Universiteit van Amsterdam

Nikhef

KM3NeT

Status of KM3NeT-ORCA

Lake Louise Winter Institute

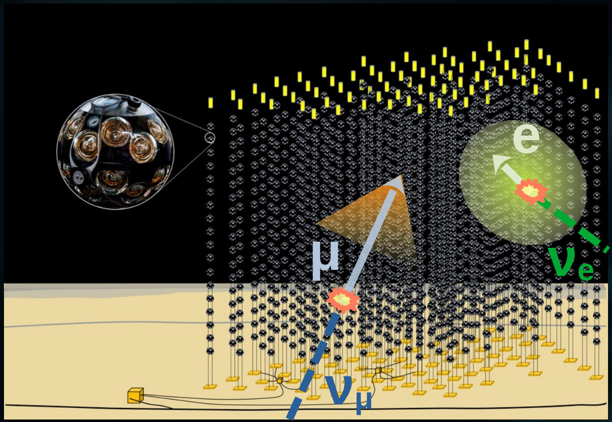
Bouke Jung
on behalf of the KM3NeT collaboration

- KM3NeT: Multi-site deep-sea neutrino detector

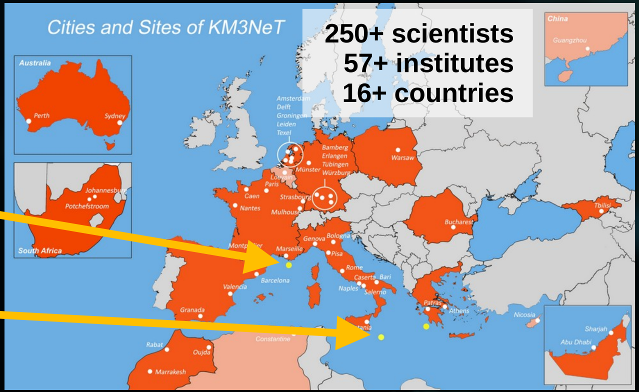
- Detection of Cherenkov photons produced in neutrino interactions

- Building block:
  - 115 Detection Units per block
  - 18 Digital Optical Modules per DU
  - 31 3” **PMT**s per DOM

  } **64,170 PMTs** per block



- Single collaboration, two experiments:
  - KM3NeT-**ORCA**
    Oscillations Research with Cosmics in the Abyss
  - KM3NeT-**ARCA**
    Astroparticle Research with Cosmics in the Abyss

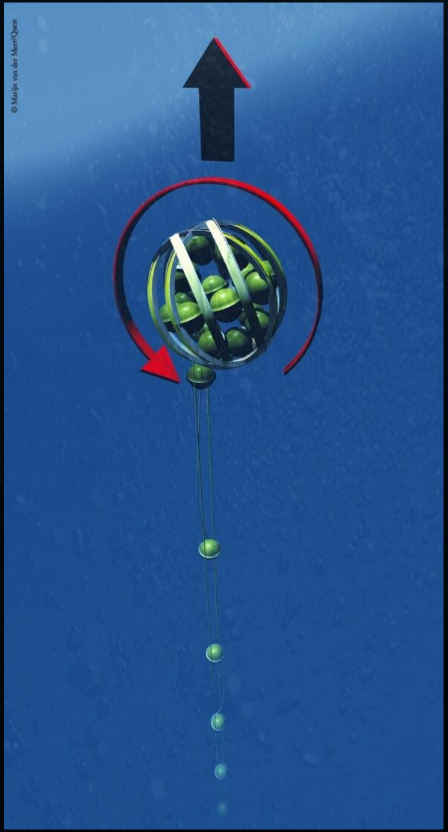


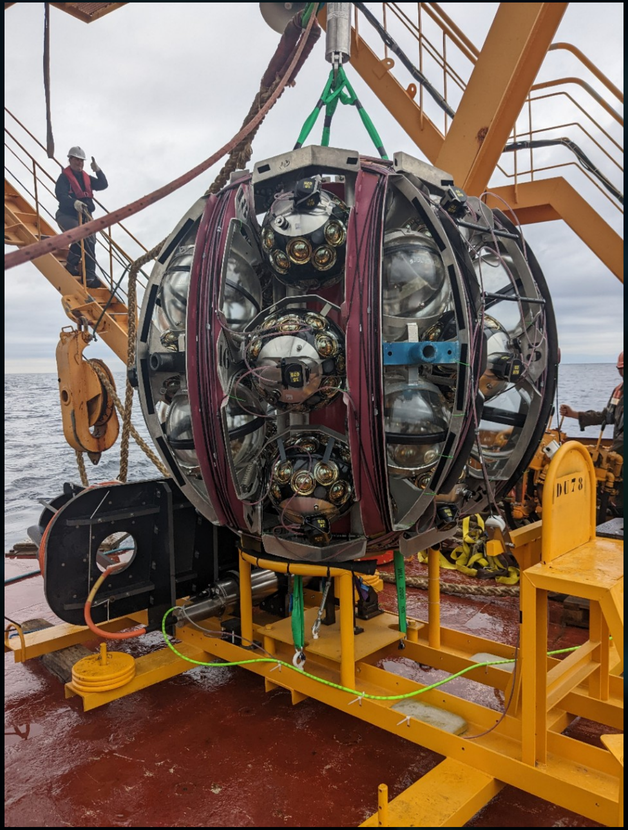
Deployment

Nik hef

KM3NeT

DOI: *10.1088/1748-0221/15/11/P11027*





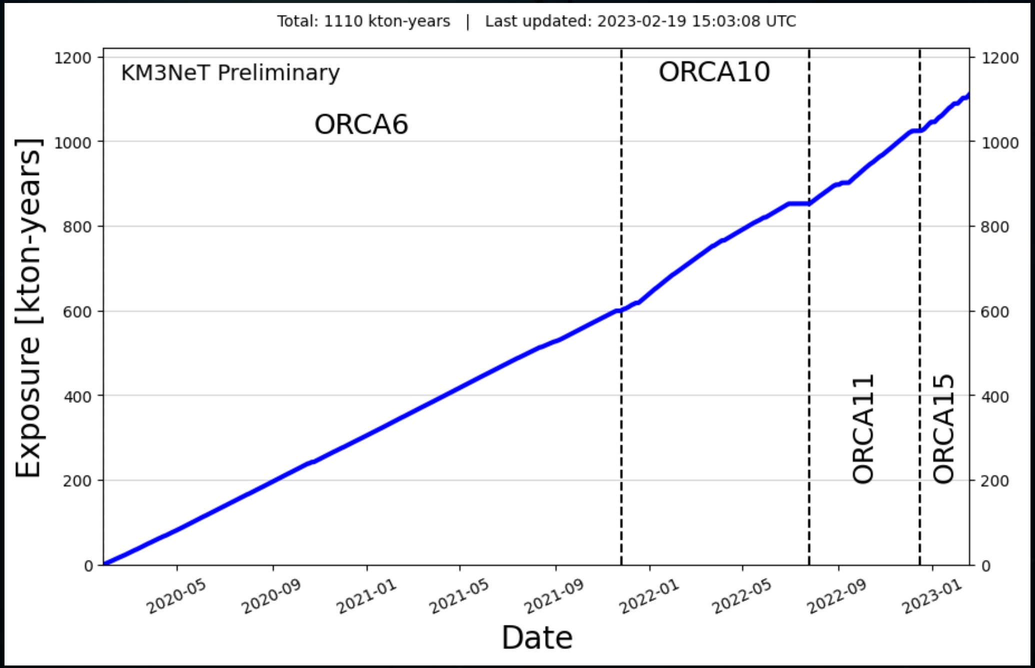
Fast deployment using reusable launcher modules

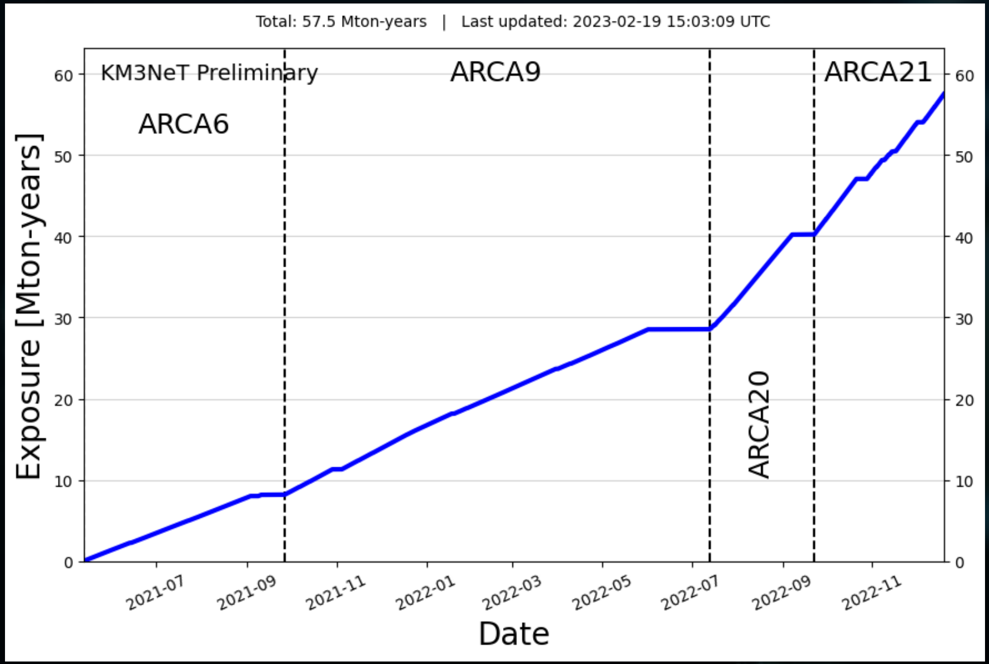
- Deployment via ship crane
- Sink to ocean floor using anchor
  - ~2.5 (3.5) km for ORCA (ARCA)
- Submarine for inspection + release
- Self-unfurling through buoyancy

