From ANTARES to KM3NeT neutrino telescopes in the Mediterranean sea

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On behalf of ANTARES and KM3NeT Collaborations

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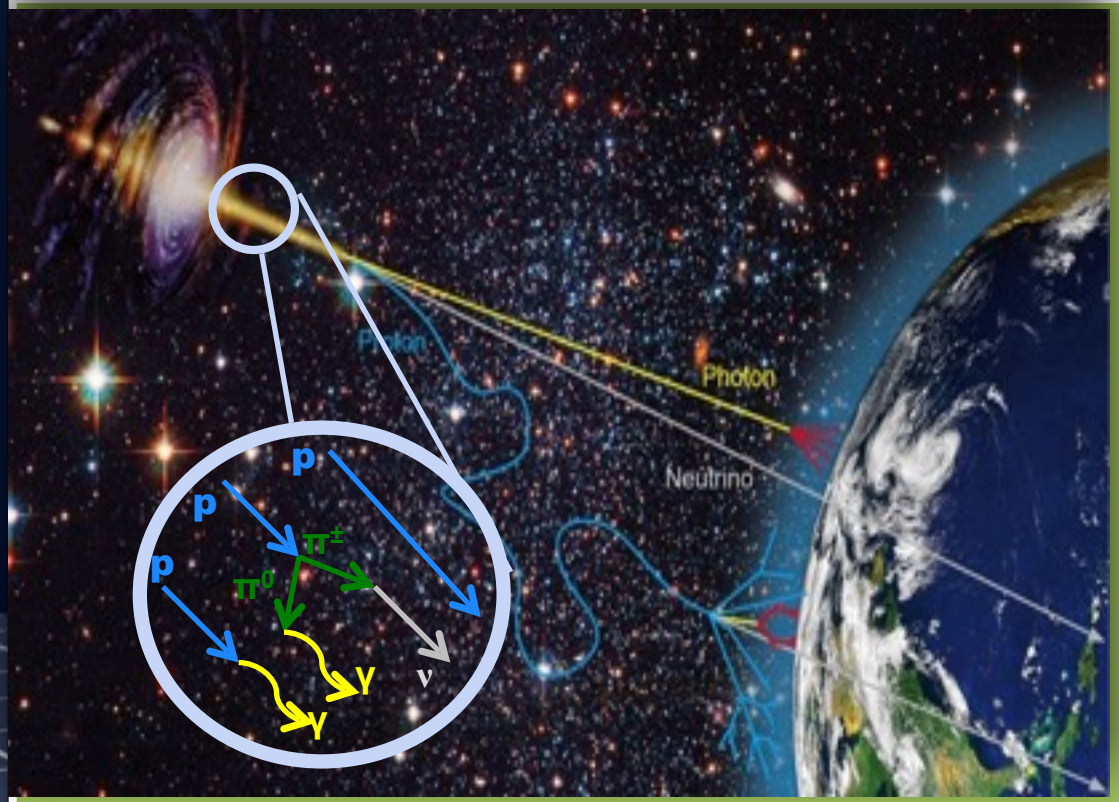
Outline

- Neutrino astronomy
- Detection principle
- ANTARES and KM3NeT detectors
- Detectors performances
- ANTARES: *Latest results*
- KM3NeT: *status and preliminary results*.
- Conclusion

Neutrino Astronomy



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

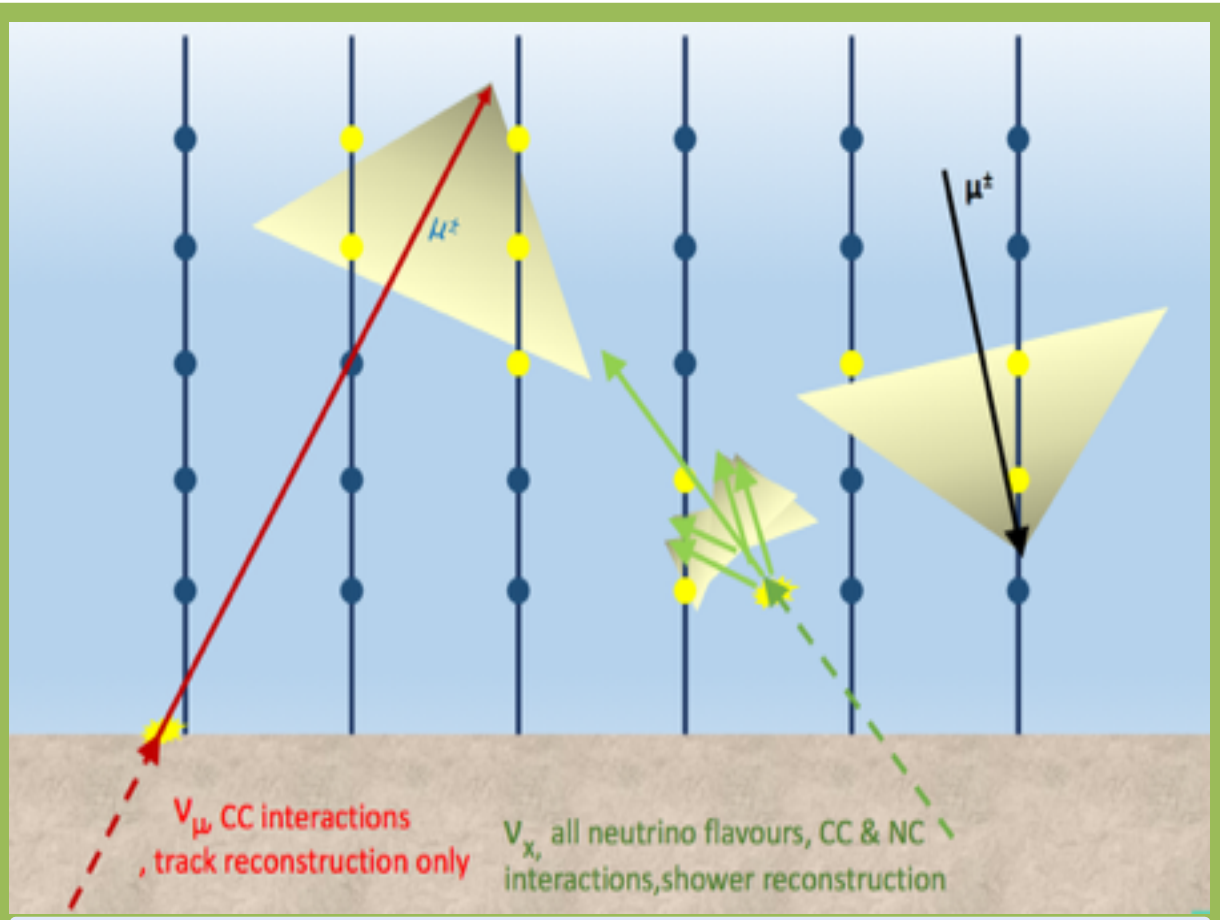
High Energy Gamma Rays
✔ Produced both by hadronic and leptonic mechanisms
✘ Absorbed on dust and radiation

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

Neutrinos: *neutral, stable and weakly interacting*

- Not affected by magnetic fields,
- point back to the source.
- Travel long distance.
- Penetrate regions with are opaque to photons.

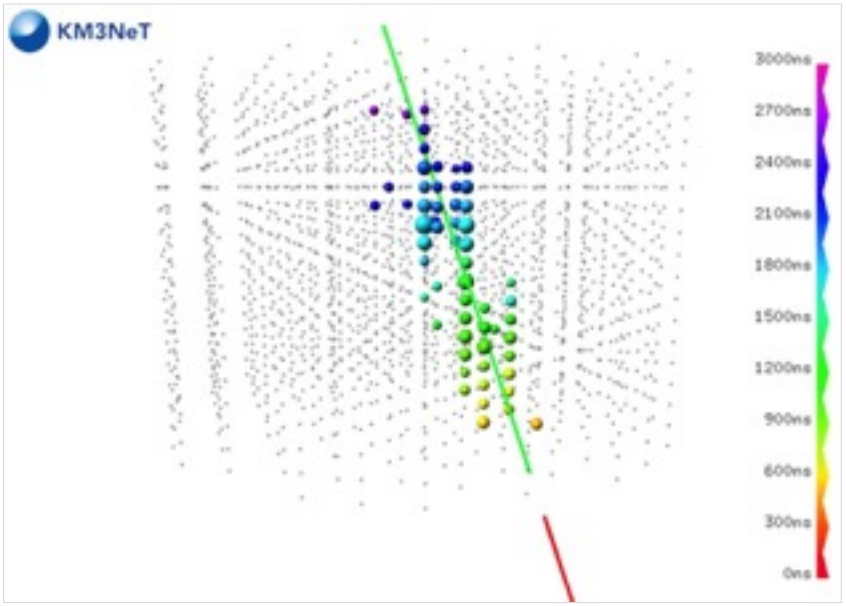
Detection principle



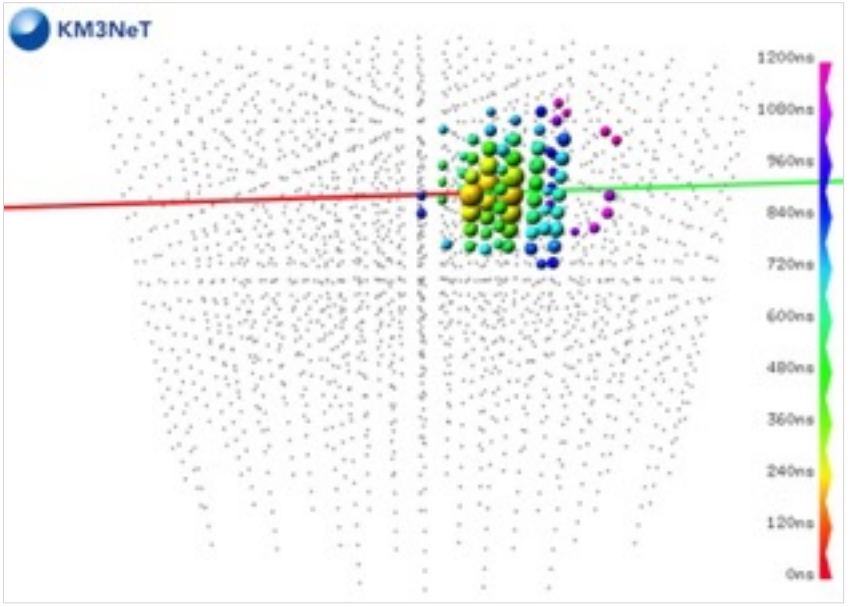
Low ν X-section requires large detector volumes

- Detector deployed in deep water (ice) to reduce down going atmospheric muons.
- Cherenkov radiation *(emitted by the particles produced in neutrino interaction)* detected by arrays of PMTs.
- Position, time and charge used to reconstruct the direction and energy of the event.

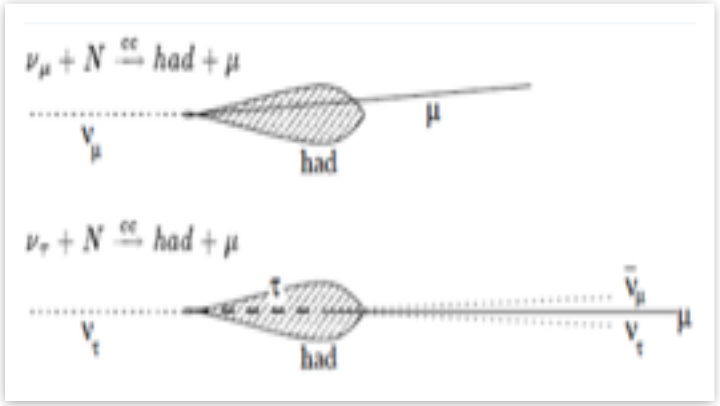
Event topologies

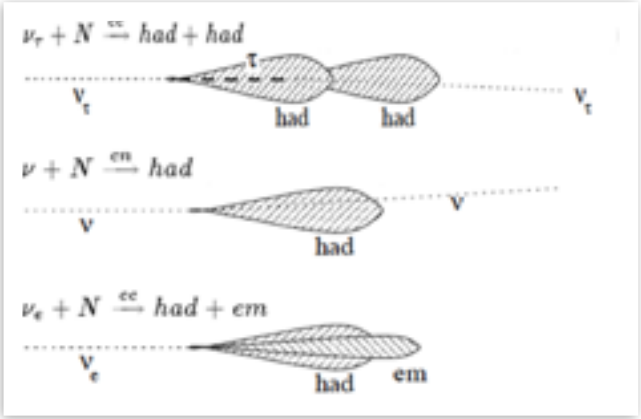


Upgoing ν_μ CC event (or ν_τ) —>μ : “track like”
Interaction can occur far from the detector providing a ***large Effective Volume***.



