Dark Sectors at LHCb

Constantin Weisser, MIT
on behalf of the LHCb collaboration
DPF, July 29 2019
The Chasm

lightest DM particle could be stable because it is (dark) charged

What if there is no connection between the SM and Dark Sector up to the Planck scale?
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lightest DM particle could be stable because it is (dark) charged
The force carriers of the two sectors can couple if the sectors are somehow connected (even at a large mass scale).
Portals

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See: Natalia Toro, DPF Tue 8.50am
Models of Dark Matter & Dark Sectors
The dark photon mixes with the SM photon. The coupling to SM particles is proportional to electric charge.

$$\alpha' = \epsilon^2 \alpha_{EM}$$

1 or 2 loops: roughly $10^{-3} \lesssim \epsilon \lesssim 10^{-5}$
Visible $A'$ decays

DM–DM self interactions and 1 or 2 loop regime bound a naively interesting region.

Plot from Ilten, Soreq, Thaler, Williams, Xue [1801.04847]
Visible A’ decays

Pre LHCb

\[ \tau = \sigma^{\text{LHCb}}_{T} (cT = 14 \mu\text{m}) \]

\[ eT = 1 \text{ cm} \]

See: Anika Peter, DPF Tue 11.30am
Astrophysical Evidence on Heavy & Light Dark Species

Plot from Ilten, Soreq, Thaler, Williams, Xue [1801.04847]
- Single-arm forward spectrometer (2 < \eta < 5; 1 < \theta < 15^\circ)
- Excellent lifetime (\sigma_t = 45 fs) and mass (\sigma_m = 0.4\%) resolution
- Unique particle ID
Flexible triggering scheme needed to select even low energy candidates.
LHCb Inclusive $A' \rightarrow \mu^+ \mu^-$

Production: Pseudoscalar Meson Decay, Drell Yan, ...

1. Count $A'$ Candidates
2. Compare to prompt $\gamma^*$
3. Set Limits / Claim Discovery

$\Rightarrow$ Fully data-driven search
LHCb Limits: 2016 data

Run 2 sensitivity: prompt: 1.5 –2.5x gain; displ: much bigger region covered

Can recast as searches for other vector models (B, B–L, protophobic, …)
Run 2 Extensions

- No Iso
- B Tag
- Non-Standard Topology
- $A' \rightarrow e^+ e^-$
Scalar (Higgs) Portal

\[ \chi \]

e.g. \( \chi \) responsible for an inflationary period in the early universe

Bezrukov, Gorbunov, JHEP 05 (2010) 010 [0912.0390]
Penguin diagrams are sensitive to many BSM scenarios. Dark higgs will have sizable coupling to the top and a large decay rate to muons.
**Dark Higgs Limits**

LHCb sensitivity is limited by size of VELO

Bonus: Run 1+2 LHCb data has world leading sensitivity to ALPs with dominant gluon coupling
CODEX-b

A proposed COnpact Detector for EXotics at LHCb

Complimentary due to lifetime acceptance
Excellent sensitivity to most long-lived particle models
Including dark Higgs.

Gligorov, Knapen, Papucci, Robinson [1708.09395]
Dark Sectors are dark matter scenarios worth exploring.

LHCb has world leading sensitivity to different models.
Theories of Dark Matter

- MSSM
- NMSSM
- Supersymmetry
- Extra Dimensions
- Warped Extra Dimensions
- Light Force Carriers
- Sterile Neutrinos
- Dark Photon
- QCD Axions
- Axion-like Particles
- Axion DM
- Q-balls
- Solitonic DM
- UED DM
- T-odd DM
- RS DM
- Asymmetric DM
- Self-Interacting DM
- Hidden Sector DM
- WIMPless DM
- mSUGRA
- pMSSM
- Gravitino DM
- R-parity Conserving
- R-parity Violating
- Dirac DM
- Quark Nuggets
- Littlest Higgs
- Little Higgs
- T-theory
Invisible $A'$ decays
## Recasting A' as any Vector

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<tbody>
<tr>
<td>A'</td>
<td>-(g_e)</td>
<td>0</td>
<td>(\frac{2g_e}{3})</td>
<td>(-\frac{g_e}{3})</td>
</tr>
<tr>
<td>B</td>
<td>-(\left(\frac{g_e}{4\pi}\right)^2)</td>
<td>0</td>
<td>(\frac{1}{3})</td>
<td>(\frac{1}{3})</td>
</tr>
<tr>
<td>B-L</td>
<td>-1</td>
<td>-1</td>
<td>(\frac{1}{3})</td>
<td>(\frac{1}{3})</td>
</tr>
<tr>
<td>Proto phobic</td>
<td>-1</td>
<td>0</td>
<td>(-\frac{1}{3})</td>
<td>(\frac{2}{3})</td>
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Serendipity in A' Searches

Accounting for production, branching ratio and detection efficiency, existing and future searches can be recast to any vector model.

Recast your model with https://gitlab.com/philen/darkcast

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- 6 RPC layers at 4 cm intervals on each box face with 1 cm granularity
- 5 equally spaced triplets along the depth to minimize distance between reconstructed vertex and 1st measurement. $\epsilon_{\text{tracking}} \sim O(1)$.
- 50–100 ps timing from RPC’s foreseen for mass reconstruction
Can the portals help us discover dark matter?