→ **Multiple strings per campaign**

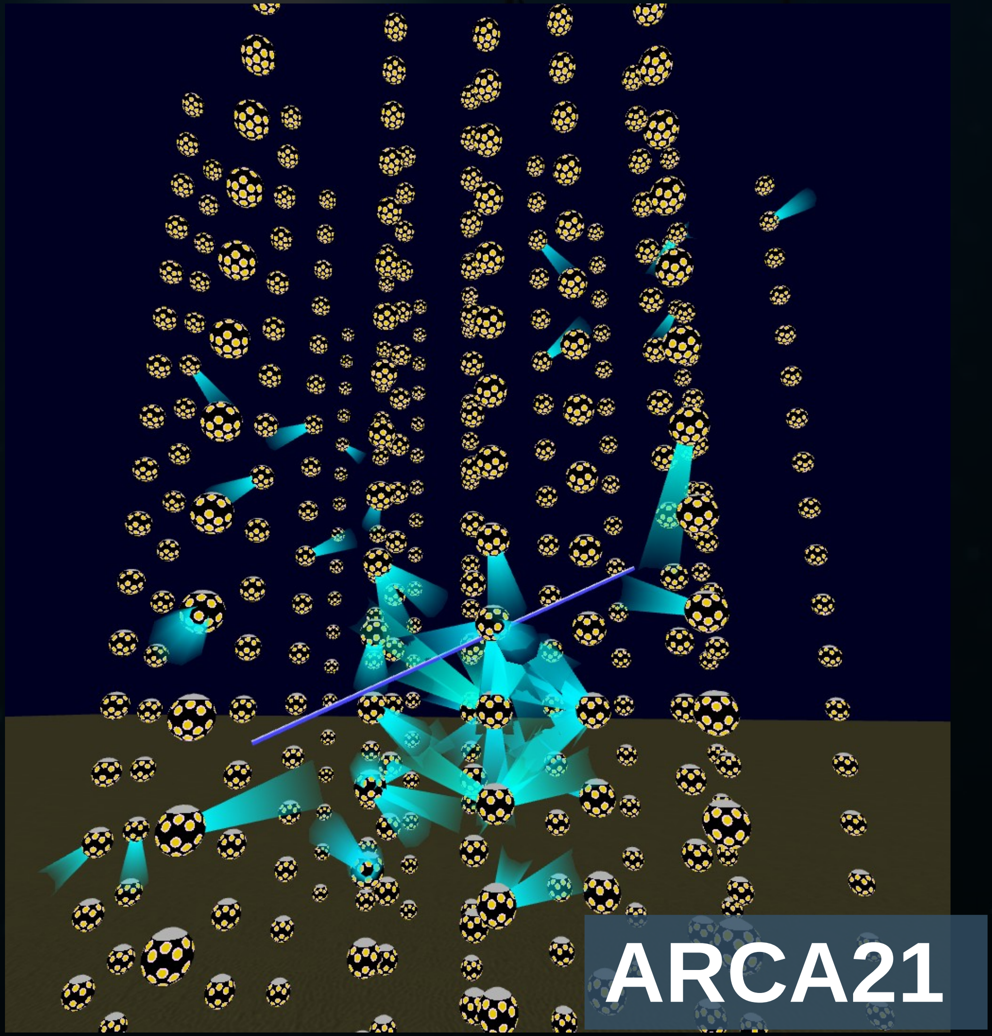
Cumulative exposure

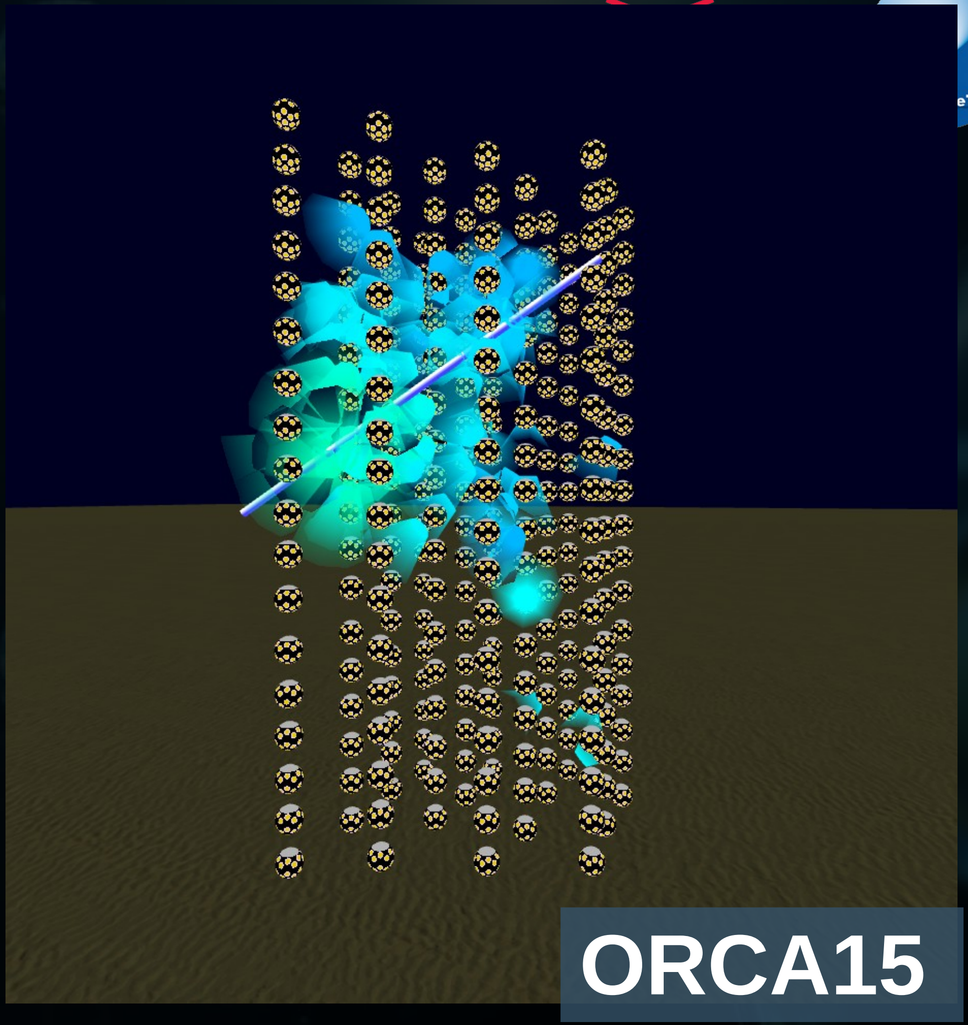
~10% of both detectors deployed as of January 2023
→ Already collecting useful data!





Figures by João Coelho


ARCA21


ORCA15

Absolute pointing

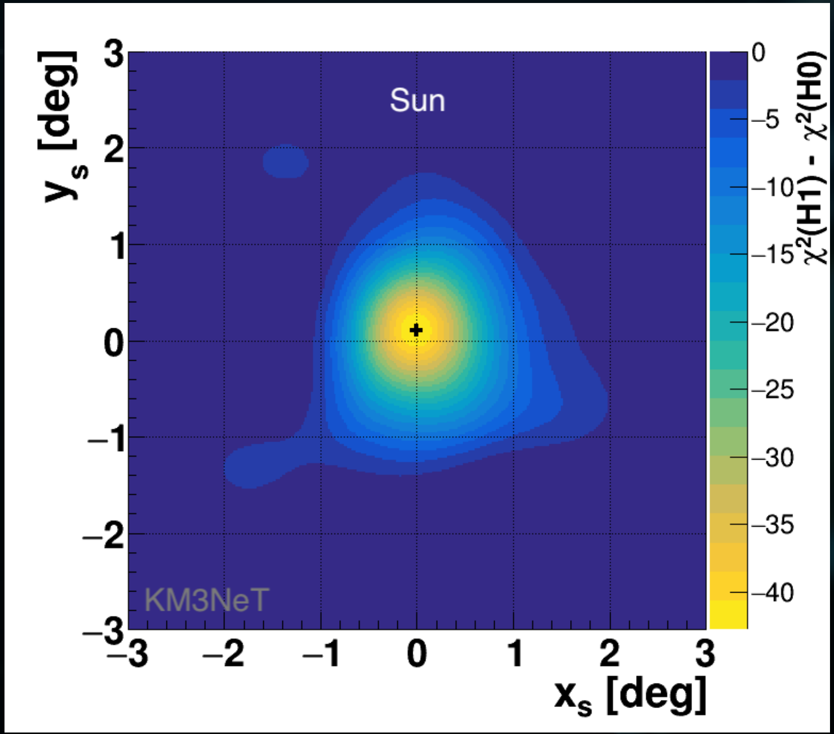
No reference light source
for absolute pointing

But Cosmic Ray shadows provide
natural calibration source!

= dip in observed CR flux behind
celestial bodies (Predicted by Clark in 1957)

→ Important for confirming pointing resolution!

arXiv:2211.08977



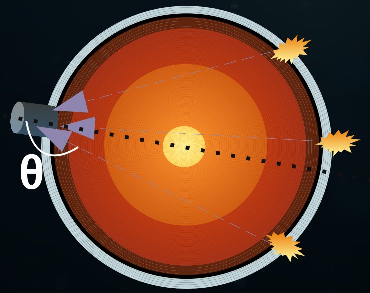
	Moon	Sun
Significance	4.2 σ	6.2 σ
Amplitude	0.71 ± 0.27	1.31 ± 0.34
Width	0.49° ± 0.15°	0.65° ± 0.13°

Oscillations Research with KM3NeT

Main goal: Establish **N**eutrino **M**ass **O**rdering (NMO)

Based on idea by Akhmedov et al.
(*DOI: 10.1007/JHEP02(2013)082*)

→ Huge atmospheric ν-detectors can distinguish NMO based on matter effects



Can probe vast range of L/E!

