Dark-matter top-quark interactions at the LHC

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outline

1. work-in-progress on monojet and $t\bar{t} + \not{E}_T$ signatures for scalar and pseudoscalar mediators [Haisch,ER, preliminary results]
2. the $jj + \not{E}_T$ signature [Haisch,Hibbs,ER '13]
3. what is there and what will be there in POWHEG

introduction

dark-matter top-quark interactions

- study spin-0 mediators and LHC discovery/exclusion potential
- if MFV assumed, the most relevant DM-SM interactions are those involving top quarks
- we wanted to look how searches in monojets and $t\bar{t} + \not{E}_T$ compare (and how they compare with direct-detection limits)
- we have explored this both in the EFT limit and with a simplified model

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simplified model

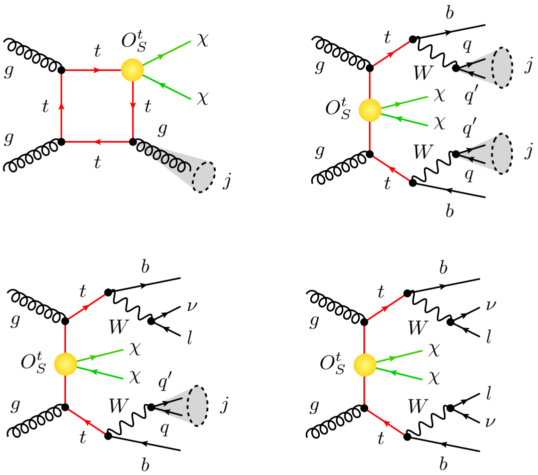
$$\mathcal{L} \supset g^S_{\rm DM}\,(\bar\chi\chi)\,S + g^S_{\rm SM}\sum_q \frac{m_q}{v}\,(\bar q q)\,S + i g^P_{\rm DM}\,(\bar\chi\gamma_5\chi)\,P + i g^P_{\rm SM}\sum_q \frac{m_q}{v}\,(\bar q\gamma_5 q)\,P$$

EFT description

$$O^q_S = \frac{m_q}{\Lambda^3_S}\,\bar\chi\chi\,\bar q q\,, \qquad O^q_P = \frac{m_q}{\Lambda^3_P}\,\bar\chi\gamma_5\chi\,\bar q\gamma_5 q \qquad \Lambda = \left(\frac{v M^2}{g_{\rm SM}\,g_{\rm DM}}\right)^{1/3}$$

- unless stated, we always keep full top-mass dependence
- for simplicity, same factors for up-down type families: $g^{P/S}_{\rm SM} \equiv g^{P/S}_{\rm u,SM} = g^{P/S}_{\rm d,SM}$

available searches



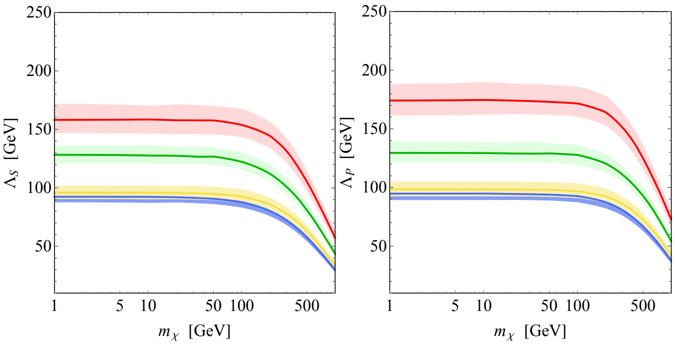
- monojet:
  - 1408.3583 (CMS)

  $t\bar{t}$ dileptonic:
  - B2G-13-004 (CMS)

  $t\bar{t}$ single-lepton:
  - 1410.4013 (ATLAS)

