Generalizing the U(1) Current

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Introduction

[Submitted on 15 Jan 2018 (v1), last revised 9 Jul 2018 (this version, v2)]

Serendipity in dark photon searches

Philip Ilten, Yotam Soreq, Mike Williams, Wei Xue

- Dug up a paper from 2018 on recasting A' constraints to other U(1) current couplings
  - https://arxiv.org/abs/1801.04847, published in JHEP

- Abstract: Searches for dark photons provide serendipitous discovery potential for other types of vector particles. We develop a framework for recasting dark photon searches to obtain constraints on more general theories, which includes a data-driven method for determining hadronic decay rates. We demonstrate our approach by deriving constraints on a vector that couples to the B−L current, a leptophobic B boson that couples directly to baryon number and to leptons via B-γ kinetic mixing, and on a vector that mediates a protophobic force. Our approach can easily be generalized to any massive gauge boson with vector couplings to the Standard Model fermions, and software to perform any such recasting is provided at this https URL .

"Darkcast"

- They provide easy to use code, which includes a long list of reach estimates
  - I put our latest/greatest reach numbers into code
  - They admit to not treating displaced estimates properly

Introduction

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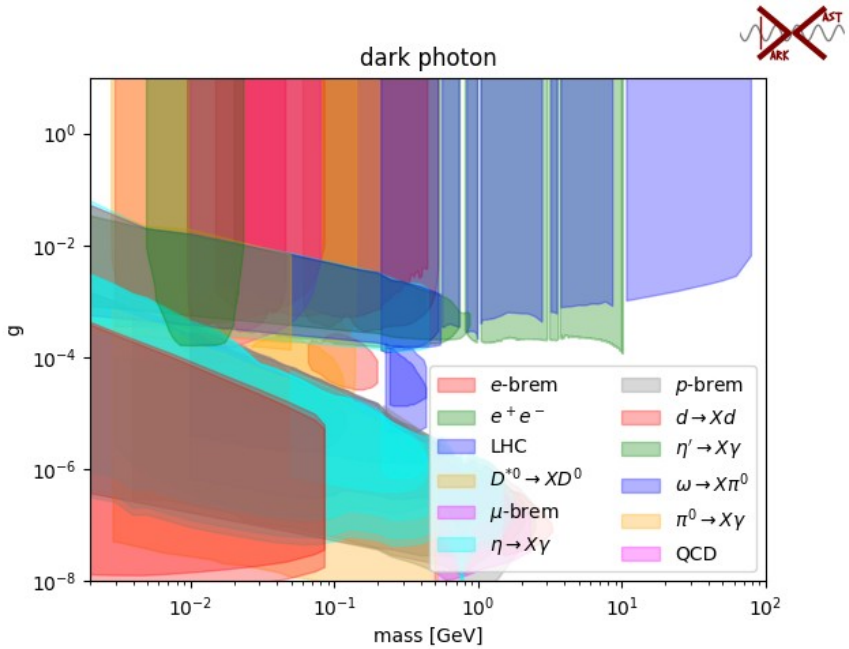
Coupling	A'	$B-L$	B	Protophobic
g_X	εe	g_{B-L}	g_B	$g_{\not p}$
$x_{u,c,t}$	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$-\frac{1}{3}$
$x_{d,s,b}$	$-\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{2}{3}$
$x_{e,\mu,\tau}$	-1	-1	$-\frac{e^2}{(4\pi)^2}$	-1
$x_{\nu_e,\nu_\mu,\nu_\tau}$	0	-1	0	0

Primer Info (sorry kinda dense)

- They define a “generalized” coupling parameter $\mathcal{L} \subset g_X \sum_f x_f \bar{f}\gamma^\mu f X_\mu + \sum_\chi \mathcal{L}_{X\chi\bar{\chi}}$,
  - X is a generalized vector boson
  - Dark photons will have g = εe in this generalization
- Rates can then be written in general wrt A’ as: $\frac{\sigma_{eZ\to eZX}}{\sigma_{eZ\to eZA'}} = \frac{\sigma_{e^+e^-\to X\gamma}}{\sigma_{e^+e^-\to A'\gamma}} = \frac{(g_X x_e)^2}{(\varepsilon e)^2}$.
  - See paper for more details on what $g_X x_e$ looks like for the various X’s

