

Probing ν_R -philic Z' at the DUNE near detector

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Based on **G.C.**, Bhupal Dev (WUSTL) and Xun-Jie Xu (IHEP-CAS) [arXiv: 2204.11876]

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- We'll explore how this feature is useful for probing this scenario at DUNE.

- We consider Z^0 coupled to ν_R with relevant lagrangian,

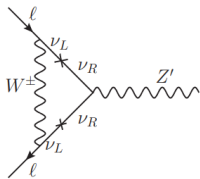
$$\mathcal{L} = g^0 Z^0 \bar{\nu}_R \nu_R + m_D \bar{\nu}_L \nu_R + \frac{M_R}{2} \bar{\nu}_R \nu_R +$$

How dark is this Dark Photon ?

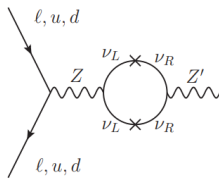
- We consider Z^0 coupled to R with relevant lagrangian,

$$L = g^\theta Z^0 R R + m_D L R + \frac{M_R}{2} R R +$$

- In absence of kinetic mixing with SM, this Z^0 can interact with SM particles through these loop-level diagrams,



$$g_f^{(W)} = \frac{\rho_- \bar{2} G_F m_D^2}{8 \cdot 2} g^\theta ;$$



$$g_f^{(Z)} = \frac{\rho_- \bar{2} G_F m_D^2}{8 \cdot 2} g^\theta Q_f^{(Z)} ;$$

where $Q_f^{(Z)} = I_3 - Q_{em} S_W^2$.

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- The far detector consists of 4 massive liquid argon detectors each about 10 kilotons.
- Uses liquid argon time projection chamber (LArTPC) technology, which provide excellent particle identification and energy measurements.

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- a high-pressure gaseous argon TPC (HPgTPC) surrounded by an electromagnetic calorimeter (ECAL) in a 0.5 T magnetic field

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DUNE produces a large flux of charged mesons (mostly π and K) that decay leptonically, leading to a large flux of SM neutrinos.

The effective couplings of Z^0 to normal matter and neutrinos:

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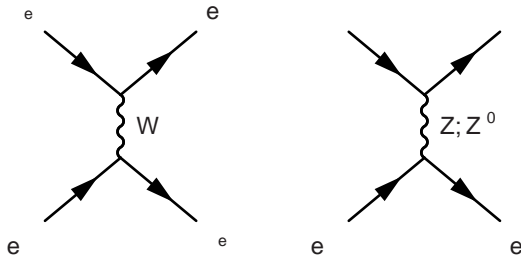
$$L = \bar{\psi} [g_{eL} P_L + g_R P_R] Z^0 + \bar{\nu} [g_\nu P_L] Z^0 ;$$

For later use, we define

$$g = \frac{q}{g_L^2 + g_R^2} ;$$

and

$$r = \frac{g}{g_e} ; (g_L ; g_R) = (\cos \theta ; \sin \theta) g_e :$$



Differential cross section for elastic neutrino-electron scattering including both the SM and the new physics contributions:

$$\frac{d}{dT} = \frac{2m_e G_F^2}{E} \left(c_L^2 + c_R^2 \right) \left(1 - \frac{T}{E} \right)^2 c_L c_R \frac{m_e T}{E^2} ;$$

where

$$c_L = c_L^{(SM)} + \frac{p}{2} \frac{g_{eL} g}{2G_F (2m_e T_e + m_{Z^0}^2)} ; \quad c_L^{(SM)} = \frac{1}{2} + s_W^2 + e ;$$

$$c_R = c_R^{(SM)} + \frac{p}{2} \frac{g_{eR} g}{2G_F (2m_e T_e + m_{Z^0}^2)} ; \quad c_R^{(SM)} = s_W^2 ;$$

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The event rate of elastic neutrino-electron scattering at the detector is computed by

$$\frac{dN}{dT} = N_e \text{ POT} \int (E) \frac{d(T; E)}{dT} (T_{\max} - T) dE ;$$

assuming $m_{Z^0} = 100 \text{ MeV}$ and $P_{g_e g^-} = 10^{-4}$

At the neutrino production site of DUNE, Z^0 can be produced from the proton beam striking the target. Due to its weak loop-level couplings to SM fermions, the produced Z^0 boson can be long-lived.

assuming $\tau = 100$,

The number of events are calculated as

$$N_{\text{det}} = \int \frac{dN_{\text{prod}}(p_{Z^0})}{dp_{Z^0}} P_{\text{decay}}(p_{Z^0}) BR_{Z^0 \rightarrow \text{vis}} ;$$

