High-Energy Neutrino Detection Techniques

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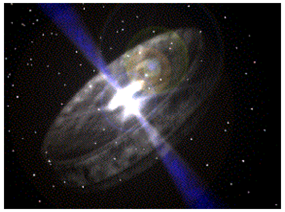
Gamma-Ray Bursts in the Multi-messenger Era, Paris June 2014

Outline

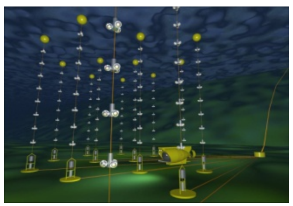


Neutrino astronomy

Historical aspects

Scientific motivations

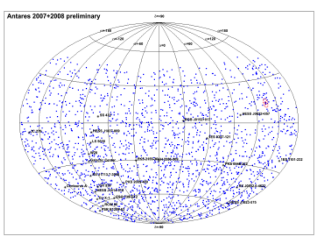
Cosmic neutrino sources



Neutrino telescope

Detection principles

Current telescopes



Selected results

First Discovery by IceCube? ← Diffuse Flux

Searches for point sources

Multi-messenger search

Future prospects

First ideas early 60's…science

Ann.Rev.Nucl.Sci
10 (1960) 1

NEUTRINO INTERACTIONS[1]

By Frederick Reines[2]

IV. COSMIC AND COSMIC RAY NEUTRINOS

As we have seen, interactions of high-energy particles with matter produce neutrinos (and antineutrinos). The question naturally arises whether the neutrinos produced extraterrestrially (cosmic) and in the earth's atmosphere (cosmic ray) can be detected and studied. Interest in these possibilities stems from the weak interaction of neutrinos with matter, which means that they propagate essentially unchanged in direction and energy from their point of origin (except for the gravitational interaction with bulk matter, as in the case of light passing by a star) and so carry information which may be unique in character. For example, cosmic neutrinos can reach us from other galaxies whereas the charged cosmic ray primaries reaching us may be largely constrained by the galactic magnetic field and so must perforce be from our own galaxy. Our more usual source of astronomical information, the photon, can be absorbed by cosmic matter such as dust. At present no acceptable theory of the origin and extraterrestrial diffusion of cosmic rays exists so that the cosmic neutrino flux can not be usefully predicted. An observation of these neutrinos would provide new information as to what may be one of the principal carriers of energy in intergalactic space.

The situation is somewhat simpler in the case of cosmic-ray neutrinos: they are both more predictable and of less intrinsic interest. Cosmic-ray

Greisen, 1960, Proc. Int. Conf on Instrum for HE physics

One may even anticipate eventual high-energy neutrino astronomy, since neutrino travel in straight lines, unlike the usual primary cosmic rays, and the neutrinos will convey a new type of astronomical information quite different from that carried by visible light and radio waves

First ideas early 60's…method

Ann.Rev.Nucl.Sci
10 (1960) 63

COSMIC RAY SHOWERS[1]

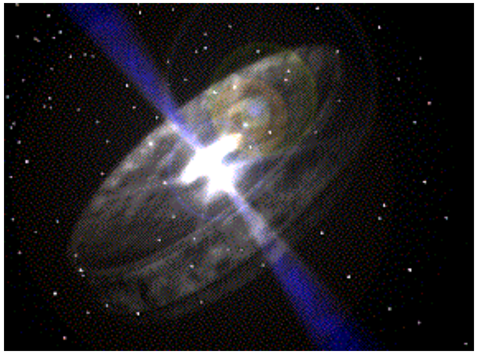
By Kenneth Greisen

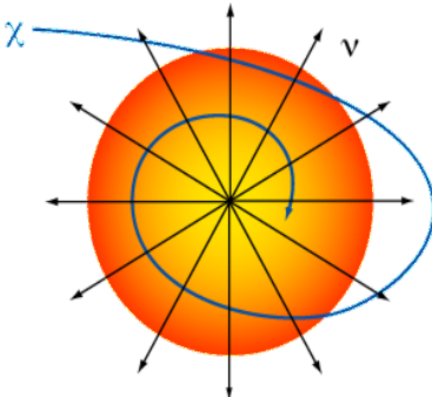
Let us now consider the feasibility of detecting the neutrino flux. As a detector, we propose a large Cherenkov counter, about 15 m. in diameter, located in a mine far underground. The counter should be surrounded with photomultipliers to detect the events, and enclosed in a shell of scintillating material to distinguish neutrino events from those caused by μ mesons. Such a detector would be rather expensive, but not as much as modern accelerators and large radio telescopes. The mass of sensitive detector could be about 3000 tons of inexpensive liquid. According to a straightforward

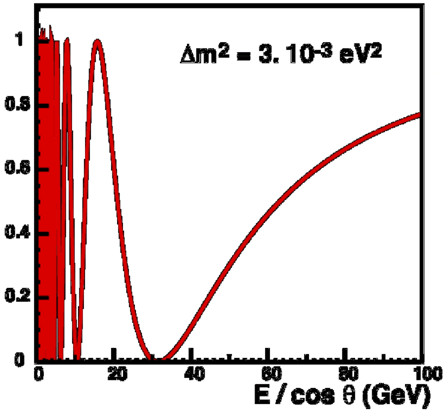
For example, from the Crab nebula the neutrino energy emission is expected to be three times the rate of energy dissipation by the electrons, leading to a flux of $6 \cdot 10^{-4}$ Bev/cm.^{2}/sec. at the earth. In the detector described above, the counting rate would be one count every three years with the lower of the theoretical cross sections—rather marginal, though the background from other particles than neutrinos can be made just as small. The detector has the virtue of good angular resolution to assist in distinguishing rare events having unique directions.

Fanciful though this proposal seems, we suspect that within the next decade, cosmic ray neutrino detection will become one of the tools of both physics and astronomy.

Neutrino telescopes: science scope







High Energy	Medium Energy	Low Energy
$E_\nu > 1$ TeV	10 GeV $< E_\nu <$ 1 TeV	10 GeV $< E_\nu <$ 100 GeV

ν from extra-terrestrial sources

Dark matter search

ν oscillations

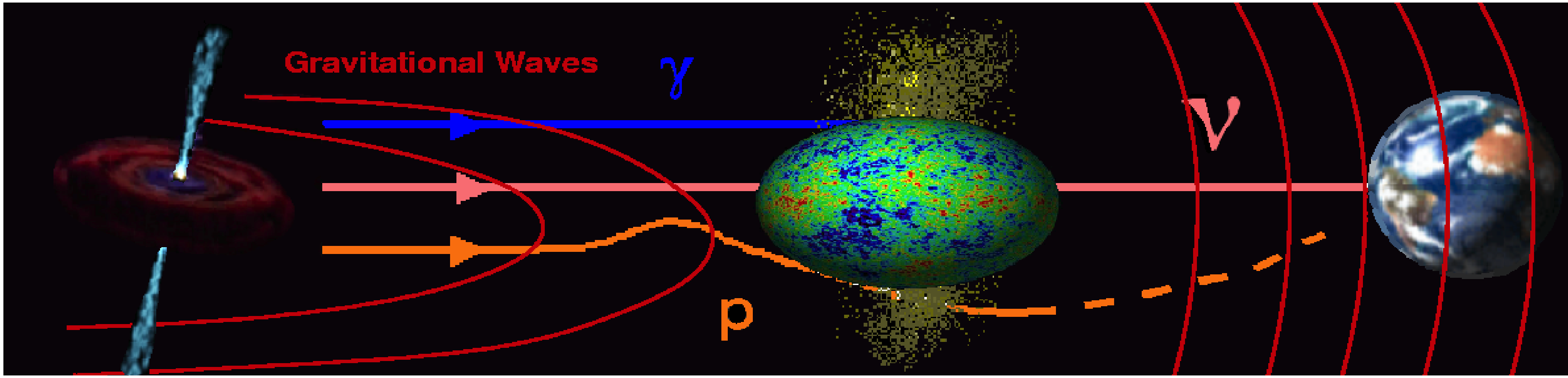
Origin and production mechanism of HE CR

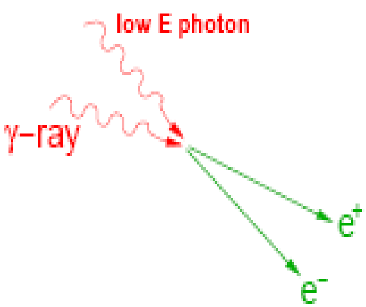
Primary goal

Exotic particle physics
Monopoles, nuclearites,…

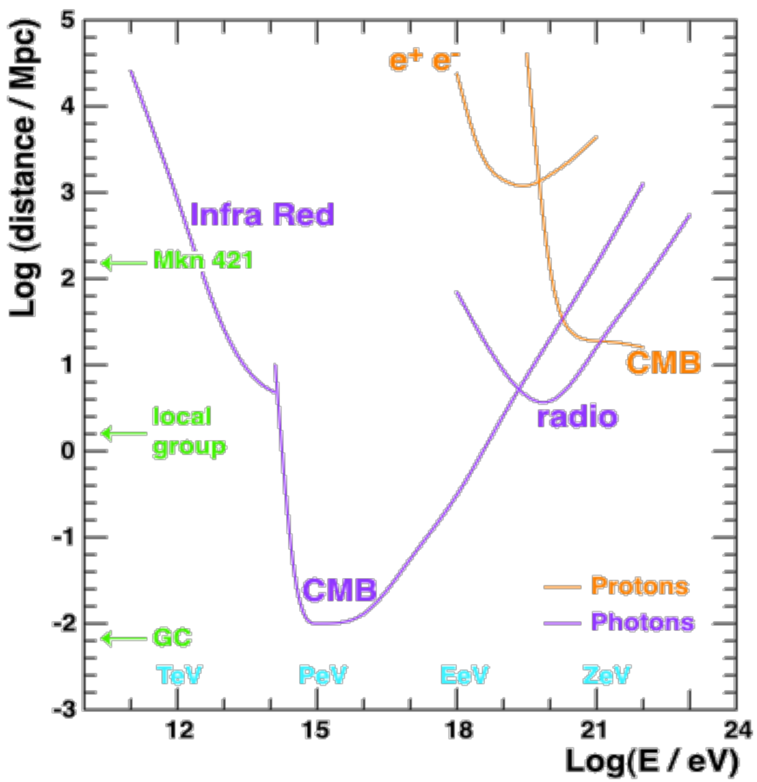
Marine sciences: oceanography, biology, geology…

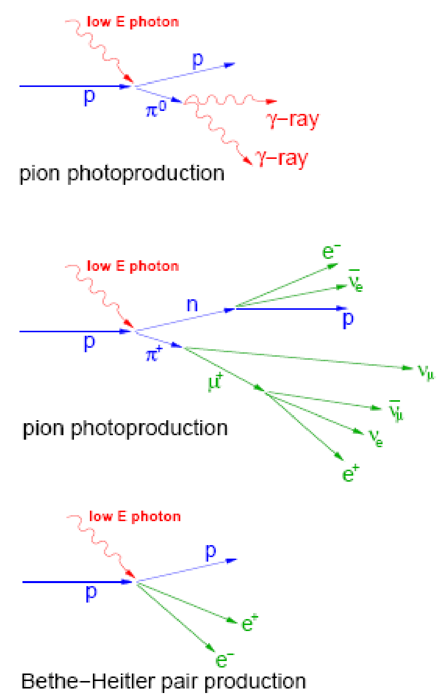
Multi-messenger astronomy



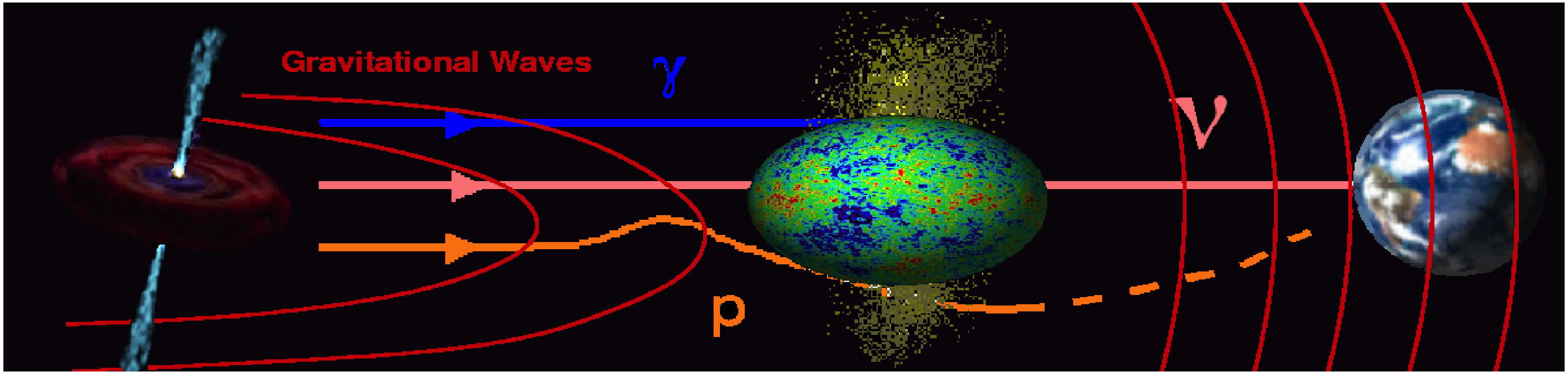


photon−photon pair production





Multi-messenger astronomy



Neutrino

⇒Transient sources

⇒ Cosmological distances

⇒Core of astrophysical bodies

⇒ Point source

⇒ Unambiguous signature of hadronic acceleration

Mutli-wavelength/messenger analysis → Modeling of the source

« Guaranteed » Flux / Upper Bounds

- Benchmark extragalactic muon neutrino flux

  Waxman & Bahcall, 1999

Estimated energy density of UHECR:

$$E^2 \frac{d\dot{N}_{\rm CR}}{dE}\bigg|_{E_{\rm min}} \approx 10^{44}\,{\rm erg\,Mpc^{-3}yr^{-1}}$$

Energy lost to ν in pγ interactions over Hubble time:

$$E_\nu^2 \frac{dN_\nu}{dE_\nu} \approx \frac{3}{8}\epsilon_\pi\, t_{\rm H}\, E^2 \frac{d\dot{N}_{\rm CR}}{dE}.$$

Resulting total ν flux:

$$[E_\nu^2 \Phi_\nu]_{\rm WB} \approx 2.3 \times 10^{-8} \epsilon_\pi \xi_z \ {\rm GeV cm^{-2} s^{-1} sr^{-1}}$$

$E^{-2}\, I(E) = 4.5\ 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}
~ 500 events /yr/ km^2

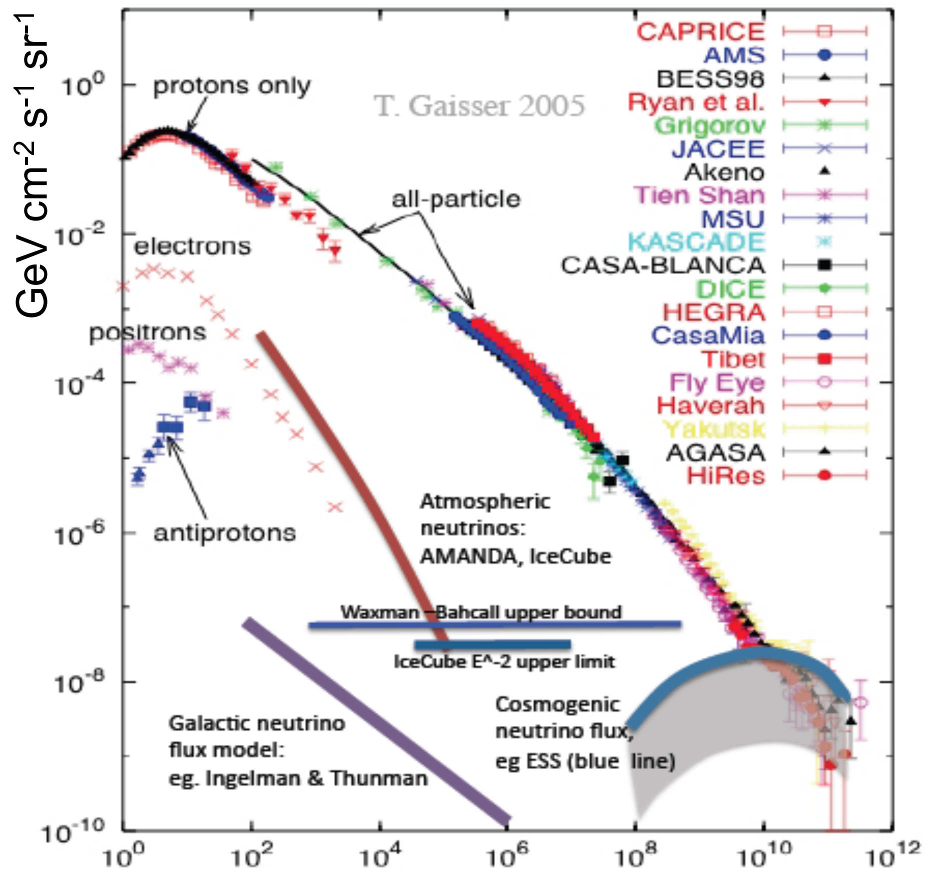
Hypothesis: UHECR are protons,
if not scales with p fraction

- Cosmogenic neutrino flux

  Berezinsky & Zatsepin, 1969
  UHECR p interact with CMB =>GZK cut off

$$p^+ + \gamma_{bkg} \longrightarrow \Delta^+ \longrightarrow \pi^+ + n^0$$

UHE ν



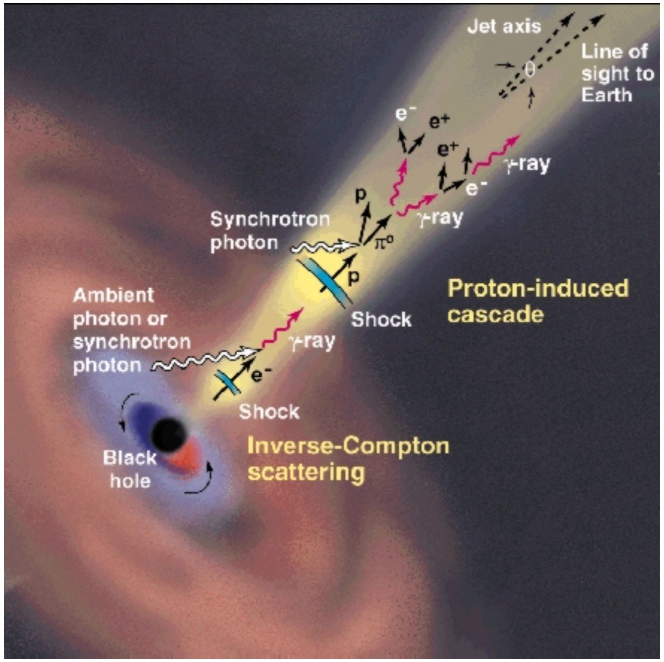
Models currently being probed by existing neutrino telescopes

Potential extragalactic sources

Active Galactic Nuclei (AGN)

Steady (though flaring) sources

Observed luminosities $10^9 - 10^{15}\ L_\odot$

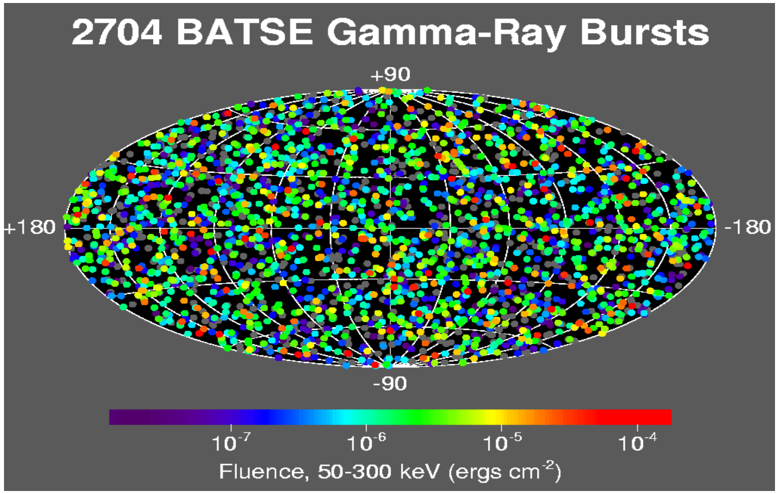


Gamma Ray Bursters (GRB)

Short emissions (~1s)
Very bright ~ $10^{18} \times L_\odot$

Counterparts : z up to 8.3

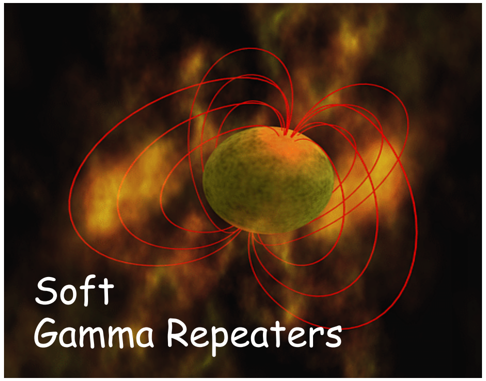
BATSE : 1 burst/day



Starburst Galaxies

supernovae -> cosmic rays + dense gas -> pions

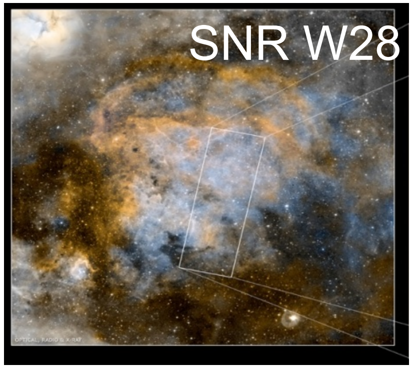
Potential Galactic sources



- **Microquasars** X-ray binaries with compact object (neutron star or black hole) accreting matter and re-emitting it in relativistic jets (intense radio & IR) flares.
→ HEN from jets

- **SGRs** X-ray pulsars with a soft γ-ray bursting activity.
Magnetar model: highly magnetized neutron stars whose outbursts are caused by global star-quakes
→ HEN from GRB-like flares

- Supernovae Remnants
Evidence for hadron acceleration
SN1006, W28, W44, W49B, W51C …



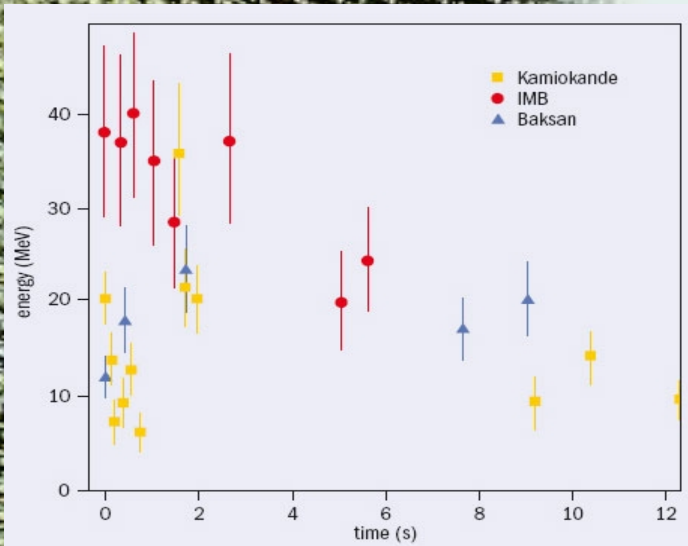
- Dense regions
Sun, Galactic Centre, Interstellar medium