Contained ν_x NC event : “shower”
Events contained in the detector:
smaller Effective Volume

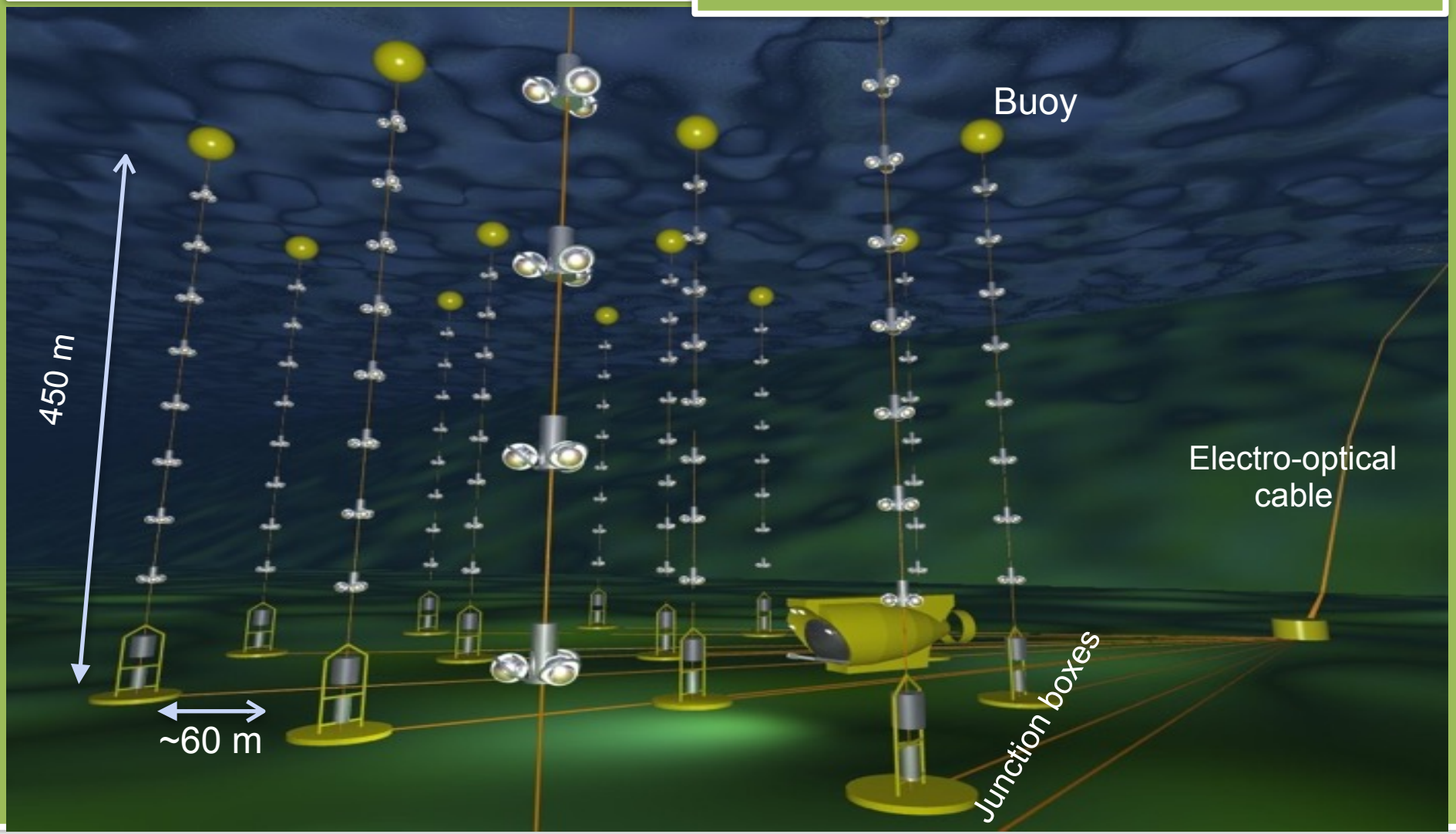




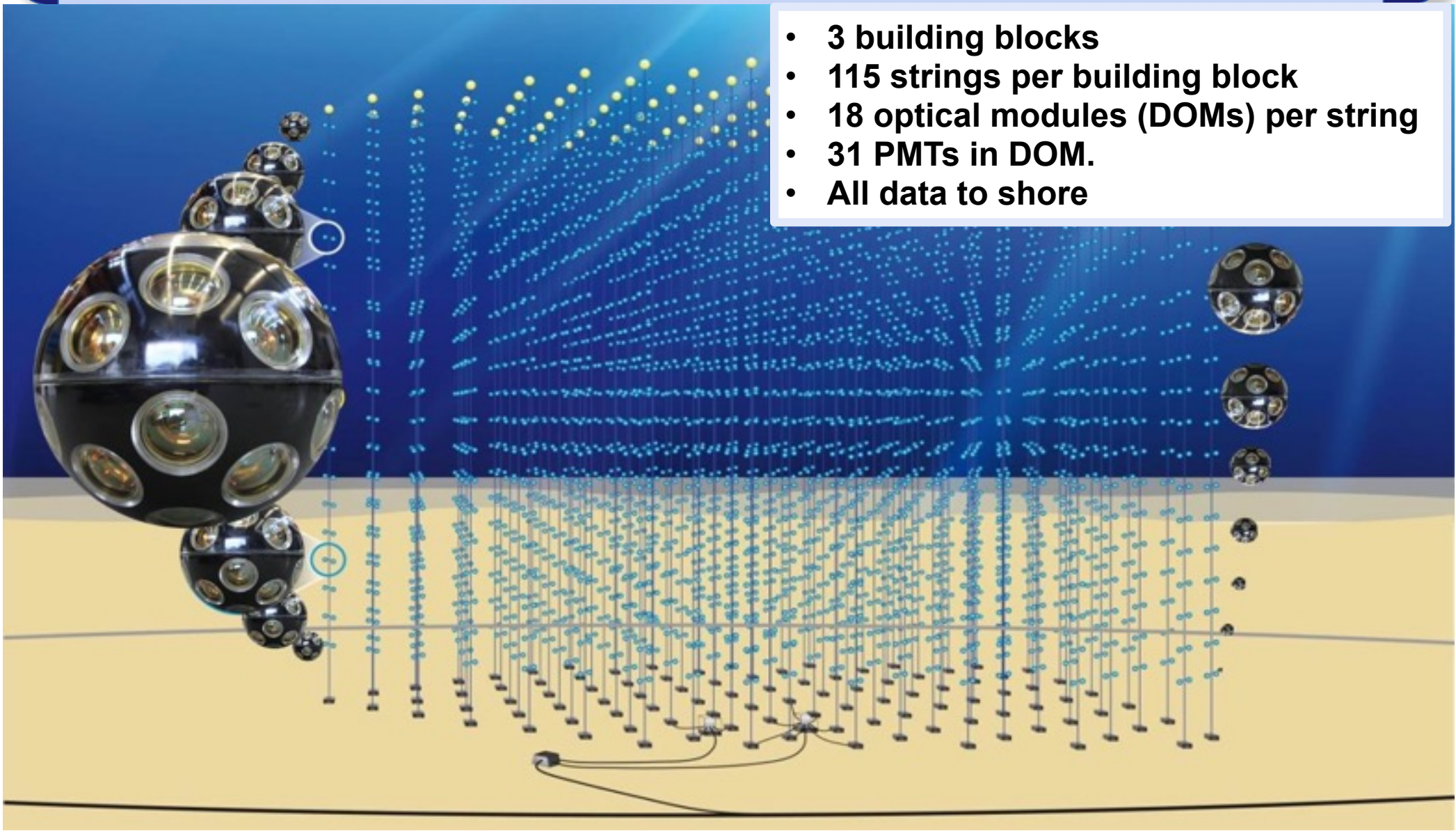
The ANTARES detector

- First detection line in 2006
- Completed 2008
- 2475m depth in Mediterranean sea

- 3D array of 885 OM.
- 12 lines, 25 storeys / line
- 3 PMTs per storey
- ~15 Mton instrumented

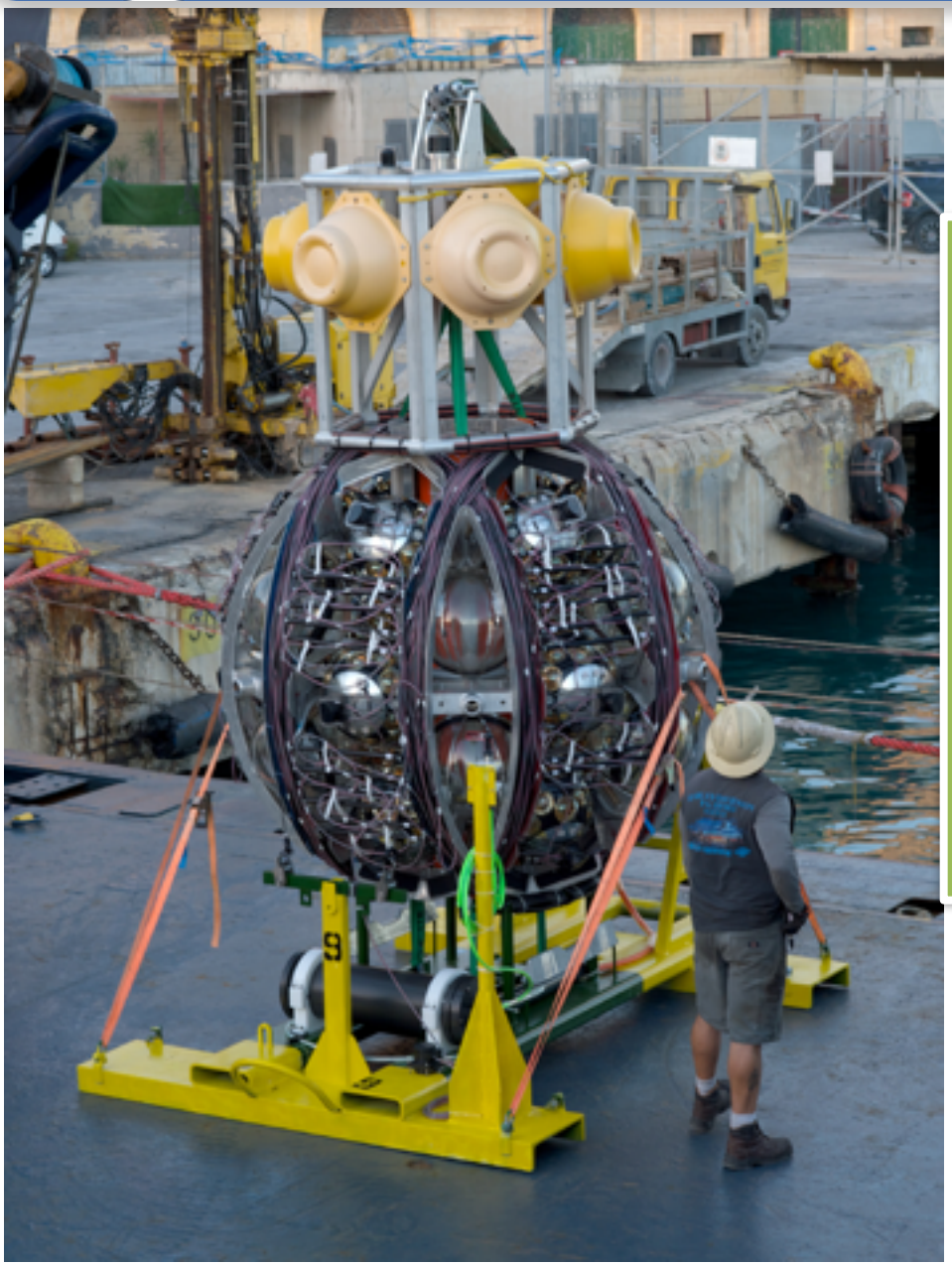


The KM3NeT detectors



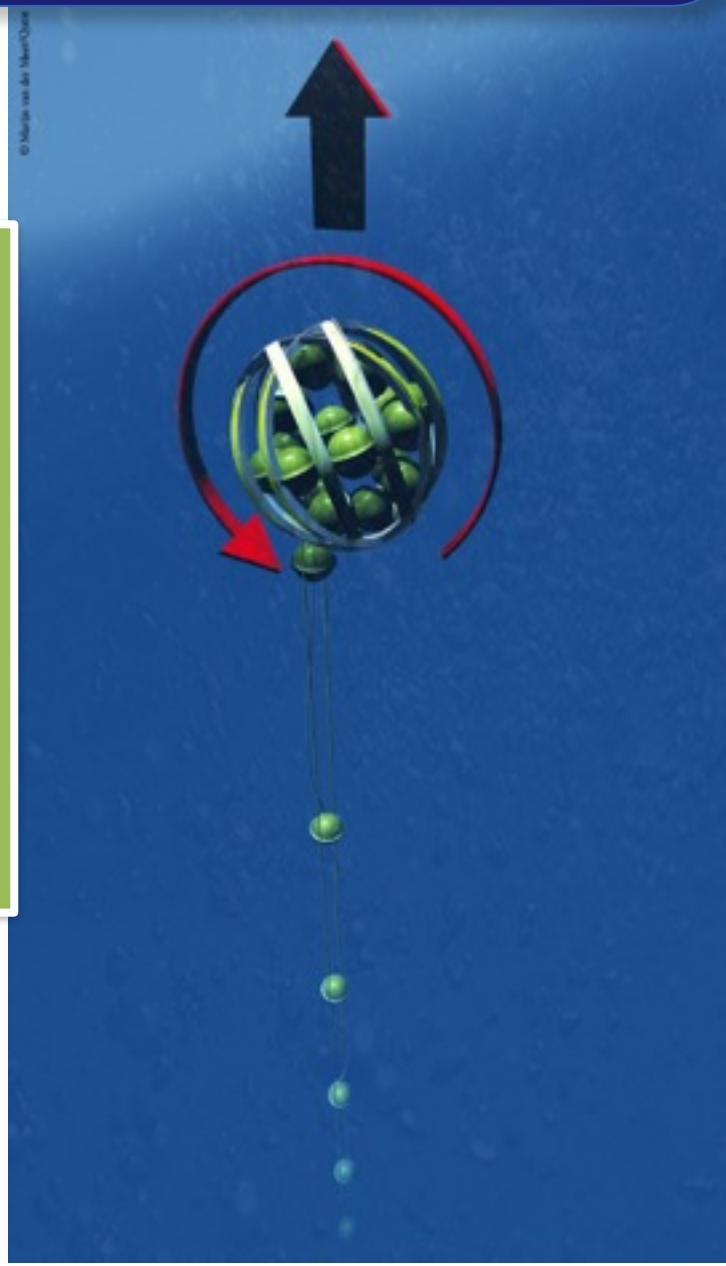
- 3 building blocks
- 115 strings per building block
- 18 optical modules (DOMs) per string
- 31 PMTs in DOM.
- All data to shore

Detectors deployment



←**Deploy** to sea bed Release by ROV.

