Probing Beyond the Standard Model Physics with the Deep Underground Neutrino Experiment

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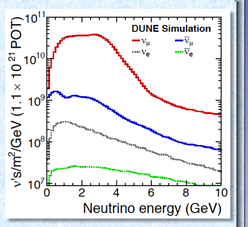
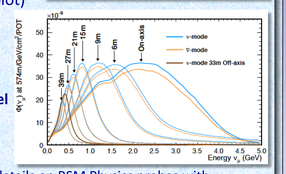
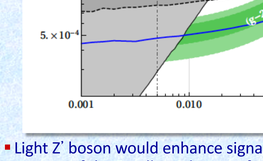
DUNE - Deep Underground Neutrino Experiment

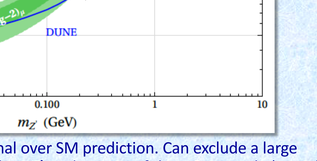
- 1300 km baseline between Fermilab and SURF
- New LBNF ν beam, 1.2 MW for 120 GeV protons from Fermilab's Main Injector, upgradeable to 2.4 MW (plot shows neutrino-mode flux)
- On-axis LArTPC Far Detector with 40 kton fiducial mass, located at SURF, SD, 1.5 km underground
- Near Detector at Fermilab, 575 m from target, 60 m depth, 67 ton fid. LArTPC + Multi-Purpose Tracker, off-axis capability (fluxes shown in plot)





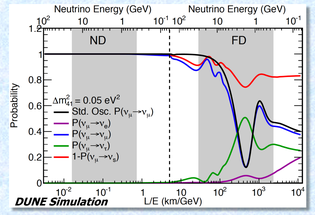
- **Primary Physics goals:**
  - Study ν oscillations, look for leptonic CP violation, determine ν mass ordering
  - **Look for Physics beyond the Standard Model**
  - Look for nucleon decay
  - Study ν from Supernova burst
- See DUNE TDR Physics volume, chapter 8, for full details on BSM Physics probes with DUNE: **https://arxiv.org/abs/2002.03005**

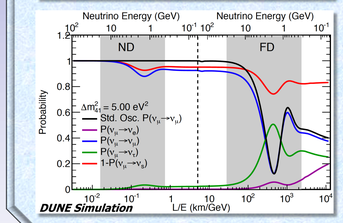


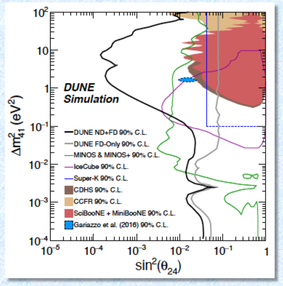


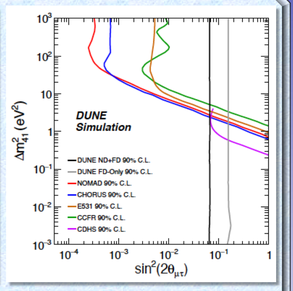
Search for Light Sterile Neutrino Mixing

- DUNE can look for new light ν sterile states through:
  - CC and NC disappearance between ND and FD
  - Non-standard FD ν_e CC appearance
  - ν_μ CC disappearance and ν_e CC appearance in the ND baseline
  - Deviations from standard behavior in atmospheric ν sample at FD

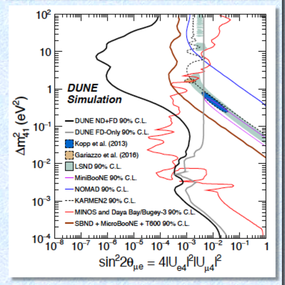






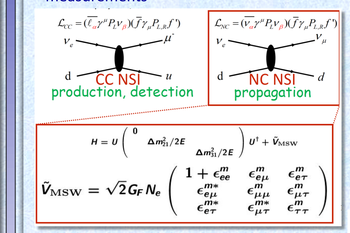


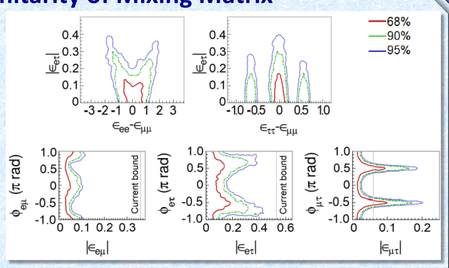
- Plots to the left show mixing probabilities for 3 and 3+1 ν models as a function of L/E
  - Grey bands show ν beam regions probed by ND and FD
  - For small values of Δm^2_{41}, distortions seen at FD only
  - For values of $\Delta m^2_{41} > 1$ eV^2, distortions at ND and flat normalization deficit at FD
- Plot above and plots to the the right show DUNE's sensitivities to the sterile mixing angles in a 3+1 model, for oscillations in both detectors using a GLoBES implementation.
  - On its own, DUNE can probe the sterile mixing parameter space at the same level or better than present and future experiments



