Dark Matter + Heavy Quarks in scalar interactions at hadron colliders

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Outline

- The theoretical framework
- A "modified mono-jet" analysis
- Expected sensitivity to SI interactions

arXiv:1307.7834v2 [hep-ex] 1 Aug 2013

Dark Matter at the LHC Workshop, Chicago, Sep 19-21, 2013

~~Model-independent~~ EFT for DM

- WIMP hypothesis has been tested for decades and tight limits exist by now
  - Time to explore alternative approaches

- Effective field theory (EFT) offer simplified approach to DM
  - Dark matter is pair-produced at the LHC
  - Interaction between DM and SM is mediated by new particles
    - New particles too heavy to be directly seen at the LHC
  - Interactions are described through contact operators
    - Scalar, vector, axial-vector, tensor
  - For each operator, all observables (relic abundance, direct detection signal, collider signal) depend on single scale, M_*
    - Easy to combine results from direct, indirect, collider searches

See for example: Beltran, Hooper, Kolb, Krusberg, Tait, JHEP, 1009:037, 2010

Current DM searches at colliders

- Signature: missing E_T + $X_{visible}$ – "mono-X" approach
  - E_t^{miss} : χ particles are invisible in the detector
  - $X_{visible}$: energetic jet, photon, W, Z, … used to tag event
- Very competitive with direct searches
  - SD interactions: ~ best limits for most masses
  - SI interactions: best limits for low mass -- m_χ <O(10 GeV)
- Mono-X analyses already published for 7 & 8 TeV LHC data
  - See for example 7 TeV mono-jet and mono-photon publications:
    - ATLAS, JHEP 04 (2013) 075, arXiv:1210.4491 [hep-ex]
    - CMS, JHEP 09 (2012) 094, arXiv:1206.5663 [hep-ex]
    - ATLAS, Phys. Rev. Lett. 110 (2013) 011802, arXiv:1209.4625 [hep-ex]
    - CMS, Phys. Rev. Lett. 108 (2012) 261803, arXiv:1204.0821 [hep-ex]

Theory background

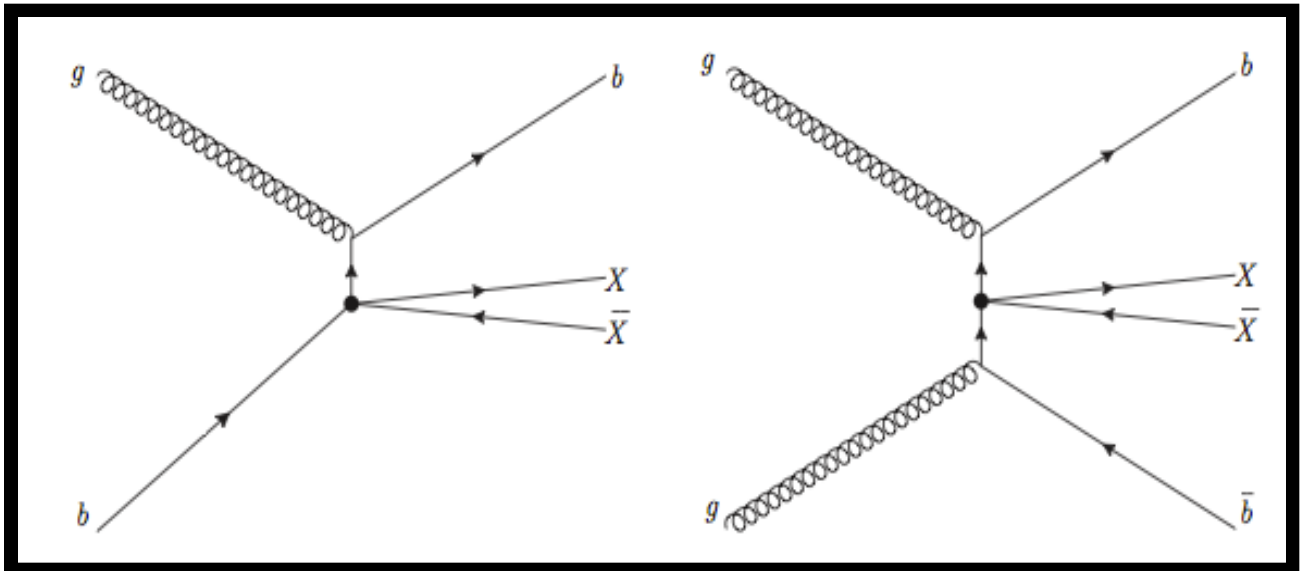
- We focus on an effective scalar interaction between DM and quarks described by D1 operator

