Single top quark + Dark Matter

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Dark matter searches at colliders

Simplified dark matter models

$$\mathcal{L}_S = \mathcal{L}_{\text{SM}} + \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2} m_\phi^2 \phi^2 + i\bar{\chi}\partial\!\!\!/\chi - m_\chi \bar{\chi}\chi - g_\chi \phi \bar{\chi}\chi - \sum_{\text{fermions}} g_v \frac{y_f}{\sqrt{2}} \phi \bar{f} f \ ,$$

$$\mathcal{L}_A = \mathcal{L}_{\text{SM}} + \frac{1}{2}(\partial_\mu A)^2 - \frac{1}{2} m_A^2 A^2 + i\bar{\chi}\partial\!\!\!/\chi - m_\chi \bar{\chi}\chi - i g_\chi A \bar{\chi}\gamma^5\chi - \sum_{\text{fermions}} i g_v \frac{y_f}{\sqrt{2}} A \bar{f}\gamma^5 f$$

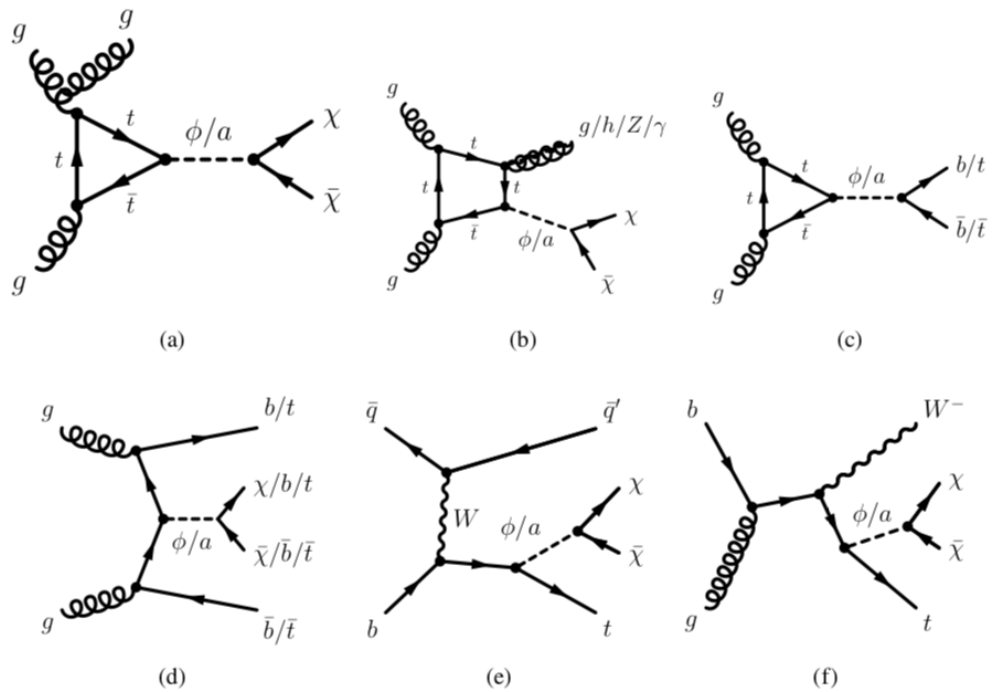
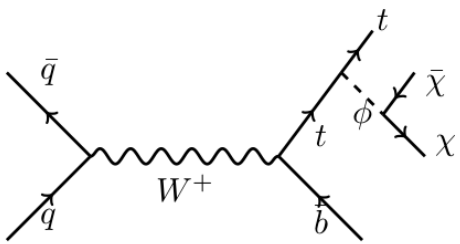
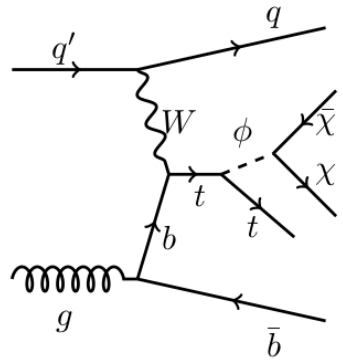


Figure: taken from ATLAS-CONF-2018-051

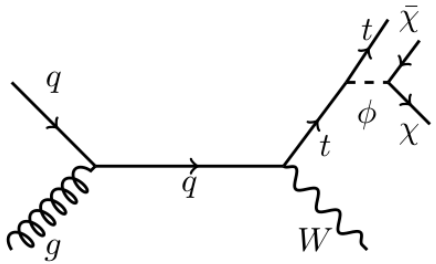
Associated production of DM with single top quark[1]



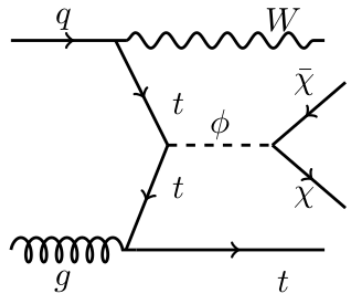
$t\bar{b}$+ DM

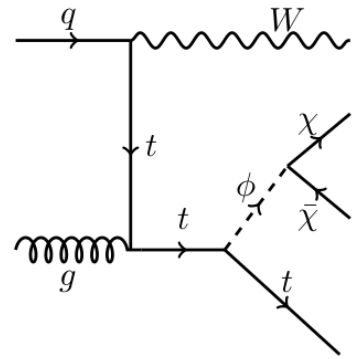


$t\bar{b}q$+ DM



tW+ DM





Polarized top quark

[1] Pinna *et al*, Phys. Rev. D **96**, 035031 (2017), T. Plehn, J. Thompson and S. Westhoff, Phys. Rev. D **98** (2018), 015012

