

Probing CP nature of a mediator in associated production of
dark matter with single top quarkGENEVIEVE BELANGER^{*}, ROHINI M. GODBOLE[†], CHARANJIT K. KHOSA^{§1} AND
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We consider associated production of dark matter with single top quark, in a simplified dark matter model with spin-0 mediators. The produced top quark is polarized and the polarization depends on the CP of the mediator. We calculate both the cross-section and top polarization for these processes. We compute angular asymmetries which demonstrate the difference between the polarization expected for the scalar or pseudoscalar mediator. Both the cross section and top polarization are sensitive to the CP property of the mediator, depending on the mediator mass. We find that these polarization asymmetries add value to the determination of the CP property of the mediator particularly in the case of a state with indeterminate CP.

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1 Introduction

Simplified dark matter models provide a convenient theoretical framework to interpret LHC results for dark matter(DM) searches. Associated production of a heavy quark pair with DM has been one of the important DM search channels from the very beginning of collider DM searches. However, it has been shown recently that associate production of single top with a pair of DM particles can also provide interesting reach[1] and the experimental collaboration has already started considering this channel[2]. DM production in association with single top has also been studied in Ref. [3] in a simplified model and in the context of two Higgs doublet model with an additional pseudoscalar in Ref. [4].

We consider a simplified dark matter model with a spin-0 mediator (Φ). The Lagrangian we consider for the mediator couplings to the SM fermions and DM is :

$$\mathcal{L}_\Phi = g_\chi \Phi \bar{\chi} (\cos \theta + i \sin \theta \gamma^5) \chi + \frac{g_v \Phi}{\sqrt{2}} \sum_{f=t,b} \frac{m_f \bar{f}}{v} (\cos \theta + i \sin \theta \gamma^5) f - \frac{1}{2} m_\Phi^2 \Phi^2 - m_\chi \bar{\chi} \chi. \quad (1)$$

Here θ is the CP phase parameter $\theta = 0$ ($\frac{\pi}{2}$) represents pure scalar (pseudoscalar) state and $v = 174$ GeV. We consider the case where the mediator has couplings only to the third generation fermions.

In this scenario, $t\bar{t}$ pair production process in association with DM, had been used to study the CP nature of the mediator [5, 6]. In this study the angular correlation between the two decay leptons has been exploited as an observable specific to the CP property. We consider associated production of dark matter (χ) with single top in a simplified dark matter model with a spin-0 mediator (Φ) and we investigate the effect of the CP nature of the mediator on the cross-section and on the top polarization. The production processes are shown in Figure 1.

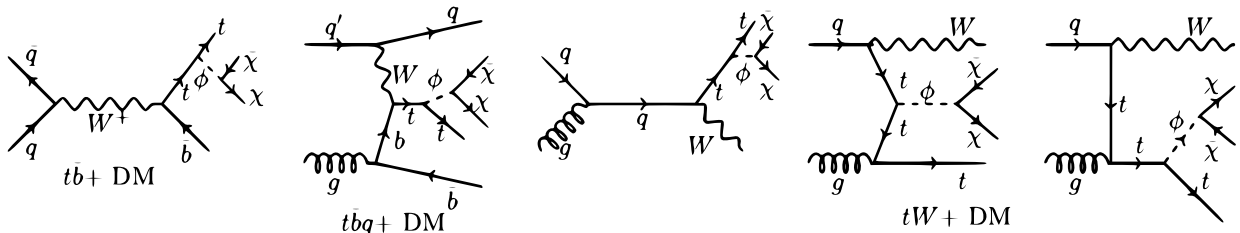


Figure 1: Feynman diagrams for the dark matter production processes in association with single top quark

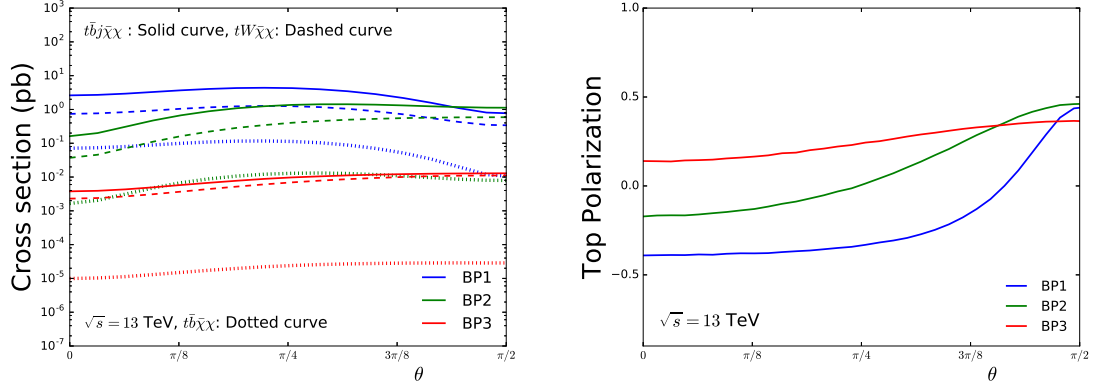


Figure 2: Cross-section (including both t and \bar{t} processes) for single top in association with DM for the three benchmark points (left panel) and top polarization for $pp \rightarrow$ single top + DM processes (right panel), as a function of CP phase θ

