

PHENO 2023

Latest topics in particle physics and related issues in astrophysics and cosmology

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Jets, dark sectors, and
other mysteries...

Constraining light dark Z with low-energy experiments

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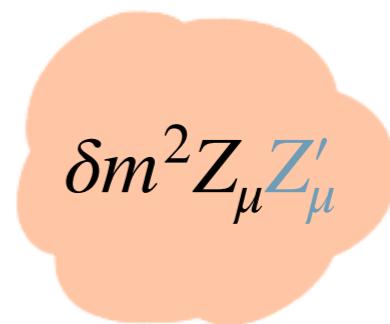
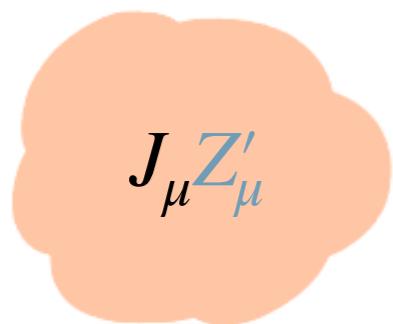
In Collaboration with Leon M. G de la Vega, Jens Erler, and R. Ferro



$U(1)$ Gauge extensions of the SM

$$E_6 \rightarrow SO(10) \times U(1)$$

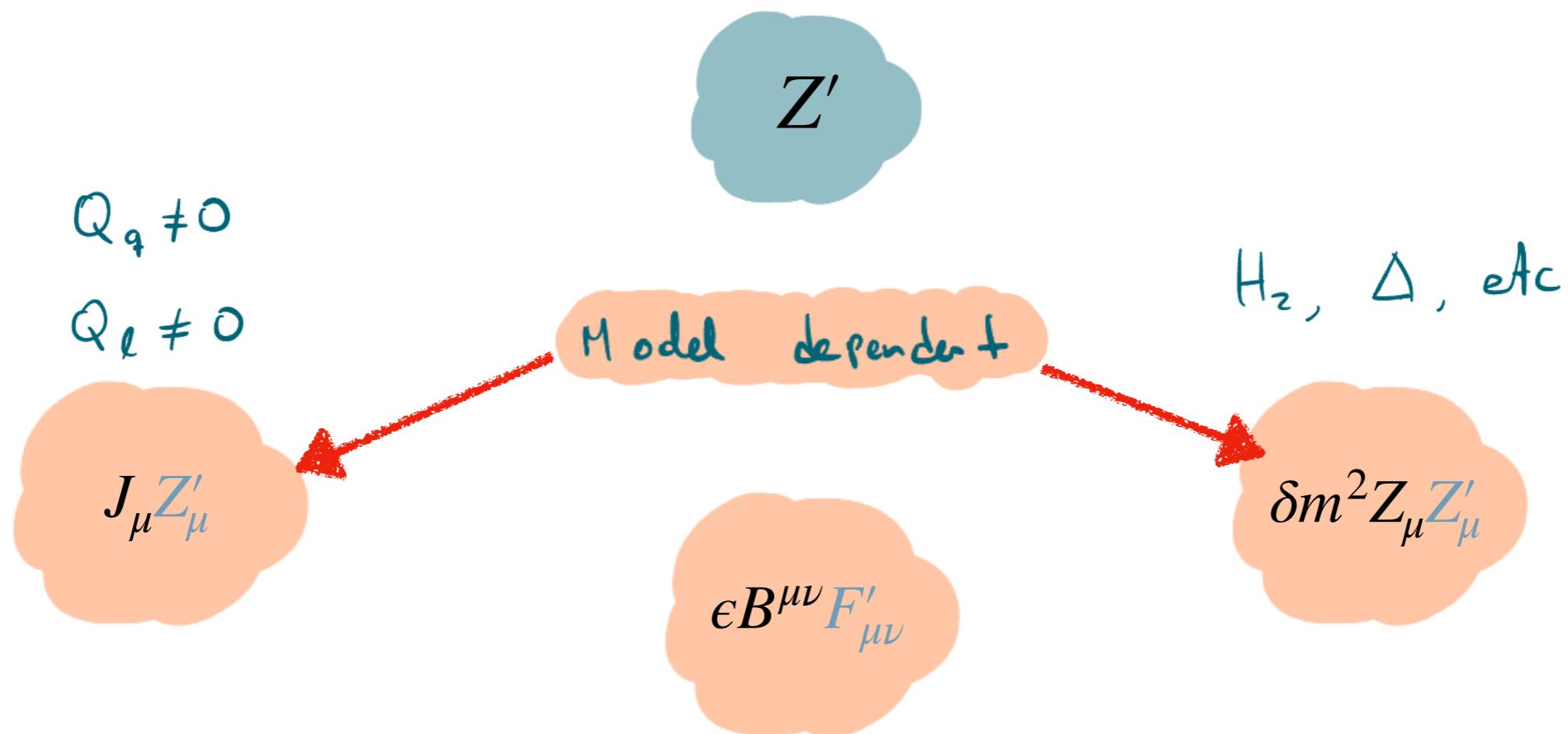
$$SO(10) \rightarrow SU(5) \times U(1)$$



$U(1)$ Gauge extensions of the SM

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$$SO(10) \rightarrow SU(5) \times U(1)$$



Light Z'

$$\mathcal{L} \supset \frac{m_{Z'}^2}{2} Z'^\mu Z'_\mu + i g' Z'_\mu (Q_f \bar{f} \gamma^\mu f)$$

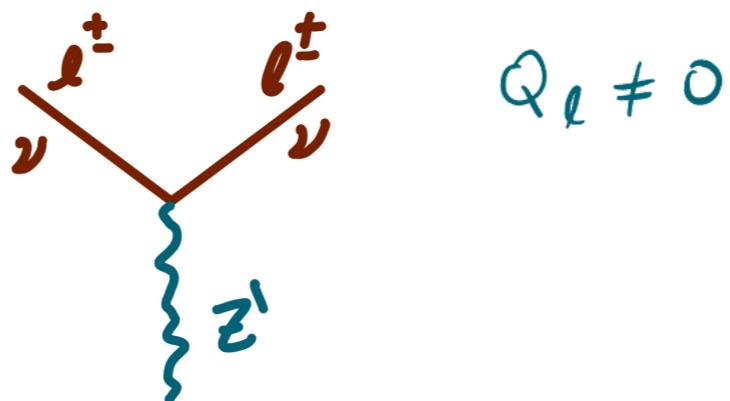
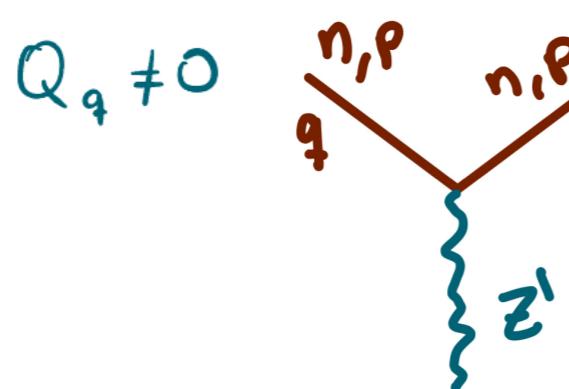
SSB

$$\langle \phi_i \rangle = \frac{v_i}{\sqrt{2}}$$

$$m_{Z'}^2 = \sum_i g' Q_i^2 v_i^2$$

small g'