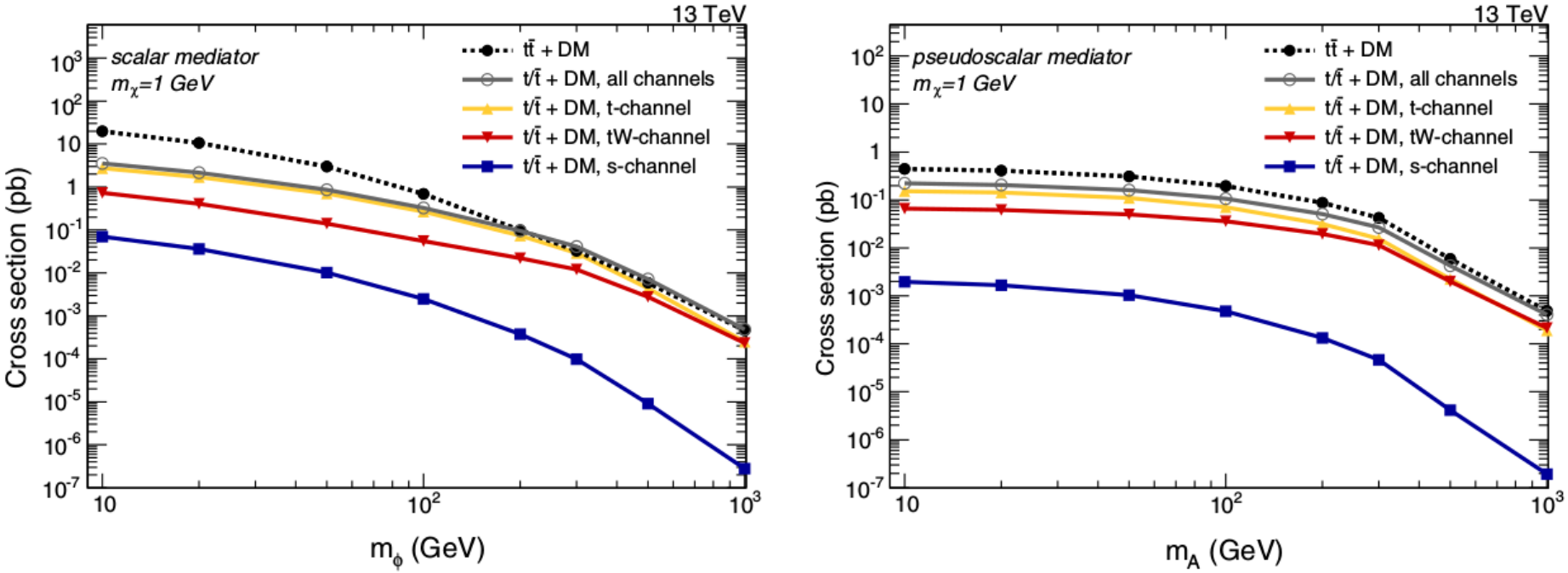
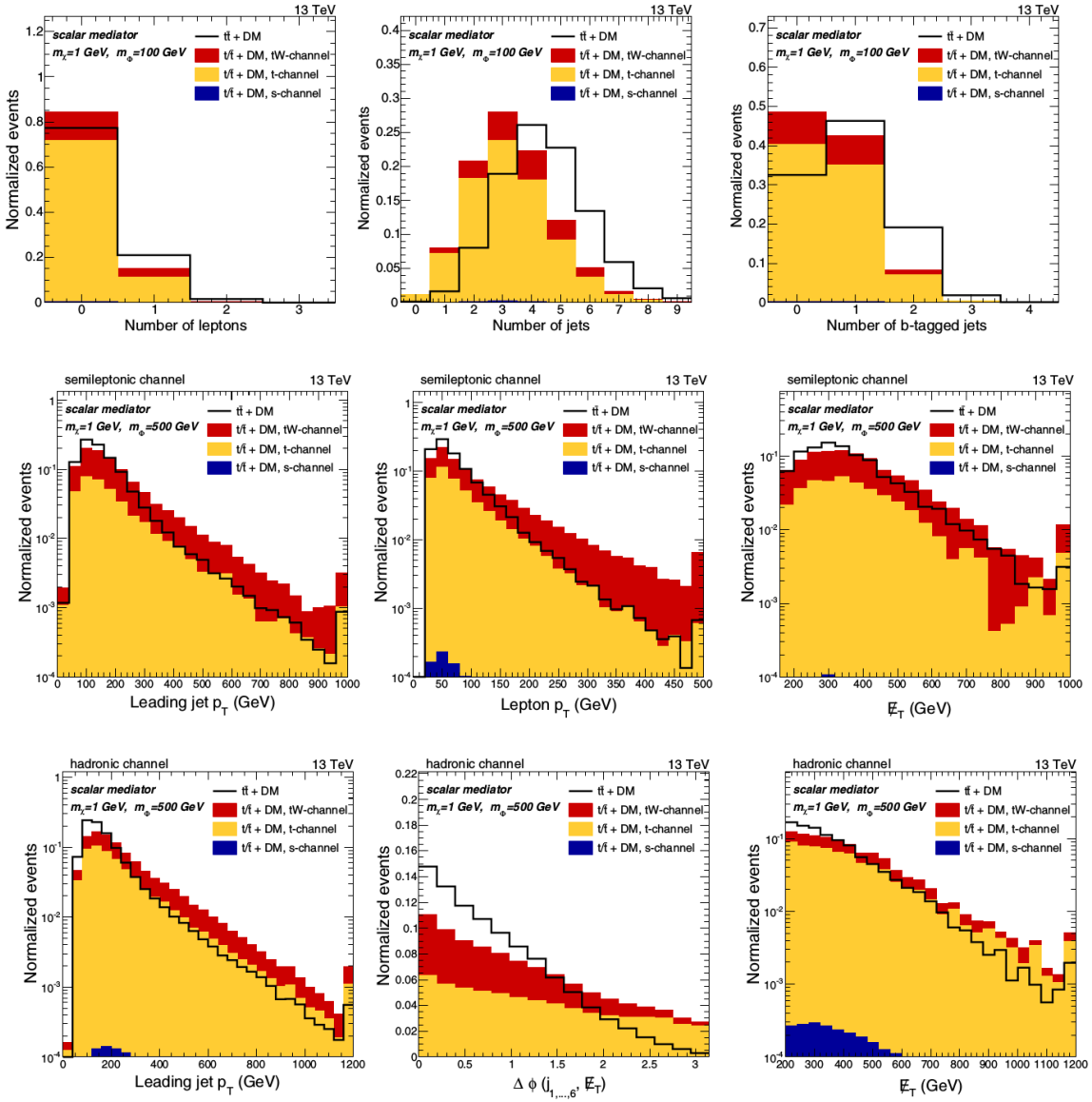


