Searches for new phenomena in dilepton final states using the ATLAS detector

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for the ATLAS Collaboration

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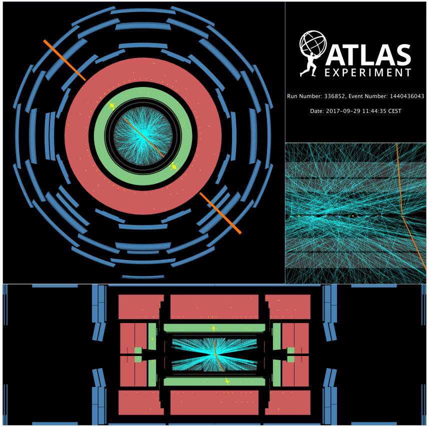
Motivation

- Many Beyond the Standard Model (BSM) theories that predict new phenomena decaying to dilepton final states
- Grand Unified Theory (GUT)
  - Unification of Standard Model forces at very high energies
  - existence of dark matter and neutrino masses
- Seesaw mechanism
  - Address the question of neutrino mass generation
- Leptonic final states are historically channels of discovery and precision measurements
  - Low-background and efficient experimental signature
  - ATLAS detector's excellent energy and momentum resolution



ee ATLAS event display
$m_{ee} = 4.06$ TeV

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 139)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

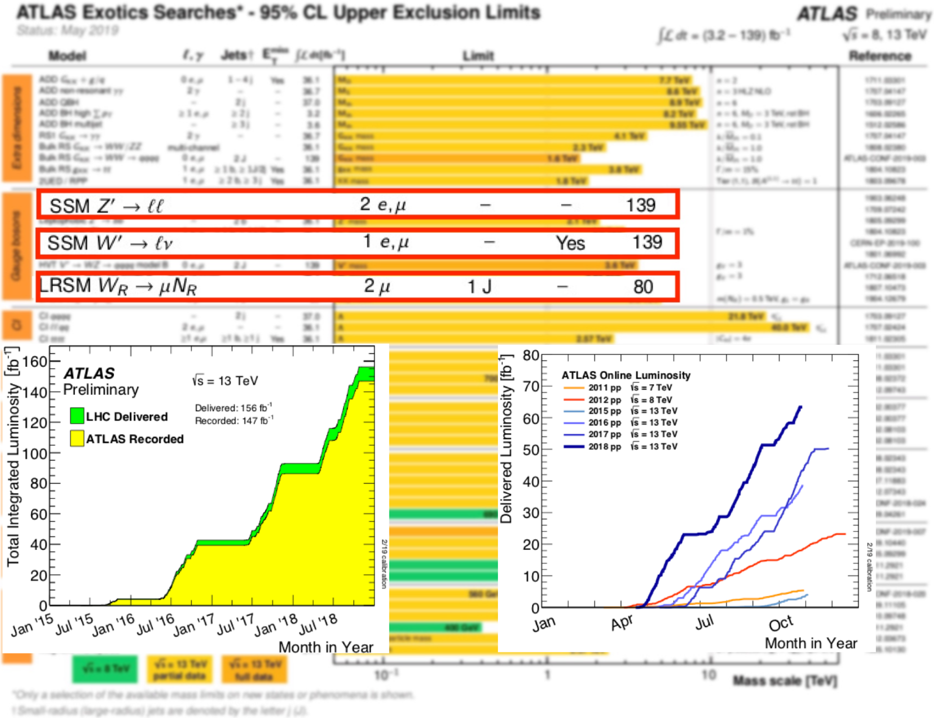
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	$1-4$ j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WW \to qqqq$	$0\ e, \mu$	2 J	–	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	139	W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \to \tau\nu$	$1\ \tau$	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WZ \to qqqq$ model B	$0\ e, \mu$	2 J	–	139	V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	$2\ \mu$	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^{-}	1703.09127
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	36.1	Λ 40.0 TeV	η_{LL}^{-}	1707.02424
	CI $tttt$	$\geq 1\ e,\mu$	≥ 1 b, ≥ 1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4$, $\lambda = 0.2$, $m(\chi) = 10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$	1902.00377
	Scalar LQ 3rd gen	$2\ \tau$	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d \to t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/$\geq 3\ e,\mu$	≥ 1 b, ≥ 1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt) = 1$, $c(T_{5/3} Wt) = 1$	1807.11883
	VLQ $Y \to Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb) = 1$, $c_R(Wb) = 1$	1812.07343
	VLQ $B \to Hb + X$	$0\ e,\mu$, $2\ \gamma$	≥ 1 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	$\kappa_B = 0.5$	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	$1\ e, \mu$	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	$1\ e, \mu$	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	$2\ \mu$	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g\rvert = 1 g_D$, spin 1/2	1905.10130

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV partial data | $\sqrt{s}$ = 13 TeV full data