- Exploit matter resonances

$$P^{m}_{3\nu}(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\,\sin^2 2\theta^{m}_{13}\,\sin^2\left(\frac{\Delta^{m} m^2_{31} L}{4E_\nu}\right)$$

$$\sin^2 2\theta^{m}_{13} \equiv \sin^2 2\theta_{13}\left(\frac{\Delta m^2_{31}}{\Delta^{m} m^2_{31}}\right)$$

$$\Delta^{m} m^2_{31} \equiv \sqrt{\left(\Delta m^2_{31}\cos 2\theta_{13} - 2E_\nu A\right)^2 + \left(\Delta m^2_{31}\sin 2\theta_{13}\right)^2}$$

+ for ν; - for $\bar{\nu}$ in NO

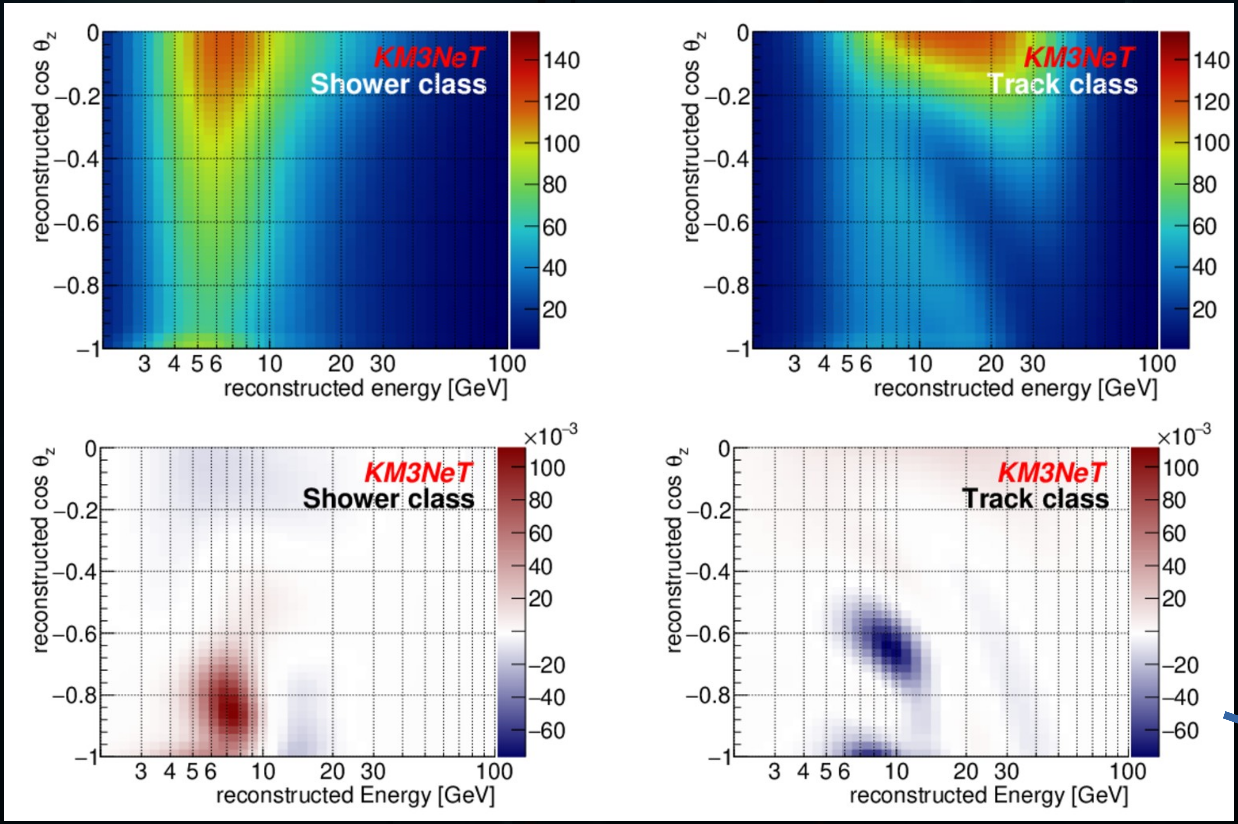
$$\Delta m^2_{ij} \equiv m^2_i - m^2_j$$

+ natural asymmetry σ_ν vs $\sigma_{\bar{\nu}}$ (~ 2:1)

➡ Net difference in expected atmospheric neutrino event rates between **N**ormal **O**rdering (NO) or **I**nverted **O**rdering (IO)

Oscillations Research with KM3NeT

DOI: 10.1140/epjc/s10052-021-09893-0



1) Simulate expected 3 yrs exposure event rate

2) Reconstruct events

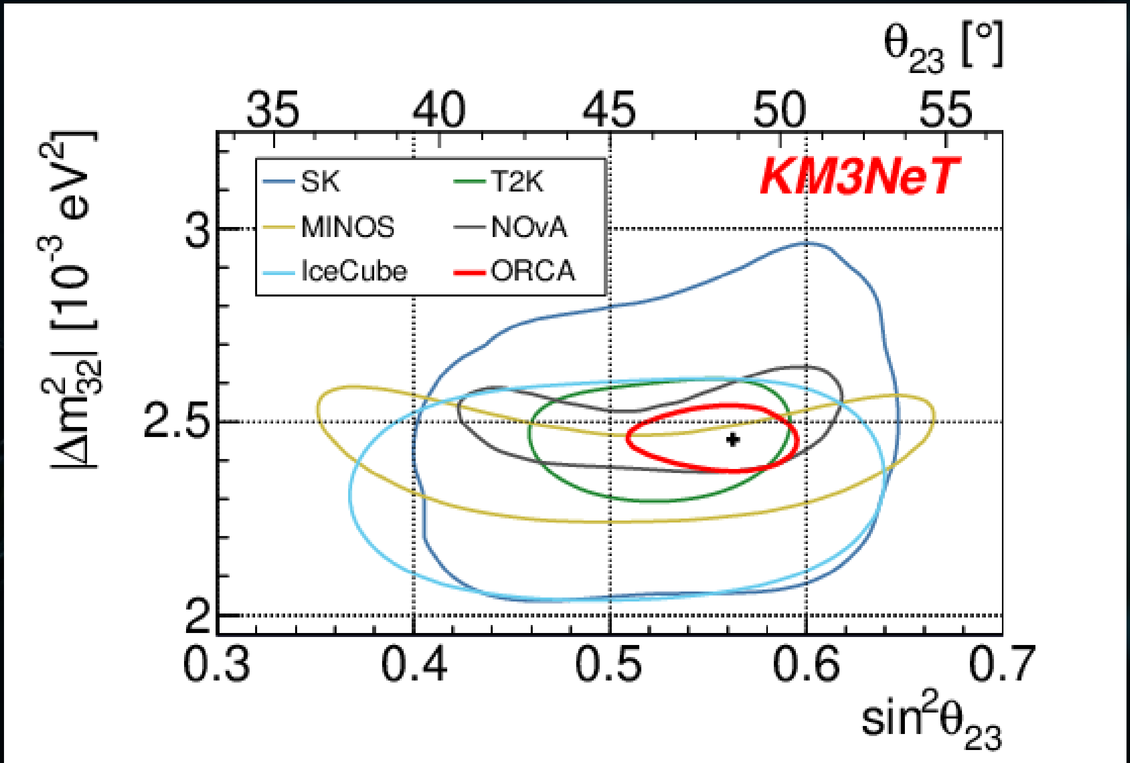
3) Classify events based on Random Decision Forests
   1) Remove noise + atmospheric $\mu^{\pm}$
   2) Classify neutrino event topology

4) Calculate Poissonian log-likelihood ratio of NO vs IO

Blue: $N_{NO} < N_{IO}$
Red: $N_{NO} > N_{IO}$

NMO sensitivity

DOI: 10.1140/epjc/s10052-021-09893-0



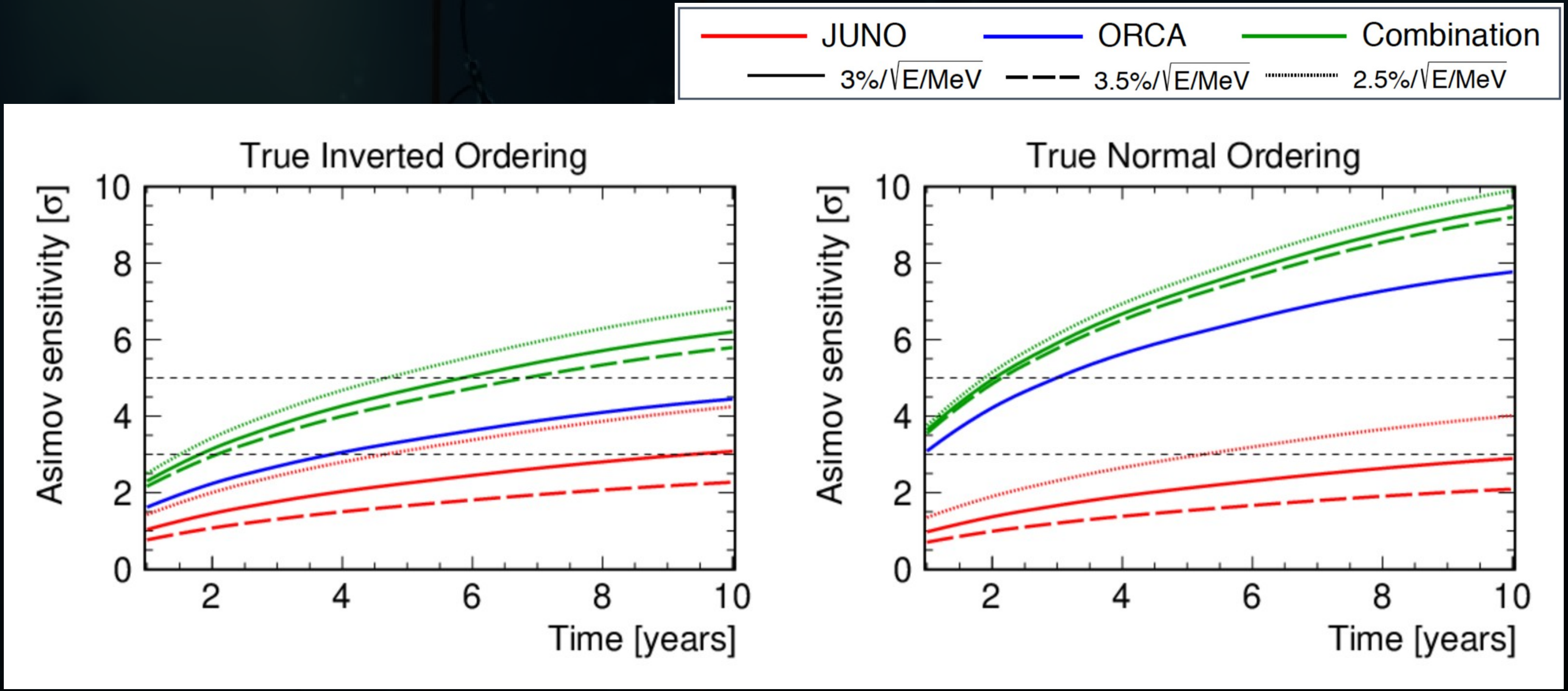
3σ NMO determination
in 1.3 (5) years if true NMO = NO (IO)

