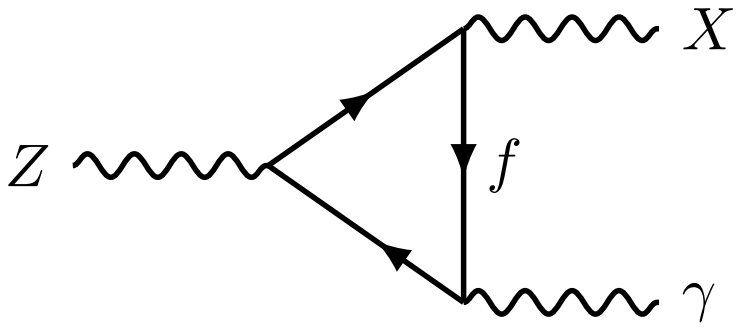
New constraints on Bad Gauge symmetries

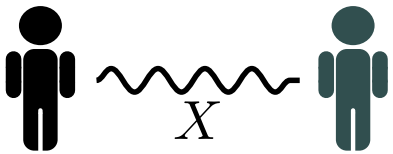
1705.06726, 1707.01503, 17XX.XXXXX

Jeff Dror, Robert Lasenby, and Maxim Pospelov

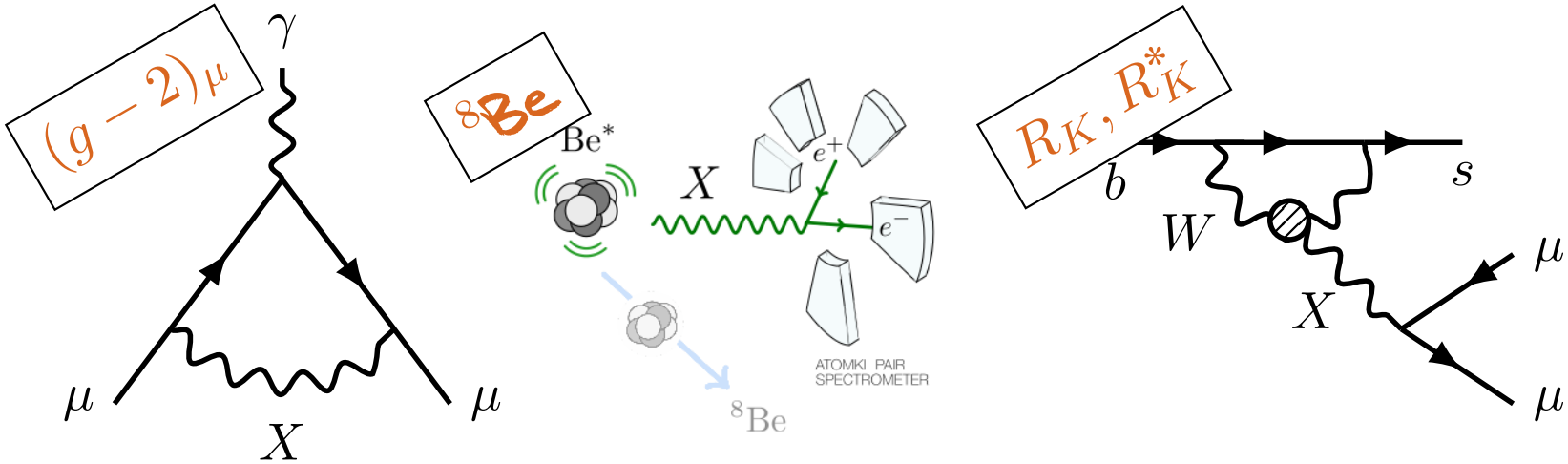


Motivation

- Why new vectors?
  1. Portal to dark sector:



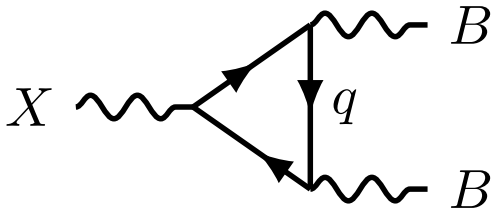
  2. Useful to explain experimental-anomalies



- Safe choices: $F_{\mu\nu}X^{\mu\nu}, X_\mu J^\mu_{B-L}, X_\mu J^\mu_{L_\mu - L_\tau}$
- Can we generalize the vector portal?

