Momentum Dependent Dark Matter Operators and Monojets at the LHC

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With
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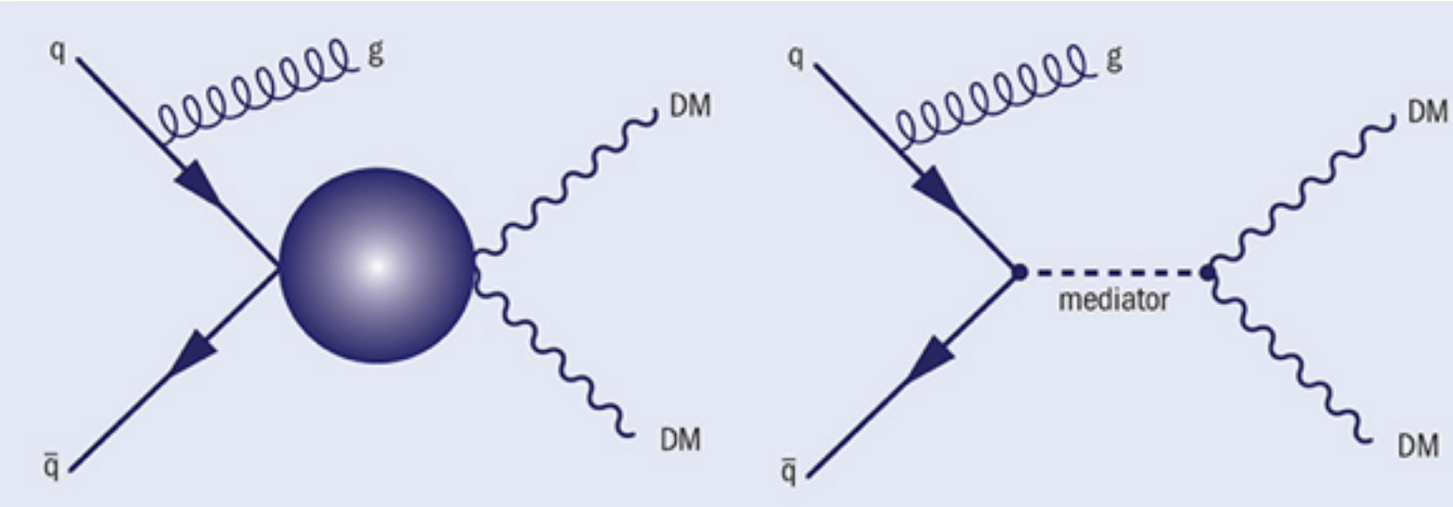
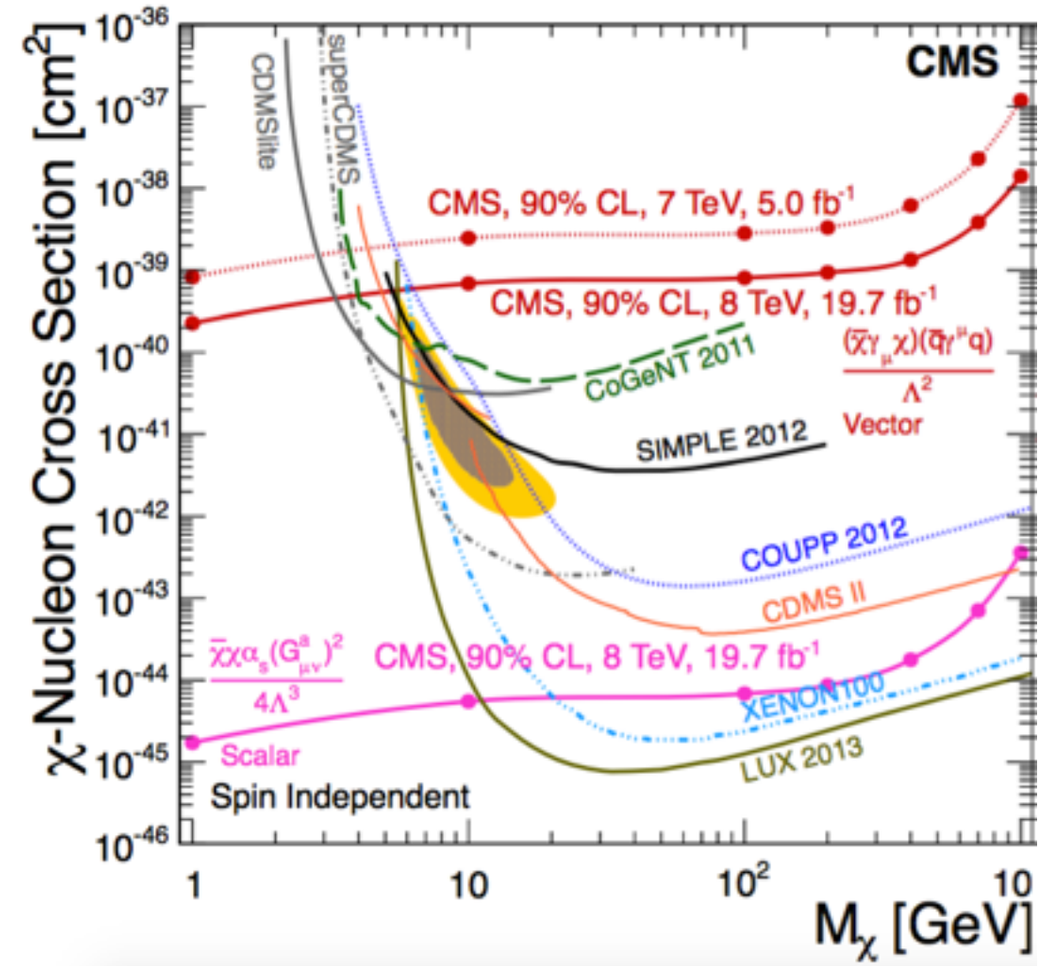
arXiv: 1605.02684 (Les Houches Proceedings)

The Physics Case

✳ Dark Matter Searches at LHC —> Mono-X + MET searches





$$\mathcal{L}_\chi^{\rm eff} = \frac{1}{\Lambda^2}\bar{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q \qquad \sigma_p^{\rm SI} = \frac{f^2\mu_{\chi n}^2}{\pi\Lambda^4}$$

σ (j + MET) ~ $1/\Lambda^4$

$$\mathcal{L}_{\rm vector} = g_{\rm q}\sum_{q=u,d,s,c,b,t} Z'_\mu\bar{q}\gamma^\mu q + g_\chi Z'_\mu\bar{\chi}\gamma^\mu\chi$$

$$\mathcal{L}_{\rm axial-vector} = g_{\rm q}\sum_{q=u,d,s,c,b,t} Z'_\mu\bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu\bar{\chi}\gamma^\mu\gamma^5\chi.$$

Operators beyond this description ?

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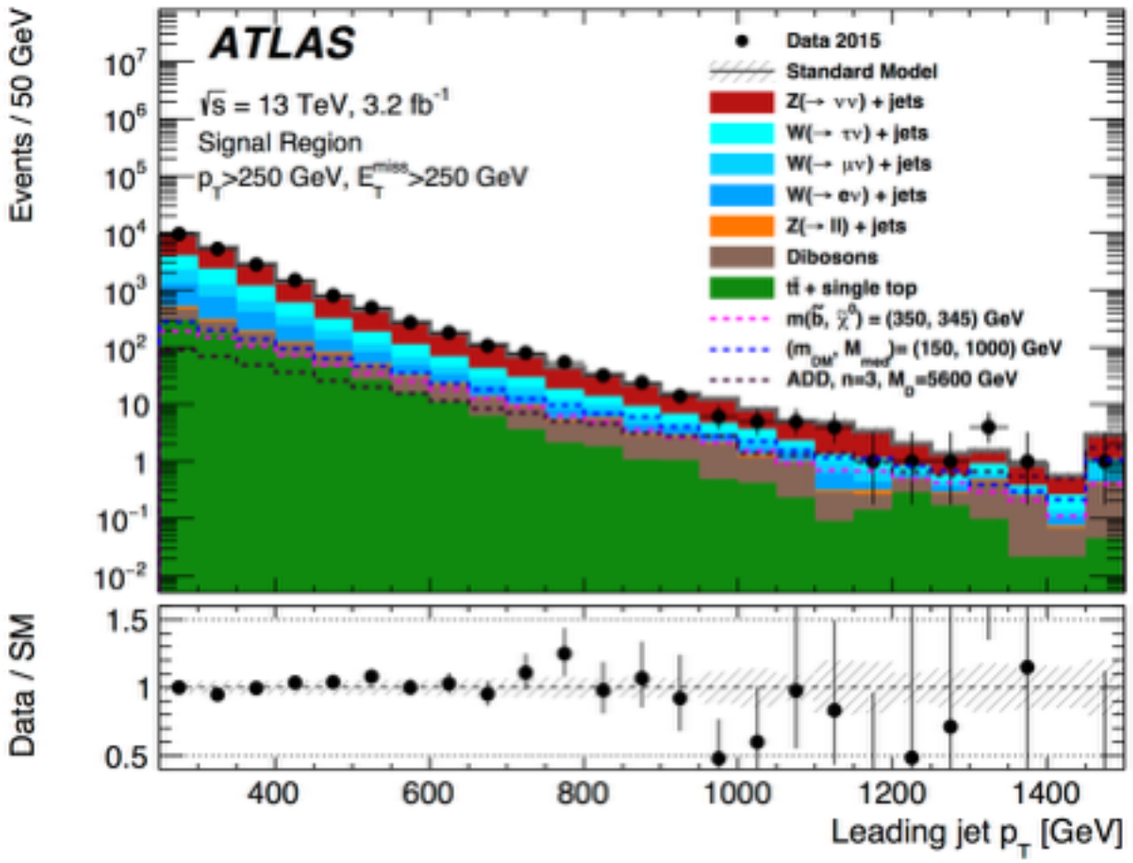