>95% CL constraint on θ_{23}-octant
after 6 years for $|\sin^2\theta_{23} - 0.5| < 0.05$

Combined NMO sensitivity

Great enhancement in combination with JUNO:
→5σ determination of NMO after 6 years

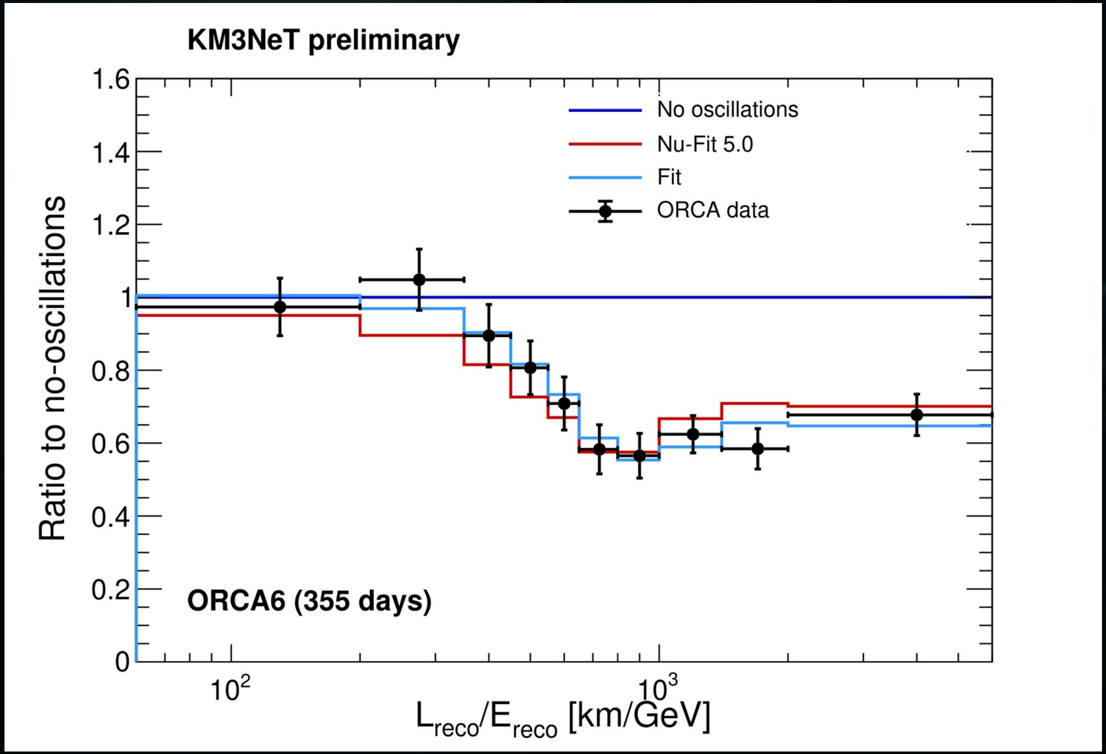
DOI: 10.1007/JHEP03(2022)055

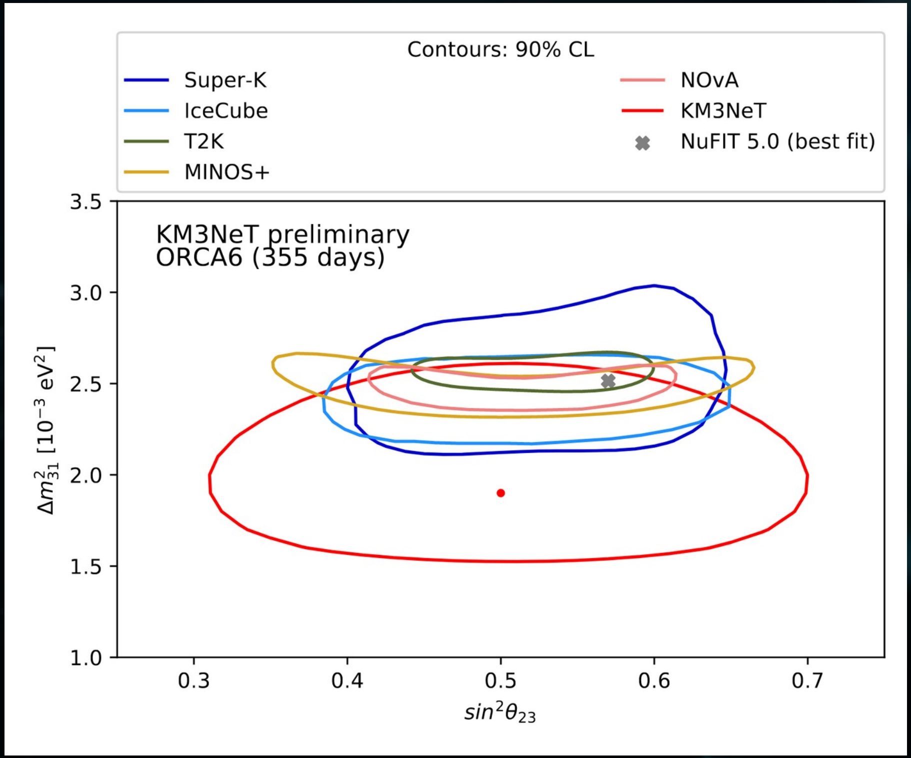


First measurements with ORCA6

First measurements with 355 days ORCA6 exposure were shown at ICRC 2021
Update will be shown at ICRC 2023

Ph.D. thesis, L. Nauta (2022)





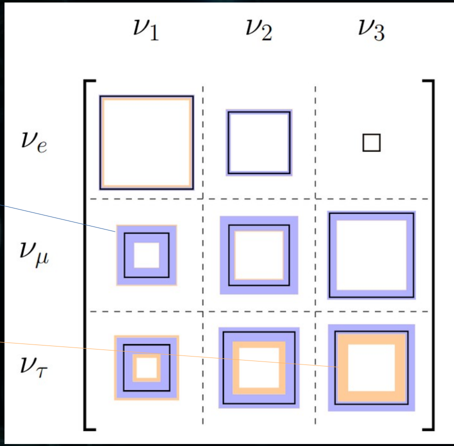
Tau-neutrino appearance

KM3NeT-ORCA will provide one of the largest atmospheric tau-neutrino datasets (>3k events / yr) !

Allows unprecedented constraints on ν_τ-normalisation (= observed / expected ν_τ rate)

→ Probe PMNS unitarity!

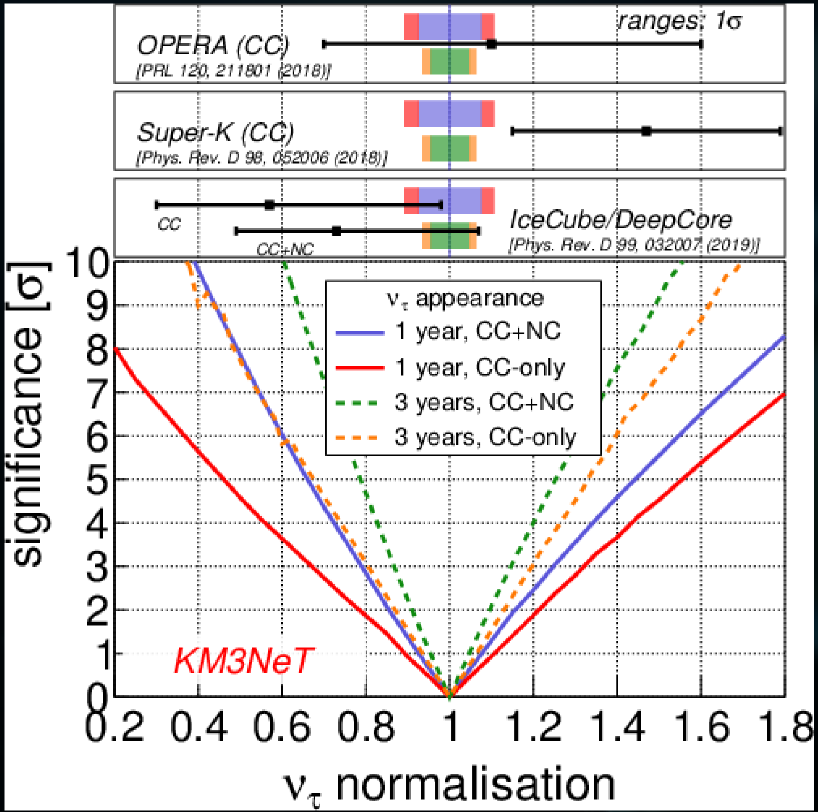
Ph.D thesis, S. Hallmann (2021)



Uncertainty with unitarity constraint

Uncertainty without unitarity constraint

DOI: 10.1140/epjc/s10052-021-09893-0

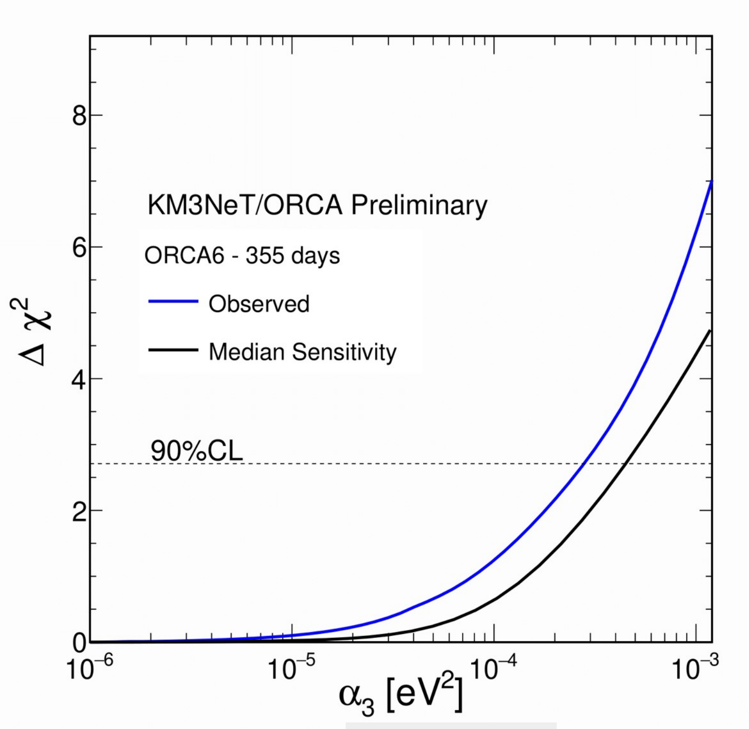


First constraints with ORCA6 @ ICRC 2023 !

