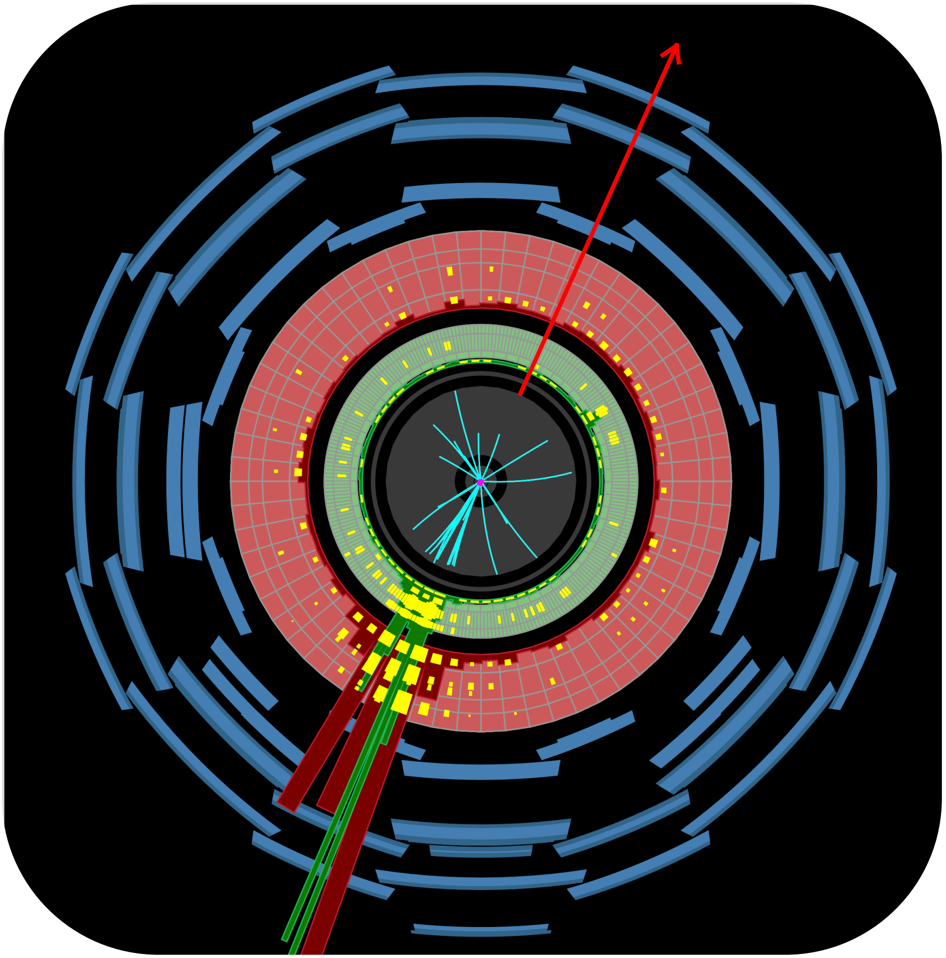
Monojet and EW backgrounds

September 20th, 2016

Arely Cortes-Gonzalez
on behalf of the 2015 data analysis team

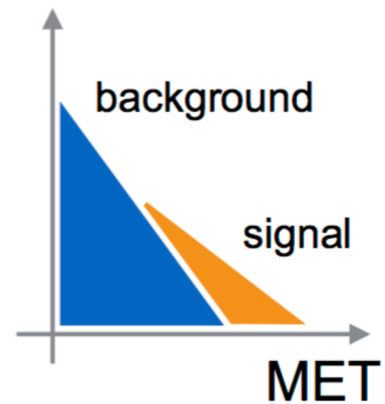
Intro



Leading jet p_T of 973 GeV, balanced by a E_T^{miss} of 954 GeV

The monojet topology constitutes a clean and distinctive signature in searches for new physics beyond the Standard Model (SM) at colliders.

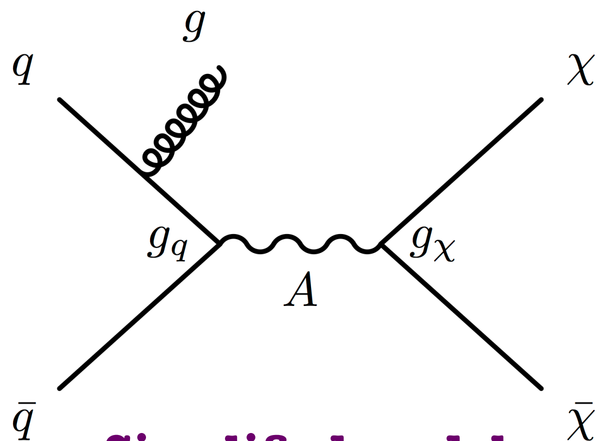
Search for high MET excesses.



ATLAS latest publication:
2015 data paper: 3.2 fb-1
Phys. Rev. D 94 (2016) 032005

Intro

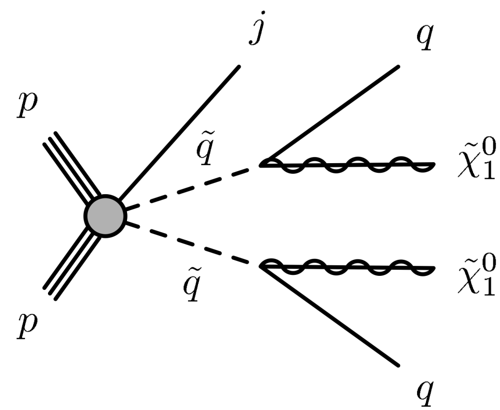
Dark Matter - WIMPs



Simplified models:

- s-channel axial vector + ISR jet.
- Model as function of 4 parameters:
  - m_{DM}, m_{med}, g_{DM}, g_q.
- Assume minimal mediator width.

Compressed SUSY



$\tilde{t}_1 \rightarrow c + \tilde{\chi}_1^0$

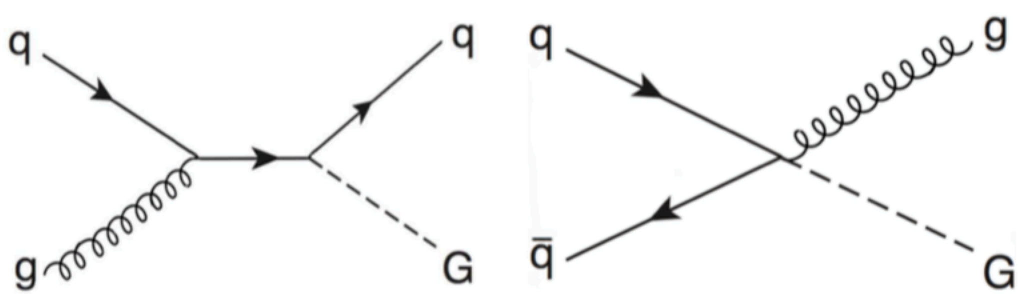
$\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$

$\tilde{q} \rightarrow q + \tilde{\chi}_1^0$

$\Delta m \equiv m_{\tilde{q}_1} - m_{\tilde{\chi}_1^0}$

squark+LSP production in simplified models: compressed scenario + ISR.

ADD – Large Extra Dimensions



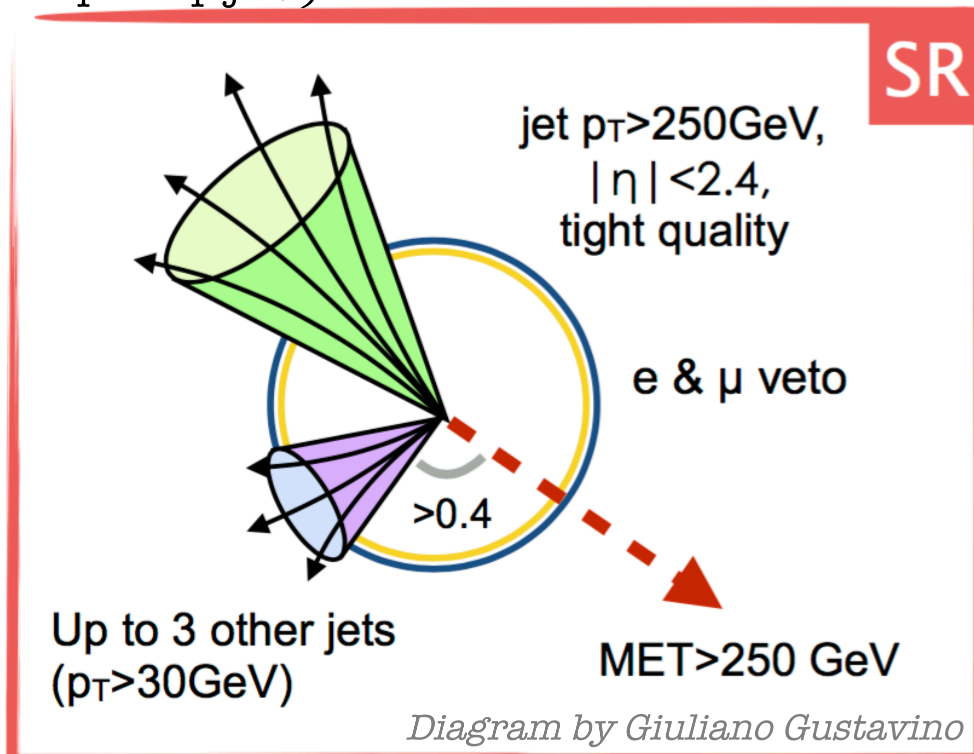
ADD models:
Assume n additional dimensions of radius R. Effective Planck mass in $4+n$ dimensions is $M_{Pl}^2 \sim M_D^{(2+n)} R^n$. Production of Kaluza-Klein tower of graviton modes (E_T^{miss}).