- Fermi Bubbles

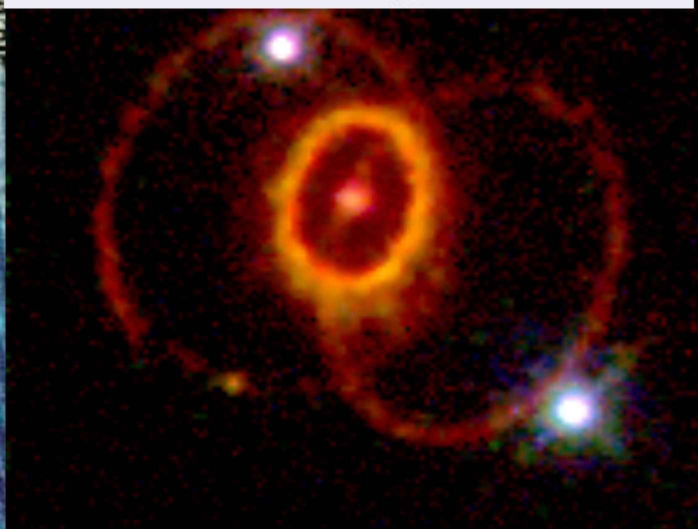
→ Mostly seen by Northern Hemisphere NT

→ Cutoff in PeV region

First extraterrestrial (LE) neutrinos…

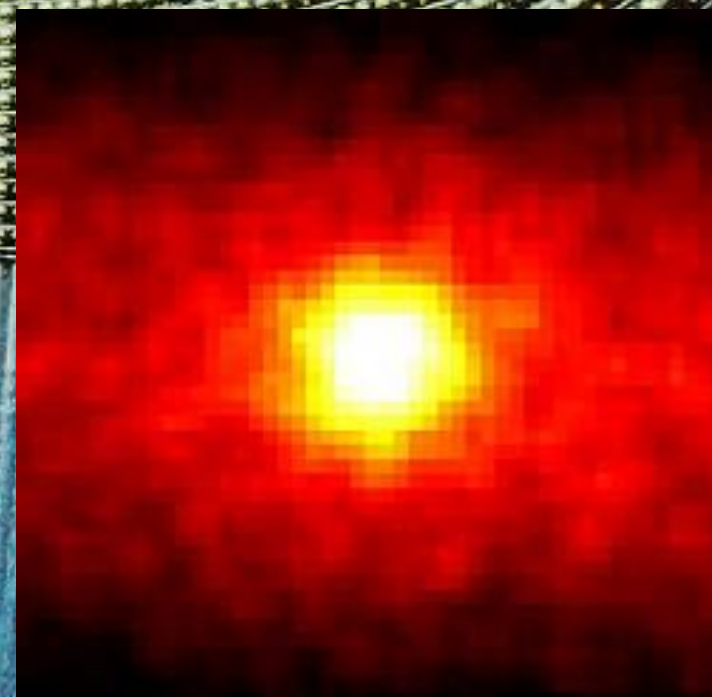


Kamiokande then SuperKamiokande



Neutrinos from
SN1987A
25 events in 12 s

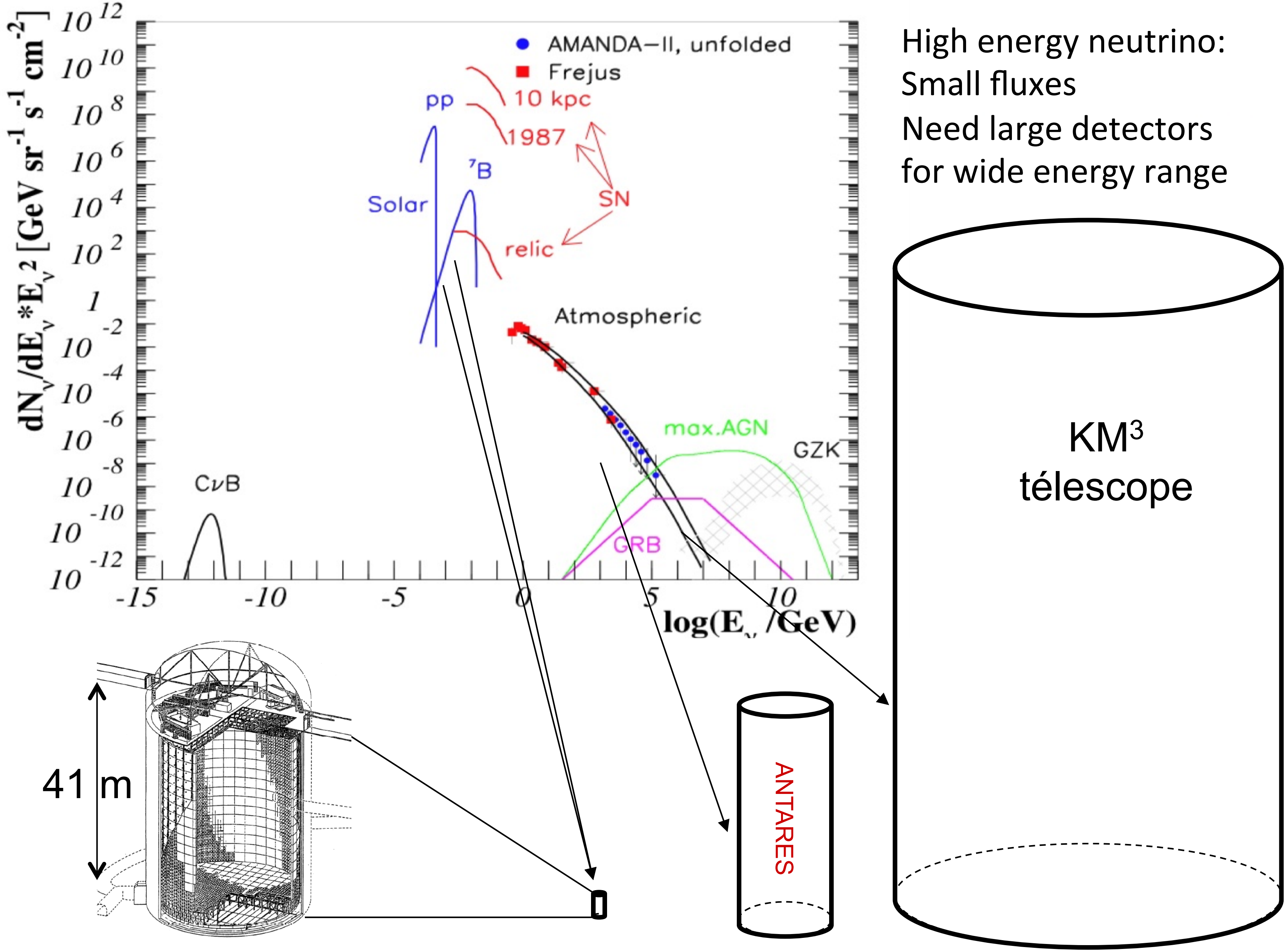
~MeV



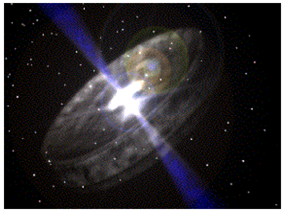
The Sun seen by
SuperKamiokande

From MeV ν to PeV ν

High energy neutrino:
Small fluxes
Need large detectors
for wide energy range



Outline



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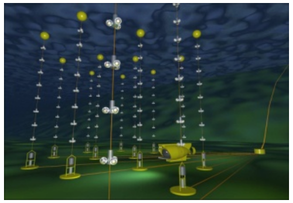
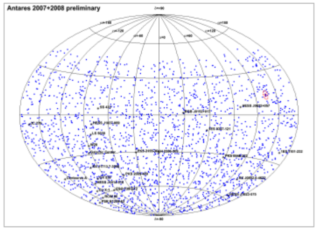


Neutrino telescope

Detection principles

Current telescopes



Selected results

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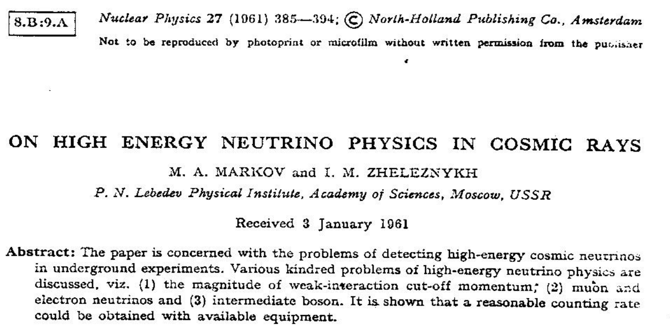
Future prospects

Markov idea: muon neutrino



8.B:9.A

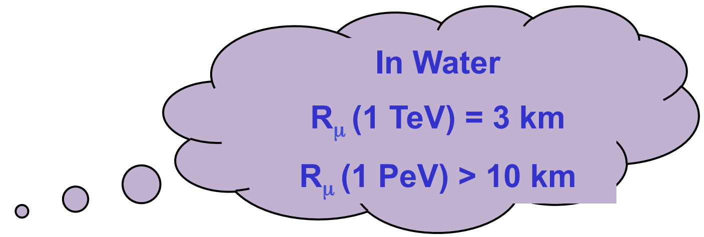
Nuclear Physics 27 (1961) 385—394; © *North-Holland Publishing Co., Amsterdam*

ON HIGH ENERGY NEUTRINO PHYSICS IN COSMIC RAYS

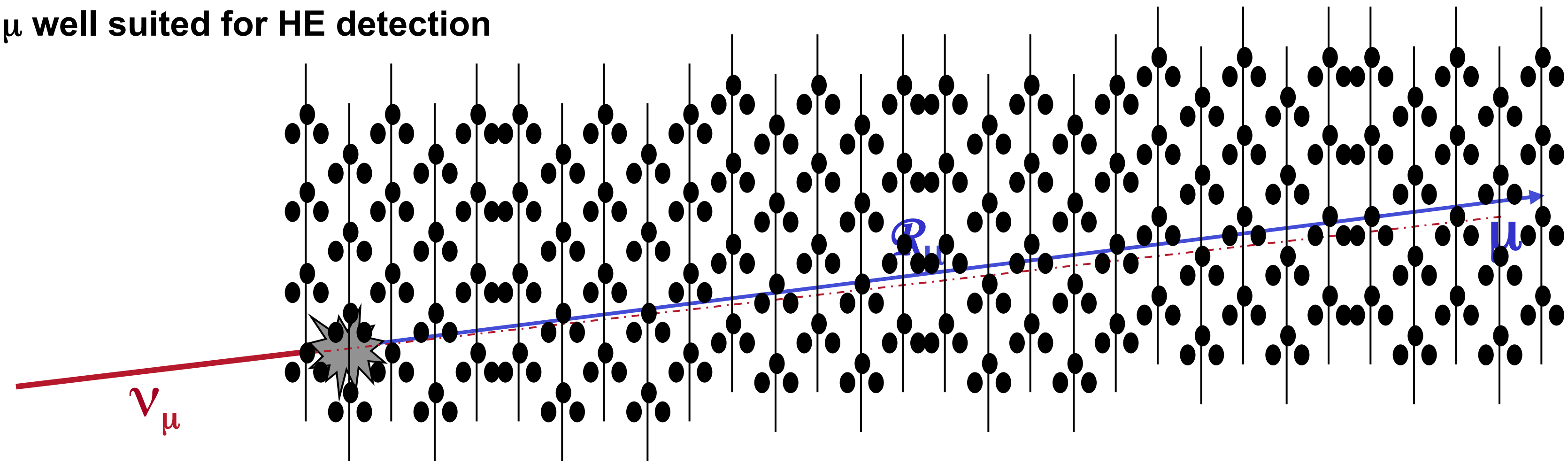
M. A. MARKOV and I. M. ZHELEZNYKH
P. N. Lebedev Physical Institute, Academy of Sciences, Moscow, USSR

Received 3 January 1961

Abstract: The paper is concerned with the problems of detecting high-energy cosmic neutrinos in underground experiments. Various kindred problems of high-energy neutrino physics are discussed, viz. (1) the magnitude of weak-interaction cut-off momentum; (2) muon and electron neutrinos and (3) intermediate boson. It is shown that a reasonable counting rate could be obtained with available equipment.



μ well suited for HE detection



- Detection effective volume increases with E_ν
- Angle between ν and μ decreases with E_ν
- Interaction cross section increases with E_ν

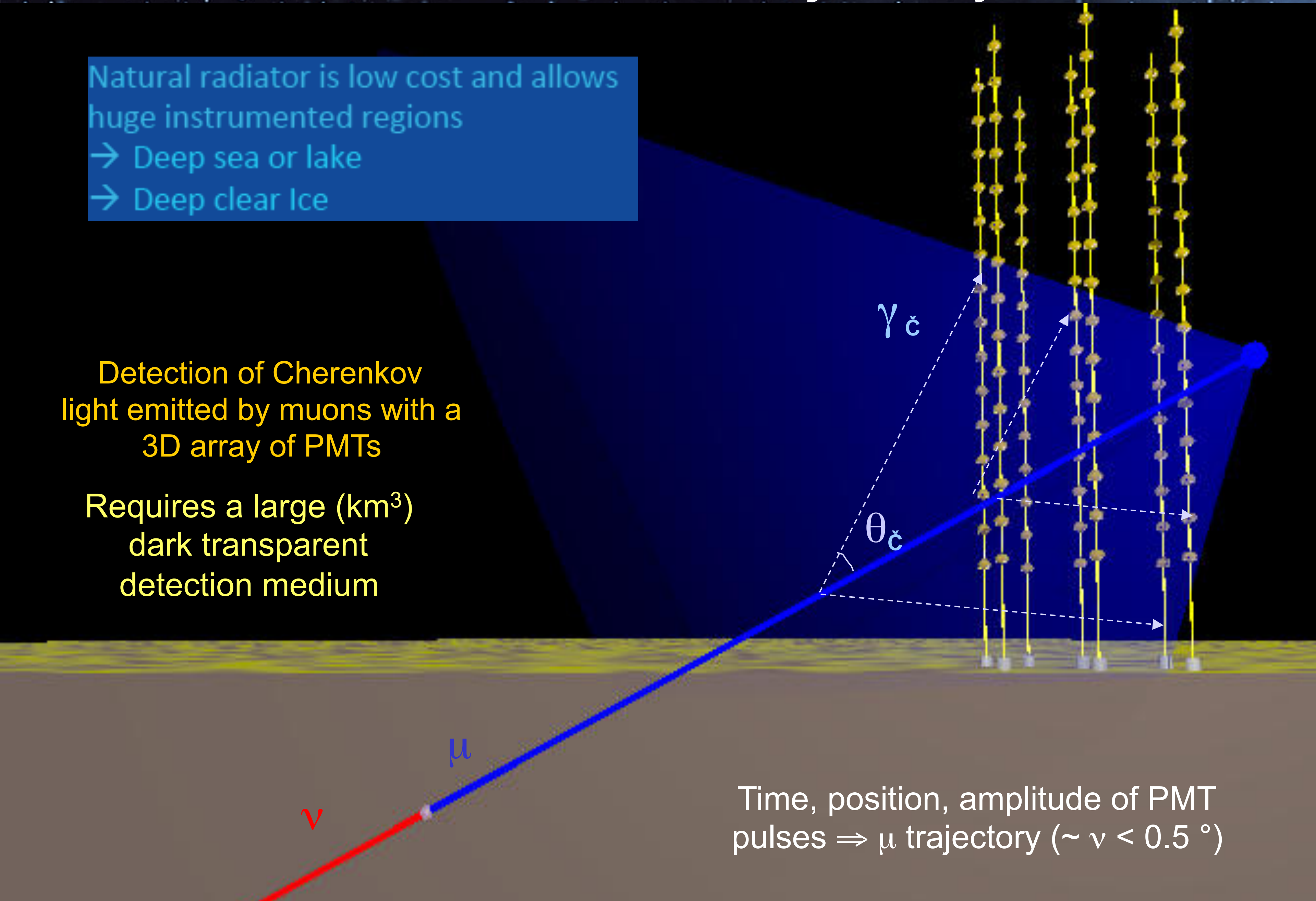
- Angular resolution 0.5°/0.1° for ice/water 1km³
- dE/dx resolution factor 2-3

Reconstruction of muon trajectory

Natural radiator is low cost and allows huge instrumented regions
→ Deep sea or lake
→ Deep clear Ice

Detection of Cherenkov light emitted by muons with a 3D array of PMTs

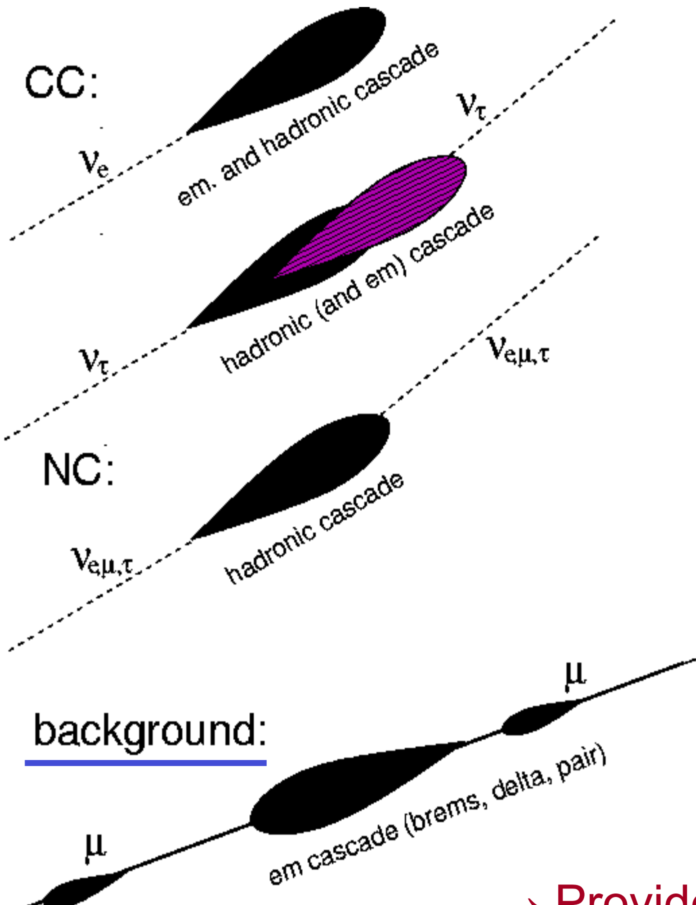
Requires a large (km^3) dark transparent detection medium



Time, position, amplitude of PMT pulses ⇒ μ trajectory (~ ν < 0.5 °)

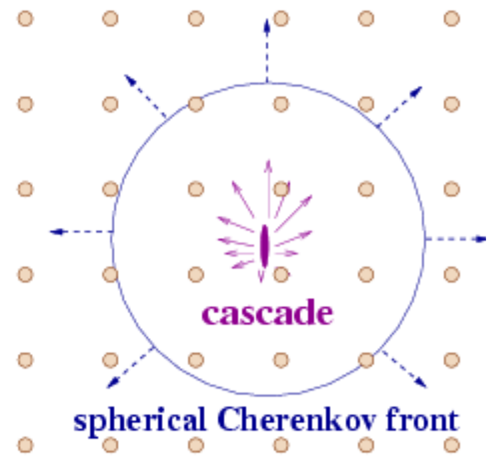
Other neutrino interaction topologies

$\nu_e:\nu_\mu:\nu_\tau = 1:2:0$ at source $\xrightarrow{oscillation}$ $\nu_e:\nu_\mu:\nu_\tau = 1:1:1$ at Earth !



So-called "cascade" events

Generic reconstruction:



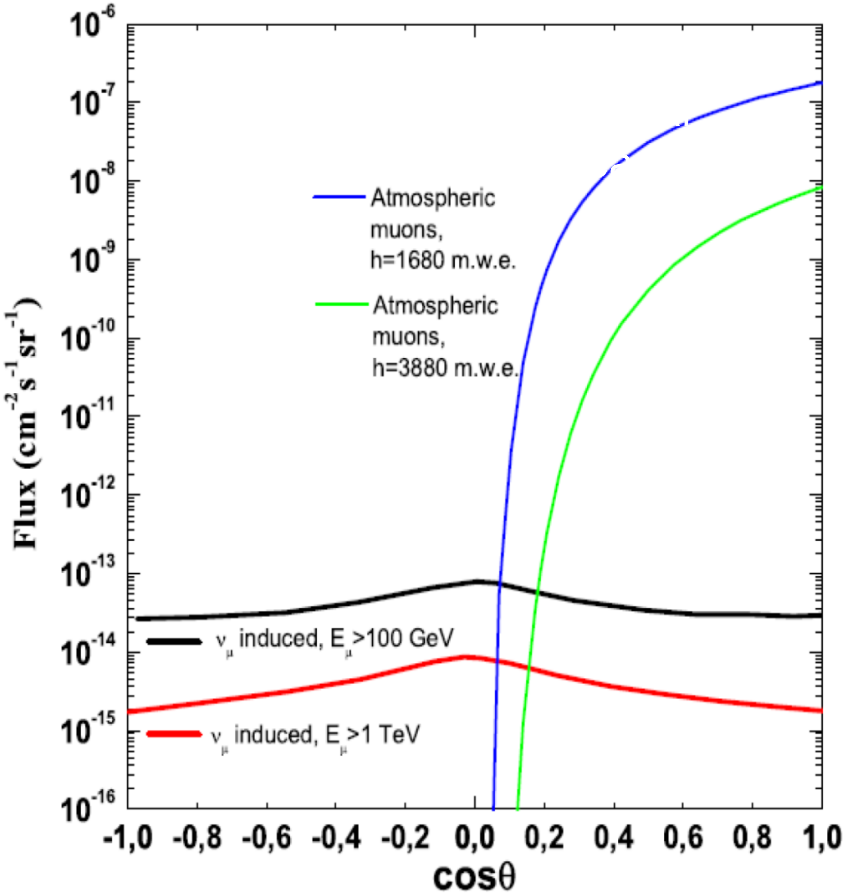
Bright point

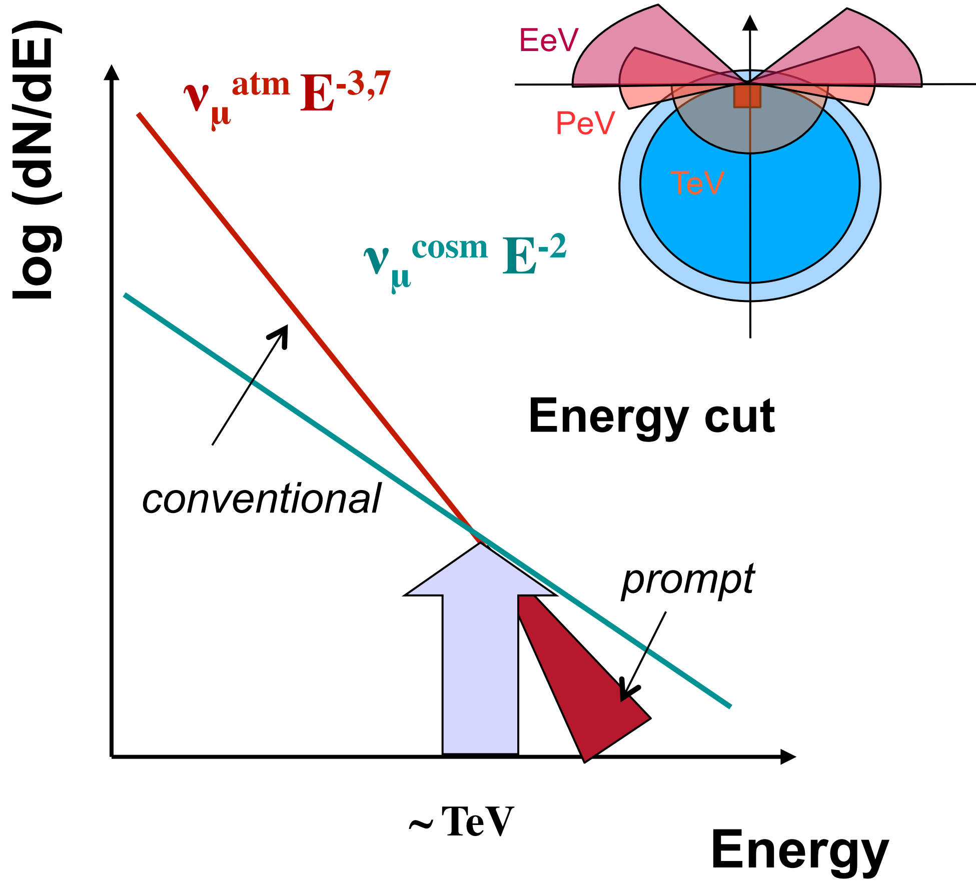
→ Provide sensitivity to all neutrino flavors – Increase overall detector sensitivity

- Angular resolution 15° / 5° at 100 TeV for ice / water
- Energy resolution ~ 15%

Atmospheric background vs cosmic ν's

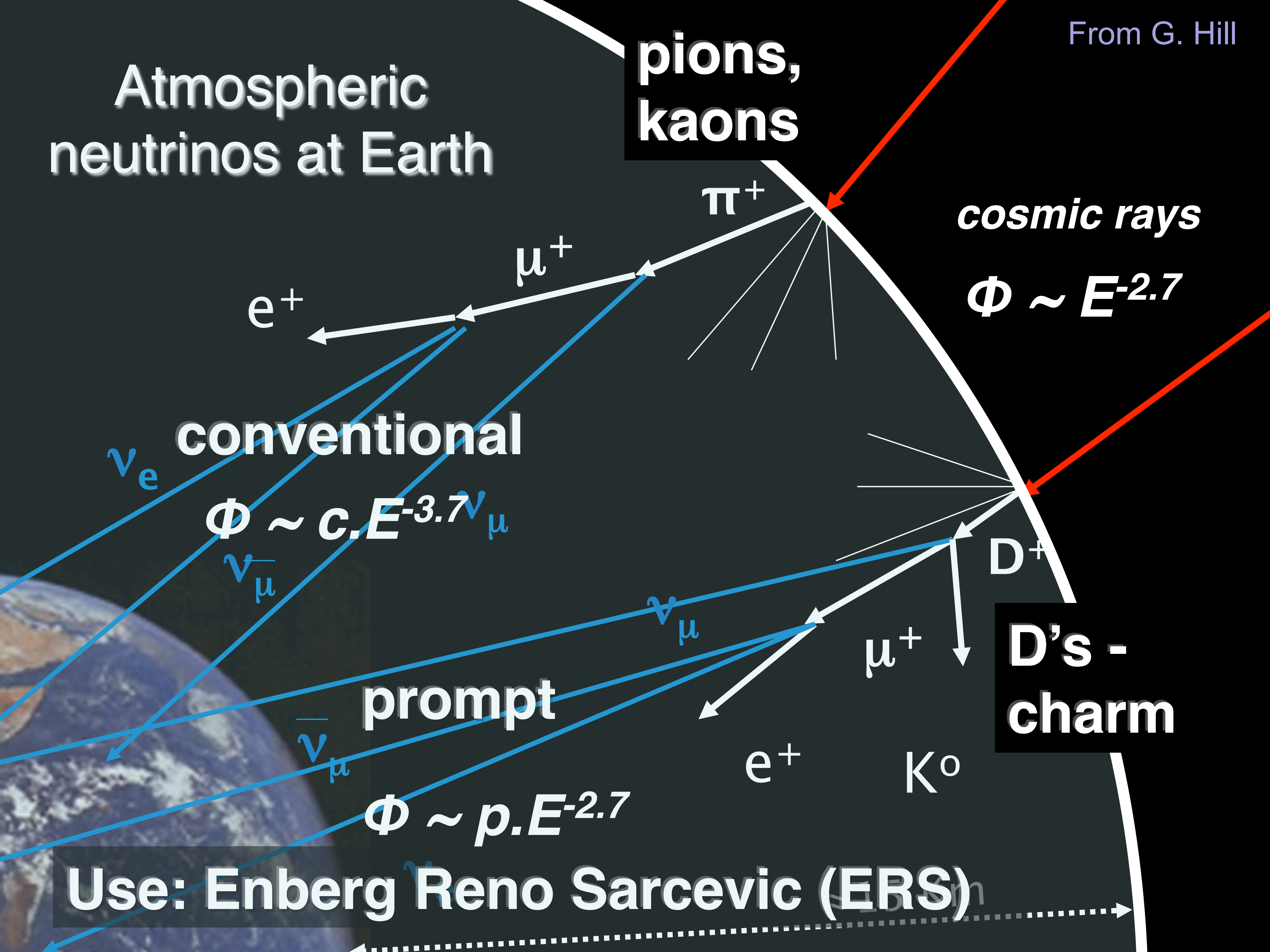
Atmospheric muons: shield detector, look down, apply veto





