Smiting New Physics with Neutrino Tridents

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INTRODUCTION

The future neutrino oscillation programme opens up the possibility to perform many measurements of **rare neutrino processes at near detectors**. Some of these processes can be particularly sensitive to new physics at low scales, even if very weakly coupled.

Neutrino trident production, the scattering of a neutrino off the coulomb field of a nucleus (see diagram on the right), is a unique probe of light new physics, as was shown in Ref. [1].

In this work we estimate the potential of the near detector at the Deep Underground Neutrino Experiment (**DUNE**) to probe a

$$\mathbf{U(1)_{L_\mu - L_\tau}}$$

extension of the SM with **coherent** neutrino trident events. We extend the work in [1] by including backgrounds and performing a more complete analysis of the sensitivity.

THEORY

We start with the interaction Lagrangian for the $L_\mu - L_\tau$ model

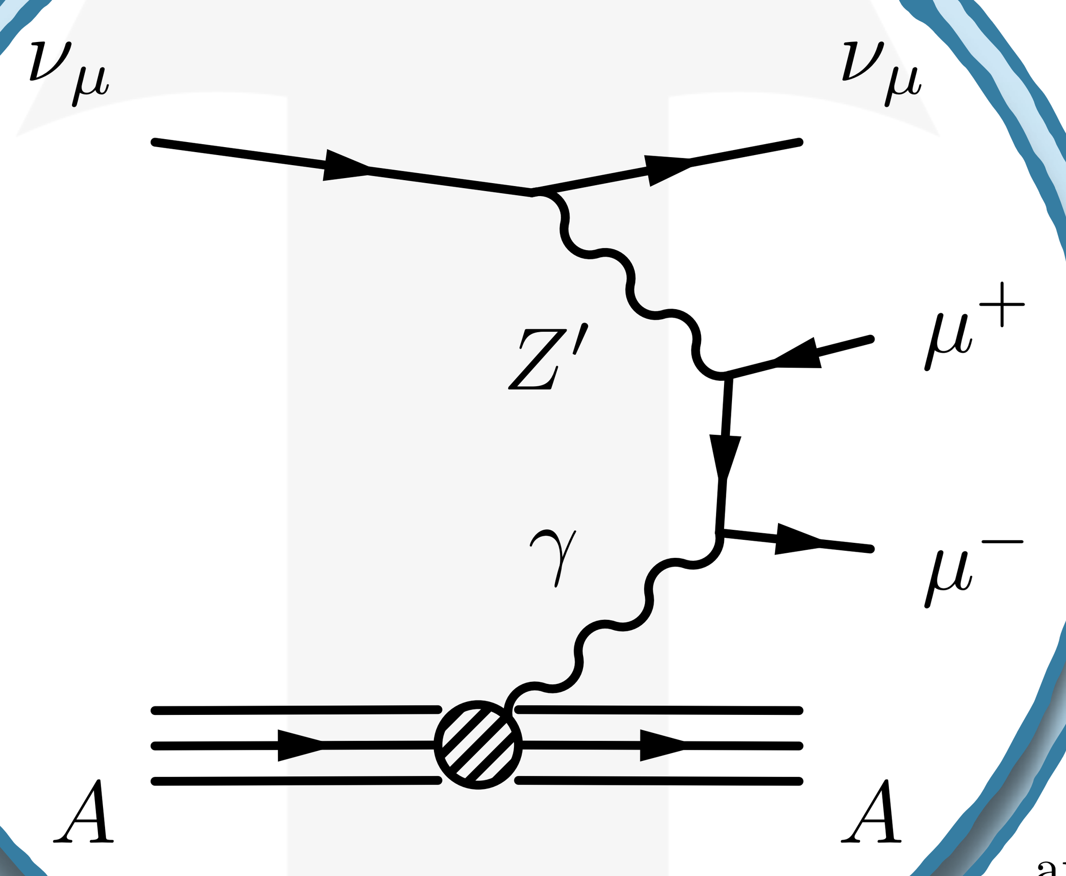
$$\mathscr{L}_{\text{int}} \supset g' Z'_\alpha \left(\overline{L}_\mu \gamma^\alpha L_\mu - \overline{L}_\tau \gamma^\alpha L_\tau + \overline{\mu}_R \gamma^\alpha \mu_R - \overline{\tau}_R \gamma^\alpha \tau_R \right),$$

where L_α is the left-handed lepton doublet, and α_R the right-handed charged lepton field. We assume that the $U(1)_{L_\mu - L_\tau}$ breaking mechanism does not affect our analysis, and treat the mass $M_{Z'}$ of our new boson as a free parameter.

