Celebrating the 60th Birthday of Werner Hofmann
Max-Planck-Institut für Kernphysik, 18.04.2013

High-Energy Neutrino Searches

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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The plan for this presentation:

- Introduction
- Present neutrino telescopes:
  ANTARES, IceCube and their recent results
- KM3NeT
- Summary

Sincere thanks to all colleagues who provided advice and material for preparing this presentation

Introduction

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The multi-messenger context

- High-energy neutrinos are produced whenever and where ever nuclei are accelerated to TeV and above
- These neutrinos come with gamma-rays
- Not all gamma-rays are accompanied by neutrinos

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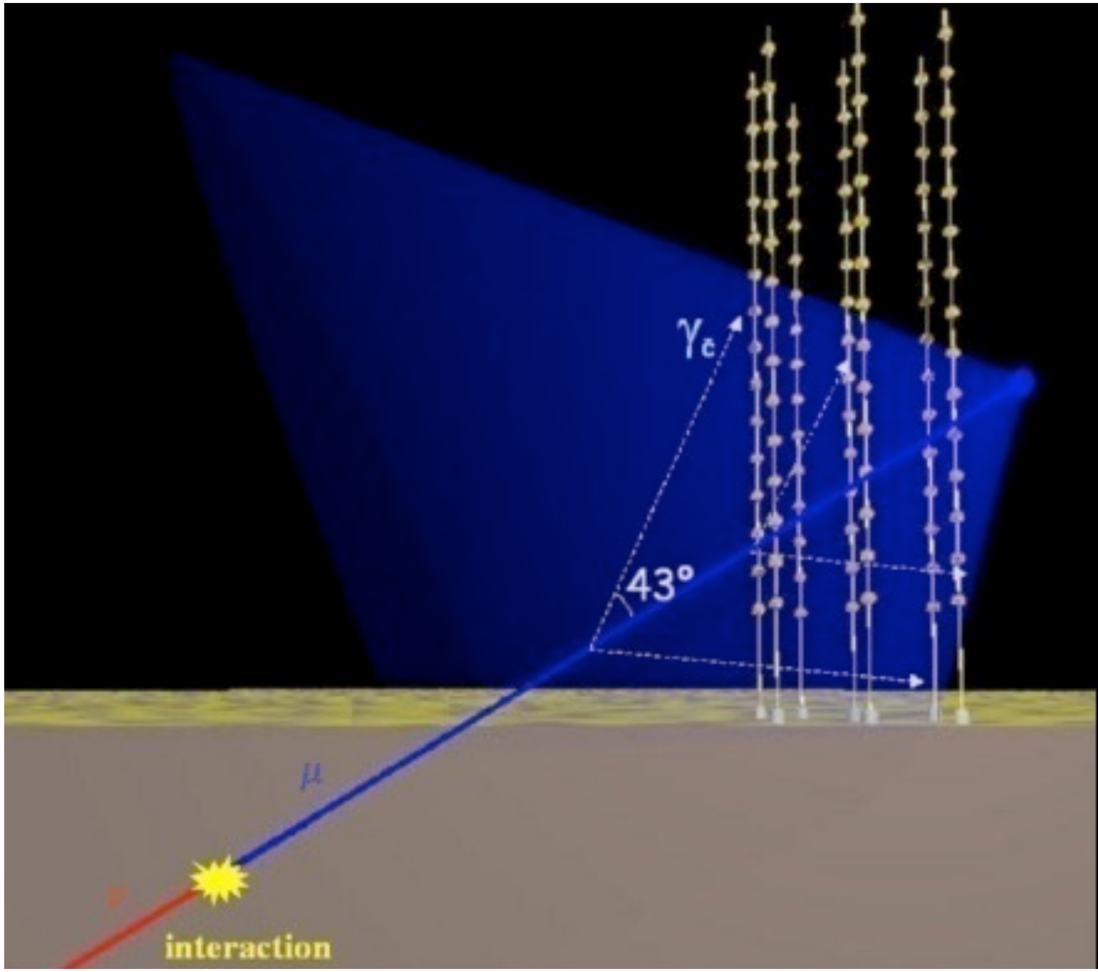
How does a neutrino telescope work?

- Neutrino interacts in the (vicinity of the) telescope
- Charged secondaries cross the detector volume (water or ice) and stimulate Cherenkov emission
- Recorded by a 3D-array of photo-sensors
- Most important channel: $\nu_\mu + N \rightarrow \mu + X$
- Energy range : 10(0) GeV – some PeV
- Angular resolution: <1° for E>1 TeV
- Δ[log(E)] ~ 0.3



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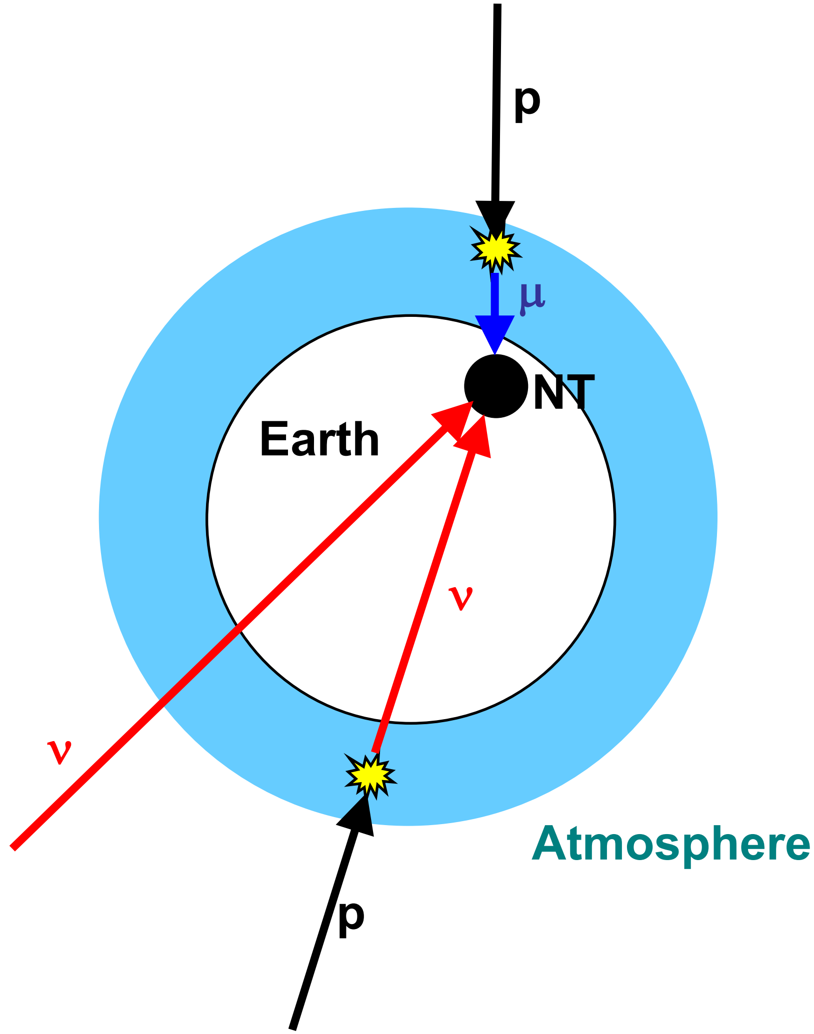
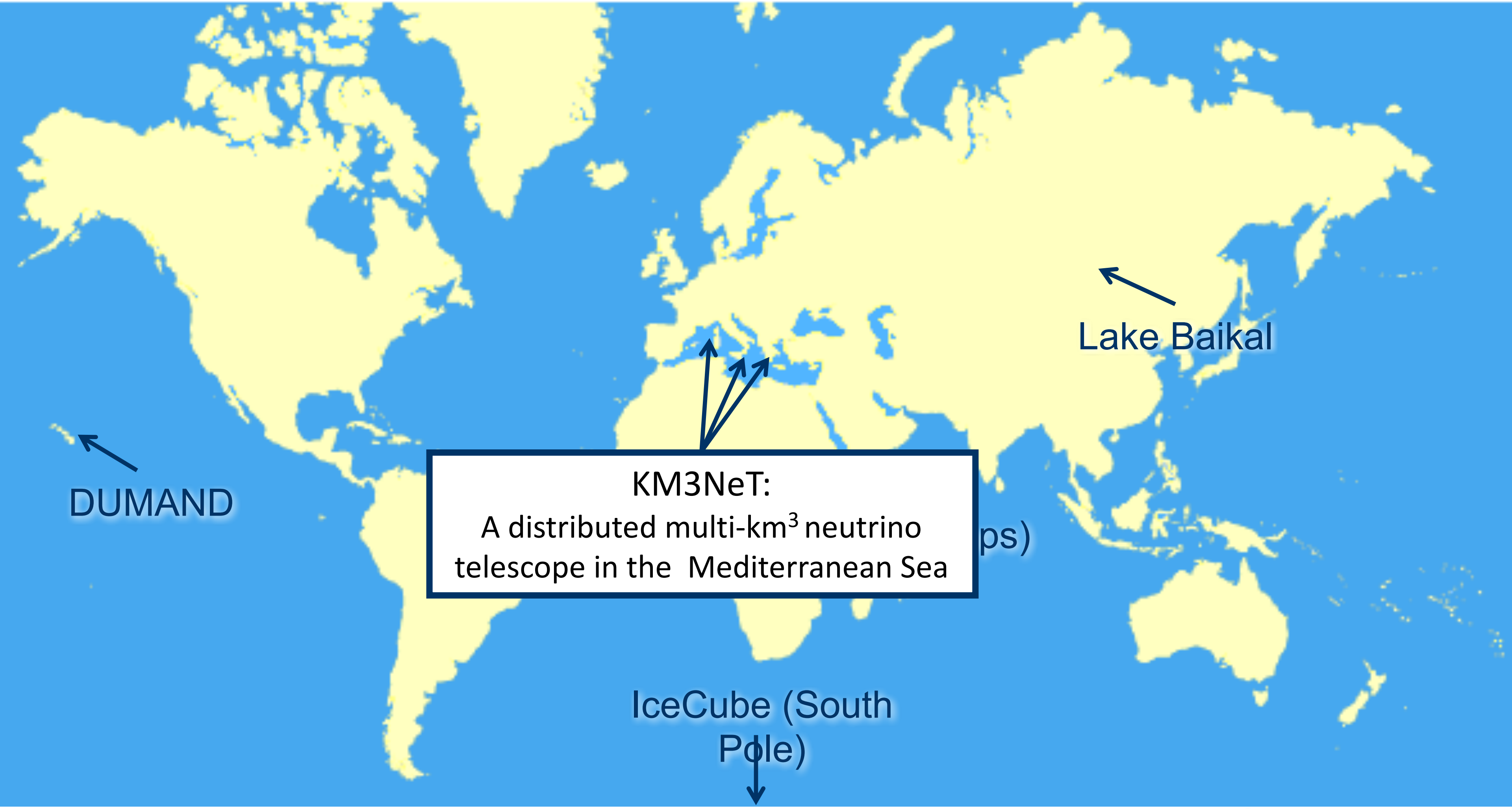
Backgrounds, or maybe not