  $t\bar{t}$ hadronic:
  - 1410.4013 (ATLAS)
- $t\bar{t} + \not{E}_T$ analysis not totally straightforward (especially with 1 or 2 hadronic decays)
- validated successfully (our EFT results match ATLAS paper)

EFT analysis (with exact top mass dependence)



red: monojet , blue: hh , green: ℓh, yellow: $\ell\ell$

- bands from scale uncertainties
- bounds from monojet search currently provide the best constraints
- from $t\bar{t} + \not{E}_T$, the single-lepton search seems to be the more promising
- difference between P and S at low m_χ: $\Lambda_P \simeq (3/2)^{1/3}\Lambda_S$
- $m_\chi \gtrsim 100$ GeV: S bound falls faster because of scaling property of cross-section (P: β vs S: β^3, where $\beta = \sqrt{1 - 4m_\chi^2/m_{\chi\bar{\chi}}^2}$)

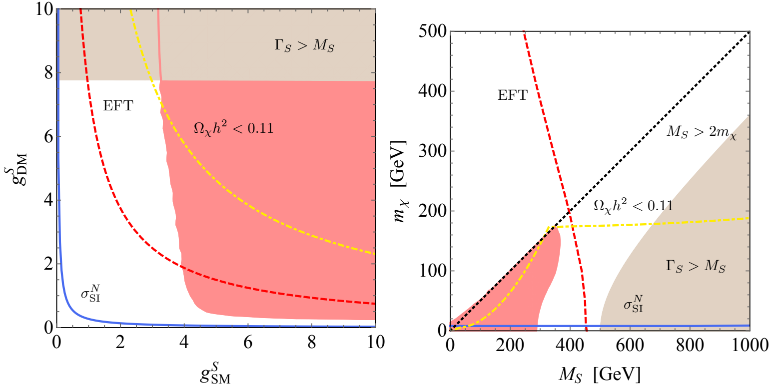
simplified model

$$\mathcal{L} \supset g^S_{\rm DM}\,(\bar\chi\chi)\,S + g^S_{\rm SM}\sum_q \frac{m_q}{v}\,(\bar q q)\,S + i g^P_{\rm DM}\,(\bar\chi\gamma_5\chi)\,P + i g^P_{\rm SM}\sum_q \frac{m_q}{v}\,(\bar q\gamma_5 q)\,P$$

- 4 free parameters: g_{DM}, g_{SM}, m_χ, $M_{S/P}$
- width always computed: include $S \to \chi\bar\chi$, $S \to t\bar t$, $S \to gg$ and $S \to b\bar b$

- this is the minimal width, within the simplified model we are considering
- no approximate NLO/LO K-factor for monojet x-section, since NLO for $H/A + j$ with top-mass dependence is not known (if $m_t \to \infty$, $K \simeq 1.6$)
- PDF: MSTW2008LO
  $\mu = H_T/2$, where $H_T = \sqrt{m^2_{\chi\bar\chi} + p^2_{T,j}} + p_{T,j}$
  `Pythia6`

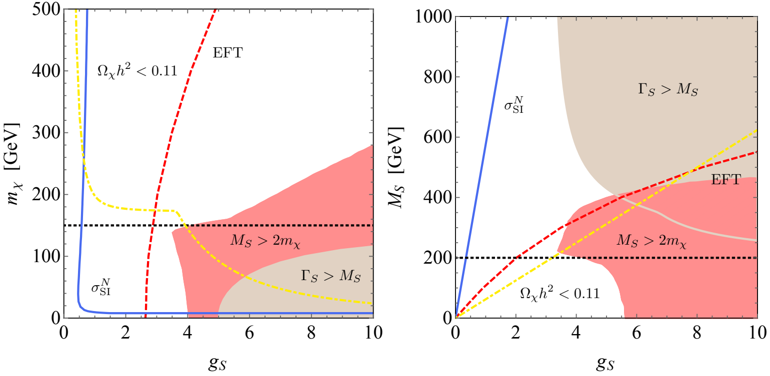
scalar: results



- left: $m_\chi = 100$ GeV, $M_S = 300$ GeV.
- right: $g = 4$ (not very weak, but within perturbative regime)

