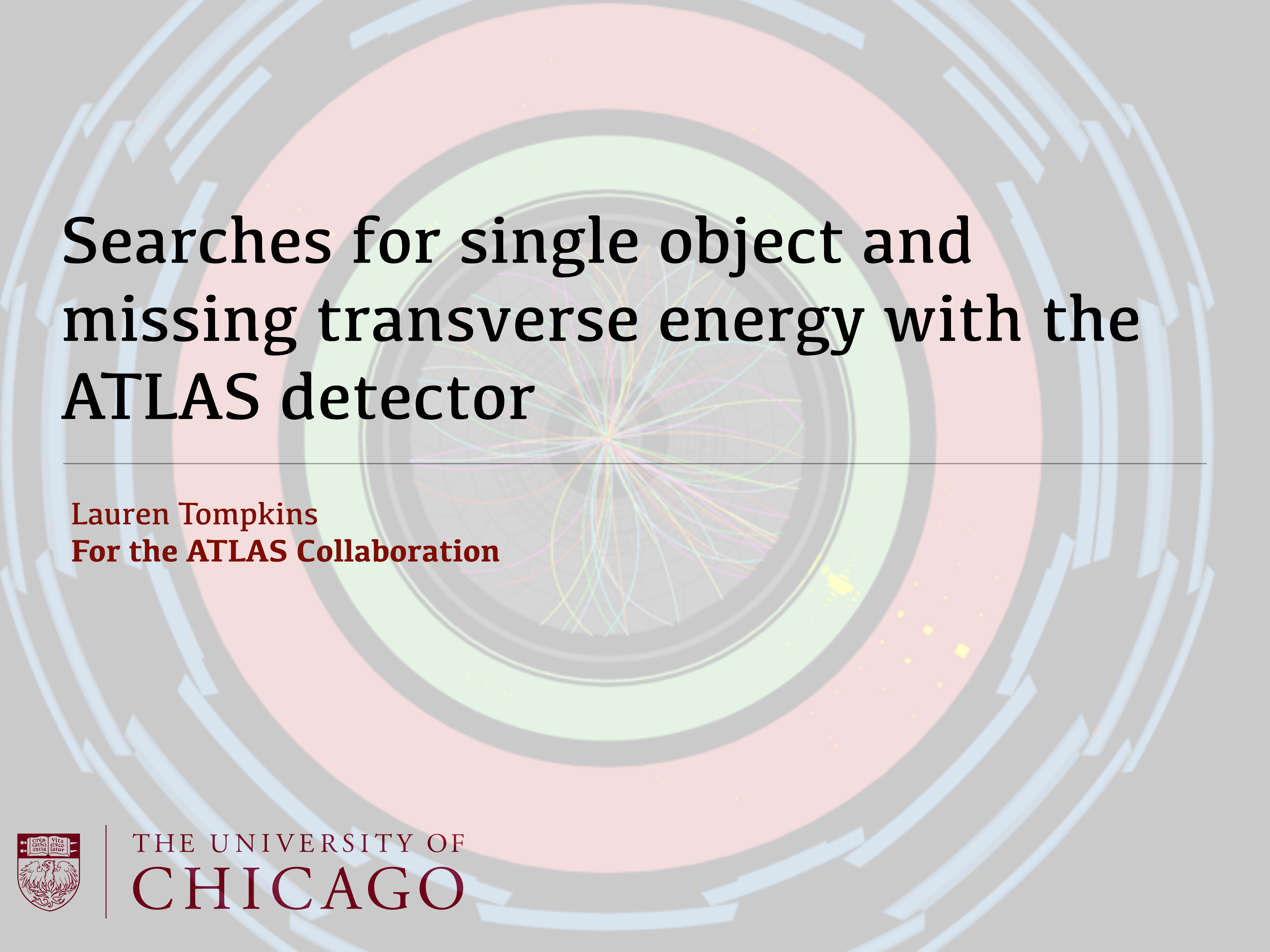
Searches for single object and missing transverse energy with the ATLAS detector



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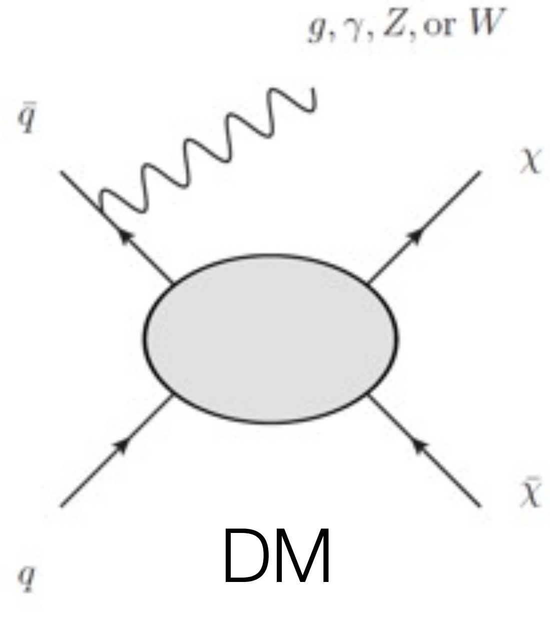
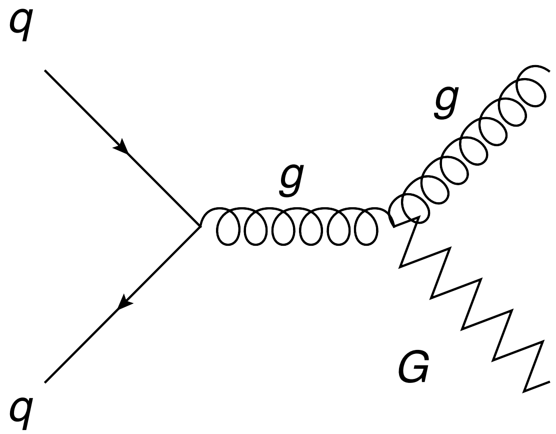
Invisible new physics

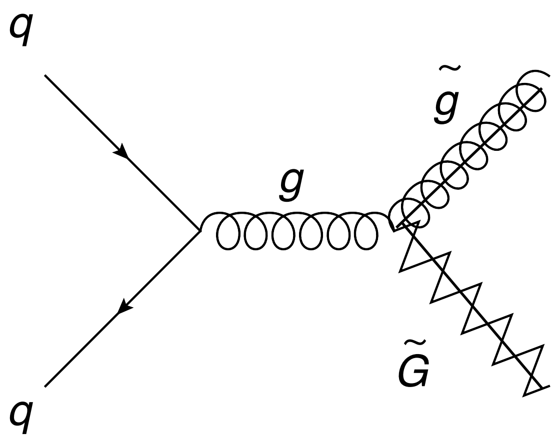
- New physics which does not decay to SM particles is well-motivated, for example:
  - Dark matter
  - Gravitons propagating in extra space-time dimensions
  - Gravitinos from super symmetric models
- But invisible objects are hard to see! Need some evidence they were produced:
  - Use standard model objects as tags:photon, jet, **W/Z**
- Single object + missing energy signatures are a powerful, **general** search strategy for invisible new physics
  - Simple final states with well-known backgrounds



DM



Gravitons



Gravitinos

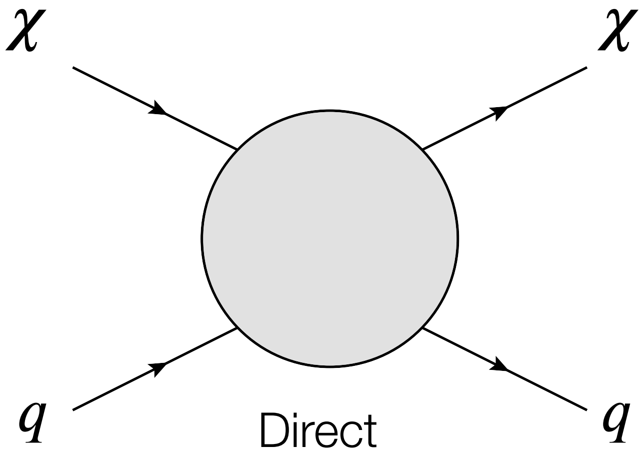
Outline

- Start with Physics motivation
- Explain the common elements of the 3 analyses
- Describe analysis and show results for:
    - **NEW** 20 fb^{-1} mono-W/Z analysis:
        - ATLAS-CONF-2013-073
    - Monojet and monophoton analysis (7 TeV & partial 8 TeV datasets)
        - Monojet: ATLAS-CONF-2012-147
        - Monophoton: arXiv:1209.4625
- Discuss interpretations as limits on new physics

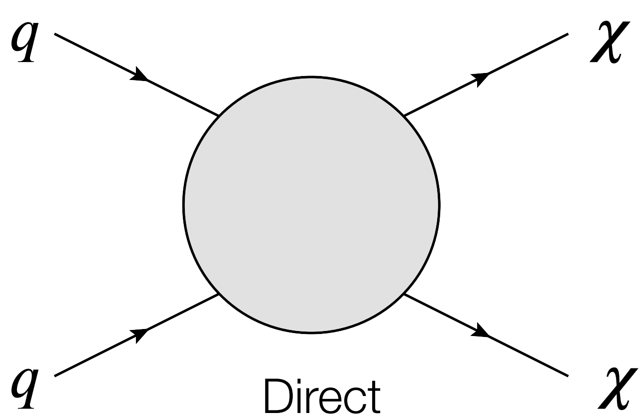
- Full results found here: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Dark Matter at Colliders

- Direct production of DM at colliders is a complementary approach to direct and indirect detection methods
  - DM is pair produced, events are tagged by ISR jet, photon or W/Z



