Dark Matter Searches at the LHC

E. Barberio, The University of Melbourne
On behalf of the ATLAS and CMS collaborations

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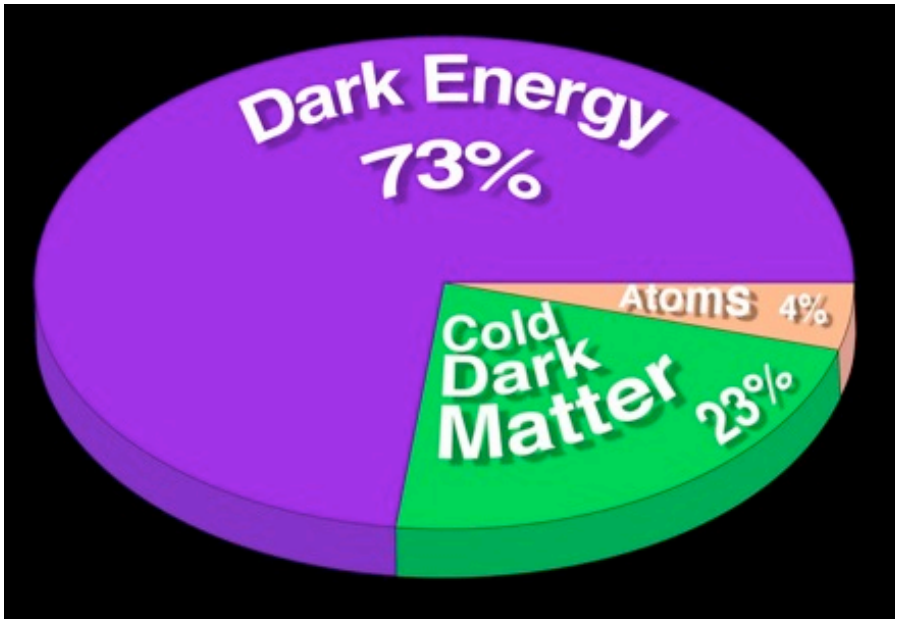
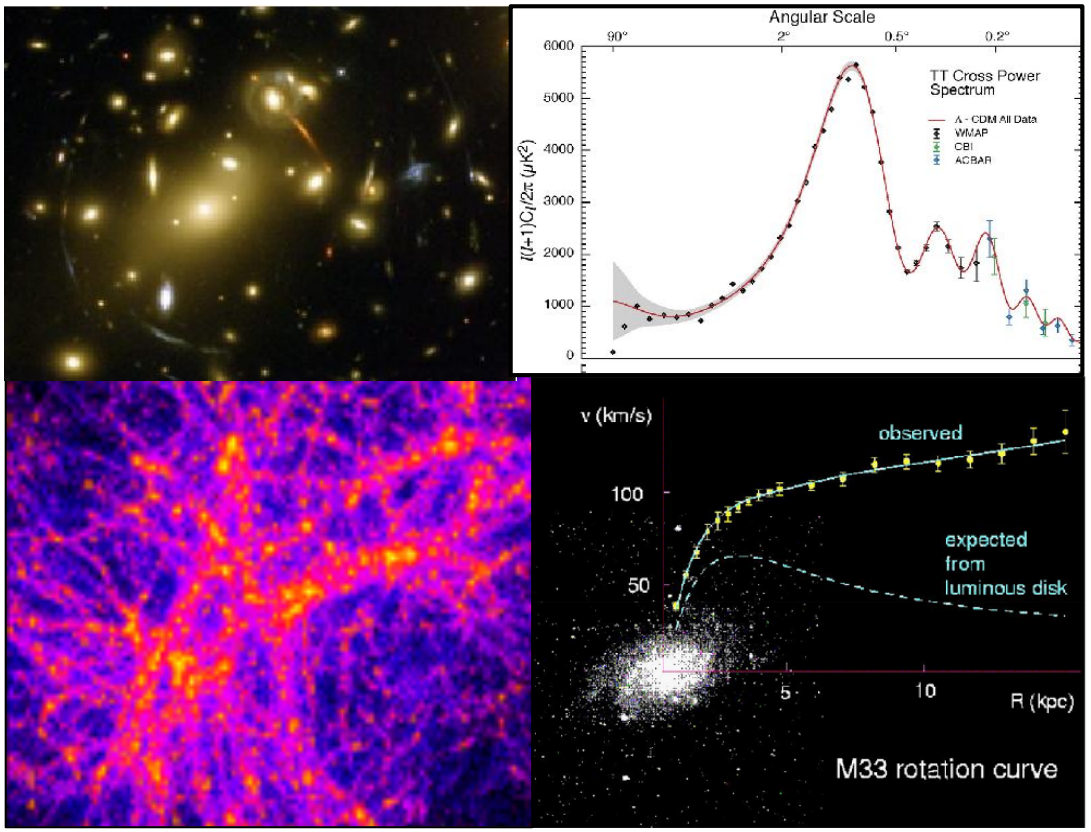
Dark Matter Observation



Cosmological observation

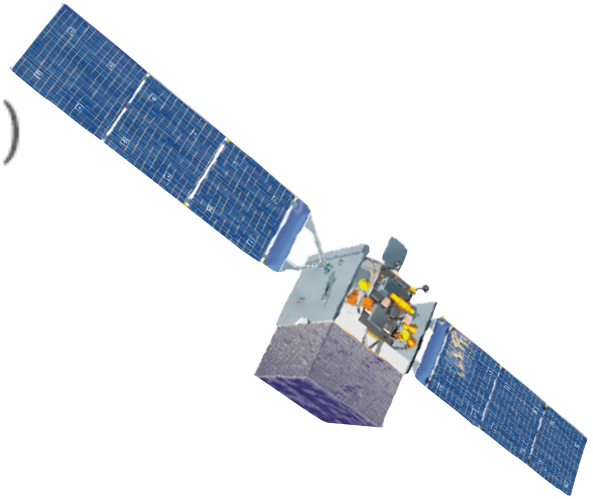


Dark matter properties:

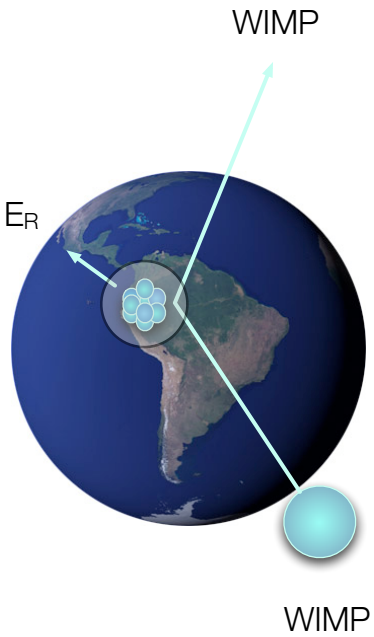
- Stable,
- Gravitationally interacting,
- Cold (non relativistic),
- Dark (Does not interact with light)

Dark Matter Interaction

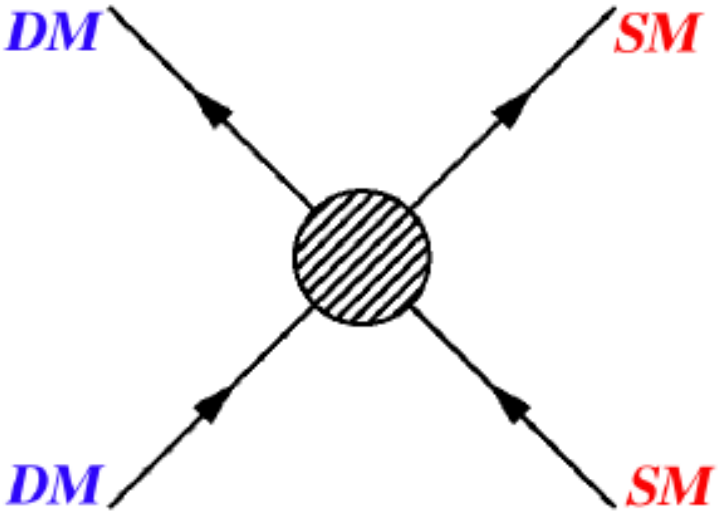
For WIMPs



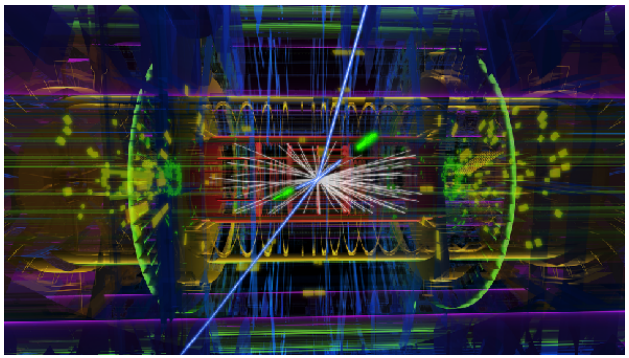
thermal freeze-out (early Univ.)
indirect detection (now)



direct detection



production at colliders



Dark Matter Production at Colliders

- Probe SM – dark matter particle interactions up to the TeV scale
- Measure the properties of the dark matter particles (once detected)
- Develop methods to enhance the complementarity with direct and indirect dark matter searches

Dark Matter Models

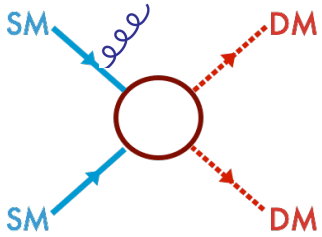
Completeness

Complexity

EFT

Contact interaction

valid for Q^2 much smaller than effective scale

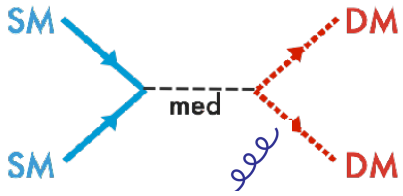


Simplified Models

Renormalisable theories

information on dark matter particle and mediator

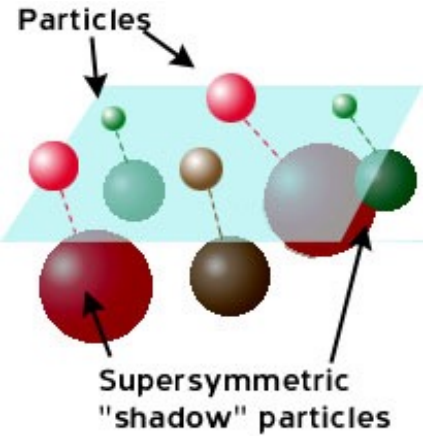
LHC Run-2 DM searches harmonised



Complete Theories

More Complex Models

complex phenomenology (e.g. SUSY)

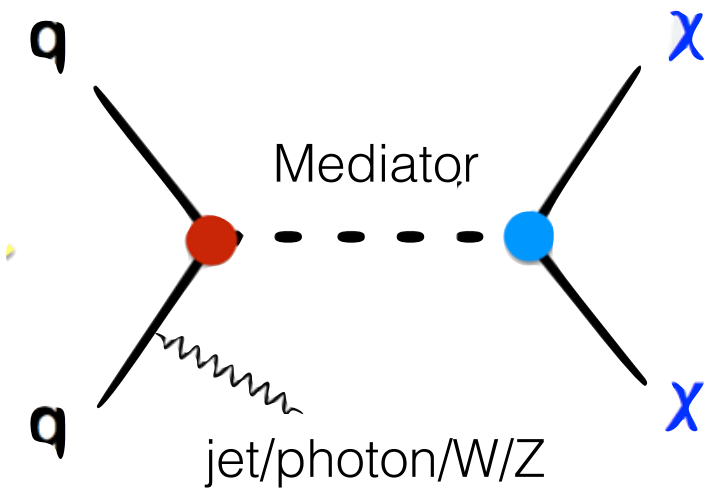


LED

MSSM

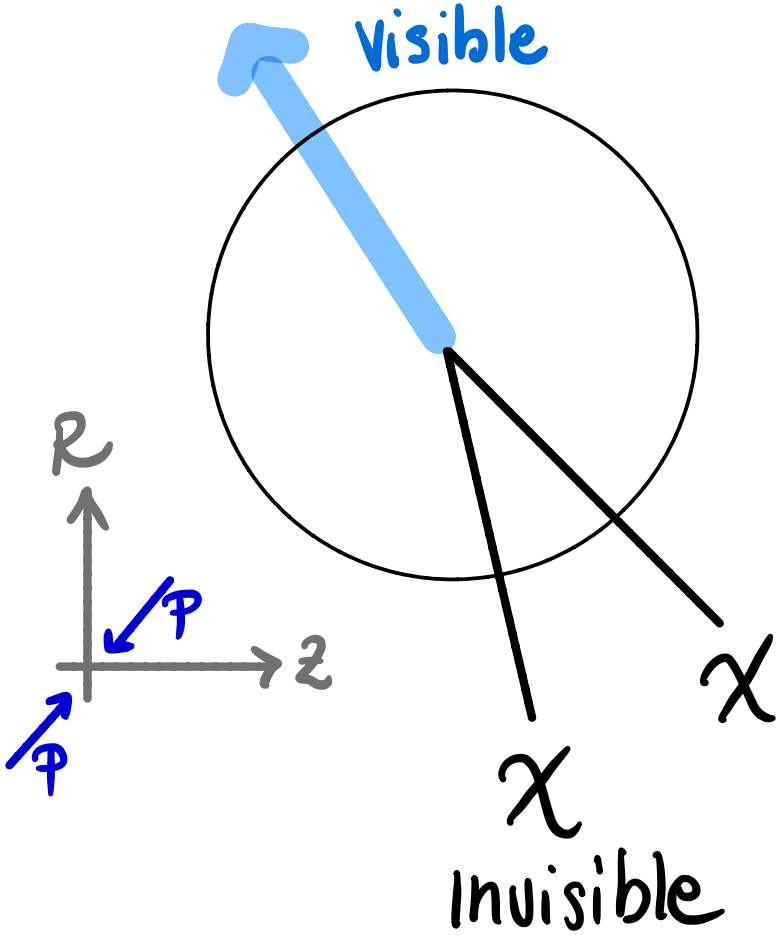
Direct production

Generally referred to as "Mono-X" searches



Search for deviation from the Standard Model expectation

Missing transverse energy plus visible objects



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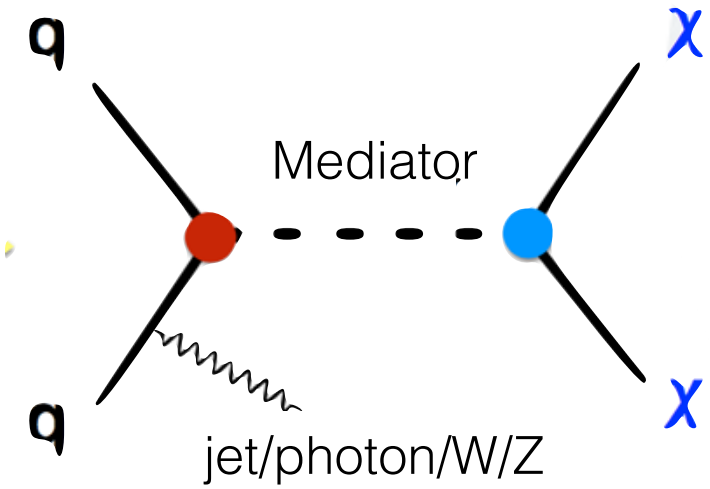

