APPEC Town Meeting - Neutrino Telescopes

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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Paris, April 6th, 2016

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

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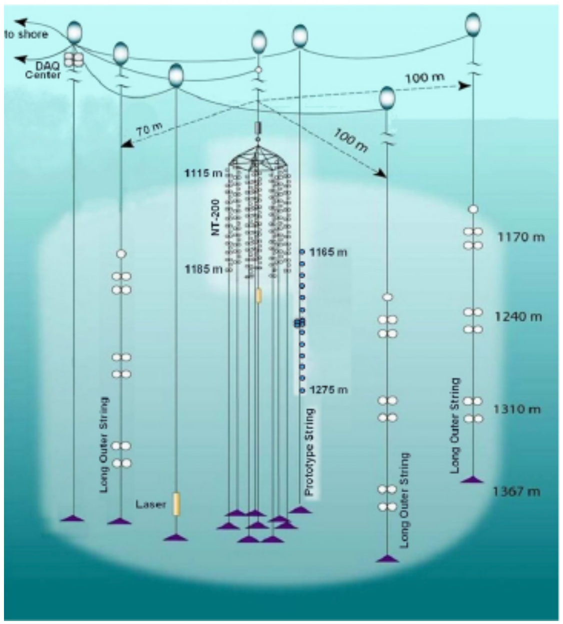
Short Summary

recent results from neutrino telescopes

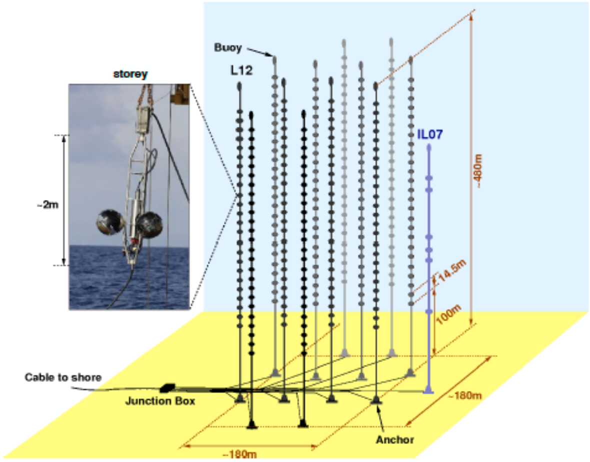
Existing neutrino telescopes

Baikal



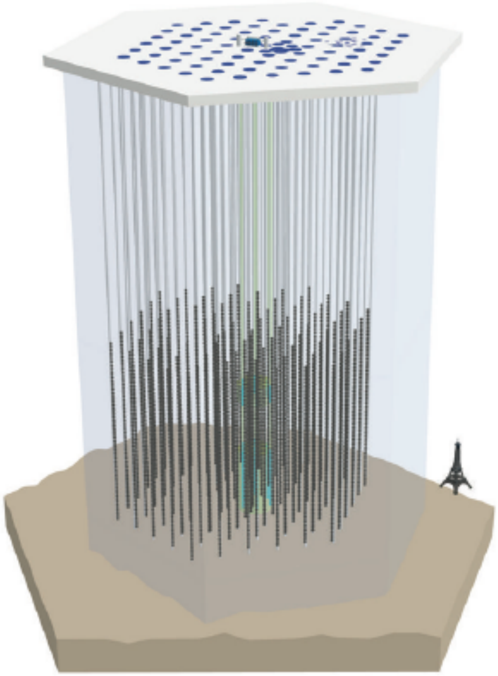
Lake Baikal,
228 PMTs
0.0005 km3

ANTARES



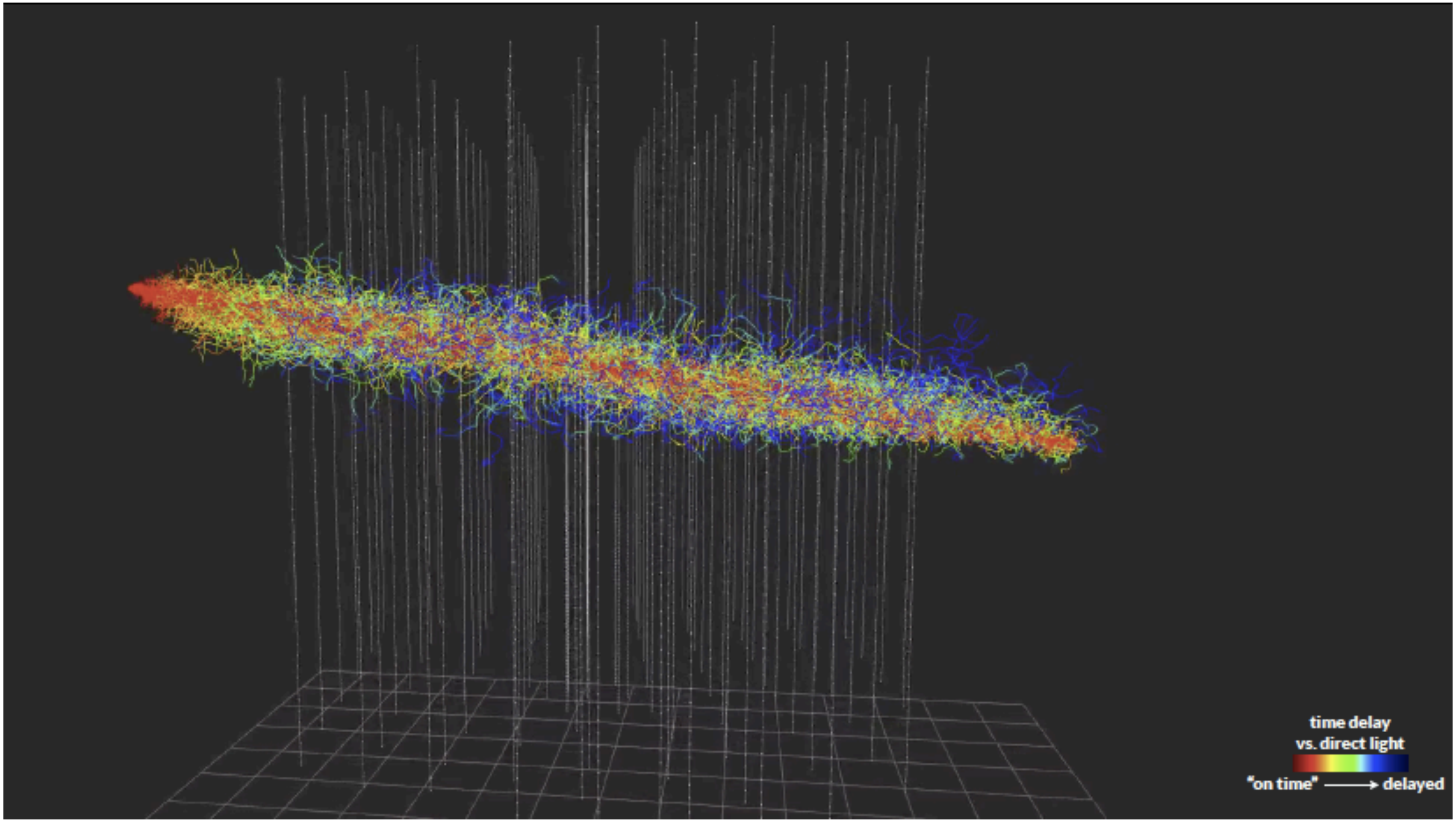
Mediterranean Sea,
885 PMTs
0.01 km3

IceCube



South Pole glacier,
5160 PMTs
1 km3

Simulation: Cherenkov photons from a muon track



Credit: C.Kopper

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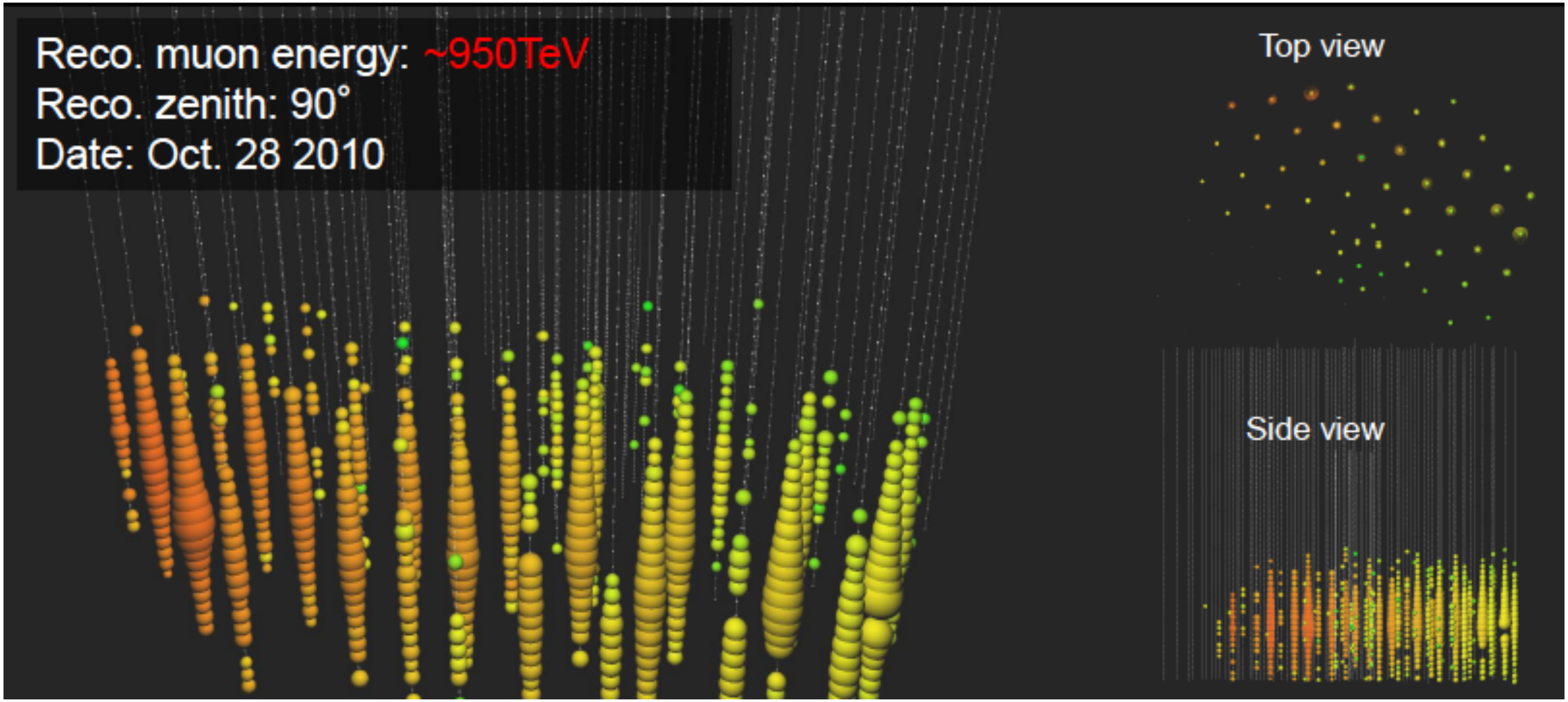
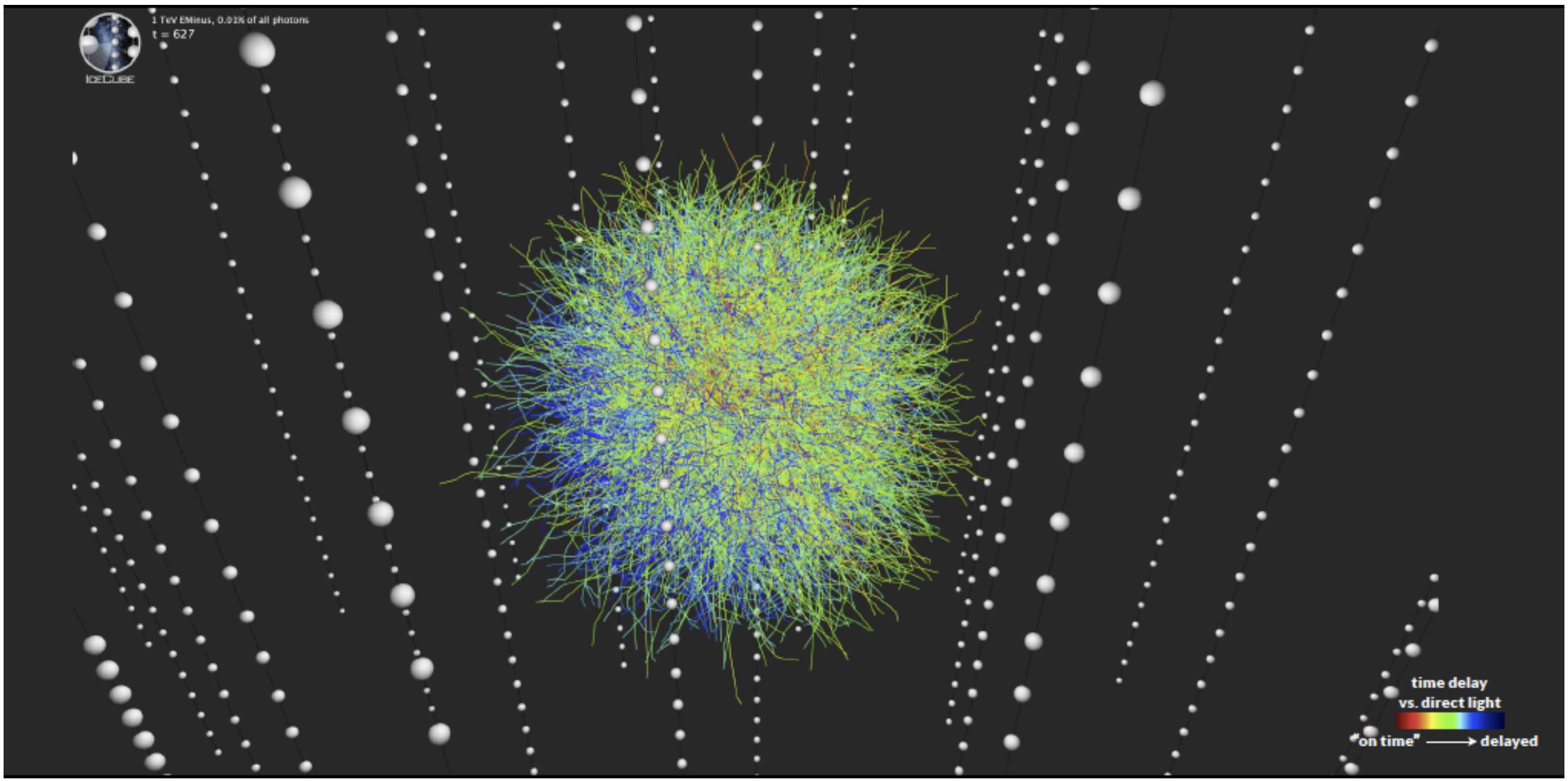
Detected Cherenkov photons from a muon track



