Recent results from the ANTARES Neutrino Telescope

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on behalf of the ANTARES Collaboration

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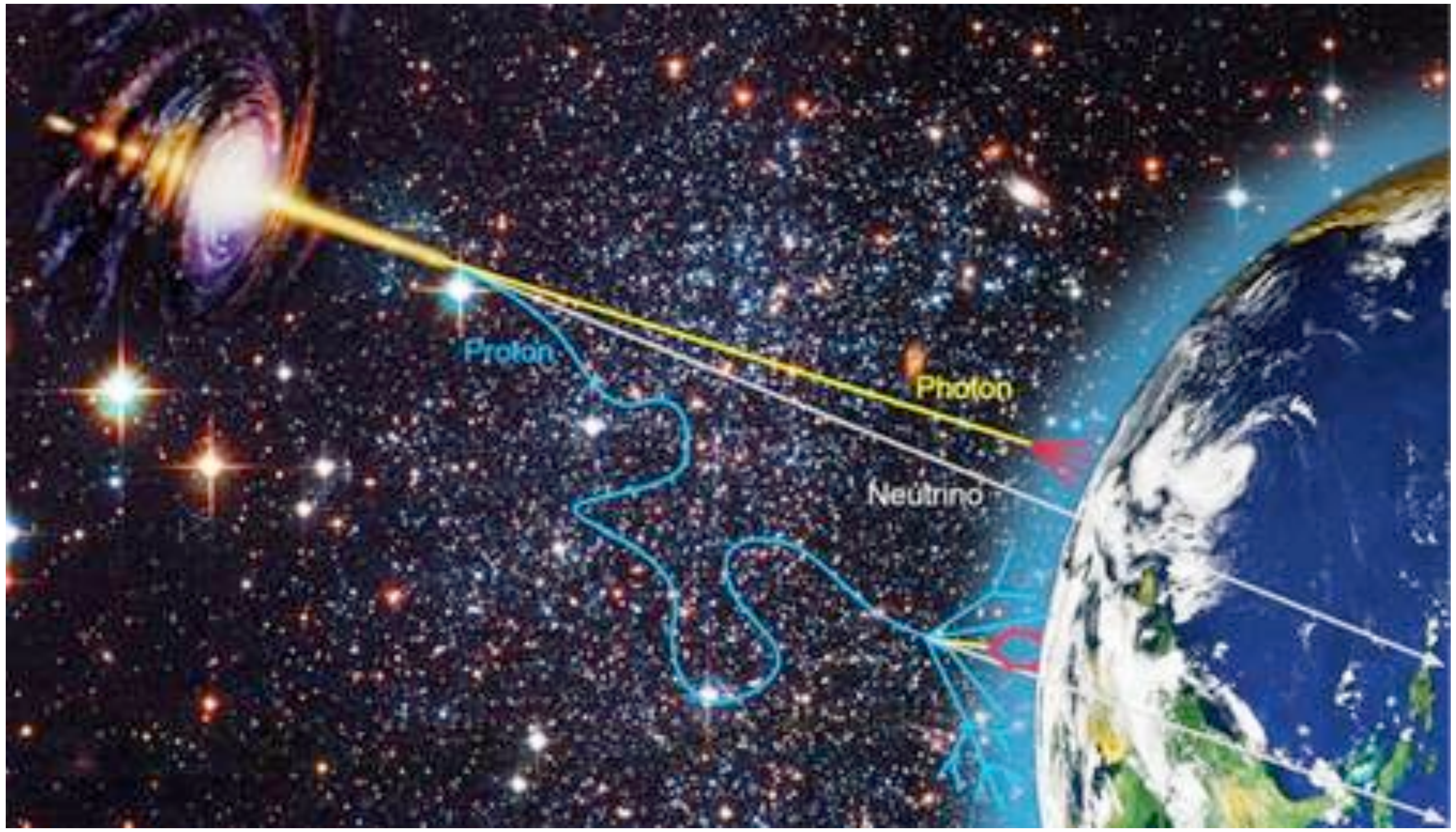
Introduction

- Neutrino telescope
- Analysis
  - Neutrinos oscillations
  - Relativistic magnetic monopoles
  - Point like sources
  - Dark Matter (Sun, GC, Dwarf)
  - GRB
  - Fermi Bubble
- Summary

Multi messager astronomy

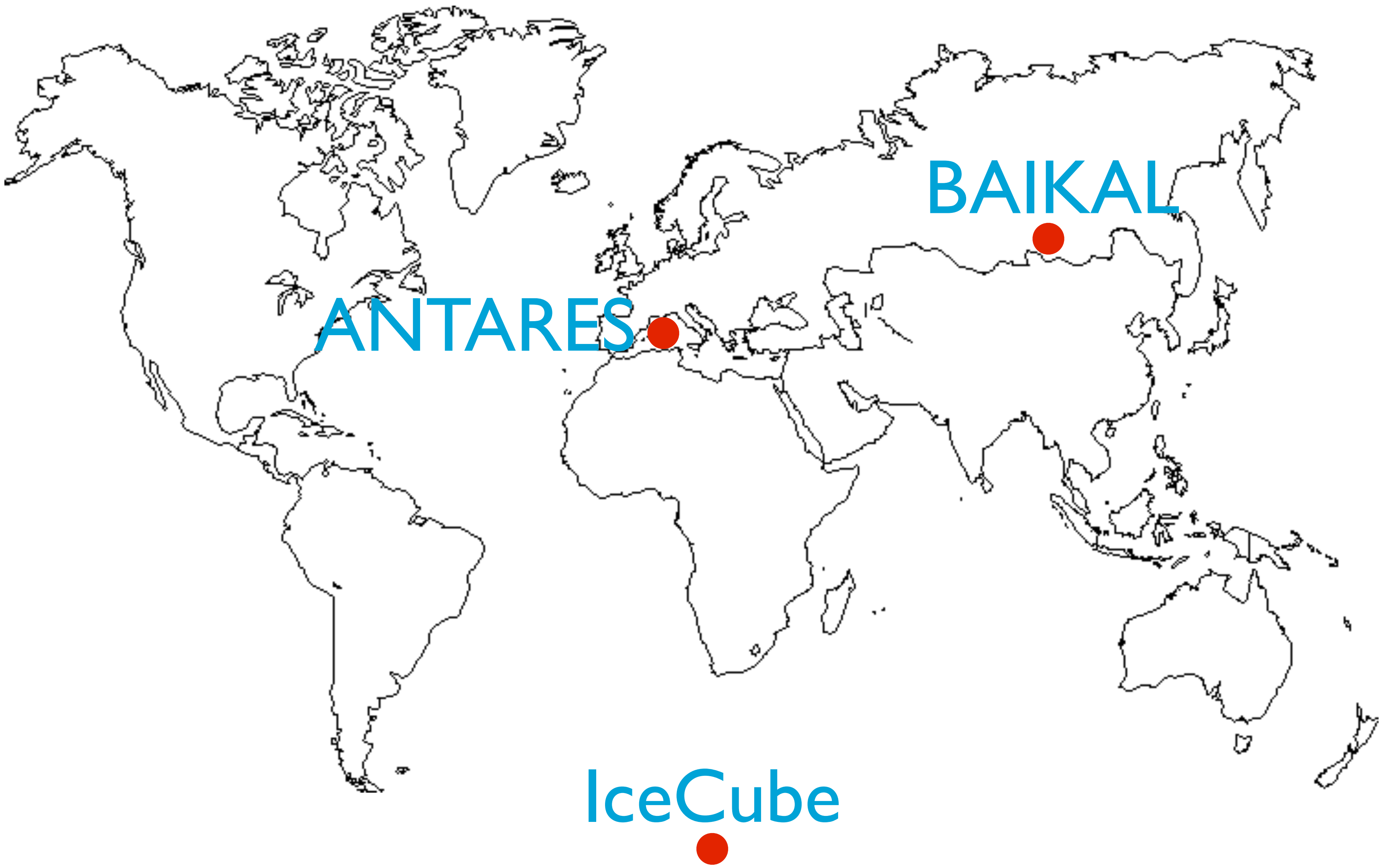


Why neutrino astronomy

- neutrinos point back to the source
- neutrinos travel cosmological distances
- neutrinos escape optically thick sources
- neutrinos are a clear sign of hadron acceleration