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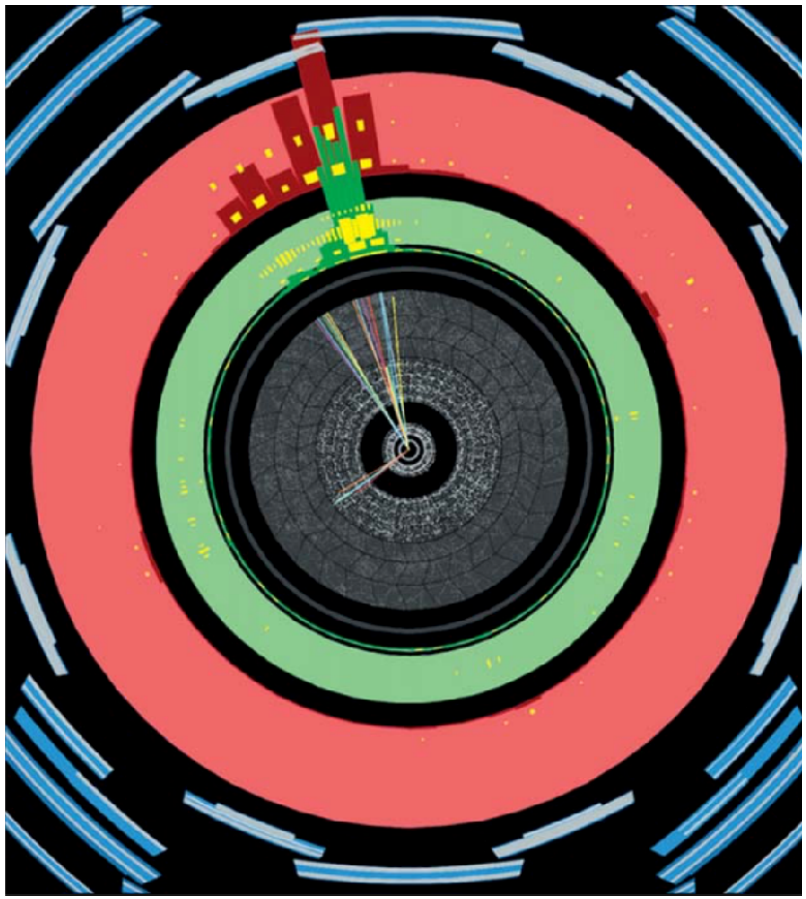
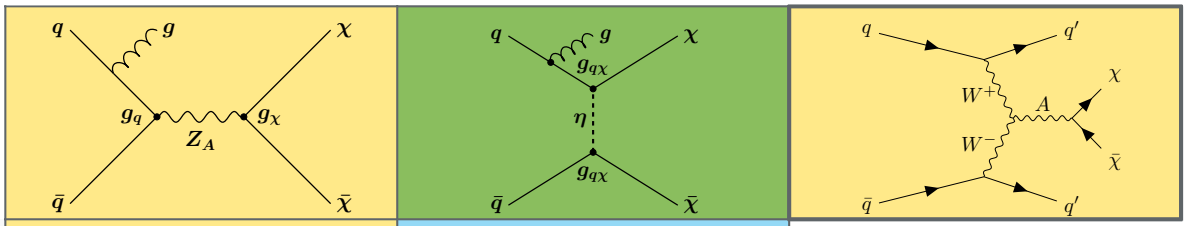


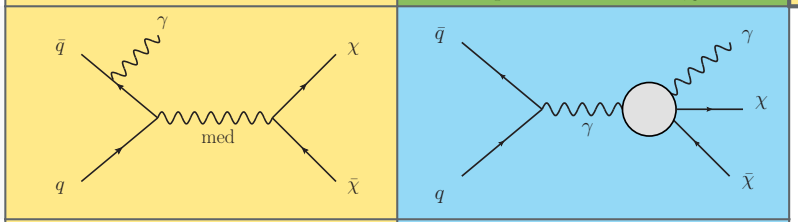
ATLAS mono-jet candidate

Mono-X / Missing Energy

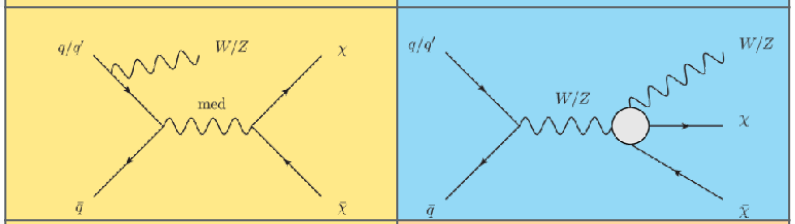
Mono-Jet & Xsec Ratio



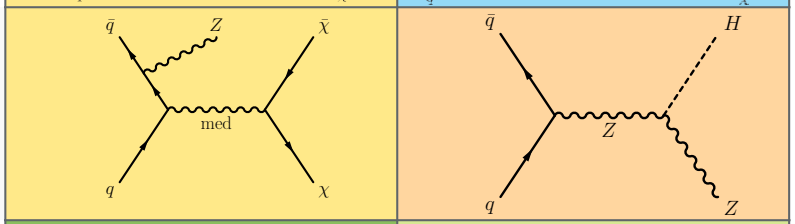
Mono-Photon



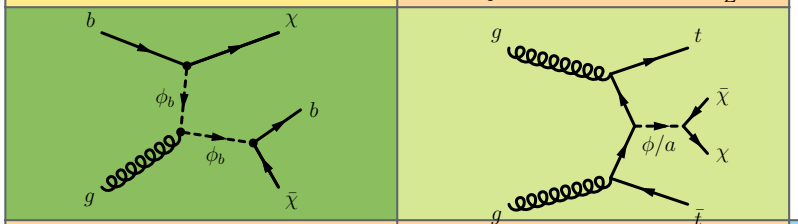
Mono-W/Z hadronic



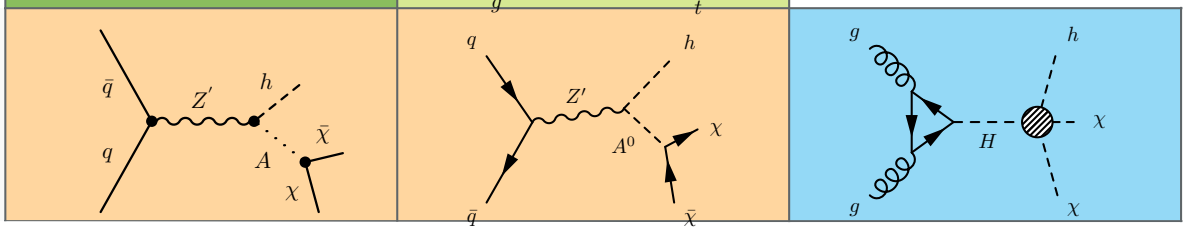
Mono-Z(ll)



Heavy Quarks (t,b)



Mono-H

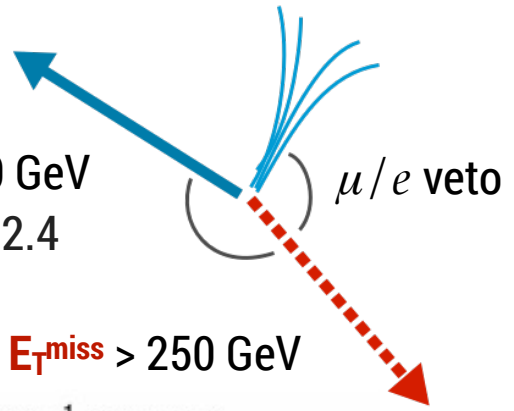


	Properties of the new Mediator		
Model Type	**spin**	**parity**	**color**
Simpli	1	+1, -1	neutral
Simpli	0	+1, -1	neutral
Simpli	0	+1	charged
Simpli	Models with a Higgs boson		
EFT	Higher-dimension operators		

CMS: PRD 97 (2018) 092005
ATLAS : JHEP 01 (2018) 126

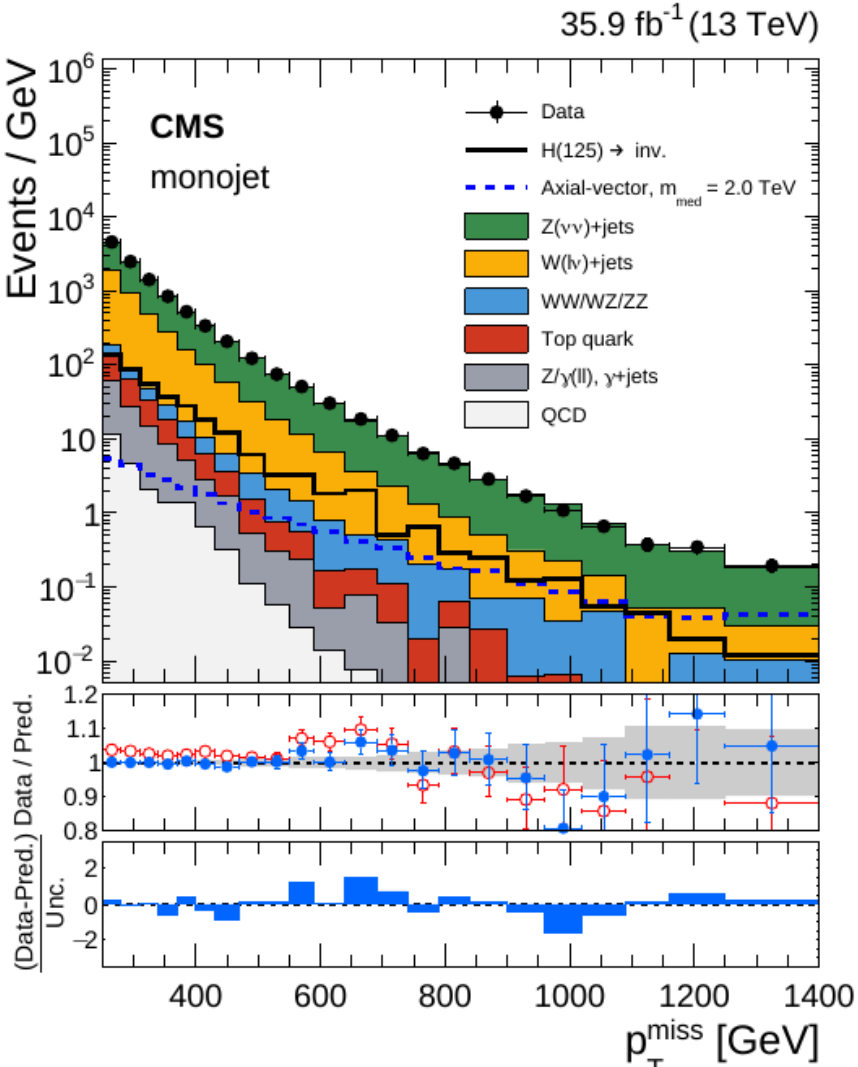
Mono-jet/V(had) Search

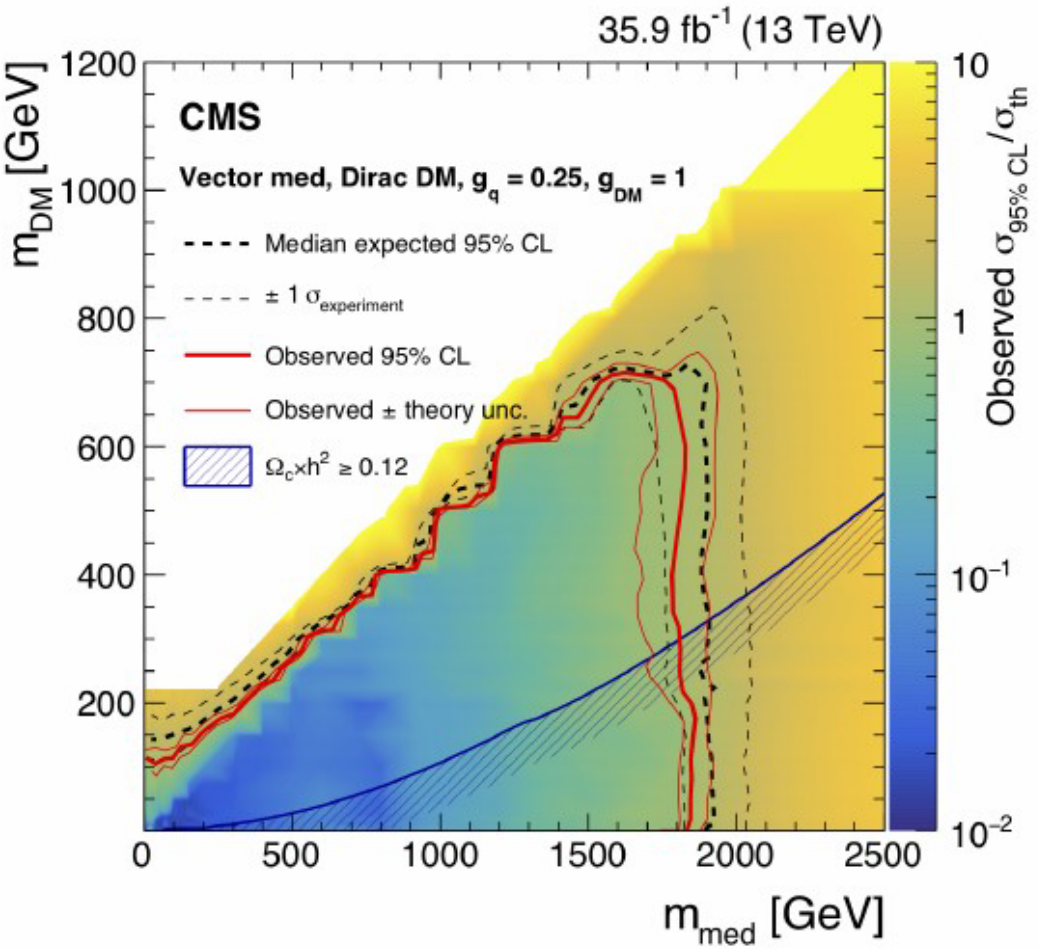
more than 3 **jets**
p_T > 30 GeV



Most powerful search at hadron colliders

- Main backgrounds: Z($\nu\nu$) + jets - O(55-70%), W(lν)+jets O(35-20%)
- Precision on the background estimate: 2-7%

