Searches for WIMP dark matter in mono-X events at the LHC

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Outline

- Producing WIMPs in pp collisions
  - Effective field theory operators
  - Experimental signature
- Mono-X searches
  - ATLAS monojet search at 8 TeV
  - ATLAS monophoton search at 8 TeV
  - Other mono-X searches

Producing WIMPs at the LHC

- Weakly interacting massive particles (WIMPs) are a popular DM candidate
  - Many experiments dedicated to WIMP search
- WIMPs interact with Standard Model particles at the level of weak interaction
- Annihilation of partons into WIMPs (χ) could be detectable at the LHC

$$gg \to \chi\bar{\chi}$$

$$q\bar{q} \to \chi\bar{\chi}$$

Effective interactions

$$gg \to \chi\bar{\chi}$$
$$q\bar{q} \to \chi\bar{\chi}$$

Name	Initial state	Type	Operator
C1	qq	scalar	$\frac{m_q}{M_\star^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
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	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

C1, C5: χ is a scalar

D1, D5, D8, D9, D11: χ is a fermion

Effective interactions

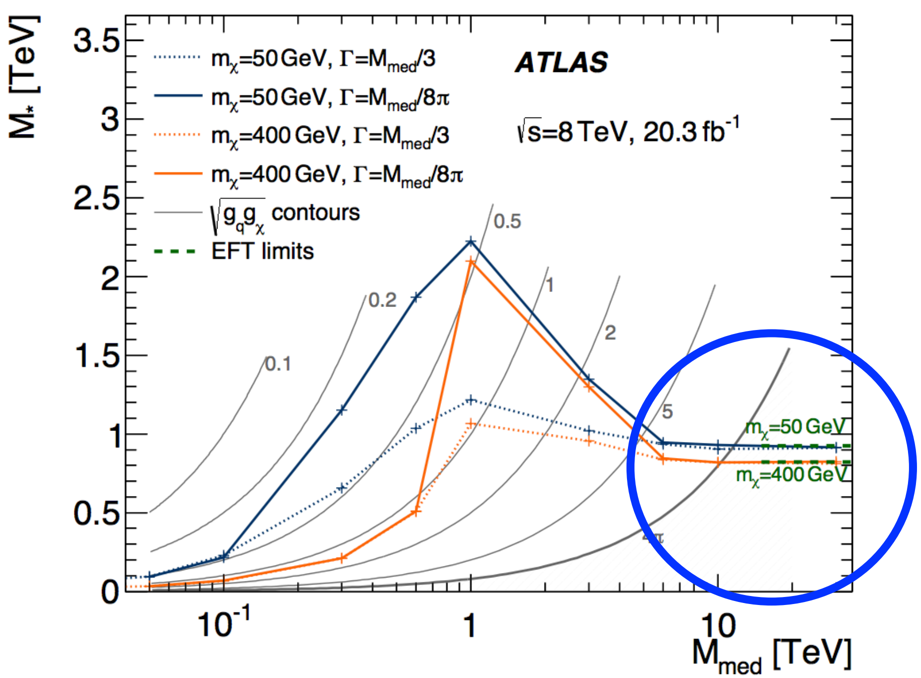
$$gg \rightarrow \chi\bar{\chi}$$
$$q\bar{q} \rightarrow \chi\bar{\chi}$$

- This effective field theory approach treats parton annihilation to DM as a point interaction
- When is this approach valid?
  - Momentum transferred in hard scatter < mass of mediator particle
  - What region of (m_χ, M*) space does this correspond to?
  - Can relate mass of mediator particle to suppression scale (M*) and coupling constant for the interaction

Effective interactions

$$gg \to \chi\bar{\chi}$$
$$q\bar{q} \to \chi\bar{\chi}$$

- What if EFT approach is not valid at LHC?
  - Can also consider simplified models where a light mediator particle is introduced
  - At large mediator masses, EFT works well



