Searches for Dark Matter with the ATLAS Detector using Resonances with Jets

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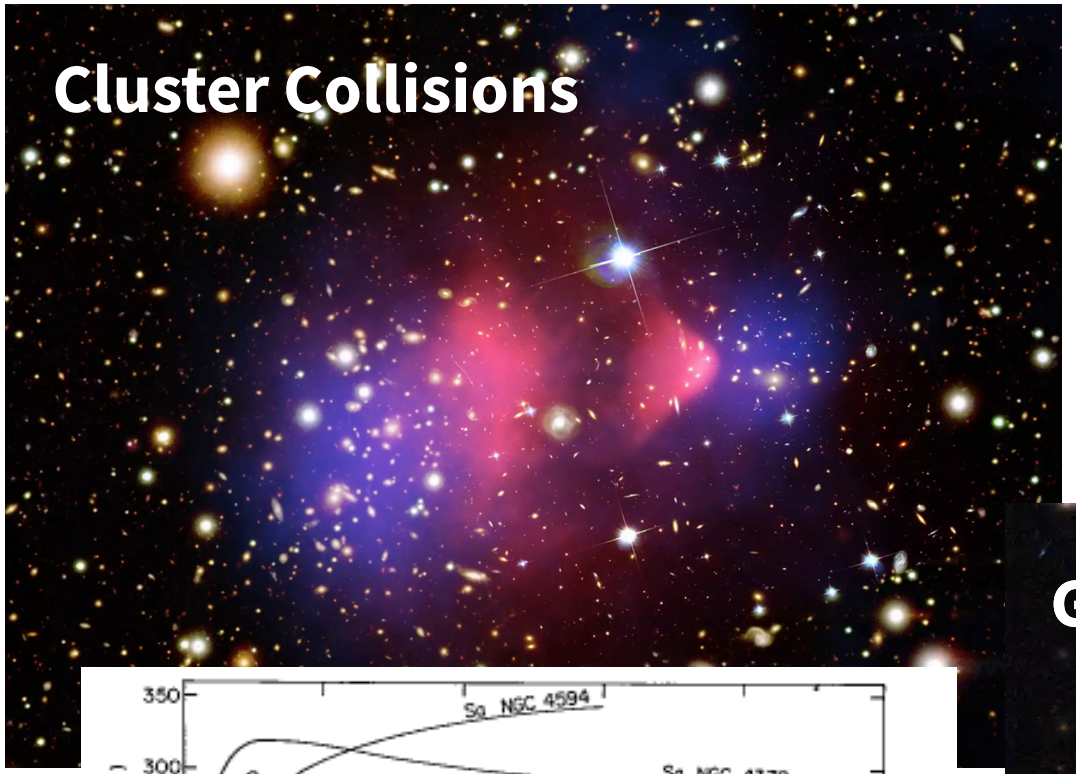
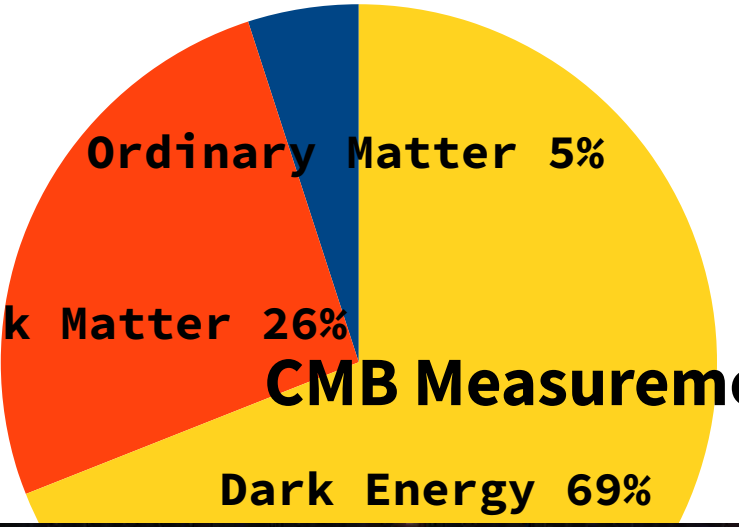
for the ATLAS Collaboration

16/05/10

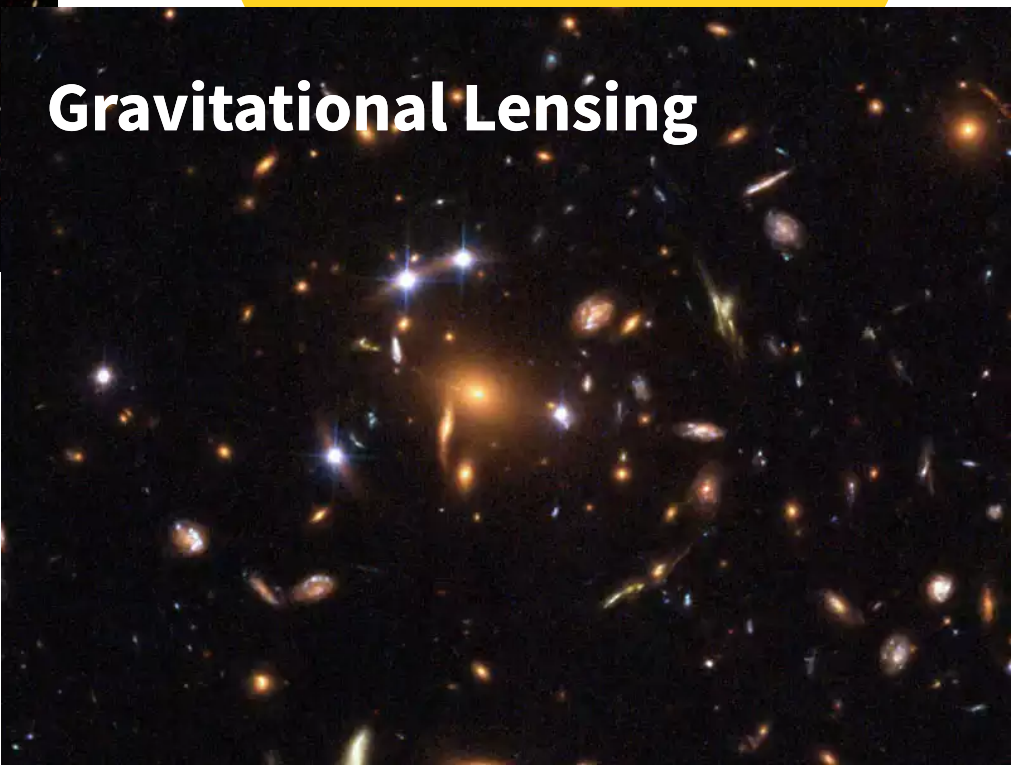
PHENO2016

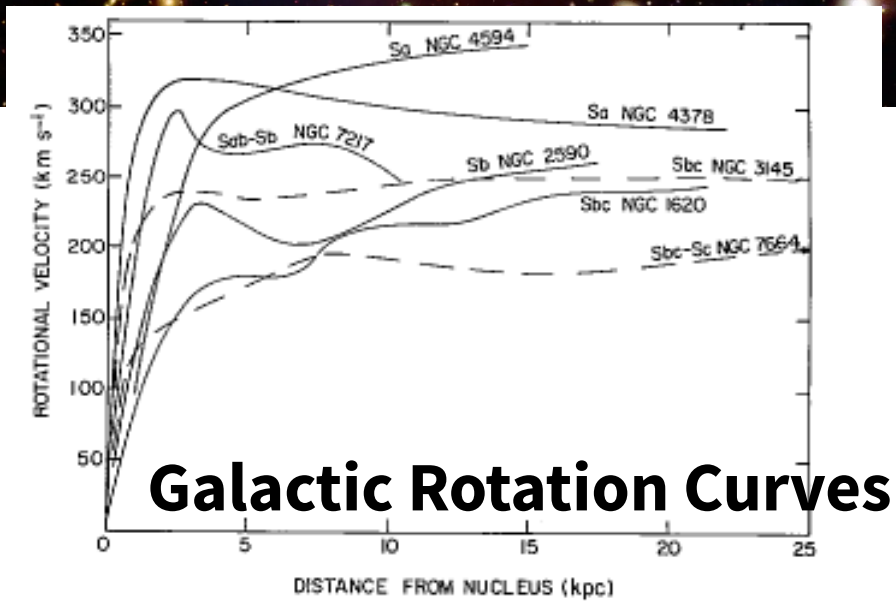
Why Dark Matter?





CMB Measurements

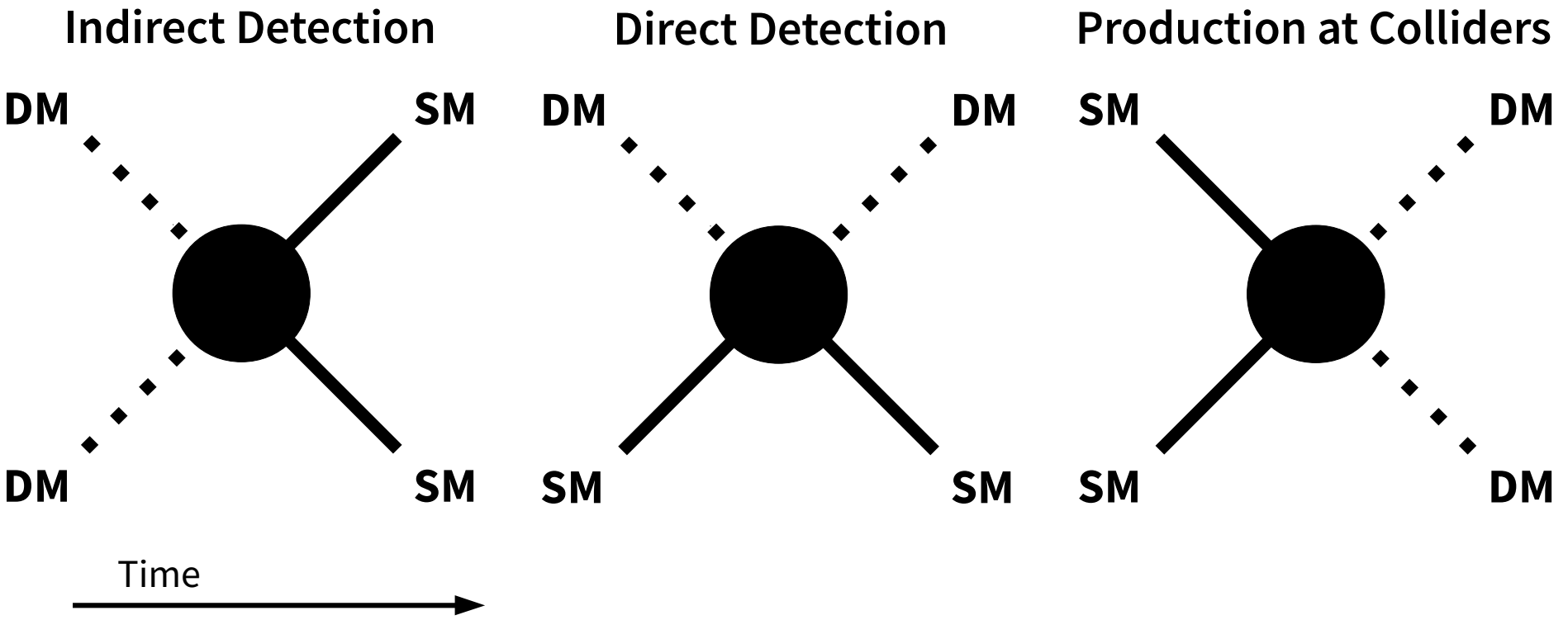




Galactic Rotation Curves

Searching for Dark Matter

To detect Dark Matter, it must interact with Standard Model* somehow.



* aka laboratory equipment

Searching for Dark Matter

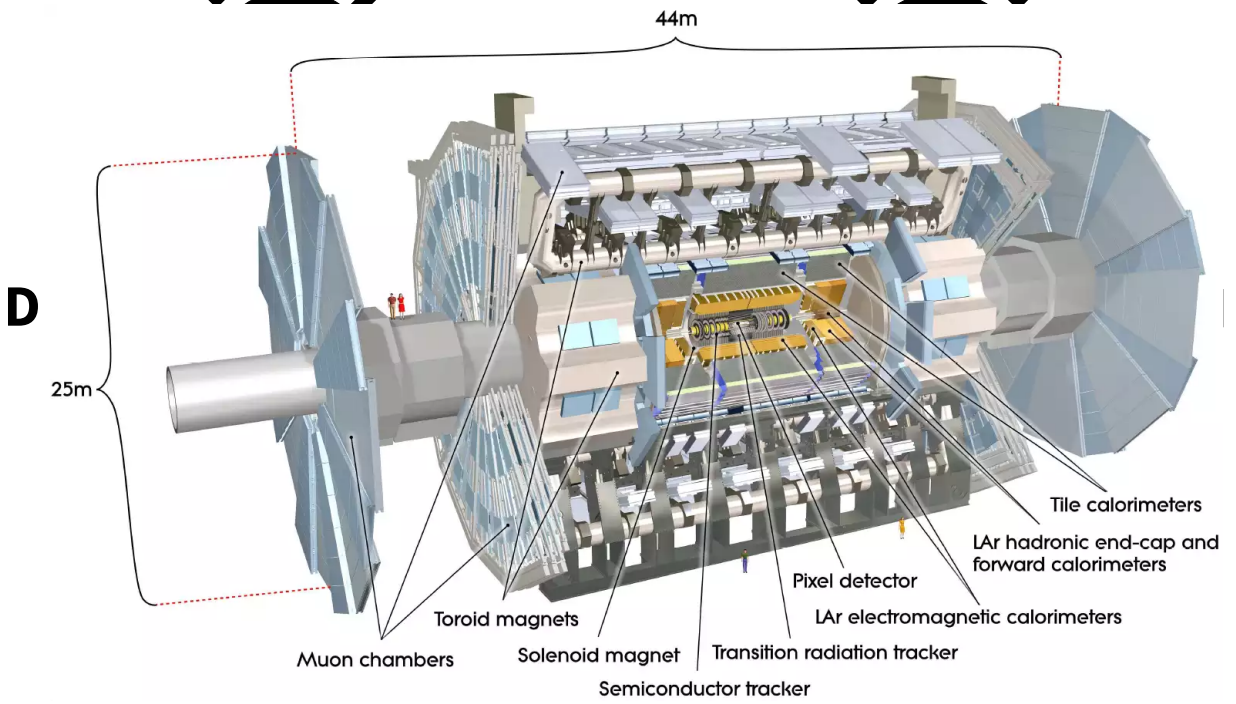
To detect Dark Matter, it must interact with Standard Model* somehow.