Direct
Detection



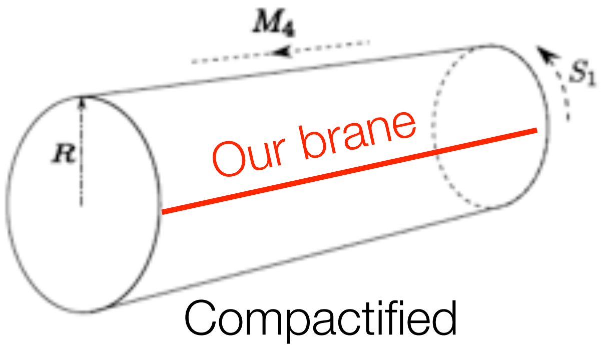
Direct
Production

- New physics is expressed with a contact interaction, use effective field theory to describe interactions in a model independent way
  - Valid when scale of interaction is less than mediator mass

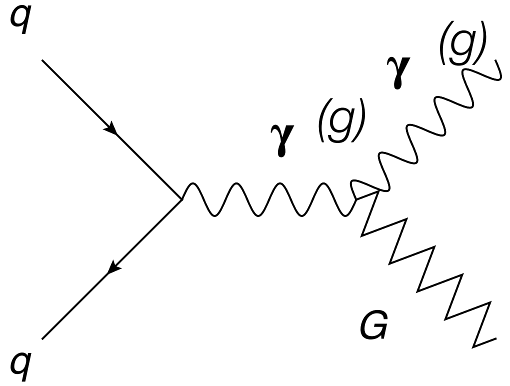
Name	Type	Operator	Coefficient
D1	scalar (qq)	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D5	vector	$\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q$	$1/M_*^2$
D8	axial-vector	$\bar{\chi}\gamma^{\mu}\gamma^5\chi\bar{q}\gamma_{\mu}\gamma^5 q$	$1/M_*^2$
D9	tensor	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D11	scalar (gg)	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
C1	scalar	$\chi^{\dagger}\chi\bar{q}q$	m_q/M_*^2

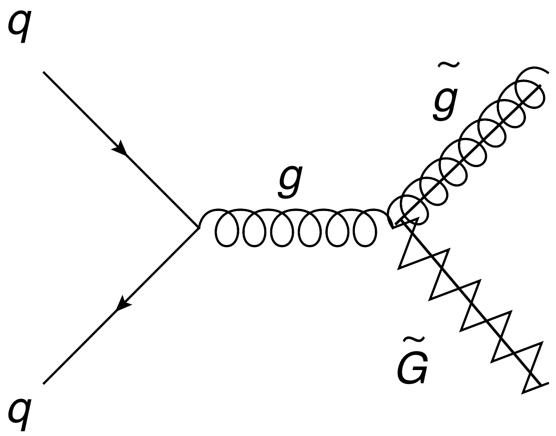
Large Extra Dimensions & Gravitinos

- LED are a proposed solution the heirarchy problem
  - Gravity exists in the other dimensions “diluting” it
  - ADD model has compact new dimensions
    - Leads to massive gravitons which can be radiated by gluons or quarks
- Introduces new fundamental scales to explain Planck mass for n extra dim: $M_{Pl}^2 = M_D^{2+n} R^n$



Compactified dimensions



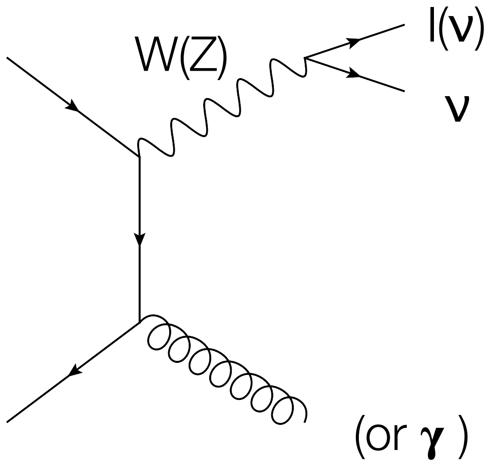


- GMSB scenario can give rise to very light gravitino related to SUSY breaking scale: $m_{3/2} \sim \langle F \rangle / \bar{M}_{pl}$
- Gravitino mass can range from few eV to TeV depending on <F>
  - Probe of very high mass physics
  - Directly constrains SUSY breaking scale
- At LHC Gravitinos are produced in association with squarks and gluinos

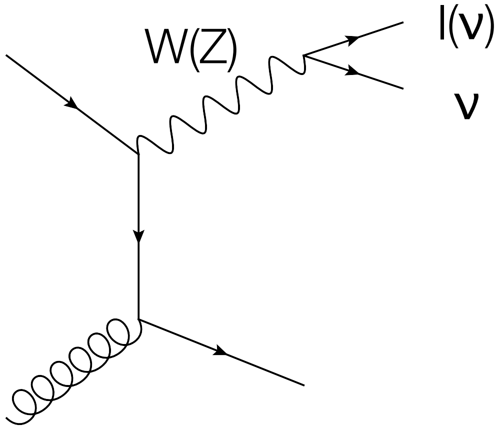
Framework for “Mono-X” analyses

- Select events with a high p_T X* and large missing energy
  - Veto on leptons to get rid of EWK backgrounds
  - Veto events where the MET is in the direction of a secondary jet in the event to get rid of MET from jet mis-measurement
  - Veto events with > 1 extra jet for top, multijet backgrounds

✳ (X= jet,γ,W/Z)



- Remaining backgrounds are
  - Irreducible, real MET + jet:
    - Dominant: Z->nunu + X
    - W->lnu, Z->ll + X where l is not measured
  - Reducible, estimated from data: Beam-backgrounds, multi-jet
  - MC driven: top, diboson



- Estimate W/Z+jets backgrounds from data from W/Z➛lepton control regions:

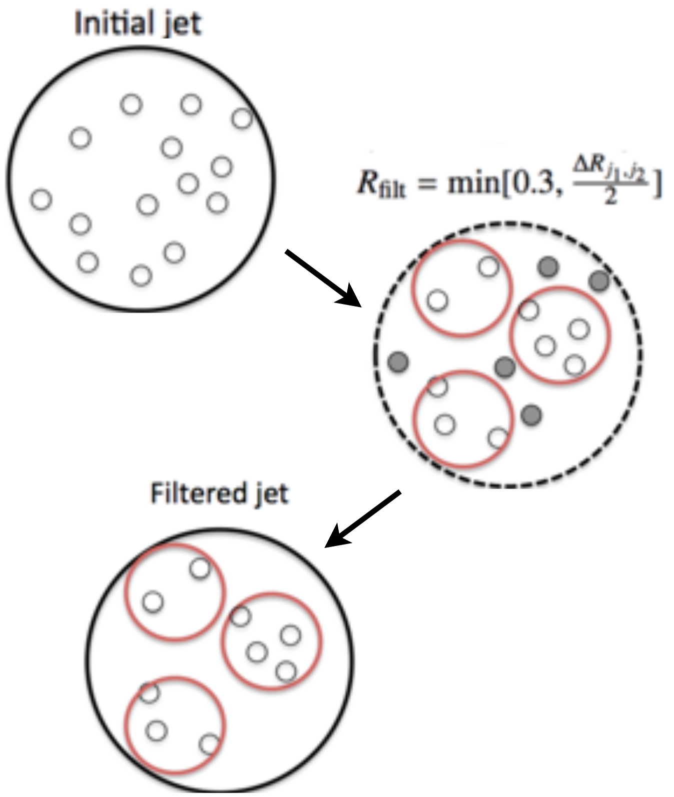
$$N_{\mathrm{b}}^{SR} = N_{\mathrm{meas}}^{CR} \times C \times \frac{N_{\mathrm{MC.b}}^{SR}}{N_{\mathrm{MC.b}}^{CR}}$$

- Then count N^{SR} events and look for SM deviations

Introducing Mono-W/Z

NEW!!

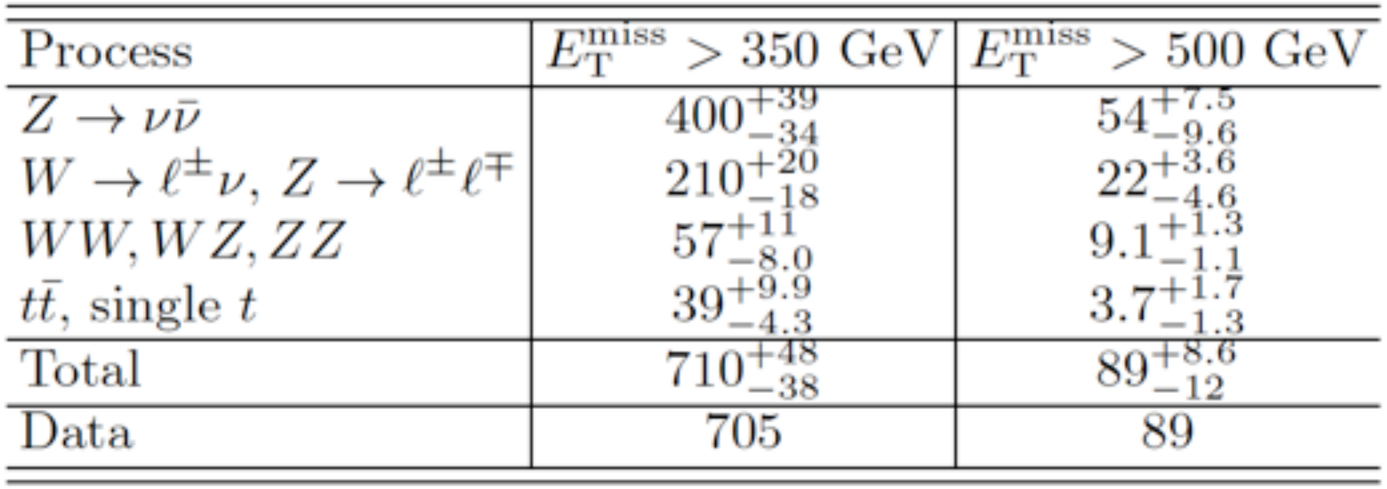
- W&Z bosons can be produced via ISR
  - Used for DM searches
  - Rate is significantly lower than QCD ISR,but DM interactions can lead to signal enhancements through positive interference
- To maximize the limited statistics, look for hadronic W&Z decays
- Hadronic W/Z Selection:
  - Cambridge-Aachen filtered large-R jet* with
    - $p_T > 250$ GeV, $|\eta| < 1.2$,
    - 50 GeV < M_{jet} < 120 GeV
    - $\sqrt{y} > 0.4$, where $\sqrt{y} = \min(p_{T1}, p_{T2})/M_{jet}\Delta R_{1,2} = \sqrt{d_{12}}/M_{jet}$
- Two signal regions:
  - MET > 350 GeV, 500 GeV