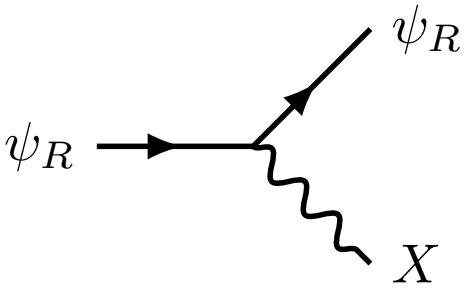
Gauging "bad" symmetries

- We can gauge symmetries broken in the SM!
- Breaking can be
  - at quantum-level (e.g., baryon number vector)



$\rightarrow$ broken by triangle diagrams

  - at tree level (e.g., containing axial couplings)



$\rightarrow$ broken by m_ψ

- $\partial_\mu J^\mu_X \neq 0$ leads to rates enhanced by $(E/m_X)^2$
  - $\Rightarrow$ unitarity violation

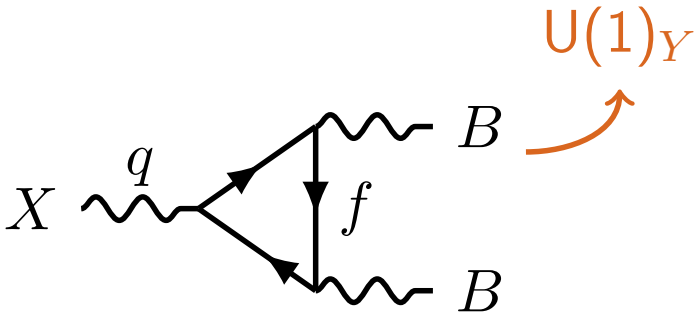
Loop-level breaking

- Focus on symmetries violated by the chiral anomaly
- Can see breaking at amplitude level using Ward Identity:

$$q_\rho \mathcal{M}^\rho(q) = 0$$

- Chiral anomaly:

$$\mathcal{M}^{\mu\nu\rho} =$$



- UV divergent: chose regulator which preserves SM

$$q_\rho \mathcal{M}^{\mu\nu\rho} = \frac{g_X g'^2}{12\pi^2} \sum_{f \in \text{quarks}} X_f Y_f^2 \epsilon^{\mu\nu\rho\sigma} k_\rho p_\sigma$$

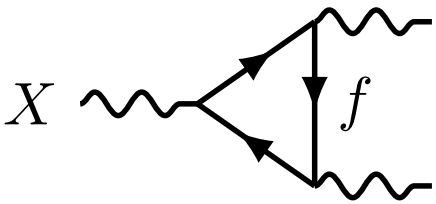
- Now study assumption further

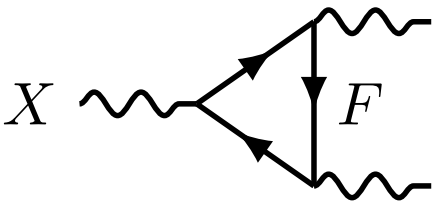
Theory needs "fixing"

- Introduce heavy $U(1)_X$ chiral fermions (SM-chiral ruled out)

$$m_F \lesssim \frac{4\pi m_X}{g_X}$$

[- Preskill (1991)]

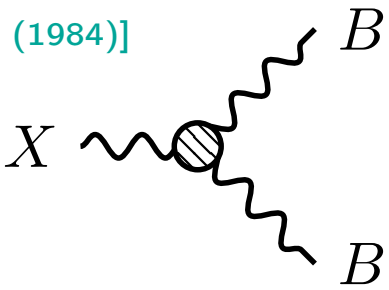




Cancel anomaly: $\sum_f X_f Y_f^2 = -\sum_F X_F Y_F^2$

[- D'Hoker, Farhi (1984)]

- But these fermions don't decouple!
- For $E \ll m_F$ have effective interactions:

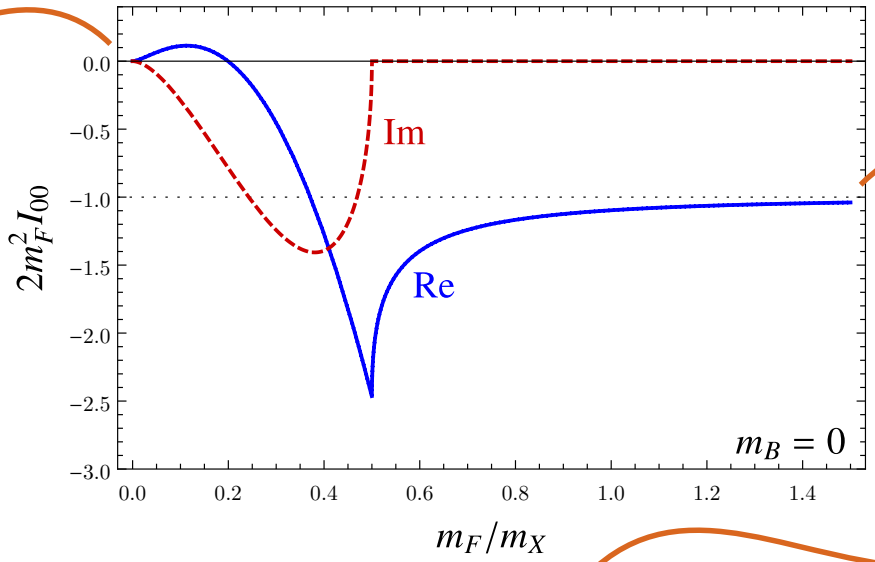


UV theory

- Massless SM + new fermions, F:

$$-q_\rho \mathcal{M}^{\mu\nu\rho} = \left(0 + \frac{g'^2 g_X}{12\pi^2} \sum_F 2m_F^2 I_{00}(m_F) X_F Y_F^2\right) \epsilon^{\nu\rho\lambda\sigma} p_\lambda k_\sigma$$

anomaly cancelled



constant value for $m_F \gg m_X$!

$$= -\sum_f X_f Y_f^2$$

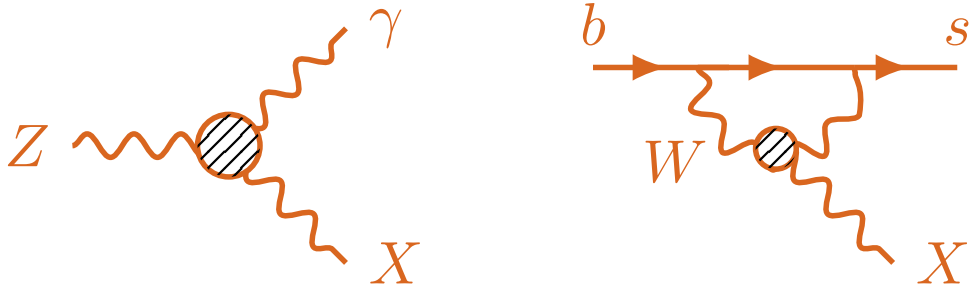
$$\lim_{m_F \gg m_X} q_\rho \mathcal{M}^{\mu\nu\rho} = -\frac{g'^2 g_X}{12\pi^2} \overbrace{\sum_F X_F Y_F^2} \epsilon^{\nu\rho\lambda\sigma} p_\lambda k_\sigma$$

Effective interactions

- Longitudinal model dominates, $X_\mu \to \partial_\mu \varphi / m_X$
- Triangle diagrams arise from,

$$\mathcal{L}_{\text{eff}} = \frac{g_X}{16\pi^2}\Big[\sum_f X_f Y_f^2\Big]\frac{\varphi}{m_X}\left(g^2 W^a \tilde{W}^a - g'^2 B\tilde{B}\right)$$

- In EFT (integrate out F) need to add to Lagrangian!
- New processes: [JD,Pospelov,Lasenby - 1705.06726]

