Dark matter searches at the LHC

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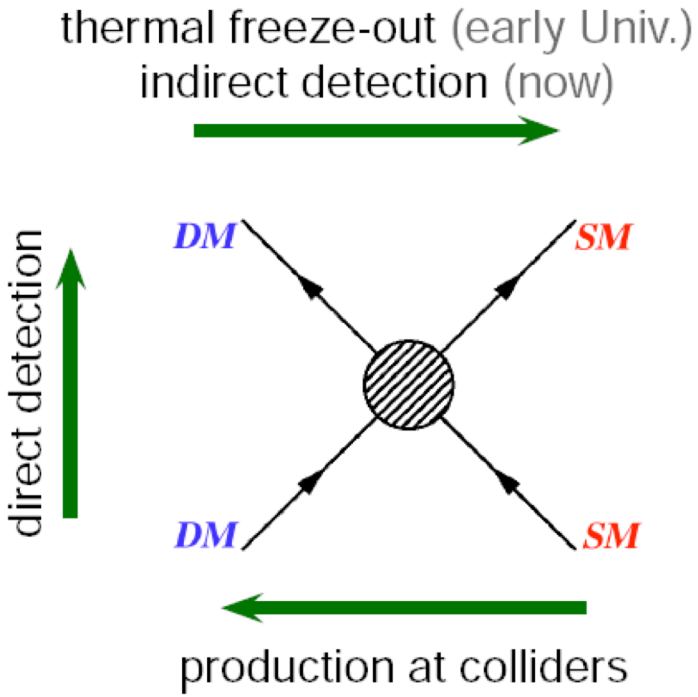
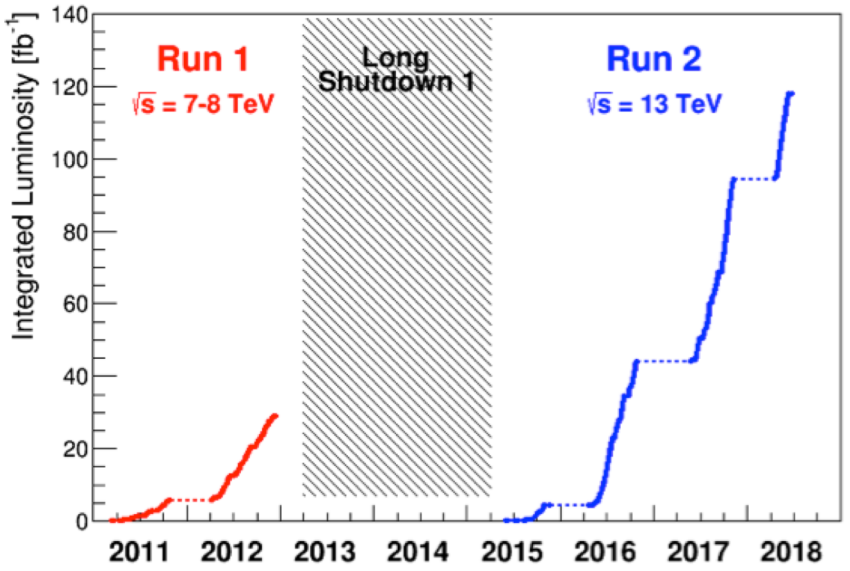
DM searches at colliders

Why search for and study dark matter at colliders?

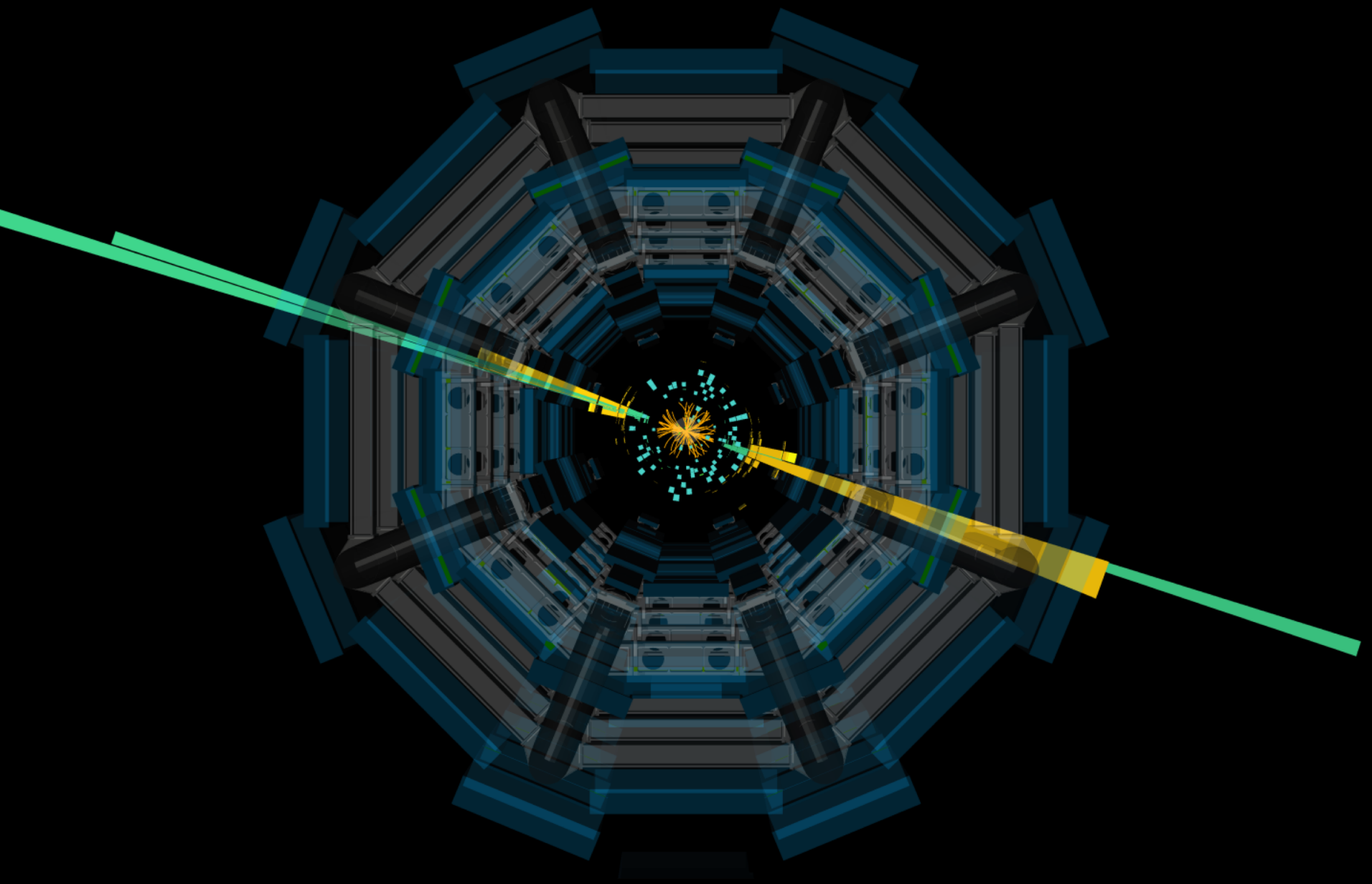
- WIMP paradigm: interactions, energy reach
- Complementarity of sensitivity and properties measurement





- Search for mediator of the SM–DM
- Search for stable DM candidate(s) themselves

Dijet searches

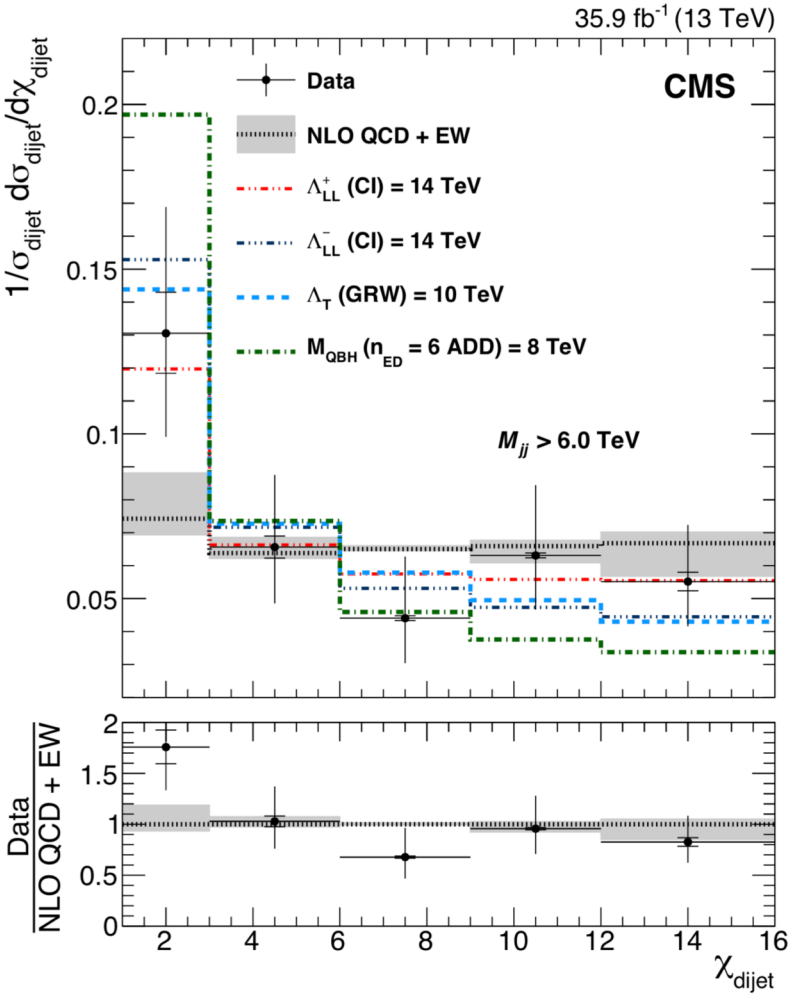


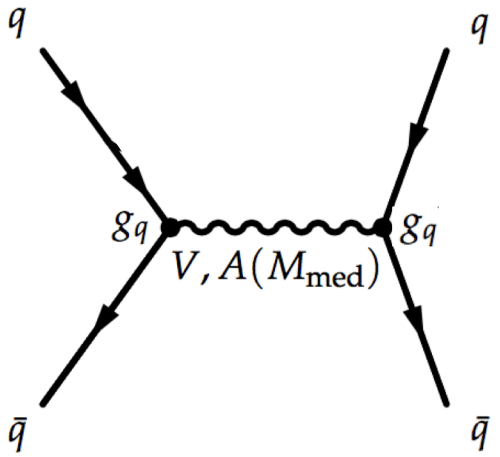
Dijet searches for mediators

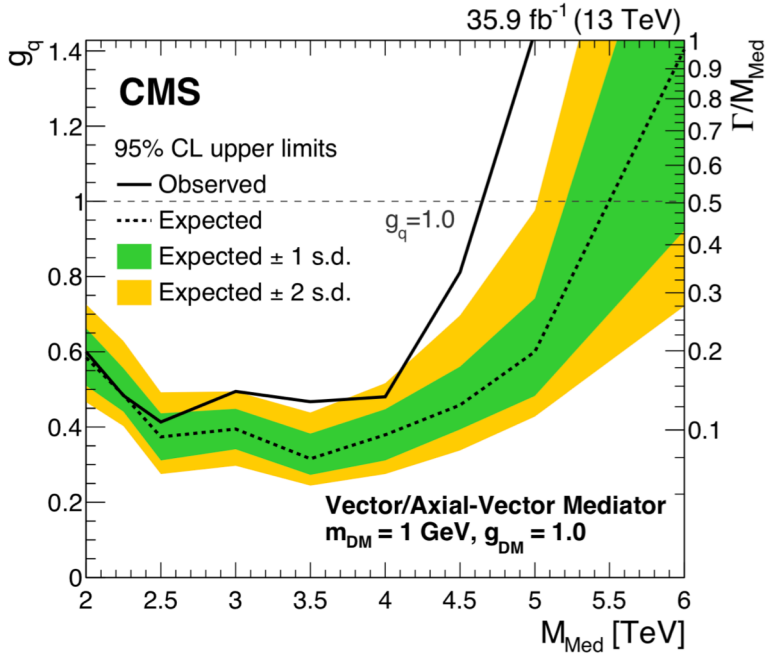
arXiv:1803.08030

In high-energy pp collisions search for production of the DM—SM mediator (g_q^2)

Study dijet angular correlations







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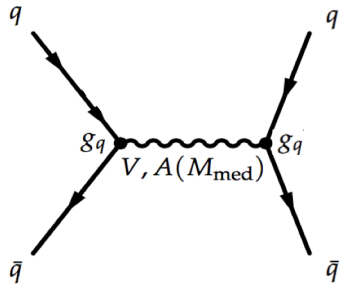
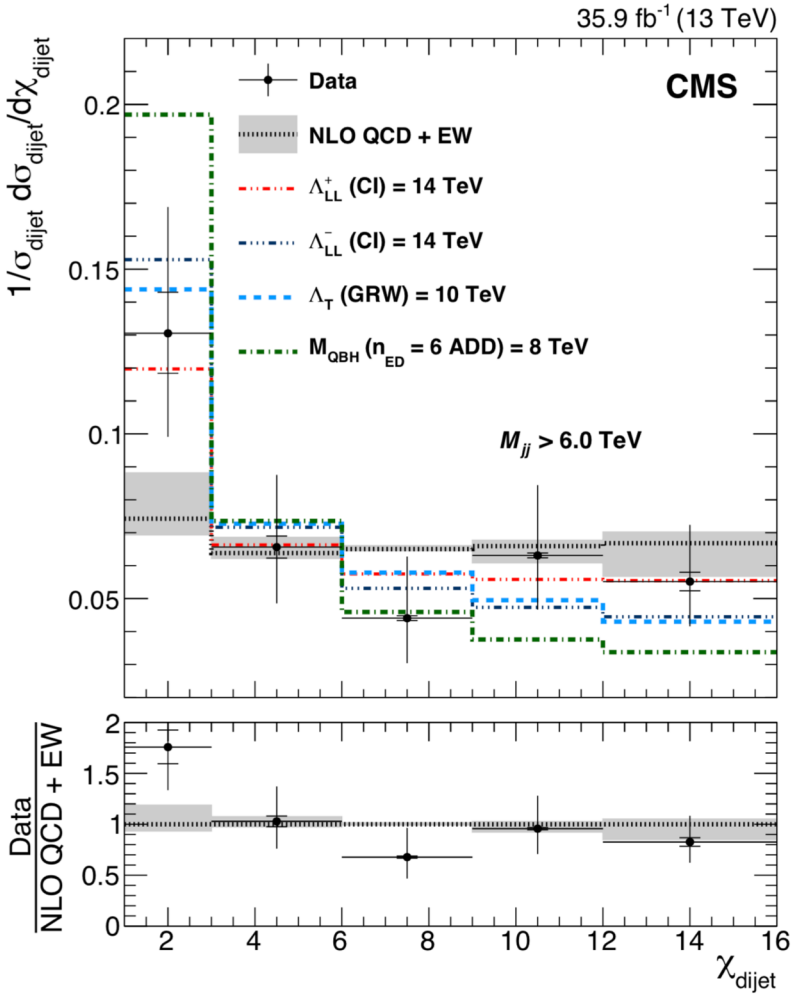
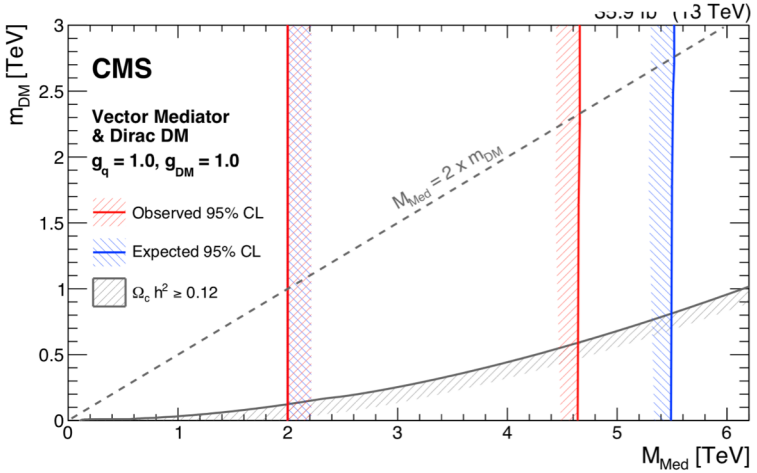
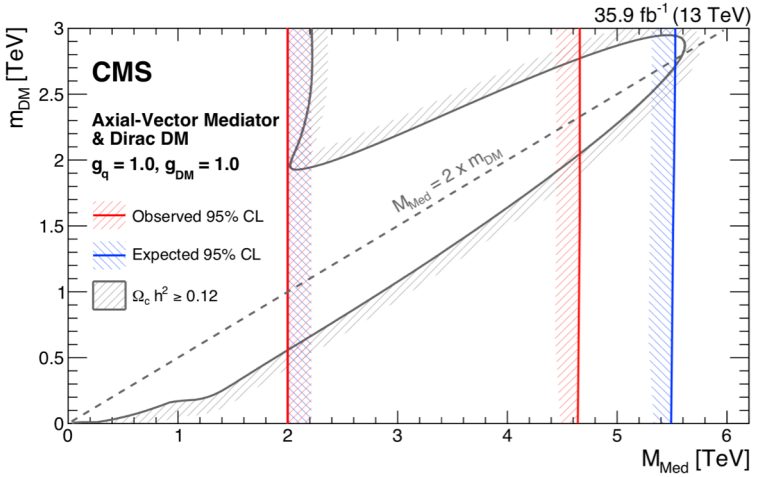






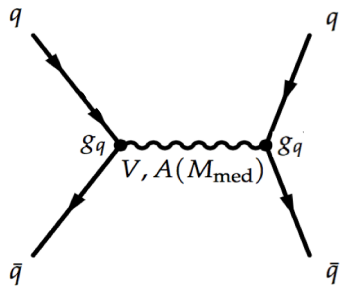


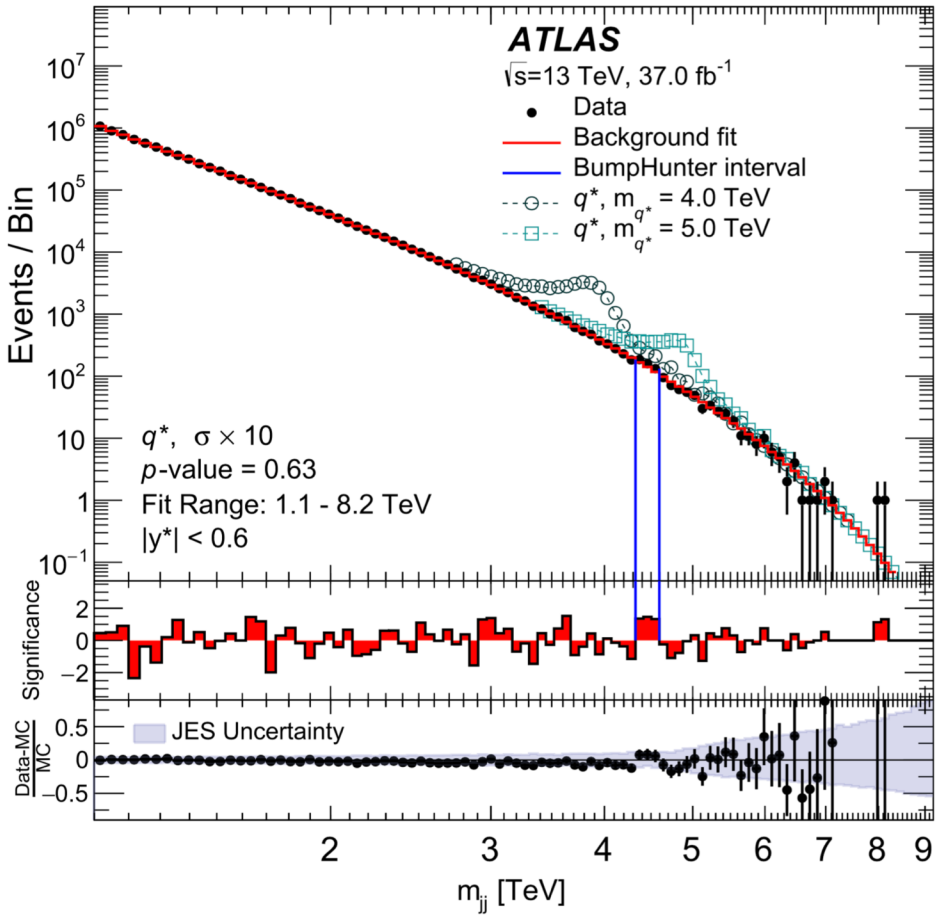
Dijet searches for mediators

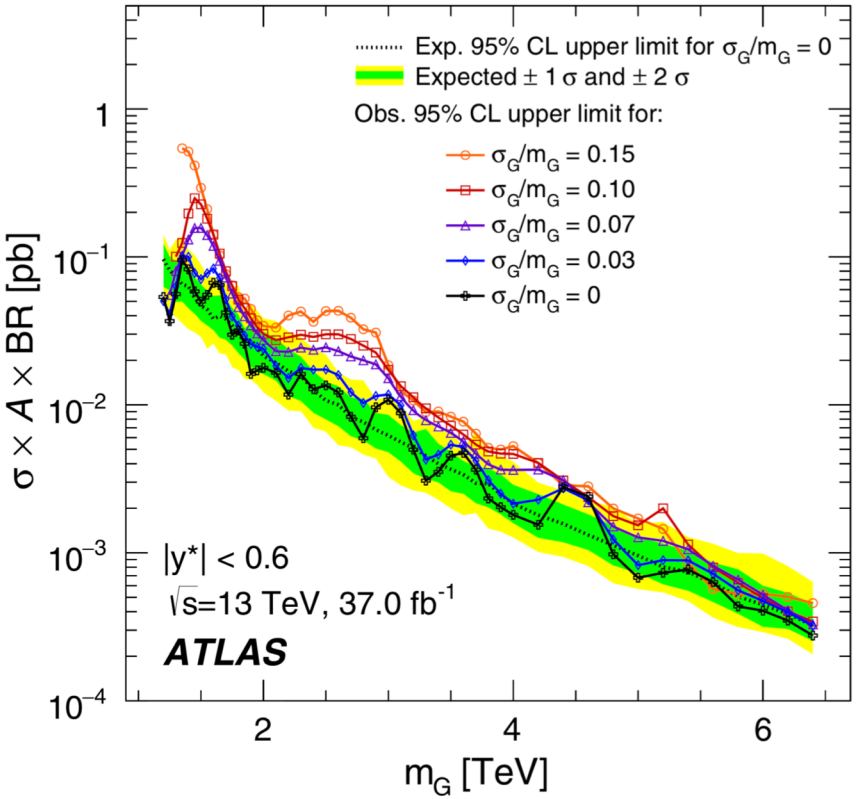
PRD 96, 052004 (2017)