Indirect Detection

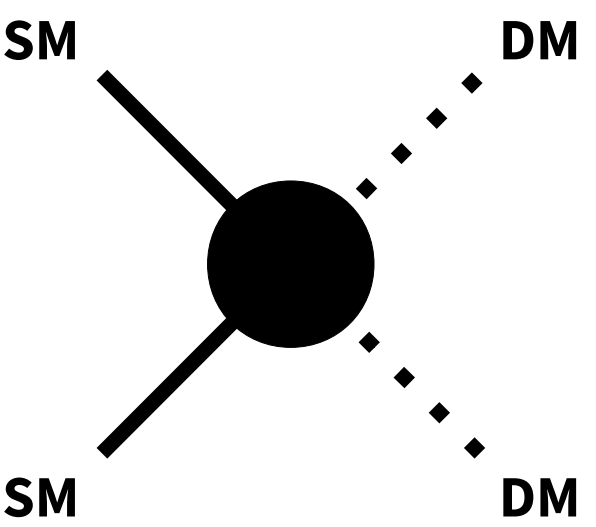
DM → SM

Direct Detection

DM → DM



Production at Colliders

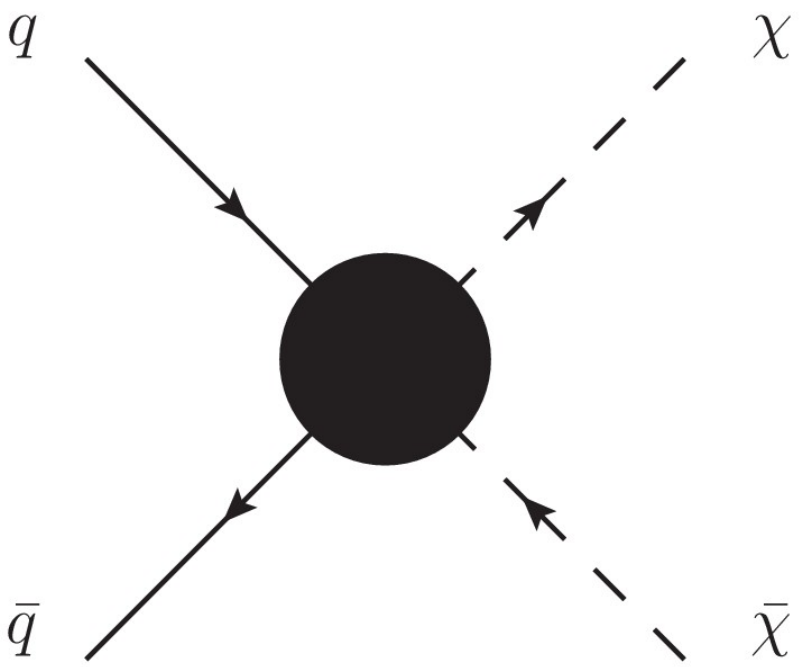


ATLAS Searches

* aka laboratory equipment

EFT Dark Matter Model

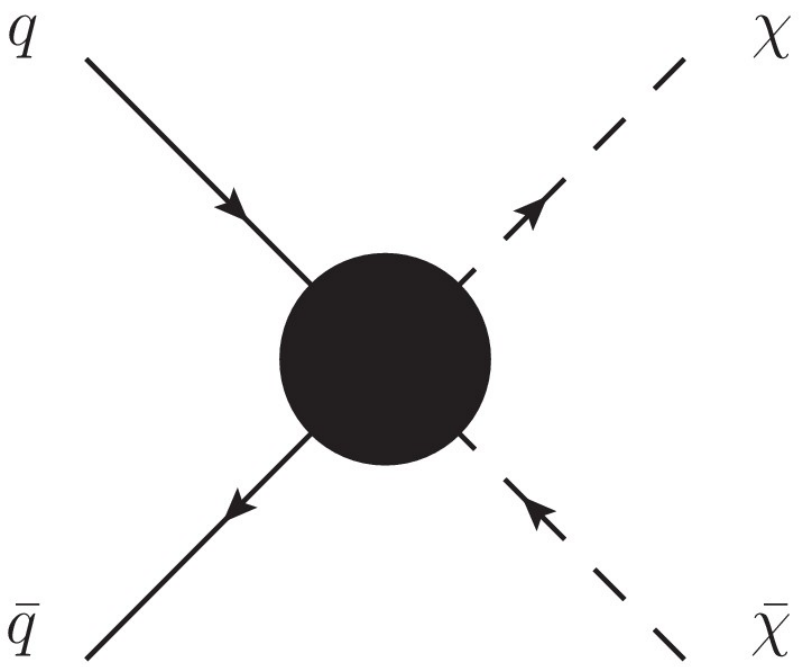
Used in Run 1



New particle (Dark Matter) with a **parametrizable interaction** to the Standard Model.

EFT Dark Matter Model

Used in Run 1



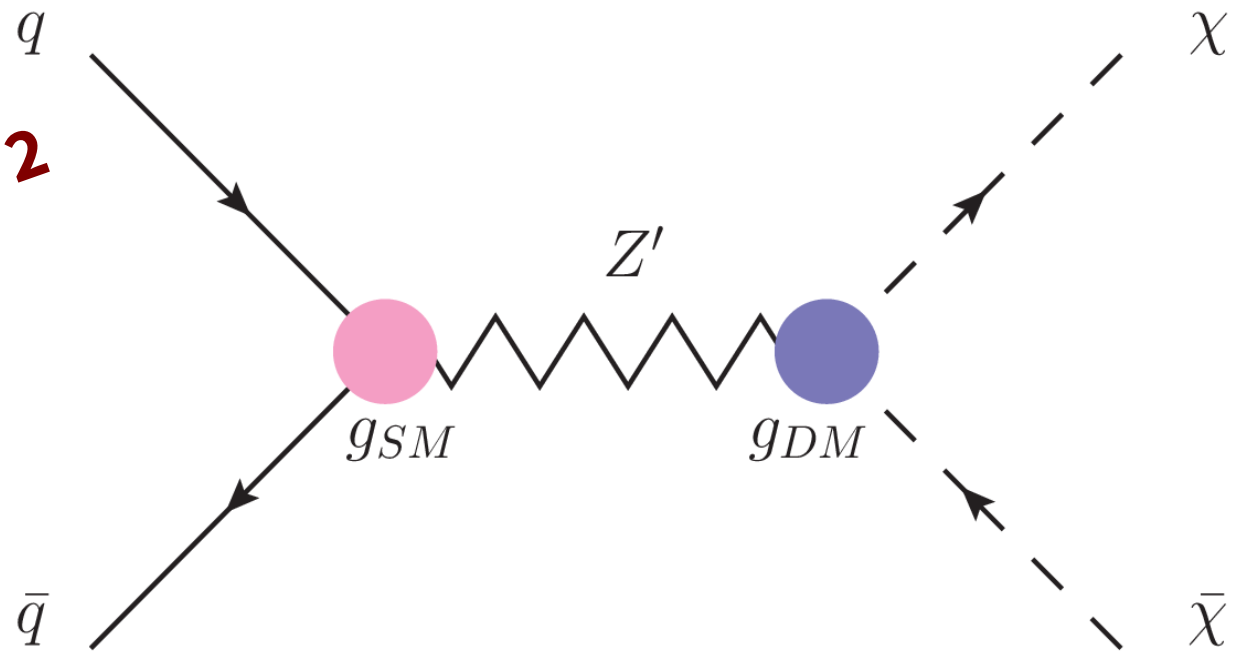
New particle (Dark Matter) w
the Standard Model.

Works great for heavy Dark Matter, but...

- not ideal for light Dark Matter
- hides richer phenomenology

Simplified Dark Matter Model

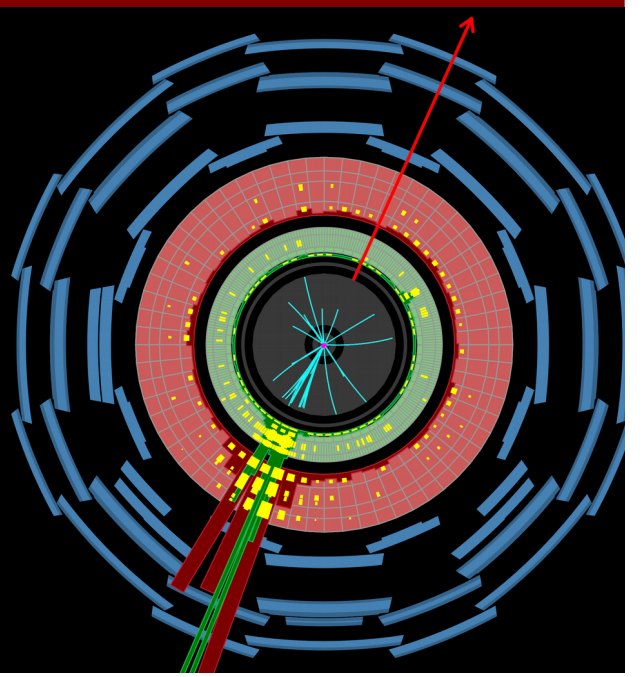
New in Run 2

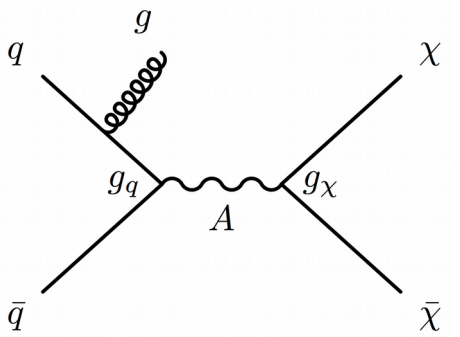


- **Model recommended by the LHC Dark Matter Forum** arXiv:1507.00966, arXiv:1603.04156
  - An (**axial**) mediator (mass m_R) couples to Dark Matter (mass m_{DM})
  - Independent couplings to quarks (g_{SM}, flavor independent) and DM (g_{DM})
- **Common model used by all searches and all LHC experiments!**

Why Jets in DM Signal?

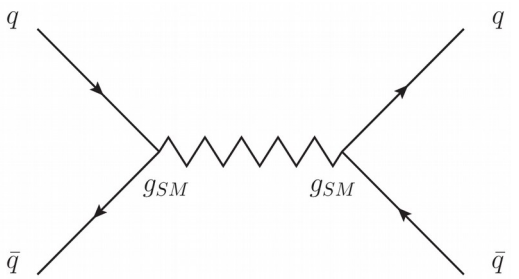
Dark Matter particles are not seen by the detector





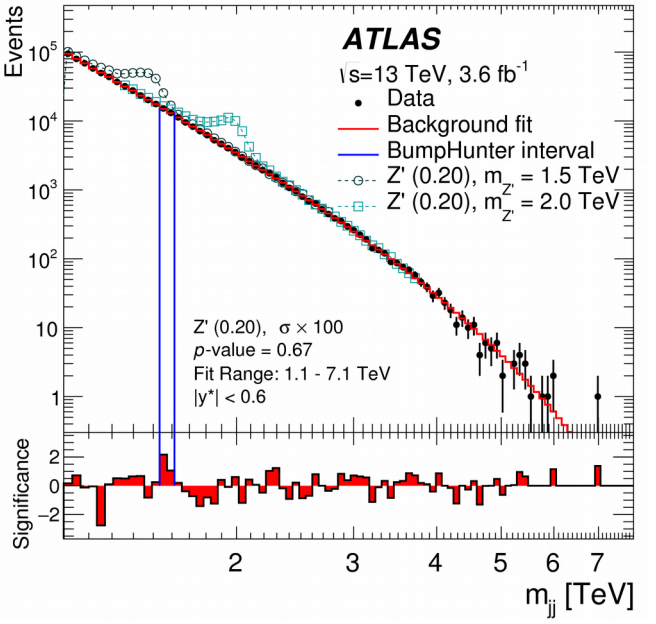
MET+X Searches

- Produce DM with an ISR object
- Search for momentum imbalance in transverse plane (MeT) from DM



