Coannihilating Dark Matter and the B-Physics Anomalies

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[M. Baker, D. Faroughy, ST] soon to appear!
B-Physics Anomalies

- $b \to s \ell \ell$: Deficit of the neutral-current transition in $\mu$ vs. $e$

\[
R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)} \mu \bar{\mu})}{\mathcal{B}(B \to K^{(*)} e \bar{e})}
\]

- $R_K$ survived the latest update by the LHCb even after employing the full dataset of Run I and II independently at 3.1$\sigma$!

- Fits obtained by including also other anomalous observables in this channel and varying relevant NP WCs yield pulls at a staggering 5$\sigma$ level!

- $b \to c \tau \nu$: Enhancement of the charged-current transition in $\tau$ vs. $\ell$

\[
R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)} \tau \bar{\nu})}{\mathcal{B}(B \to D^{(*)} \ell \bar{\nu})} \approx 3\sigma
\]
Vector Leptoquark and 4321!

- **Leptoquarks** (LQs), i.e. particles that couple to quark-lepton currents, are the only viable candidates to a combined solution to the $B$-physics anomalies.

- In particular, the vector LQ $U_1 \sim (3,1)_{2/3}$ provides the most compelling explanation, since it can simultaneously accommodate both anomalies!

- It is realized as a gauge boson of spontaneously broken gauge symmetries: the so-called ‘4321’ models based on the $SU(4) \times SU(3)' \times SU(2)_L \times U(1)_X$ group (originating from the Pati-Salam model).
DM and coannihilation effects

- There are 4321 multiplets that can host a DM candidate!
  \[ \Psi = \begin{pmatrix} \psi^1 & \psi^2 & \psi^3 & \chi \end{pmatrix}^T \] is singlet, two Majorana fermions mass eigenstates \( \chi_1, \chi_2 \)
  
  - top-like partner \( \psi \sim (3,1)_{2/3} \)

- \( \chi \) receives a naturally small Majorana mass \( \Delta_\psi \equiv \frac{m_\psi - m_{\chi_1}}{m_{\chi_1}} \lesssim 0.3 \)

- Coannihilating effects regulate the relic abundance for varying \( \Delta_\psi \).

- The dominant process that sets the primordial relic abundance for \( m_\chi \sim m_\psi < m_U \) is \( \overline{\chi}_1 \psi \rightarrow \text{SM} \) mediated via \( U \) (LQ portal to DM).
Relic surface

set by the $B$-physics anomalies

$$\Omega h^2 = 0.120, \quad g_U = \frac{m_U}{1.8 \text{ TeV}}$$
Collider constraints (\(\psi\) pair-production)

- Direct and indirect DM detection constraints are not relevant. Collider searches for the \(\psi\) are the only viable option.

- We study \(\psi\) pair-production and find that due to the compression of the mass spectrum, the decay products of the \(\psi\) carry low momenta and fail to pass the experimental selection criteria of existing searches.
Collider constraints ($\psi$ pair-production)

- We propose a new search based on a MET-sensitive novel search.

- We estimate that the search will set a lower bound of 500 GeV for $m_{\chi'}$. 

![Graphs showing distributions of $S_T$ and $R_T$ for different processes with MET sensitive signals.](image-url)
Collider constraints ($\psi$-onium)

- Another important consequence of the compressed spectrum is the tiny decay rate of $\psi$. These particles are enough long-lived in order to hadronize after their production.

- Bound QCD states ($\bar{\psi}\psi$) (analogous to quarkonia) may lead to distinguishing signatures via EW decay to dileptons.