A Dark Force for Baryons

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Motivations

Facts:

- Baryonic and dark matter are stable
- They have comparable abundances ($\rho_{\rm DM} \approx 5\,\rho_{\rm B}$)

Is there a fundamental, dynamical relation between baryonic and dark matter?

Outline

1. **Why is the proton stable?**
   - Proton stability requires weak-scale DM
   - A common origin for visible and dark matter

2. **Constraining the baryonic dark force**
   - Collider bounds
   - Direct detection bounds

3. **Conclusions**

Why is the proton stable?

- Within the SM the proton is stable because of an **accidental**, anomalous symmetry $U(1)_B$ of the renormalizable formulation. Generic BSM physics triggers proton decay (SUSY)

Dynamical explanation:

- **Proton decay can be avoided (at any order in perturbation theory and beyond the ren. level) in theories in which $U(1)_B$ is embedded into a local symmetry, e.g. $U(1)_{B_{gauge}}$** [1] [Dynamical condition]

Indeed, $\mathcal{L}_{p-decay} = \Psi_p \mathcal{O}$, with Ψ_p the proton interpolating field, can be avoided provided $1 + B_{gauge}(\mathcal{O}) \neq 0$

[Example: SUSY without R-parity]

[1] Murayama and Carone '95

Proton stability $\Leftrightarrow$ DM

- **New chiral fermions are required to cancel the anomalies** [analogy: the leptons in the SM allow you to define $B - L$. However, $B - L$ does not forbid $\mathcal{L}_{p-decay} = \Psi_p L$, with $\Psi_p = QQQ$: a new symmetry, and new chiral fields, are required!]
- Technically, **this implies the existence of stable BSM chiral particles** with their own anomalous symmetry $U(1)_{B_{dark}}$:

$$B_{gauge} = B - B_{dark} + \dots \tag{1}$$

  [... here stands for additional, vectorlike (nonchiral) terms]
- **The lightest SM singlet field(s) carrying B_{dark} will be the dark matter**

Consequences:

i) **The DM arises as a consequence of proton stability**

ii) **The DM is at/below the weak scale**
[it is the lightest particle of an EW chiral sector]

iii) **Both baryons and DM will feel a new "baryonic/dark" force, e.g.** $U(1)_{B_{gauge}}$
$[B, \, B_{dark} \subset B_{gauge}]$

...

...

iv) $B - B_{dark}$ appears as an accidental, exact **global** symmetry [after all, B and B_{dark} must be there to stabilize p and X...]

Baryogenesis ($\eta_B \neq 0$) requires $\eta_{B_{dark}} \neq 0$: baryons and DM are asymmetric, with comparable primordial asymmetries and weak scale masses: [2]
DM and baryons have comparable abundances $\rho \sim m\eta$ [$\rho_{DM} \sim 5\rho_B$ if $m_X <$ few$\times$10 GeV]

[2] D. B. Kaplan '92

Phenomenology

At low energies these models are described by:

- the SM Lagrangian with gauged baryon number [universal charges: no FCNC]
- the dark/baryonic gauge boson Z_B [with, say, $O(1)$ GeV $\lesssim m_B \lesssim O(100)$ GeV !!!]
- a weak-scale DM field X (here a Dirac fermion) with generic coupling to Z_B:

$$D^\mu X = [\partial^\mu + i g_B (q_V + q_A \gamma^5) Z_B^\mu] X \tag{2}$$

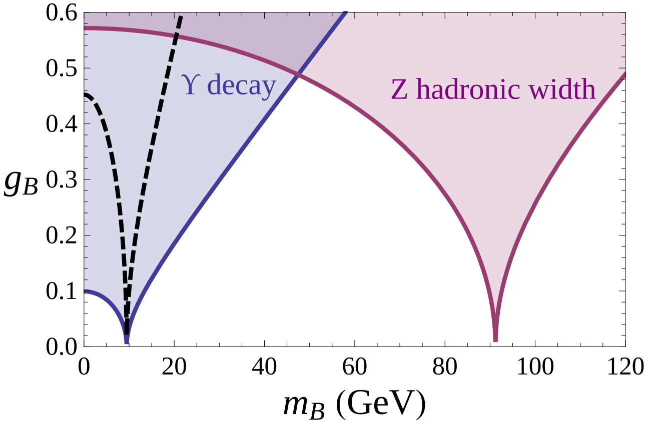
- kinetic mixing [we assumed $\mathrm{Tr}(B_{gauge} Y) = 0$ so $c_Z \sim 10^{-2}$]