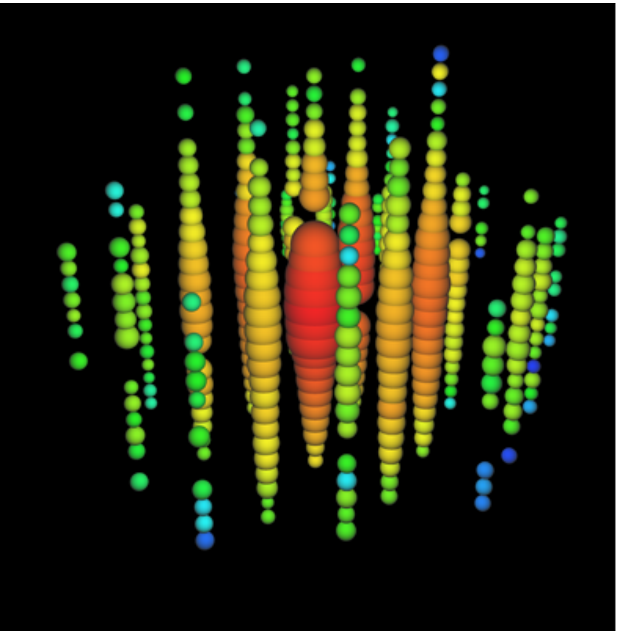
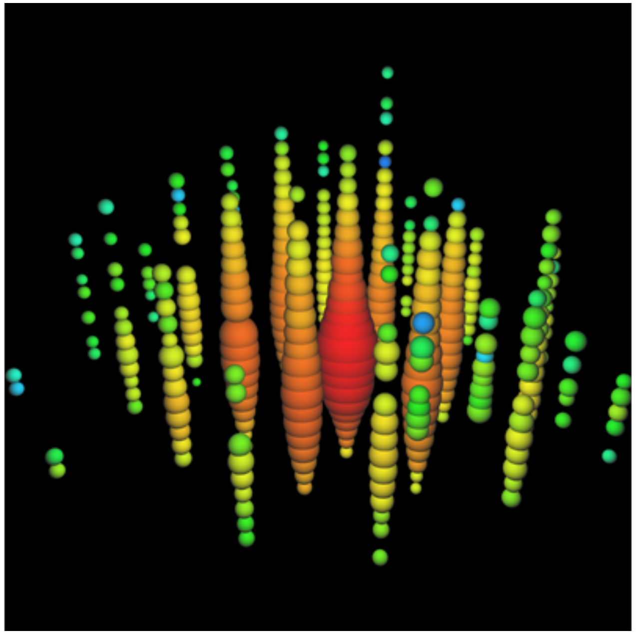
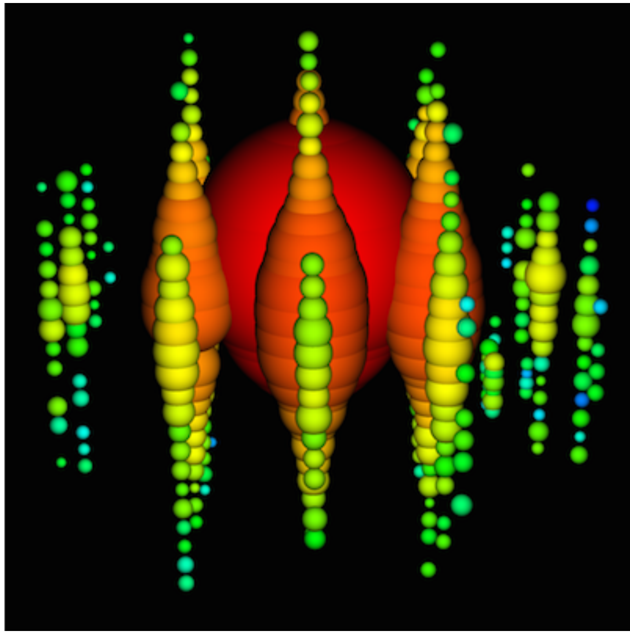
Simulation: Cherenkov photons from a cascade event



Credit: C.Kopper

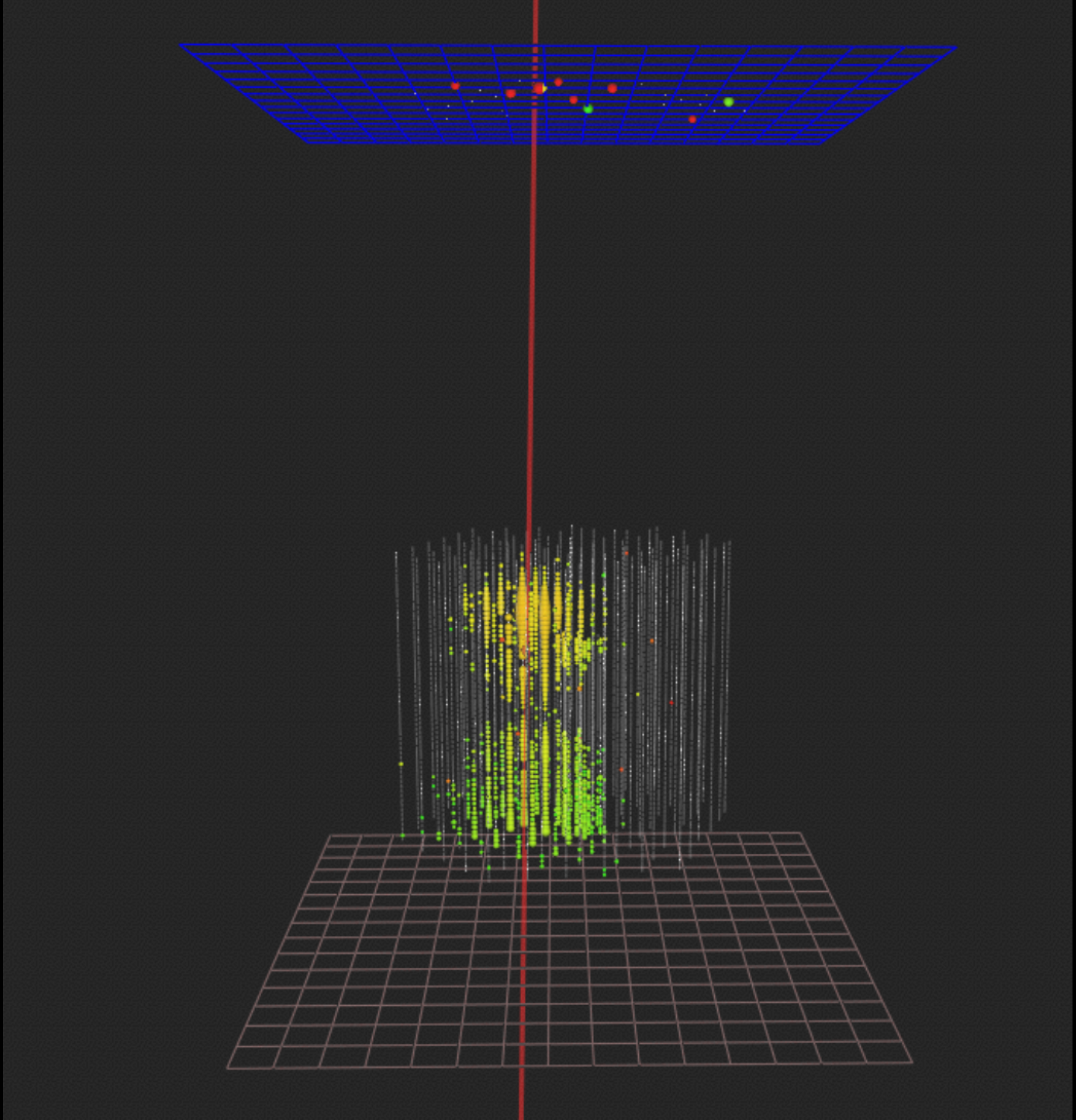
IceCube

Photons detected from cascade events:

430 TeV

1 event:
5 sigma
discovery?



Recent results from neutrino telescopes:

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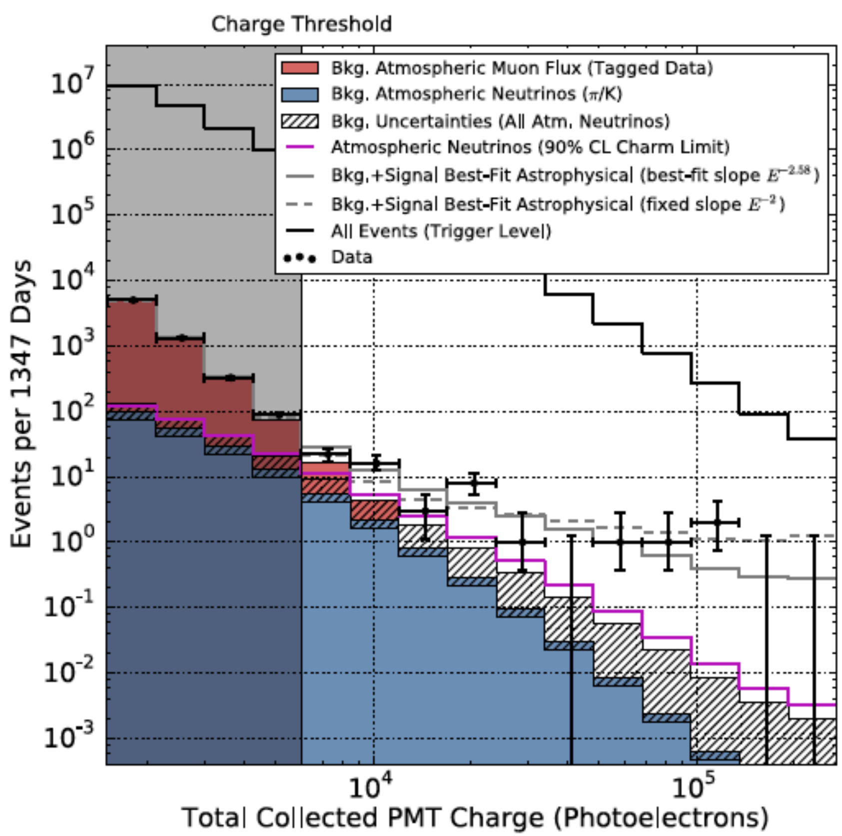
- Diffuse cosmic neutrino flux – **discovery** by IceCube in 2013 !!
- Further investigations (***astronomy***):
  - Point sources
  - Extended source
  - Flaring sources
  - Combined neutrino telescopes signals
  - Multimessenger signals
- World-best limits for spin-dependent ***dark matter*** search
- Measurement of atmospheric ***neutrino oscillations***
- Exotic particles: magnetic monopoles, nuclearites, sterile neutrinos…
- Associated sciences: geophysics, sea science….