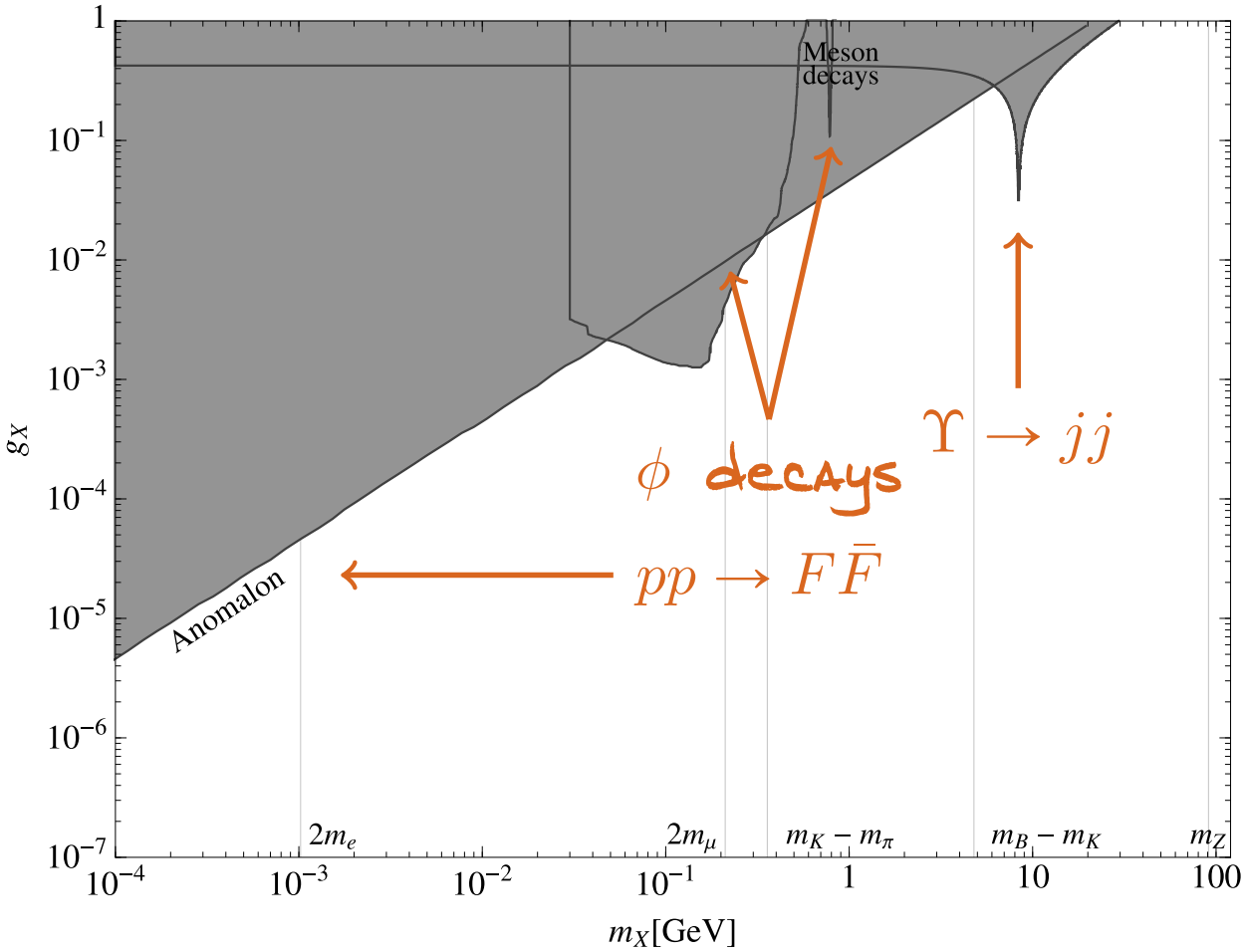


- These grow with energy for $E \ll m_F$: $|\mathcal{M}|^2 \propto E^2/m_X^2$!

Example: B vector

- Non-enhanced limits:

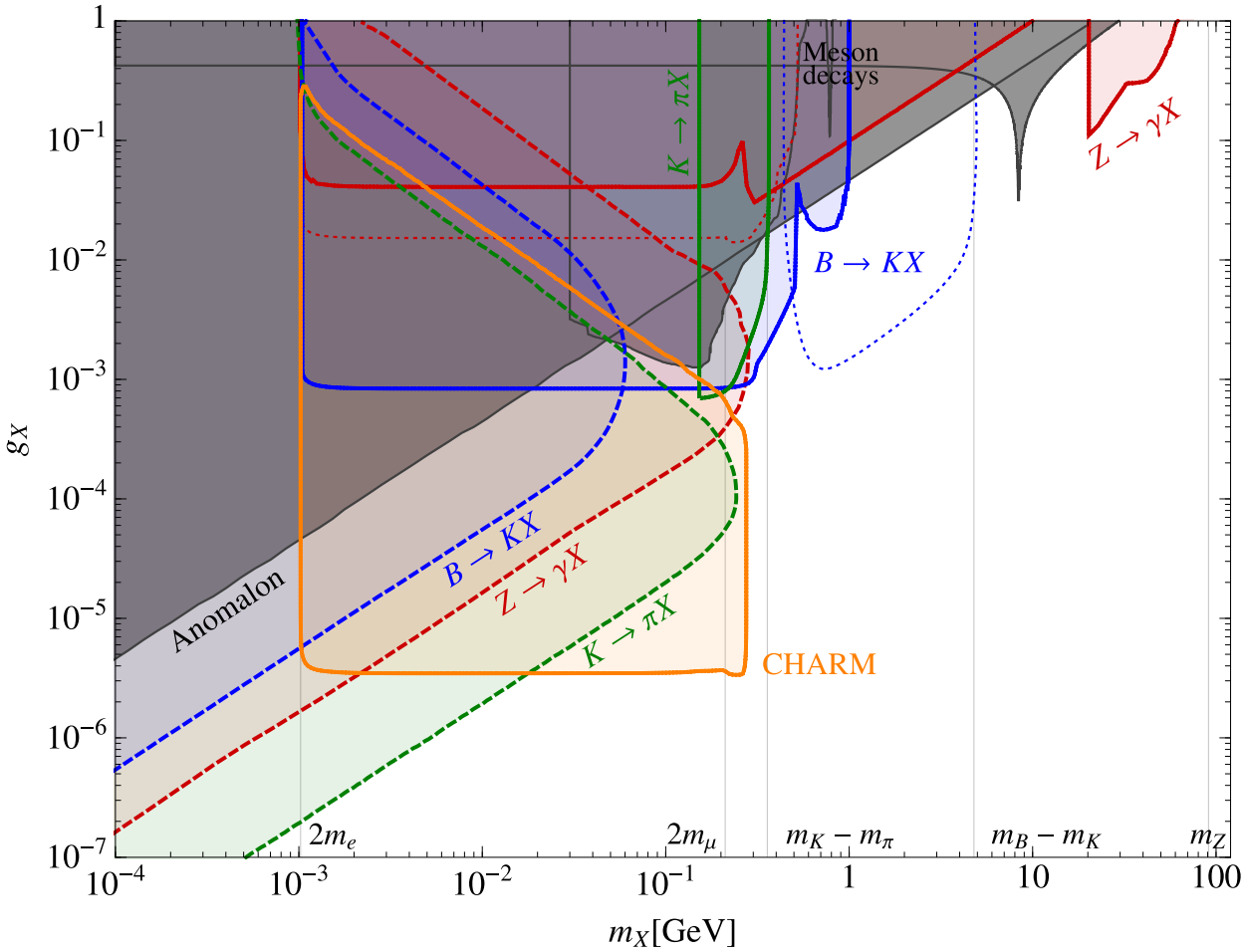
[Carone,Murayama - hep-ph/9501220]
[Tulin - 1404.4370]
[Dobrescu,Frugiuele - 1404.3947]



Example: B vector

- All limits:

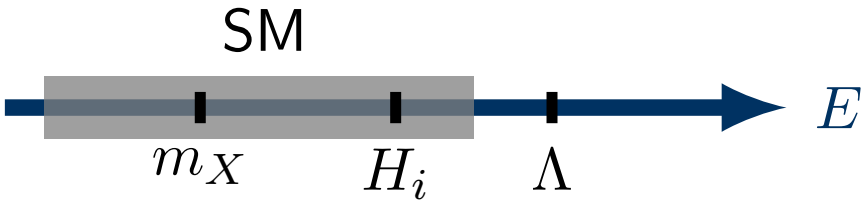
[JD,Pospelov,Lasenby - 1705.06726]



Tree-level breaking

- Ampliudes grow with energy... even at tree-level
- Need modification of EW sector

[1609.02188 - Ismail,Keung,Tsao,Unwin]
[1609.09072 - Kahn,Krnjaic,Mishra-Sharma,Tait]



$$\Lambda \lesssim m_X/g_X$$

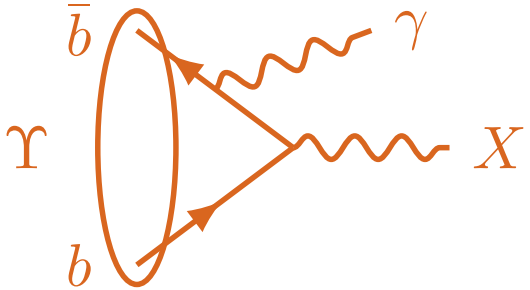
- Below this scale, $\partial_\mu J_X^\mu \neq 0$!
- For $E \ll \Lambda$:

$$|\mathcal{M}|^2 \propto E^2/m_X^2$$

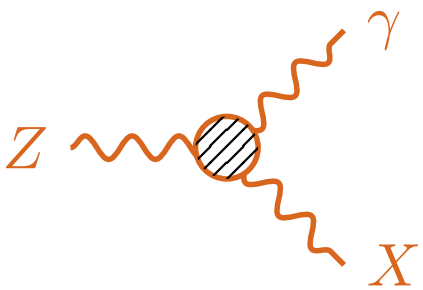
Where are the enhanced rates?

