Section 8 of Dark matter via t-channel production

REPORT OF THE LHC DARK MATTER WORKING GROUP

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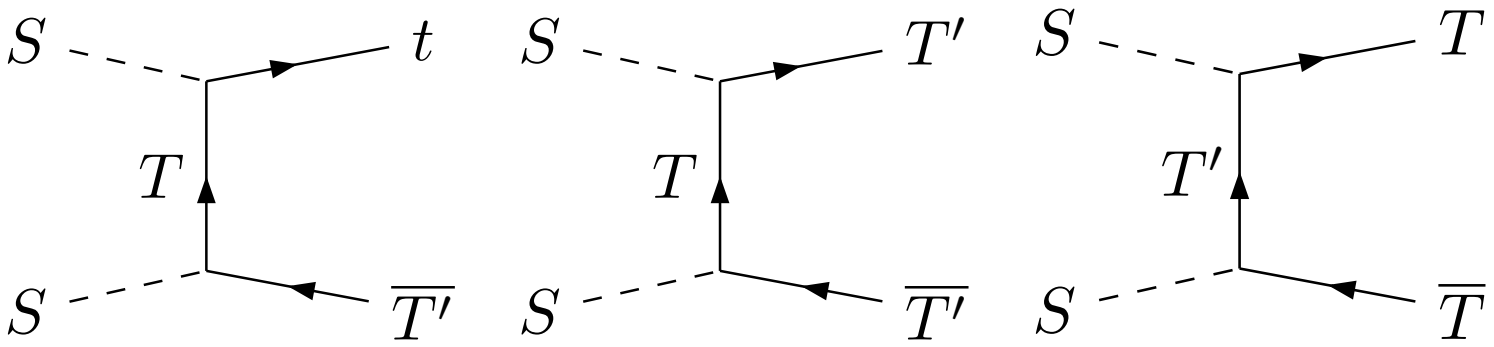
Subsection 8.1

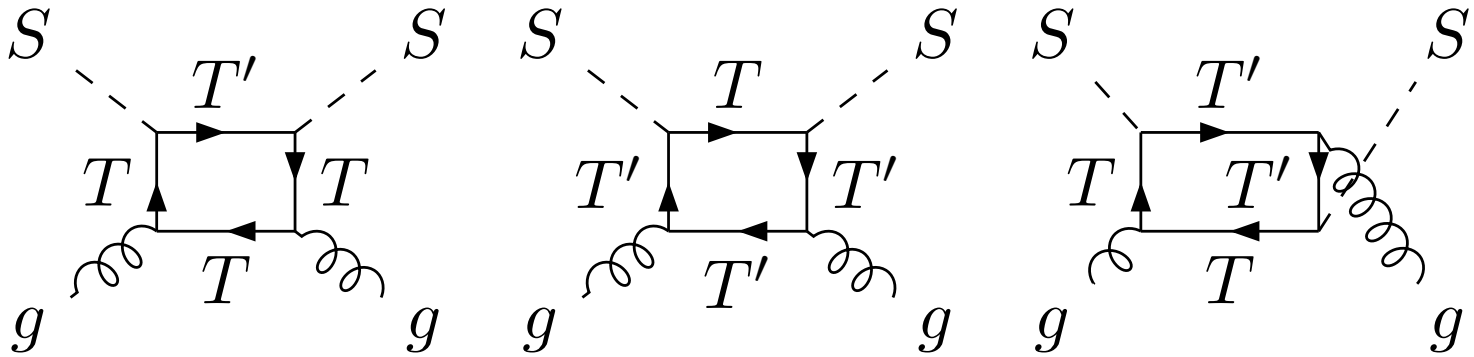
Top-philic composite dark matter

- Some composite models have VLQs which mediate the interactions b/n DM and SM. DM and top quark interactions can be mediated by several vector-like top partners.
- The minimal composite model predicts the existence of a composite scalar heavy DM candidate S that couples to the SM top quark via a Yukawa-type interaction involving a heavy vector-like fermionic mediator T.
- Composite UV completions usually include both new states of even and odd Z_2 parity and when the phenomenology of simplified models with a fermionic mediator is studied, a new fermionic T' parity-even top partner is ignored. This Z_2-even T' partner is usually present in composite models.