*for details on jet substructure performance, see:arXiv:1306.4945

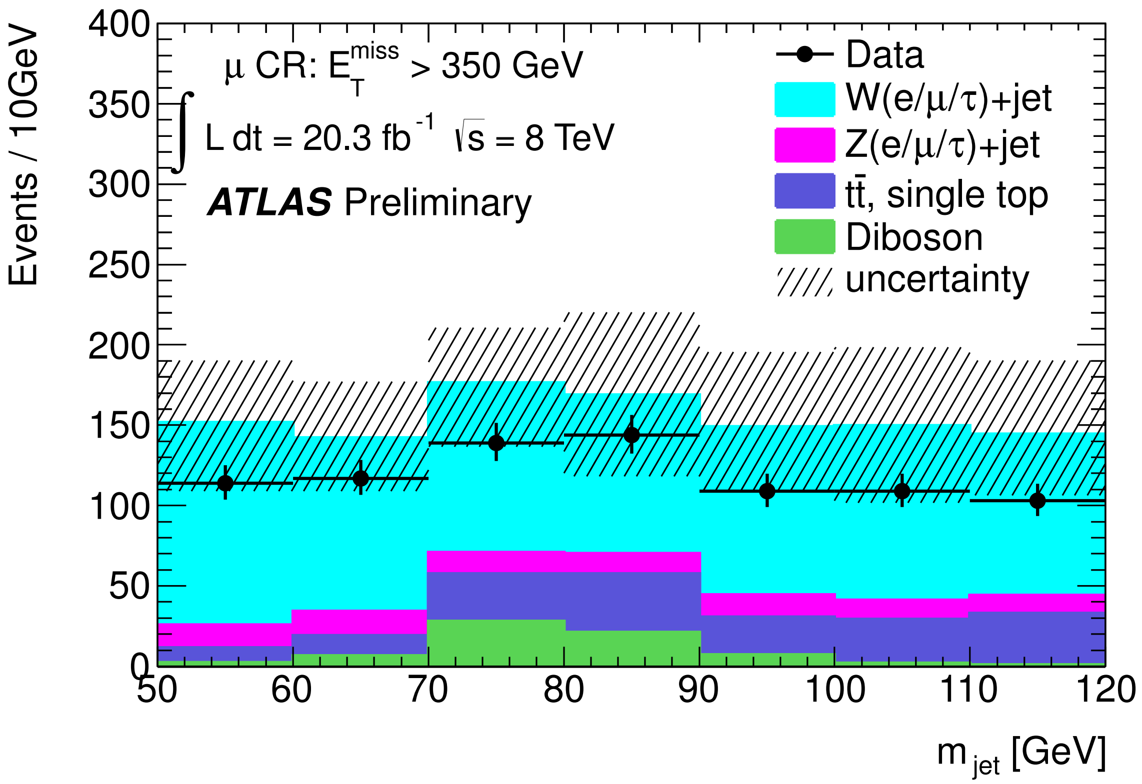
Backgrounds

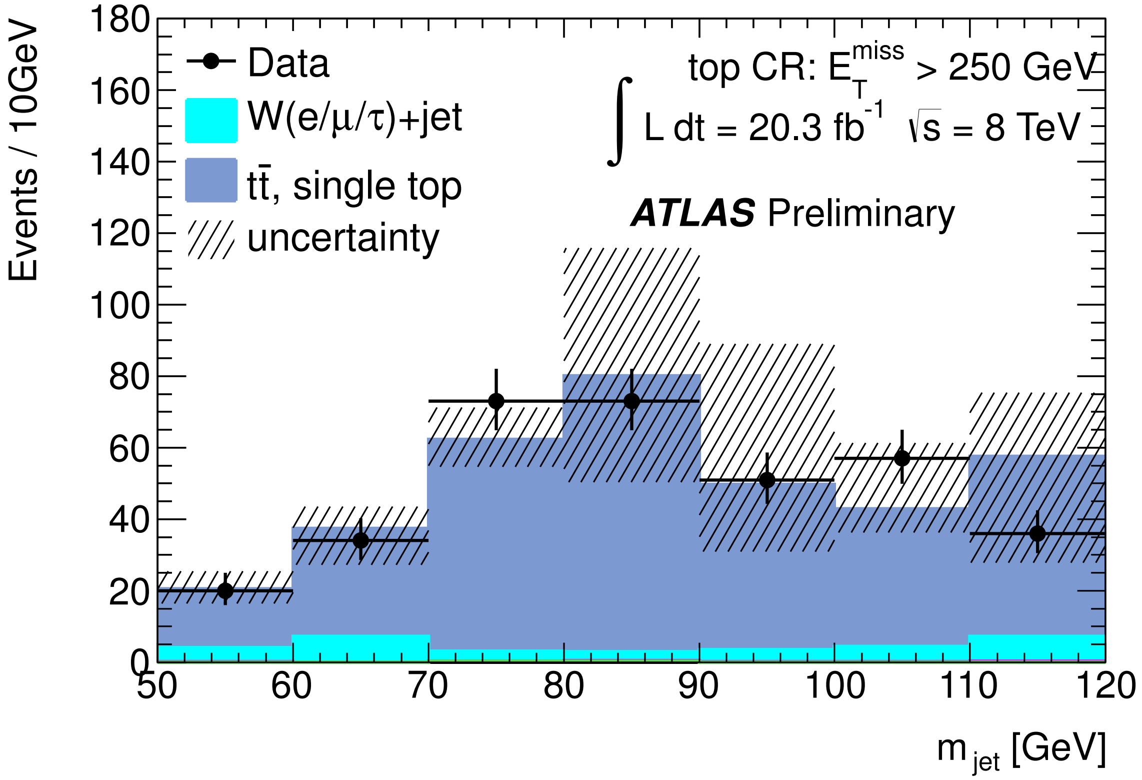
- Control regions: W➛μν, Z➛μμ, ttbar
  - ttbar to validate hadronic W reconstruction



Process	$E_T^{\text{miss}} > 350$ GeV	$E_T^{\text{miss}} > 500$ GeV
$Z \to \nu\bar{\nu}$	400^{+39}_{-34}	$54^{+7.5}_{-9.6}$
$W \to \ell^{\pm}\nu,\ Z \to \ell^{\pm}\ell^{\mp}$	210^{+20}_{-18}	$22^{+3.6}_{-4.6}$
WW, WZ, ZZ	$57^{+11}_{-8.0}$	$9.1^{+1.3}_{-1.1}$
$t\bar{t}$, single t	$39^{+9.9}_{-4.3}$	$3.7^{+1.7}_{-1.3}$
Total	710^{+48}_{-38}	$89^{+8.6}_{-12}$
Data	705	89

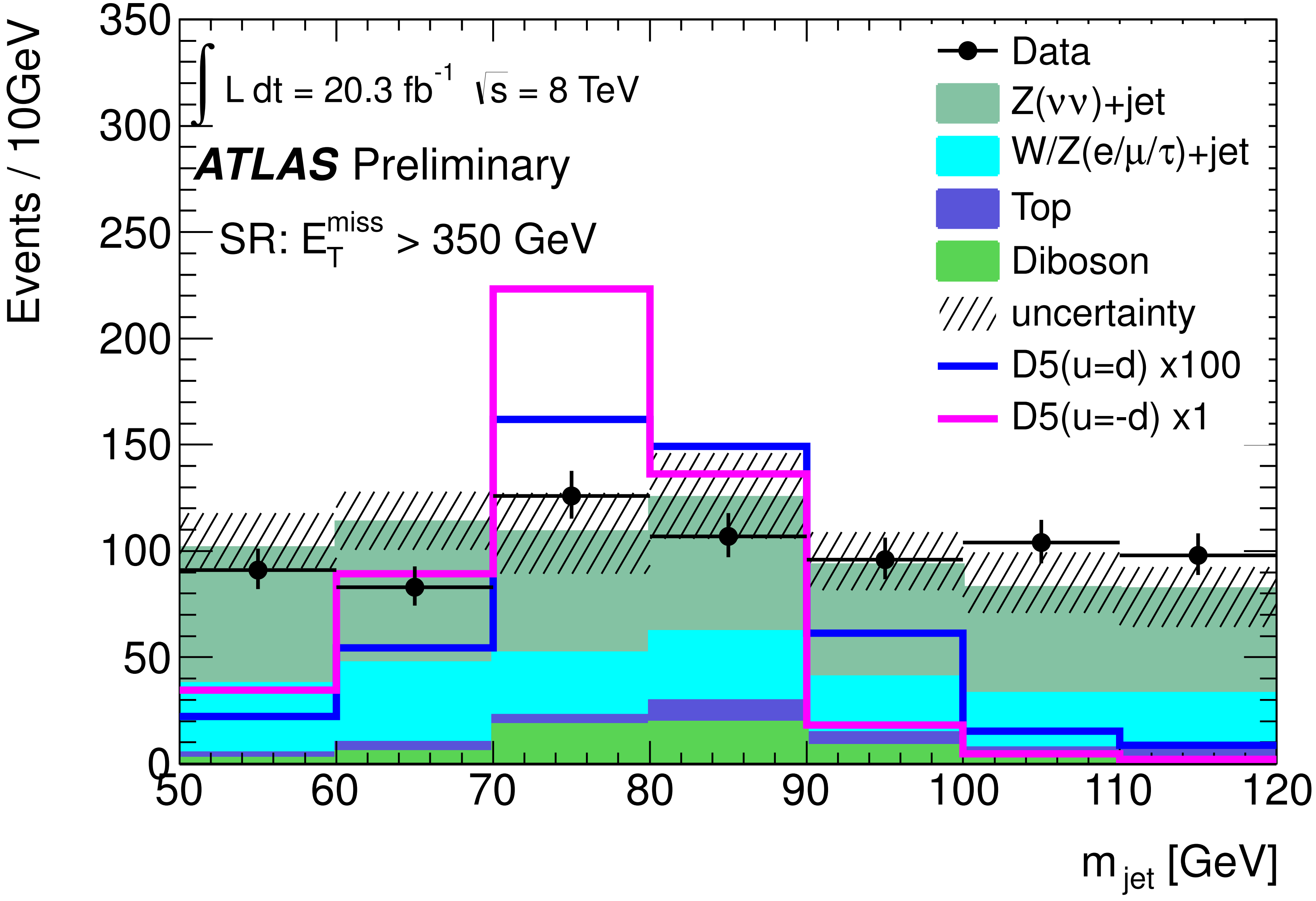
- Primary background source (85%): Z/W + jets
  - QCD jet passes hadronic W/Z selection
- Uncertainty dominated by limited CR statistics





