FCNC in Concurrent Dark Photon & Dark Z Model

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PHENO 2022
University of Pittsburgh

May 10, 2022

THE UNIVERSITY of MISSISSIPPI

Introduction

- Hidden dark sector models have been studied in the past to explain low energy anomalies (such as $g-2$ of muon, Atomic Parity Violation (APV), Higgs decays etc.)
- However these models can also contribute to Flavor Changing neutral currents (FCNC) which have long-standing hints of presence of NP.
- FCNC decays are sensitive probes of new physics (NP).
- Alternately, measurements of FCNC processes can strongly constrain many extensions of the Standard Model(SM) such as those of the $U(1)_D$.

FCNC in Dark $U(1)_D$ - Formalism

- We assume that Z_D is associated with a $U(1)_D$ gauge symmetry of a dark sector.
- Z_D gauge boson couples to the SM bosons via kinetic mixing, parametrized by ε, and $Z - Z_D$ mass matrix mixing, parametrized by $\varepsilon_Z = (M_{Z_D}/mZ)\delta$.

$$\mathcal{L}_{gauge} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}\frac{\varepsilon}{\cos\theta_W}B_{\mu\nu}Z_D^{\mu\nu} - \frac{1}{4}Z_{D\mu\nu}Z_D^{\mu\nu} \tag{1}$$

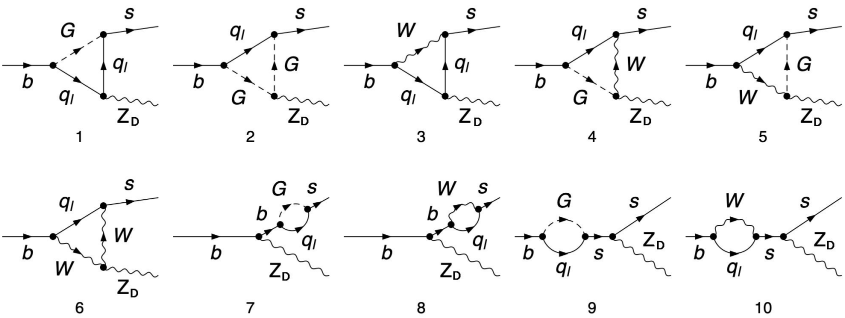
- As a consequence of the mixing, the Z_D coupling with the SM results into an interaction Lagrangian

$$\mathcal{L}_{int} = \left(-e\varepsilon J_\mu^{em} - \frac{g}{2\cos\theta_W}\frac{M_{Z_D}}{m_Z}\delta' J_\mu^{NC}\right) Z_D^\mu \tag{2}$$

where, $\delta' \simeq \delta + \frac{M_{Z_D}}{m_Z}\varepsilon\tan\theta_W$

FCNC in Dark $U(1)_D$ - Diagrams

$$b \rightarrow s\ Z_D$$



FCNC in Dark $U(1)_D$

- The FCNC amplitudes with the dark Z decays were calculated in *F. Xu, JHEP 06, 170 (2015), 1504.07415* without the dipole term in the amplitude.
- Furthermore, the phenomenology was discussed with the dark boson off shell.
- Here, we fit the parameters of the dark Z model, namely M_{Z_D}, ε & ε_Z, to the available data on the branching fraction of $B \to K^{(*)}\ell^+\ell^-$ decays in the bins of q^2.
- We mostly focus in the mass range $0.01 \leq M_{Z_D}/GeV \leq 2$.
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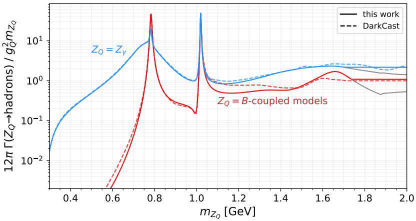
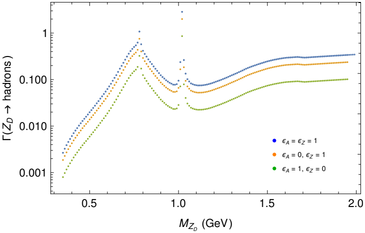
Hadronic Effects in Decay Width

- In the mass range of interest, Z_D can decay into charged or neutral leptons as well as into light hadrons, if kinematically allowed.
- The region $0.5 < M_{Z_D}/GeV < 2$ is plagued by hadronic resonances such as $\pi\pi$, $\pi^0\gamma$ etc.
- Perturbative QCD fails to provide a reliable way to evaluate vector boson decays into hadrons, so one has to, instead, turn to chiral perturbation theory.
- Earlier analysis did not consider the effect of hadronic resonances in the decay width.
- Using the vector-meson dominance model, one can estimate the decay width to hadrons as done by *Foguel et al., JHEP 04 (2022) 119* for light mediators.





