IceCube sterile neutrino searches

Snowmass 2022 – Ben Smithers

1

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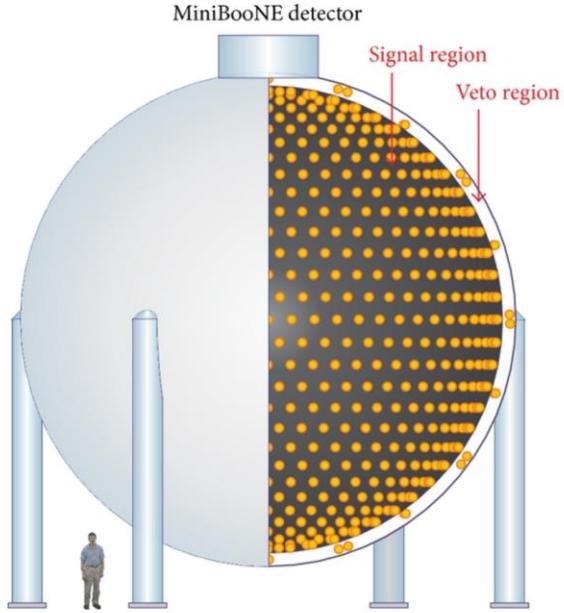
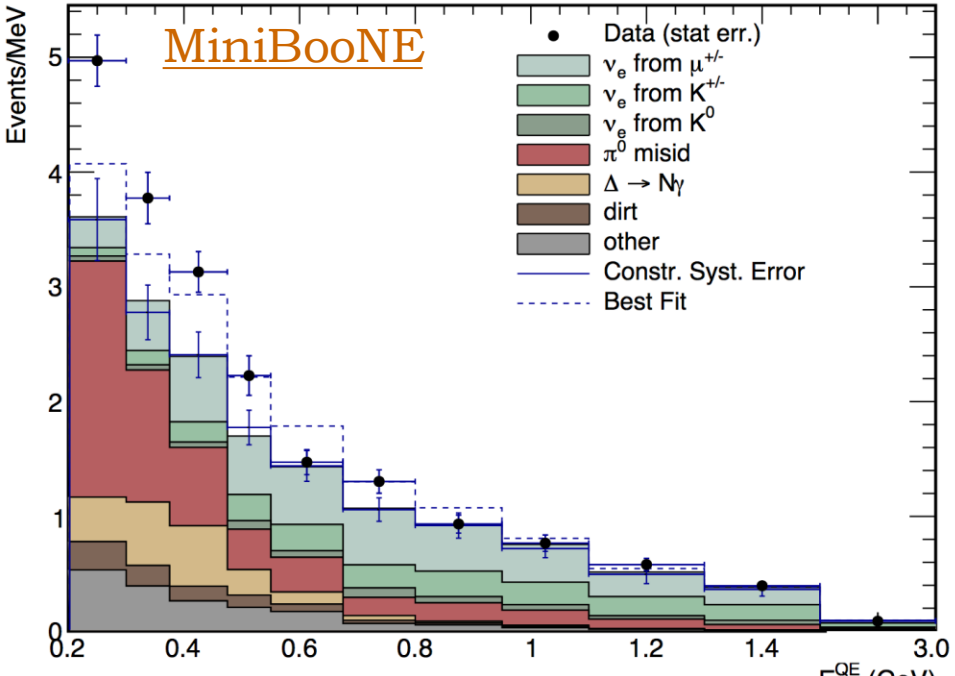
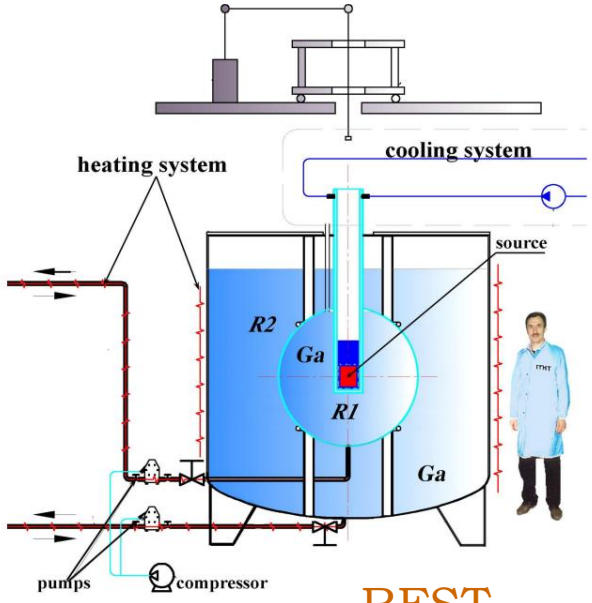
Motivations

- Anomalous MiniBooNE nu-e appearance results
- Could be addressed with 3+1 sterile neutrino model
  - Non-interacting flavor states,
  - “Light” mass-squared splitting ~1eV^2
- Many, many, more anomalous results since then

