Neutrino oscillation analysis with Super-Kamiokande's highest-resolution events

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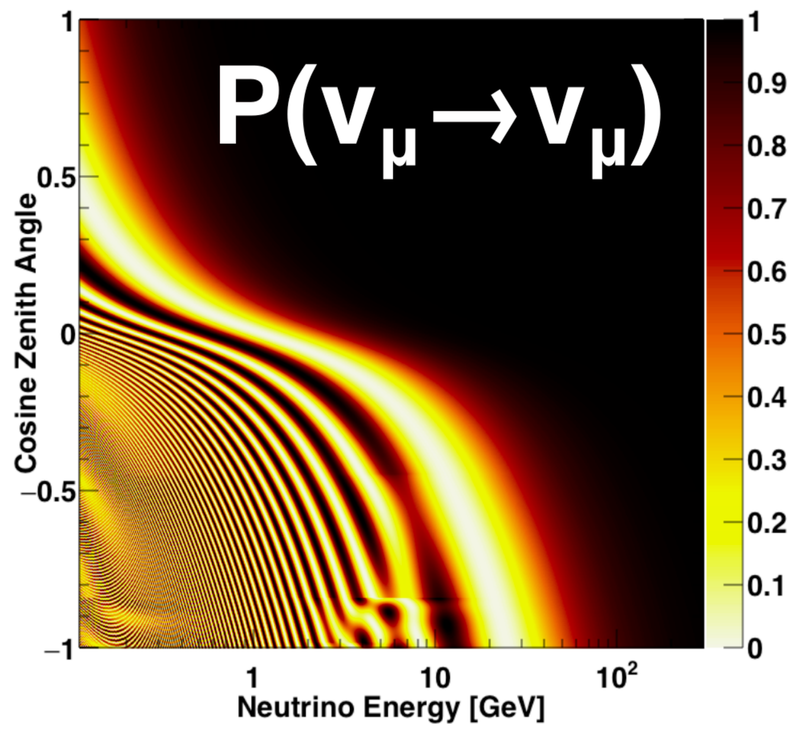
Atmospheric Neutrino Oscillations