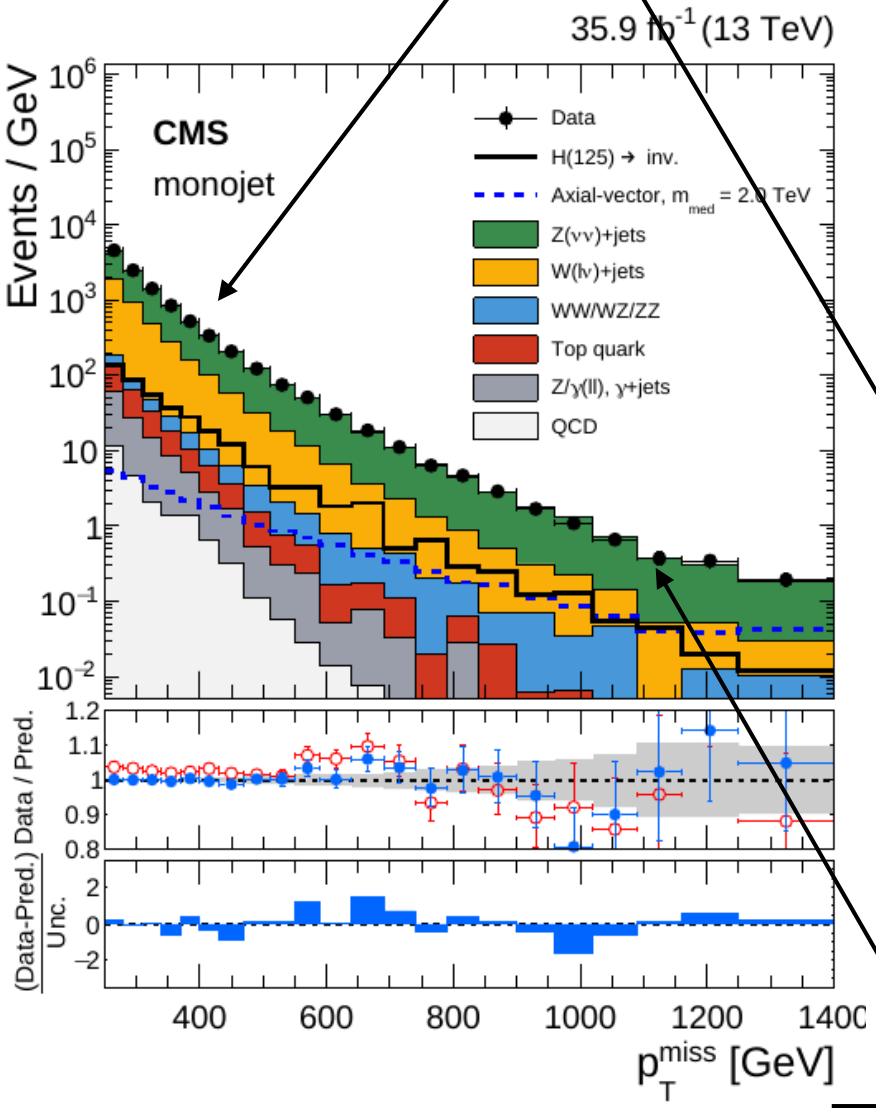


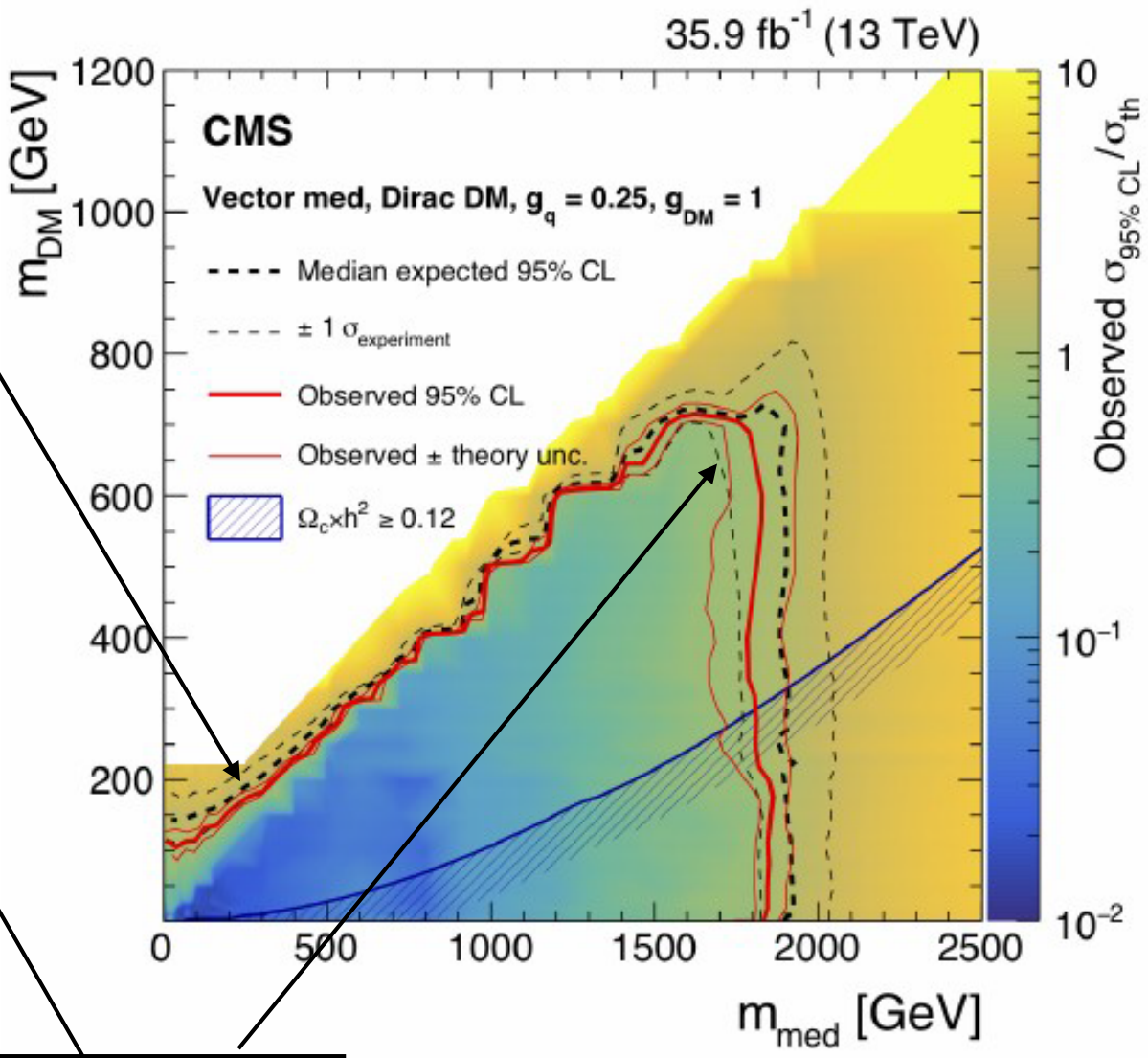


CMS: PRD 97 (2018) 092005
ATLAS : JHEP 01 (2018) 126

Mono-jet/V(had) Search

Systematically limited



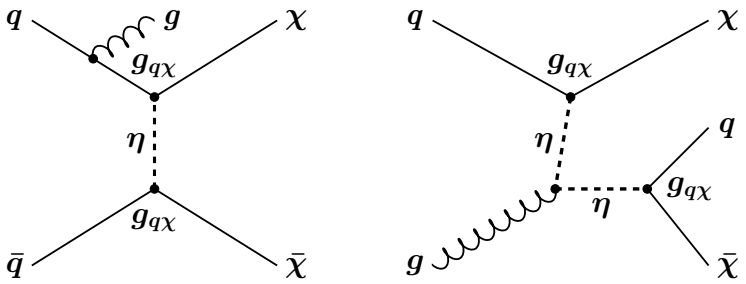


Statistically limited

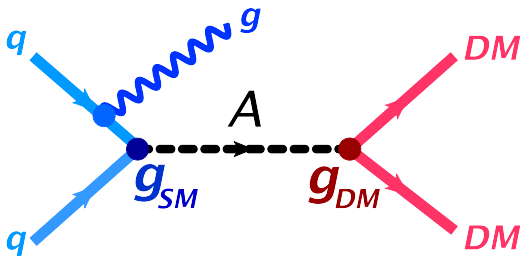
CMS: PRD 97 (2018) 092005
ATLAS : JHEP 01 (2018) 126

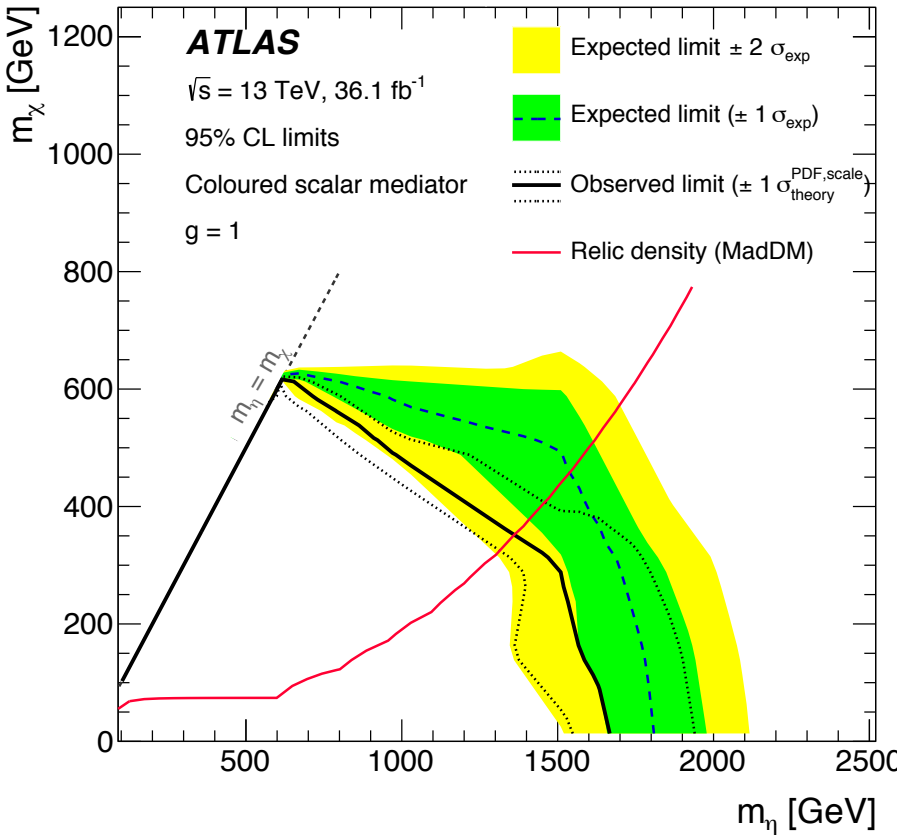
Mono-jet Searches

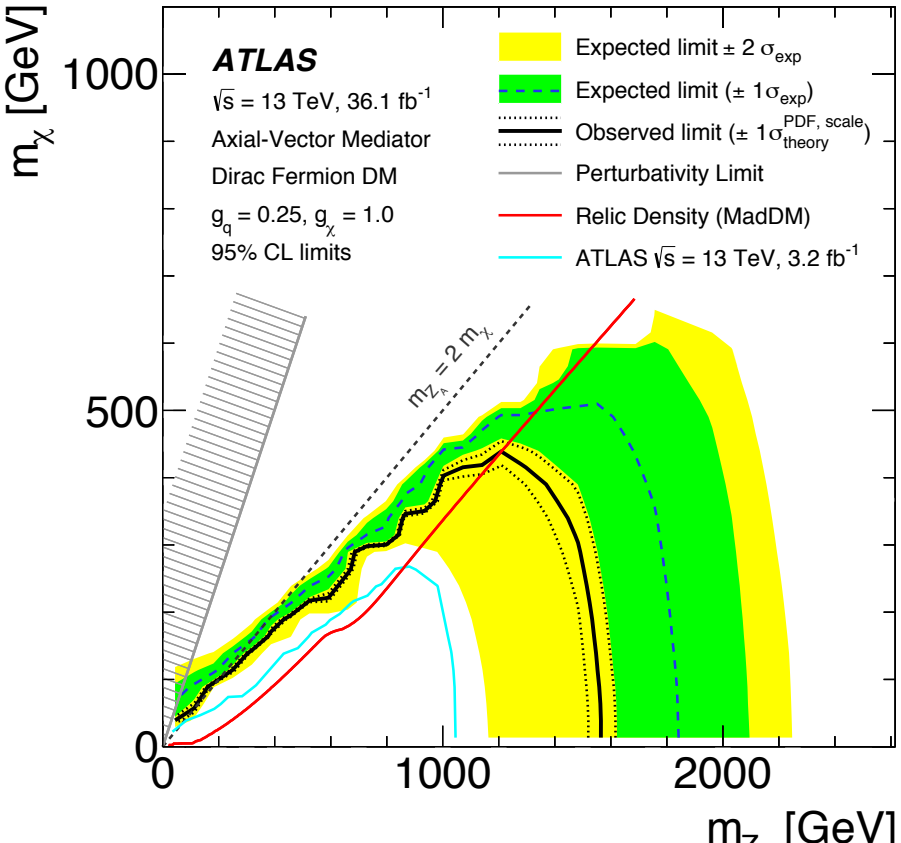
Scalar coloured 't-channel'