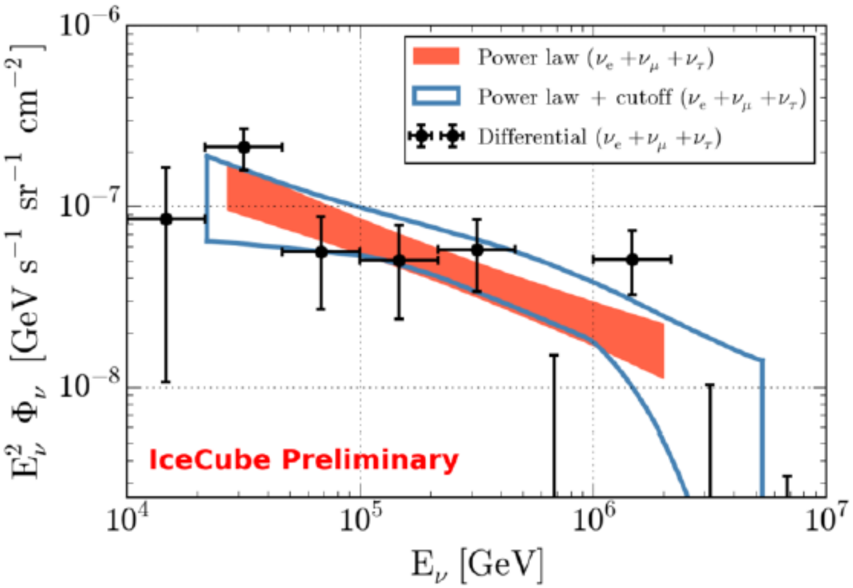
IceCube: diffuse cosmic neutrino flux

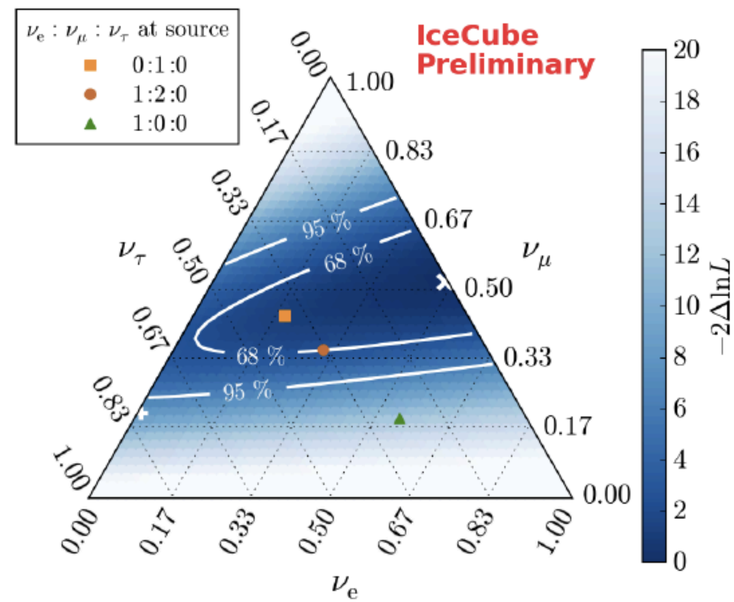
- Diffuse astrophysical neutrino flux – discovery by IceCube in 2013 !!



4 years data taking
starting HE events: 54
expected: 12.6 atm. muons
9 atm. neutrinos
6.5 σ
C.Kopper, ICRC 2015

Diffuse cosmic neutrino flux





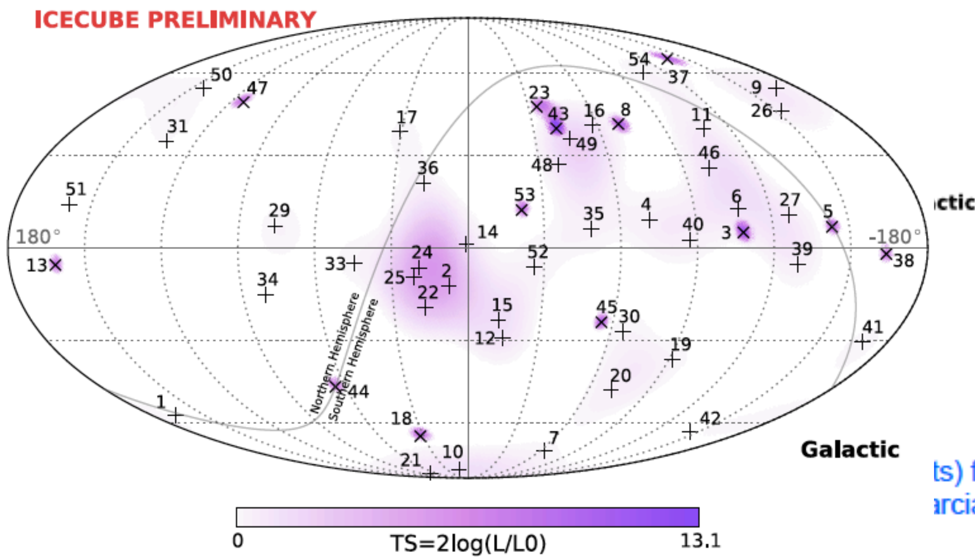
Spectral index
$\Phi_{astro\ \nu}$ = const $E^{-\gamma}$

Best fit $\gamma \sim 2.5$

Flavour composition:
hadronic (π,K) origin

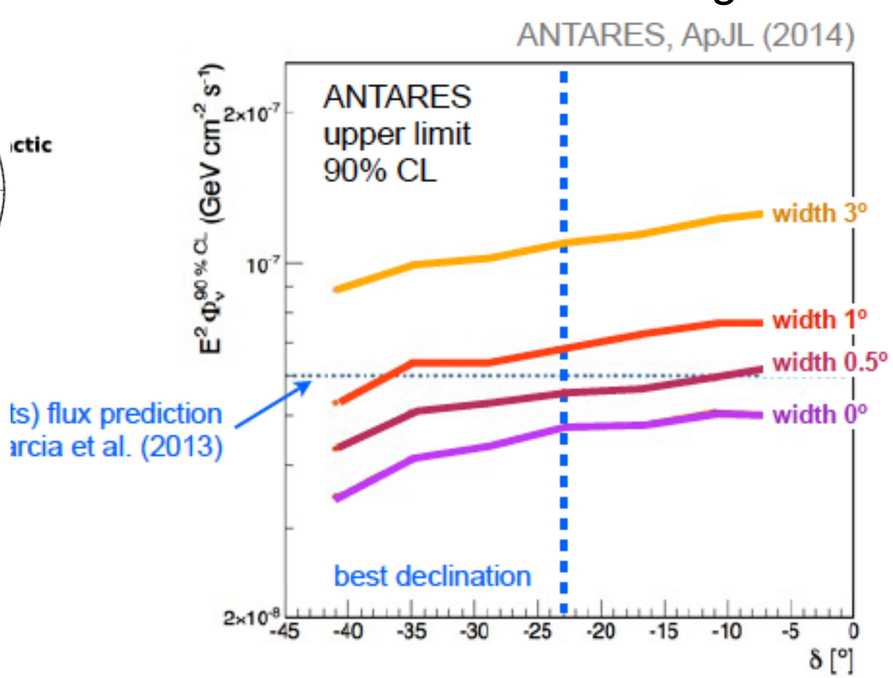
IceCube HE Skymap

- Analyzed with a variant of the standard PS method (w/o energy)(i.e. scrambling in RA)
- Most significant excess close to (but not at!) the Galactic Centre
- Significance: 44% (not significant)
- Other searches (multi cluster, galactic plane, time clustering, GRB correlations) not significant either



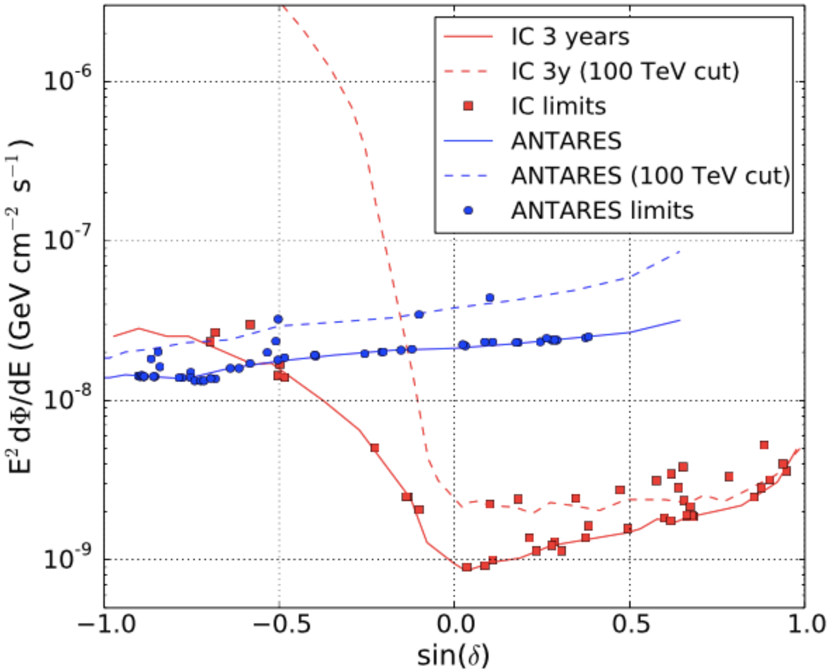
taken from C.Kopper, ICRC 2015

ANTARES rules out point source in cluster region



Combined ANTARES – IceCube search

Point source search limits and sensitivities



First combined search for neutrino point sources in the Southern hemisphere with ANTARES and IceCube neutrino telescopes; **ANTARES and IceCube collaborations**, Submitted to The Astrophysical Journal, Nov. 2015 (e-print archive arXiv:1511.02149)

→ Next generation neutrino telescopes with higher sensitivity !

Atmospheric neutrino oscillation

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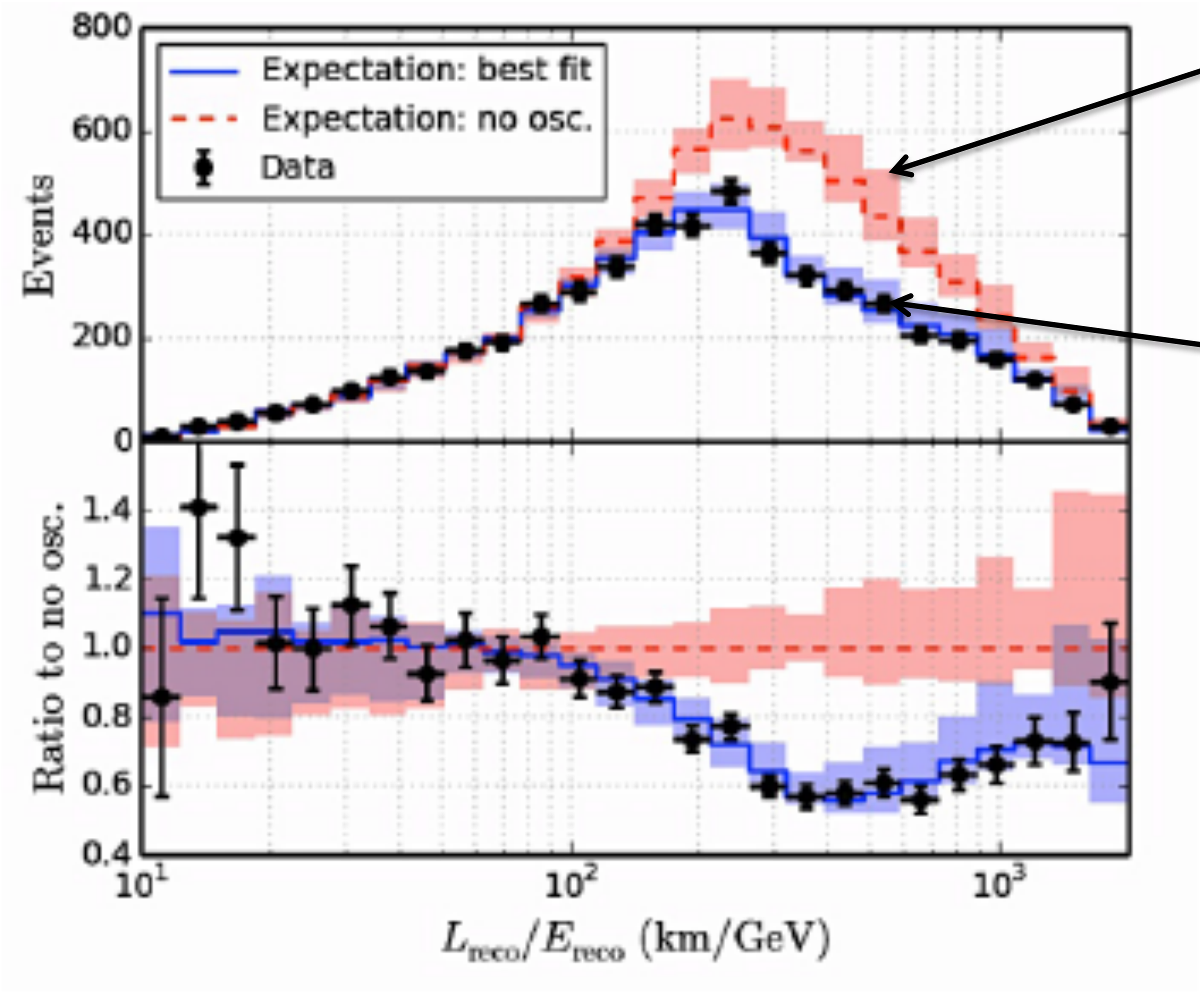

expectation
no oscillation

expectation with
oscillation;
measured data

IceCube
Phys.Rev.D (2015)