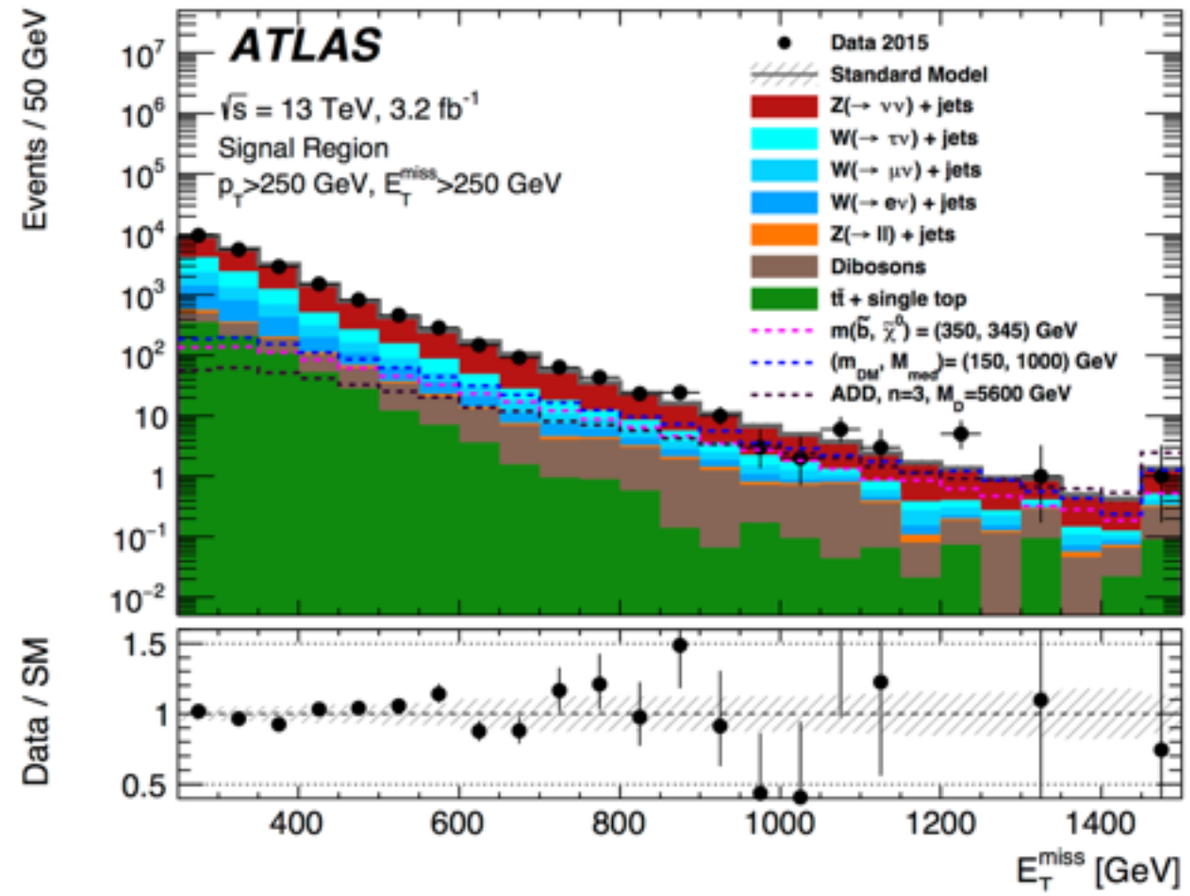

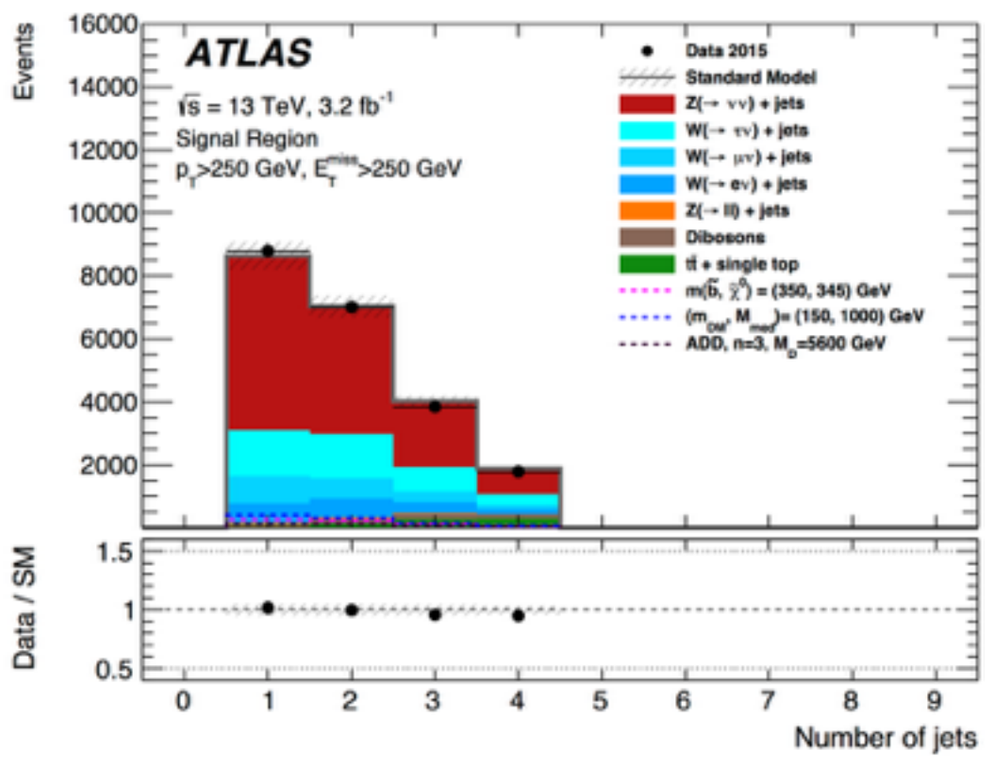

Can kinematic distributions tell us something about the DM operators

The Physics Case : An alternative scenario

- Is more physics captured in the momentum and MET distribution.
- Momentum dependent operators .
- Motivation :
  - Composite Higgs scenarios with pNGBs.
  - Derivative couplings suppressed by 1/f (shift symmetry).

Minimal Higgs Portal

$$\mathcal{L}_\eta = \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu\eta\partial^\mu\eta - \frac{1}{2}\mu_\eta^2\eta^2 - \frac{1}{4}\lambda_\eta\eta^4 - \frac{1}{2}\lambda\eta^2 H^\dagger H + \frac{1}{2f^2}(\partial_\mu\eta^2)\partial^\mu(H^\dagger H)$$

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No momentum dependence

The Physics Case : Derivative couplings

Monojet cross section in the off-shell region

$$\hat{\sigma}(gg \to gh^* \to g\eta\eta) \propto \frac{\theta(p_h^2 - 4m_\eta^2)}{(p_h^2 - m_h^2)^2 + \Gamma_h^2 m_h^2} \left(\frac{p_h^2}{f^2} - \lambda\right)^2 \sqrt{1 - \frac{4m_\eta^2}{p_h^2}}$$

$$p_h^2 > 4m_\eta^2 > m_h^2.$$

$$m_\eta \gtrsim m_h/2,\ \lambda \lesssim 1$$

- ✤ Cross section too small to be constrained/ observed at the LHC.
- ✤ Higgs Couplings force f > 500 GeV.
- ✤ Cross section for MD couplings ~ 1fb

The Physics Case : The singlet scalar case

$$\mathcal{L}_{\eta,s} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu\eta\partial^\mu\eta - \frac{1}{2}m_\eta^2\eta\eta + \frac{1}{2}\partial_\mu s\partial^\mu s - \frac{1}{2}m_s^2 ss$$
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m_s, m_η, f, $c_{s\eta}$, $c_{\partial s\eta}$ and c_{sg}

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Recasting the 8 TeV ATLAS monojet in Madanalysis5

- This analysis targets direct $\tilde{t}_1$ pair production in compressed spectra scenarios
- In particular it is optimised for $\tilde{t}_1 \to c + \tilde{\chi}_1^0$ using a monojet and c-tagged search strategies

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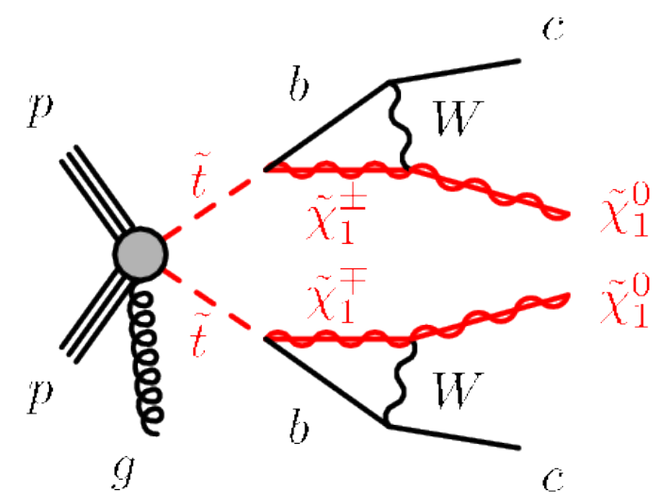