Atmospheric neutrinos: search for

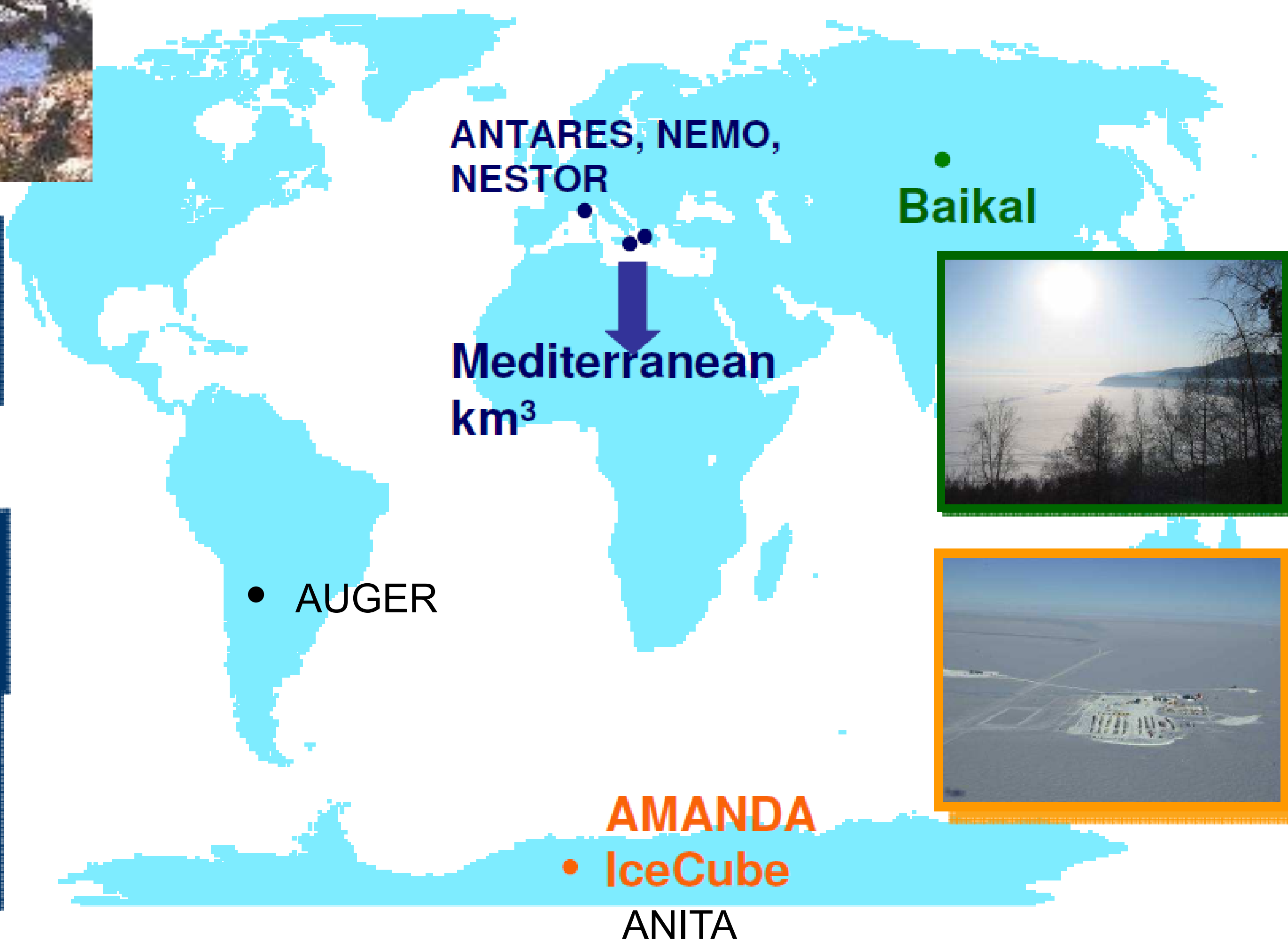
- An excess at High Energy
- Anisotropies, spatial clustering
- Time / space coincidence with other cosmic probes



From G. Hill
Atmospheric neutrinos at Earth
pions, kaons
π^+
cosmic rays
$\Phi \sim E^{-2.7}$
μ^+
e^+
conventional
ν_e
$\Phi \sim c.E^{-3.7}$
ν_μ
$\bar{\nu}_\mu$
D^+
ν_μ
μ^+
D's - charm
prompt
$\bar{\nu}_\mu$
e^+
K^o
$\Phi \sim p.E^{-2.7}$
Use: Enberg Reno Sarcevic (ERS)

Neutrino telescopes (TeV)

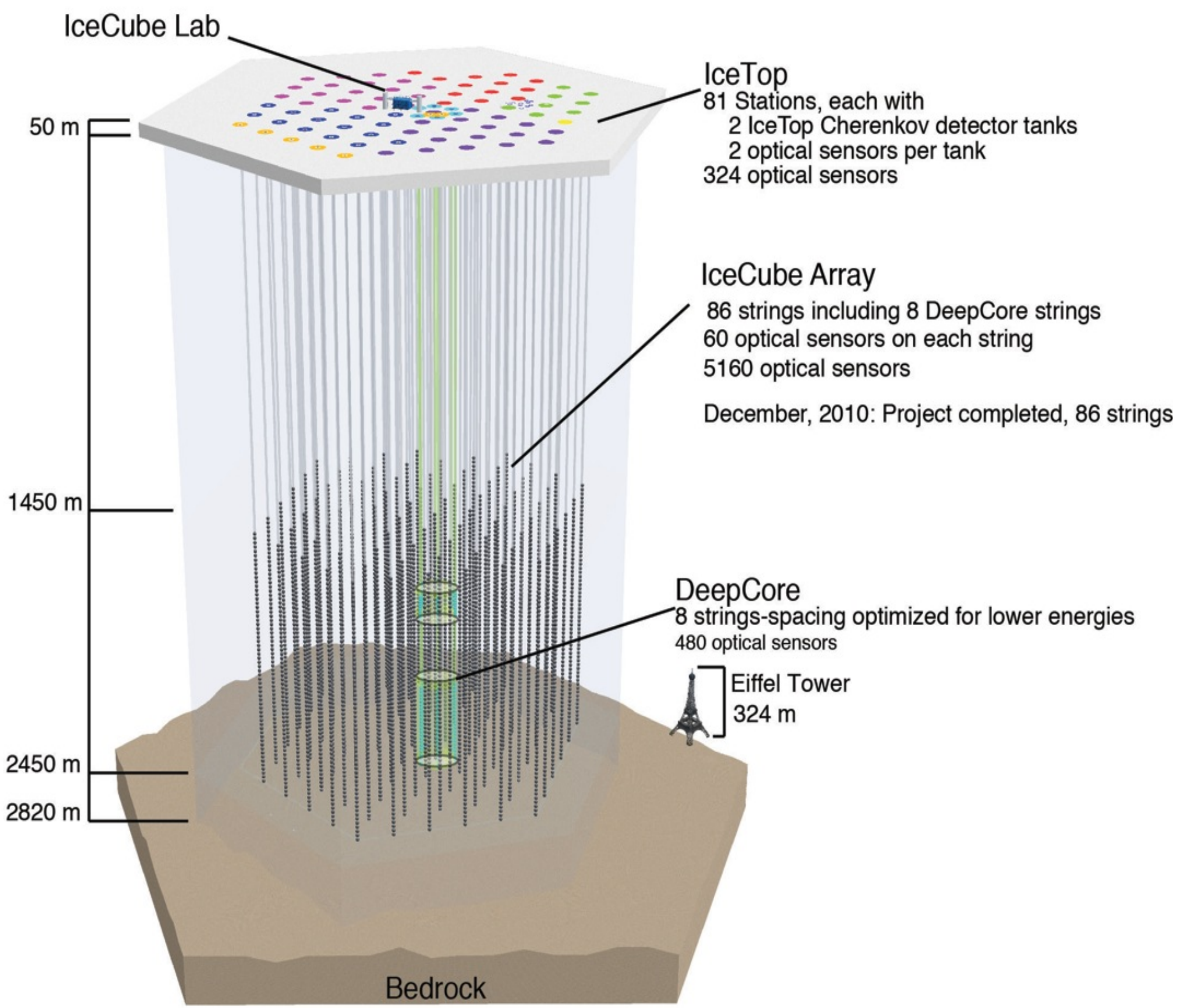
{ANTARES, BAIKAL, ICECUBE} currently working

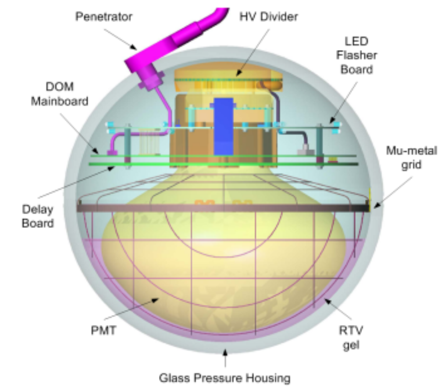


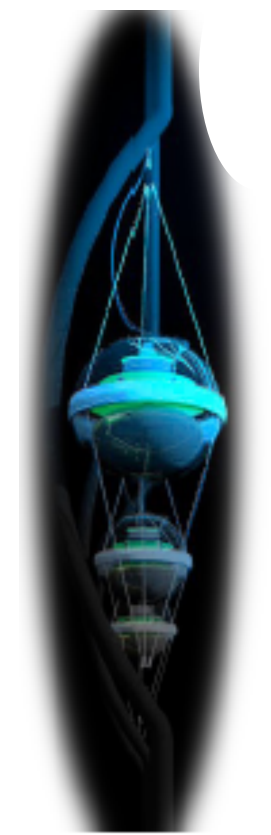
{ANTARES, NEMO, NESTOR} $\in$ KM3NeT collaboration

IceCube : the biggest NT in the world

Completed since December 2010.







Water Versus Ice

- Complementarity to IceCube South Pole

  Excellent view of Galaxy

- Long (homogeneous) scattering length

  Good pointing accuracy

- Deep sites: 2500→5000m

  Shielding from downgoing muons

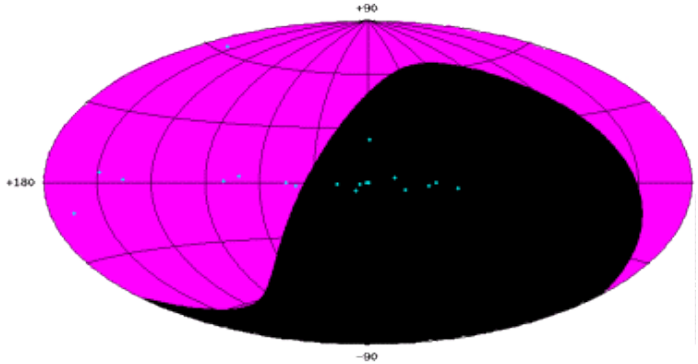
- Logistically attractive

  Close to shore (deployment / repair)

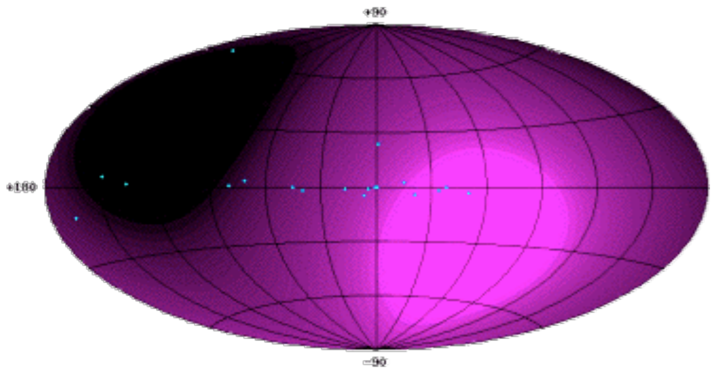
- K40 optical background

  Useful for calibration, but requires causality filters

South Pole visible sky

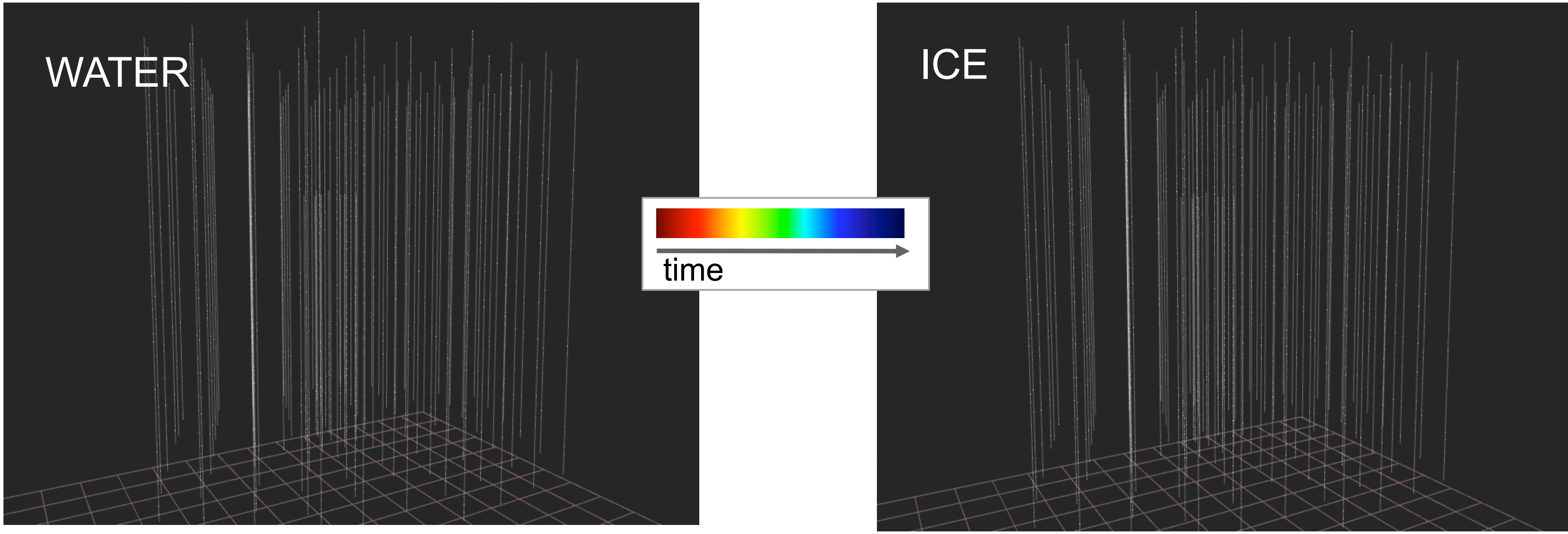


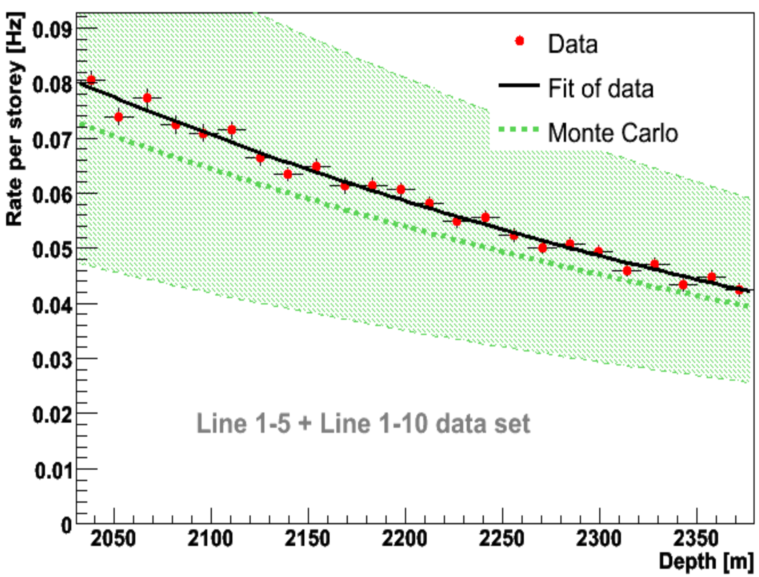
Mediterranean visible sky

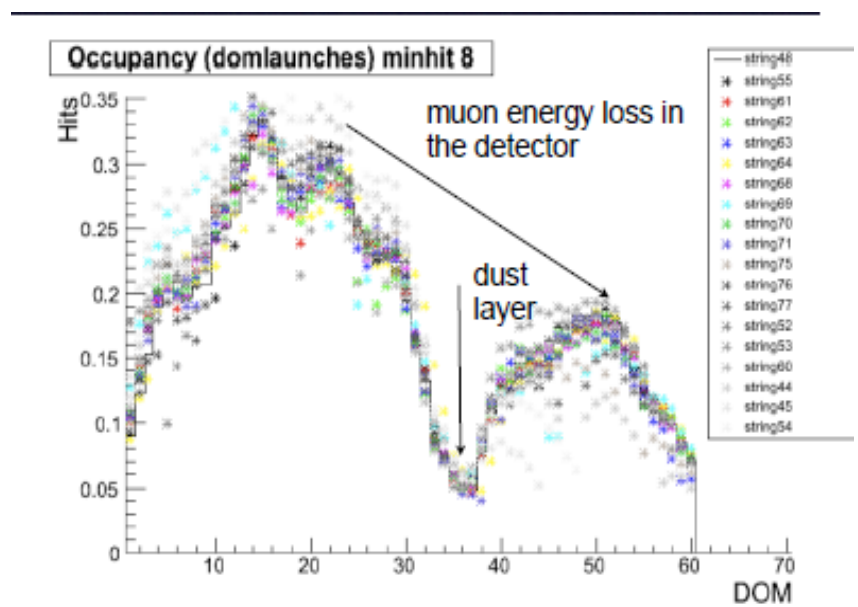


Most of the HESS TeV Sources visible by Northern NT

Water Versus Ice





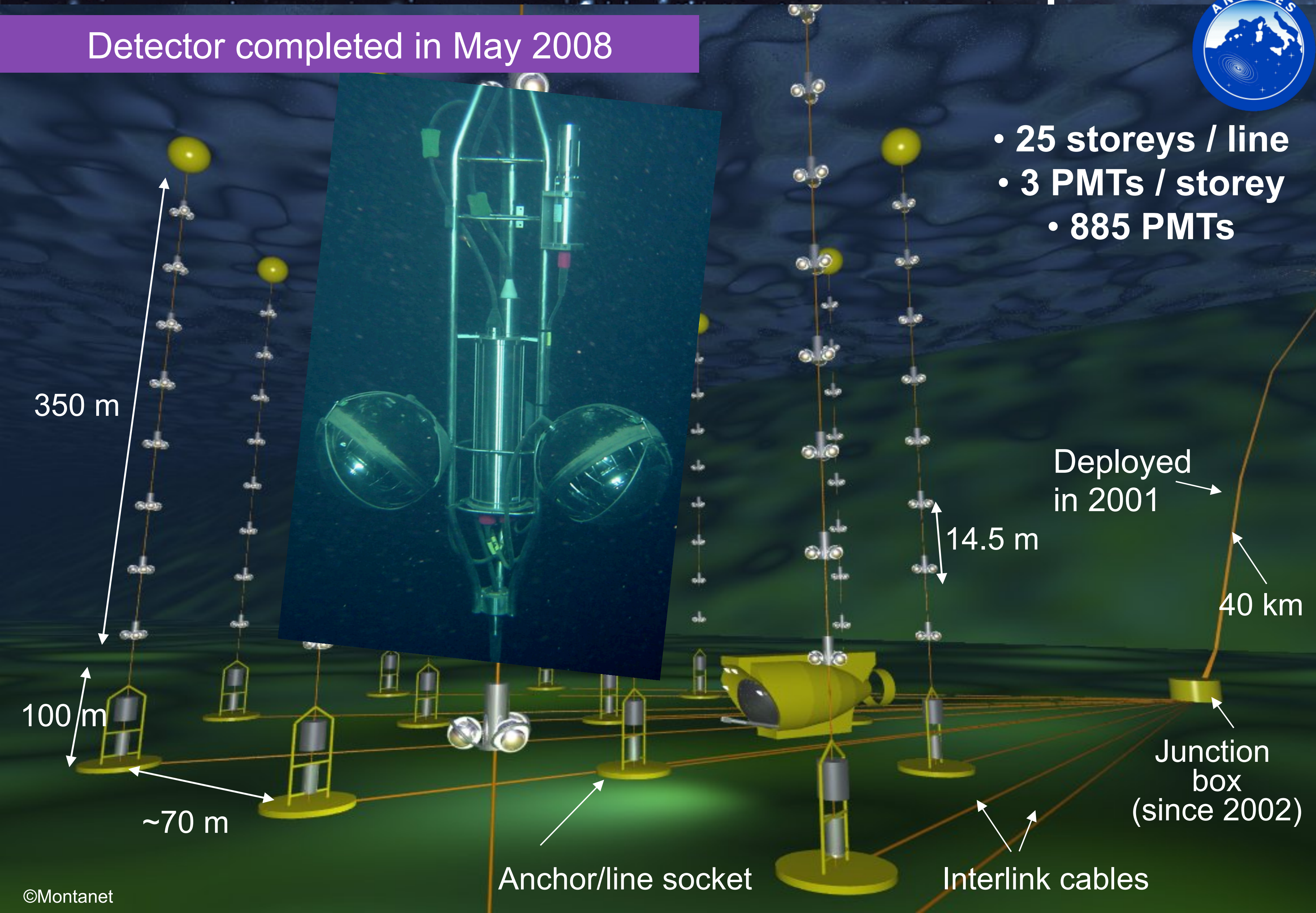



Toulon
M.Pacha
Antares
Electro-optical
Cable of
40 km
42 50'N, 6 10'E
Google
© 2008 Cnes/Spot Image
Image © 2008 DigitalGlobe
Image NASA

The ANTARES neutrino telescope

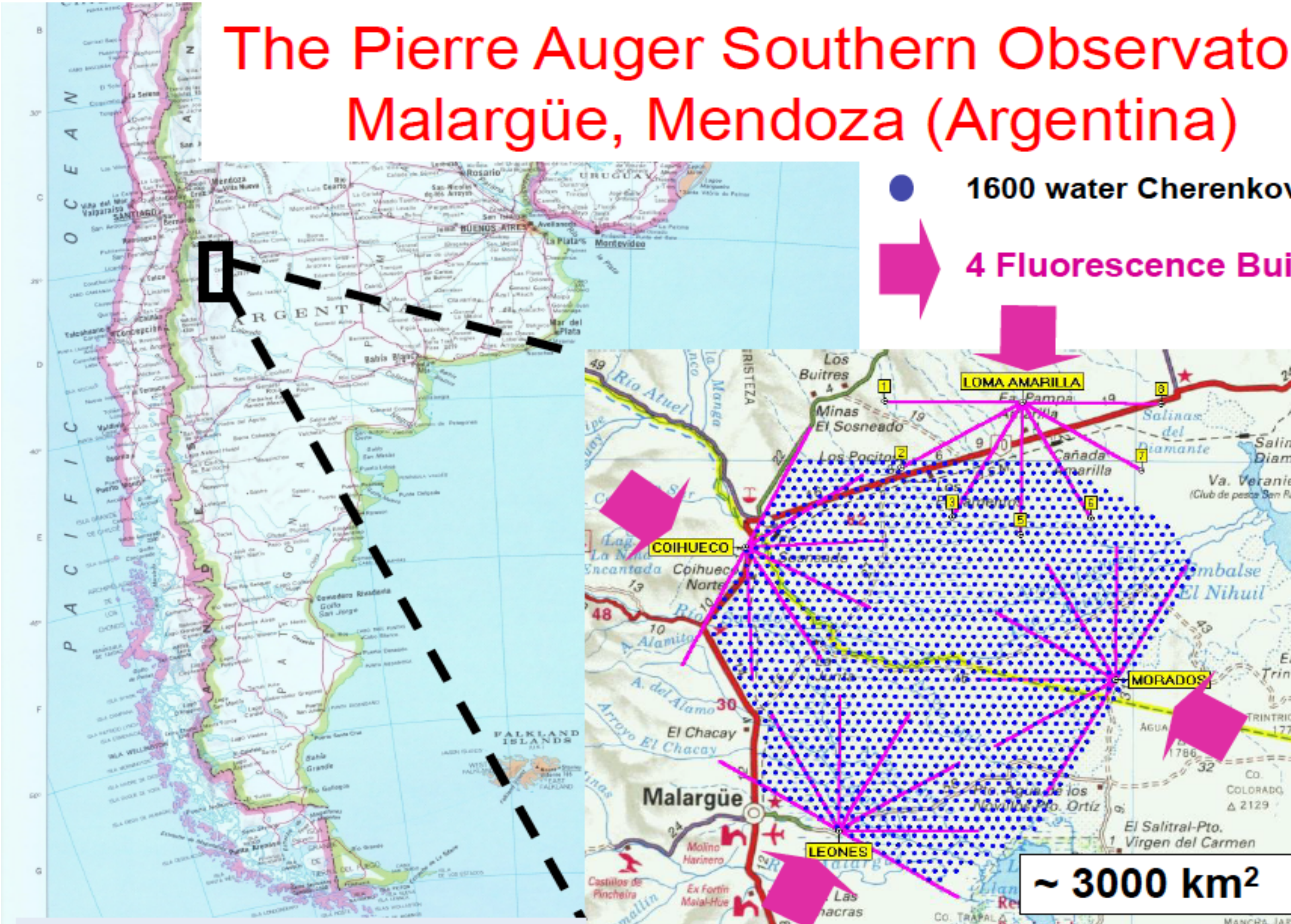
Detector completed in May 2008

- **25 storeys / line**
- **3 PMTs / storey**
- **885 PMTs**



Neutrino detection with surface arrays

The Pierre Auger Southern Observatory: Malargüe, Mendoza (Argentina)