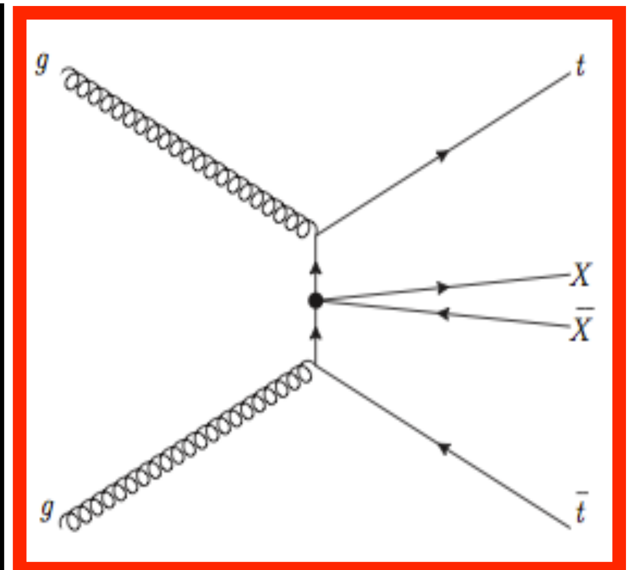
$$O_{scalar} = \sum_q \frac{m_q}{M_*^3} \bar{q} q \bar{\chi} \chi$$

  - M_* single scale that describes strength of interaction
- $O_{scalar} \sim m_q$ enhances couplings to t and b
  - Kinematic and PDF suppression for t and b are not a showstopper
    - Probing dark matter couplings to top and bottom at the LHC
      T.Lin, R.Kolb and L.Wang, Phys.RevD.88.063510, arXiv:1303:6638
  - Standard mono-jet analysis not very sensitive to O_{scalar}
    - Exploiting b and t in final state improve limits on O_{scalar} substantially
  - Advantages for background suppression
    - b-tagging leading jet suppresses backgrounds by $\sim 10^2$

DM + heavy jets at the LHC

Signal:





Direct b production:
Smaller contribution to x-section

$t\bar{t}$ channel:
dominant contribution

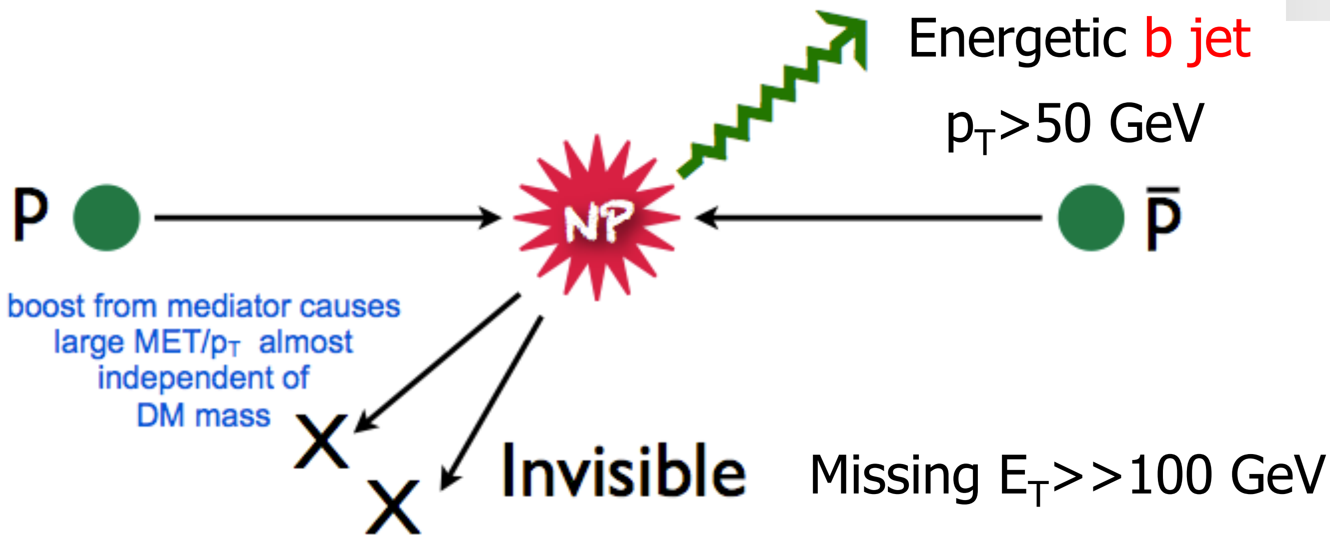
Backgrounds:

- Z+jets, W+jets, Standard Model $t\bar{t}$ production

Scenarios and Simulation

- Work conducted in the Snowmass context
- Simulation
  - Signal: MadGraph5 and PYTHIA
    - x-section for DM+b normalized using MCFM Dark (at NLO)
  - Background: common Snowmass production
  - Detector simulation: ”Snowmass detector” in DELPHES 3
    - b-tag efficiency ~70%, mis-tag rate: 1% (10%) for qq (cc)
- Scenarios considered
  - Scenario 1: LHC Run 2
    - 300 fb^{-1} at 14 TeV with pileup of 50 (circa 2020)
  - Scenario 2: Very High-luminosity LHC
    - 3000 fb^{-1} at 14 TeV with pileup of 140
  - Scenario 3: High-energy LHC
    - 3000 fb^{-1} at 33 TeV with pileup of 140

