Presentation of LHC results within EFT to simplified model frameworks

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April 11, 2018, Dark Matter at the Dawn of Discovery

Overview/Introduction

the story of DM models at LHC searches:

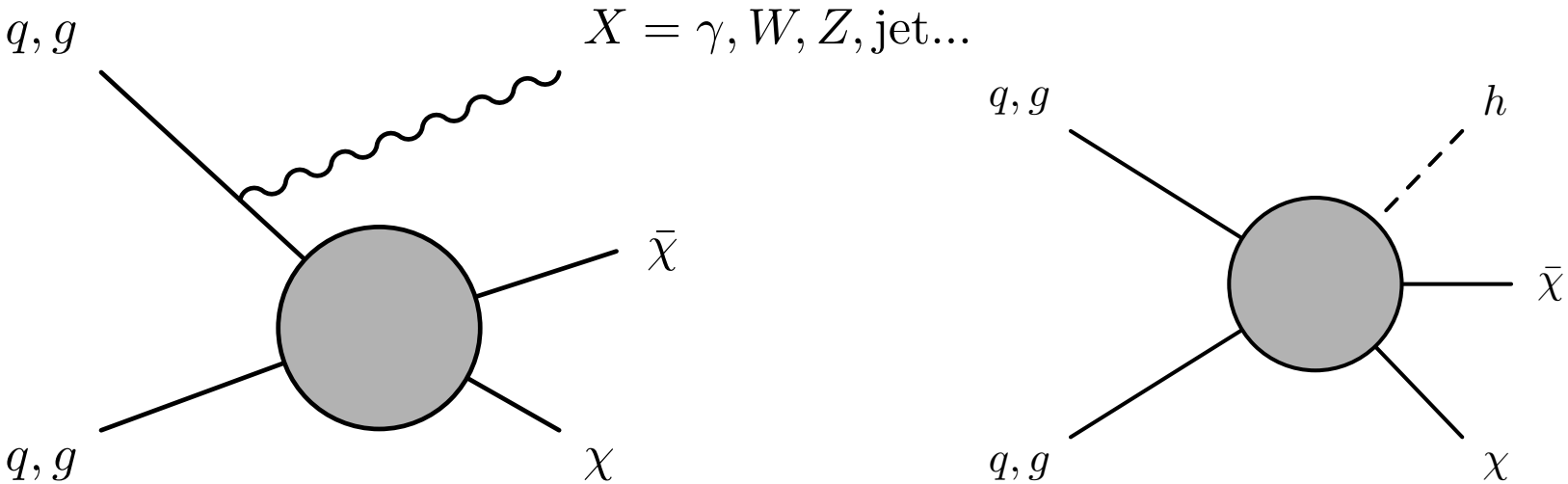
- started with EFTs
  - simple*, model independent*, could compare to DD*
  - not-UV complete, serious validity issues for LHC searches
- moved to simplified models
  - complimentary resonance searches
  - different simplified models for different mono-X signatures
- increased interest in more complete simplified models
  - 2HDM-a, 2HDM-S, 2HDM-Z'
  - can provide framework to interpret many mono-X signatures
  - avoids unitarity issues with previous simplified models (see Martin's talk)

cohesive DM model interpretation at the LHC

$\rightarrow$ primary goal of the LHC DMWG

Effective Field Theories

- popular in Run 1, seemed straightforward to compare to DD
- few parameters: m_χ, Λ
- setting limits straightforward: scale σ by varying Λ
  - thought valid because kinematics don't vary with Λ
  - do this for different m_χ



