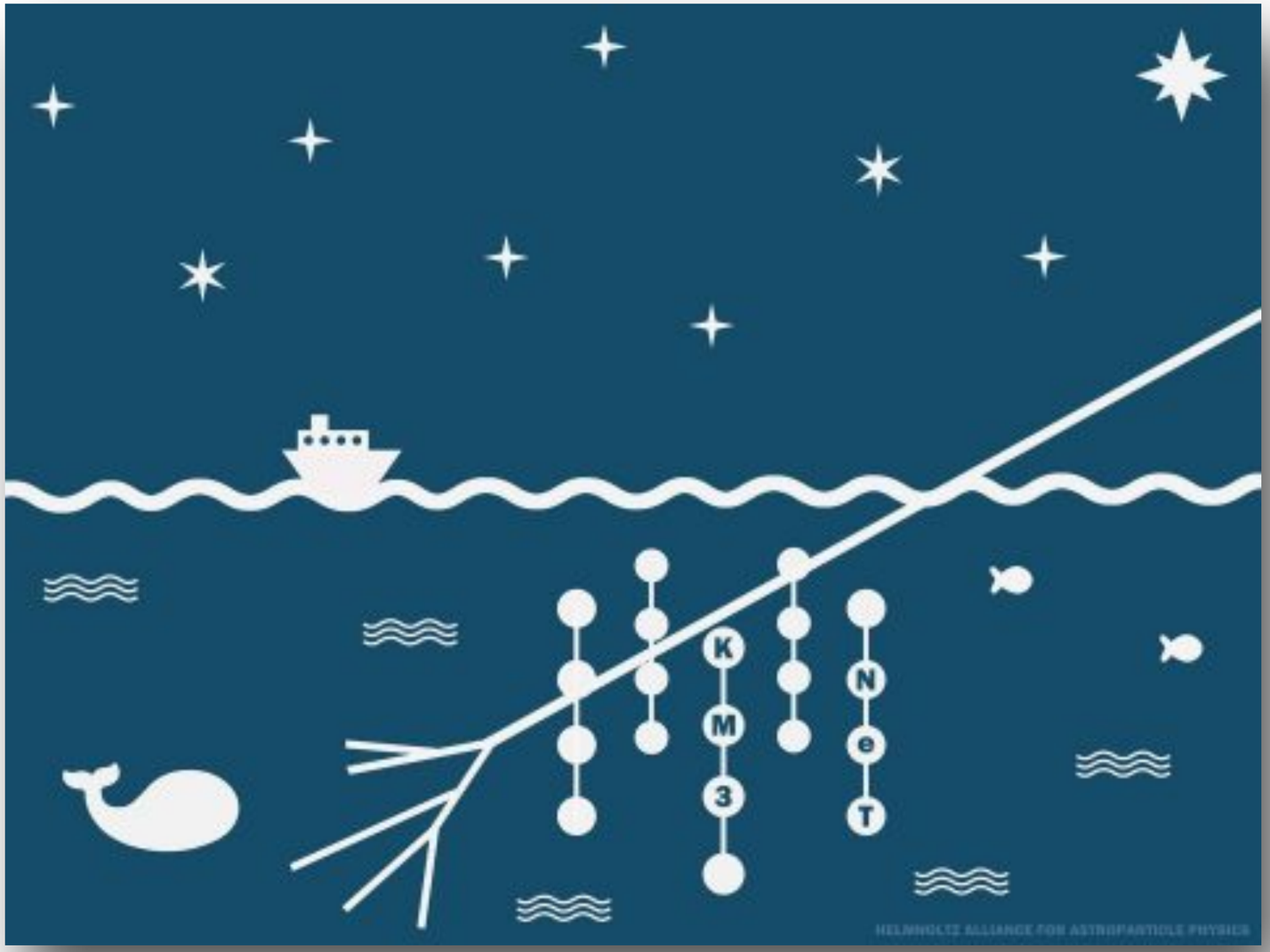
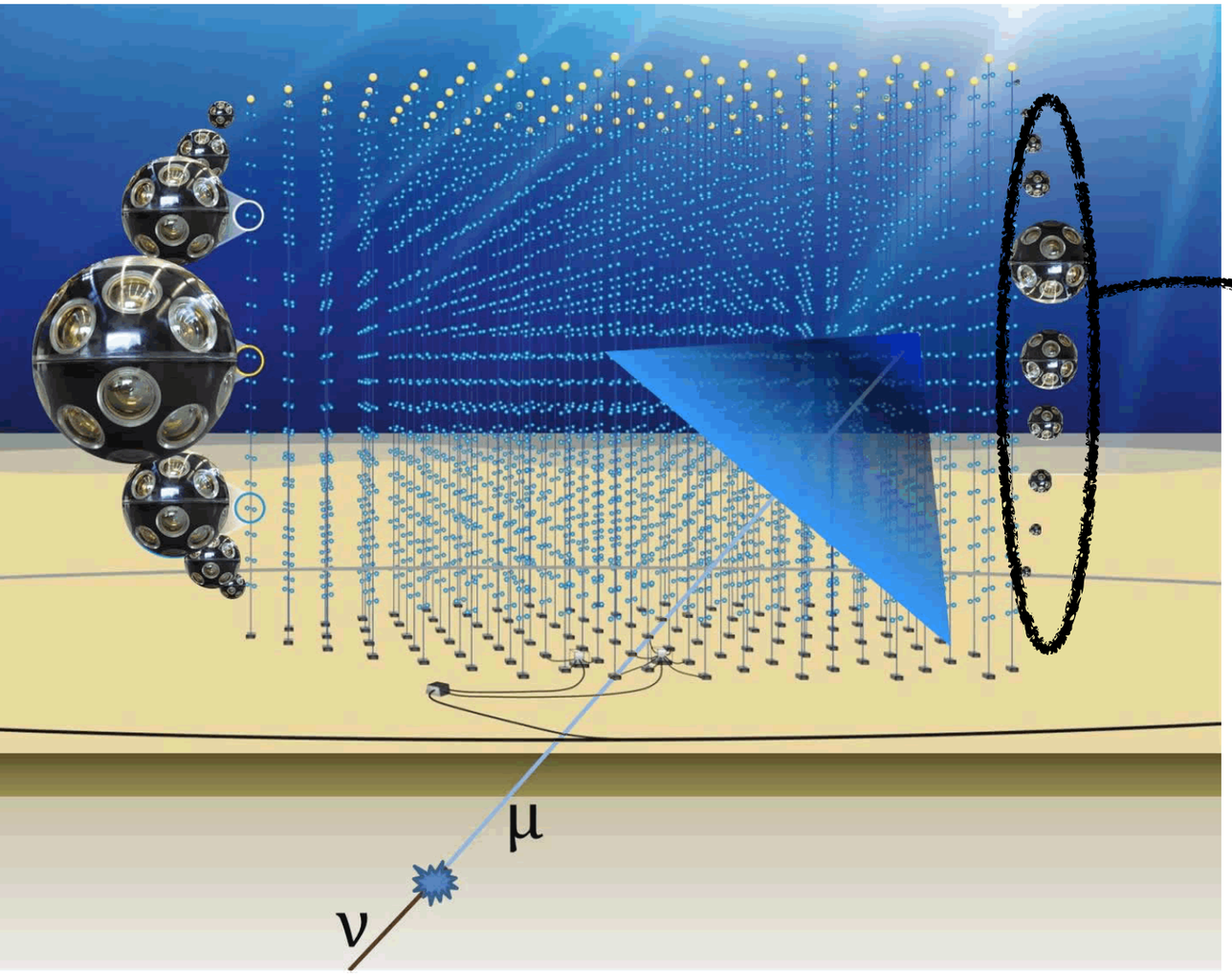
Particle Physics with ORCA



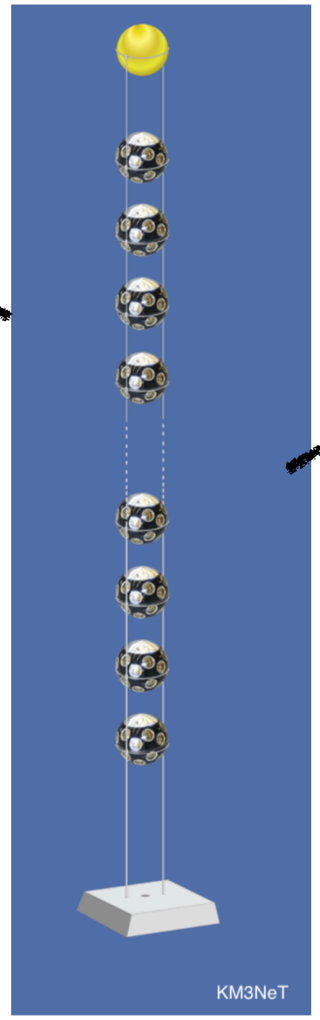
A. Domi

VLVnT Conference 2018, Dubna

ORCA & ARCA Detection Technology



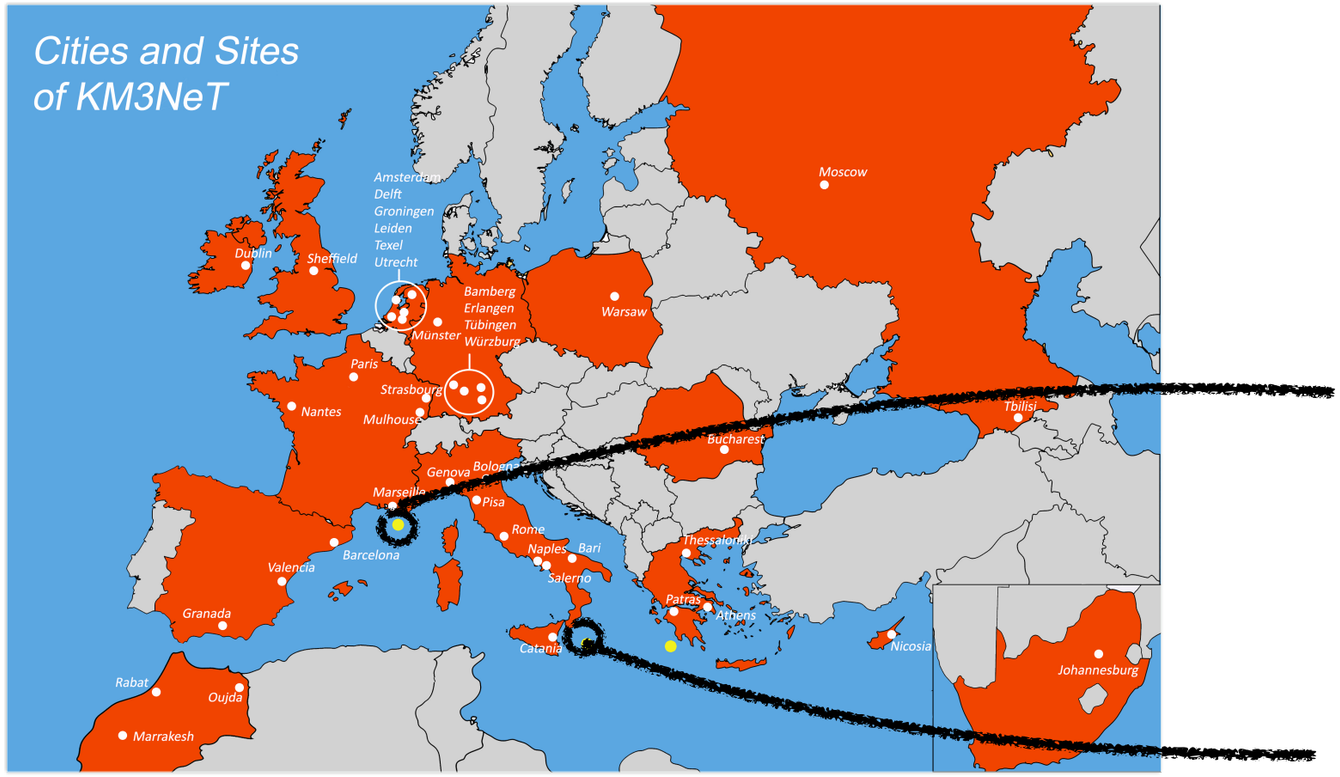
3 Building Blocks (BB):
1 BB for ORCA, 2 BBs for ARCA
115 Detection Units (DUs) per BB

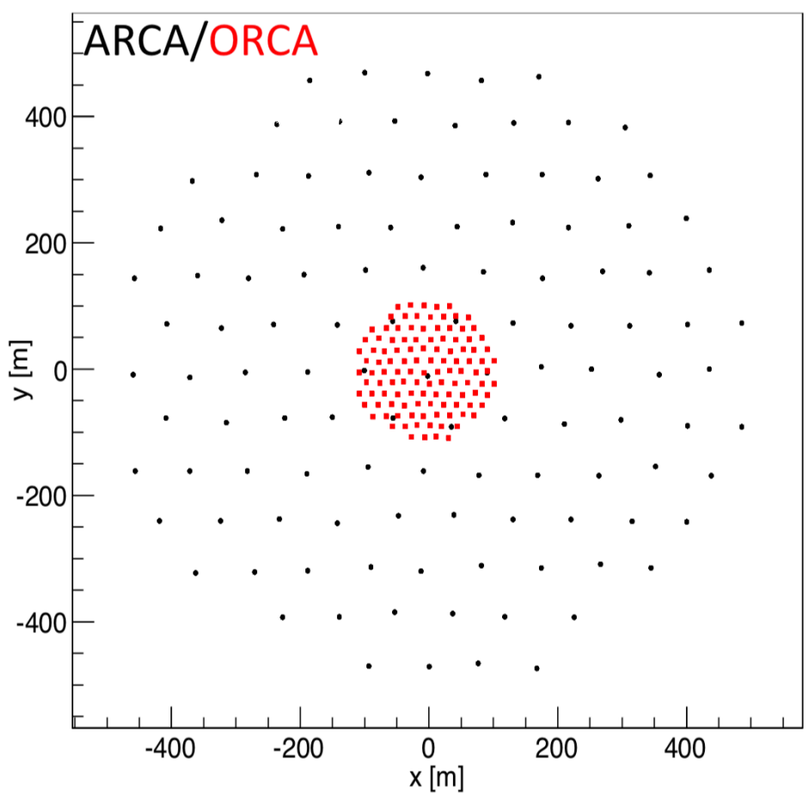


DU: 18 DOMS
ORCA - h 200 m
ARCA - h 700 m

DOM: 31 PMTs 3"

ORCA/ARCA DETECTORS





ORCA:

DENSE BUILDING BLOCK OPTIMISED FOR INTERMEDIATE ENERGIES (1-100 GEV)

