DM Searches with ATLAS

Les Rencontres de Physique de La Vallée d'Aoste

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La Thuile
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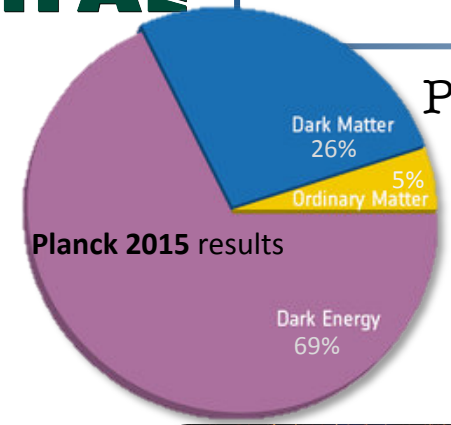
Outline

- Introduction / Motivation.
- ATLAS 8 TeV and 13 TeV data.
- **Searches** for **DM+X**:
  - Mono-jet.
  - Mono-photon.
  - Mono-W/Z. 13 TeV
  - Heavy Flavor +E_T^{miss}.
  - Higgs + DM, Higgs → invisible. 13 TeV
- Conclusions.

Motivation for DM



Presence of a **dark matter** component in the universe inferred from the observation of its gravitational interactions.

- **Rotation of stars** around the center of the galaxies is not consistent with the amount of mass *observed*.

- **Collisions of cluster of galaxies**.

← The bullet cluster.

- **Gravitational Lensing**:

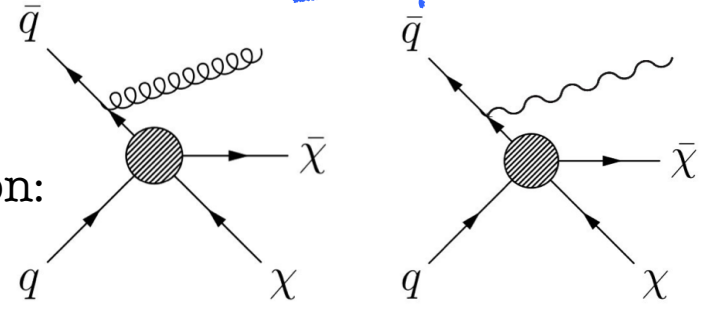
Large distortion of images of distant galaxies due to gravitational lensing (indication of DM in galaxy clusters).

- **Requirements**:
  - Stable.
  - Electrically Neutral.
  - Massive & weakly interacting.
- **Candidates**:
  - SUSY particles? E.g. LSP
  - WIMPs.

At colliders like the LHC, WIMPs can be produced in pairs.

Escaping detection

- We can tag those events via the presence of an energetic jet, a photon or a boson from initial state radiation:



Dark Matter

Effective theories of SM interaction with **WIMPs**.

- **Effective Lagrangian** approach with parameters M* and m_χ.

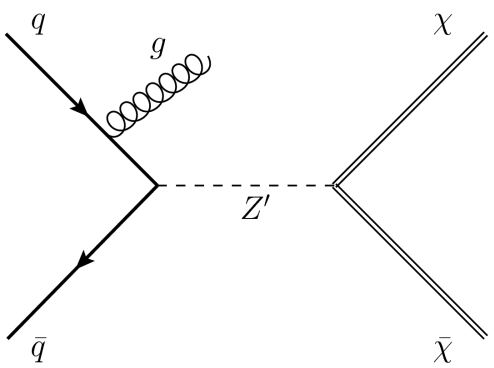
$$M^{*2} = \frac{M^2}{g_1 g_2}$$

  Assuming interaction is mediated by a heavy particle with mass M and coupling g_1 and g_2.

- χ taken as a *Dirac fermion*.

Name	Initial state	Type	Operator
C1	qq	scalar	$\frac{m_q}{M_\star^2}\bar{\chi}\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

- Different operators, with different structures, are considered.
- Comparison with direct detection experiments and complementary results at low mass.
- *Theory only applicable when M is **much larger** than the energy scale present in the reaction.*



New focus for Run II

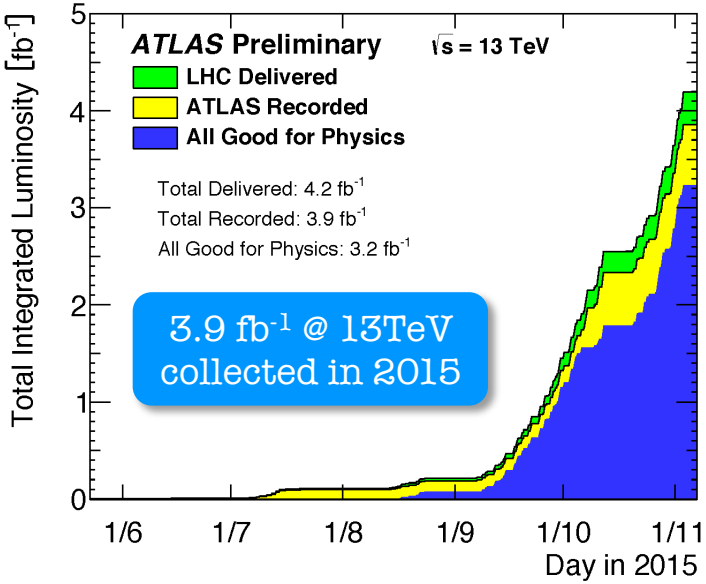
Natural solution to **EFT validity**:

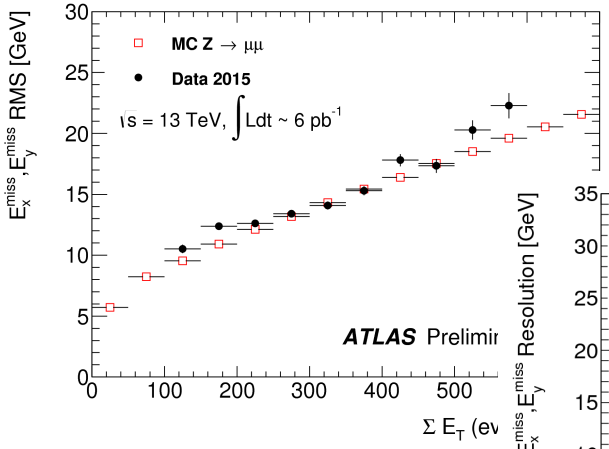
simplified models (with mediator).

- Three regimes can be studied: off-shell, resonance, contact interaction.

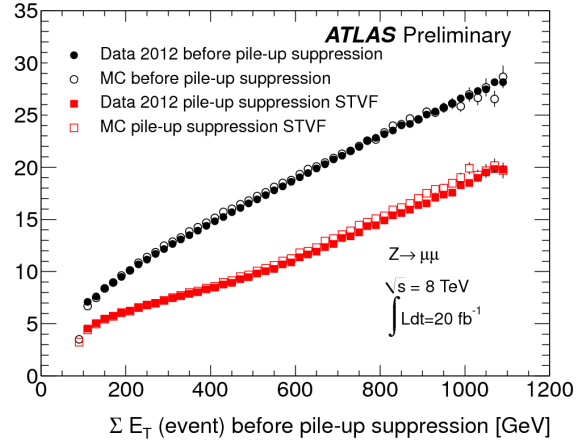
ATLAS Data

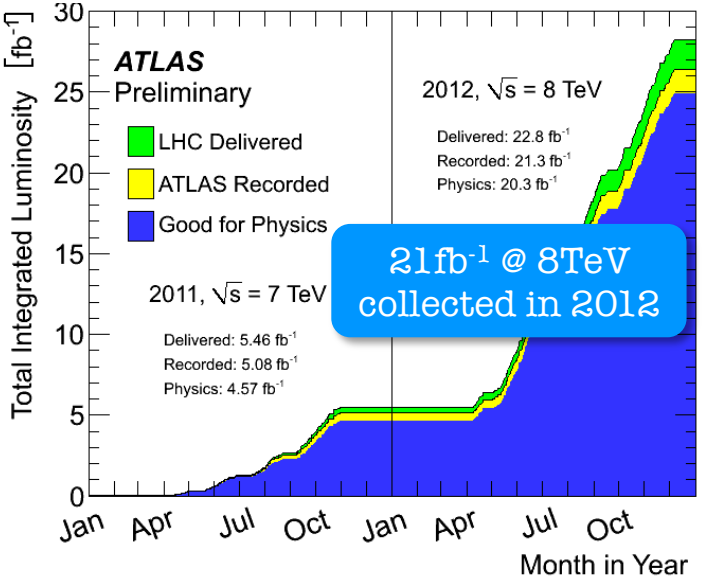
Excellent data taking efficiency! Many analyses now using the 2015 dataset.



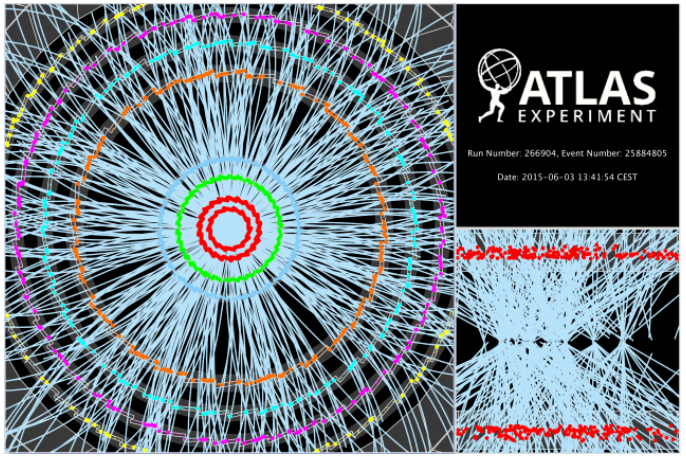


These analyses rely in a good measurement of missing transverse momentum.





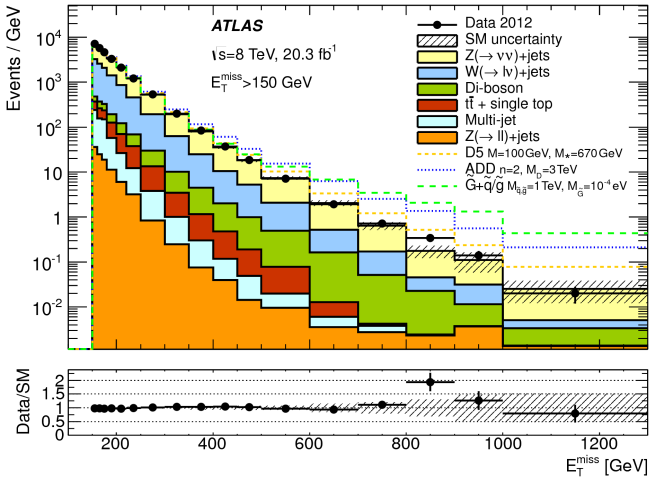
Challenging pileup conditions require a lot of work to achieve great physics performance.