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The visible decay width is

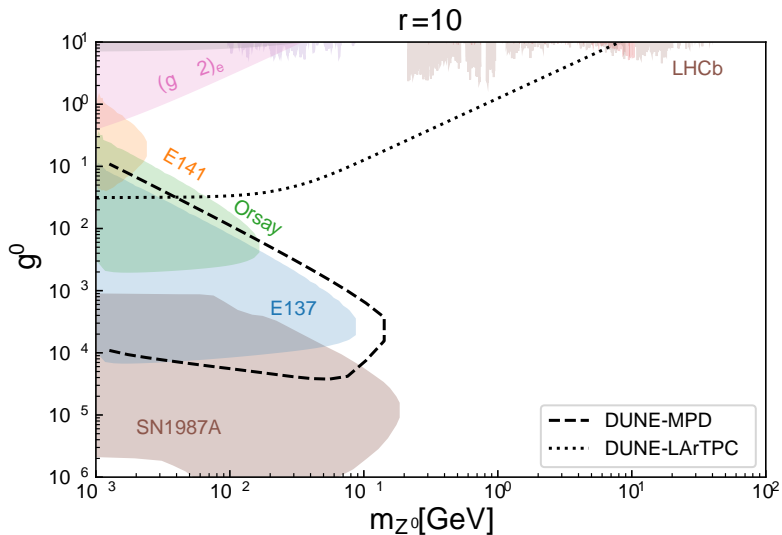
$$BR_{Z^0 \rightarrow \text{vis}} = \frac{\Gamma_{Z^0 \rightarrow \text{vis}}}{\Gamma_{Z^0}}$$

when $\Gamma_{Z^0 \rightarrow \text{vis}} = \Gamma_{Z^0 \rightarrow e^+e^-} + \Gamma_{Z^0 \rightarrow q\bar{q}}$, we have $BR_{Z^0 \rightarrow \text{vis}} = 1$

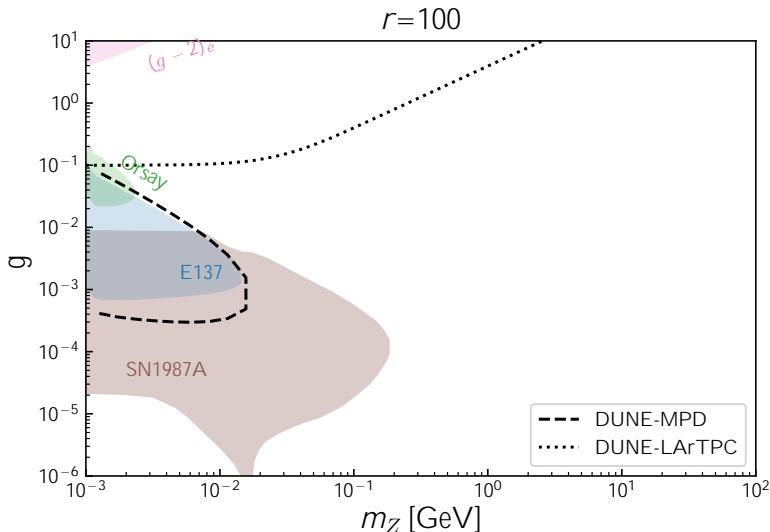
The sensitivity reach of DUNE MPD to the R -philic Z^0 with loop-induced couplings. The results depend on the ratio

Combined Results

For $r = 1$, DUNE-MPD exhibits a significant advantage over other beam dump experiments in the mass range $0.1 \text{ GeV} < m_{Z^0} < 1 \text{ GeV}$.



- For larger r such as $r = 10$ or 100 , DUNE-LArTPC will be able to generate the leading constraints, exceeding collider bounds from BaBar, LHCb, etc.



- Hidden $U(1)$ symmetries in R sector give rise to dark gauge boson : R -philic Z^0 .
- Loop-suppressed couplings to SM and larger couplings to ν , neutrino experiments are the most suited to probe this scenario.
- We consider two complementary near DUNE detectors LArTPC and DUNE-MPD (HPgTPC); could be sensitive to Z^0 signals via elastic ν - e scattering and via Z^0 decay.
- Larger ν couplings lead to higher elastic ν - e scattering rates in DUNE-LArTPC but make Z^0 decay less visible in DUNE-MPD due to the enhanced invisible decay width.
- Excellent prospect of DUNE probing new physics hidden in the sector of R .

Thank you!

Additional Slide

- The ArgonCube shares same aspects of form and functionality with the FD, reduces sensitivity to nuclear effects and detector-driven systematic uncertainties in extracting the oscillation signal at the FD.
- Muons with momentum higher than 0.7 GeV/c will not be contained in the LArTPC volume. Since muon momentum is critical to determining the incoming neutrino's energy, a magnetic spectrometer is needed downstream of the LArTPC to measure the momentum and charge of the muons i.e. MPD.
- Both ArgonCube and MPD can move off-axis relative to the beam, providing access to different neutrino energy spectra.