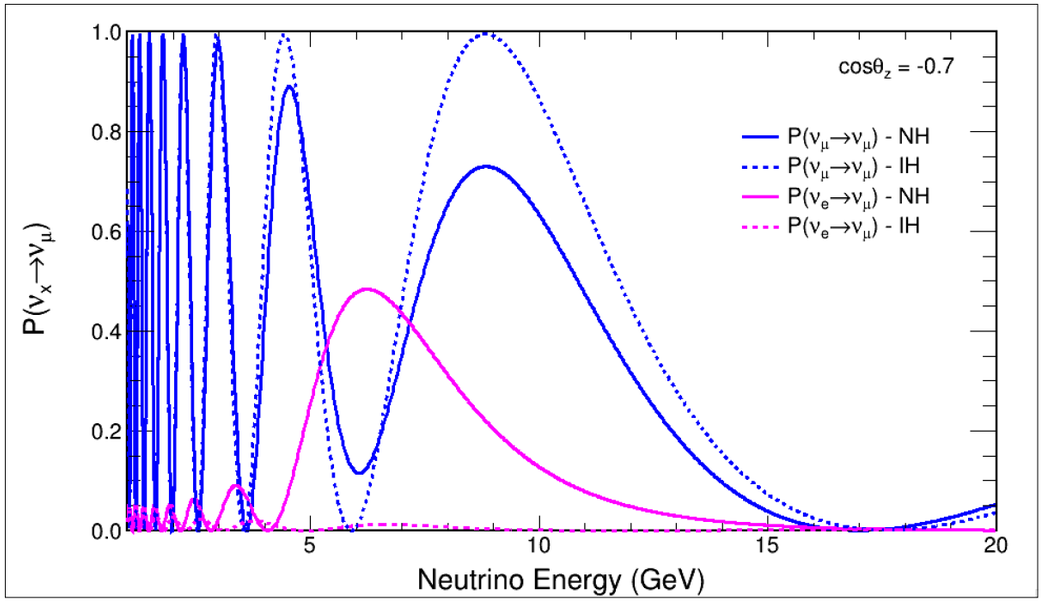
TOTAL OF 64170 PMTS

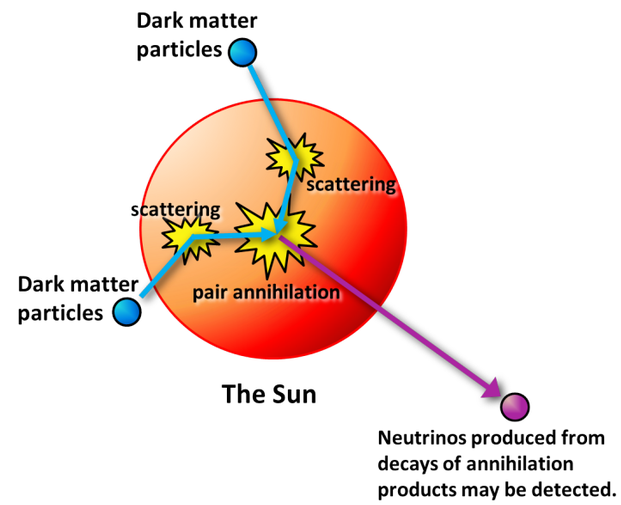
ARCA:

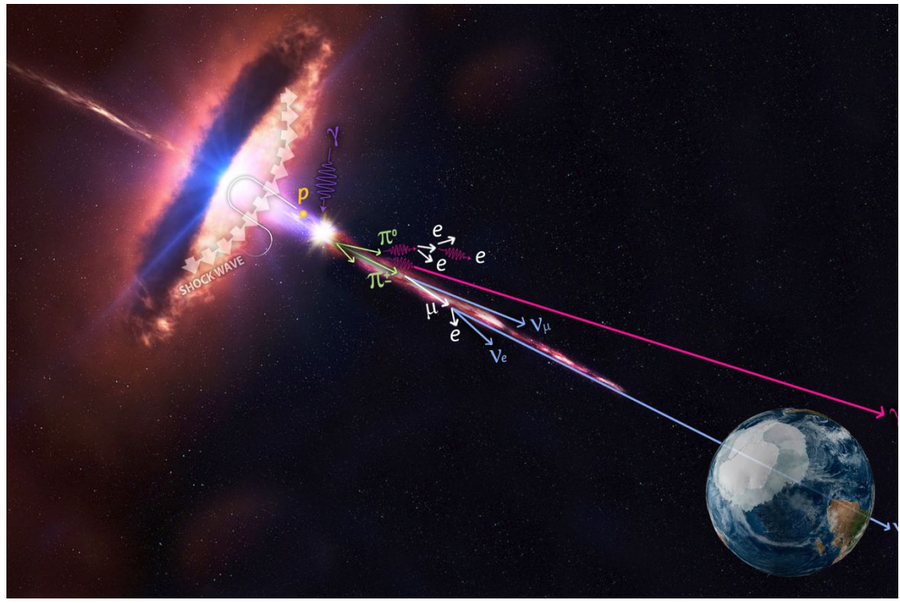
SPARSE BUILDING BLOCKS OPTIMISED FOR HIGH ENERGIES (>1 TEV)

	ORCA	ARCA
String spacing	23 m	90 m
Vertical spacing	9 m	36 m
Depth	2470 m	3500 m
Instrumented mass	1x 8 Mton	2x 0.6 Gton

ARCA & ORCA Science Scope



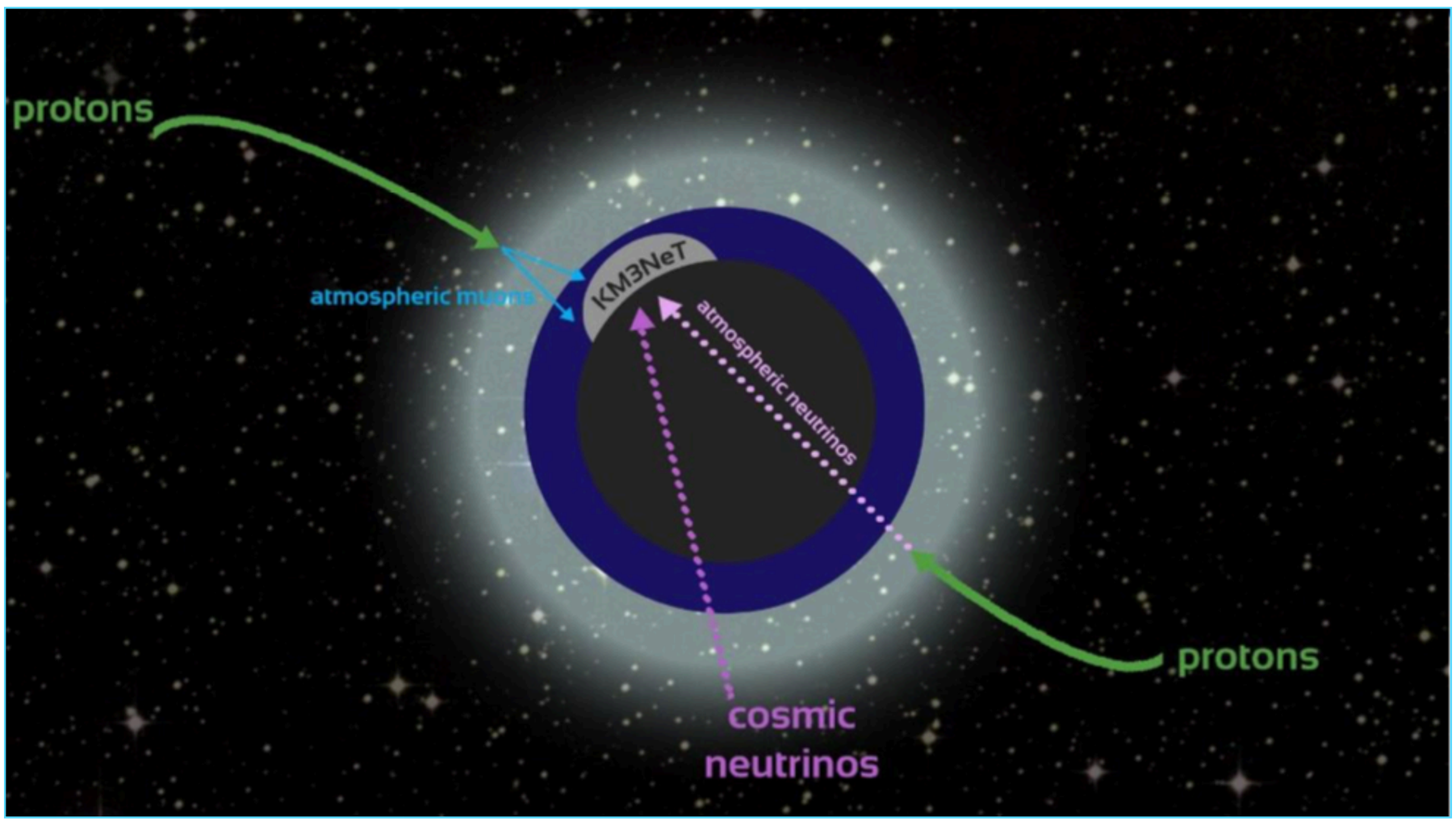




Low Energy:	Intermediate Energy:	High Energy:
MeV < E_ν < 100 GeV	10 GeV < E_ν < 1 TeV	E_ν > 1 TeV
ν oscillations, Supernovae…	Dark Matter search, Monopoles…	ν from extra-terrestrial sources…
KM3NeT/ORCA	KM3NeT/ORCA+ARCA	KM3NeT/ARCA

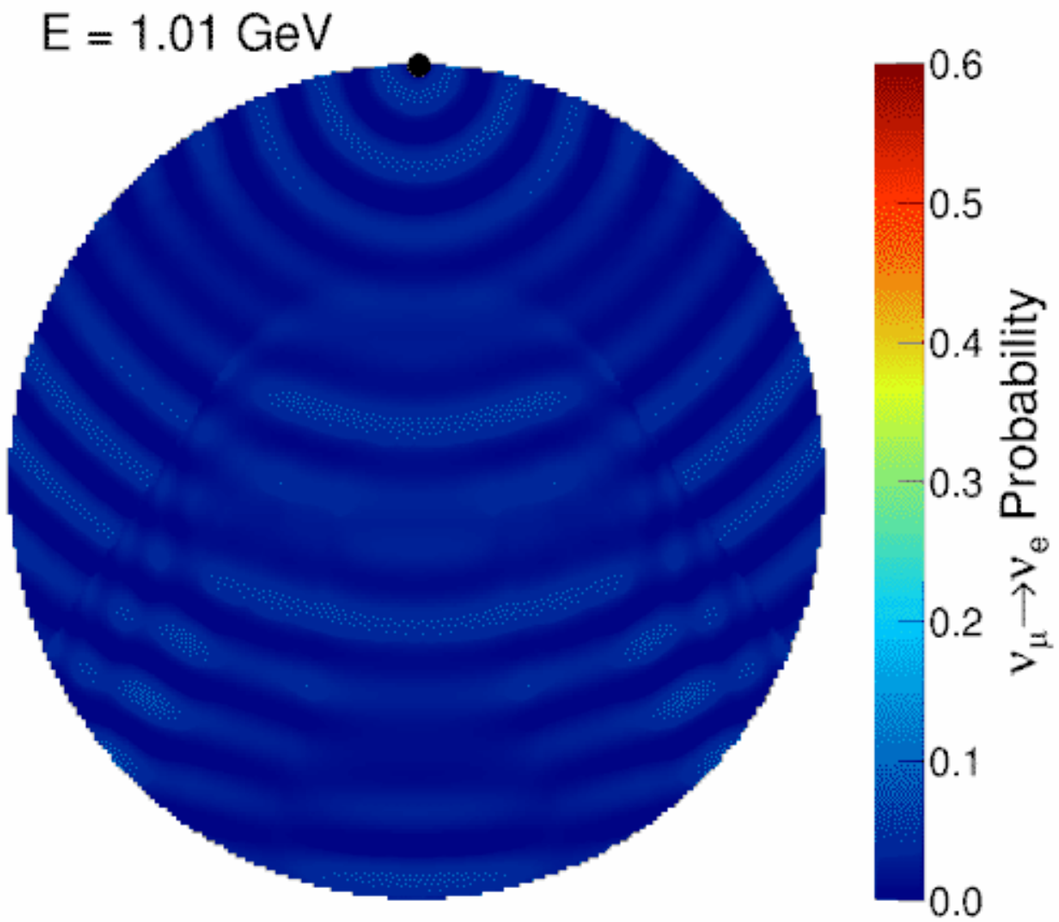
Measure of Mass Ordering

- **Source:** Atmospheric neutrinos.
  - Free, natural beam of known composition (HKKM 2014 flux).



Measure of Mass Ordering

- ν_e interaction with electrons.
- Oscillation pattern distorted by Earth's matter effects:
  - Resonance in the oscillation probabilities in the few-GeV range.
  - **Earth Model:** PREM Model [1] with 42 layers and realistic Z/A values.