Limits from monojet search

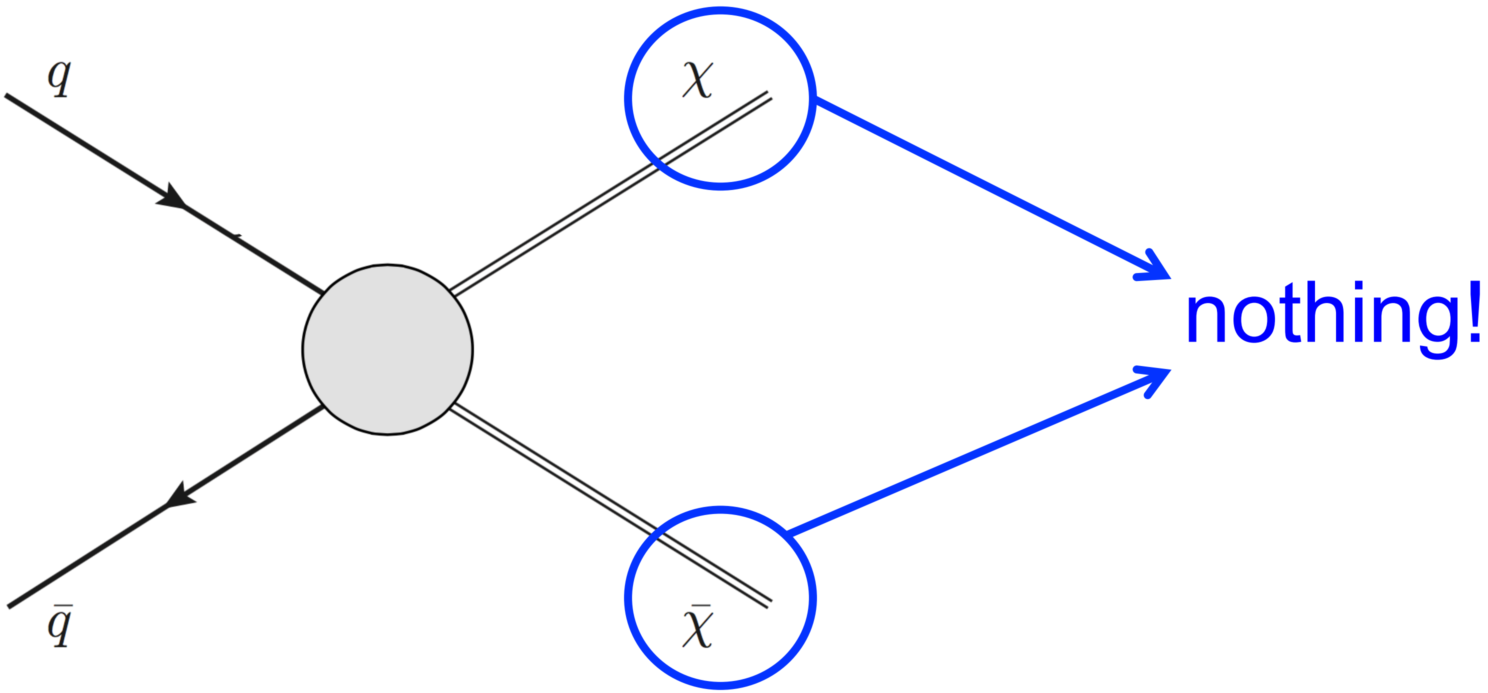
$$q\bar{q} \to Z' \to \chi\bar{\chi}$$

WIMP production at the LHC

What does the detector see?

$$gg \rightarrow \chi\bar{\chi} \text{ or } q\bar{q} \rightarrow \chi\bar{\chi}$$

This looks exactly like an event where there was no hard scatter… it won't even be recorded!

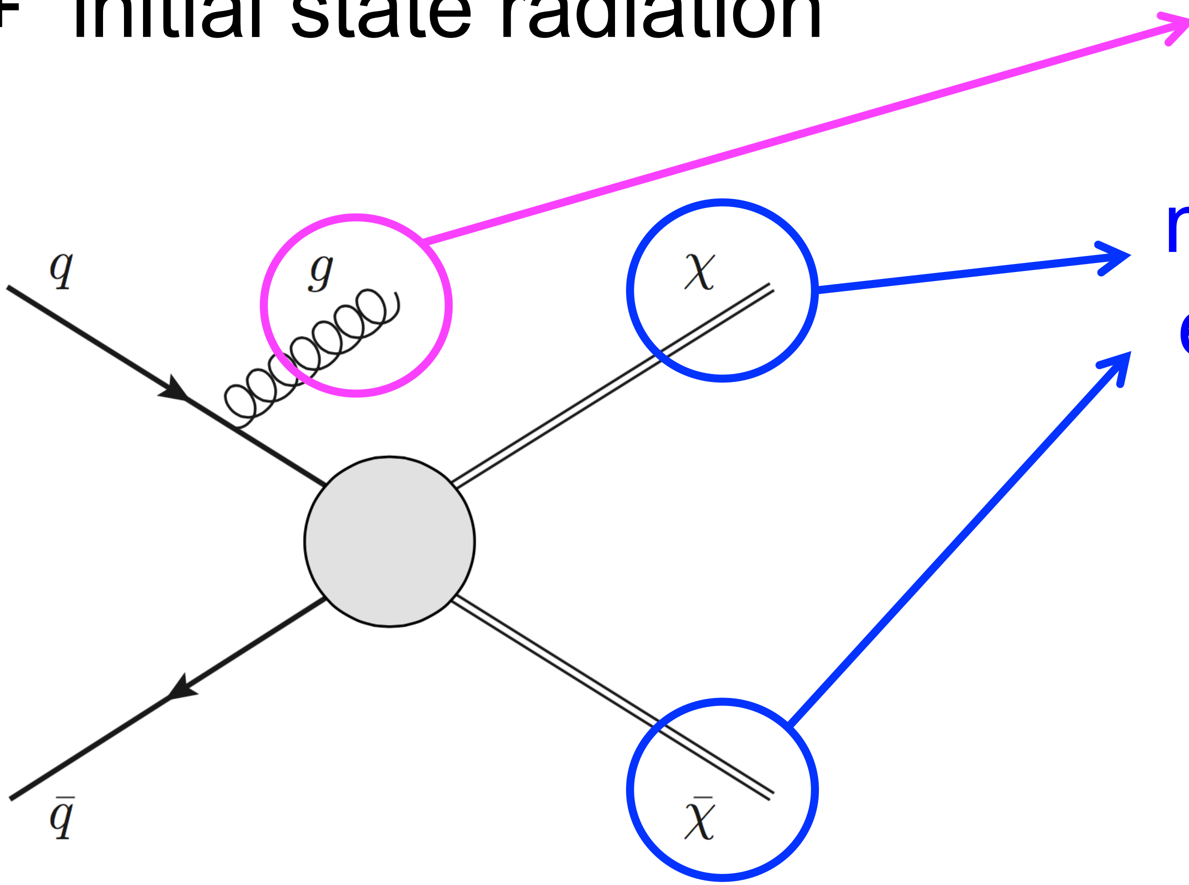


WIMP production at the LHC

What does the detector see?