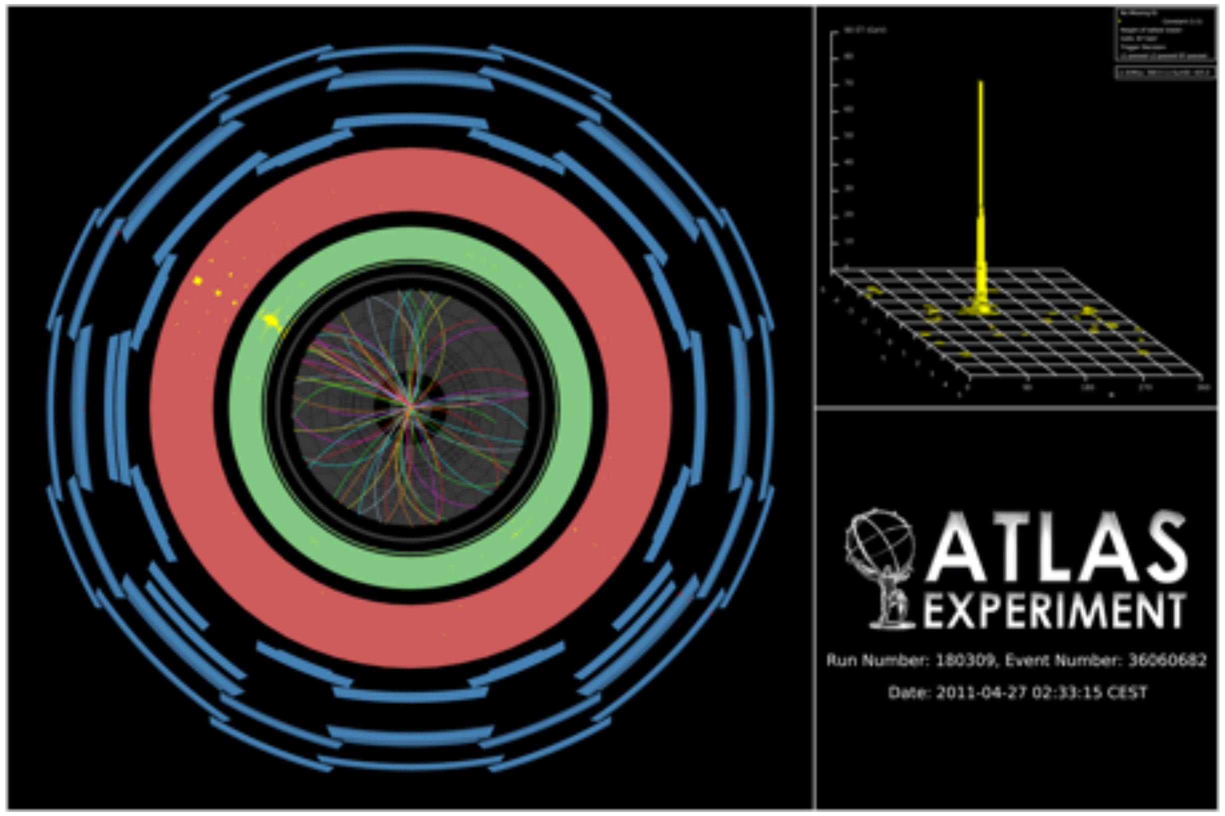
Results

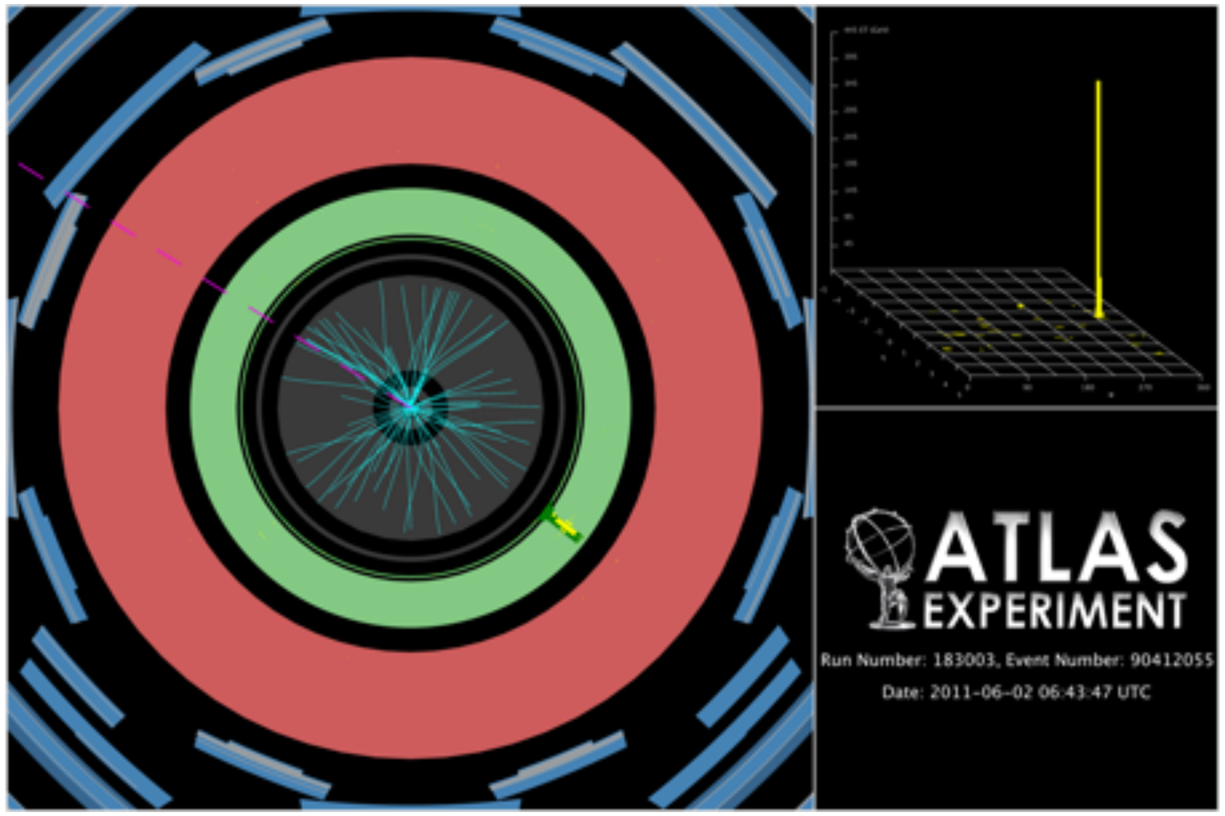
- No excess over the standard model found



Monojet & Monophoton Analyses

- Mono-jet: require R = 0.4 anti k_T jet with p_T > 120 GeV, MET > 120 GeV
  - 4 signal regions with symmetric jet p_T and MET cuts: >120 GeV, > 220 GeV, > 350 GeV and > 500 GeV
  - Results from 8 TeV, 10.5 fb^{-1}

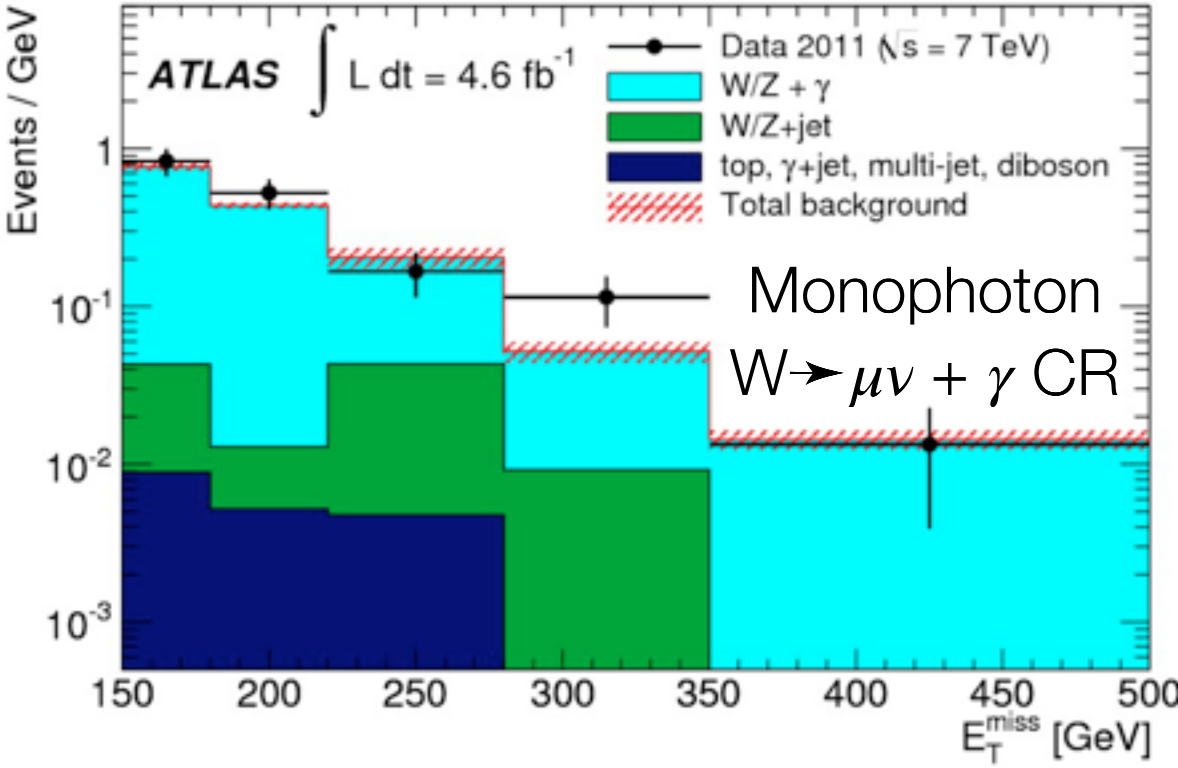




- Mono-photon: require high p_T, isolated photon with p_T > 150 GeV, MET > 150 GeV
  - Results from 7 TeV, 4.6 fb^{-1}