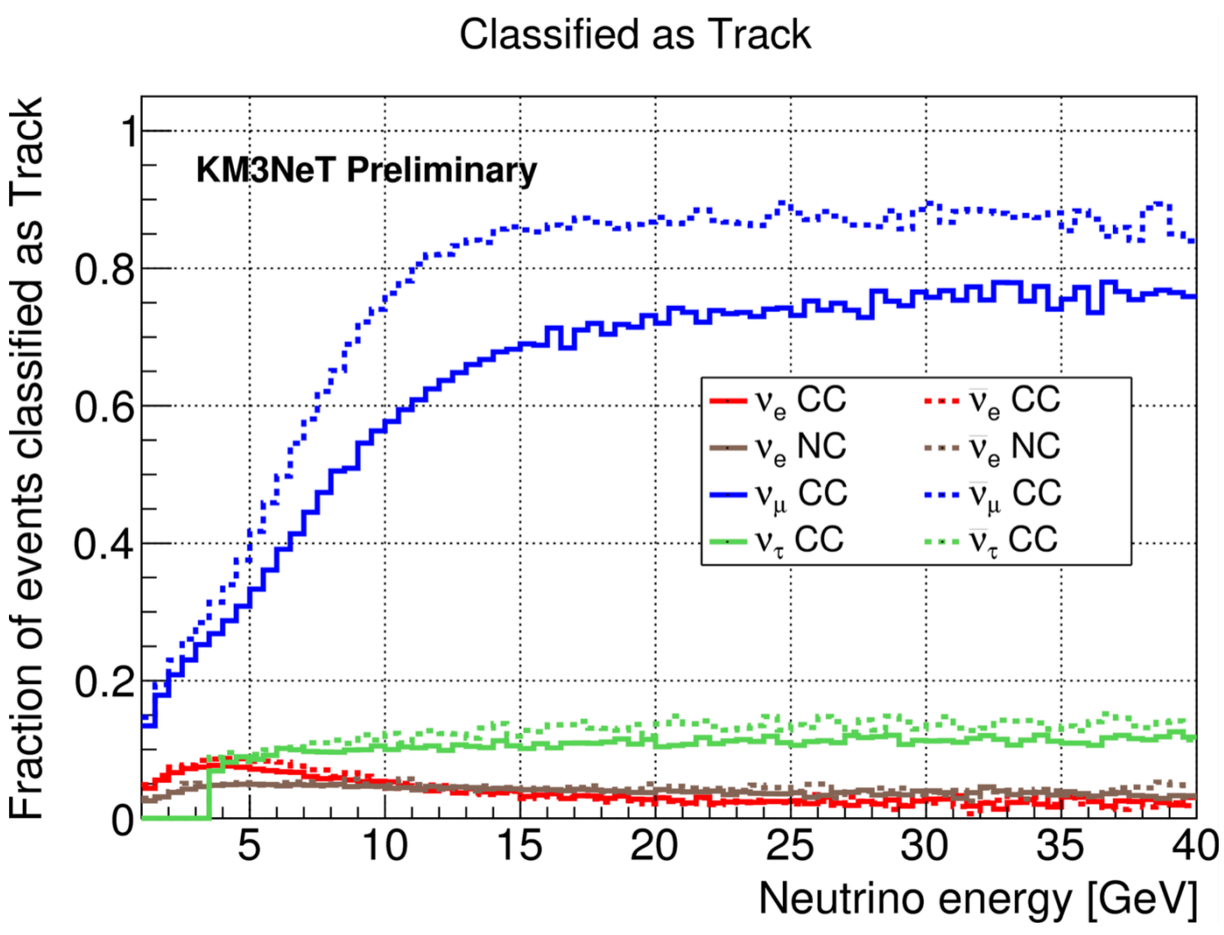


Animation Ref: J. Coelho - http://www.apc.univ-paris7.fr/Downloads/antares/Joao/animations/

[1] Adam M. Dziewonski and Don L. Anderson. Preliminary reference Earth model. Physics of the Earth and Planetary Interiors, 25(4):297–356, 1981.

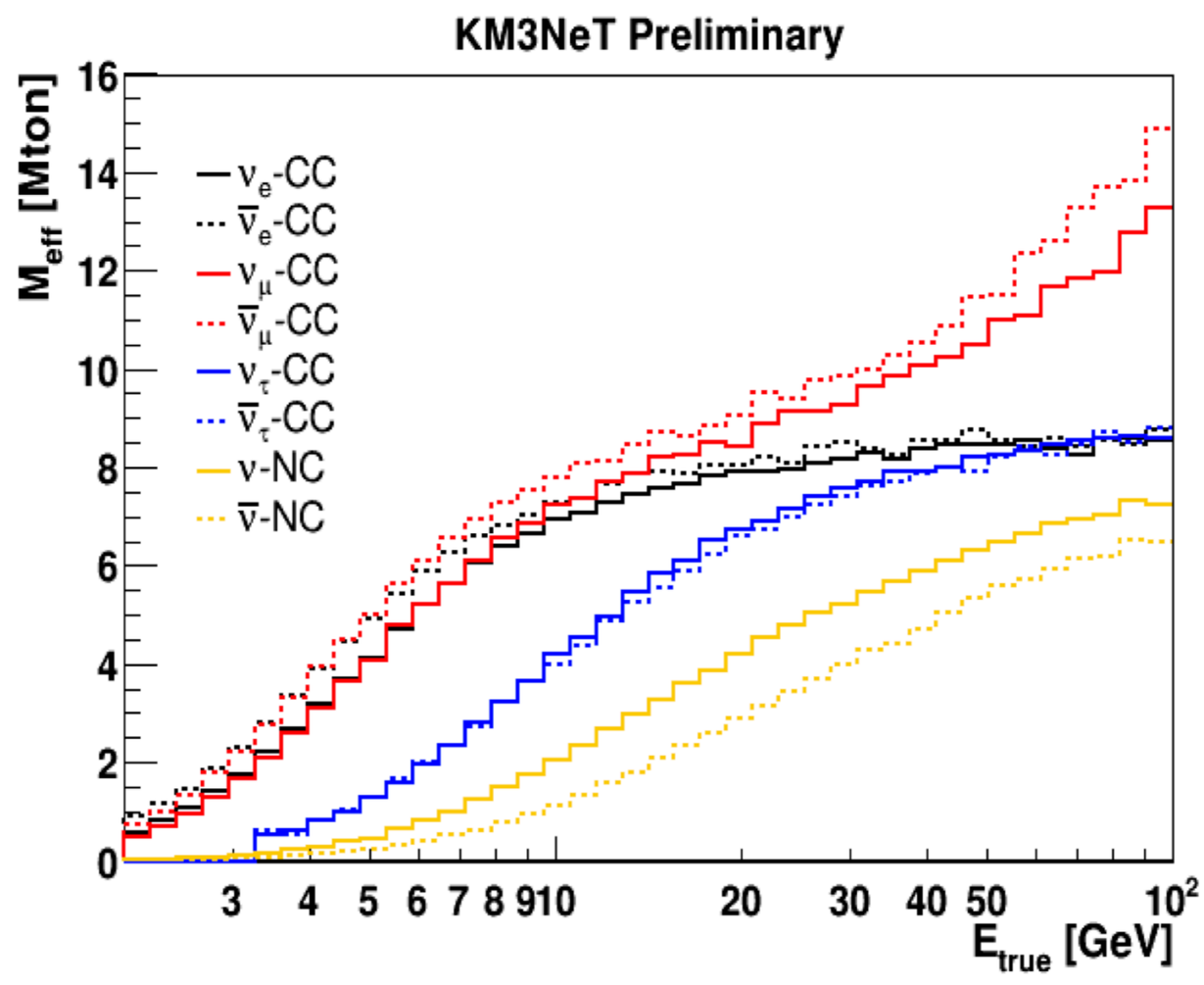
Event Selection and Detector Response

- **Random decision forests to reject background and distinguish between track-like and shower-like events.**



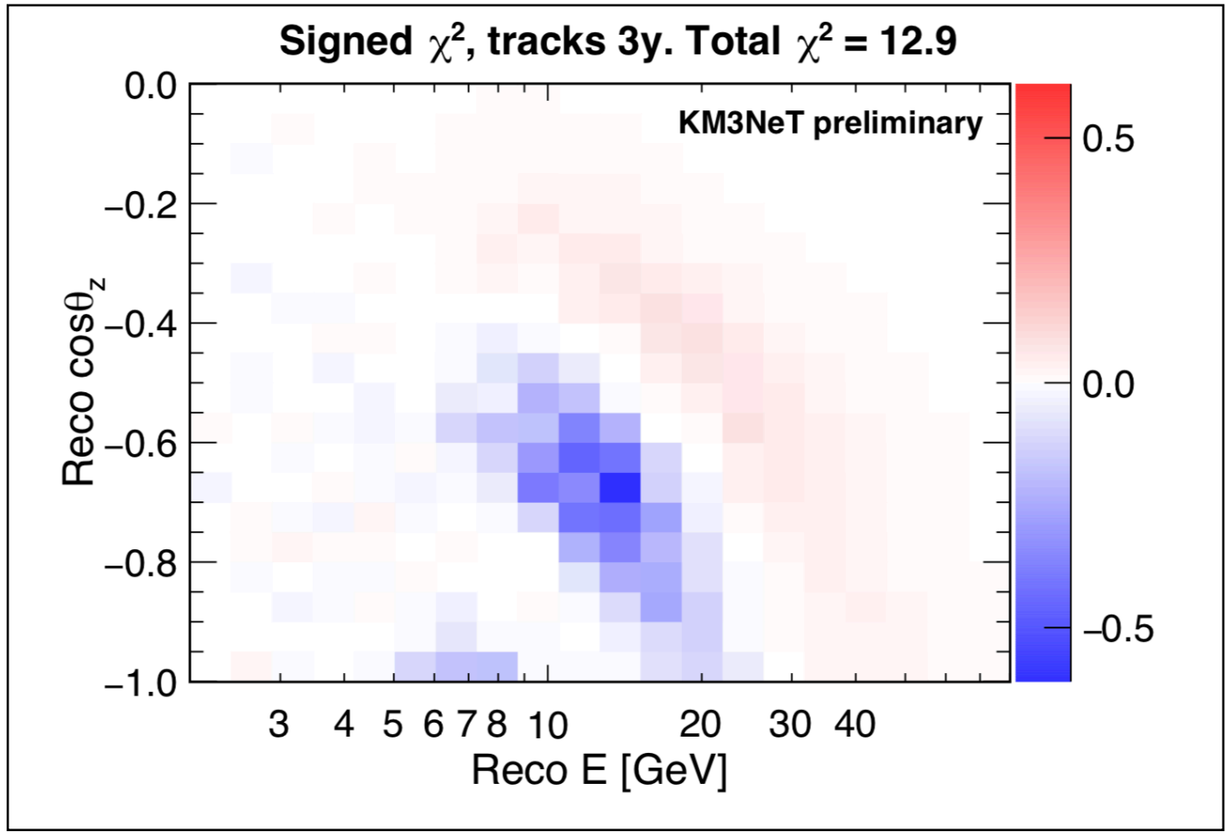
Multi-dimensional response matrix is built from detector simulations.

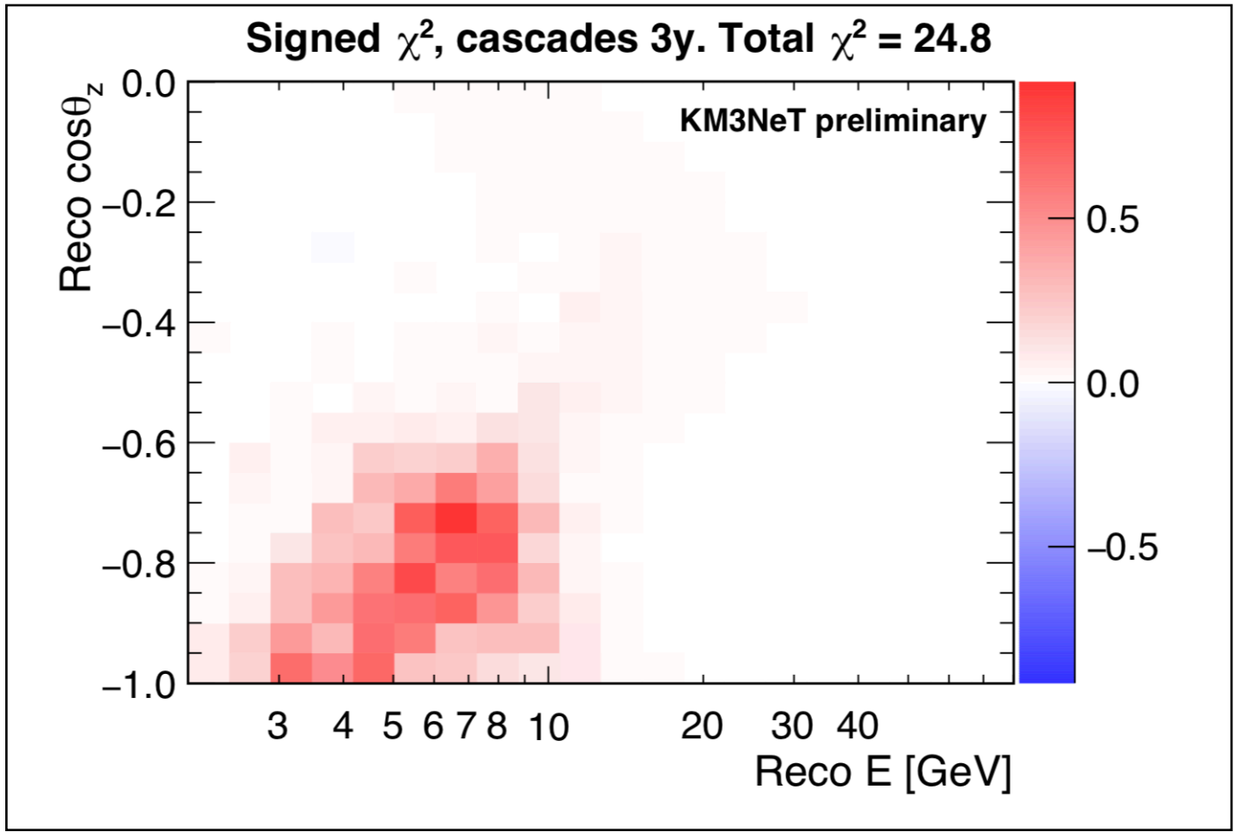
ORCA's effective mass:



Sensitivity to NMO

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

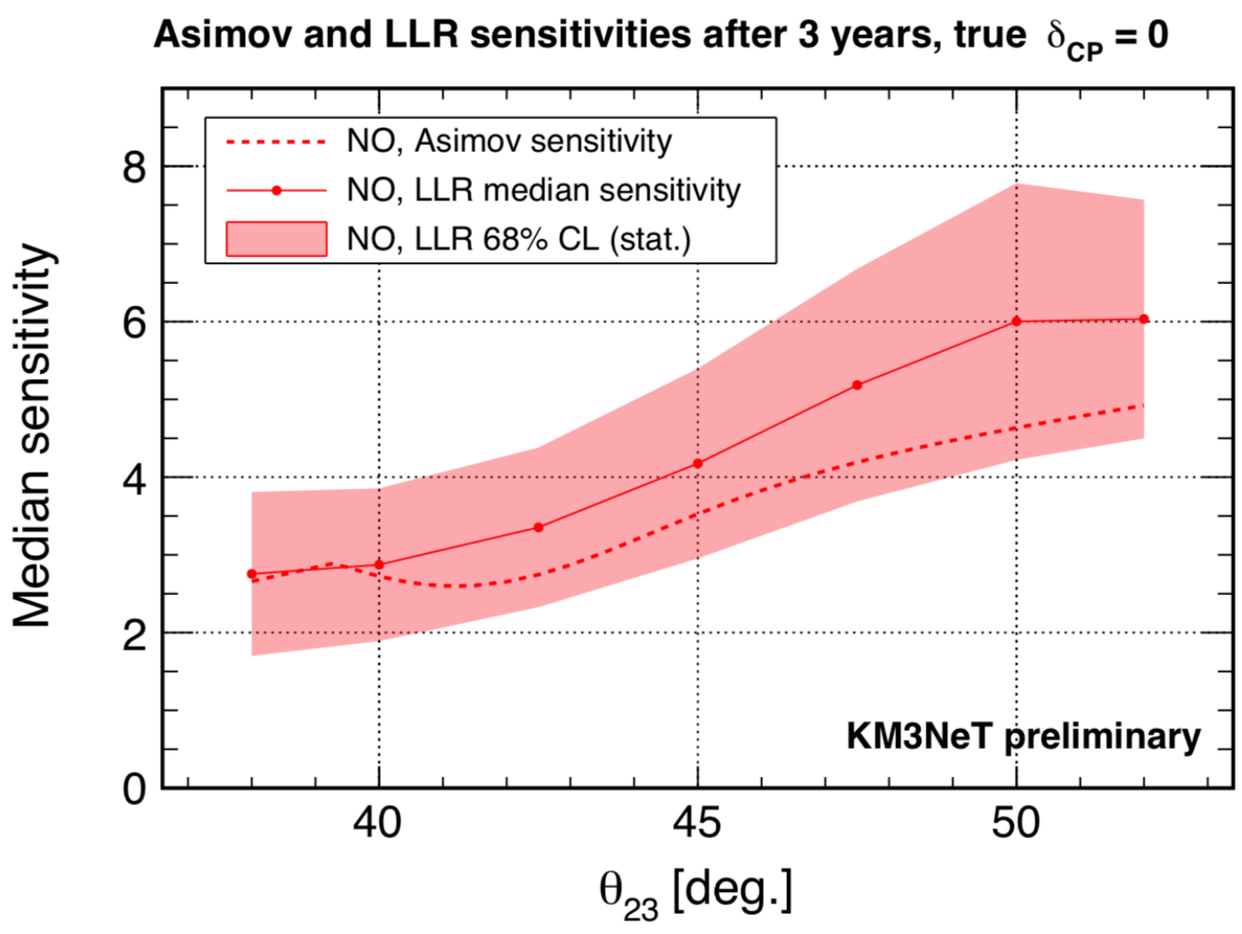


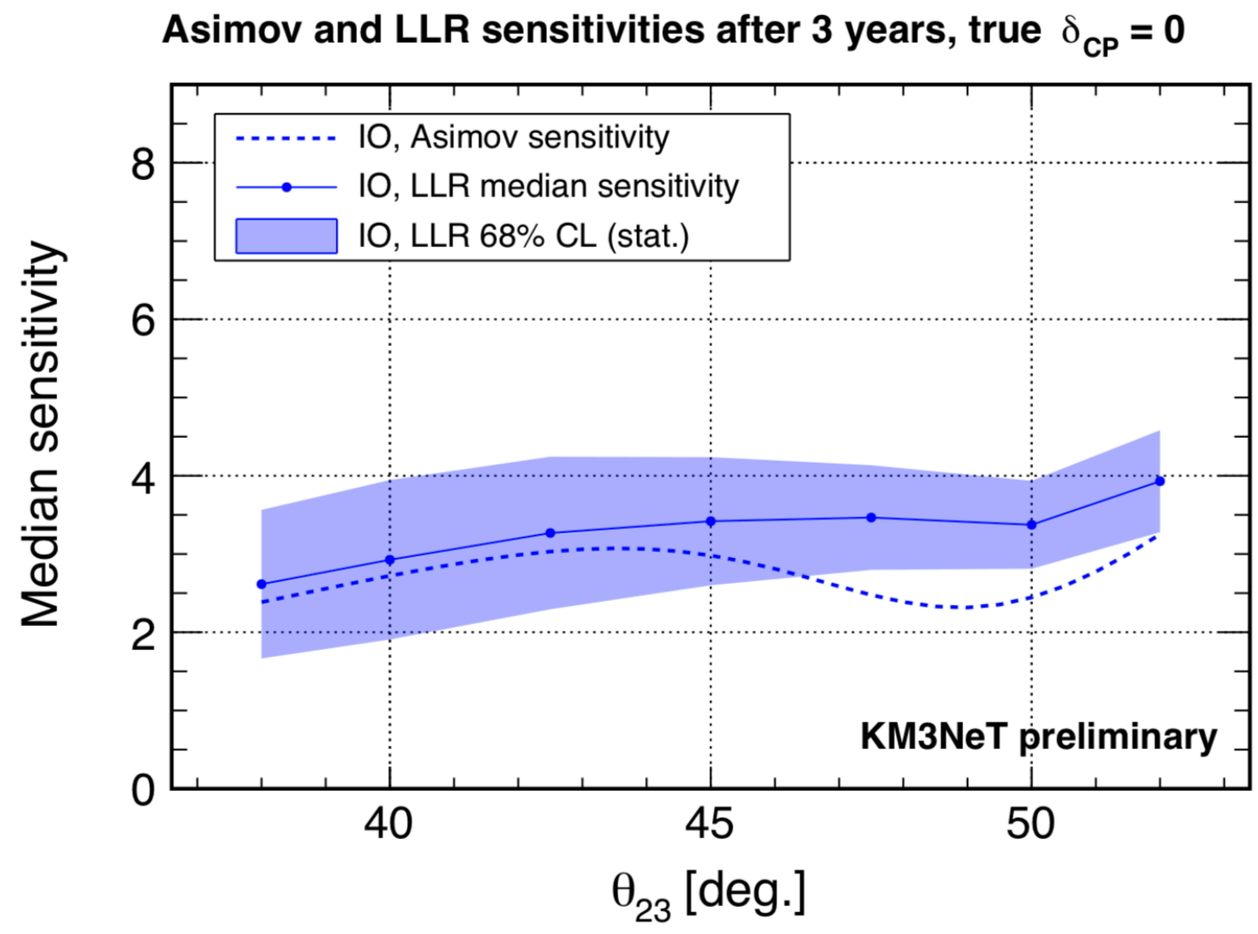


Ref: S. Bourret, L. Quinn: PoS Neutrino 2018

Sensitivity to NMO

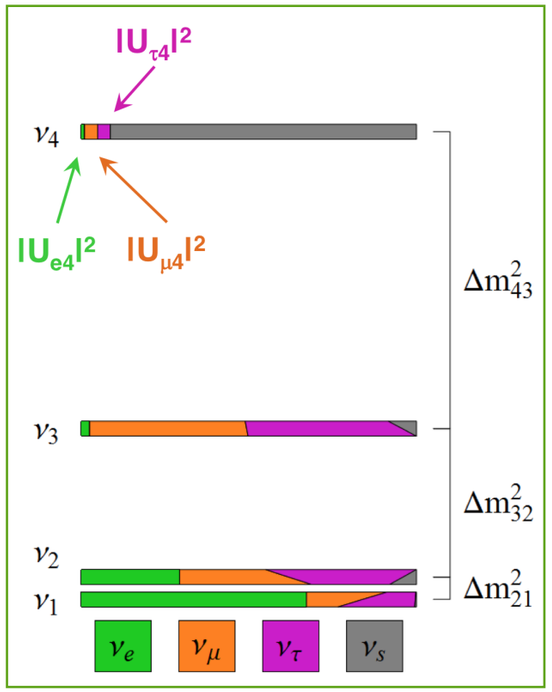
Statistical Methods: LLR tets statistic + χ^2 minimisation





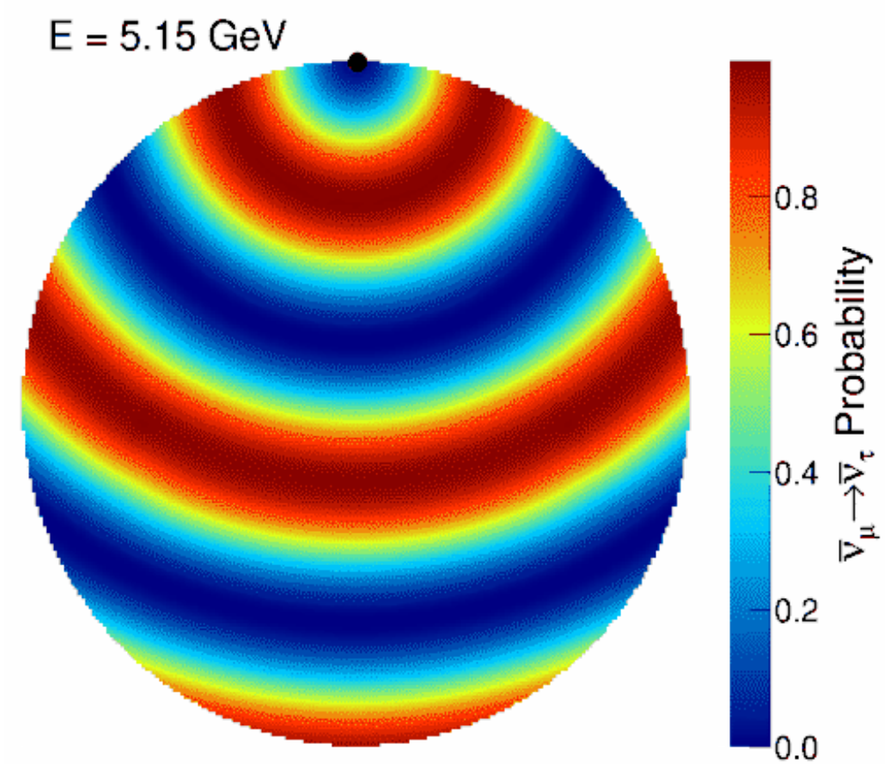
Ref: S. Bourret, L. Quinn: PoS Neutrino 2018

Search for Sterile Neutrinos



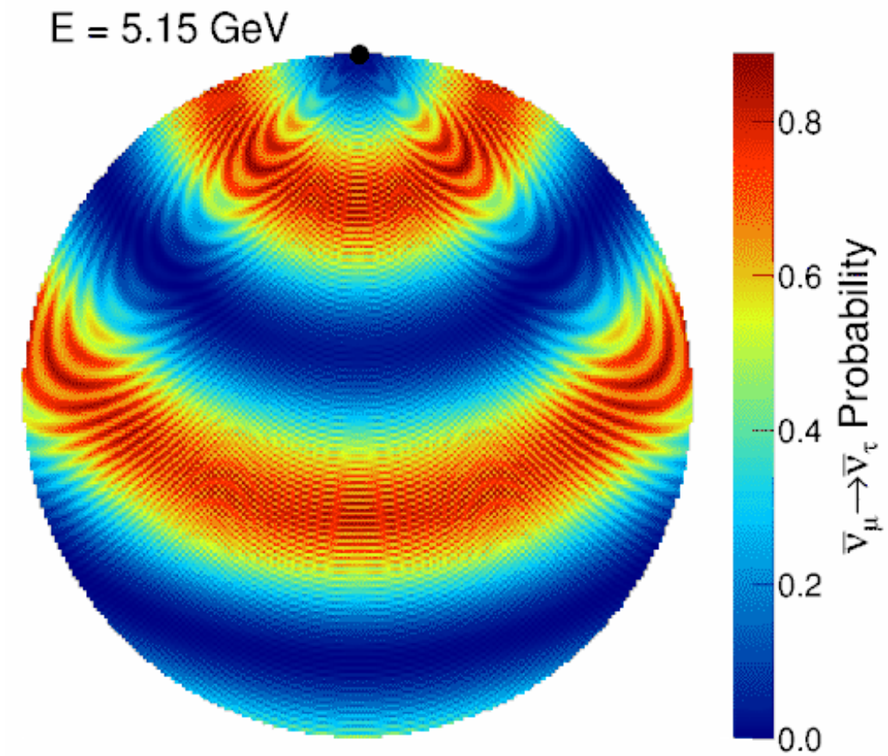
- **Source:** Atmospheric neutrinos.
- The possible presence of a light sterile neutrino affects the oscillation pattern through the Earth.

STANDARD 3 ν CASE



STERILE NEUTRINO

$\Delta m^2_{41} = 0.3\ eV^2$; $|U_{e4}|^2 = 0.04$; $|U_{\mu 4}|^2 = 0.02$; $|U_{\tau 4}|^2 = 0.18$;

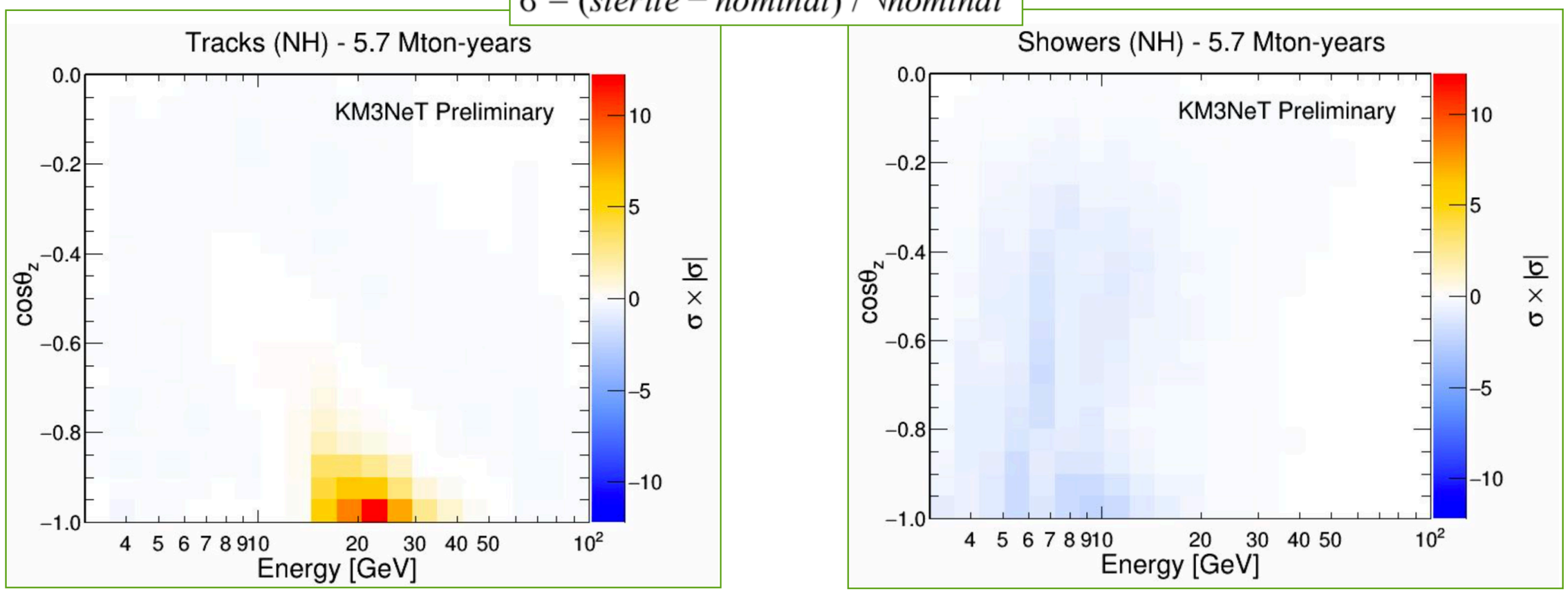


Animation Ref: J. Coelho - http://www.apc.univ-paris7.fr/Downloads/antares/Joao/animations/

Search for Sterile Neutrinos

- **Detector response** evaluated with Letter of Intent [1] configuration (new sensitivity will be available soon).