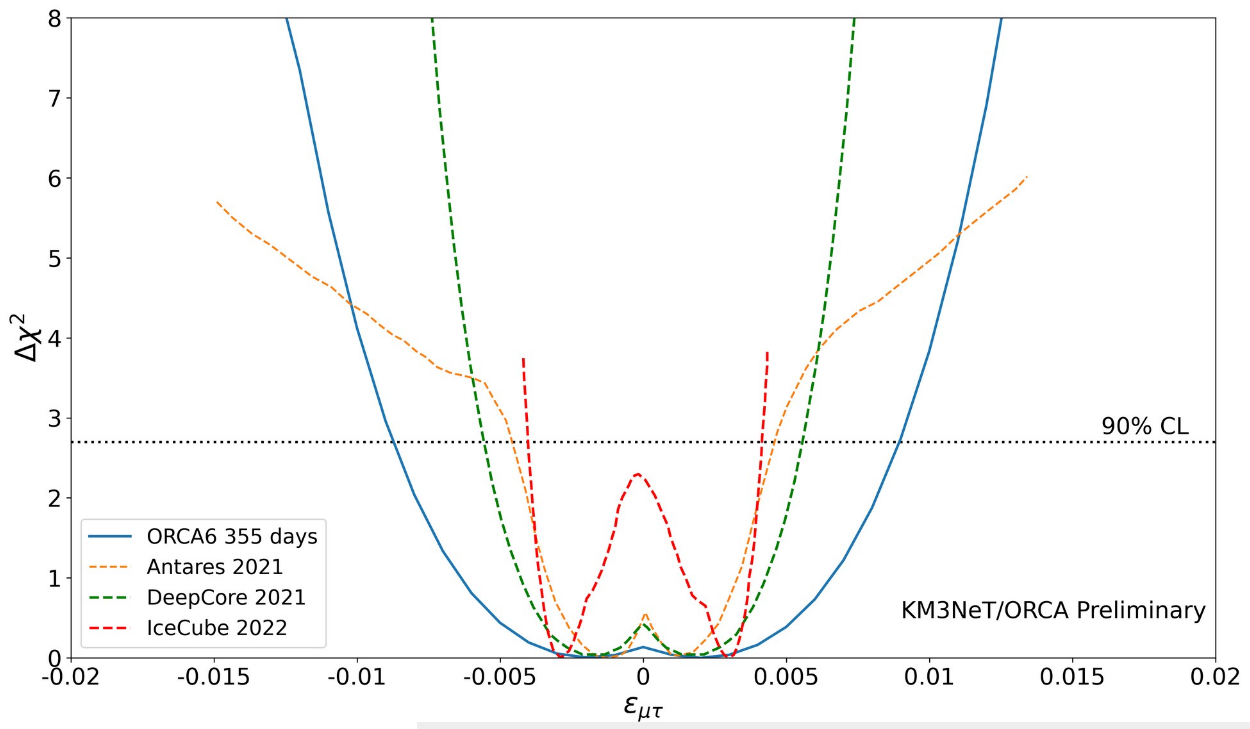
BSM neutrino physics

Competitive constraints for neutrino decay and for NSI with 355 days of ORCA 6 presented @ ICHEP 2022

DOI: 10.22323/1.414.0578



$= m_3 / \tau_3$



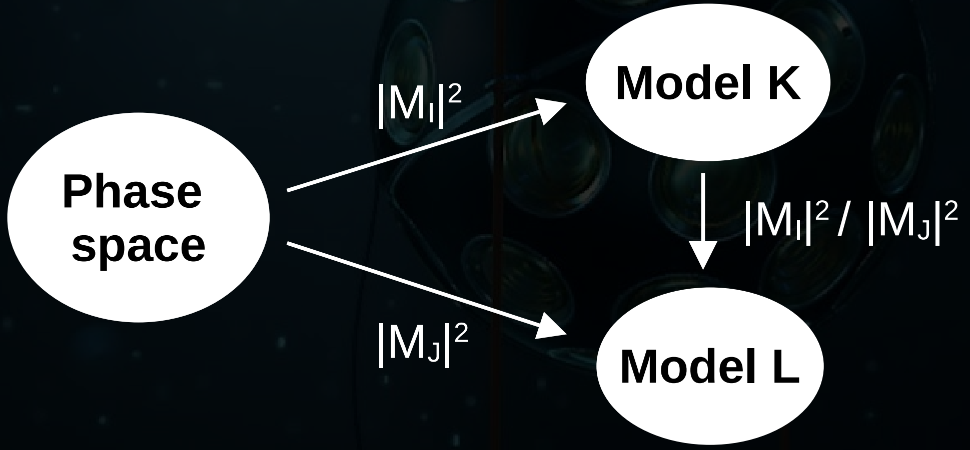
= effective coupling ν_μ + {e,d,u} → τ + {e,d,u}

My work: generic reweighting

Some studies require dedicated MC
E.g.: heavy neutral leptons, prompt muons from CR interactions, cross-sections…

Full detector response simulation can be prohibitive

Possible solution offered by generic reweighting on MC-truth information
(c.f. *DOI 10.1007/JHEP10(2014)078*)



First generic applications for muon- & neutrino-MC reweighting have been set up

Working on proof of concept with tau-neutrino normalisation

Conclusions

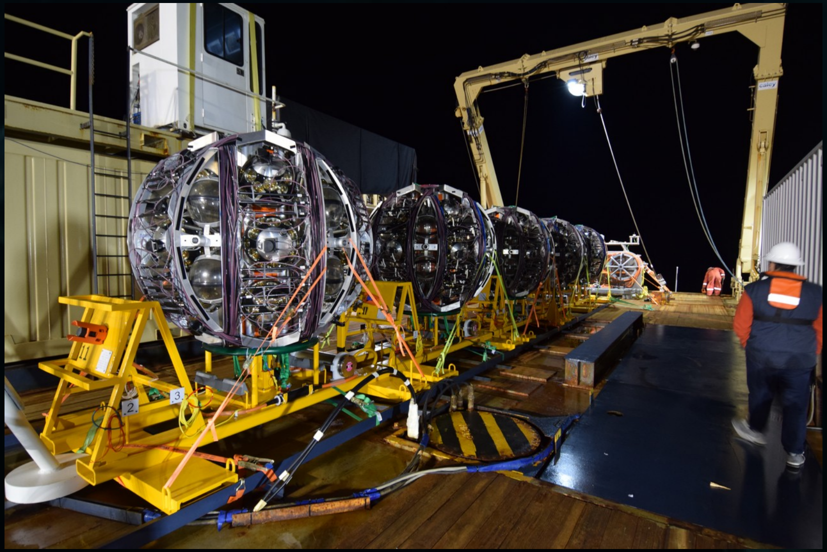
KM3NeT has entered mass production stage
with stable expansion rate

>10% of expected building blocks deployed as of Jan. 2023

Already taking data since the very first lines

First scientific results presented

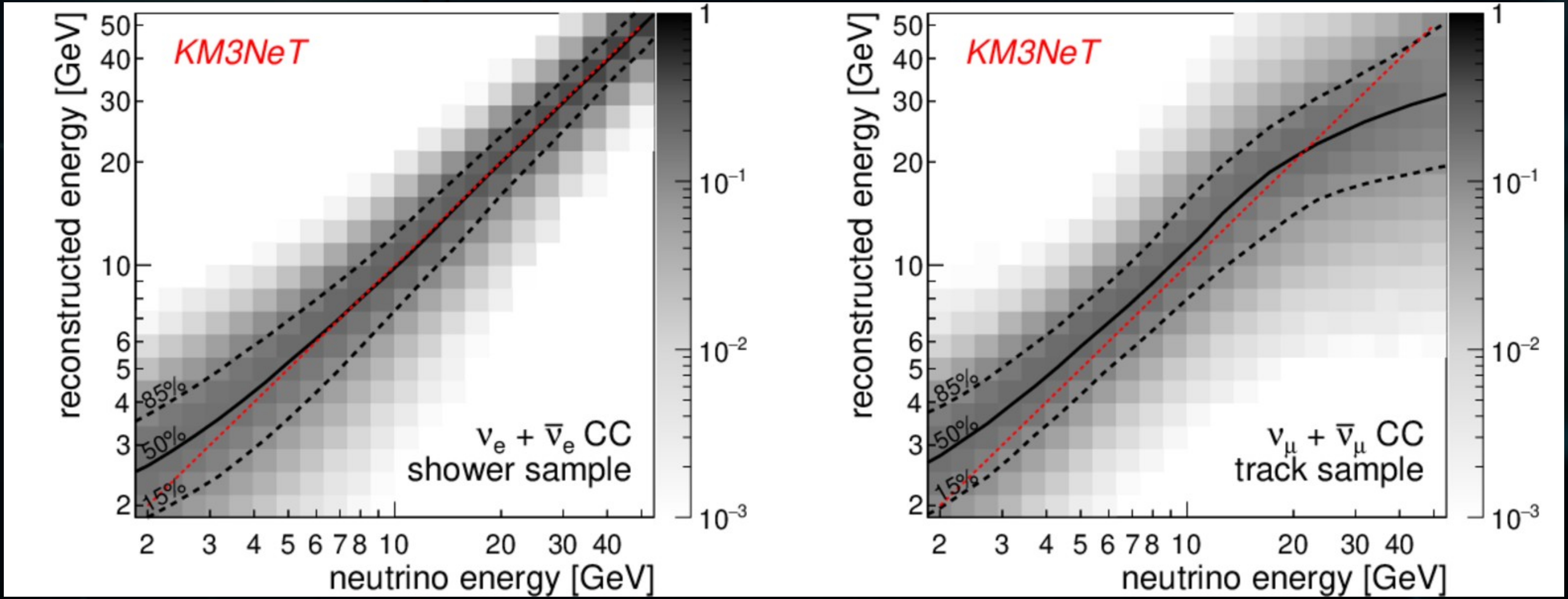
Much more to come!