Monojet

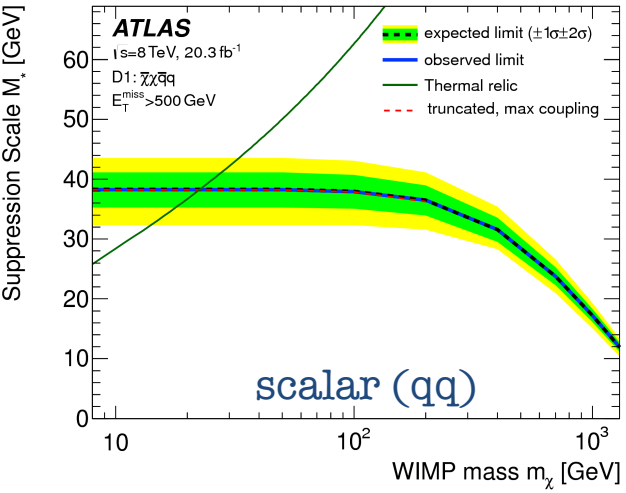
arXiv: 1502.01518

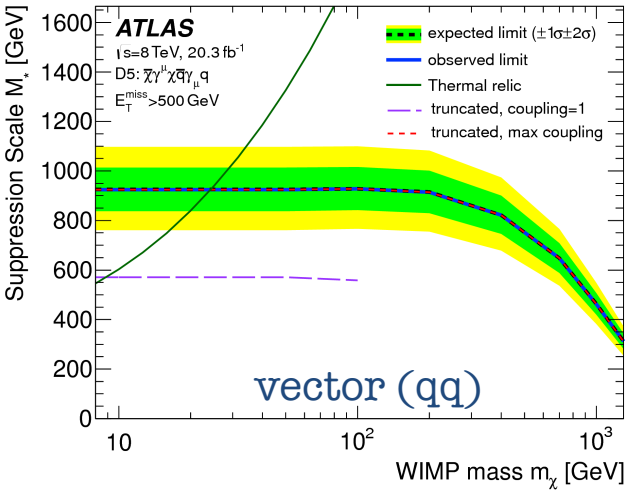
- Monojet-like selection:
  - *High p_T jet + E_T^{miss}. High p_T^{J1}/E_T^{miss} to reject high multiplicity events.*
  - *Main bkg Z(→νν) estimated from W(μν) and Z(ll) control regions.*
- Several SR defined in inclusive bins of $\mathbf{E_T^{miss}}$.
- Better sensitivity for DM at large E_T^{miss}.

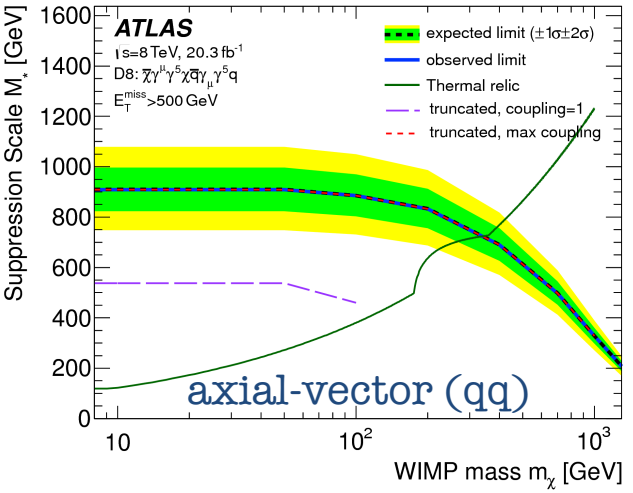


WIMP production

95% CL limits on the visible cross-sections are translated into limits on **M* as a function of m_χ** for different operators.



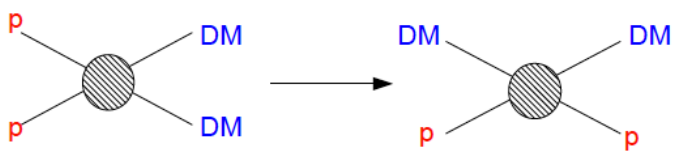




Thermal relic indicates the values for M* and m_χ leading to the proper abundance (WMAP).

Truncation: As a ***minimal*** requirement: $Q_{tr} < M_{med} = f(couplings, M^*)$.

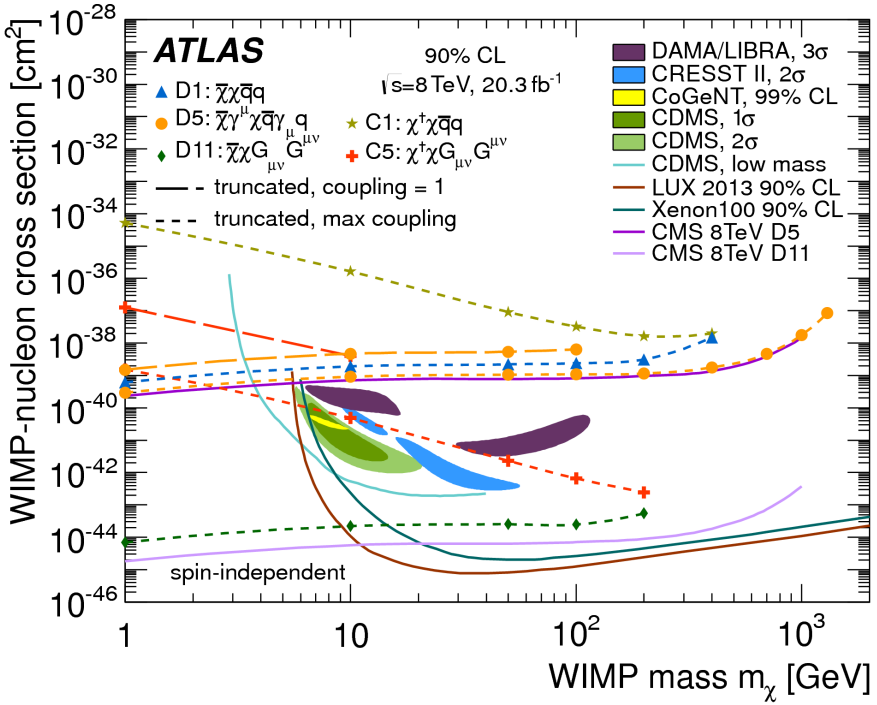
Monojet

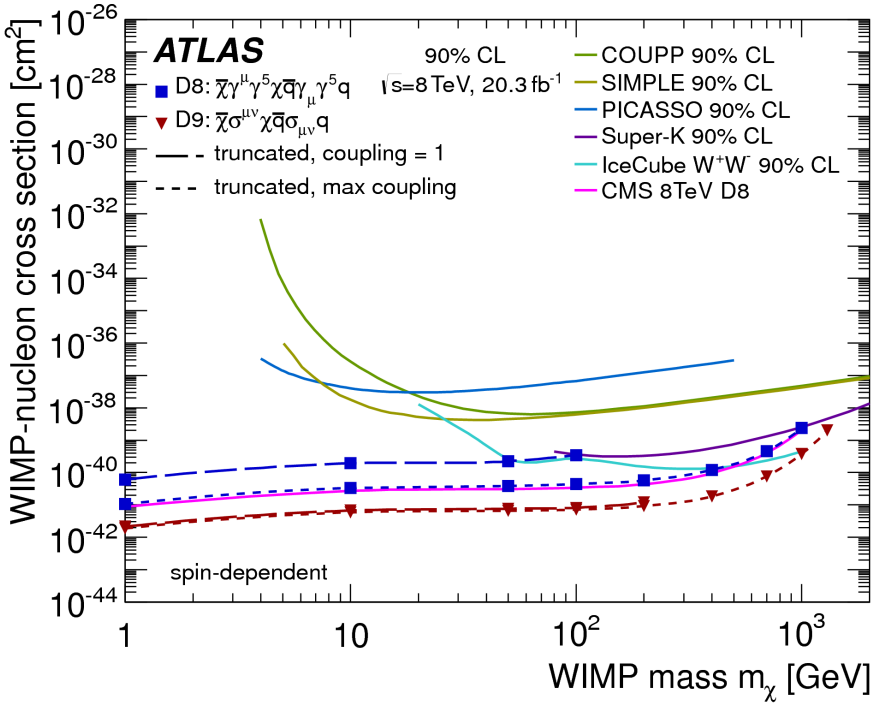


Different operators contribute either to **spin-dependent** or **spin-independent** WIMP-nucleon cross sections:

90% CL limits.

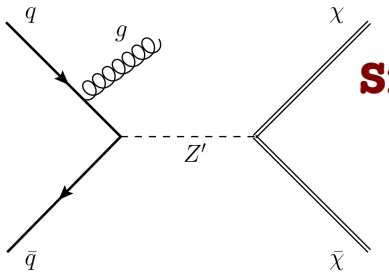
Under **assumption of the validity of the EFT (for given operators)**, LHC results are competitive to direct detector experiments (mainly for m_χ **<10GeV**).



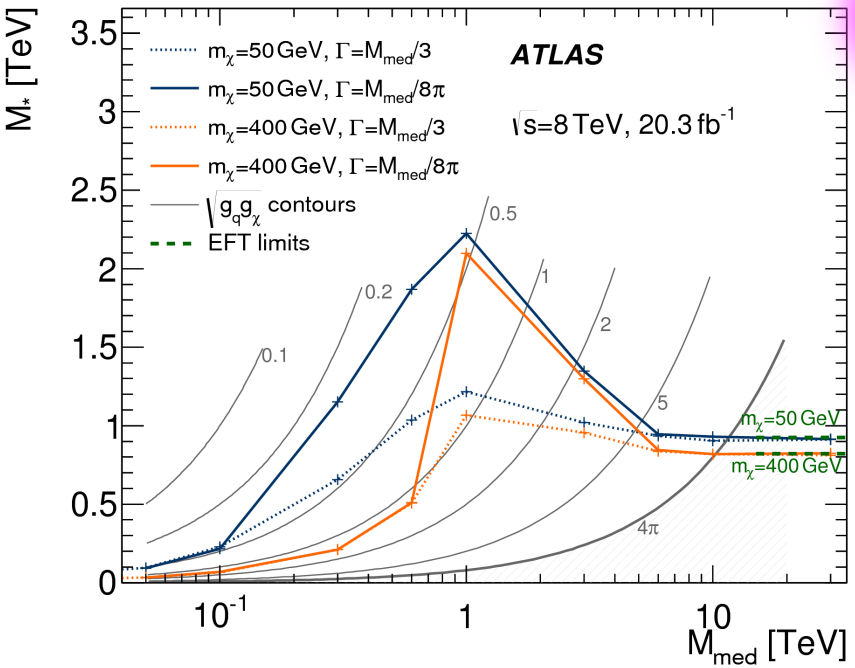


Truncation: As a ***minimal*** requirement: $Q_{tr} < M_{med} = f(couplings, M^*)$.

Monojet



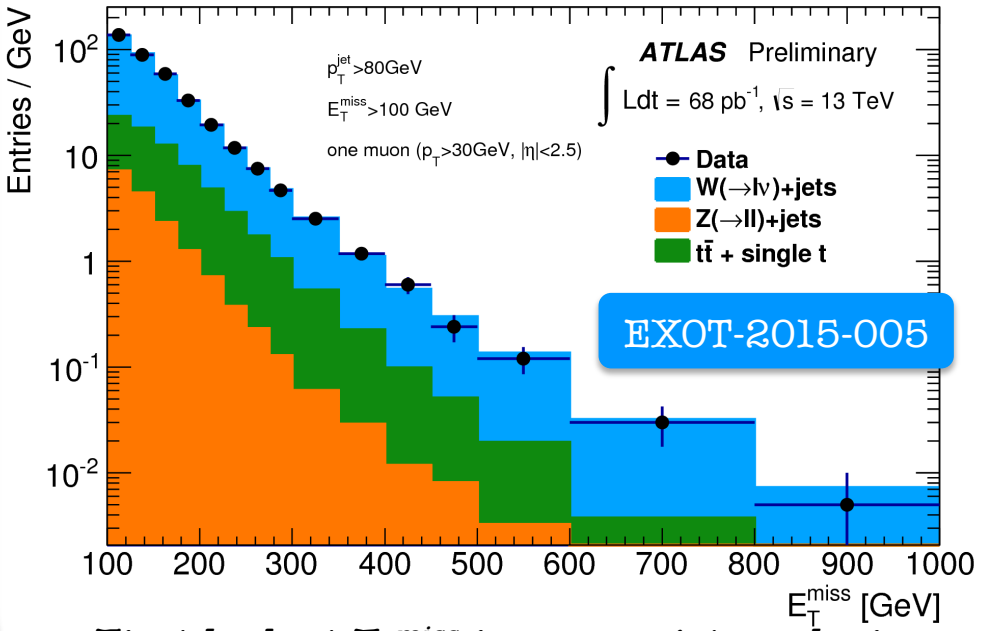
Simplified models : a pair of WIMPs couples to a pair of quarks explicitly via a new mediator particle, a new vector boson Z' (mediator).



In the region with very high mediator mass results converge with the EFT limits.