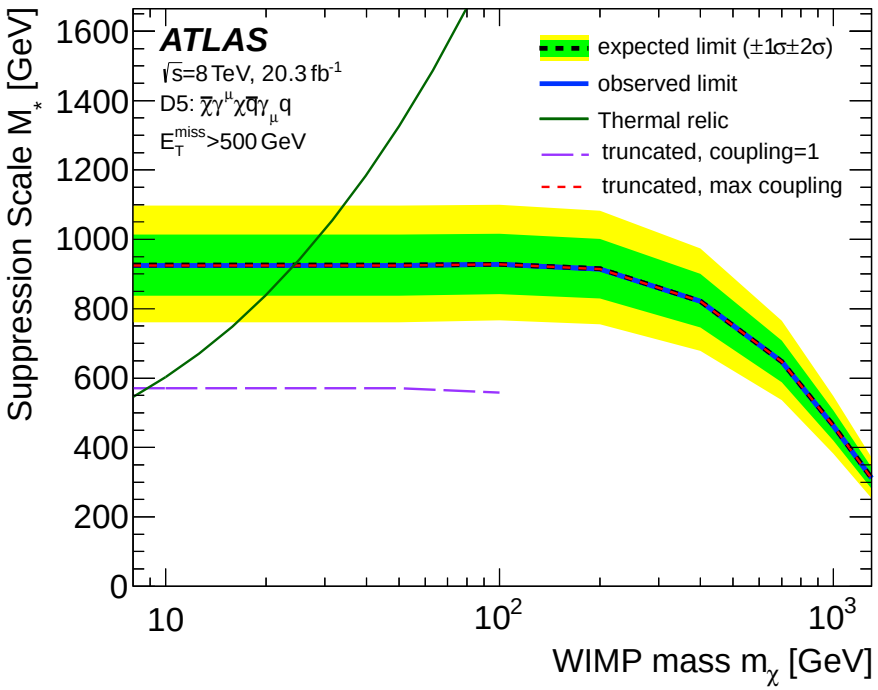
Some EFT Limits

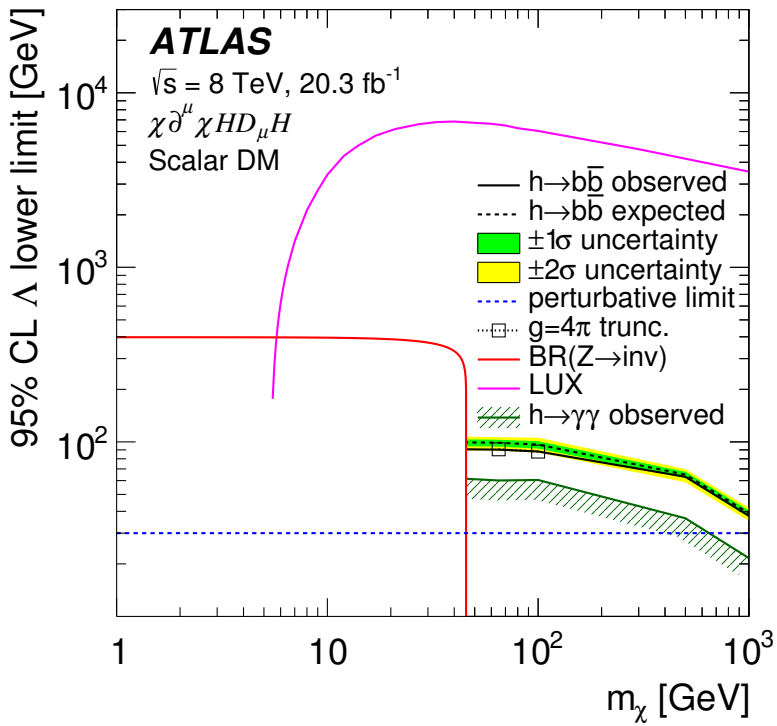
validity issues pointed out after early results

- EFT valid when $M_{\mathrm{med}} \gg Q_{\mathrm{tr}}$

solution - apply a truncation method $\rightarrow$ throw out invalid events

- lose sensitivity
- must assume underlying UV completion
  $\rightarrow$ might as well use simplified model

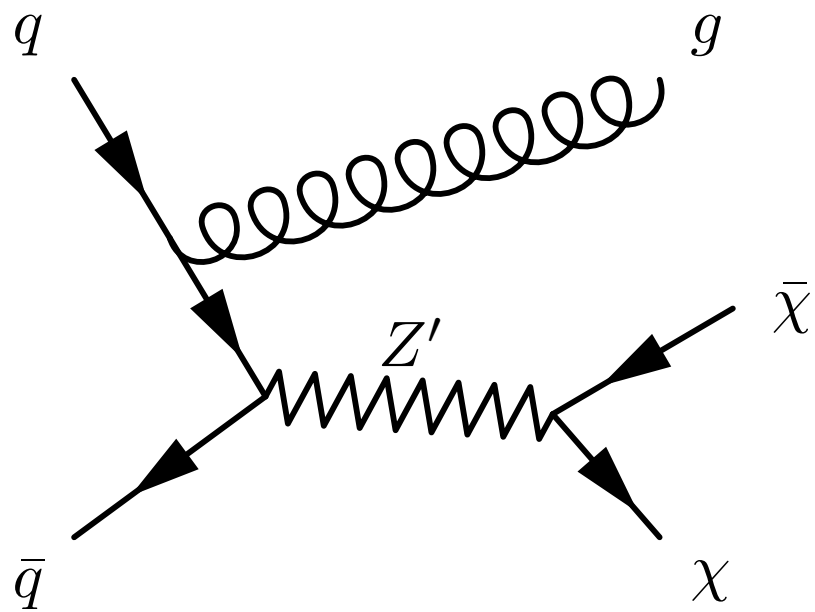




EXOT-2013-13, EXOT-2014-20

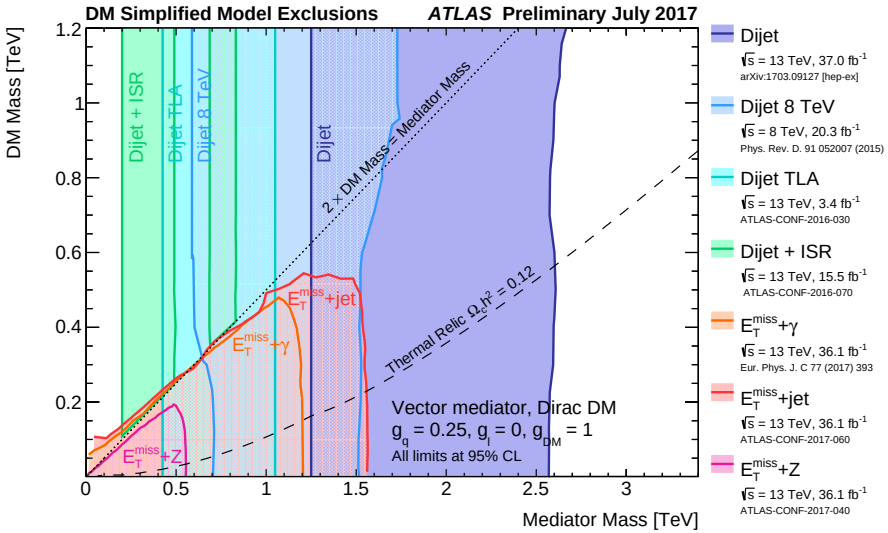
Simplified Model Approach

- typically introduce minimal new parameters
  - e.g. new mediator + tree level diagram
- basic mono-jet example here:
  - s-channel, vector boson mediator, fermionic DM
- parameters:
  - g_q, g_χ, M_{med}, m_χ
- which parameters to use?
  - want DM channel dominant
  - want distinct kinematics