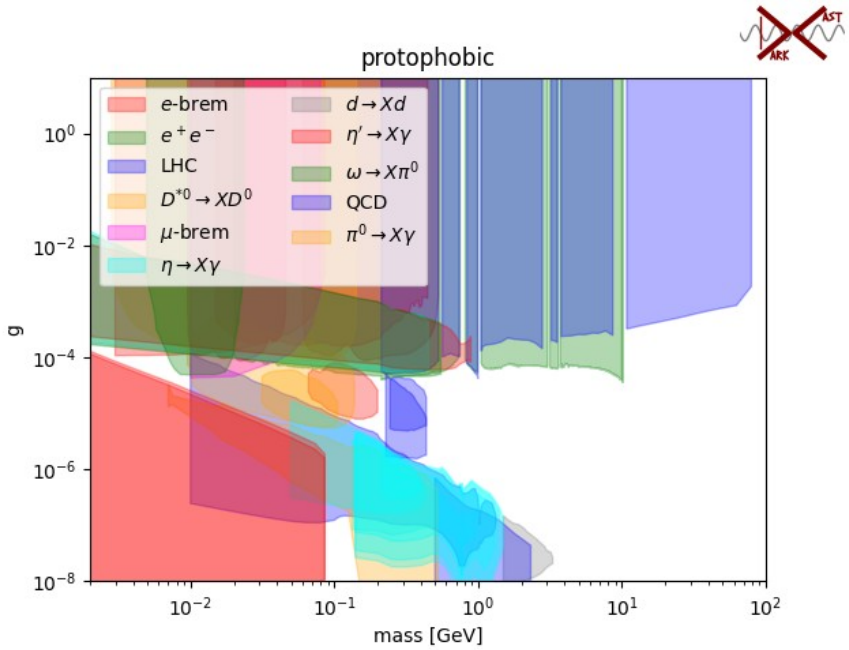
This is from their code using their full list of reaches with HPS updated



Production Mechanism	$B-L$	B	Protophobic
$\frac{\sigma_{eZ\to eZX}}{\sigma_{eZ\to eZA'}}$	$\frac{g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{e^4 g_B^2}{(4\pi)^4(\varepsilon e)^2}$	$\frac{g_p^2}{(\varepsilon e)^2}$
$\frac{\sigma_{e^+e^-\to X\gamma}}{\sigma_{e^+e^-\to A'\gamma}}$	$\frac{g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{e^4 g_B^2}{(4\pi)^4(\varepsilon e)^2}$	$\frac{g_p^2}{(\varepsilon e)^2}$
$\frac{\sigma_{pZ\to pZX}}{\sigma_{pZ\to pZA'}}$	$\frac{g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{g_B^2}{(\varepsilon e)^2}$	0
$\frac{\sigma_{\{u\bar{u},c\bar{c}\}\to X}}{\sigma_{\{u\bar{u},c\bar{c}\}\to A'}}$	$\frac{g_{B-L}^2}{4(\varepsilon e)^2}$	$\frac{g_B^2}{4(\varepsilon e)^2}$	$\frac{g_p^2}{4(\varepsilon e)^2}$
$\frac{\sigma_{\{d\bar{d},s\bar{s},b\bar{b}\}\to X}}{\sigma_{\{d\bar{d},s\bar{s},b\bar{b}\}\to A'}}$	$\frac{g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{g_B^2}{(\varepsilon e)^2}$	$\frac{4g_p^2}{(\varepsilon e)^2}$
$\frac{\sigma_{p\to X}}{\sigma_{p\to A'}}$	0	0	$\frac{g_p^2}{(\varepsilon e)^2}$
$\frac{\sigma_{\omega\to X}}{\sigma_{\omega\to A'}}$	$\frac{4g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{4g_B^2}{(\varepsilon e)^2}$	$\frac{g_p^2}{(\varepsilon e)^2}$
$\frac{\sigma_{\phi\to X}}{\sigma_{\phi\to A'}}$	$\frac{g_{B-L}^2}{(\varepsilon e)^2}$	$\frac{g_B^2}{(\varepsilon e)^2}$	$\frac{4g_p^2}{(\varepsilon e)^2}$