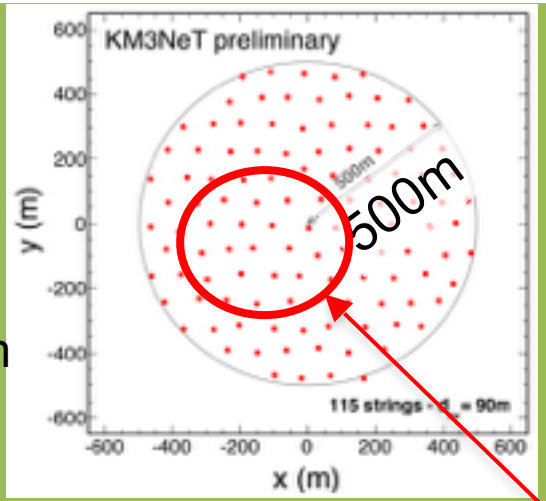
Unfurl→ Collect frame



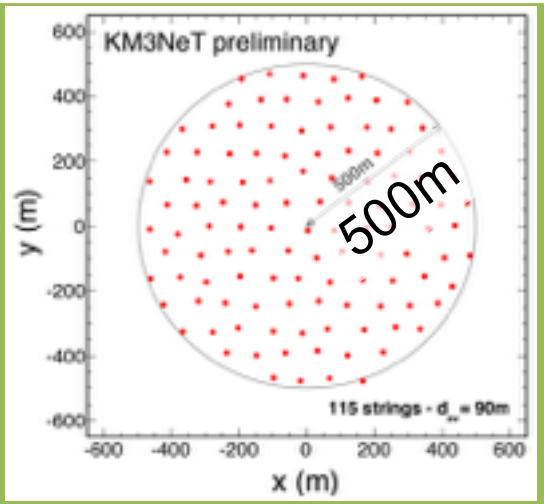
KM3NeT: ARCA & ORCA

ARCA
Astroparticle Research with Cosmics in the Abyss
@ TeV to PeV scale

Vertical DOM distance = 36 m

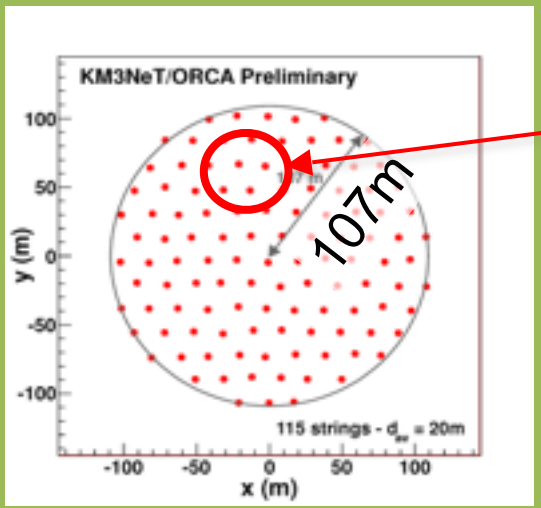


+



ORCA
Oscillation Research with Cosmics in the Abyss
@ GeV scale

Vertical DOM distance = 9 m

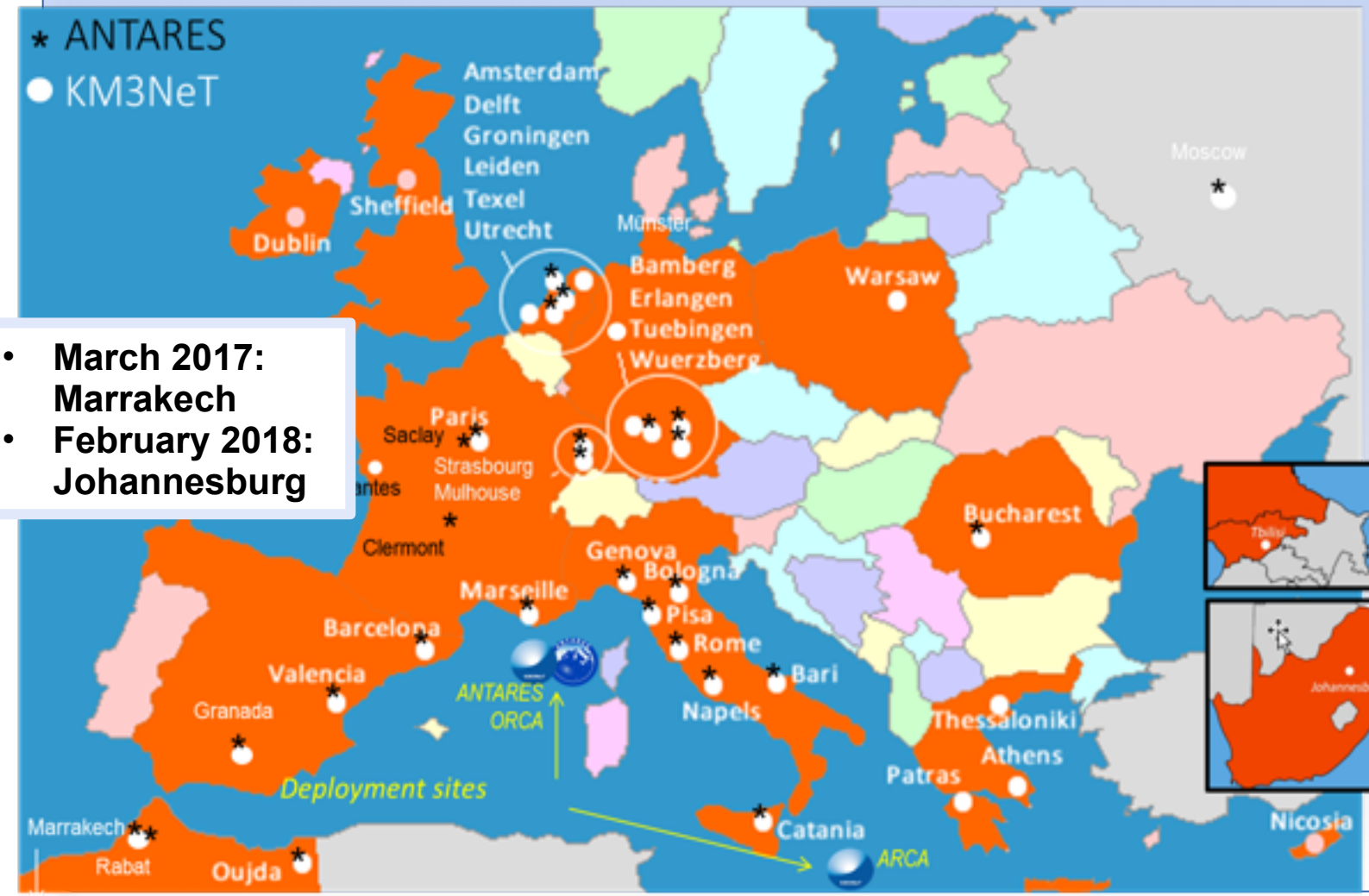


Phase1 (fully funded)

Phase 2 partially funded

KM3NeT 2.0 Letter of Intent: JPG 43 (2016)

ANTARES & KM3NeT collaborations



- **March 2017: Marrakech**
- **February 2018: Johannesburg**

2 sites

@Toulon, FR

- ANTARES
- KM3NeT/ORCA

@Capo Passero, IT

KM3NeT/ARCA

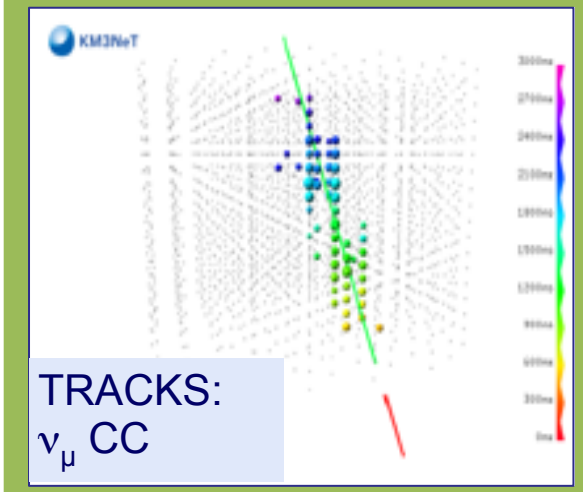
3rd site

under study

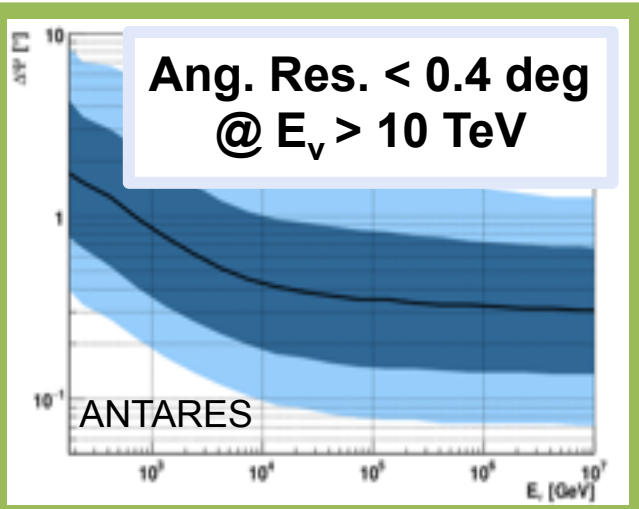
@ Pylos,GR

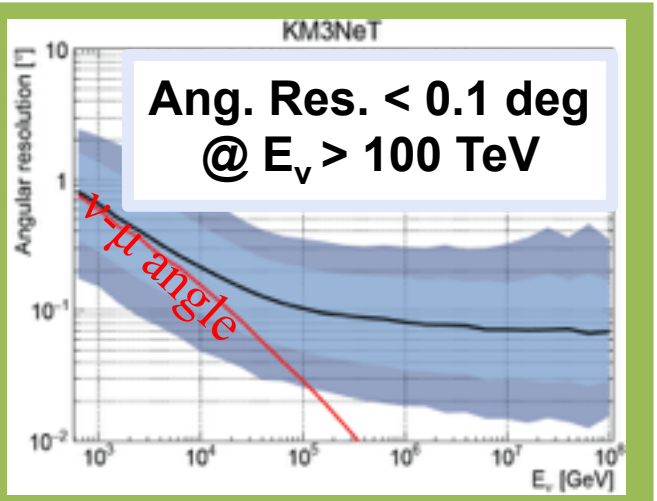
> 250 researchers
~ 51 institutes
15 countries

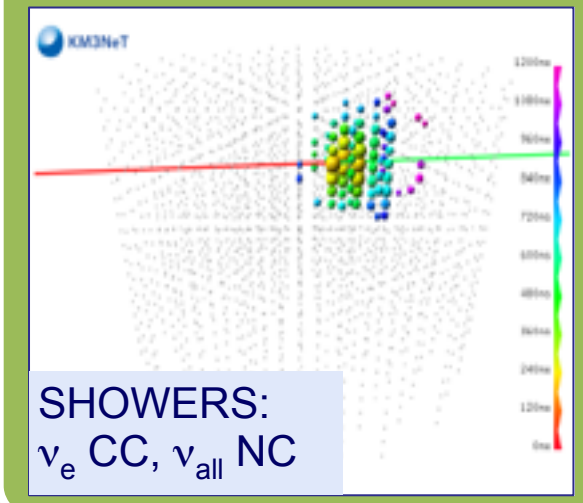
Detectors performances
ANTARES vs KM3NeT/ARCA