Event Selection

- **Electrons**:
  - *Baseline*: p_T>20GeV, loose identification, |η|<2.47.
  - *Signal*: Baseline + Tight identification + d_0 and z_0 cuts. Track-based isolation in CR_{ele}
- **Muons**:
  - *Baseline*: p_T>10GeV, medium identification, |η|<2.5.
  - *Signal*: Baseline + d_0 and z_0 cuts.
- **Jets**: p_T > 30 GeV, |η|<2.8, JVT cut (remove pile-up jets).
- **E_T^{miss}**: Baseline muons as invisible.

Events selection

- E_T^{miss} trigger.
  - Online threshold at 70 GeV.
- Leading jet p_T > 250 GeV.
- E_T^{miss} > 250 GeV.
- Multijets background rejection: $\Delta\phi(E_T^{miss}, jets^{1,2,3,4}) > 0.4$
- N_{jets} (p_T>30GeV) ≤ 4.
- NCB rejection: Leading jet: |η|<2.4 and passes tight cleaning.

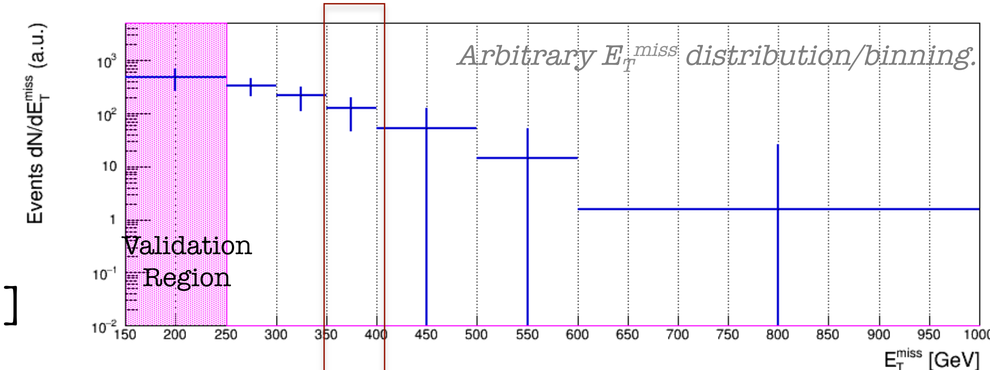


Analysis Strategy

Simplified shape fit

A **global fit** (CRs+SR) is performed simultaneously in **all** the **exclusive** E_T^{miss} bins:
[250, 300, 350, 400, 500, 600, 700, ∞]

A validation region is defined:
150 GeV $< E_T^{miss} <$ 250 GeV.



In each bin of E_T^{miss} we define a SR and the corresponding control regions.

SR: Veto on **baseline** leptons

CR$_{wmn}$: $N_\mu^{signal} = 1$, $N_e^{base} = 0$; 30 GeV $< m_T <$ 100 GeV.

CR$_{ele}$: $N_\mu^{base} = 0$, $N_e^{signal} = 1$. Track-based isolation

CR$_{zmm}$: $N_\mu^{signal} = 2$, $N_e^{base} = 0$; 66 GeV $< m_{\mu\mu} <$ 116 GeV.

CR$_{zee}$: $N_\mu^{base} = 0$, $N_e^{signal} = 2$; 66 GeV $< m_{ee} <$ 116 GeV.

(SR + 3 CRs) x 7 E_T^{miss} regions

Three **normalization factors** per E_T^{miss} bin are used to constraint the V+jets background: μ_{ele}^{bin}, μ_{wmn}^{bin}, μ_{zmm}^{bin} (***free parameters***).
Systematic uncertainties are treated as **nuisance parameters** with Gaussian shapes in a fit based on the profile likelihood method.

Analysis Strategy

Simplified shape fit

A **global fit** (CRs+SR) is performed simultaneously
in **all** the **exclusive** E_T^{miss} bins:
[250, 300, 350, 400, 500, 600, 700, ∞]
A validation region is defined:
150 GeV < E_T^{miss} < 250 GeV.

Binning *chosen in base of expected statistics (CRs), signal sensitivity, …*
Poisson terms for each region/bin,
systematics correlated among bins.

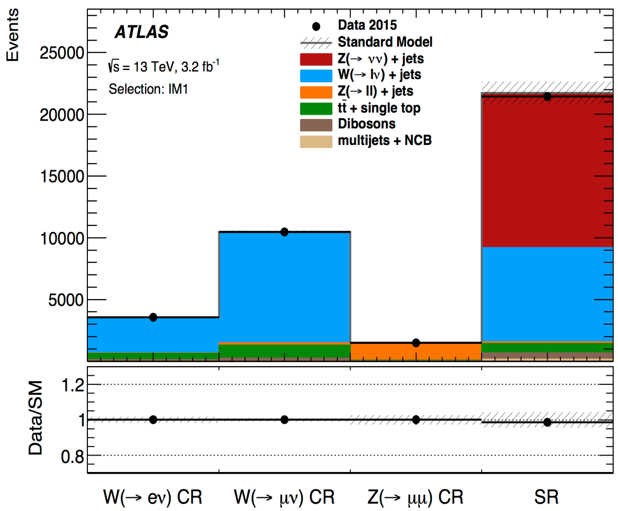
Inclusive signal region	IM1	IM2	IM3	IM4	IM5	IM6	IM7
E_T^{miss} (GeV)	> 250	> 300	> 350	> 400	> 500	> 600	> 700
Exclusive signal region	EM1	EM2	EM3	EM4	EM5	EM6	
E_T^{miss} (GeV)	[250–300]	[300–350]	[350–400]	[400–500]	[500–600]	[600–700]	

Inclusive signal regions also defined (as in previous publications), to provide "model independent" limits on **visible cross section**.

Signal model limits quoted in paper computed from the global fit.

Analysis Strategy

E_T^{miss} > 250 GeV

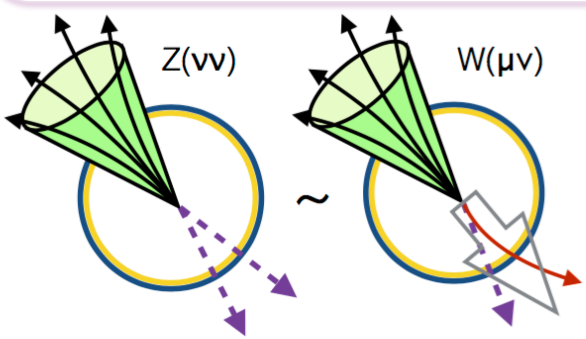


Residual dominant background from **Z(νν)+jets**, followed by **W(lν)+jets**.

- **V+jets** backgrounds: normalization factors from fit.
  - Except Z(ee)+jets, estimated from MC.
  - Sherpa 2.1.1. CT10 PDF. Normalized to NNLO pQCD predictions.
- **t-tbar**, **single top** and **DiBosons** from MC.
  - t-tbar, single top with POWHEG-BOX v2 (single top t-channel with v1). CT10 PDF. Parton shower with PYTHIA-6.428.
  - DiBosons with Sherpa 2.1.1. CT10 PDF. Normalized to NLO pQCD predictions.
- **Non-collisions** background and **multi-jets** are estimated with data-driven methods.

3 E_T^{miss}–dependent normalization factors used to constraint the V+jets bkg (μ_{ele}^{bin}, μ_{wmn}^{bin}, μ_{zmm}^{bin}).

Control region	background process	norm. factor
$W \to e\nu$	$W(\to e\nu)$, $W(\to \tau\nu)$, $Z/\gamma^*(\to \tau^+\tau^-)$	μ_{ele}
$W \to \mu\nu$	$W(\to \mu\nu)$, $Z(\to \nu\bar{\nu})$	μ_{wmn}
$Z \to \mu\mu$	$Z/\gamma^*(\to \mu^+\mu^-)$	μ_{zmm}



Z(νν)+jets: dominant background.

Irreducible bkg -> estimated using CR_{wmn} and "E_T^{miss}" with muons considered as invisible particles.

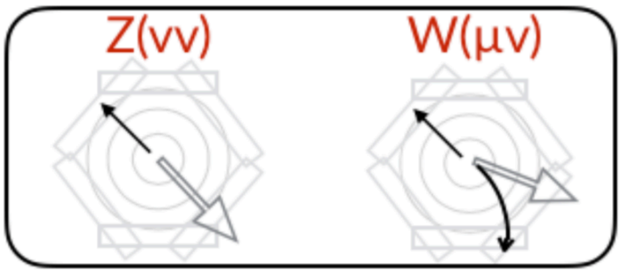
Muons treated as invisible → E_T^{miss} ~ boson p_T

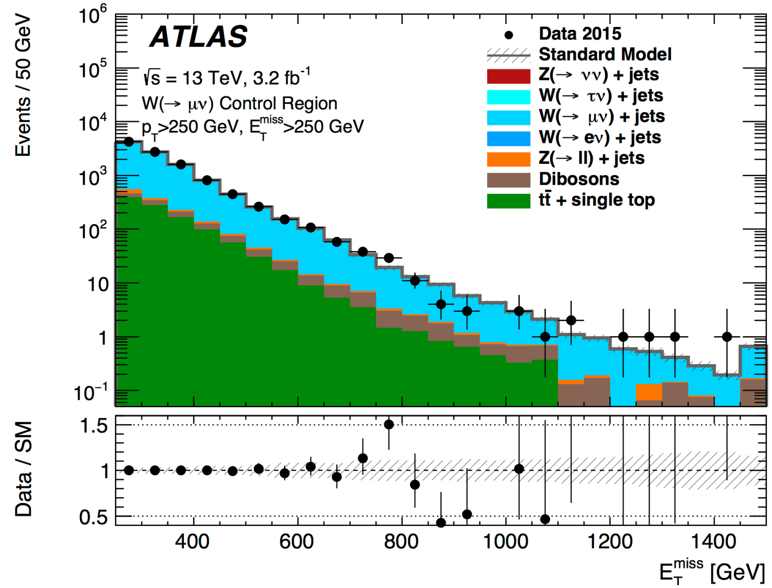
Systematic uncertainty for this assumption.

