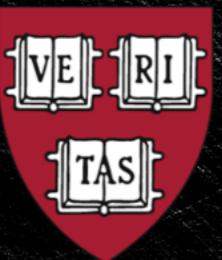
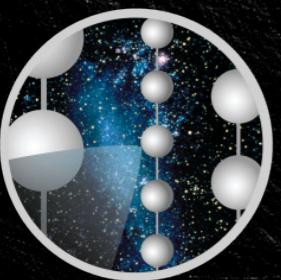


NuFact 2022  
(Utah, US)

# New Sensitivities for eV-scale Sterile Neutrino Searches with IceCube

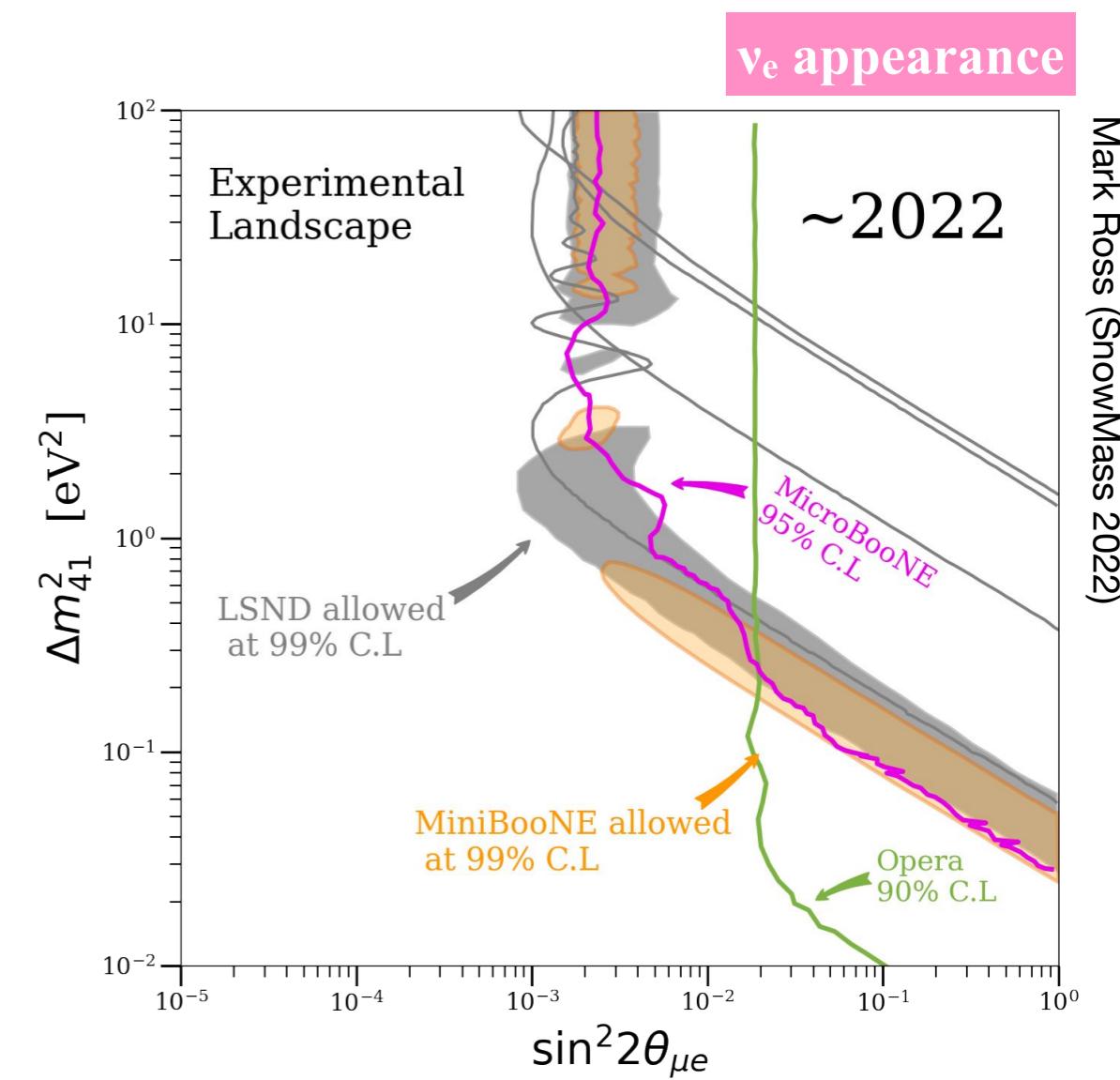
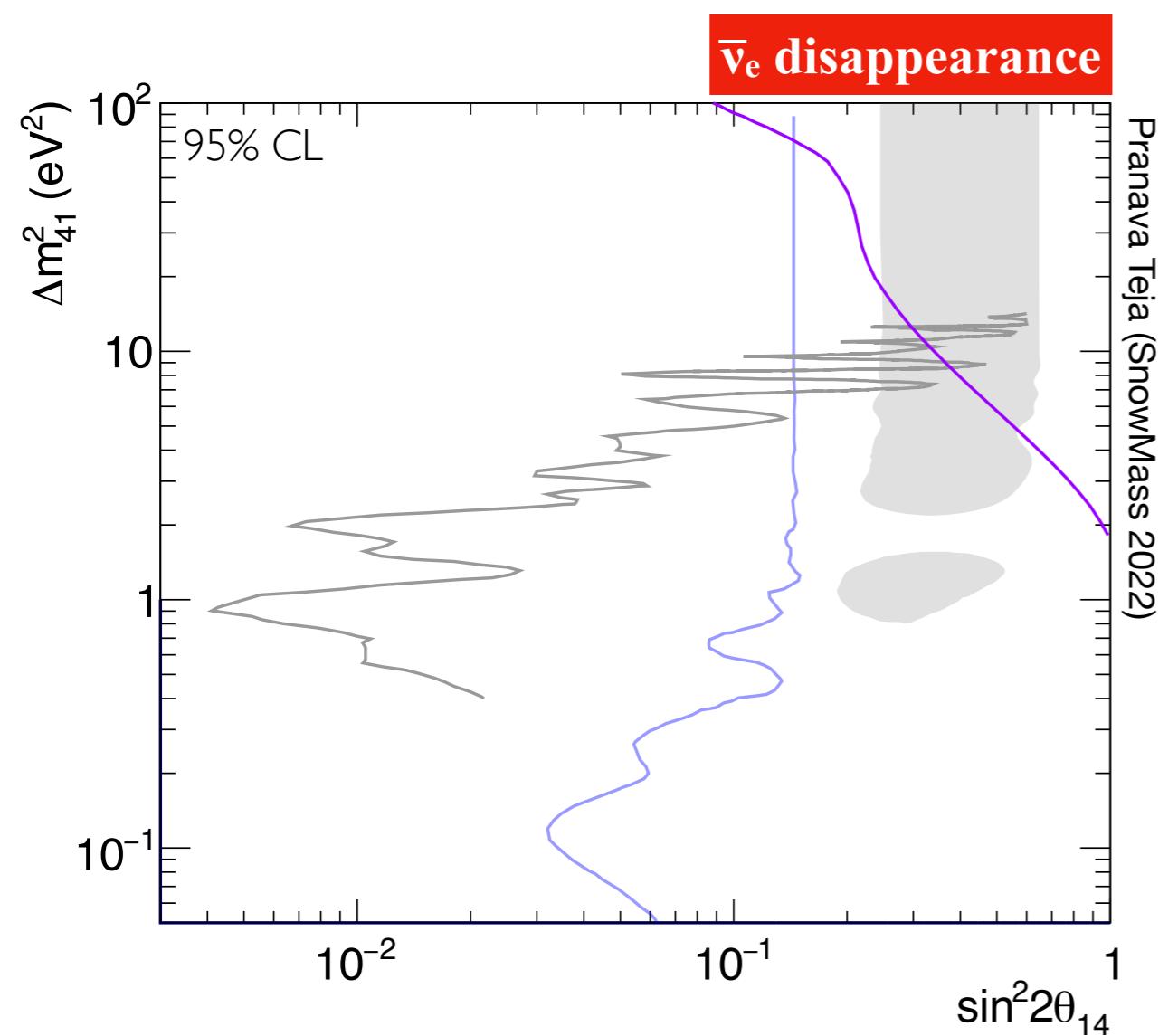
Alfonso Garcia

[alfonsogarciasoto@fas.harvard.edu](mailto:alfonsogarciasoto@fas.harvard.edu)



