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]

$\mathcal{CP}$ ■ UCLouvain

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- Although SM particles are uncharged under $U(1)_R$, this Z' can still interact through loop-level couplings.
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- We'll explore how this feature is useful for probing this scenario at DUNE.

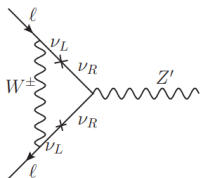- We consider Z' coupled to ν_R with relevant lagrangian,

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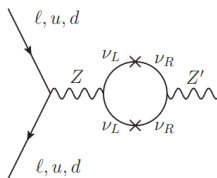

$$g_f^{(W)} = \frac{\sqrt{2} G_F m_D^2}{8\pi^2} g' , \quad g_f^{(Z)} = \frac{\sqrt{2} G_F m_D^2}{8\pi^2} g' Q_f^{(Z)} .$$

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

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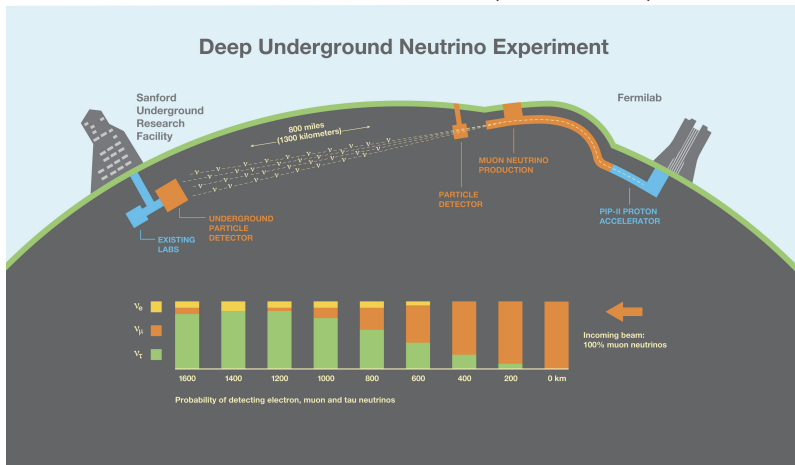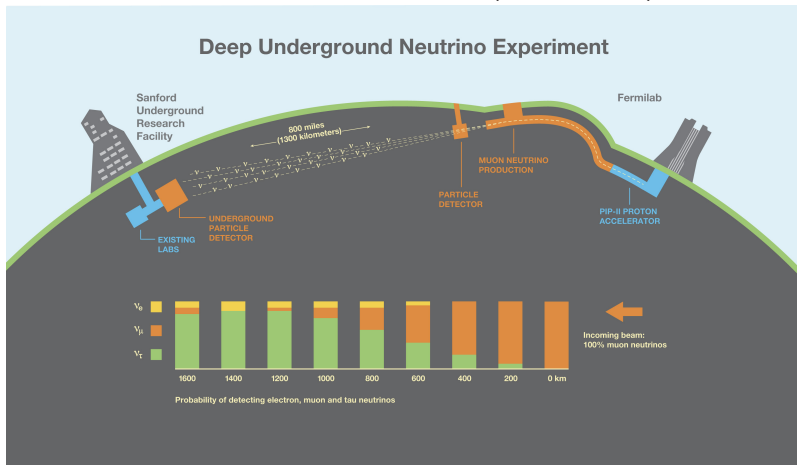
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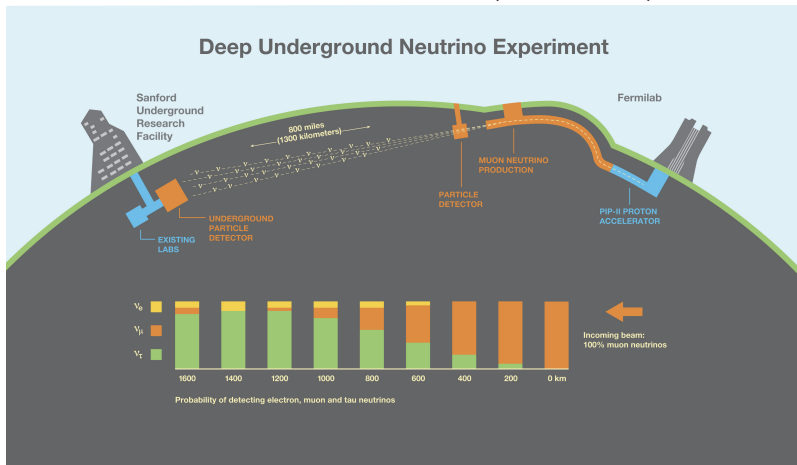
- The far detector consists of 4 massive liquid argon detectors each about 10 kilotons.
- Uses liquid argon time projection chamber (LArTPC) technology, which provide excellent particle identification and energy measurements.