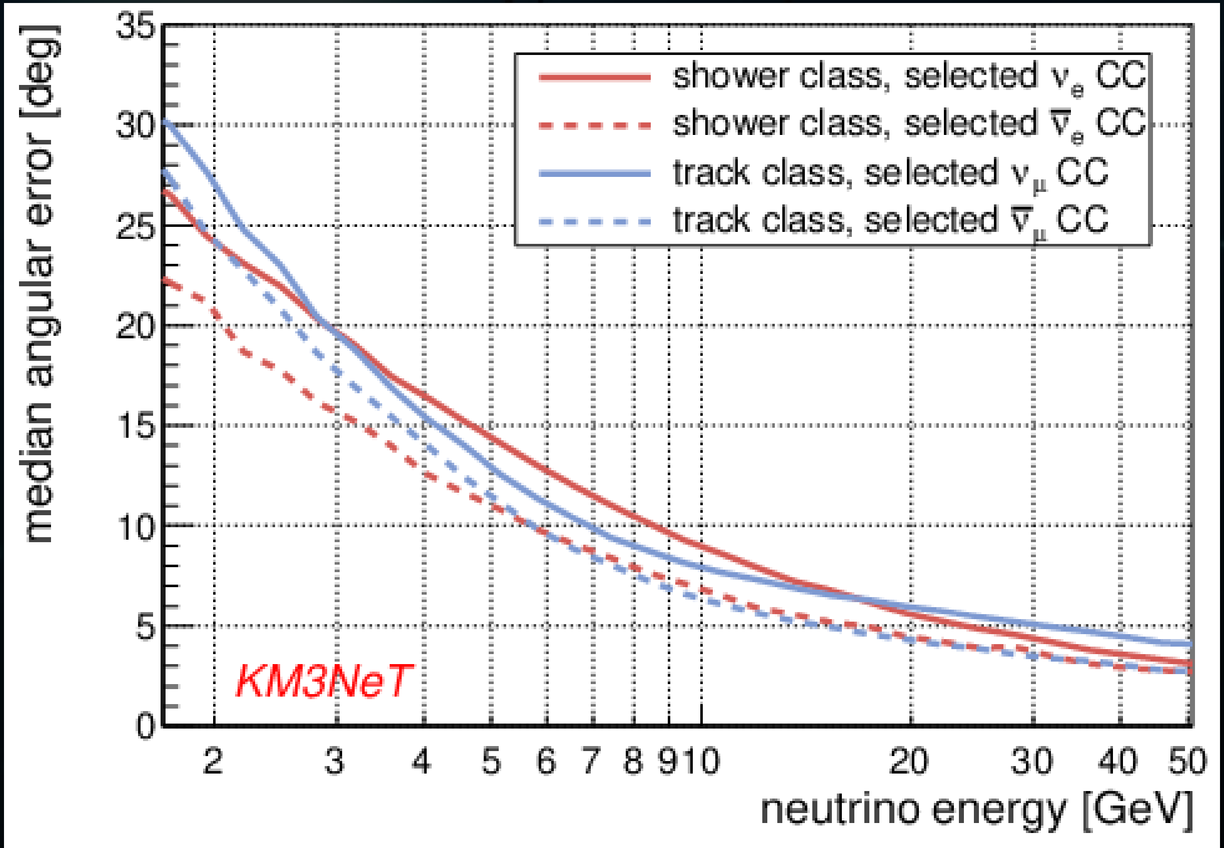
EXTRA

Detector Performance

$\Delta E / E \sim 25\%$ for ν_e @ 10 GeV
$\Delta E / E \sim 35\%$ for ν_μ @ 10 GeV

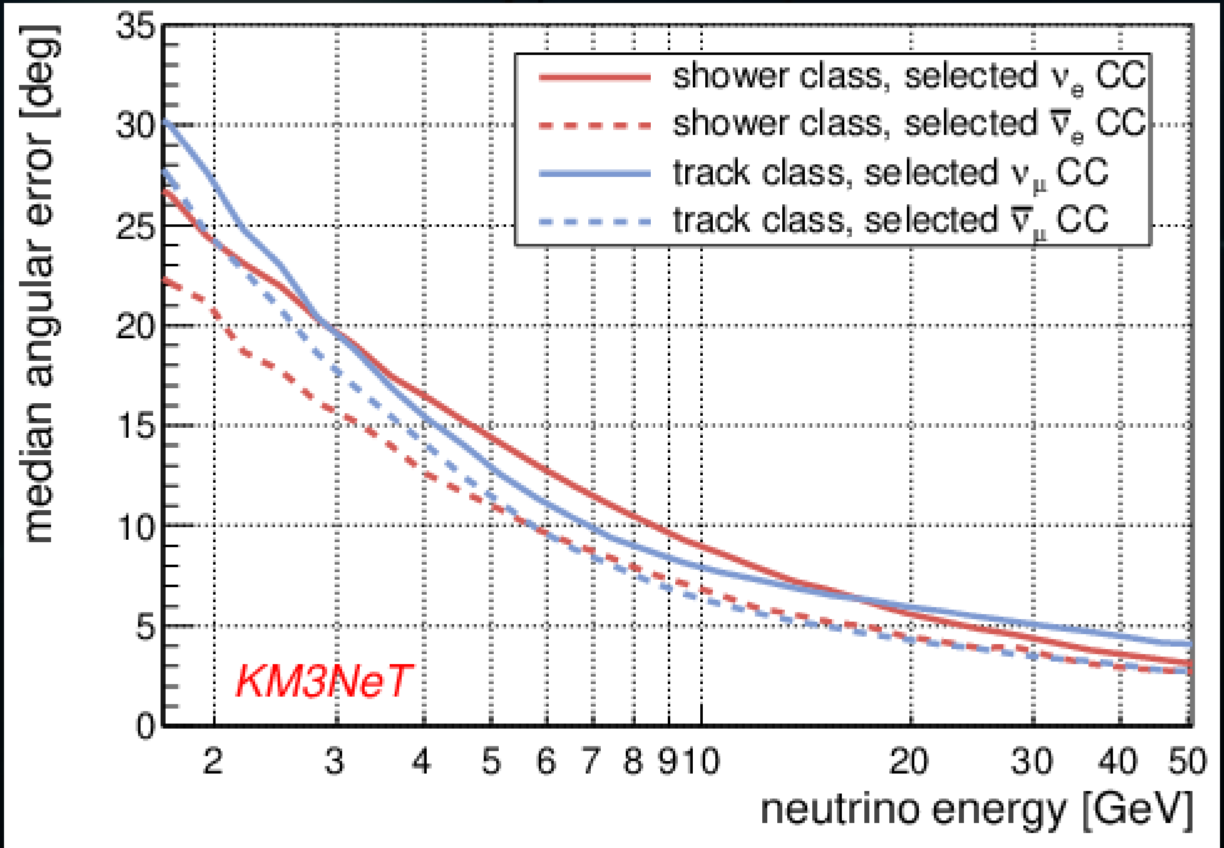


Detector Performance



9.3° / 7.0° / 8.3° / 6.5°
for ν_e / $\bar{\nu}_e$ / ν_μ / $\bar{\nu}_\mu$ @ 10 GeV

