Probing Large Extra Dimension at DUNE using Beam Tunes

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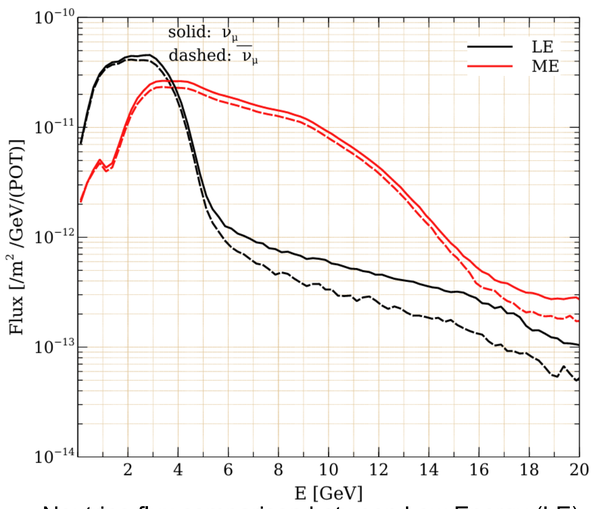
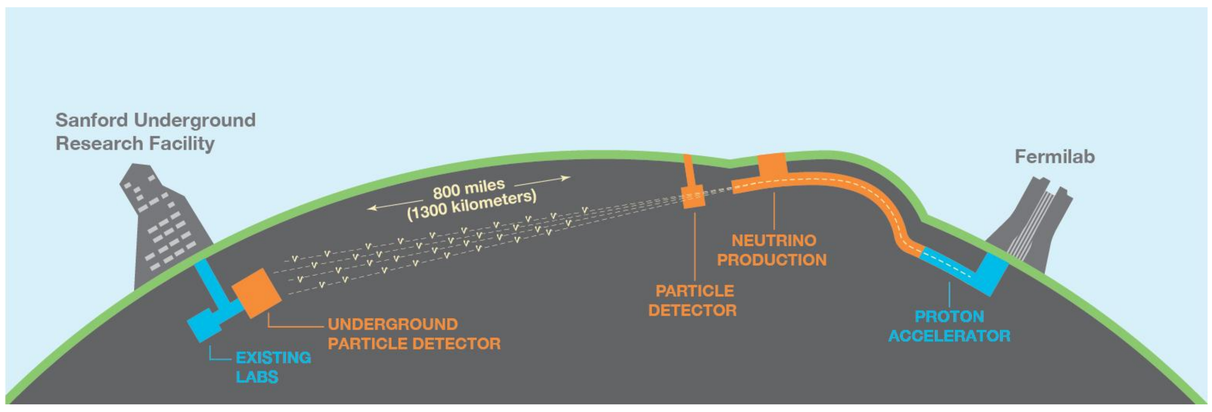
DUNE

- Next-generation long-baseline neutrino experiment (1300 km baseline).
- Primary goals:
  - Measure leptonic CP violation
  - Determine neutrino mass ordering
  - Test physics beyond the Standard Model
- High-resolution liquid argon time projection chambers (LArTPCs).
- Excellent sensitivity to energy-dependent oscillation patterns.
- Flexible beam modes: Low Energy (LE) and Medium Energy (ME).
- Well-suited to probe new physics such as sterile neutrinos or extra dimensions.

