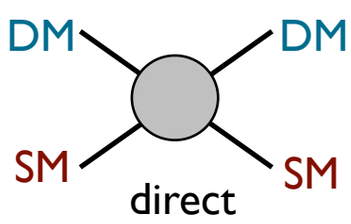
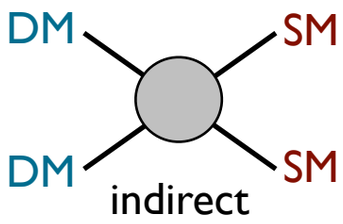
ATLAS Search for Dark Matter in Monojet-Events

Ruth Pöttgen, ISAPP 2013



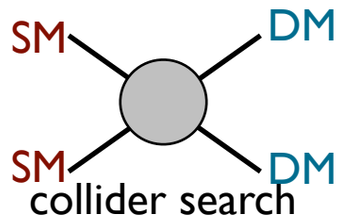
direct

(WIMP-nucleon scattering)



indirect

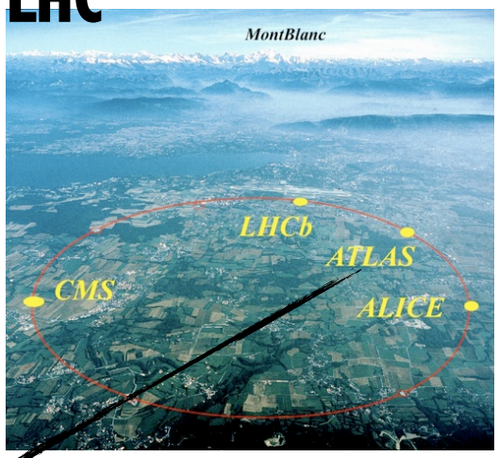
(annihilation)

