ANTARES and KM3NeT: status and perspectives

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Astroteilchenphysik in Deutschland, Mainz, 18.09.2018

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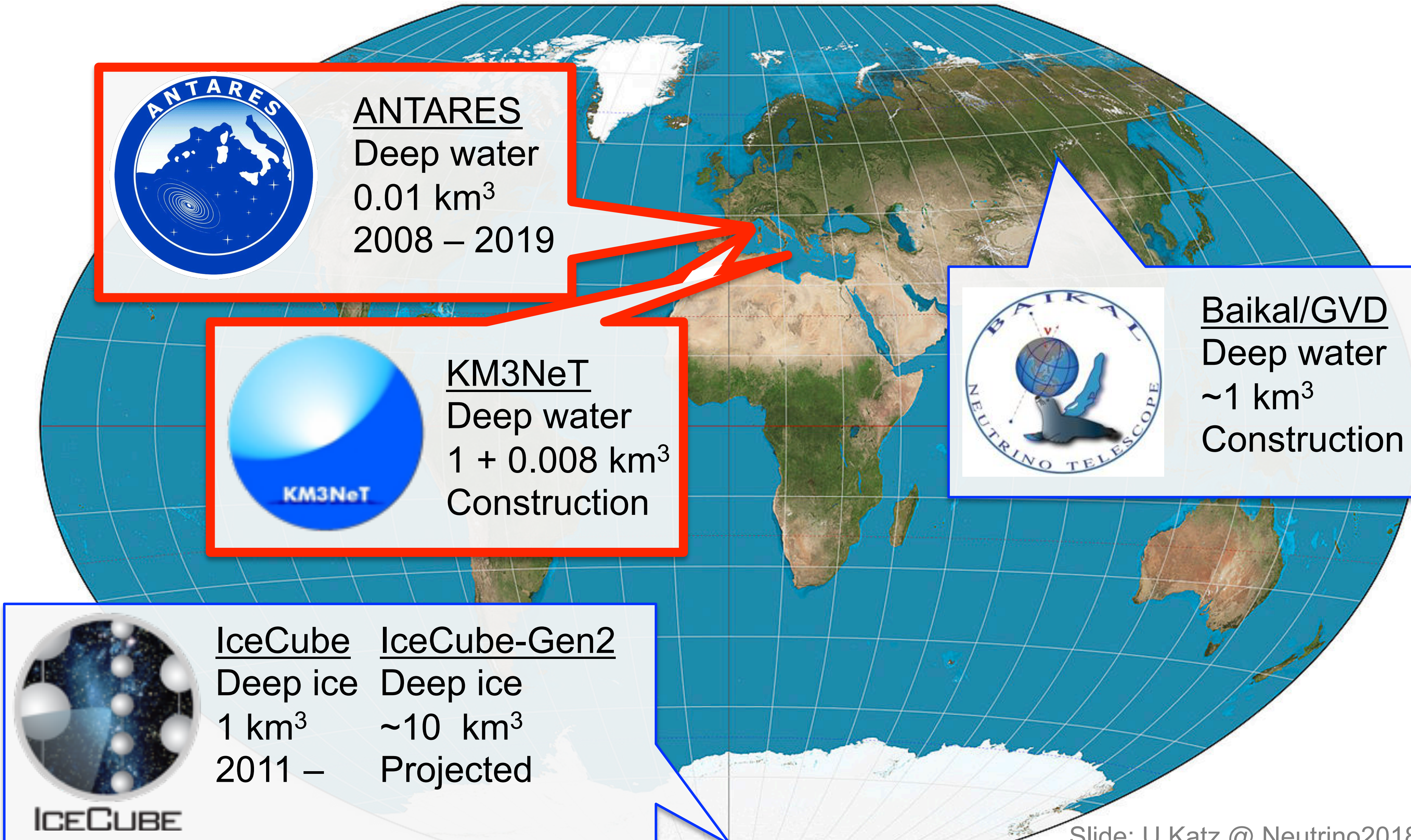
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

The neutrino telescope world map 2018



Slide: U.Katz @ Neutrino2018

ANTARES and KM3NeT

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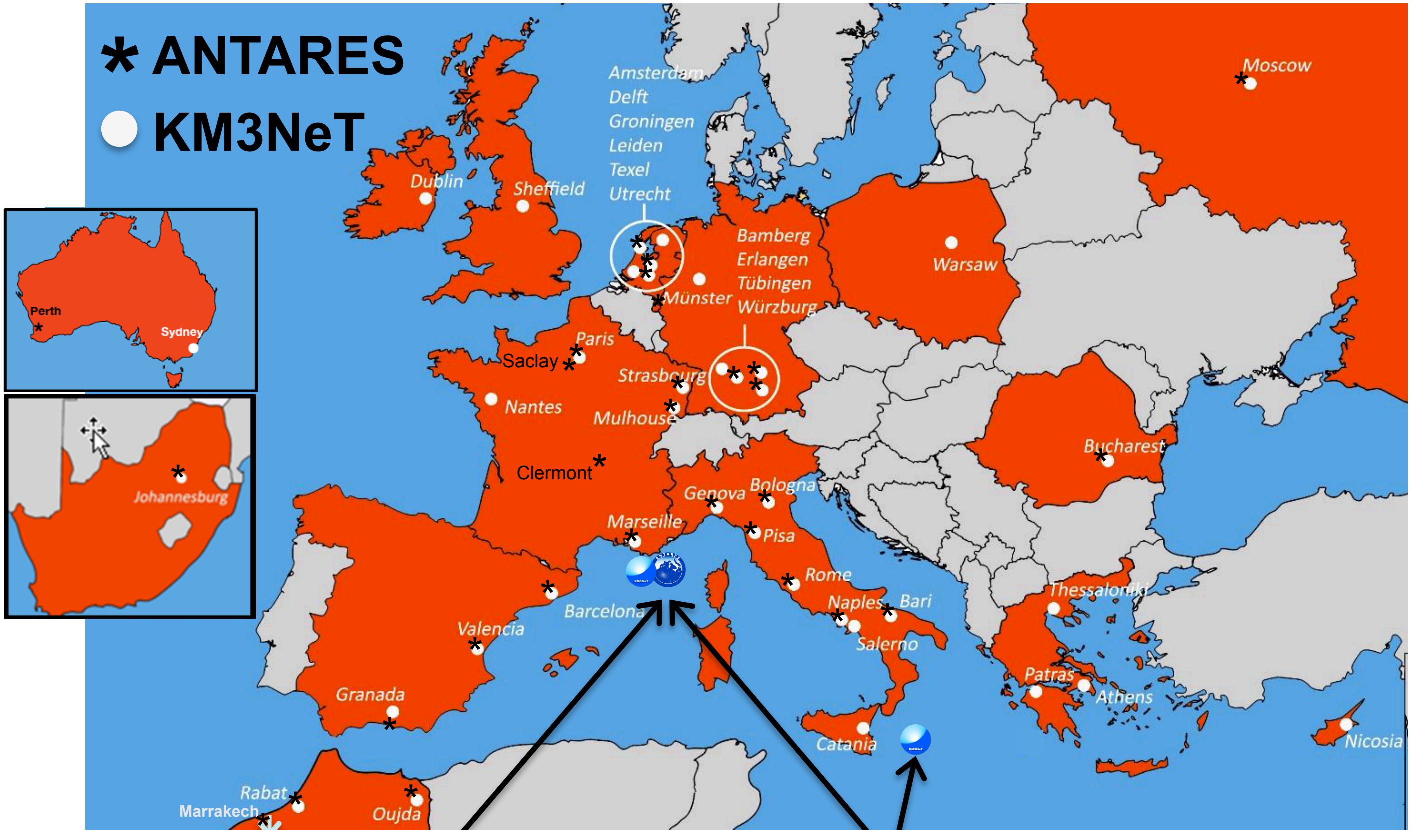


ANTARES
data taking since 2007,
-2500m under sea level,
off Southern French coast

KM3NeT
under construction

ARCA near Sicily, -3500m

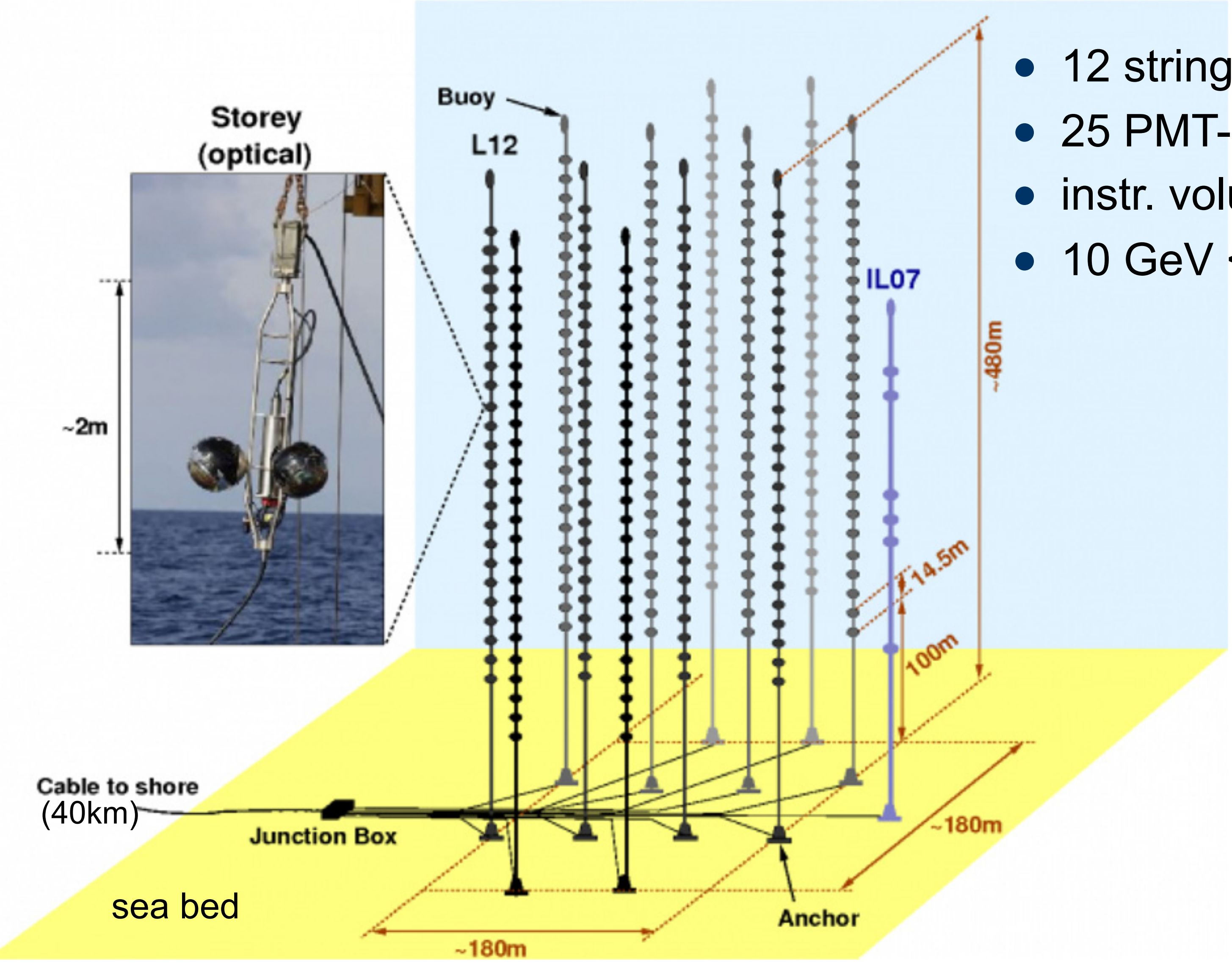
ORCA near ANTARES site

ANTARES

ANTARES detector

Nucl.Instrum.Meth. A656 (2011) 11

- 12 strings (885 x 10'' PMTs)
- 25 PMT-triplets per string
- instr. volume: ~0.01 km^3
- 10 GeV < E_ν < few PeV



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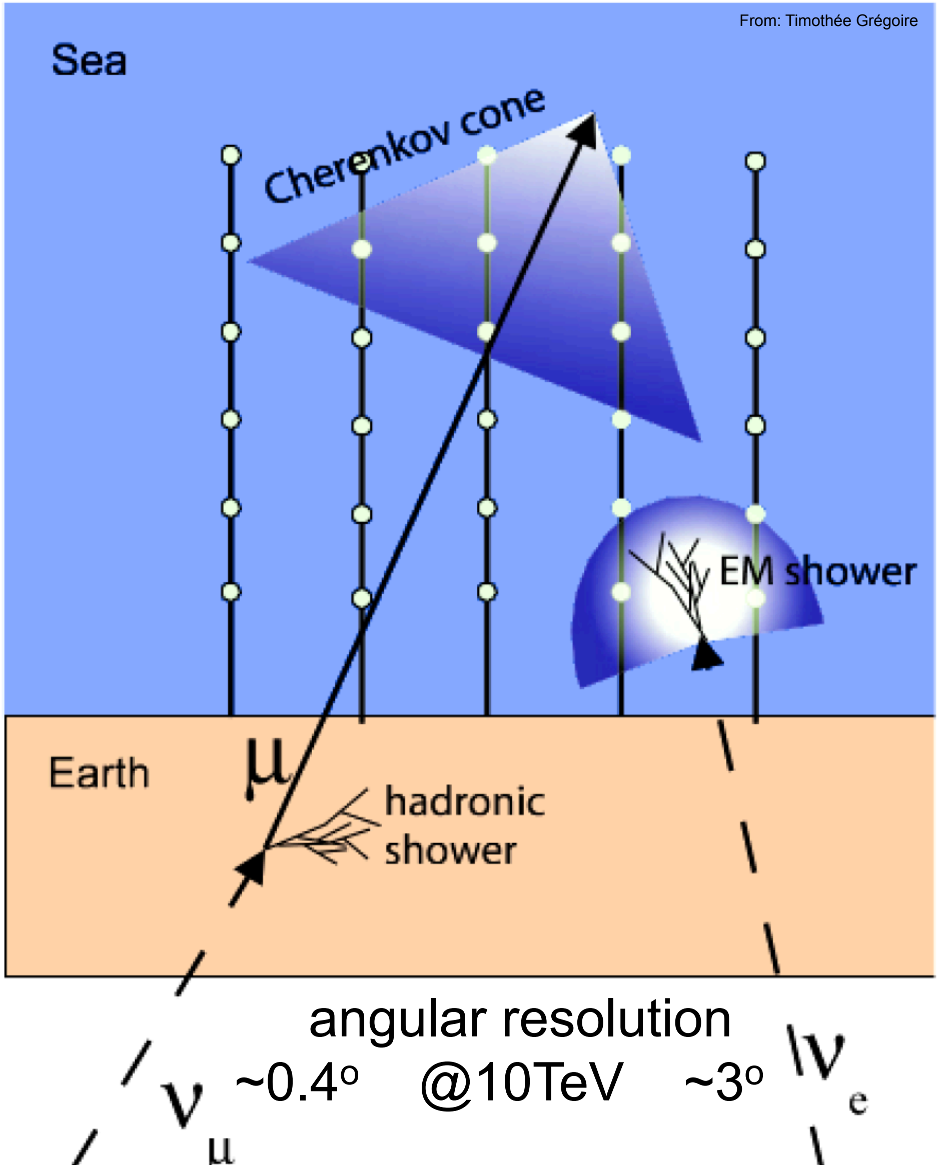


📖 Nucl.Instrum.Meth. A656 (2011) 11

- 12 strings (885 x 10'' PMTs)
- 25 PMT-triplets per string
- instr. volume: ~0.01 km^3
- 10 GeV < E_ν < few PeV

- Detection principle same as IceCube, but different medium:
  - less photon scattering
  - more optical noise

Recent ANTARES results

- **Diffuse flux**: ApJL 853 L7 (2018), Phys.Rev.D 96 (2017) 062001
- Point source: Phys. Rev. D 96 (2017) 082001, ApJ 823 (2016) 65

