Vulcano Workshop 2012
Frontier Objects in Astrophysics and Particle Physics
28 May – 2 June 2012

Neutrinos as Cosmic Messengers in the Era of IceCube, ANTARES and KM3NeT

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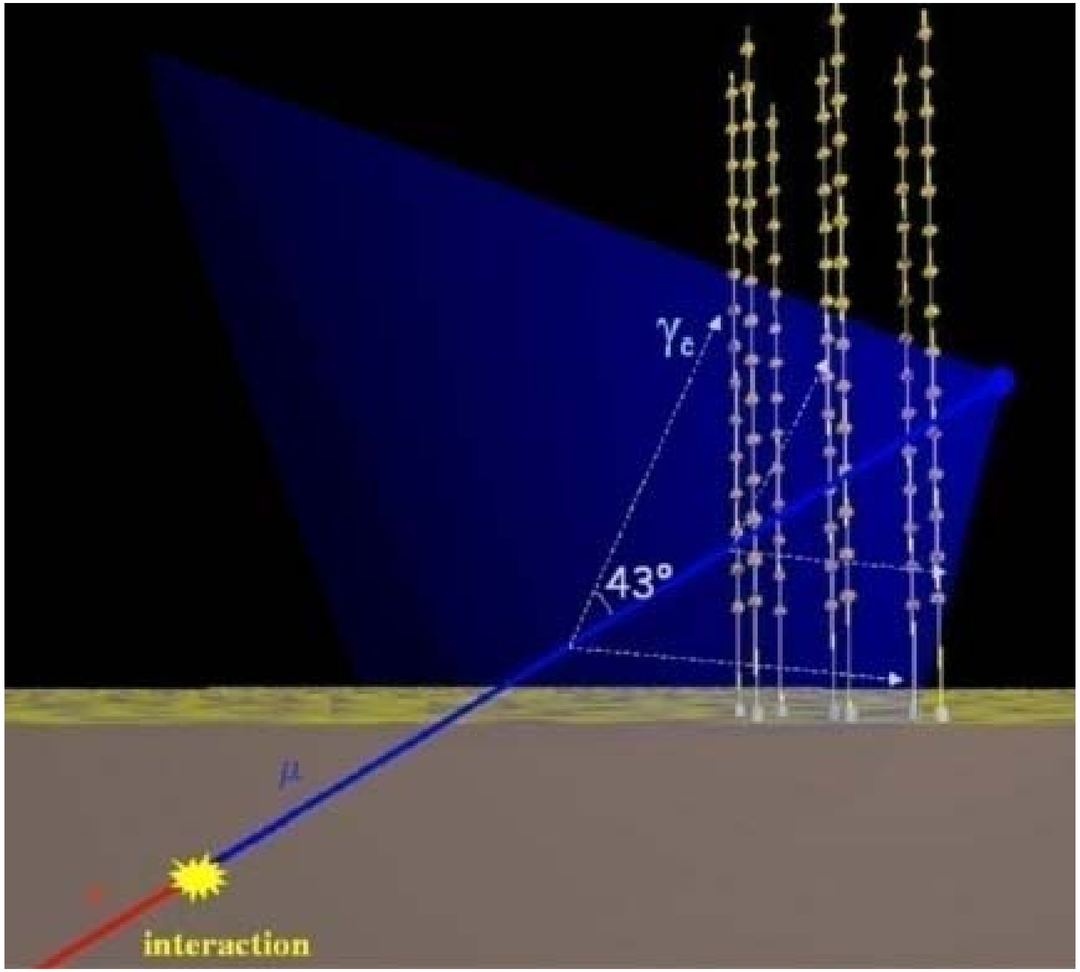
The plan for the next 20 minutes:

- Introduction
- Current neutrino telescopes:
  ANTARES and IceCube
- Results so far
- The future of neutrino astronomy: KM3NeT
- Summary

Introduction

How does a neutrino telescope work?

- Neutrino interacts in the (vicinity of) the telescope
- Charged secondaries cross the detector volume (water or ice) and radiate Cherenkov 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°(0.3°) for E>1(10) TeV
- Δ[log(E)] ~ 0.3



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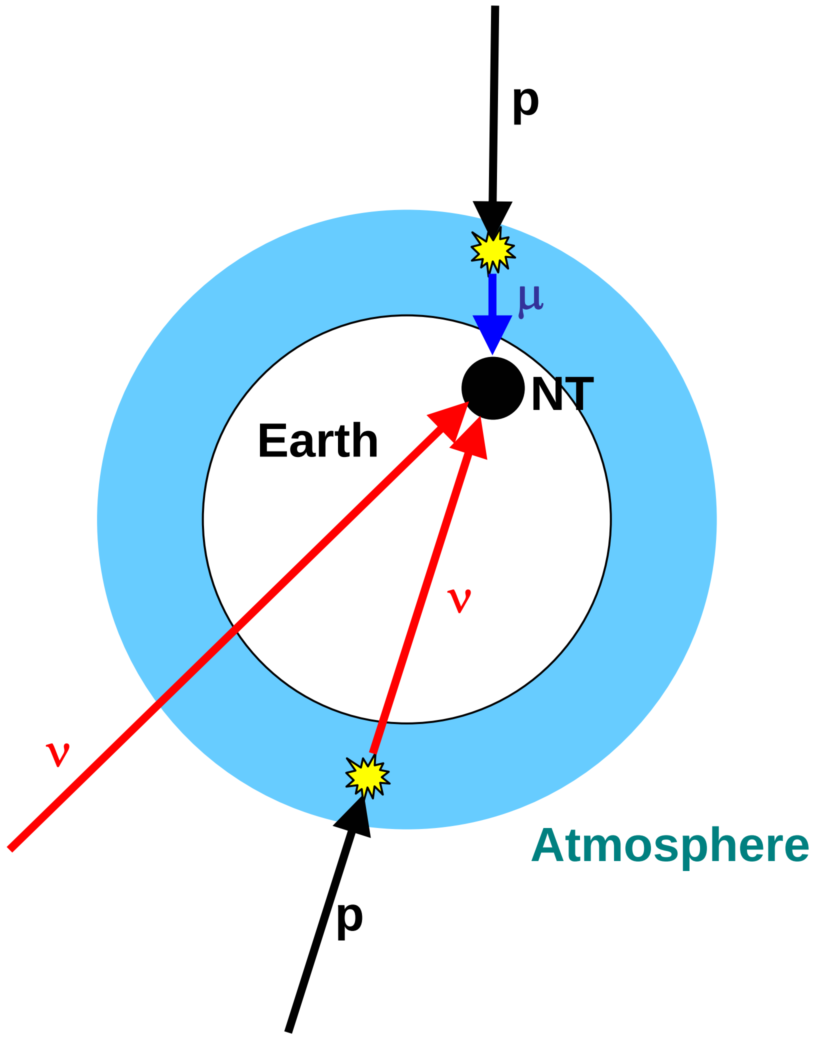
Backgrounds

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



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The neutrino telescope world map