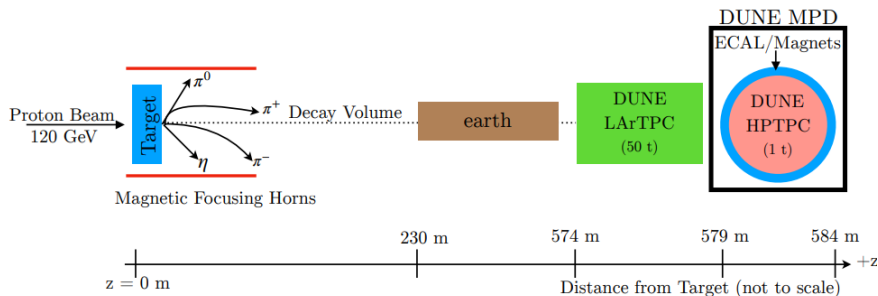- The ND will measure the initial unoscillated ν_μ and ν_e energy spectra.

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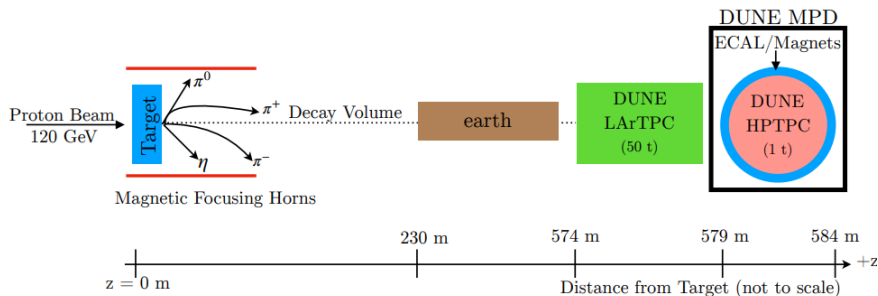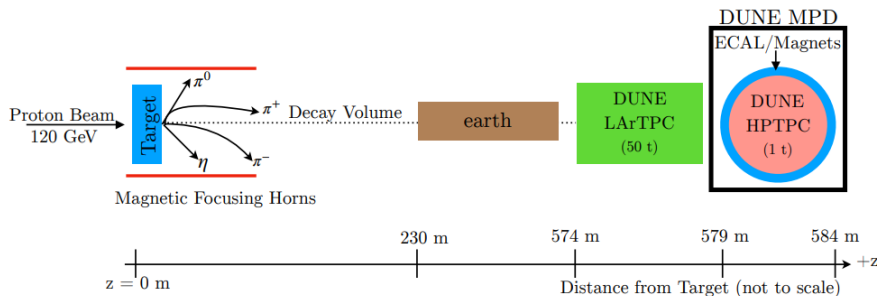
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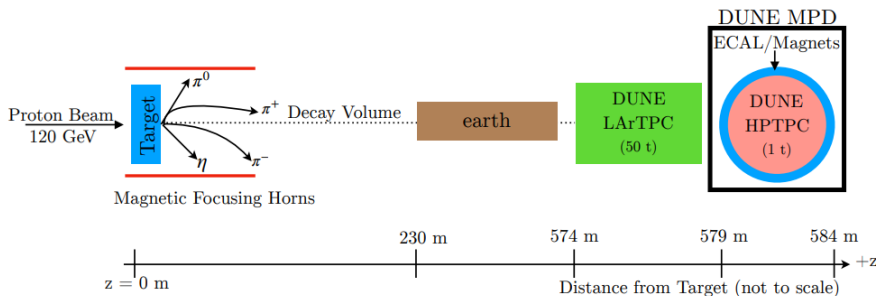