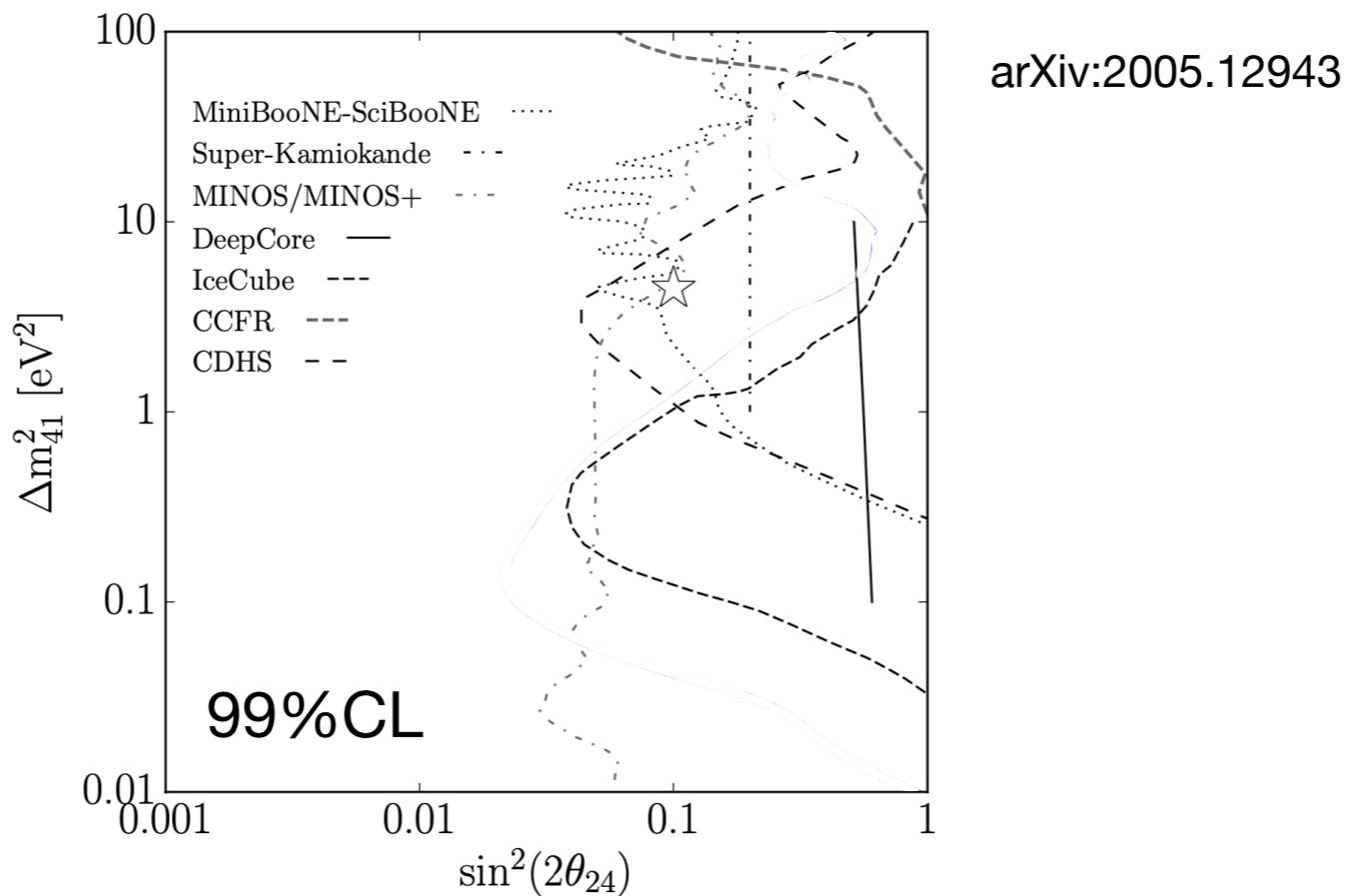
# 3+1 puzzle

- Anomalies not explain with SM oscillations:
  - Disappearance -> Gallium (BEST) and reactor spectra (Neutrino-4).
  - Appearance -> LSND and MiniBooNE.
- Other measurements are in tension with results from anomalies.



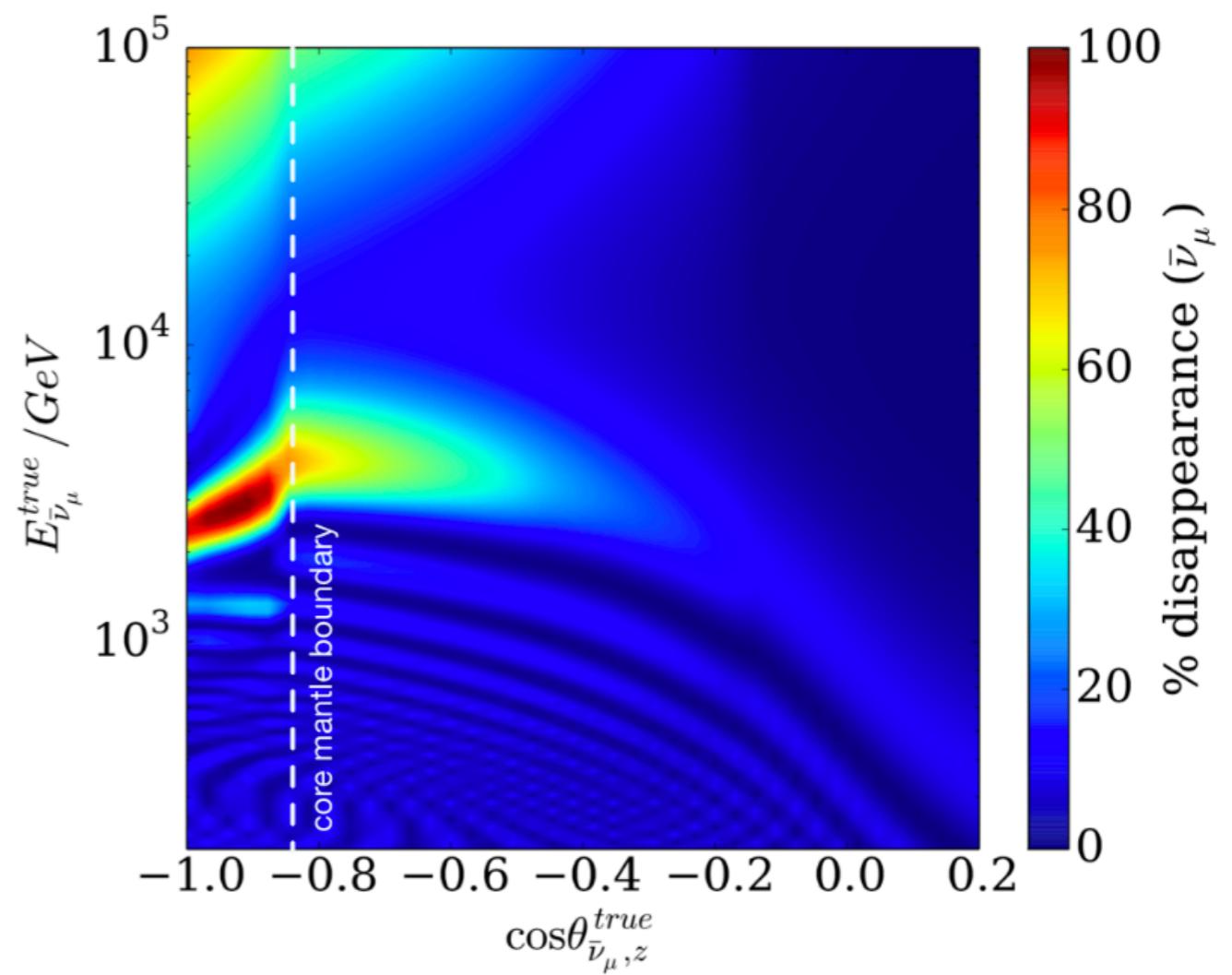
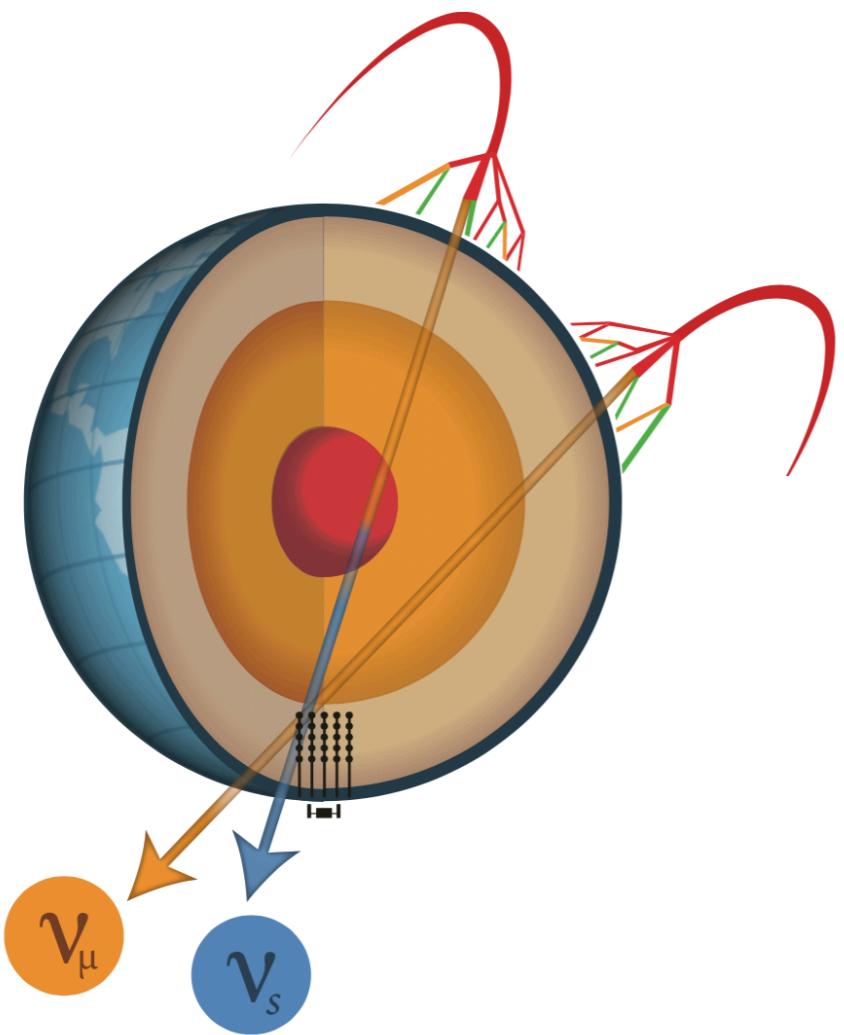
# $\nu_\mu$ disappearance in 3+1 model

- Atmospheric neutrinos:
  - Oscillation pattern change at few GeV for neutrinos crossing the Core.
- Accelerators:
  - Event rate deficits expected in the near and far detectors.
- No anomalies have been observed in this channel.
  - Strong constraints on  $|U_{\mu 4}|^2 \rightarrow 3+1$  model fails explaining the full picture.