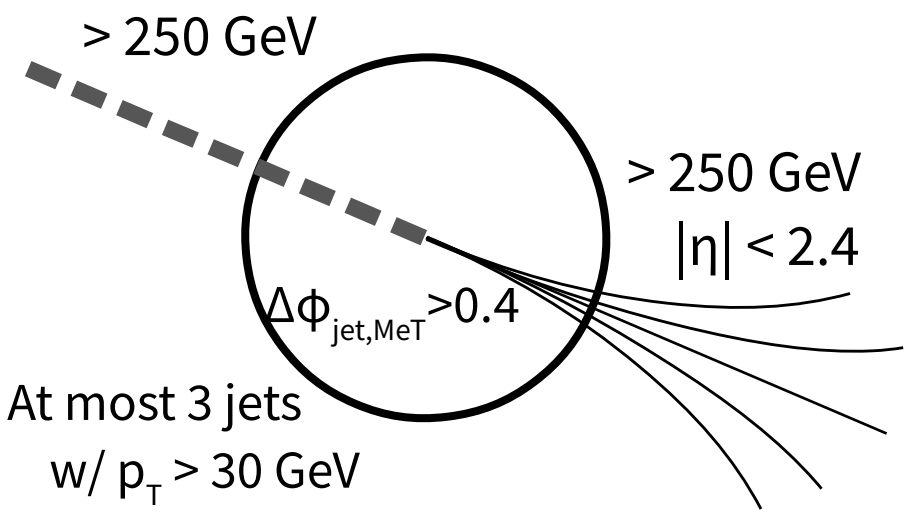
Dijet Searches

- Decay Z' back into quarks and look for a bump in m_{jj} spectrum
- A signal does not mean DM, but lack of signal will constrain the simplified DM model

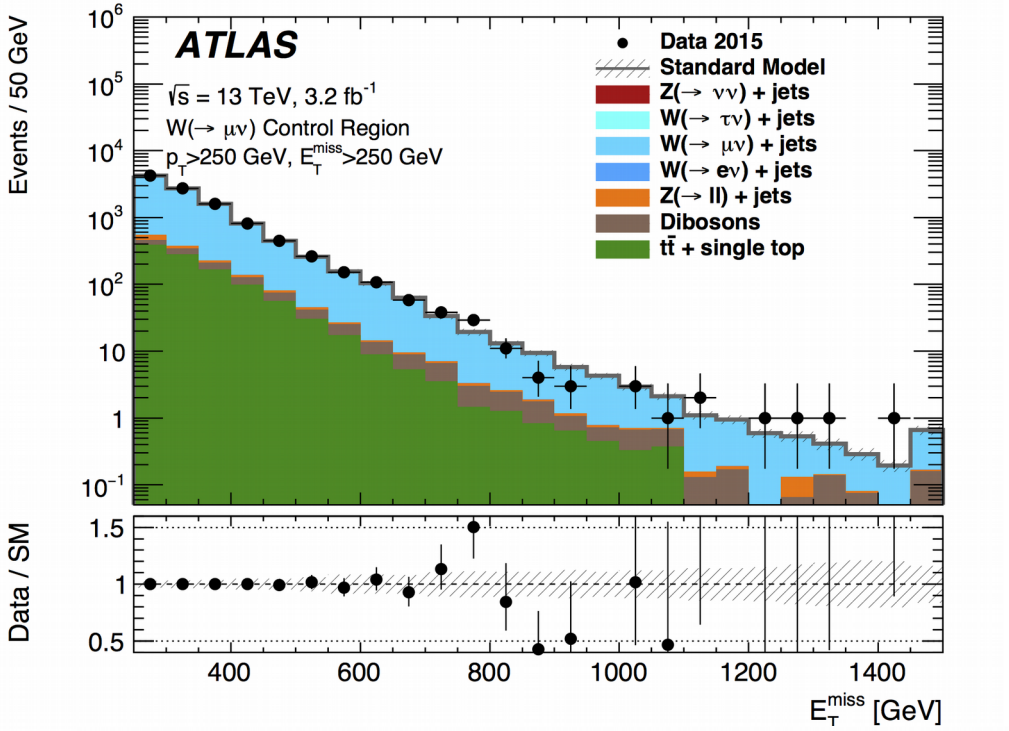


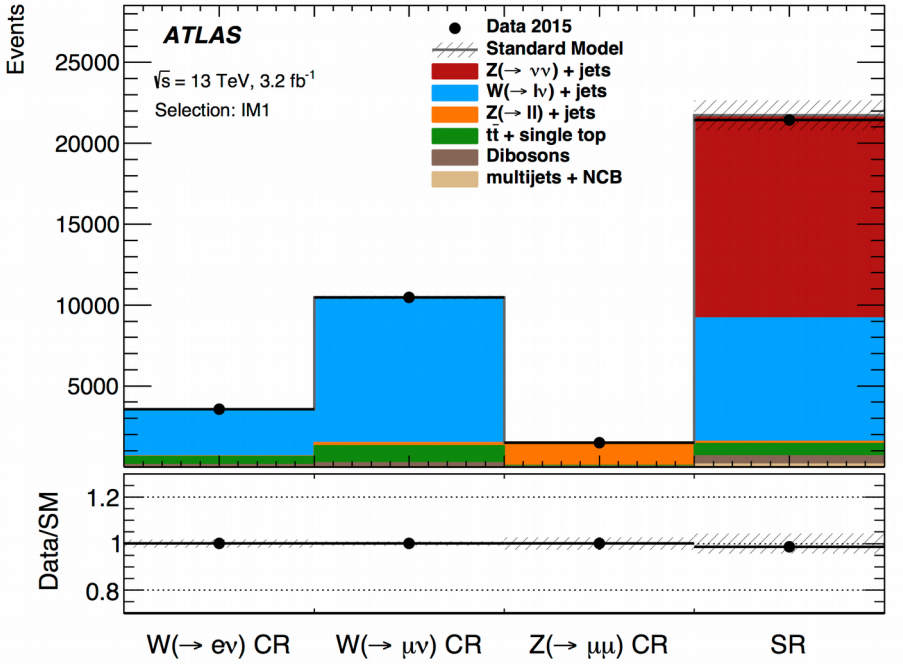
MET+Jet

EXOT-2015-03



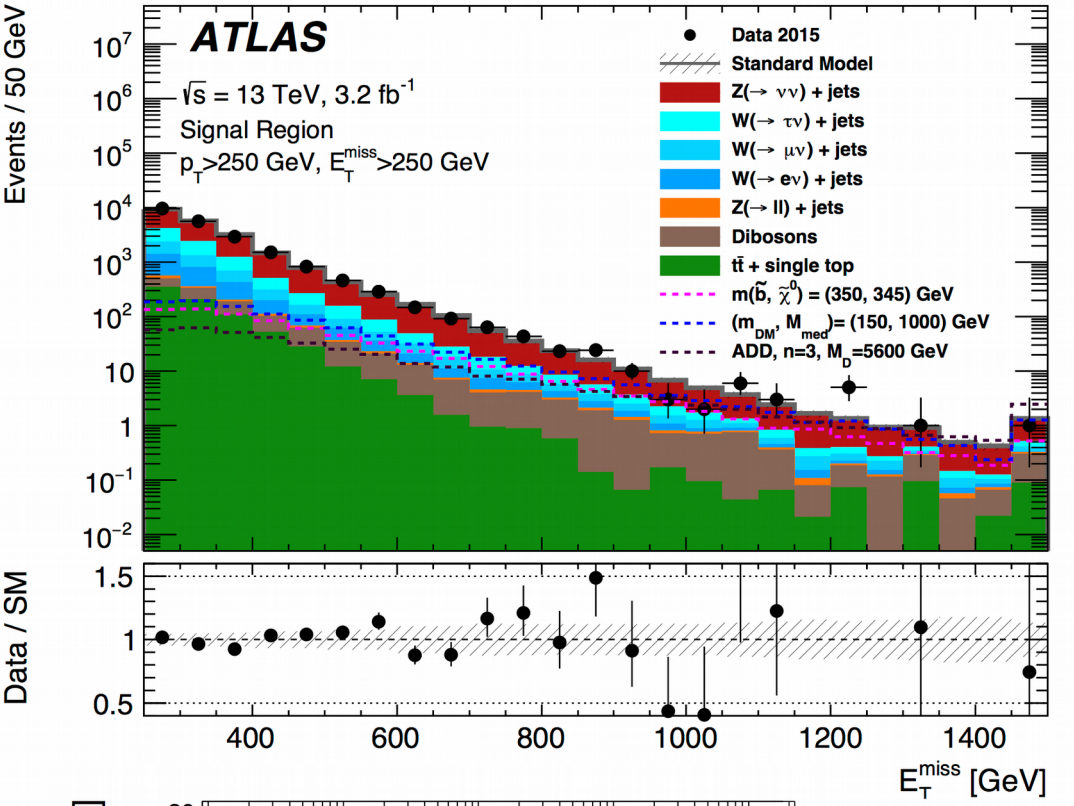
- **Inclusive and exclusive signal regions in MeT**
  - 6 bins in range 250 GeV to 700 GeV
- **Z→νν+jets background determined from W→μν+jets events**
  - Similar data-driven technique for other boson backgrounds
  - Simultaneous fit done in CRs+SR
- **Jet smearing for multi-jet background**
- **Other backgrounds determined using MC**