$gg \rightarrow \chi\bar{\chi}$ or $q\bar{q} \rightarrow \chi\bar{\chi}$

\+ initial state radiation



1 jet

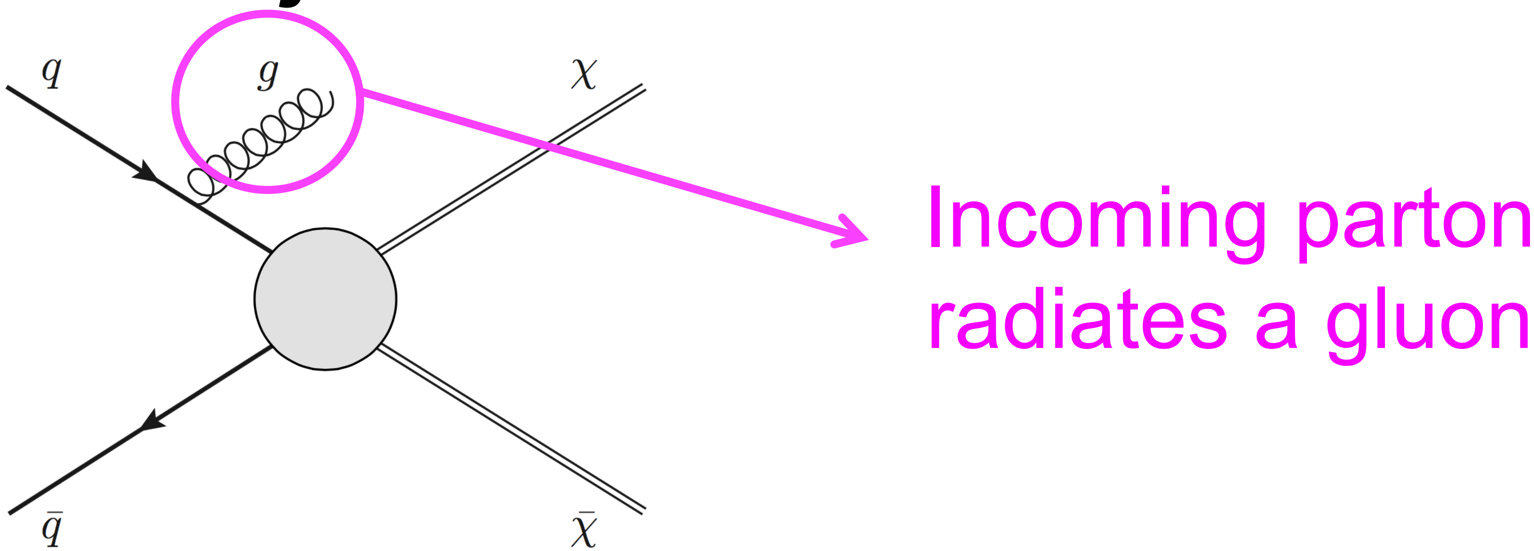
\+

missing energy

Mono-X & E_T^{miss}

- Mono-X searches look for
  1. a familiar object (e.g. jet, SM particle)
  2. a momentum imbalance (E_T^{miss})
- Many possible sources of E_T^{miss}:
  - New physics! (e.g. WIMPs)
  - Neutrinos
  - Mis-measurements
  - Non-collision background (e.g. detector effects)

Monojet searches



Main sources of background include:

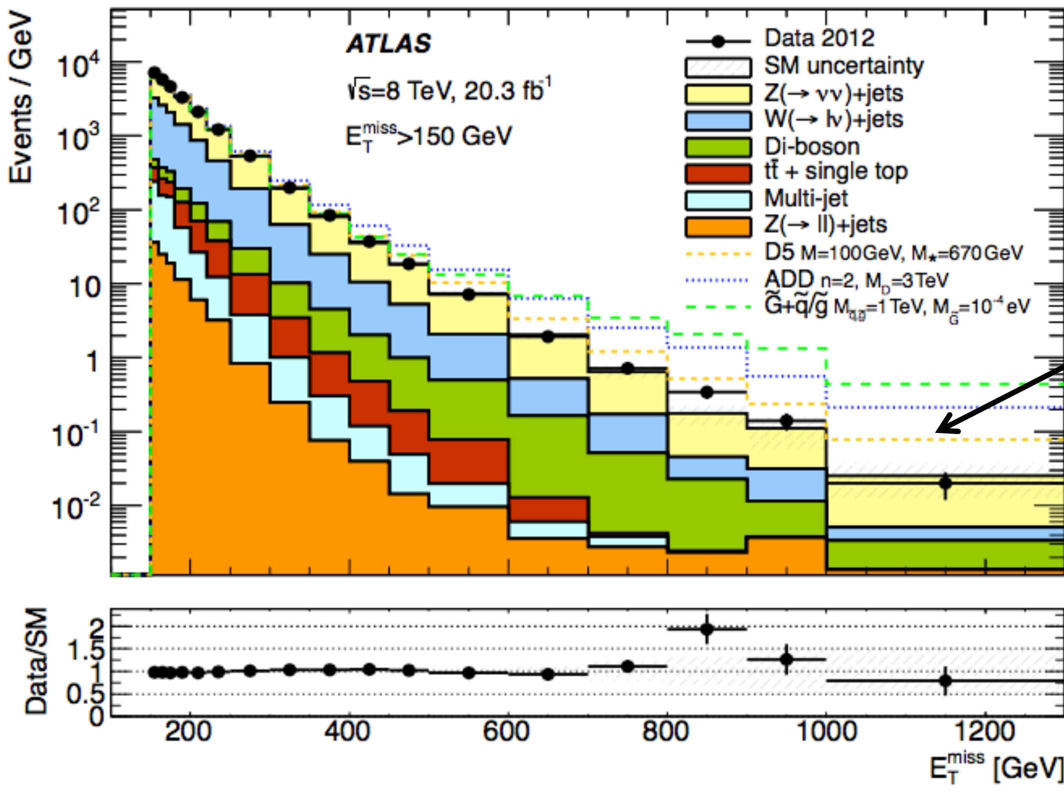
- Z+jets with $Z \to \nu\nu$
- W+jets with $W \to \ell\nu$

ATLAS monojet search $\sqrt{s} = 8$ TeV

Monojet-like events must have…

- At least one high energy jet
- Large missing energy
- No leptons
- Energy of leading jet not too small compared to missing energy
- Jet and missing momentum not pointing in the same direction