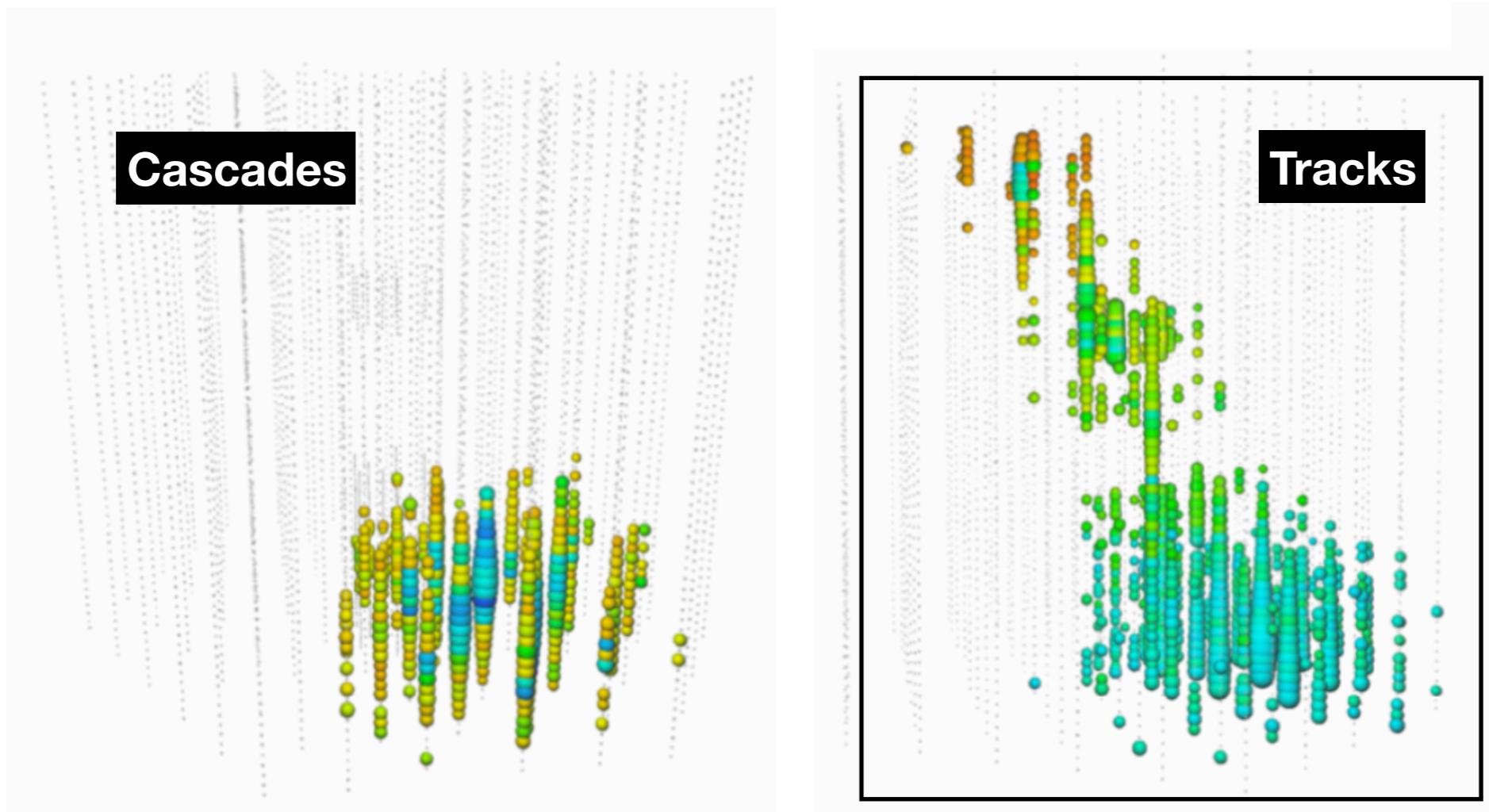
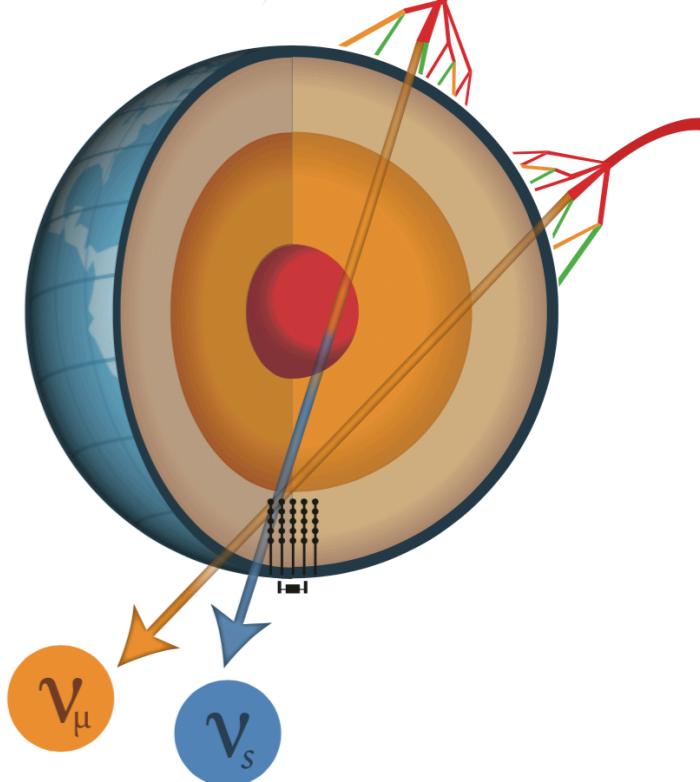
# Where can we improve?

- Novel analysis from IceCube using  $\nu_\mu$  at  $\sim$ TeV energies.
- Resonant disappearance is expected for  $\bar{\nu}_\mu$  crossing the Earth core when eV-scale sterile neutrino is present.



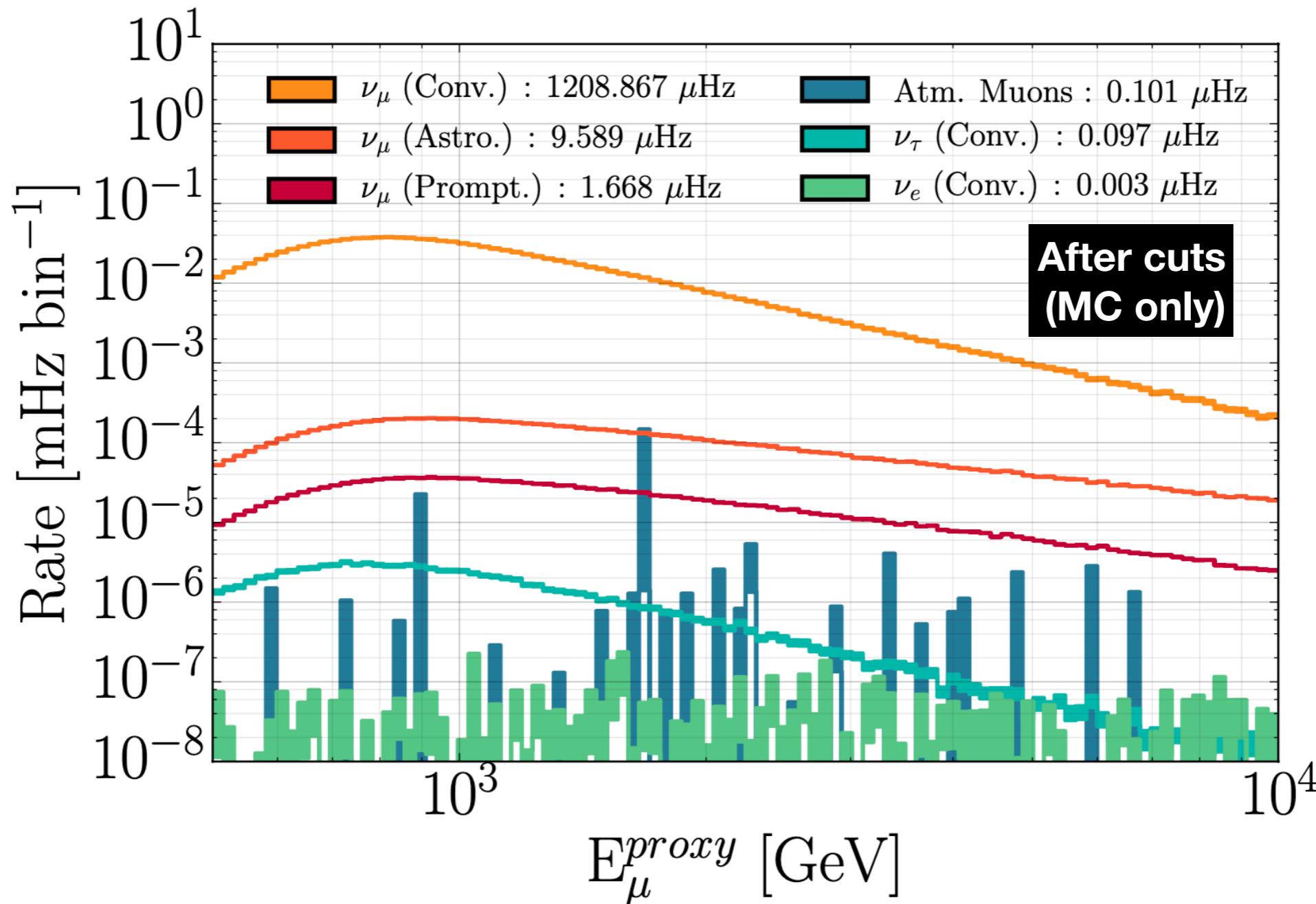
# Analysis strategy

- $\nu_\mu$  crossing the core of the Earth in the TeV regime.
  - Look for up-going track-like patterns.
  - The earth acts as a shield to block atmospheric muons.
  - Other neutrinos look very different in the interaction volume.



