Hunting neutrinos in the Deep Sea
Status and prospects of KM3NeT

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News announced April 2018: 12.7 Mio Euro for KM3NeT
NWO's 'Nationale Roadmap Grootschalige Wetenschappelijke Infrastructuur'

What can the neutrino do for us?

- Unique messenger from the distant Universe
- Can unveil new physics
- Could play a role in the issue of Dark Matter

⇒ Observations of neutrinos from cosmic sources (TeV-PeV energies)

⇒ Observations of neutrinos from interactions of cosmic rays with the atmosphere (GeV-TeV energies)

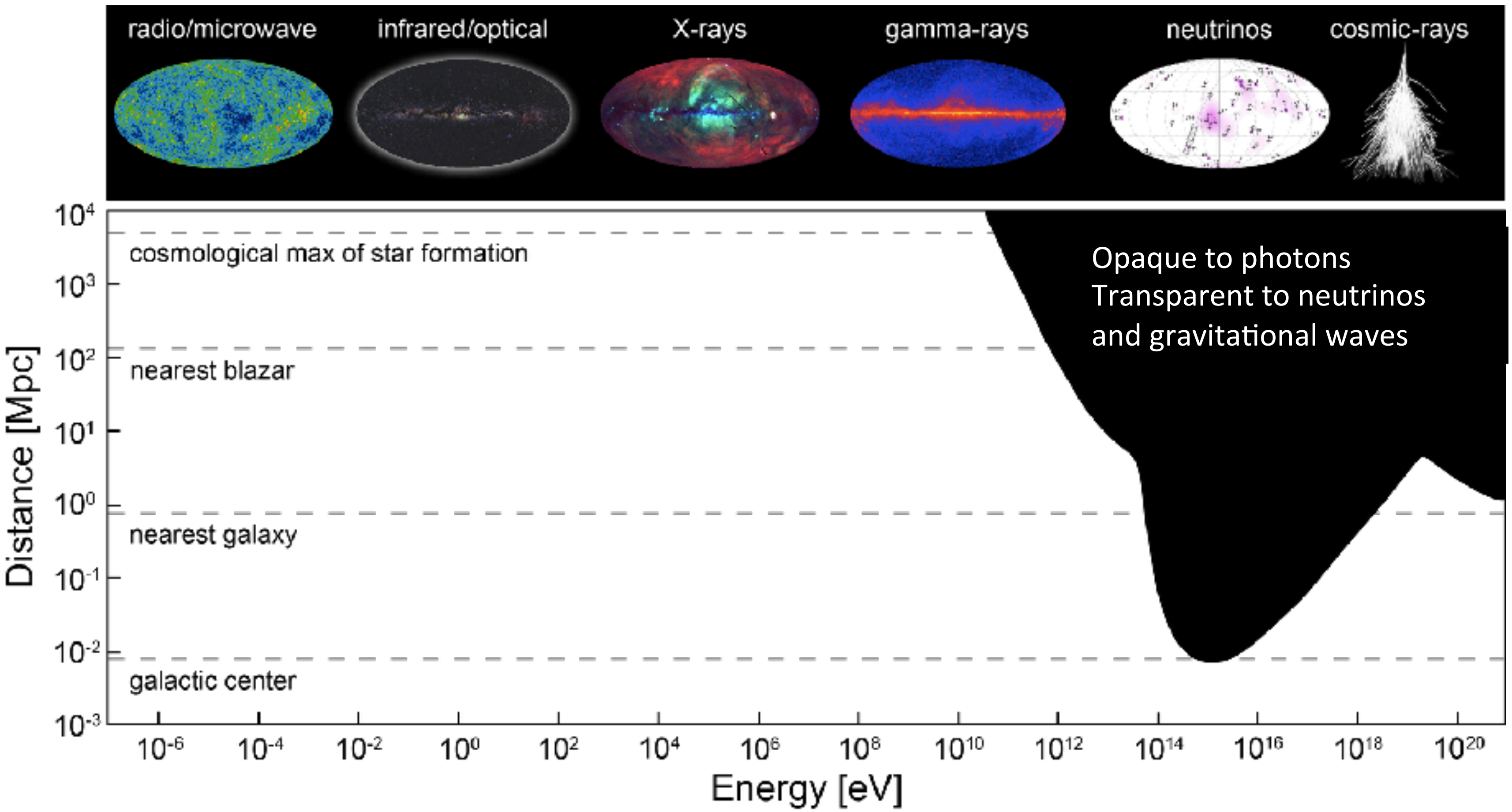
- Cosmic Neutrinos
- Atmospheric neutrinos

- KM3NeT ARCA/ORCA
- First Data

- ARCA prospects
- ORCA prospects
- Beam option for ORCA (P2O)

Cosmic neutrinos

The visible Universe



$\gamma + \gamma_{\text{background}} \rightarrow e^+e^-$
$p + \gamma \rightarrow \Delta^+$

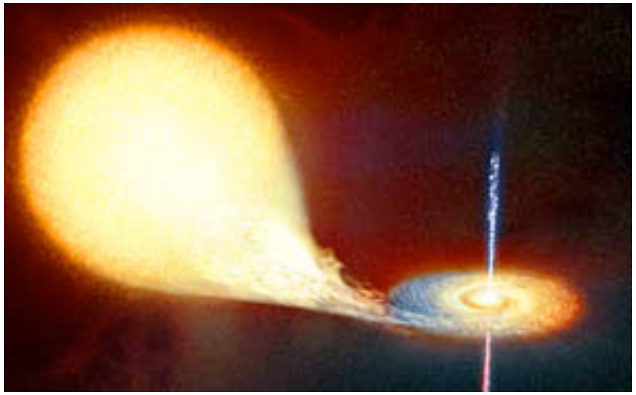
Large part of the Universe can not be observed with high energetic photons and protons

Cosmic accelerators provide energy to particles orders of magnitude beyond accelerators on Earth

- What are the sources of the high energy cosmic rays?
- How are particles accelerated?

Multimessenger observations crucial

Galactic:
Supernova Remnants (SNRs), Microquasars,…



Extragalactic:
Active Galactic Nuclei (AGNs),
Gamma Ray Bursts (GRBs), …

Gamma ray – neutrino connection

- Gamma ray photons can originate from pion decay (hadronic scenario) or synchrotron radiation or inverse Compton scattering (leptonic scenario)

- Currently origin of observed TeV gamma rays from cosmic sources not well known

=> Neutrino detection unique probe to prove hadronic scenario (presence of protons)

$$p+\gamma \rightarrow \Delta^{+} \begin{cases} \rightarrow p+\pi^{0} \\ \rightarrow n+\pi^{+} \end{cases}$$

$$\pi^{0} \rightarrow \gamma\gamma$$

Observable as TeV photons

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$

$$\hookrightarrow e^{+} + \bar{\nu}_{\mu} + \nu_{e}$$

High energy neutrinos

$$p+p \rightarrow \pi^{\pm} + X$$

$$\hookrightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu})$$

$$\hookrightarrow e^{\pm} + \bar{\nu}_{\mu}(\nu_{\mu}) + \nu_{e}(\bar{\nu}_{e})$$

Neutrinos travel undeflected
from the sources
=> Direct identifcation of cosmic accelerators

Different source scenarios

$$\nu_e : \nu_\mu : \nu_\tau$$

'Standard '

-> charged pion decay, muon decay

1 : 2 : 0

Muon damped source

-> strong magnetic fields, muon decay suppressed

-> pion decay dominant

0 : 1 : 0

Neutron beam source

-> extremely strong magnetic field

-> cosmic rays heavy nuclei

1 : 0 : 0

Neutrino oscillations during propagation from source to Earth

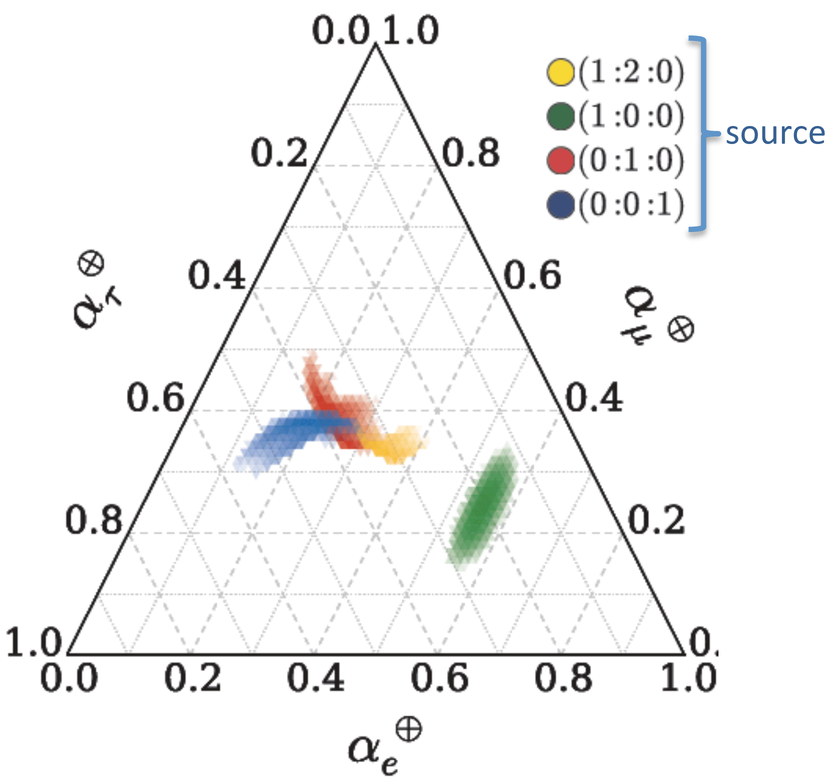
=> Flavour ratio not conserved

Note: Also different neutrino/antineutrino ratios

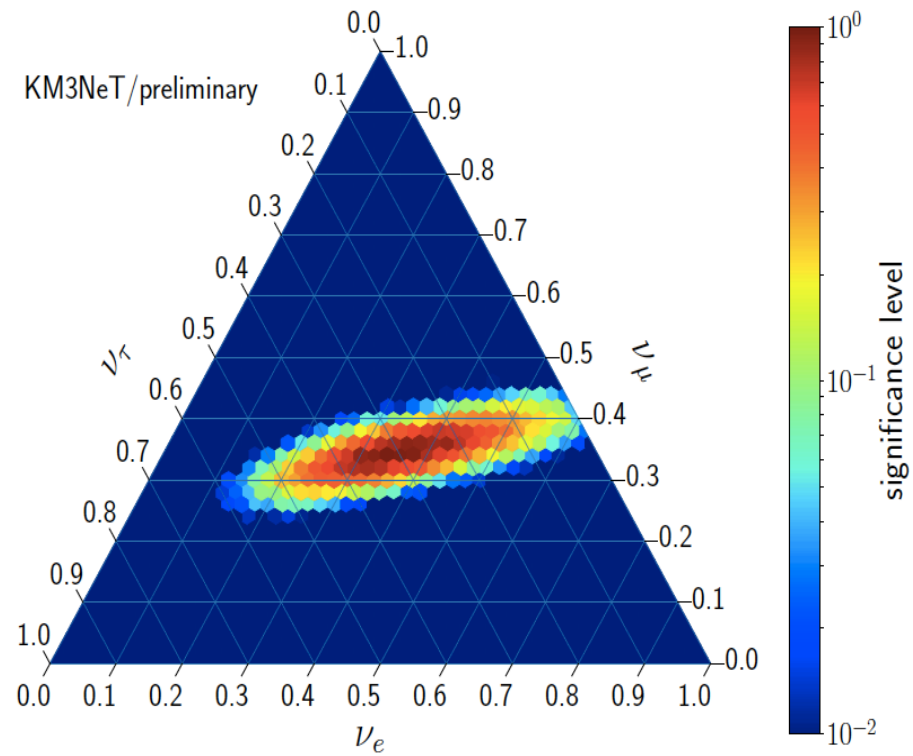
Neutrino flavor ratio

‘Standard’ phase space
-> Deviations indicate new physics

First preliminary estimate for KM3NeT sensitivity
(reconstruction improvements e.g. in tau
double bang reconstruction not yet included)



C. Arguelles, T. Katori and J. Salvado
Phys.Rev.Lett. 115 (2015) 161303



T. Eberl, T. Heid, ICRC 2017
PoS(ICRC2017)1006

Rapidly developing field:

2013++ : IceCube detects cosmic neutrinos
(excess of high energy neutrinos)

2018: IceCube announces discovery of first
cosmic high energy neutrino source

=> For the first time multimessenger observations
including neutrinos!

1) High energy neutrino detected at similar time as enhanced gamma-ray flaring of a blazar TXS0506 (independent alerts) -> 3σ

2) IceCube scanned archival data at given position
-> 3.5σ discovery of a flaring period
13 signal events in 5 months period

Search in the Mediterranean Sea (ANTARES)

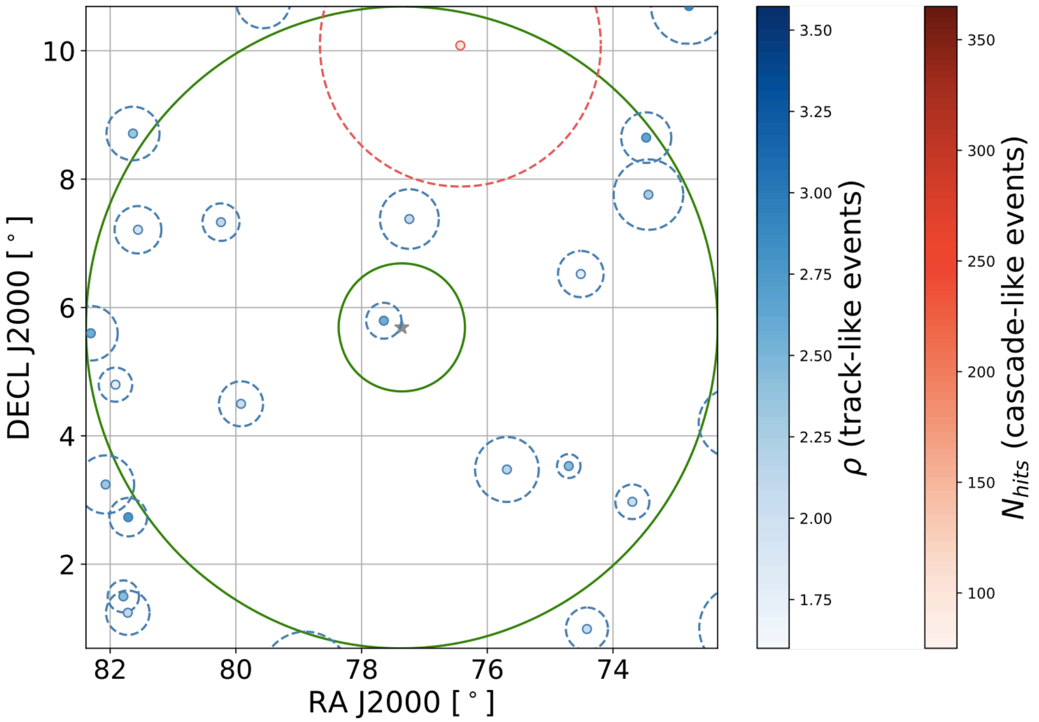
Search for neutrino signal at given position in 9 years

- Fit for signal: $n_{sig} = 1.03$
- Pre-trial p-value of 3.4% to be compatible with background only
- In the list of 107 pre-selected sources, only two have smaller p-value
- Search for flaring coincident with IceCube flaring periods: No signal found (consistent with flux estimates by IceCube)

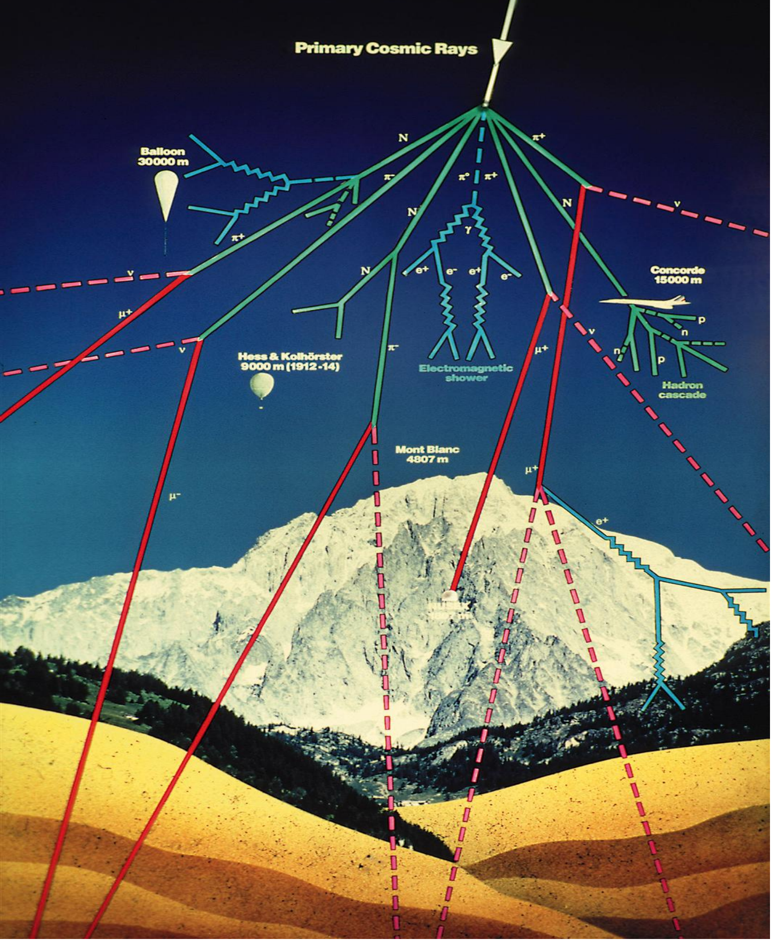
Independent verification of IceCube observations desirable

More statistics needed also with full sky coverage

Blue: Track candidates
Red: Cascade candidates
Circles provide error regions
Green circes: 1 and 5 degrees



Atmospheric neutrinos



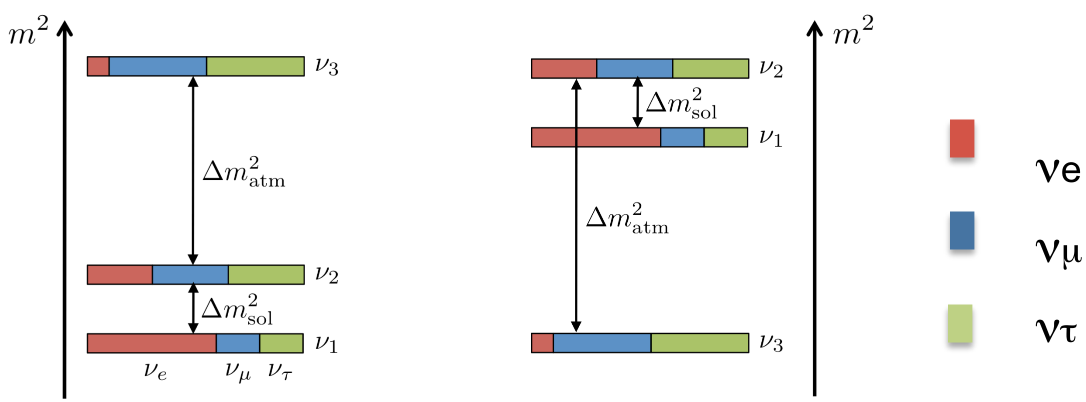
Neutrino beam for free

-> Cosmic ray interactions with the atmosphere

Large statistics for oscillation studies
=> Access to subtle signatures in oscillation patterns

- Neutrino Mass ordering
- Tau neutrino appearance
- Non-Standard-Interaction
- Sterile Neutrinos
- Earth Tomography
- ….

Normal Ordering (NO) Inverted Ordering (IO)



Neutrino Oscillations

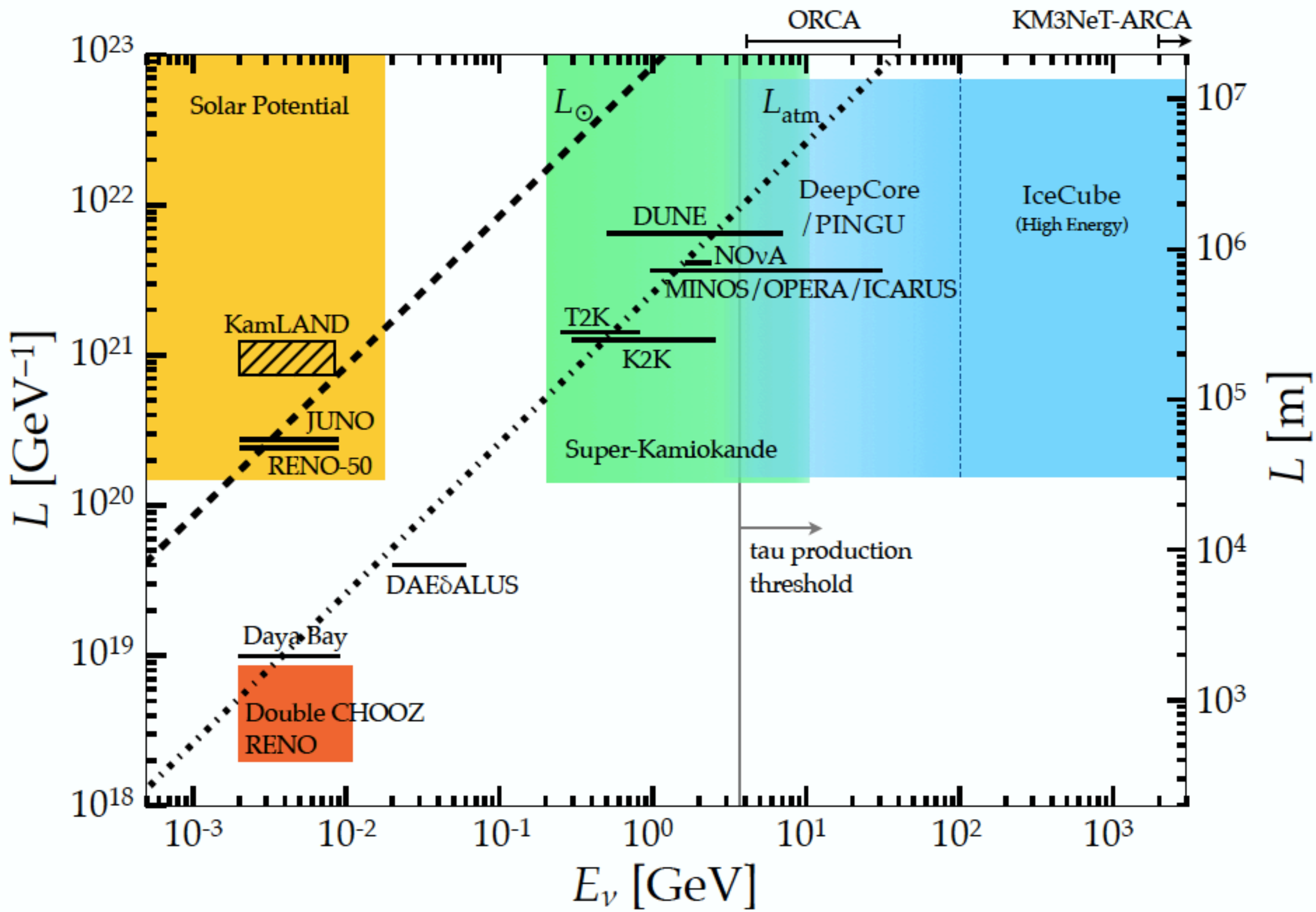
Flavor eigenstates are not equal to mass eigenstates

Flavor eigenstate | Mixing matrix → | Mass eigenstate

νe, $\nu \mu$, $\nu \tau$ → $\nu 1$, $\nu 2$, $\nu 3$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13} e^{i\delta_{CP}} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c_{12} c_{13} & s_{12} c_{13} & s_{13} e^{-i\delta_{CP}} \\ -s_{12} c_{23} - c_{12} s_{23} s_{13} e^{i\delta_{CP}} & c_{12} c_{23} - s_{12} s_{23} s_{13} e^{i\delta_{CP}} & s_{23} c_{13} \\ s_{12} s_{23} - c_{12} c_{23} s_{13} e^{i\delta_{CP}} & -c_{12} s_{23} - s_{12} c_{23} s_{13} e^{i\delta_{CP}} & c_{23} c_{13} \end{bmatrix}.$$



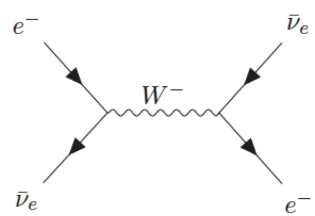
Neutrino telescope energy and baselines in comparison to accelerator/reactor experiments

Neutrino oscillations in matter

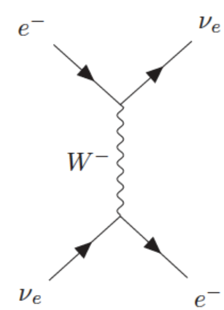
Propagation of electron (anti-)neutrinos in the Earth affected by matter potential (Mikheyev-Smirnov-Wolfenstein effect)

Forward scattering on electrons
$\Rightarrow$ change of effective mass for the electron neutrinos
$\Rightarrow$ change of oscillation pattern

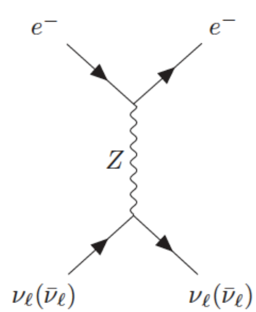
=> Sensitive to Neutrino Mass hierarchy



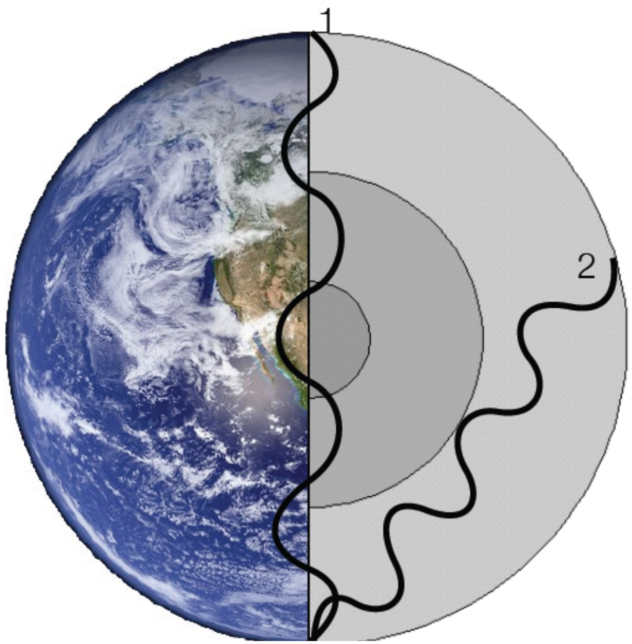
(a)