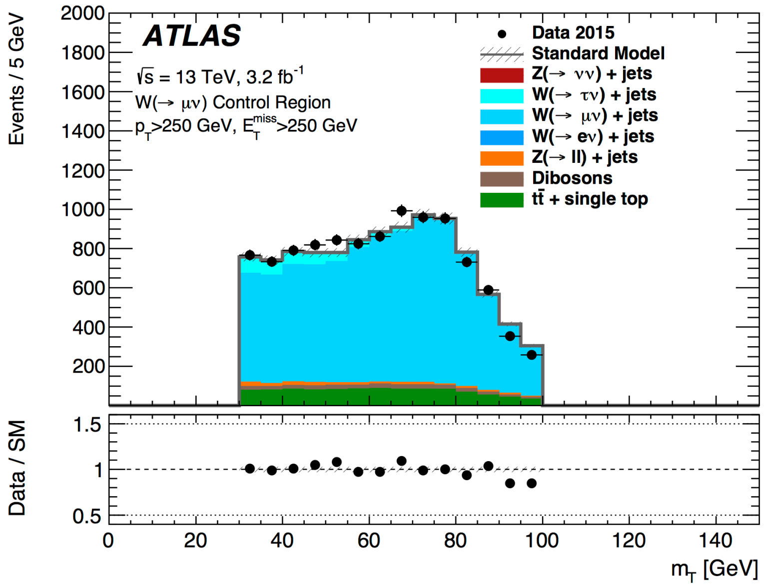
Single Muon CR

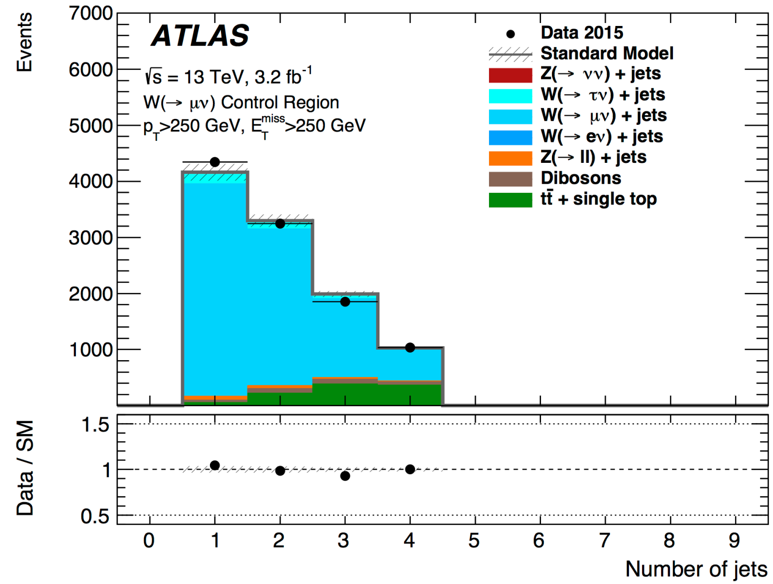
$N_{\mu}^{signal} = 1$, $N_e^{base} = 0$
30 GeV < m_T < 100 GeV.

CR$_{wmn}$







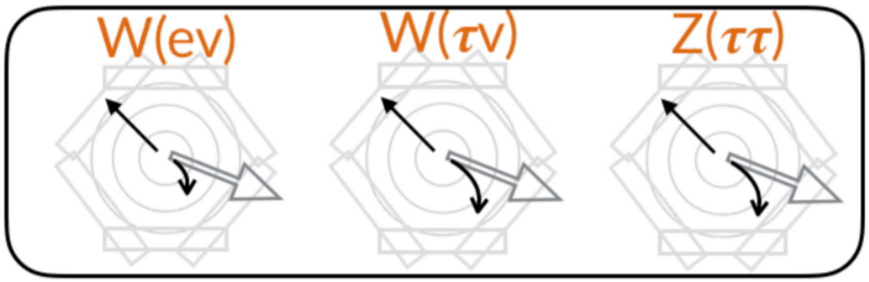


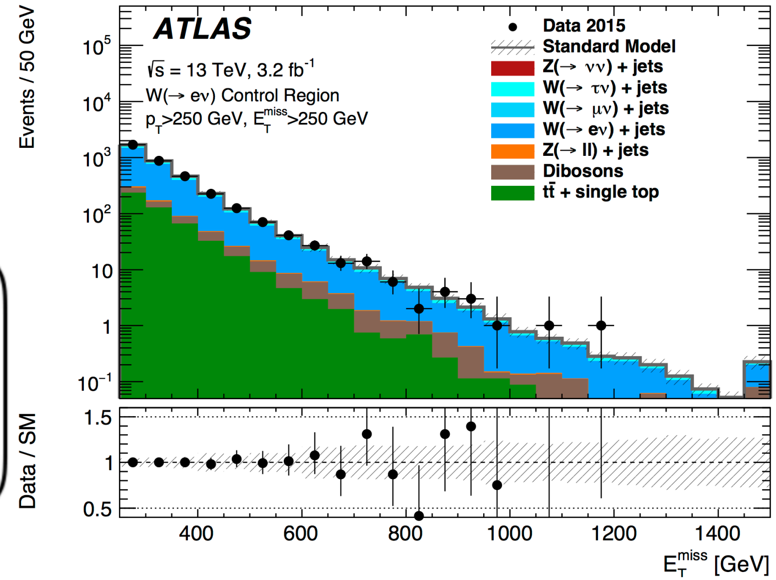
Yields pre/post-fit available in paper and/or as auxiliary material

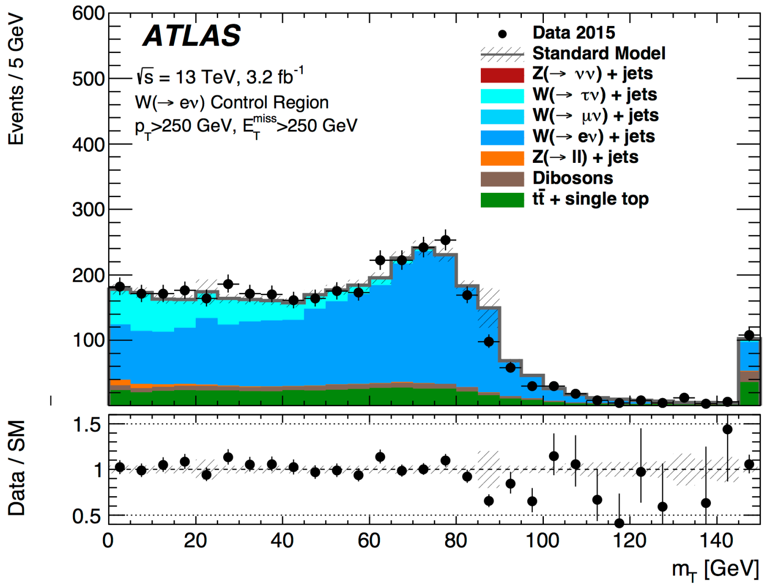
Single Electron CR

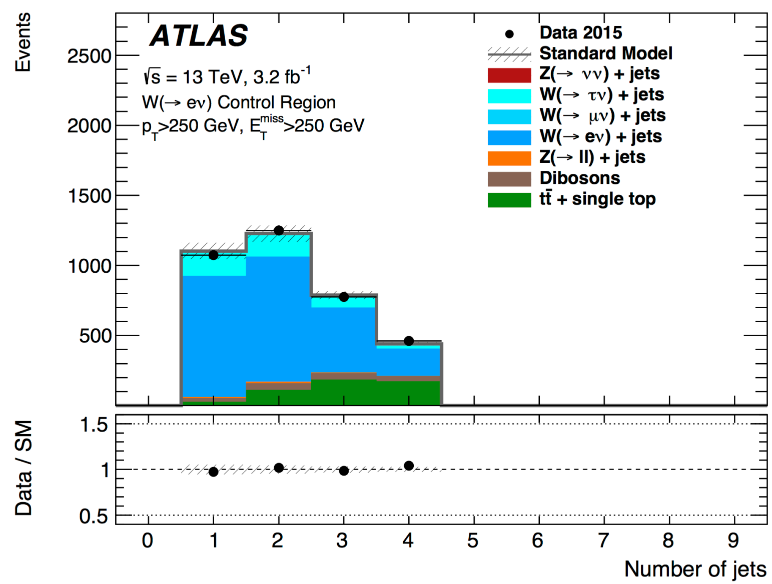
$N_{\mu}^{base} = 0$, $N_{e}^{signal} = 1$.
Track-based isolation