Links to SLHA files for the processes studied in the paper

sbottom pair production with sbottom → bottom + neutralino

stop pair production with stop → charm + neutralino

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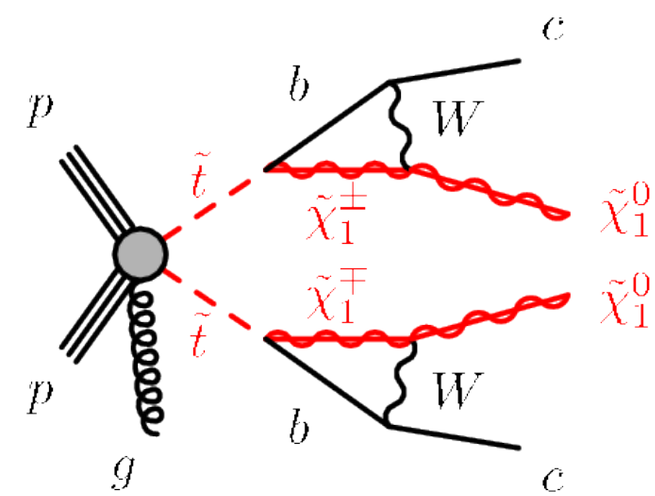

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		200, 125		200, 195		250, 245	
	All	181902	100%	103191	100%	48103	100%

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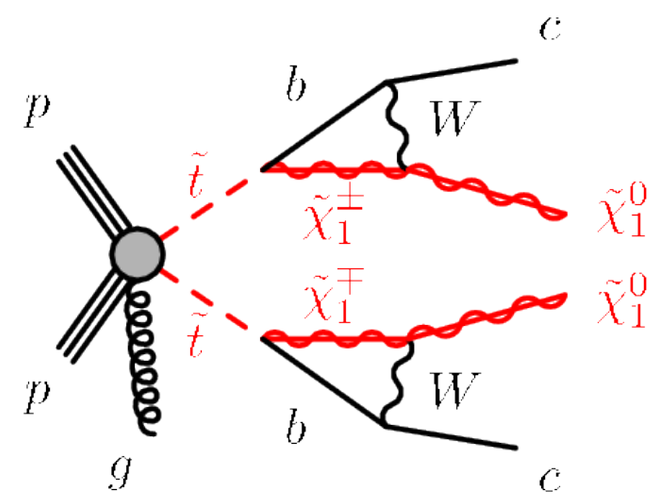

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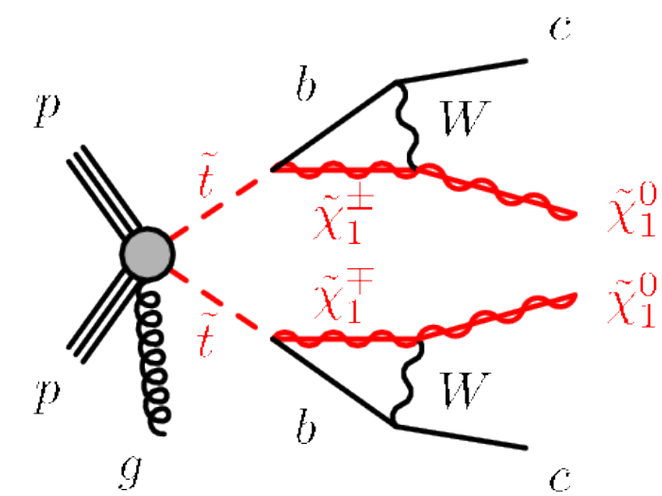

Links to SLHA files for the processes studied in the paper

sbottom pair production with sbottom → bottom + neutralino

stop pair production with stop → charm + neutralino

stop pair production with stop → bottom + f f' + neutralino

SR	Cut	$m_{\tilde{t}_1}$ [GeV], $m_{\tilde{\chi}_1^0}$ [GeV]					
		200, 125		200, 195		250, 245	
	All	181902	100%	103191	100%	48103	100%

Communication with ATLAS sorted this problem out

Recasting the 8 TeV ATLAS monojet in Madanalysis5

Information | Citations (1) | Files

Madanalysis 5 implementation of the ATLAS monojet analysis documented in arXiv:1407.0608, Phys. Rev. D. 90, 052008

Sengupta, Dipan; Chalons, Guillaume (LPSC, Grenoble)

cut	$\tilde{t} \to c\tilde{\chi}_1^0$ (200/125) cutflow # events (scaled to σ and $\mathcal{L}$)	$\tilde{t} \to c\tilde{\chi}_1^0$ (200/125) cutflow # events (official)	$\tilde{t} \to c\tilde{\chi}_1^0$ (200/195) cutflow # events (scaled to σ and $\mathcal{L}$)	$\tilde{t} \to c\tilde{\chi}_1^0$ (200/195) cutflow # events (official)
Initial # of events	376047.3		376047.3	
$\not{E}_T > 80$ GeV Filter	192812.8 (−48.7%)	181902.0	104577.6 (−72.2%)	103191.0
$\not{E}_T > 100$ GeV	136257.1 (−29.3%)	97217.0	82619.0 (−21.0%)	64652.0 (−37.3%)
Trigger, ...	-	82131.0 (−15.5%)	-	57566.0 (−30.3%)
Lepton veto	134894.2 (−1.0%)	81855.0 (−15.8%)	82493.9 (−0.2%)	57455.0 (−11.1%)
$N_{\text{jets}} \leq 3$	101653.7 (−24.6%)	59315.0 (−27.5%)	75391.5 (−8.6%)	52491.0 (−8.6%)
$\Delta\phi(\not{E}_T, \text{jets}) > 0.4$	95568.8 (−2.1%)	54295.0 (−8.5%)	70888.1 (−1.2%)	49216.0 (−6.2%)
$p_T(j_1) > 150$ GeV	17282.8 (−81.9%)	14220.0 (−73.8%)	25552.0 (−64.0%)	20910.0 (−57.5%)
$\not{E}_T > 150$ GeV	10987.8 (−36.4%)	9468.0 (−33.4%)	21569.1 (−15.6%)	18297.0(−12.5%)
M1 Signal Region				
$p_T(j_1) > 280$ GeV	2031.2 (−81.5%)	1627.0 (−82.8%)	4922.0 (−77.2%)	3854.0 (−78.9%)
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M2 Signal Region				
$p_T(j_1) > 340$ GeV	858.0 (−92.2%)	721.0 (−92.4%)	2509.0 (−88.4%)	1897.0 (−89.6%)
$\not{E}_T > 340$ GeV	344.4 (−59.9%)	282.0 (−60.9%)	1758.9 (−29.9%)	1518.0 (−20.0%)
M3 Signal Region				
$p_T(j_1) > 450$ GeV	204.3 (−98.1%)	169.0 (−98.2%)	773.3 (−96.4%)	527.0 (−97.1%)
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Disparities

- Issues :
  - JET + MET trigger efficiencies.
  - PYTHIA Tunes/Monte Carlo Configurations.
  - Which cross section to normalise to ?

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Disparities

Good Validation

- Issues :
  - JET + MET trigger efficiencies.
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  - Which cross section to normalise to ?

Recasting the 13 TeV ATLAS monojet in Madanalysis5

$\tilde{t} \to c\tilde{\chi}_1^0$ (350/345) cutflow				
cut	# events (scaled to σ and $\mathcal{L}$)	relative change	# events (Official)	relative change
Initial number of events	12906	-	12096	
$E_T^{\rm miss} > 100$ GeV	3930	32%	4354	36 %
Trigger, Event cleaning...	-	-		
Lepton veto	3138	26%	4354	36
$N_{\rm jets} \leq 3$	2926	24%	3870	32 %
$\Delta\phi(E_T^{\rm miss}, {\rm jets}) > 0.4$	2776	23 %	3507	29 %
$p_T^{\rm j1} > 250$ GeV	698	6 %	675	5.5%
$E_T^{\rm miss} > 250$ GeV	636	5.2 %	578	4.8 %
M1 Signal Region				
250 GeV $< {\rm E_T^{miss}} <$ 300 GeV	124	1.02 %	109	0.9 %
M2 Signal Region				
300 GeV $< {\rm E_T^{miss}} <$ 350 GeV	130	1.07%	123.1	1.01%
M3 Signal Region				
350 GeV $< {\rm E_T^{miss}} <$ 400 GeV	104	0.85%	99	0.82%
M4 Signal Region				
400 GeV $< {\rm E_T^{miss}} <$ 500 GeV	129	1.06 %	126	1.04 %
M5 Signal Region				
500 GeV $< {\rm E_T^{miss}} <$ 600 GeV	74	0.6 %	61	0.5 %
M6 Signal Region				
600 GeV $< {\rm E_T^{miss}} <$ 700 GeV	35	0.3 %	32	0.3%
M7 Signal Region				
${\rm E_T^{miss}} >$ 700 GeV	40	0.3 %	35.2	0.3 %