ATLAS monojet search √s = 8 TeV



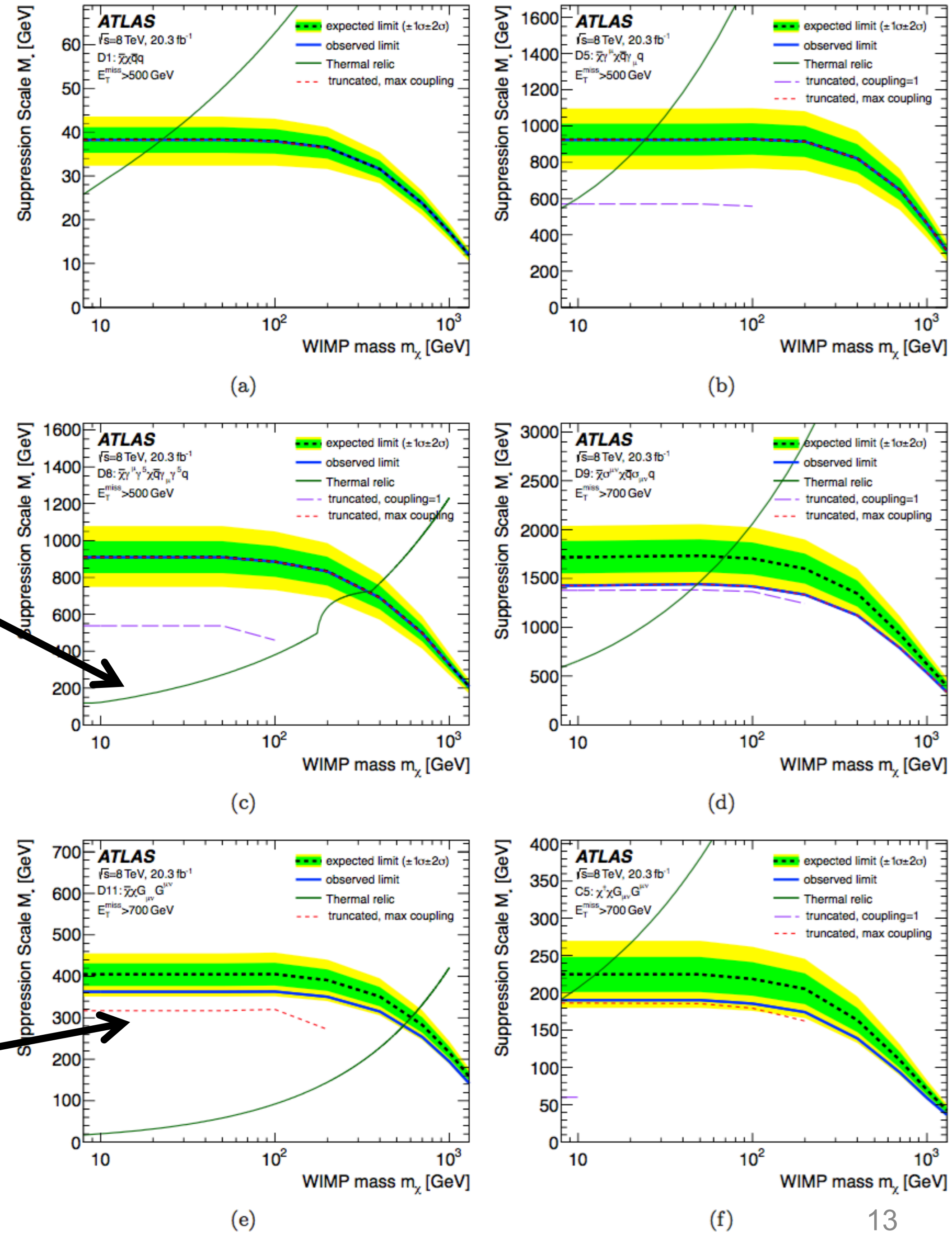
No excess observed

Example WIMP signal in orange

- Different EFT operators give different predictions for E_T^{miss} distribution

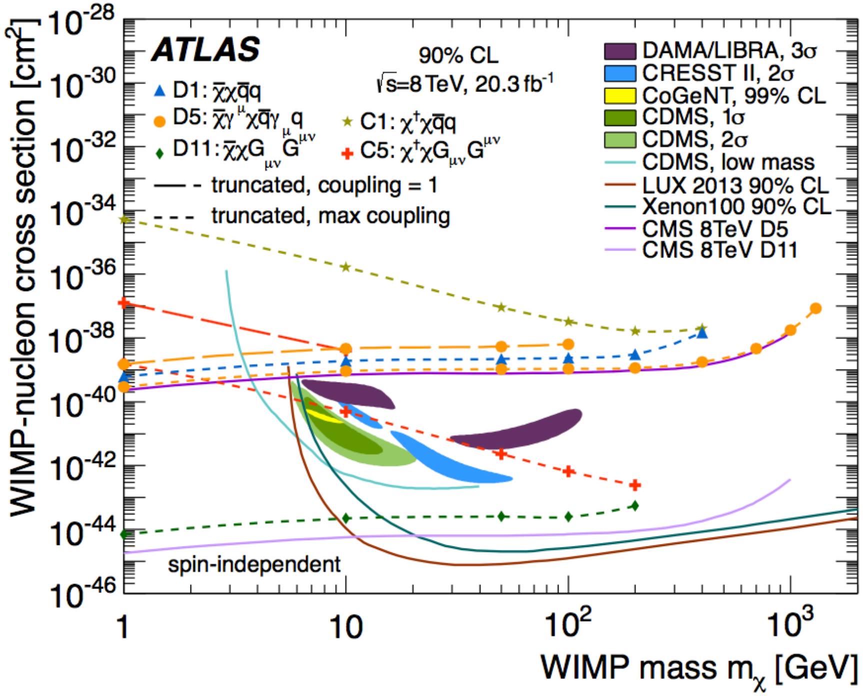
Monojet limits

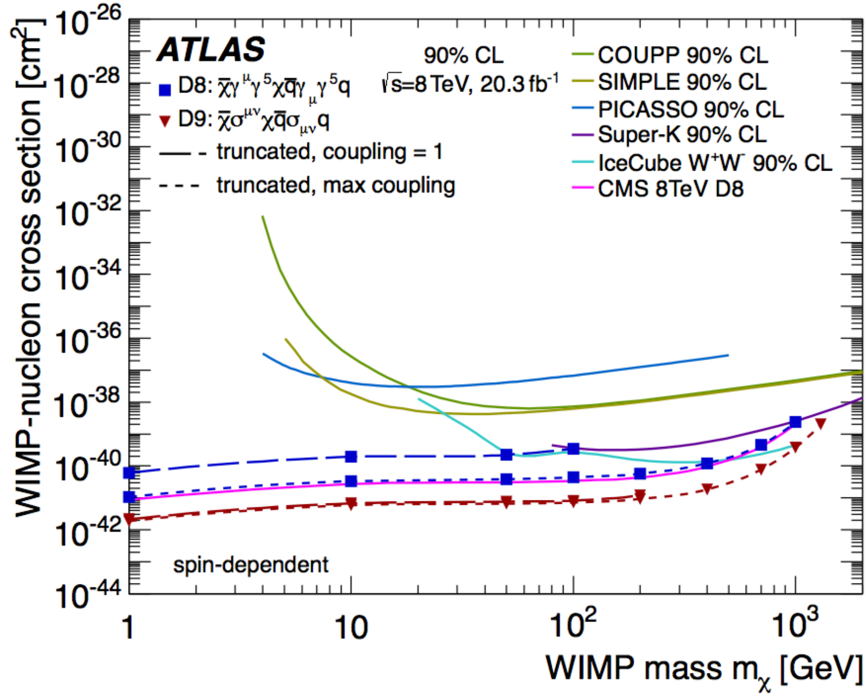
- Exclusion in parameter space of m_χ and M*
- Green line: values that correspond to relic abundance of DM measured by WMAP