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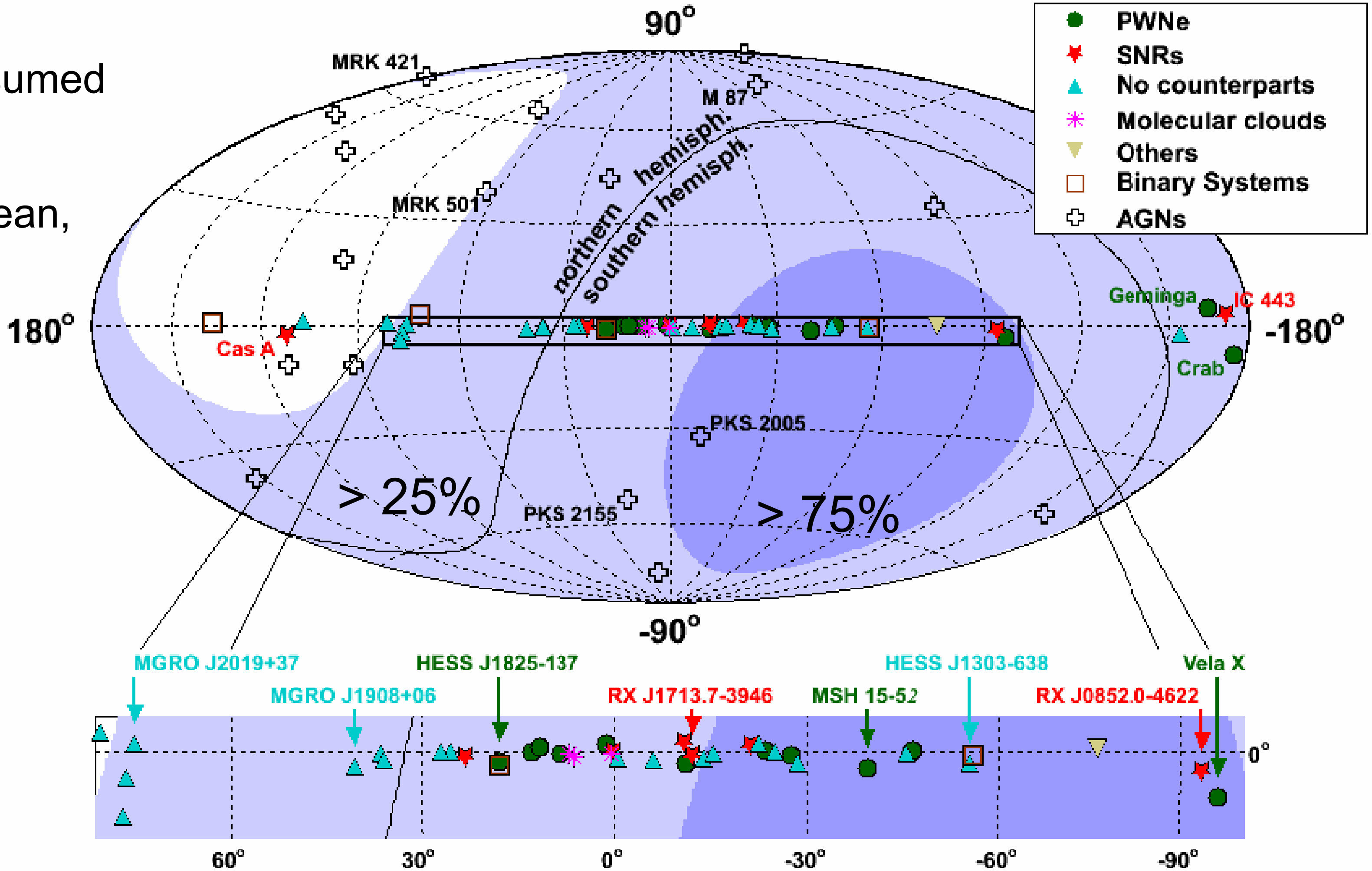
South Pole and Mediterranean fields of view

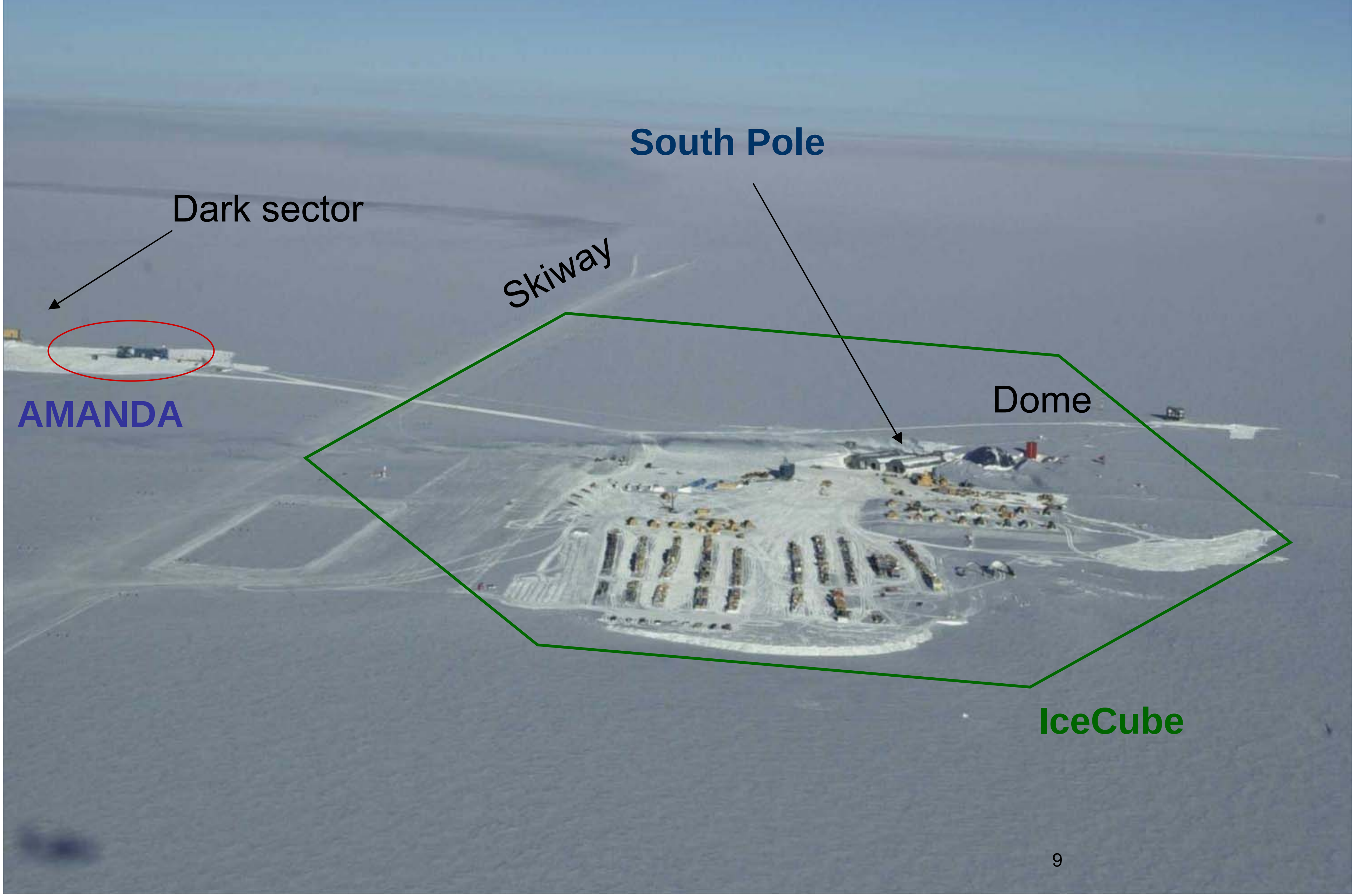
2π downward sensitivity assumed

In Mediterranean, visibility of given source can be limited to less than 24h per day