➡ complementary to gamma and cosmic rays

Neutrino telescopes



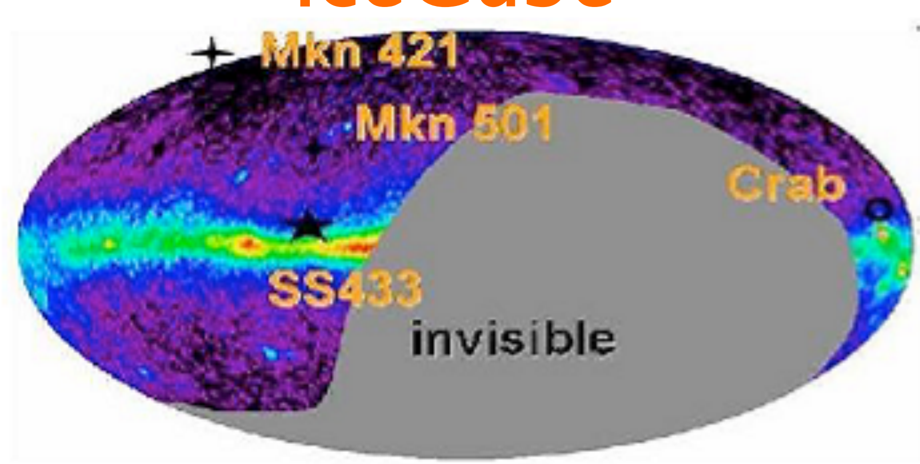
Resolution

ANTARES 0.3-0.4°

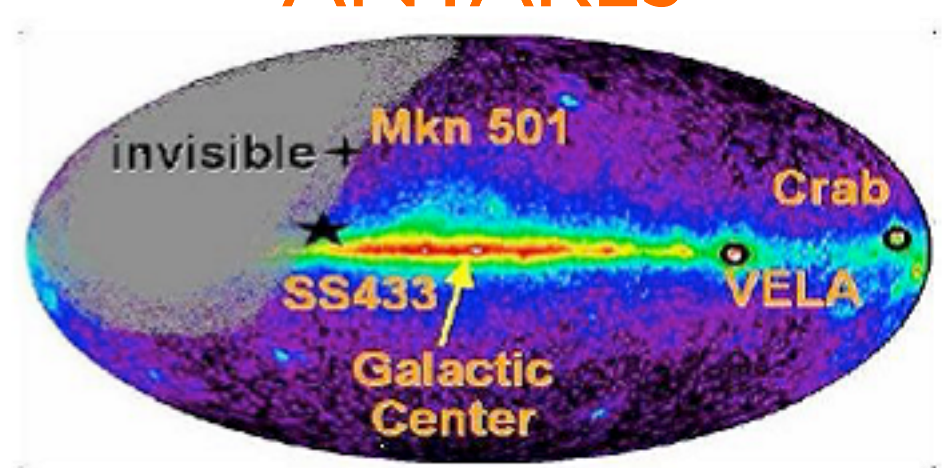
IceCube $\lesssim 1°$

Visibility

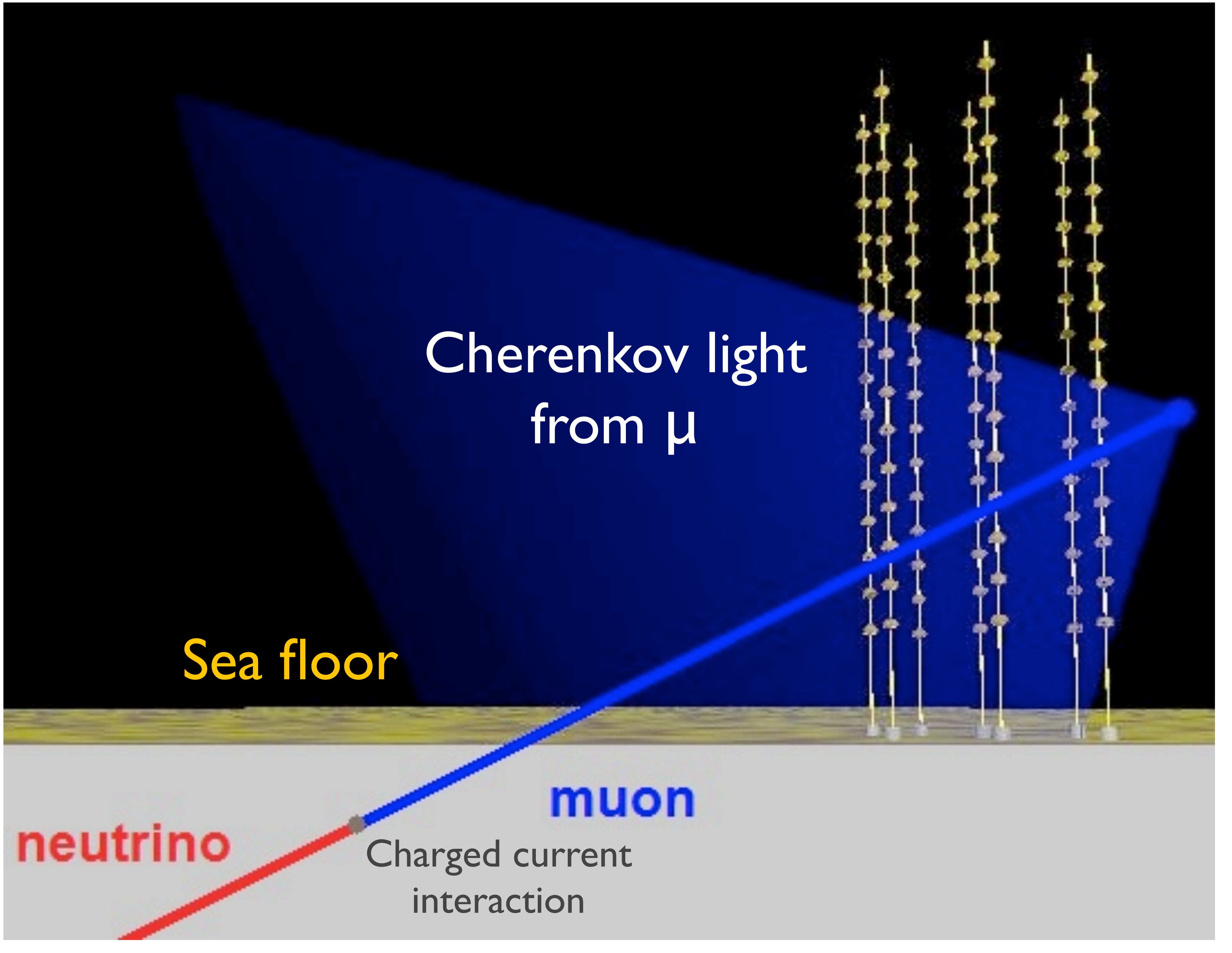
IceCube



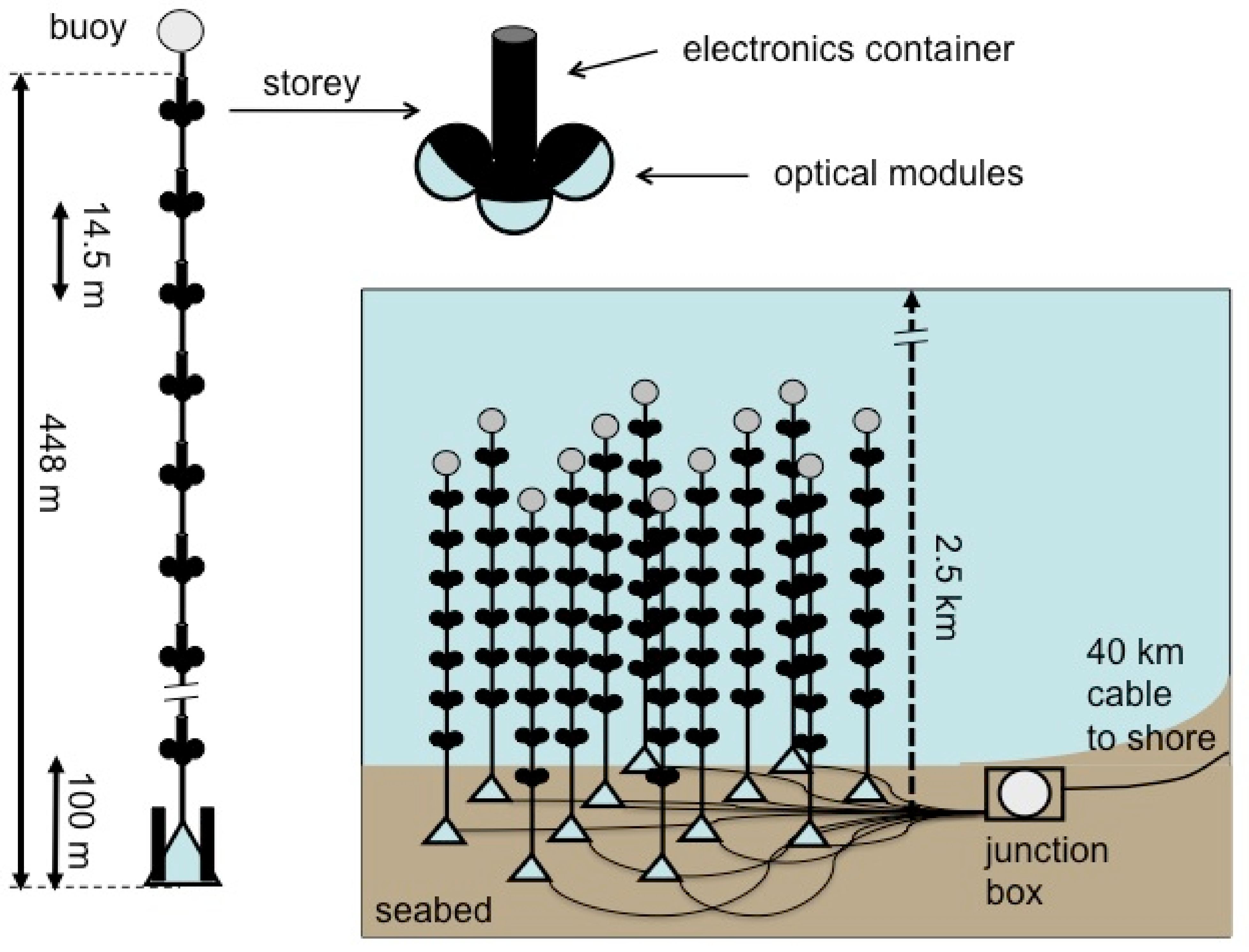
ANTARES



Detection principle



ANTARES detector

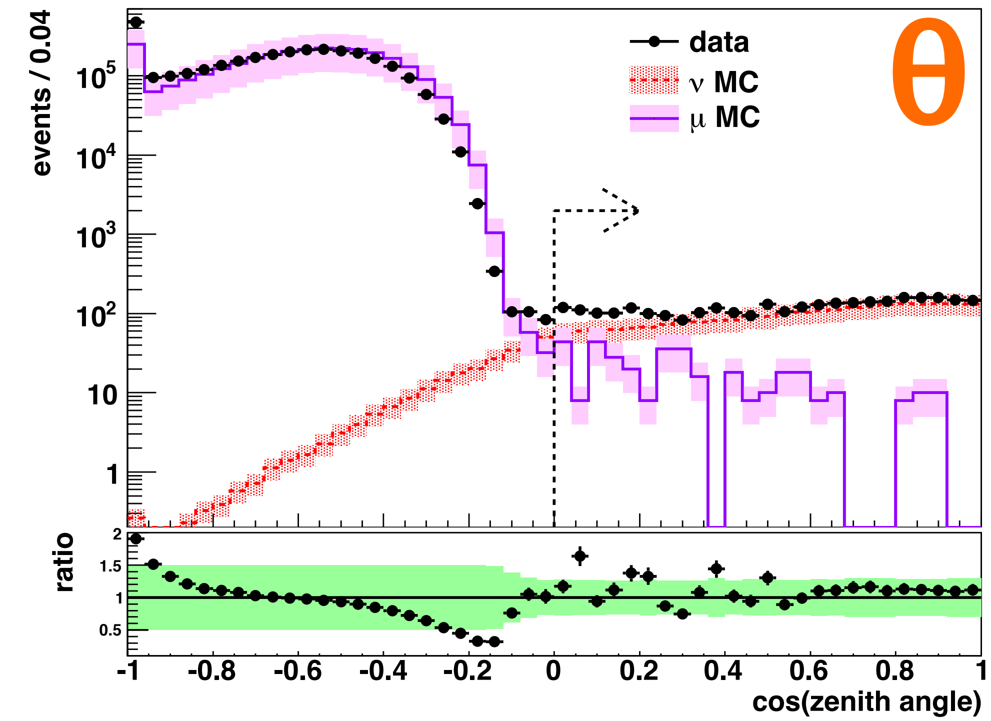


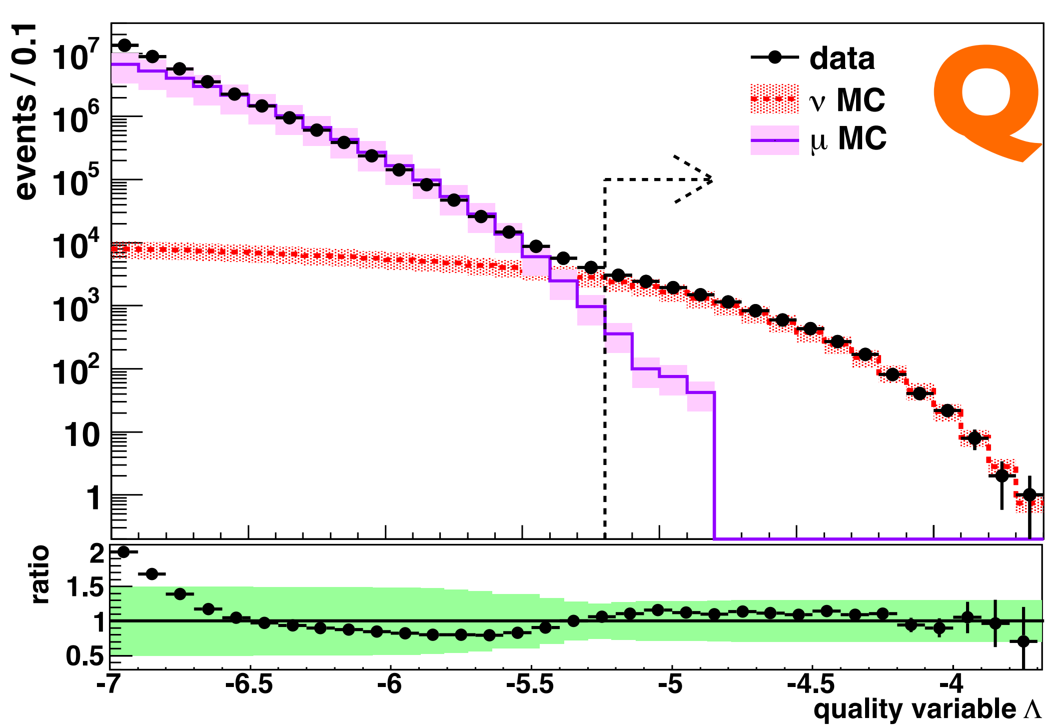
Atmospheric muon background

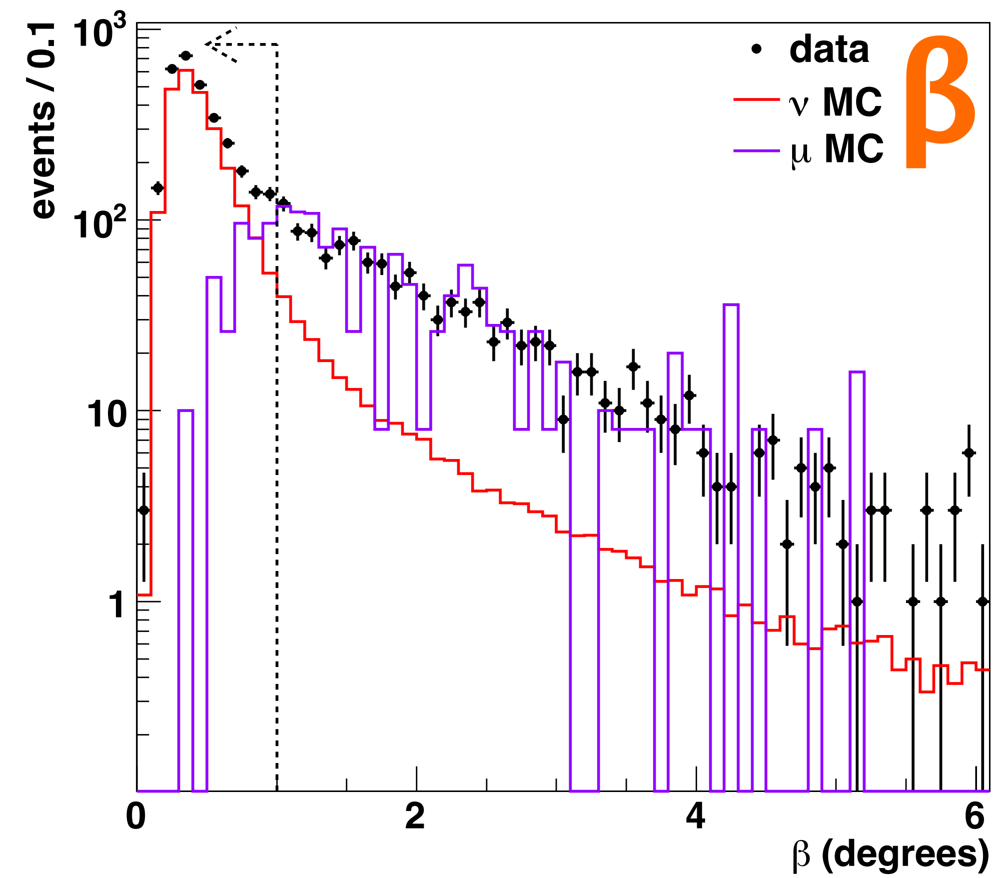
Events per day

- 10^6 astmospheric muons (downgoing particles)
- 4 atmospheric neutrinos (upgoing particles)
- ?? cosmic neutrinos (upgoing particles)

➡ preselection on the zenith angle θ, the quality variable Q and the angular error β







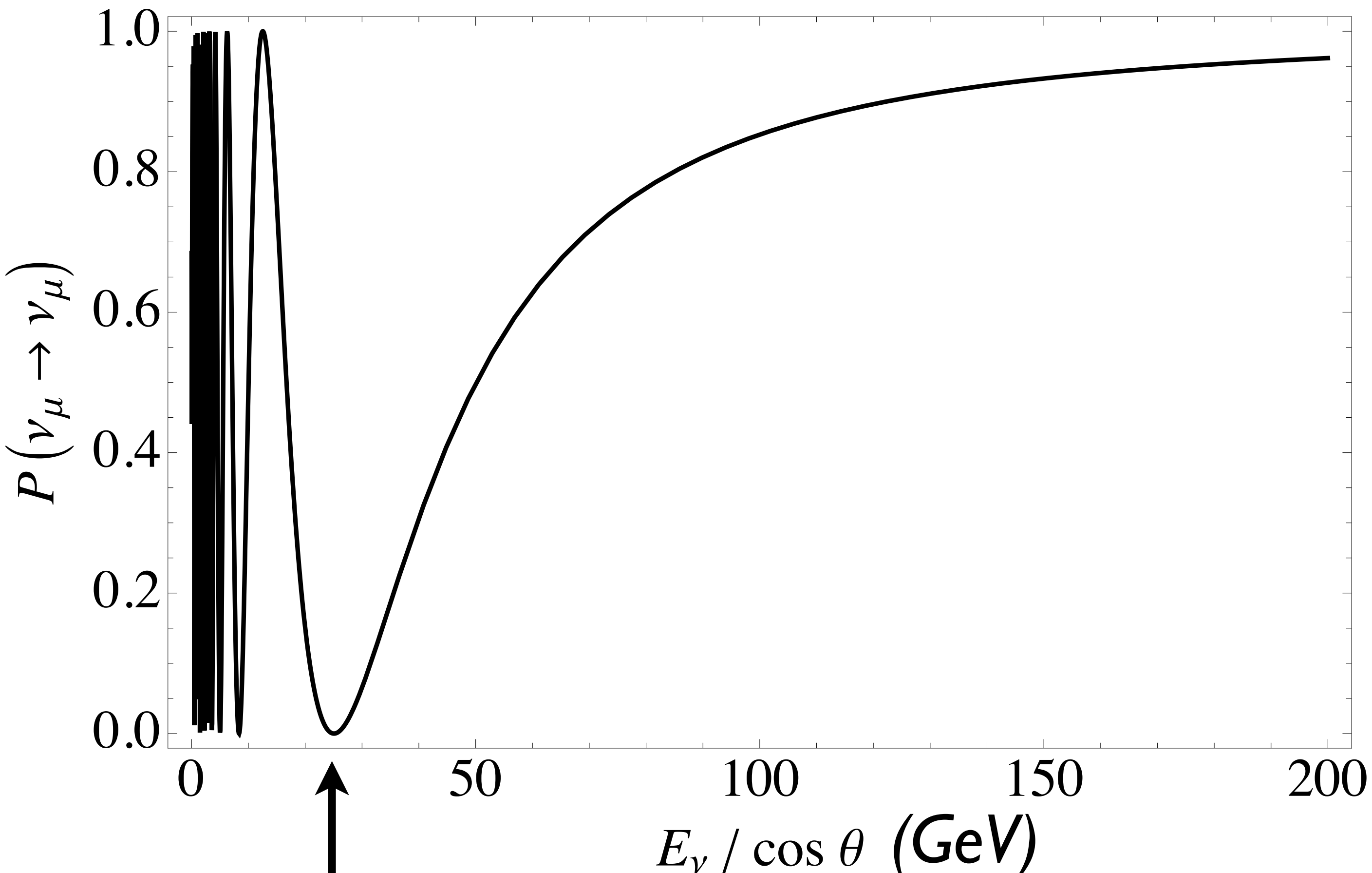
Neutrino oscillations

oscillations with atmospheric neutrinos

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{32} \sin^2(\frac{1.27 \ \Delta m^2_{32} \ L}{E_\nu})$$

$$\Rightarrow P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{32} \sin^2(\frac{16200 \ \Delta m^2_{32} \ \cos\theta}{E_\nu})$$

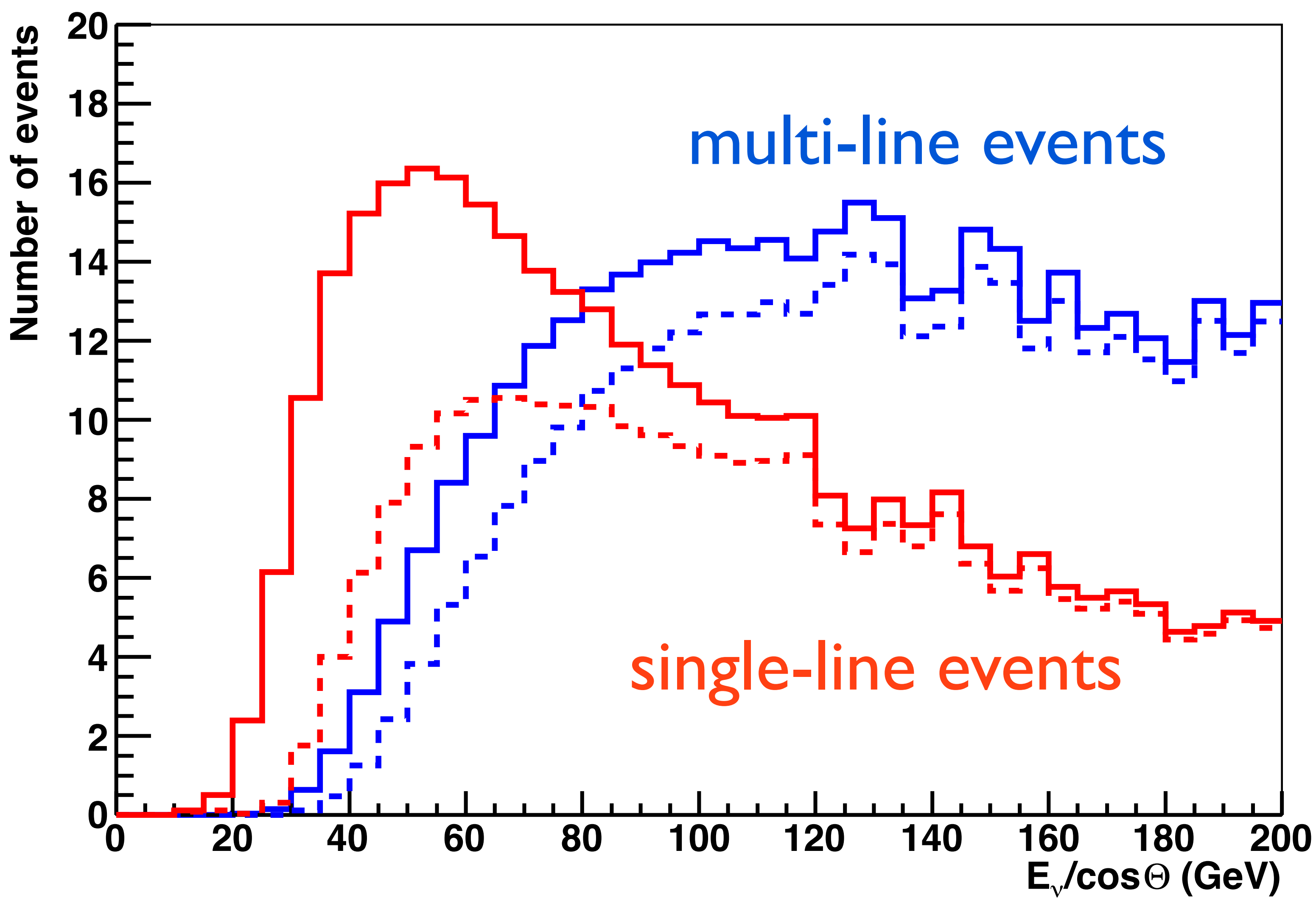
observables



24 GeV for cos θ = 1

⇒ vertical upgoing neutrinos with (cos θ = 1) and E_ν =24 GeV expected to be suppressed