- Red/purple lines: region where EFT treatment is valid



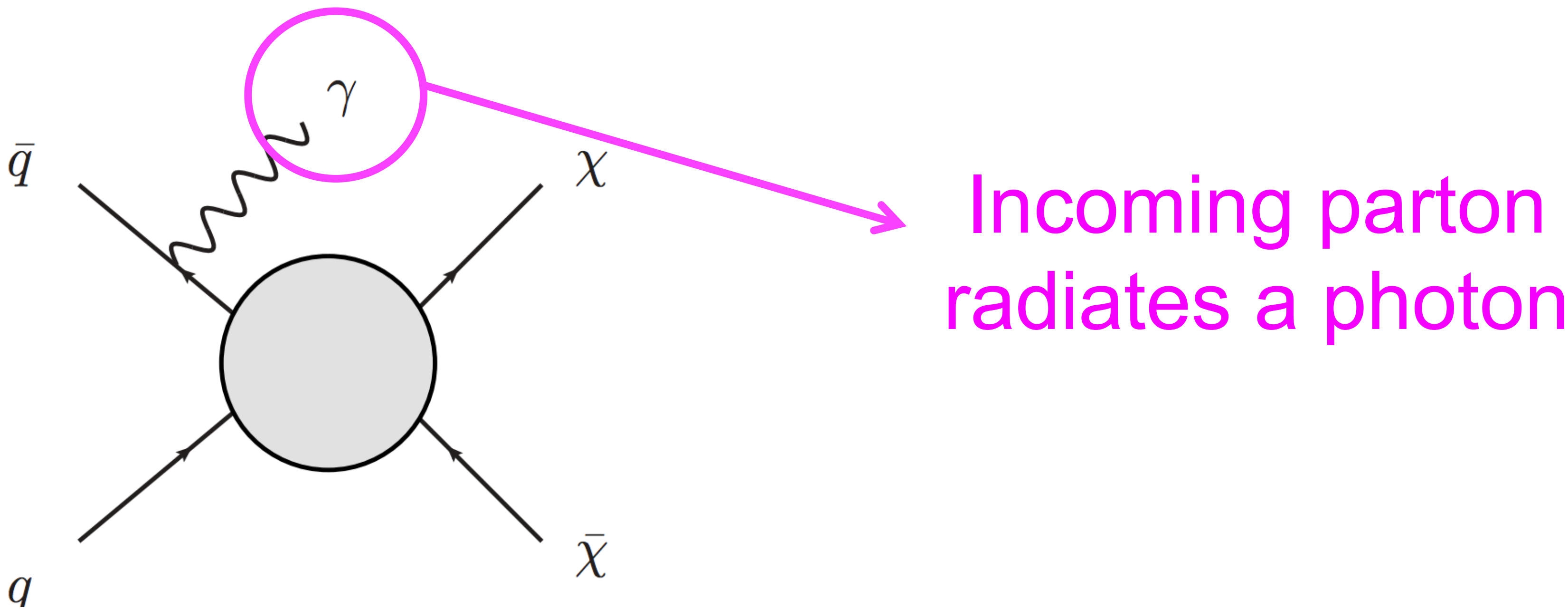
Monojet limits
Compare to direct detection

- Must make assumption about coupling to convert limits in (m_χ, M*) to (m_χ, $\sigma_{\text{WIMP-Nucleon}}$)
- Limits from colliders do well at low m_χ, especially for spin-independent interactions





Mono-photon searches



Main sources of background include:

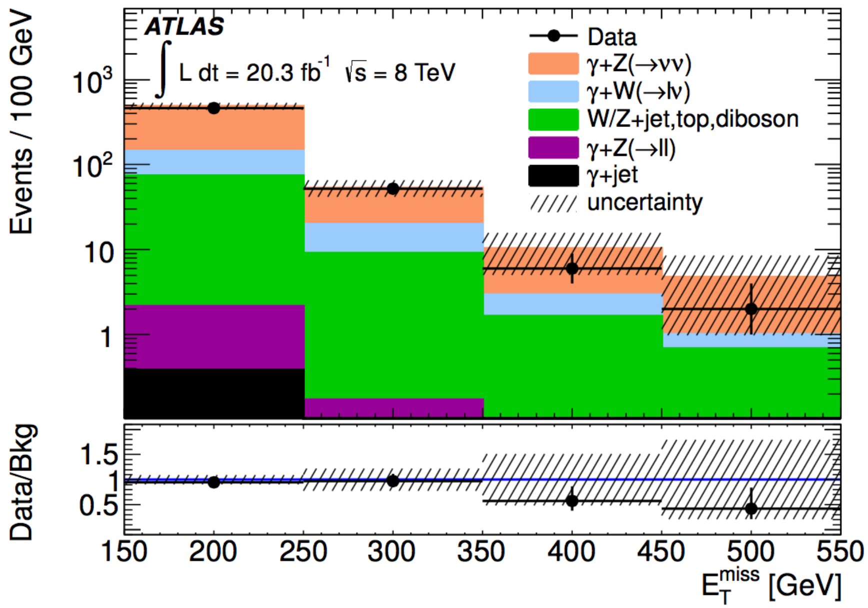
- Z+γ with $Z \rightarrow \nu\nu$
- Z+γ / W+γ with mis- or un-identified lepton

ATLAS mono-photon search $\sqrt{s}$ = 8 TeV

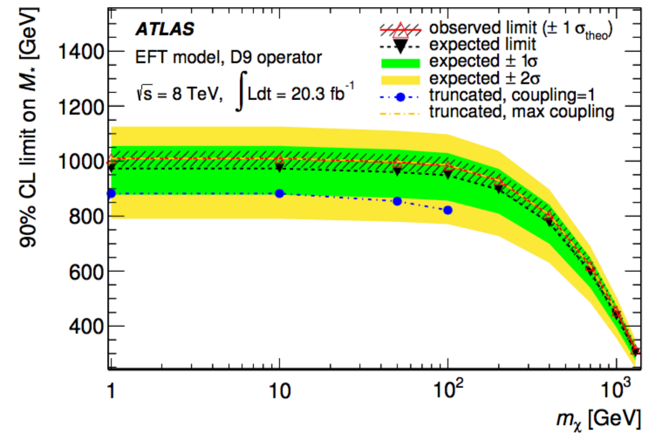
Mono-photon events must have…

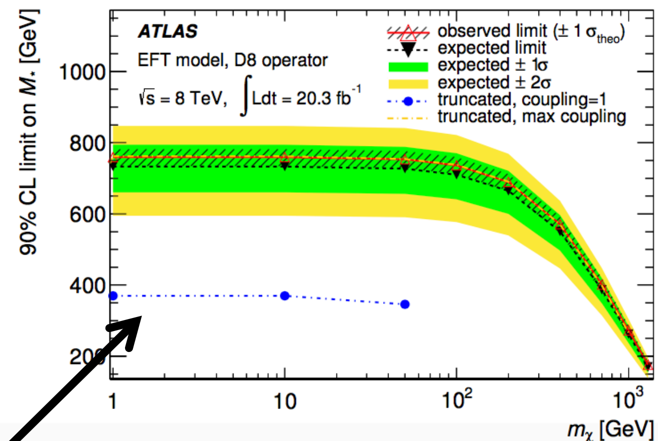
- At least one high energy photon
- Large missing energy
- No leptons
- Photon and missing momentum do not point in the same direction
- No more than one jet
  - No jets in the same direction as the photon

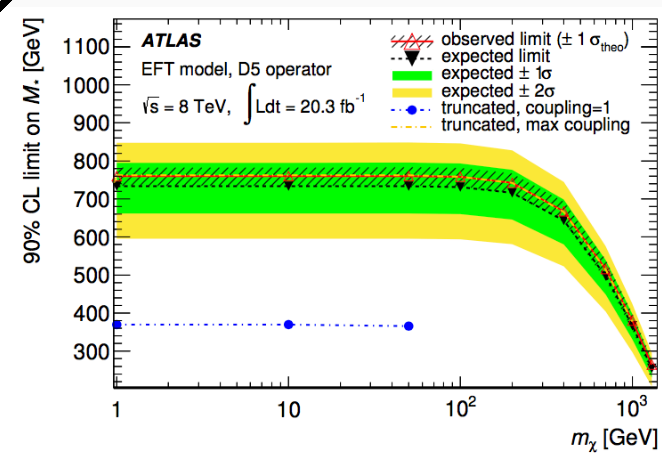
Mono-photon limits



- Again, no excess is observed
- Exclusion drawn for three of the operators from slide 4
- Blue dashed lines: region where EFT treatment is valid