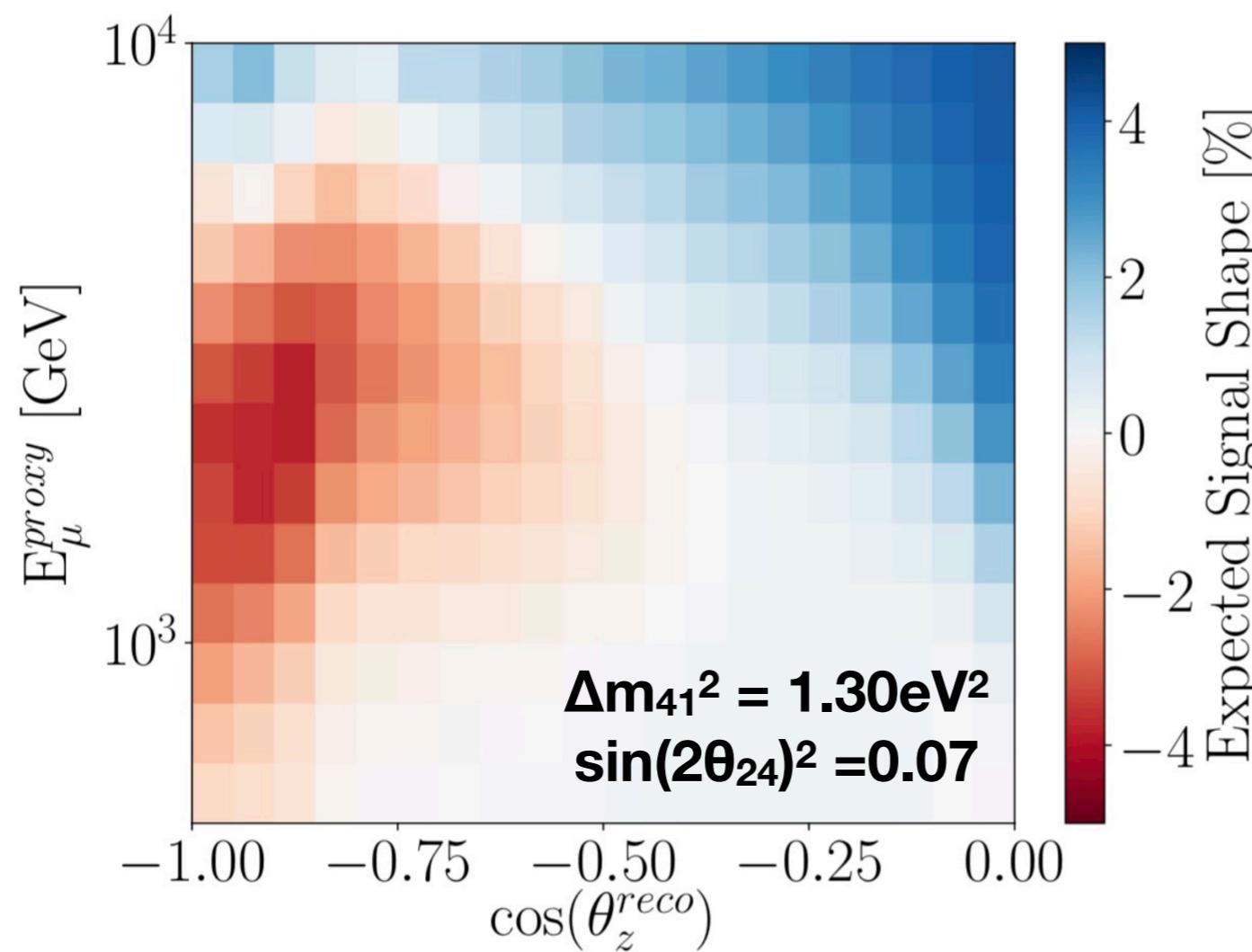
# Event selection

- Tight cuts to reduce atmospheric muon contamination.
- Thousands of tracks every year with  $\nu_\mu/\bar{\nu}_\mu$  purity >99.9%!



# Main limitations

- Can not distinguish  $\nu_\mu/\bar{\nu}_\mu \rightarrow$  resonant effect is reduced.
- Energy of the neutrino is not directly observable (most of events outside volume).
- Many systematics (atm+cosmic neutrino flux, detector eff., cross sections).

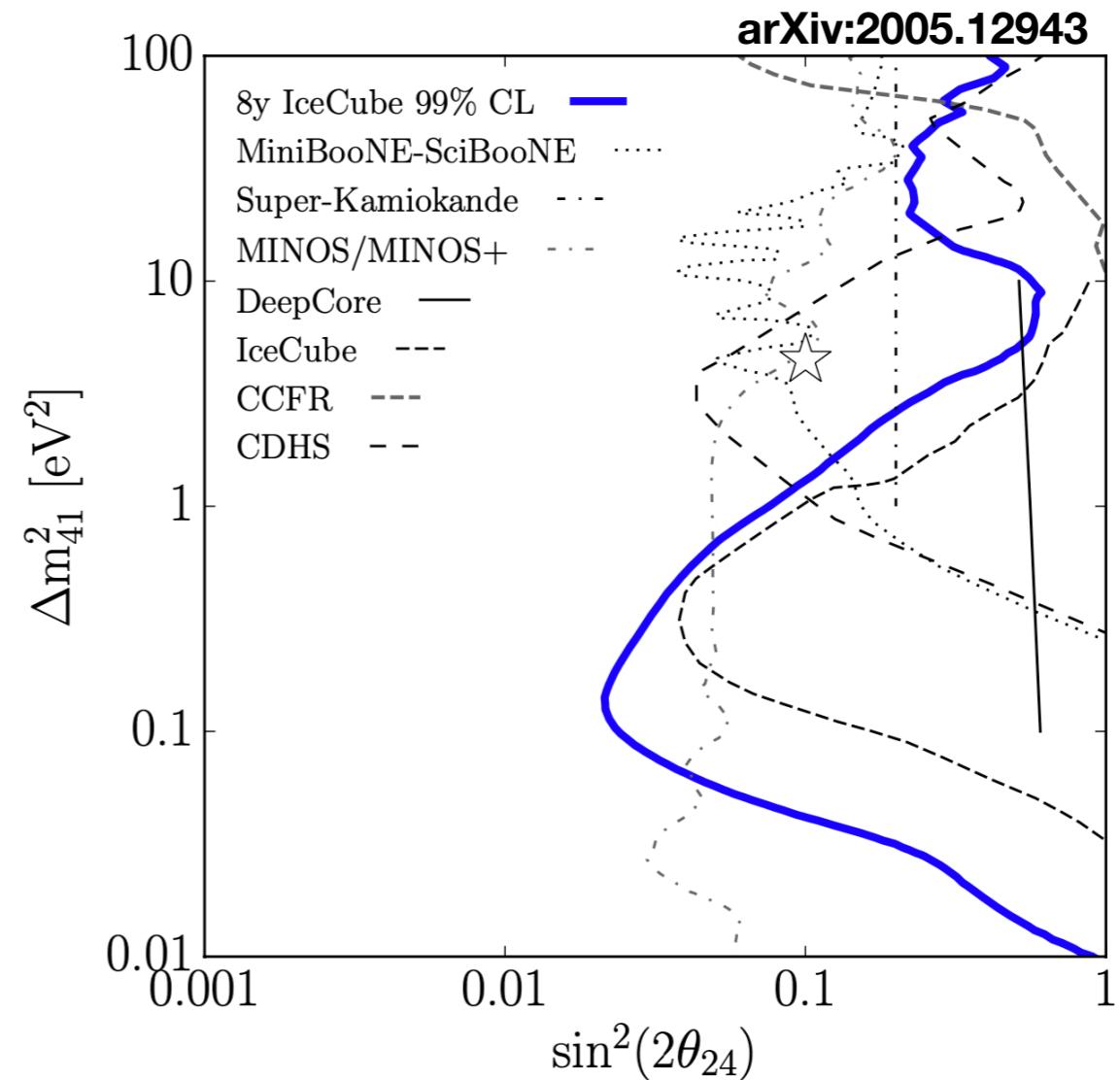
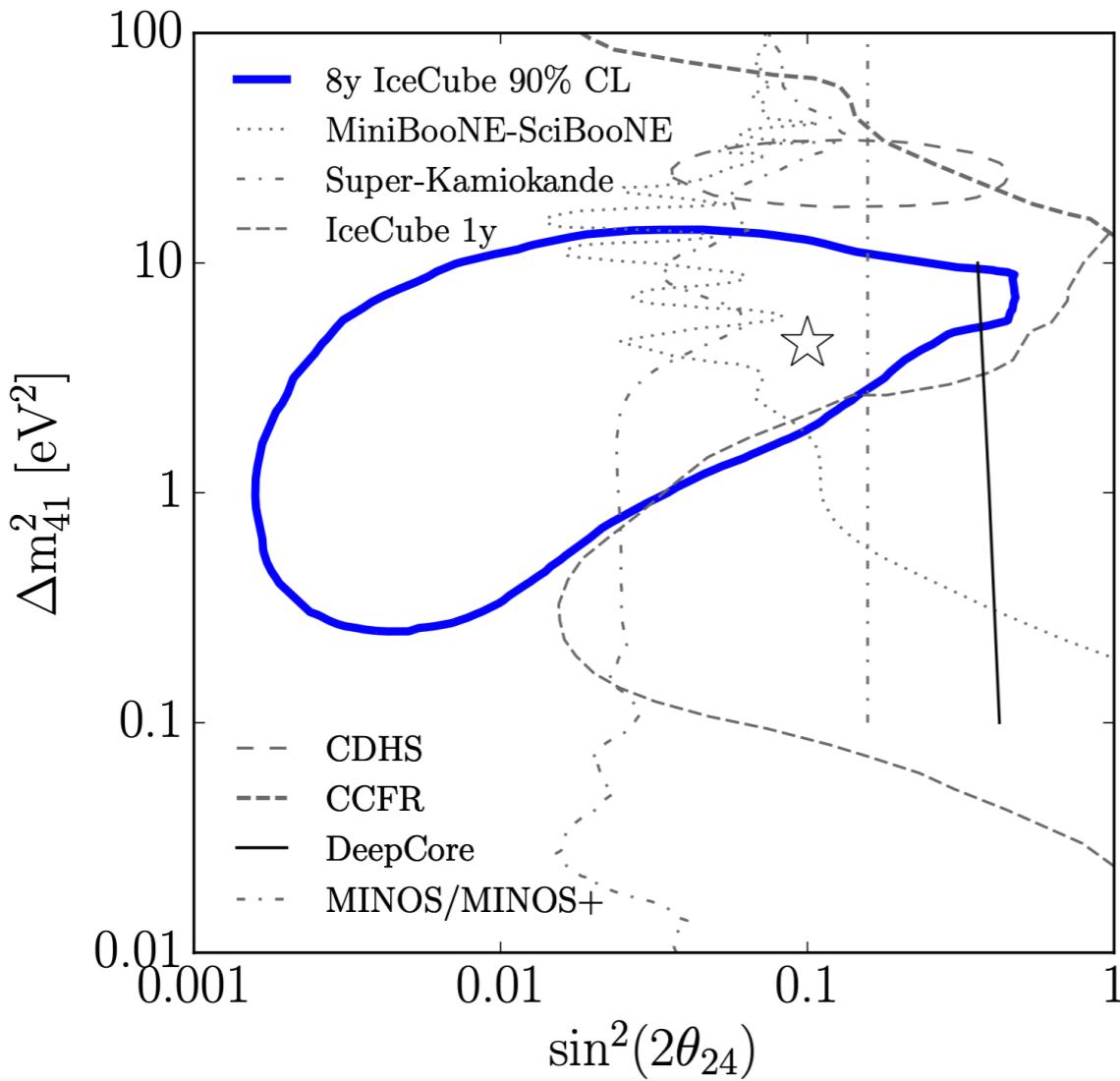


**Oscillation pattern still clear  
for some 3+1 parameters!**



# How it compares to others?

- Leading constraints in some regions of the phase space!
  - Result is consistent with no sterile hypothesis (p-value=8%).
  - Best fit point lies in an interesting region and remains stable for different time periods.
- Can we do better?