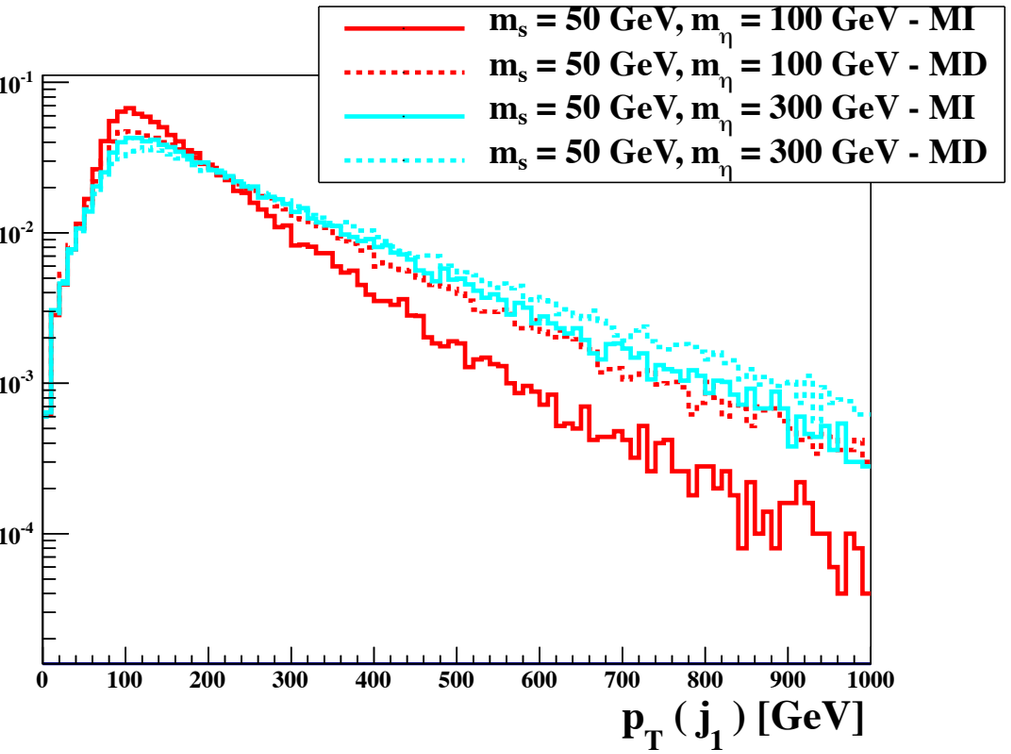
Disparities

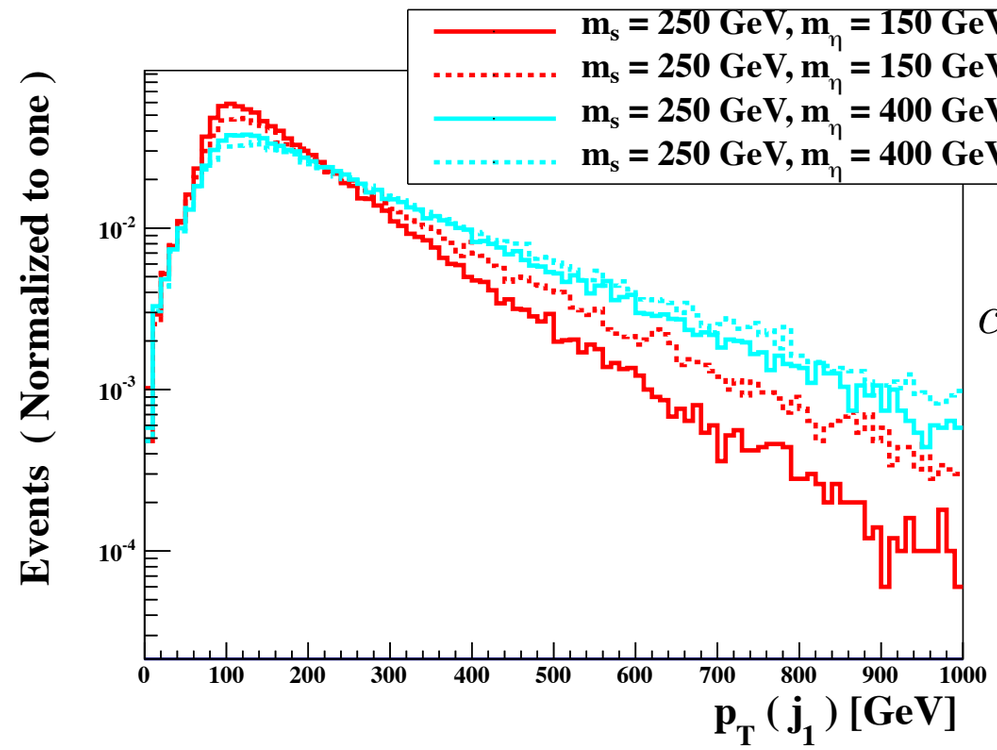
Good Validation

- Issues :
  - JET + MET trigger efficiencies.
  - PYTHIA Tunes/Monte Carlo Configurations.
  - Cross section normalization ?

Results

Momentum Dependence





$c_{gs} = 100$ and $f = 1$ TeV,

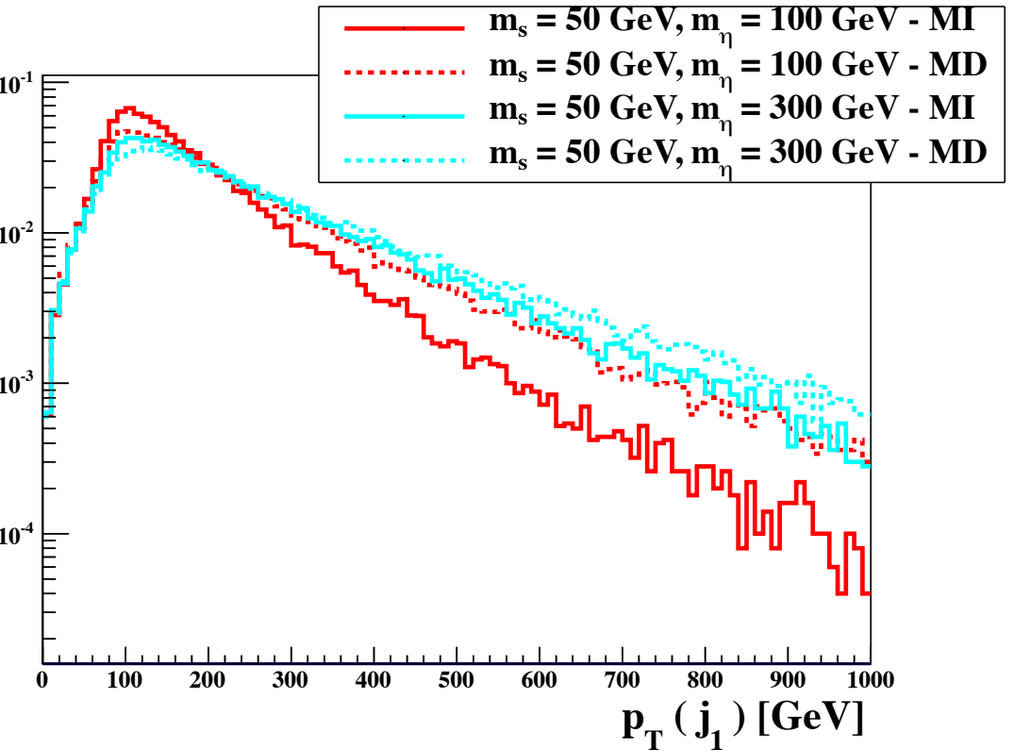
$c_{\partial s\eta} = 2.5$

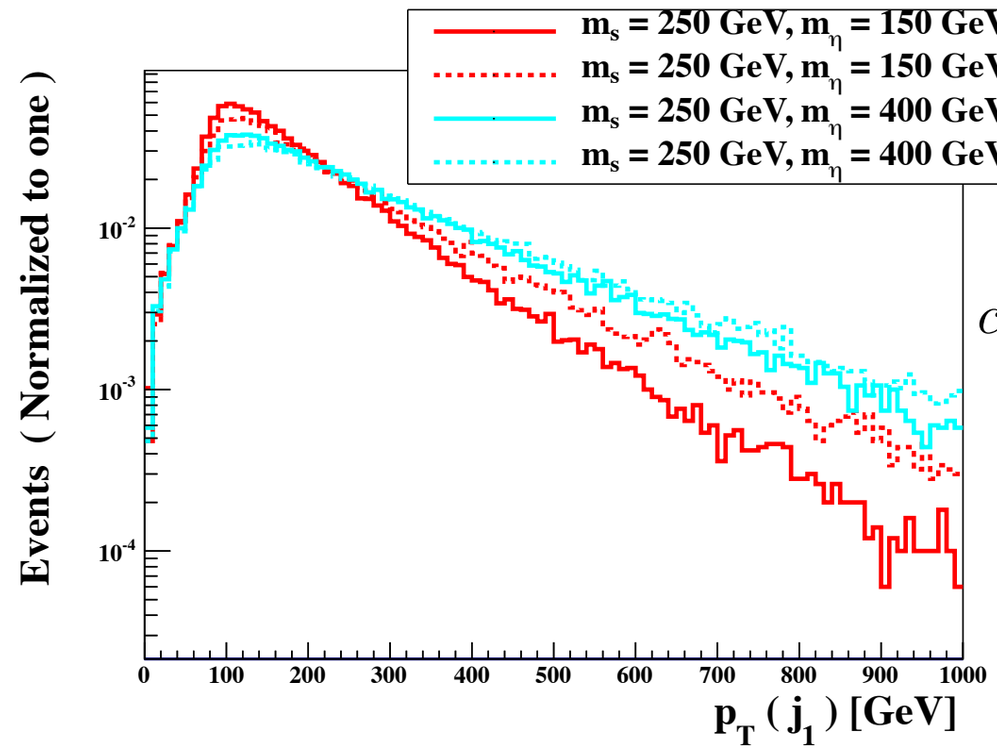
$c_{s\eta} = 0.5$

Unitarity ?