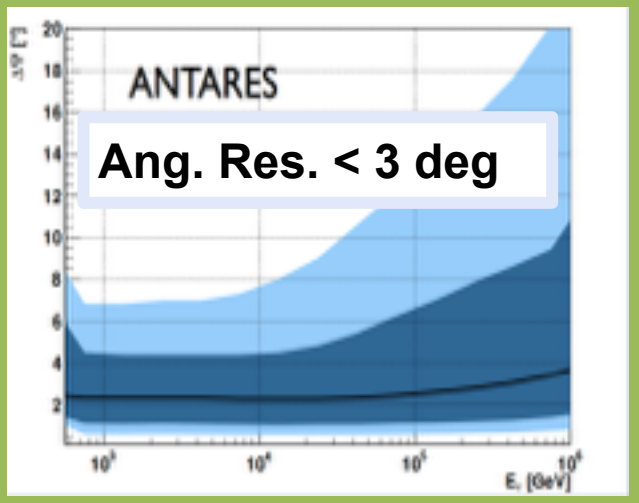
TRACKS:
ν_μ CC

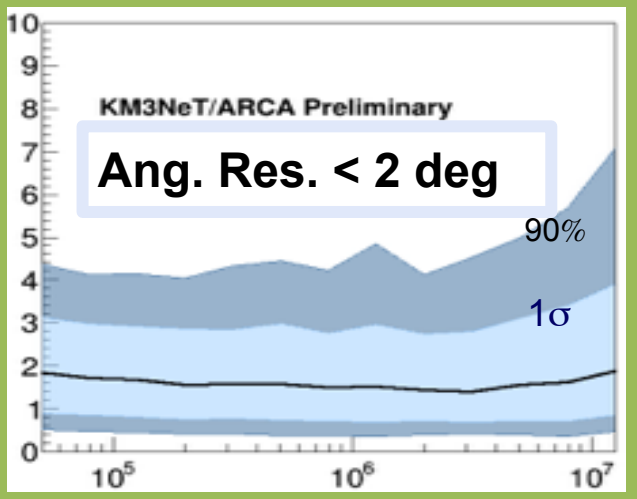






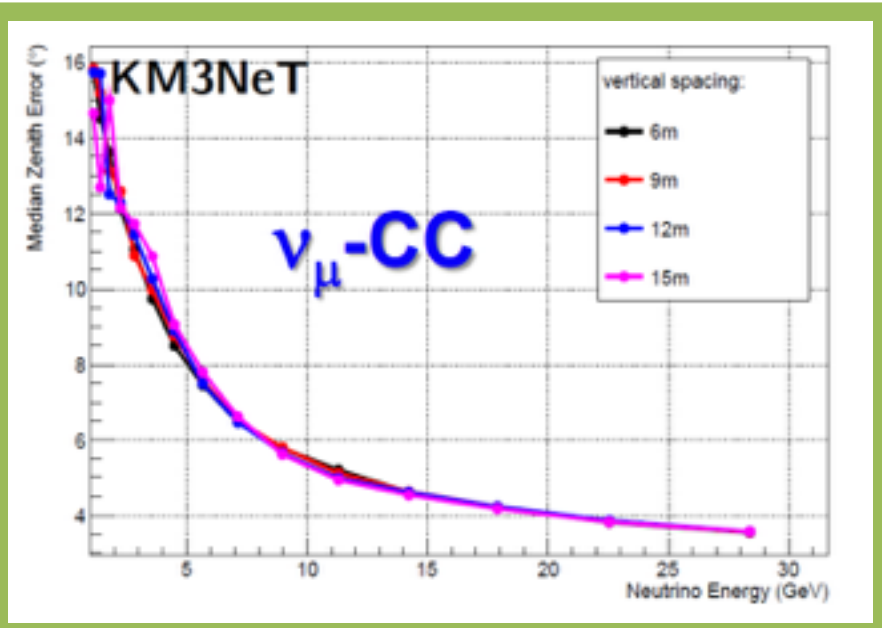
SHOWERS:
ν_e CC, ν_{all} NC

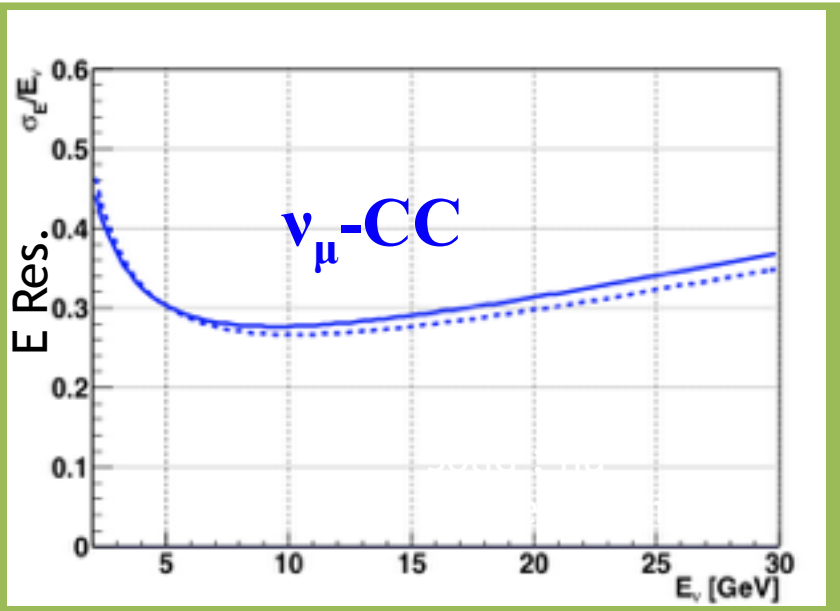




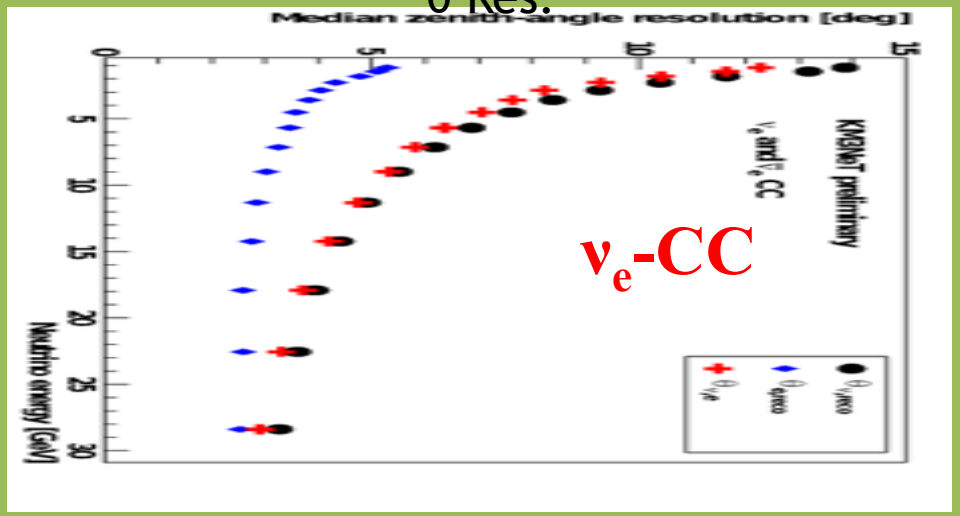
KM3NeT/ORCA performance

θ Res.

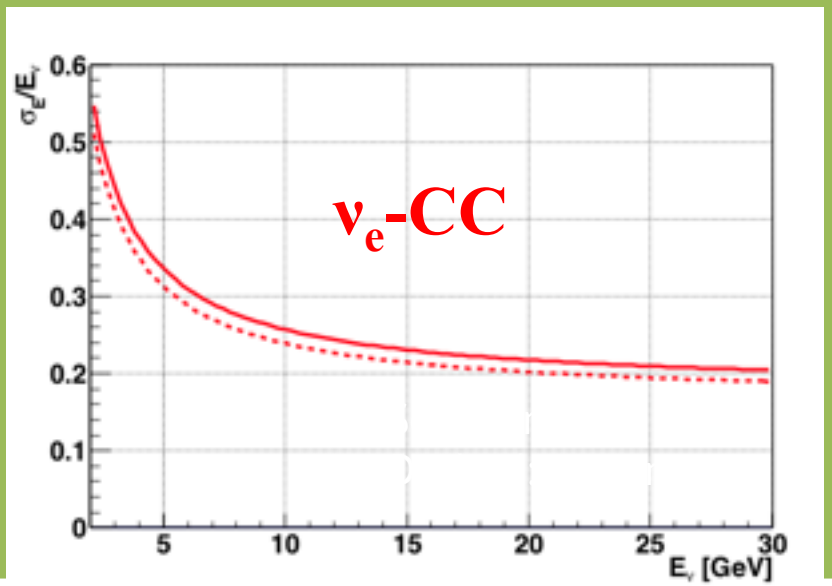




θ Res.



E Res.



7°(5°) for 5(10) GeV for both channels

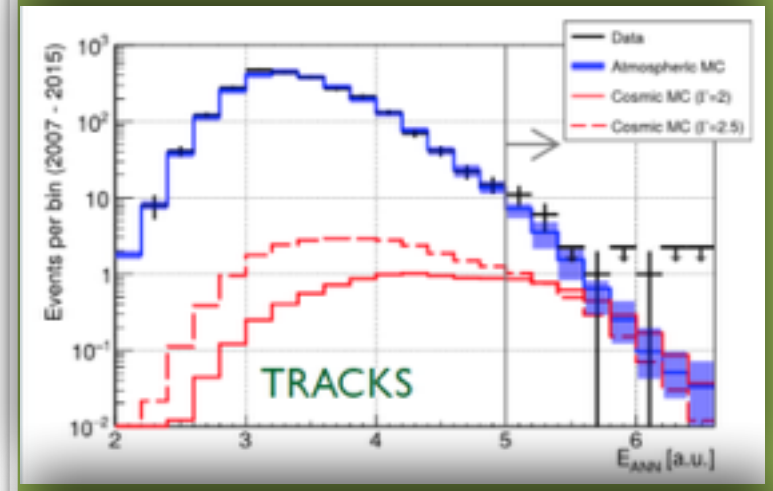
Energy resolution below 30% in relevant energy range

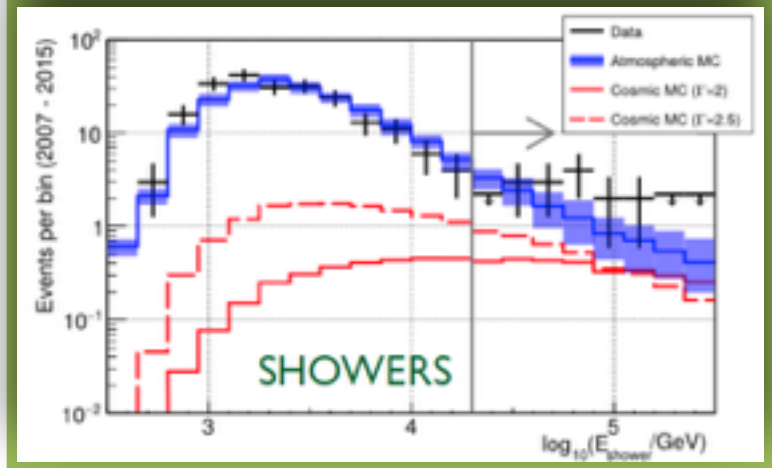
ANTARES latest results

- **Diffuse flux search**
- **Point-source search**
- **Galactic plane search**

Diffuse flux search

All-sky / All flavour diffuse neutrino search (years 2007-2015)





Reconstructed events after quality cuts:

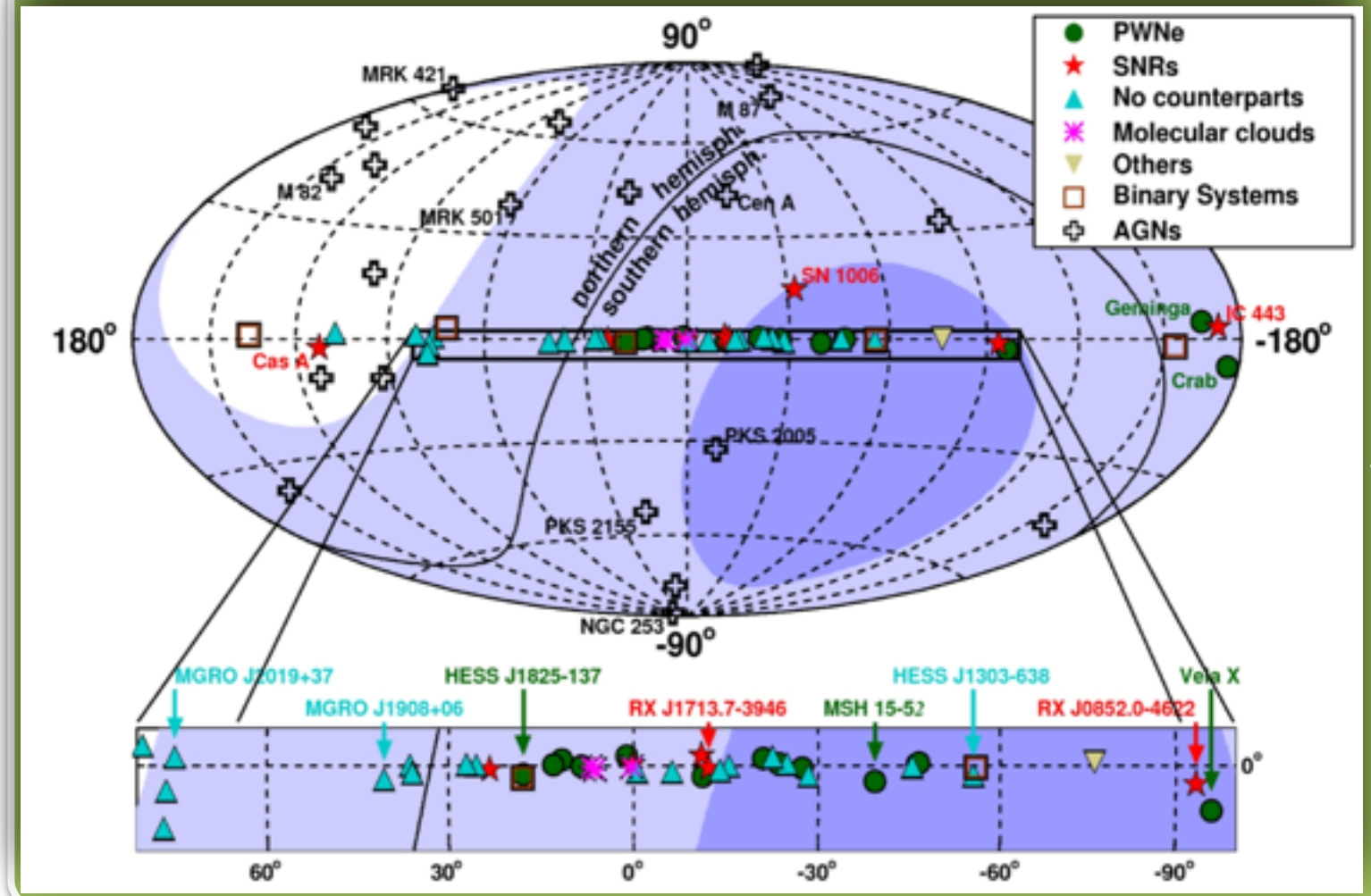
	Bkg expectation	Signal expectation	Nb events measured
Tracks	**13.5+/-4**	**3-3.5**	**19**
Showers	**10.5+/-4**	**3-3.5**	**14**

Results compatible with IceCube diffuse flux:

- 1.6 σ excess
- Null cosmic neutrino contribution rejected at 85% C.L.