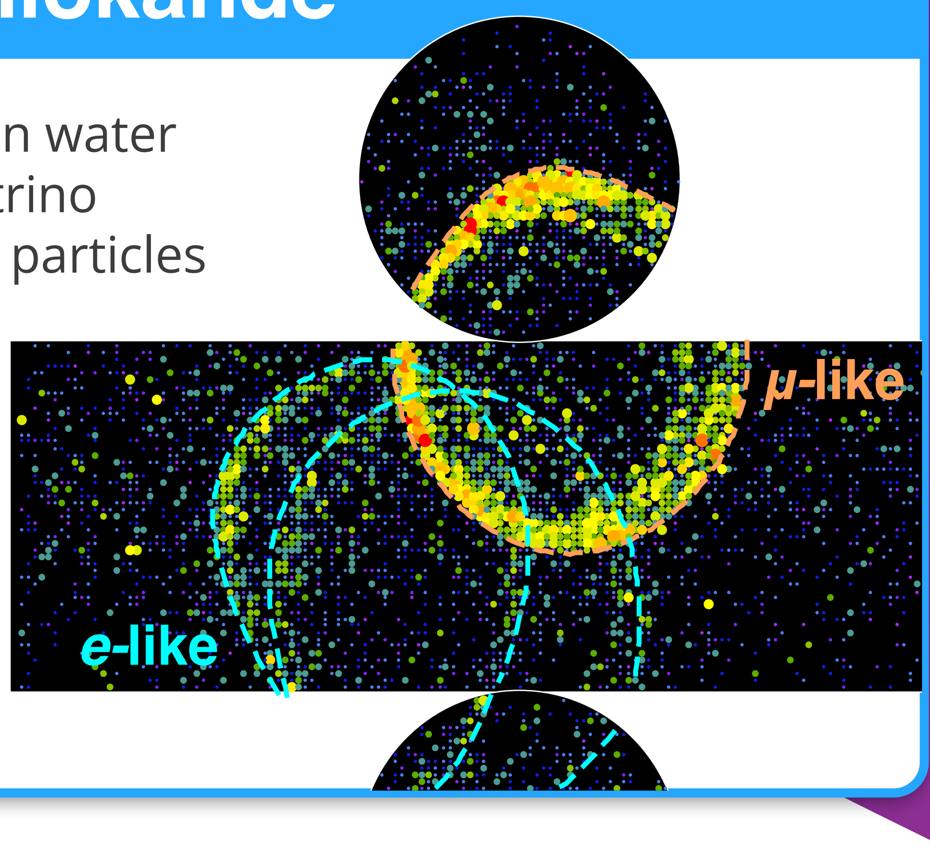


Atmospheric neutrinos have energies ranging from MeV to TeV. Detected at the surface, their baselines span approximately 10 km–13000 km.

Atmospheric neutrino oscillations are driven by the Δm^2_{32} squared-mass difference. Their baselines and energies allows us to probe oscillations across several orders of magnitude in *L/E*.