Analysis strategy



- Signature: large E_T^{miss} recoiling against energetic b-jet(s)
  - Lepton veto to suppress W+jet and Z+jet, SM tt backgrounds
- "Direct b production" channels
  - Low jet multiplicity, ~1 b-jet
- "tt" channel
  - Higher probability of >1 b-jet, harder E_T^{miss} spectrum

From T. Lin et al., arXiv:1303:6638

Background suppression

- B-tagging is very powerful in suppressing SM backgrounds

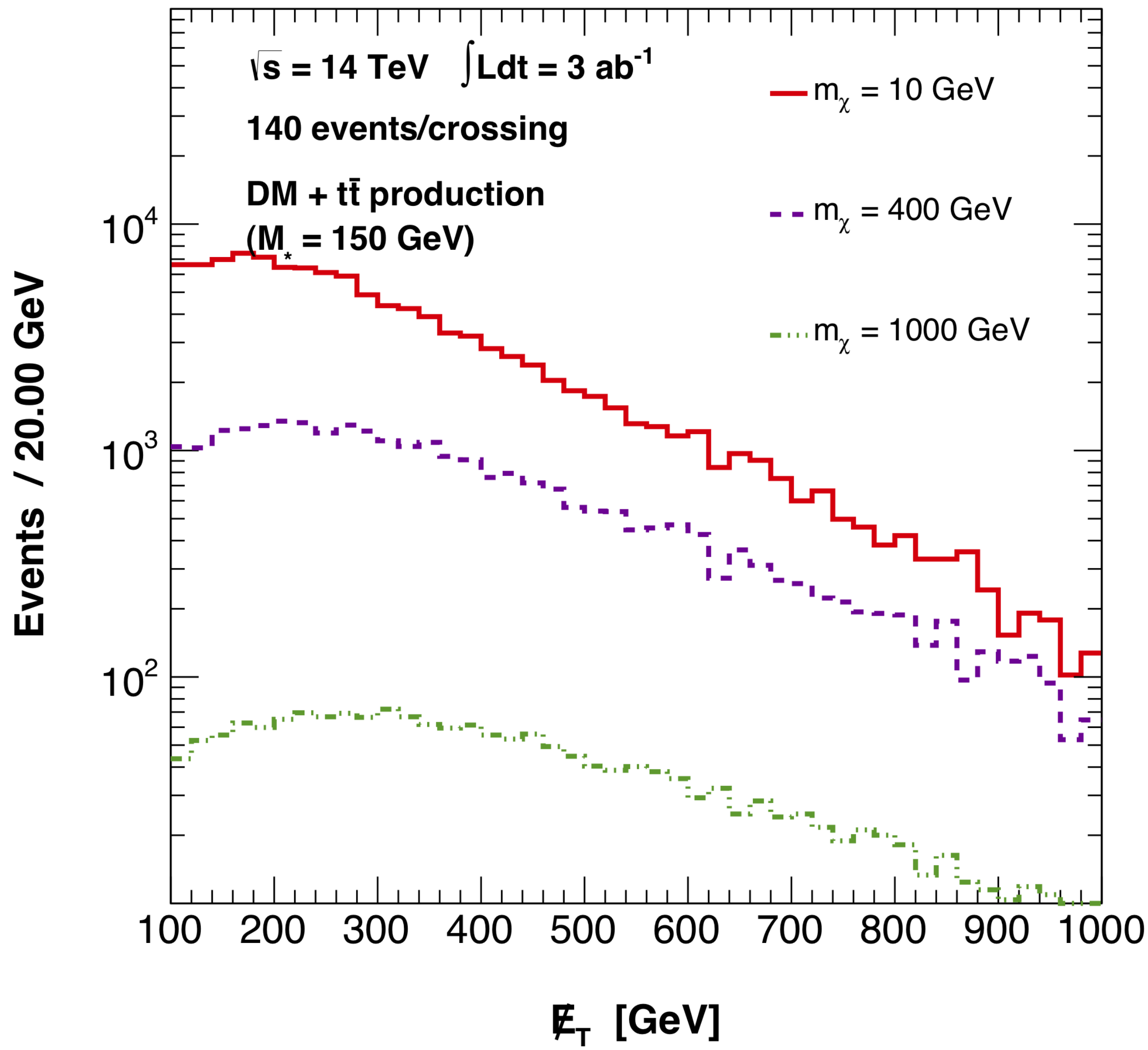
	Process	Monojet	b-tag on j_1
Background	Z+jets(fake)	406 fb	7 fb
	$Z+b$+jet	6.7 fb	3 fb
	W+jets,$W+b$	95 fb	2 fb
	$t\bar{t}$+jets	16 fb	6 fb
Signal	$\bar{X}X$+jets	11 fb	0.7 fb
	$\bar{X}X+b$+jets	65 fb	33 fb
	$\bar{X}X+t\bar{t}$	244 fb	113 fb

