Searches for Physics beyond the Standard Model in Monojet and Monophoton events with the ATLAS Detector

7TeV Monojet (submitted to JHEP):
arxiv:1210.4491
7TeV Monophoton (submitted to PRL):
arxiv:1209.4625

8TeV Monojet:
ATLAS-CONF-2012-147

Kruger2012 Workshop
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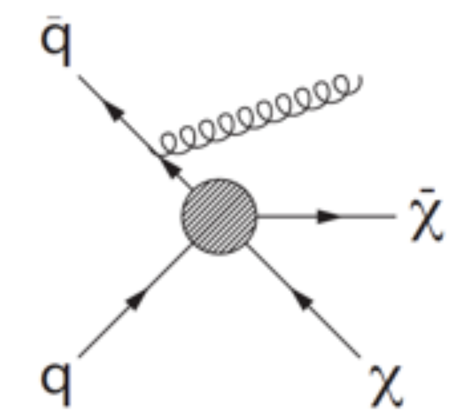
Ruth Pöttgen
on behalf of the
ATLAS Collaboration

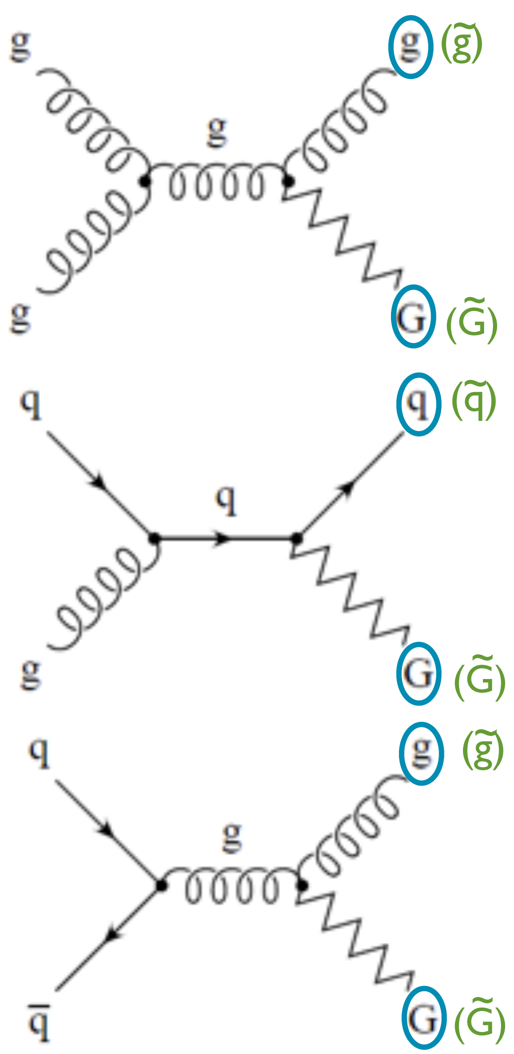
PRiSMA
Bundesministerium für Bildung und Forschung
BMBF-Forschungsschwerpunkt ATLAS Experiment
Physics on the TeV-scale at the Large Hadron Collider
FSP 101 ATLAS
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ
CERN
ATLAS

Introduction

- various models for new physics predict new particles that do not interact in the detector
- signature: unbalanced jet or photon => missing transverse energy (E_T^{miss})
  - from ISR
    - pair production of Weakly Interacting Massive Particles (WIMP)
      - dark matter candidates

monophoton@7TeV
monojet@7TeV
monojet@8TeV





- in the final state
  - production of ADD graviton of Large Extra Dimensions (LED)
    - ingredients to solution to hierarchy problem

monophoton@7TeV
monojet@7TeV
monojet@8TeV

first time at ATLAS

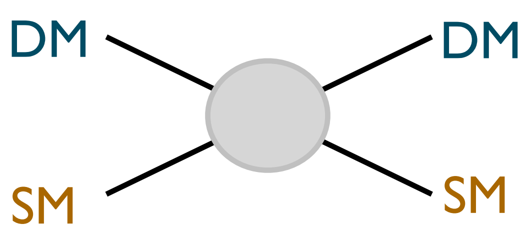
  - production of squark/gluino together with a gravitino
    → parton + gravitino
    - gauge-mediated SUSY breaking (GMSB) scenarios
    - gravitino as LSP

monojet@8TeV

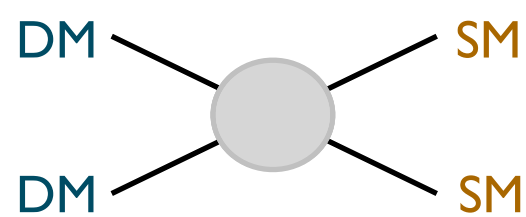
WIMP Pair Production

http://arxiv.org/abs/1008.1783

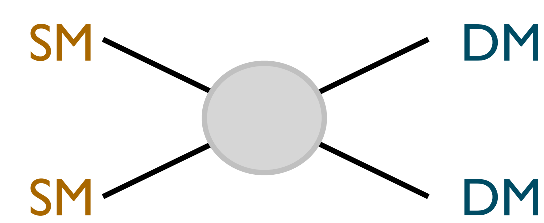
- WIMPs popular candidate for dark matter (DM)
- different search approaches:



indirect
(WIMP-nucleon scattering)



direct
(annihilation)



collider searches
(pair production)

- assumption: interaction mediated by a new particle too heavy to be directly produced @LHC
  - effective field theory approach (contact interaction)

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

- suppression scale of effective theory: M_*

$$M_* \sim \frac{M}{\sqrt{g_\chi g_{SM}}}$$

- M: mediator mass
- g_χ : coupling to DM
- g_{SM} : coupling to SM

LED ADD Graviton

http://arxiv.org/abs/hep-ph/9803315v1

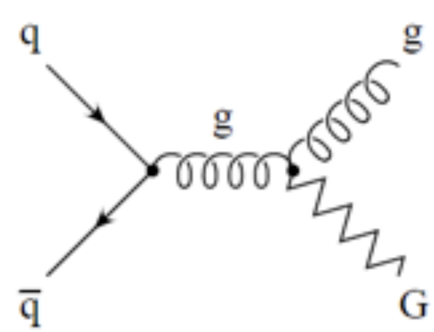
- Arkani-Hamed, Dimopoulos, Dvali model of large extra dimensions (LED)
- possible way to solve hierarchy problem
- gravity propagates in 4+n-dimensional bulk of space-time

  => fundamental Planck scale M_D

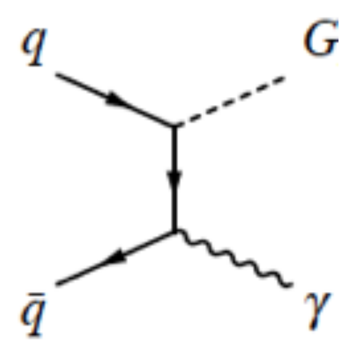
  related to 4-dimensional Planck scale (M_{Pl}) as $M_{Pl}^2 \sim M_D^{2+n} R^n$

  - n: number of extra dimensions
  - R: size of extra dimensions

- appropiate choice of R for given n results in M_D of O(TeV)
- compactification of extra dimension => Kaluza-Klein towers of massive Graviton modes



monojet signature



monophoton signature

Gravitino Production

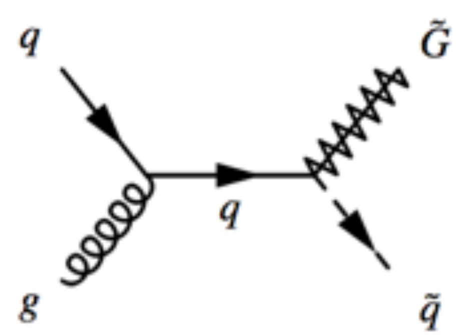
http://arxiv.org/abs/hep-ph/0610160v2

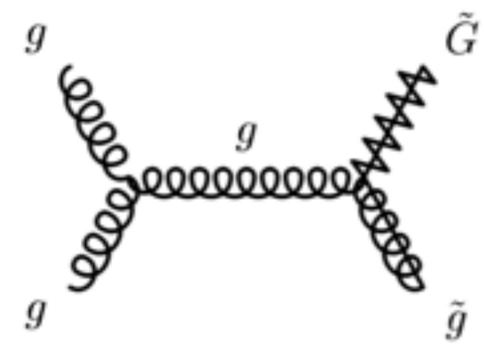
- gauge-mediated SUSY breaking (GMBS) scenarios: gravitino often assumed LSP

  mass ~10^{-4}-10^{-5}eV

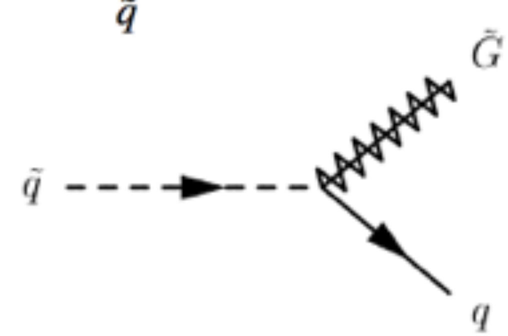
- gravitino Dark Matter candidate (though not uniquely, too light)

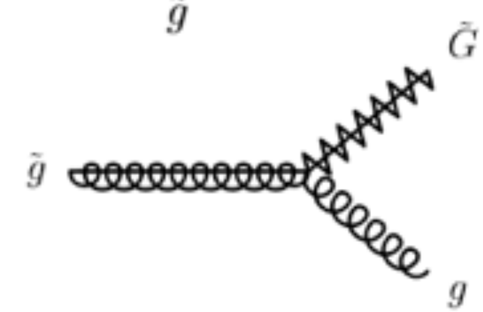
- gravitino mass $m_{\tilde{G}}$ related to SUSY breaking scale F: $m_{\tilde{G}} \sim F/M_{Pl}$
- cross section for gravitino-squark/gluino production $\sim 1/(m_{\tilde{G}})^2$
  - becomes dominant in scenarios with very light gravitinos (low-scale SUSY breaking)





- superparticle decays further, dominantly in quark/gluon+gravitino

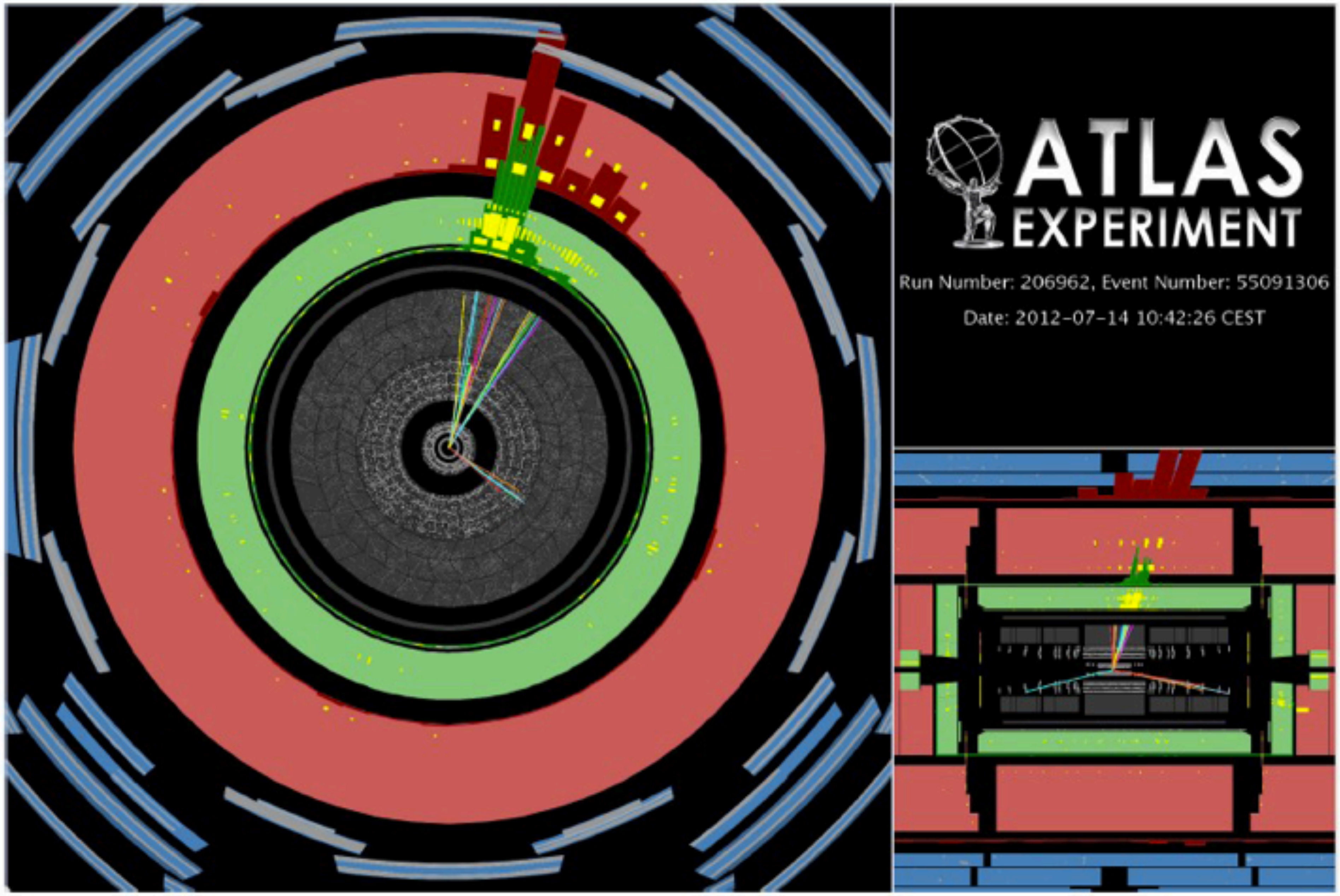




- results in jet + missing transverse energy from gravitinos

Monojet Event Candidate in ATLAS

- from 2012 data



- E_T^{miss} = 863 GeV
- jet p_T = 852 GeV

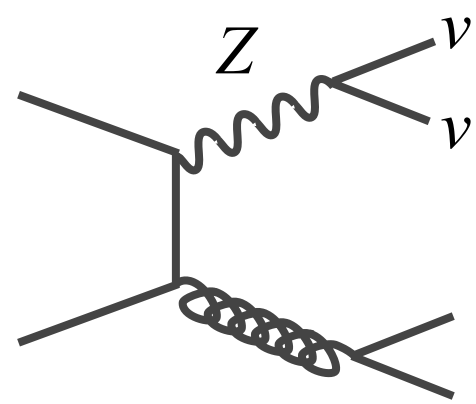
Background Contributions

data driven

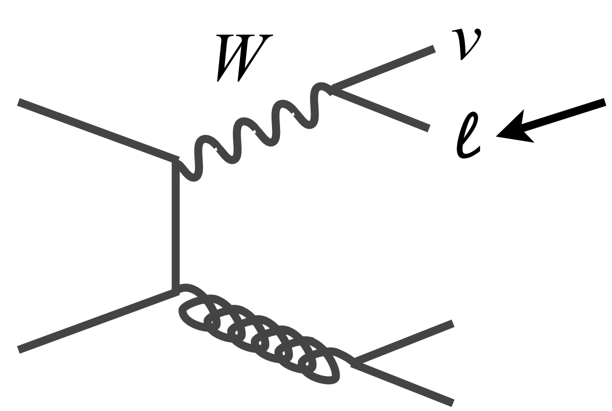
- $Z(\nu\nu)$ + jet/photon
  - irreducible, largest contribution
- $W(\ell\nu)/Z(\ell\ell)$ + jet/photon
  - leptons not identified
  - W/Z+jets contributes to monophoton when jet or electron mis-reconstructed as photon
- Multi-jet/γ+jets
- Non-collision background (NCB)
  - beam halo, cosmic muons...

} *small contribution (≤ 1-2%)*

monojet/monophoton/both



jet/γ or
jet mis-identified as γ



undetected or hadronic τ decay/
mis-identified as γ

jet/γ or
jet mis-identified as γ

purely simulation based

- single top
- $t\bar{t}$
- Diboson/Diphoton

} *small contribution (≤ 1-2%)*

Event Selection

MONOJET (2011/2012)

- E_T^{miss} trigger
- good data quality (4.7/fb, 10.5/fb)
- primary vertex, jet cleaning
- at most 2 jets with p_T>30GeV, $|\eta|$<4.5
- $|\Delta\varphi(E_T^{miss}, 2^{nd}\ jet)|>0.5$
- leading jet: $|\eta|$<2.0 (central)
- 4 signal regions (SR)
  - symmetric cuts on E_T^{miss}, leading jet p_T
  - lower bounds: [120, 220, 350, 500] GeV
- lepton vetos (electron, muon)

MONOPHOTON (2011)

- E_T^{miss} trigger
- good data quality (4.6/fb)
- primary vertex, jet cleaning
- at most 1 jet with p_T>30GeV, $|\eta|$<4.5
- overlap removal for E_T^{miss}, γ and jet
- photon: $|\eta|$<2.37
  - excluding calorimeter barrel/endcap transition ($1.37<|\eta_\gamma|<1.52$)
- E_T^{miss} & photon p_T > 150GeV
- lepton vetos (electron, muon)

Electroweak Background

- W($\nu\ell$)/Z($\ell\ell$) + jet/photon control regions ($\ell=\mu,e$)
- simulation-based transfer factors (ratios!)
    - significant reduction of theoretical and experimental uncertainties

estimated number of background events in SR

number of events in control region

number of events for given background contribution in SR from simulation

$$N_{\mathrm{SR}}^{\mathrm{predicted}} = (N_{\mathrm{CR}}^{\mathrm{Data}} - N_{\mathrm{CR}}^{\mathrm{Bkg}}) \cdot C \cdot \frac{N_{\mathrm{SR}}^{\mathrm{MC}}}{N_{\gamma/\mathrm{jet}/E_{\mathrm{T}}^{\mathrm{miss}}}^{\mathrm{MC}}}$$

correction factors (efficiencies, acceptances...)