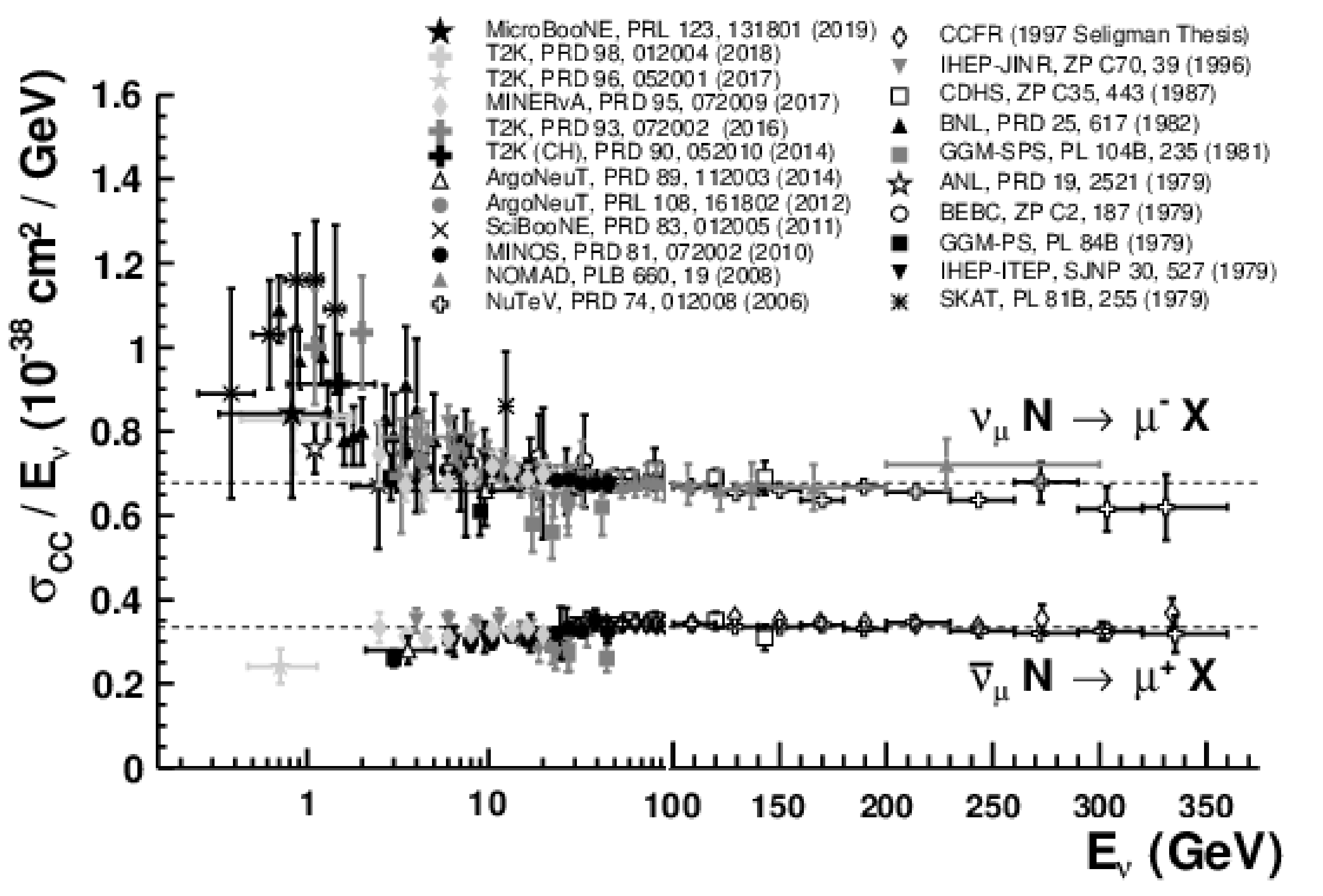
Detector Performance



9.3° / 7.0° / 8.3° / 6.5°
for ν_e / $\bar{\nu}_e$ / ν_μ / $\bar{\nu}_\mu$ @ 10 GeV

Neutrino cross-sections

PDG figure 52.1

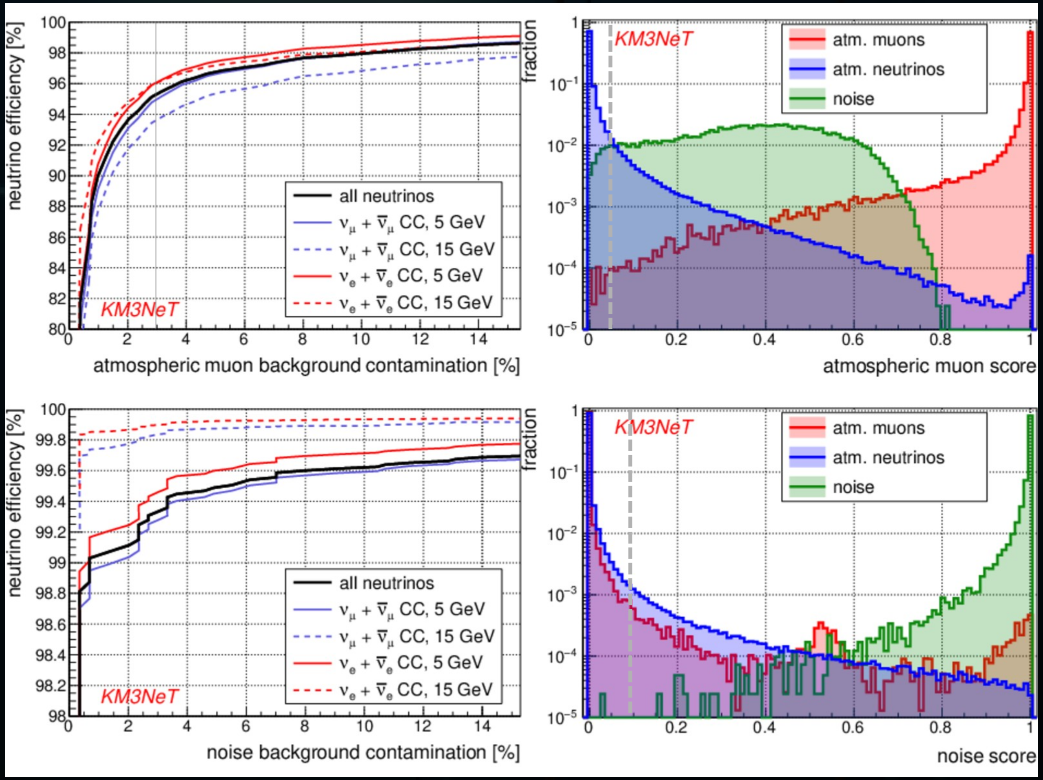


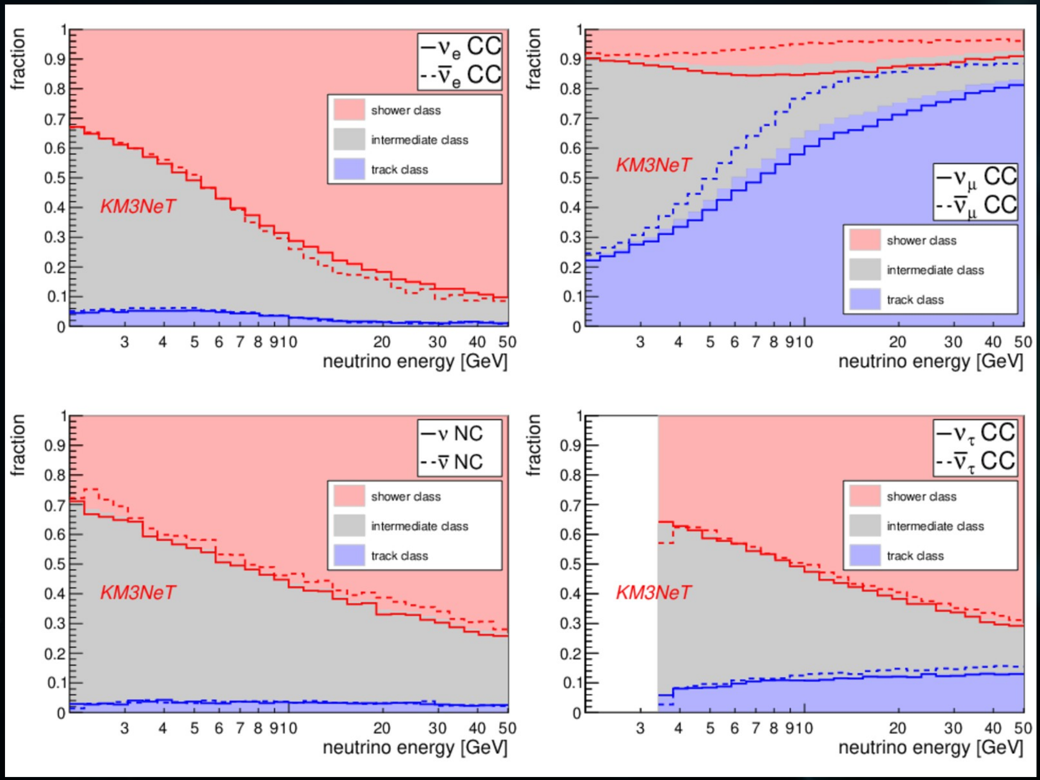
$$\sigma_\nu : \sigma_{\bar{\nu}} \sim 2 : 1$$

Event classification

Particle Identification based on Random Decision Forests; 3 scores:

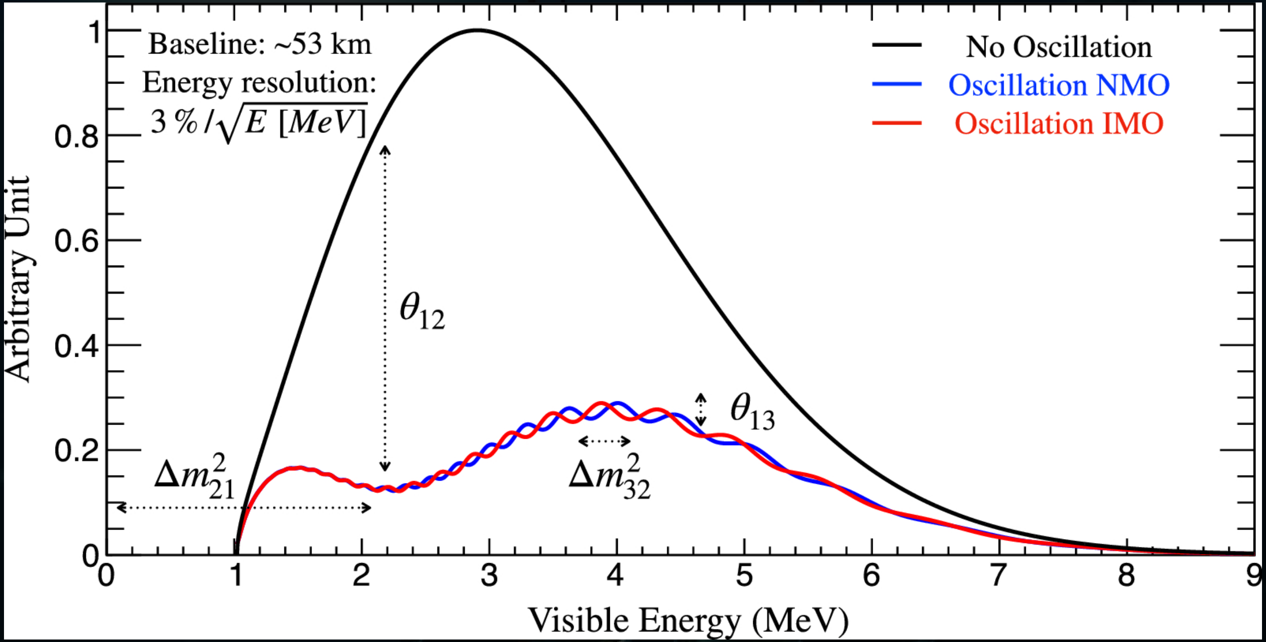
1) muon score, 2) noise score, 3) track score