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

Point-source flux search



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

Best pointing telescope from North Hemisphere

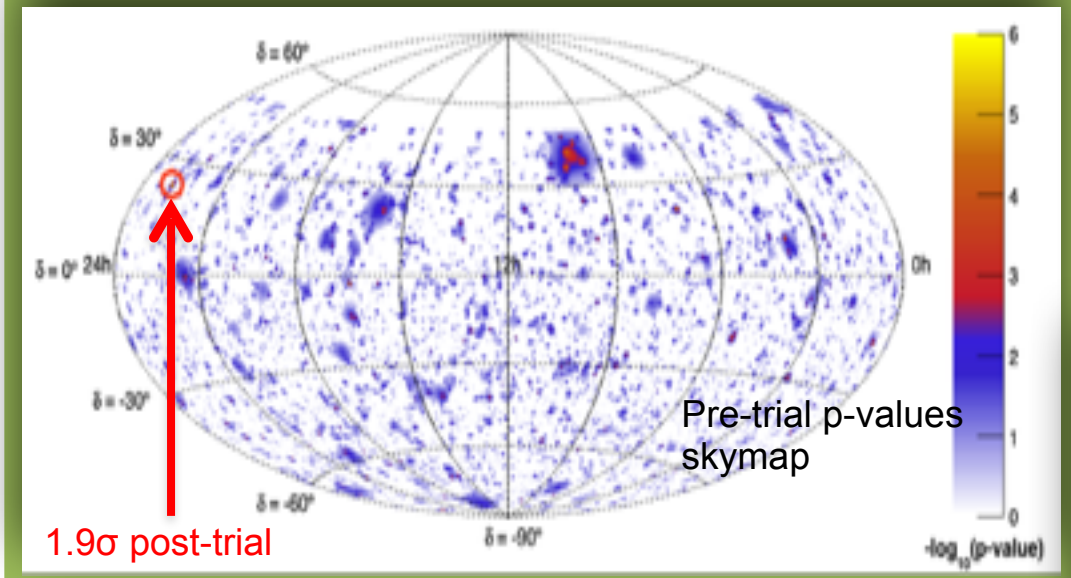
Searches:

- Full-sky
- Candidate list
- Galactic centre
- SagittariusA*

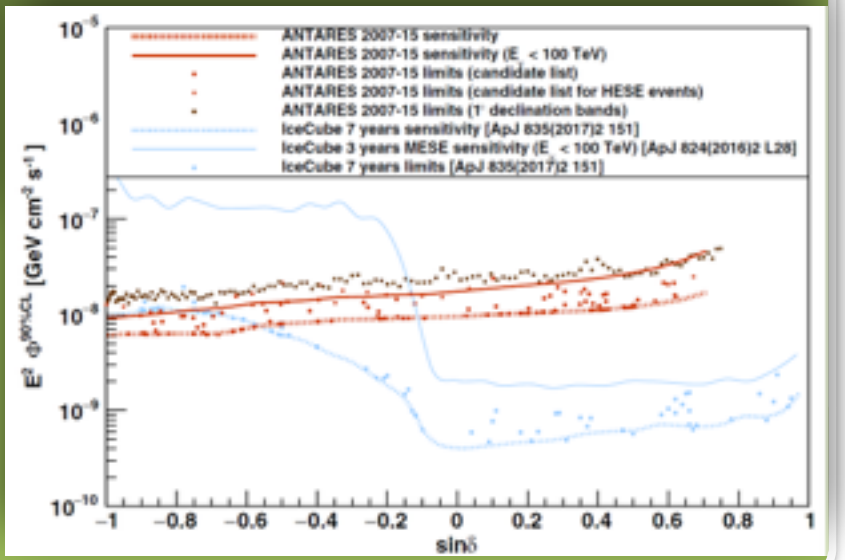
Point-source flux search

All flavour neutrino source search (2007 to 2015):
7622 track-like + 180 shower-like events

PRD 96, (2017)



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

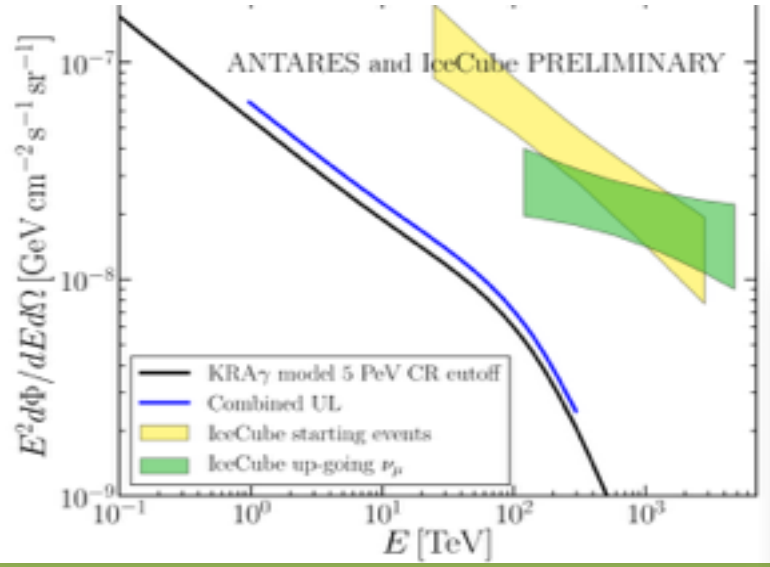


- No resolved point source
- Most sensitive limits for a large fraction of Southern sky, especially @ E<100 TeV.

Galactic Plane search

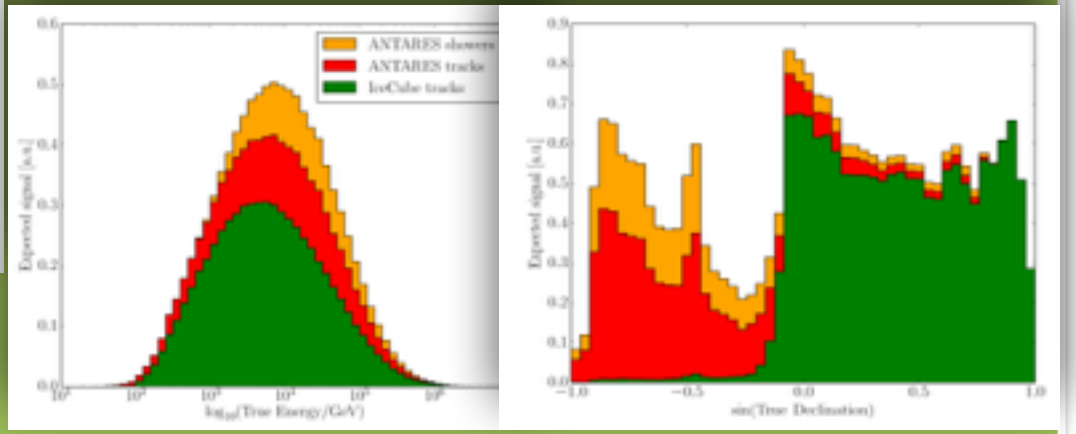
- **"KRAγ":** model introduced recently to explain the high-energy gamma ray diffuse Galactic emission.
- KRAγ reproduces *Fermi data & Milagro data.* *(ApJ. Lett., 815:L25, 2015)*

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 (assuming KRAγ with cutoff at 5 PeV)

Relative contribution of ANTARES and IceCube



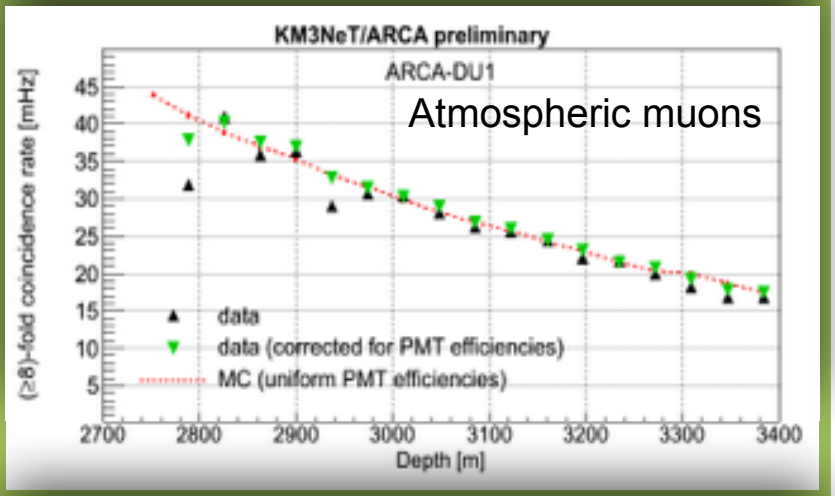
KM3NeT
Status & Preliminary results

- KM3NeT Status
- KM3NeT/ARCA
  - Diffuse flux expected performance
  - Point-source expected performance
- KM3NeT/ORCA
  - Neutrino Mass Hierarchy

KM3NeT Status
(First detections)

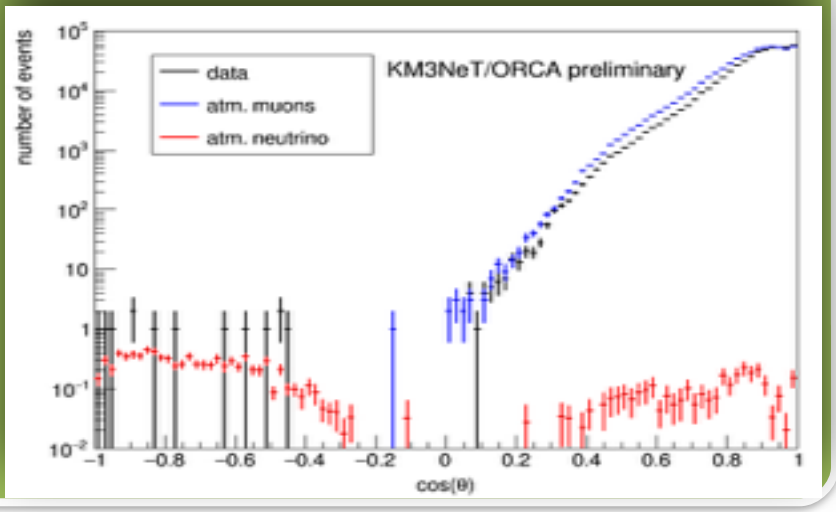
ARCA

- 3 strings deployed: Dec. 2015 & May 2016
- 2 out of 3 operated, string #3 with short in power system, recovered.
- Full restoration of seabed network by mid-2019



