ANTARES and KM3NeT:
Latest results of the neutrino telescopes in the Mediterranean

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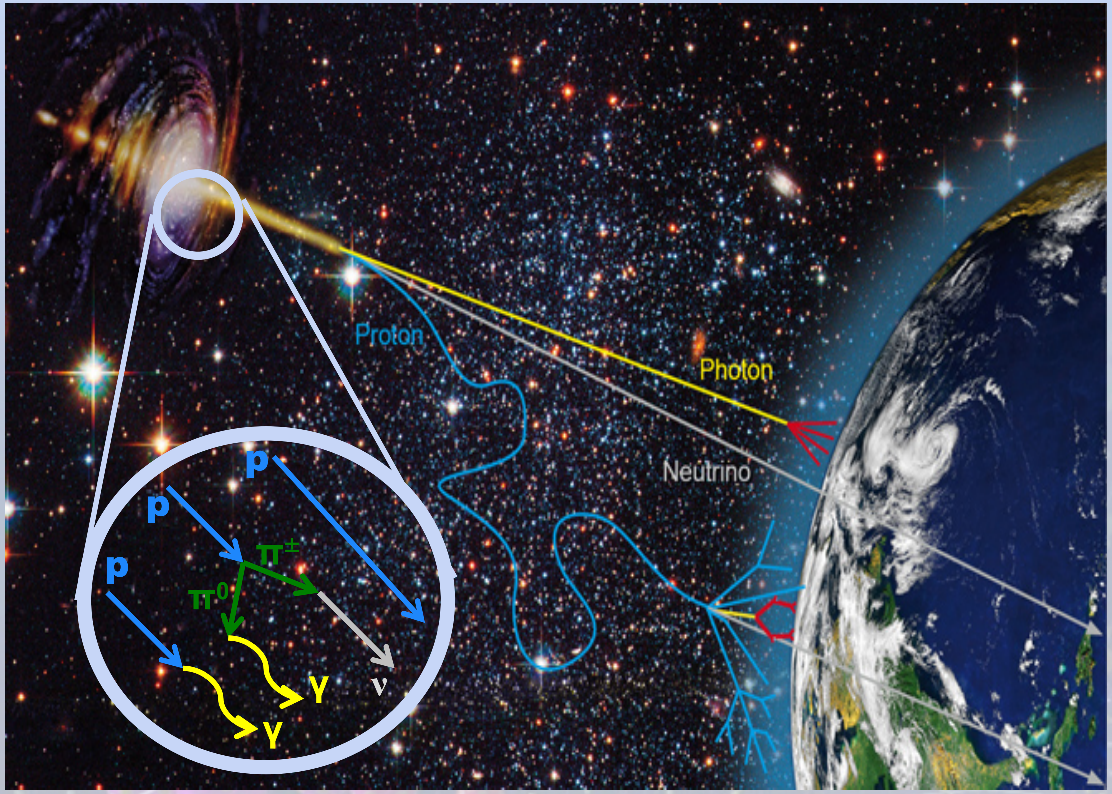
on behalf of ANTARES and KM3NeT collaborations

ANTARES and KM3NeT:
Latest results of the neutrino telescopes in the Mediterranean

- Neutrino astronomy
- ANTARES and KM3NeT detectors
- Detector performances
- ANTARES latest results
- KM3NeT status and expected results
- Conclusions

Neutrino astrophysics



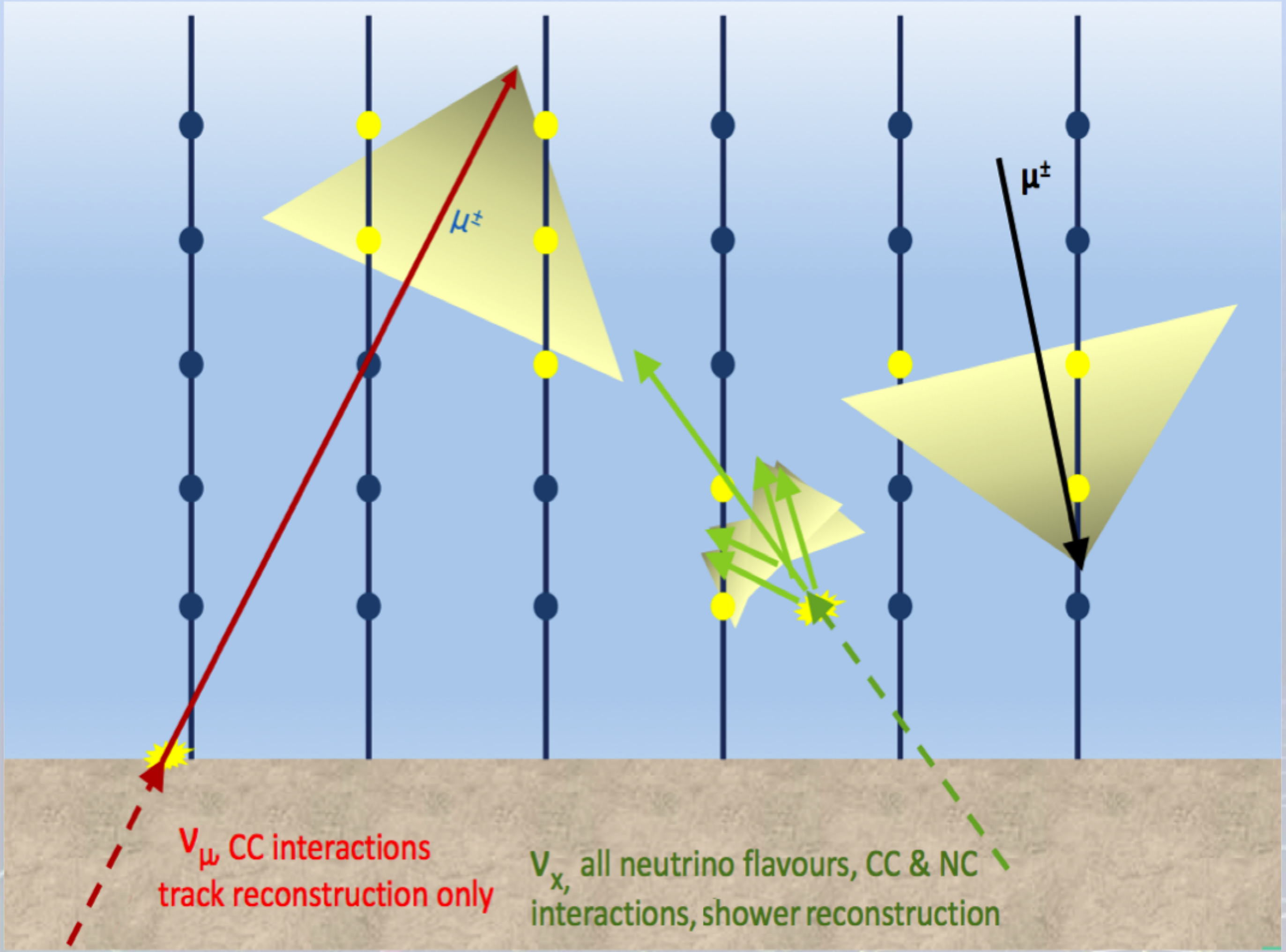
Charged Cosmic Rays
✔ Copiously produced
✘ Directions scrambled by magnetic fields

High Energy Gamma Rays
✔ Produced both by hadronic and leptonic mechanisms
✘ Absorbed on dust and radiation

UltraHigh Energy Cosmic Rays
✔ Not strongly deflected by magnetic field
✘ Limited by GZK cut-off

Neutrinos ✔ Not affected by magnetic fields and radiation, not absorbed by matter
✘ Very low interaction cross section

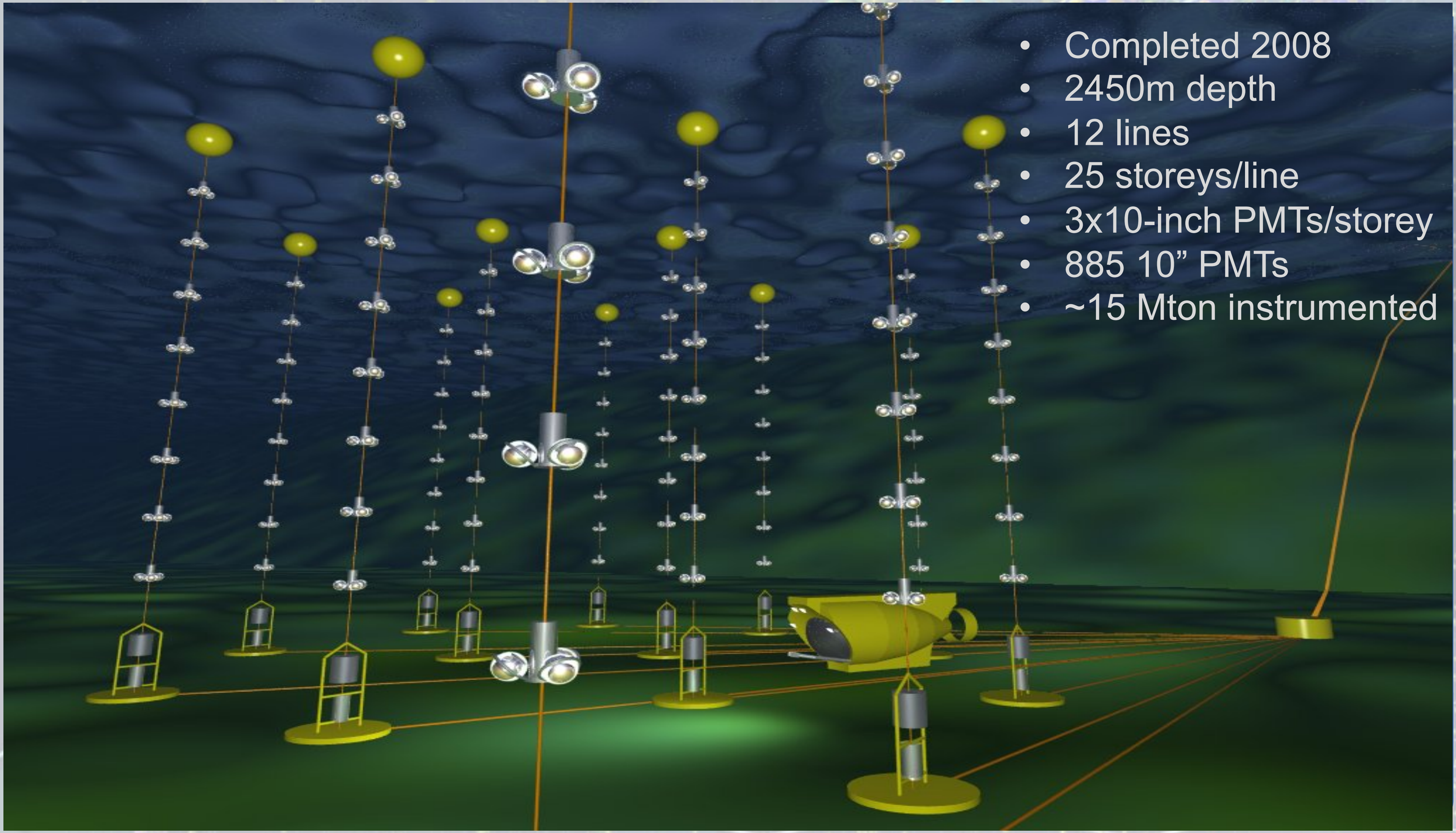
Neutrino detection principle



An array of PMT detects the Cherenkov light induced by the particles produced in the neutrino interaction

