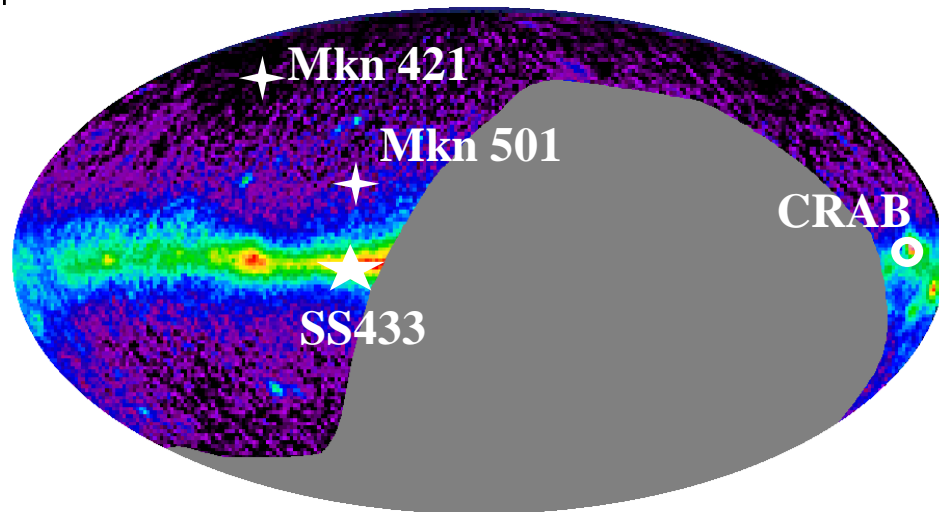
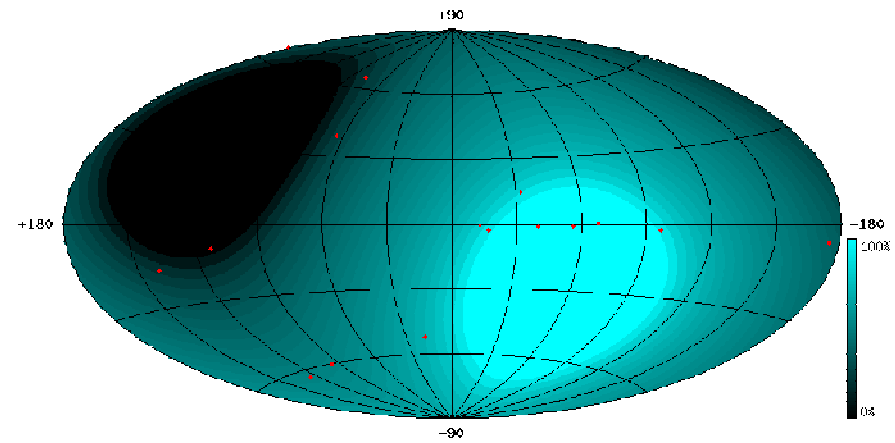
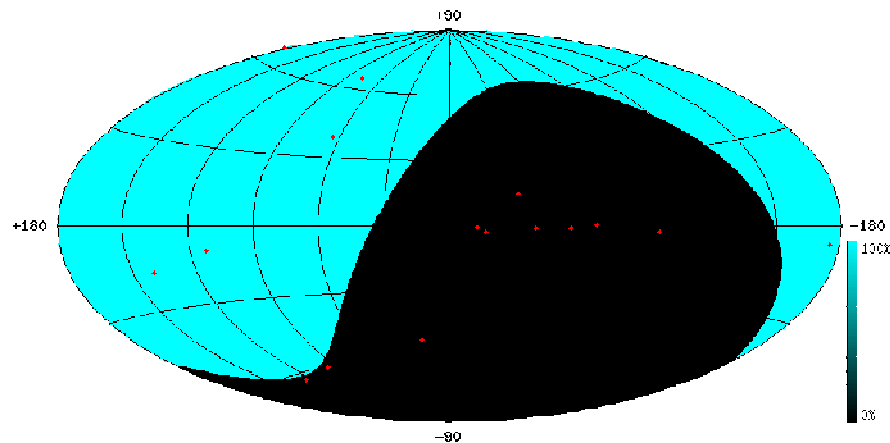


Region of Sky Observable by Neutrino Telescopes



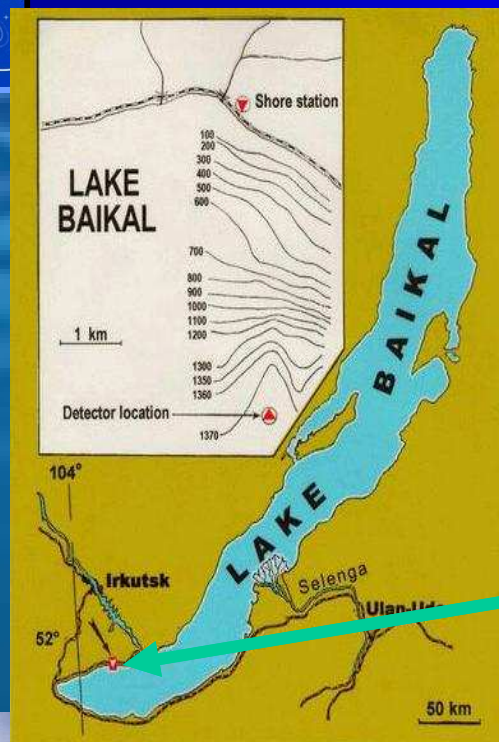
AMANDA/IceCube (South Pole)
(Ice: $\sim 270066^{\circ}$)

ANTARES/KM3 (43° North)
(water: $\sim 0.270011^{\circ}$)

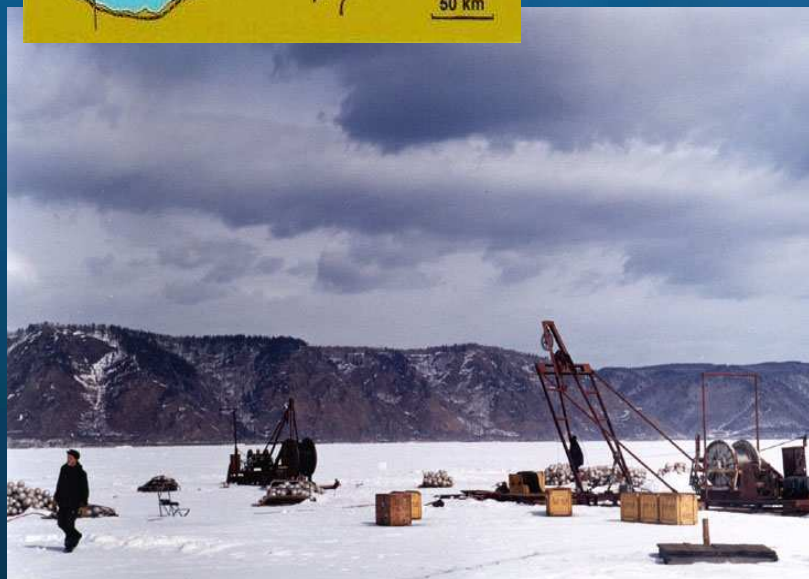




Baikal

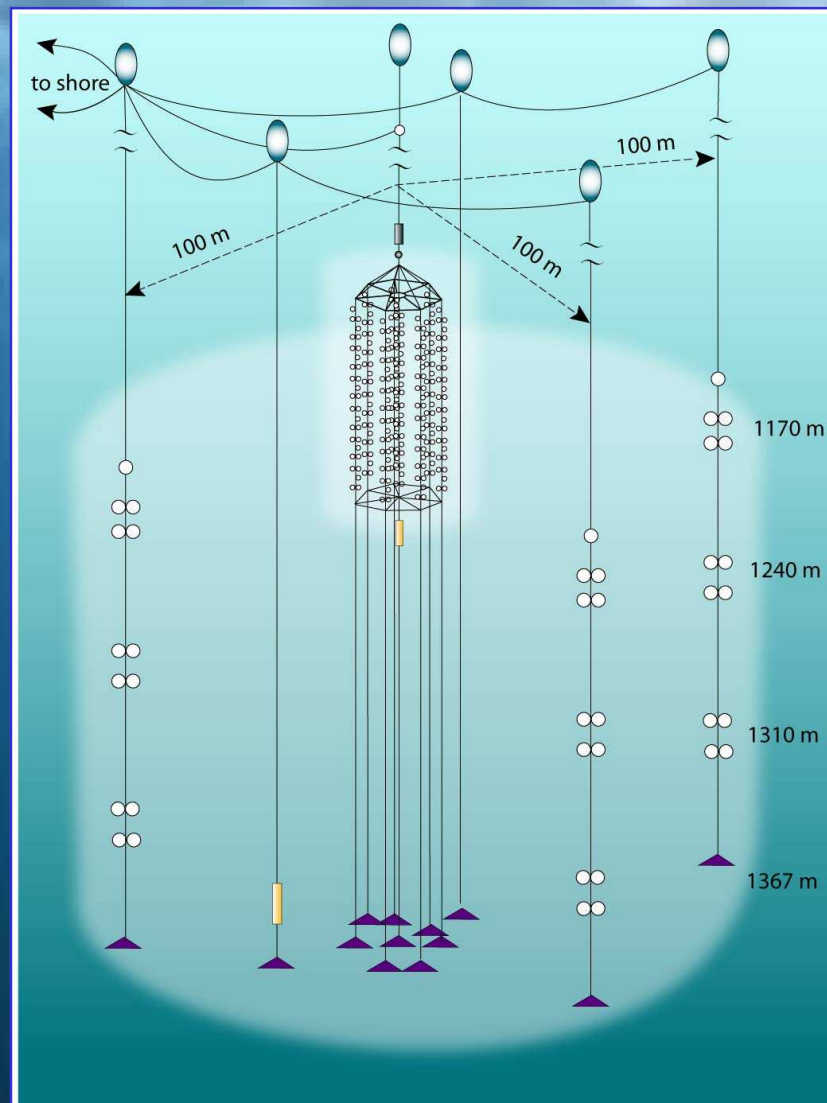


Site



2009 August

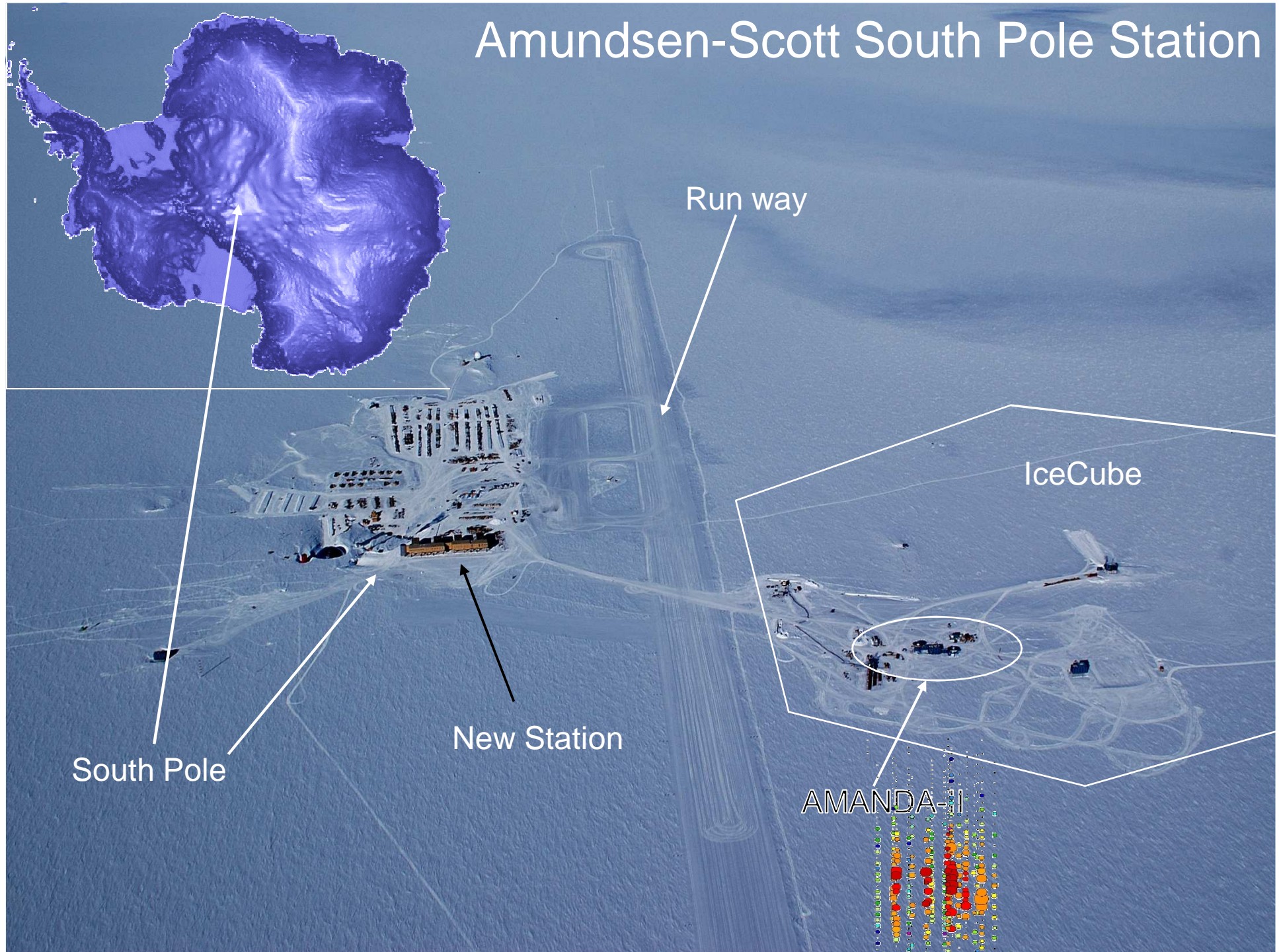
Lepton Photon 2009



Per Olof Hulth

19

Amundsen-Scott South Pole Station





IceCube timeline

In the ice:

2005: 1 string

2006: 9 strings

2007: 22 strings (publishing)

2008: 40 strings (analyzing)

2009: 59 strings (running)
(includes 1 DeepCore string)

Planned:

2010: 77 strings

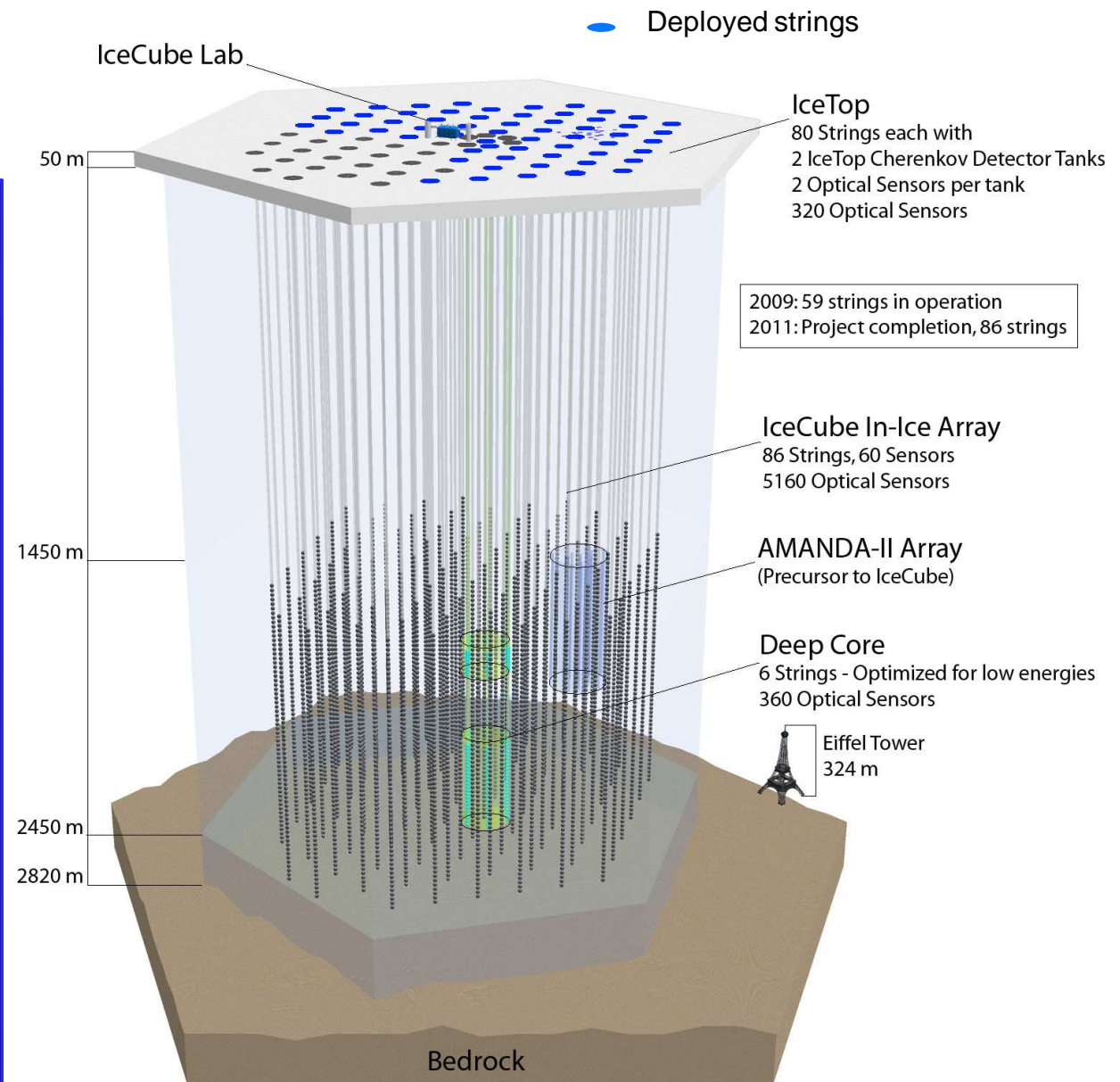
(includes 6 DeepCore strings)

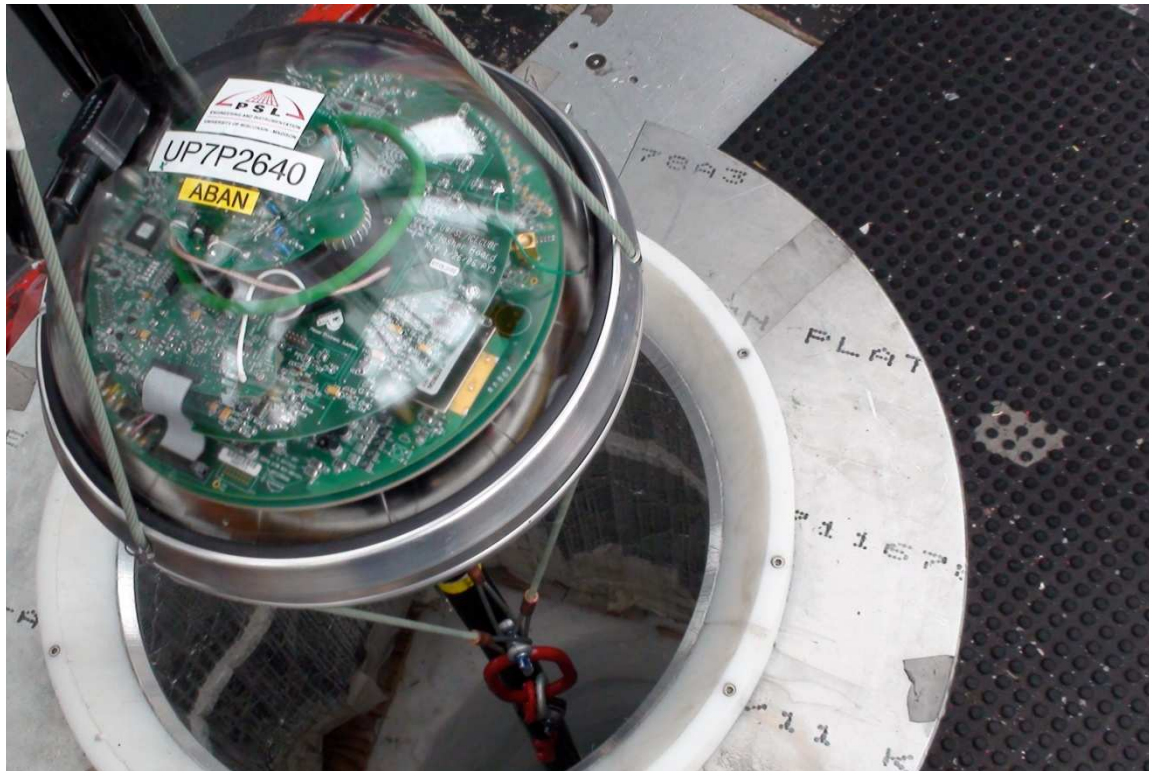
2011: 86 strings

(includes 6 DeepCore strings)

15-year design lifetime

IceCube





IceCube Lab

2009 August
20

Lepton Photon 2009

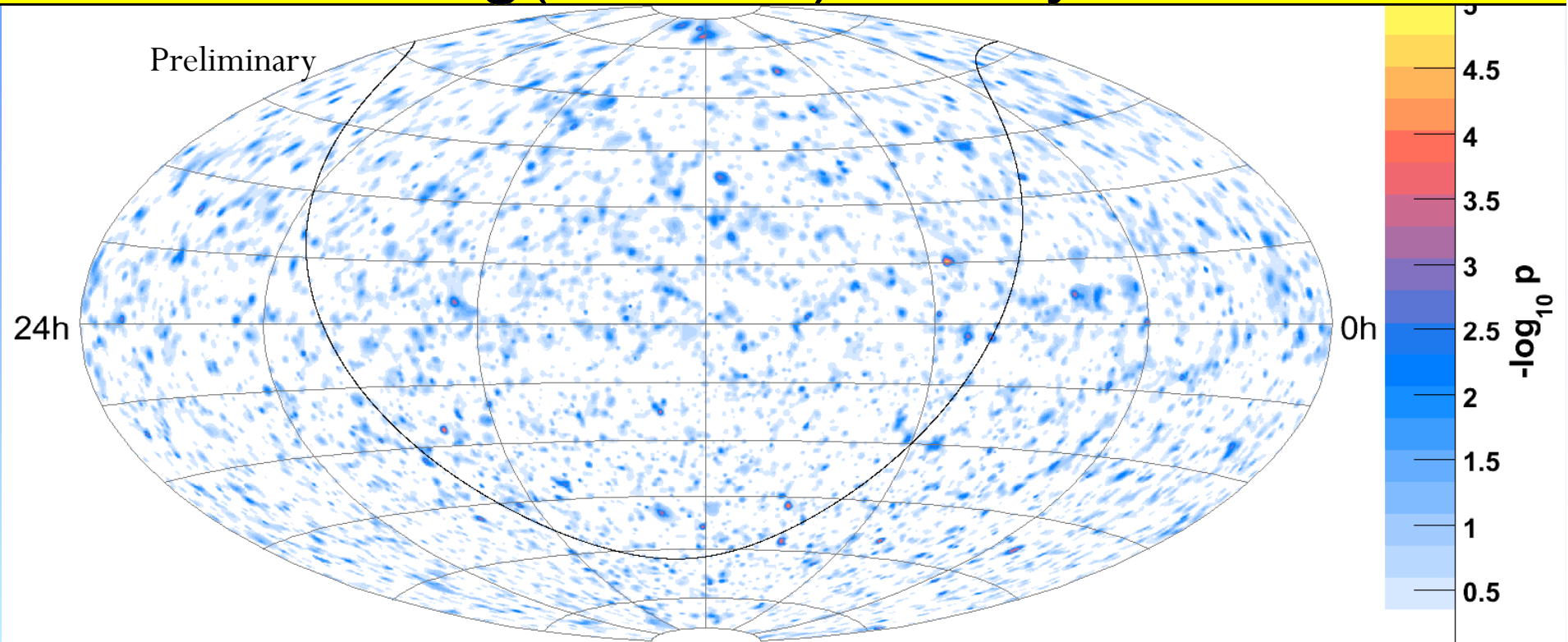


South Pole and Christmas tree

Per Olof Hulth

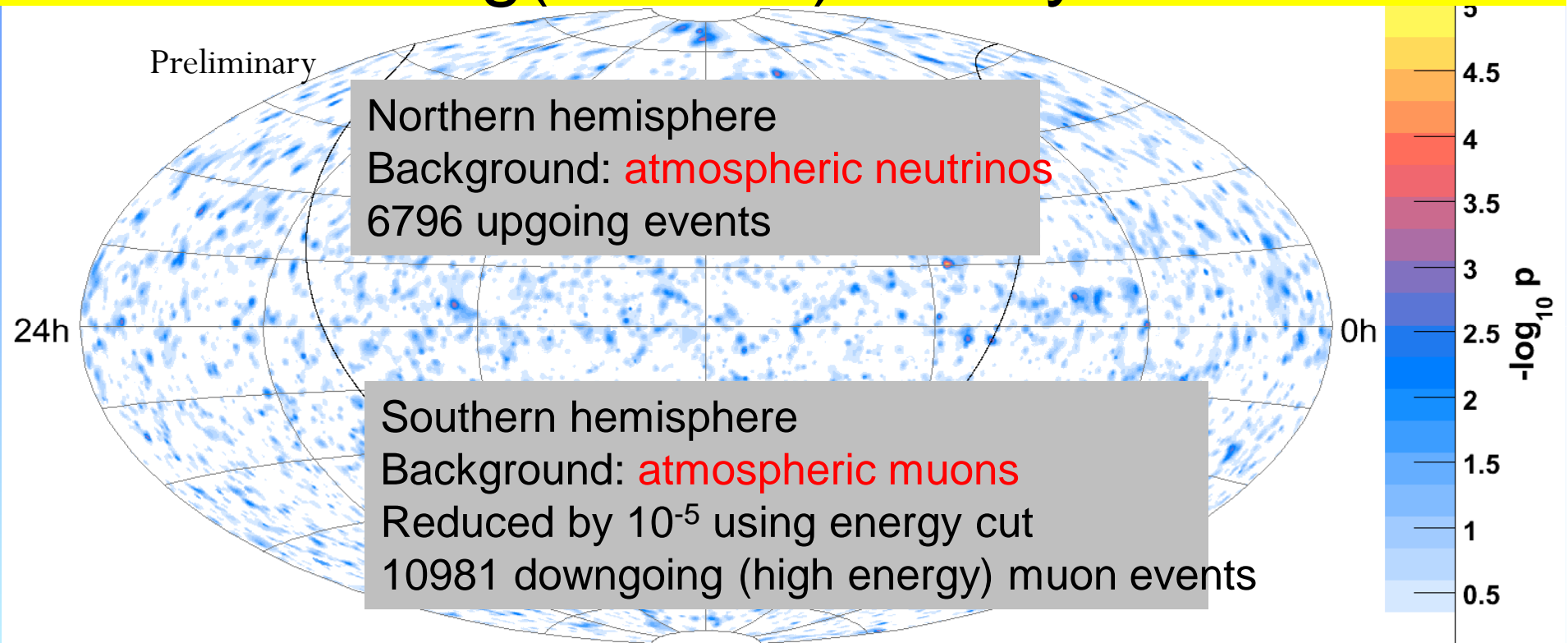
22

Search for point sources - 40-string(6month) all-sky results



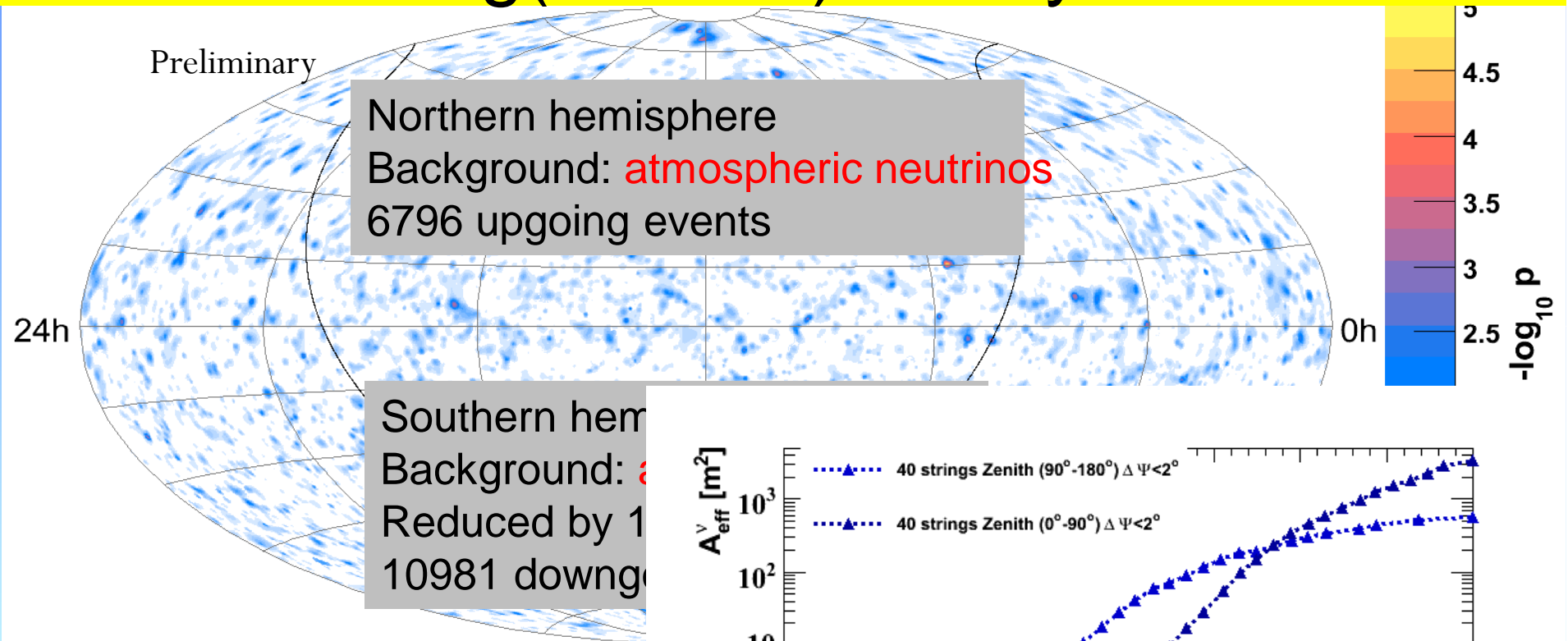
175.5 days livetime,
17777 events:
6796 up-going,
10981 down-going