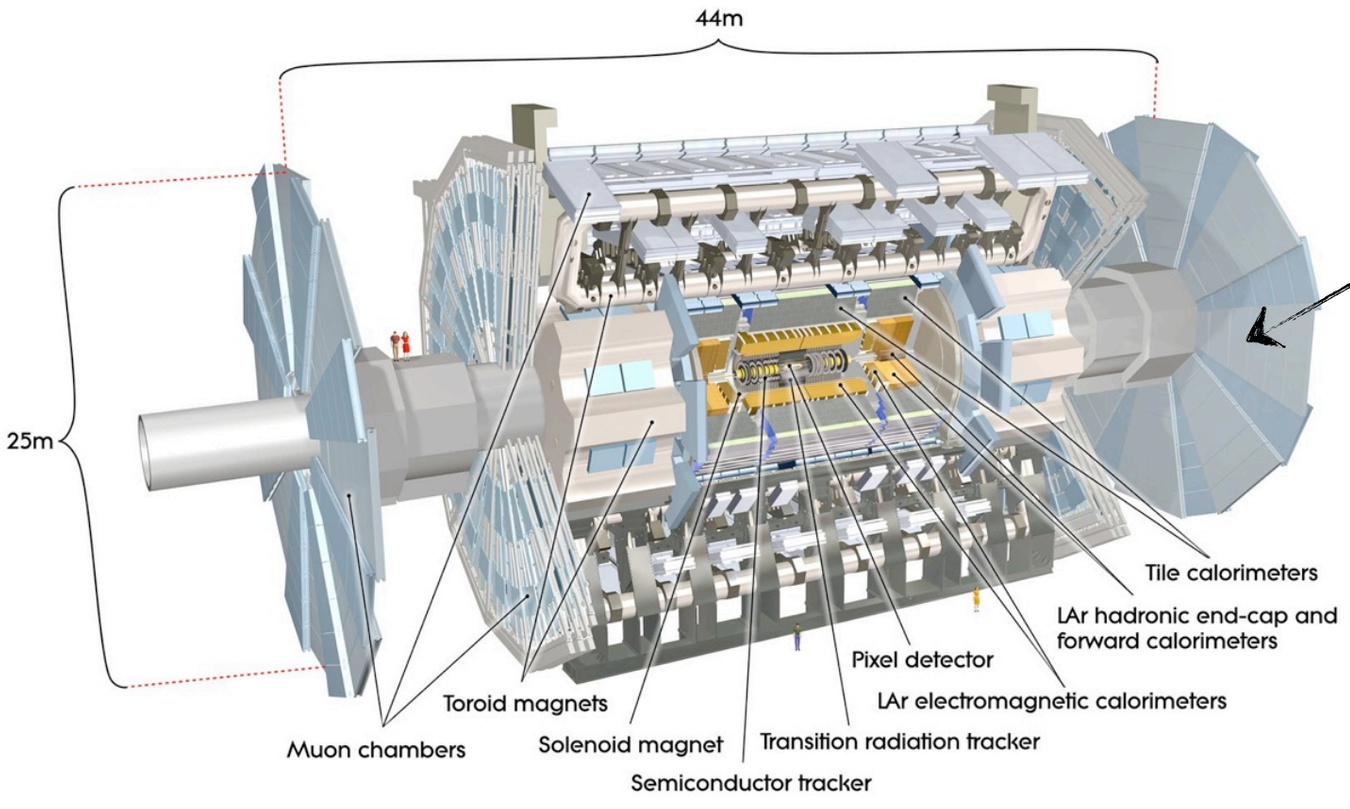


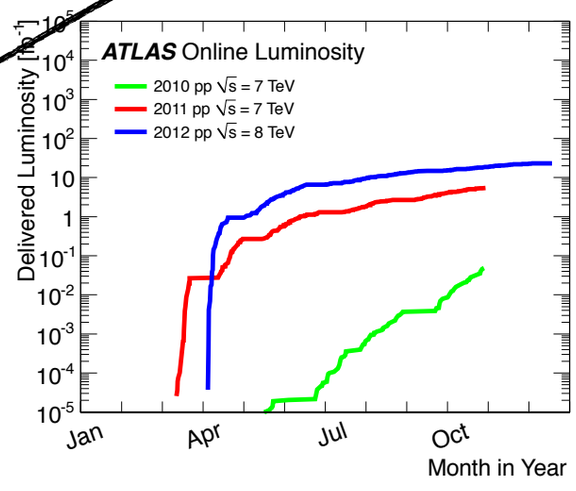
collider search

(pair production)