low scale v_i



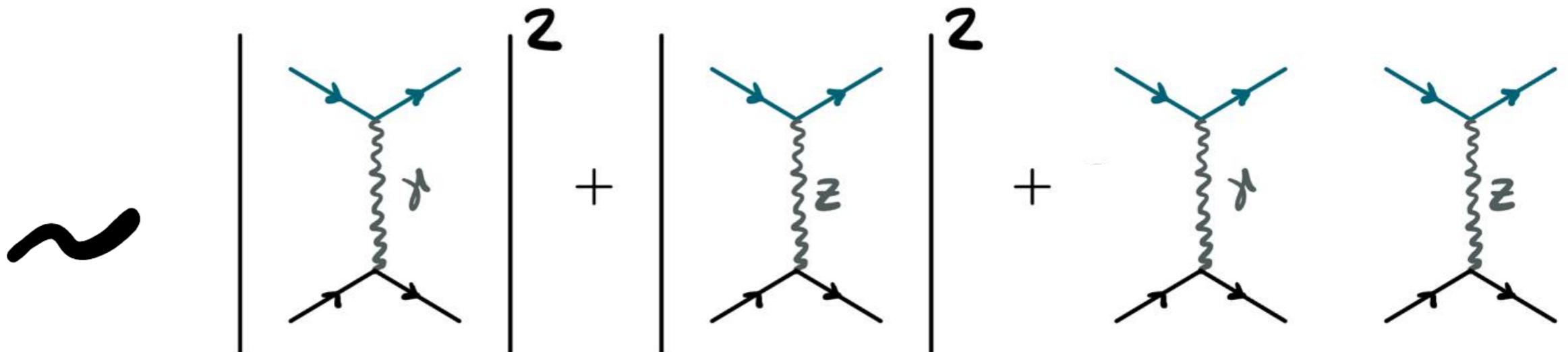
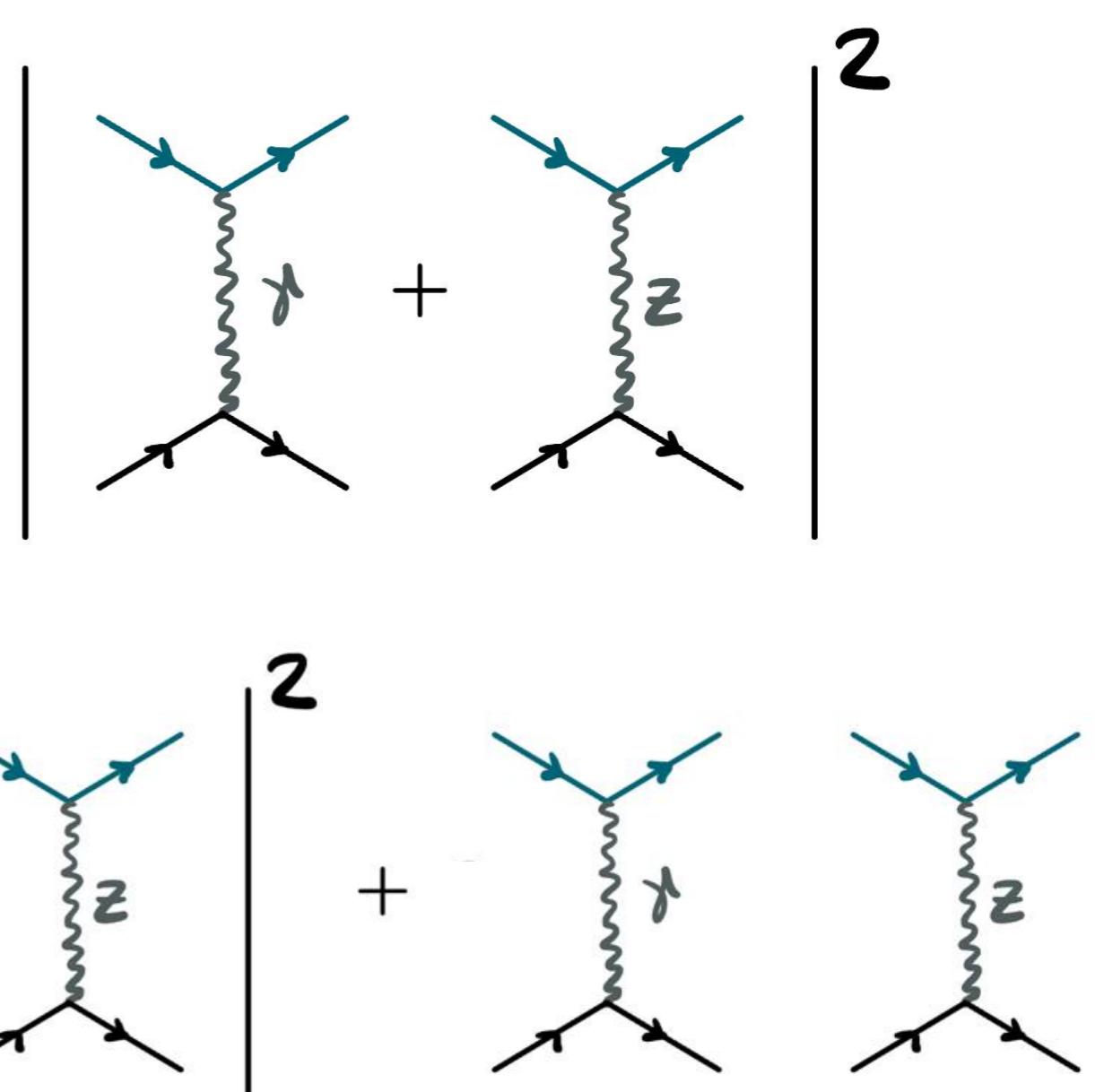
Parity Violation