Search for point sources - 40-string(6month) all-sky results

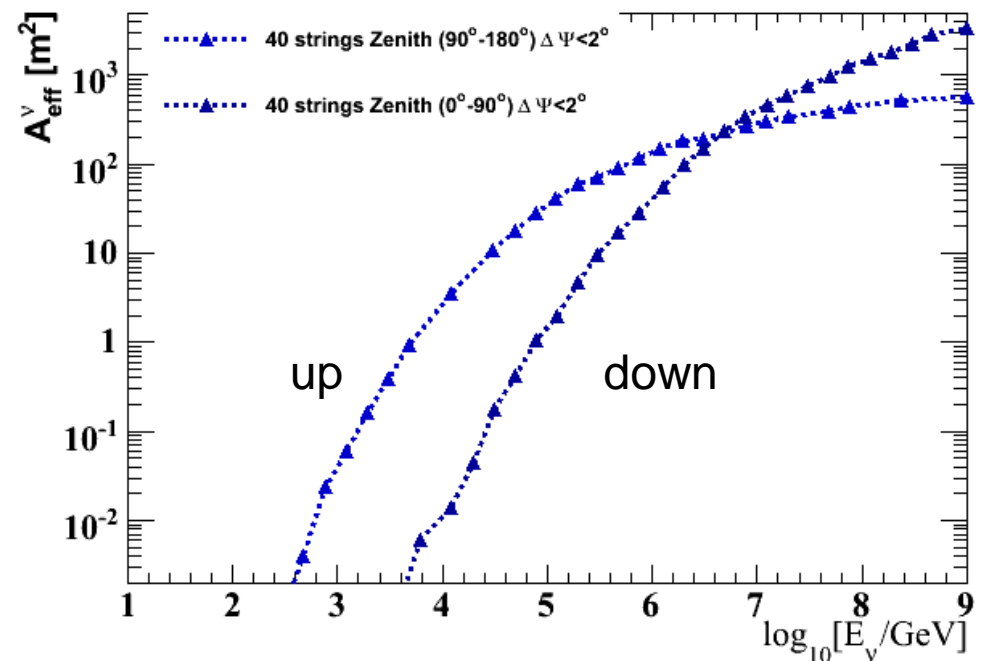


175.5 days livetime,
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6796 up-going,
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Search for point sources - 40-string(6month) all-sky results



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





The ANTARES Collaboration





The ANTARES Site & Infrastructure

Shore Station

IFREMER Toulon Centre

FOSELEV Marine Shipyard



The ANTARES Detector

- 900 PMTs
- 12 lines
- 25 storeys / line
- 3 PMTs / storey

2500m

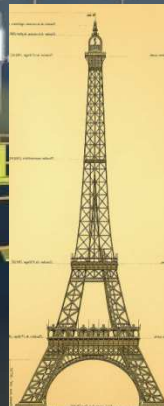
40 km to shore

450 m

Junction Box

70 m

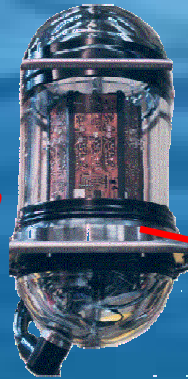
Interlink cables



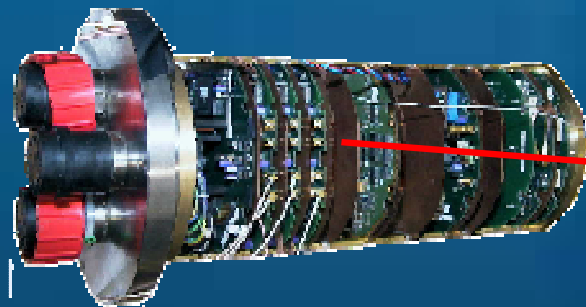
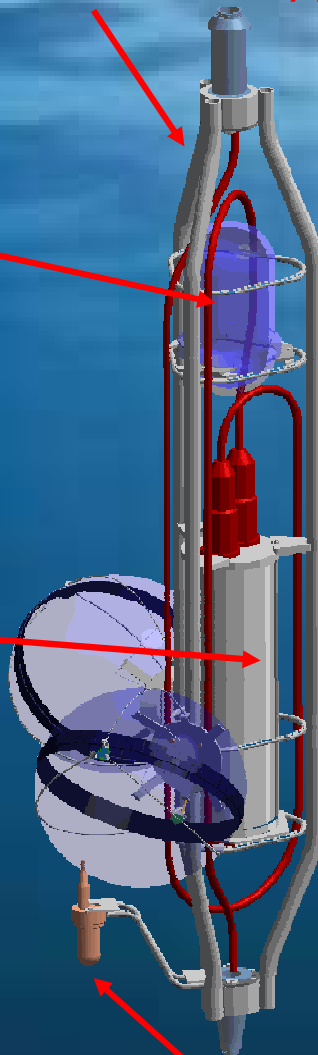


Basic Detector Element: a storey

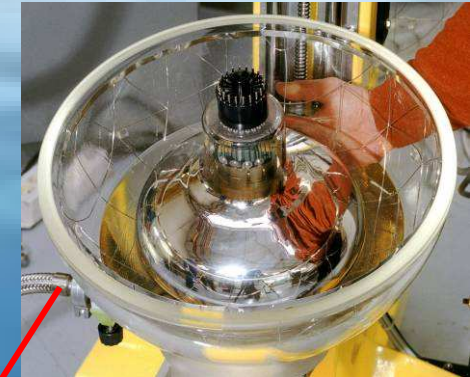
Optical Beacon
with blue LEDs:
timing calibration



titanium frame: *support structure*



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



Optical Module:
10" Hamamatsu PMT
in 17" glass sphere
($\sigma_{\text{TTS}} \approx 1.3 \text{ ns}$)
photon detection



Hydrophone:
acoustic positioning



ANTARES Site Exploration

1996 - 2000 Measurements with autonomous lines

- | | |
|------------------------------------|----------------|
| 1) Optical background study: | 15 deployments |
| 2) Biofouling-sedimentation study: | 4 deployments |
| 3) Optical properties study: | 28 deployments |

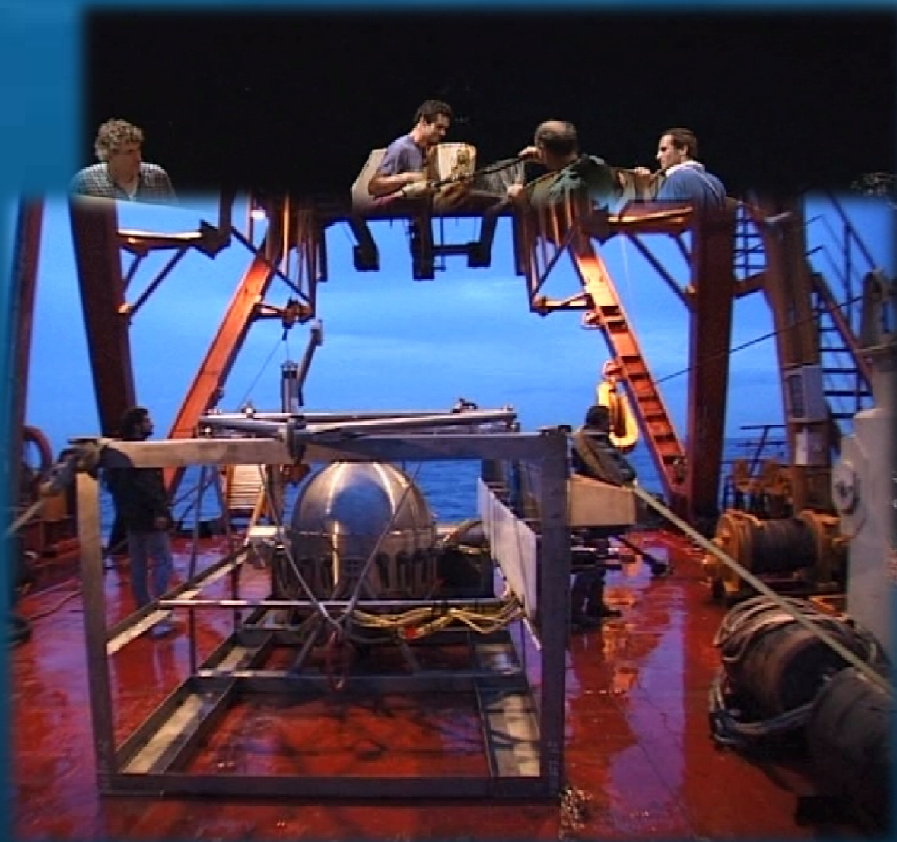




Building the Detector - 1 Main Cable and Junction Box

2001 Deployment of 45 km electro-optical cable (Alcatel)

2002 Deployment of Junction Box





Building the Detector - 2 Line Deployment

- 2003-2005 Various prototype lines
- 2006 Lines 1, 2
- 2007 Lines 3, 4, 5, 6, 7, 8, 9, 10
- 2008 Lines 11, 12

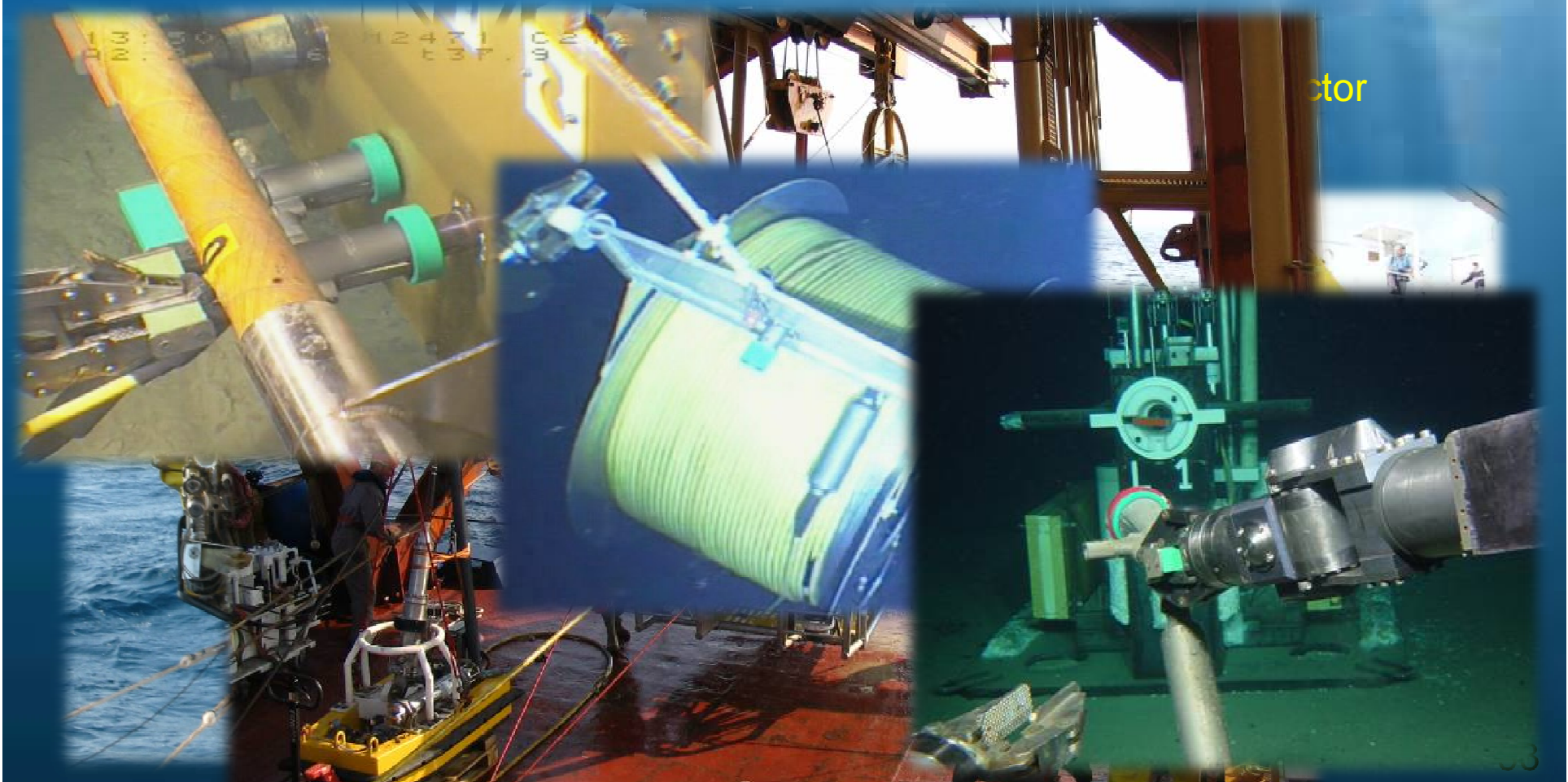




Building the Detector - 3 Line Connections

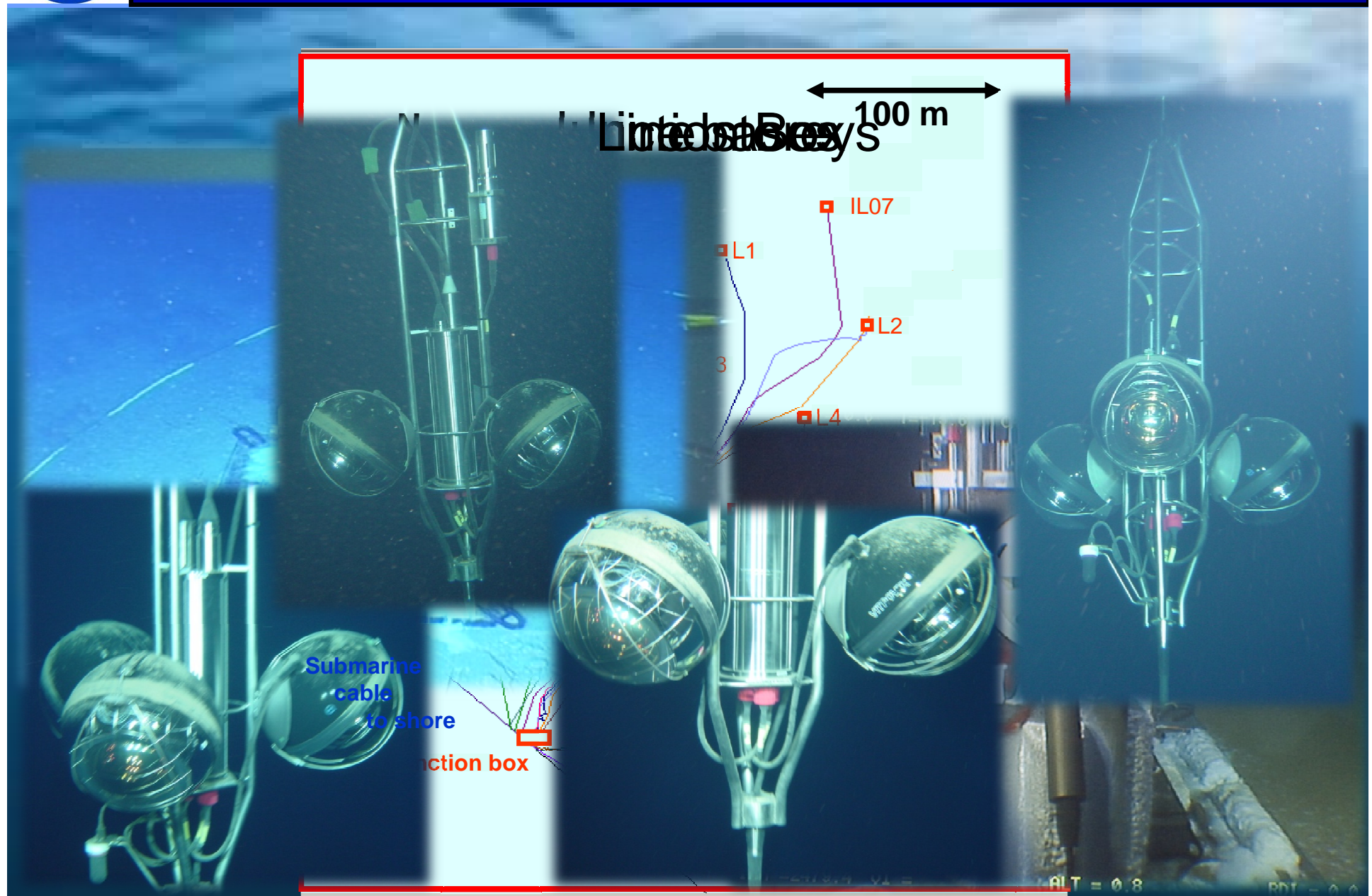
- 2006 Line 1, Line 2
- 2007 Lines 3 - 5, Lines 6 -10
- 2008 Lines 11, 12

ector





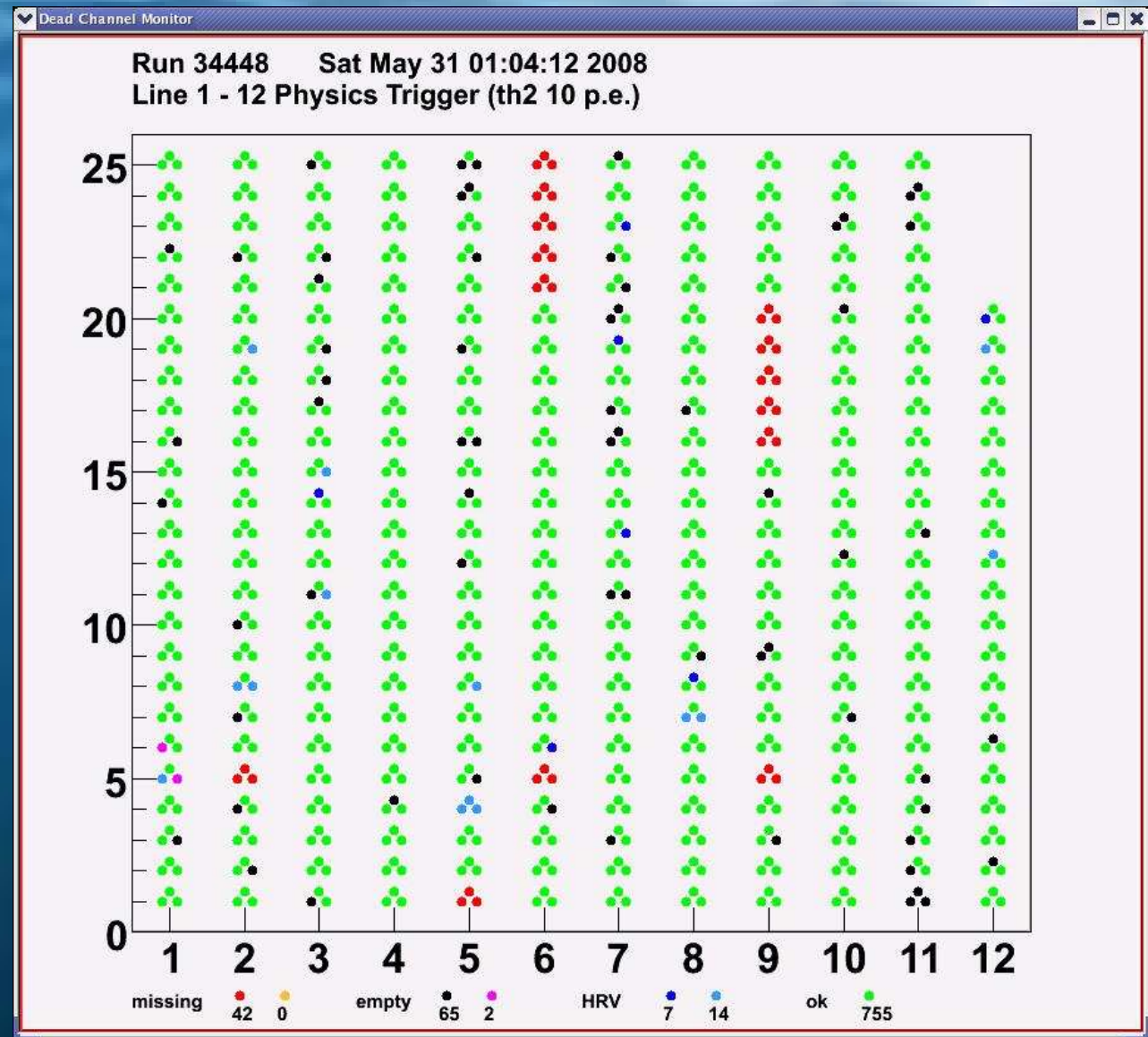
Detector on Seabed





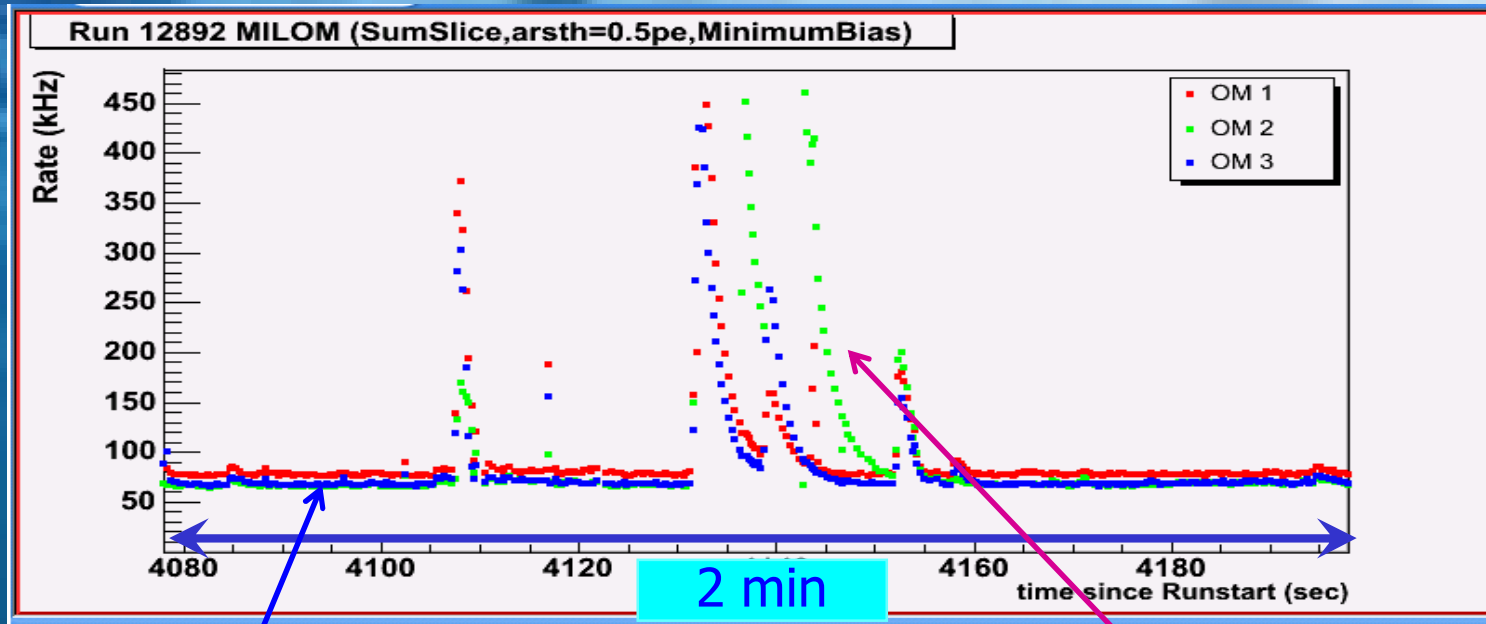
Detector status after completion

- 88% of modules operational
- Regular maintenance of in-situ infrastructure foreseen





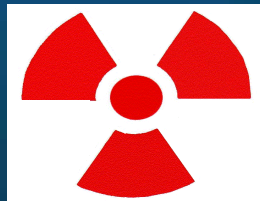
Counting Rates (short timescale)



Continuous baseline:

Radioactivity in the sea (^{40}K)
+ bioluminescent bacteria

^{40}K



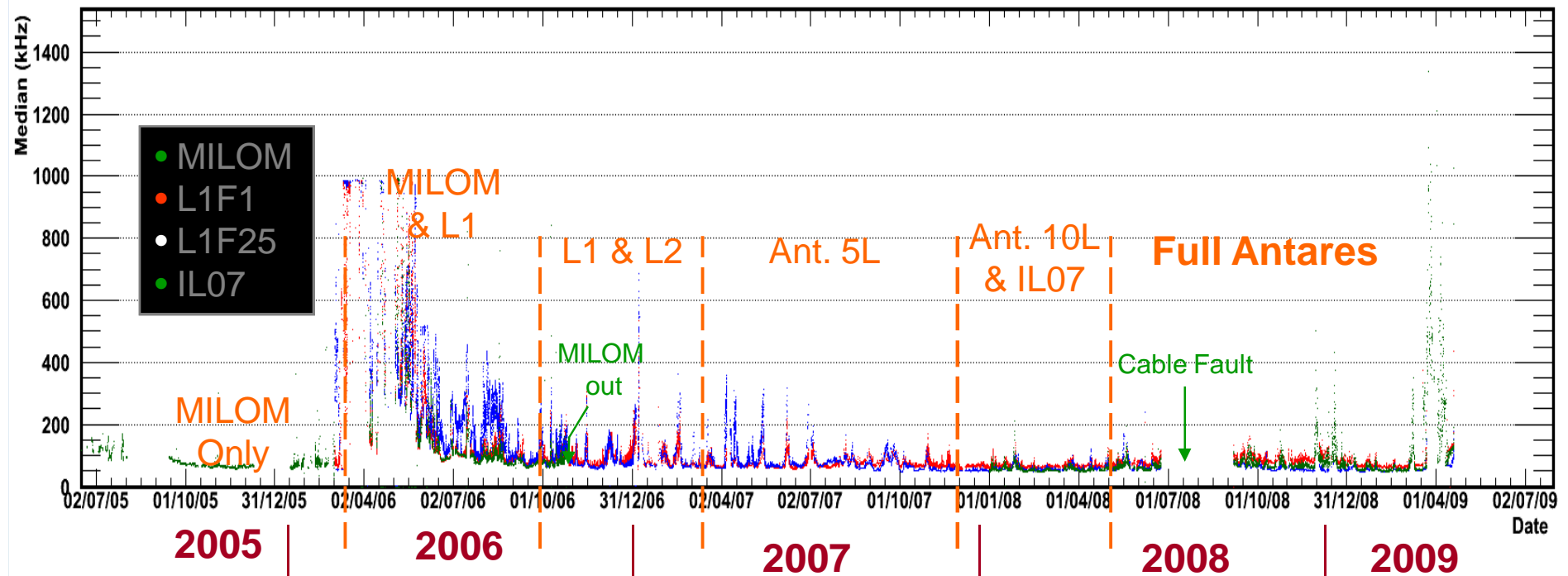
Bursts:

bioluminescence from
Macroscopic organisms

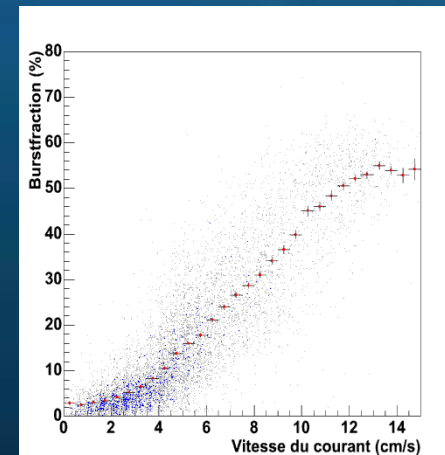




Counting Rates (long timescale)