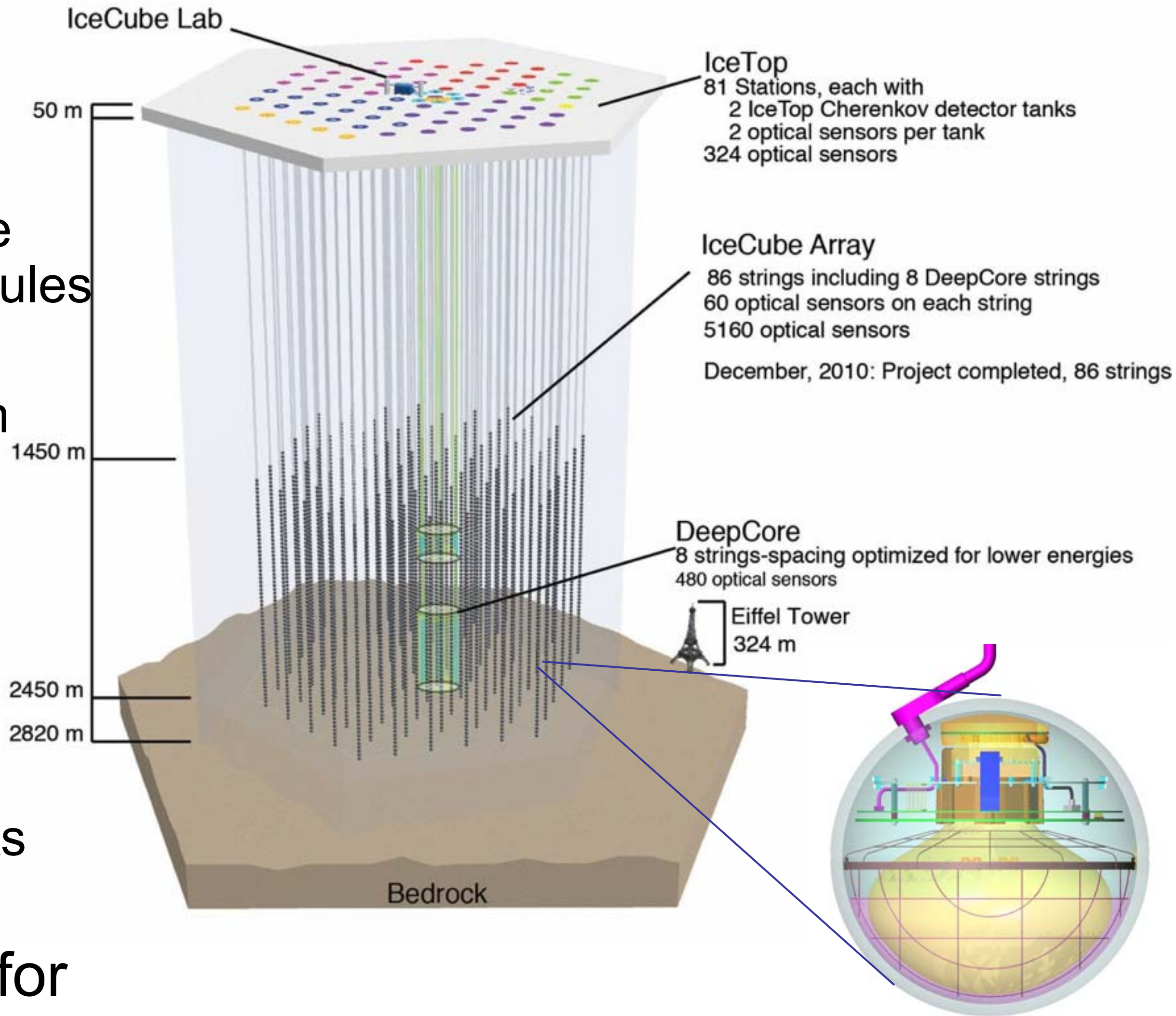
Current Neutrino Telescopes: IceCube and ANTARES

IceCube: a km^3 detector in the Antarctic ice



IceCube as of June 2012

- 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 emerging
- PINGU/MICA: Plans for future low-energy extensions



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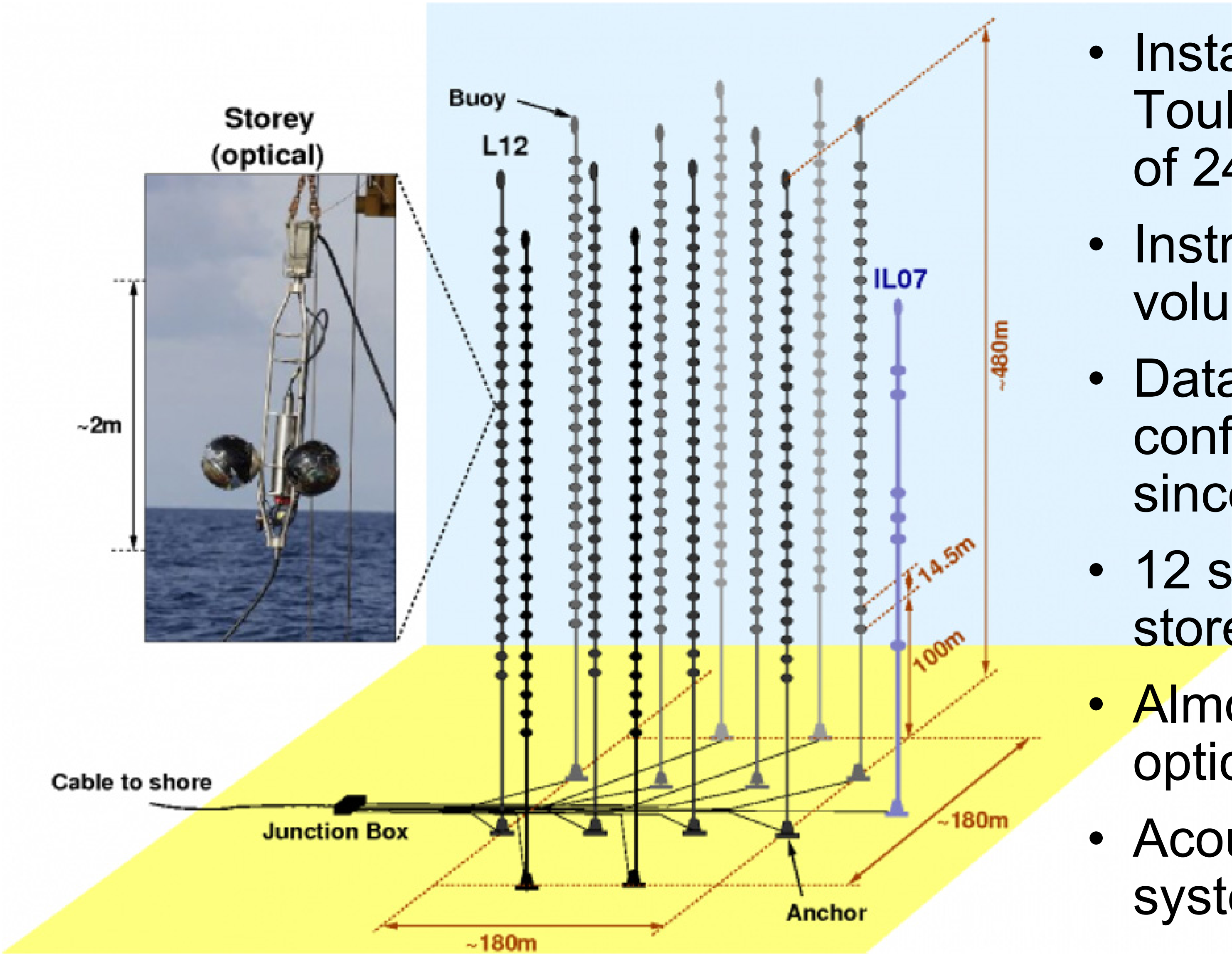
ANTARES: The first NT in the deep sea