Results

Momentum Dependence





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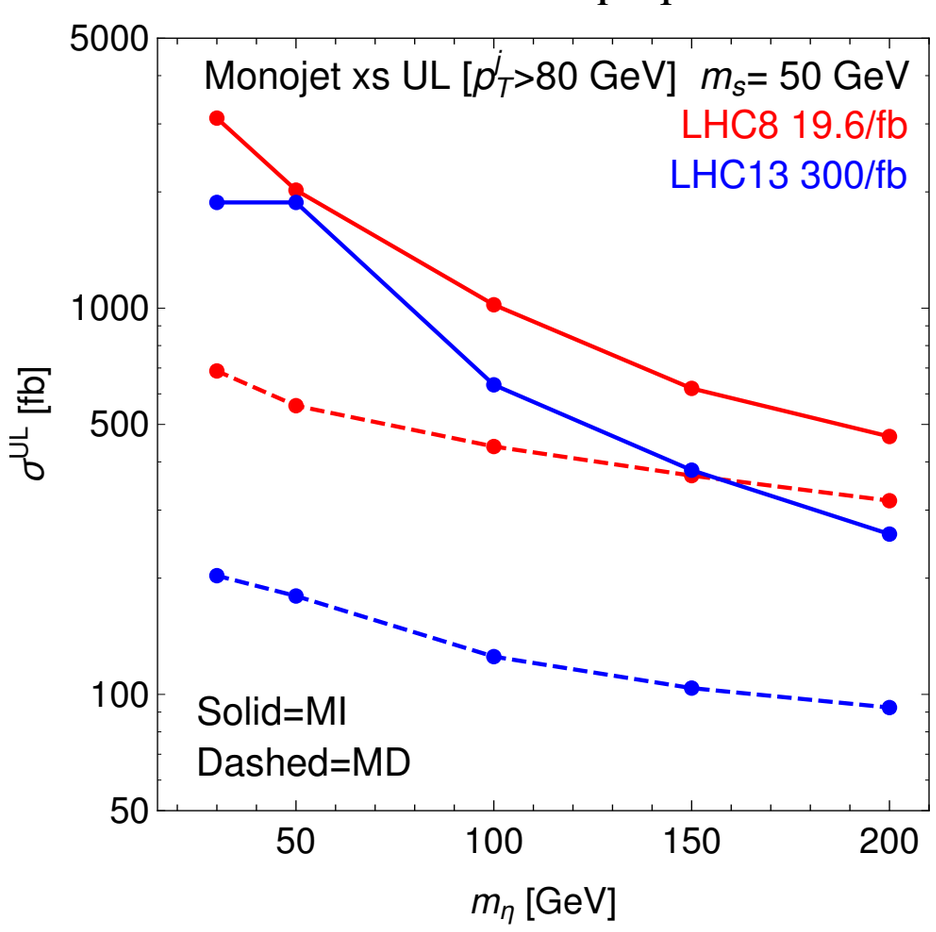
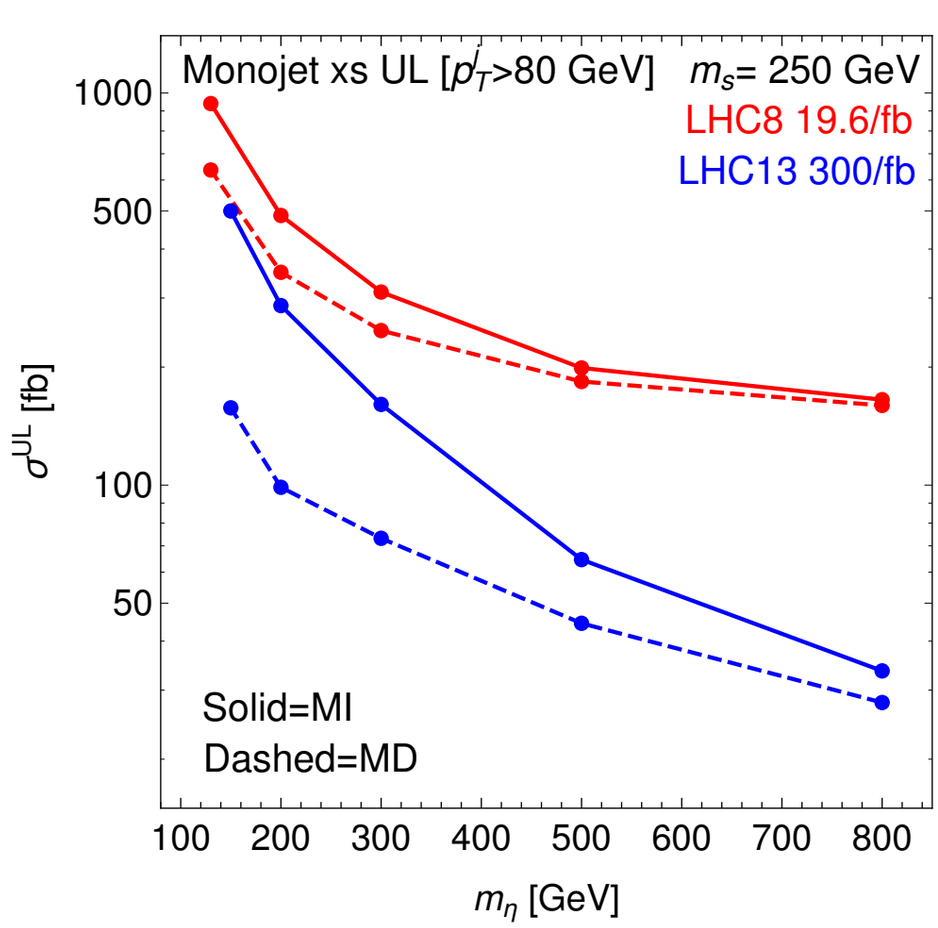
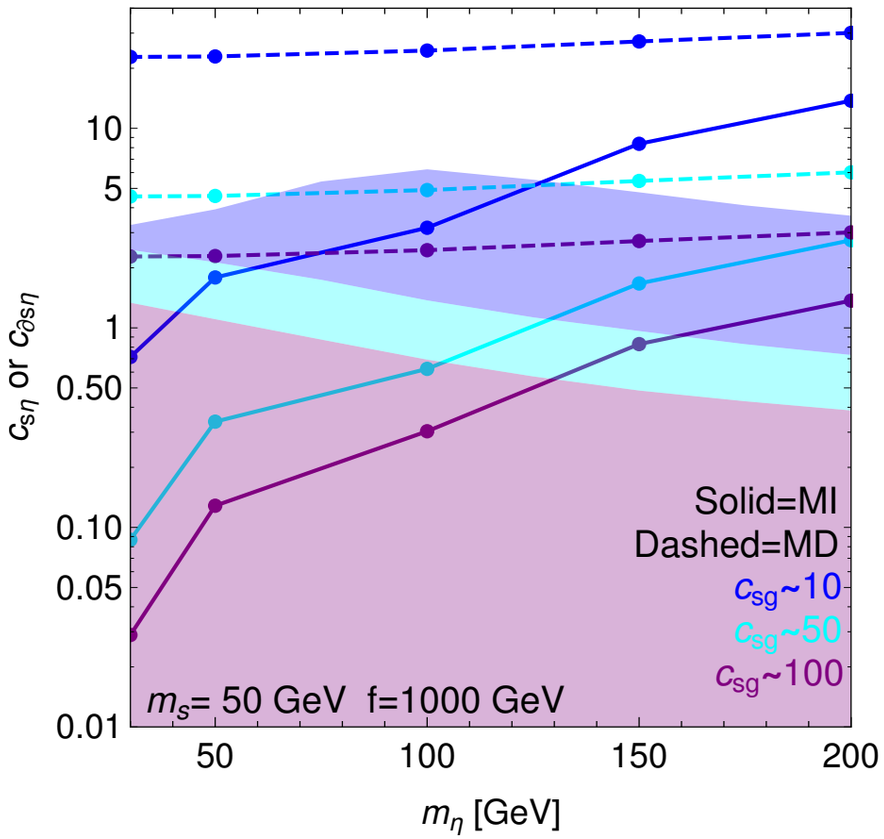
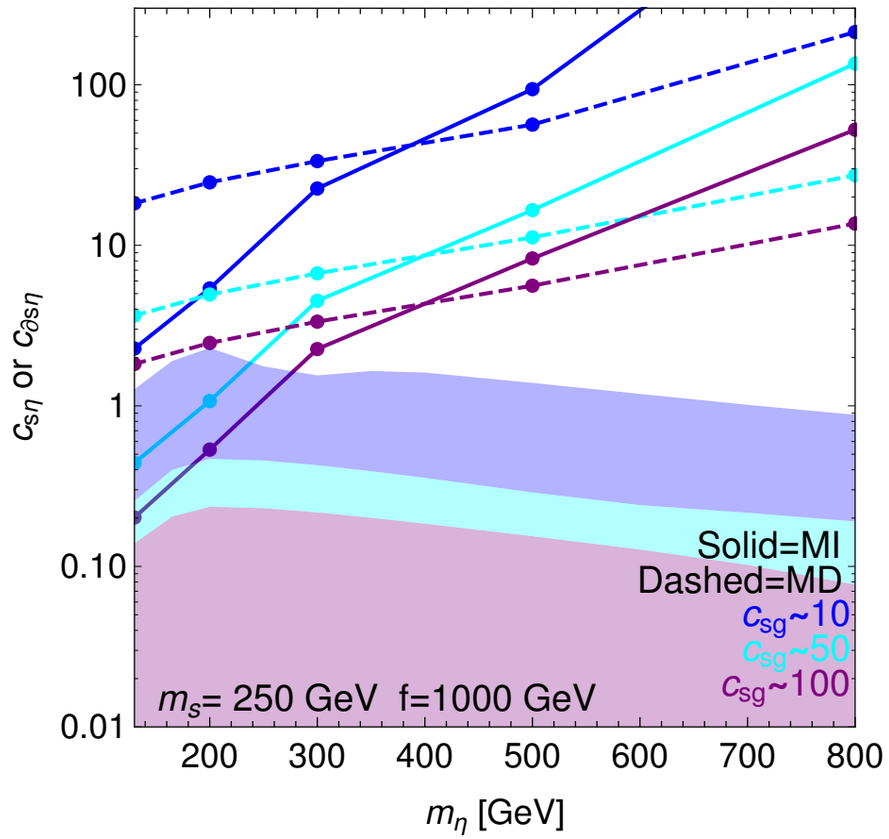




Results


10
5
1
0.50
0.10
0.05
0.01
50
100
150
200
$c_{s\eta}$ or $c_{\partial s\eta}$
m_η [GeV]
Solid=MI
Dashed=MD
c_{sg}~10
c_{sg}~50
c_{sg}~100
m_s= 50 GeV f=1000 GeV