Representative Feynman diagrams of contributions to DM annihilation that involve a top partner T'. Such diagrams either lead to the production of a T' partner in the final state (first and second diagrams), or proceed via virtual t-channel T' exchanges (third diagram)



Representative one-loop Feynman diagrams of contributions to DM-nucleon scattering that involve a top partner T', i.e. with at least one T' state in the loop.



For the non-minimal scenario already studied:

The T′ partner must have a mass $m_{T'} \geq 1.3$ TeV to avoid conflict with the ATLAS and CMS searches for T′ → TS.

The presence of T′ state could alter DM production in association with a jet via additional box diagrams involving T and T′ partners.
For the parameter space region favoured by cosmology these additional diagrams do not increase the cross section.

Regardless, mono-jet contributions to the DM signal at the LHC, arising from the pp → SSj process, remain negligible relative to those originating from the pp → $T\bar{T}$ process.

In the case of $t\bar{t}$ production in association with missing transverse energy:

When $m_S < m_{T'} < m_T$ or $m_{T'} < m_S < m_T$ standard vector-like searches are not affected.

T' is not allowed to decay into TS ($m_{T'} \geq 1.3$ TeV still valid).

If $m_{T'} > m_T + m_S$ then $T' \rightarrow TS$ opens up and we have contributions to the $t\bar{t}ET$ signal from

$pp \rightarrow T'\bar{T'} \rightarrow TS\bar{T} \rightarrow tS\bar{S}\bar{t}SS$. This channel affects the bounds on T and T':

For light DM, T must be of at least 1.25 TeV so there is no way to relax T'.

For heavy DM, there is no $m_T + m_S < 1.3$ TeV (the m_T mass). There is no way to relax collider bounds in the non-minimal model.

Sub-section 8.2

Frustrated dark matter models

- Typical simplified dark matter model paradigm:
  DM χ interacts with SM field + some mediator
- More recent work studies colour-charged mediators (in particular, sextets) that couple to SM quarks with non-SM colour structures
- These models are examples of **frustrated dark matter** (fDM) with *no* tree-level DM DM → SM SM interactions
- fDM is a new subclass of next-generation DM models, previously explored by LHCDMWG
- For t-channel white paper, mediator production in association with $W^{\pm}$, which produces jets (possibly leptons) with sizeable E^{miss}

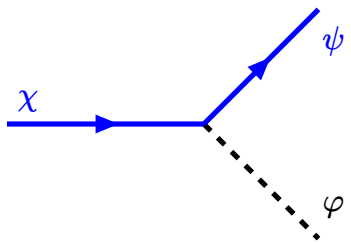
A frustrated DM model

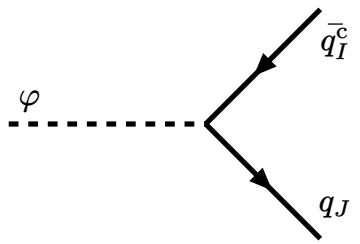
- Suppose χ is Dirac and couples to color sextets

  ψ (Dirac), φ (scalar) with quantum numbers $(\mathbf{6}, \mathbf{1}, Y)$

- Most general renormalizable model and building blocks:

$$\mathcal{L} \supset y_\chi \, \varphi^{\dagger s} \bar{\chi} \psi_s + \lambda_{IJ} K_s{}^{ij} \, \varphi^{\dagger s} \overline{q^{\rm c}}_{{\rm R}Ii} q_{{\rm R}Jj} + \text{H.c.}$$

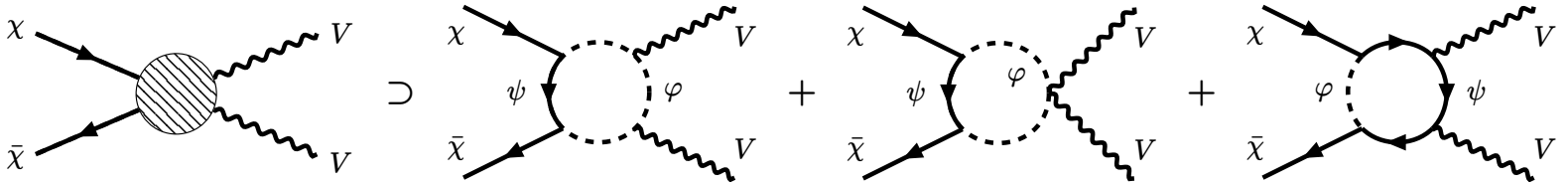




- For DM stability, impose $\mathbb{Z}_2$ symmetry and require $m_\psi > m_\chi$
- We choose $Y = 4/3$ so that φ couples to up-type quarks