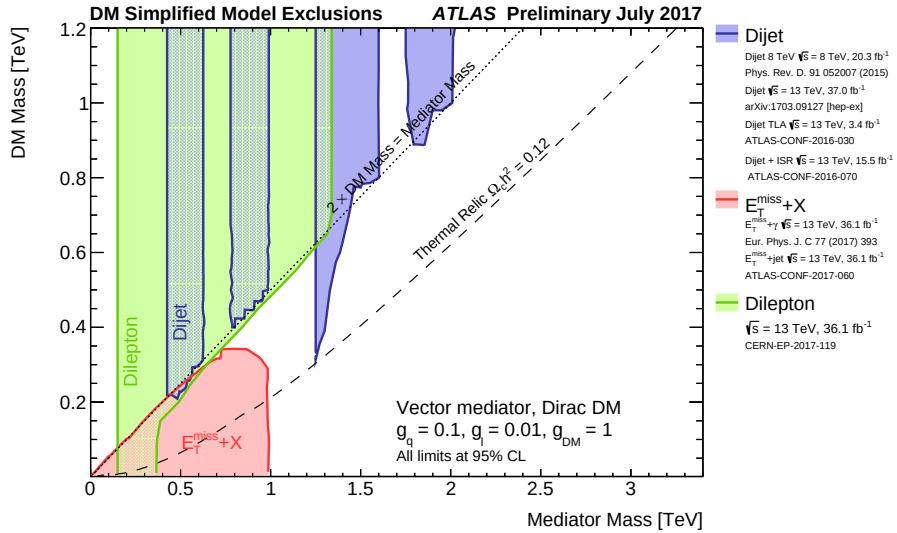


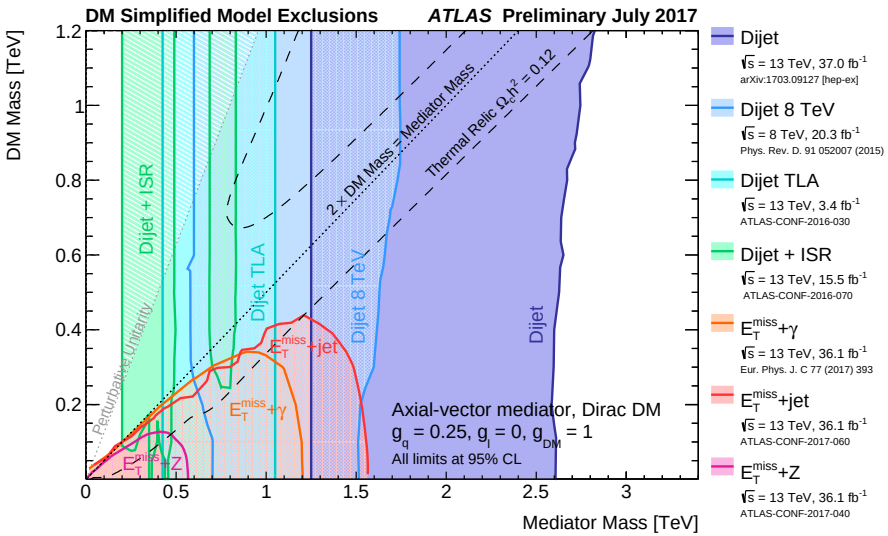
When is the DM Channel Dominant?

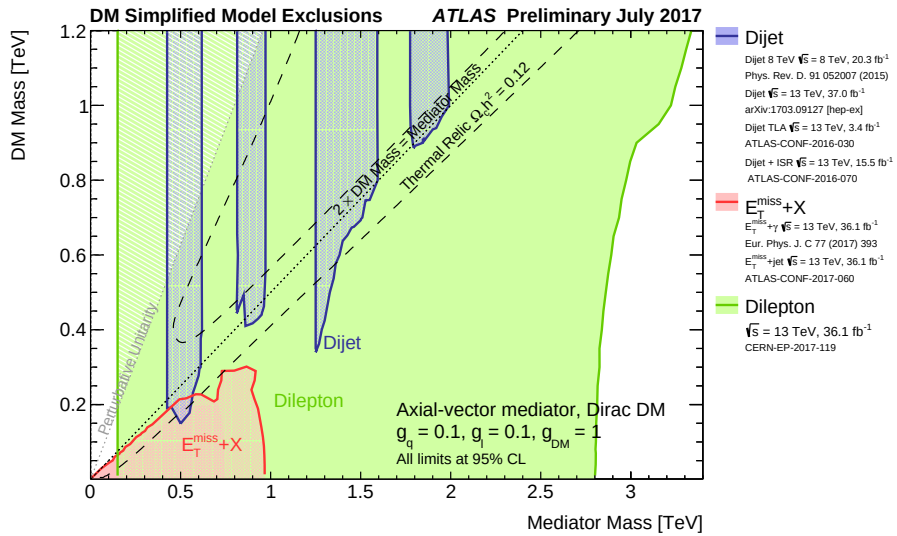
$g_\chi = 1,\ g_q = 0.25$



$g_\chi = 1\ ,\ g_q = 0.1$





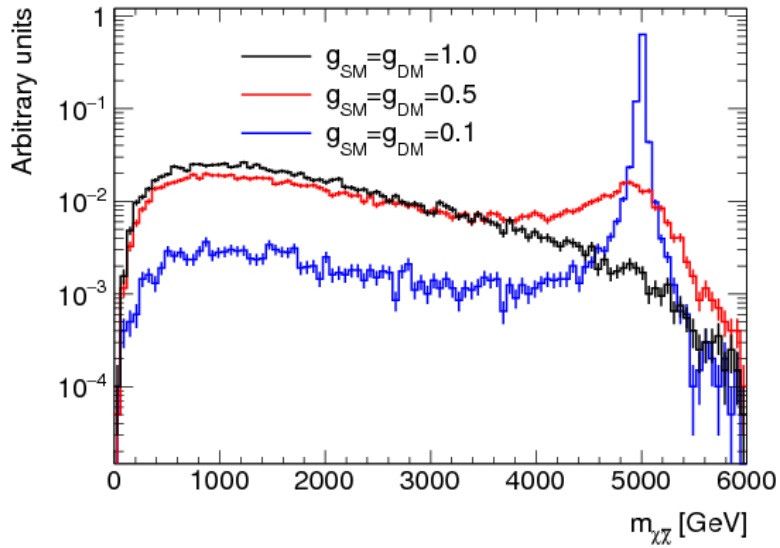


tune g_χ up and g_q down!