# New event selection

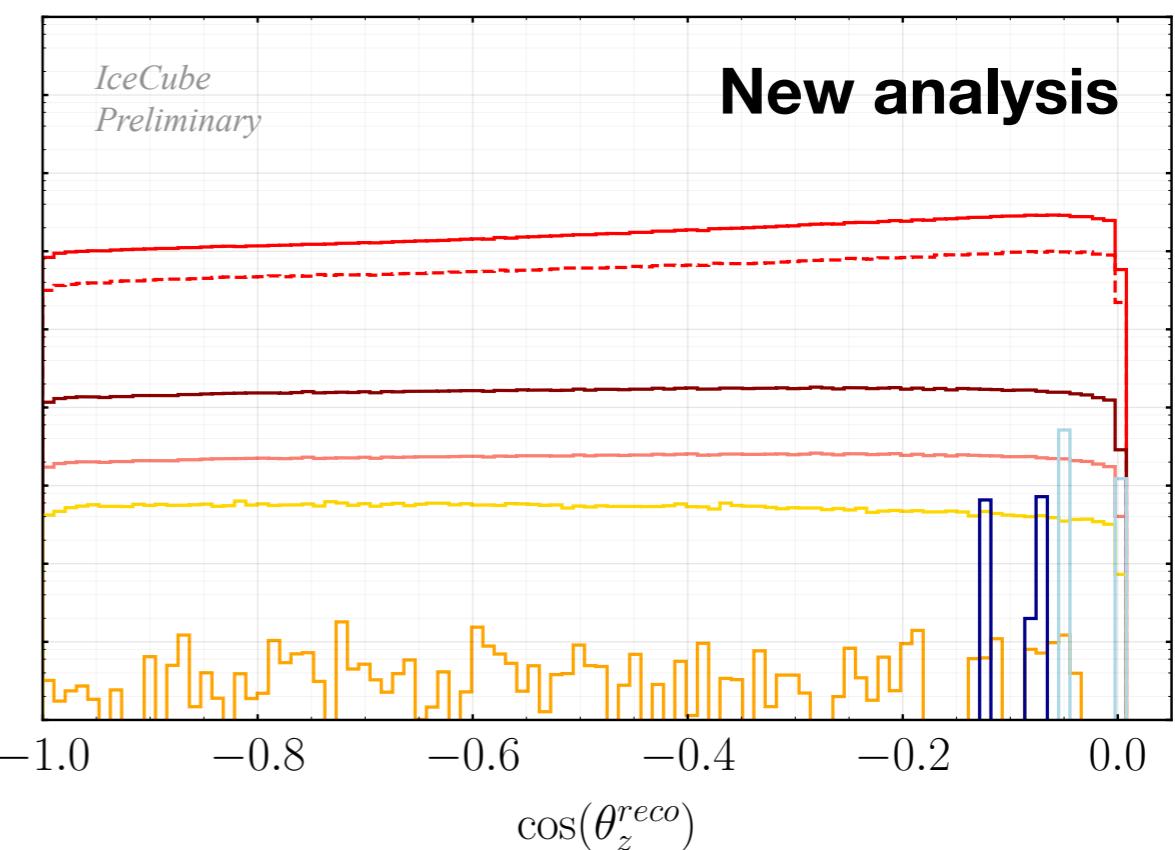
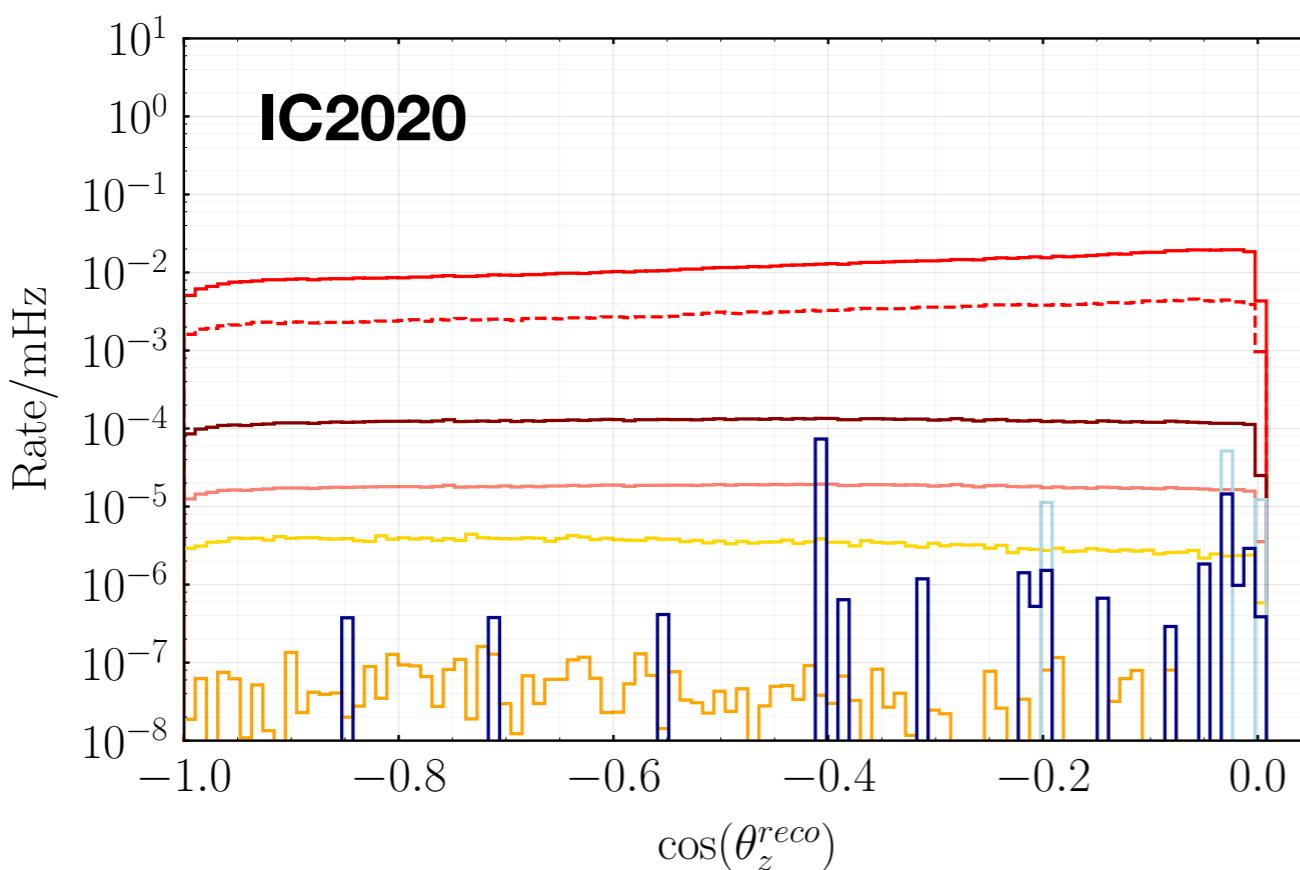
- Moving from simple cuts to BDTs.
- Reduce the contamination of atmospheric muon (<2.5 events/y).
- Higher muon neutrino efficiency (factor 1.4).

—  $\nu_\mu$  (Conv.) : 1155.529  $\mu\text{Hz}$   
- - - . + Start : 293.828  $\mu\text{Hz}$   
—  $\nu_\mu$  (Prompt) : 1.704  $\mu\text{Hz}$   
—  $\nu_\mu$  (Astro) : 11.844  $\mu\text{Hz}$

—  $\nu_e$  (All) : 0.004  $\mu\text{Hz}$   
—  $\nu_\tau$  (All) : 0.326  $\mu\text{Hz}$   
—  $\mu$  (bundles) : 0.075  $\mu\text{Hz}$   
—  $\mu$  (single) : 0.101  $\mu\text{Hz}$