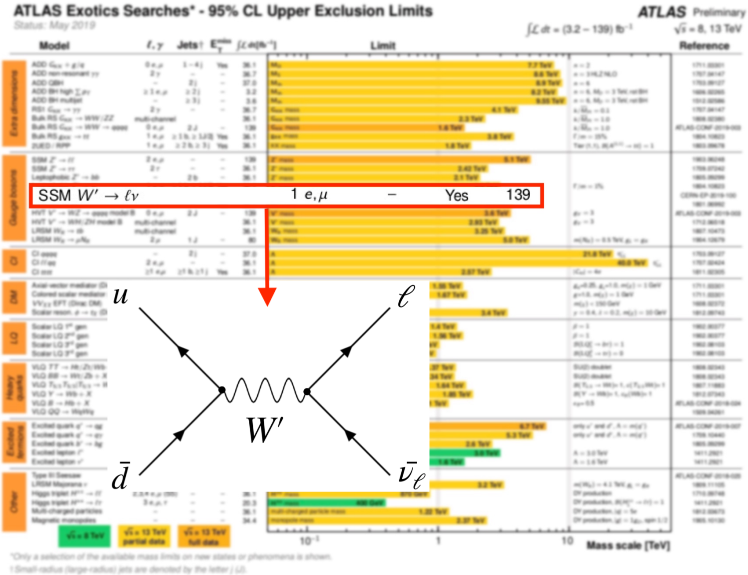
Mass scale [TeV] (10^{-1}, 1, 10)

*Only a selection of the available mass limits on new states or phenomena is shown.

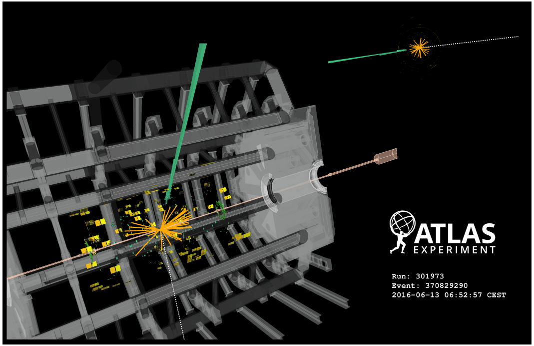
†Small-radius (large-radius) jets are denoted by the letter j (J).

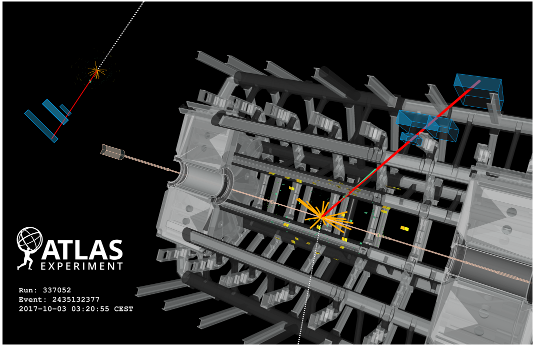

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
ATLAS Preliminary
Model
Limit
Reference
SSM $Z' \to \ell\ell$ 2 e,μ – – 139
SSM $W' \to \ell\nu$ 1 e,μ – Yes 139
LRSM $W_R \to \mu N_R$ 2 μ 1 J – 80
Mass scale [TeV]
ATLAS
Preliminary
$\sqrt{s}$ = 13 TeV
LHC Delivered
ATLAS Recorded
Delivered: 156 fb^{-1}
Recorded: 147 fb^{-1}
Total Integrated Luminosity [fb^{-1}]
Jan '15
Jul '15
Jan '16
Jul '16
Jan '17
Jul '17
Jan '18
Jul '18
Month in Year
ATLAS Online Luminosity
2011 pp $\sqrt{s}$ = 7 TeV
2012 pp $\sqrt{s}$ = 8 TeV
2015 pp $\sqrt{s}$ = 13 TeV
2016 pp $\sqrt{s}$ = 13 TeV
2017 pp $\sqrt{s}$ = 13 TeV
2018 pp $\sqrt{s}$ = 13 TeV
Delivered Luminosity [fb^{-1}]
Jan
Apr
Jul
Oct
Month in Year

arXiv:1906.05609



Lepton $+E_T^{miss}$ Search - High mass events





- $p_T^e = 1.1$ TeV
- $E_T^{miss} = 1.1$ TeV
- $m_T = 2.2$ TeV

- $p_T^\mu = 2.4$ TeV
- $E_T^{miss} = 2.7$ TeV
- $m_T = 5.0$ TeV

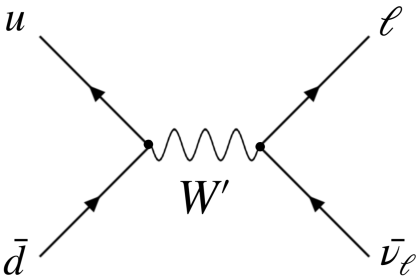
Highest mass event for μ channel. One of the highest for e channel

Analysis overview

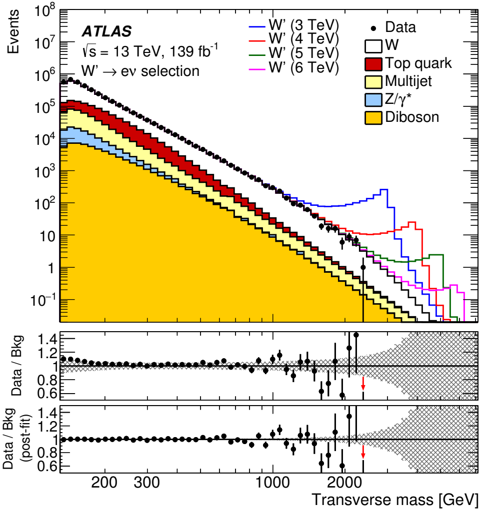
Additional charged gauge bosons W′ appearing in extended gauge models