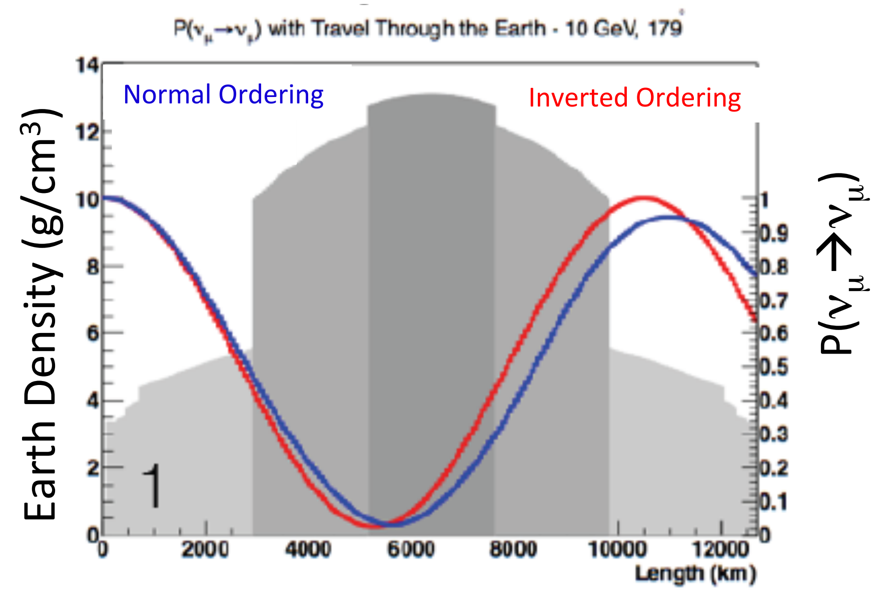


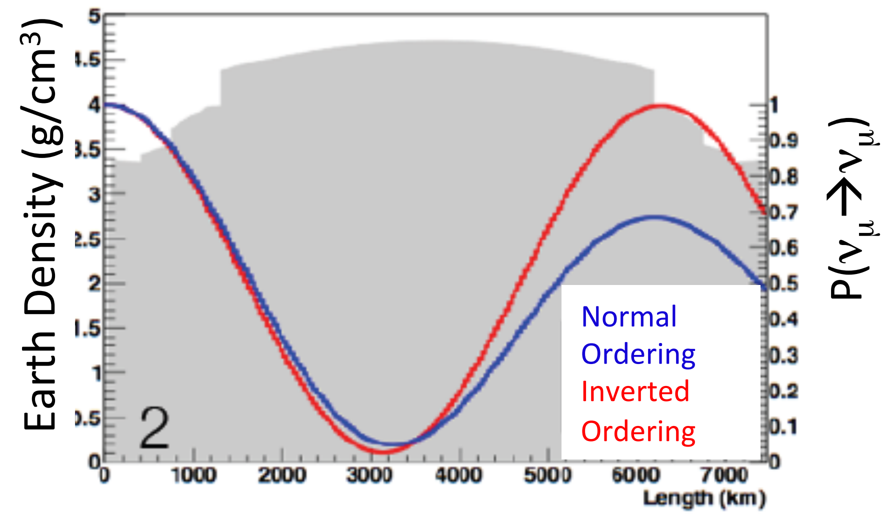
(b)



Matter effects

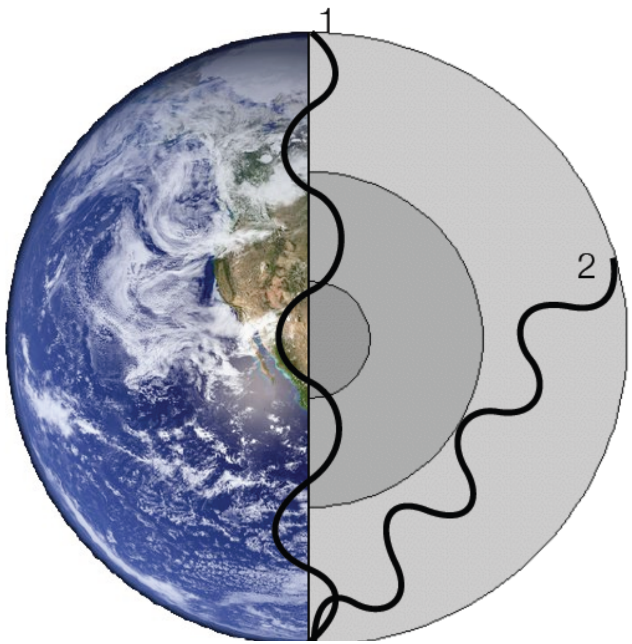


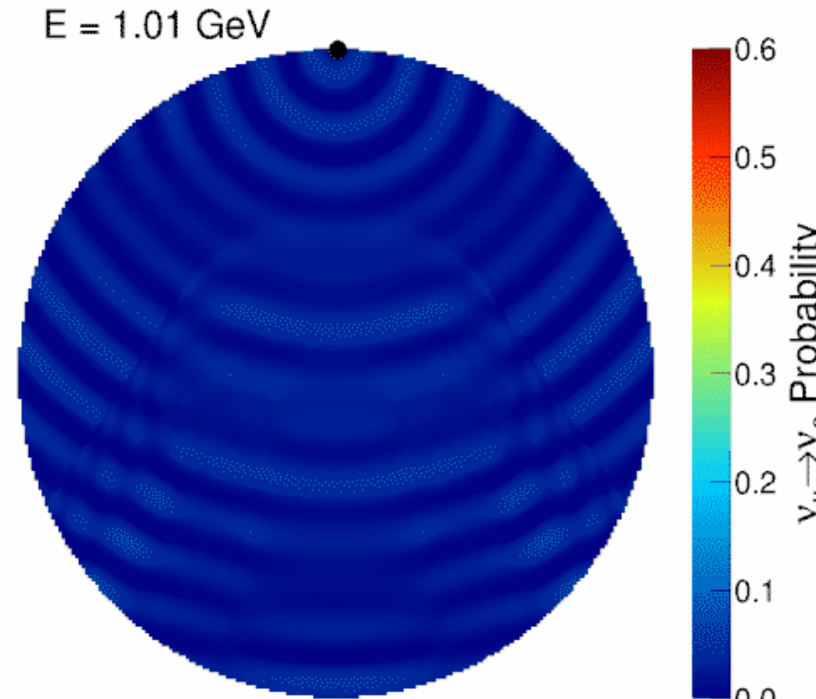




- Oscillation pattern changes
- Depends on mass ordering
- Pattern for neutrinos with NO is similar to antineutrinos with IO
  => Ratio neutrino/antineutrino determines strength of signature

Matter effects





http://www.apc.univ-paris7.fr/Downloads/antares/Joao/animations/

- Oscillation pattern changes
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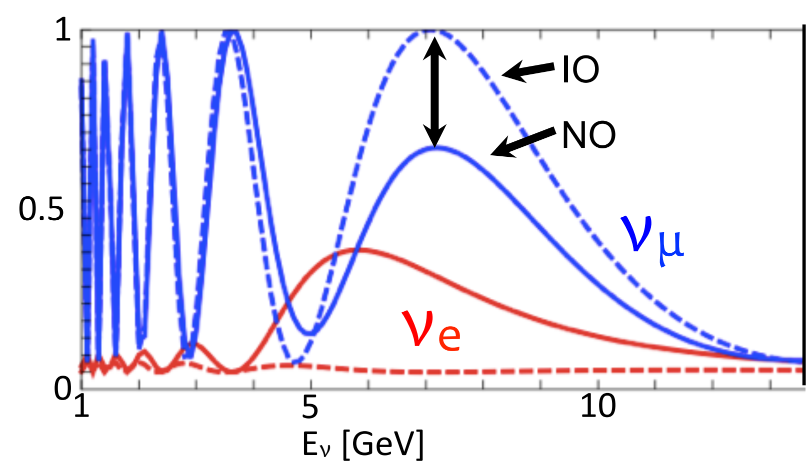
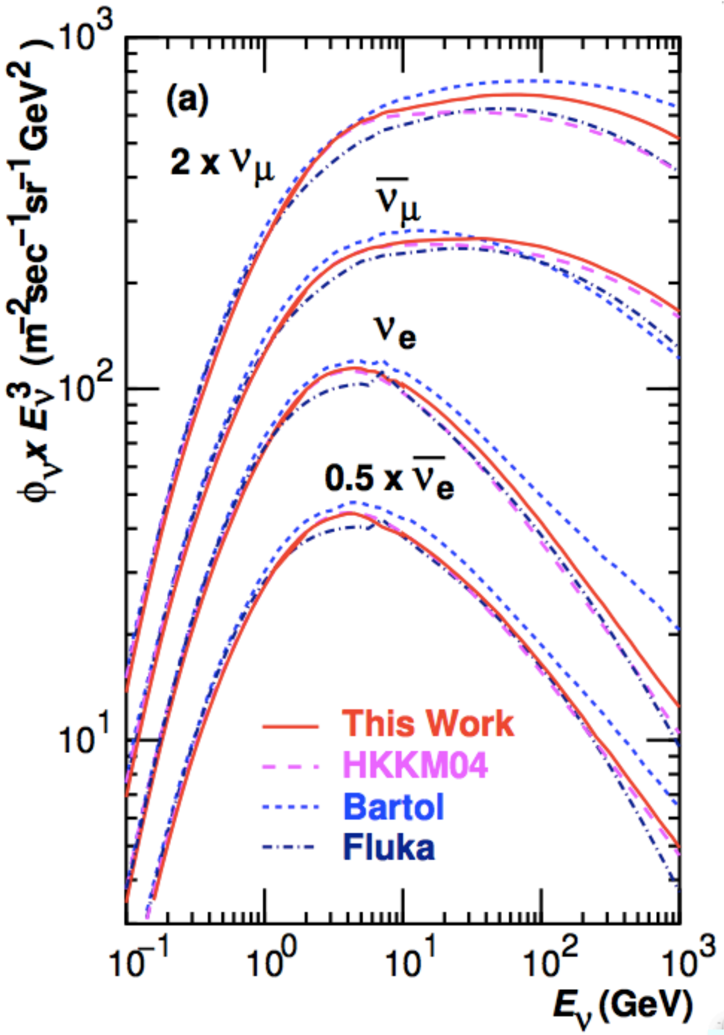
$P(\nu_\mu \rightarrow \nu_\mu)$ for θ=126

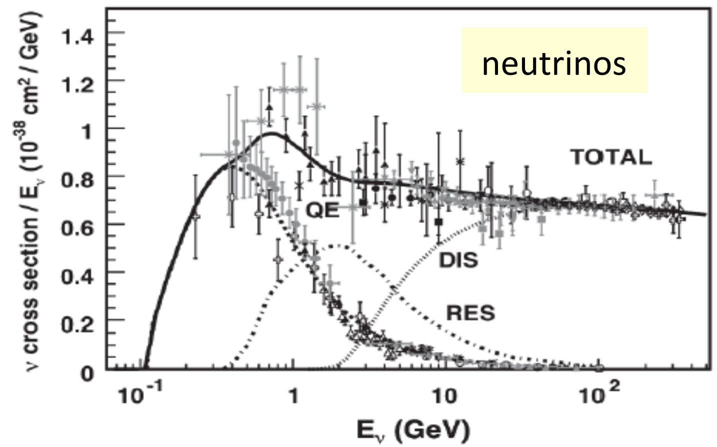


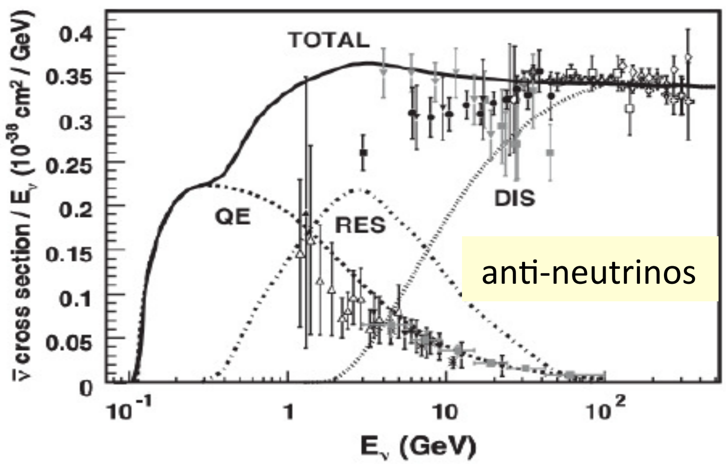
Atmospheric neutrino flux

+

Interaction cross sections



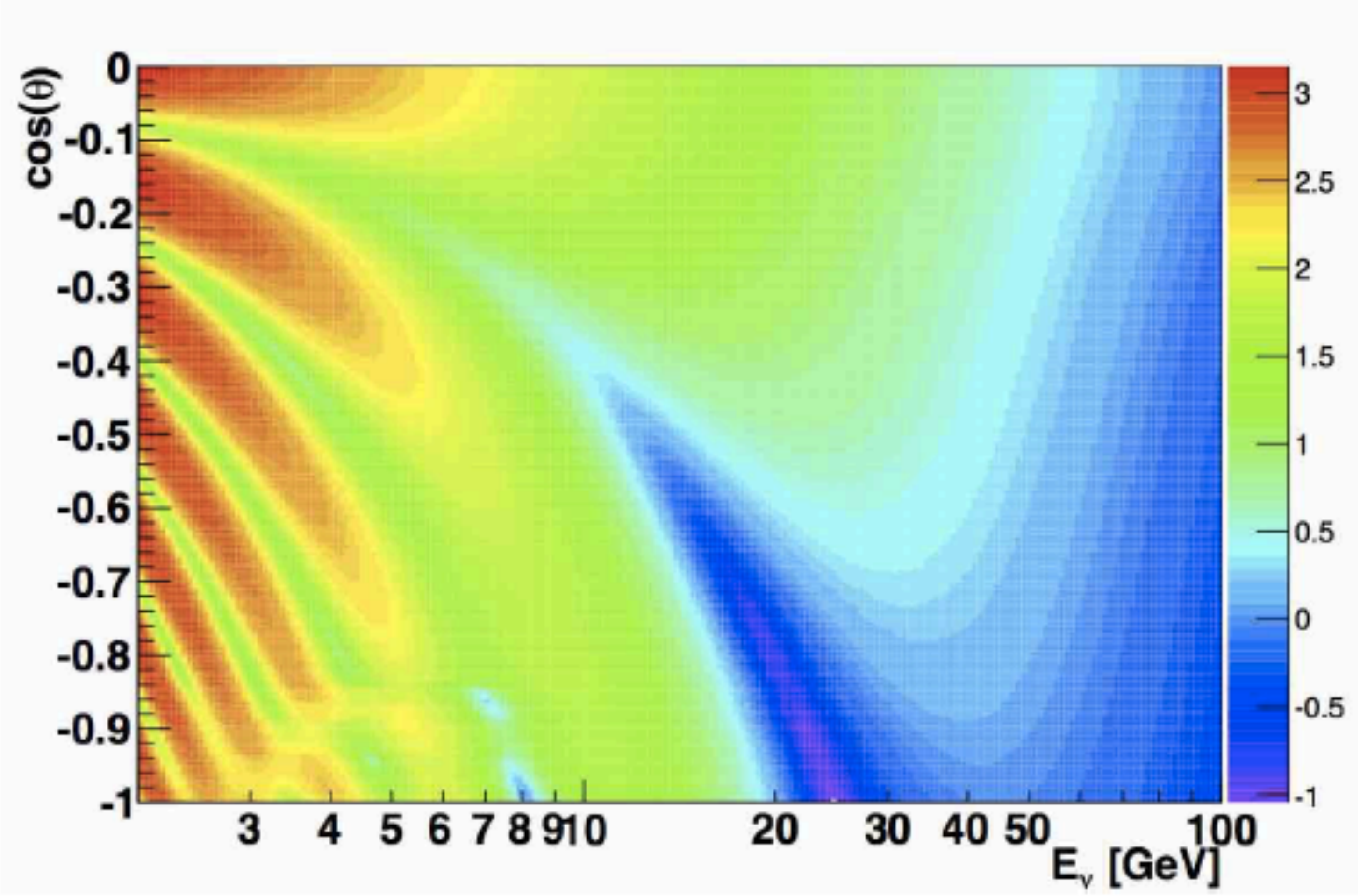




Honda et al, Phys. Rev. D75, 043006 (2007)

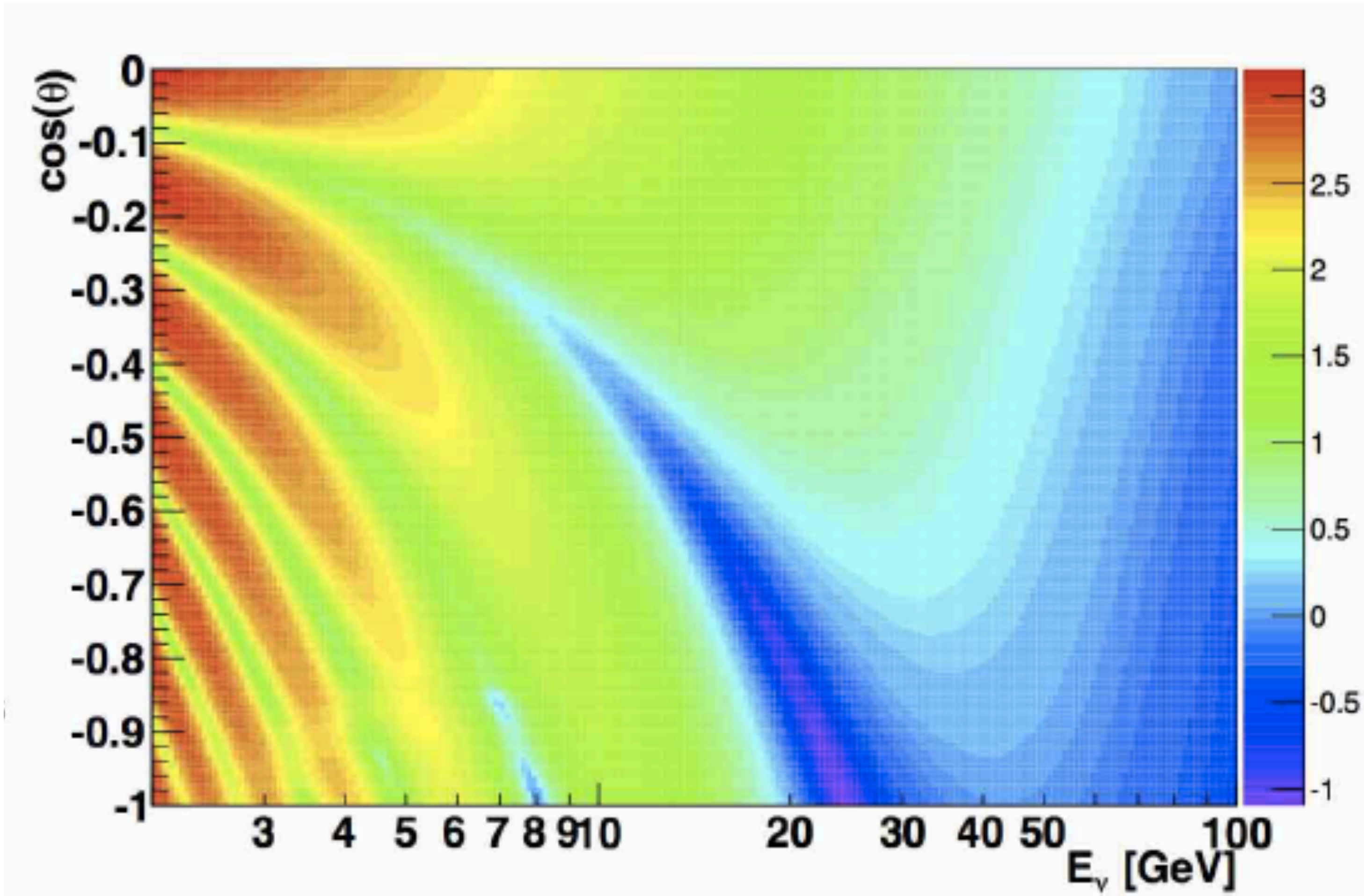
- Neutrino flux ~1.3 times higher than anti-neutrino flux
- Neutrino cross section ~2 times higher than for antineutrinos

ν_μ event rate
Normal Ordering



Signal at low energies (3-10 GeV)
=> dense detector required

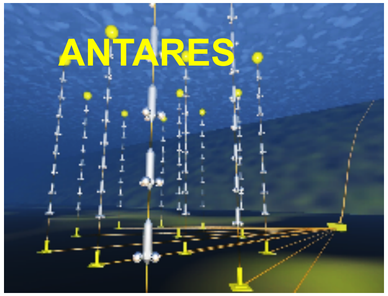
ν_μ event rate
Inverted Ordering



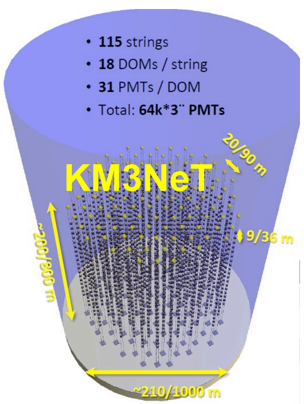
Signal at low energies (3-10 GeV)
=> dense detector required

GNN
The Global Neutrino Network

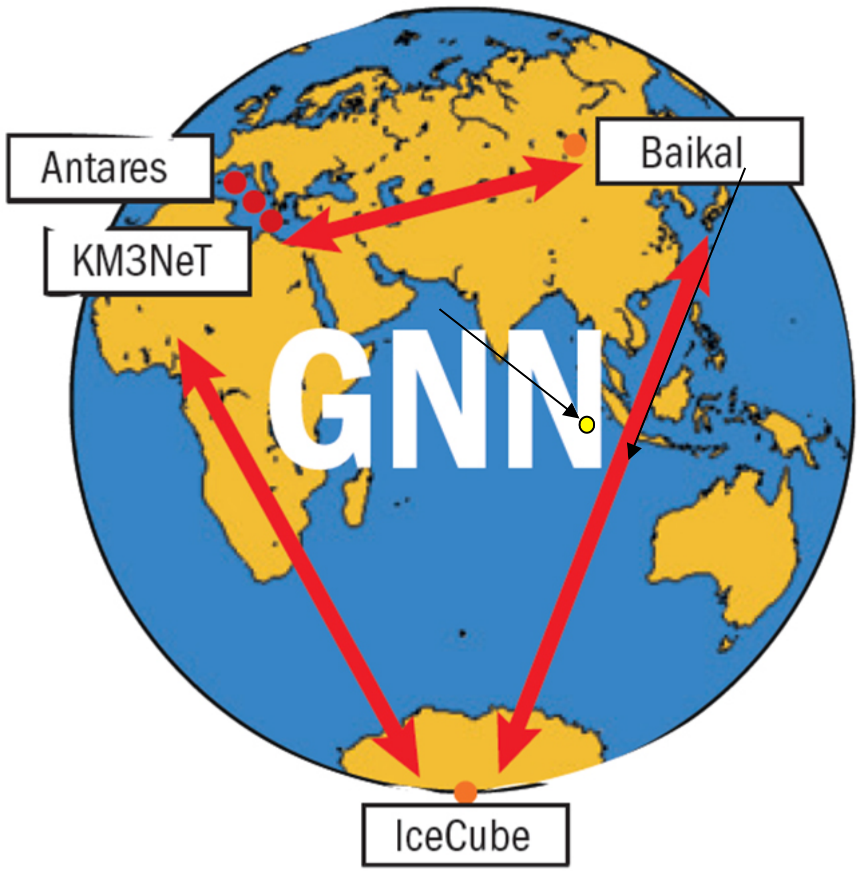
Running since 2007



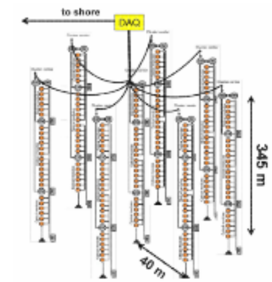
0.01 km^3



1 + 0.008 km^3



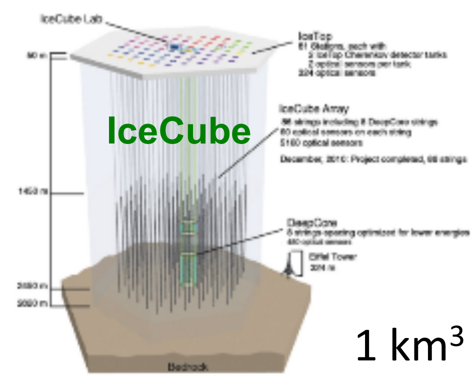
GVD (Baikal)



1 km^3

3 of 8 clusters installed 2015-2018
(to be finished 2021)

Running since 2009



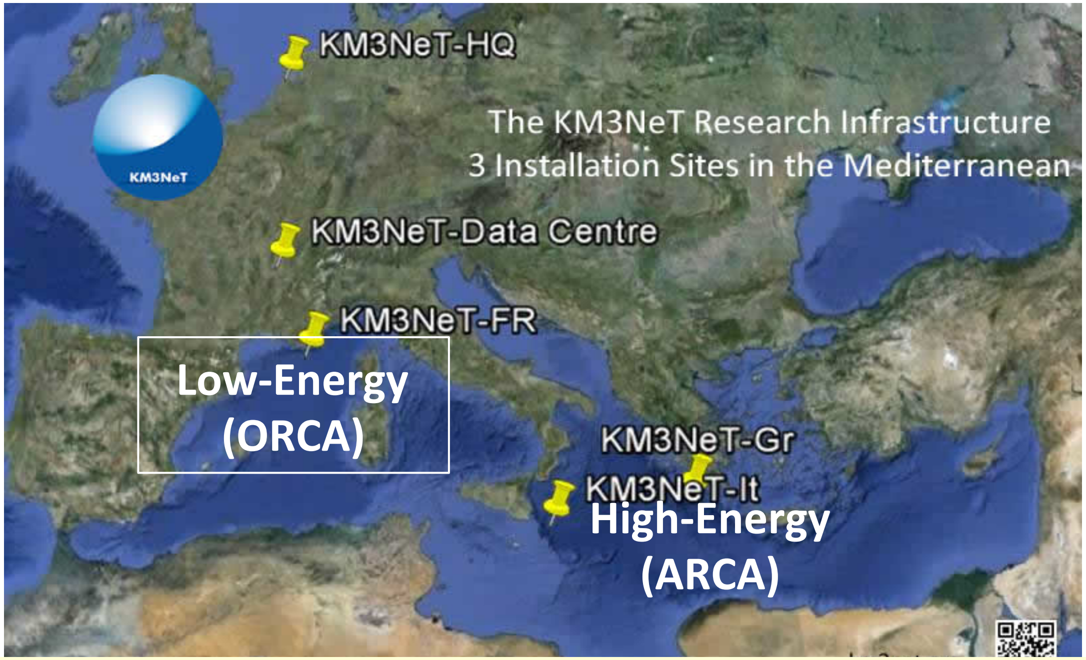
1 km^3

KM3NeT

KM3NeT is a research infrastructure:

- Study of the origin of cosmic neutrinos (high energy neutrinos)
- Measurement of fundamental neutrino properties (low energy neutrinos)
- Deep Sea Observatory (Oceanography, bioacoustics, bioluminescence, seismology)

Single Collaboration
Single Technology
Single Management



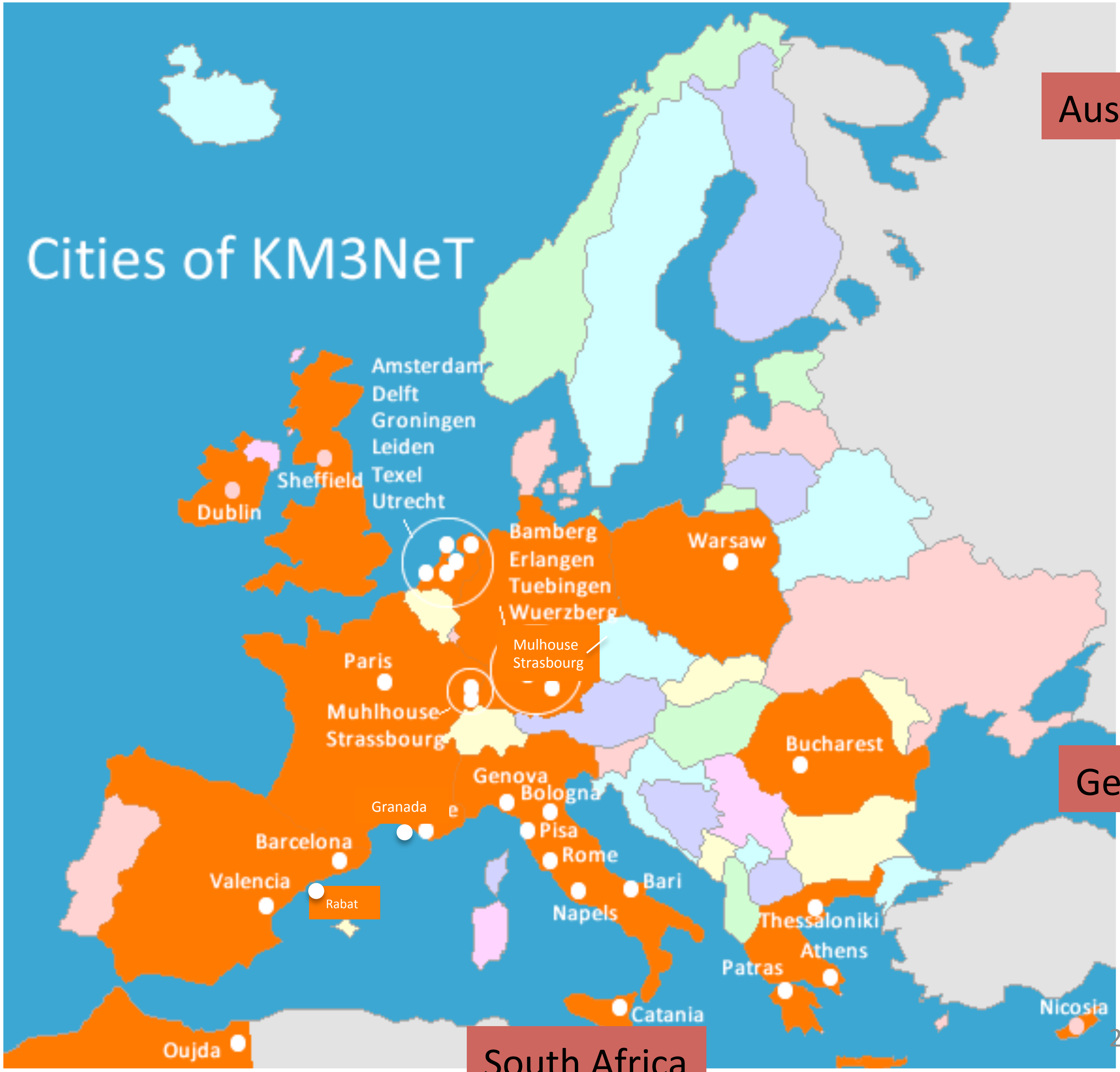
ARCA- **A**stroparticle **R**esearch with **C**osmics in the **A**byss
ORCA- **O**scillation **R**esearch with **C**osmics in the **A**byss

KM3NeT LoI , arXiv:1601.07459 [astro-ph.IM]
Journal of Physics G: Nuclear and Particle Physics, 43 (8), 084001, 2016

KM3NeT Collaboration

15 Countries
>40 Institutes
>220 Scientists

Expanding!