Protophobic X Boson

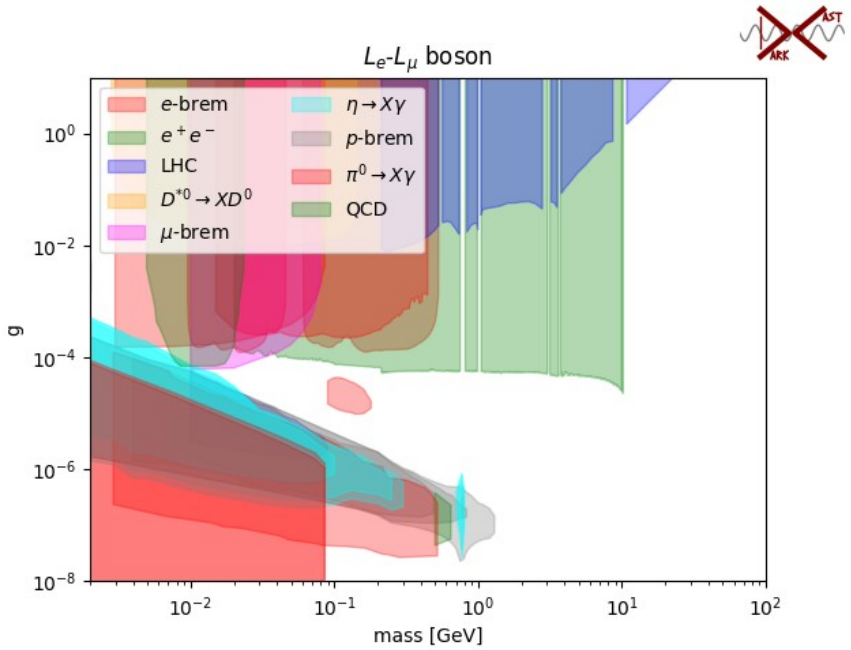
- Popular idea for explaining X17 while still satisfying constraints from NA48/2 on $\pi^0 \rightarrow e+e-\gamma$
- General model idea with “tunable” couplings to each fermion, including a constraint on the ratios of a handful of them
  - HPS has a competitive reach for this since we only care about leptons



More info on this model can be found at https://arxiv.org/abs/1604.07411

CLFV to e-mu

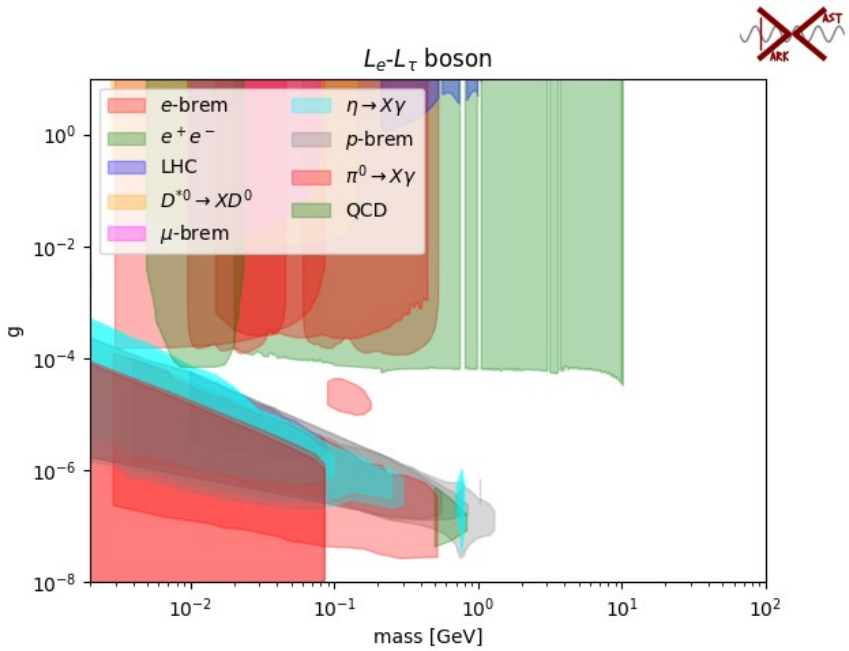
- Details on these models not discussed in darkcast paper
  - Reach estimates provided in code, maybe reach out to authors to learn more about details but no way this is done correctly for us
- Potential to improve our reach here by including muons in final state
- We quite possibly will always have some unique sensitivity to this