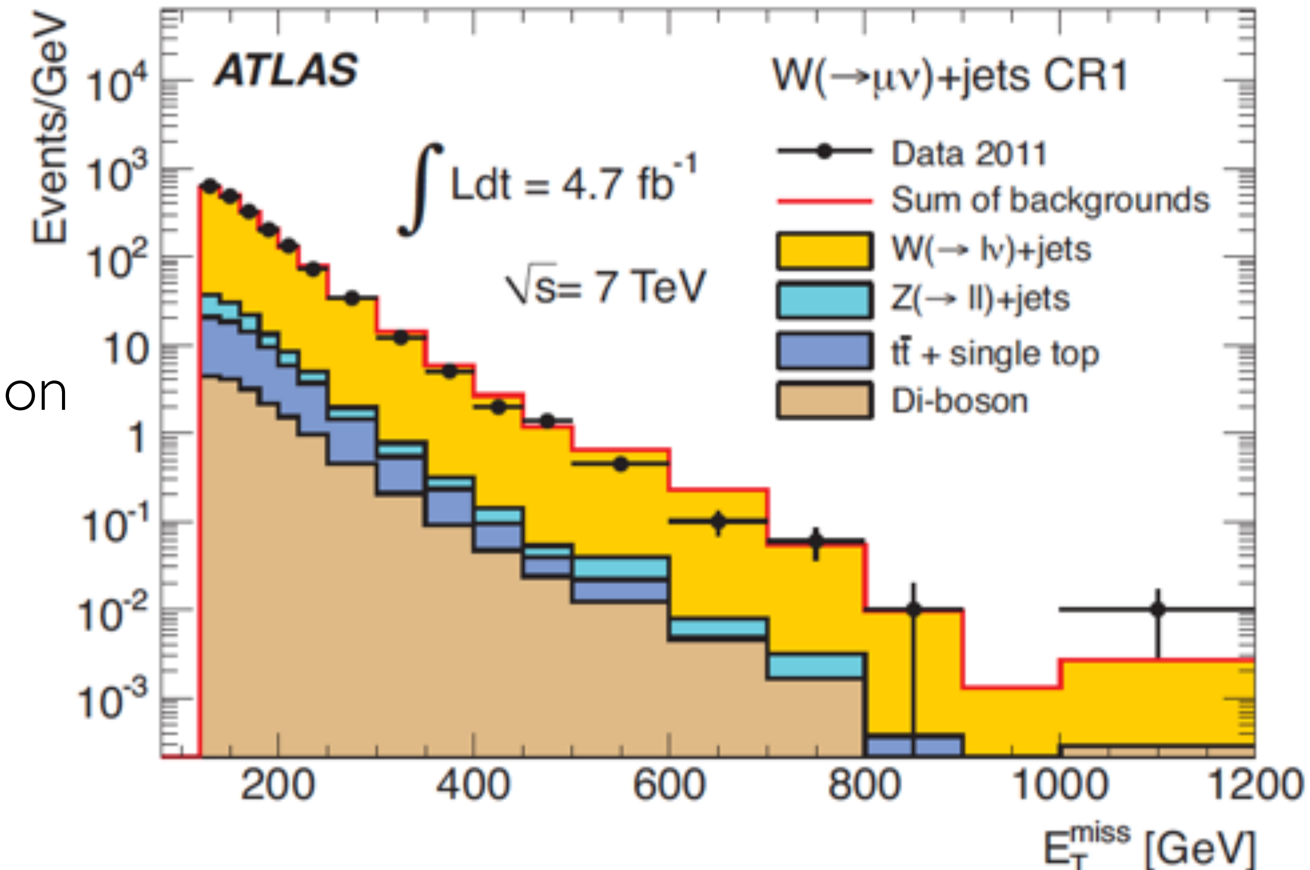
simulated events of CR process with only jet/γ&E_T^{miss} cuts applied

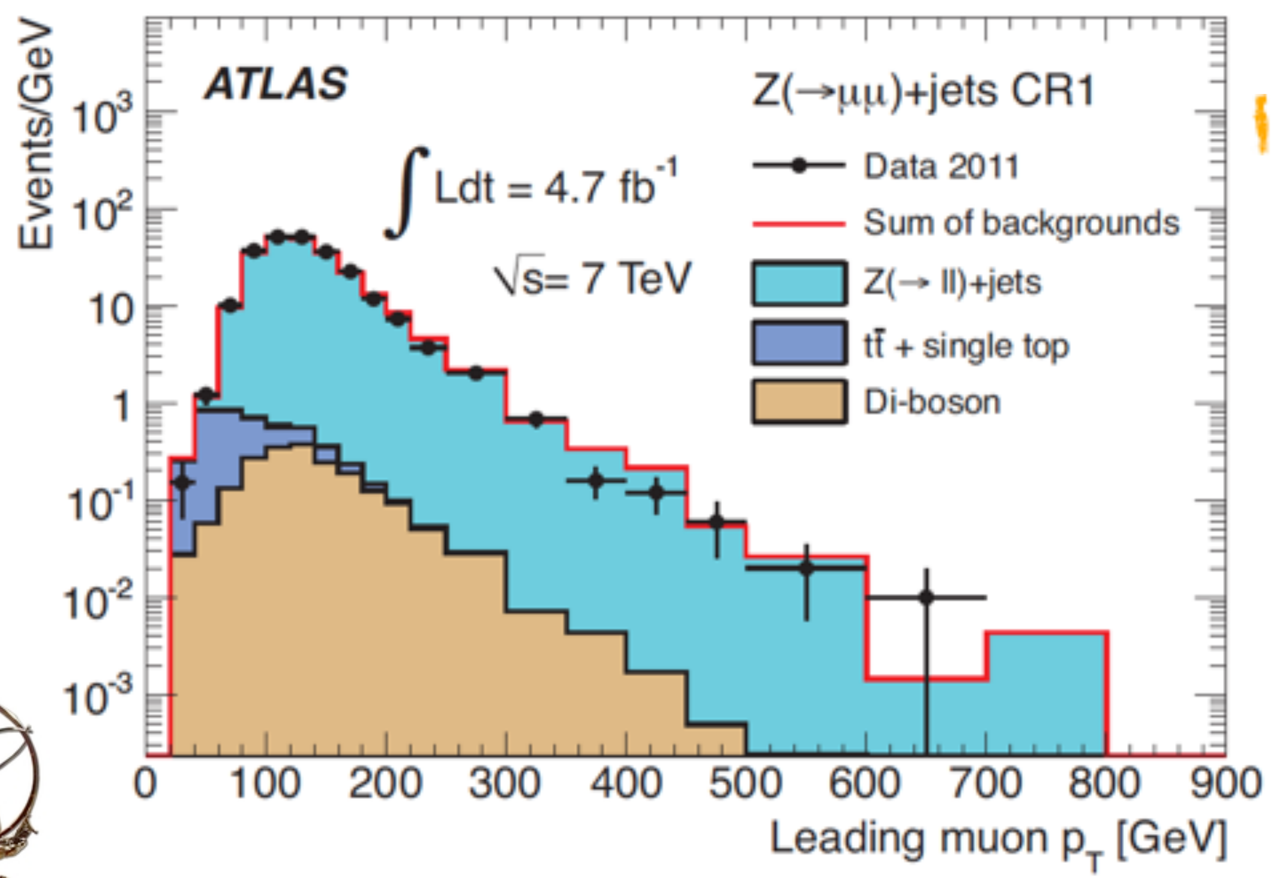
- different CRs used for different SR background processes

Electroweak Background

monojet@7TeV

- Monojet CR distributions (2011)
  - $W(\mu\nu)$+jets CR
    - exactly 1 reconstructed muon
    - 40GeV < m_T
    - remaining SR cuts





- $Z(\mu\mu)$+jets CR
  - exactly 2 reconstructed muons
  - 66GeV < $m_{\mu\mu}$ < 116GeV
  - remaining SR cuts

Background Systematic Uncertainties

MONOJET (2011)

- Jet & E_T^{miss} energy scale and resolution:
  1-6%
- Lepton scales/identification:
  <1%
- correction factors in EW estimation:
  ~1%
- Non-electroweak backgrounds:
  0.1-1.1%
- parton shower/hadronisation modelling:
  3%

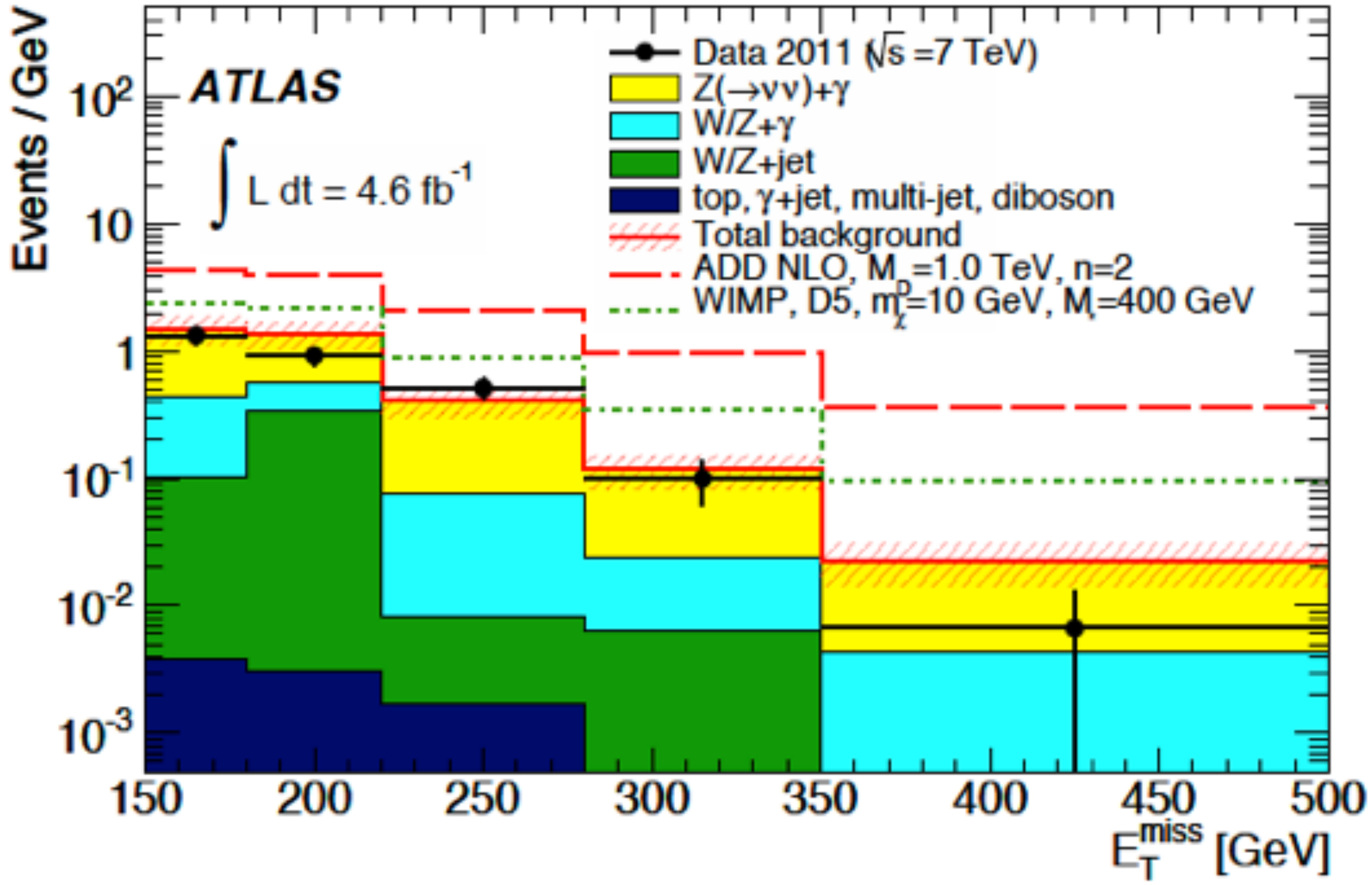
MONOPHOTON

- photon energy scale:
  0.9%
- photon energy resolution, isolation, identification efficiency:
  1.1%
- lepton identification efficiencies
  0.3%
- jet energy scale , resolution
  0.9% , 1.2%
- PDF choice, renormalisation/factorisation scales in W/Z+ γ samples:
  1.0%
- trigger, lepton energy scale and resolution, pile-up, luminosity
  combined <0.5%
- parton shower/hadronisation modelling
  6.9%

Results - Monophoton2011

monophoton@7TeV

- no significant deviation from Standard Model prediction

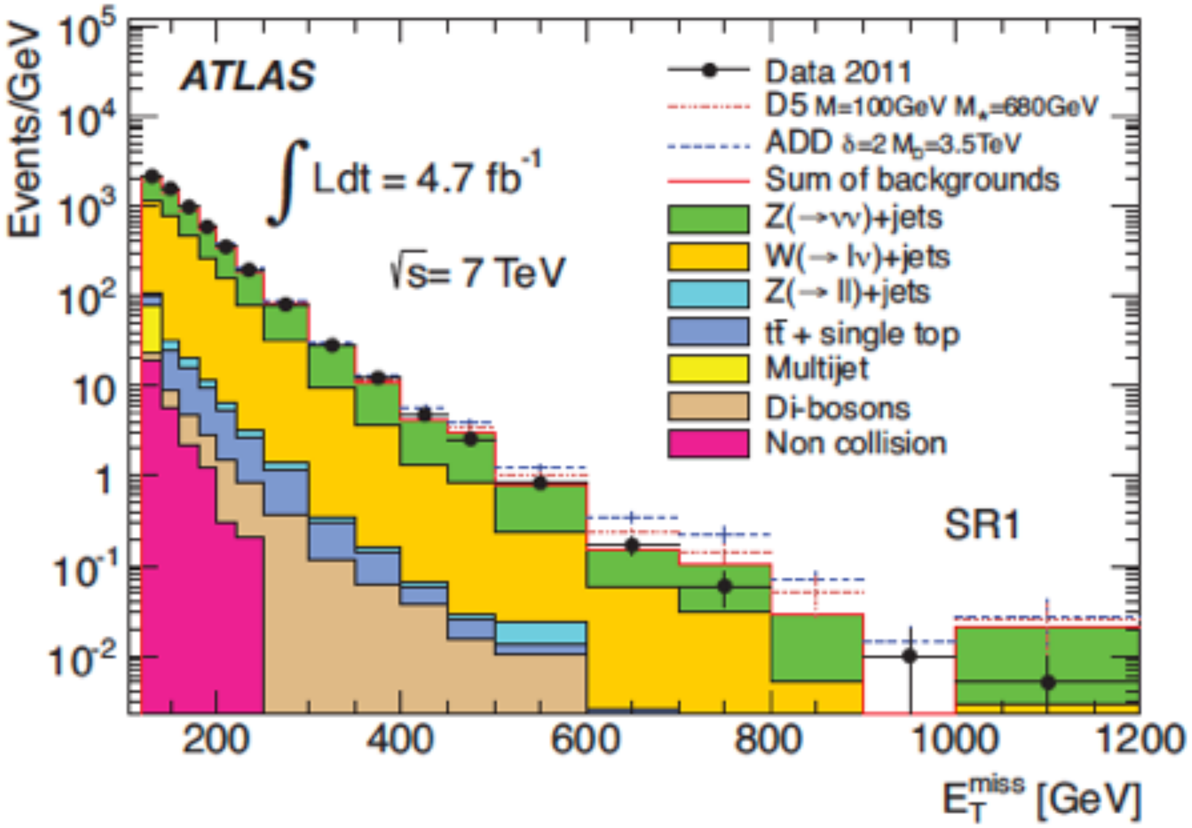


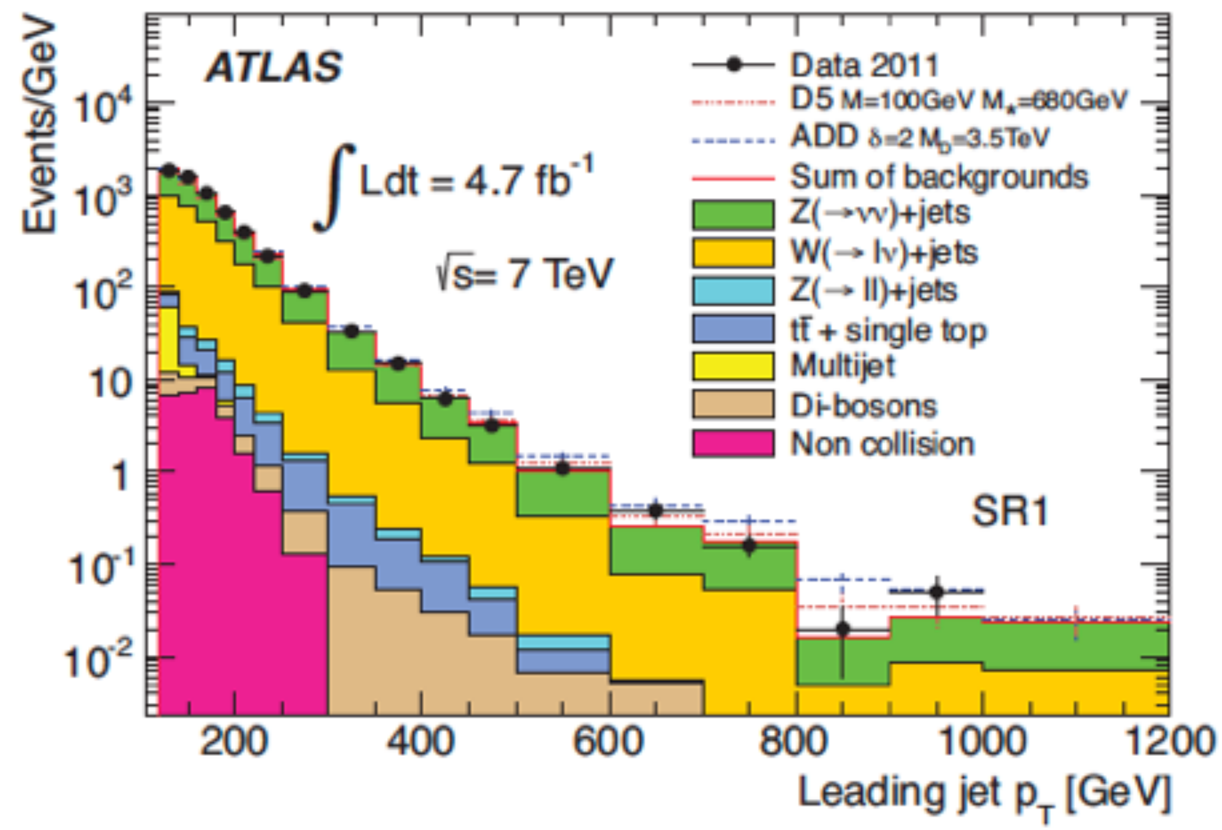
Background source	Prediction	± (stat.)	± (syst.)
$Z(\to \nu\bar{\nu}) + \gamma$	93	± 16	± 8
$Z/\gamma^*(\to \ell^+\ell^-) + \gamma$	0.4	± 0.2	± 0.1
$W(\to \ell\nu) + \gamma$	24	± 5	± 2
W/Z + jets	18	–	± 6
Top	0.07	± 0.07	± 0.01
$WW, WZ, ZZ, \gamma\gamma$	0.3	± 0.1	± 0.1
γ+jets and multi-jet	1.0	–	± 0.5
Total background	137	± 18	± 9
Events in data (4.6 fb^{-1})	116		

