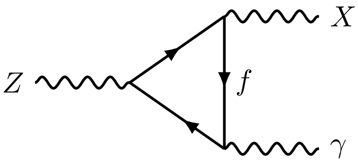
New constraints on vectors coupled to non-conserved currents

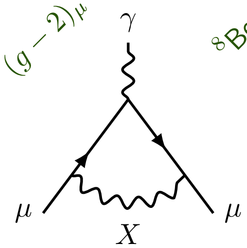
1705.XXXXX/1706.XXXXX

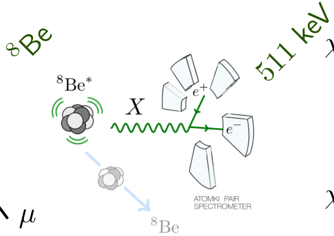
Jeff Dror, Robert Lasenby, and Maxim Pospelov

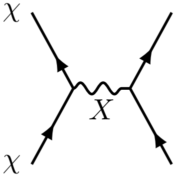


Why new gauge symmetries?

- Why introduce additional gauge symmetries?
  - Useful to explain experimental-anomalies



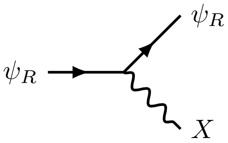




  - X can be mediator to dark sector
  - Ensure baryon stability
- What can we gauge?
  - Safe choices → good symmetries of SM (e.g., $B-L$)
  - What else?

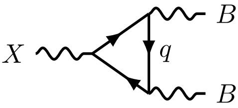
Gauging "bad" symmetries

- We can gauge symmetries broken in the SM!
- Breaking can be
  - at tree level (e.g., containing axial couplings)



→ broken by m_ψ

  - and/or through chiral anomaly (e.g., baryon number)



→ broken by triangle diagrams

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

Tree-level Breaking

- Need new physics
- Tree-level breaking → need extended EWSB sector,

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

$$\Lambda \lesssim m_X/g_X$$

- Below this scale, $\partial_\mu J^\mu_X \neq 0$!
- For $E \ll m_F$:

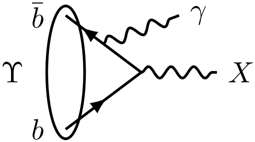
$$|\mathcal{M}|^2 \propto E^2/m_X^2$$

- Can use Goldstone Boson Equivalence ($X_\mu \to \partial_\mu \varphi/m_X$):
- Also creates $\varphi G\tilde{G}$,$\varphi F\tilde{F}$

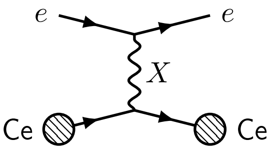
Where are the enhanced rates?

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

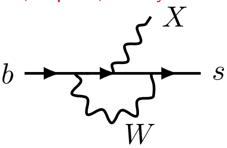
hep-ph/0607318 - Fayet



1609.09072 - Kahn,Krnjaic,Mishra-Sharma,Tait



- JD,Pospelov,Lasenby



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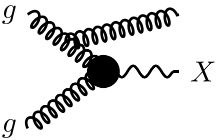


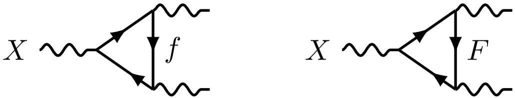
- Other processes for different tree-level breaking

Loop-level Breaking

- If broken by chiral anomaly - introduce additional (heavy) fermions:

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

- Preskill(1991)



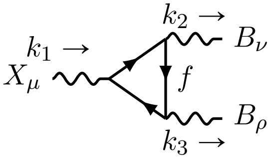
$$\sum_f X_f Y_f^2 = -\sum_F X_F Y_F^2$$

- Heavy fermions don't decouple! - D'Hoker, Farhi (1984)
- Lead to effective interactions:

$$\propto \epsilon^{\mu\nu\rho\sigma} X_\mu B_\nu \partial_\rho B_\sigma + \ldots$$

"Deriving" the 3-pt vertex

- In a symmetric regularization scheme:



$$k_i^\mu \mathcal{M}_{\mu\nu\rho} = C \times \epsilon_{\nu\rho\lambda\sigma} k_j^\lambda k_k^\sigma$$

scary...

- violates $U(1)_X$ AND $U(1)_Y$!
- Consider adding,

$$\mathcal{L} \supset C \times \epsilon^{\mu\nu\rho\sigma} X_\mu B_\nu \partial_\rho B_\sigma$$

- In UV, corresponds to non-decoupling of heavy fermions
- Including this,

$$k_2^\mu \mathcal{M}_{\mu\nu\rho} = k_3^\mu \mathcal{M}_{\mu\nu\rho} = 0\,, \quad k_1^\mu \mathcal{M}_{\mu\nu\rho} \neq 0$$

- Upshot: unique effective 3pt vertex

Effective interactions

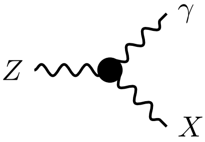
- We have effective interactions,

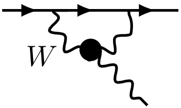
$$\Delta\mathcal{L} \propto \epsilon^{\mu\nu\rho\sigma} X_\mu B_\nu \partial_\rho B_\sigma + \ldots$$