$$e_R + P \rightarrow e_R + P$$

$$e_L + P \rightarrow e_L + P$$

$$A_{PV} = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$

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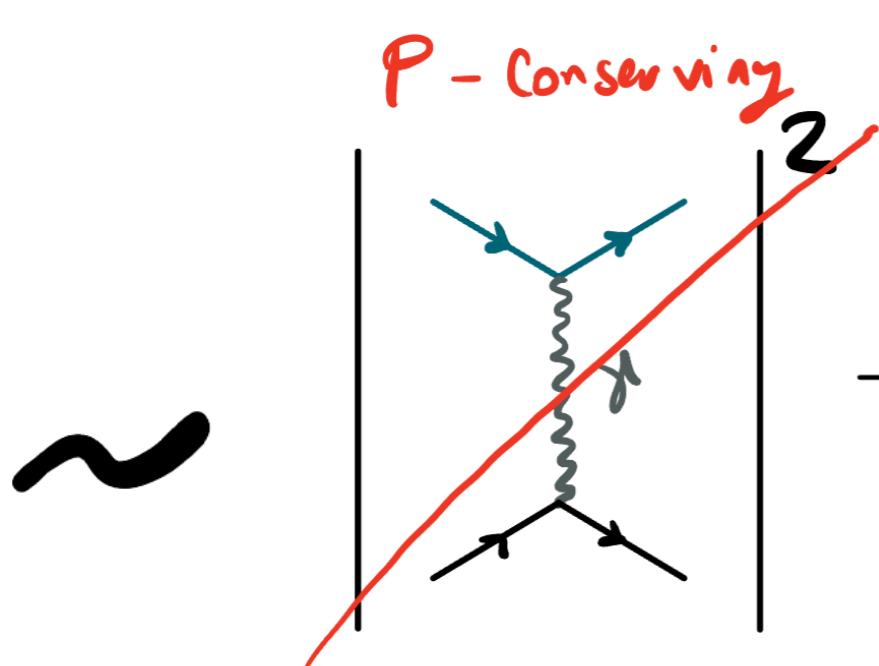
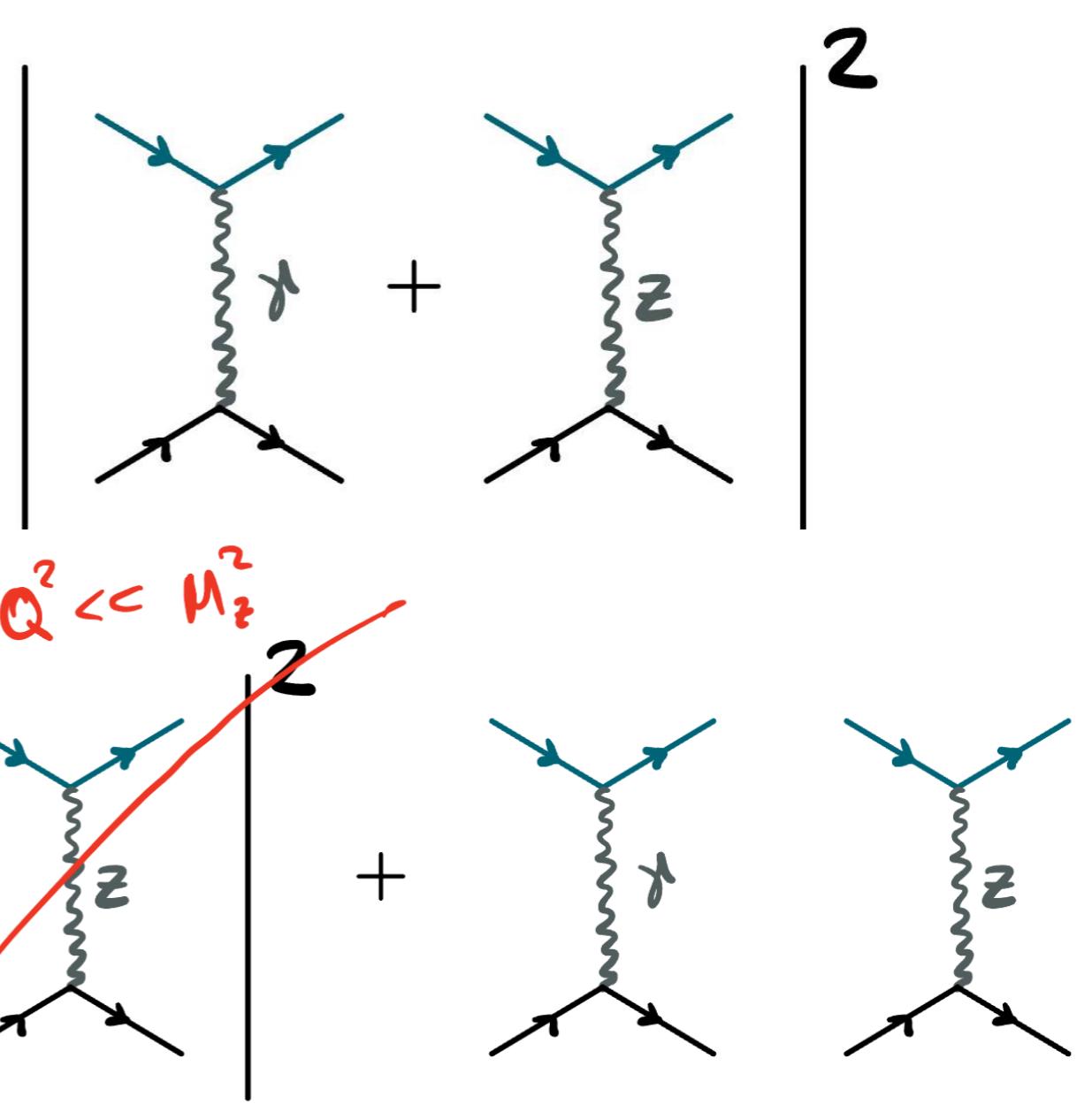
Parity Violation

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\sim



Dark Z

H. Davoudiasl, H.-S. Lee, and W. J. Marciano (2012)

$$\epsilon B^{\mu\nu} F'_{\mu\nu}$$

$$\delta m^2 Z_\mu Z'_\mu$$

$$SU(2)_L \times U(1)_Y \times \textcolor{teal}{U}(1)_d \rightarrow U(1)_Q$$

$$\mathcal{L}_{mass}^{(3 \times 3)} = \frac{1}{2} \begin{pmatrix} W_3, & B, & Z_d \end{pmatrix} \sum_i \begin{pmatrix} g^2 y_i^2 v_i^2 & -g g_Y y_i^2 v_i^2 & -g g_d y_i \textcolor{teal}{y}'_i v_i^2 \\ -g g_Y y_i^2 v_i^2 & g_Y^2 y_i^2 v_i^2 & g_d g_Y y_i \textcolor{teal}{y}'_i v_i^2 \\ -g g_d y_i \textcolor{teal}{y}'_i v_i^2 & g_d g_Y y_i \textcolor{teal}{y}'_i v_i^2 & g_d^2 \textcolor{teal}{y}'_i^2 v_i^2 \end{pmatrix} \begin{pmatrix} W_3 \\ B \\ Z_d \end{pmatrix}$$

Diagonalization

$$\mathcal{L}_{int} = (ieJ_Q, \quad ig_Z J_Z, \quad ig_d J_D) T_W T_\epsilon^{-1} T_W^{-1} T_\alpha^{-1} \begin{pmatrix} A \\ Z \\ Z' \end{pmatrix}$$

$$\begin{pmatrix} A \\ Z \\ Z' \end{pmatrix} = T_\alpha T_W T_\epsilon \begin{pmatrix} W_3 \\ B \\ Z_d \end{pmatrix}$$

Compute scattering σ
 Induced cap. $Z^\lambda \bar{J}_Q^\mu$ and $Z^\lambda \bar{J}_Z^\mu$

Non-diagonal propagator

Z_d is **decoupled** from J_Q and J_Z

Z_d **effect** in \hat{Z} and \hat{A}

$$D^{\mu\nu}(p^2) = \eta^{\mu\nu} \begin{pmatrix} D_{\hat{A}\hat{A}}(p^2) & D_{\hat{A}\hat{Z}}(p^2) & D_{\hat{A}Z_d}(p^2) \\ D_{\hat{A}\hat{Z}}(p^2) & D_{\hat{Z}\hat{Z}}(p^2) & D_{\hat{Z}Z_d}(p^2) \\ D_{\hat{A}Z_d}(p^2) & D_{\hat{Z}Z_d}(p^2) & D_{Z_dZ_d}(p^2) \end{pmatrix}$$

$$\Pi_{\hat{Z}\hat{Z}}^{\text{mixing}}(p^2) = \frac{(\delta M_d M_Z - \epsilon p^2 \tan \theta_W)^2}{p^2 - M_d^2},$$

$$\Pi_{\hat{A}\hat{Z}}^{\text{mixing}}(p^2) = \epsilon p^2 \frac{\delta M_d M_Z - \epsilon p^2 \tan \theta_W}{p^2 - M_d^2},$$

$$\Pi_{\hat{A}\hat{A}}^{\text{mixing}}(p^2) = \frac{\epsilon^2 p^4}{p^2 - M_d^2}.$$