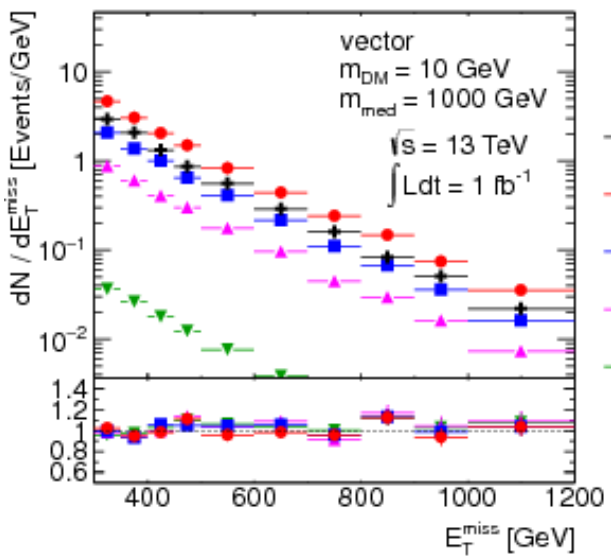
ExoticsPublicResults

Coupling Parameter Scans (arXiv:1507.00966)

$M_{\text{med}} = 5$ TeV, $m_\chi = 10$ GeV



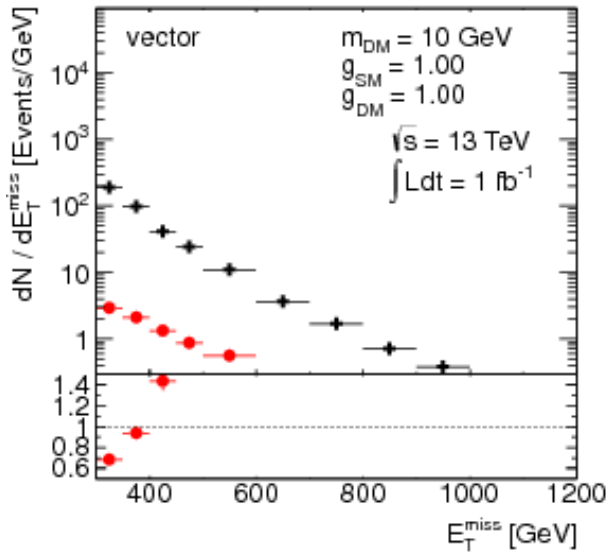
$M_{\text{med}} = 1$ TeV, $m_\chi = 10$ GeV



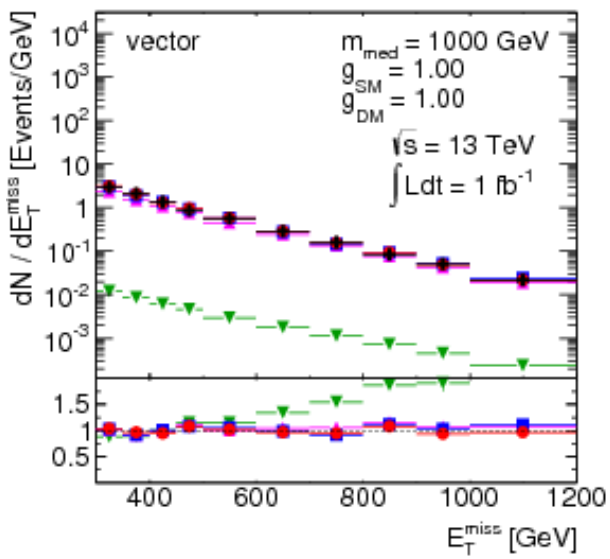
g_{SM}	g_{DM}	Γ/m_{med}	$\sigma \times A_{300}$ [fb]	$\sigma \times A_{500}$ [fb]
1.00	1.00	0.504	4.8e+02	1.2e+02
1.45	1.45	1.059	7.5e+02	1.8e+02
0.25	1.00	0.056	3.5e+02	9.0e+01
0.50	0.50	0.126	1.5e+02	3.8e+01
0.10	0.10	0.005	6.3e+00	1.6e+00

Mass Parameter Scans (arXiv:1507.00966)

- increased M_{med} = lower σ
- increased M_{med} = increased E_T^{Miss}



m_{med} [GeV]	Γ/m_{med}	$\sigma \times A_{300}$ [fb]	$\sigma \times A_{500}$ [fb]
100	0.424	1.9e+04	1.8e+03
1000	0.504	4.8e+02	1.2e+02



m_{DM} [GeV]	Γ/m_{med}	$\sigma \times A_{300}$ [fb]	$\sigma \times A_{500}$ [fb]
10	0.504	4.8e+02	1.2e+02
30	0.504	4.9e+02	1.2e+02
100	0.504	4.8e+02	1.2e+02
300	0.502	3.8e+02	1.0e+02
1000	0.477	2.4e+00	7.9e-01

Final Parameter Scan Choices (arXiv:1507.00966)