ORCA

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



Construction

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

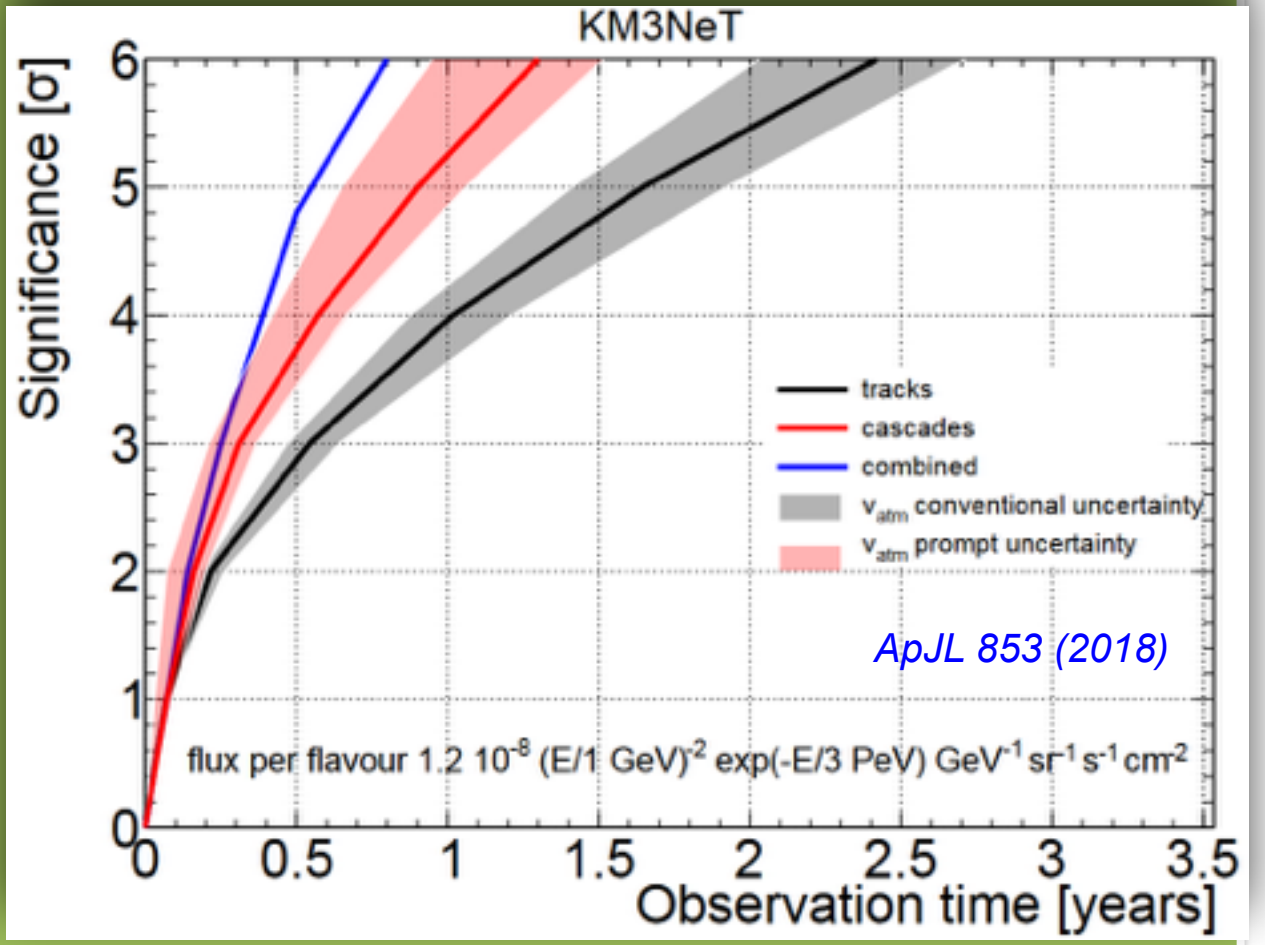
Diffuse flux sensitivity KM3NeT / ARCA

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

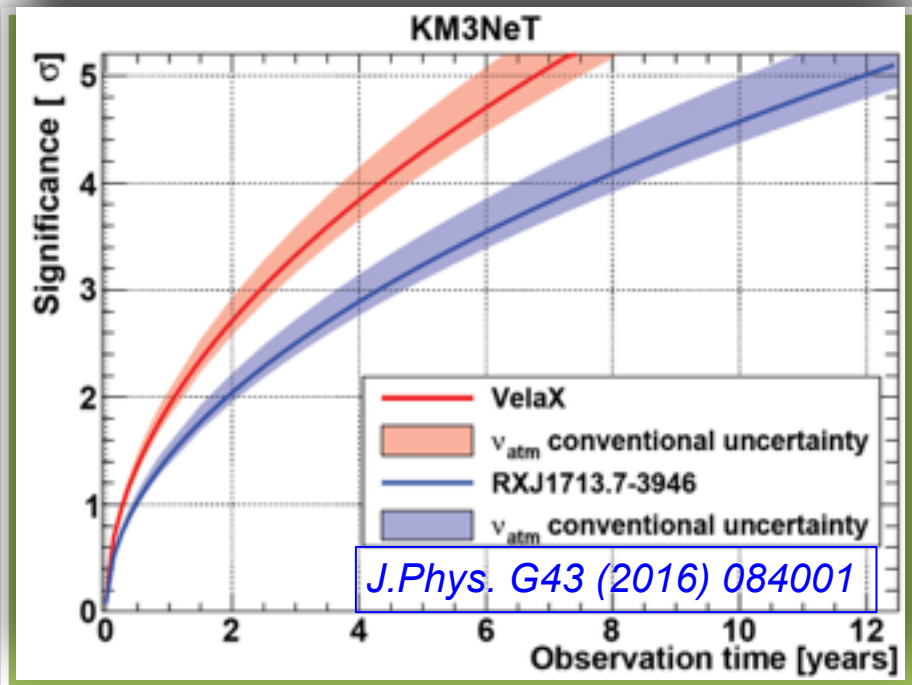
Tracks like per ARCA year:
- 6 signal
- 4 background

Cascades like per year:
- 16 signal
- 9 background

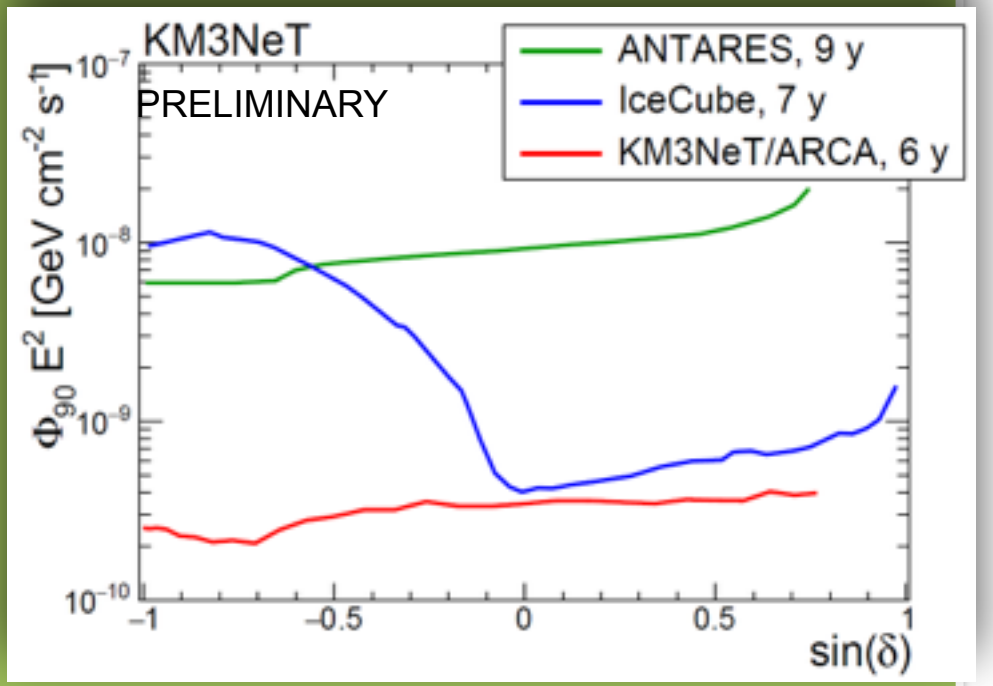
For a given source direction, ***KM3NeT and IceCube are complementarity,*** in their field of view, energy range and flavour coverage



KM3NeT / ARCA
Point source performance



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

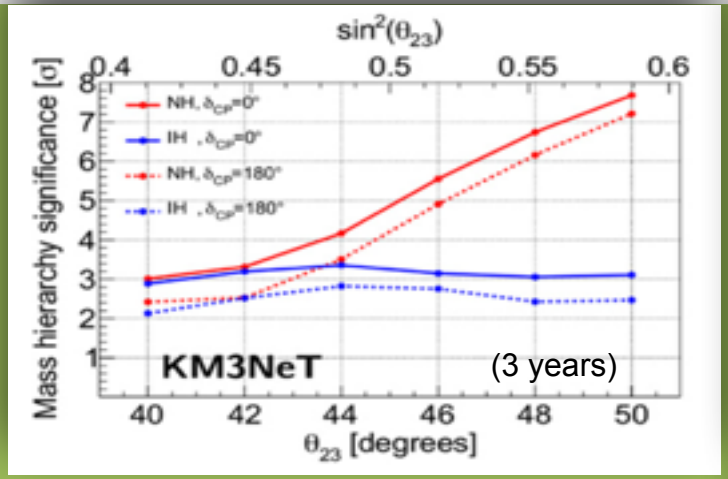


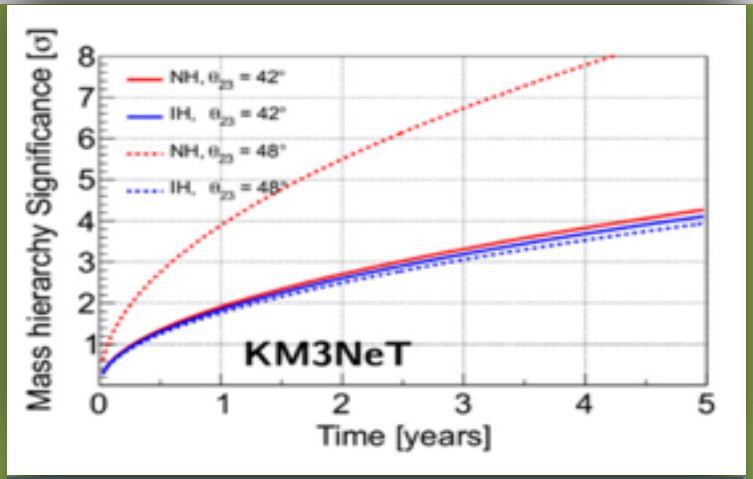
- We compare detector sensitivities, not discovery potential at a given time.
- IceCube will have nearly 10 years of data when KM3NeT will start operation.

Neutrino Mass Hierarchy & Oscillations KM3NeT/ORCA

JPG 43 (2016)

Neutrino Mass Hierarchy significance

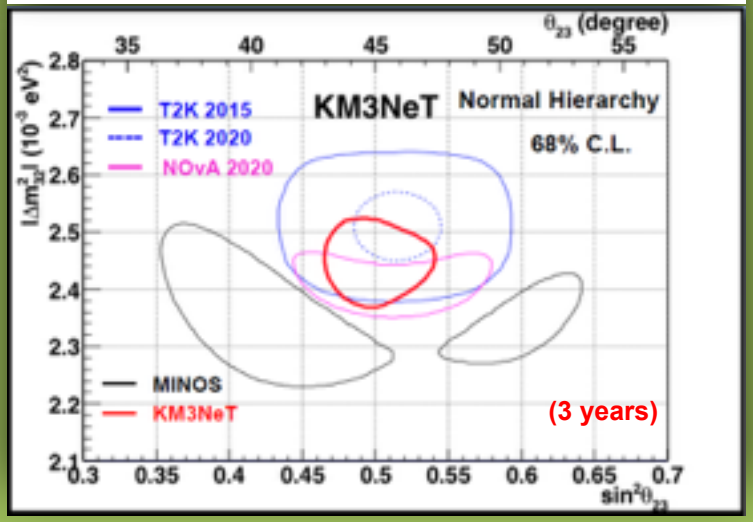




- 3σ NMH median significance after 3 years

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

- If NH and θ_{23} in second octant, then significant improvement of sensitivity: 5σ.
- MH sensitivity comes from both track and shower events.



Summary

ANTARES :

- 18th June 2018: celebration of ANTARES ‘s 10th anniversary.
- Solid results from various searches of neutrino emission (point-like, diffuse, dark matter, ...)
- Several combined analyses with IceCube

KM3NeT:

- Completion of both detectors expected in 2020.
- ARCA: Confirmation of IceCube flux in less than one year
- ORCA: Competitive with JUNO, determination of neutrino mass hierarchy in ~3 years.