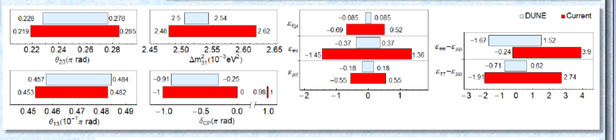
Searches for NSI and Non-Unitarity of Mixing Matrix

- Probe non-standard interactions (NSI) between neutrinos and matter by looking for effects on standard oscillation parameter measurements





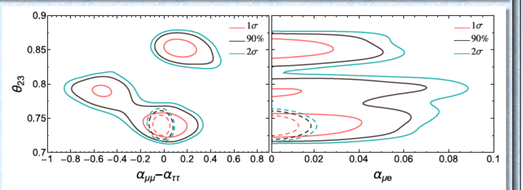
- Top right plot shows potential DUNE 68%, 90%, and 95% CL. constraints on NSI parameters as a function of θ_{23}
- Middle panel shows comparison of 1D DUNE constraints to current constraints



- If neutrinos acquire mass through (type I) seesaw mechanism, extra heavy state(s) mean mixing matrix need not be unitary

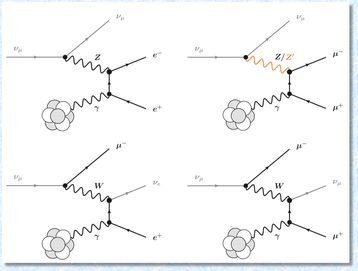
$$N = \begin{pmatrix} 1-\alpha_{ee} & 0 & 0 \\ \alpha_{\mu e} & 1-\alpha_{\mu\mu} & 0 \\ \alpha_{\tau e} & \alpha_{\tau\mu} & 1-\alpha_{\tau\tau} \end{pmatrix} U$$

- Plot to the right shows constraints with DUNE alone (solid) and with present constraints (dashed)



Search for Neutrino Tridents

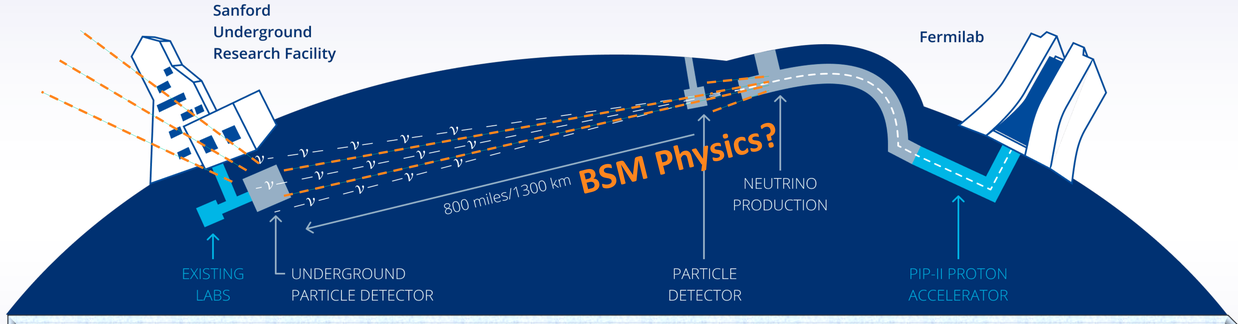
- Rare electroweak process resulting in lepton-pair production through ν interaction in Coulomb field of nucleus
- SM cross section $\mathcal{O}$(6-7) smaller than for charged-current int. at DUNE ν energies
- Table shows SM signal events per ton of LAr/year (ND LArTPC ~ 67 ton fid. mass) for beam data taken in neutrino (top) or antineutrino mode (bottom)



Process	Coherent	Incoherent
$\nu_\mu \to \nu_\mu \mu^+ \mu^-$	1.17 ± 0.07	0.49 ± 0.15
$\nu_\mu \to \nu_\mu e^+ e^-$	2.84 ± 0.17	0.18 ± 0.06
$\nu_\mu \to \nu_e e^+ \mu^-$	9.8 ± 0.6	1.2 ± 0.4
$\nu_\mu \to \nu_e e^+ e^-$	0	0
$\bar{\nu}_\mu \to \bar{\nu}_\mu \mu^+ \mu^-$	0.72 ± 0.04	0.32 ± 0.10
$\bar{\nu}_\mu \to \bar{\nu}_\mu e^+ e^-$	2.21 ± 0.13	0.13 ± 0.04
$\bar{\nu}_\mu \to \bar{\nu}_e e^+ \mu^-$	0	0
$\bar{\nu}_\mu \to \bar{\nu}_e e^+ e^-$	7.0 ± 0.4	0.9 ± 0.3

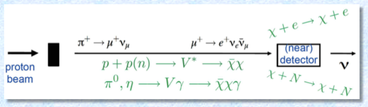
- Using topological cuts on trident interactions with final-state muons and background interactions generated with DUNE ND LArTPC sim., select 10.2 signal events and 130 bkg per year (10^6 bkgd. rejection)
  - Primary bkgd. from ν_μ CC with single π production