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Pole Observables

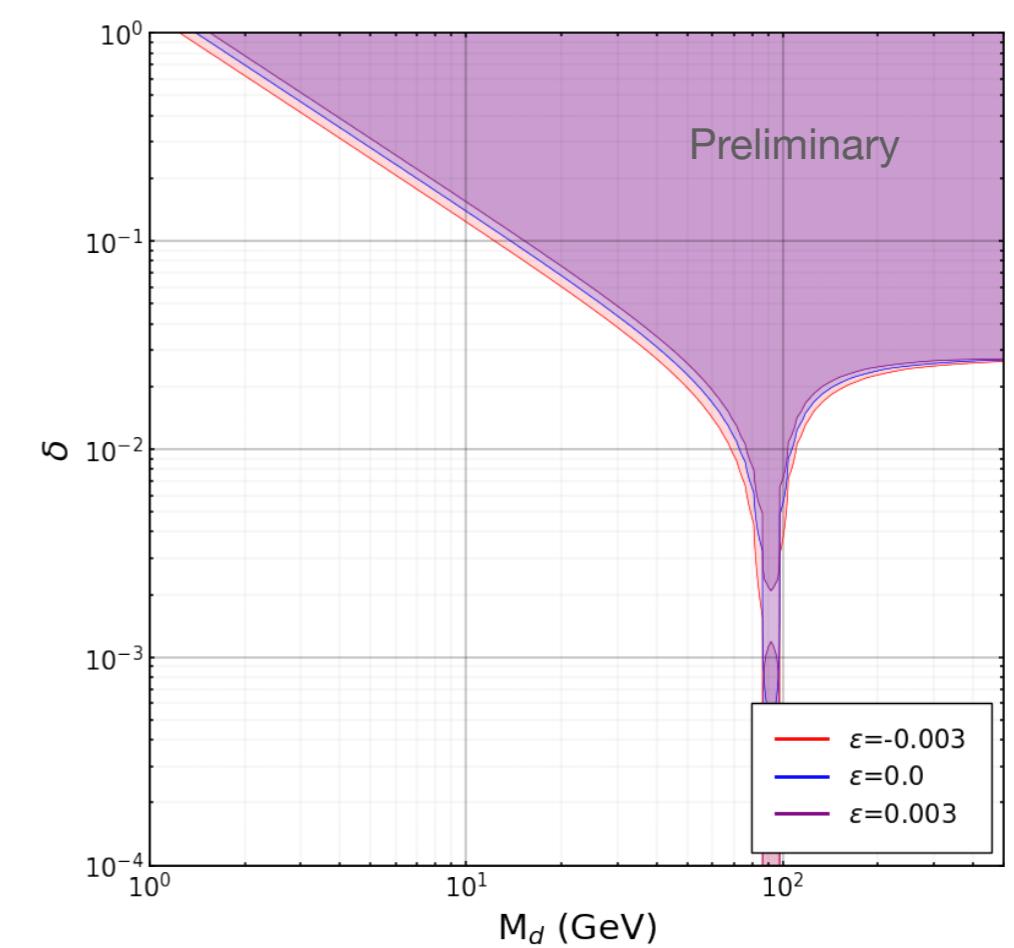
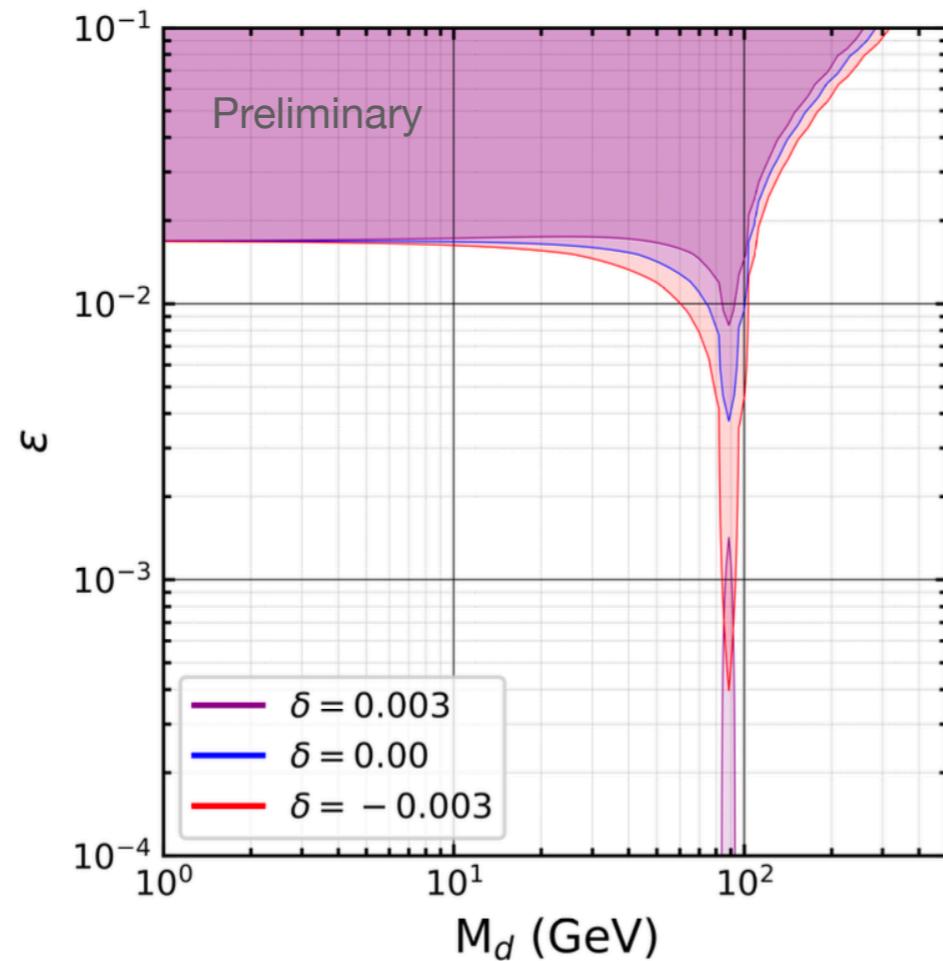
See for instance D. Curtin, R. Essig, S. Gori, and J. Shelton (2015)

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$$\Delta \sin^2 \theta_W(p^2) = -\hat{s}\hat{c} \frac{\Pi_{\hat{A}\hat{Z}}^{\text{mixing}}(p^2)}{p^2} + \frac{\hat{s}^2\hat{c}^2}{\hat{c}^2 - \hat{s}^2} \frac{\Pi_{\hat{Z}\hat{Z}}^{\text{mixing}}(M_Z^2)}{M_Z^2}.$$

$$\rho \rightarrow \rho_{SM} - \frac{\Pi_{\hat{Z}\hat{Z}}^{\text{mixing}}(-Q^2)}{Q^2 + M_Z^2} = \rho_{SM} + \frac{\left(\delta M_d M_Z + \epsilon Q^2 \tan \hat{\theta}_W\right)^2}{(Q^2 + M_d^2)(Q^2 + M_Z^2)} = \rho_{SM} + \Delta\rho.$$

$\Delta\chi^2 > 2.7$



The SLAC E158 (PV Moller scattering)