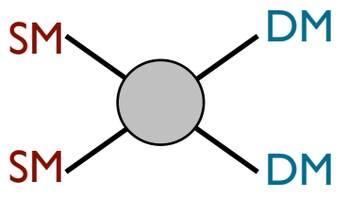
LHC



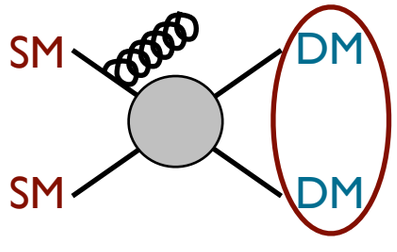




- we can't see



- but we **can** see



E_T^{miss}

- use high energetic jet as tag

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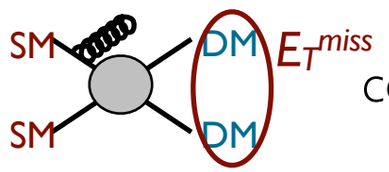
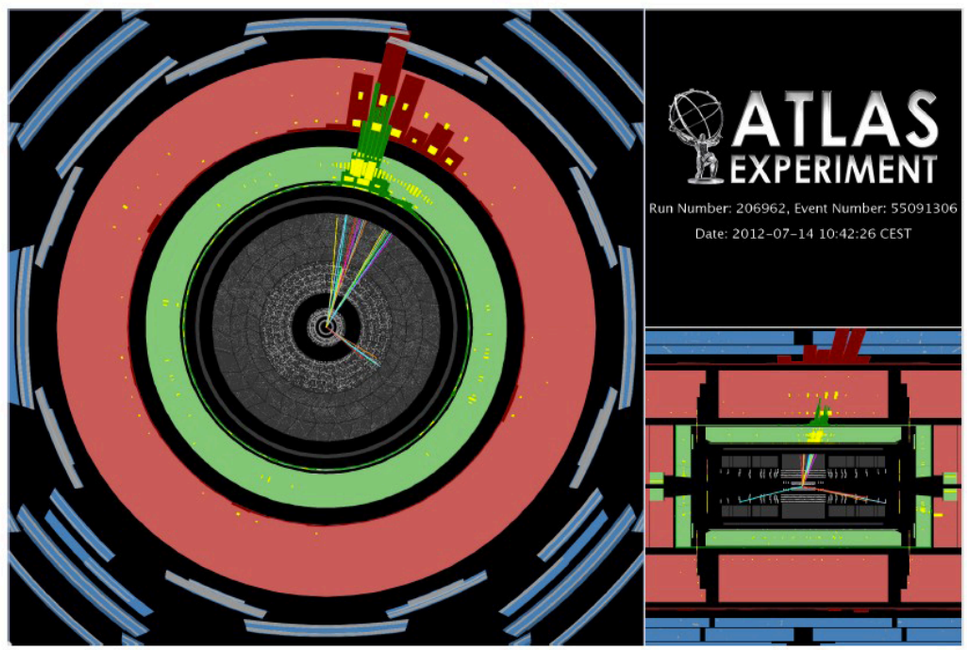
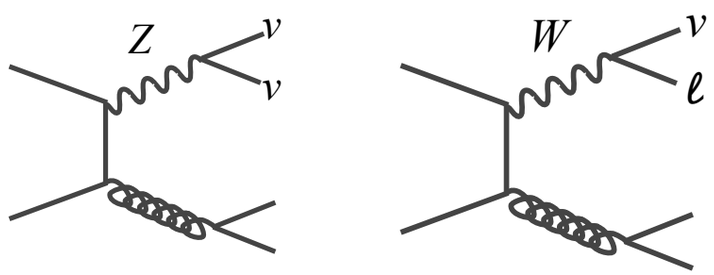
Event Selection

- in the detector, 

could look like this



- but some Standard Model processes could, too



  - $Z(\nu\nu)$+jets: largest contribution, irreducible
  - $W(\nu\ell)/Z(\ell\ell)$+jets: leptons not identified/not in acceptance

  } ~95% of background

  - multi-jet events (QCD), di-boson & top-quark production, non-collision backgrounds (NCB)

- **Event Selection**
  - large E_T^{miss}
  - high jet p_T
  - veto on electrons or muons
  - additional cuts to suppress QCD, NCB
    - 4 signal regions (SR): E_T^{miss} and leading jet p_T above 120, 220, 350, 500 GeV