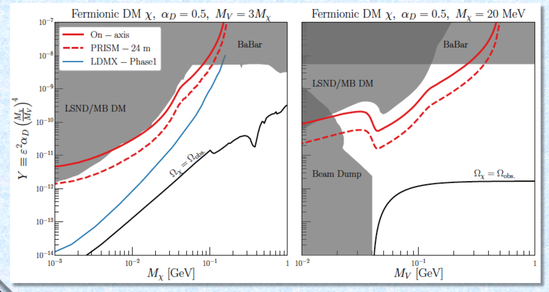
- Light Z' boson would enhance signal over SM prediction. Can exclude a large portion of the 2σ allowed region for a Z' explanation of the g-2 anomaly (green)



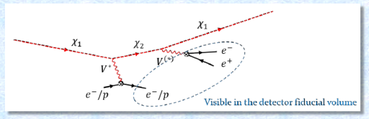
Searches for Dark Matter

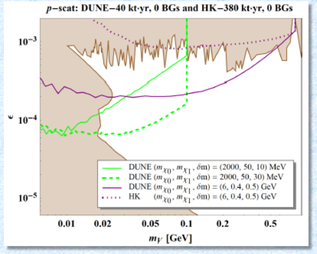
- Sub-GeV (light) dark matter particles could be produced by LBNF in large amounts
- DM particles are detected through NC interactions in the ND – large backgrounds from standard ν interactions
- Plot below shows DUNE reach for the case of elastic scattering between DM and electrons for two different DM parameters, both with ND on-axis and at various off-axis positions



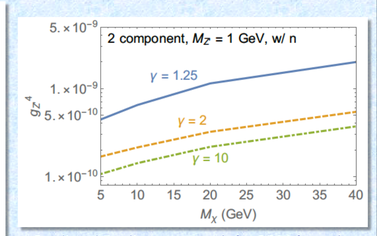


- Cold dark matter captured by the Galaxy center or the Sun may lead to production of lighter, boosted dark matter (BDM) via annihilation or decay
- BDM particles can interact with electrons or nucleons in DUNE detectors
- Look for scattered electrons or recoil protons





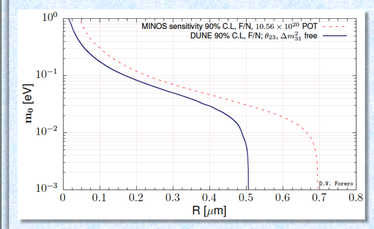
- Sensitivities for galactic BDM detection compared to Hyper-K



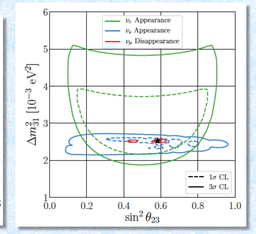
- Predicted 5σ discovery reach for BDM from the Sun assuming different boost γ factors
  - Atmospheric and neutron bkgds. are included

Other BSM Physics Opportunities with DUNE

- **Near Detector + Far Detector**
  - Large Extra-Dimensions through distortions of 3-flavor oscillation pattern caused by mixing of neutrinos with Kaluza-Klein modes
  - CPT Violation and Lorentz violation through comparison of disappearance measurements during neutrino and antineutrino beam running
  - Nonstandard long-baseline ν_τ appearance, using high-energy beam configuration for enhanced rate of ν_τ CC interactions
  - Atmospheric ν signatures of WIMP annihilation in the center of the Sun

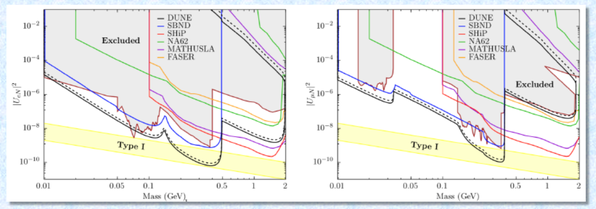


- DUNE exclusion limit for large extra-dimensions compared to published MINOS results



- 1σ and 3σ sensitivities to measuring atmospheric osc. parameters with ν_τ appearance, compared to ν_e appearance and ν_μ disappearance

- **Near Detector Only**
  - Heavy Neutral Leptons (HNLs), such as right-handed partners of active neutrinos, vector, scalar, or axion portals to the Hidden Sector, and light supersymmetric particles, by looking for topologies of rare event interactions and decays
  - Nonstandard short-baseline ν_τ appearance, using high-energy beam configuration for enhanced rate of ν_τ CC interactions.



- DUNE HNL 90% CL sensitivity regions for dominant mixings $|U_{eN}|^2$ (left) and $|U_{\mu N}|^2$ (right) compared to present exclusions and future projects

http://www.dunescience.org/

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