Fermionic dark matter in leptoquark portal

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Outline

- Introduction
- Model
  - Relic density
  - Direct detection
  - Collider bounds
- Results
- Summary
One of the main reasons for the need of BSM physics is indirect evidence of Dark Matter consisting 26% of our Universe.

Popular scenario: `WIMP’

- Mass range GeV — TeV
- Weak interaction

Portal: WIMP can interact directly to SM &/or via BSM particle

Higgs portal, Z portal...

anything e.g., Z’ portal
Ways to probe WIMP models

Indirect detection

Annihilation

Direct detection

Scattering

Production

Colliers

DM

SM

DM

SM
**Leptoquark portal DM**

Diagram showing leptoquark interactions with quarks and leptons:

- **Scalar (S, R)**
- **Vector (V, U)**

**R-parity violating SUSY**

**GUT like SU(5), SU(4) etc**

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**Can accommodate a SM singlet fermion, would be DM candidate**

| Interaction | \((SU(3)_C, SU(2)_L, U(1)_Y)\) | Spin |
|-------------|----------------------------------|------|
| \(\bar{d}^C_R X \psi\) | \(S_1 (\bar{3}, 1, 1/3)\) | 0 |
| \(\bar{u}^C_R X \psi\) | \(\bar{S}_1 (\bar{3}, 1, -2/3)\) | 0 |
| \(\bar{Q}_L X \psi\) | \(\bar{R}_2 (3, 2, 1/6)\) | 0 |
| \(\bar{Q}^C_L \gamma^\mu X_\mu \psi\) | \(\bar{V}_2 (\bar{3}, 2, -1/6)\) | 1 |
| \(\bar{u}_R \gamma^\mu X_\mu \psi\) | \(U_1 (3, 1, 2/3)\) | 1 |
| \(\bar{d}_R \gamma^\mu X_\mu \psi\) | \(\bar{U}_1 (3, 1, -1/3)\) | 1 |

**Tree level proton decay**

**Only viable case with Majorana DM**

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**Dirac DM scenario compatible with relic density is excluded by XENON 2018 data**

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**DAE-BRNS HEP 2018, Chennai**
Model

Model

Lagrangian with new interaction terms

\[ \mathcal{L} \subset - \frac{1}{2} (D_\nu U_\mu - D_\mu U_\nu)^\dagger (D^\nu U^\mu - D^\mu U^\nu) + m_U^2 U_\mu^\dagger U^\mu - \frac{1}{2} m_\chi \chi \chi \\
- y_L \bar{Q}_L \gamma_\mu U_\mu L_L - y_R \bar{d}_R \gamma_\mu U_\mu e_R - y_\chi \bar{u}_R \gamma_\mu U_\mu \chi \]

Can induce tree level 3-body & 1-loop decay of \( \chi \)

No tree level decay of \( \chi \) if \( m_\chi < m_U \)

DM stability assured with \( Z_2 \) symmetry
Relic density

\[ \langle \sigma v \rangle = \frac{3 y^4 \tan^2 \theta}{8\pi \left( m^2 + m^2_U - m^2 \right)^2} \left( 1 - \frac{m^2_q}{m^2} \right)^{1/2} \]

Dominant annihilation channel to \( t\bar{t} \)

For \( m_\chi < m_t \), \( \chi\chi \rightarrow u\bar{u}, c\bar{c} \) are insufficient for observed relic density.

Co-annihilation channels: \( \chi U \rightarrow tg \quad \chi U \rightarrow Wb \)

Efficient at \( m_\chi \approx m_U \)

Effective near \( t \) resonance only

Model parameters: \( m_\chi, m_U, y_\chi \)
Direct detection

- Effective interaction of the DM with $u$-quark

$$\mathcal{L}_{\text{eff}} \simeq - \frac{y^2_\chi}{4 (m_U^2 - m_\chi^2)} \bar{\chi} (1 - \gamma_5) \gamma^\mu u \bar{u} (1 - \gamma_5) \gamma^\mu \chi$$

- DM-nucleon scattering cross section

$$\sigma_{\text{SD}} = \frac{3m_\chi^2 m_N^2 \Delta_u^N}{4\pi (m_\chi + m_N)^2} \frac{y^4_\chi}{(m_U^2 - m_\chi^2)^2}$$

Model parameters: $m_\chi$, $m_U$, $y_\chi$
## Collider bounds

| Mediator mass | DM mass |
|---------------|---------|
| Direct production at LHC | |
| Large rate due to color charge | |
| Final state topologies | |
| $U\bar{U} \rightarrow t\bar{t}\chi\chi, jj\chi\chi$ | |

CMS 13 TeV data excludes $<1.5$ TeV with 100% BR to $t\nu$

[CMS, 1805.10228]
Collider bounds

| Mediator mass                          | DM mass                                      |
|----------------------------------------|----------------------------------------------|
| 🌤️Direct production at LHC             | 🌤️Monojet(photon) + $E_T$                     |
| Large rate due to color charge         | EW process, suppressed                        |
| Final state topologies                 |                                              |
| $U\bar{U} \rightarrow t\bar{t}\chi\chi$, $jj\chi\chi$ | $pp \rightarrow \chi\chi j$ generated using |
| CMS 13 TeV data excludes <1.5 TeV with 100% BR to $t\nu$ | $qg \rightarrow \chi\chi q$ dominates for |
| [CMS, 1805.10228]                      | large parton distribution & ATLAS 13 TeV data excludes < 200 GeV |
|                                        | satisfying relic with $y_\chi = 1$           |
|                                        | [ATLAS, 1711.03301]                           |

[$pp \rightarrow \chi\chi j$ generated using $qg \rightarrow \chi\chi q$ dominates for large parton distribution & ATLAS 13 TeV data excludes < 200 GeV satisfying relic with $y_\chi = 1$ [ATLAS, 1711.03301] ]
# Collider bounds

| Mediator mass | DM mass |
|---------------|---------|
| Direct production at LHC | Monojet(photons) + $E_T$ |
| Large rate due to color charge | EW process, suppressed |
| Final state topologies | |
| $U\bar{U} \rightarrow t\bar{t}\chi\chi, jj\chi\chi$ | |

Combining $m_U > 1$ TeV

$m_\chi > 200$ GeV

$gg \rightarrow \chi\chi q$ dominates for large parton distribution & ATLAS 13 TeV data excludes $< 200$ GeV satisfying relic with $y_\chi = 1$

CMS 13 TeV data excludes $< 1.5$ TeV with 100% BR to $t\nu$

[CMS, 1805.10228]

[ATLAS, 1711.03301]
Results

One coupling sensitive to all three properties of DM model

Indirect data excludes DM mass up to 400GeV
[Cuoco et. al, 1711.05274]

Future Direct detection experiments can probe the entire parameter space
Summary

☑ DM model mediated by colored particle—leptoquark is discussed

☑ One Yukawa type coupling responsible for relic density, direct & indirect detection

☑ Collider bounds exclude DM mass < 200 GeV

☑ AMS-02 data excludes DM mass < 400 GeV

☑ Latest LUX results allow region compatible with relic density

☑ LZ experiment can probe entire region up to perturbativity limit
Summary

- DM model mediated by colored particle—leptoquark is discussed
- One Yukawa type coupling responsible for relic density, direct & indirect detection
- Collider bounds exclude DM mass < 200 GeV
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- Latest LUX results allow region compatible with relic density
- LZ experiment can probe entire region up to perturbativity limit