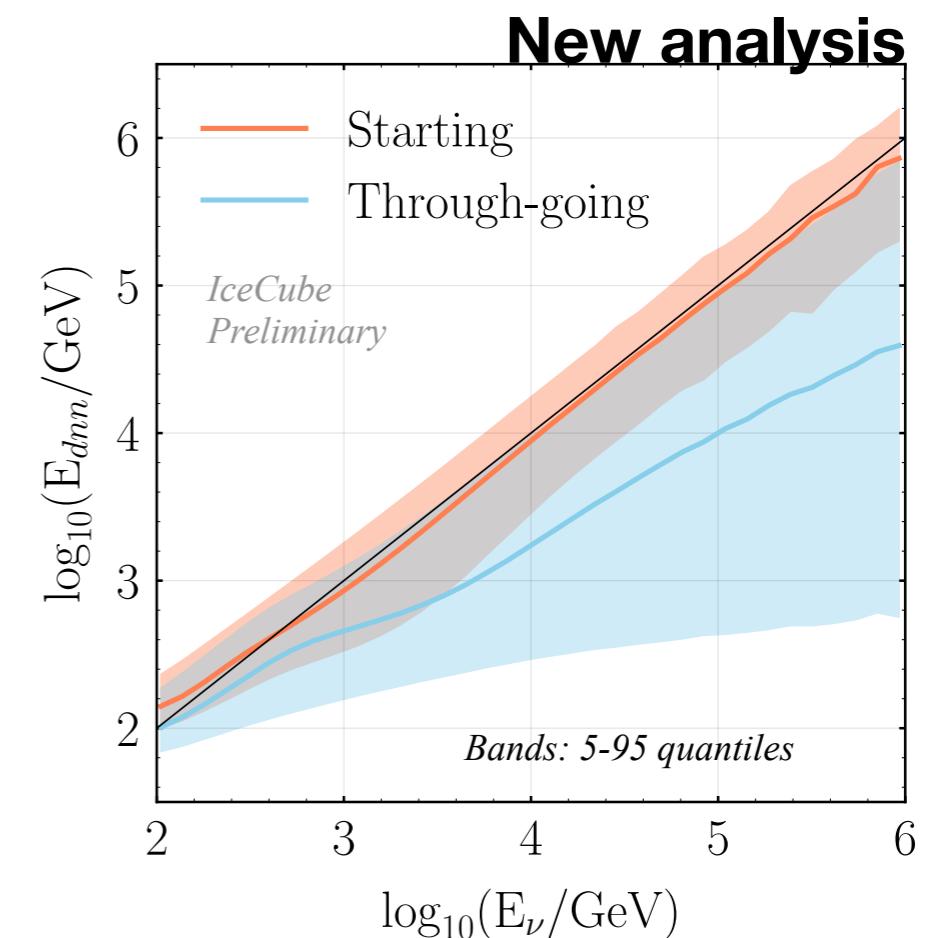
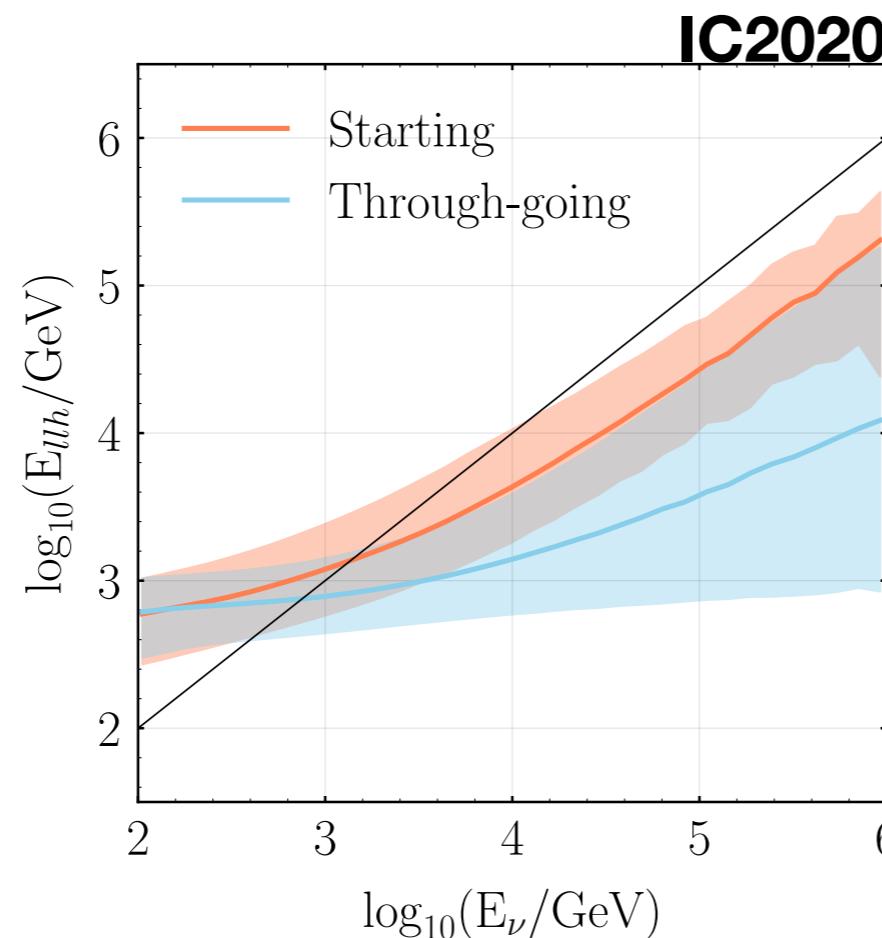
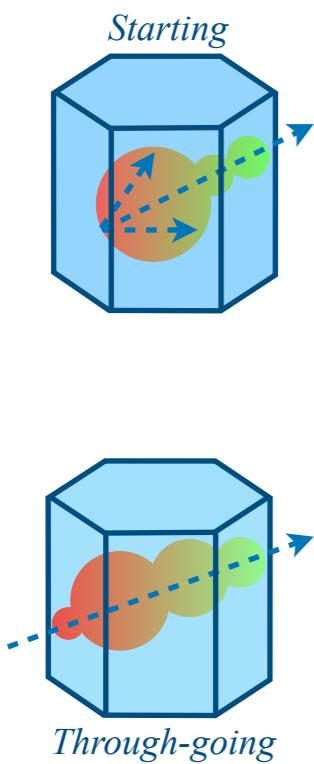
—  $\nu_\mu$  (Conv.) : 1680.58  $\mu\text{Hz}$   
- - - . + Start : 609.915  $\mu\text{Hz}$   
—  $\nu_\mu$  (Prompt) : 2.207  $\mu\text{Hz}$   
—  $\nu_\mu$  (Astro) : 15.348  $\mu\text{Hz}$

—  $\nu_e$  (All) : 0.004  $\mu\text{Hz}$   
—  $\nu_\tau$  (All) : 0.497  $\mu\text{Hz}$   
—  $\mu$  (bundles) : 0.064  $\mu\text{Hz}$   
—  $\mu$  (single) : 0.014  $\mu\text{Hz}$



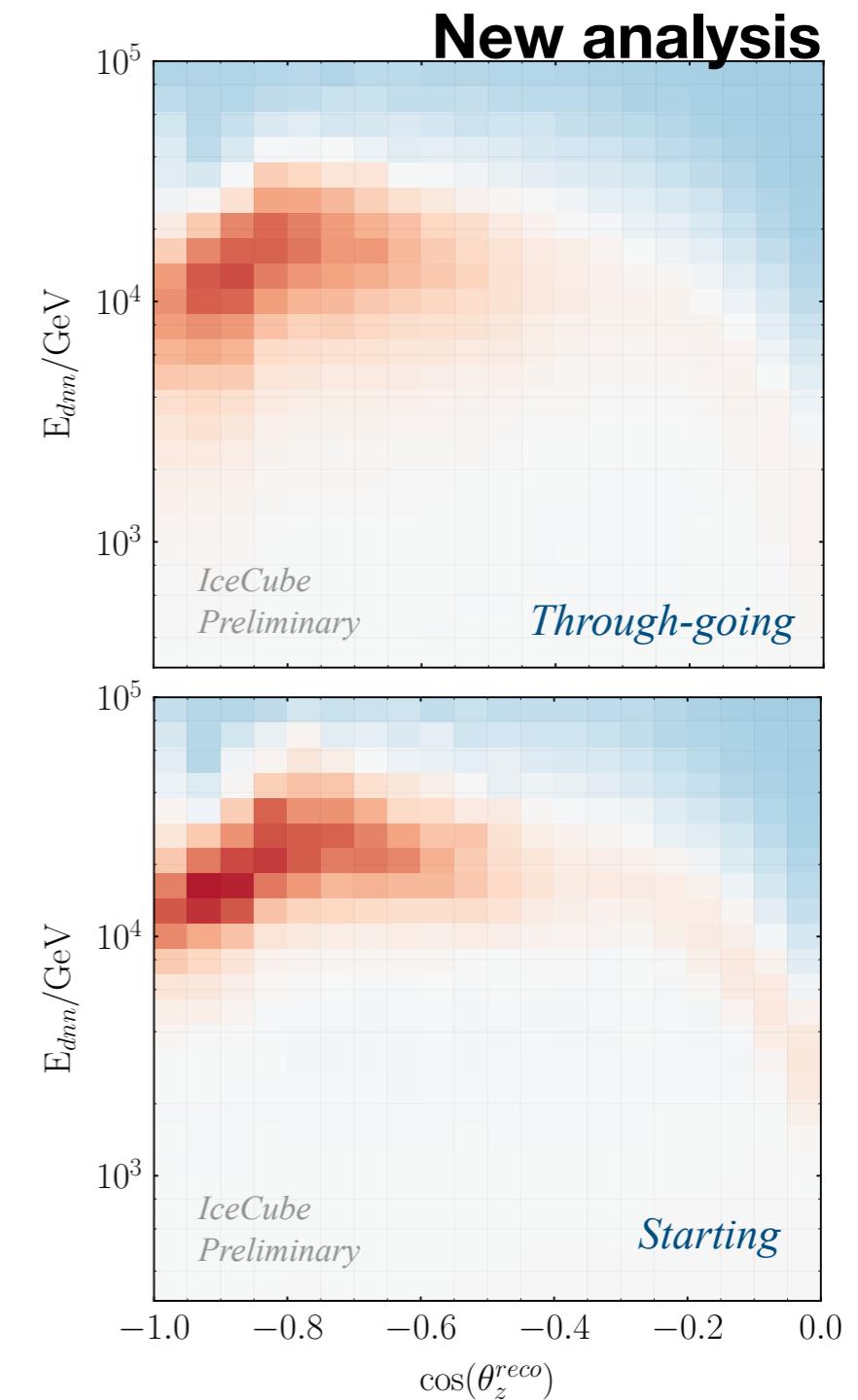
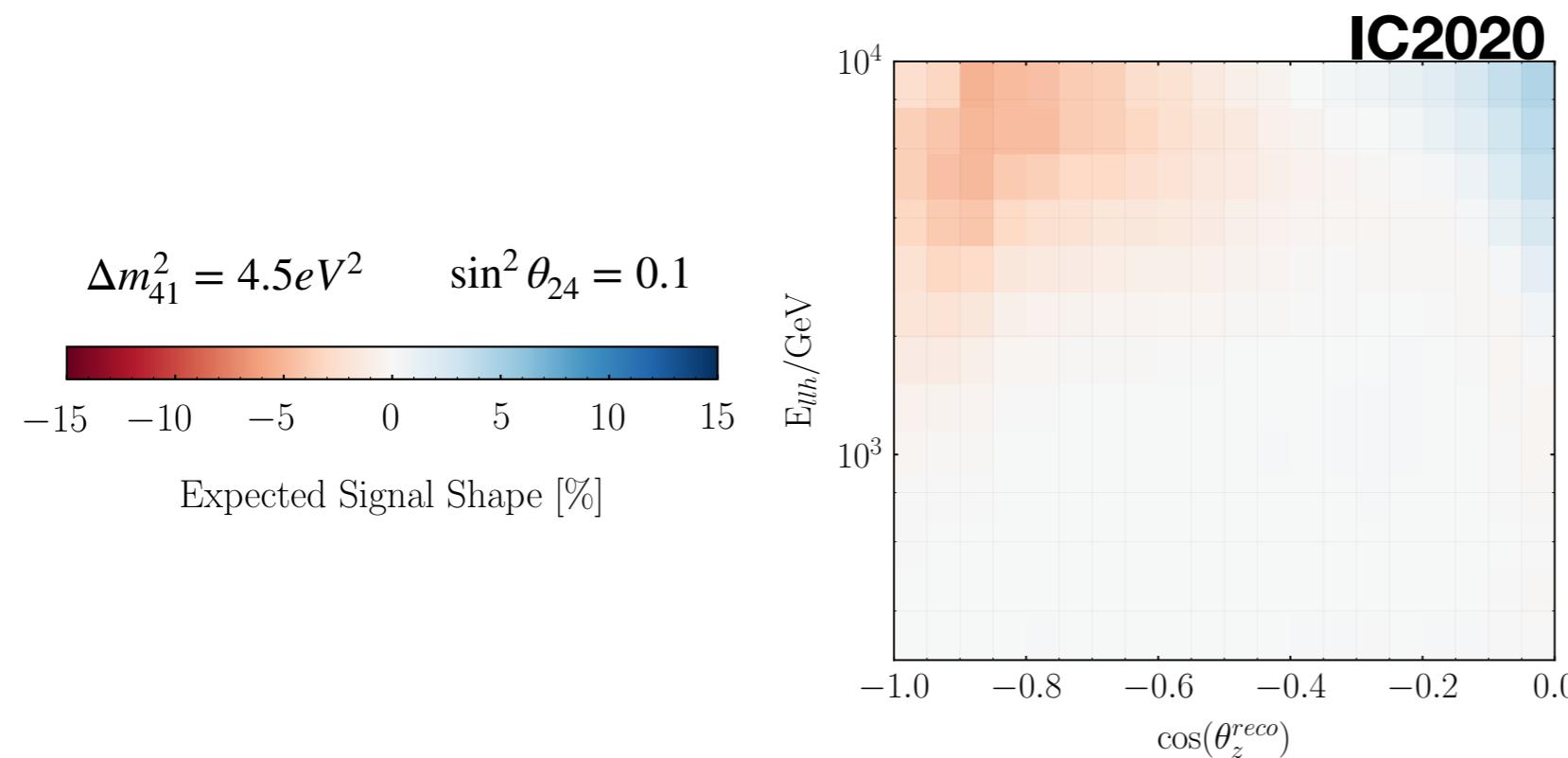
# New energy estimator

