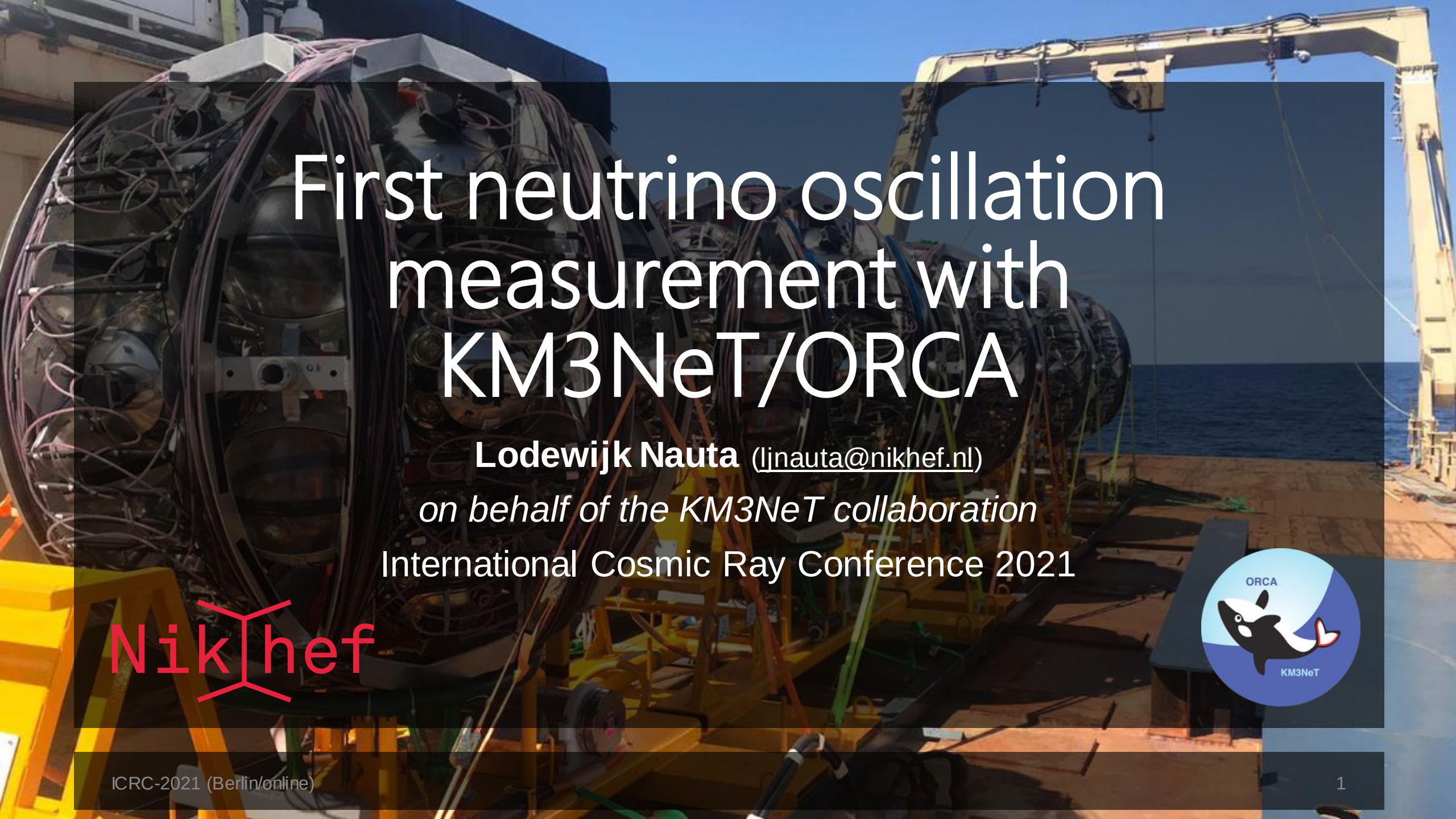


First neutrino oscillation measurement with KM3NeT/ORCA

Lodewijk Nauta (ljnauta@nikhef.nl)

on behalf of the KM3NeT collaboration

International Cosmic Ray Conference 2021

Nikhef

KM3NeT/ORCA detector

KM3NeT detectors

- Water based Cherenkov telescopes
- Neutrino interactions result in charged particles emitting Cherenkov radiation
- Deployed in Mediterranean Sea at depths >= 2.5km

ORCA is designed for low energy

- Interactions from **atmospheric neutrinos**
- Projected **full detector in 2025**
- **Main goal**:
  measure neutrino mass ordering