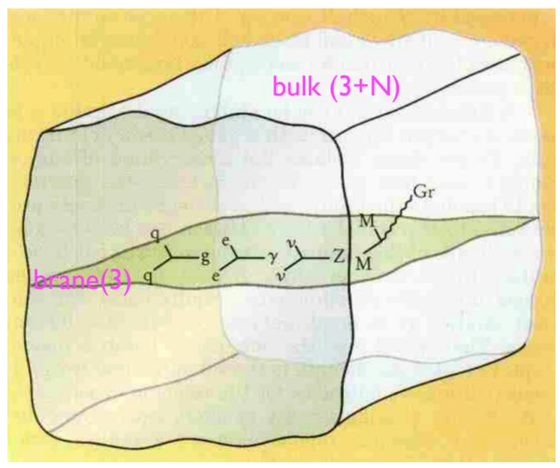


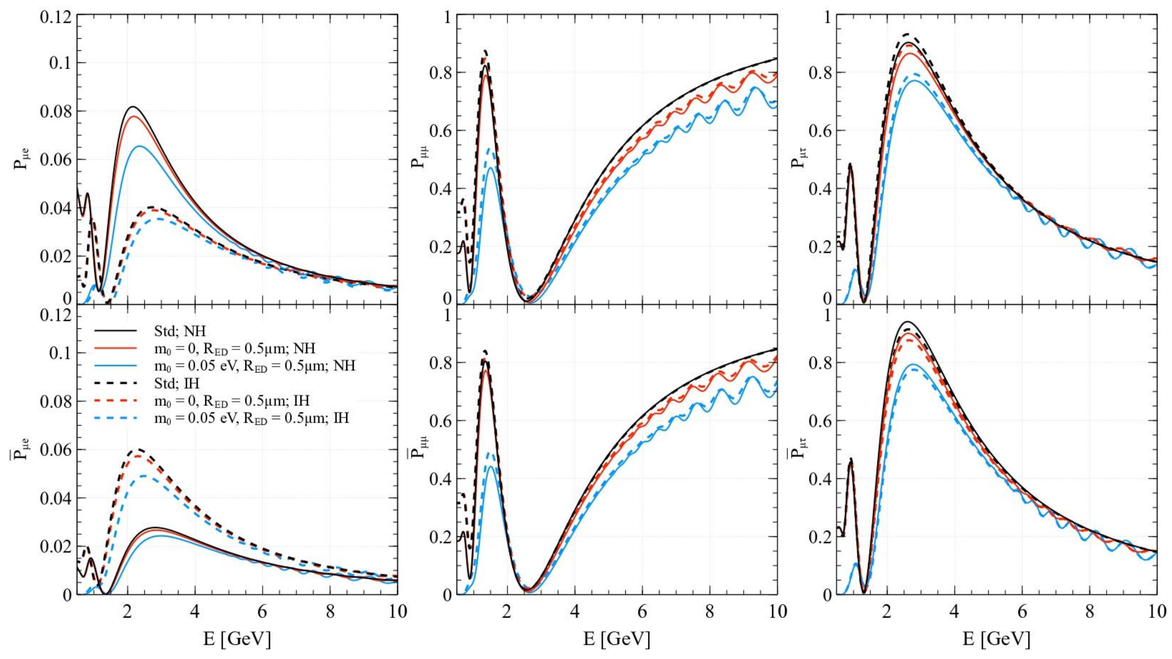
Neutrino flux comparison between Low Energy (LE) and Medium Energy (ME) beam tunes.



Large Extra Dimension

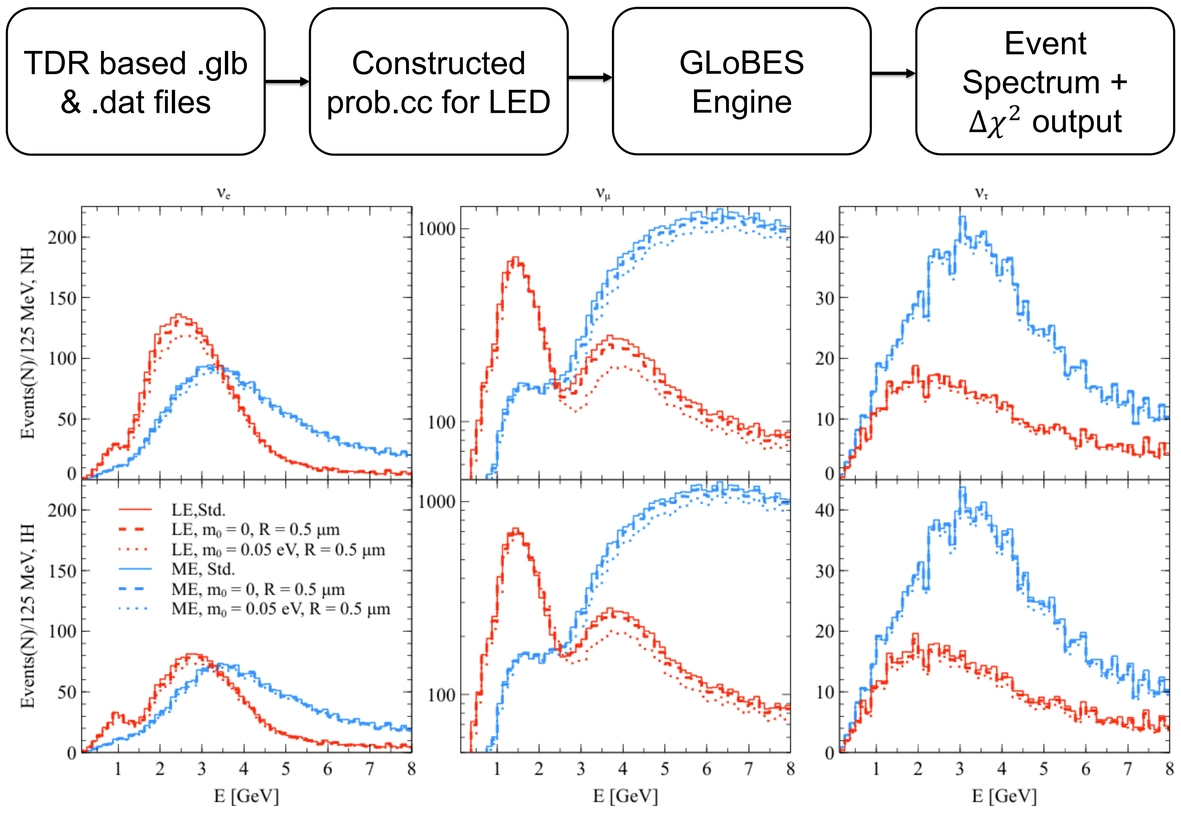
- LED model explains tiny neutrino masses via compact extra dimensions.
- Right-handed neutrinos propagate in a flat extra spatial dimension.
- Leads to Kaluza-Klein (KK) modes that mix with active neutrinos.
- Active neutrinos can oscillate into KK modes:
  - Suppression of standard oscillation probabilities
  - Fast oscillation "wiggles" at high energies
- Two key parameters:
  - Lightest Dirac mass m_0
  - Radius of extra dimension R_{ED}