- Operators that violate $U(1)_X$ produce enhanced rates
- Consider an axially-coupled vector

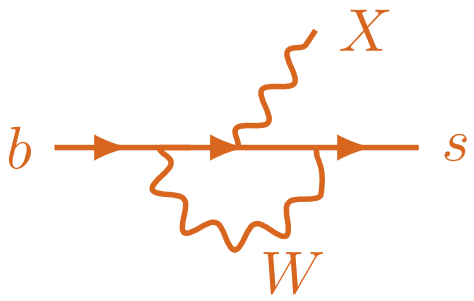
[Fayet - hep-ph/0607318]



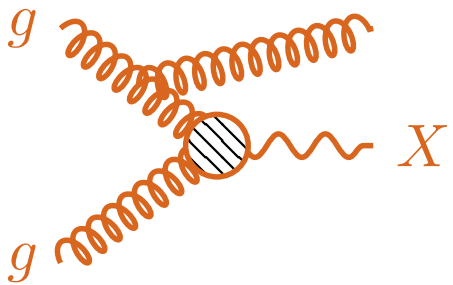
[JD,Pospelov,Lasenby - 1705.06726]



[JD,Pospelov,Lasenby - 1707.01503]



[JD,Pospelov,Lasenby - 1707.01503]

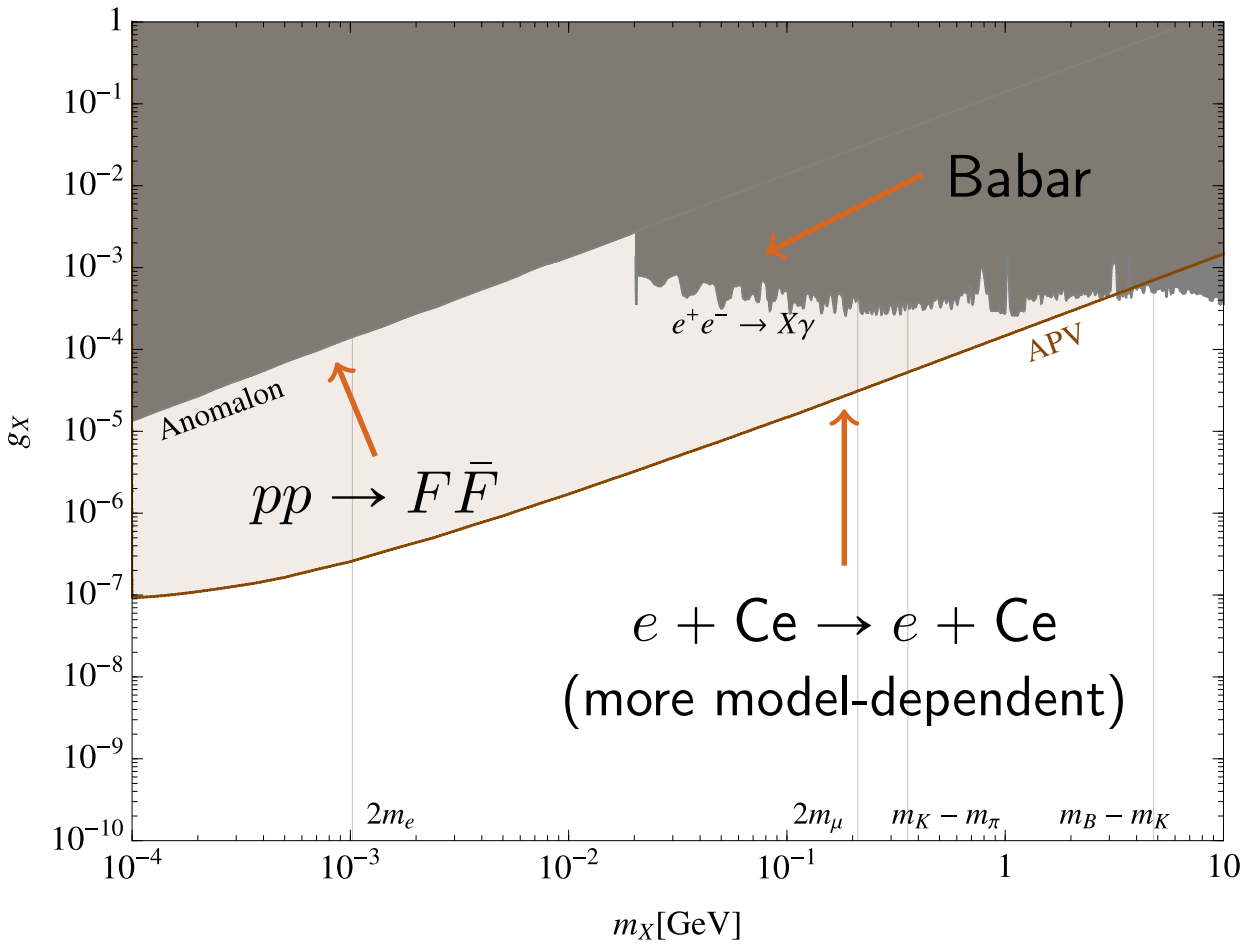


- Other processes for different tree-level breaking

Example: $U(1)_R$-coupled vector

- Non-enhanced limits:

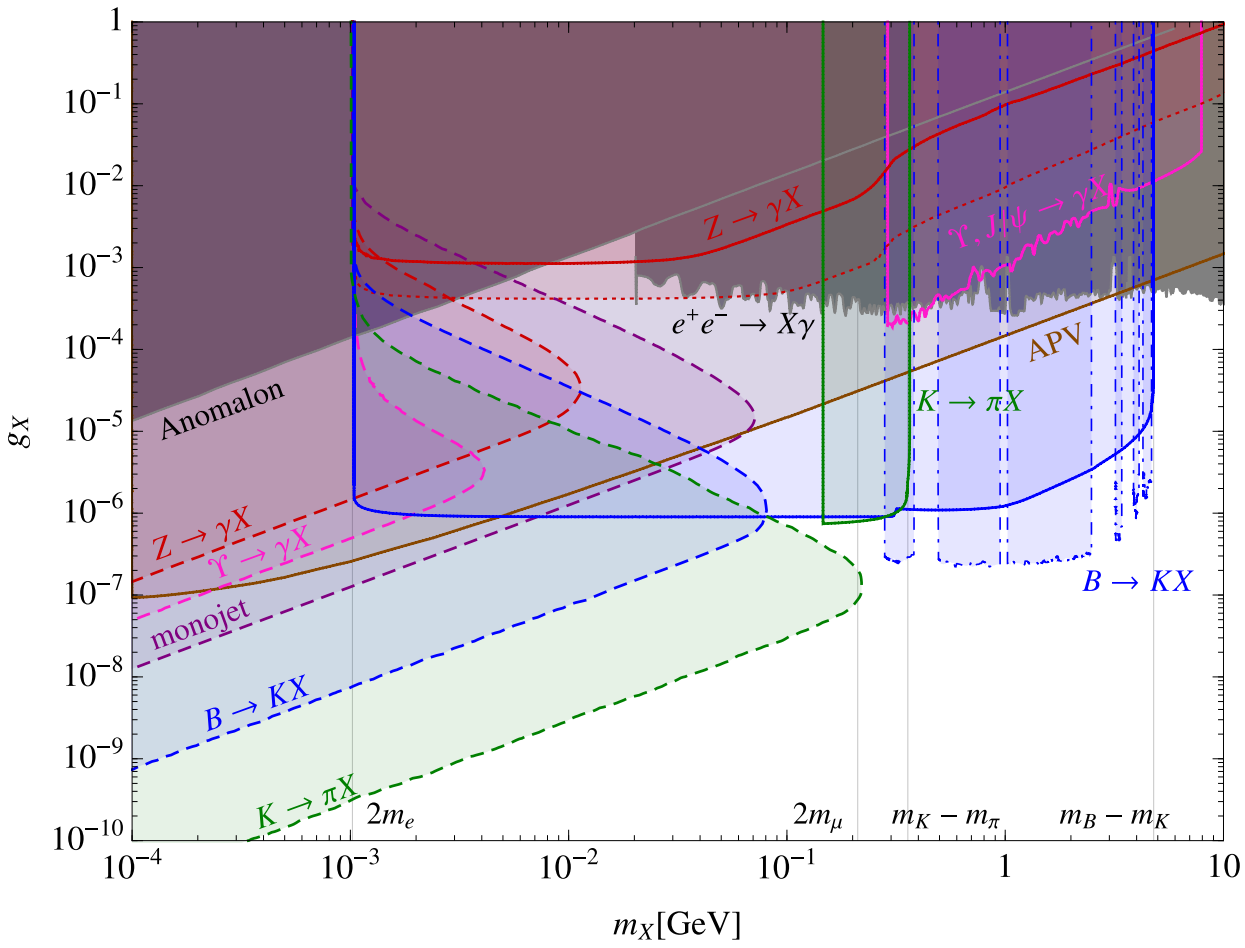
[Fayet - hep-ph/0702176]
[Babar - 1406.2980]
[Dobrescu,Frugiuele - 1404.3947]