CR_{ele}







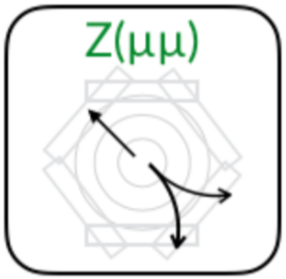


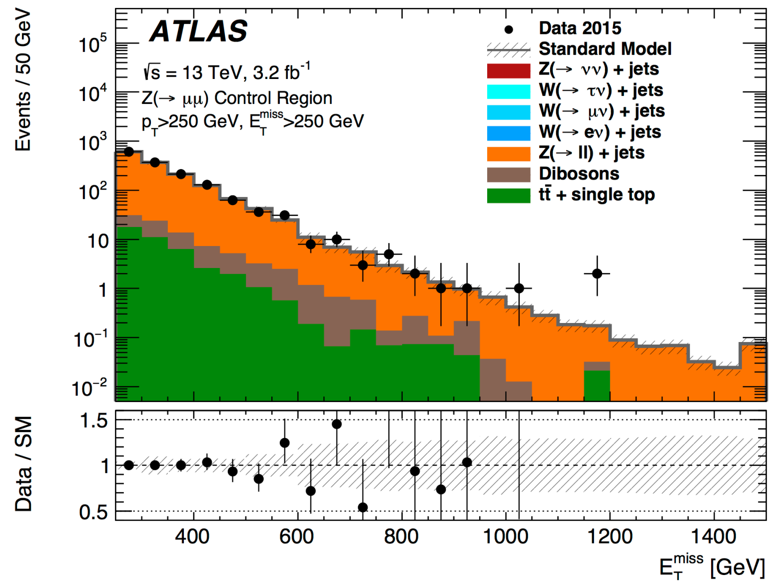
Yields pre/post-fit available in paper and/or as auxiliary material

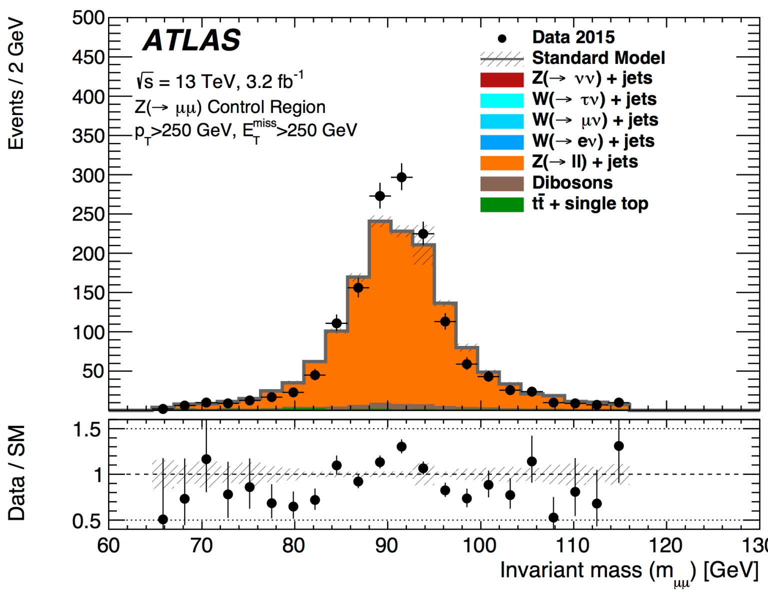
Di-Muon CR

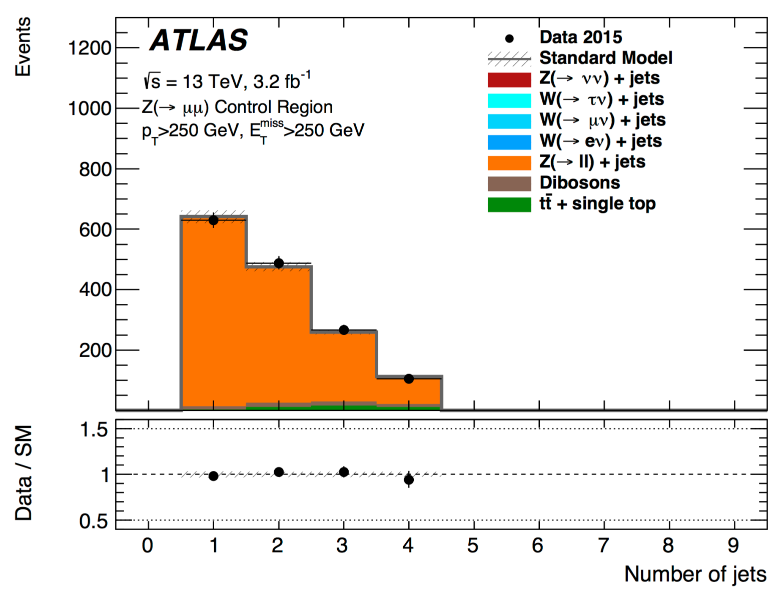
$N_{\mu}^{signal} = 2$, $N_{e}^{base} = 0$ **CR_{zmm}**

66 GeV $< m_{\mu\mu} <$ 116 GeV.







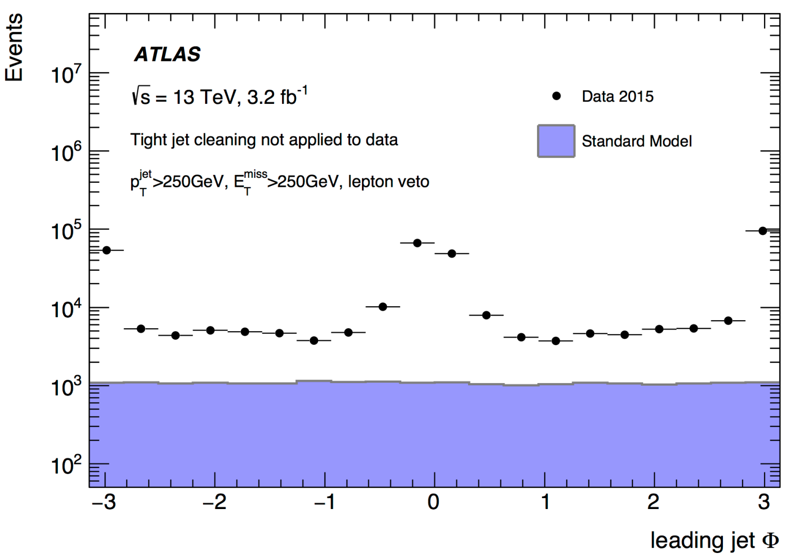


Yields pre/post-fit available in paper and/or as auxiliary material

Other backgrounds

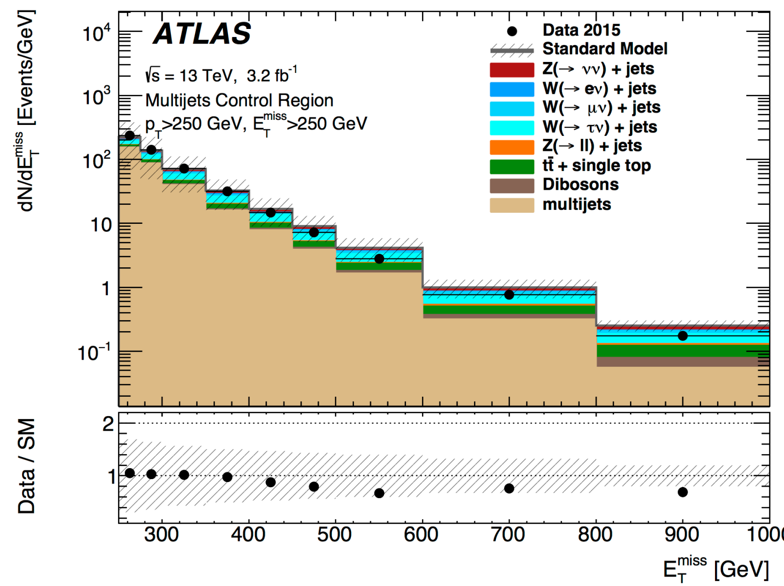
Non-Collisions bkg

- Mostly beam-induced.
- Estimated using beam-induced-bkg tagger based on match between muon segment and calo cluster.



Multijets

- Fake E_T^{miss} from mis-measured jets.
- Estimated using jet smearing and multi-jets dominant region (for normalization).



From MC

t-tbar, single top, DiBosons, Z(ee)+jets.

Yields pre/post-fit available in paper and/or as auxiliary material

V+jets systematic uncertainties

V+jets theoretical uncertainties

For V+jets samples four parameters are varied to calculate uncertainties on the modeling:

- Matrix element matching (**CKKW**). Nominal value: 20GeV. The systematic variations considered is to increase (decrease) this value to 30 GeV (15 GeV).
- **Renormalization** scale. μ_R is varied by a factor of 2 and ½ with respect to the nominal.
- **Factorization** scale. μ_F is varied by a factor of 2 and ½ with respect to the nominal.
- **Resummation** scale. μ_{QSF} is varied by a factor of 2 and ½ with respect to the nominal.

WZ transfer uncertainty

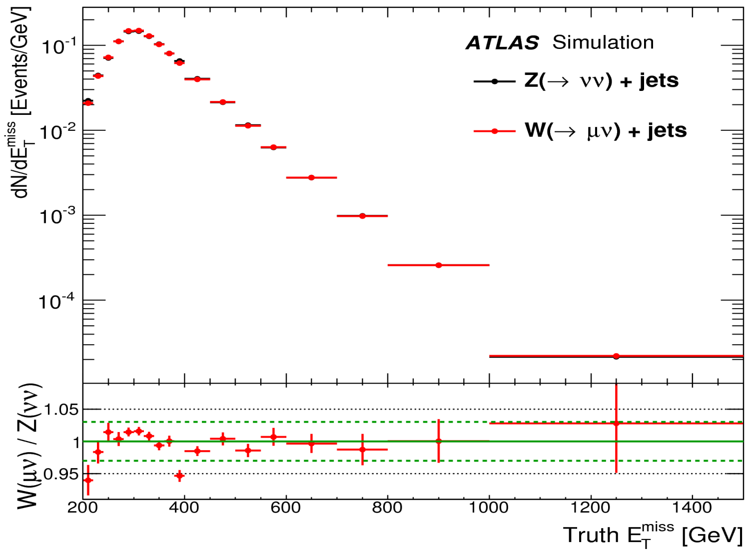
We compute a systematic uncertainty applicable ***only to Z(vv)+jets*** in the SR.