Wilson Coefficients

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Bigg[\sum_{i=1\ldots6} C_i \mathcal{O}_i + \sum_{i=7,8,9,10,S,P} (C_i \mathcal{O}_i + C_i^{'} \mathcal{O}_i^{'}) \Bigg] + h.c. \tag{3}$$

$$\mathcal{O}_9 = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l), \qquad \mathcal{O}_9^{'} = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_R b)(\bar{l}\gamma^\mu l) \tag{4}$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l), \qquad \mathcal{O}_{10}^{'} = \frac{e^2}{g^2} (\bar{s}\gamma_\mu P_R b)(\bar{l}\gamma^\mu \gamma_5 l) \tag{5}$$

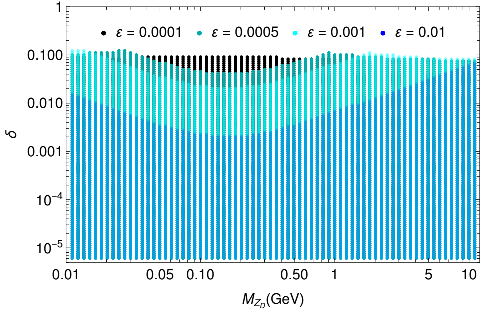
$$\begin{aligned} M_{Z_D} &= \langle H_2 | \bar{d}_i \gamma_\mu P_{L/R} d_j | \bar{H}_1 \rangle \Big[\{ \big(E^{0,A}_{c_1,c_2}\big)_{L/R} + \big(E^{0,Z}_{c_1,c_2}\big)_{L/R} \} g^{\mu\nu} \\ &+ \{ \big(E^{2,A}_{c_1,c_2}\big)_{L/R} + \big(E^{2,Z}_{c_1,c_2}\big)_{L/R} \} \left(g^{\mu\nu} q^2 - q^\mu q^\nu \right) \Big] V_\nu^{Z_D} \\ &+ \langle H_2 | \bar{d}_i i q_\mu \sigma^{\mu\nu} P_{L/R} d_j | \bar{H}_1 \rangle \{ \big(M^{1,A}_{c_1,c_2}\big)_{L/R} + \big(M^{1,Z}_{c_1,c_2}\big)_{L/R} \} V_\nu^{Z_D} \end{aligned} \tag{6}$$

Atomic Parity Violation

- A consequence of the sub-GeV dark Z is atomic parity violation.
- The model parameters are tightly constrained from existing data on the weak charge of proton and Caesium atom from parity violating electron scattering experiments.

$$Q_W^{p,SM} = -2g_{AV}^{ep}\left(1 - \frac{\alpha}{2\pi}\right); \quad g_{AV}^{ep} = -1/2 + 2\sin^2\theta_W$$

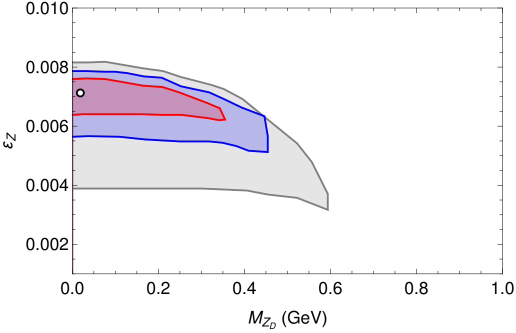
- In presence of the dark Z, $\sin^2\theta_W \to \kappa_d \sin^2\theta_W$ where, $\kappa_d = 1 - \varepsilon(\delta + \frac{M_{Z_D}}{m_Z}\varepsilon\tan\theta_W)\frac{m_Z}{M_{Z_D}}\cot\theta_W f(Q^2)$



Preliminary Results

Case A : Dark Z model

- The best fit point : $M_{Z_D} = 18.5$ MeV, $\varepsilon = 0.00765$, $\varepsilon_Z = 0.00712$
- Pull wrt SM = 4.7
- $\varepsilon_Z = 0.00712 \Rightarrow \delta \sim 35$! Problem with APV!

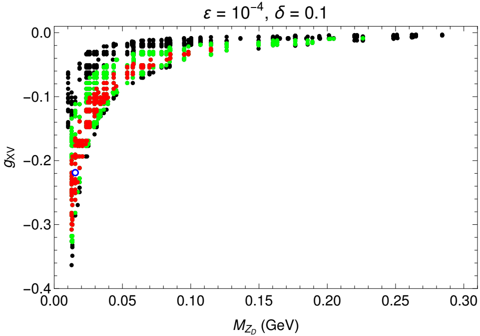


Preliminary Results

Case B : Add a short distance NP

$$\mathcal{L}_{int} \supset g_{XV}\bar{\mu}\gamma^{\mu}\mu Z_{D\mu} \tag{7}$$

- This does not affect APV observables.
- For the fit we fix $\delta = 0.1$ and $\varepsilon = 10^{-4}$ and obtain the best fit at : $M_{Z_D} = 15.4$ MeV, $g_{XV} = -0.22$ with a pull of 4.2 from the SM.



Conclusion & Work in Progress

- The dark Z model provides a good explanation of the $B \to K\ell\ell$ data.
- But we need a very large mixing.
- Short distance NP can help overcome this issue.
- We can relax the APV constraints by considering short-distance NP to the first generation fermions.
- We are also exploring the contributions to $B \to K\nu\nu$ and semileptonic K-meson decays.

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Acknowledgements

- This work was supported by the NSF Grant No **PHY-191514**.
- I would also to thank Alakabha Datta (UM), Ahmed Hammad (Seoultech), Danny Marfatia (UoH) and Ahmed Rashed (Ain Shams U., Cairo) for fruitful collaboration on this project.

THANK YOU!