13 TeV

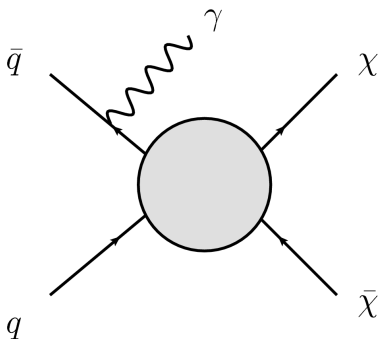
Analysis with 2015 data is ongoing.
Emphasis on simplified models



First look at E_T^{miss} in a monojet analysis control region (first 68 pb^{-1} of data).

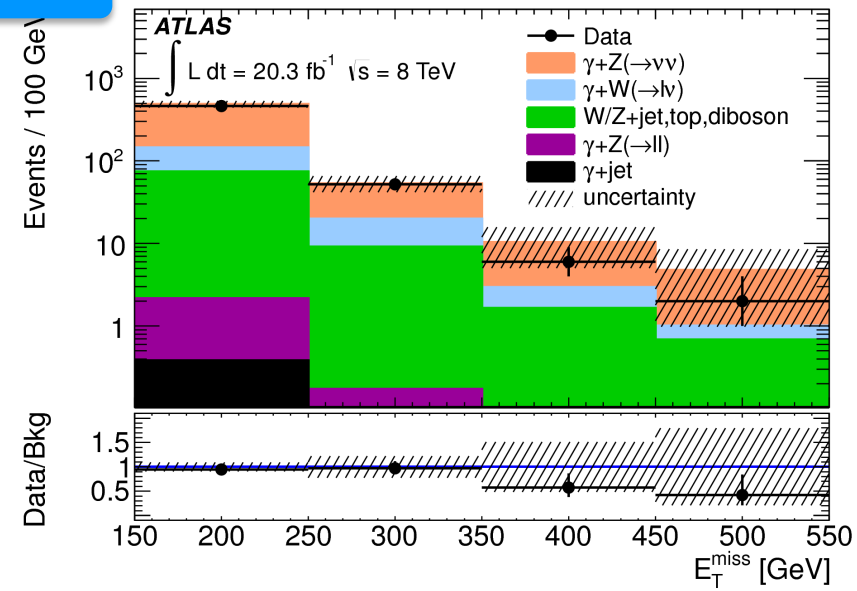
Mono-photon

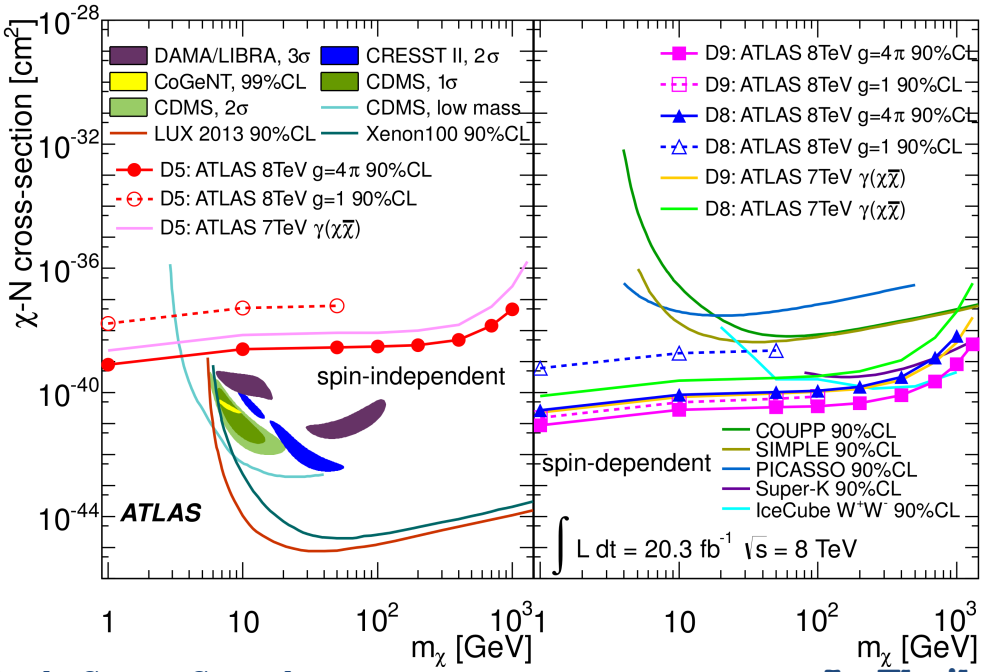
arXiv: 1411.1559

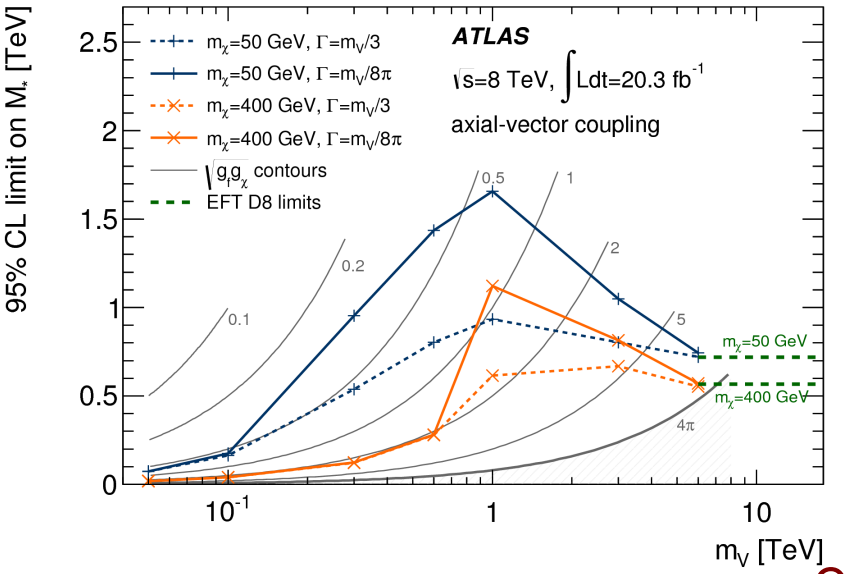


Isolated (*tight*) photon:
$p_T(\gamma) > 125$ GeV, $|\eta^\gamma| < 1.37$.
$E_T^{miss} > 150$ GeV,
veto on leptons,
$N_{jets}(p_T > 30\ \text{GeV}) < 2$,
$\Delta\phi(E_T^{miss}, \text{jets}/\gamma) > 0.4$.

Good agreement between observation in data and SM expectation.







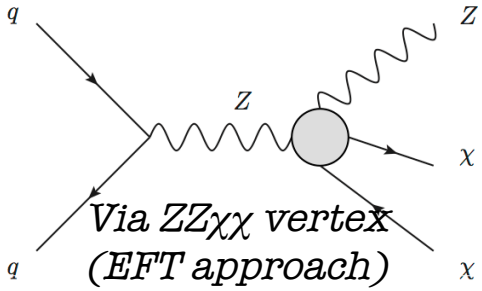
Mono-W/Z

13 TeV

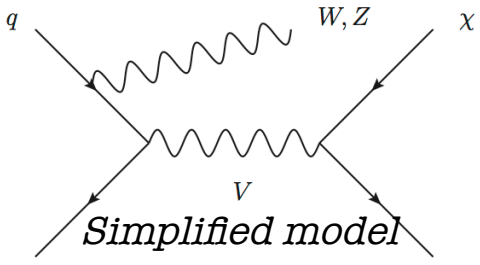
ATLAS-CONF-2015-080

Search based on the *hadronic* decay products of W/Z: boosted boson recoiling against a pair of DM particles.

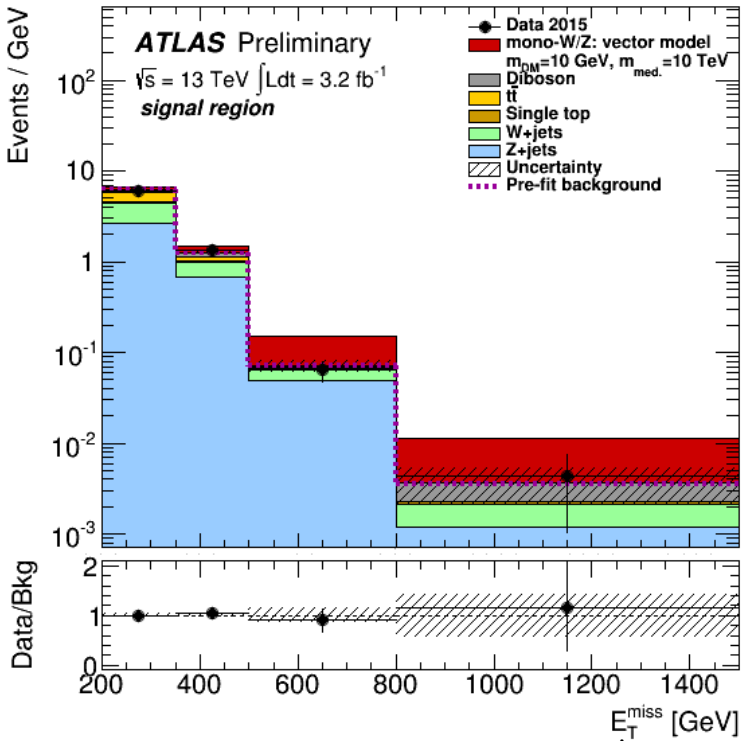
Decays reconstructed as a **boson-tagged large-R jet.**



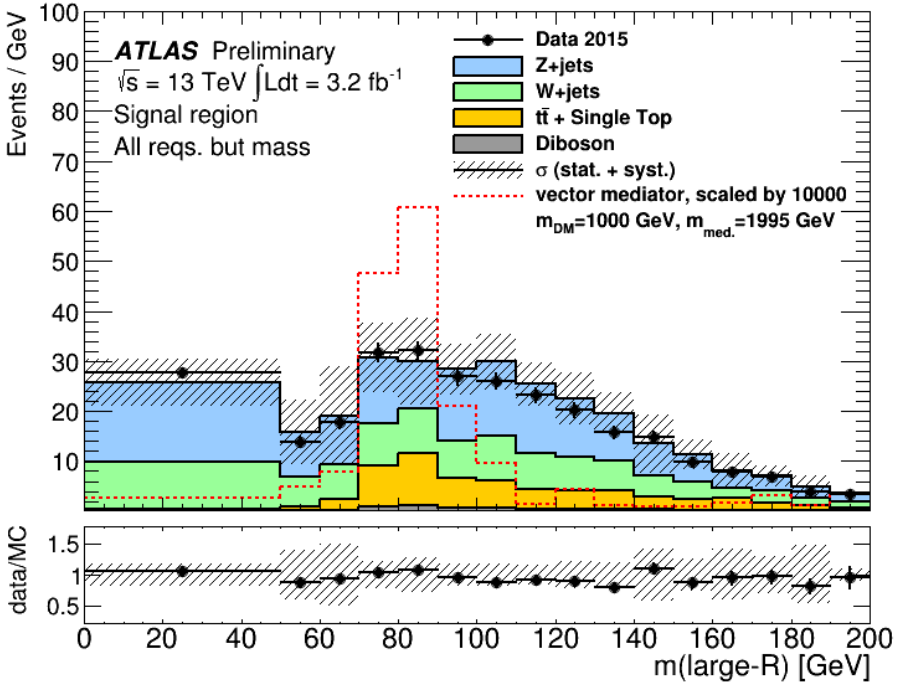
Via ZZχχ vertex (EFT approach)



Simplified model



Events are selected with a E_T^{miss} trigger, veto in leptons, one large-R jet.

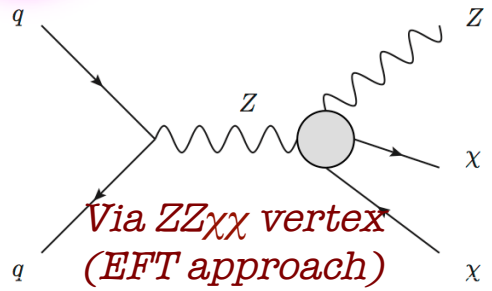


Boson-tagging is done according to the jet mass and substructure.