- Main limitation -> poor energy resolution
  - Energy reconstruction algorithm not optimised for this specific search.
  - Through-going muons are not the best proxy to reconstruct neutrino energy.
- How can we improve our energy estimator?
  - New energy reconstruction using NN.
  - Dedicated event selection for starting events -> better proxy from neutrino energy.



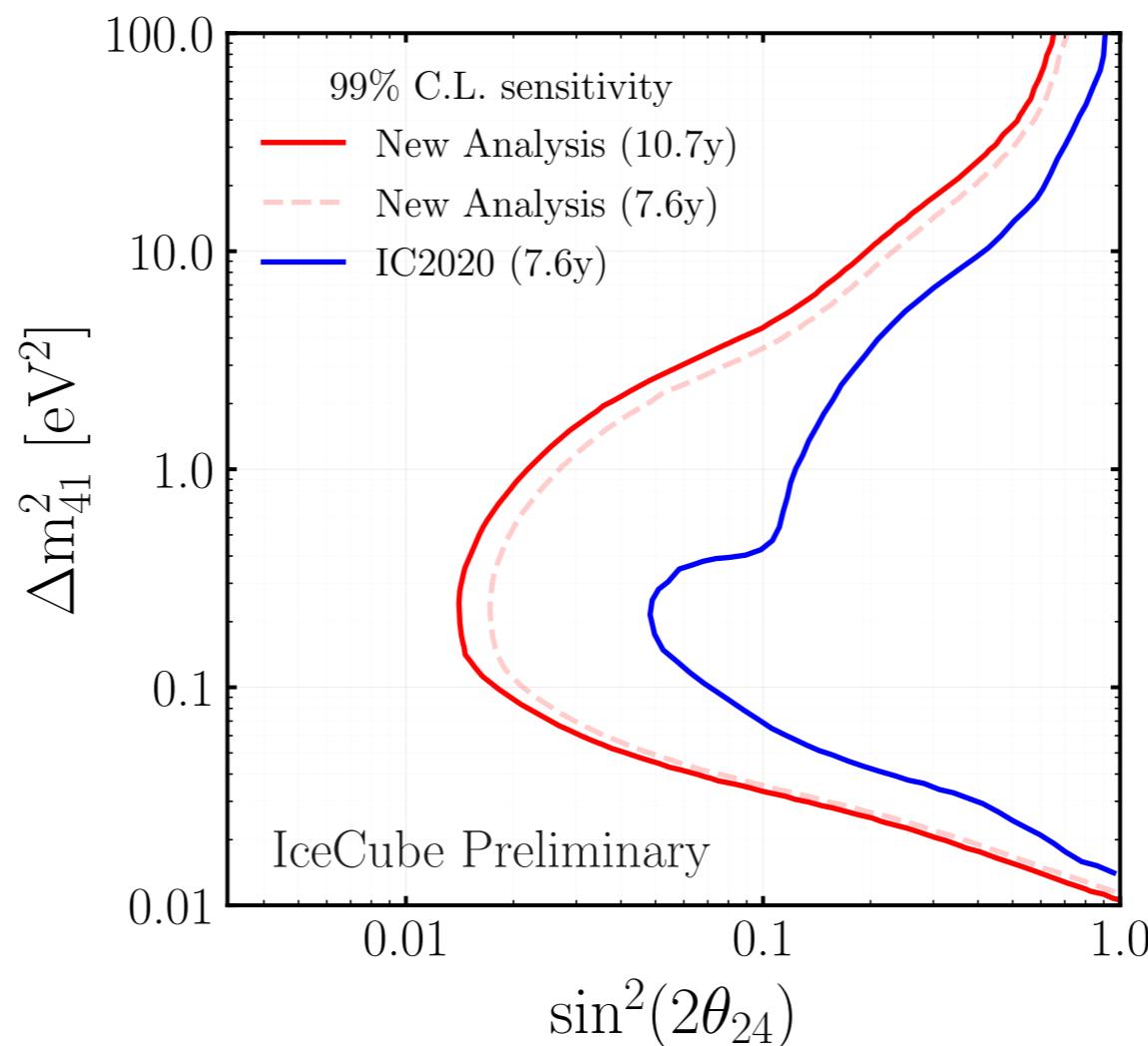
# Prospects

- New energy reconstruction and events selection will boost the sensitivity to constrain sterile neutrino models.
- Extending the energy range will allow us to study in more detail the hints observed in previous analysis.
- Promising results comparing shape-only differences.



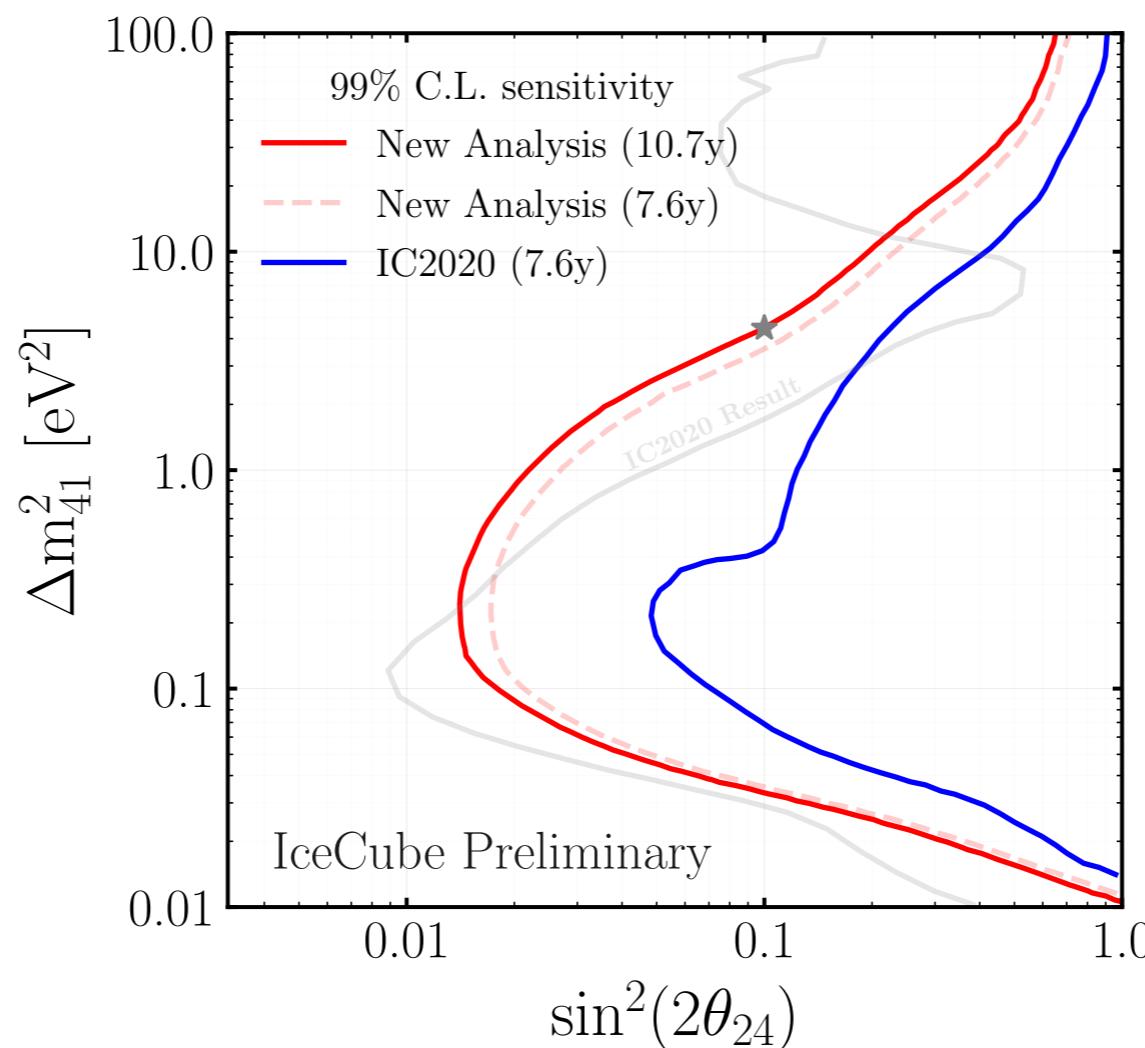
# Prospects

- Sensitivities assuming  $\Theta_{34}=0$  in both analysis.
- Significant improvement in the 0.1-5 eV<sup>2</sup> region.
  - Most of the gain due to new event selection and energy reconstruction.