Notice that this means that the uncertainty won't be further constrained by the SR+CRs fit.

- W vs Z MC modelling.
  - 3% flat in E_T^{miss}.
- EW radiative NLO correction differences in W+jets and Z+jets.
  - 1-4% vs. boson p_T on Z(vv).

E1 (250-300)	E2 (300-350)	E3 (350-400)	E4 (400-500)	E5 (500-600)	E6 (600-700)	E7 (>700)
±3.5%	±3.5%	±4.0%	±4.0%	±4.0%	±5.0%	±6.0%
I1 (>250)	I2 (>300)	I3 (>350)	I4 (>400)	I5 (>500)	I6 (>600)	I7 (>700)
±3.5%	±3.5%	±4.0%	±4.0%	±4.5%	±5.0%	±6.0%

WZ-transfer uncertainty



SUSY-2013-21
Eur. Phys. J. C (2015) 75:299

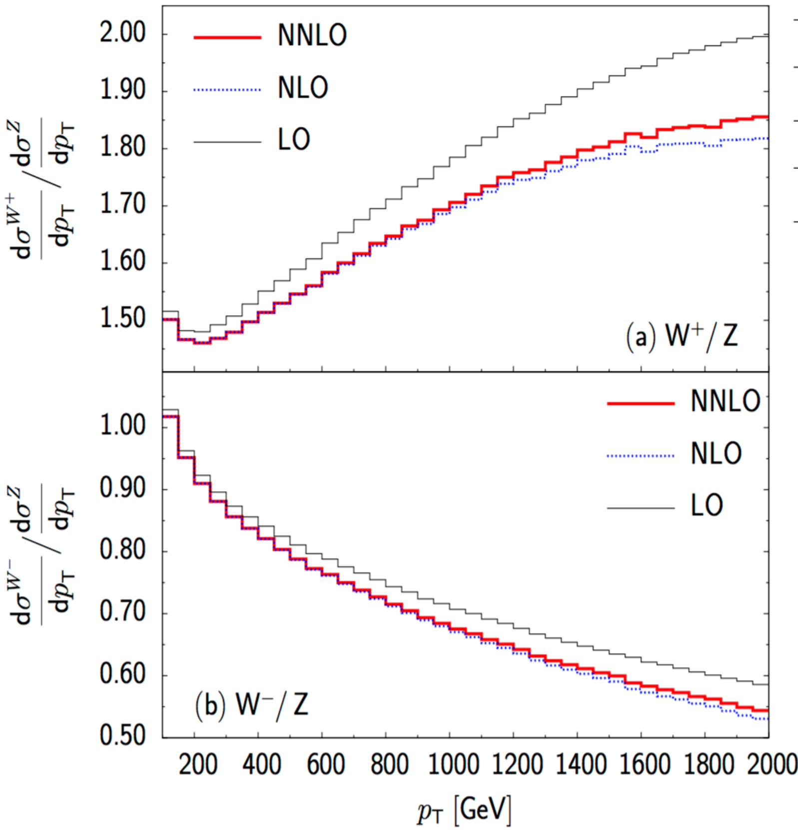
W vs Z MC modelling (3% flat in E_T^{miss}).

Comparison of the generated E_T^{miss} distribution between Z(νν)+jets and W(μν)+jets processes (E_T^{miss} >220 GeV SR). In the W(μν) case: a muon with p_T >10 GeV and |η| < 2.4 is required (30 < m_T < 100 GeV). The E_T^{miss} calculation includes the contribution of the muon and neutrino from the W decay in the final state.

NB: Plot from 8 TeV data analysis.

WZ-transfer uncertainty

EW radiation correction differences in W+jets and Z+jets.



Electroweak corrections to hadronic production of W bosons at large transverse momenta
Johann H. Kühn, A. Kulesza, S. Pozzorini, M. Schulze.
Nucl.Phys.B797:27-77,2008

EW correction by theoretical calculations						
E1 (250-300)	E2 (300-350)	E3 (350-400)	E4 (400-500)	E5 (500-600)	E6 (600-700)	E7 (>700)
$(-0.4^{+1.6}_{-0.8})\%$	$(0.1^{+1.6}_{-1.0})\%$	$(-0.7^{+1.8}_{-1.2})\%$	$(0.2^{+1.8}_{-1.4})\%$	$(0.4^{+2.1}_{-1.9})\%$	$(1.5^{+2.5}_{-2.3})\%$	$(1.7^{+2.4}_{-3.5})\%$
I1 (>250)	I2 (>300)	I3 (>350)	I4 (>400)	I5 (>500)	I6 (>600)	I7 (>700)
$(-0.3^{+1.6}_{-1.0})\%$	$(-0.1^{+1.7}_{-1.3})\%$	$(-0.1^{+2.2}_{-1.5})\%$	$(0.4^{+2.1}_{-1.7})\%$	$(0.8^{+2.4}_{-2.2})\%$	$(1.6^{+2.3}_{-2.8})\%$	$(1.7^{+2.4}_{-3.5})\%$

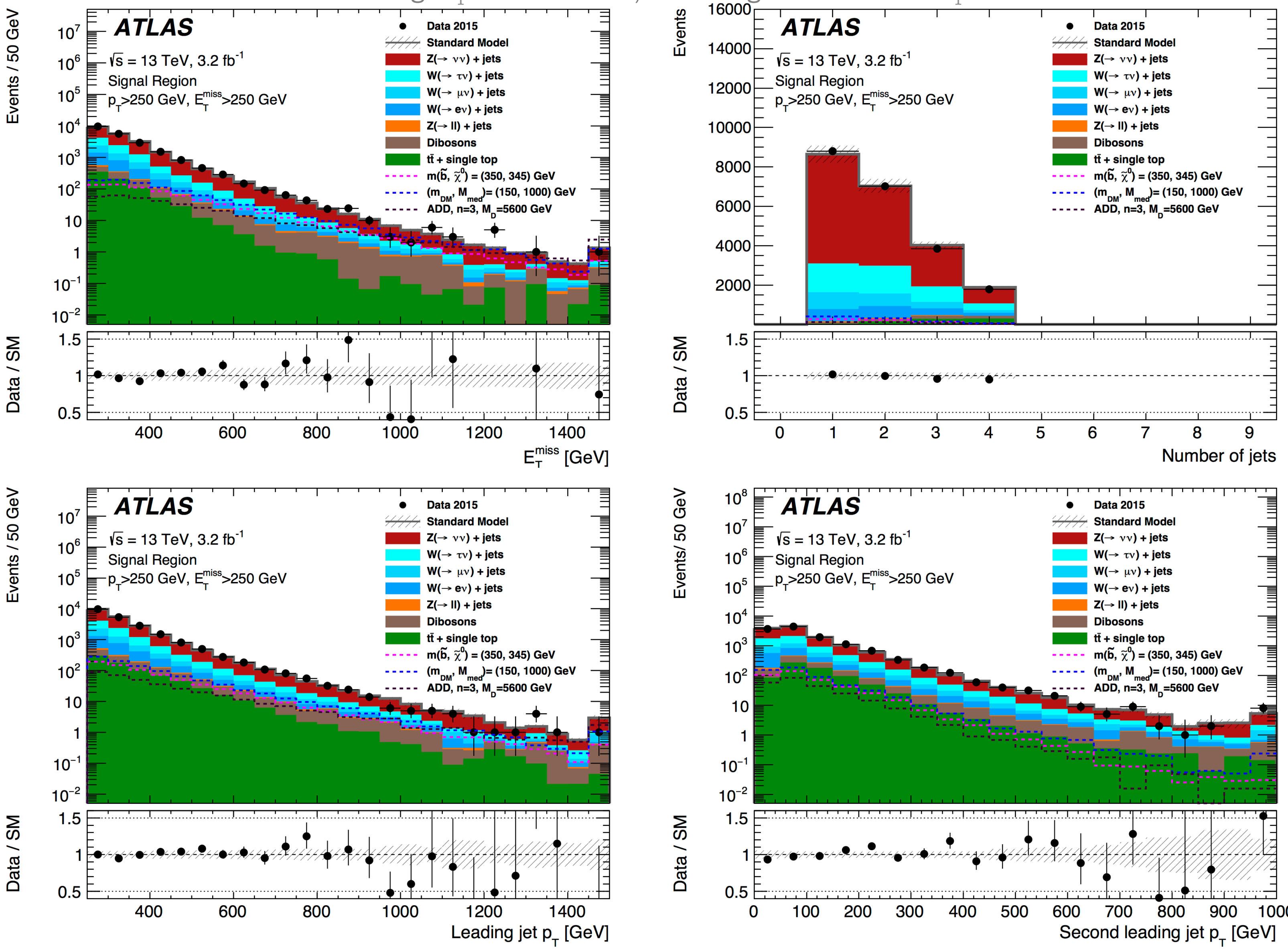
W/Z QCD/EWK corrections at higher orders computed by authors of the paper for our different event selections.

They use NNPDF. The uncertainties in the calculation are dominated by the *photon induced PDFs* .

Since the uncertainties are as large as the corrections themselves, the prescription followed by us was not to apply the corrections, but rather take the central total deviation (of W/Z+jet ratio), adding linearly the biggest error bar, as uncertainty for the Z(vv) background.