- Multi-messenger:
  - **TXS 0506+056**: ApJL 863 L30 (2018)
  - **Gravitational Waves**: ApJL 850 L35 (2017), ApJL 848 L12 (2017), Eur.Phys.J. C77 (2017) 911, Phys.Rev.D96 (2017) 022005, Phys.Rev.D93 (2016) 122010
  - FRB: MNRAS 475 (2018) 1427 , MNRAS 469 (2017) 4465

- Dark Matter: Physics of the Dark Universe 16 (2017) 41, Phys. Lett. B 769 (2017) 249, Phys. Lett. B 759 (2016) 69-74, JCAP 05 (2016) 016
- Magnetic Monopoles: JHEP 07 (2017) 054

- Earth and Sea science: Sci.Rep. 7 (2017) 45517, J.Geophys.Res. 122 (2017) 2291

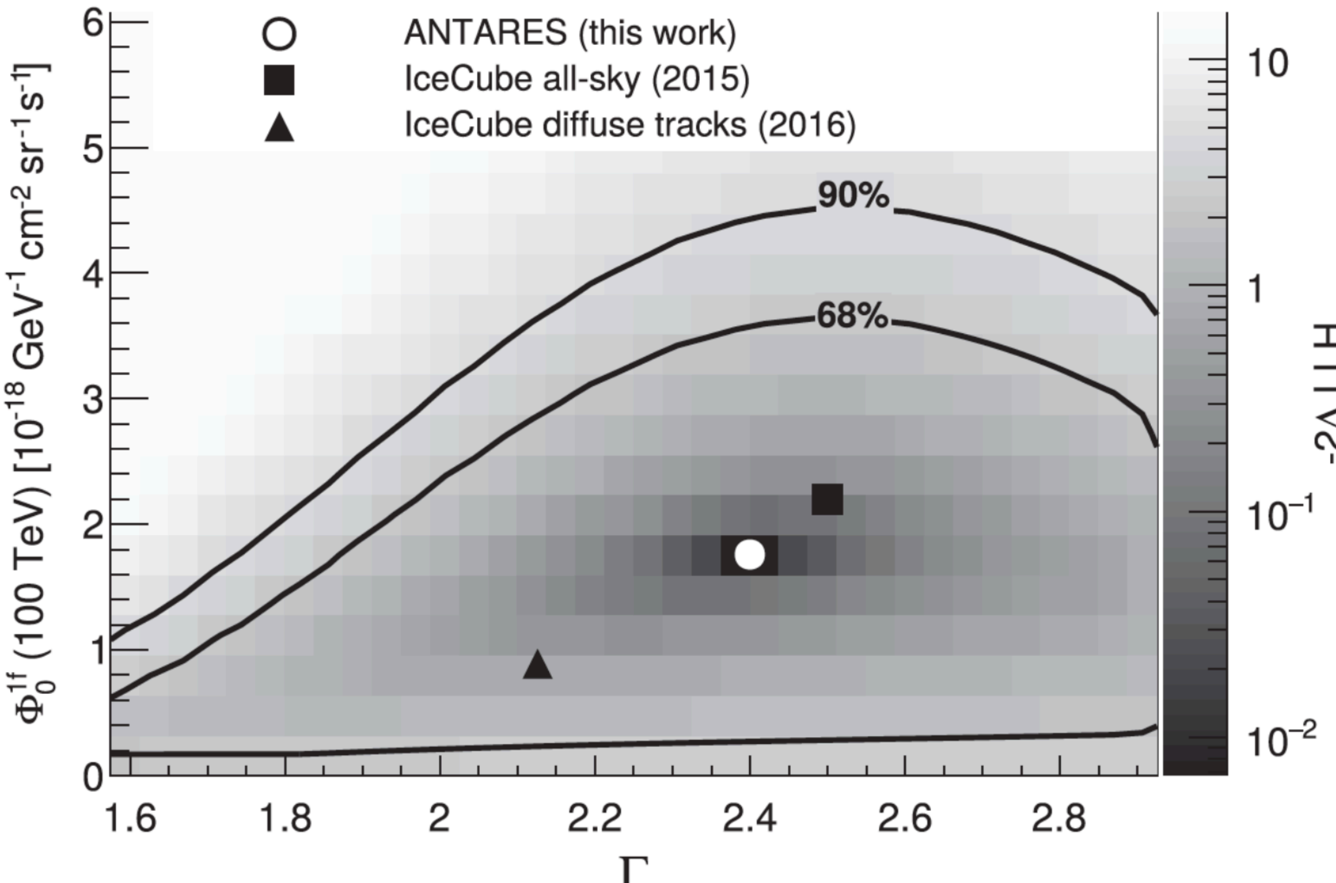
- Long-term detector operation: Eur.Phys.J. C78 (2018) 669

- Event reconstruction: Astron.J. 154 (2017) 275, Eur.Phys.J. C77 (2017) 419

Diffuse neutrino flux: all-sky / all-flavour search

ApJL 853 L7 (2018)

- Search for excess in high-energy neutrinos (tracks & showers)
- Result: 33 events in data, while 24±7 (stat + syst) background expectation
- Null cosmic neutrino contribution rejected at 85% C.L.



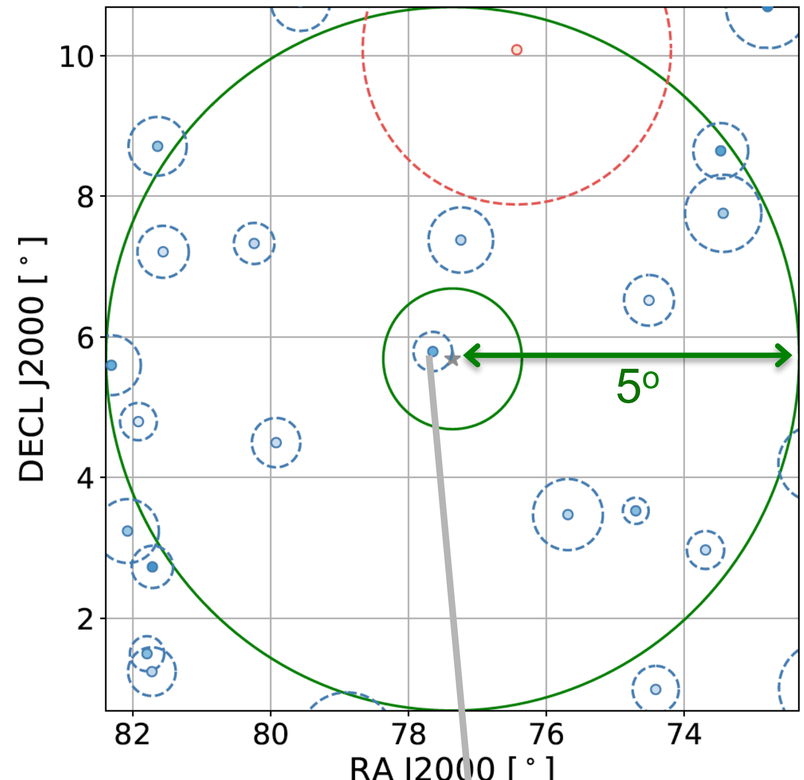
Data sample:
2007-2015
(2450d lifetime)

IceCube-170922A & TXS 0506+056

ApJL 863 L30 (2018)

Online search for neutrinos associated to IC-170922A

- Result: no event within 3° and ±1h

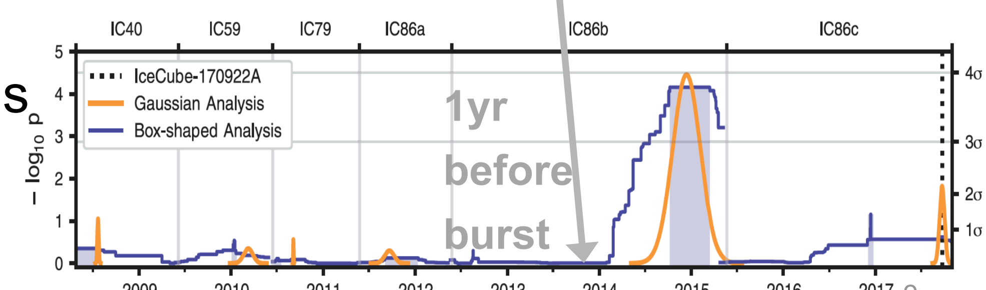


Time-integrated search for neutrinos from TXS 0506+056

- Added to standard point-source search list with 106 sources
- 1.03 signal events (3.4% pre-trial)
- 3rd most significant source (87% post-trial)

Search for neutrinos in bursting period

- Standard time-dependent analysis
- Result: no event within periods defined by IC analysis

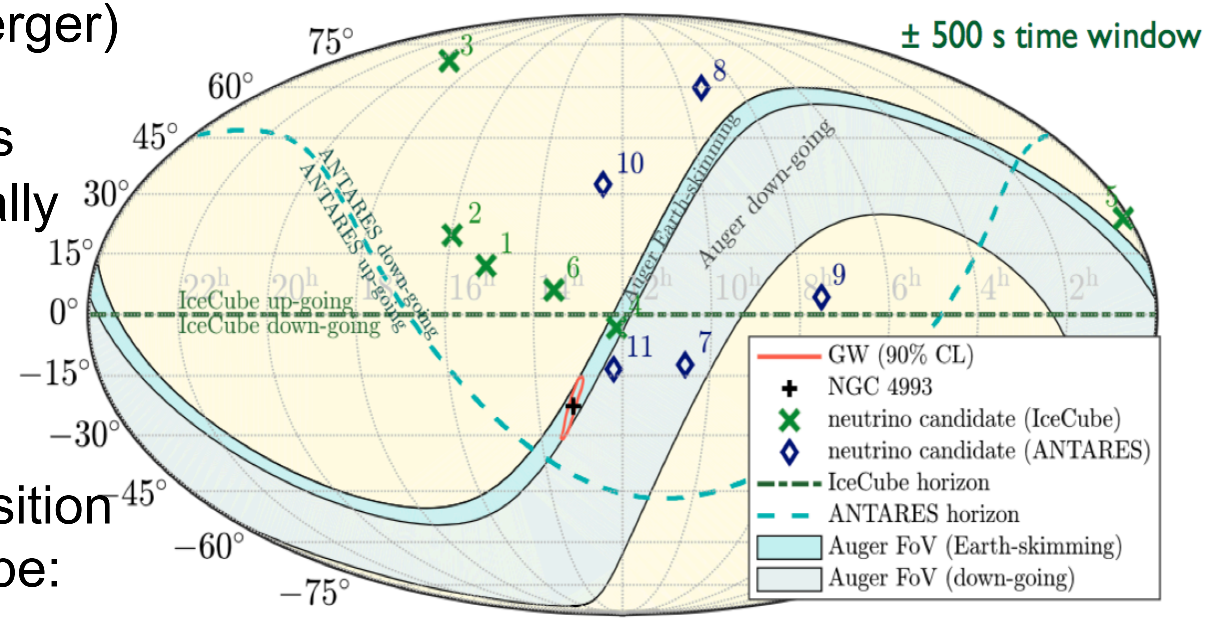


Gravitational wave follow-up

- Phys.Rev.D93 (2016) 122010
- Phys.Rev.D96 (2017) 022005
- Eur.Phys.J. C77 (2017) 911
- ApJL 848 L12 (2017)
- ApJL 850 L35 (2017)

- High-energy neutrino follow-up for several GW events/candidates:
  - GW150914 (BBH merger)
  - LVT151012 (candidate)
  - GW151226 (BBH merger)
  - GW170104 (BBH merger)
  - GW170817 (BNS merger)

→ No neutrino candidates temporally & directionally coincident with GW

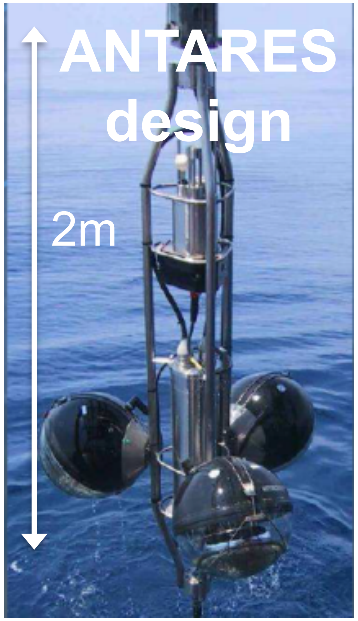


- Unfavorable source position for ANTARES and IceCube: above horizon

Outlook: ANTARES will be operational during 3rd Virgo/LIGO run

KM3NeT

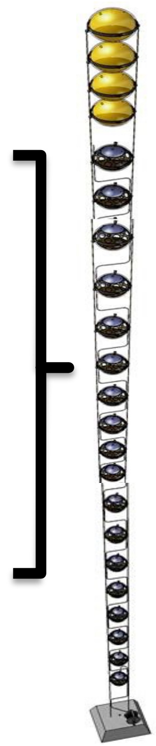
KM3NeT detector design

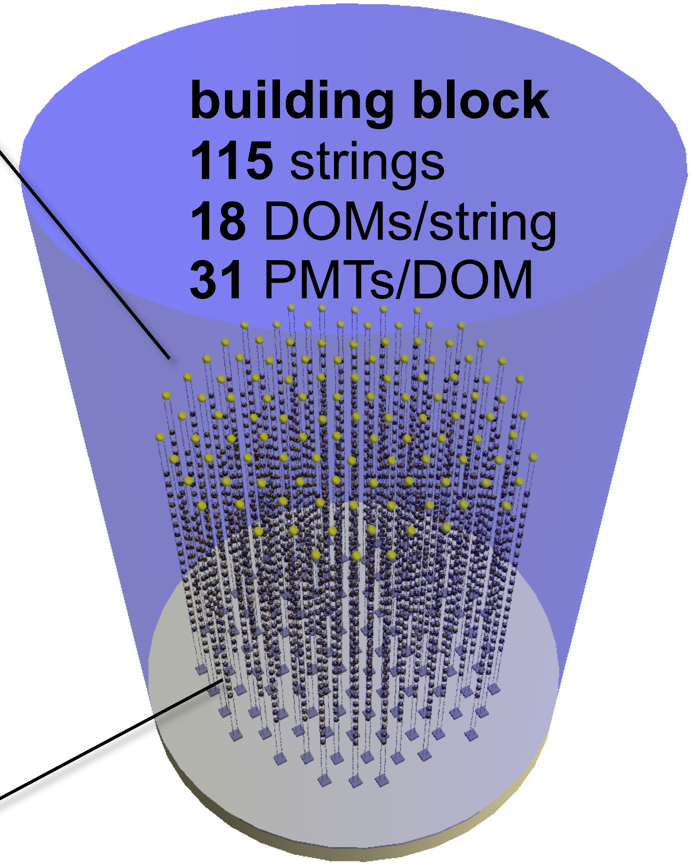


3 x 10'' PMTs

Digital Optical Module (DOM)

31 x 3"-PMTs
(19↓, 12↑)