50 *GeV* Polarized e^- with an H target
 $Q^2 = 0.026 \text{ GeV}^2$

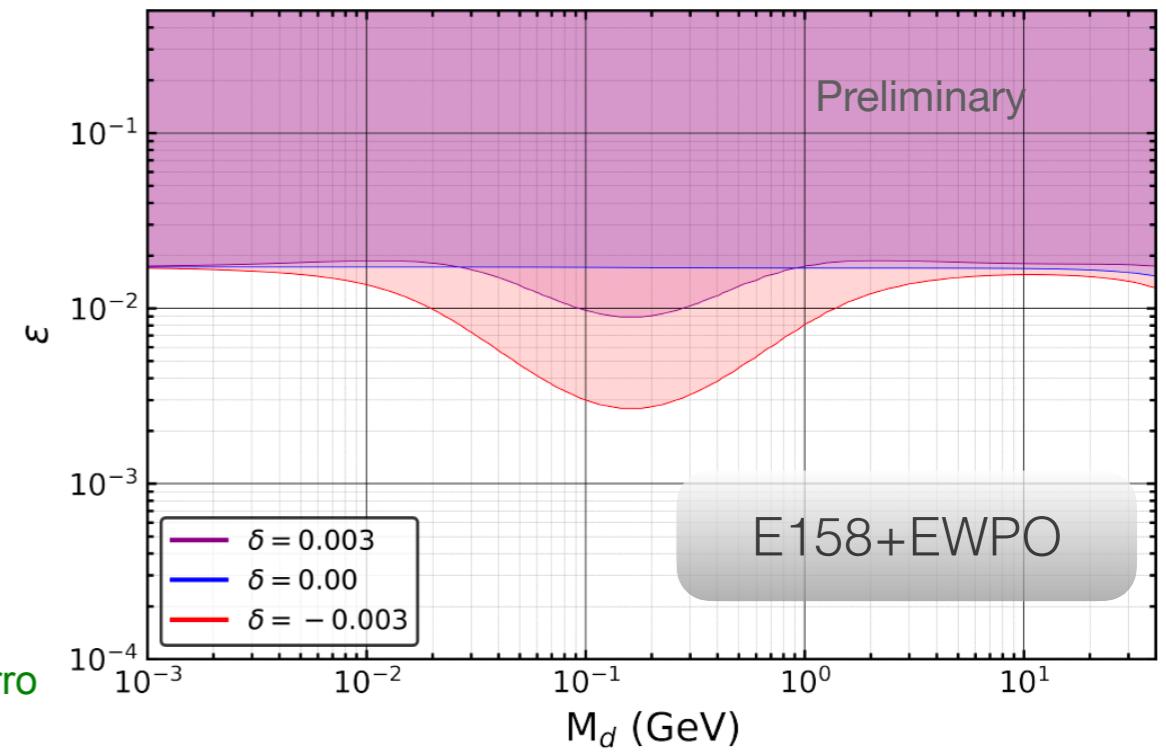
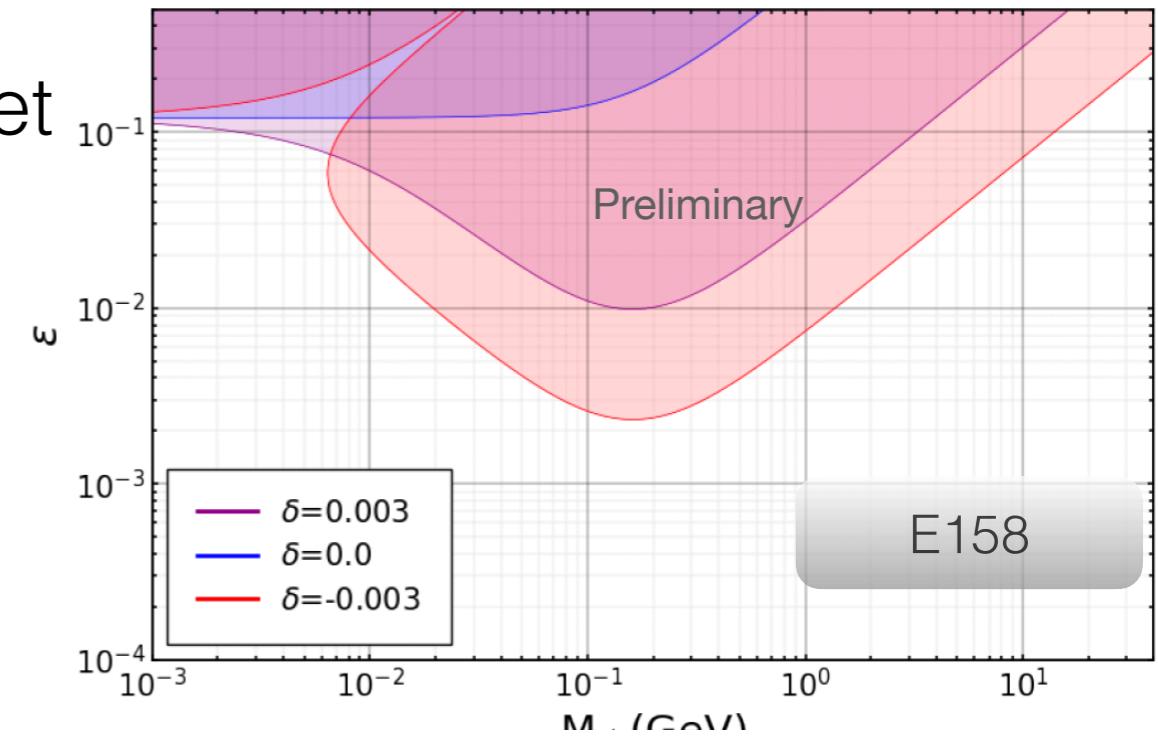
$$A_{PV} = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R} = -131 \pm 14 \text{ (sys)} \pm 10 \text{ (stat)} \times 10^{-4}$$

$$A_{PV}^{tree} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} \frac{1-y}{1+y^4+(1-y)^4} Q_W^e$$

$$Q_W^{e \text{ BSM}} = (1 + \Delta\rho - \Delta\alpha) Q_W^{e \text{ (SM)}} - 4\Delta \sin^2 \theta_W$$