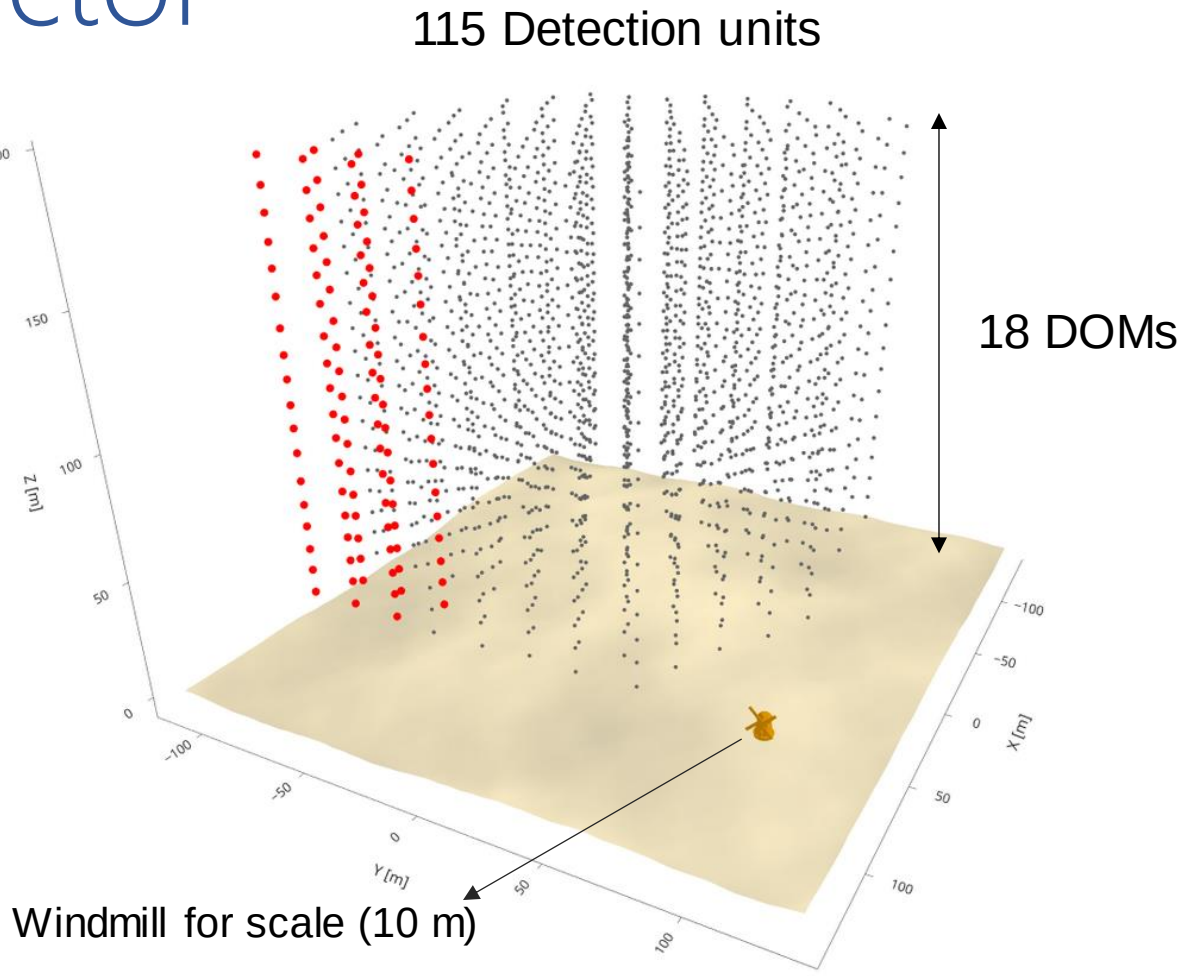
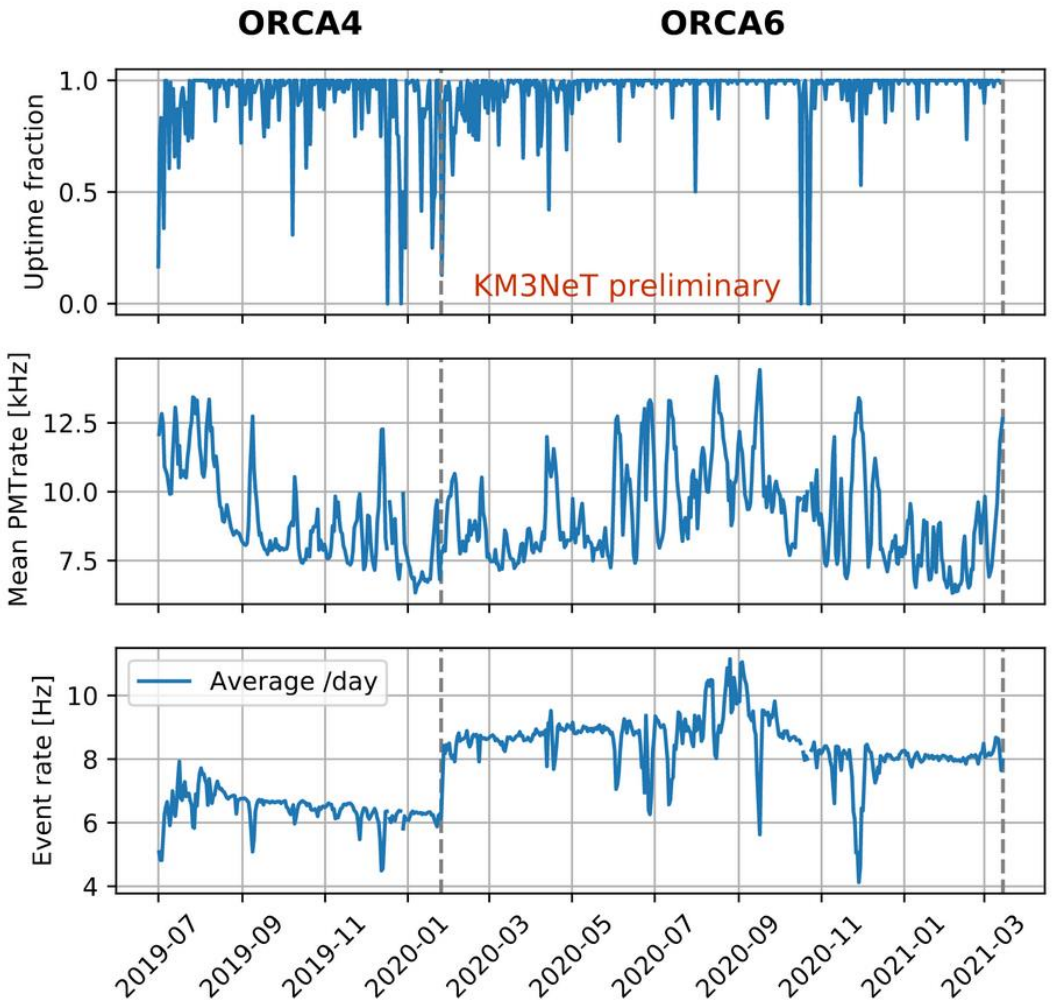


Figure: The full ORCA detector in black, in red the currently deployed ORCA6 strings.

Data taking with ORCA

- **Steady data taking** since 2019 with 4 Detection Units (ORCA4)
- Early 2020: 6 DUs (ORCA6)
  - Detector size increase visible in rate increase
- **Efficient** data taking:
  - 96% uptime
  - 92% passes run selection
- ORCA4 exposure: 191.9 days
- ORCA6 exposure: 385.8 days