- Atmospheric neutrinos from cosmic-ray interactions in atmosphere
  - irreducible
  - important calibration source
  - allow for oscillation studies
- Atmospheric muons from cosmic-ray interactions in atmosphere above NT
  - penetrate to NT
  - exceed neutrino event rate by several orders of magnitude
- Sea water: light from K40 decays and bioluminescence



The neutrino telescope world map



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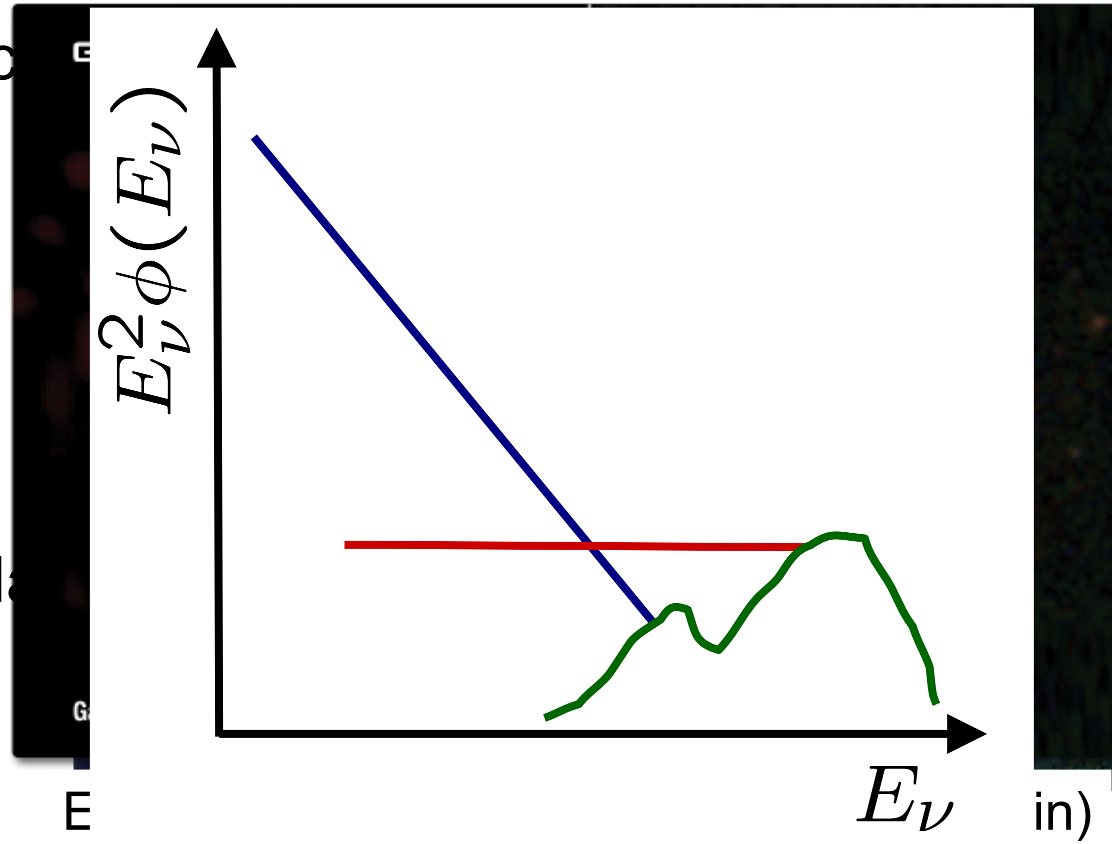
Example targets of neutrino astronomy

- Galactic neutrino sourc
- Extragalactic sources
- Transient sources
- Diffuse neutrino flux
- Neutrinos from Dark Ma
  annihilations
- Particle physics with
  atmospheric neutrinos
- Search for exotics
  (monopoles, nuclearites,



E in)

xy

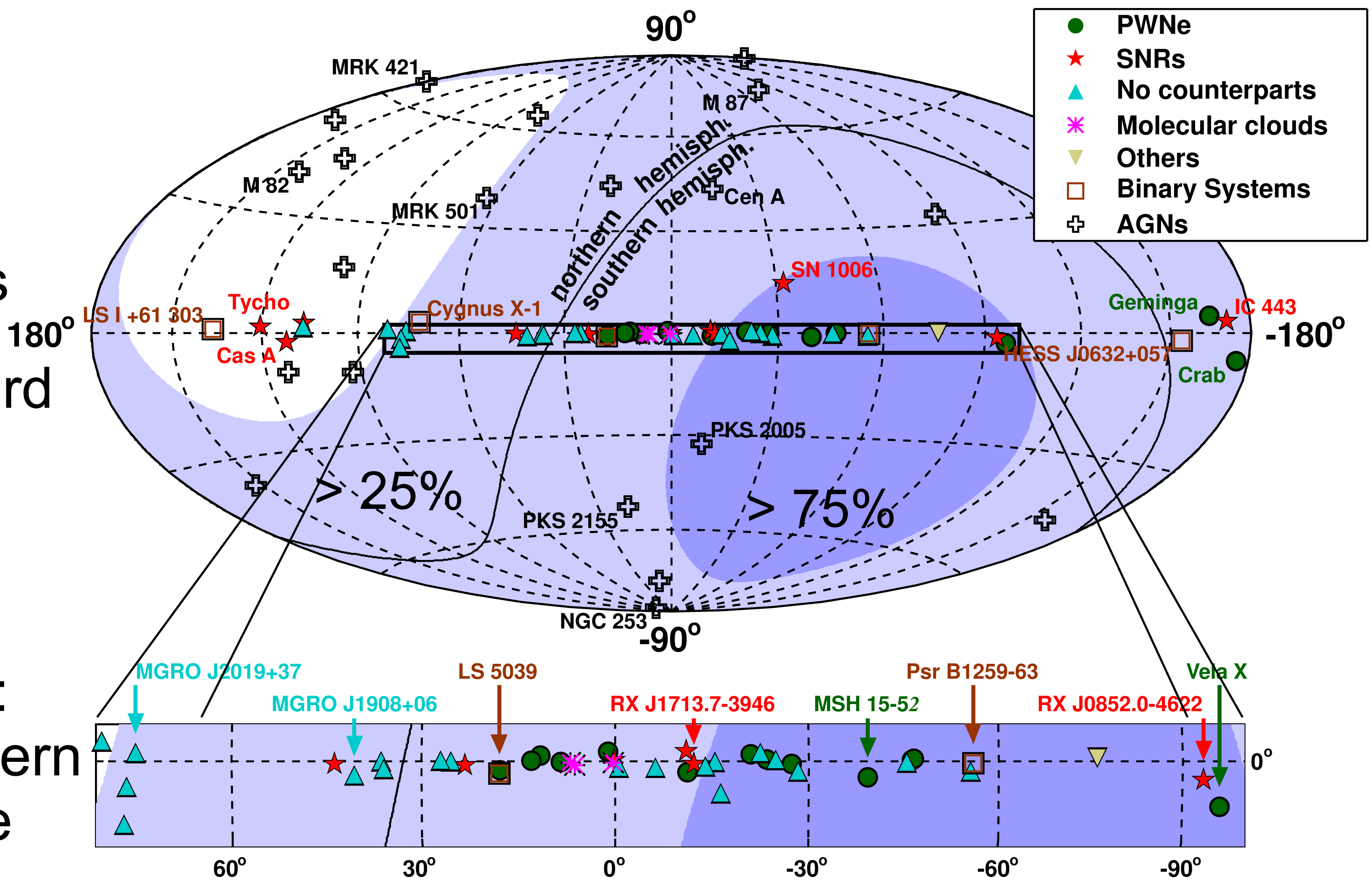
Isotropic high-energy neutrino flux
above atmospheric neutrino background
from unresolved astrophysical sources
or of cosmogenic origin (GZK)

South Pole and Mediterranean fields of view

Galactic coordinates

2π downward sensitivity assumed

IceCube @ South Pole: Sees Northern hemisphere



ANTARES, IceCube and (a restricted selection of) their recent results

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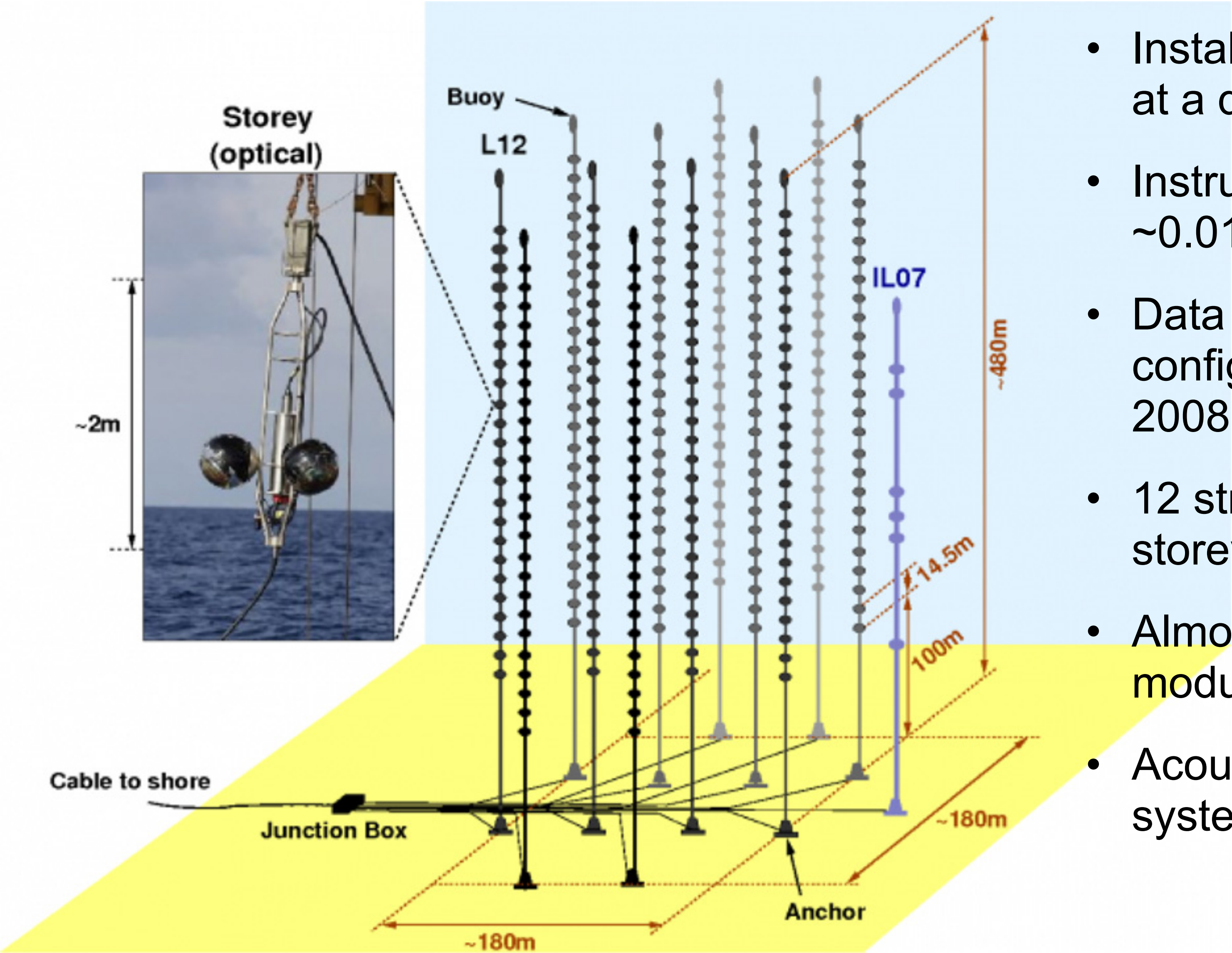
ANTARES: The first NT in the deep sea



