http://antares.in2p3.fr

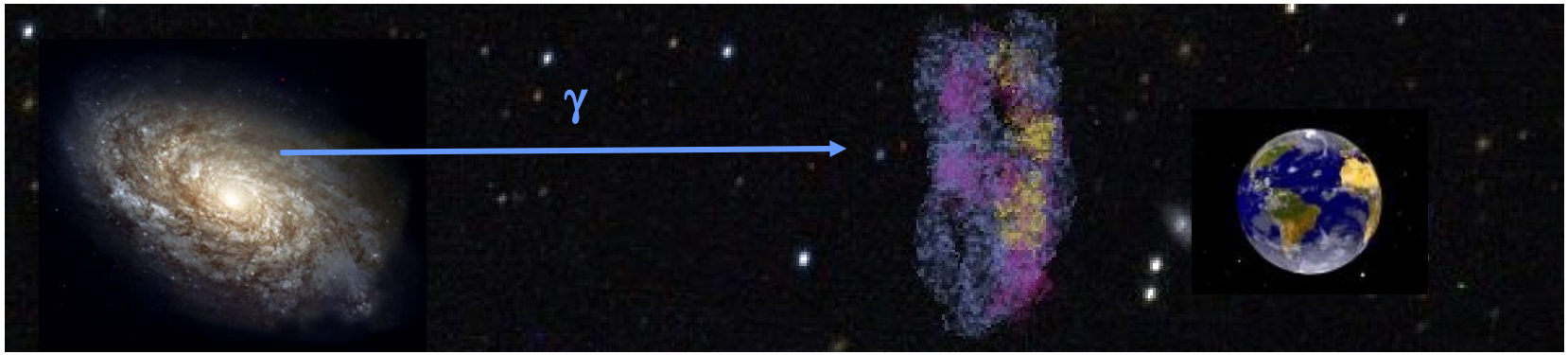
Status Report of the ANTARES Neutrino Telescope

Bruny BARET (APC - Paris 7)

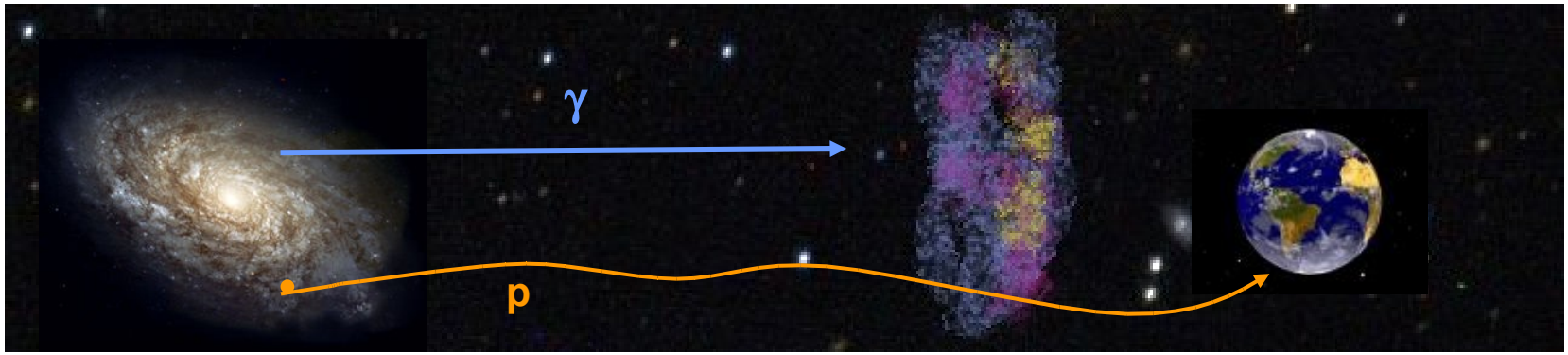
for

the ANTARES Collaboration

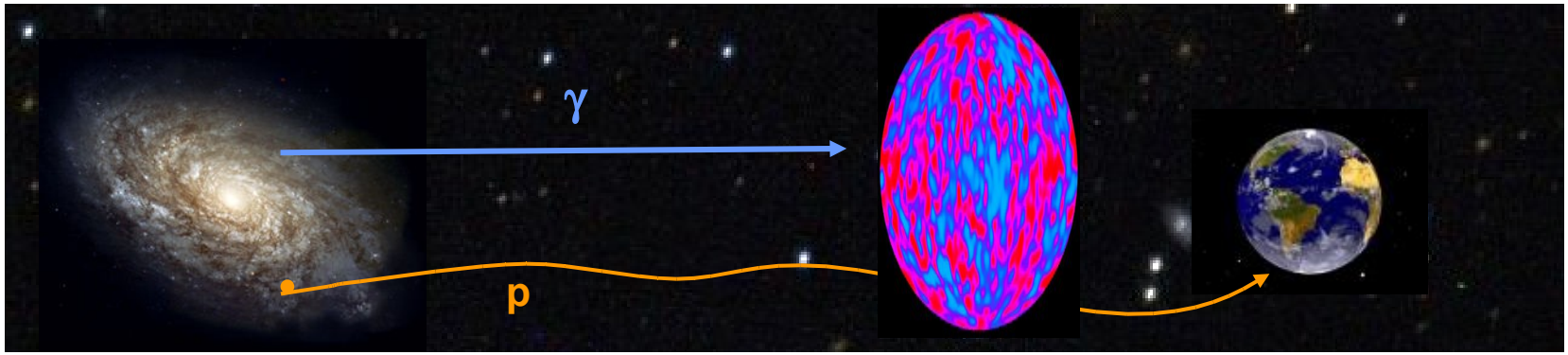
Neutrino Astronomy

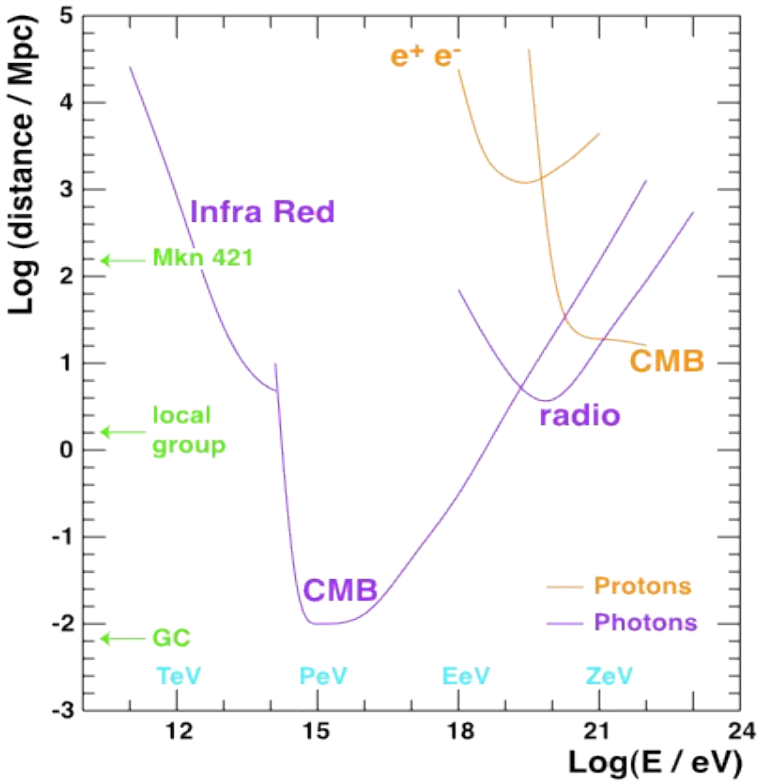


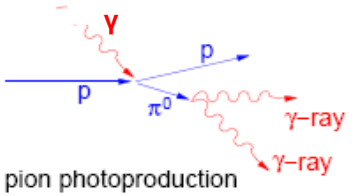
Neutrino Astronomy



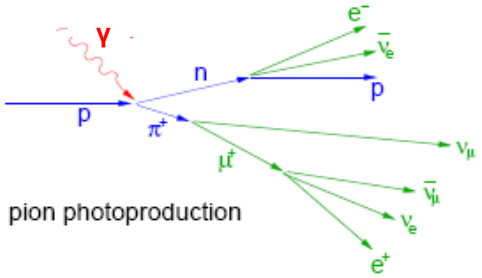
Neutrino Astronomy



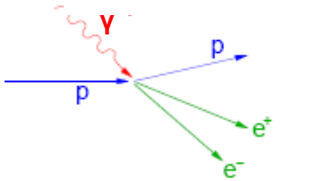




pion photoproduction

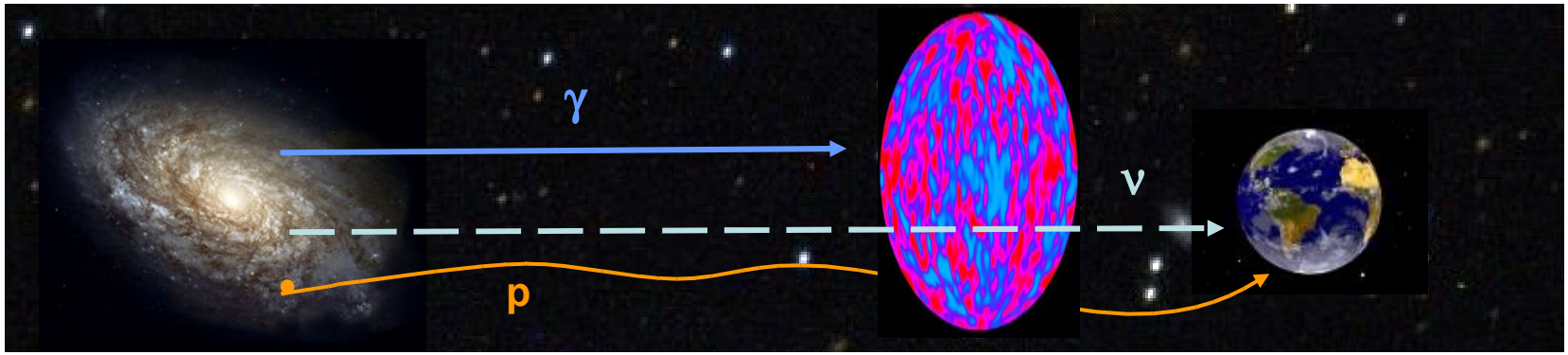


pion photoproduction



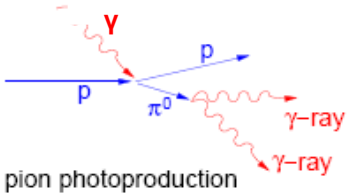
Bethe–Heitler pair production

Neutrino Astronomy



High-energy neutrinos as cosmic messengers

- no absorption:
  travel across cosmological distances
- no deflection by magnetic fields:
  pointing accuracy
- weakly interacting:
  emerge from dense objects
- produced in photopion interactions:
  trace the hadronic processes in astrophysical sources



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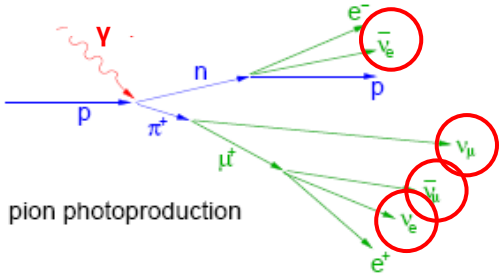

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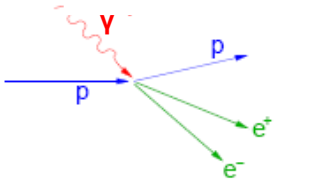


Bethe–Heitler pair production

What to look at?

γ TeV sources seen by HESS.
&
AUGER UHECR AGN connection?

Galactic

Acceleration sites:

- SNR, magnetars microquasars
- AGN, GRB...

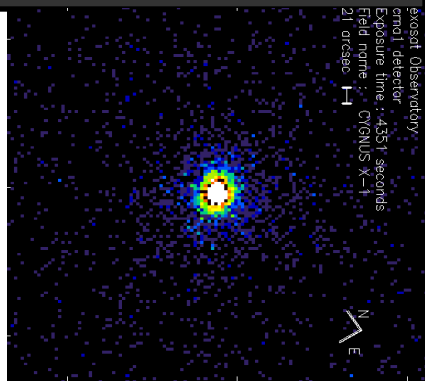
Exotics:

- Wimps, monopoles
- Quantum decoherence...

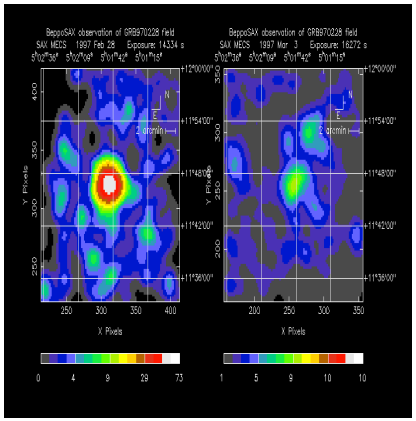
Extragalactic

Some are GW emitters
=>Eric's talk

SNR



Xray binaries

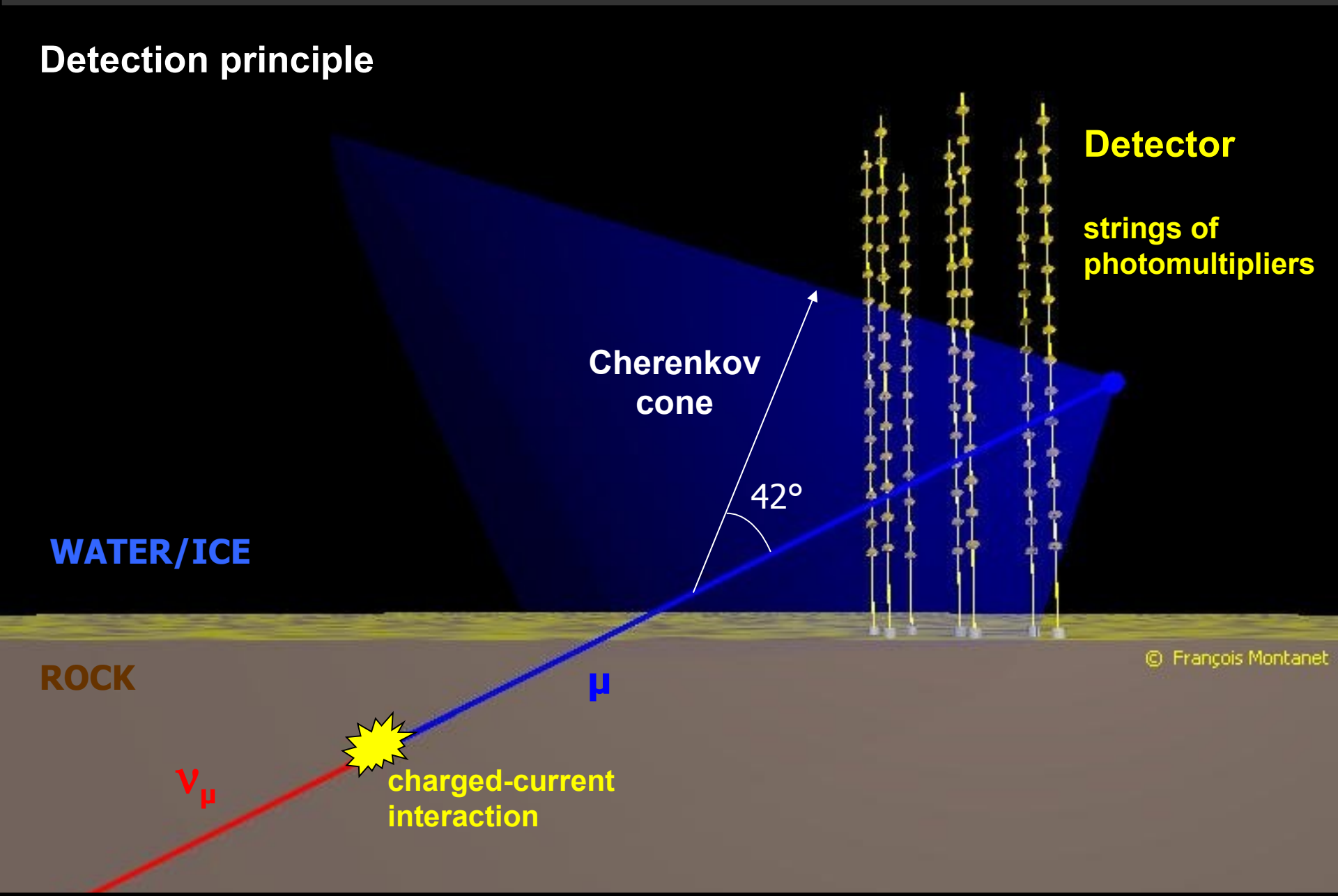


G.R.B.

near AGN

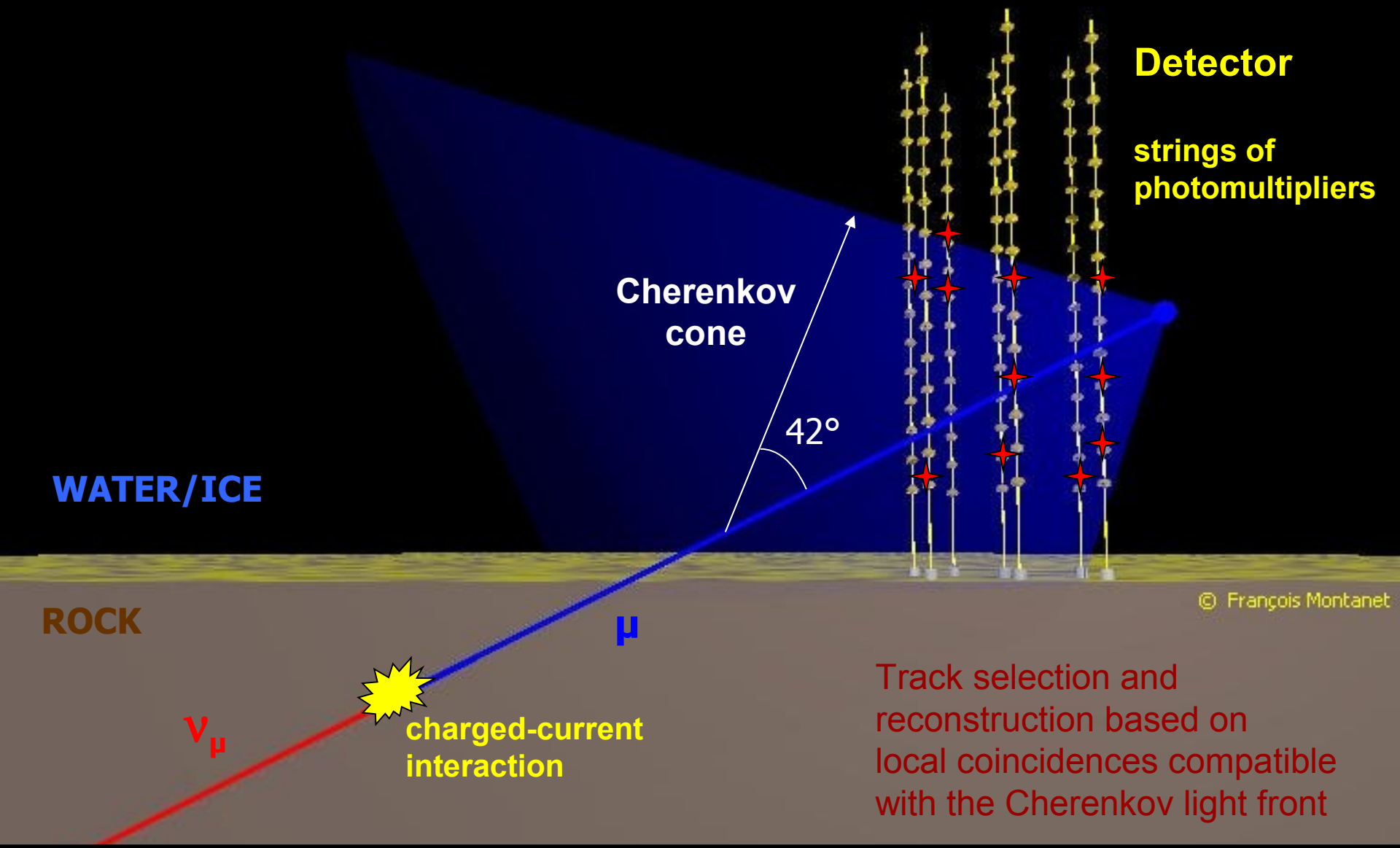
Neutrino Astronomy

Detection principle



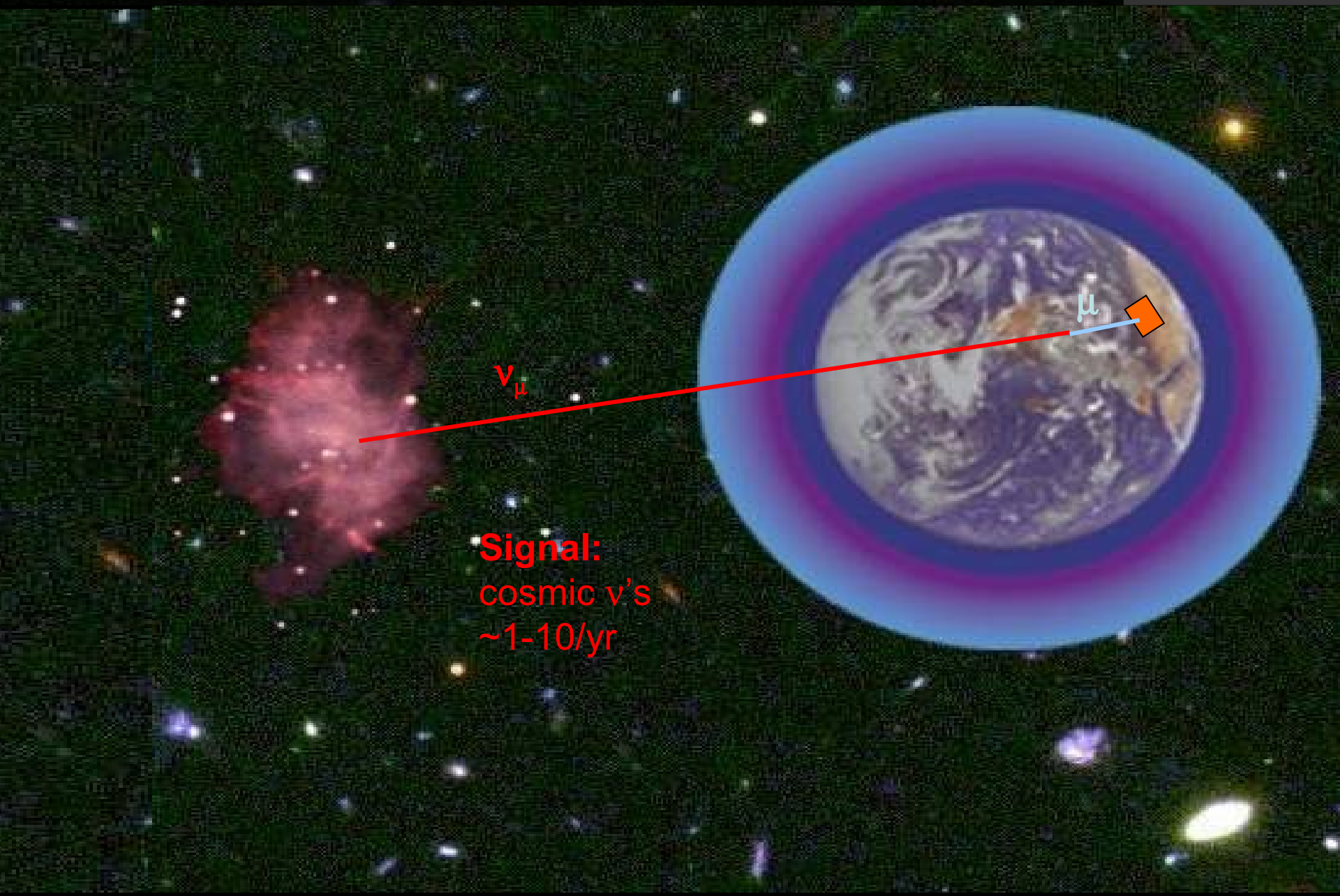
Neutrino Astronomy

Detection principle



Track selection and reconstruction based on local coincidences compatible with the Cherenkov light front

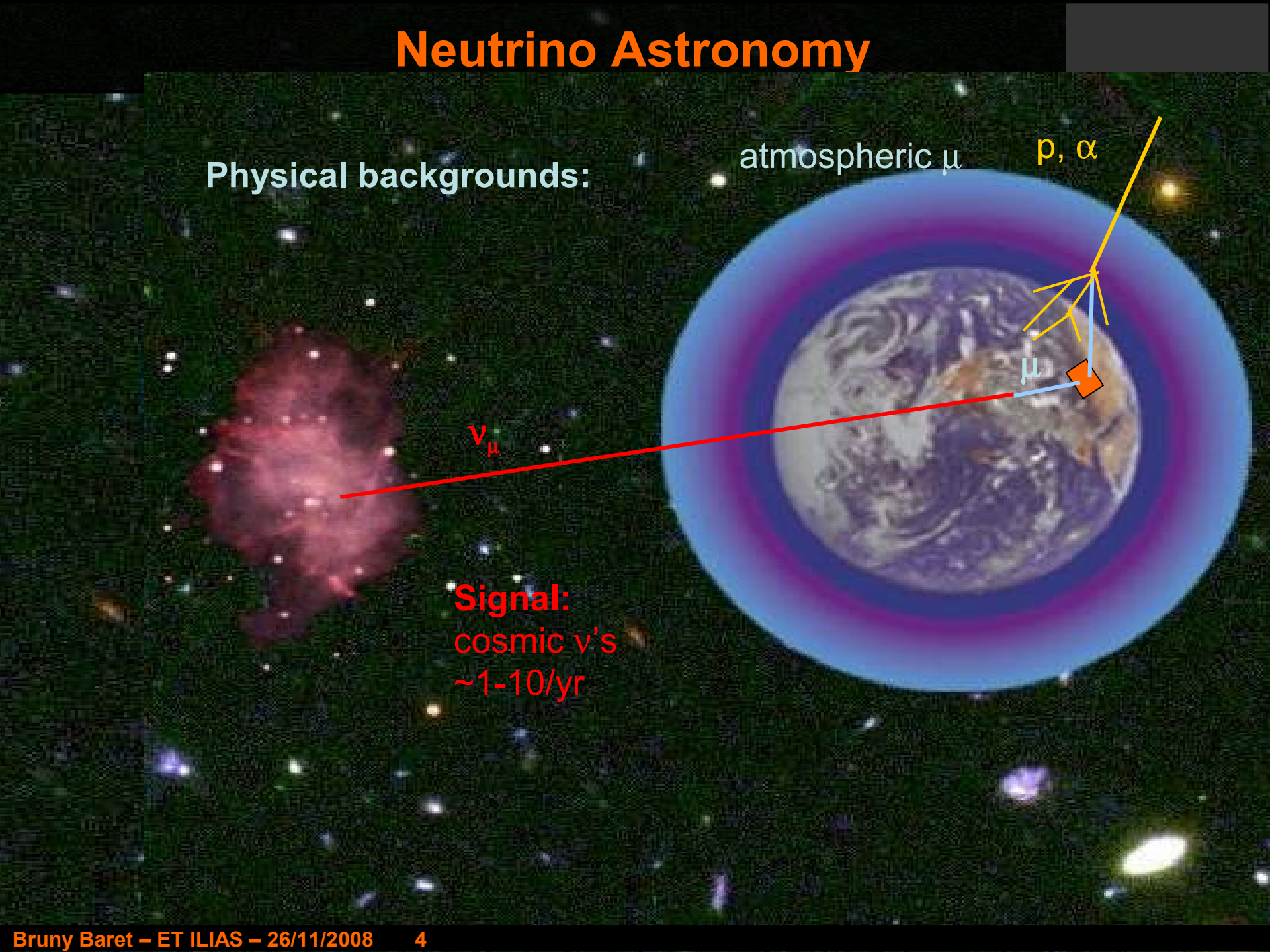
Neutrino Astronomy



Signal:
cosmic ν's
~1-10/yr

Neutrino Astronomy

Physical backgrounds:



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Neutrino Astronomy

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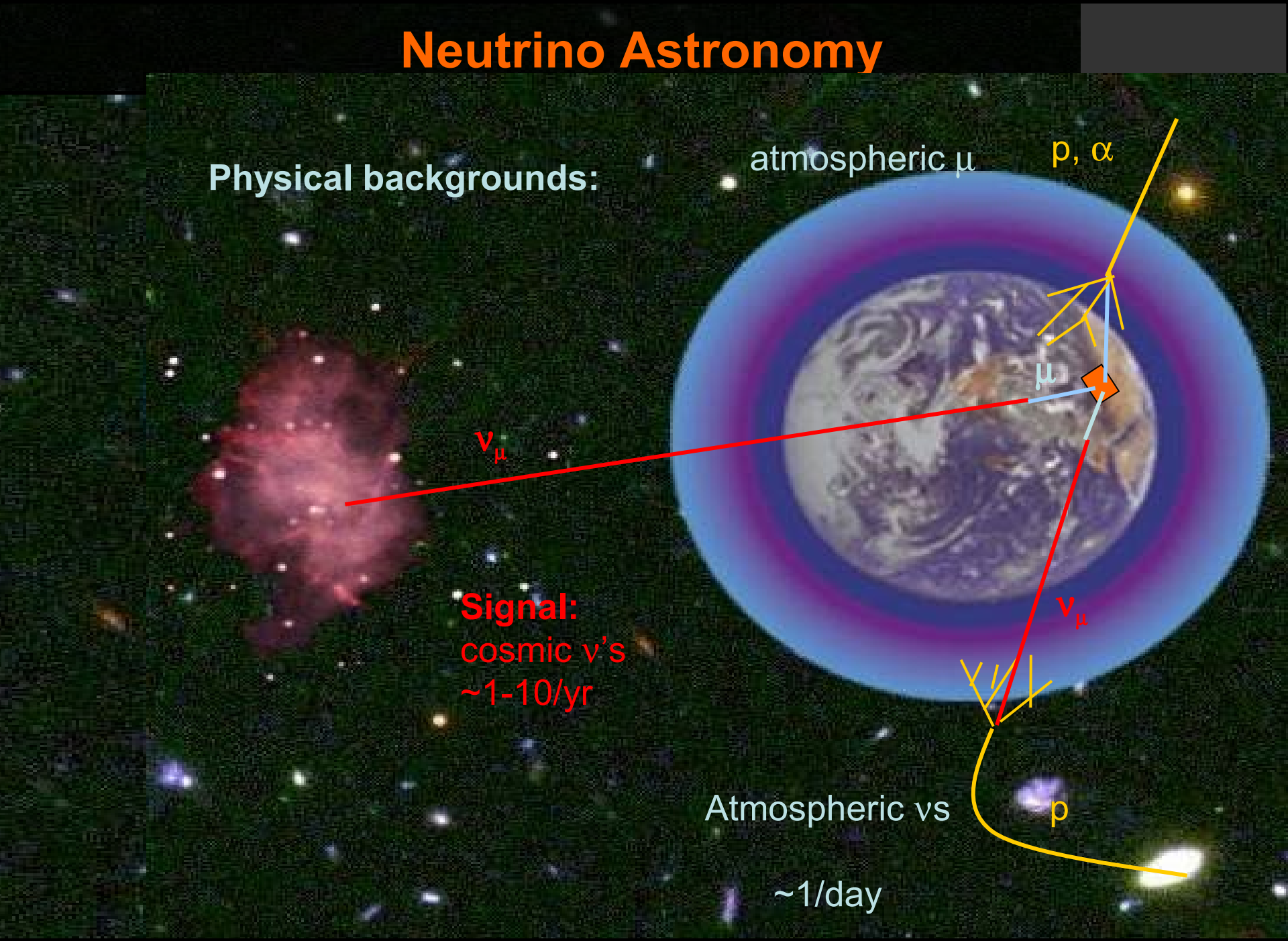
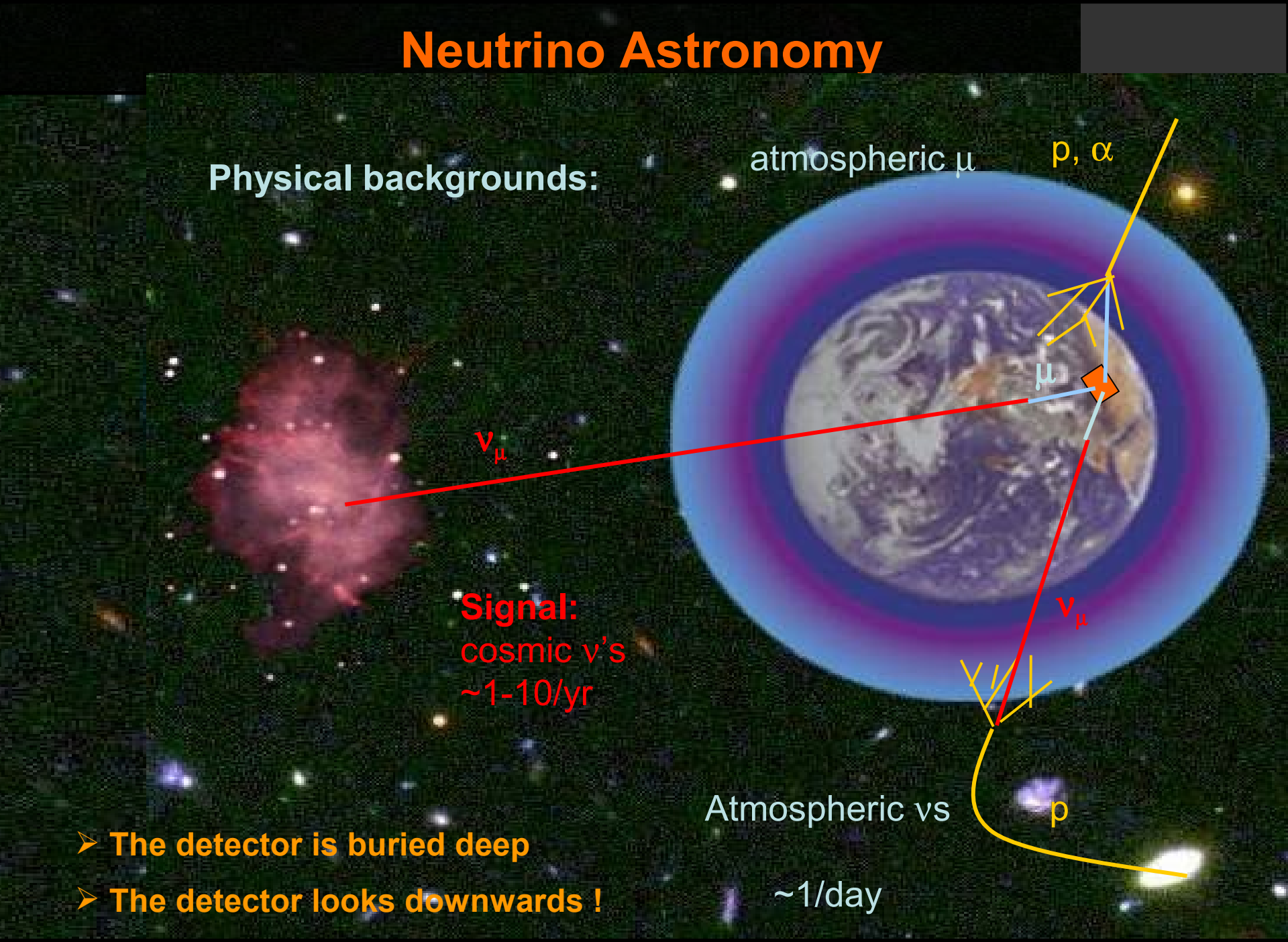