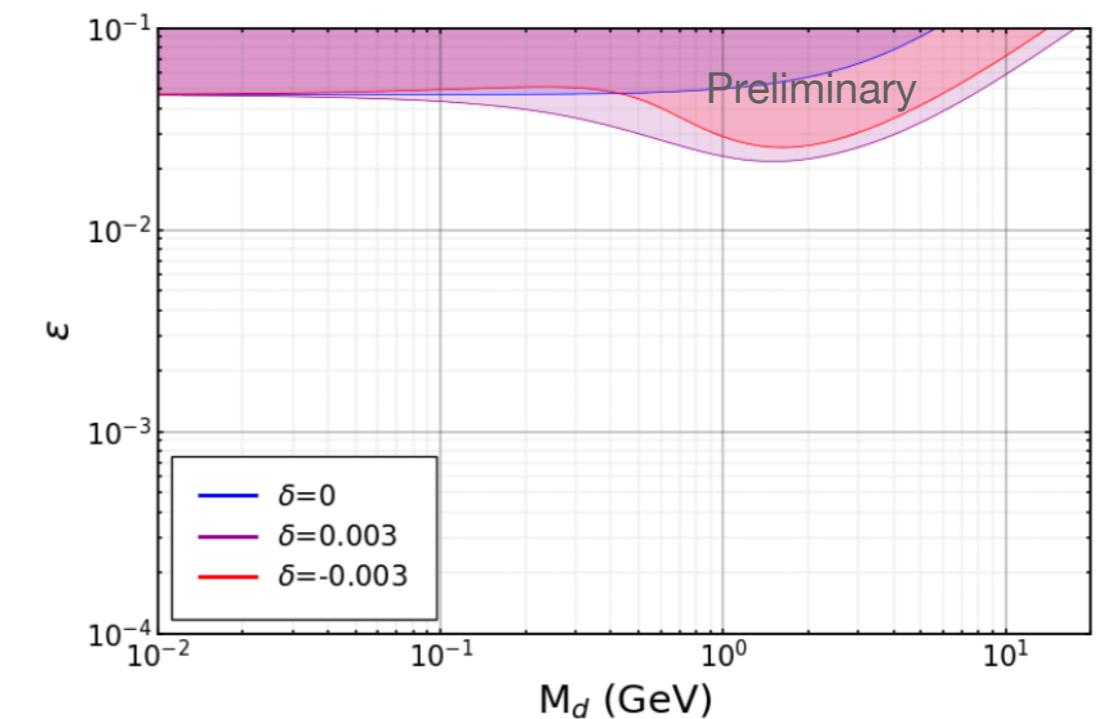
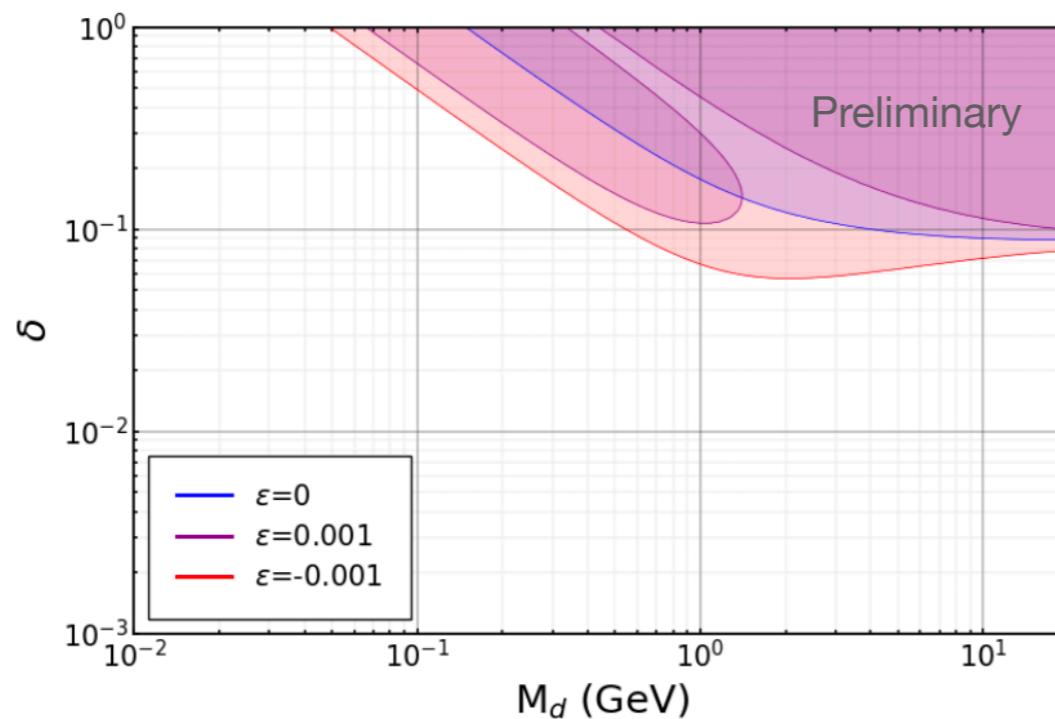
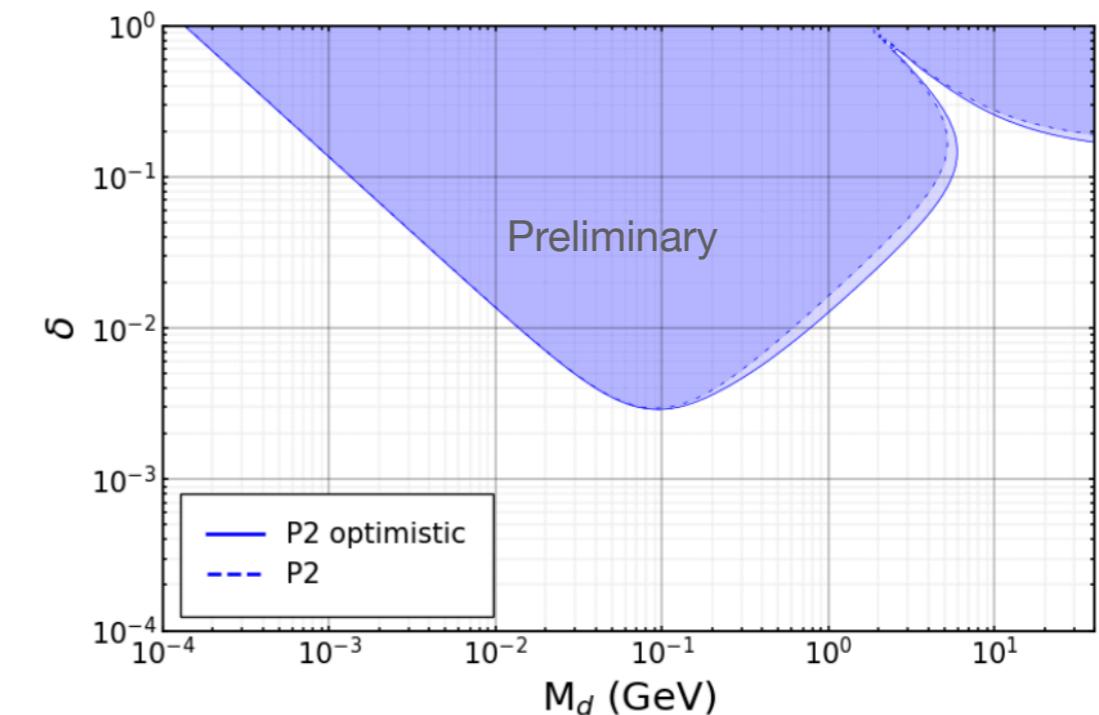
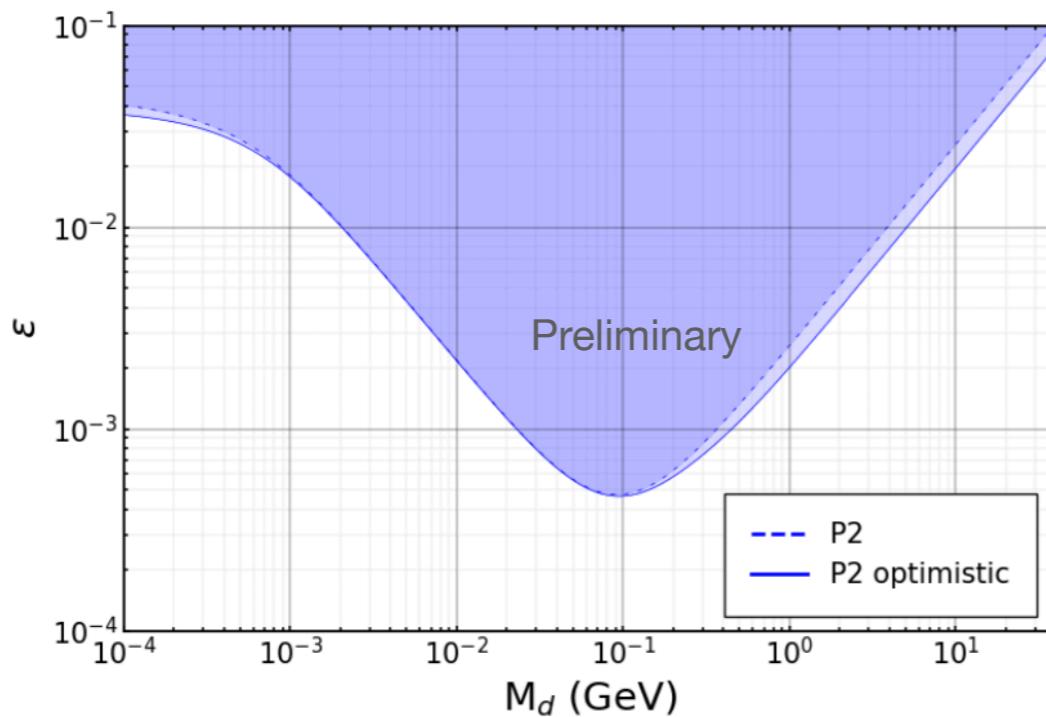
$$\Delta\chi^2 > 2.7$$

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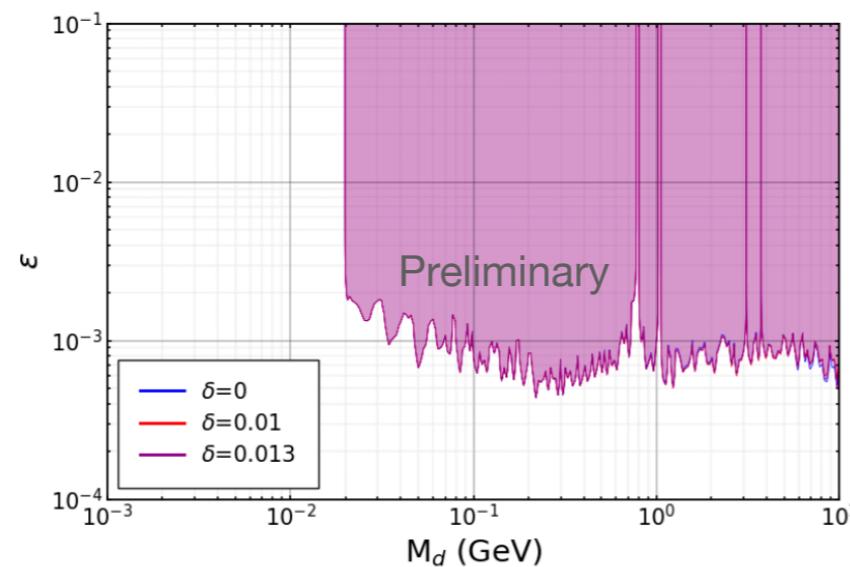


Future PV (P2 and Solid)