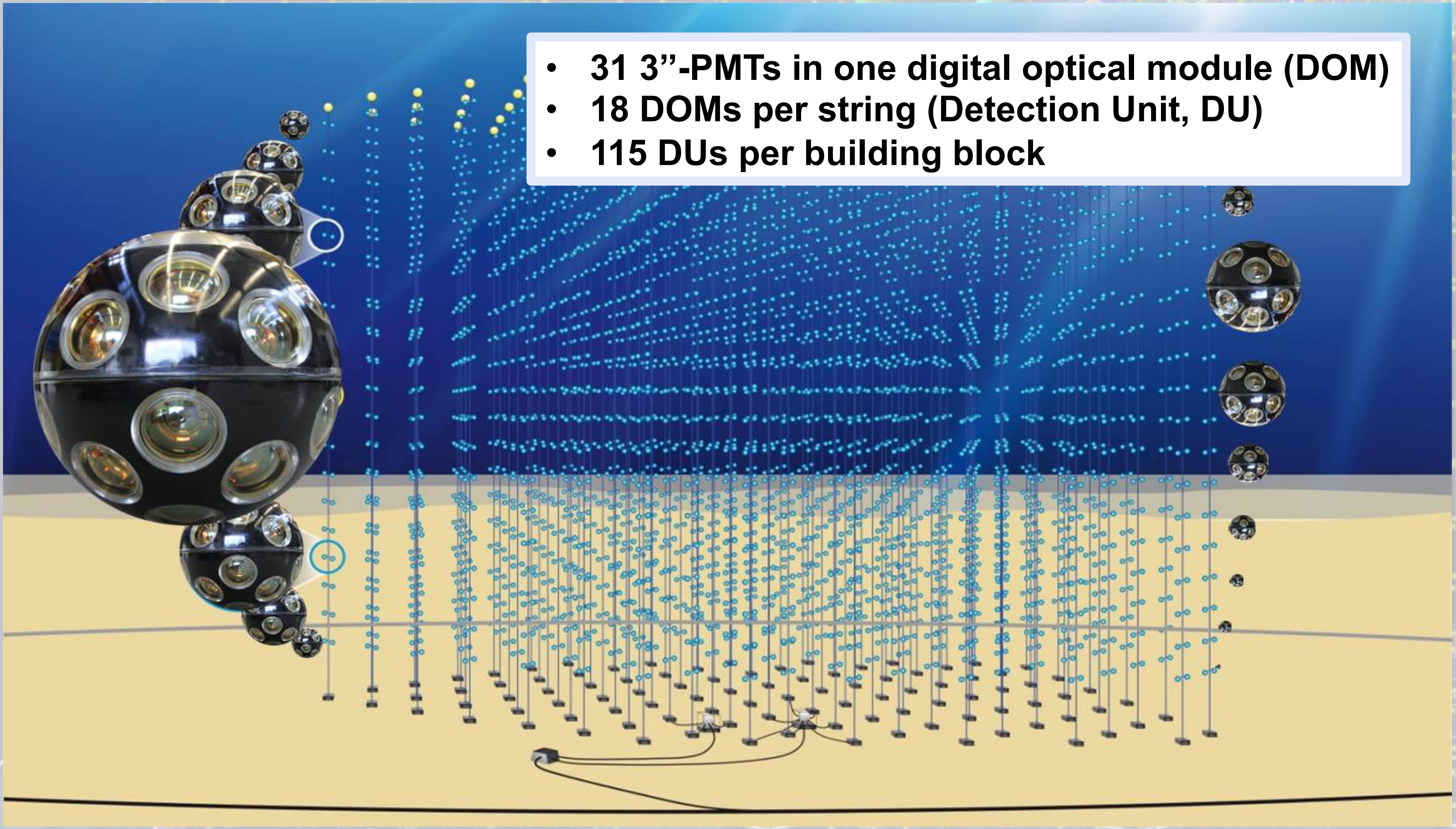
The measurement of position and time of the detected photon allows the reconstruction of the direction and the energy of the event

The ANTARES detector



- Completed 2008
- 2450m depth
- 12 lines
- 25 storeys/line
- 3x10-inch PMTs/storey
- 885 10” PMTs
- ~15 Mton instrumented

The KM3NeT detector



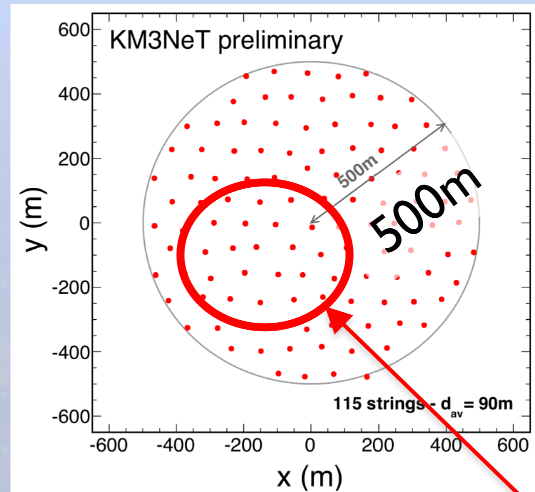
- 31 3''-PMTs in one digital optical module (DOM)
- 18 DOMs per string (Detection Unit, DU)
- 115 DUs per building block

ANTARES & KM3NeT technologies

Advantage of KM3NeT
1) Segmented photocathode, unambiguous recognition of coincident hits
2) Directional sensitivity
3) 4π solid angle coverage by each DOM
4) Reduced cost and risk of failure thanks to a simple mechanical structure of the detection unit

KM3NeT ARCA & ORCA

ARCA
Astroparticle Research with Cosmics in the Abyss
Line distance = 90 m
Vertical DOM dist. = 36 m
Depth = 3500 m



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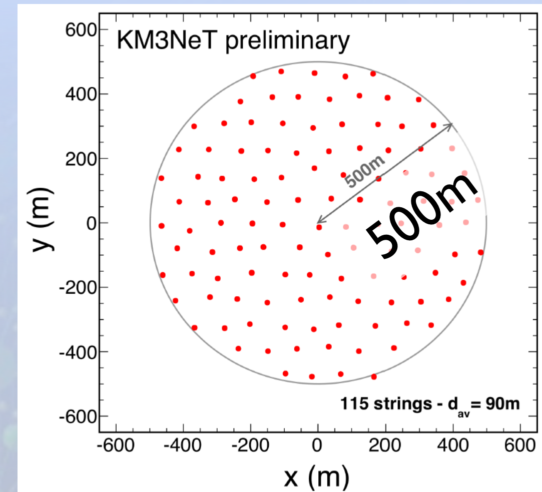
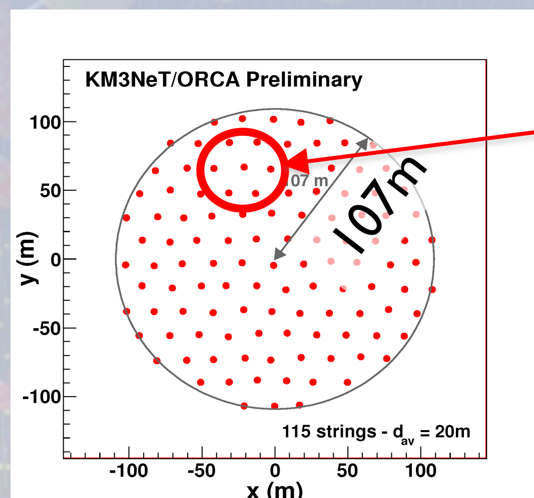


ORCA
Oscillation Research with Cosmics in the Abyss
Line distance = 20 m
Vertical DOM dist. = 9 m
Depth = 2475 m

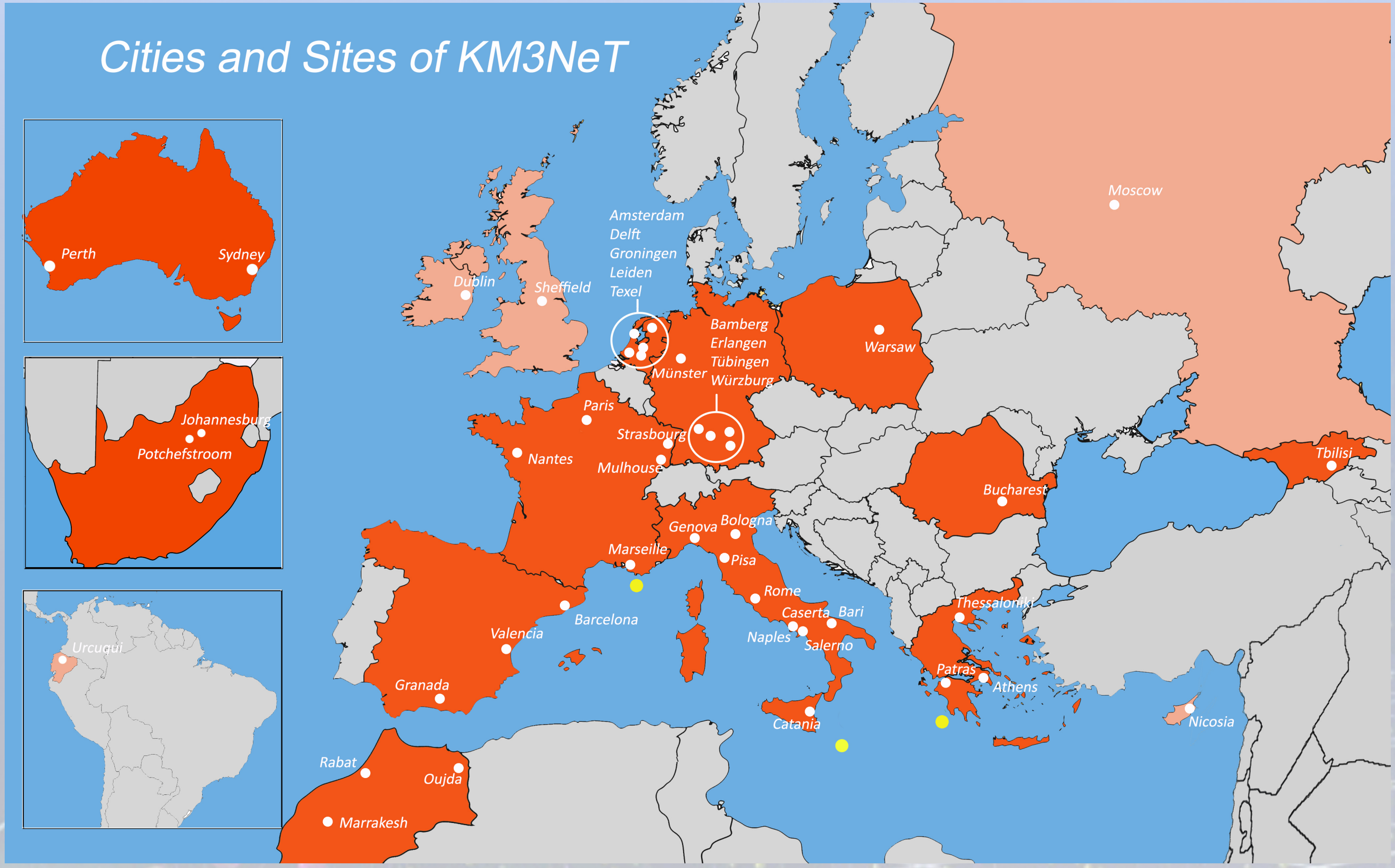


Phase1 (fully funded)