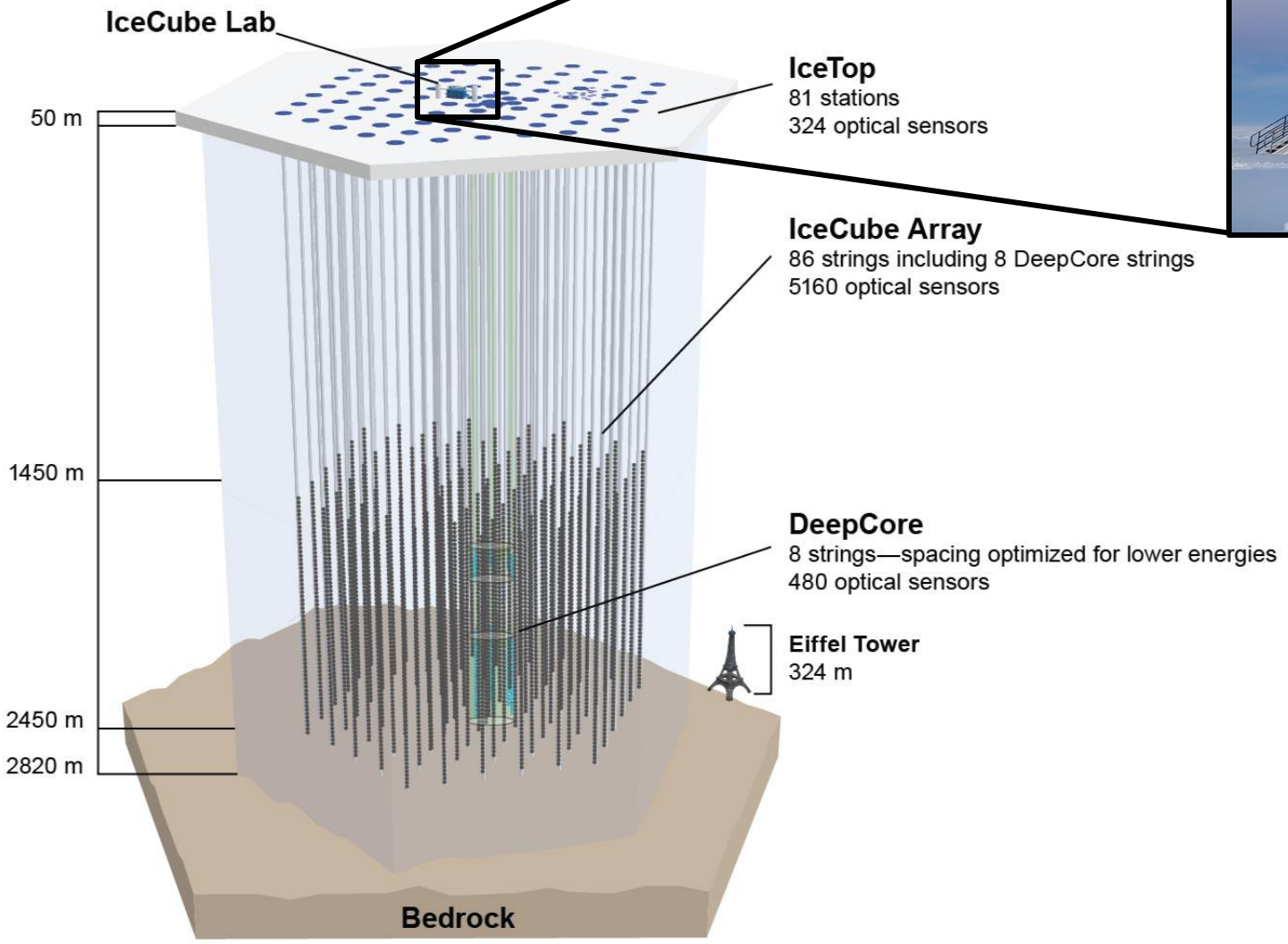


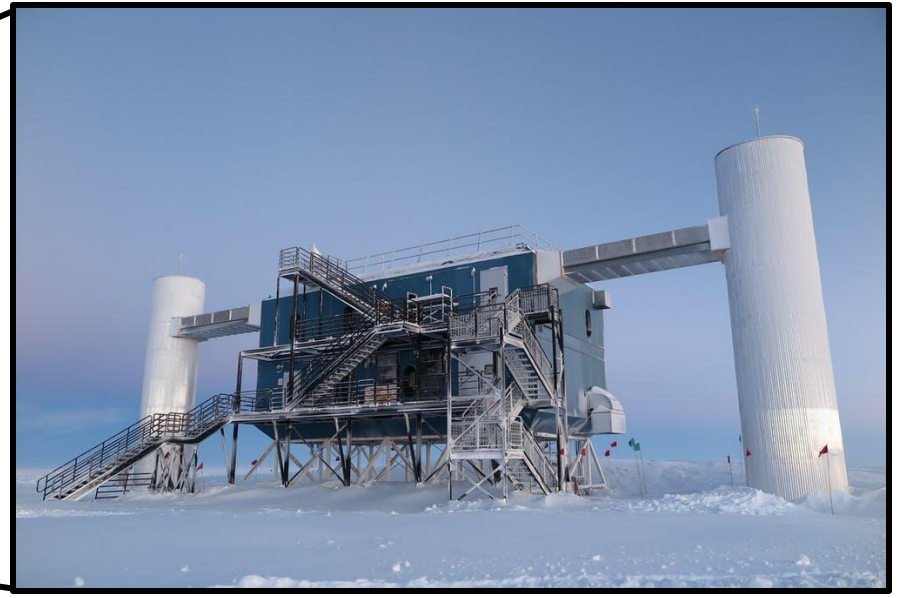




BEST

IceCube



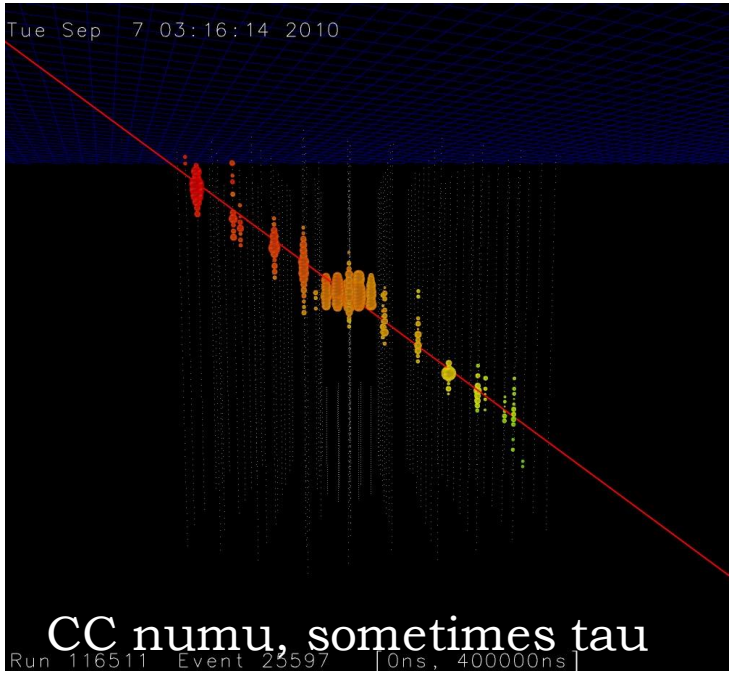


- Formally, IceCube Neutrino Observatory
- Array of 5160 light-sensing DOMs instrumented in south pole ice
- More densely instrumented region called DeepCore – sensitive to low-E oscillations
- Sparsely instrumented section sensitive to higher-E oscillations

Event Morphologies

Tracks

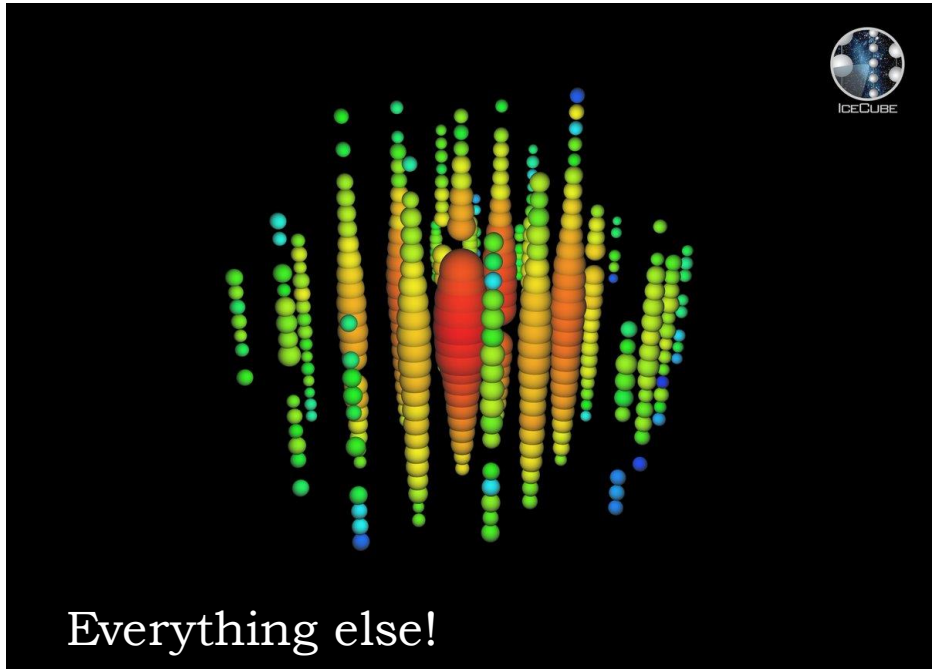
- Poorly contained (lower energy resolution)
- Point with certainty (good angular resolution)
- Higher statistics