Atmospheric neutrino oscillation

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IceCube 2015

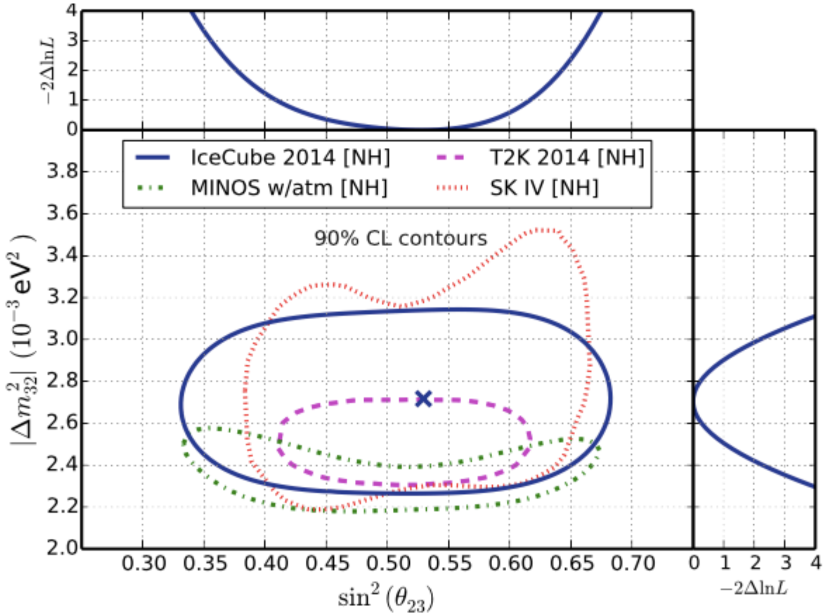
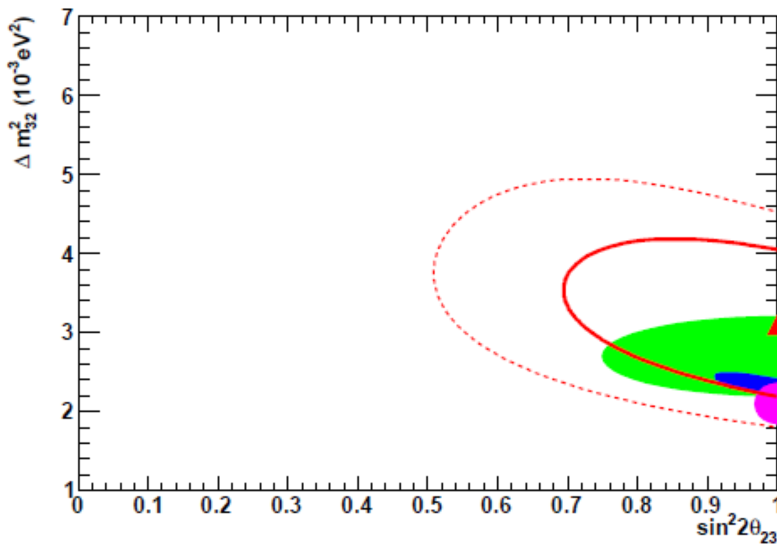


FIG. 7. 90 % confidence contours of the result in the $\sin^2\theta_{23}-\Delta m^2_{32}$ plane in comparison with the ones of the most sensitive experiments [8–10]. The log-likelihood profiles for individual oscillation parameters are also shown (right and top). A normal mass ordering is assumed.

$$|\Delta m^2_{32}| = 2.72^{+0.19}_{-0.20} \times 10^{-3}\ \mathrm{eV}^2$$
$$\sin^2(\theta_{23}) = 0.53^{+0.09}_{-0.12}$$

ANTARES 2010



Current and future plans for neutrino telescopes

High Energy neutrino astronomy

Lake Baikal GVD

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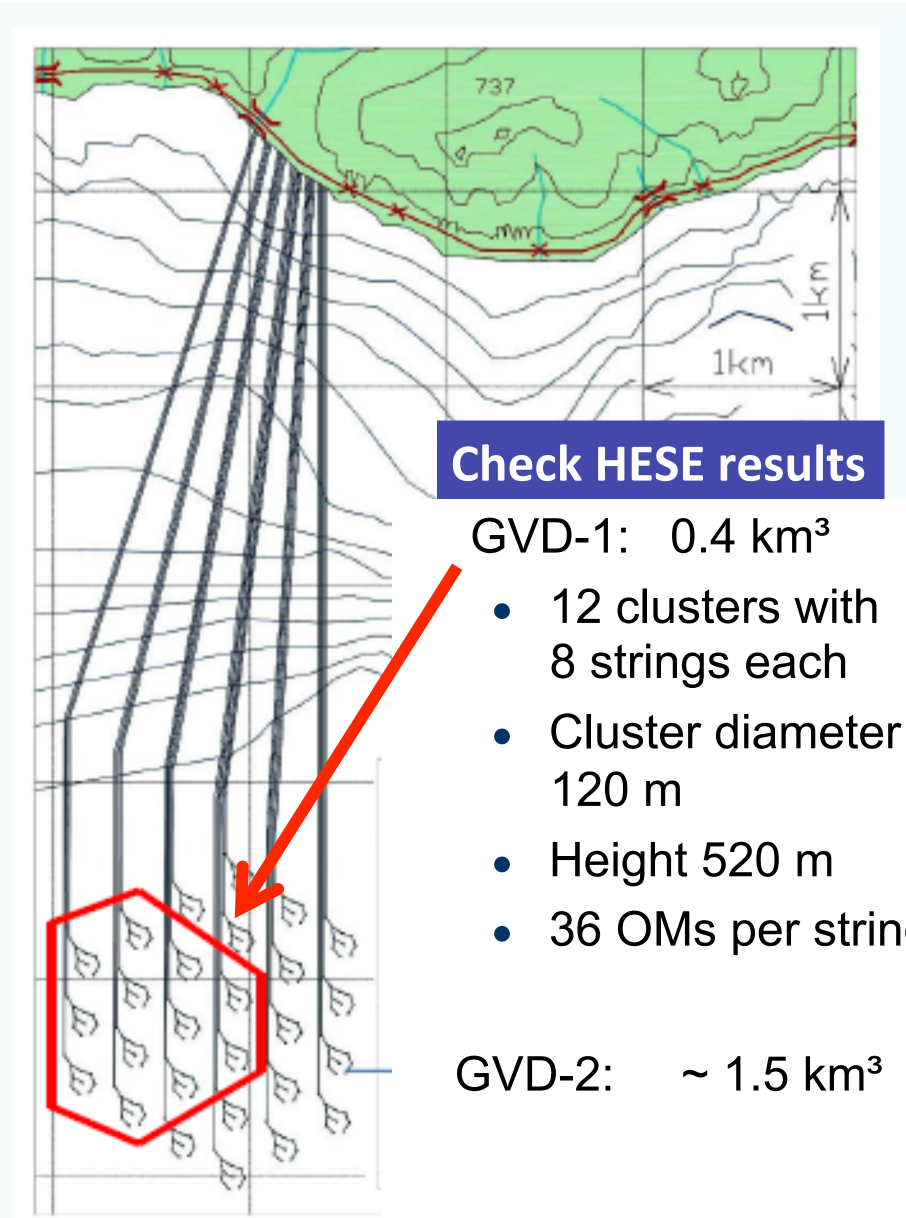
GVD: Phase 1 (2020); Phase 2 (2025)

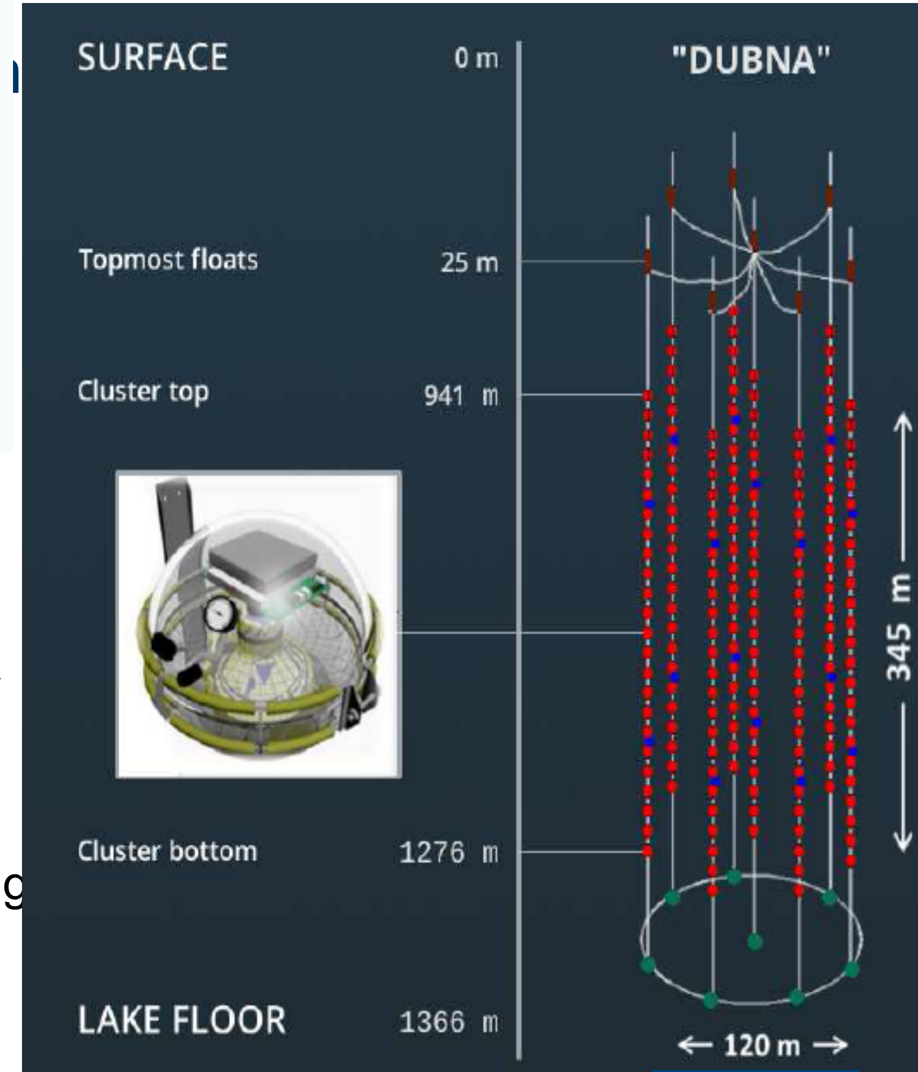


Check HESE results

GVD-1: 0.4 km³

- 12 clusters with 8 strings each
- Cluster diameter 120 m
- Height 520 m
- 36 OMs per string