JUNO status

DOI: 10.1016/j.ppnp.2021.103927

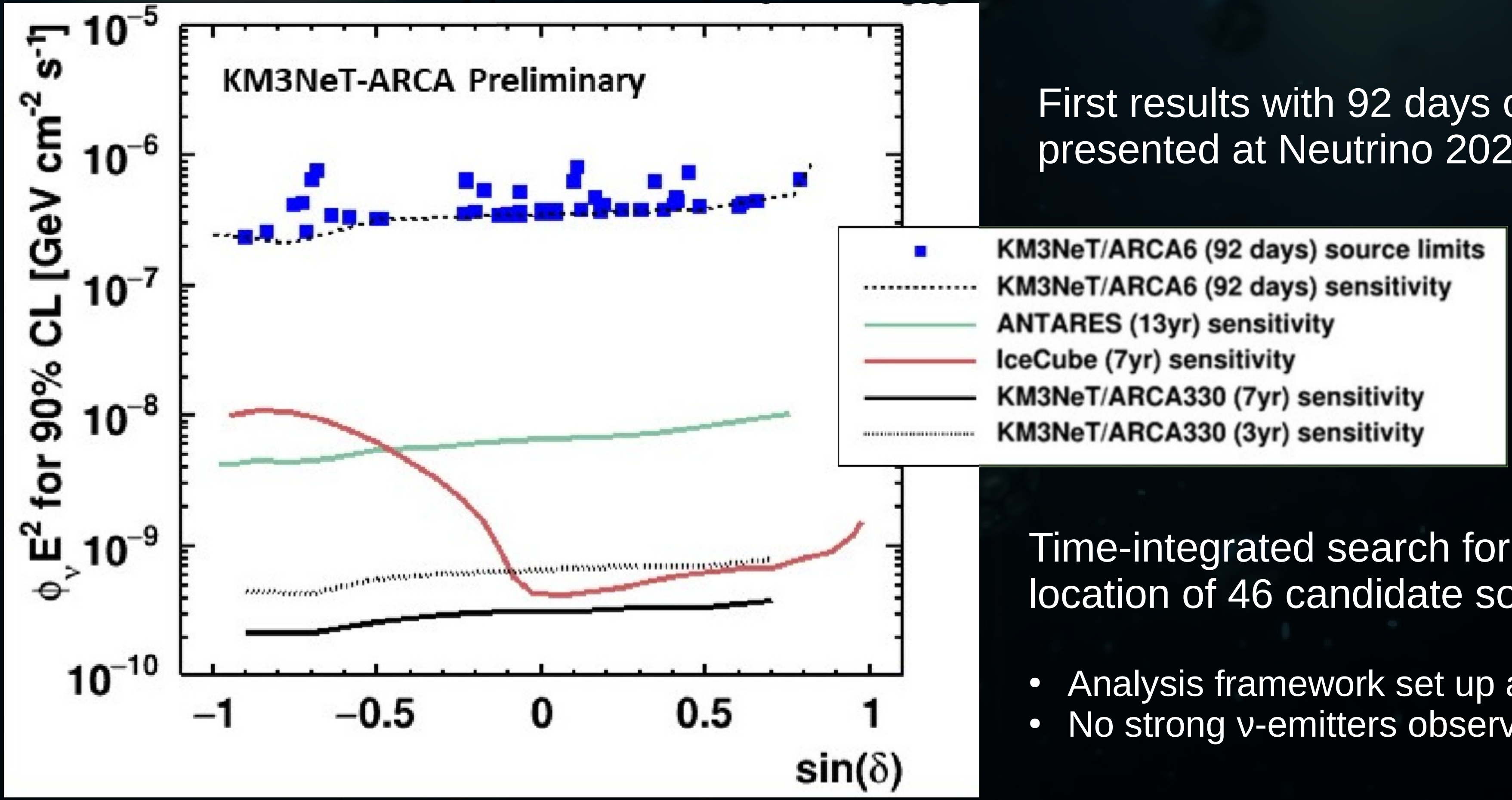


Summer 2022

approved	civil construction	detector construction	detector completion
2013	*2015*	*2022*	*2023*

From *ICHEP 2022 talk* by Jie Cheng

Cosmic neutrino point searches



First results with 92 days of ARCA 6 presented at Neutrino 2022 (P0745)

Time-integrated search for ν-excess at location of 46 candidate sources

- Analysis framework set up and working
- No strong ν-emitters observed yet

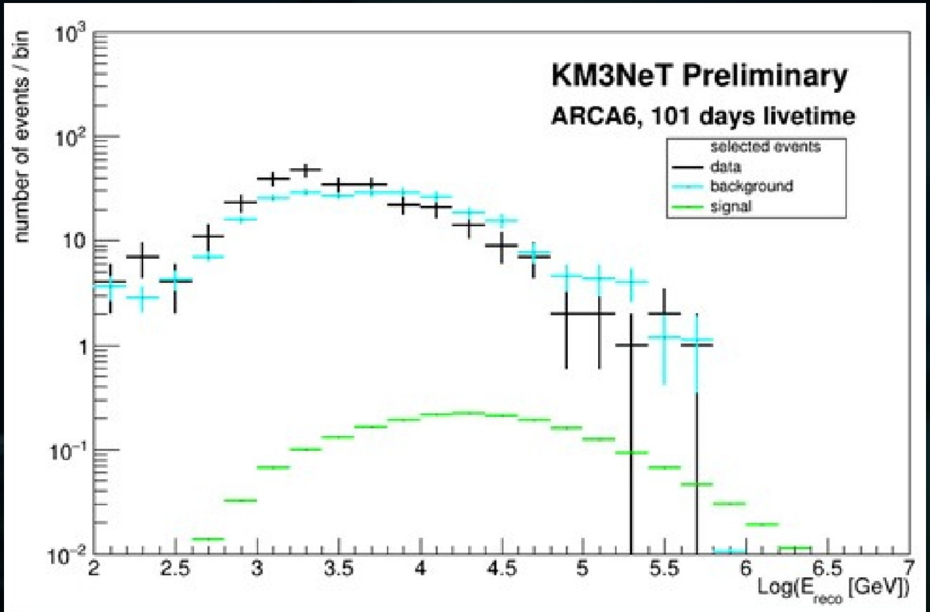
Diffuse cosmic neutrino flux

Carries information about cosmic rays:

- Production mechanism
- Acceleration mechanism
- Composition

First study with 101 days of ARCA 6 presented at Neutrino 2022 (P0173)

- No high-energy excess of neutrinos observed
- Results compatible with background



Sensitivity and discovery potential assuming ICRC 2019 IceCube diffuse cosmic neutrino flux

For the diffuse cosmic neutrino flux of [2]: $1.44 \times 10^{-18} (E/100\text{TeV})^{-2.28}$ [$\text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$]		Number of events
$\Phi_{90\%CL}$ [$\text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$]	$\Phi_{5\sigma}$ [$\text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$]	$N_{atm.mu\&nu} = 68.4$
17.3×10^{-18}	51.4×10^{-18}	$N_{cosmic\ nu} = 1.3$

Galactic Ridge

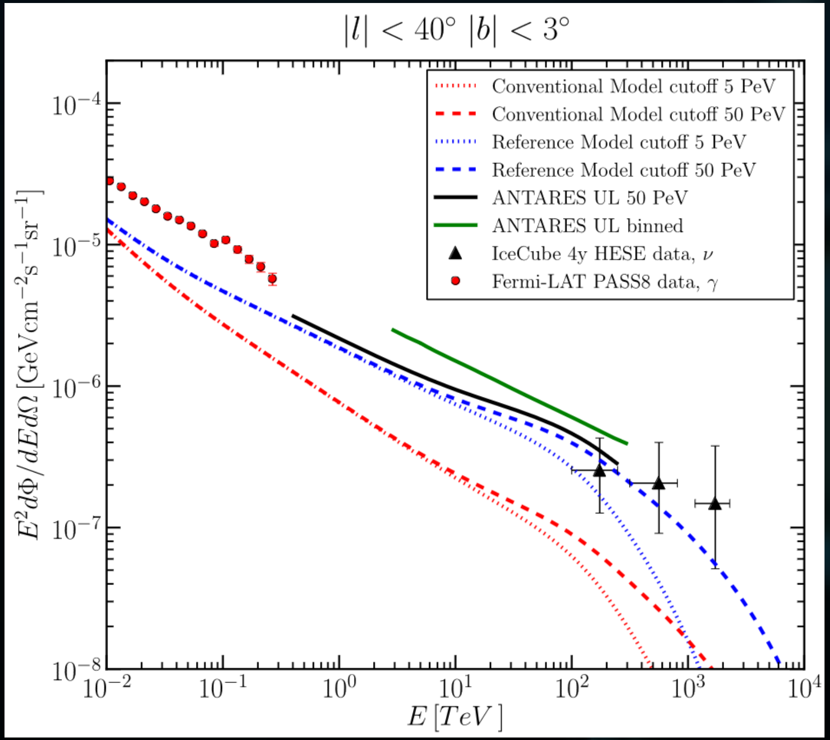
Search for ν from CR interactions in interstellar medium

First results with 100 days of ARCA6 presented at Neutrino 2022 (P0173)

- Small excess found, but not significant
- → flux upper limit of < 6.2 x 10-4 GeV-1 cm-2 s-1 sr-1

Simulated signal flux 1.2×10^{-8} (E/1GeV)$^{-2.4}$ [GeV $^{-1}$ cm^{-2} s^{-1} sr $^{-1}$]	
MC simulated signal in ON region	1.81×10^{-4}
Background events: mean over 9 OFF regions (sum)	4.3 (39)
ON region events:	8

DOI: 10.1103/PhysRevD.96.062001



Further neutrino astronomy

Many more studies ongoing:

- Starburst diffuse analysis
- Combined γ-ray + ν analysis
- Gamma-Ray Burst (GRB) analysis
- Periodic source analysis
- Gravitational Waves follow-ups
- Online direct follow-ups
- Core-Collapse Supernova Neutrinos
- …
-