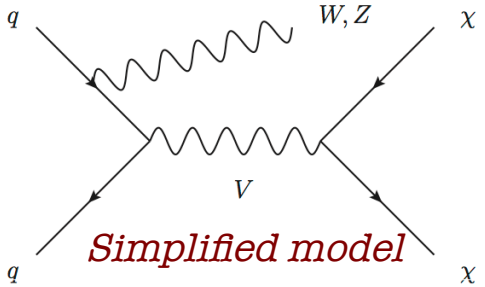
Mono-W/Z

13 TeV

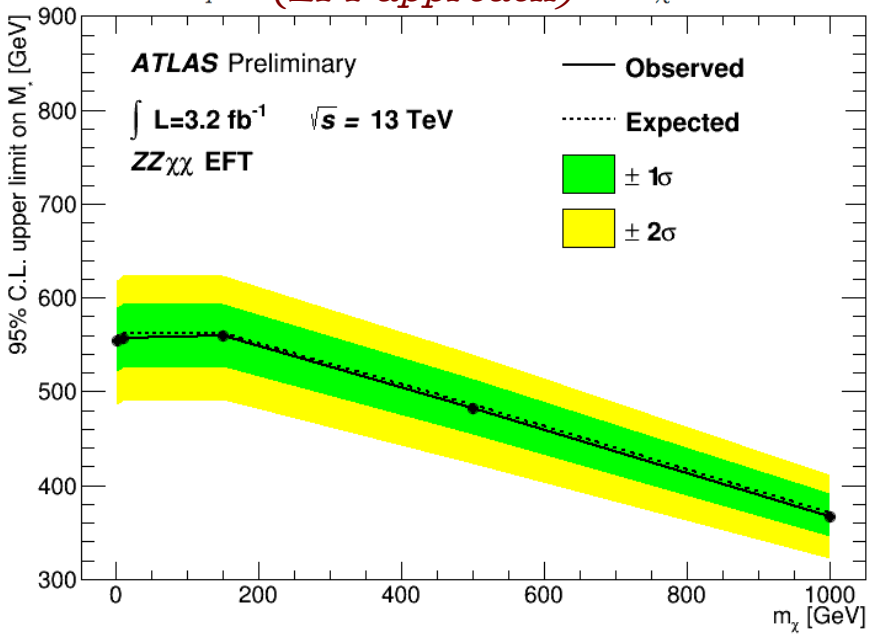
ATLAS-CONF-2015-080



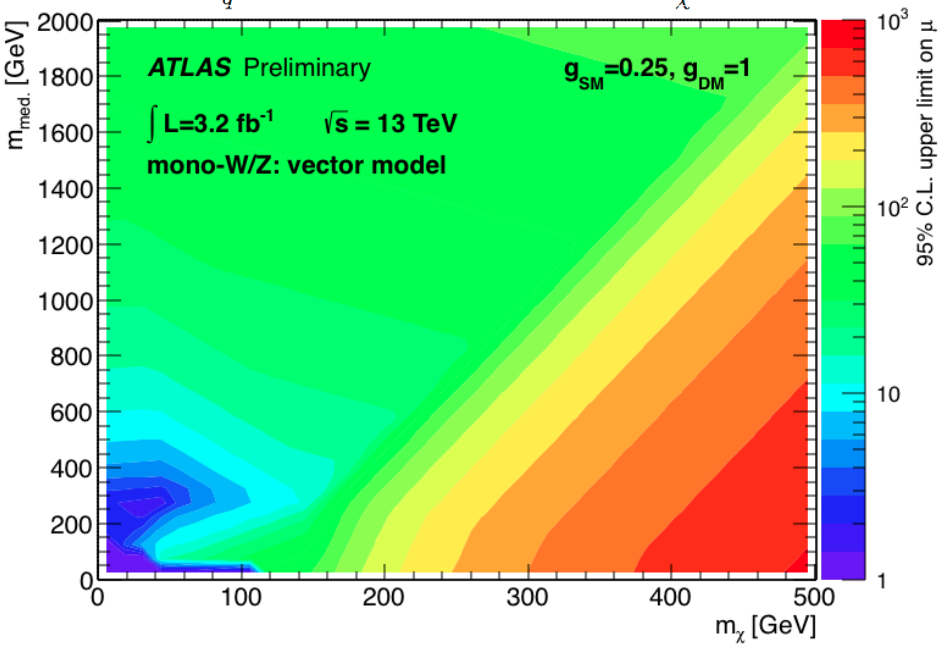
Via ZZχχ vertex (EFT approach)



Simplified model



For the ZZχχ EFT, limits are translated into constraints on the mass scale, M⋆.



Limits on the signal strength μ for the vector-mediated simplified model generated with couplings g_{SM} = 0.25 and g_{DM} = 1.

Mono-Z(ll)

8 TeV, 20.3 fb^{-1}

arXiv: 1404.0051

Search for **DM** in **Z-boson (ll) +E_T^{miss}**

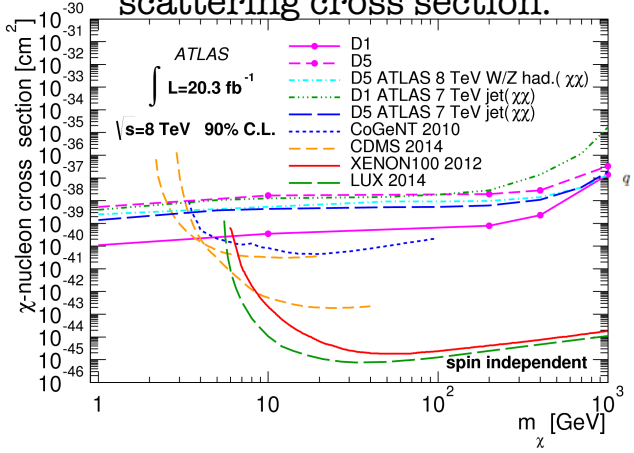
7+8 TeV, 4.7+20 fb^{-1}

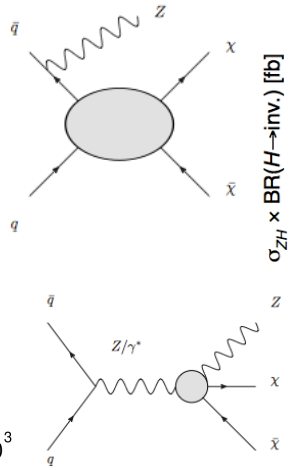
arXiv: 1402.3244

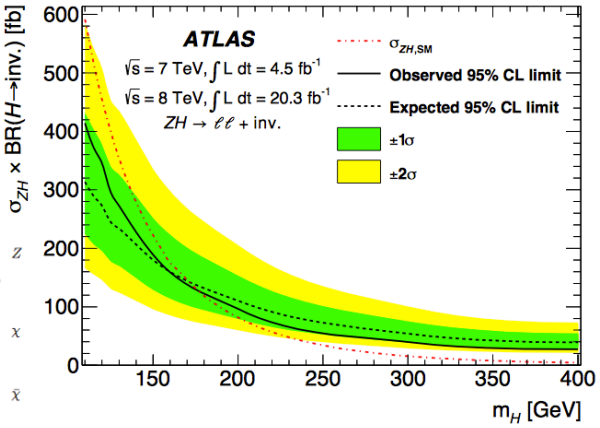
Mono-Z (ll)

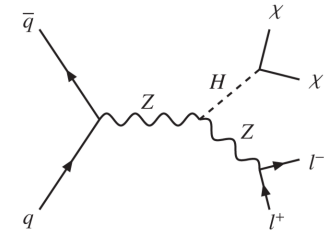
Search Higgs→invisible

Limits on the χ-nucleon scattering cross section.



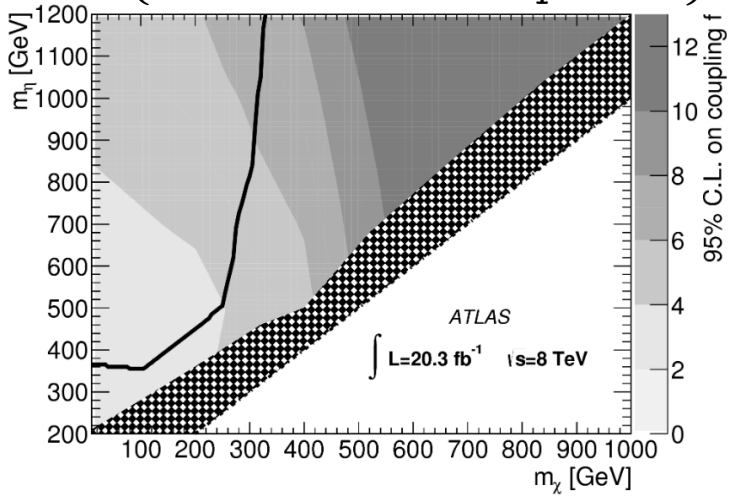


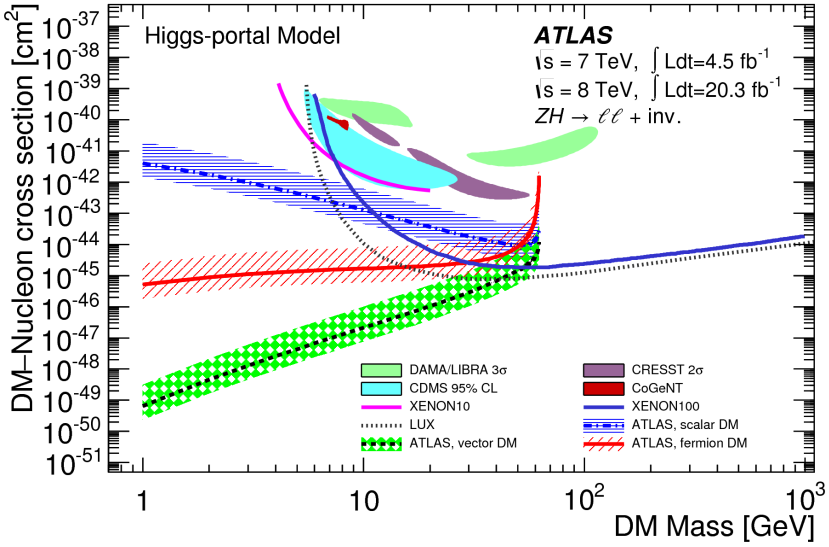




The limit on the BR are interpreted in terms of DM–nucleon scattering cross section within a **Higgs-portal DM scenario**.

Limits are set on the coupling and mediator mass (mediator is a scalar particle).





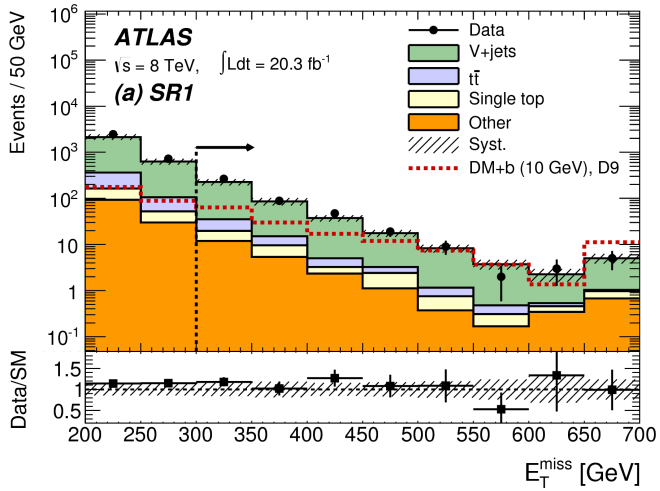
Heavy Flavor + E_T^{miss}

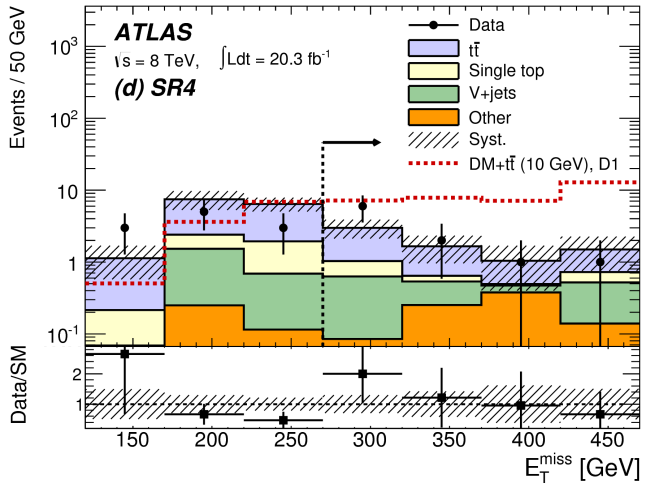
Search for DM pair production in association with heavy quarks (b, t).