Results - Monojets2011

monojet@7TeV

- agreement with Standard Model prediction





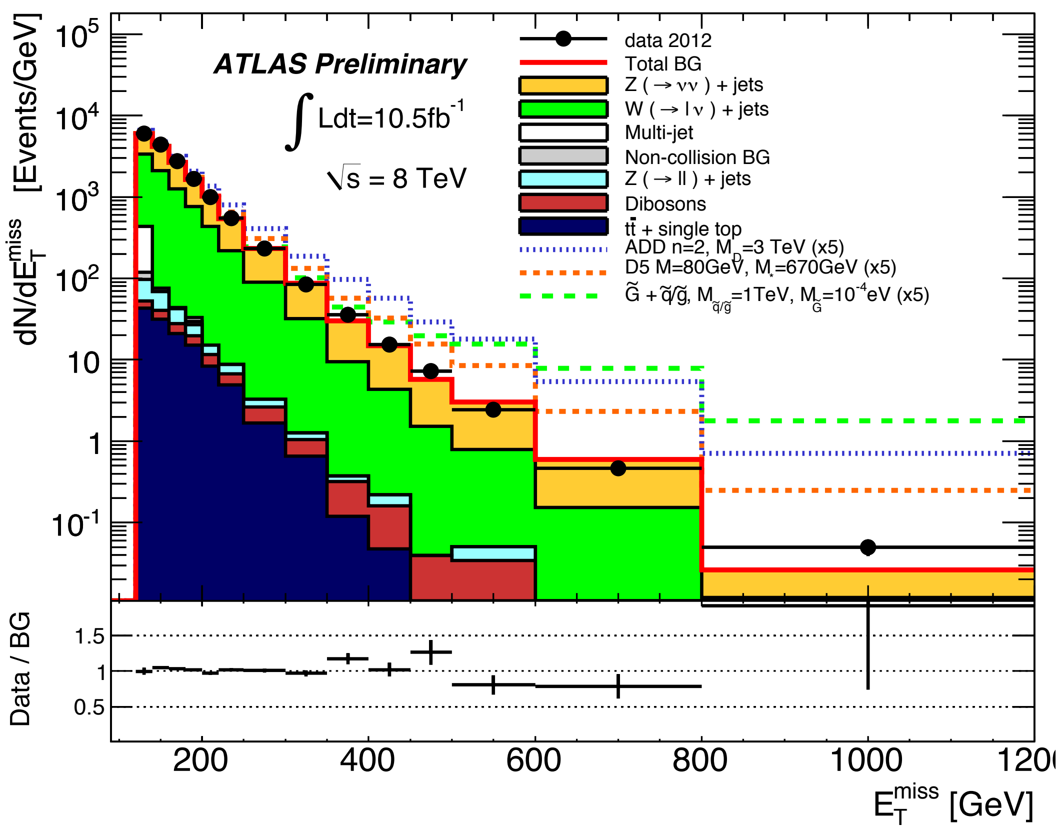
	SR1	SR2	SR3	SR4
$Z \to \nu\bar{\nu}$+jets	63000 ± 2100	5300 ± 280	500 ± 40	58 ± 9
$W \to \tau\nu$+jets	31400 ± 1000	1853 ± 81	133 ± 13	13 ± 3
$W \to e\nu$+jets	14600 ± 500	679 ± 43	40 ± 8	5 ± 2
$W \to \mu\nu$+jets	11100 ± 600	704 ± 60	55 ± 6	6 ± 1
$t\bar{t}$ + single t	1240 ± 250	57 ± 12	4 ± 1	-
Multijets	1100 ± 900	64 ± 64	8^{+9}_{-8}	-
Non-coll. Background	575 ± 83	25 ± 13	-	-
$Z/\gamma^* \to \tau\tau$+jets	421 ± 25	15 ± 2	2 ± 1	-
Di-bosons	302 ± 61	29 ± 5	5 ± 1	1 ± 1
$Z/\gamma^* \to \mu\mu$+jets	204 ± 19	8 ± 4	-	-
Total Background	124000 ± 4000	8800 ± 400	750 ± 60	83 ± 14
Events in Data (4.7 fb^{-1})	124703	8631	785	77

- lower bounds on E_T^{miss} & leading jet p_T:
  - SR1: 120 GeV
  - SR2: 220 GeV
  - SR3: 350 GeV
  - SR4: 500 GeV

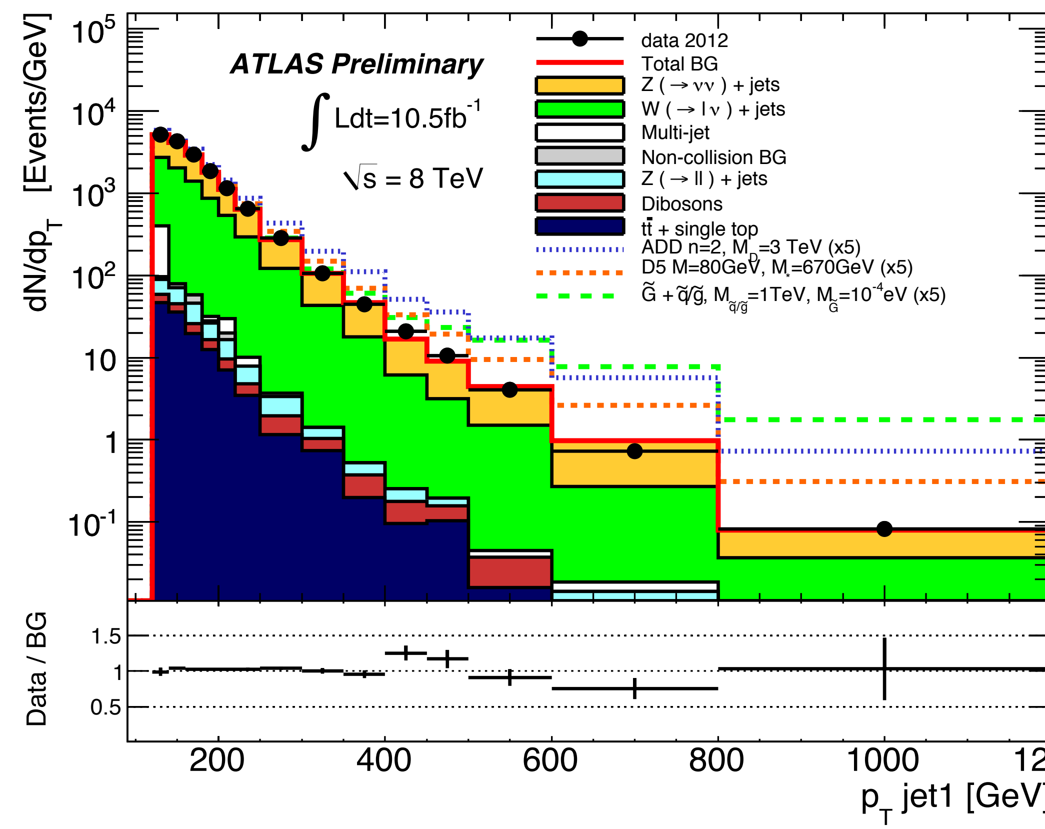
Results - Monojets2012 monojet@8TeV

- only small changes wrt 2011 analysis

SR1



SR1



- no significant excess
  - no significant improvement wrt 2011 limits
    - due to small statistics in background simulation samples
  - preliminary result
    final result will benefit from simulation samples with higher statistics
    - NEW interpretation: Gravitino + squark/gluino production

Interpretation

- different theoretical frameworks considered
  - ADD Large Extra Dimensions (LED)
  - WIMP pair production

  } results with 2011 data will be presented (monojet & monophoton)

  - gravitino production ⟶ results from 2012 monojet analysis

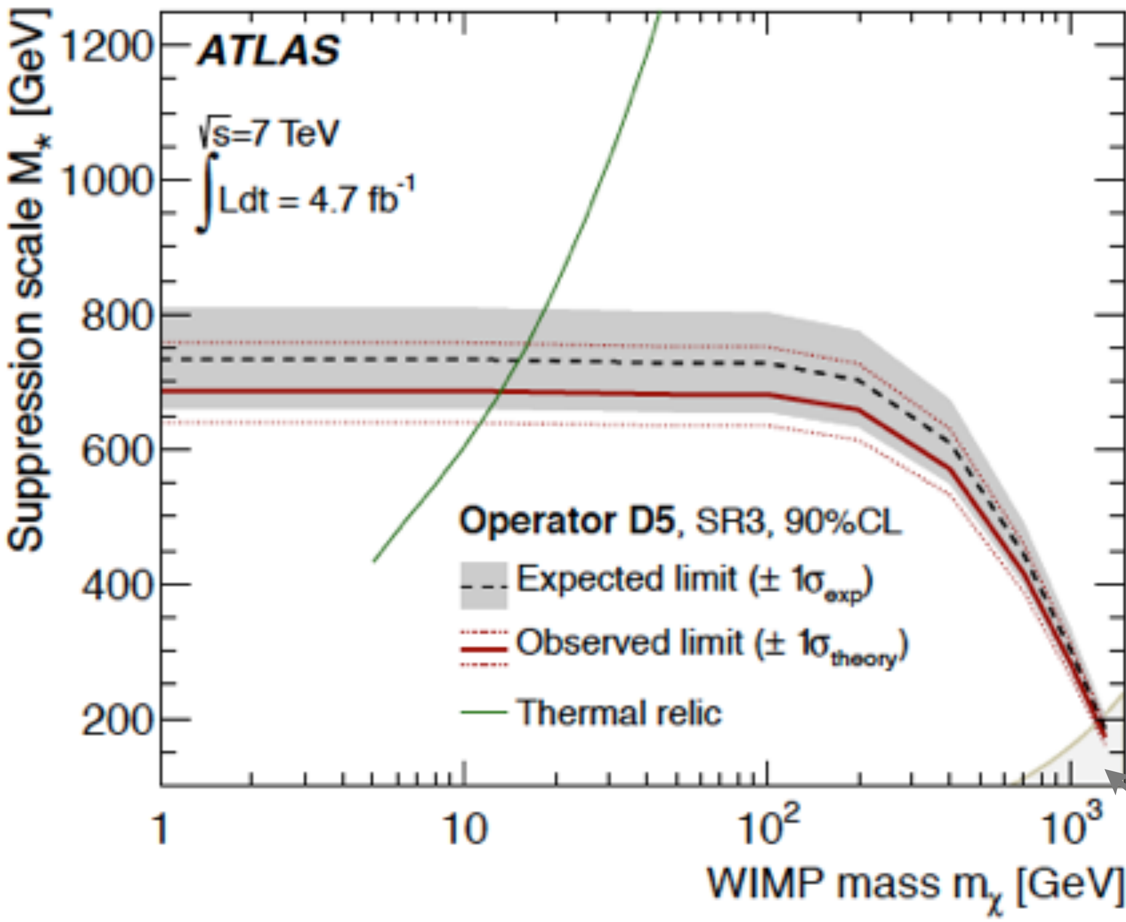
- systematic uncertainties on signal predictions
  - similar treatment for all interpretations

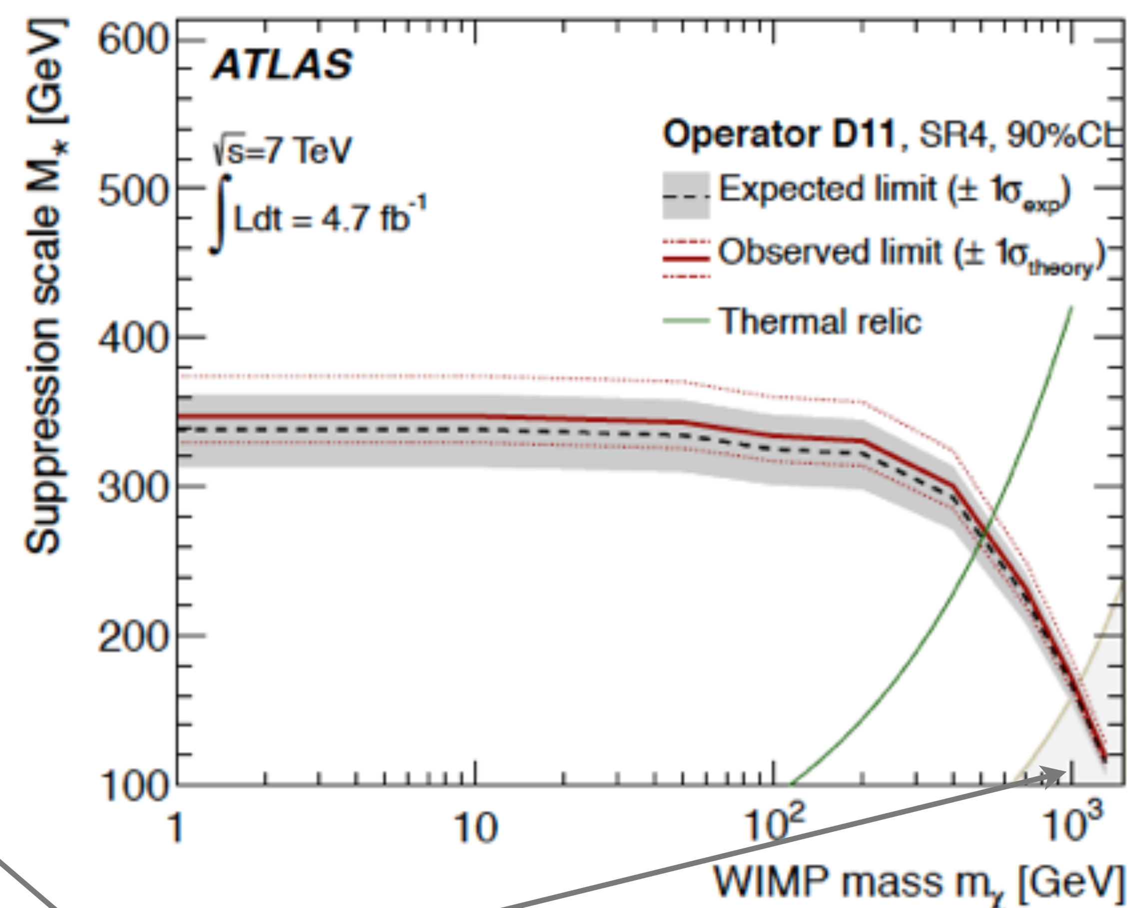
THEORY
- Parton Distribution Functions (PDF)
- renormalistion and factoristation scales
- Initial/Final State Radiation (ISR/FSR)

EXPERIMENT
- Jet and E_T^{miss} energy scale and resolution
- Trigger
- Luminosity

Interpretations - WIMP Pair Production

- cross section determines relic abundance of DM in the universe (measured by WMAP)
- cross section depends on suppression scale M* and WIMP mass
  - for each value of m_χ a certain value of M* results in 'correct' relic density (green line)
- lower limits on M* as function of WIMP mass





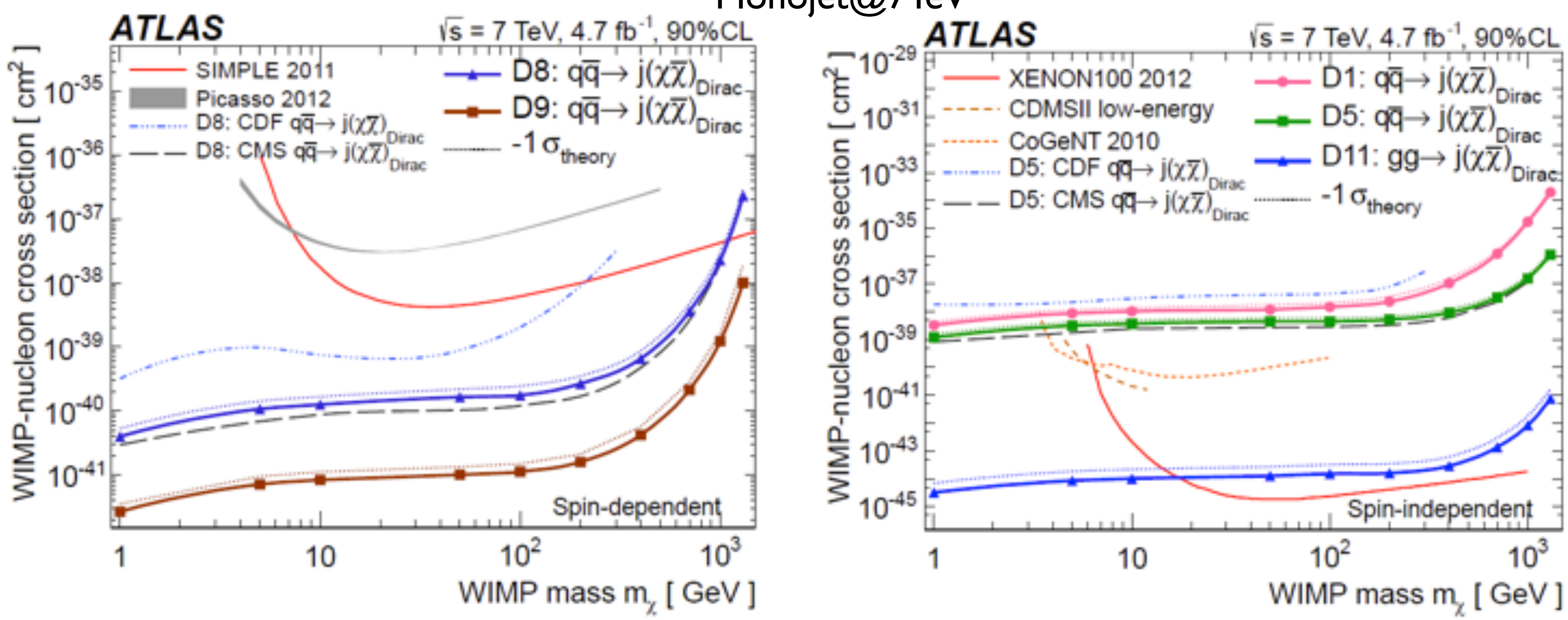
effective theory not valid

- limits above thermal relic line => conflict with WMAP measurement

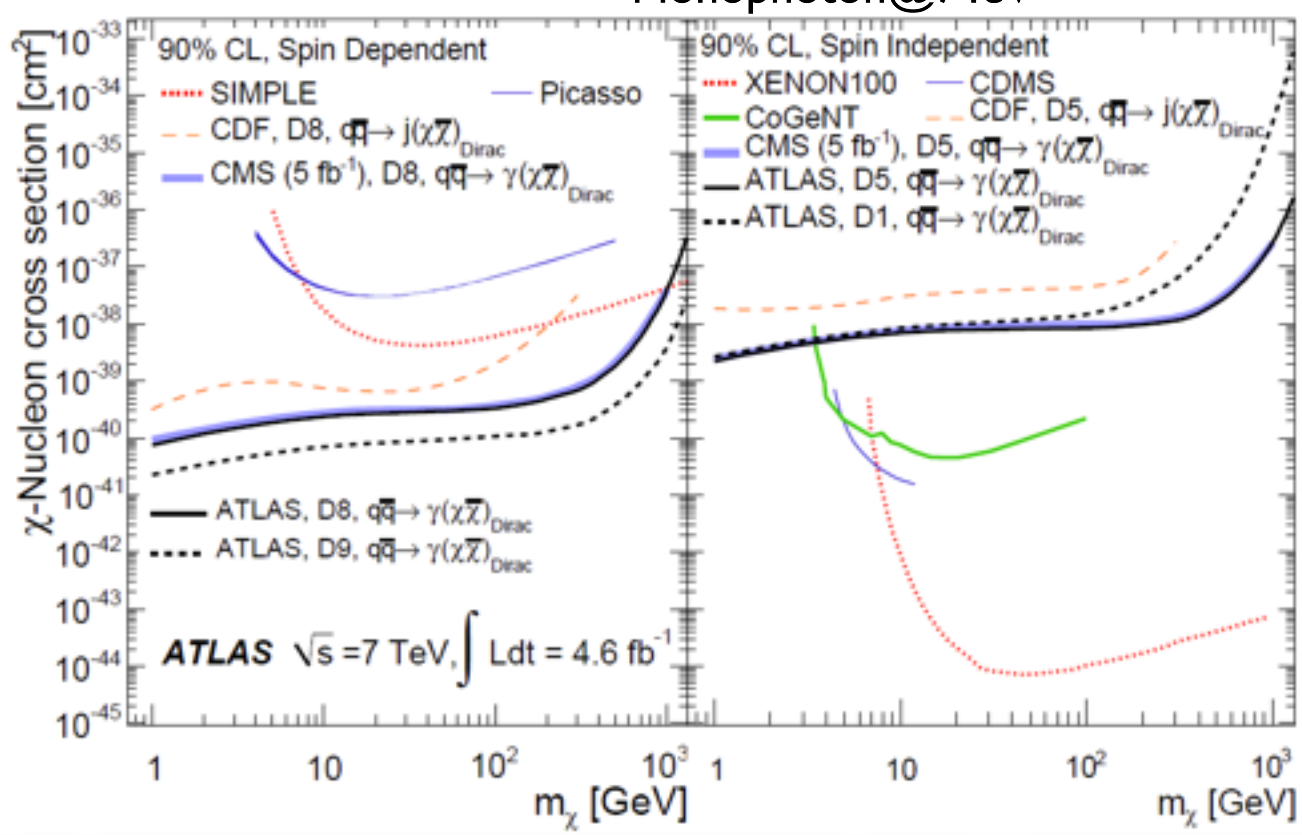
Interpretations - WIMP Pair Production

- limits on M* can be translated into (upper) limits on WIMP-Nucleon scattering cross section