We compute the **neutrino-nucleus coherent trident** cross section ($\sigma_{\nu A}$) under the equivalent photon approximation, writing

$$\sigma_{\nu A} = \frac{Z^2 \alpha}{\pi} \int \frac{\mathrm{d}Q^2}{Q^2} \int \frac{\mathrm{d}s}{s} |F(Q^2)|^2 \, \sigma_{\nu\gamma}(s),$$

where $\sigma_{\nu\gamma}$ is the neutrino photon cross-section. This allows us to use a 3 body phase space treatment. In the SM, 5 distinct diagrams contribute, where the Z and W interference leads to a 30% suppression [2].



ANALYSIS

The coherent trident cross section in the SM is 5 orders of magnitude smaller than the standard CC one. We estimate that the DUNE ND would see **≈4.2 coherent SM trident events/ton of LAr** in a 3.3x10[21] P.O.T. neutrino run.

The **kinematics** of trident events is affected by the light neutral boson, shifting the invariant mass to even lower values (see Fig. 1).

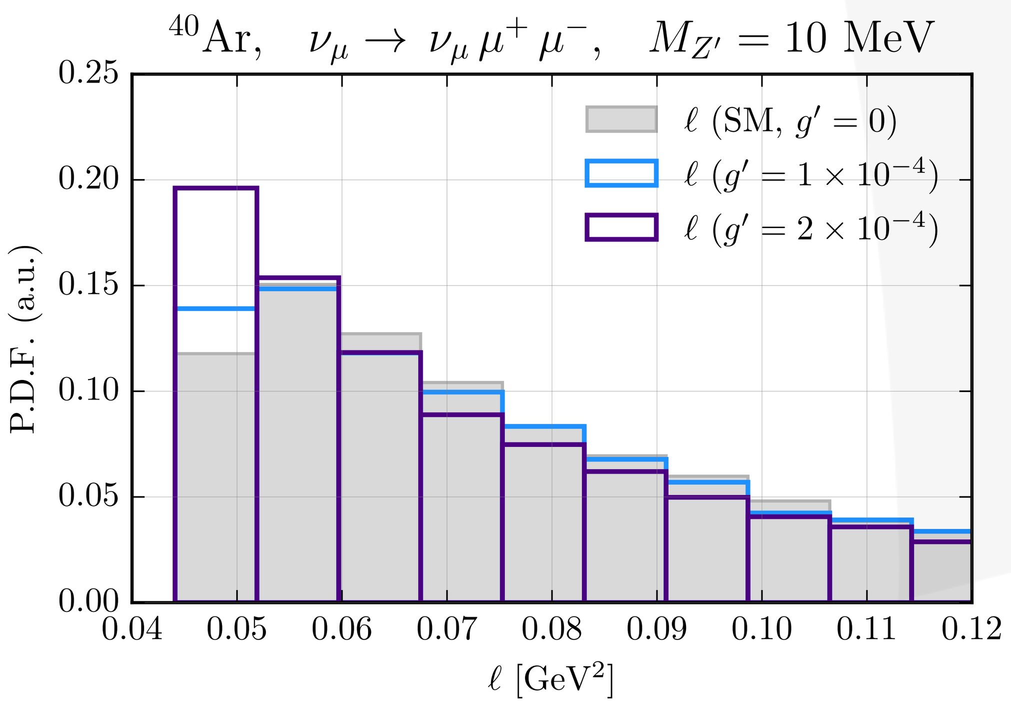


Fig.1: Event distribution for SM and BSM trident processes at the DUNE ND (flux convolved and energy smeared). Our energy thresholds are 30/100 MeV for muons/pions.