$$\frac{c_Z}{2} g_B \, Z_{\mu\nu} Z_B^{\mu\nu} \tag{3}$$

Signatures

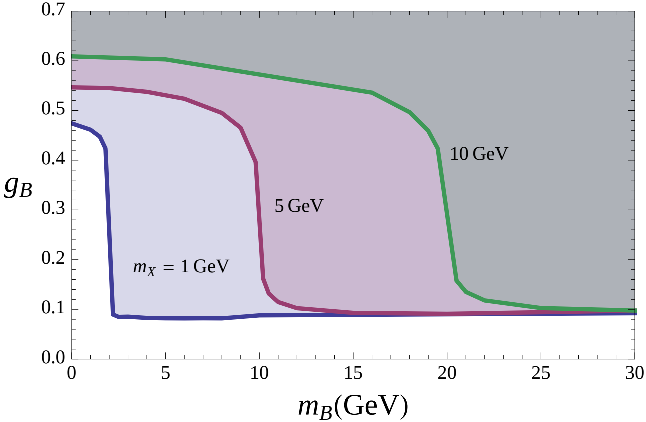
1. corrections to hadronic processes
   [Z_B much less constrained than a Z' coupled to leptons]
2. missing energy
   [leads to the strongest bounds (Υ, monojet+MET, direct det. exp.)]

B-factories+LEP



$\Upsilon \to$ nothing (or $\Upsilon \to$ hadrons) and $Z \to$ hadrons

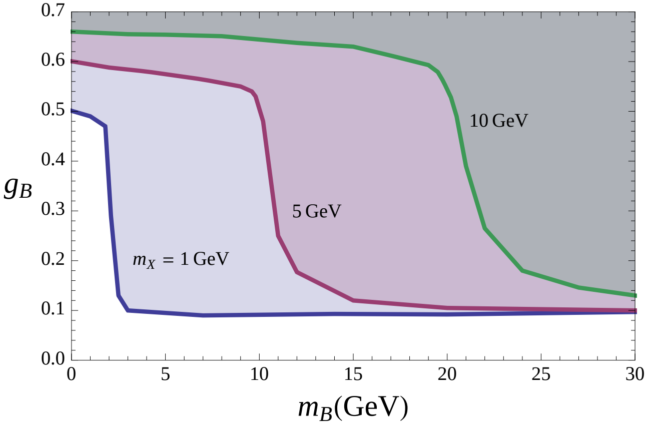
Monojet+MET (Tevatron) for $q_V = 1$



$p\overline{p} \to j + X\overline{X}$

(ATLAS improves the bounds by a factor $\sim 1.5 - 2$!!!)

Monojet+MET (Tevatron) for $q_A = 1$



Direct detection

If $X\overline{X} \to Z_B^* \to q\overline{q}$ is the dominant annihilation mode:

- $\underline{q_V \neq 0}$

$$\sigma_{SI} \sim \frac{\mu^2}{\pi}\left(q_V \frac{g_B^2}{m_B^2}\right)^2 \quad (4)$$

  the allowed parameter space lies below the current threshold ($m_X \lesssim 1-2$ GeV)

- $\underline{q_V = 0}$

$$\frac{d\sigma_{SI}}{dE_R} \propto \left(q_A \frac{g_B^2}{m_B^2}\right)^2 \left[O(v^2) + O(q^2/\mu_N^2)\right] \quad (5)$$

  the signal is below the current bounds for any m_X

Conclusions

- I proposed a *dynamical framework* to protect proton stability. It applies to generic extensions of the SM (SUSY)
- A connection between proton stability and DM naturally arises (the DM has weak scale mass and is asymmetric)
- The signatures are not "clean" (hadronic processes and ME), such that masses down to the GeV scale and coupling of weak magnitude are not excluded!
- (Assuming that Z_B exchange saturates $DM - \overline{DM}$ annihilat.) the allowed parameter space
  — for $q_V \neq 0$ is confined to $m_X \lesssim 1 - 2$ GeV (direct det.)
  — for $q_V = 0$ is still remarkably large

Thank You

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