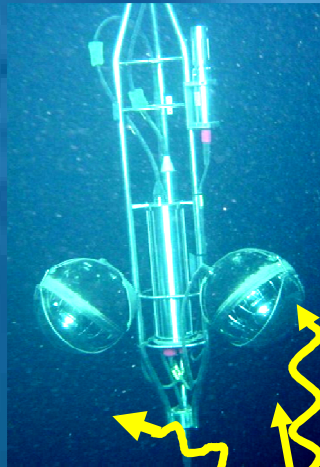


Long term variations due to seasonal and sea current variability





In situ calibration with Potassium-40

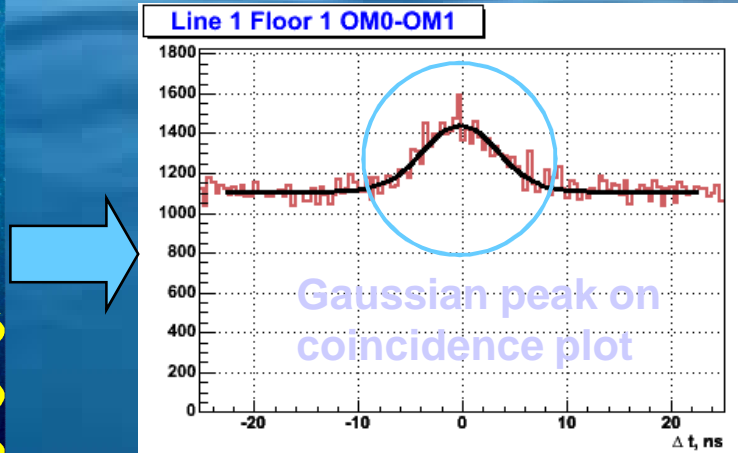


γ
Cherenkov

e^- (β decay)

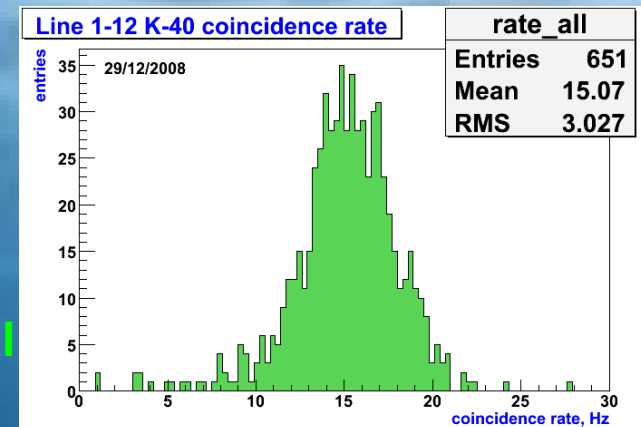
^{40}K

^{40}Ca

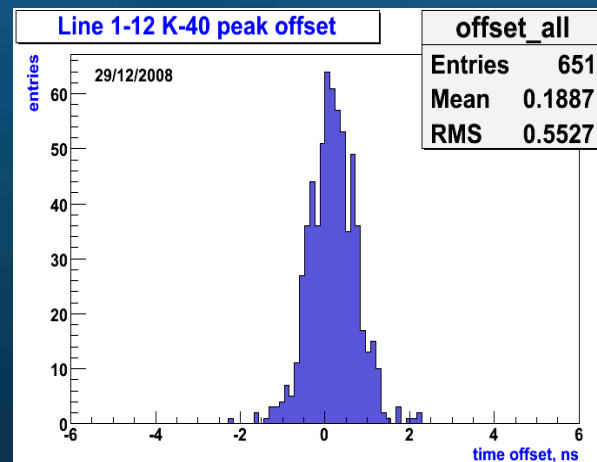


Integral under peak

Peak offset



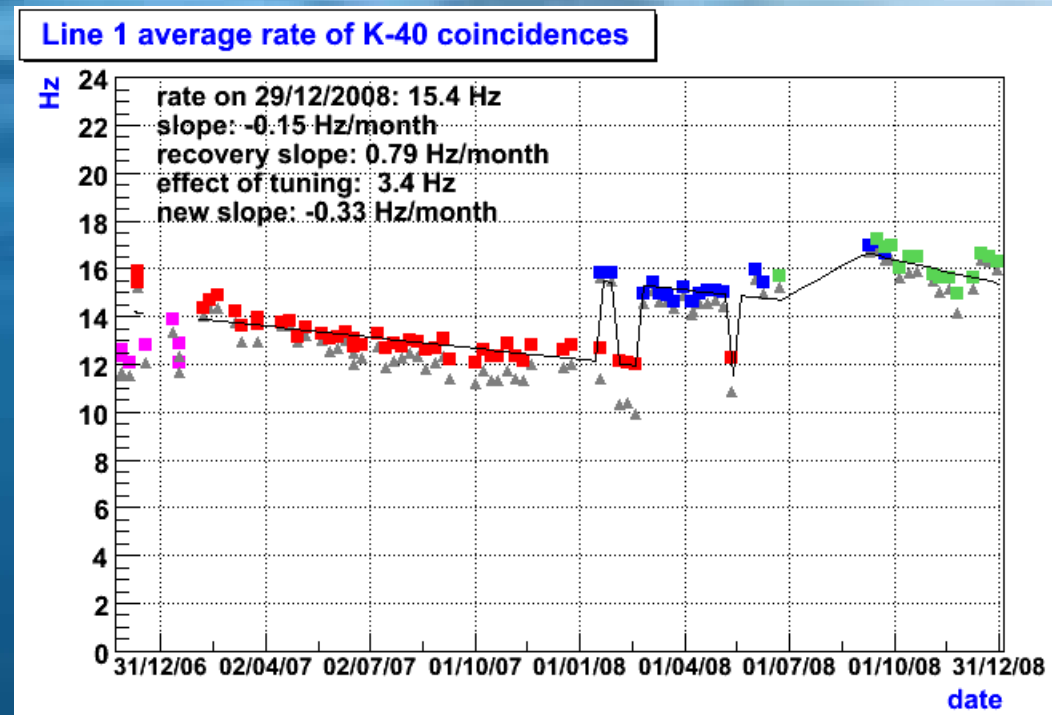
Precision (~5%)
monitoring of OM
efficiencies



Cross check of
time calibration



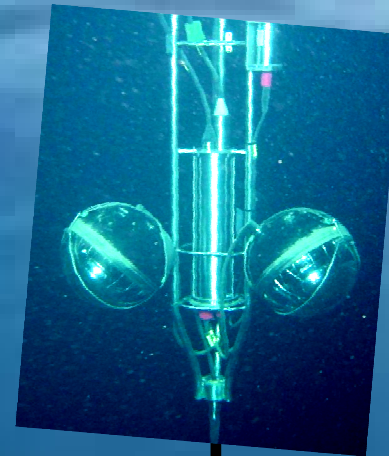
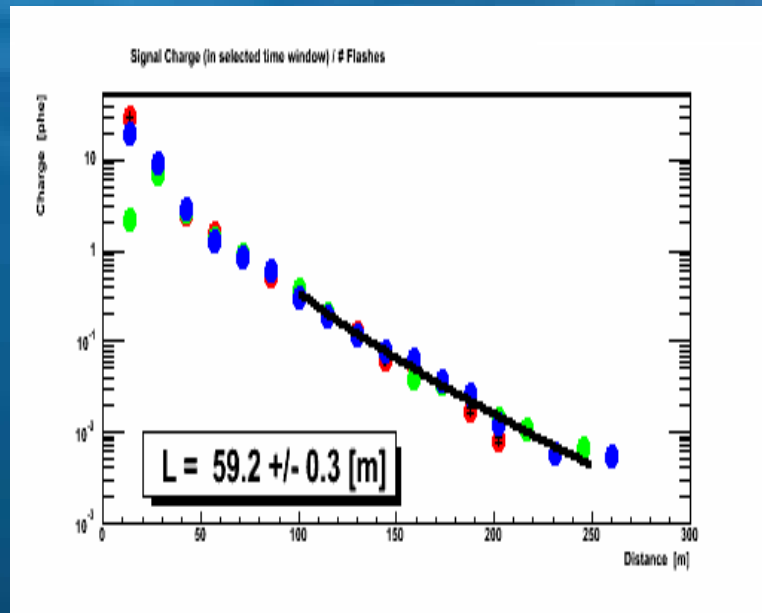
Time evolution of K40 coincidence rate



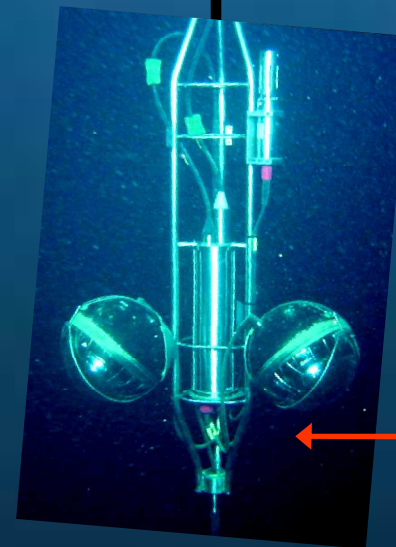
- All OM pairs of Line1 during more than 2 years
- OM gain drop reduces efficiency
- Recovery after threshold retuning
- Recovery due to HV off during period of cable repair



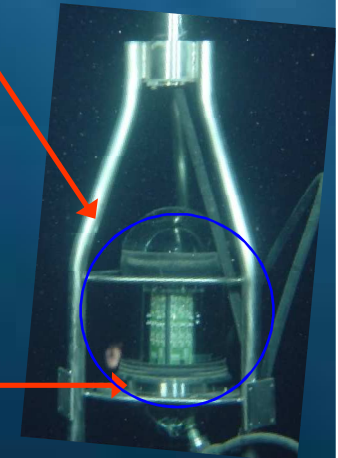
Light Absorption Measured using Beacons



~150 m



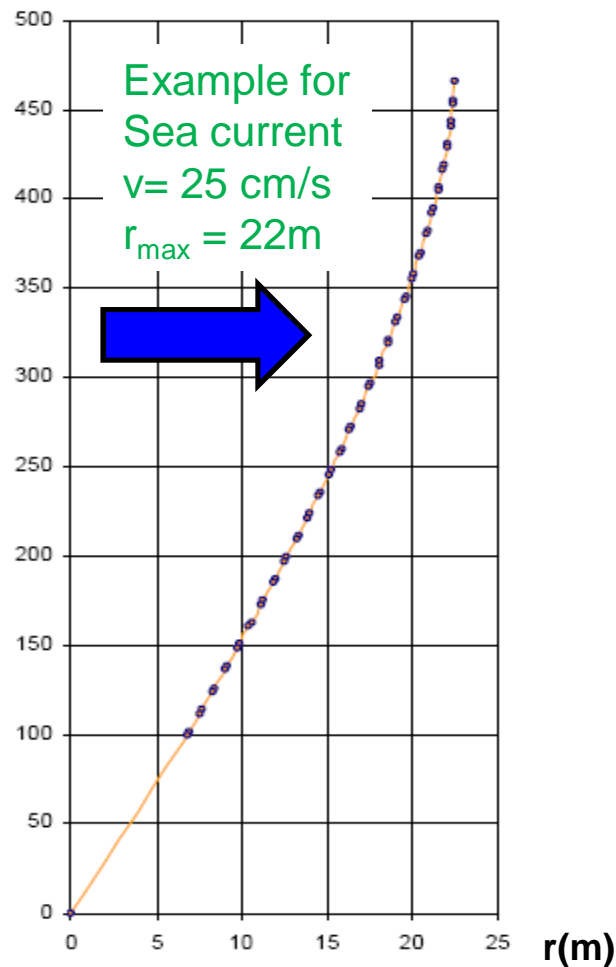
~70 m



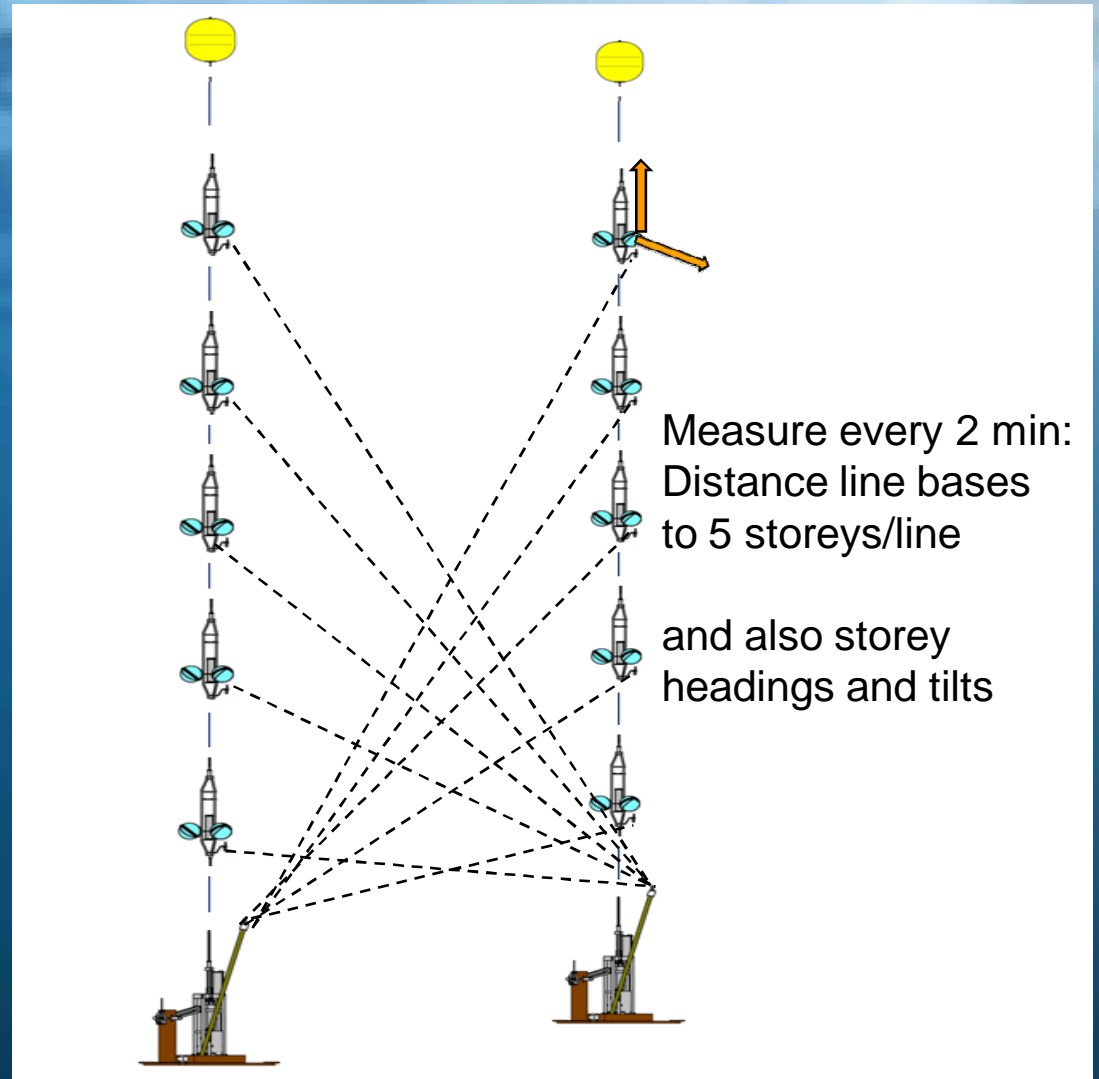


Position Alignment

Z(m)



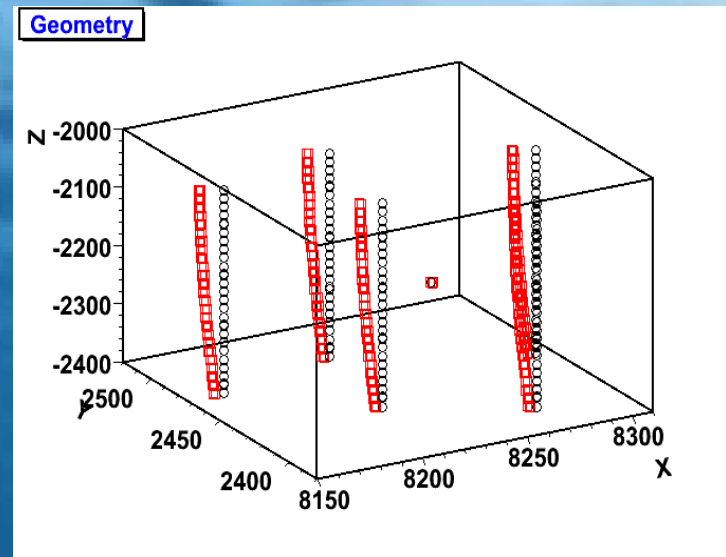
$$r = (a z - b \ln[1-cz]) v^2$$





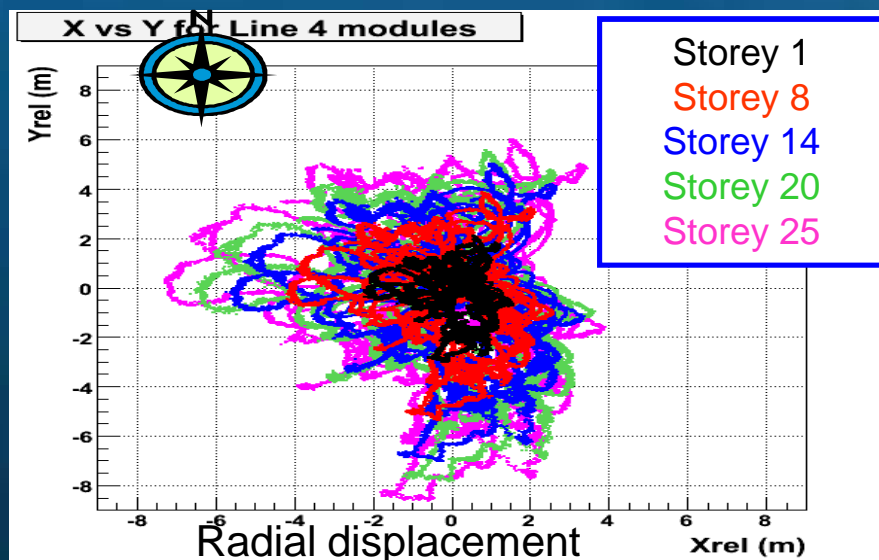
Line position measurements

Acoustic positioning:
Hydrophone positions
from July→Dec 2007

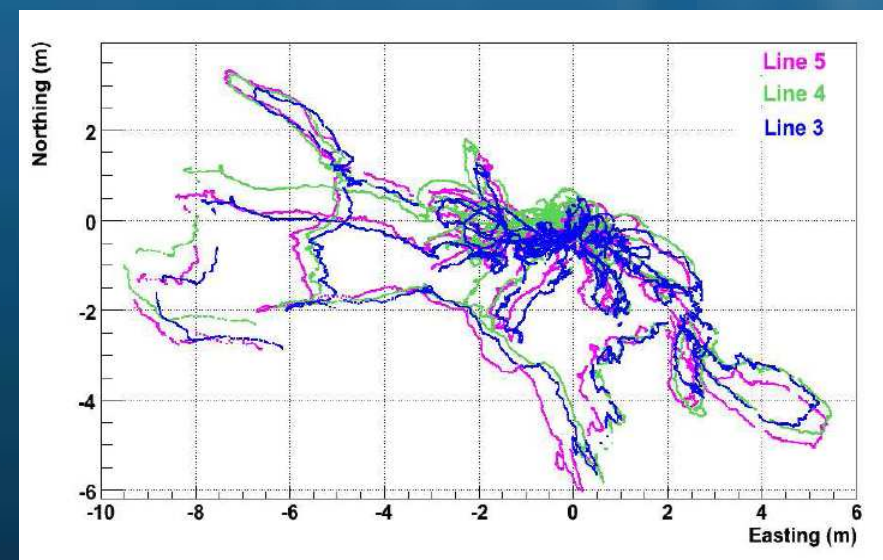


Acoustic positioning:
Precision ~ few cms

Within a line



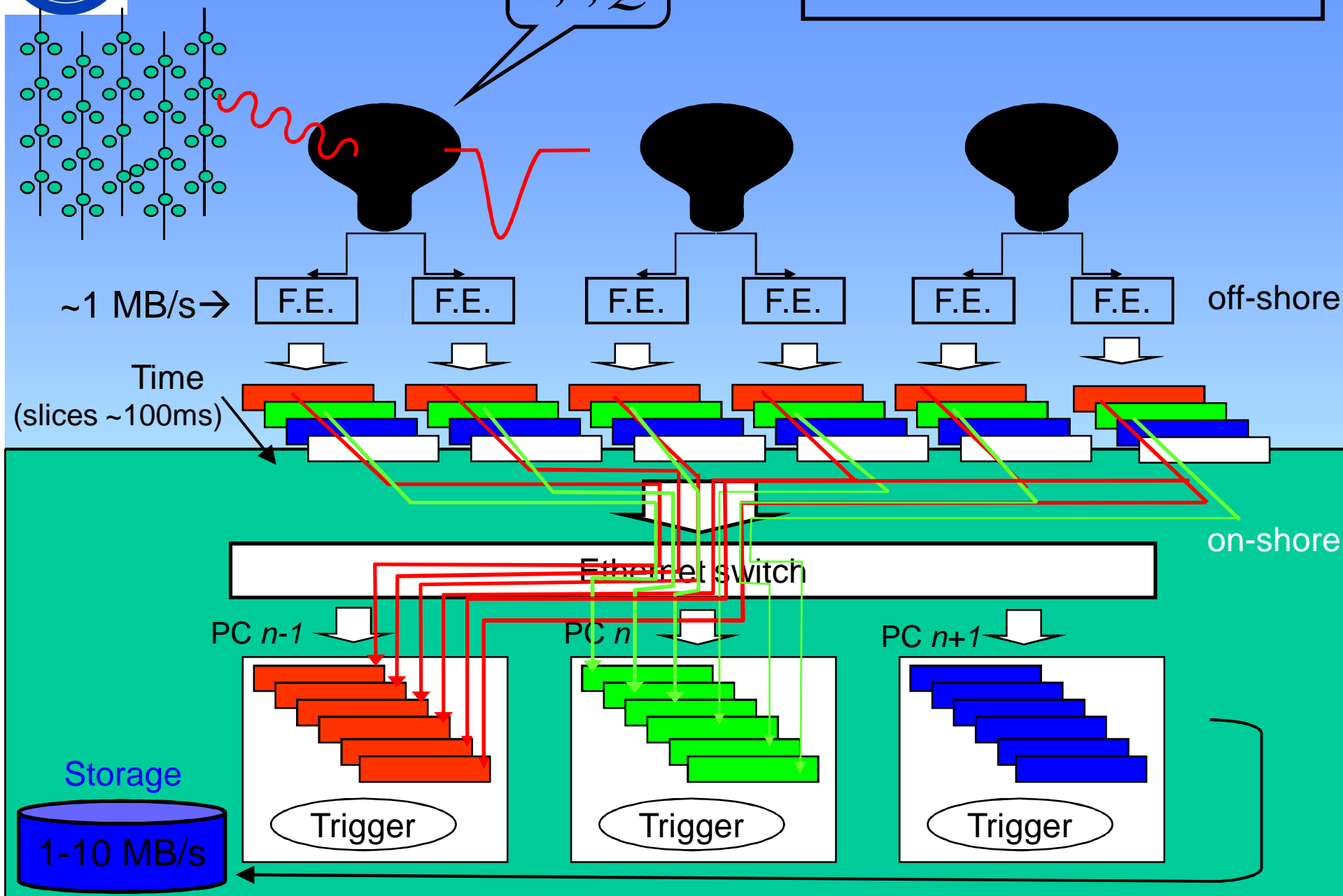
Between lines





Data Acquisition

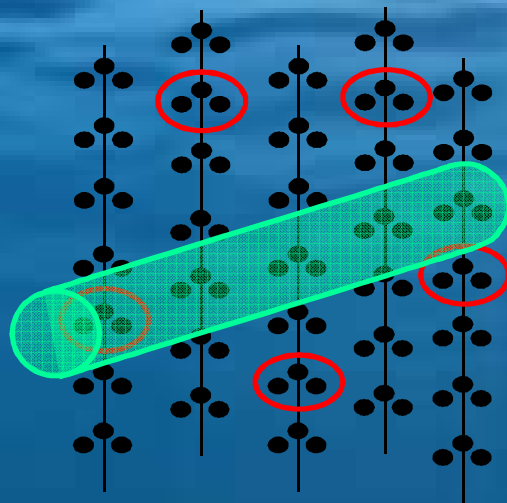
x, t, Q







Online Triggers

3N- directional scan



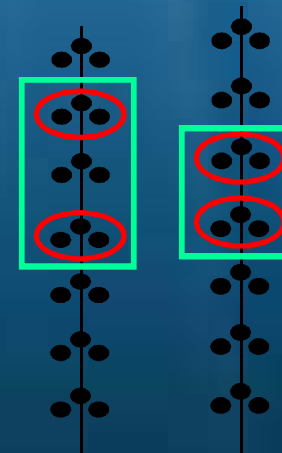
 = 1 local coincidence (20ns) of 2 out of 3
or a single large amplitude ($>3\text{spe}$)

Trigger 3N = 5  within $2.2\mu\text{s}$,
and causally related

2T3

Trigger 1T3 = 2  in 3 adjacent storeys

Trigger 2T3 = 2 x 1T3 within $2.2\mu\text{s}$



Galactic Centre-directional trigger



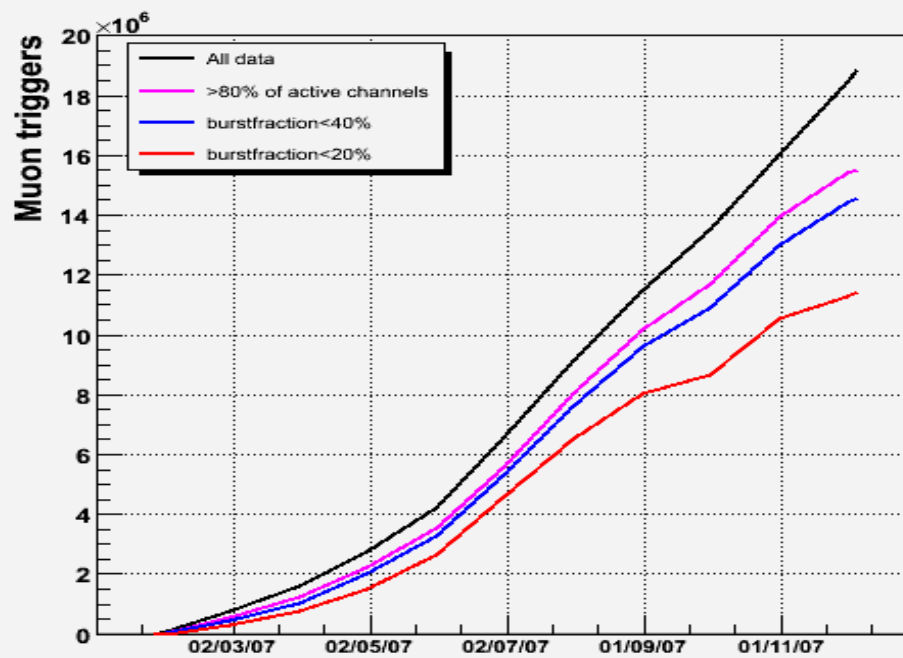
Number of triggers

5 lines (2007)

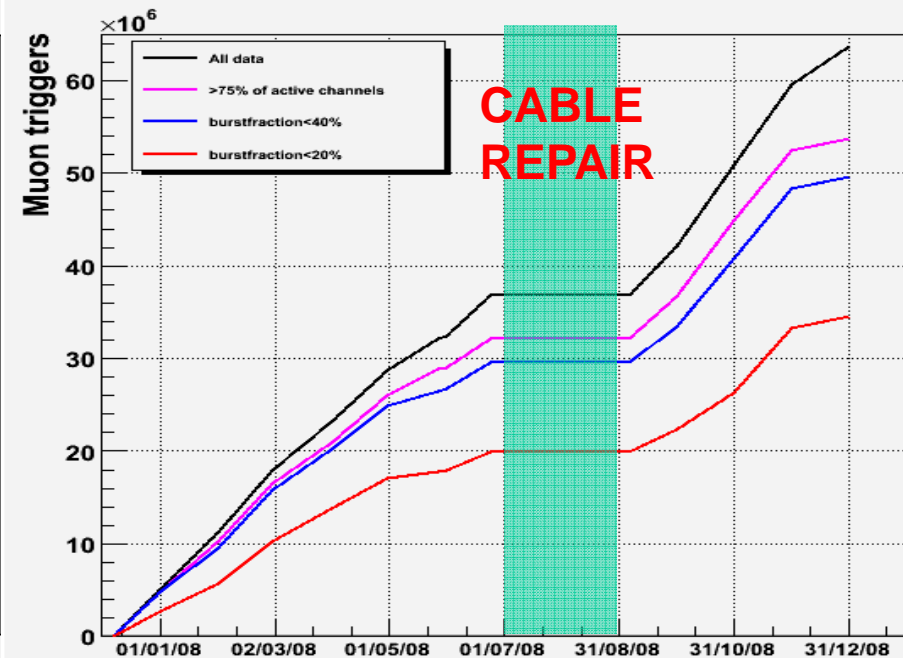
$19.10^6 \mu$

10 or more lines (2008)

$65.10^6 \mu$



Total : 240 days = 80% of calendar
Selected : 167d = 70% of total

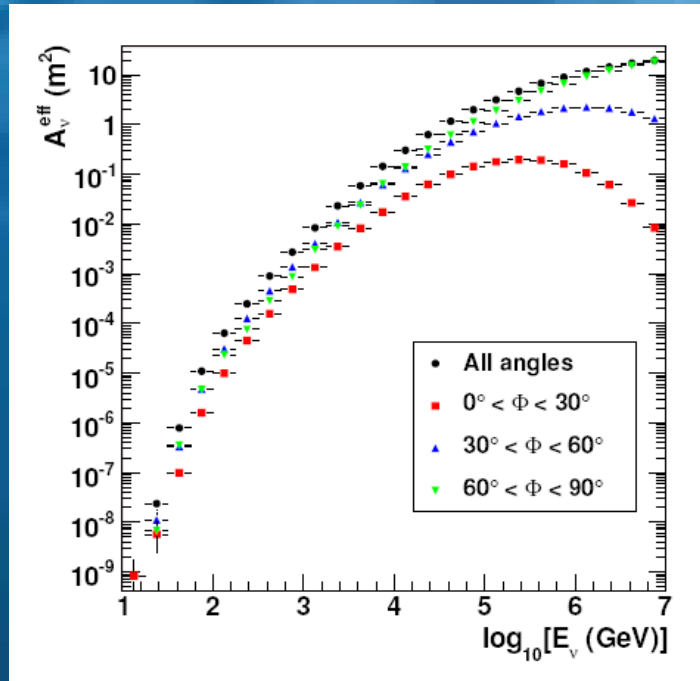


Total : 243 days = 83% of calendar
Selected : 173d = 71% of total



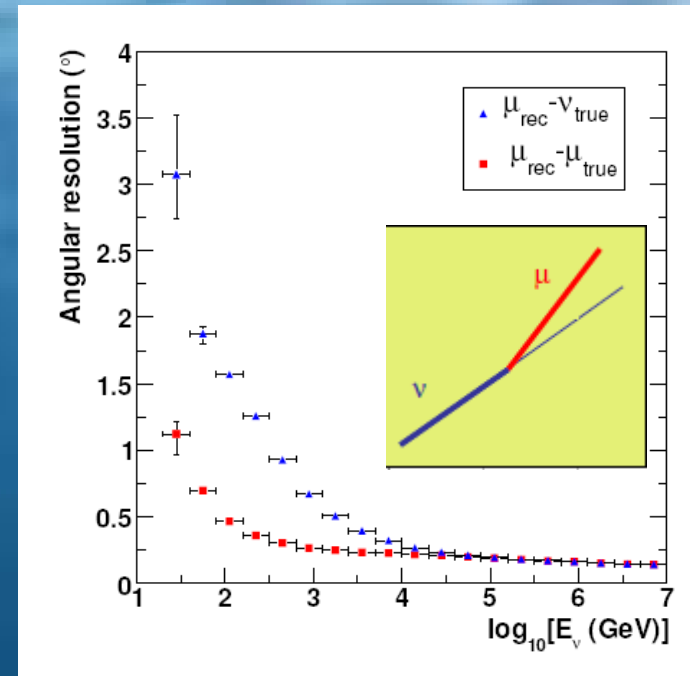
Expected Performance (full detector)

Neutrino effective area



- For $E_v < 10 \text{ PeV}$, A_{eff} grows with energy due to the increase of the interaction cross section and the muon range.
- For $E_v > 10 \text{ PeV}$ the Earth becomes opaque to neutrinos.