- 1600 water Cherenkov tanks
- 4 Fluorescence Buildings

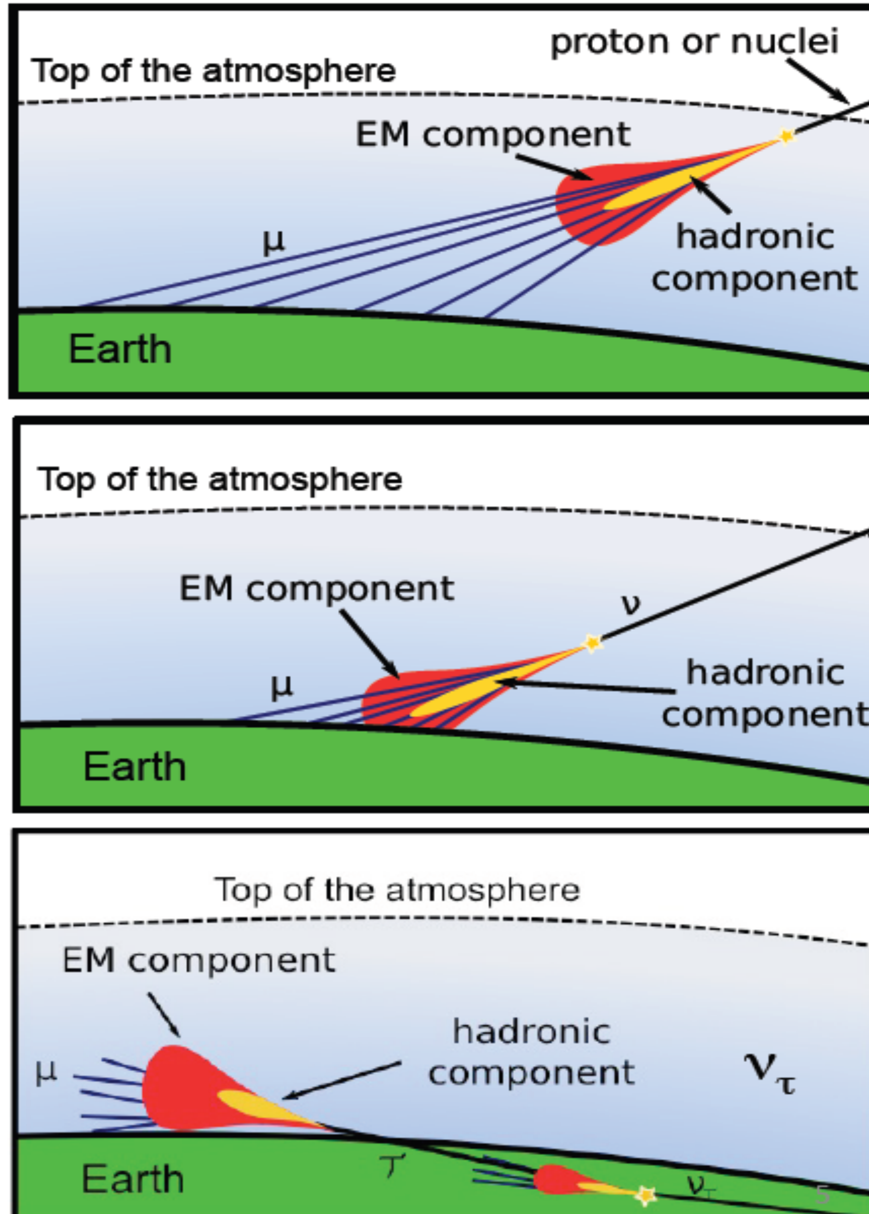
35.5º S, 69.3º W
1400 m a.s.l. (880 g cm^{-2})

Neutrino detection with surface arrays

Inclined showers & UHE neutrinos

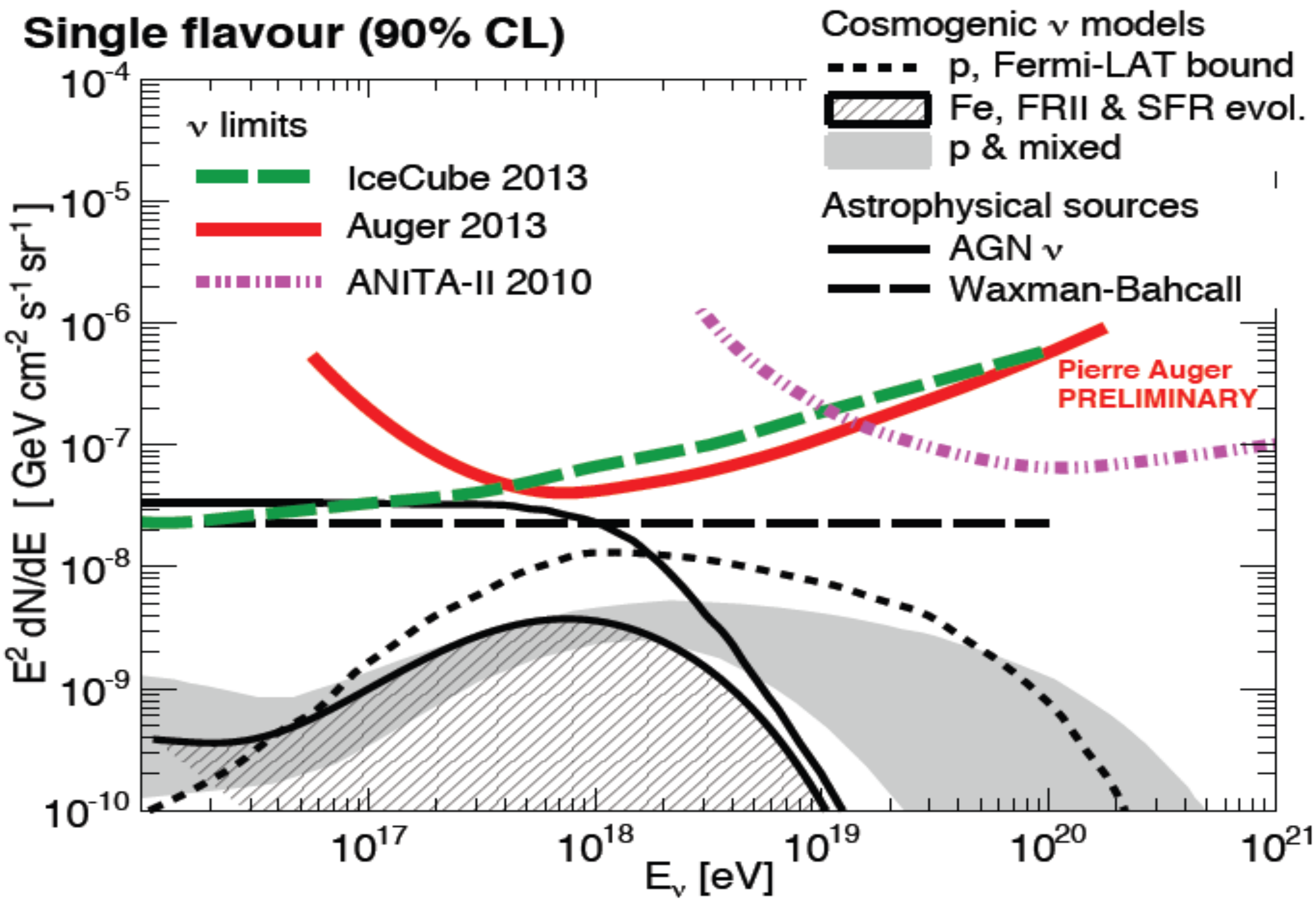
- Protons & nuclei initiate inclined showers high in the atmosphere.
  - Shower front at ground:
    - mainly composed of muons
    - electromagnetic component absorbed in atmosphere.
- Neutrinos can initiate "deep" showers close to ground.
  - Shower front at ground: electromagnetic + muonic components

Searching for neutrinos ⇒ searching for inclined showers with electromagnetic component



No candidate found : upper limits

Differential limits to diffuse flux of UHEν

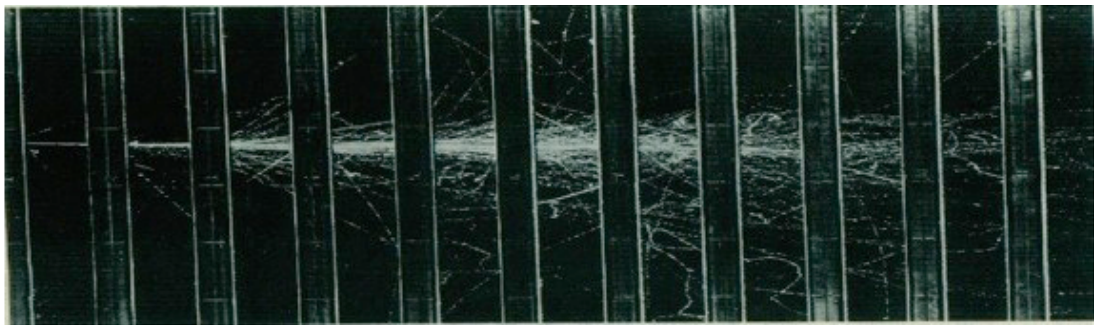


All limits converted to single flavour and given per half a decade of energy

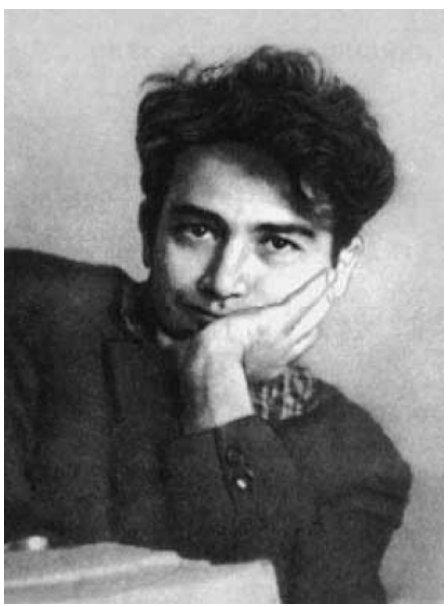
Radio detection: The Askaryan Effect

- EM shower in dielectric (ice) → moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim E^2$) if λ > Moliere radius

e^+, e^-, γ →

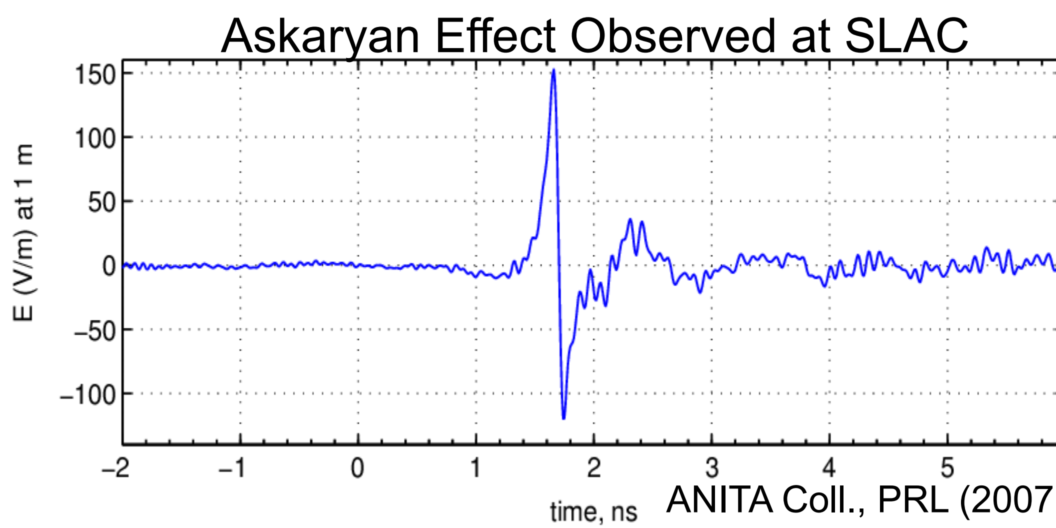


Typical Dimensions:
$L \sim 10$ m
$R_{moliere} \sim 10$ cm



G. Askaryan

→ Radio Emission is much stronger than optical for UHE showers

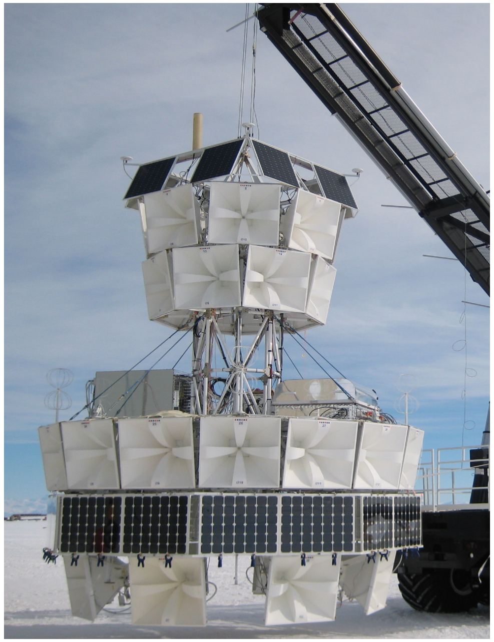


ANITA Coll., PRL (2007)

ANITA-I & ANITA-II: Best Limit > 10^{19} eV

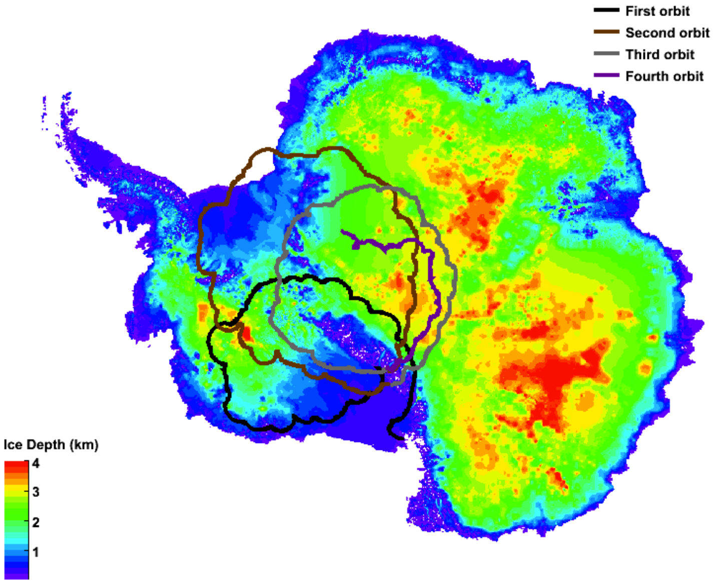
NASA Long Duration Balloon, launched from Antarctica

ANITA-I: 35 day flight 2006-07
ANITA-II: 30 day flight 2008-09



Instrument Overview:

- 40 horn antennas, 200-1200 MHz
- Direction calculated from timing delay between antennas
- In-flight calibration from ground
- Threshold limited by thermal noise



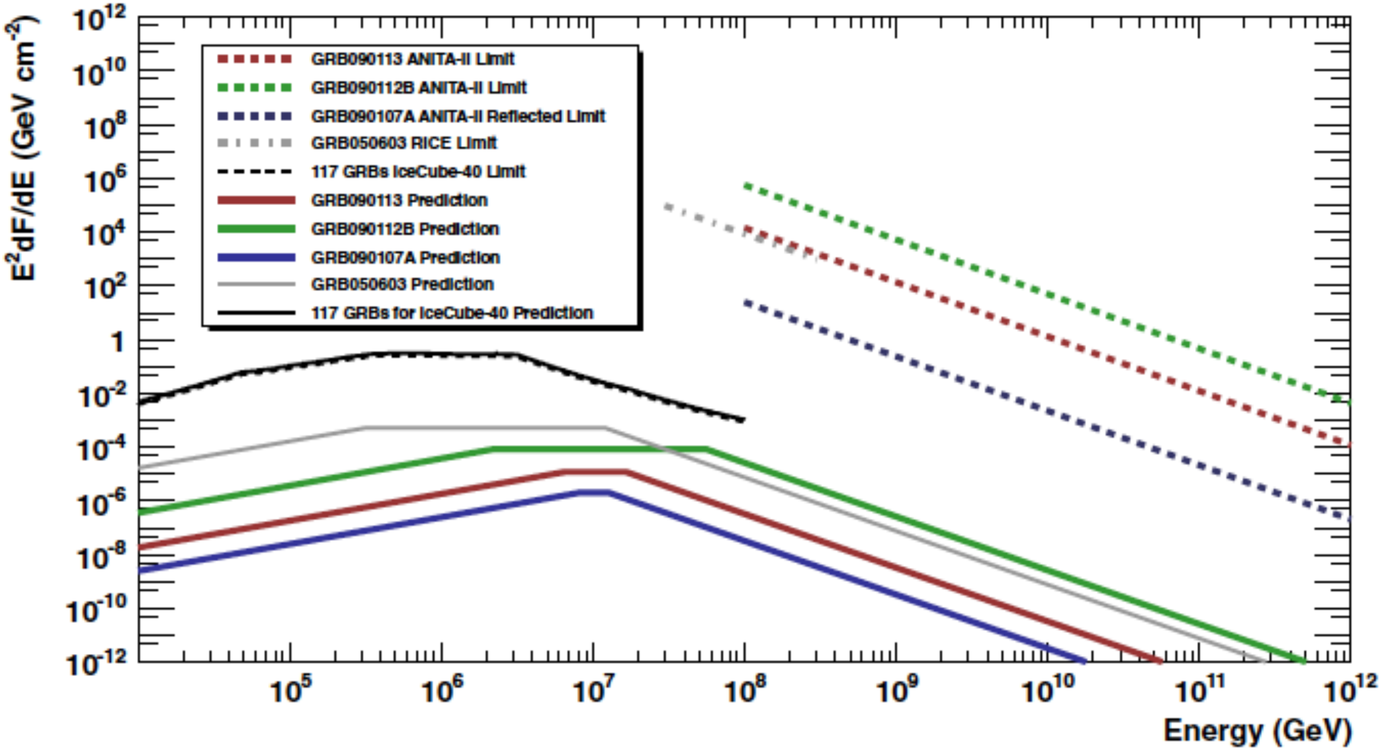
UHE Neutrino Search Results:

	ANITA-I	ANITA-II
Neutrino Candidate Events	1	1
Expected Background	1.1	0.97 +/- 0.42

ANITA III 2014-2015 : Factor of 5 improvement in sensitivity compared to ANITA-II

ANITA's limit on GRB neutrino fluence

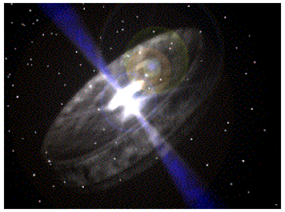
📖 The Astrophysical Journal, 736:50 (4pp), 2011 July 20



Precursor search
100 s
prior to GRB
also performed
(0 events)

- 31 day of ANITA-II flight, 26 GRBs recorded by Swift or Fermi.
- 12 GRBs occurred during quiet periods → 0 event observed (0.0044 expected bkg)
- 0 events observed in the remaining 14 bursts
- 90% (FC) CL limit on the E^{-4} prompt neutrino fluence $10^8 < E$ GeV $< 10^{12}$ of $E^4\Phi = 2.5 \times 10^{17}$ GeV^3 cm^{-2} from GRB090107A.

Outline

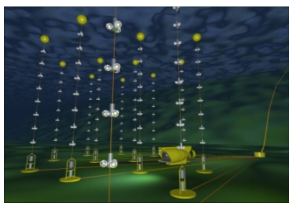


Neutrino astronomy

Historical aspects

Scientific motivations

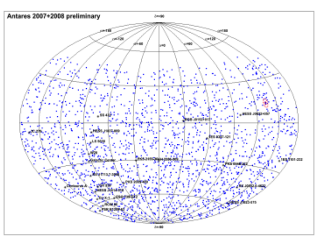
Cosmic neutrino sources



Neutrino telescope

Detection principles

Current telescopes



Selected results

First Discovery by IceCube? ← Diffuse Flux

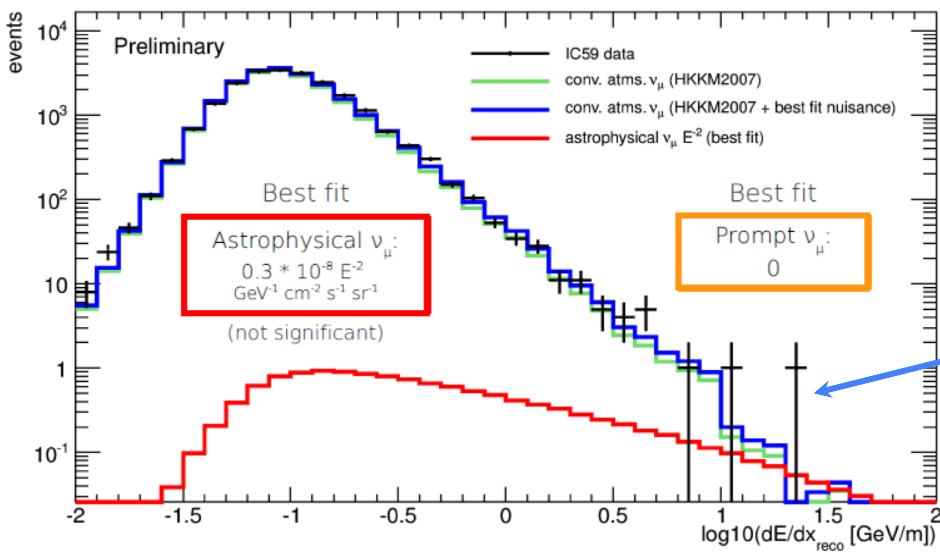
Searches for point sources

Multi-messenger search

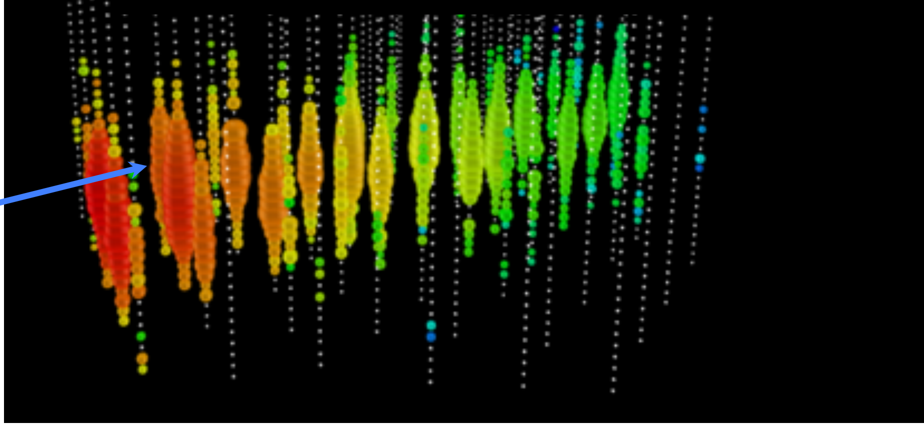
Future prospects

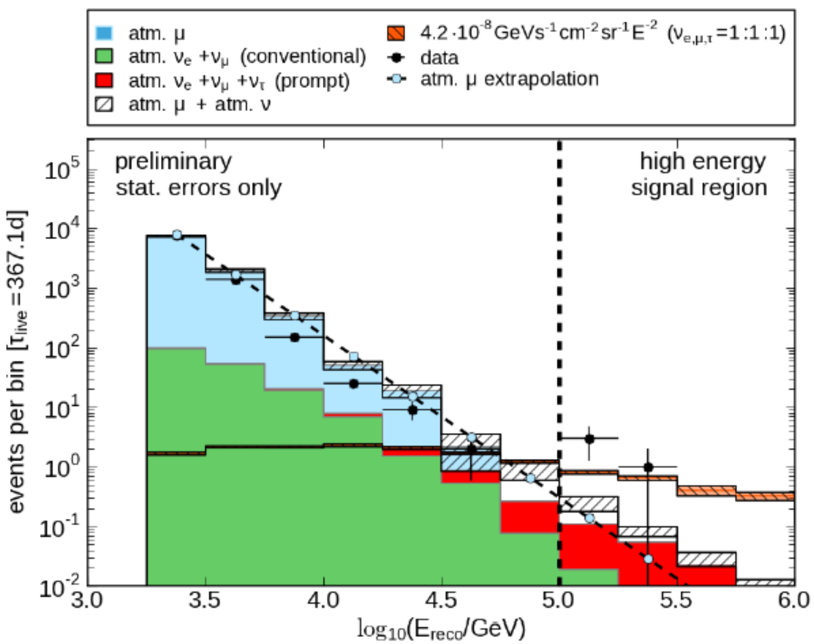
First hints: diffuse searches

The final ν_μ energy spectrum – Best fit

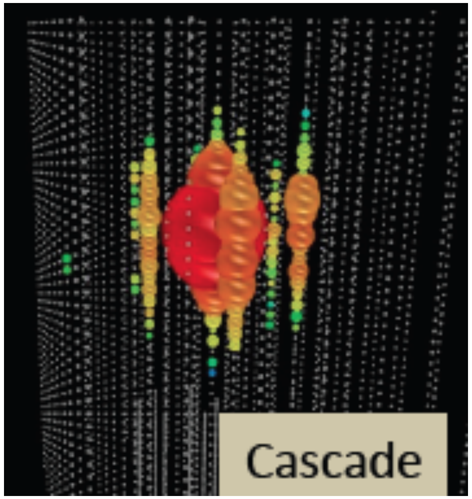


IC 59 muons
~1 PeV neutrino



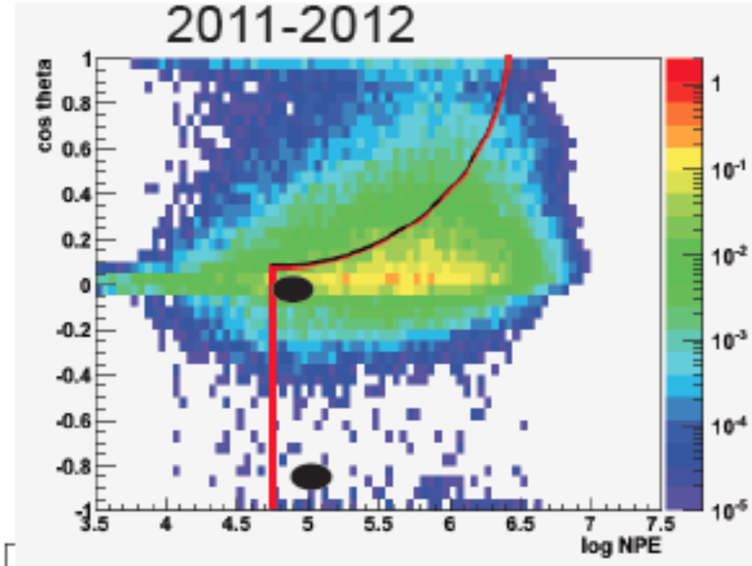


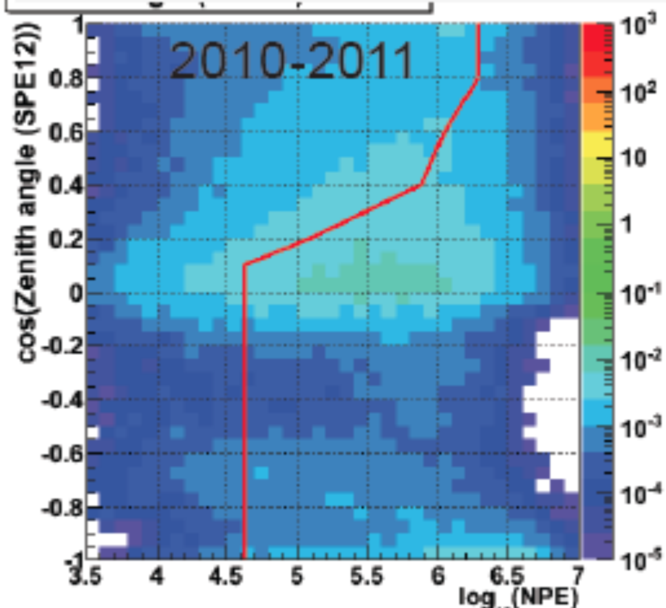
More events observed than expected for E>100 TeV
2.4 σ excess