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

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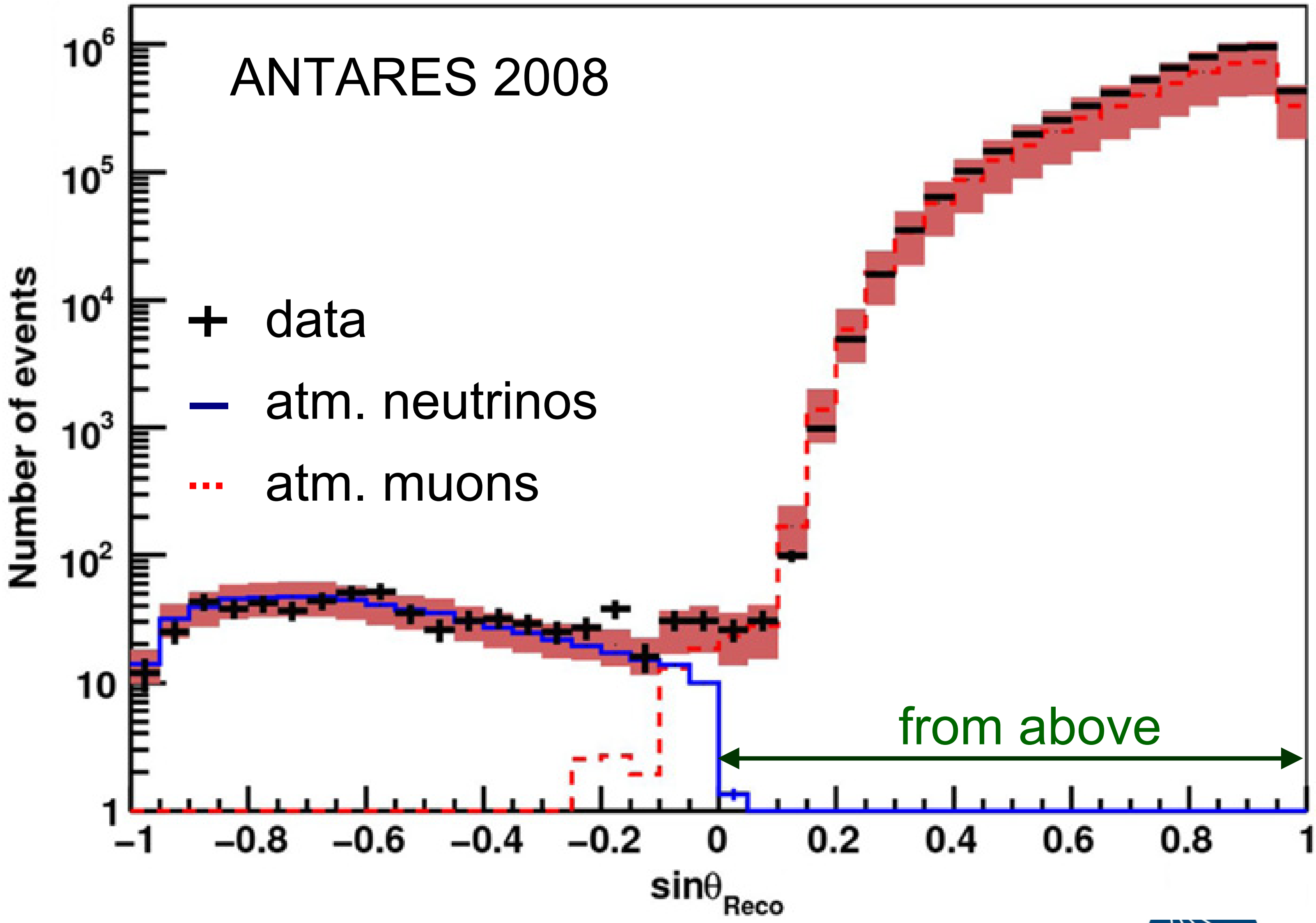
ANTARES achievements

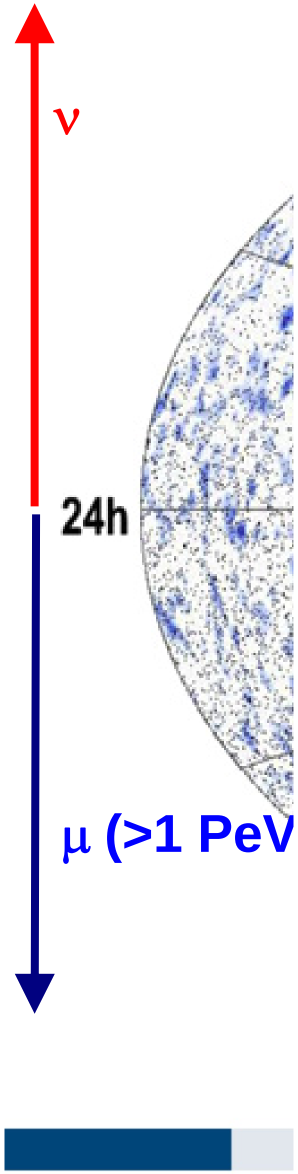
- Proof of feasibility and long-term operation of a deep-sea neutrino telescope
- Position and orientation calibration of optical modules with required accuracy
  - acoustic positioning by triangulation
  - compasses and tilt-meters
- Time synchronisation at nanosecond level
- Use of optical technologies for readout
- All data to shore: Every PMT hit above threshold (typically 0.3 pe) is digitised and transmitted to shore
- Trigger/filter logic by computer farm on-shore

