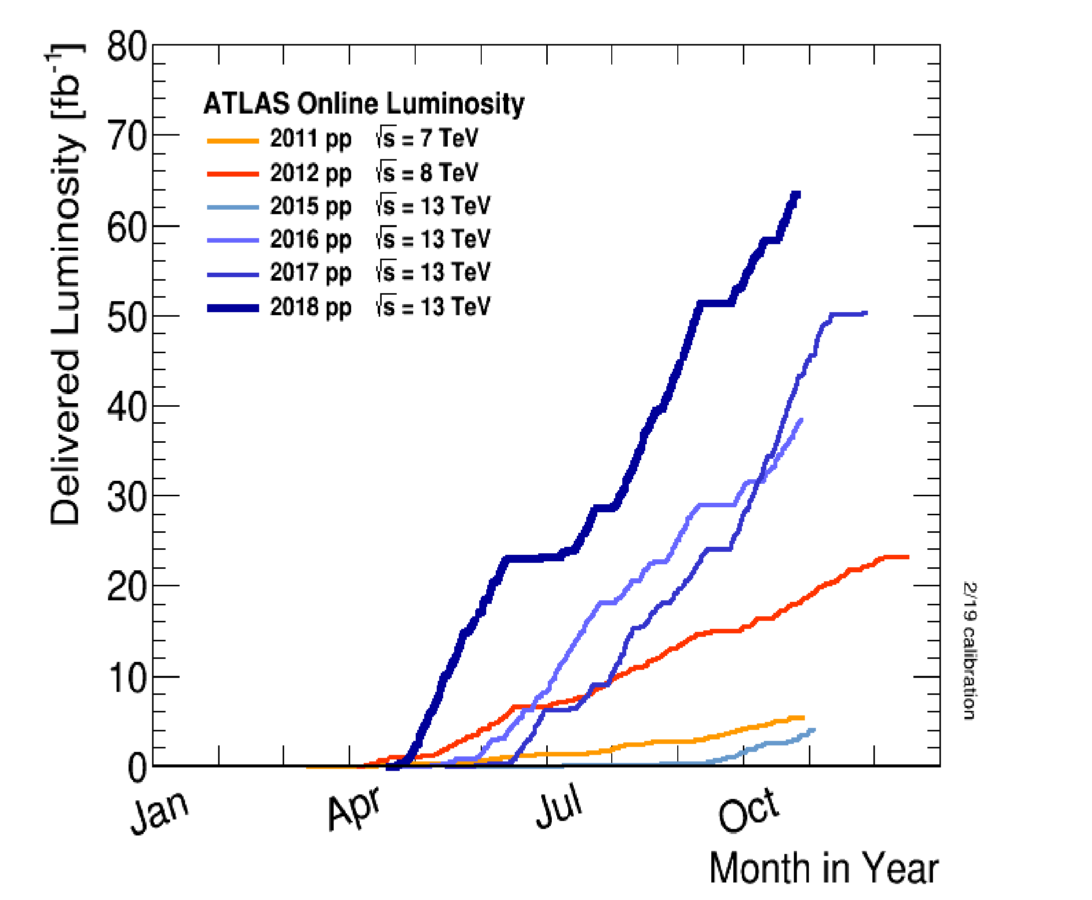
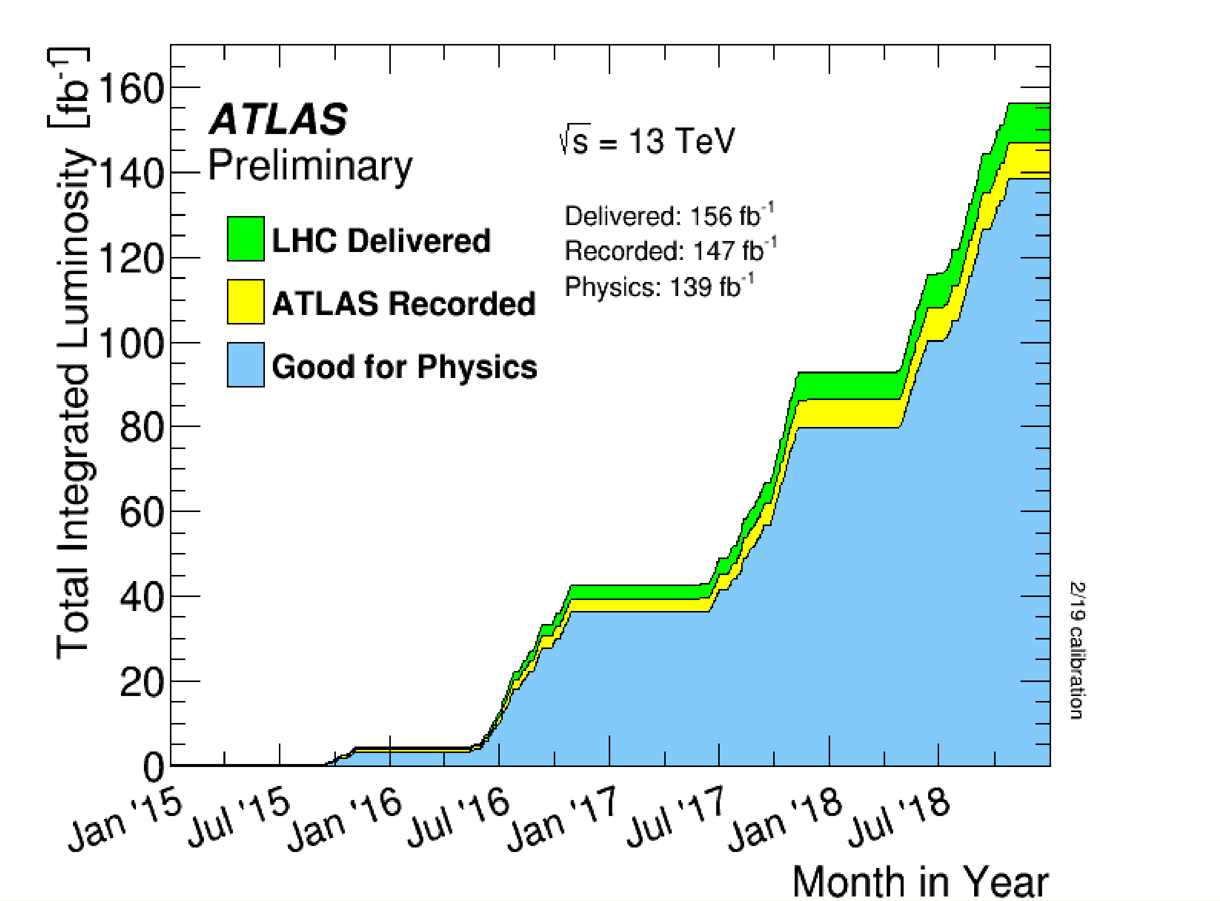
SEARCHES FOR NEW PHENOMENA IN LEPTONIC FINAL STATES USING THE ATLAS DETECTOR