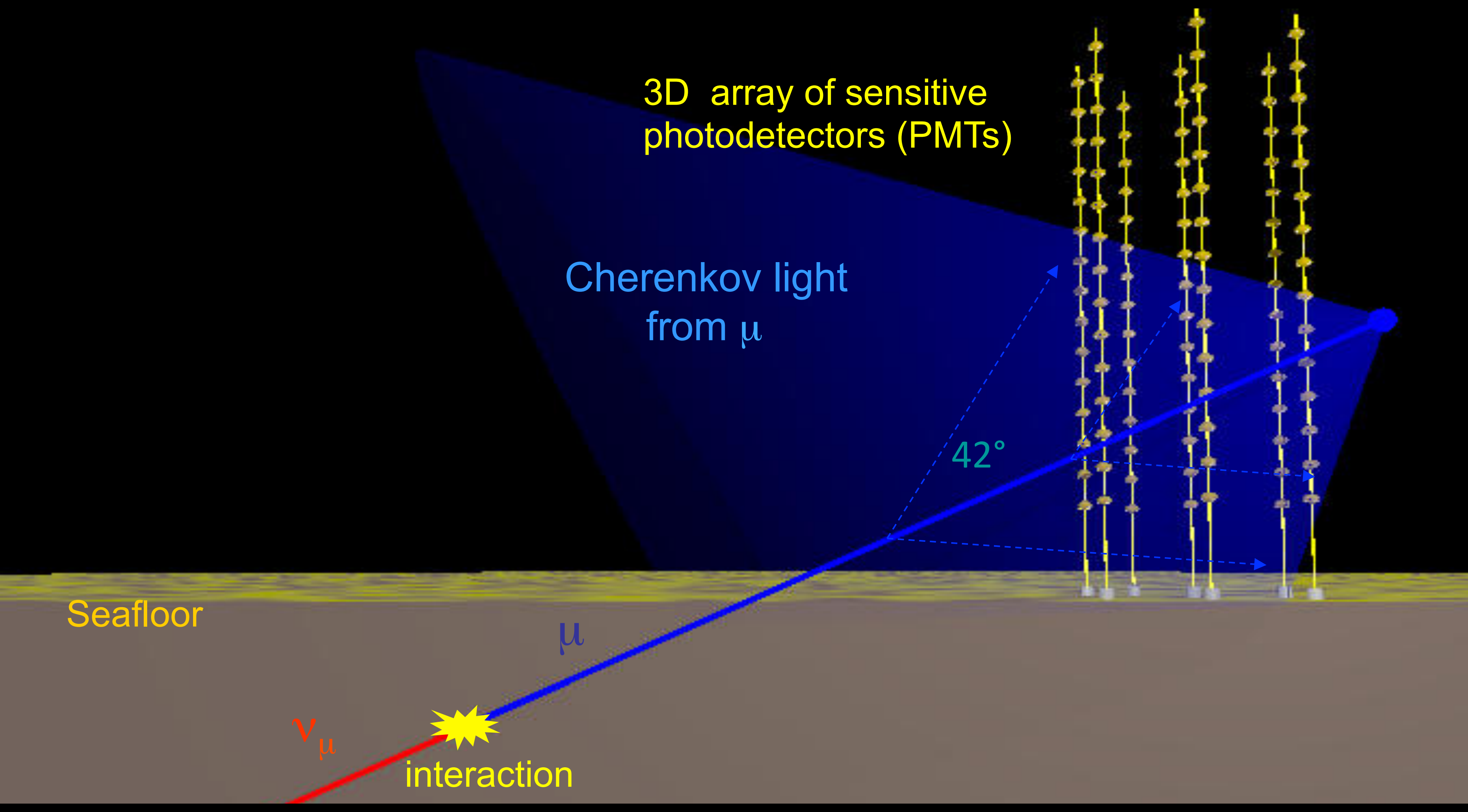


Australia

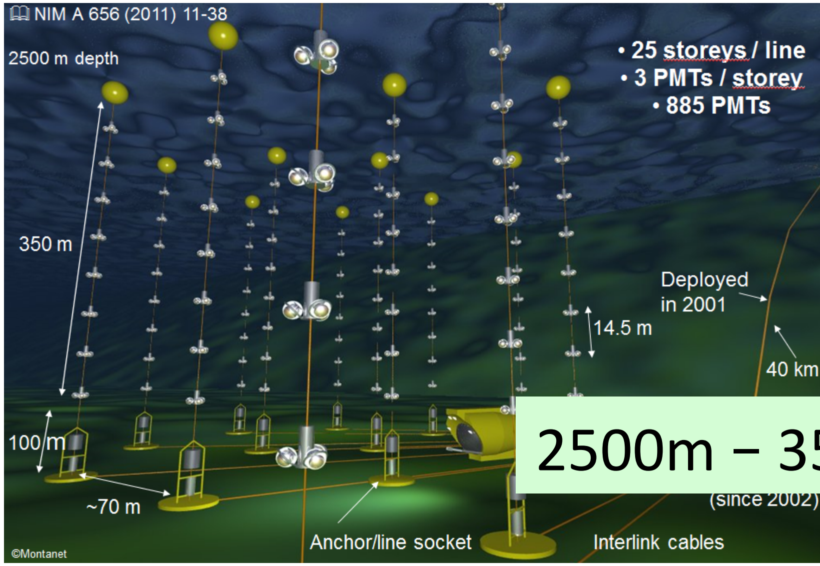
Georgia

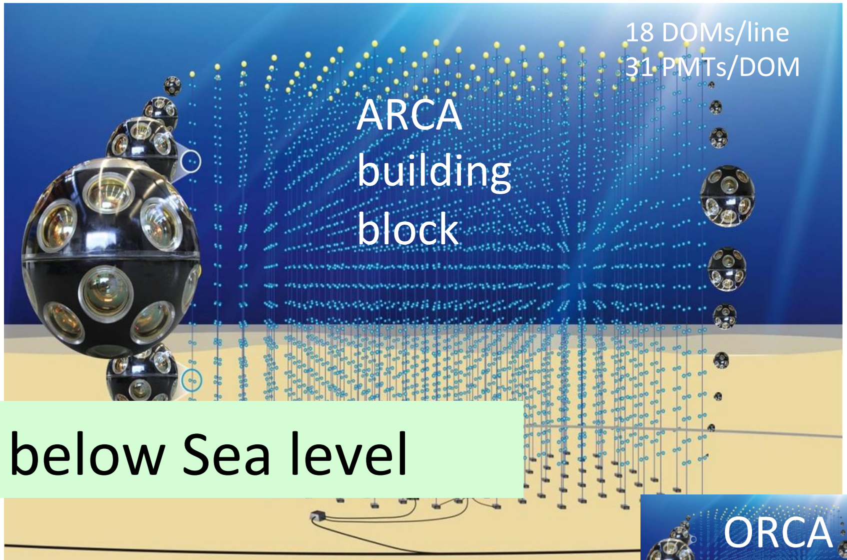
South Africa

Neutrinos are only weakly interacting -> Large detection volume required
-> Use natural Ice/Water resources



The ANTARES/KM3NeT Neutrino Telescopes





2500m – 3500m below Sea level

- Running since 2007
- 40km from French coast
- 12 lines,

- First strings deployed 2016
- 2x115 strings Italian site (ARCA)
- 1x115 French site (ORCA)

ORCA	ANTARES	ARCA
Low energy	Medium energy	High energy
3 GeV – 50 GeV	10 GeV < E < 1 TeV	E > 1 TeV

*Earth and Sea sciences:*Oceanography, Biology, Geology, Climate monitoring

Atmospheric neutrinos
Neutrino oscillations
Neutrino mass ordering

Dark Matter
Exotics

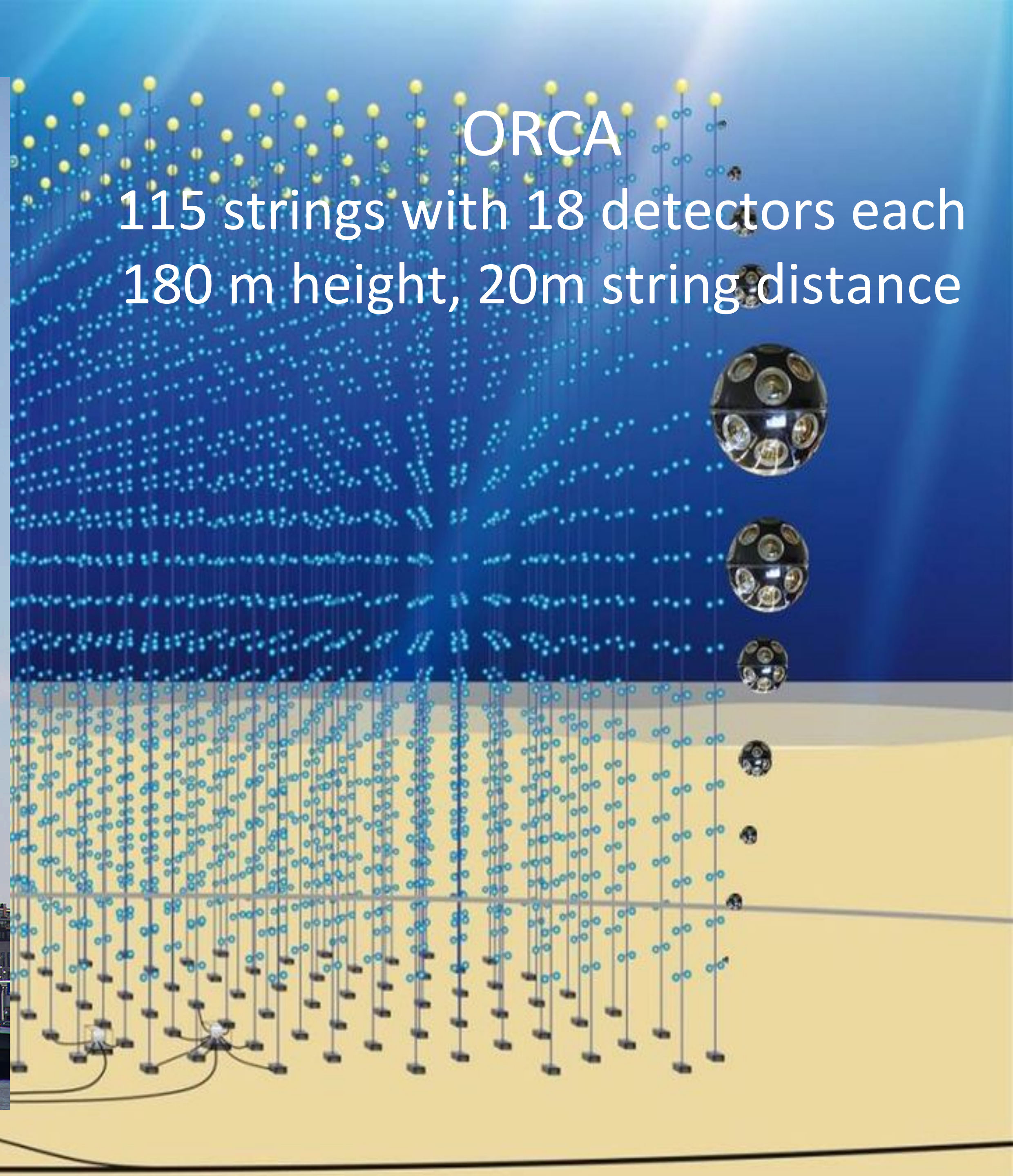
Cosmic Sources

ORCA

115 strings with 18 detectors each

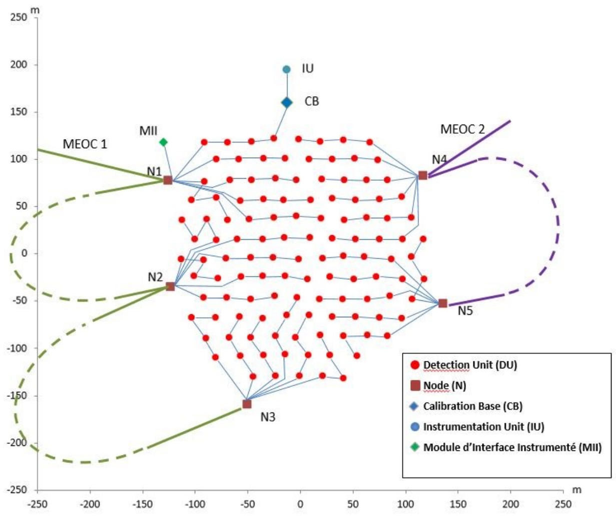
180 m height, 20m string distance

Highest building in the Netherlands:
Maastoren (164m)
Rotterdam

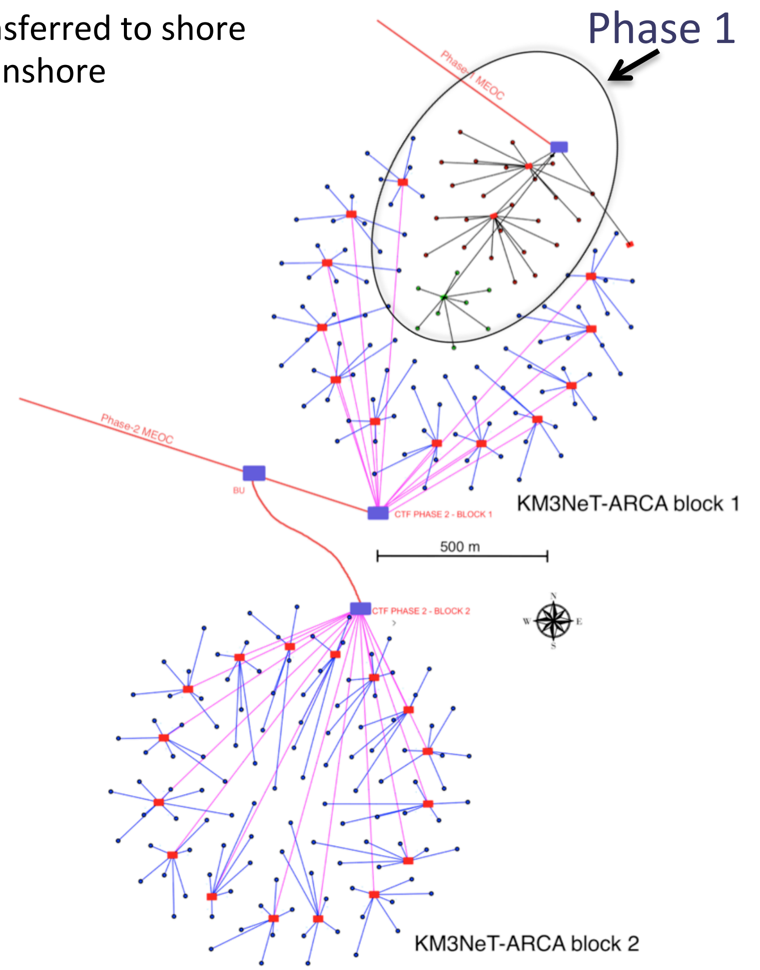


ORCA Phase-2 footprint

ARCA Phase-2 footprint



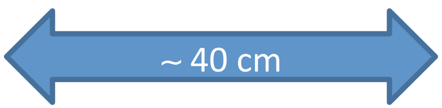
All data transferred to shore
-> filtering onshore



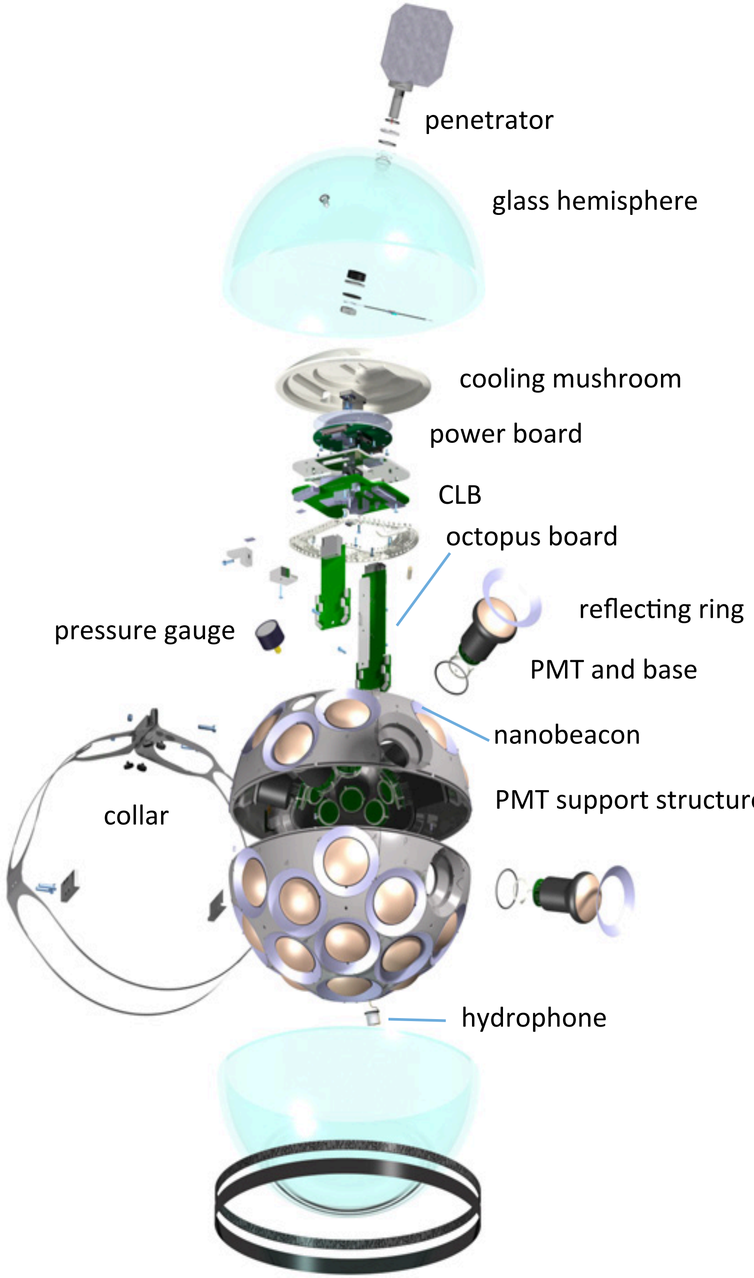
Phase-1: 24 / 6 strings
Phase-2: 2*115 / 115 strings
for ARCA/ORCA

String distance 90m / 23m
DOM distance on a string: 35m / 9m

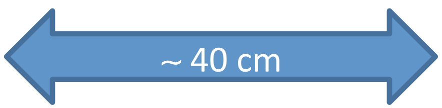
ARCA phase-1 will be ≈ 0.1 km^3



- 31 3” PMTs
- Light reflector rings
- LED beacon
- acoustic piezoelectric
- Tiltmeter/compass
- Gbit/s fibre DWDM for data transmission
- Hybrid White Rabbit for time synchronization



- Photocathode corresponding to 3 10” PMTs
- Digital photon counting
- Directional information



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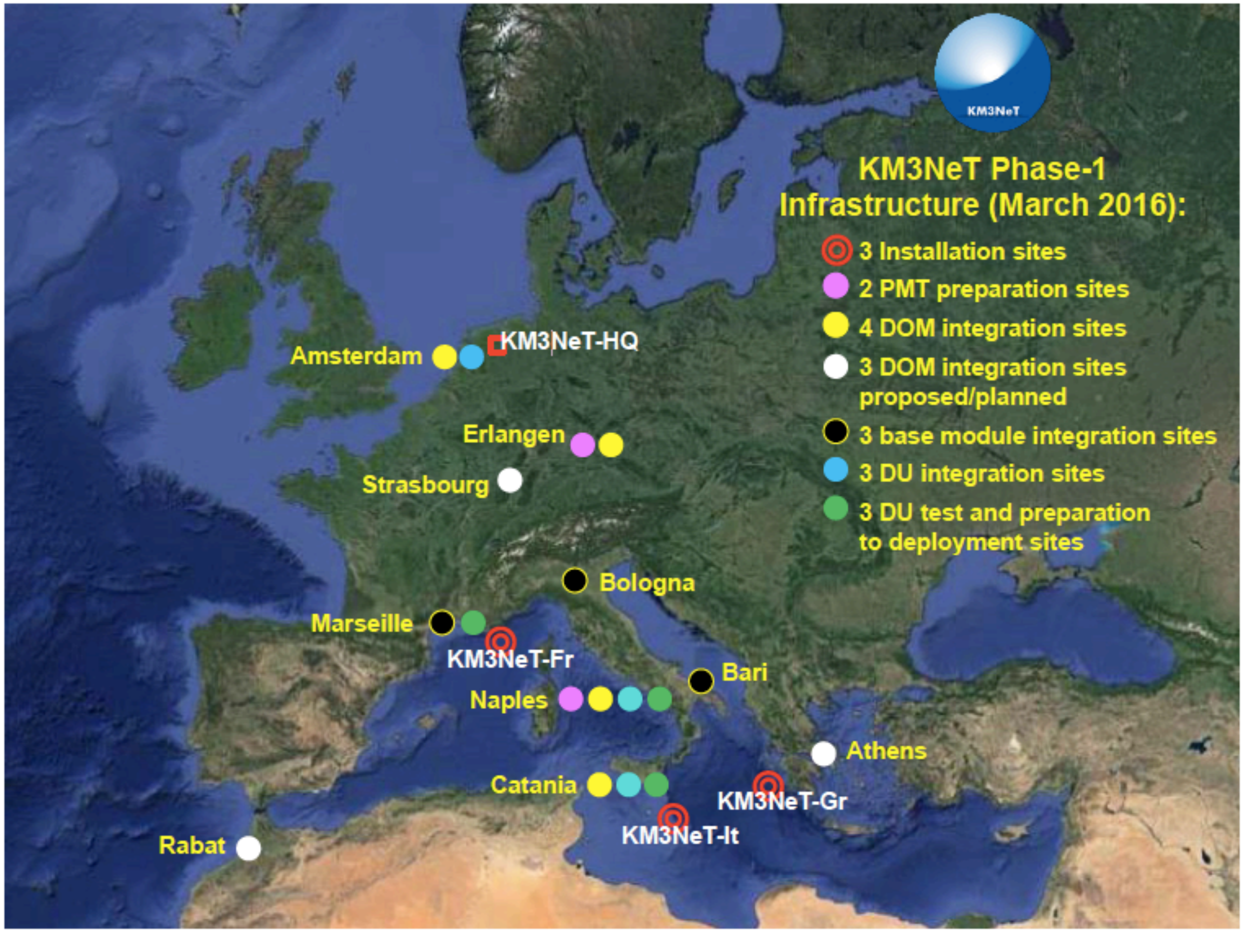
Detector production

Currently:

- 7 DOM production sites
  -> 5-12 DOMs/week/site

- 4 DU production sites
  -> 1 DU/month/site

More sites getting ready



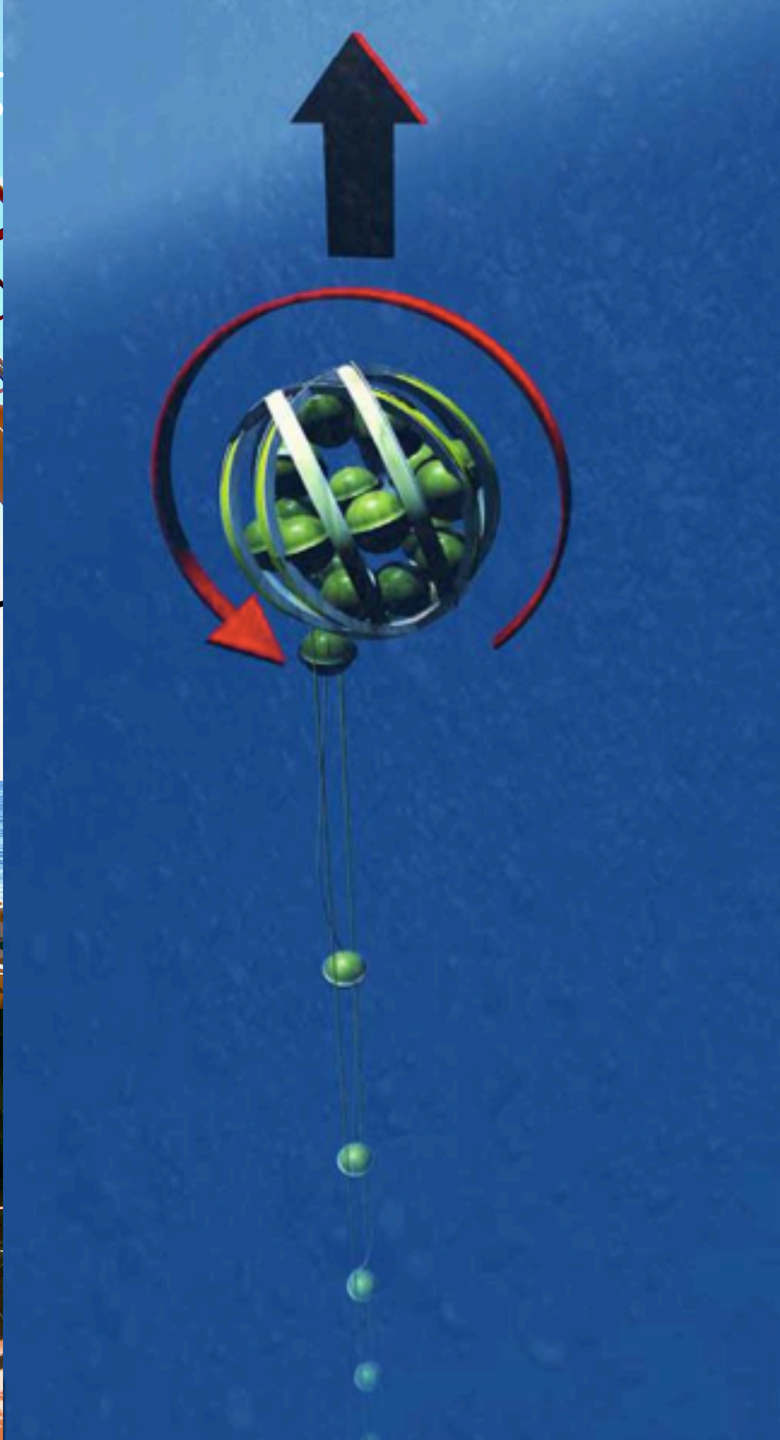
Once upon a time …

… first steps of the first DOMs (2014)