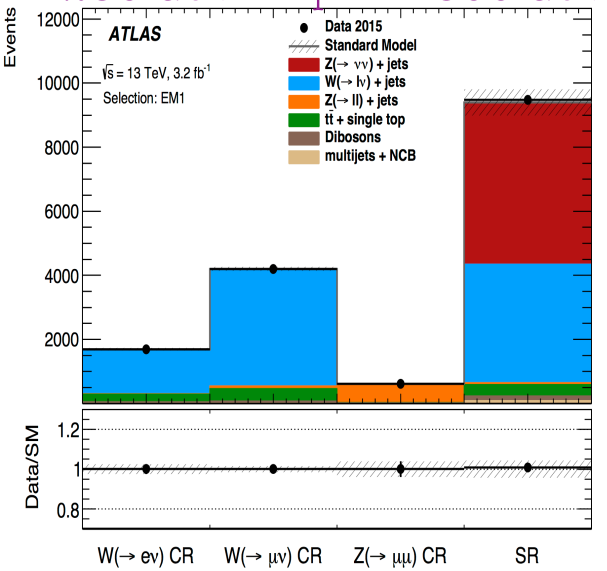
Signal Region *(no excesses)*

Plotting: E_T^{miss} > 250 GeV, but using the exclusive E_T^{miss} bins fit.

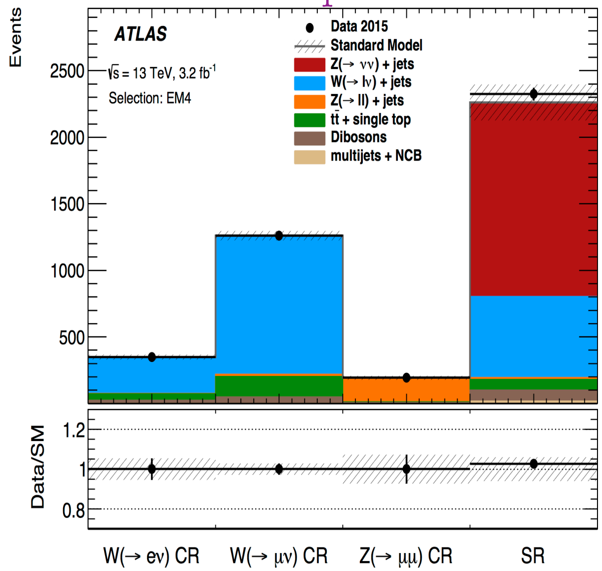


Signal Region *(no excesses)*

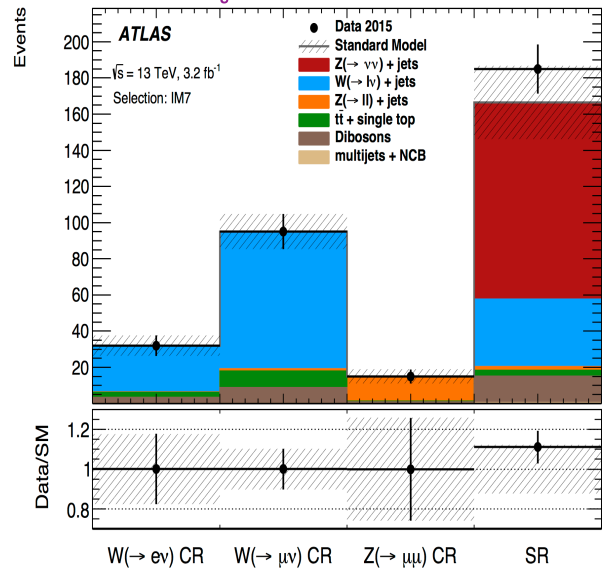
250 GeV < E_T^{miss} < 300 GeV



400 GeV < E_T^{miss} < 500 GeV



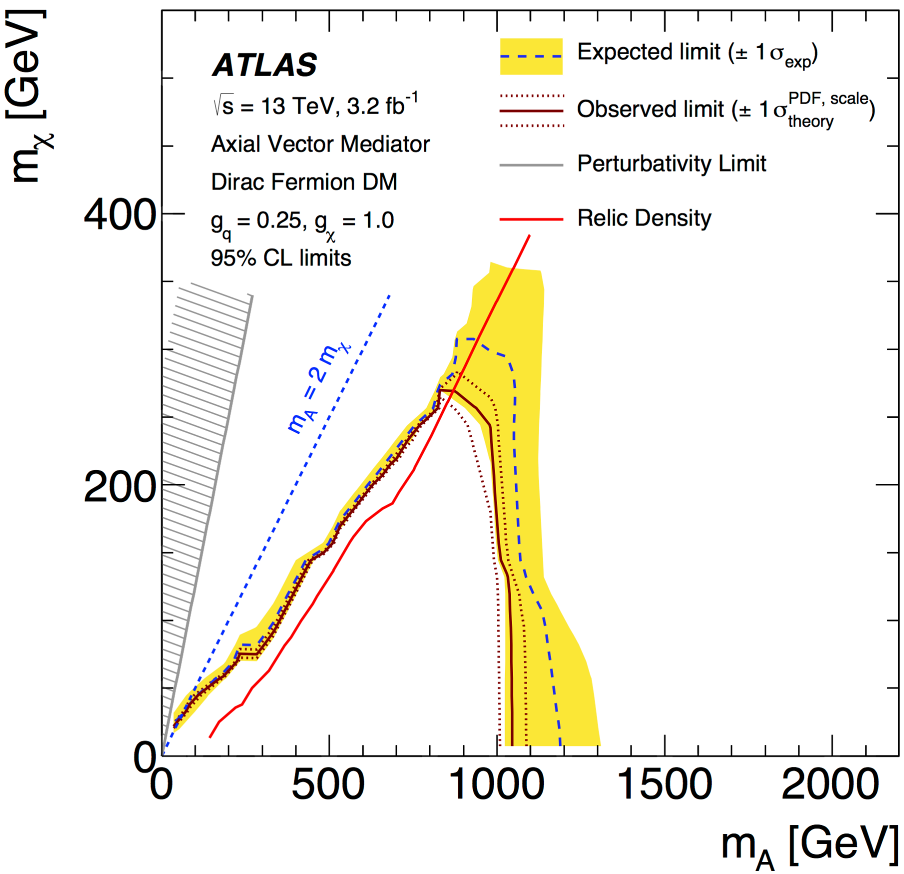
E_t^{miss} > 700 GeV



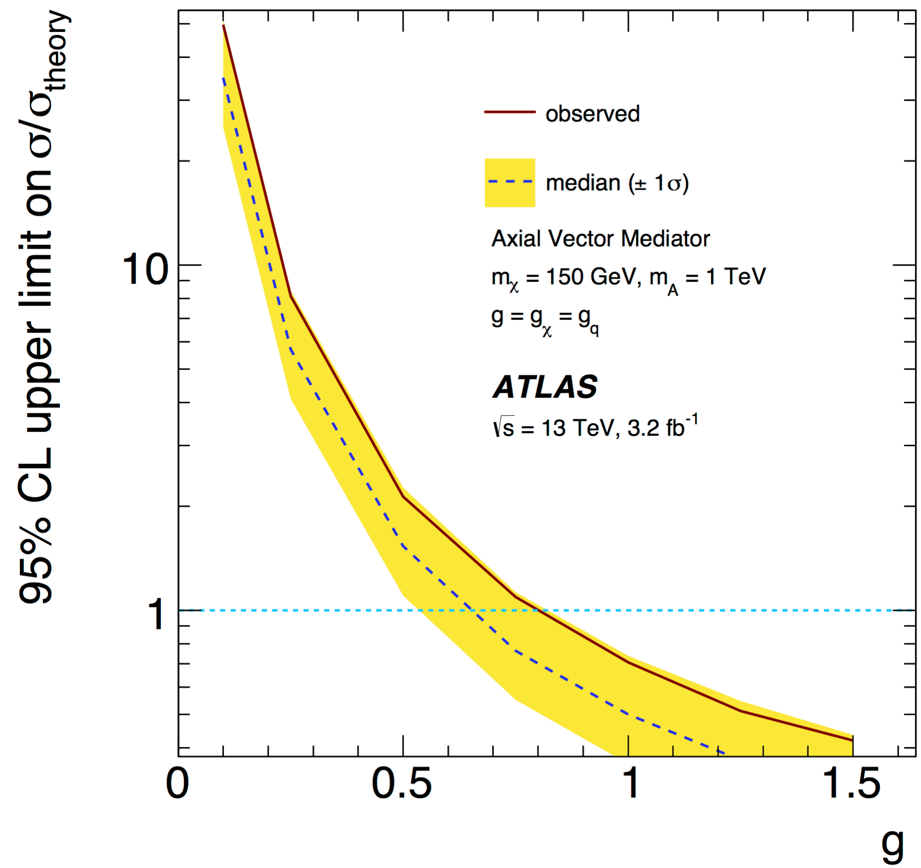
Signal Region	IM1	IM2	IM3	IM4	IM5	IM6	IM7
Observed events (3.2 fb^{-1})	21447	11975	6433	3494	1170	423	185
SM prediction	21730 ± 940	12340 ± 570	6570 ± 340	3390 ± 200	1125 ± 77	441 ± 39	167 ± 20
Signal Region	EM1	EM2	EM3	EM4	EM5	EM6	
Observed events (3.2 fb^{-1})	9472	5542	2939	2324	747	238	
SM prediction	9400 ± 410	5770 ± 260	3210 ± 170	2260 ± 140	686 ± 50	271 ± 28	

Yields pre/post-fit available in paper and/or as auxiliary material (for each process).