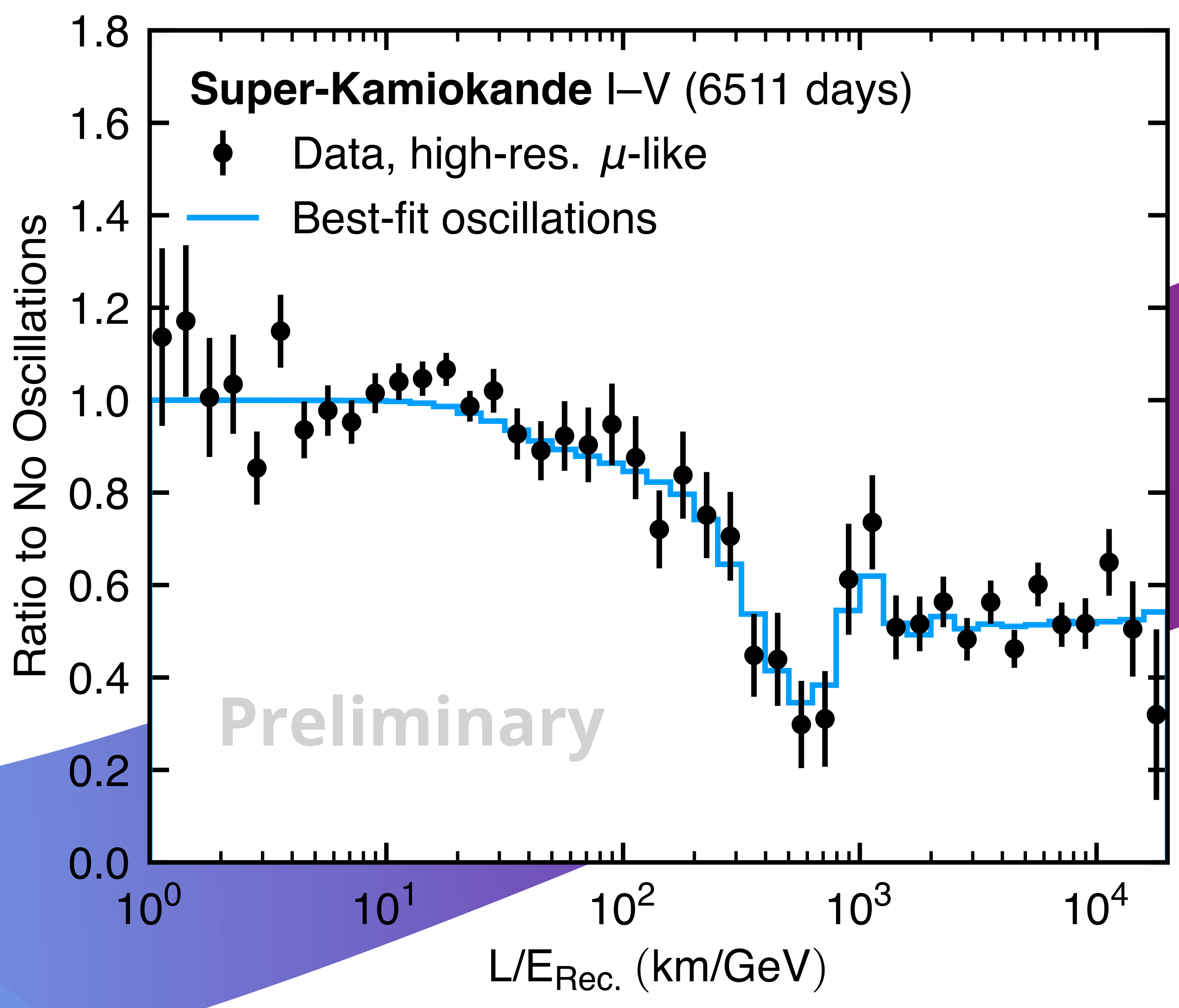
Super-Kamiokande

Super-Kamiokande (Super-K) is a 50-kiloton water Cherenkov detector located in Japan. Neutrino interactions in the water produce charged particles which create ring patterns of hit PMTs.



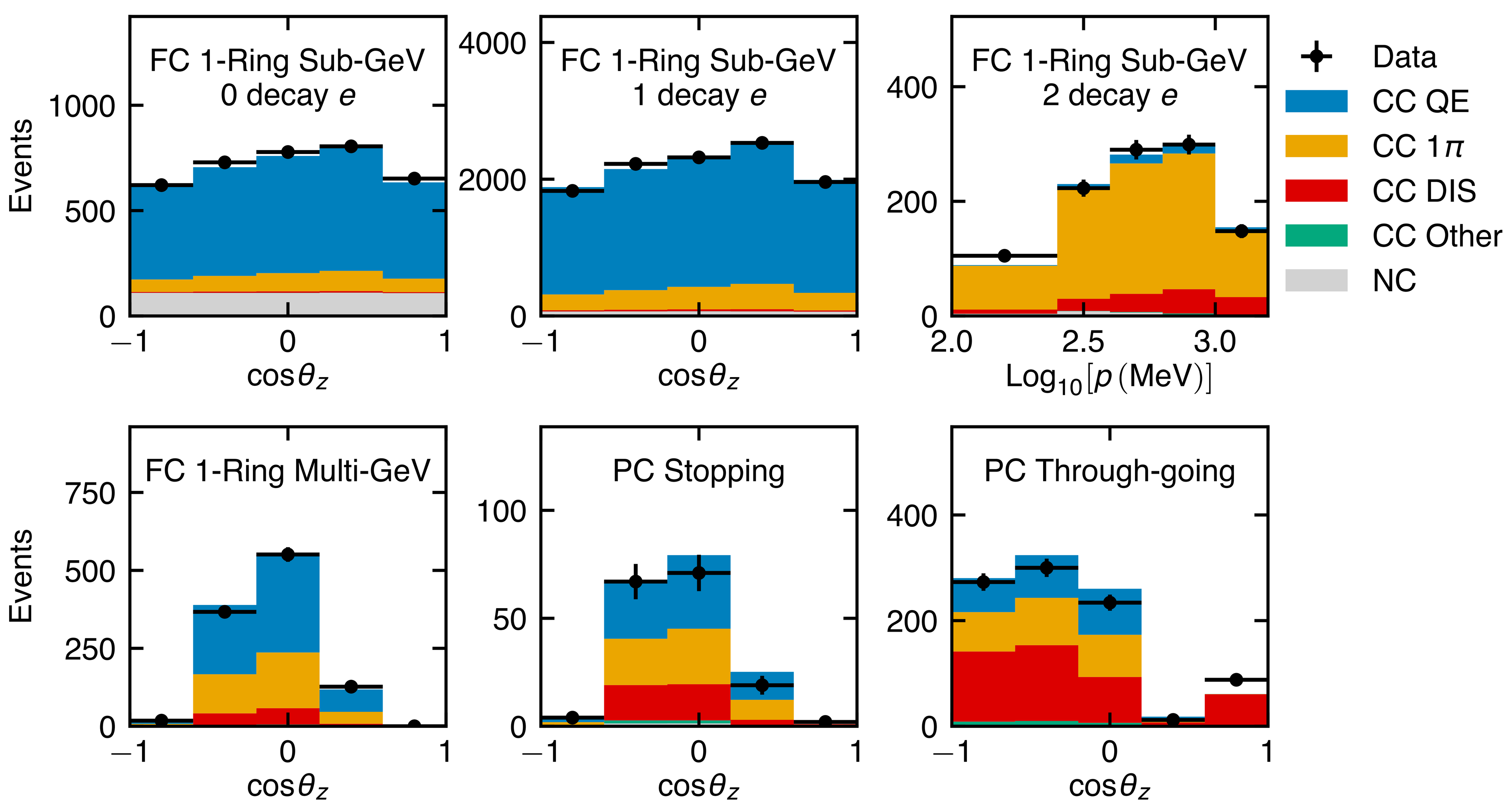
Cherenkov rings are reconstructed to determine each particle's momentum, direction, and PID (μ-like or *e*-like).