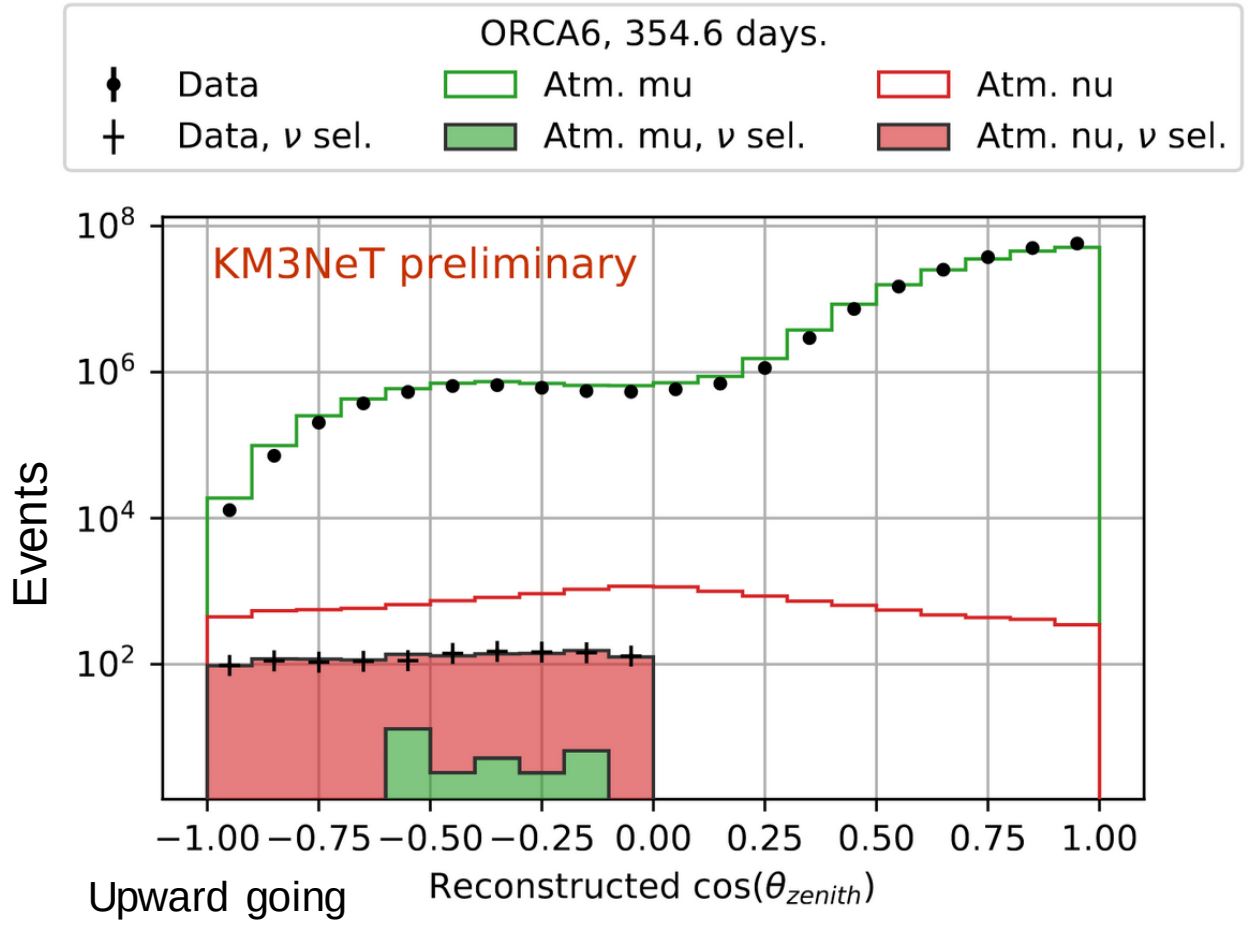
Selection criteria and cuts

- Run selection:

  ORCA6 354.6 days (out of 385.8 days)

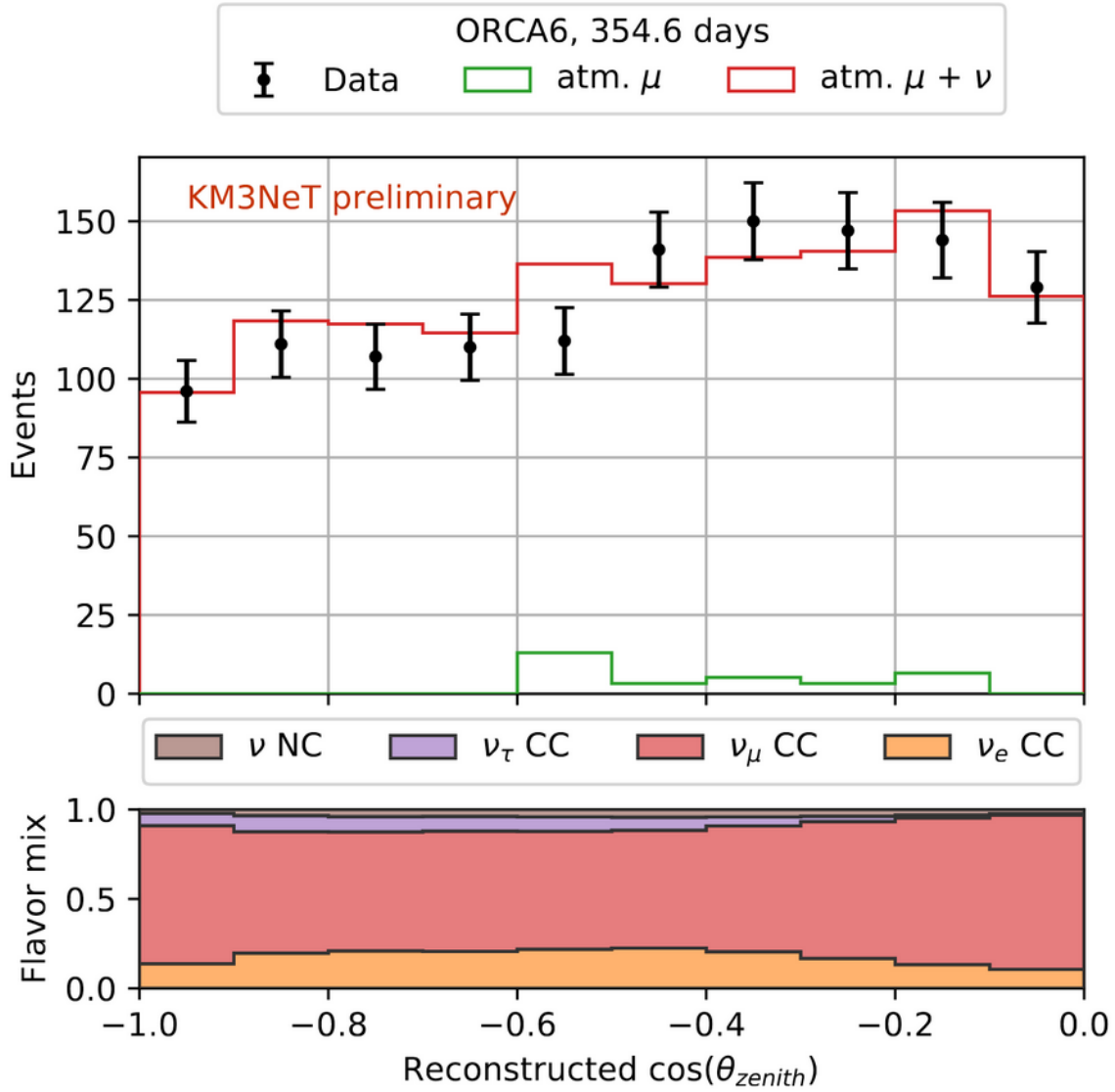
- Containment cuts
- Reconstruction quality cuts
- Physics cuts