Neutrino Astronomy

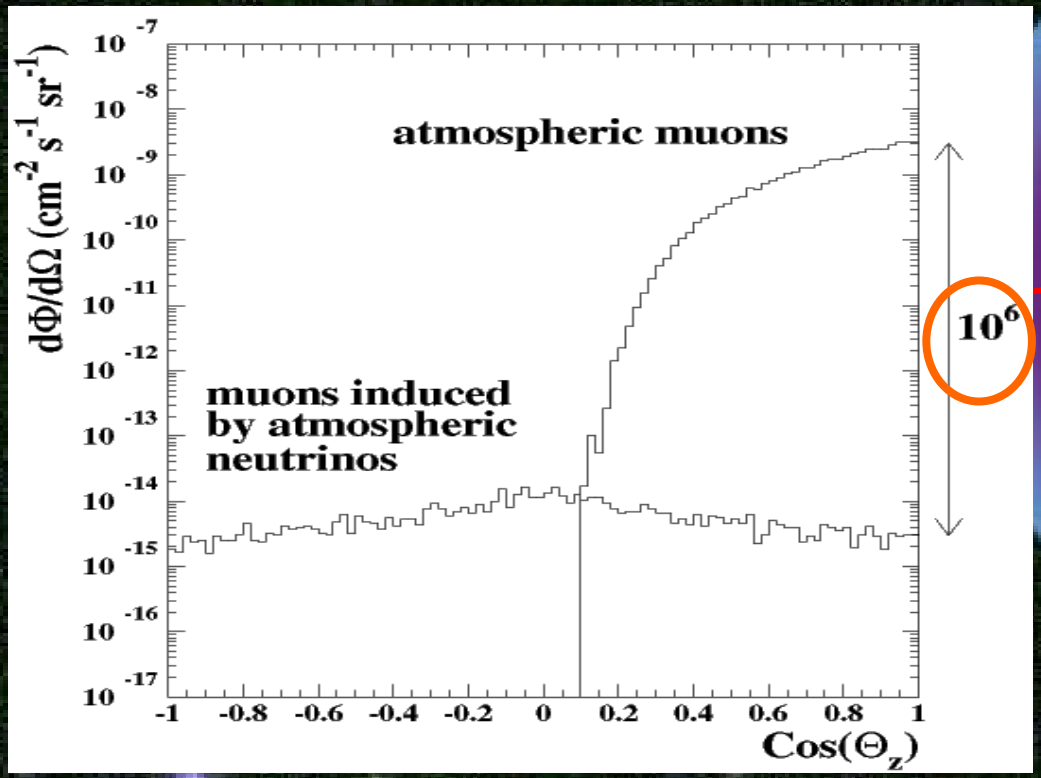
Physical backgrounds:

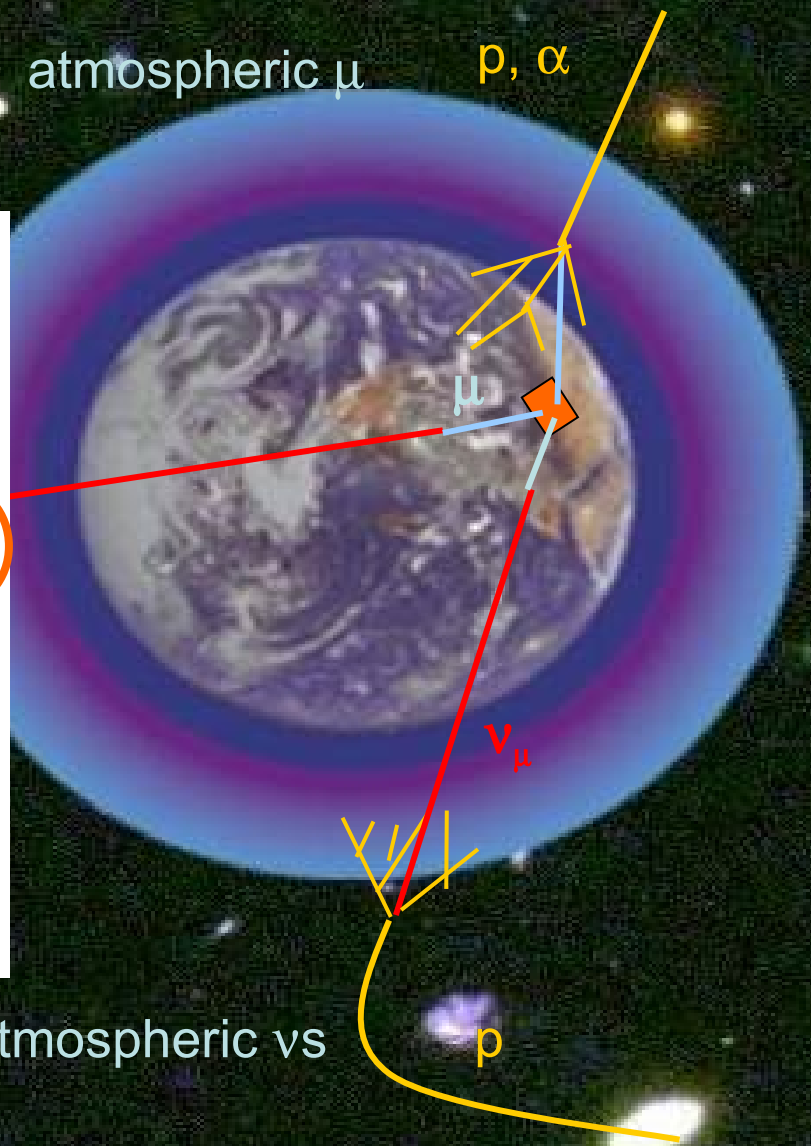


- **The detector is buried deep**
- **The detector looks downwards !**

Neutrino Astronomy

Physical backgrounds:





Atmospheric νs ~1/day

- The detector is buried deep
- The detector looks downwards !

How to discriminate from background?

Pointlike excesses

Background:
•homogenous and isotropic locally
Signal:
•pointlike

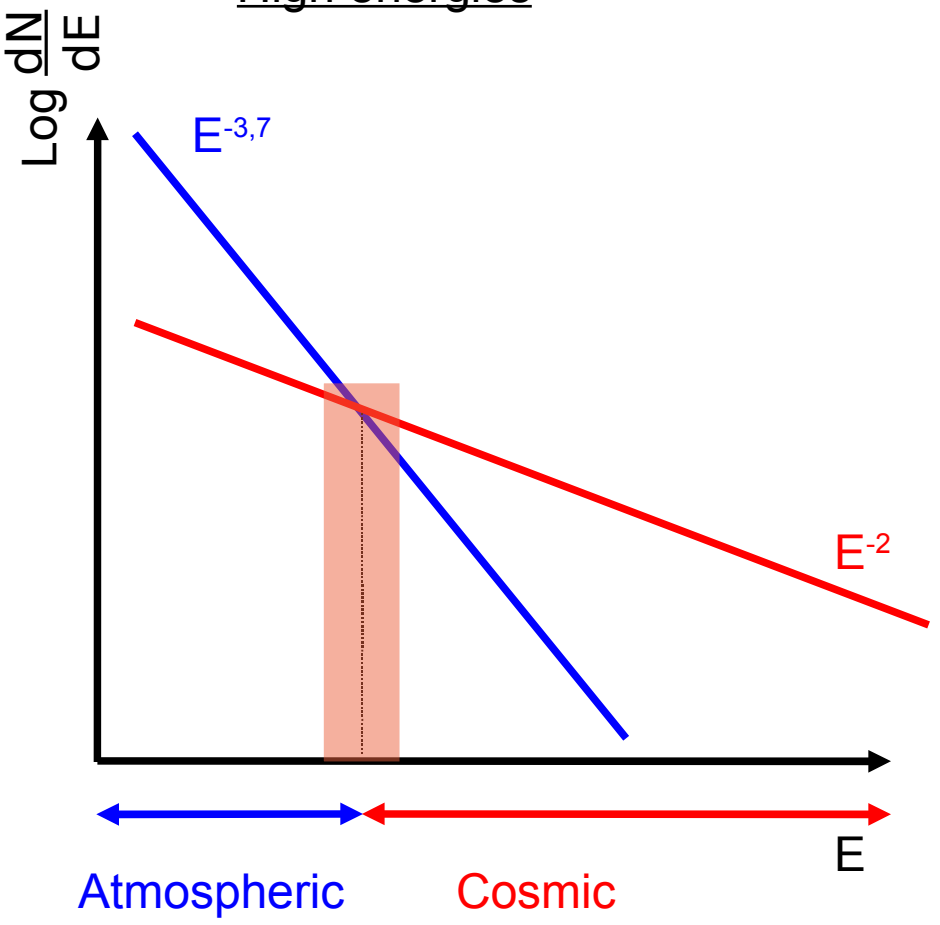
Bakground events within resolution R:
$N(R) \propto R^2$

Ice

$\frac{N(1°)}{N(0.3°)}$ =10 !!!!

Water

High energies

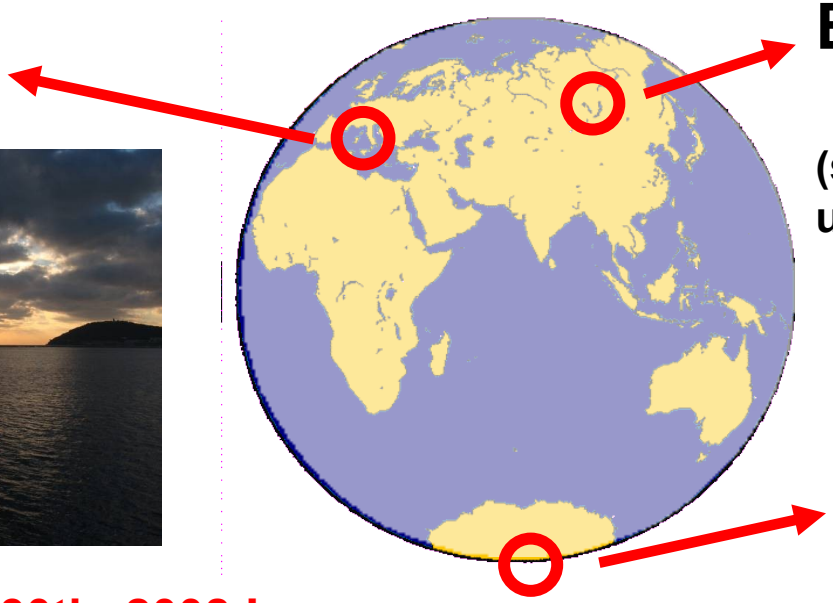


~1TeV

Diffuse flux, pointsources

Neutrino Astronomy

Currently operating HE neutrino telescopes

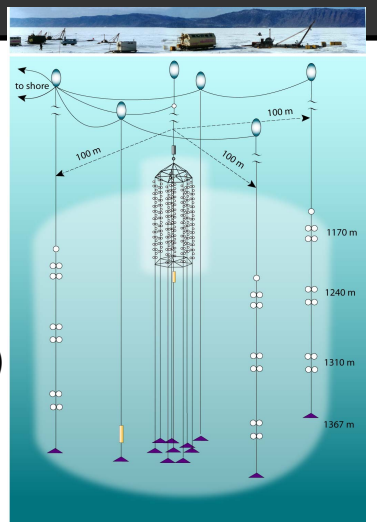


ANTARES

completed May 30th, 2008 !

BAIKAL

(since 1998, upgraded 2005)



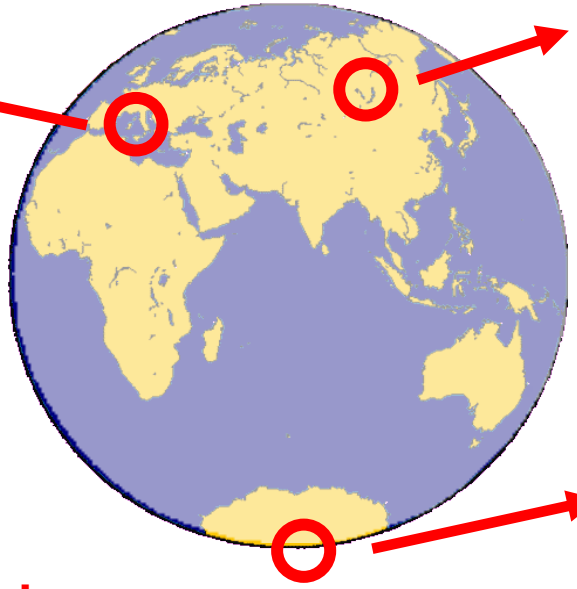
AMANDA/ICE CUBE

(since 2000, still deploying)

Neutrino Astronomy

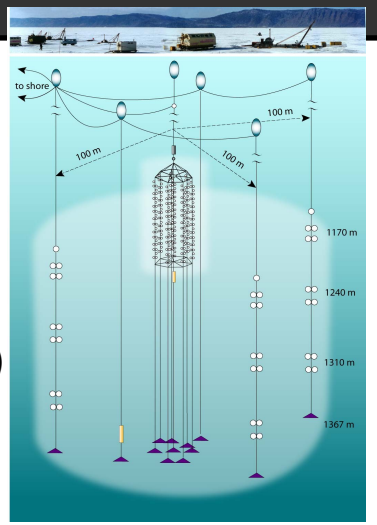
Currently operating HE neutrino telescopes

ANTARES



BAIKAL

(since 1998, upgraded 2005)

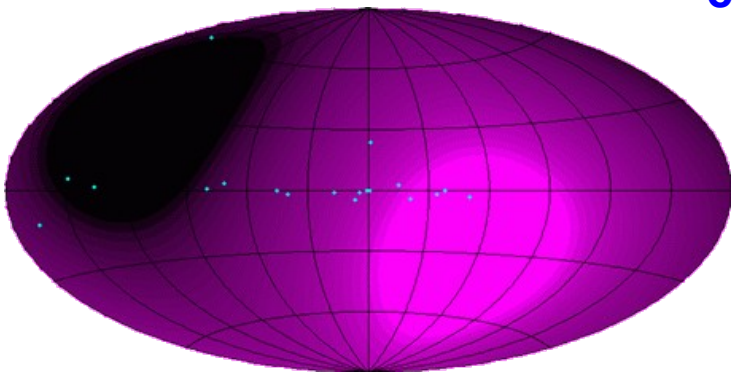


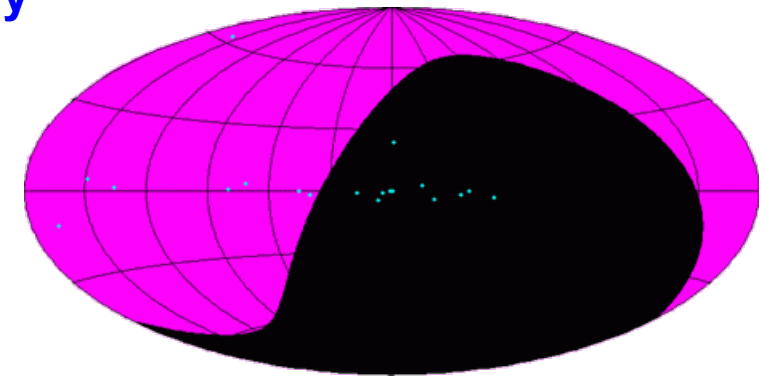
AMANDA/ICE CUBE

(since 2000, still deploying)

completed May 30th, 2008 !

complementary skies

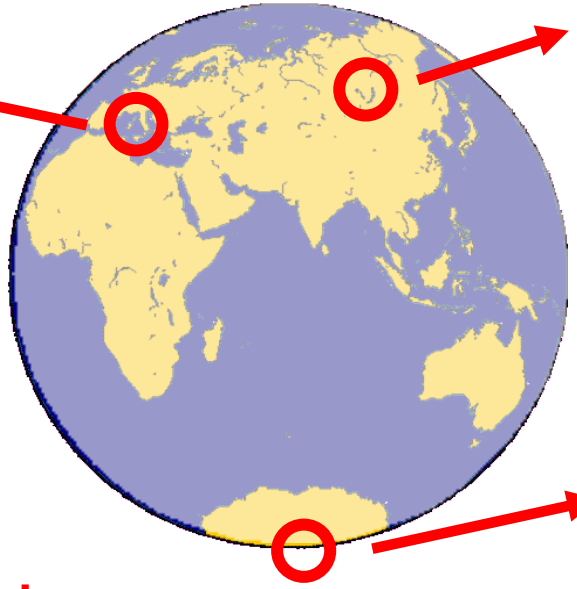




Neutrino Astronomy

Currently operating HE neutrino telescopes

ANTARES



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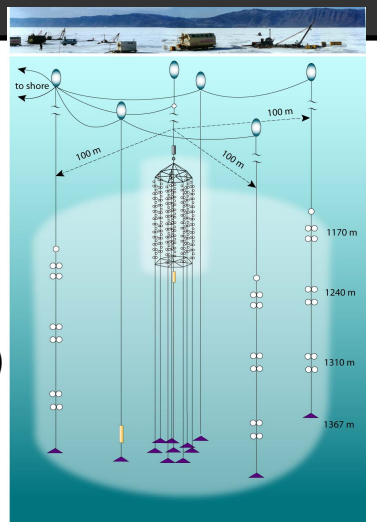

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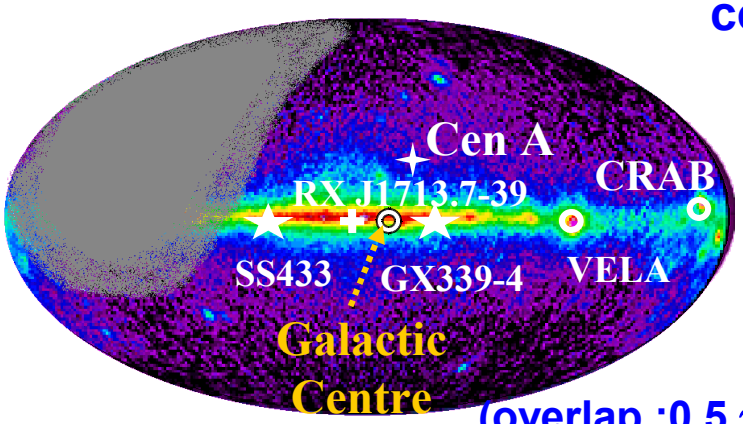
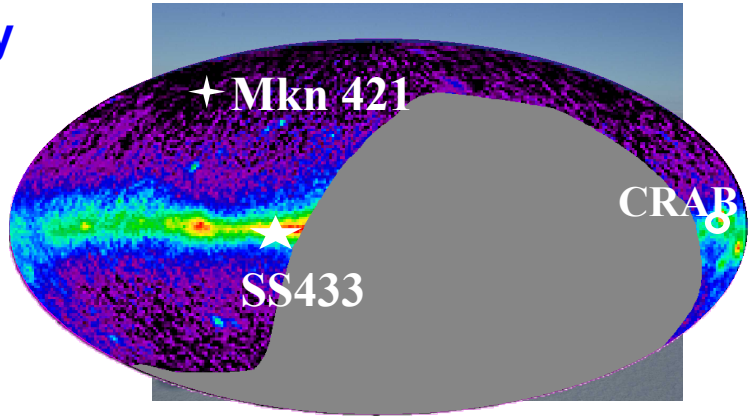


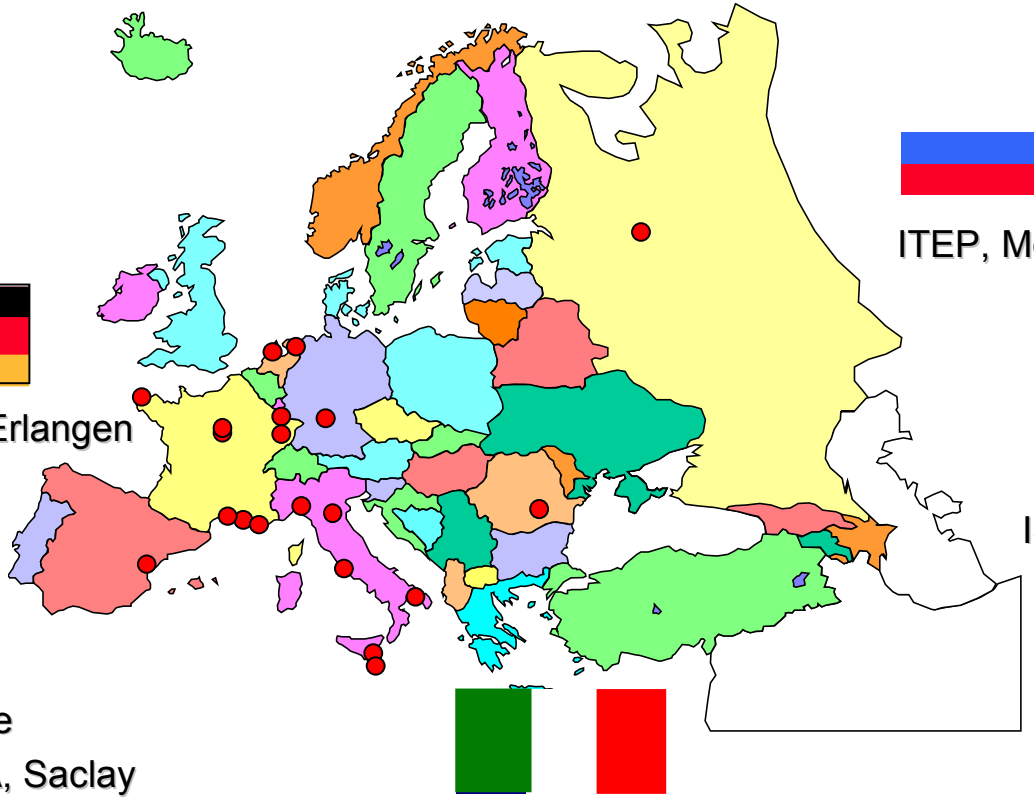
complementary skies



(overlap :0.5 π sr instantaneous,1.5 π sr per day)

The ANTARES Collaboration

7 countries, 22 laboratories, ~150 engineers, sea scientists & physicists



NIKHEF, Amsterdam
KVI Groningen
NIOZ Texel

University of Erlangen

IFIC, Valencia
UPV, Valencia

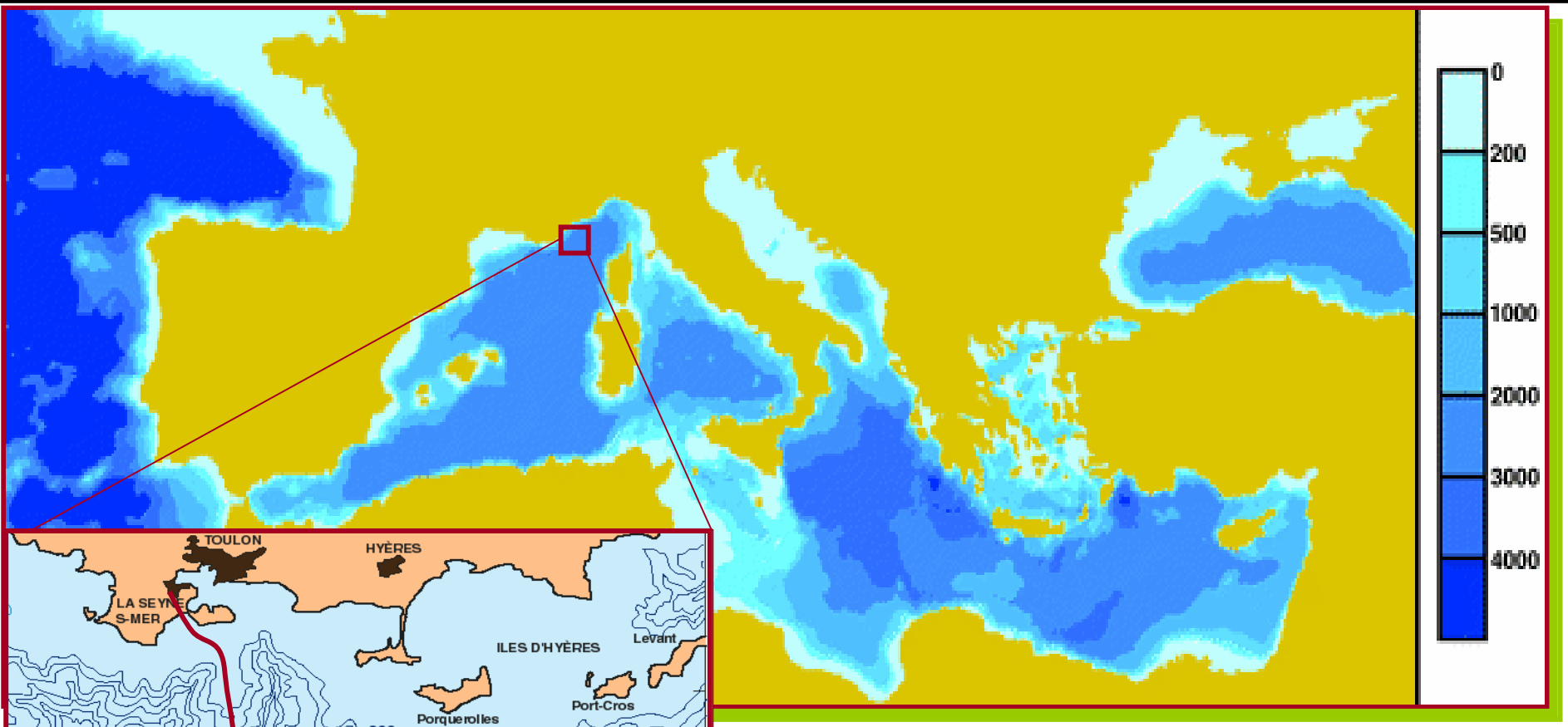
CPPM, Marseille
DSM/IRFU/CEA, Saclay
APC Paris
IPHC (IReS), Strasbourg
Univ. de H.-A., Mulhouse
IFREMER, Toulon/Brest
C.O.M. Marseille
LAM, Marseille
GeoAzur Villefranche

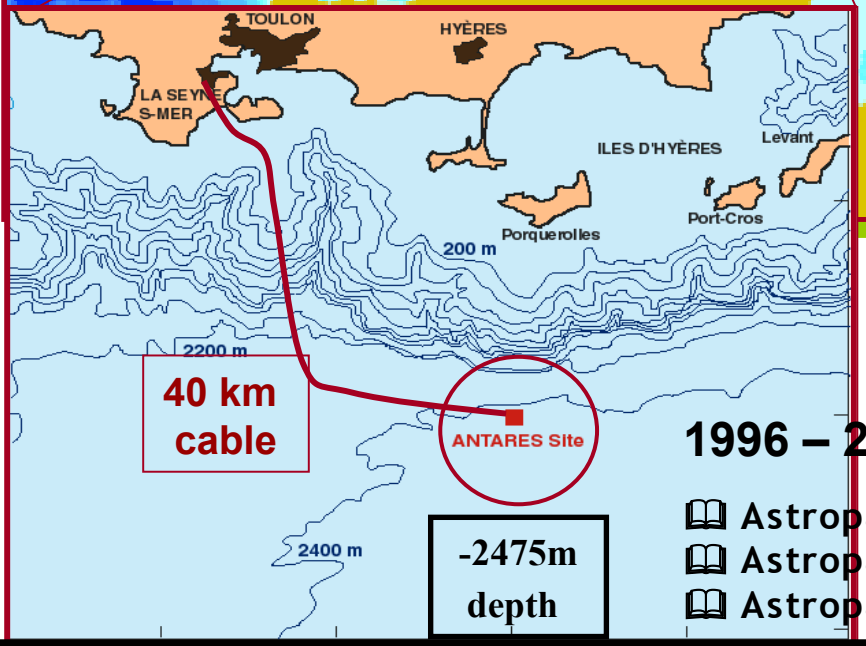
ITEP, Moscow

ISS, Bucharest

University/INFN of Bari
University/INFN of Bologna
University/INFN of Catania
LNS – Catania
University/INFN of Pisa
University/INFN of Rome
University/INFN of Genova

The ANTARES Site

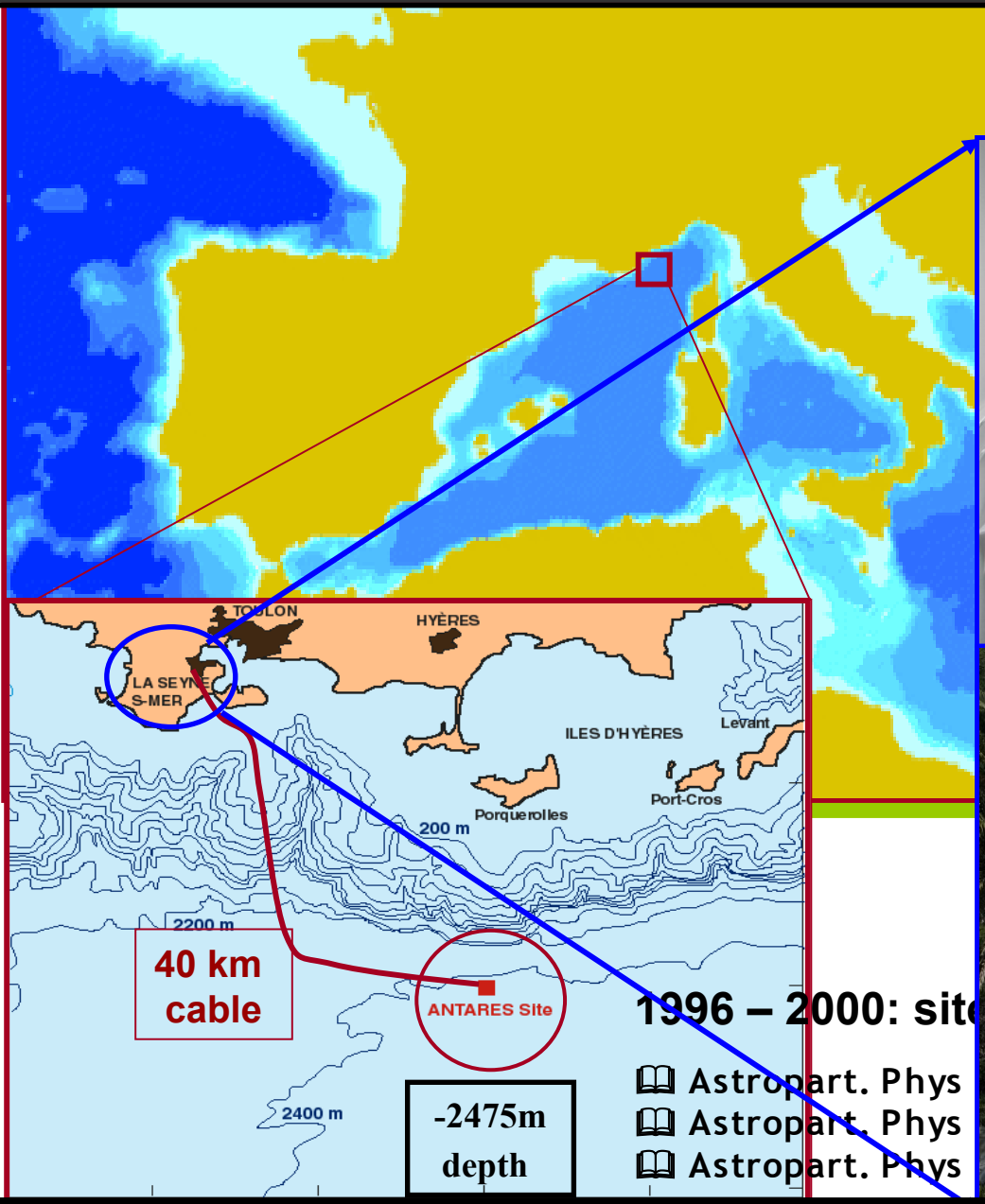




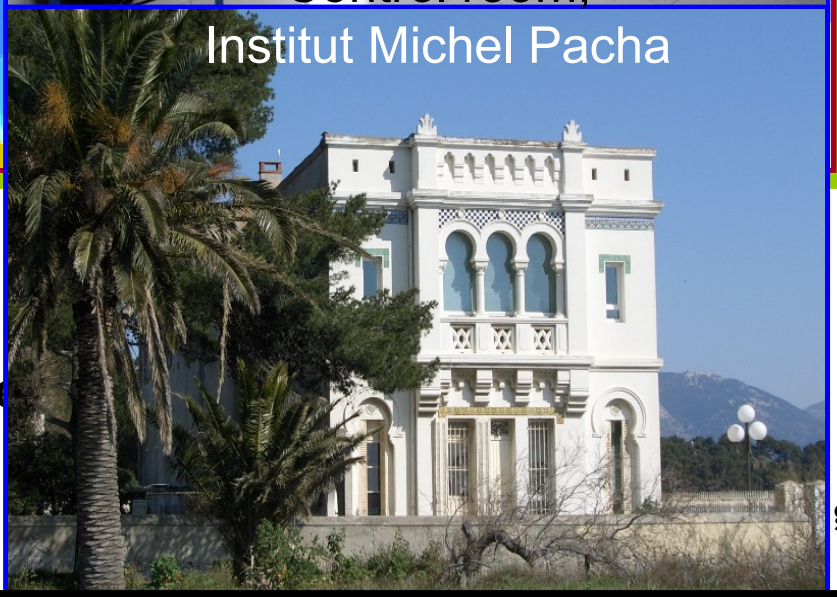
1996 – 2000: site exploration campaigns (~50)