Signatures; parameter space

- Tree-level couplings to SM particles are phase-space suppressed but loop couplings abound —



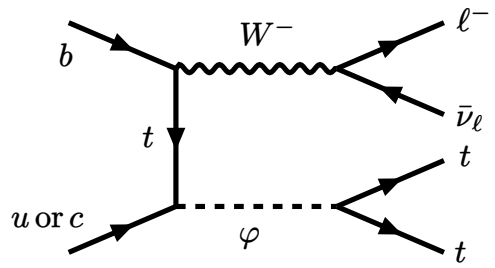
- φ-qq couplings λ_{IJ} constrained by FCNC searches: impose MFV or some flavor texture forbidding *e.g.* $\varphi^\dagger$-cc

- Direct searches (dijet, multijet, jets + $E_{\mathrm{T}}^{\mathrm{miss}}$...) require color-sextet mediators m_φ, $m_\psi \sim 1\,\mathrm{TeV}$ and $\lambda_{IJ} \sim \mathcal{O}(0.1)$

- t-channel $\varphi + W^-$ production (+ H.c.) has not been explored but has $\mathcal{O}(1)\,\mathrm{fb}$ cross sections for $m_\varphi \sim 1\,\mathrm{TeV}$ (at $\sqrt{s} = 13\,\mathrm{TeV}$ LHC)

Preliminary work (1)

- Representative diagram for this t-channel process:

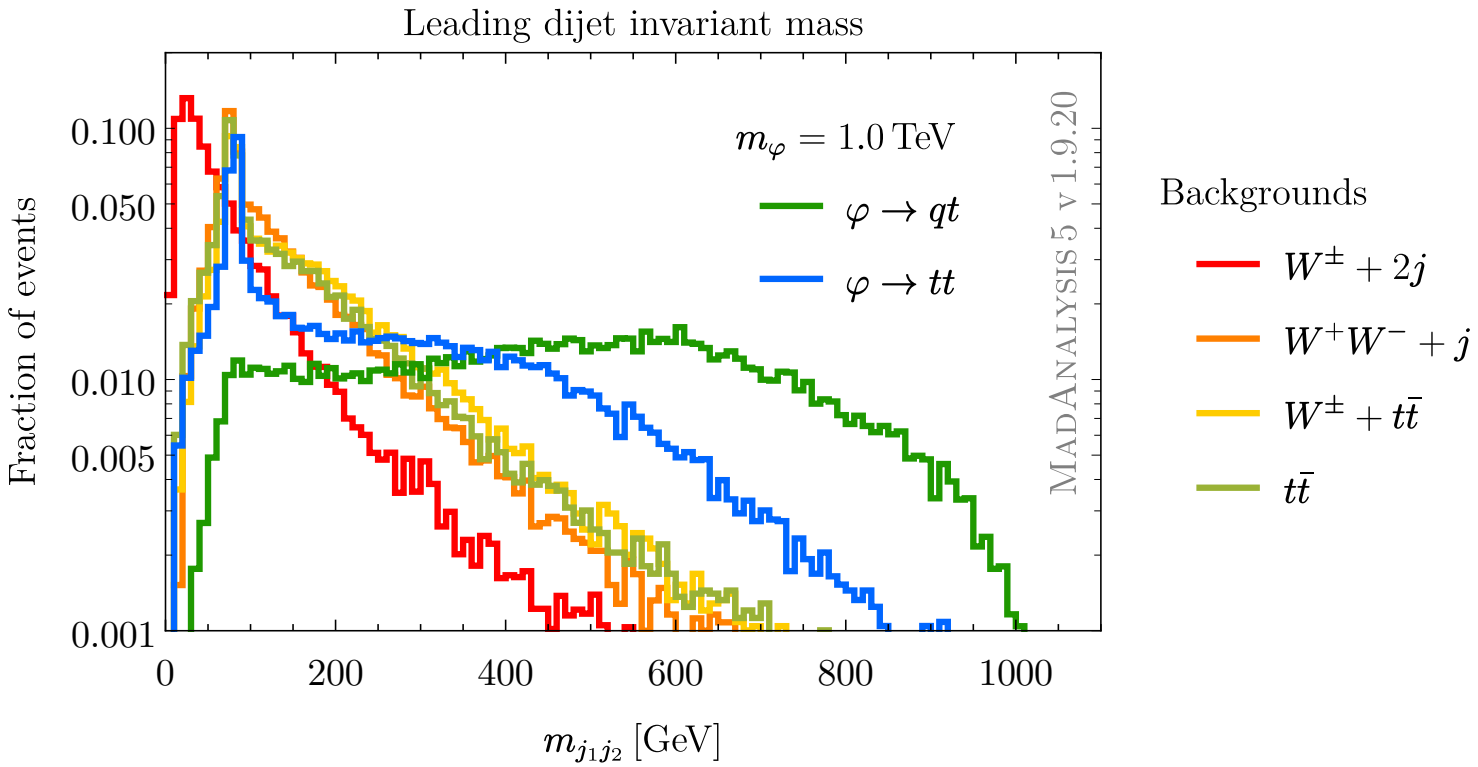


- Note $\varphi \to \psi\bar{\chi}$ is possible/interesting
- φ couples only to right-handed quarks $\Longrightarrow$ chirality flip $\propto y_q$ for exchanged quark
- Optimal cross sections achieved for top-quark exchange + non-diagonal φ-$q_I q_J$ $(I \neq J)$ couplings:

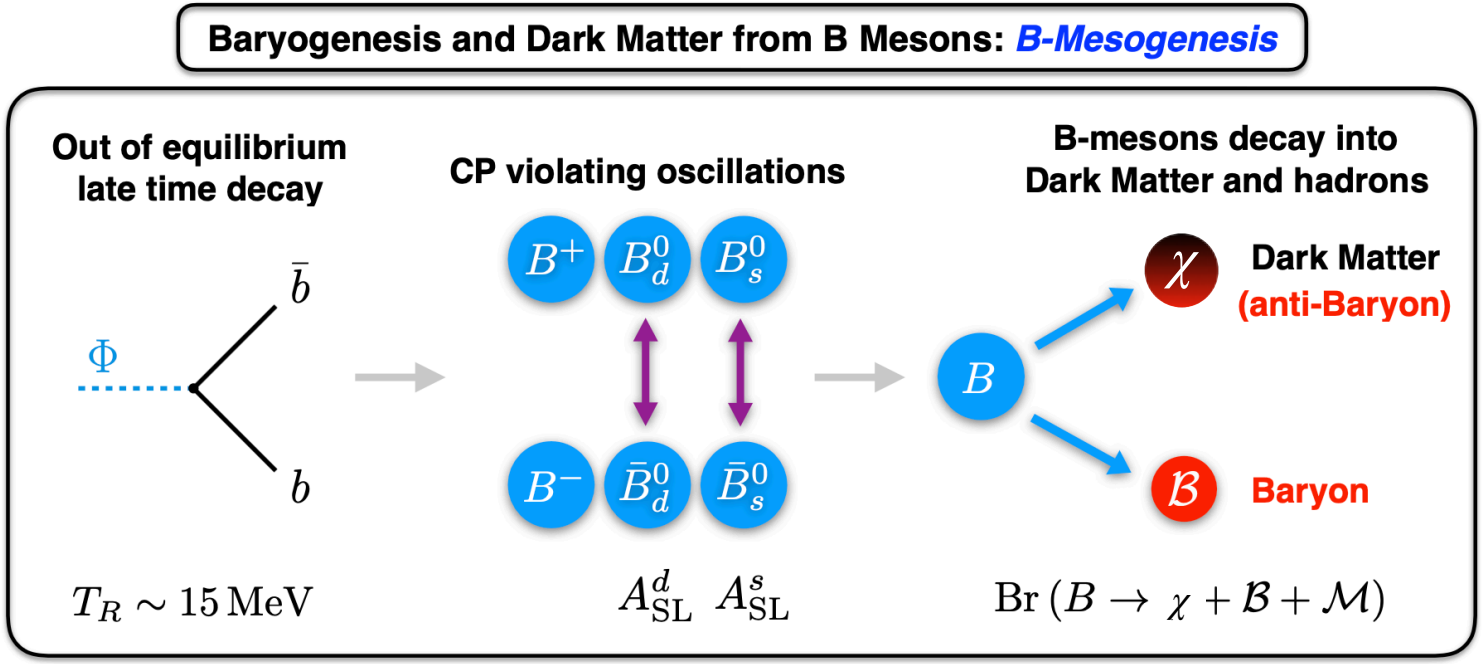
$$\lambda_{IJ} = \begin{pmatrix} 0.1 & 0 & 0.25 \\ 0 & 0 & 0.25 \\ 0.25 & 0.25 & 0.75 \end{pmatrix} \quad \text{in basis } (u, c, t)$$