→ uniform angular coverage

→ directional information

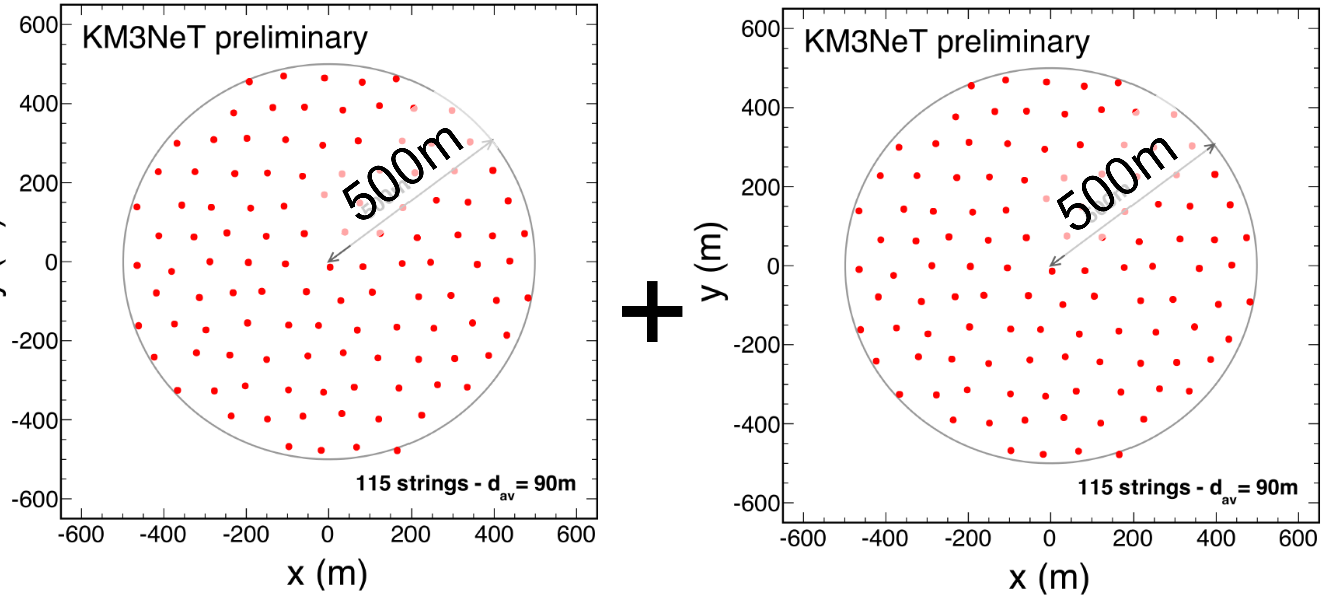
→ single photon counting

→ cost / photocathode area

KM3NeT: ARCA and ORCA

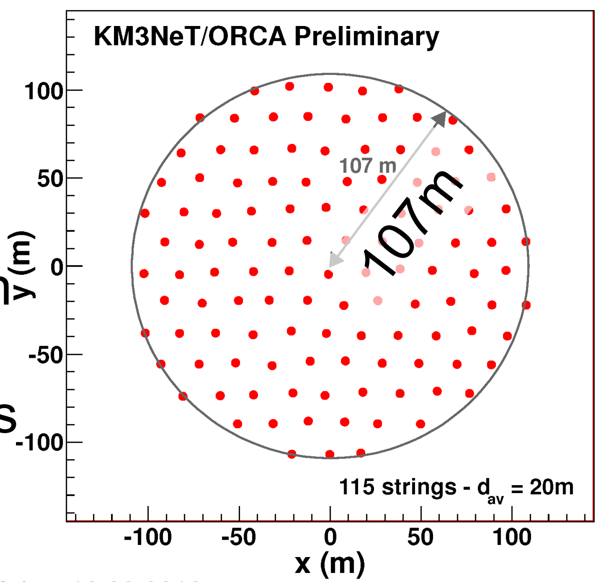
ARCA (Astroparticle Research with Cosmics in the Abyss)

- Large & sparse detector for TeV-PeV neutrino astronomy
- Size: 2x 0.5Gton



ORCA (Oscillation Research with Cosmics in the Abyss)

- Small & dense detector for oscillation physics of ~GeV atmospheric neutrinos
- Size: 8Mton



KM3NeT Letter of Intent: J.Phys. G43 (2016) 084001

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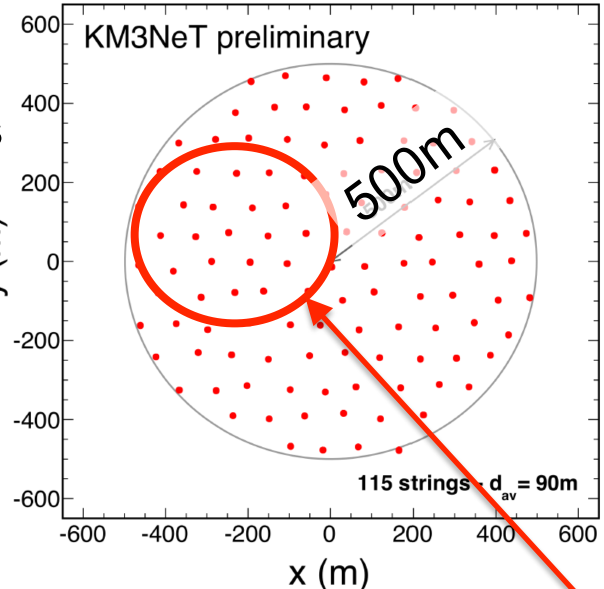

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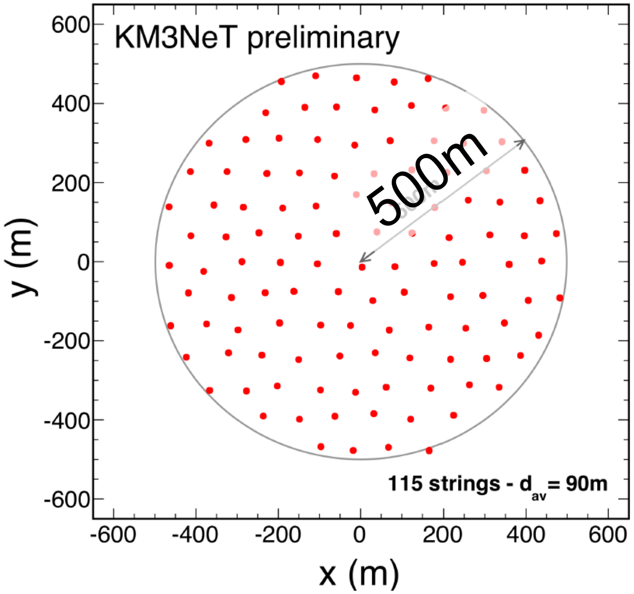

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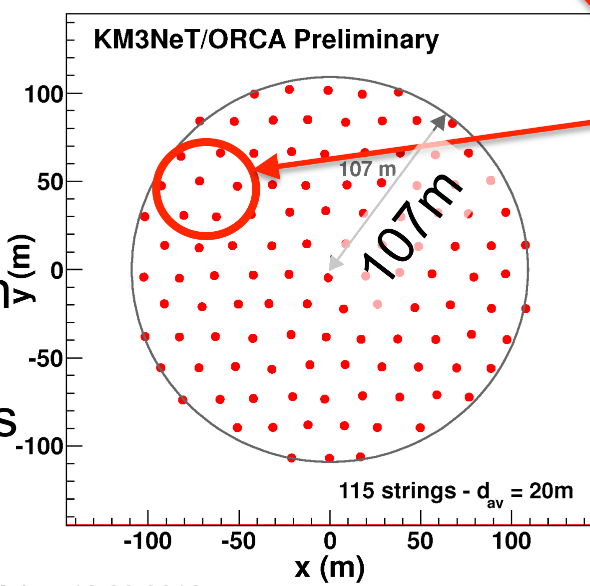

Phase 1 (fully funded)

Phase 2 partially funded

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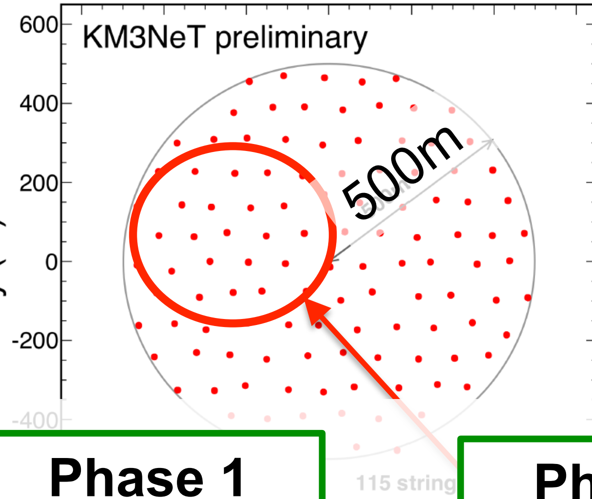

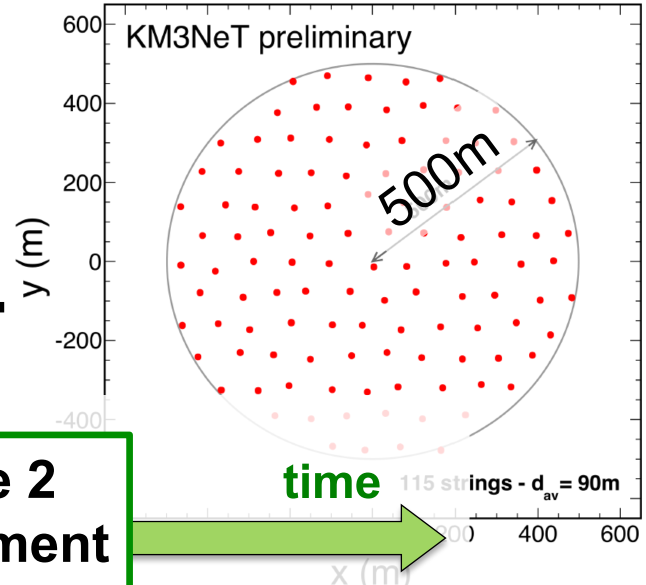

Phase 1 Deployment till 2019

Phase 2 Deployment 2019-21

time

Phase 1 (fully funded)

Phase 2 partially funded

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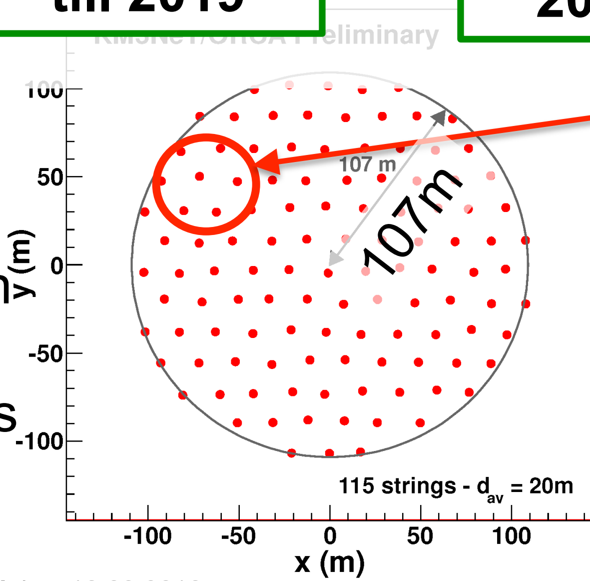

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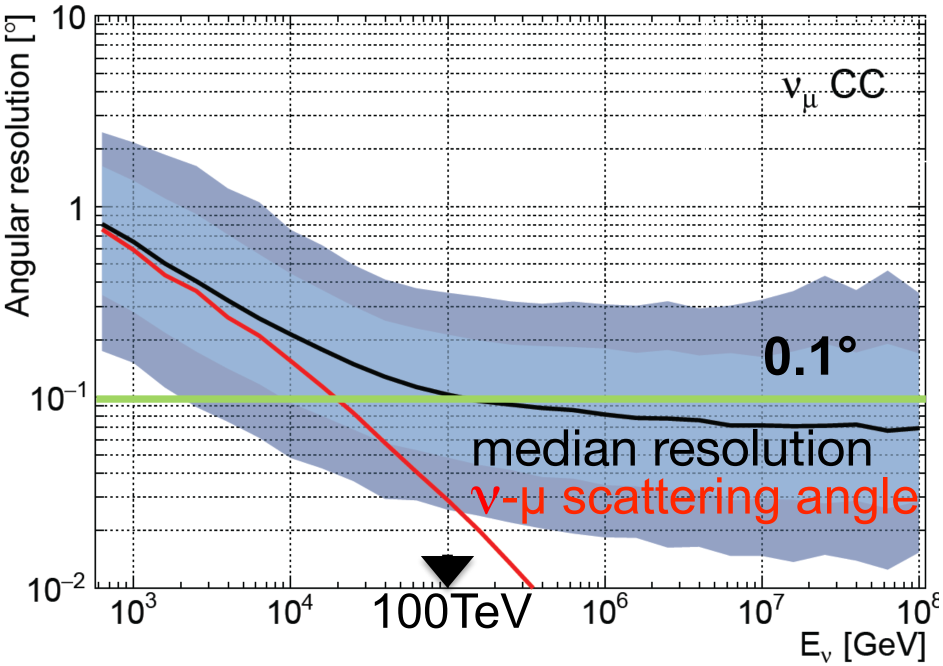
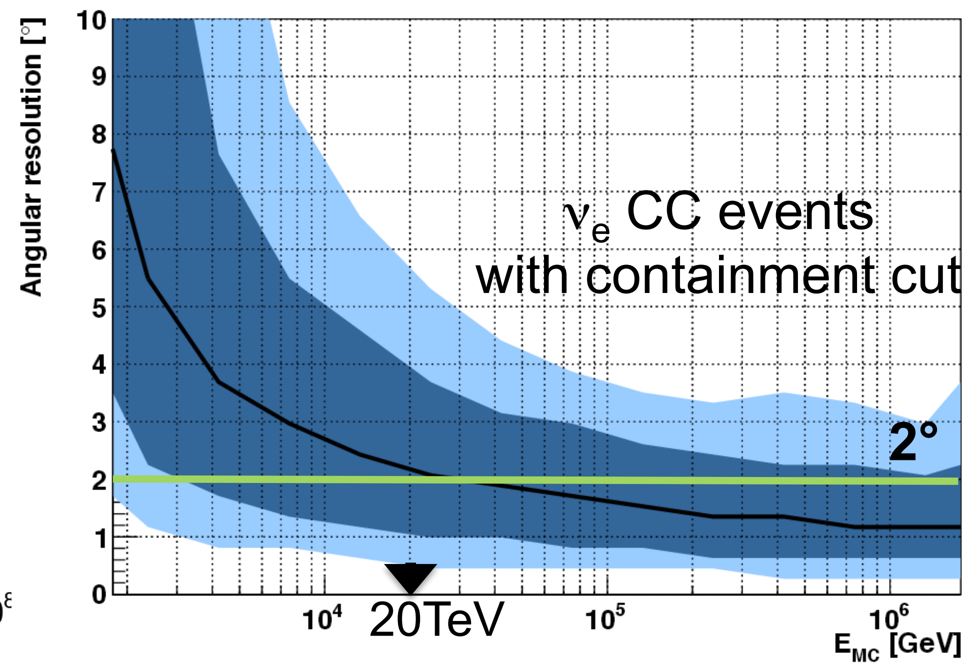
ARCA: reconstruction resolutions

J.Phys. G43 (2016) 084001

Track-like events



Shower-like events

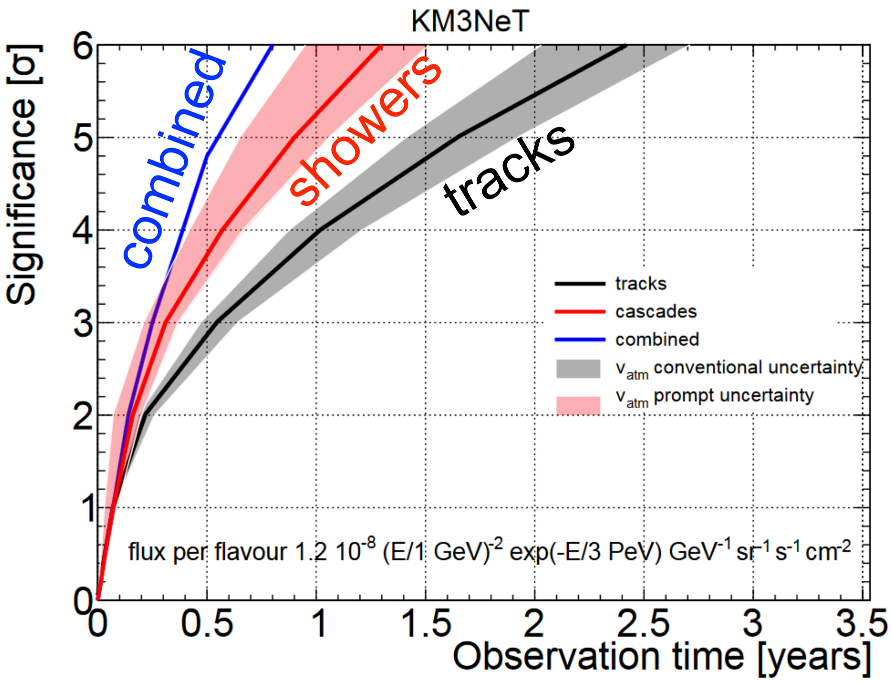


- Good resolution for tracks & showers
  - → all-flavour neutrino astronomy
  - → helps in source associations