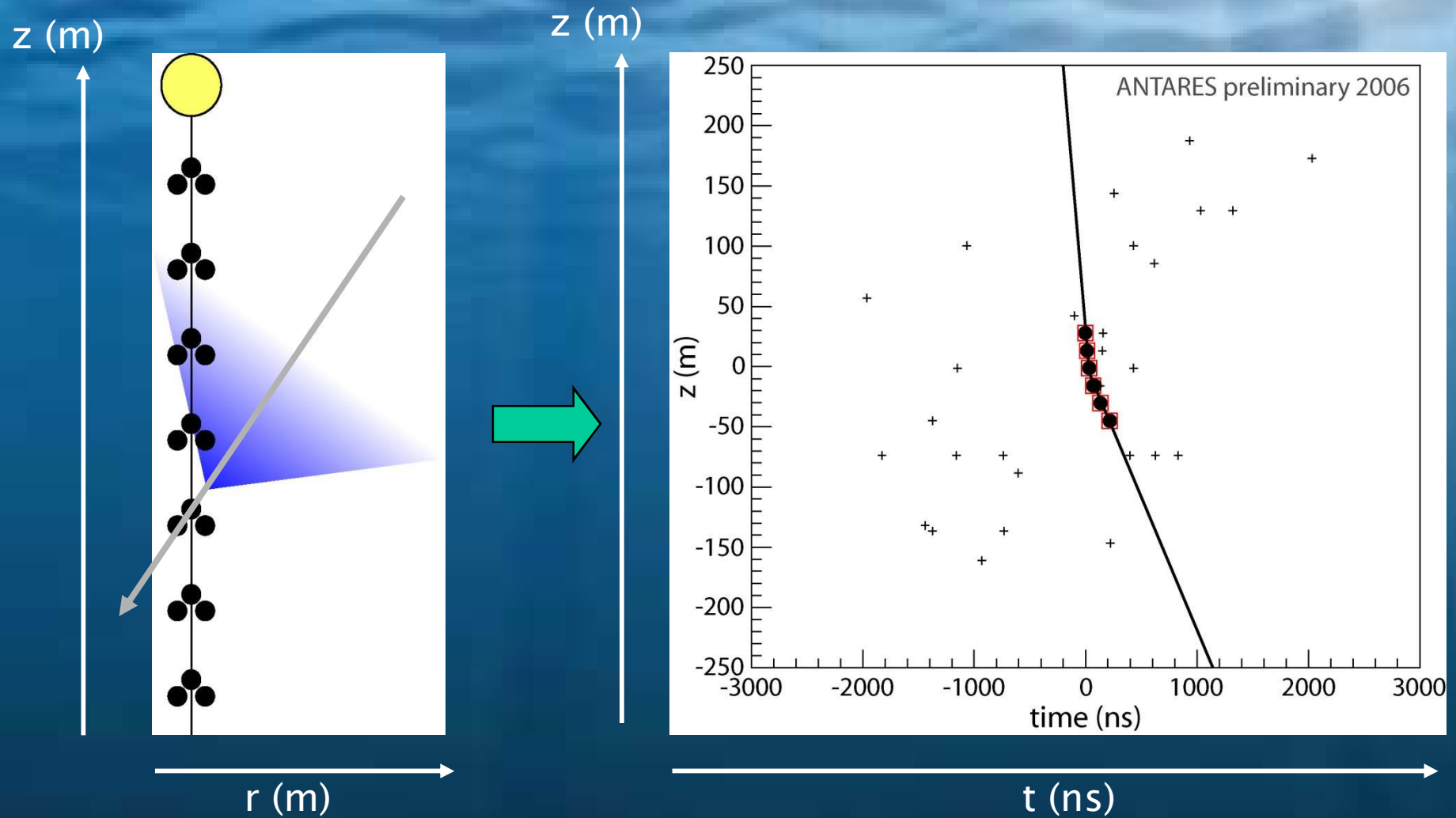
Angular resolution



- For $E_v < 10 \text{ TeV}$, the angular resolution is dominated by the ν - μ angle.
- For $E_v > 10 \text{ TeV}$, the resolution is limited by track reconstruction uncertainties.



Event Displays

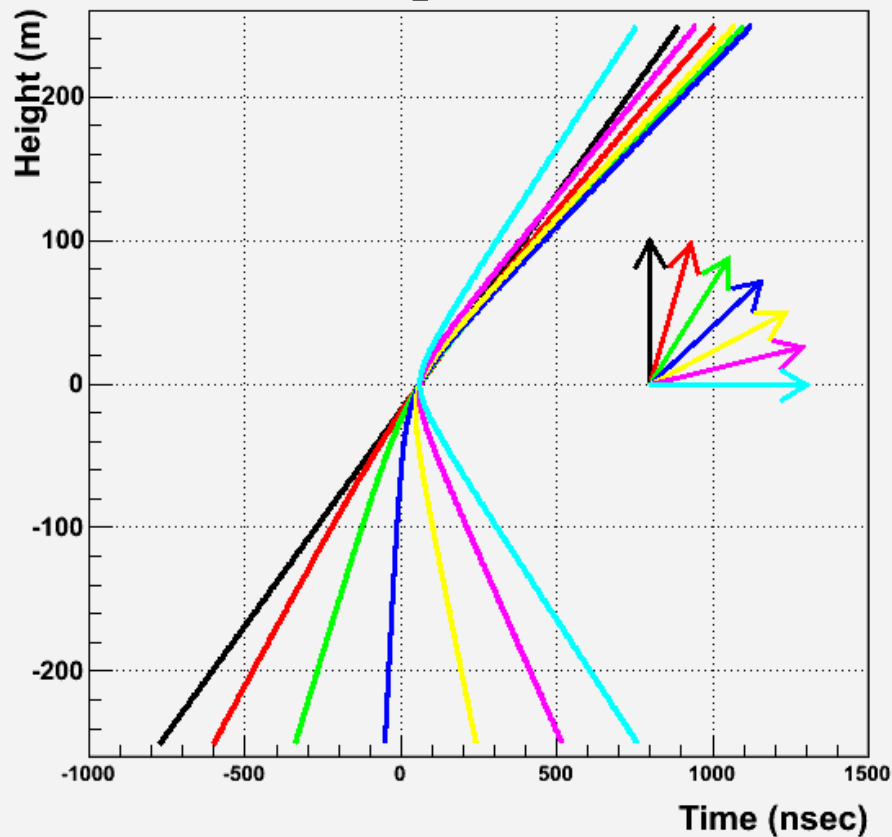




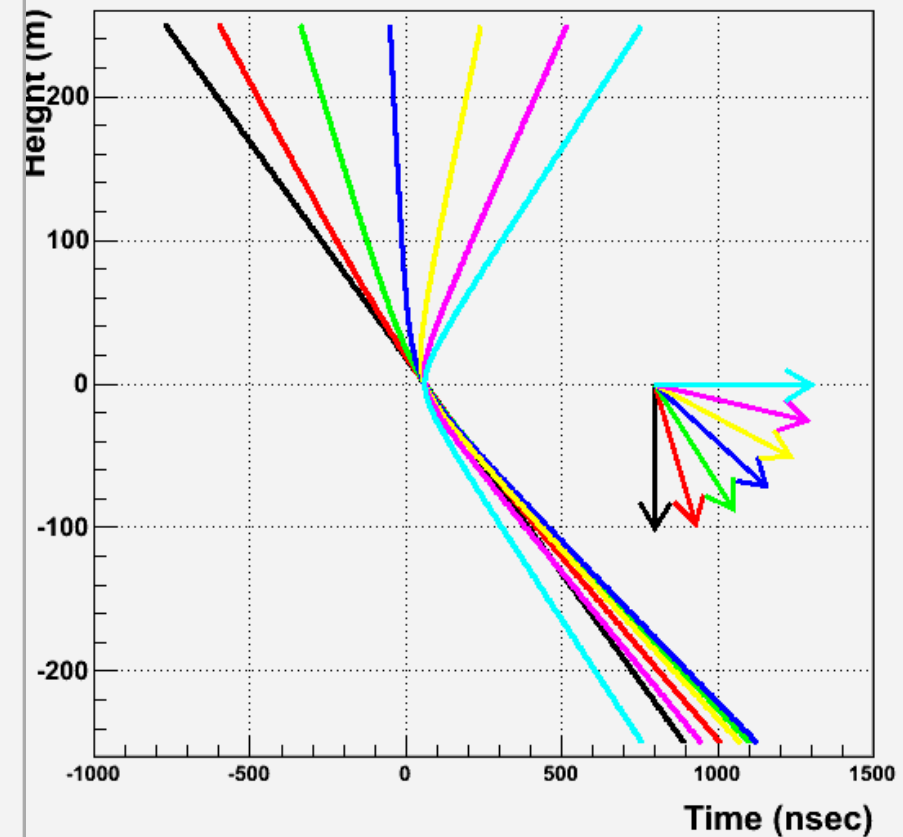
Event Displays

Hits are plotted for each line: z coordinate (height) as function time
Characteristic pattern in function of zenith angle and point of closest approach between line and track

upward



downward





Event Display: Atmospheric Muons

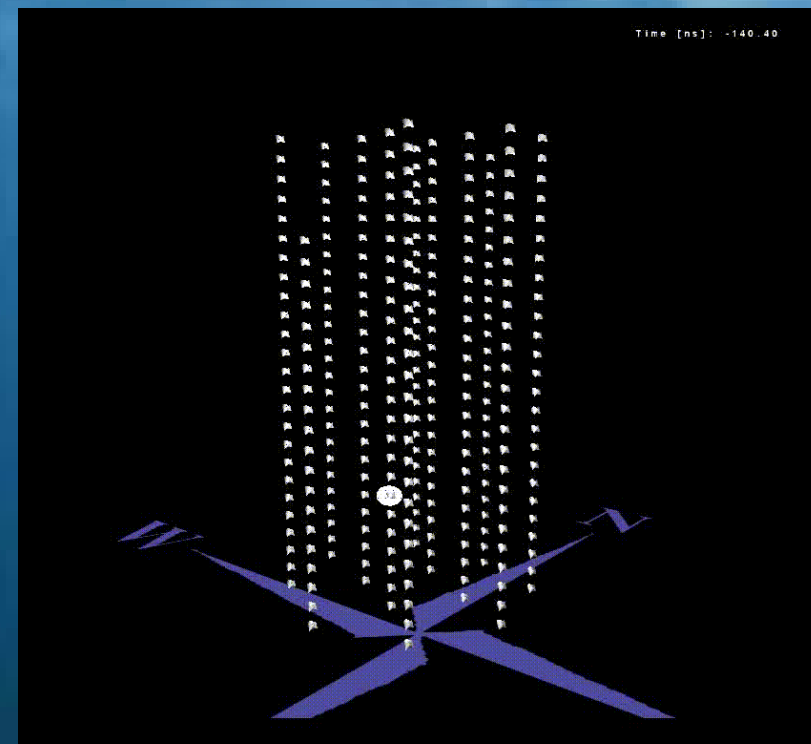
height

Zenith : 144.3
Fit on 11 line(s)



time

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





Event Display: Neutrino-induced muon

height

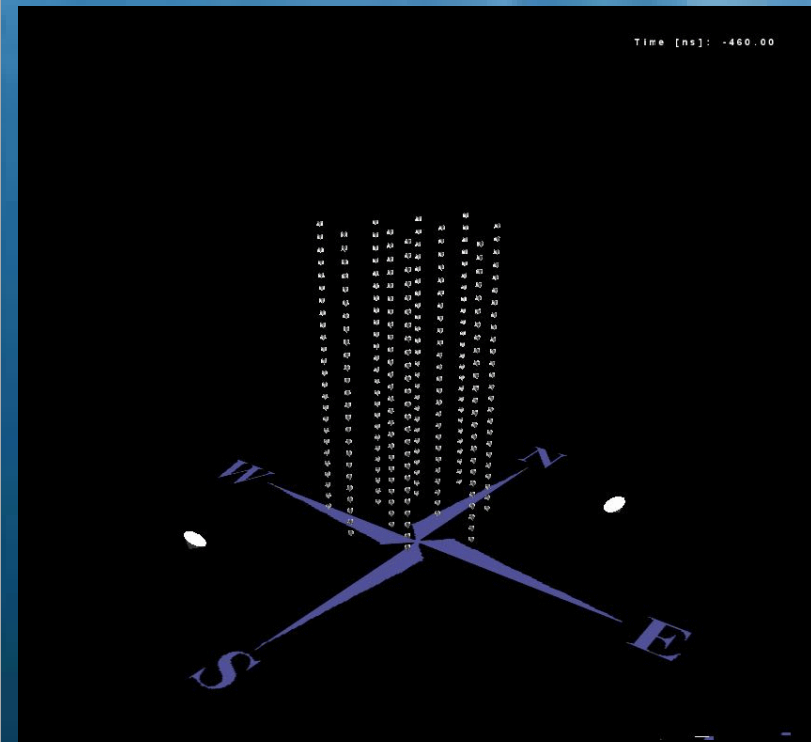
Zenith : 34.8
Fit on 5 line(s)

Run 34927 Frame 7155
Wed Jun 18 00:08:10 2008
Trigger bits 80002020
Line 1-12 Physics Trigger (th)

1 2 3 4 5 6 photons
● ● ● ● ● ●

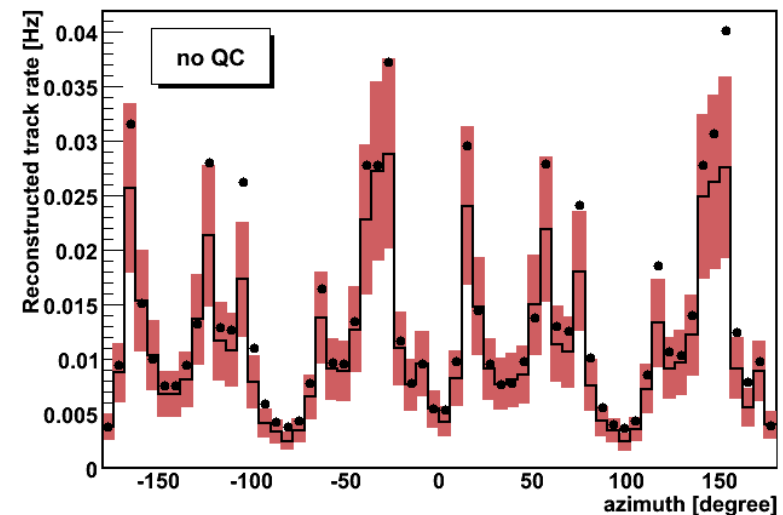
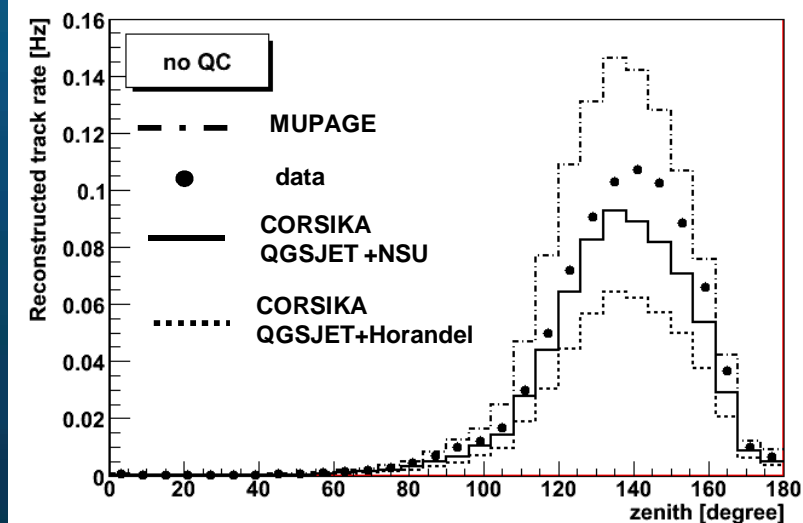
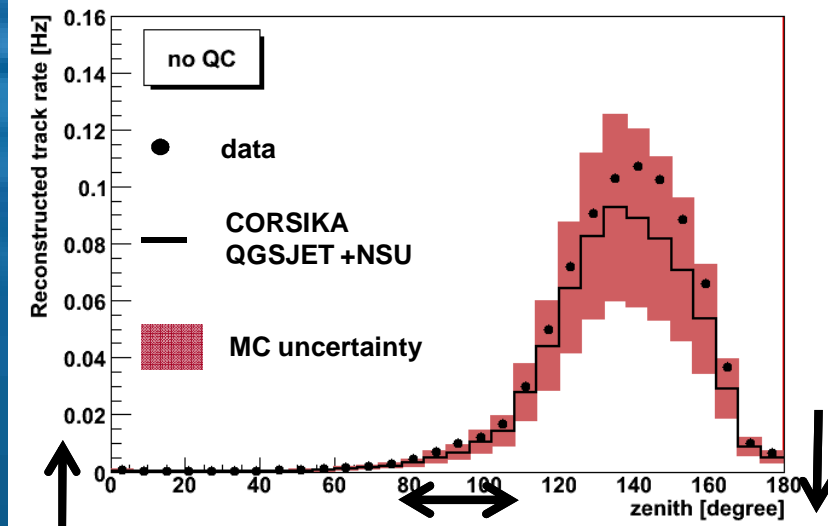


Example of a **reconstructed up-going muon** (i.e. a neutrino candidate) detected in 6/12 detector lines:





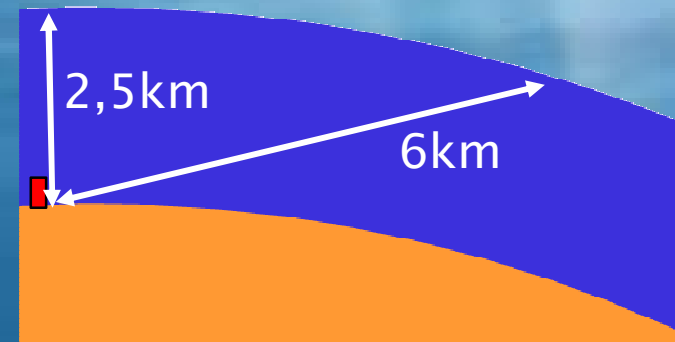
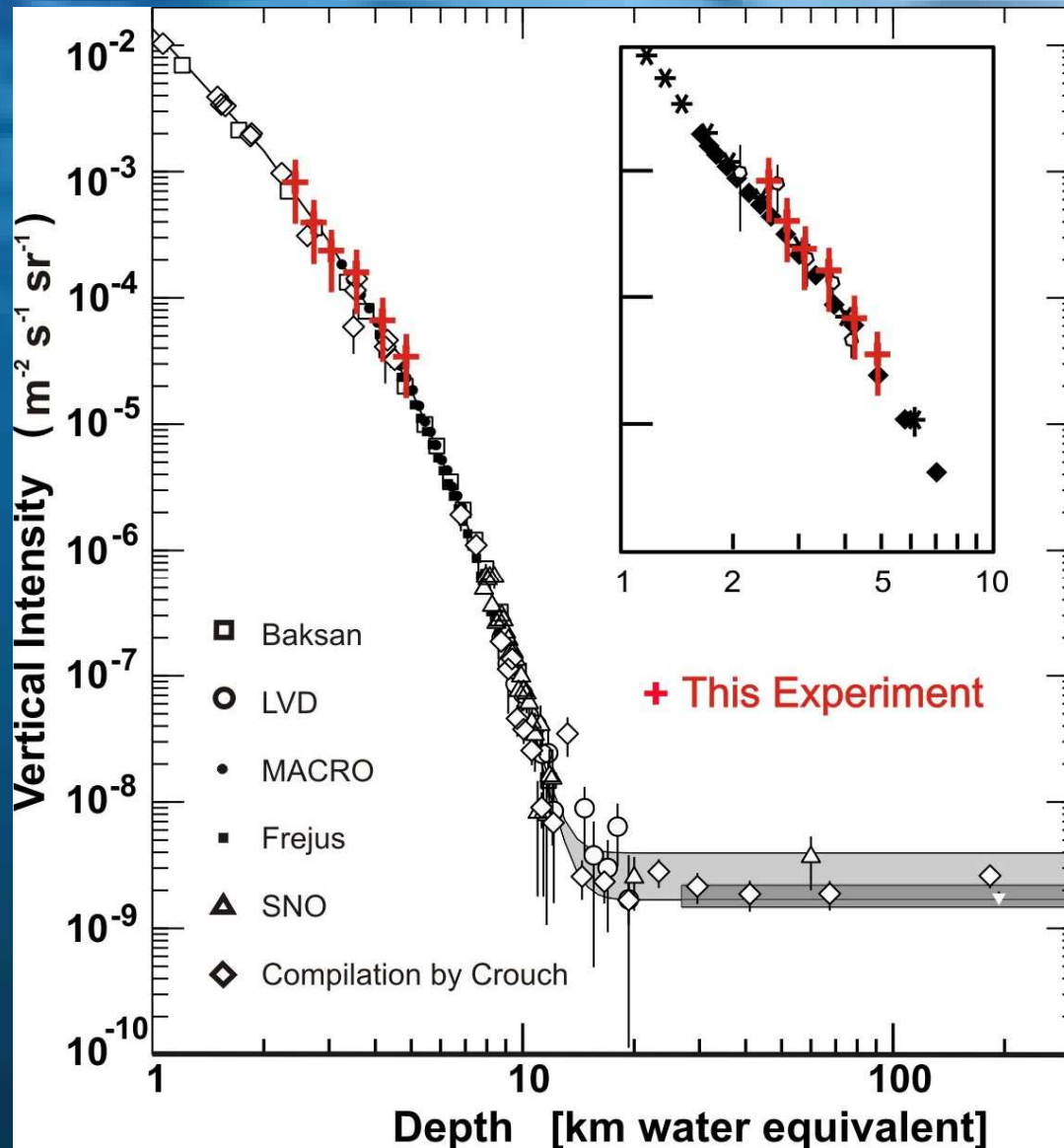
DATA-MC COMPARISON FOR DOWNGOING EVENTS (5-LINES)



- No quality cuts applied
- Agreement within (substantial) theoretical + MC uncertainty
- Main experimental errors stem from OM efficiency and acceptance and optical water properties (λ_{abs} λ_{scatt})



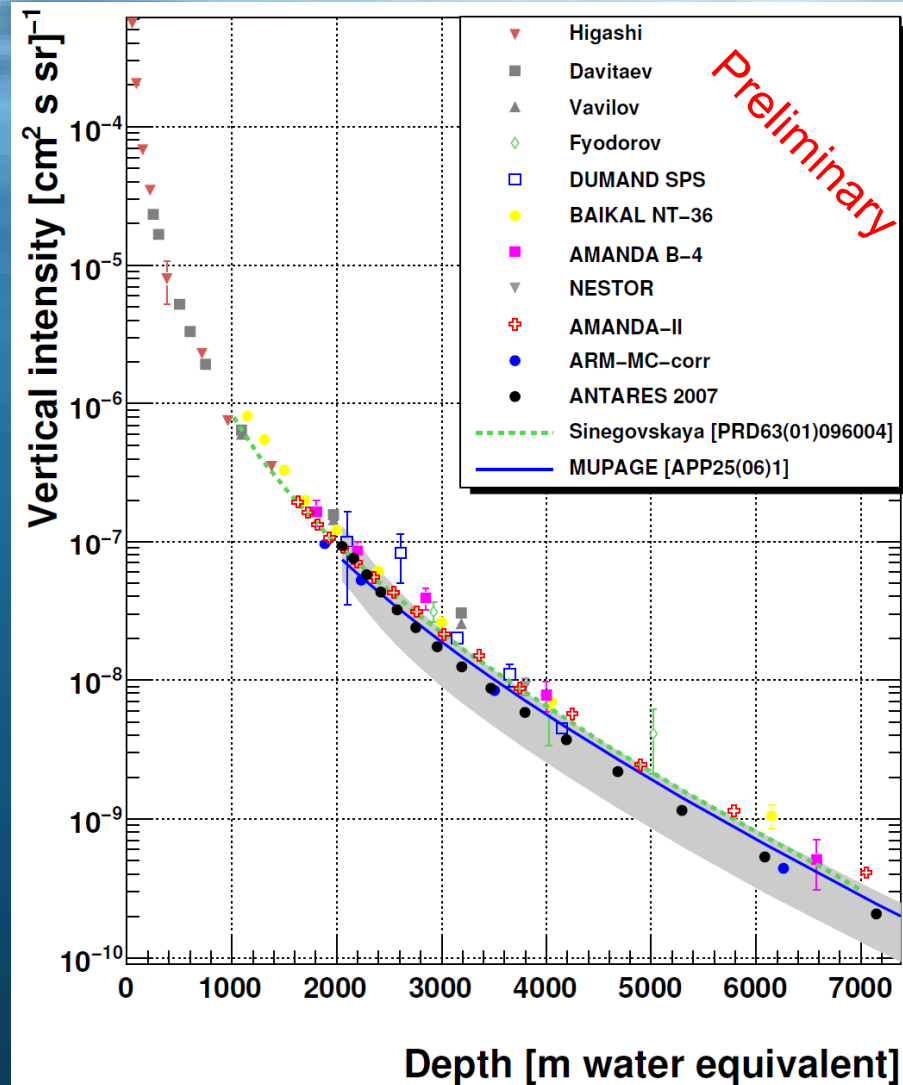
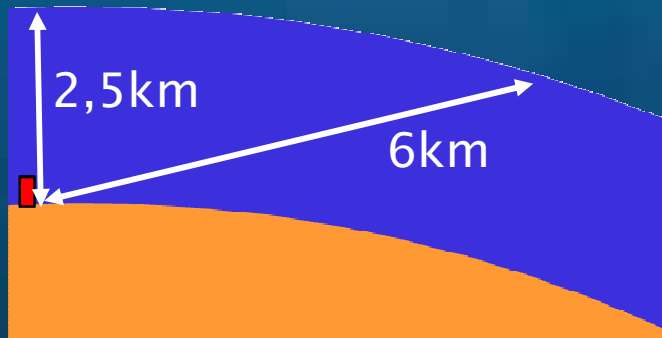
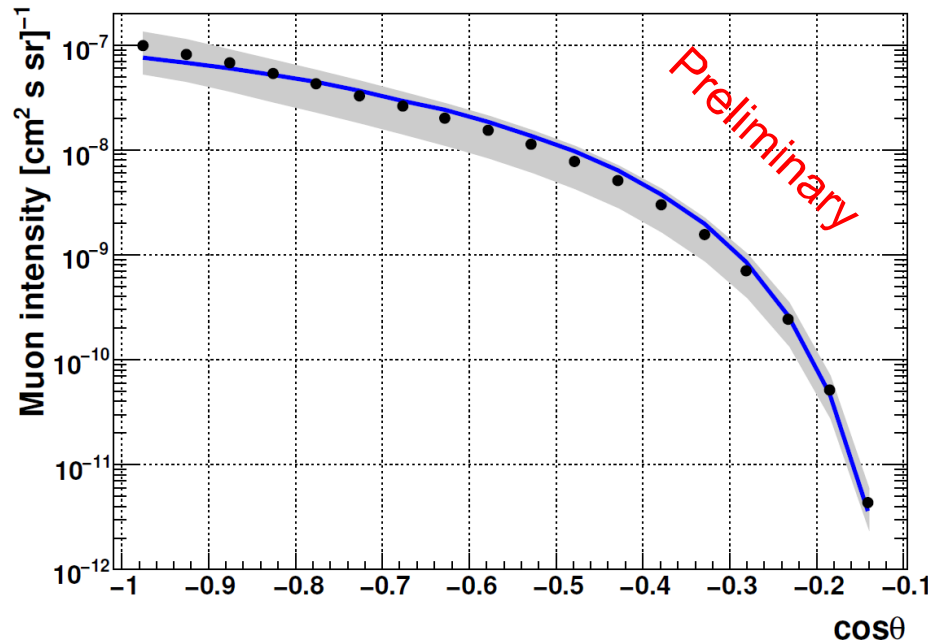
Depth intensity relation-1 line