Monojet@7TeV



Monophoton@7TeV



- spin-dependent interaction: collider competitive over large mass region

- spin-independent interaction: collider competitive at small masses

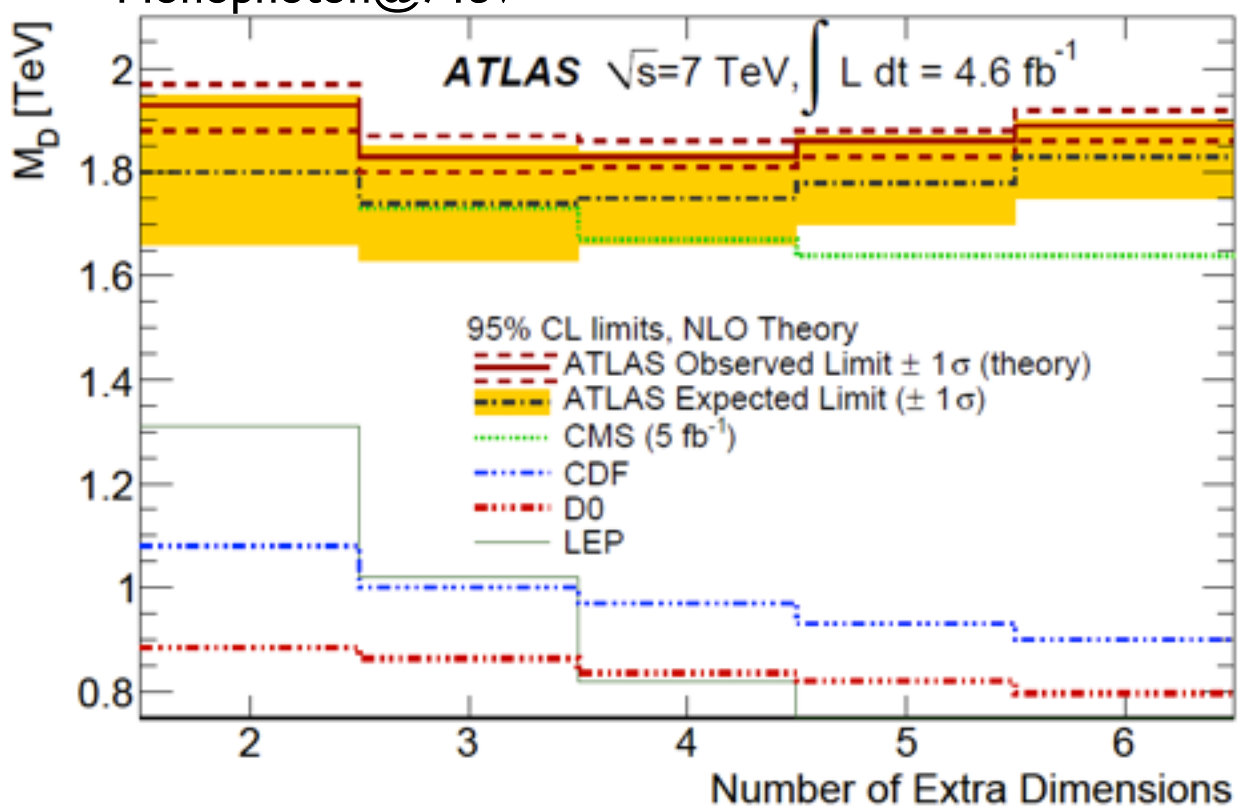
Interpretations - LED ADD Graviton

- cross section related to 2 parameters: M_D and n
  - M_D: fundamental Planck scale in 4+n dimensions

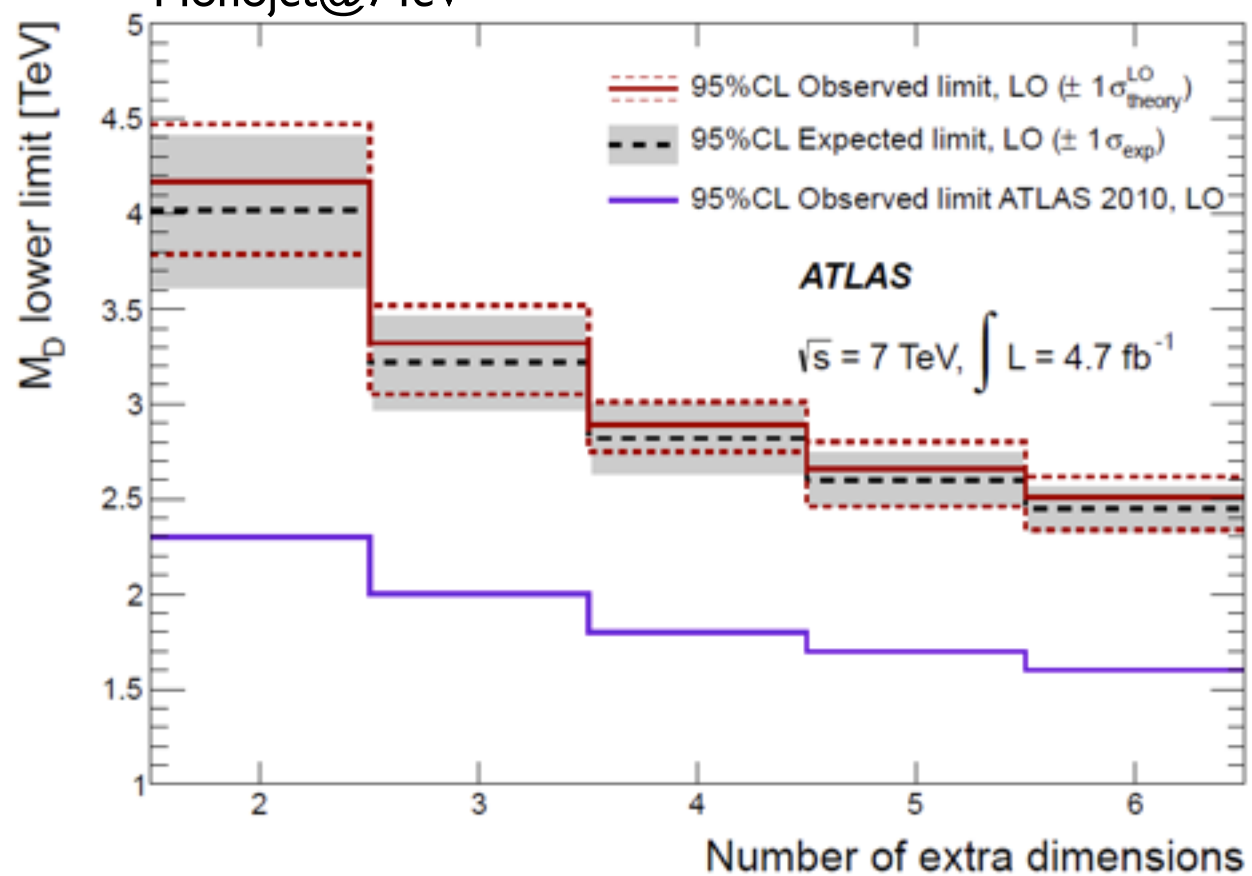
$$\sigma(n, M_D) = \sigma(n, M_{D_0}) \times \left[\frac{M_{D_0}}{M_D}\right]^{n+2}$$

- for each n set (lower) limits on M_D

Monophoton@7TeV



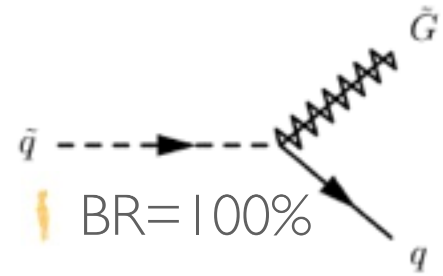
Monojet@7TeV



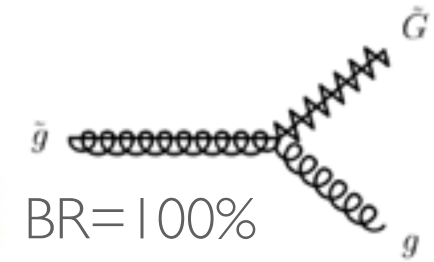
Interpretations - Gravitino Production

monojet@8TeV

- GMSB assuming very light Gravitinos
- considering region where NWA (Narrow Width Approximation) valid $\Gamma < \frac{1}{4} m_{\tilde{q},\tilde{g}}$
- degenerate squark/gluino masses

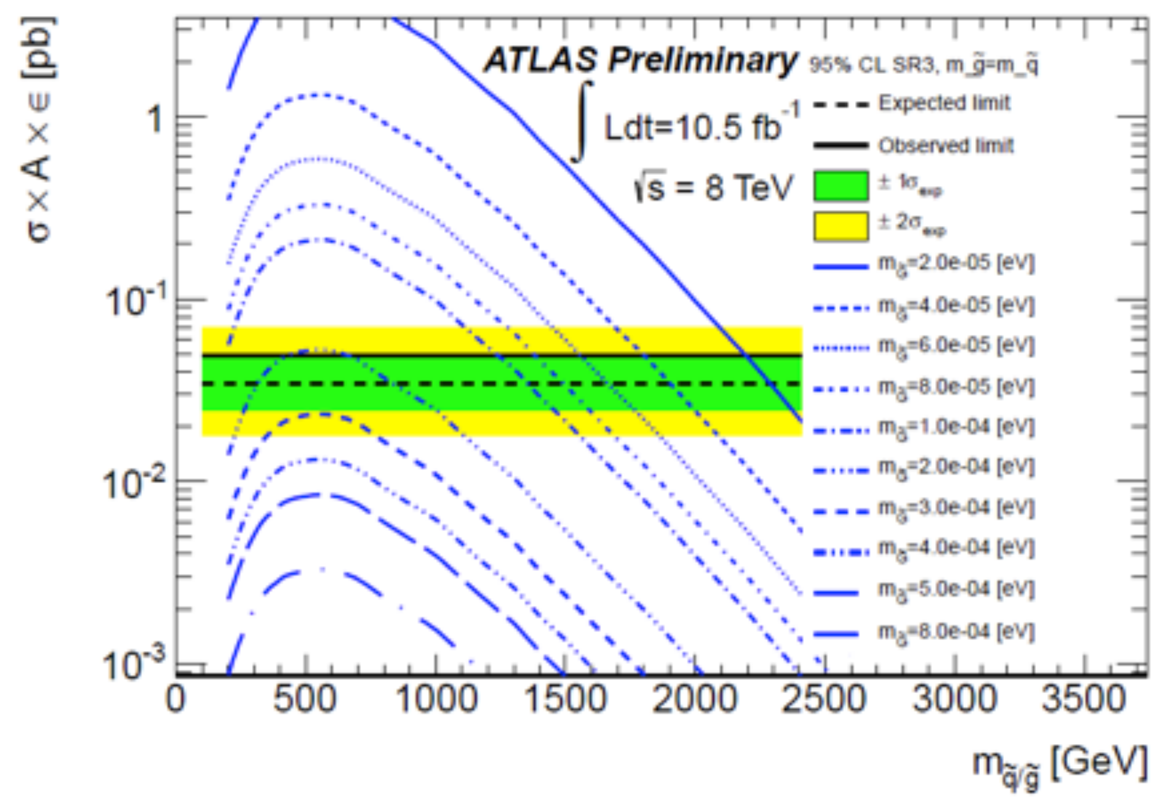


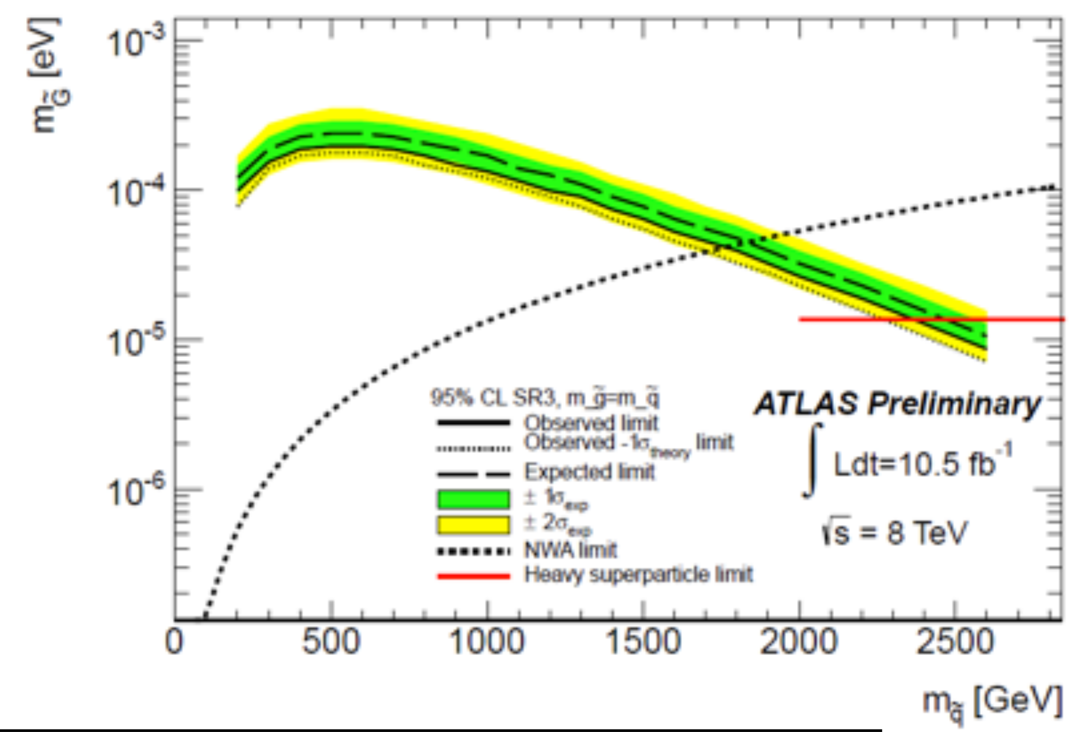
- BR=100%



- BR=100%

$$\Gamma_{\tilde{g}(\tilde{q})\to g(q)\tilde{G}} = \frac{m^5_{\tilde{g}(\tilde{q})}}{48\pi \overline{M}^2_{\rm Pl} m^2_{3/2}}$$





$m_{\tilde{q}/\tilde{g}}$	observed limit on $m_{\tilde{G}}$ @95%CL
500GeV	1×10^{-4}eV
1.7TeV	4×10^{-5}eV

considerable improvement wrt limits from LEP/Tevatron (1.37×10^{-5}eV assuming high superparticle mass)

Summary&Outlook

SUMMARY

- monojet and monophoton signatures predicted by various models for new physics
- both analyses done with ~5/fb of 7TeV LHC collision data
- monojet analysis updated with 10.5/fb of 8TeV LHC collision data (preliminary results)
- no significant deviation from Standard Model prediction
- limits for ADD and WIMP interpretations
- 2012: including new interpretation: gravitino + squark/gluino
  - first ATLAS result on this model
  - best lower bound on gravitino mass to date

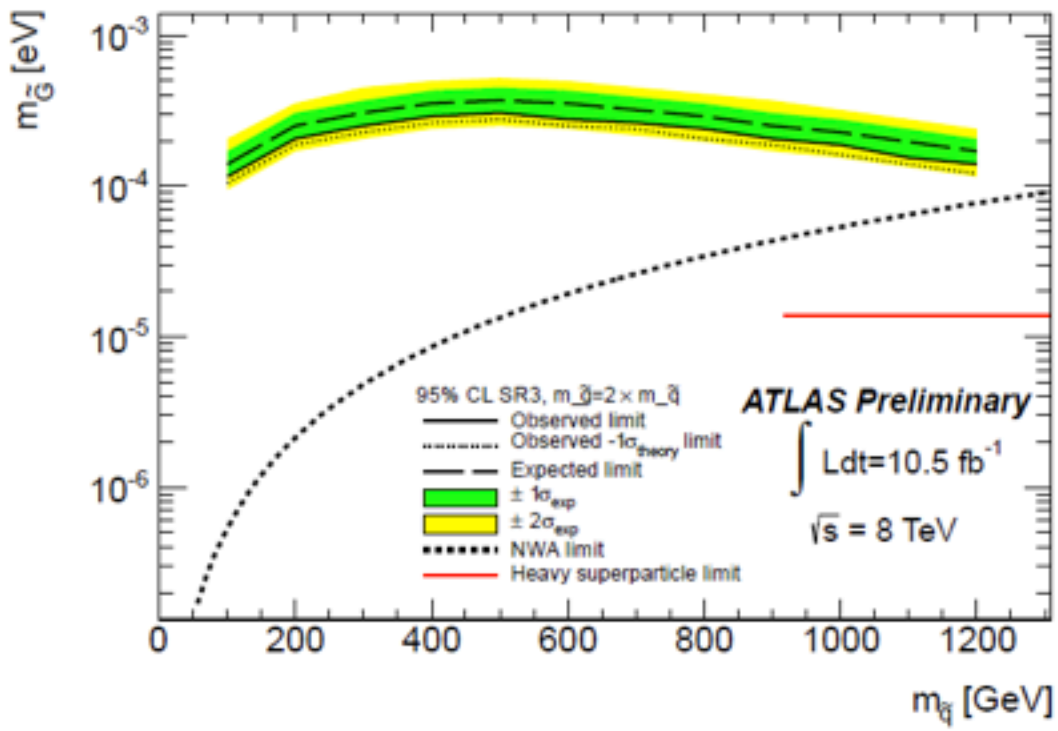
OUTLOOK

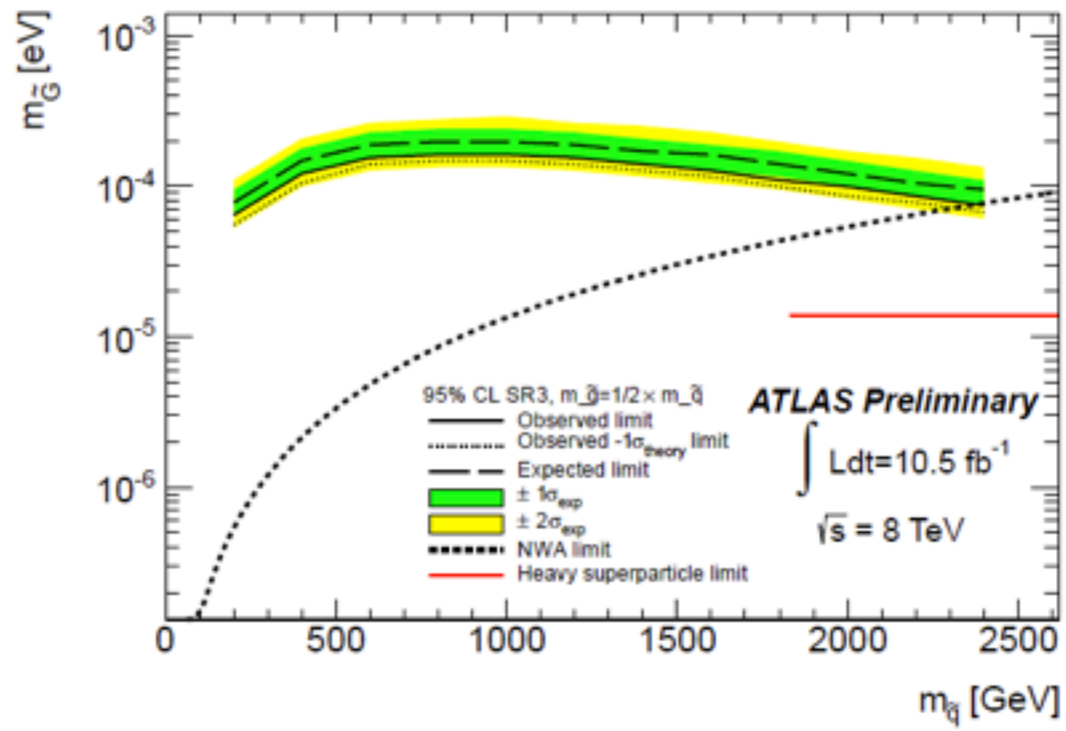
- full 2012 data set about twice as large (~20/fb)
- new simulation with higher statistics
- potential optimisation for specific models
- include more models