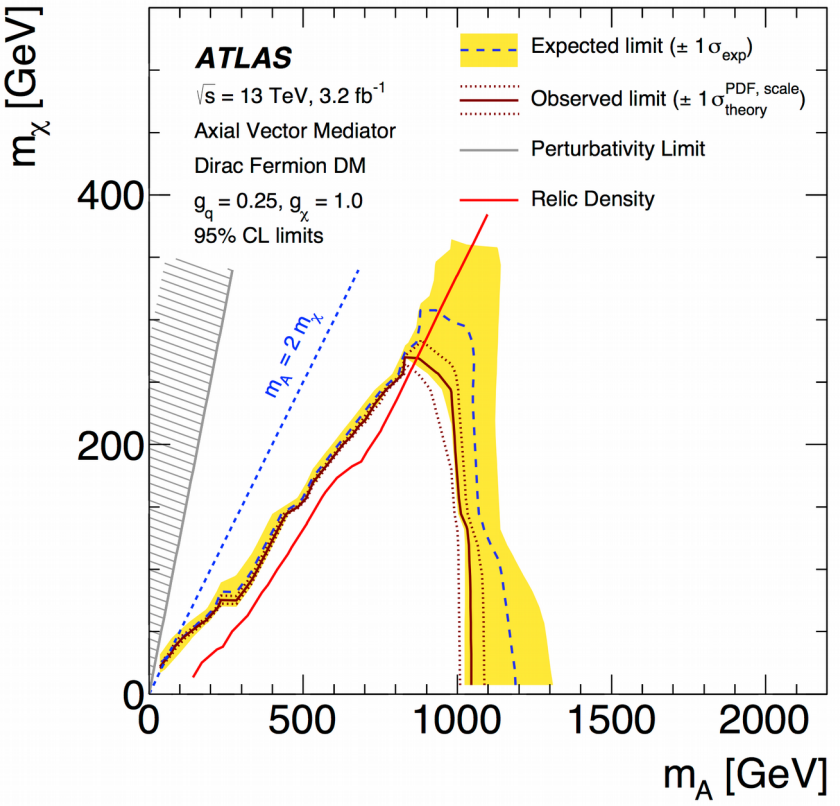


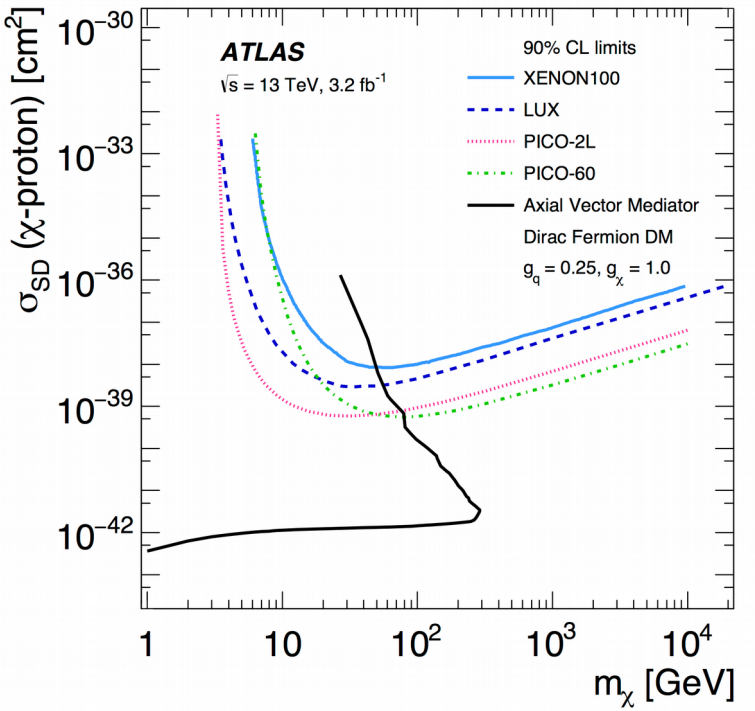


MET+Jet Results

- No signal seen → limits
- Also limits on extra dimension and SUSY models

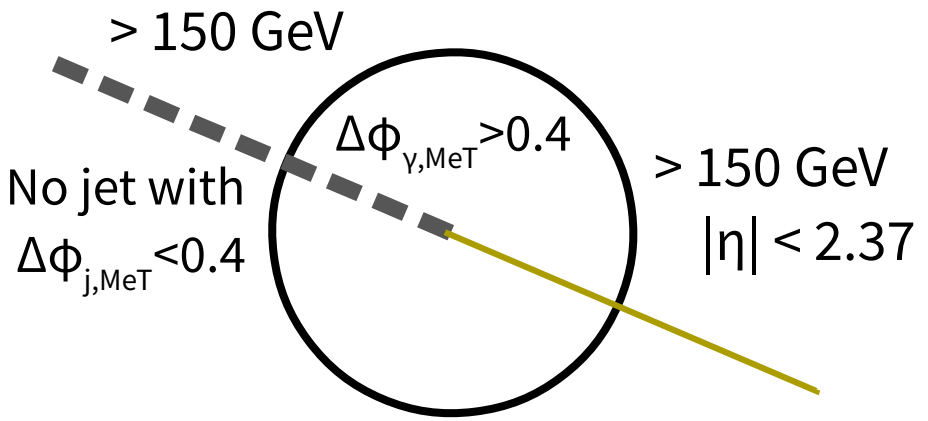


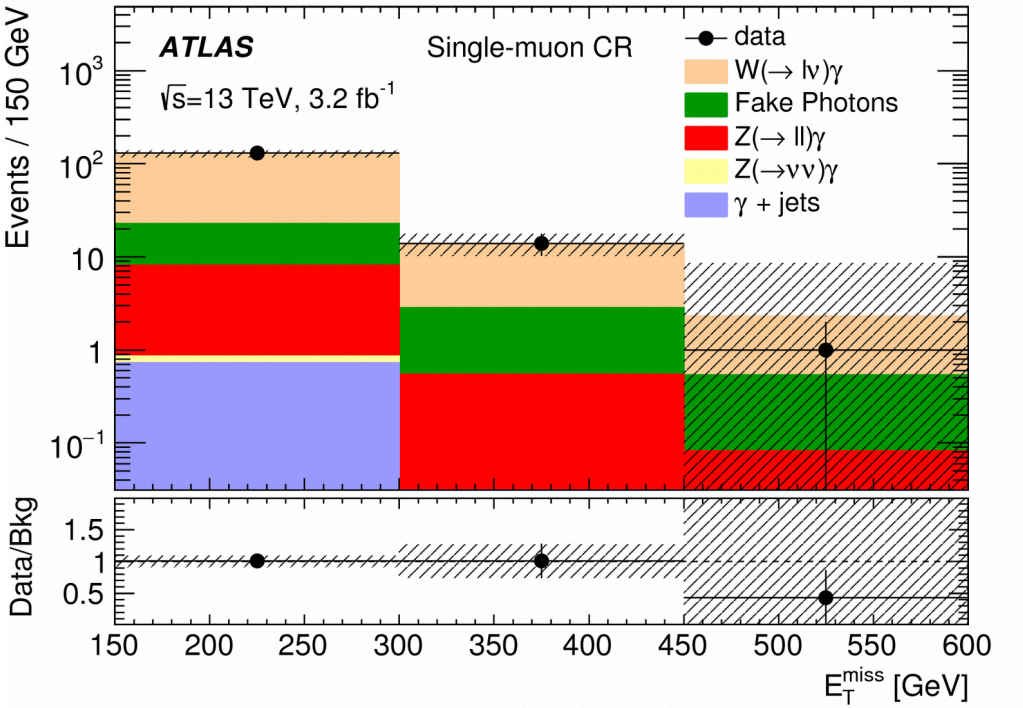




MET+Photon

EXOT-2015-05



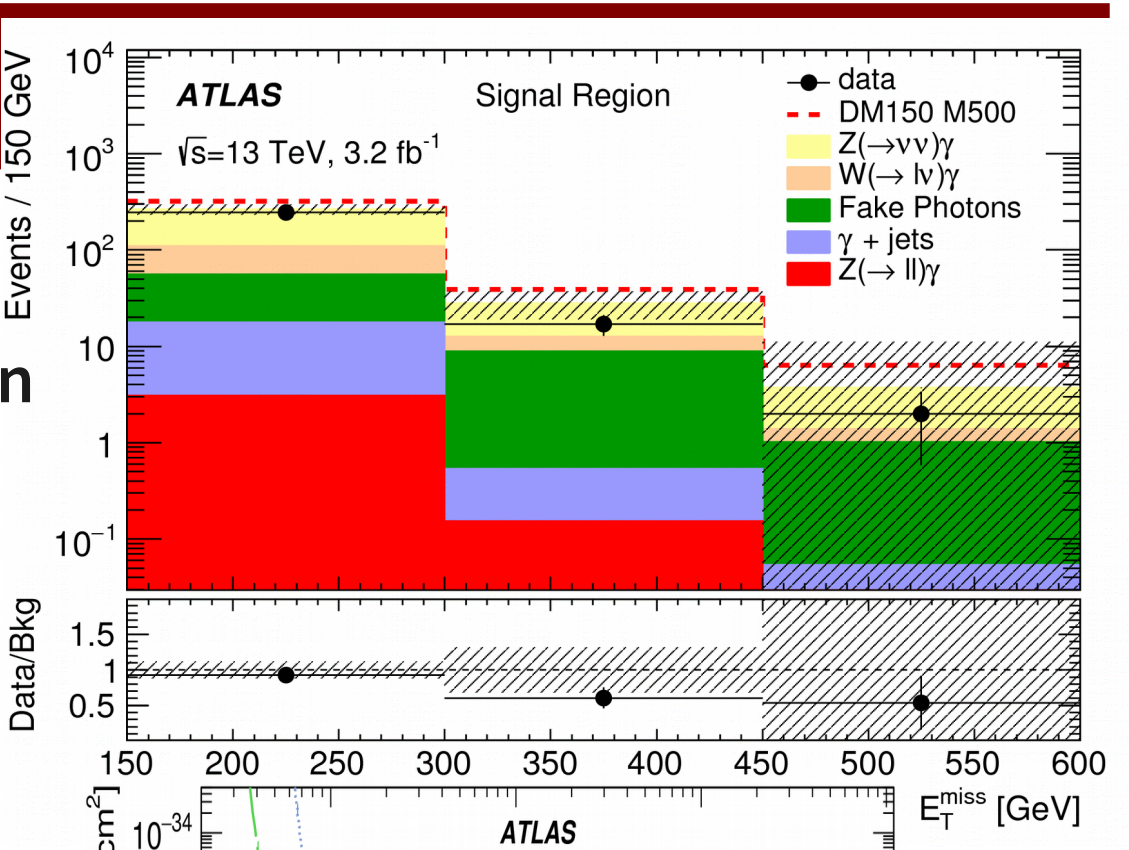


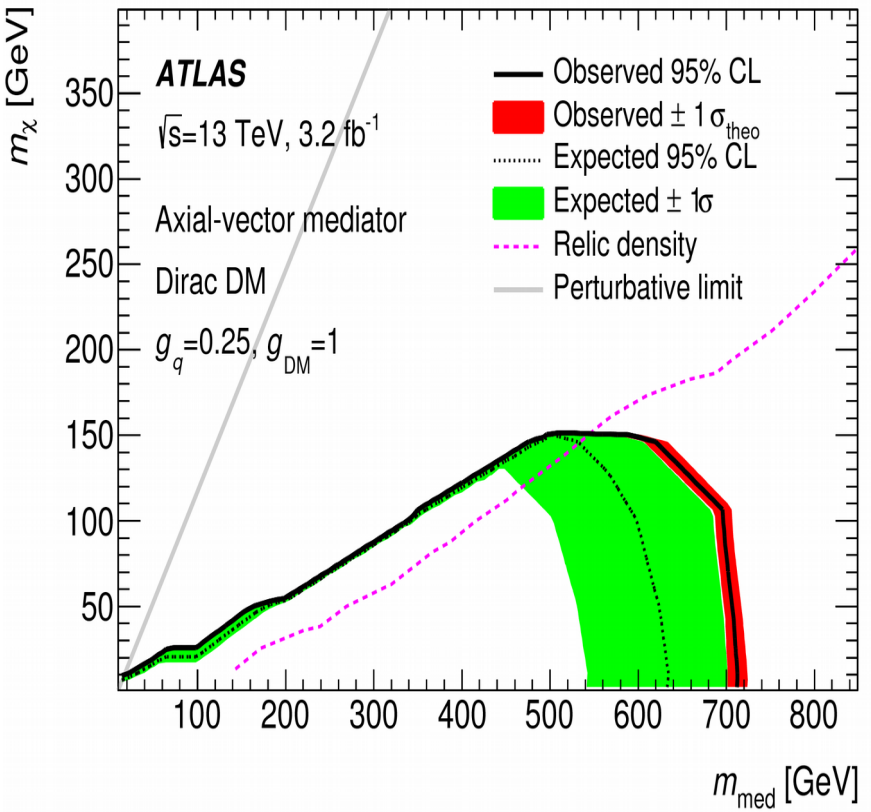
- **Single bin Signal Region (and control regions)**
- **Z/W background k-factors estimated via simultaneous fits to Z/W control regions**
  - Same k-factor for Z→νν + γ as for Z→ll+γ
- **Data-driven estimation of photon fakes**
  - Miss-ID'ed electrons from e+γ sample scaled by measured miss-ID rate
  - ABCD method for miss-ID'ed jets

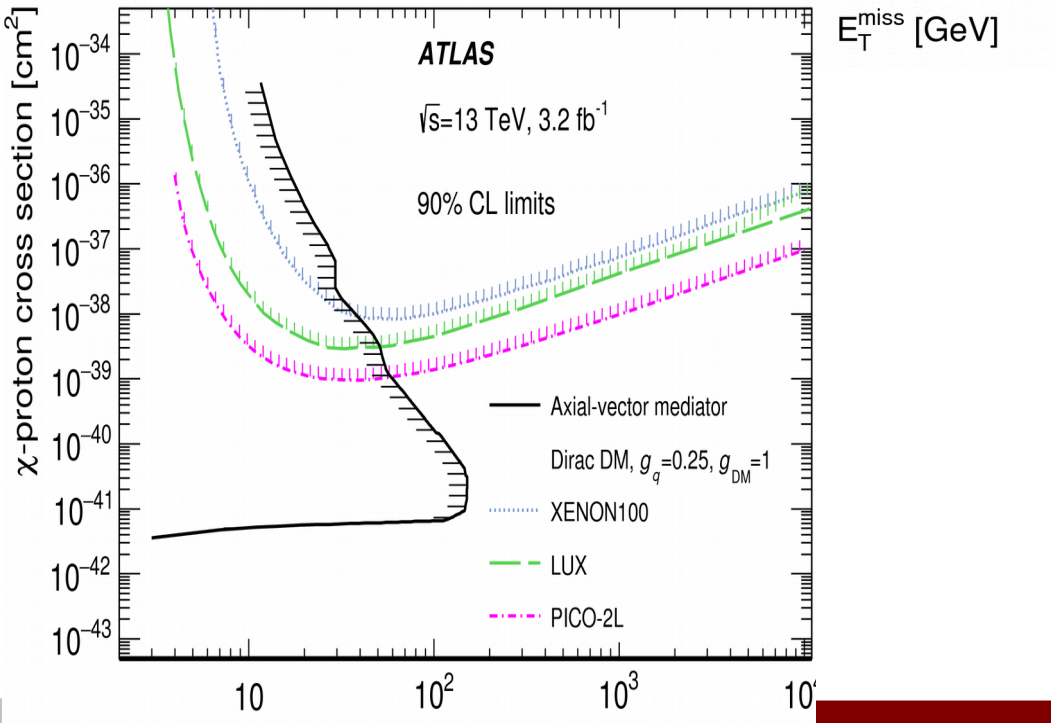
	1muCR	2muCR	2eleCR	PhJetCR
Observed events	145	29	20	214
Fitted Background	145±12	27±4	23±3	214±15
$Z(\to \nu\nu)\gamma$	0.15±0.03	0.00±0.00	0.00±0.00	8.6±1.4
$W(\to \ell\nu)\gamma$	119±17	0.14±0.04	0.11±0.03	22±4
$Z(\to \ell\ell)\gamma$	7.9±1.3	26±4	20±3	1.2±0.2
γ + jets	0.7±0.5	0.00±0.00	0.03±0.03	166±17
Fake photons from electrons	1.7±1.5	0.05±0.05	0.00±0.00	5.8±5.1
Fake photons from jets	16±11	1.1±0.8	2.5±1.3	9.9±3.1
Pre-fit background	105±14	23±2	19±2	209±50

MET+Photon Results

- No signal seen → limits
- Also limits on extra dimension and effective γγχχ coupling