Spin-1 axial-vector s-channel

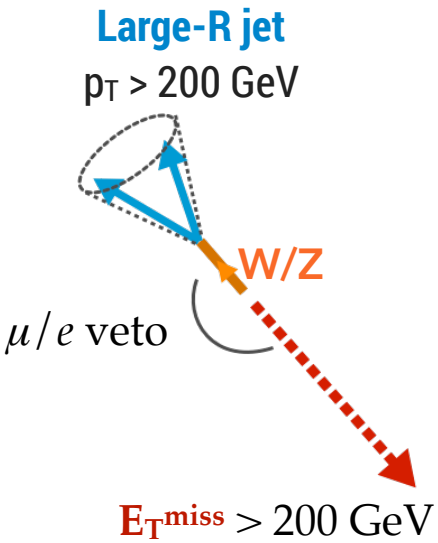






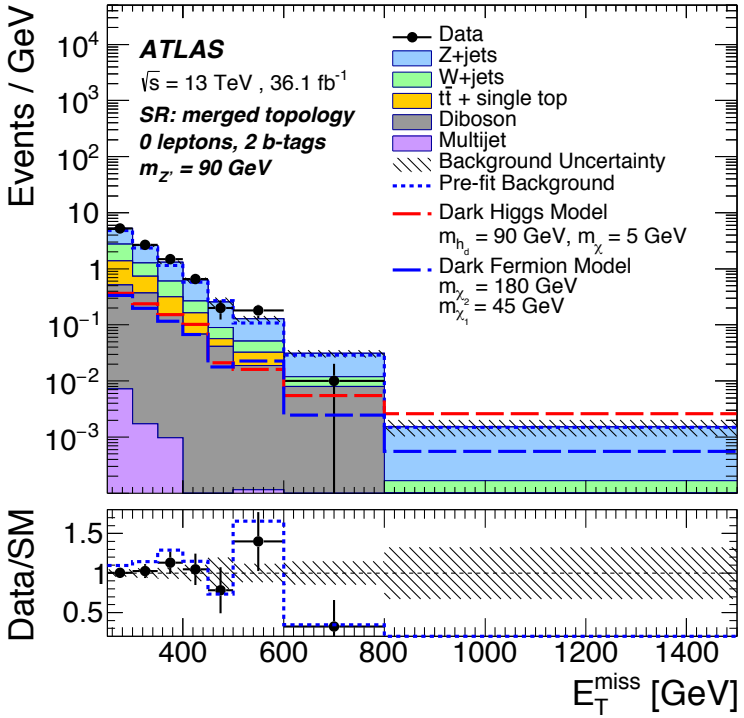
JHEP 10 (2018) 180

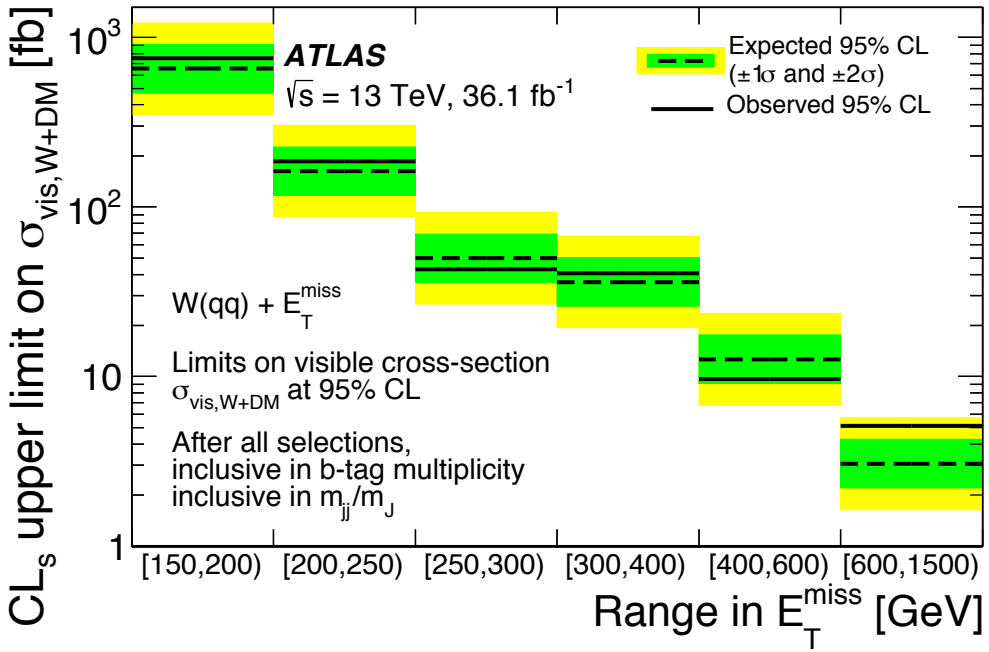
Mono-V(hadronic) Search

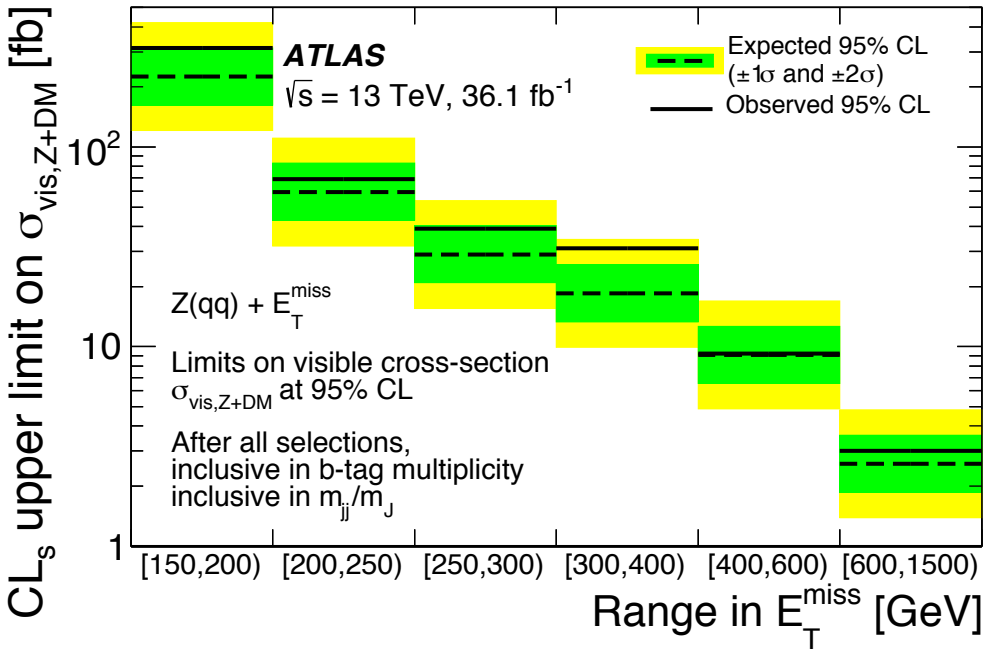


Large-R jets for boosted W/Z hadronic decays

- Sub-structure information for discrimination
- Z(vv)/W(lv)+jets dominant background → normalised in CRs
- main uncertainty: large-R jet modelling





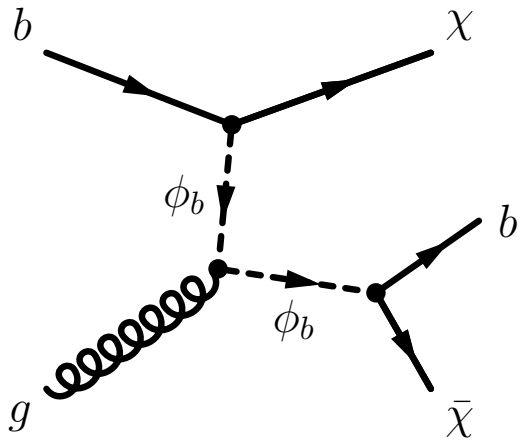


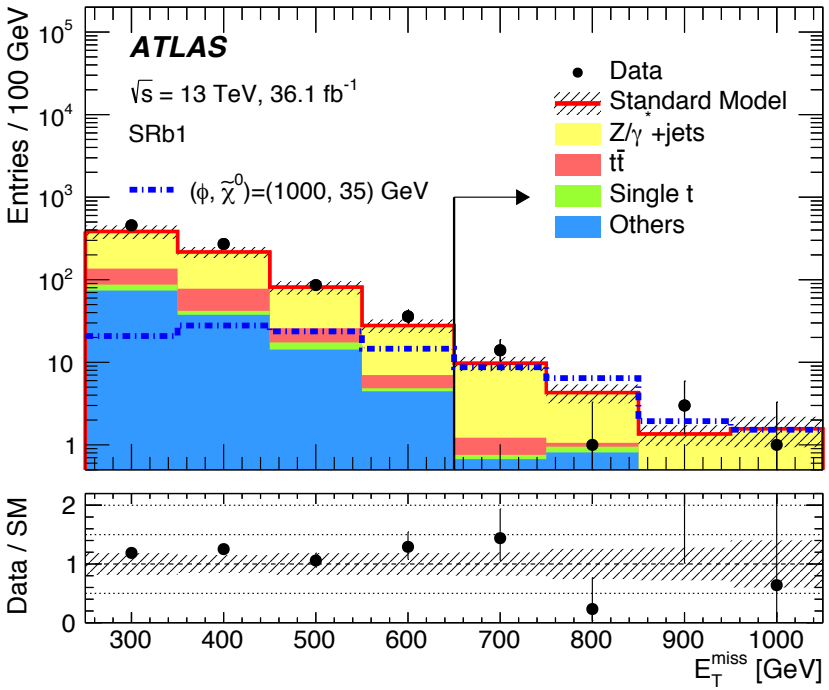
Dark matter with b and t

- Favoured if couplings are Yukawa-like
- Scalar or pseudo-scalar mediators

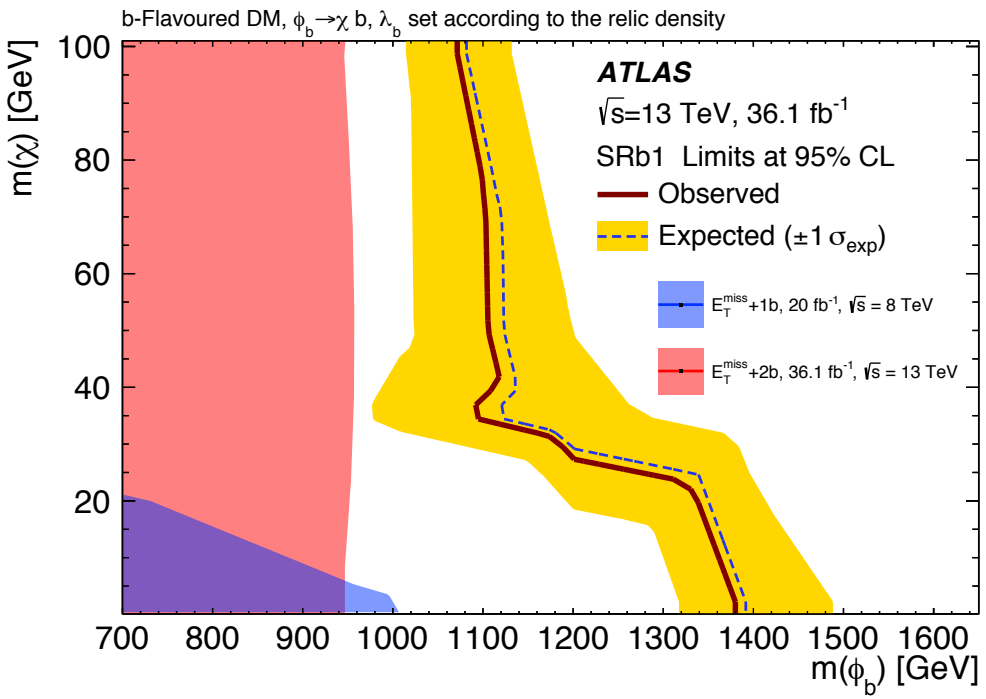
ATLAS: JHEP 06 (2018) 108, EPJC 78 (2018) 18
CMS: PRL 122 (2019) 011803, JHEP 03 (2019) 141,

Mono-b plus MET





b-flavored dark matter



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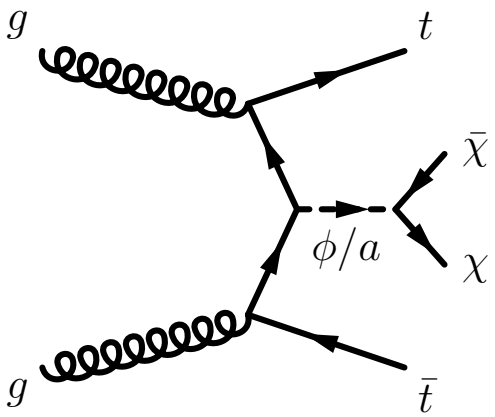
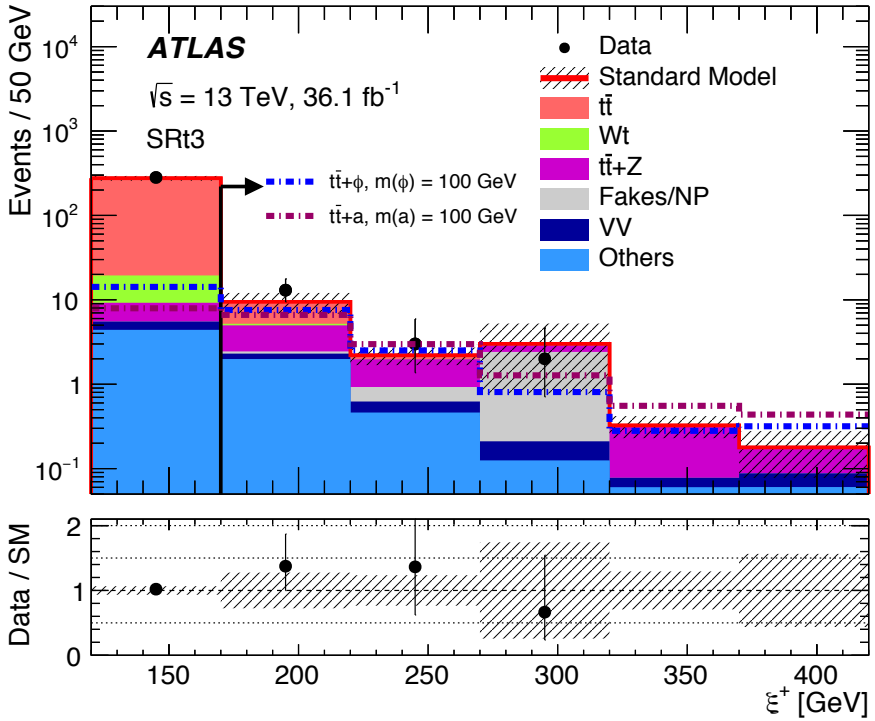
Dark matter with b and t

ATLAS: JHEP 06 (2018) 108, EPJC 78 (2018) 18
CMS: PRL 122 (2019) 011803, JHEP 03 (2019) 141,

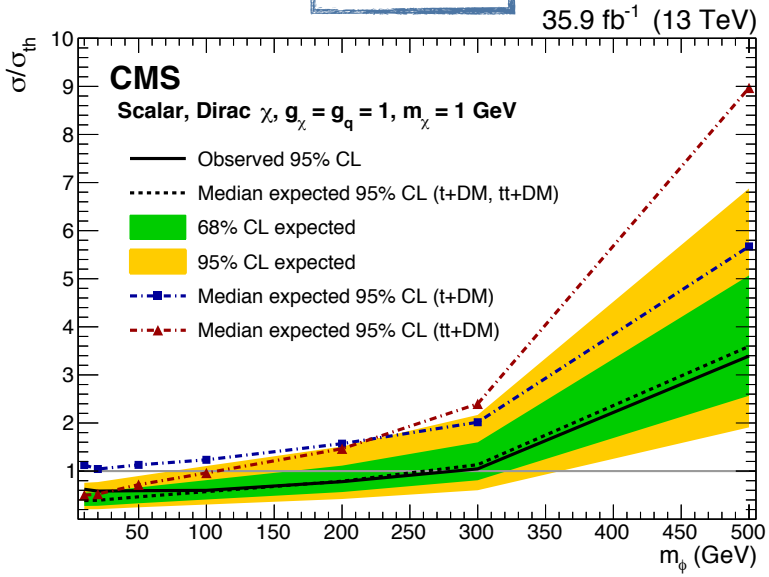
Met+ top



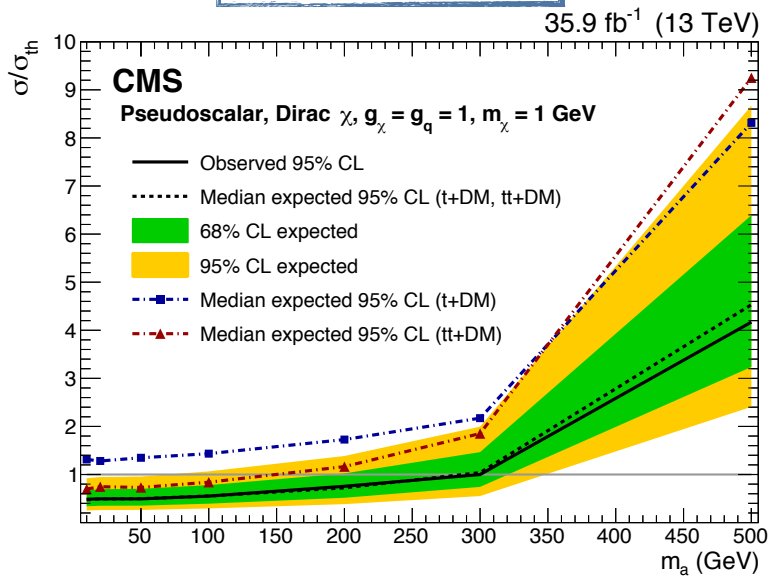
Reject top pairs background with top reconstruction or mT2-based variables



Scalar



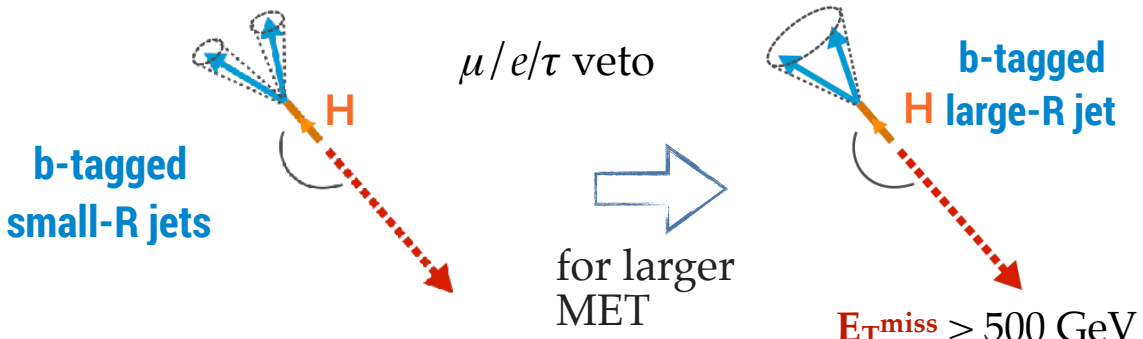
Pseudo-scalar



Mono-h(bb) Search

ATLAS-CONF-2018-039
CMS: arXiv:1908.01713

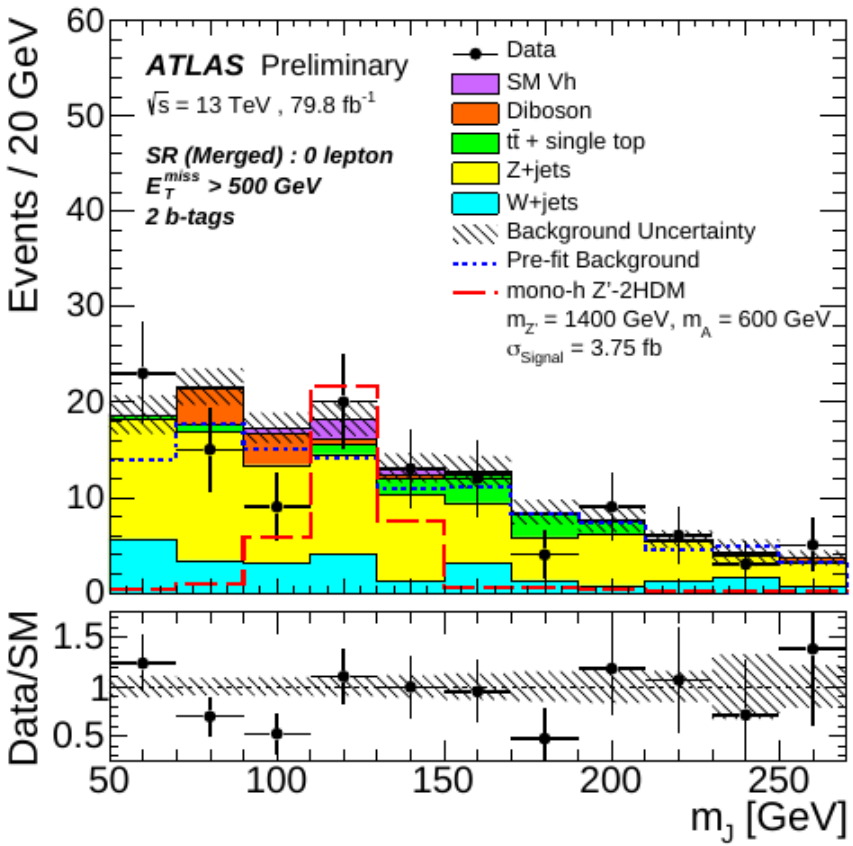
Probe coupling of Higgs boson to mediator