The ANTARES collaboration:
*Performance of the First ANTARES
Detector Line.*
AP 31 (2009) 277



5 LINES (2007): DEPTH VS. INTENSITY



See talk: M. Bazzotti, 8/7/09, HE340

Work on reducing systematics is ongoing



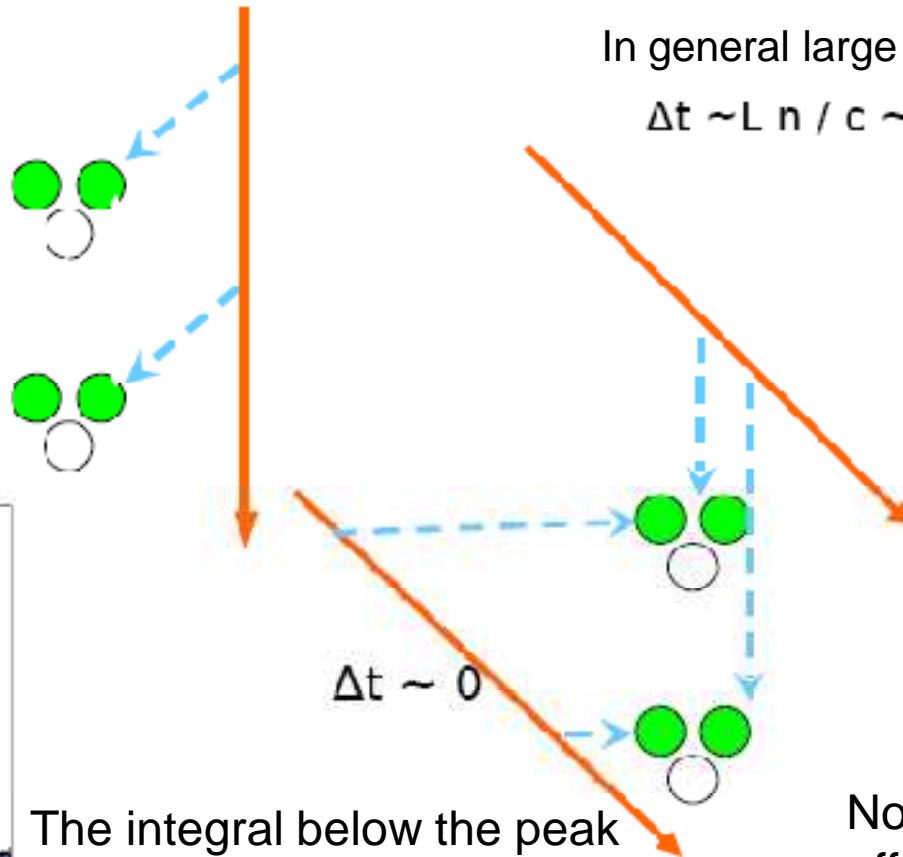
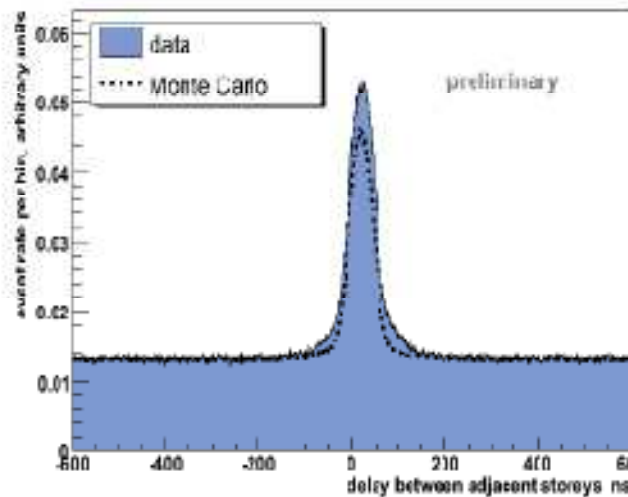
Delay between adjacent storeys

Fixed for vertical muons

$$\Delta t = L / c \approx 50 \text{ ns}$$

In general large distribution

$$\Delta t \sim L n / c \sim 70 \text{ ns}$$



The integral below the peak is proportional to the μ flux

Shape is sensitive to angular acceptance of optical modules and angular distribution of muon flux

No systematic effects of trigger or reconstruction



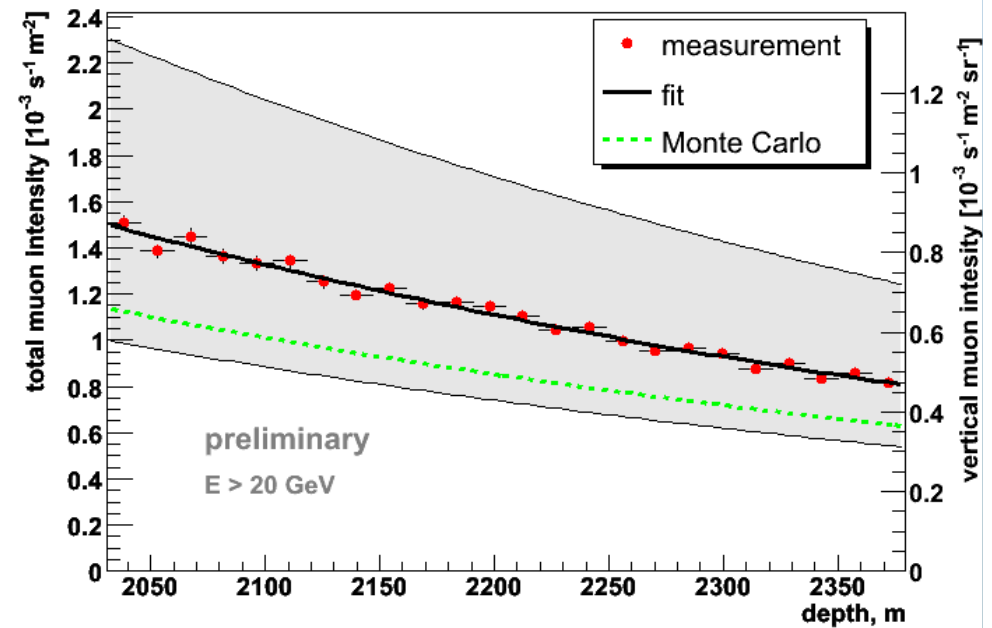
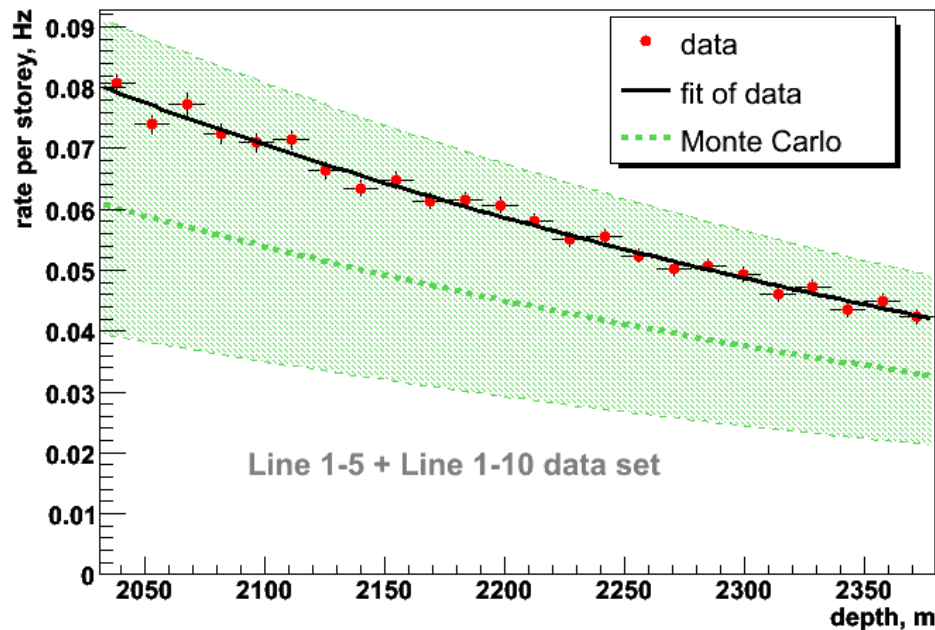
Vertical muon intensity

Muon flux measured without track reconstruction
Error dominated by detector systematics

- angular acceptance of PMTs
- absolute PMT efficiencies

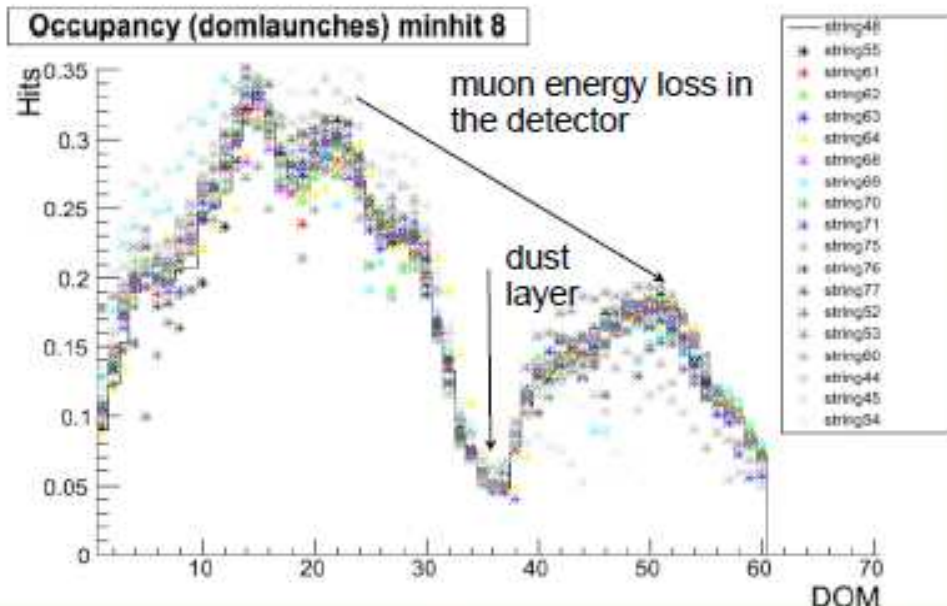
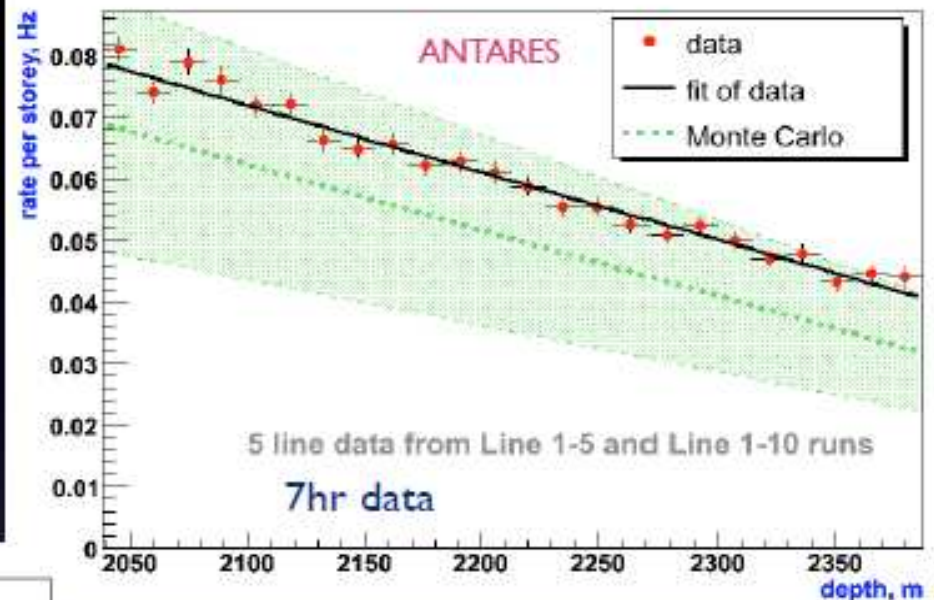
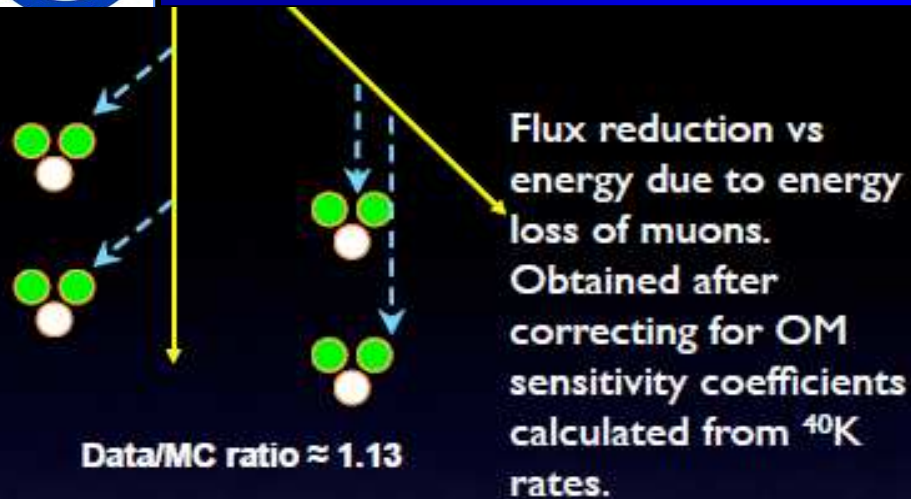
Measured Rate

Derived Flux





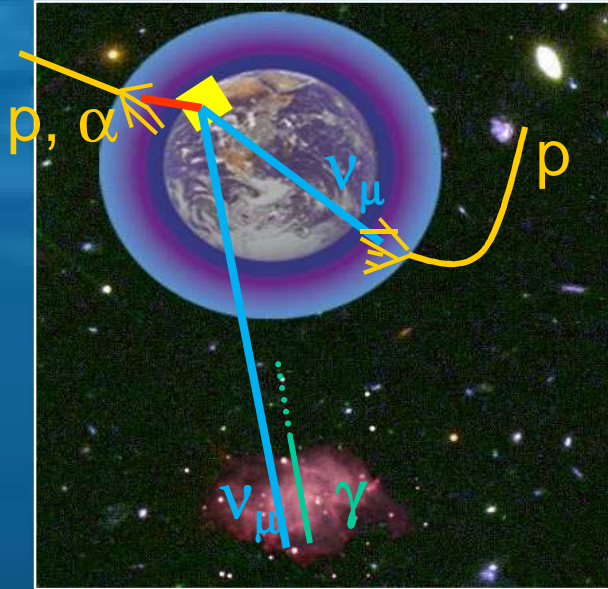
Depth Dependency: ICECUBE vs ANTARES



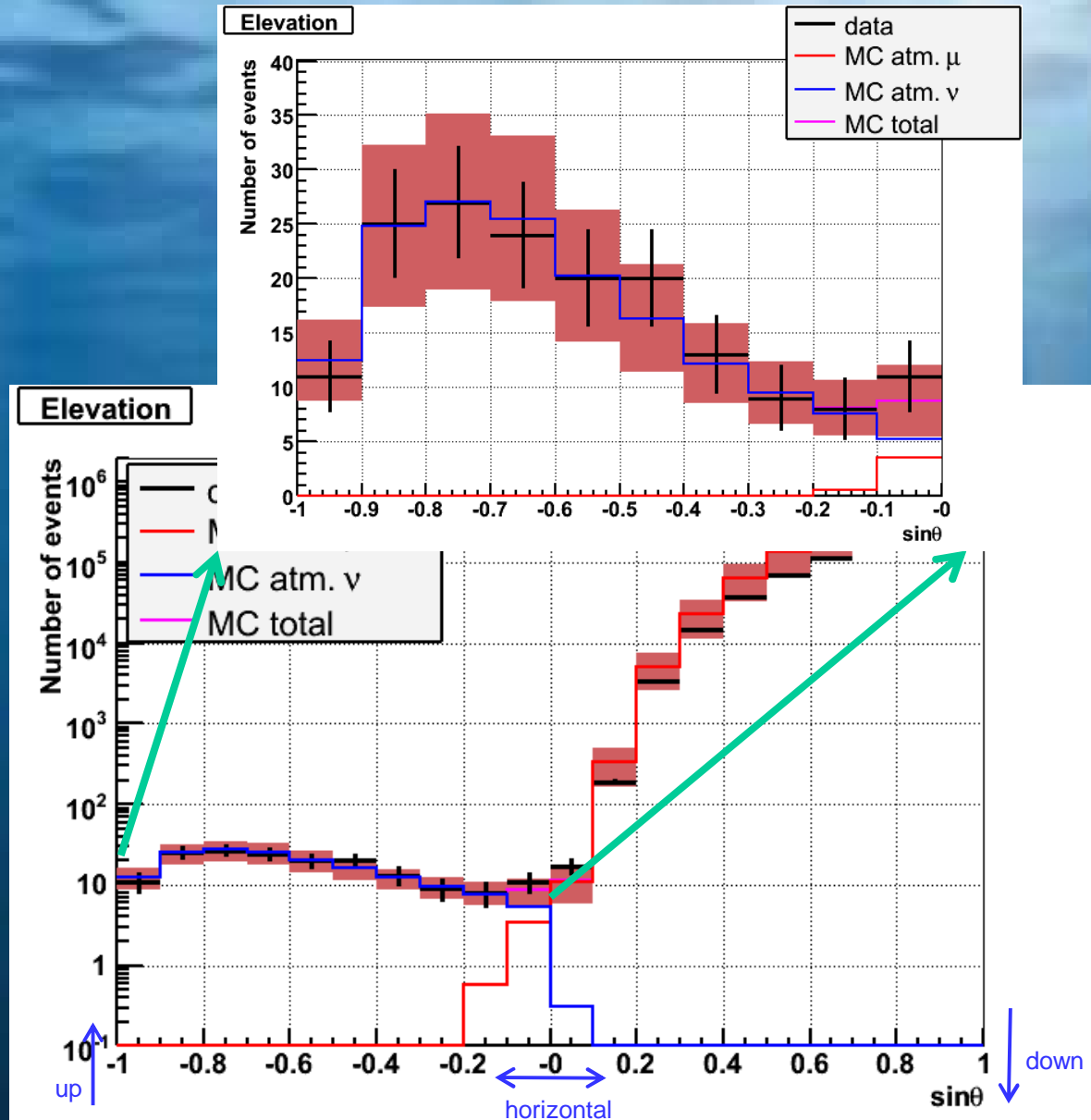
IceCube: Main uncertainty in ice due to depth dependence of ice absorption and scattering



5 LINE DATA (2007): ANGULAR DISTRIBUTION



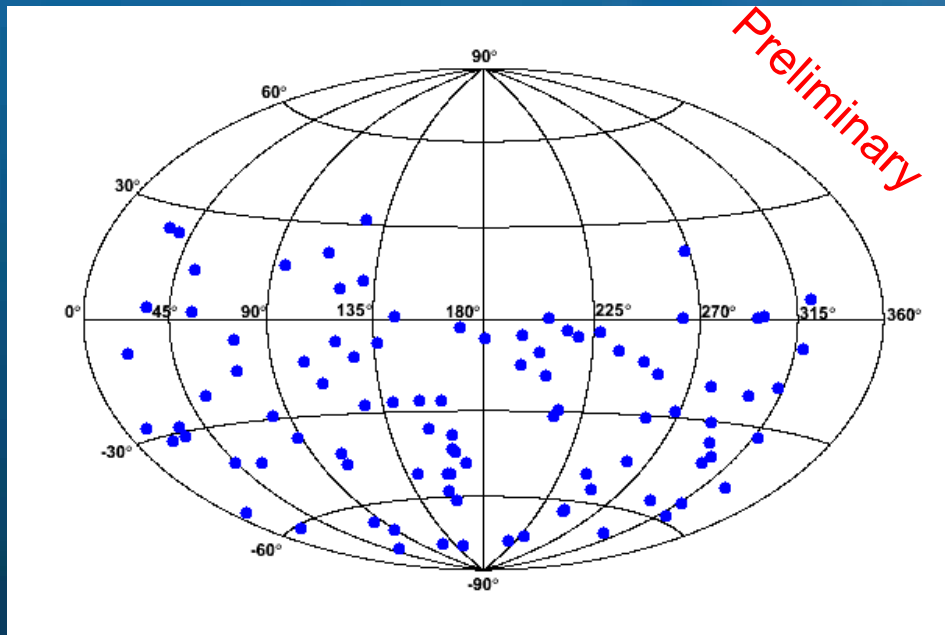
168 active days
168 upward events
(multi-line fit)





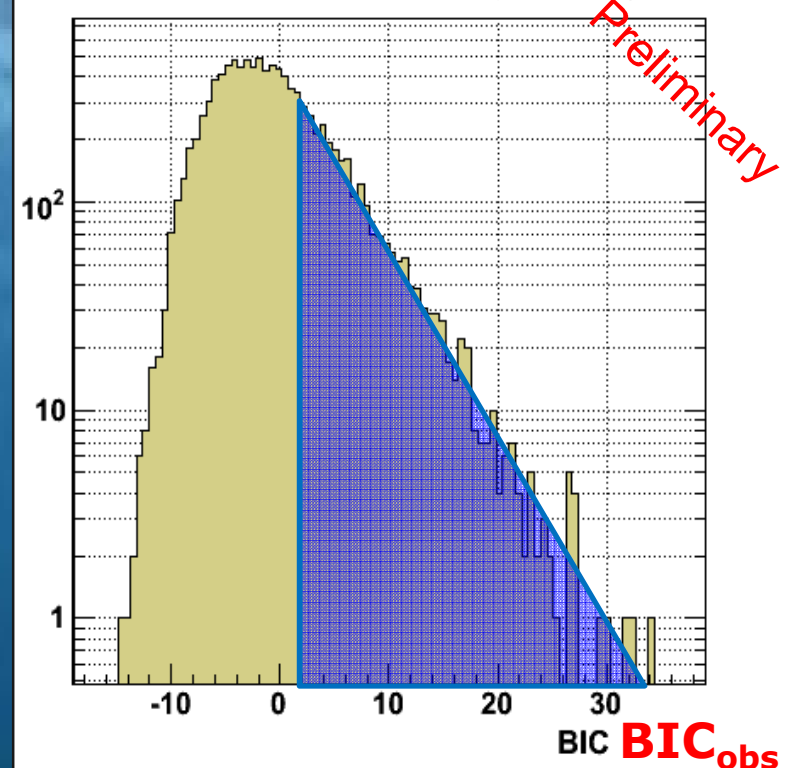
All-Sky Point Search Results

- Stringent cuts to ensure low background and good angular resolution.
- Expectation-Maximisation algorithm



See talk S. Toscano, 13/7/09, OG2.5

BIC distribution of only background



In our sample :

$BIC_{obs} = 1.4$ (highest value)

p-value = 0.3 (1σ excess)

($\delta = -63.7^\circ$ RA = 243.9 $^\circ$)

No significant excess found

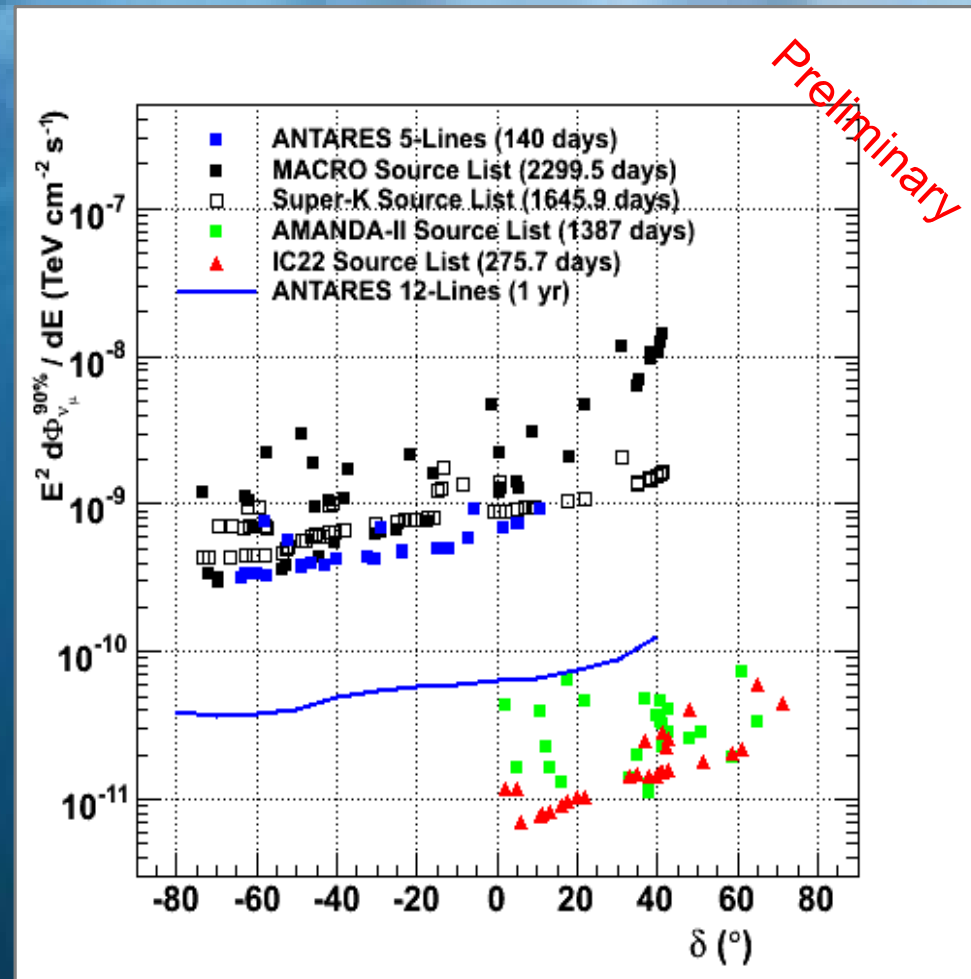


SOURCE CANDIDATE LIST

Search applied to **25 selected sources**

Source name	δ (°)	RA (°)	$n_{2.5^\circ}$	P-value	ϕ_{90}
PSR B1259-63	-63.83	195.70	0	-	3.1
RCW 86	-62.48	220.68	0	-	3.3
HESS J1023-575	-57.76	155.83	1	0.004	7.6
CIR X-1	-57.17	230.17	0	-	3.3
HESS J1614-518	-51.82	243.58	1	0.088	5.6
GX 339	-48.79	255.70	0	-	3.8
RX J0852.0-4622	-46.37	133.00	0	-	4.0
RX J1713.7-3946	-39.75	258.25	0	-	4.3
Galactic Centre	-29.01	266.42	1	0.055	6.8
W28	-23.34	270.43	0	-	4.8
LS 5039	-14.83	276.56	0	-	5.0
HESS J1837-069	-6.95	279.41	0	-	5.9
SS 433	4.98	287.96	0	-	7.3
HESS J0632+057	5.81	98.24	0	-	7.4
ESO 139-G12	-59.94	264.41	0	-	3.4
PKS 2005-489	-48.82	302.37	0	-	3.7
Centaurus A	-43.02	201.36	0	-	3.9
PKS 0548-322	-32.27	87.67	0	-	4.3
H 2356-309	-30.63	359.78	0	-	4.2
PKS 2155-304	-30.22	329.72	0	-	4.2
1ES 1101-232	-23.49	165.91	0	-	4.6
1ES 0347-121	-11.99	57.35	0	-	5.0
3C 279	-5.79	194.05	1	0.030	9.2
RGB J0152+017	1.79	28.17	0	-	7.0
IC22 hotspot	11.00	153.00	0	-	9.1

ϕ_{90} (10^{-9} TeV cm $^{-2}$ s $^{-1}$)