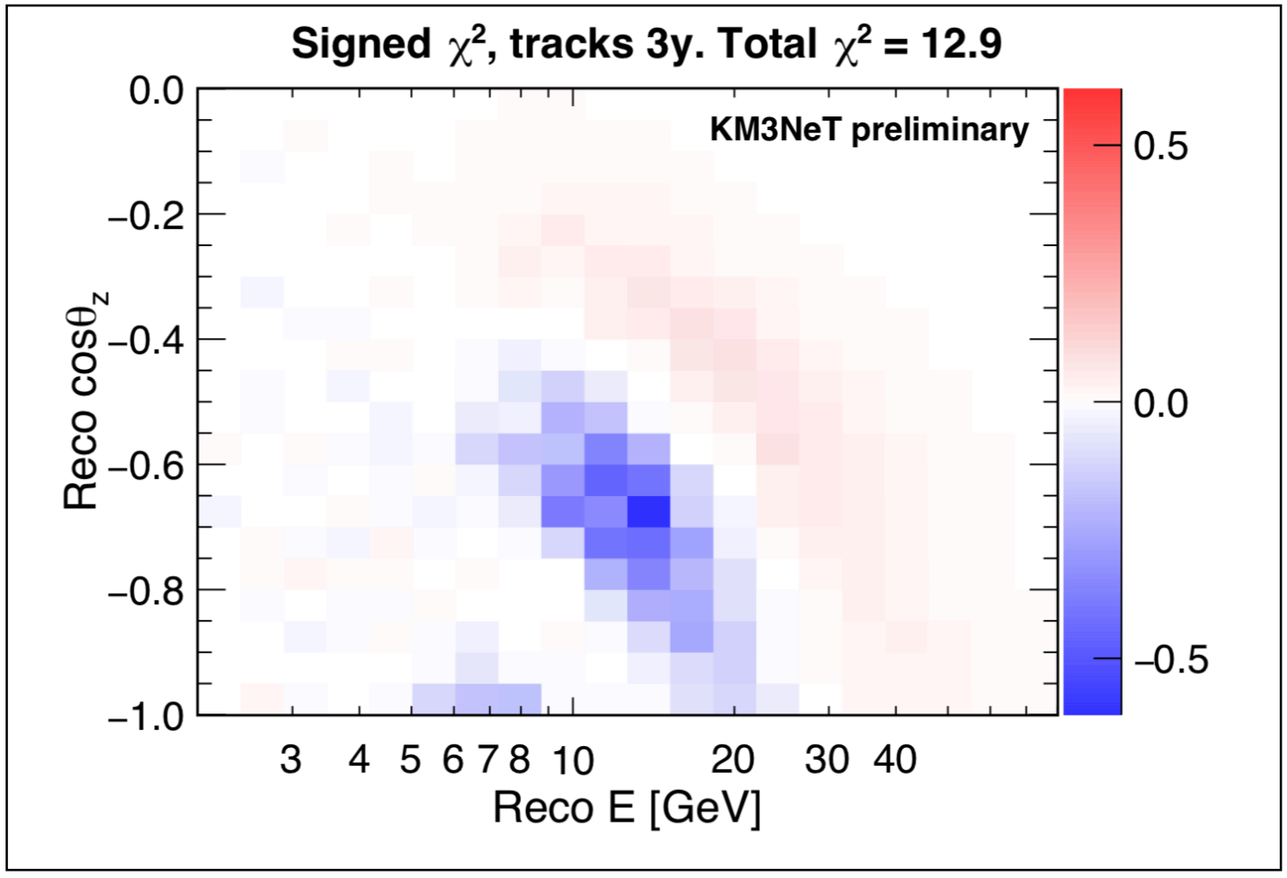
$$\sigma = (sterile - nominal) / \sqrt{nominal}$$



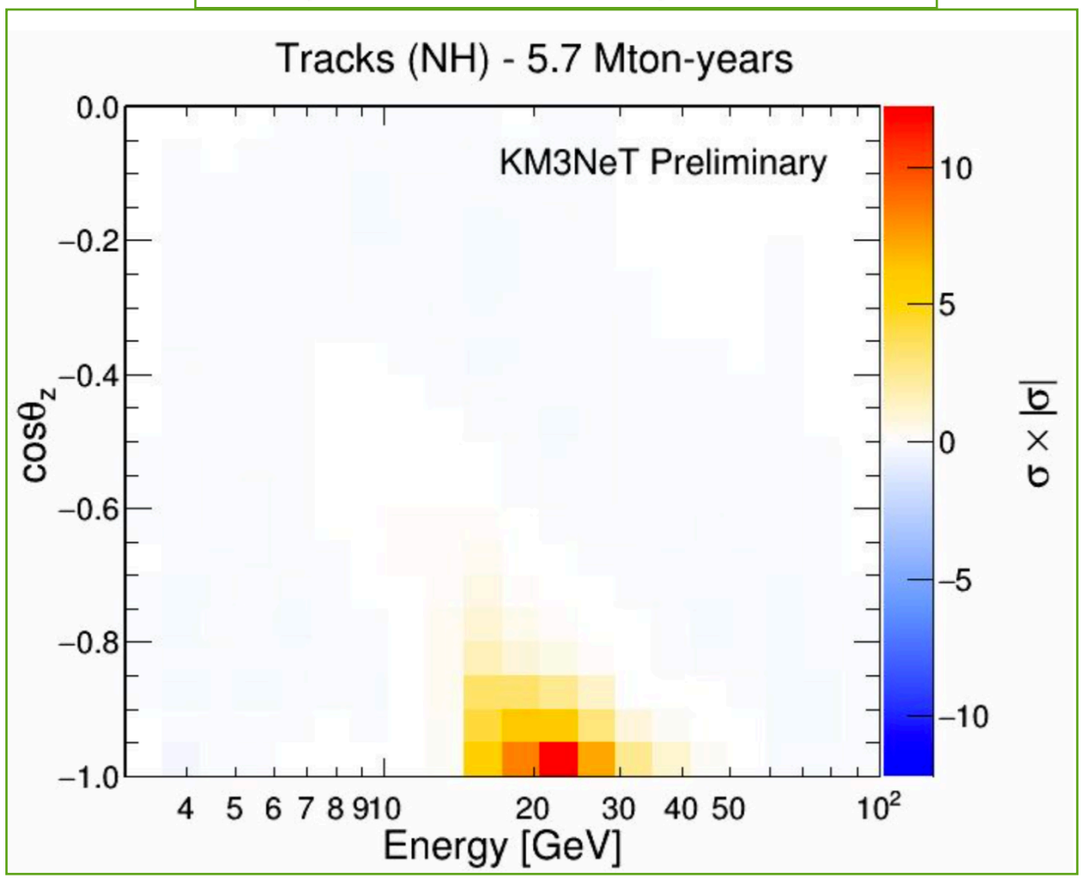
[1] KM3NeT LoI: arXiv:1601.07459

Different impact of NMO and Sterile Neutrino

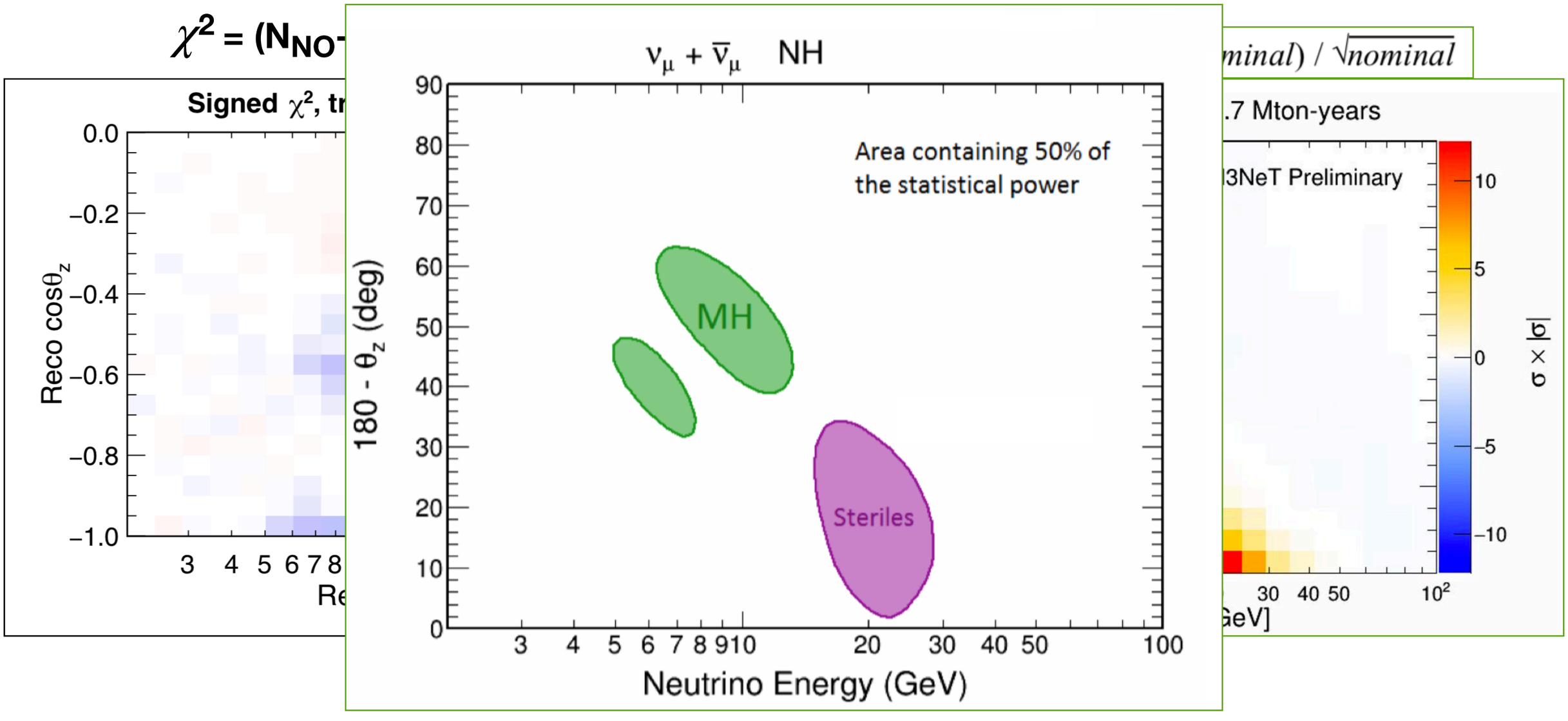
$\chi^2 = (N_{NO}-N_{IO})|N_{NO}-N_{IO}|/N_{NO}$