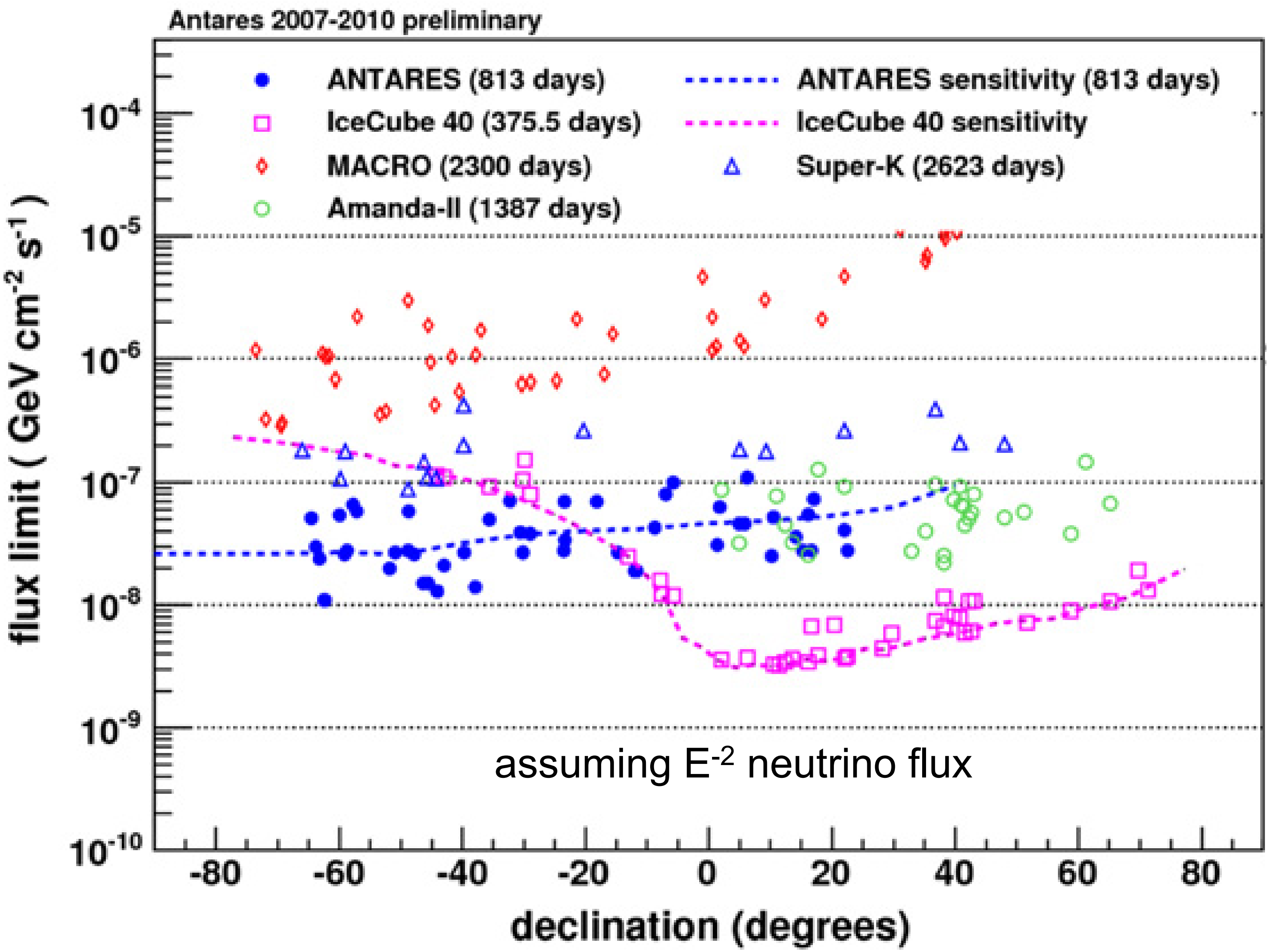
IceCube and ANTARES Results

Understanding detector and signals



Search for steady point sources

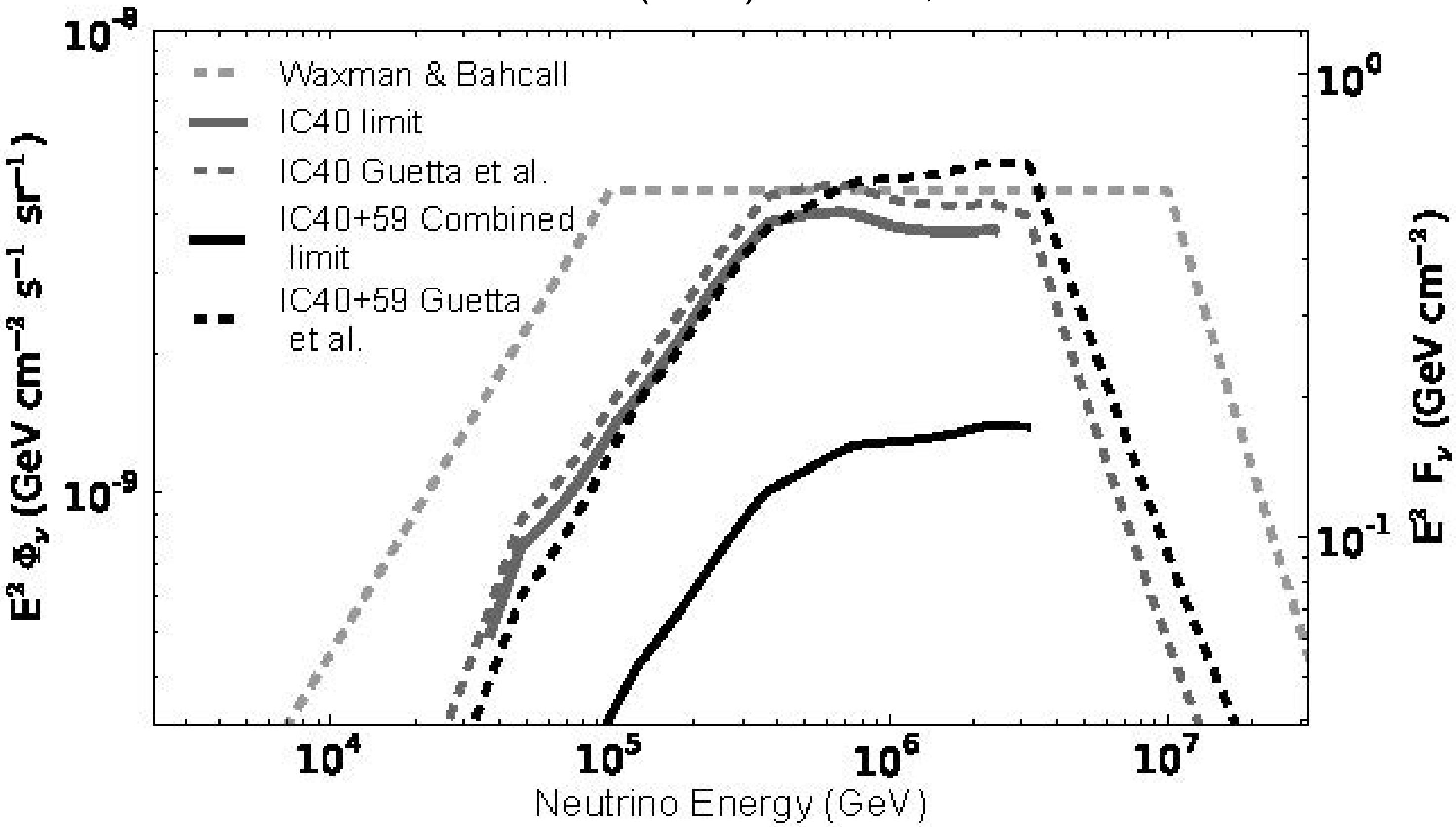




Transient point sources: GRBs

- New: IceCube analysis (40+59 strings)
- Result about factor 3 below model expectation
- Start to seriously cut into parameter space
- Beware: large model uncertainties (see Hümmer et al., arXiv:1112.1076)