6511 live days accumulated with pure water (SK I–V, 1996-2020), gadolinium-loaded water since 2020.



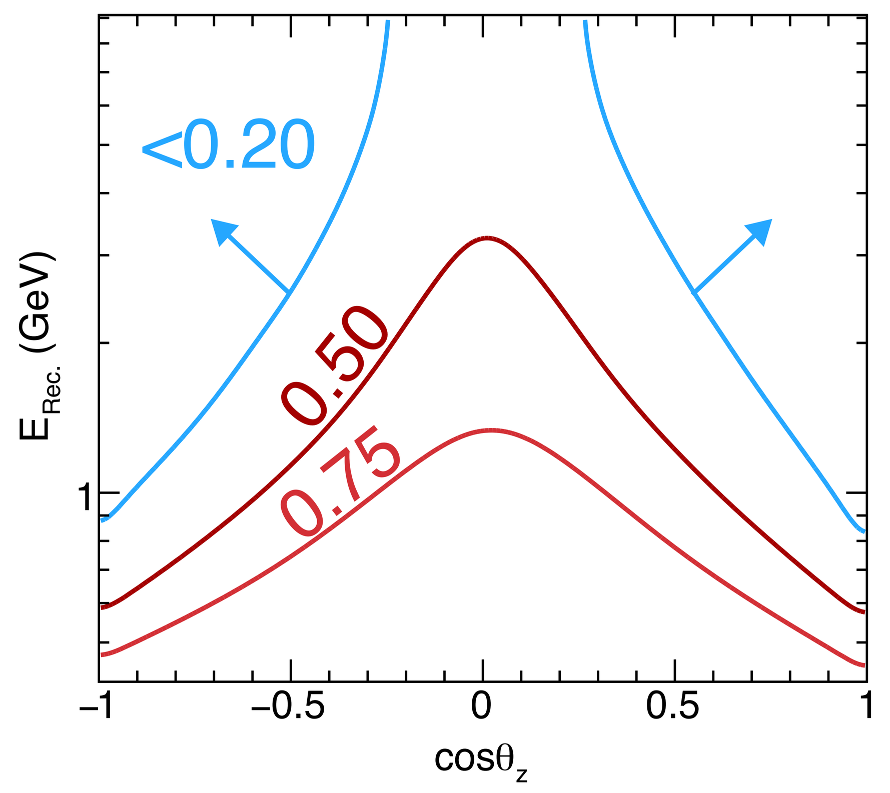
Low-resolution Constraints

Low-resolution μ-like events constrain cross section and flux uncertainties. Events that fail the resolution cut are binned into samples enhanced in different interaction processes and included in the fit.