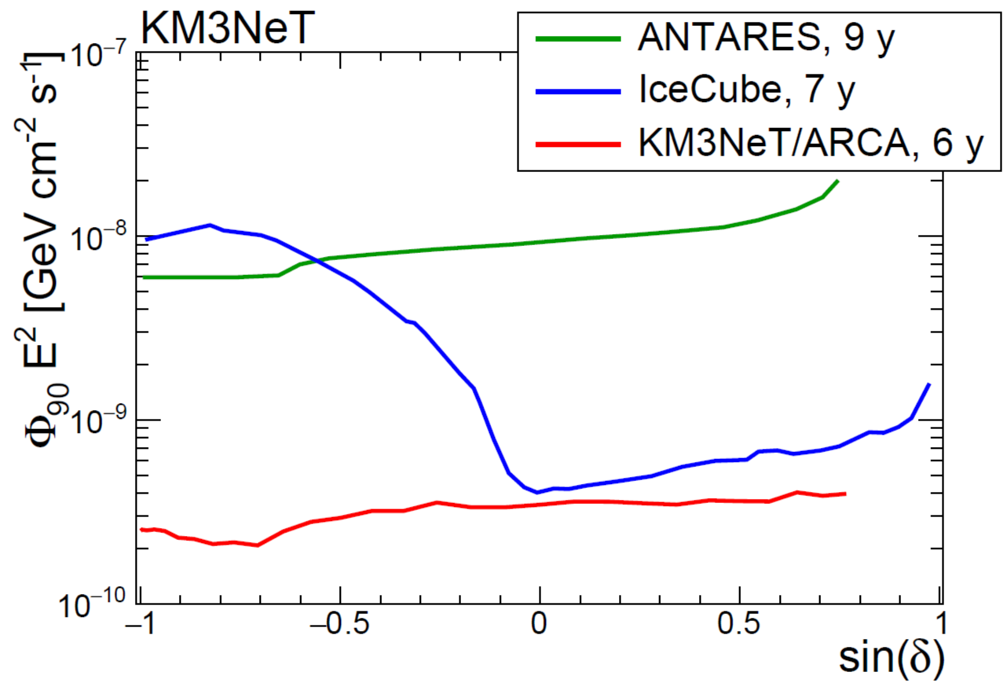
ARCA: physics potential

J.Phys. G43 (2016) 084001
PoS(ICRC2017)999

Diffuse neutrino flux sensitivity



Point sources sensitivity

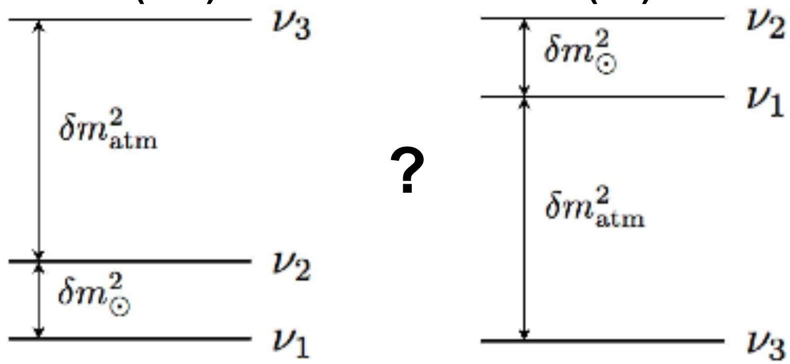


- Expected 5σ significance on diffuse IC flux in <1year
- Goal: don’t just re-discover IC flux, investigate it!

- KM3NeT/ARCA will improve ANTARES sensitivity by one order of magnitude

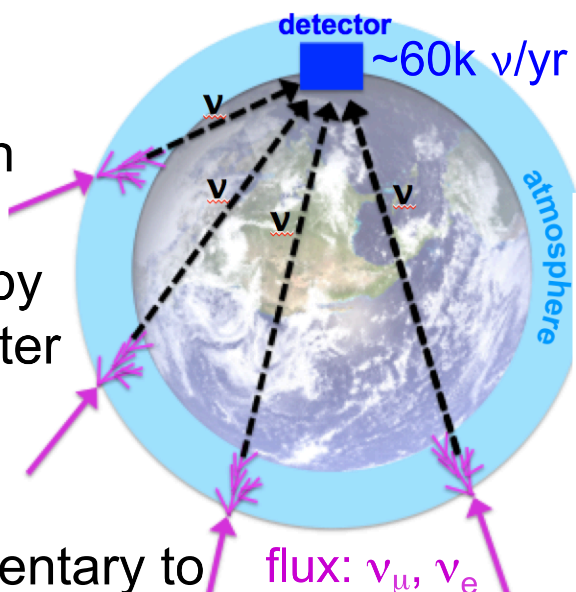
ORCA: neutrino mass ordering

Normal Ordering (NO) | **Inverted Ordering (IO)**



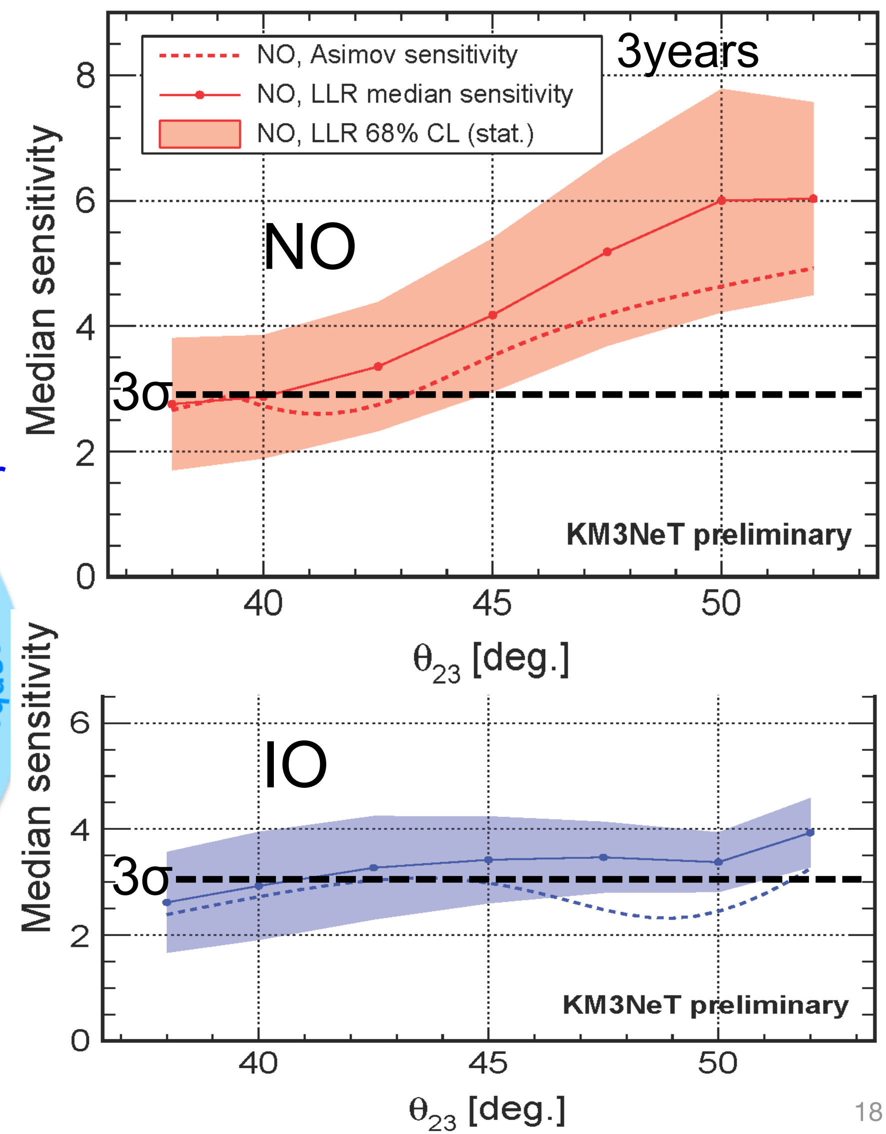
Method:

- Oscillation pattern distorted by Earth matter effects: NO ↔ IO
- Complementary to beam and reactor exp.



@Neutrino2018

Asimov and LLR median sensitivity after 3 years, $\delta_{CP} = 0$



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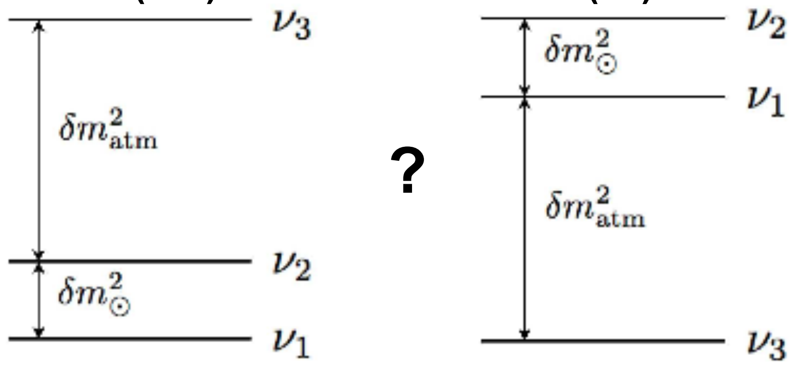

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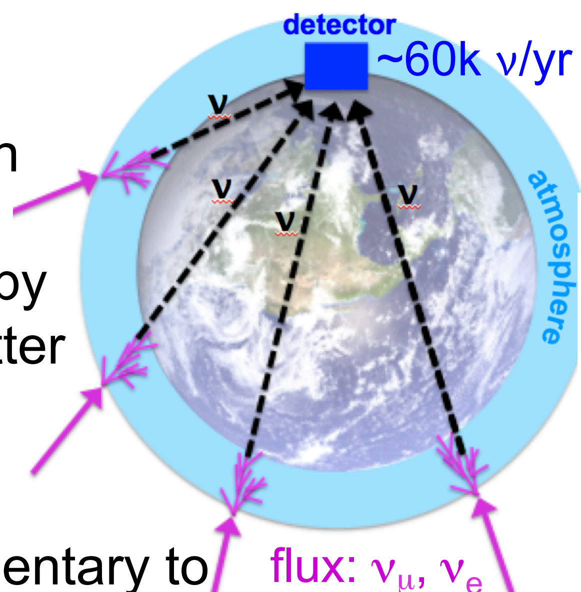

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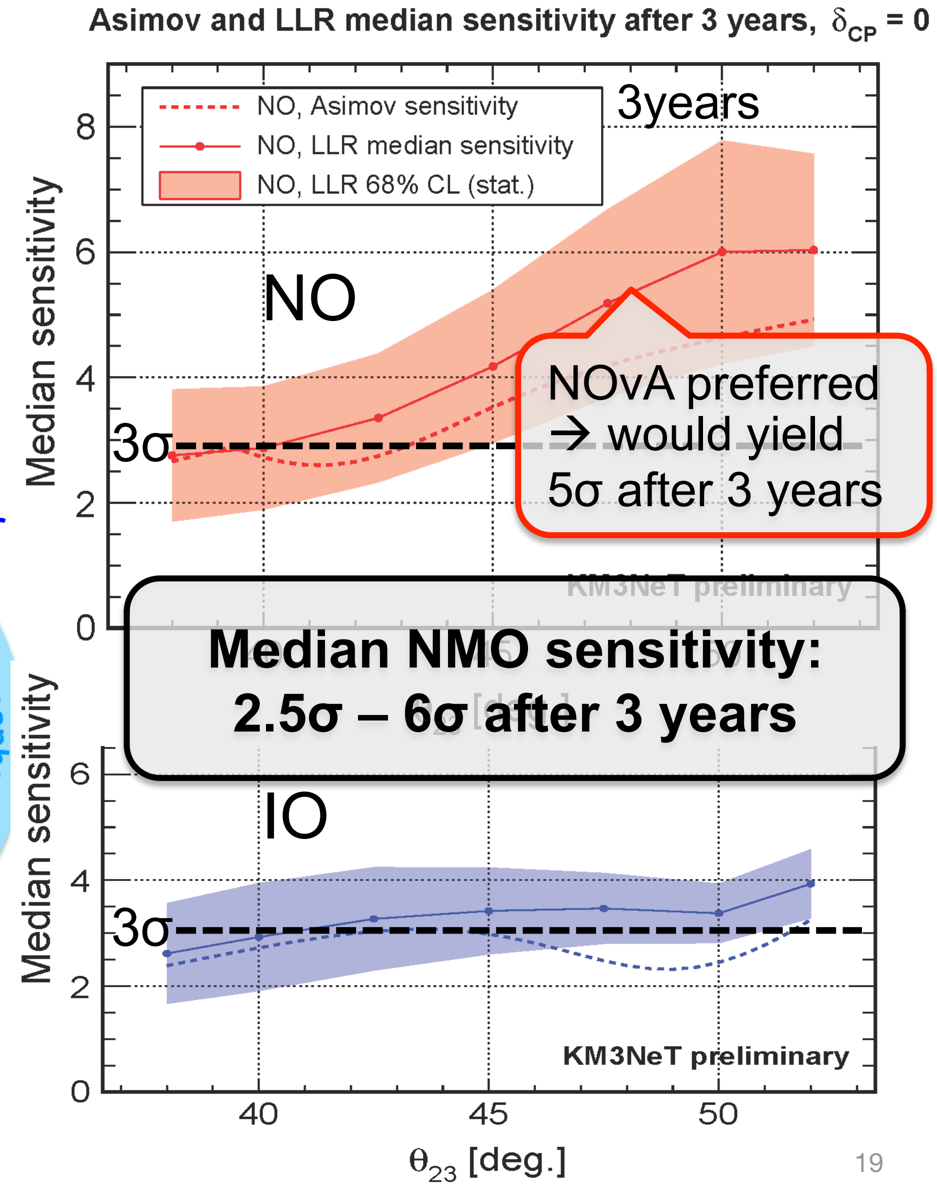
@Neutrino2018