- Installed near Toulon at a depth of 2475m
- Instrumented volume ~0.01km^3
- Data taking in full configuration since 2008
- 12 strings with 25 storeys each
- Almost 900 optical modules
- Acoustic sensor system

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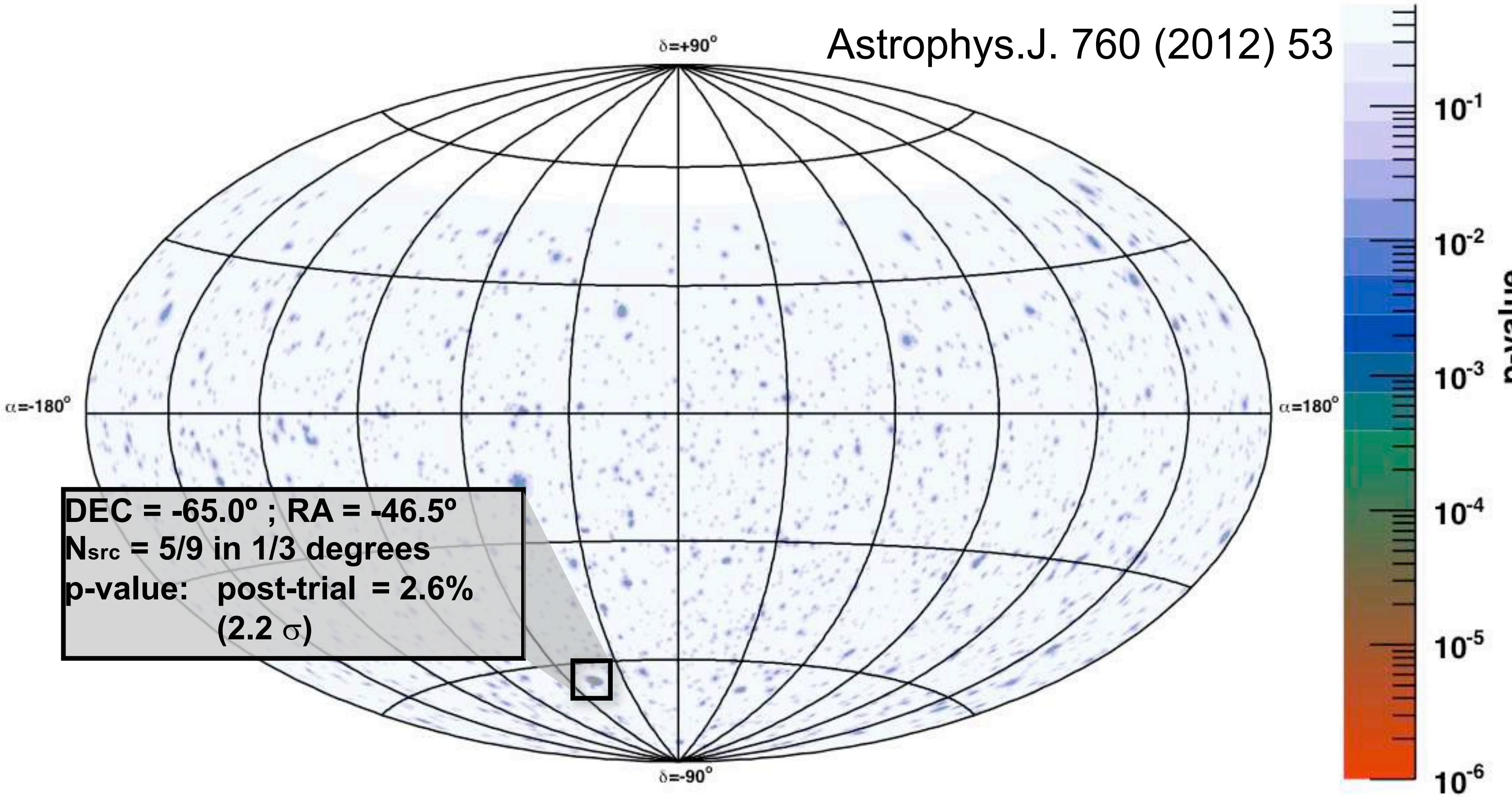
ANTARES: Point source search

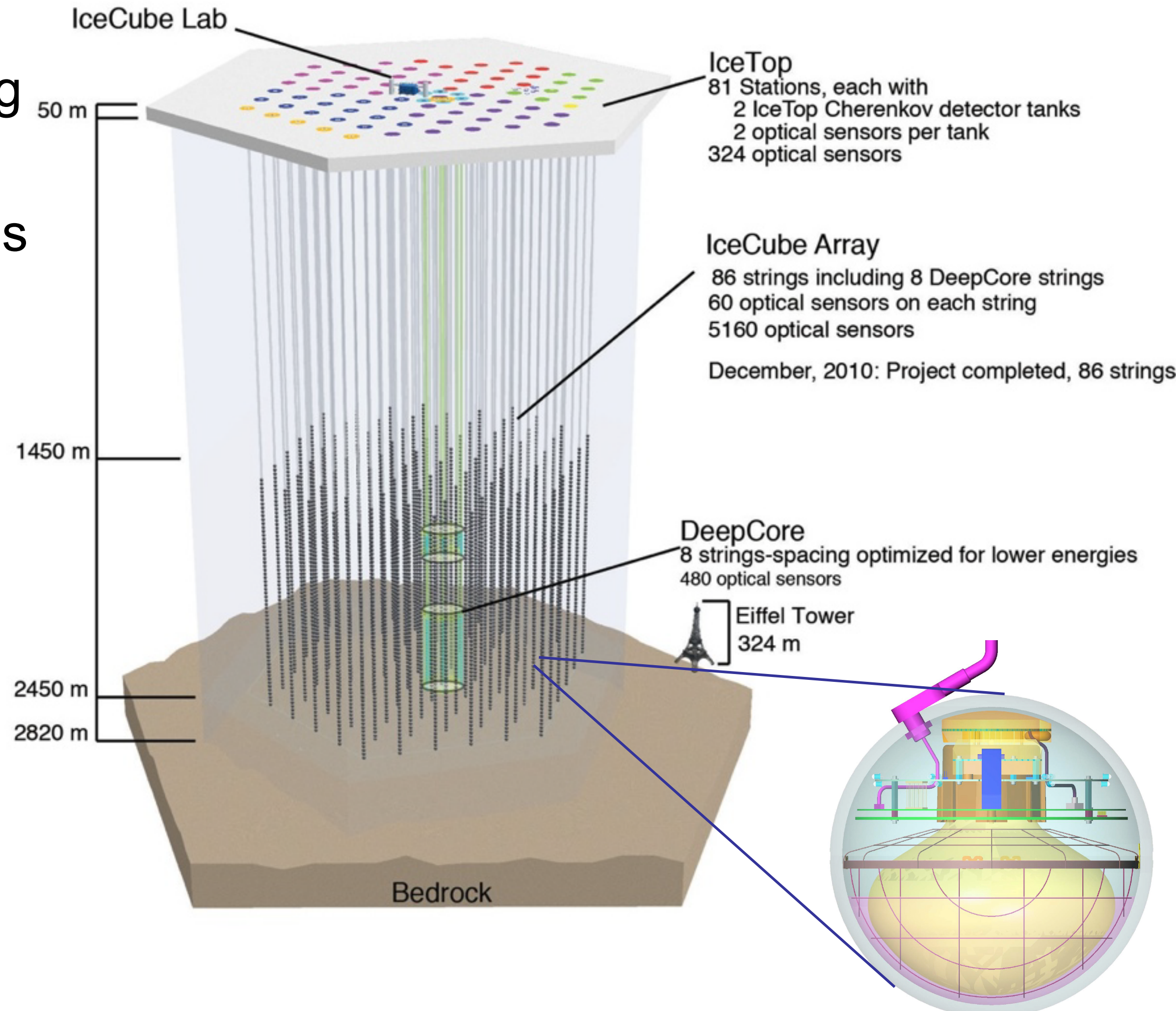


- 4 years of data, 3058 neutrino candidate events
- Search for neutrinos from selected source candidates (no significant signal)