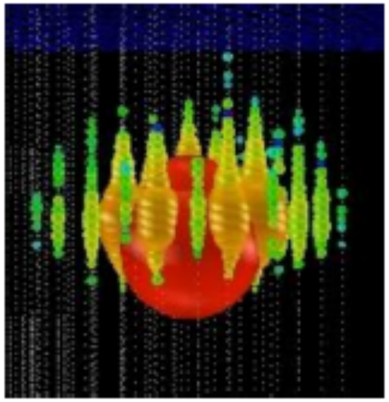


IC79+IC86 ν UHE Search

2 events observed in the PeV energy region in IC 86 sample

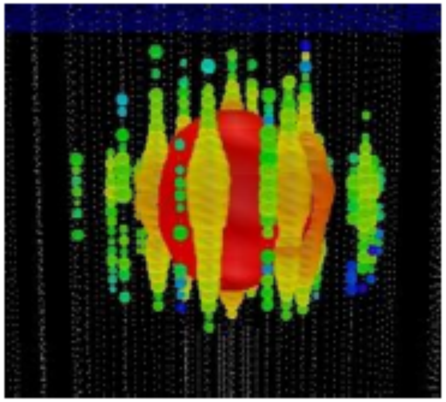






Ernie

GMT: 2012/1/3 9:34:01



Bert

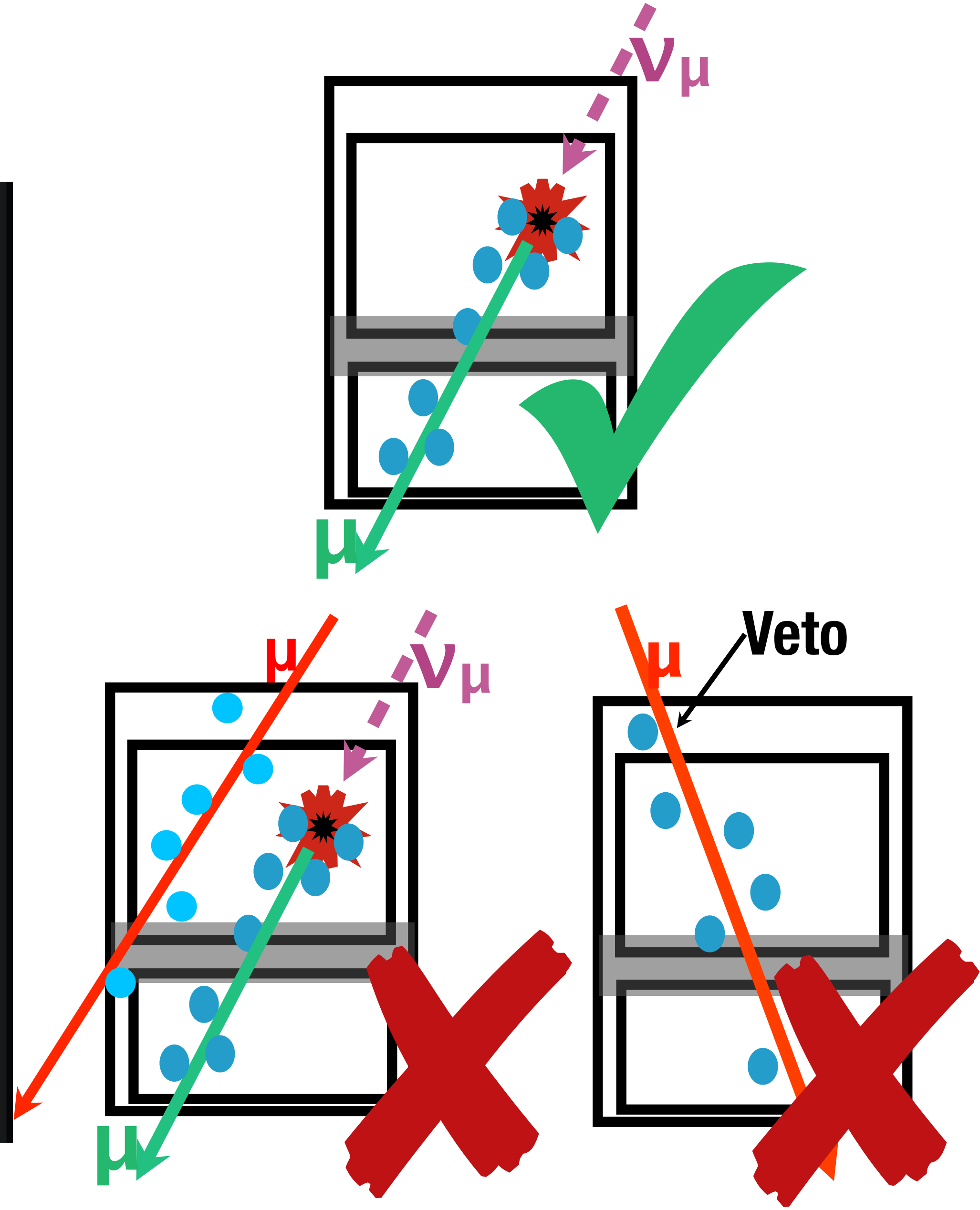
GMT: 2012/8/8 12:23:18

2.9 σ beyond conventional background

Follow up analysis

2 yr : May 2010 – May 2012 (662 days)

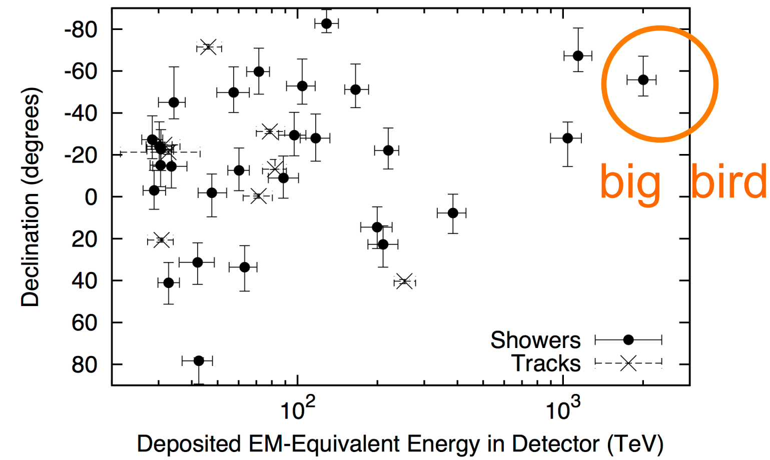
- Explicit contained search at high energies (cut: $Q_{tot}>6000$)
- 400 Mton effective fiducial mass
- Use atmospheric muon veto
- Sensitive to all flavors in region above 60TeV
- Three times as sensitive at 1 PeV
- Estimate background from data



Follow up analysis: the IceCube signal

2 year analysis:
28 events
4.1σ
(Science 342, 2013)

3 year analysis:
37 events
5.7σ
(arXiv:1405.5303, sub.PRL)



7 → 9 track-like events

1° angular resolution

muon takes some energy away

total expected background: 11 events

21 → 28 cascade-like events

10° - 45° angular resolution

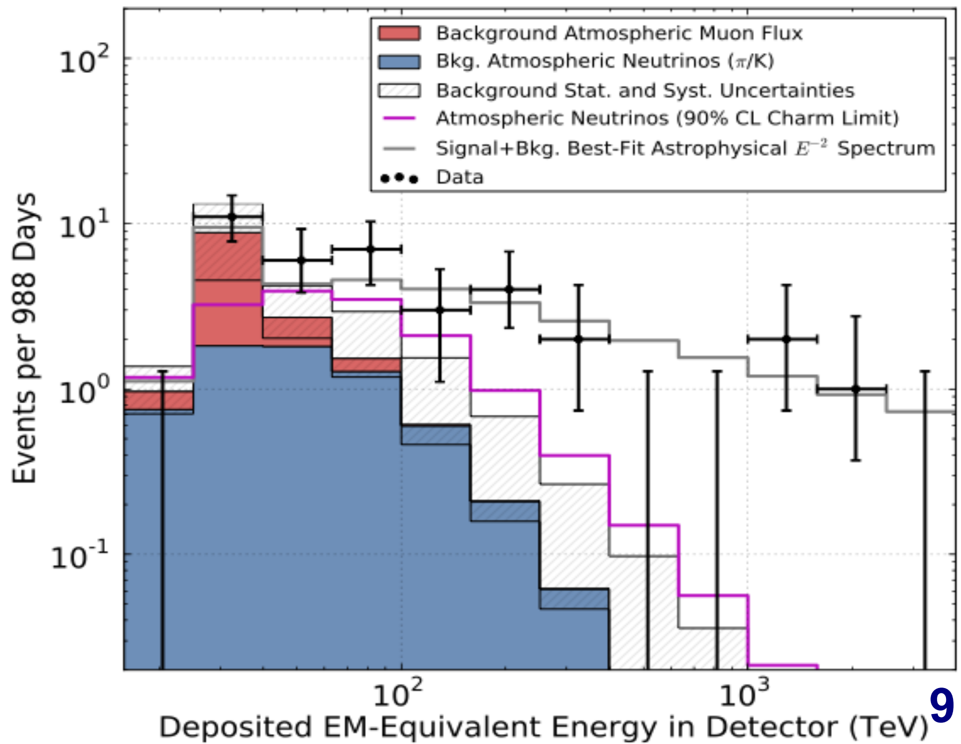
15% visible energy reconstruction

Best fit (per flavor):

$0.95 \pm 0.3 \times 10^{-8}\ E^{-2}\ GeV\ cm^{-2}\ s^{-1}\ sr^{-1}$

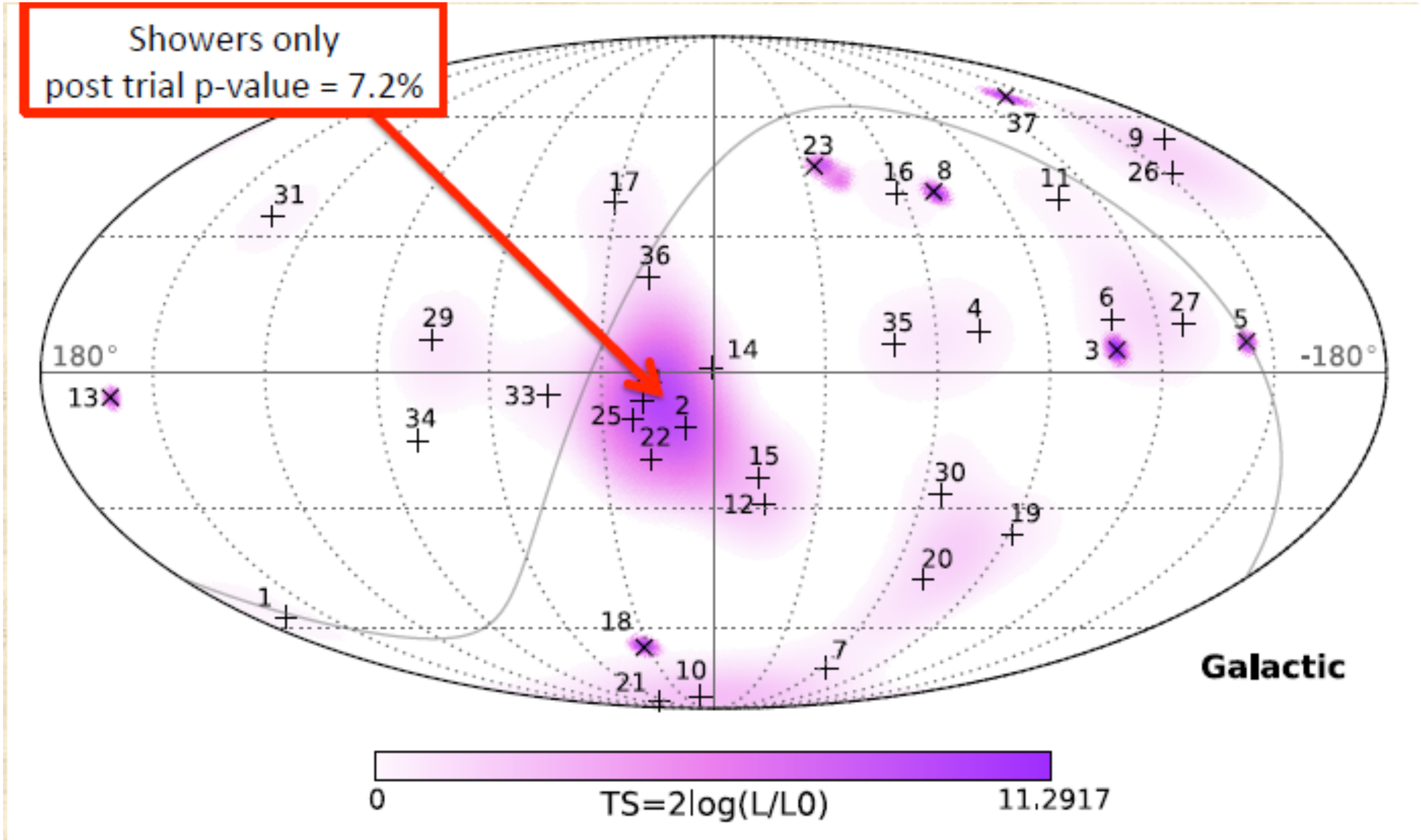
highest energy event @ 2 PeV

cutoff at ~2.3 PeV ?



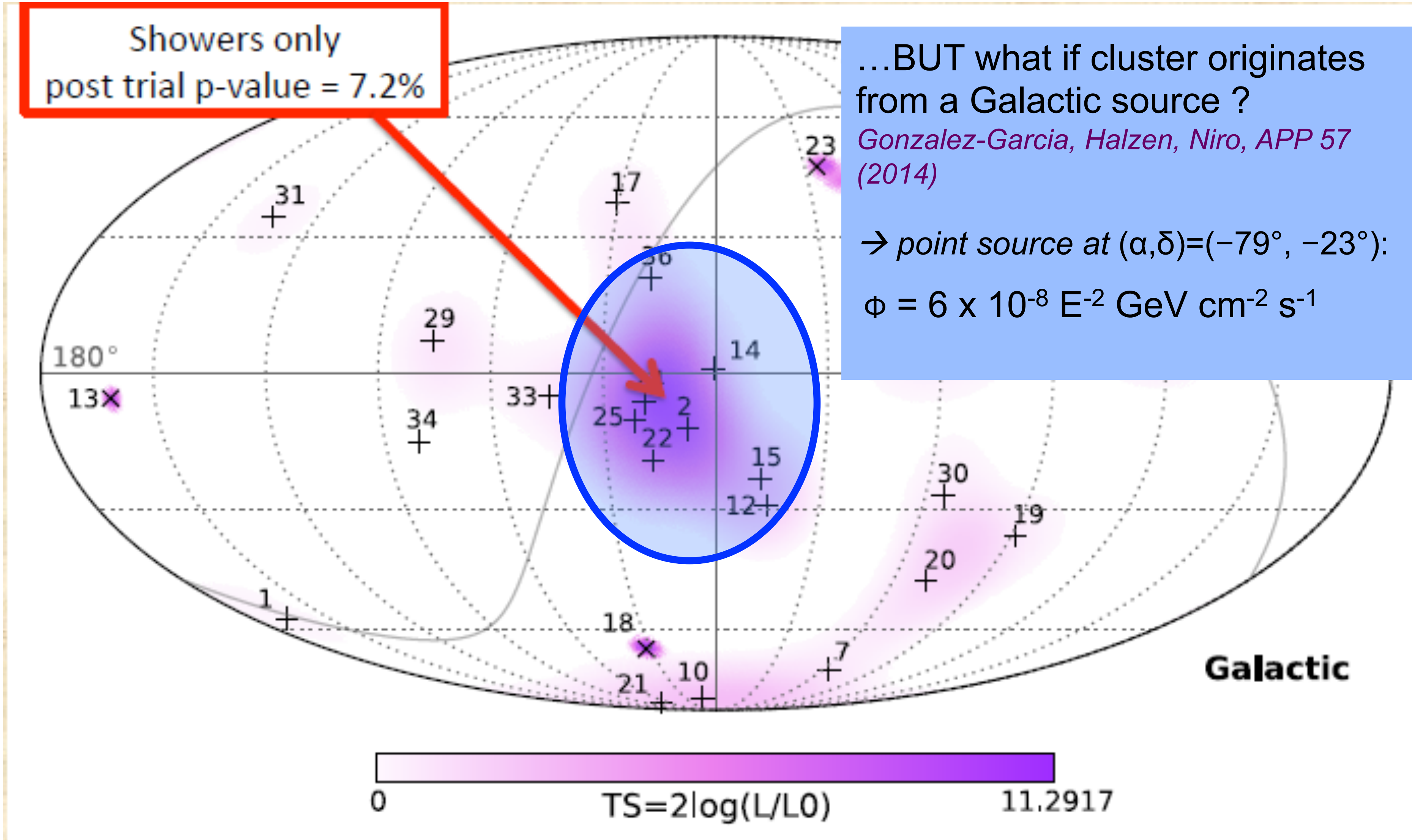
Follow up analysis: the IceCube signal

Hint of clustering near Galactic Center ? … no claim for signal



A source near the Galactic Center?

Hint of clustering near Galactic Center ? … no claim for signal



…BUT what if cluster originates from a Galactic source ?

Gonzalez-Garcia, Halzen, Niro, APP 57 (2014)

→ *point source at* (α,δ)=(−79°, −23°):

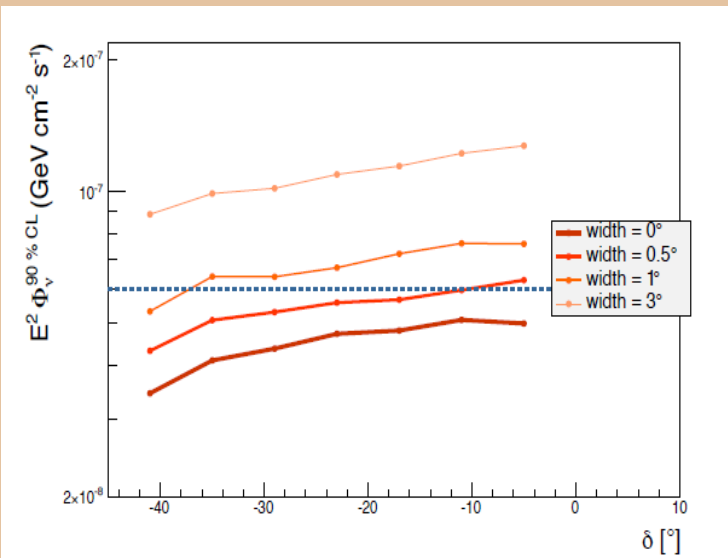
$\Phi = 6 \times 10^{-8}\ E^{-2}$ GeV cm^{-2} s^{-1}

A source near the Galactic Center?

Hint of clustering near Galactic Center ? … no claim for signal

ANTARES search for neutrino source around GC:

- scan in declination
- allow for extended sources: 0°, 0.5°, 1°, 3°



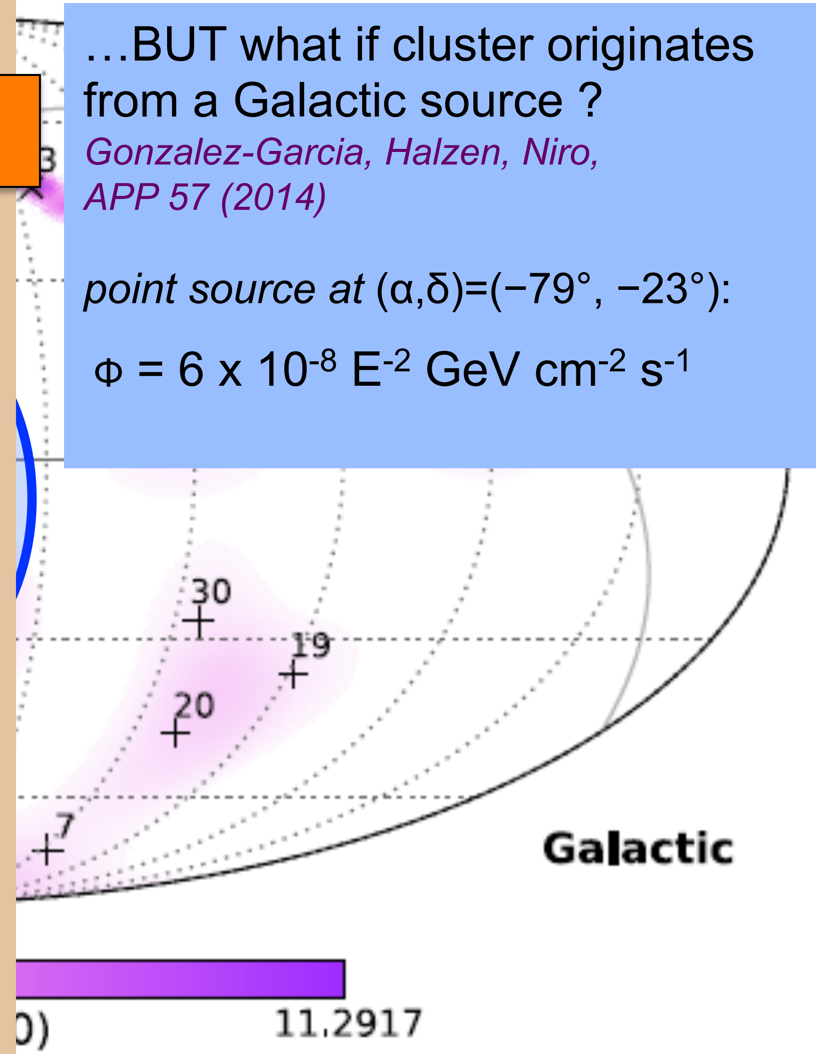
ANTARES excludes point source (up to 1° extension) as origin of the IceCube cluster

…BUT what if cluster originates from a Galactic source ?