Backgrounds

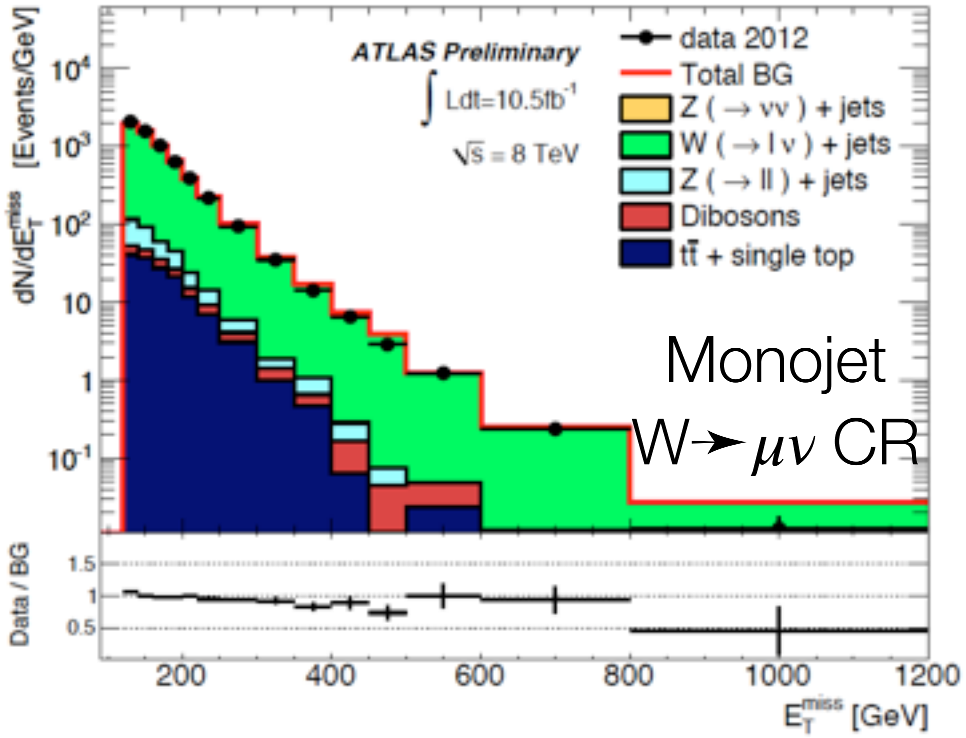
- W/Z+jet(γ) make up 97-98% of background
- Uncertainty dominated by MC stats on CR extrapolation factors
- Monojet:
    - 350 GeV SR expect ~2200 evts
- Monophoton: expect ~140 evts



Monophoton

W➛$\mu\nu$ + γ CR

Bkgd **Mono-jet**	$N_{\rm exp}^{\rm SR3}$ ± (stat.data) ± (stat.mc) ± (sys)
W/Z + jets	2164 ± 51 ± 102 ± 69
$t\bar{t}$ + single t + $WW/WZ/ZZ$	21 ± - ± 3 ± 3
Multijet + Non-collision	-
Total	2180 ± 70 ± 120 ± 100



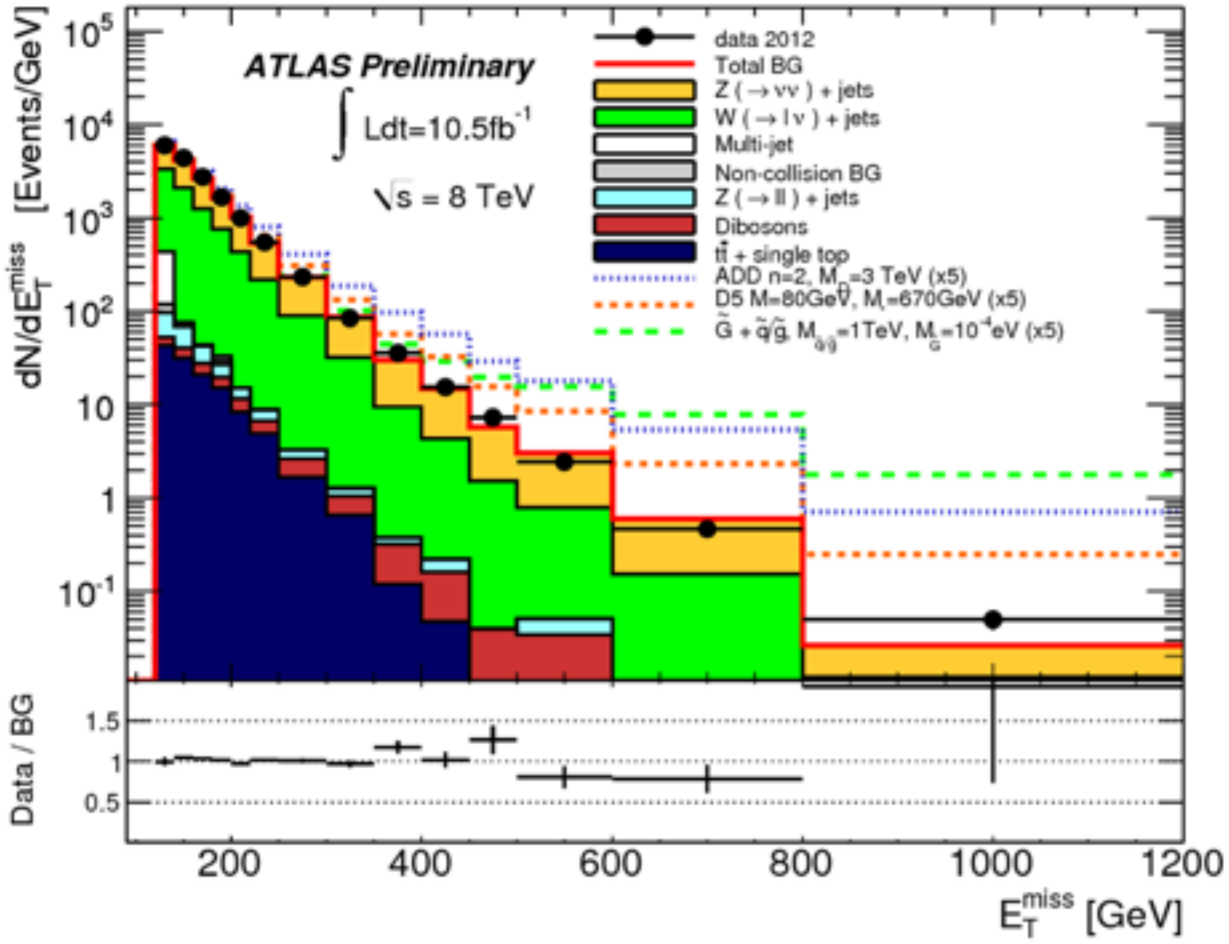
Monojet

W➛$\mu\nu$ CR

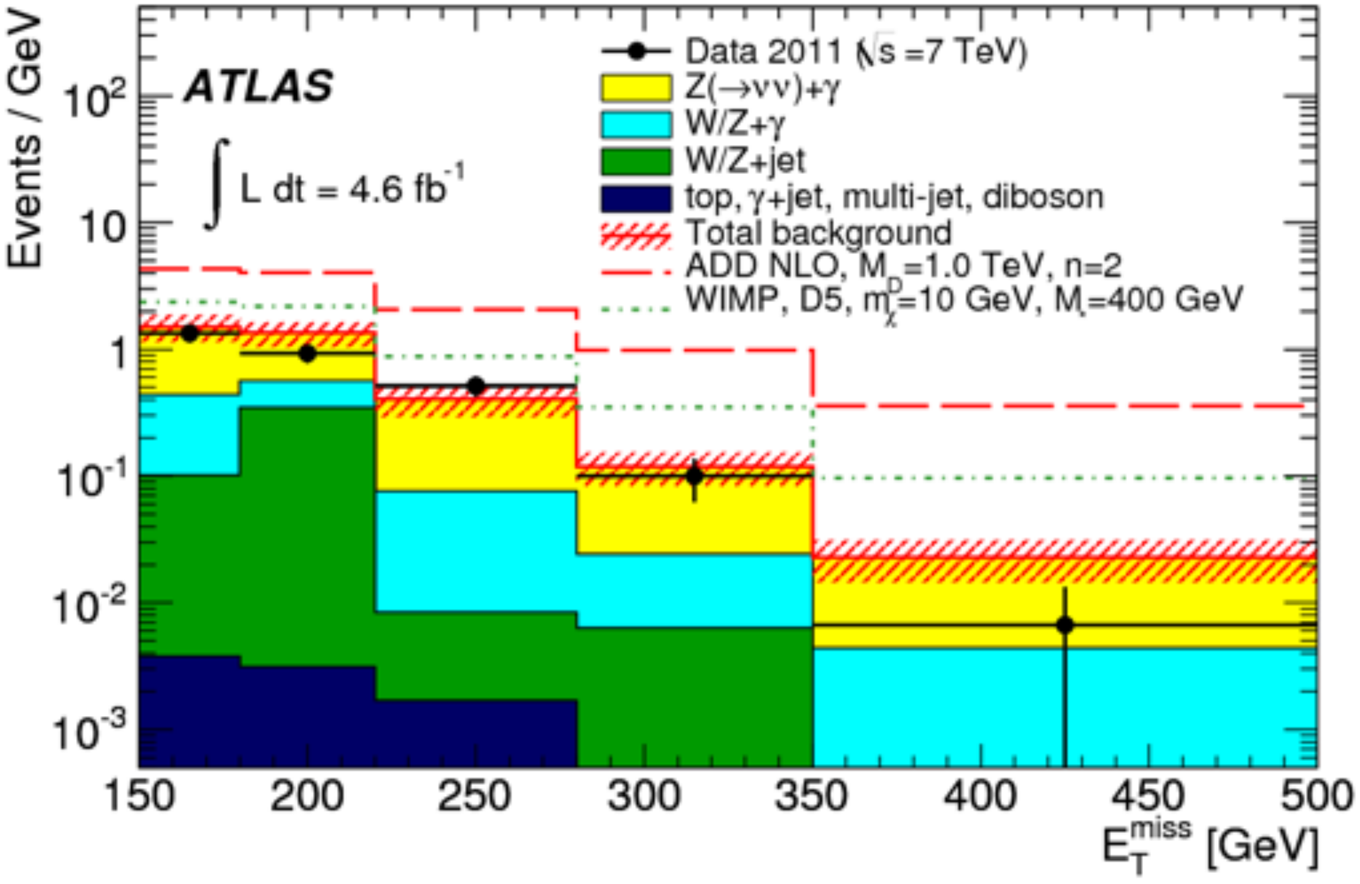
Bkgd **Mono-photon**	$N_{\rm exp}$ ± (stat) ± (sys)
W/Z + γ	117.4 ± 16.8 ± 8.2
W/Z + jets	18 ± - ± 6
$t\bar{t}$ + single t + $WW/WZ/ZZ/\gamma\gamma$	0.4 ± 0.1 ± 0.1
Multijet + γ + jets	1.0 ± - ± 0.5
Total	137 ±17 ± 9