- Decay of $W' \to l\nu$
- Events with a single lepton (e or μ) and missing transverse energy (E_T^{miss})

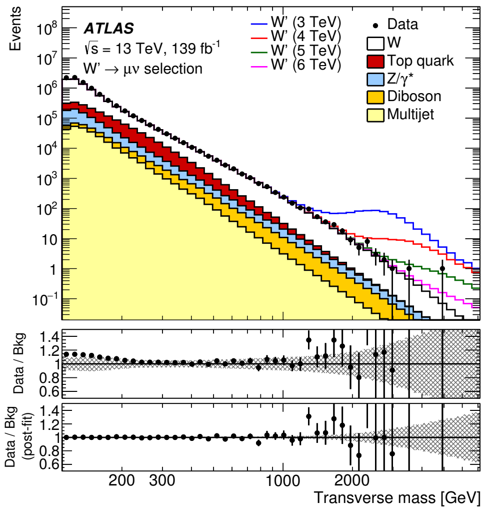
- Deviations from SM prediction in $\mathbf{m}_T$ distribution
- $m_T = \sqrt{2 p_T E^{\mathrm{T}}_{\mathrm{miss}} (1 - \cos\phi_{l\nu})}$
- Benchmark model: Sequential Standard Model (SSM)
- Same couplings to fermions as SM W



Background estimation



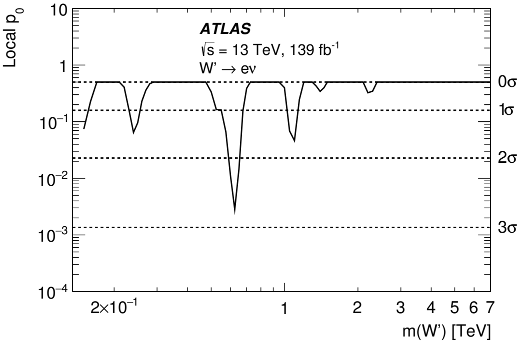
$e\nu$ channel



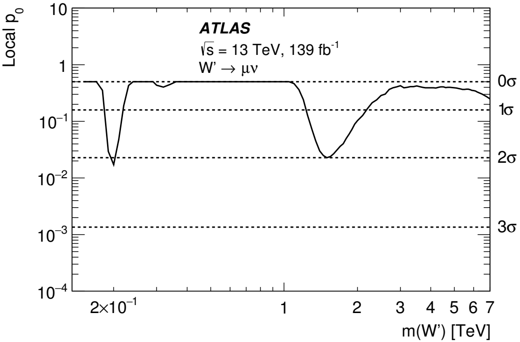
$\mu\nu$ channel

- Background distribution evaluated from simulation (template-based analysis)
- Data-driven estimate of the multi-jet background

Results



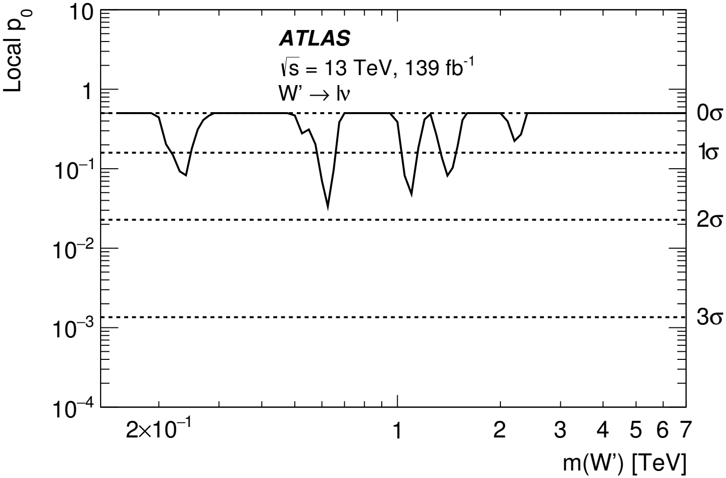
$e\nu$ channel



$\mu\nu$ channel

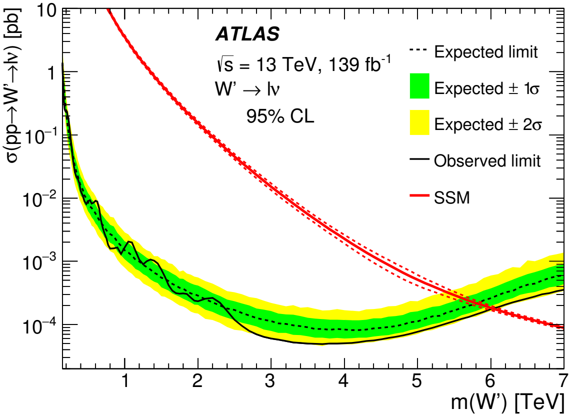
- Local p-value distribution for W' bosons in the SSM with mass between 0.15 and 7 TeV in $e\nu$ and $\mu\nu$ channel
  - Largest excess: $m_{W'} = 625$ GeV ($e\nu$, 2.8σ local, 1.3σ global significance)
  - Largest excess: $m_{W'} = 200$ GeV ($\mu\nu$, 2.1σ local, 0.4σ global significance)