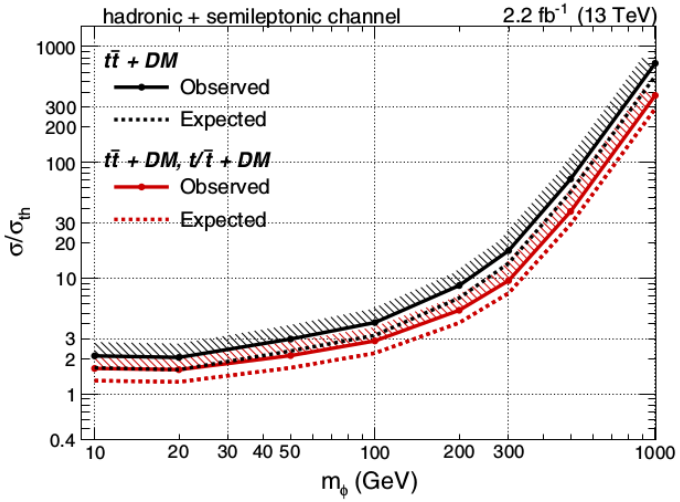
Figure: Cross-section for the $t/\bar{t}$+ DM processes[2] ($g_v = g_\chi = 1$)

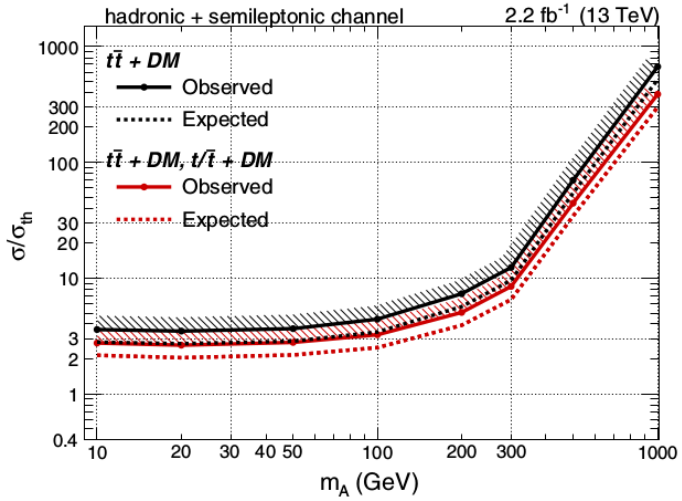
[2] Pinna *et al*, Phys. Rev. D **96**, 035031 (2017)