In high-energy pp collisions search for production of the DM—SM mediator (g_q^2)

Perform dijet resonance search



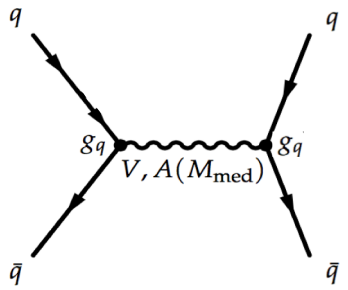




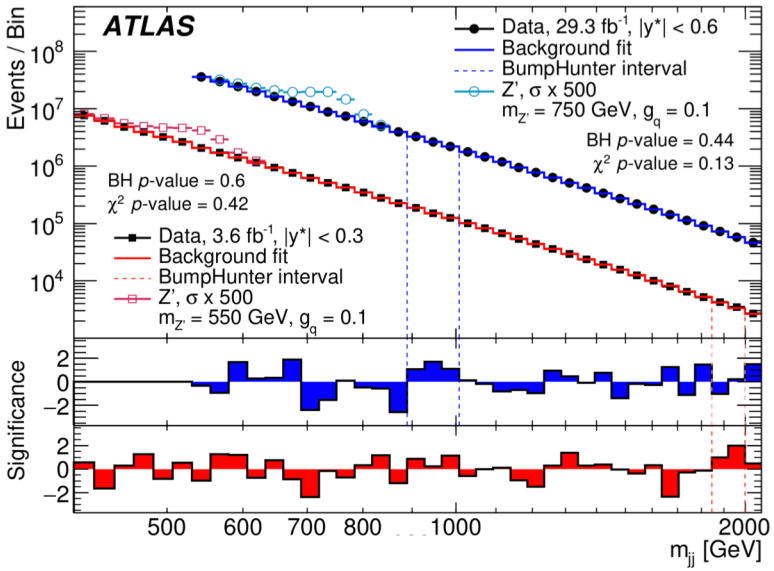
Dijet searches for mediators

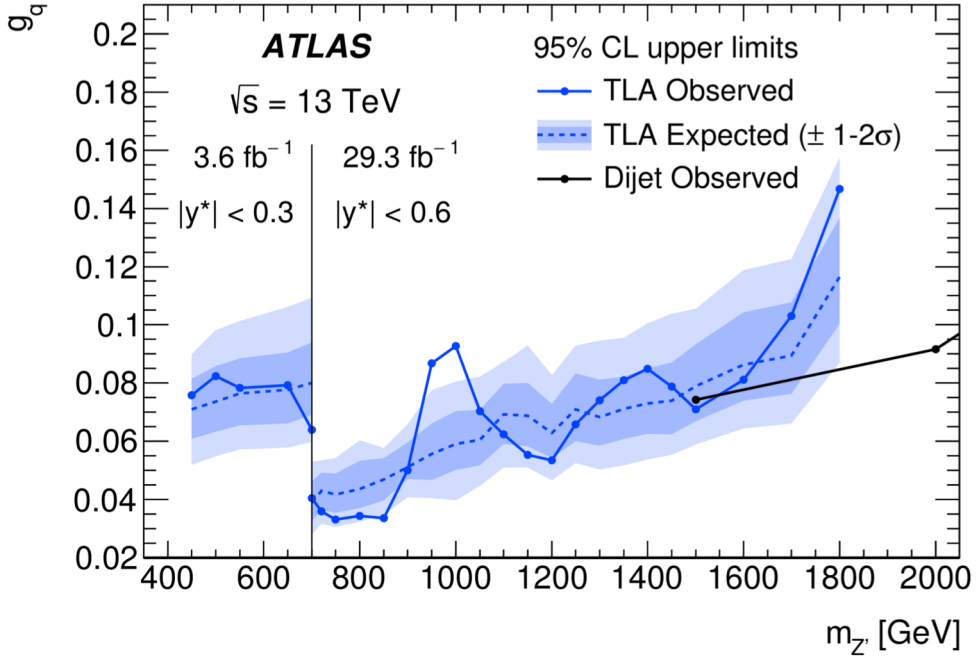
PRD 96, 052004 (2017)

Sensitivity to low mass mediators is a challenge of data rate: *new techniques*!

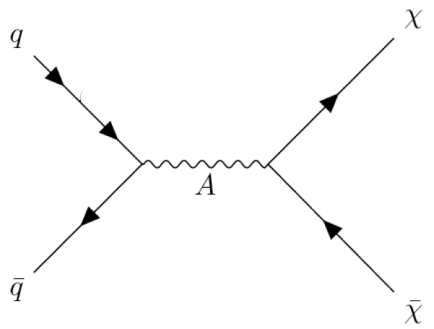


- Sensitivity to the coupling to quarks, g_q, improved by a factor of two
- Gaussian signals limited to cross-section times acceptance of:
  6.5 pb at 450 GeV, to 0.4 pb at 700 GeV, to 0.05 pb at 1800 GeV.



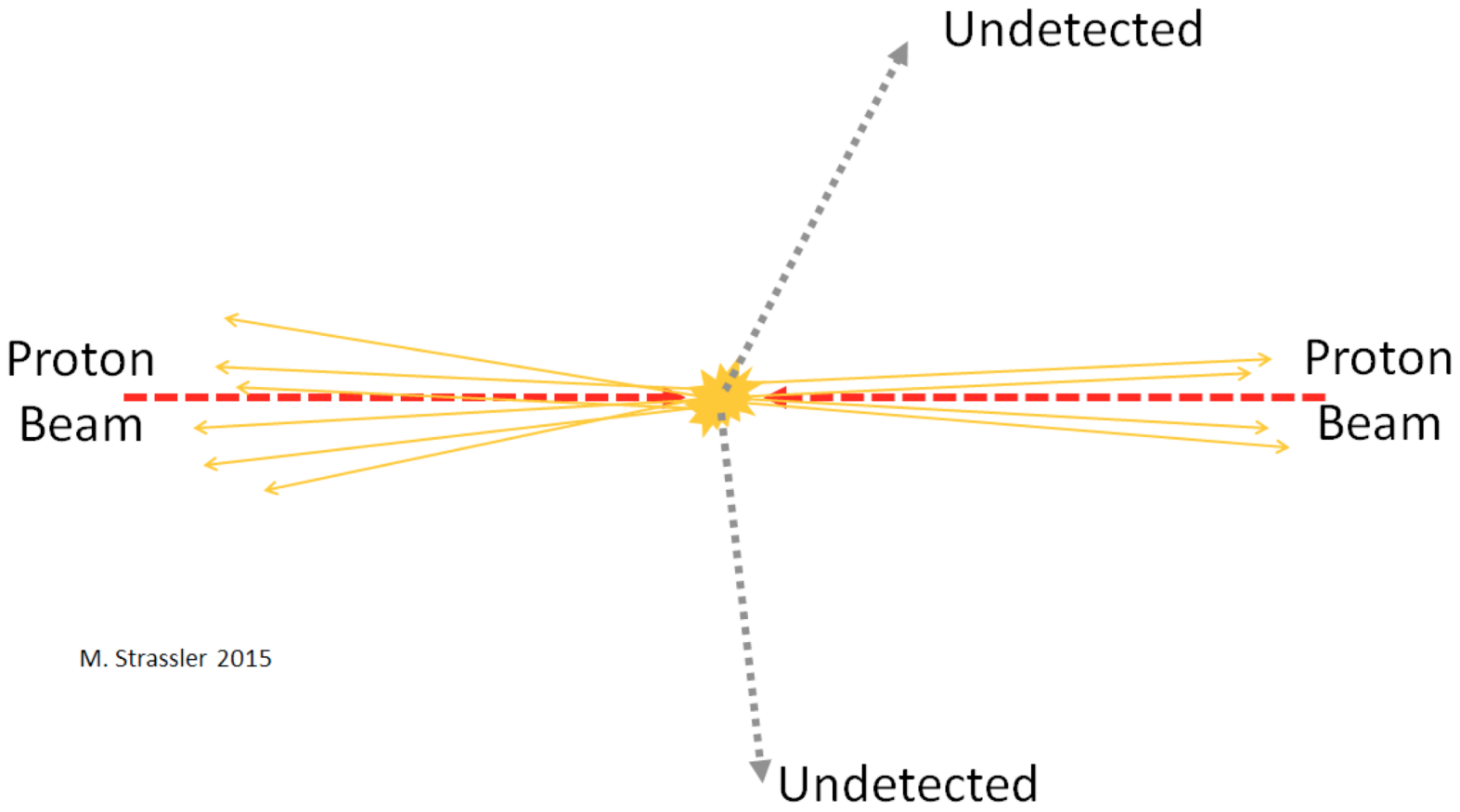


Searching for DM at colliders



How else can we search for dark matter at colliders?

Inherently a missing energy signature
Issue of detectability

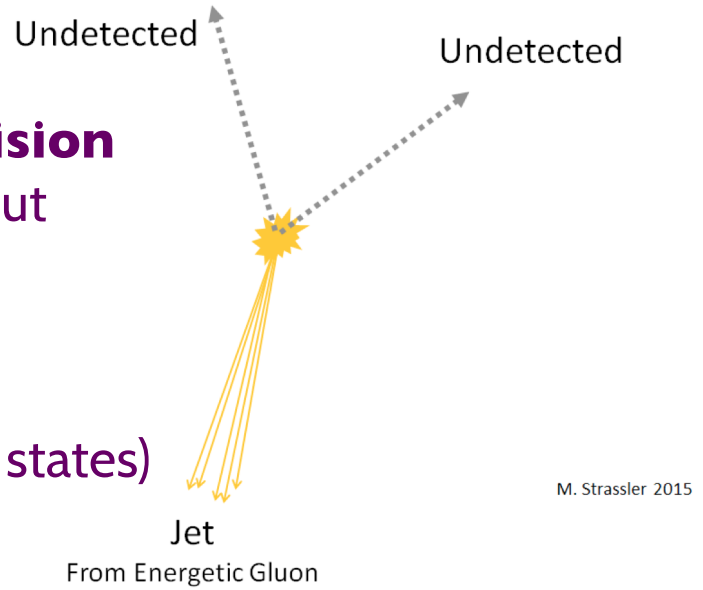


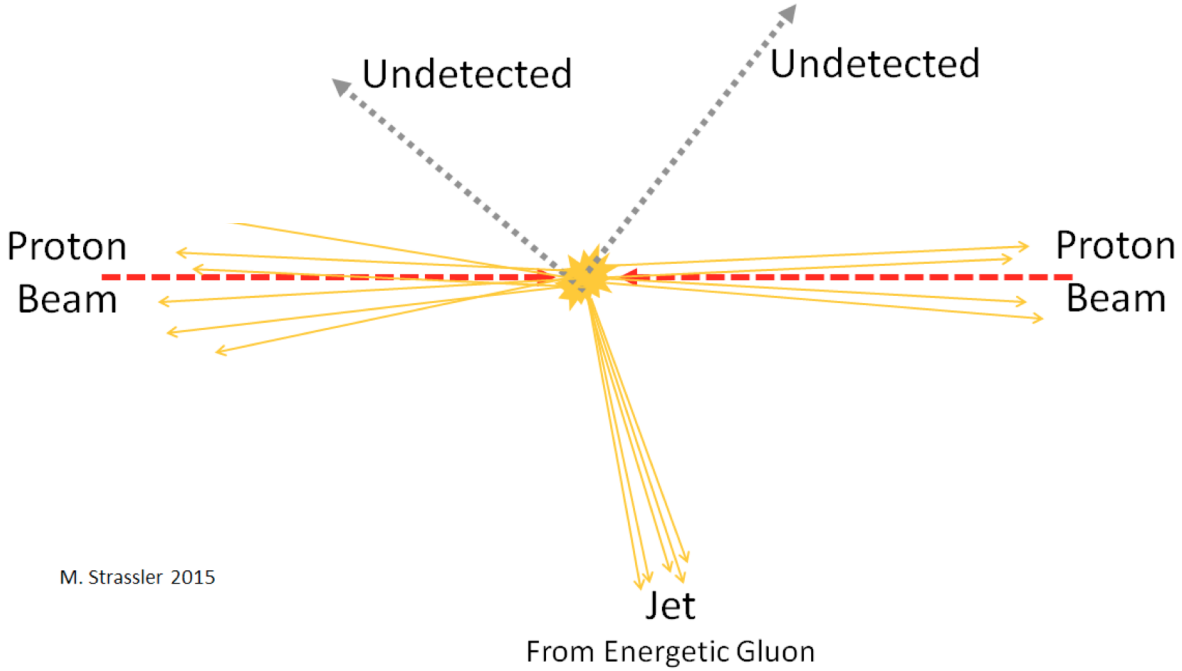
General dark matter signatures

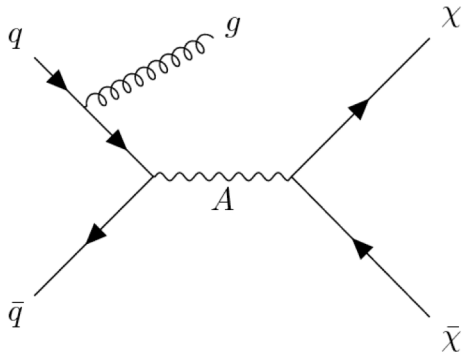
Need a visible object to identify collision

Simplest case is one hadronic jet recoiling, but many possibilities exist to 'tag' dark matter…

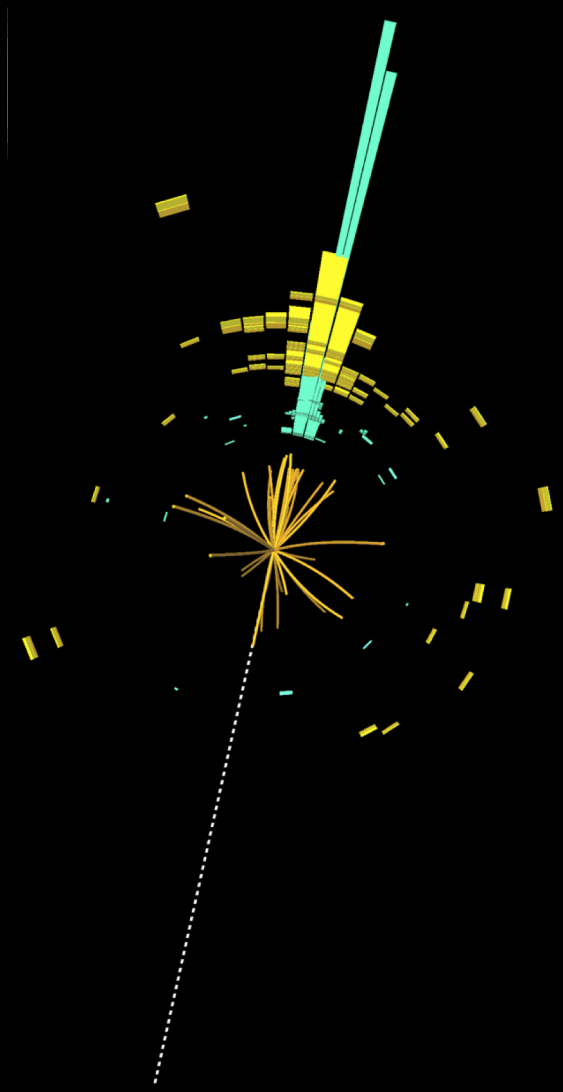
Maximise inclusivity of search (limited by experiment), and coverage (topologies, final states)