100
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0.10
0.01
200
300
400
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600
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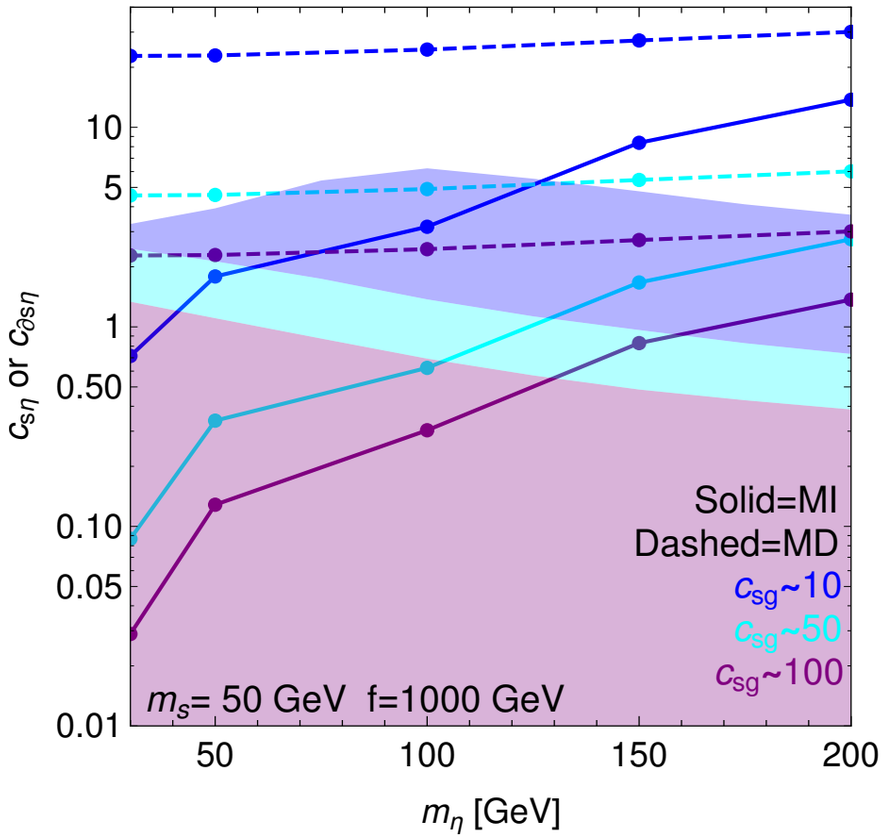
$c_{s\eta}$ or $c_{\partial s\eta}$
m_η [GeV]
Solid=MI
Dashed=MD
c_{sg}~10
c_{sg}~50
c_{sg}~100
m_s= 250 GeV f=1000 GeV