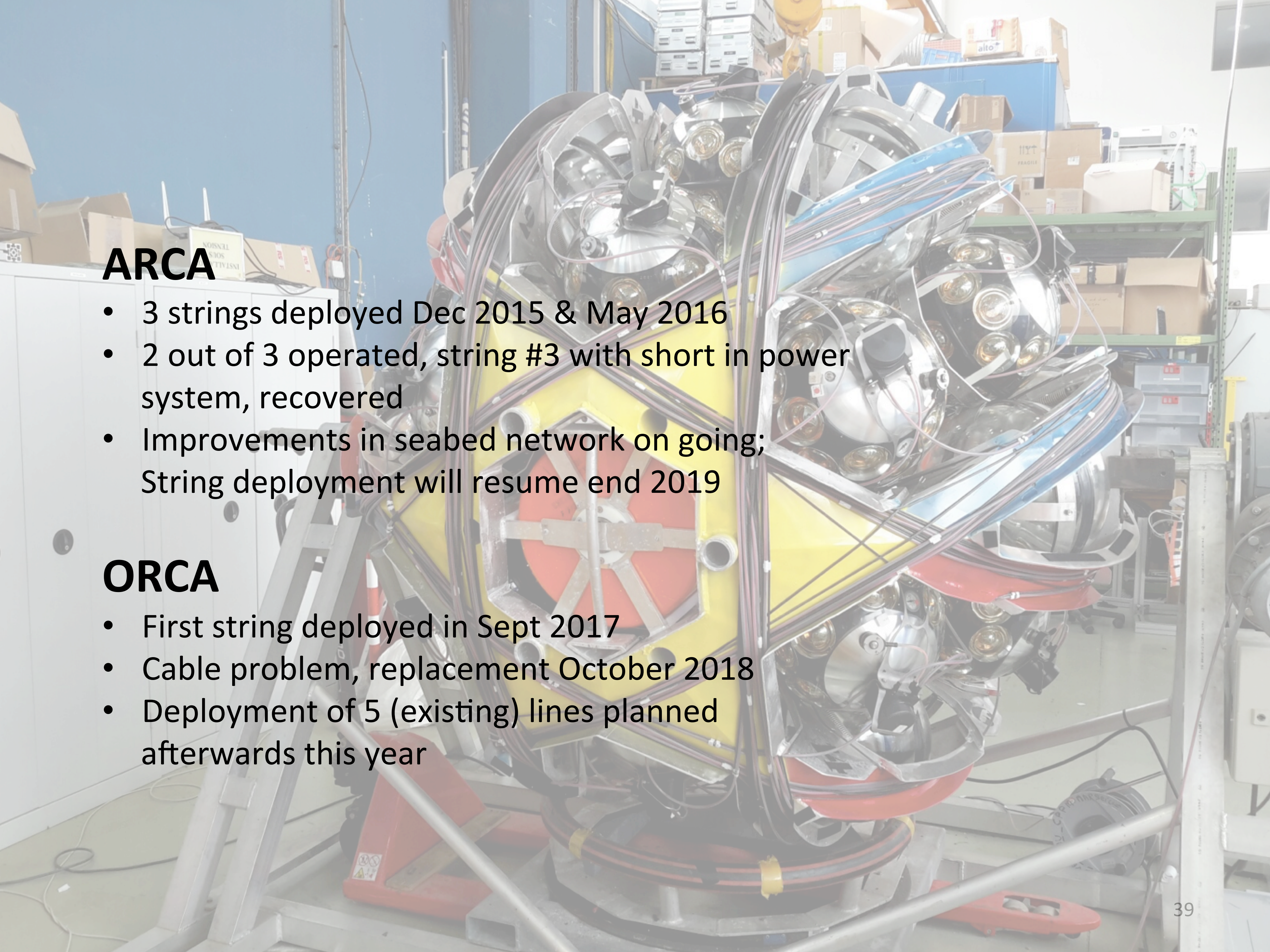

2018: Detector mass production at Nikhef
218 of 392 DOMs produced at Nikhef
6 of 9 strings produced at Nikhef


First light for the first full string at the ARCA site (December 2015)

Deployment of first ORCA string
September 2017



After successful deployment of first ORCA line



ARCA

- 3 strings deployed Dec 2015 & May 2016
- 2 out of 3 operated, string #3 with short in power system, recovered
- Improvements in seabed network on going; String deployment will resume end 2019

ORCA

- First string deployed in Sept 2017
- Cable problem, replacement October 2018
- Deployment of 5 (existing) lines planned afterwards this year

Background in the Seawater

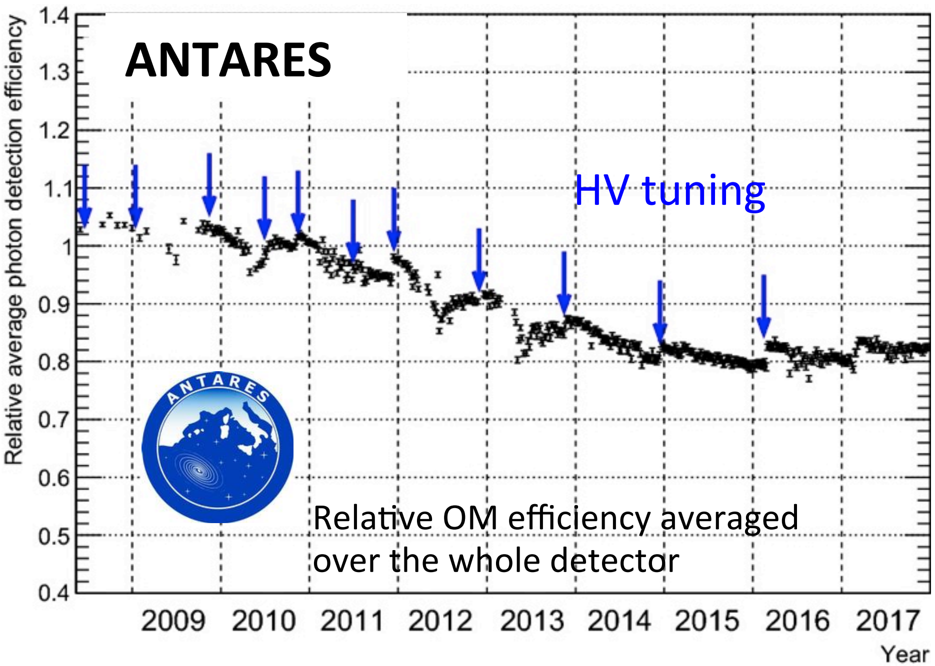
Cherenkov light related to the radioactive decay of ^{40}K dissolved in the sea water

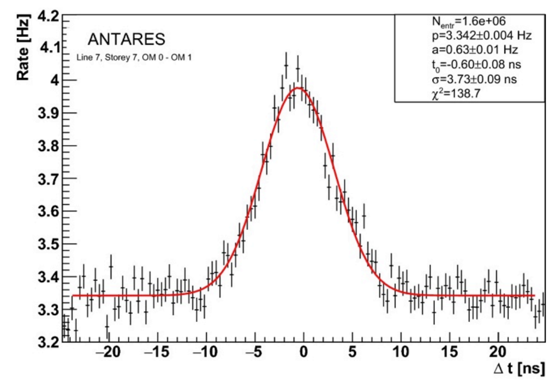
⇒ Main signal on PMTs from ^{40}K

⇒ Homogeneous/isotropic signal

-> excellent calibrator!

$$
\begin{aligned}
&^{40}\mathrm{K} \rightarrow \quad {}^{40}\mathrm{Ca} + e^- + \bar{\nu}_e && (89.3\%)\\
&^{40}\mathrm{K} + e^- \rightarrow \quad {}^{40}\mathrm{Ar}^* + \nu_e && (10.7\%)\\
&\qquad\qquad \hookrightarrow \quad {}^{40}\mathrm{Ar} + \gamma &&
\end{aligned}
$$





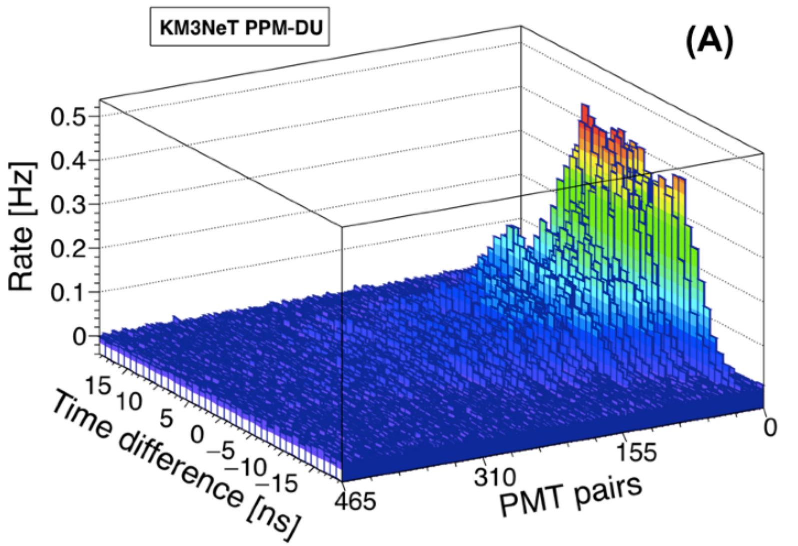
distribution of the time difference between hits on two adjacent OMs)ANTARES)

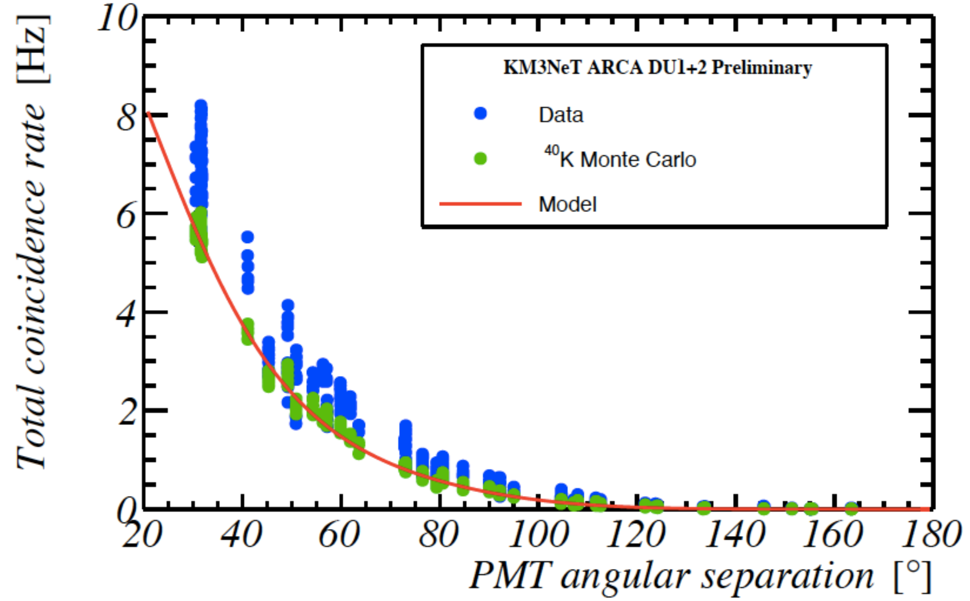
A. Albert et al., EPJC 78 (2018) 669

Longterm monitoring of efficiencies in ANTARES (9 years)
-> Excellent stability, ~20% efficiency loss

KM3NeT: Calibration using potassium decay in sea water

Hit time differences –
all PMT pair combinations on a DOM





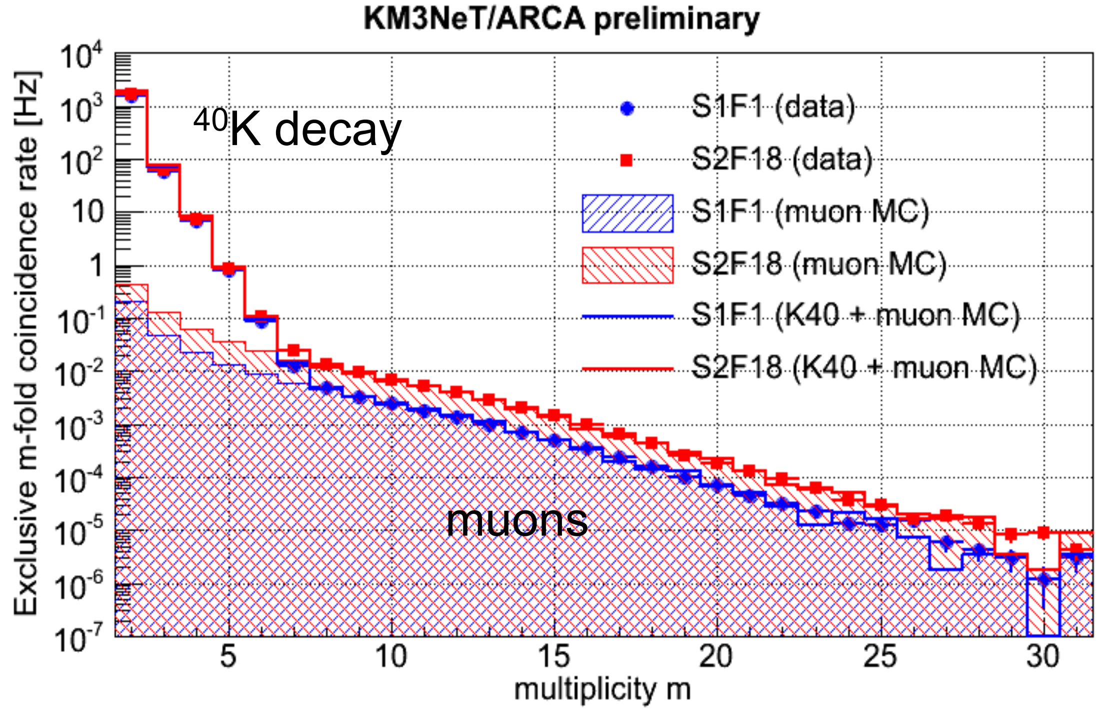
Single rate on one PMT: 6kHz
2-fold coincidence rate on a DOM: 500Hz

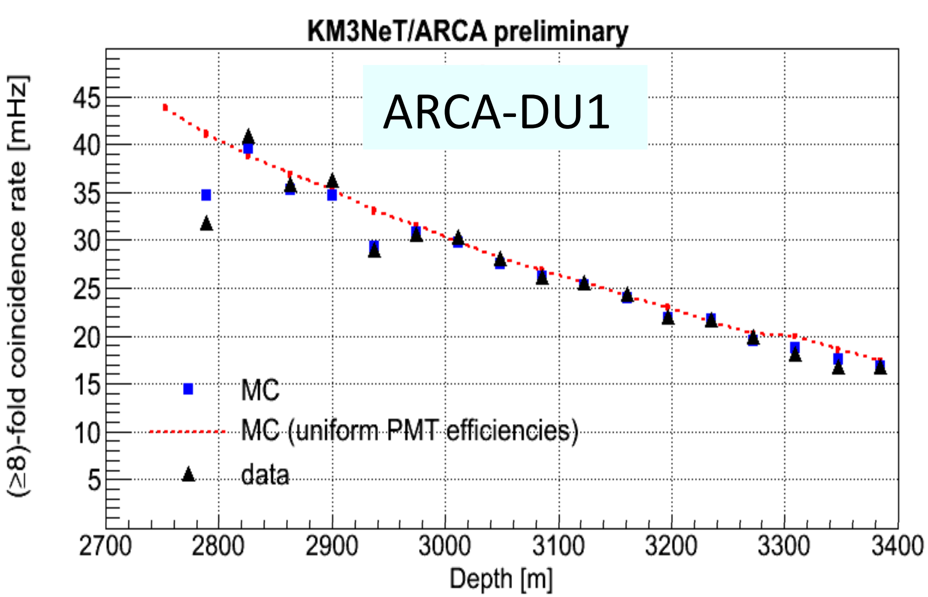
Correlated signal between PMT pairs:

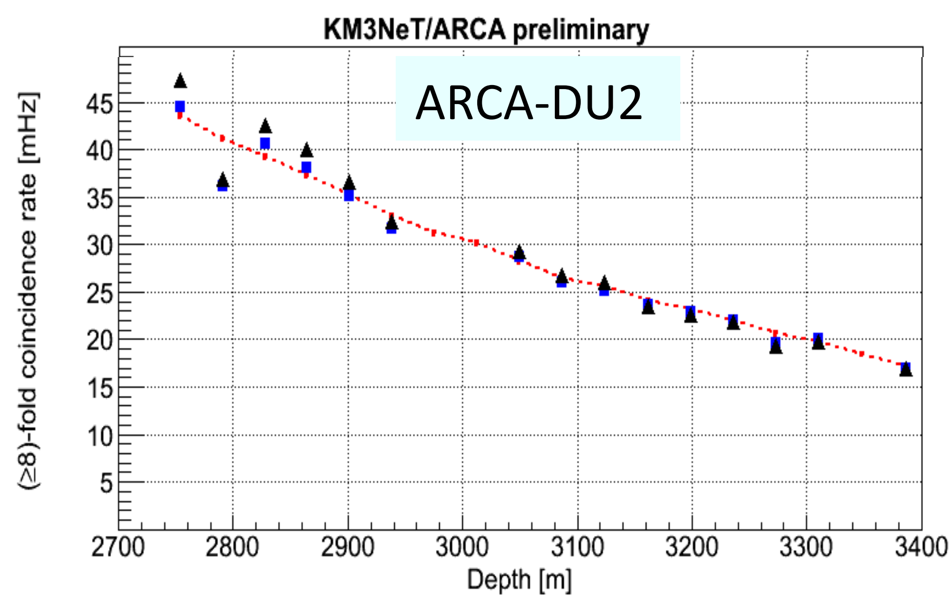
- Height => Efficiency determination
- Position => Time calibration (nanosecond accuracy)
- Width => Time spread of PMT

Coincidence size on a DOM:
Low coincidences: ^{40}K
High coincidences: muons

Rate of high coincidences
Proportional to muon rate
=> Measure depth dependence of muons



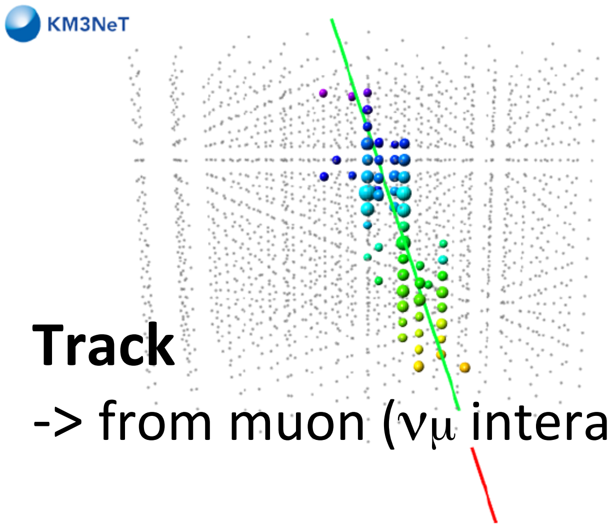




KM3NeT/ARCA
Muon track

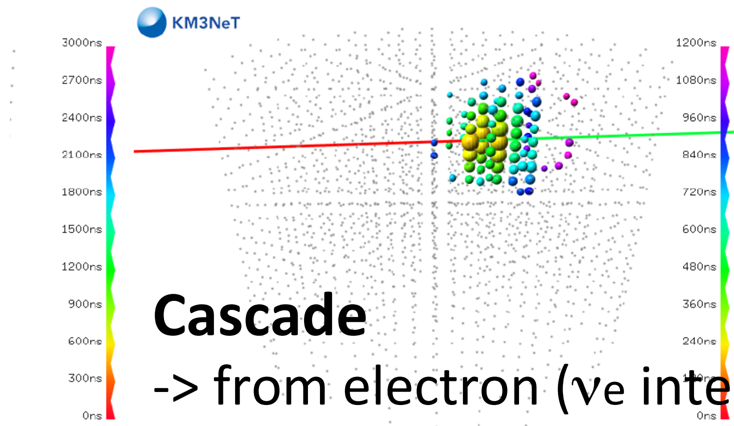
Event display by Aart Heijboer
(see also cherenkov.nl)

Different neutrino flavor signatures



Track

-> from muon (ν_μ interaction)

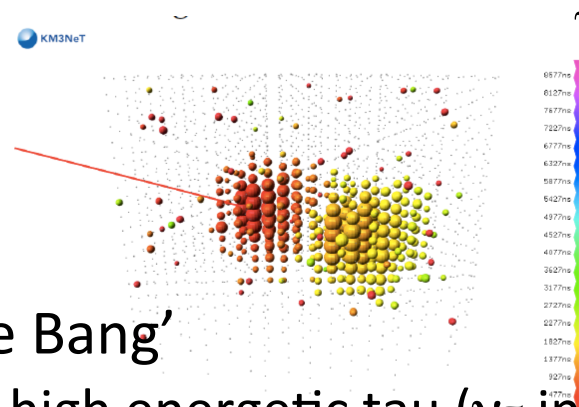


Cascade

-> from electron (ν_e interaction)

-> from neutral current

ν_e / ν_μ / ν_τ interactions



'Double Bang'

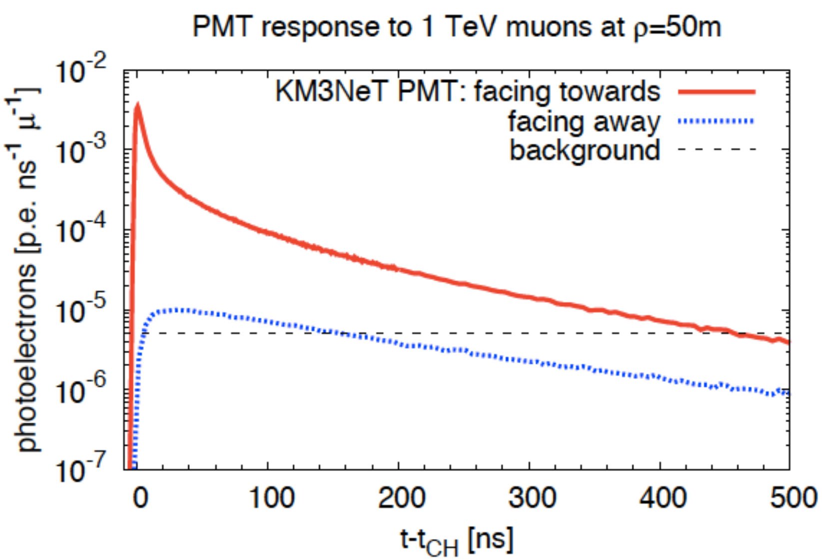
-> from high energetic tau (ν_τ interaction)

No distinction between neutrinos/antineutrinos
Flavor identification not always uniquely possible

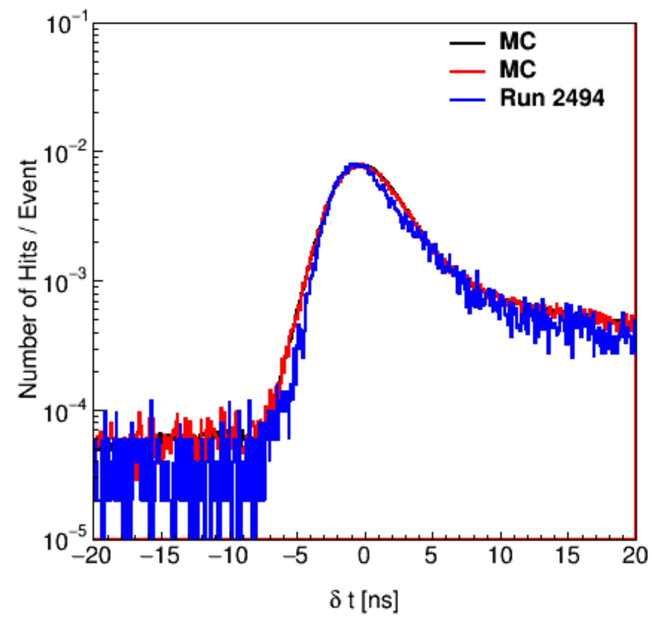
Excellent scattering properties in water:

Narrow time residuals (comparing expected time of direct signal with measured time

Simulation of high energy muon



ORCA data - preliminary



First neutrino analysis

82 days of data taking with first ORCA line

cos(theta) > 0 [0.5]

----

observed : 13 [10]

atm. muon: 1 [0]

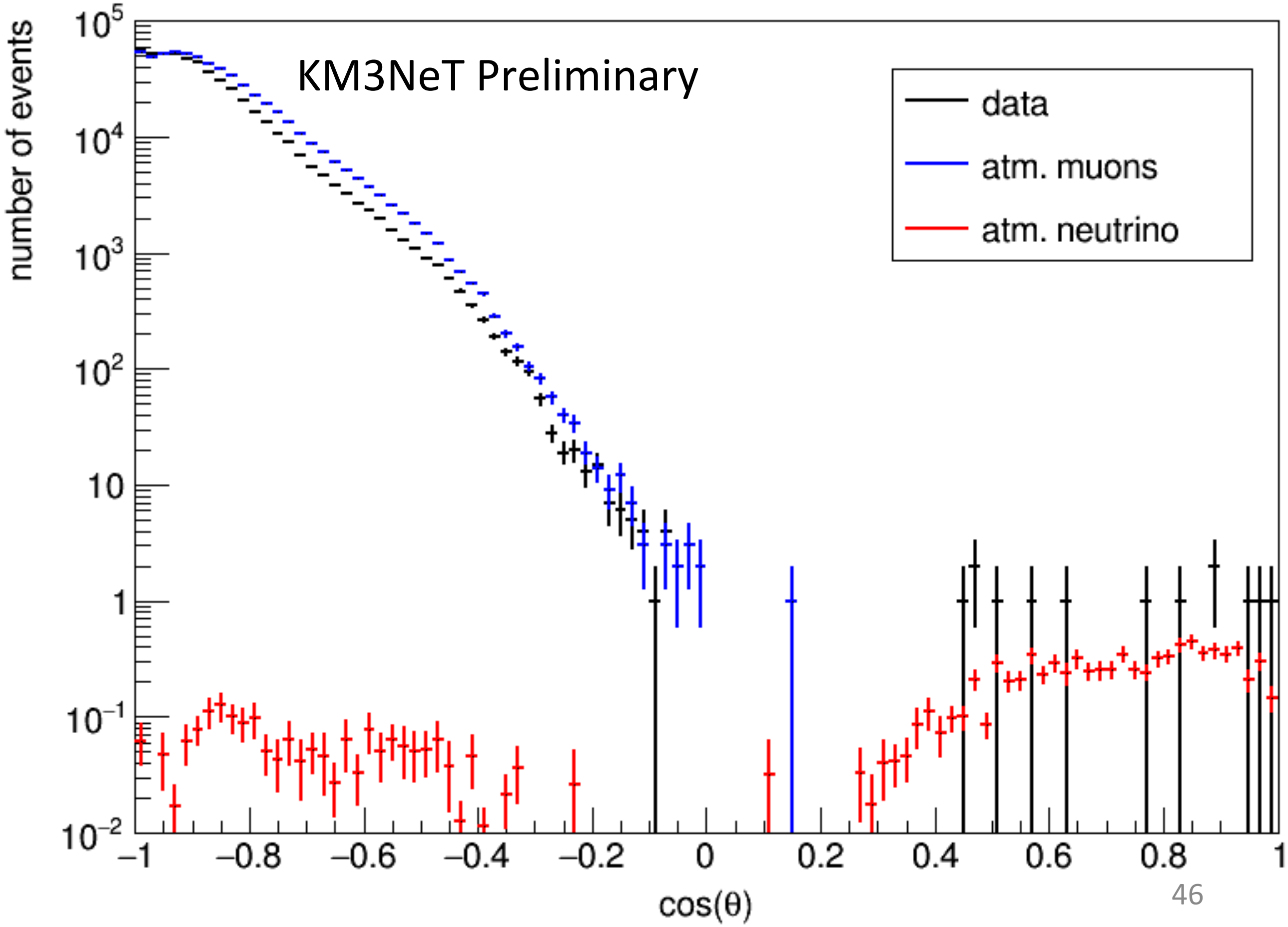
neutrino : 8.33 [7.36]