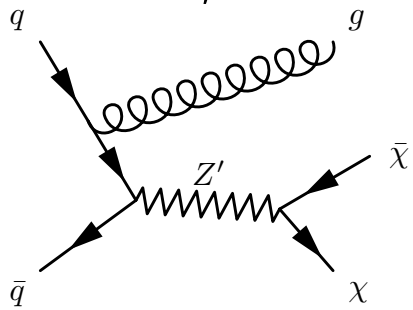
- s-channel, vector boson mediated, fermionic DM
- $g_\chi = 1$ and $g_q = 0.25$*

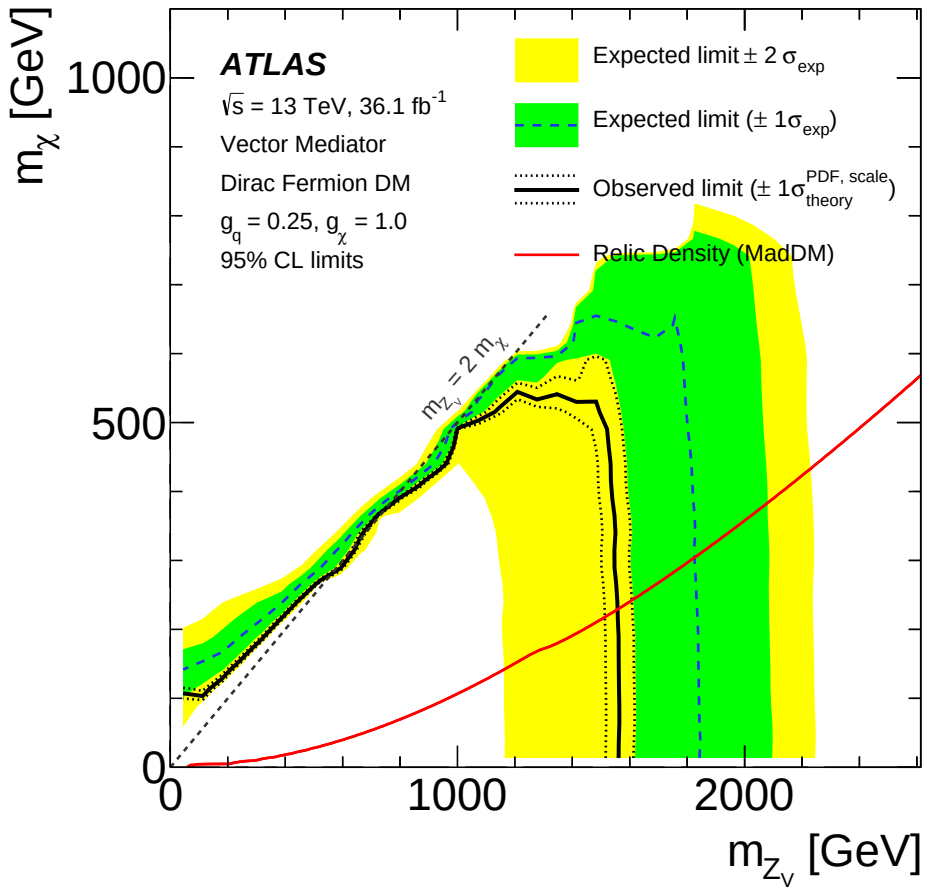
m_χ / GeV	M_{med} / GeV									
1	10	20	50	100	200	300	500	1000	2000	10000
10	10	15	50	100						10000
50	10		50	95	200	300				10000
150	10				200	295	500	1000		10000
500	10						500	995	2000	10000
1000	10							1000	1995	10000

- save CPU time by simulating sparse grid
- interpolate signal significance to set limits

Example Interpretation Results (EXOT-2016-27)