Results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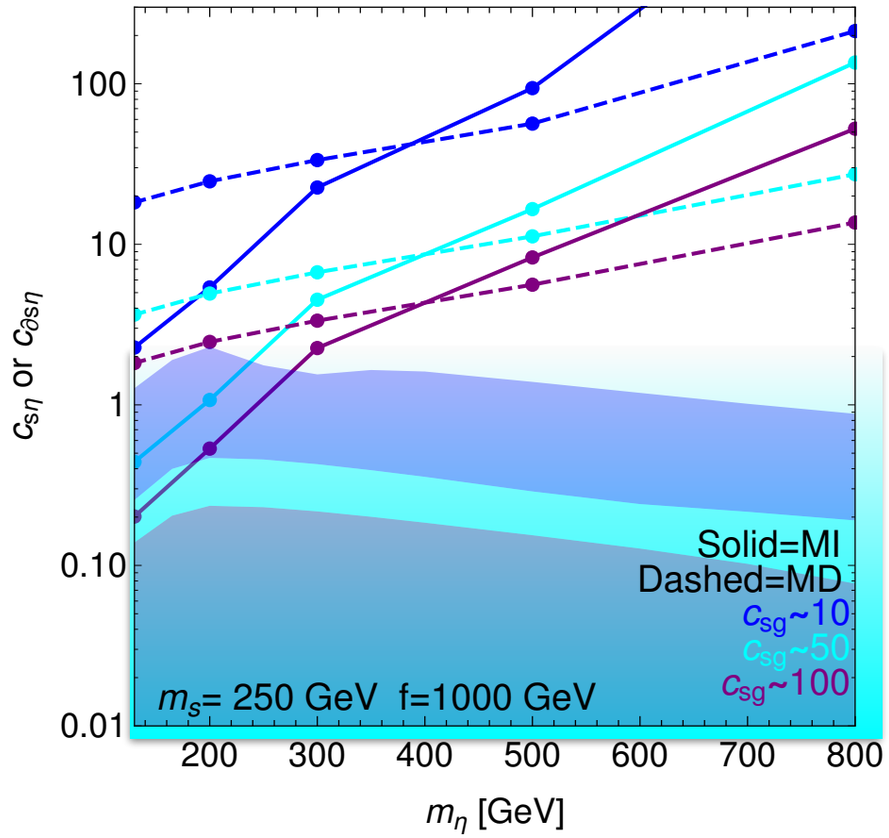
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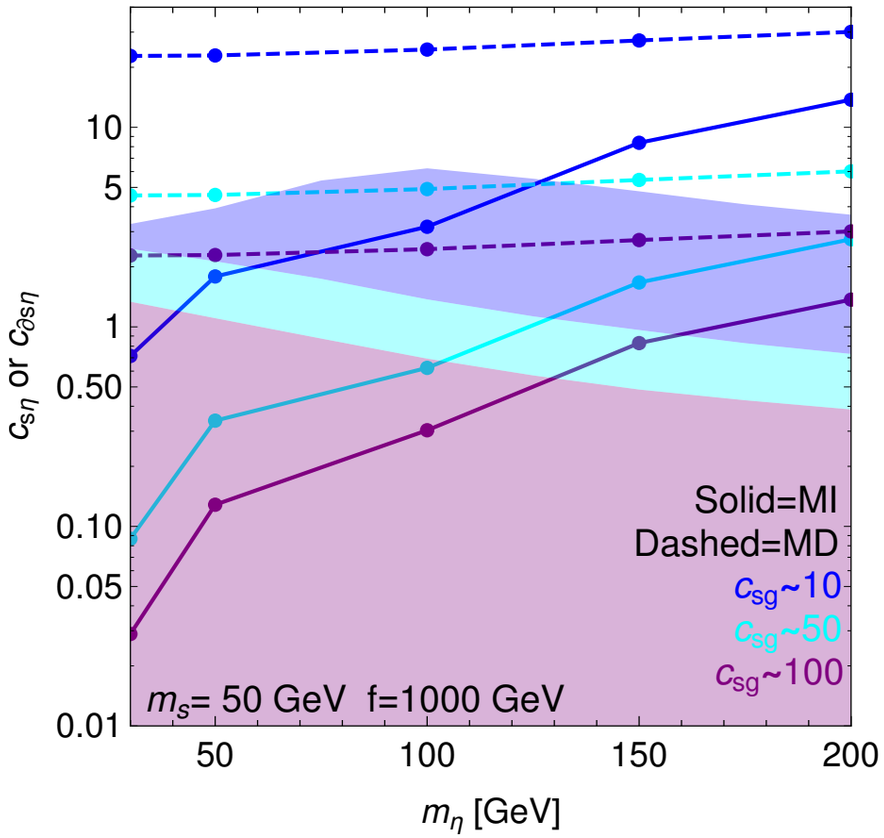
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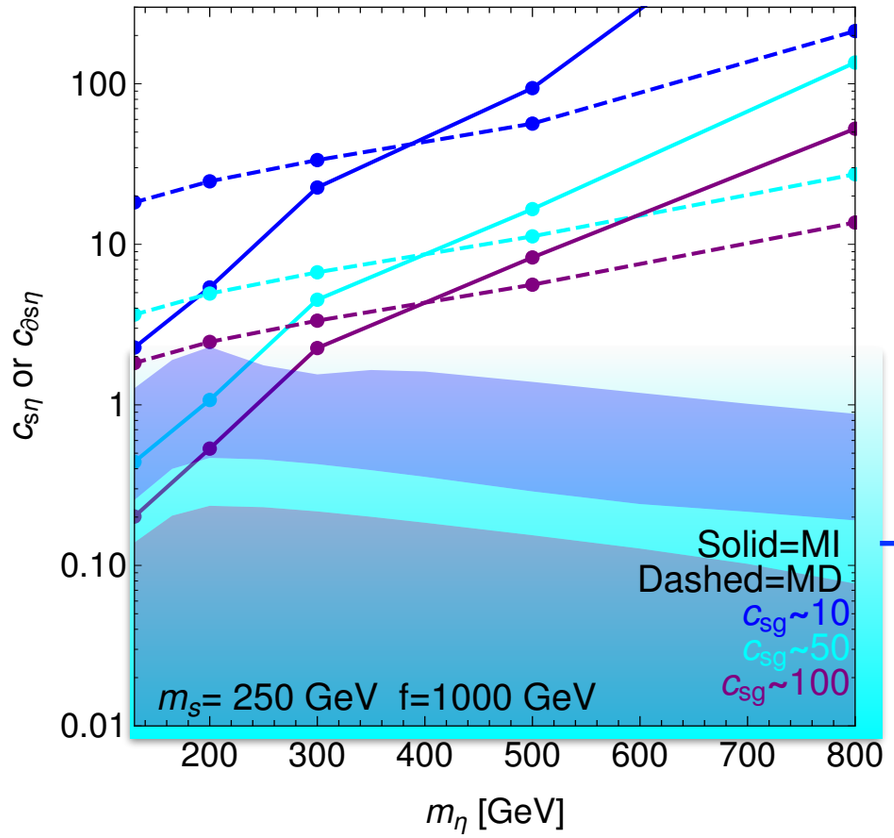
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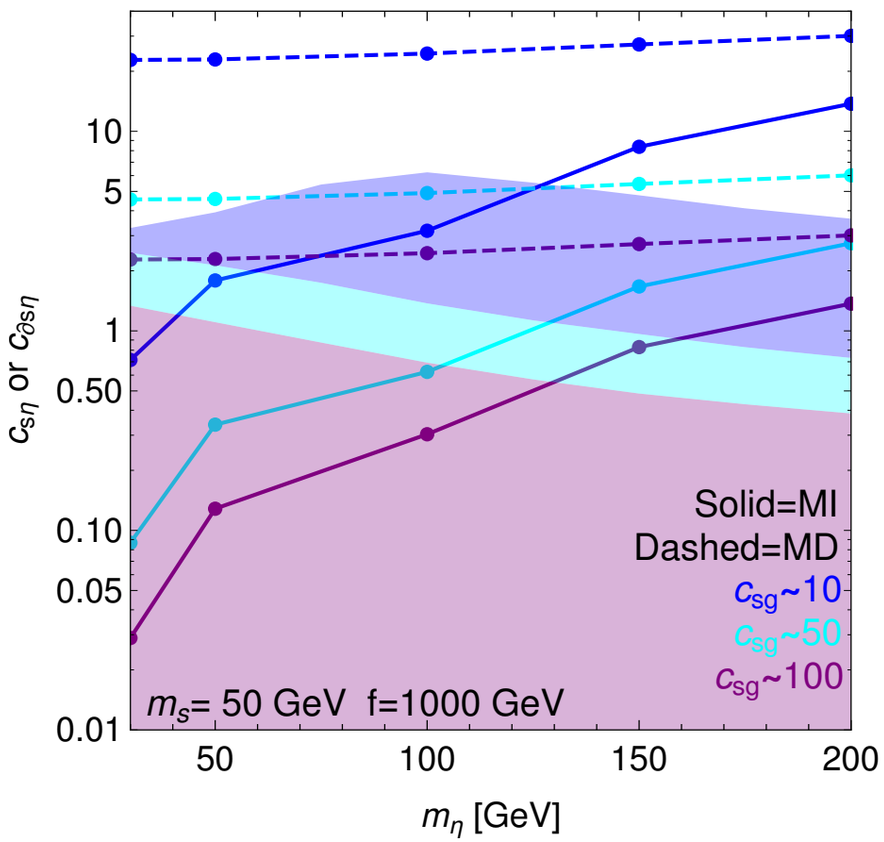
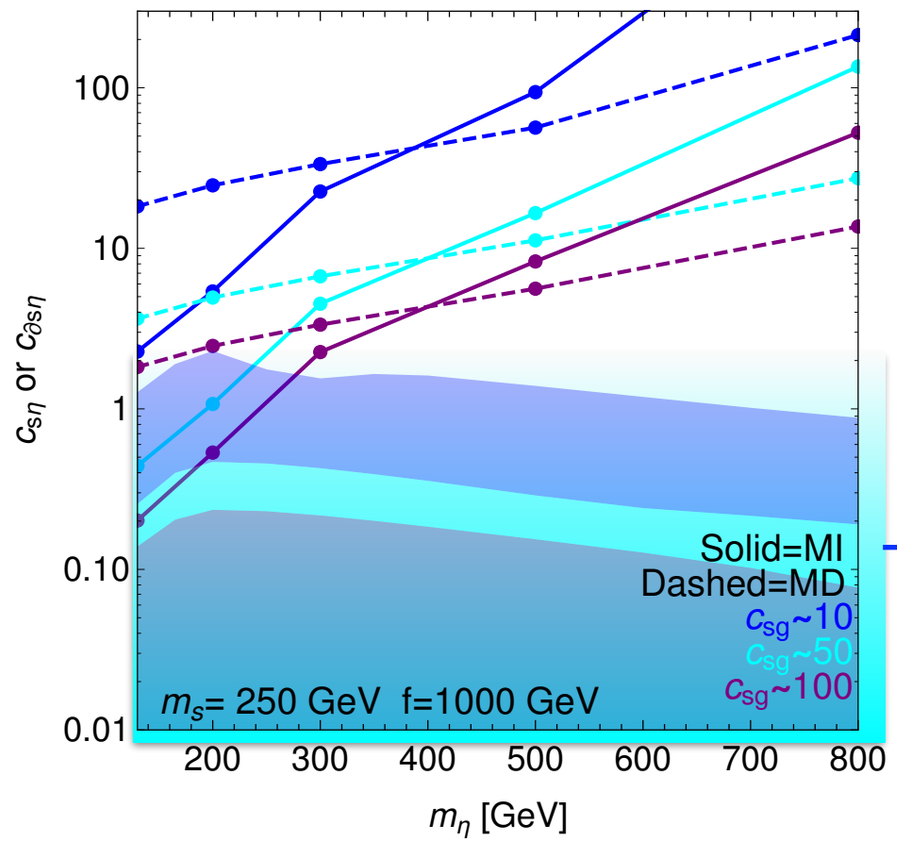
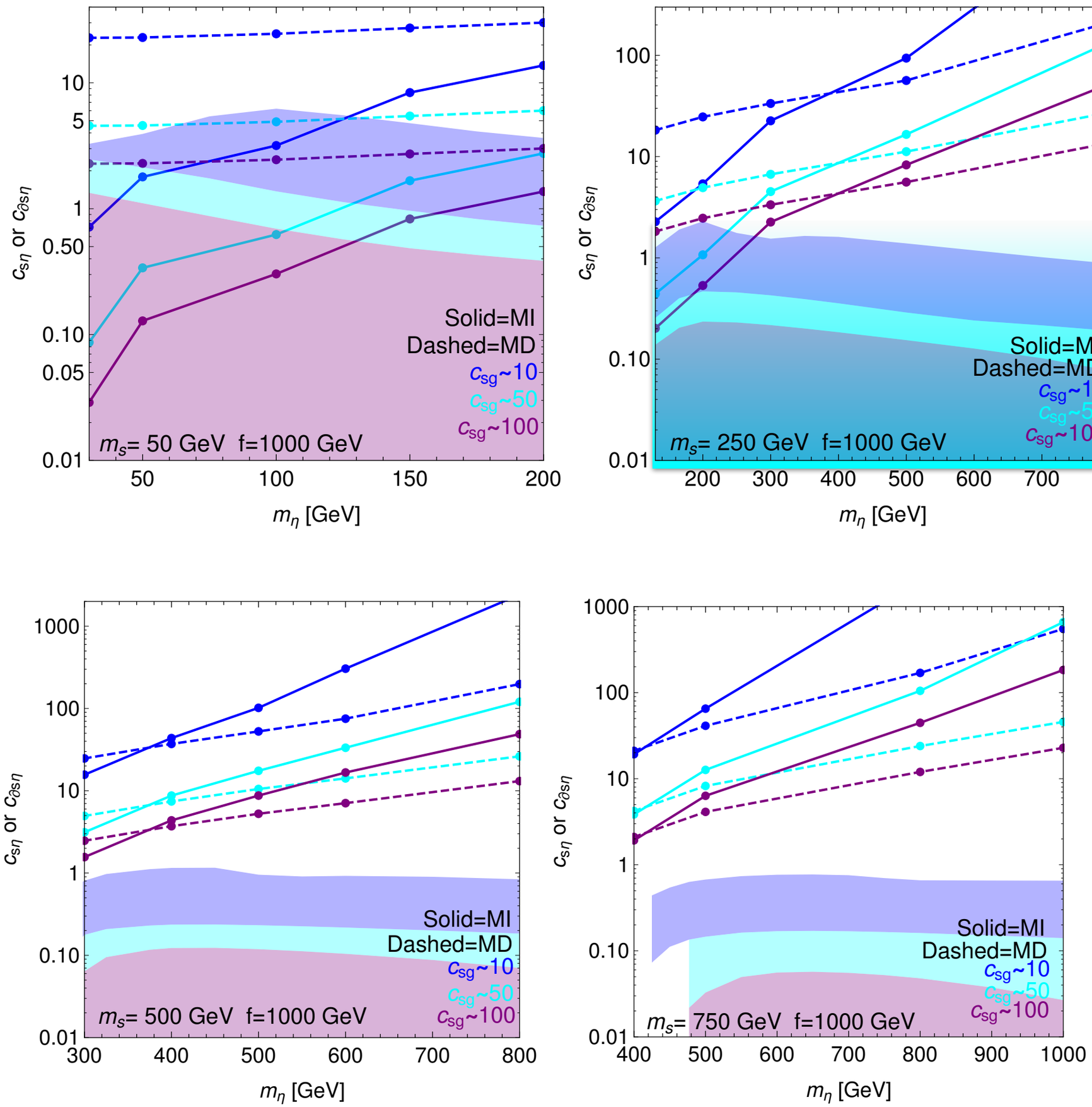




Disallowed by relic density

Results



Disallowed by relic density

Conclusions

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  - Theoretically well motivated and alternative to MI operators at the LHC
  - Stronger momentum dependence —> Larger sensitivity to cuts.
  - For low DM mass , MD operators more constrained.
  - Required
    - Astrophysical complementarity
    - An efficient search strategy at 13 TeV.
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  - Proper documentation of the results.
  - LHE files/ PYTHIA Cards/Shower Tunes/Efficiencies/Trigger criteria.