- Goldstone boson equivalence (φ looks like ALP)

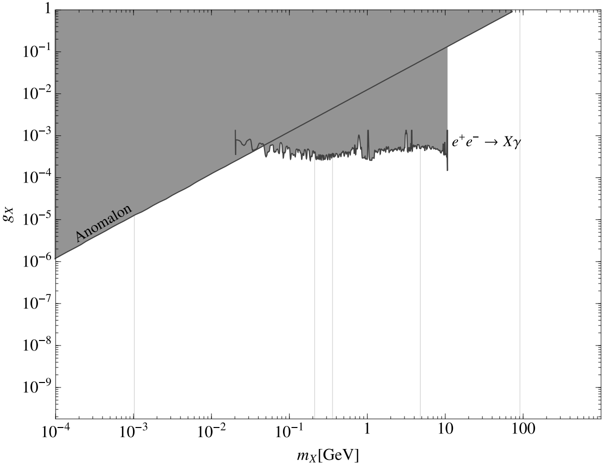
$$\Delta\mathcal{L} \propto \frac{\varphi}{m_X} B_{\mu\nu}\tilde{B}^{\mu\nu} + \ldots$$

- New processes: - JD,Pospelov,Lasenby

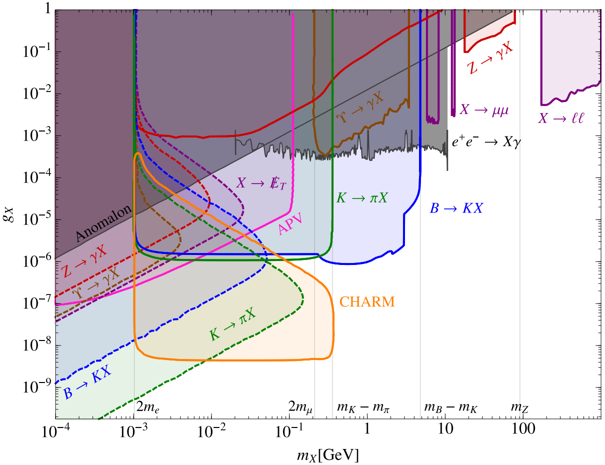




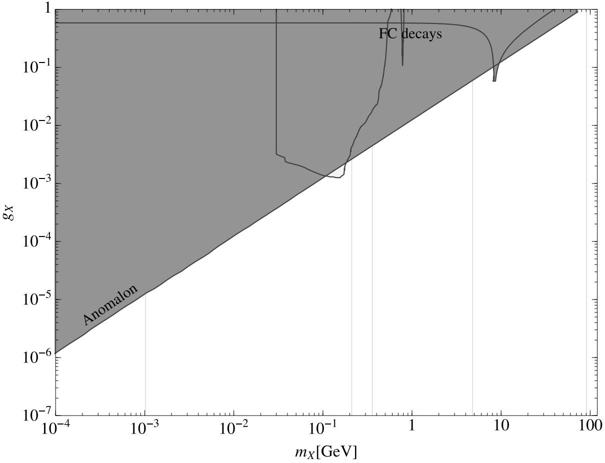
- Non-enhanced limits:



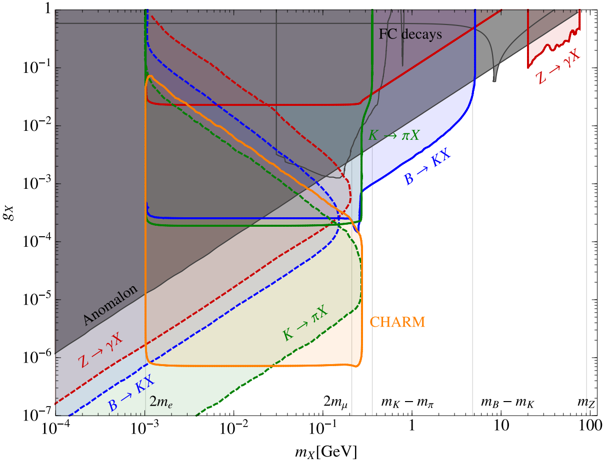
- All limits:


Anomalon
$Z \to \gamma X$
$\Upsilon \to \gamma X$
$X \to \not{E}_T$
APV
$K \to \pi X$
$B \to KX$
CHARM
$X \to \mu\mu$
$X \to \ell\ell$
$e^+e^- \to X\gamma$
$2m_e$
$2m_\mu$
$m_K - m_\pi$
$m_B - m_K$
m_Z
g_X
m_X[GeV]

- Non-enhanced limits:



- All limits:


FC decays
Anomalon
$Z \to \gamma X$
$B \to KX$
$K \to \pi X$
CHARM
$2m_e$
$2m_\mu$
$m_K - m_\pi$
$m_B - m_K$
m_Z
g_X
m_X[GeV]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 100

Take home message

- Can gauge non-conserved currents
  - broken at tree-level?
  - broken at loop-level?
- Constraints on these models grow with energy!
- Flavor changing dominate for $m_X \lesssim m_B$
- Other ways to form tree-level breaking of U(1)$_X$
  - generation non-universal
    - tree-level FCNC
  - isospin violating couplings
    - Wud, $W\ell\nu$ break U(1)$_X$
- Rule out most ^{8}Be anomaly models
- Moral:

careful what you gauge!