CC numu, sometimes tau

Cascades

- Relatively easy to contain
- Blob-like (poor angular resolution)
- Low stats, often overlooked for BSM searches

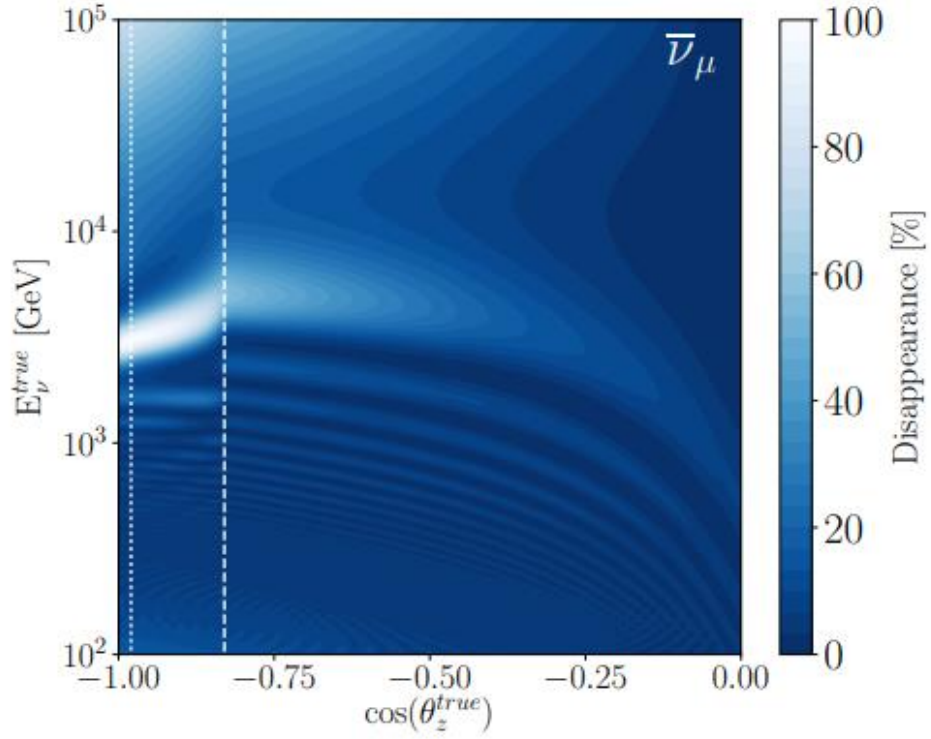


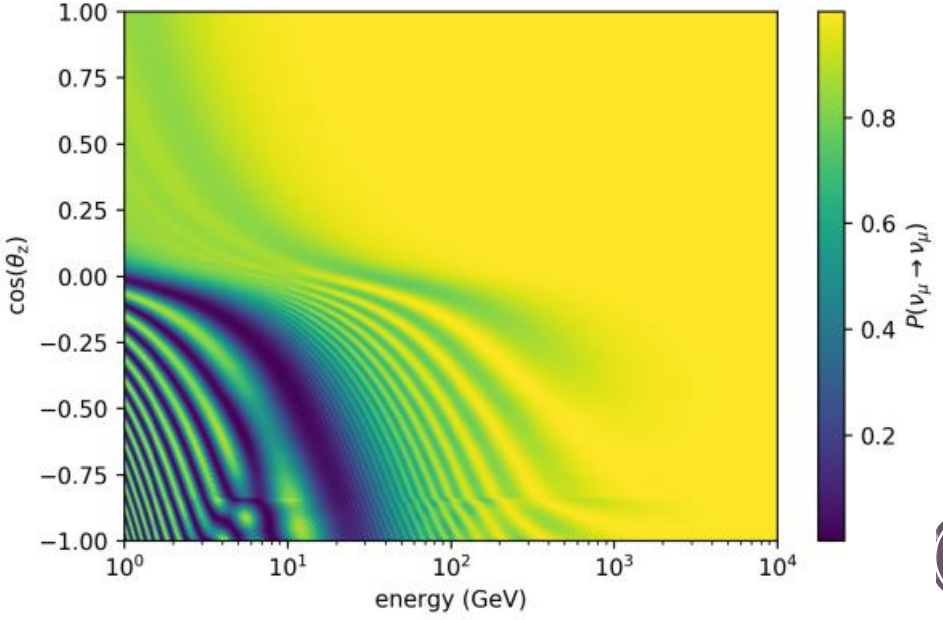
Everything else!

Dominant Oscillations

- High Energies
  - ~500GeV to 10 TeV
  - Whole detector
  - BSM oscillations dominate
  - Both atmospheric and astrophysical

- Low Energies
  - ~5-50 GeV
  - DeepCore
  - Both BSM and regular effects intermingle
  - Atmospheric nu