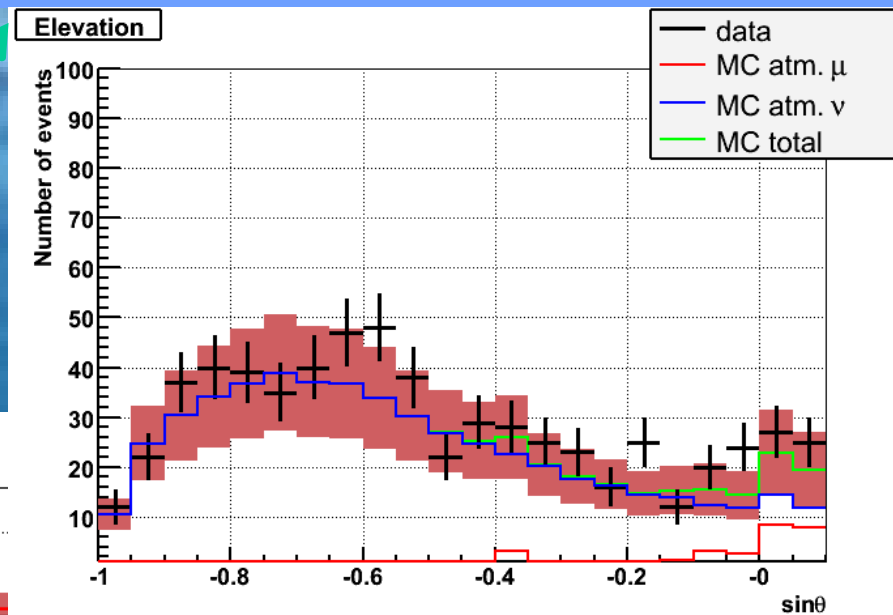
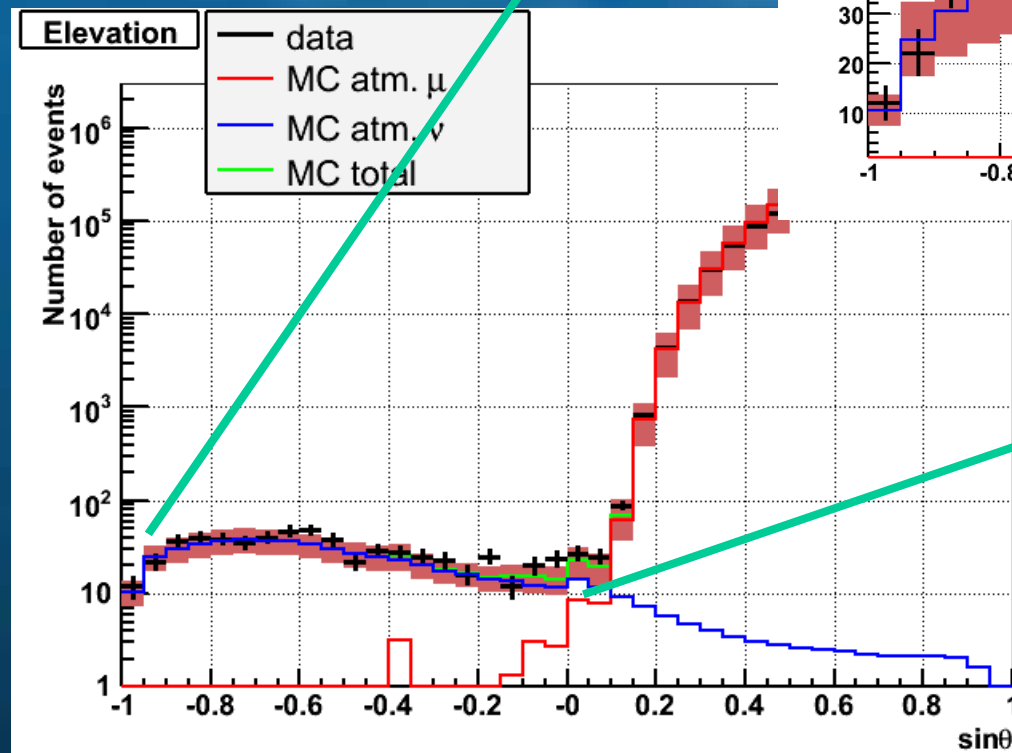


- The lowest value corresponds to a **p-value pre-trial of 3σ**
- Expected in 10% of the experiments when looking at 25 sources (post-trial probability)

Competitive limits in southern sky



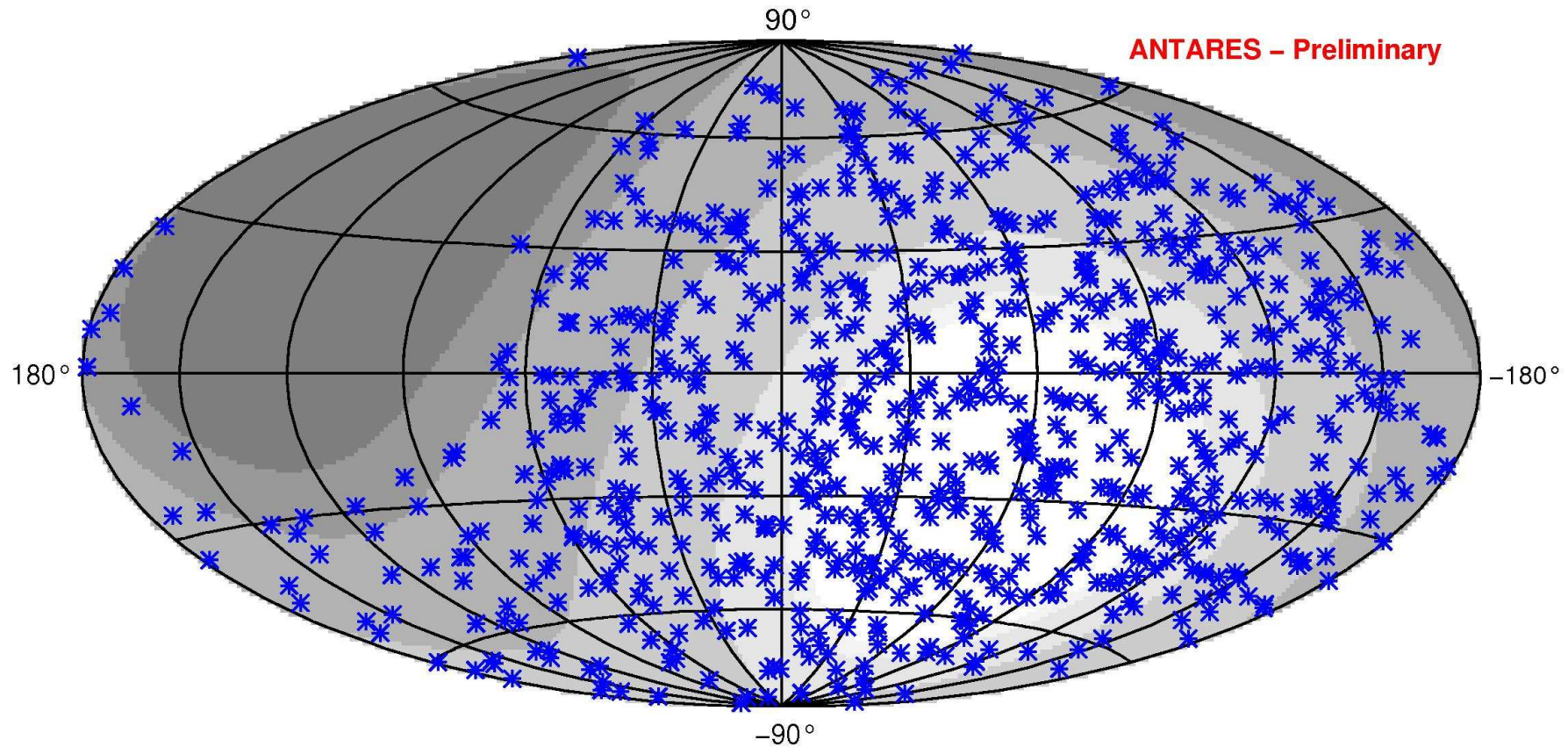
2008 DATA



174 active days
582 upgoing events
(multi-line fit)



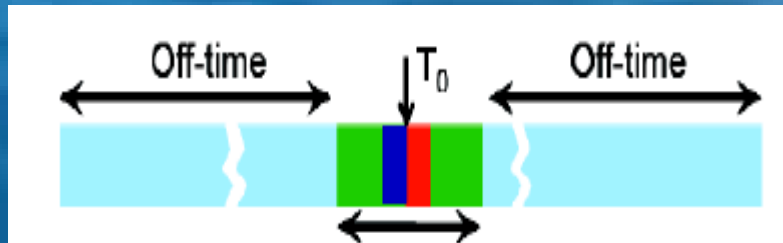
BLINDED 2007+2008 SKYMAP





Transients with ANTARES

Triggered search



Requires Satellite trigger

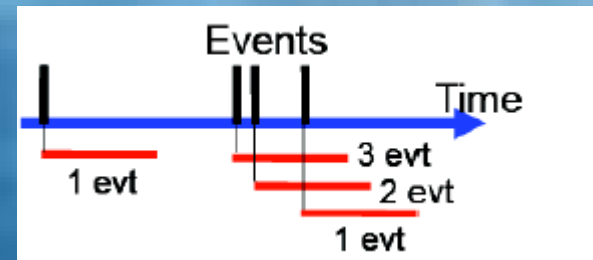
Low backgrounds due to direction and time coincidences

Dump all L0 data in 2min window around trigger (i.e. no trigger losses)

Special track reconstruction using known direction

See poster M. Bouwhuis, 341, OG2.4

Rolling search



Full sky search

24hr/24hr

Sliding time window around events

Fast online reconstruction \Rightarrow optical follow up to identify source

Also sensitive to dark bursts

See talk D. Dornic, 13/7/09, OG2.5

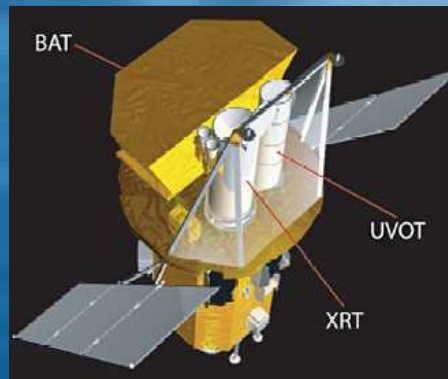


Triggered Search: Time Delays

GRB alerts from three satellites



INTEGRAL

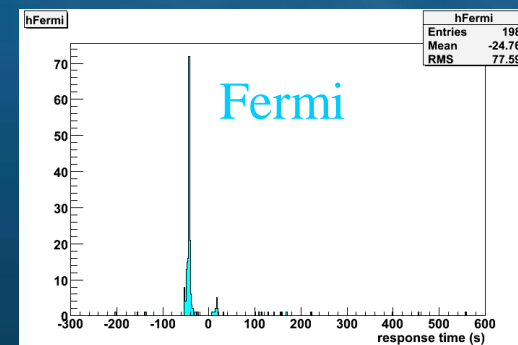
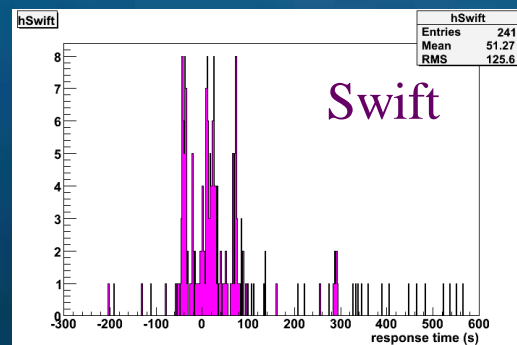
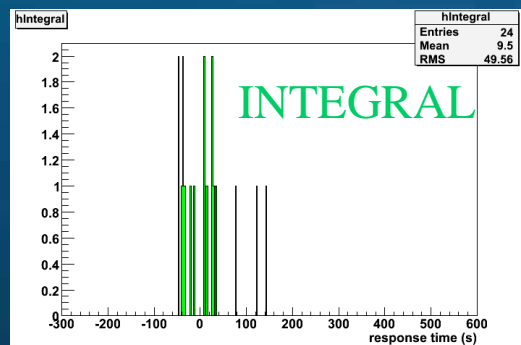


Swift



Fermi

Response time = time delay – buffering time



24 alerts from INTEGRAL

241 alerts from Swift

198 alerts from Fermi

(From February 2007 to May 2009)



Rolling Search Triggers

- Multiplet of neutrino events

From the same direction and within a short time window

$$R_2^{atm} \approx 2 \left(\frac{\Delta\Omega}{2\pi} \Delta t \right) (R_1^{atm})^2$$

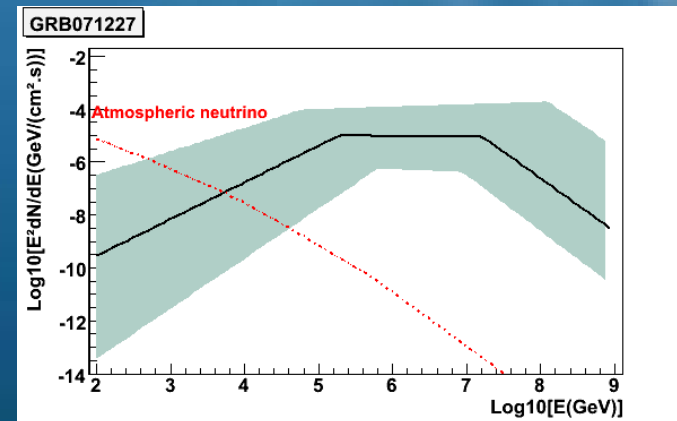
Application to ANTARES:

$$R_{1atm} \approx 1000 \text{ yr}^{-1}$$

$$\left. \begin{array}{l} \Delta\Omega = 3^\circ \times 3^\circ \\ \Delta t = 15 \text{ min} \end{array} \right\} R_{2atm} \approx 0.005 \text{ yr}^{-1}$$

- Single High Energy Neutrino

Above ~20 - 50 TeV, the background rate begins to be negligible



Cuts tuned to give 1-2 triggers per month



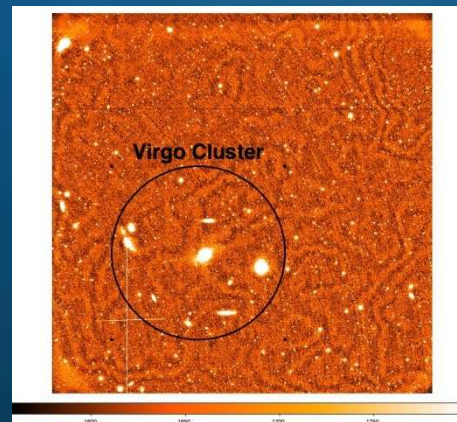
Optical Follow-Up

TAROT (Télescope à Action Rapide pour les Objets Transitoires)

Two robotic 25 cm diameter telescopes

- TAROT Calern, France
- TAROT La Silla, Chile

Field of view of $1.86^\circ \times 1.86^\circ$
10s pointing
Magnitude $V < 17$ (10s)
 $V < 19$ (100s)

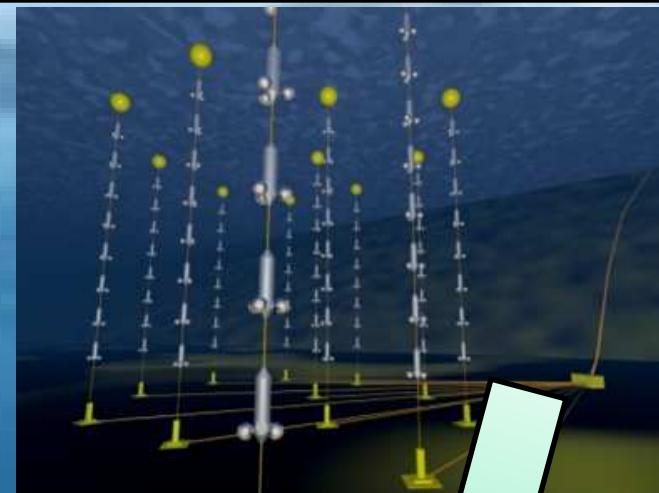


TAROT La Silla

Operational since May 2009



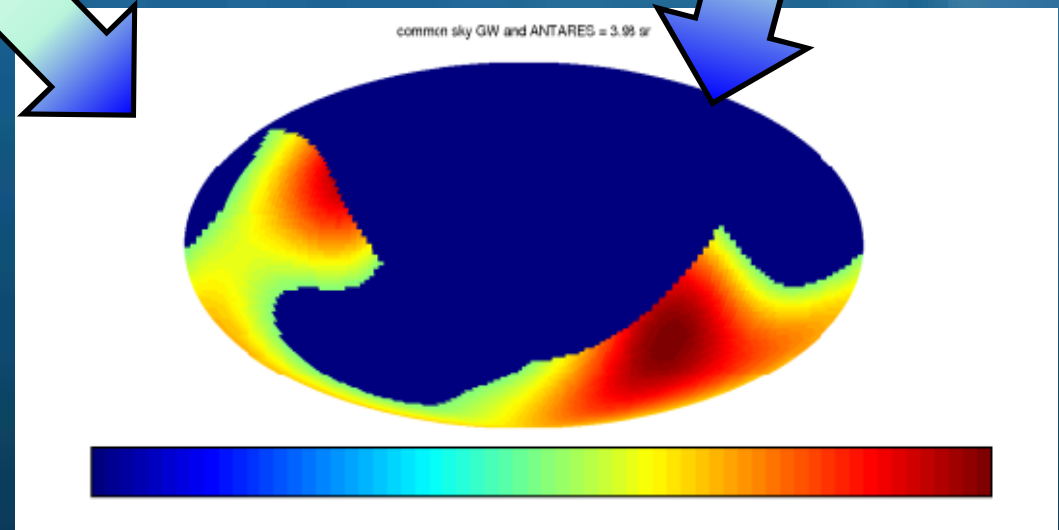
GRAVITATIONAL WAVES AND NEUTRINOS



Common sky coverage for
VIRGO+LIGO+ANTARES
In geocentric coordinates

(assumes ANTARES has 100%
visibility in its antipodal hemisphere
and 0% elsewhere)

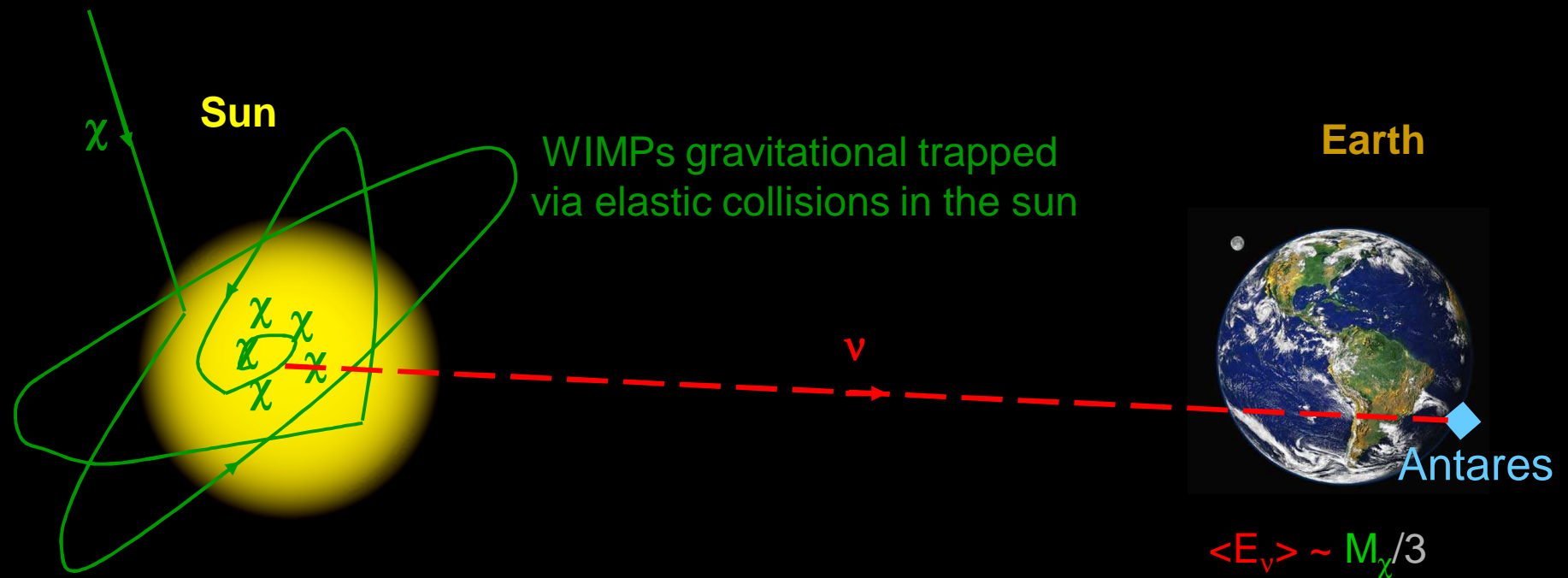
Drafting of MOU in progress





Indirect Search for Dark Matter

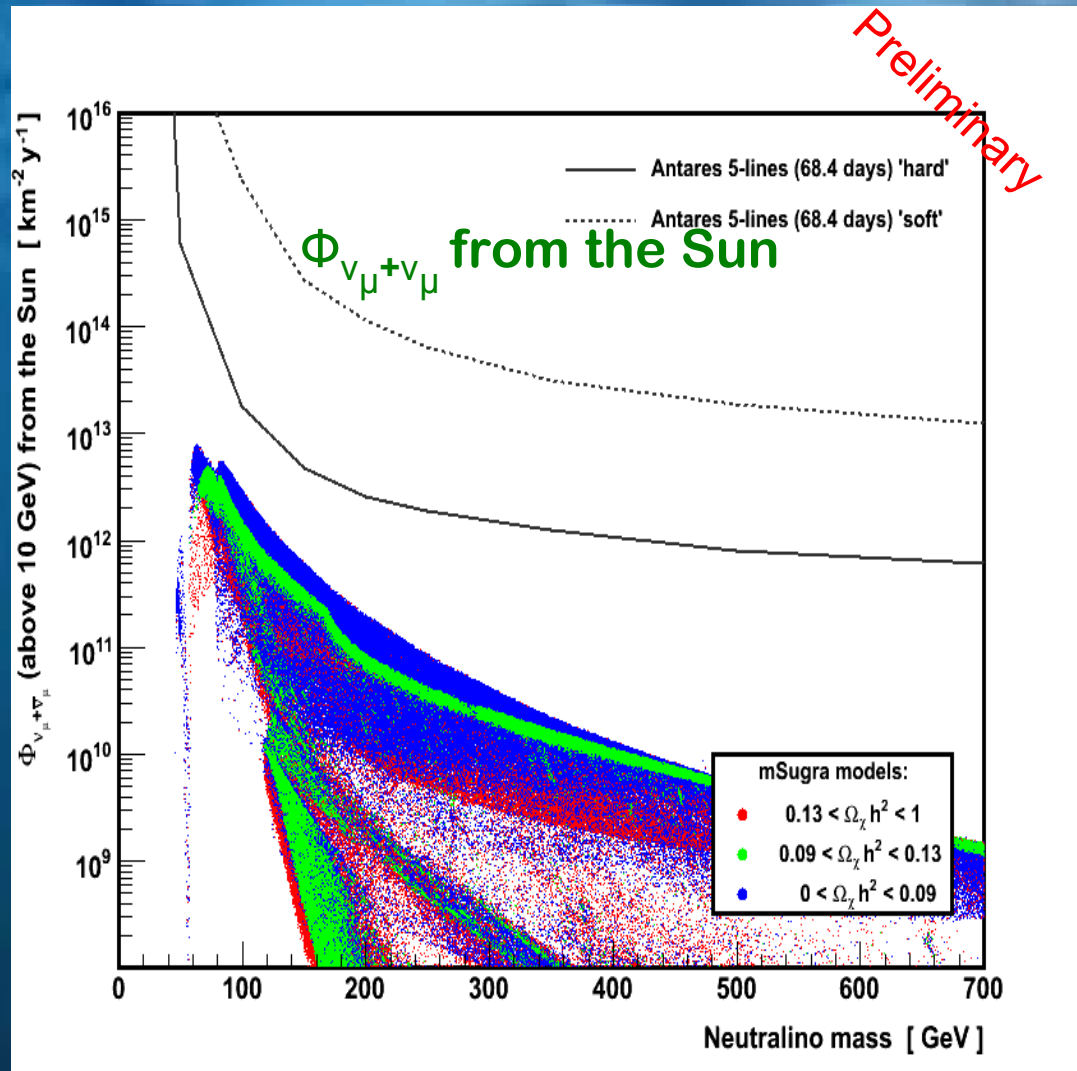
dark matter annihilations in the sun



$$\begin{aligned} \chi \chi &\rightarrow WW, ff \\ W, f &\rightarrow \nu \chi \end{aligned}$$



DARK MATTER SEARCH: NEUTRINO LIMITS



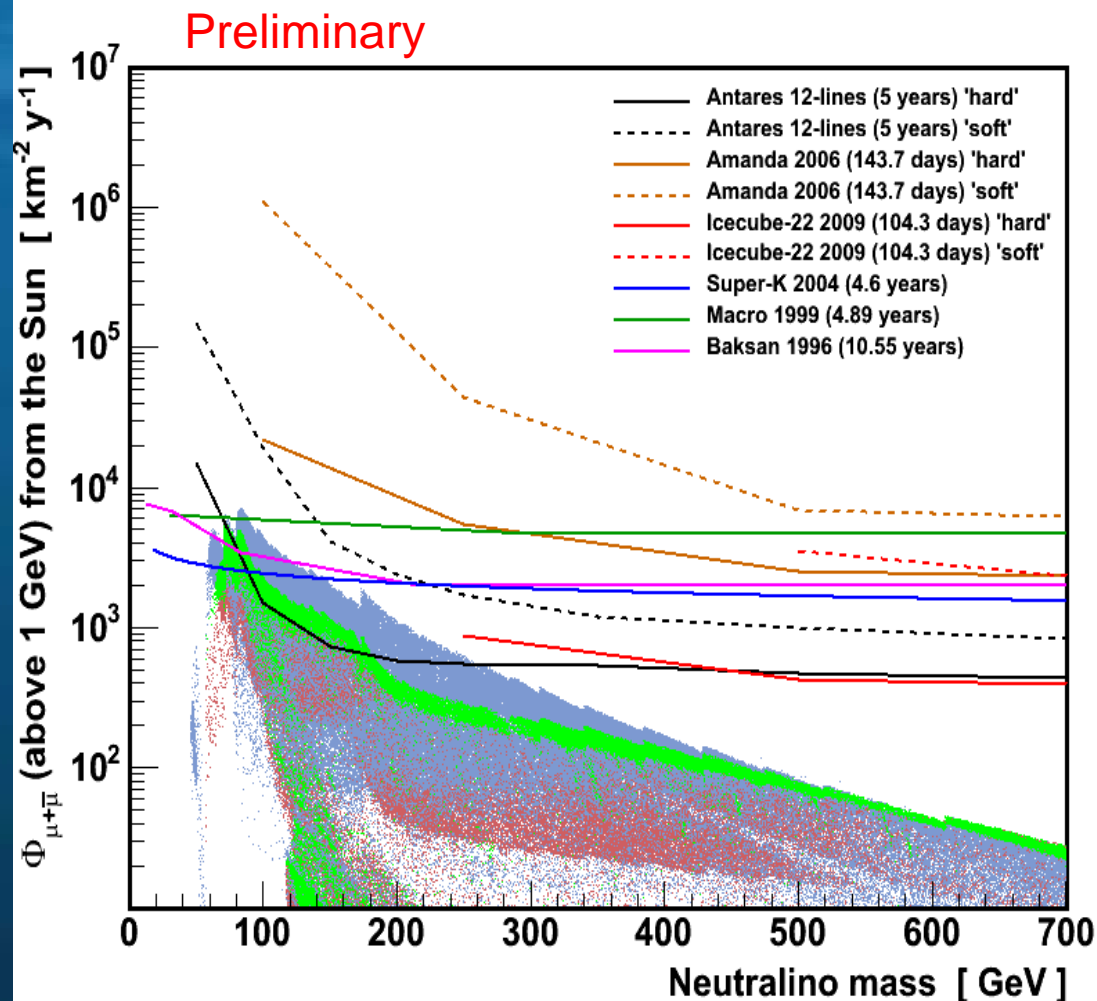
- 5-line data, 68.4 days
- No excess observed (90% C.L. limits) à la Feldman-Cousins
- mSugra model predictions

green : WMAP favoured relic density
red : > WMAP favoured relic density
blue : < WMAP favoured relic density