ORCA: further physics topics

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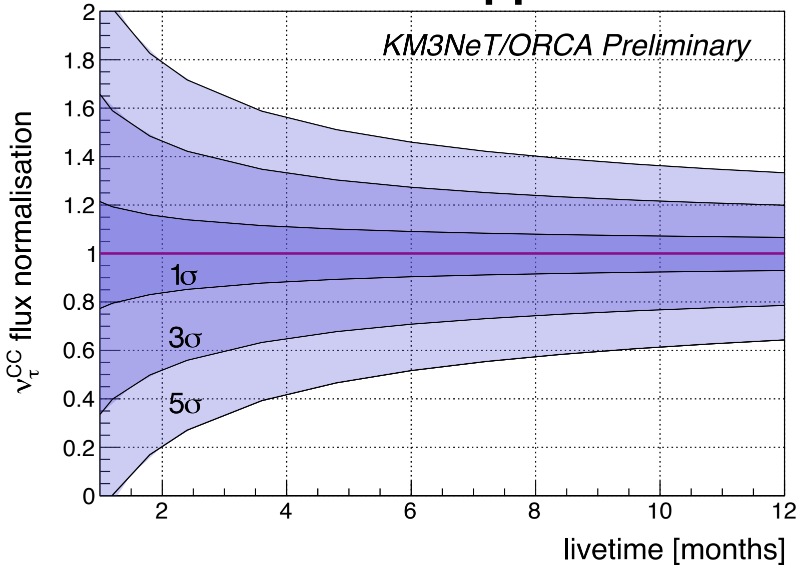
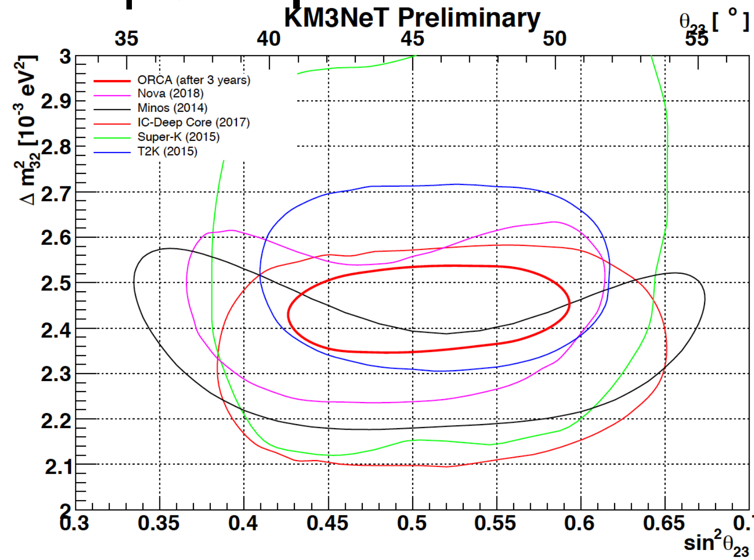
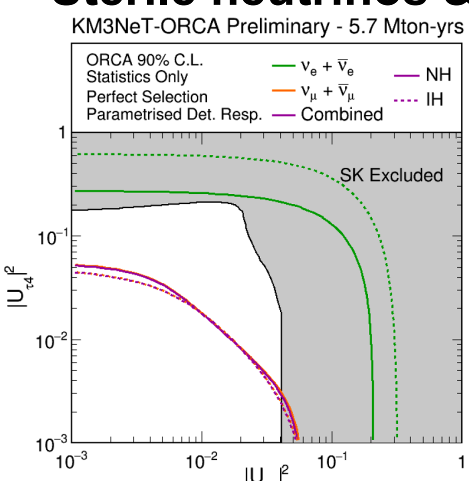
Tau neutrino appearance

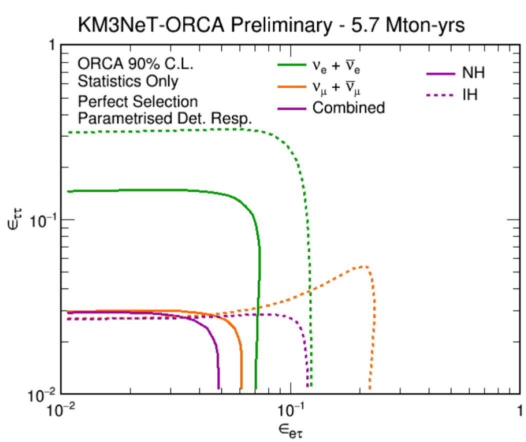


|Δm32| & θ23 precision measurement



Sterile neutrinos & non-standard interactions





Additional physics topics:

- Indirect search for DM
- Supernovae monitoring
- GeV-TeV ν-astrophysics
- …

KM3NeT construction status

ARCA

- 3 strings deployed in Dec 2015 & May 2016

  2 out of 3 operated, string #3 with short in power system, recovered
- Problem in sea-bed infrastructure in April 2017
- Full restoration of sea-bed infrastructure by mid-2019

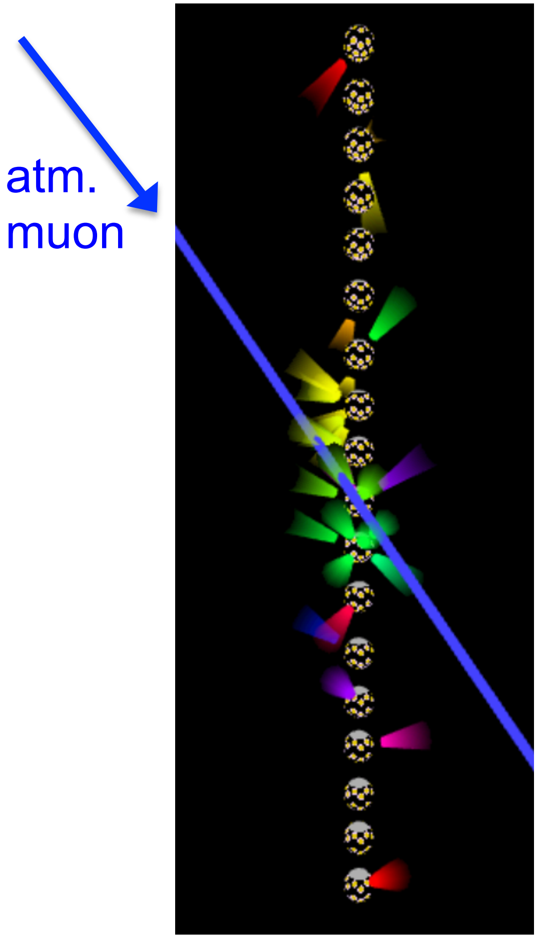
ORCA

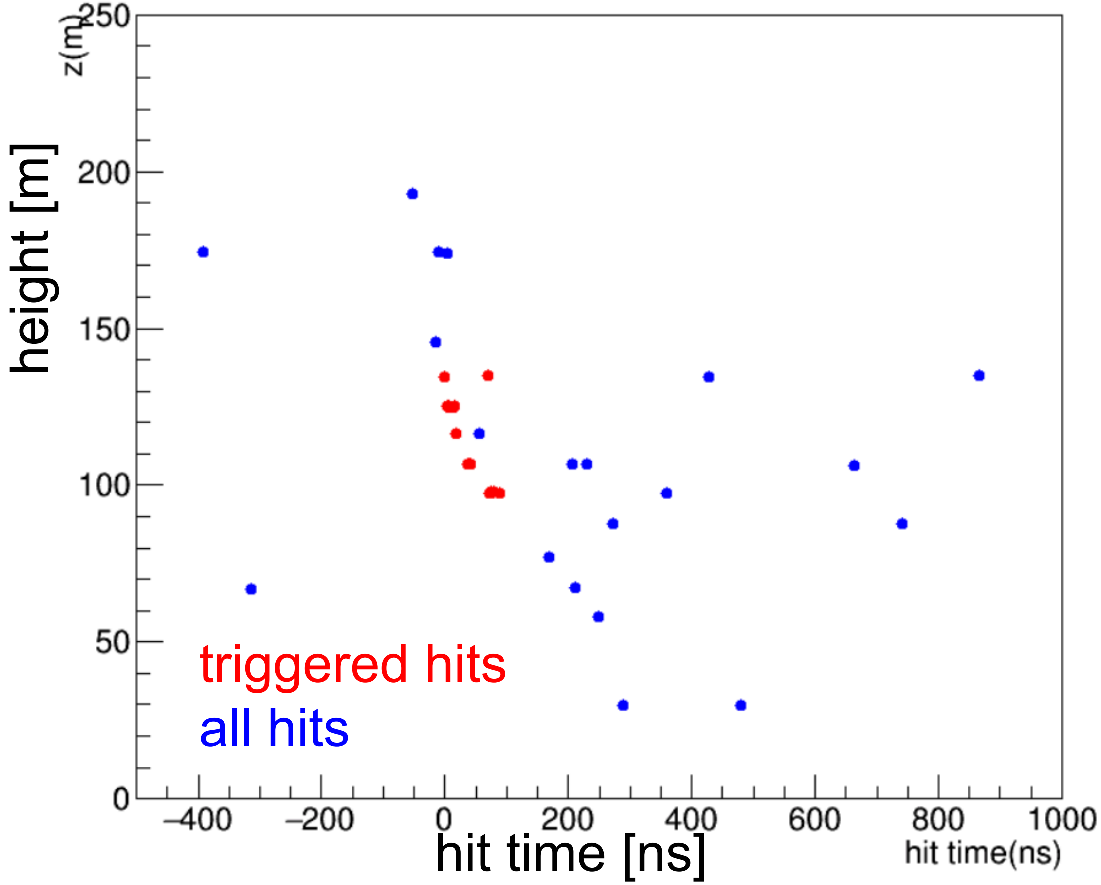
- Successful deployment & operation of first string in Sept 2017
- Failure of deep-sea cable in Dec 2017, replacement in fall 2018
- Resume operation shortly thereafter with installation of 3 strings, and up to 3 more strings by end of this year

Construction of DOMs and strings is proceeding in parallel

First ORCA data analyses

- First reconstructed event few hours after deployment of 1st string





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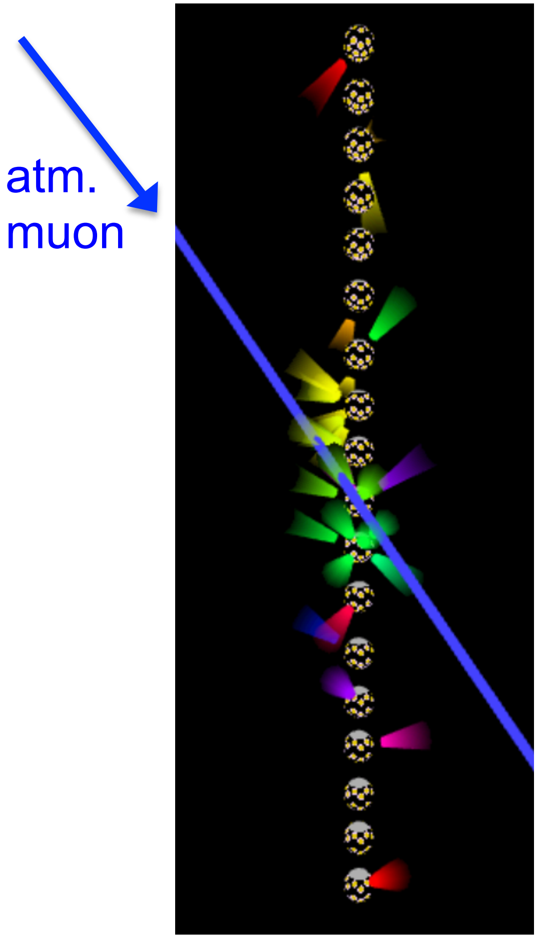
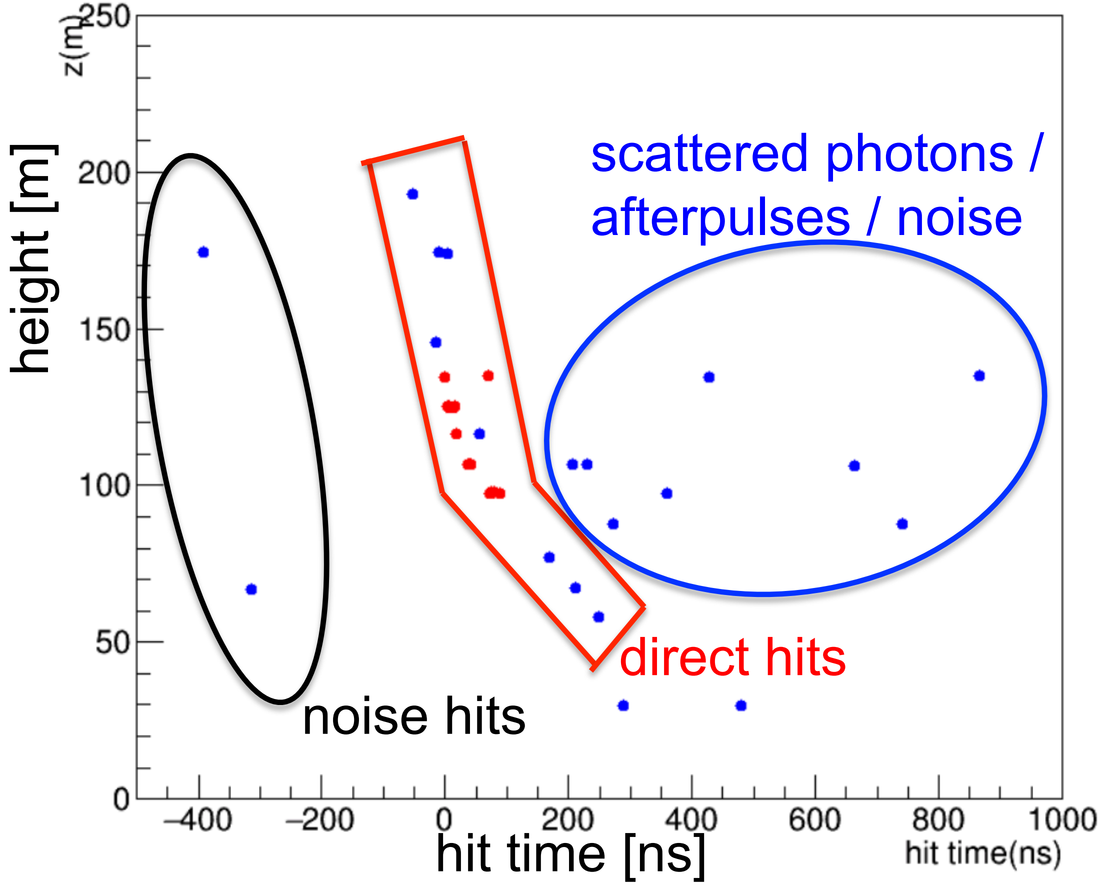


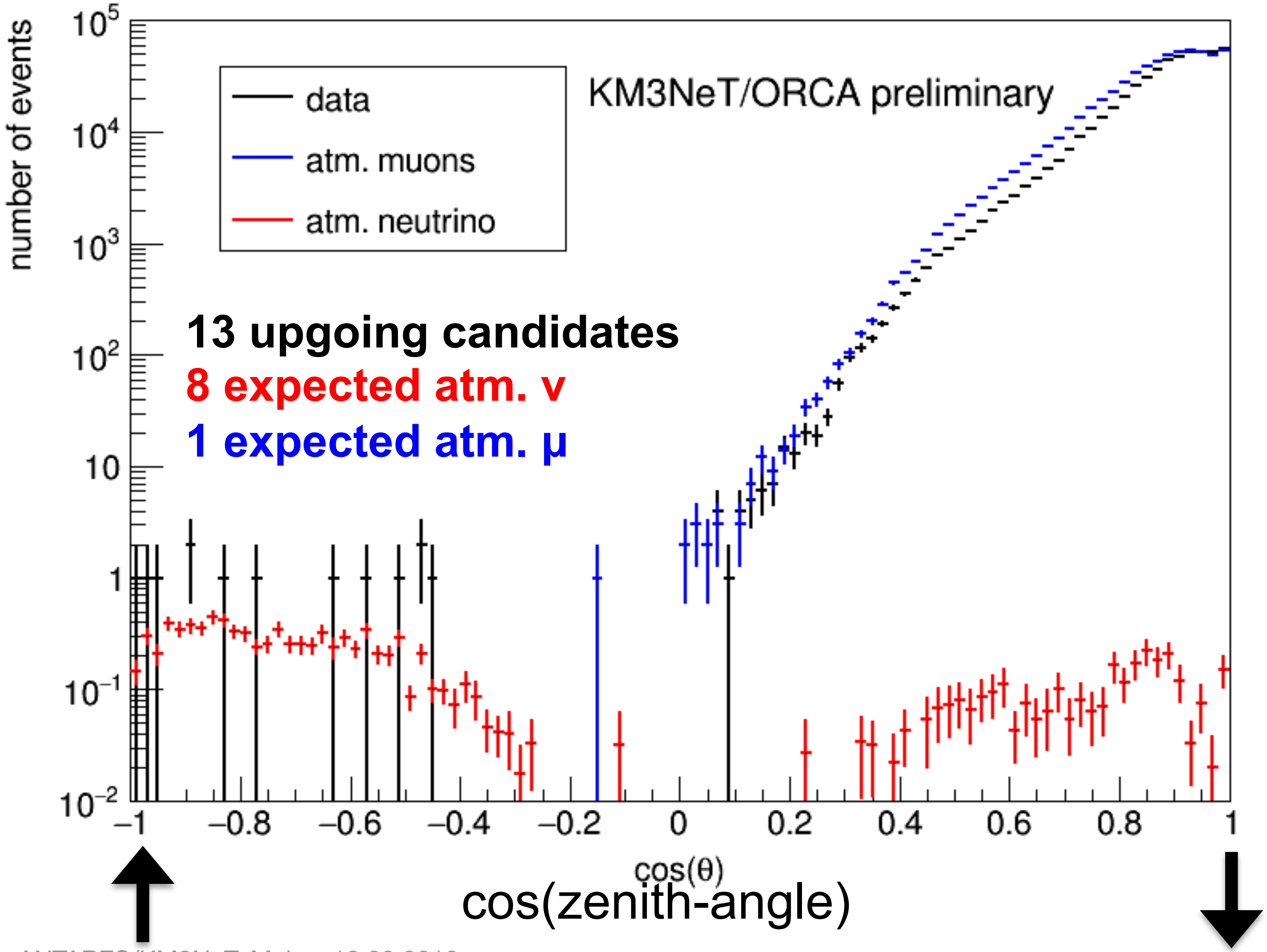


First ORCA data analyses

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

📖 paper in preparation

- First atmospheric neutrino sample
- Continuous data taking: ~98% physics data (total 82 days)



cos(zenith-angle)

Conclusions & outlook

ANTARES

- >10 years of continuous data taking
- Solid results from various searches for astrophysical neutrino emission
- Active multi-messenger program & operational during Virgo/LIGO O3

KM3NeT

- ARCA: all-flavour neutrino astronomy
- ORCA: neutrino oscillation physics
- Detectors under construction: 3 (out of 355) strings deployed
- Data analysis ongoing → first neutrino sample
- Currently, problem with cable (ORCA) & sea-bed infrastructure (ARCA)
- Resume operation soon; installation of further strings in 2018

Possible future KM3NeT options

- δ_{CP} with beam from Protvino (P2O) or atm. ν (super-dense ORCA)

Thank you for your attention !