Gonzalez-Garcia, Halzen, Niro, APP 57 (2014)

point source at $(\alpha,\delta)=(-79°, -23°)$:

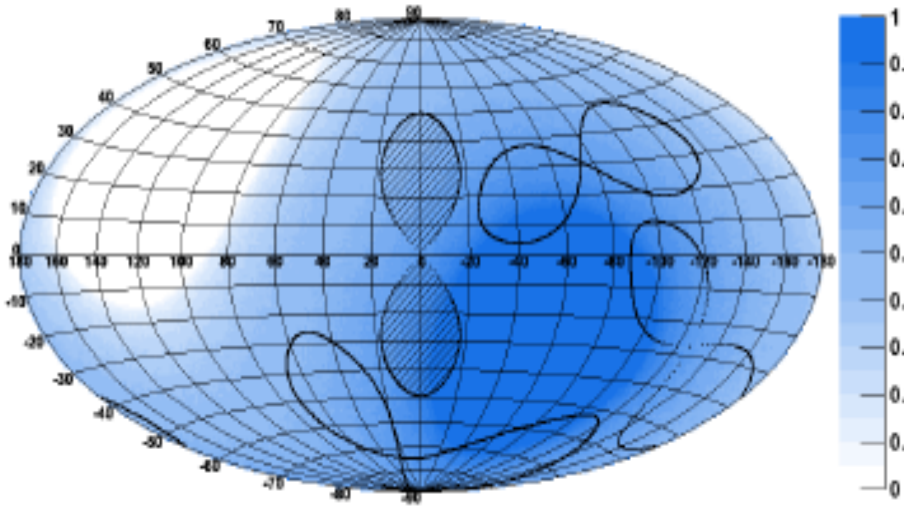
$\Phi = 6 \times 10^{-8}\, E^{-2}$ GeV cm^{-2} s^{-1}



Search for a Diffuse Emission from the Fermi Bubbles

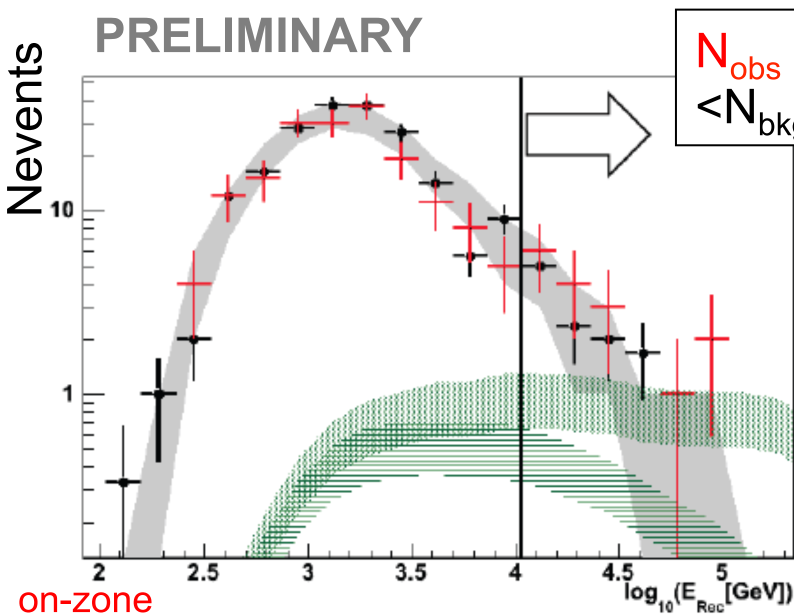
- Excess of γ- (and X-)rays in extended "bubbles" above and below the GC

Galactic wind model involves hadronic processes
📖 Crocker & Aharonian, PRL 2011
$\Phi_\nu \approx 0.4 \times \Phi_\gamma$ 📖 M. Su et al., Ap. J. 724 (2010)



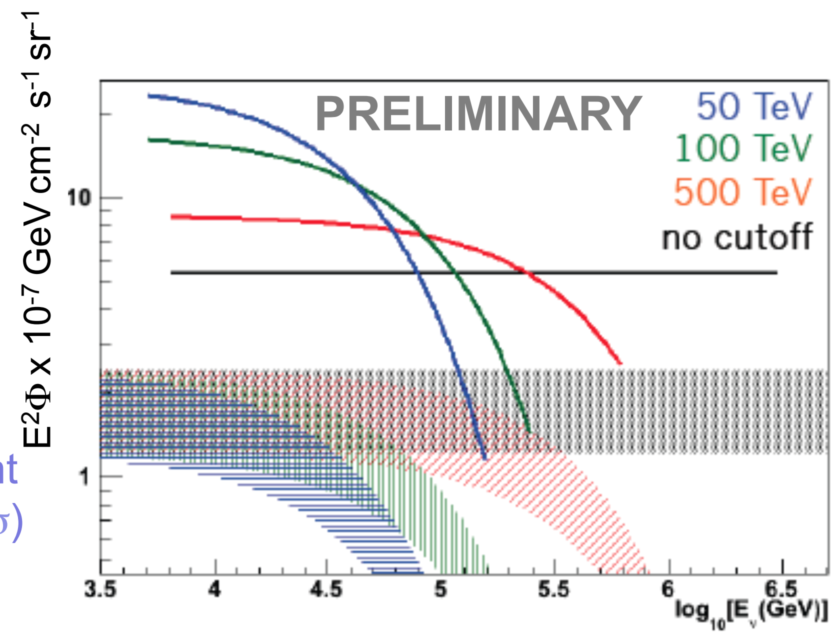
- In the field of view of ANTARES

background estimated from average of
3 non-overlapping "off-zone" data regions
(same size, shape and average detector efficiency)



N_{obs} = 16
$\langle N_{bkg} \rangle$ = 11

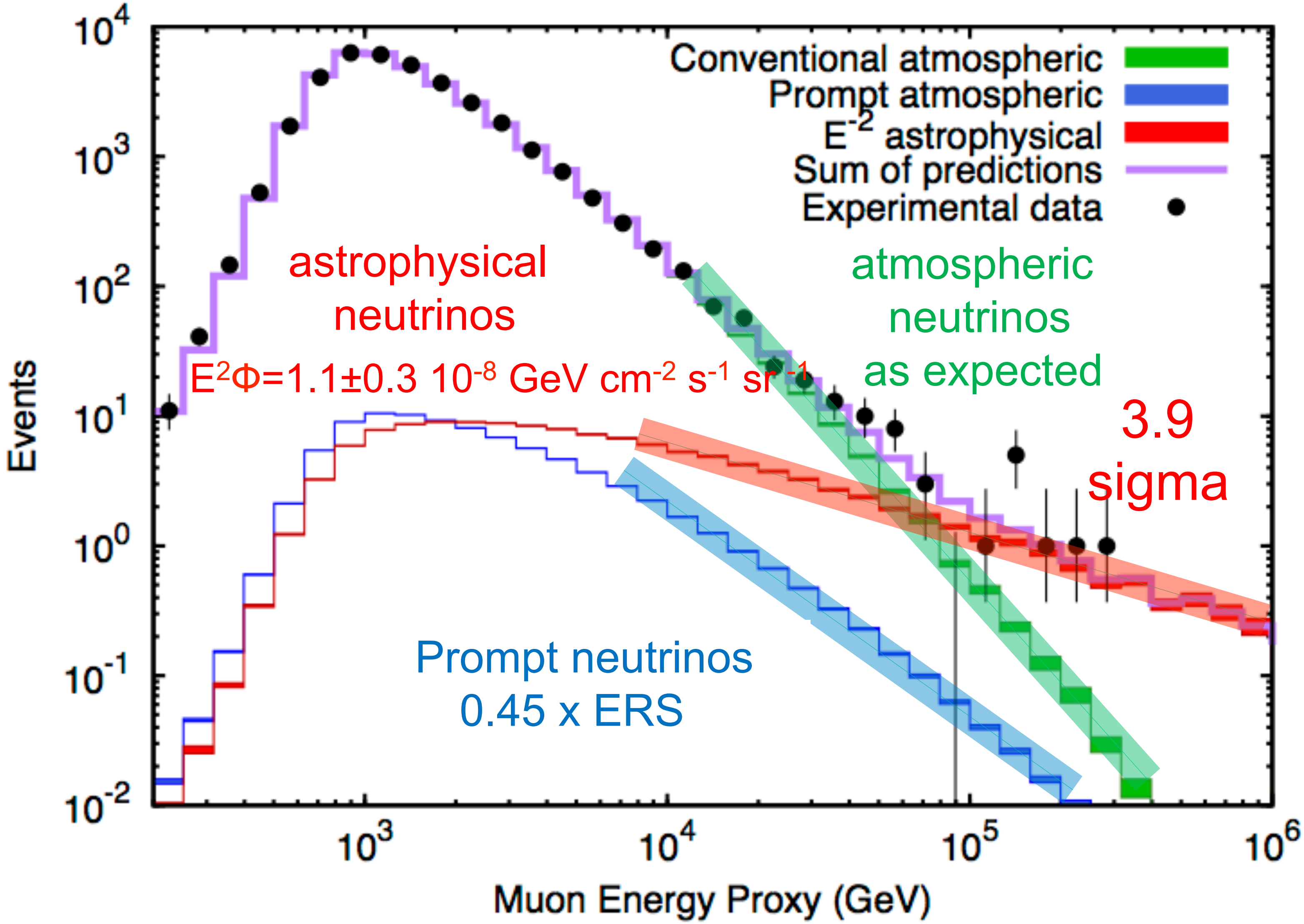
No significant excess (1.2 σ)



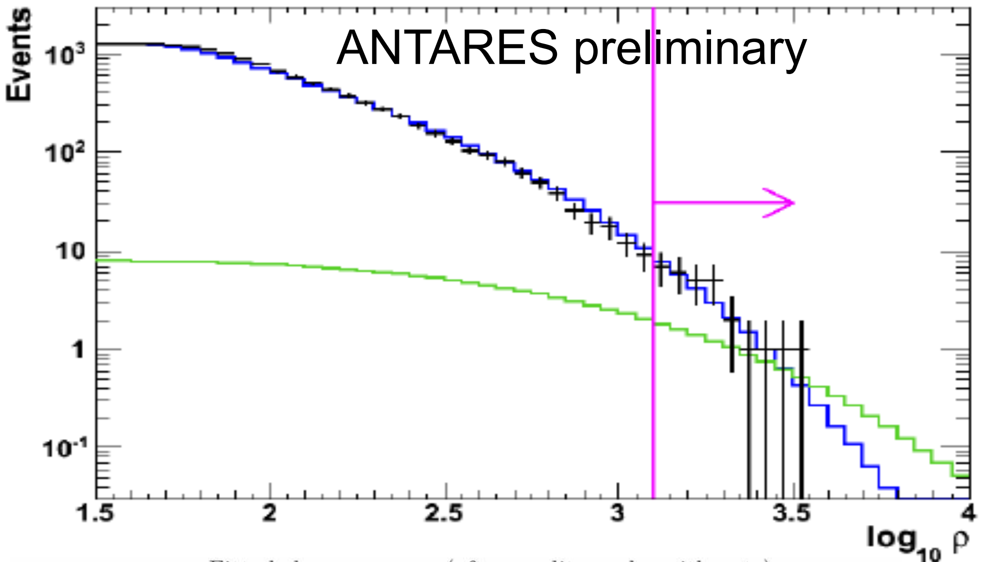
on-zone
off-zone average
expected signal (≠ cutoff, 50TeV cutoff)

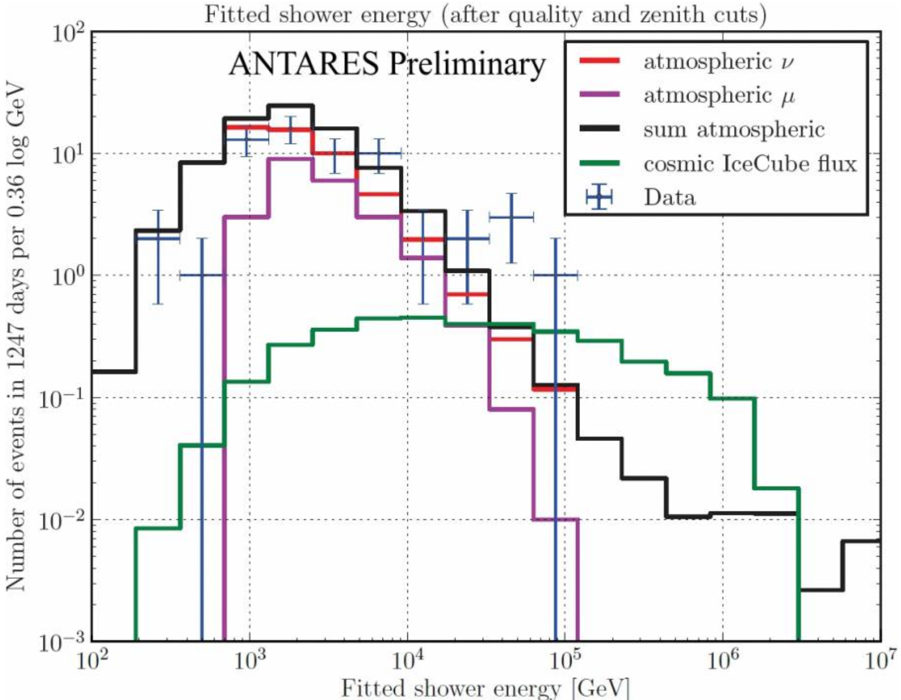
Diffuse flux now confirmed with muons

Hint from IC59 (1.8 sigma); now IC79/86-1 upgoing muon neutrinos give 3.9 σ



ANTARES Diffuse Neutrino Searches





Muons (2008-2011) 855 days
8 observed events (8.4 expected) flux limit (90%CL):
5.1×10^{-8} GeV/cm^2/s/sr

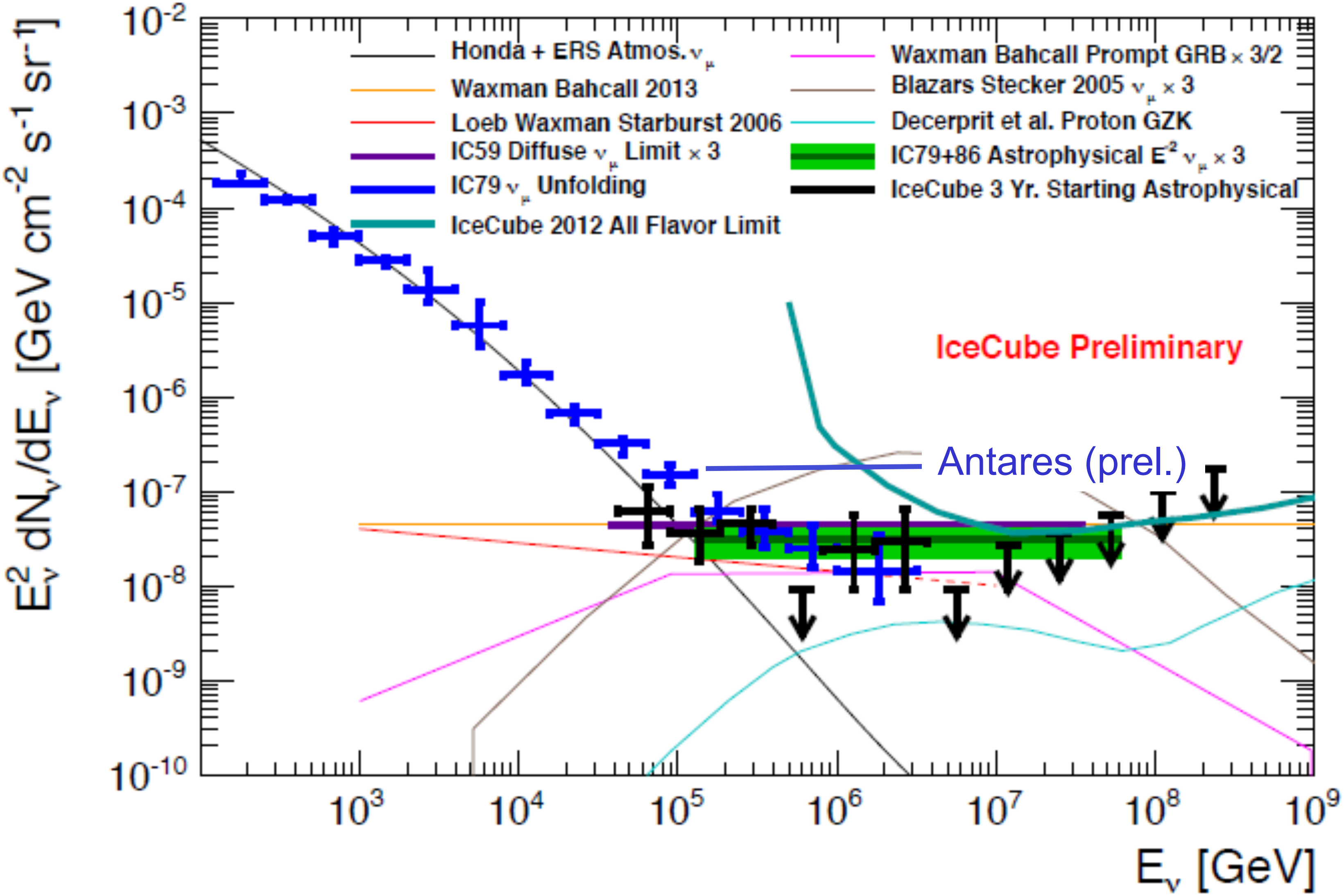
45 TeV < E < 10 PeV

Cascades (2008-2012) 1247 days
sensitivity: 2.5×10^{-8} GeV/cm^2/s/sr

8 events observed, 4.9 expected
1.5 σ excess
signal: 1.32×10^{-8} GeV/cm^2/s/sr

Flux limit (90%CL)
4.92×10^{-8} GeV/cm^2/s/sr
23 TeV < E < 7.8 PeV
Angular resolution ~6-7°

Current picture

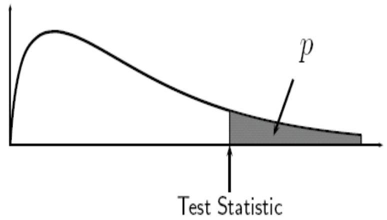


Point source searches

Methods
📖 Neunhoffer and Kopke NIM A 558 (2006) 561
📖 Hill and Rawlins, Astrop. Phys., 19, 393, (2003)

Summarized generic "blind" analysis (Optimized with scrambled data set)

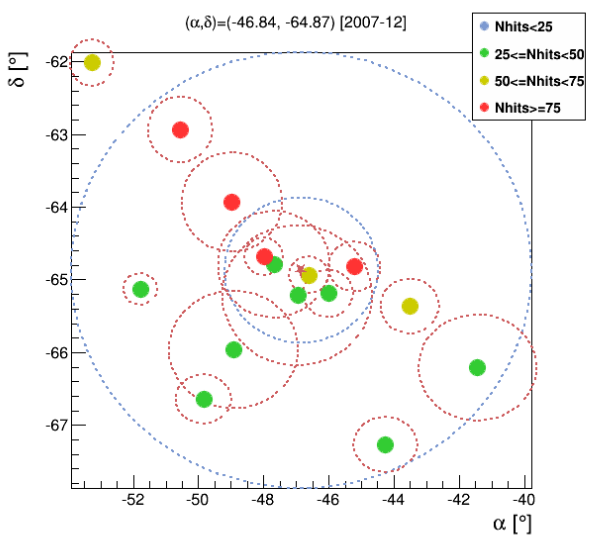
- Use Clusterization algorithm
- Calculate a statistic given data (eg. Likelihood ratio)
- Compute *p-value* (probability to observe such statistic from bkg)
- Compute post-trial significance probability to observe *p-value* from many experiments

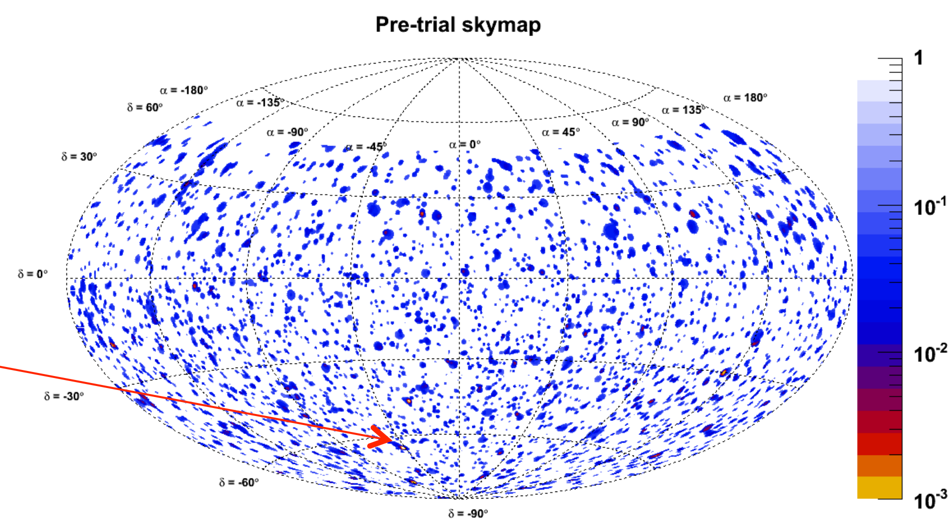


These analyses can be performed for :

- All sky search
- Predefined list of known sources
- Collection of sources of same kind summed up (stacking analysis)

Most significant cluster, 6 (14) events in 1° (3°) : p-value = 2.7% (2.2 σ)





Search for neutrino point sources

❖ Antares updated muon search 2007-2012 (1340 days)

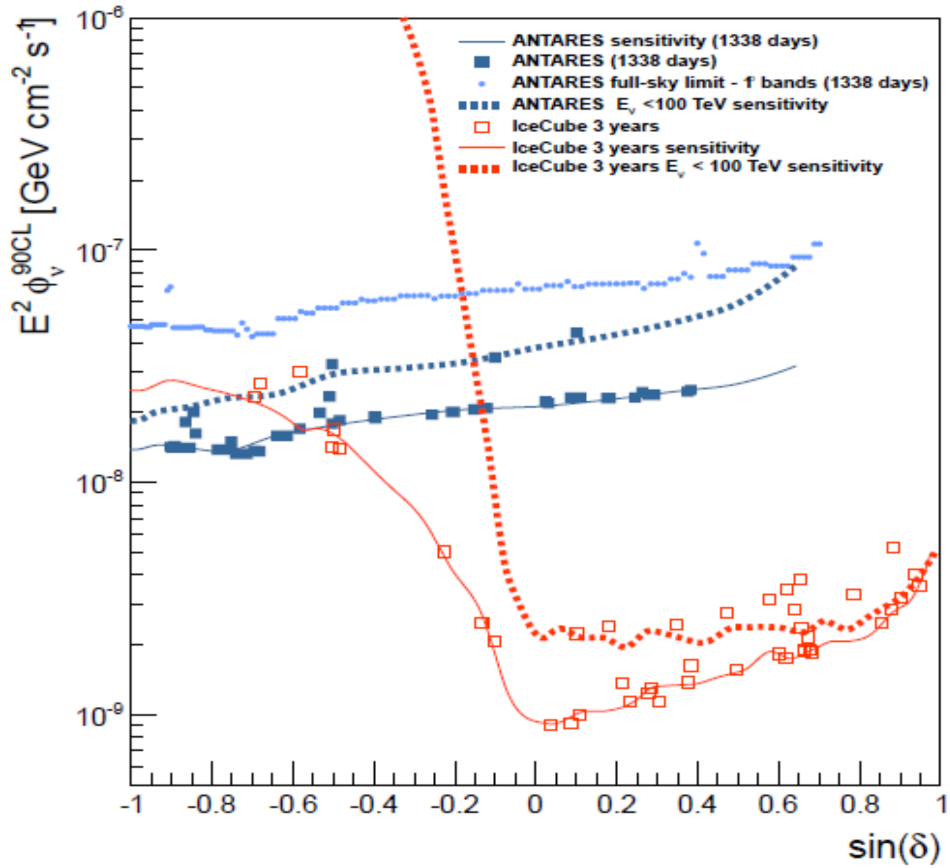
- 5516 neutrino candidates (90 % of which being better reconstructed than 1º)
- No significant excess
- Same most significant cluster with 6 additional events: p-value = 2.1% (2.3 σ)
  Compatible with background hypothesis

- Fixed search top 5 most significant

source	$\alpha_s[°]$	$\delta_s[°]$	p	$\phi^{90\%CL}$
HESSJ0632+057	98.24	5.81	0.07	4.40
HESSJ1741-302	265.25	-30.20	0.14	3.23
3C279	194.05	-5.79	0.39	3.45
HESSJ1023-575	155.83	-57.76	0.82	2.01
ESO139-G12	264.41	-59.94	0.95	1.82

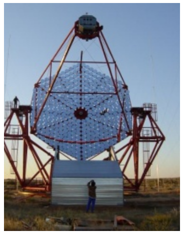
Limits on normalization factor
$(E/GeV)^{-2}\ 10^{-8}\ GeV^{-1}\ cm^{-2}\ s^{-1}$

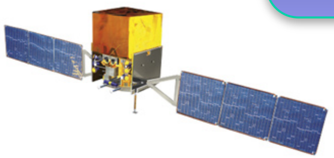
Significance post-trial 6.1% (1.9 σ)

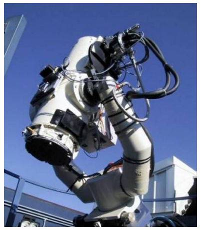


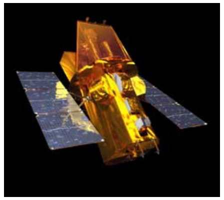
📖 S. Adrian-Martinez et al., Astrophys. J. Lett. 786 L5, 2014

The multi-messenger program









GeV-TeVγ-rays
Fermi / HESS…

UHECR
Auger

Neutrino HE

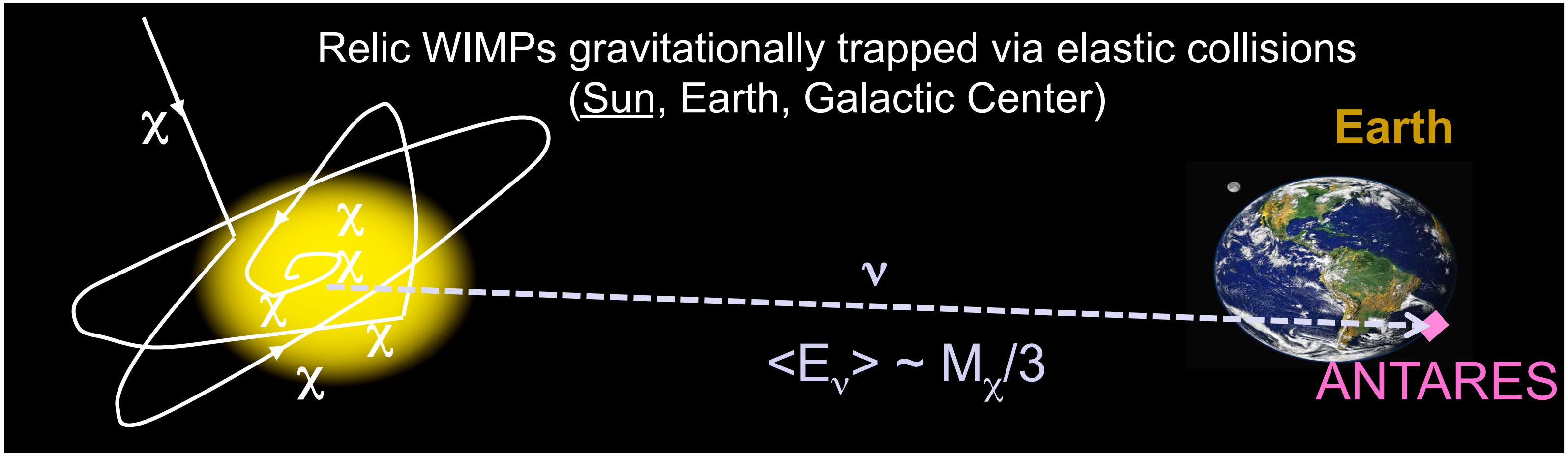
Optic / X-ray
TAROT,
ROTSE / Swift,
ZADKO

Gravitational
Waves
Virgo / Ligo

⇒ A way to better understand the sources and the related physics mechanisms
⇒ A way to increase the detector sensitivities (uncorrelated backgrounds)

Extensively covered by other speakers

Indirect search for Dark Matter



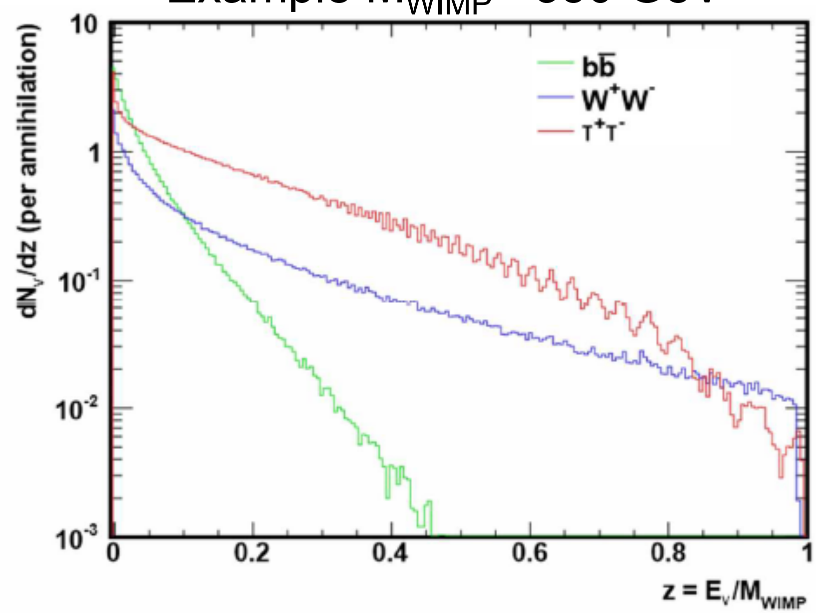
- HE neutrinos from the Sun → Clean DM signature