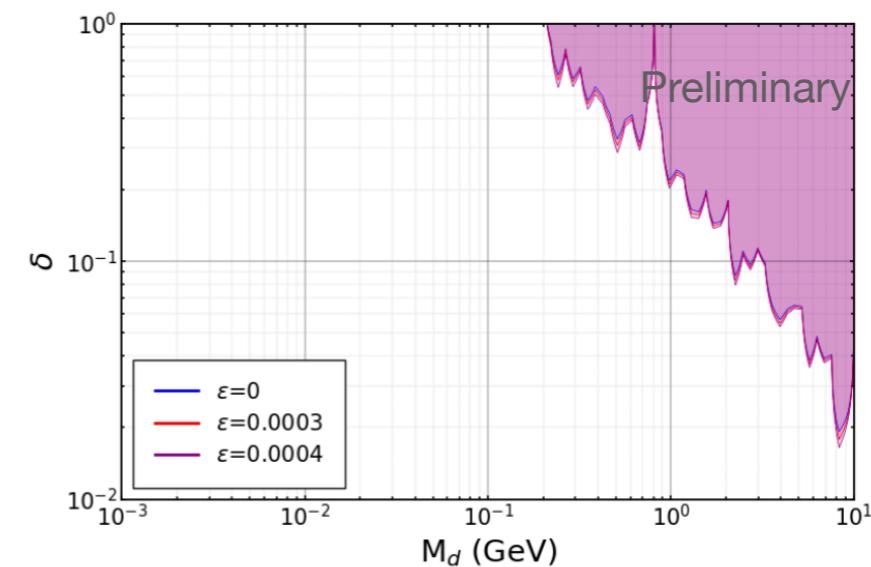
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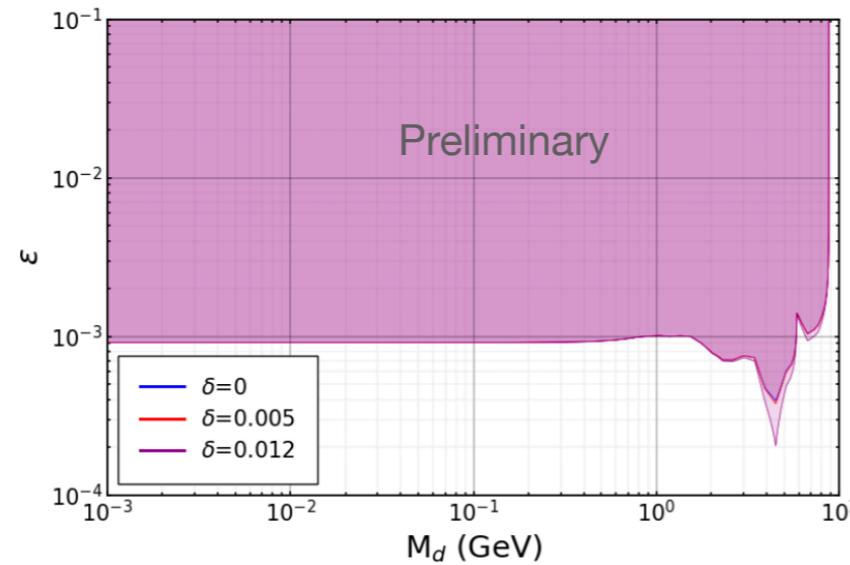
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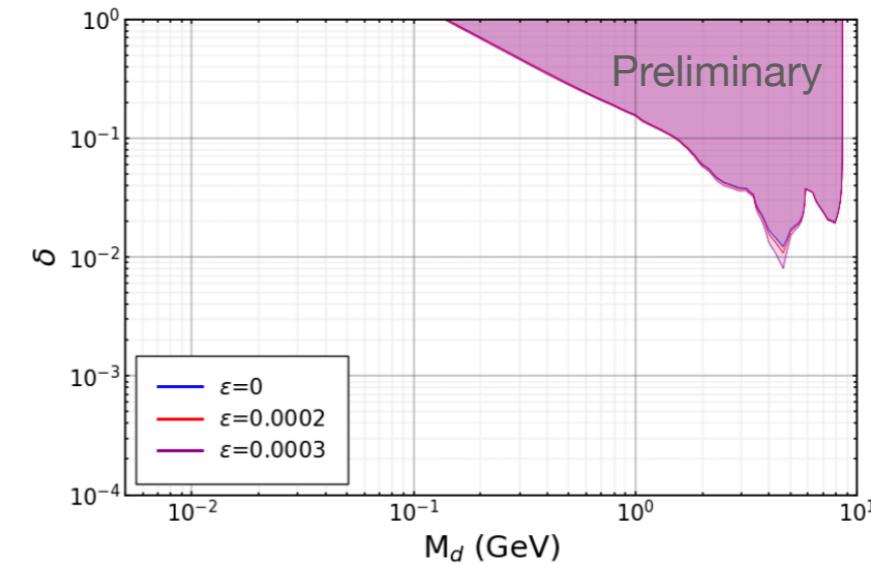
(a) $\epsilon - M_d$ plot for BaBar to lepton pairs, assuming the $B_d = 0$.



(b) $\delta - M_d$ plot for BaBar to lepton pairs, assuming the $B_d = 0$.



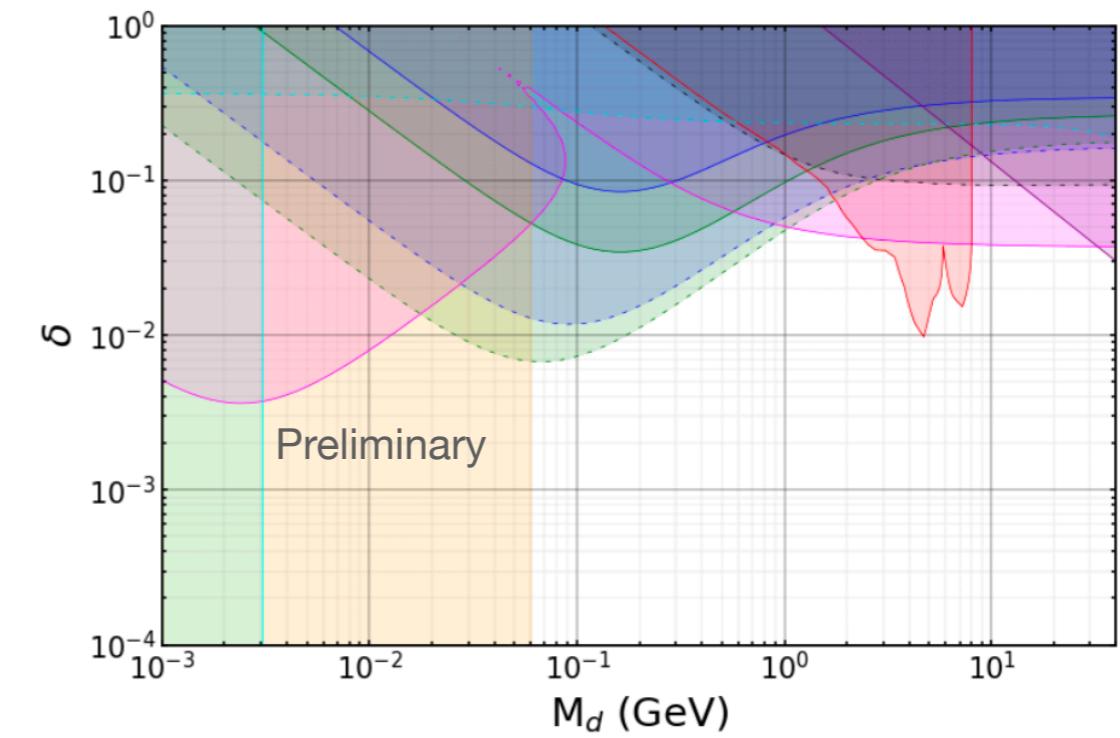
(c) $\epsilon - M_d$ plot for BaBar to invisible, assuming the $B_d = 1$.