$\varepsilon_{back} \sim 2\%$

$\varepsilon_{signal} \sim 50\%$

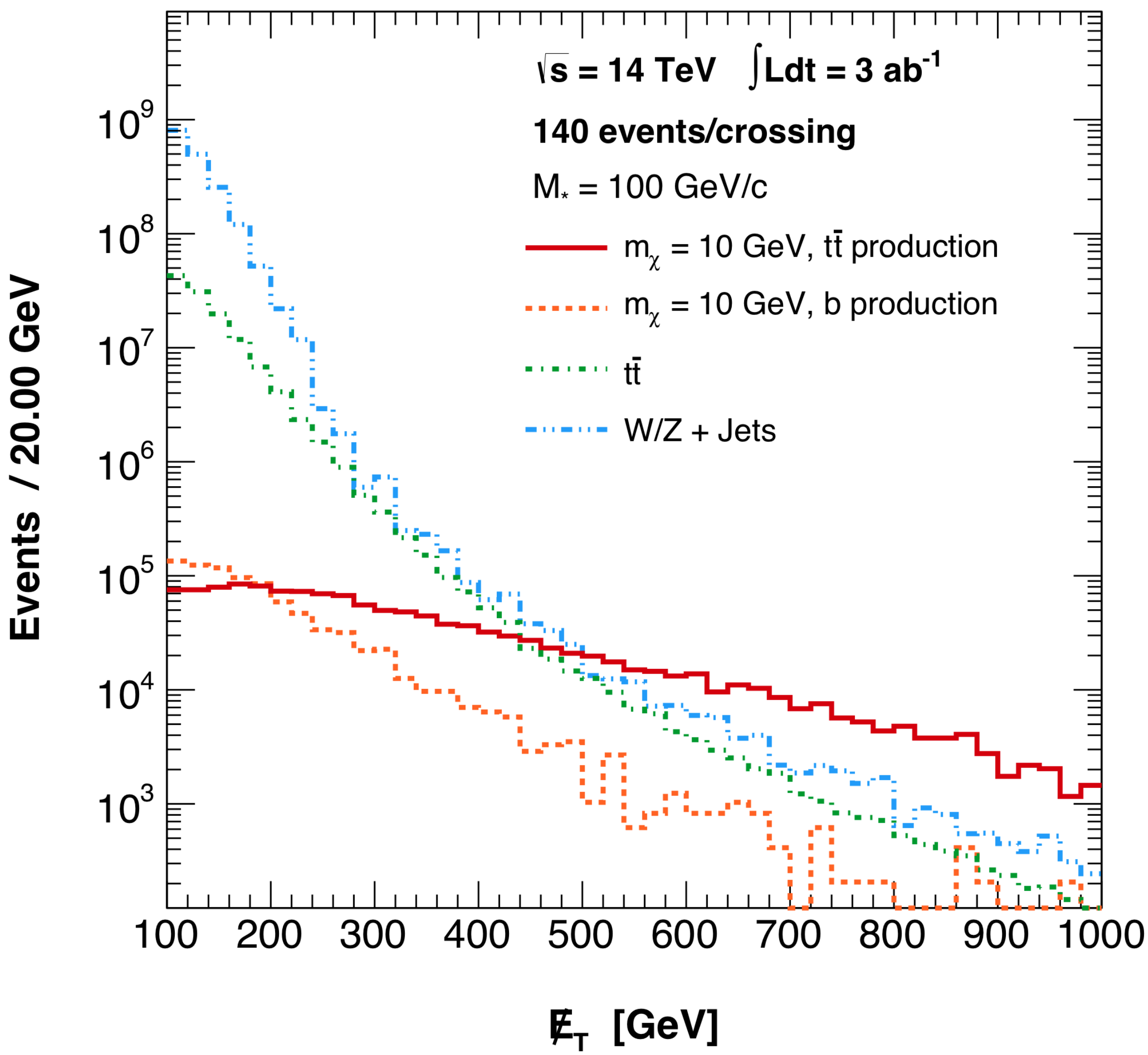
Expected signal (M_*=50GeV, m_χ =10GeV) and background at 8 TeV
Basic cuts applied: E_T^{miss}>350 GeV, p_T^{lead}>100 GeV