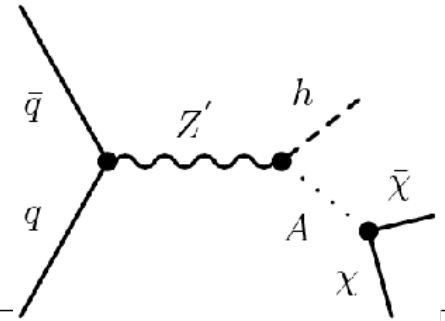


150 GeV< E_T^{miss} < 500 GeV

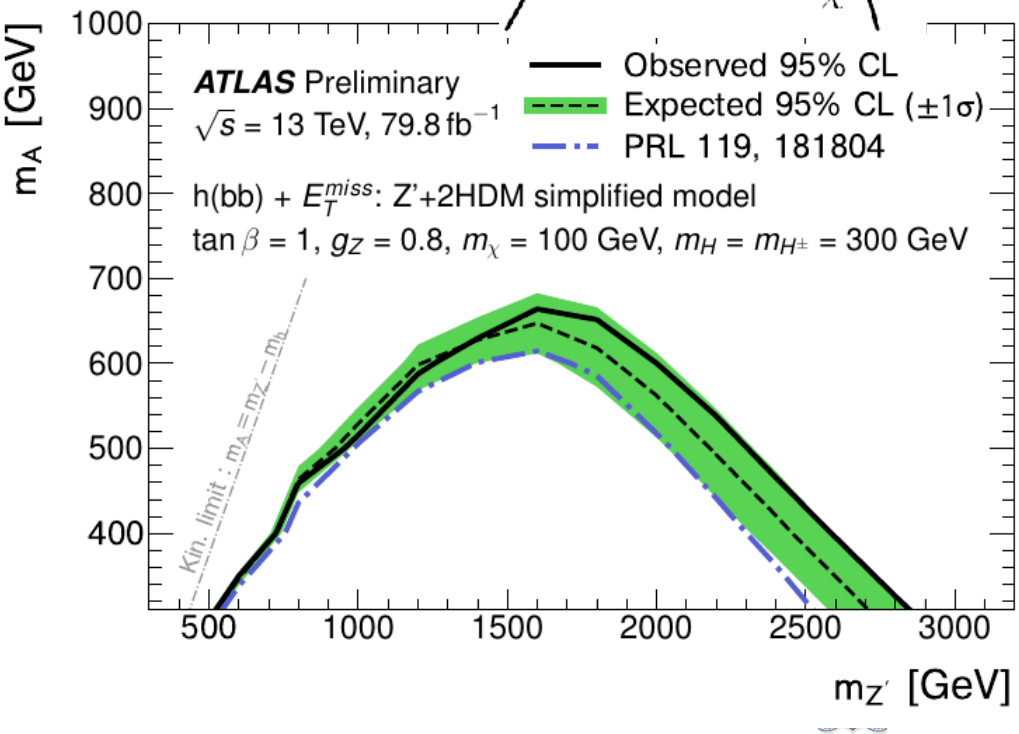
E_T^{miss} > 500 GeV

- m(jj) resonance or m(J)[~m(h),
- top and Z+jets dominant backgrounds,
- normalised in lepton control regions



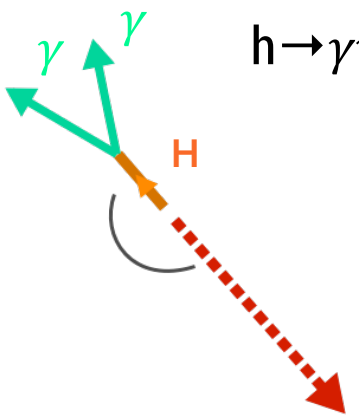


Z'-2HDM



Mono-h($\gamma\gamma$) Search

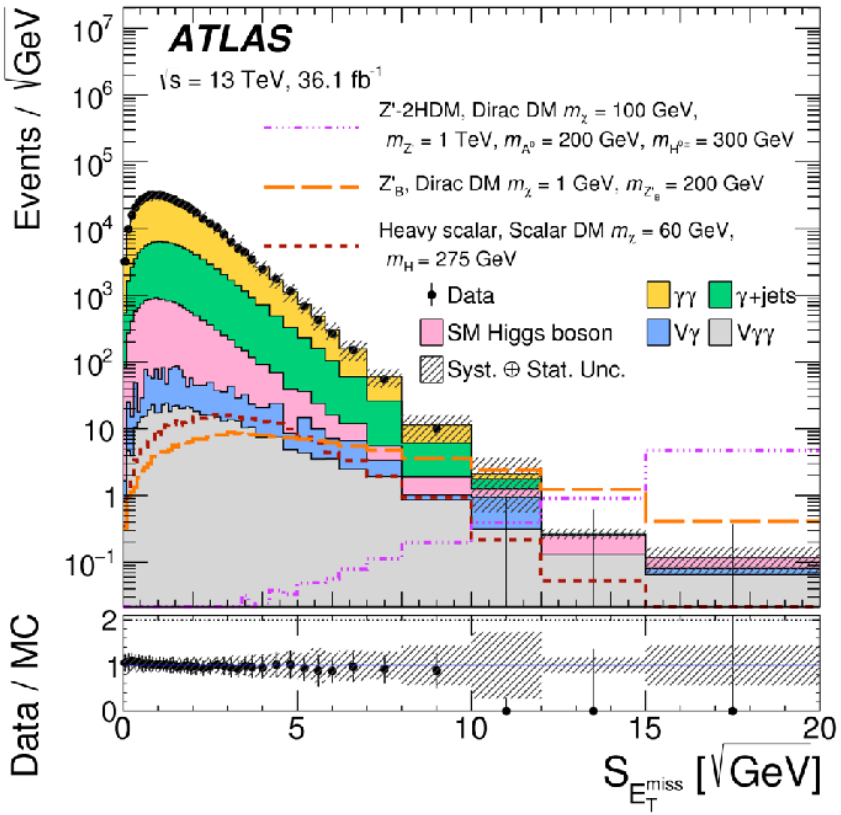
ATLAS: PRD 96 (2017) 112004
CMS: arXiv:1908.01713

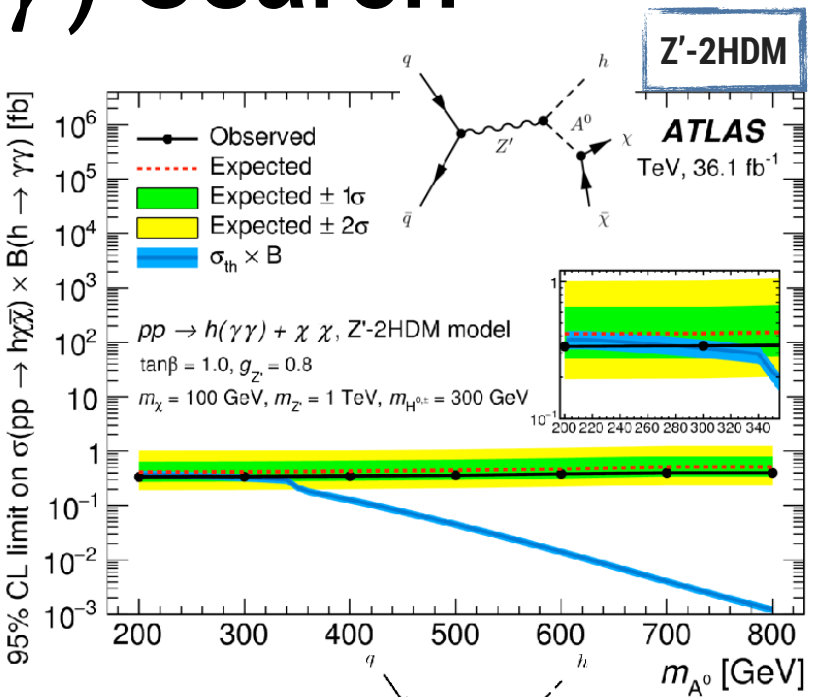


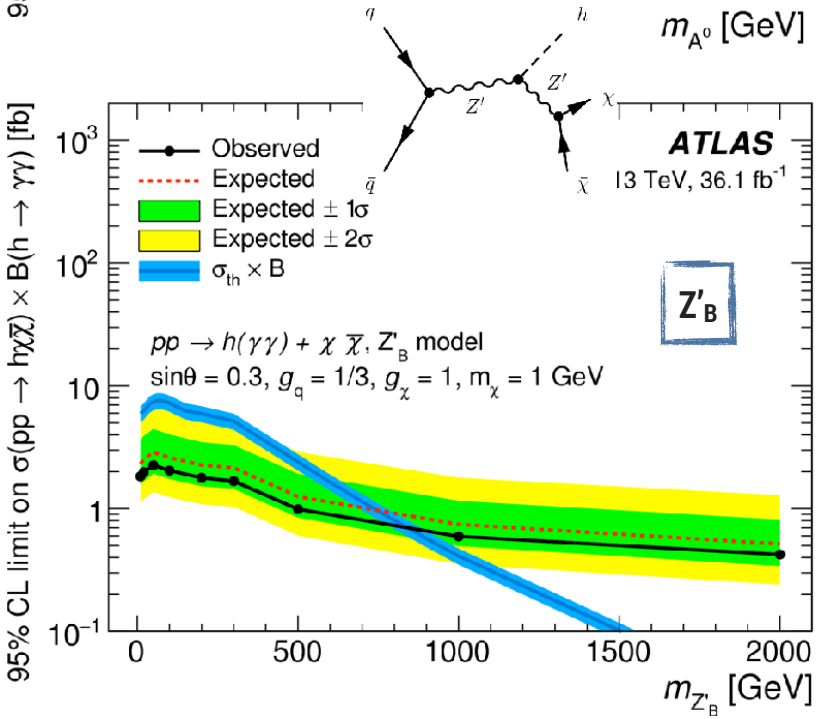
h→$\gamma\gamma$ low rate but clean signal

- background from $\gamma\gamma$ or Vγ
- large MET from pile-up jets
- look for resonances in m($\gamma\gamma$)