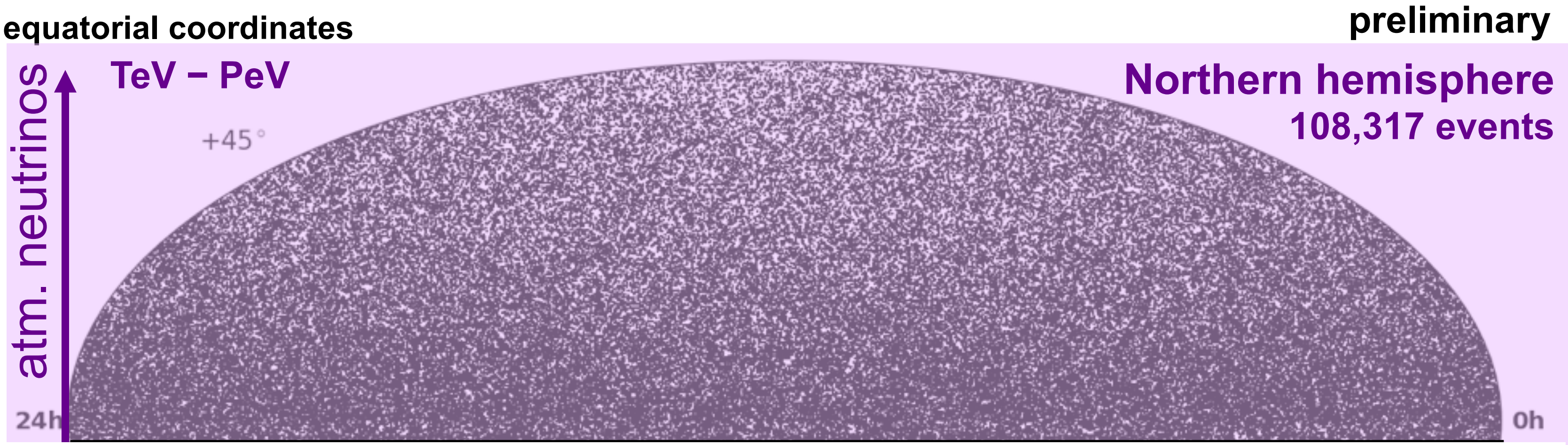
IceCube: A km^3 detector in the Antarctic ice

IceCube: Completed in December 2010

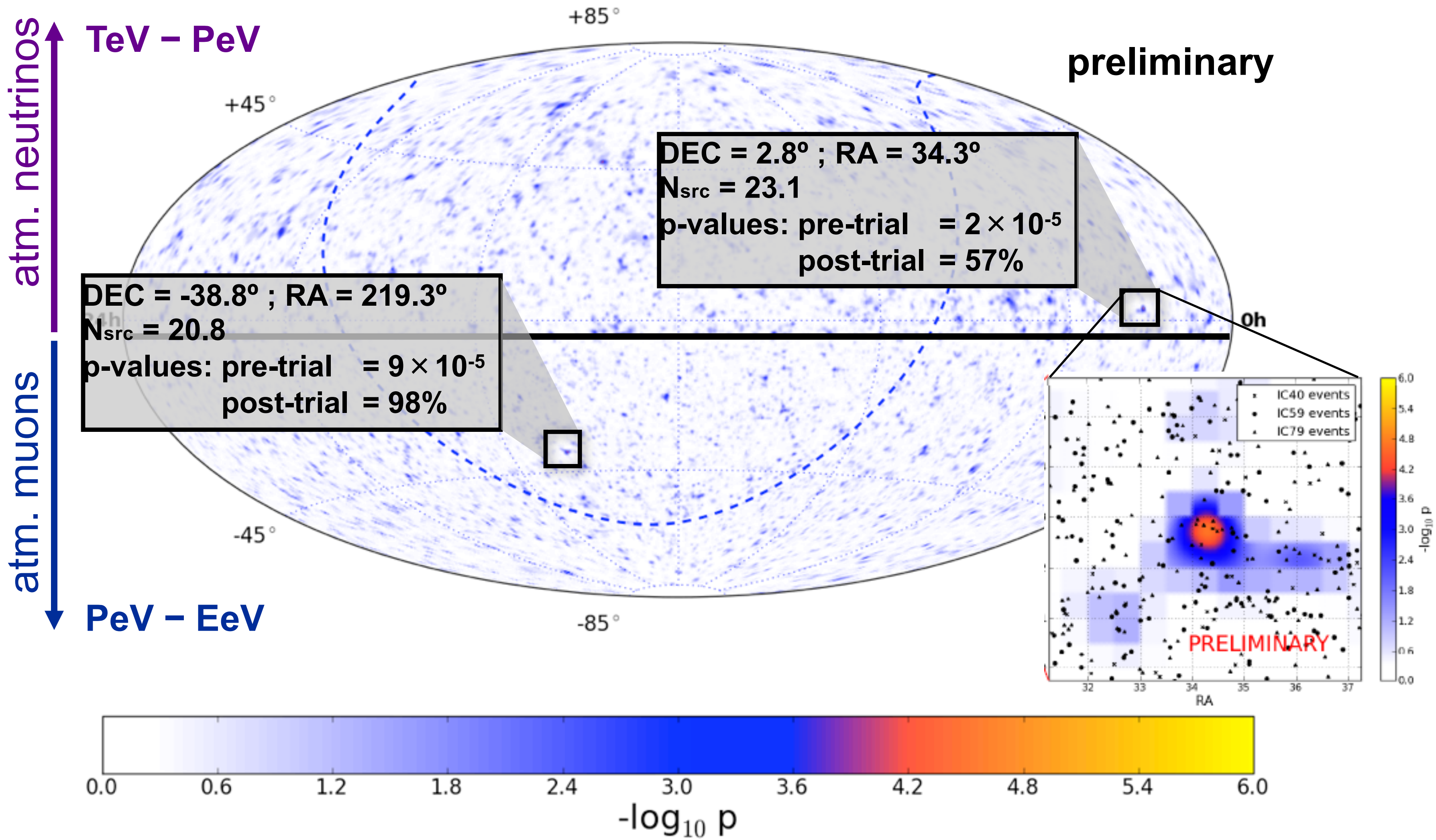
- 86 strings altogether
  - 125 m horizontal spacing
  - 17 m vertical distance between Optical Modules
  - 1 km^3 instrumented volume, depth 2450m
- Deep Core
  - densely instrumented region in clearest ice
  - atmospheric muon veto by IceCube
  - first Deep Core results
- Plan for future low-energy extension (PINGU)



IceCube: Event skymap (IC40+59+79)



IceCube: Significance map (IC40+59+79)



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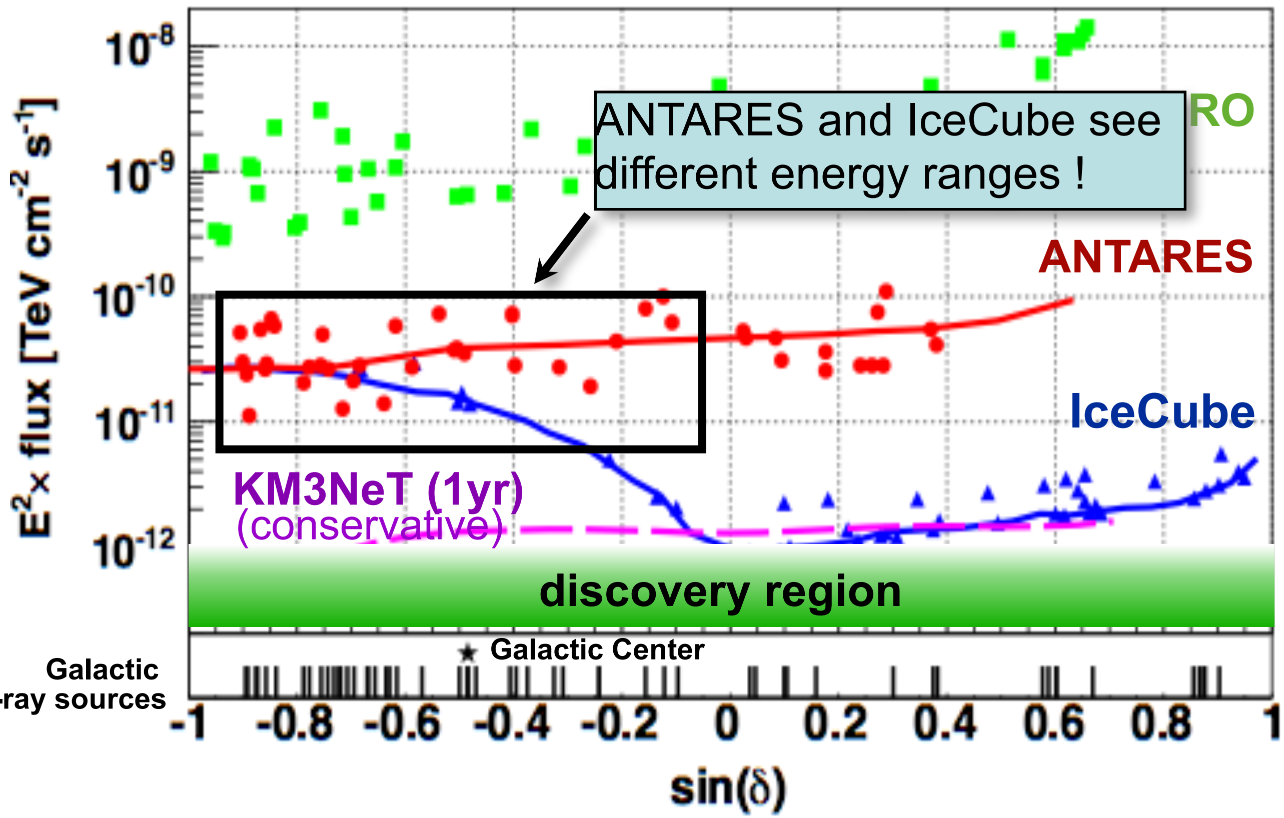
IceCube: Sensitivities & limits (IC40+59+79)

90% CL sensitivity / upper limits for E^{-2} spectrum



Predictions

Halzen, **Kappes**, O'Murchadha (2008)
Kappes, Hinton, Stegmann, Aharonian (2006)
Kistler, Beacom (2006)
. . .