Dr. Marc Bret Cano
On behalf of the ATLAS collaboration

cLHCP 2019
23-27 October
Dalian, China

Performance of the LHC & ATLAS detector



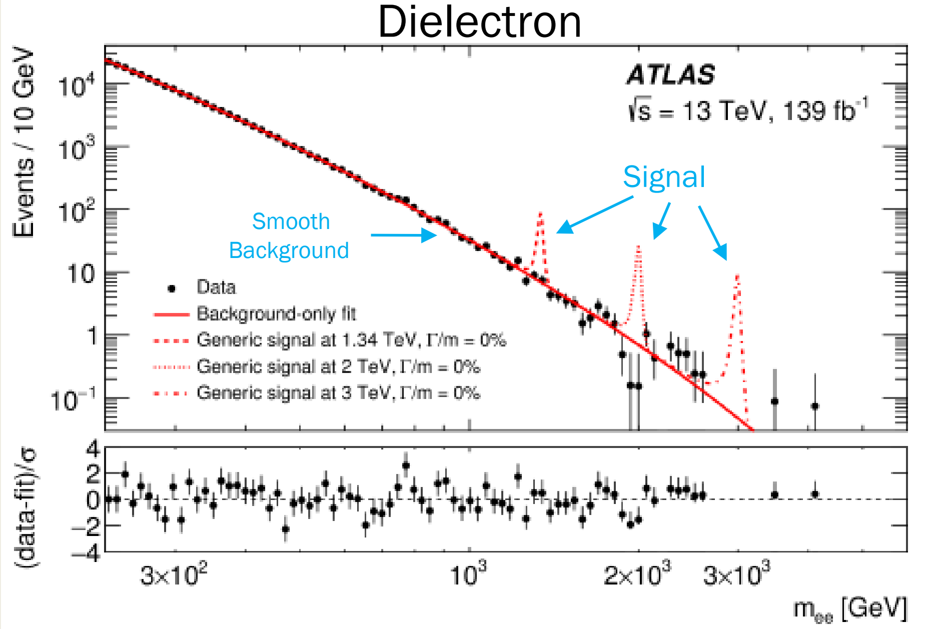


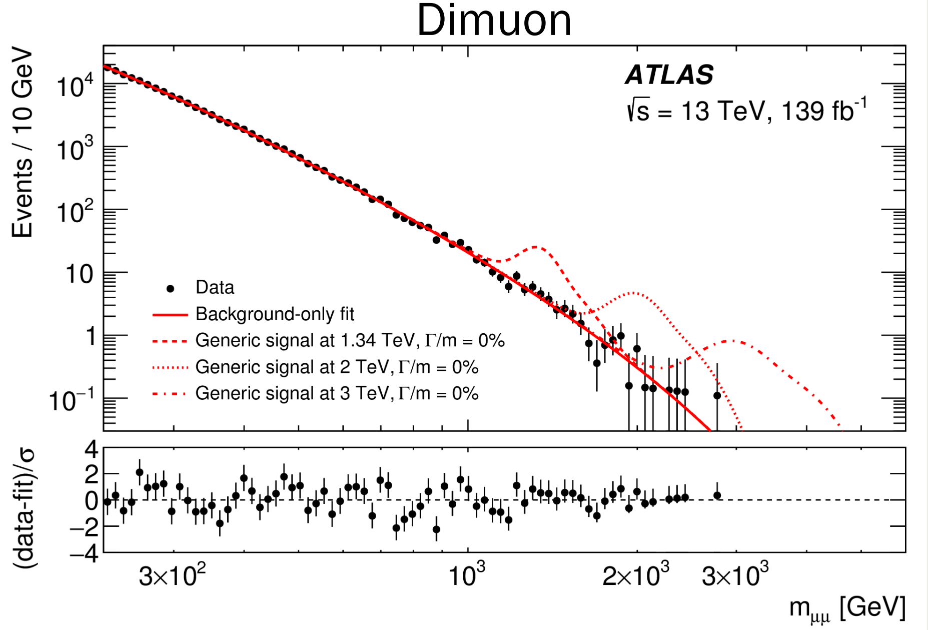
- A total of 139 fb^{-1}collected during the 2015-18 period
- Currently in shutdown until 2021

Outline

- Search in high-mass same-flavor dilepton final state (arXiv 1903.06248, 139 fb^{-1})
- Search for a right-handed gauge boson decaying into a high-momentum heavy neutrino and a charged lepton (arXiv 1904.12679, 80 fb^{-1})
- Search for a new heavy gauge boson resonance decaying into a lepton and missing transverse momentum (ATLAS-CONF-2018-017, 80 fb^{-1})

Dilepton Search: Analysis Strategy





- First ATLAS full Run-2 result

AIM

- Search for “bumps” in the dielectron and dimuon invariant mass spectra

EVENT SELECTION

- Look for events with exactly two electrons or two muons and an invariant mass below 6000 GeV