Mono-X signatures

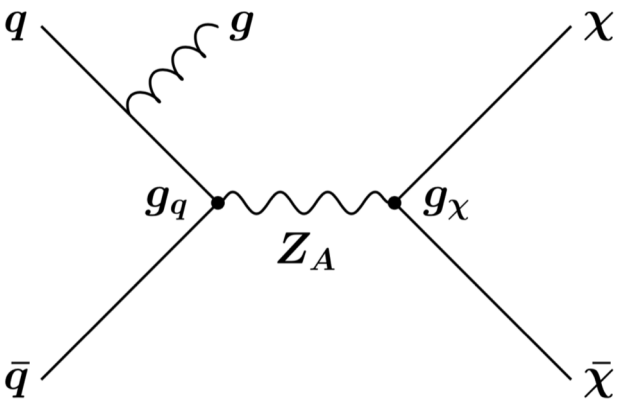


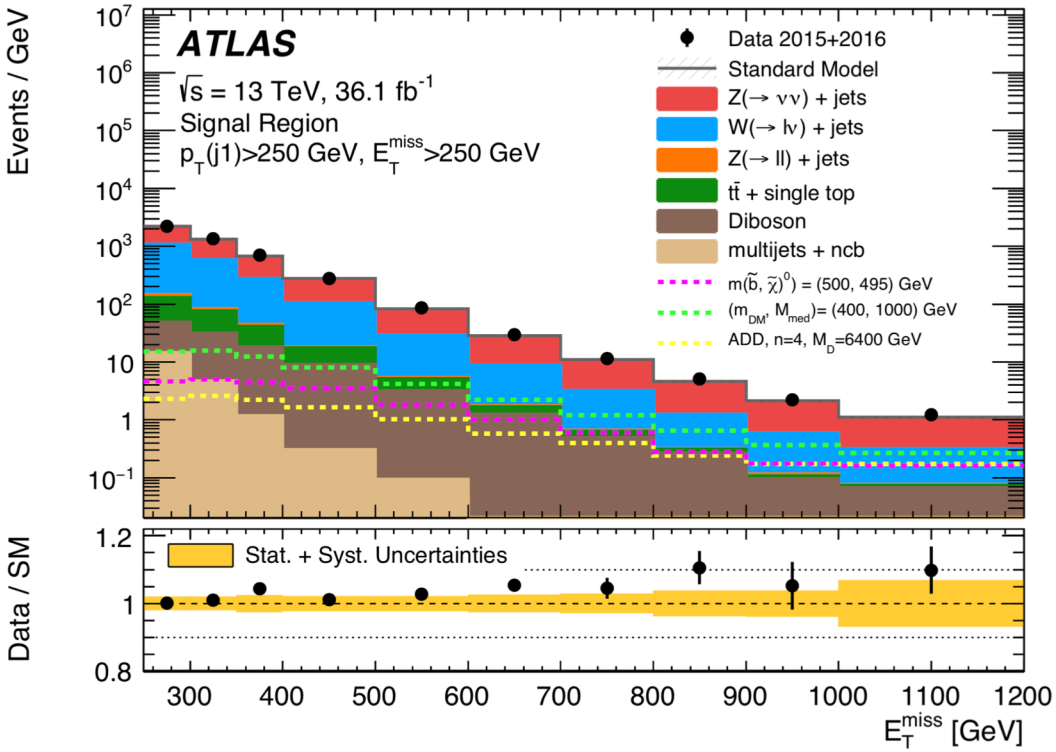
Monojet searches

arXiv:1711.03301

Monojet searches often most sensitive

Quark couplings restricted by dijet searches





Monojet searches

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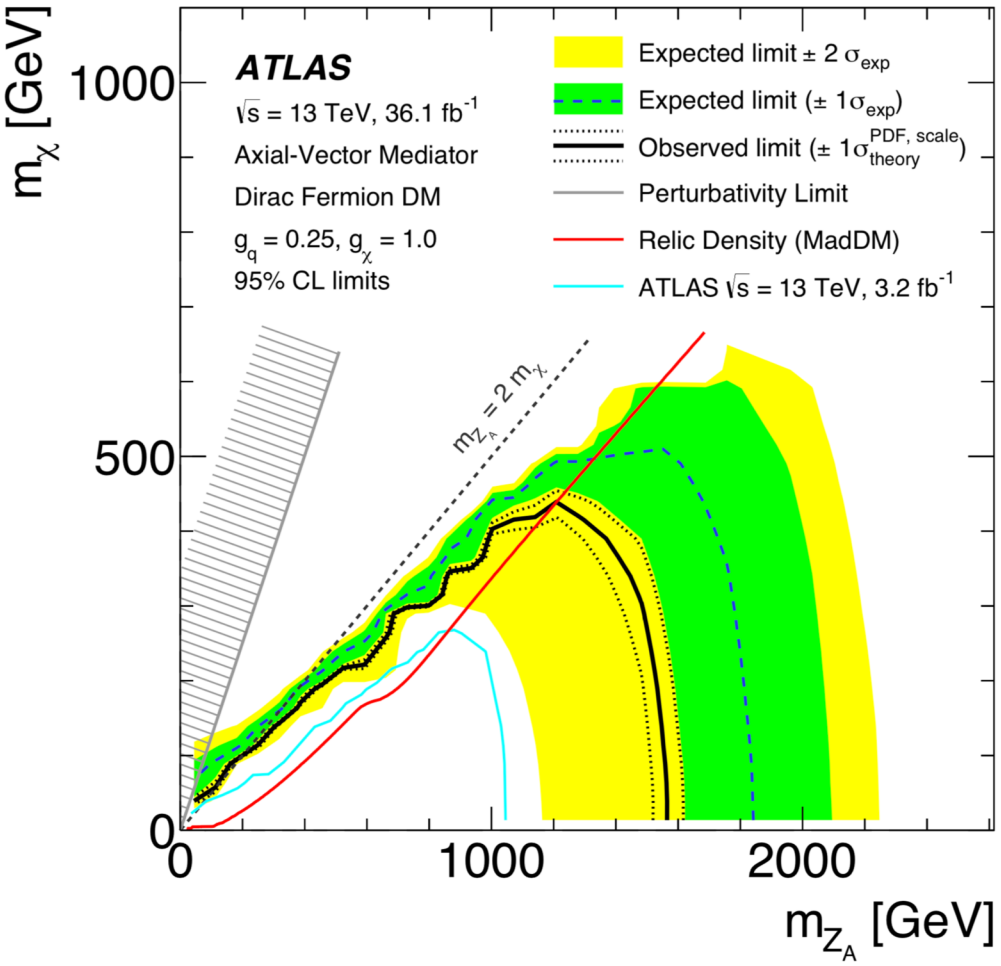
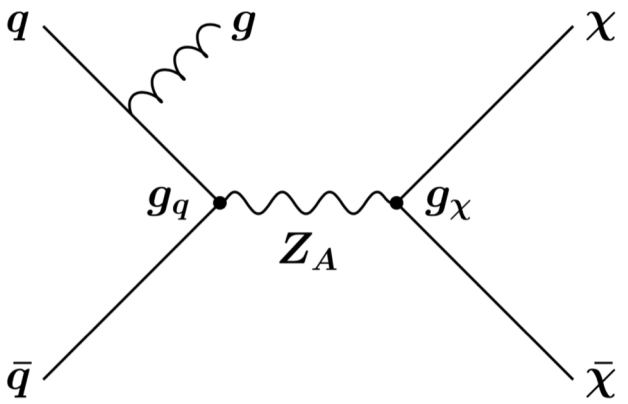
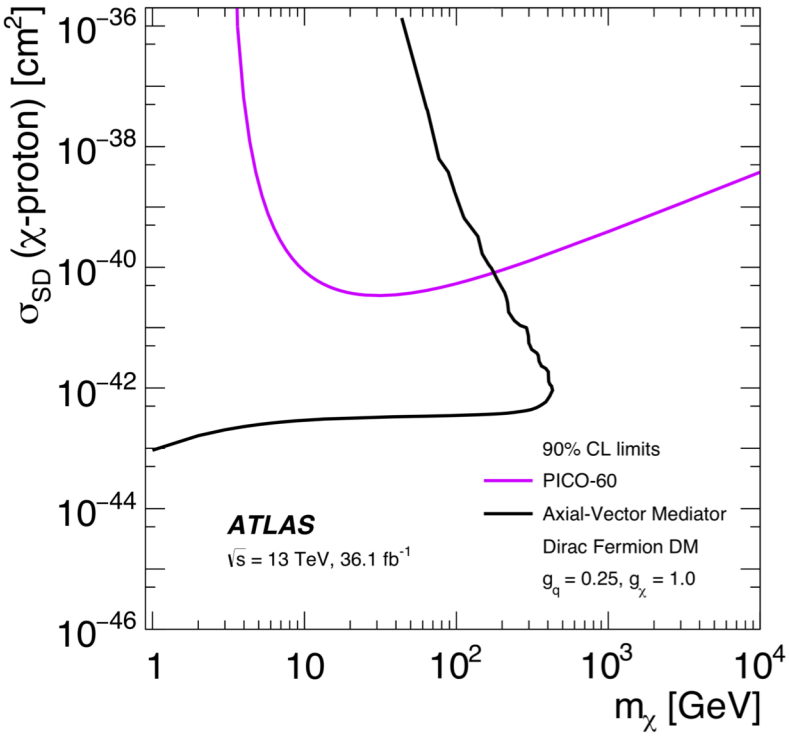
Monojet searches often most sensitive

Exclusion region (95% C.L) in mediator–DM mass plane:







Monojet searches

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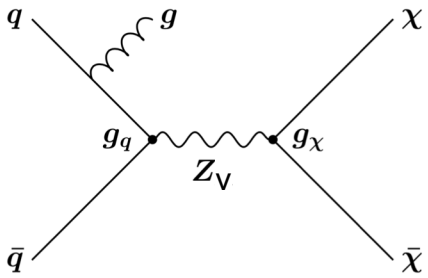
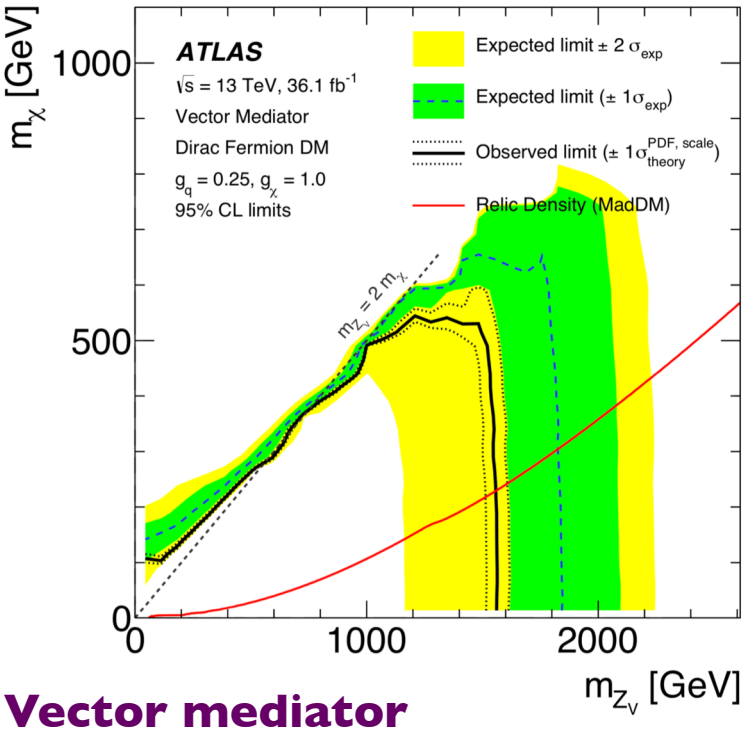
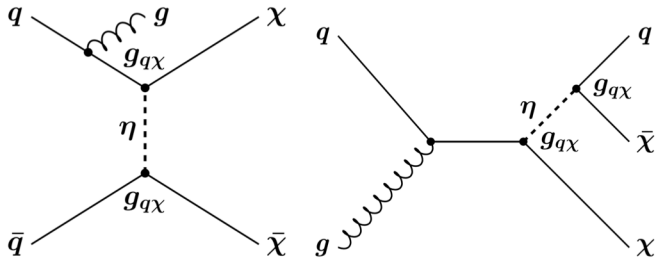
Monojet searches often most sensitive

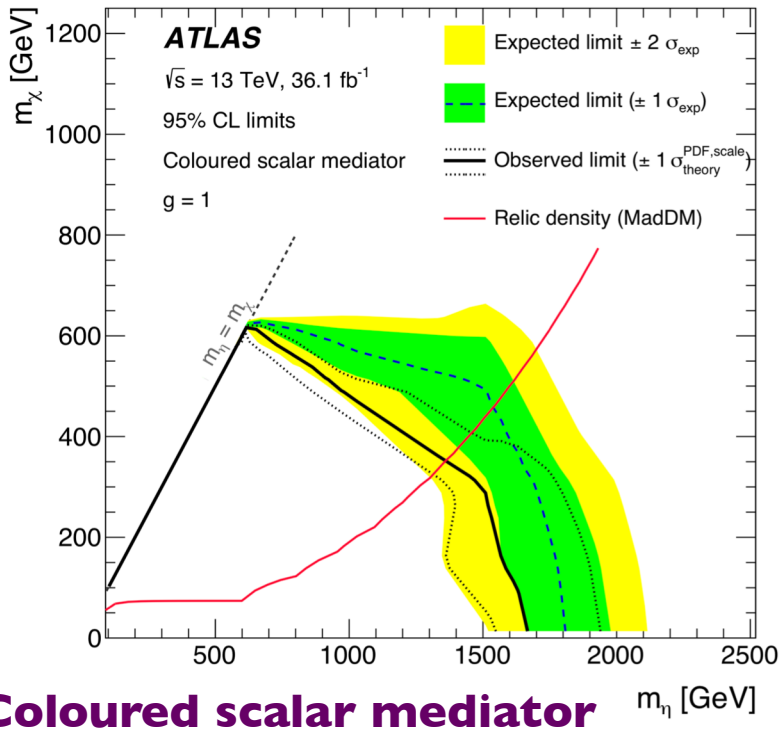
Very general, so can be recast in terms of various models





Vector mediator

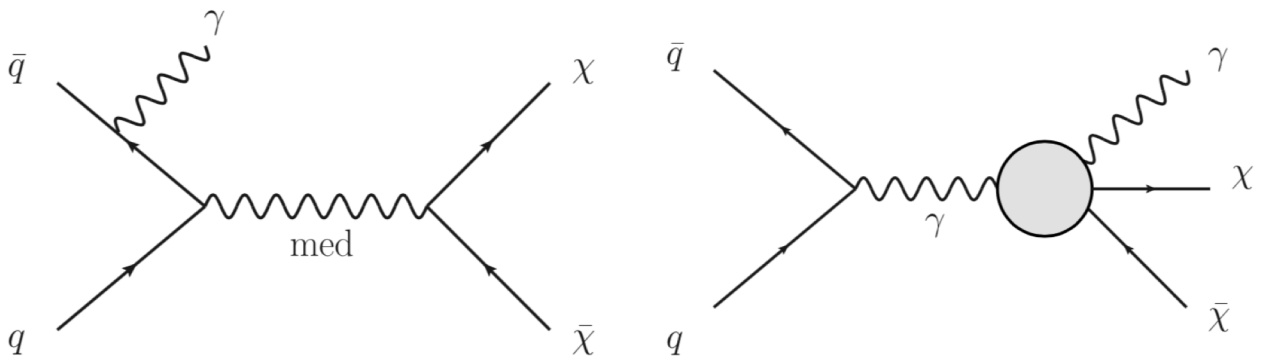


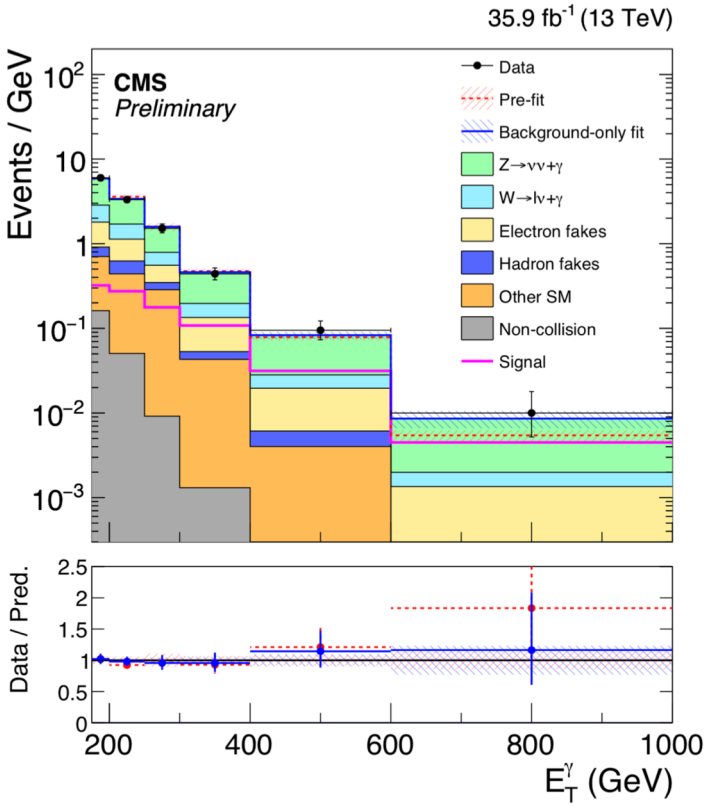


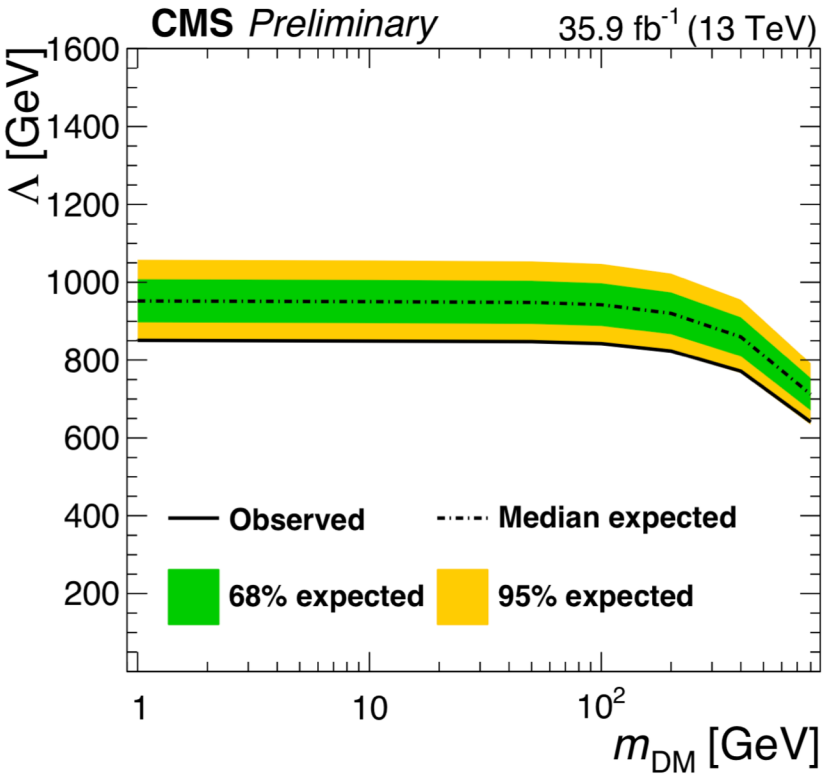
Coloured scalar mediator

Monophoton searches

CMS PAS EXO-16-053



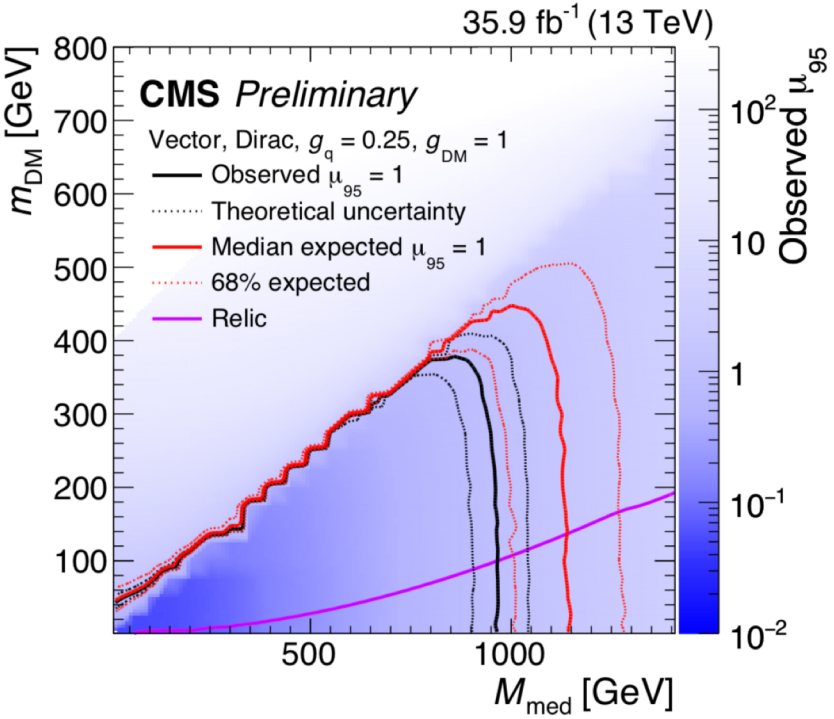


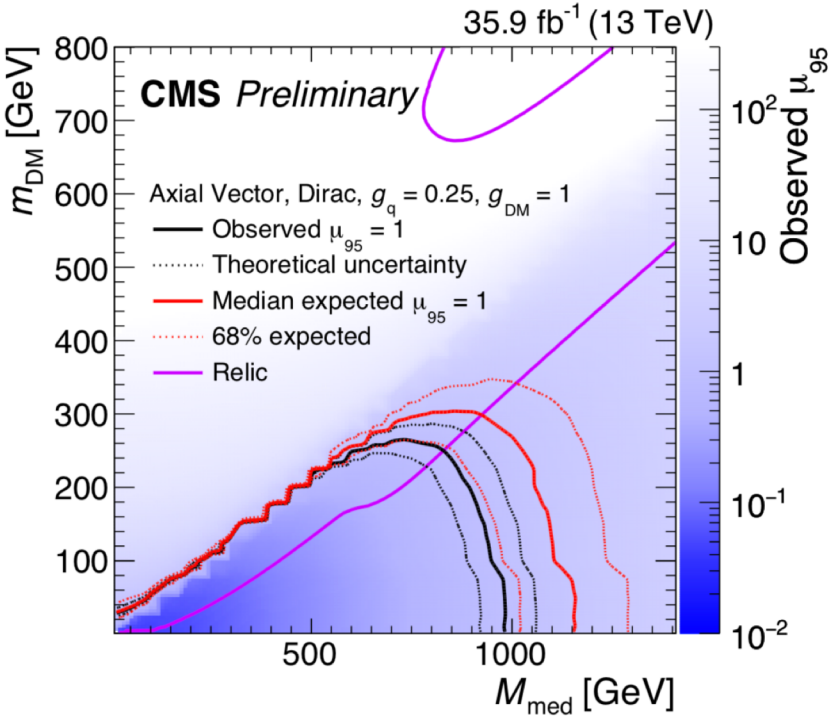


Monophoton searches

CMS PAS EXO-16-053

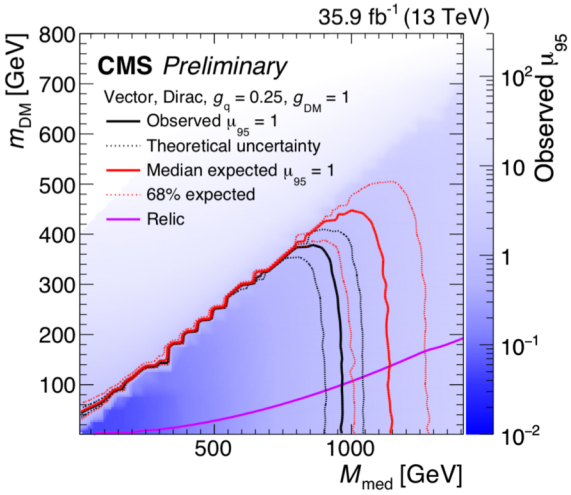
Dark matter exclusion (95% C.L) in mediator—DM mass plane