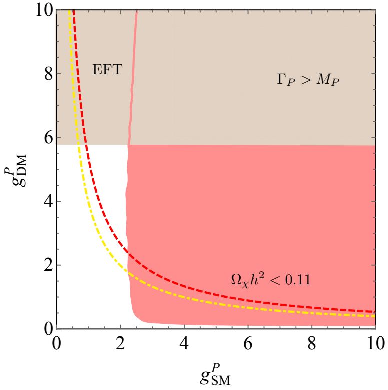
- LHC8 can exclude $g^S_{\mathrm{SM}} \gtrsim 3$ and $g^S_{\mathrm{DM}} \gtrsim 0.2$
- weakly-coupled scalar mediators seem hard to probe
- direct-detection (LUX) much more constraining

scalar: results



- left: $M_S = 300$ GeV, right: $m_\chi = 100$ GeV.

pseudoscalar: results



- $m_\chi = 100$ GeV, $M_S = 300$ GeV.
- again can exclude couplings, but not when they are quite small

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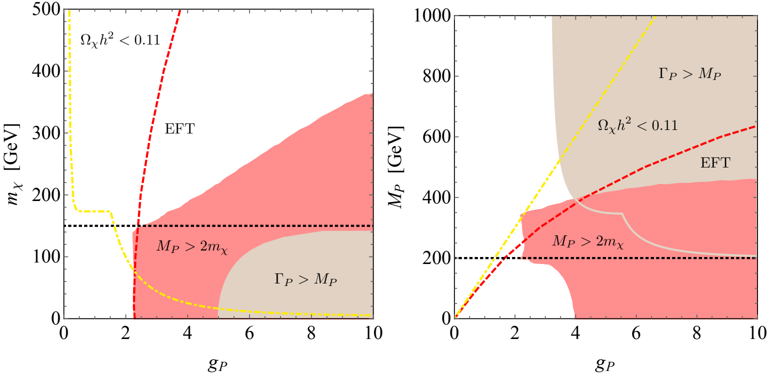
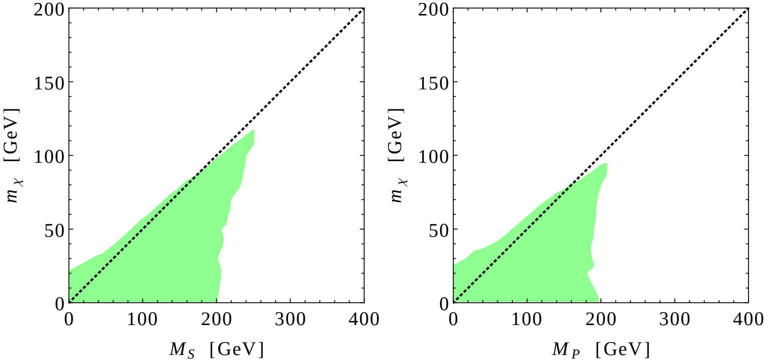
- no direct-detection (spin-dependent DM-nucleon x-section is momentum suppressed)

pseudoscalar: results



- left: $M_S = 300$ GeV, right: $m_\chi = 100$ GeV.
- overall picture looks similar to scalar case, but more exclusion potential, since x-section is larger:
  - matrix-element different (e.g. $(3/2)^2$ ennhancement...)
  - if $2m_\chi > M_S$ different scaling with β: offshellness production for P case much less suppressed