Nature 484 (2012) 351-353; arXiv:1204.4219



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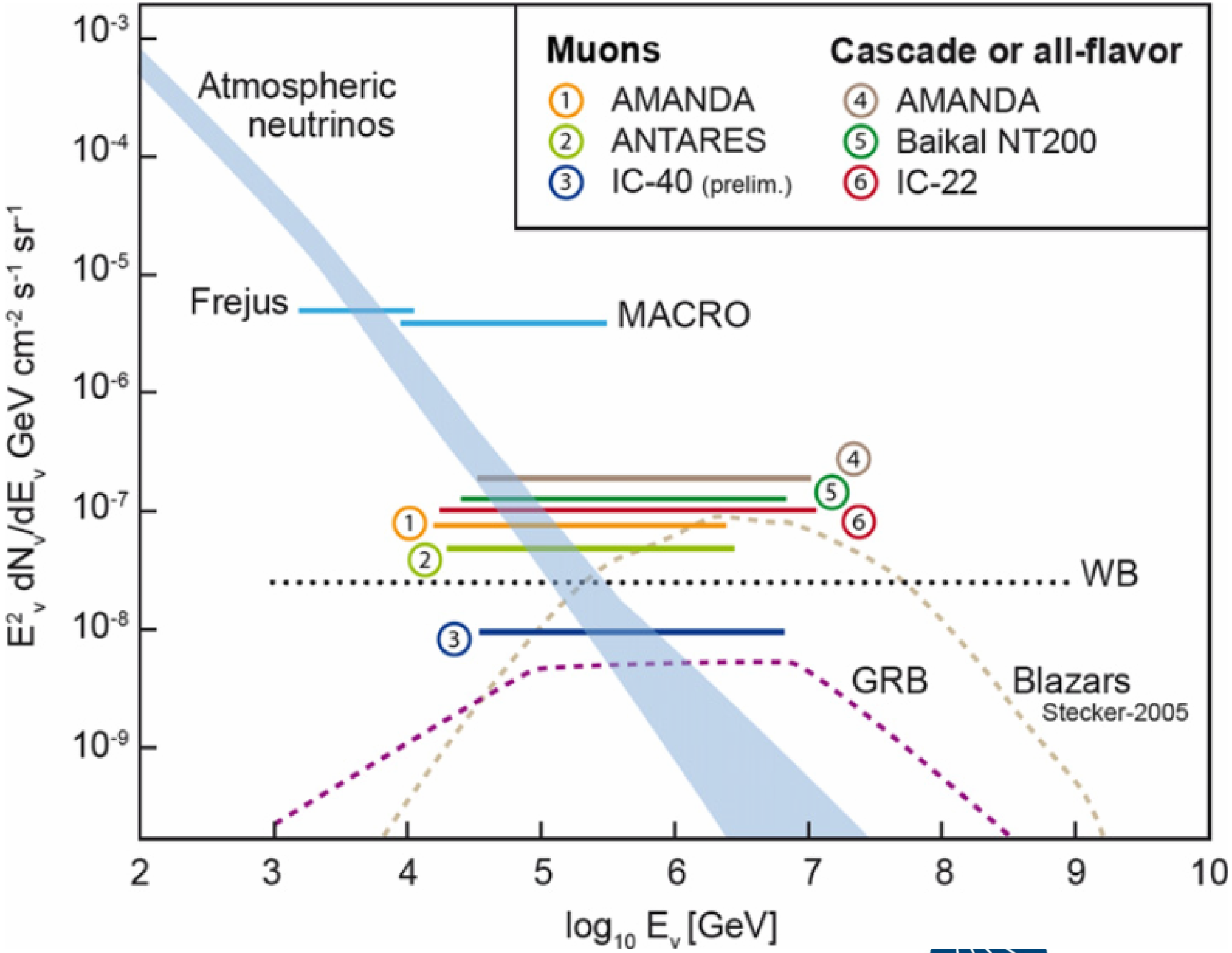
Diffuse fluxes

UK, C.Spiering, Prog. Nucl. Part. Phys. 67 (2012) 651

- Search for excess at high energies above atm. neutrino flux
- Assume E^{-2} energy spectrum
- No signal seen → limits
- Approaching regime of predictions



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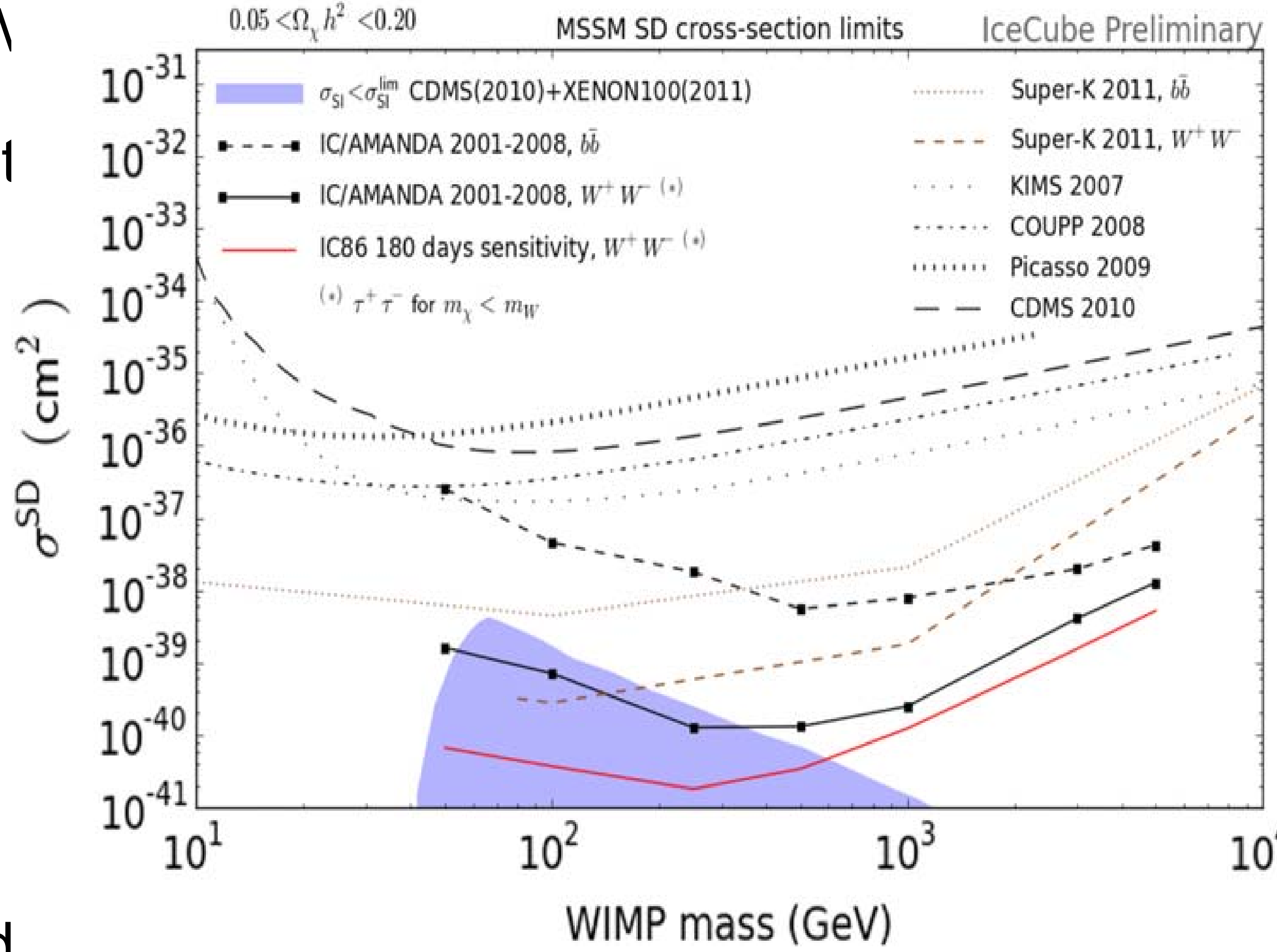
Sensitivity to dark matter (WIMPs)

- Assumption: WIM accumulation in Sun, subsequent annihilation
- Search for neutrino flux from the Sun
- Particularly sensitive to spin-dependent cross section (Sun = protons)
- Requires low energy threshold



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Where we are (summary)

… not yet there!