Phase 2 partially funded

KM3NeT 2.0 Letter of Intent: arXiv:1601.07459 and J.Phys. G43 (2016) 084001

ANTARES & KM3NeT collaborations



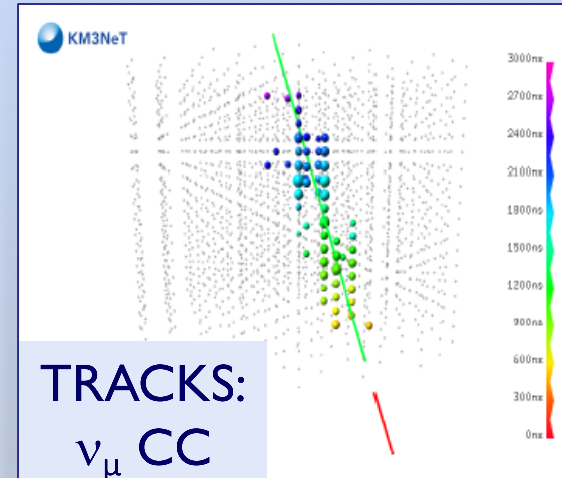
2 sites:
Toulon, FR
ANTARES
KM3NeT/ORCA

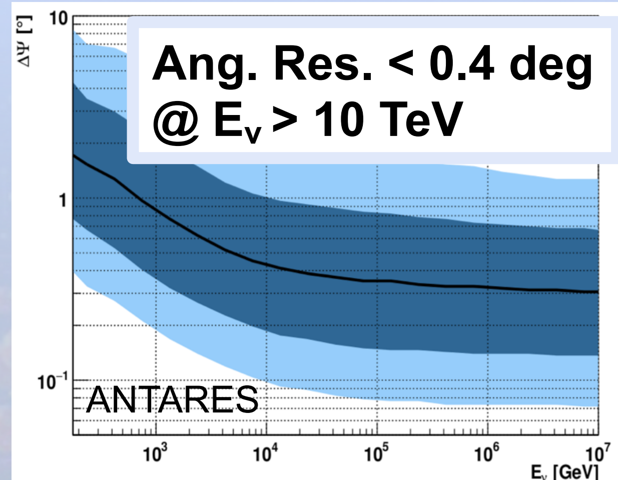
Capo Passero, IT
KM3NeT/ARCA

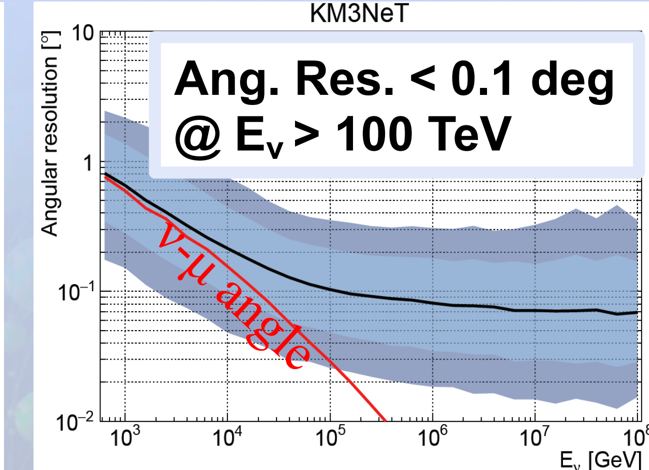
3d site
under study
(Pylos,GR)

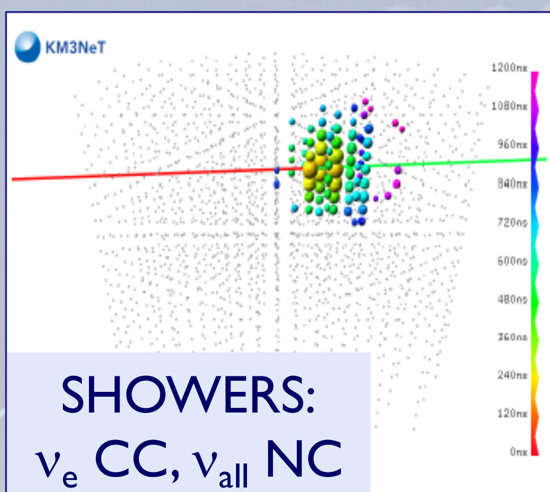
~40 institutes
14 countries

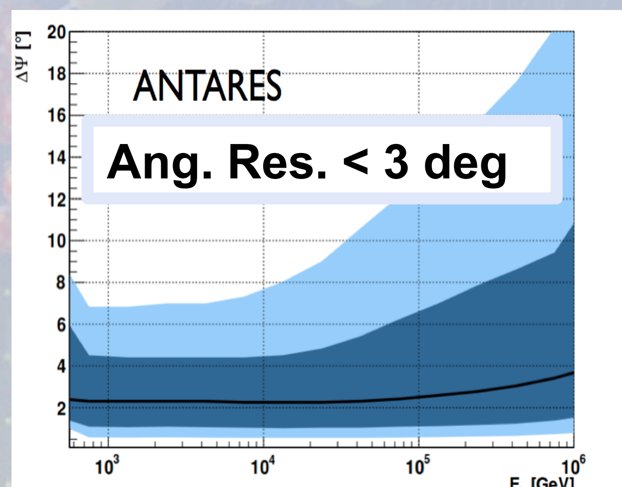
ANTARES vs KM3NeT-ARCA performances

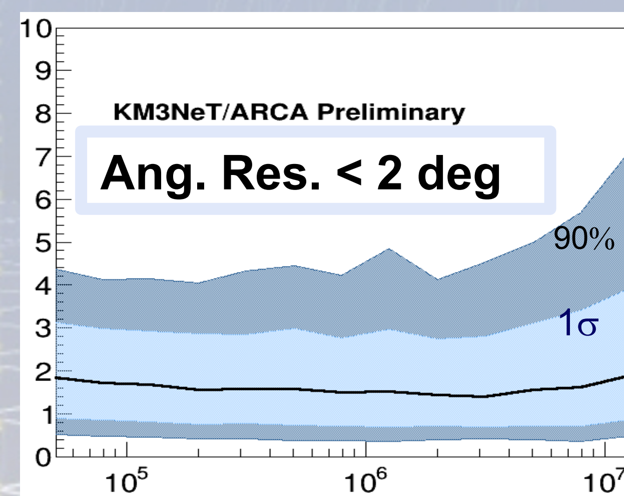






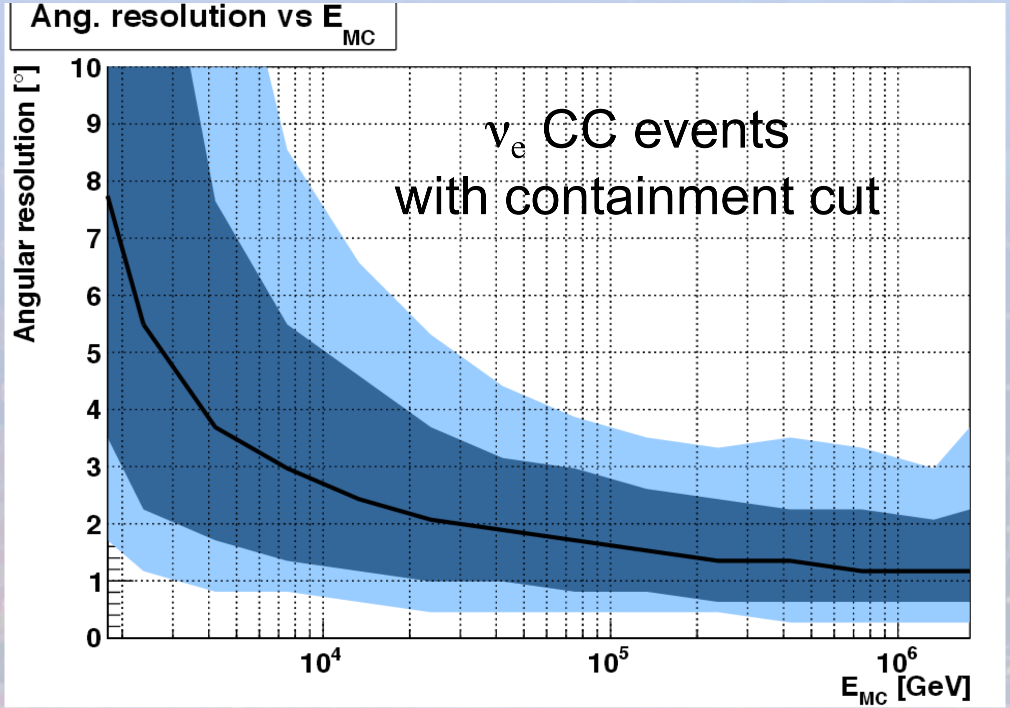






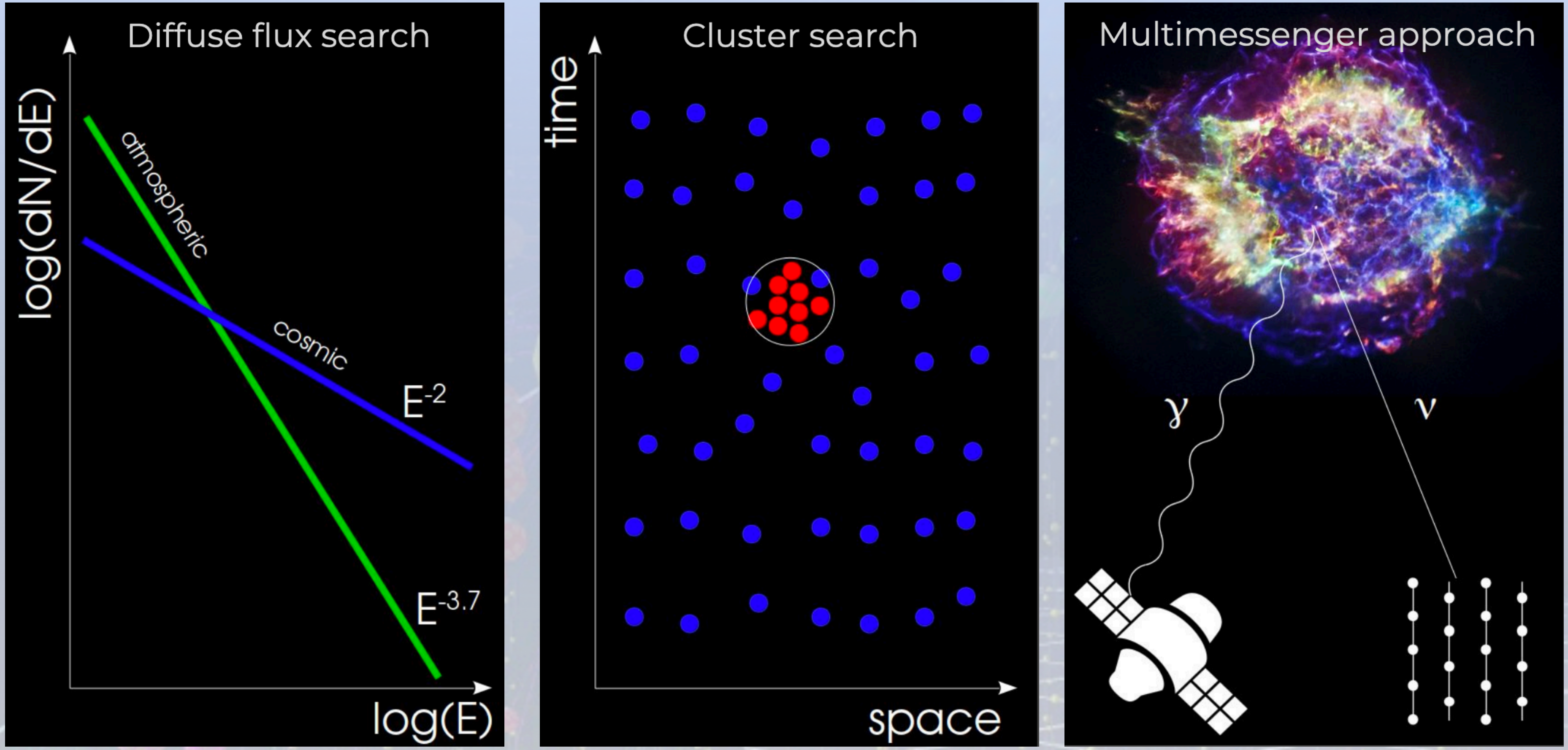
KM3NeT-ORCA performance

Showers



- Muon energy accuracy: Δ(log10 E)=0.25-0.3 @ E > 10 TeV
- Shower energy accuracy: 5-10% at E > some 10 TeV