$E_T^{miss} > 90$ GeV

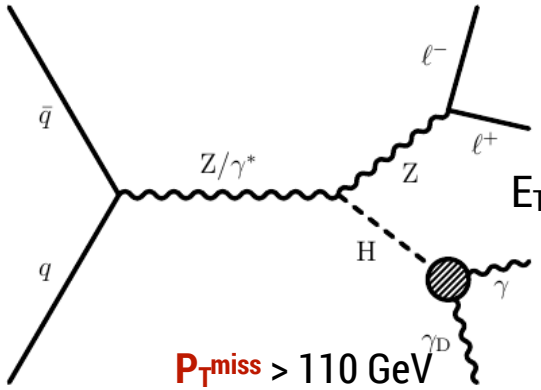






Mono-Z(ll)γ Search

New signature
arXiv:1908.02699

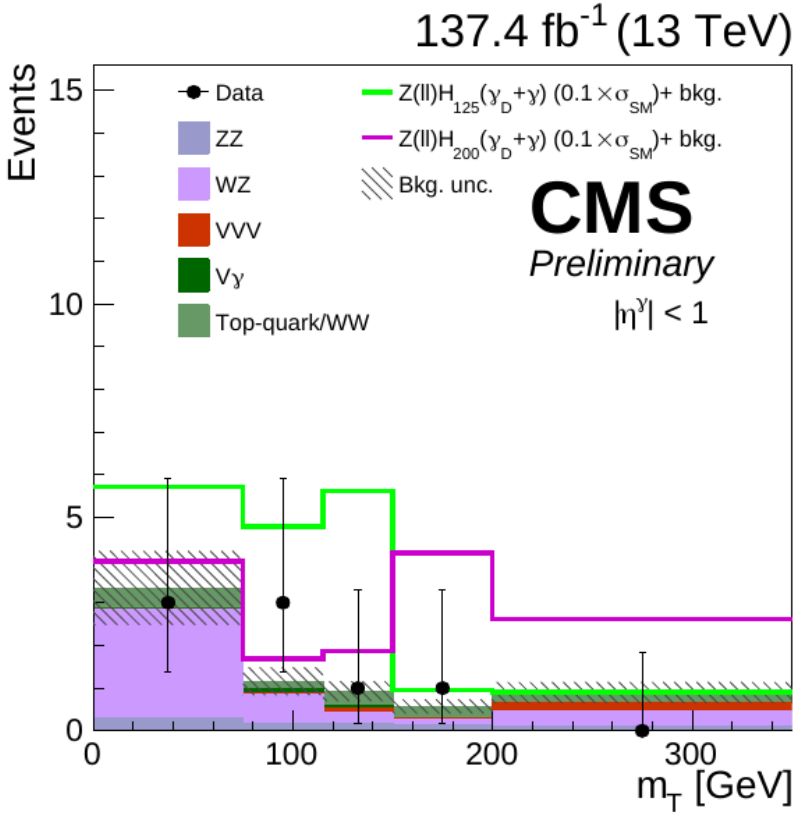


$E_T^{\gamma} > 25$ GeV

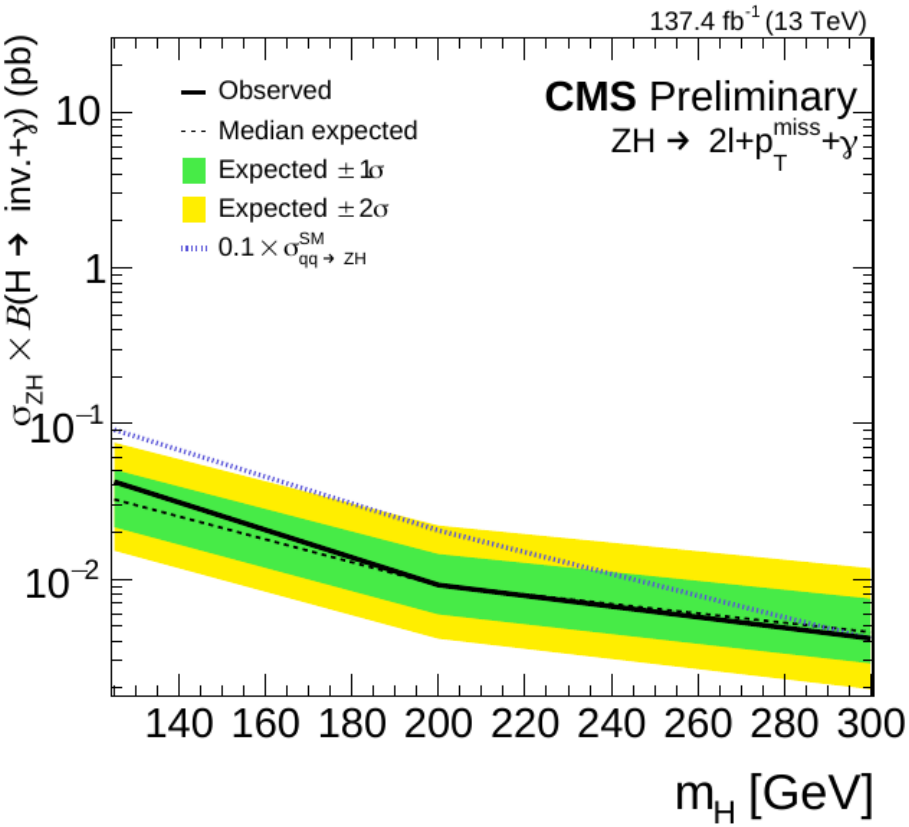
$P_T^{miss} > 110$ GeV

Massless dark photon

- Low-background signature
- Main backgrounds: ZW+ZZ estimated through CRs



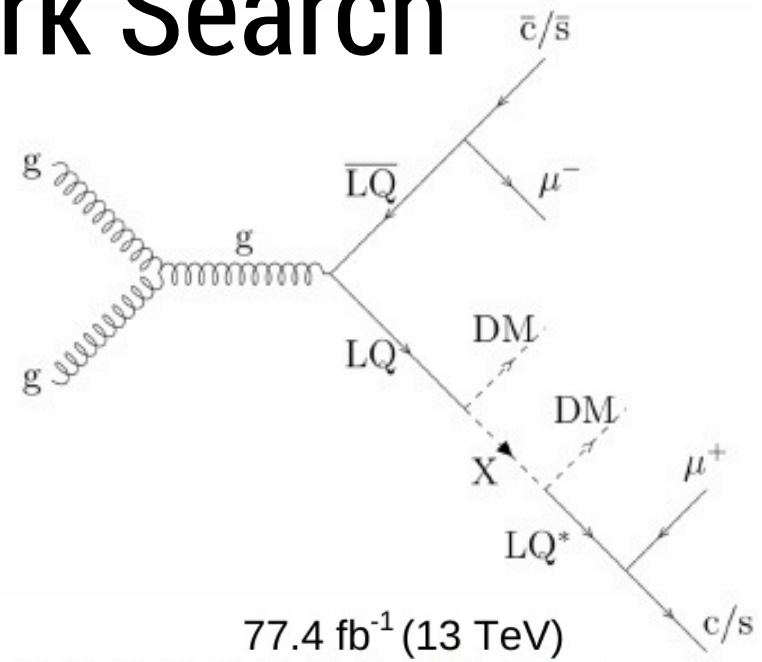
signal extracted by fitting mT in bins of |η(γ)|

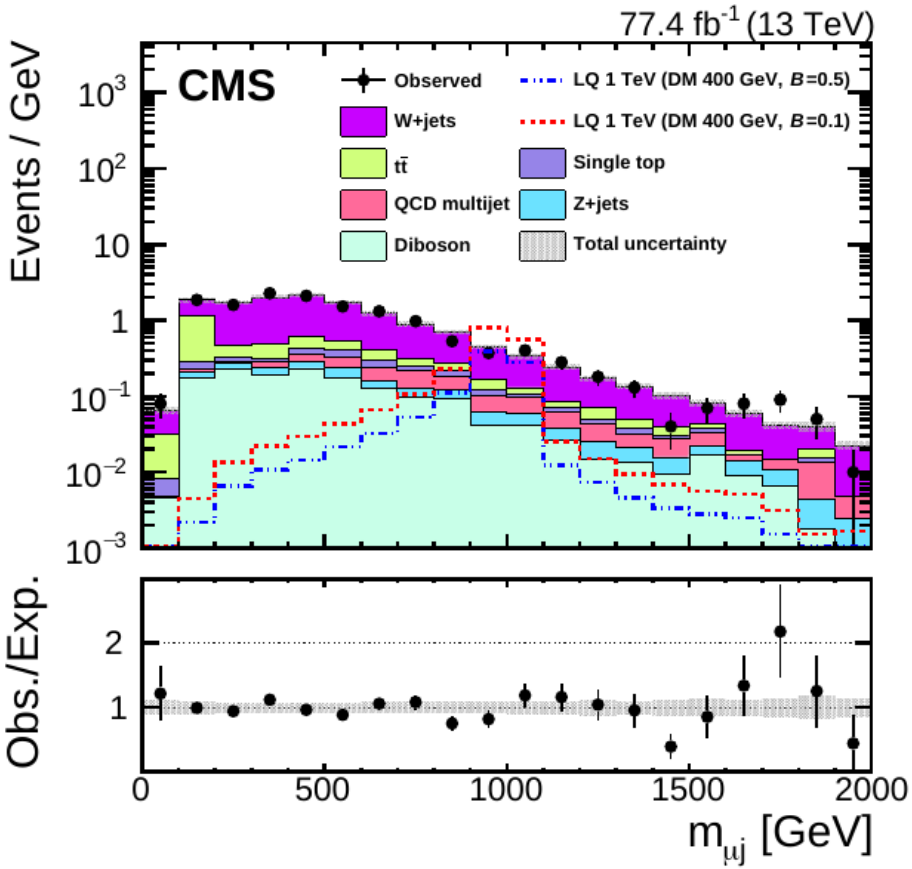


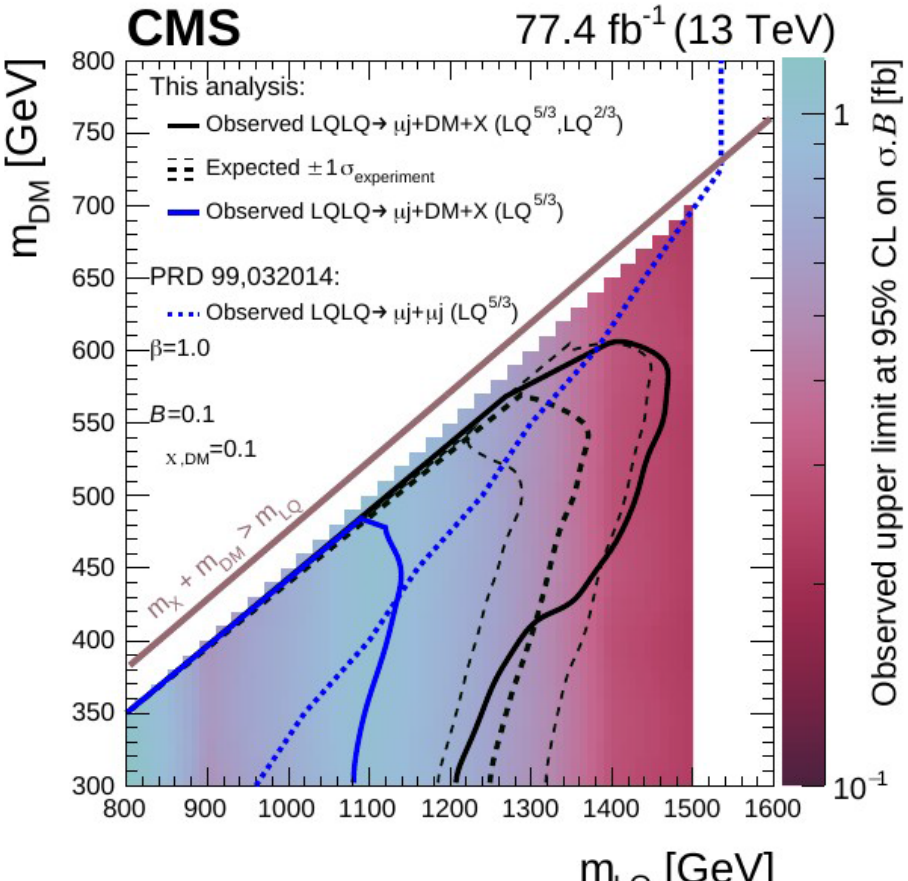
CMS: PLB 795 (2019) 76

Mono-Leptoquark Search

- Leptoquark (c/s+μ)
- p_{Tmiss} > 100 GeV, p_T(μ/j) > 50/100 GeV
- e/τ/b/Z vetoes
- look for a peak in m(μ/j) distribution







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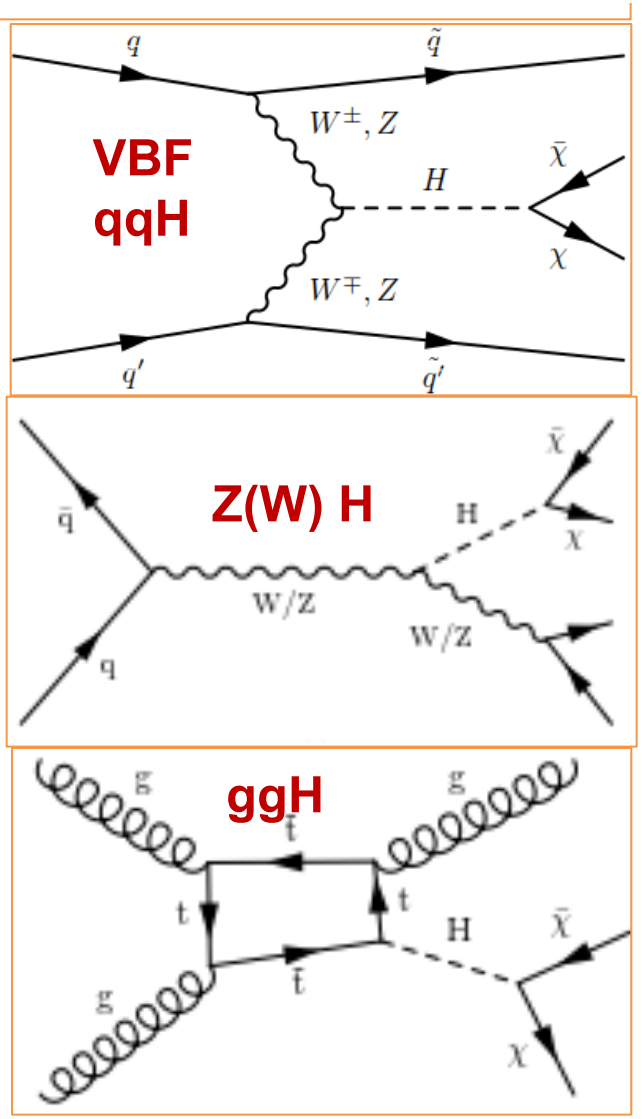
Higgs Portal

Most sensitive channel is VBF production



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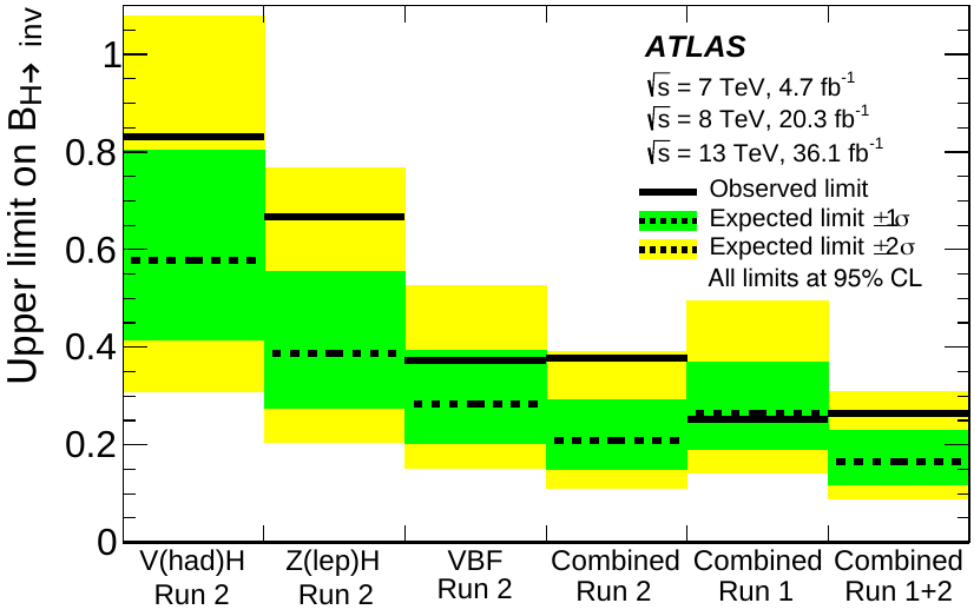
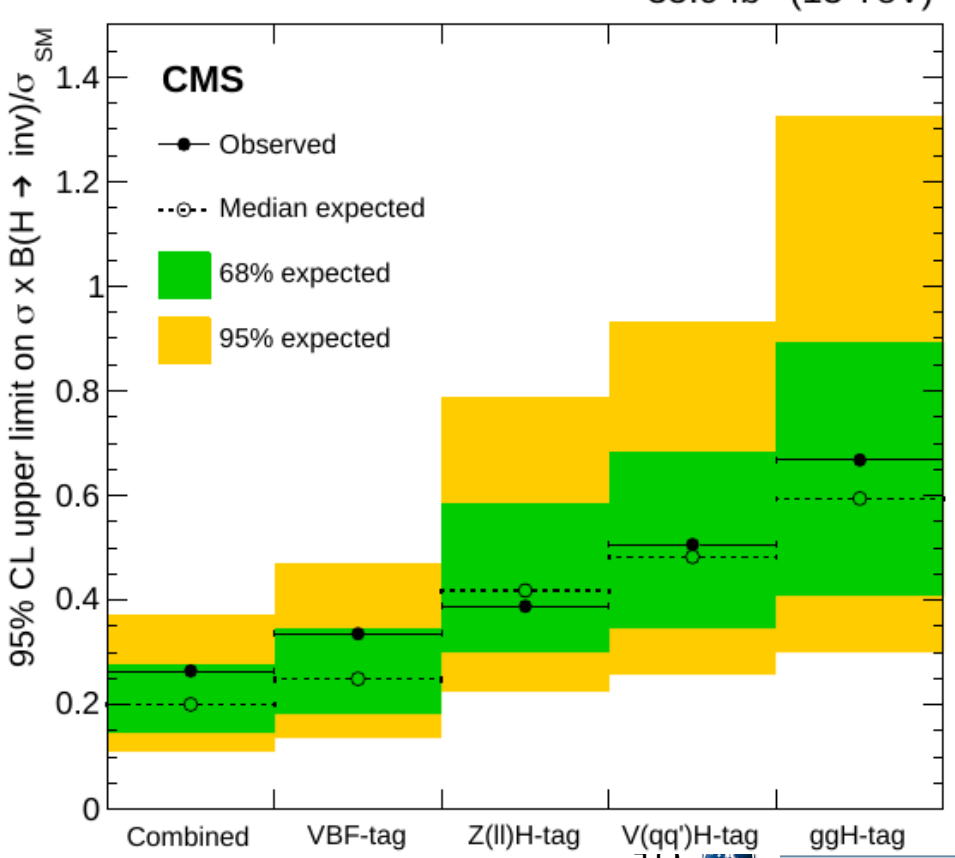