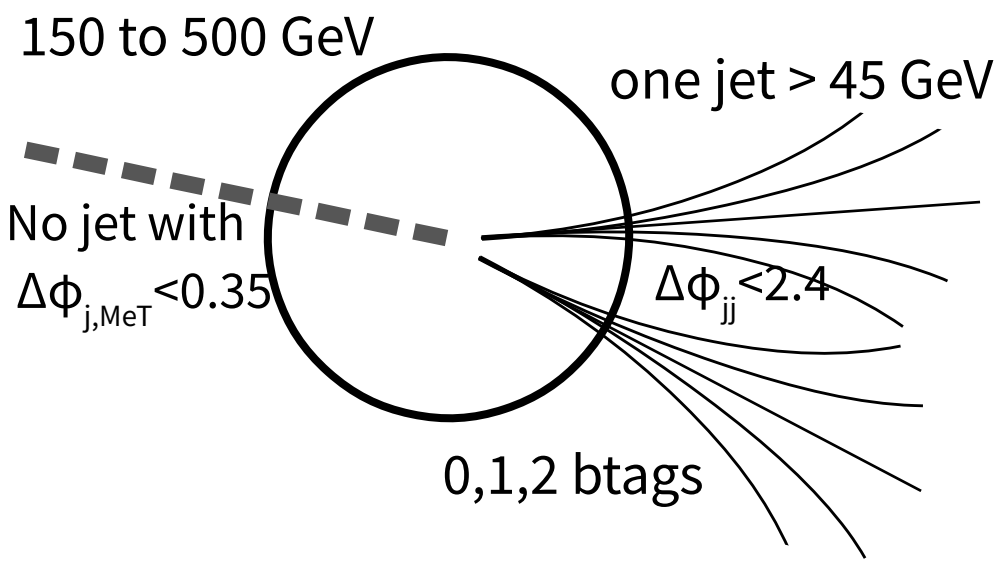




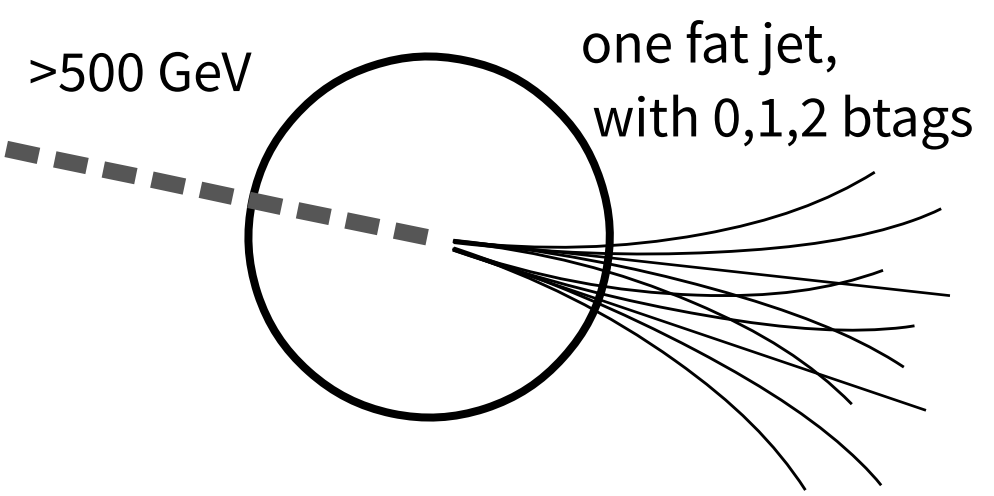
MET+H(→bb)

ATLAS-CONF-2016-019

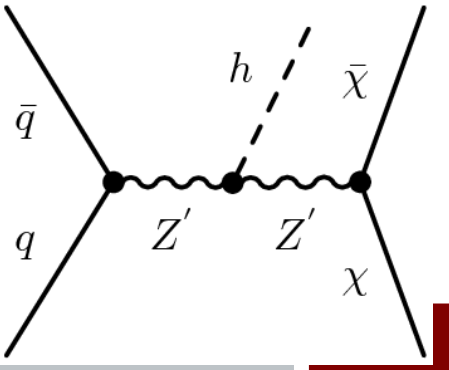
Resolved



Merged



- **Add Z' + Higgs coupling to simplified model**
- **Searches for a ~125 GeV bump in m_{jj}/m_J distributions, divided by N_{bjets}**
- **Background estimated by simultaneous fitting control regions**
  - m_{jj}/m_J sidebands constrain Z→νν+jets
  - one-muon CR to constrain W+jets and ttbar
  - two-lepton CR to constrain Z+jets



MET+H(→bb)

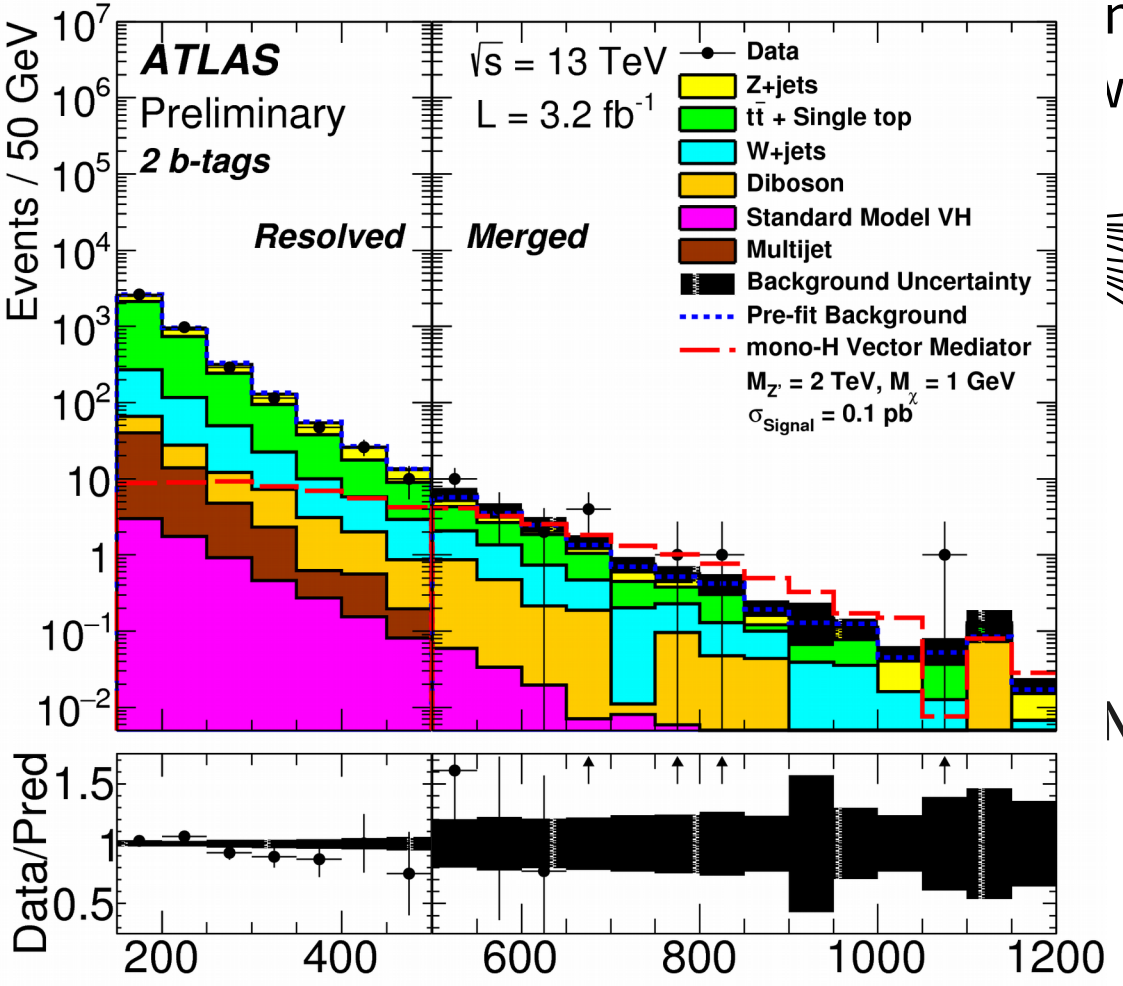
ATLAS-CONF-2016-019

Resolved | **Merged**

150 to 500 GeV

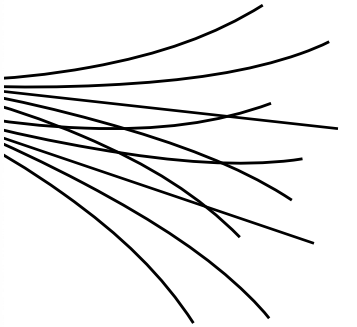
No jet with $\Delta\phi_{j,MeT}$<0.35

0,1,2 bt



ne fat jet,

vith 0,1,2 btags



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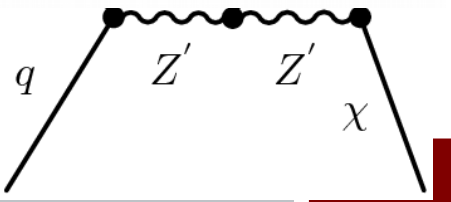
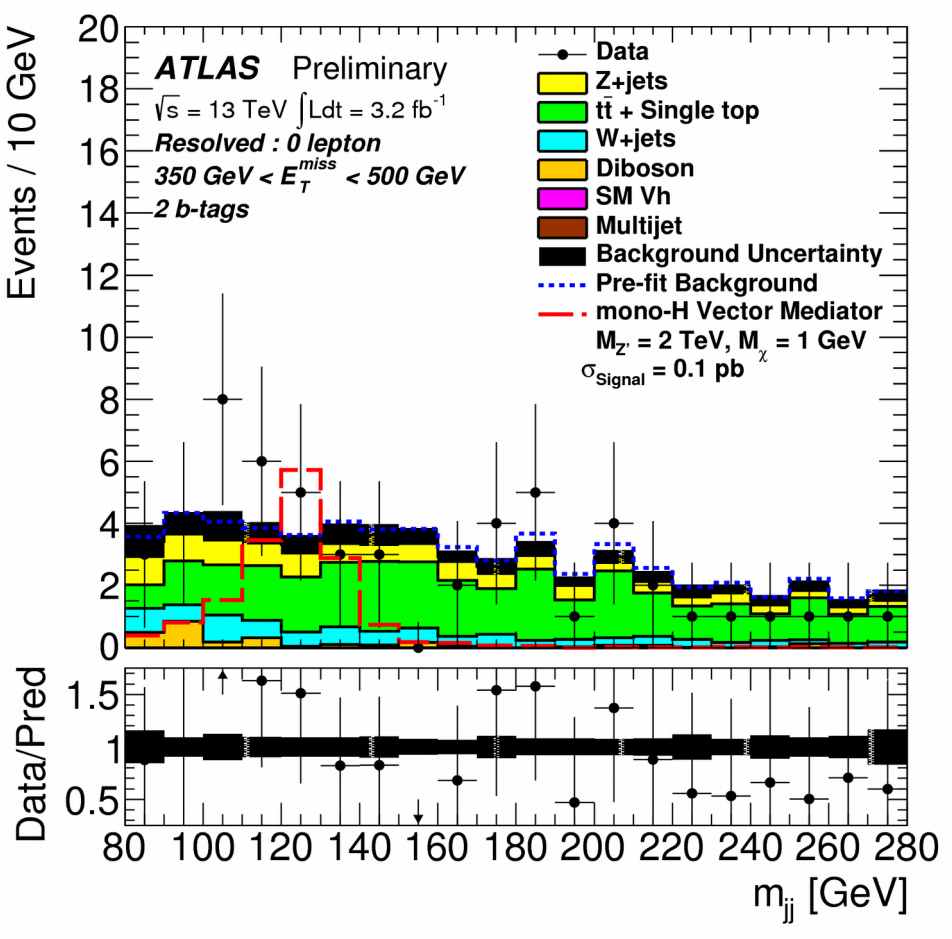
- **Searches for a ~125 G**
- **Background estimate**
  - m_{jj}/m_J sidebands constra
  - one-muon CR to constra
  - two-lepton CR to constrain Z+jets