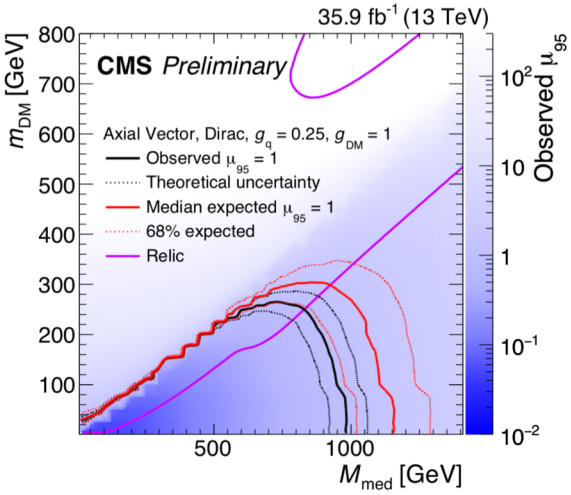


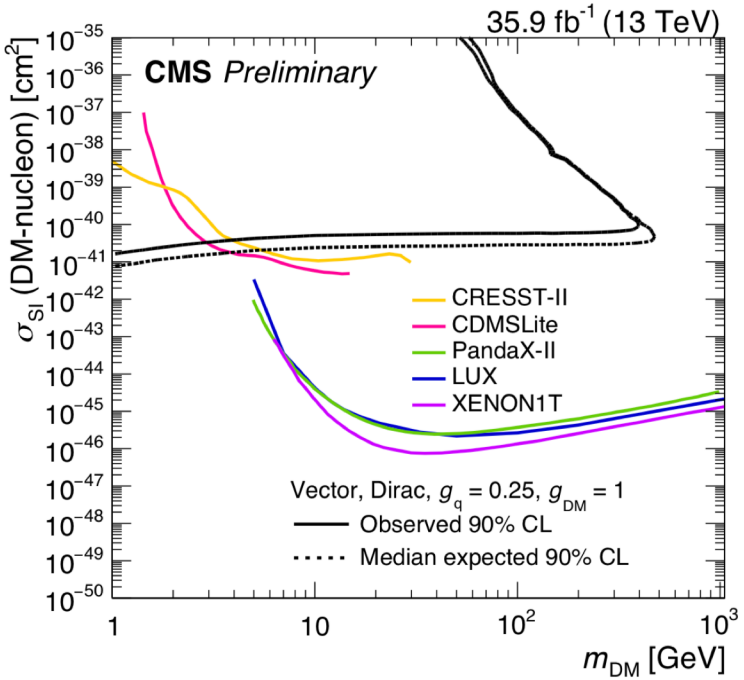


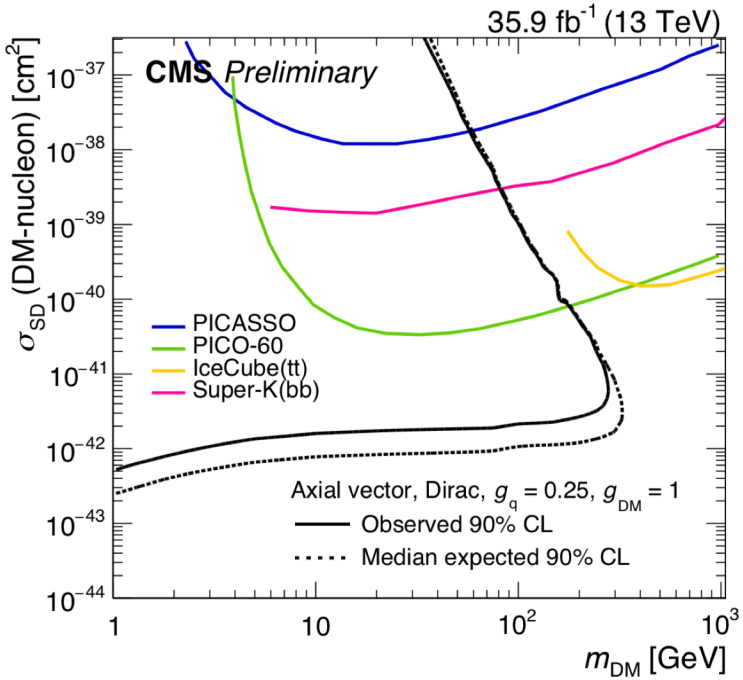
Monophoton searches

CMS PAS EXO-16-053

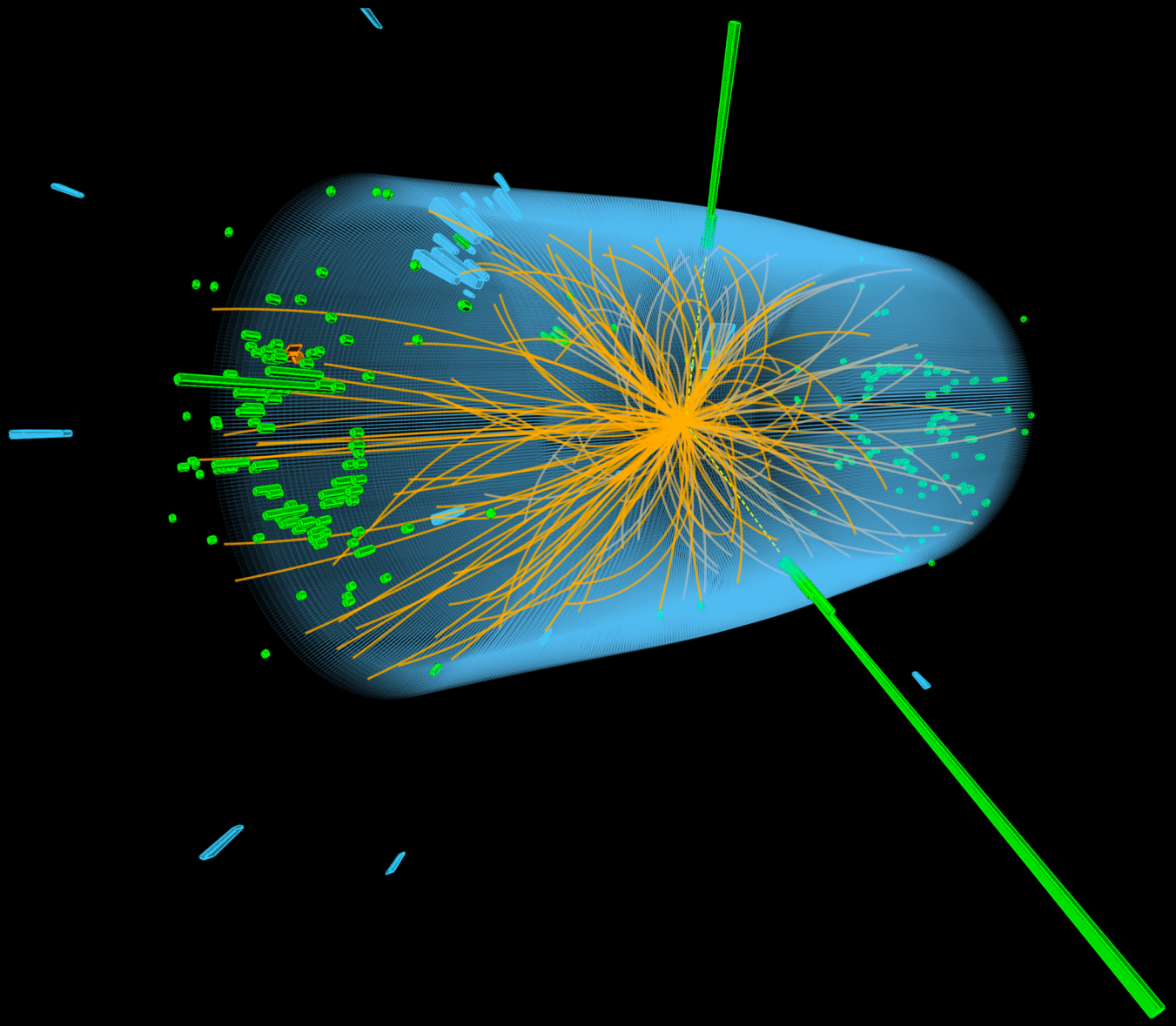








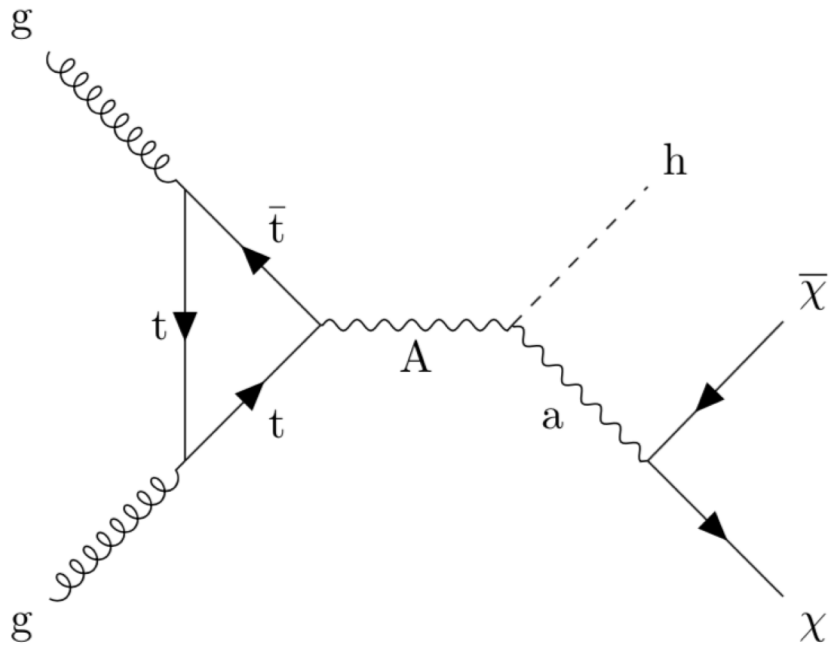
The Higgs boson as a window into dark matter

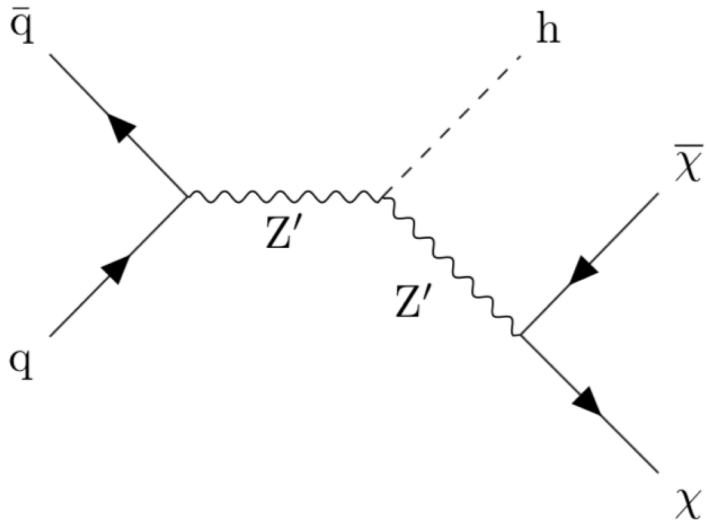


Higgs bosons as a tag for Dark Matter

CMS PAS EXO-16-050

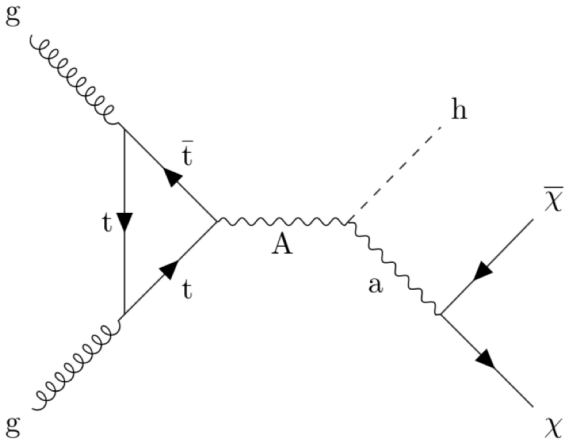
Search for Higgs in various decay modes (di-photon, di-tau, di-b) alongside large missing transverse energy