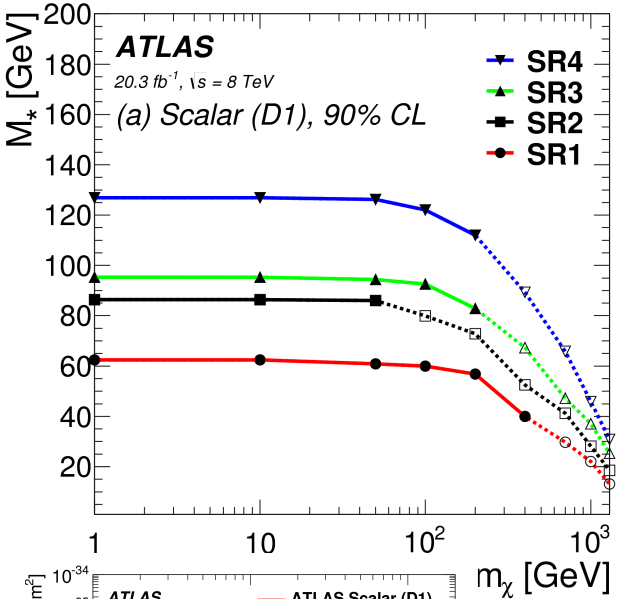
arXiv: 1410.4031

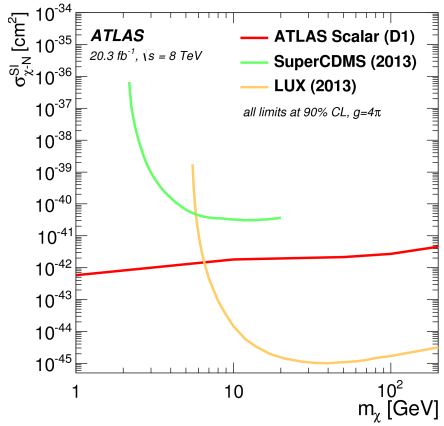
Define 4 SRs based on high E_T^{miss}, at least 1 **b-jet** and different jet multiplicities.

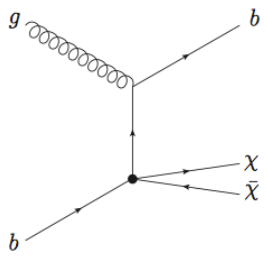
DM+tt search in hadronic and single-lepton channels.

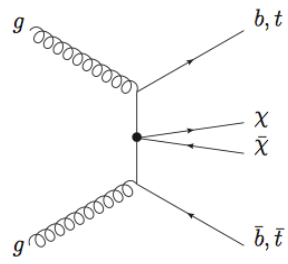


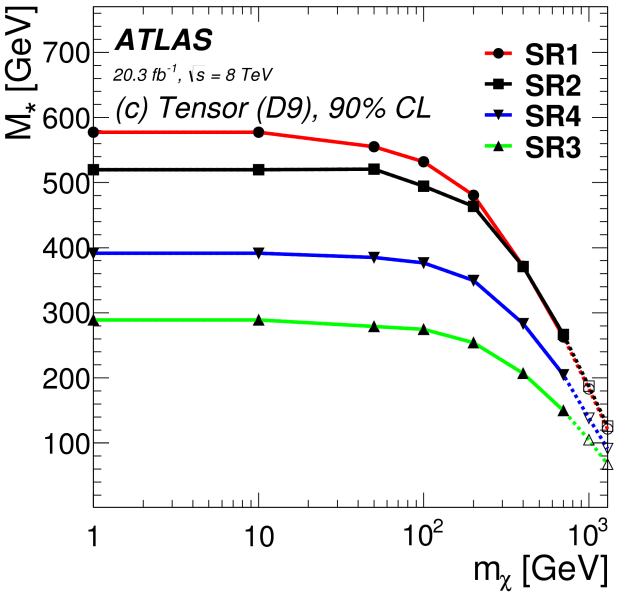










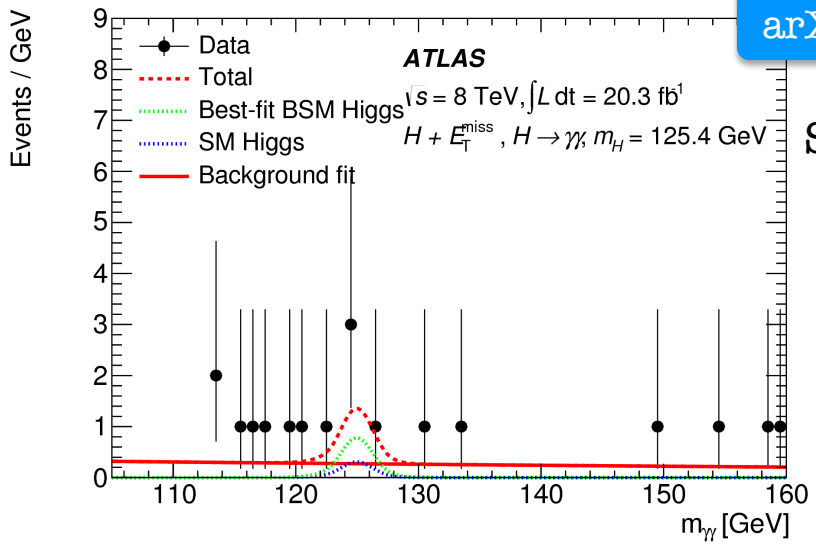


Significant improvement on **scalar** operators.

First limits on tensor couplings with heavy quarks.

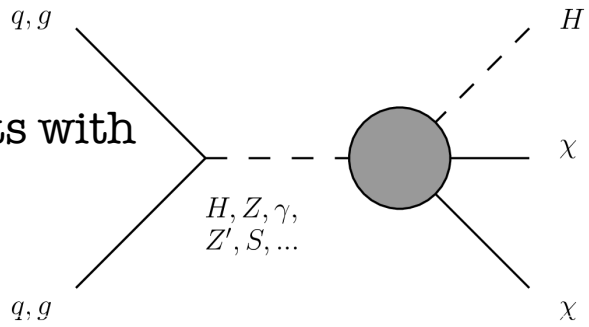
DM + Higgs Boson

arXiv: 1506.01081



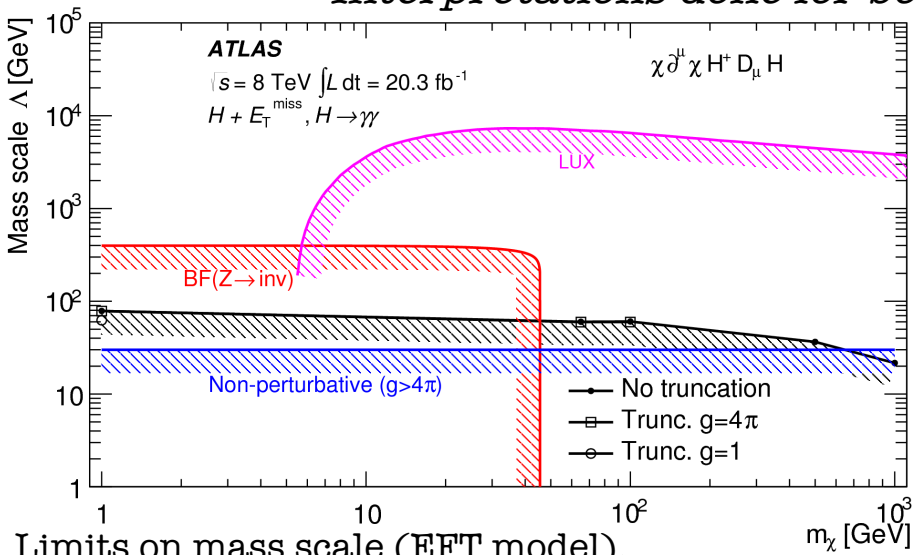
Search for DM in events with
E_T^{miss} and H→γγ

γγ-trigger ,
E_T^{miss} > 90 GeV,
$p_T(\gamma\gamma)$>90 GeV,
105 GeV < $m_{\gamma\gamma}$ < 160GeV

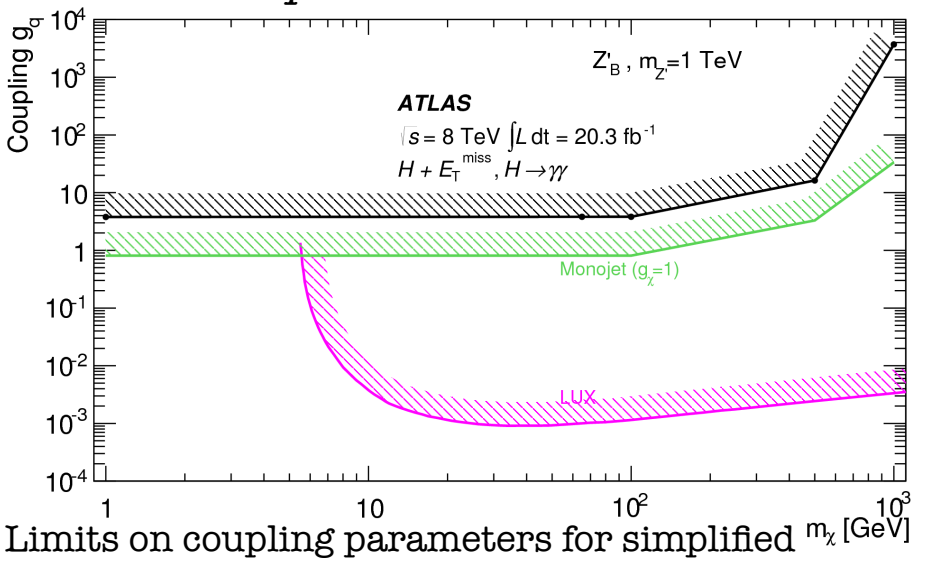


Unbinned maximum-likelihood fit to the observed $m_{\gamma\gamma}$ spectrum used to estimate contributions from different sources.

Interpretations done for both EFT and simplified models.

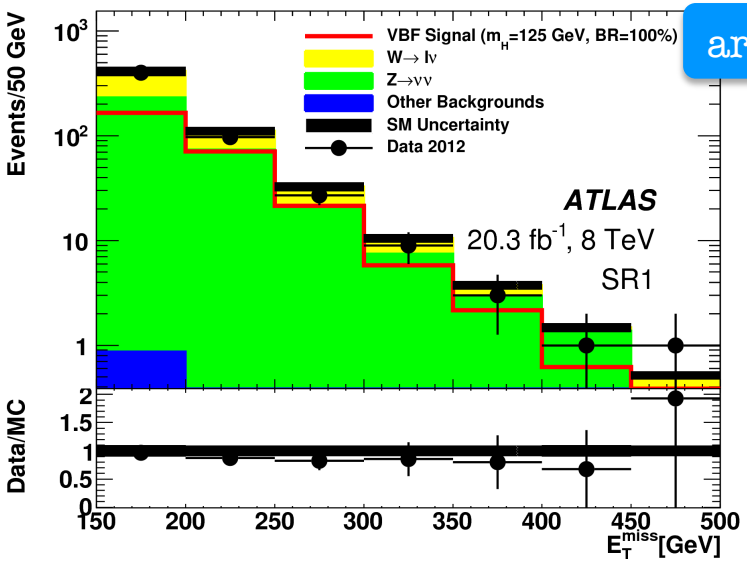


Limits on mass scale (EFT model).