- 🕮 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 ANTARES Site



Control room, Institut Michel Pacha

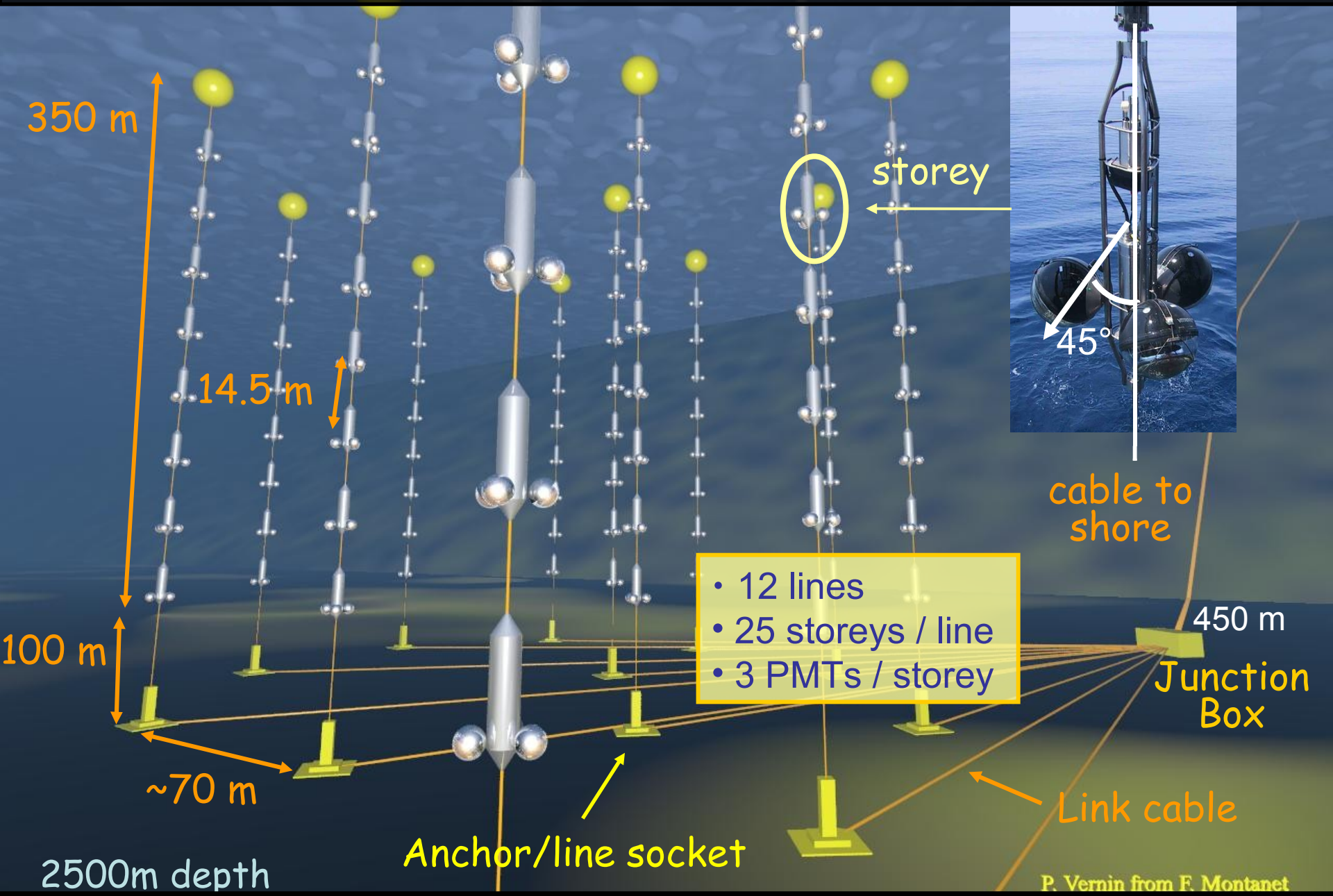


1996 – 2000: site

- Astropart. Phys
- Astropart. Phys
- Astropart. Phys

g)

The ANTARES Detector

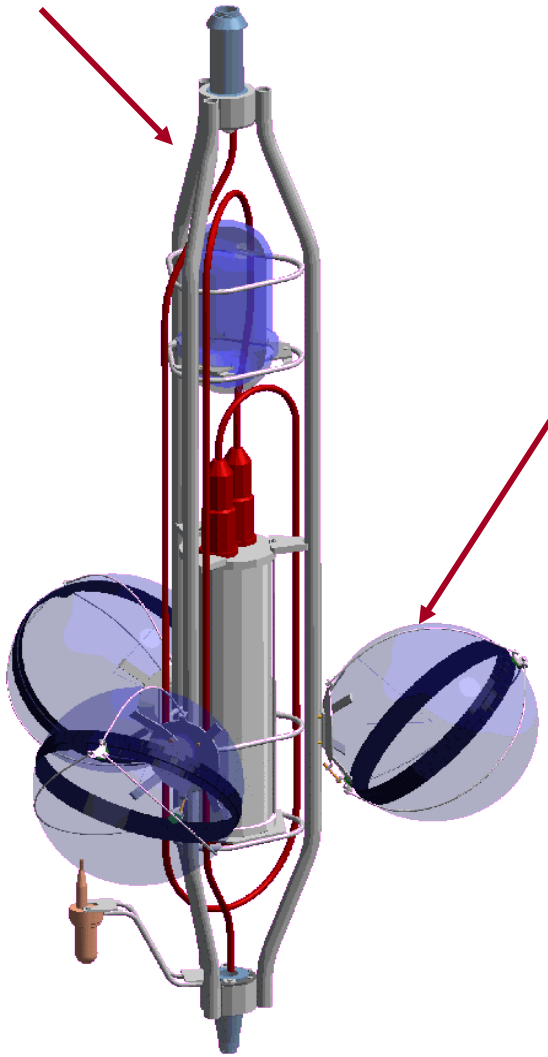


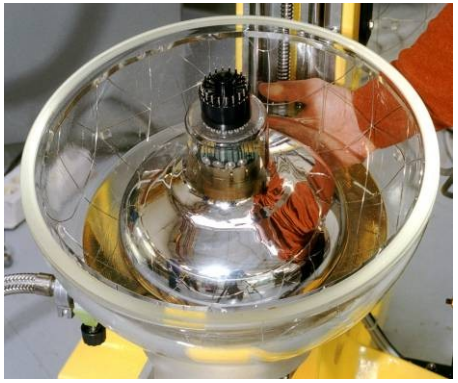
The ANTARES Detector

Titanium frame : mechanical support

The ANTARES Detector

Titanium frame : mechanical support



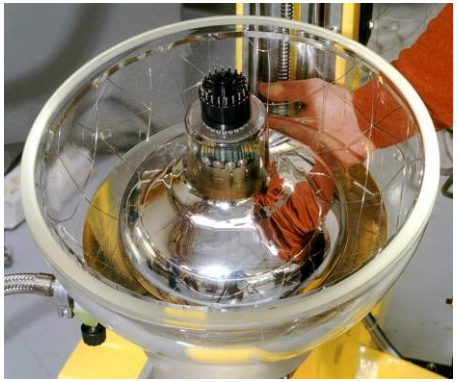


Optical Module (OM):
10" Hamamatsu
photomultiplier

📖 NIM A484 (2002) 369
📖 NIM A555 (2005) 132

The ANTARES Detector

Titanium frame : mechanical support



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📖 NIM A484 (2002) 369
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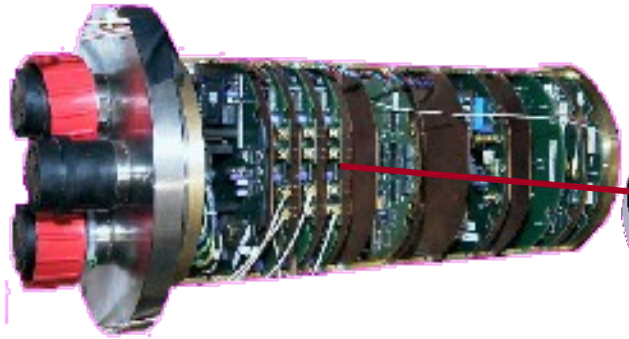
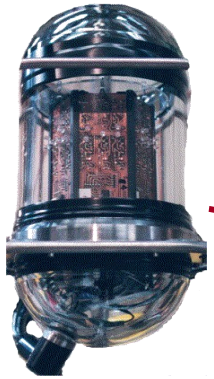


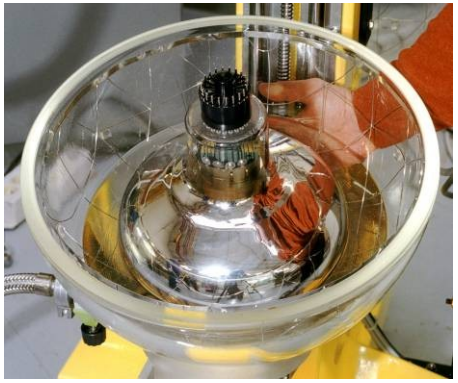
Local Control Module:
Front-end ASIC,
📖 NIM A504 (2003) 258
DAQ/SC,
tiltmeter
compass

The ANTARES Detector

Titanium frame : mechanical support



LED Beacon:
Time calibration
📖 NIM A578 (2007) 498



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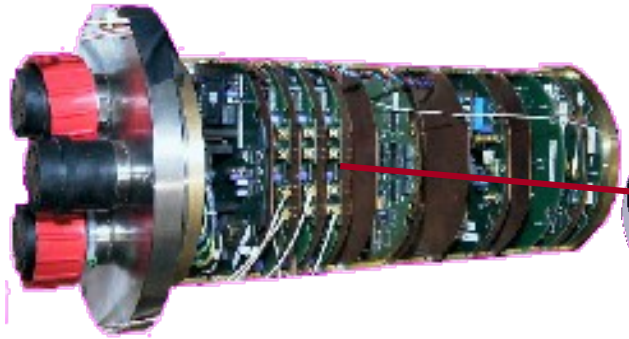

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Front-end ASIC,
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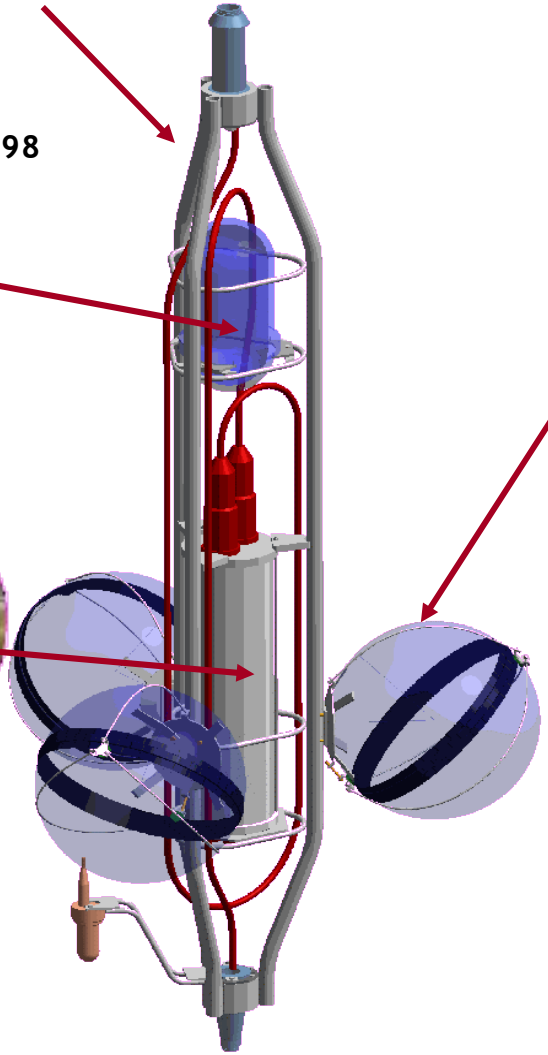
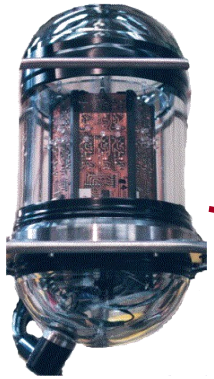
DAQ/SC,
tiltmeter
compass



The ANTARES Detector

Titanium frame : mechanical support



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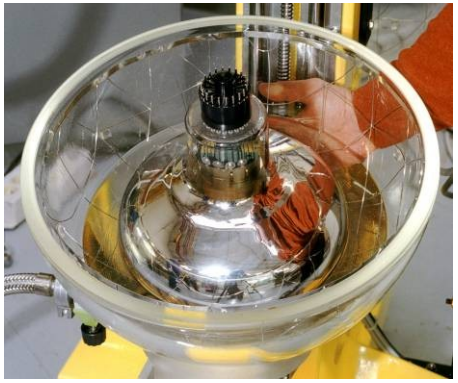

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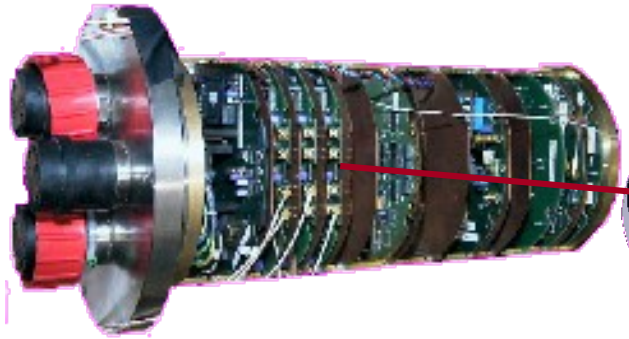
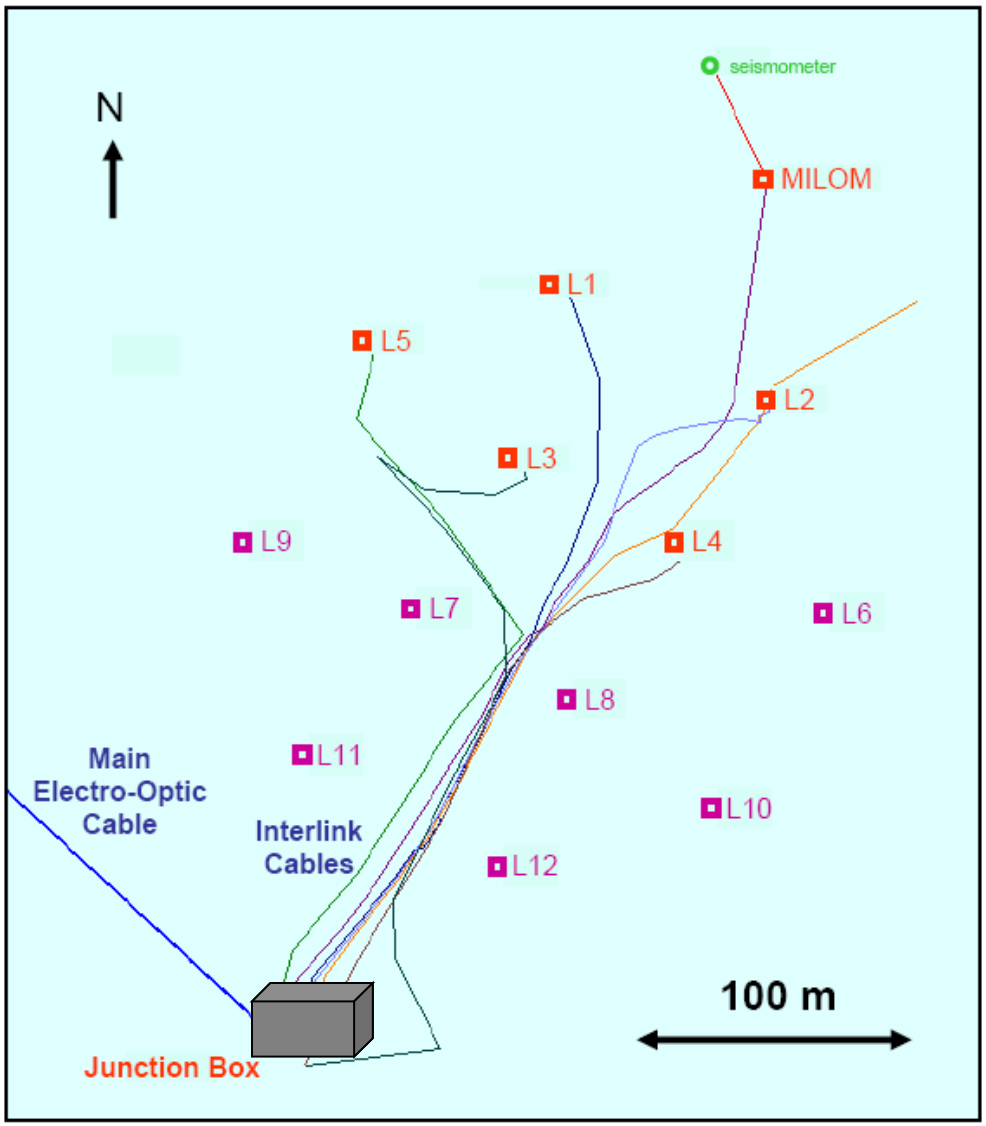


Local Control Module:
Front-end ASIC,
📖 NIM A504 (2003) 258
DAQ/SC,
tiltmeter
compass

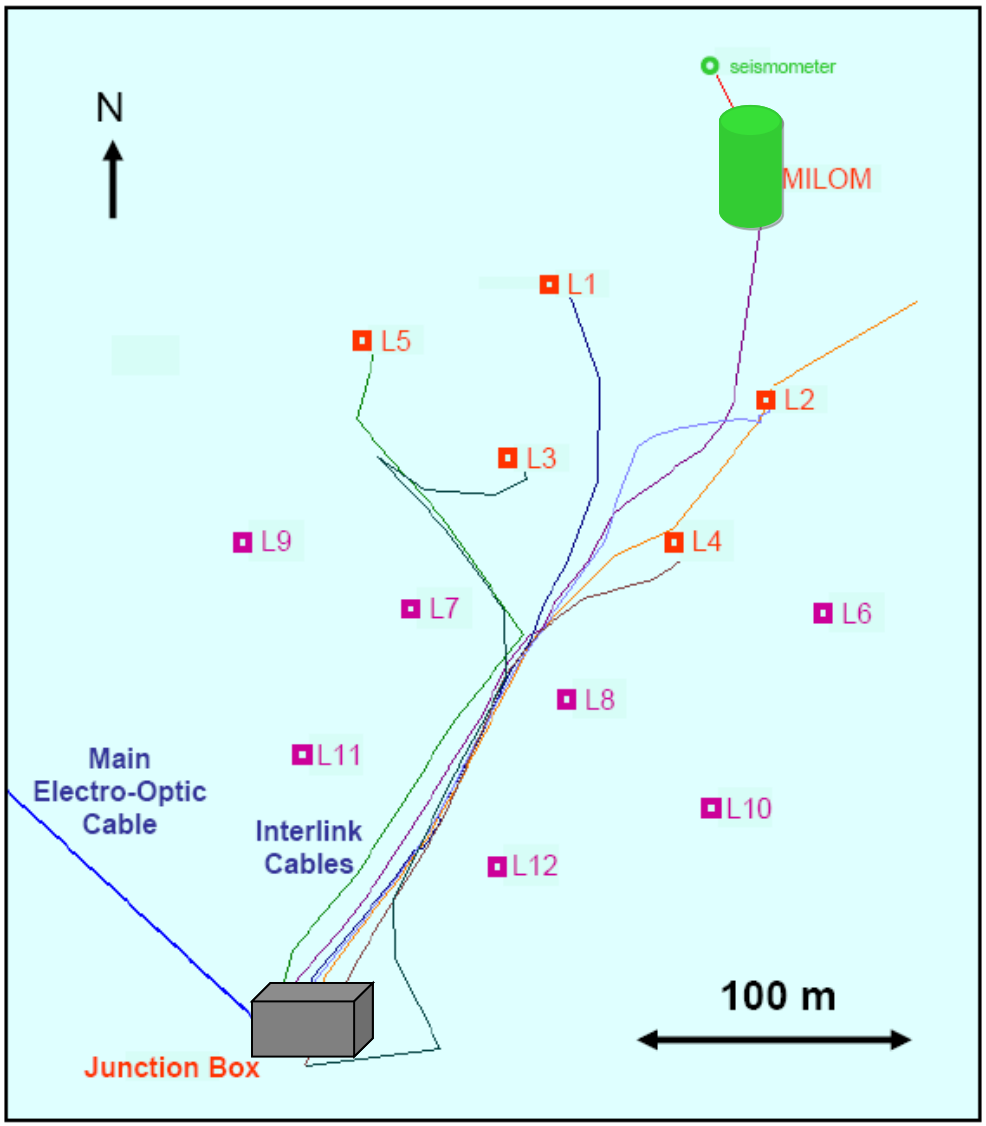
Hydrophone:
Acoustic
positioning

The ANTARES Detector: deployment phases

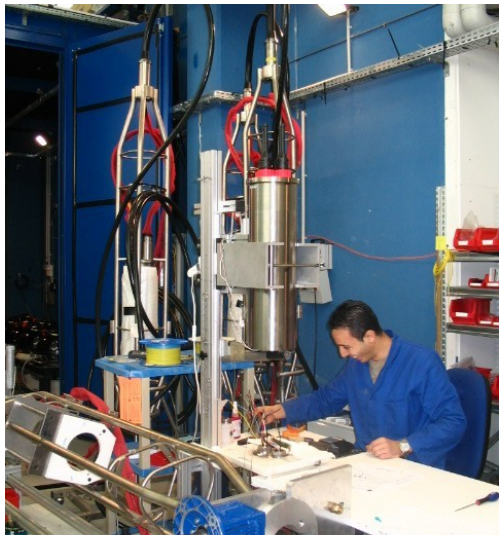


- 2002: deployment of Junction Box

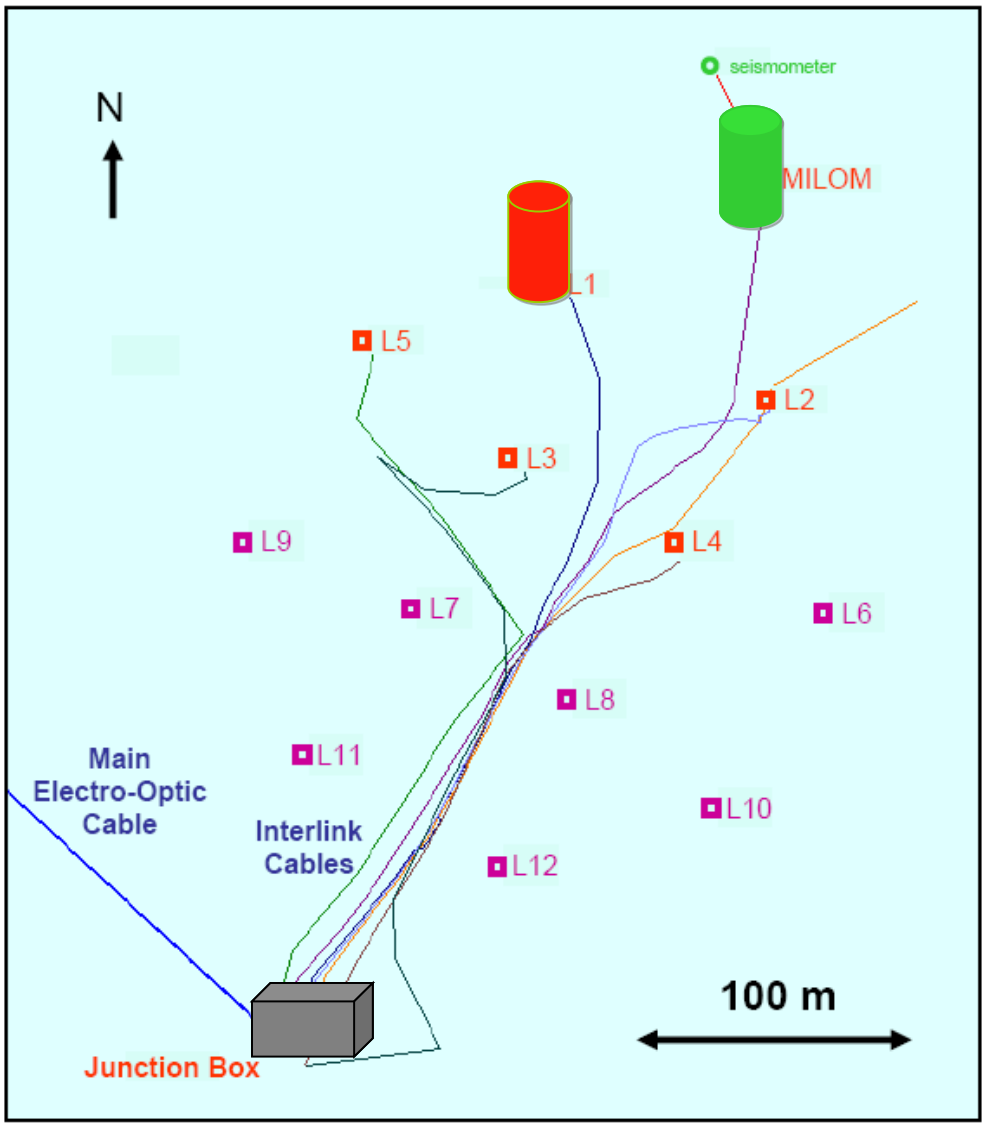
The ANTARES Detector: deployment phases



- April 2005: MILOM
(mini-instrumented line with OMs)