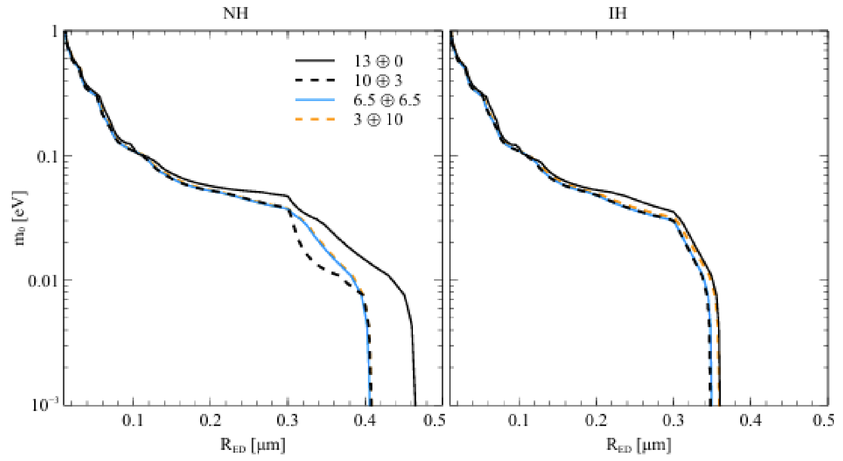
Analysis using GLoBES

- Simulation performed using GLoBES with LED-modified probability engine.
- Based on DUNE Far Detector:
  - 1300 km baseline
  - LArTPC technology
- Considered both LE and ME beam modes.
- Included three oscillation channels:
  - $\nu_\mu \to \nu_e$, $\nu_\mu \to \nu_\mu$, $\nu_\mu \to \nu_\tau$
- χ^2 analysis with Poisson statistics, including:
  - Statistical fluctuations
  - Systematic uncertainties
  - Priors on oscillation parameters
- Workflow and expected event rates shown below.

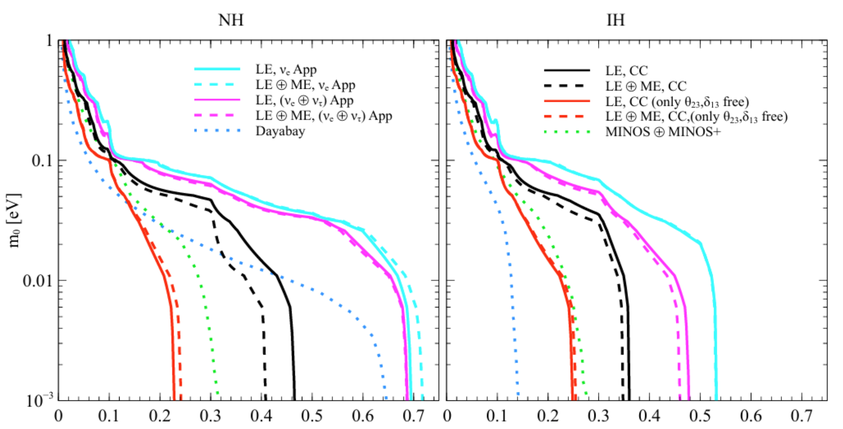


Results

- Performing χ^2 analysis to test LED vs. standard 3-flavor scenario.
- Parameter space :
  - Lightest Dirac mass m_0
  - Radius of extra dimension R_{ED}
- Used simulated event rates with LE and ME beam combinations.
- Total runtime fixed to 13 years; legend indicates LE/ME split.
- 90% C.L. exclusion contours shown below.
- Upper-right region of each panel is excluded.
- Best sensitivity :
  - 10 yr LE + 3 yr ME (black dashed line)
  - $R_{ED} \lesssim 0.41 \mu m$ for NH
  - $R_{ED} \lesssim 0.34 \mu m$ for IH
- Also compared :
  - LE-only vs. LE+ME
  - DUNE results vs. external limits(Daya Bay, MINOS)



Exclusion contours at 90% C.L. for various LE/ME beam runtime combinations (total 13 years).
The dashed black line (10 yr LE ⊕ 3 yr ME) shows the strongest exclusion in the NH case.
Upper-right region is excluded.



Comparison of LED sensitivity across beam/channel setups and external experiments.
Solid: LE-only,
dashed: LE+ME (10⊕3),
dotted: Daya Bay / MINOS(+).
Optimistic fits yield stronger constraints.

Conclusion

- DUNE can effectively probe Large Extra Dimensions via oscillation measurements.
- LED effects significantly alter standard oscillation probabilities.
- DUNE can exclude large regions in the $m_0 - R_{ED}$ parameter space at 90% C.L.
- Beam configuration strongly affects sensitivity.
- Best exclusion: 10 yr LE + 3 yr ME beam combination.
- Beam optimization is crucial in future searches for BSM physics.

Special thanks to Dr. Masud for his guidance.