Section 8 of Dark matter via t-channel production

REPORT OF THE LHC DARK MATTER WORKING GROUP

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Subsection 8.1

Top-philic composite dark matter

- Top-philic scalar DM models represent very simple, testable and viable models of WIMP DM:
  [S.W. Baek, P. Ko, P. Wu (2016)],[Colucci, Fuks, Giacchino etal. (2018)]
  - very few new particles and parameters
    (one DM scalar *S* and a vector-like fermion mediator *T*),
  - renormalizable,
  - simple cosmology (thermal relic, standard evolution),
  - testable in DM direct detection, indirect detection (photons), and at colliders.

- VLQs which primarily couple to the SM top quark are common in many SM extensions (extra dimensions, little Higgs, twin Higgs, VLQ extensions of SUSY, Composite Higgs Models ….)

- If *S* and *T* are part of a UV completion with additional states/dynamics at typical scale Λ (of a few TeV), integrating out the additional states induces higher-dimensional operators in the top-philic scalar DM Lagrangian.

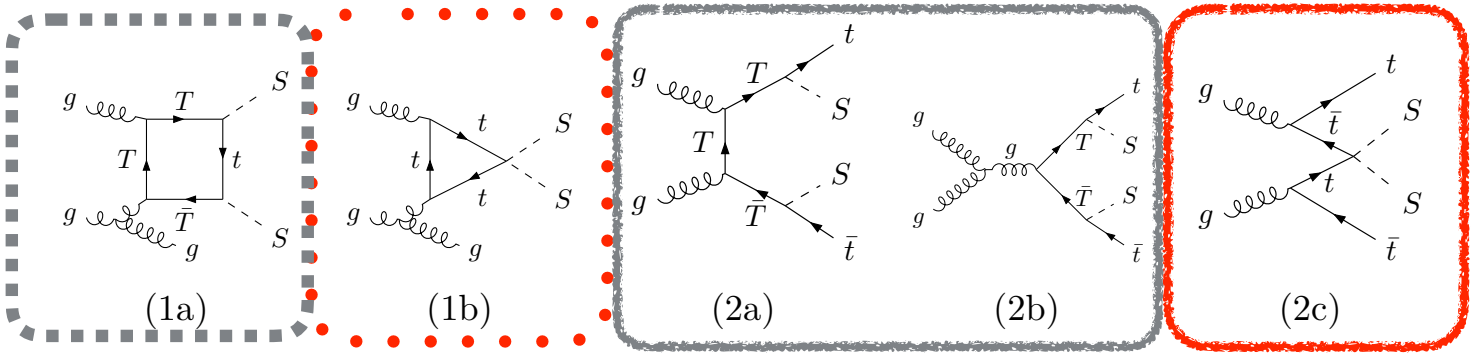
$$\mathcal{L} = i\bar{T}\not{D}T - m_T\bar{T}T + \frac{1}{2}\partial_\mu S\partial^\mu S - \frac{1}{2}m_S^2 S^2 + \left[\tilde{y}_t S\bar{T}P_R t + h.c.\right] + \frac{1}{2}\lambda S^2\phi^\dagger\phi + \frac{C}{\Lambda}SS t\bar{t}.$$