Deutsche Forschungsgemeinschaft

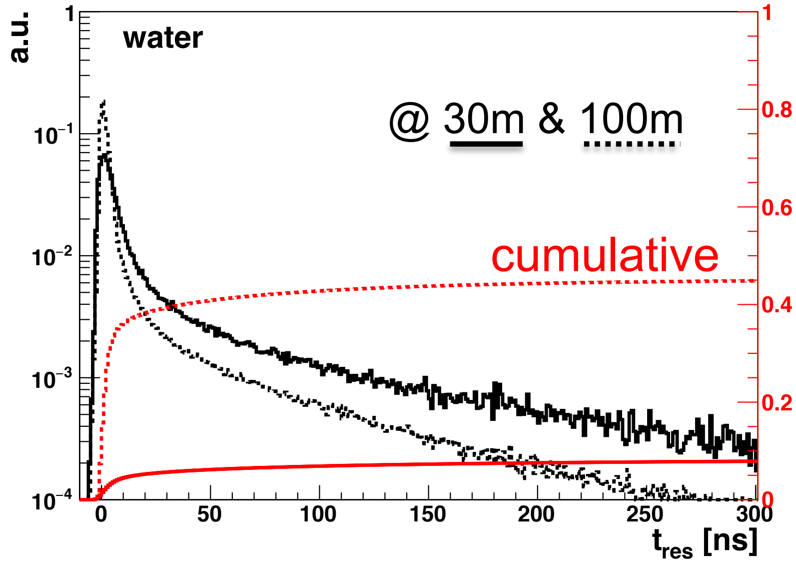
Horizon 2020
European Union Funding
for Research & Innovation

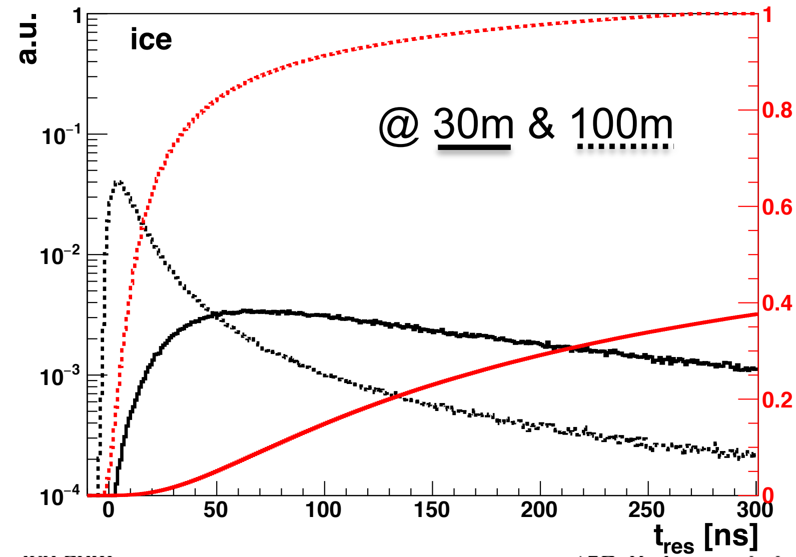
Bundesministerium
für Bildung
und Forschung

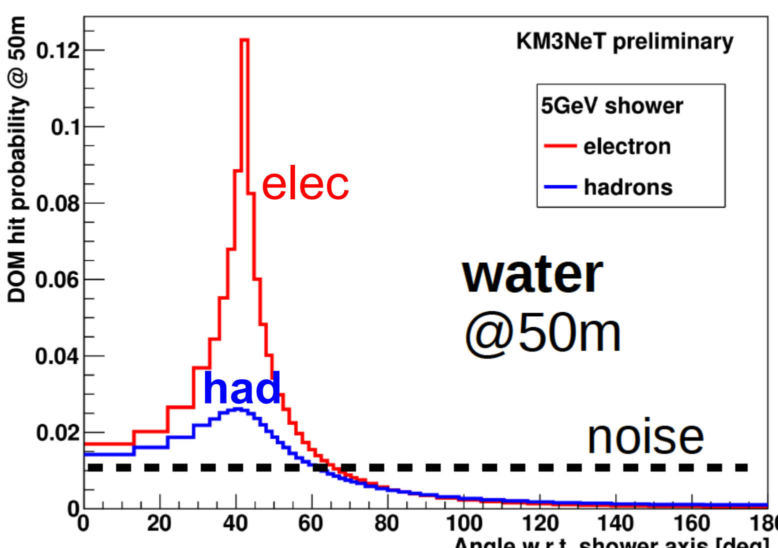
BACKUP

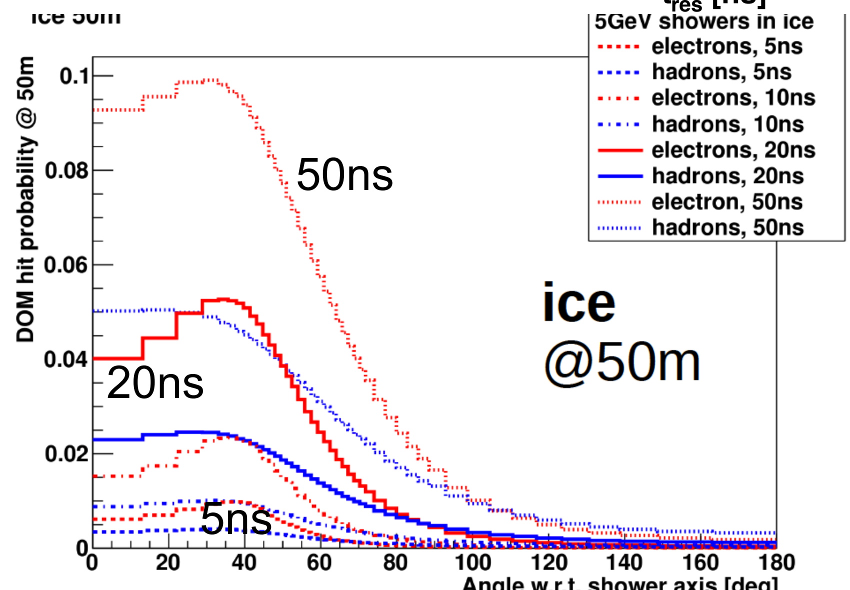
Comparison: water vs ice

Time residual: t_res = t_expected − t_measured









Diffuse neutrino flux: all-sky / all-flavour search

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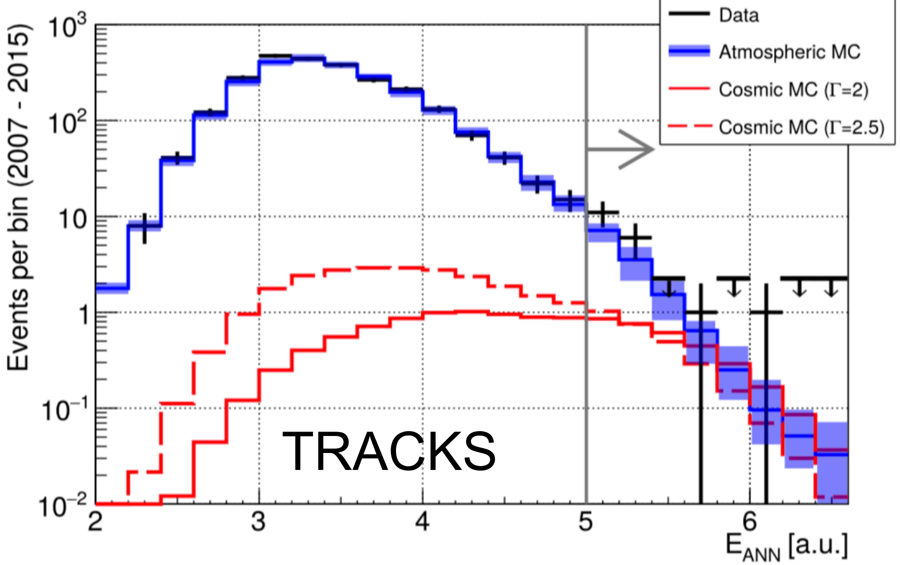
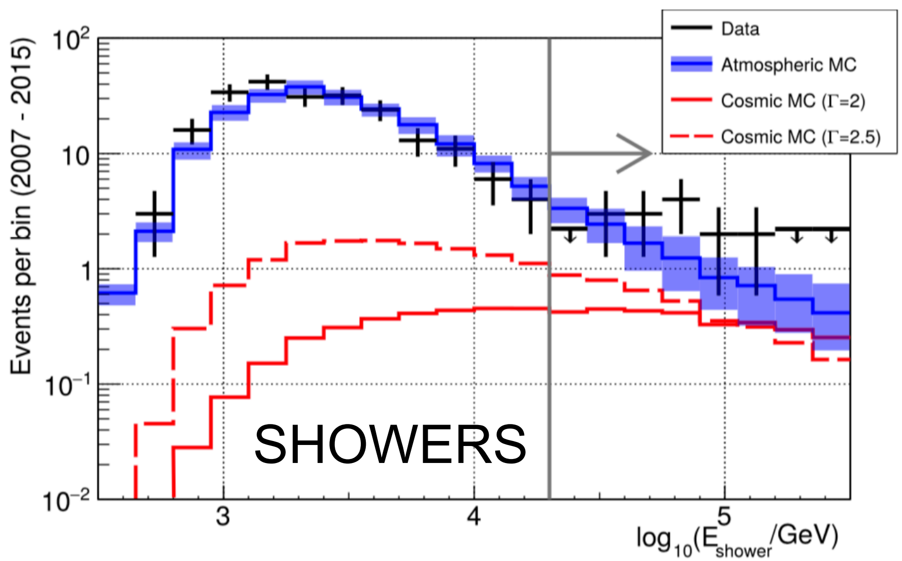
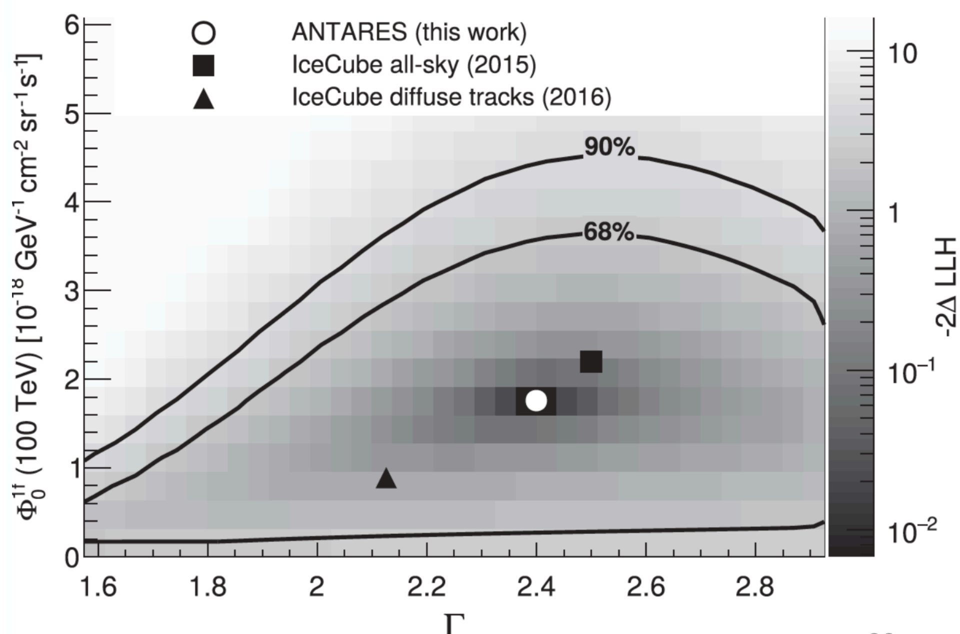
Data sample: 2007-2015 (2450d lifetime)

📖 **ApJL 853 L7 (2018)**





- Result: 33 events (19 tracks + 14 showers) in data, while 24±7 (stat. + syst.) background expectation
- null cosmic neutrino contribution rejected at 85% CL
- compatible with IceCube signals