$\sigma = (sterile - nominal) / \sqrt{nominal}$

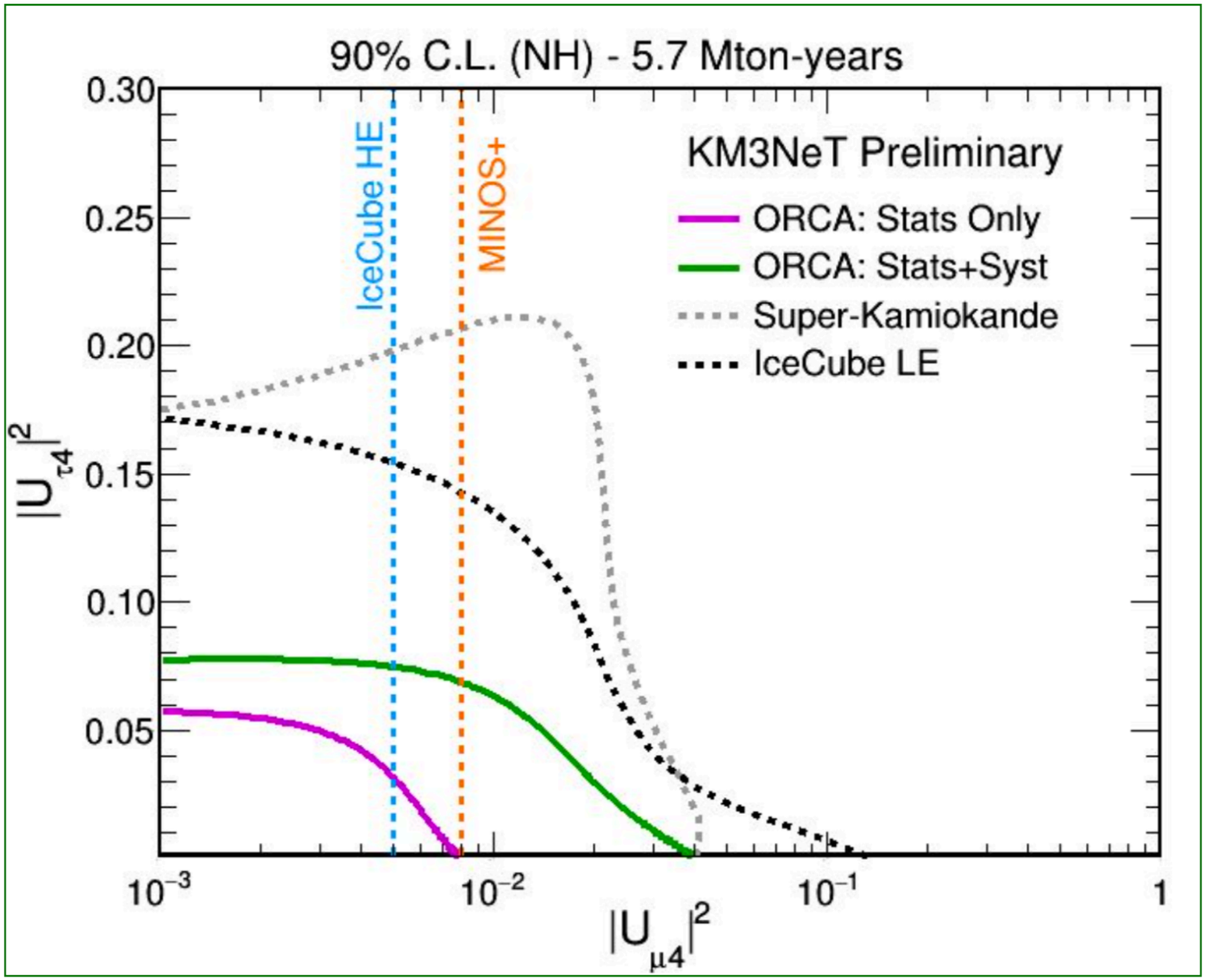


Different impact of NMO and Sterile Neutrino



Sensitivity to Sterile Neutrino

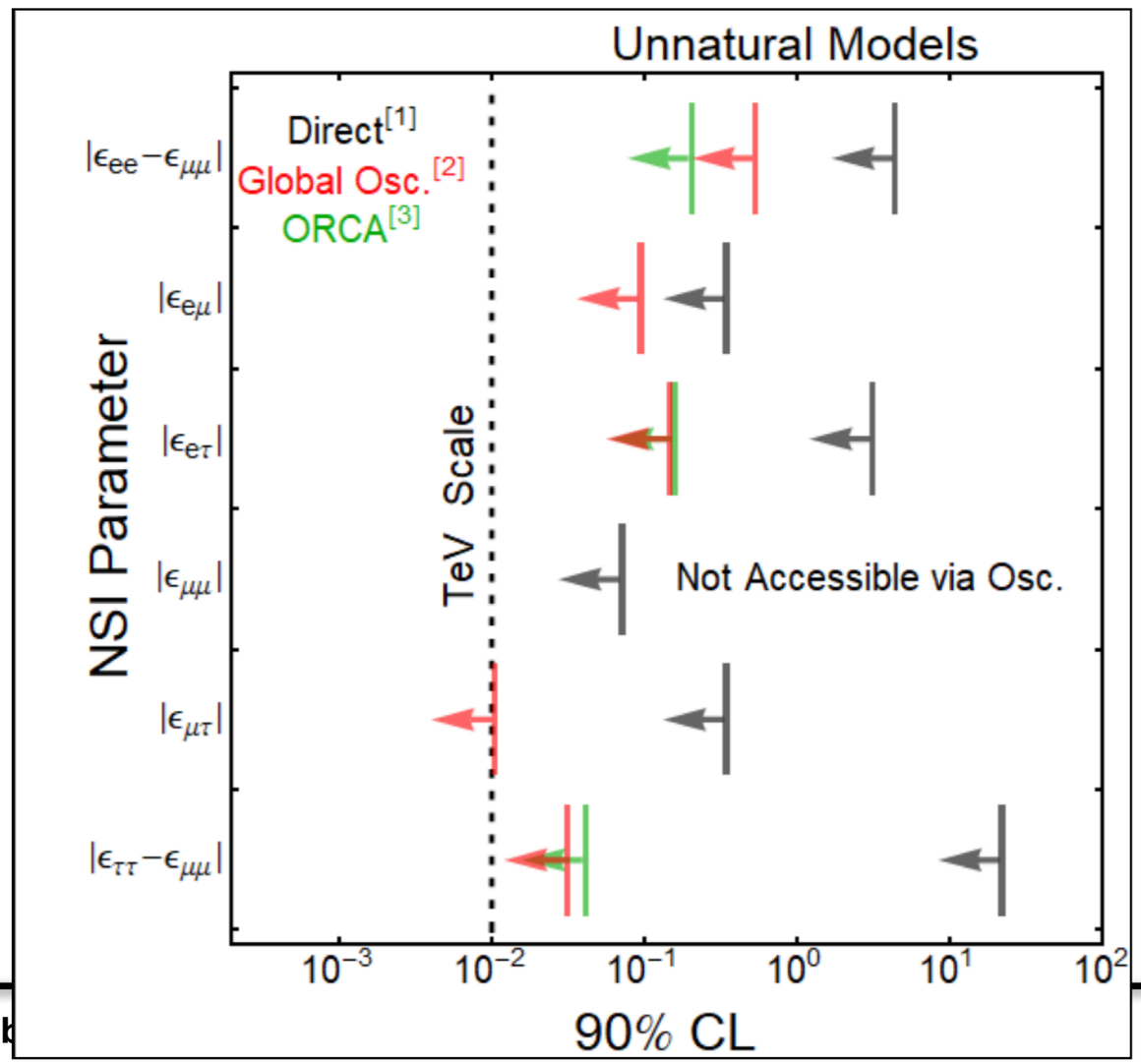
ORCA Sensitivity to 1 sterile neutrino for 1 year of data taking!

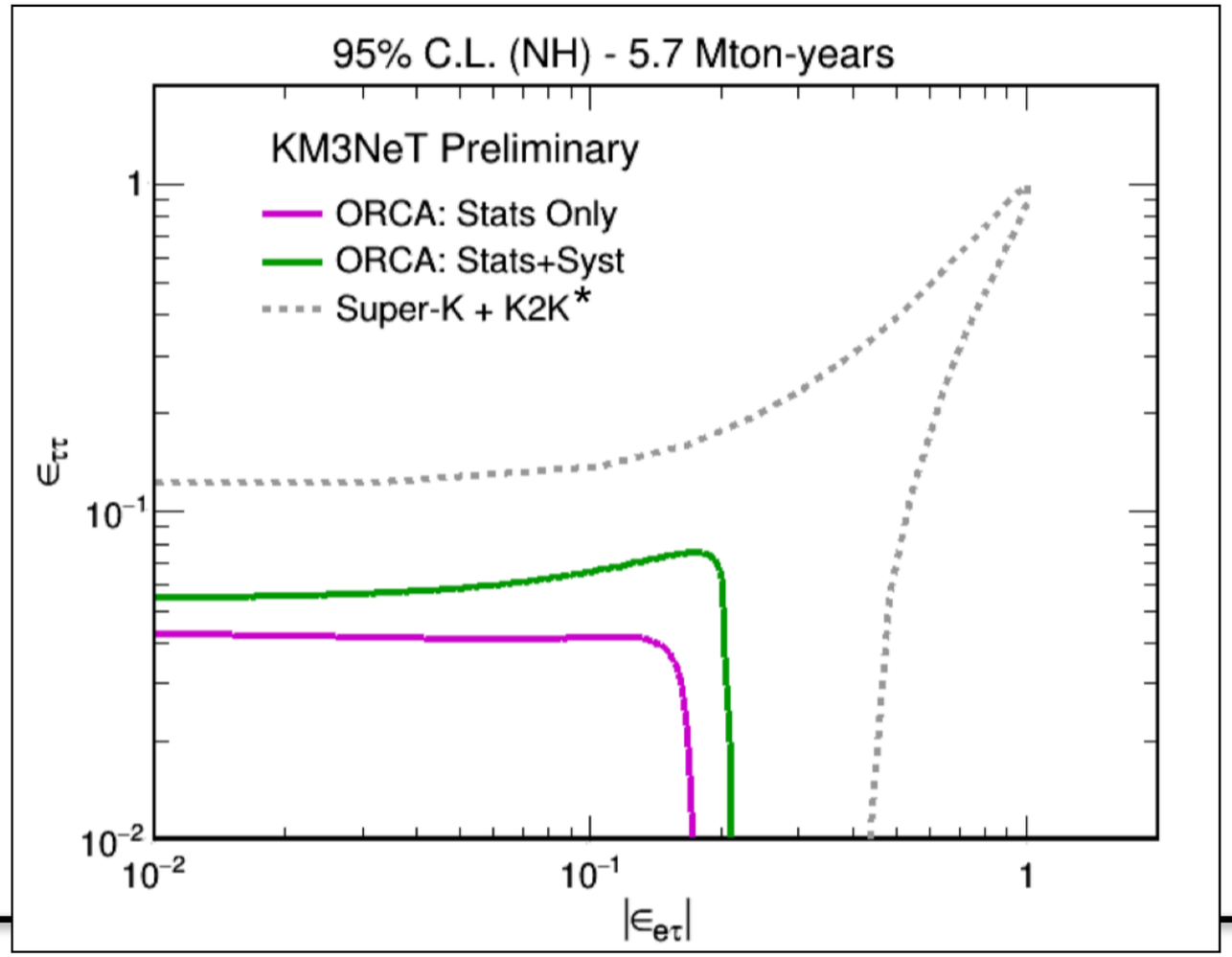


Ref: J. Coelho, ICRC proceeding, DOI: 10.22323/1.301.1027

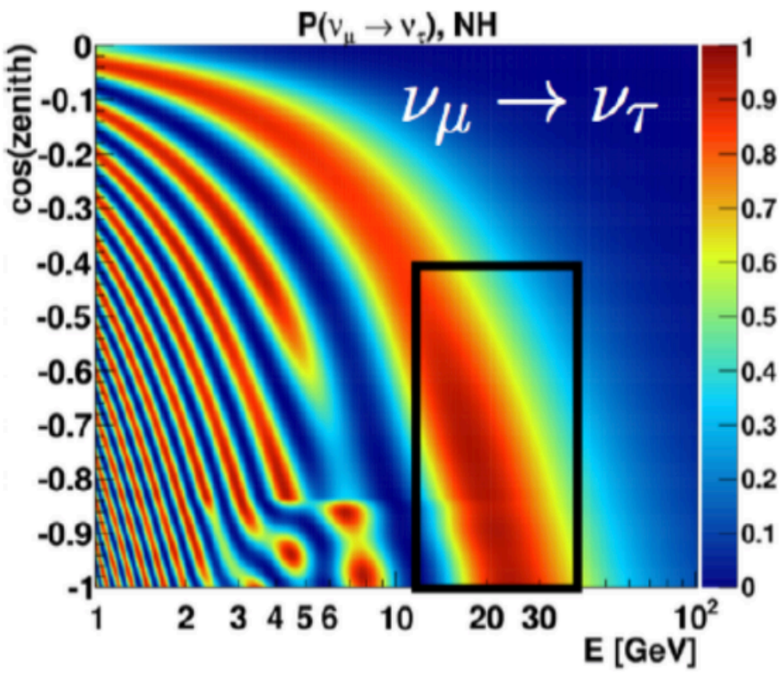
Non Standard Interactions (NSI)

- ORCA sensitive to NSI effects of order 10% of the Fermi int.
- Direct bounds are more than 10x larger in some cases.
- ORCA improves over current atmospheric scale bounds.
- Limits competitive with global limits from oscillation.

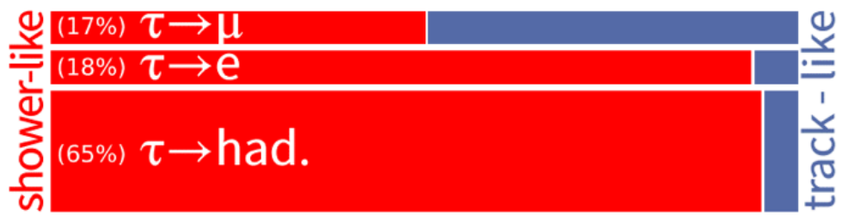




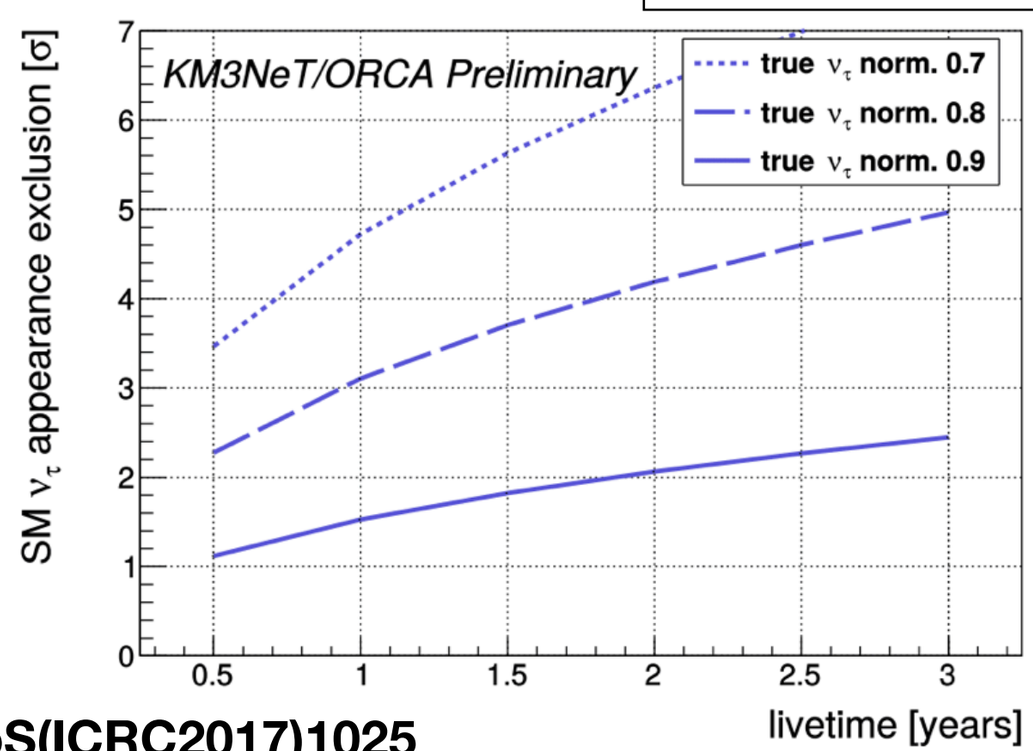
Tau Neutrino Appearance

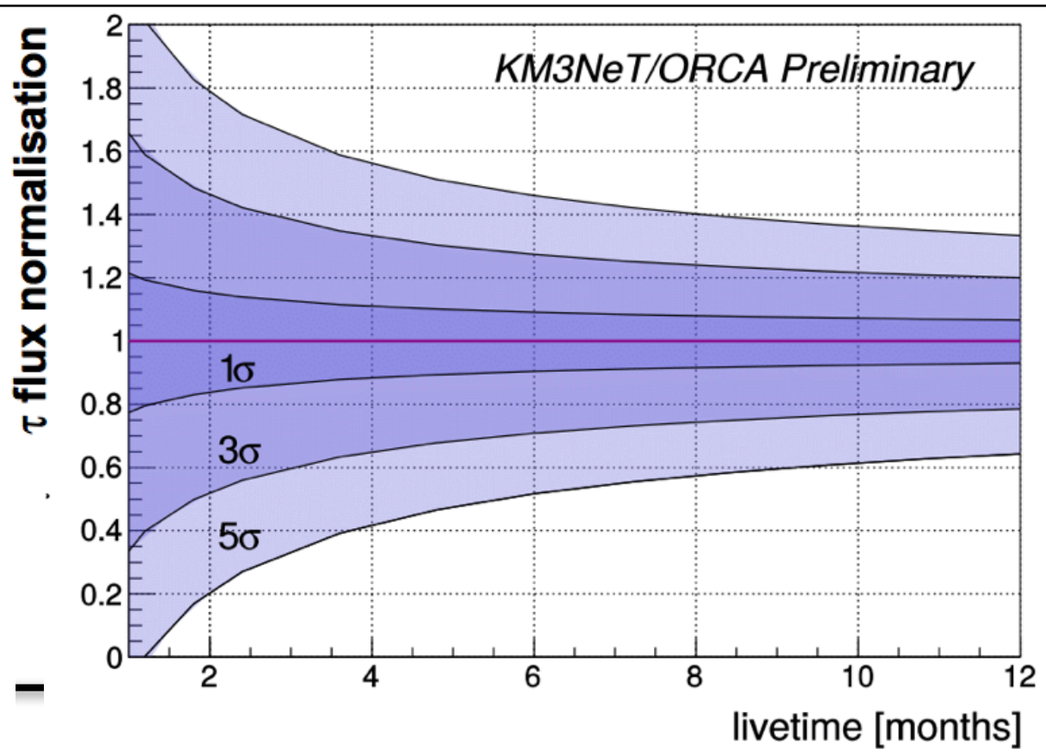


- ν_τ appearance tests unitarity of 3ν mixing matrix and BSM theories.
- 20% deviation from unitarity can be detected with 5σ in 5 years.
- ~3000 ν_τ^{CC} events/year with full ORCA.
- ν_τ events predominantly shower-like.