- Models where Lightest SUSY Particle (LSP) is stable (R-parity conservation) are considered
- Self-annihilation in c,b,t quarks, τ leptons or W, Z,H bosons induce HE neutrino flux
  - → b quarks (soft spectrum)
  - → τ leptons
  - → W bosons (hard spectrum)

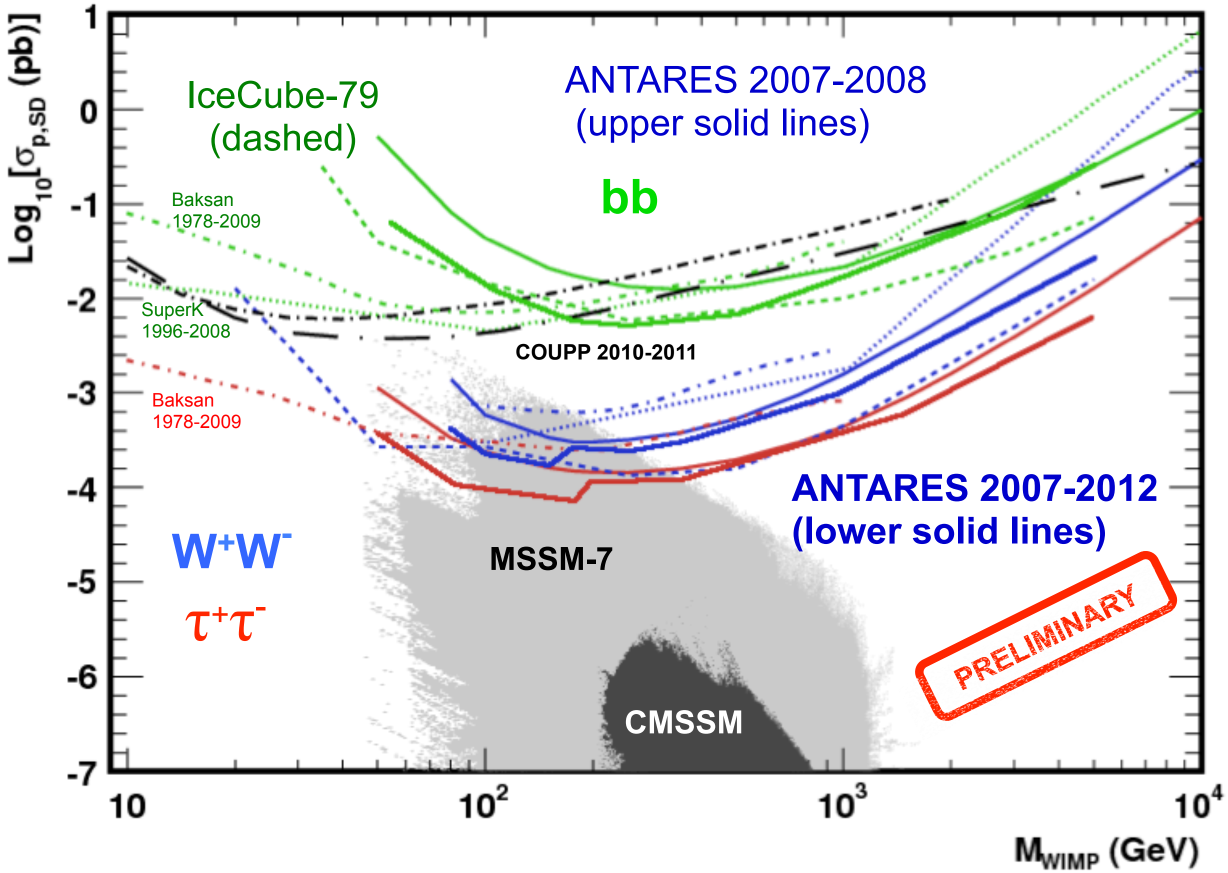
  benchmarks

- Model-independent simulation using WIMPSIM 📖JCAP01(2008)021
- Interactions in the Sun, flavor oscillations, and regeneration of ν_τ in the Sun accounted

Example M_{WIMP}= 350 GeV



Sun – Limits on spin-dependent cross-sections



Conversion to limits on WIMP-proton SD-x sections assumes equilibrium between capture and annihilation rates inside the Sun

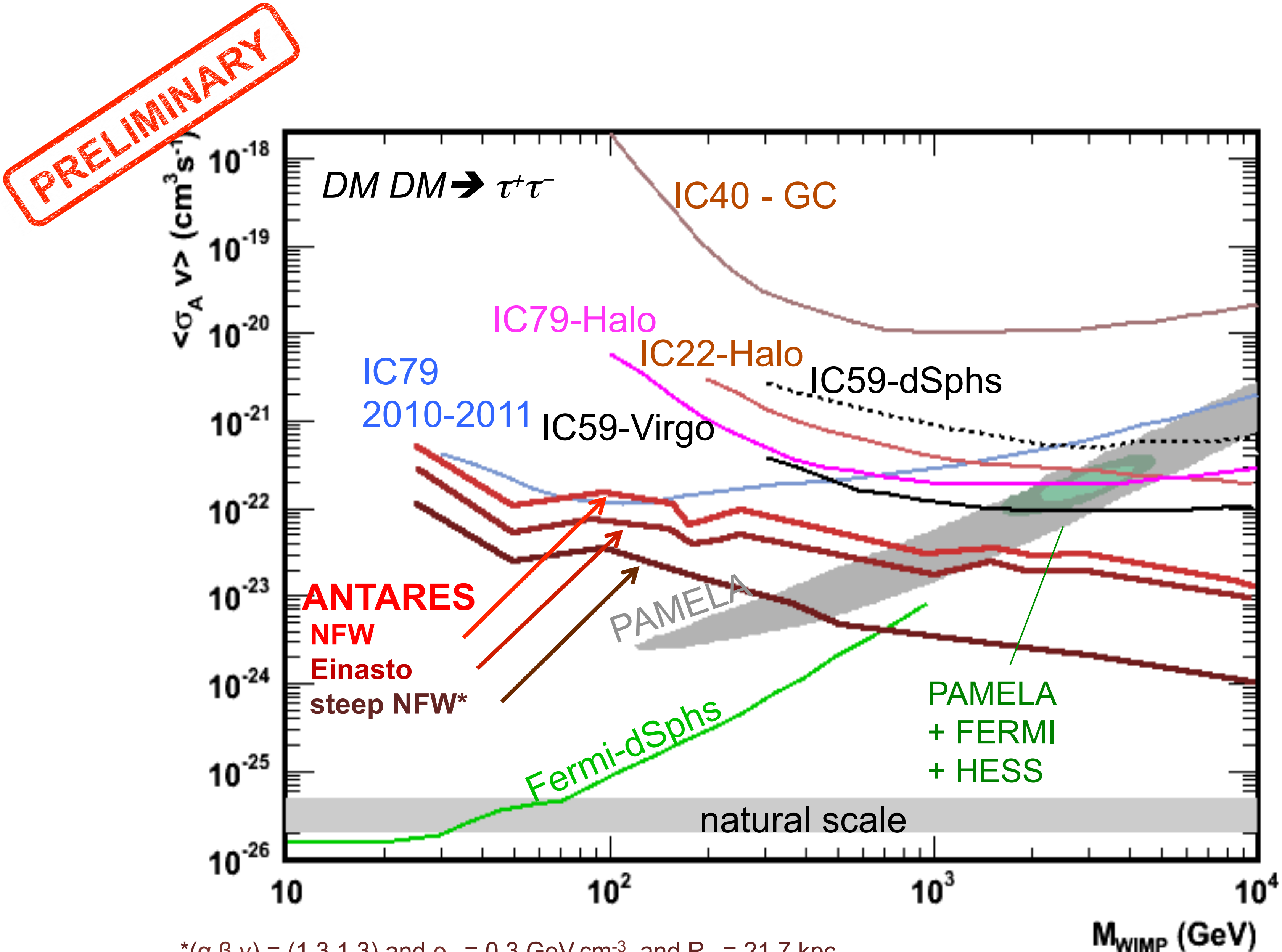
Much better sensitivity of ν-telescopes on SD cross-section w.r.t. direct detection (due to capture on H in the Sun).

First ANTARES results published in JCAP11 (2013) 032

MSSM-7 and CMSSM predictions take into account recent experimental constraints (Higgs mass,etc…).

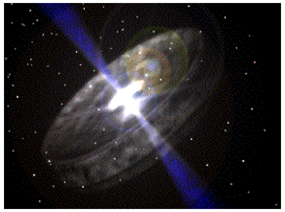
There is still room for improvement in ANTARES: better reconstruction at low energies, binned method, more data “on tape”, …

Galactic Centre – Limits on $<\sigma_A v>$

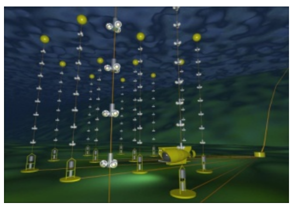


*$(\alpha,\beta,\gamma) = (1,3,1.3)$ and $\rho_S = 0.3$ GeV.cm^{-3}, and $R_S = 21.7$ kpc.

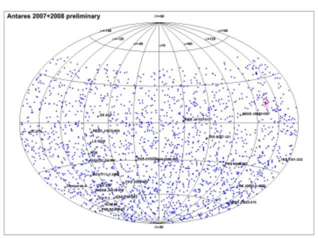
Outline



Neutrino astronomy
Historical aspects
Scientific motivations
Cosmic neutrino sources



Neutrino telescope
Detection principles
Current telescopes

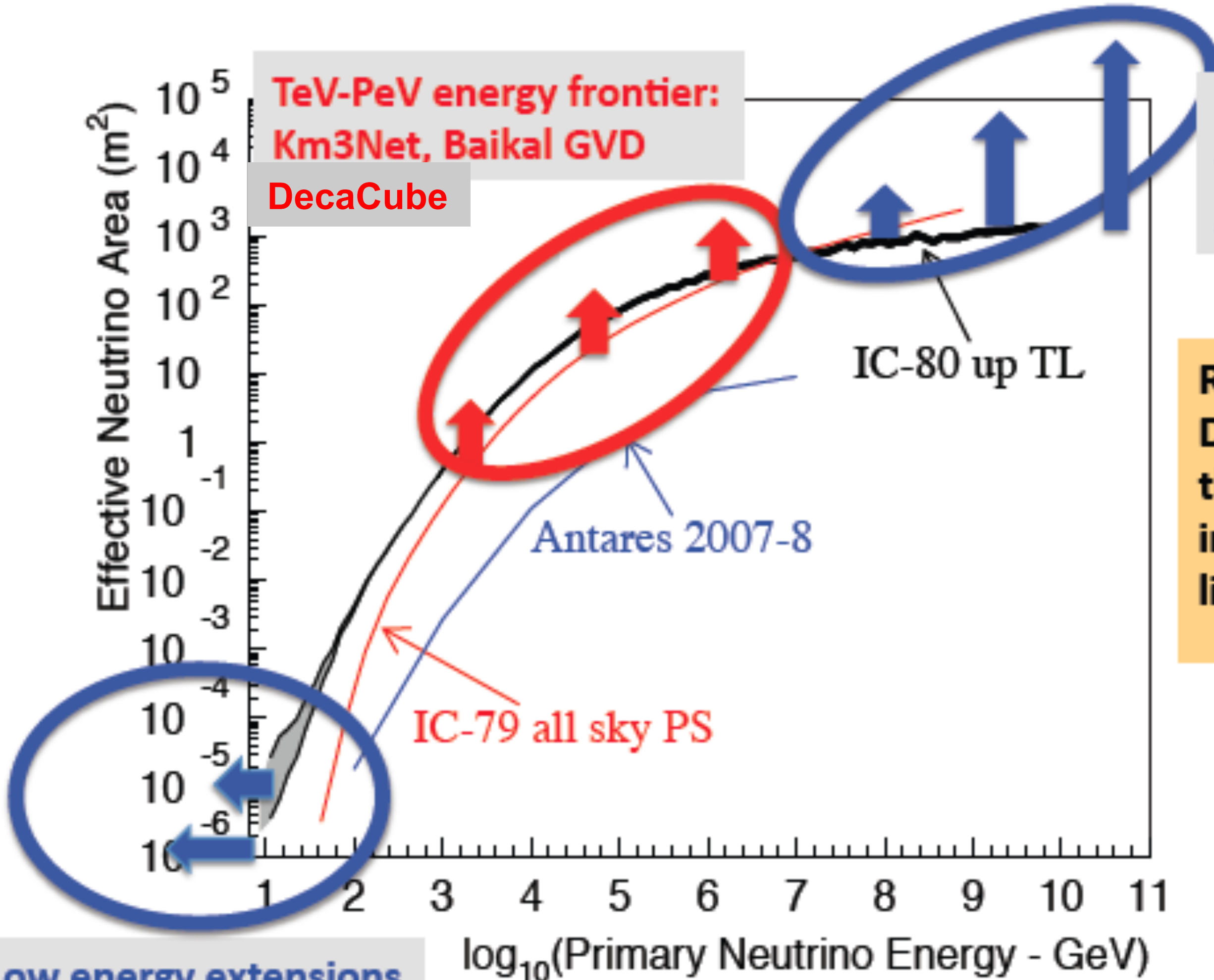


Selected results
Diffuse Flux
Search for point sources
Multi-messenger search
GWHEN searches

KM3NeT

Future prospects

Future neutrino detectors



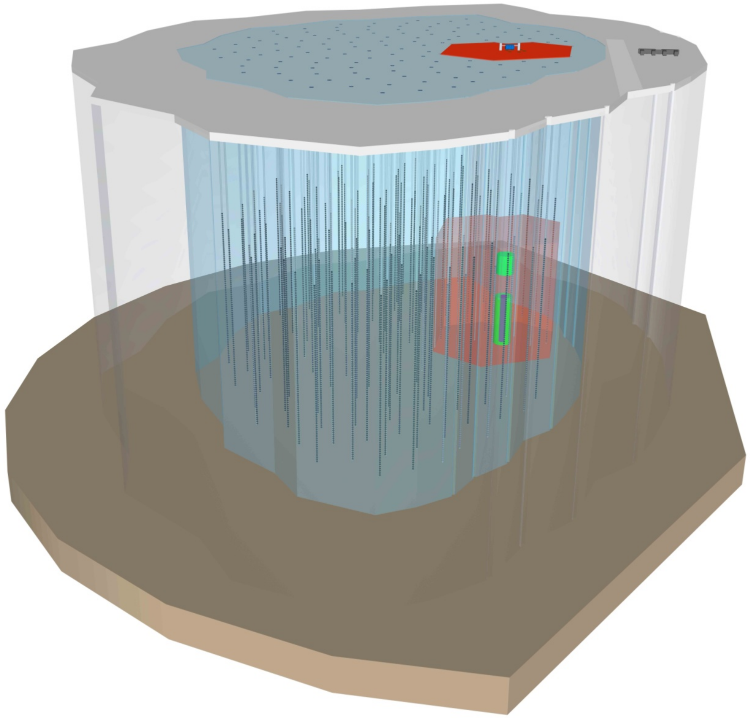
UHE energy detectors for GZK neutrino flux: ARA, ARIANNA

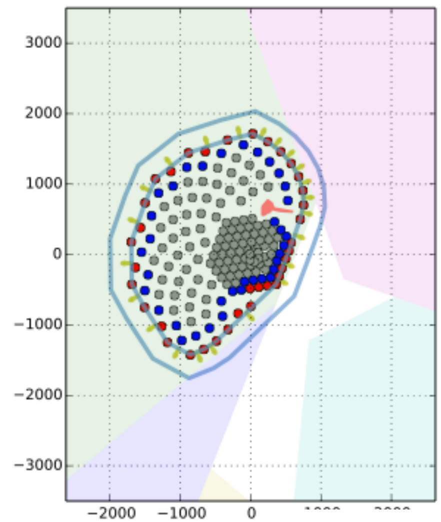
Radio detection in ice: Detection volume and thus sensitivity increases roughly linearly with energy!

Low energy extensions to IceCube, DeepCore: PINGU, MICA

ORCA

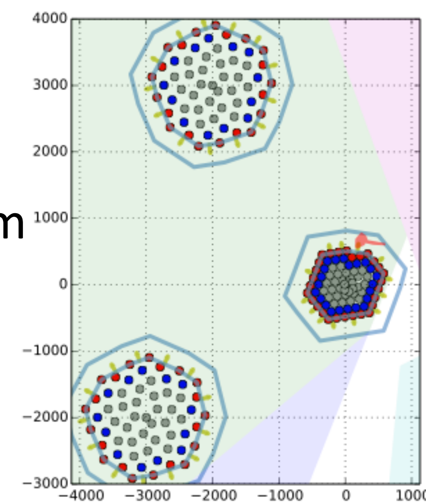
DecaCube





IceCube + 96 strings
Spacing 240 m

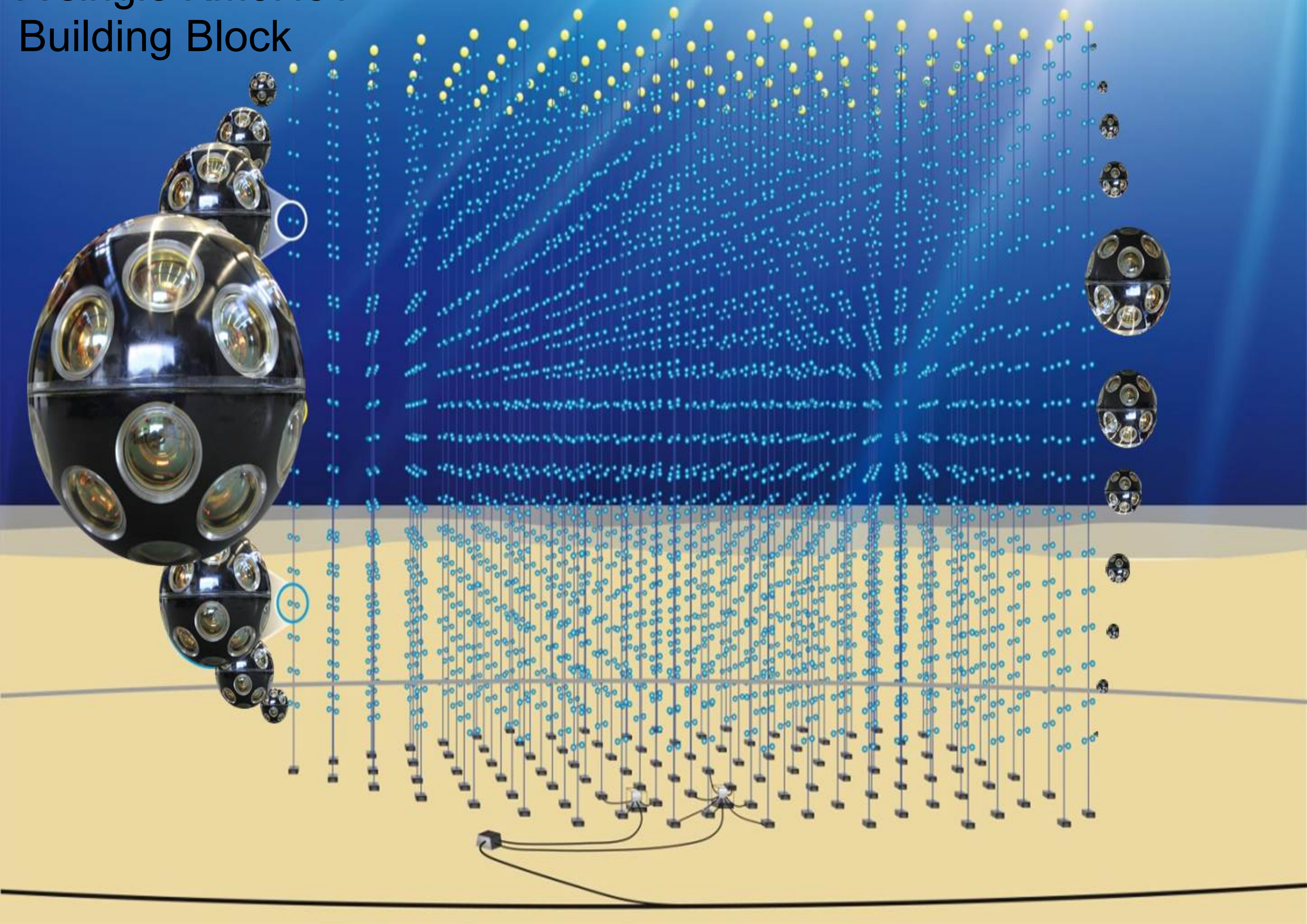
IceCube +
2 x 60 strings
spacing 240 m



- ~ 100 strings
- + surface veto detector
- + PINGU for oscillations (40 strings)
- Start 2018/19?

Albrecht Karle, Arlington Meeting April 24, 2014

A single KM3NeT Building Block



KM3NeT

- Multi-km^3 deep sea neutrino telescope in the Mediterranean Sea, substantially exceeding ANTARES/IceCube in sensitivity

- Two sites: Toulon, France, and Capo Passero, Sicily

- Staged implementation:

Phase-1 in progress (31 M€)		31 strings (2 sites) (local funding)
Phase-1.5	(LoI in prep.)	230 strings (2 sites, 2 building blocks)
Phase-2		600 strings (6 building blocks)

- Central physics goals:
  - Investigation of IceCube signal (Phase 1.5)
  - Neutrino Astronomy (neutrino "point" sources) (Phase 2)

- Nodes for deep-sea research in marine sciences (EMSO)

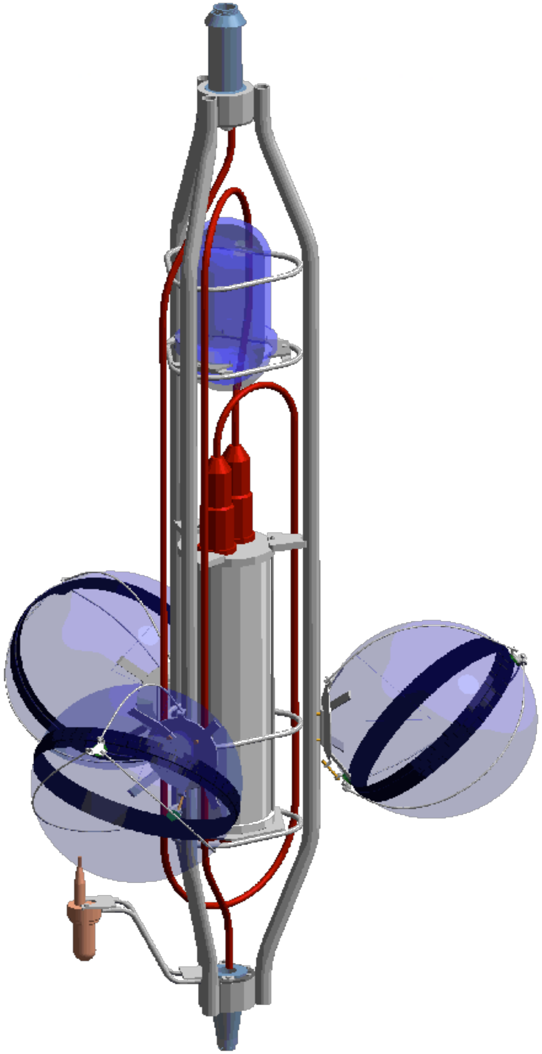
- Possibility of a site optimised for low energy (neutrino mass hierarchy) under study → ORCA (cf PINGU in the IC context 🕮 arXiv:1306.5846) Parallel to phase 1.5

The Multi-PMT Digital Optical Module

17 inch

>

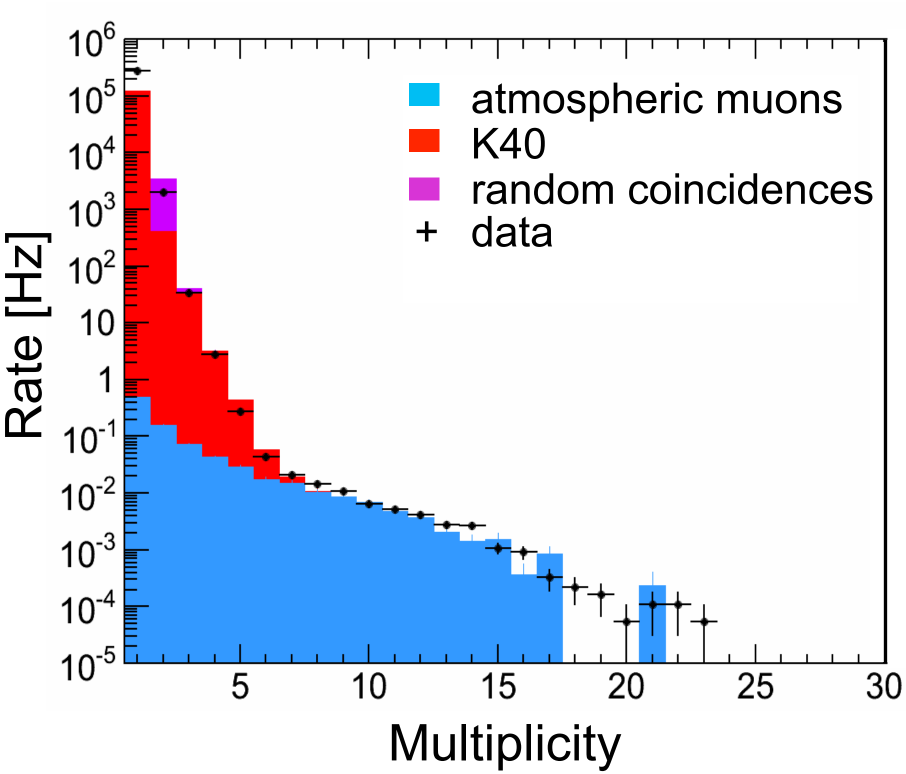
ANTARES Storey

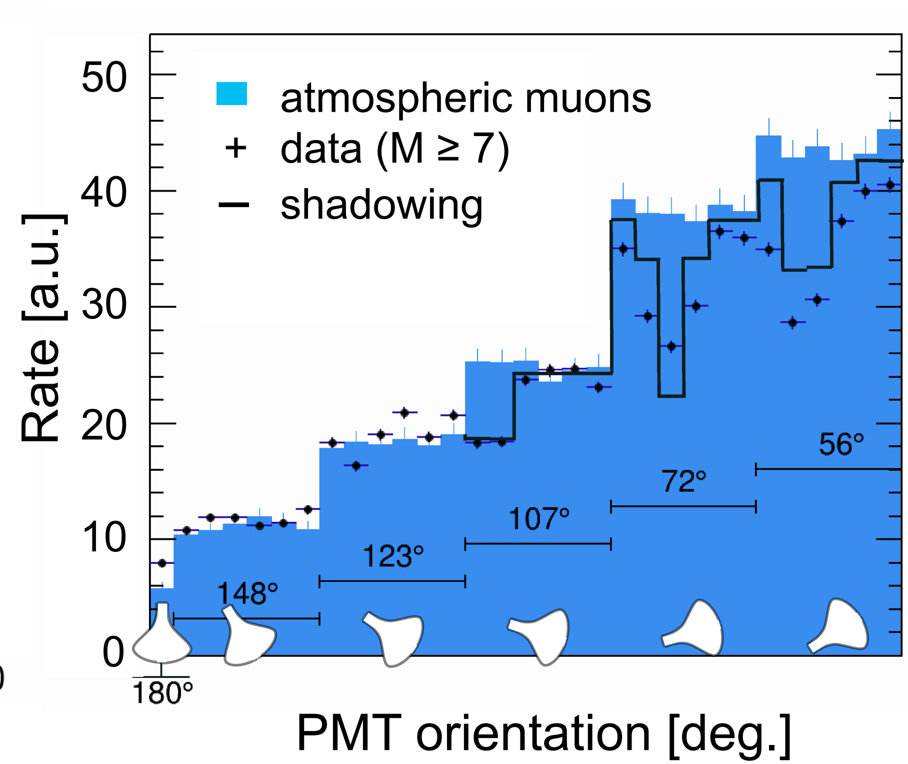


- Digital photon counting
- Directional information
- Wide angle of view
- Single pressure transition
- Cost reduction cf ANTARES