Neutrino oscillations



solid line : no oscillations
dashed line : with oscillations

more multi-line events at high energy (70m between lines)

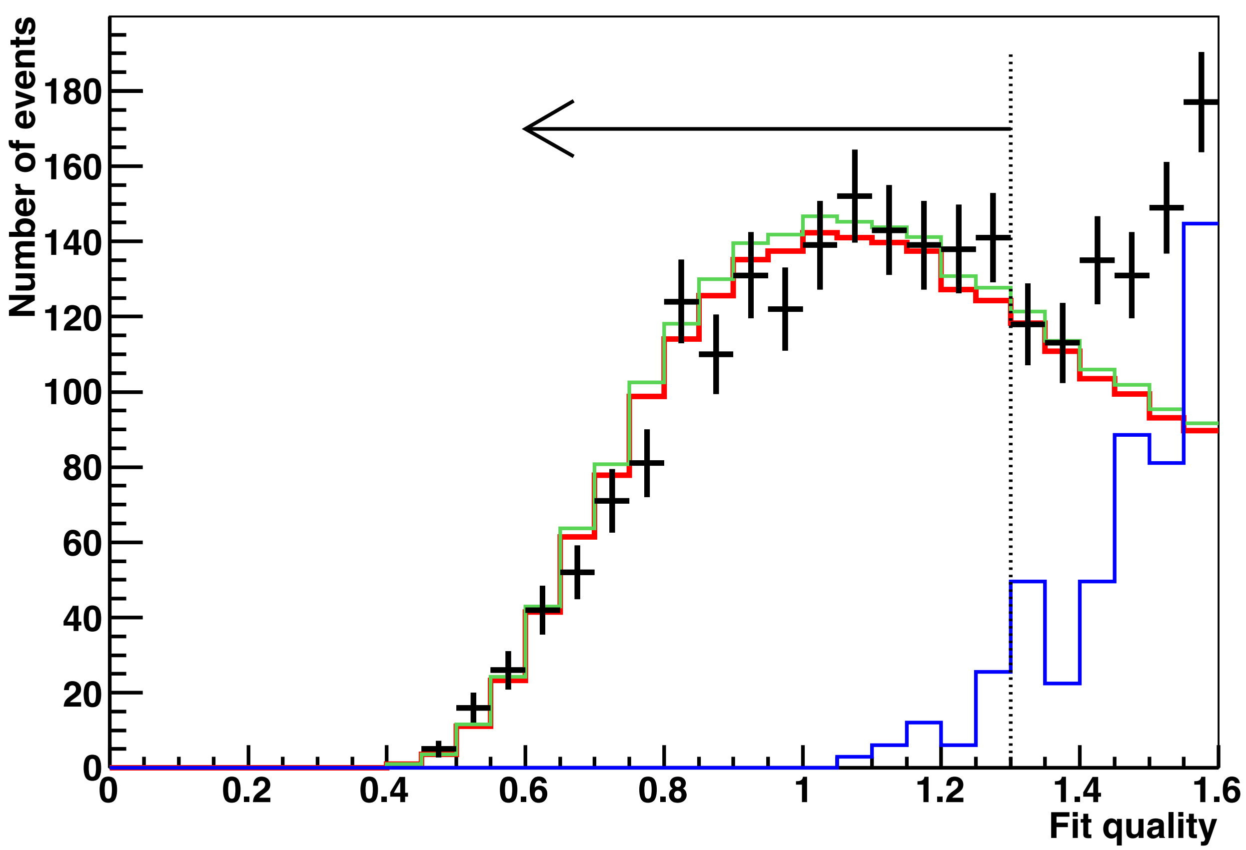
Neutrino oscillations

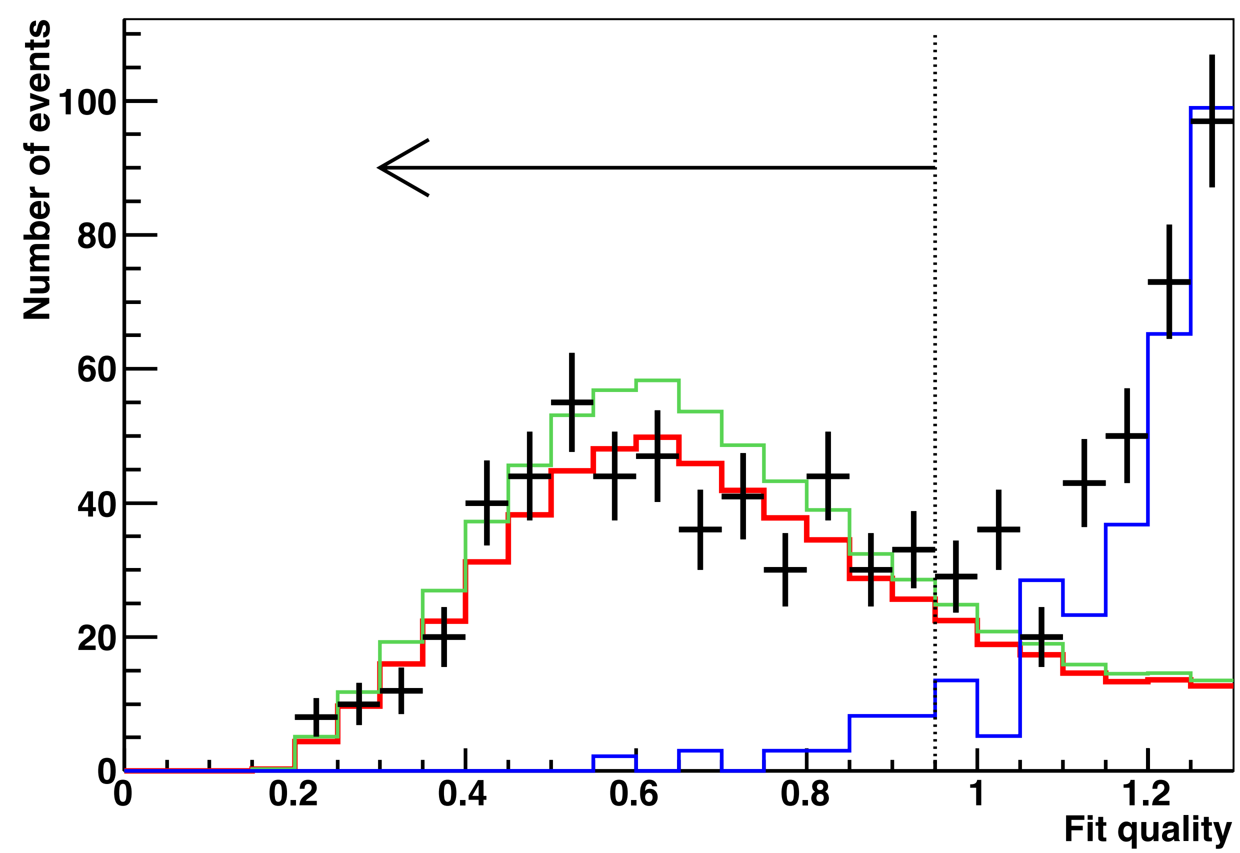
Multi-line events

- track direction > 9° (to the horizon)
- zenith angle resolution : 0.8°
- $N_{storeys} > 5$
- cut on track fit quality (< 5% muon contamination)

Single-line events

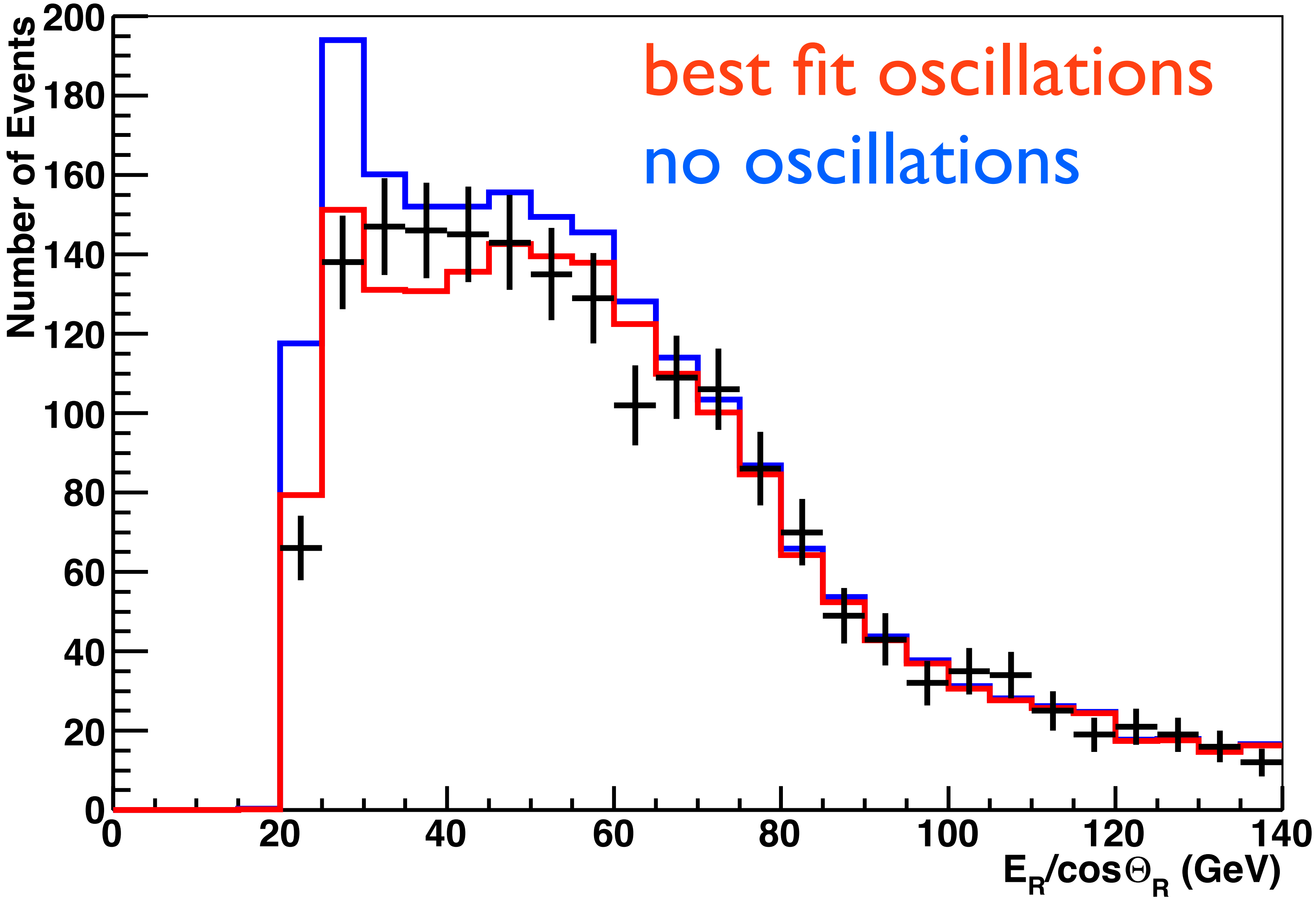
- fit without azimuth angle
- vertical events
- zenith angle resolution : 3°
- $N_{storeys} > 7$
- cut on track fit quality (< 5% muon contamination)





Neutrino oscillations

2007-2010 data (863 days)



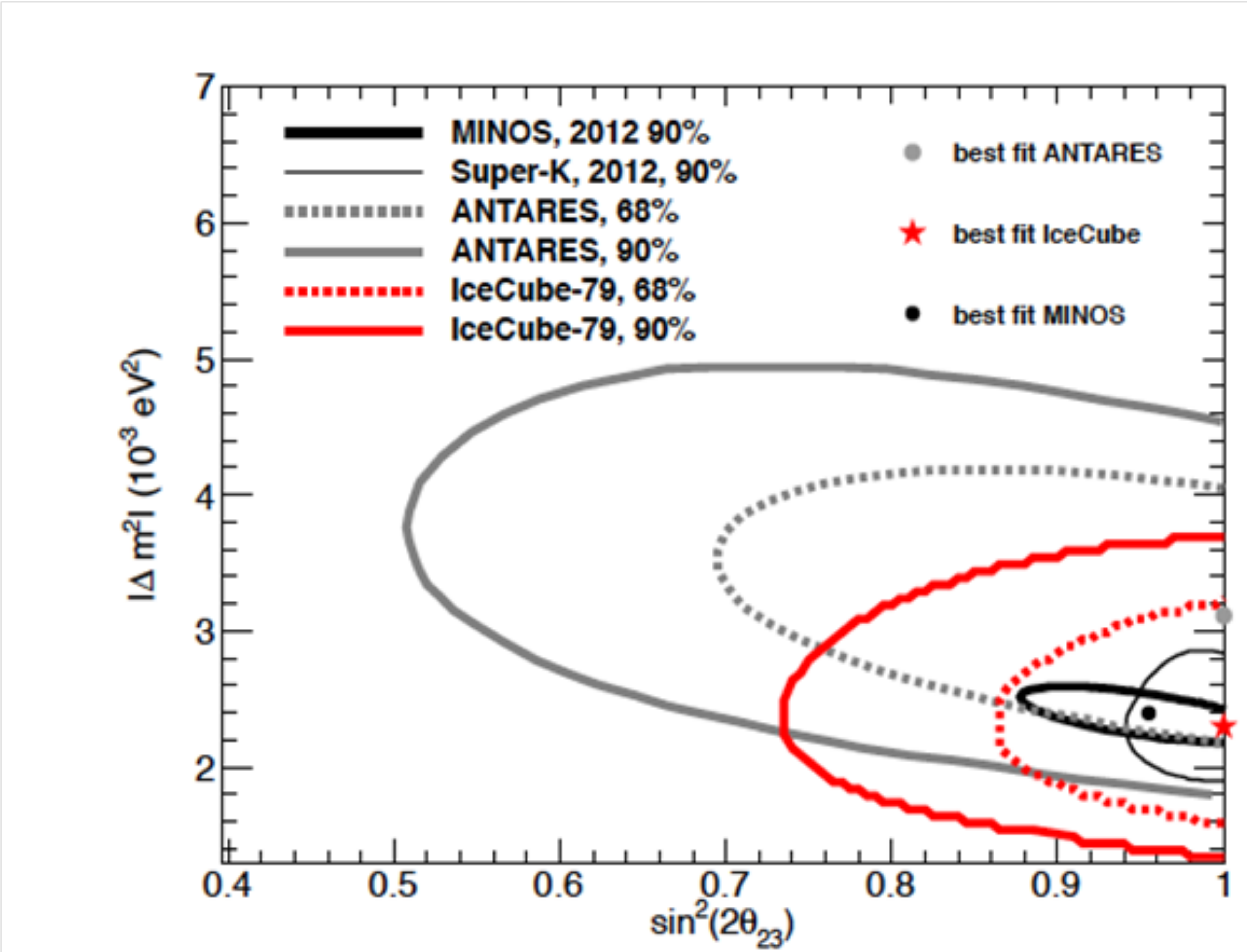
Best fit

$\sin^2 2\theta_{23} = 1$

$\Delta m^2_{23} = 3.1\ 10^{-3}\ \mathrm{eV}^2$

Neutrino oscillations

[Phys. Lett. B 714 (2012) 224]

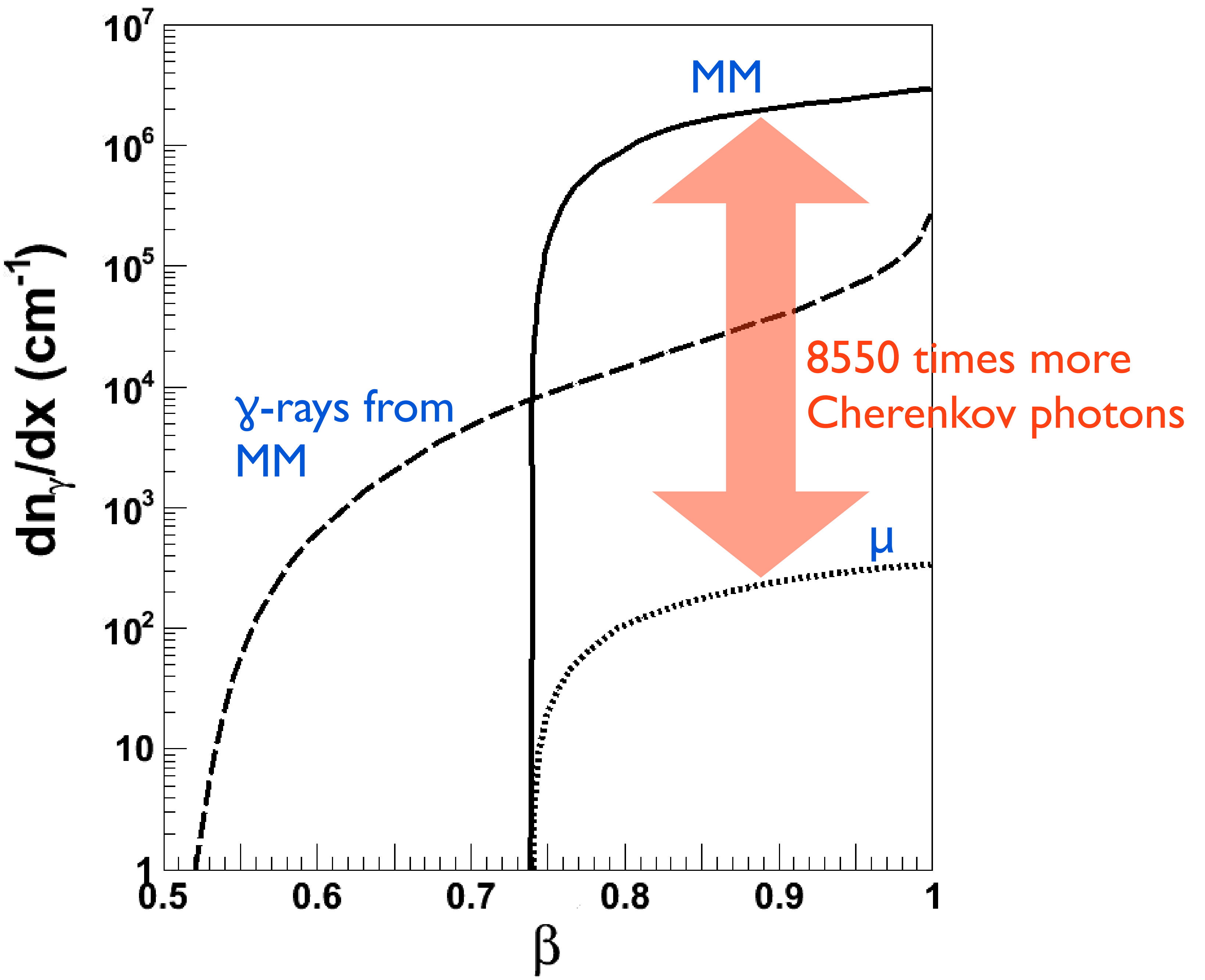


Relativistic magnetic monopoles

required in many models of spontaneous symmetry breaking ('t Hooft, Polyakov)