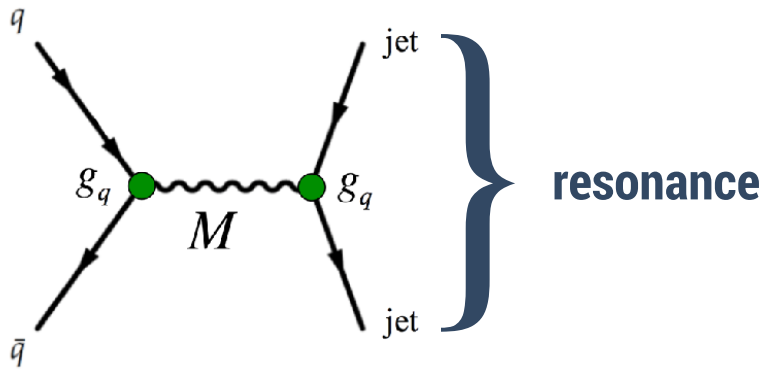
all data	combined	$m_{DM} < m_H / 2$
ATLAS	BR(H→inv) < 0.26 (0.17 exp) @95% CL	
CMS	BR(H→inv) < 0.19 (0.15 exp) @95% CL	

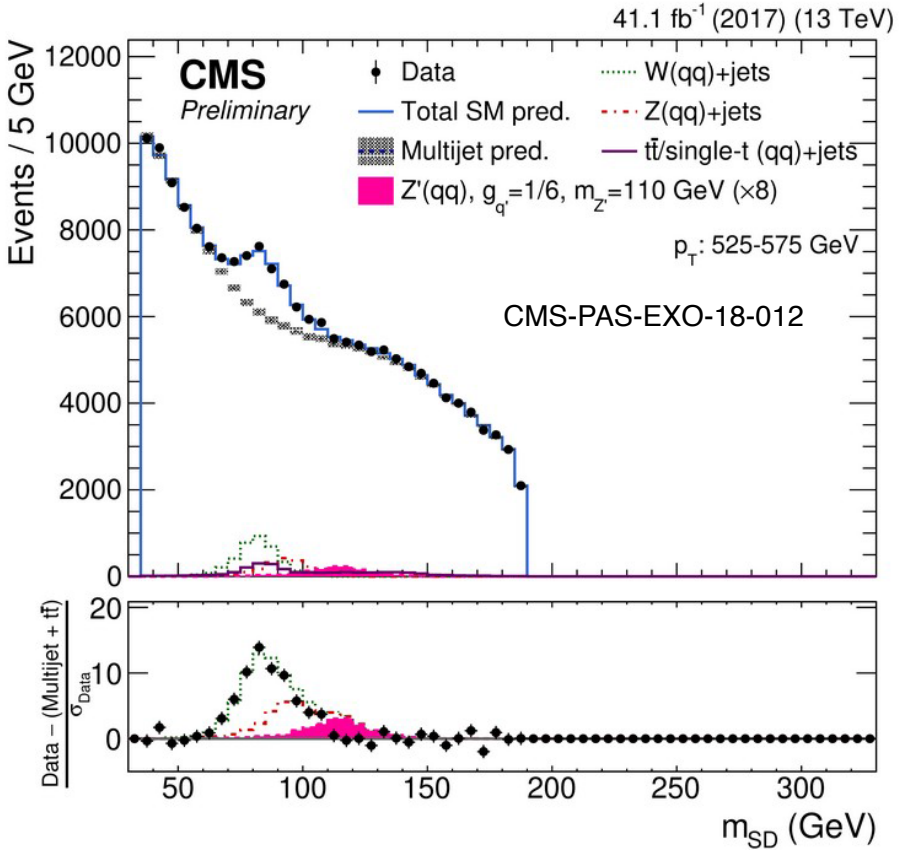
Searches for the Mediators

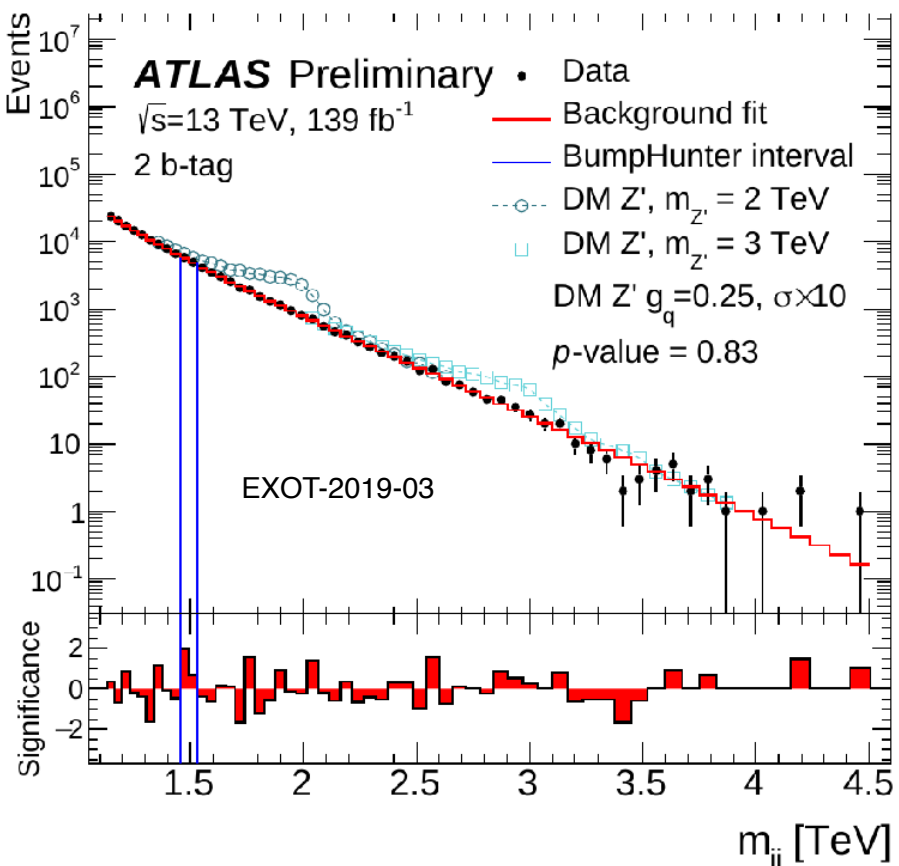
No dark matter in the final state: model dependent indirectly constrain

Constraints on couplings (See exclusion plots)

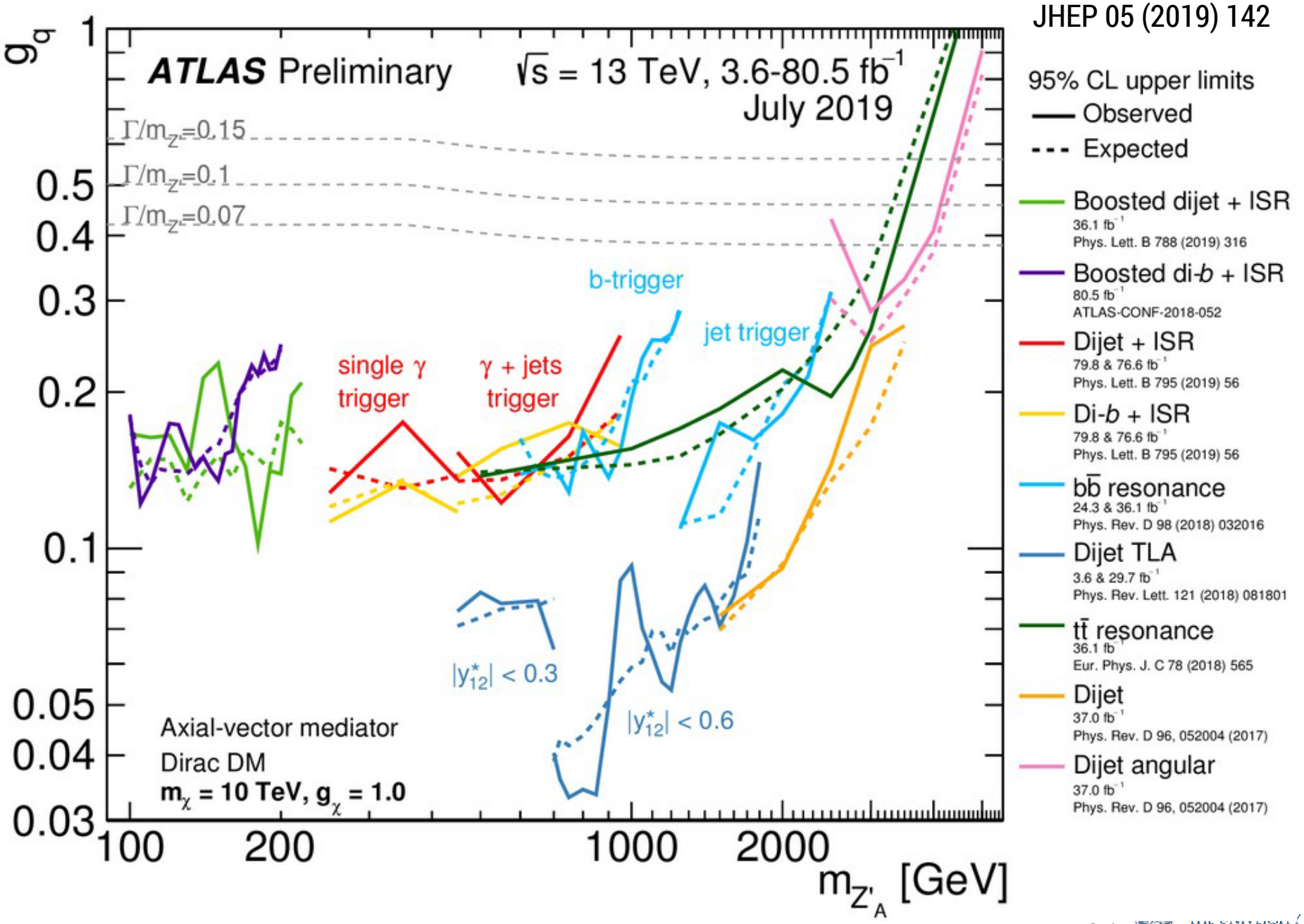
Traditional bump-hunting: look for **di-jet resonances**