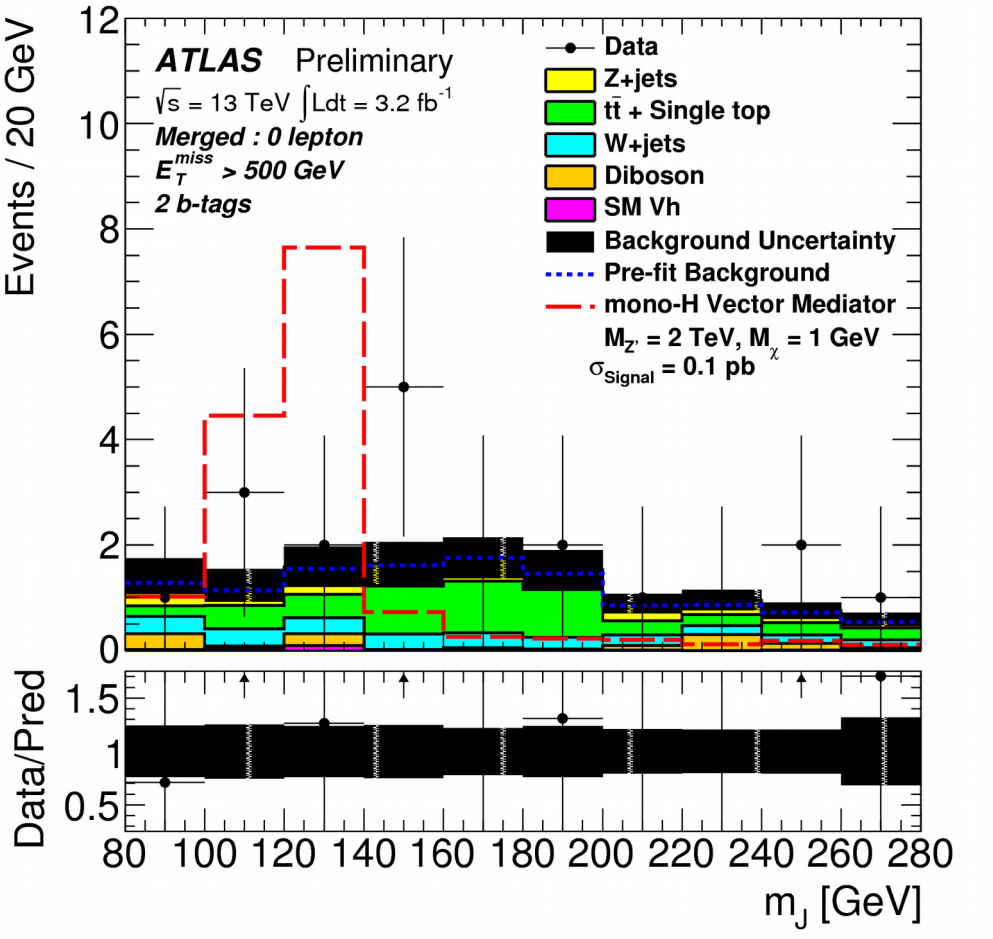
N_{bjets}



MET+H(→bb) Results

- No signal seen → limits





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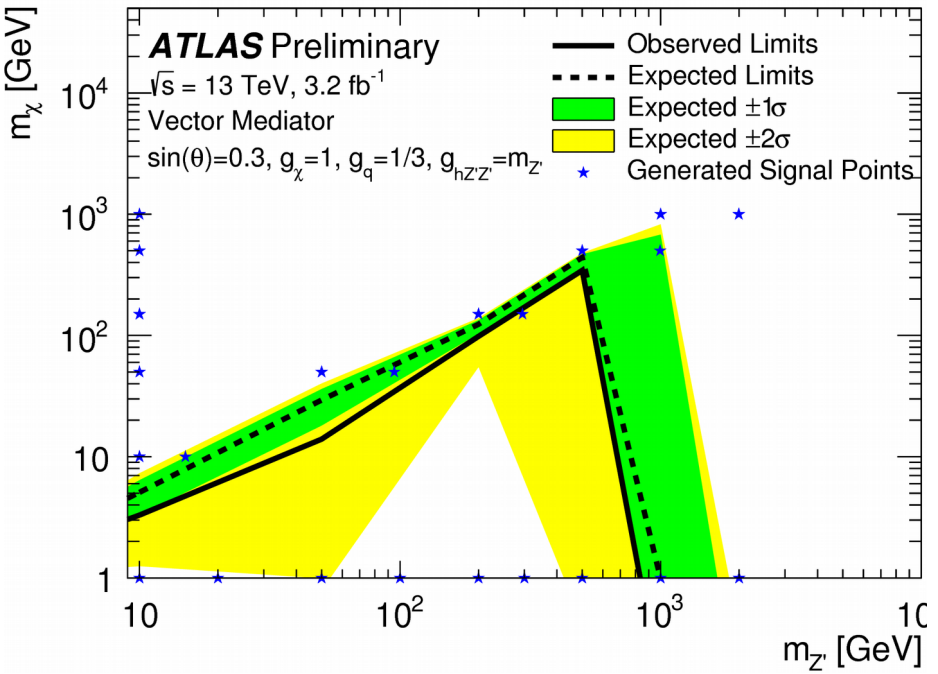
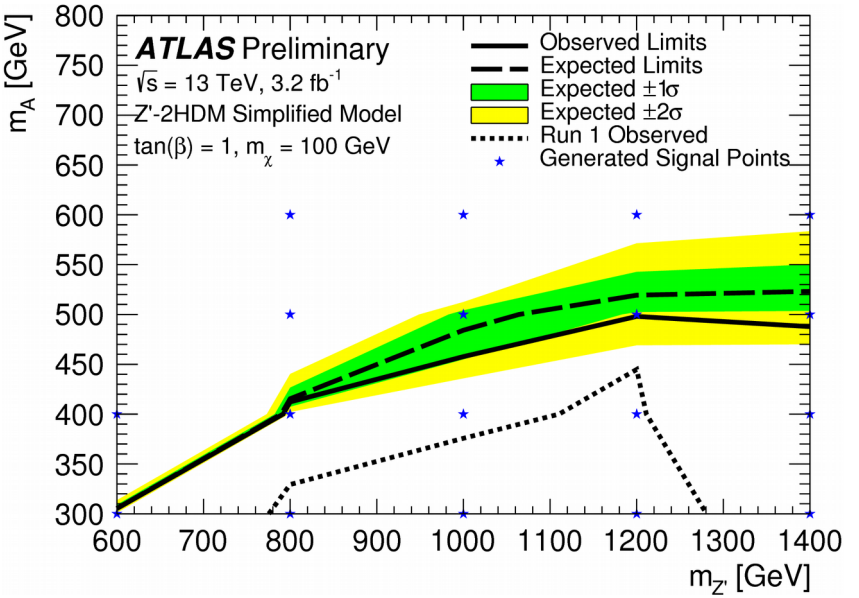
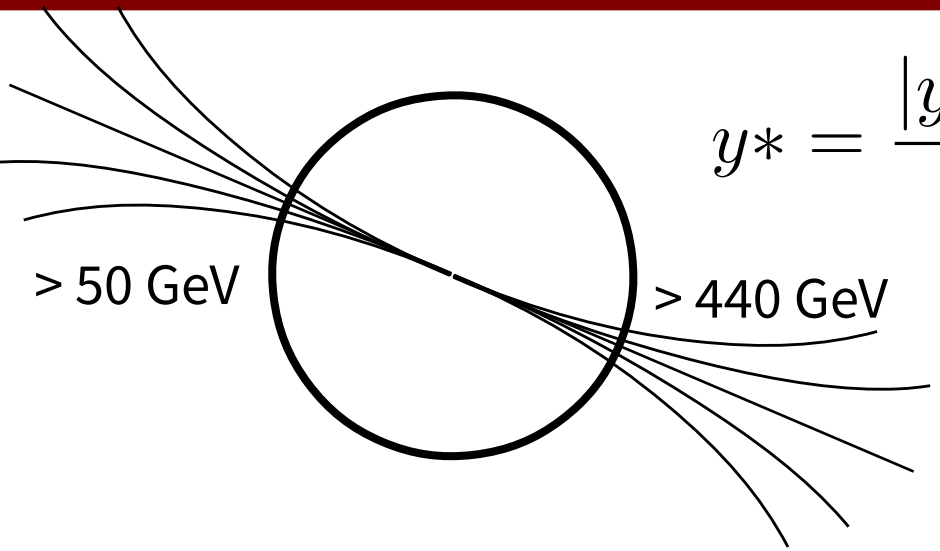




Dijet

EXOT-2015-02

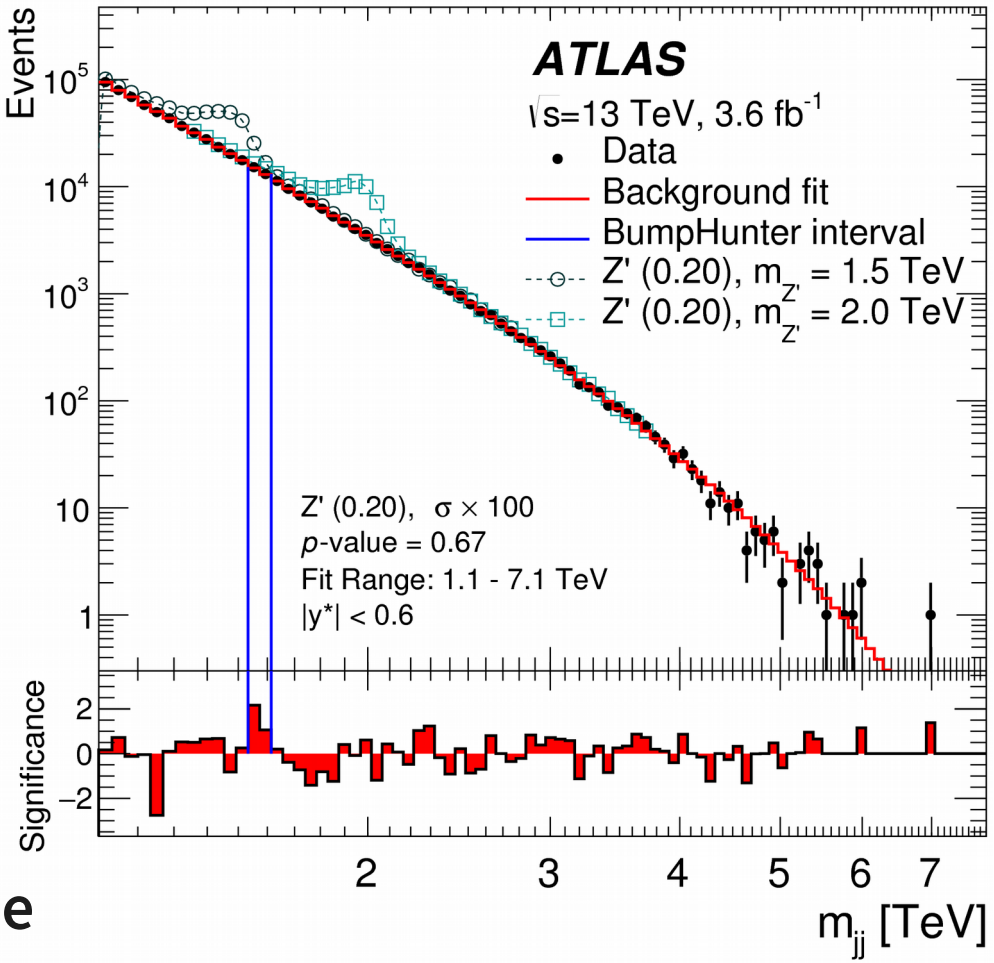


$$y* = \frac{|y_1 - y_2|}{2} < 0.6$$

- Search for bump on smooth m_{jj} spectrum
- QCD background modeled with a falling function

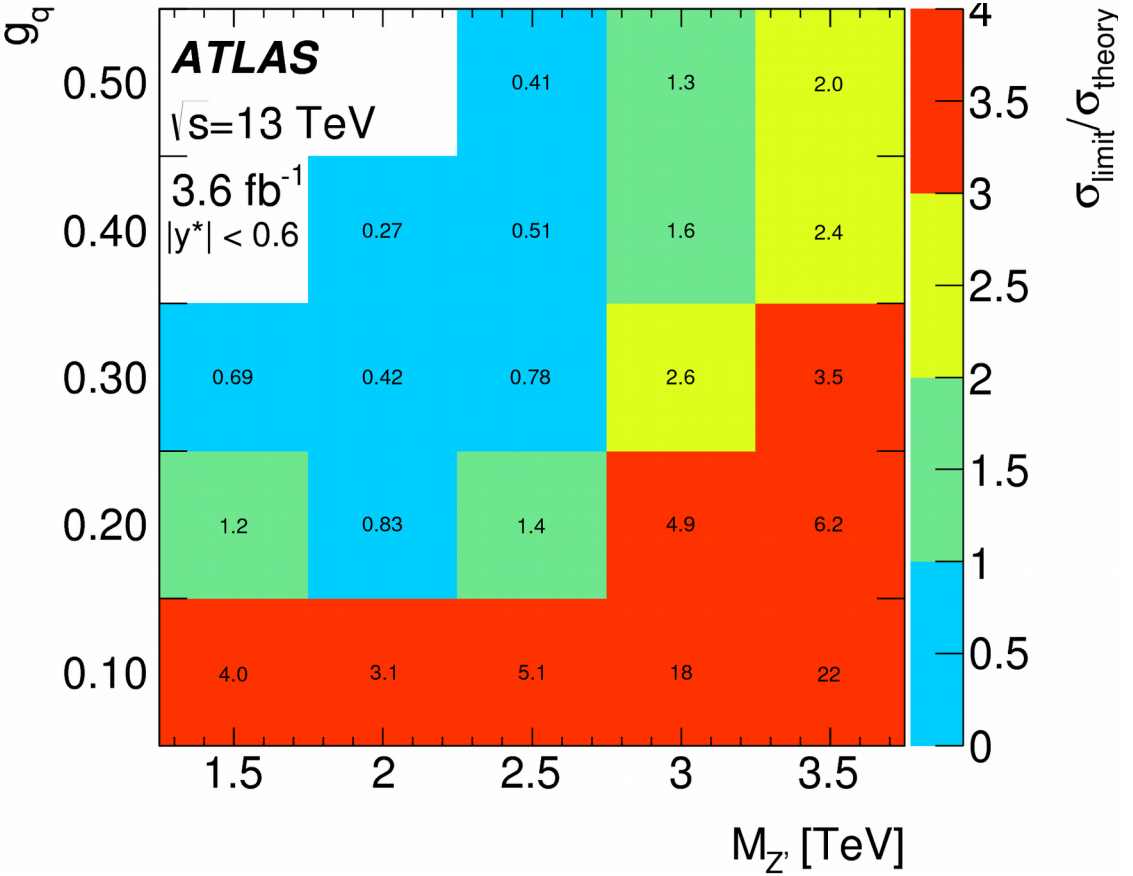
$$p_0(1-x)^{p_1}x^{p_2}, x = \frac{m_{jj}}{\sqrt{s}}$$

