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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- ${}_R$'s are motivated BSM candidates - masses, dark matter and matter-antimatter asymmetry (${}_B$)

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- Here, couplings to neutrinos are generically larger than its loop-induced couplings to electrons.
- We'll explore how this feature is useful for probing this scenario at DUNE.

- We consider Z^0 coupled to $\;_R$ with relevant lagrangian,

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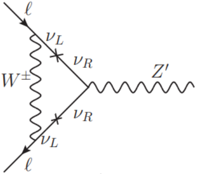
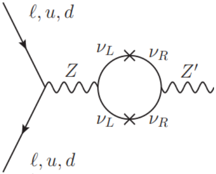
- In absence of kinetic mixing with SM, this Z^{0} can interact with SM particles through these loop-level diagrams,





$$g_f^{(W)} = \frac{\sqrt{2} G_F m_D^2}{8 \;{}^2} g^{0}; \qquad g_f^{(Z)} = \frac{\sqrt{2} G_F m_D^2}{8 \;{}^2} g^{0} Q_f^{(Z)}:$$

where $Q_f^{(Z)} \quad I_3 \quad Q_{em} s_W^2$.

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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 identi cation and energy measurements.

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

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

e scattering

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

$$L = \overline{}\,[g_{eL} \quad P_L + g_R \quad P_R]\, Z^0 \quad + \overline{}\,[g \quad P_L]\, Z^0 \quad ;$$

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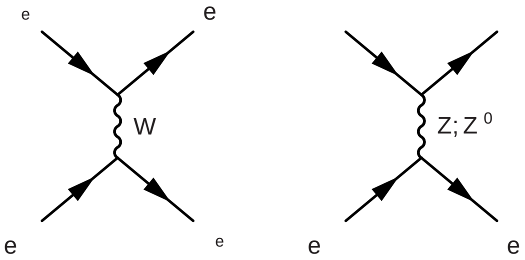
For later use, we de ne

$$g \quad \sqrt{g_L^2 + g_R^2} \, ;$$

and

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



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

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

where

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

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

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

$$\frac{d\sigma}{dT} = \frac{2 m_e G_F^2}{\pi}\left[c_L^2 + c_R^2\left(1-\frac{T}{E_\nu}\right)^2 - c_L c_R \frac{m_e T}{E_\nu^2}\right];$$

where

$$c_L = c_L^{(SM)} + \frac{g_{eL}\, g_\nu}{2\sqrt{2} G_F \left(2 m_e T_e + m_{Z'}^2\right)}; \quad c_L^{(SM)} = -\frac{1}{2} + s_W^2 + \delta_{e};$$

$$c_R = c_R^{(SM)} + \frac{g_{eR}\, g_\nu}{2\sqrt{2} G_F \left(2 m_e T_e + m_{Z'}^2\right)}; \quad c_R^{(SM)} = s_W^2 :$$

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

$$\frac{dN}{dT} = N_e \, {}_{POT} \int \Phi(E_\nu) \frac{d\sigma(T; E_\nu)}{dT} \Theta(T_{max} - T)\, dE_\nu ;$$

e scattering

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

DUNE as beam dump

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

assuming $r = 100$,

The number of events are calculated as

$$N_{det.} = \int dp_{Z'} \frac{dN_{prod.}(p_{Z'})}{dp_{Z'}} P_{decay}(p_{Z'}) BR_{Z' \to vis.};$$

$$P_{decay} = e^{-L_1/L_{Z'}} \left(1 - e^{-L_2/L_{Z'}}\right)$$

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$$P_{decay} \; = \; e^{\;L_1 = L_{Z'}} \quad 1 \quad e^{\;L_2 = L_{Z'}}$$

The visible decay width is

$$BR_{Z' \to \; vis.} \quad 1 \quad \frac{Z' \to \quad \bar{}}{Z'} \, .$$

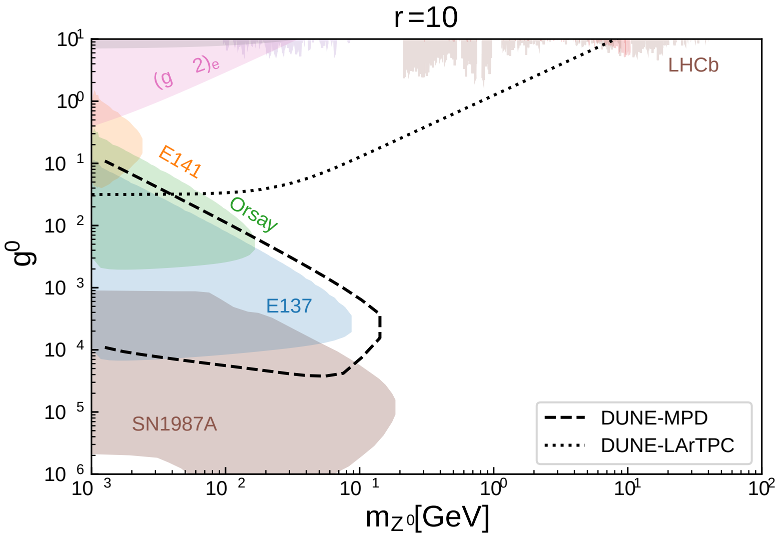
when $g \qquad g_e$ and g_q, we have $BR_{Z' \to \; vis.} \qquad 1$

DUNE as beam dump

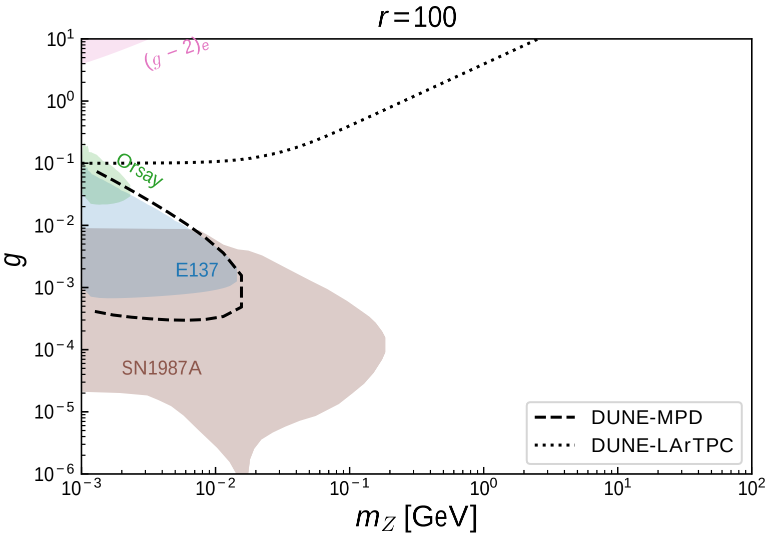
The sensitivity reach of DUNE MPD to the $_R$-philic Z^0 with loop-induced couplings. The results depend on the ratio

Combined Results

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


r =10
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
g'
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
$m_{Z'}$[GeV]
(g − 2)e
E141
Orsay
E137
SN1987A
LHCb
DUNE-MPD
DUNE-LArTPC

- 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 , 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 -e scattering and via Z^0 decay.
- Larger couplings lead to higher elastic -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

DUNE Near Detector

- The ArgonCube shares same aspects of form and functionality with the FD, reduces sensitivity to nuclear e ects 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 o -axis relative to the beam, providing access to di erent neutrino energy spectra.