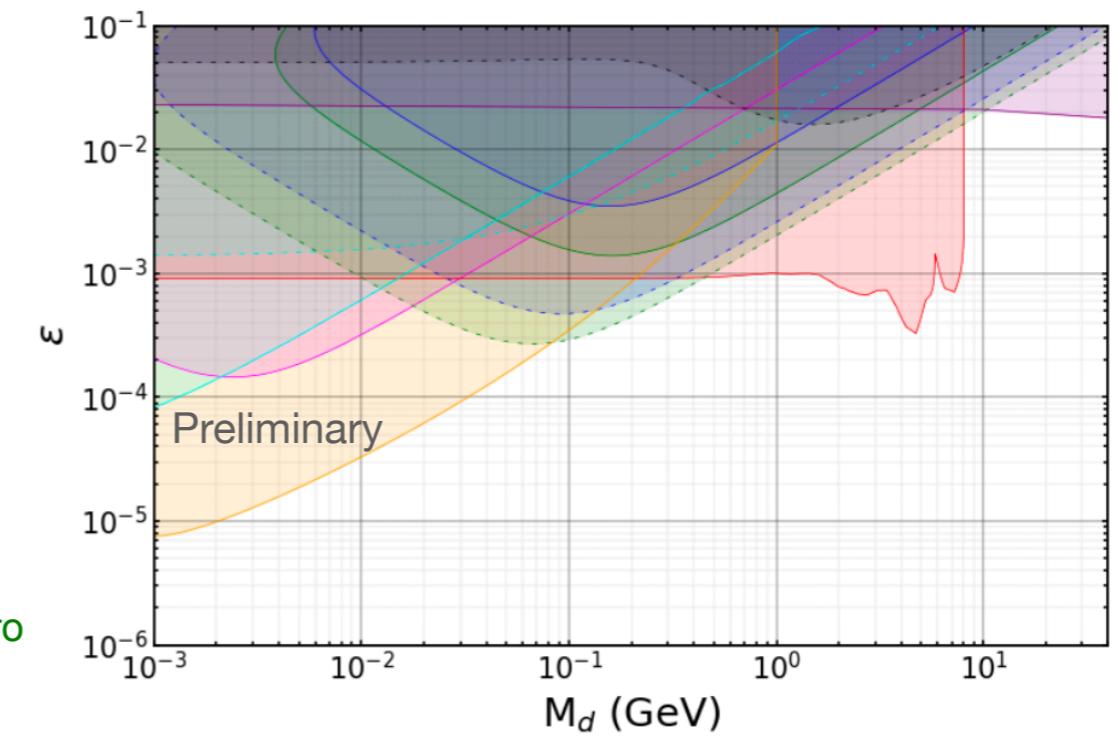
(d) $\delta - M_d$ plot for BaBar to invisible, assuming the $B_d = 1$.

Summary

$$\epsilon = -2 \times 10^{-4} \quad \delta = -5 \times 10^{-3}$$



(a) $\delta - M_d$ plot

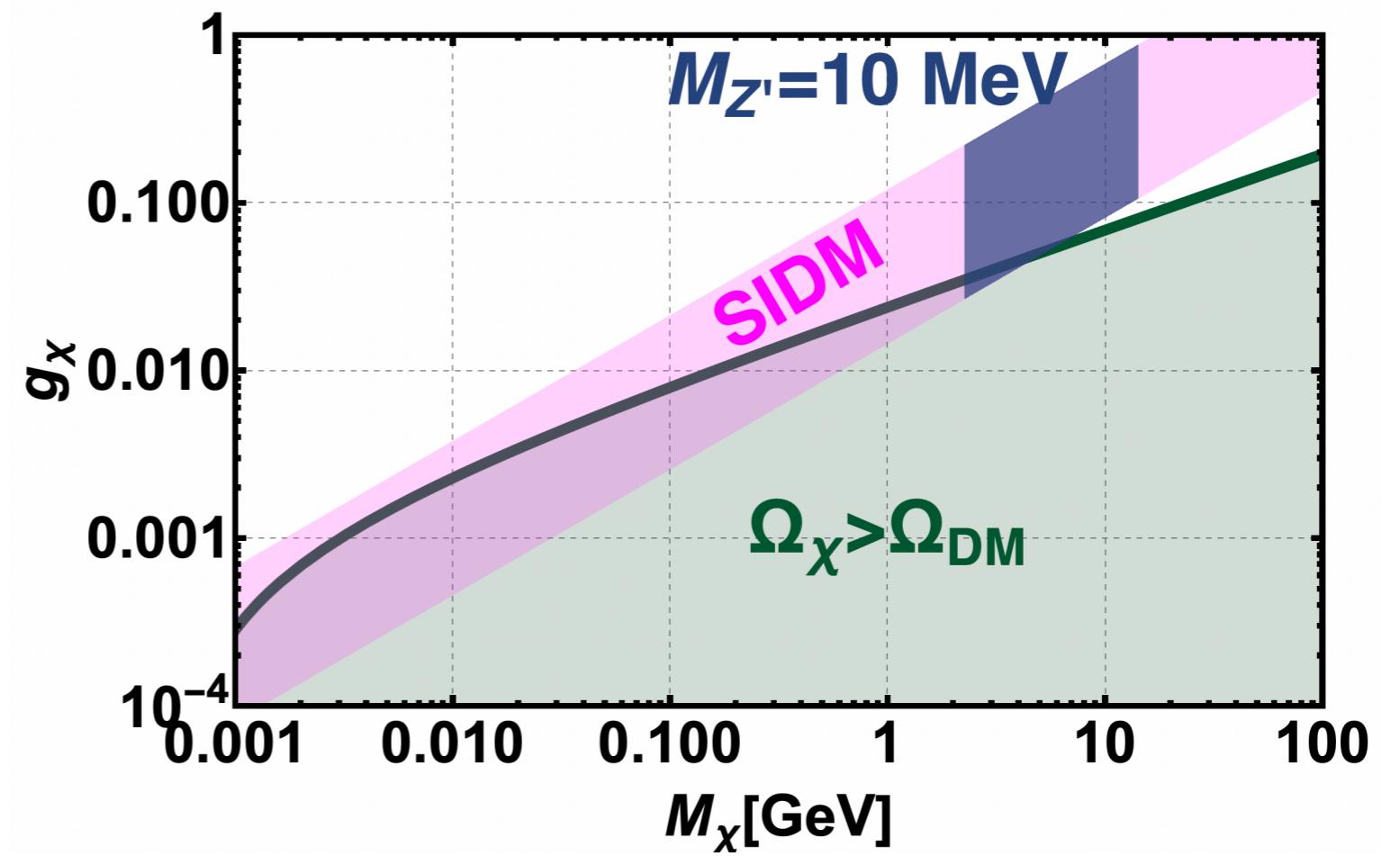
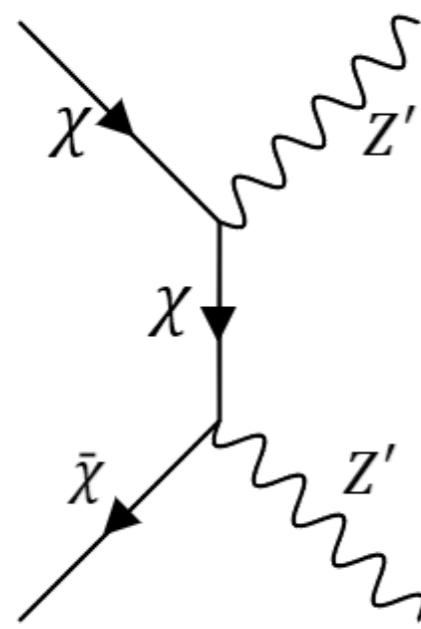


(b) $\epsilon - M_d$ plot.

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Dark Z portal DM

For a dark Z DM portal see talk by L.M. G. de la Vega in this workshop



L.M. de la Vega, EP and Wudka (2022)

Conclusions

- Light gauge boson can play a role in low energy experiments
- PV experiments can constrain the dark Z scenario for masses from few MeV to GeV
- Combining with EWPO further constrain the light dark Z scenario
- If dark Z is a portal to DM, self interacting DM and constraints from dark sector