Results



- Local p-value distribution for W' bosons in the SSM with mass between 0.15 and 7 TeV in combined channel
  - Largest excess: $m_{W'} = 625$ GeV (1.8σ local, 0.5σ global significance)

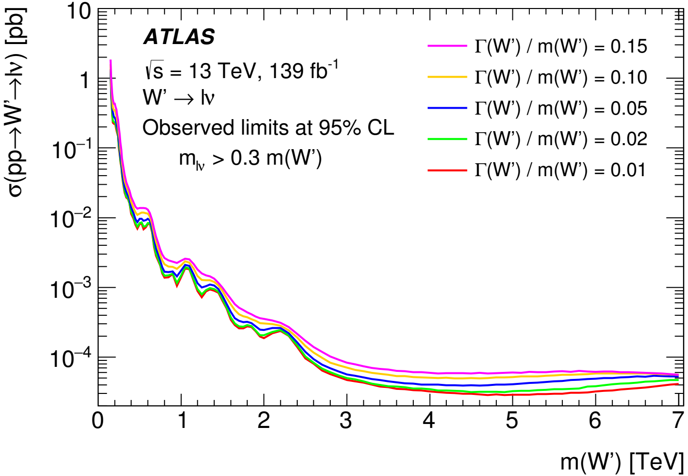
Benchmark limits



	$m(W')$ lower limit [TeV]	
Decay	Observed	Expected
$W' \to e\nu$	6.0	5.7
$W' \to \mu\nu$	5.1	5.1
$W' \to \ell\nu$	6.0	5.8

- Upper limits on the cross-section on the production of a W' SSM boson decaying to only one lepton generation ($\sigma \times$BR) are computed at the 95% CL
- Bayesian analysis with a uniform positive prior probability distribution for $\sigma \times$BR

Generic limits



- Generic fiducial cross section limits set on $m_{\ell\nu} > 0.3 \times m_{W'}$
- Different choices of $\Gamma(W')/m(W')$ ranging between 1% and 15%

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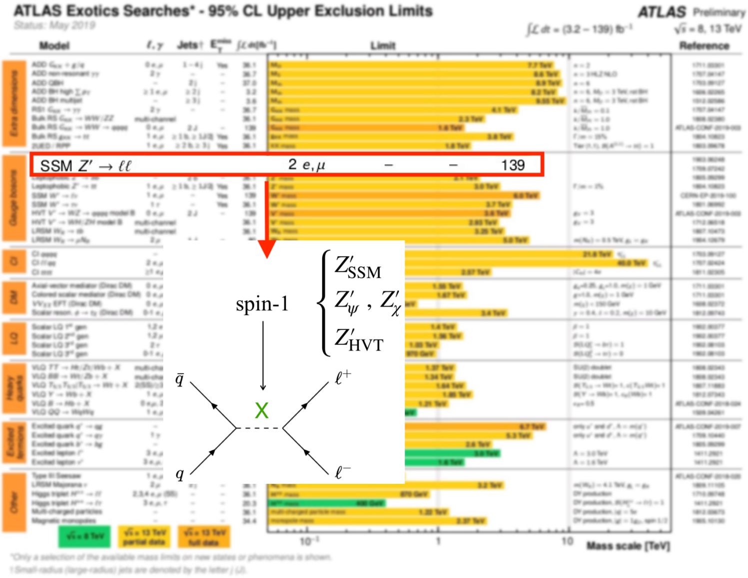
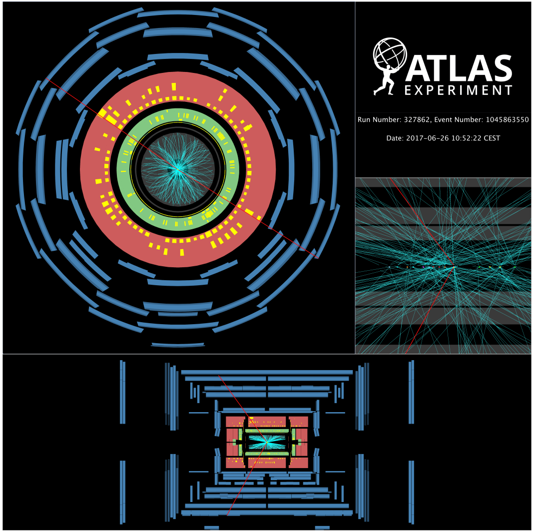
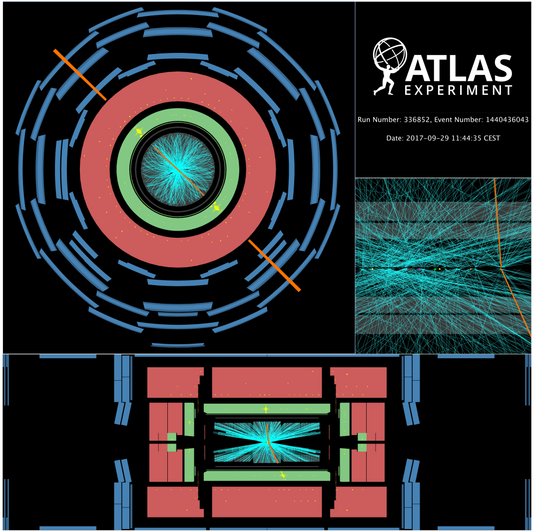