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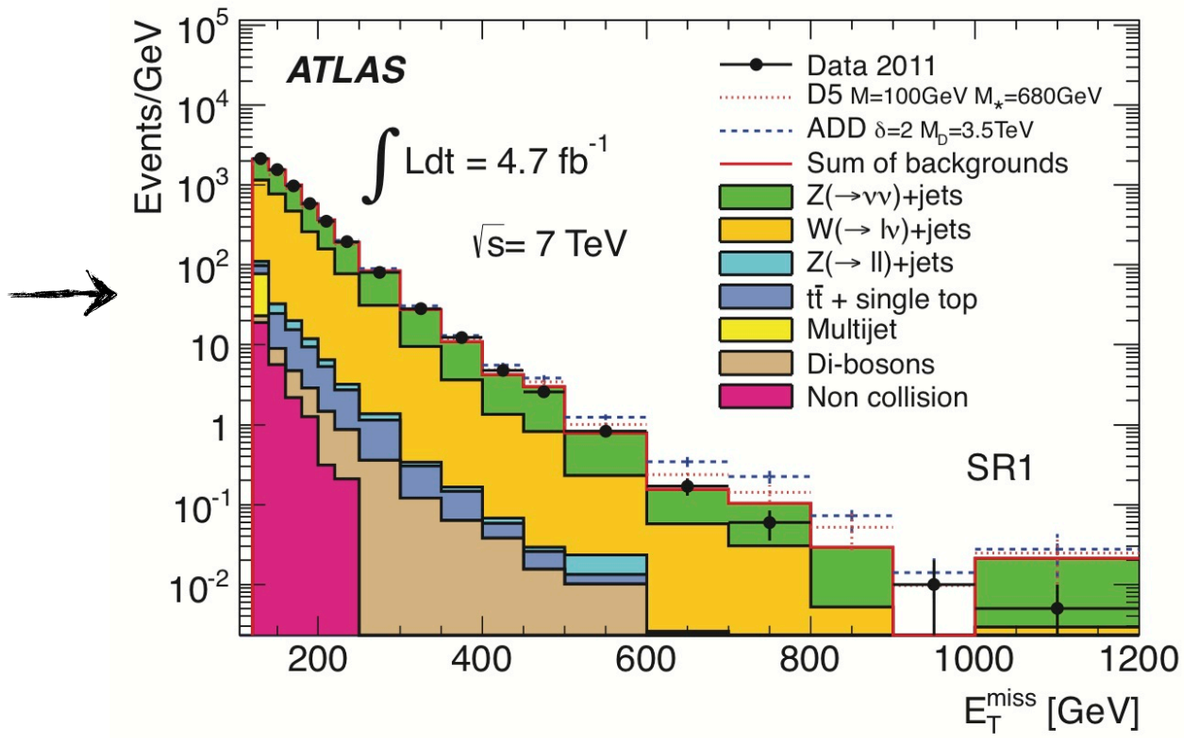
background Estimation

- *W/Z*+jets backgrounds:
  data control regions with identified e or μ,
  transfer factors from simulation
- multi-jet background:
  control region in data,
  extrapolate p_T spectrum into SR
- NCB: estimated in data from jet timing
- top/di-boson: directly from simulation

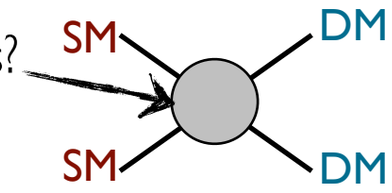


no excess above SM prediction → **exclusion limits** on cross section for new physics:

observed upper limit @90%CL: **0.026pb** (SR3), **0.055pb** (SR4)

Theory

- What's this?



something like this

operator		coefficient	initial state	type
$\bar{\chi}\chi\bar{q}q$	(D1)	$\frac{m_q}{M_\star^3}$	$q\bar{q}$	scalar
$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	(D5)	$\frac{1}{M_\star^2}$	$q\bar{q}$	vector
$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	(D8)	$\frac{1}{M_\star^2}$	$q\bar{q}$	axial vector
$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	(D9)	$\frac{1}{M_\star^2}$	$q\bar{q}$	tensor
$\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$	(D11)	$\frac{1}{4M_\star^3}$	gg	scalar

- **Prerequisites**
  - WIMPs exist, can be pair-produced
  - interaction mediated by new heavy particle
  - mediator too heavy to be produced directly
  - effective field theory approach
    → contact interaction
  - suppression scale M_*
    depends on mediator mass and couplings
  - for Dirac-fermionic WIMPs: 14 operators,
    describing different initial states/types of interaction
    (choose representative subset)
  - cross section depends on WIMP mass (m_χ) and M_*

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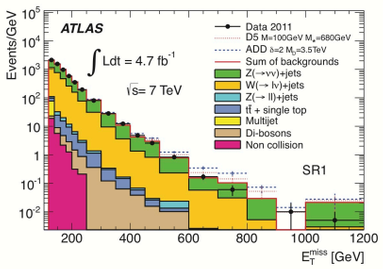
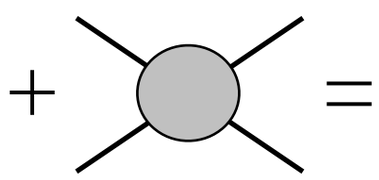
Results 2011