Using GENIE, we also estimate what the number of **background** events for trident-like signatures would be. We identify the main source as mis-ID $CC1\pi^\pm$ events. We assume a muon and pion mis-ID rate of 10% and cut on any visible hadronic activity, leading to a total (no kinematical cuts) background rate of

$$N_B \approx 3 \times 10^{-3} N_{\text{CC}}^{\nu_\mu}.$$

We note that kinematical cuts on invariant mass, for example, can lead to background number as low as $10^{-6} N_{\text{CC}}^{\nu_\mu}$.

We performed a sensitivity study using info. on the **total rate and spectral distributions** of coherent trident events (see Figs. 2 and 3). For the detector simulation, we assume parameters as in Ref. [3].

RESULTS

We show the impact of detector mass in Fig. 2 and different approaches for the analysis in Fig. 3.

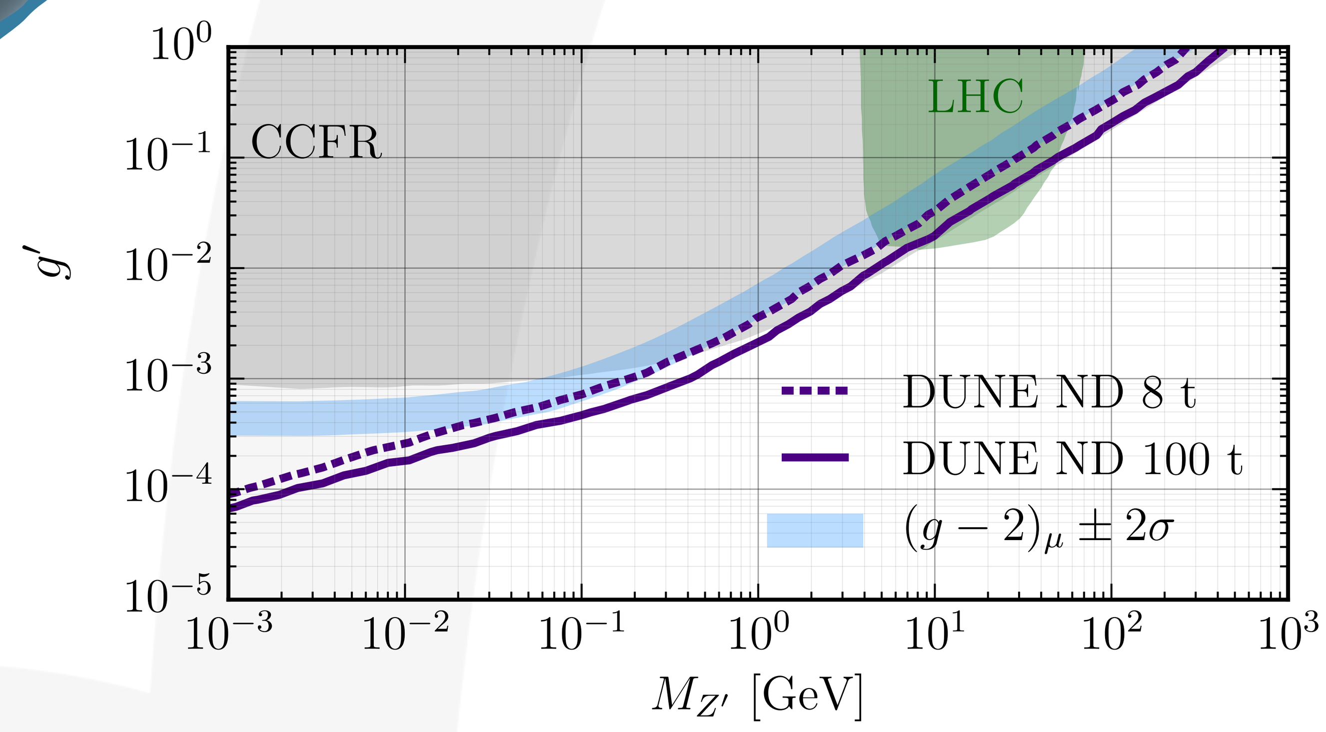


Fig.2: DUNE ND sensitivity in a total rate analysis with no background. We also show the LHC $Z \to 4\mu$ bound and the CCFR bound from a trident measurement [4] (95% C.L).