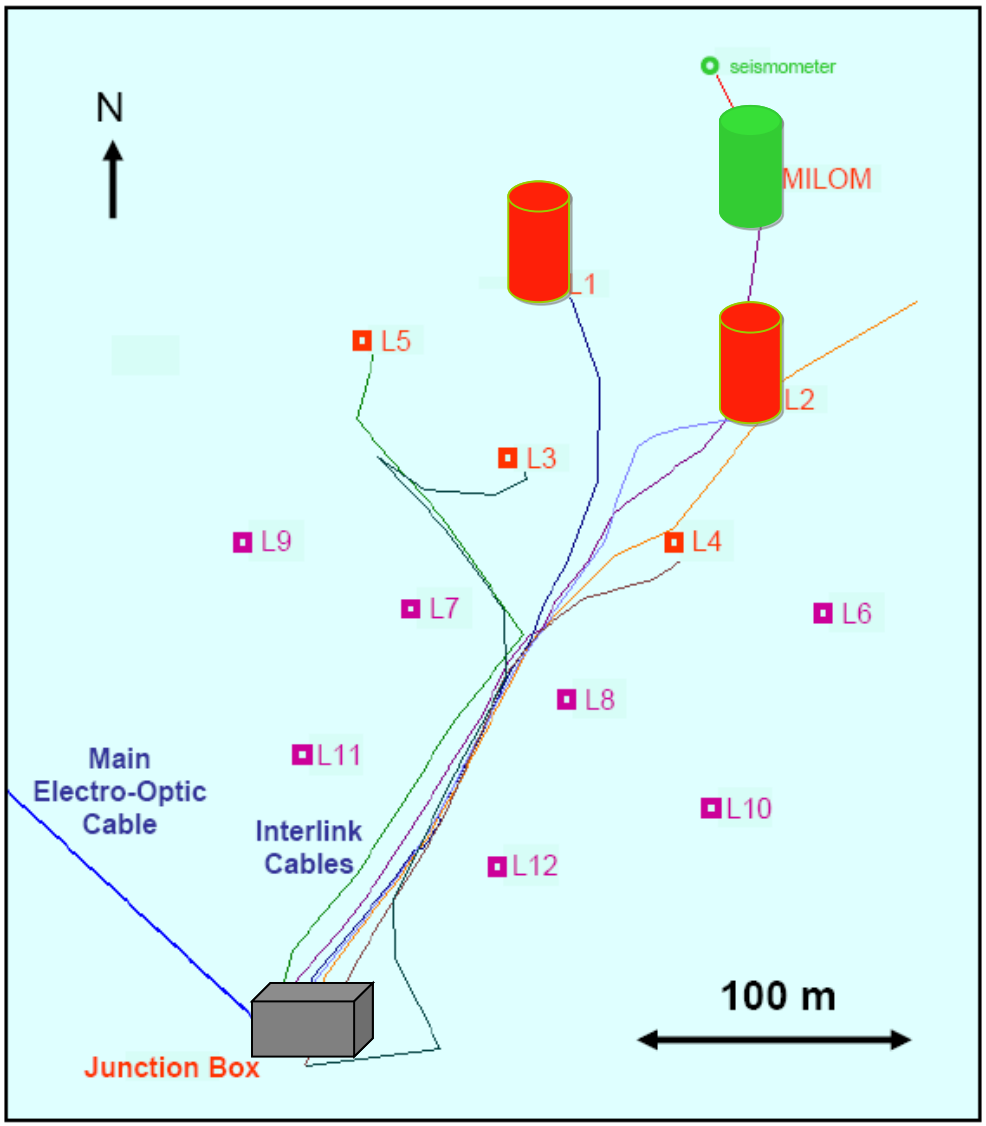


The ANTARES Detector: deployment phases



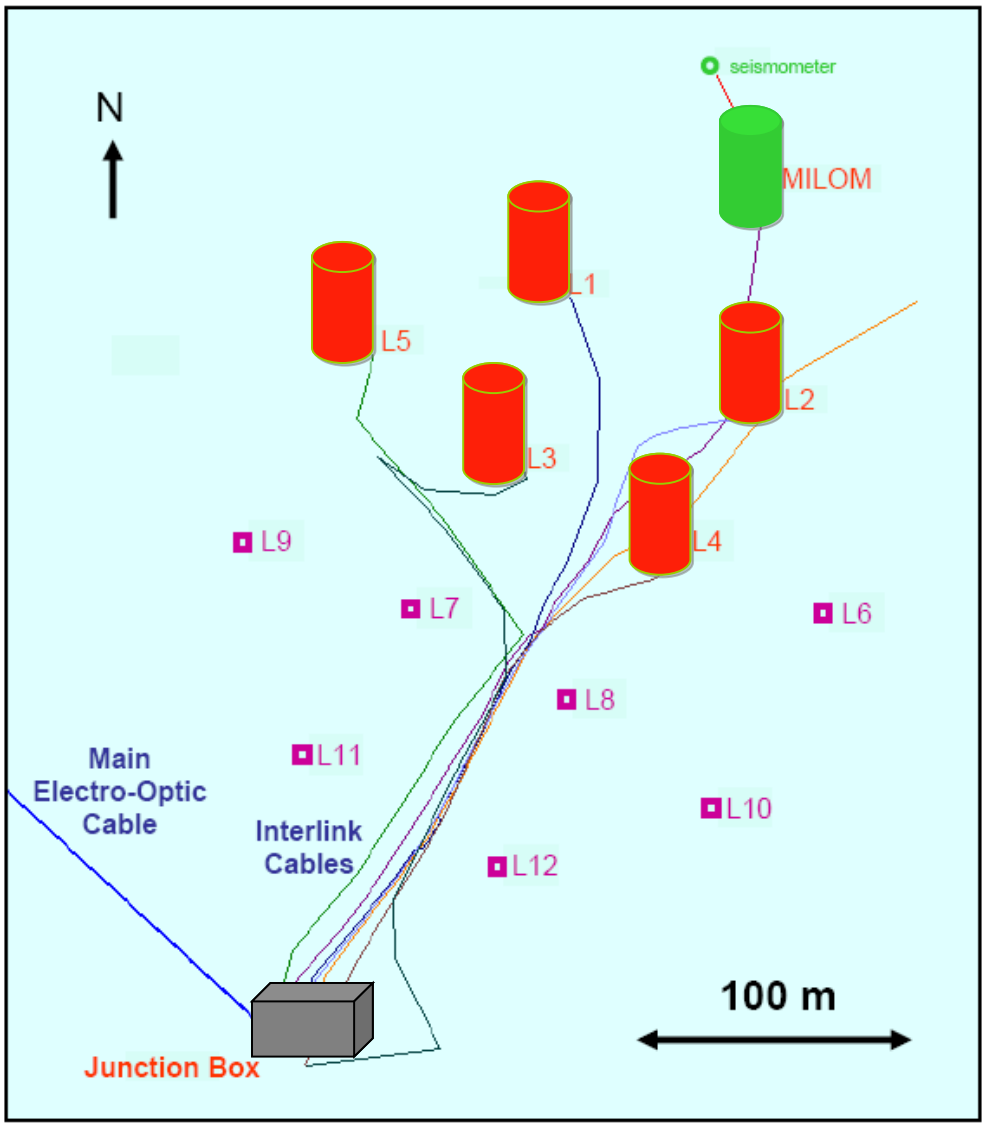
- March 2006: first line

The ANTARES Detector: deployment phases

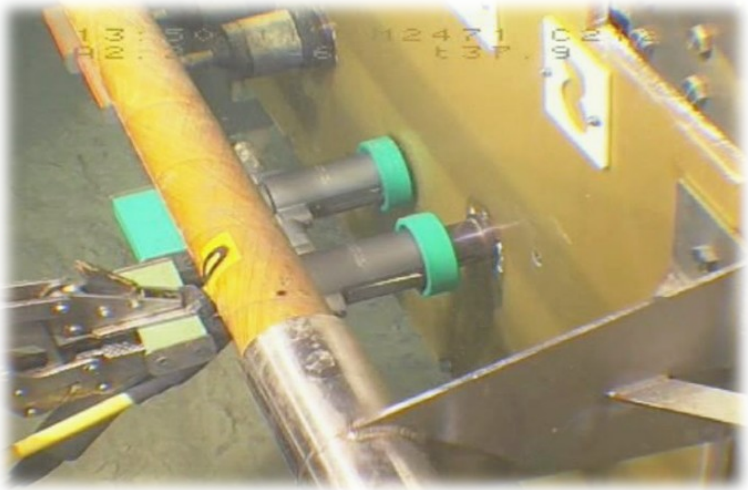


- September 2006: Line 2

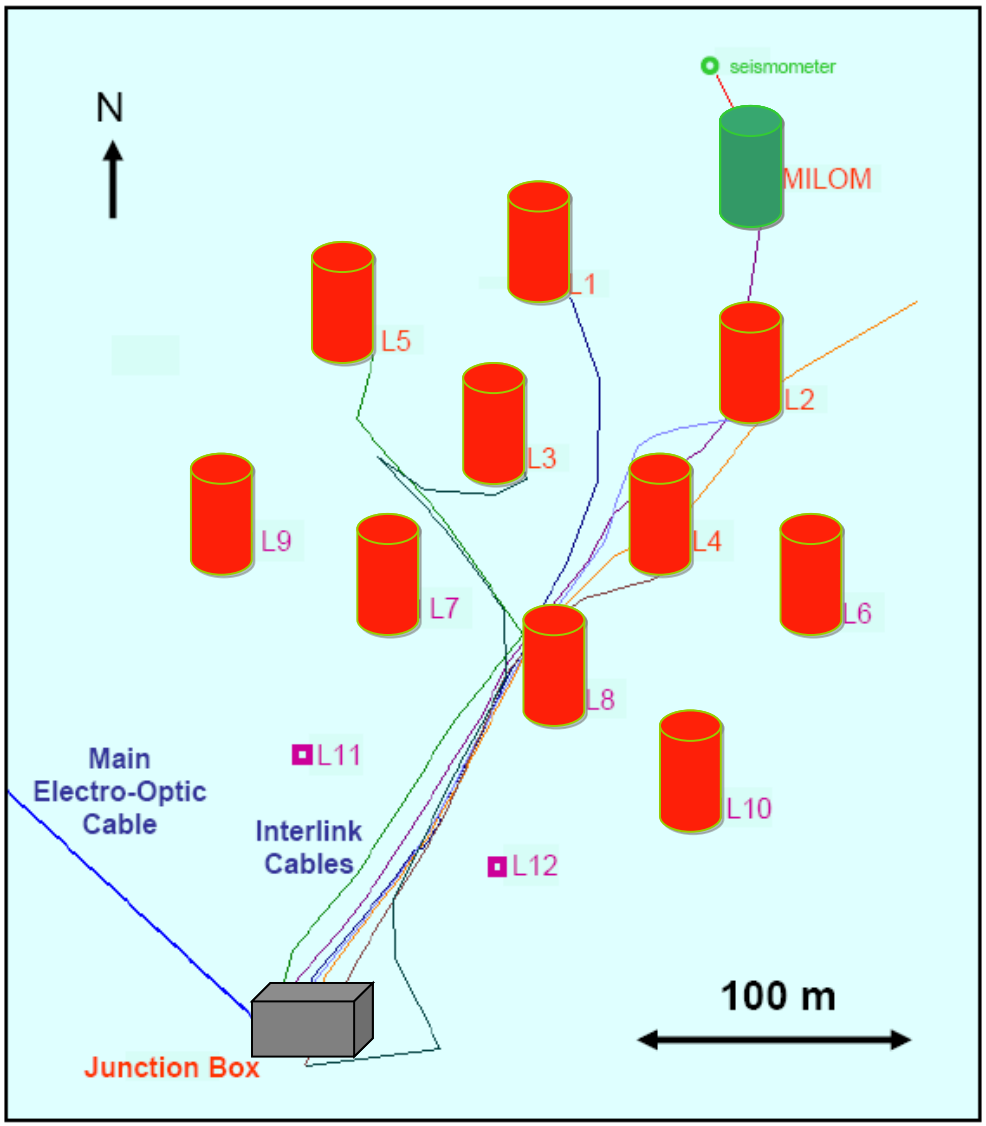
The ANTARES Detector: deployment phases



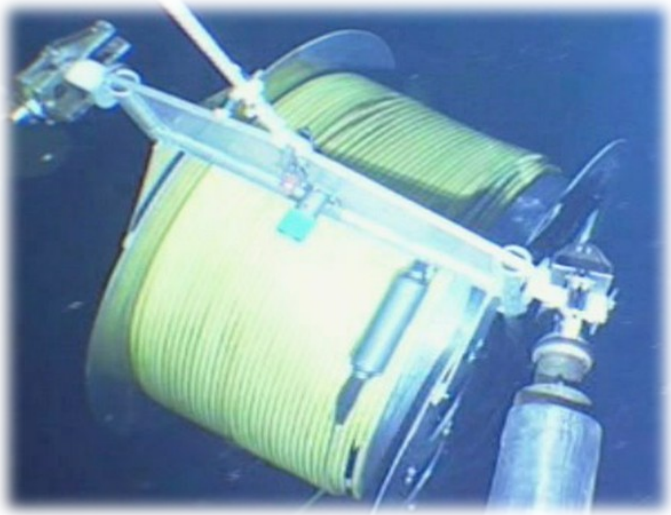
- January 2007: Lines 3 – 4 - 5

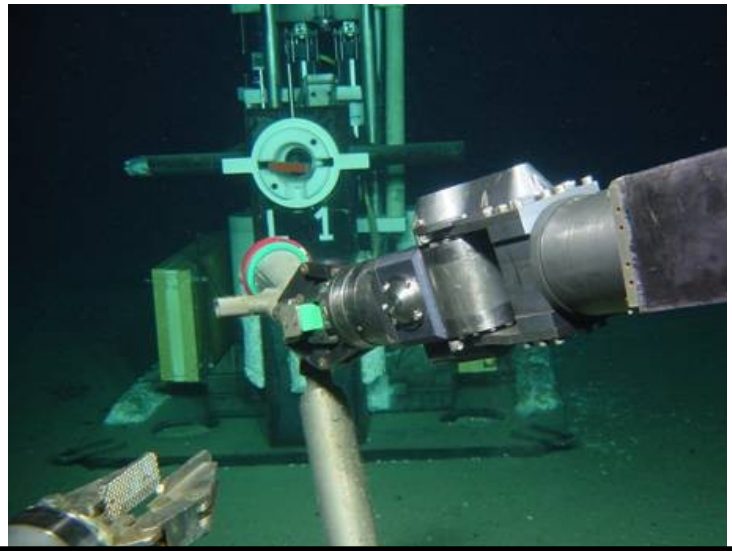


The ANTARES Detector: deployment phases

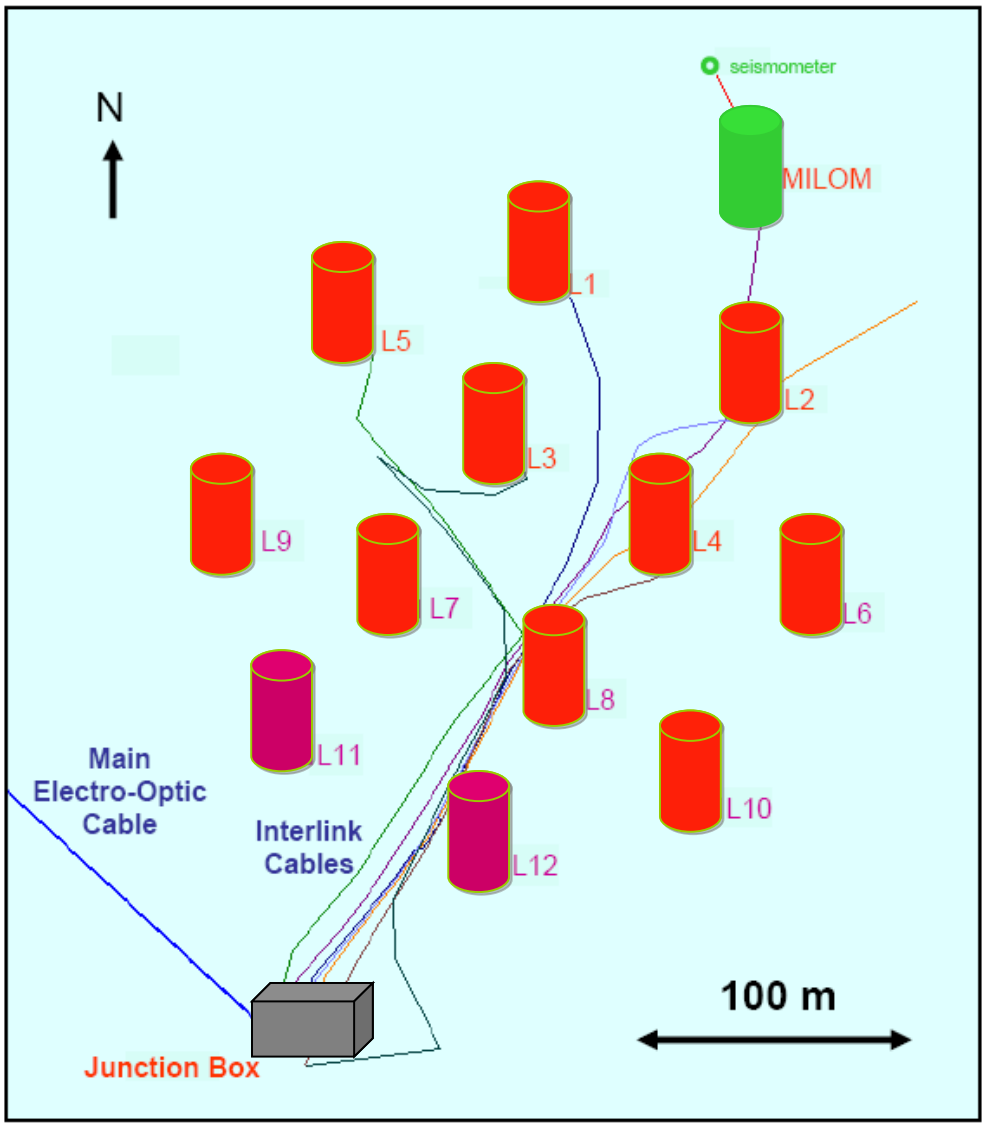


- December 2007: Lines 6 to 10
  + new Instrumented Line (IL)





The ANTARES Detector: deployment phases

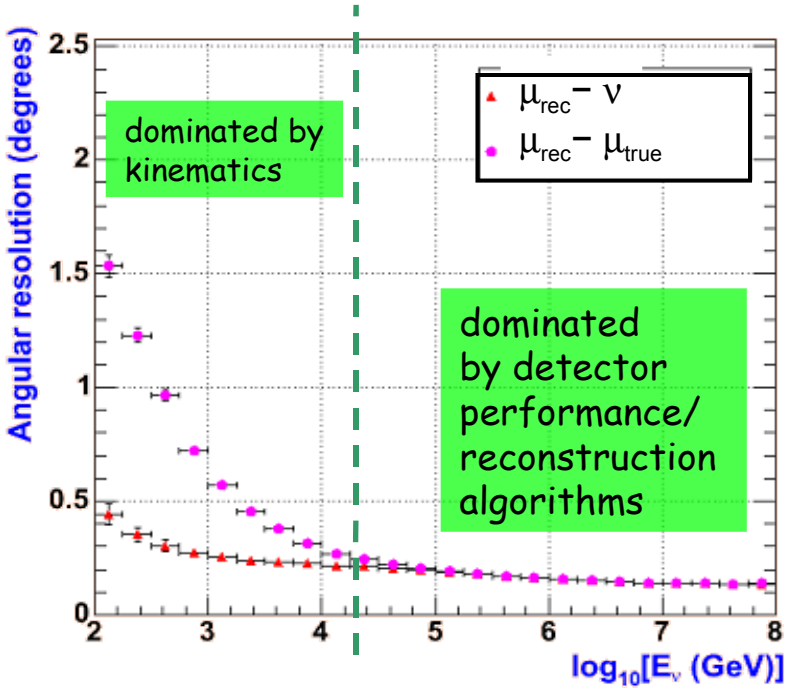


- **30th of May 2008:**
  Lines 11 & 12 connected

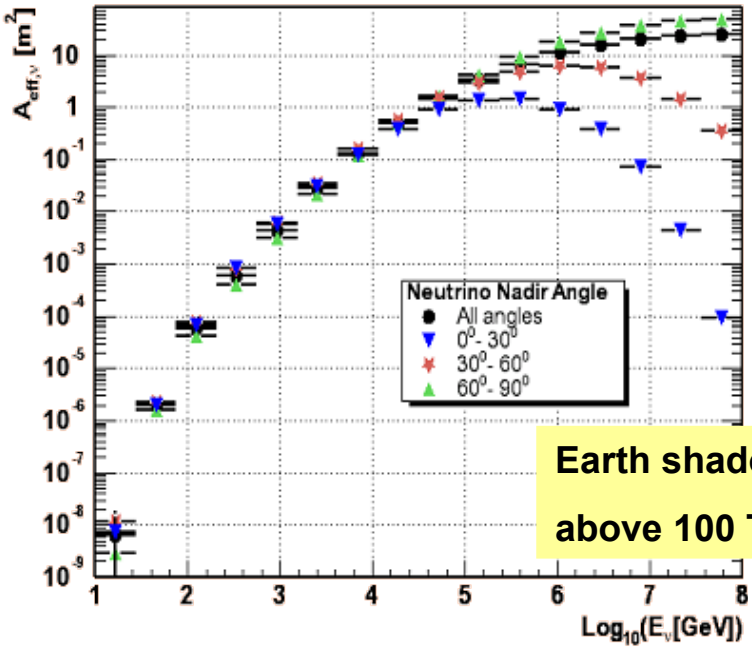
The ANTARES detector is complete!

The ANTARES Detector: expected performance

Angular resolution

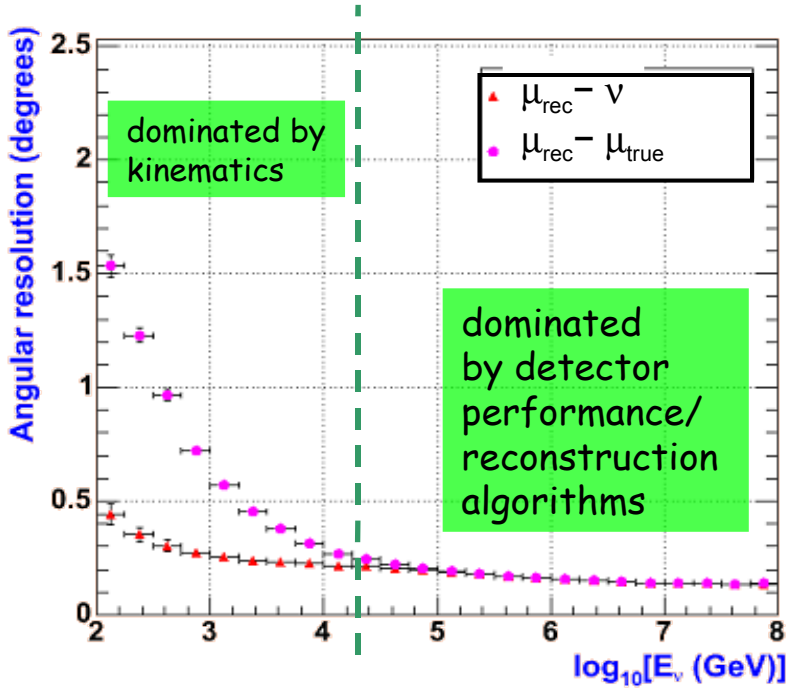


Effective area for ν [m²]

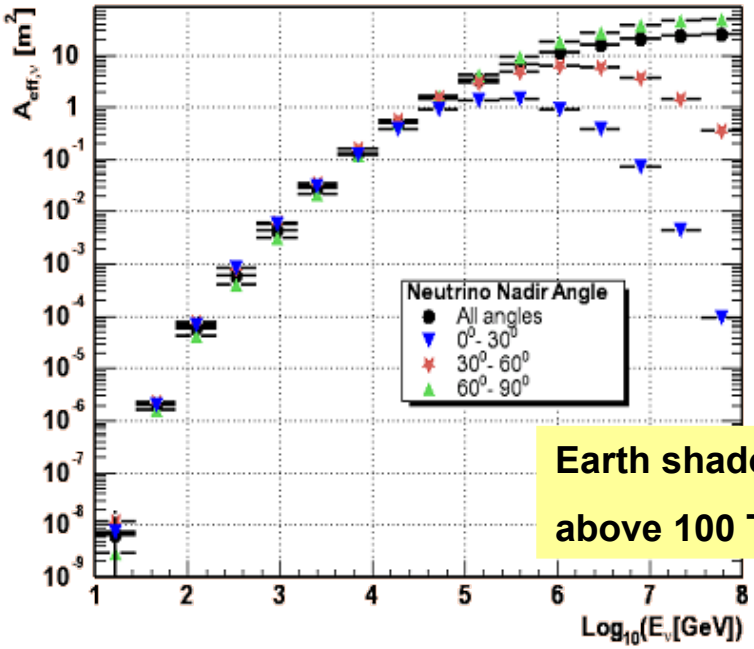


The ANTARES Detector: expected performance

Angular resolution



Effective area for ν [m²]



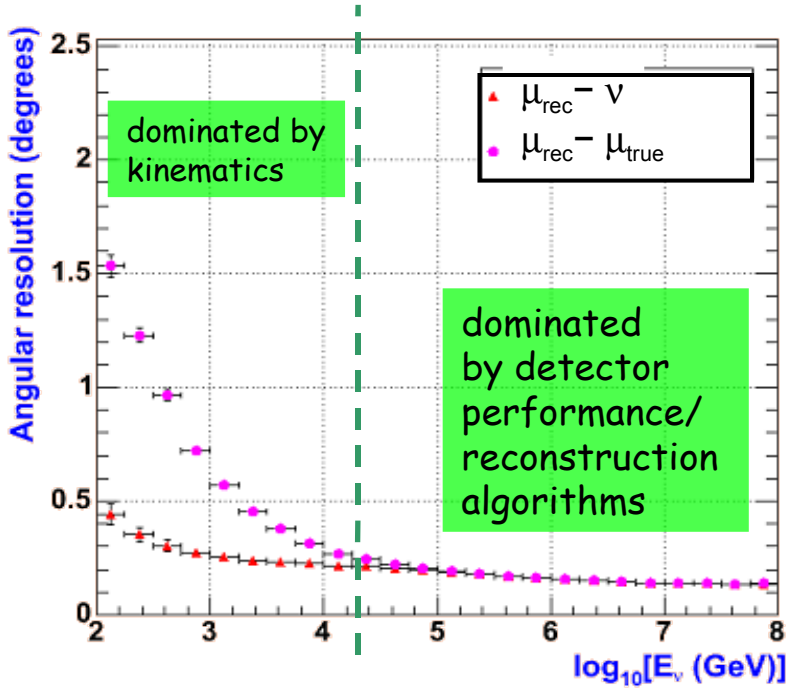
Expected angular resolution better than 0.3° above a few TeV

Limitations:

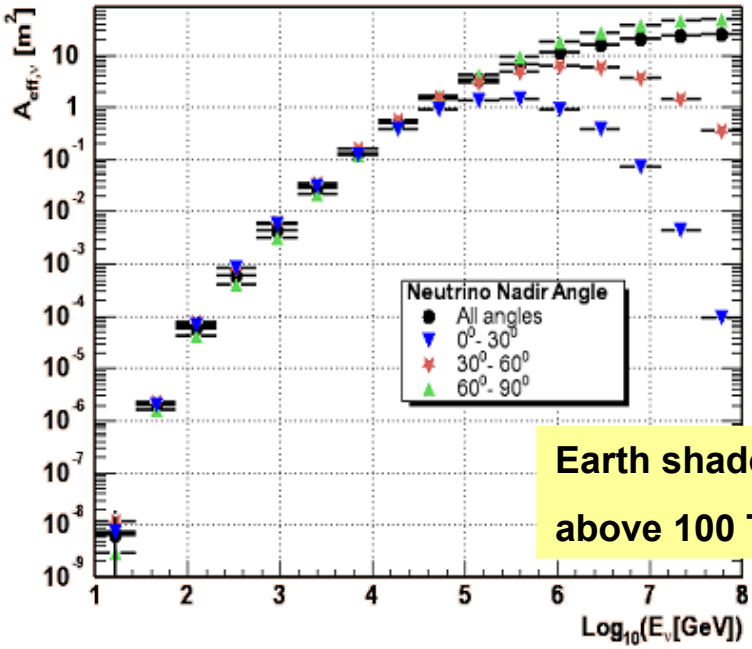
- **light scattering + chromatic dispersion in sea water: σ ~ 1.0 ns**
- **transit time spread in photomultipliers: σ ~ 1.3 ns**
- **electronics + time calibration: σ < 0.5 ns**
- **OM position σ < 10 cm (↔ σ < 0.5 ns)**

The ANTARES Detector: expected performance

Angular resolution



Effective area for ν [m²]



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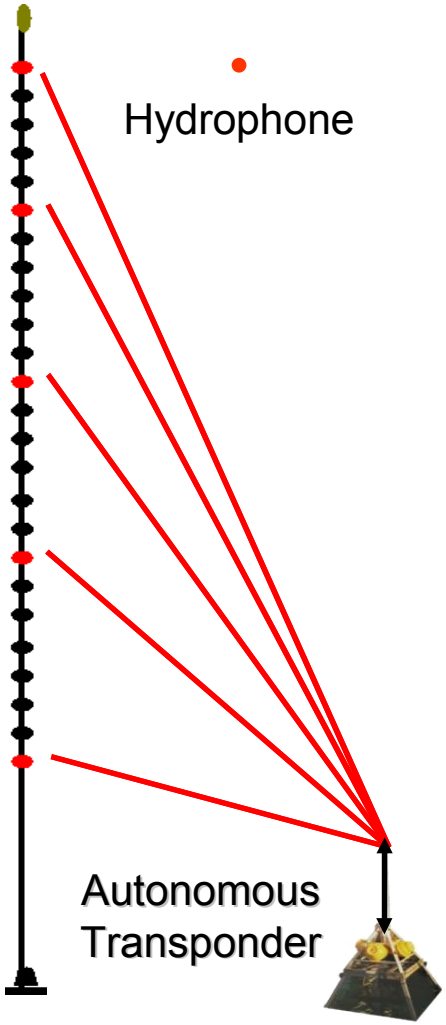
- **OM position σ < 10 cm (↔ σ < 0.5 ns)**

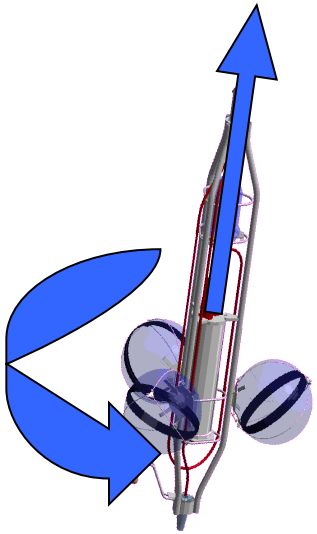
→ Importance of timing and position calibration of the detector

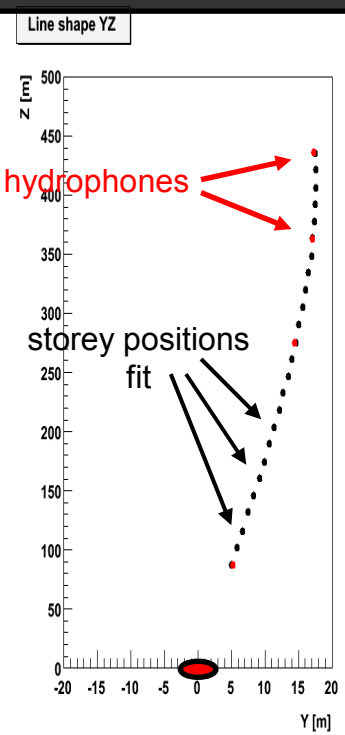
Positioning system

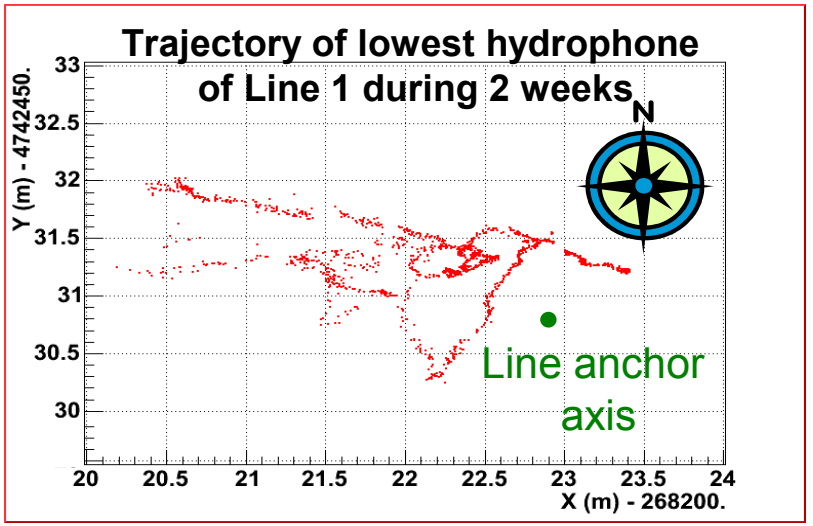
Line positioning:
acoustic triangulation
with hydrophones

+ tiltmeter/compass
on every frame





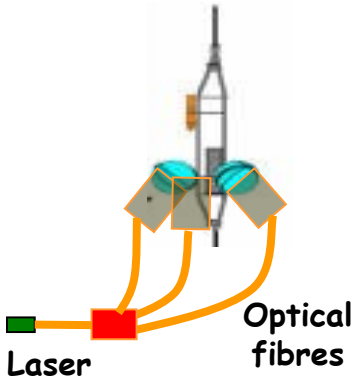




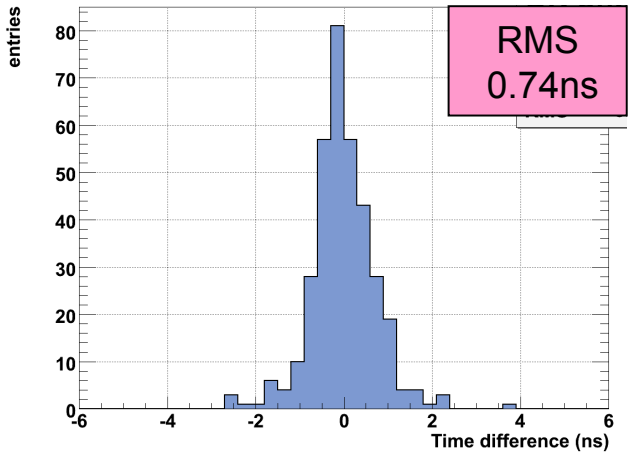
Time calibration

- **Relative timing calibration: ~ 0.5 ns**

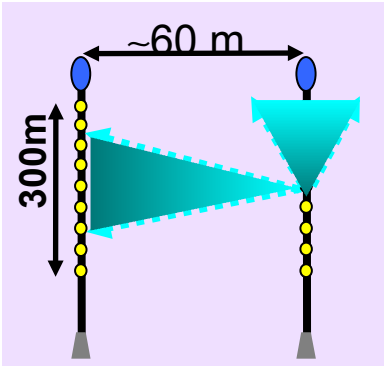
Dark room measurements:



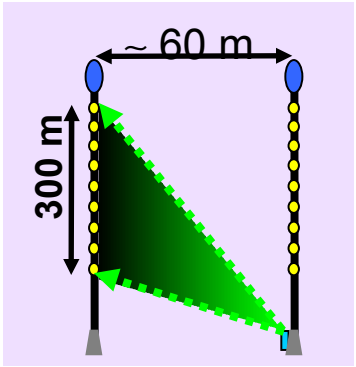
Δt(OM1-OM0)



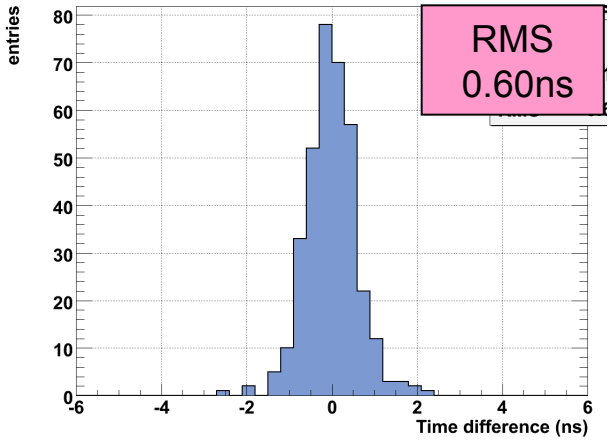
In situ measurements: use optical beacon system