3 (+1) +1 parameters

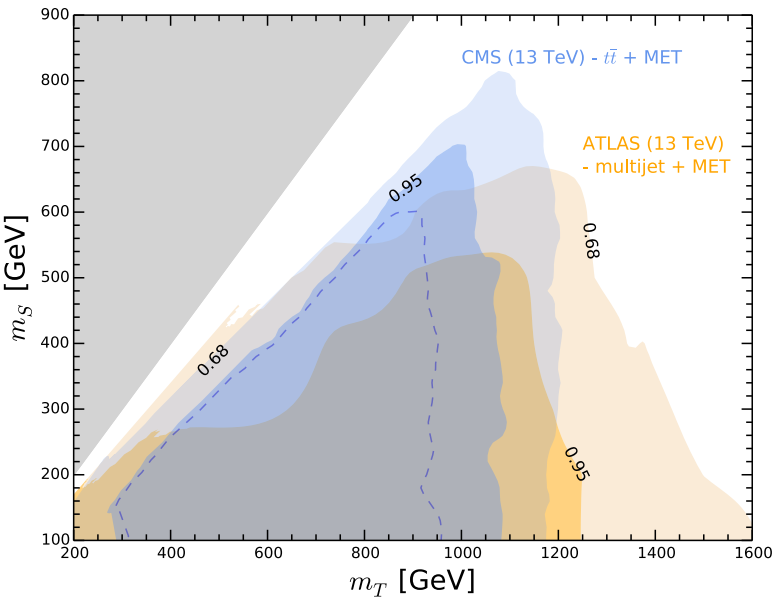
top-philic DM

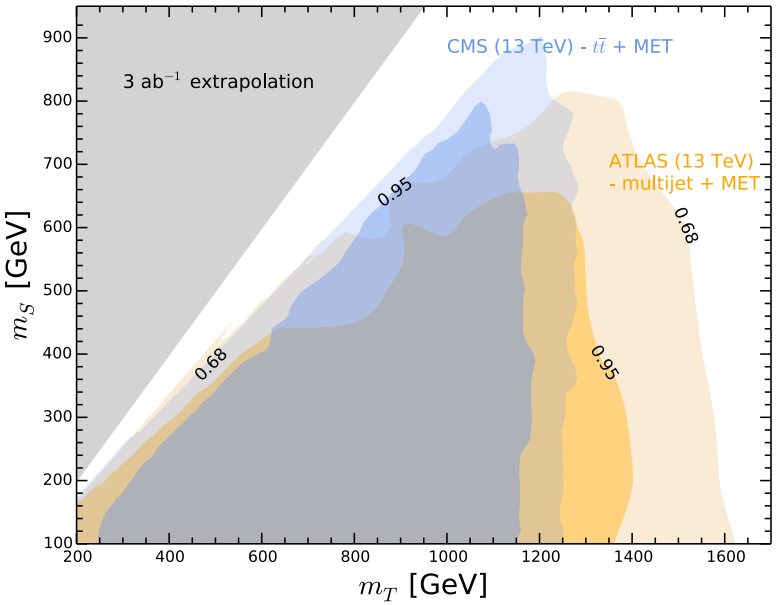
new !

small cross *dominant* *subdominant*



... but since [Colucci, Fuks, Giacchino et al. (2018)], new searches are available so we at least update collider





Sub-section 8.2

Frustrated dark matter models

- All mediator fields couple both to χ and to SM fields

  carry SM gauge charges that preclude renormalizable gauge-invariant interactions between the DM and any SM fermion.

- Interactions of the DM are ***frustrated*** in the sense that the specific mediator assignments preclude its tree level interaction with the SM

$$\mathrm{SM} \longleftrightarrow \text{mediators} \begin{cases} \varphi \text{ (scalar)} \\ \psi \text{ (Dirac)} \end{cases} \longleftrightarrow \mathrm{DM}\ \chi$$

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{med}} + \mathcal{L}_{\chi},$$

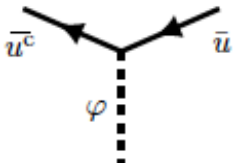
$$\mathcal{L}_{\mathrm{med}} = (D_\mu \varphi)^{\dagger s}(D^\mu \varphi)_s - m_\varphi^2 \varphi^{\dagger s}\varphi_s + \bar{\psi}^s(\mathrm{i}\not{D} - m_\psi)\psi_s + \mathcal{L}_{\mathrm{decay}}$$

$$\mathcal{L}_\chi = \bar{\chi}(\mathrm{i}\not{\partial} - m_\chi)\chi + y_\chi(\varphi^{\dagger s}\bar{\chi}\psi_s + \mathrm{H.c.})$$