- The ND consists of
  - a LArTPC called ArgonCube
  - a high-pressure gaseous argon TPC (HPgTPC) surrounded by an electromagnetic calorimeter (ECAL) in a 0.5 T magnetic field

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- We assume data collection of 5 years each in ν ("forward horn current") and $\bar{\nu}$ ("reverse horn current") modes.
- DUNE produces a large flux of charged mesons (mostly $\pi^{\pm}$ and $K^{\pm}$) that decay leptonically, leading to a large flux of SM neutrinos.
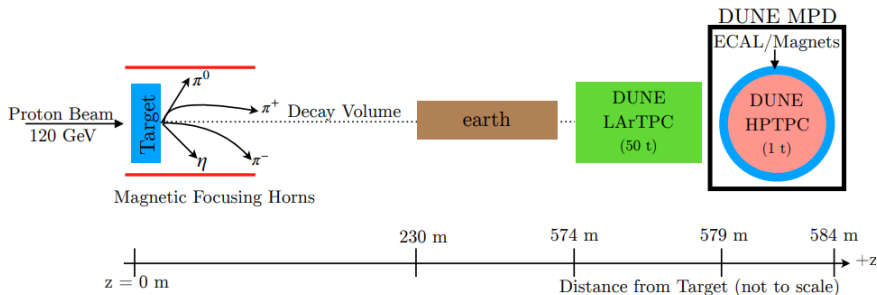
- The effective couplings of Z' to normal matter and neutrinos:

$$\mathcal{L} = \overline{\psi}\left[g_{eL}\gamma^{\mu}P_L + g_R\gamma^{\mu}P_R\right]Z'_{\mu}\psi + \overline{\psi_{\nu}}\left[g_{\nu}\gamma^{\mu}P_L\right]Z'_{\mu}\psi_{\nu},$$

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- For later use, we define

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

and

$$r \equiv \frac{g_\nu}{g_e},\ \ (g_L,\ g_R) = (\cos\beta,\ \sin\beta)g_e\,.$$
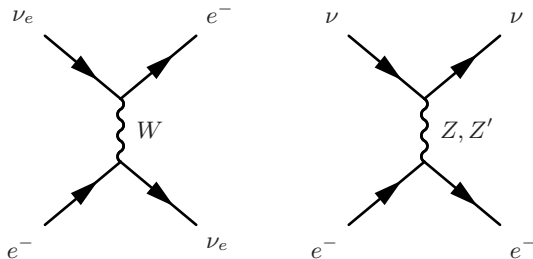
- Differential cross section for elastic neutrino-electron scattering including both the SM and the new physics contributions:

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

where

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

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

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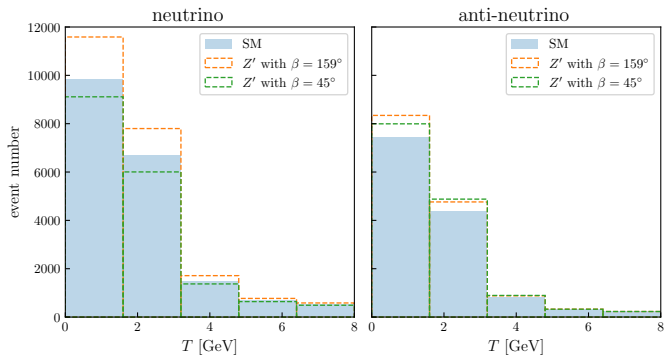
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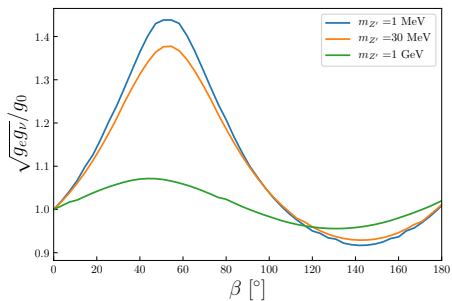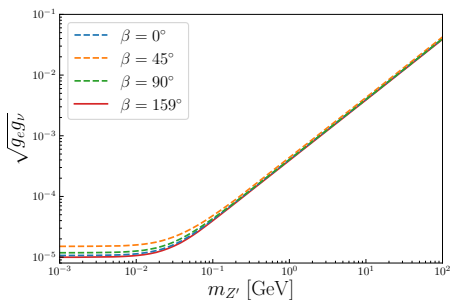
$$c_R = c_R^{(\mathrm{SM})} + \frac{g_{eR} g_\nu}{2\sqrt{2} G_F \left(2m_e T_e + m_{Z'}^2 \right)}, \quad c_R^{(\mathrm{SM})} = s_W^2.$$