4 LED beacons along each line

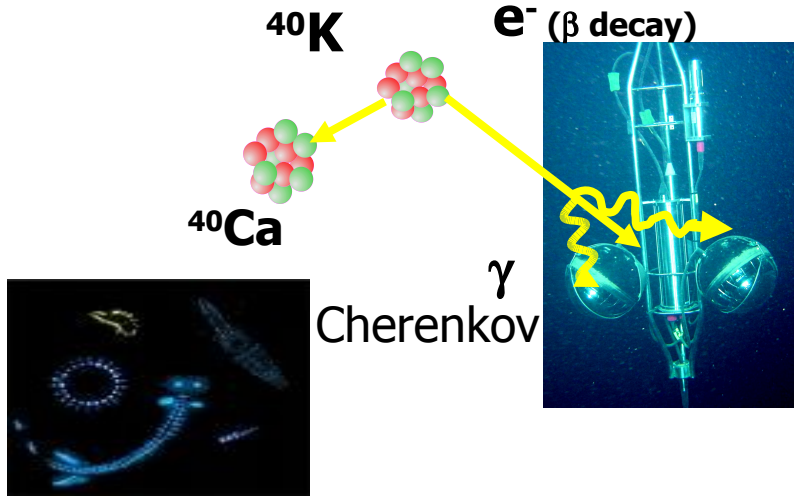


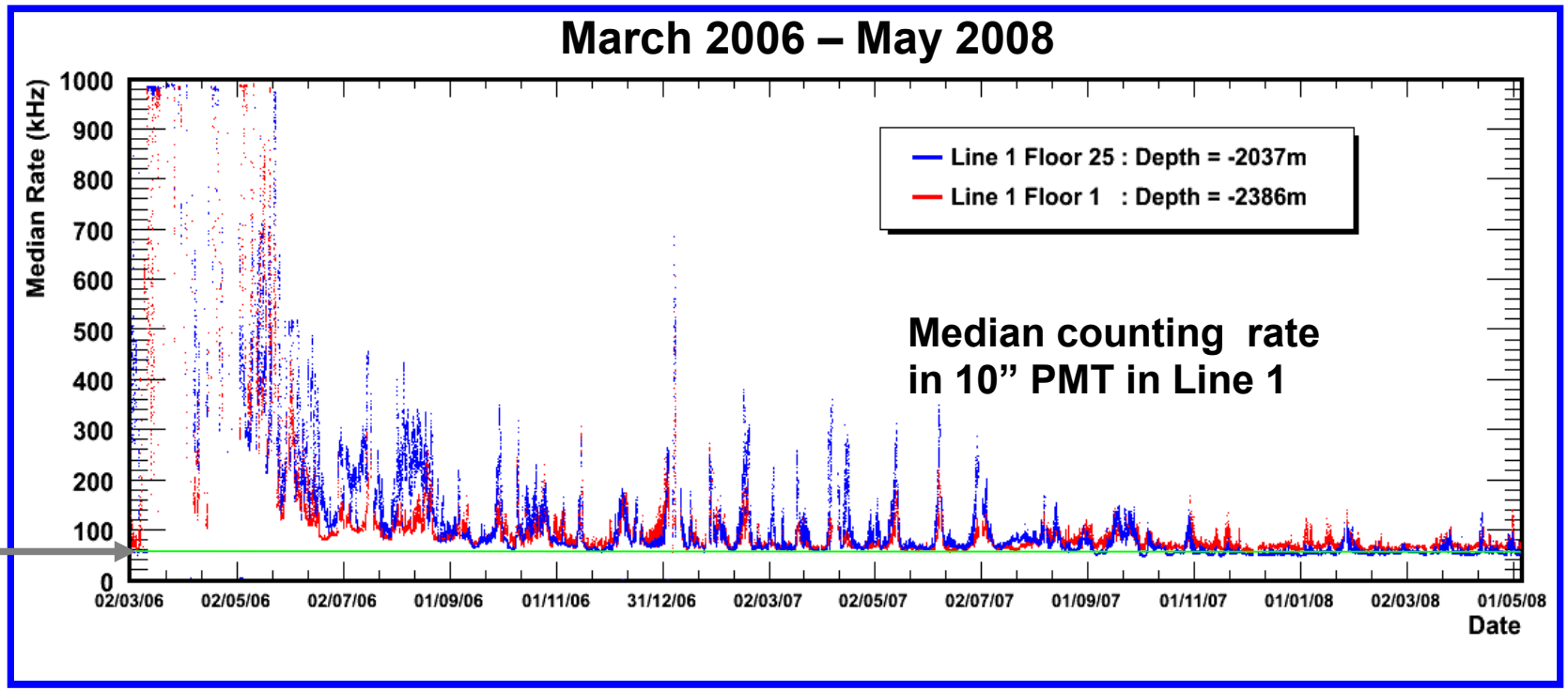
2 Laser beacons at the bottom of the central lines



Optical backgrounds

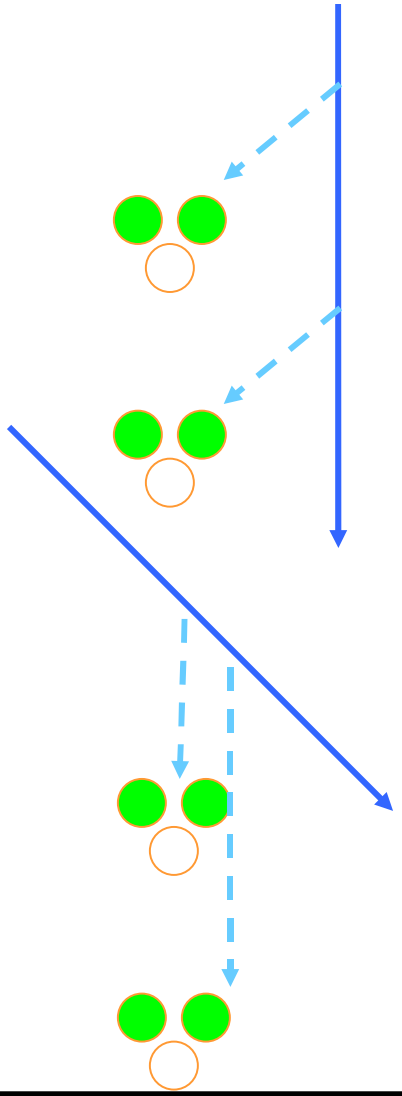
- K^{40} ~40 kHz
- Bioluminescence
  - Continuum ~ 30 kHz (but variable)
  - Short bursts: up to > MHz



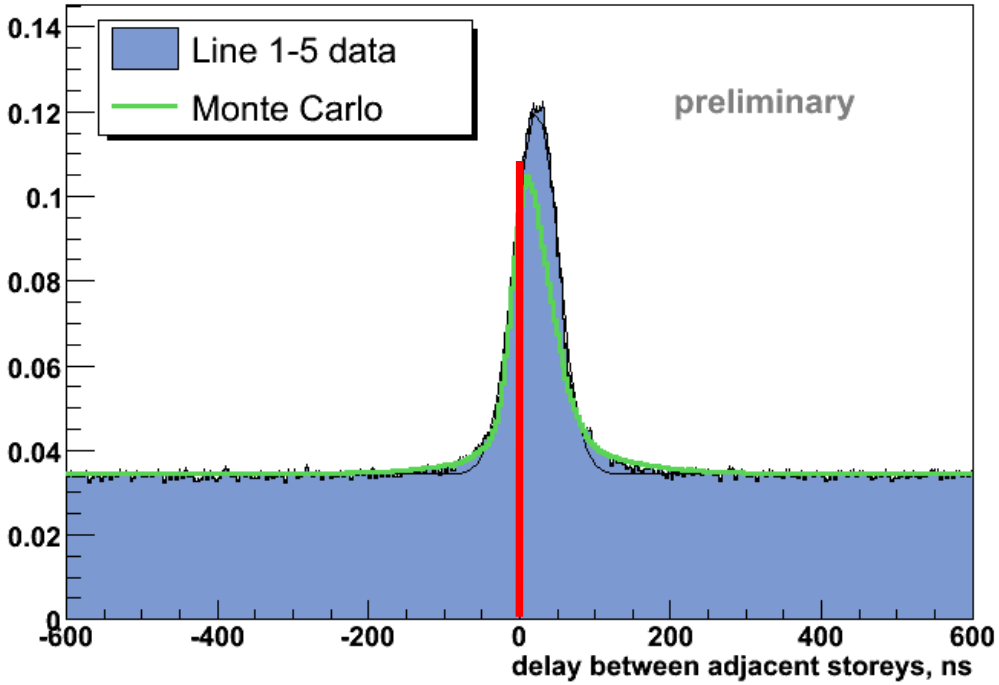


Muon rate v.s. depth

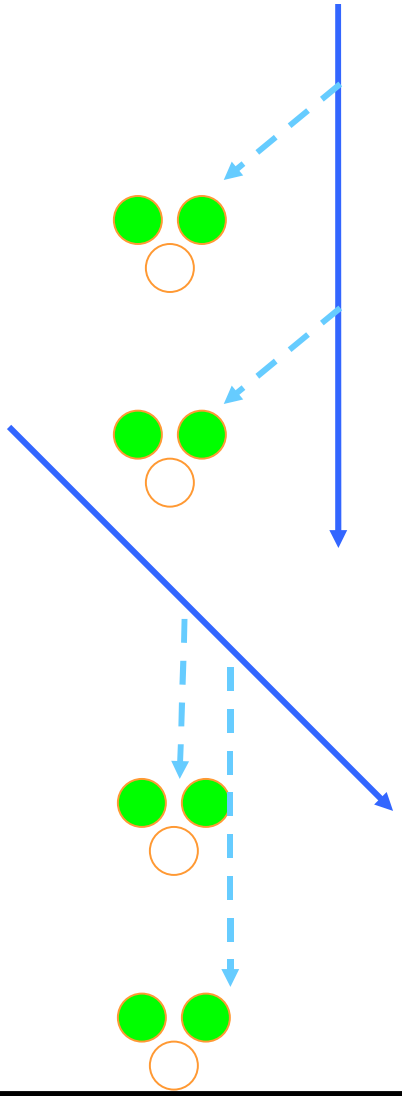
2 pairs of coincidences in adjacent storeys



±20 ns in same storey

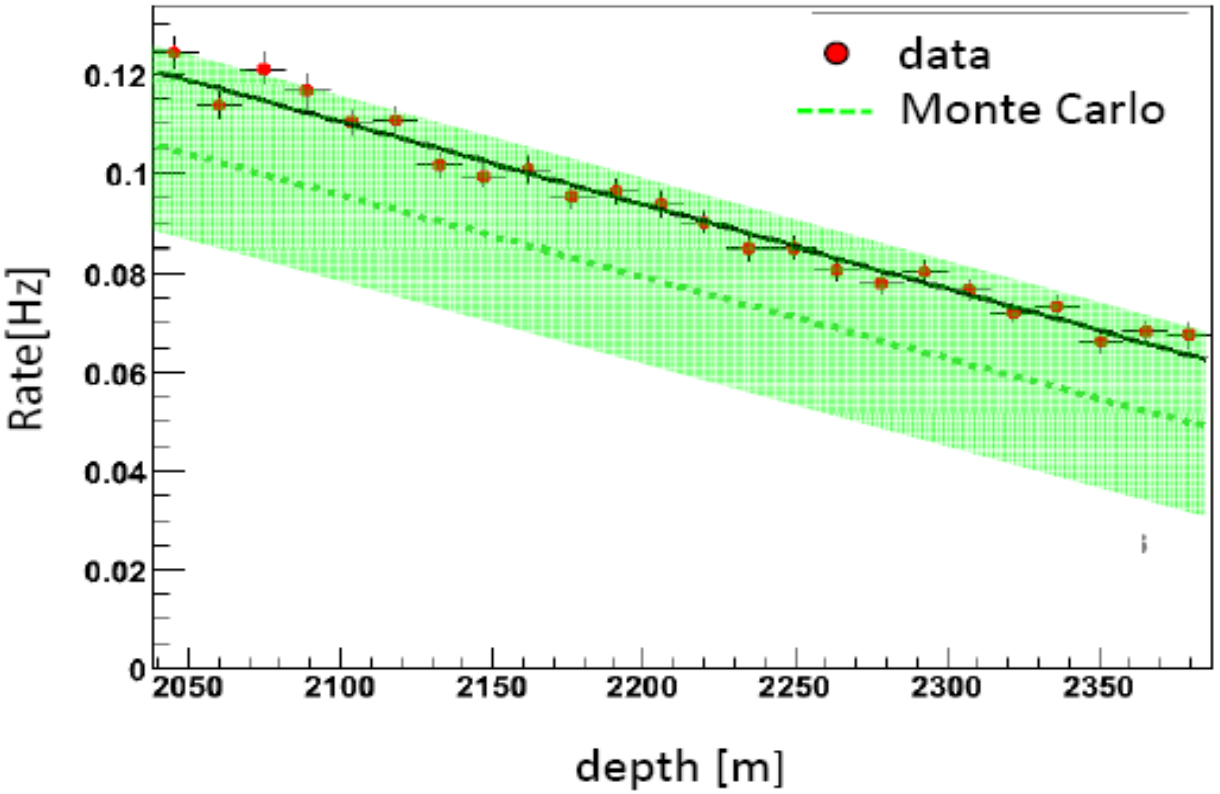


Muon rate v.s. depth

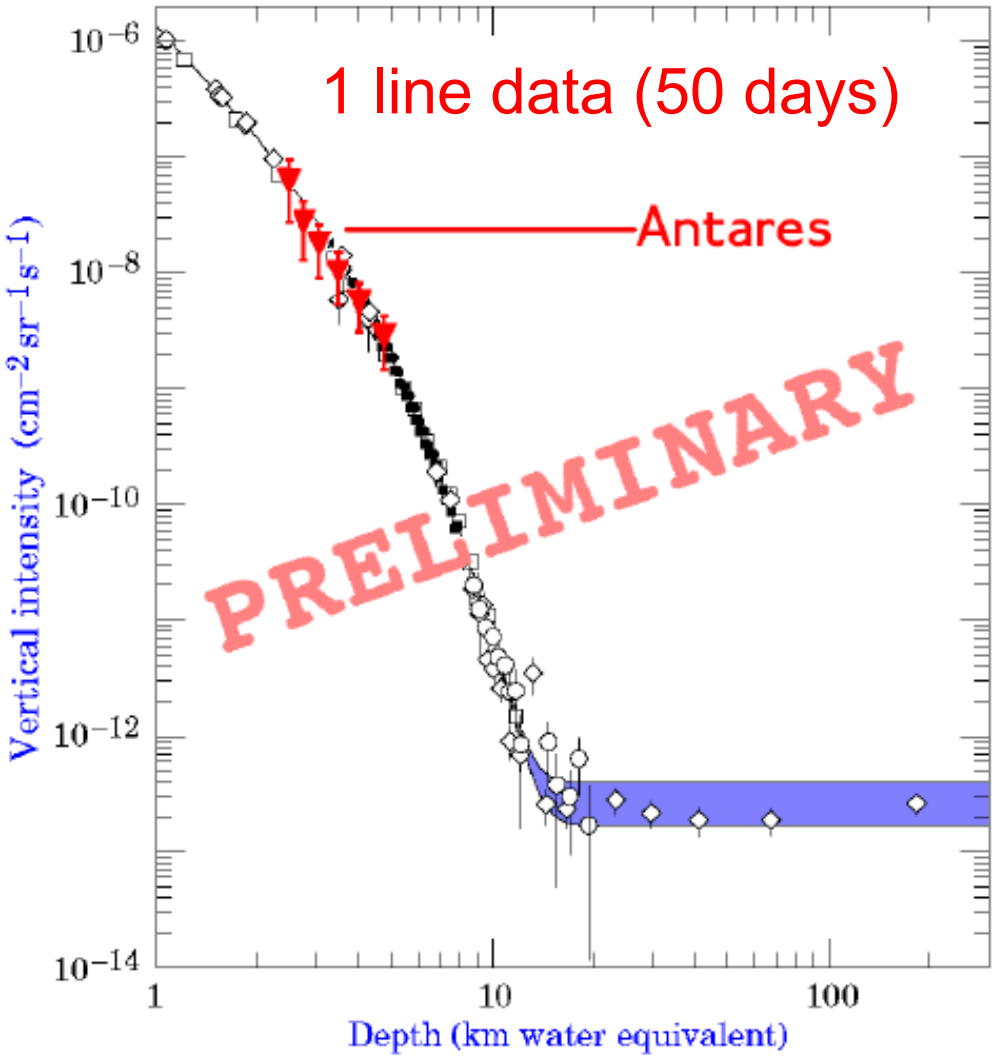


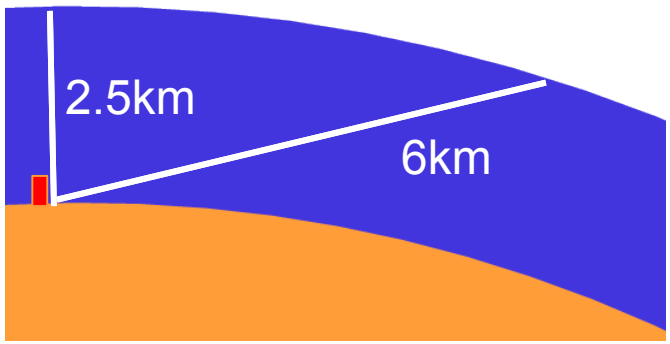
2 pairs of coincidences in adjacent storeys

±100 ns between consecutive storeys



1 line vertical muon flux





submitted

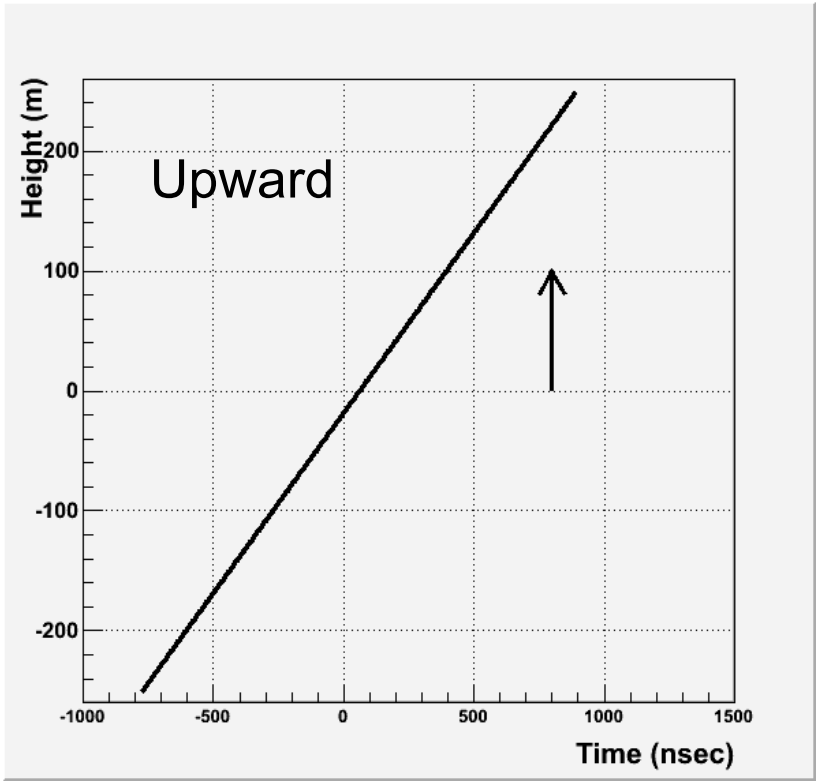
Events topology

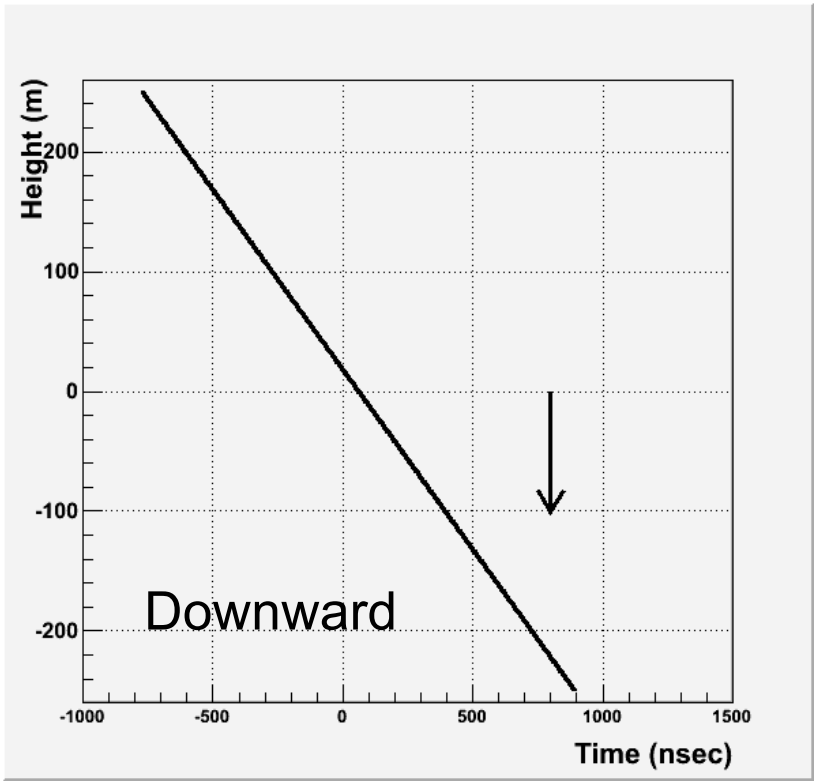
For 1 line

Arrival time (t) of γ v.s. altitude (z)

$\Rightarrow$ Vary with zenithal angle and distance

$\Pi(z,t) \cap \check{C}$ Cone $\Rightarrow$ Hyperbol





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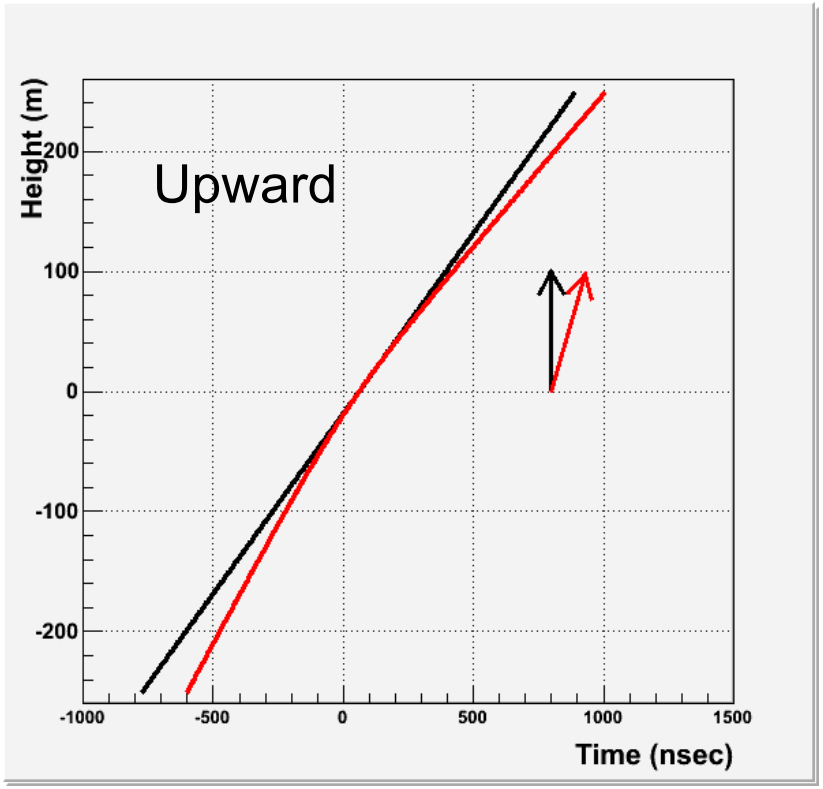

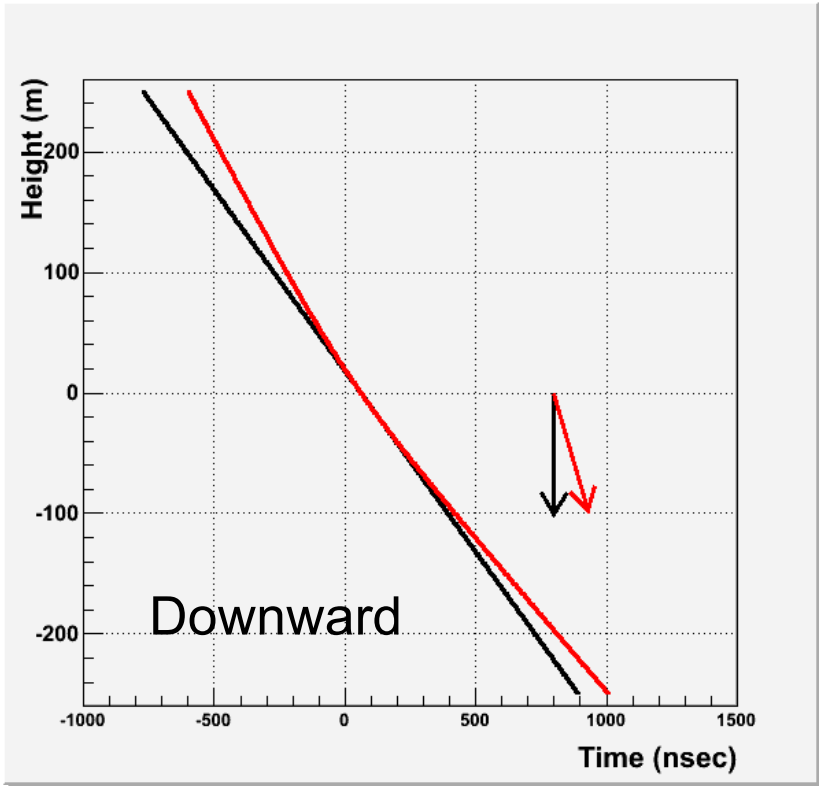

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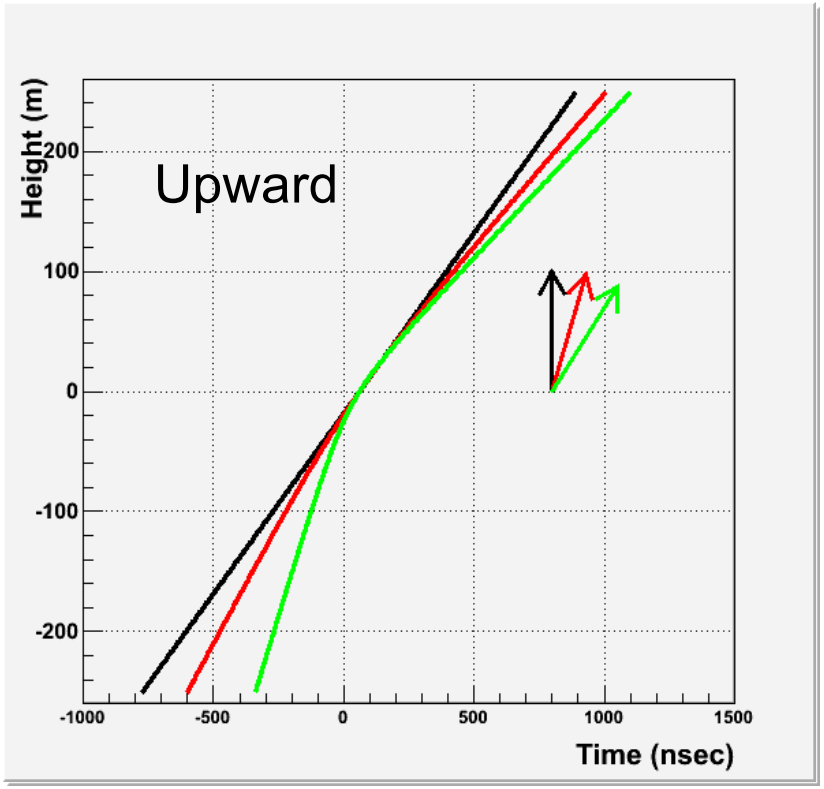

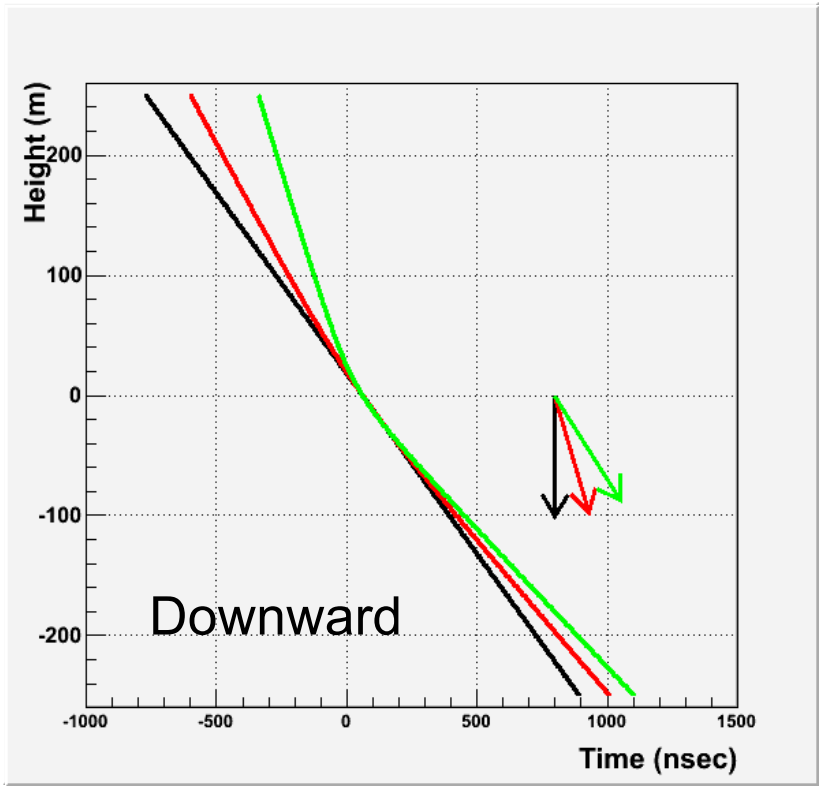

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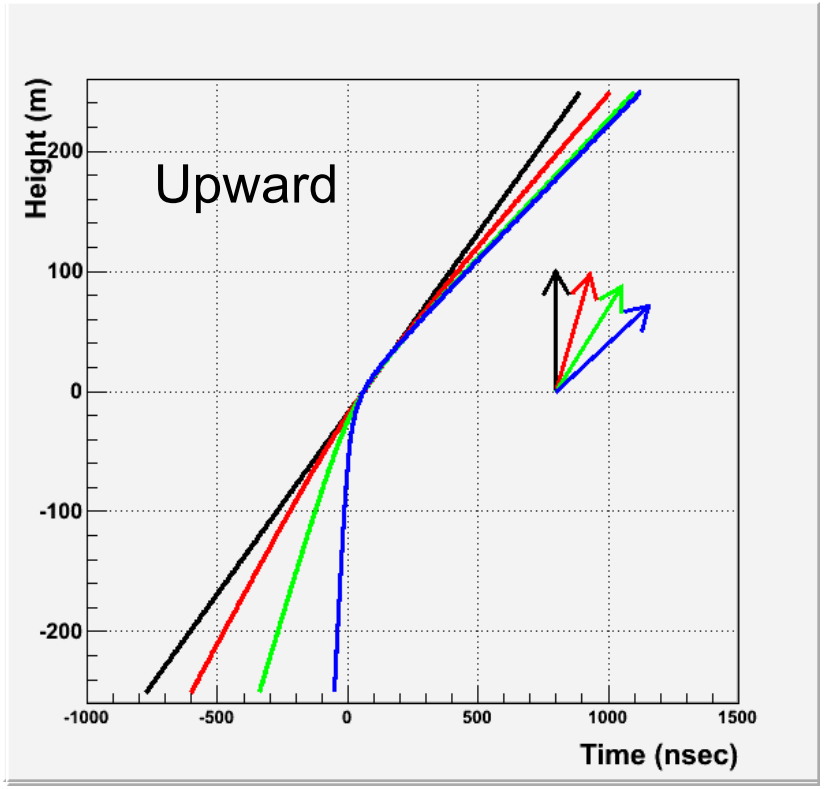

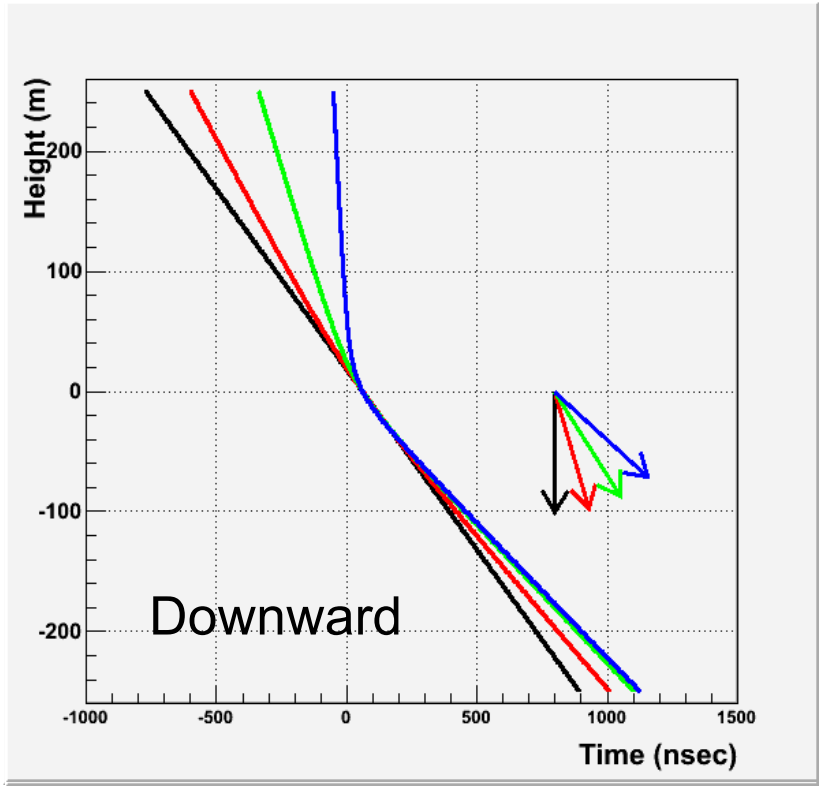

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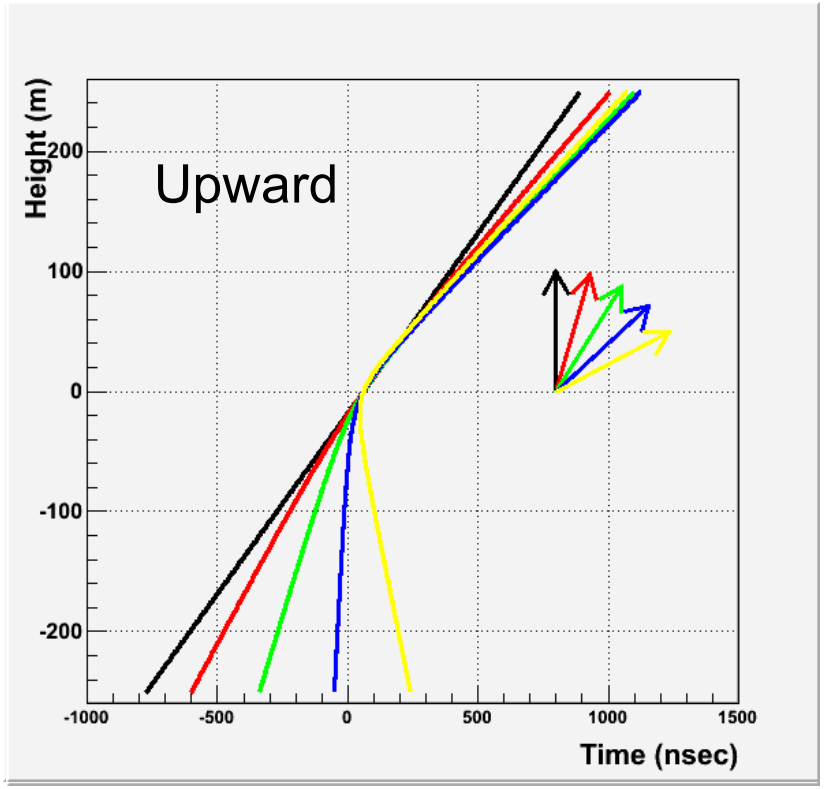