- Expected improvements: Statistics, reconstruction quality
- Attention: IceCube for Southern hemisphere (sin(δ)<0) not sensitive to neutrino fluxes with cutoff at 10…100TeV (typical Galactic sources)
- Full access to Galactic sources only from Northern detector

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IceCube: Neutrinos from GRBs (IC40+59)

- Search for neutrinos from observed GRBs
- Increased sensitivity due to reduced time window
- 117+98 GRBs in Northern sky for IC40 and IC59 (plus 85 Southern GRBs)
- 0 neutrinos observed
- Severely constrains models

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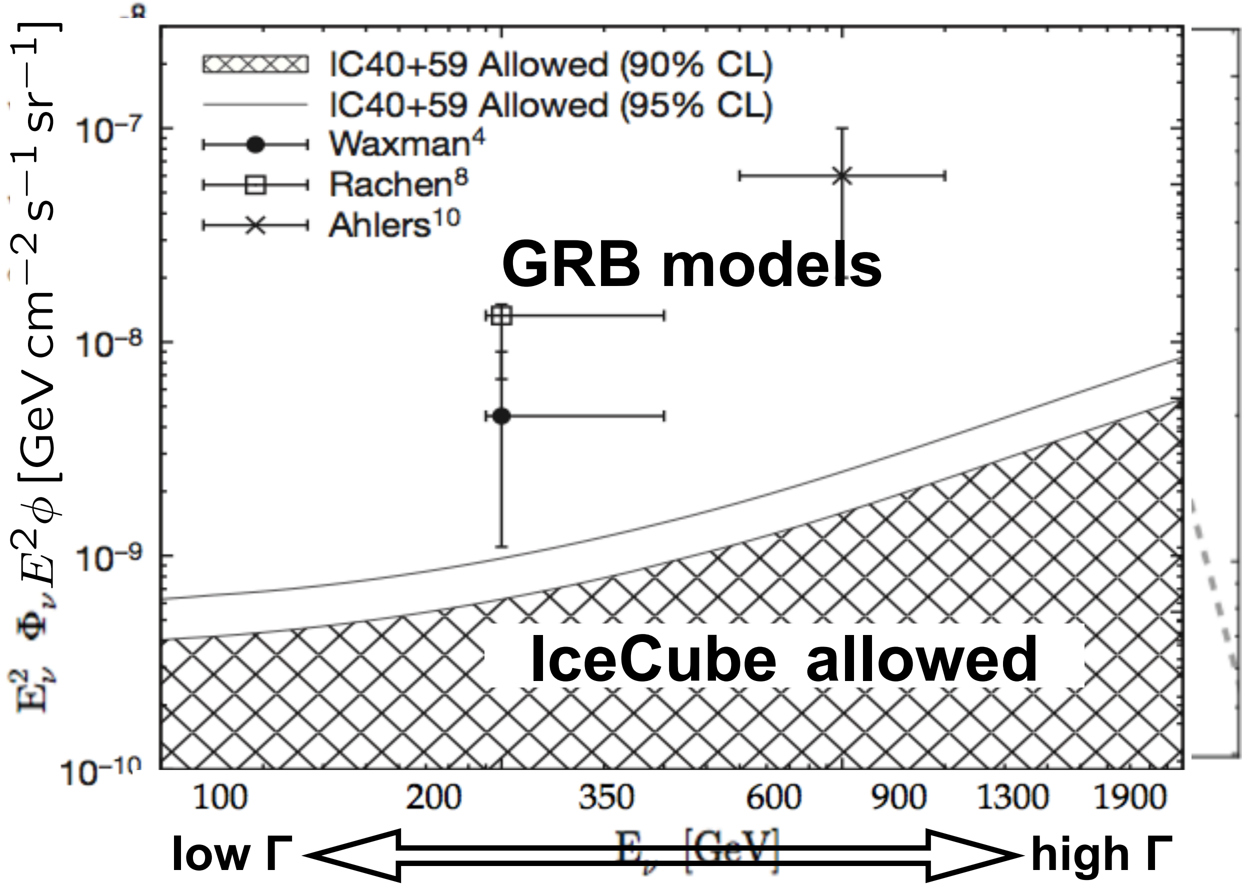

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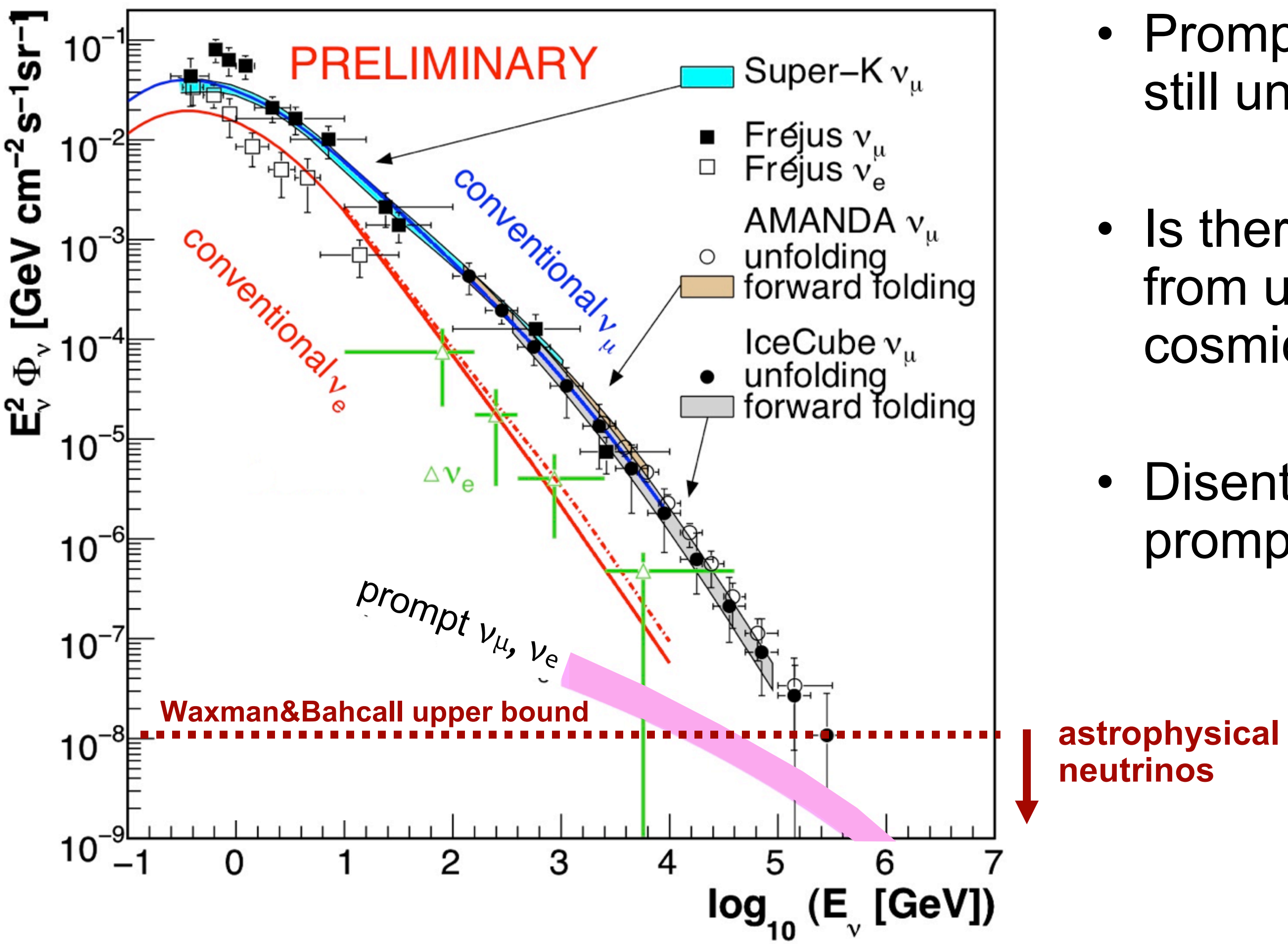
IceCube: Diffuse neutrino flux



- Prompt component still unmeasured
- Is there a diffuse flux from unresolved cosmic sources?
- Disentangling cosmic and prompt fluxes challenging

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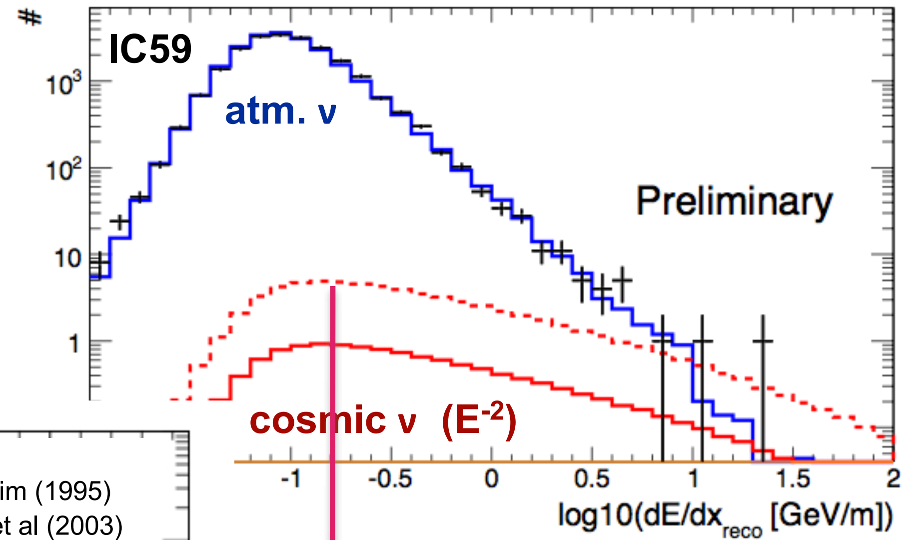
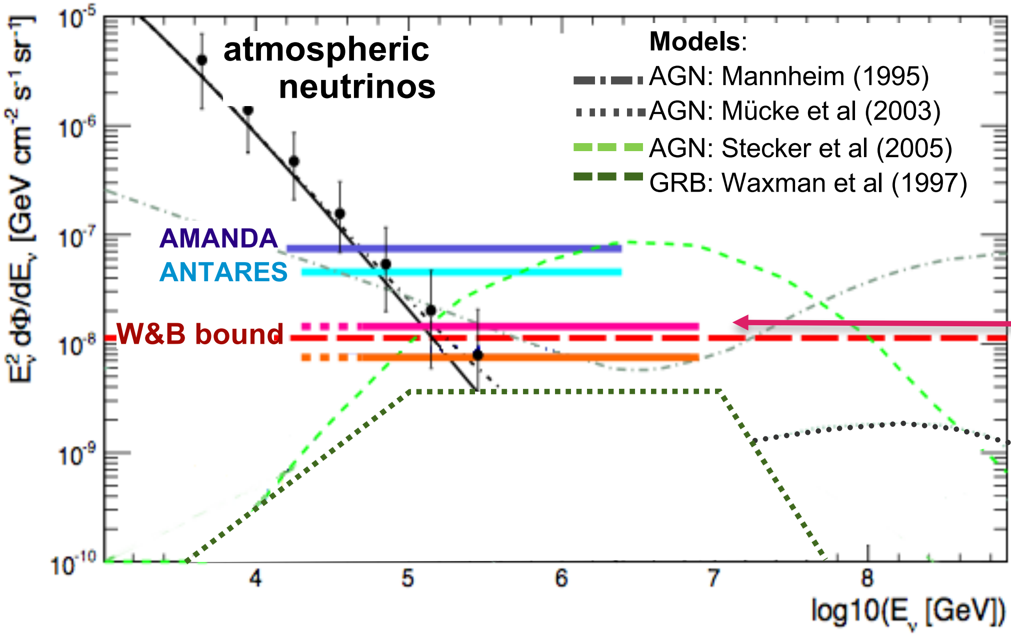
Atmospheric muon neutrinos (IC59)

- Search for excess in high-energy tail
- Observed spectrum slightly harder than predicted
  → Limit > sensitivity