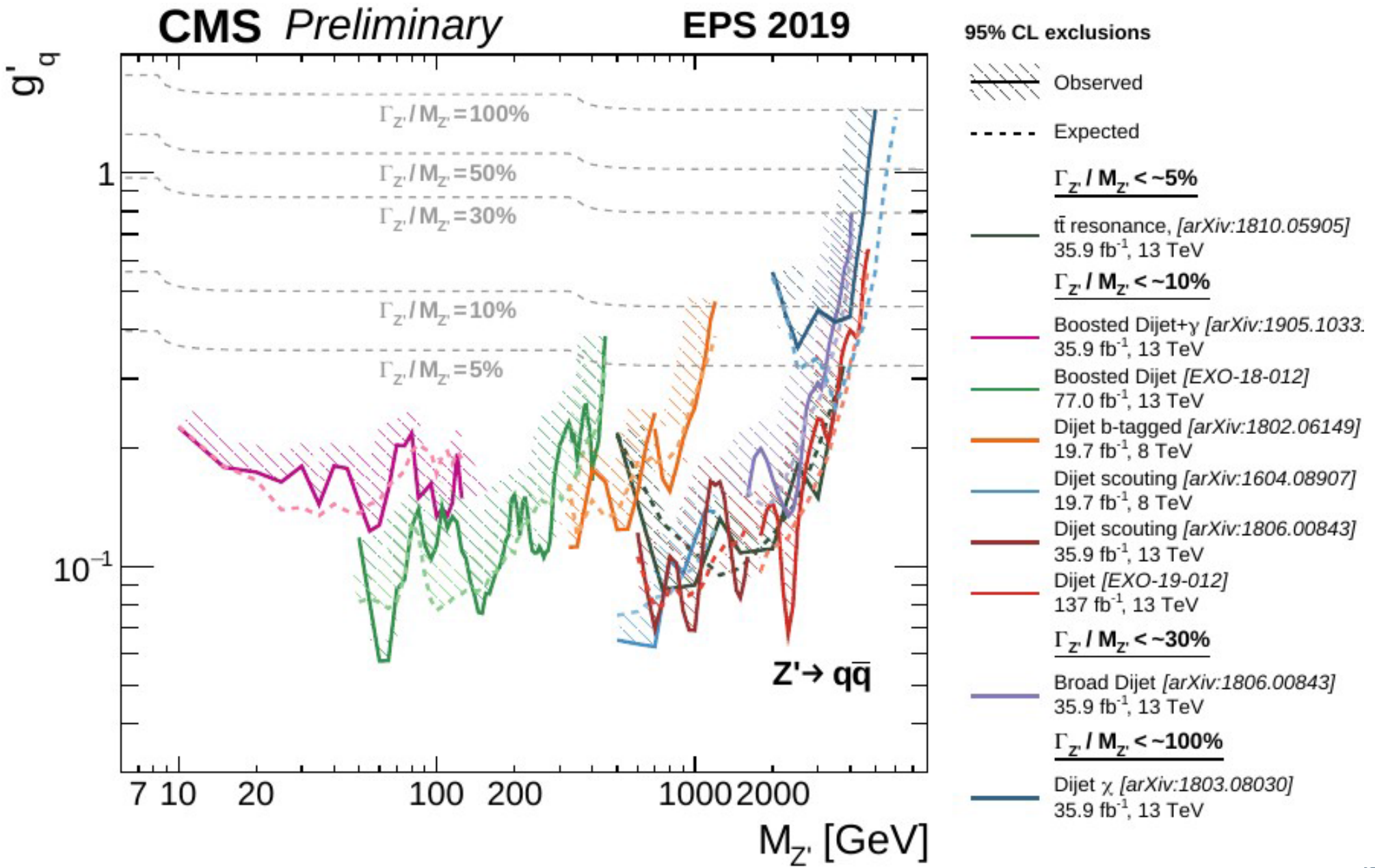




Constraints on Couplings



Constraints on Couplings



Interpretation

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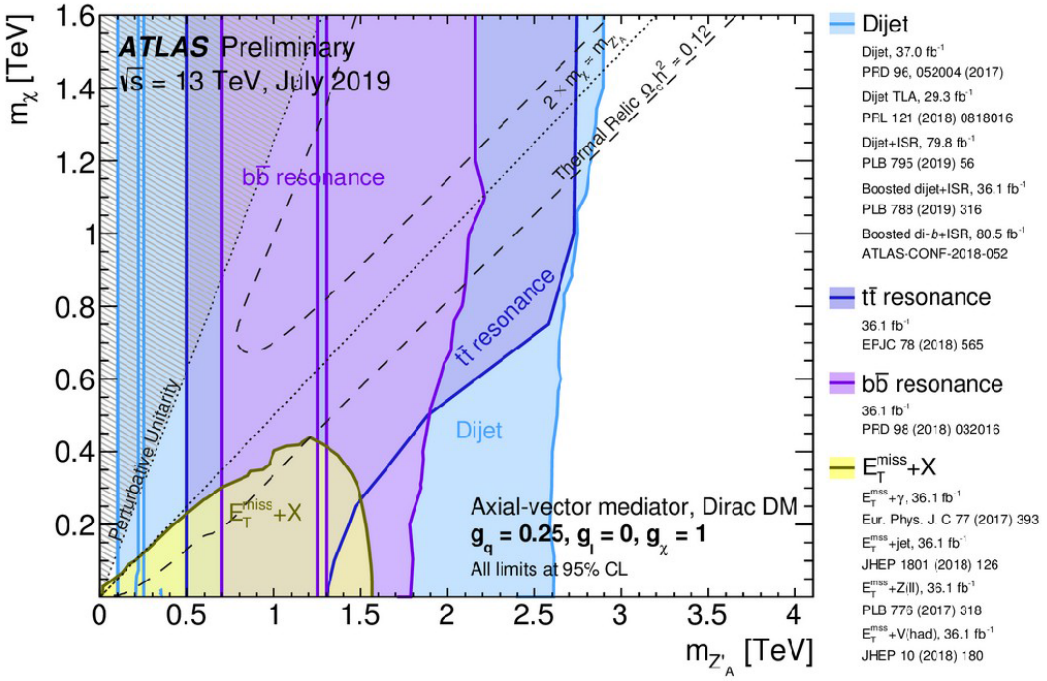
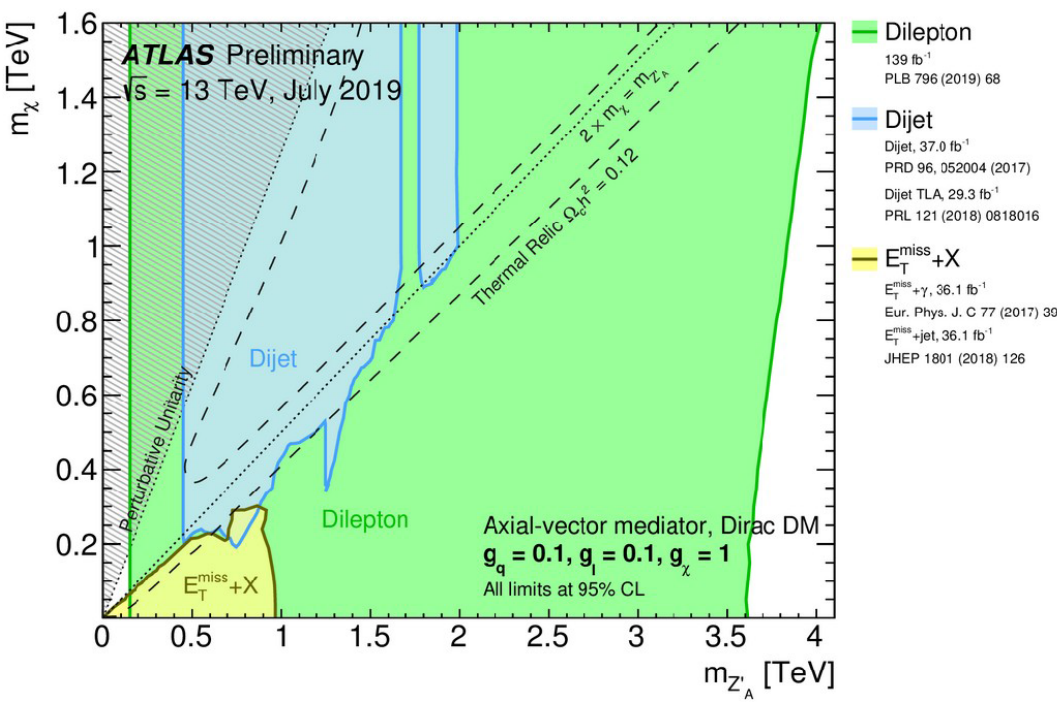
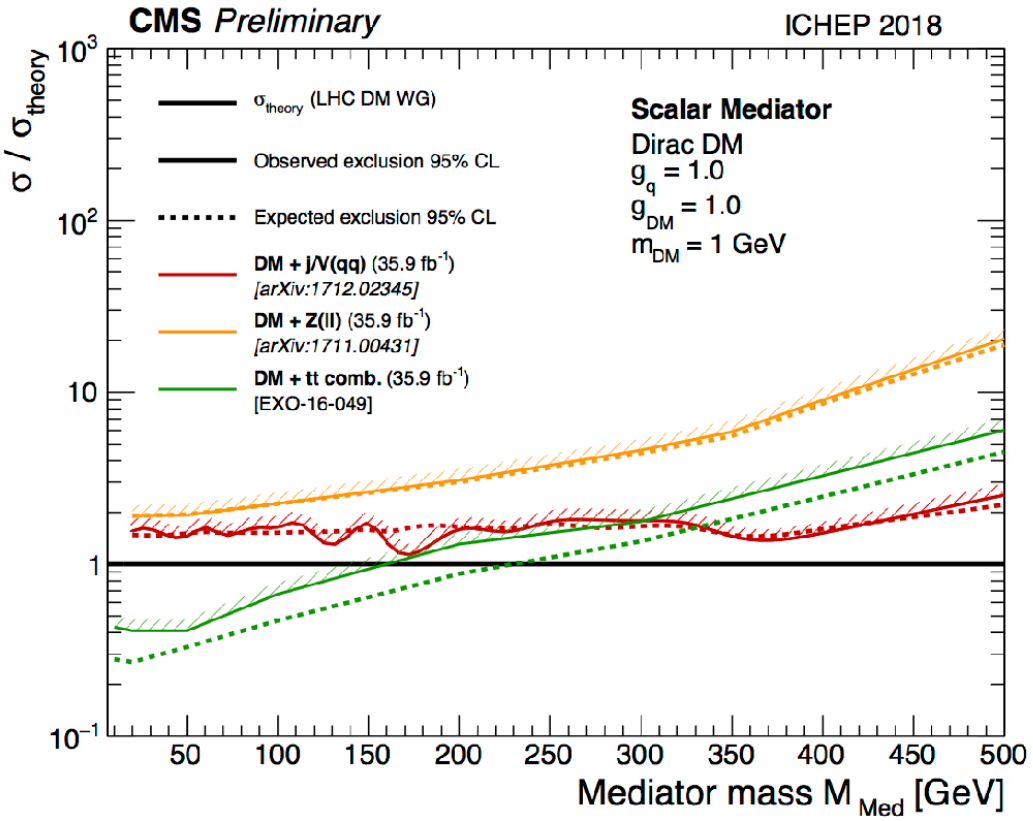
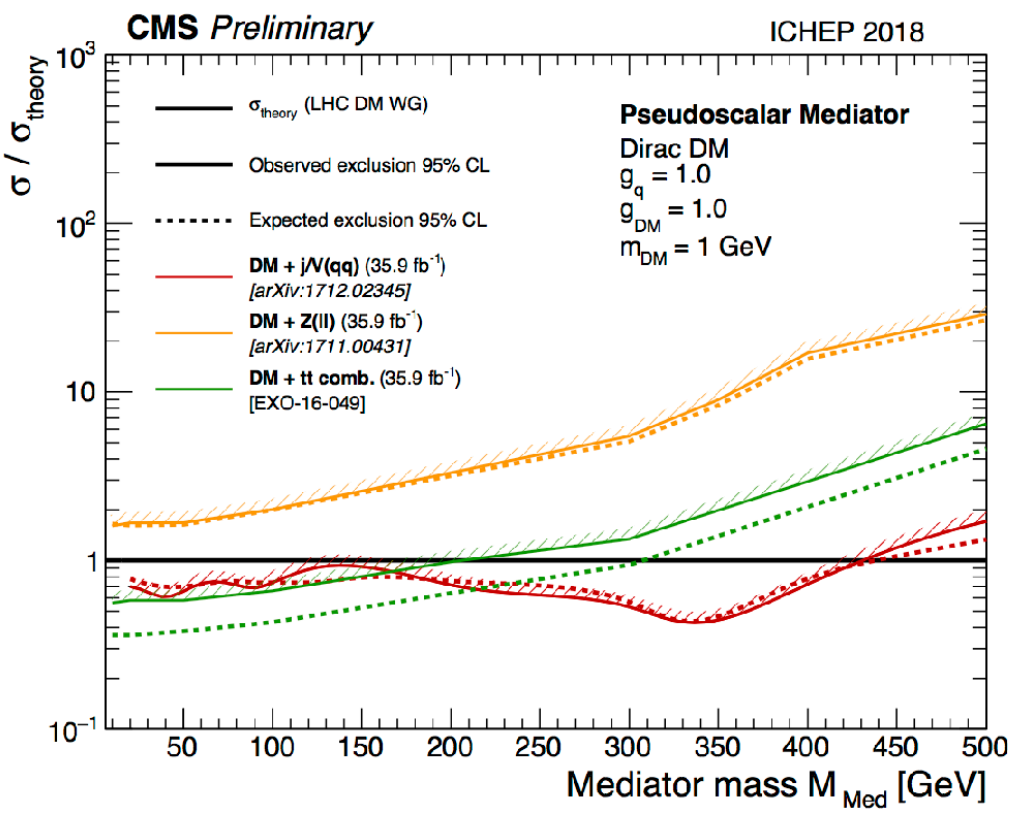




Exclusions directly depend on couplings and Dark Matter

Interpretation





Exclusions directly depend on couplings and Dark Matter

Comparison with Direct Detection

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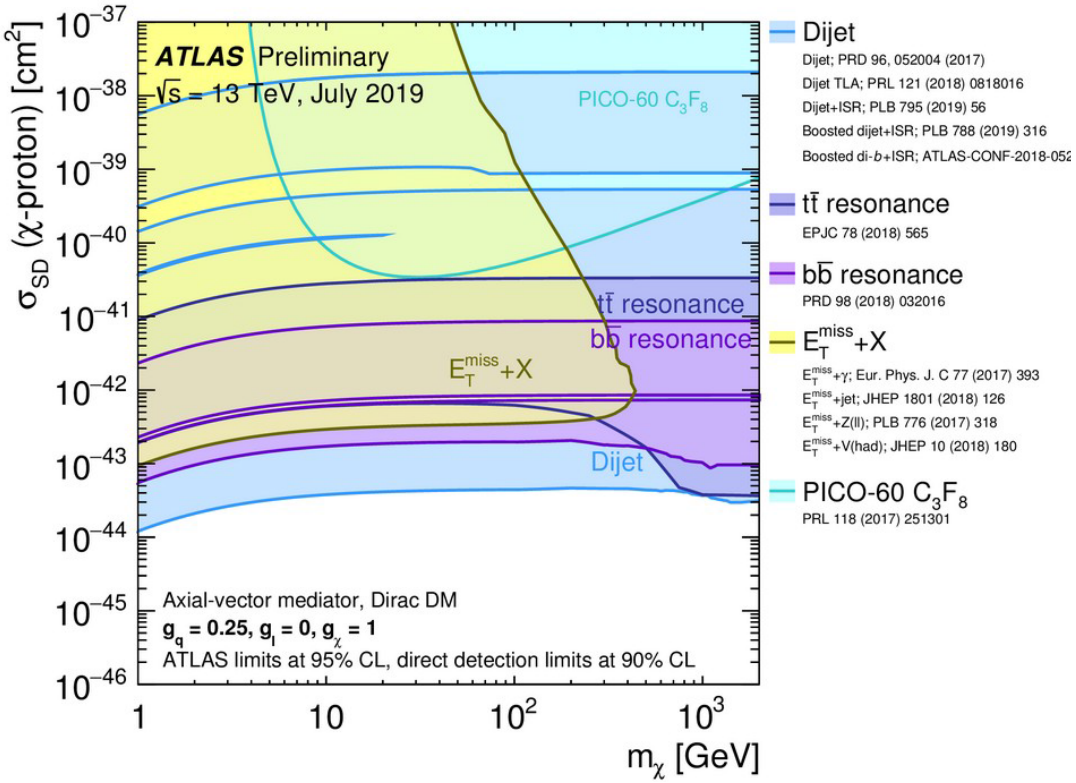

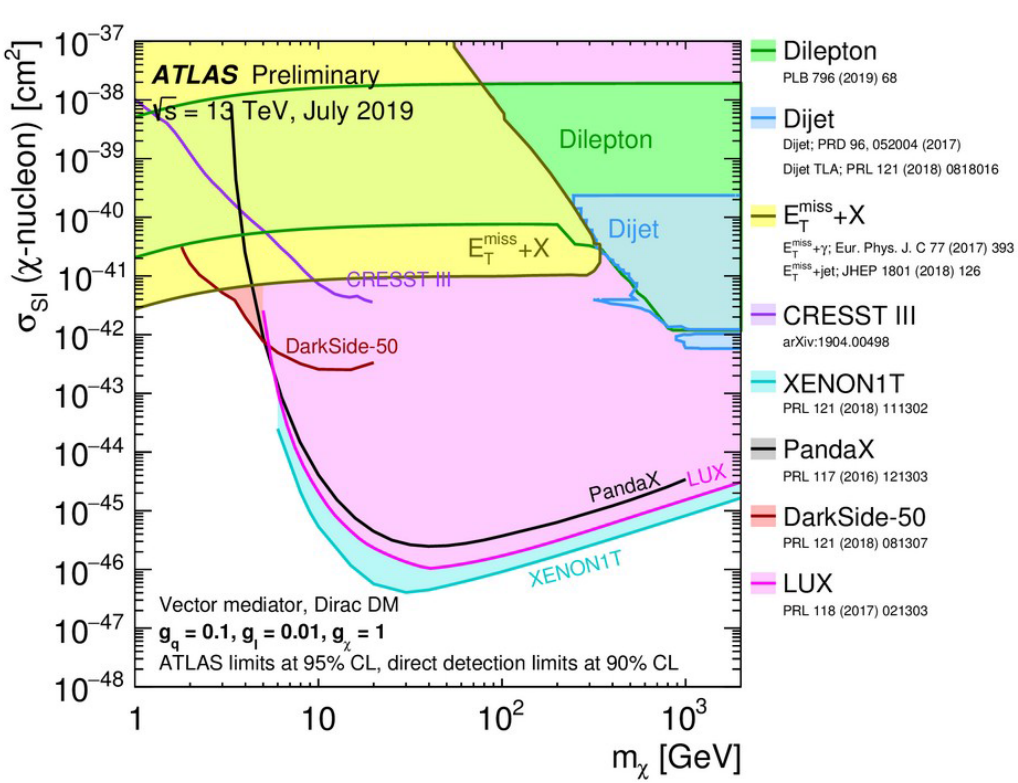

Model dependent comparison

Complementarity between LHC and direct detection experiments

Conclusion/Outlook

Much more to come from Run2 data.. … and then….

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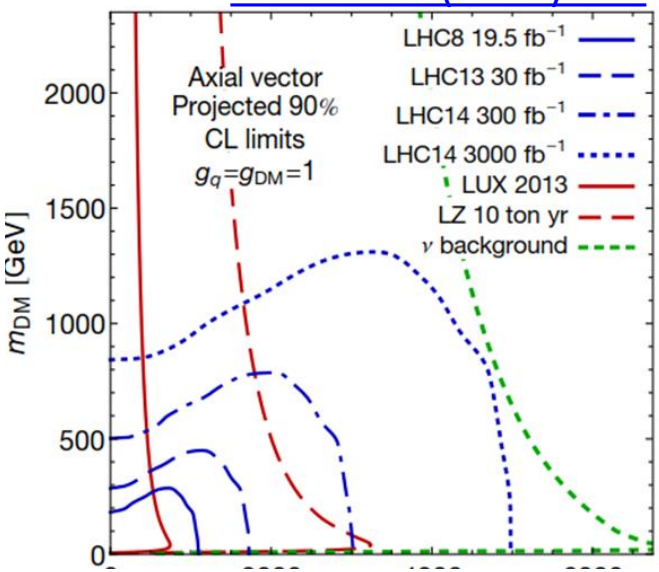

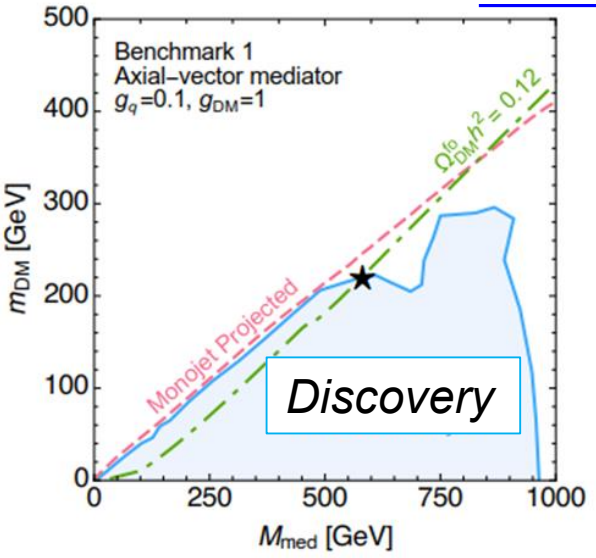

arXiv:1712.04793