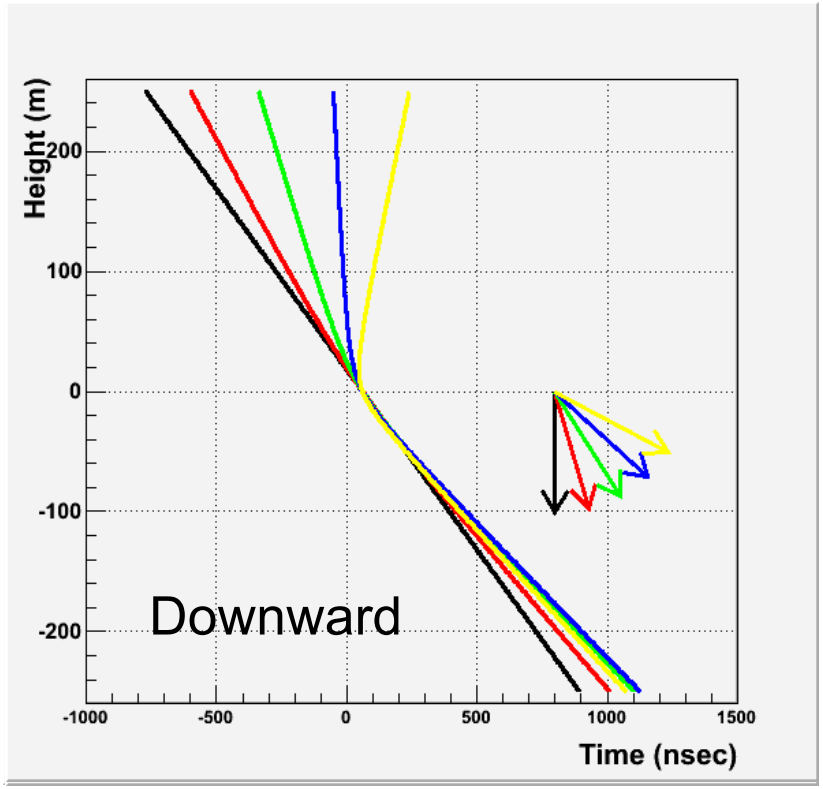

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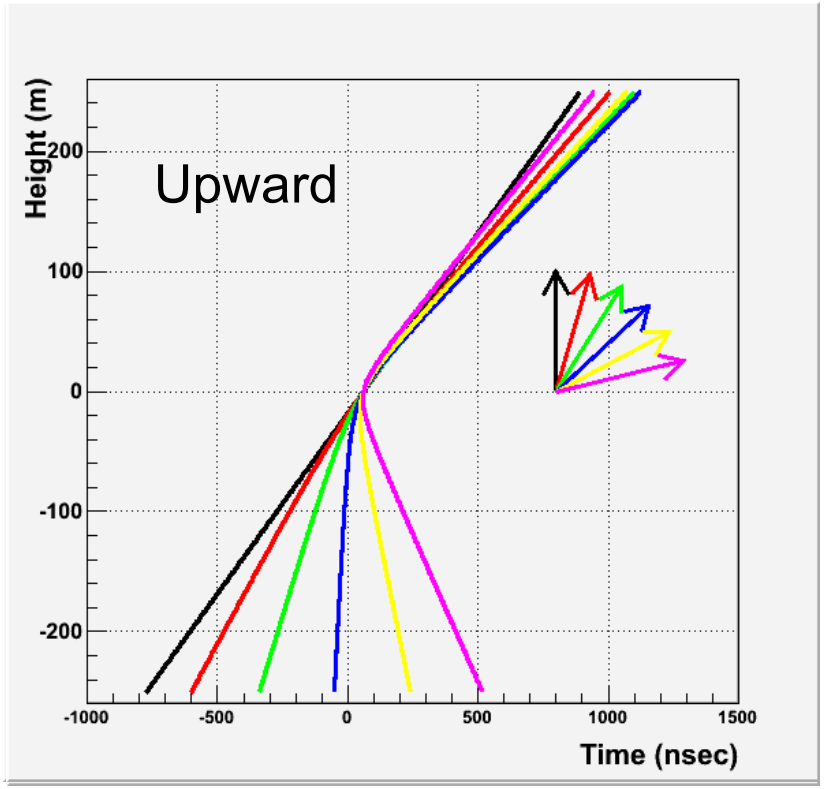

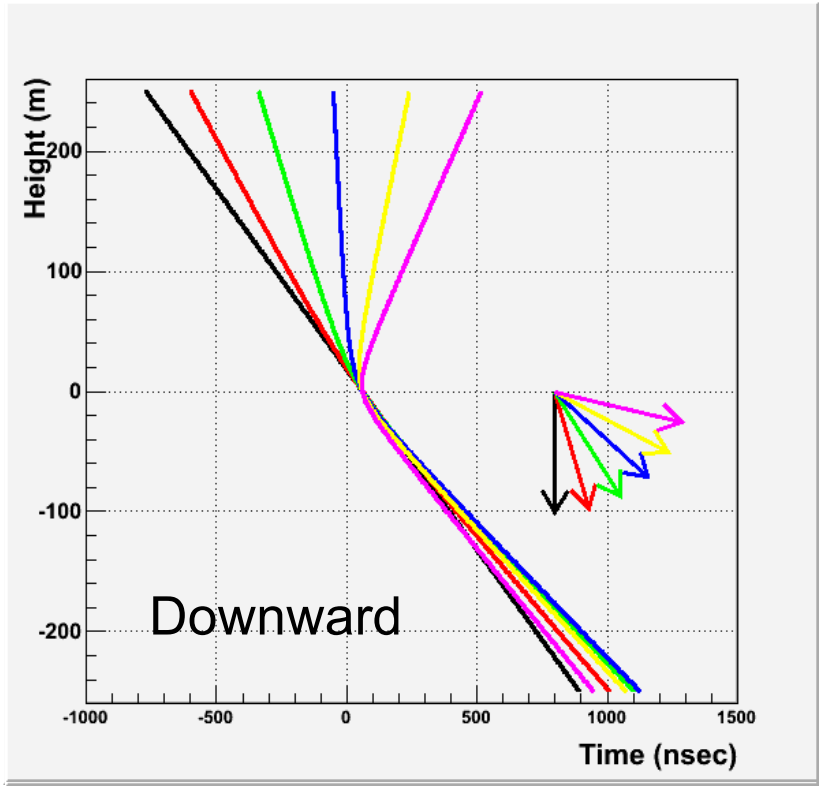

Events topology

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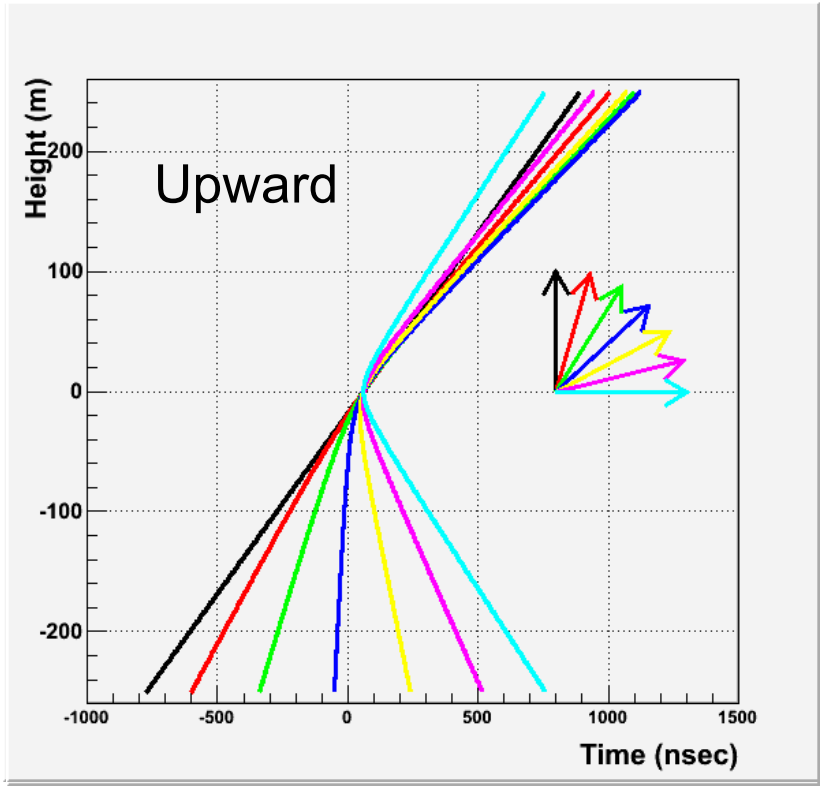
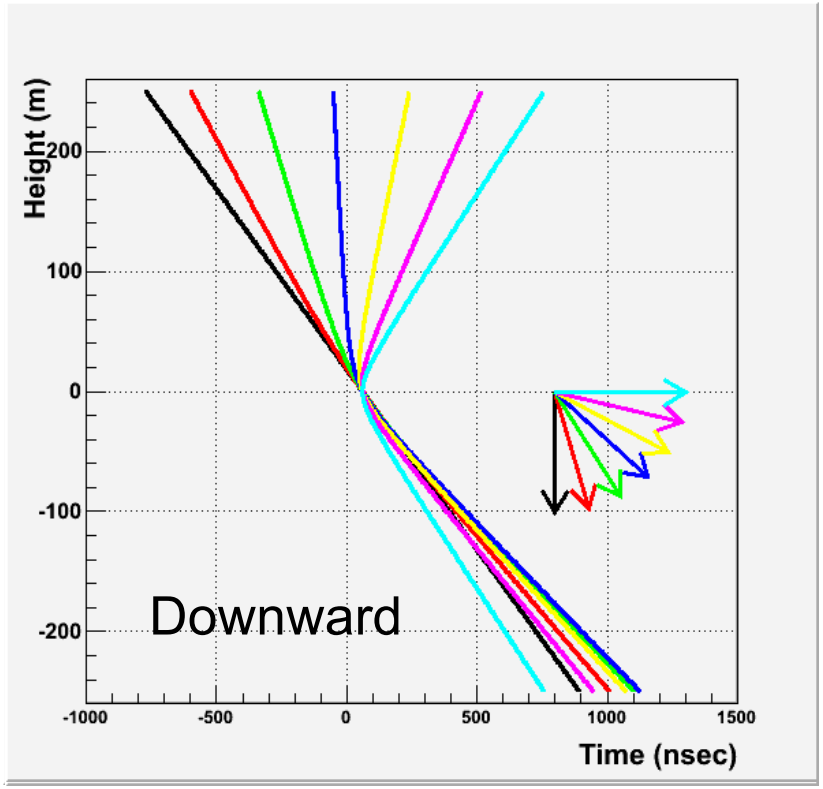
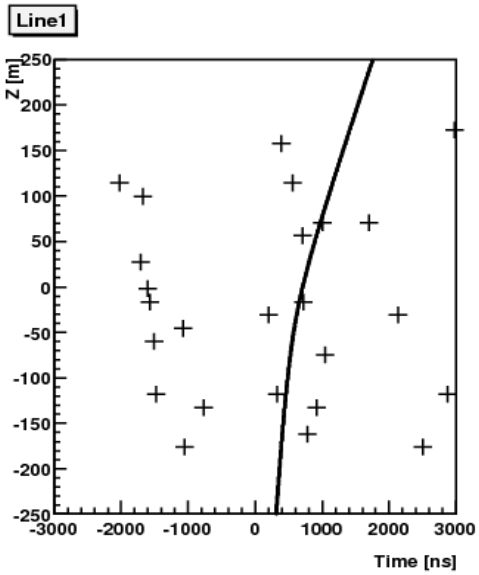
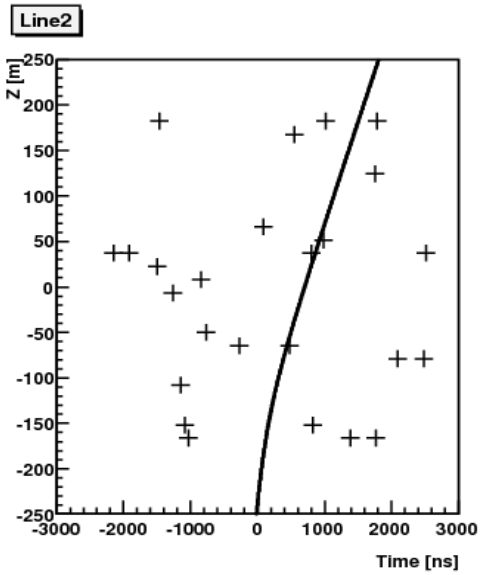


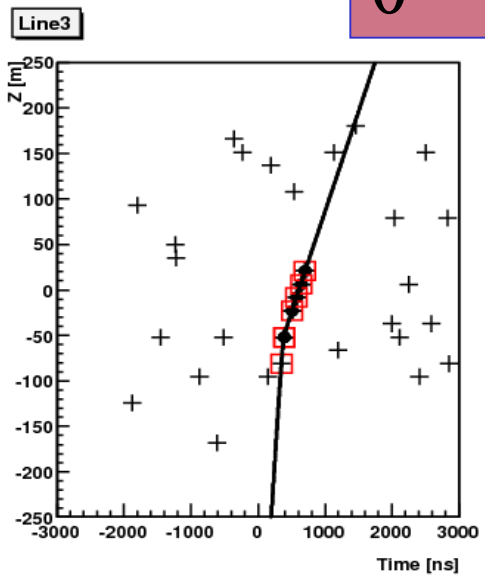


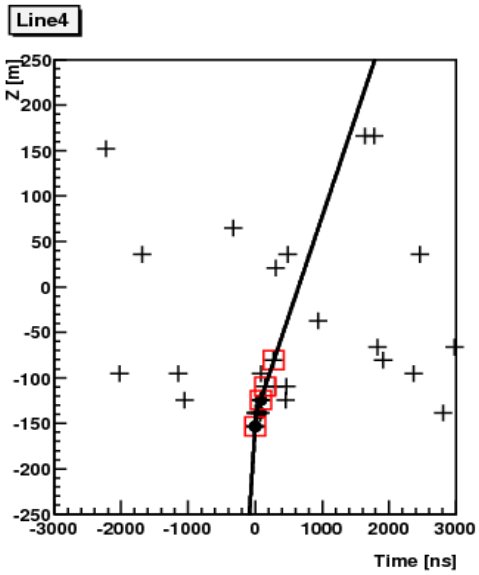
An upgoing ν candidate in the 5 Lines detector

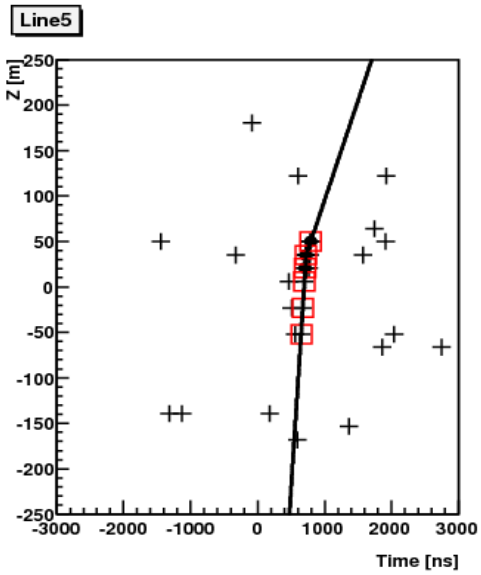
$\theta = 35^{o}$

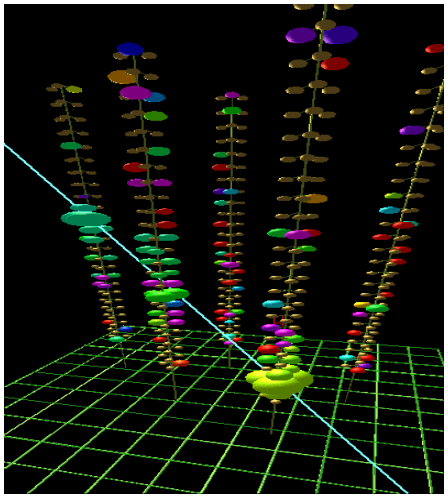




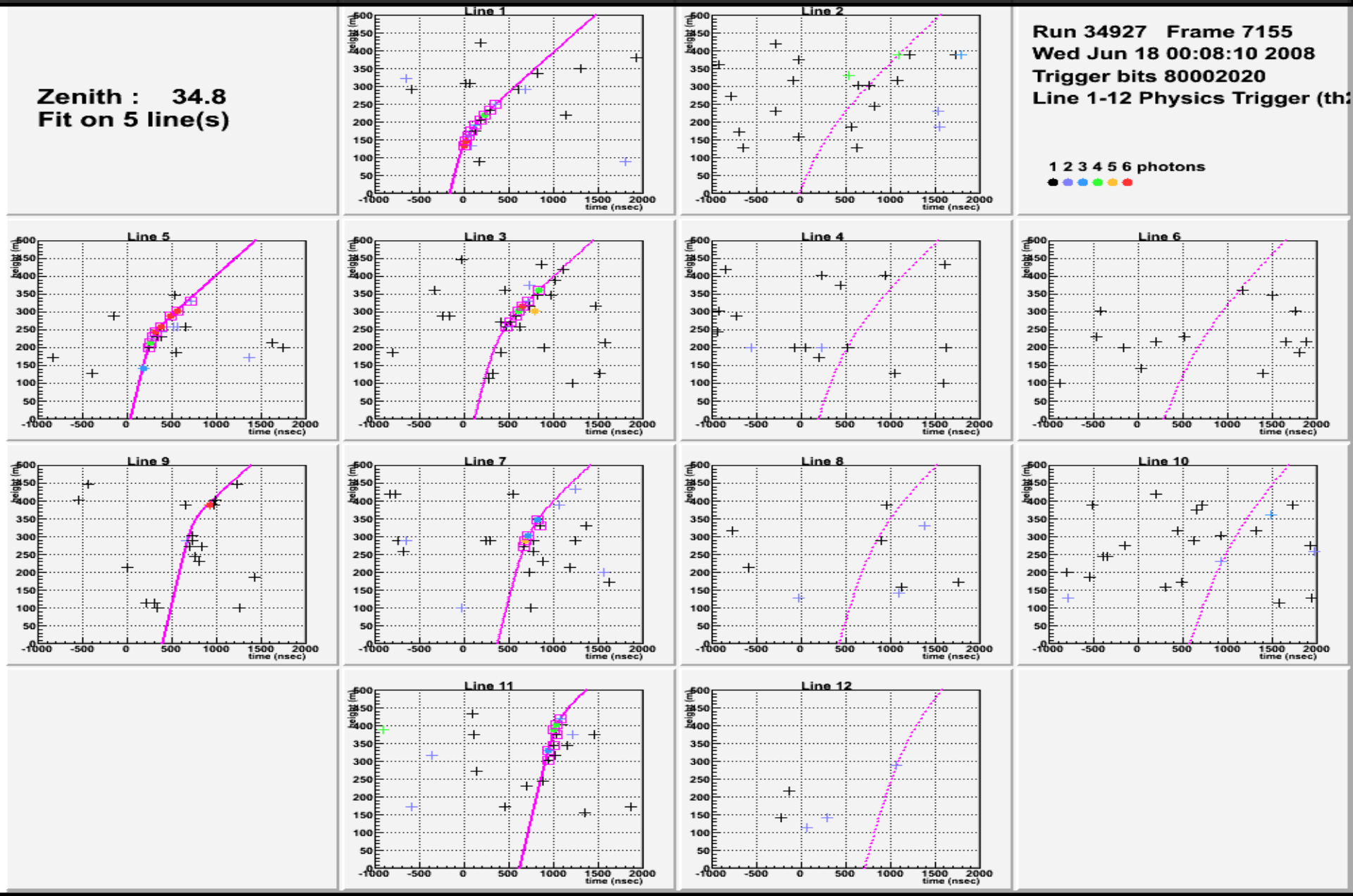






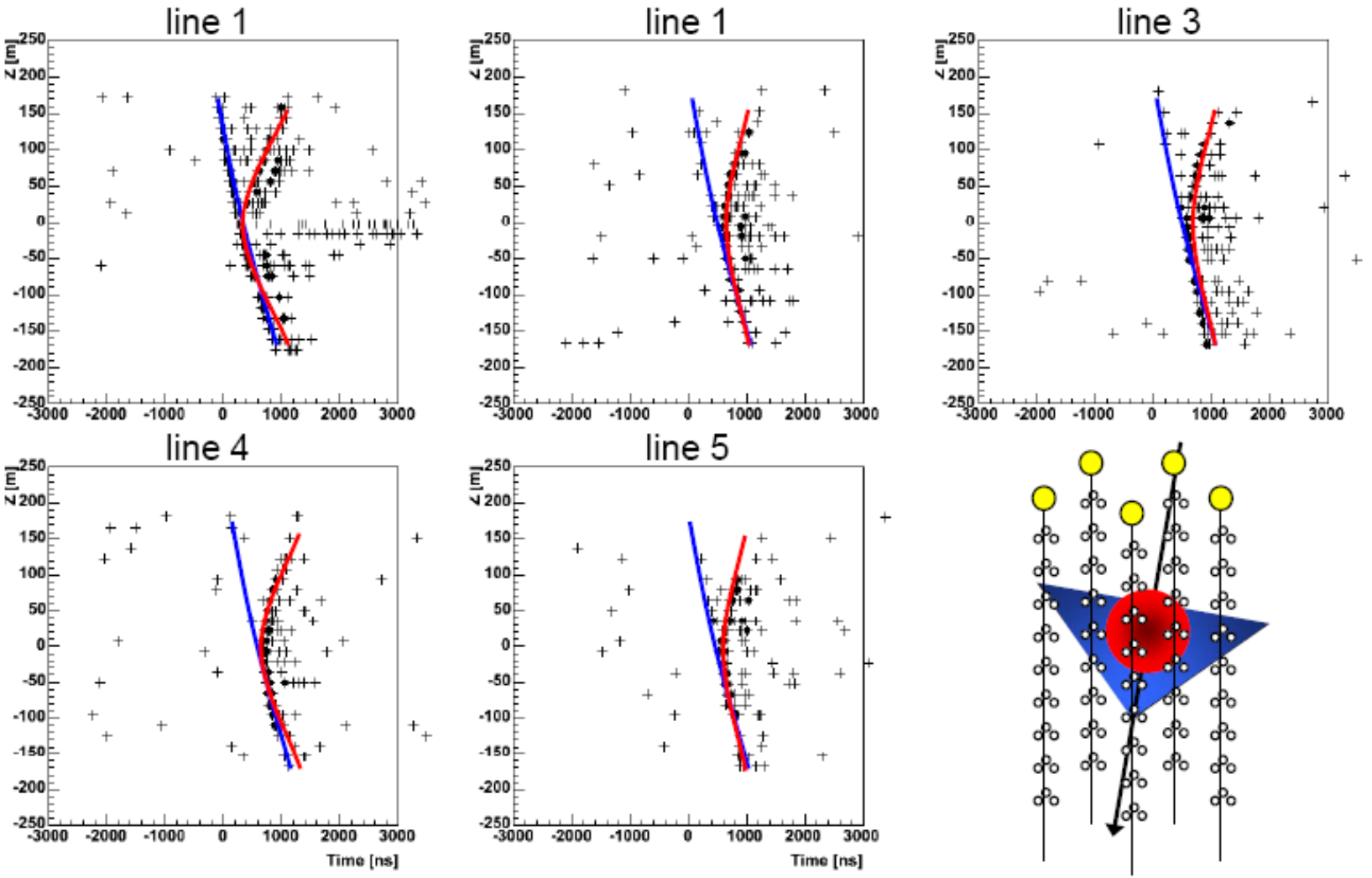


A ν in the 12 Lines detector



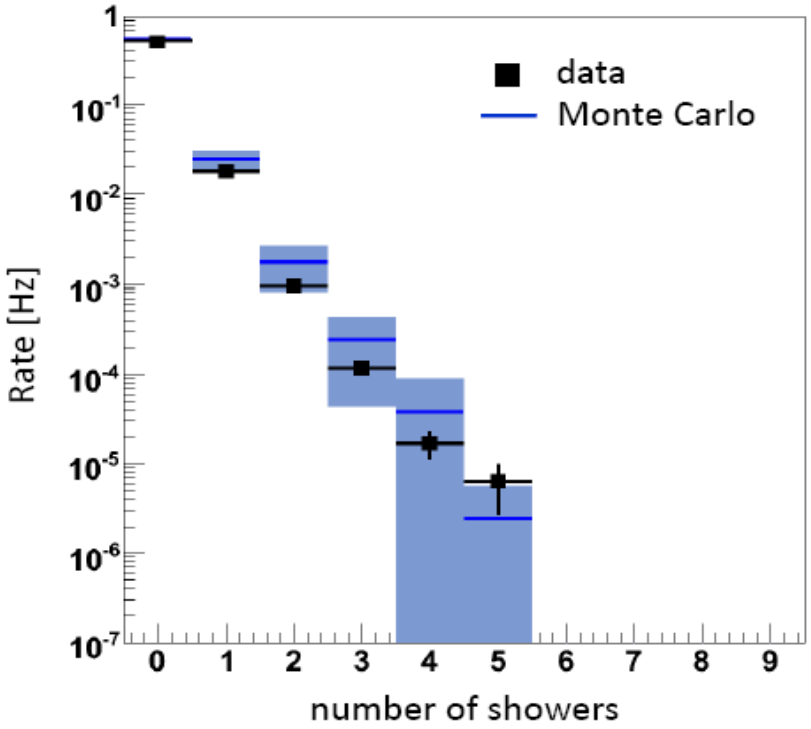
E-M shower detection

From muon bremsstrahlung



On line event display http://www.nikhef.nl/~mjg/display/

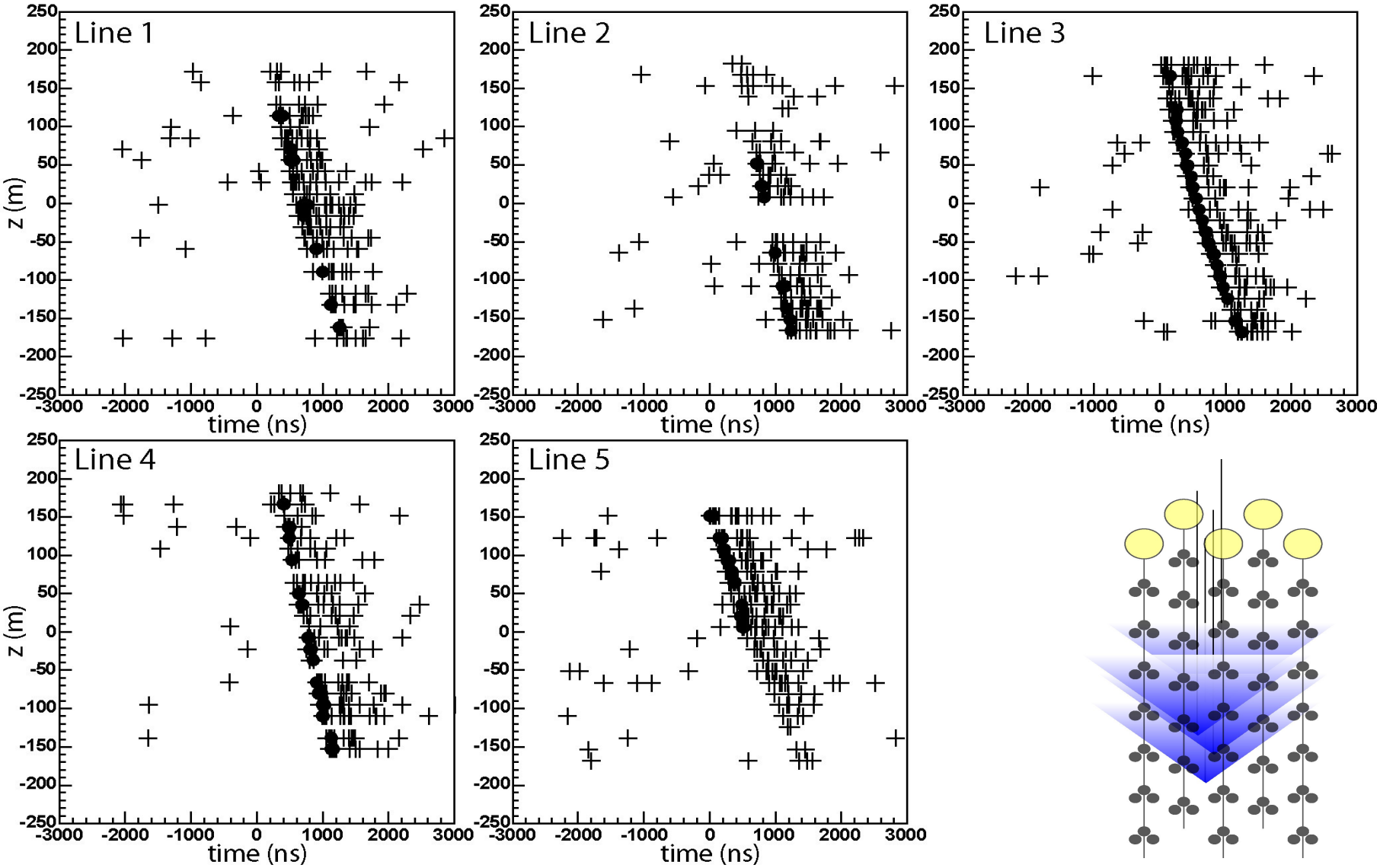
E-M shower detection



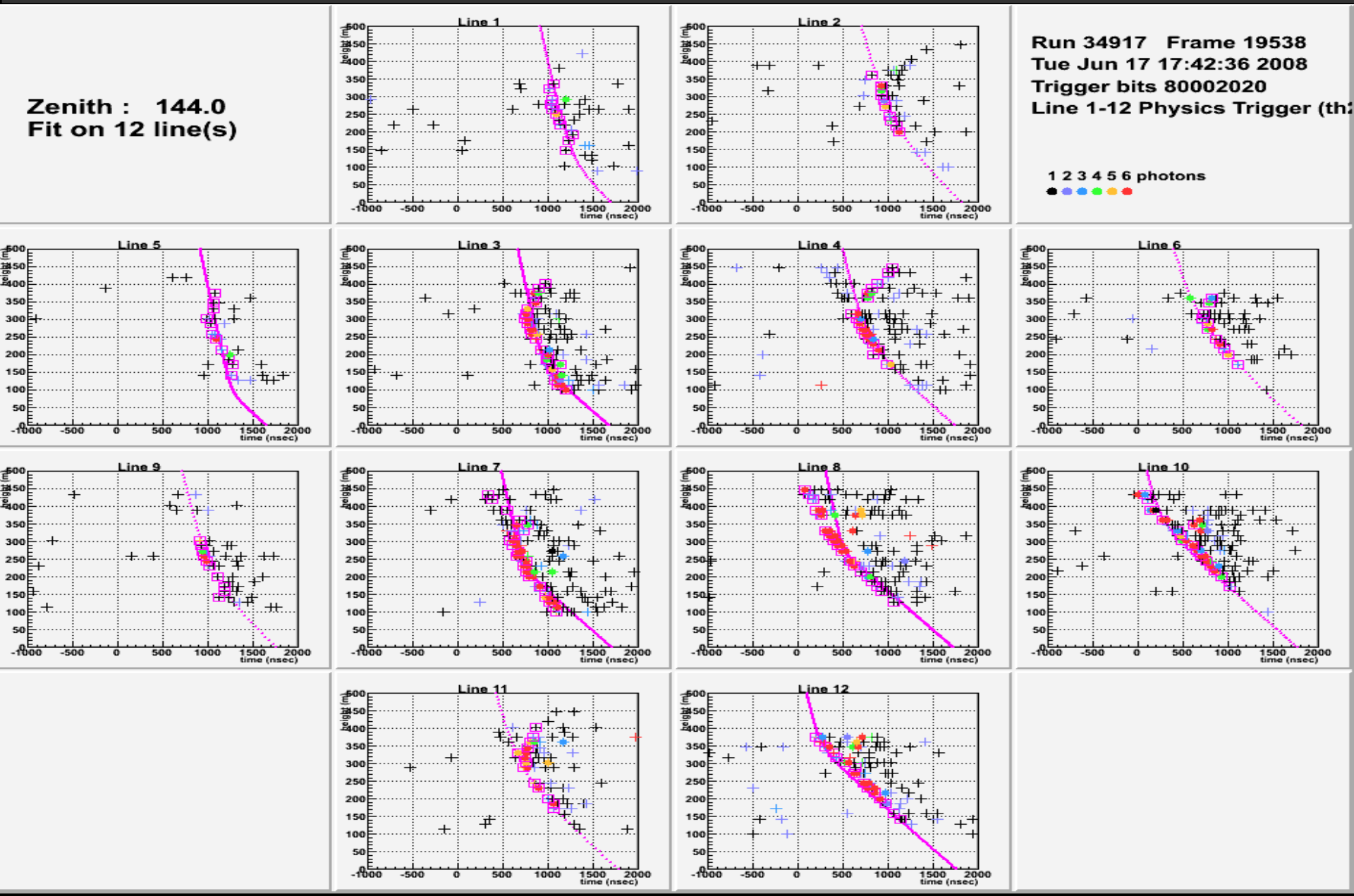
Systematic effects:

- ±20% absorption length
- PMT acceptance

A muon bundle in the 5 Line detector

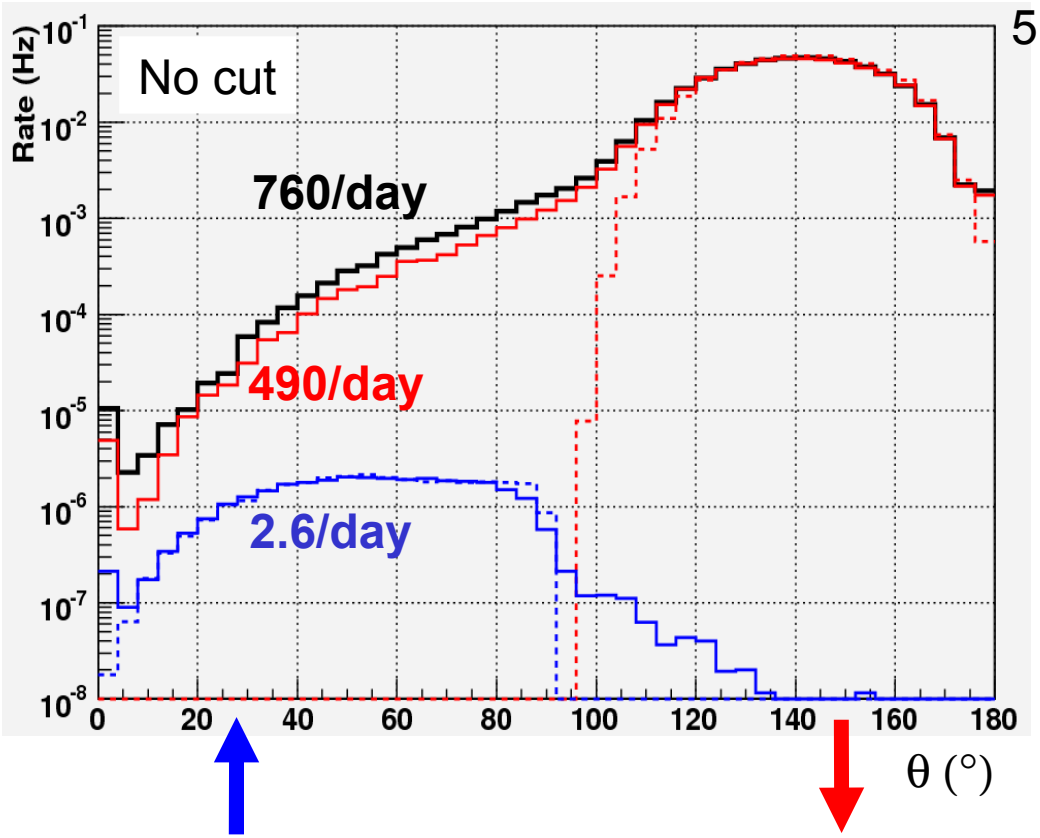


12 line muon bundle and E-M shower



MC-Data agreement and cuts on ν_{atm}-μ_{atm}

Muons ——— **Reconstruction**
Neutrinos - - - - - - - - **MC truth**
Data

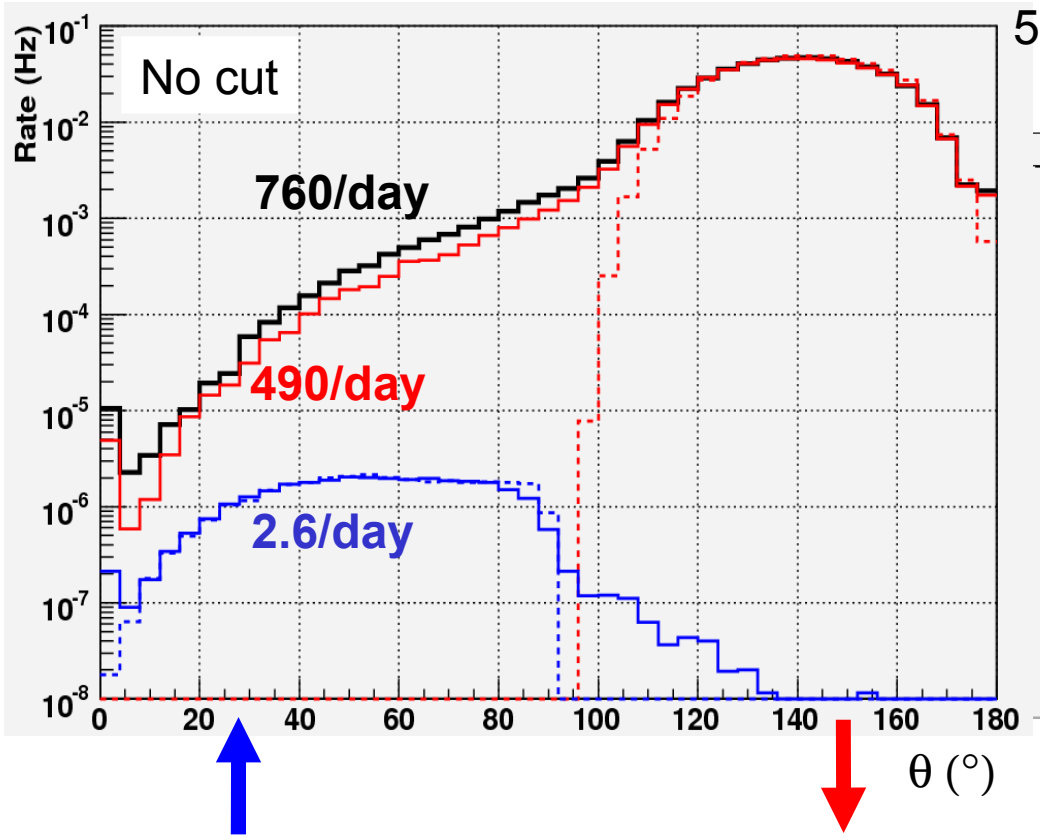


5 lines

Before cuts: difference MCtruth/Reco.
=>contamination by atmospheric μ reconstructed as upward

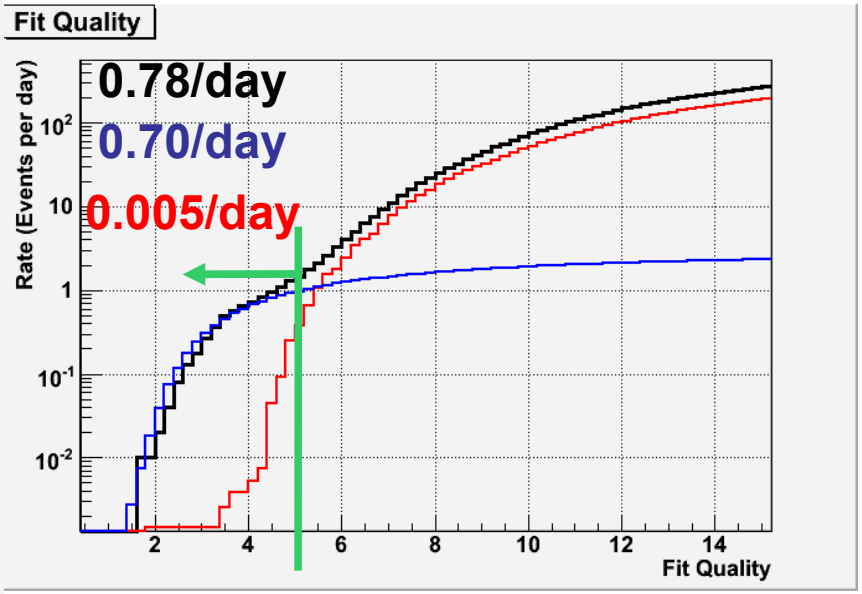
MC-Data agreement and cuts

Muons ——— **Reconstruction**
Neutrinos - - - - - - - - **MC truth**
Data



5 lines

Upward tracks:



Before cuts: difference MCtruth/Reco.
=>contamination by atmospheric μ reconstructed as upward

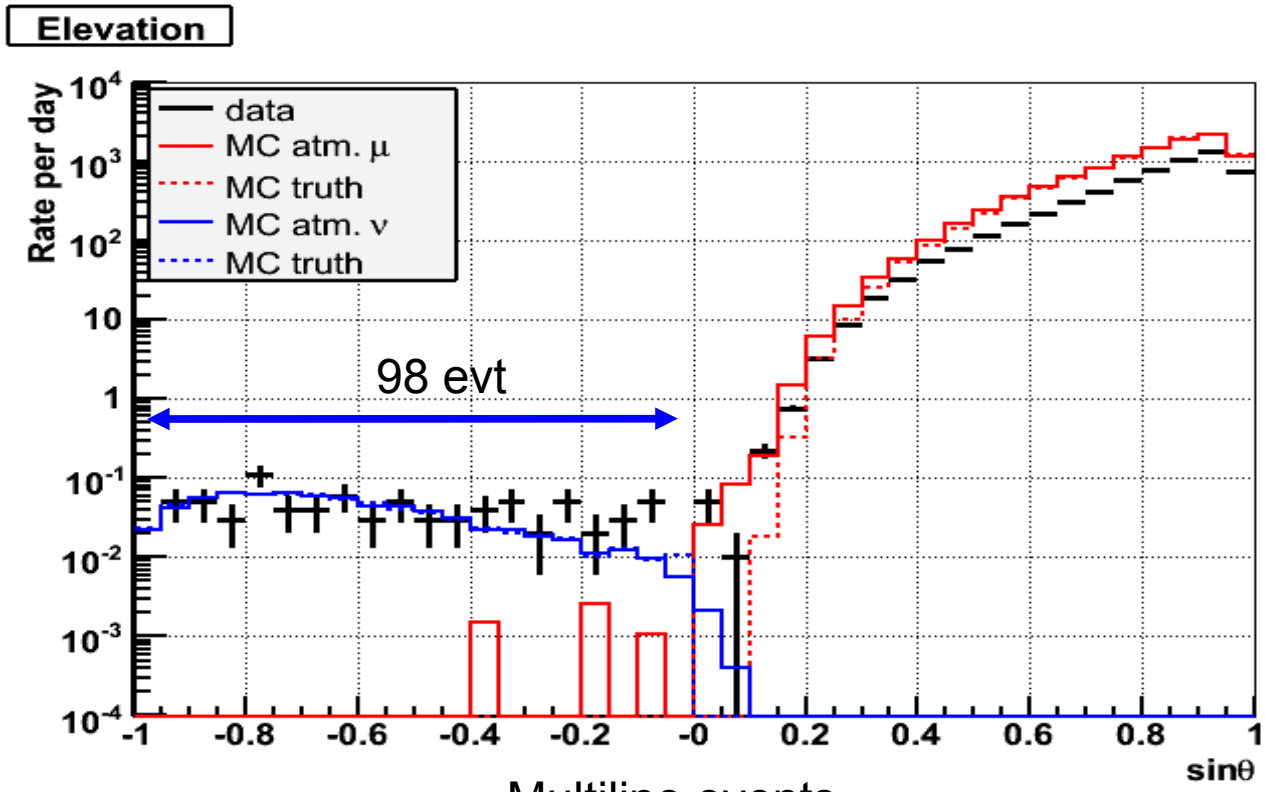
Quality cut:
⇨get rid of badly reconstructed μ
~99.5% ν purity

Data with the 5 Line detector 06->12/2007

MC = Corsika
Horandel flux
QGSJET hadronic model

139 active days

Track $\chi 2$ cut

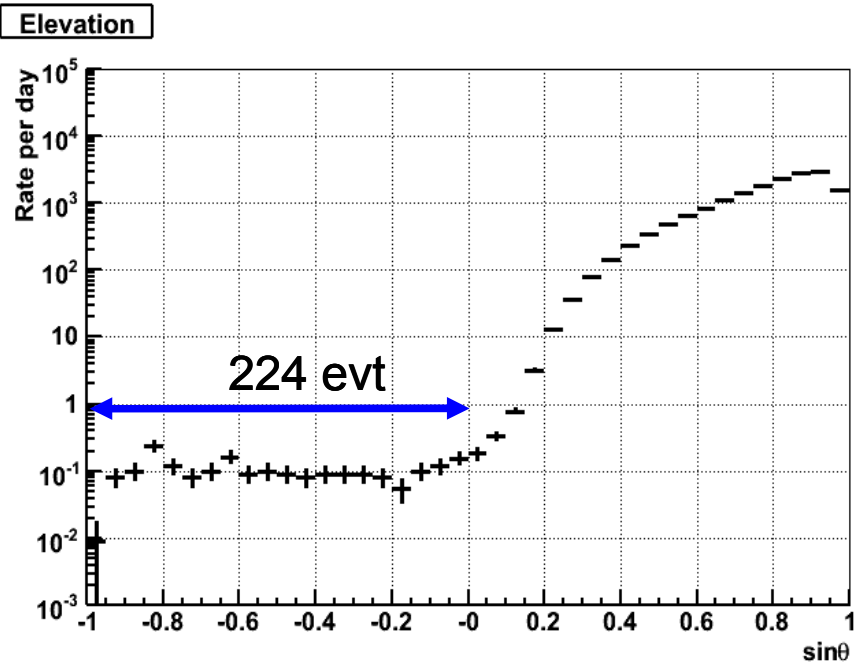


Multiline events

+58 single line events

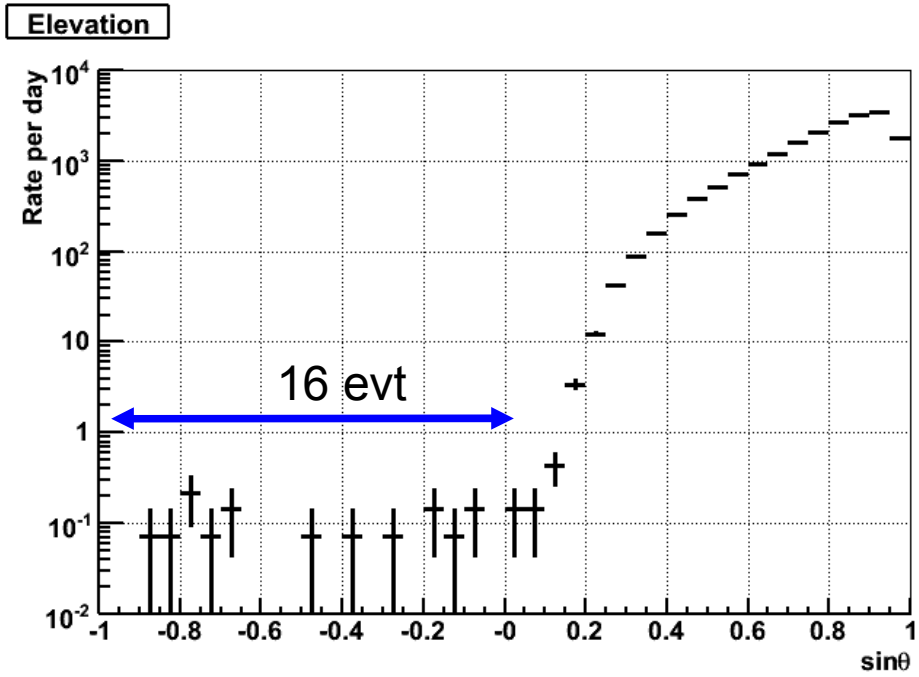
More and more lines...

10 lines 12/07-04/08
109 active days



+88 single line evt.

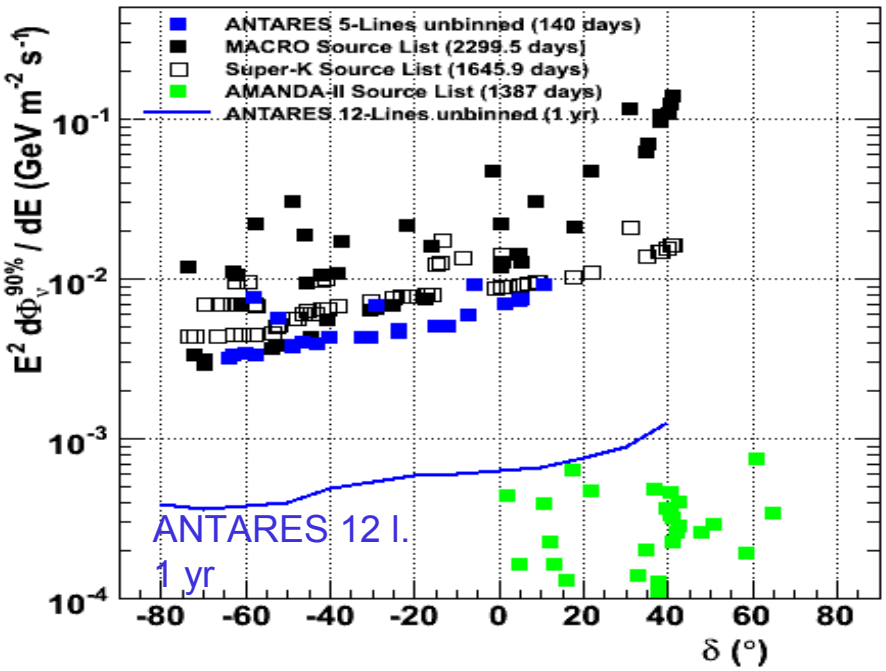
12 lines 06/07
14 active days



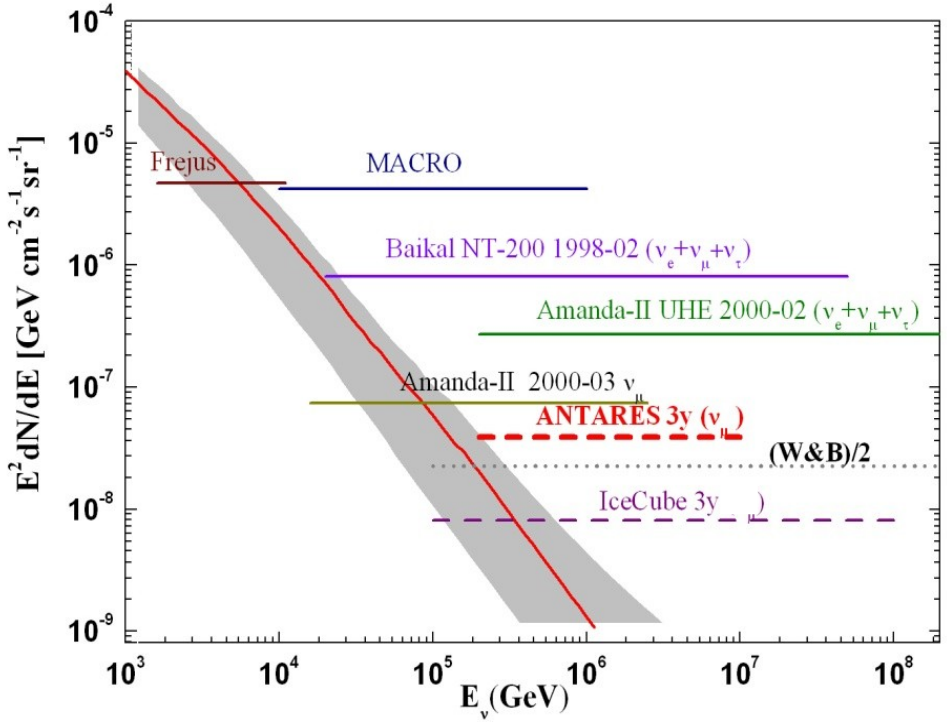
+11 single line evt.

First limits & expected sensitivities

Point Sources of neutrinos



Diffuse flux of neutrinos



Conclusions & outlook

- ANTARES detector complete, alive and working !
- Technology proven

  - Detector under control
- Data analysis in progress

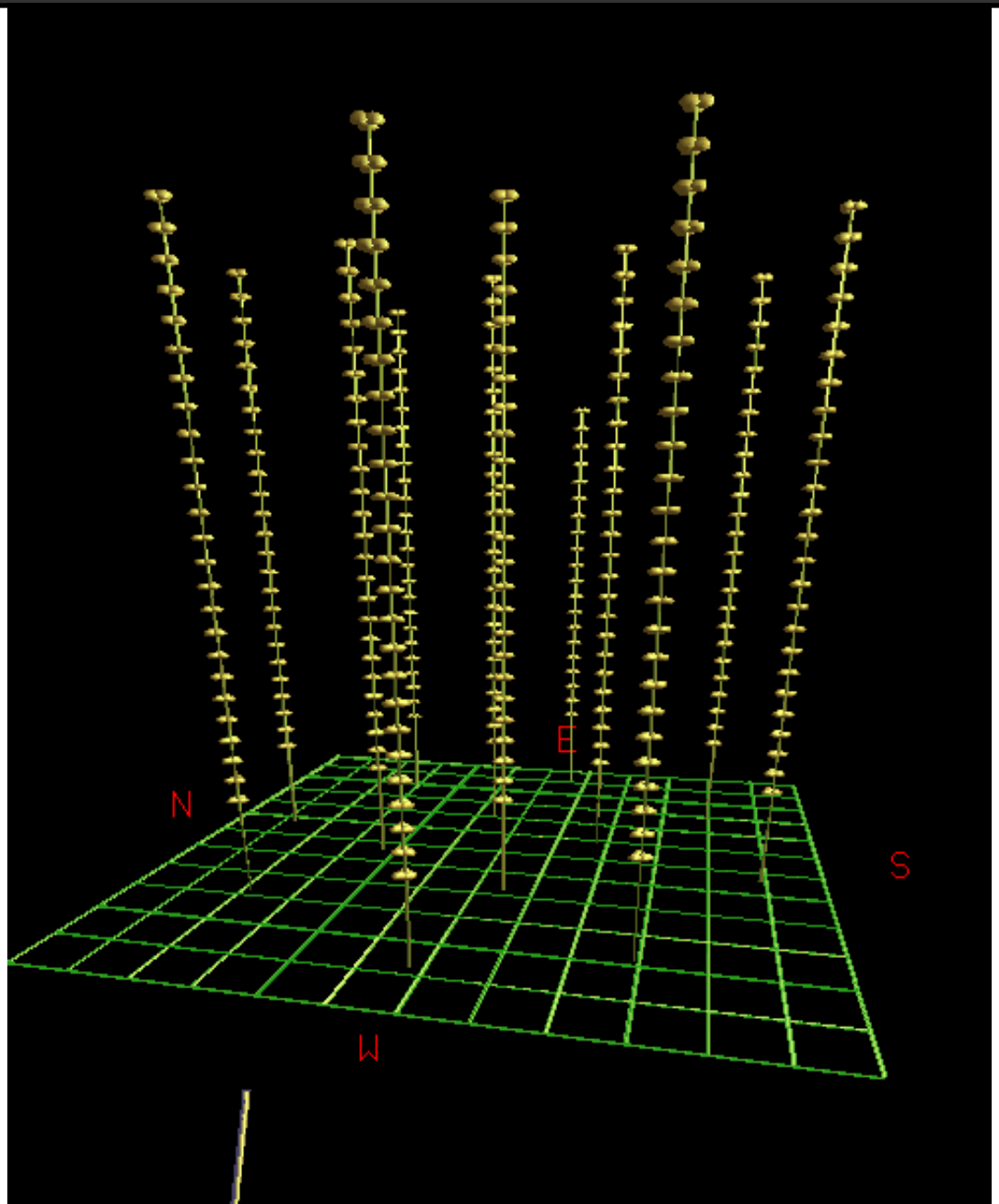
  - nearly 500 neutrino events selected

  - first physics results and much more coming

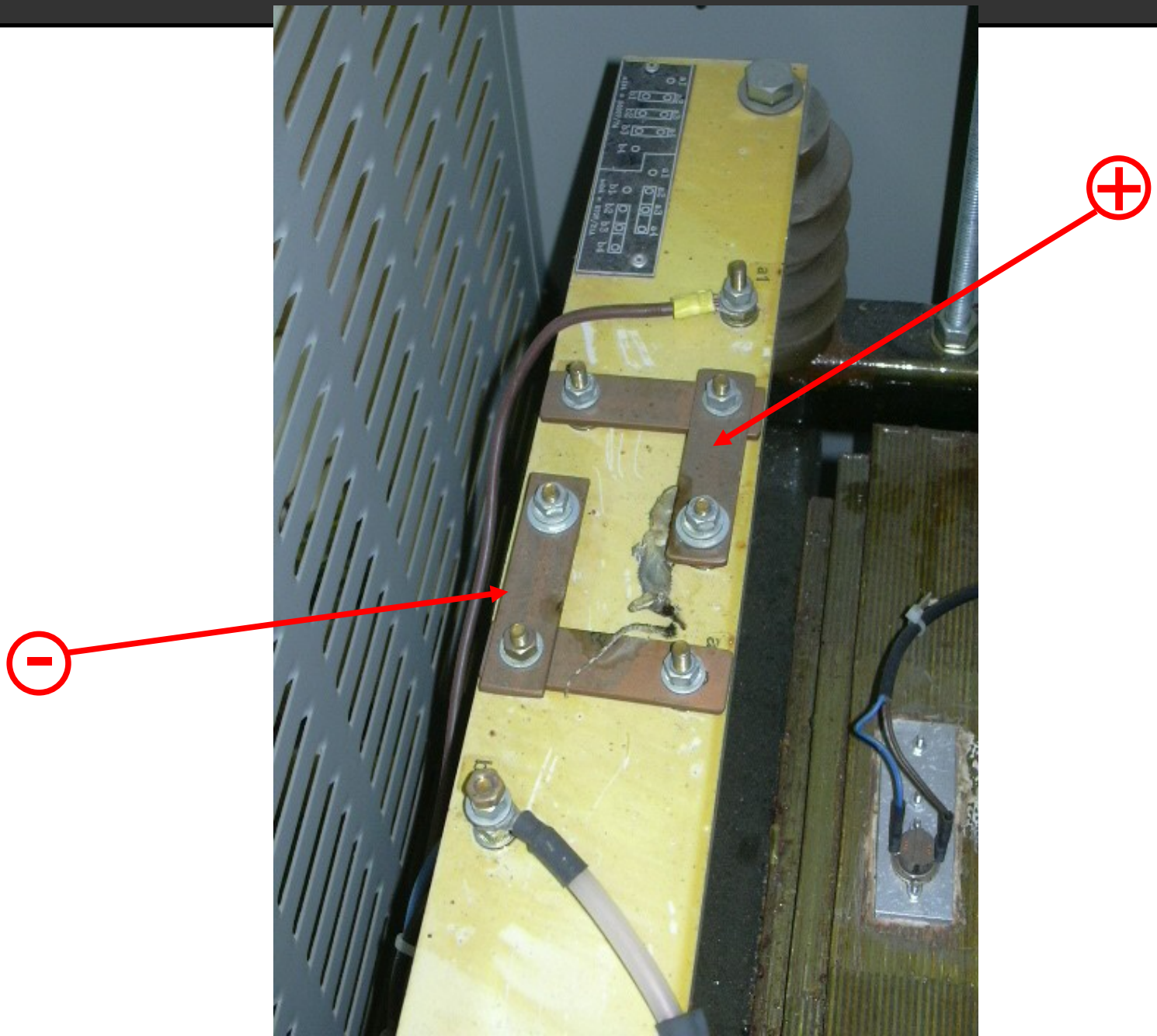
Stay tuned!

- Ready for next step with KM3NeT Detector.....

It's alive!



Lizard suicide



Hard work to repair

New spokesman

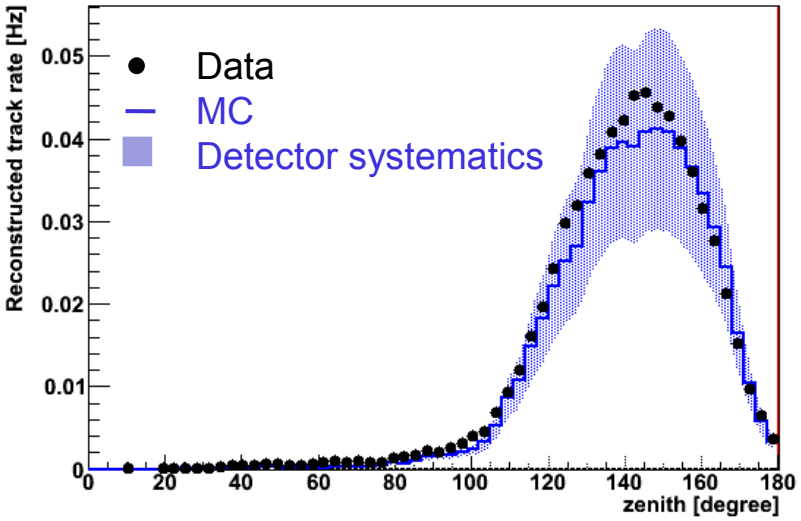
http://antares.in2p3.fr/News/CableReparation/cablefix.swf

Backup: optical properties

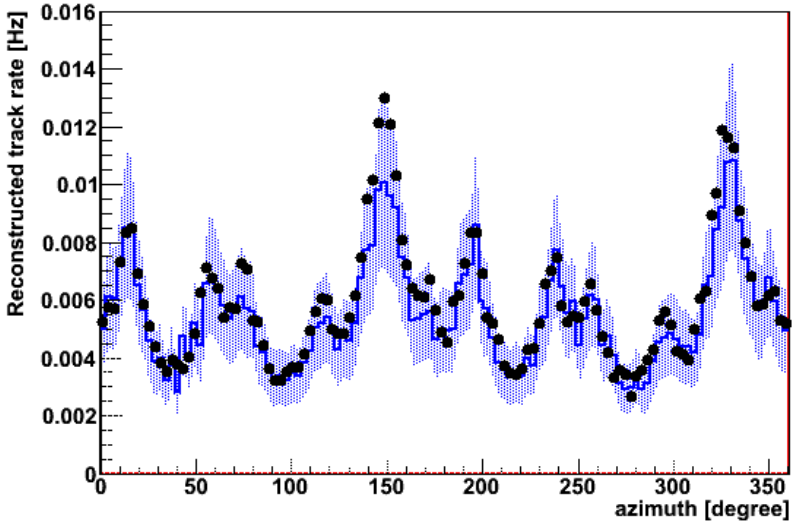
[$\lambda \sim 460$ nm] (blue)	Absorption length [m]	Scattering length [m]	Angular Resolution [°] (< 0.1km^2, E>10 TeV)
South Pole Ice	≤ 100	≤ 25	3°
Lake Baikal	≥ 15	> 300	1.5°
Mediterranean Sea	55	> 300	0.2°

Detector Systematics

Zenith angle



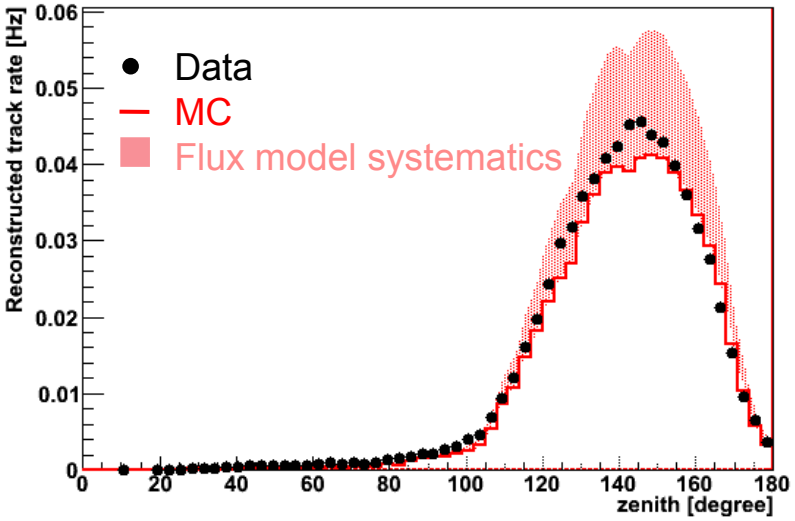
Azimuth angle



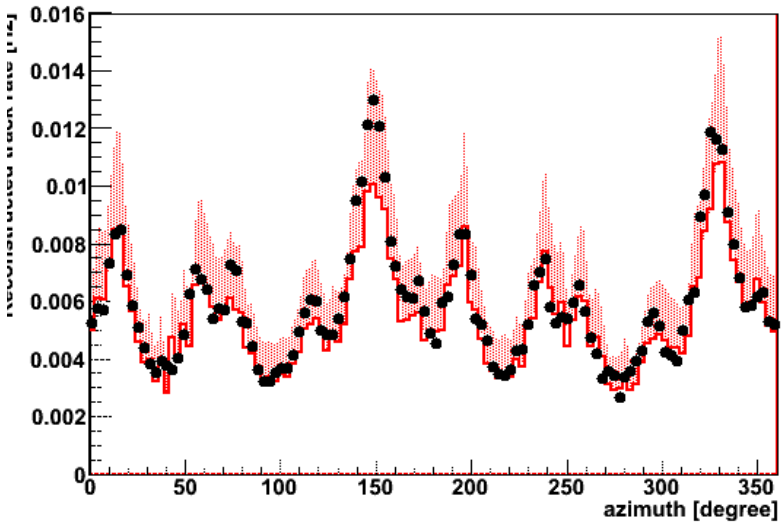
- systematic error due to +/- 10% on absorption length = +25%/-20%;
- syst. err. due to -15% on PMT efficiency (QE, eff. area etc) = -15%;
- syst. err. due to cutoff in angular accept. = +20%/-15%;
- total systematic uncertainty +/- 30%.