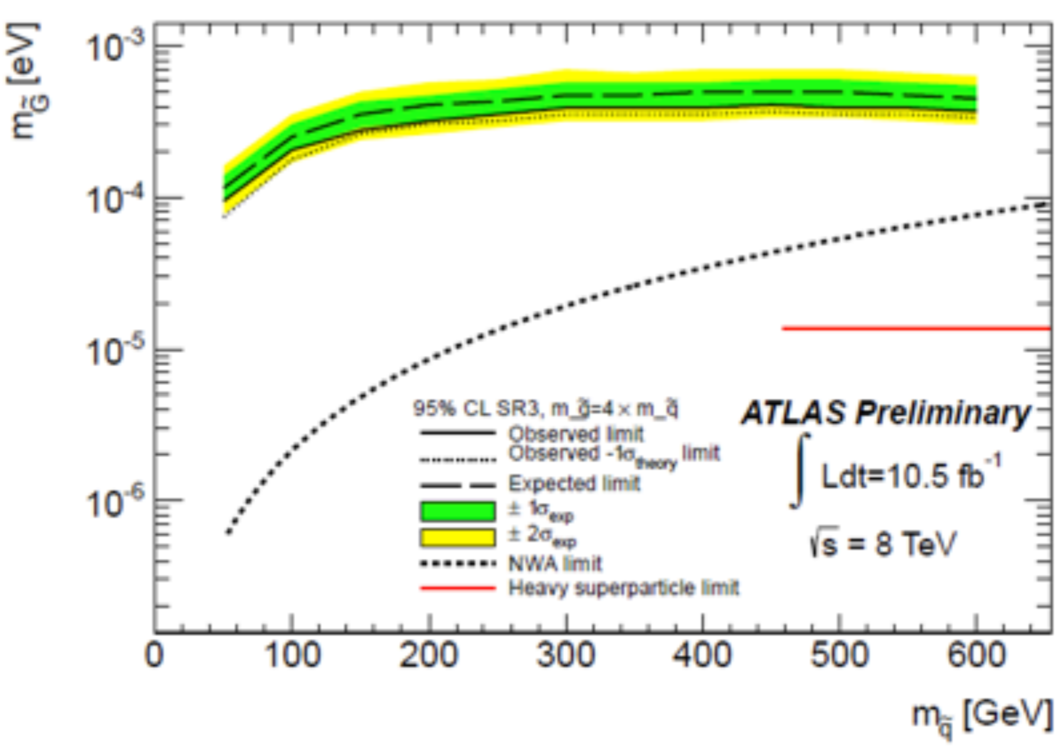
BACKUP

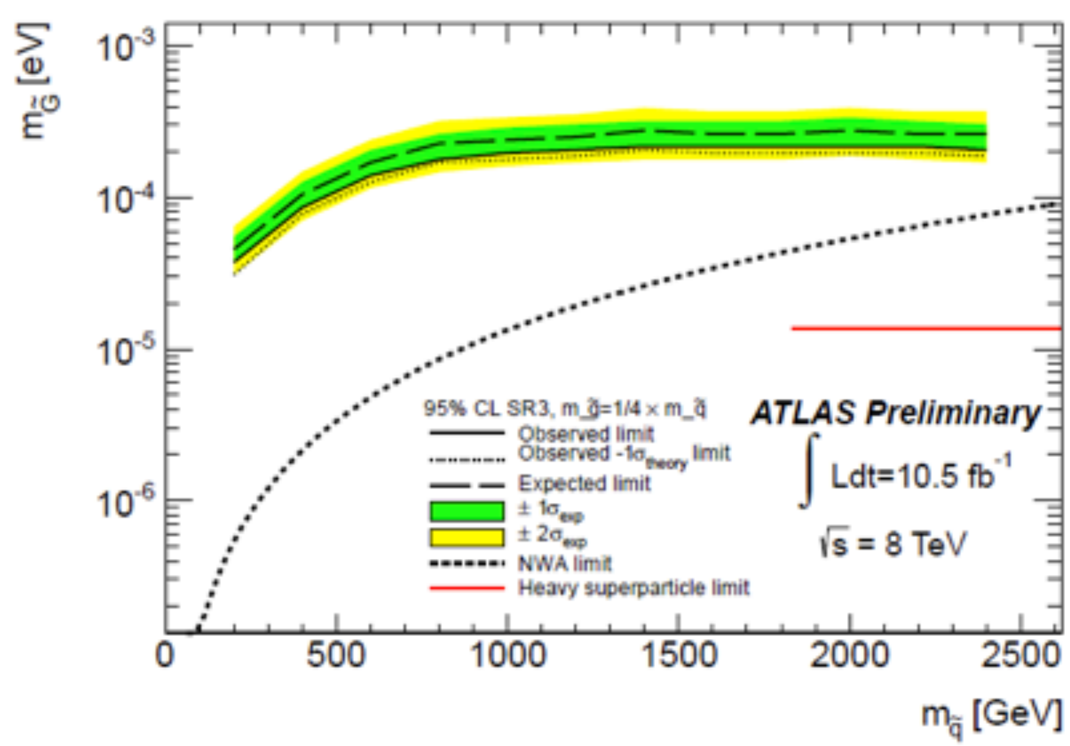
Results - Monojets2012 monojet@8TeV

- more Gravitino limits (different mass configurations)



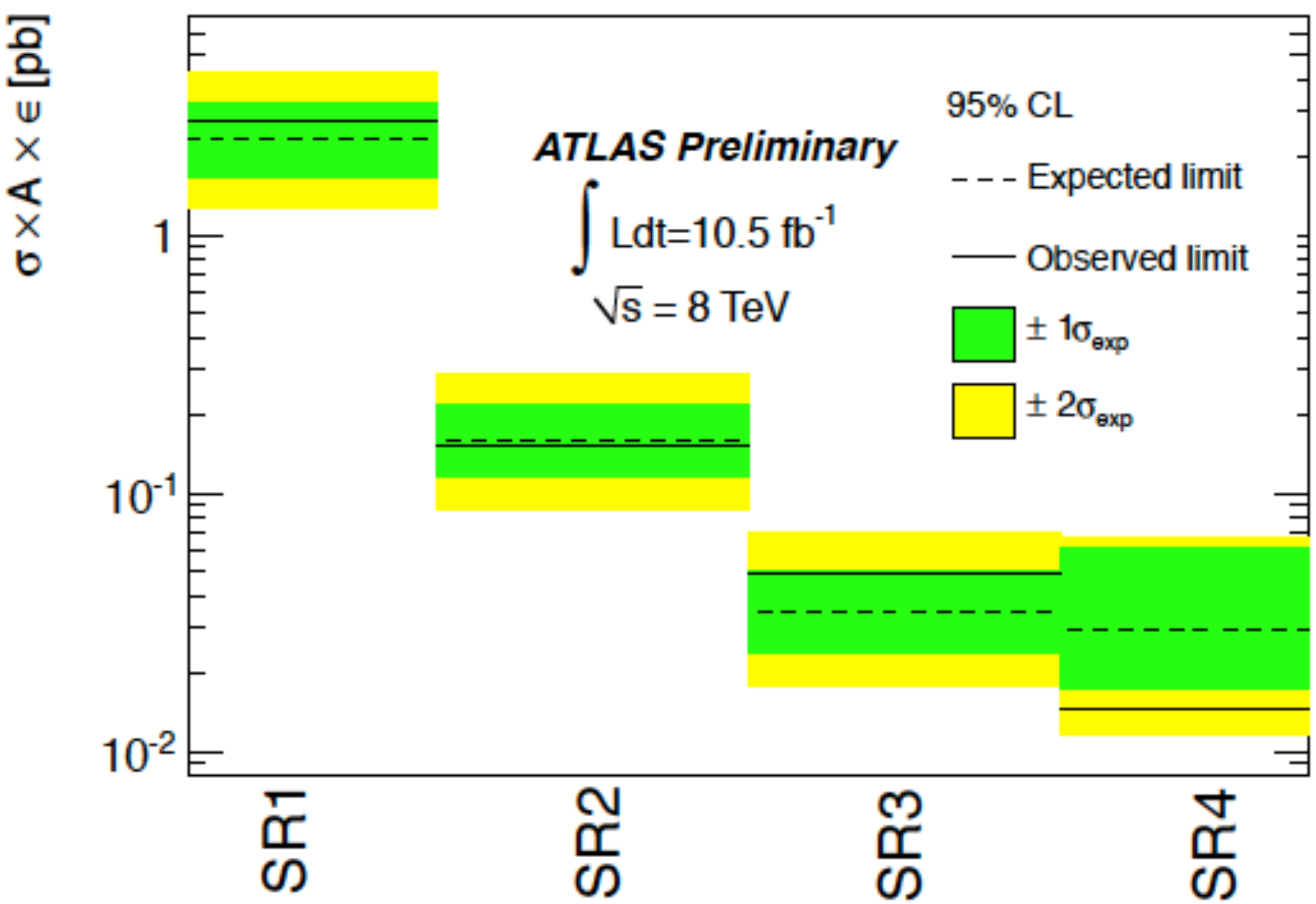






Model Independent Limits
monojet@8TeV

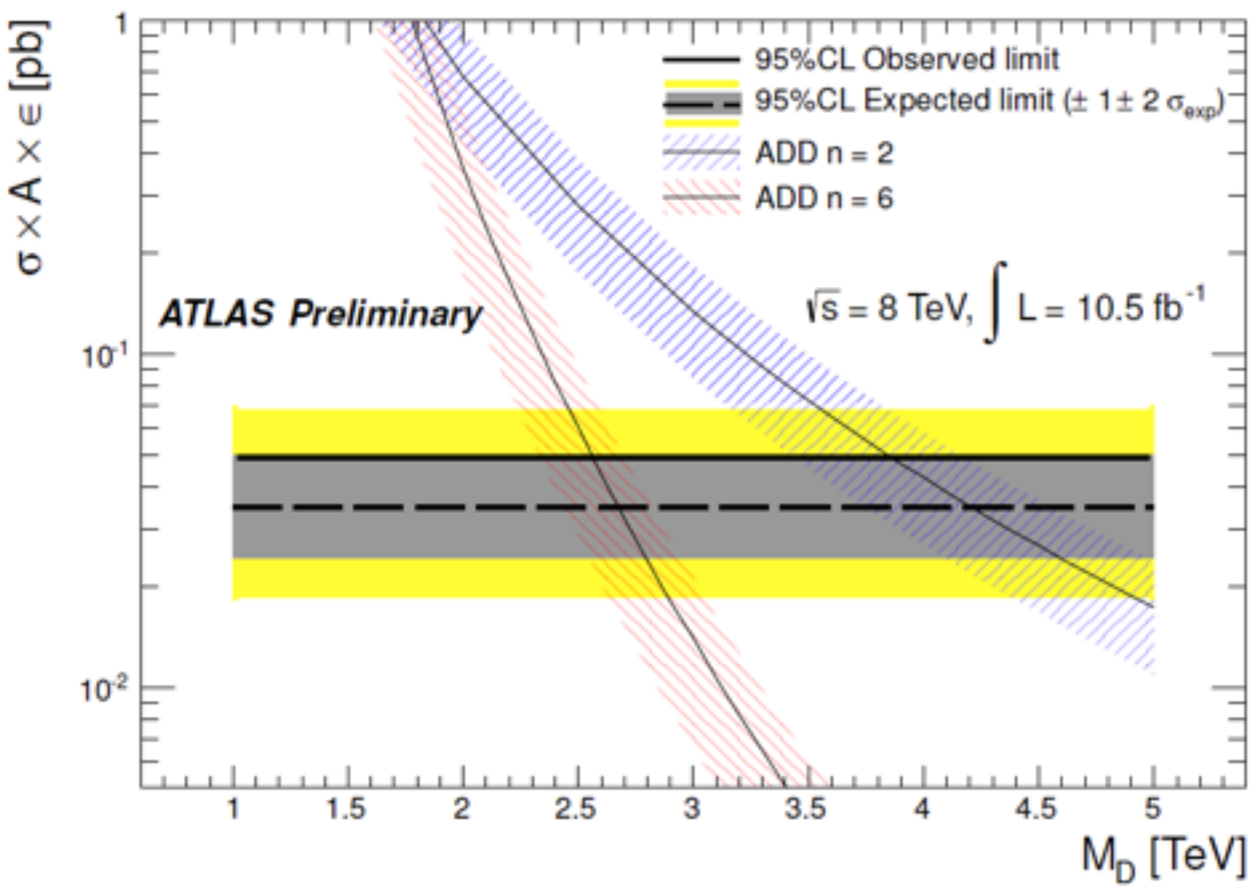
- limits on visible cross section, $\sigma \times A \times \varepsilon$
- Monojet (8TeV)



SR	observed limit @ 95%CL [pb]
1	2.8
2	0.16
3	0.05
4	0.02

- large uncertainties in SR3 & SR4 due to poor statistics in simulation samples

- best limits from SR3

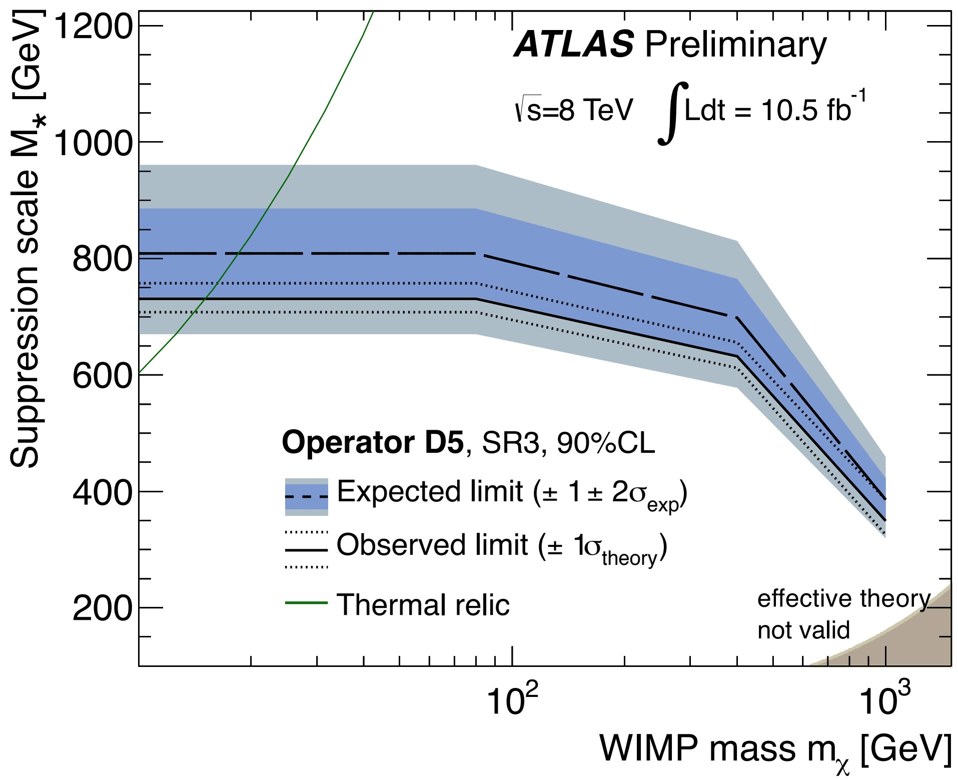


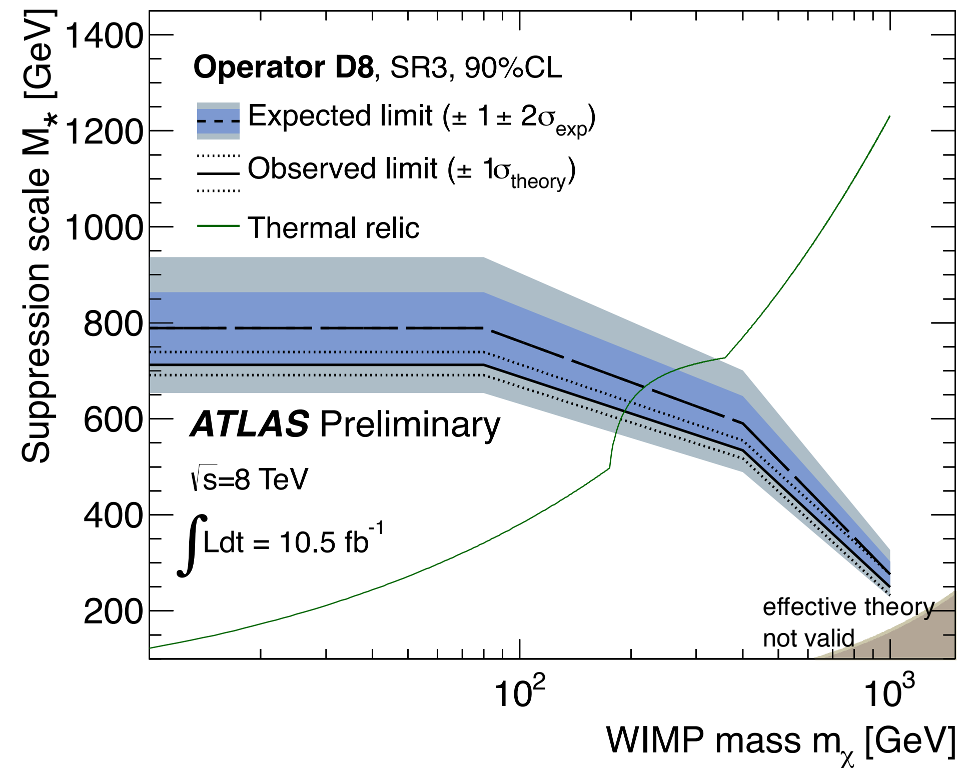
- improvement wrt to 7TeV only for n=6
  - reason: poor MC statistics