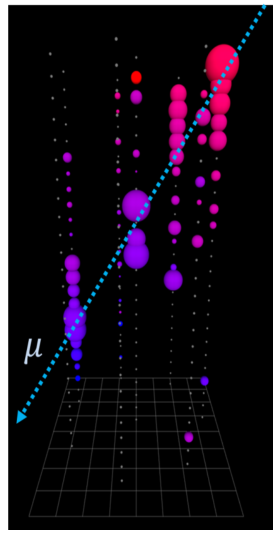
GVD-2: ~ 1.5 km³

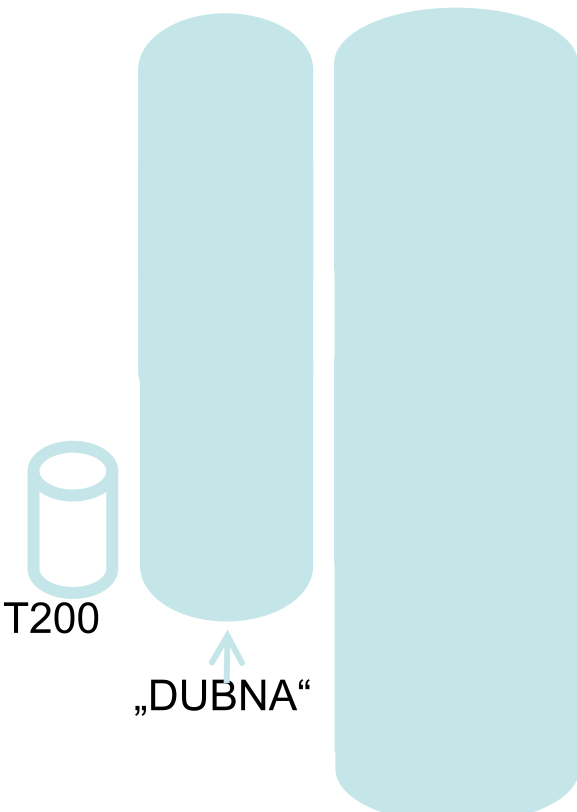


2015 still 80 m

From NT200 to GVD Clusters

- DUBNA cluster with 80 m diameter working since April 2015
- A down-going muon in the DUBNA cluster



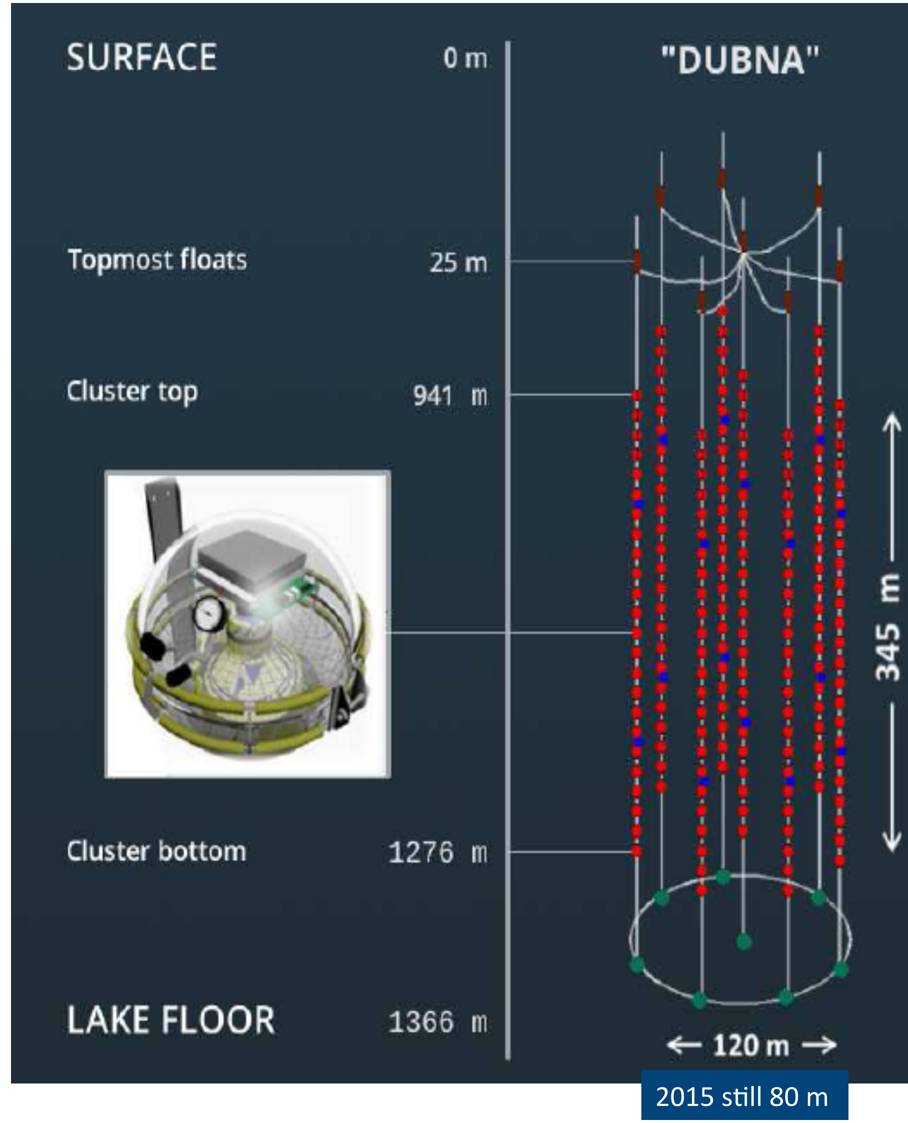


NT200

„DUBNA“

final cluster

(1 of 10-12 in Phase-1)



High Energy neutrino astronomy

IceCube Gen2 HEA

IceCube Gen2

A wide band neutrino observatory (MeV – EeV) using several detection technologies – optical, radio and surface veto - to maximize the science

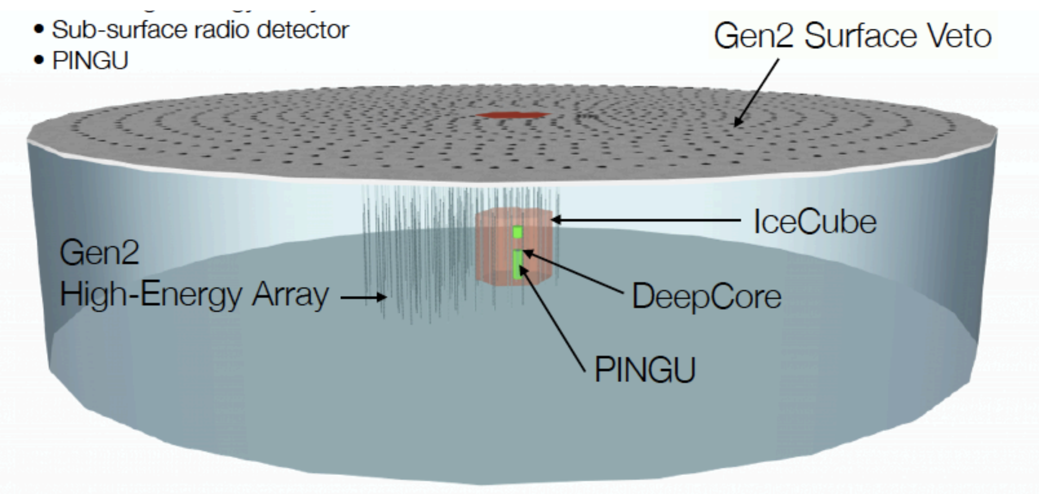
- Improve statistics of HE events;
  → identify sources
  → physics of sources and environment

- neutrinos from CR propagation

- cosmogenic (GZK) neutrinos
- 1→ 5 events per year

- Surface array: CR physics and atmospheric veto

Multi-component observatory:
- Surface air shower detector
- Gen2 High-Energy Array
- Sub-surface radio detector
- PINGU



IceCube Gen2 - HEA

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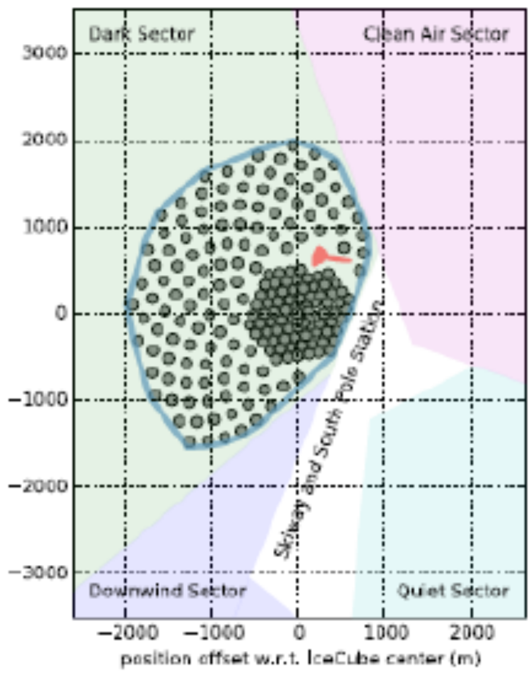
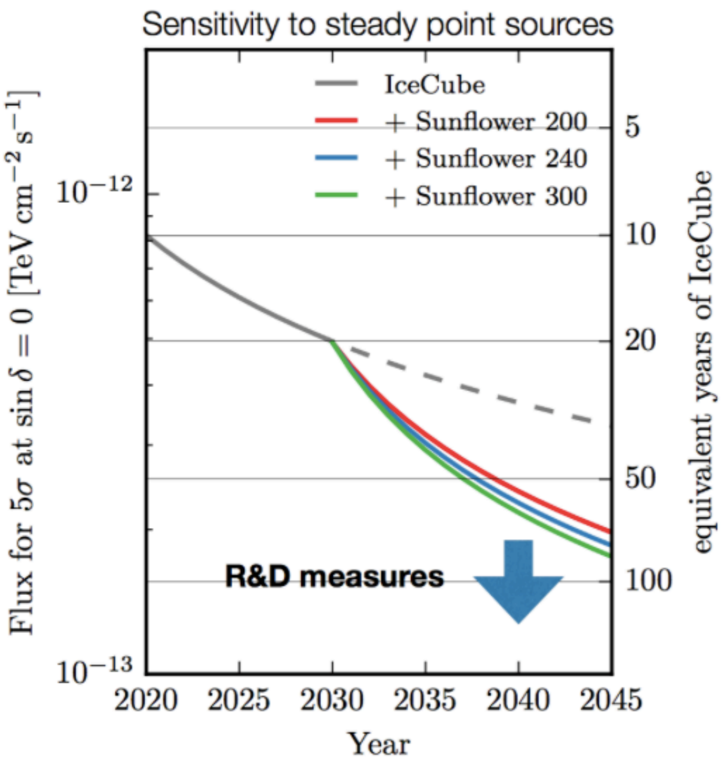




120 strings;
80 DOMs per string, length 1.3 km
200 – 300 m horizontal spacing
5 – 10 km^2

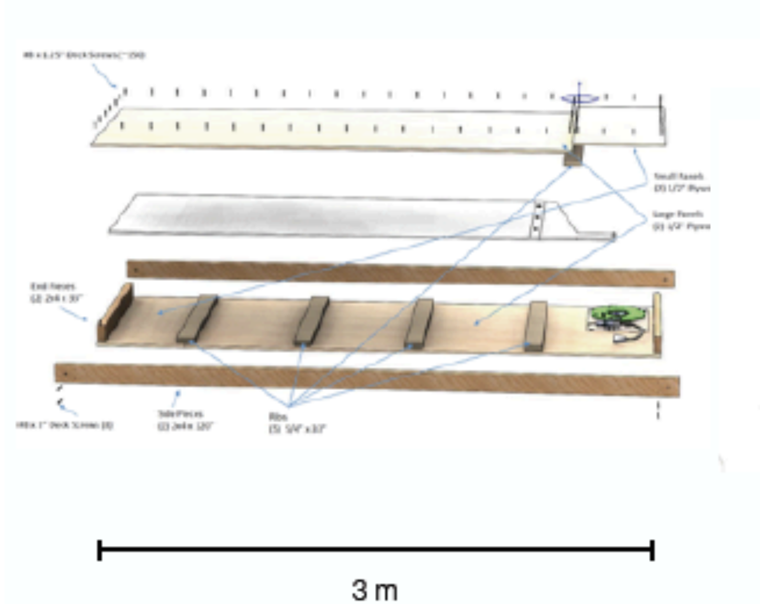
- For just a big IceCube:
  → factor 2-3 gain in sensitivity
- More significant improvements
  → new technology

IceCube Gen2 – surface detector technology

IceTop tanks

- Good CR detectors
- Operated at South Pole since 2007
- Deployment requires effort at Pole

Scintillator panels



- Easier deployment
- Low cost (cheap materials, small PMTs)