  1237 neutrino candidates



Data / MC comparison: Zenith angle

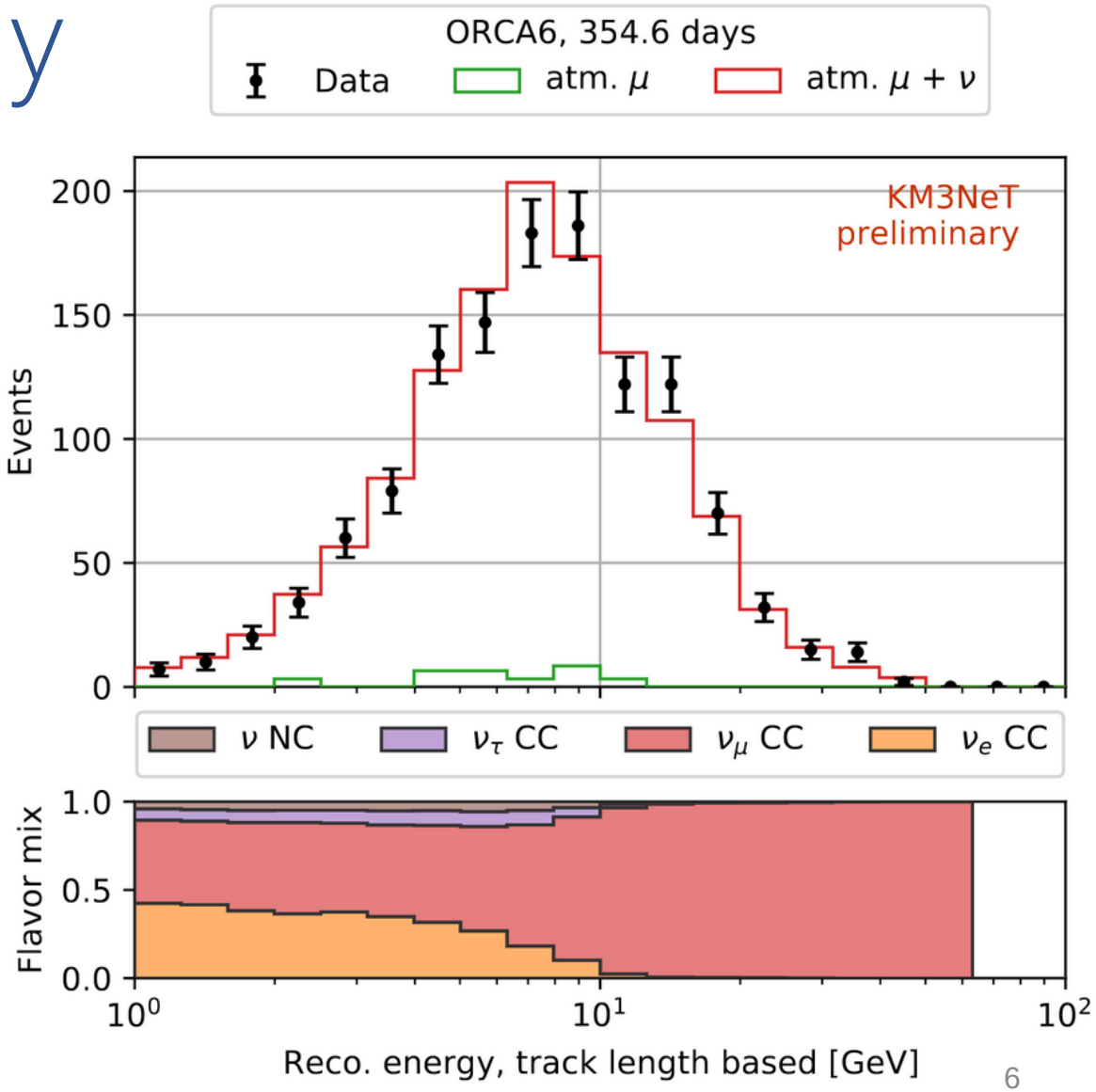
- **Good Data / MC agreement**
- Small set of muons that pass cuts: very **clean signal**, S/B = 40
- ν_τ appears at significant distances
- Only **track hypothesis** is currently used: signal dominated by $\boldsymbol{\nu_\mu}$



Data / MC comparison: Reconstructed energy

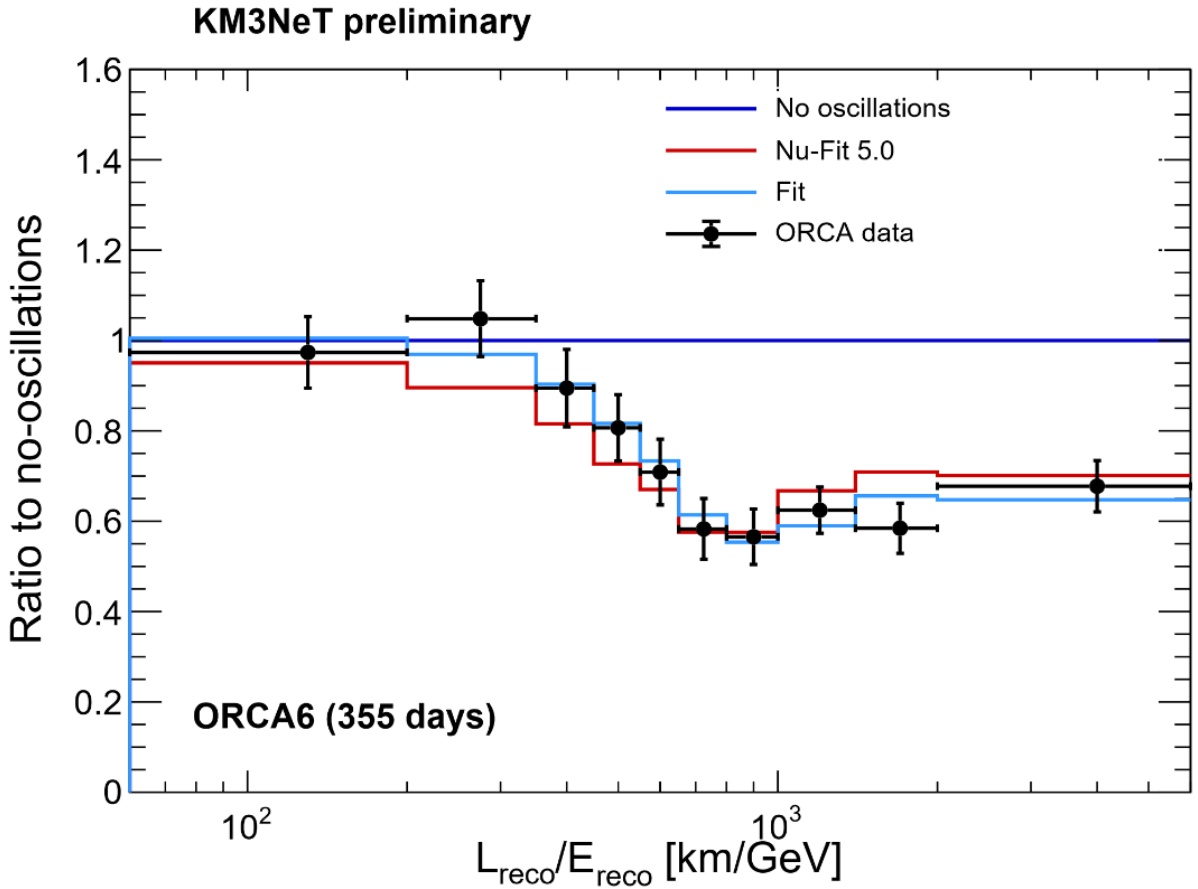
Strong **dependence** on **shape** of detector:

- Light capture is **limited** by size and shape of detector
- The detector shape is "very **vertical**"
- **Peak** at 10 GeV comes from horizontal detector size
- **Tail** towards 50 GeV comes from more vertical events



Neutrino oscillation pattern

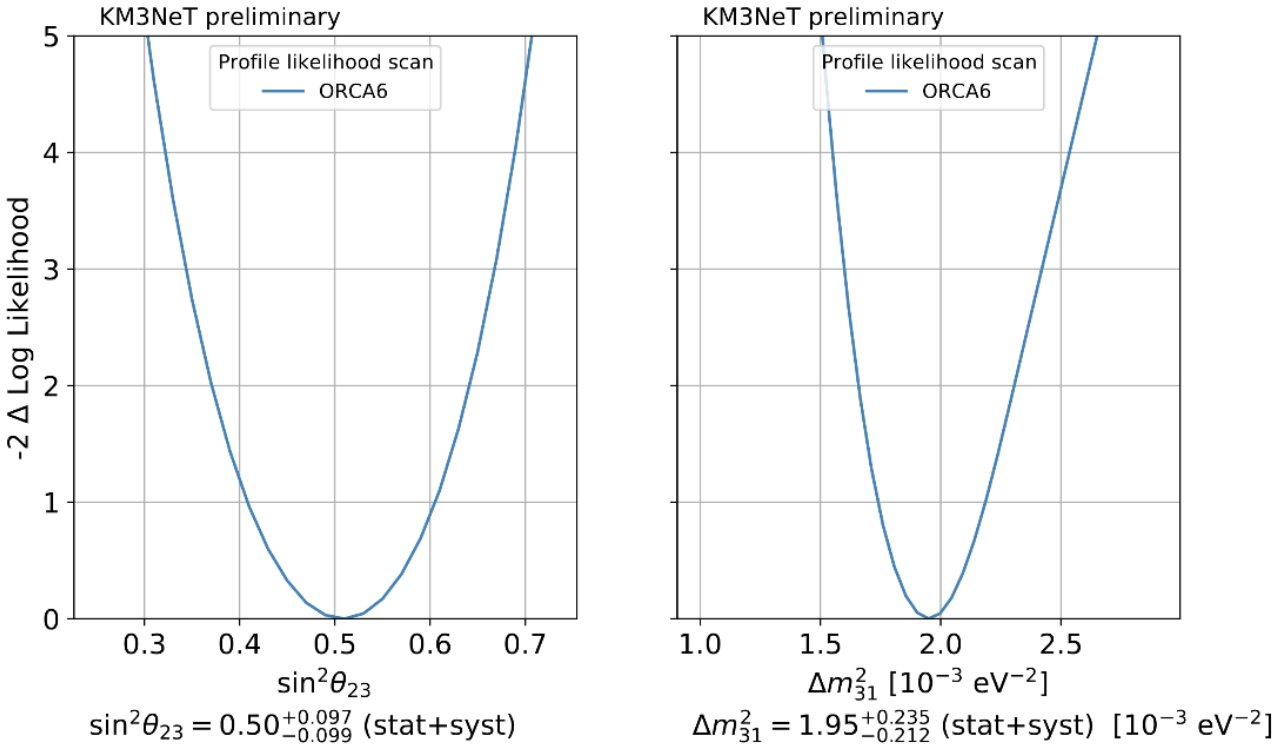
- No oscillations vs oscillations (normal ordering)
- **Ratio** with respect to 'no oscillations'
- Binning is chosen to have similar statistics per bin
- Dip is at **larger L/E** than Nu-Fit 5.0
- Calculate $\Delta\chi^2$ for ORCA6: preference to oscillations of **5.9 σ**