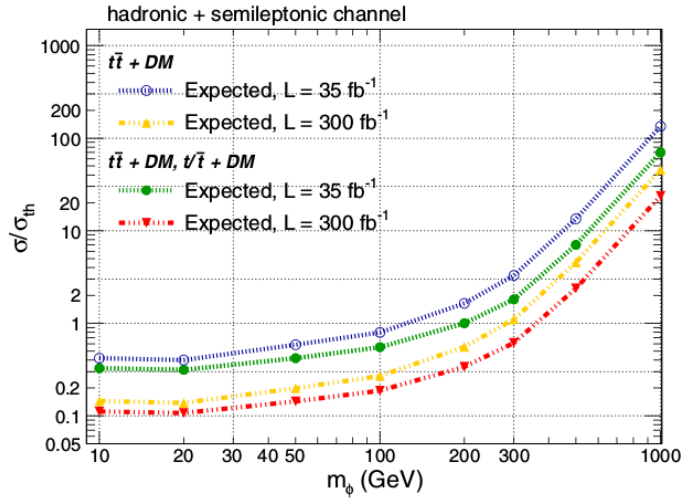
Kinematic distributions

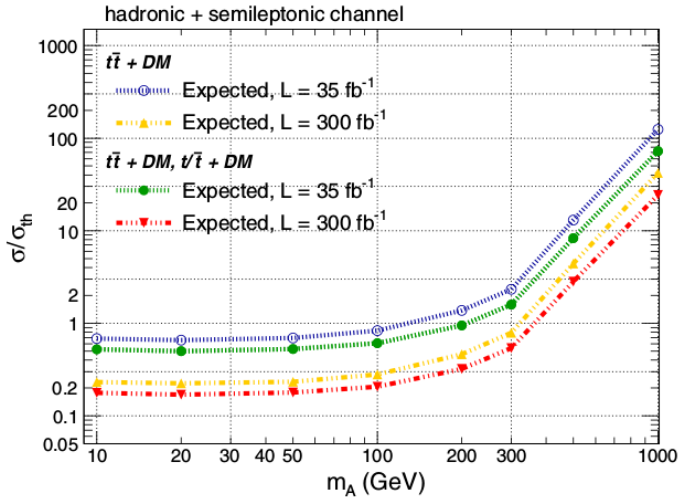


Impact on exclusion limit[3]





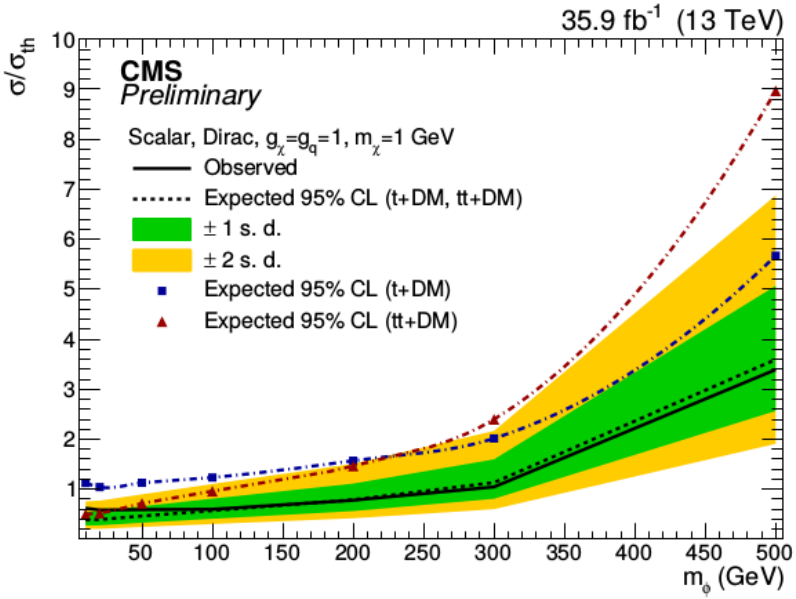


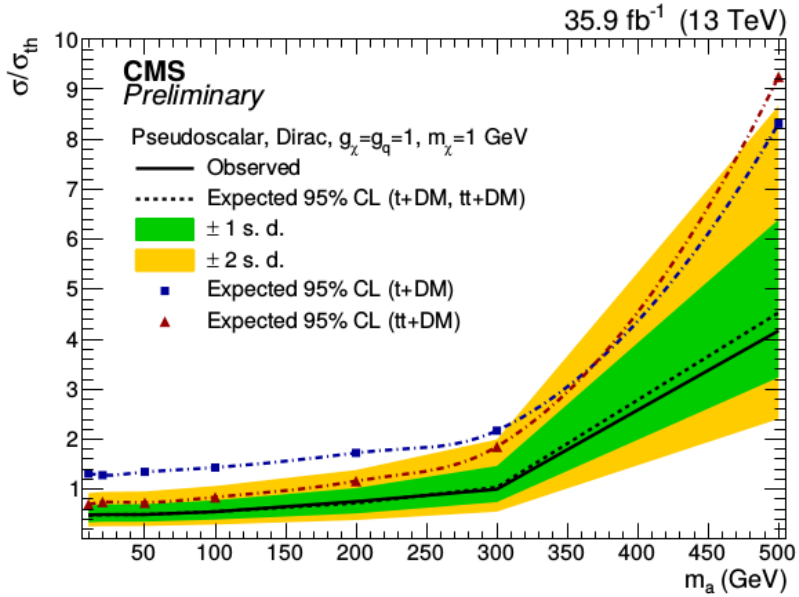


[3] Pinna *et al*, Phys. Rev. D **96**, 035031 (2017)