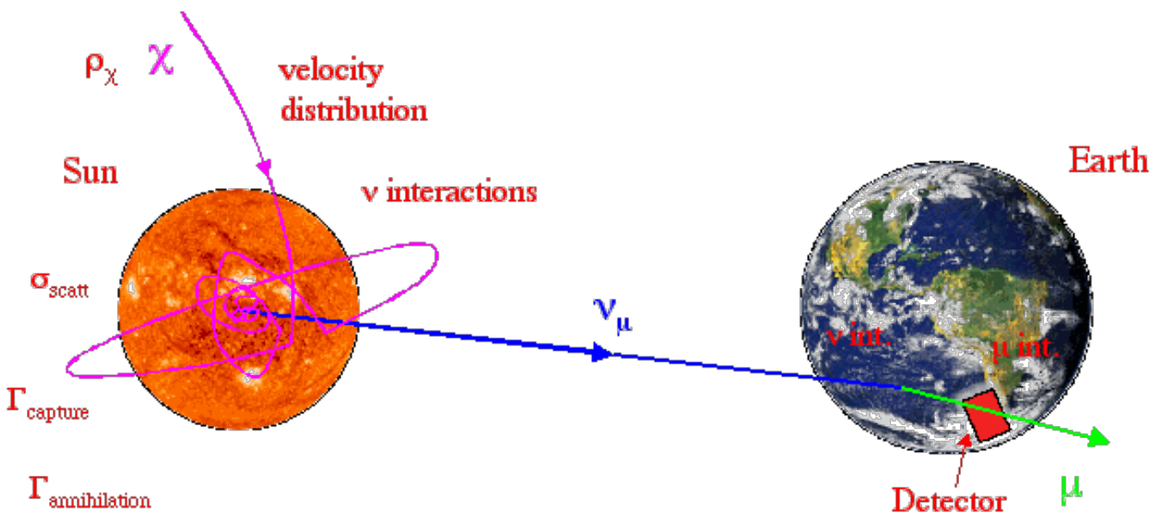
- Confirm exclusion of non-appearance (=0) already with 2 months of data





Ref: PoS(ICRC2017)1025

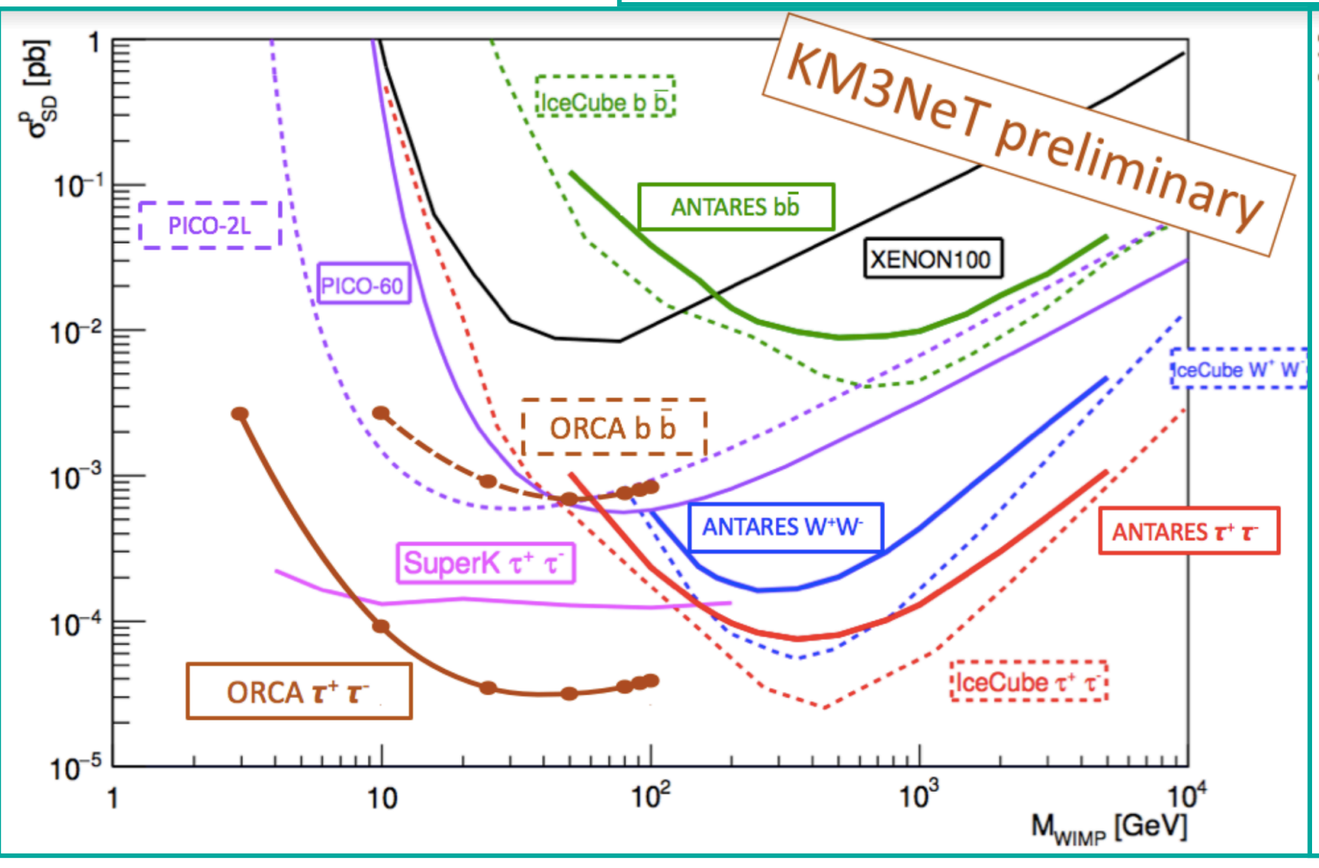
Indirect Detection of Dark Matter

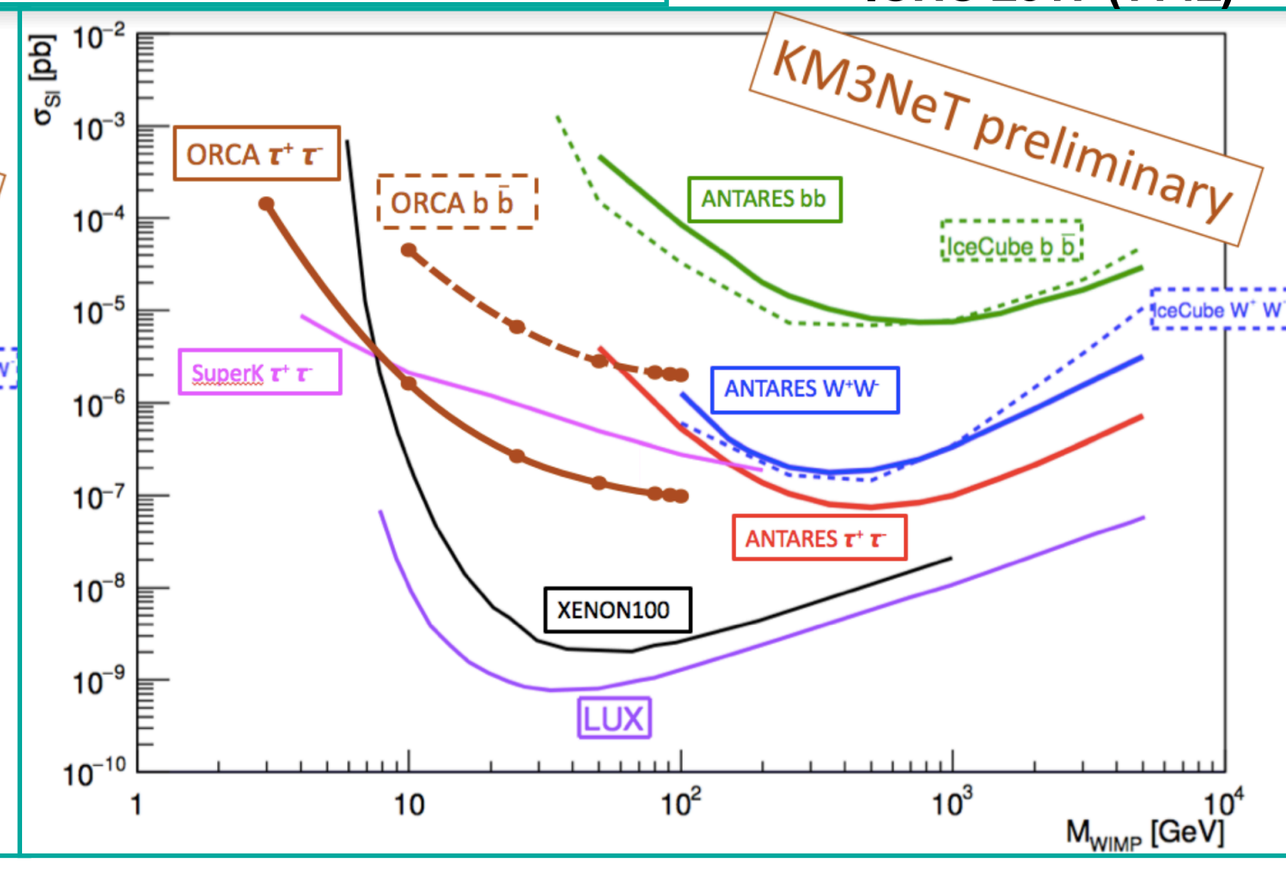


- DM annihilation in the Sun.
- ν production (E > GeV).
- Constrain DM-DM cross section.
- Sensitivity obtained with LoI detector.

ORCA sensitivity after 3 years of data taking

Ref. V. Kulikovskiy ICRC 2017 (1142)

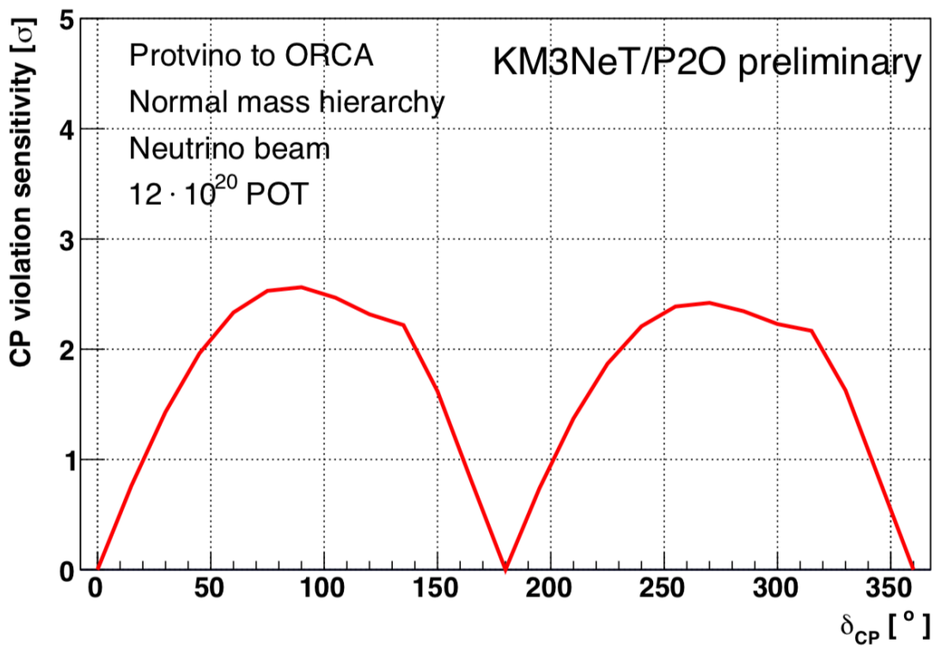




POSSIBLE EXTENSIONS: P2O -> Protvino2ORCA Beam

Protvino U70 proton accelerator:

- 2-7 GeV Neutrino Beam (to be constructed).
- Sensitivity to Mass Ordering at least 5σ after 1 year of beam.
- Sensitivity to measure CP phase.

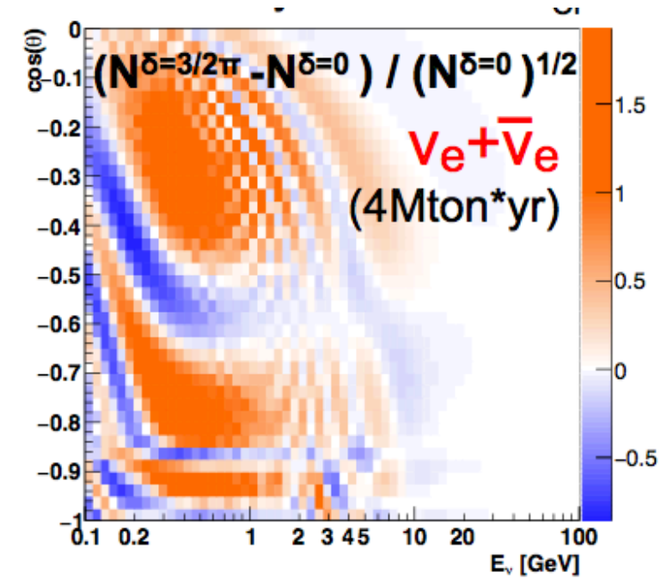


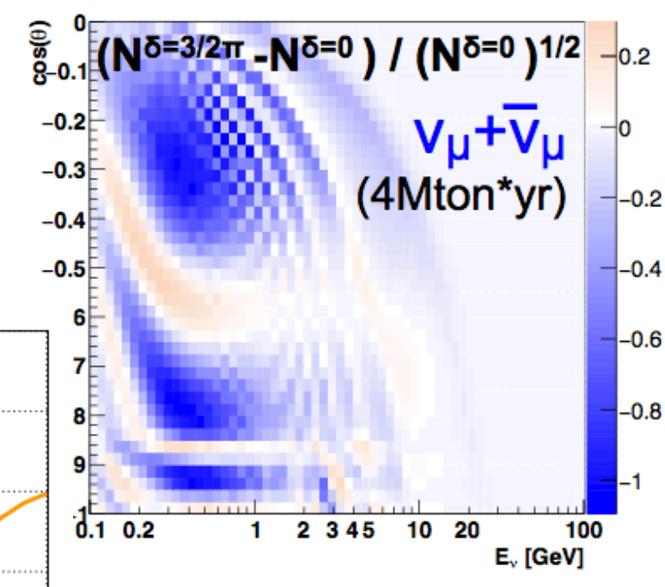
➡ See talk of Brunner with updated sensitivity.