# Prospects

- Sensitivities assuming  $\Theta_{34}=0$  in both analysis.
- Significant improvement in the 0.1-5 eV<sup>2</sup> region.
  - Most of the gain due to new event selection and energy reconstruction.
- Preferred region from previous analysis will be further studied.



# Conclusions

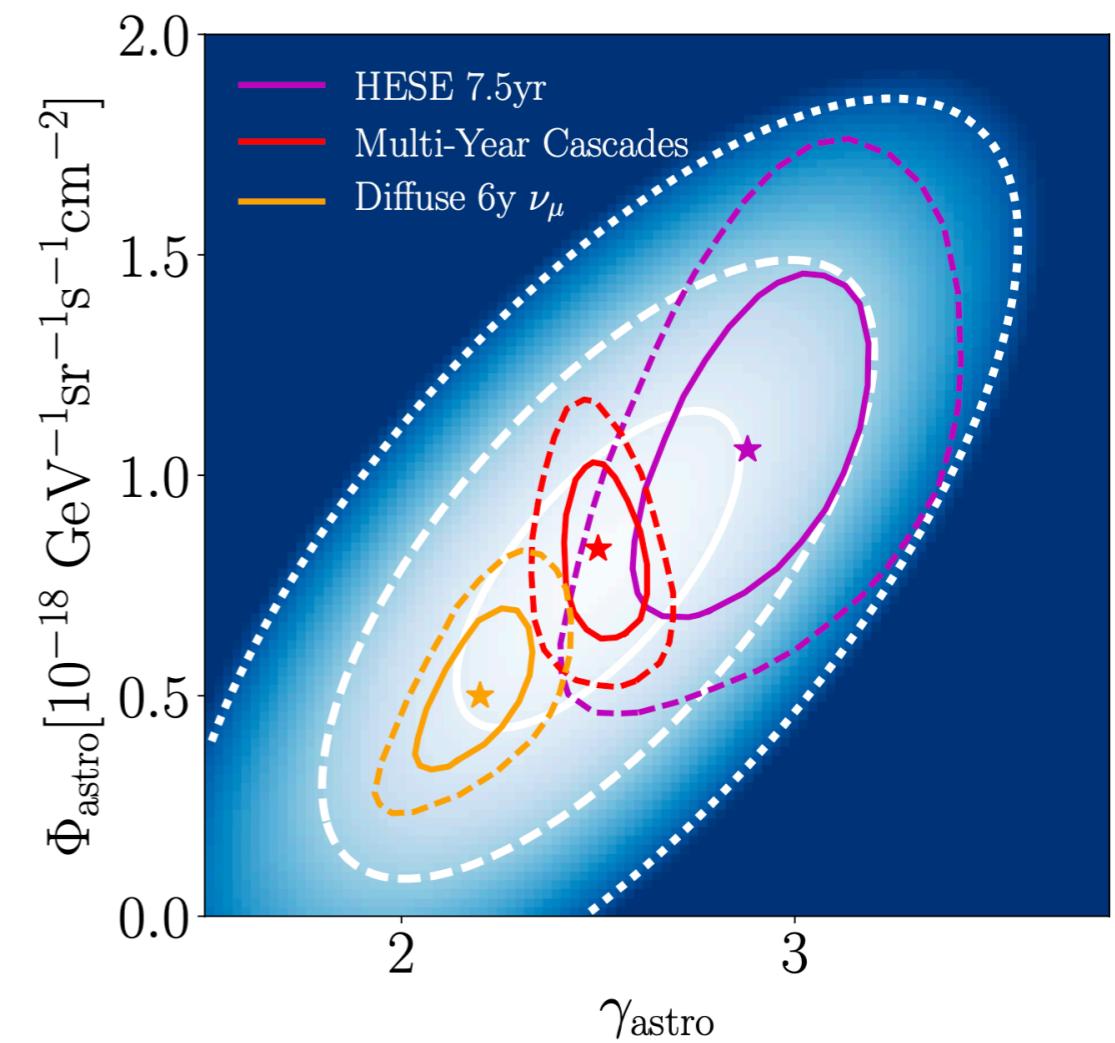
- Sterile neutrinos are one of the hot topics in the neutrino community.
  - Several results still not understood.
- IceCube can study 3+1 models using neutrinos energies never explored before.
  - First analyses have shown very competitive constraints.
- New analysis aims to shed some light on the 3+1 puzzle.



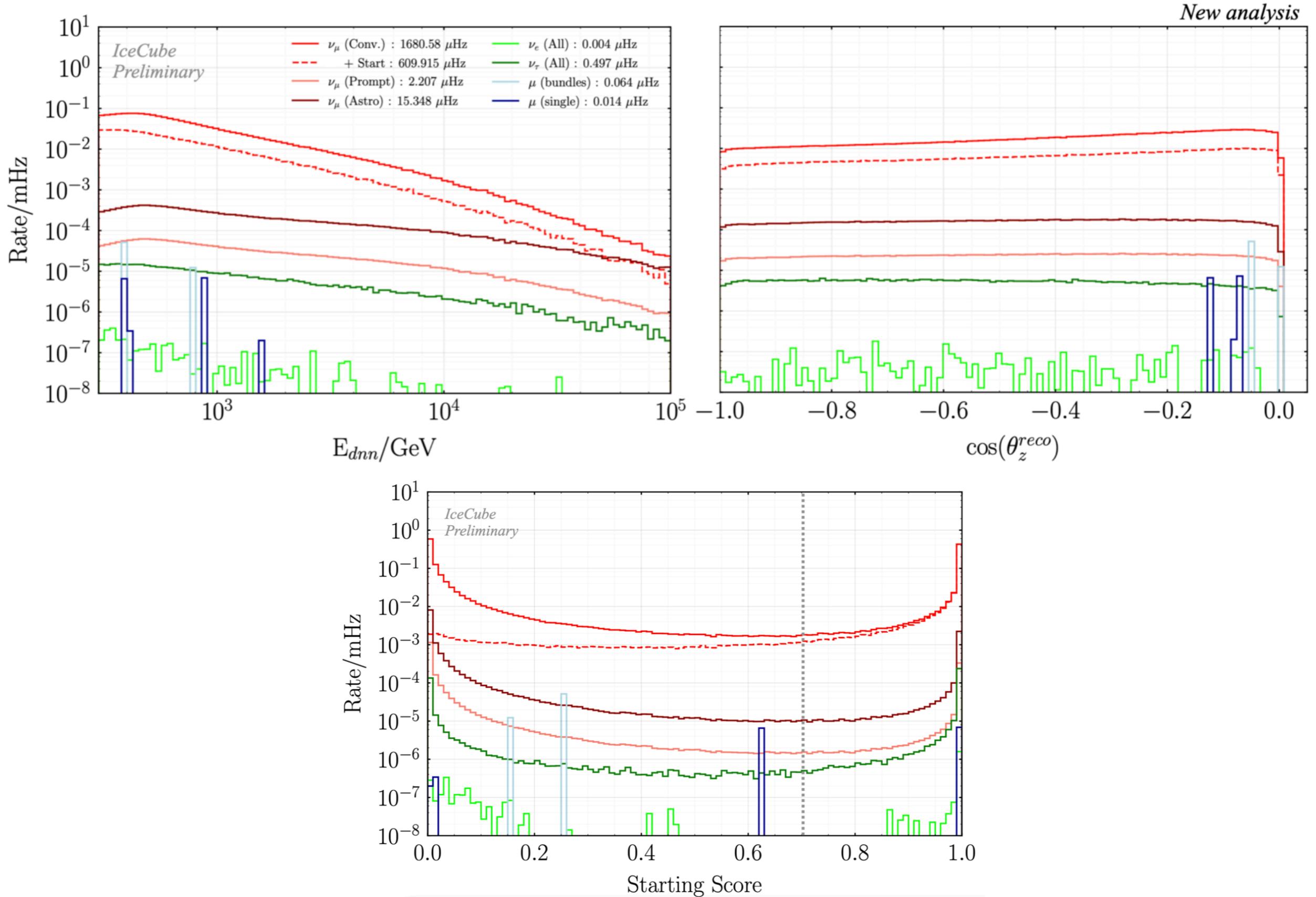
# BONUS

# Systematics

Parameter	Central	Prior (Constraint)	Boundary
<b>Detector parameters</b>			
DOM efficiency	0.97	$0.97 \pm 0.10$	[0.94, 1.03]
Bulk Ice Gradient 0	0.0	$0 \pm 1.0^*$	NA
Bulk Ice Gradient 1	0.0	$0 \pm 1.0^*$	NA
Forward Hole Ice ( $p_2$ )	-1.0	$-1.0 \pm 10.0$	[-5, 3]
<b>Conventional Flux parameters</b>			
Normalization ( $\Phi_{\text{conv.}}$ )	1.0	$1.0 \pm 0.4$	NA
Spectral shift ( $\Delta\gamma_{\text{conv.}}$ )	0.00	$0.00 \pm 0.03$	NA
Atm. Density	0.0	$0.0 \pm 1.0$	NA
Barr WM	0.0	$0.0 \pm 0.40$	[-0.5, 0.5]
Barr WP	0.0	$0.0 \pm 0.40$	[-0.5, 0.5]
Barr YM	0.0	$0.0 \pm 0.30$	[-0.5, 0.5]
Barr YP	0.0	$0.0 \pm 0.30$	[-0.5, 0.5]
Barr ZM	0.0	$0.0 \pm 0.12$	[-0.25, 0.5]
Barr ZP	0.0	$0.0 \pm 0.12$	[-0.2, 0.5]
<b>Astrophysical Flux parameters</b>			
Normalization ( $\Phi_{\text{astro.}}$ )	0.787	$0.0 \pm 0.36^*$	NA
Spectral shift ( $\Delta\gamma_{\text{astro.}}$ )	0	$0.0 \pm 0.36^*$	NA
<b>Cross sections</b>			
Cross section $\sigma_{\nu_\mu}$	1.00	$1.00 \pm 0.03$	[0.5, 1.5]
Cross section $\sigma_{\bar{\nu}_\mu}$	1.000	$1.000 \pm 0.075$	[0.5, 1.5]
Kaon energy loss $\sigma_{KA}$	0.0	$0.0 \pm 1.0$	NA



# 1D distributions



# Acknowledgements

**This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101025085.**