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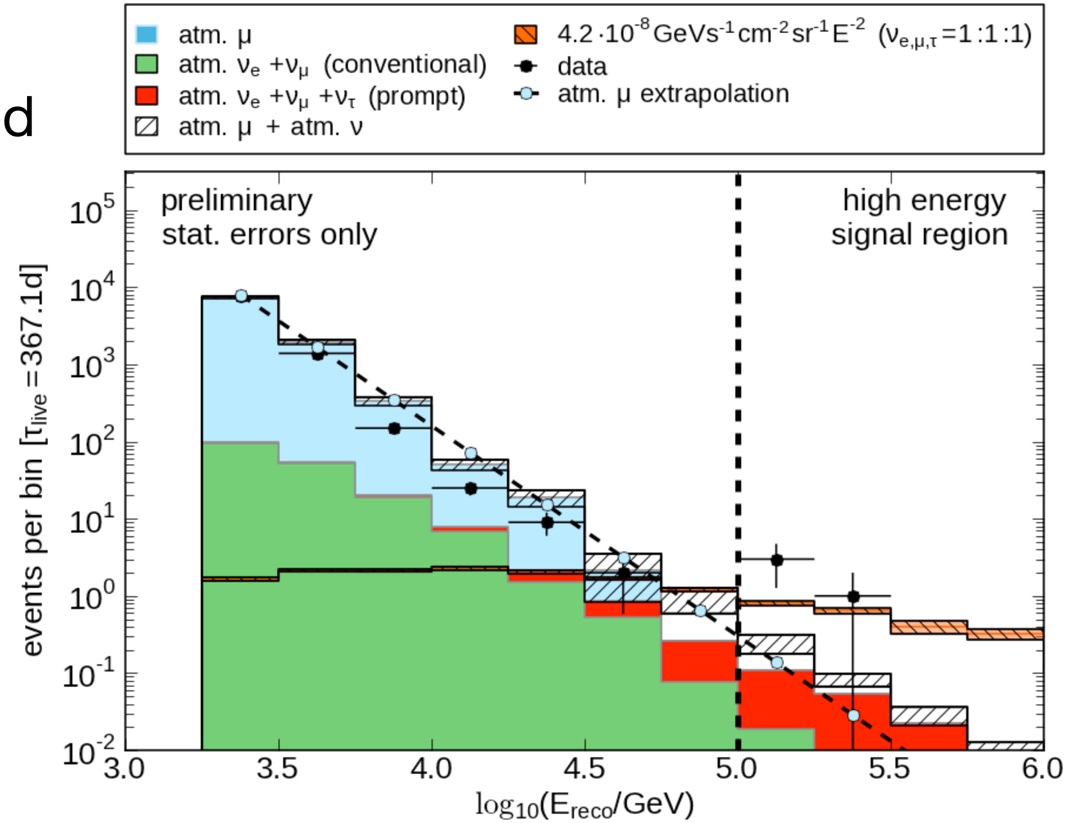
Searching for a high-energy ν_e excess

$\nu_e N \to eX$:

- all energy inside detector
- low atmospheric background
- cascade channel good for excess search



IC40 cascade analysis:

- 3 events found >100 TeV
- Estimated background: (0.4+prompt) events
- Significance 2.4σ

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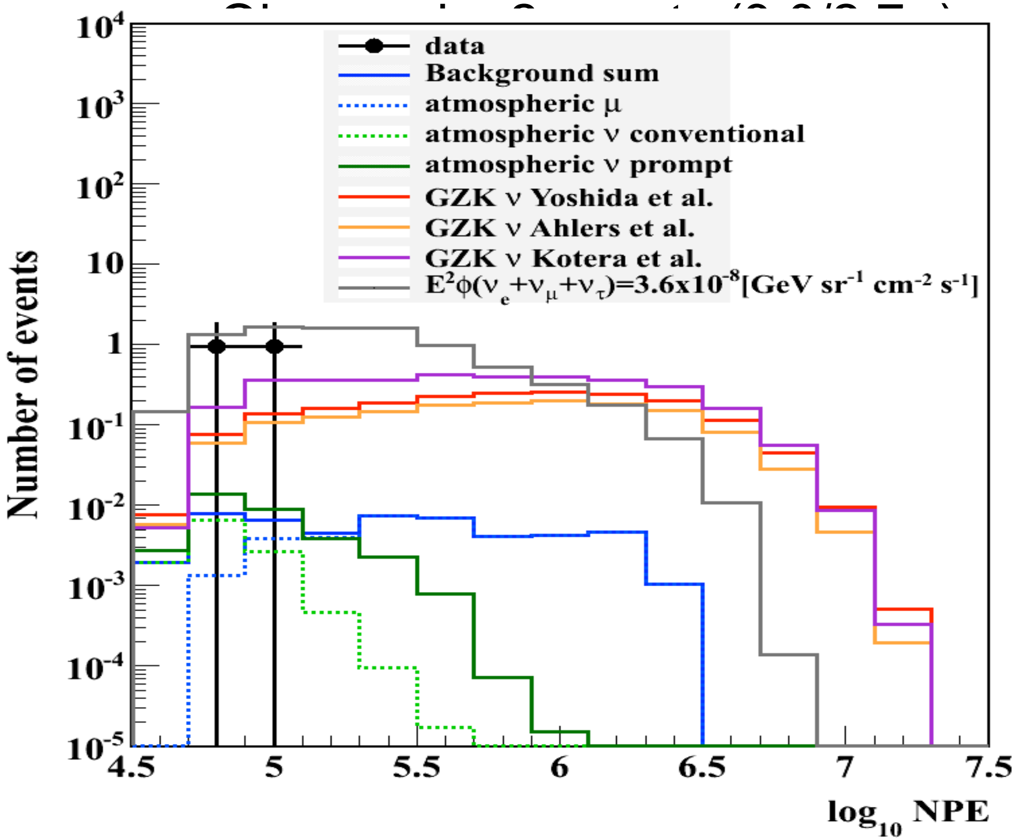
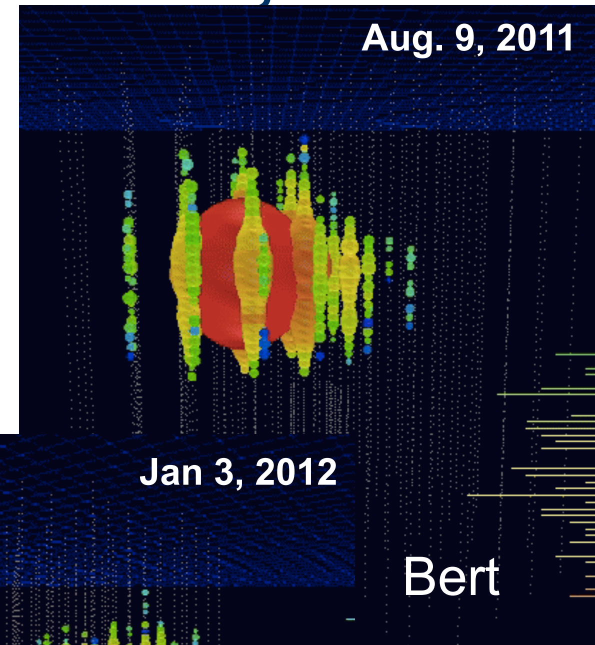
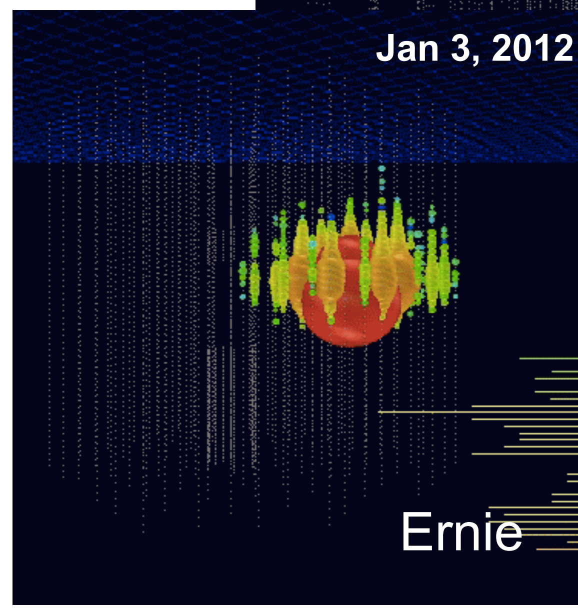
Cosmogenic neutrinos (IC79+86-I, 670 days)

- Optimized cuts for UHE neutrinos:
  - Expected background = 0.05/0.08 (without/with prompt)