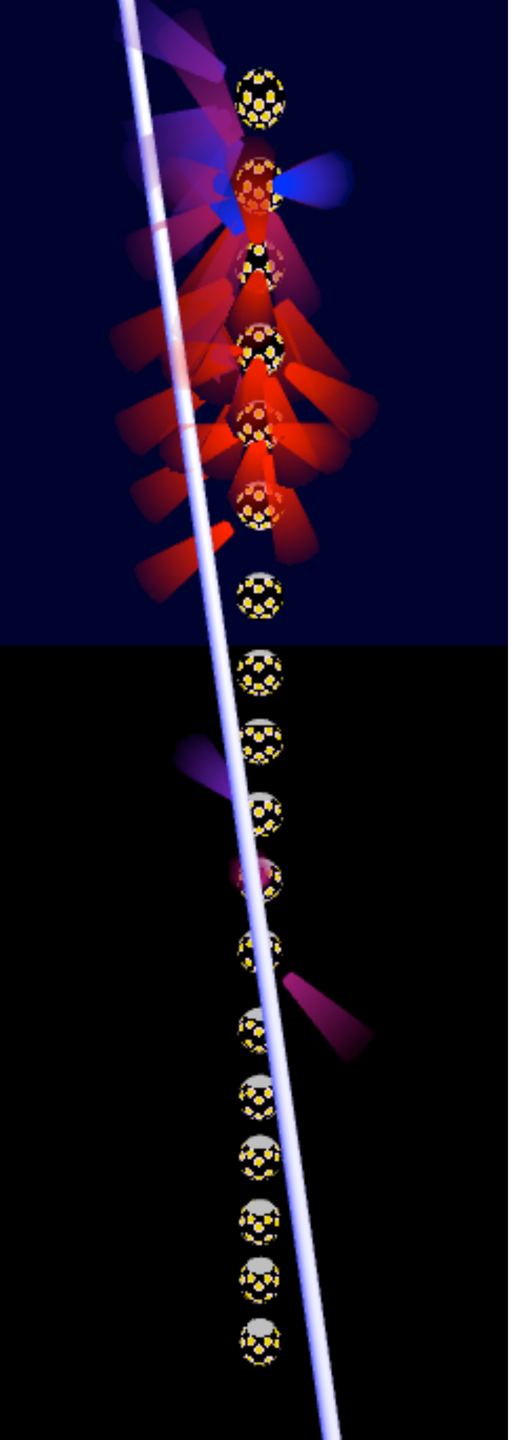
ν_μ : 5.44 [4.89]

ν_e : 1.36 [1.17]

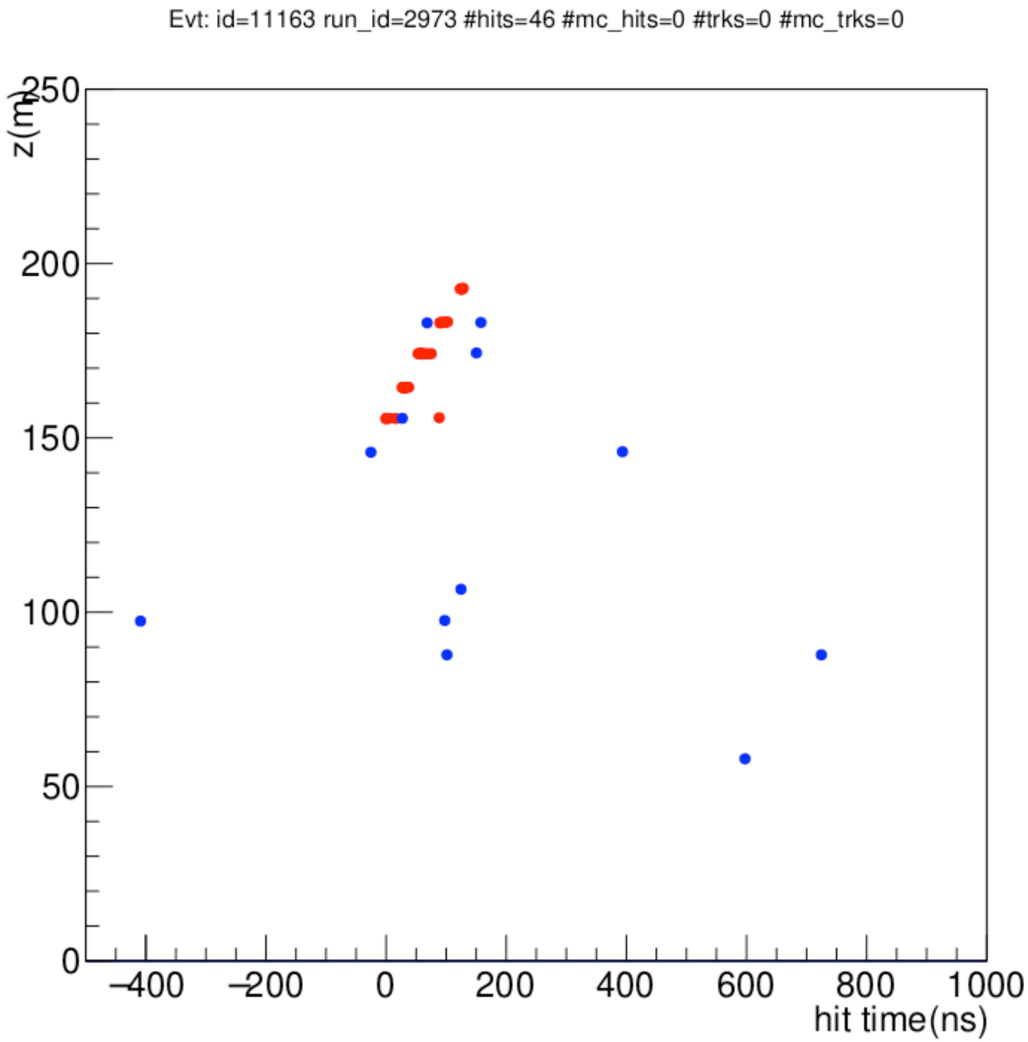
ν_τ : 0.96 [0.83]

ν_{NC} : 0.57 [0.47]





Selected Neutrino Candidate



Estimated energy 5-15 GeV

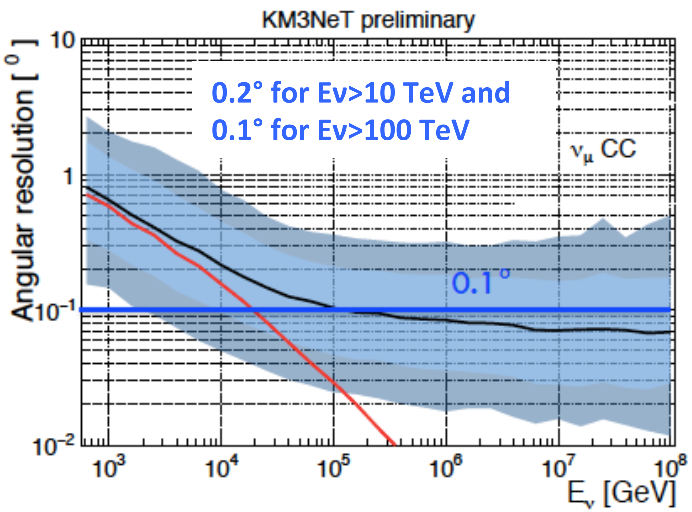
KM3NeT/ARCA prospects

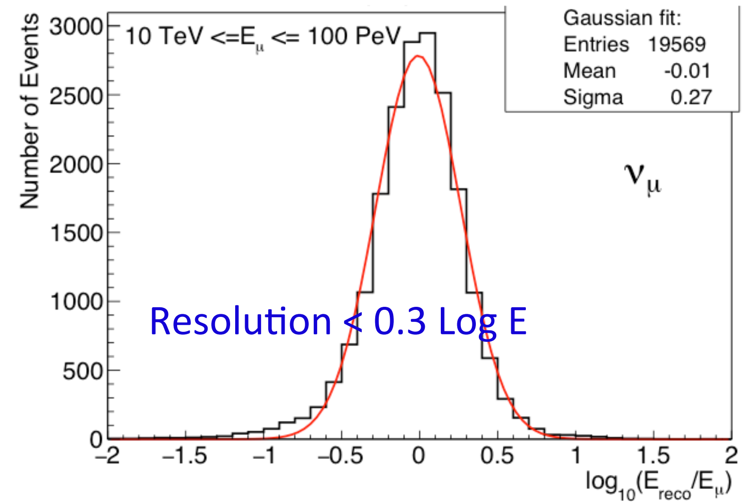
KM3NeT/ARCA

Angular resolution

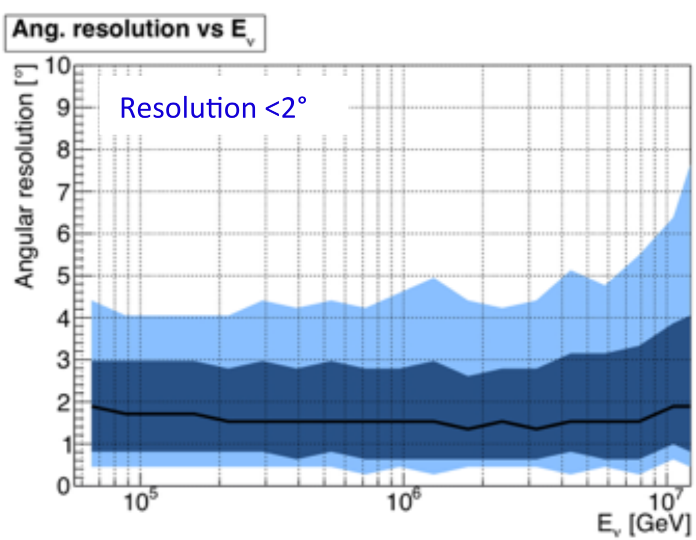
Energy resolution

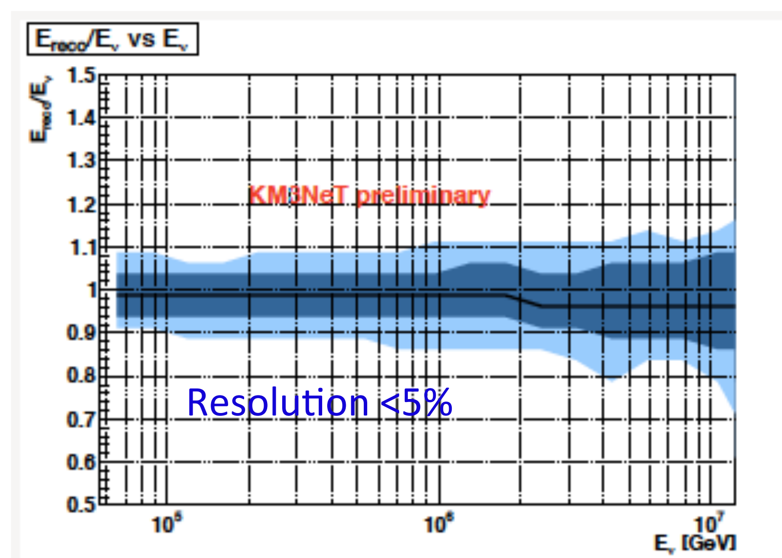
Tracks





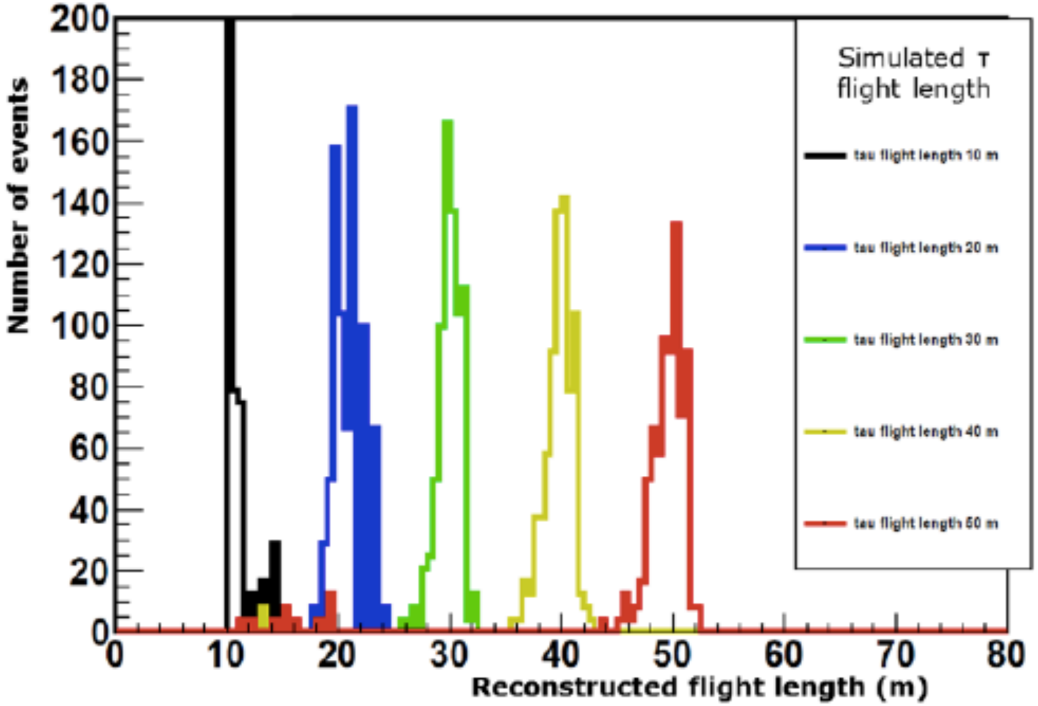
Showers

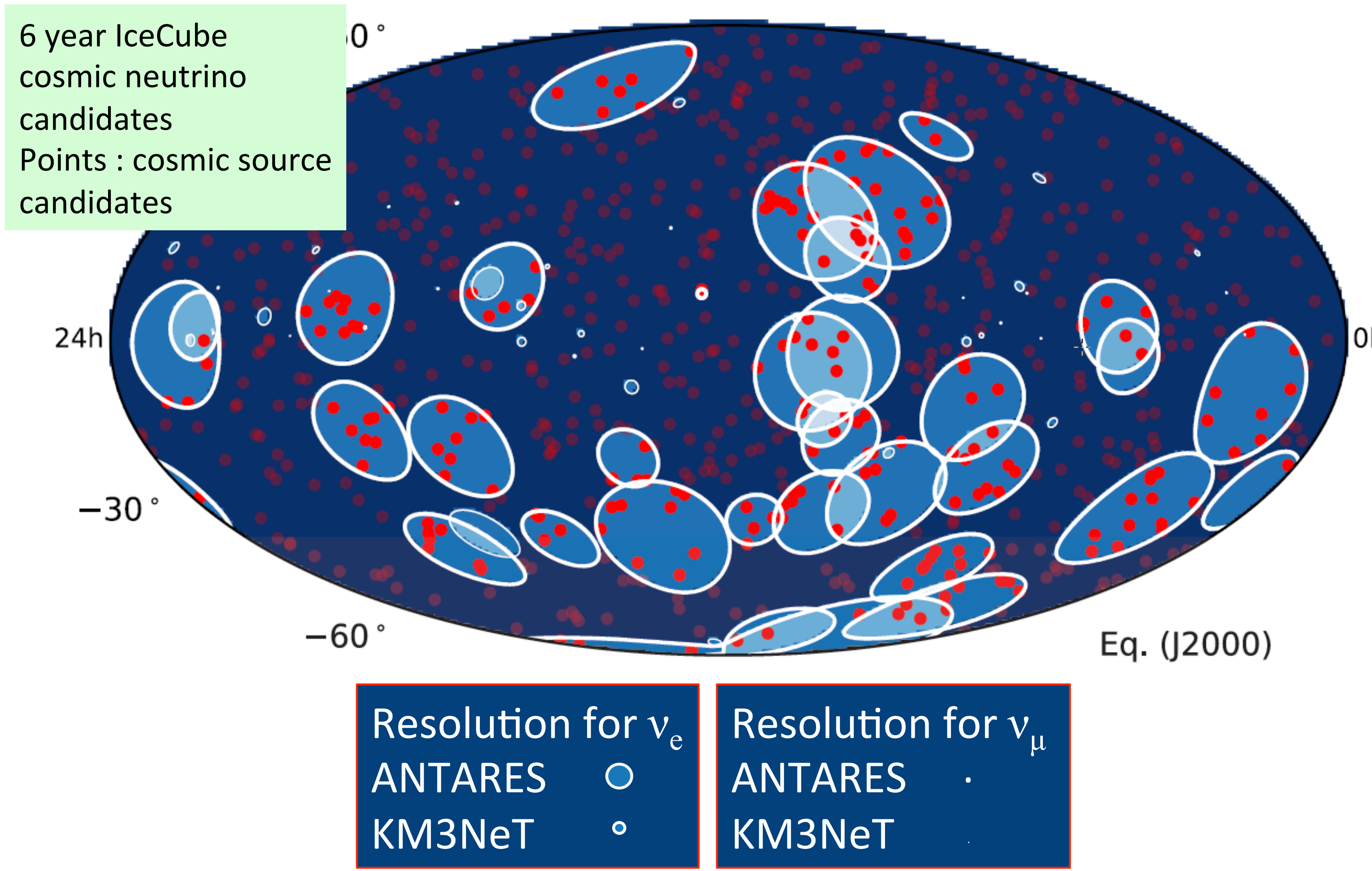




KM3NeT/ARCA

'Double Bang' Tau neutrino signature identifcation:
Resolution of flight distance



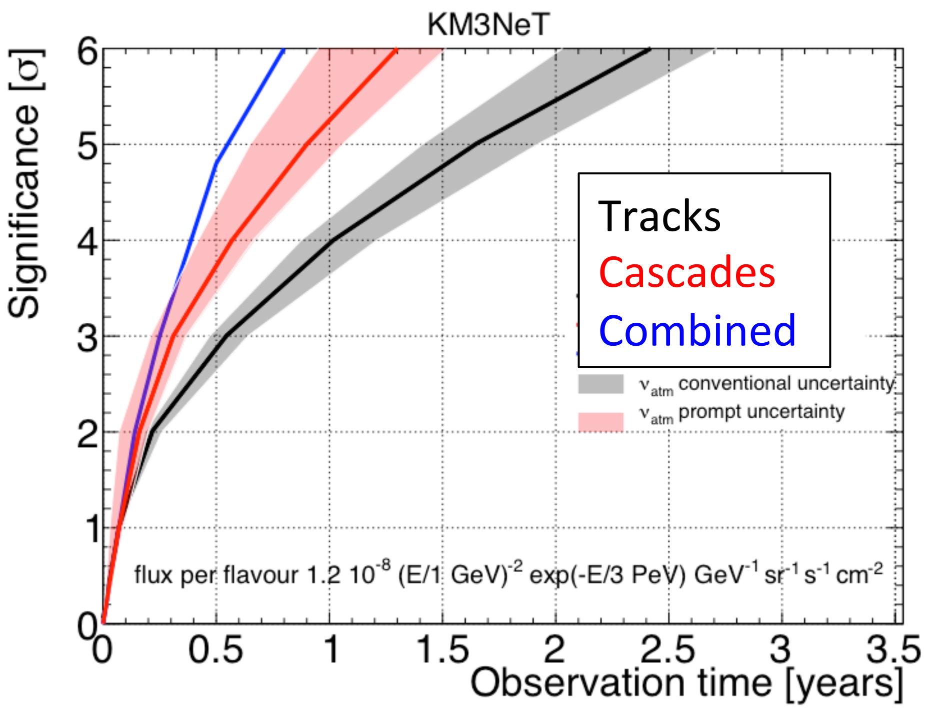


From Resconi/Heijboer ICRC 2017

Cosmic diffuse flux

Investigate IceCube flux (assume isotropic and flavour symmetric)

$$\Phi(E) = 1.2 \cdot 10^{-8} (E / 1\ \mathrm{GeV})^{-2} \exp(-E / 3\ \mathrm{PeV})\ \mathrm{GeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$$



- **Tracks**

Pre-cuts on θ_{zen} >80°, reconstruction quality parameter, number of hits (proxy for muon energy)

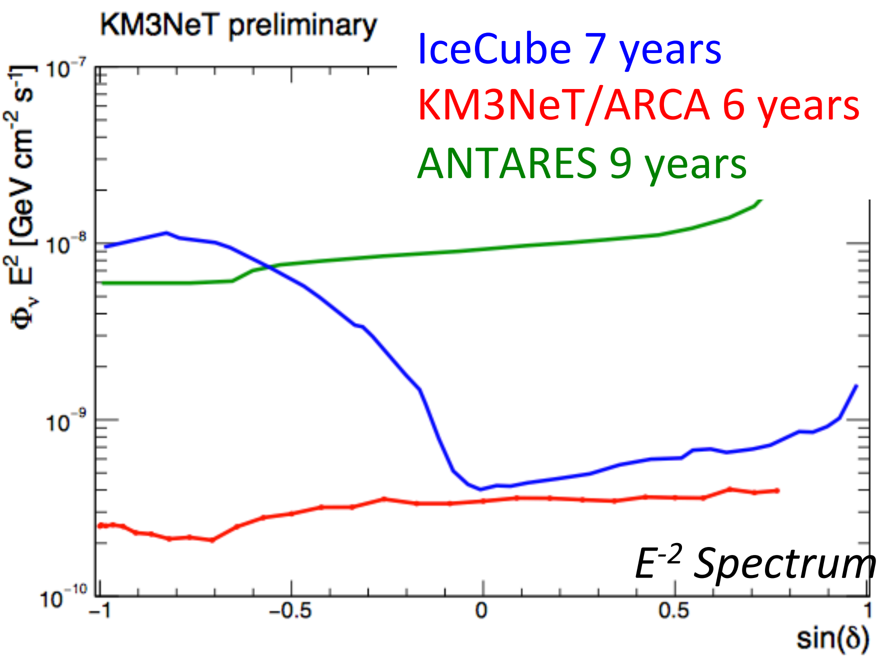
- **Cascades**

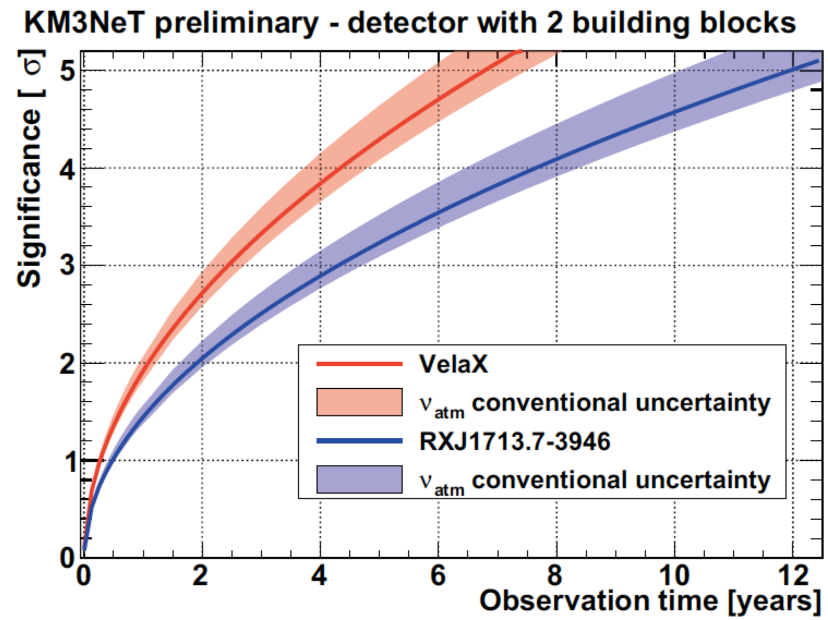
Containment of vertex

All sky analysis based on BDT and maximum likelihood.