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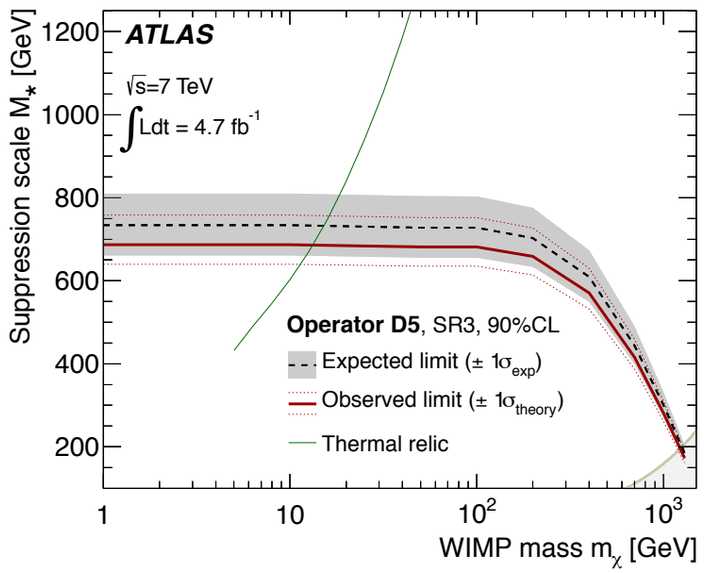
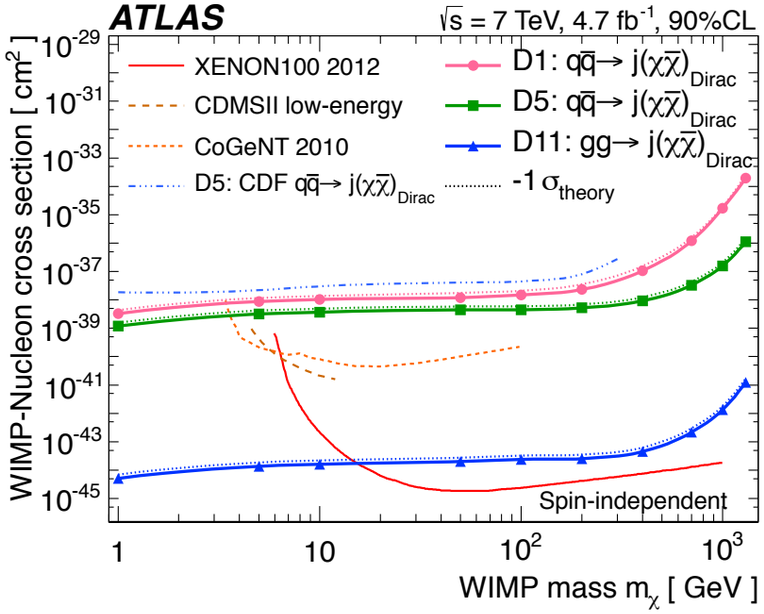
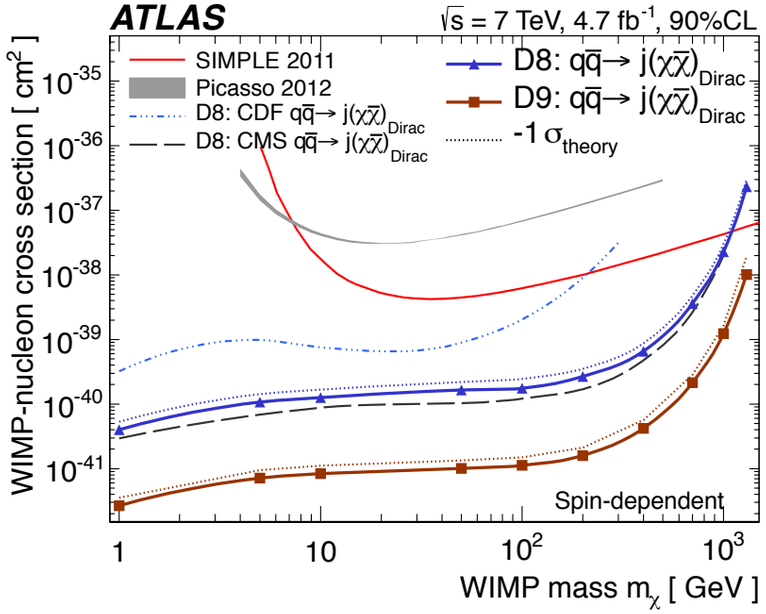