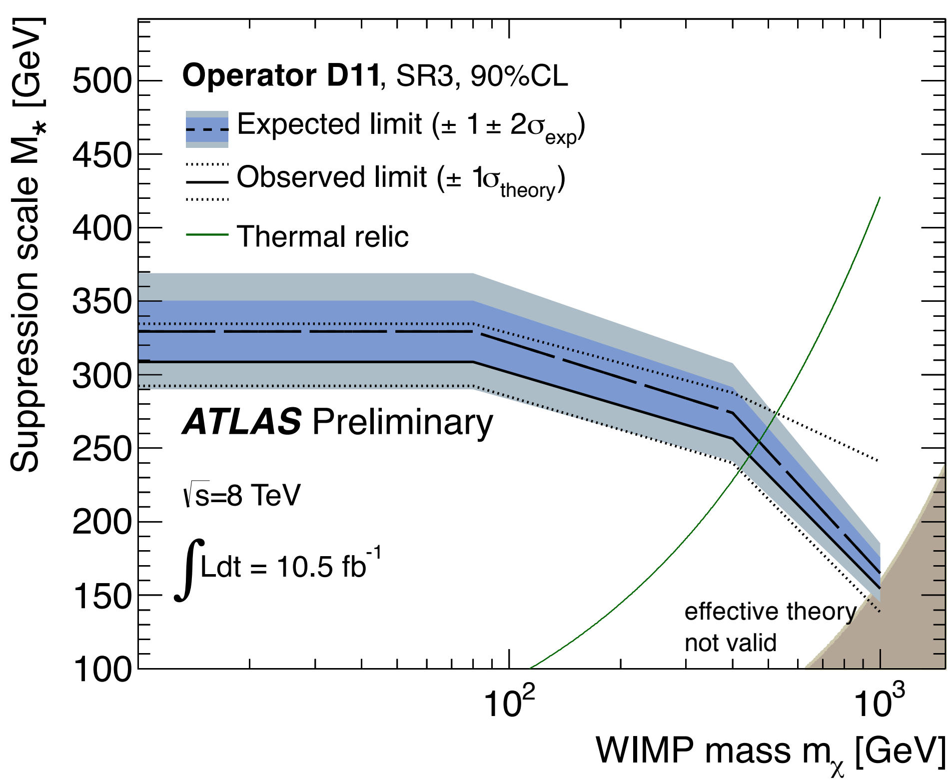
95% CL limits on ADD model using LO signal cross sections						
n extra-dimensions	95% CL observed limit on M_D [TeV]			95% CL expected limit on M_D [TeV]		
	$+1\sigma$(theory)	Nominal	-1σ(theory)	$+1\sigma$	Nominal	-1σ
2	+0.32	3.88	−0.42	−0.36	4.24	+0.39
3	+0.21	3.16	−0.29	−0.24	3.39	+0.46
4	+0.16	2.84	−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

Interpretations - WIMP Pair Production monojet@8TeV

- reduced number of operators/mass points considered







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)

- limits for D5,D8 ~10% stronger wrt 7TeV
- improvement for D11 hampered by poor simulation statistics

Model Independent Limits 2011

- Monojet

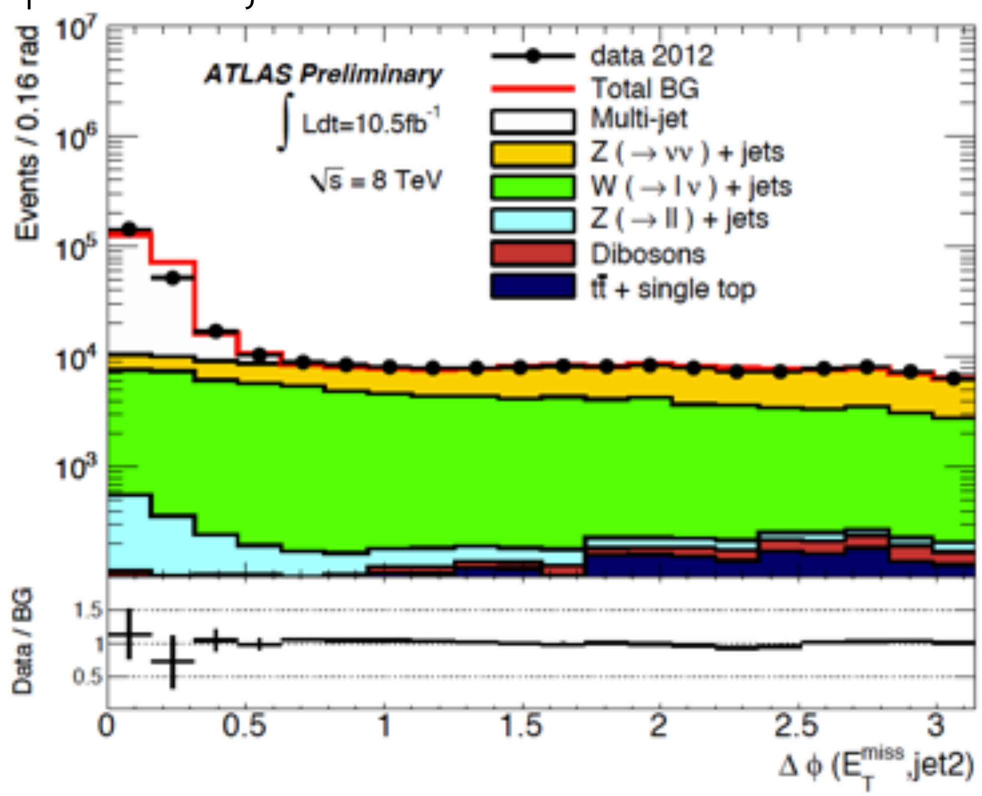
	SR1	SR2	SR3	SR4
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ at 90% [pb]	1.63	0.13	0.026	0.0055
$\sigma_{\mathrm{vis}}^{\mathrm{exp}}$ at 90% [pb]	1.54	0.15	0.020	0.0064
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ at 95% [pb]	1.92	0.17	0.030	0.0069
$\sigma_{\mathrm{vis}}^{\mathrm{exp}}$ at 95% [pb]	1.82	0.18	0.024	0.0079

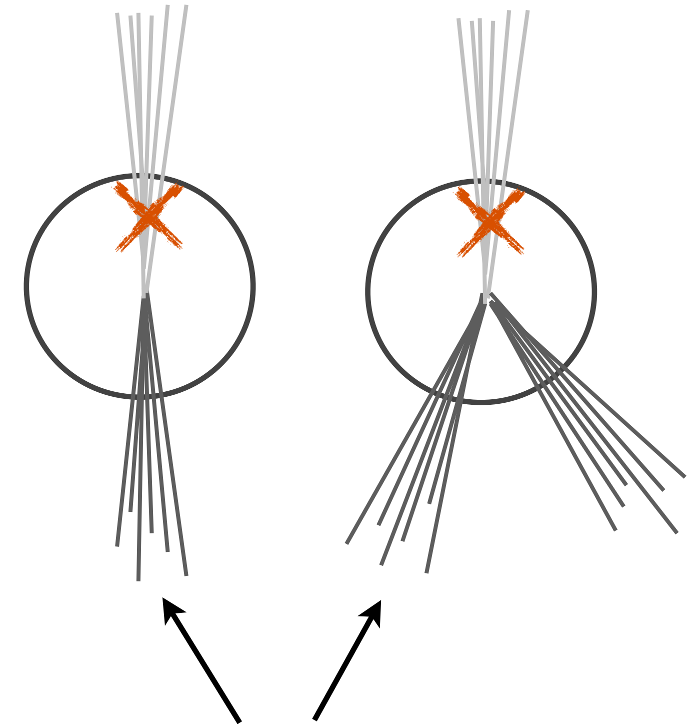
- Monophoton
  - 5.6fb @90%CL
  - 6.8fb @95%CL

Multijet/γ+jet Background

- events with additional jet(s), where one jet is mis-measured or lost

- require additional jet with p_T > 30GeV
- invert **Δφ** cut between E_T^{miss} and additional jet
  - example monojet





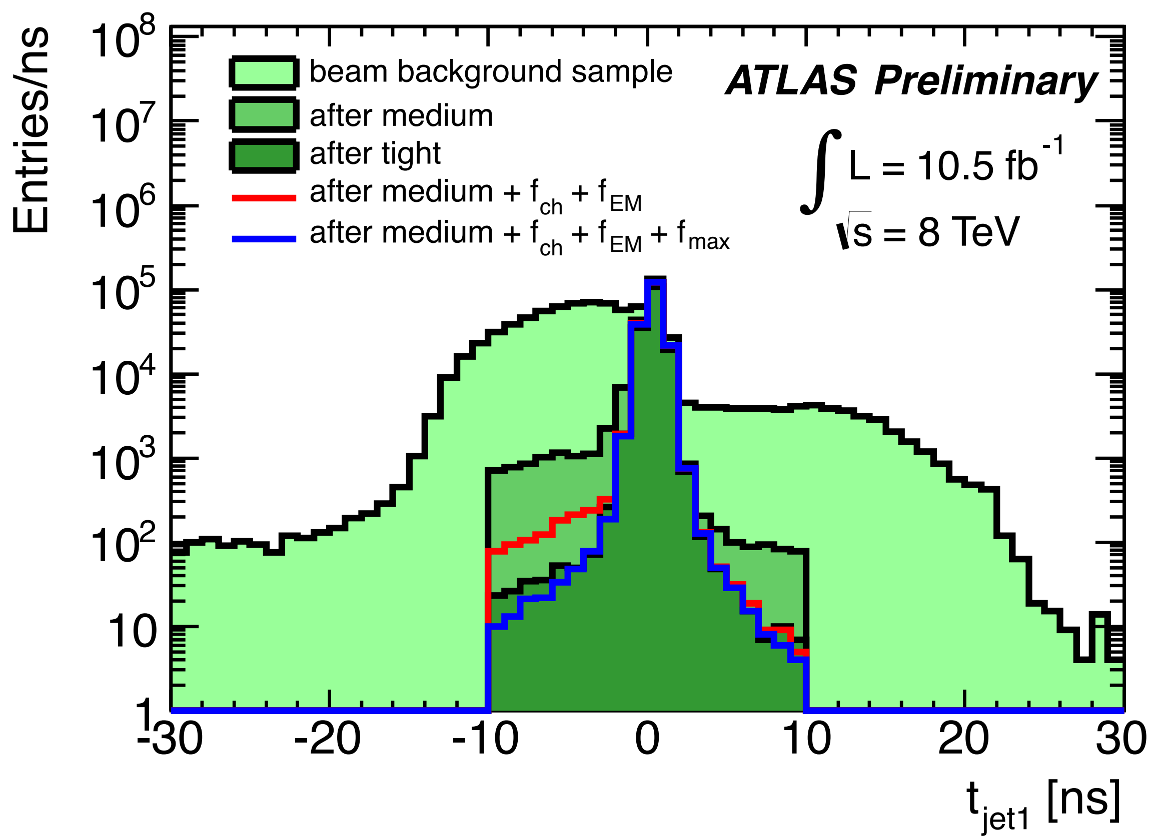
these could be photons as well

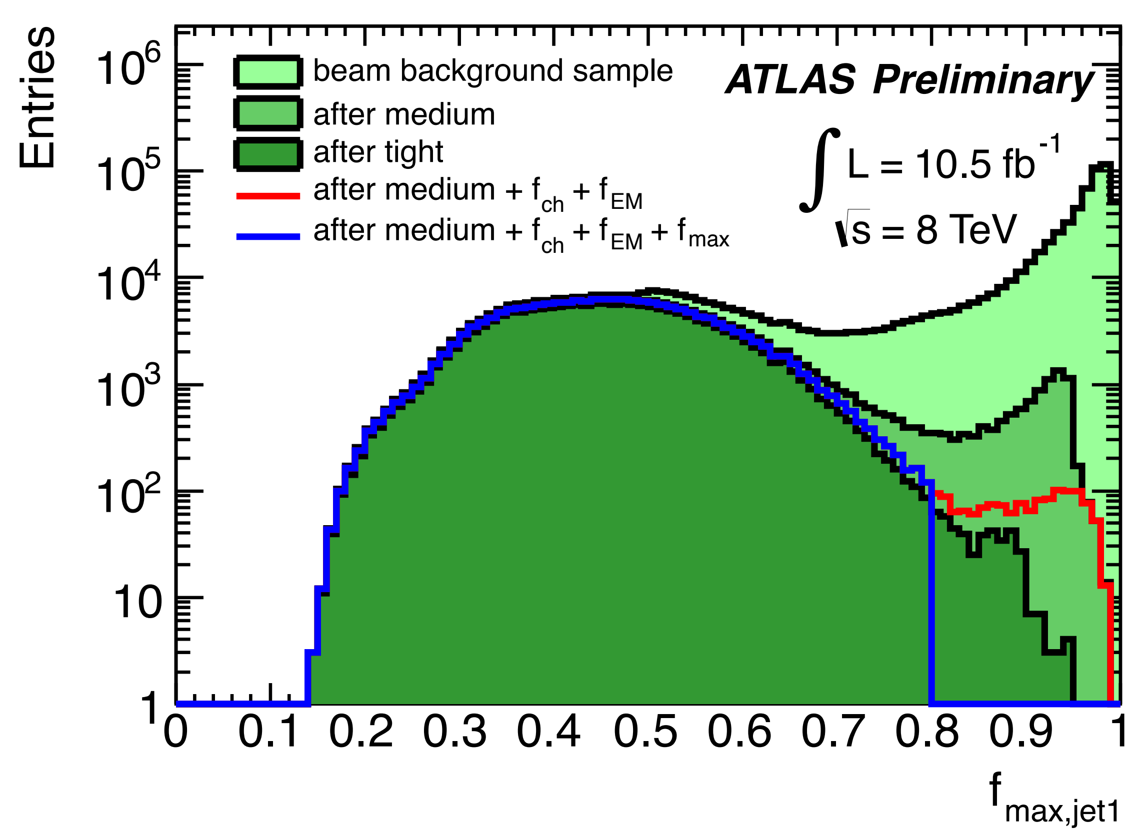
- fit p_T spectrum and extrapolate below 30GeV
  - systematic uncertainties from extrapolation and background subtraction

Non-collision Background

- cosmic muons, beam halo
- reduced by dedicated ATLAS jet cleaning cuts
- remaining contribution estimated from data (negligible for monophoton)
  - in 2011 based on timing information from forward muon detectors
  - in 2012 based on timing distribution of leading jet

- new cleaning cut using f_{max}





Selection Details

MONOJET (2011/2012)

- E_T^{miss} trigger (98% efficient @120GeV)
- at least 1 primary vertex with ≥1 track
- leading jet:
  - em fraction>0.1
  - charge fraction>0.4
  - maximum fraction in one calorimeter layer < 0.8

MONOPHOTON (2011)

- E_T^{miss} trigger (98% efficient @150GeV)
- primary vertex with ≥5 tracks
- overlap removal:
  - $|\Delta\varphi(\gamma, E_T^{miss})|>0.4$
  - $|\Delta\varphi(\text{jet}, E_T^{miss})|>0.4$
  - $|\Delta R(\text{jet}, \gamma)|>0.4$

Lepton Vetos

MONOJET (2011/2012)

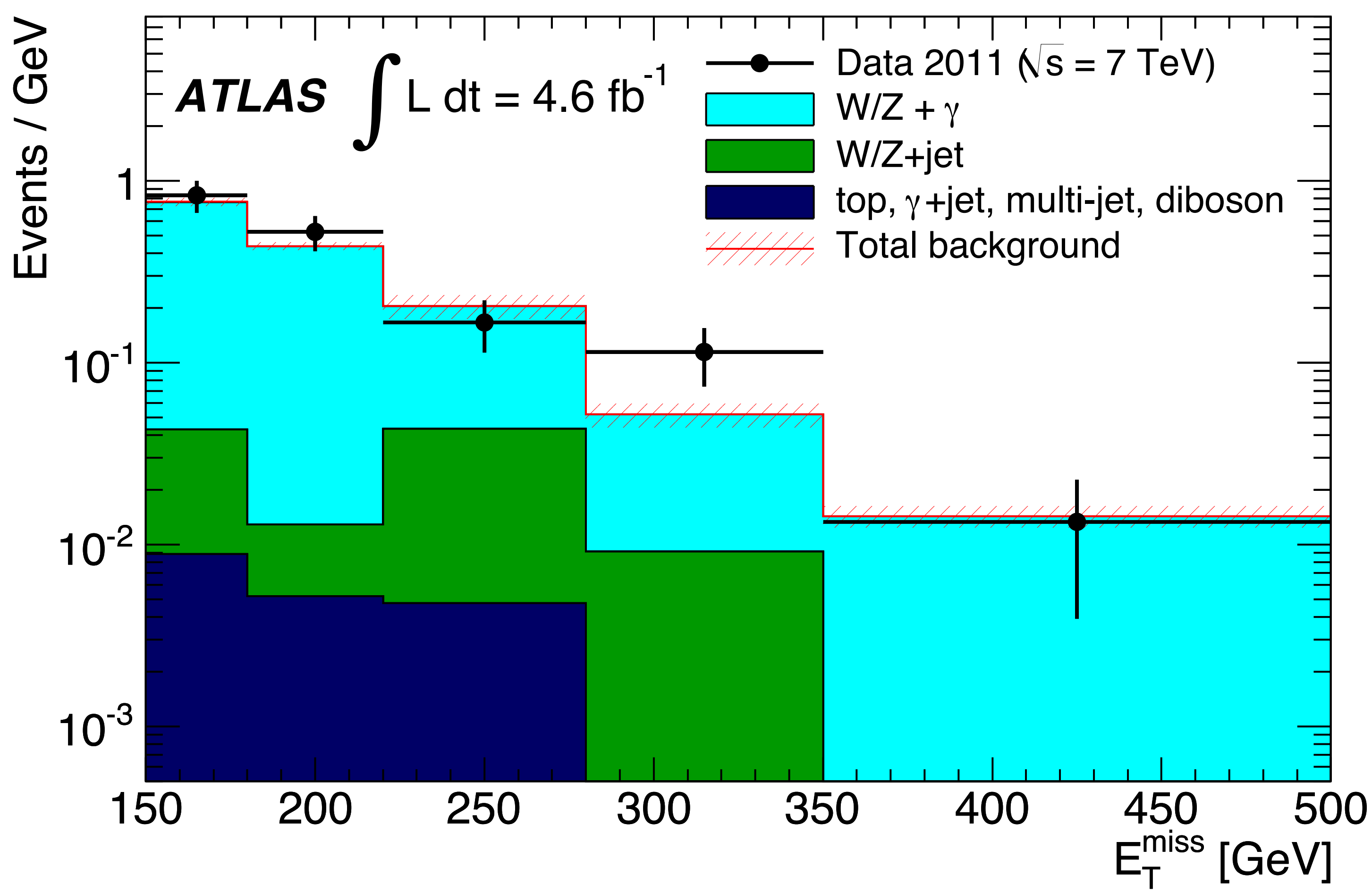
- electrons:
  - p_T>20GeV
  - $|\eta|$<2.47
  - "medium++" quality
  - overlap removal with jets
- muons:
  - p_T>7GeV
  - $|\eta|$<2.5
  - isolation requirement

MONOPHOTON (2011)

- electrons:
  - p_T>20GeV
  - $|\eta|$<2.47
  - "medium++" quality
- muons:
  - p_T>10GeV
  - $|\eta|$<2.4
  - no isolation requirement