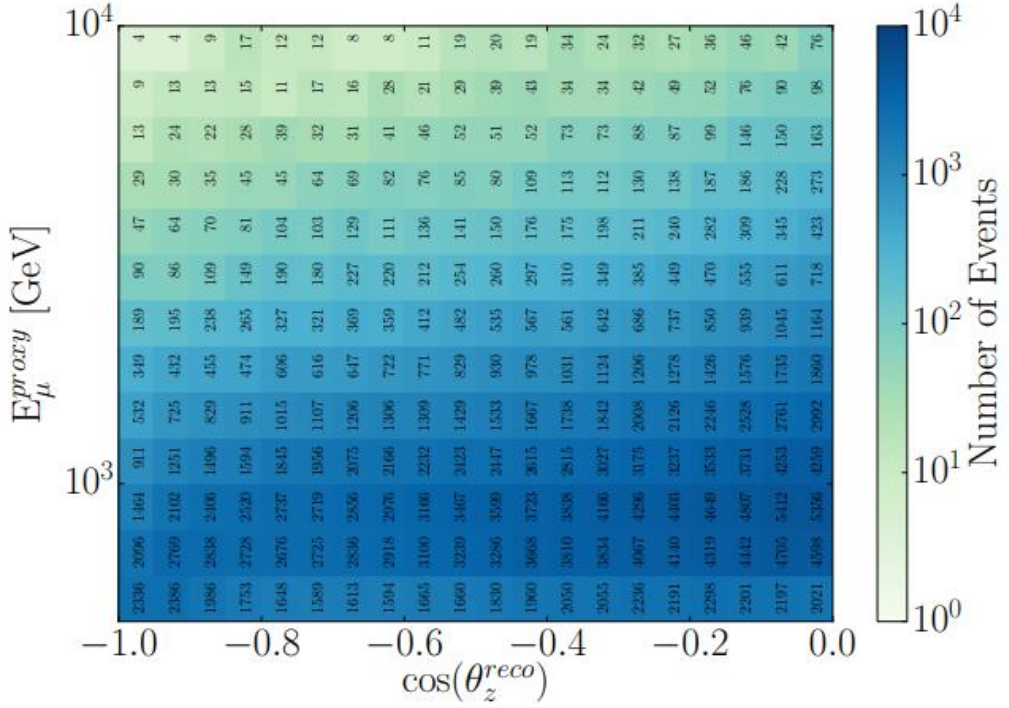


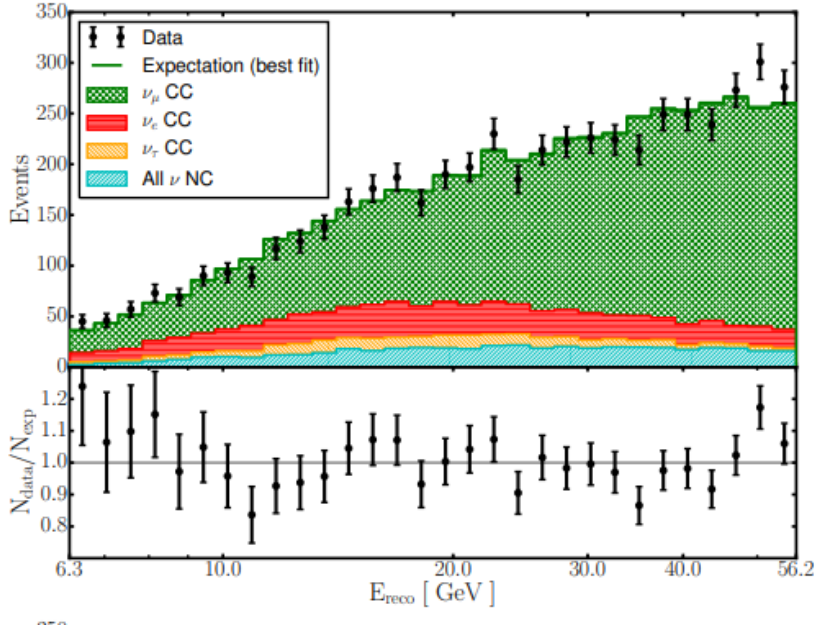
6

Past Analyses

Two Regimes

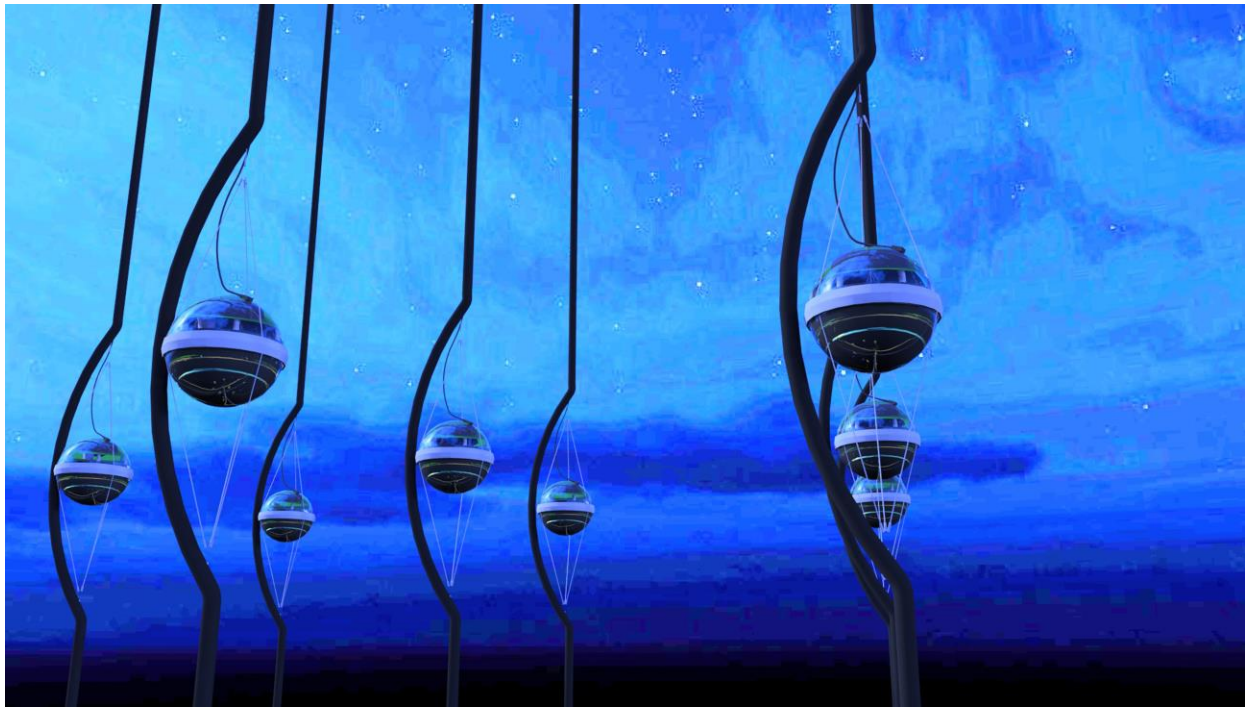
- High-energy, ~500GeV to 10 TeV, with
  - 8 years of IceCube
  - 305,735 up-going muon neutrino events
  - **High-energy cascades analysis on the way**
- Low-energy, ~5-50 GeV, with
  - 3 years of DeepCore
  - Approx 5118 events, assorted
  - **OscNext, full 8-year analysis with ~260k events, coming soon**
  - **IceCube Upgrade will improve low-E sensitivity with a dense infill**





Systematic uncertainties

- High-energy, ~500GeV to 10 TeV
  - Hole Ice, Absorption/Scattering
  - DOM efficiency
  - Barr parameters, atmospheric density
  - Flux normalizations, slope
  - Cross section
  - Kaon energy loss rates
- Low-energy, ~5-50 GeV
  - Hole ice effects
  - DOM efficiency
  - Cross sections
  - Flux normalization, slope
  - nu/anu ratios