Additive concept (ACTs, radio)

- Reduced energy threshold
- Add resolution, particle ID,…

IceCube Gen2 – in ice technology

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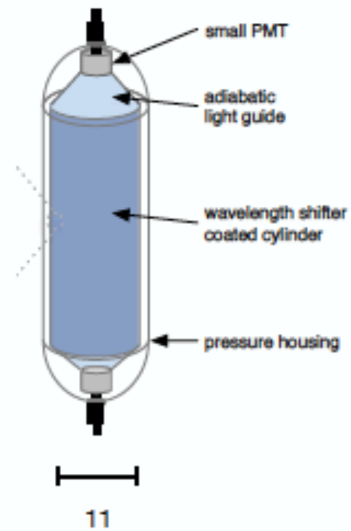
mDOM

- Directional information
- More sensitive area per module

D-Egg

- Directional information
- More sensitive area per module
- Smaller geometry

WOM



- more sensitive area per $
- Small diameter
- Lower noise rate

LOM

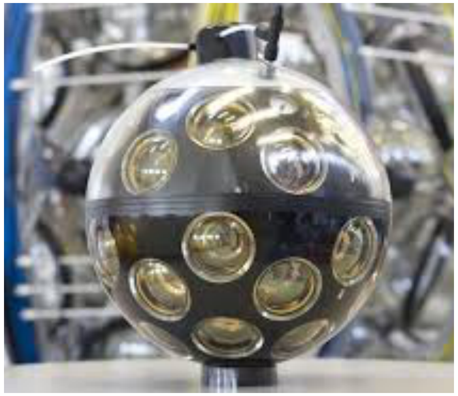
- Small diameter
- Directional info.
- More area per module

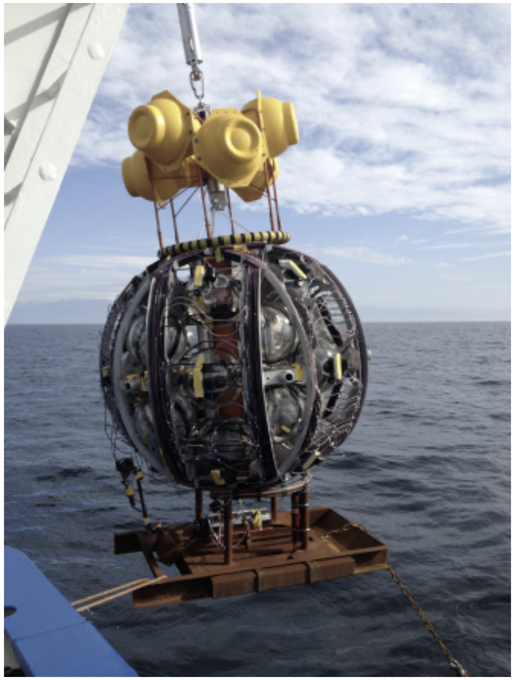
High Energy neutrino astronomy

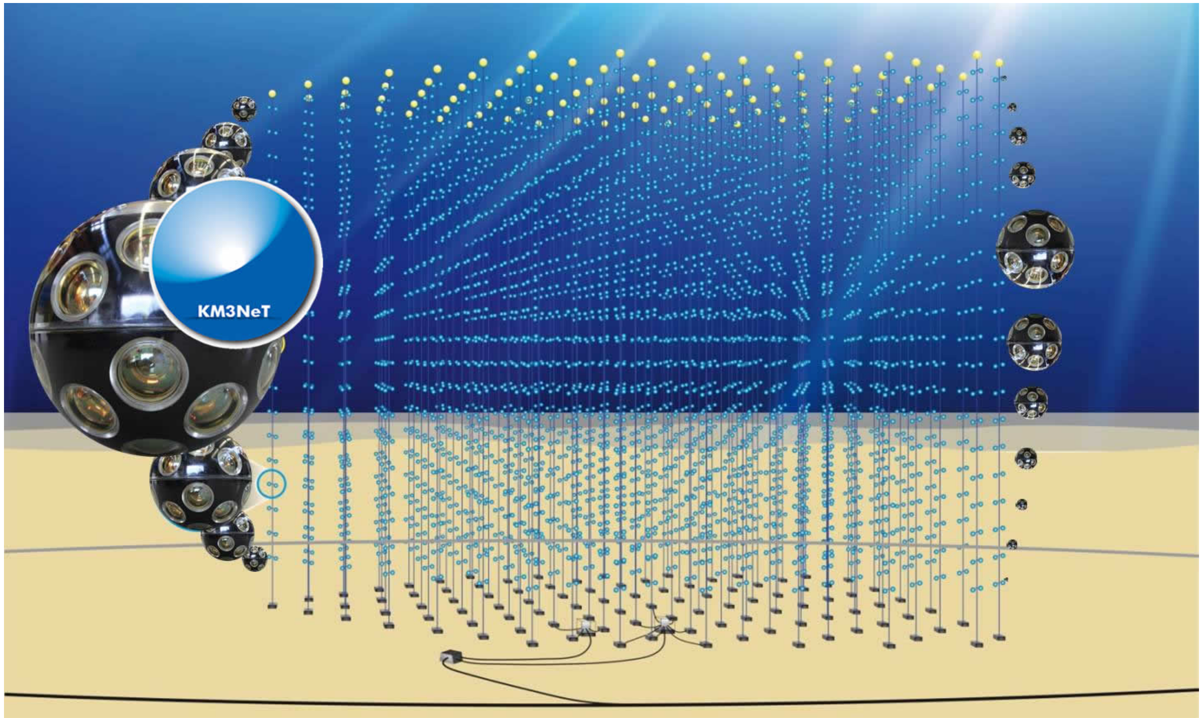
KM3NeT - ARCA

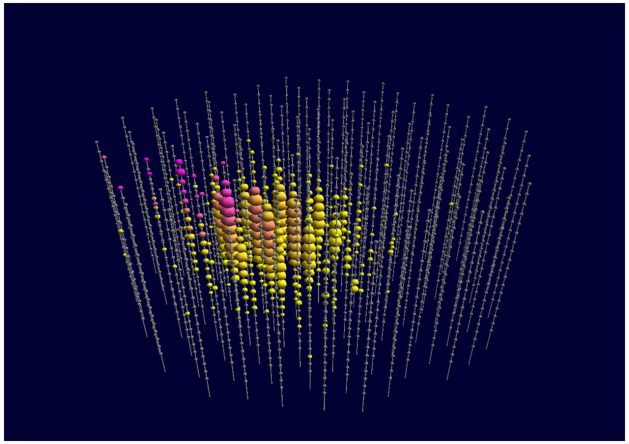
KM3NeT- ARCA

Capo Passero, Italy
ca. 1 km^3
2 blocks of 115 strings each
18 DOMs per string,
36m vertical, 90m horizontal
l distance
31 3” PMTs per OM



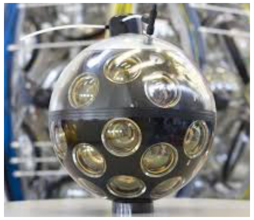


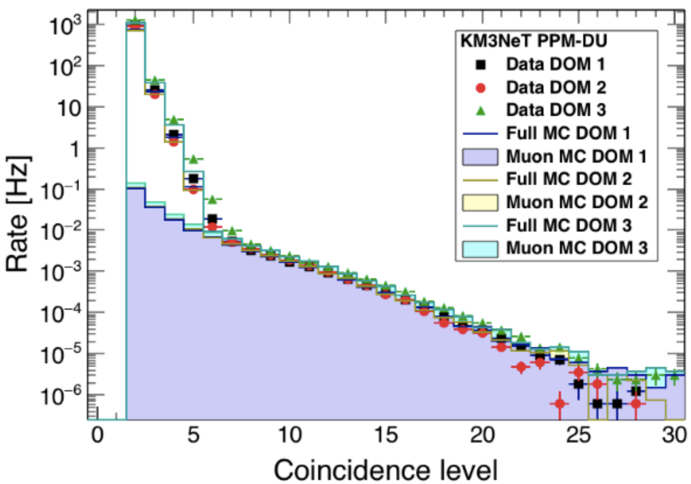


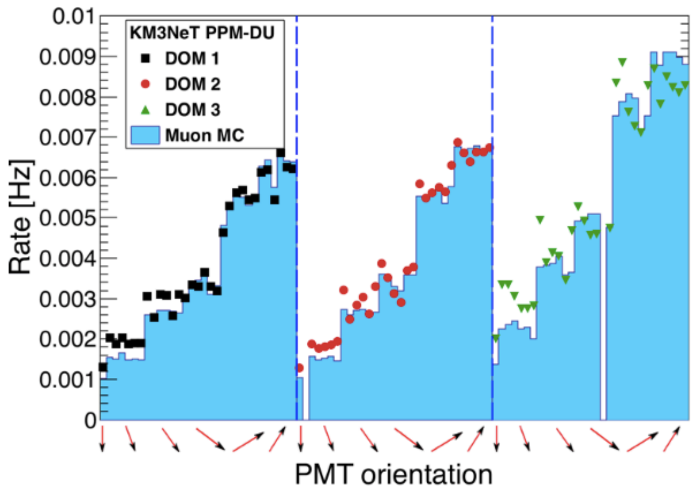


KM3NeT Phase 1 (2015 – 2017)

- 24 strings at Italian site → ARCA
  7 strings at French site → ORCA
- prototype line deployed 2014; system works successfully
  very good agreement between data and MC
  results published EPJ C 76 (2016) 54
- first full line deployed 2015, fully functional

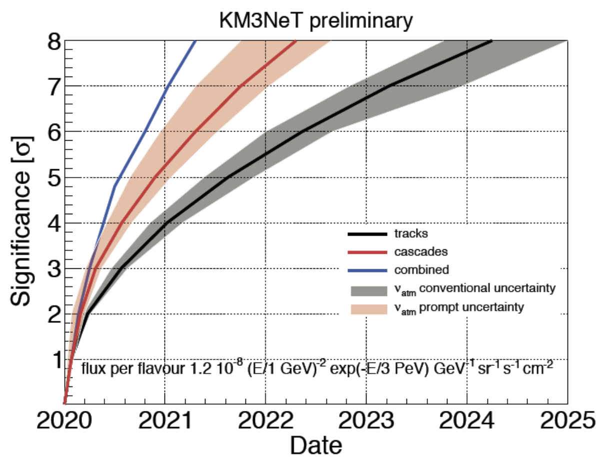


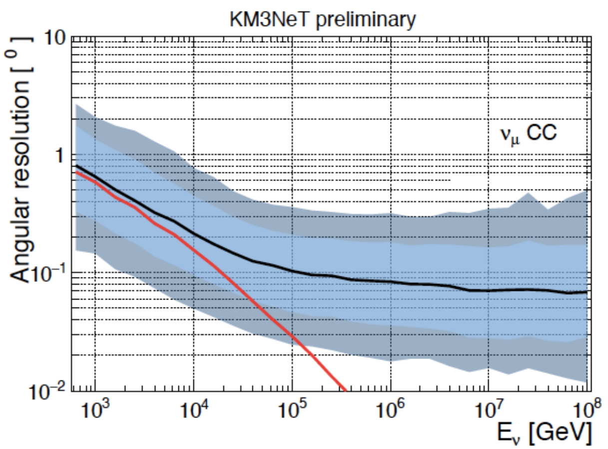




KM3NeT Phase 2 - ARCA

- ca. 1 km^3 ; measure IceCube flux (5σ in less than 1year) with different systematics





- excellent angular resolution (0.1° ν_μ, 2° cascades):
  all flavor neutrino astronomy
- field of view complementary to IceCube:
  KM3NeT/IceCube: same sources at different energies
  optimized sensitivity to Galatic Centre

Neutrino Mass Hierarchy – ORCA and PINGU

Neutrino mass ordering: ORCA/PINGU

Neutrinos propagating through the Earth:

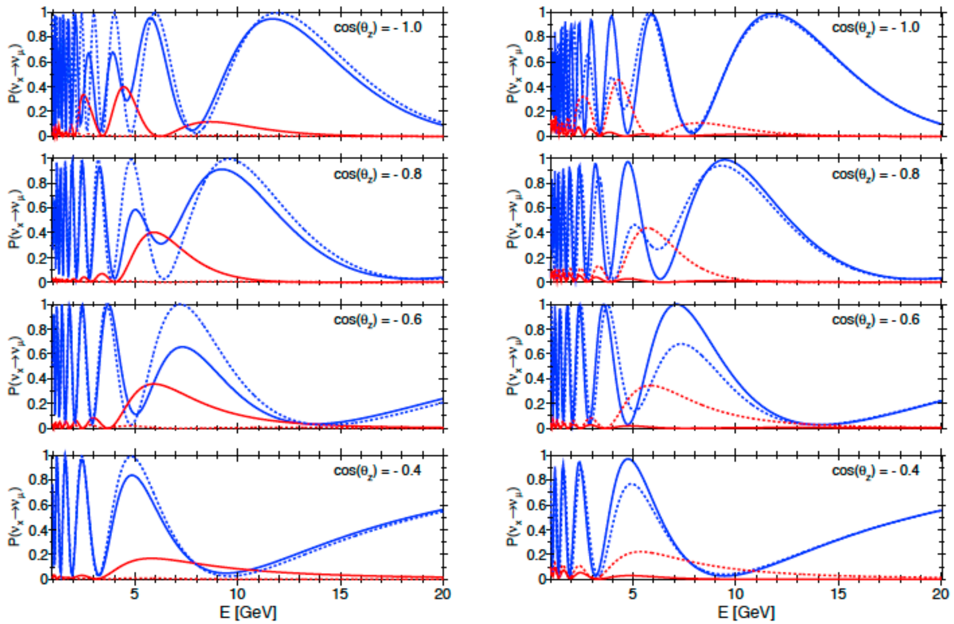
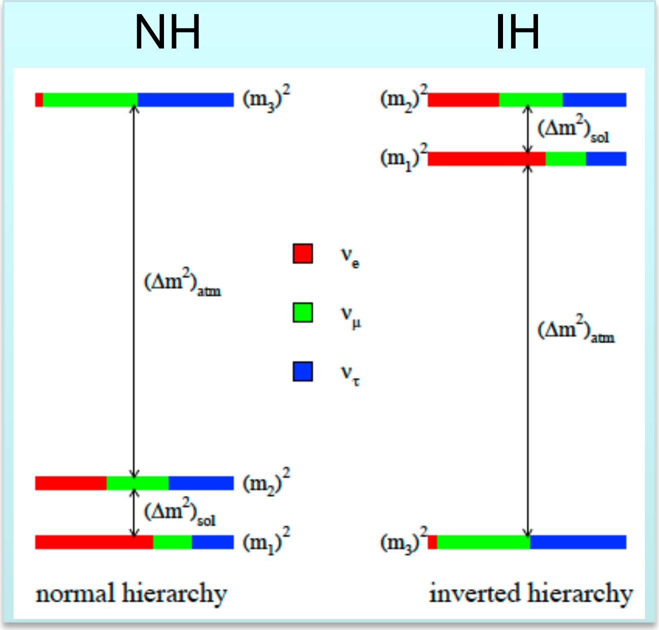


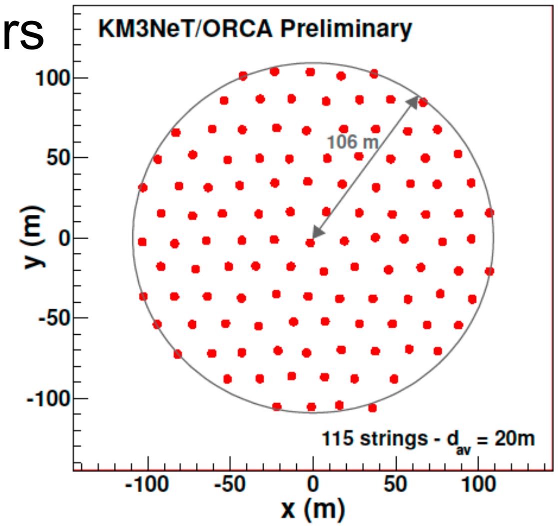
Figure 46: Oscillation probabilities $\nu_\mu \to \nu_\mu$ (blue lines) and $\nu_e \to \nu_\mu$ (red lines) as a function of the neutrino energy for several values of the zenith angle (corresponding to different baselines). The solid (dashed) lines are for NH (IH). For neutrinos (left) and for antineutrinos (right).



Measurement of atmospheric neutrinos offers sensitivity to mass hierarchy

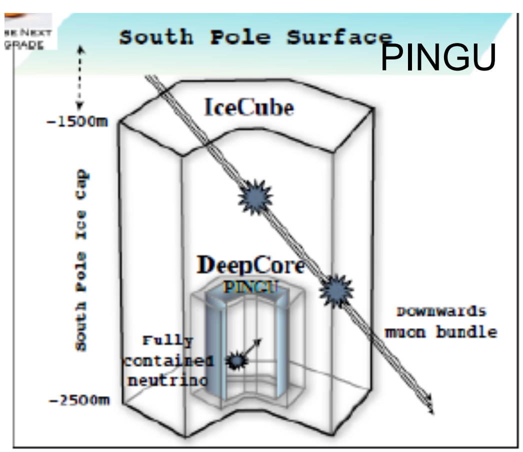
Physics with ORCA/PINGU

- Detector concept:
  - Dense instrumentation with photo sensors
  - Few megatons effective volume



- Neutrino Oscillations:
  - Neutrino mass ordering
  - Δm^2_{atm} and $\sin^2\Theta_{23}$
  - Octant of Θ_{23}

- Astroparticle physics:
  - Dark matter WIMP search (<100 GeV)
  - MeV neutrinos from gal. SN (PINGU)



- Geophysics with atm. neutrinos
  - Chemical comp. Earth core

IceCube Gen2 - PINGU

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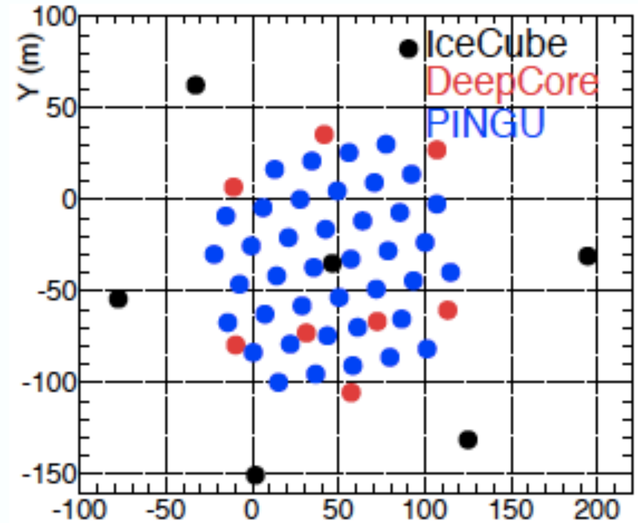
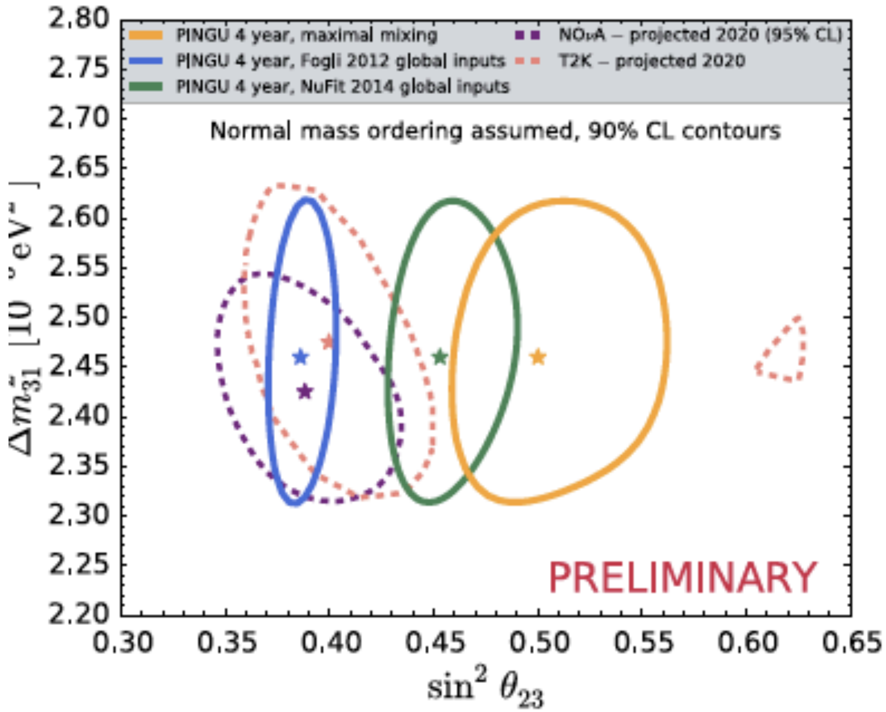
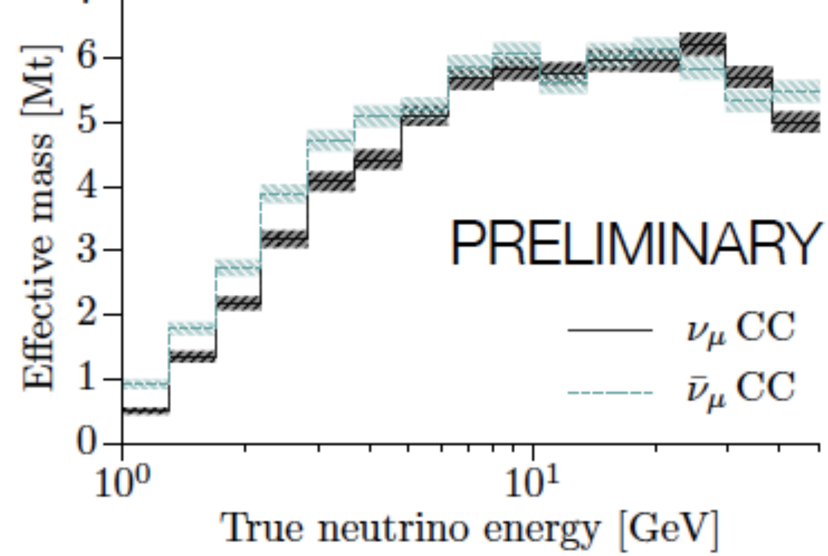
Baseline geometry:

- 40 strings (22 m spacing)
- 96 DOMs per string
- 6 Mton effective mass

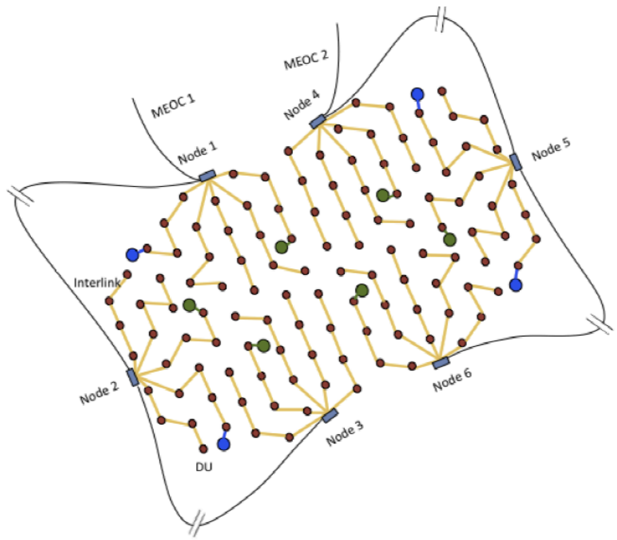


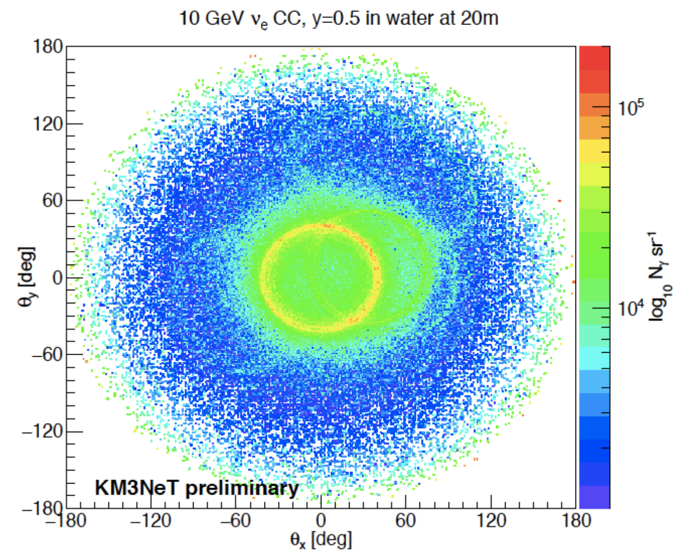


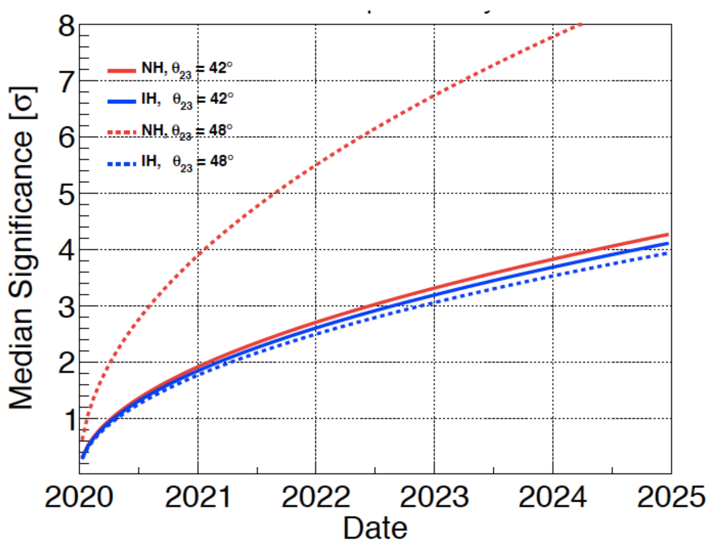
PINGU LOI arXiv:1401.2046



KM3NeT- ORCA – neutrino mass ordering







ORCA
115 strings, 20m spacing horizontal
18 DOMs per string, 6 m spacing vertical
31 3” PMTs per OM
Toulon site