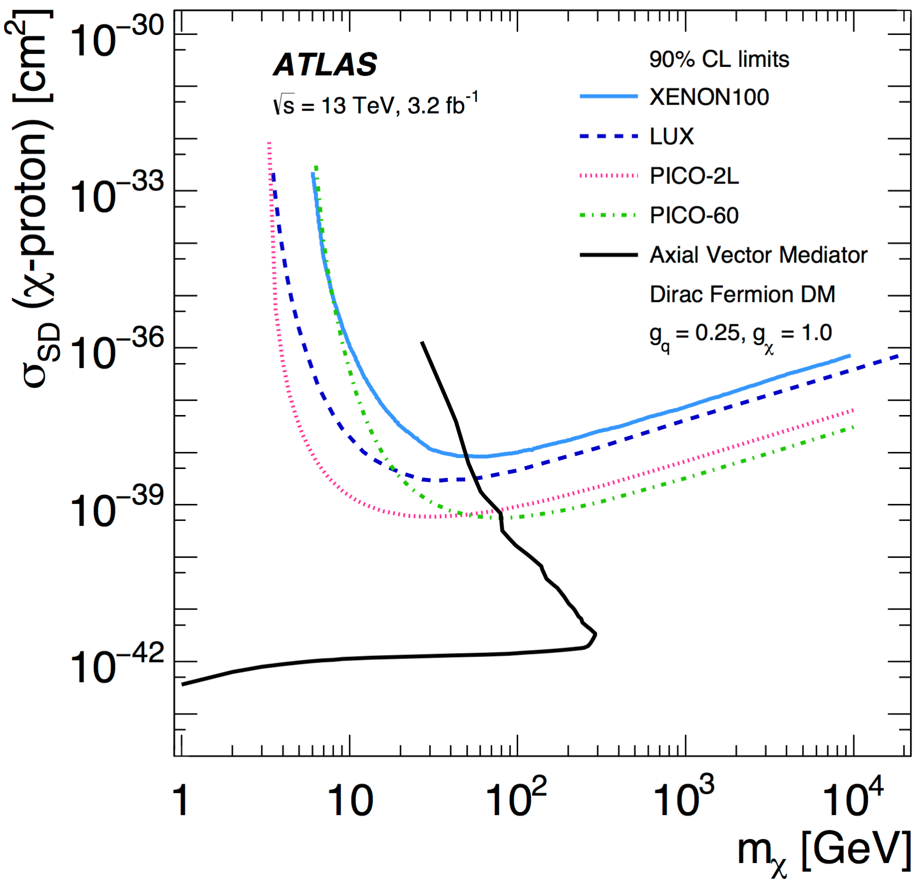
Axial vector mediator, $g_q = 0.25$, g_{DM} 1.0.

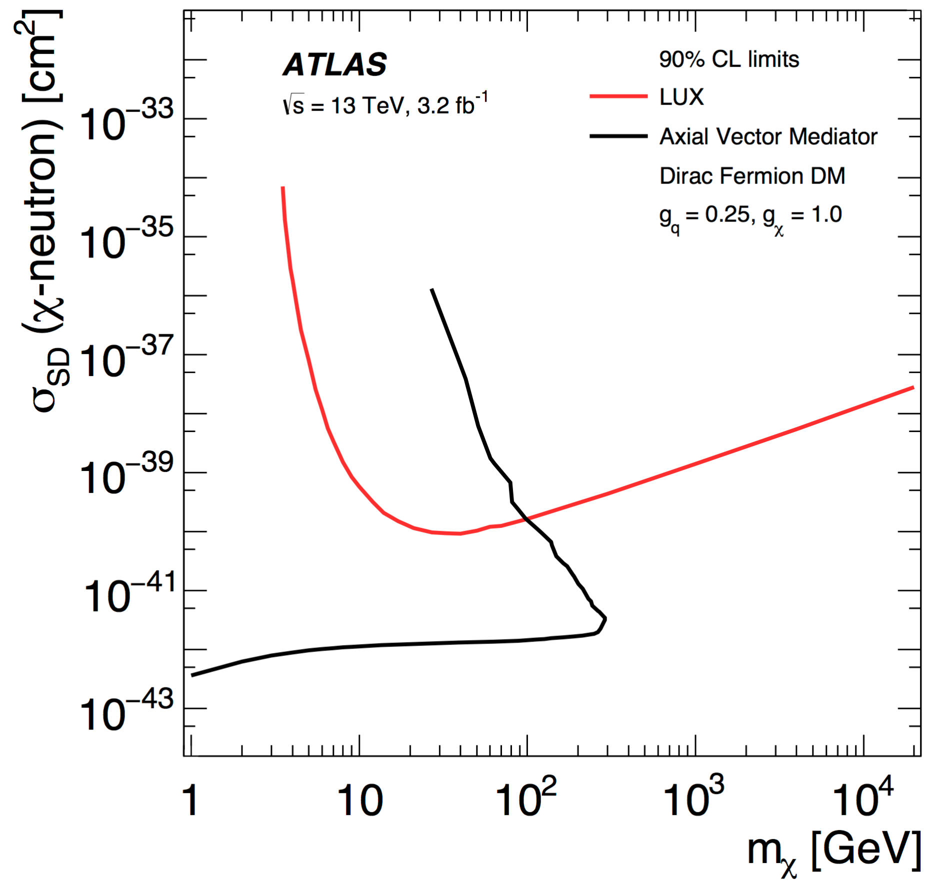


$g_q = g_{DM}$, m_{DM} = 150GeV, m_A = 1TeV

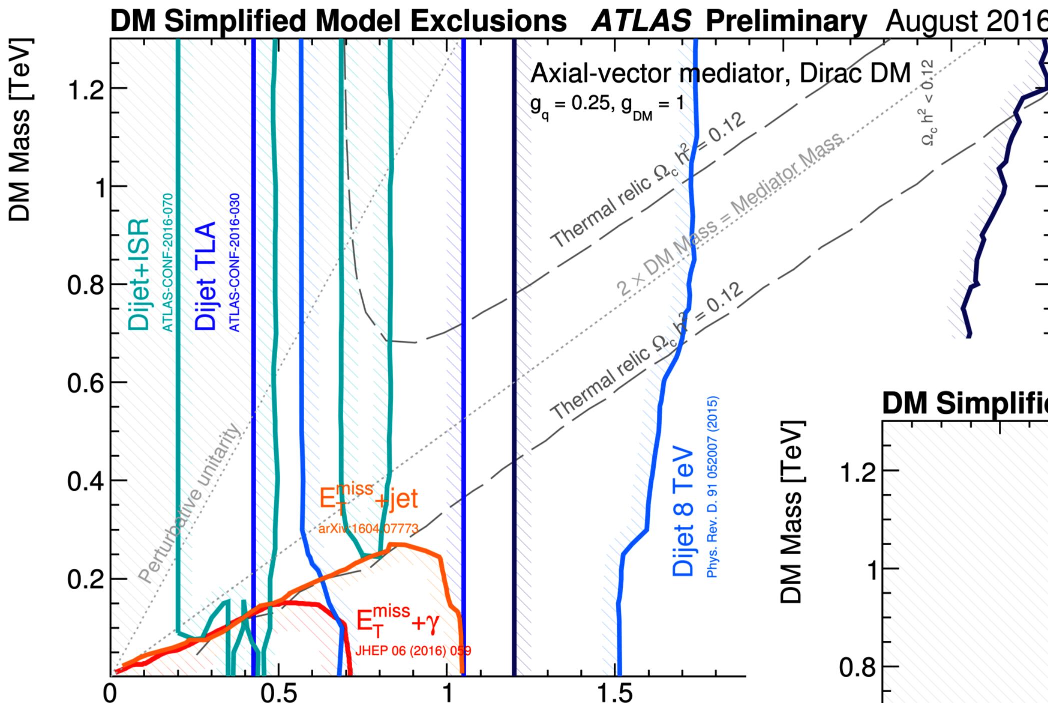


Axial vector mediator, $g_q = 0.25$, g_{DM} 1.0.



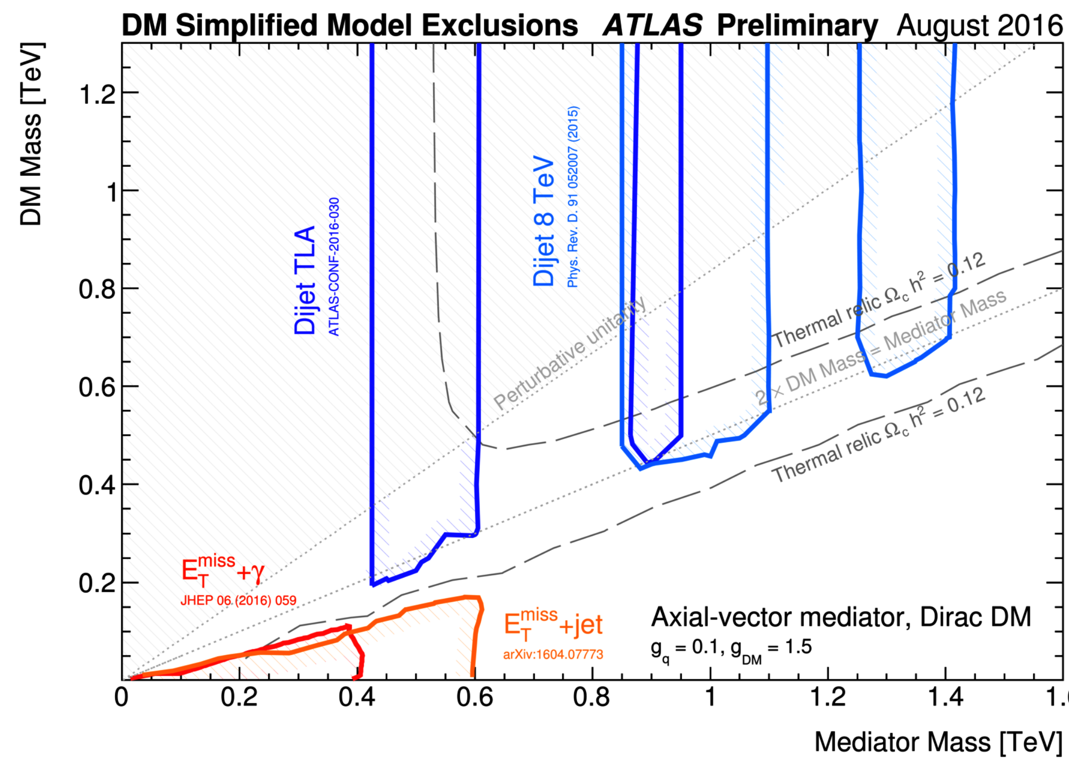


[**DM**] Interpretations



Summary plots

(discussed yesterday)