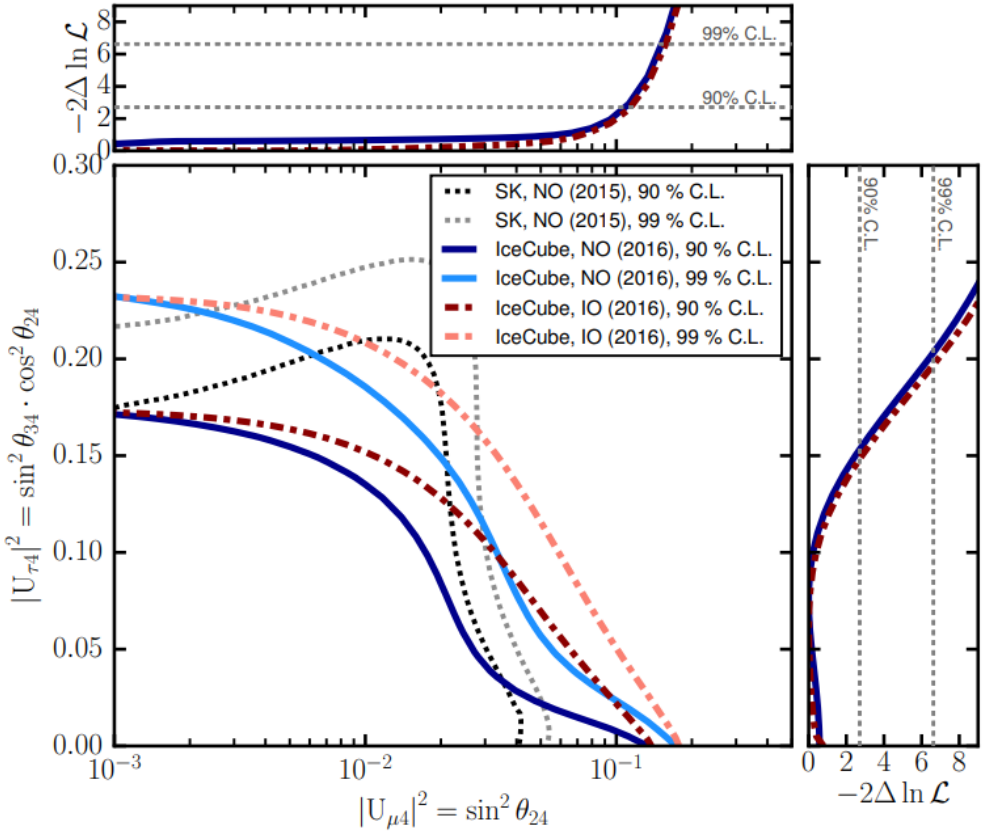


Low-E Results (~5-50 GeV)

- Low-Energy DeepCore analysis
- All-flavor, all-interaction, up-going
- Fit to standard nu mixing parameters,

$$\Delta m^2_{32} = 2.52 \cdot 10^{-3}\ \mathrm{eV}^2, \sin^2\theta_{23} = 0.541$$

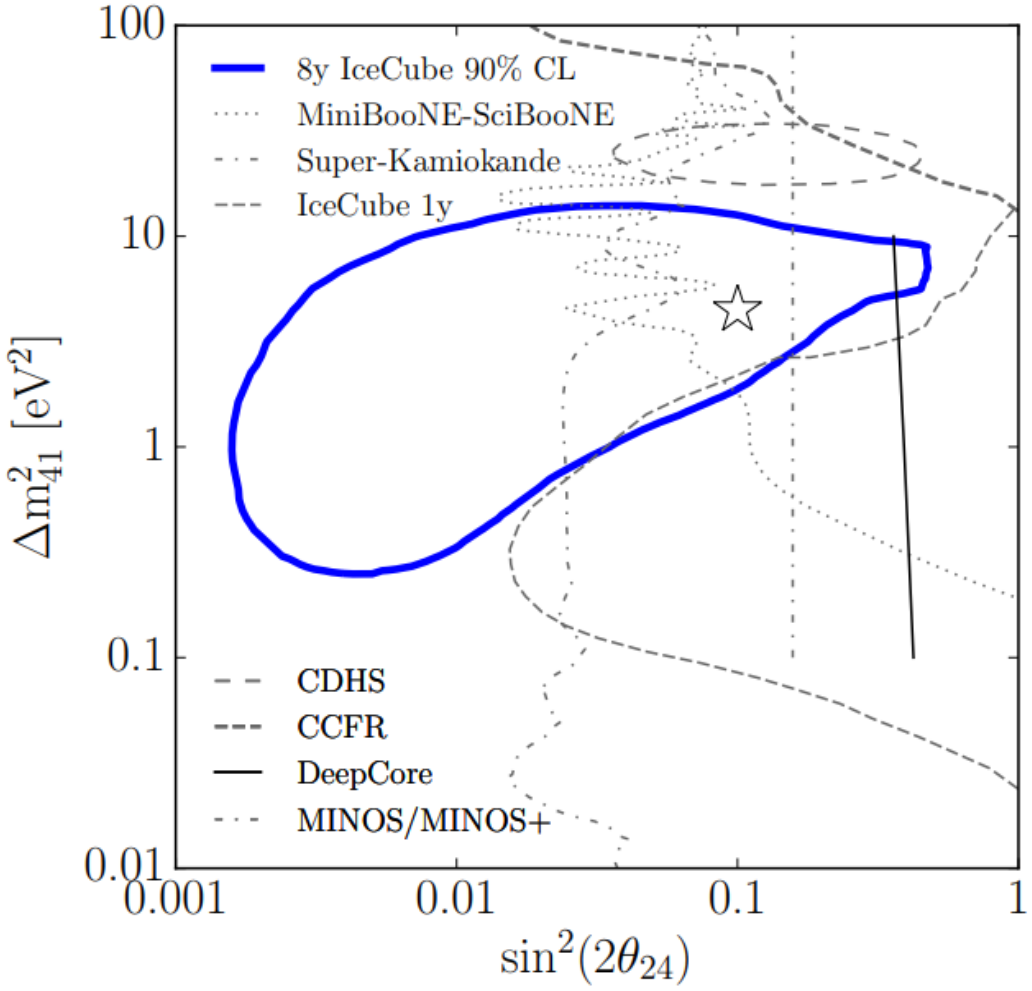
- First results consistent with 3-neutrino model
- Nuisance parameters fit near nominal values



10.1103/PhysRevD.95.112002

High-E Results (~500 GeV – 10TeV)

- High Energy, matter effect
- Fits to all nuisance parameters
- Closed contour, best fit
  - $Sin^2(2\theta_{24})=0.10$, $\Delta m_{41}^2=4.5eV^2$
- Exclusion contour at 99% CL
- Potentially statistically weak signal hint at 90%CL
- Motivates cross-checking in other channels
- Published in
  - PRD 10.1103/PhysRevD.102.052009
  - PRL 10.1103/PhysRevLett.125.141801

