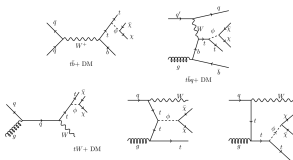# CP nature of a mediator : Single top quark + Dark Matter

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Ongoing work, In collaboration with :
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# *Simplified dark matter models*



- Heavy flavour quark pair and dark matter processes are the conventional channels for DM searches
- **Single top production associated with the pair of dark matter is an additional channel** [1]
- Lagrangian for the mediator couplings to the SM fermions and DM is

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

$\theta$ : CP phase parameter, $\theta = 0 \to$ pure scalar state, $\theta = \frac{\pi}{2} \to$ pure pseudoscalar state, $v = 174$ GeV

- **Simultaneous determination of cross-section and top polarization to probe the CP property of the mediator**

[1]Pinna *et al*, Phys. Rev. D **96**, 035031 (2017)

# Cross-section and Polarization

- BP1 ($m_\phi \approx 2m_b$): $m_\Phi$=10 GeV, $m_\chi$=4.5 GeV, $g_\chi$=0.35
- BP2 : $m_\Phi$=100 GeV, $m_\chi$=49 GeV, $g_\chi$=0.5
- BP3 : $m_\Phi$=400 GeV, $m_\chi$=180 GeV, $g_\chi$=1

DM is underabundant and the DM direct detection constraints (from DarkSide50 and Xenon1T) are satisfied
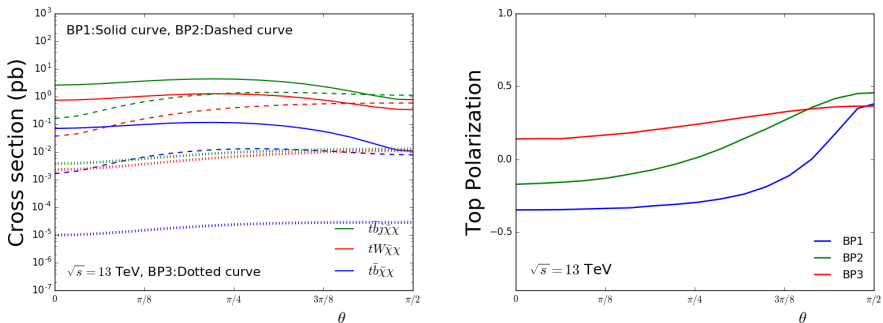


*Figure :* Cross-section (including both $t$ and $\bar{t}$ processes) for single top in association with DM (left panel), Top polarization for $pp \rightarrow$ single top + DM processes(right panel)

$$P = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

Polarization as a function of $\theta$ behaves differently than the cross-section

# *How to measure Polarization?*

**Observables which reflect polarization** : angular observables are robust measures of polarization unaffected by BSM in top decay[2]

- Polar asymmetry

$$A_l^\theta = \frac{\sigma(\cos\theta_l > 0) - \sigma(\cos\theta_l < 0)}{\sigma(\cos\theta_l > 0) + \sigma(\cos\theta_l < 0)}$$

  $\theta_l$ : angle of the charged lepton (from top decay) with top direction of motion
- Azimuthal asymmetry : in top quark production plane

$$A_l^\phi = \frac{\sigma(\cos\phi_l > 0) - \sigma(\cos\phi_l < 0)}{\sigma(\cos\phi_l > 0) + \sigma(\cos\phi_l < 0)}$$
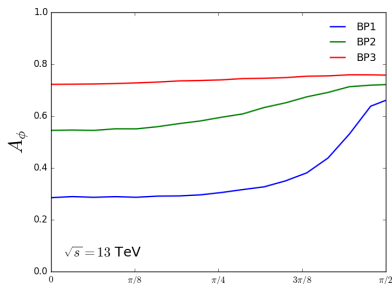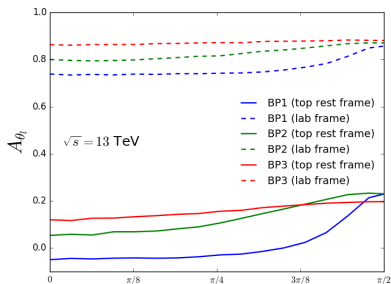


*Figure :* Charged lepton polar asymmetry (left panel) and azimuthal asymmetry for $pp \rightarrow$ single top $+$ DM processes(right panel)

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[2]Godbole *et al*, JHEP **0612** (2006) 021

# *Summary*

- We consider single top quark and DM channel for CP measurement

- Cross-section is approximately same for scalar and pseudoscalar processes

- **Top polarization is different for the scalar and pseudo scalar mediator and thus offers distinction**

- Charged lepton asymmetries are sensitive to CP phase of the mediator-fermion couplings if the mediator is not very heavy

- Further analysis of sensitivity of the asymmetries is in progress

- Model files are generated using FeynRules and cross-section is calculated using MadGraph 2.5.5 (pdf- NNPDF30.lo.as.130, lhaid-263000)
- 5-flavour scheme (massive b quark) for all the process except t-channel $t\bar{b}j +$ DM ($+ \bar{t}bj +$DM) process where 4 flavour scheme is considered
- **Model parameters** : $m_\chi, m_\Phi, g_\chi$, and $g_v$ : we fix $g_v=1$ and consider three benchmark points(BP) for other parameters