Astrophysical Neutrinos: Search methods

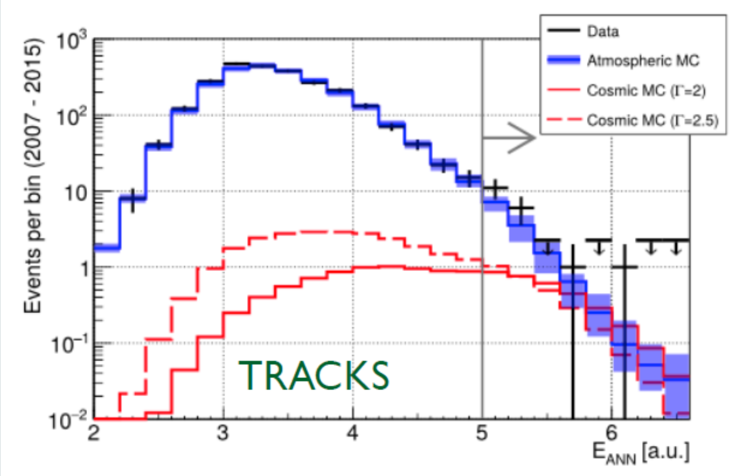


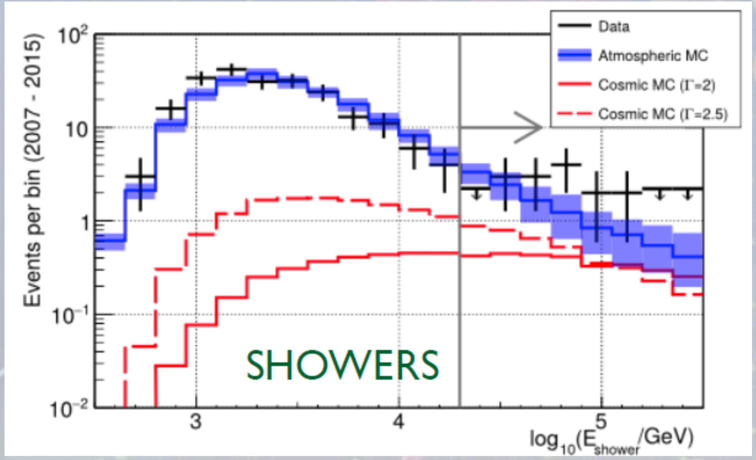
Latest results from ANTARES

- Diffuse flux search
- Point-source search
- Galactic plane
- Multi-messenger strategies
    - Gravitational waves
    - Fast Radio Burst (FRB)
    - Bright Gamma Ray Burst (GRB)
- Moon shadow

Diffuse flux search

All-sky / All-flavor neutrino search (years 2007-2015)





Reconstructed events after quality cuts:

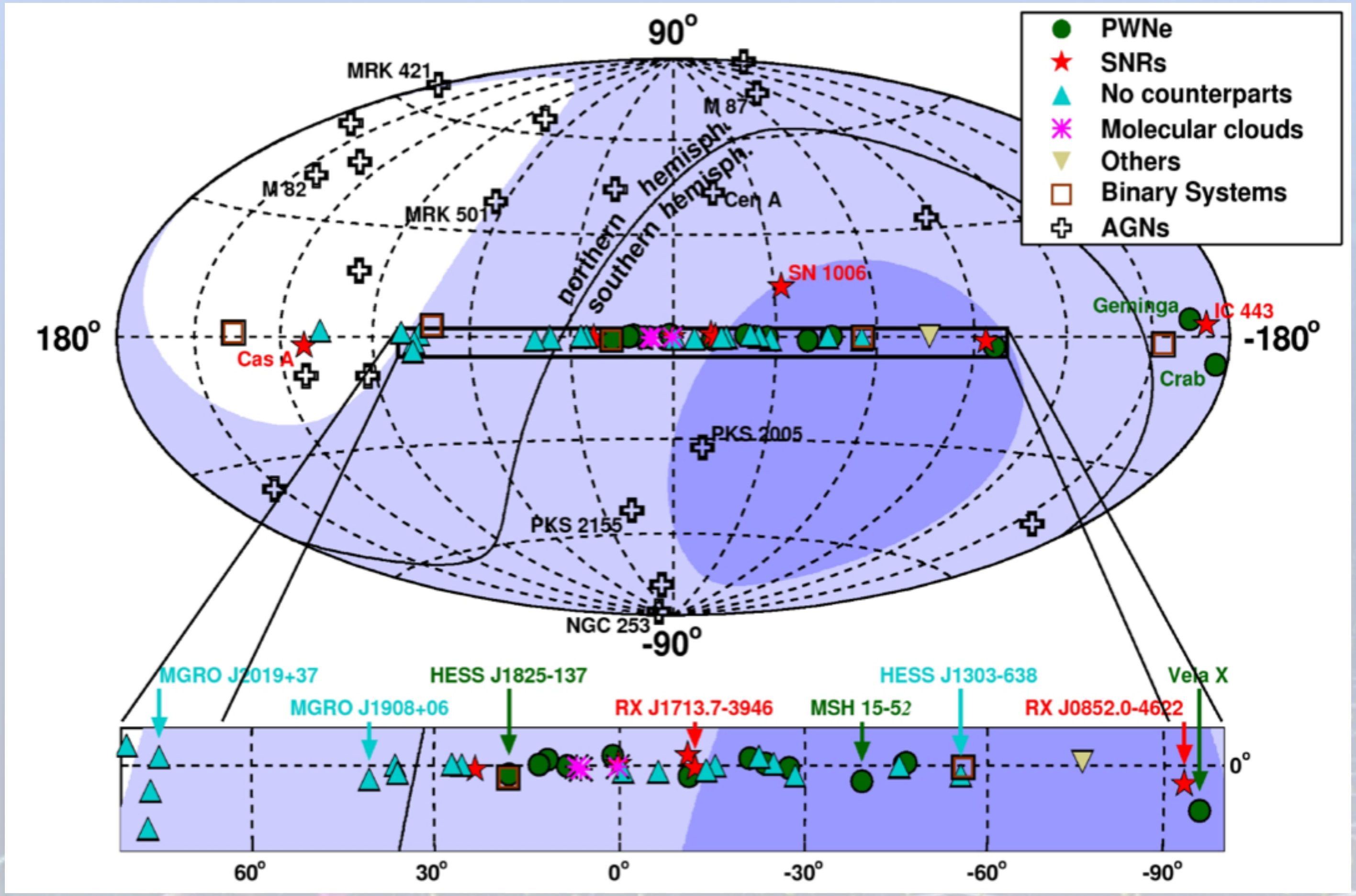
	Bkg expectation	Signal expectation	N events measured
Tracks	**13.5+/-4**	**3-3.5**	**19**
Showers	**10.5+/-4**	**3-3.5**	**14**

Results compatible with IceCube diffuse flux:

- 1.6 σ excess
- Null cosmic neutrino contribution rejected at 85% CL

Astrophys. J. Lett. 853, L7 (2018)

Point-source flux search



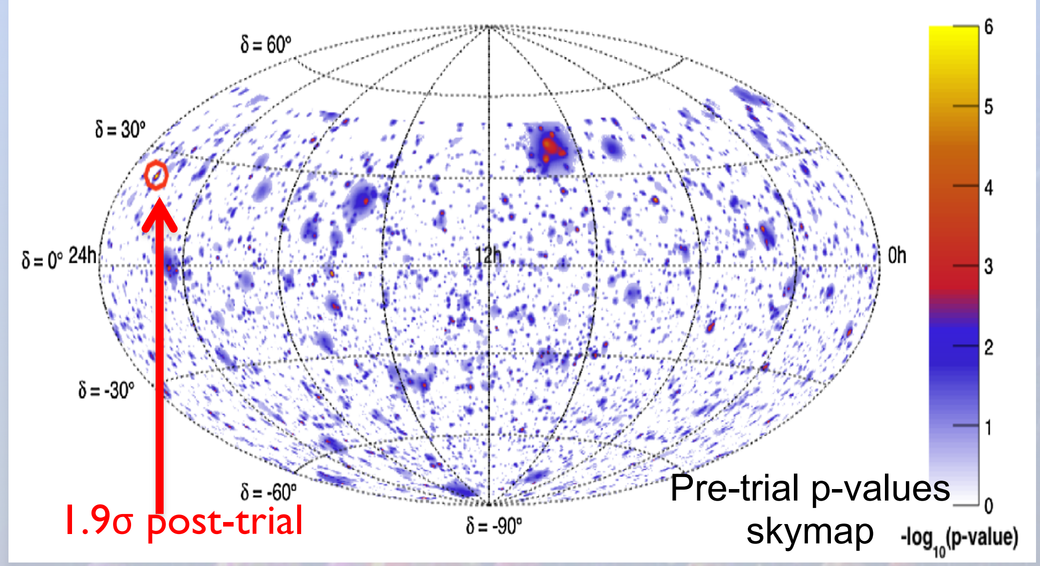
Most of the galactic gamma ray sources are in the southern sky

Best pointing from a N-Hemisphere telescope

Searches:
- Full-sky
- Candidate list
- Galactic centre

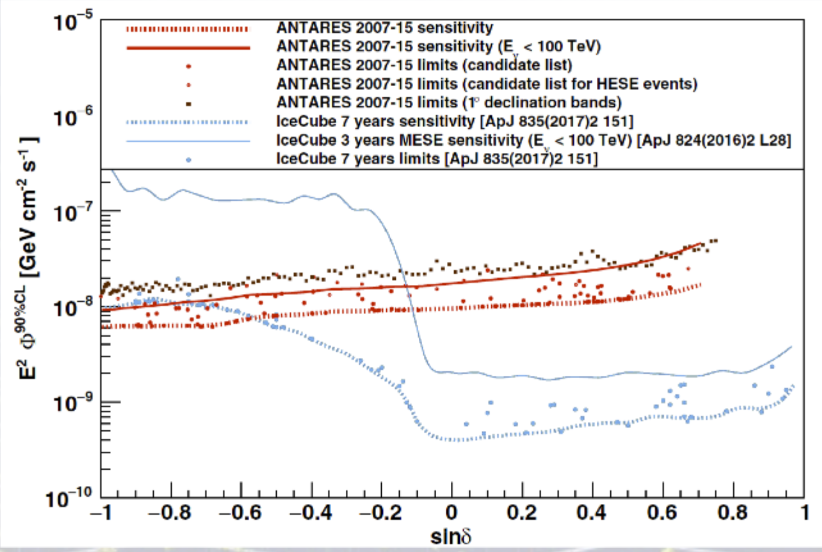
Point-source flux search

All-flavor neutrino search (years 2007-2015): 7622 track-like + 180 shower-like events



Phys. Rev. D 96, 082001 (2017)

Sensitivities and upper limits (90% C.L.)



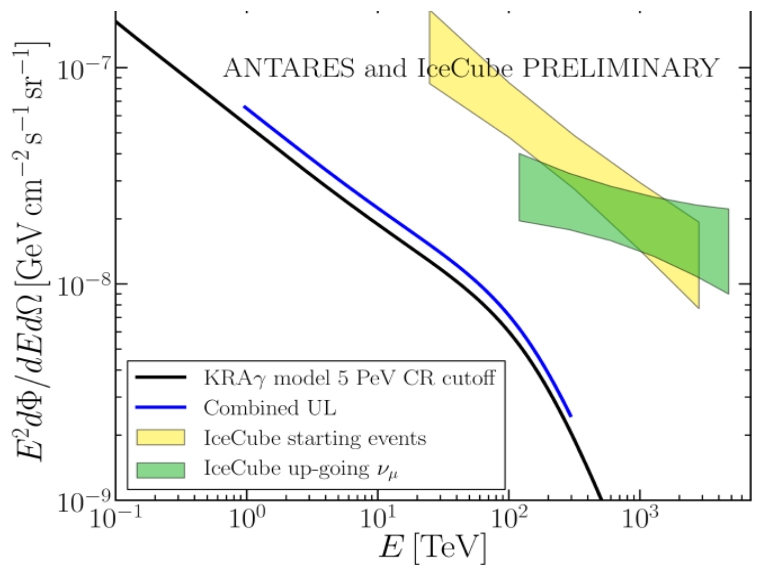
Most sensitive limits for a large fraction of Southern sky, especially at E<100 TeV

Galactic Plane search

"KRA Gamma model" has been introduced recently to explain the high-energy gamma ray diffuse Galactic emission.
This model reproduces Fermi & Milagro data