Sextet Mediators

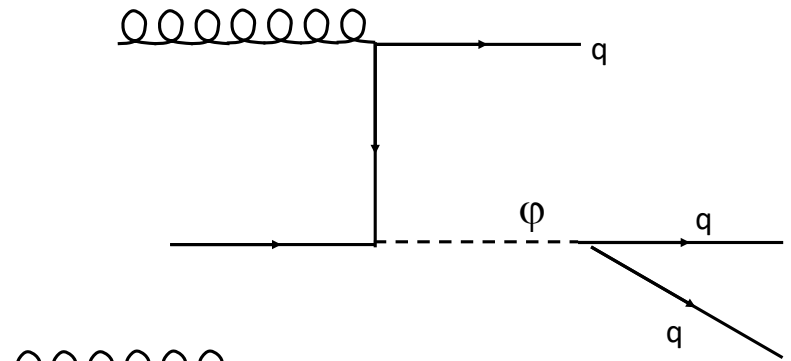
Field	Description	$SU(3)_c \times SU(2)_L \times U(1)_Y$ representation	Couples to SM?
χ	Dark matter	$(\mathbf{1},\mathbf{1},0)$	
φ	Scalar mediator	$(\mathbf{6},\mathbf{1},\frac{4}{3})$	✓
ψ	Dirac mediator		

$$\mathcal{L}_{\text{decay}} = \lambda_{IJ} K_s{}^{ij}\, \varphi^{\dagger s} \overline{q^c_{\mathrm{R}Ii}} q_{\mathrm{R}Jj} + \text{H.c.} \quad \text{with} \quad q \in \{u, d\},$$

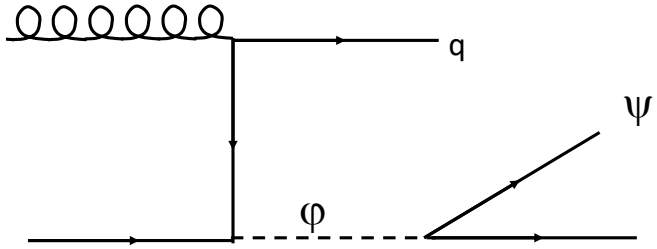


$Y = 4/3$

T channel Single Mediator Production

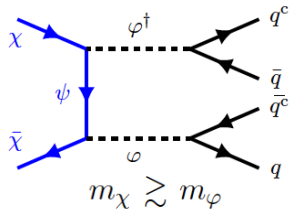


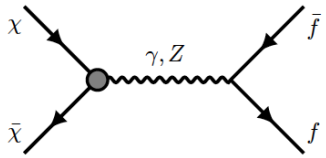
Quark pair

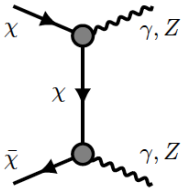


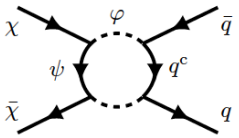
Cascade decay

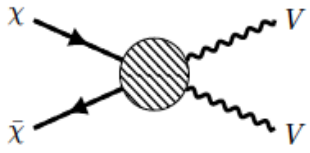
DM annihilation channels











Sub-section 8.3

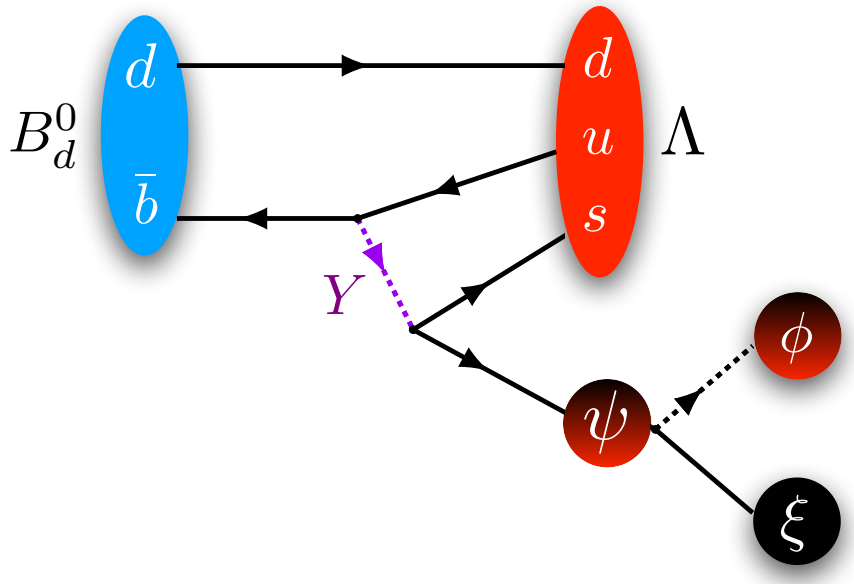
B-mesogenesis models

- Baryogenesis and DM are linked with baryon asymmetry directly related to B-meson observables
- This relates the CP violation in the B^0 system to Baryogenesis
- DM is then an anti-Baryon and generates an asymmetry between the two sectors thanks to the CP violating oscillations and subsequents decays of B-mesons.
- This requires a new decay mode of the B-meson into DM and a visible baryon!
- A t-channel model without a Z_2 symmetry which yields a diquark coupling in the Lagrangian