Likelihood scan

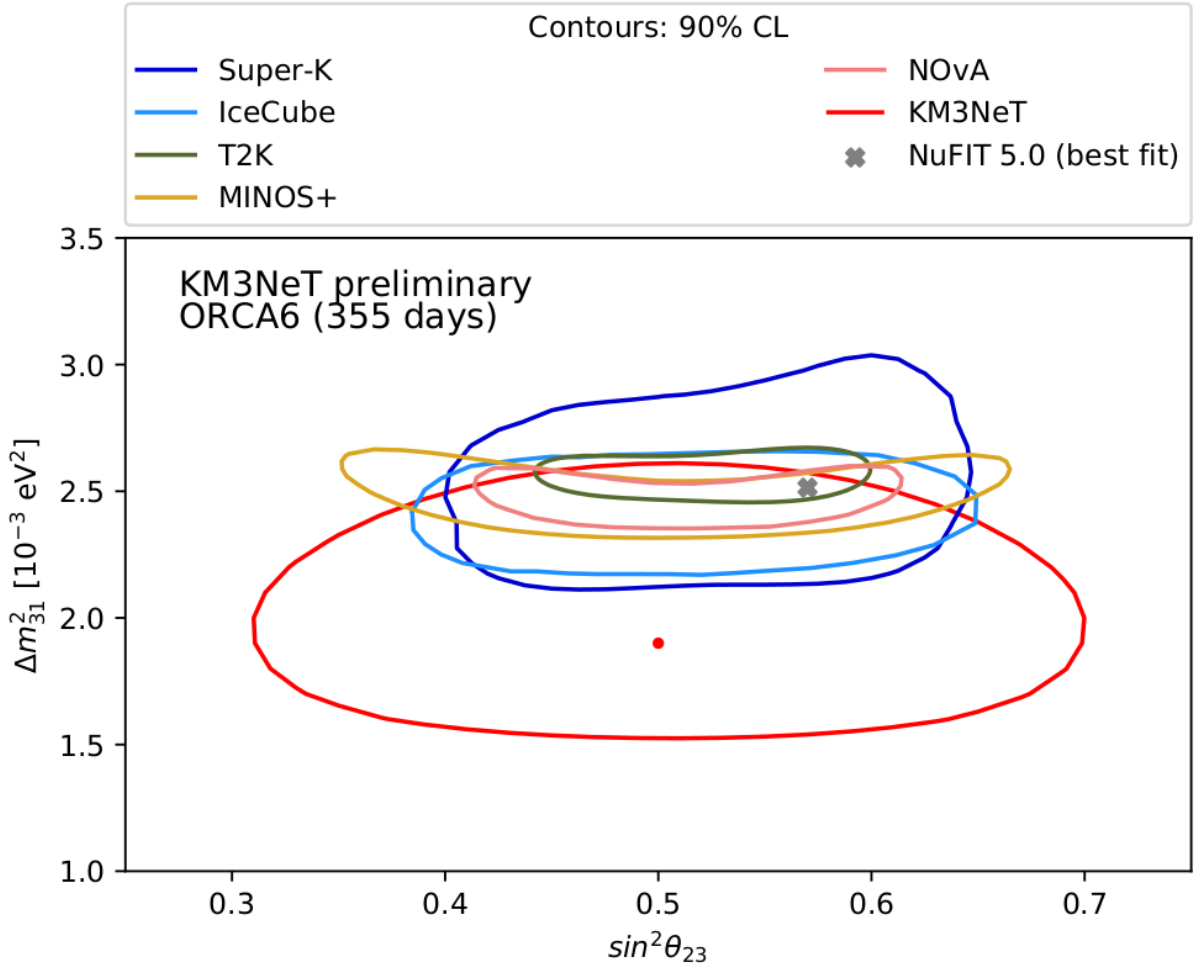
- Sensitivity to oscillation parameters
- Profiled: minimize all nuisance parameters at sampled points, this results in the most **conservative** NLL estimate
- Includes systematic uncertainties

- The Nu-Fit best fit point is 1.9 σ away from the found minimum



Sensitivity to neutrino oscillations

- Systematics include
  - Flux
  - Cross-section
  - Detector systematics
  - Overall normalization
- ORCA6 is **becoming competitive** with other experiments
- Nu-Fit point is **within 90% CL** of current KM3NeT analysis
- Shower channel is **not** included yet



Summary & outlook

Summary:

- **5.9 σ** preference of **oscillations** over no oscillations
- ORCA6 neutrino oscillation sensitivity is **becoming competitive** with other experiments

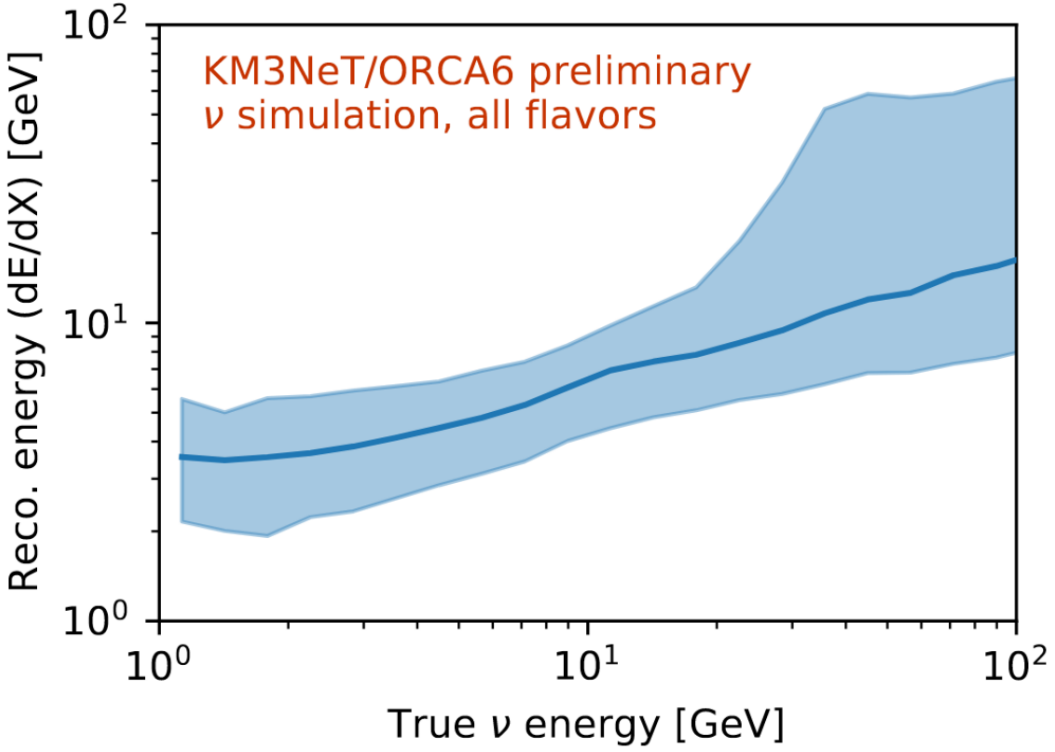
Outlook:

- **ORCA is ready for oscillation physics!**
- Improvements:
  - Include shower reconstruction
  - Add Particle Identification
  - Energy resolution improvements from a larger detector
- September 2021, planned **7 DU deployment** for ORCA: 13 DUs in total