Results

Mono-jet



Mono-photon

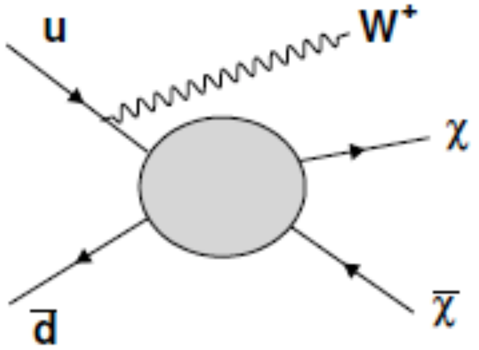


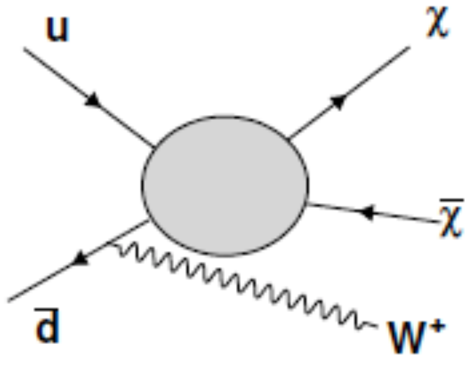
- Good agreement with Standard Model seen for both analyses in all signal regions
  - Monojet (SR3): Exp. 2180±170, Obs. 2353
  - Monophoton: Exp. 137±20, Obs. 116

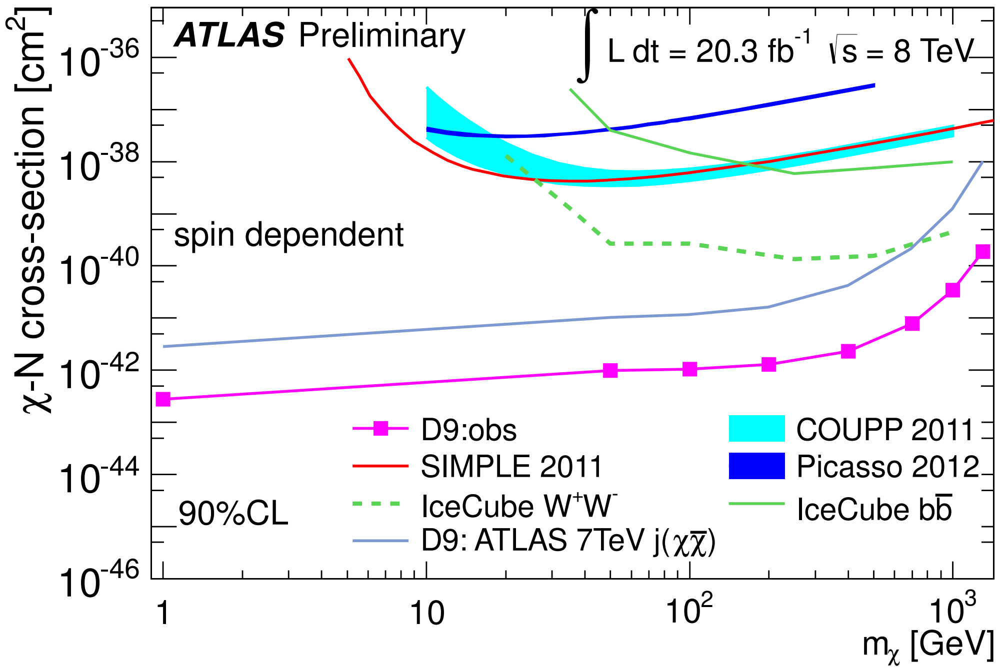
Interpretations

Dark Matter
Extra Dimensions
Gravitino production

Mono-W/Z Limits



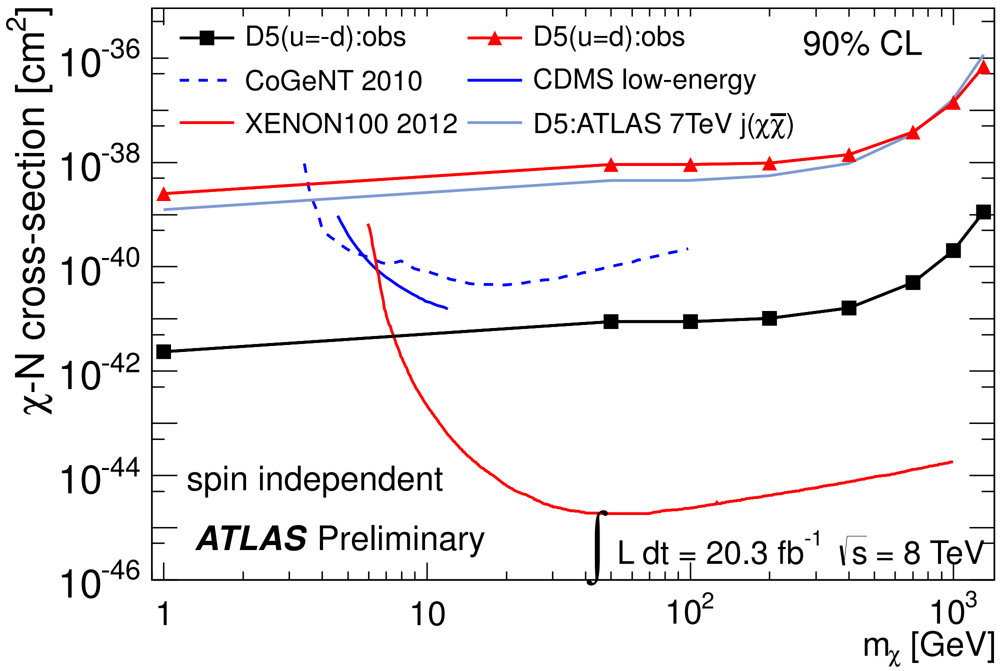




- Limits expressed in terms of m_χ , χ-n cross-section and M*

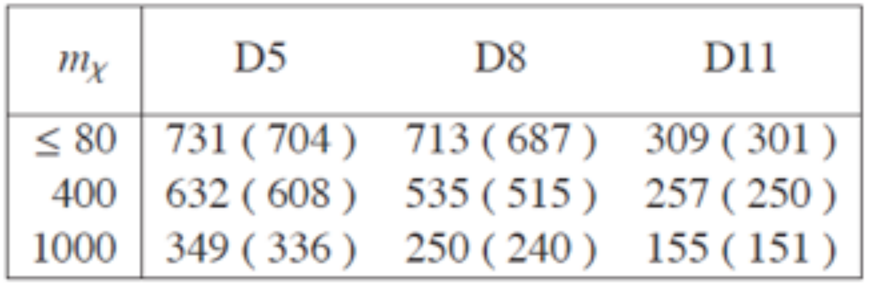
- Set strong spin-dependent limits
  - Tensor operator (D9)

- Vector operator (D5) spin-independent limits also very strong when u & d have opposite coupling