s-channel, vector boson mediated, fermionic DM

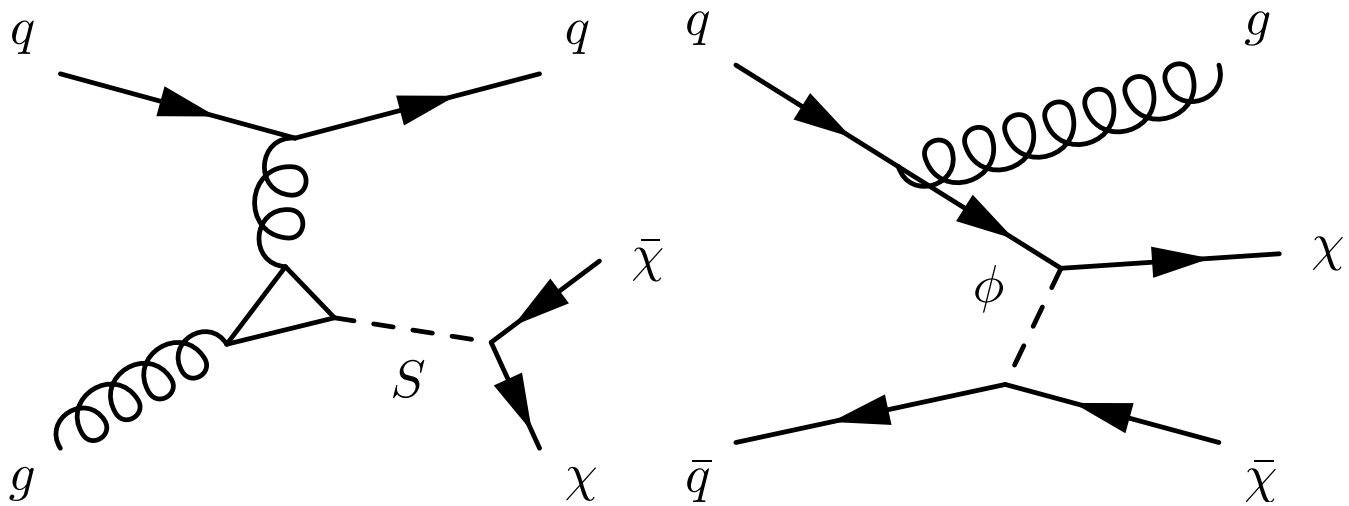




Other Mono-Jet Simplified Models

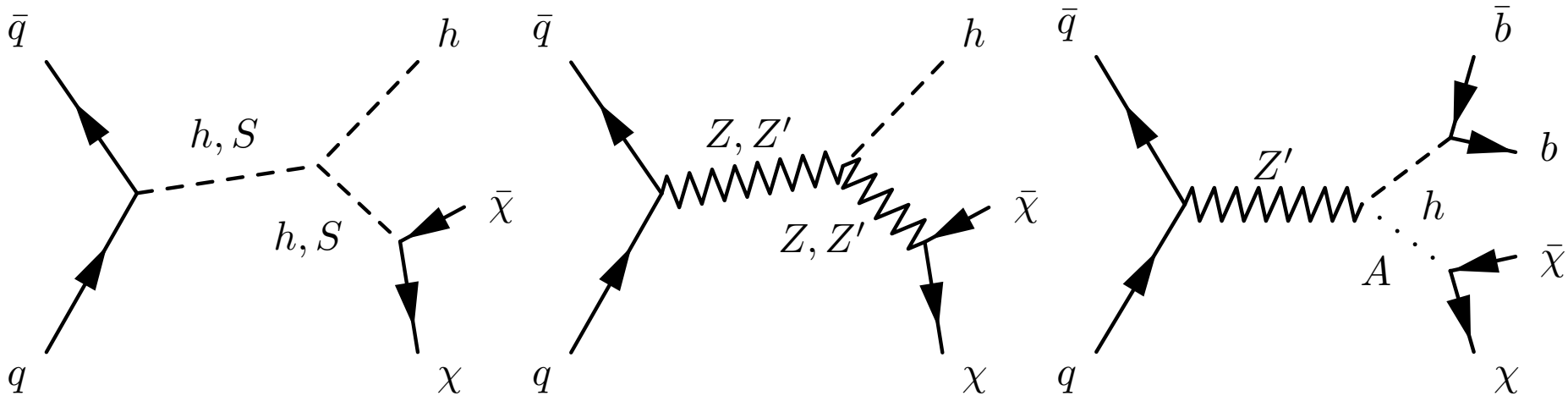
similar strategy:

- write down simplified model:
  - s-channel, t-channel
  - vector, axial vector, scalar, pseudoscalar mediator
  - fermionic, scalar DM
- scan over parameters (masses/couplings)
  - search for where DM channel dominant
  - find parameter set with distinct kinematics
- carry out search, discover or set limits