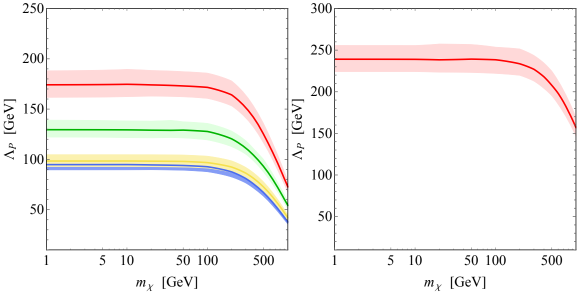
$t\bar{t} + \not{E}_T$: single-lepton final state



- using same analyses validated succesfully in EFT case
- with current cuts, they don't allow to extend the parameter space already probed by monojet searches
- should an excess be found, correlations (e.g. among b-jets) would allow to study the nature of the mediator (see later...)

status/summary

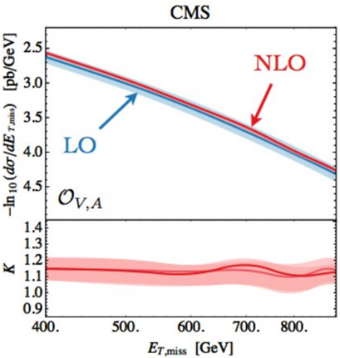
- we are also studying prospects at 14 TeV...



left: LHC8 right: LHC14, cuts in recent ATLAS "future-prospects" study, 25 invfb
$p_{T,j_1} > 300$ GeV, $p_{T,j} > 50$ GeV, jet-veto, $\not{E}_T > 800$ GeV, ...

- seem difficult to test weakly-coupled regime (or heavy mediators) for these models
- LHC14 will improve (although control on SM backgrounds uncertainties will start to play an important role)

structure of the interaction



- shapes of spectra are always extremely similar
- different operators will give different x-sections, but it seems impossible to distinguish between $\mathcal{O}_V, \mathcal{O}_A, \mathcal{O}_S, \mathcal{O}_G, \ldots$ just by using monojets.
- what about looking into 2-jets events?

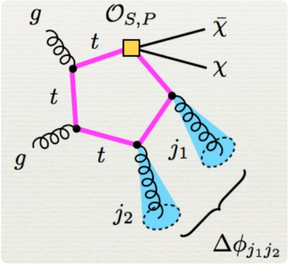
DM + 2 jets (EFT)

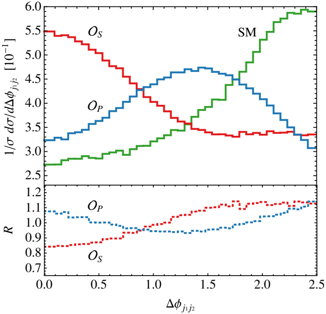
- we looked at the case where DM-SM interactions take place via

$$\mathcal{O}_S = \frac{m_t}{\Lambda^3}\,(\bar{t}t)\,(\bar{\chi}\chi) \quad \text{or} \quad \mathcal{O}_P = \frac{m_t}{\Lambda^3}\,(\bar{t}\gamma_5 t)\,(\bar{\chi}\gamma_5\chi)$$

- bounds from $j + E_{T,\mathrm{miss}}$ and $t\bar{t} + E_{T,\mathrm{miss}}$:
  $\Lambda \gtrsim 150 - 170$ GeV [$m_\chi = 50$ GeV]

- (normalized) azimuthal correlation $\Delta\Phi_{jj}$:
  - ☞ distinguish between background and signal hypothesis
  - ☞ distinguish between $\mathcal{O}_S$ and $\mathcal{O}_P$ (and $\mathcal{O}_{V/A}$)
- LHC 14 TeV w/ CMS cuts + $m_{jj} > 600$ GeV:
  $\sigma(E_{T,\mathrm{miss}} + jj) \simeq 0.3\sigma(E_{T,\mathrm{miss}} + j)$, $\sigma_S \simeq \sigma_B$





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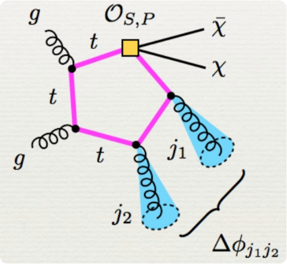