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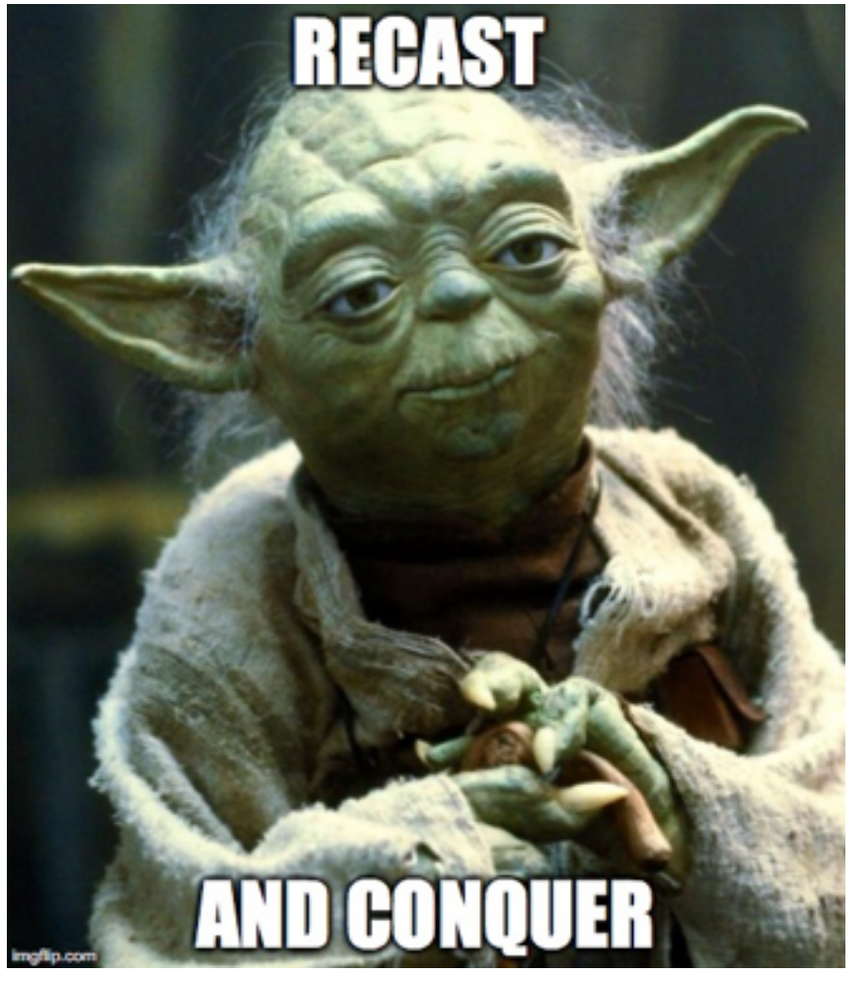
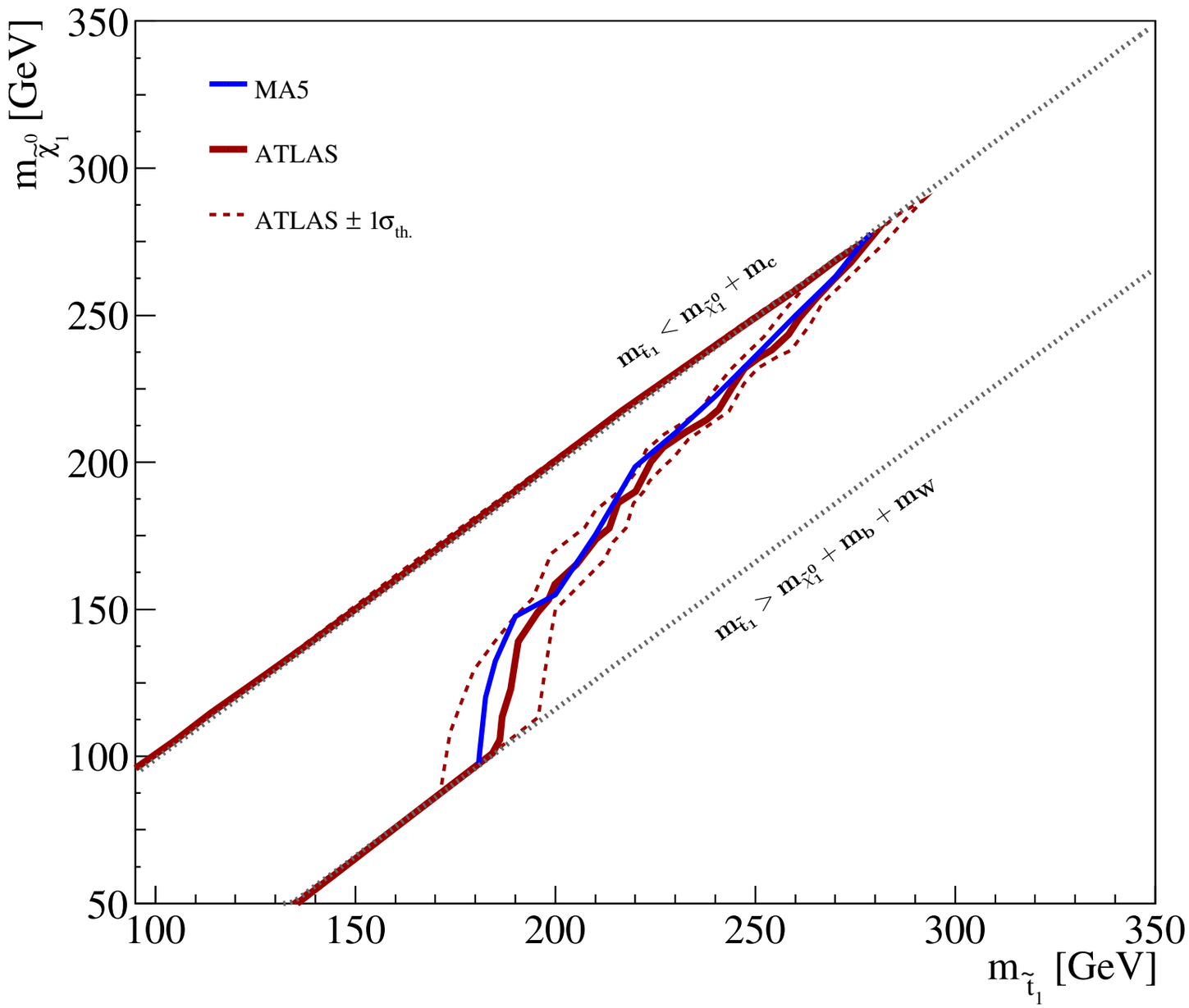
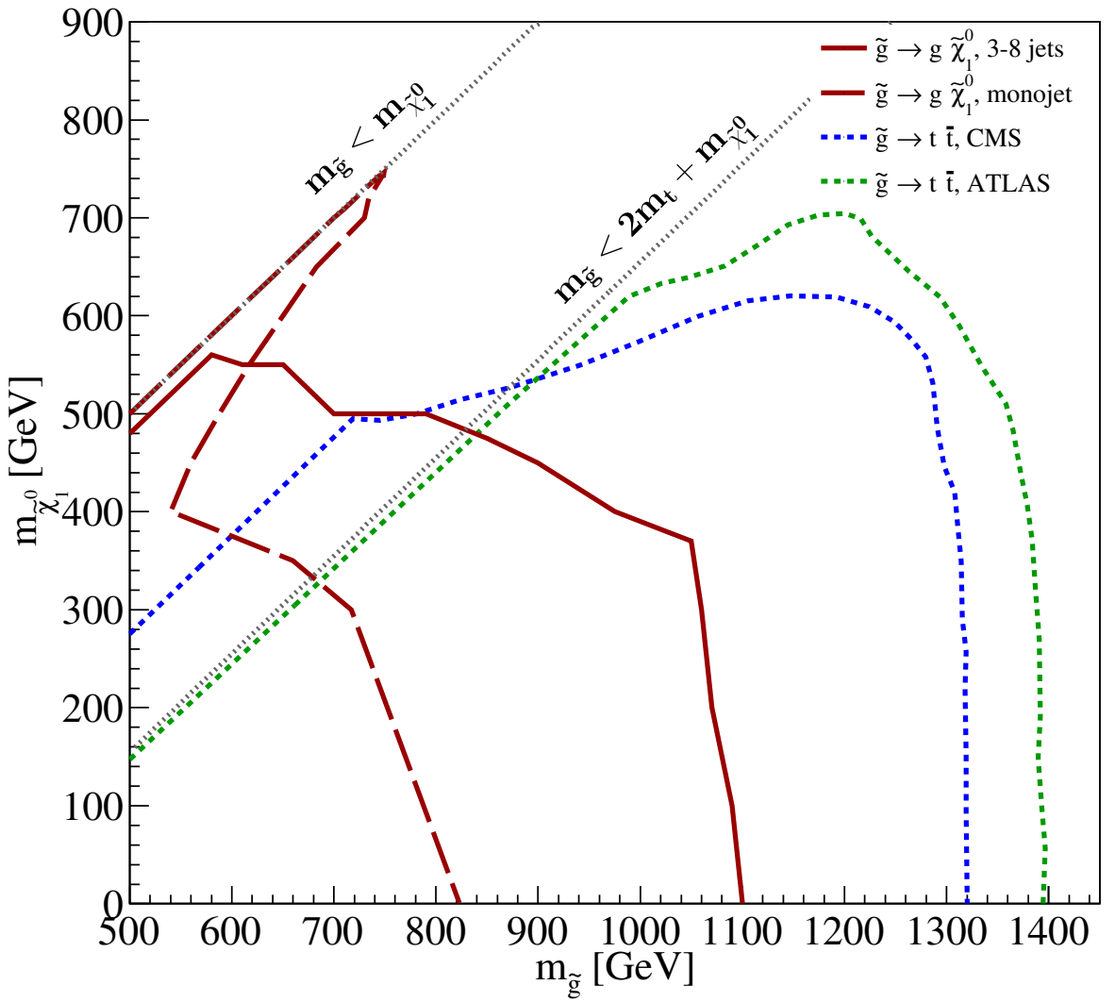


Exclusion Curve



Radiative Gluino Decay



- Existing Run I analyses can provide sensitivity to $\tilde{g} \to g + \tilde{\chi}_1^0$
- Can probe small $\Delta m = m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$
- Less sensitive at high $m_{\tilde{g}}$ compared to published analyses
- Recasted analyses soon available on MA5 PAD

Validation plots