Limits on coupling parameters for simplified models with heavy mediator (m_{med}=1TeV).

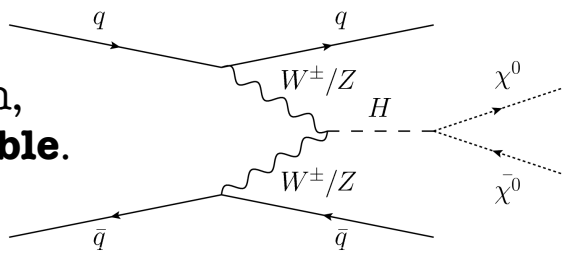
DM + Higgs Boson



arXiv: 1508.07869

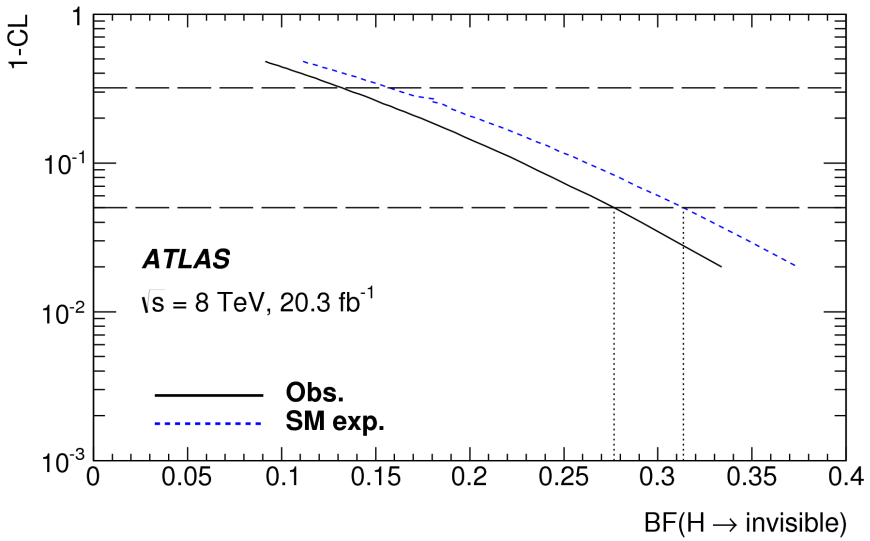
VBF Higgs production, Higgs decaying to **invisible**.

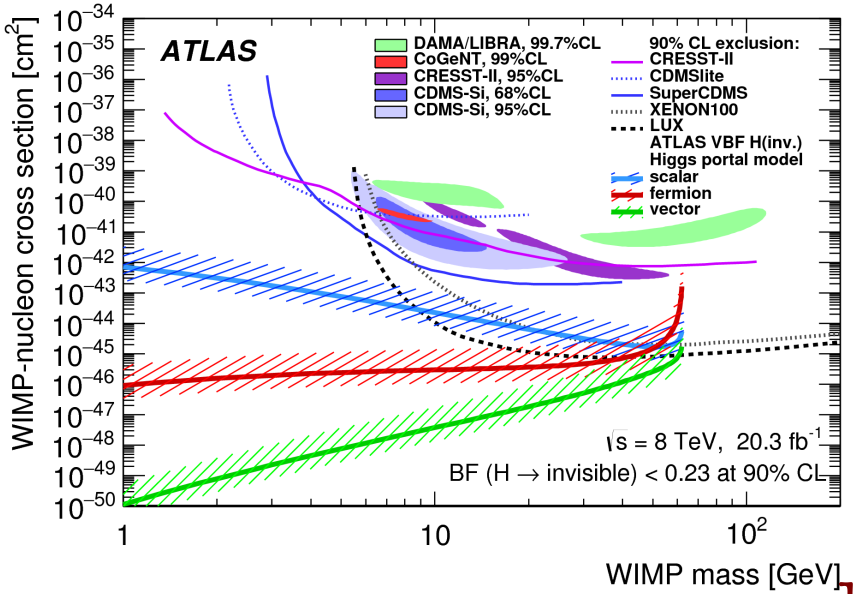
VBF H(→ invisible) signal



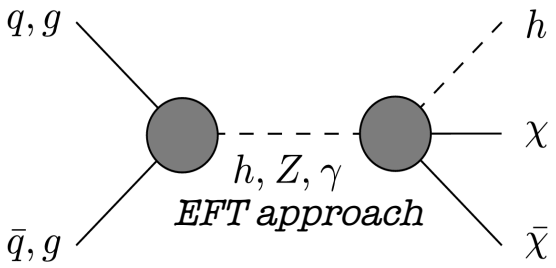
Analysis defines 3 SR (high E_T^{miss}): different requirements on the m_{jj} of two leading jets and their separation in pseudorapidity $\Delta\eta_{jj}$.

The results from the BF(H→ invisible) limit in the Higgs-portal scenario, translated into the WIMP--nucleon cross section



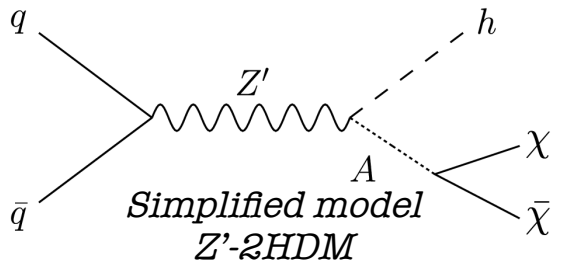


DM + Higgs Boson

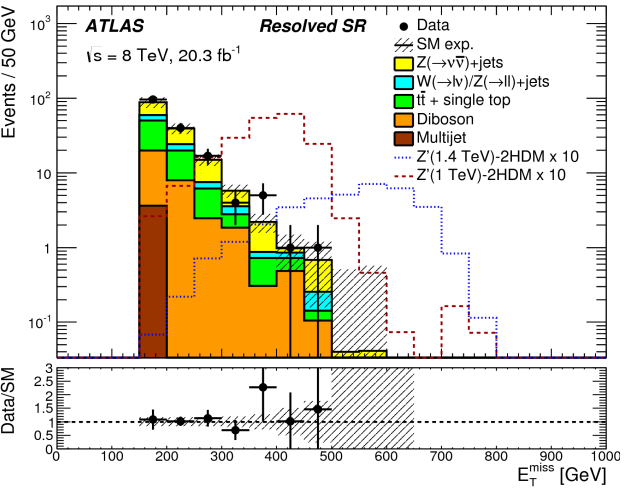


arXiv: 1510.06218

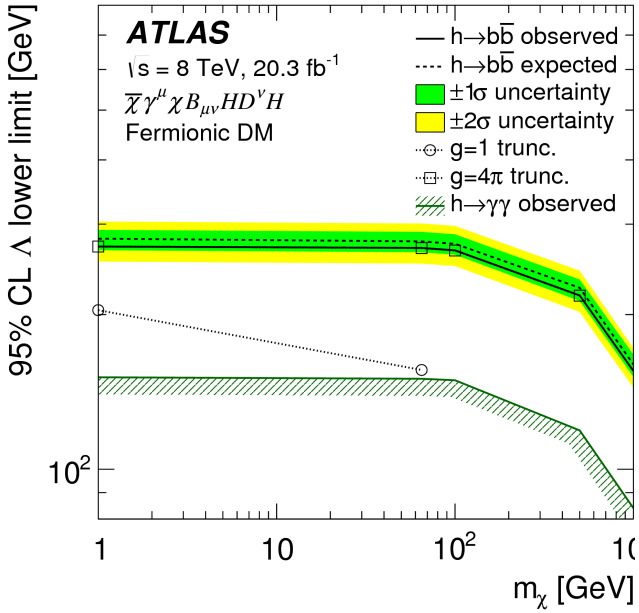
Search for DM pair production in association with a Higgs boson decaying to a **pair of bottom quarks**.

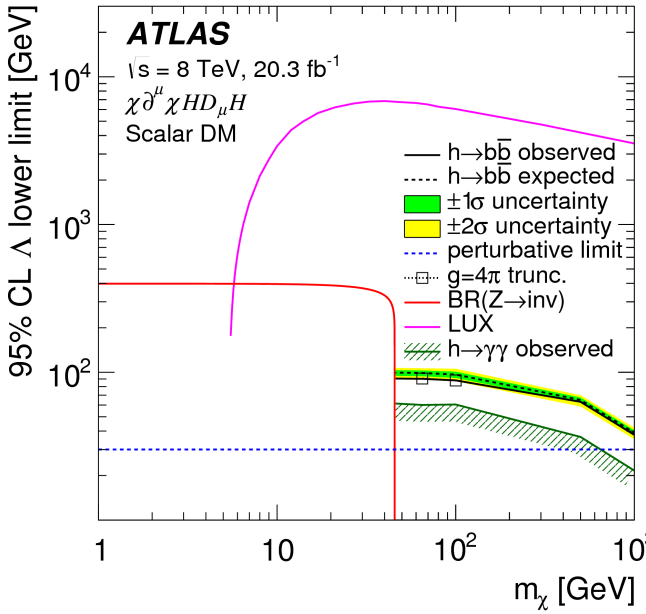


Two SRs considered: resolved and boosted channels, both triggered with high E_T^{miss}.



In the resolved scenario the 2 b-quarks are reconstructed separately; for the boosted channel they are found inside single large-R boosted jet.





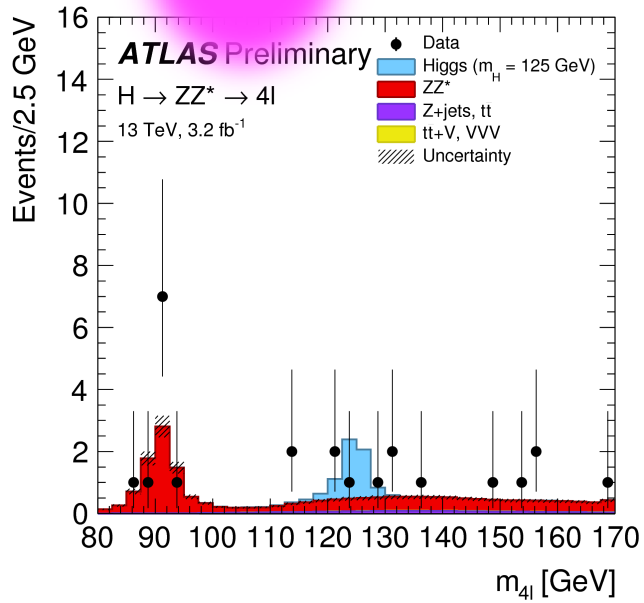
Limits on the suppression scale as a function of the DM mass for fermionic and scale EFT operators.

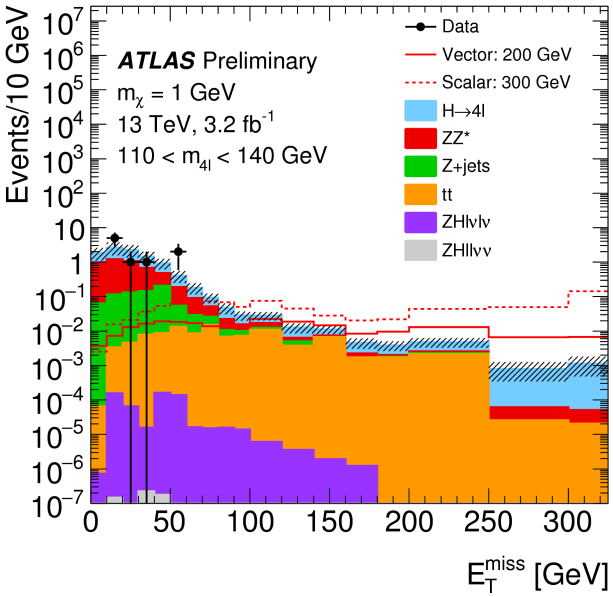
A **truncation** method is adopted (limits computed in which only simulated events with $Q_{tr} = m_{\chi\chi} < m_V$ are retained).