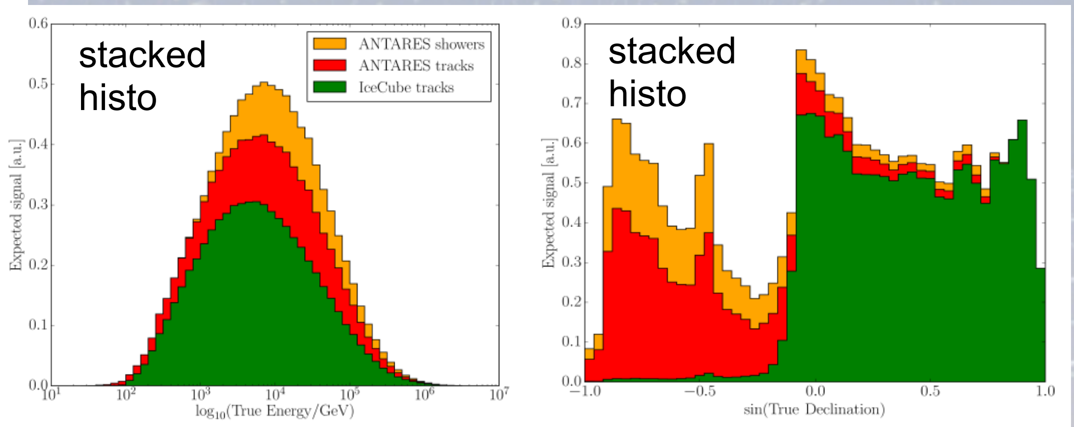
ApJ. Lett., 815:L25, 2015

Phys. Rev. D96 (2017) 062001
ApJ 849 (2017) 67

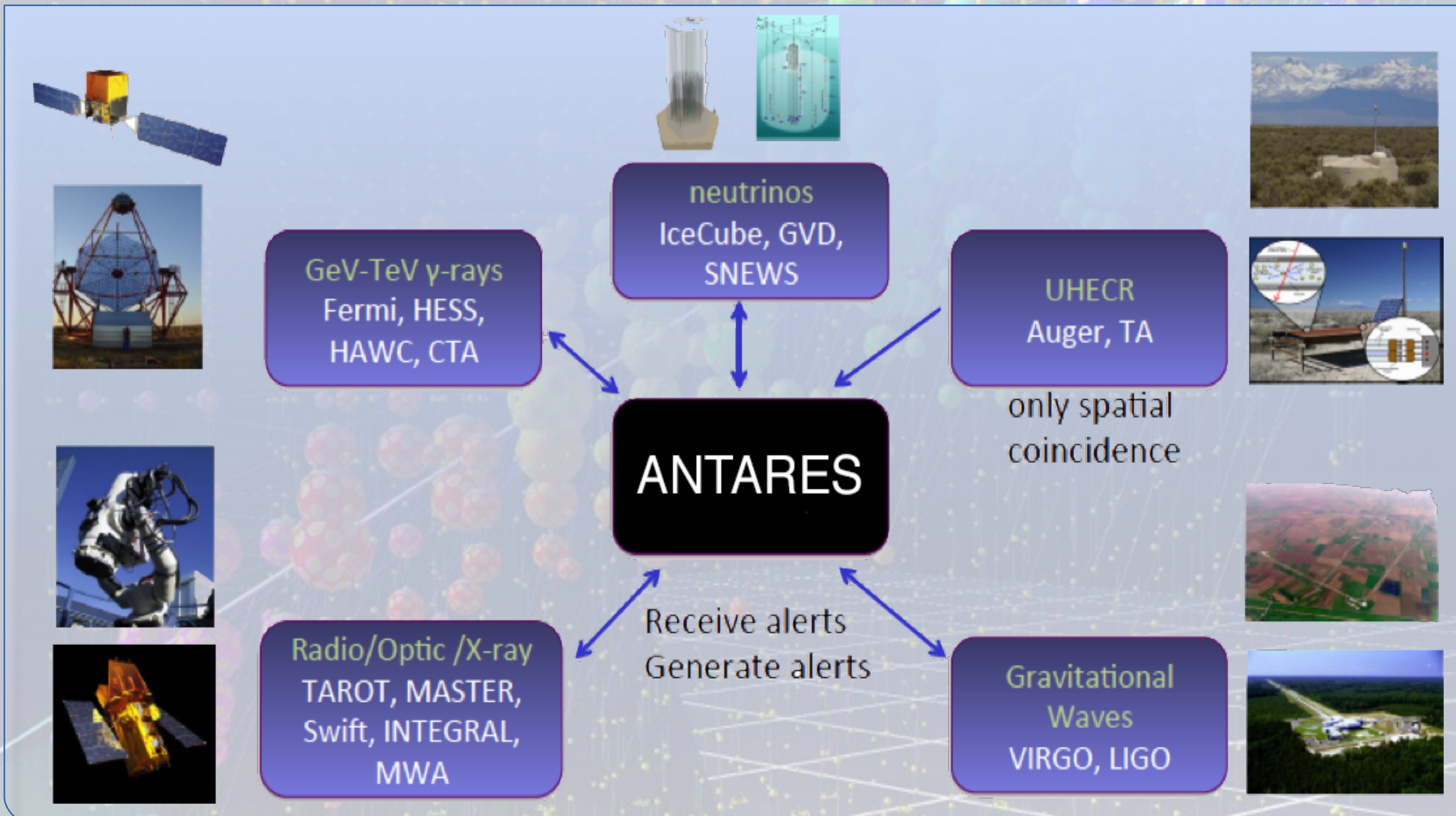


Combined U.L. (ANTARES+ IceCube) excludes the diffuse Galactic neutrino emission as the major cause of the "spectral anomaly" between the two hemispheres measured by IceCube

Relative contribution of ANTARES and IceCube



Multi-messenger strategies

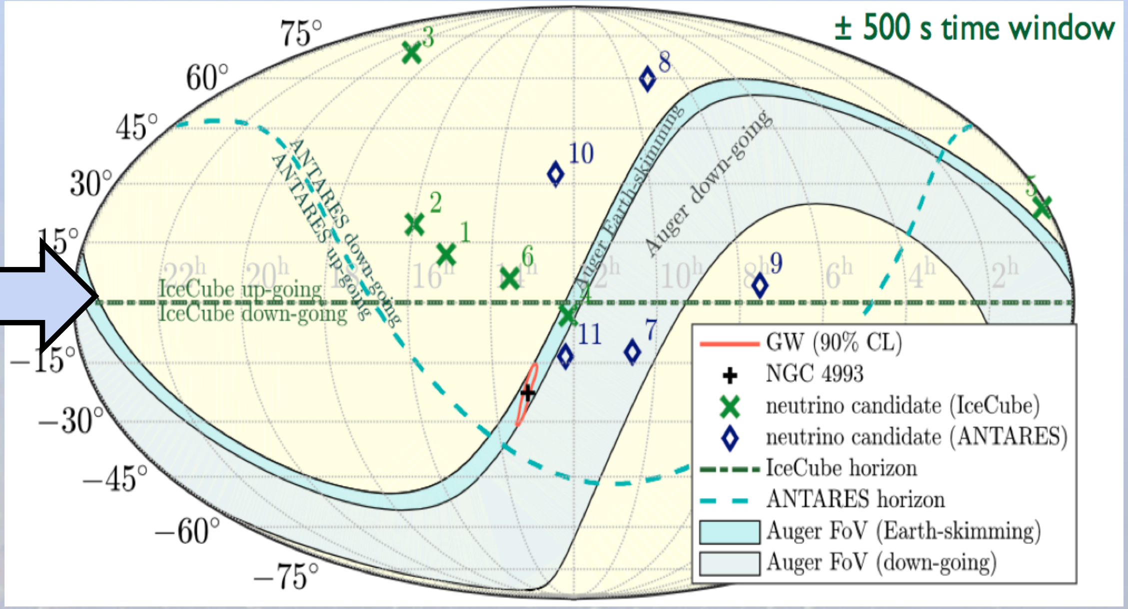


Gravitational Waves

Recent spotlight on the GW events detected by the Ligo-Virgo Collaboration:

- GW150914 (BBH merger)
- GW151226 (BBH merger)
- LVT151012 (candidate)
- GW170104 (BBH merger)
- GW170817 (NS merger)

Neutrino follow-up on all of them, joint searches with IceCube (and also Pierre Auger Observatory)

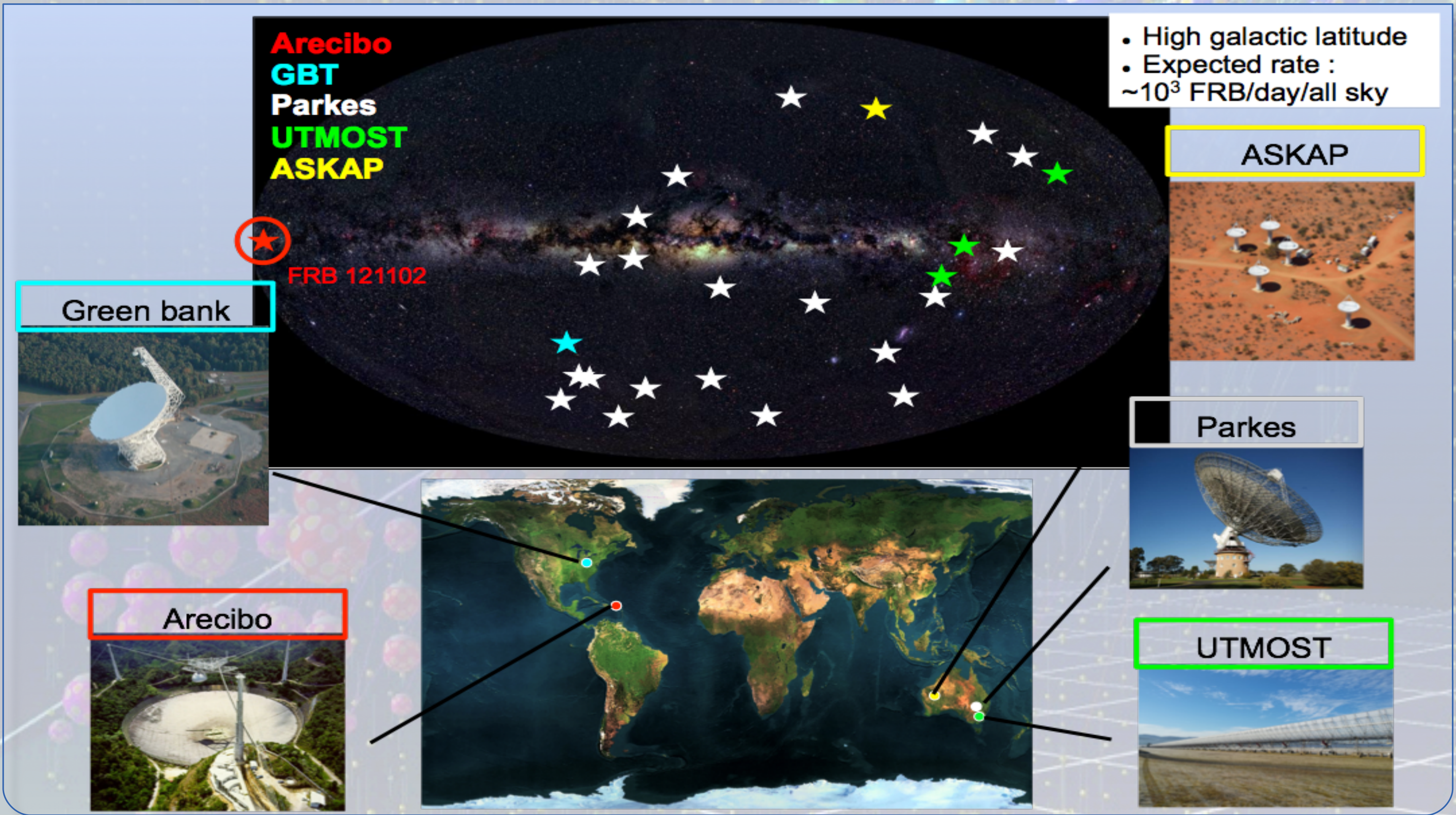


So far no coincidences with neutrino from the region of interest at 90% C.L.:

- not so likely for BH-BH merging;
- the jet of the NS-NS event (GW170817) was not aligned to our Line of Sight to provide a visible neutrino signal → upper limit on the neutrino fluence from each events over the whole spectrum ApJL 850 L35 (2017)

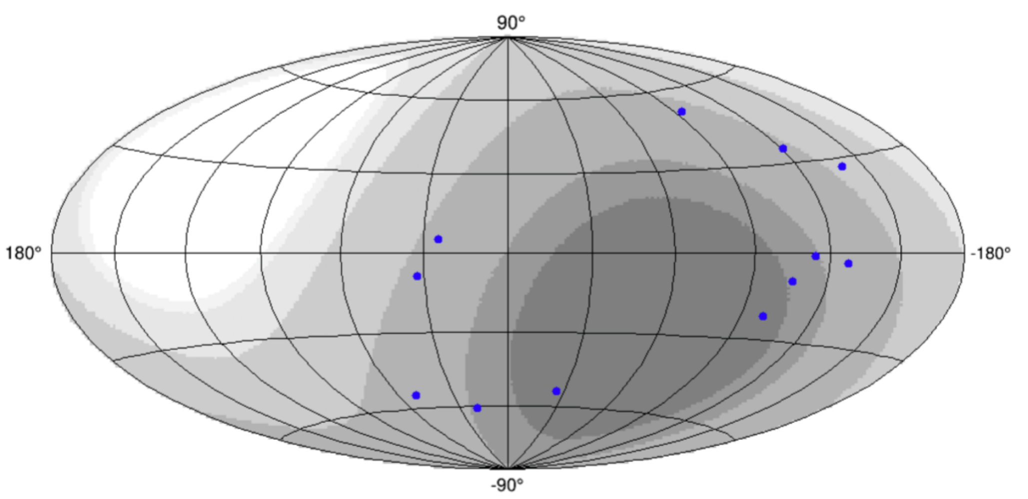
ANTARES and a few KM3NeT lines operational for Virgo/LIGO run 03 !