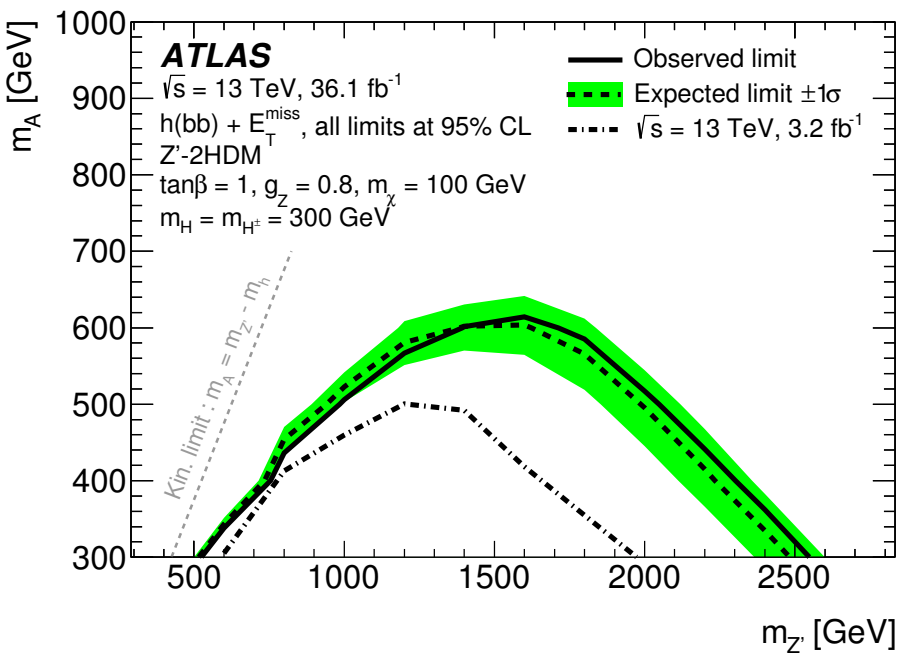
Mono-Higgs Simplified Models

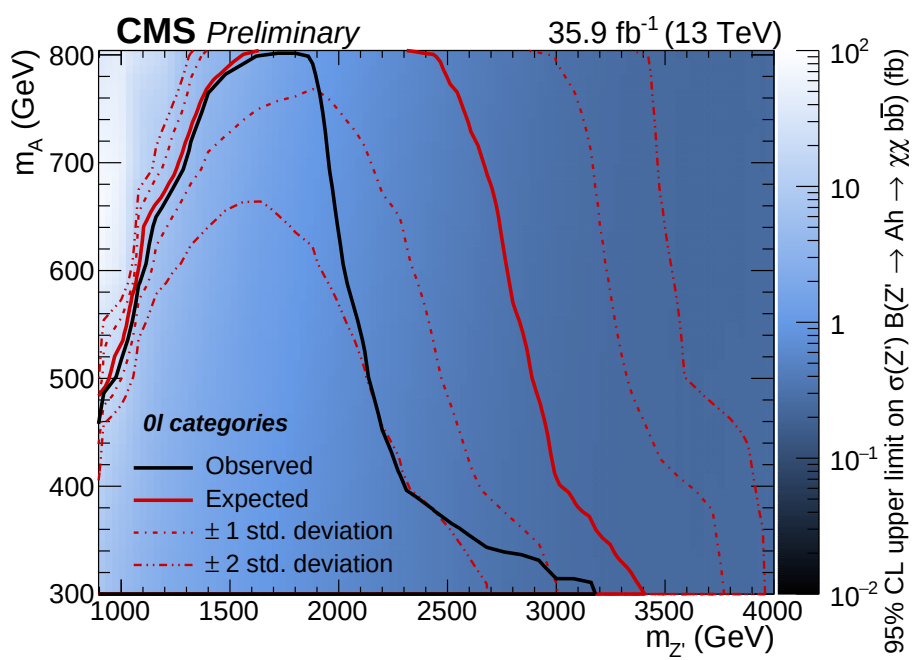
- somewhat more complicated than mono-jet models
- most models contain more parameters than M_{med} and m_χ
- would be nice to have a model to do both mono-jet/g/Z/W and mono-Higgs...



ATLAS vs CMS Mono-Higgs Interpretation

- ATLAS observable: m_h; CMS observable: $m_{h+E_T^{\mathrm{Miss}}}$
- CMS result is a recast of search for a resonance decaying into $h + V$ or $h + E_T^{\mathrm{Miss}}$
- caveat: difference in other 2HDM parameters
  - CMS used $m_H = m_{H^\pm} = m_A$, ATLAS used $m_H = m_{H^\pm} = 300\ \mathrm{GeV}$
  - can directly compare for $m_A = 300\ \mathrm{GeV}$ - CMS still does better
- should we look directly for M_{med} for some models?
  - (e.g. models with resonance features = most simplified models)

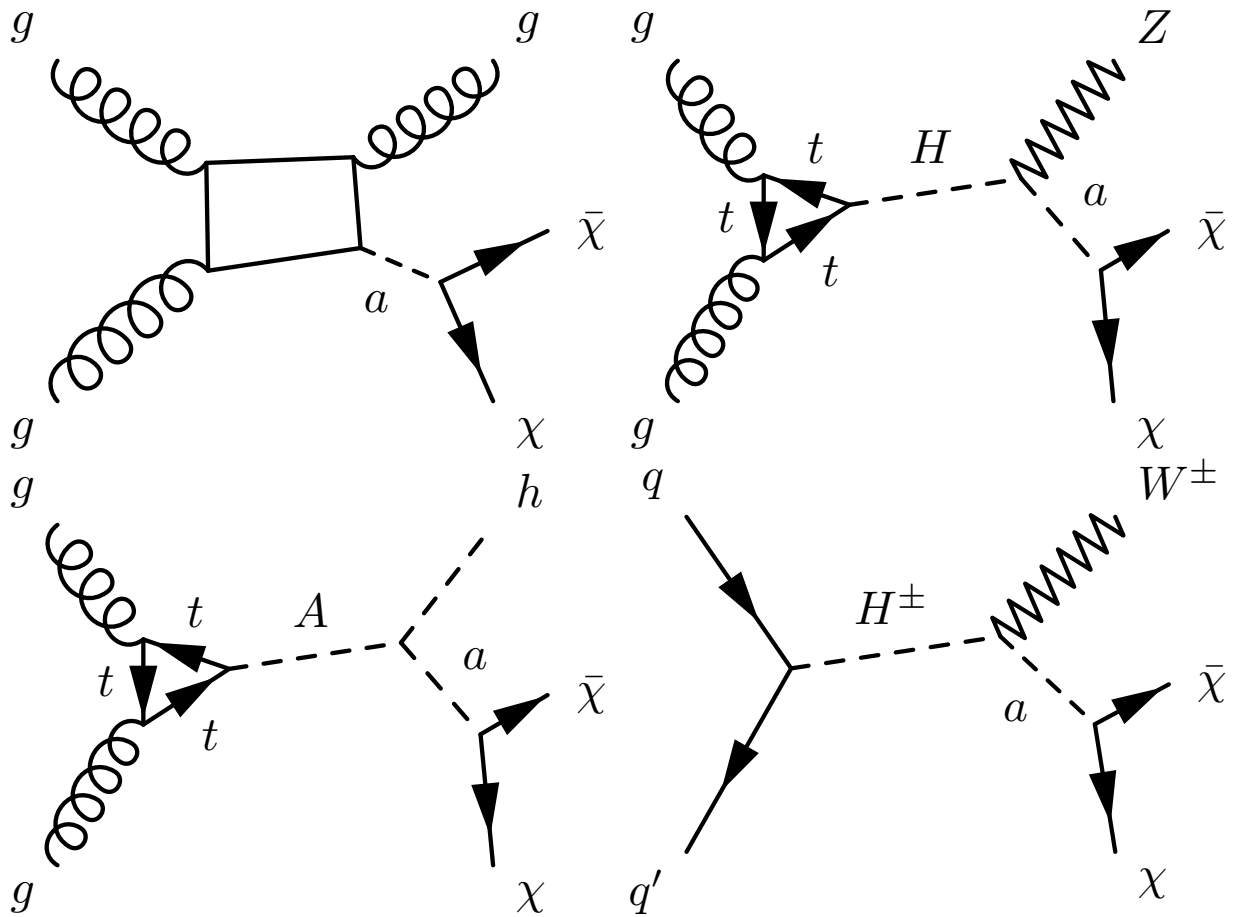




EXOT-2016-25, CMS-PAS-B2G-17-004

A New Model: 2HDM-a

- allows for interpretation of many mono-X searches
- actively considered as benchmark model for LHC searches
  - highlight in several talks at DM@LHC last week and here this week
- avoids unit. issues of previous sim. models (see Martin's talk)