Discovery at 5σ (50% probability) in 6 months of ARCA

Sensitivity to Point Sources

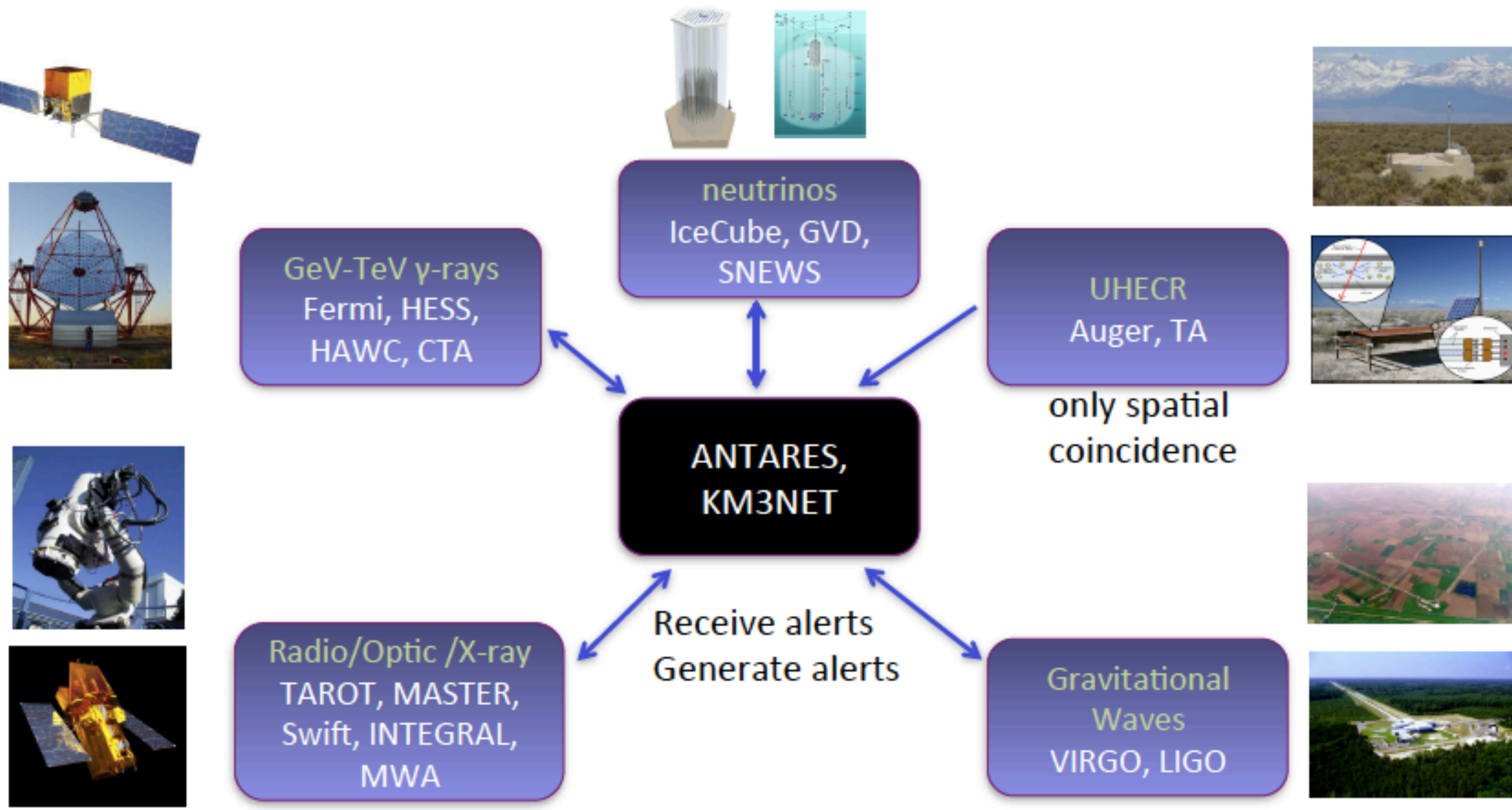




KM3NeT:

- Complementary view on the sky to IceCube
- Better angular resolution for all flavours than IceCube
- Detection of sources feasible within 5 years

Multimessenger network

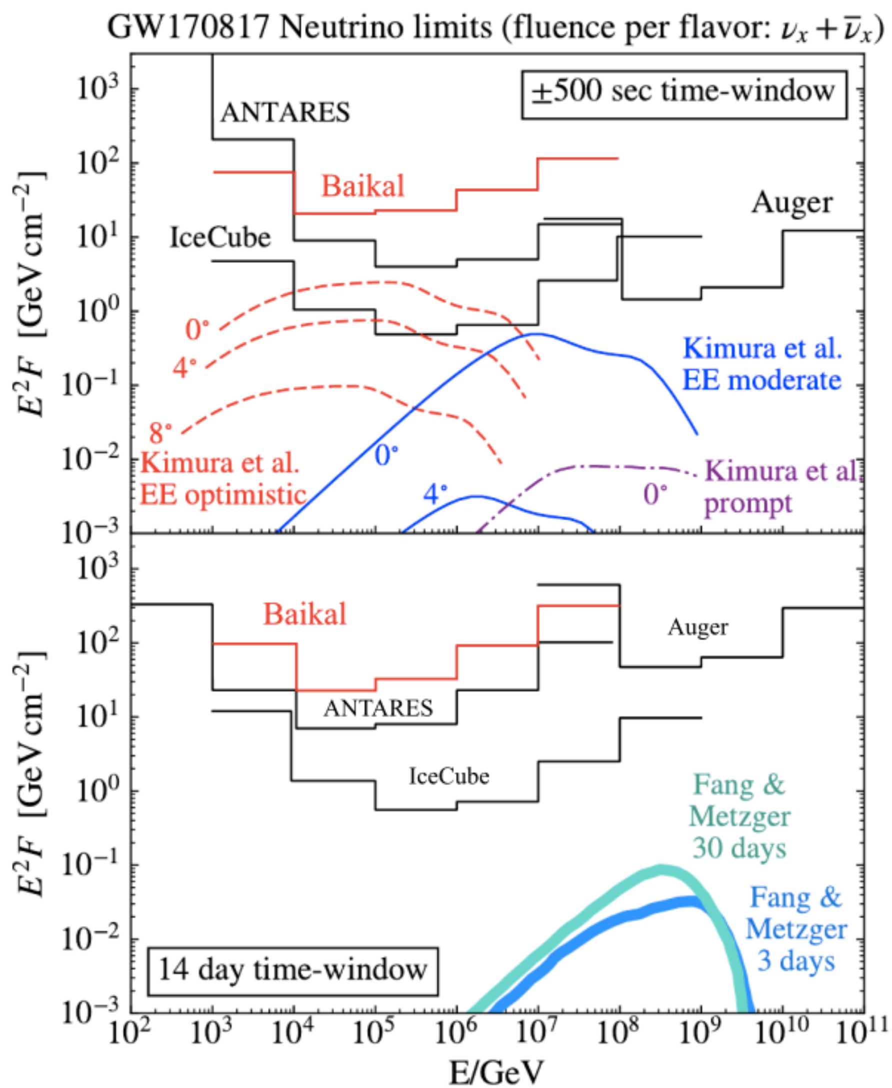


Follow-up also of Gravitational Wave Candidates:

Binary neutrino star merger GW170817:

Depending on assumed environment model predictions for neutrino observations can vary (jet angle)

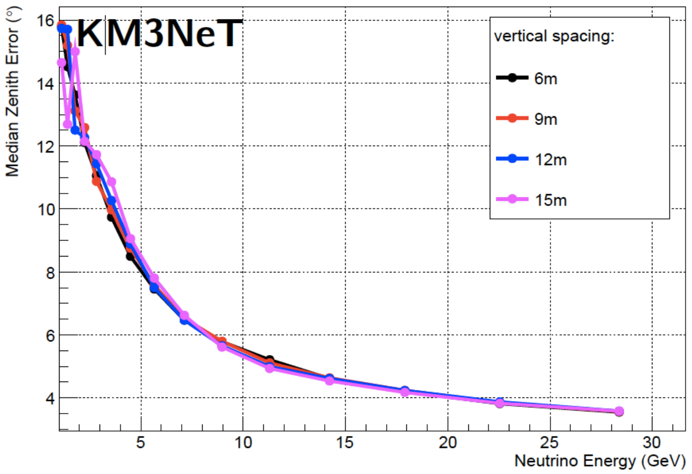
=> Optimistic scenarios close to current sensitivity limits



KM3NeT/ORCA prospects

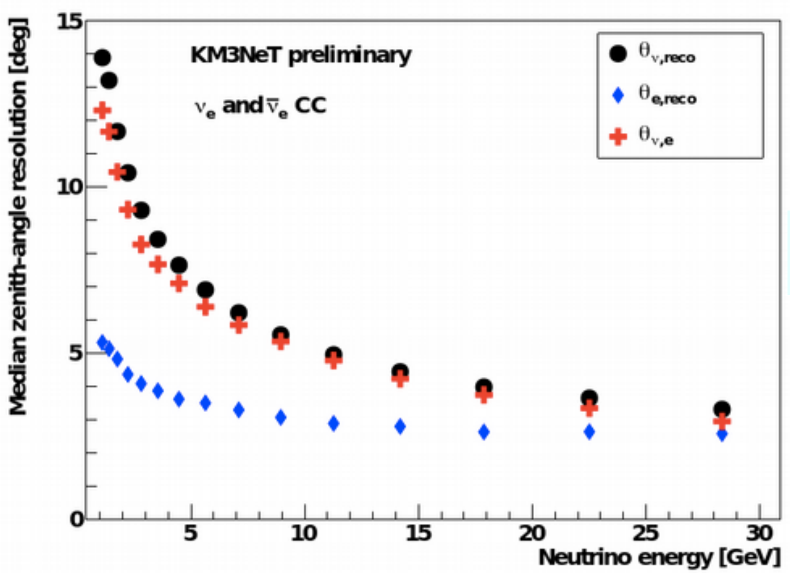
KM3NeT/ORCA

Angular resolution



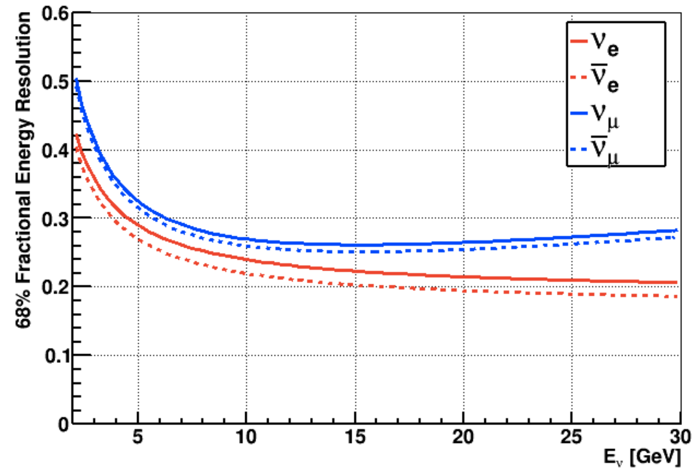
Tracks

Dominated by kinematical limit
<5deg for E>10 GeV



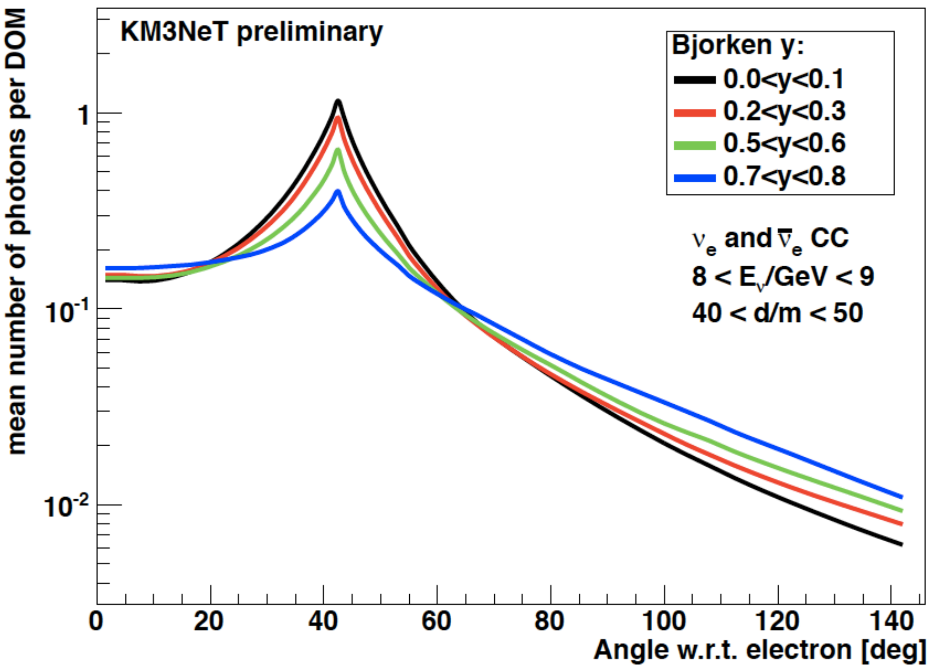
Showers

Energy resolution

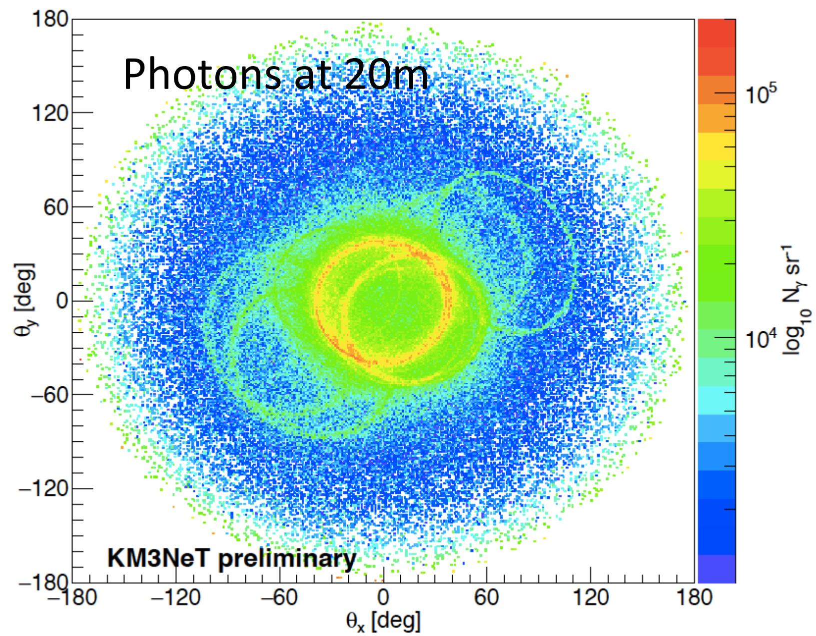


<25% for E>10 GeV for both tracks and showers

Inelasticity (shown for ν_e CC events)



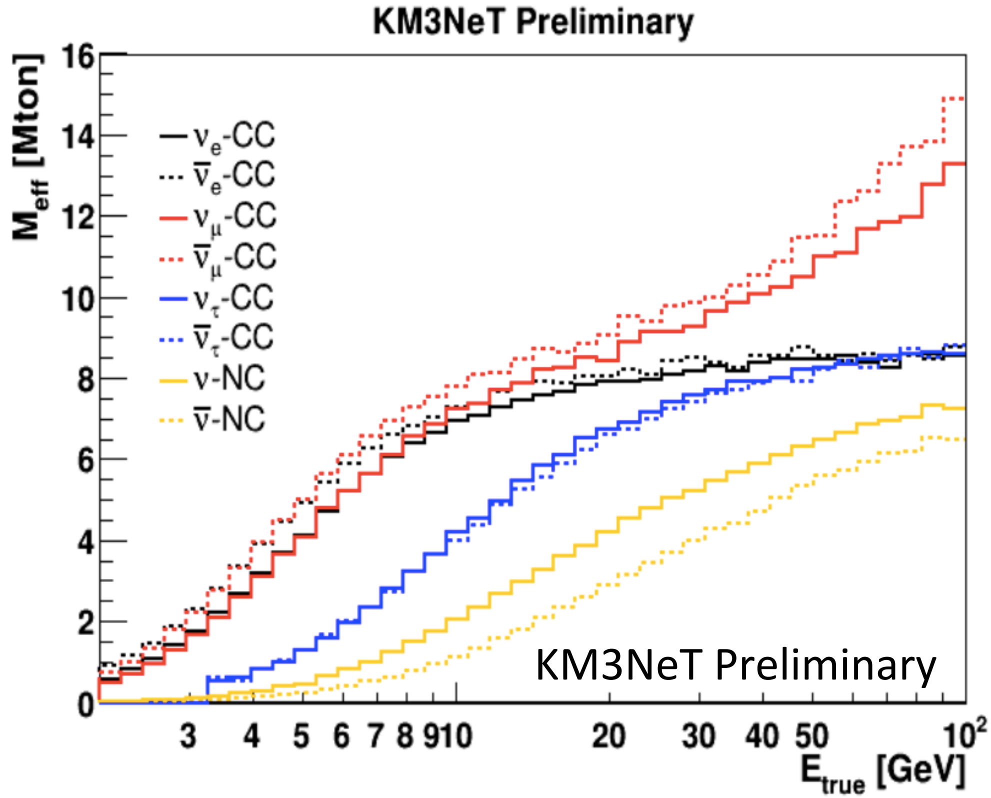
Simulated ν_e^{CC} event with E=10GeV, y=0.5



Neutrinos and antineutrinos have different inelasticity distributions
=> Distinction neutrino/antineutrino could be (limited) feasible

Not yet used in ν NMO evaluation, improvement for sensitivity expected

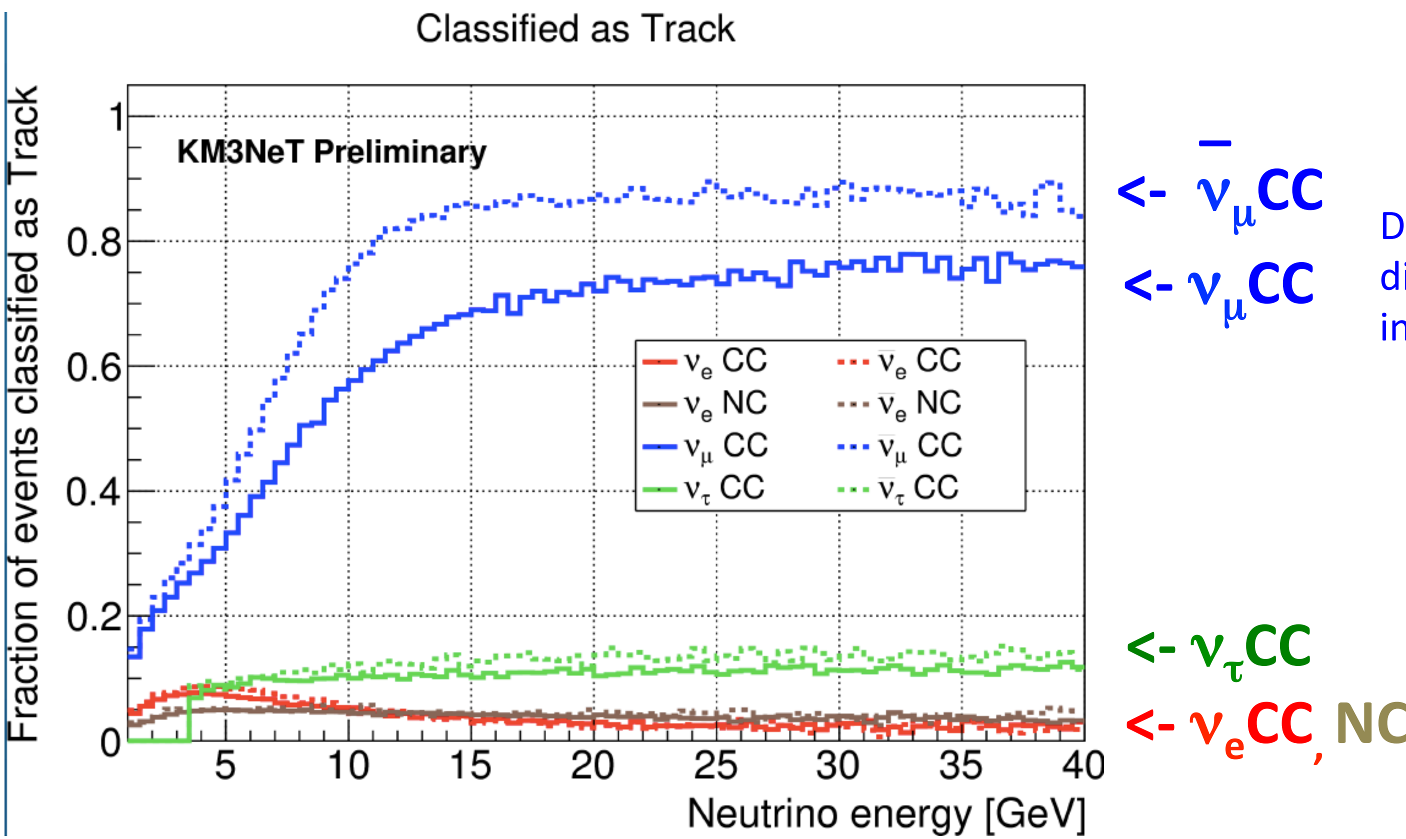
Effective Mass



- New trigger -> enhanced sensitivity at lower energies
- ν_μ, ν_e reaching instrumented mass (8Mton) at 10GeV
- ν_μ larger effective mass at higher energies due to long track length (sensitive to larger volume around the detector)

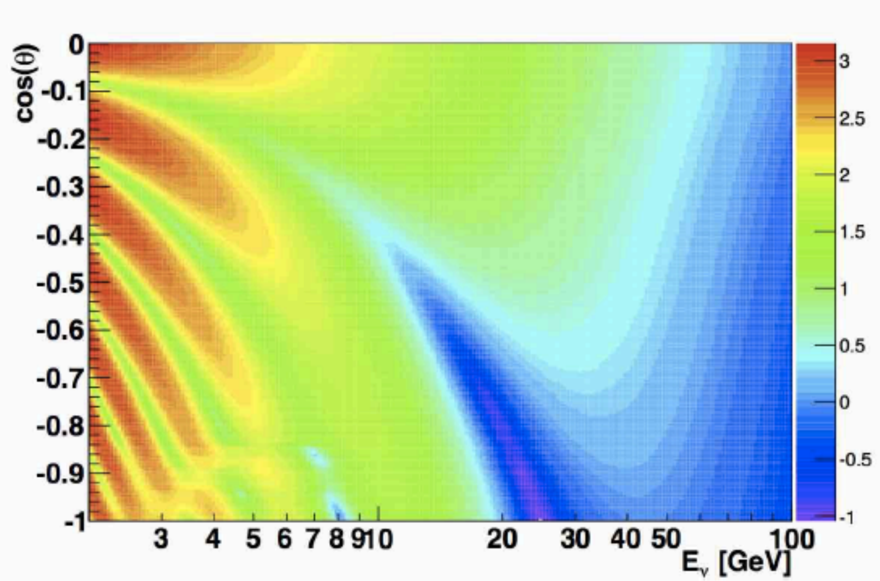
Flavour Identification

- Discrimination of track-like (ν_μ^{CC}) and cascade-like (ν^{NC}, $\nu_{e/\tau}^{CC}$) events
  - Classification uses "Random Decision Forest"
  - Better than 80% above 10 GeV for all channels but ν_μ^{CC}
  - Improvements with Deep Learning underway



Difference due to different inelasticities

Recap: Oscillation pattern to measure (ν_μ)

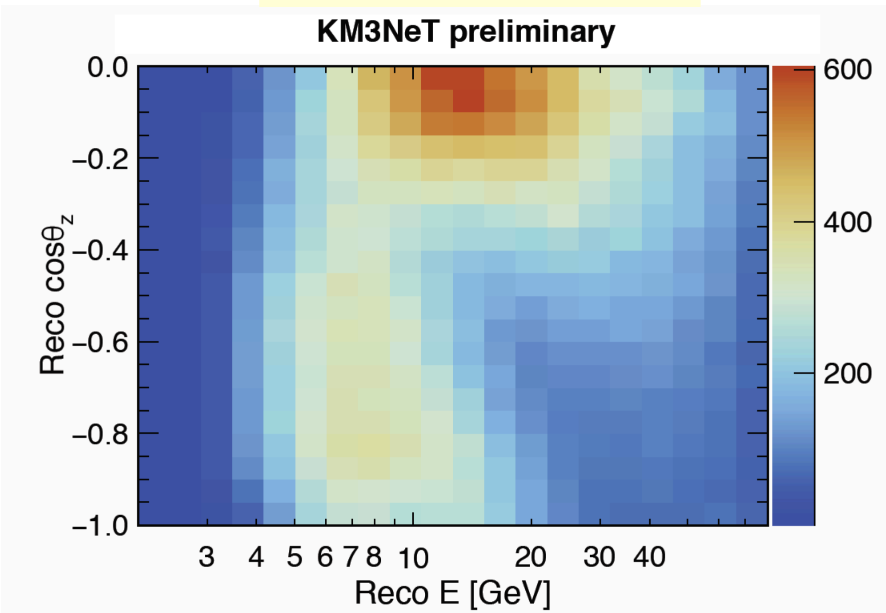


Detector effects will smear the pattern:
- Energy/Angular resolution
- Flavour identification

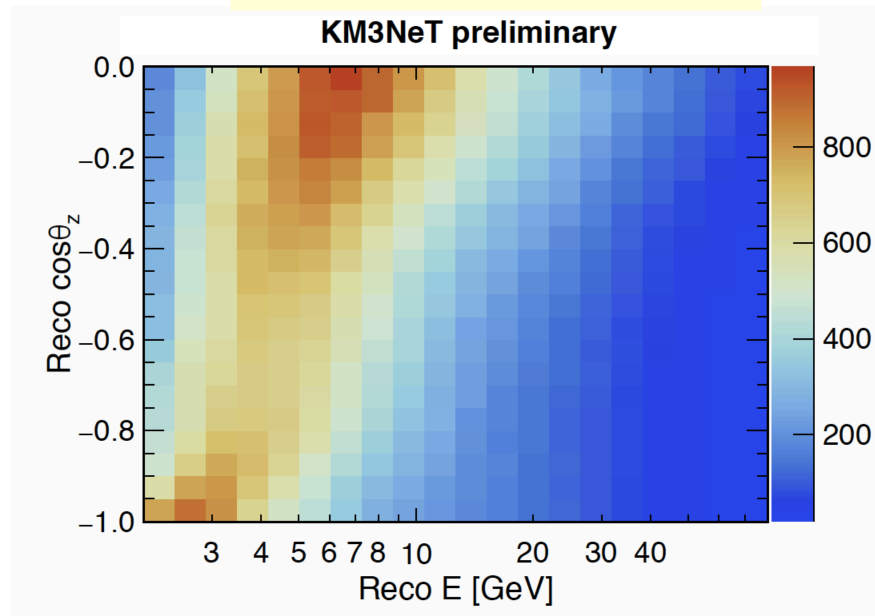
Reconstructed events

channel	events/y	channel	events/y
ν_e CC	14700	ν_τ CC	2900
$\bar{\nu}_e$ CC	5700	$\bar{\nu}_\tau$ CC	1300
ν_μ CC	21300	ν NC	5300
$\bar{\nu}_\mu$ CC	9900	$\bar{\nu}$ NC	1500

Classified as Track



Classified as Cascade

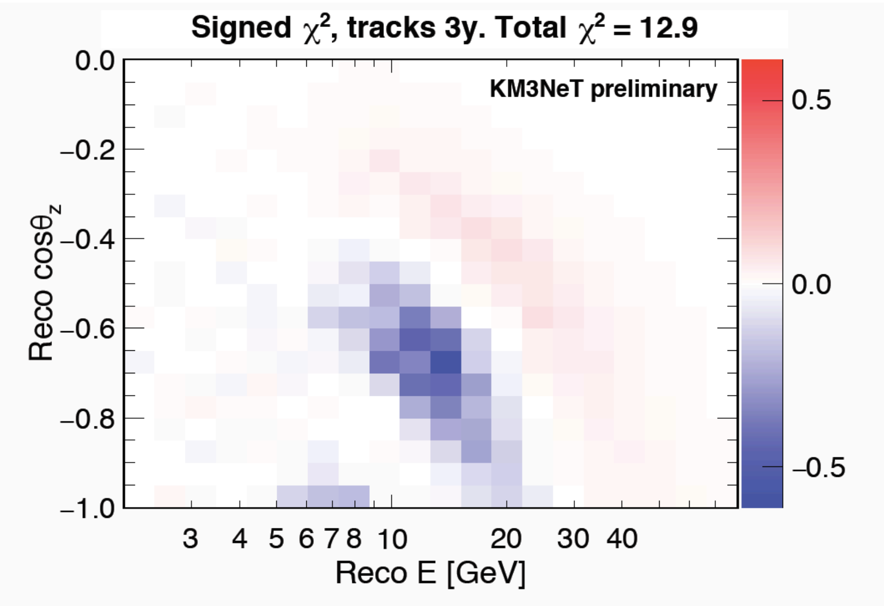


Event distribution for 3 years

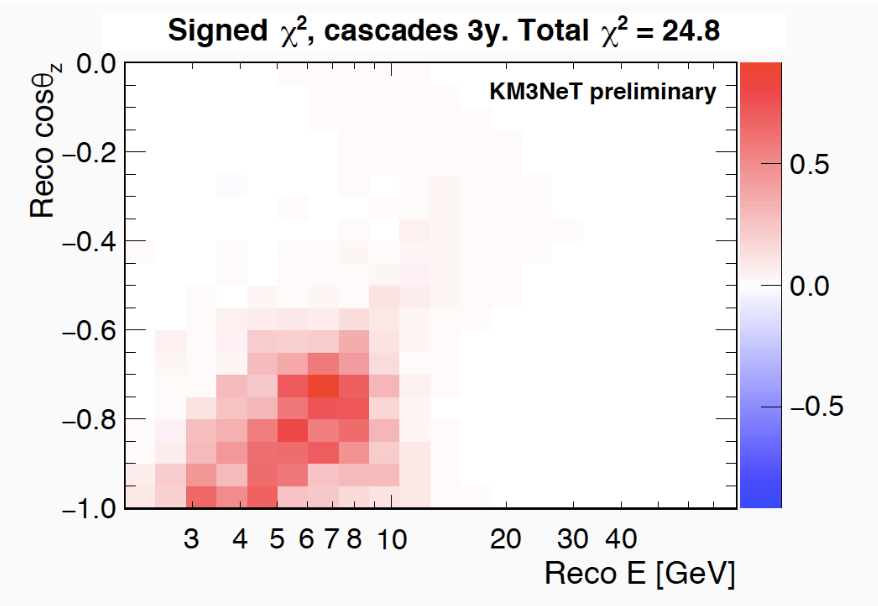
Asymmetry between NO and IO

$$\chi^2 = \frac{(N_{NO} - N_{IO})\,|N_{NO} - N_{IO}|}{N_{NO}}$$

Track-like events



Cascade-like events



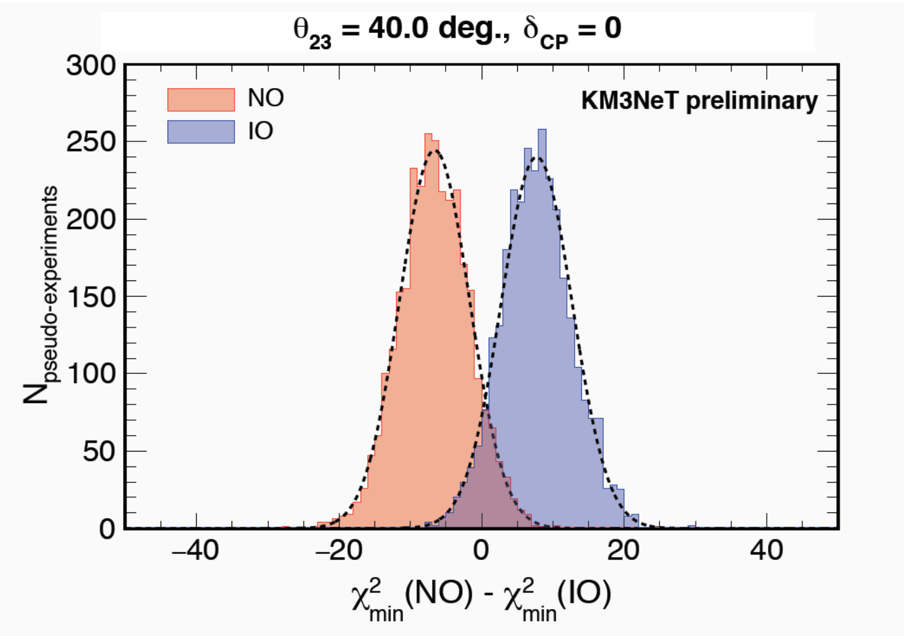
Cascades contribute most of sensitivity to the neutrino mass ordering