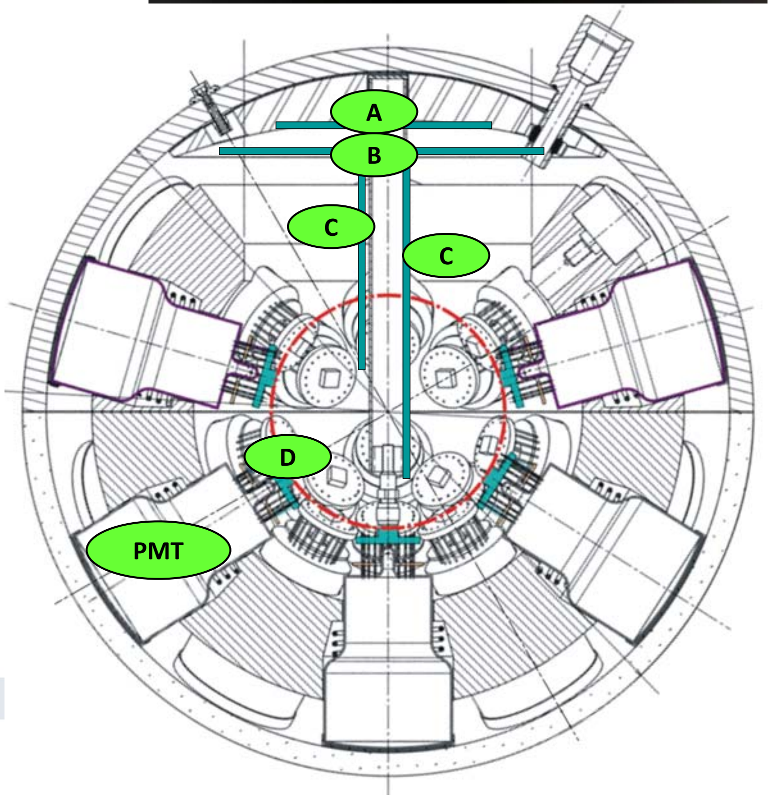
The Future: KM3NeT

The KM3NeT project

- EU-funded Design Study and Preparatory Phase (2006-2012)
- Multi-km^3 NT in Mediterranean Sea, exceeding IceCube substantially in sensitivity
- Central physics goals (by priority):
  - Galactic neutrino “point sources” (energy 1-100 TeV)
  - Extragalactic sources
  - High-energy diffuse neutrino flux
- Current status
  - ~40 M€ available for first construction phase
  - final prototyping and last design decisions 2012/13
  - start of construction 2013/14

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
  - improved 1-vs-2 photo-electron separation → better sensitivity to coincidences
  - directionality



Recent developments:

- Detector will be constructed in 2 or more building blocks (technical reasons: power, data bandwidth, cables, deployment operations, complexity of se -floor network, …)
- Mechanical structure (towers vs. s der discussion
- Geometry according to Tec Report: Hexagonal blocks with units each, at 180m distance
- Now: Optim lly for Galactic sources (energy cut-o me 10 TeV)
  → Distance between detection units reduced to 100-130m
  → Effective area increases at intermediate and decreases at high energies

Footprint optimisation is ongoing

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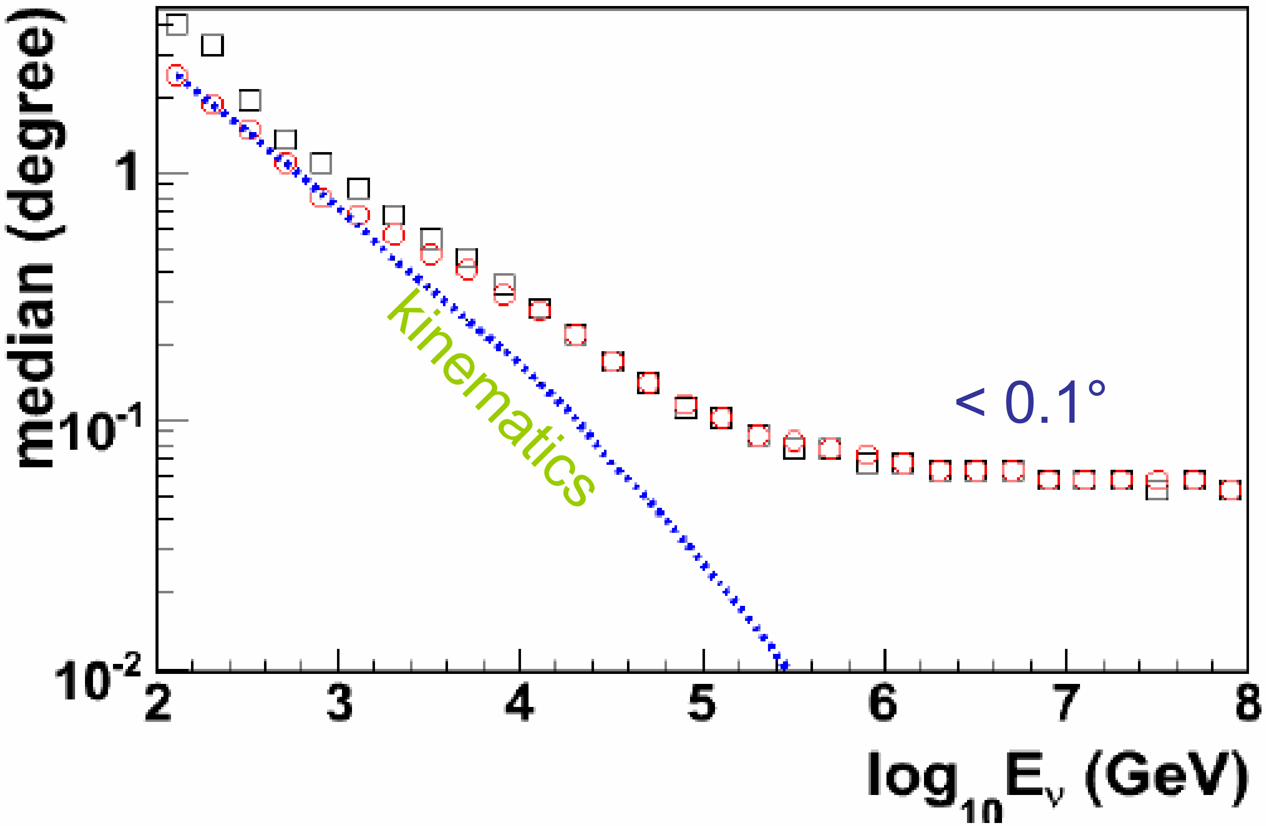
Angular resolution

- Investigate distribution of angle between incoming neutrino and reconstructed muon
- Dominated by kinematics up to ~1TeV