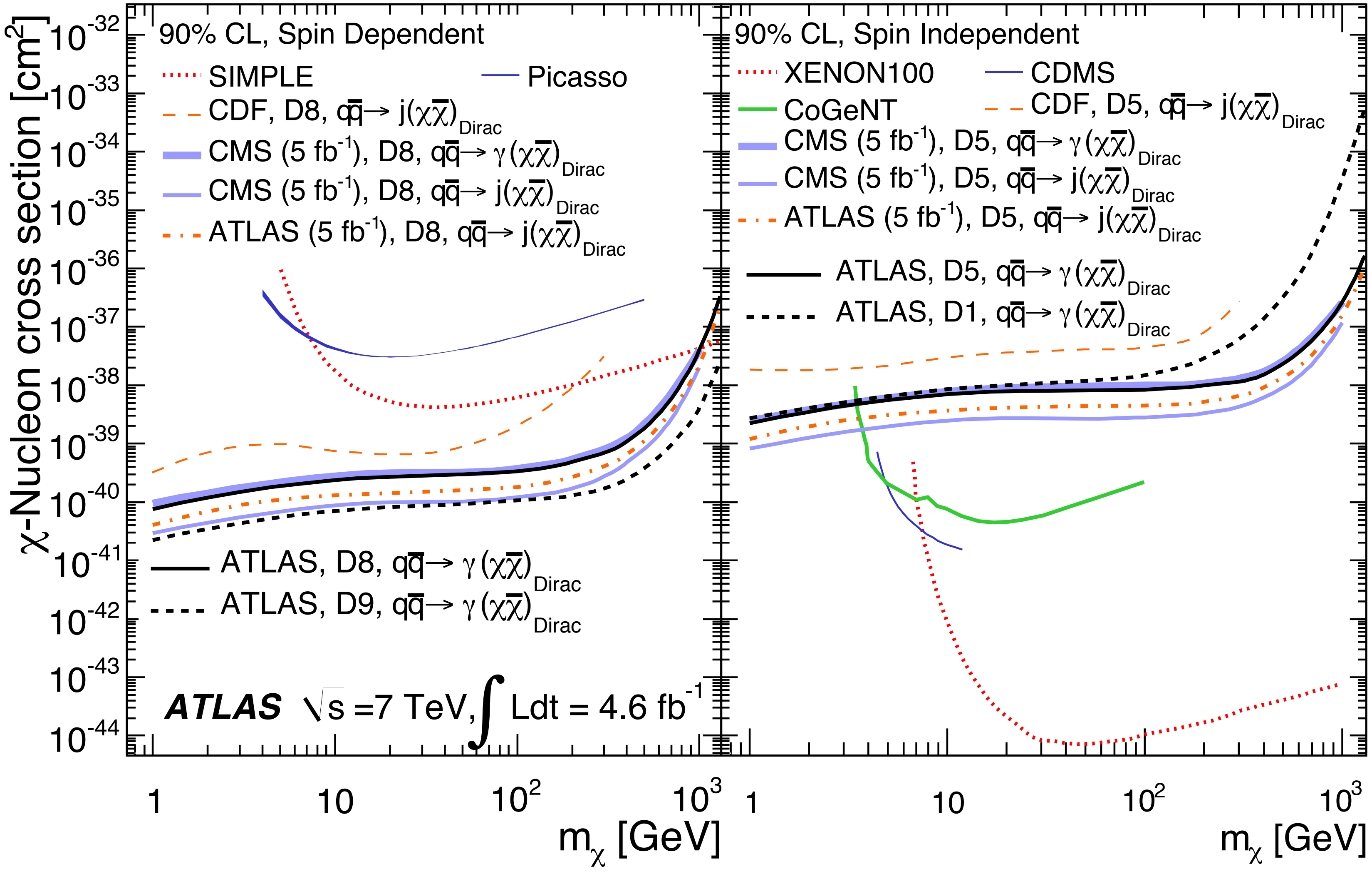
Mono-photon and jet limits

Monojet 10.5 fb^{-1} M* limits



m_χ	D5	D8	D11
≤ 80	731 (704)	713 (687)	309 (301)
400	632 (608)	535 (515)	257 (250)
1000	349 (336)	250 (240)	155 (151)

Monophoton + Monojet 5 fb^{-1} limits

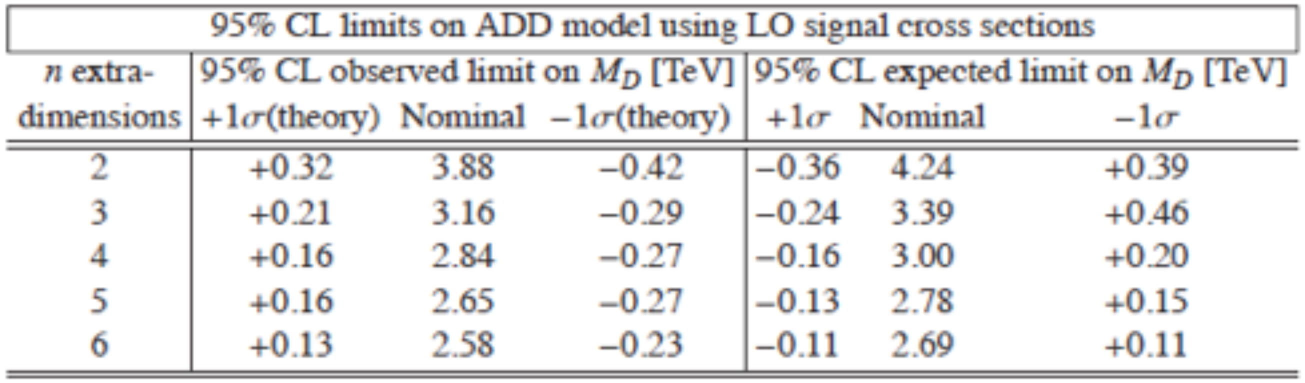


- Within EFT framework, **low mass** and **spin-dependent** limits are stronger than direct detection limits