Systematics from flux model

Zenith angle

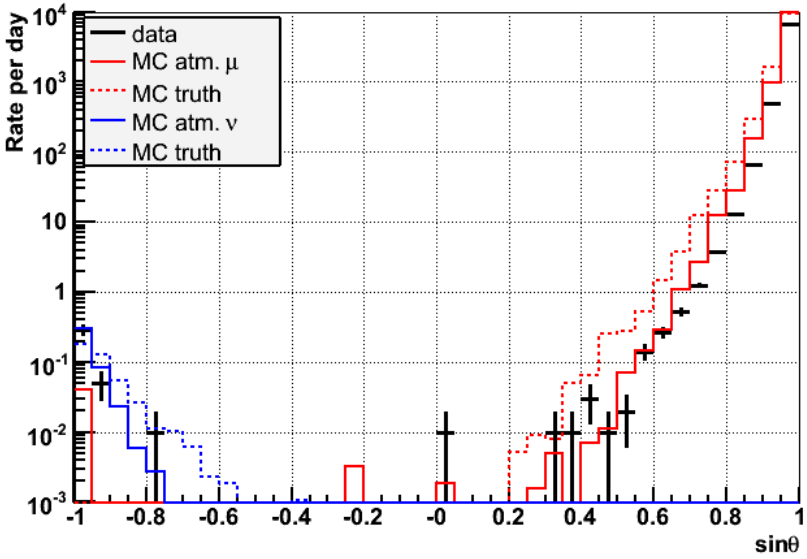


Azimuth angle

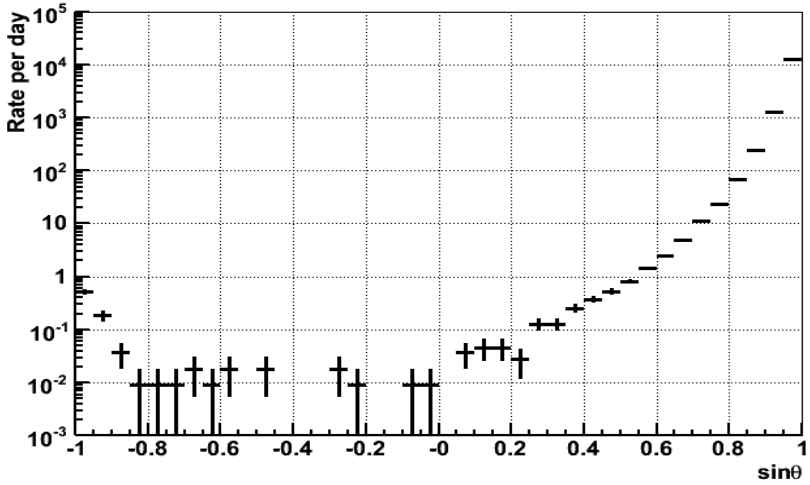


- +30% for primary flux;
- +25% for the hadronic shower model;
- total systematic uncertainty +40%.

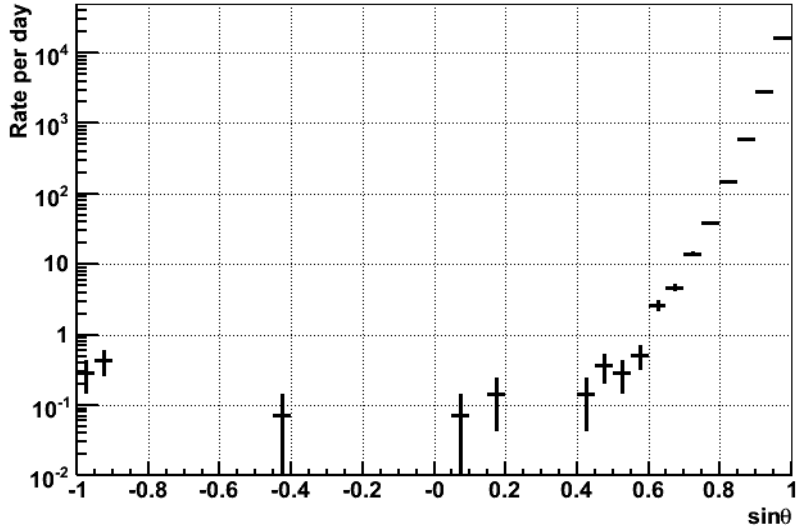
Elevation



Elevation

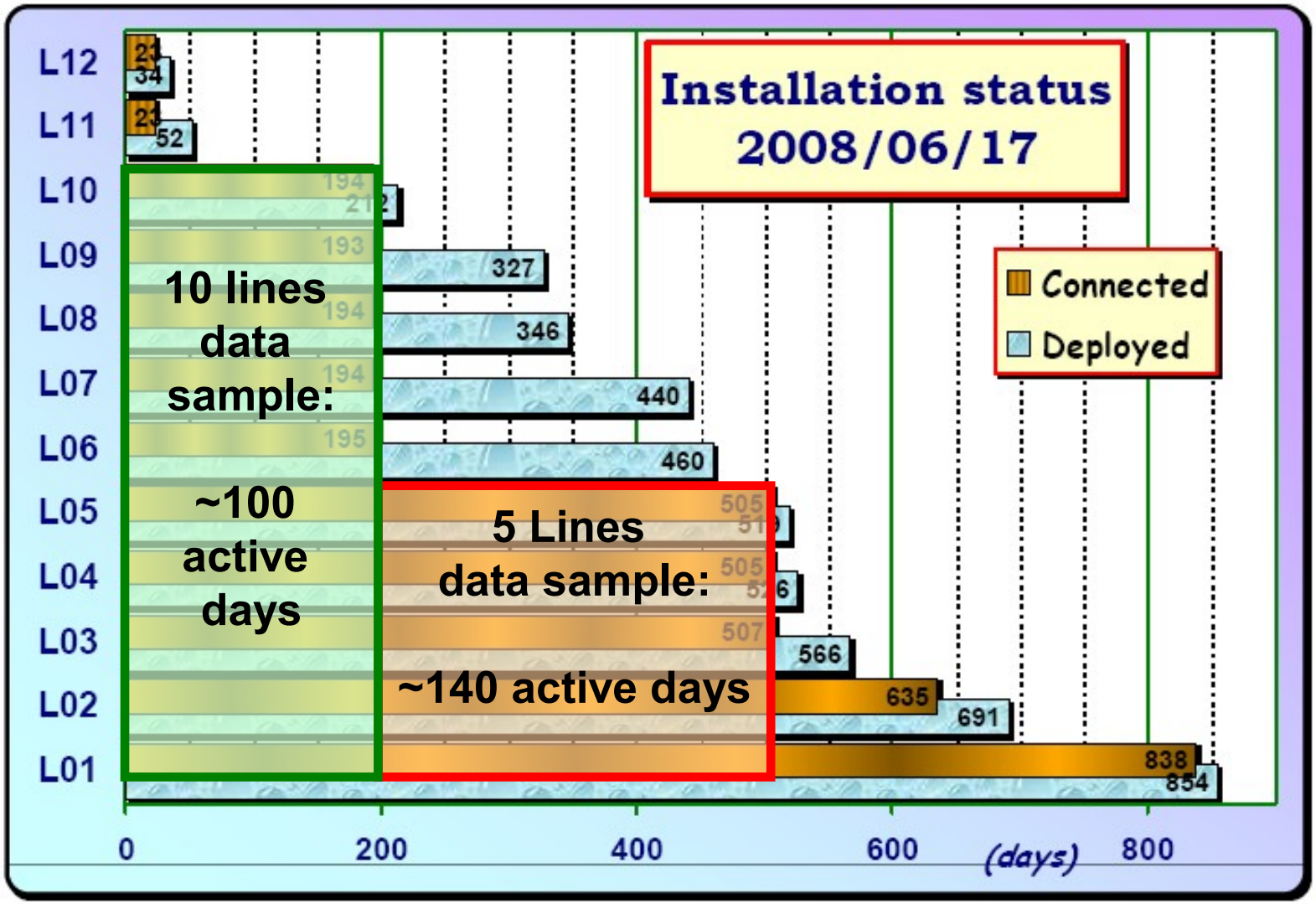


Elevation



The ANTARES Detector: deployment phases

Duration of lines in the sea

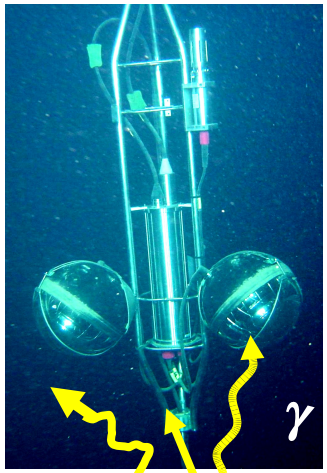


…and Junction Box in water for 5 ½ years

Time calibration with Potassium 40

Presence of ^{40}K in salty water: $^{40}K \rightarrow {}^{40}Ca\ \bar{\nu}_e\ e^-$

can be used for charge and time calibration of the detector



γ
Cherenkov

e^- (β decay)

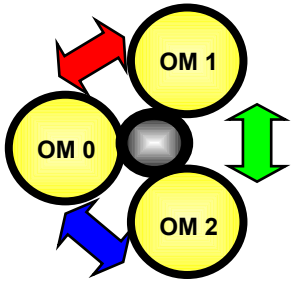
^{40}K

on average
~35 photons

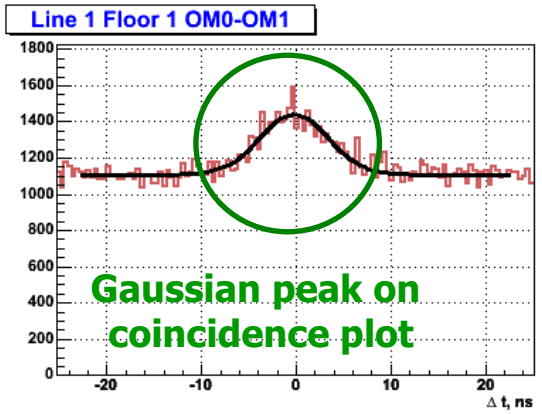
^{40}Ca

^{40}K decay

(β or EC)



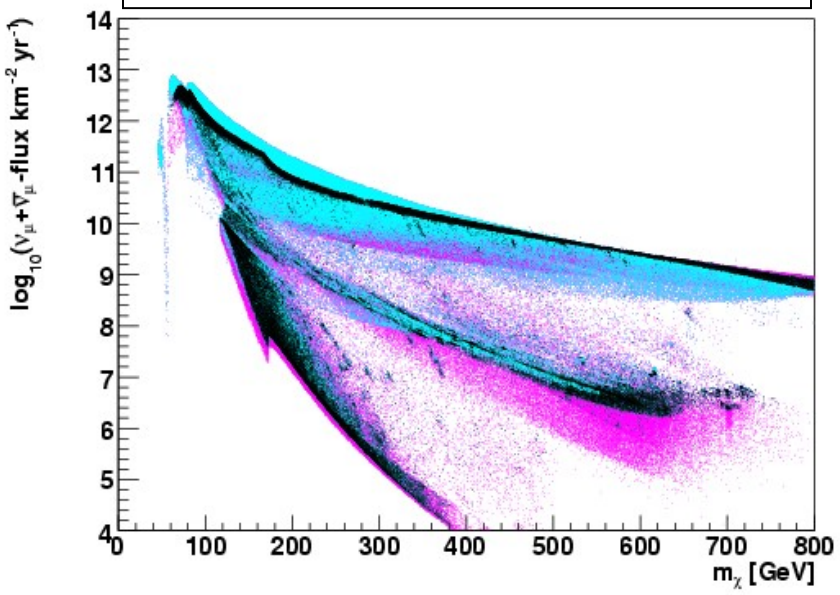
Taking
differences
by pairs



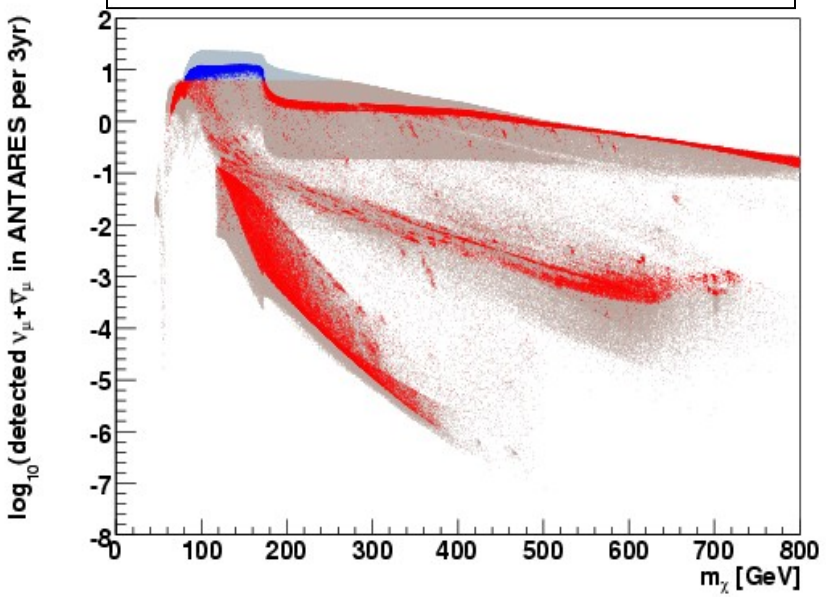
Expected neutrino flux from the Sun

- **Neutralino LSP in mSugra theory**
- **mSugra parameter space through: $m_0, m_{1/2}, A_0, \tan(\beta), \mathrm{sign}(\mu)$**

Expected neutrinos flux from the source



Expected neutrinos events



All models studied

$0{,}094 < \Omega h^2 < 0{,}129$ (WMAP 3yr constraint)

$\Omega h^2 < 0{,}094$

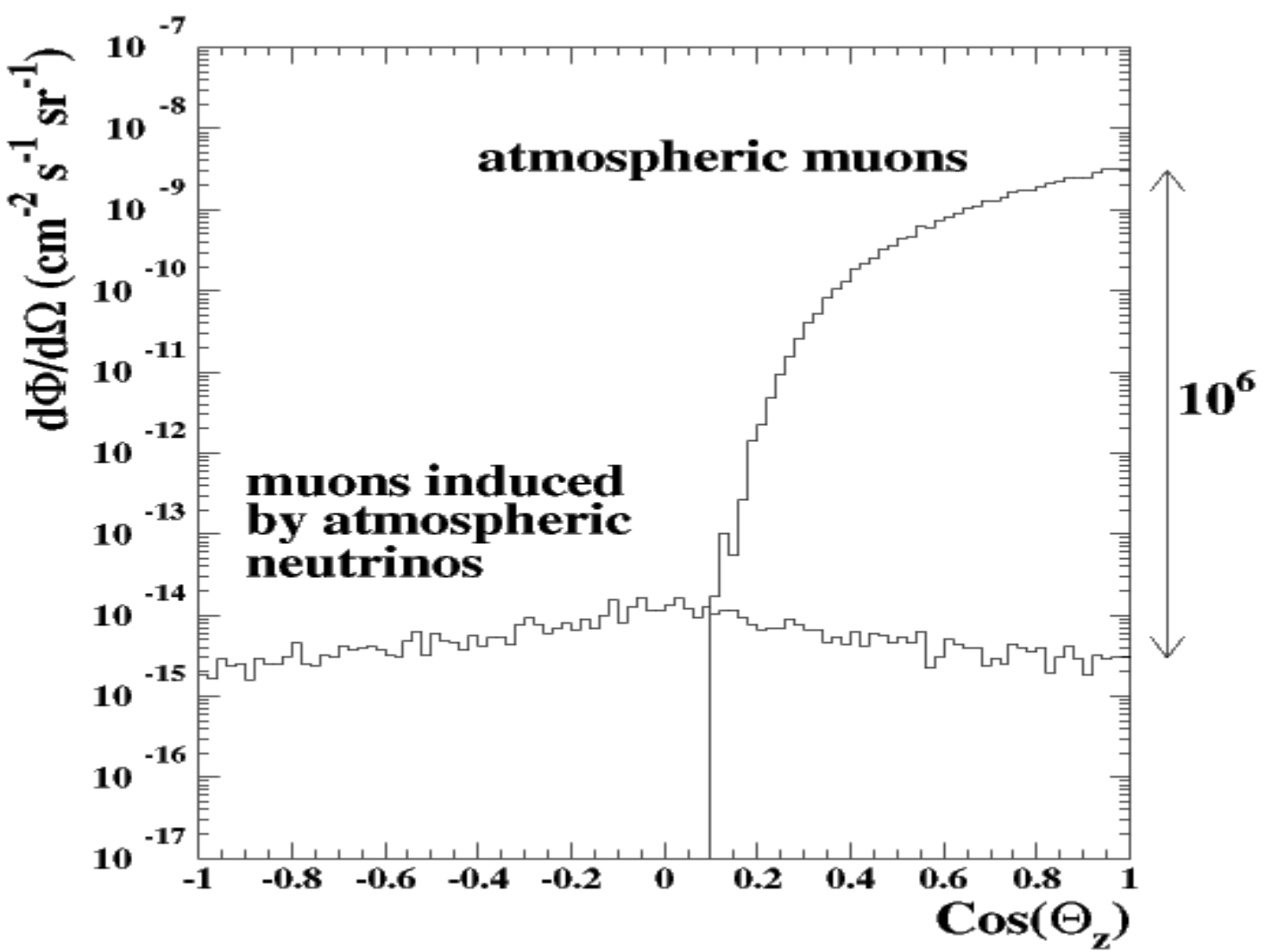
All models studied

$0{,}094 < \Omega h^2 < 0{,}129$ (WMAP 3yr constraint)

Average upper limit signal

Backup : Background noise expected...

Muons distribution over zenith angle



Backup : Trigger

Before to really reconstruct a muon track, there are five data processing levels from the data taking to the discovering of potential events:

- Level 0 (L0) : All hits
- Level 1 (L1) : local trigger search
  - local coinciding hits in a time gate (~20 ns) on 2 PMTs of the same floor
  - and/or all hits with charge > threshold param. (~2.5 p.e.)
- Level 2 (L2) : global trigger search
  - Space-time relation between signals due to unscattered light from the same muon trajectory or bright point
  - assuming: high relativitic muons, slowest possible speed c/n (n~1.35). For two hits, causality implies:

$$\Delta t = \frac{n}{c} \Delta x$$

Δt : time between hits

Δx : diff. Between PMTs positions

Backup : Trigger

- Level 2 (L2) :
  - if the number of correlated hits > "minClusterSize" parameter(~4) → Cluster

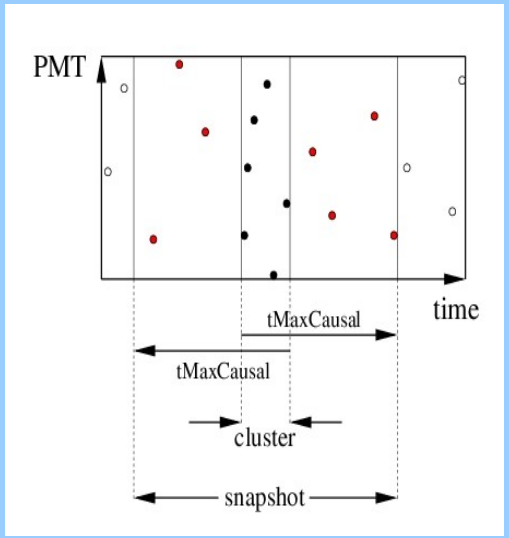
  For example for a 3D Trigger:

  ✓ Minimum number of hits in the cluster = 5

  ✓ Minimum number of floors in the cluster = 5

  ✓ Minimum charge of the largest hits in the cluster = 0.3 p.e.

  ✓ etc…



- Level 3 (L3) : merging of overlapping events
  - each event contains a snapshot of all hits in a time window around the cluster

  tmaxCausal ~ 2.2 μs
  - All hits within causality condition added
- Level 4 (L4) : event building
  - All raw hits collected in a snapshot and combined into "PhysicsEvent" with data of clusters

Backup : Trigger

After, all processing levels used into different forms of triggers which look for:

- 1D : time correlated hits in a given direction (L0 data in input)
- 3D : time correlated hits from any directions (L1 data in input)
- MX : similar to 1D + one local coincidence (1 L1) to speed up the processing of L0 data

And the number of L0 or L1 levels for each trigger can vary…

At the end, the muon track reconstruction strategy can apply to the selected hits…

Backup : Reconstrustion Strategy

- Step 1 : Linear prefit by χ^2-minimization over local coincidences and integrated charge of hits
- step 2 : M-estimator minimization

$$G = \sum_i K(-2\sqrt{1 + A_i r_i^2/2}) - (1 - K) f_{ang}(a_i)$$

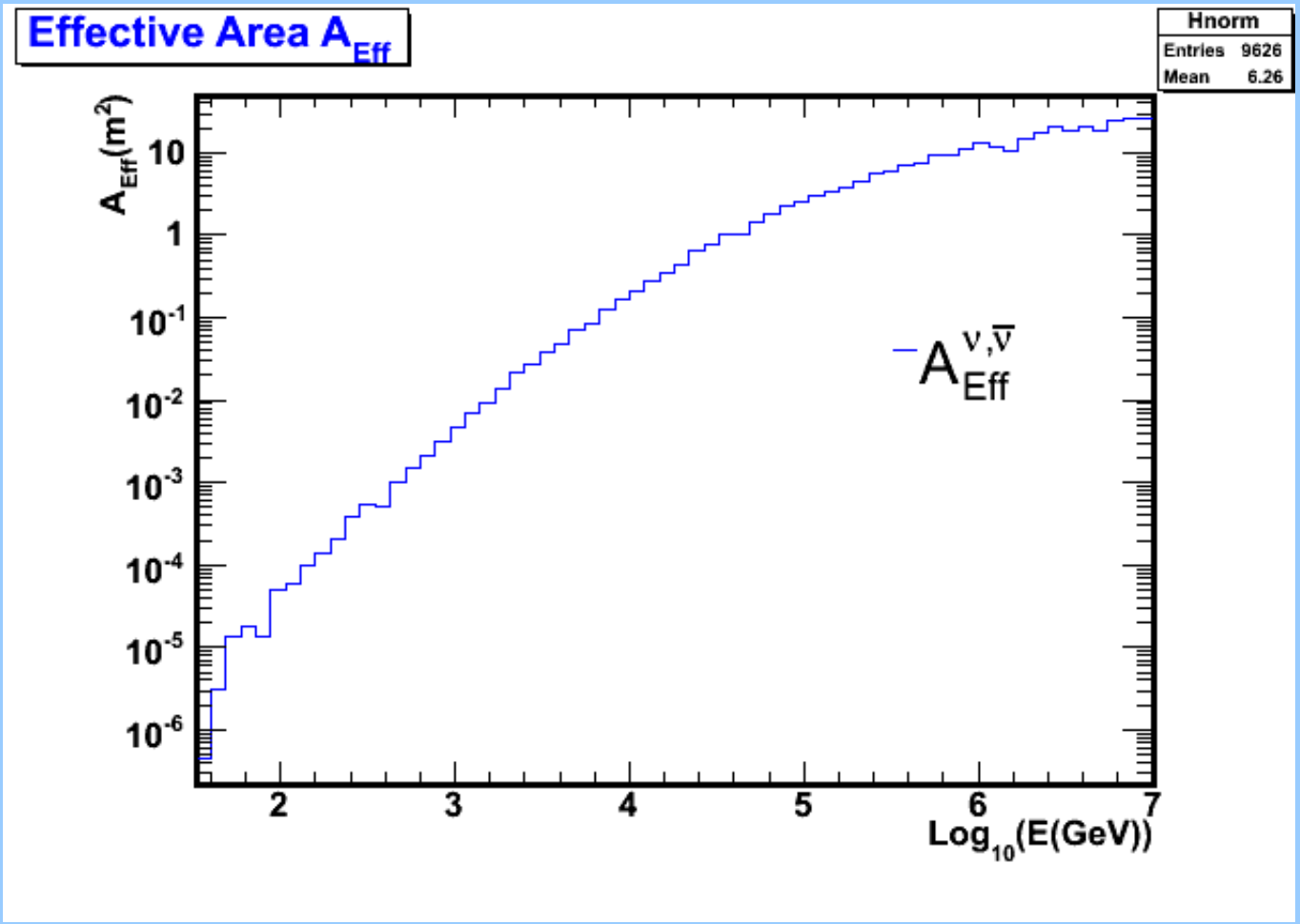
A_i = charge, r_i = time residual, f_{ang} = angular factor, K=0.05 (MC simulation)

- step 3 : Likelihood-maximization

$$P(\,event \mid track\,) = prod_i\, P(\,t_i \mid t_i^{th}\,)$$

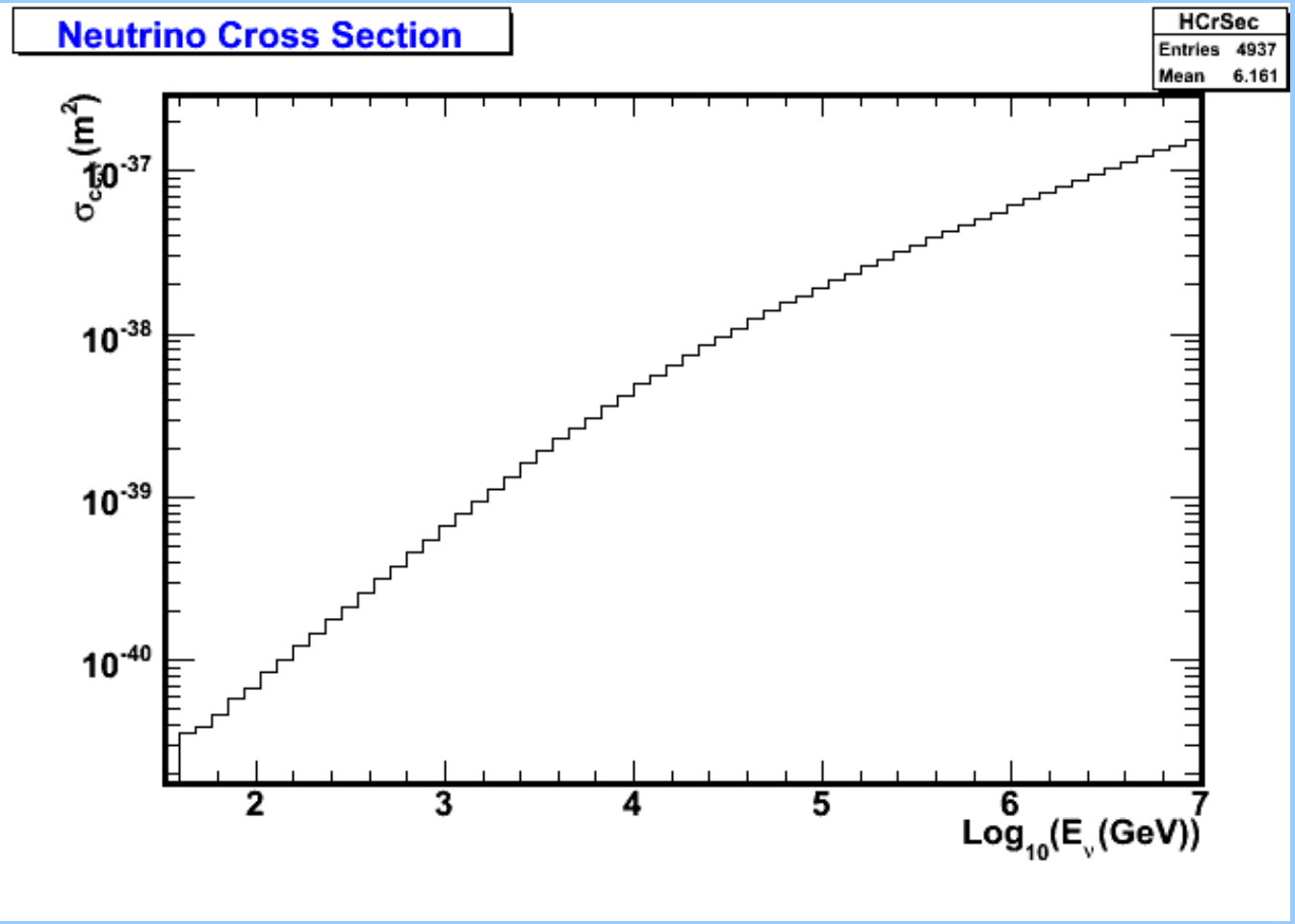
A likelihood cut is preformed to discriminate the « real » up-going events compare to the down-going muon misreconstructed.

Backup : Neutrinos Effective Area



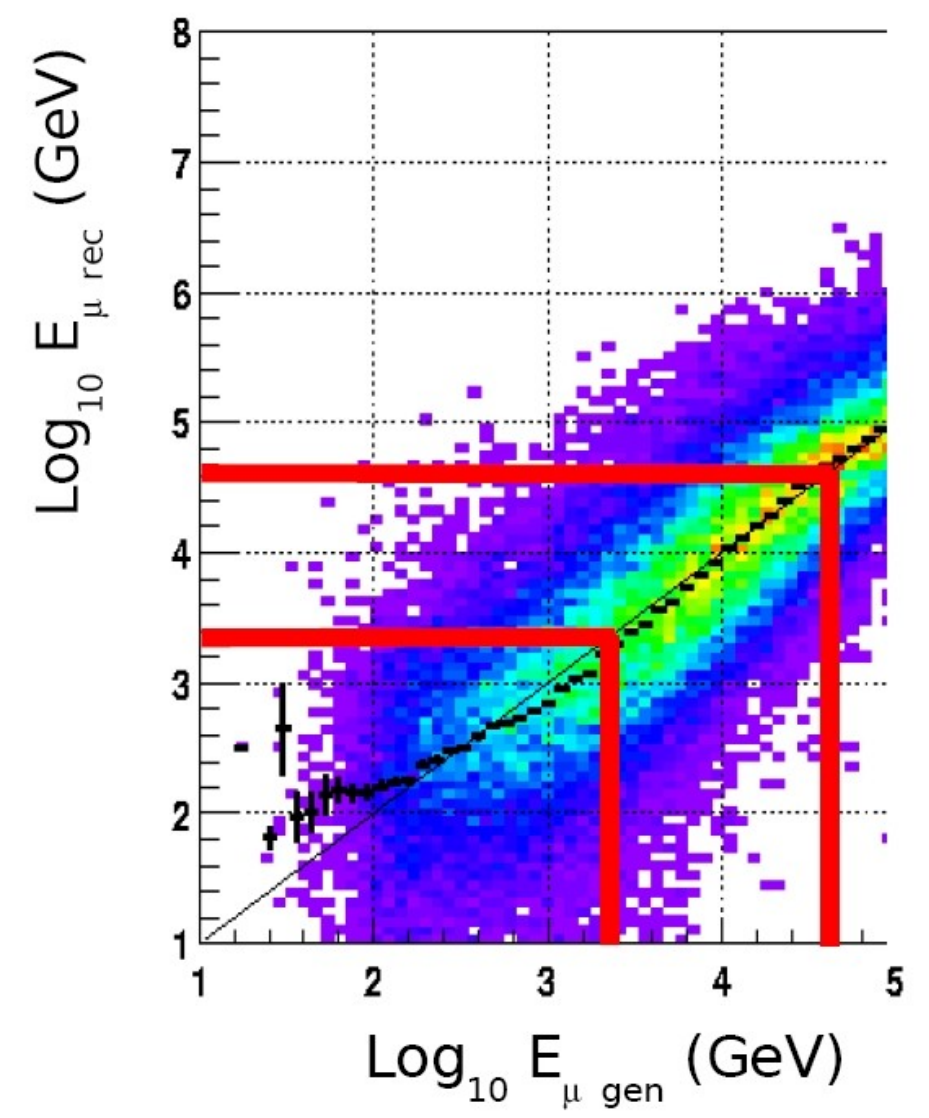
$$A^{\nu}_{Eff}(E_\nu, \Omega_\nu) \alpha (\rho N_A) \times \sigma(E_\nu) \times e^{-N_A \sigma(E_\nu) \int \rho \, dl}$$

Backup : Neutrinos cross sections



$\sigma_{cc,\nu}$ from CTEQ coll. Parton Distribution Functions

Backup : Energy reconstruction



Factor 2 or 3 at low energy (<O(TeV))