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

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

$\nu - e$ scattering

- assuming $m_{Z'} = 100$ MeV and $\sqrt{g_e g_\nu} = 10^{-4}$

$\nu - e$ scattering

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 $r = 100$,
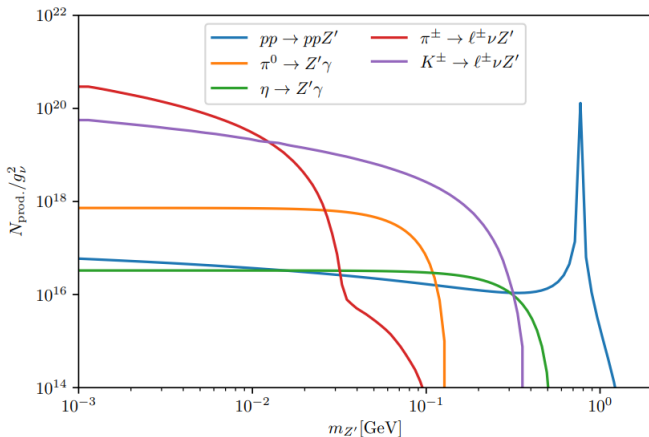
- The number of events are calculated as

$$N_{\text{det.}} = \int dp_{Z'} \frac{dN_{\text{prod.}}(p_{Z'})}{dp_{Z'}} P_{\text{decay}}(p_{Z'}) \, \text{BR}_{Z' \to \text{vis.}},$$

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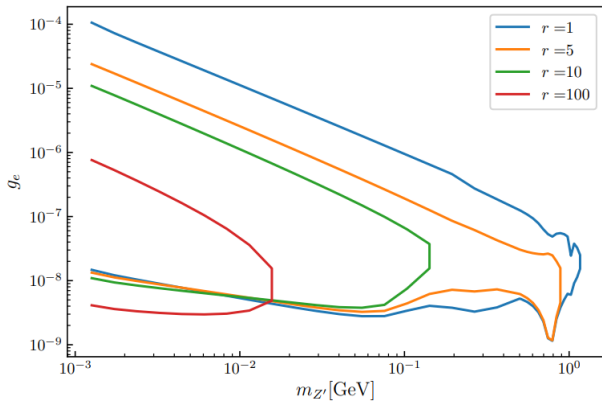
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- The visible decay width is

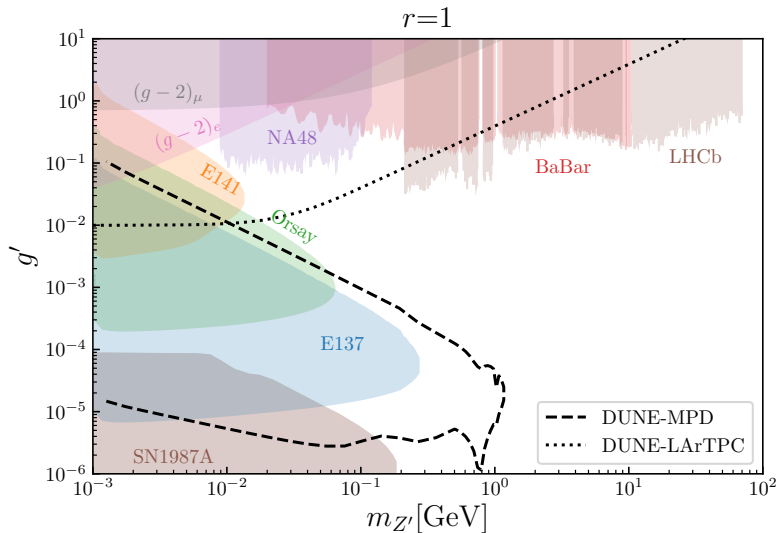$$\text{BR}_{Z' \to \text{vis.}} \equiv 1 - \frac{\Gamma_{Z' \to \nu\bar{\nu}}}{\Gamma_{Z'}} \,.$$