KM3NeT Detection Units ready for deployment

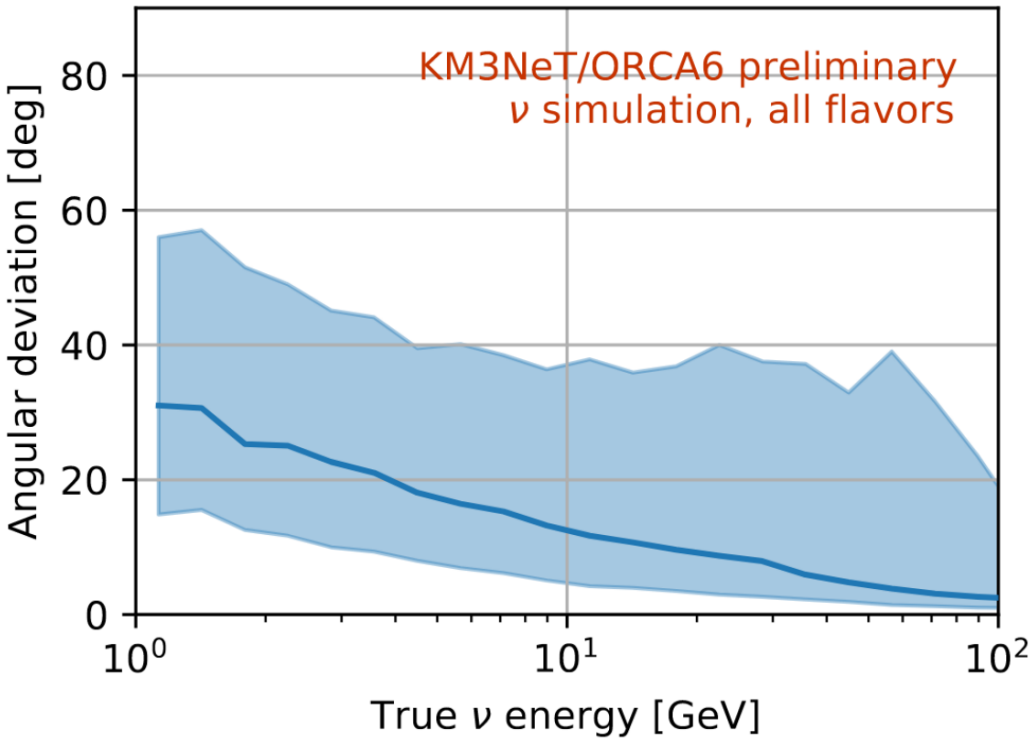
Backup

Backup
Energy resolution



- Energy resolution degrades for tracks *larger* than the detector
  - Higher E particles get pushed towards ~10 GeV reconstructed energy
  - These particles have not oscillated
- Investigation in progress
- Work-around:
  - Add cut at 50GeV
  - No oscillations above 20GeV

Backup
Angular resolution



- Excellent angular resolution at current scale
- ORCA6 is very vertical
- ORCA6 has 5% of the volume of the full detector

Backup
Detector shape impact

- All selected ORCA6 tracks are shown
- Color indicates track length
- More vertical tracks are brighter
- **Consistent with “detector shape” hypothesis**

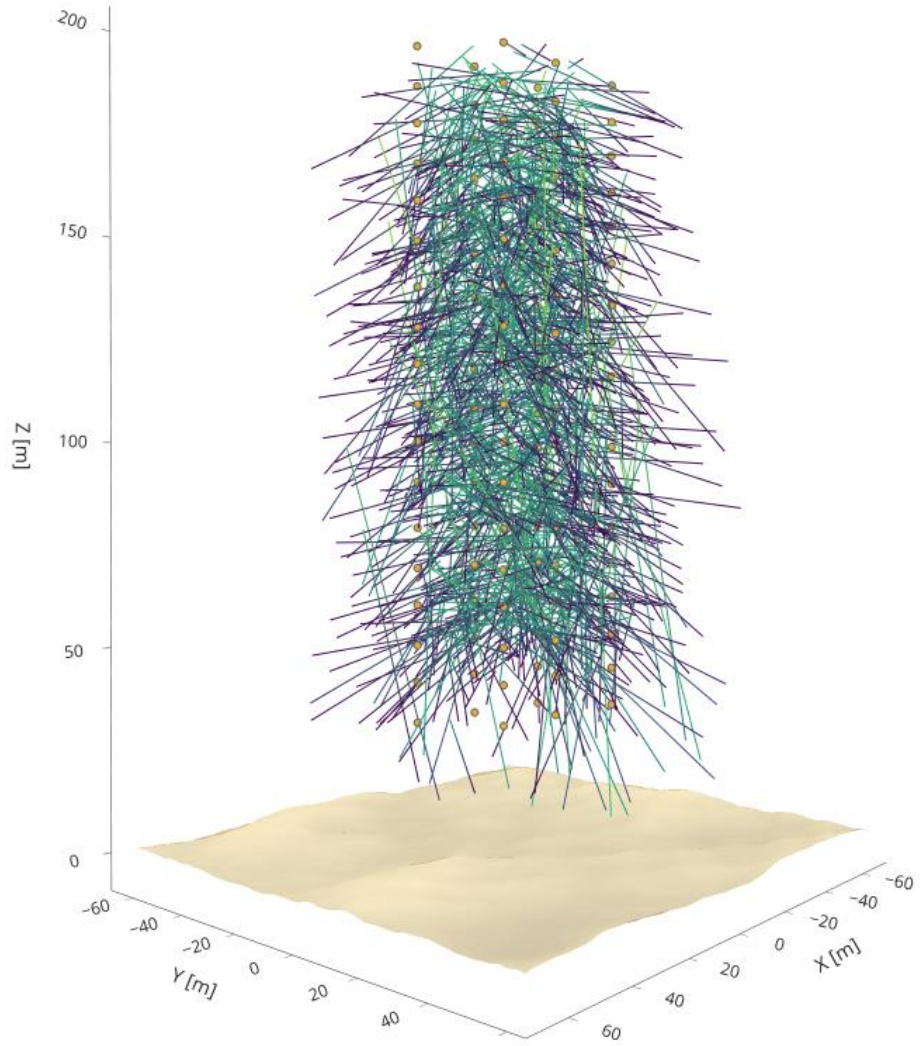
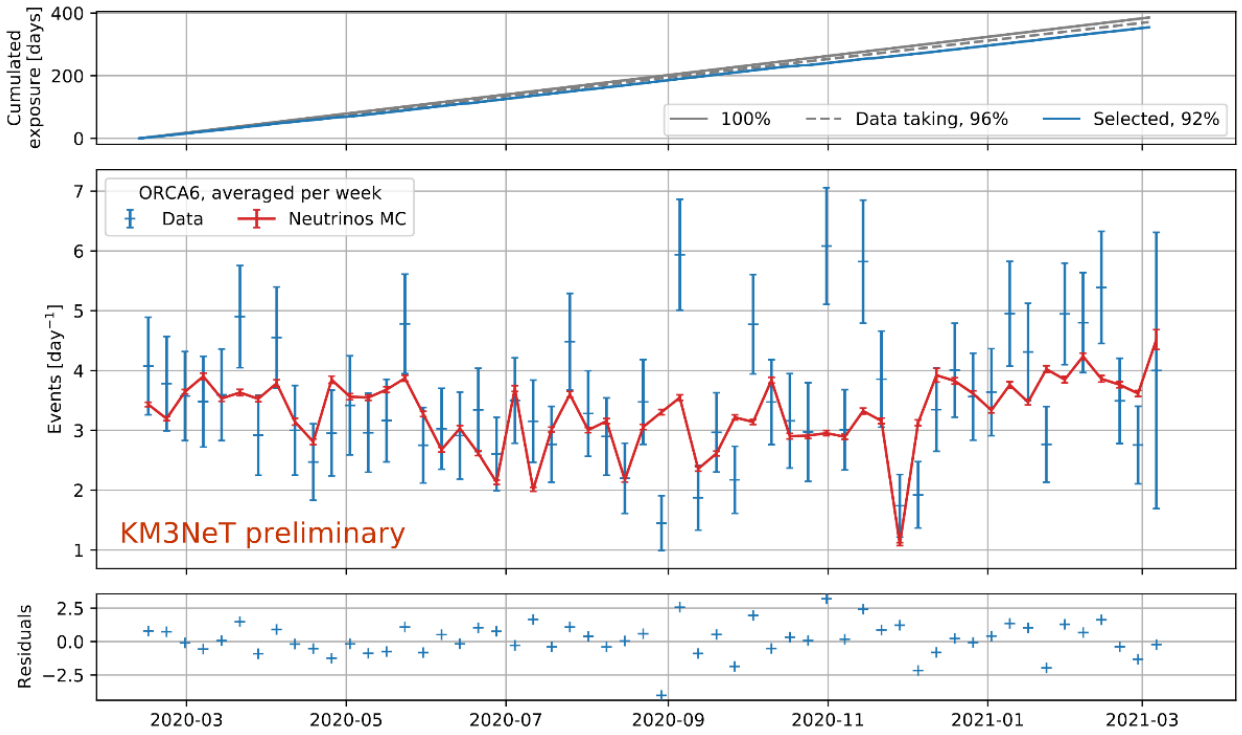