Example: $U(1)_R$-coupled vector

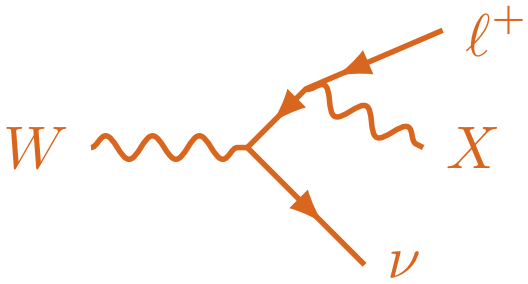
- All limits:

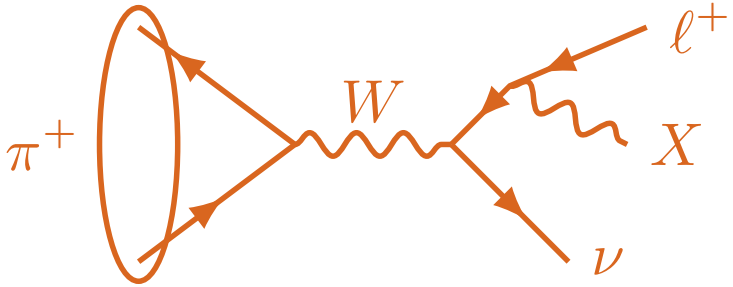
[JD,Pospelov,Lasenby - 1707.01503]



Weak-isospin violation

- Can build models that charged current violates U(1)$_X$
- Occurs if couple only one particle of SU(2) doublet to X
- Enhanced processes:





[Karshenboim, McKeen, Pospelov - 1401.6154] [JD,Pospelov,Lasenby - 1707.01503]

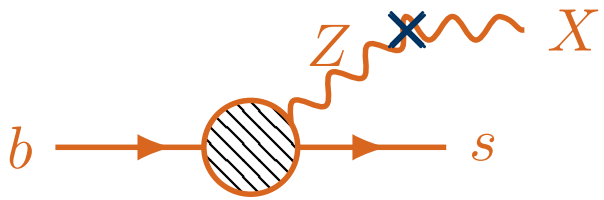
- $\pi^+ \to e^+ \nu X$ is particularly stringent
- SM rate for $\pi^+ \to e^+ \nu (\gamma^* \to e^+ e^-) \propto m_e^2$ (at tree-level)
- Not the case for X rate

EW coupling

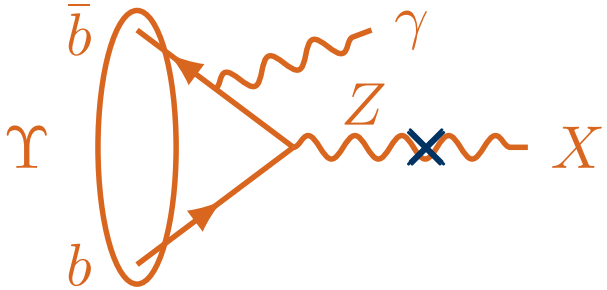
- X could couple to EW sector (other then kinetic mixing)
- Such couplings are not $\mathrm{U}(1)_X$ invariant
- Prominent example: mass-mixing:

$$\mathcal{L} \supset \delta m^2 X_\mu Z^\mu$$

- Enhanced rates, $\propto \delta m^2$



[JD,Pospelov,Lasenby - 17XX,XXXXX]



[JD,Pospelov,Lasenby - 1705.06726]

Take home message

- Can gauge non-conserved currents
  - broken at tree-level?
  - broken at loop-level?
- Constraints on these models grow with energy!
- FCNC's dominate for $m_X \lesssim m_B$
- Other ways to form tree-level breaking of U(1)$_X$
  - isospin violating couplings (e.g., Wud, $W\ell\nu$ break U(1)$_X$)
  - EW couplings of EW (e.g., $\mathcal{L} \supset \delta m^2 X_\mu Z^\mu$)
- Rule out most ^{8}Be anomaly models
- Moral:

careful what you gauge!