E_t^{miss} vs m_χ and M_*



tt production of DM

E_t^{miss}: signal vs background

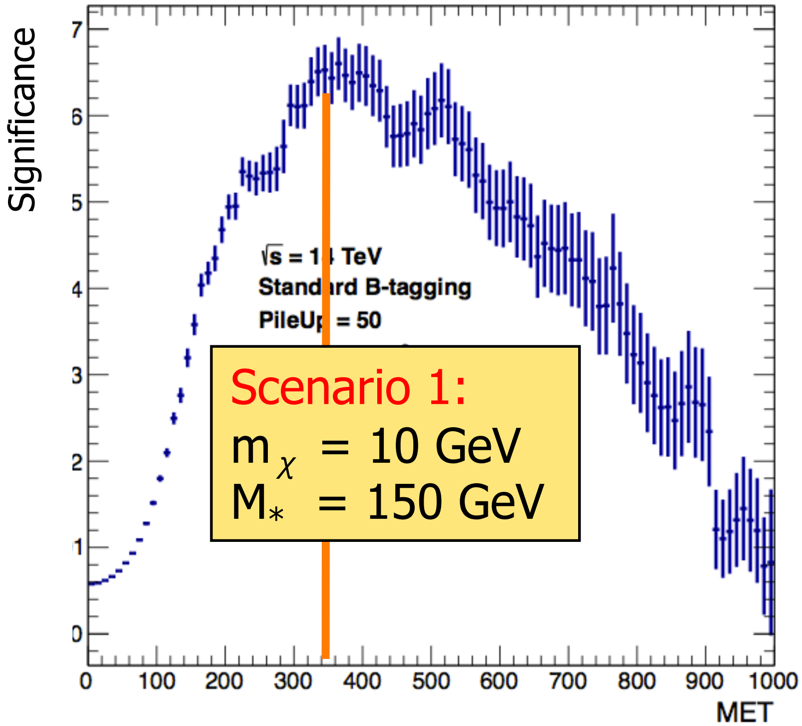


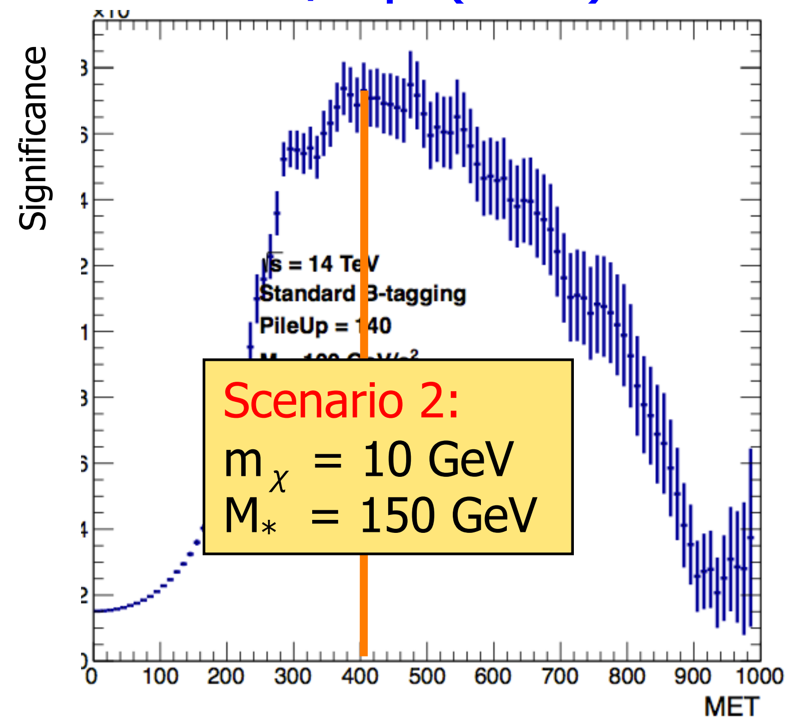
Signal assumptions:

- $M_* = 100$ GeV
- $m_\chi = 10$ GeV

Cut optimization

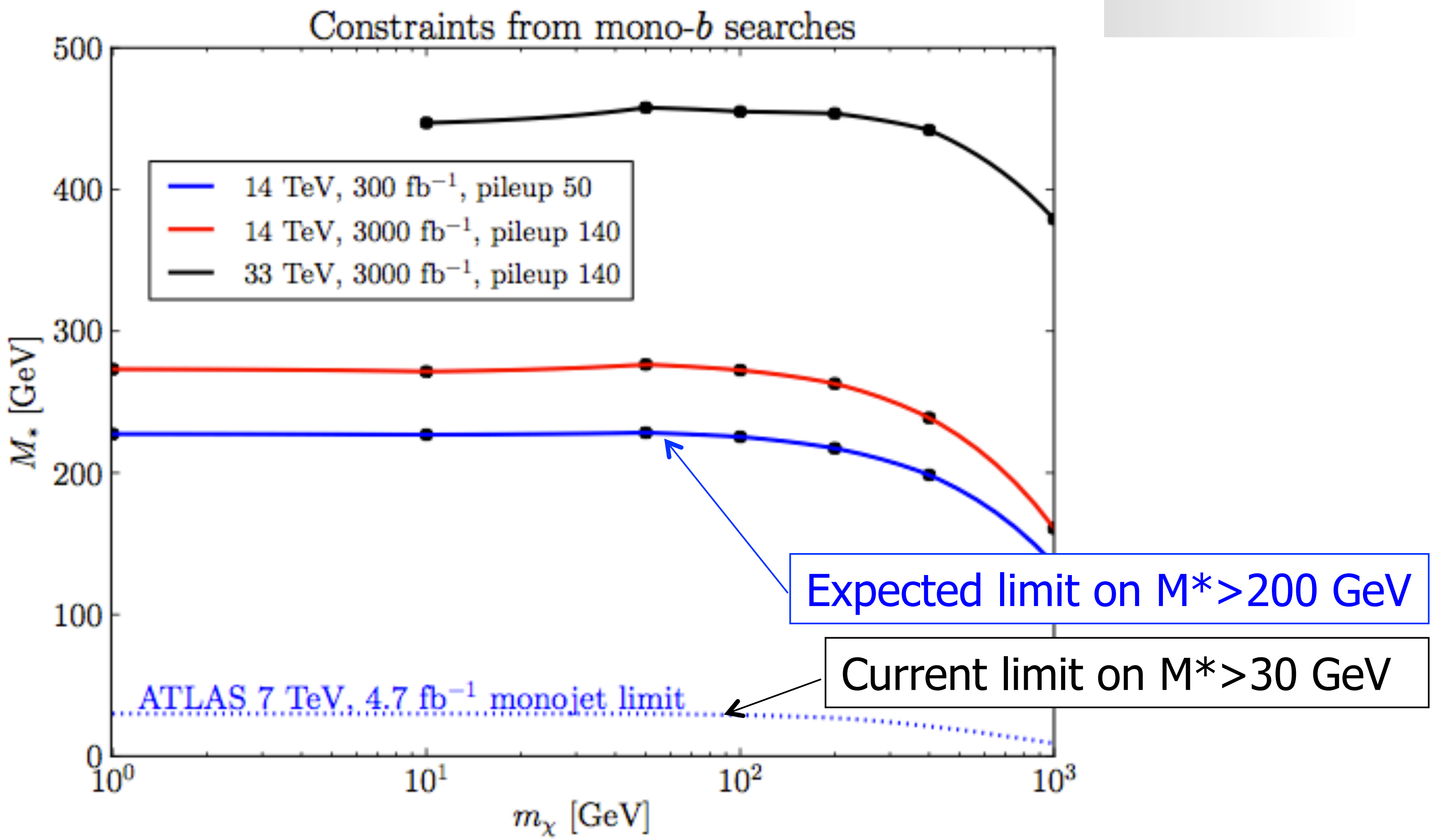
Cut on E_T^{miss} optimized for each scenario and various m_χ hypotheses maximizing Significance=S/sqrt(S+B)