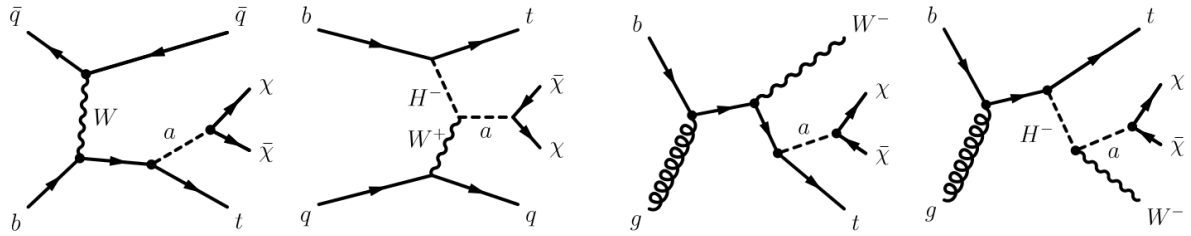
CMS-PAS-EXO-18-010

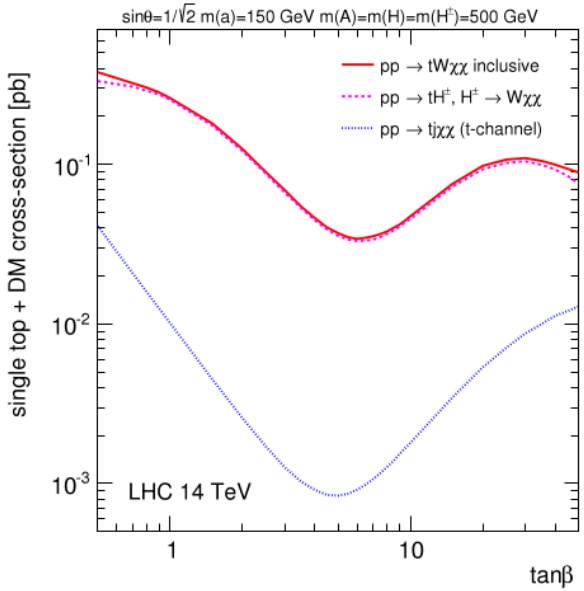
Various improvements are incorporated into this search that are designed to enhance the sensitivity to the $t/t + DM$ final state over that of previous analyses. Similar to previous searches [16], several orthogonal signal regions (SR) are defined and statistically combined in a simultaneous global fit of the p_T^{miss} spectrum. Events are separated into orthogonal categories based on the number of b jets (n_b), with $n_b = 1$ or $n_b \geq 2$, and additional requirements on the number of forward jets are placed (0 or ≥ 1 forward jet). The minimum requirements on the number of jets is also lowered to enhance the sensitivity specifically to the $t/\bar{t} + DM$ model. Control regions (CR) enriched in the major background processes are included in the fit in order to improve the estimates of the background contributions.

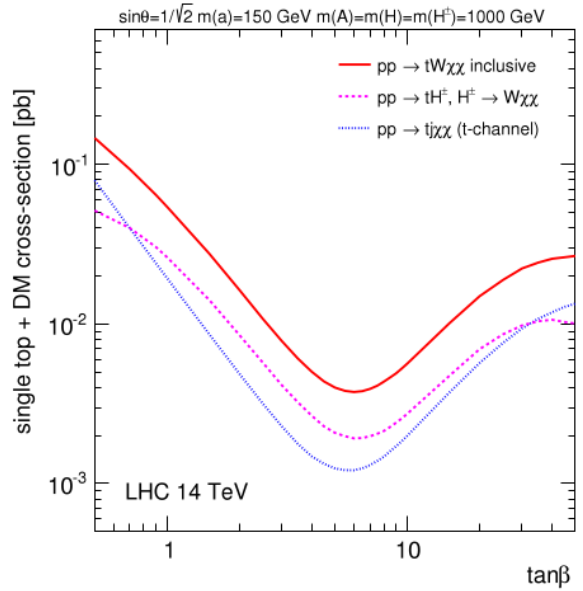




2HDM and a pseudoscalar mediator[4]