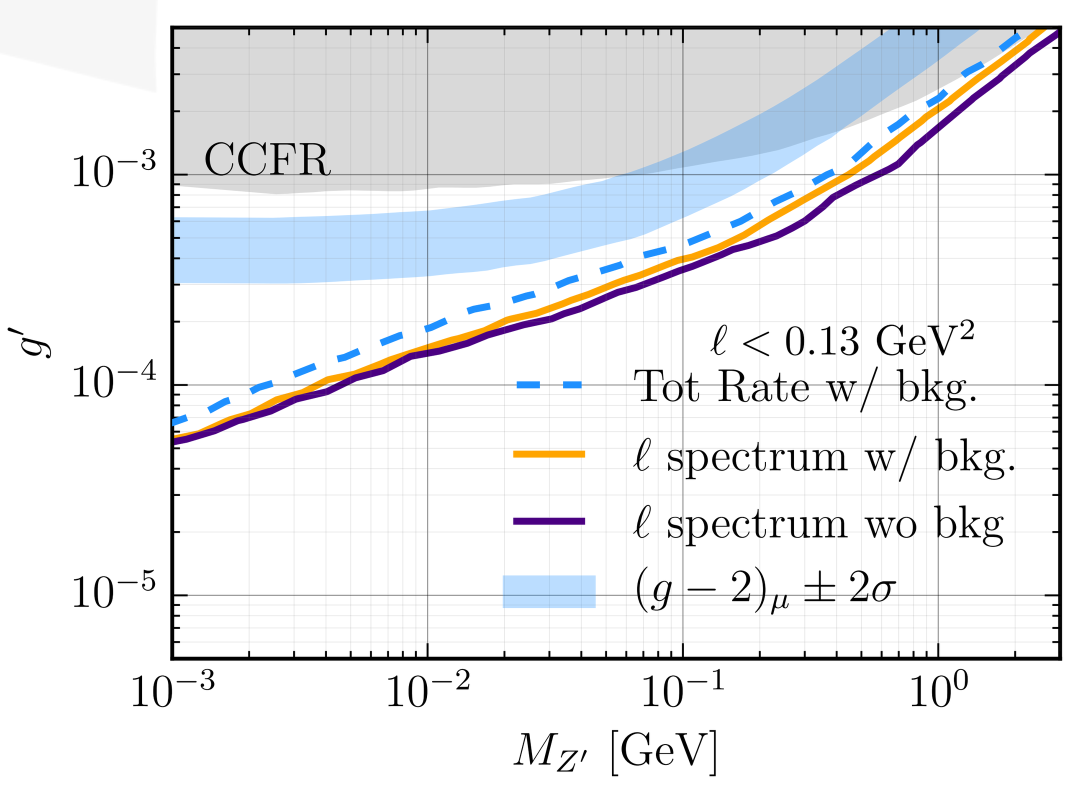


Fig.3: Sensitivity with a **100t** near detector using different methods for our analysis. Cuts on invariant mass can greatly reduce the effect of backgrounds.

We conclude that DUNE can fully exclude the (g-2) motivated parameter space of our model when backgrounds are kept under control with kinematical considerations. Spectral analyses in the low Z' mass region can enhance background rejection, as the invariant masses involved are very small.

References:
[1] W. Altmannshofer *et al.* (2014), *Neutrino Trident Production: A Powerful Probe of New Physics with Neutrino Beams,* arXiv:1406.2332.
[2]G. Magill and R. Plestid (2016), *Neutrino Trident Production ar the Intensity Frontier*, arXiv:1612.05642.
[3] T. Allion *et al.* (2015), *Experiment Simulation Configurations Used in DUNE CDR*, arXiv:1606.09550.
[4] S. Mishra *et al.* (CCFR Collaboration, 1991), *Neutrino tridents and W-Z interference*, Phys. Rev. Lett. 66, 3117.