Minimal Particle Content

Field	Spin	Q_{EM}	Baryon no.	$\mathbb{Z}_2$	Mass
Φ	0	0	0	+1	$11 - 100\,\mathrm{GeV}$
Y	0	$-1/3$	$-2/3$	+1	$\mathcal{O}(\mathrm{TeV})$
ψ	1/2	0	-1	+1	$\mathcal{O}(\mathrm{GeV})$
ξ	1/2	0	0	-1	$\mathcal{O}(\mathrm{GeV})$
ϕ	0	0	-1	-1	$\mathcal{O}(\mathrm{GeV})$

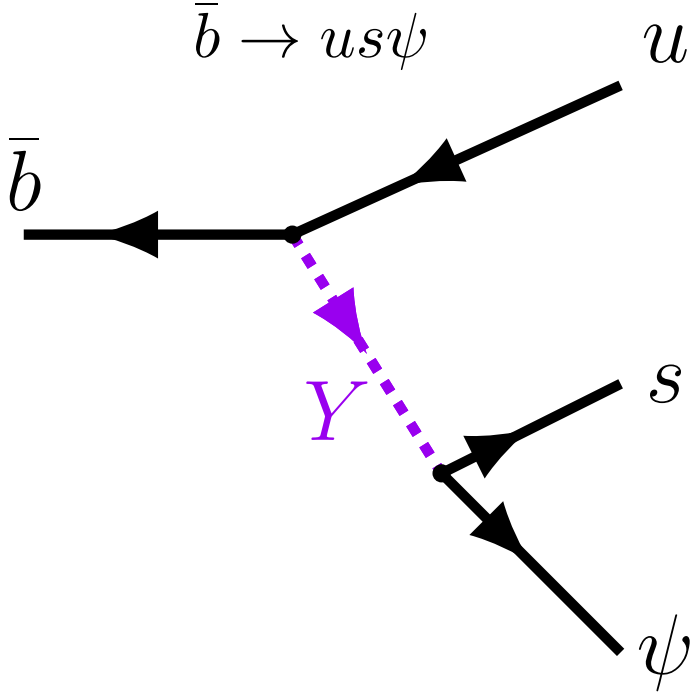
B-mesons decay into DM (missing energy) and a Baryon



The Dark Sector:

ϕ : **Charged *Stable* Scalar anti-Baryon** ξ : **Dark *Stable* Majorana Fermion**

- **Minimal Dark sector interaction** $\mathcal{L} \supset -y_d\,\bar{\psi}\,\phi\,\xi$ **with Z_2 symmetry**
- **Constraints:**
  - ***$\psi \to \phi\xi$* Decay:** $m_\phi + m_\xi < m_\psi < 4.3\,\mathrm{GeV}$
  - **DM Stability:** $|m_\xi - m_\phi| < m_p + m_e$
  - **Proton Stability:** $m_\psi > m_\phi > m_p - m_e \simeq 0.94\,\mathrm{GeV}$



Y: Colored Triplet Scalar

$$Y \sim (3, 1, -1/3)$$

$$Y \sim (3, 1, 2/3)$$

Same Quantum Numbers as a SUSY squark!

$$\mathrm{Br}\,(B \to \psi + \mathrm{Baryon} + \mathcal{M}) \simeq 10^{-3} \left(\frac{m_B - m_\psi}{2\,\mathrm{GeV}}\right)^4 \left(\frac{1.6\,\mathrm{TeV}}{M_Y} \frac{\sqrt{y_{ub} y_{\psi s}}}{0.6}\right)^4$$

Perturbativity requires: $M_Y < 10\,\mathrm{TeV}$