- MM produce Cherenkov emission when $\beta_{MM} > \beta_{th} = 1/n$
for sea water, n~1.35
➡ $\beta_{th} = 0.74$

- when $\beta_{MM} > 0.51$, MM ionizes sea water leading to indirect Cherenkov emission from knock off electron produced along its path

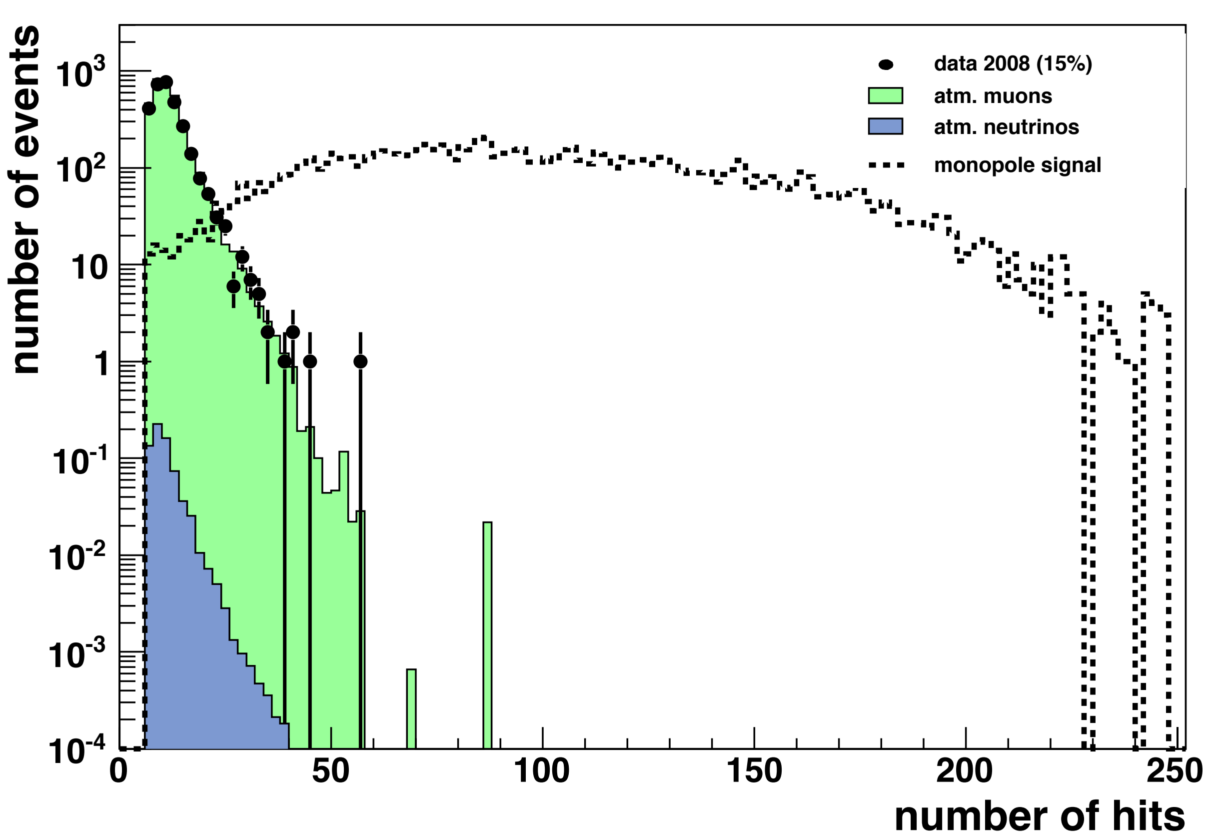


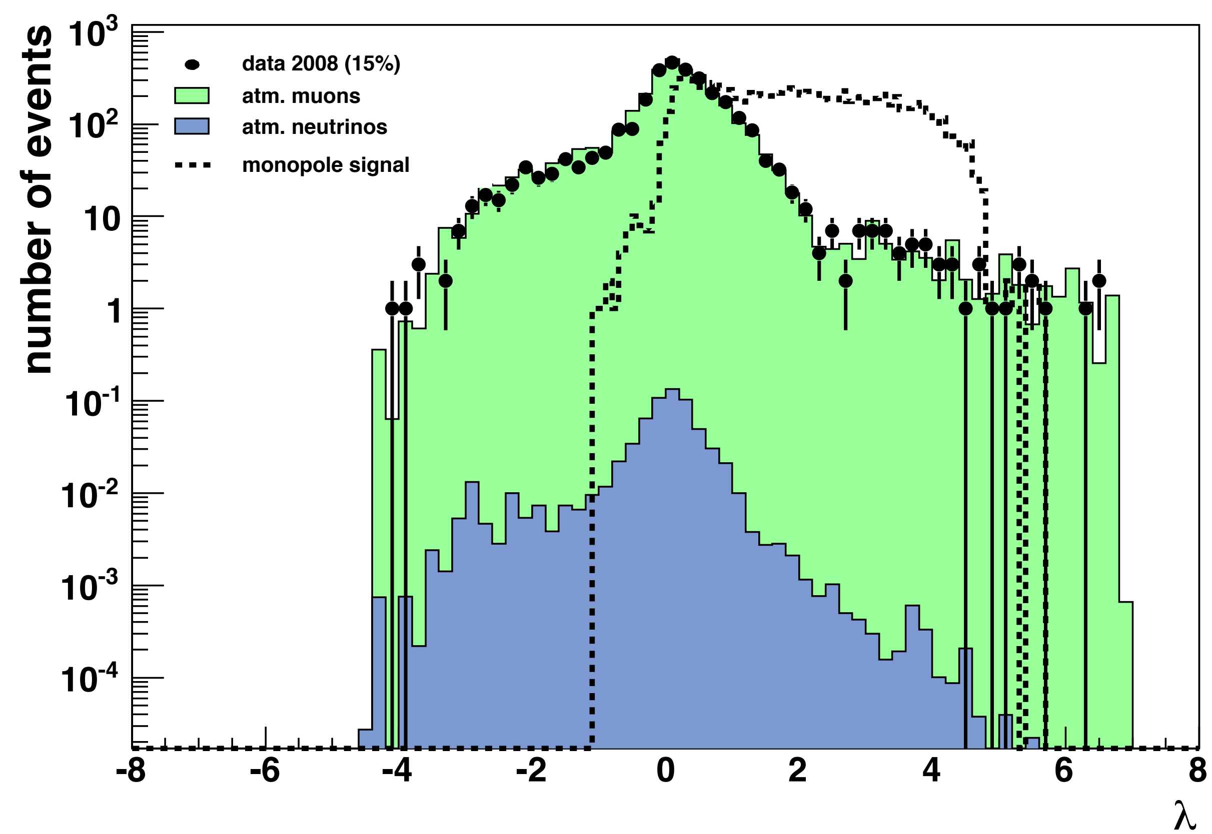
Relativistic magnetic monopoles

Analysis with 15% data sample

- Cherenkov effect more important for MM
  - ➡ cut on number of hits
- modified track reconstruction with β free
  - ➡ cut on the ratio λ

$$\text{with } \lambda = \log \frac{Q_{\beta_{rec}=1}}{Q_{\beta_{rec}=free}}$$

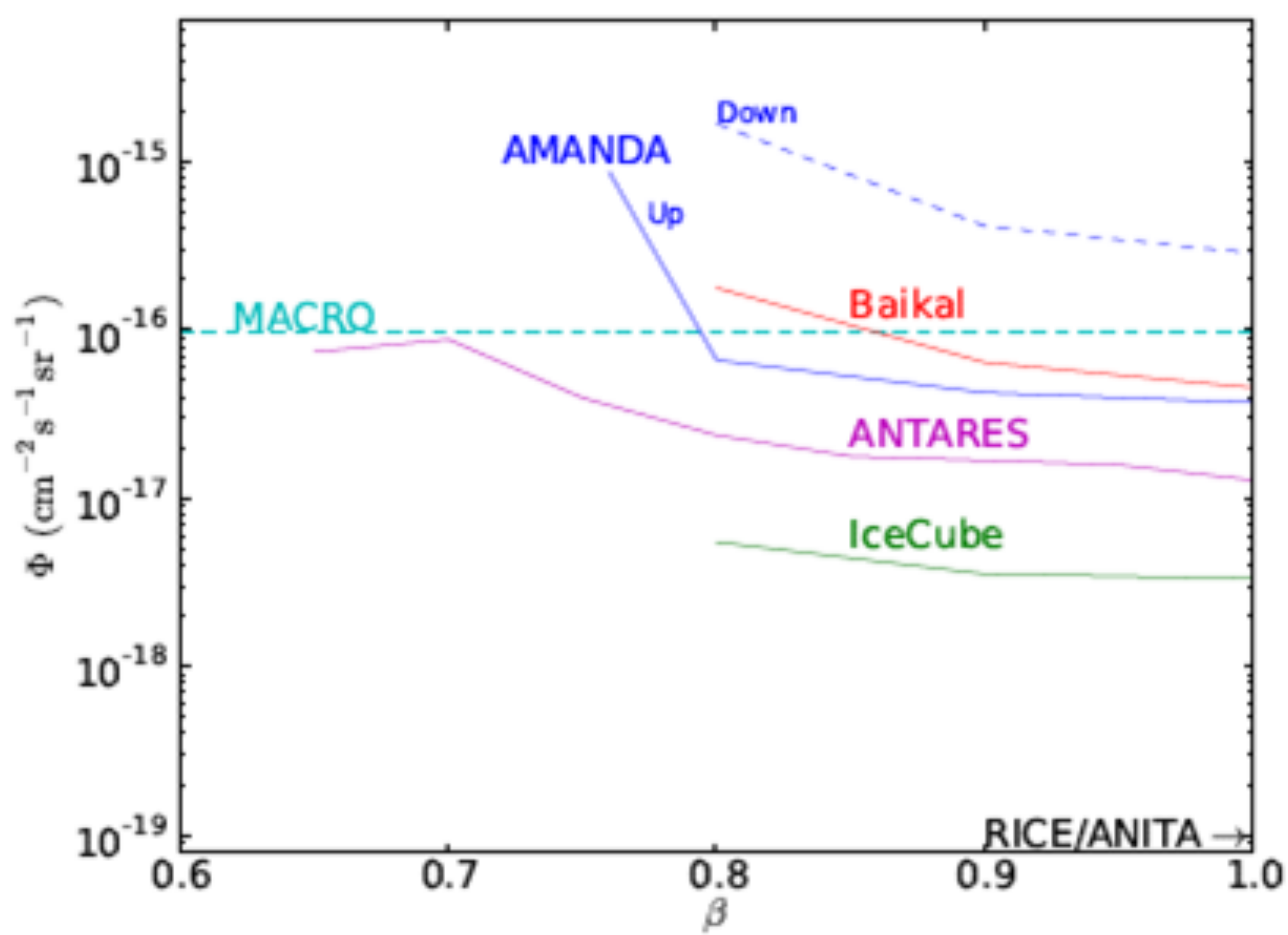




Relativistic magnetic monopoles

[Astroparticle Physics 35(2012) 634-640]

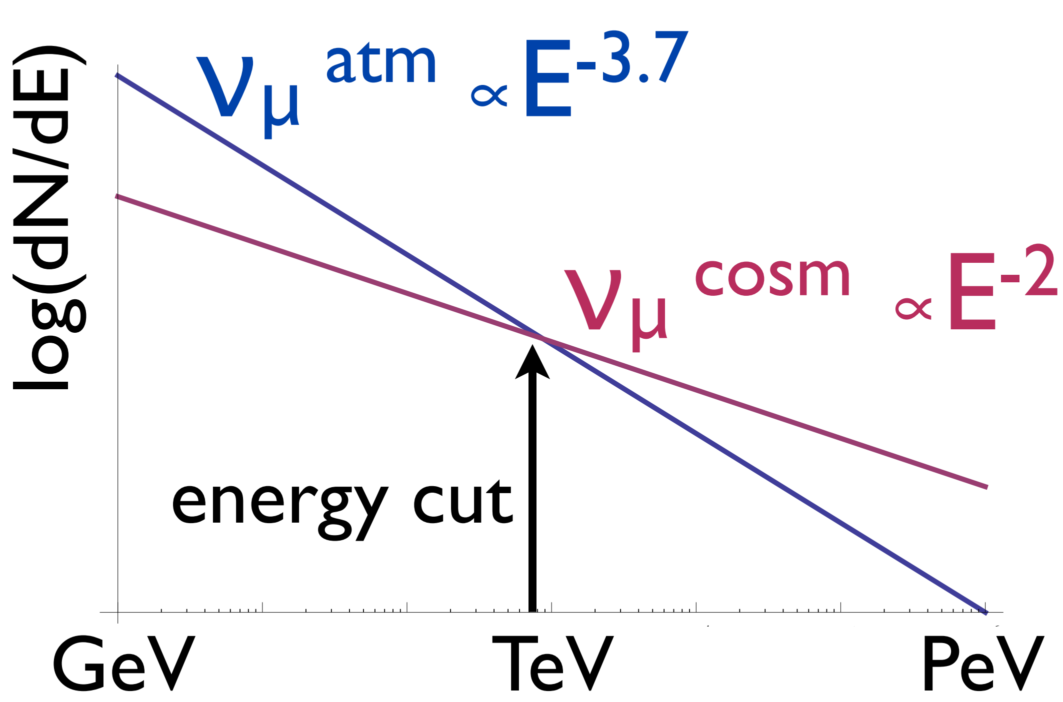
ANTARES 2007-2008 data (116 days)



