Atmospheric Neutrinos

- High-energy cosmic ray interactions at the top of the atmosphere produce an intense flux of neutrinos.
- Atmospheric neutrinos provide a rich source of oscillation physics
  - Baseline: from 10-13000 km
  - Energy spans 4 orders of magnitude.
- The 40 kton DUNE Far Detector [1], to be built at the Sanford Underground Research Facility in South Dakota will offer unique capabilities for studying atmospheric neutrinos.
- The 4850 ft rock overburden will shield against cosmic ray backgrounds.
- The use of Liquid Argon TPC detector technology will provide excellent energy resolution, angular resolution and particle ID capabilities.
- The large mass of the DUNE detector will deliver high event yields, enabling precision measurements of atmospheric neutrino oscillations.

Atmospheric Neutrino Oscillation Physics

- Atmospheric neutrinos offer a unique probe of oscillations:
  - All flavors of neutrinos and antineutrinos.
  - Upward-going multi-GeV neutrinos are sensitive to matter effects via MSW resonance.
  - Can probe neutrino mass hierarchy, $\theta_{23}$ octant and $\delta_{CP}$ phase.
  - Test standard oscillation model over multiple oscillation wavelengths.
  - Search for exotic phenomena.
  - Atmospheric neutrino data can help resolve the ambiguities that arise in beam-only oscillation analyses.

Simulation

- Sensitivity to oscillations evaluated using a 4-vector simulation and pseudo-reconstruction [2].
- Neutrino interactions on argon are simulated using Bartol 3D flux model [3] and GENIE [4].
- Parameterised thresholds, resolutions, and particle ID are applied to the final-state 4-vectors.
- Events are classified as fully contained (FC) or partially contained (PC) based on containment of final-state leptons.
- Final-state protons and decay electrons are also tagged for statistical separation of $\nu/\bar{\nu}$.

Neutrino Oscillation Sensitivities

- Oscillation sensitivities are calculated using a joint fit to $\nu_{\mu}$-like and $\nu_{e}$-like spectra, with 18 systematic parameters.
- MSW resonance enables determination of mass hierarchy.
  - Resonance occurs for neutrinos in case of normal hierarchy, and for antineutrinos in case of inverted hierarchy.
  - Ability to determine mass hierarchy is nearly independent of $\delta_{CP}$ phase, unlike accelerator neutrino experiments.
  - Sensitivity of DUNE comparable to Hyper-K despite smaller detector mass, due to better resolution of energy and angle.
- Moderate sensitivity to both $\theta_{23}$ octant and $\delta_{CP}$ phase.

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