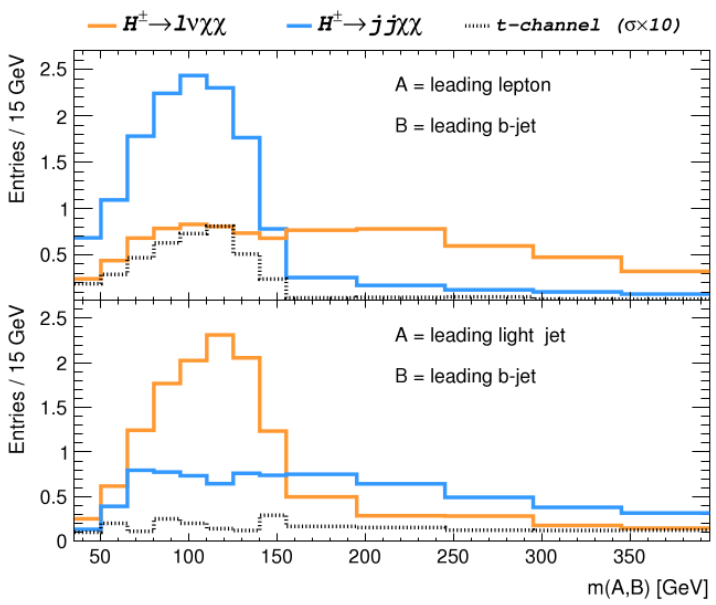


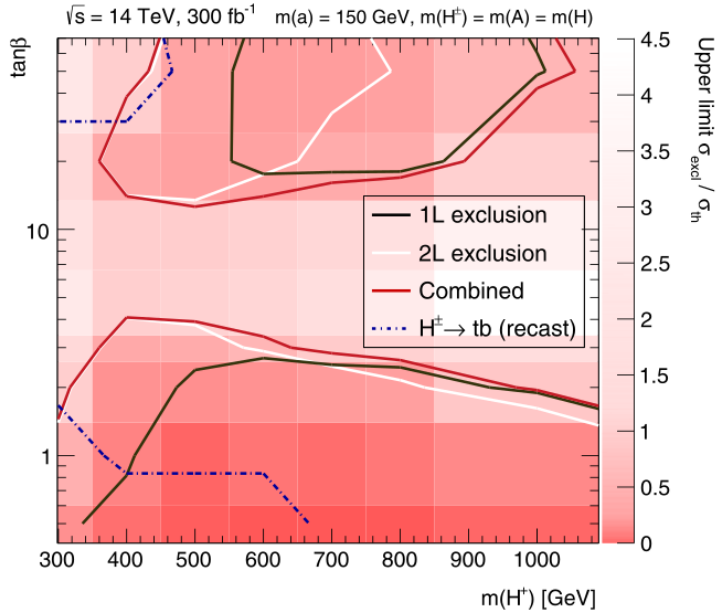


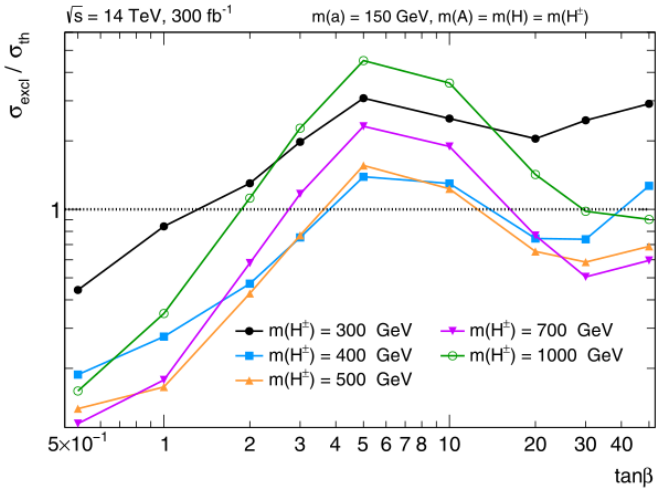
$$V_P = \frac{1}{2} m_P^2 P^2 + P\left(i b_P H_1^\dagger H_2 + \text{h.c.}\right) + P^2\left(\lambda_{P1} H_1^\dagger H_1 + \lambda_{P2} H_2^\dagger H_2\right)$$

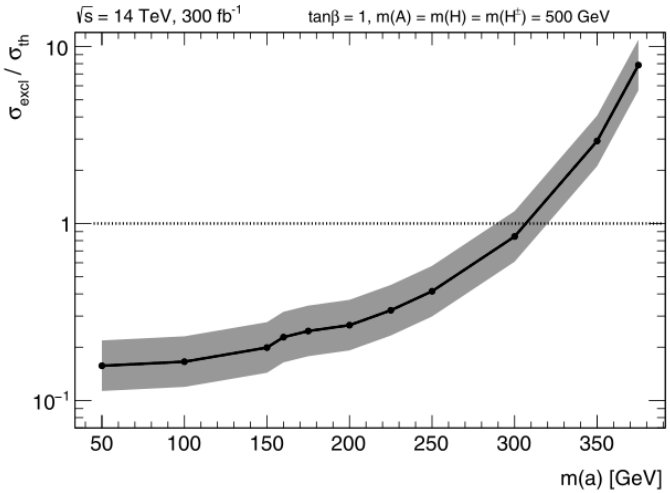
$$\mathcal{L}_\chi = -i y_\chi P \bar{\chi} \gamma_5 \chi \,.$$

[4] P. Pani and G. Polesello,Phys. Dark Univ. **21**, 8 (2018)









[5] P. Pani and G. Polesello,Phys. Dark Univ. **21**, 8 (2018)

CP nature of a mediator via single top channel[6]

- Mediator (spin 0) couplings to the SM fermions and DM :

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

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

- **Simultaneous determination of cross-section and top polarization**

[6] Ongoing work, In collaboration with : Genevieve Belanger, Rohini M. Godbole, and Saurabh D. Rindani, arxiv:1811.11048(hep-ph)

- Model parameters: m_χ, m_Φ, g_χ, and $g_v = 1$
  - BP1 ($m_\phi \approx 2m_b$): m_Φ=10 GeV, m_χ=4.5 GeV, g_χ=0.35
  - BP2 : m_Φ=100 GeV, m_χ=49 GeV, g_χ=0.5
  - BP3 : m_Φ=400 GeV, m_χ=180 GeV, g_χ=1
- Model files are generated using FeynRules and cross-section is calculated using MadGraph
- Top polarization