2 Cross section and top polarization

Model files are generated using FeynRules and cross-section is calculated using MadGraph 2.5.5 (pdf- NNPDF30.lo.as.130, lhaid-263000). We consider 5-flavour scheme (massive b quark) for all the process except t-channel $t\bar{b}j$ ($\bar{t}bj$) +DM process where 4 flavour scheme is considered. We have four model parameters : $m_\chi, m_\Phi, g_\chi,$ and g_v . We fix $g_v=1$ and consider the three benchmark points(BP) given in Table 1, for other parameters. For these BPs, the upper bound on the relic density of DM is satisfied along with the DM direct detection constraints from DarkSide50[7] and Xenon1T[8]. The cross-section for single top and DM processes as a function of θ is shown in Figure 2 for each BP. Here we fix the mediator width to the scalar case value ($\theta = 0$) for all values of θ . We calculate the top polarization

$$P = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}, \quad (2)$$

using helicity amplitudes in MadGraph, here σ_+ and σ_- are the cross-sections for the positive and negative helicity top quarks. We can see in Figure 2 that the top polarization and the cross-section have a different θ dependence. Hence polarization can provide additional discriminatory power. Note in particular that for the cross-section, the difference between BP1 and BP2 decreases at large values of θ whereas the polarization remains a good discriminant.

	m_ϕ	m_χ	g_χ
BP1	10 GeV	4.5 GeV	0.35
BP2	100 GeV	49 GeV	0.5
BP3	400 GeV	180 GeV	1.0

Table 1: Benchmark points for the model parameters

3 Observables which reflect polarization

Angular observables provide robust measures of polarization unaffected by physics beyond the standard model in top decay (see e.g.[9, 10]). We compute the polar asymmetry

$$A_{\theta_l} = \frac{\sigma(\cos \theta_l > 0) - \sigma(\cos \theta_l < 0)}{\sigma(\cos \theta_l > 0) + \sigma(\cos \theta_l < 0)}, \quad (3)$$

where θ_l is an angle of the charged lepton (from top decay) with top direction of motion and the azimuthal asymmetry (about the top quark production plane)

$$A_\phi = \frac{\sigma(\cos \phi_l > 0) - \sigma(\cos \phi_l < 0)}{\sigma(\cos \phi_l > 0) + \sigma(\cos \phi_l < 0)}. \quad (4)$$

We can see from Figure 3 that A_ϕ has a strong dependence on θ when ϕ is light

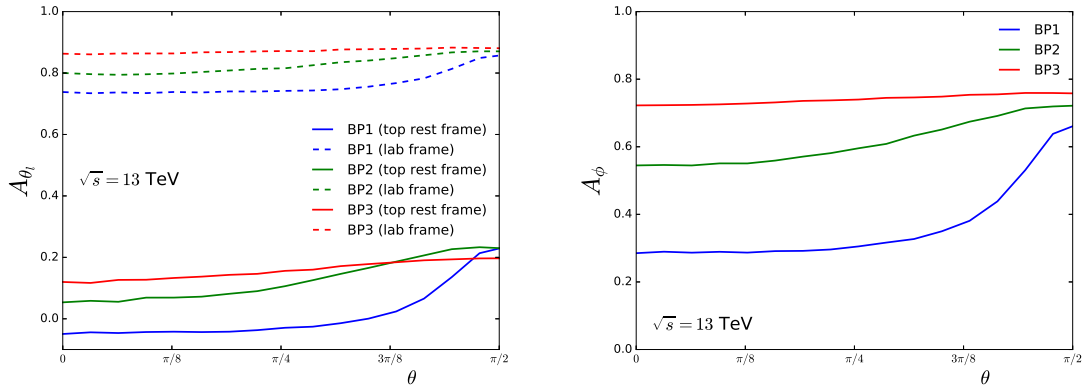


Figure 3: Charged lepton polar asymmetry (left panel) and azimuthal asymmetry for $pp \rightarrow$ single top + DM processes (right panel), as a function of CP phase θ

whereas the dependence of A_{θ_l} on the CP phase is milder. Moreover note that A_ϕ can be a good discriminant between BP1 and BP2 for any value of θ .

4 Summary and Conclusion

We study the effect of the CP property of the mediator in simplified dark matter models. We consider associated production of DM with single top and calculate the cross-section as well as top polarization. We find that the cross-section and top polarization have a different behaviour with respect to the CP phase θ thus offering complementary discriminatory power. Further study of the experimental sensitivity for these observables is in progress.

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