Bonus

CR yields

CR_{ele}

Inclusive Selection	IM1	IM2	IM3	IM4	IM5	IM6	IM7
Observed events (3.2 fb^{-1})	3559	1866	992	532	183	72	32
SM prediction (post-fit)	3559 ± 60	1866 ± 43	992 ± 32	532 ± 23	183 ± 14	72 ± 8	32 ± 6
SM prediction (pre-fit)	3990 ± 320	2110 ± 170	1142 ± 94	654 ± 54	216 ± 19	85 ± 8	34 ± 3
Exclusive Selection	EM1	EM2	EM3	EM4	EM5	EM6	
Observed events (3.2 fb^{-1})	1693	874	460	349	111	40	
SM prediction (post-fit)	1693 ± 41	874 ± 30	460 ± 21	349 ± 19	111 ± 11	40 ± 6	
SM prediction (pre-fit)	1880 ± 150	971 ± 79	488 ± 40	439 ± 36	131 ± 12	50 ± 5	

CR_{wmn}

Inclusive Selection	IM1	IM2	IM3	IM4	IM5	IM6	IM7
Observed events (3.2 fb^{-1})	10481	6279	3538	1939	677	261	95
SM prediction (post-fit)	10480 ± 100	6279 ± 79	3538 ± 60	1939 ± 44	677 ± 26	261 ± 16	95 ± 10
SM prediction (pre-fit)	10500 ± 710	6350 ± 460	3560 ± 280	2010 ± 160	700 ± 57	256 ± 23	106 ± 9
Exclusive Selection	EM1	EM2	EM3	EM4	EM5	EM6	
Observed events (3.2 fb^{-1})	4202	2741	1599	1262	416	166	
SM prediction (post-fit)	4202 ± 65	2741 ± 52	1599 ± 40	1262 ± 36	416 ± 20	166 ± 13	
SM prediction (pre-fit)	4140 ± 260	2800 ± 190	1540 ± 120	1310 ± 100	444 ± 35	150 ± 14	

CR_{zmm}

Inclusive Selection	IM1	IM2	IM3	IM4	IM5	IM6	IM7
Observed events (3.2 fb^{-1})	1488	877	505	293	100	33	15
SM prediction (post-fit)	1488 ± 39	877 ± 30	505 ± 22	293 ± 17	100 ± 10	33 ± 6	15 ± 4
SM prediction (pre-fit)	1520 ± 98	910 ± 59	487 ± 34	271 ± 19	89 ± 7	32 ± 3	13 ± 1
Exclusive Selection	EM1	EM2	EM3	EM4	EM5	EM6	
Observed events (3.2 fb^{-1})	611	372	212	193	67	18	
SM prediction (post-fit)	611 ± 25	372 ± 19	212 ± 15	193 ± 14	67 ± 8	18 ± 4	
SM prediction (pre-fit)	610 ± 42	422 ± 36	217 ± 15	182 ± 13	57 ± 4	19 ± 2	

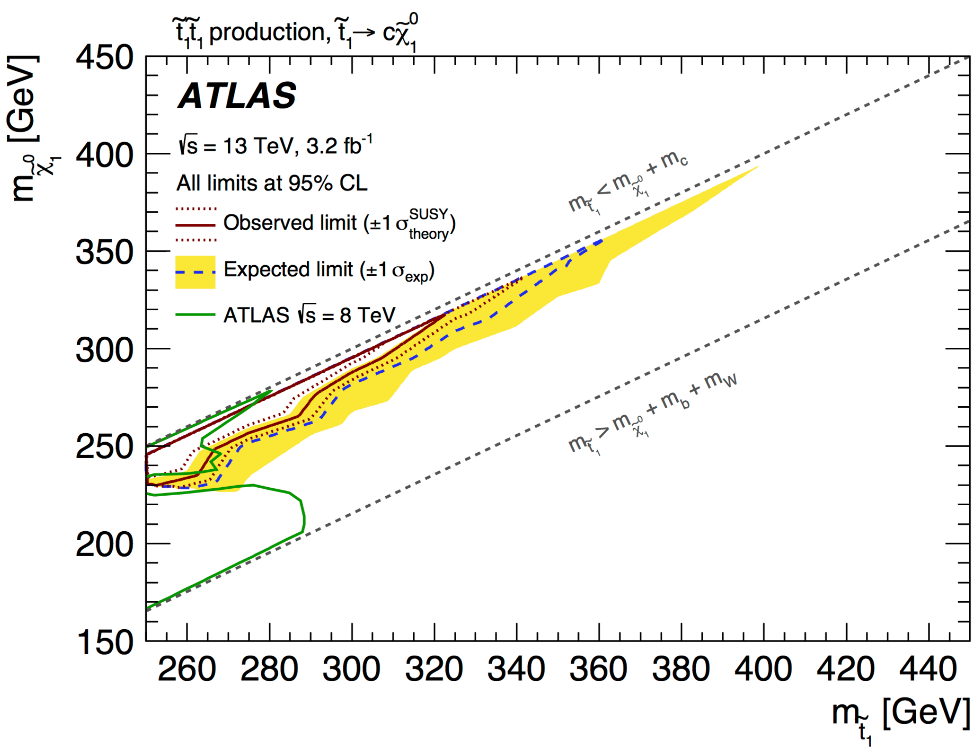
Model Independent

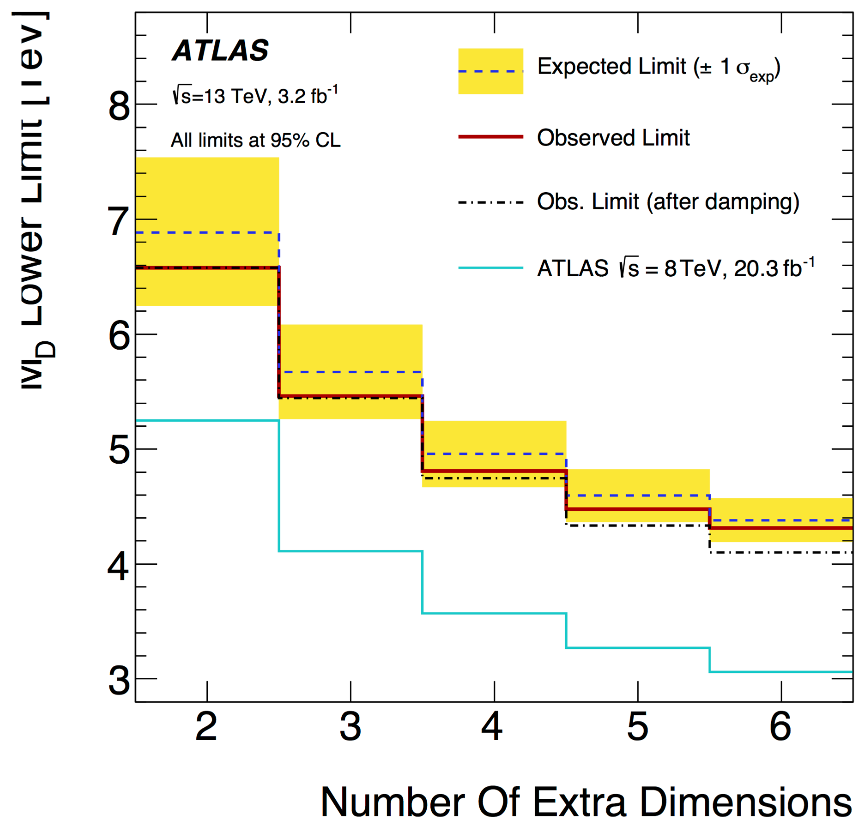
Simplest interpretation: take inclusive MET bins and put limits on number of signal events S. Convert into visible cross-sec*on (1/L*S^{95}).
Provide info on A and eff on auxiliary material

Table 9: Observed and expected 95% CL upper limits on the number of signal events, S^{95}_{obs} and S^{95}_{exp}, and on the visible cross section, defined as the product of cross section, acceptance and efficiency, $\langle\sigma\rangle^{95}_{obs}$, for the IM1–IM7 selections.

Signal channel	$\langle\sigma\rangle^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{exp}
IM1	553	1773	1864^{+829}_{-548}
IM2	308	988	1178^{+541}_{-348}
IM3	196	630	694^{+308}_{-204}
IM4	153	491	401^{+168}_{-113}
IM5	61	196	164^{+63}_{-45}
IM6	23	75	84^{+32}_{-23}
IM7	19	61	48^{+18}_{-13}

SUSY & ADD


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$
ATLAS
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
All limits at 95% CL
Observed limit ($\pm 1\ \sigma_{theory}^{SUSY}$)
Expected limit ($\pm 1\ \sigma_{exp}$)
ATLAS $\sqrt{s}$ = 8 TeV
$m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0} + m_c$
$m_{\tilde{t}_1} > m_{\tilde{\chi}_1^0} + m_b + m_W$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]


ATLAS
$\sqrt{s}$=13 TeV, 3.2 fb^{-1}
All limits at 95% CL
Expected Limit ($\pm$ 1 σ_{exp})
Observed Limit
Obs. Limit (after damping)
ATLAS $\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}
M_D Lower Limit [TeV]
Number Of Extra Dimensions