Dilepton Search - Highest mass events



$m_{\mu\mu} = 2.75$ TeV



$m_{ee} = 4.06$ TeV

Analysis overview

- First ATLAS full-Run 2 result (139 fb^{-1})
- Search for new resonances in m_{ee} and $m_{\mu\mu}$

Event Selection:

- Two same flavor leptons
  $225 < m_{ll} < 6000$ GeV

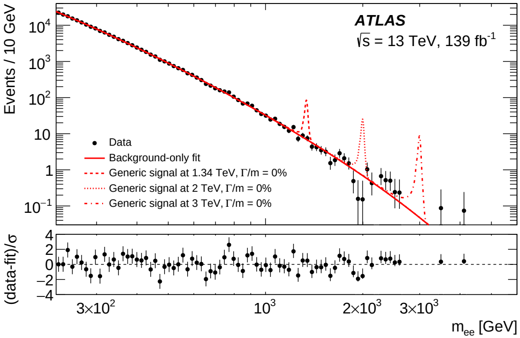
Background:

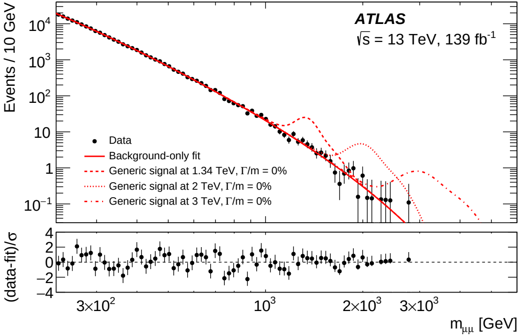
- Parametric functional fit to data

$$f_{\ell\ell}(m_{\ell\ell}) = a \cdot f_{BW,Z}(M_{\ell\ell}) \cdot (1 - x^c)^b \cdot x^{\sum_{i=0}^{3} p_i \log(x)^i}$$

Generic Signal:

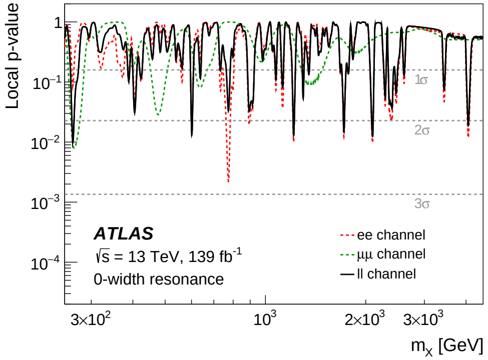
- Non-Relativistic Breit-Wigner $\otimes$ (Gauss+Crystal-Ball)
  - Accounts for detector effects
- Fiducial region defined for hypothetical signal X
  - $m_{\ell\ell}^{true} > (m_{\ell\ell} - 2\Gamma_X)$
  - $|\eta| < 2.5$, $p_{T,\ell\ell} > 30$ GeV

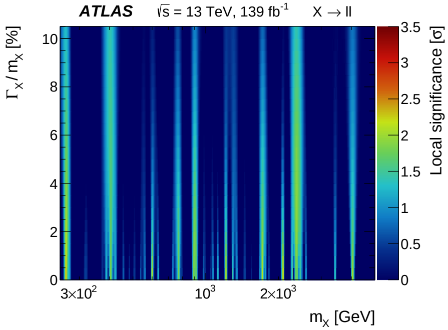




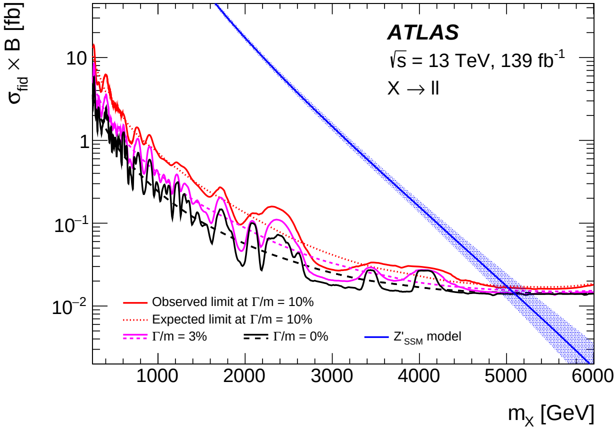
Results

- Local significance for 0-width resonance
- Largest excess:
  - 774 GeV (ee, 2.9σ local, 0.1σ global significance)
  - 267 GeV ($\mu\mu$, 2.4σ local, 0.3σ global significance)
- Combination of ee and $\mu\mu$ channels assumed the lepton flavor universality explicitly
  - 264 GeV (Combination 2.3σ local, $\sim 0\sigma$ global significance)
- Measured local significance as a function of pole mass (m_X) and signal width (Γ_X/m_X)