See talk: G. Lim, 10-11/07 - OG 2.5



DARK MATTER SEARCH: MUON LIMITS



12 lines, 5 years, ν flux

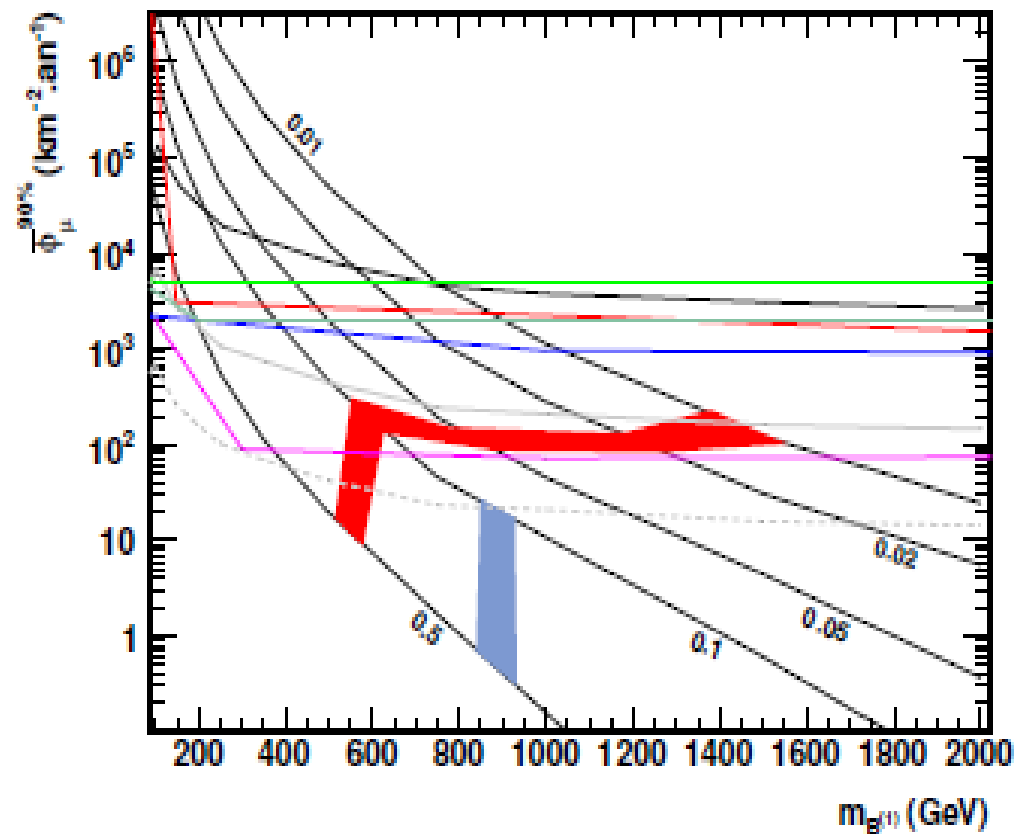
Most of focus point region excluded for $m < 180 \text{ GeV}$

mSUGRA flux predictions:

- : > WMAP favoured relic density
- : within WMAP favoured relic density
- : < WMAP favoured relic density



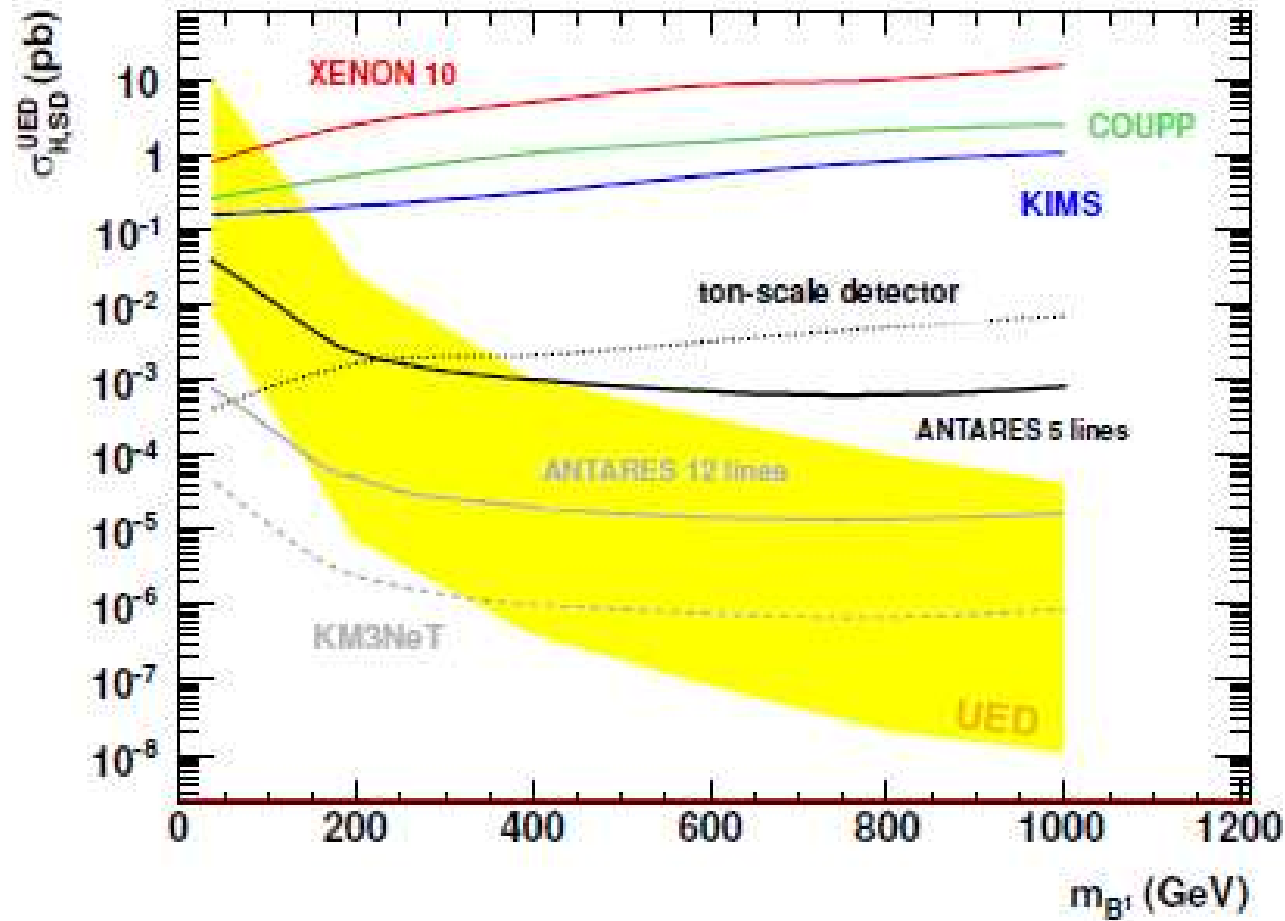
DARK MATTER SEARCH: KALUSA-KLEIN



- BAKSAN (1978-1995)
- MACRO (1989-1998)
- SuperKamiokande (2004)
- AMANDA-II (2003)
- ICECUBE (5 ans)
- ANTARES 5 lignes (167.7 j)
- ANTARES 12 lignes (5 ans)
- KM3NeT (5 ans)
- LKP $\tilde{B}^{(1)}$ seule
- LKP $\tilde{B}^{(1)}$ & Coannihilations

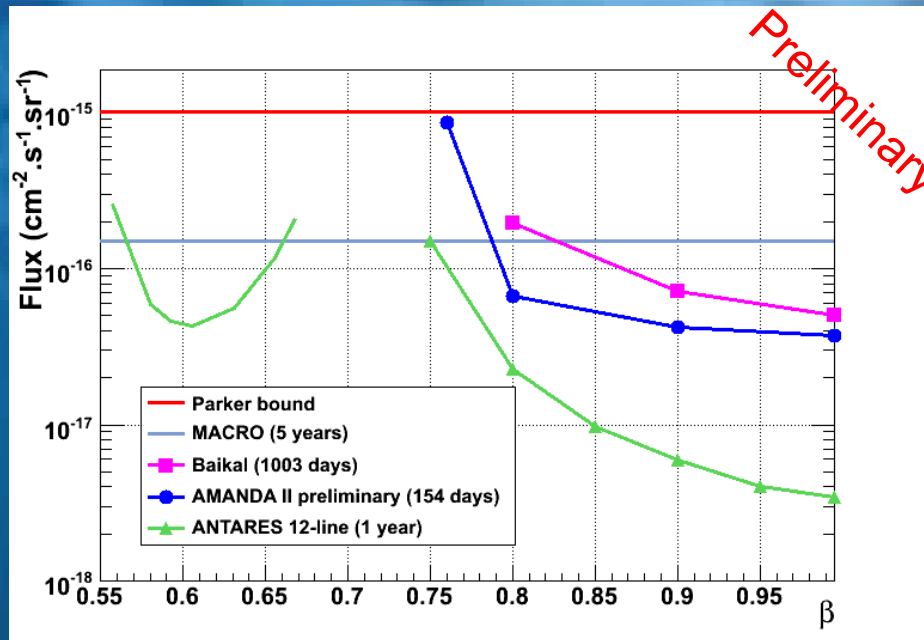


DARK MATTER SEARCH: KALUSA-KLEIN



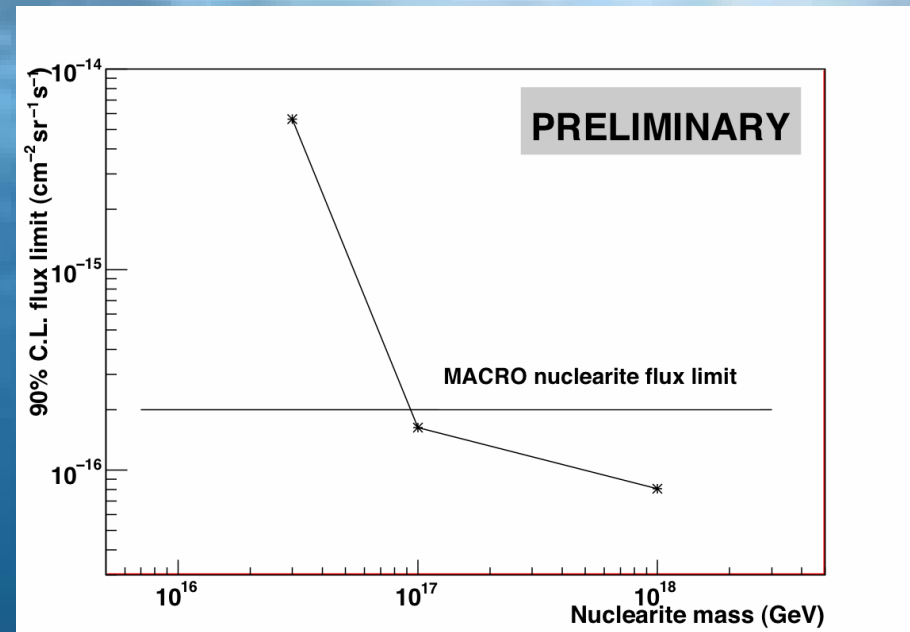


Search for Monopoles & Nuclearites



Search for monopoles

- Extremely high energy deposition
- Direct Cherenkov light for $\beta > 0.74$
- δ -rays for $\beta > 0.51$



Search for nuclearites

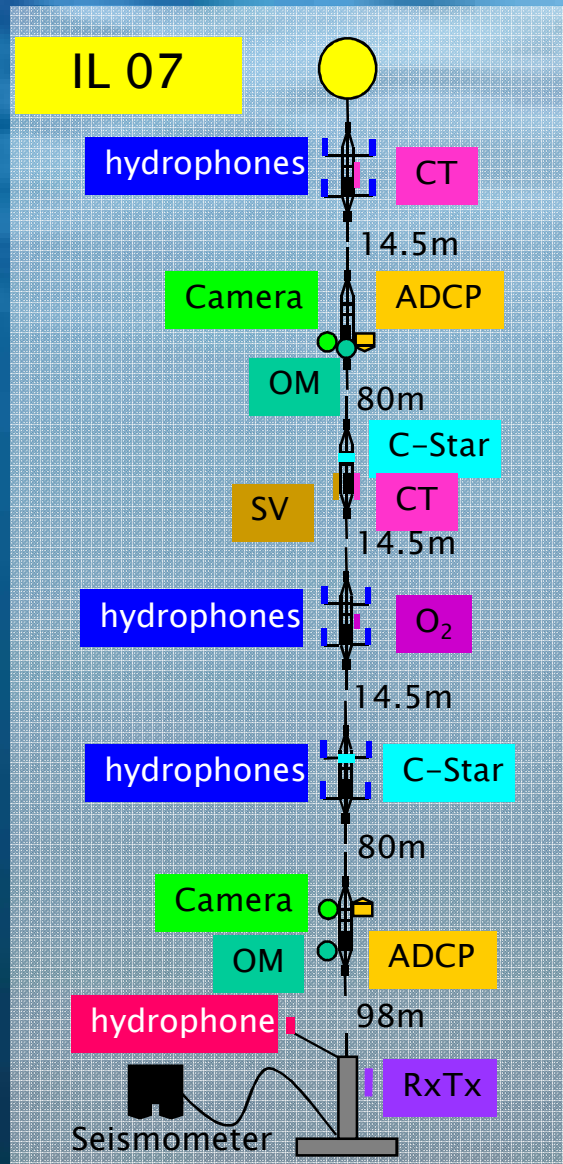
(strangelets, quark nuggets, Q-balls).

- Very characteristic signature: an extended source of photons “heated wire”
- 84 days of 5-line data

See talk: G. Pavalas, 9/7/09, HE695



Earth and Sea Sciences



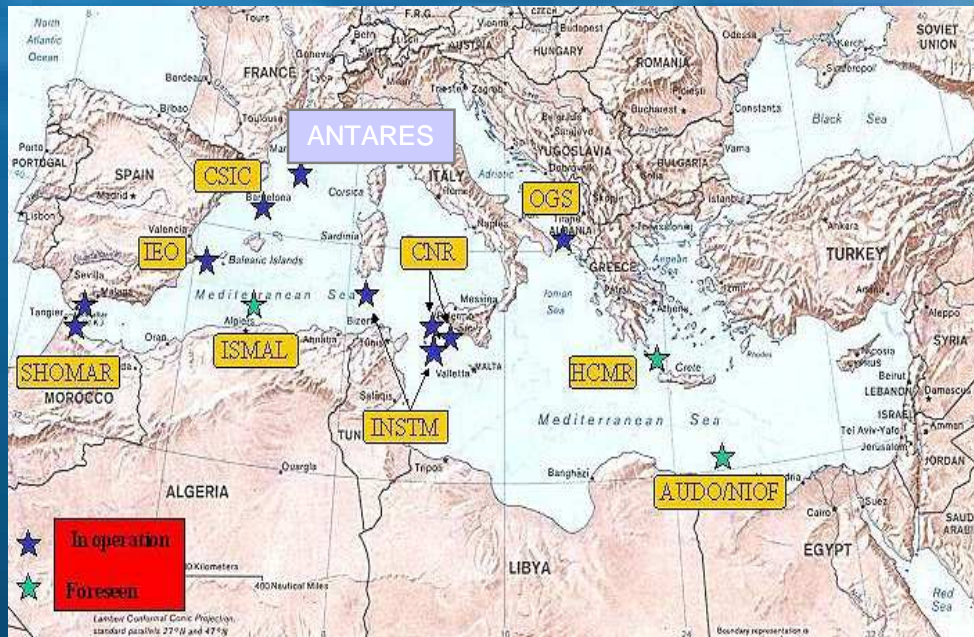
- Seismology
- Acoustic Detection
- Oceanography
- Bioluminescence
- Environmental Monitoring



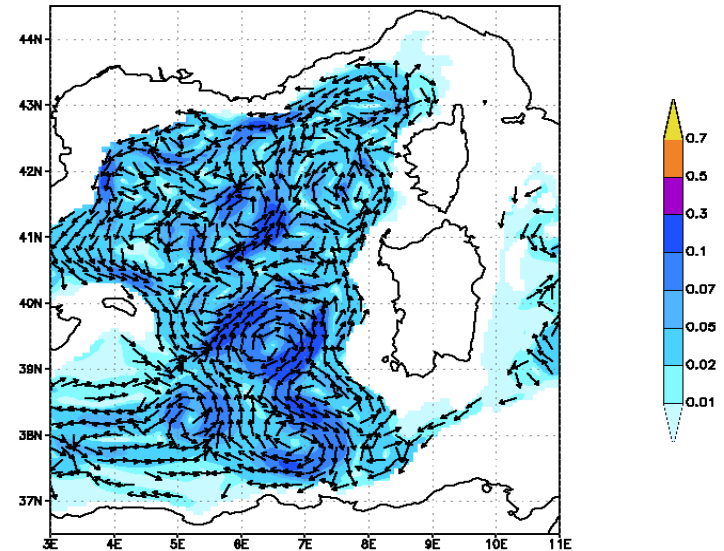
Oceanography

Programme Hydro-Changes of CIESM

(Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée)



velocity [m/s] – date 070129 depth 1000 m



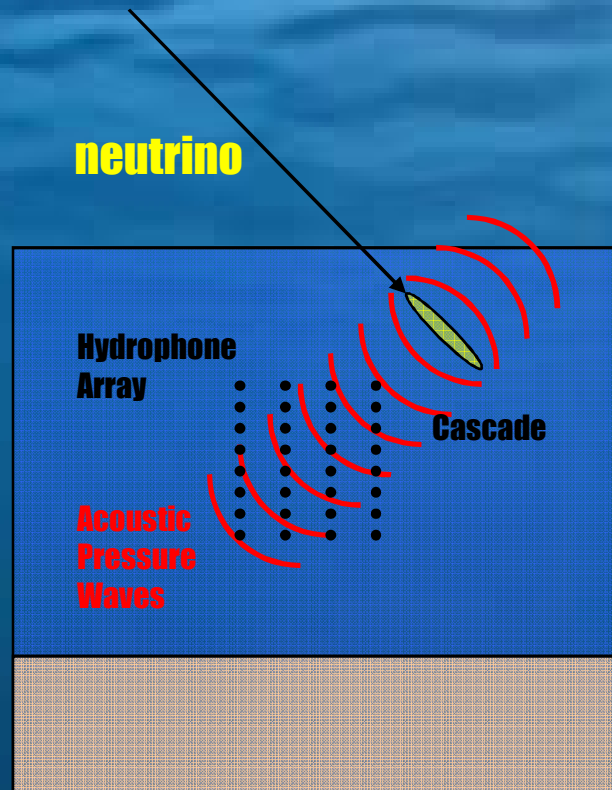
Circulation studies in the Mediterranean Sea

Collaboration with Centre d'Océanologie de Marseille

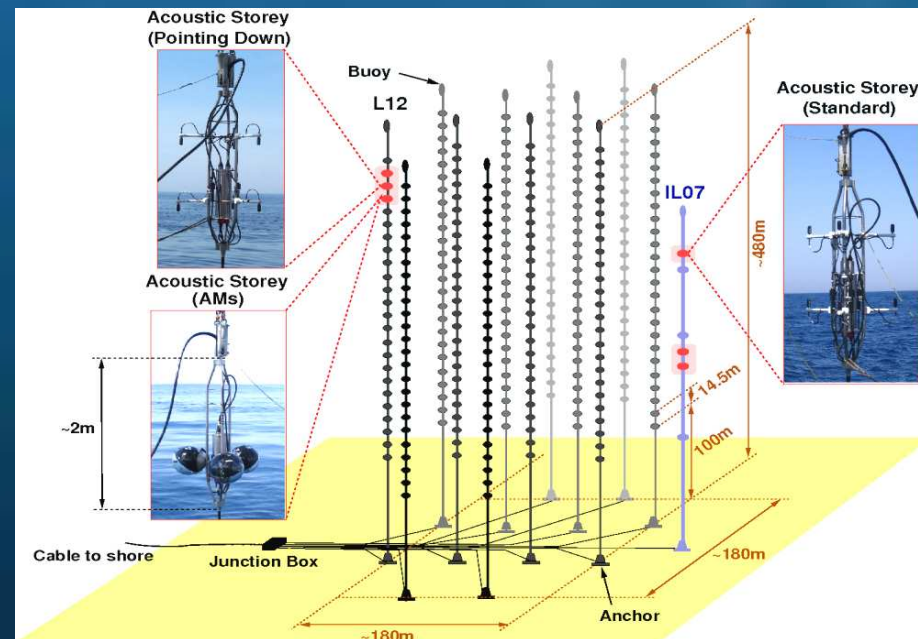




Acoustic Detection of Neutrinos

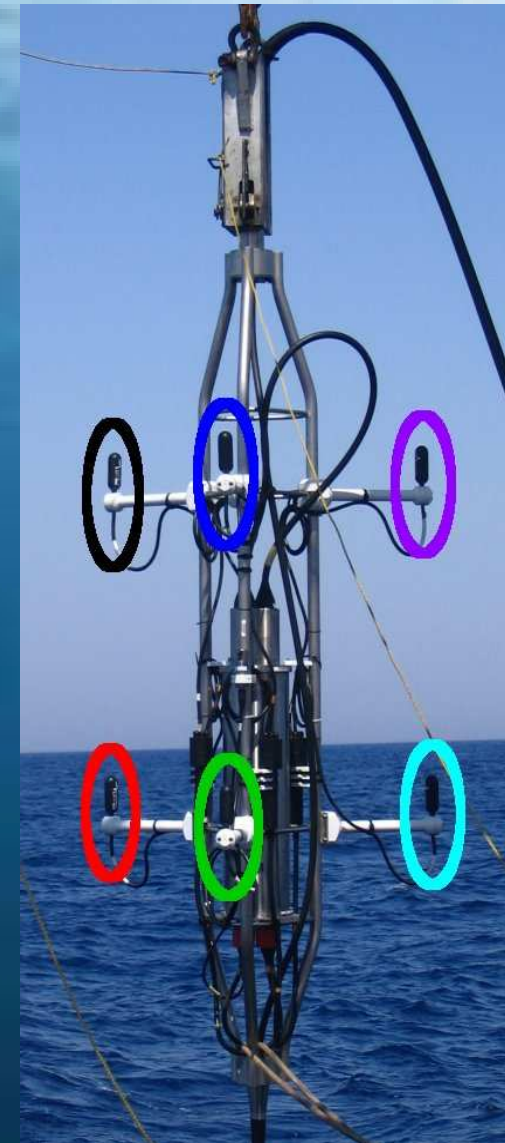
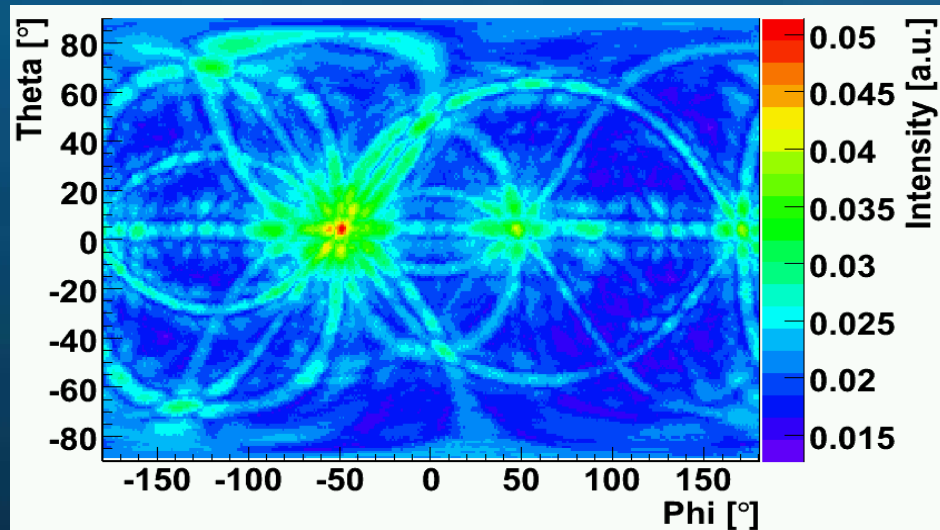
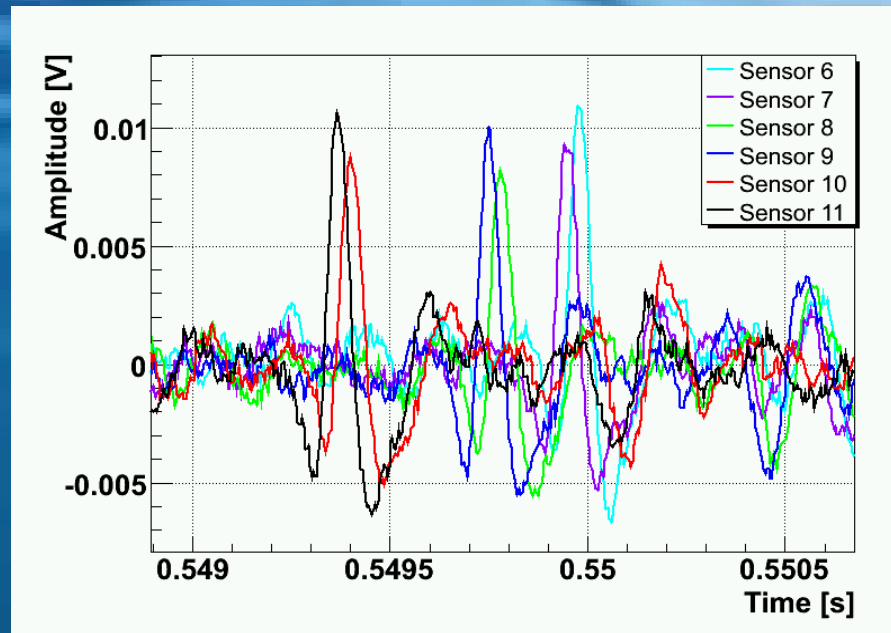


Coordinated by Univ. Erlangen

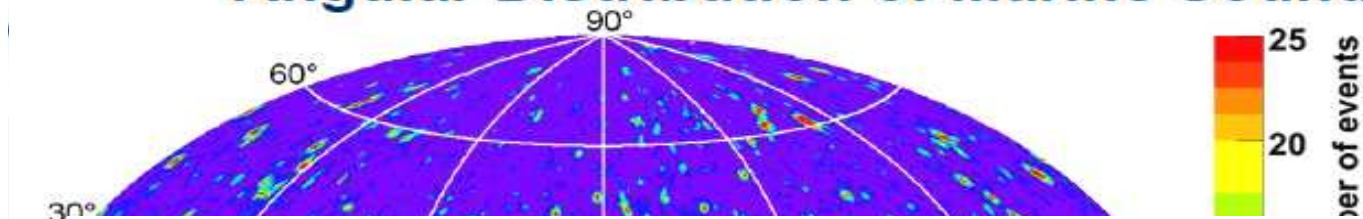




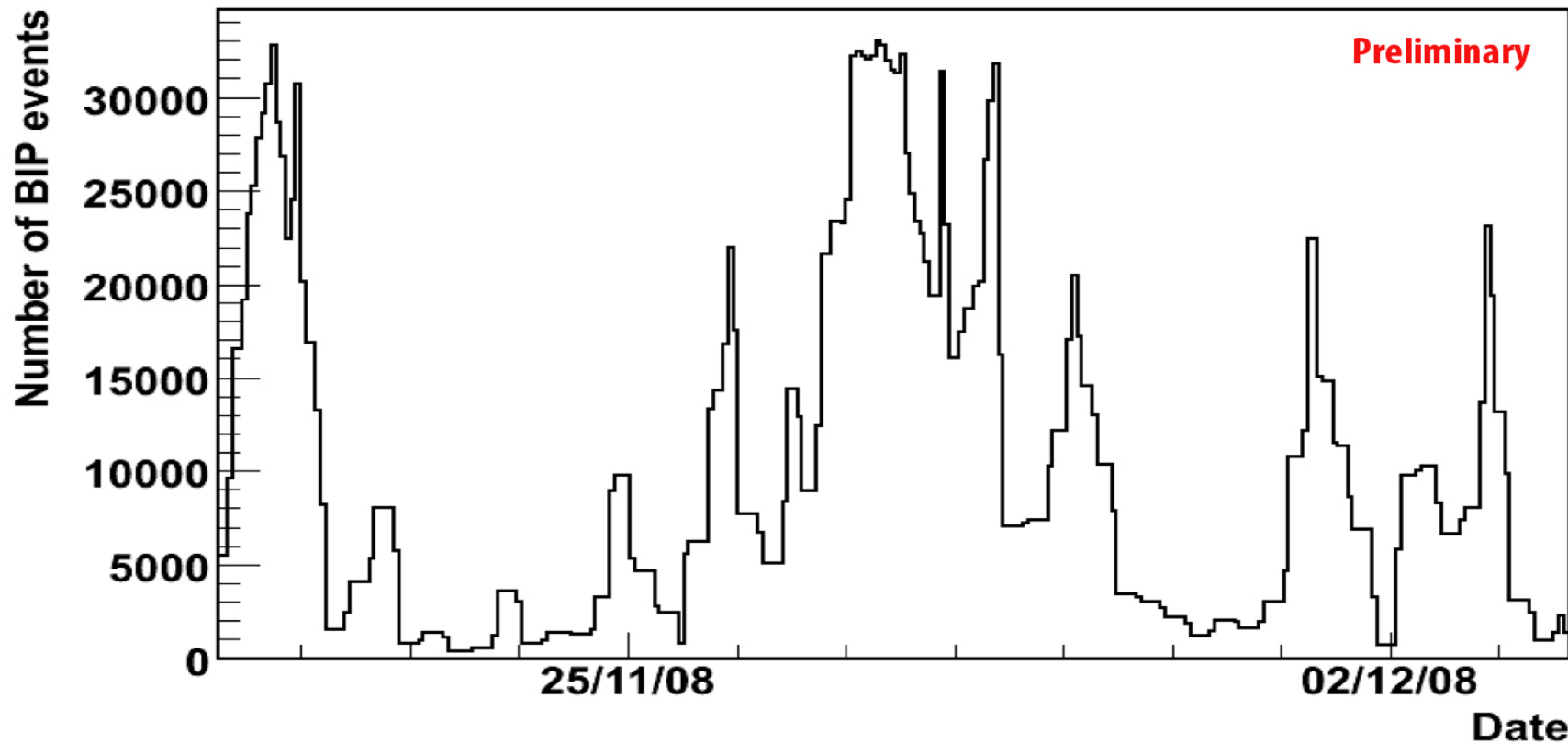
Localisation of Acoustic Signals



Angular Distribution of Marine Sound Sources



Online Filter: Bipolar Events over Time

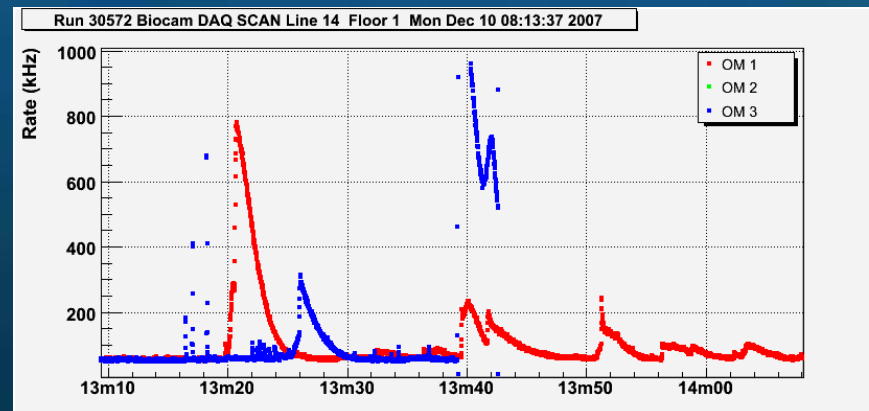




World's Deepest Online Camera



AXIS221 vidéosurveillance
Sensistivity: 0.1 lux
Field of view: up to 90 degrees
Infra red night vision