ADD Limits

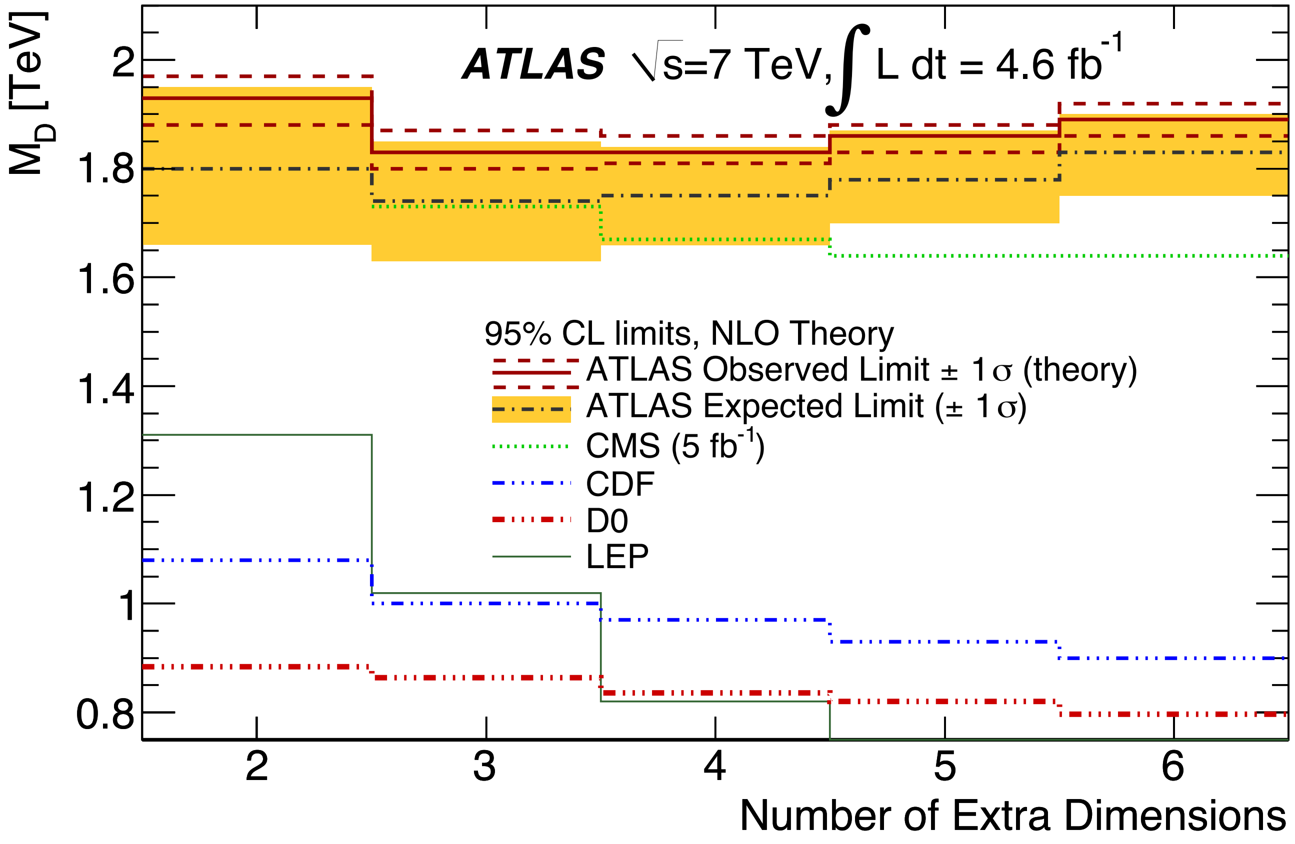
$$M_{Pl}^2 = M_D^{2+n} R^n$$

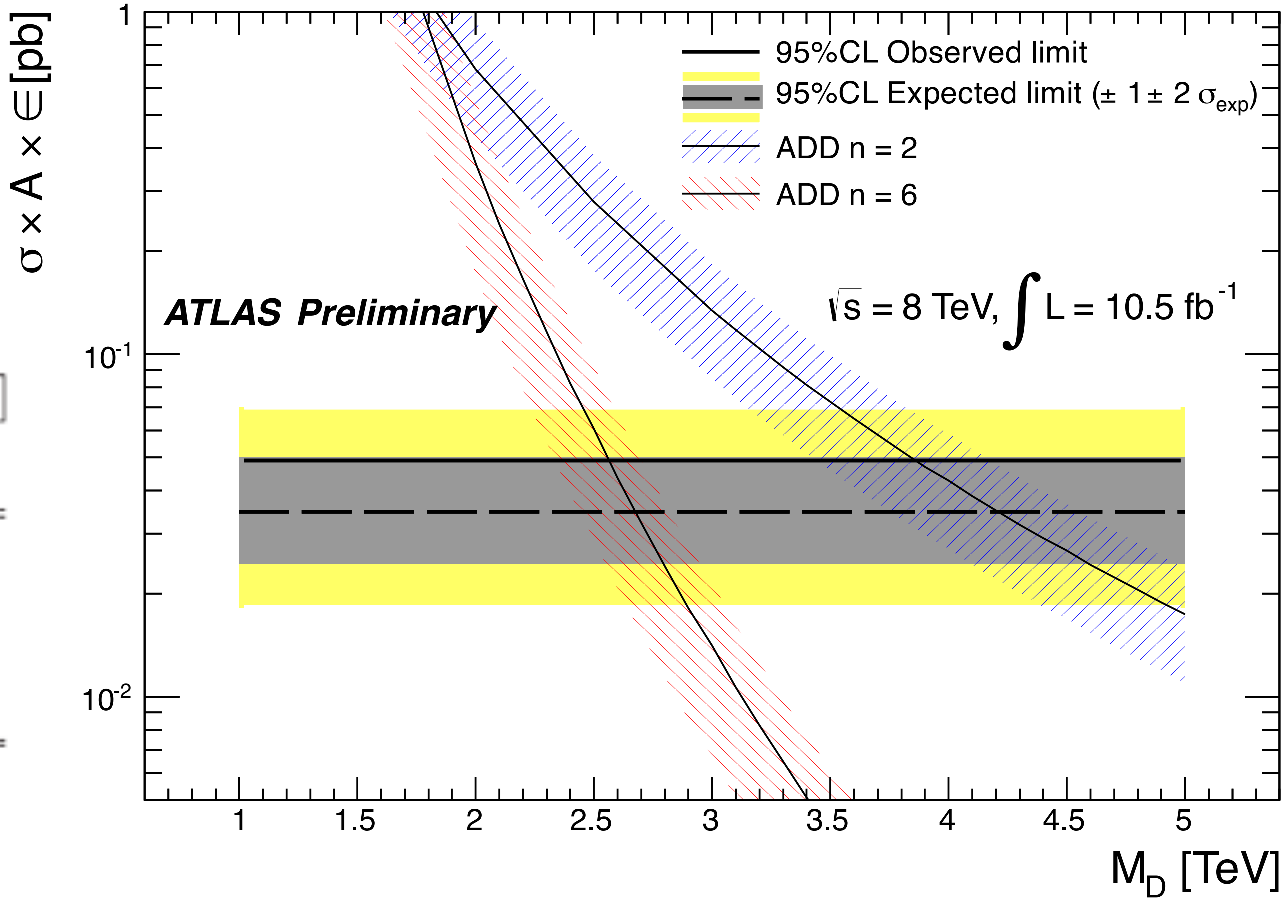
- Both analyses set limits up to n = 6 for M_D
- Monojet 8 TeV limits (10 fb^{-1}):
    - 2.5-3.9 TeV
- Monophoton 7 TeV limits (5 fb^{-1}):
    - 1.8-1.9 TeV



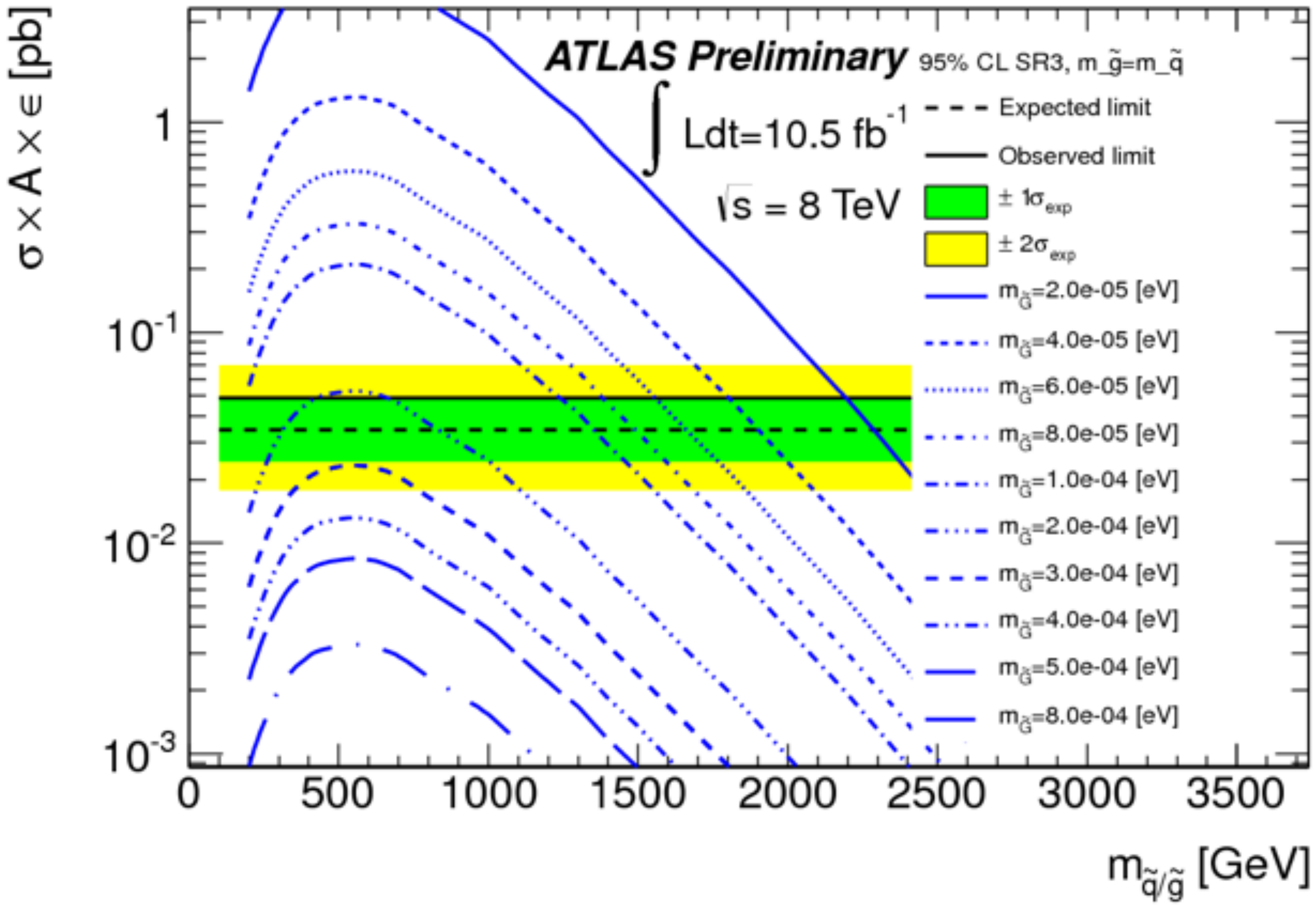
95% CL limits on ADD model using LO signal cross sections

n extra-dimensions	95% CL observed limit on M_D [TeV]			95% CL expected limit on M_D [TeV]		
	$+1\sigma$(theory)	Nominal	-1σ(theory)	$+1\sigma$	Nominal	-1σ
2	+0.32	3.88	−0.42	−0.36	4.24	+0.39
3	+0.21	3.16	−0.29	−0.24	3.39	+0.46
4	+0.16	2.84	−0.27	−0.16	3.00	+0.20
5	+0.16	2.65	−0.27	−0.13	2.78	+0.15
6	+0.13	2.58	−0.23	−0.11	2.69	+0.11





Gravitino Production



- Gravitino production limits set by 10 fb^{-1} monojet analysis:
  - M_G > 2e-4 eV
  - √F > 645 GeV

$$m_{3/2} \sim \langle F \rangle / \bar{M}_{pl}$$

Conclusions

- Presented results for new physics in mono-jet, photon, W&Z and missing transverse energy searches
- Good agreement is found with the Standard Model
- Limits set for 3 different new physics scenarios:
  - Dark Matter (jet, photon, W/Z)
  - Graviton from LED (jet, photon)
  - Gravitino (jet)
- Updates to mono-jet with full 2012 dataset expected by end of the summer

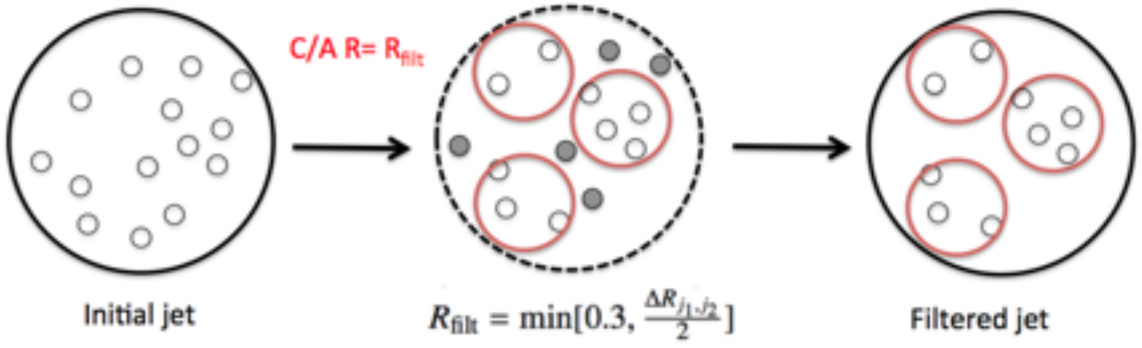
Additional Material

Mono W/Z Event Selection

- Event Selection:
  - Cambridge-Aachen filtered large-R jet* with
    - $p_T > 250$ GeV, $|\eta| < 1.2$,
    - 50 GeV < M_{jet} < 120 GeV
    - $\sqrt{y} > 0.4$, where $\sqrt{y} = \min(p_{T1}, p_{T2})/M_{jet}\Delta R_{1,2} = \sqrt{d_{12}}/M_{jet}$
  - MET > 250 GeV
  - No more than 1 additional anti-k_T 0.4 jet with $p_T > 40$ GeV, $|\eta| < 4.5$
  - $\Delta\phi(\text{jet}_2, \text{MET}) < 0.4$
  - Lepton veto

Large-R Jet Reconstruction

- For highly boosted objects objects, decay products have narrow dR distribution
- To recover efficiency & resolution:
  - Use a single large R Cambridge/Aachen jet encompassing all decay products
  - Revert last step of clustering and look for two low mass, symmetric sub-jets
  - Recluster constituents of sub-jets, keep 3 hardest new sub-jets
- Process greatly improves jet mass measurement, QCD separation



arXiv:1306.4945