Sensitivity determination

To optimally distinguish between IH and NH:

Likelihood ratio test with nuisance parameters

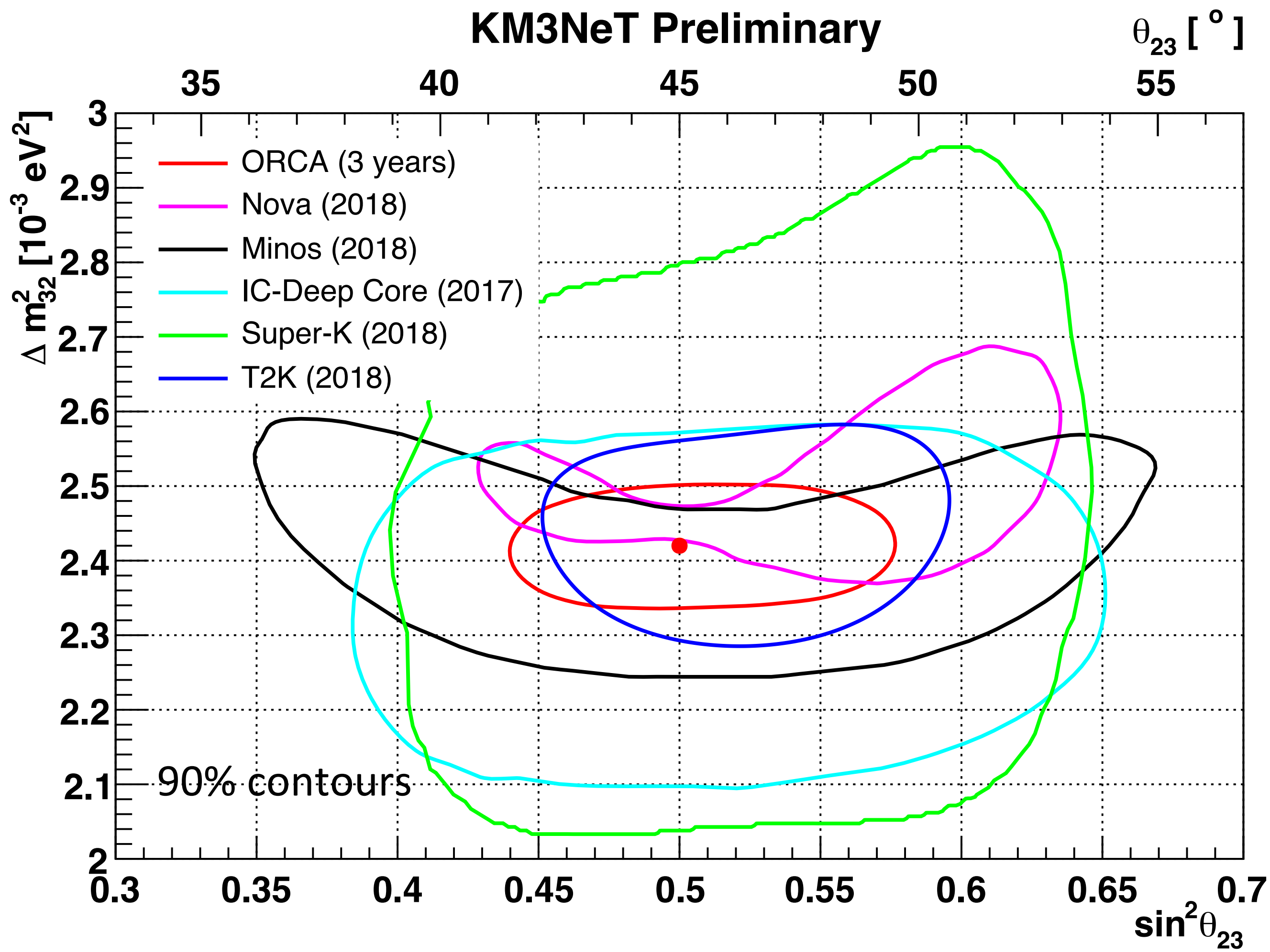
1) Create pseudo-experiments for given set of oscillation parameters
2) Fit parameters assuming NH
3) Fit parameters assuming IH
4) Evaluate Test statistics distribution: $\chi 2_{NO} - \chi 2_{IO}$



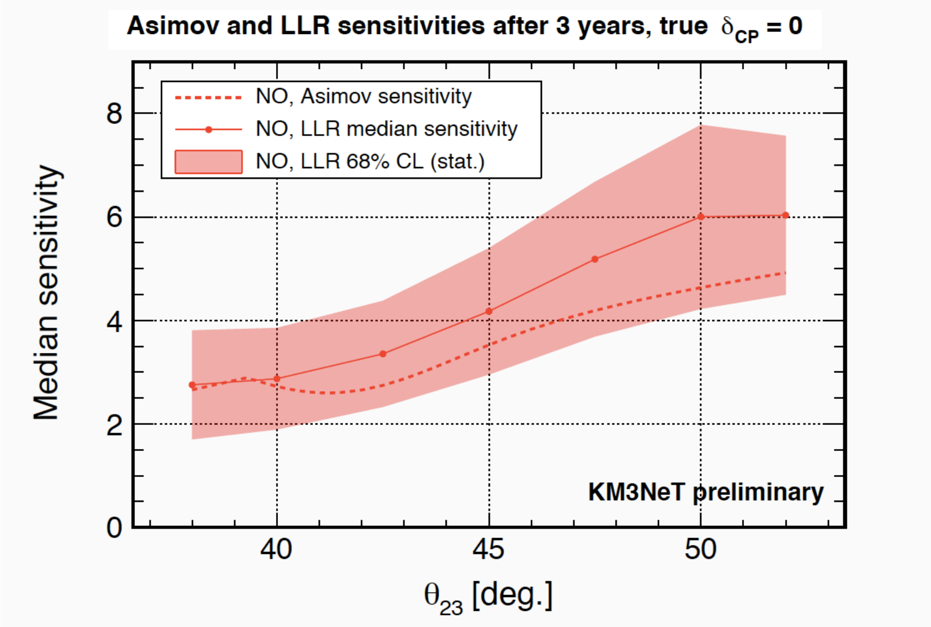
Systematics

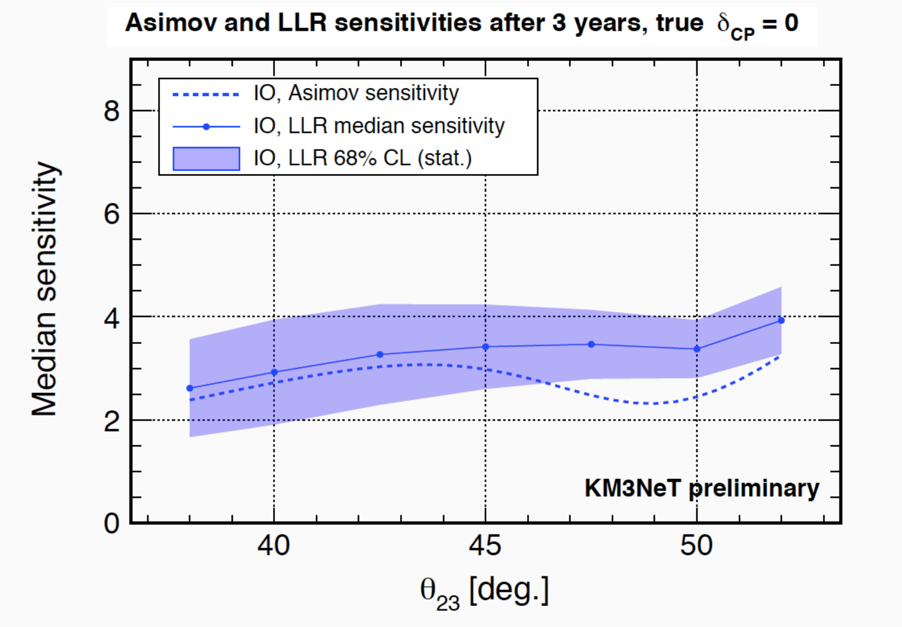
		true value	constraint
$\lvert\Delta M^2\rvert$ (eV^2)	fitted	$2.48\ 10^{-3}$	free
$\lvert\Delta m_{21}{}^2\rvert$($eV^2$)	fix	$8.53\ 10^{-5}$	-
θ_{13}(°)	fitted	8.42	0.26
θ_{12}(°)	fix	33.4	-
θ_{23}(°)	fitted	38-52	free
δ_{CP}	fitted	$0,2\pi$	free
Flux spectral index	fitted	0	free
ν/ν skew	fitted	0	0.03
Tracks normalization	fitted	1	free
Cascades normalization	fitted	1	free
NC events normalization	fitted	1	0.1

Constraints on oscillation parameters



Asimov ($\Delta\chi 2$) and LLR sensitivities as function of θ_{23}

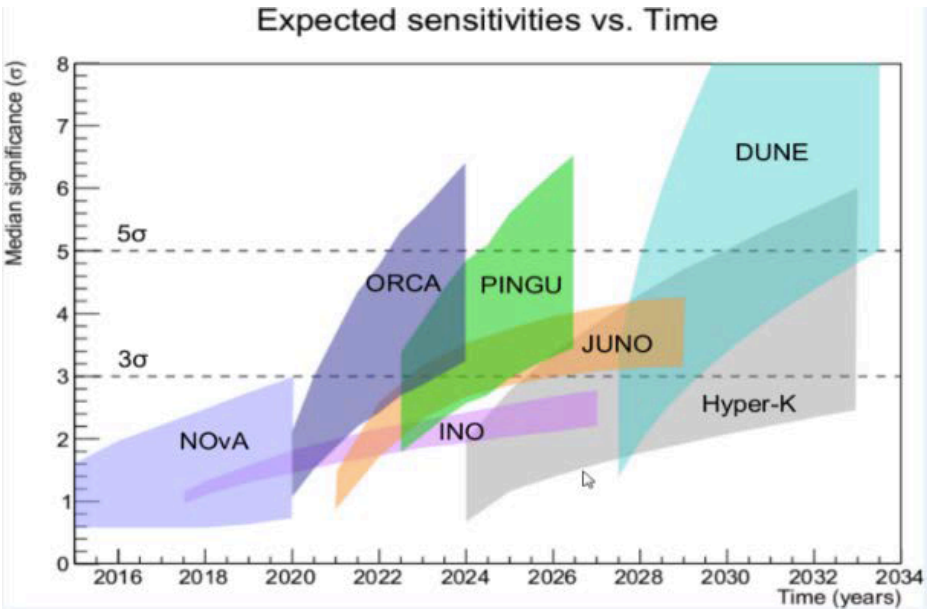




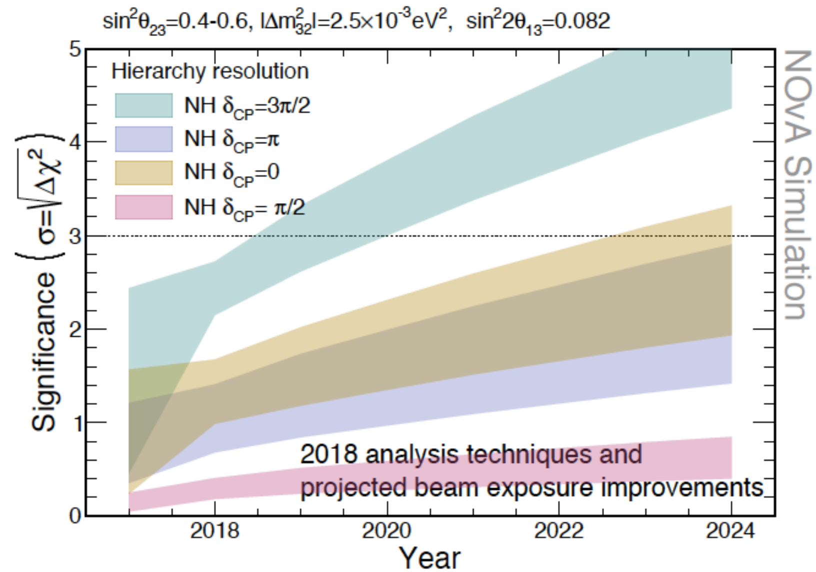
Fit in 2 'flavour' bins (track/shower), no separation by inelasticity
⇒ Improvements expected by increasing number of bins
(e.g. flavour 'probability', inelasticity, energy resolution, …)

2-6σ median sensitivity after 3 years depending on oscillation parameters
⇒ External constraints on oscillation parameters can help improving the sensitivity

Timelines (to be updated)



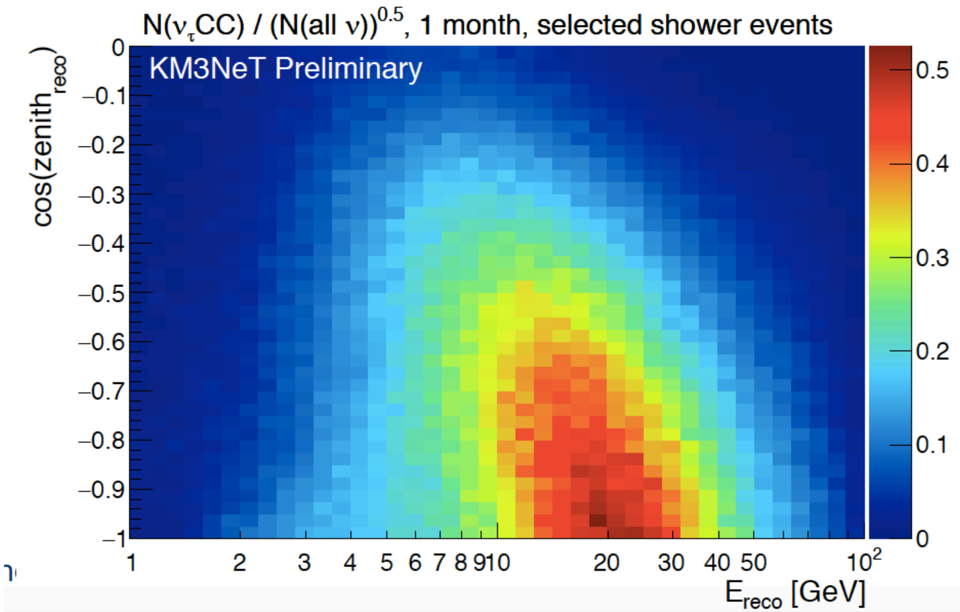
NOVA

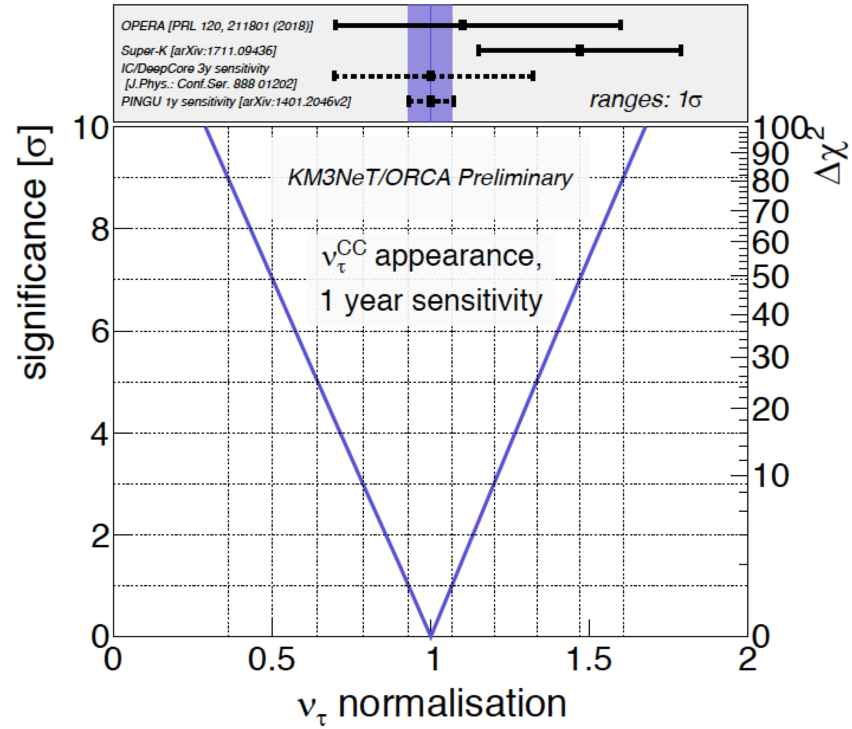


Currently NOVA: 1.8σ preference for NO and θ_{23} upper octant

For normal hierarchy 3σ for > 30% of true δ values by 2024

ν_τ appearance

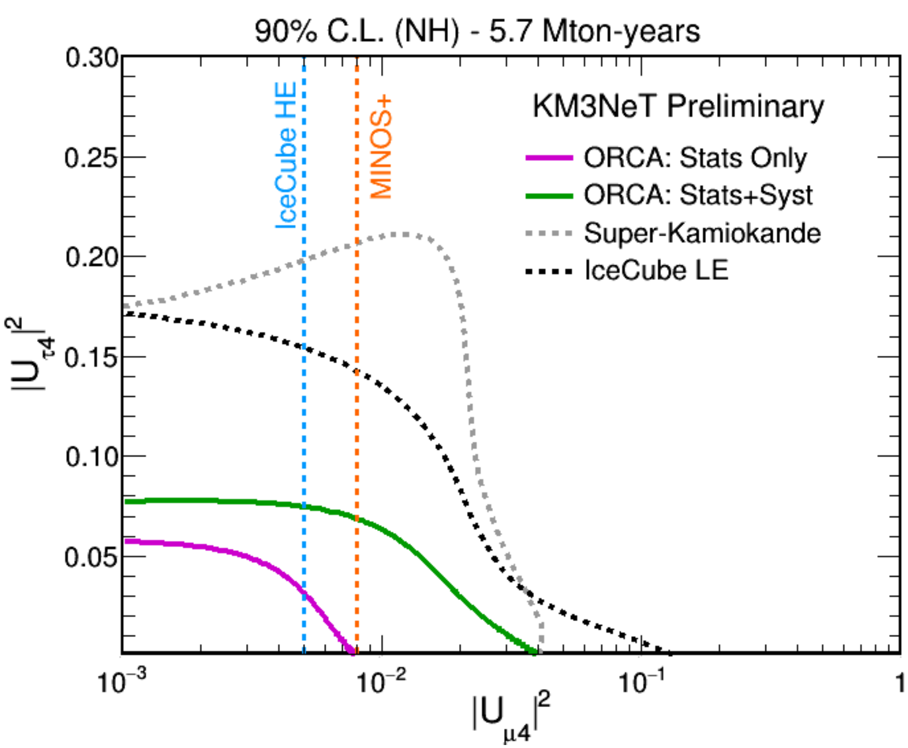


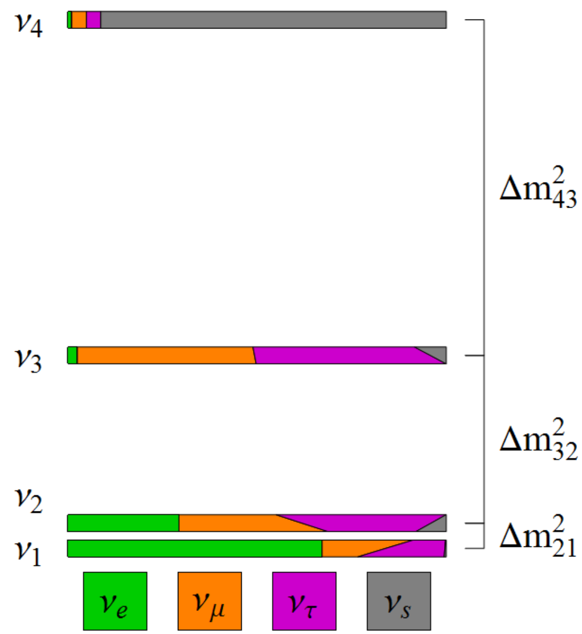


- Flux normalisation constrained (3σ) within 20% after 1 year
- Exclusion of 20% deviation from expected standard model flux normalisation with 5σ after 3 years

Sterile neutrinos

- Adding eV scale sterile neutrino
  => **suppression of $\nu_\mu \rightarrow \nu_\tau$ oscillation** at ~20 GeV
- With 1 year of data ORCA is sensitive to $|U_{\tau 4}|^2$ values smaller than current limits set by SK





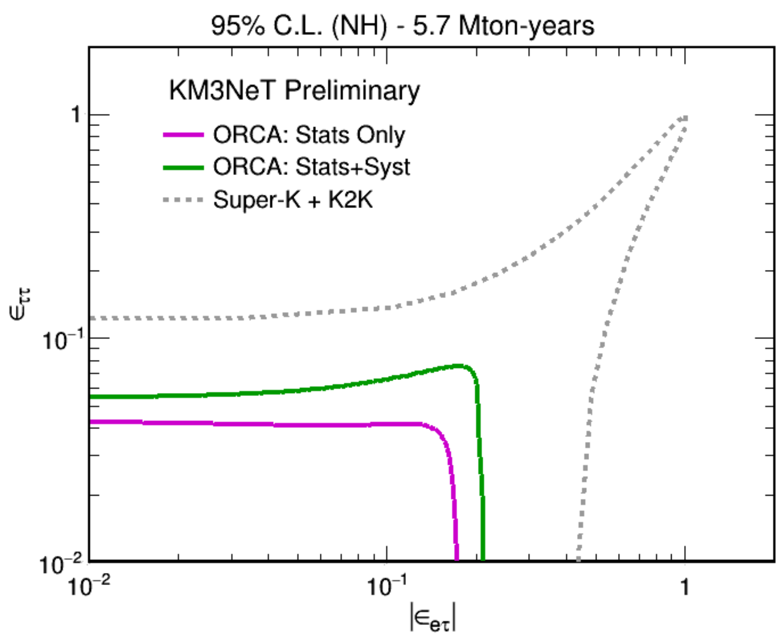
- Fitted: 4 syst. + 2 osc. (θ_{23}, ΔM^2)
- $U_{e4} = 0$

Non-Standard Interactions (NSI)

$$\begin{pmatrix} |\varepsilon_{ee}| < 4.2 & |\varepsilon_{e\mu}| < 0.33 & |\varepsilon_{e\tau}| < 3.0 \\ & |\varepsilon_{\mu\mu}| < 0.068 & |\varepsilon_{\mu\tau}| < 0.33 \\ & & |\varepsilon_{\tau\tau}| < 21 \end{pmatrix}$$

Rept. Prog. Phys. 76, 044201 (2013)

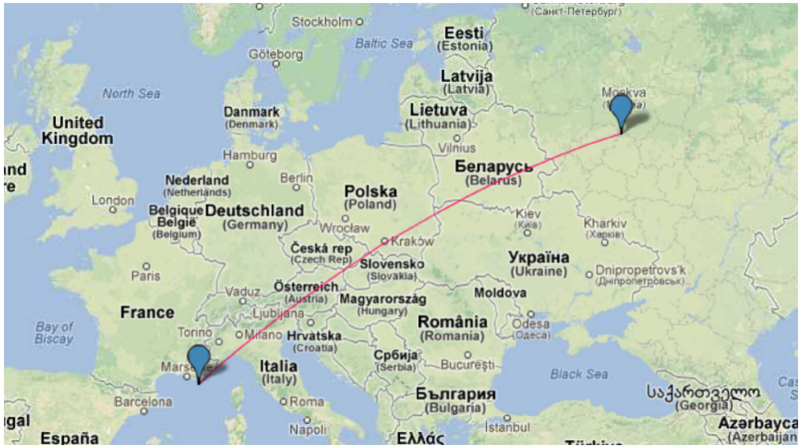
With only 1 year of data, ORCA sensitive to NSI effects below these limits:



- Fitted: 4 syst. + 2 osc. (θ_{23}, ΔM^2)
- 95% C.L. in ($|\varepsilon_{ee}|$, $|\varepsilon_{e\tau}|$, $|\varepsilon_{\tau\tau}|$) space
  → 2D projection for $|\varepsilon_{ee}| = 0$
- SK + K2K limits from *arXiv:0506143*

Beam option for ORCA

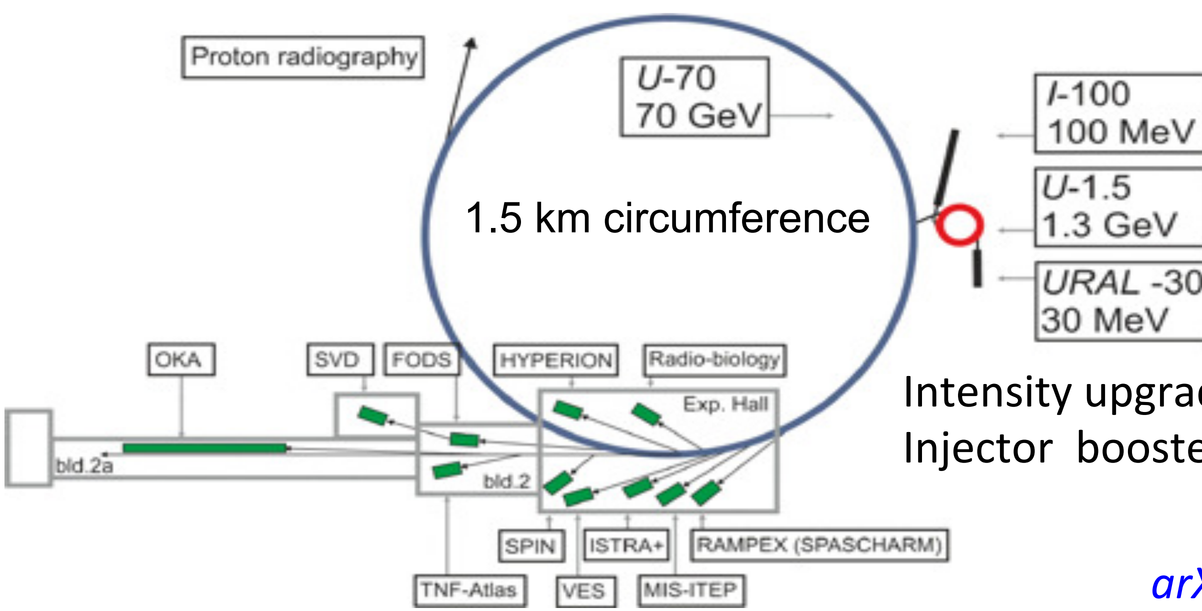
Neutrino Beam: Protvino – ORCA (P2O)