“Point like” sources

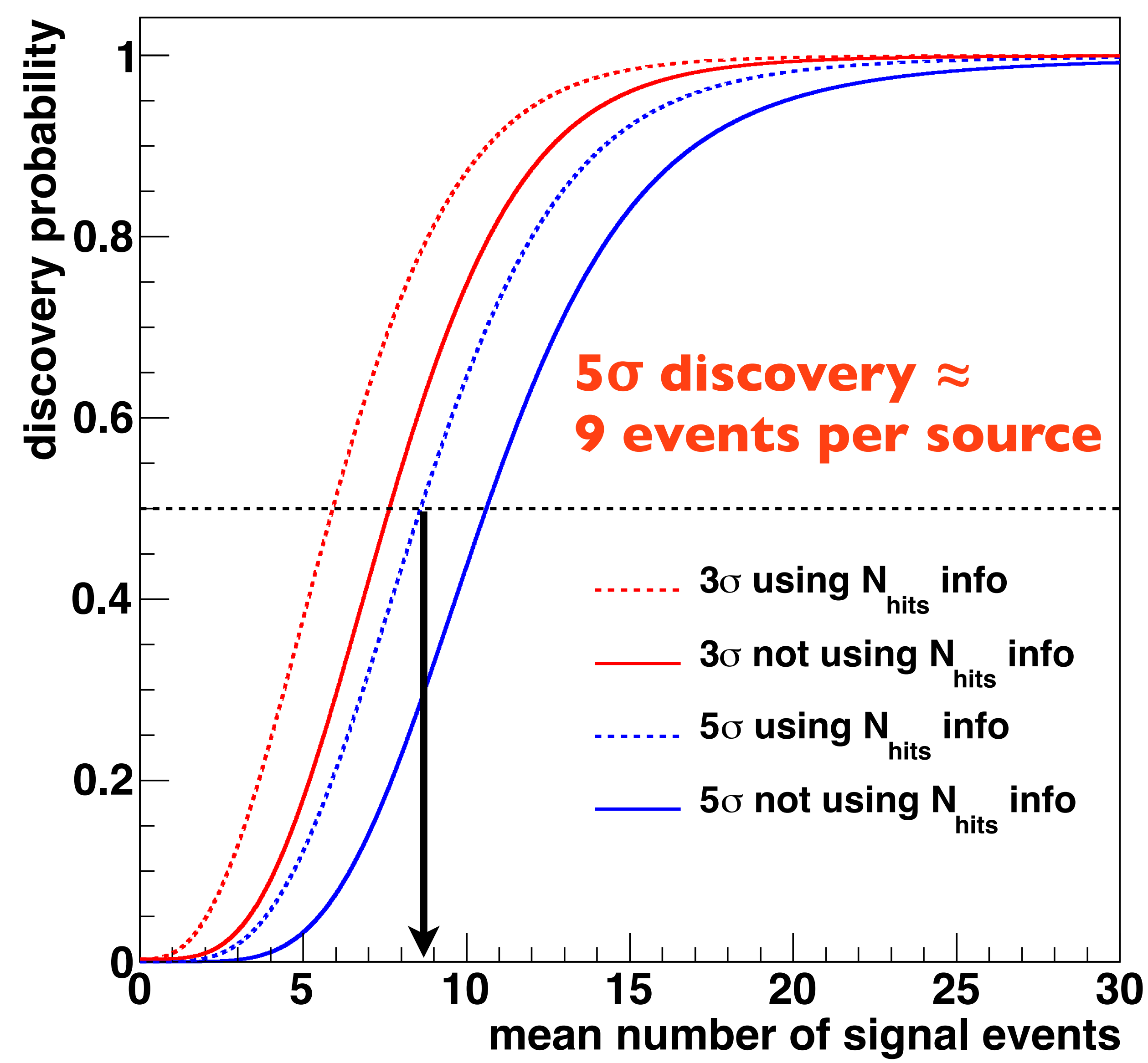
Analysis performed for

- All sky search
- preselected candidates
  - 51 γ-ray sources
  - 11 from gravitational lensing



Clusterization algorithm

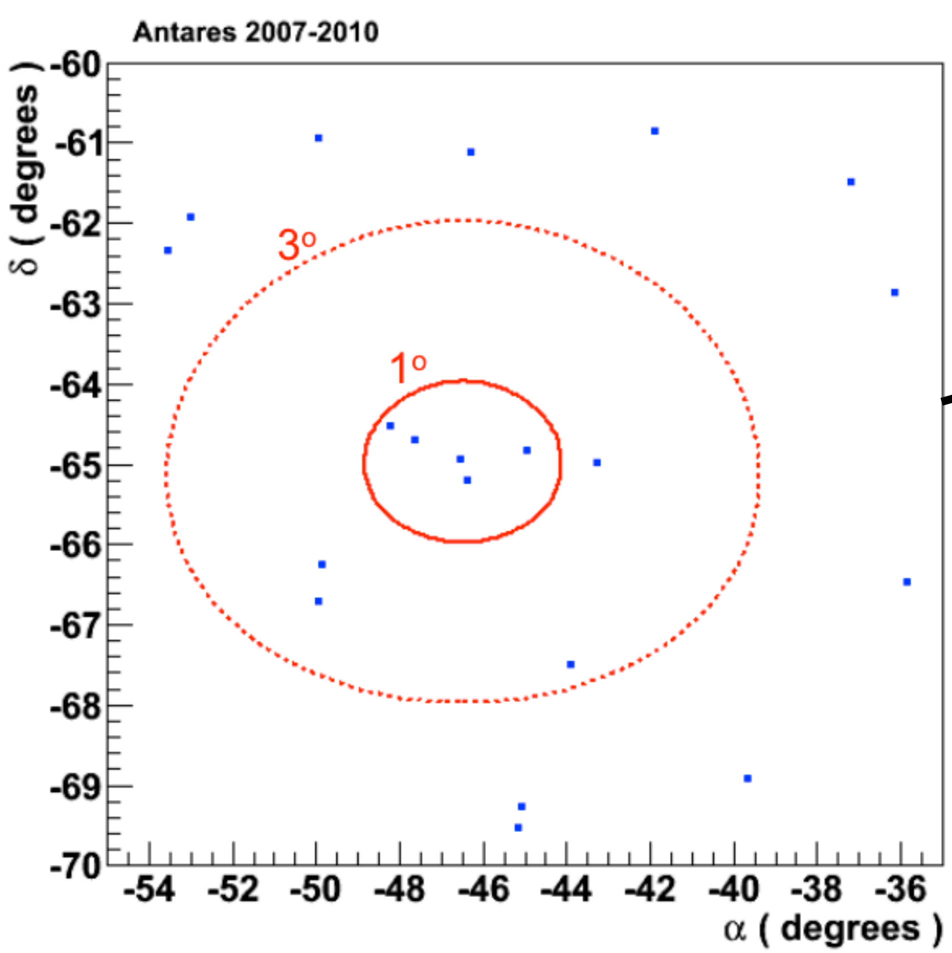
(unbinned maximum likelihood method)

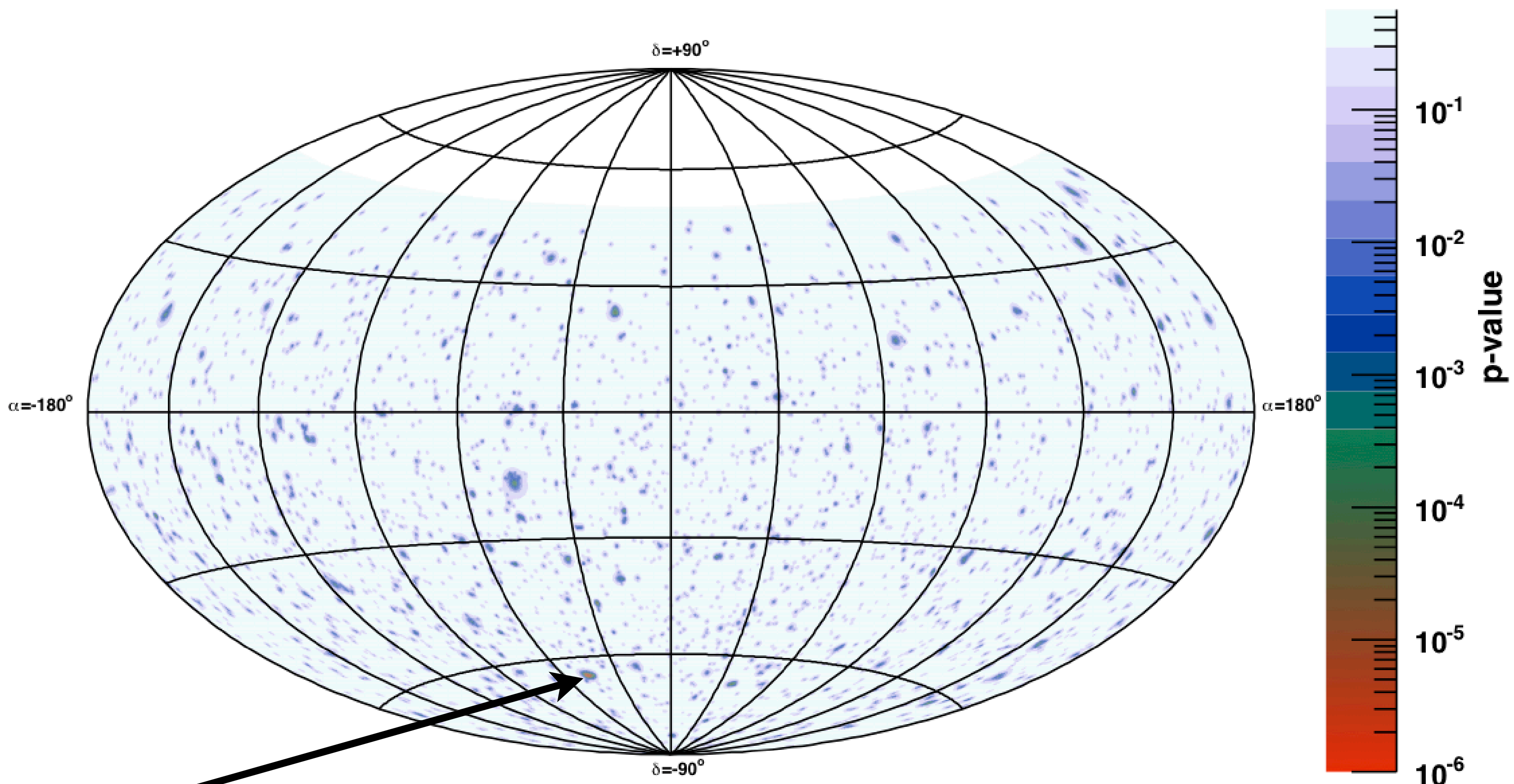


"Point like" sources

All sky method with ANTARES 2007-2010 data
→ no significant excess

- 3058 neutrino candidates (85% purity)
- best cluster (-46.5°,-65.0°)
  ➡ 2.2σ with 5(9) events in 1(3)°



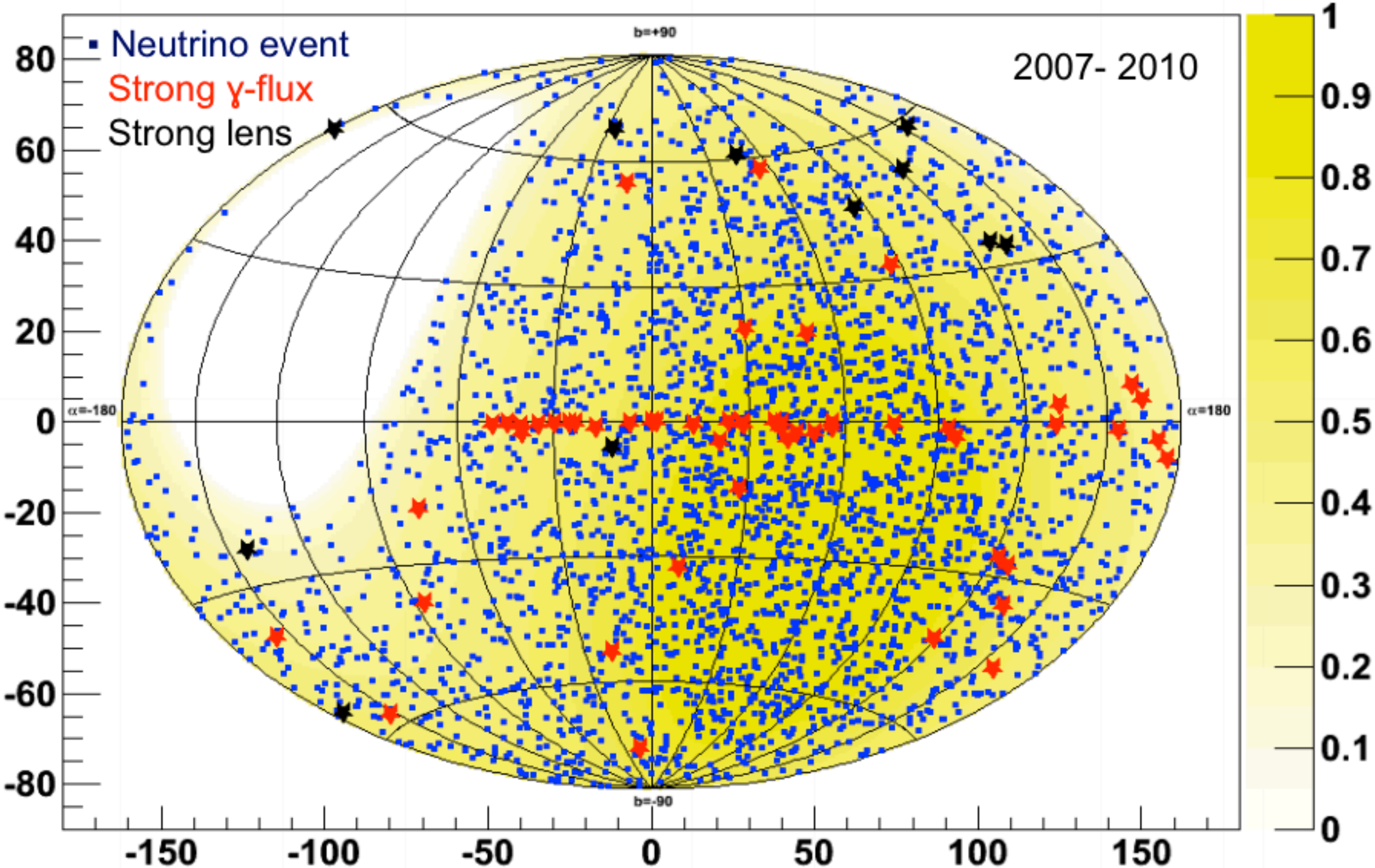


✦ Angular resolution 0.5 ± 0.1 degrees
✦ 3/4 of the sky visible, most of Galactic Plane including Galactic center

“Point like” sources

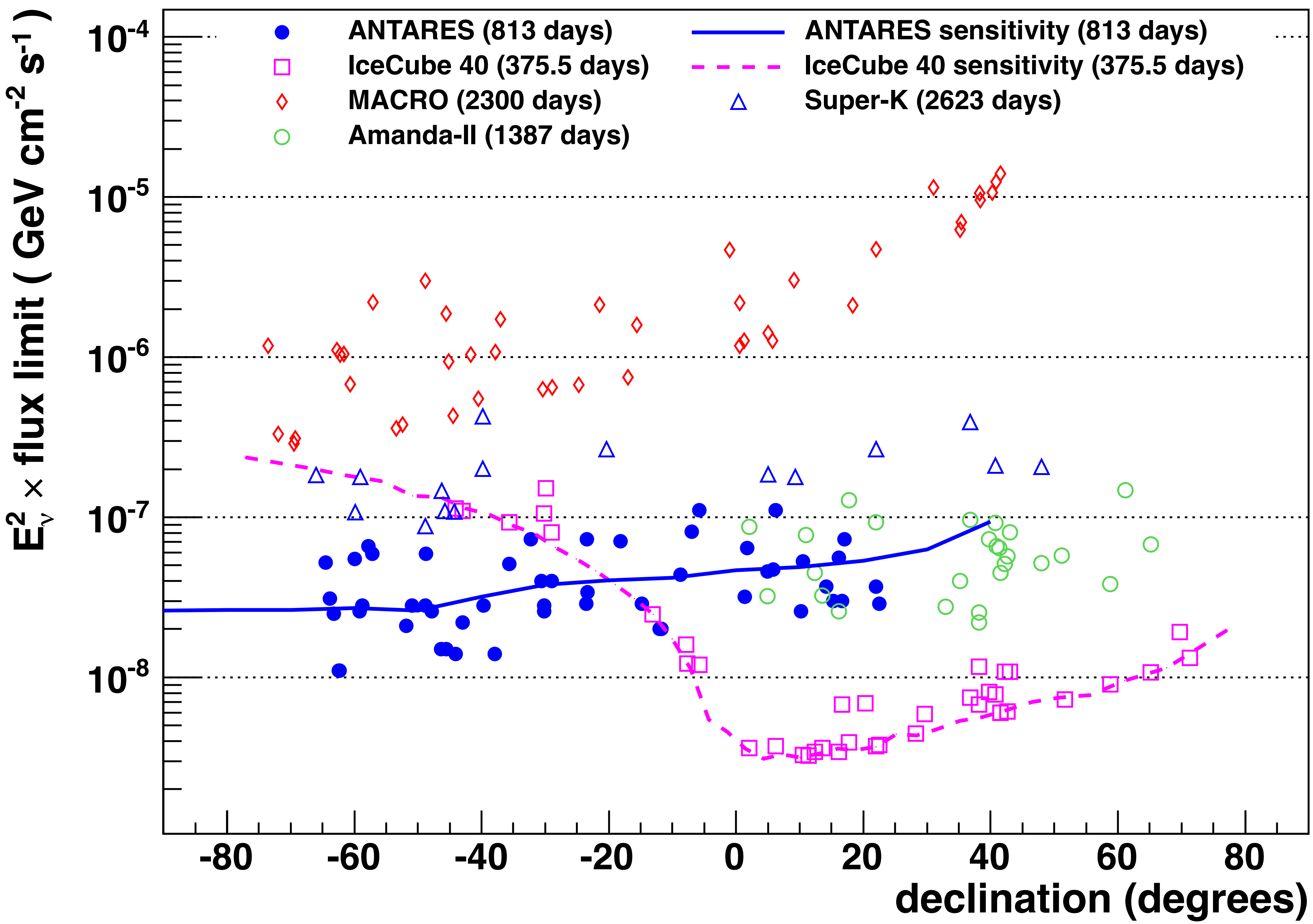
Preselected candidates method with 2007-2010 data