References: [1] Phys. Rev. Lett. **93** 101801 (Super-K) [2] Phys. Rev. D **86** 052007 (MINOS) [3] Phys. Rev. D **109** 072014 (Super-K)

High-resolution Event Selection

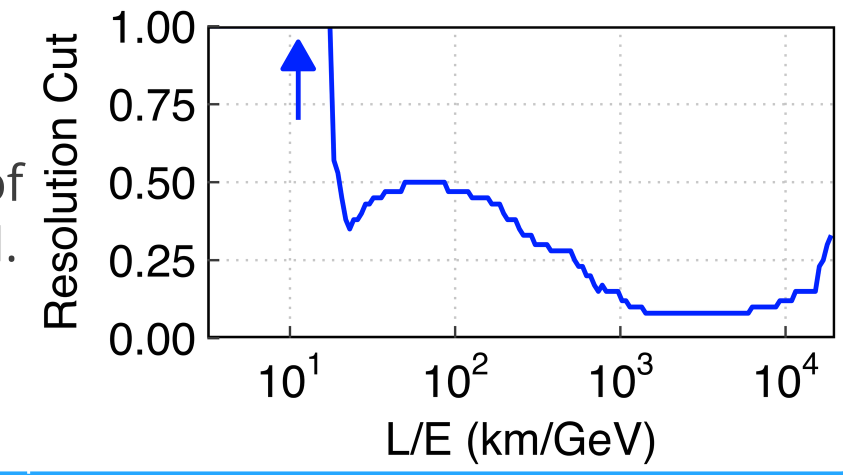


We obtain the distribution of true *L/E* values for each reconstructed neutrino energy ($E_{Rec.}$) and lepton direction ($\cos\theta_z$) using MC[1].

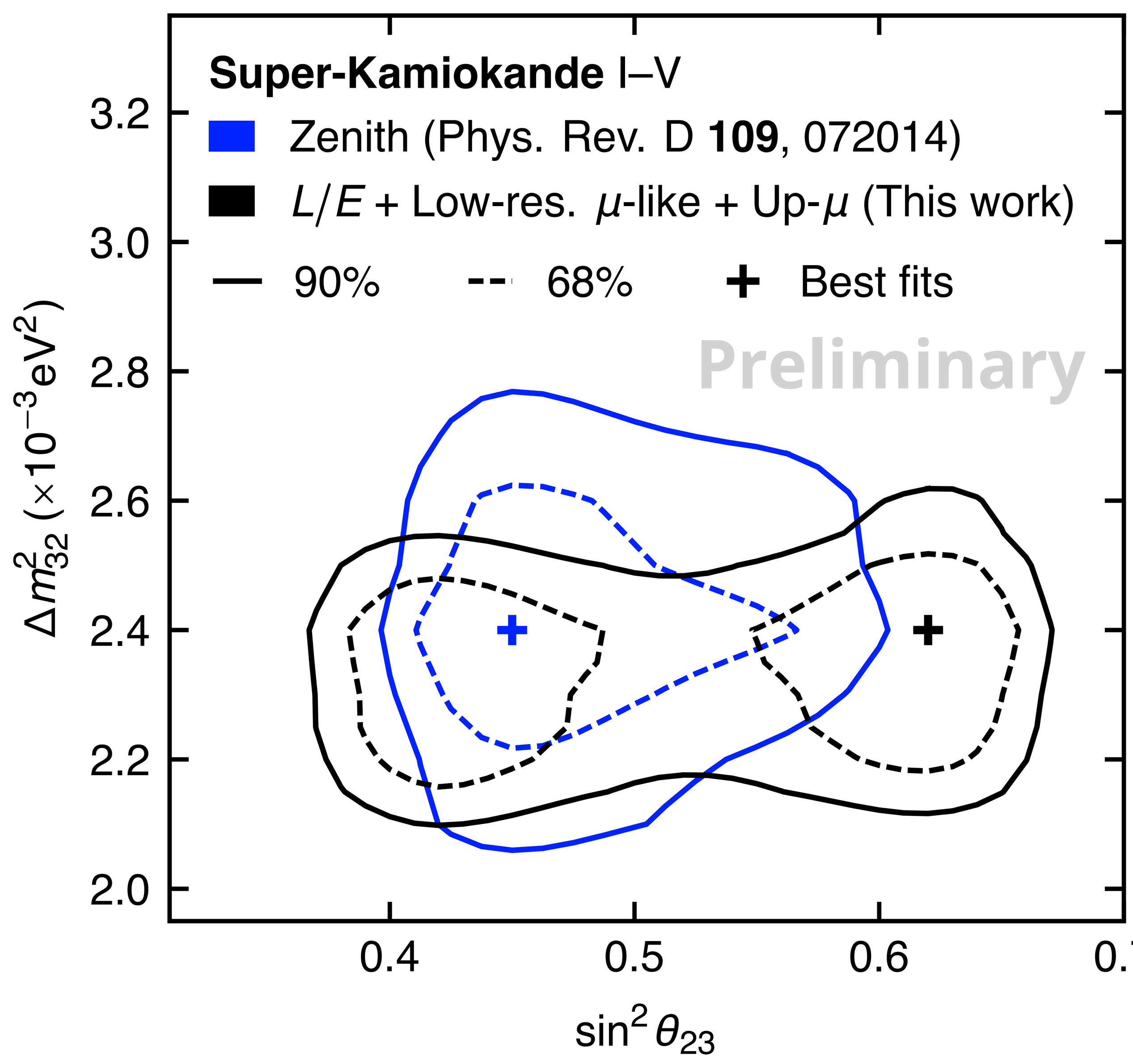
Event-by-event resolution defined as width of the true *L/E* distribution[2]. Observe high-energy events pointed away from the horizon have the best resolutions.