Fast Radio Bursts



Fast radio bursts

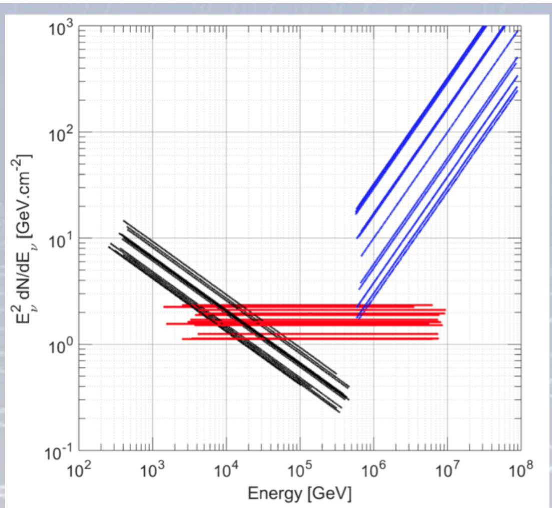
12 fast radio burst selected for ANTARES analysis



FRB	z_{DM}	T_0 (UTC)	RA (°)	dec (°)	radio telescope
131104	0.59	18:03:59	101.04	-51.28	Parkes
140514	0.44	17:14:09	338.52	-12.31	Parkes
150215	0.55	20:41:41	274.36	-4.90	Parkes
150418	0.49	04:29:04	109.15	-19.01	Parkes
150807	0.59	17:53:55	340.10	-55.27	Parkes
151206	1.385	06:14:56	290.36	-4.13	Parkes
151230	0.76	17:03:26	145.21	-3.45	Parkes
160102	2.13	08:28:38	339.71	-30.18	Parkes
160317	0.70	08:30:58	118.45	-29.61	UTMOST
160410	0.18	08:16:54	130.35	6.08	UTMOST
160608	0.37	03:52:24	114.17	-40.78	UTMOST
170107	0.48	20:05:45	170.79	-5.02	ASKAP

90% C.L. ANTARES upper limits on the neutrino fluence for the power law spectral models with
- γ = 1.0 (blue)
- γ = 2.0 (red)
- γ =2.5 (black)

for each FRB.



Bright gamma ray burst

4 bright GRB have been selected:
GRB080916C, GRB110918A, GRB130427A and GRB130505A

MNRAS 469,906–915 (2017)

Upper limits

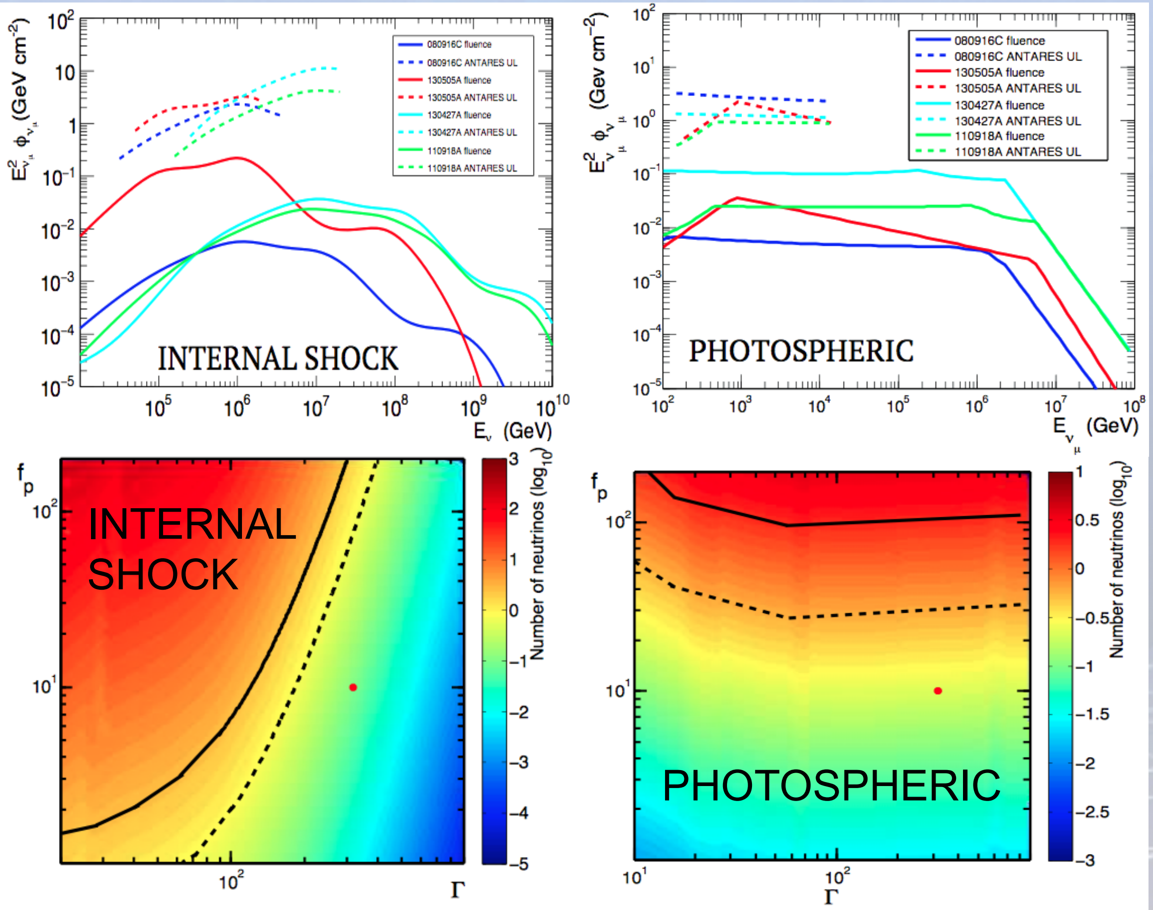
Two model investigated:

- photospheric
- internal shock

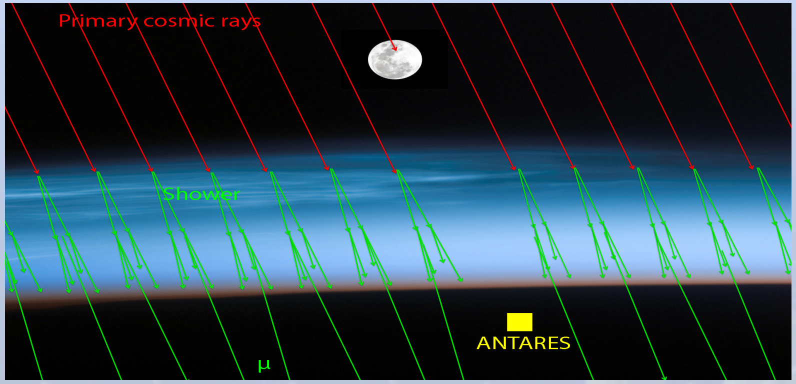
Constraints on baryonic component f_p and Lorentz factor Γ

•90% C.L. (solid line)

•50% C.L. (dashed line)



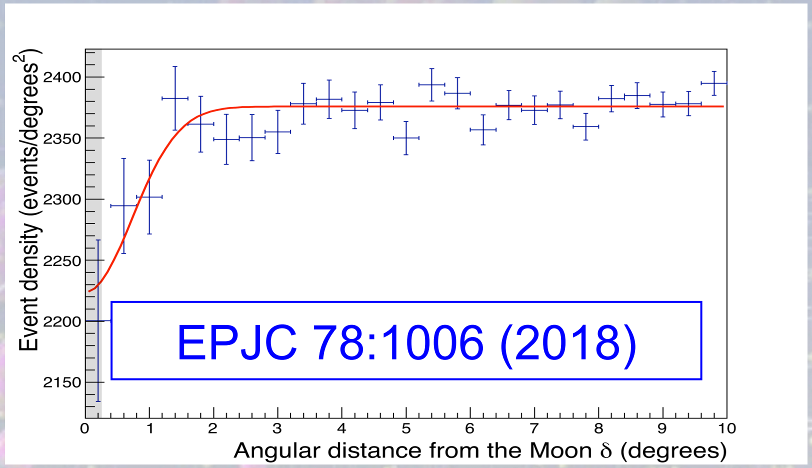
Moon shadow

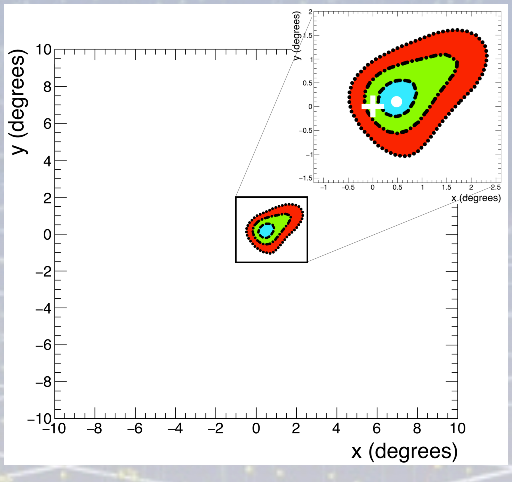


One possibility to measure the pointing accuracy is to analyse the shadow of the Moon, i.e. the deficit in the atmospheric muon flux in the direction of the Moon induced by absorption of cosmic rays.

Moon shadow significance **3.5 σ**; Angular resolution **0.73° ± 0.14°**

The position of the Moon shadow is consistent with **not shifted pointing**.