→ no significant excess



“Point like” sources

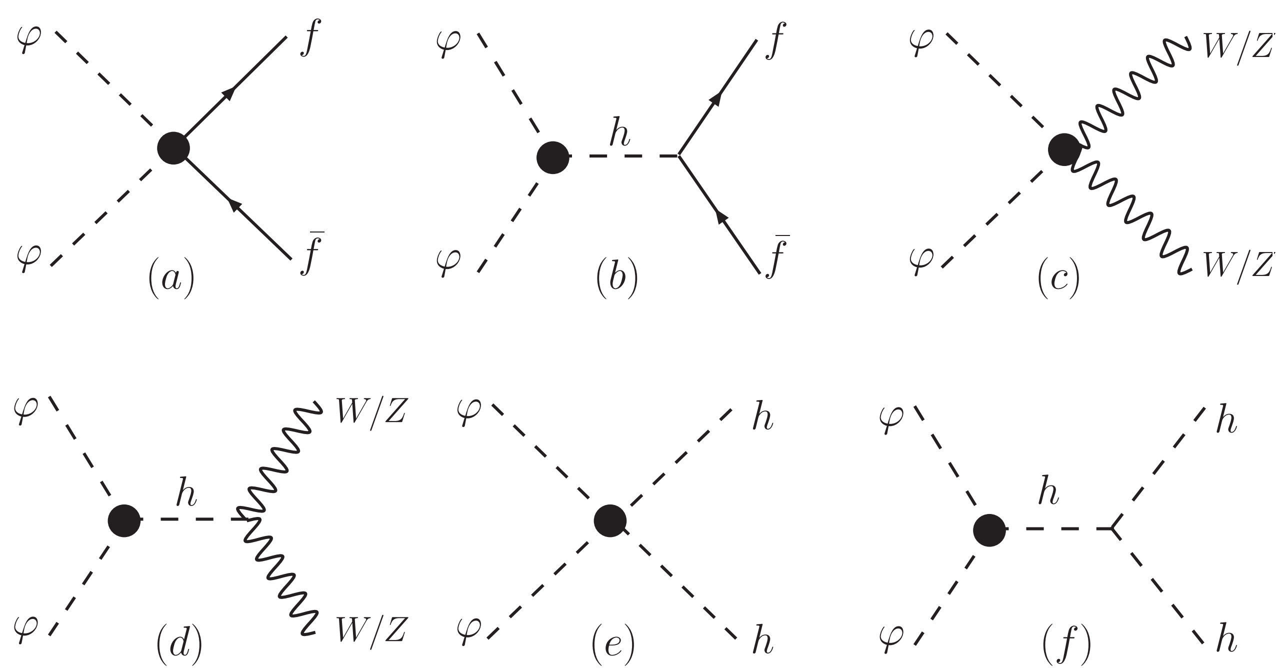
[Astrophysical Journal 760:53(2012)]



Dark Matter

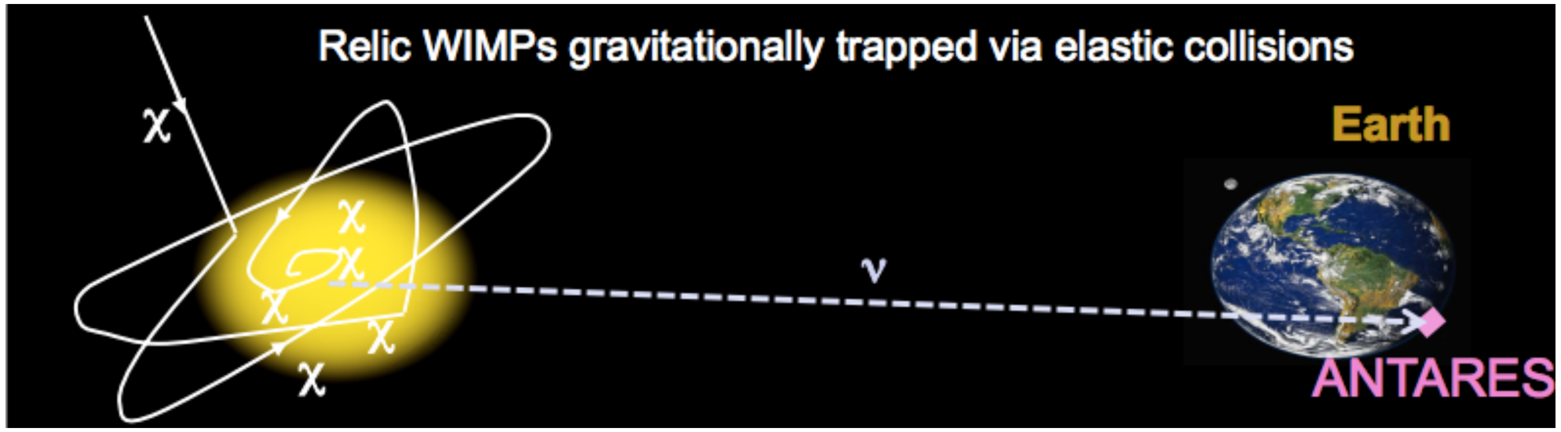
Indirect search of dark matter with neutrino telescopes

- WIMPs constitute the best explanation for Dark Matter (SuSy or Kaluza Klein Model)
- Many sources candidates : Sun, galactic center, dwarf galaxies, Earth, galactic halo
- Dark matter annihilations product neutrinos in many channels (depending of the selected model)



➡ Search of neutrinos with a DM candidate mass hypothetis between 10 GeV/c^2 and 10 TeV/c^2

Dark Matter



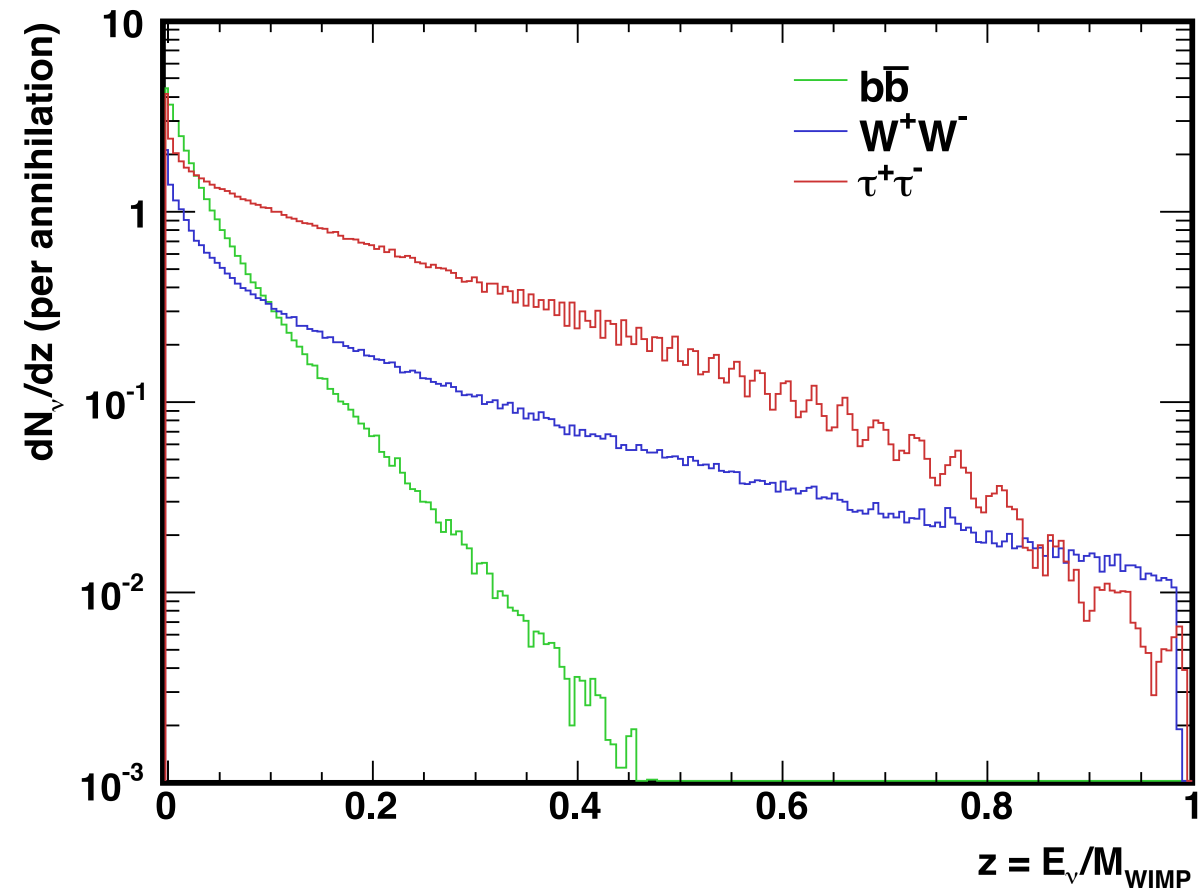
Clean signal

- no ɣ-rays contamination
- solar neutrinos < GeV
- astrophysical neutrinos > TeV

Neutrinos signal coming on Earth

- Benchmarks channel
  - ✦ $b\bar{b}$ (soft spectrum)
  - ✦ $\tau^+\tau^-$ (hard spectrum)
  - ✦ W^+W^- (hard spectrum)
- Model-independent simulation using WIMPSIM
- Interactions in the Sun, flavor oscillations and regeneration of ν_τ accounted

M_{WIMP} = 350 GeV/c^2



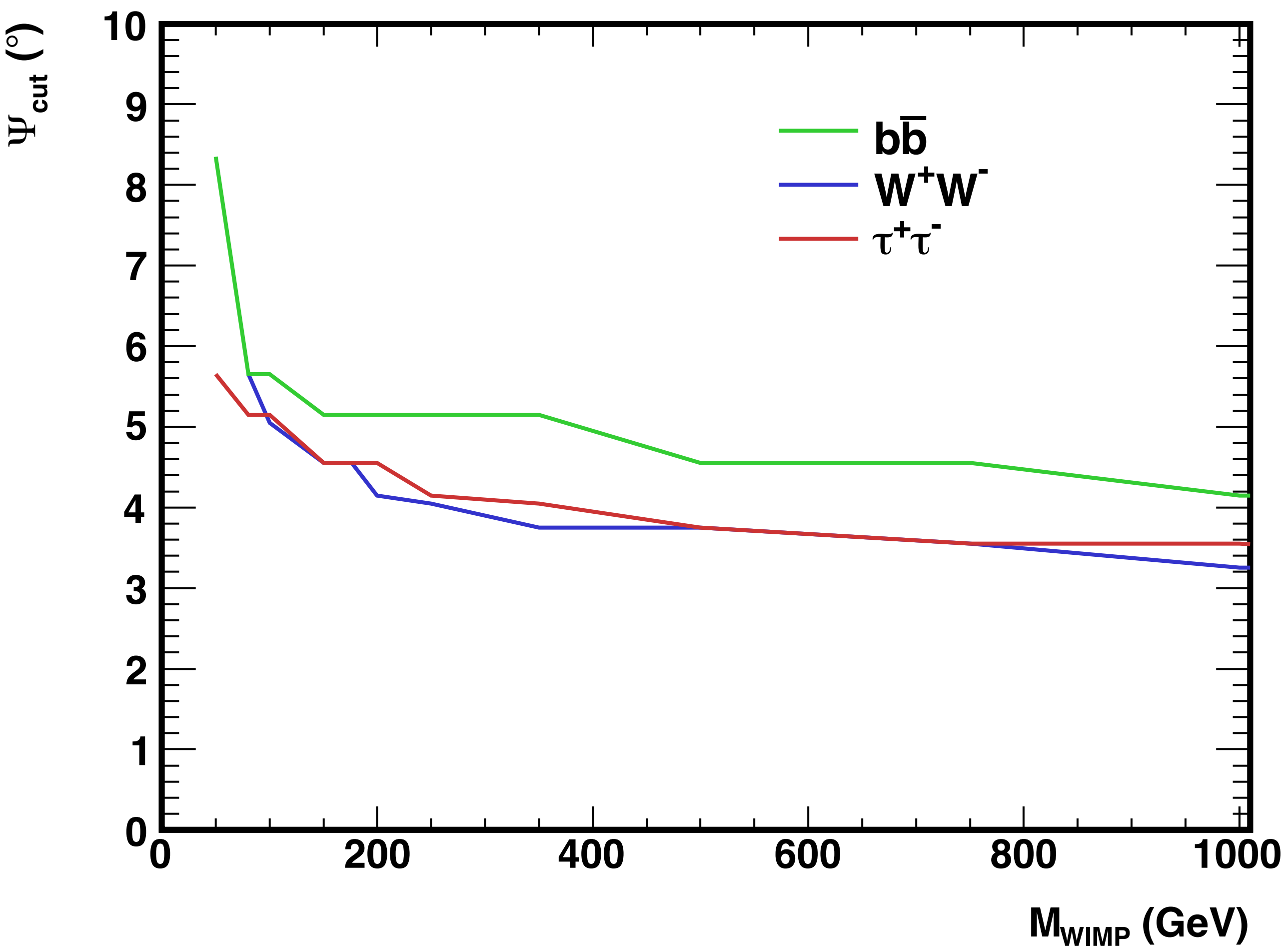
Dark Matter

Analysis performed for 2007-2008 data (295 days)

Background from ν_{atm} and μ_{atm} estimated from MC simulation and scrambled data

- Selection
  - ✦ χ^2 track < χ^2 bright point
  - ✦ upgoing events
  - ✦ multi-lines events
  - ✦ more than 5 hits per event
  - ✦ selection on triggers
  - ✦ direction of the Sun

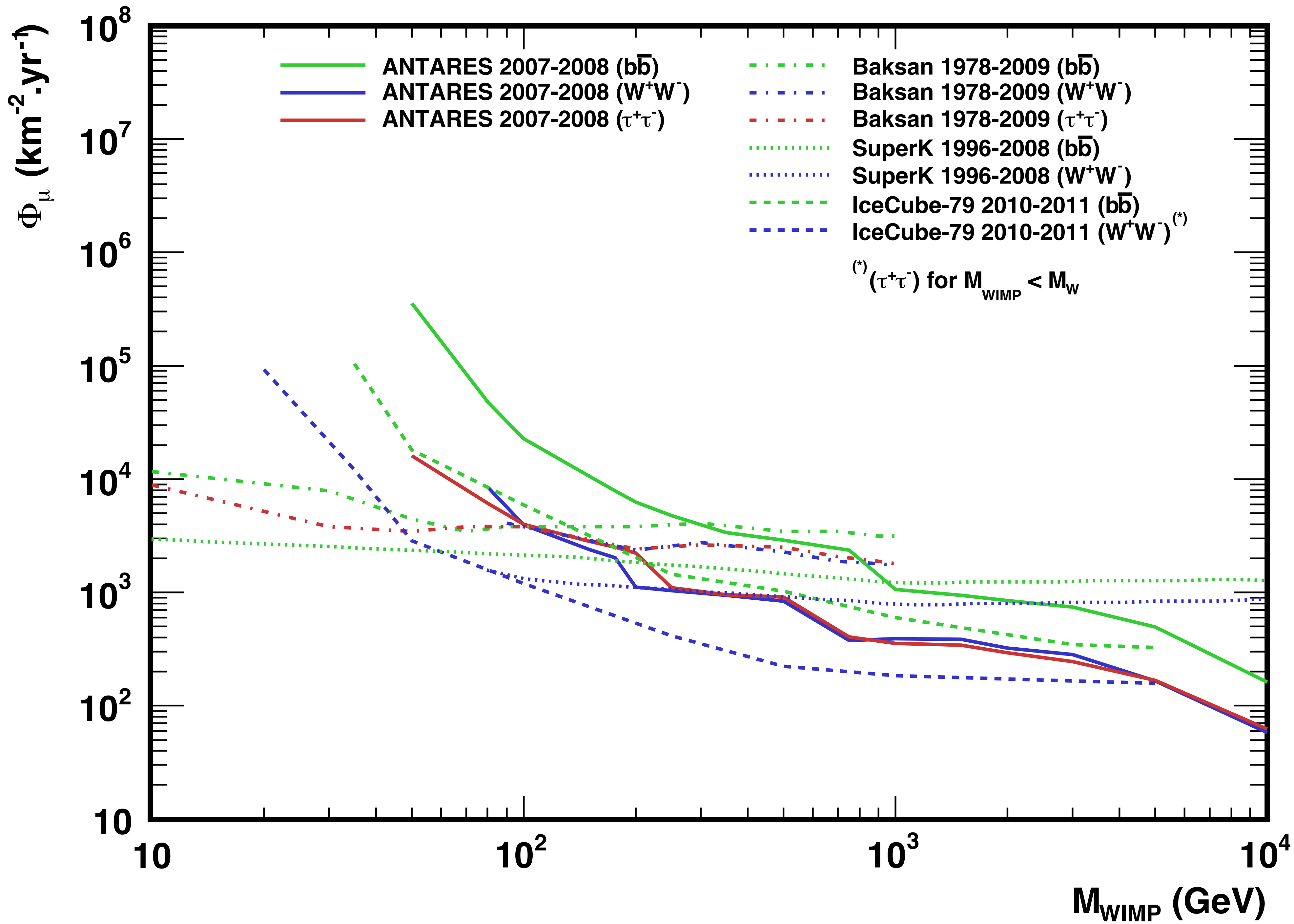
Optimum cut angle between the muon tracks and the Sun's direction



Dark Matter

in the Sun

[arXiv:1302.6516]



Dark Matter

Neutrino flux from dark matter self-annihilation

$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu}(E_\nu, \Delta\Omega) = \Phi^{pp}(E_\nu) J(\Delta\Omega)$$