L/E-dependent resolution cut optimizes statistics against precision in each *L/E* bin. Figure of merit = $\sum_i |L/E_{True,i} - L/E_{Rec.,i}| / \sqrt{N}$.

97% $\nu_\mu+\bar{\nu}_\mu$ CC purity for events passing the resolution cut.



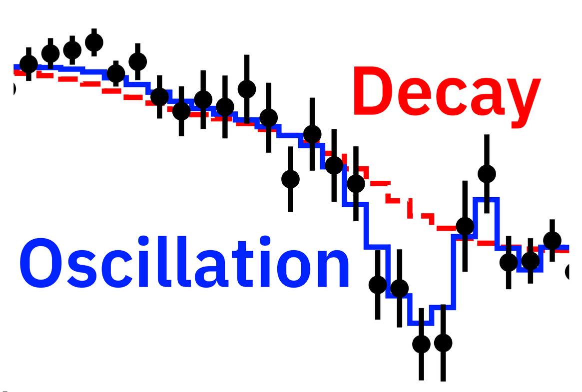
Oscillation Results



The 1σ-allowed ranges of Δm^2_{32} and $\sin^2\theta_{23}$ values are (2.2–2.5)×10^{-3} eV^2 and (0.4–0.65). The constraint on Δm^2_{32} is improved compared to the SK I–V zenith angle analysis[3]. Without electron neutrinos, this analysis is insensitive to the octant of θ_{23}, so a larger range of $\sin^2\theta_{23}$ values are allowed.

Discussion

A muon neutrino disappearance analysis using 6511 days of atmospheric neutrino data selecting Super-Kamiokande's highest-resolution events improves Super-K's measurement of Δm^2_{32}.



The high-resolution data also show a clear oscillatory pattern out to *L/E* ~ 1000 km/GeV, providing a powerful constraint on non-oscillation disappearance models (~6σ rejection of neutrino decay).

Future work will combine the high-resolution muon neutrino event selection with Super-K's electron neutrino data to enhance the sensitivity to three-flavor oscillation effects.