Latest results from KM3NeT

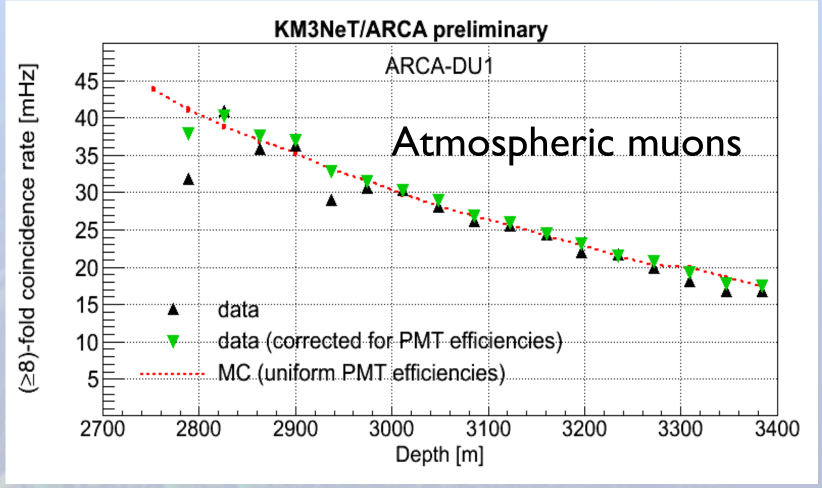
- Status and first detections
- KM3NeT-ARCA
  - Diffuse flux expected performance
  - Point-source expected performance
- KM3NeT-ORCA
  - Neutrino mass hierarchy sensitivity

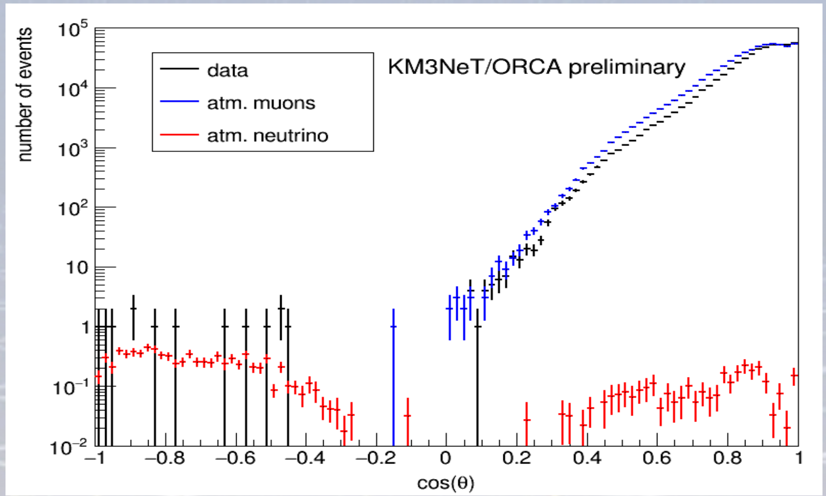
Status and first results

ARCA
- 3 strings deployed Dec 2015 & May 2016
- 2 out of 3 operated, string #3 with short in power system, recovered
- Full restoration of sea-bed network

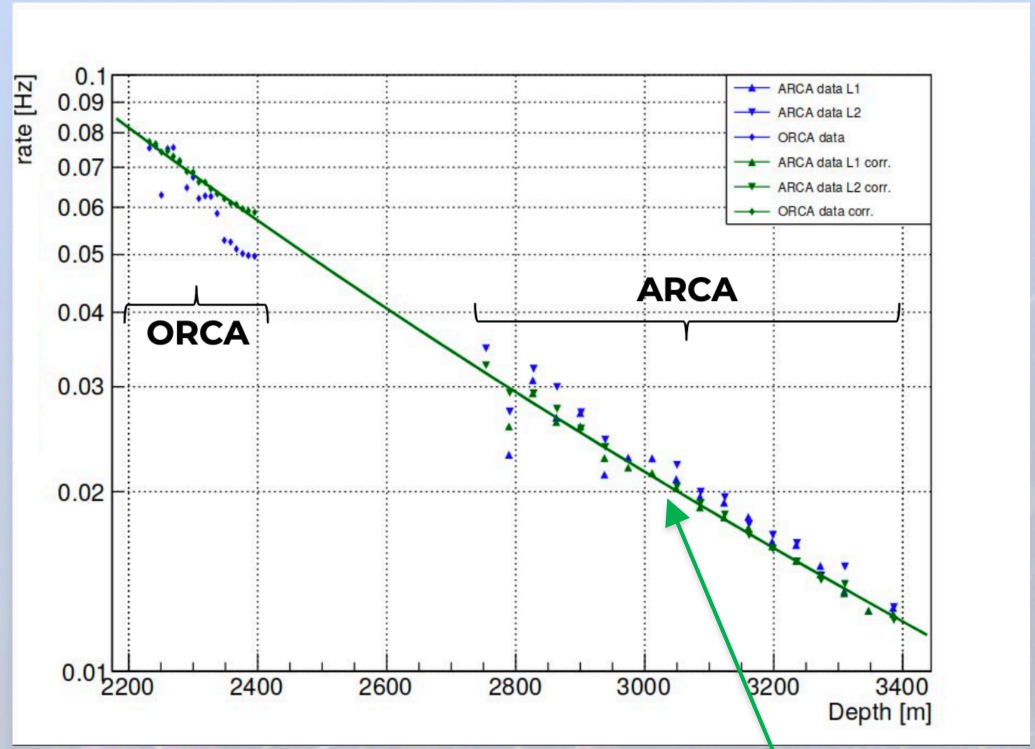
ORCA
- Successful deployment & operation of first string (Sept 2017)
- Cable problem, replacement in summer 2018, resumed operations

DOM and DU assembly proceeding
Deployment foreseen after repairs, consistent with schedule





First results of KM3NeT



- Event = Coincident hits in 8+ PMTs from the same module, within 15 ns
- ARCA: 1269 hours , 2 strings
- ORCA: 320 hours , 1 string
- Correction for DOM dependent PMT efficiency applied

Muon flux model from Phys. Rev. D 58 (1998) 054001

Deployment of a KM3NeT string... KM3NeT is becoming a reality !

INFN
Istituto Nazionale di Fisica Nucleare
KM3NeT
ANTARES

Diffuse flux performance (KM3NeT-ARCA)

Expected 5σ significance on diffuse IC flux in < 1year:

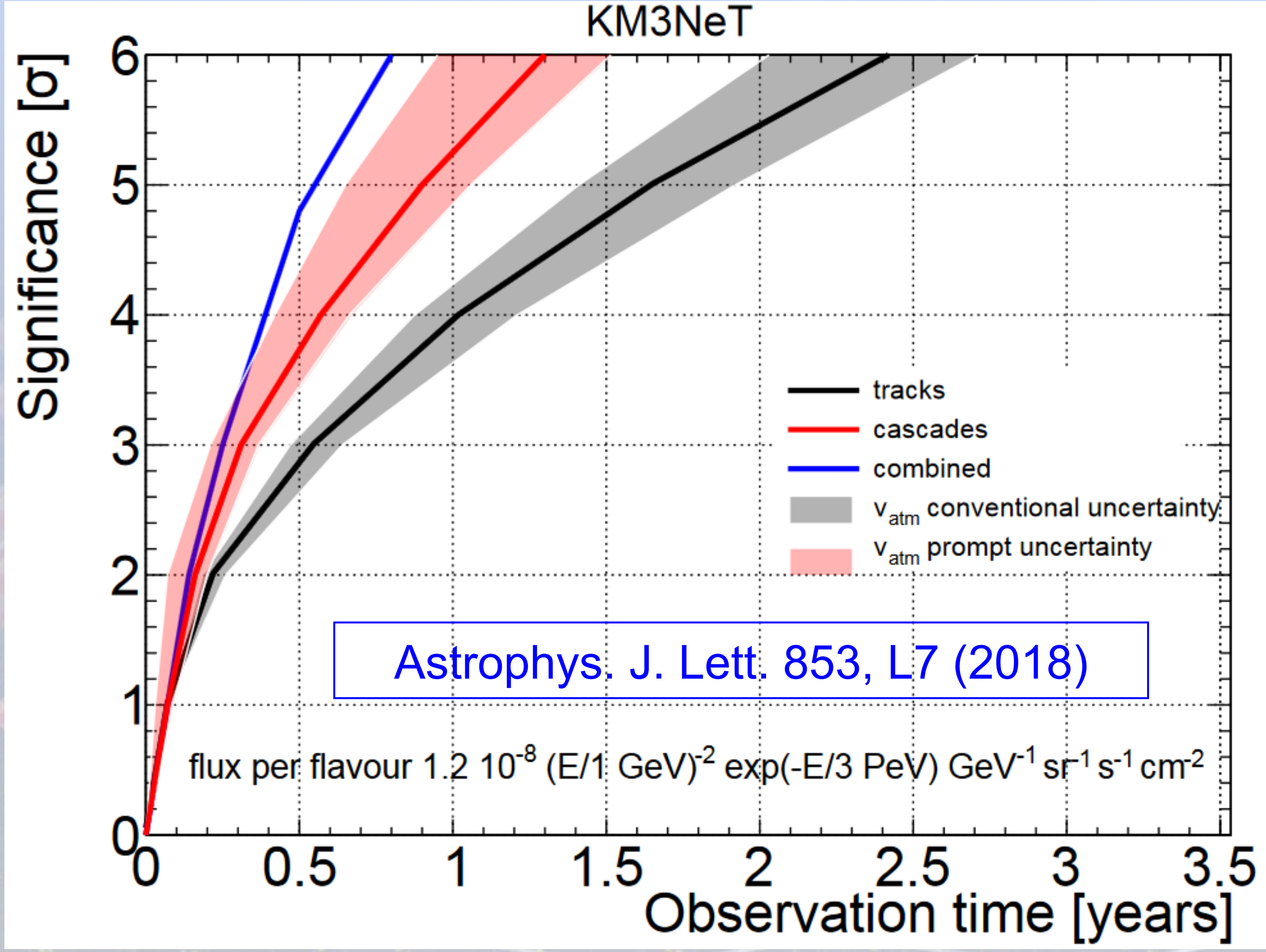
Tracks per year:

- 6 signal
- 4 background

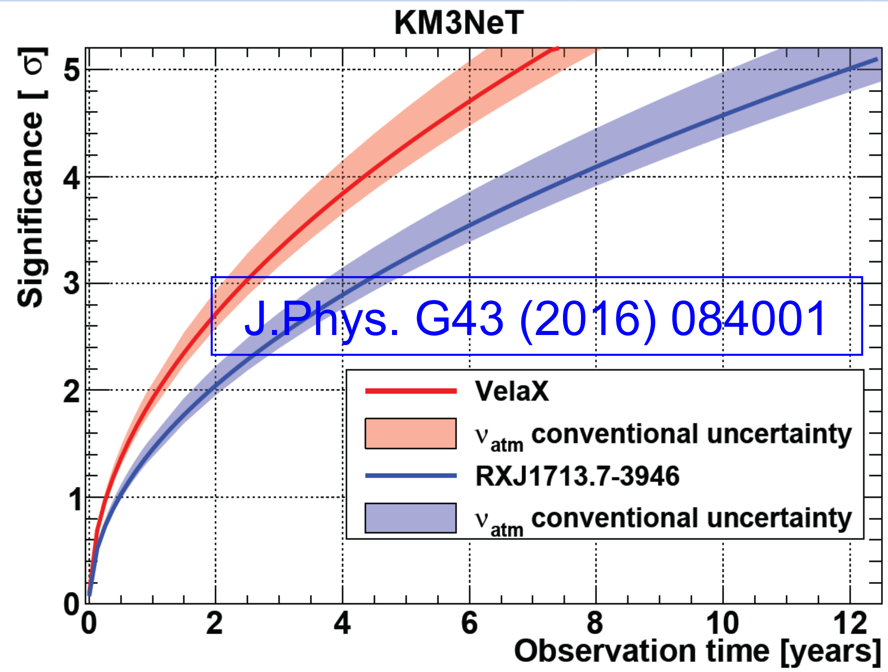
Cascades per years:

- 16 signal
- 9 background

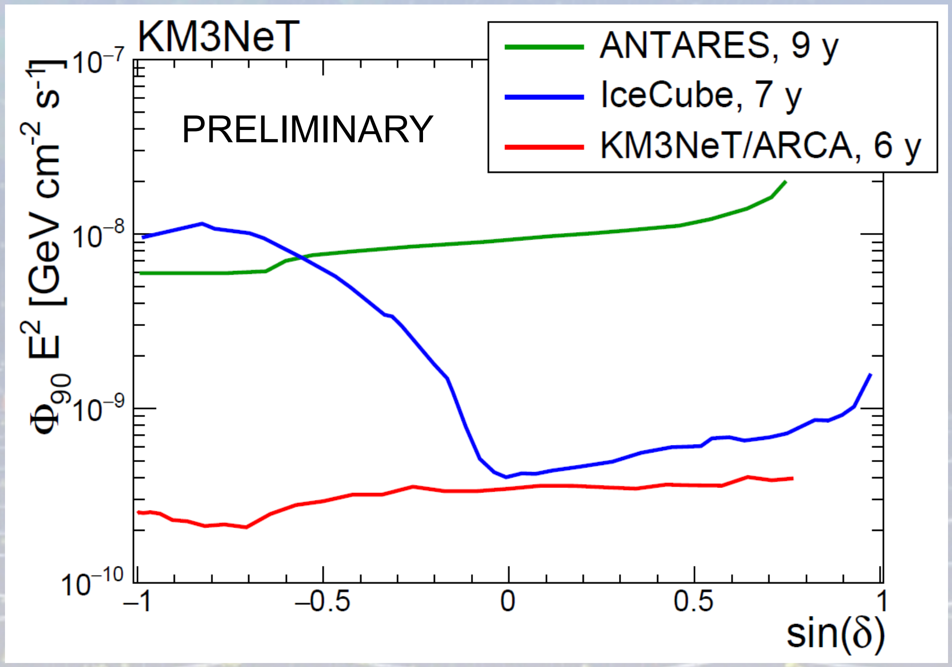
KM3NeT and IceCube are complementarity in their field of view and energy range