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

Cross-section and polarization

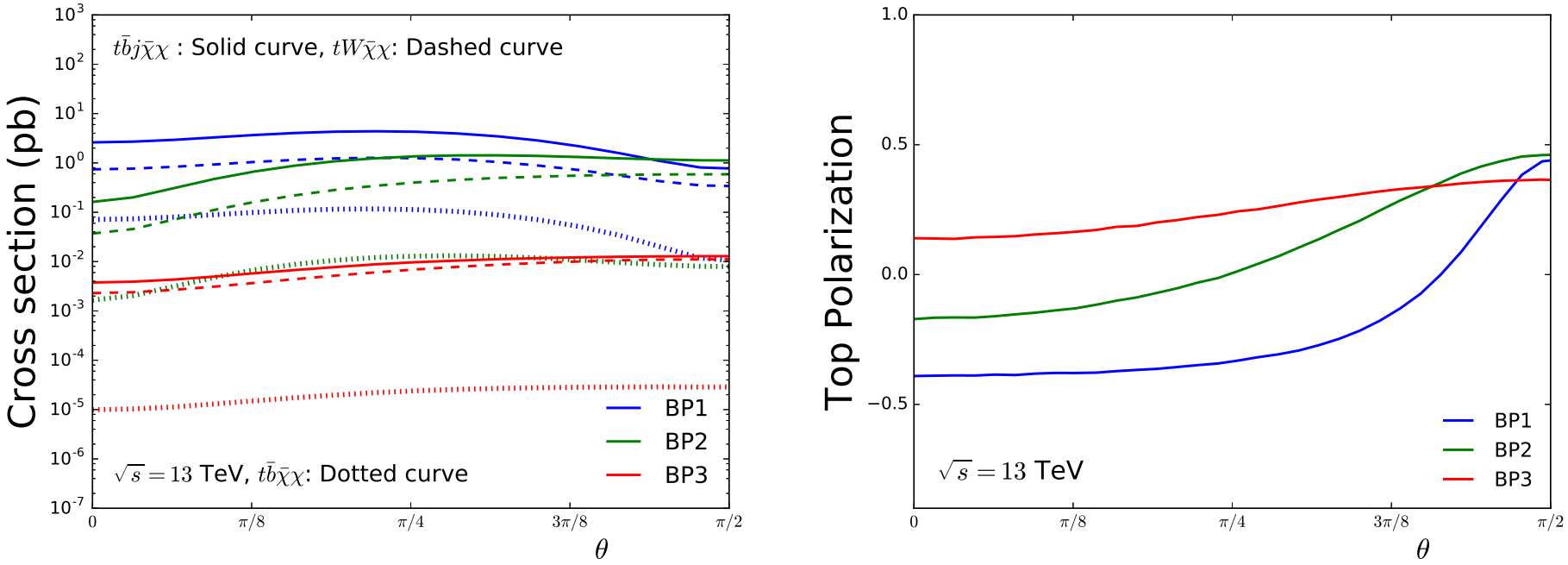


Figure: Cross-section (including both t and $\bar{t}$ processes) for single top in association with DM (left panel), Top polarization for $pp \rightarrow$ single top + DM processes(right panel)

Polarization as a function of θ behaves differently than the cross-section

How to measure polarization?

Observables which reflect polarization : angular observables are robust measures of polarization[7]

- Polar asymmetry

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

  θ_l : angle of the charged lepton (from top decay) with top direction of motion

- Azimuthal asymmetry (about the top quark production plane)