$(\mathrm{cm}^{-2}\mathrm{s}^{-1})$

- E_ν : neutrino energy
- $\Delta\Omega$: opening angle

Particle physics

Neutrinos production from dark matter self-annihilation (Particle physics)

$$\Phi^{pp}(E_\nu) = \frac{1}{4\pi} \frac{<\sigma_{ann} v>}{\delta m_\chi^2} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}$$

$(\mathrm{cm}^3\mathrm{s}^{-1}\mathrm{GeV}^{-3})$

Astrophysics

Factor J, dark matter quantity in a given galaxy (Astrophysics)

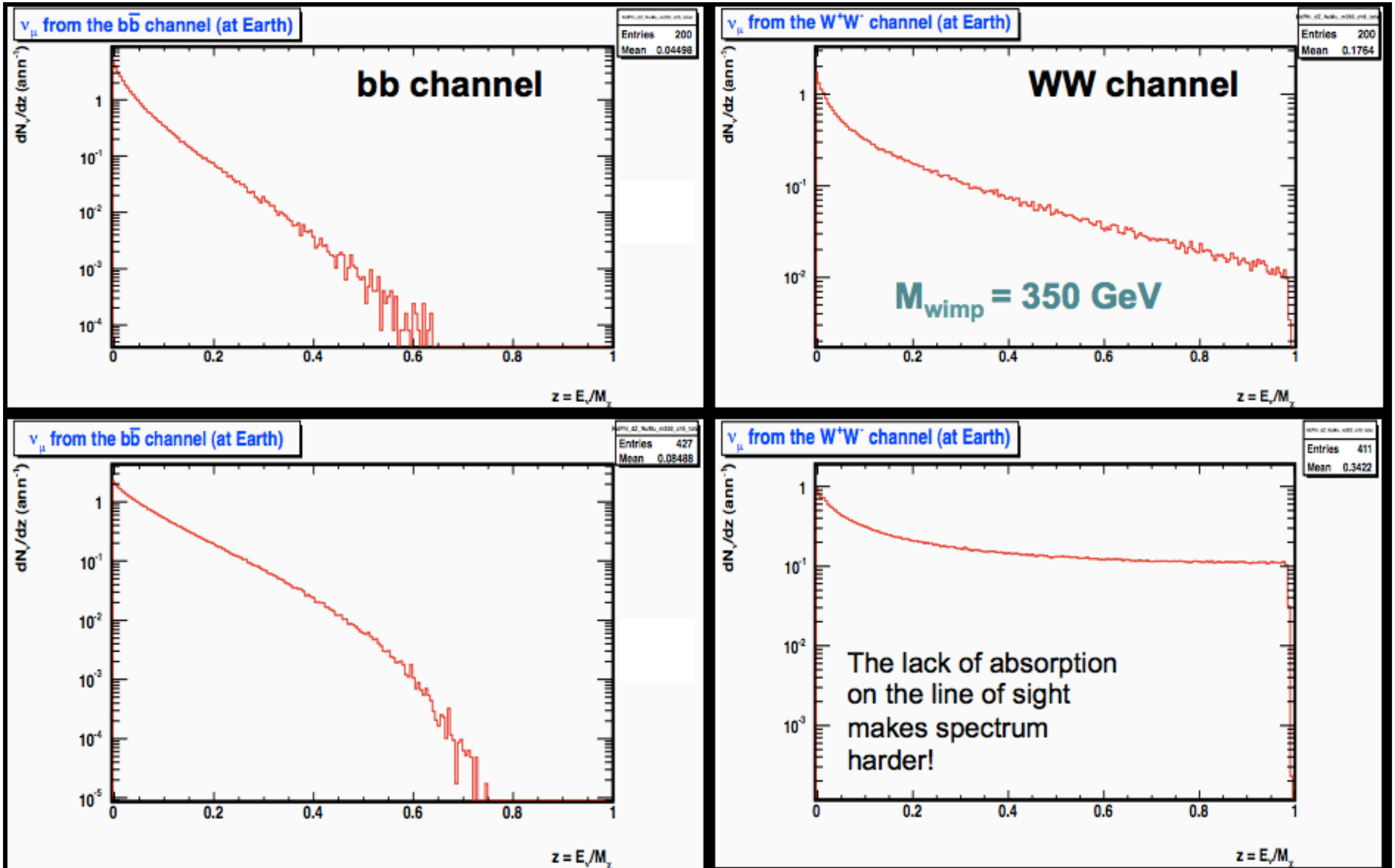
$$J(\Delta\Omega) = \int_{\Delta\Omega} \int_{los} \rho^2(\ell, \Omega) \mathrm{d}\ell \mathrm{d}\Omega$$

$(\mathrm{GeV}^2\mathrm{cm}^{-5})$

Dark Matter

in GC and dwarf galaxies

Neutrinos coming from the Sun (top) and from GC/DG (bottom)



Dark Matter

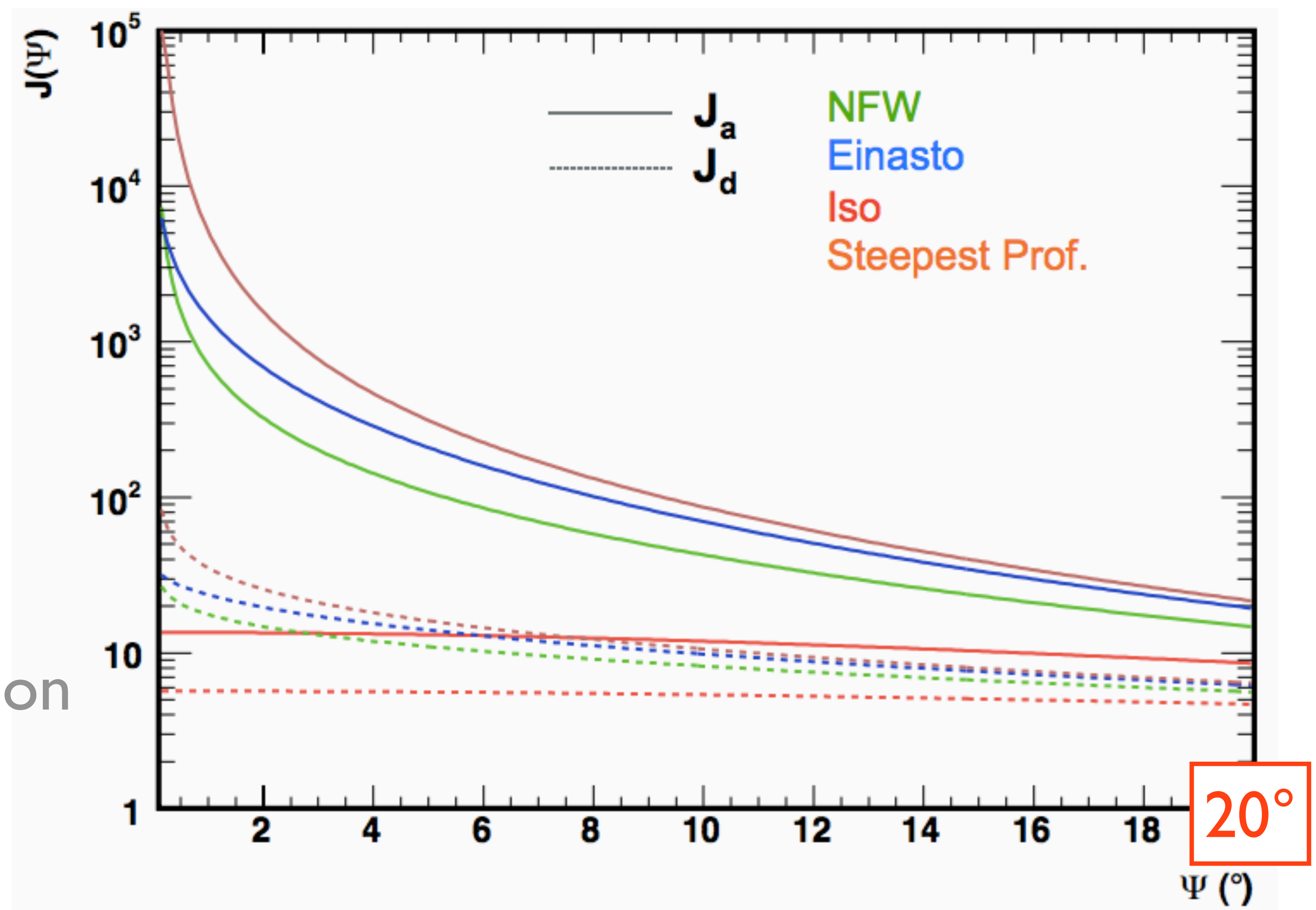
Strongest dark matter quantity

$$J = \int_{\Delta\Omega} \int_{\text{los}} \rho^2(\ell, \Omega) d\ell d\Omega$$

$\Delta\Omega = 2\pi(1 - \cos\alpha_{int})$

dark matter profile

Different dark matter profile give different J-factor

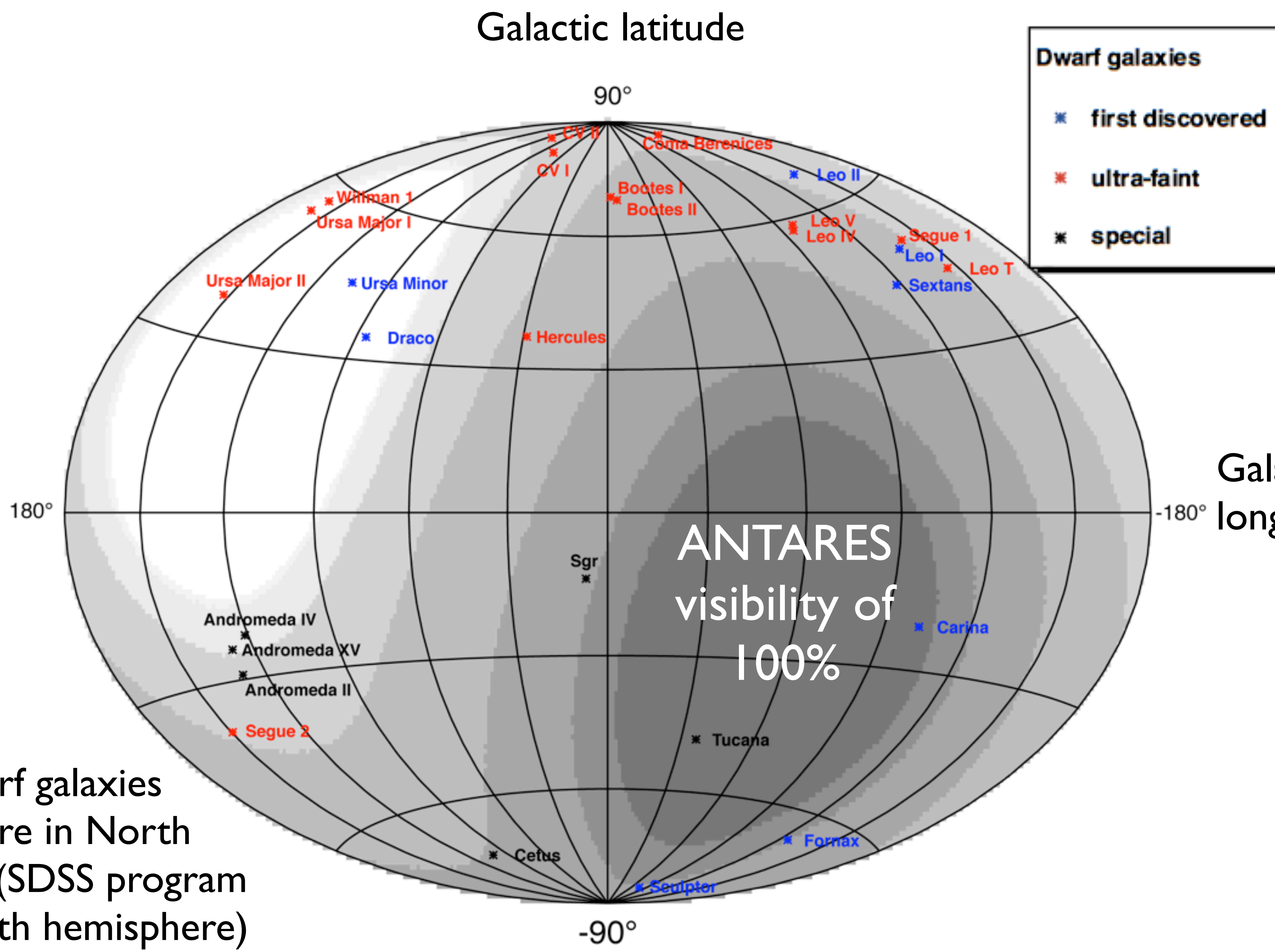


J_a : J-factor from DM annihilation

J_d : J-factor from DM decay

Dark Matter

Best ratio dark matter / ordinary matter

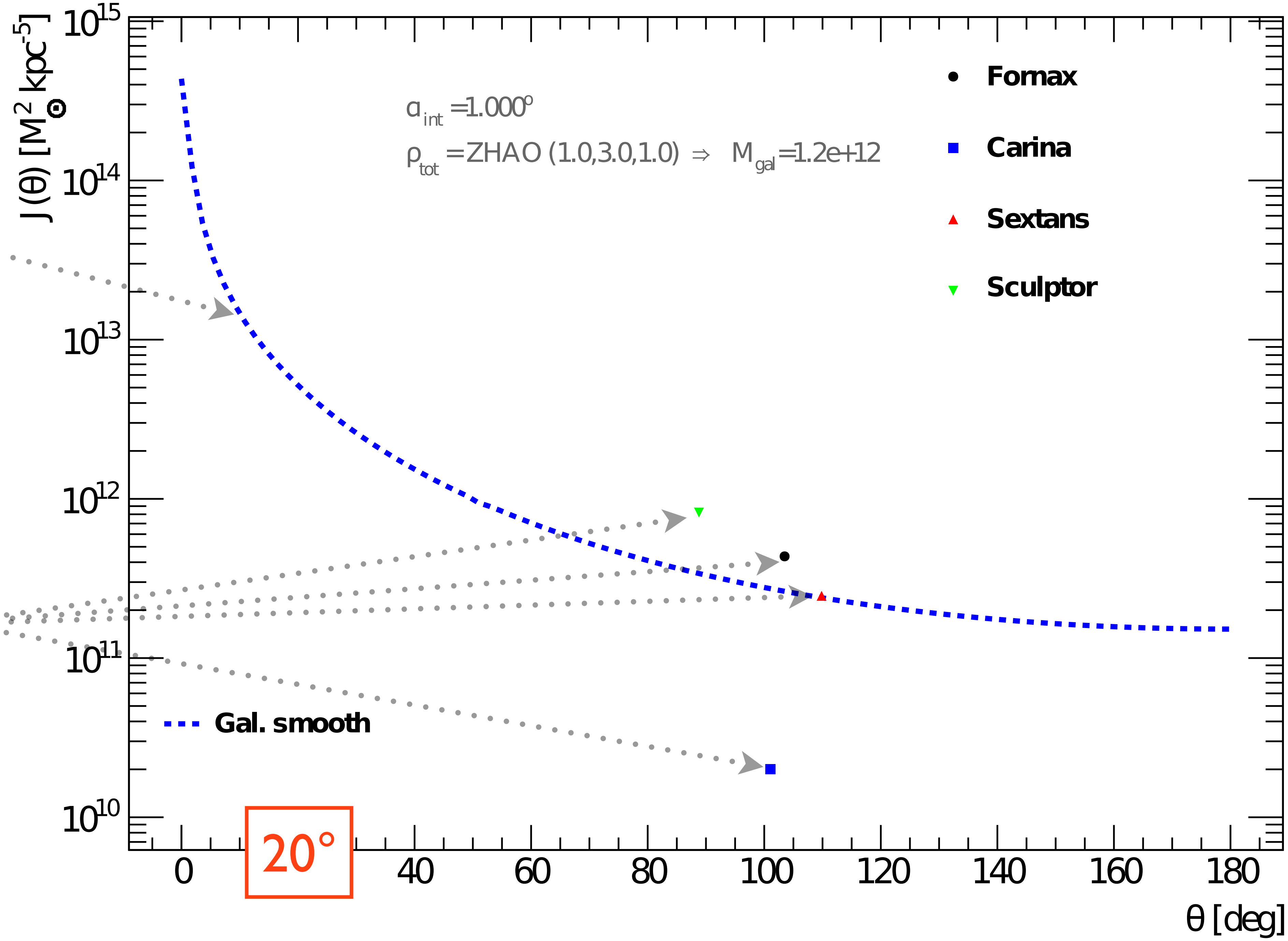


Most of dwarf galaxies discovered are in North hemisphere (SDSS program surveys North hemisphere)

Dark Matter

J-factor of Milky Way for a given dark matter profile

J-factor of dwarf galaxies for the best dark matter profile for each one



GRB

[JCAP 1303 (2013) 006]