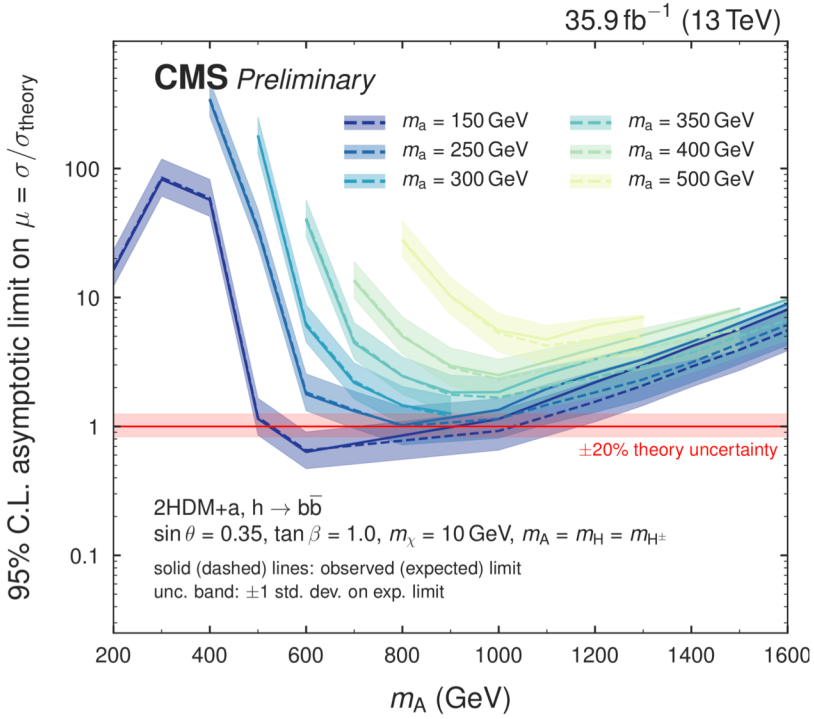


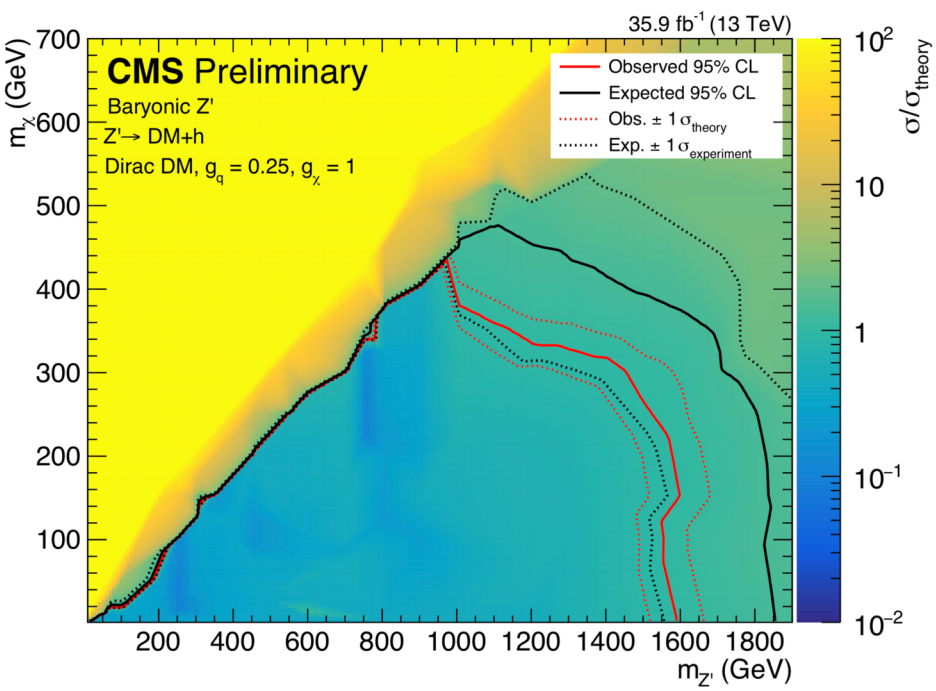
Higgs bosons as a tag for Dark Matter

CMS PAS EXO-16-050



2HDM+a model

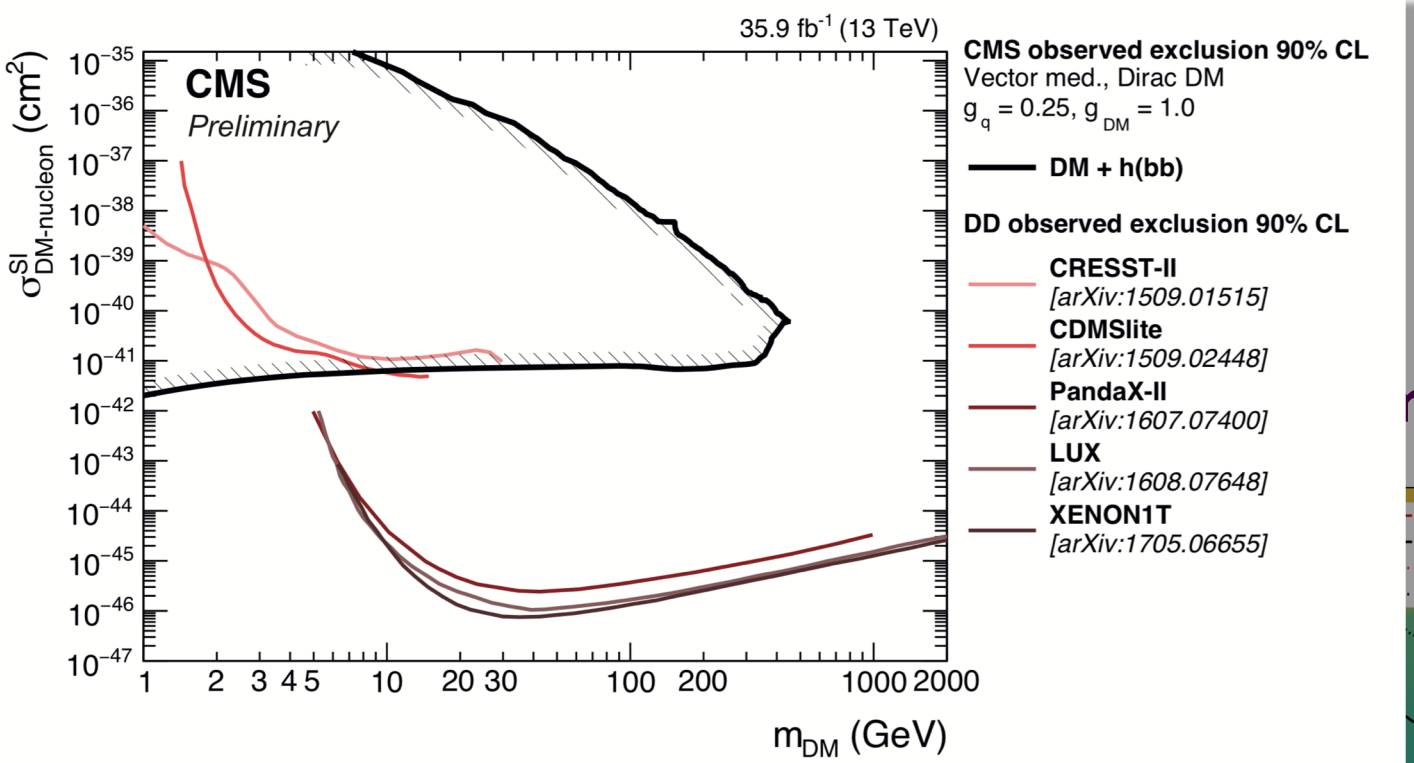


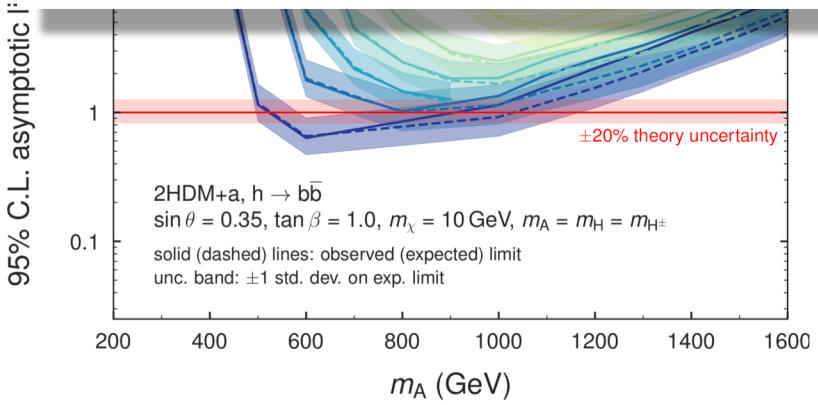


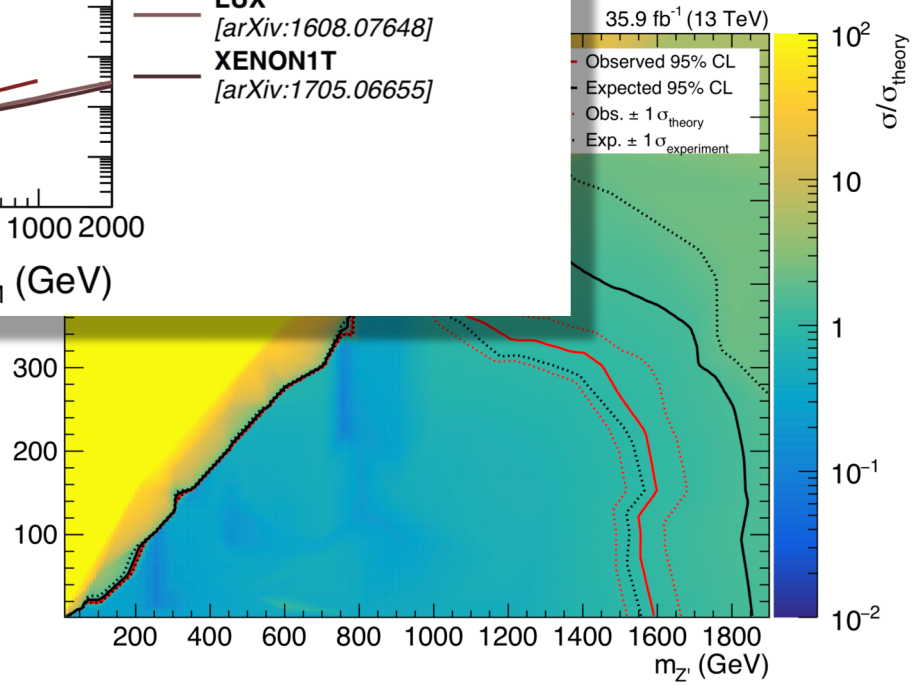
Baryonic Z' model

Higgs bosons as a tag for Dark Matter

CMS PAS EXO-16-050





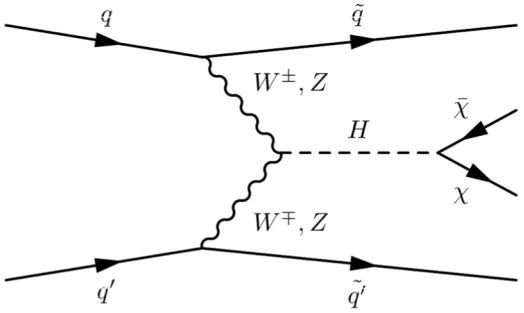


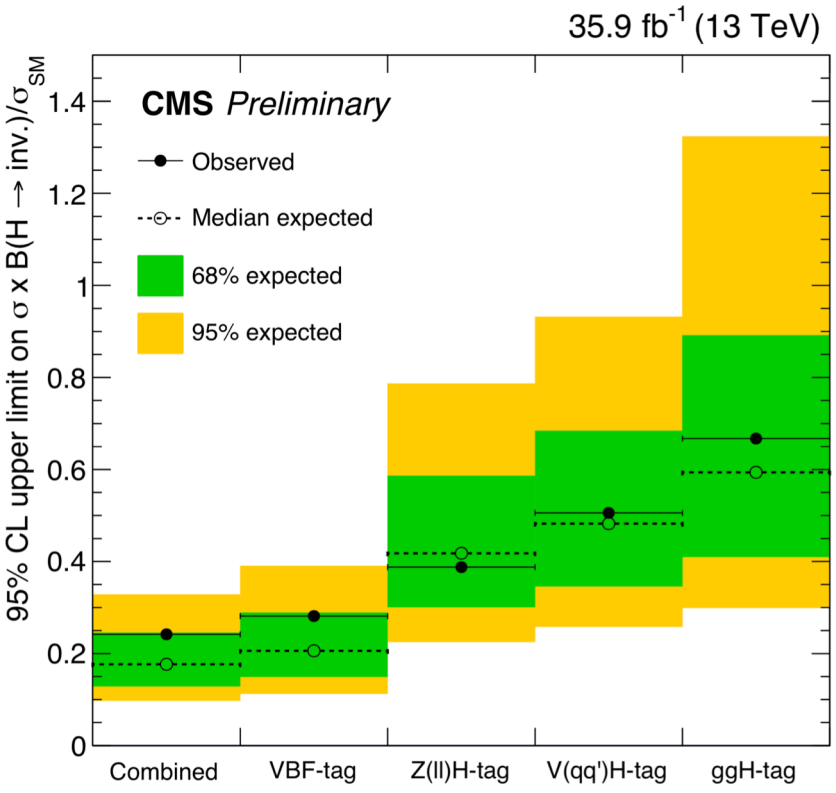
Higgs bosons as a source of Dark Matter

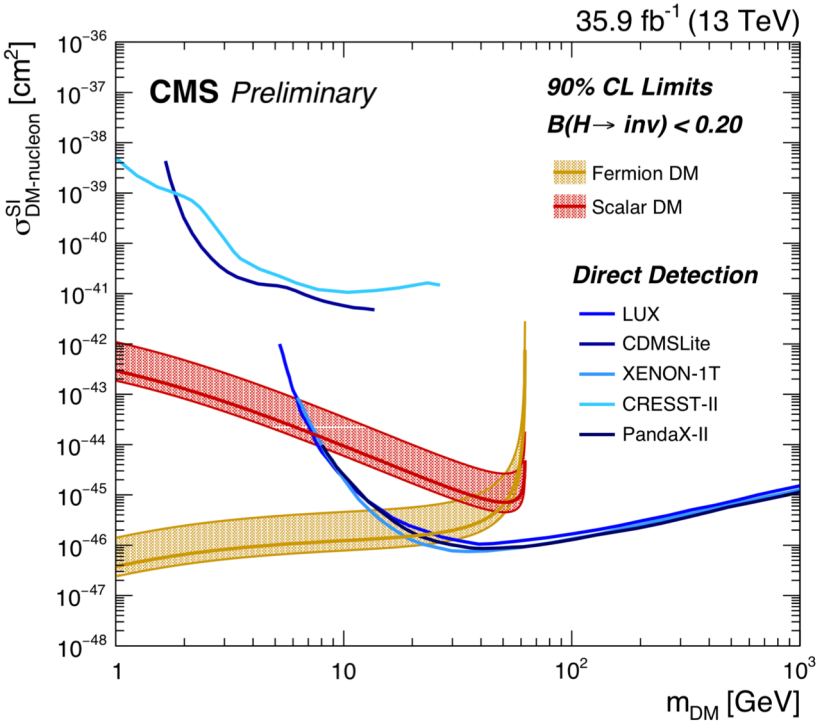
CMS-PAS-HIG-17-023;

The Higgs can act as a direct mediator for dark matter

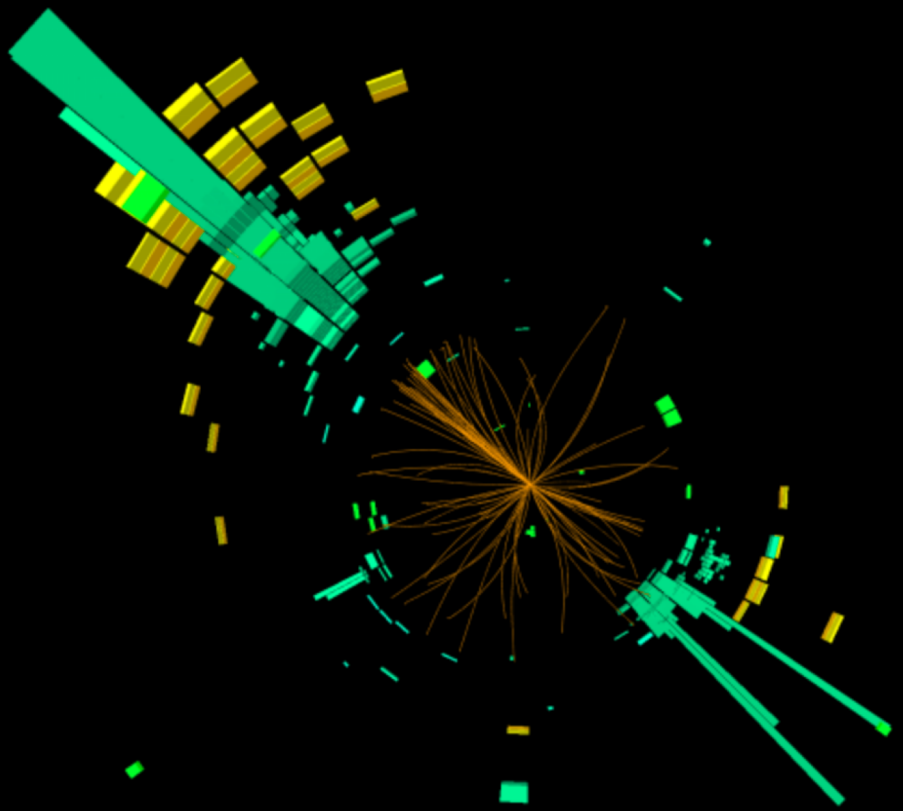
Most sensitive channel is vector boson fusion







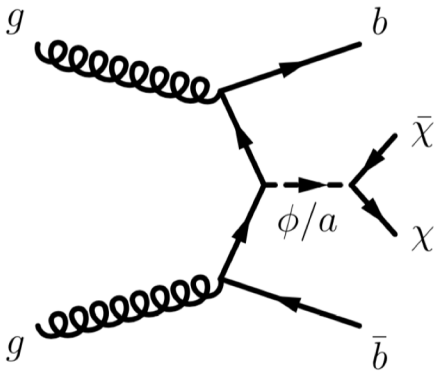
Flavourful dark matter

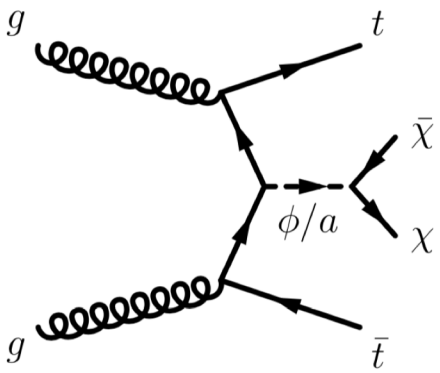


Dark matter + heavy quarks

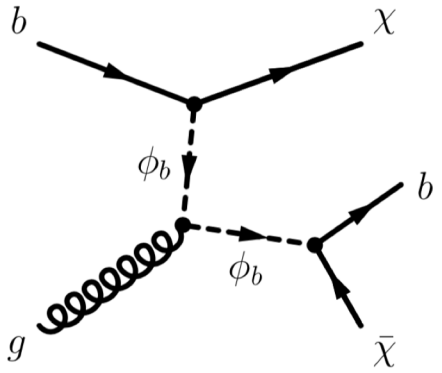
EPJC 78 (2018) 18; CMS PAS EXO-16-049

Interaction of dark matter and flavour unknown: searches for dark matter produced in association with tt/bb





Colour neutral scalar/pseudoscalar models

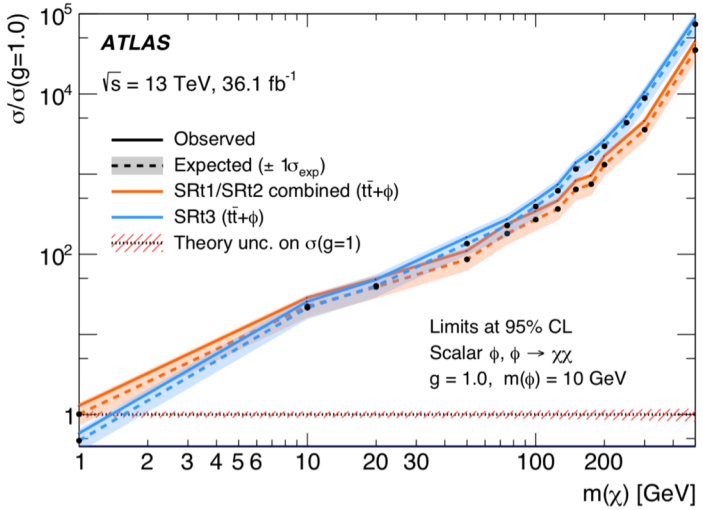


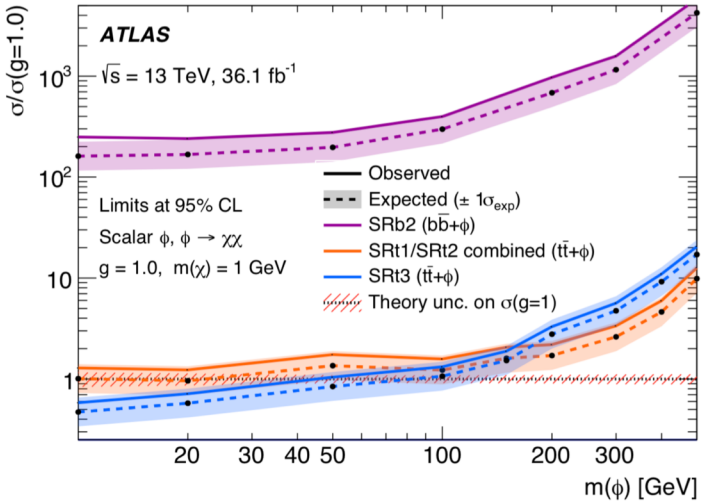
Colour-charged scalar mediator model

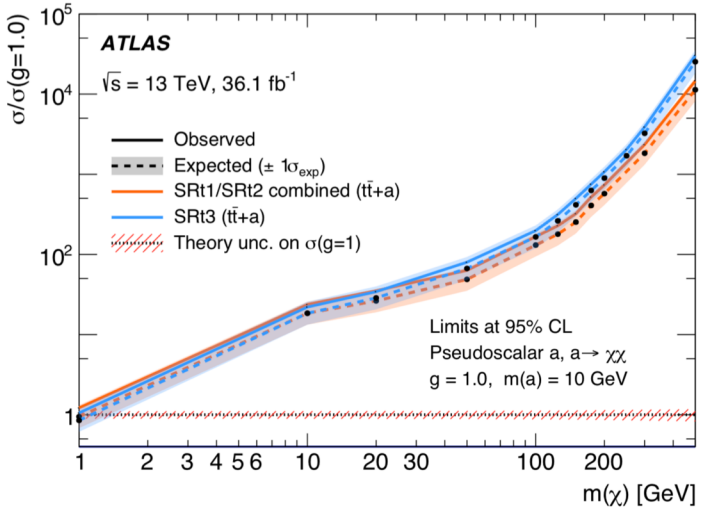
Dark matter + heavy quarks

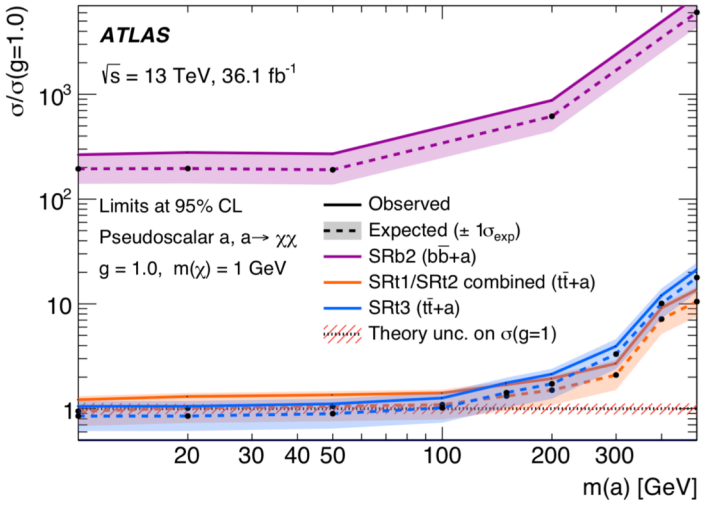
EPJC 78 (2018) 18

Bottom searches not yet able to exclude nominal values, exclusions in top searches:





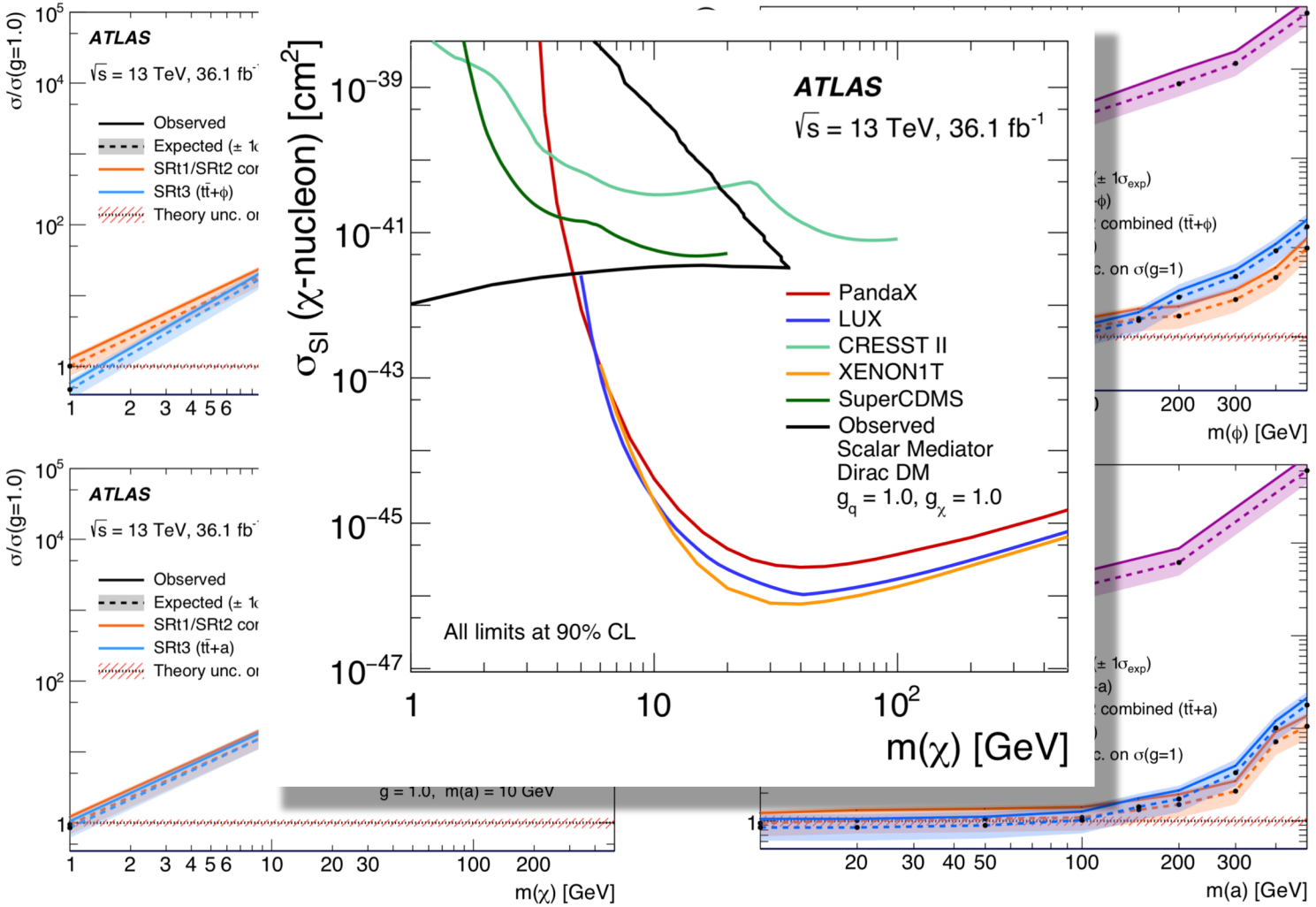




Dark matter + heavy quarks

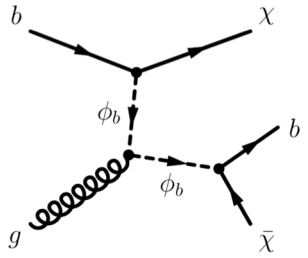
EPJC 78 (2018) 18

Translate results into spin-independent nucleon cross-sections:

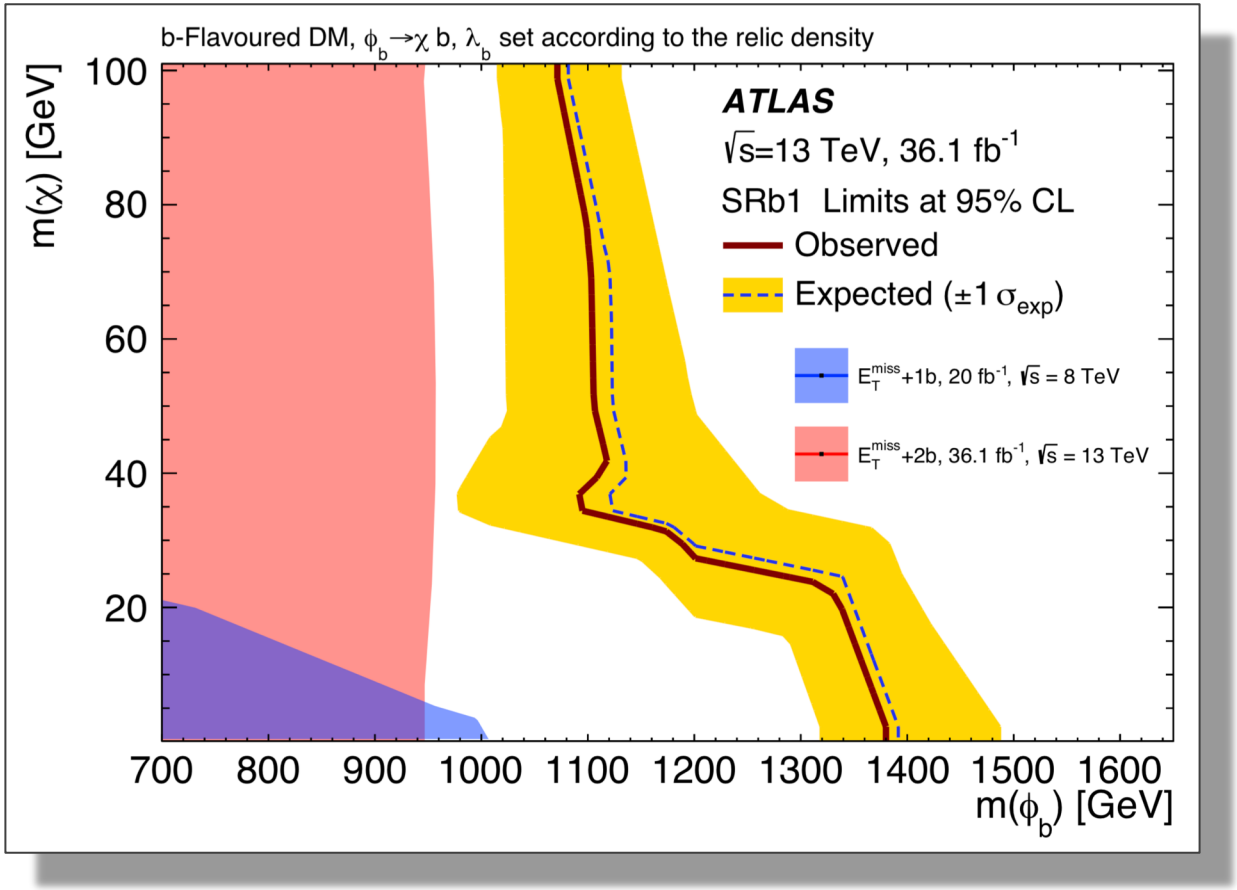


Dark matter + heavy quarks

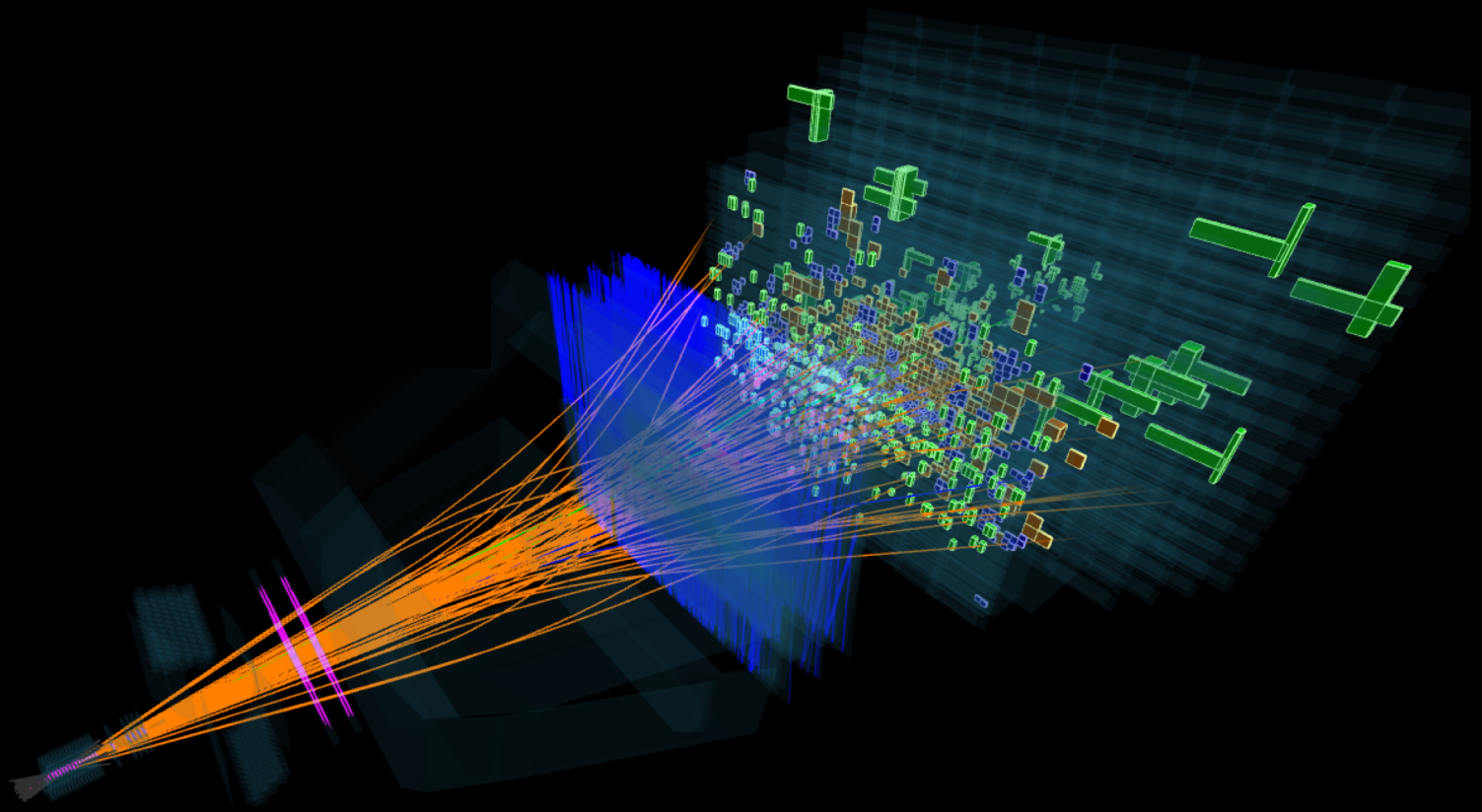
EPJC 78 (2018) 18; CMS PAS EXO-16-049



Colour-charged mediator searches can constrain models relevant to explain Fermi-LAT excess:
Mediators excluded below 1.1 TeV for m_{DM}~35 GeV



Low mass resonances

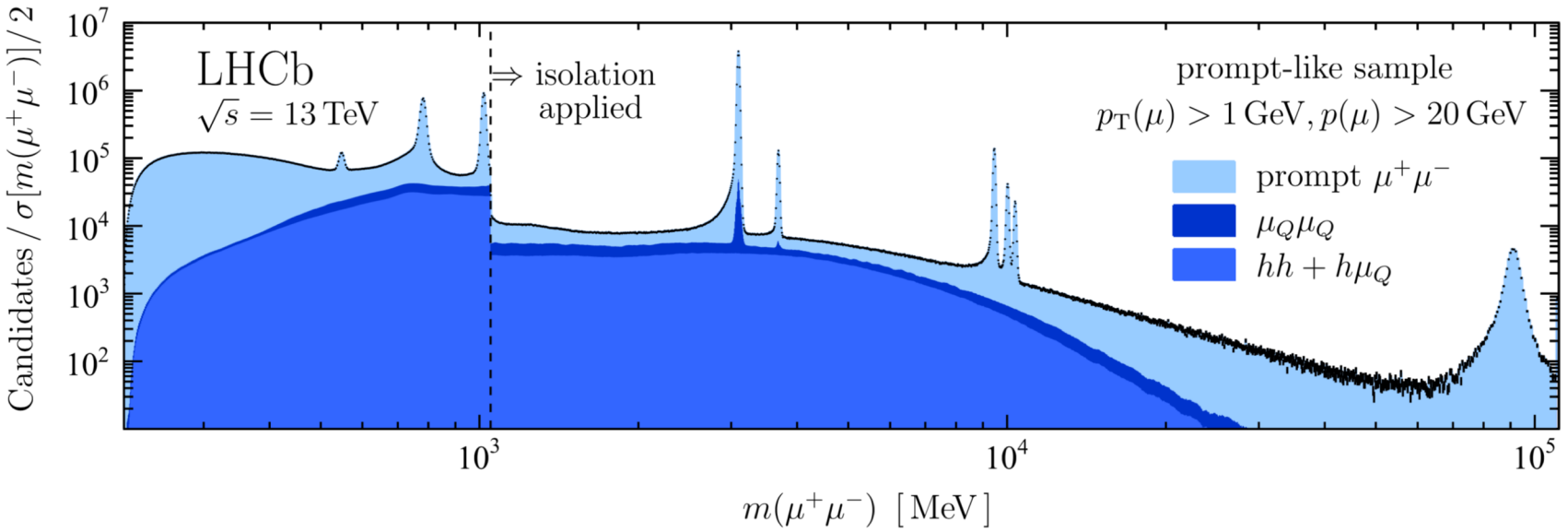


Dark photon search

PRL 120, 061801 (2018)

Huge di-muon event yields and high resolution at LHCb allows for prompt like and long-lived dark photon resonance search

- Limits are placed on the γ–A' kinetic-mixing strength.



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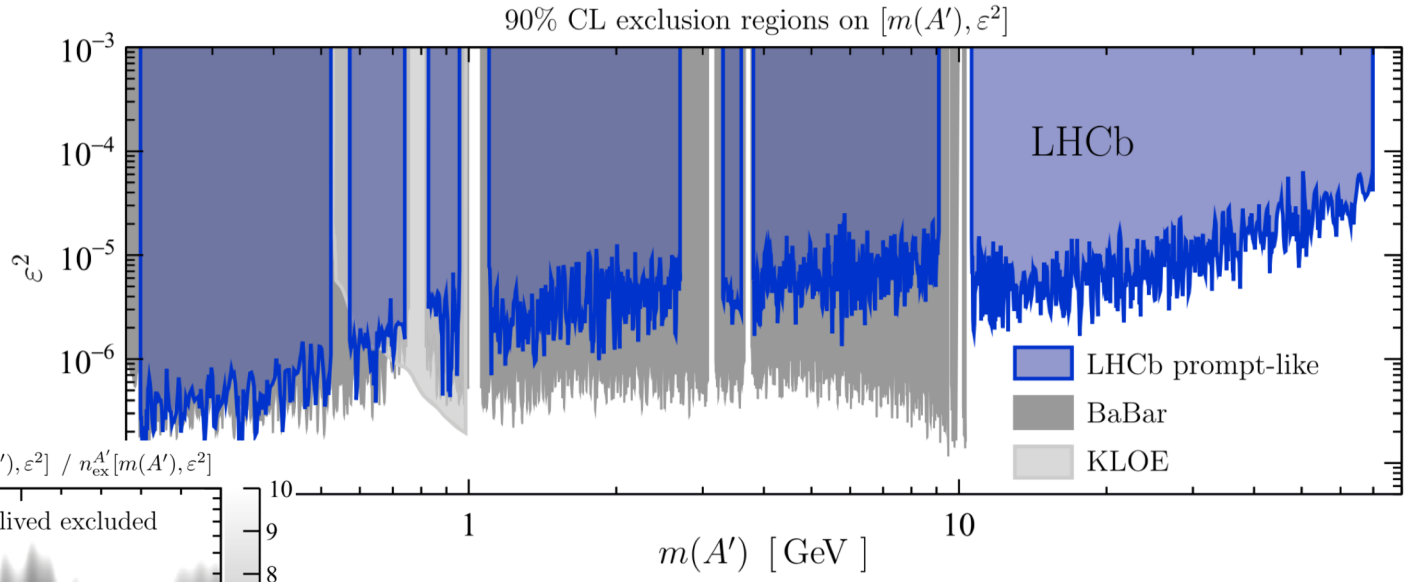
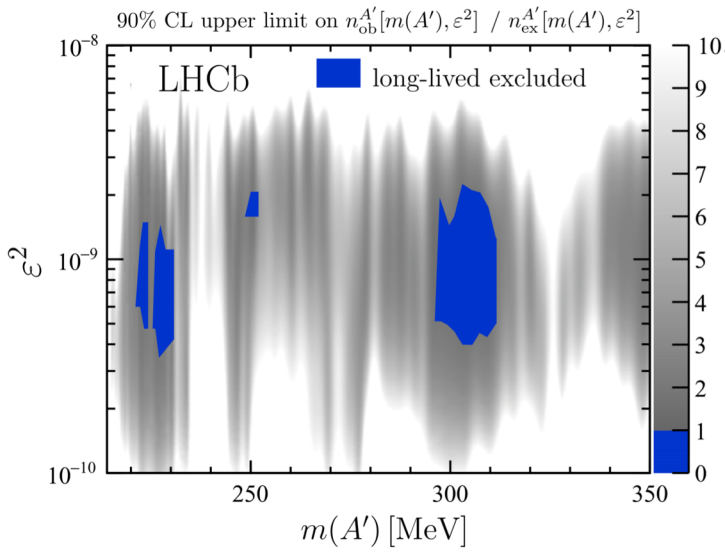


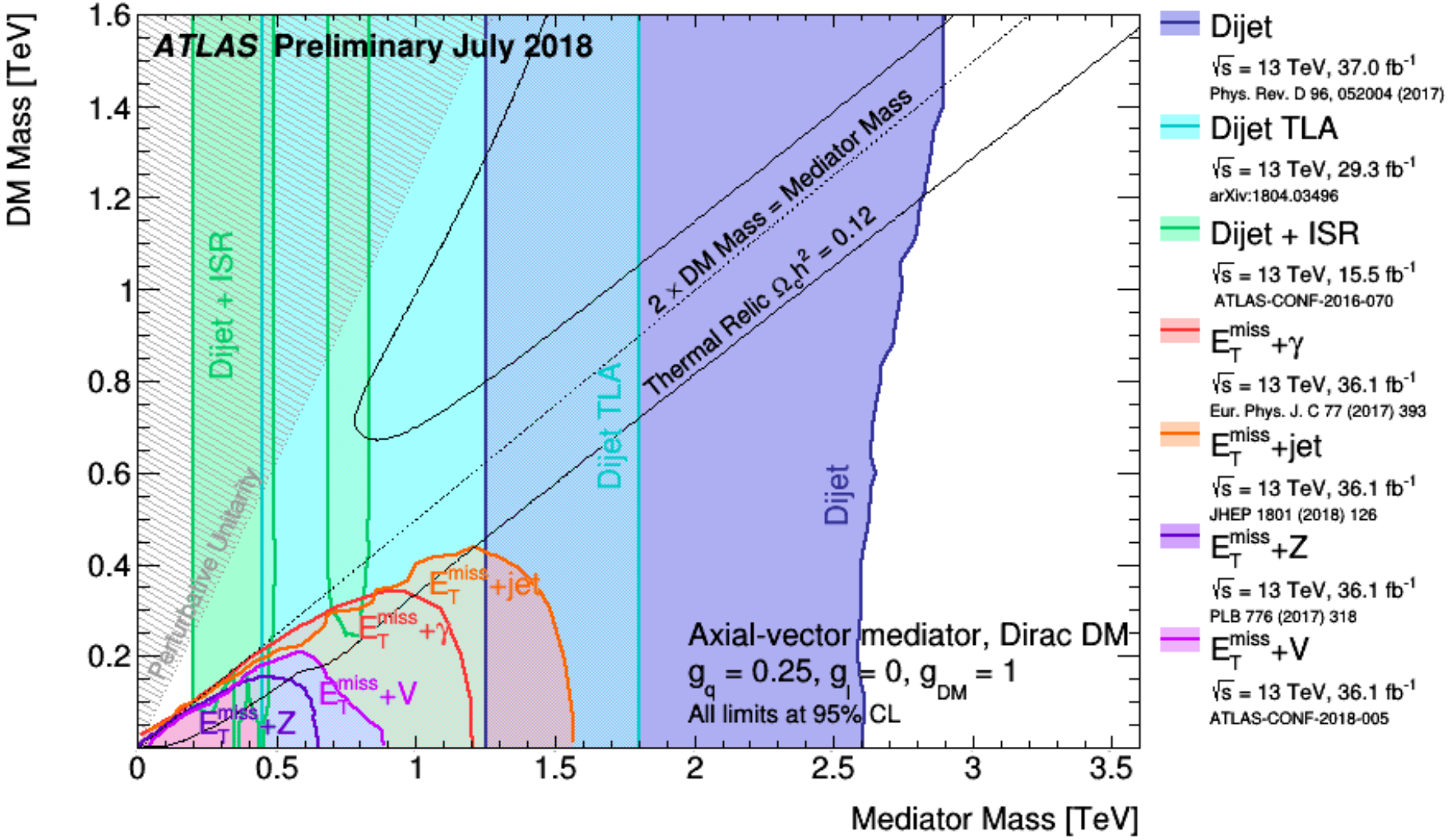


No significant excess found: largest in prompt at 5.8 GeV and in long-lived at 239 MeV

A global view

The status in simplified models

Can connect various searches with simplified model interpretation to provide global picture of sensitivity