Electroweak Background Monophoton

- muon control region
  - inverting the muon veto



Electroweak Backgrounds, Monojet

- different CRs used for different SR background processes
  - 2011

SR	$Z \to \nu\bar{\nu}$+jets	$W \to \tau\nu$+jets $W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \tau^+\tau^-$+jets $Z \to \mu^+\mu^-$+jets
CR	$W \to e\nu$+jets $W \to \mu\nu$+jets $Z \to e^+e^-$+jets $Z \to \mu^+\mu^-$+jets	$W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \mu^+\mu^-$+jets

- 2012

BKG contribution	CR used	cross check
$Z(\nu\nu)$	$W(\mu\nu)$	$Z(\mu\mu)$
$Z(\mu\mu)$		$Z(\mu\mu)$
$W(\mu\nu)$		$Z(\mu\mu)$
$W(\tau\nu)$		$W(e\nu)$
$Z(\tau\tau)$	inclusive $W(e\nu)$	
$W(e\nu)$		

- complete formula (2011)

$$N_{\mathrm{SR}}^{\mathrm{predicted}} = (N_{\mathrm{CR}}^{\mathrm{Data}} - N_{\mathrm{CR}}^{\mathrm{Bkg}}) \cdot C \cdot \frac{N_{\mathrm{SR}}^{\mathrm{MC}}}{N_{\mathrm{jet}/\mathrm{E_T^{miss}}}^{\mathrm{MC}}} =$$

$$\frac{(N_{\mathrm{CR}}^{\mathrm{Data}} - N_{\mathrm{CR}}^{\mathrm{multijet}}) \cdot (1 - f_{\mathrm{EW}})}{A_\ell \cdot \epsilon_\ell \cdot \epsilon_{Z/W} \cdot \epsilon_\ell^{\mathrm{trig}} \cdot \mathcal{L}_\ell} \times \epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}}^{\mathrm{trig}} \times \mathcal{L}_{E_{\mathrm{T}}^{\mathrm{miss}}} \times \frac{N_{\mathrm{SR}}^{\mathrm{MC}}}{N_{\mathrm{jet}/\mathrm{E_T^{miss}}}^{\mathrm{MC}}}$$

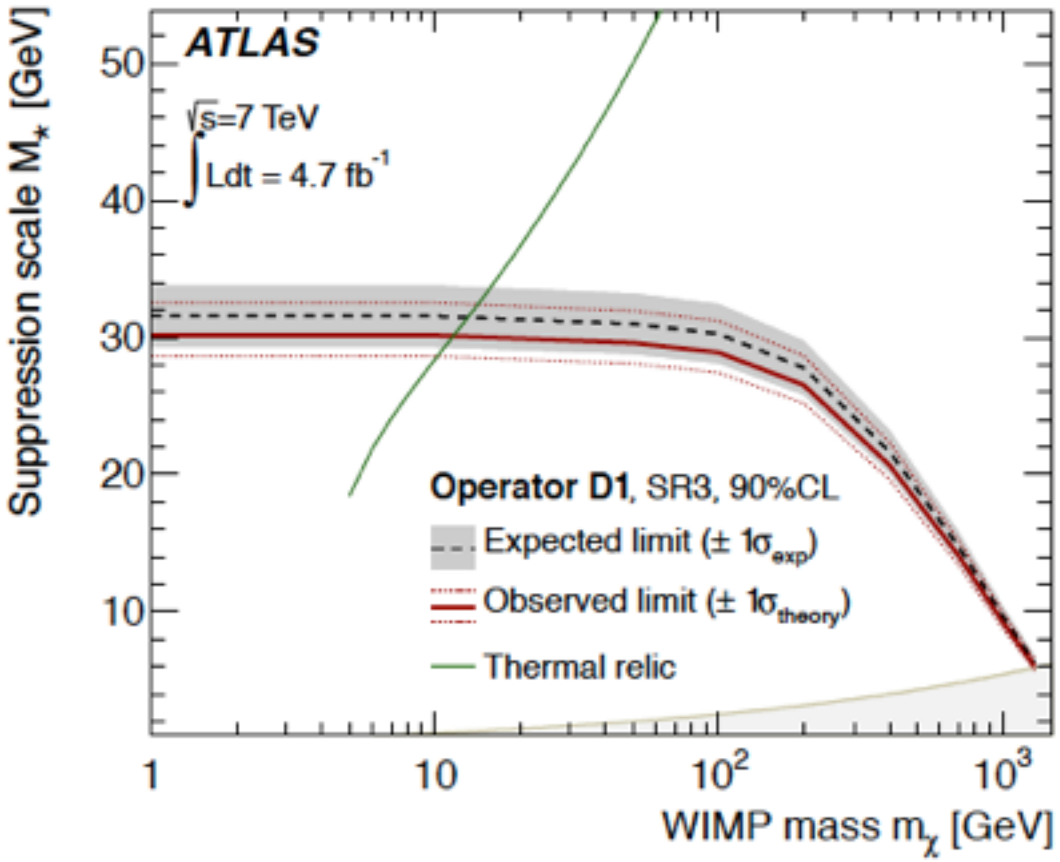
Systematics Monojet

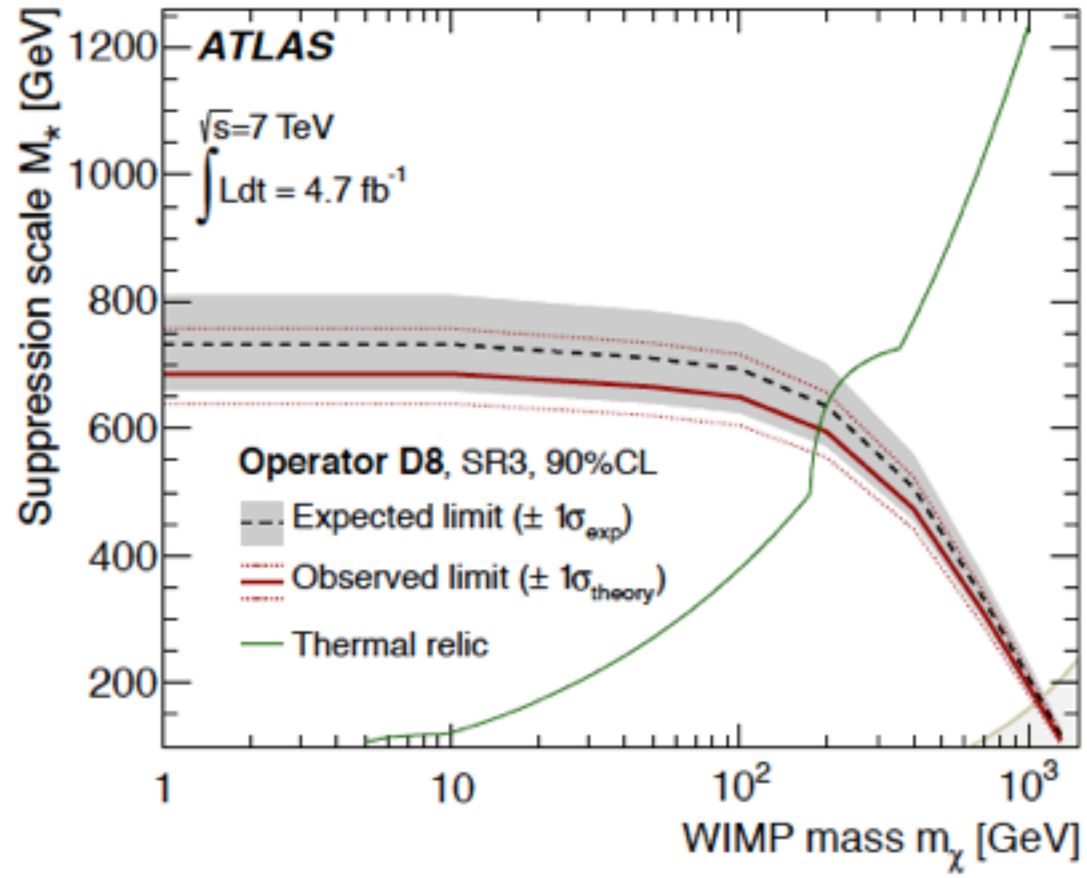
- 2011

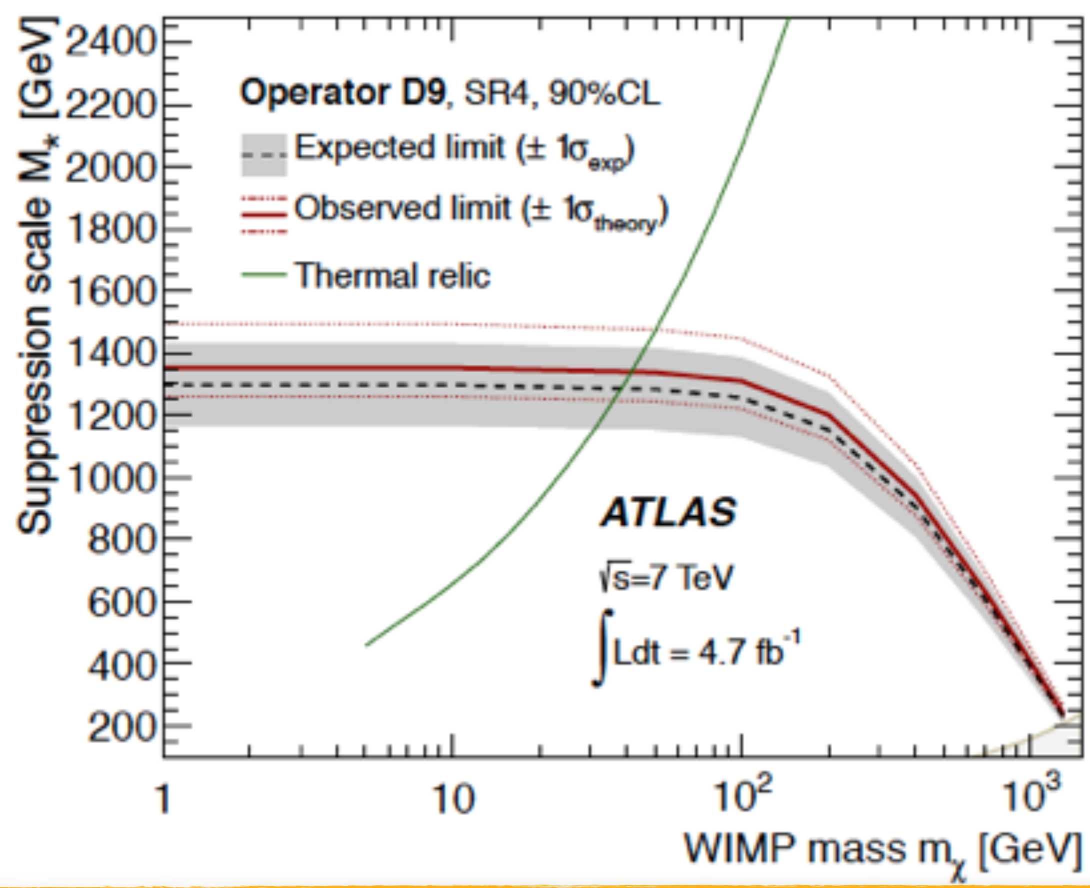
Source	SR1	SR2	SR3	SR4
JES/JER/E_T^{miss}	1.0	2.6	4.9	5.8
MC Z/W modelling	2.9	2.9	2.9	3.0
MC statistical uncertainty	0.5	1.4	3.4	8.9
$1 - f_{EW}$	1.0	1.0	0.7	0.7
Muon scale and resolution	0.03	0.02	0.08	0.61
Lepton scale factors	0.4	0.5	0.6	0.7
Multijet BG in electron CR	0.1	0.1	0.3	0.6
Di-boson, top, multijet, non-collisions	0.8	0.7	1.1	0.3
Total systematic uncertainty	3.4	4.4	6.8	11.1
Total data statistical uncertainty	0.5	1.7	4.3	11.8

- 2012
  - Jet & E_T^{miss} energy scale and resolution:
    2-4% (on transfer factors)
  - Lepton identification efficiencies:
    1-3% (on transfer factors)
  - Non-electroweak backgrounds:
    <1% (on total background)
  - parton shower/hadronisation modelling:
    3% (on total background)

Monojet WIMP Limits 2011







WIMP Limits 2011

- Monojet @ 90(95)%CL

m_χ	D1	D5	D8	D9	D11
1	30 (29)	687 (658)	687 (658)	1353 (1284)	375 (361)
5	30 (29)	687 (658)	687 (658)	1353 (1284)	375 (361)
10	30 (29)	687 (658)	687 (658)	1353 (1284)	375 (361)
50	30 (29)	682 (653)	666 (638)	1338 (1269)	370 (357)
100	29 (28)	681 (653)	650 (623)	1310 (1243)	360 (347)
200	27 (26)	658 (631)	595 (570)	1202 (1140)	357 (344)
400	21 (20)	571 (547)	475 (455)	943 (893)	324 (312)
700	14 (14)	416 (398)	311 (298)	629 (596)	250 (241)
1000	9 (9)	281 (269)	196 (188)	406 (384)	185 (178)
1300	6 (6)	173 (165)	110 (106)	240 (227)	128 (123)

- observed lower limits on the suppression scale M∗ [GeV] for SR with best expected limit (SR3 for D1, D5 and D8, SR4 for D9 and D11).
- central values (=> w/o theoretical uncertainties)

- Monophoton @ 90%CL

m_χ	D1	D5	D8	D9
1GeV	31	585	585	794
1.3TeV	5	156	100	188

- observed lower limits on the suppression scale M∗ [GeV]

ADD Limits 2011

- Monojet @ 95%CL

n	M_D [TeV] LO	M_D [TeV] NLO	R [pm] LO	R [pm] NLO
2	4.17	4.37	2.8×10^7	2.5×10^7
3	3.32	3.45	4.8×10^2	4.5×10^2
4	2.89	2.97	2.0	1.9
5	2.66	2.71	7.1×10^{-2}	7.0×10^{-2}
6	2.51	2.53	0.8×10^{-2}	0.8×10^{-2}

- lower (upper) limits on M_D (R) for n=2–6 extra dimensions using SR4
- central values (=> w/o theoretical uncertainties)

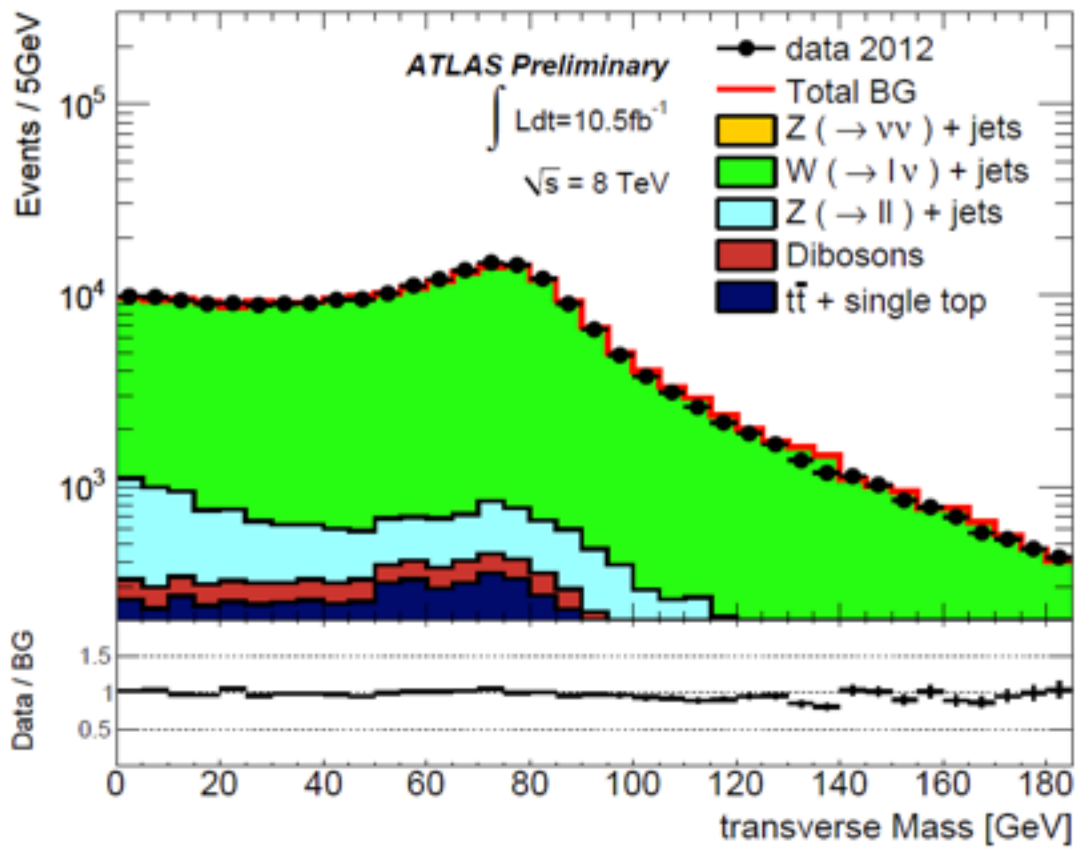
- Monophoton @ 95%CL

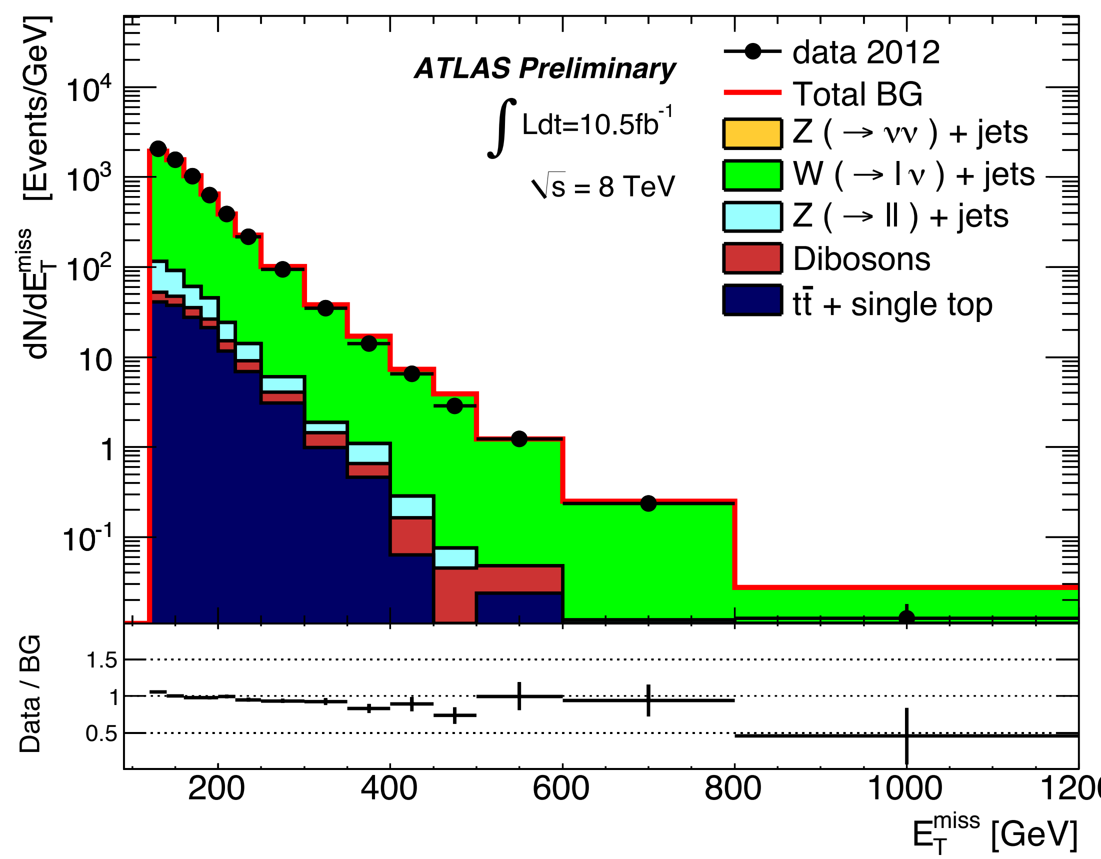
n	M_D [TeV]
2	1.93
3	1.83
4	1.83
5	1.86
6	1.89