Mono-Higgs

13 TeV

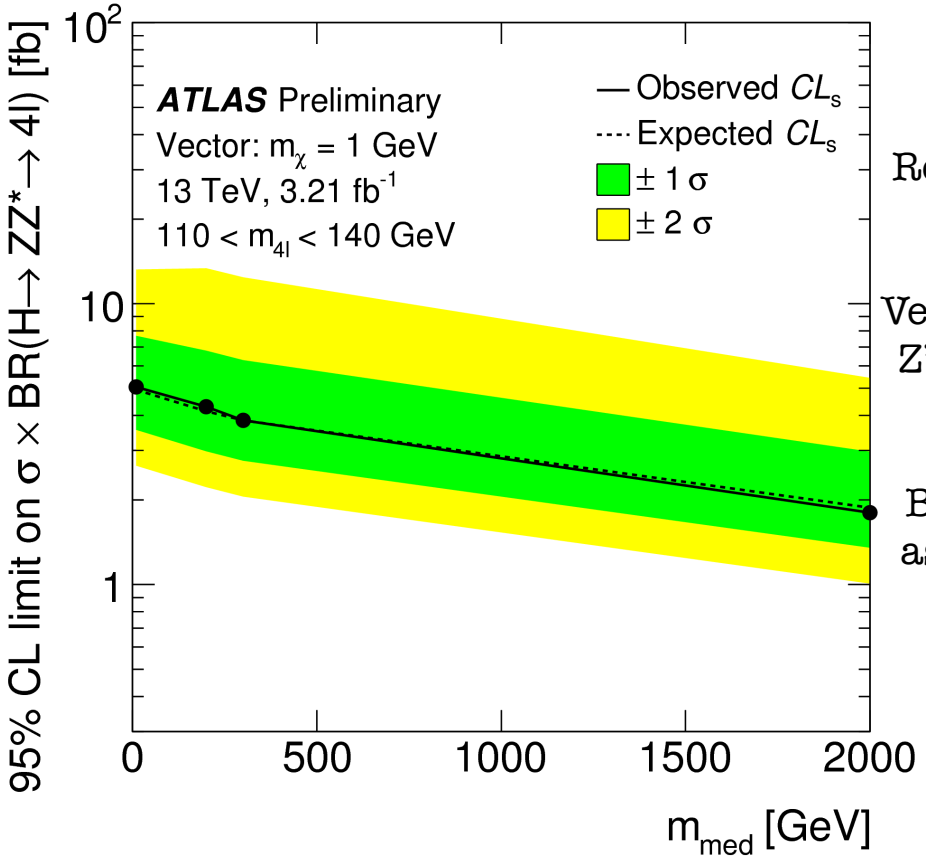
ATLAS-CONF-2015-059





Dark matter production in association with a Higgs boson $H \rightarrow ZZ^* \rightarrow 4l$ is searched for in events with large E_T^{miss}.

Events with 4 leptons (e, μ) are selected, a lepton pair should have 50 GeV < m_{ll} < 106 GeV.



Results for two simplified models: Vector mediator Z' and a heavy scalar S.

BR(H->inv) is assumed to be zero.

Conclusions

ATLAS has carried out a broad and very detailed program on DM searches with the full 8 TeV data.

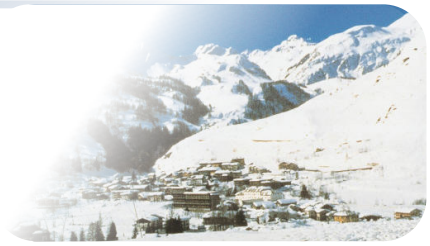
13 TeV data analysis are now coming out!

- Searches for DM have an important role in the LHC program, with a great number of analyses and techniques being employed.
  - Limits on M* and WIMP-nucleon scattering cross section set.
- High level of interest from non-LHC experiments (e.g. direct DM searches).
  - Limits at low M_{χ} are unique to the LHC.
- Wide range of signatures covered, using both EFT and simplified models.
- First results at 13 TeV are presented... **More updates coming soon!**
  - Significant increase in sensitivity for many signal models is expected.
  - Simplified models are becoming the main focus.

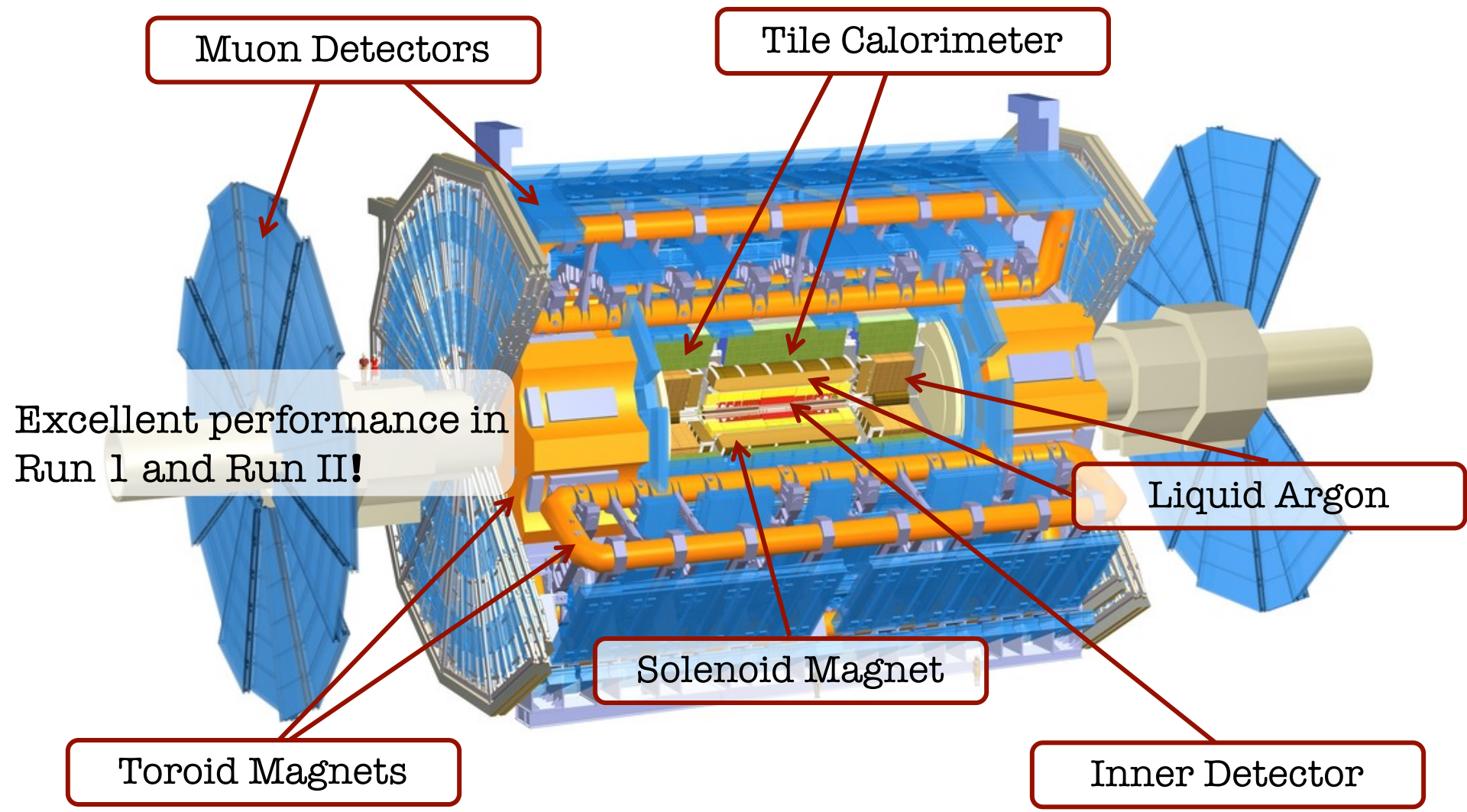
Stay tuned!

Many Thanks!

Bonus slides

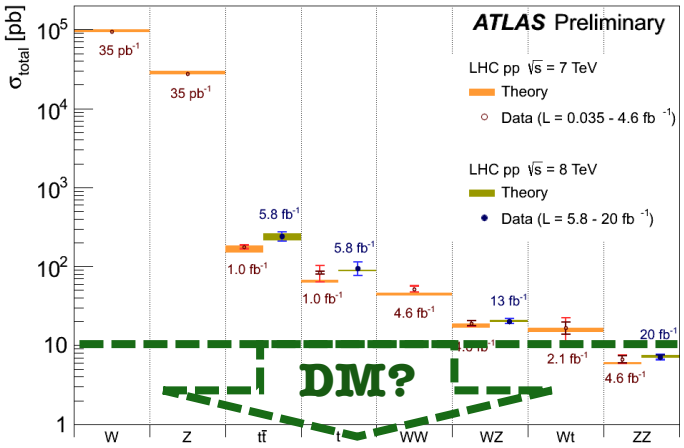


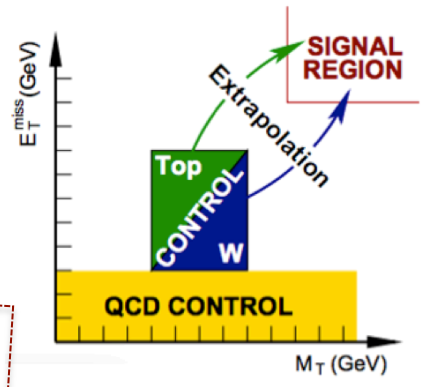
ATLAS Detector



Excellent performance in Run 1 and Run II!

Analysis Strategy





Standard Model
V, VV, VVV, top, multijets, Higgs...

Irreducible Backgrounds
Dominant source: Normalize MC in data control regions.
Subdominant source: MC.

Reducible Backgrounds
Determined from data.
Methods analyses dependent.

Validation
Cross check SM predictions with data

Signal Region

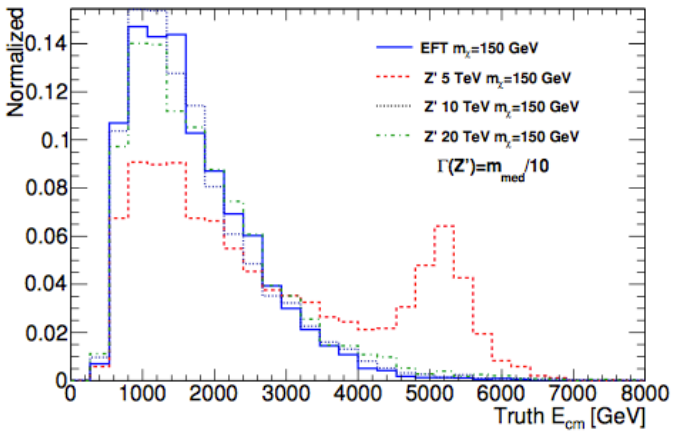
Combined fit of all regions and backgrounds (including syst. uncert.)

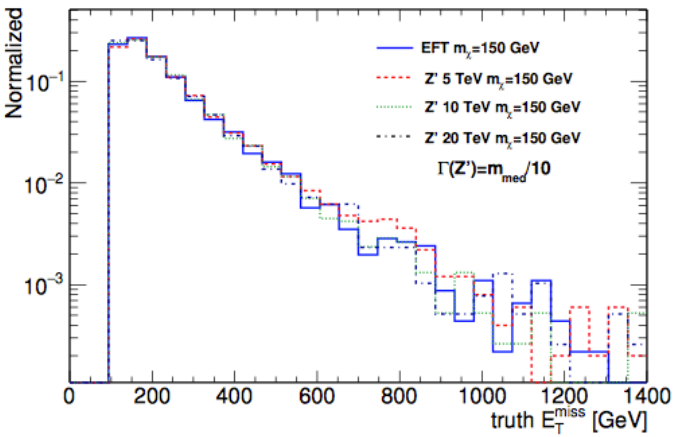
Monojet Analysis in Run II

- Monojet analysis with 2015 data is ongoing.
- As in Run I focusing on several signal models:
  - SUSY compressed scenarios.
  - Dark matter (emphasis on simplified models).
  - Large extra dimensions.