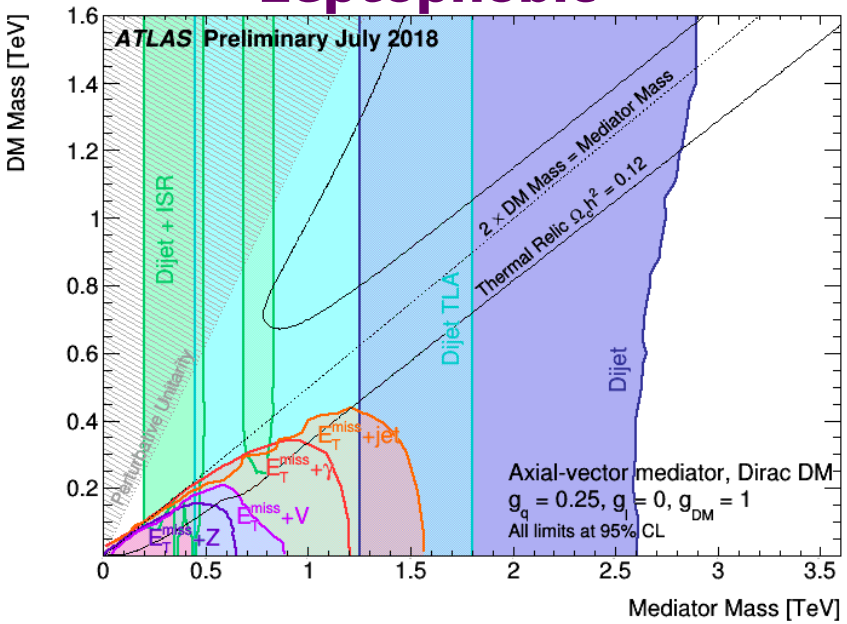


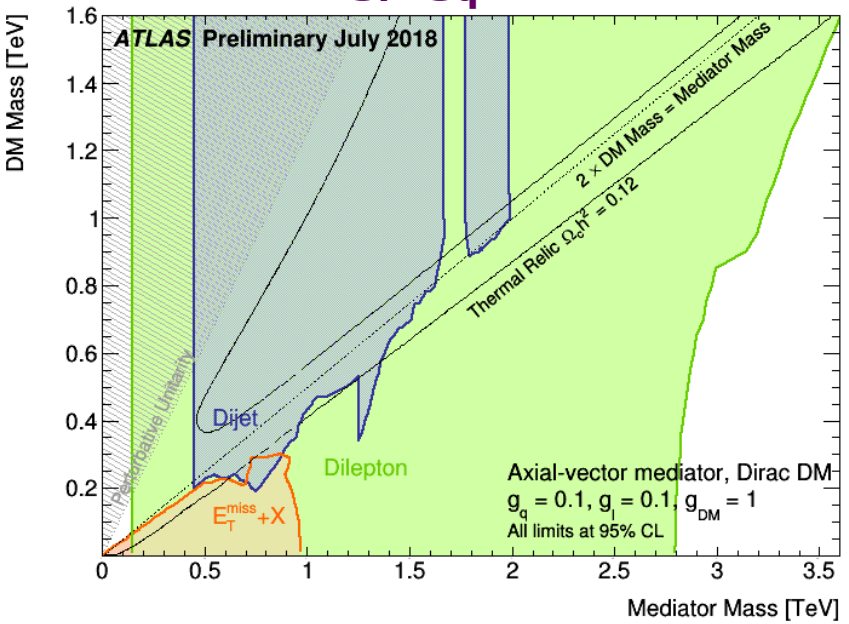
The status in simplified models

The

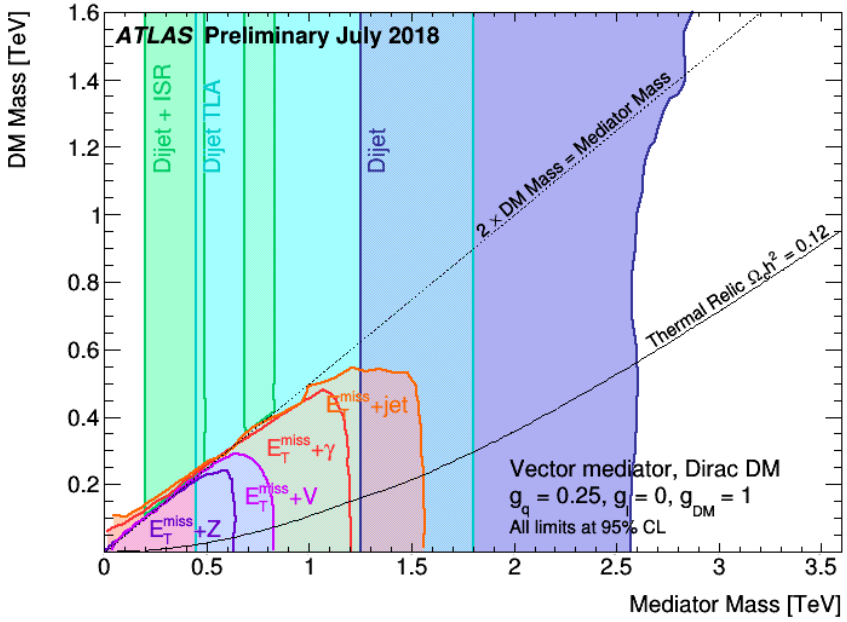
Leptophobic

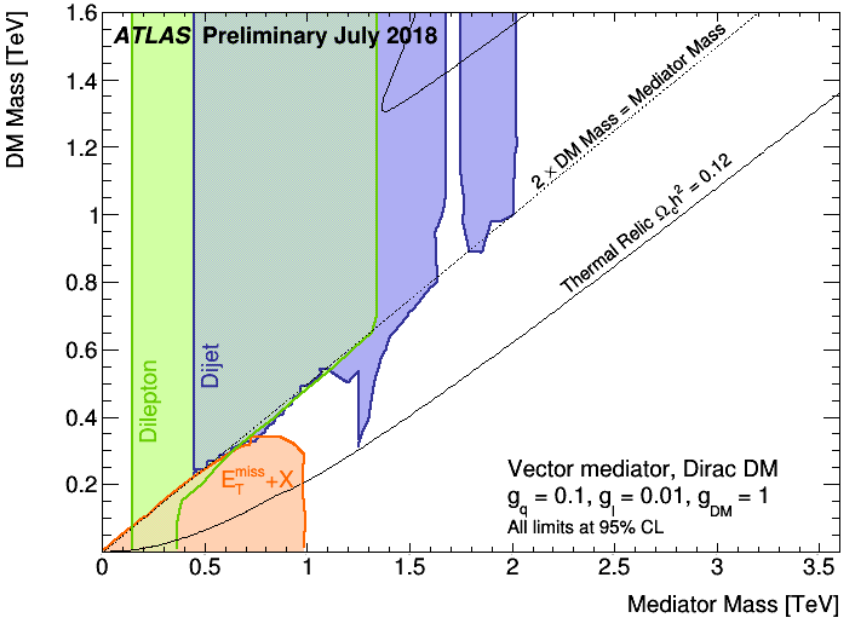
$g_l=g_q=0.1$





Axial vector mediator

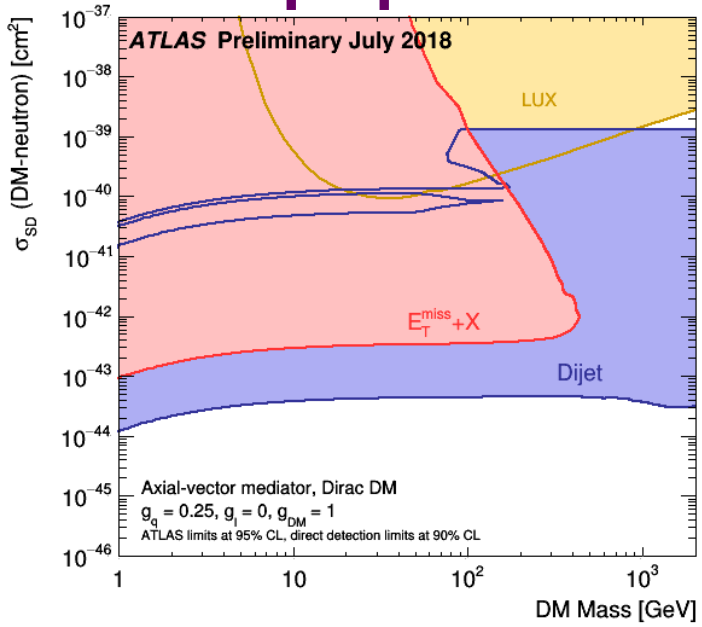




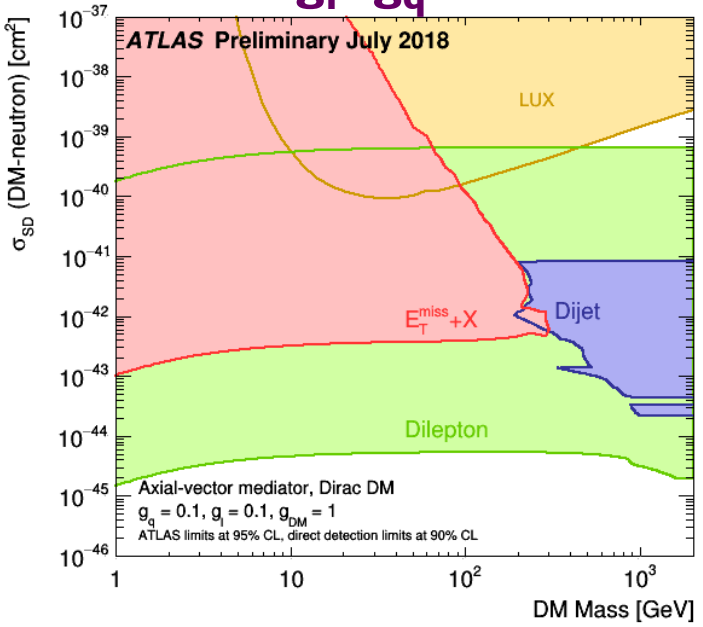
Vector mediator

The status in simplified models

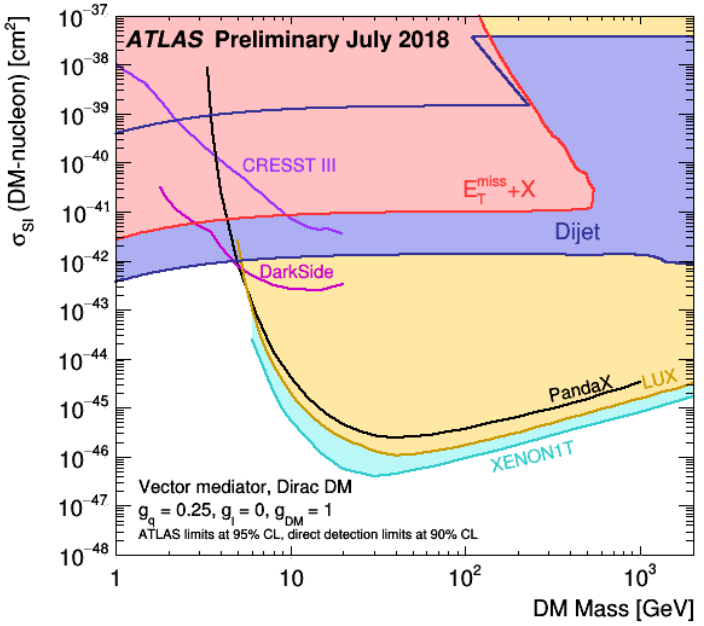
Leptophobic

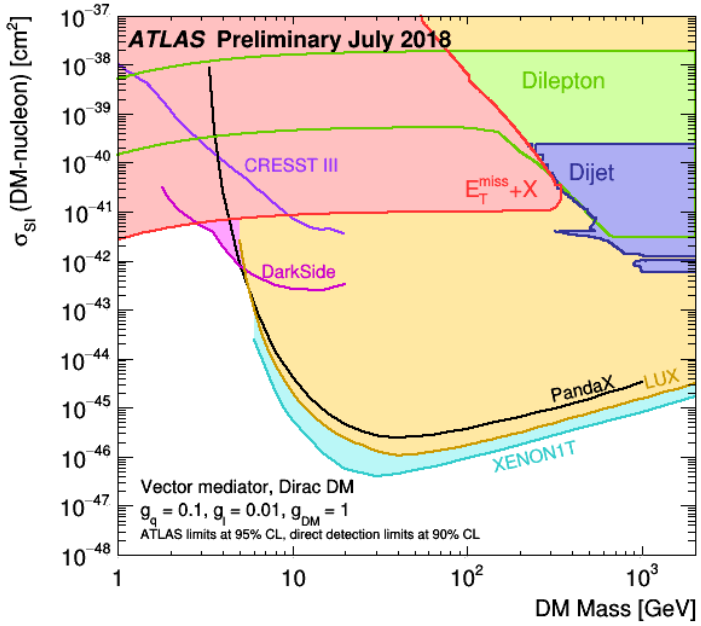


$g_l=g_q=0.1$



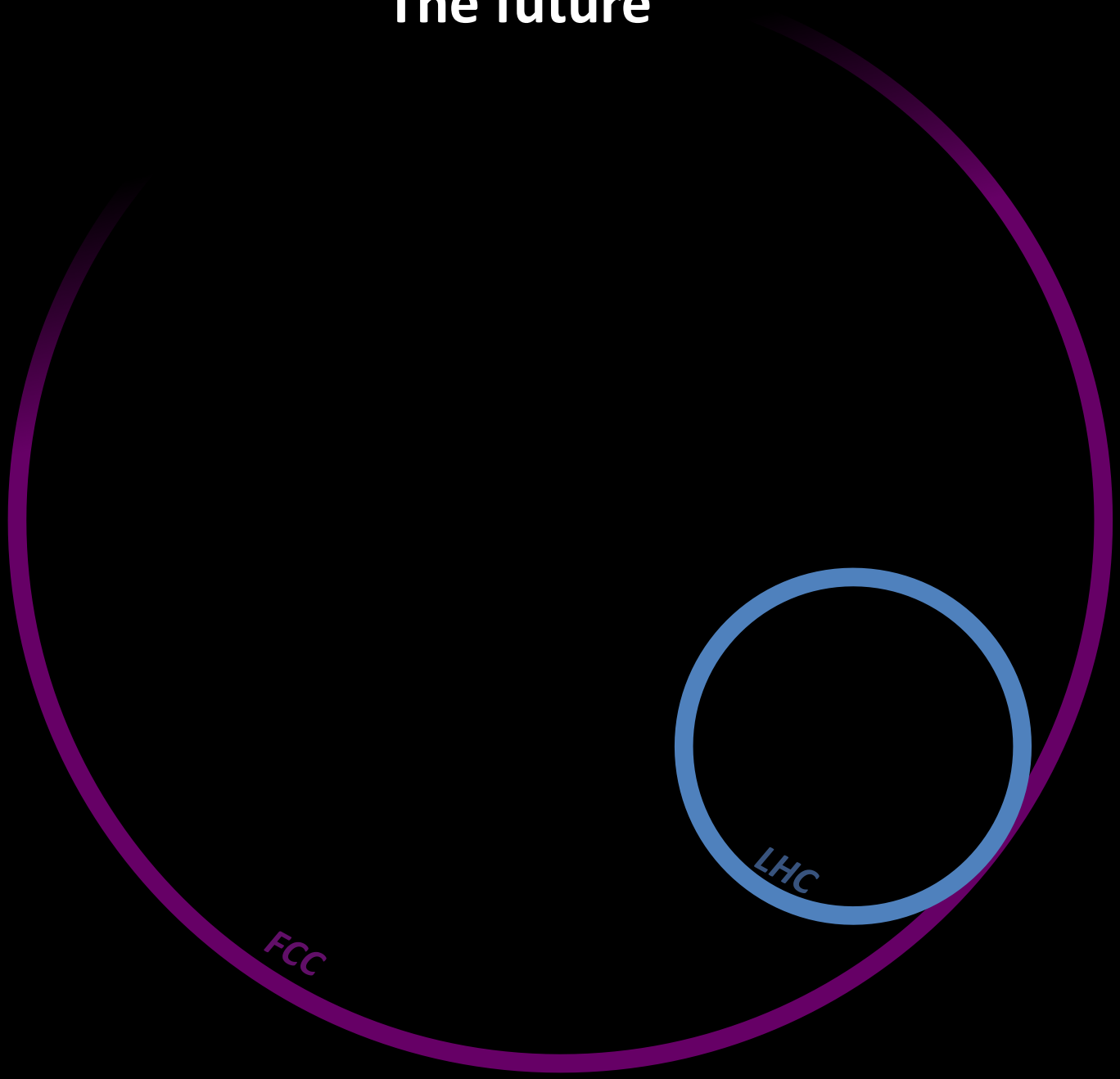
Spin-dependent





Spin-independent

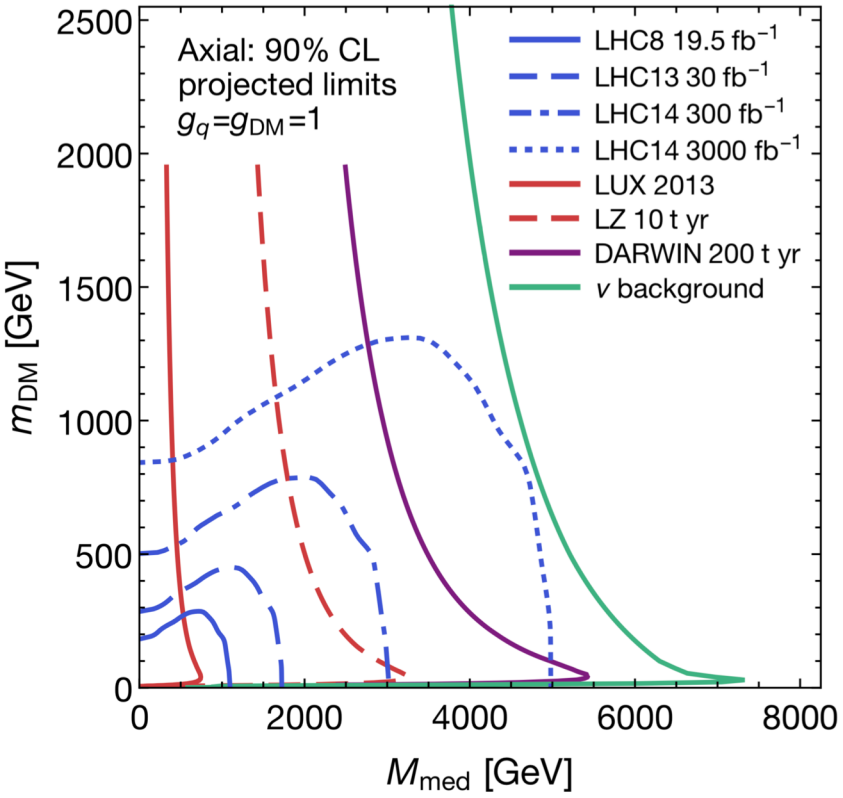
The future

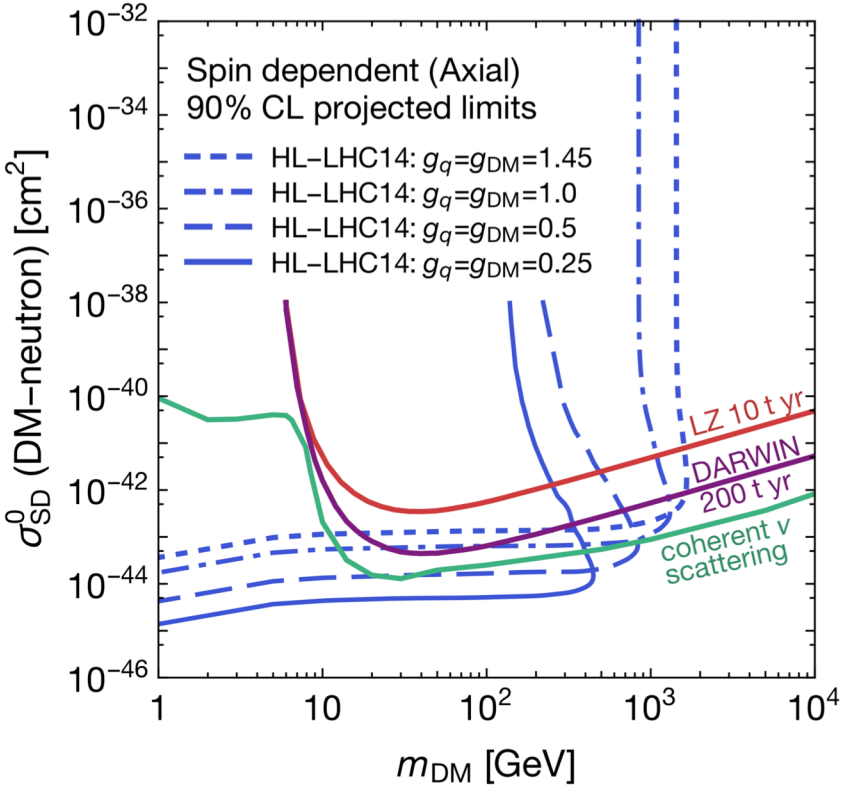


Prospects for searches

arXiv:1409.4075

Excellent complementarity of direct and collider sensitivity as we move into the 2020s:





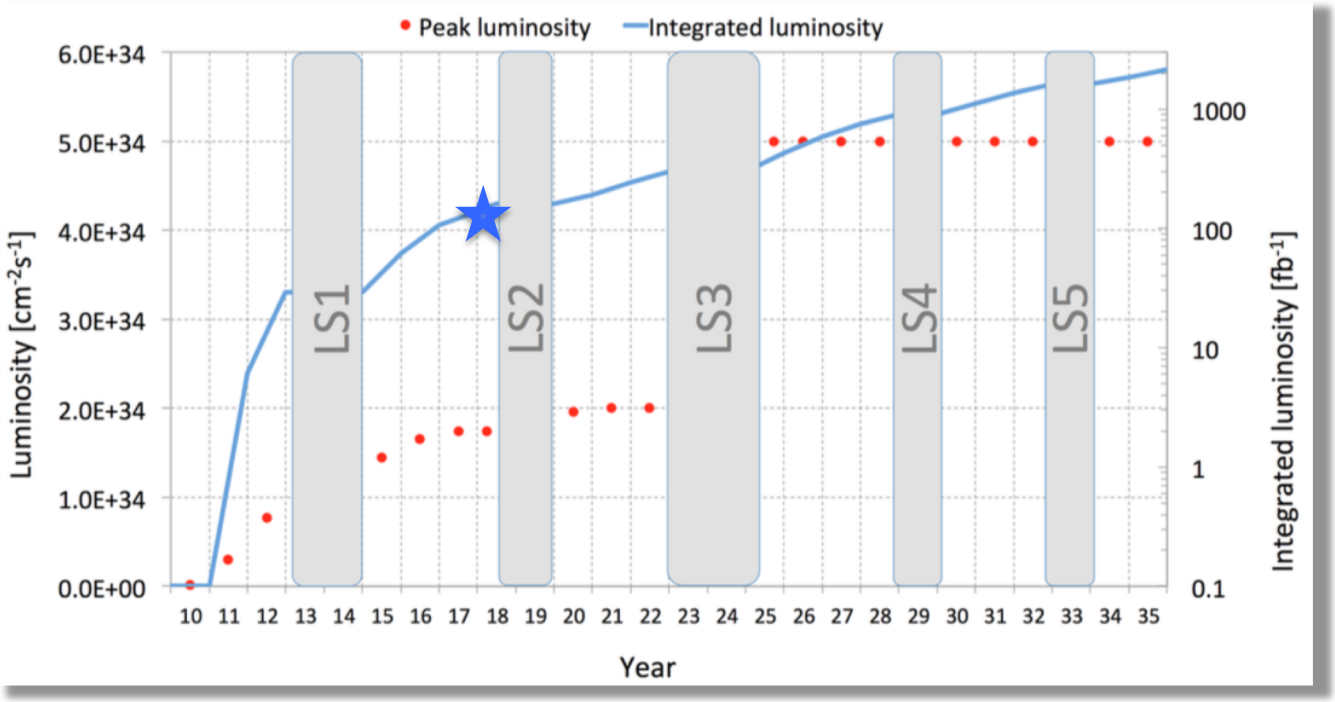
Ensuring longevity / reinterpretability

Key considerations

New dark matter theory in future?
Looking for the wrong things?
Improvements in SM modelling?
A global view on searches?

Reinterpretation.
Over-optimisation.
Recalculation of limits.
Maximising sensitivity.

LHC luminosity evolution places increasing importance of making most of data we have!

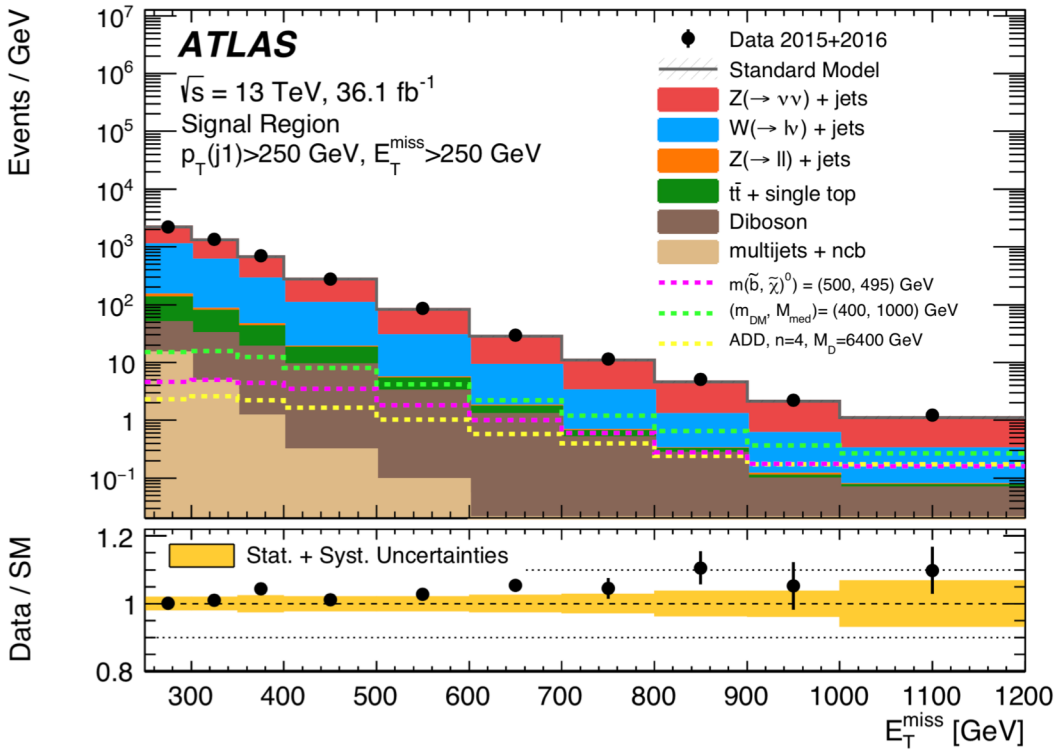


Reinterpretability

Currently on the market:

Fit of models to 'detector-level' data

Needs signal generation, trustworthy detector simulation, implementation of (sometimes complex) detector-specific event selections.

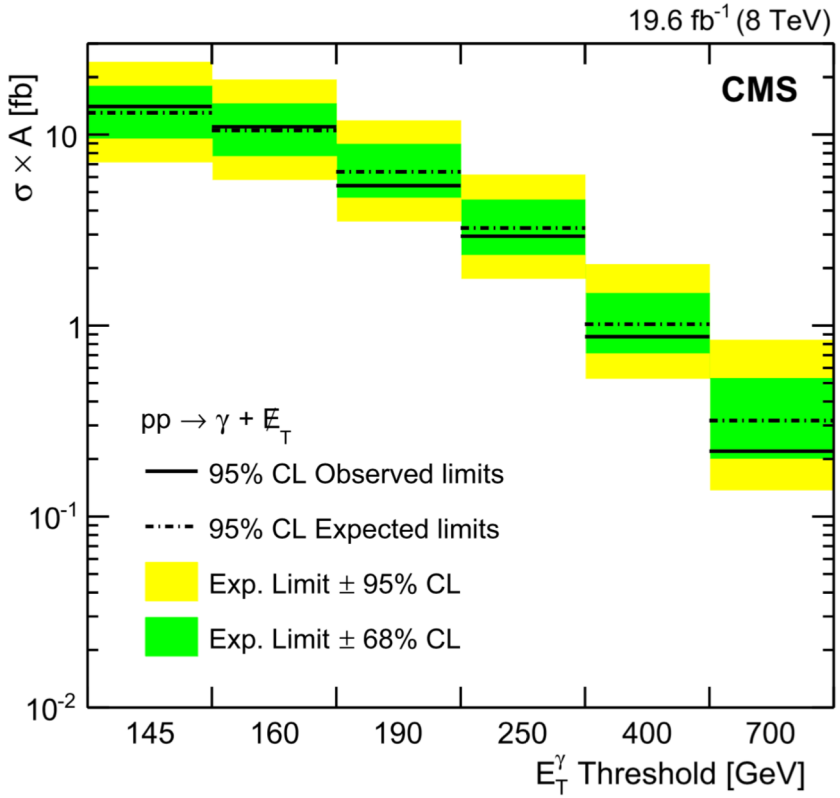


Reinterpretability

Currently on the market:

Comparison to model-independent limits

Needs signal generation, implementation of (sometimes complex) detector-specific event selections. Has imposed detector efficiency! – limitation



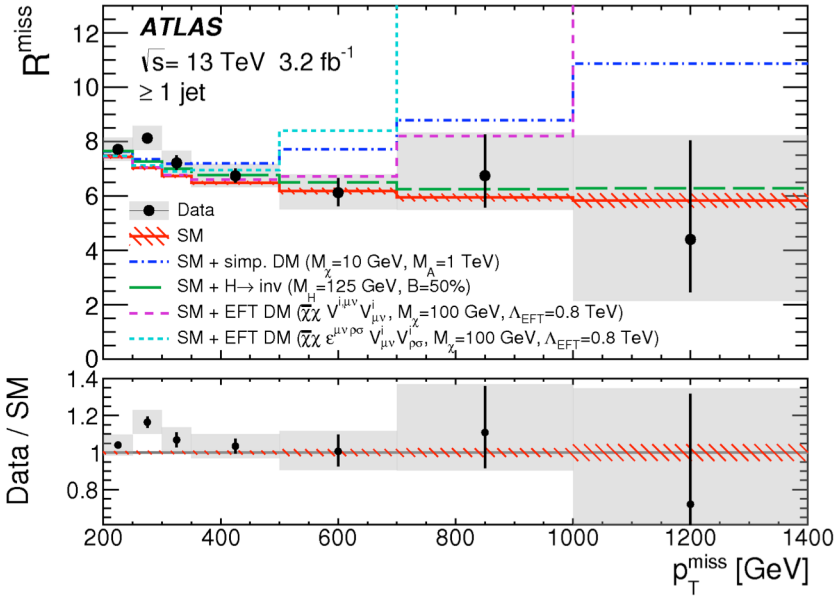
Reinterpretability

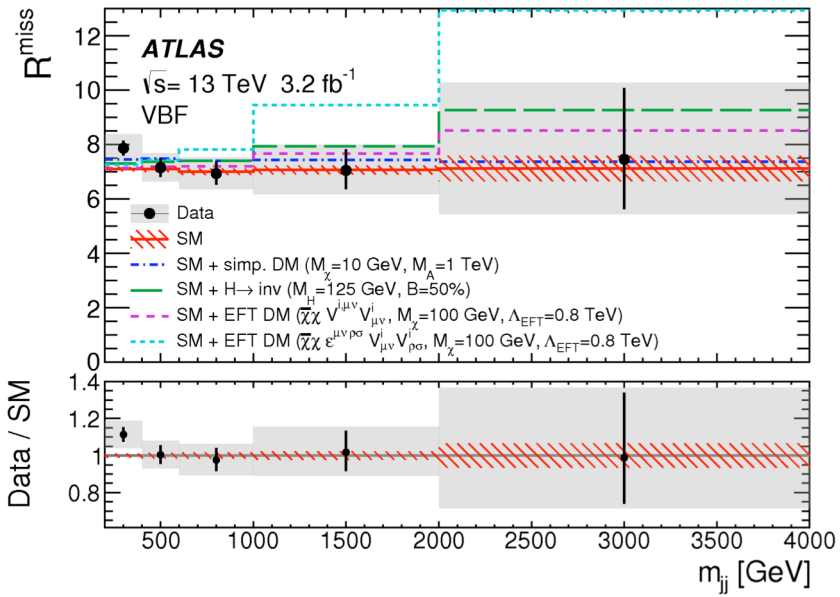
EPJC 77 (2017) 11, 765; arXiv:1707.03263

Currently on the market:

First 'particle-level' production cross-sections sensitive to DM

Needs signal generation. Event selections in public code, model and detector-independent. No loss of sensitivity in reinterpretation.





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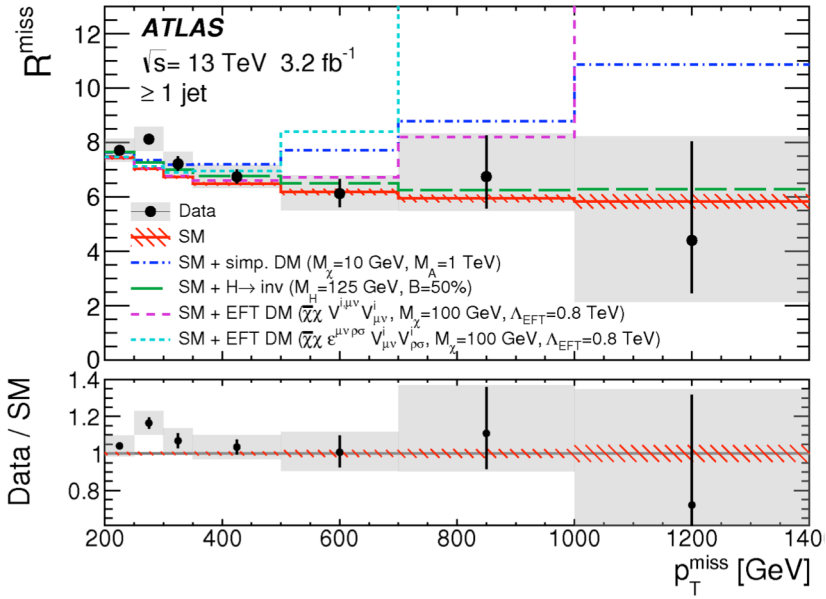
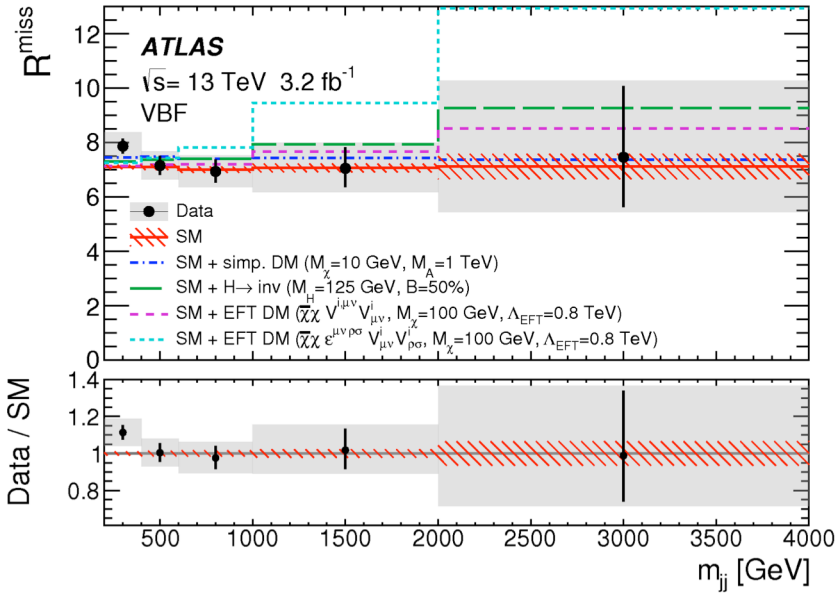
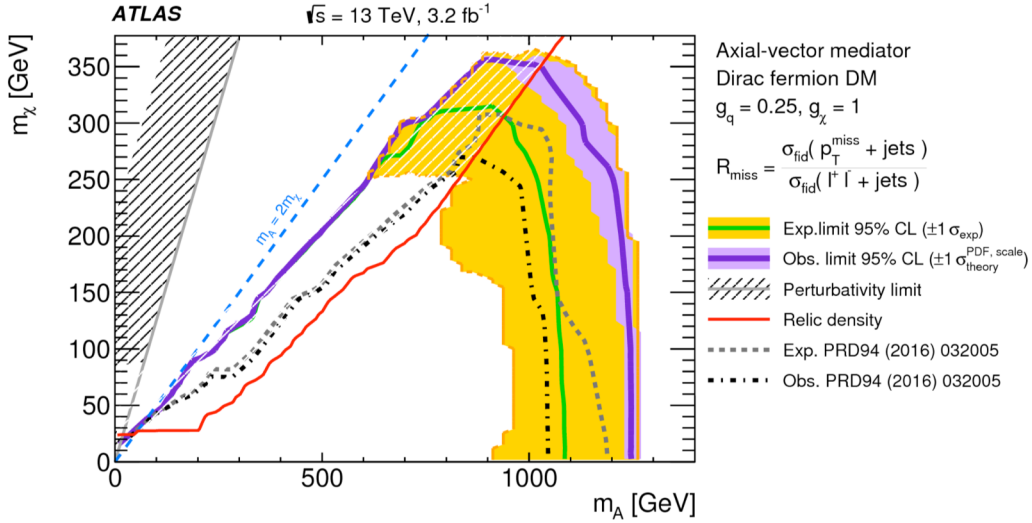
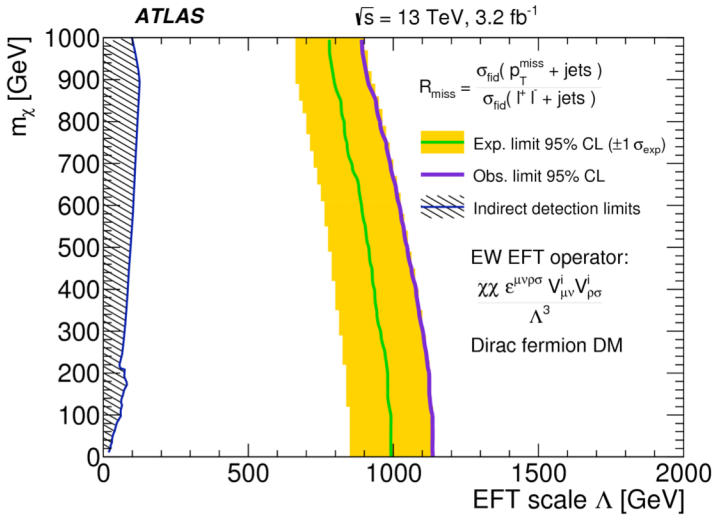




Since published used to set limits on ALPs, asymmetric DM, EFTs…





Dark matter searches: moving forward

Dark matter collider search programme is a large endeavour

- *But: are there any signatures/topologies not being explored?*

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Despite this, still far to go: should remember we are still discovering SM processes!

- *If DM very exclusive in production we have hard work ahead of us even with data++ and all existing analyses!*

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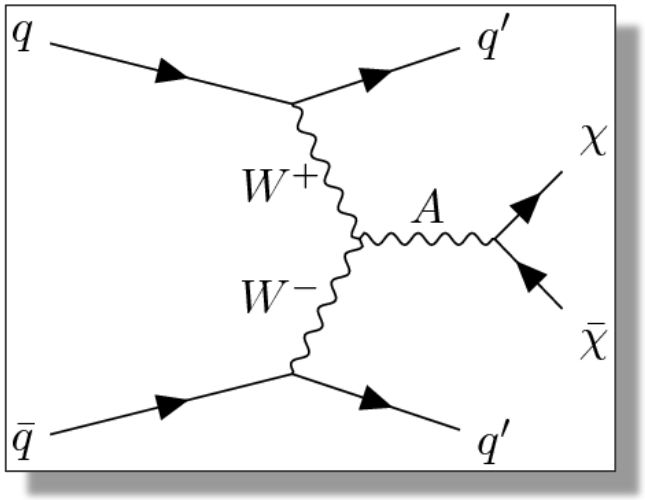

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How best present/use data for reinterpretation/combination?

- *Is community aware of how to make best use of data from the LHC for reinterpretation with DD (and vice-versa!)?*
- *Should DMUK be a forum for hands-on workshops with the aim to run through workflows and produce new results?*

Do we have fully joined-up thinking between direct detection and collider communities?

- *Can we do more? What are the barriers?*
- *Can this community highlight these issues and take the lead in tackling them?*