This is likely a good model to show at future PAC jeopardy talks

CLFV to e-tau

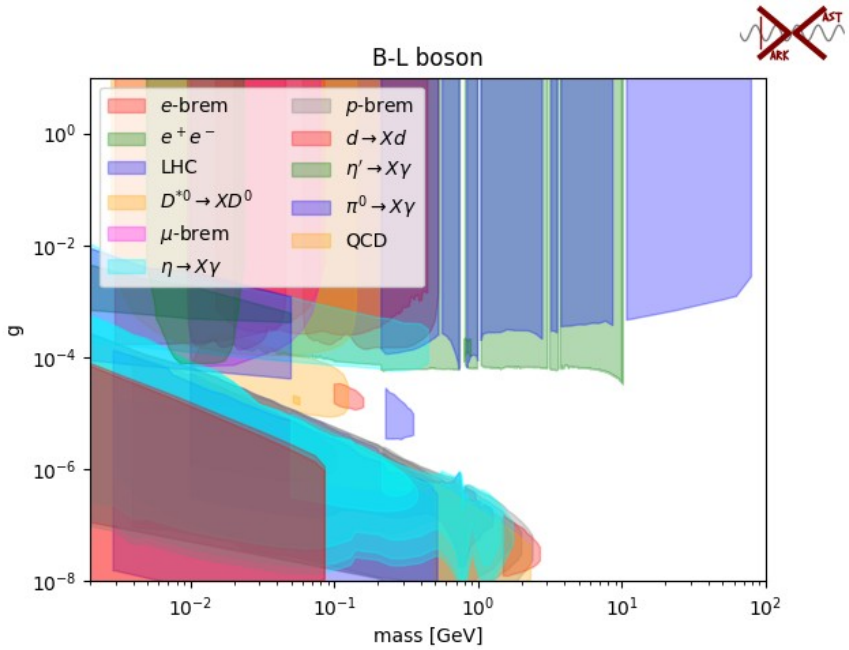
- Details on these models not discussed in darkcast paper
  - Pretty sure lifetime of these will be longer for our mass range
- Potential to improve our reach here by including muons in final state
- We quite possibly will always have some unique sensitivity to this



We will need to really master e-mu before we seriously tackle this one

B-L Currents

- This is one of my personal favorites (PhD thesis on a B-L symmetry in SM)
- This is probably the most complicated for us phenomenologically
  - There are a large number of fermion configurations that work, sometimes neutrinos
  - This is gonna make a bunch of hadrons, so tricky to figure out for HPS



DM and matter-antimatter asymmetry are convenient to couple together in a model

Discussion

- There are probably some new thesis topics in all this
- Presented in roughly the order I foresee HPS mastering them
  - We might be able to do mu-tau as well, but will need much more lumi
  - They also talk about leptophobic B decays (we ain't doing this)
- Darkcast is not treating displaced physics properly, so we will need to do some work beyond their code to get it right
- HPS has more exciting physics to look for beyond plain jane A'!
- Alic made SIMP reach estimate for APS based only on MC
- Tom has made progress towards validating hpstr momentum smearing written by PF
  - Mass resolution is worse than what Rafo had, need to meet with Rafo and Matt to discuss what could be going on

Big Version of Plain Jane A’