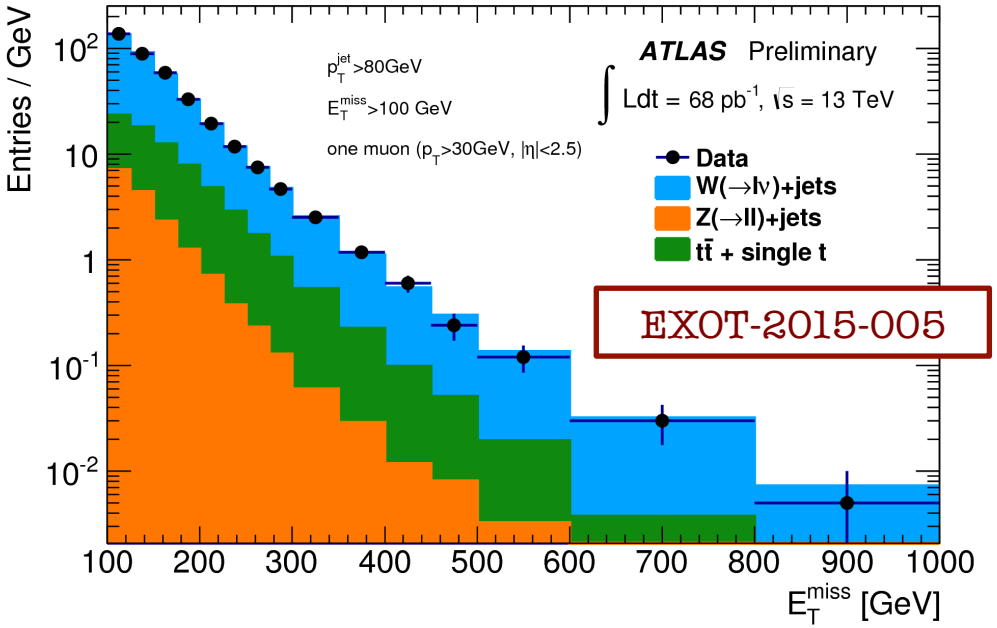
arXiv:1507.00966

Report of ATLAS/CMS DM forum





First look at E_T^{miss} in a monojet analysis control region (first 68 pb^{-1} of data).

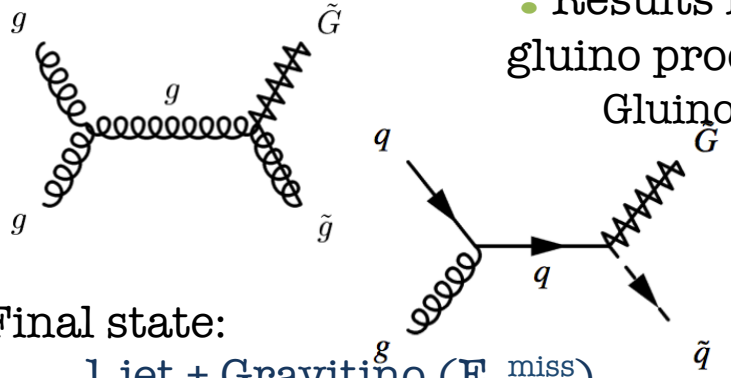


EXOT-2015-005

Monojet Gravitino

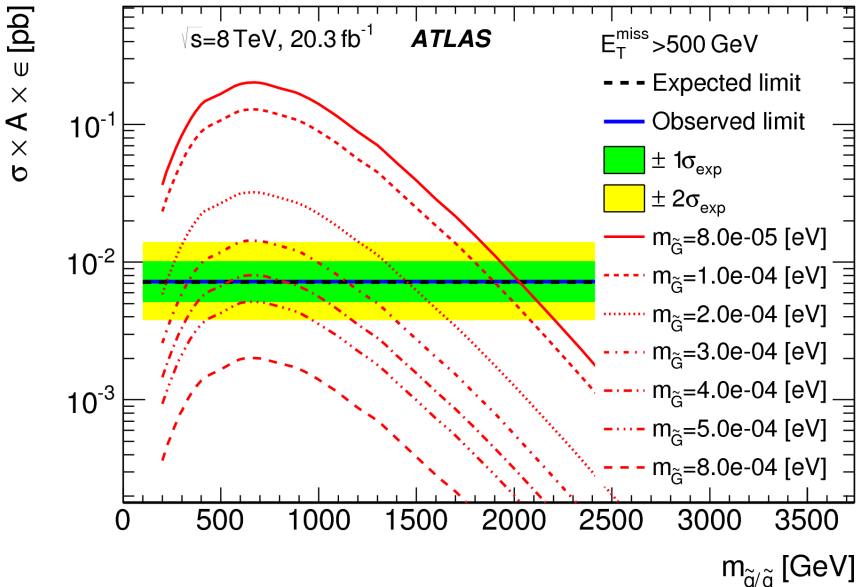
- Gravitino is considered the LSP in gauge-mediated SUSY breaking (GMSB) scenarios.
- Results interpreted in terms of GMSB gravitino+squark/gluino production.

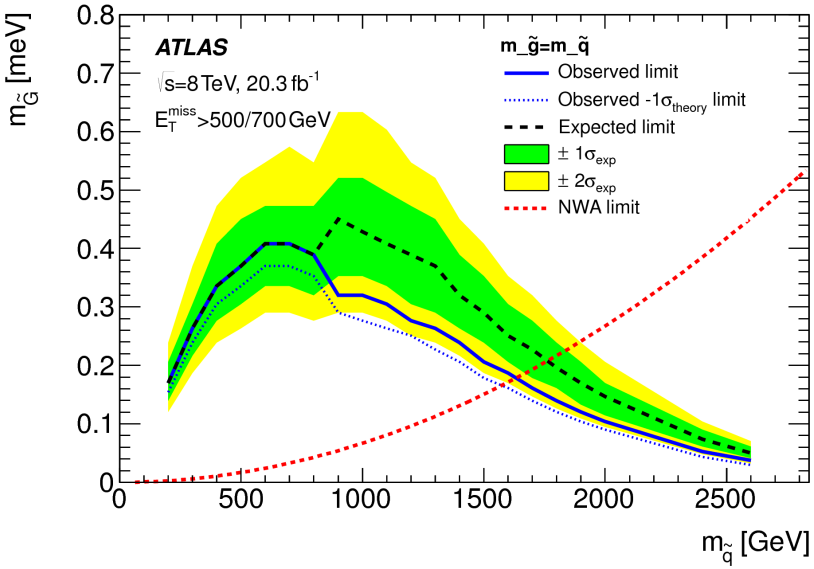
Gluinos (squarks) decay to gluon(quark) + gravitino (100%).



Final state:

1 jet + Gravitino (E_T^{miss})





95% CL limits on the mass of the GMSB gravitino as a function of the squark or gluino masses.

Excluding $M_{Gravitino}$ in the range [1x10^{-4}, 5x10^{-4}] eV depending on m_{squark} and m_{gluino}.

Mono-W/Z Searches

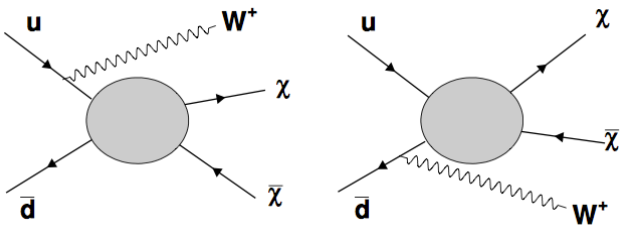
8 TeV, 20 fb^{-1}

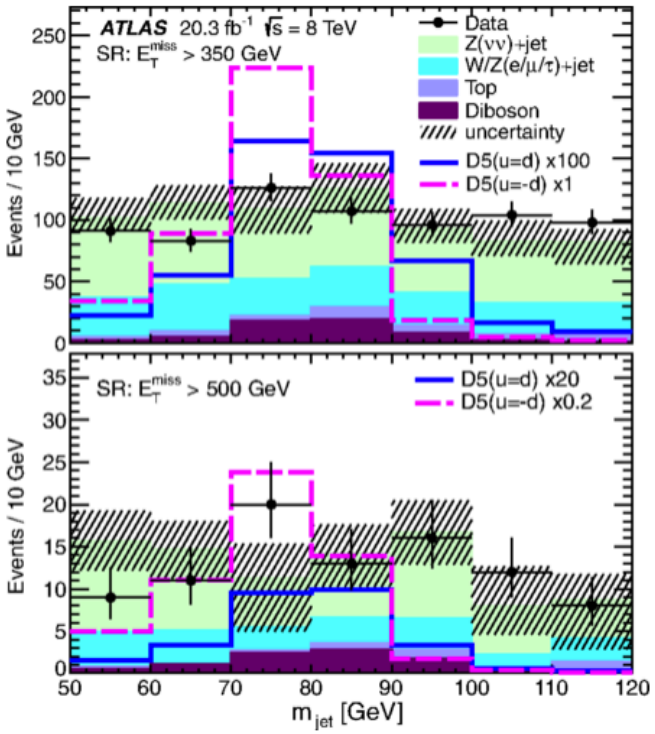
PRL 112.041802

Search based on the *hadronic* decay products of W/Z.

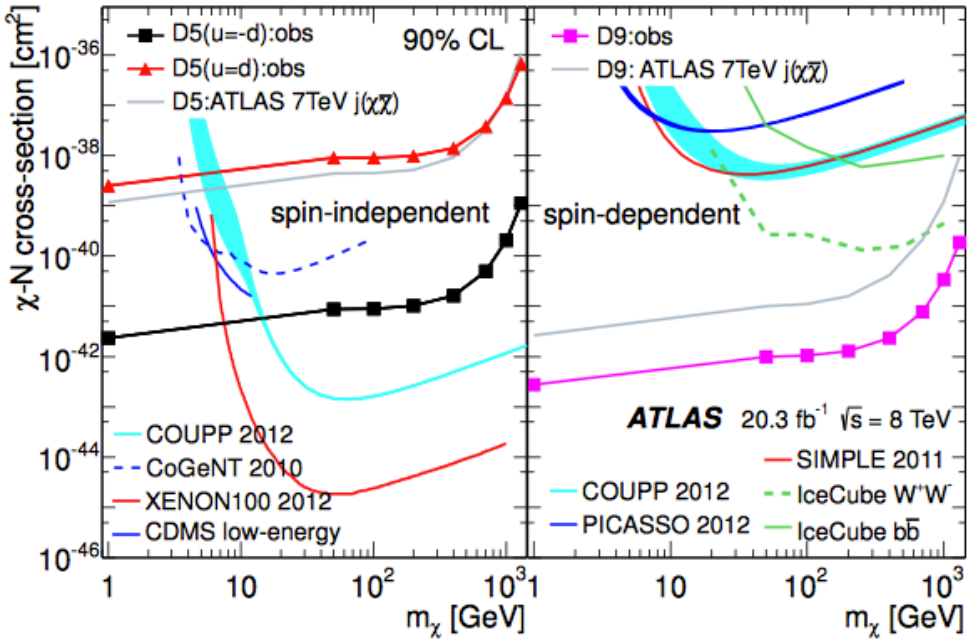
Decays reconstructed as a **single massive jet**:

- CA R=1.2 jets.
- Jet $p_T > 250$ GeV, $|\eta| < 2.1$, $50 < M_{jet} < 120$ GeV .
- No additional jet (anti-k_T 0.4) with $p_T > 40$ GeV.
- $E_T^{miss} > 350$, 500 GeV





Limits in terms of **DM-nucleon** scattering cross section.



Total	710^{+48}_{-38}	89^{+9}_{-12}
Data	705	89

Good agreement with SM expectation