Process	Scenario 1	Scenario 2	Scenario 3
$\not{E}_T$ cut [GeV]	350	400	440

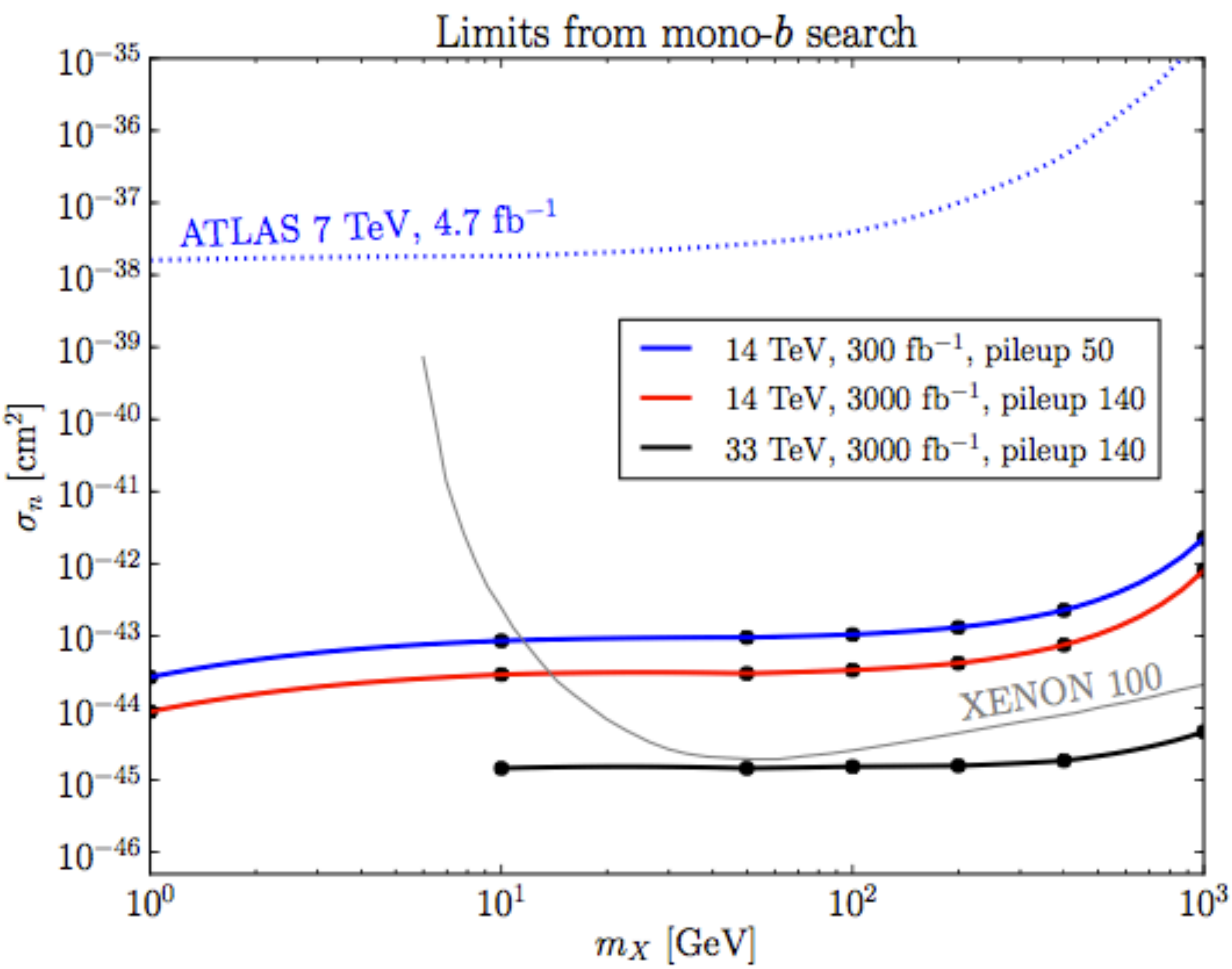
Results: constraints on M_*



90% CL limits on the scalar operator from DM plus heavy jet, including couplings to tops and bottoms

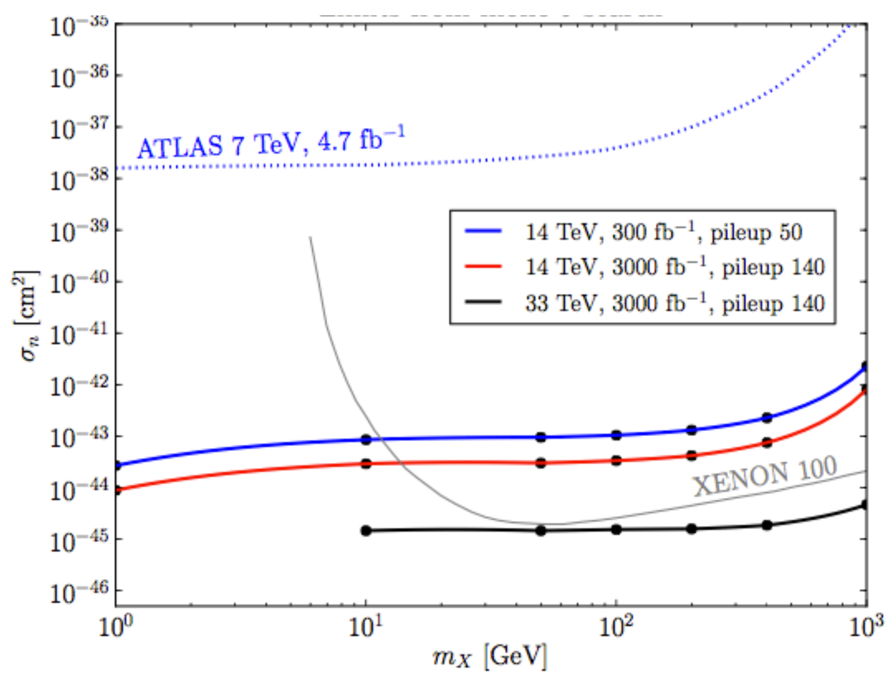
Results: constraints on $\sigma^{SI}_{DM\text{-}n}$

Using $$\sigma_n = \frac{(0.38 m_n)^2 \mu_{\chi n}^2}{\pi M_*^6} \approx 2\times 10^{-38}\,\mathrm{cm}^2 \left(\frac{30\ \mathrm{GeV}}{M_*}\right)^6$$



Conclusion

- Sensitivity to scalar interaction between DM and quarks boosted by focusing on final states with a heavy quark produced at the LHC
  - Compared to generic mono-jet
  - Signature: b-tag jets + E_t^{miss}



- Unique reach at low m_χ
  - Many "observations" of light DM

- This work based on T. Lin et al., arXiv:1303:6638
  - Other simplified models with the scalar mediator
  - e.g.: Cotta et al. arXiv:1305.6609 [hep-ph]