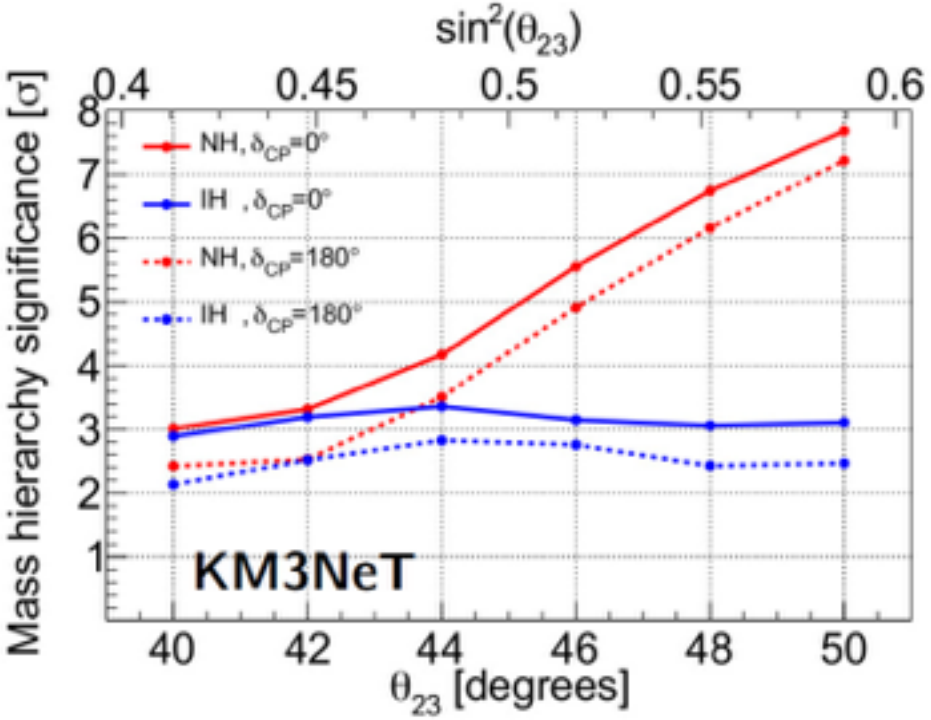
Thank you for your attention

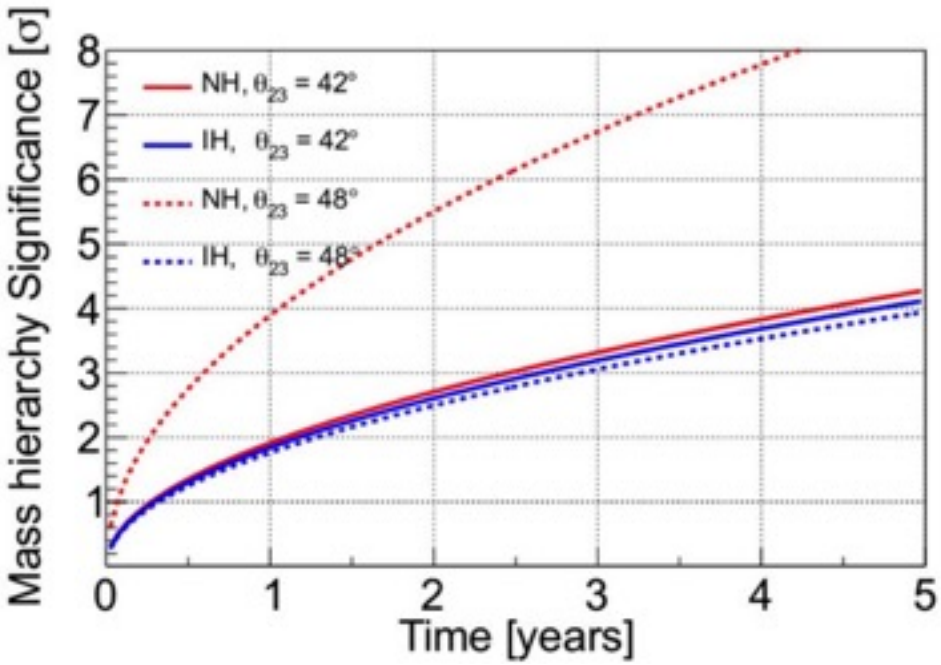
Backup

ORCA: NMH sensitivity

KM3NeT LoI sensitivity

Median significance for the determination of NMH





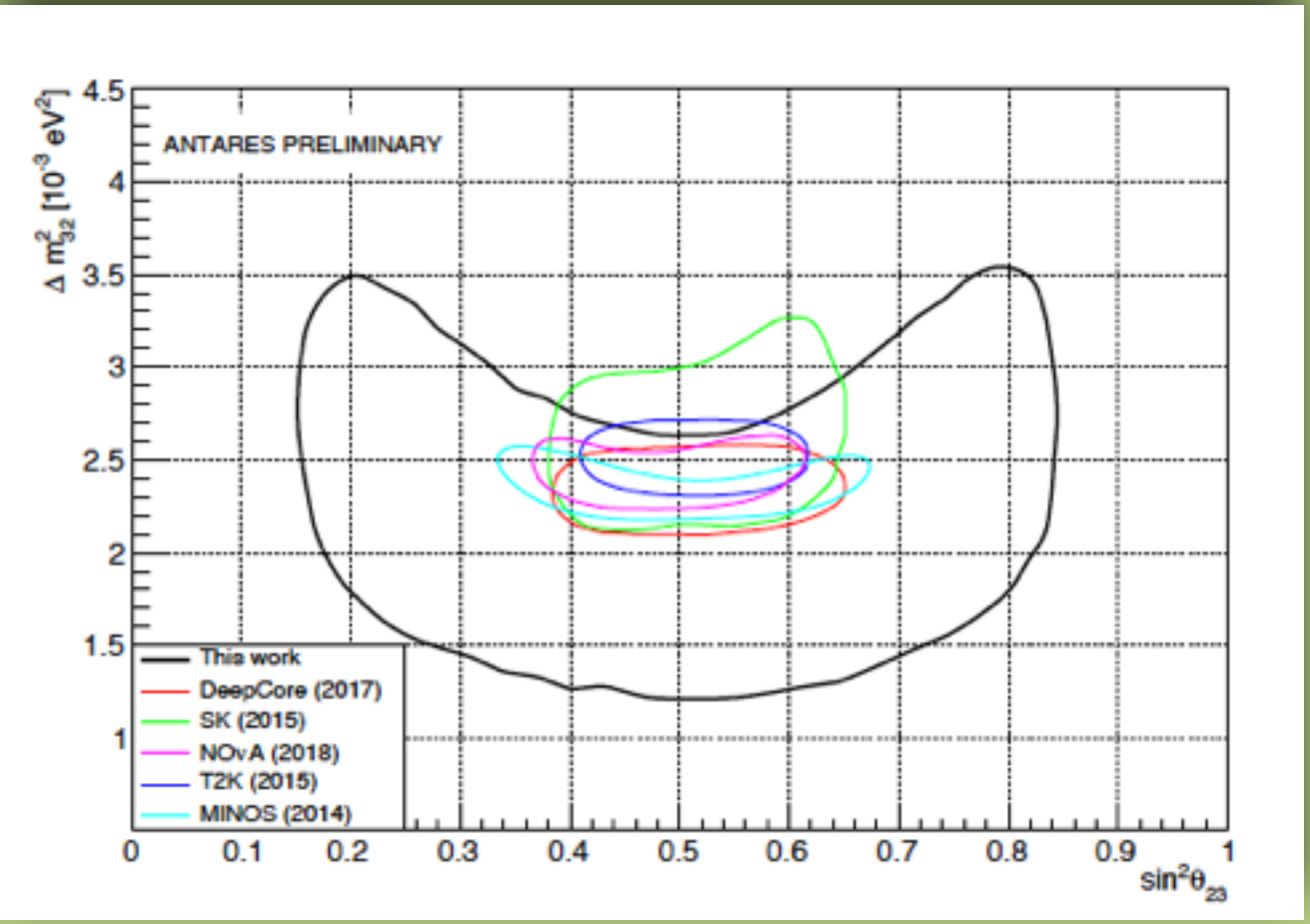
- Trigger simulation, track and shower reconstruction included.
- Expect an increase in sensitivity thanks to the improvements reached in the trigger and reconstruction
- At least 3σ sensitivity to NMH in ~3 years
- The combination of NH and upper octant of θ_{23} gives significantly improved sensitivity (>5σ in 3 years)

See KM3NeT Letter of Intent: *J. Phys. G 43 (8), 084001, 2016*

Conclusions and outlook

- KM3NeT will be the biggest detector in the Northern Hemisphere with the best angular resolution
  - ✓ Completion of both telescopes expected in 2020
- Exciting physics prospects:
  Investigate the neutrino sky with very good resolution and sky coverage with ARCA
    - Confirm IC flux in less than a year
    - Precise studies on potential HE neutrino sources
    - Constrain (or discover) hadronic scenario in galactic gamma sources
    - Allows for all flavour neutrino astronomy and spans with ARCA and ORCA a large energy window
  - ORCA will be competitive with JUNO in time and performance
    - Determination of the neutrino mass hierarchy in ~3 years

ANTARES - Oscillations 2018



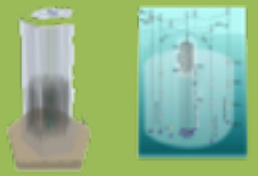
Still room for improvement: Treatment of different sources of systematic effect and refinement of quality cuts for selecting events before unblinding.

Red dashed curve: allowed parameter region at 90% C.L.

Multi-messenger strategies









neutrinos
IceCube, GVD, SNEWS

GeV-TeV γ-rays
Fermi, HESS, HAWC, CTA

UHECR
Auger, TA

only spatial coincidence

ANTARES

Receive alerts
Generate alerts

Radio/Optic /X-ray
TAROT, MASTER, Swift, INTEGRAL, MWA

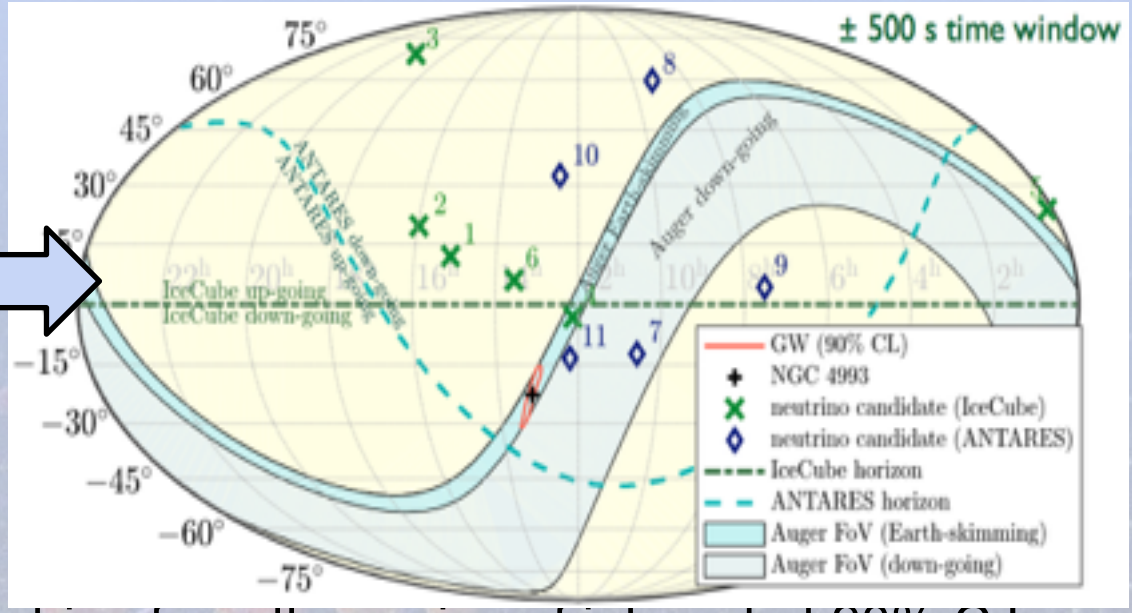
Gravitational Waves
VIRGO, LIGO

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 (BNS merger)

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

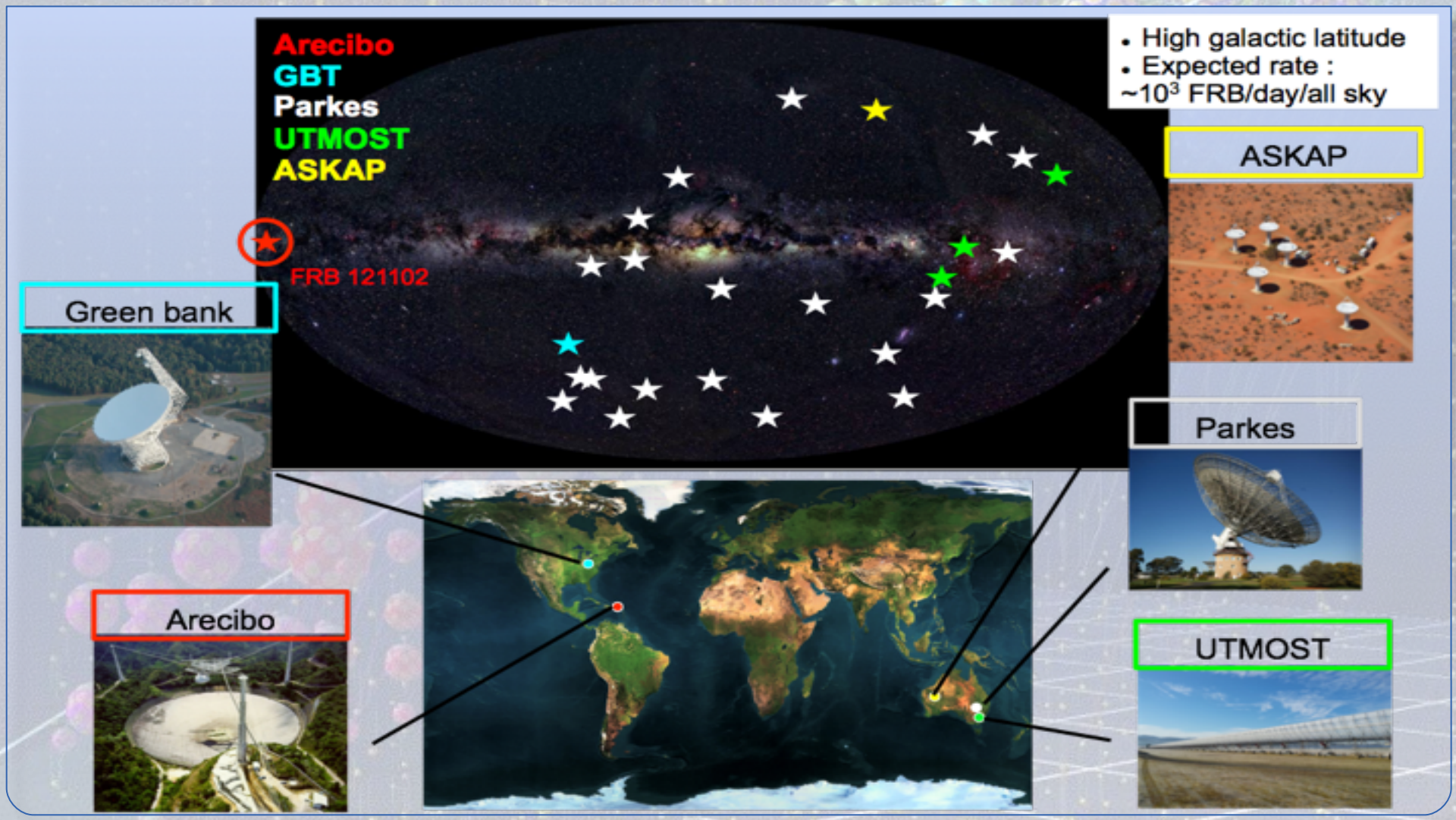


So far no coincidences with neutrino from the region of interest at 90% C.L.:

- 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

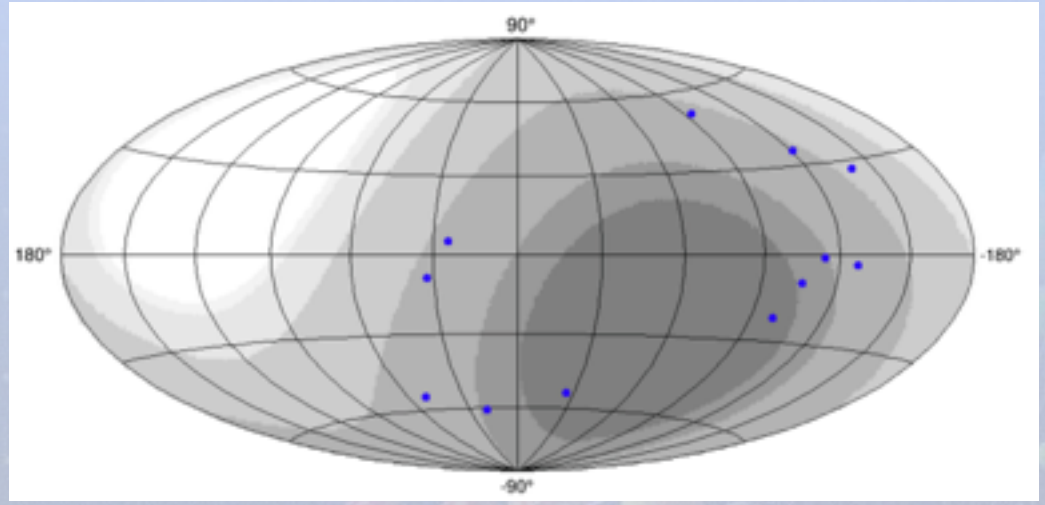
ApJL 850 L35 (2017)

Fast Radio Bursts



Fast radio bursts

12 fast radio burst selected for ANTARES analysis

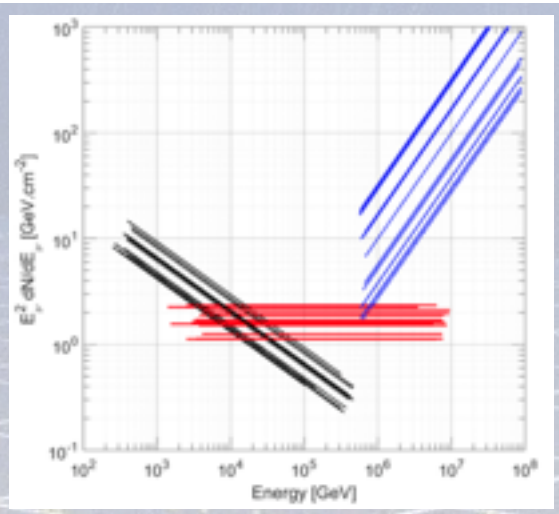


FRB	z_{DM}	T_0 (UTC)	RA (°)	dec (°)	radio telescope
131104	0.59	18:03:59	101.04	-51.28	Parkes
140514	0.44	17:14:09	338.52	-12.31	Parkes
150215	0.55	20:41:41	274.36	-4.90	Parkes
150418	0.49	04:29:04	109.15	-19.01	Parkes
150807	0.59	17:53:55	340.10	-55.27	Parkes
151206	1.385	06:14:56	290.36	-4.13	Parkes
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.



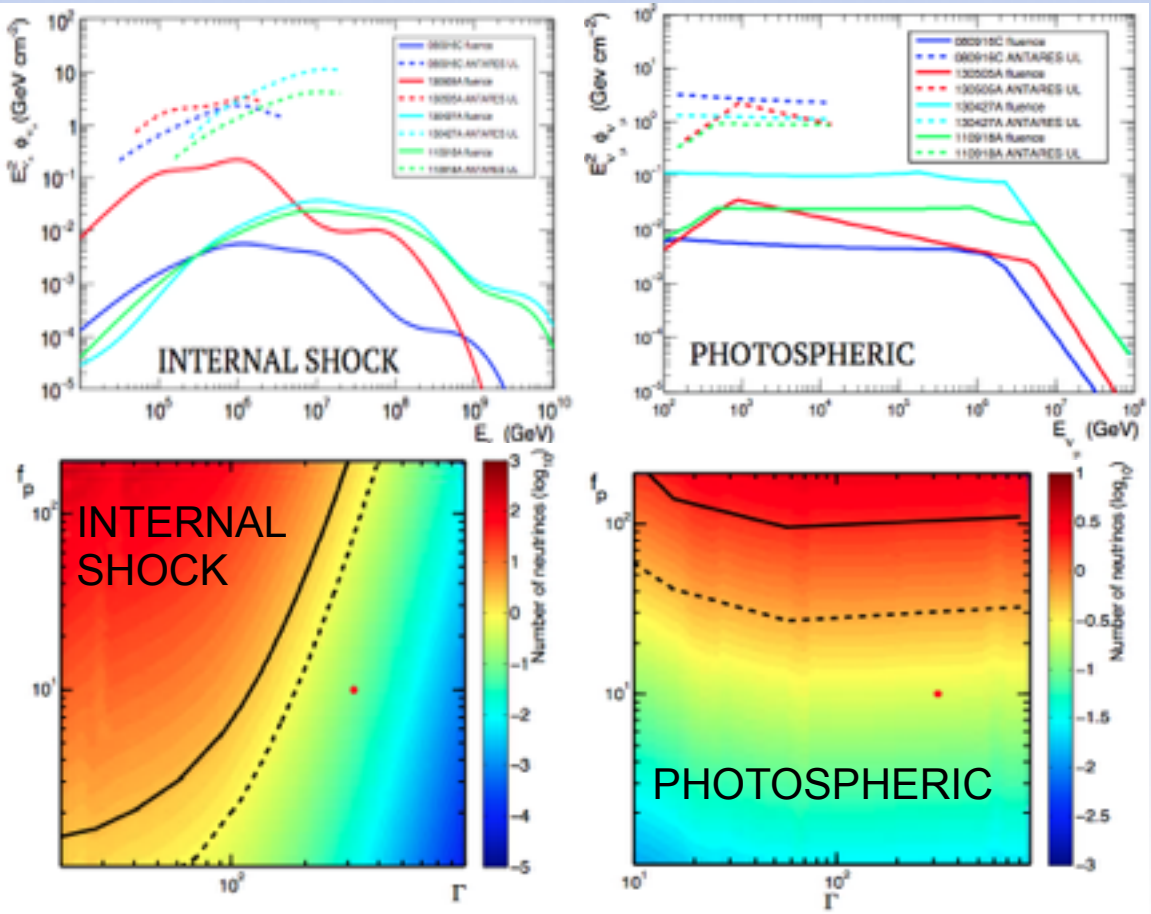
Bright gamma ray burst

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)



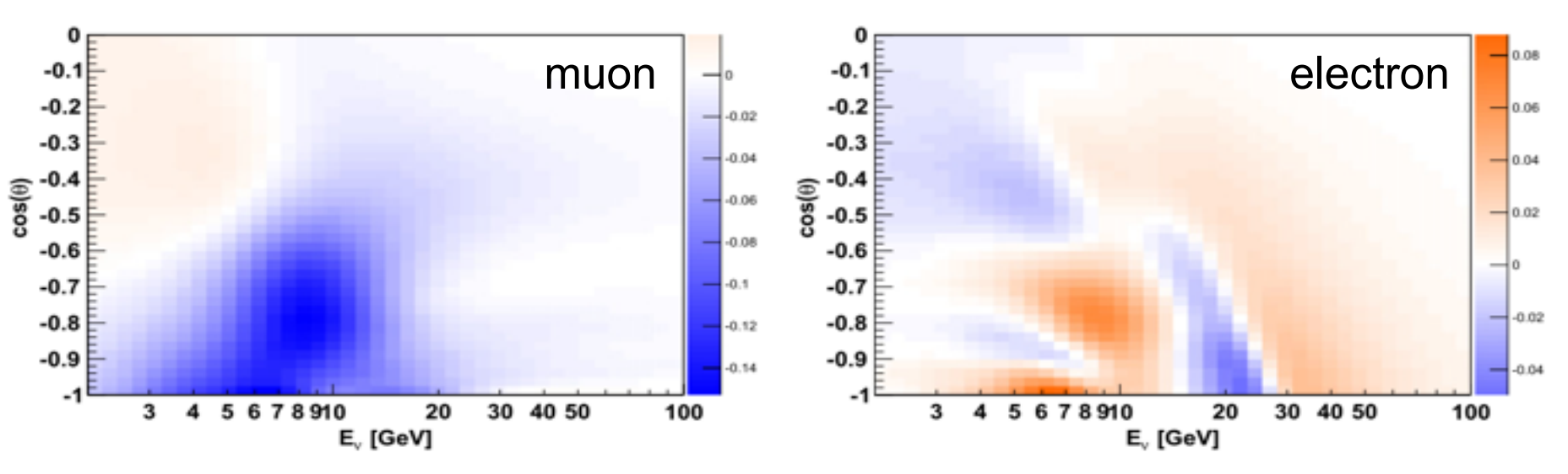
Outline

- Neutrino astronomy
- ANTARES and KM3NeT detectors
- Detectors performances
- ANTARES latest results
- KM3NeT: physics potential and preliminary results.
- Conclusions

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 and detailed understanding of systematics.

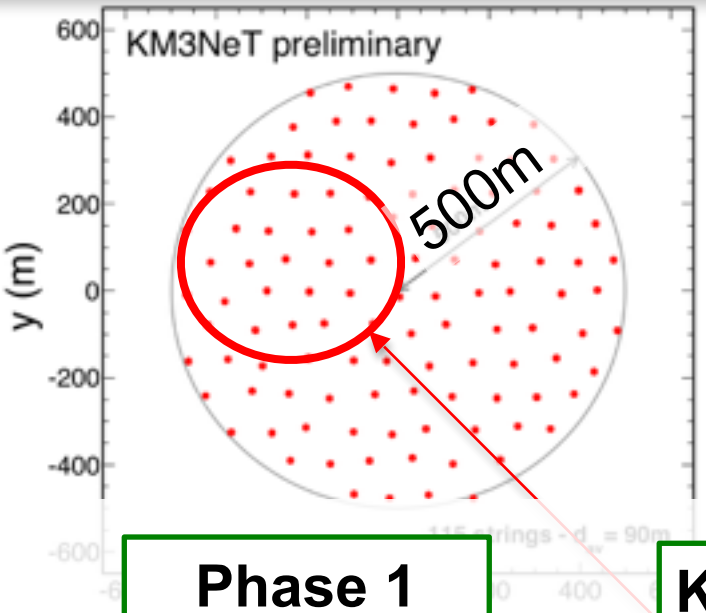
JPG 43' (2016)



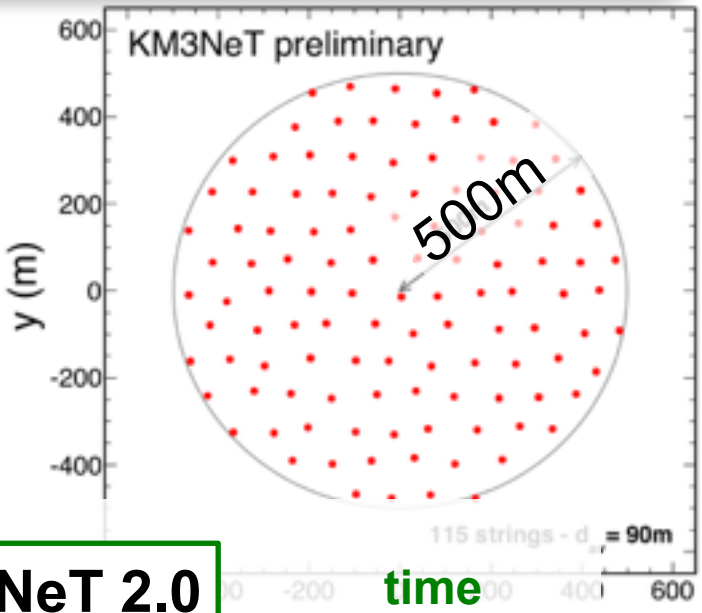
ARCA

Astroparticle Research with Cosmics in the Abyss

Vertical DOM distance = 36 m



+



Phase 1 Deployment 2018-19

KM3NeT 2.0 Deployment 2019-21

time

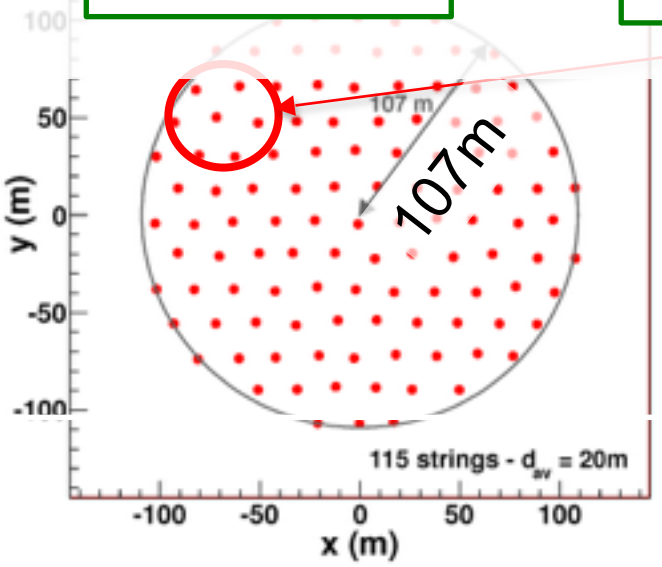
(fully funded)

Phase 2 partially funded

ORCA

Oscillation Research with Cosmics in the Abyss

Vertical DOM distance = 9 m



KM3NeT 2.0 Letter of Intent: JPG 43 (2016)