- **upper** limits on visible cross section translate into **lower** limits on suppression scale M_* as a function of m_χ





- **collider** results are translated into limits in **direct detection** plane

spin-independent interactions: collider limits stronger at small WIMP masses

spin-dependent interactions: colliders competitive over large range of WIMP masses

For questions, comments, further information - please, come see my poster :)

ATLAS Search for Dark Matter in Monojet-Events

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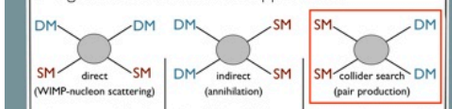
Looking for Dark Matter

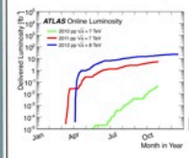
- existence of dark matter (DM) firmly established by cosmological observations at different scales [1]
- no information on type of particles it is made of or their properties
- popular candidates: WIMPs (**W**eakly **I**nteracting **M**assive **P**articles)
- 3 general classes of search approaches:



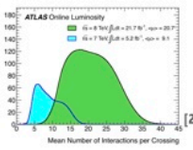
detect recoil of nuclei in a target due to **scattering** of WIMPs	look for DM **annihilation** into Standard Model (SM) particles	**production** of WIMP pairs from colliding SM particles

LHC Large **H**adron Collider (mostly **pp**)

- 27km circular tunnel
- center of mass energy: **7TeV** (2010/11), **8TeV** (2012), up to **14TeV** (2015)
- instantaneous luminosity: $8 \times 10^{33} cm^{-2} s^{-1}$ (2012), $> 10^{34} cm^{-2} s^{-1}$ (2015)

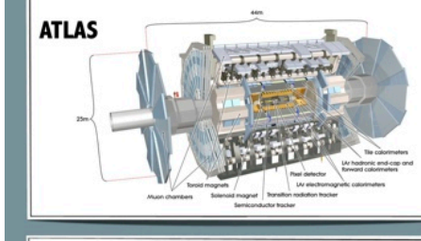


[2]



[2]

ATLAS



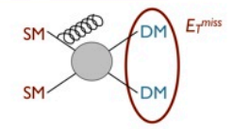
Theoretical Framework [3]

- WIMPs exist, can be pair-produced
- interaction mediated by new heavy particle
- mediator too heavy to be produced directly
- effective field theory approach
  → contact interaction
- suppression scale M_* depends on mediator mass and couplings
- for Dirac-fermionic WIMPs: 14 operators, describing different initial states/types of interaction (choose representative subset)
- cross section depends on WIMP mass (m_χ) and M_*
- E_T^{miss} spectra harder than for SM processes

operator		coefficient	initial state	type
$\bar{\chi}\chi\bar{q}q$	(D1)	$\frac{m_q}{M_*^3}$	$q\bar{q}$	scalar
$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	(D5)	$\frac{1}{M_*^2}$	$q\bar{q}$	vector
$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	(D8)	$\frac{1}{M_*^2}$	$q\bar{q}$	axial vector
$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	(D9)	$\frac{1}{M_*^2}$	$q\bar{q}$	tensor
$\bar{\chi}\chi\alpha_s(G_{\mu\nu}^a)^2$	(D11)	$\frac{1}{4M_*^3}$	gg	scalar