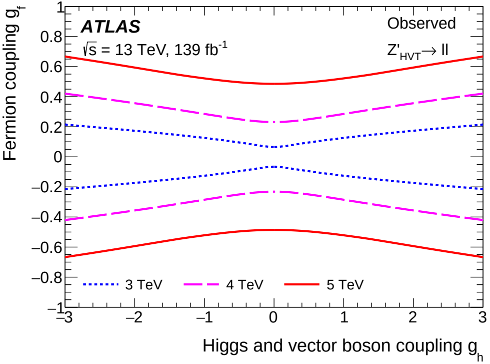
Limits



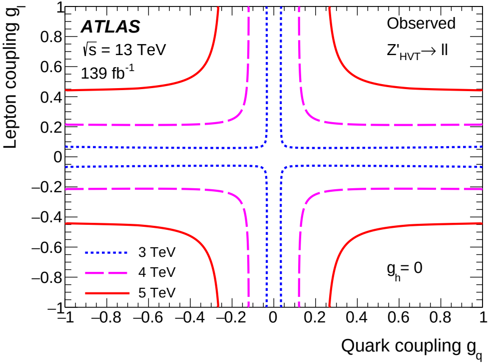
Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_ψ	4.1	4.3	4.0	4.0	4.5	4.5
Z'_χ	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

- Generic limits are calculated for various width assumptions of signal shape
- The generic cross-section limits at $\Gamma/m = 0.5\%, 1.2\%$ and 3.0% are compared with predictions of Z'_ψ , Z'_χ and Z'_{SSM} , respectively, to reinterpret them and obtain mass limits

Heavy Vector Triplet Limits



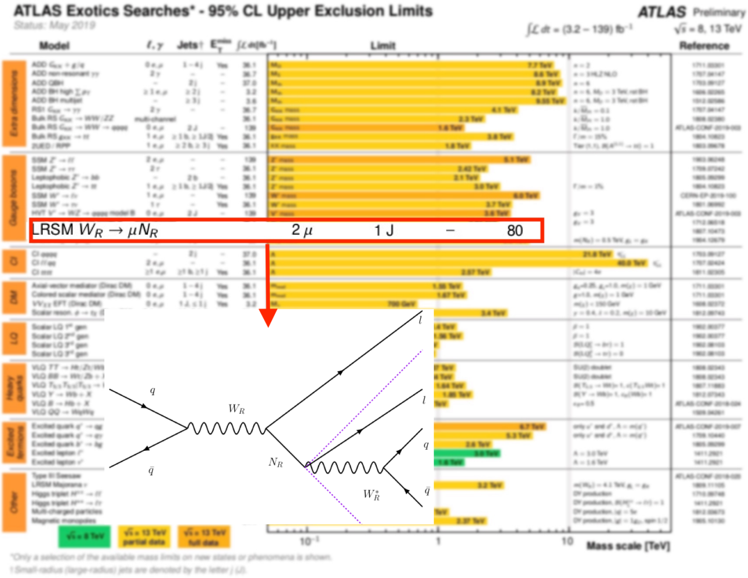
$\{g_h, g_f\}$ with $g_f = g_\ell = g_q$



$\{g_q, g_\ell\}$ with $g_h = 0$

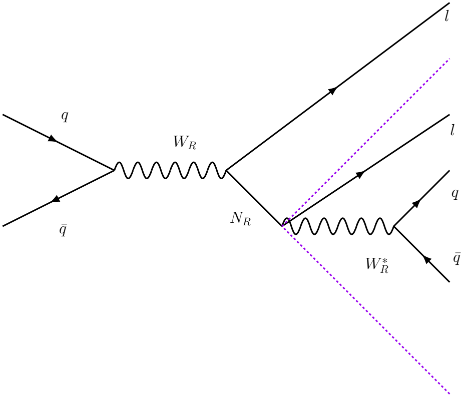
- The generic results are converted Heavy Vector Triplet (HVT) Limits
- HVT bosons can couple to fermions (f), leptons (l), and Higgs (h)
- Limits on HVT couplings for resonance masses 3, 4, and 5 TeV
  - Areas outside the curves are excluded

arXiv:1904.12679



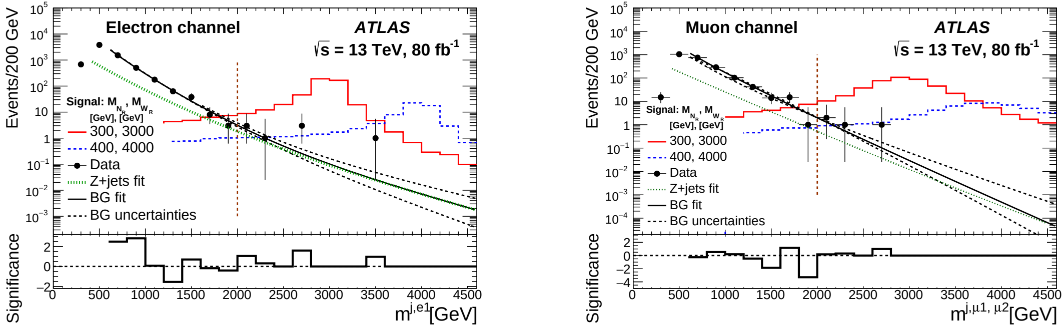
Heavy neutrino and a charged lepton - overview