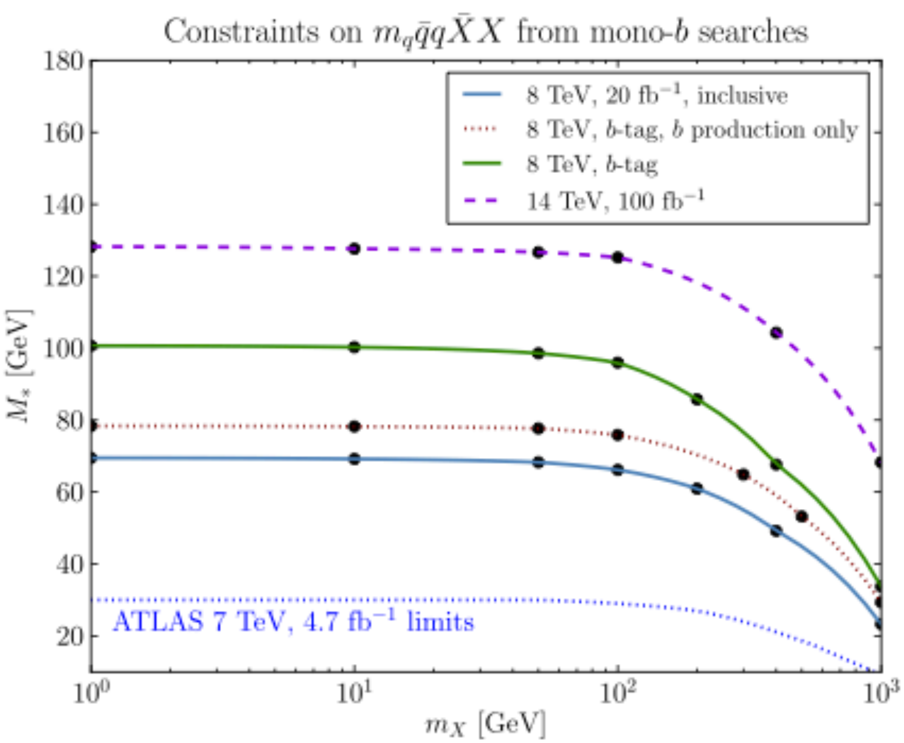
Outlook

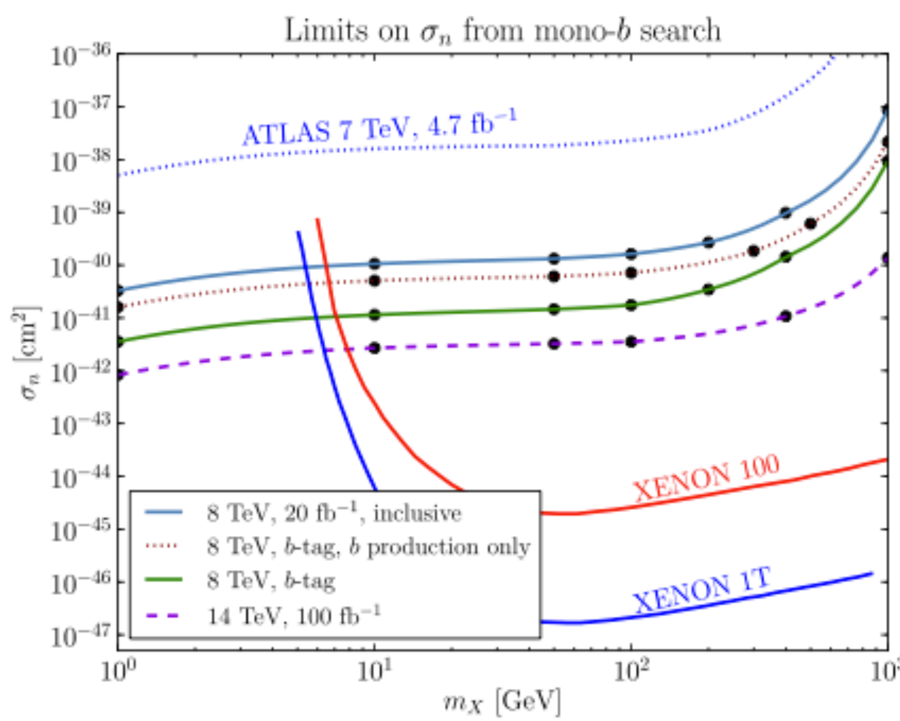
- This study is very preliminary
  - This work focused on mono-b approach: improvement expected with dedicated $t\bar{t}$ analysis
    - Expected improvement on limits on $\sigma_{n\text{-}DM}$: ~ 5
    - Probing separately b and t production: probe flavor structure of couplings between DM and quarks
  - Theory is making progress
    - e.g. build UV complete model, derive fully consistent constraints
- This work focused on long-term LHC scenarios
  - High luminosity and high energy LHC for Snowmass
  - First experimental results will be ready soon
    - 8 TeV analysis under way in ATLAS

From T. Lin et al., arXiv:1303:6638

Limits expected for 8 TeV

___ “mono-b” analysis with 20 fb @ 8 TeV





- Expected limit on M_*~100 GeV
  - Now: 30 GeV from 7 TeV standard mono-jet analysis