- lower (upper) limits on M_D for n=2–6 extra dimensions

Electroweak Background 2012

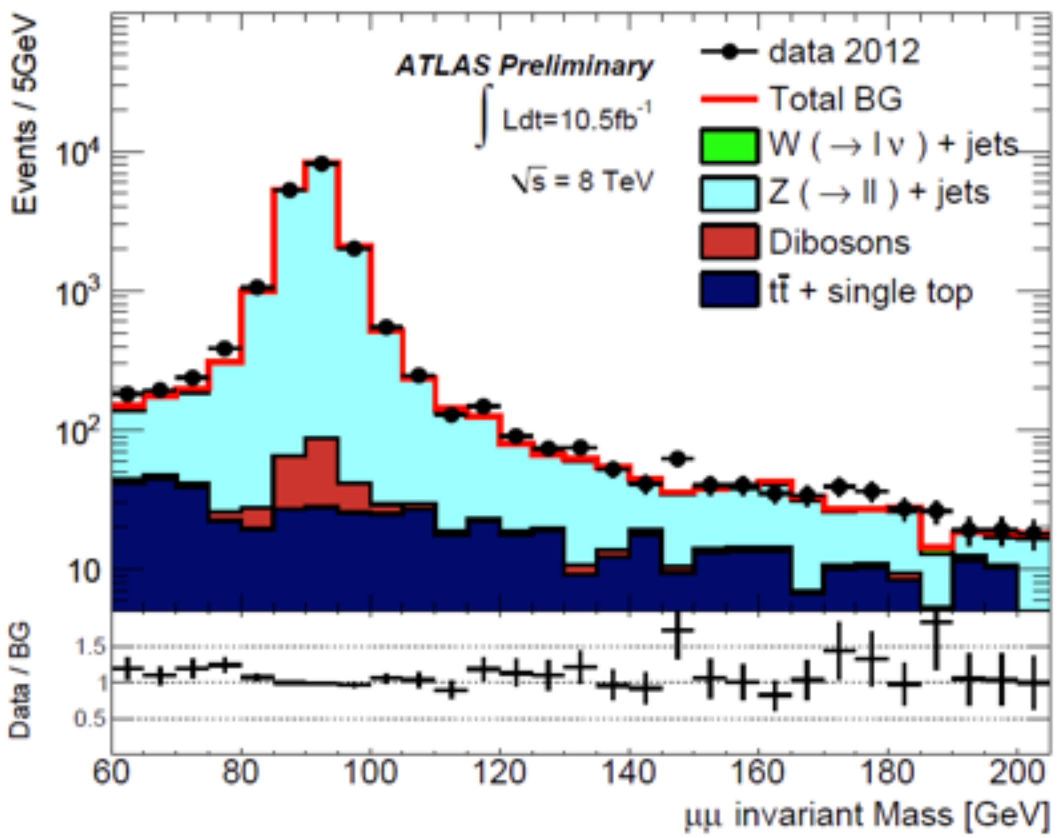
- W($\mu\nu$)+jets CR
  - exactly 1 reconstructed muon
  - 40GeV < m_T < 100GeV
  - remaining SR cuts

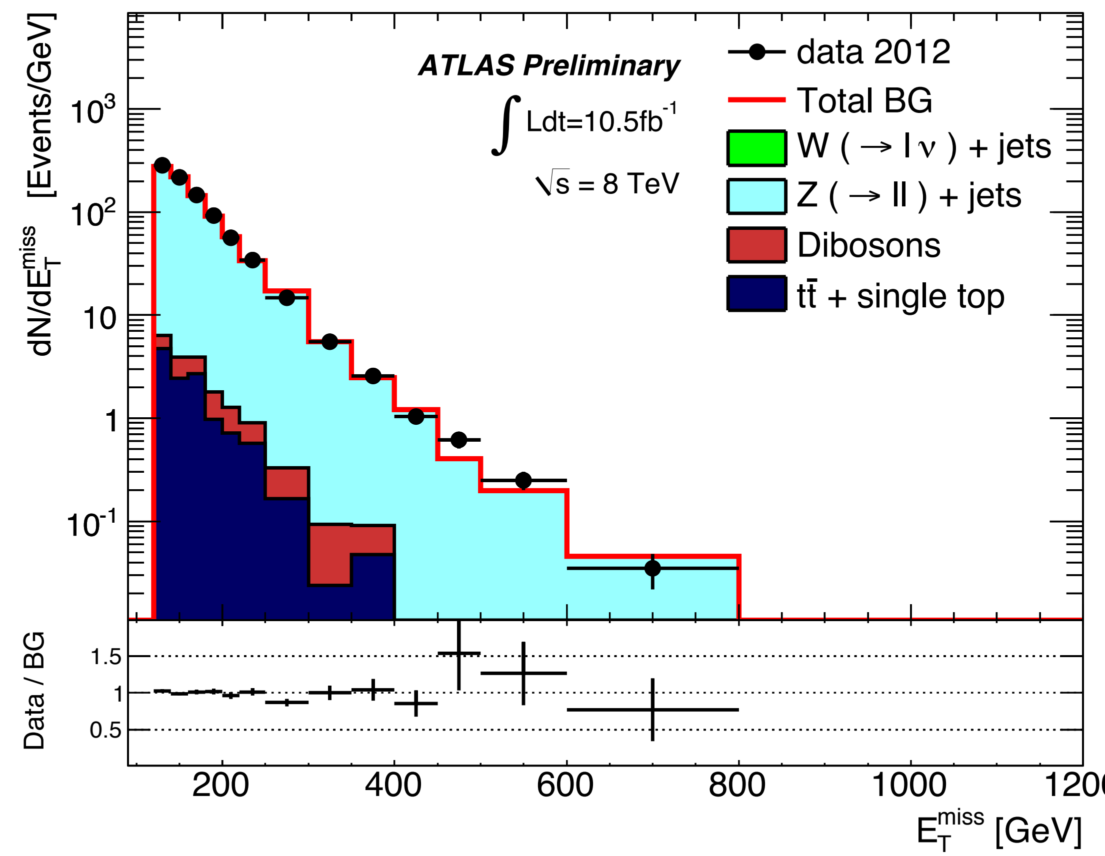




Electroweak Background 2012

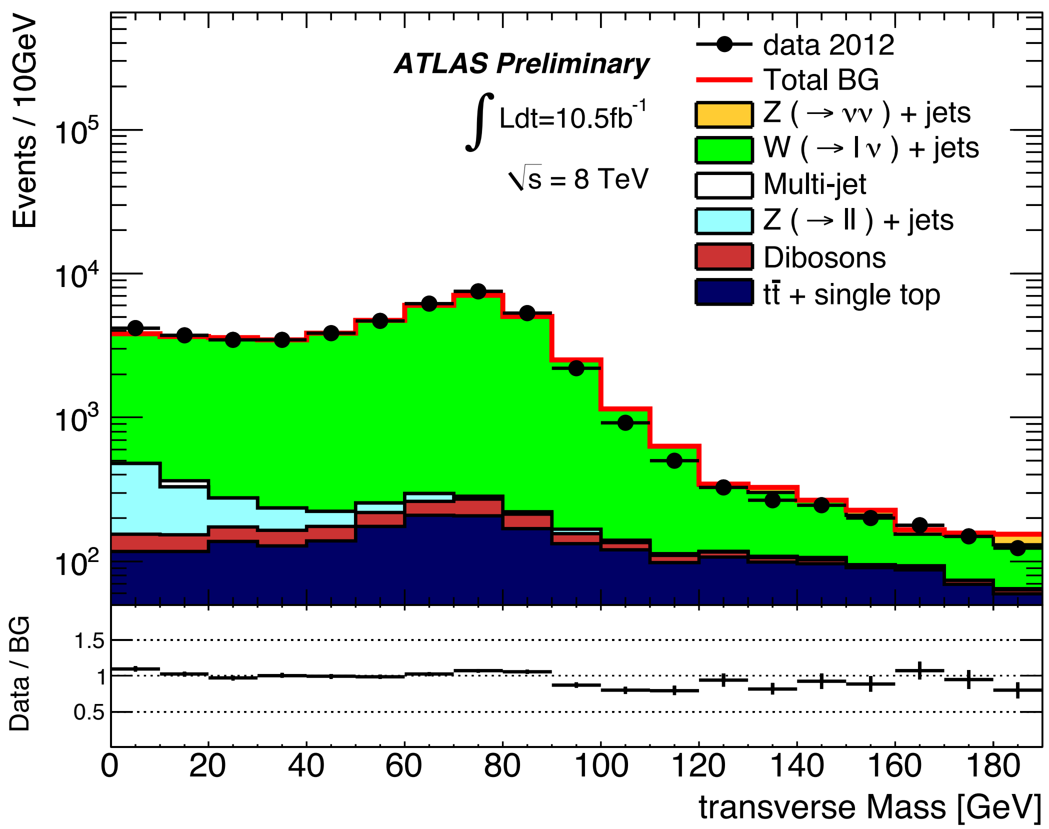
- Z($\mu\mu$)+jets CR
  - exactly 2 reconstructed muons
  - 76GeV < $m_{\mu\mu}$ < 116GeV
  - remaining SR cuts

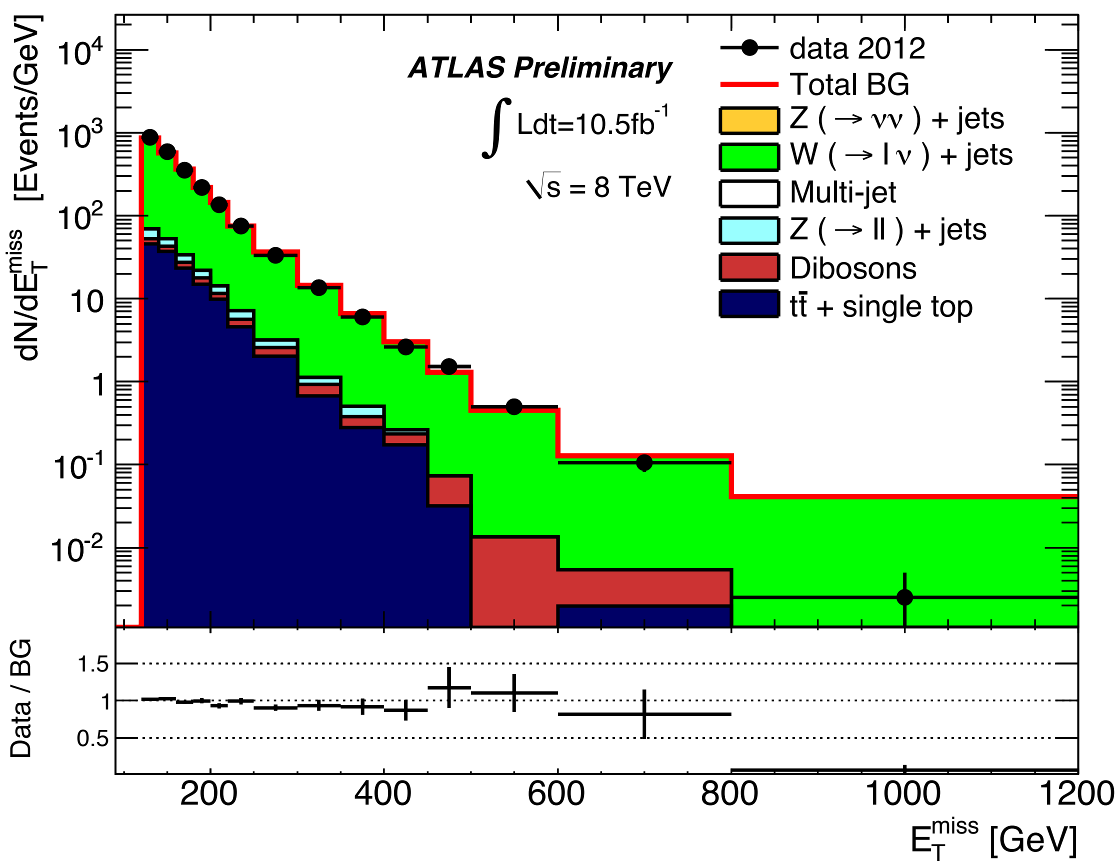




Electroweak Background 2012

- W($e\nu$)+jets CR
  - inverting the electron veto
  - no additional cuts since dominated by W





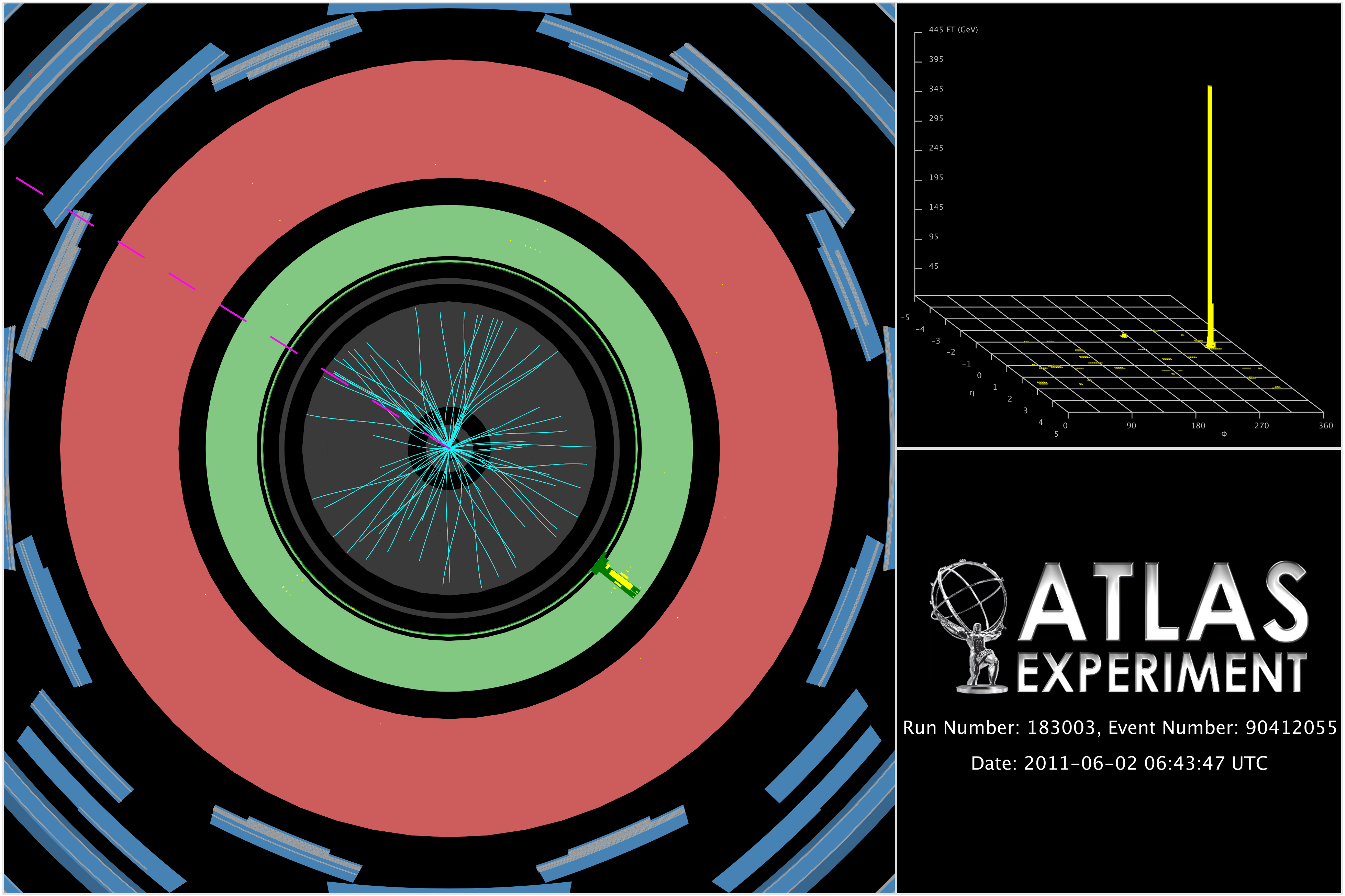
Results - Monojets2012 monojet@8TeV

- event numbers

	Background Predictions ± (stat.data)± (stat.MC) ± (syst.)			
	SR1	SR2	SR3	SR4
$Z(\rightarrow \nu\bar{\nu})$+jets	173600 ± 500 ± 1300 ± 5500	15600 ± 200 ± 300 ± 500	1520 ± 50 ± 90 ± 60	270 ± 30 ± 40 ± 20
$W \rightarrow \tau\nu$+jets	87400 ± 300 ± 800 ± 3700	5580 ± 60 ± 190 ± 300	370 ± 10 ± 40 ± 30	39 ± 4 ± 11 ± 2
$W \rightarrow e\nu$+jets	36700 ± 200 ± 500 ± 1500	1880 ± 30 ± 100 ± 100	112 ± 5 ± 18 ± 9	16 ± 2 ± 6 ± 2
$W \rightarrow \mu\nu$+jets	34200 ± 100 ± 400 ± 1600	2050 ± 20 ± 100 ± 130	158 ± 5 ± 21 ± 14	42 ± 4 ± 13 ± 8
$Z \rightarrow \tau\tau$+jets	1263 ± 7 ± 44 ± 92	54 ± 1 ± 9 ± 5	1.3 ± 0.1 ± 1.3 ± 0.2	1.4 ± 0.2 ± 1.5 ± 0.2
$Z/\gamma^*(\rightarrow \mu^+\mu^-)$+jets	783 ± 2 ± 35 ± 53	26 ± 0 ± 6 ± 1	2.7 ± 0.1 ± 1.9 ± 0.3	–
$Z/\gamma^*(\rightarrow e^+e^-)$+jets	–	–	–	–
Multijet	6400 ± 90 ± 5500	200 ± 20 ± 200	–	–
$t\bar{t}$ + single t	2660 ± 60 ± 530	120 ± 10 ± 20	7 ± 3 ± 1	1.2 ± 1.2 ± 0.2
Dibosons	815 ± 9 ± 163	83 ± 3 ± 17	14 ± 1 ± 3	3 ± 1 ± 1
Non-collision background	640 ± 40 ± 60	22 ± 7 ± 2	–	–
Total background	344400 ± 900 ± 2200 ± 12600	25600 ± 240 ± 500 ± 900	2180 ± 70 ± 120 ± 100	380 ± 30 ± 60 ± 30
Data	350932	25515	2353	268

Monophoton Event Candidate

- from 2011 data



- E_T^{miss} = 446.9GeV
- photon p_T = 449.7GeV