- Based on Left-Right Symmetric Model (LRSM) theory with right handed Neutrino (NR) mass smaller than right handed gauge boson (WR)
- Search performed with 80 fb^{-1} of ATLAS data



- Investigates signature for $W_R \to N_R \ell$ decays
  - $N_R \to \ell^{\pm} jj$
  - highly collimated objects from decays of boosted particles give large radius jets (R=1) $\to$ (j_N)
  - Final state signature $\ell^{\pm} j_N$
  - Observable: m_{W_R}
- Unique topology in e channel where j_N contains subleading electron $\to N_R$
- Complementary approach in mu channel where j_N + subleading muon $\to N_R$

Background estimation



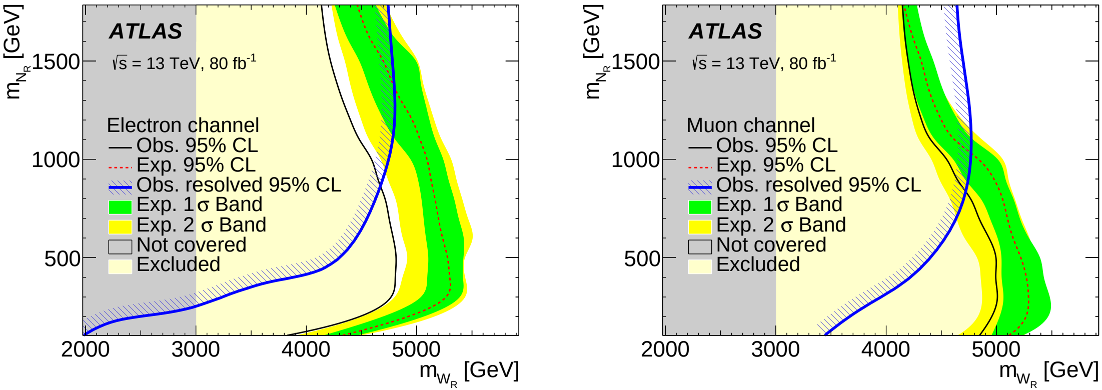
- Data-driven background estimation:
  - $m_{W_R} < 2$ TeV control region
  - extrapolated to single-bin signal region of $m_{W_R} > 2$ TeV
- Comparison of the $m_{W^R}^{reco}$ distribution between data and the fitted background prediction for the electron (left) and muon (right) channels
- Two signal scenarios considered in this search are overlayed

Results

	Electron Channel	Muon Channel
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 150$ GeV)	346^{+48}_{-75}	411^{+36}_{-48}
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 300$ GeV)	471^{+42}_{-69}	429^{+29}_{-40}
Signal ($m_{W_R} = 4$ TeV, $m_{N_R} = 400$ GeV)	66^{+6}_{-10}	57^{+4}_{-4}
Expected background	$2.8^{+0.5}_{-0.7}$	$1.9^{+0.5}_{-0.7}$
Observed events	8	4
Significance	2.4σ	1.2σ
p-value	0.0082	0.12

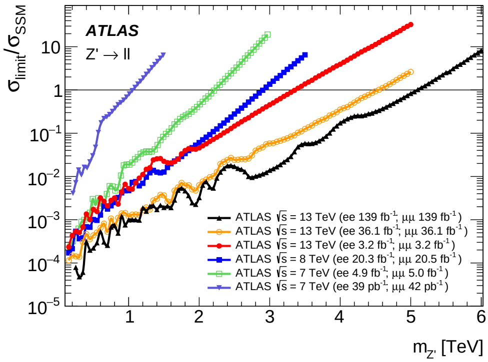
- Using single bin poisson counting experiment
- Observed yields and expected background and signal yields in the signal region
- The significance and the p-values are shown for the background-only hypothesis

Benchmark limits



- Lower limits on the masses of N_R and W_R for each of the considered signal scenarios are determined by using the profiled likelihood test statistic with the CLs method
- Model assumes equivalence of left and right-handed weak gauge couplings, universality of all the right-handed quarks and leptons, and the same masses for all three flavours of heavy right-handed neutrinos

Summary



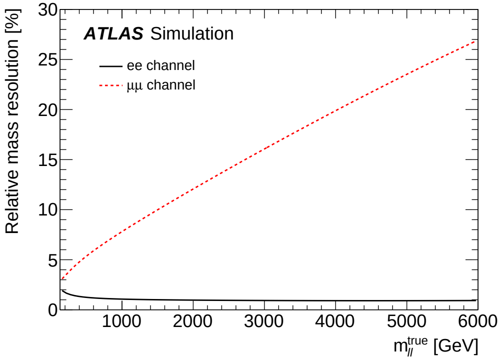
- Dilepton resonance search: PLB 796 (2019) 68
- W' Search: arXiv:1906.05609
- Heavy neutrino search:arXiv:1904.12679