Seismology



In laboratory

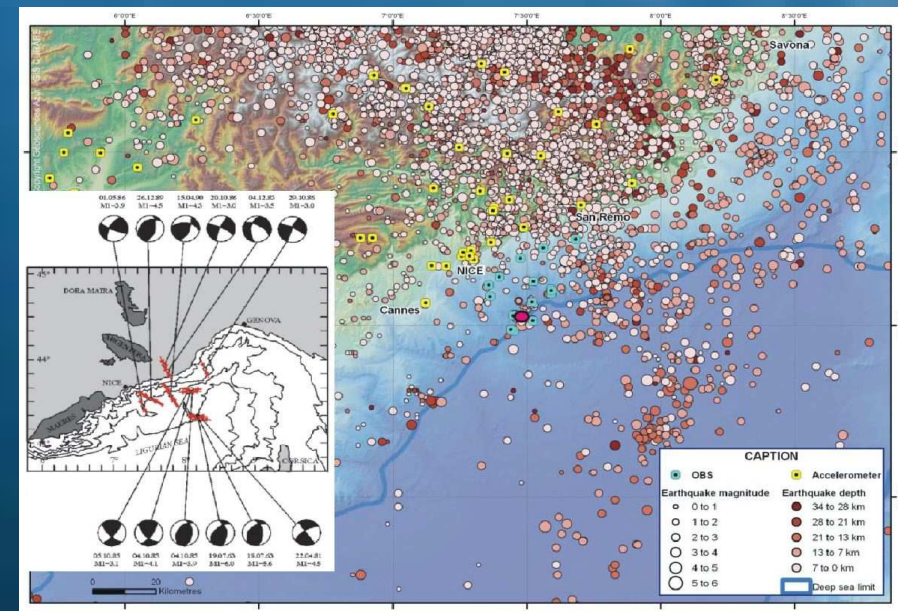


deployment



Buried at site Antares
(gain 20 dB of noise)

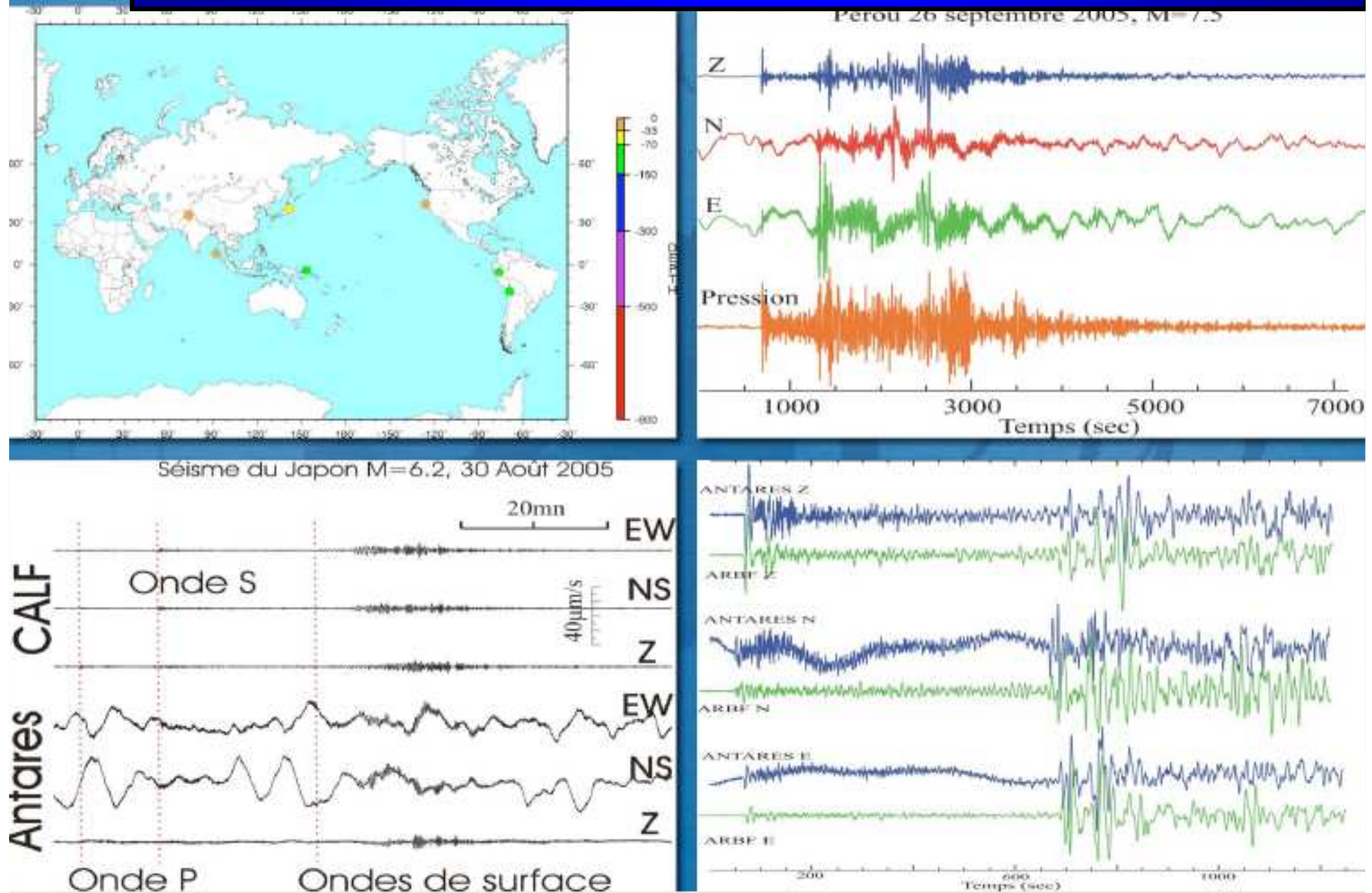
The ANTARES seismograph is part of a seismic monitoring network, complementary to the terrestrial stations.



Collaboration with Laboratoire Géosciences Azur

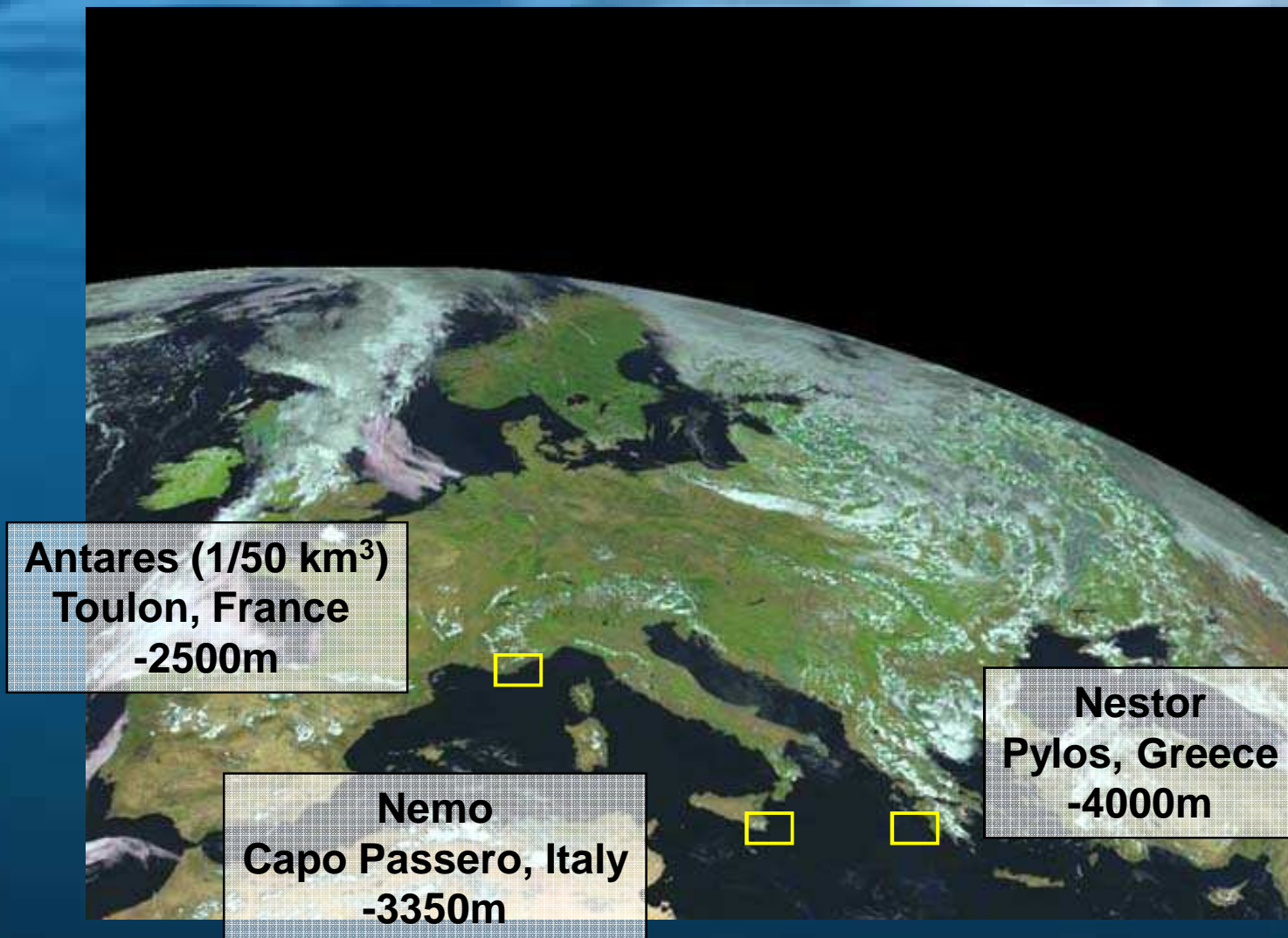


Examples of Seismic Events

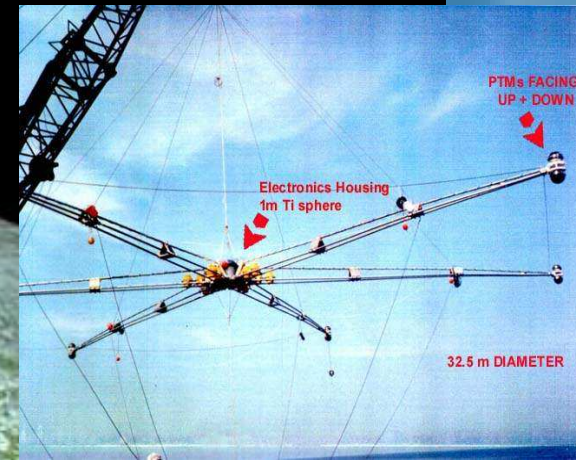
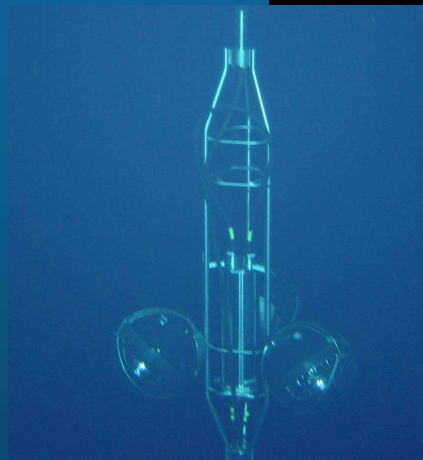




Toward a km^3 -scale detector in the Mediterranean sea



Mediterranean Efforts



Since 1996
Data taking
~150 members

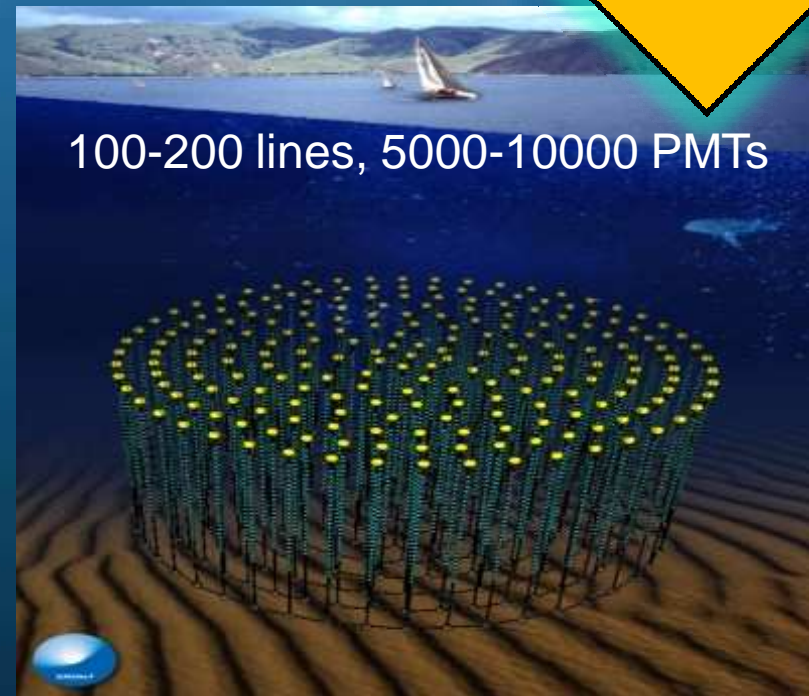
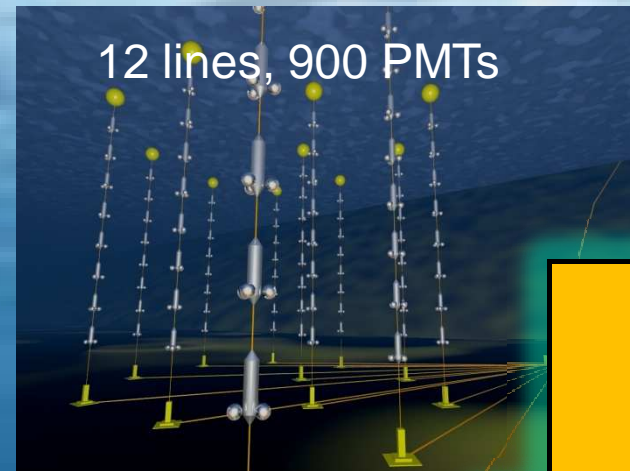
Since 2000
R&D
80 members
Nemo
Capo Passero, Italy
-3350m

Since 1990
R&D
~50 members
Nestor
Pylos, Greece
-4000m



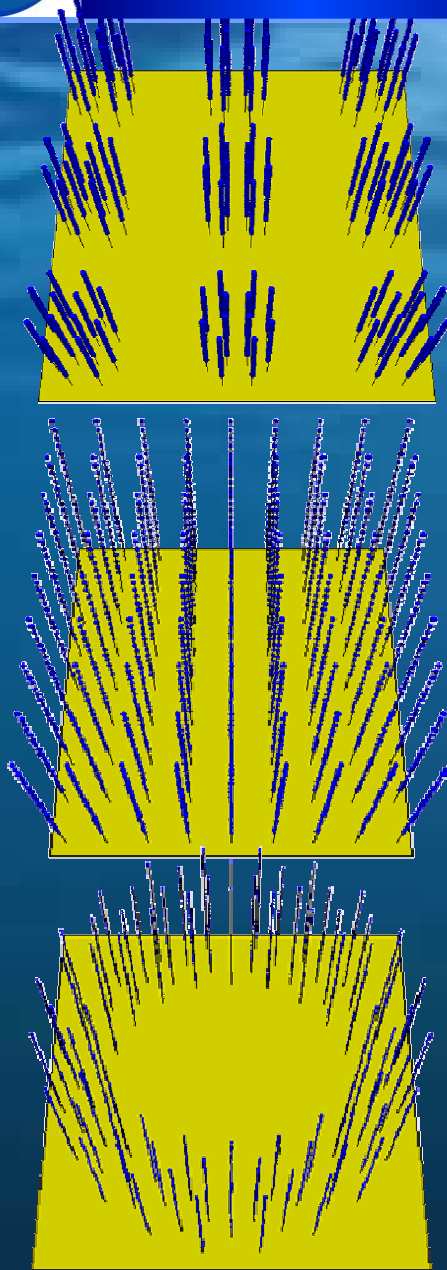
The challenge

- Maximise physics potential
 - Substantial improvement over ICECUBE
 - Instrumented volume $>1\text{km}^3$
 - Angular resolution ~ 0.1 degrees ($E > 10$ TeV)
 - Expandable
- Build in a reasonable time ~ 4 years
 - New deployment techniques
 - Speed-up integration time
 - Sub contract part of the production
 - ...
- At a reduced cost
 - Factor 2 reduction cf ANTARES
 - Simplified architecture
 - Reduced maintenance
 - Multi-line deployments
 - ...





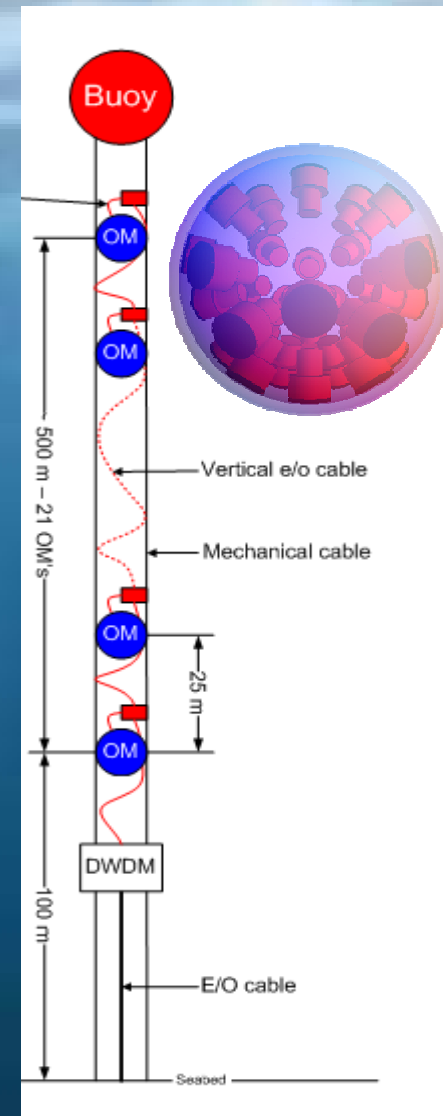
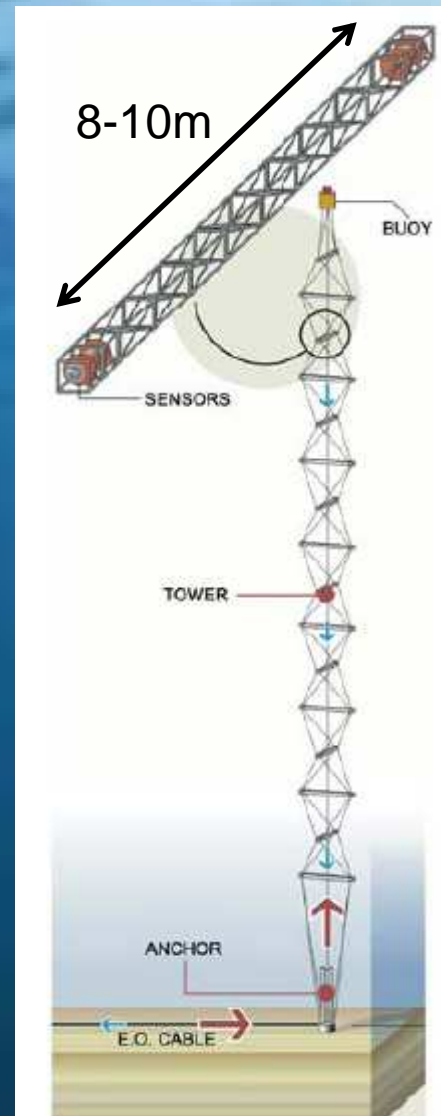
Optimisation Studies



cluster

cuboid

ring

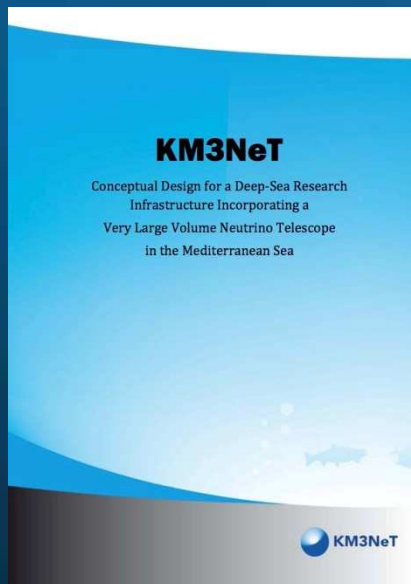
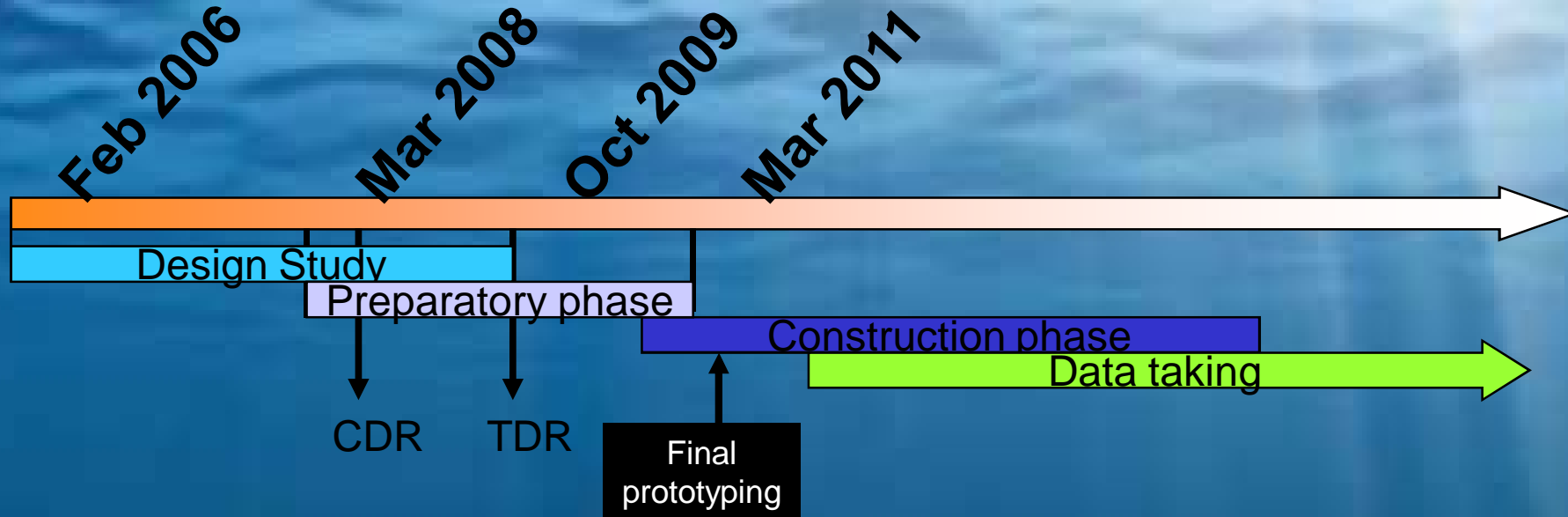


Detection structures
(under cost evaluation)



KM3NeT

Timeline Towards Construction



Downloadable from the
KM3NeT web site
<http://www.km3net.org/CDR/CDRKM3NeT.pdf>

Partially funded by FP6&FP7

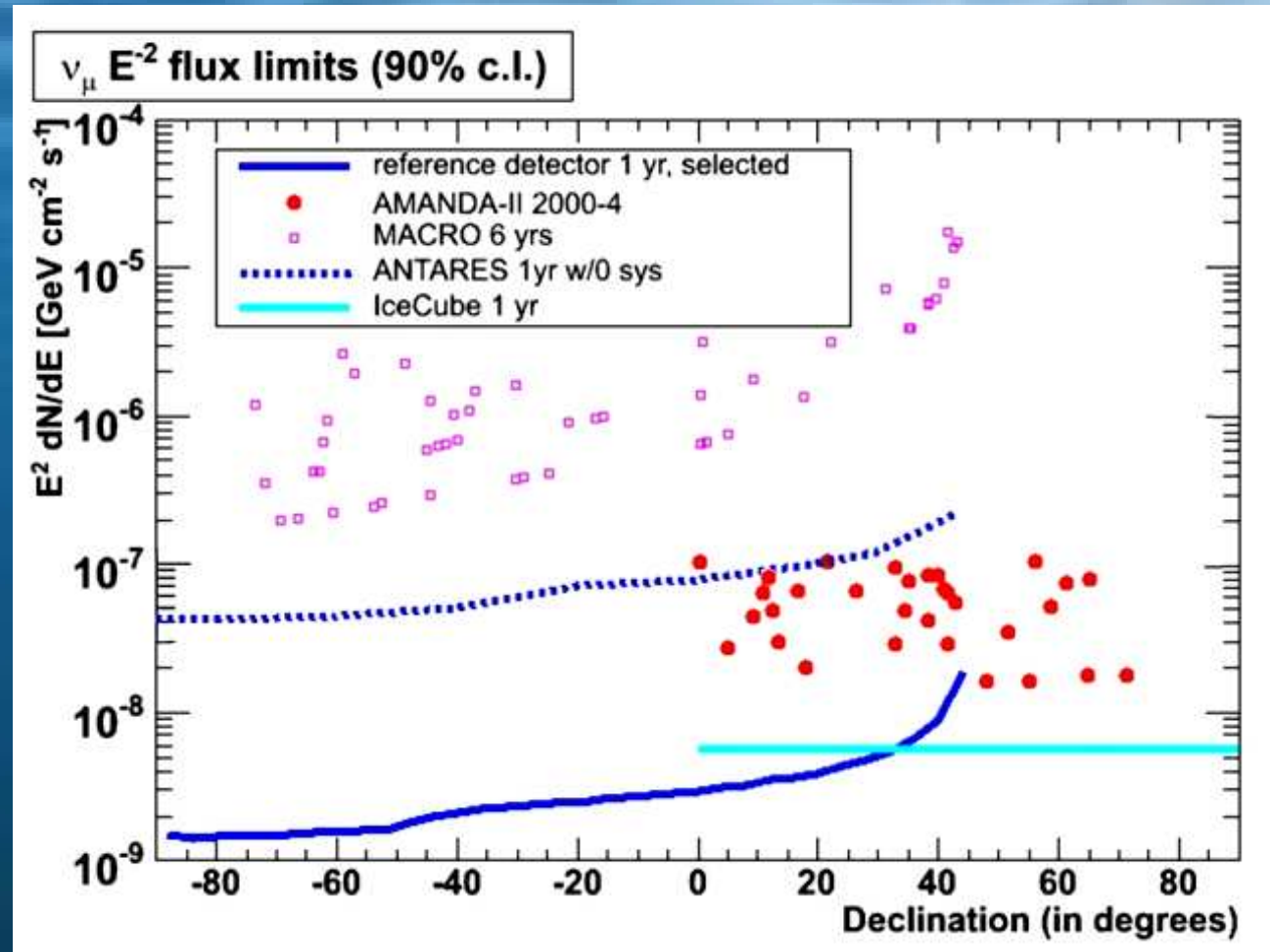
ASPERA/APPEC roadmap

ESFRI 'list of opportunities'



Point Source Sensitivity

- Based on muon detection
- Factor ~50 more than ANTARES
- Factor ~3 more sensitive than IceCube
 - Better angular resolution
 - centre galactic





Outlook



- ANTARES infrastructure completed since May 29th 2008
 - Detector operation and calibration under control
 - Maintenance capability demonstrated
- Exciting physics program ahead
 - Over a thousand neutrinos already reconstructed
 - Unexplored regions of sensitivity in southern sky
 - astronomical sources, dark matter, oscillations,
 - Multi-messenger approach
- Real-time readout and in-situ power capabilities facilitates a large program of synergetic multi-disciplinary activities: acoustics, biology, oceanography, seismology.....
- Major step towards the KM3NeT multi-disciplinary deep-sea research infrastructure