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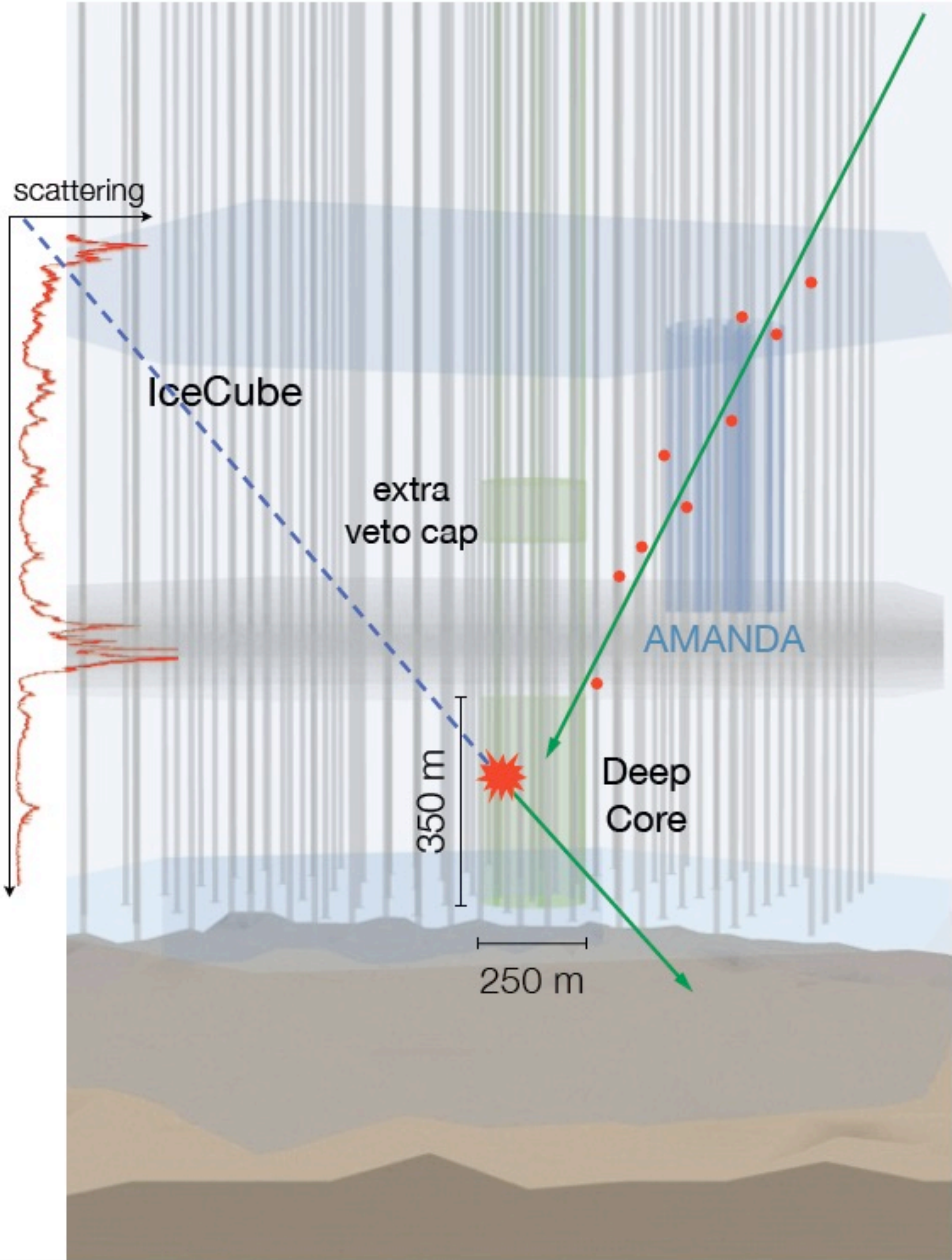
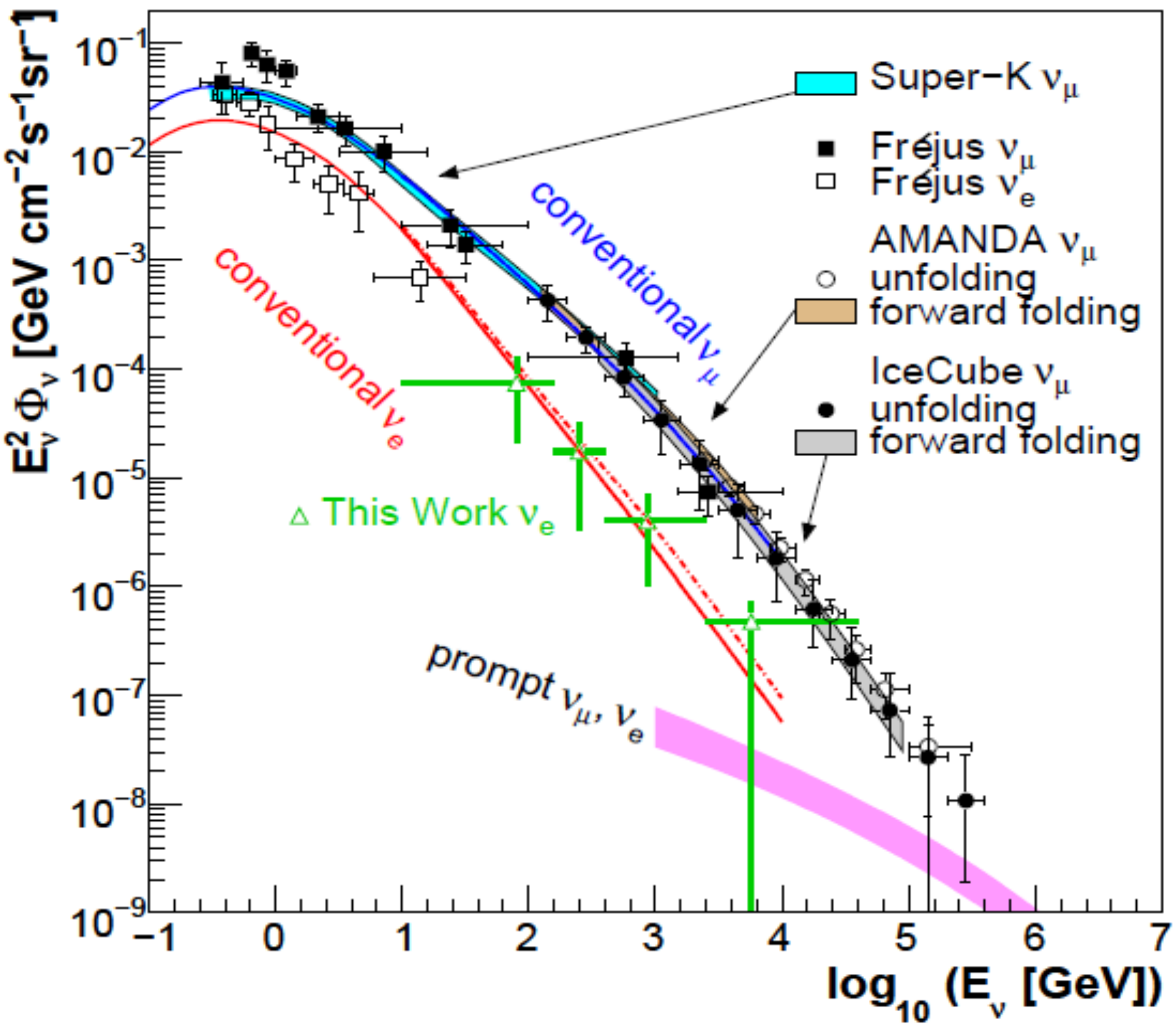
Deep Core

- 8 extra strings + 12 standard strings in clearest ice (~5 times higher photocathode density)
- Photomultipliers with high quantum efficiency
- Rest of IceCube provides active veto against penetrating muons
- Extends accessible energy range down to 10 GeV



IceCube: A first Deep Core result …

- Identification of cascades, mainly from
  $\nu_e + N \rightarrow e + X$
  $\nu_x + N \rightarrow \nu_x + X$
- Main background:
  $\nu_\mu + N \rightarrow \mu + X$
  with short μ track
- Very difficult in IceCube
- Success in Deep Core! (see arXiv:1201.0801)



KM3NeT

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Flashback March 2007, CTA meeting, Paris:

- Which architecture to use?
  (strings vs. towers vs. new design)
- How to get the data to shore?
  (optical vs. electric, electroni shore or on-shore)
- How to calibrate the detec
  (separate calibration an ction units?)
- Design of photo-dete units?
  (large vs. several s Ms, directionality, ...)
- Deployment techn gy?
  (dry vs. wet by ROV/AUV vs. wet from surface)
- And finally: path to site decision.

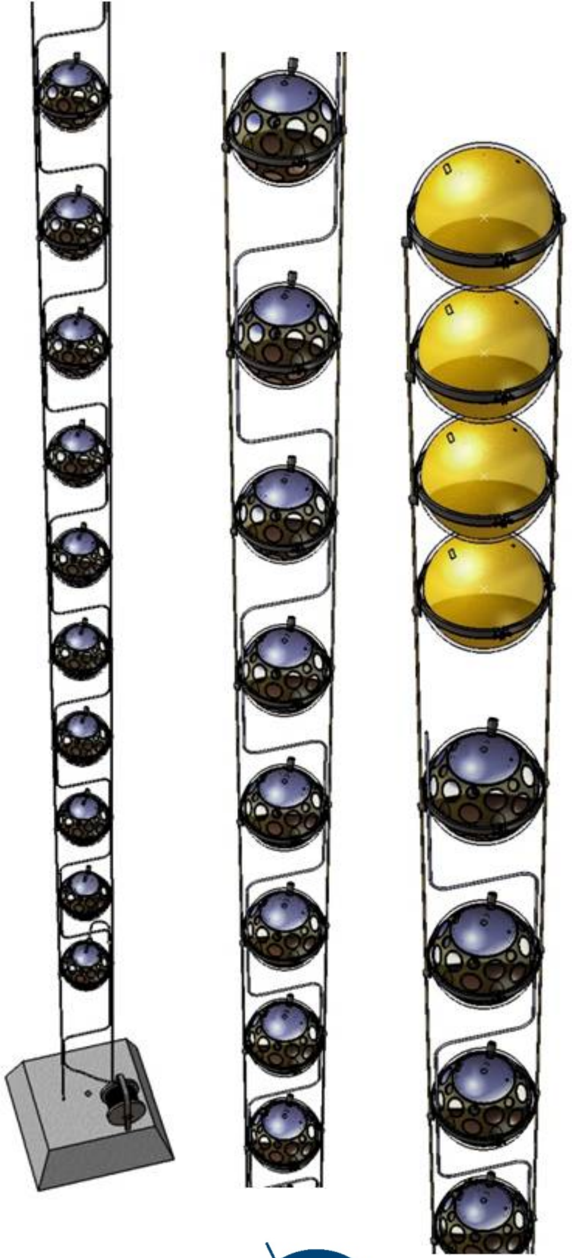
2013: All solved!

The KM3NeT project

- Multi-km^3 NT in Mediterranean Sea,
  exceeding IceCube substantially in sensitivity
- Nodes for earth/sea science instrumentation
- Central physics goals (by priority):
  - Galactic neutrino “point” sources (energy 1-100 TeV)
  - Extragalactic sources
  - High-energy diffuse neutrino flux
- Decisions taken:
  - Technology: Strings with multi-PMT optical modules
  - Multi-site installation (France, Greece, Italy)
  - 6 building blocks of ~115 strings each
- Collaboration established
- Next steps until 2015
  - prototyping and construction (~40 M€ available for first phase)

Detection units: Strings

- Mooring line:
  - Buoy (empty glass spheres,
    net buoyancy 2250N)
  - 2 Dyneema ropes (4 mm diameter)
  - 18 storeys (one OM each),
    30-36m distance, 100m anchor-first storey
- Electro-optical backbone:
  - Flexible hose ~ 6mm diameter
  - Oil-filled
  - fibres and copper wires
  - At each storey: 1 fibre+2 wires
  - Break out box with fuses at each storey:
    One single pressure transition