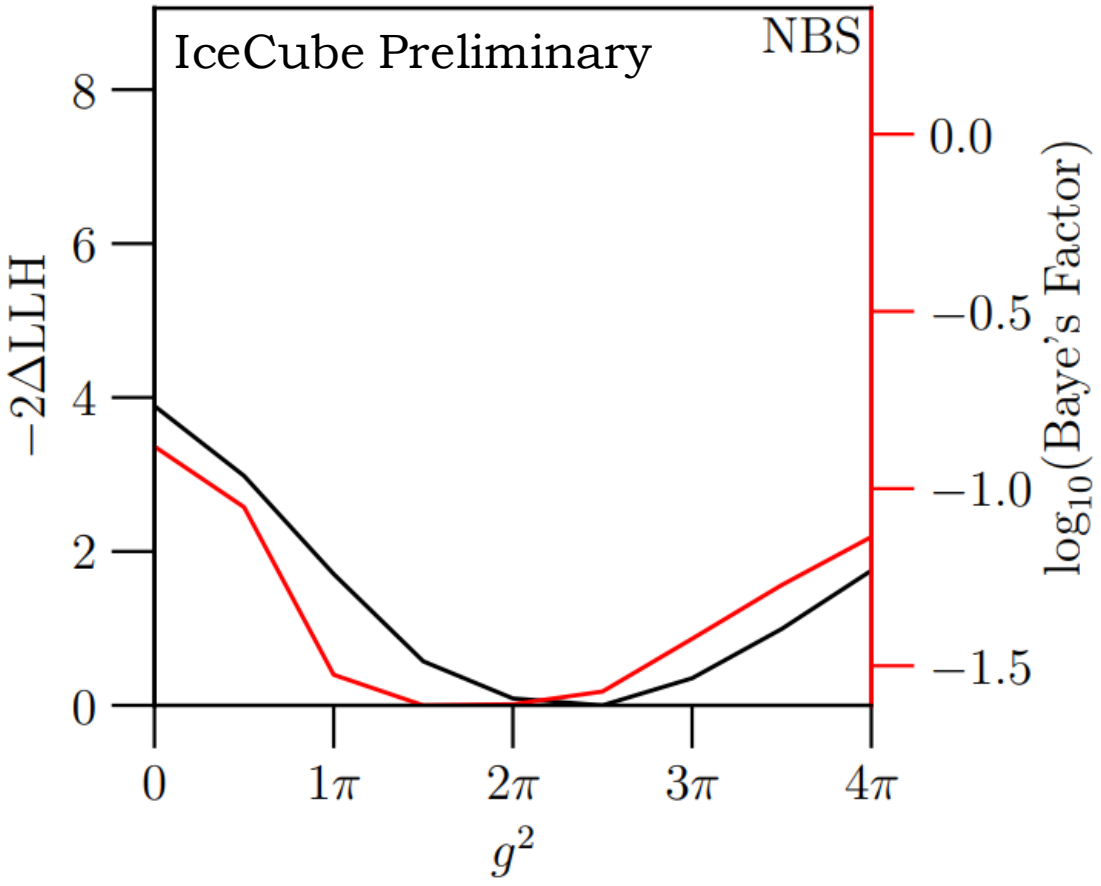


Sterile Decay Sensitivity

- An additional mass, flavor state with decay
- Same 8-year through-going muon sample
- Sterile state with lifetime

$$\frac{1}{\tau} = \Gamma = \frac{g^2 m_4}{16\pi}$$

- Analysis fits to, $\Delta m^2_{41}, \sin^2(\theta_{24}), g^2$ frequentist and Bayesian model comparison



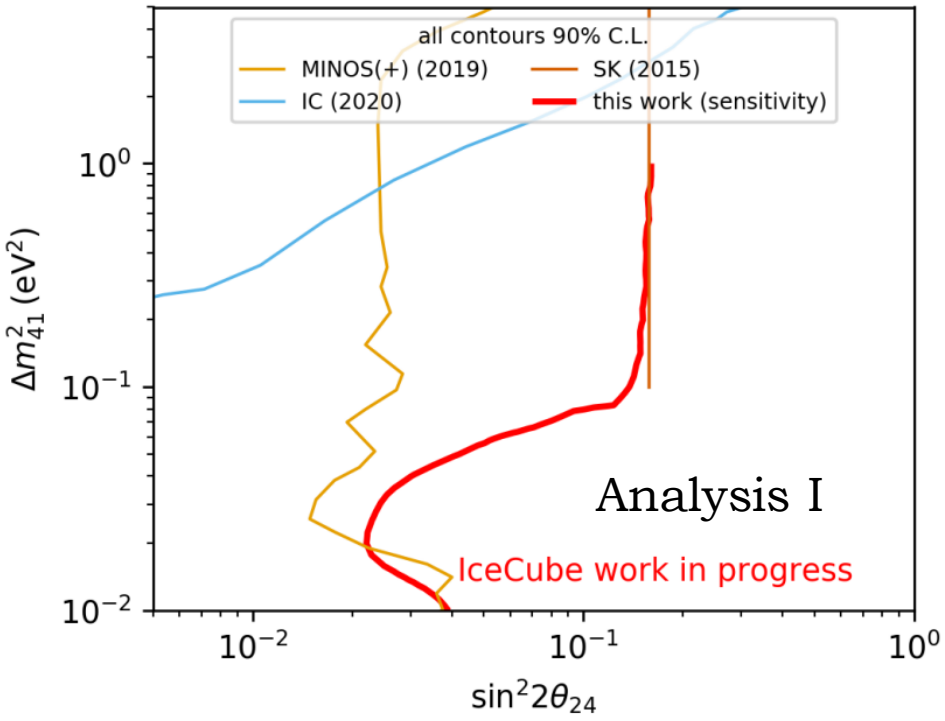
arxiv.org/abs/2110.02351

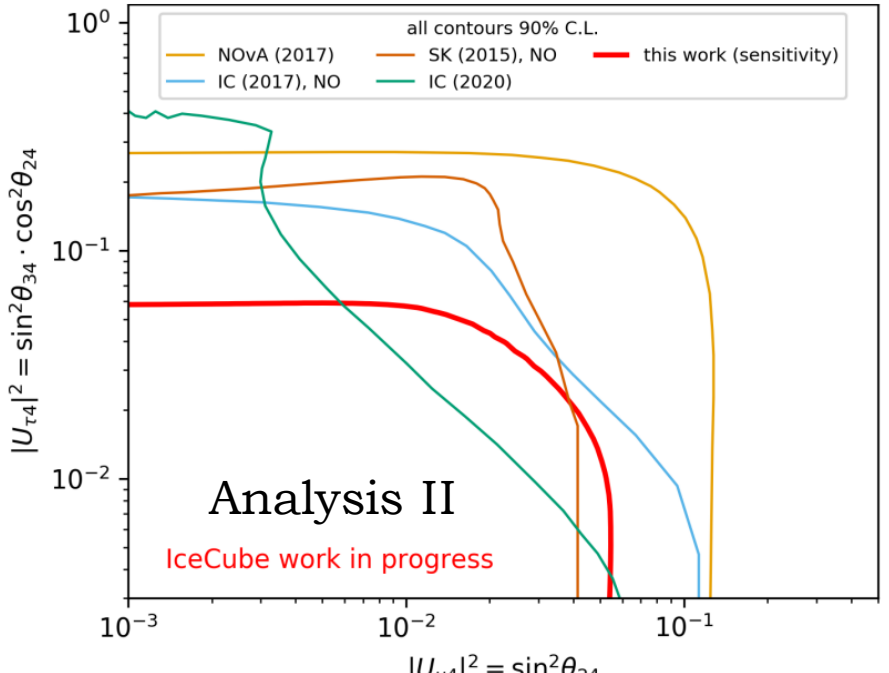
12

Upcoming analyses

OscNext Analysis

- Full 8 years of DeepCore data
- 5-300 GeV analysis
- 260k events in total
- Multiple sub-analyses
  - In both, $\Delta m^2_{32}, \theta_{23}$ free
  - Analysis II - δ_{24} free
- Improved systematic uncertainties
  - Interpolation between GENIE and CSMS DIS cross-sections
  - DOM eff, hole/bulk ice