- A non-resonnant version also available

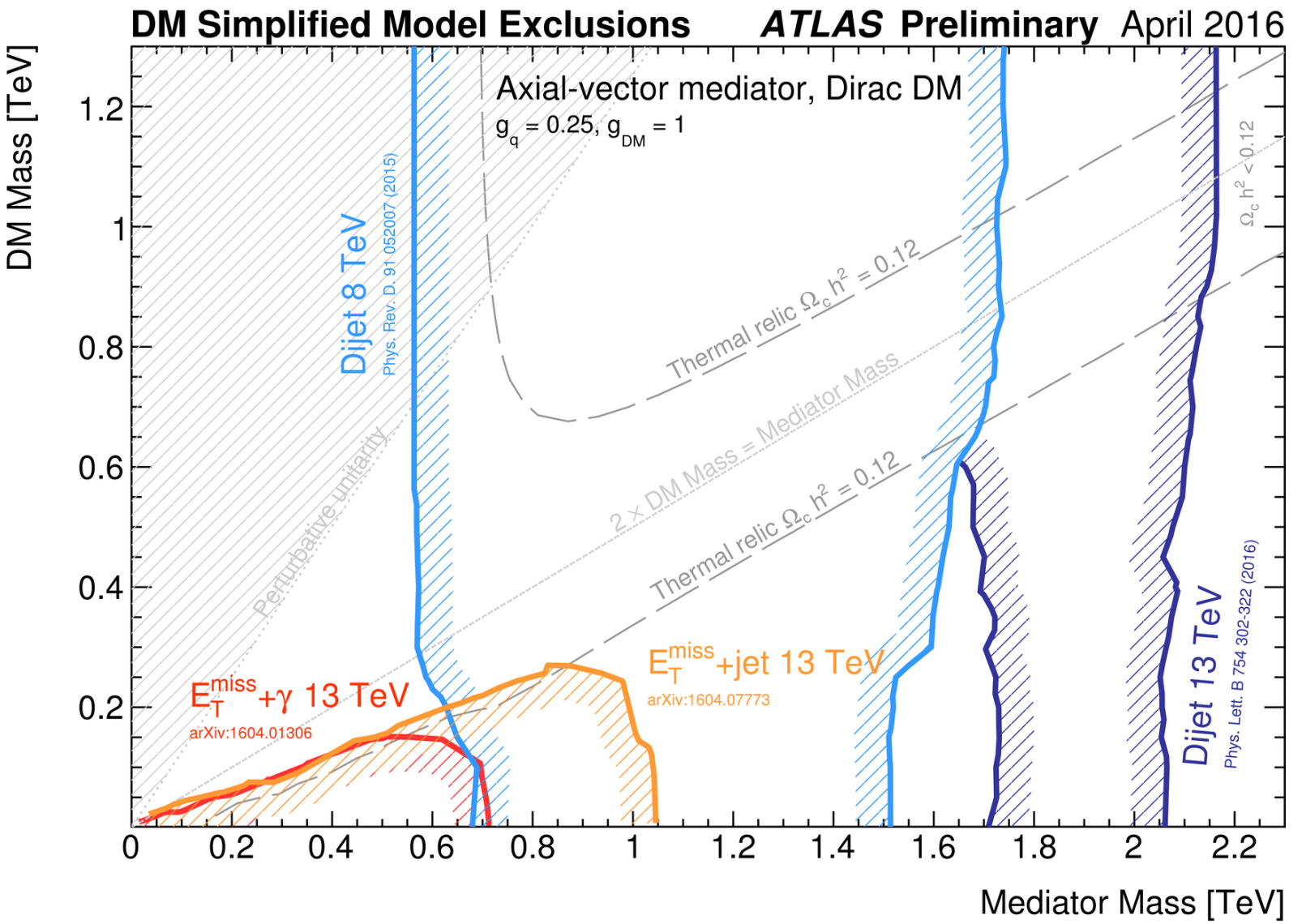


Dijet Results

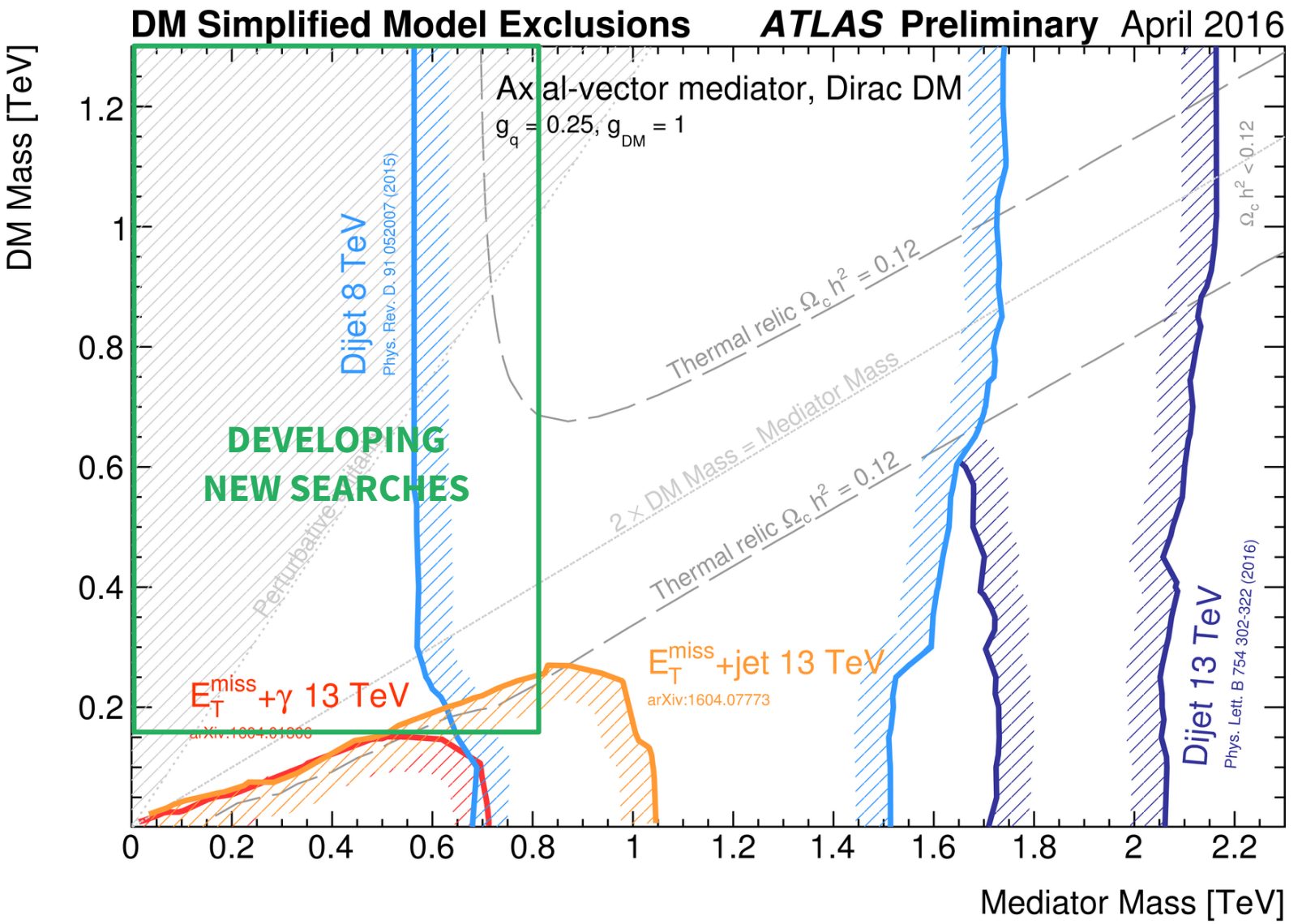
- No signal seen → limits
- Also set limits on excited quarks, QBH, W' and Gaussian signals



Summary


DM Simplified Model Exclusions
ATLAS Preliminary April 2016
Axial-vector mediator, Dirac DM
$g_q = 0.25$, $g_{DM} = 1$
DM Mass [TeV]
Mediator Mass [TeV]
Dijet 8 TeV
Phys. Rev. D 91 052007 (2015)
Perturbative unitarity
Thermal relic $\Omega_c h^2 = 0.12$
2 x DM Mass = Mediator Mass
Thermal relic $\Omega_c h^2 = 0.12$
$\Omega_c h^2 < 0.12$
E_T^{miss}+γ 13 TeV
arXiv:1604.01306
E_T^{miss}+jet 13 TeV
arXiv:1604.07773
Dijet 13 TeV
Phys. Lett. B 754 302-322 (2016)

Summary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DEVELOPING
NEW SEARCHES
Perturbative limit
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2 x DM Mass = Mediator Mass
Thermal relic $\Omega_c h^2 = 0.12$
$\Omega_c h^2 < 0.12$
E_T^{miss}+γ 13 TeV
arXiv:1604.01306
E_T^{miss}+jet 13 TeV
arXiv:1604.07773
Dijet 13 TeV
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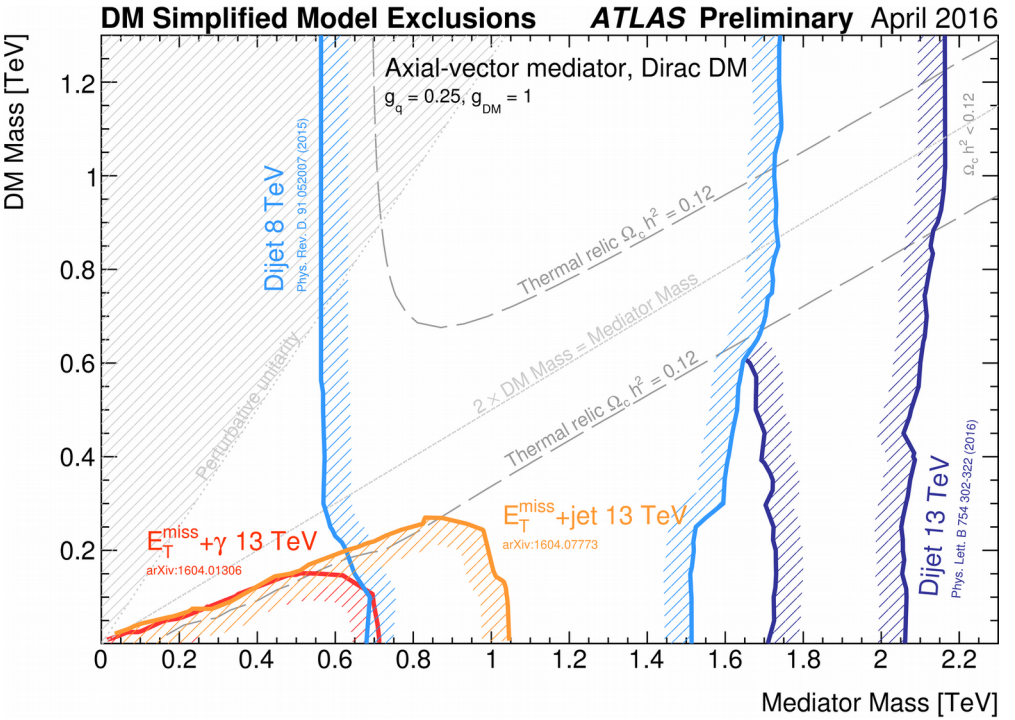
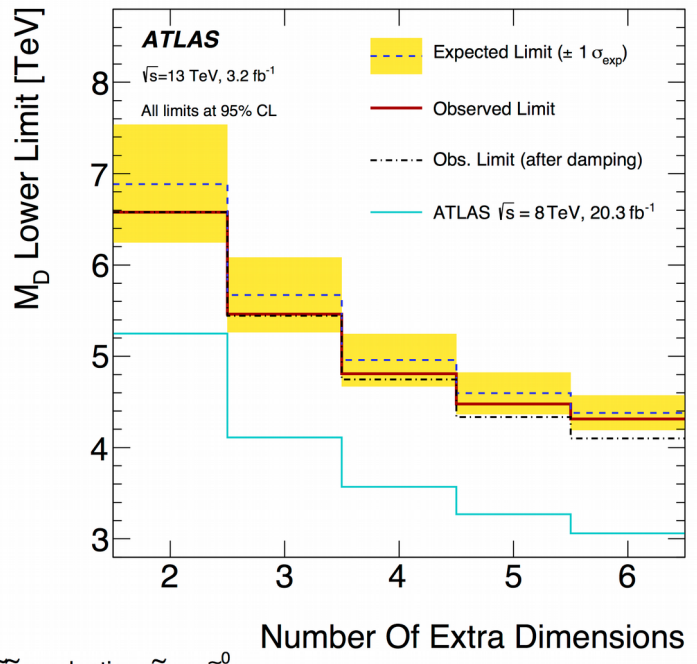
Conclusion

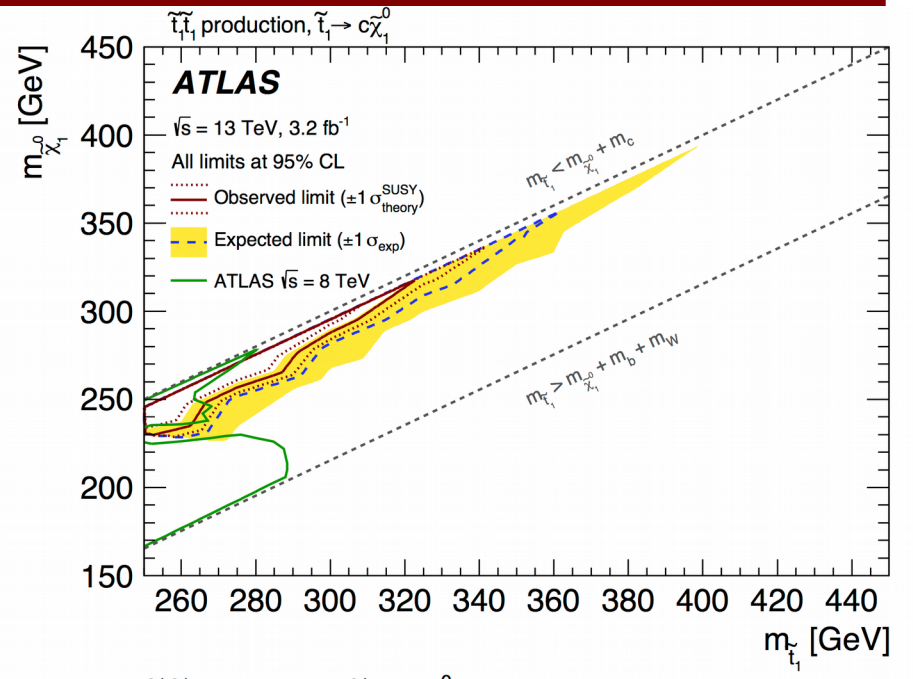
- **Rich program of Dark Matter searches in ATLAS**
  - Shown: MET+jet, MET+photon, MET+higgs, dijet
  - Not shown: MET+V, MET+heavy flavour, MET+(h→γγ), MET+h(→ZZ)
- **Now unified with a standard simplified model**
  - Can cover almost entire mediator/DM mass plane
- **Almost excluded g_{SM}=0.25, g_{DM}=1**
  - Light DM ~<200 GeV mostly excluded
  - Heavy mediators > 1 TeV excluded
- **Smaller couplings still open**