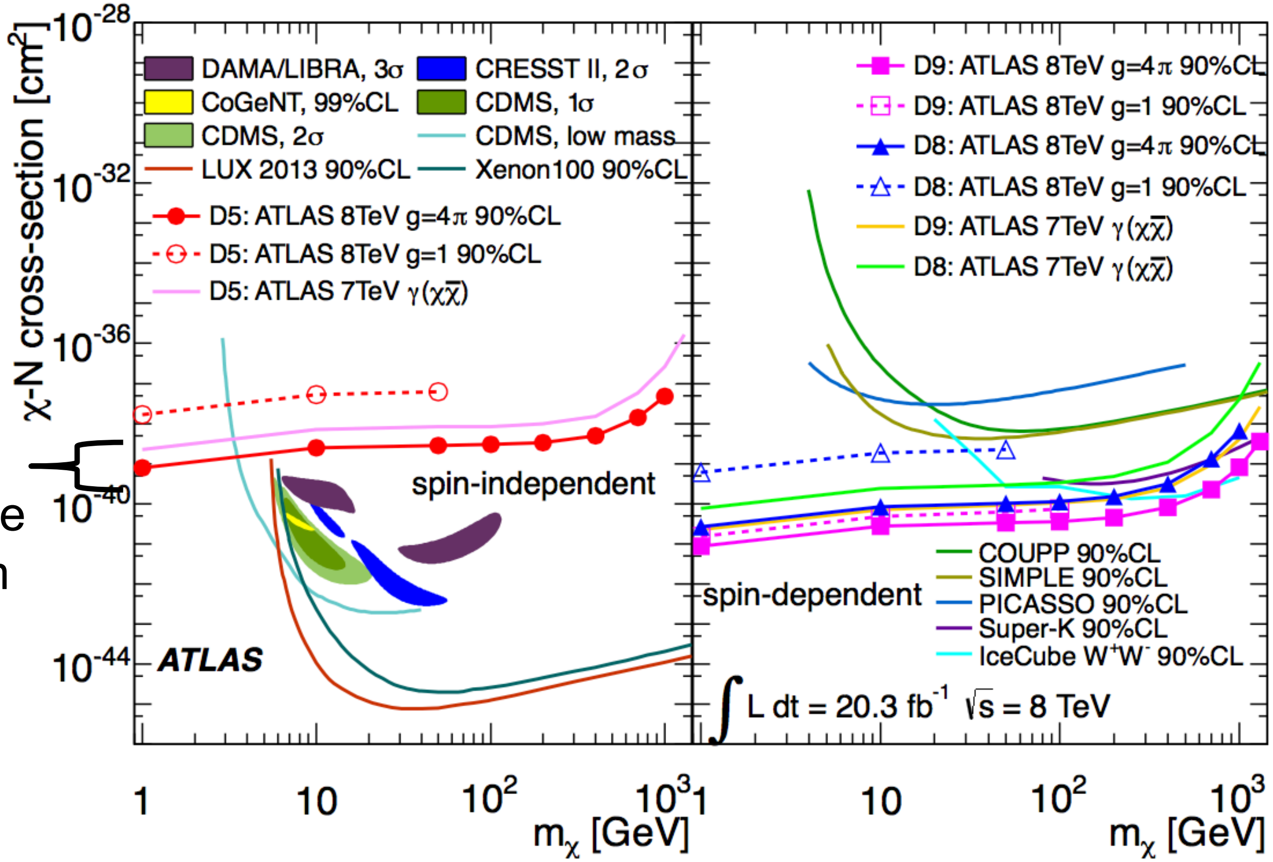




Mono-photon limits
Compare to direct detection

- Limits drawn for different choices of coupling
- Again, limits from colliders do well at low m_χ