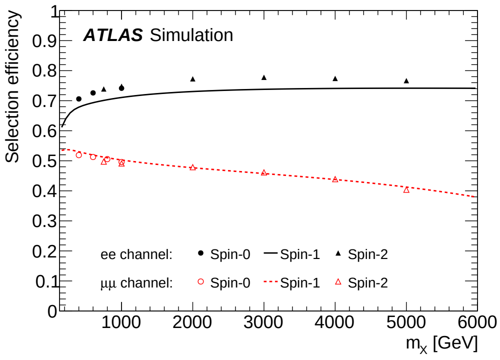
- No major surprises, dilepton analyses are pushing further the search area covering the TeV regime

Questions or Comments

BACKUP

Dilepton Search – Performance





- *ee* and $\mu\mu$ mass resolution as a function of the generated mass of the dilepton pair ($m_{\ell\ell}^{true}$)
- *ee* and $\mu\mu$ selection efficiency as a function of pole mass for spin-0, spin-1 and spin-2 resonances

- Muon selection optimized to ensure optimal momentum resolution at high-p_T

Dilepton - Systematic uncertainties

Uncertainty source for m_X [GeV]	Dielectron 300	Dielectron 5000	Dimuon 300	Dimuon 5000
Spurious signal	±12.5 (12.0)	±0.1 (1.0)	±11.7 (11.0)	±2.1 (2.2)
Lepton identification	±1.6 (1.6)	±5.6 (5.6)	±1.8 (1.8)	$^{+25}_{-20}\left(^{+25}_{-20}\right)$
Isolation	±0.3 (0.3)	±1.1 (1.1)	±0.4 (0.4)	±0.4 (0.5)
Luminosity	±1.7 (1.7)	±1.7 (1.7)	±1.7 (1.7)	±1.7 (1.7)
Electron energy scale	$^{-1.7}_{-4.0}\left(^{+1.0}_{-1.8}\right)$	$^{+0.1}_{-0.4}$ (±0.8)	-	-
Electron energy resolution	$^{+7.9}_{-8.3}\left(^{+1.1}_{-0.9}\right)$	$^{+0.4}_{-0.9}$ (±0.1)	-	-
Muon ID resolution	-	-	$^{+0.8}_{-2.3}\left(^{+0.3}_{-0.8}\right)$	$^{+0.6}_{-0.4}\left(^{+0.5}_{-0.3}\right)$
Muon MS resolution	-	-	$^{+2.8}_{-3.8}\left(^{+1.0}_{-1.3}\right)$	±2.4 (2.1)
'Good muon' requirement	-	-	±0.6 (0.6)	$^{+55}_{-35}\left(^{+55}_{-35}\right)$

- Relative impact of $\pm1\sigma$ variation of systematic uncertainties on the signal yield
  - in percent for 0 width and 10% relative width signals shown in brackets
- Only systematic uncertainties with an impact of ≥ 5 on signal considered

Lepton $+ E_{miss}^{T}$ - Systematic uncertainties

Source	Electron channel Background m_T = 2 (6) TeV	Electron channel Signal m_T = 2 (6) TeV	Muon channel Background m_T = 2 (6) TeV	Muon channel Signal m_T = 2 (6) TeV
Trigger	negl. (negl.)	negl. (negl.)	1.1% (1.0%)	1.2% (1.2%)
Lepton reconstruction and identification	4.1% (1.4%)	4.3% (4.3%)	8.9% (37%)	6.6% (38%)
Lepton momentum scale and resolution	3.9% (2.7%)	2.7% (4.5%)	12% (47%)	13% (20%)
E_T^{miss} resolution and scale	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (<0.5%)
Jet energy resolution	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (0.6%)	<0.5% (<0.5%)
Multijet background	4.4% (420%)	N/A (N/A)	0.8% (1.5%)	N/A (N/A)
Top-quark background	0.8% (1.9%)	N/A (N/A)	0.7% (<0.5%)	N/A (N/A)
Diboson extrapolation	1.5% (47%)	N/A (N/A)	1.3% (9.7%)	N/A (N/A)
PDF choice for DY	1.0% (10%)	N/A (N/A)	<0.5% (1.0%)	N/A (N/A)
PDF variation for DY	8.1% (13%)	N/A (N/A)	7.4% (14%)	N/A (N/A)
EW corrections for DY	4.2% (4.5%)	N/A (N/A)	3.7% (7.0%)	N/A (N/A)
Luminosity	1.6% (1.1%)	1.7% (1.7%)	1.7% (1.7%)	1.7% (1.7%)
Total	12% (430%)	5.4% (6.4%)	17% (62%)	15% (43%)

- Systematic uncertainties in the expected number of events as estimated for the total background and for signal with a W' SSM mass of 2 (6) TeV
- Large uncertainties in the background yields at 6 TeV have little impact on the statistical analysis due to the small background expectation high mT values

Heavy neutrino - Systematic uncertainties

Component	Electron channel [%]	Muon channel [%]
Lepton identification	4–20	4–8
Lepton isolation	4–5	1.0–1.5
Lepton reconstruction	4–5	1–4
Lepton trigger	4–5	0.5
Pile-up	< 0.5	2–3
Luminosity	2	2
Theory	10	10

- Relative systematic uncertainties of the signal yield in the signal region, in percentage for each source
- The ranges indicate the different signal samples