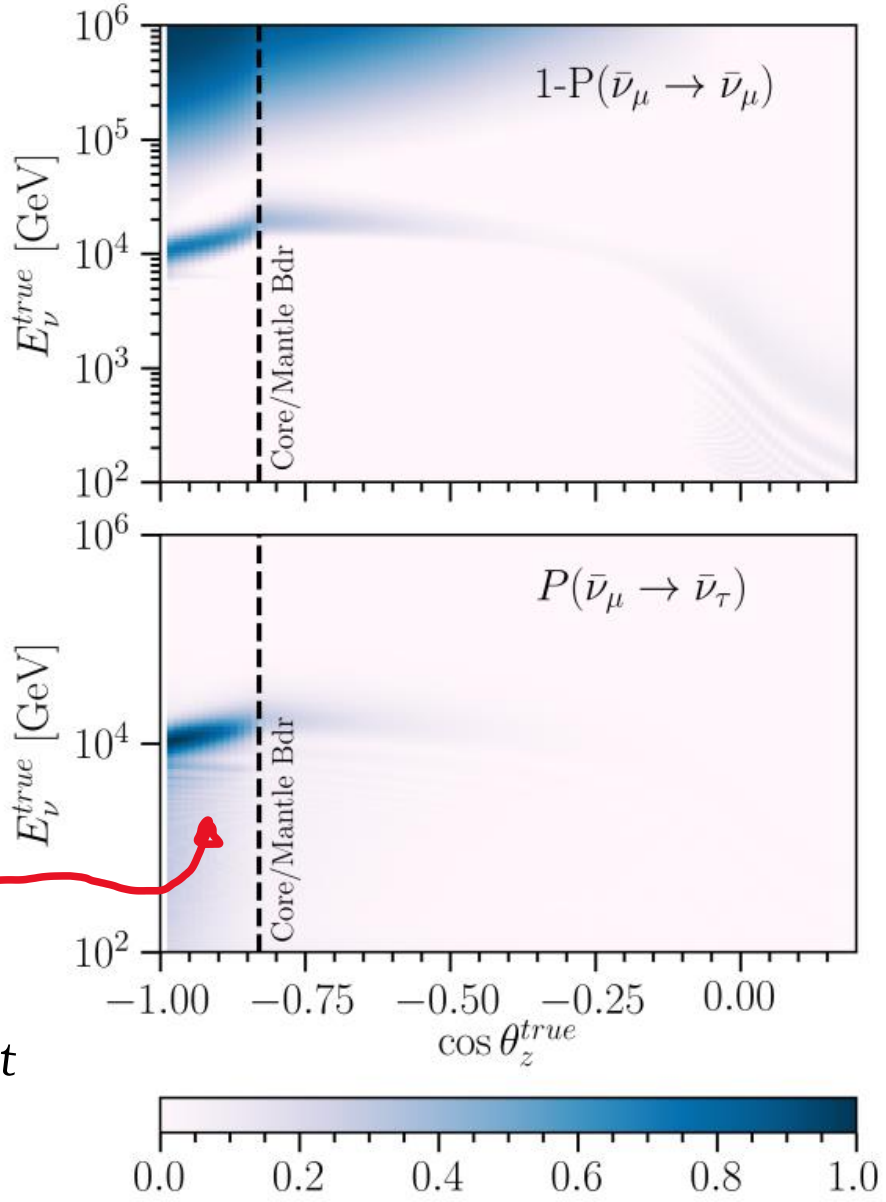


From a talk at VLVnT by Alexander Trettin

Tau Appearance

- $\nu_\mu \rightarrow \nu_s \rightarrow \nu_\tau$ resonance expected for non-zero θ_{24}, θ_{34}
- Up-going antineutrinos, passing through the Earth's core

- Leads to muon disappearance, tau appearance
- Potential for cascade appearance, direct tau appearance