IHEP/Protvino, founded 1967
100km South of Moscow

Baseline 2588km
Beam inclination : 11.7˚ ($\cos\theta = 0.2$)

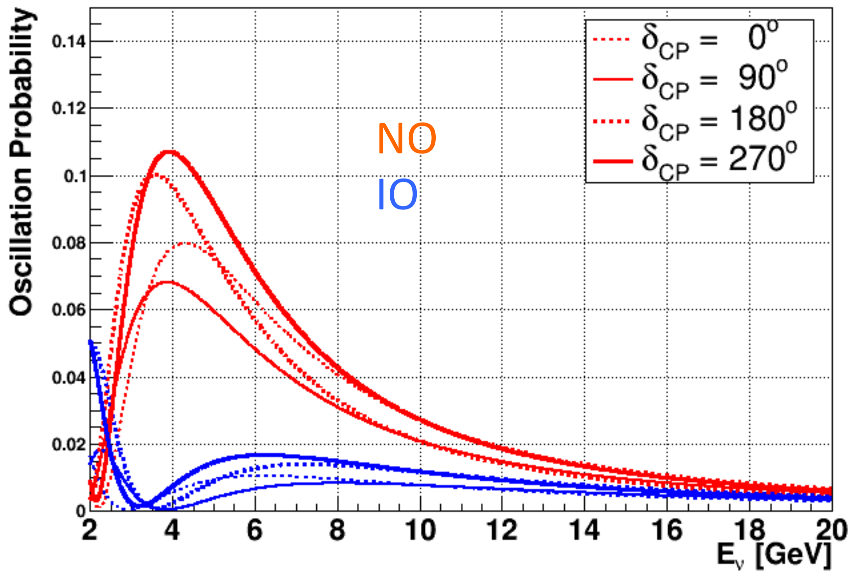
First meetings at the site with KM3NeT delegation
At VLVNT 2018 (1-4 October in Dubna) further planning for future steps



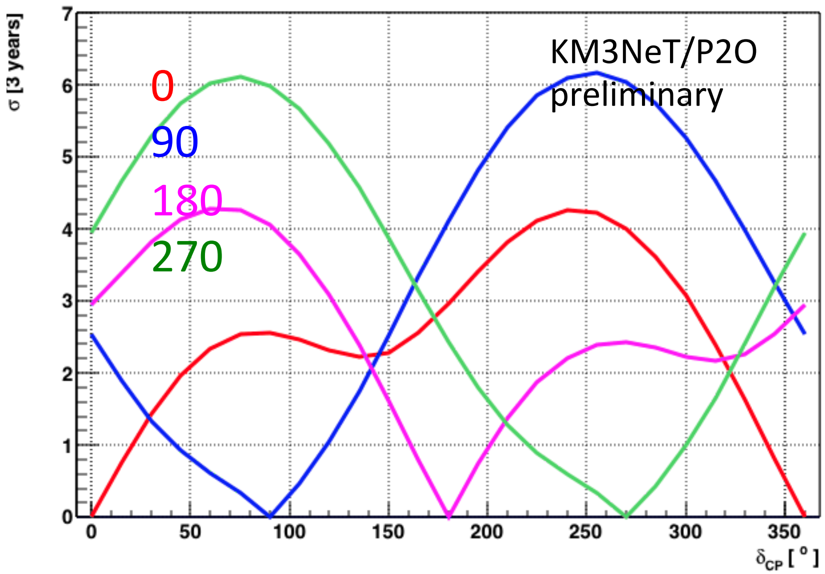
Intensity upgrade 15kW->90kW
Injector booster ->450kW

arXiv:1803.08017

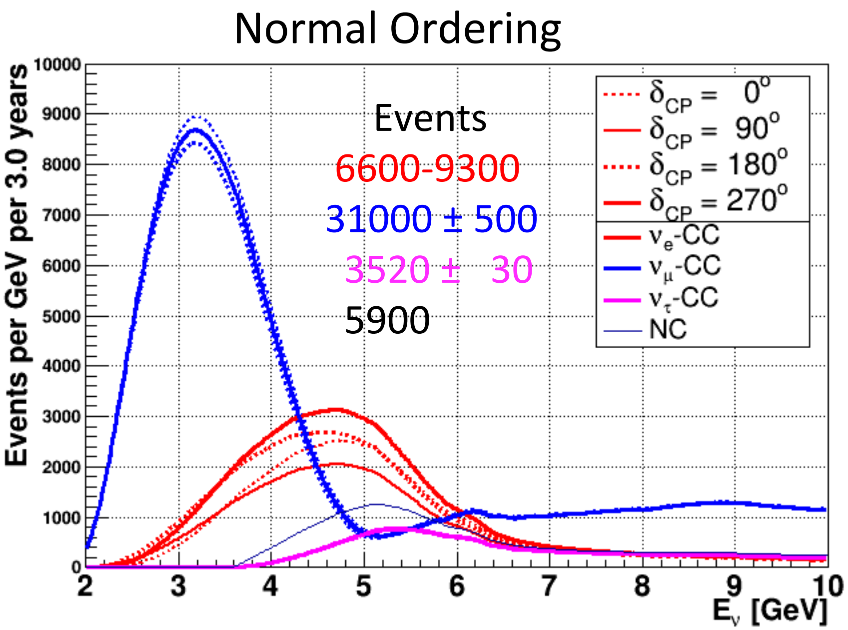
$P(\nu_\mu \rightarrow \nu_e)$

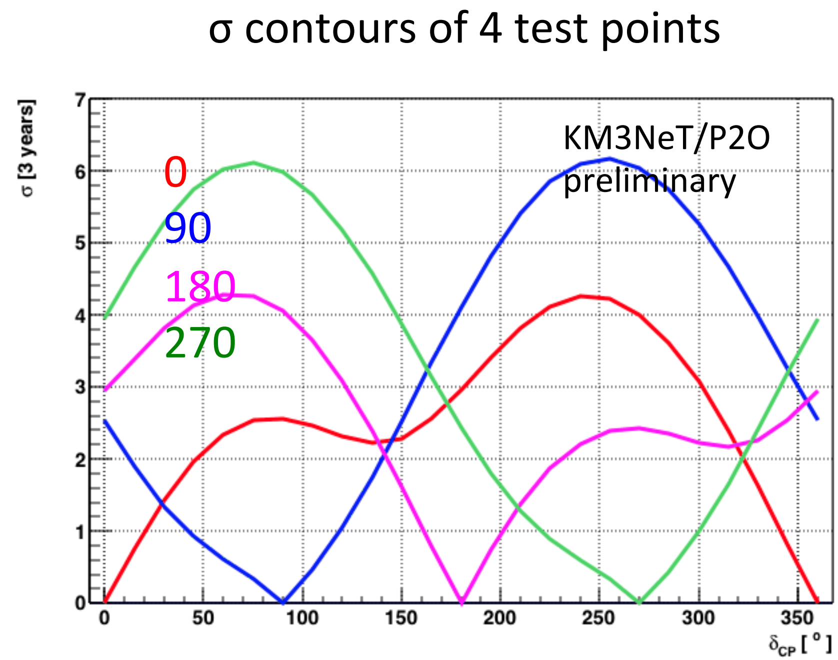


σ contours of 4 test points



- Both Neutrino Mass Hierarchy and CP violation accessible
- No degeneracies, small cross section systematics
- After 6 years non CP-violation excluded for 35% of δ_{CP} values at about 3σ
- High precision measurement of δ_{CP} within few years (with 450kW)





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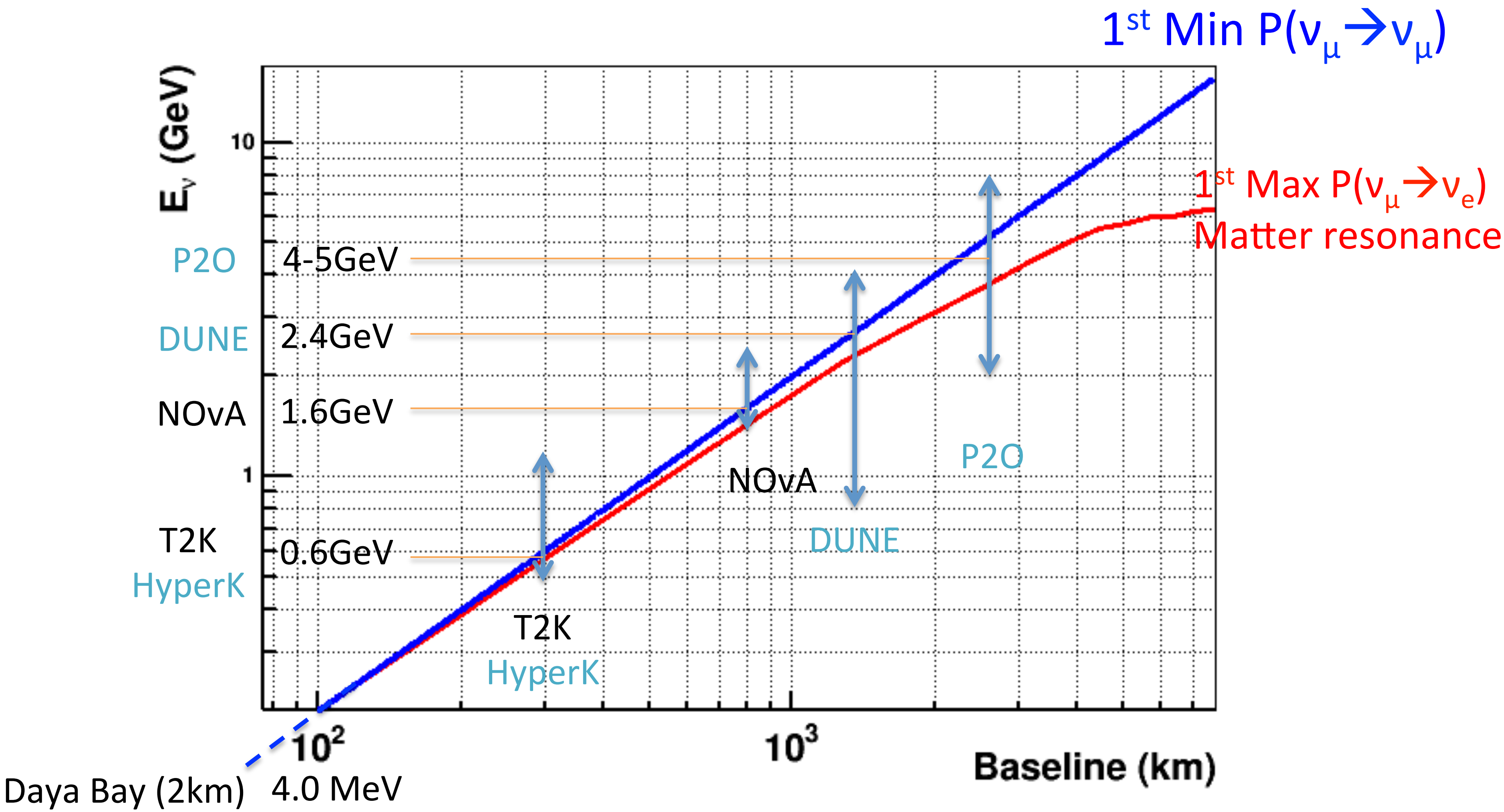
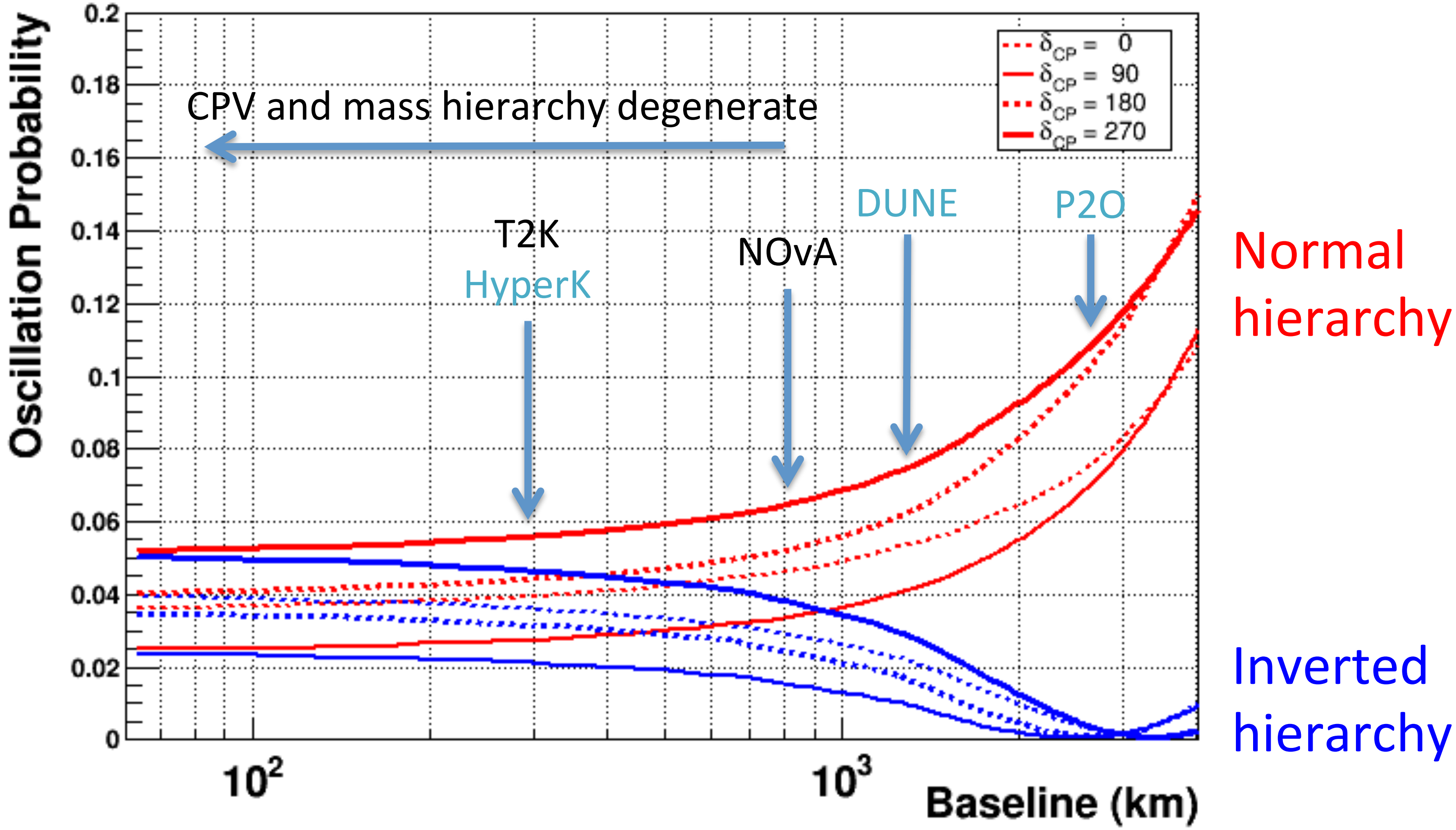
- High precision measurement of δ_{CP} within few years

Comparison of Long Baseline Projects



Comparison of Long Baseline Projects

Main Signal : Appearance of ν_e : $P(\nu_\mu \rightarrow \nu_e)$

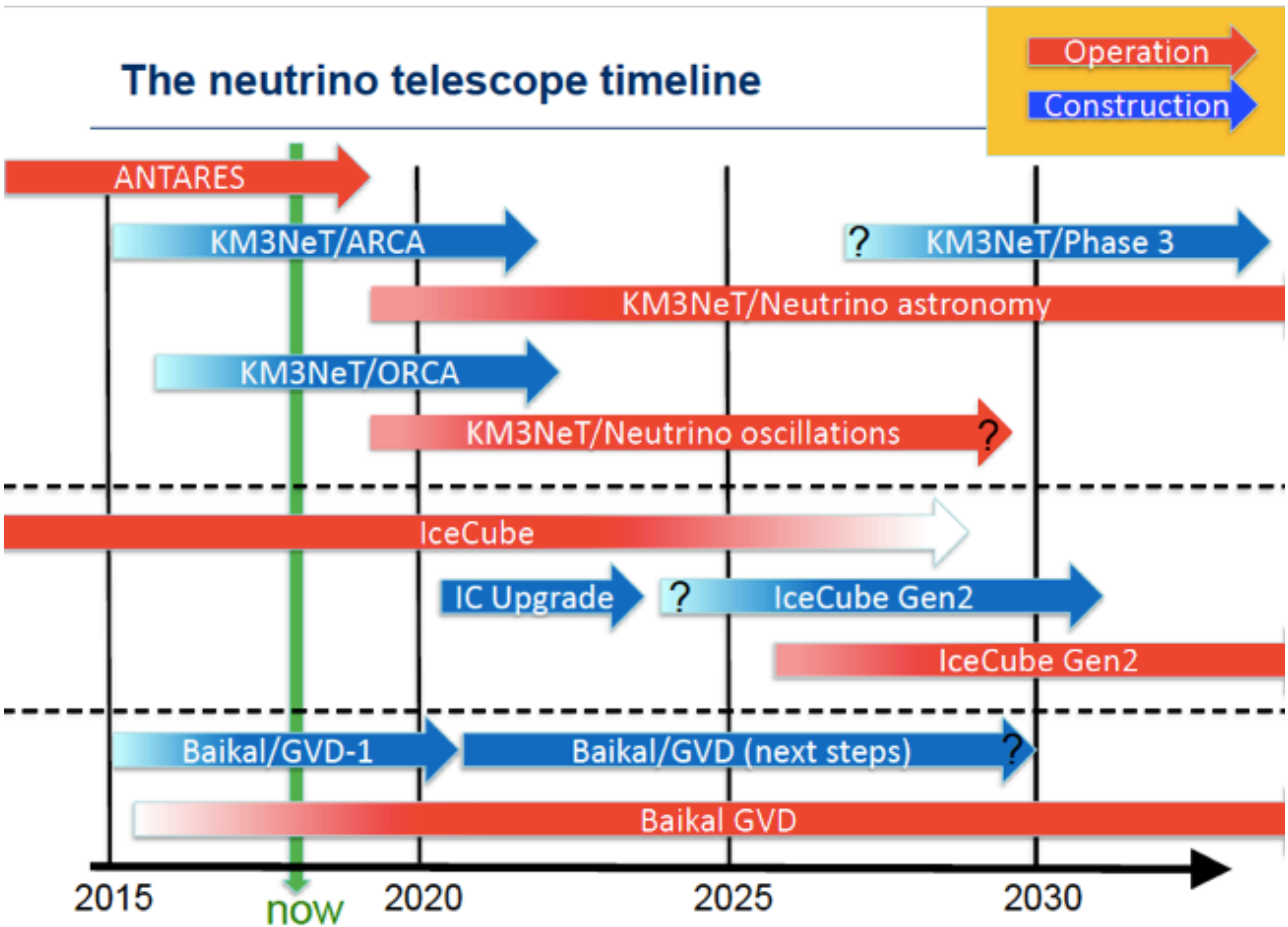


Summary

- Construction of the KM3NeT detector started

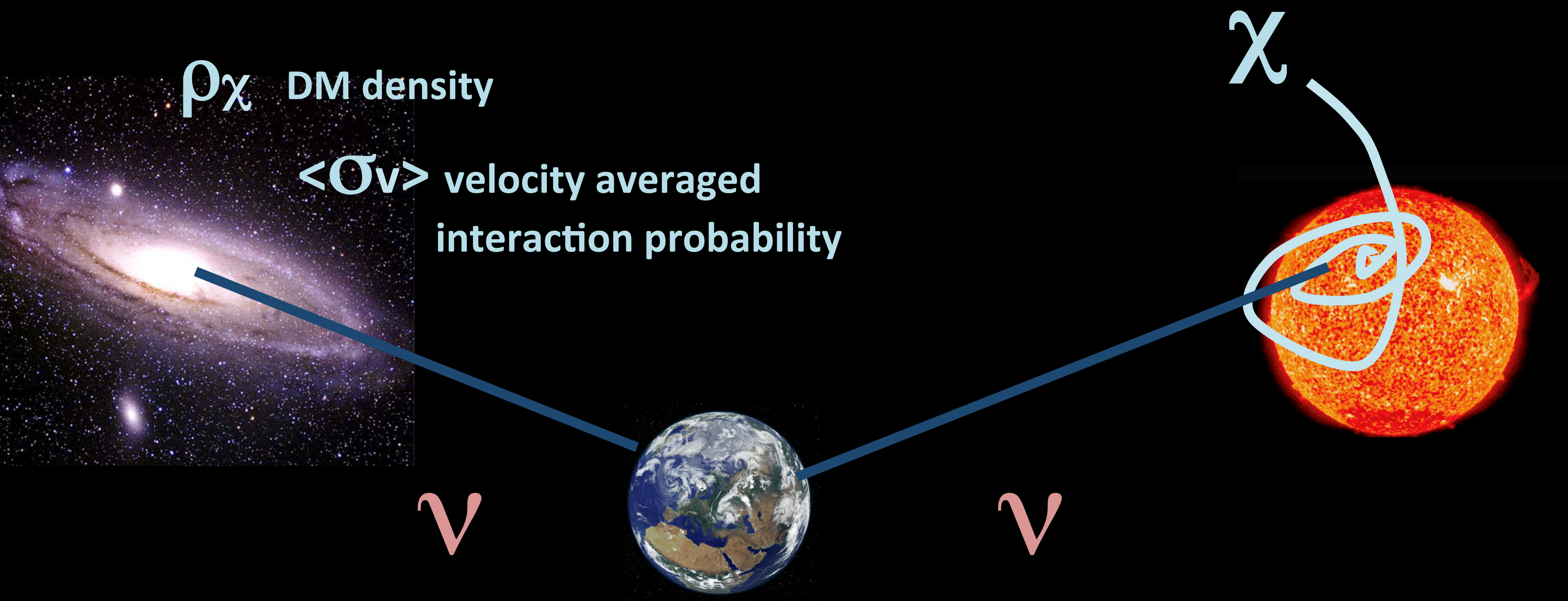
- Good prospects for measurements of neutrino mass ordering on competitive time scale and to detect cosmic neutrino sources

- KM3NeT will offer new options to explore many further topics
  - Galactic Supernovae, Dark Matter, Non-standard interactions, Earth tomography, surprises …


The neutrino telescope timeline
Operation
Construction
ANTARES
KM3NeT/ARCA
? KM3NeT/Phase 3
KM3NeT/Neutrino astronomy
KM3NeT/ORCA
KM3NeT/Neutrino oscillations ?
IceCube
IC Upgrade
? IceCube Gen2
IceCube Gen2
Baikal/GVD-1
Baikal/GVD (next steps) ?
Baikal GVD
2015
now
2020
2025
2030

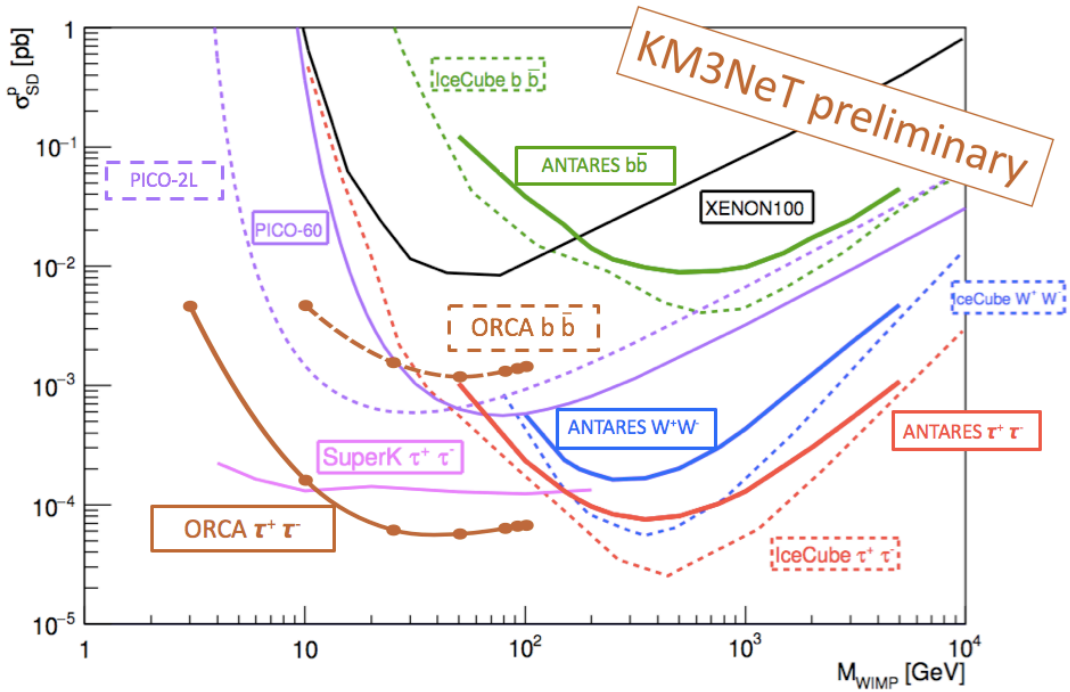
Search for Dark Matter

Dark Matter particles accumulate in heavy objects (Sun, Galactic Center, Earth)
→ Annihilation will produce 'standard' particles -> decays produce neutrinos



Dark Matter

Sensitivity on cross section vs mass of WIMP

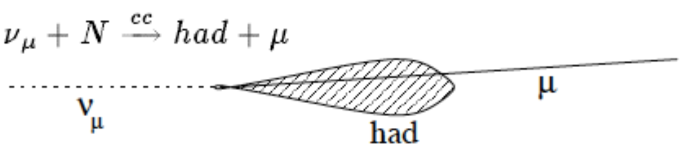


Competitive for Spin Dependent coupling

Reconstruction Methods

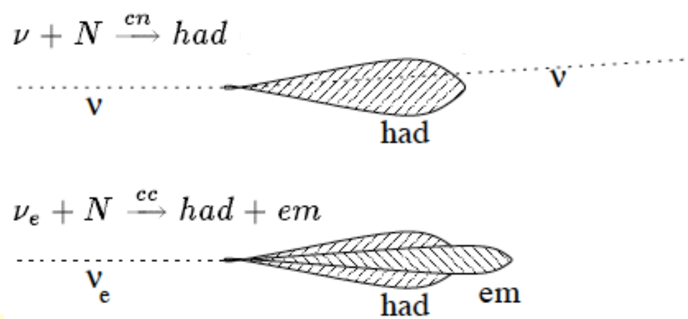
Different flavours and interactions lead to different signatures in the detector

ν_μ^{CC}



Energy loss ~0.2GeV/m -> 50m length for 10 GeV

ν_X^{NC}
$\nu_{e/\tau}^{CC}$



- Dedicated reconstruction methods for tracks and cascades
- 8 parameters are determined:
  Time, position (3), direction (2), energy, inelasticity
- Step by step procedure
  - Hit selection (time correlations)
  - Vertex & Directional fit (timing)
  - Energy & inelasticity fit (light yield & direction/vertex)

Share of costs