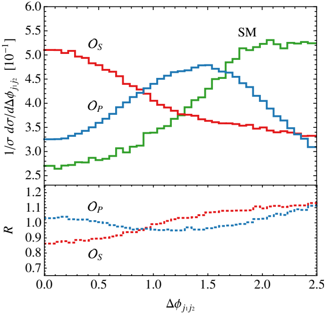

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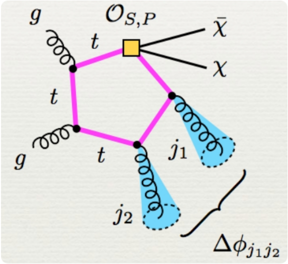
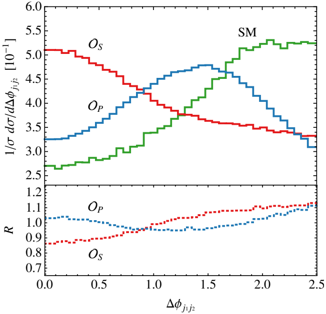
  $\sigma(E_{T,\mathrm{miss}} + jj) \simeq 0.3\sigma(E_{T,\mathrm{miss}} + j)$, $\sigma_S \simeq \sigma_B$
- pattern visible also in heavy-top limit [$G_{\mu\nu}G^{\mu\nu}\bar{\chi}\chi$]
  (although x-section overestimated (factor 10))





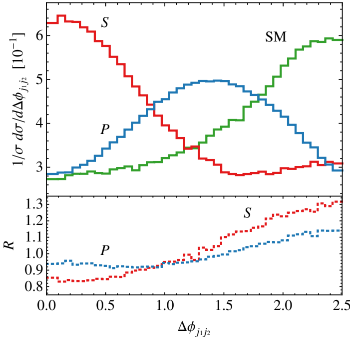
DM + 2 jets (full theory)

- with previous settings, EFT validity questionable
- studied specific case with simplified s-channel model:

$$\mathcal{L}_S = g_\chi^S \, (\bar{\chi}\chi) \, S + g_t^S \, \frac{m_t}{v} \, (\bar{t}t) \, S$$

  - (pseudo)-scalar mediator, $M_{P/S} = 500$ GeV, $m_\chi = 200$ GeV, $g = 1$
- all constraints from LHC and cosmology satisified
- width explicitly computed (here turns out $\Gamma/M \simeq 3 - 6\%$)

☞ modulation pattern survives



Conclusions

- studied scalar/pseudoscalar mediators, both in EFT and simplified models
- main conclusion: LHC effective in probing parameter space, but only if couplings are not very weak (different wrt V/A mediators, where weaker couplings probed)
- monojet searches seem to be the more competitive, although from more complex topologies or different signatures, complementary informations might be extracted
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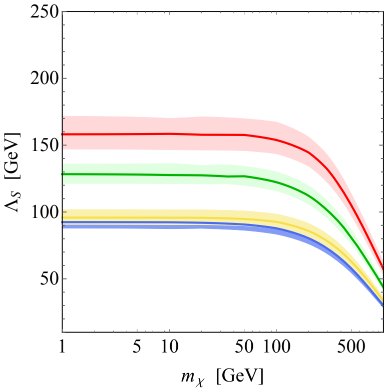
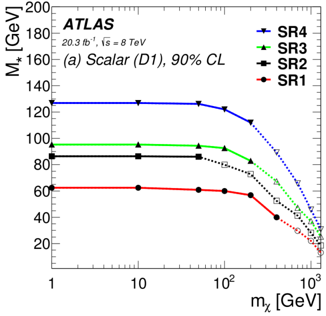
Thank you for your attention!

validation for $t\bar{t} + \not{E}_T$





left green ↔ right blue (hl)
left blue ↔ right green (hh)