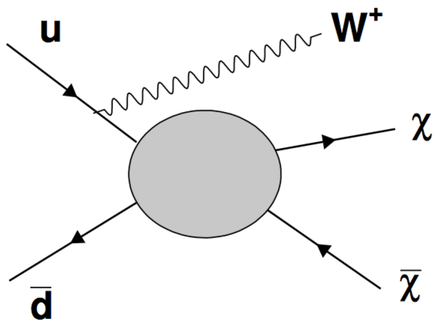
Range of comparable limits from monojet

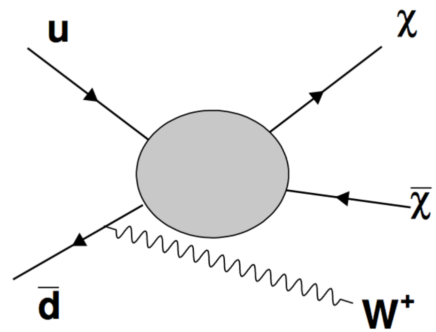


Range of comparable limits from monojet

Mono-W and mono-Z searches

Some of the potential signatures

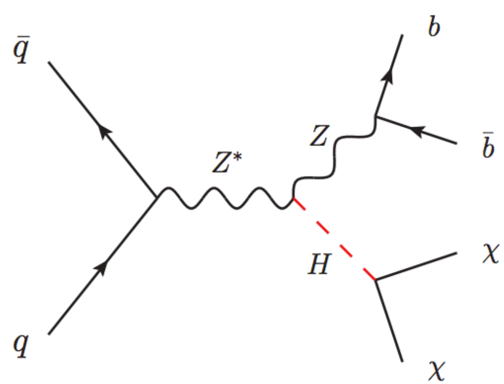




Initial state radiation

$$q\bar{q} \rightarrow W\chi\bar{\chi}$$

$$q\bar{q} \rightarrow Z\chi\bar{\chi}$$



$$q\bar{q} \rightarrow WH$$

$$q\bar{q} \rightarrow ZH$$

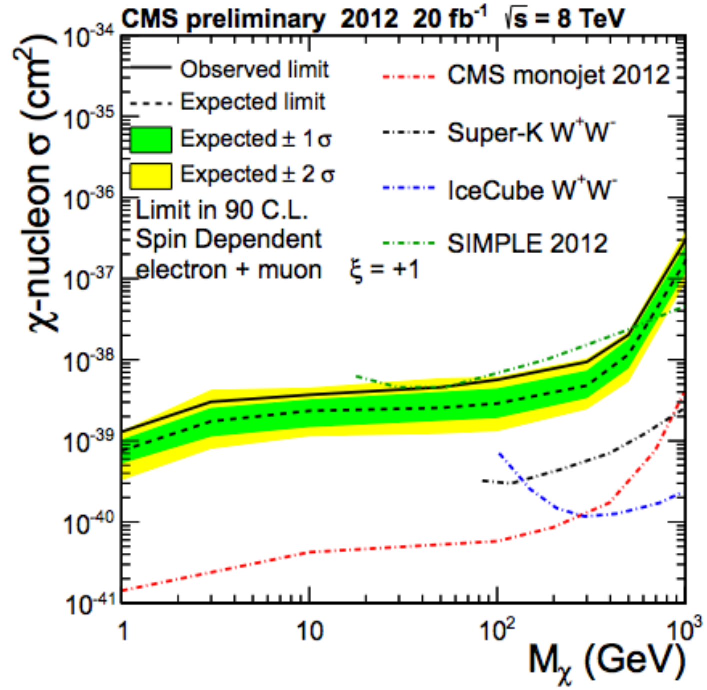
followed by

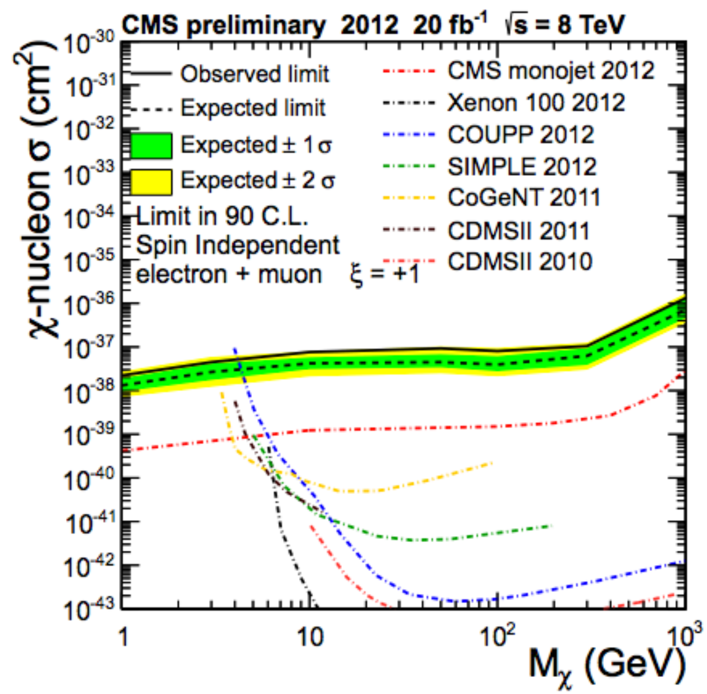
$$H \rightarrow \chi\bar{\chi}$$

Mono-lepton

$$q\bar{q} \to W\chi\bar{\chi} \text{ with } W \to \ell\nu$$

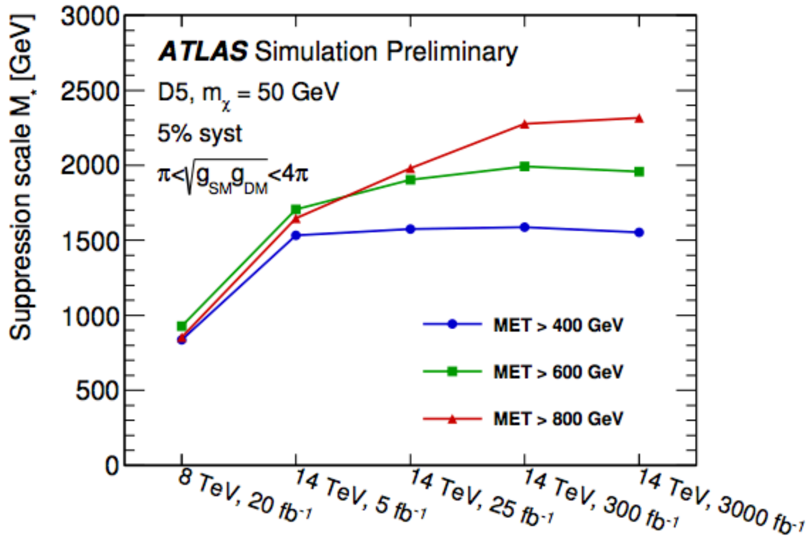
- Main background is
  $$q\bar{q} \to W \to \ell\nu$$
- You have to understand you SM background very well!
- Limits are not as strong as monojets

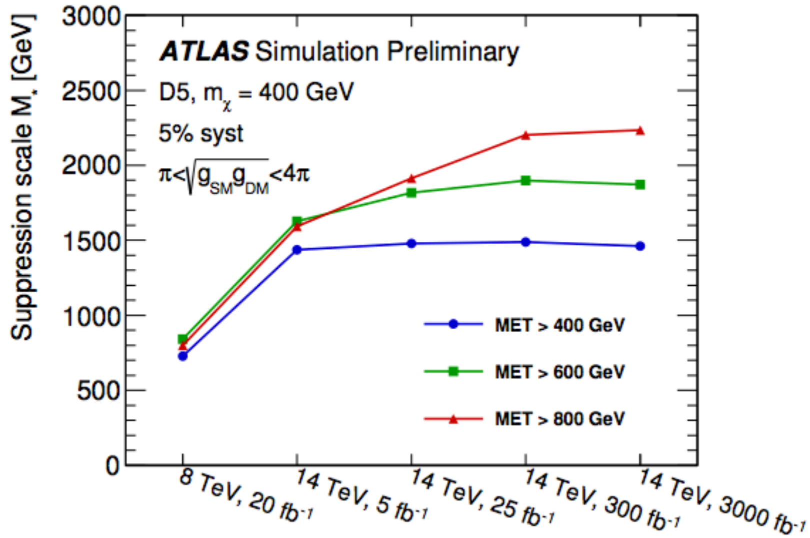




Future prospects

- Mono-X searches at the LHC have yet to detect any sign of WIMP dark matter
- LHC Run 2 will greatly expand sensitivity... stay tuned!





Assuming no signal, projected 95% CL limits

Thanks!

Main sources:

http://arxiv.org/abs/1411.1559

http://arxiv.org/abs/1502.01518v2

http://inspirehep.net/record/1327052?ln=en

http://inspirehep.net/record/1260901?ln=en

https://inspirehep.net/record/1260852?ln=en

http://arxiv.org/abs/1309.4017

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2014-007/