1st prototype

1st prototype



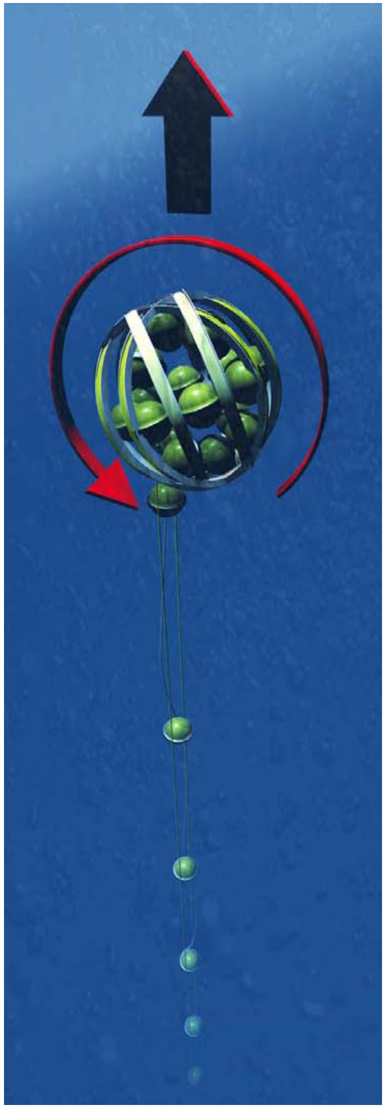


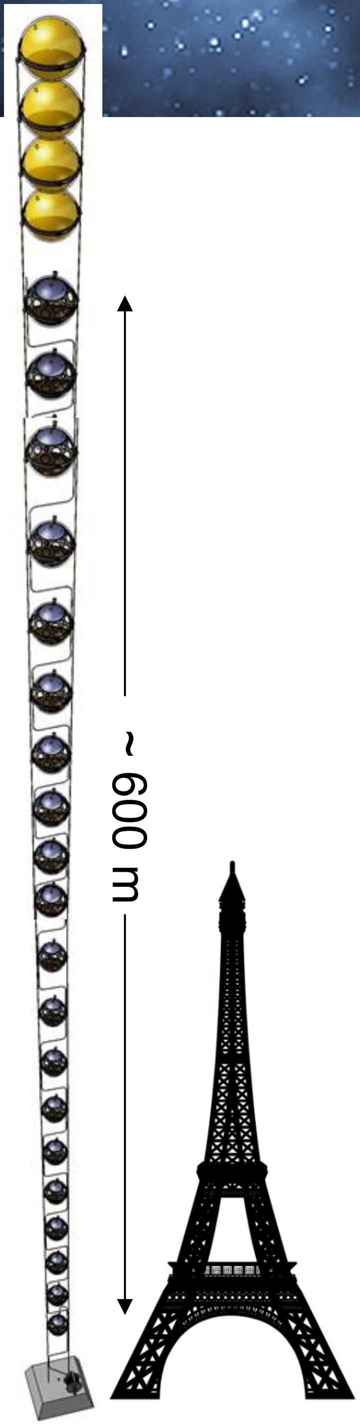
✓ photon counting

✓ directionality

📖 http://arxiv.org/abs/1405.0839

String Deployment

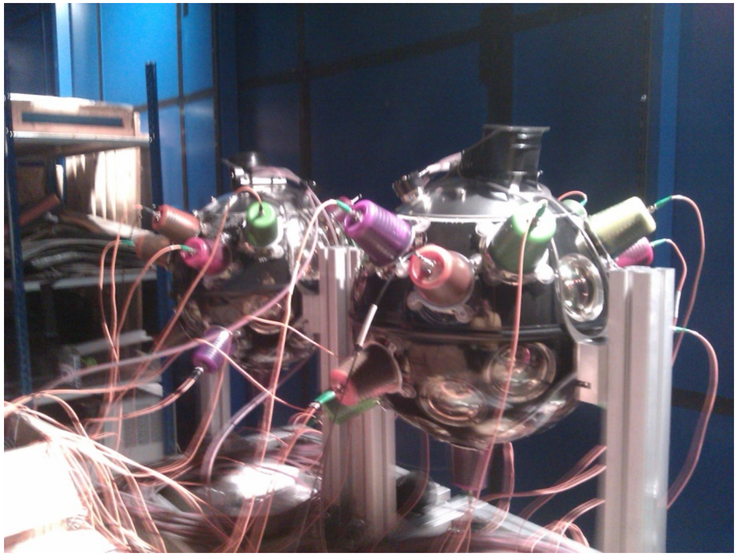




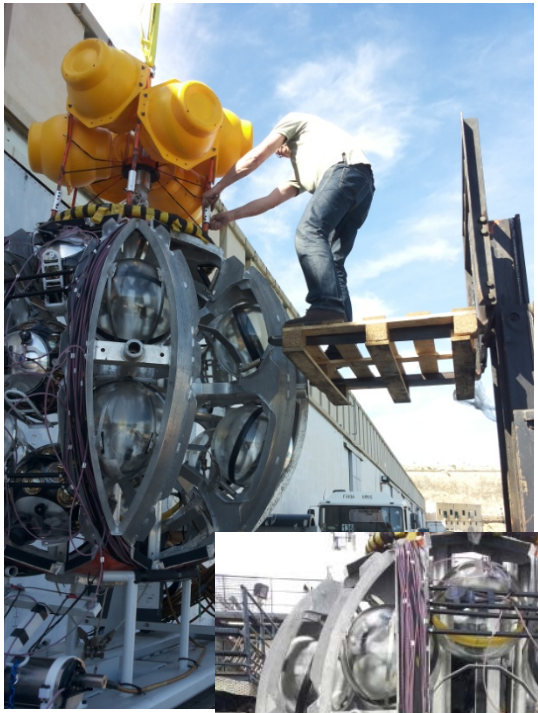
- Fast mounting of optical modules
- Rapid deployment
- Autonomous unfurling
- Recovery of launcher vehicle

Multiple deployments with a single cruise

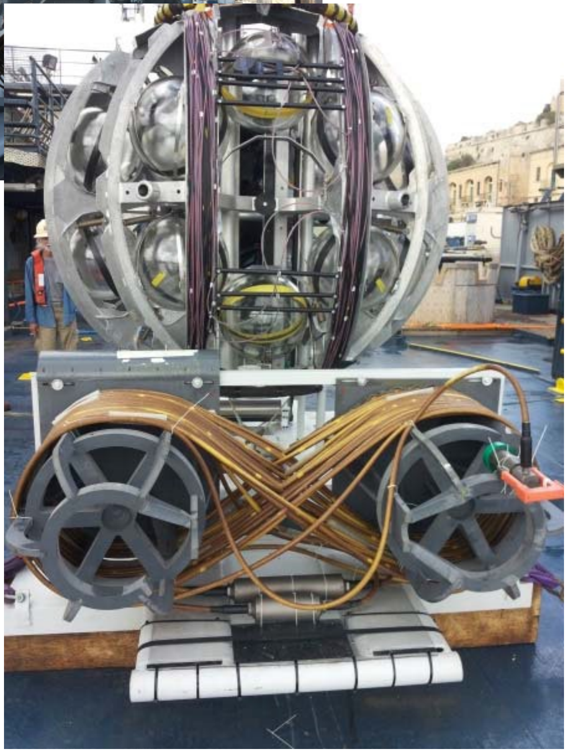
KM3NeT 'Mini-line' deployed at Capo Passero (May 7)



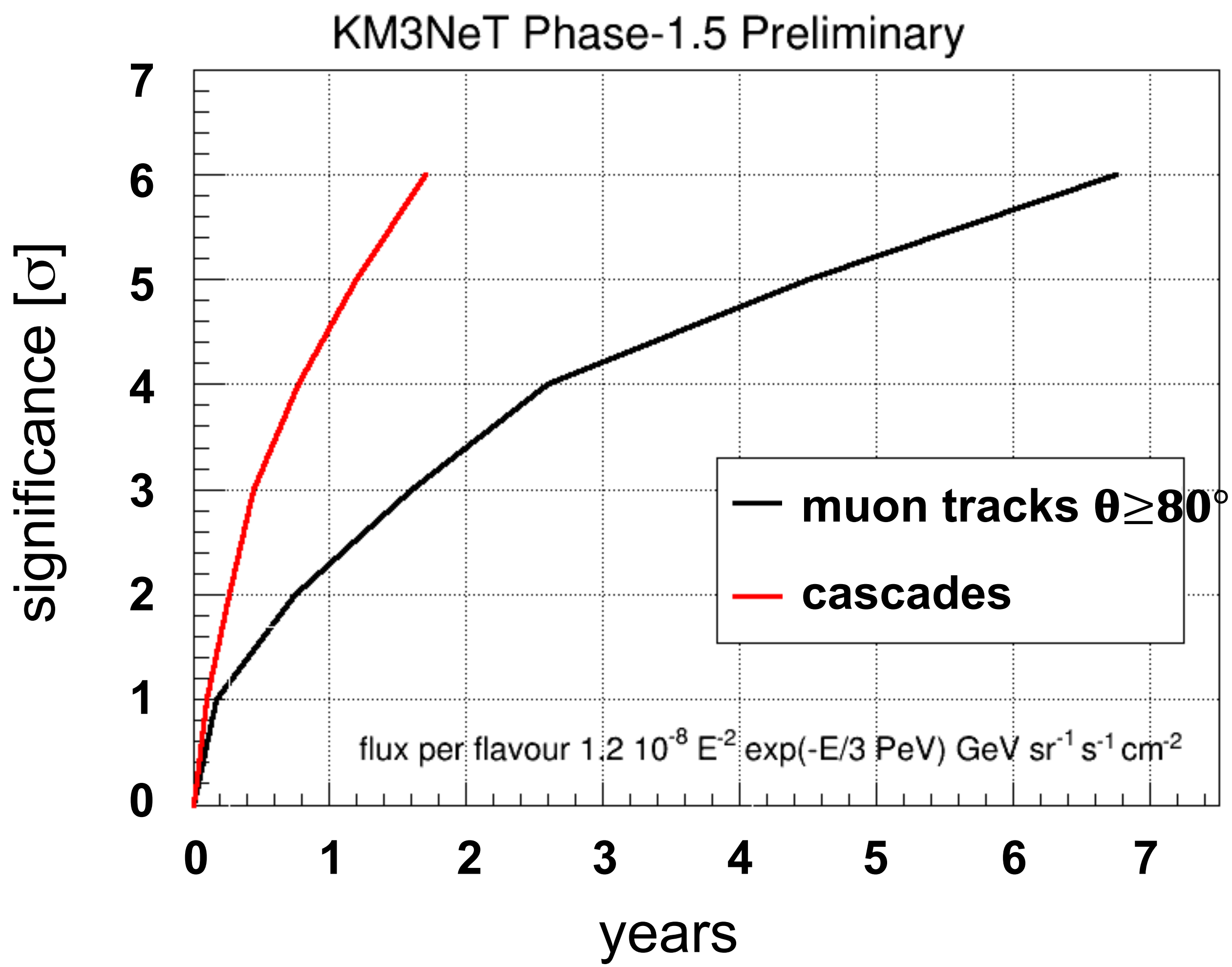
Integration
Nikhef +
CPPM



Deployment
Sicily

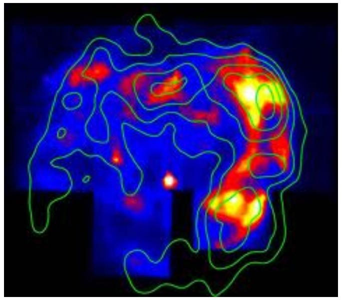


Sensitivity to the IC diffuse flux

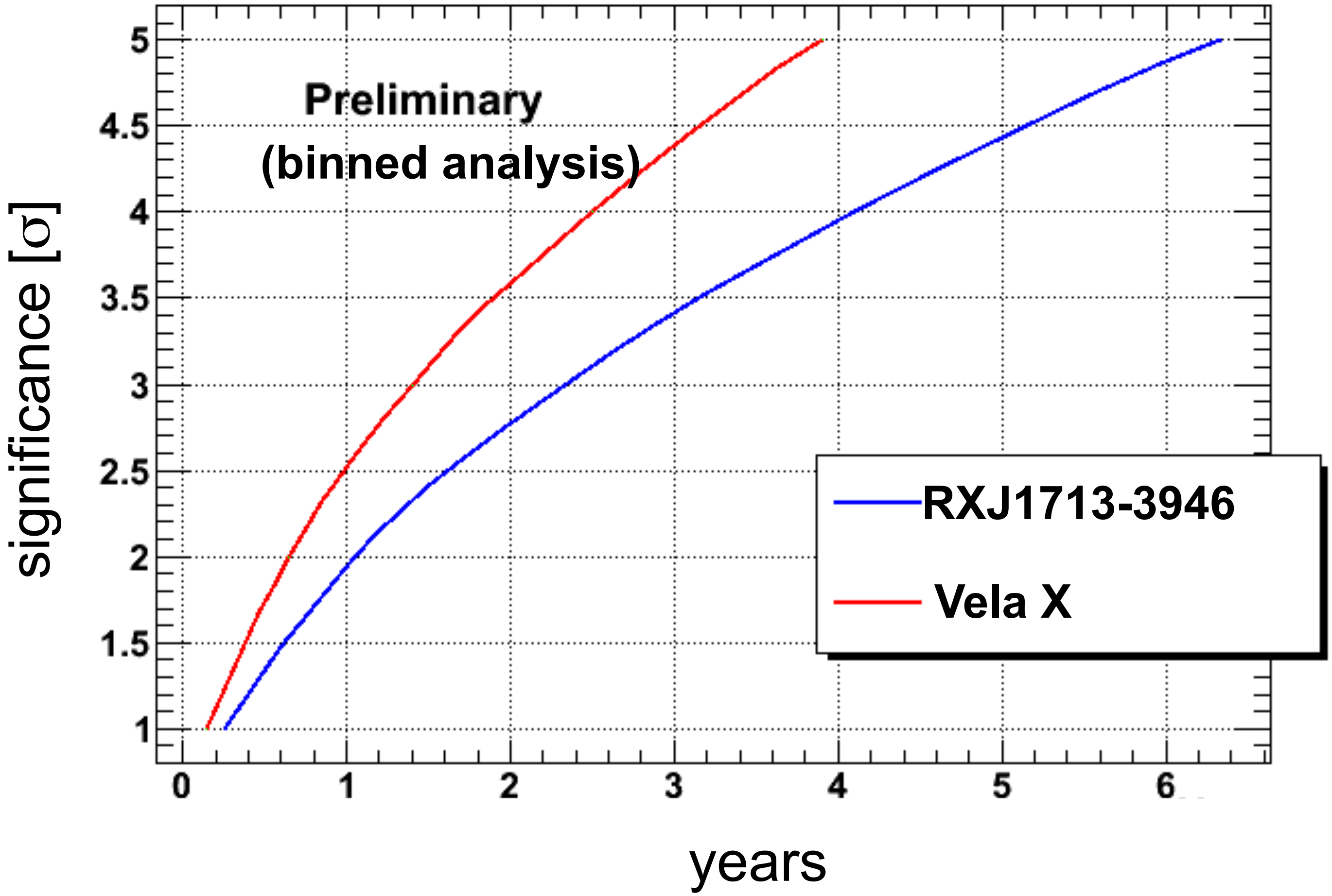


Sensitivity to Galactic Sources

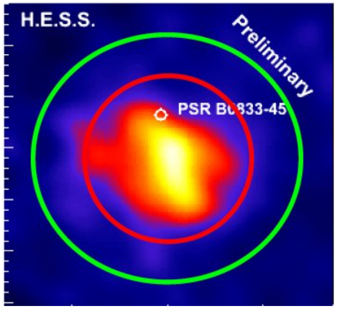
RXJ1713



📖 S.R. Kelner, *et al.*, PhRD 74 (2006) 034018.

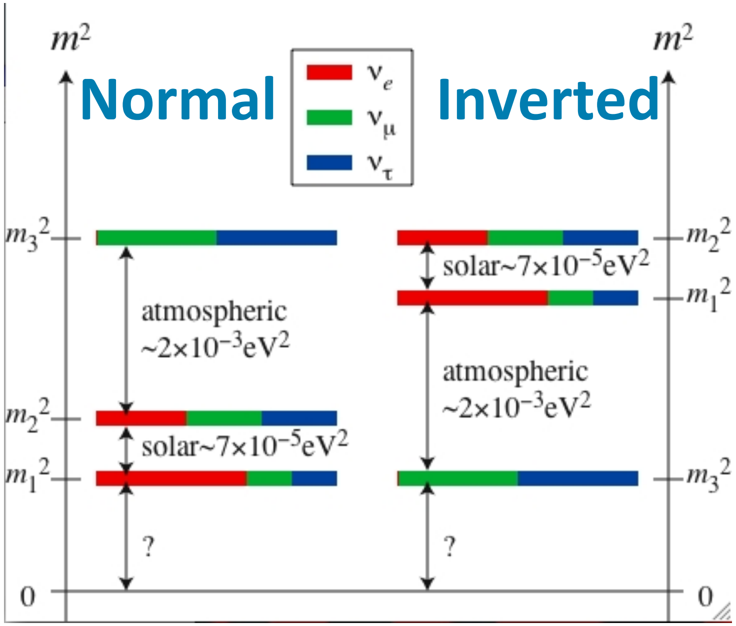


Vela X



📖 F.L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007.

Measuring the neutrino mass hierarchy?



- Free 'beam' of neutrinos
- Broad range of baselines (50-1250km)
- Broad range of energies (~GeV-PeV)
- Composite of beam well understood:

  flux (nu)~1.3 flux (anti-nu)

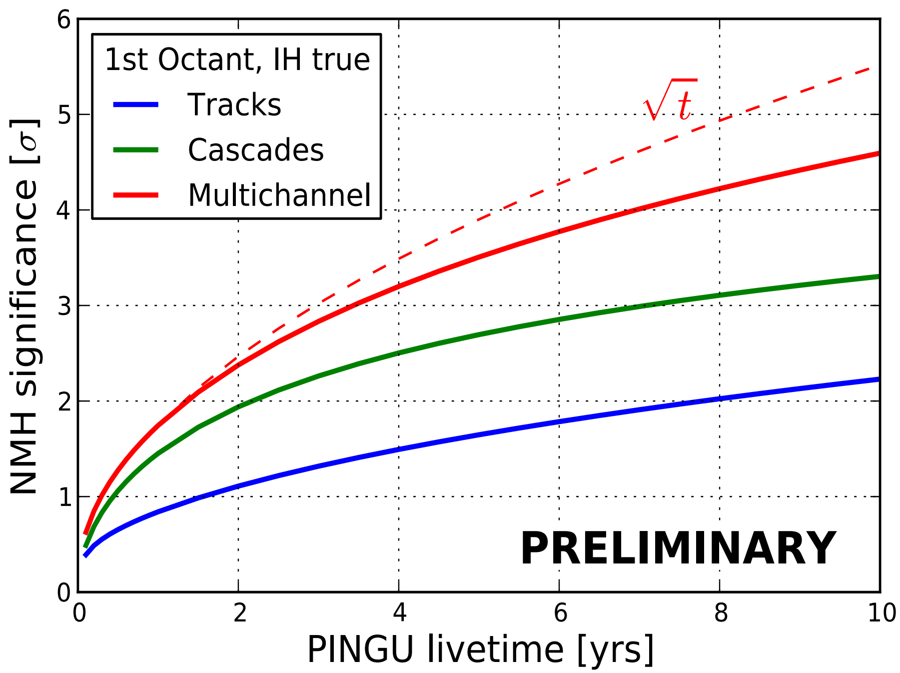
- mass effects lead to event rates at particular angles and energies which depend on the mass hierarchy and is opposite for neutrino/anti-neutrino
- At these energies $\sigma(\nu) \approx 2\sigma(\overline{\nu})$ so observe net effect

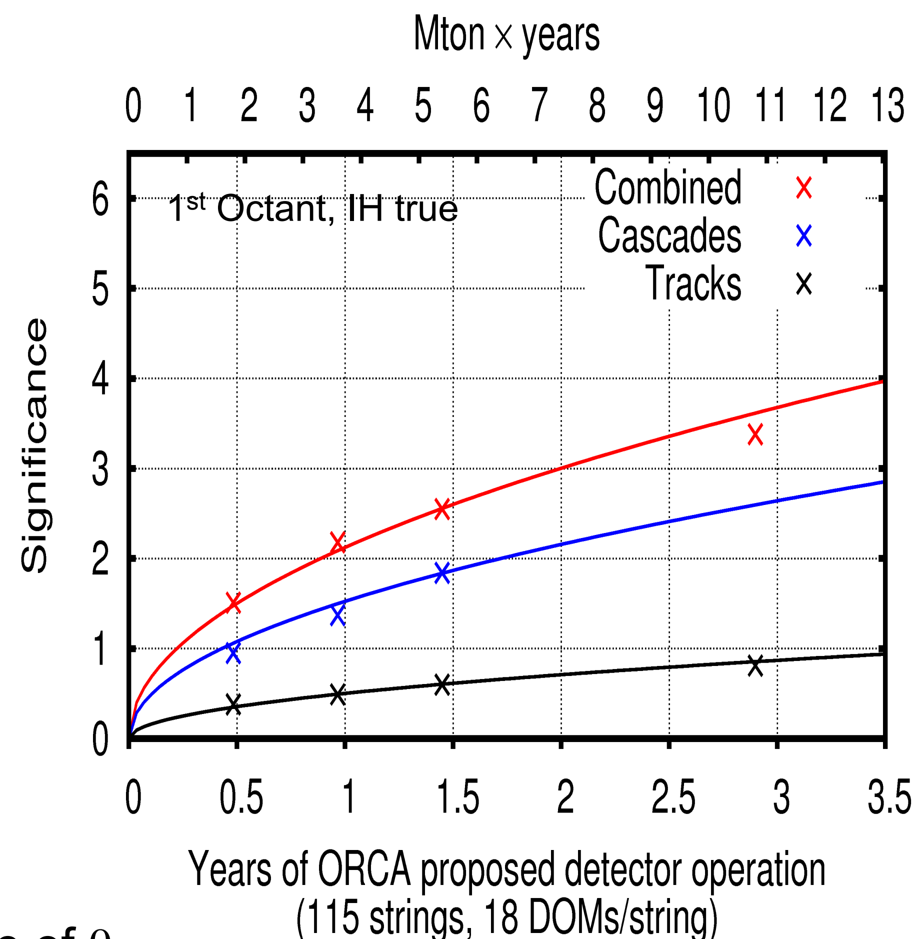
→ Fit of event count in Energy-Zenith space

📖 W. Winter : arXiv:1305.5539, Agarwalla et al. arXiv:1212.2238
📖 Akhmedov et al. JHEP 02 (2013) 082

Mass Hierarchy Sensitivities

PINGU sensitivity (40 strings, 60 OM/string, 5m/25m)	ORCA sensitivity (115 strings, 18 OM/string, 6m/20m)



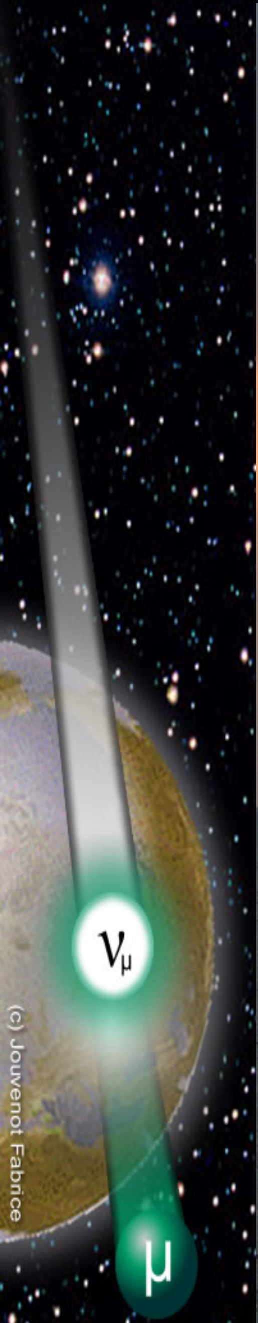


Start 2021

Start 2019

+ Factor ~4 improvement on value of θ_{23}
+ Measurement of octant

Conclusions



- Neutrino telescopes → mature technology (ice and water)
- IceCube discovery opens the field → exiting times ahead with possible extensions (HE, LE)
- ANTARES in its seventh year of operation → Thanks to it excellent angular resolution and view of Southern sky, ANTARES has competitive sensitivities despite its modest size
- KM3NeT Collaboration

  → Site choice made (Toulon, Capo Passero)

  →Technology chosen and prototypes under test

  - Phase 1.5: investigate IceCube diffuse flux
  - Phase 2: neutrino astronomy
  - ORCA looks very promising