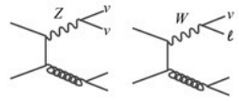
Analysis

- WIMPs do not interact in the detector
  → imbalance in detectable energy in transverse plane, E_T^{miss}
- need a 'tag'
  → energetic jet from ISR parton, recoiling against WIMP pair

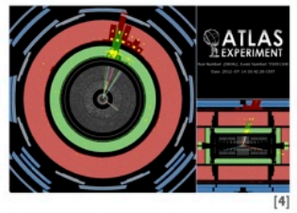


Background Contributions

- $Z(\nu\nu)$+jets: largest contribution, irreducible
- $W(\ell\nu)/Z(\ell\ell)$+jets: leptons not identified/not in acceptance
- multi-jet events (QCD): mismeasured jet(s) → E_T^{miss}
- di-boson and top quark production
- non-collision background (NCB): cosmic muons, beam halo



W/Z+jets (electroweak backgrounds): ~95% of total background



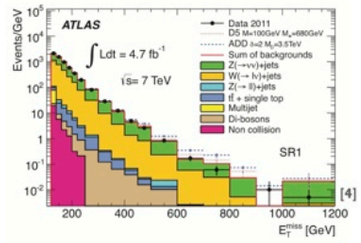
[4]

Event Selection

- high E_T^{miss} from energy deposits in calorimeter
- high p_T jet, reconstructed with antiKt (radius parameter 4)
- dedicated cuts on leading jet → reject NCB
- at most one additional jet → reject QCD
- sub-leading jet separated from E_T^{miss} → reject QCD
- veto events with identified e or μ → reject EW
- 4 signal regions (SR):
  E_T^{miss} and leading jet p_T above 120, 220, 350, 500 GeV

Background Estimation

- electroweak backgrounds:
  control regions with identified e or μ,
  transfer factors from simulation
- multi-jet background:
  control region with >1 jet,
  sub-leading jet aligned with E_T^{miss},
  extrapolate p_T spectrum into SR
- NCB: estimated in data from jet timing
- top/di-boson: directly from simulation

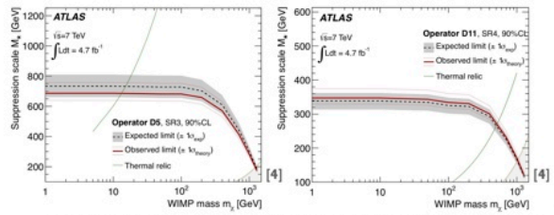


[4]

no excess above SM prediction → **exclusion limits** on cross section for new physics:
observed upper limit @90%CL: **0.026pb** (SR3), **0.055pb** (SR4) [4]

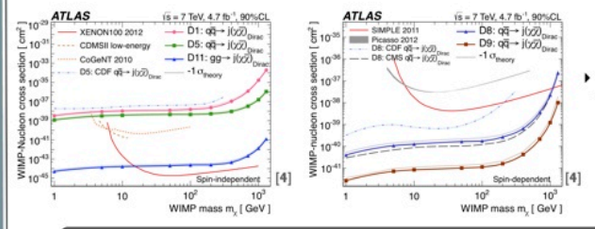
Interpretation

- **upper** limits on visible cross section translate into **lower** limits on suppression scale M_* as a function of m_χ



[4]

- limit above thermal relic line: conflict with WMAP measurement



[4]

- **collider** results are translated into limits in **direct detection** plane

spin-independent interactions: collider limits stronger at small WIMP masses
spin-dependent interactions: colliders competitive over large range of WIMP masses

Outlook

- update analysis with full 2012 dataset
  - optimisation for WIMP signal
  - include operators for scalar DM

References

[1] http://apod.nasa.gov/apod/ap060824.html
[2] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults
[3] Fox P J *et al. Phys. Rev.* D **85** 056011 (2012)
[4] ATLAS collaboration, JHEP 1304 (2013) 075

References

[1] http://apod.nasa.gov/apod/ap060824.html

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[3] Fox P J *et al. Phys. Rev.* D **85** 056011 (2012)

[4] ATLAS collaboration, JHEP 1304 (2013) 075