Point source performance (KM3NeT-ARCA)

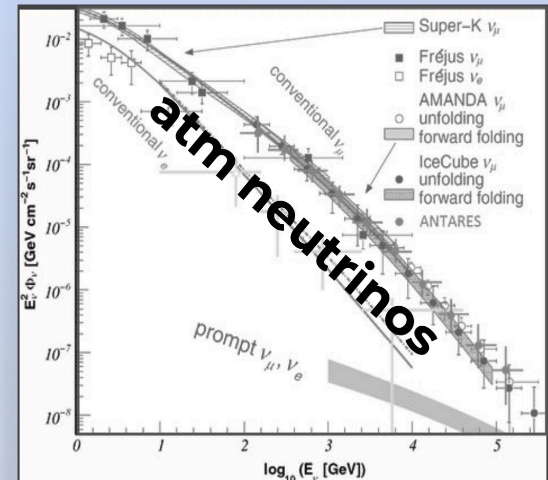


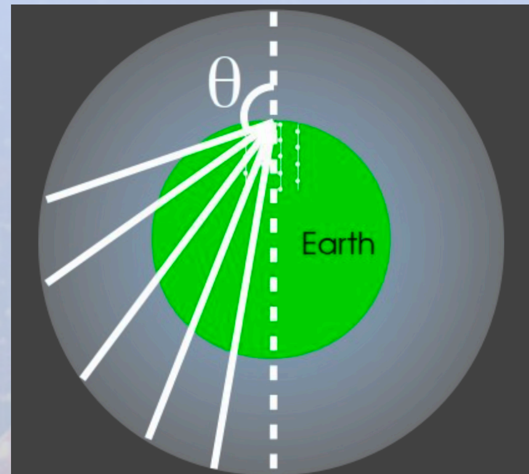
KM3NeT-ARCA significance for two of the most promising sources.
Significant discovery potential for extragalactic sources, complementing IceCube field of view.

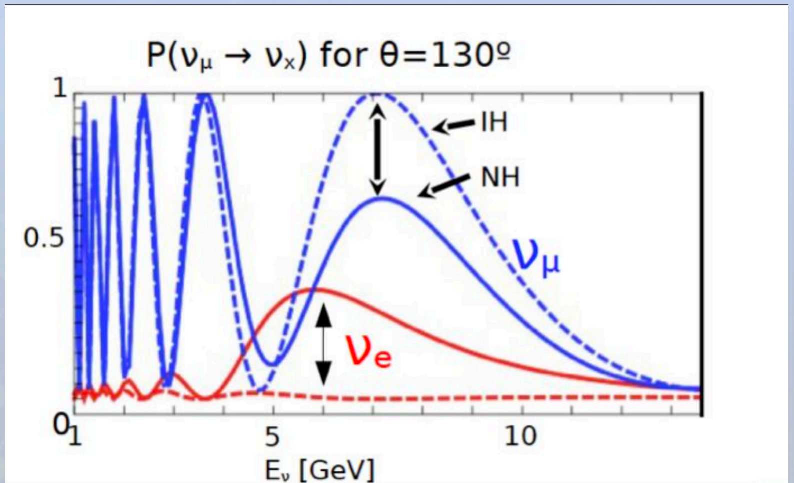


Disclaimer: We compare detector sensitivities, not discovery potential at a given time, IceCube will have ~10 years of data when KM3NeT will start operation

Neutrino Mass Hierarchy (KM3NeT-ORCA)







Atmospheric neutrino: wide energy range

+

Earth: large baseline range

+

NMH + matter: impact on oscillation probabilities

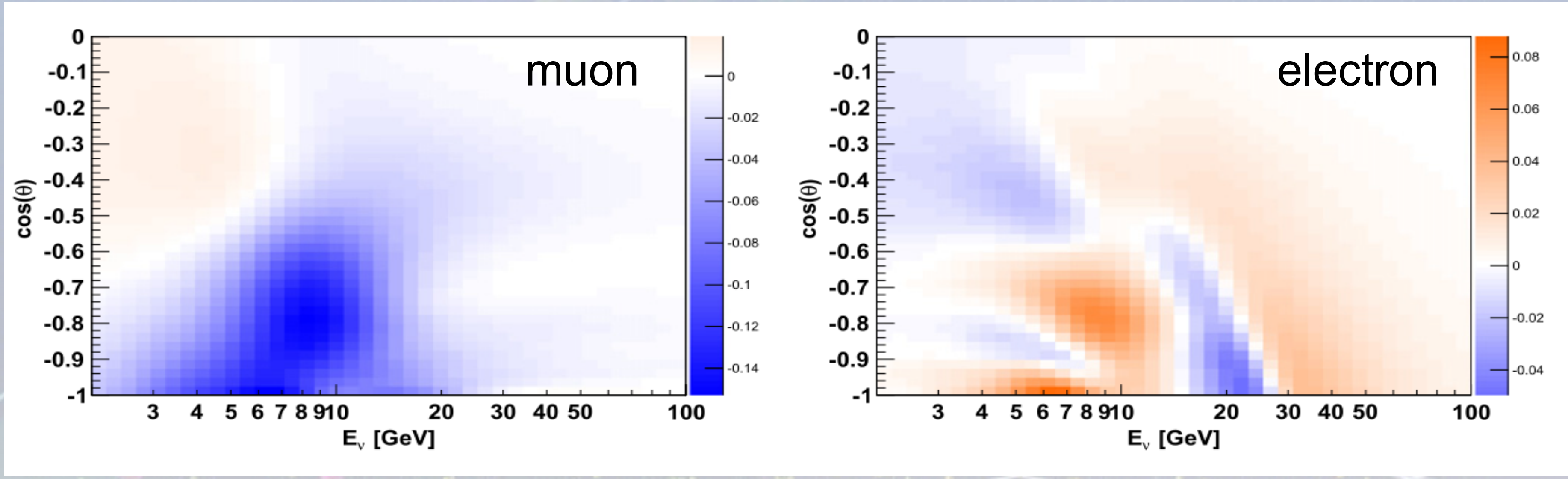
Neutrino Mass Hierarchy (KM3NeT-ORCA)

Signature of the neutrino mass hierarchy → energy-zenith distribution of atmospheric neutrinos

Measurement requires

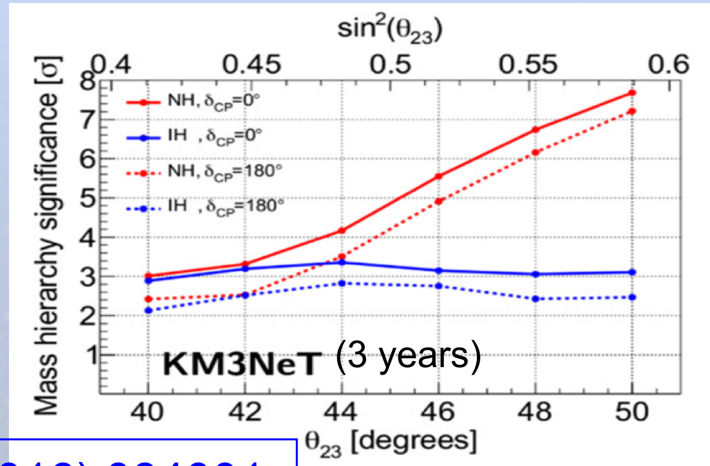
- best possible resolution in energy and zenith
- separation ν_e/ν_μ
- detailed understanding of systematics

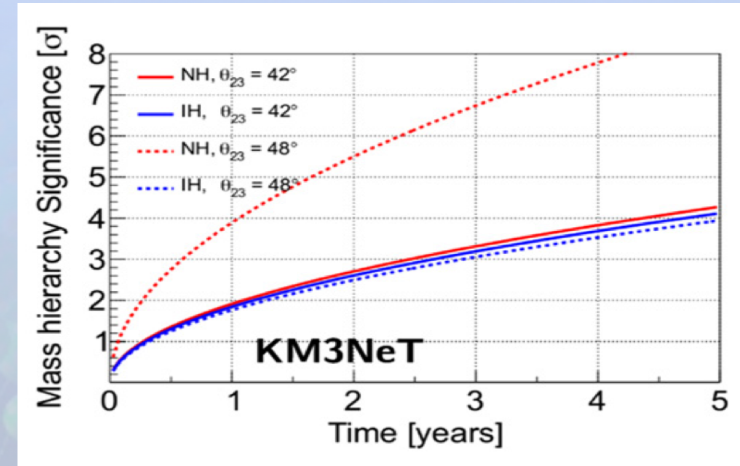
J.Phys. G43 (2016) 084001



Neutrino Mass Hierarchy (KM3NeT-ORCA)

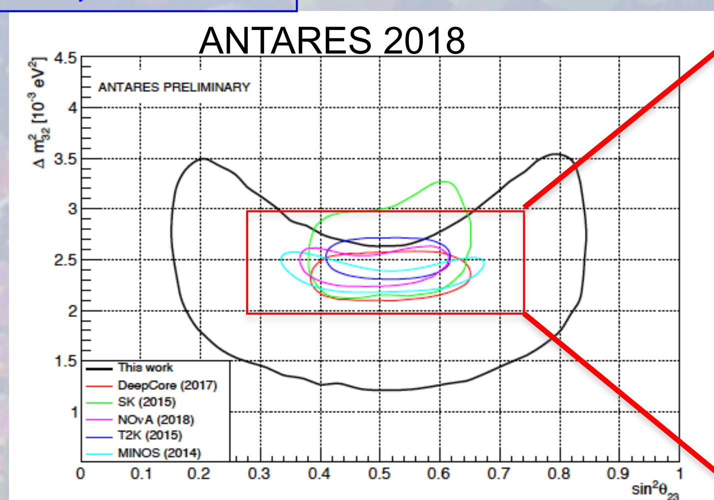
Neutrino mass hierarchy significance

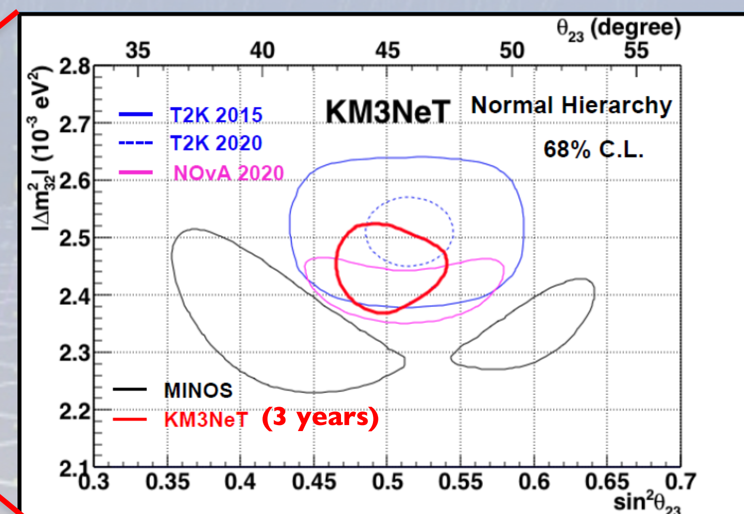




J.Phys. G43 (2016) 084001

Measurement of $\sin^2\theta_{23}$ and Δm^2_{32}





Conclusions and prespectives

- ANTARES
  - Solid results from various searches of neutrino emission (point-like, diffuse, ...)
  - Rich multi-messenger program
  - Several combined analyses with IceCube
- KM3NeT
  - ARCA: Confirmation of IceCube flux in less than one year
  - ORCA: Competitive with JUNO, indication of neutrino mass hierarchy in ~3 years

Conference Probing the Universe with Multimessanger Astronomy

28 September 2020 to 2 October 2020
Sestri Levante