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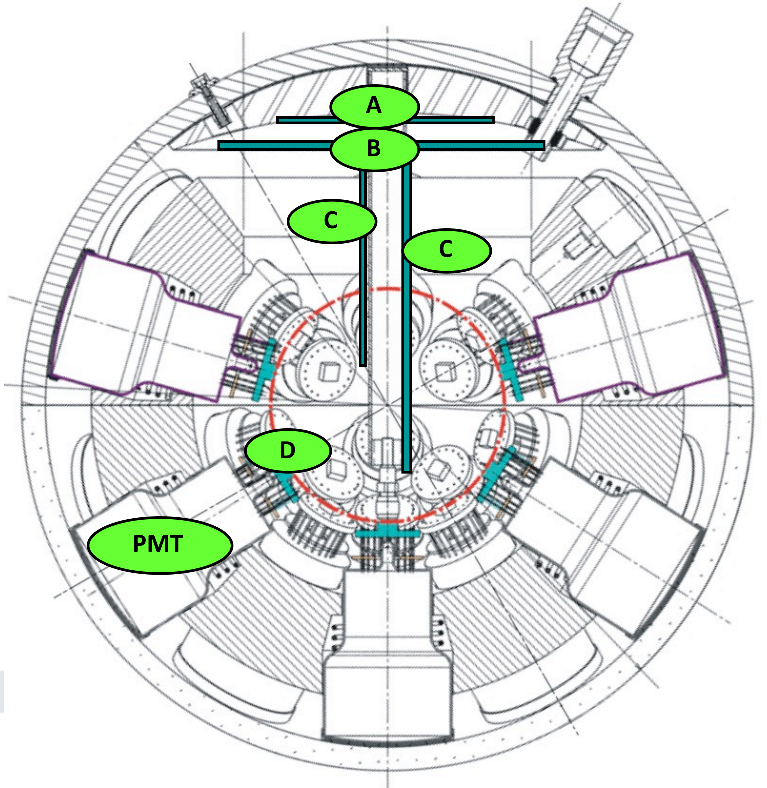
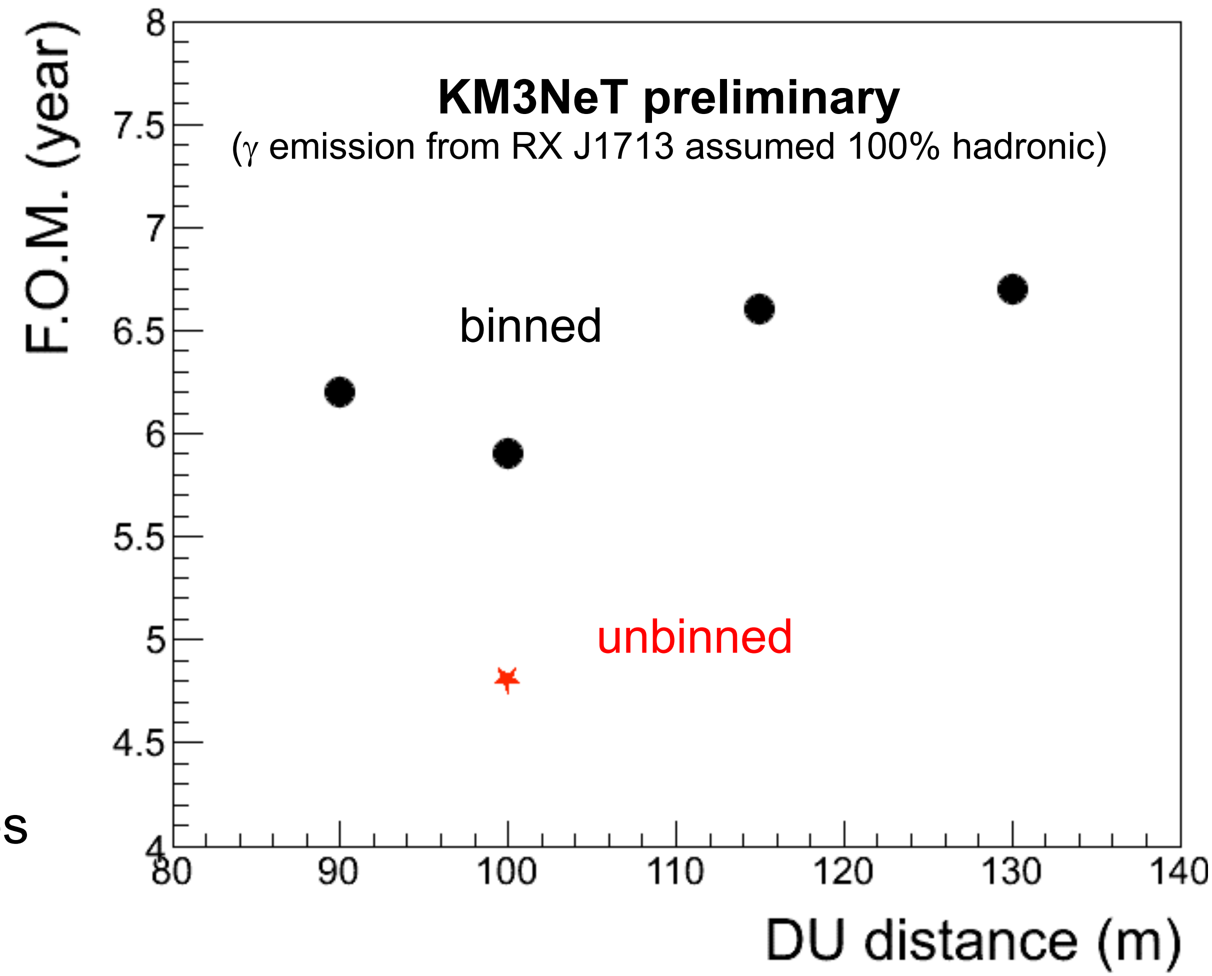
OM with many small PMTs

- 31 3-inch PMTs in 17-inch glass sphere (cathode area~ 3x10” PMTs)
  - 19 in lower, 12 in upper hemisphere
  - Suspended by compressible foam core
- 31 PMT bases (total ~140 mW) (D)
- Front-end electronics (B,C)
- Al cooling shield and stem (A)
- Single penetrator
- 2mm optical gel
- Advantages:
  - increased photocathode area
  - 1-vs-2 photo-electron separation
    → better sensitivity to coincidences
  - directionality



RX J1713: A prime candidate source

- Figure of merit (F.o.M.): time to make an observation at 5σ with 50% probability
- KM3NeT analysis very conservative; ~20% improvement by unbinned analysis
- Clear (but flat) optimum in horizontal distance between DUs
- Further candidate sources with similar or better discovery chances



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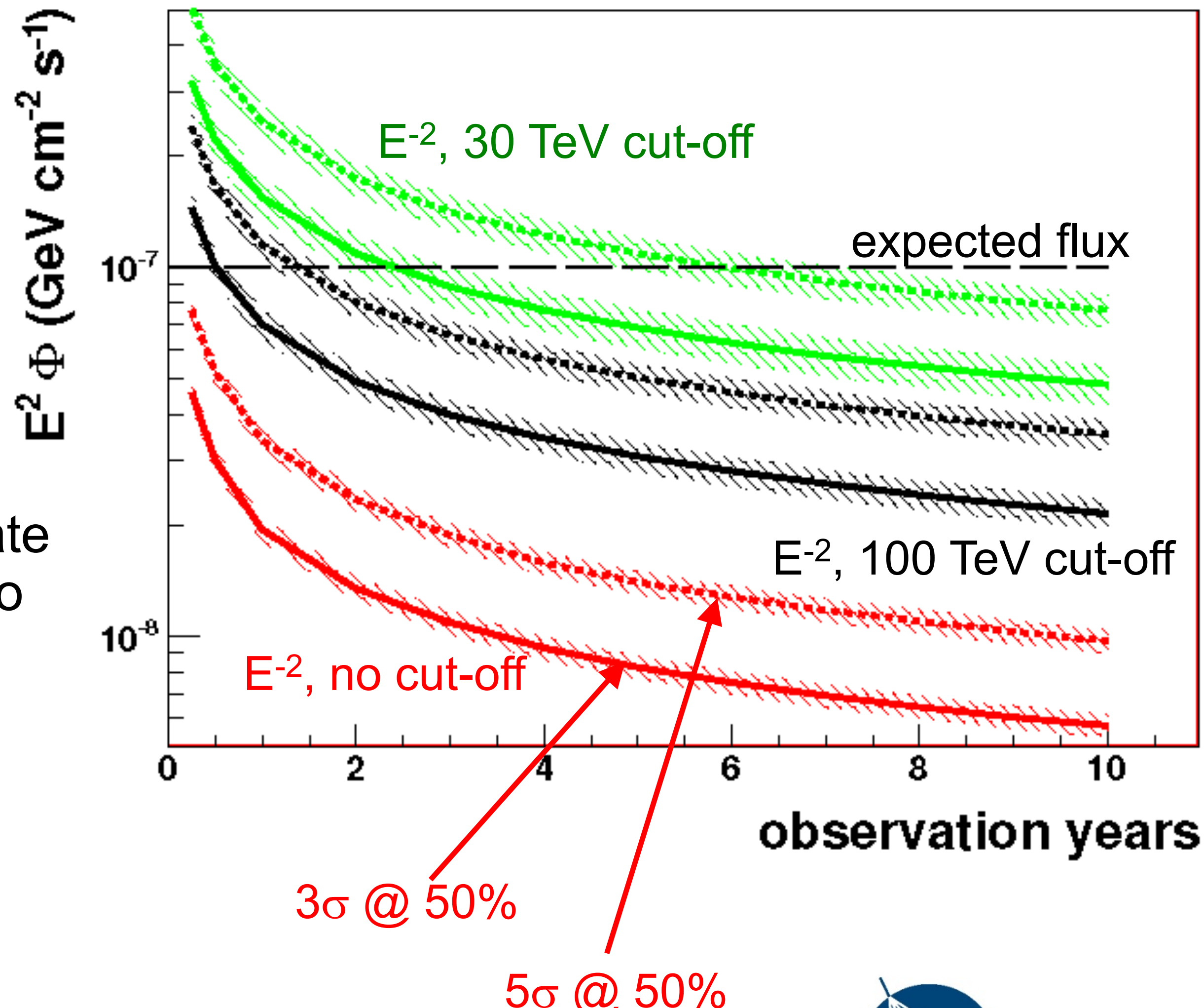
The Fermi bubbles

- Two extended regions above/below centre of Galactic plane
- Fermi detected hard γ emission (E^{-2}) up to 100 GeV
- Origin and acceleration mechanisms under debate – if hadronic, hot neutrino source candidate
- Could be first source detected by KM3NeT

Astropart.Phys.42(2013)7



Summary and Outlook

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- Neutrino telescopes in deep ice and water provide increasing sensitivity to cosmic neutrinos (>1TeV).
- Their results are significant and intriguing.
- The construction of the KM3NeT neutrino telescope in the Mediterranean Sea will start 2013/14.
- ANTERES and IceCube have demonstrated that studying neutrinos with energies down to 10 GeV is possible.
- Even lower energies can be studied with densely instrumented configurations, which may allow for a determination of the neutrino mass hierarchy with atmospheric neutrinos.
- These are exciting times for neutrino astronomers – stay tuned!

Happy Birthday, dear Werner!