KM3NeT LOI arXiv:1601.07459

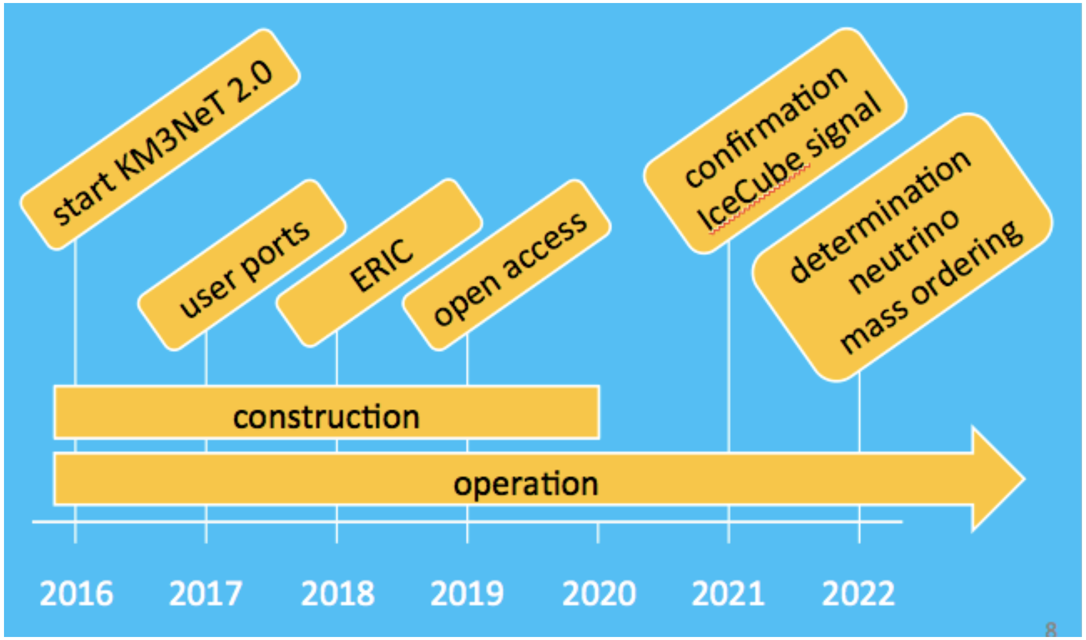
Costs and time line

IceCube Gen2 – costs and time line

- Current cost estimate IceCube Gen2: ~400 M$
  (US accounting, 50% instrumentation and deployment)
- Ongoing R&D → optimize sensitivity, costs, logistics
- Preliminary timeline:

KM3NeT 2.0 – costs and time line

- **KM3NeT is a European high priority project: ESFRI roadmap 2016**
- ORCA and ARCA: construction 2017-2020
  cost: 95 M€ (on top of phase1)
  ongoing funding request: IT 70M€ , FR 12,4M€ , NL 10M€
- Operation costs: 2 M€ per year



- KM3NeT phase 3: 100 – 125 M€, neutrino astronomy incl. Gal. sources

SWOT - Analysis

SWOT – ORCA/PINGU

- **S**trengths
  - fast to realize
  - low cost (ORCA alone: 40 M€)
  - instrumented volume not limited by cavern
  - hardware: proven technology
  - different systematics to reactor experiments
- **W**eaknesses:
  - not yet established funding
- **O**pportunities
  - time window of opportunity rel. to other experiments
  - NMH is an important parameter for CP-violation experiments
  - indirect dark matter WIMP search
- **T**hreats
  - miss time window of opportunity
  - funding unclear

SWOT – HE neutrino astronomy

- **Strengths**
  - Hardware: proven technology, reliable systems
  - Analysis: proven methods

  - IceCube and KM3NeT:
    cover complementary hemispheres resp. see
    the same sources at different energies (1TeV – 10 PeV)

  - KM3NeT ARCA:
    LOI published; unique opportunity to discover Galactic sources
    excellent angular resolution (0.1° ν_μ, 2° cascades)
    cost effective technology, low operation costs (2M€ per year)
  - IceCube Gen2 HEA:
    high statistics study of HE flux (E >10 TeV); sources
    improved sensitivity GZK neutrinos (~5 events per year)
    enhance sensitivity with veto air shower array

SWOT – HE neutrino astronomy

- **W**eaknesses:
  - KM3NeT: not yet established legal entity and project office
  - IceCube: access to South Pole difficult

- **O**pportunities
  - neutrino detection → real neutrino **astronomy**
  - modularity, expandability
  - multi messenger observations
  - Global Neutrino Network → Global Neutrino **Observatory**
  - KM3NeT: RI also for Earth and Sea Science
    access to ERDF (European funds)
    diversification of technology
  - IceCube: develop efficient technology; new transportation schemes

- **T**hreats
  - IceCube: time gap between IceCube and IceCube Gen2 too large

Proposal for recommendations to APPEC

Neutrino Telescope Considerations

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- Europe should support at least one of the efforts to determine the neutrino mass hierarchy through atmospheric neutrinos (ORCA, PINGU).

- Europe should continue to support KM3NeT and examine a funding plan for phase 2 during 2016.

- Europe should support major European contributions to IceCube-Gen2, contingent on NSF approval of the project.

- Europe should support the effort for a Global Neutrino Observatory (Baikal, IceCube, KM3NeT)

Thank you for your attention!

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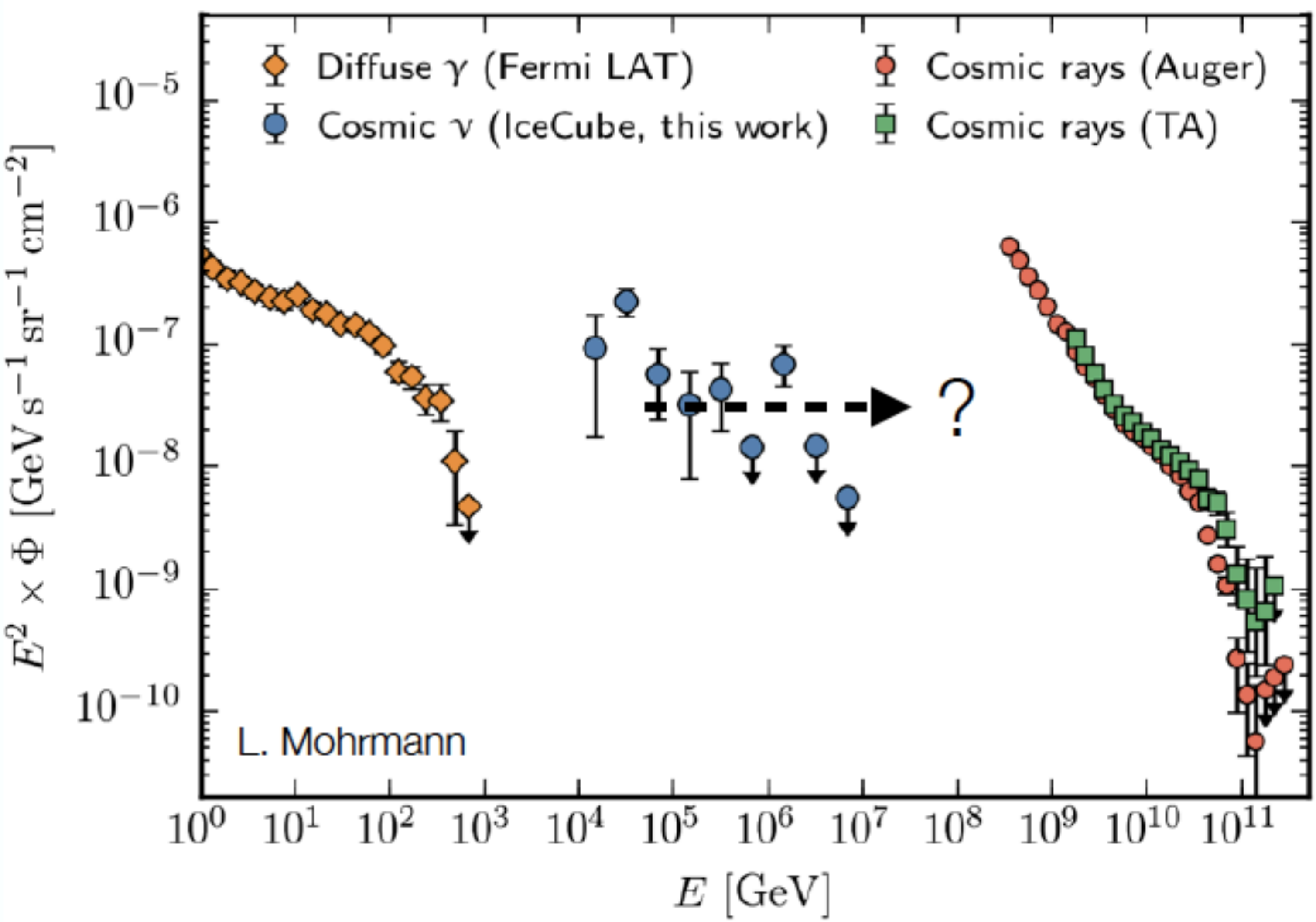
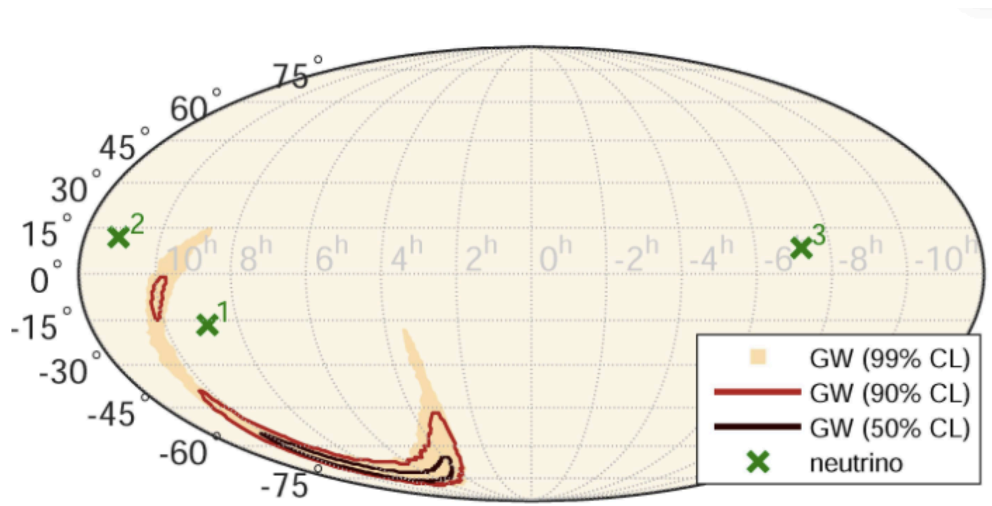
Back-up slides!

Cosmic rays, photons and neutrinos



Waxmann-Bahcall argument holds up so far…need to push spectrum measurement to higher energies to connect the sources

Gravitational waves and neutrinos?



High-Energy Neutrino Follow-Up Search of Gravitational Wave Event GW150914 with ANTARES and IceCube
ANTARES, IceCube, LIGO and Virgo Collaborations: S. Adrián-Martínez et al
(Journal) Preprint; e-print archive arXiv:1602.05411 [astro-ph.HE], 17 February 2016