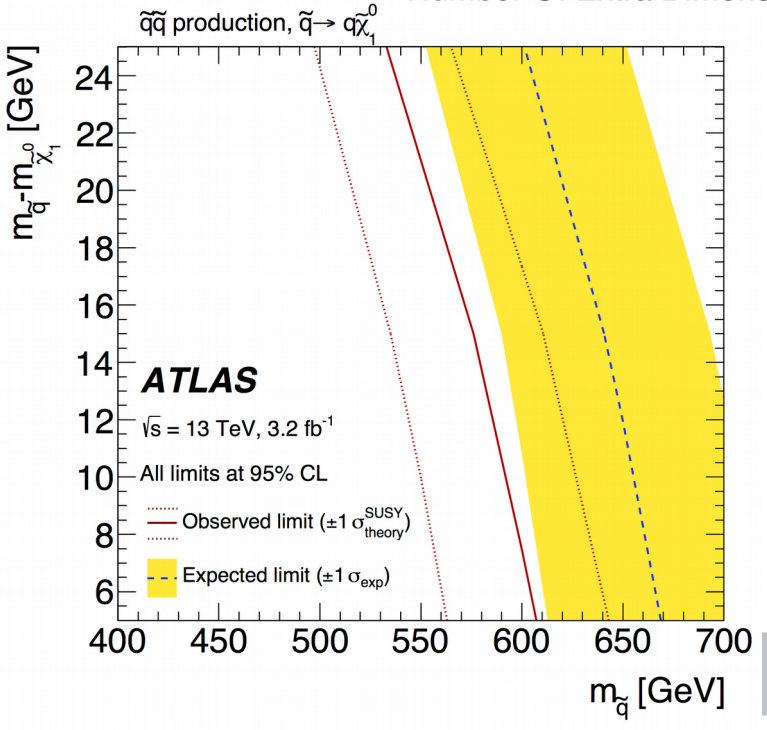


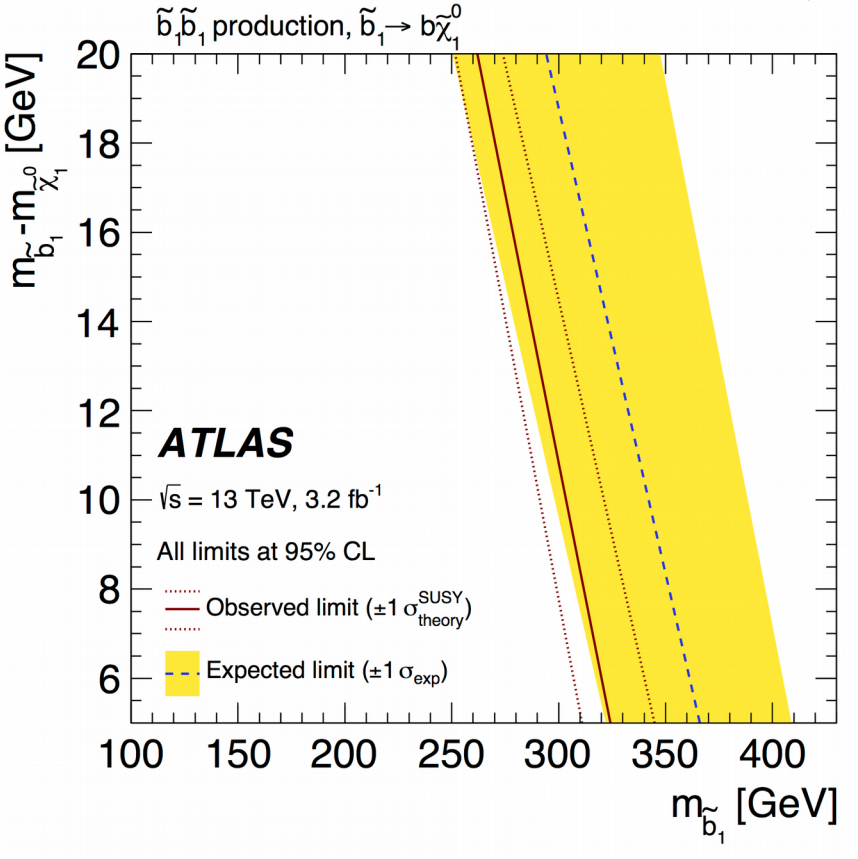
BACKUP SLIDES

Other MET+Jet Limits

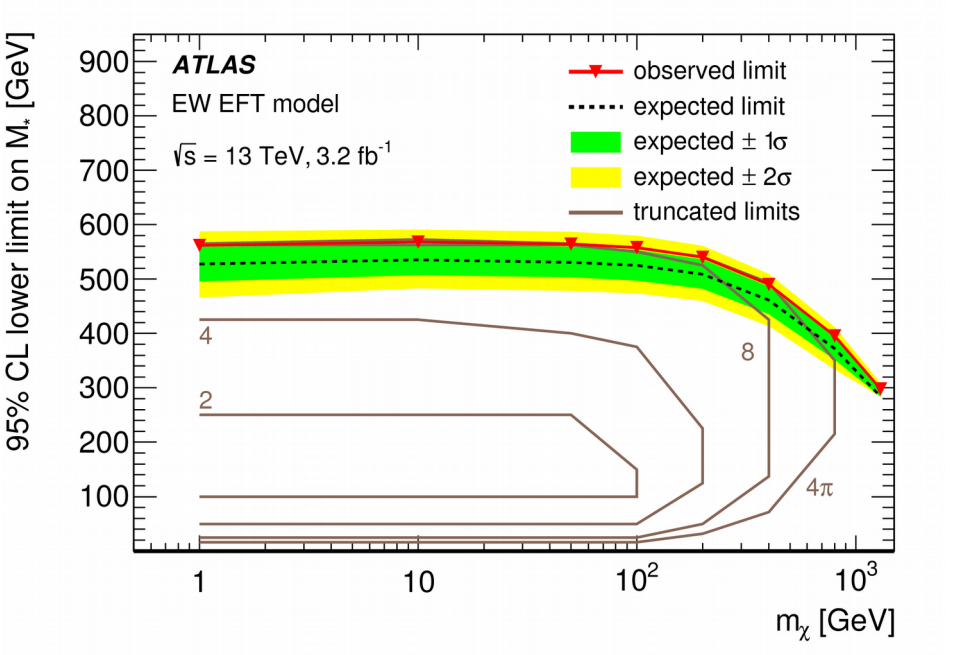


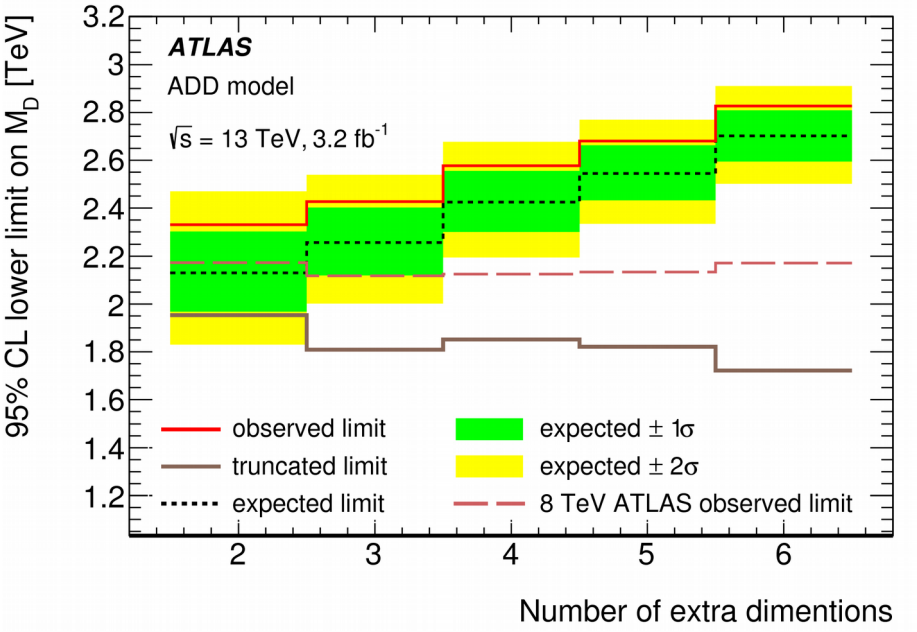






Other MET+Photon Limits





Other Dijet Limits

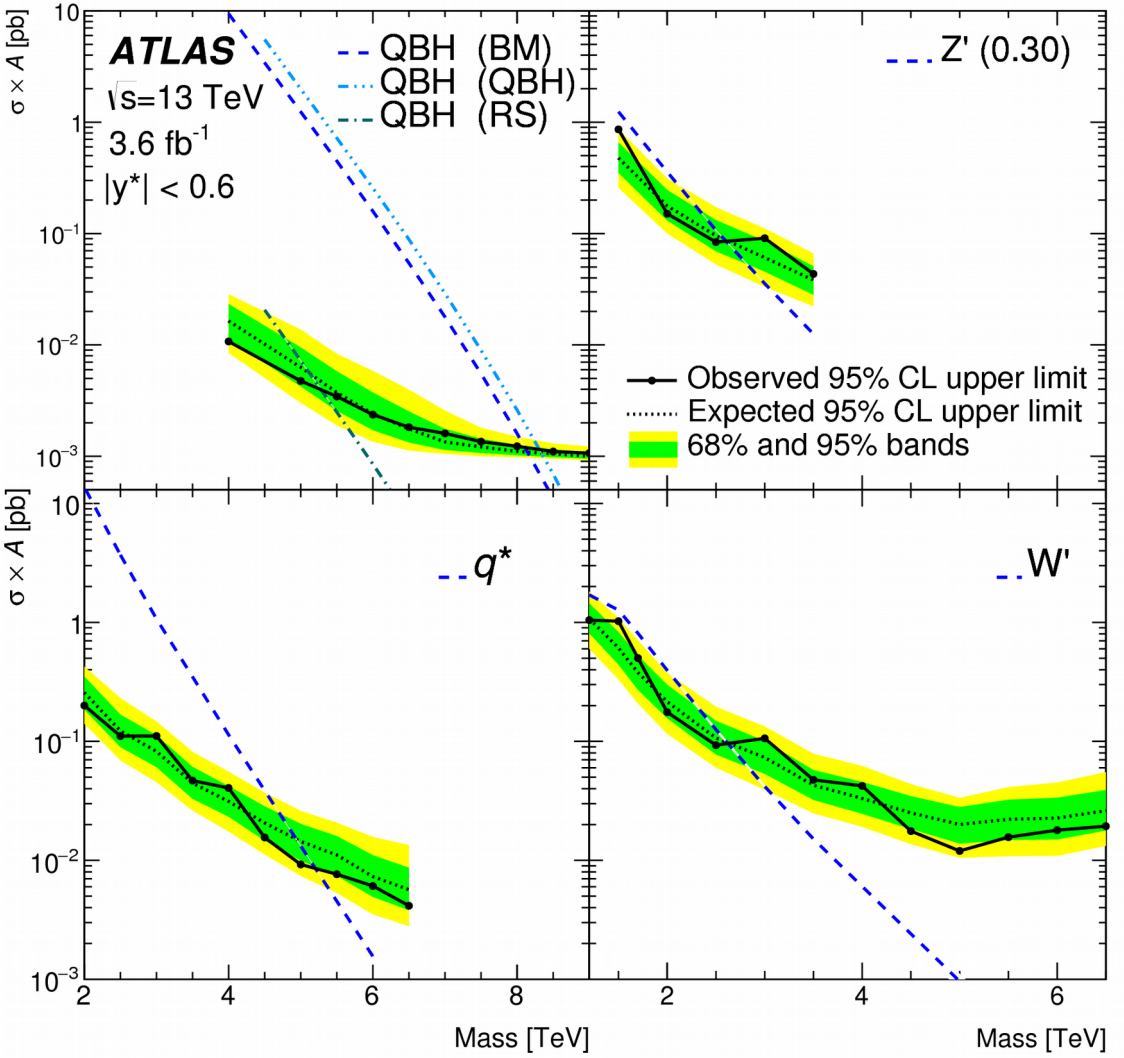


Image Credits

Bullet Cluster: http://apod.nasa.gov/apod/ap060824.html

Gravitational Lensing: http://apod.nasa.gov/apod/ap060524.html

Rotational Curves: Rubin, Ford, and Thonnard (1978), Ap. J. Lett., 225, L107.

Universe Composition: https://darkmatterdarkenergy.com/2015/03/07/planck-mission-full-results-confirm-canonical-cosmology-model/