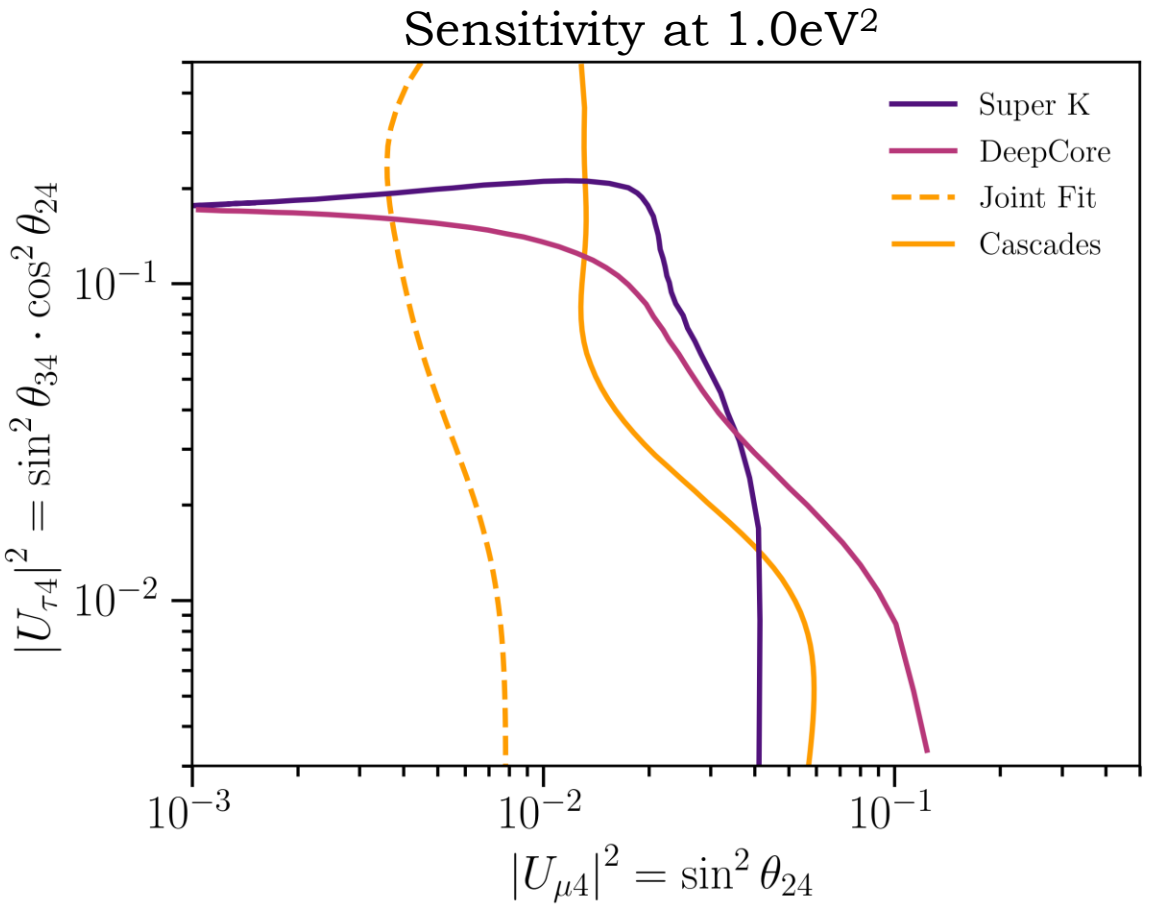


Matter-effect resonance!

Accepted by PRD:
arxiv.org/abs/2111.08722

Calculated Sensitivity

- Calculated using public IC effective areas, reconstruction efficiency
- Could discover signatures in ν_τ appearance
- Simplified systematic uncertainties
  - Flux normalization, shape
  - Ice Absorption/scattering
- Considering both
  - Cascade-only sensitivity
  - Joint track-cascade sensitivity



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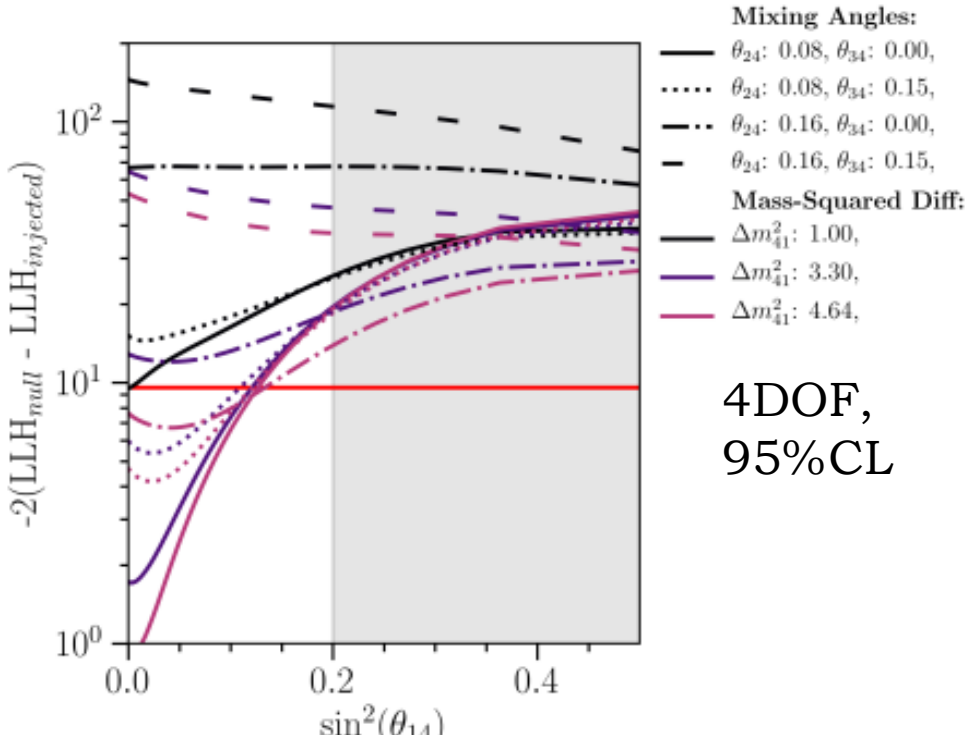
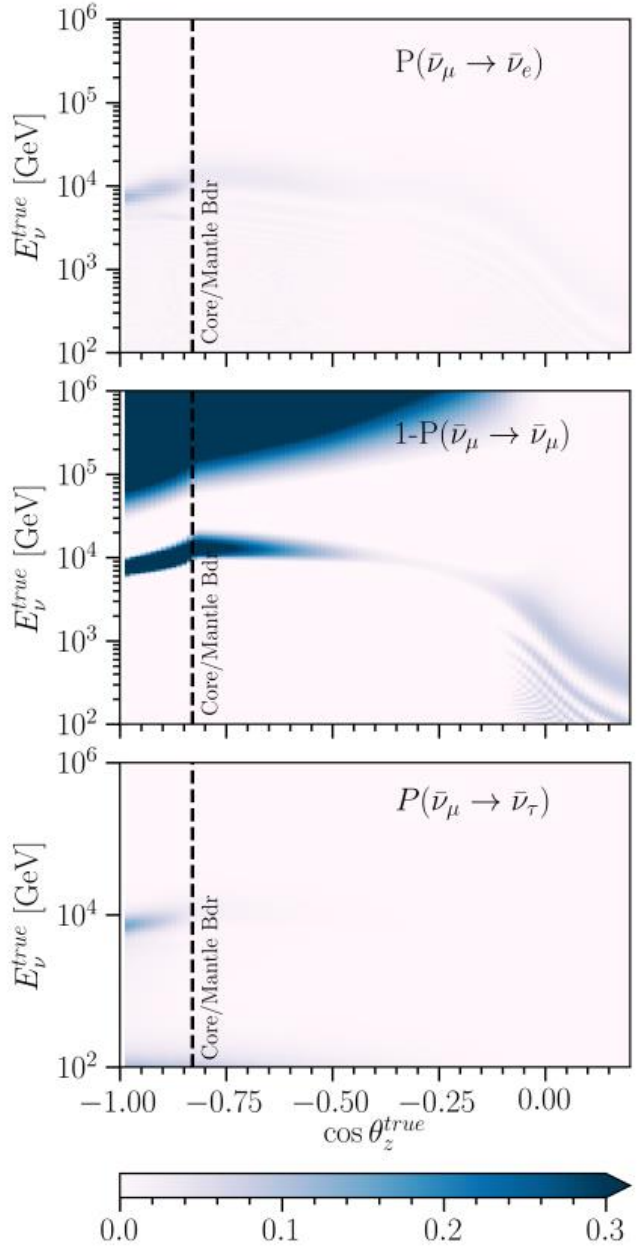
Probing θ_{14}

- Recent BEST results further support gallium anomaly
- Non-zero $\theta_{14}, \theta_{24}, \theta_{34}$ could lead to similar resonant ν_e, ν_τ appearance
- Will be able to probe BEST anomaly



4DOF, 95%CL



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Outlook

- Upcoming IceCube OscNext will improve upon previous 3yr DeepCore analysis
- High-Energy analyses incorporating cascade events
- IceCube poised to make direct tau-appearance measurement
- IceCube will be able to probe the BEST anomaly

Thank you for your time!
Questions?