Preliminary work (2)

- We are looking at signals with leptonically decaying $W^{\pm}$ and $\varphi \to$ quarks including at least one top quark
- Dijet invariant mass distributions for signals and leading backgrounds:



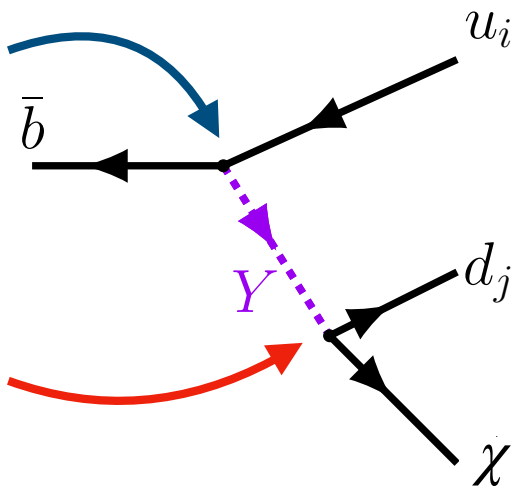
Sub-section 8.3



B meson decay mediated by coloured scalar

diquark

quark-DM t-channel

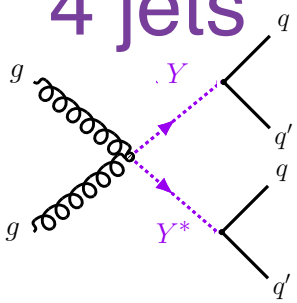
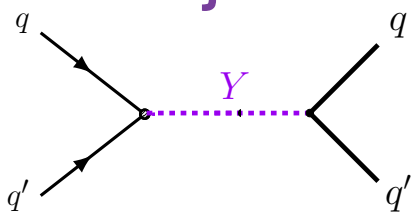
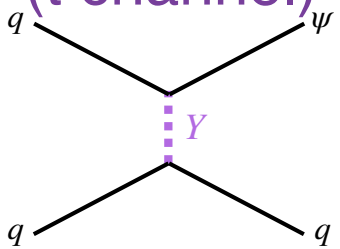
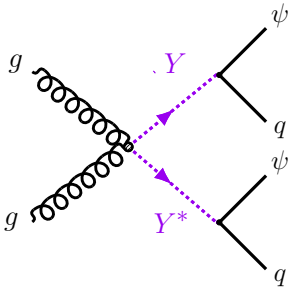
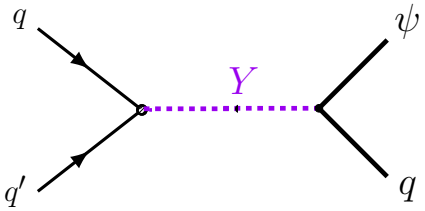


$Y \sim (3, 1, -1/3)$

or

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

LHC signals

Decay \ Production	Pair (QCD)	Single ($Y^\star \bar{q} q^c$)	Associated ($Y \bar{\chi} q^c$)
Visible ($Y^\star \bar{q} q^c$)	4 jets  $M_Y > 0.77$ TeV ATLAS 2206.09997	dijet  $y_{qq} > 0.01 - 1$ CMS 1910.08447 CMS 1806.00843	jet + MET (t channel)  $y_{qq} y_{q\chi} > 0.01 - 1$ ATLAS 2102.10874
Missing E ($Y \bar{\chi} q^c$)	2 jets + MET  $M_Y > 1.2$ TeV CMS 1908.04722 ATLAS 2010.14293	jet + MET (s channel)  $y_{qq} y_{q\chi} > 0.01 - 1$ ATLAS 2102.10874	various (t channel) $y_{q\chi} > ???$ THIS PAPER

STATUS:

✓ Introduction and model description written

✓ Non t-channel constraints being updated

✶ Need input for t-channel limits

- Not previously studied for this model
- Avoid duplicating other sections' work

➡ Full implications for baryogenesis

Questions? Ask Gonzalo Alonso Álvarez, Xabier Cid Vidal, Gilly Elor, Miguel Escudero, Carlos Vazquez Sierra