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

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

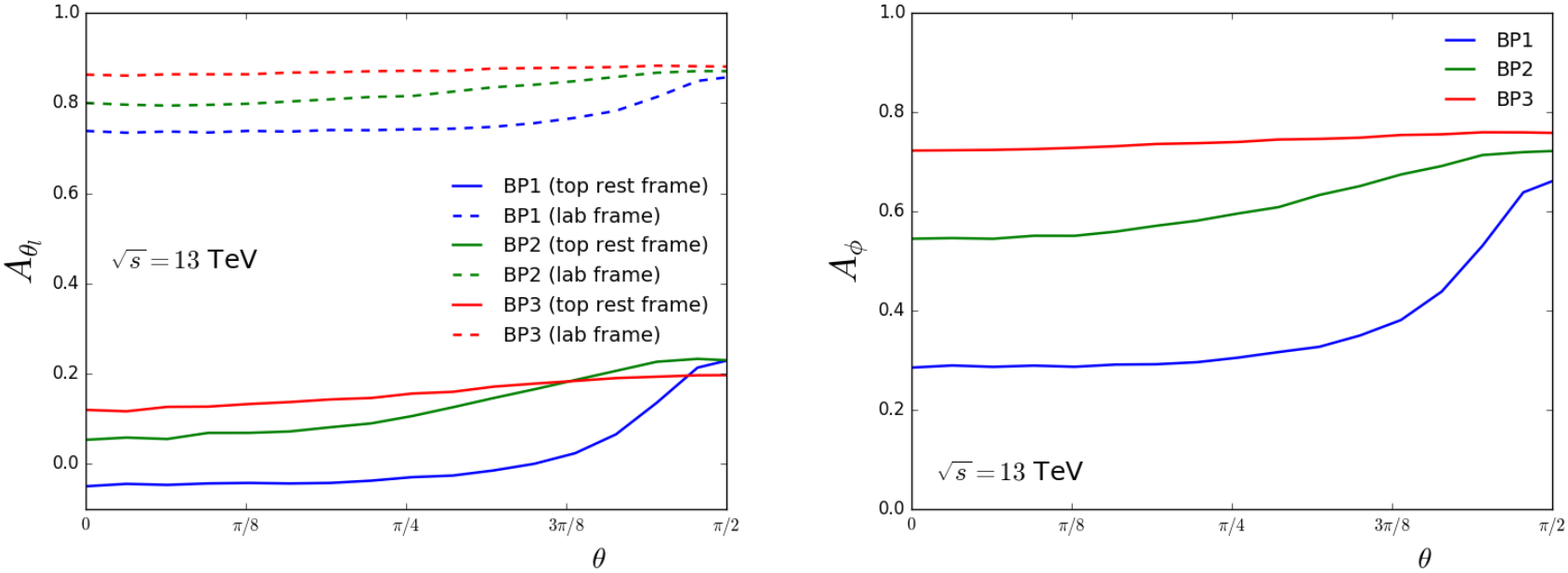


Figure: Charged lepton polar asymmetry (left panel) and azimuthal asymmetry for $pp \to$ single top + DM processes(right panel)

Associated top pair channel[8]

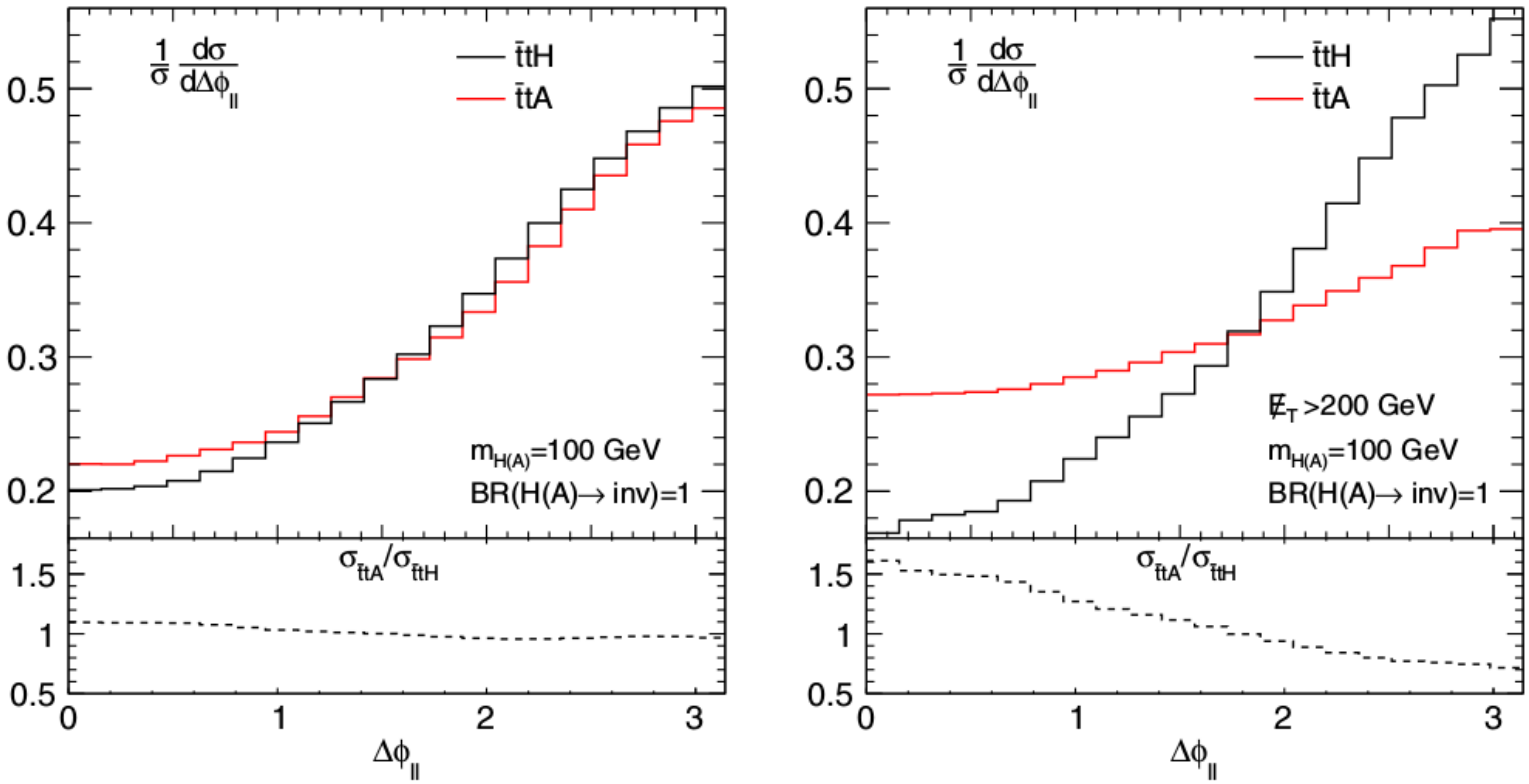


Figure: Normalised differential distribution of $\Delta\phi_{ll}$

[8] Buckley et al PRD 93, 034003 (2016)

Summary

- Single top quark and DM channel improves the experimental reach
- It could also be used to study the CP property of a mediator
    - Cross-section and top polarization have a different behaviour with respect to the CP phase θ and thus offers complementary discriminatory power

Thank you