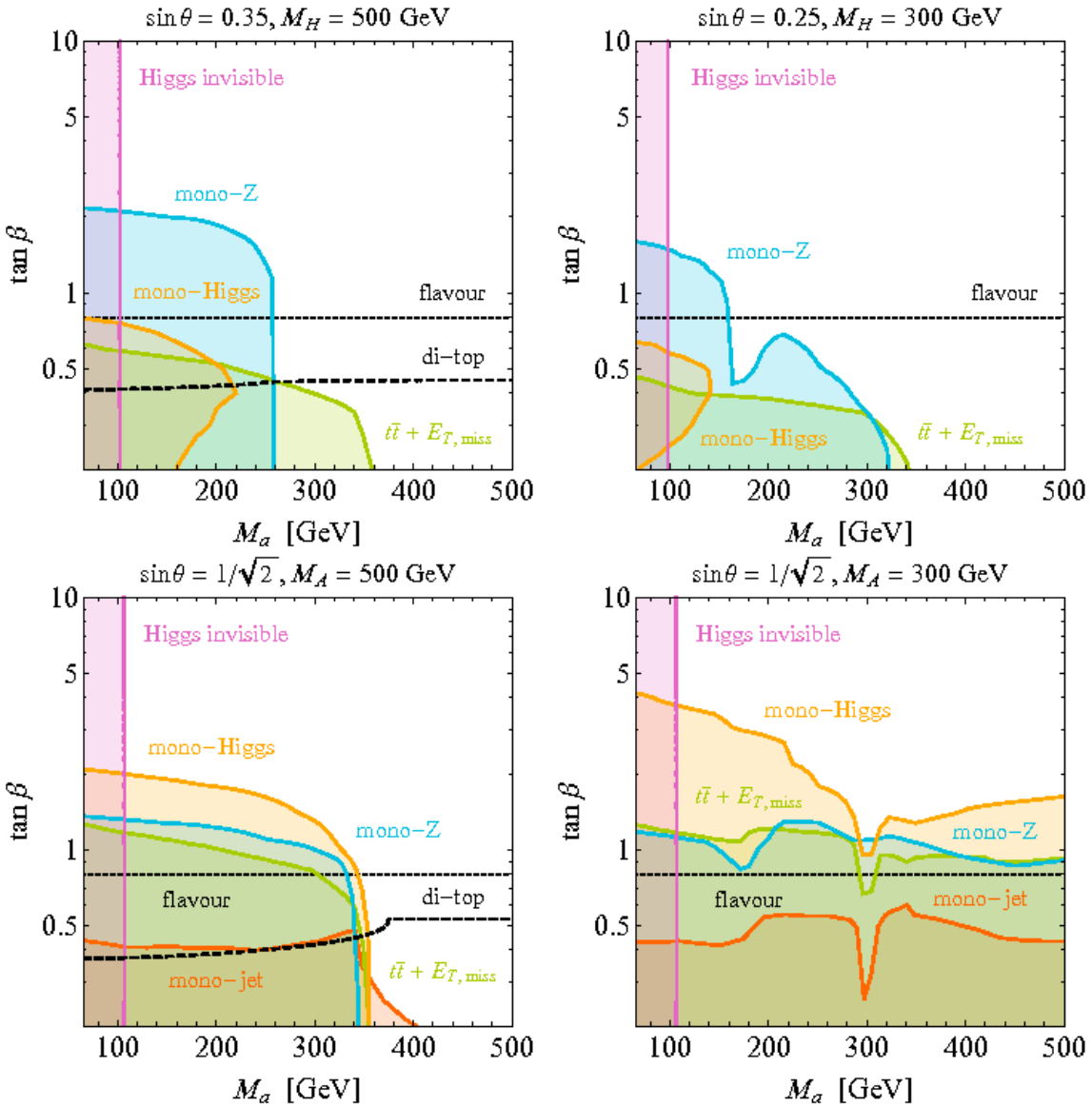


Parameters

- similar to Z'-2HDM
  - m_A, m_H, $m_{H^\pm}$, m_h, m_a
  - α, β, θ
  - m_χ, g_χ
  - A, a mix via θ and couple to χ
- some constraints and assumptions
  - Type II 2HDM
  - $\sin(\beta - \alpha) = 1 \rightarrow h =$ SM Higgs ($m_h = 125$ GeV)
  - assume $m_H = m_{H^\pm} = m_A$
  - assume $g_\chi = 1$, $m_\chi = 10, 100$ GeV
  - perturb. and unit. constraints (e.g. top Yukawa coupling) $0.3 < \tan(\beta) \lesssim 10$
- final free parameters:
  - m_a, m_A (controls how boosted signature is)
  - $\tan(\beta)$
  - $\sin(\theta)$ (controls whether $a \rightarrow \chi\bar{\chi}$ or $A \rightarrow \chi\bar{\chi}$ dominant)

Which 2HDM-*a* Signatures Dominant? (arXiv:1701.07427)

- depends on choice of parameters
- recommendations for parameter scans/interpretation underway



Summary, Questions, Discussion

- DM searches and interpretation at LHC aim for discovery
  - want models with guiding kinematic signatures
  - motivated models help explore parameter/kinematic spaces
- for meaningful exchange between experiment-theory communities, must iterate
  - these discussions led to simplified models favored over EFTs
- some questions/discussion
  - resonant vs non-resonant searches: move an $m_{X+E_T^{\mathrm{Miss}}}$ strategy?
  - how seriously should the validity of a model influence its use as a unique signature?
  - which models are theorists most interested in seeing?
  - many assumptions go into an experimental limit - are we overdoing it?