Conclusions & outlook

Phys.Rev.D93 (2016) 122010

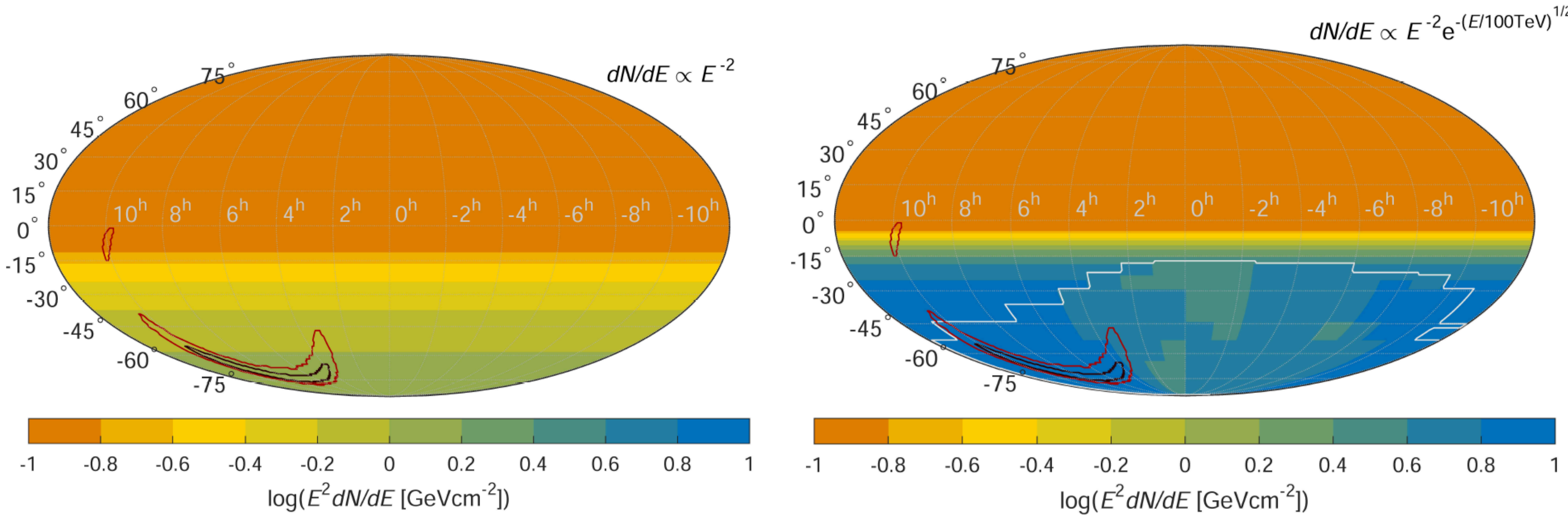
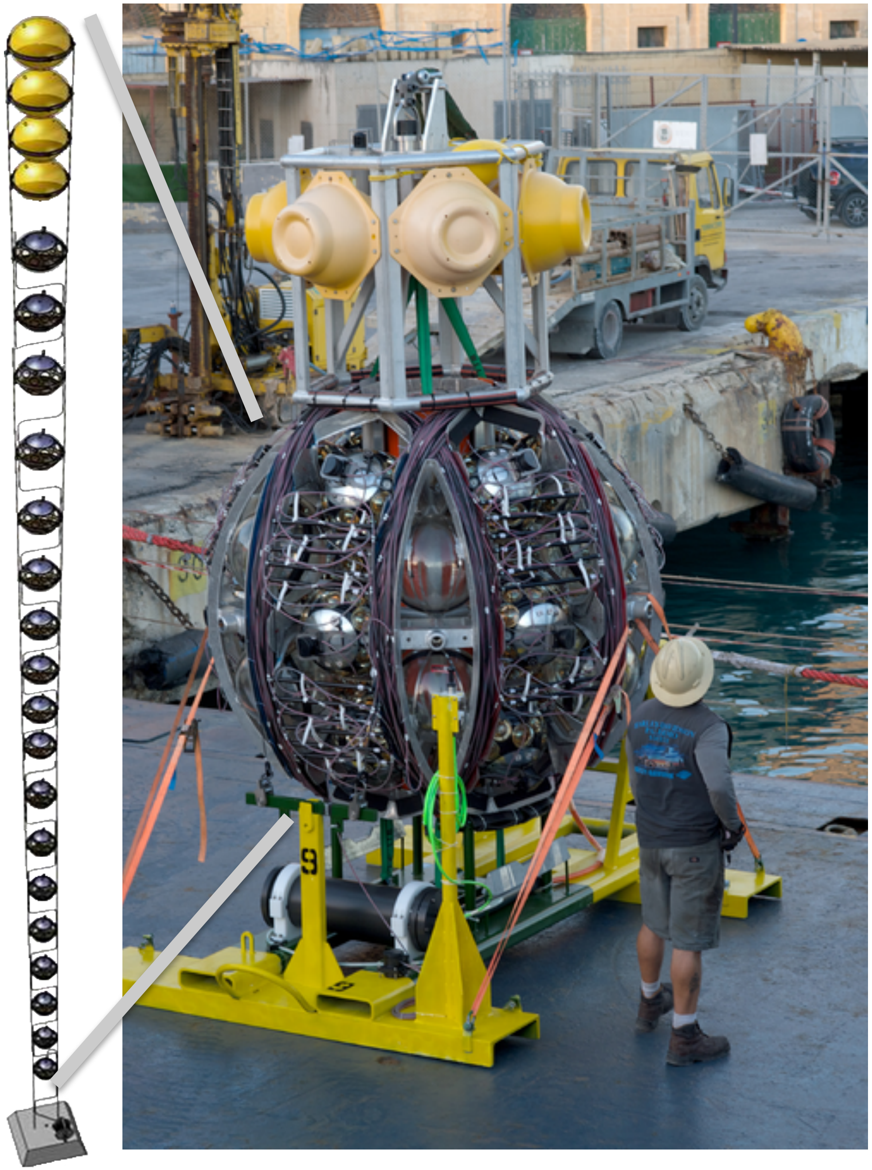


FIG. 2. Upper limit on the high-energy neutrino spectral fluence $(\nu_\mu + \overline{\nu}_\mu)$ from GW150914 as a function of source direction, assuming $dN/dE \propto E^{-2}$ (**left**) and $dN/dE \propto E^{-2}\exp[-\sqrt{(E/100\mathrm{TeV})}]$ (**right**) neutrino spectra. The region surrounded by a white line shows the part of the sky in which ANTARES is more sensitive (close to nadir), while on the rest of the sky, IceCube is more sensitive. For comparison, the 50% CL and 90% CL contours of the GW sky map are also shown.

Deployment

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS



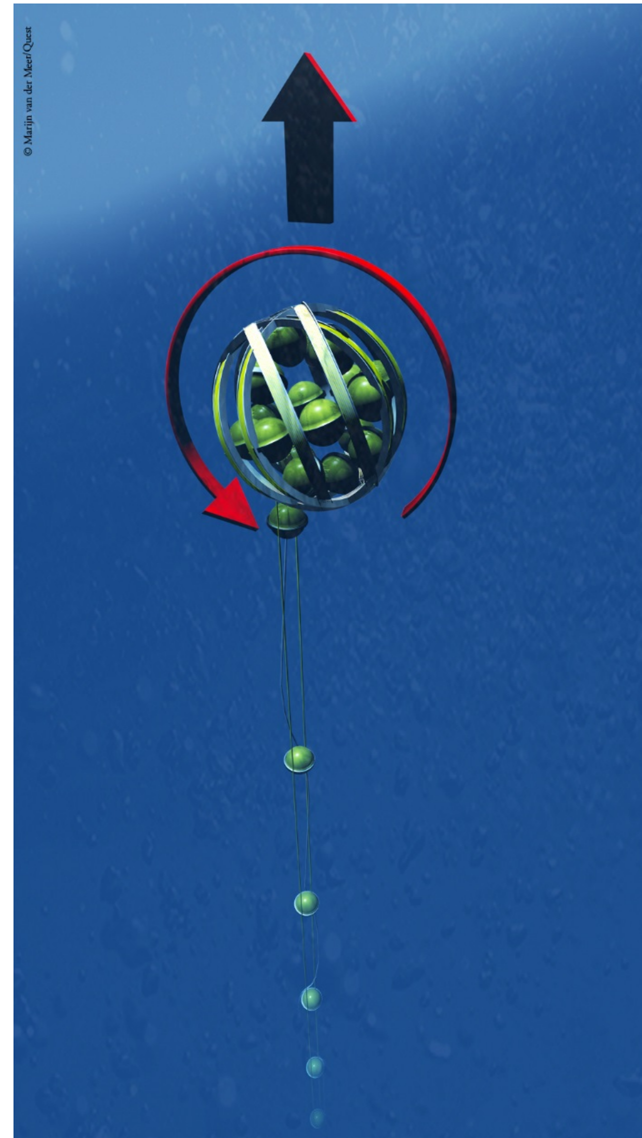
← Deploy to sea bed

Release

Unfurl →

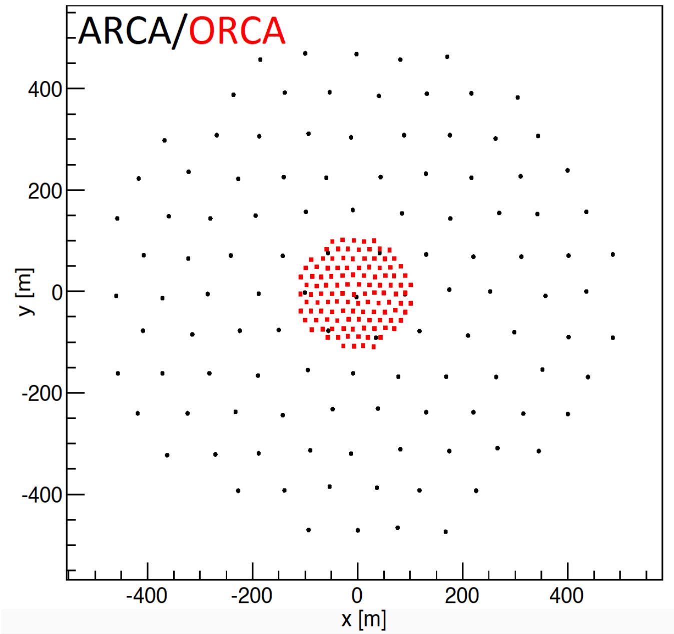
Collect frame

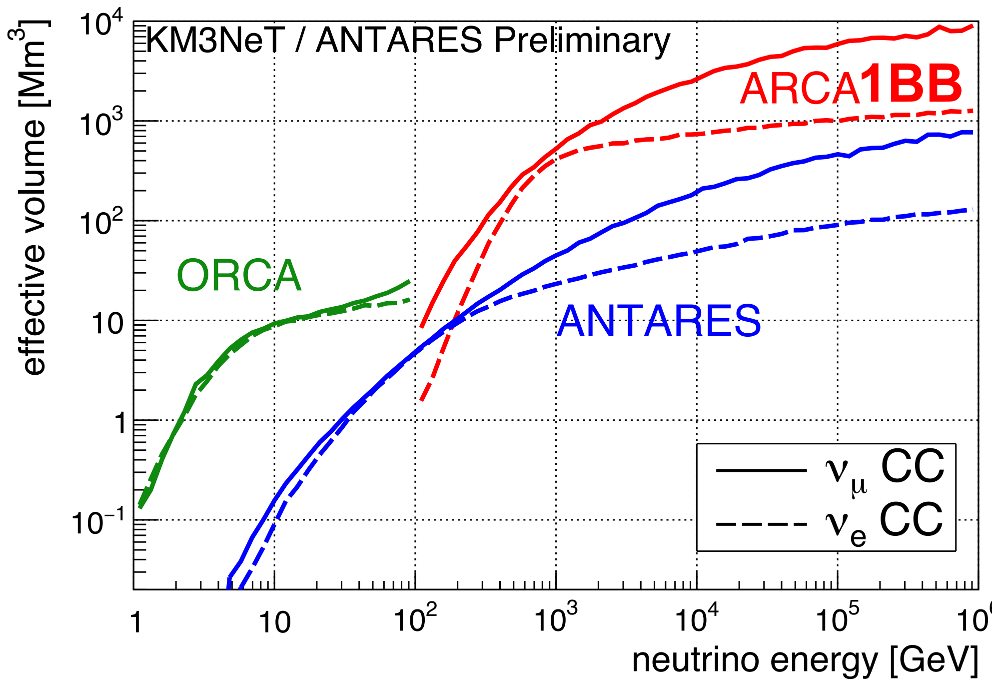
Connect cables with ROV



ARCA/ORCA Comparison

600m/150m



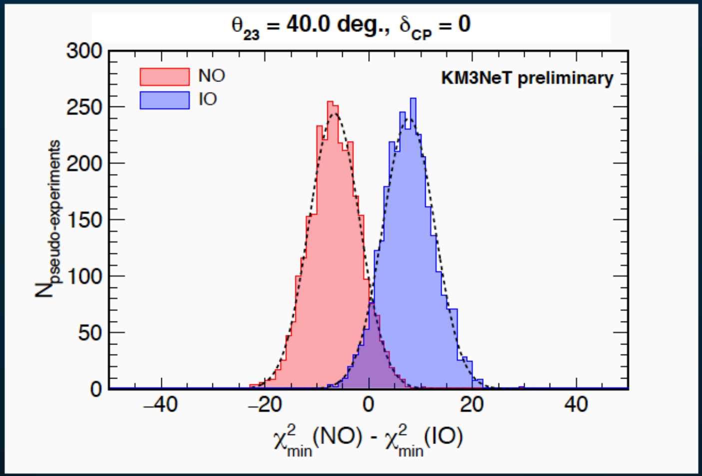


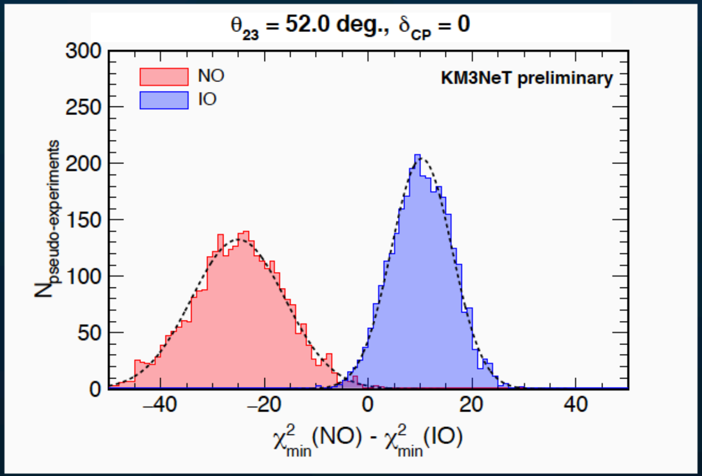
	ARCA	**ORCA**
String spacing	90m	20m
OM spacing	36m	9m
Instrumented mass	500 Mton (2x)	6 Mton

NMO Sensitivity @ Neutrino2018

Statistical methods: We report the median sensitivity to exclude the wrong ordering, based on the study of a log-likelihood ratio (LLR) test statistic:

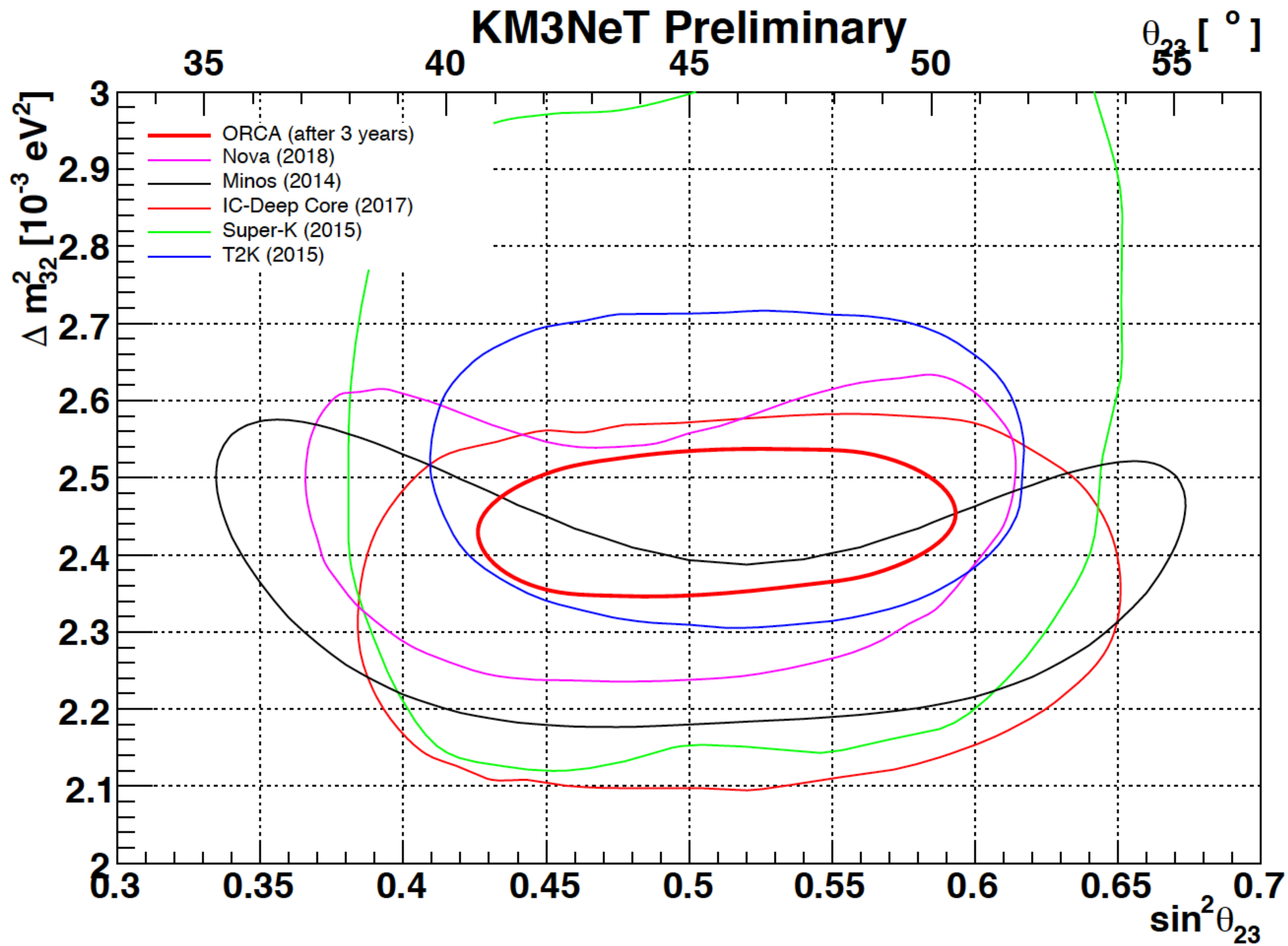
$$TS = -2 \cdot \ln \frac{\max \mathcal{L}_{NO}}{\max \mathcal{L}_{IO}} = \chi^2_{\min}(NO) - \chi^2_{\min}(IO)$$