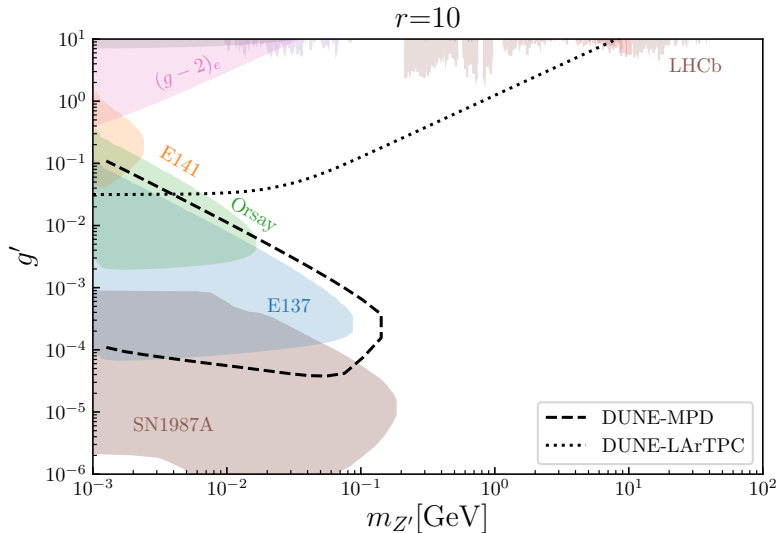when $g_\nu \gg g_e$ and g_q, we have $\text{BR}_{Z' \to \text{vis.}} \ll 1$

- The sensitivity reach of DUNE MPD to the ν_R-philic Z' with loop-induced couplings. The results depend on the ratio r
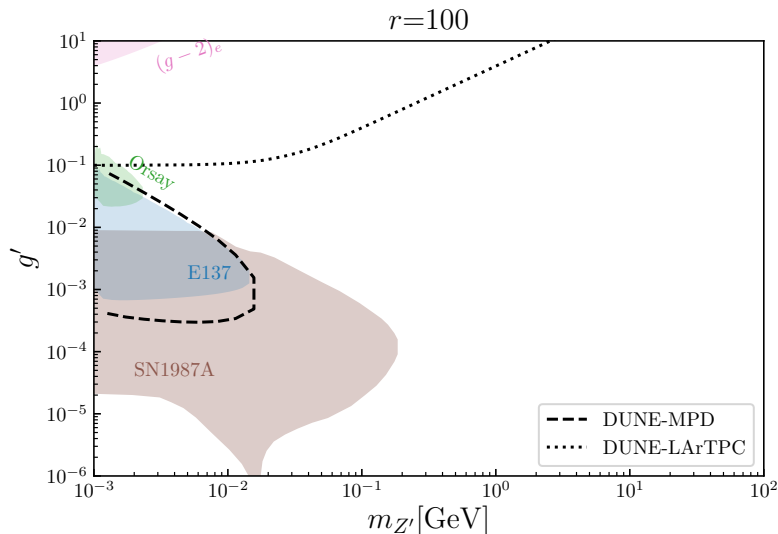
- For $r = 1$, DUNE-MPD exhibits a significant advantage over other beam dump experiments in the mass range $0.1\,\mathrm{GeV} \lesssim m_{Z'} \lesssim 1\,\mathrm{GeV}$.

$r = 1$

$r=10$

- 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.

$r{=}100$

- Hidden $U(1)$ symmetries in ν_R sector give rise to dark gauge boson : ν_R-philic Z'.
- 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' signals via elastic ν-e scattering and via Z' decay.
- Larger ν couplings lead to higher elastic ν-e scattering rates in DUNE-LArTPC but make Z' 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 ν_R.

Thank you!

Additional Slide

DUNE Near Detector

- 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.