Figure: Neutrino candidates in the ORCA6 data set. Color is a measure of length of the track, **lighter** means **longer**.

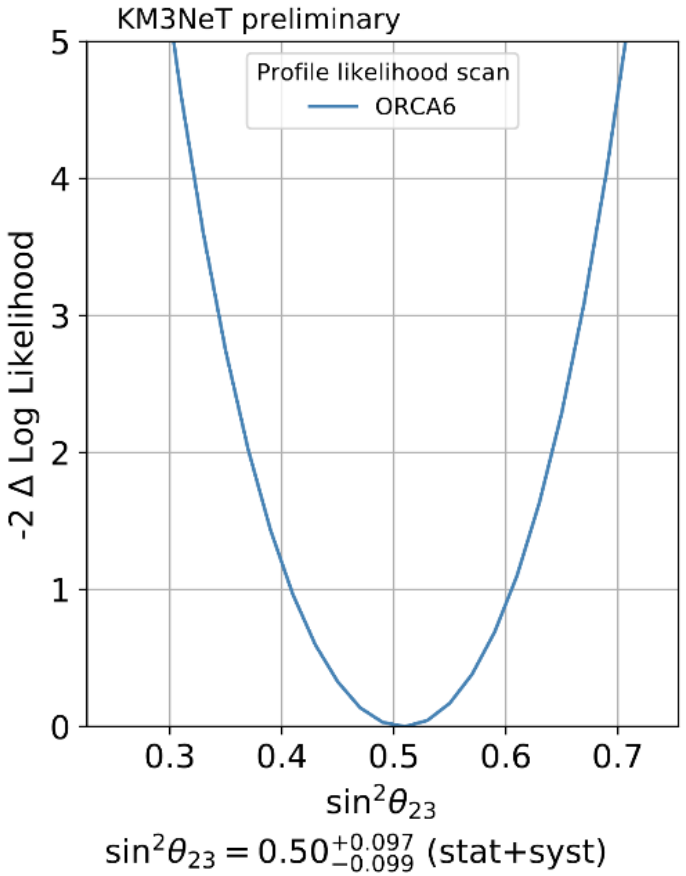
Backup
Event rates



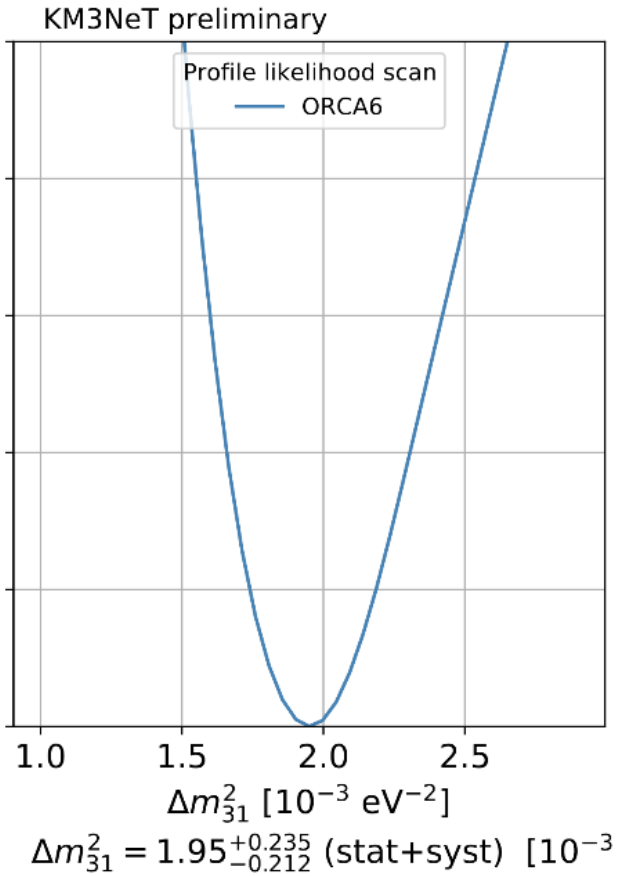
- Bioluminescence and hardware issues can cause large drops in efficiency while data taking.
- This is cut away through a veto and rate cuts

- Event rate after cuts
- Efficient data taking and selection (resp. 96% and 92%)
- Neutrino MC matches data after selection
- **Residuals show expected statistical distribution**

Backup
Fitted values for ORCA6



$\sin^2\theta_{23} = 0.50^{+0.097}_{-0.099}$ (stat+syst)



$\Delta m^2_{31} = 1.95^{+0.235}_{-0.212}$ (stat+syst) [10^{-3} eV^{-2}]