Ref: Brunner, arXiv:1304.6230

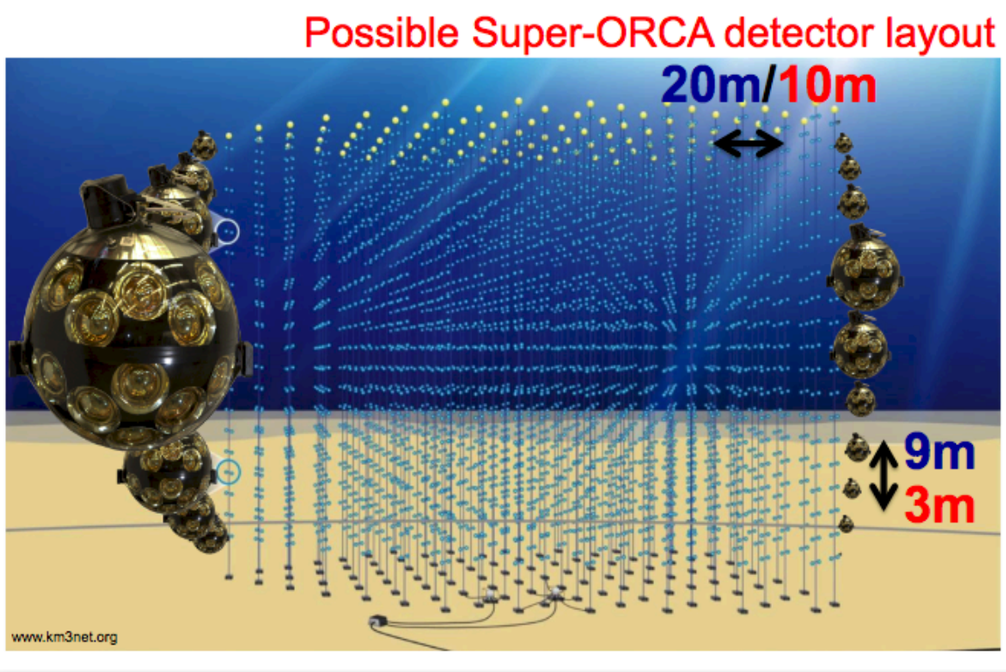
POSSIBLE EXTENSIONS: Super-ORCA

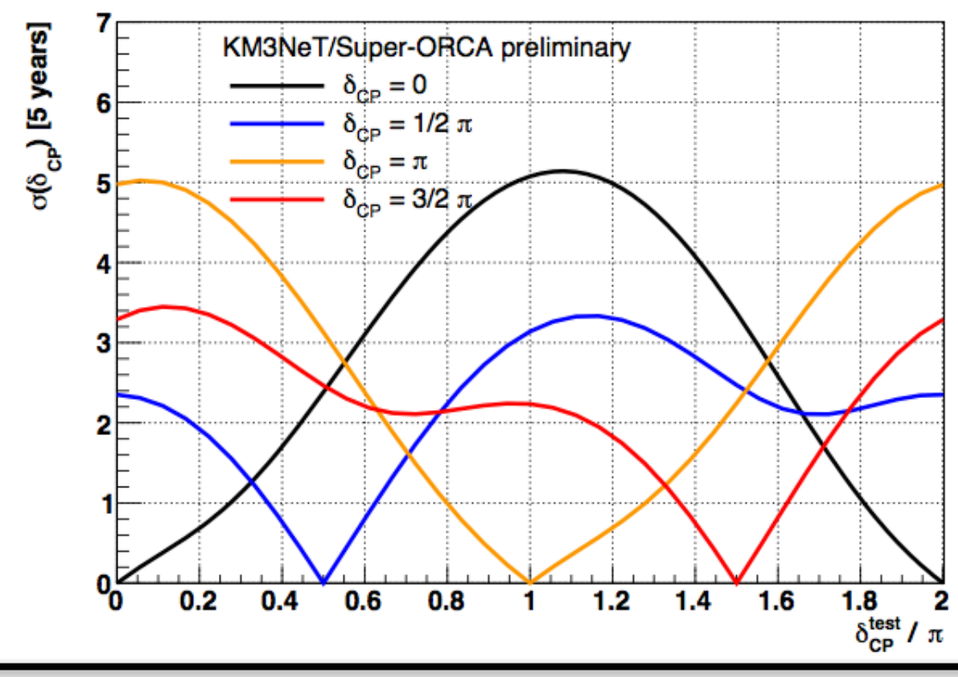
- Task: Measure δ_{CP} with atmospheric neutrinos.
  - Possible with ν energies $\lesssim$3 GeV ➟ below ORCA's energy threshold!
  - Precise flavour identification, better energy and direction resolution needed.
    - ➡ 5-10x denser detector.
    - ➡ Assumed ~115k 3" PMTs/Mton
    - ➡ ~1% density of SuperK





Ref: J. Hofestädt, T. Eberl, M. Bruchner, Neutrino 2018

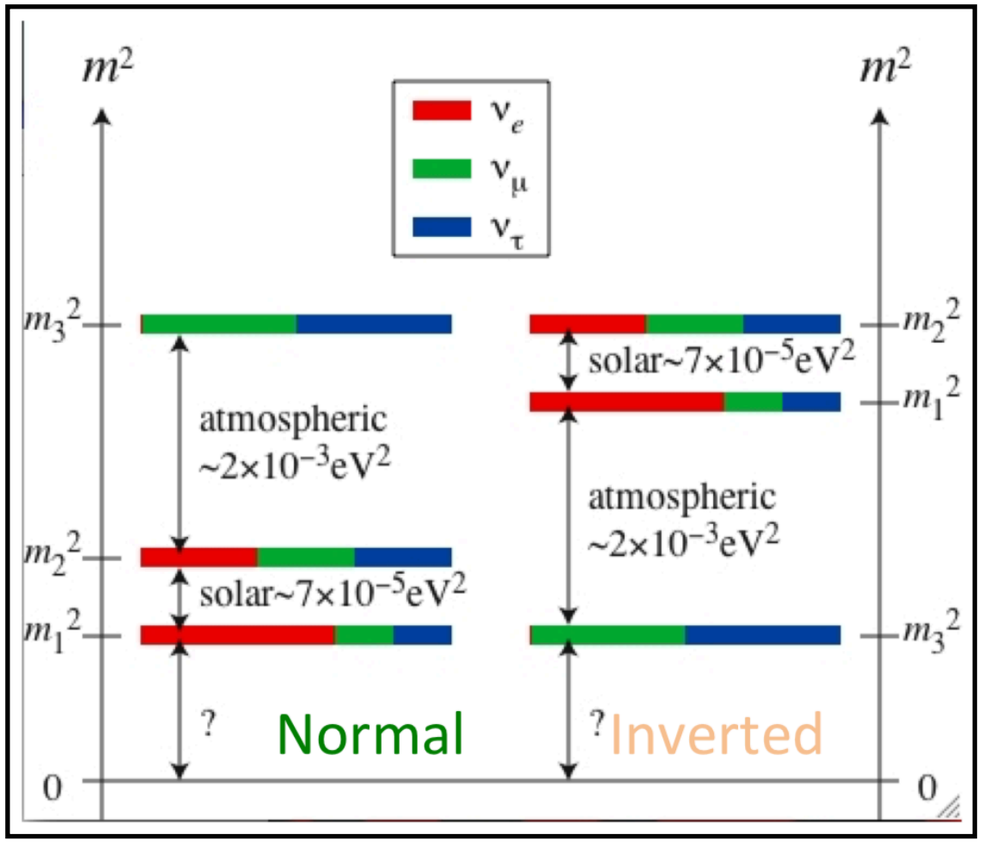




Thank you for your attention!

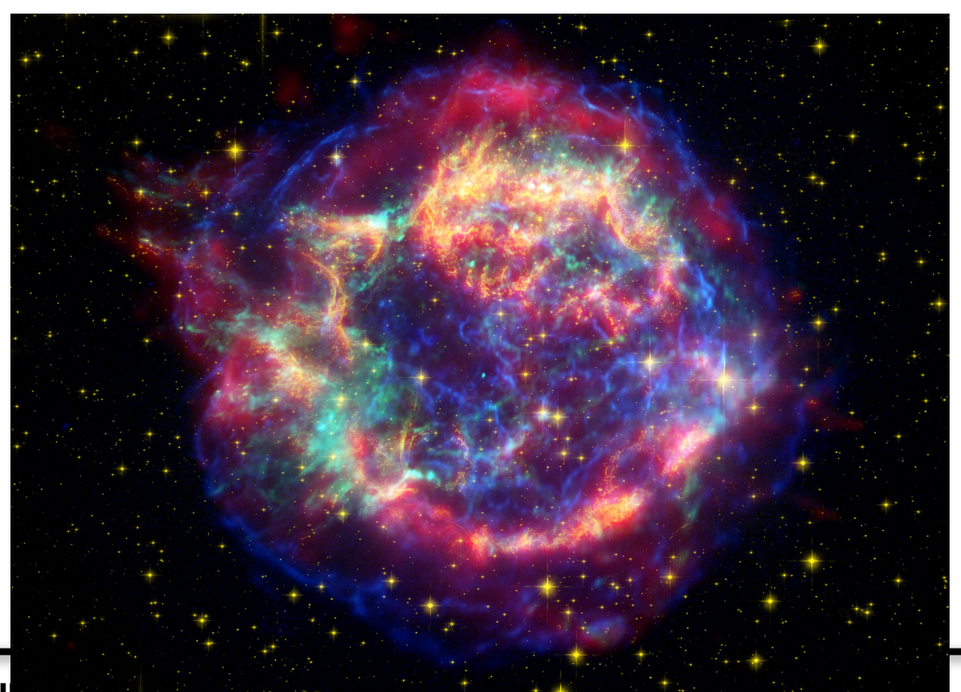
Backup Slides

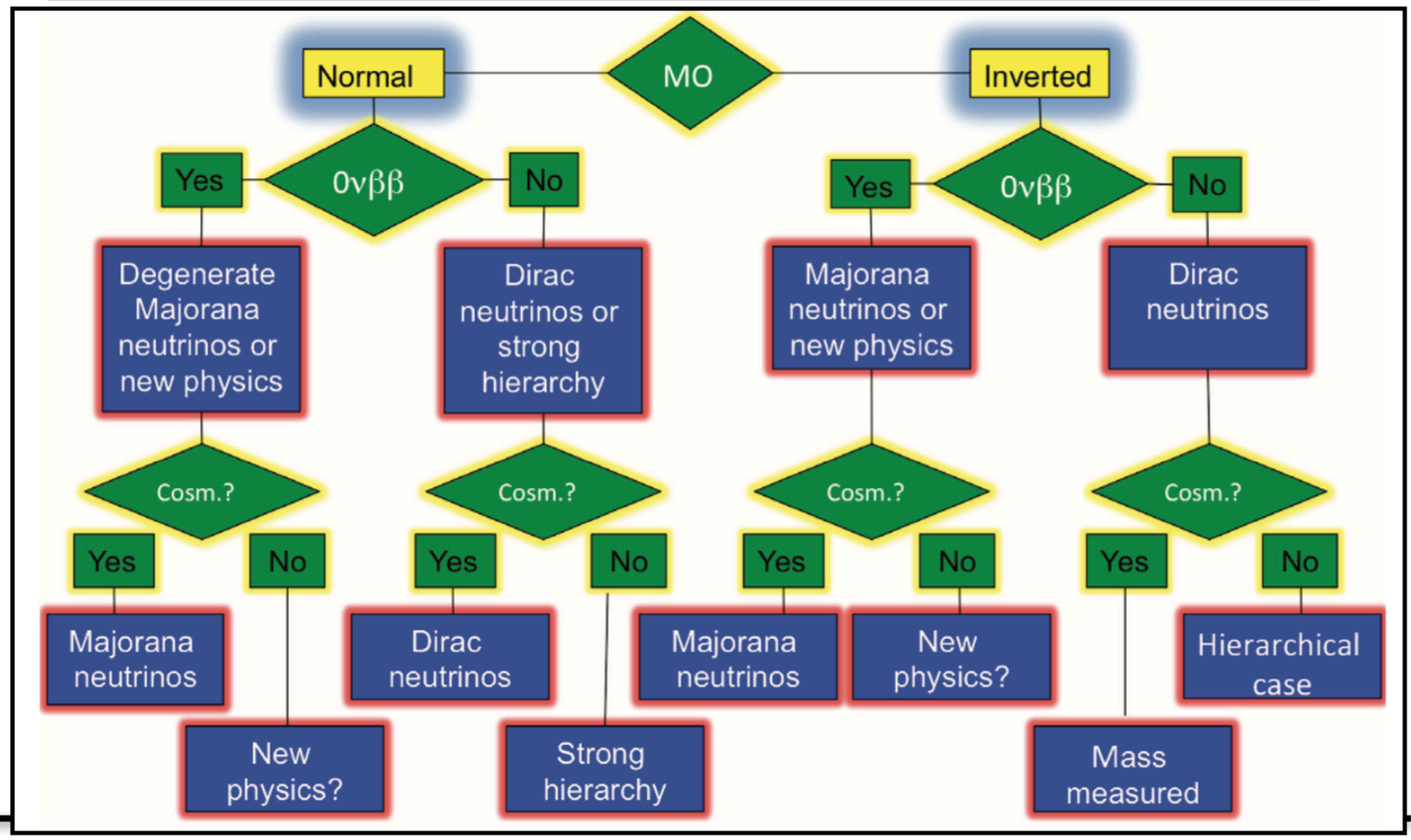
Neutrino Mass Ordering



Impact on:

- Magnitude and nature of neutrino mass.
- Distinguish between different theoretical models.
- Impact on $0\nu\beta\beta$ studies.
- Core-collapse supernovae.





W. Winter, Neutrino mass hierarchy: Theory and phenomenology

Search for Sterile Neutrinos

- 3+1 model:
  - $\Delta m^2_{41} = 0.3\ eV^2$
  - $|U_{e4}|^2 = \sin^2\theta_{14} = 0$
  - $|U_{\mu 4}|^2 = \cos^2\theta_{14}\sin^2\theta_{24} = 0.02$
  - $|U_{\tau 4}|^2 = \cos^2\theta_{14}\cos^2\theta_{24}\sin^2\theta_{34} = 0.18$
  - Loose Gaussian prior on $\Delta m^2_{31} = (2.5 \pm 0.5)\ x10^{-3}\ eV^2$
  - **Fixed mass hierarchy: normal**
  - **Starting value of θ_{23} in lower octant**

Tau neutrino appearance