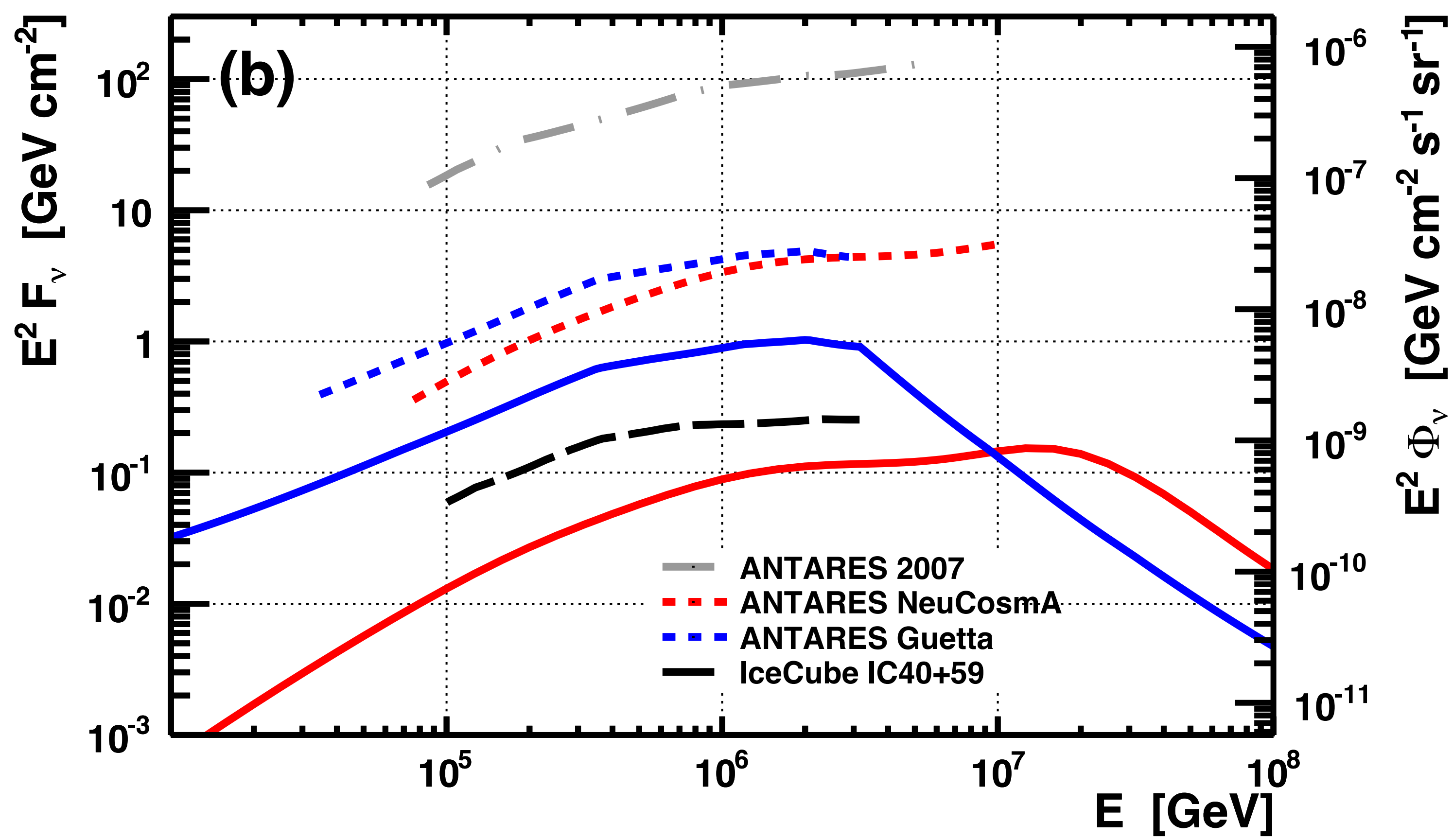
Search for neutrinos events in coincidence with observed GRB

- long GRBs
- measured spectrum
- below ANTARES horizon
- detector running and stable data-taking conditions

➡ 296 GRBs (total prompt emission duration 6.6 hours)

Analysis performed for 2007-2011 data

- Use coincidence (time and location)
- No event found (within search period and 10° around GRBs)

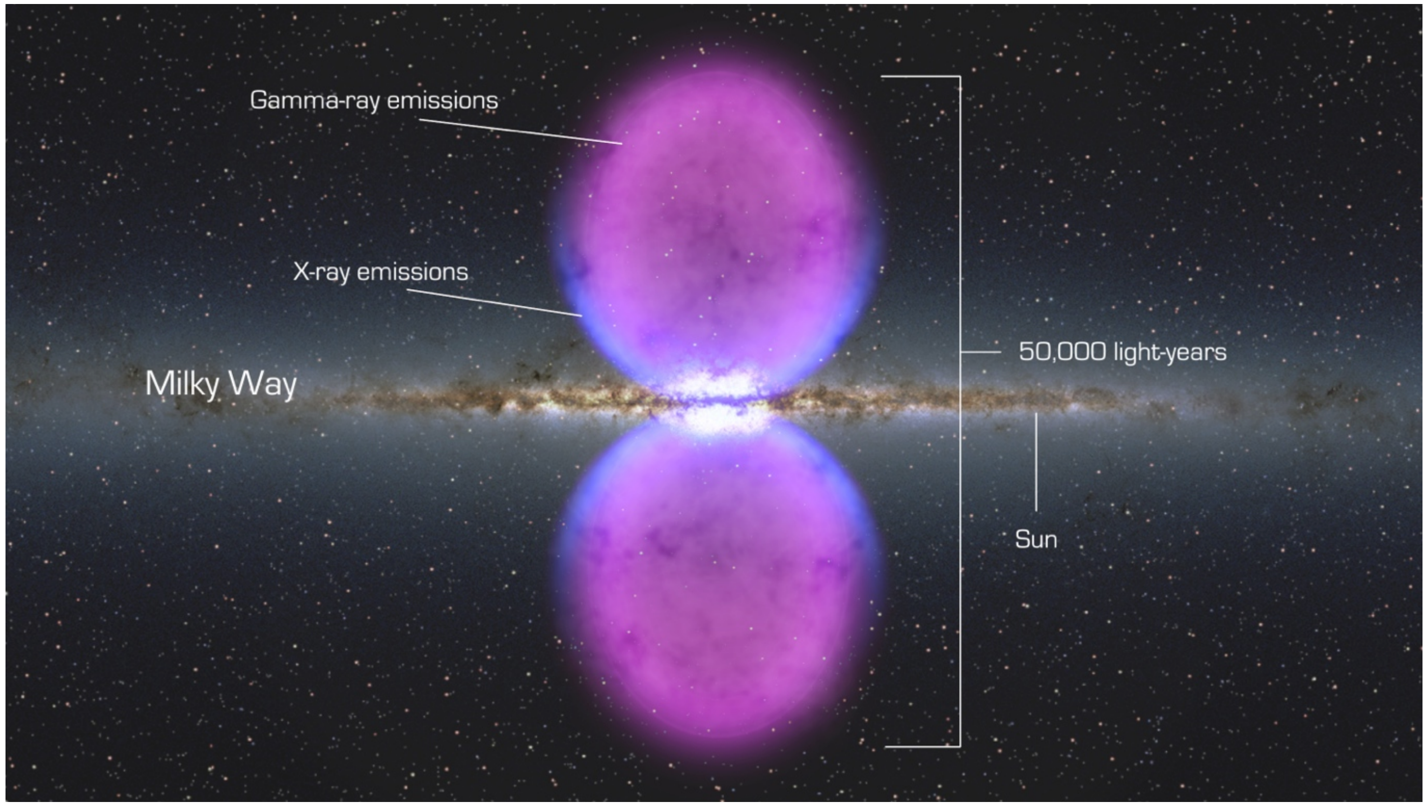


Grey : first ANTARES limit (40 GRBs)

Black : IceCube (215 GRBs)

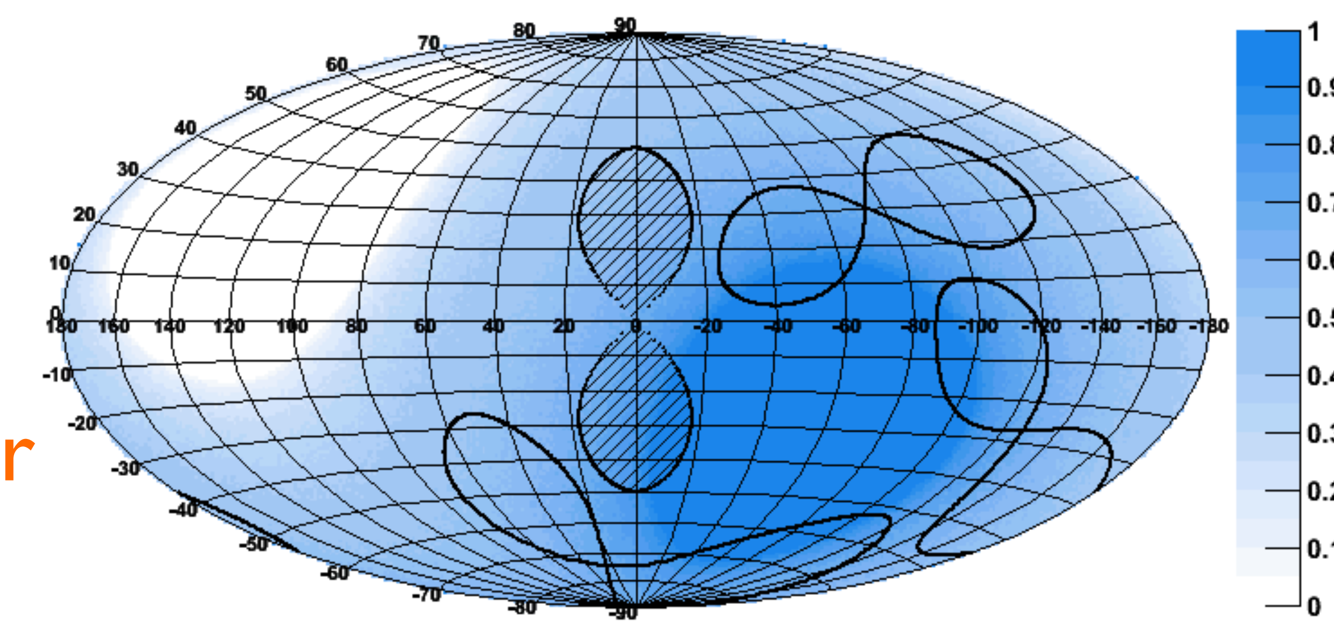
Solid lines : models (NeuCosmA and Guetta)

Fermi bubbles



- excess of ɣ and X rays above and below the galactic center
- unknown origin
- excess of ν ?

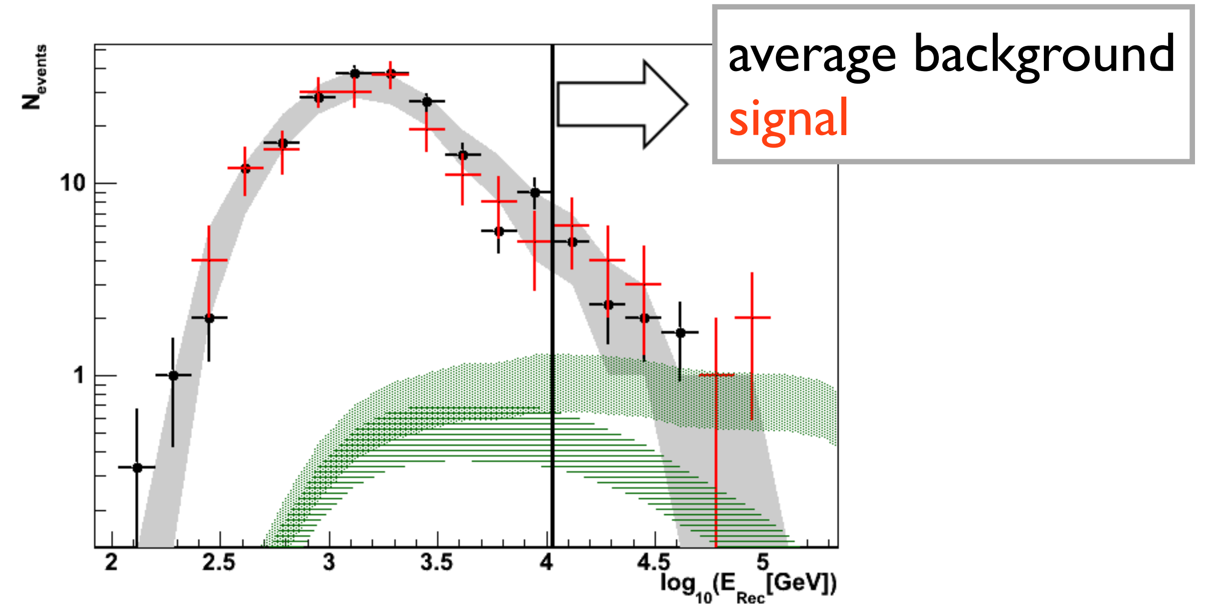
Analysis
→ determine off-zones with same visibility distribution of the detector

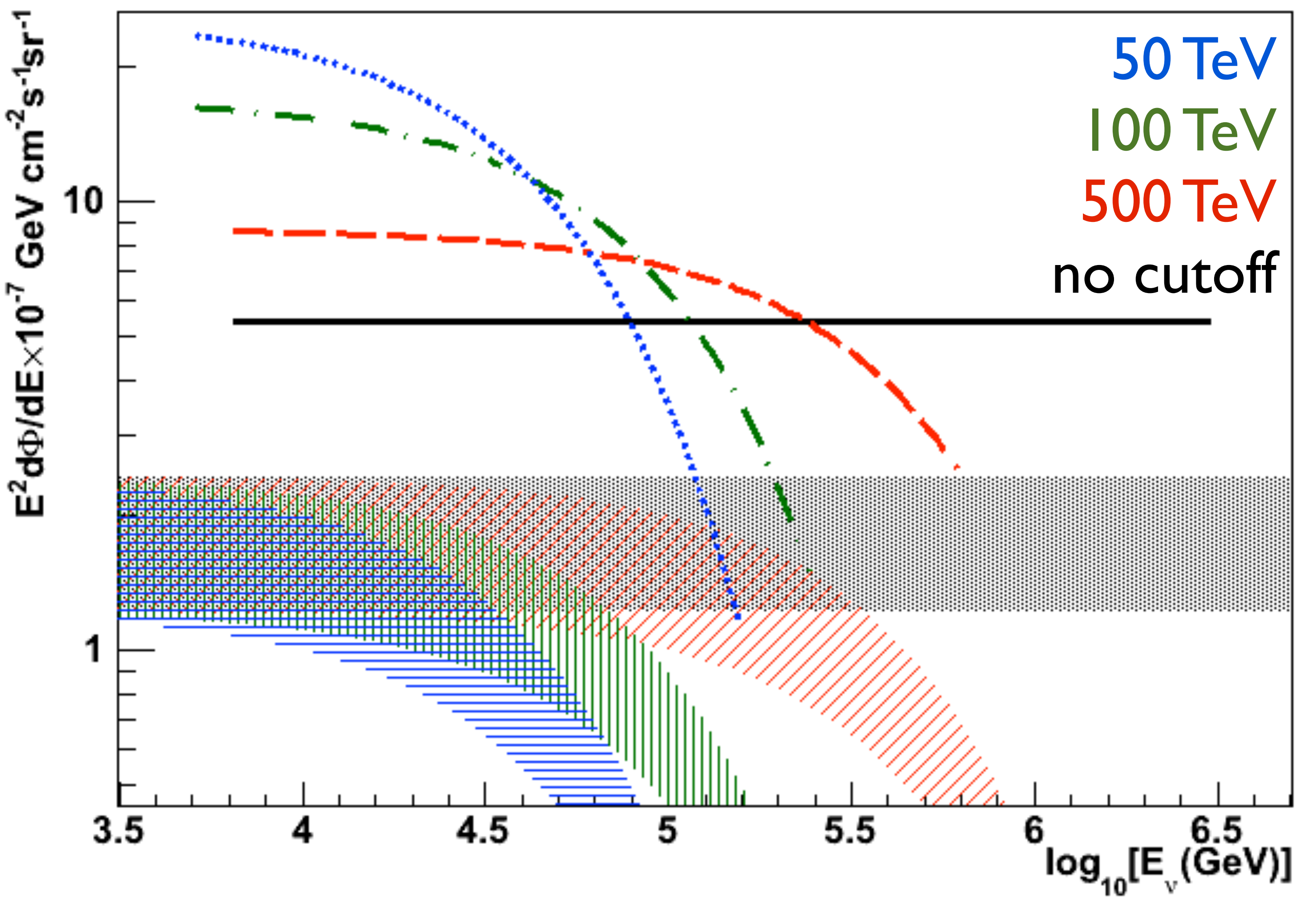


Fermi bubbles

[arXiv:1308.5260]

- 3 off-zones (background)
- ANTARES 2008-2011 data (806 days)
- N_{obs} = 16
  N_{bkg} = (12+12+9)/3 = 11
  ➡ no significant excess (1.2σ)





Summary

ANTARES running since 2007 and complete since 2008

Neutrino oscillations

↦ consistent with world data

↦ 2007-2010 data analysed

Magnetic monopole

↦ best limit for β<0.8 (below Cerenkov threshold)

Point sources

↦ 2007-2010 data analysed

↦ 2007-2012 analysis on track

Dark matter

↦ 2007-2008 data analysed for the Sun

↦ 2007-2012 analysis on track (for Sun, GC and dwarfs)

Backup

Dark Matter

in dwarf galaxies

DM mass : 200 GeV/c²