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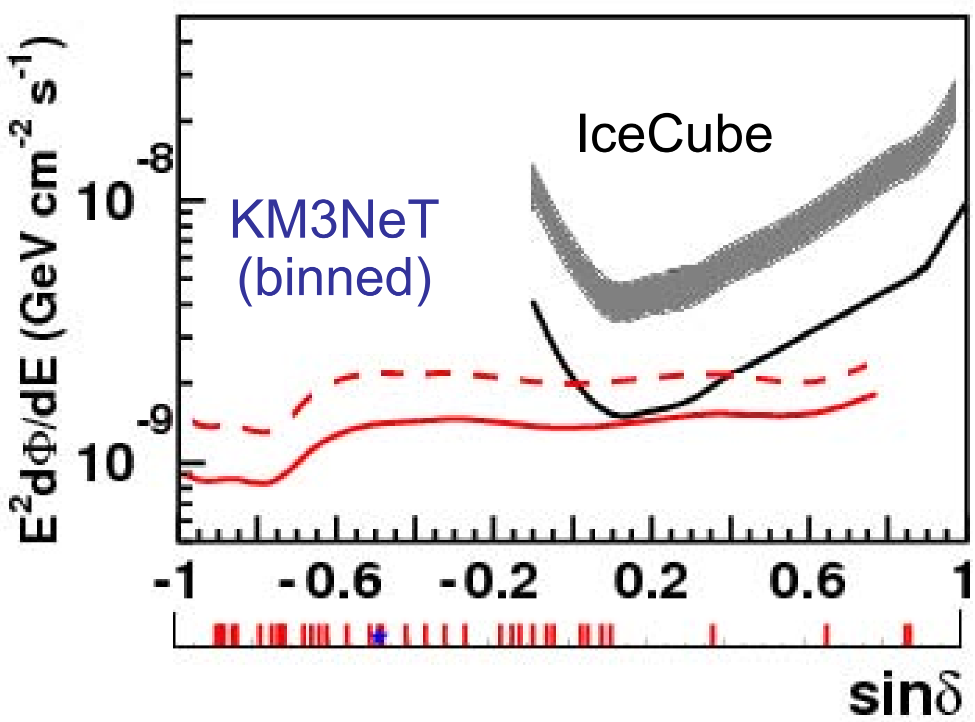
Point source sensitivity (1 year)

Expected exclusion limits / 5σ detection
(for E^{-2} source spectra, from Technical Design Report)



R. Abbasi et al. Astro-ph (2009) scaled – unbinned method

Discovery at 5σ with 50%

After optimisation for Galactic sources: Observation of RXJ1713 with 5σ within ~5-7 years if γ emission fully hadronic

□ Observed Galactic TeV-γ sources (SNR, unidentified, microquasars)
F. Aharonian et al. Rep. Prog. Phys. (2008)
Abdo et al., MILAGRO, Astrophys. J. 658 L33-L36 (2007)

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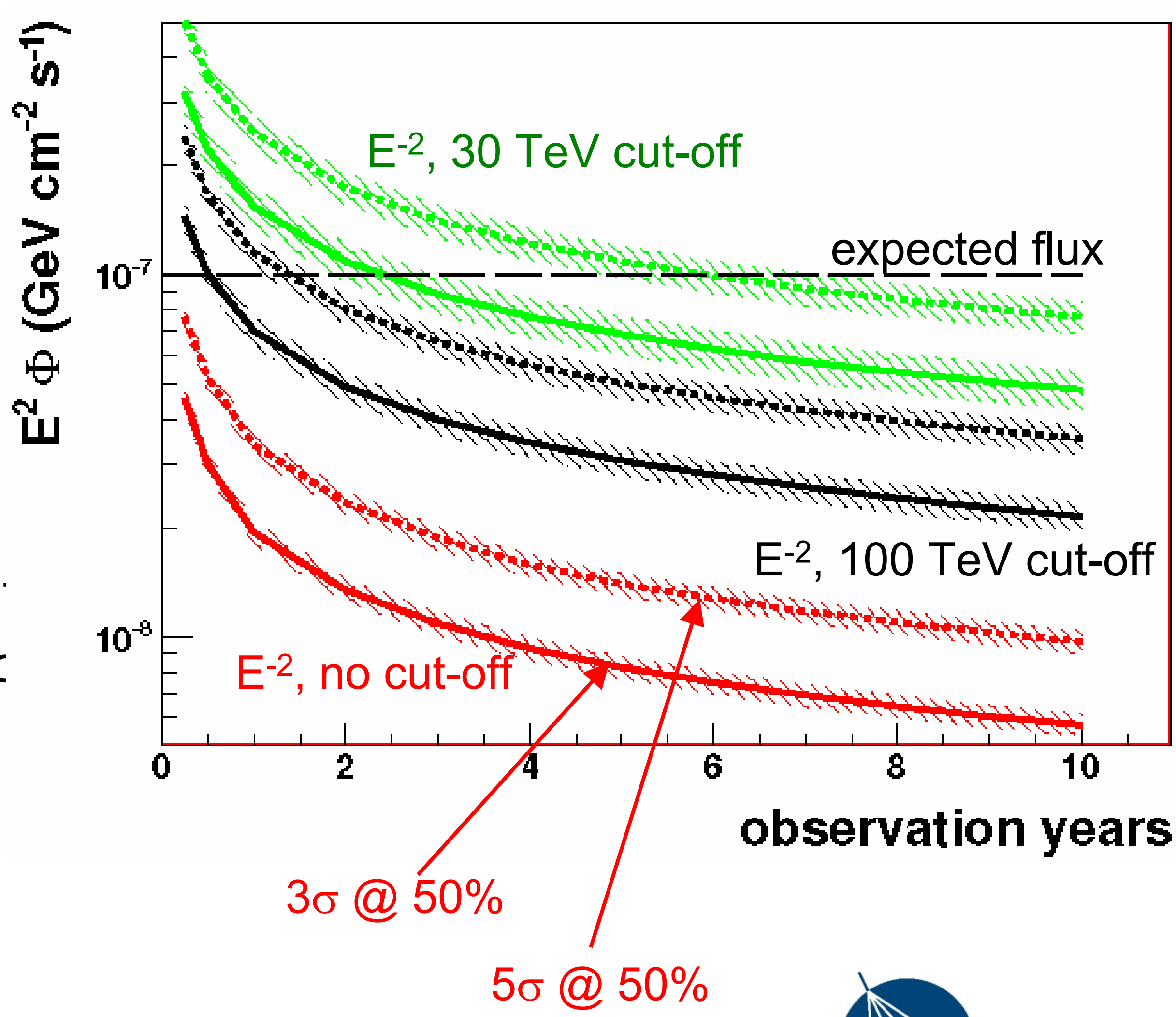
The Fermi bubbles

- 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 deba
  – if hadronic, hot neutrinc source candidate
- Could be first source detected by KM3NeT



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KM3NeT implementation parameters

- Overall investment ~220 M€
- Staged implementation expected;
  phase-1 sensitivity about equal to that of IceCube
- Science potential from very early stage of construction on
- Operational costs of full detector 4-6 M€ per year (2-3% of capital investment), including electricity, maintenance, computing, data centre and management
- Node for deep-sea research of earth and sea sciences

Summary

- Neutrino telescopes in water and ice are taking data. The technology is proven.
- No discoveries yet …
  but they may be around the corner …
  we need patience and perseverance.
- KM3NeT will soon start construction
  and provide unprecedented sensitivity
- Hope to provide you with a discovery soon – stay tuned!

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