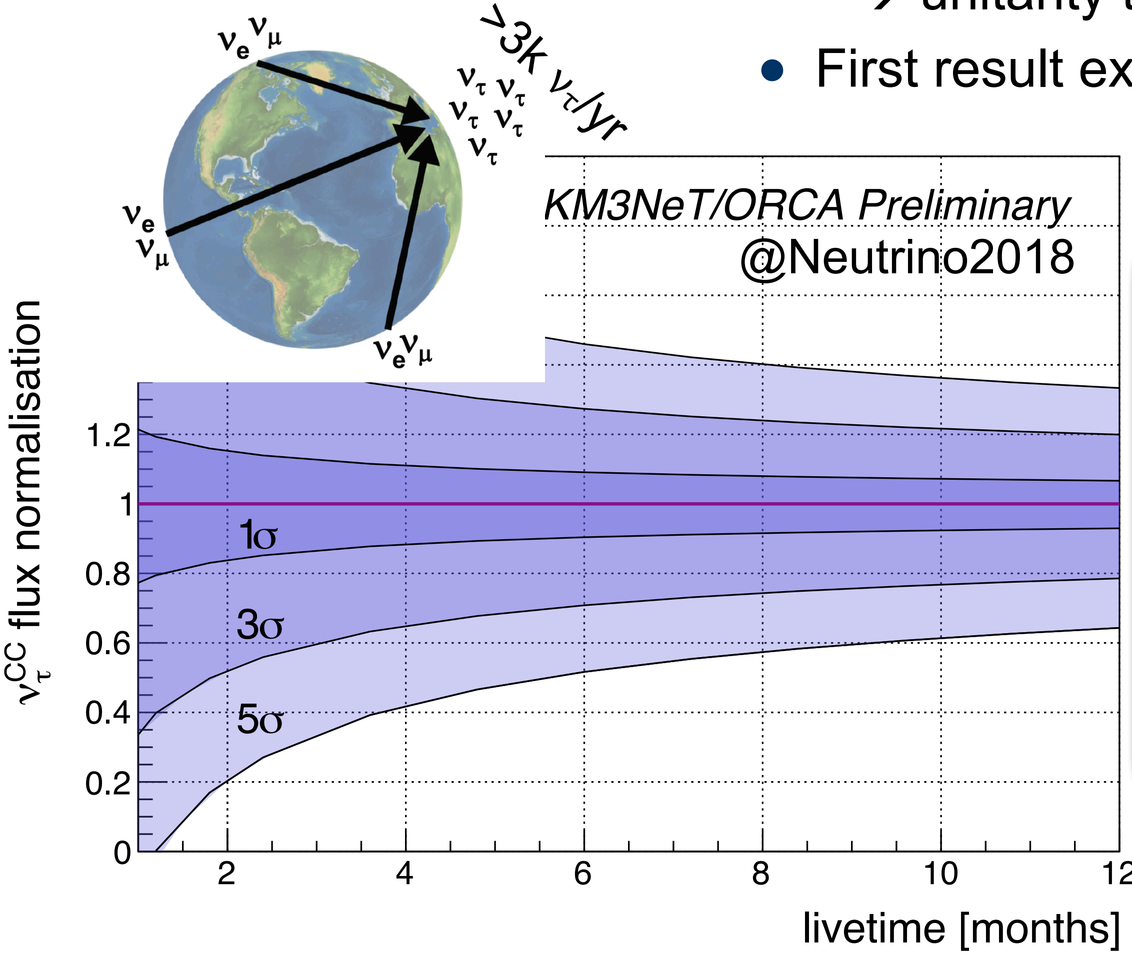
parameter	*treatment*	*true value*	*prior*
$\lvert\Delta M^2\rvert$ (eV^2)	fitted	$2.48\,10^{-3}$	free
Δm^2_{21} (eV^2)	fix	$7.53\,10^{-5}$	–
θ_{13} (°)	fitted	8.42	0.26
θ_{12} (°)	fix	33.4	–
θ_{23} (°)	fitted	38 – 52	free
δ_{CP}	fitted	$0, 2\pi$	free
Flux spectral tilt	fitted	0	free
$\nu/\bar{\nu}$ skew	fitted	0	0.03
Tracks normalisation	fitted	1	free
Cascades normalisation	fitted	1	free
NC events normalisation	fitted	1	0.10

Sensitivity to $|\Delta m_{32}|$ and $\sin^2\theta_{23}$ @ Neutrino2018



ORCA: tau neutrino appearance

- Tau neutrino appearance from atmospheric $\nu_\mu \rightarrow \nu_\tau$ (excess of showers)
- $1\sigma(\nu_\tau \text{ rate})$ ~10% after 1year with full ORCA
  → constrain tau-related PMNS elements
  → unitarity test
- First result expected with few-string array



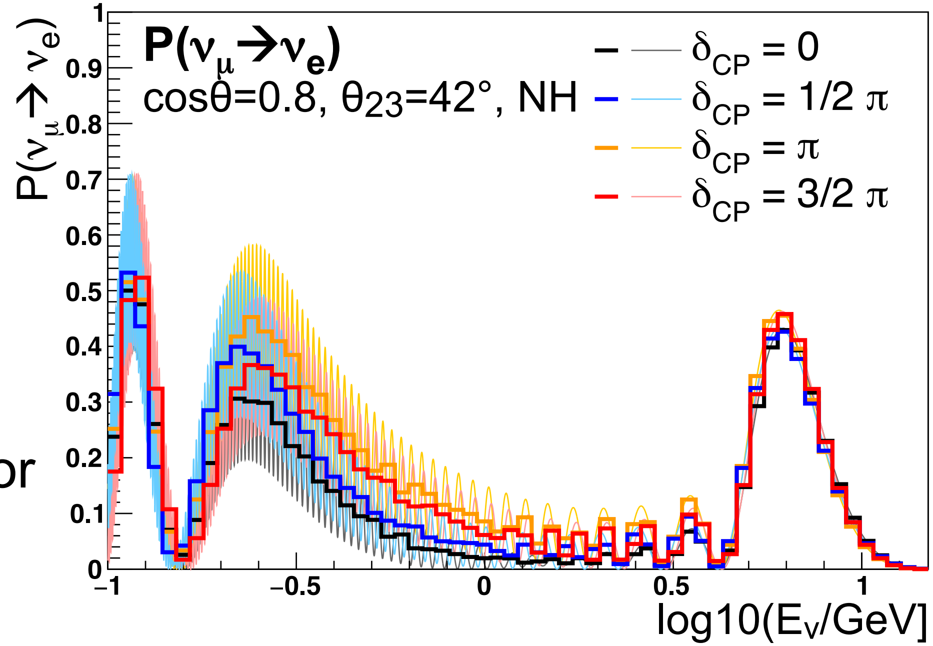
Additional physics topics:

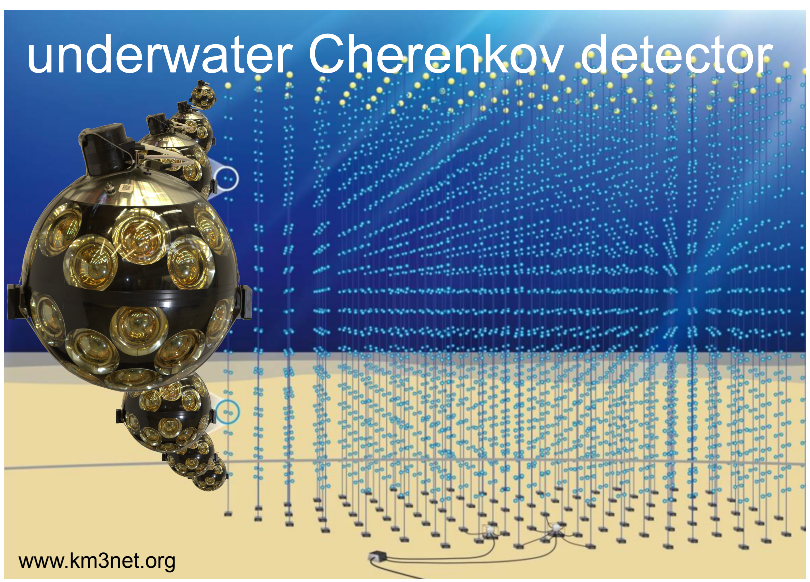
- 3ν oscillation parameters |Δm32| & θ23
- Sterile neutrinos & non-standard interactions
- Supernovae monitoring
- Indirect search for DM
- GeV-TeV ν-astrophysics
- …

Measuring δ_{CP} with atmospheric neutrinos

- Oscillation pattern of atmospheric neutrinos depends on δ_{CP}
- δ_{CP} sensitivity: E_ν<3GeV
- Good ν_e / ν_μ separation crucial

→ δ_{CP} sensitivity study for possible future multi-Mton Cherenkov detector





- KM3NeT/Super-ORCA:

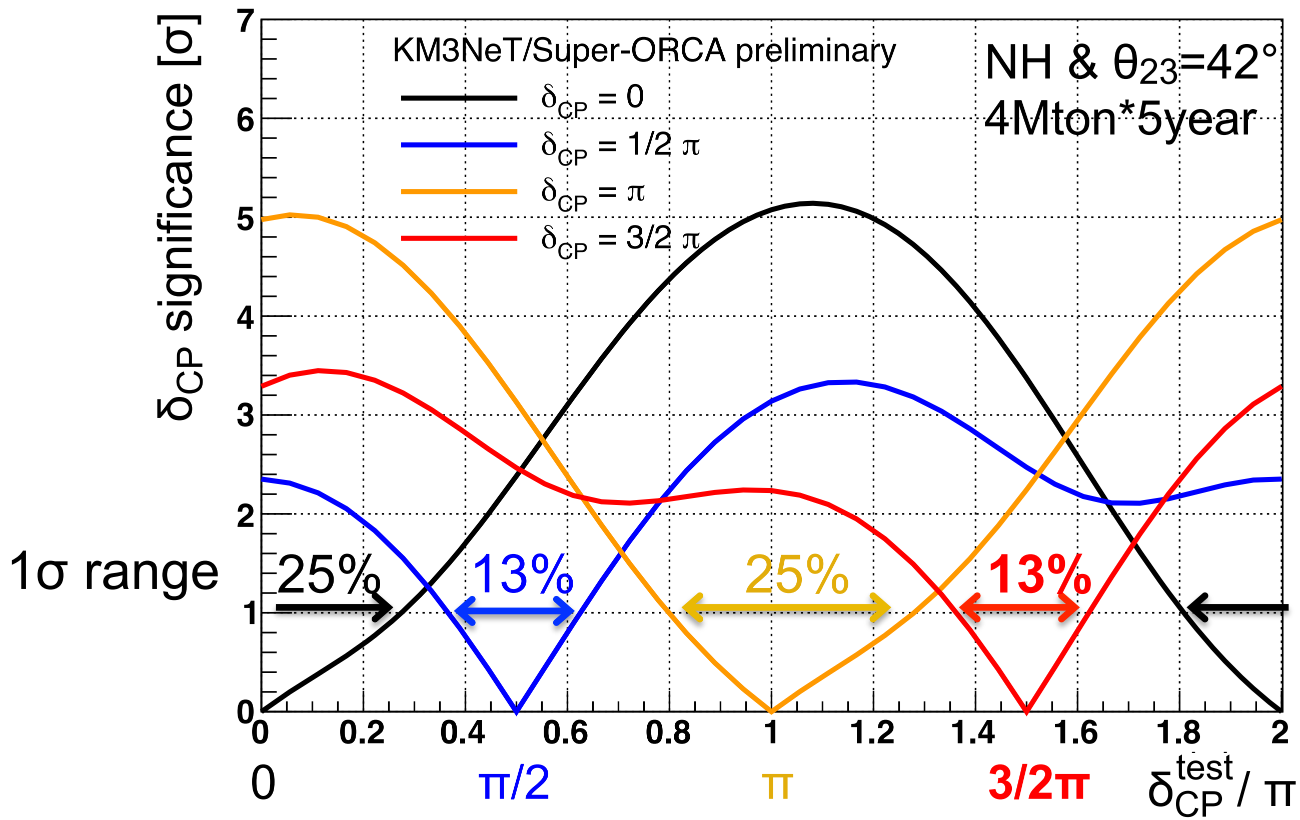
~10x denser version of ORCA
(for comparison: still ~100x smaller instrumentation density than SK)

→ ~100 detected photons per GeV

→ e/μ separation via angular light profile: ~95% purity @ E_ν=1GeV

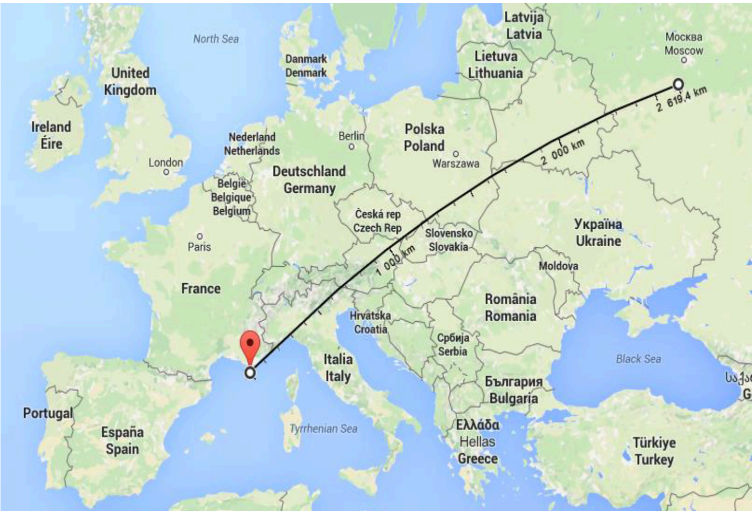
Super-ORCA: δ_{CP} sensitivity

- Method: χ^2 minimisation assuming a test δ_{CP}^{test} value and simultaneously fitting neutrino oscillation and nuisance parameters



- Maximal distinguishability between δ_{CP}=0 and δ_{CP}=π with 5σ
- 60% (70%) disfavoured with ≥2σ for true δ_{CP}=0, π (δ_{CP}=π/2, 3/2π)

P2O: Protvino to ORCA



- U70 proton accelerator in Protvino
  E = 70 GeV
- Proposed intensity upgrade
  P = **450 kW**
  ➢ Up to **4.10^{20} POT / year**
- ν_e appearance at **L = 2600 km**
- Target energy range : **3-8 GeV**
- Optimal baseline for separating NMH from δ_{CP}