CERN-EP-2019-030

arXiv 1903.06248

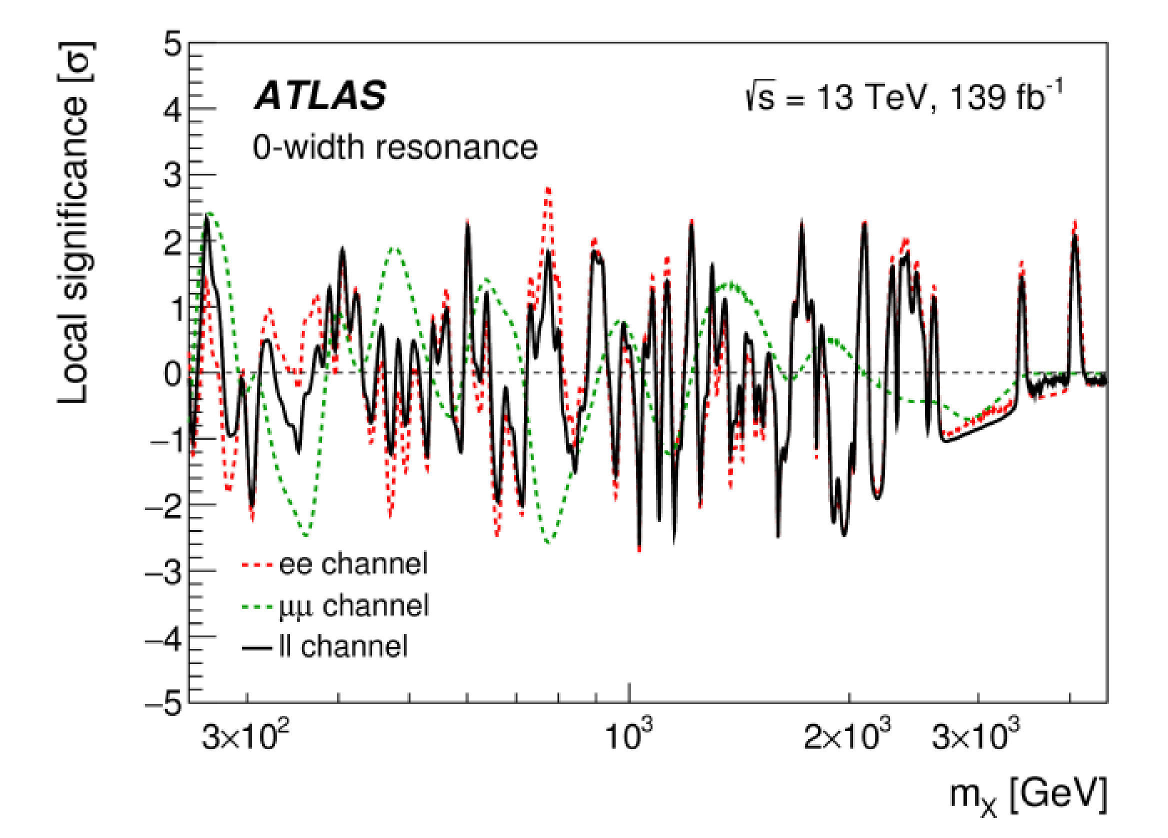
BACKGROUND ESTIMATION

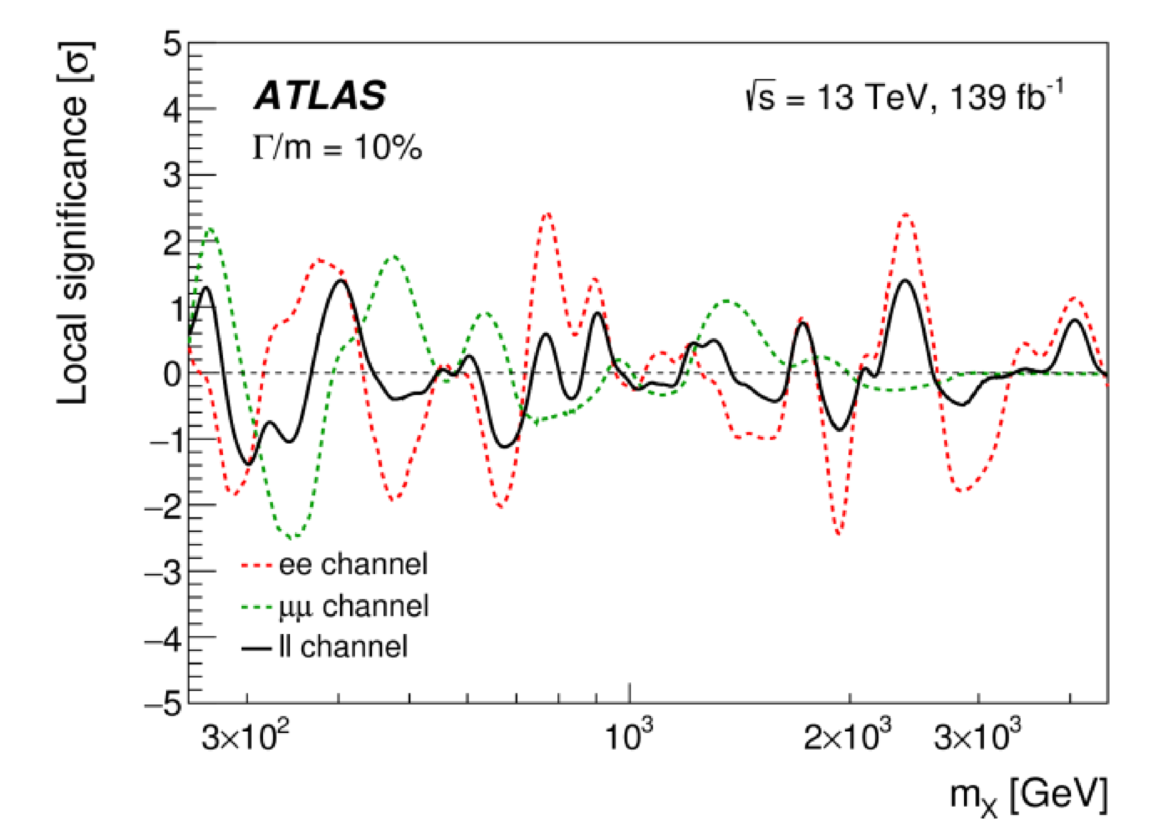
- Largely dominated by the Drell-Yan process
- Fit parametric function to data to model background (new with respect to previous versions of the analysis)
- Leads to spurious signal uncertainties, but those have a small impact on the final result

SIGNAL MODELLING

- Generic signal modelling using a convolution of Breitt-Wigner and a Gaussian to parametrize for various pole mass and width values
- Results interpreted in terms of Sequential Standard Model (SSM) and Heavy Vector Triplet (HVT)

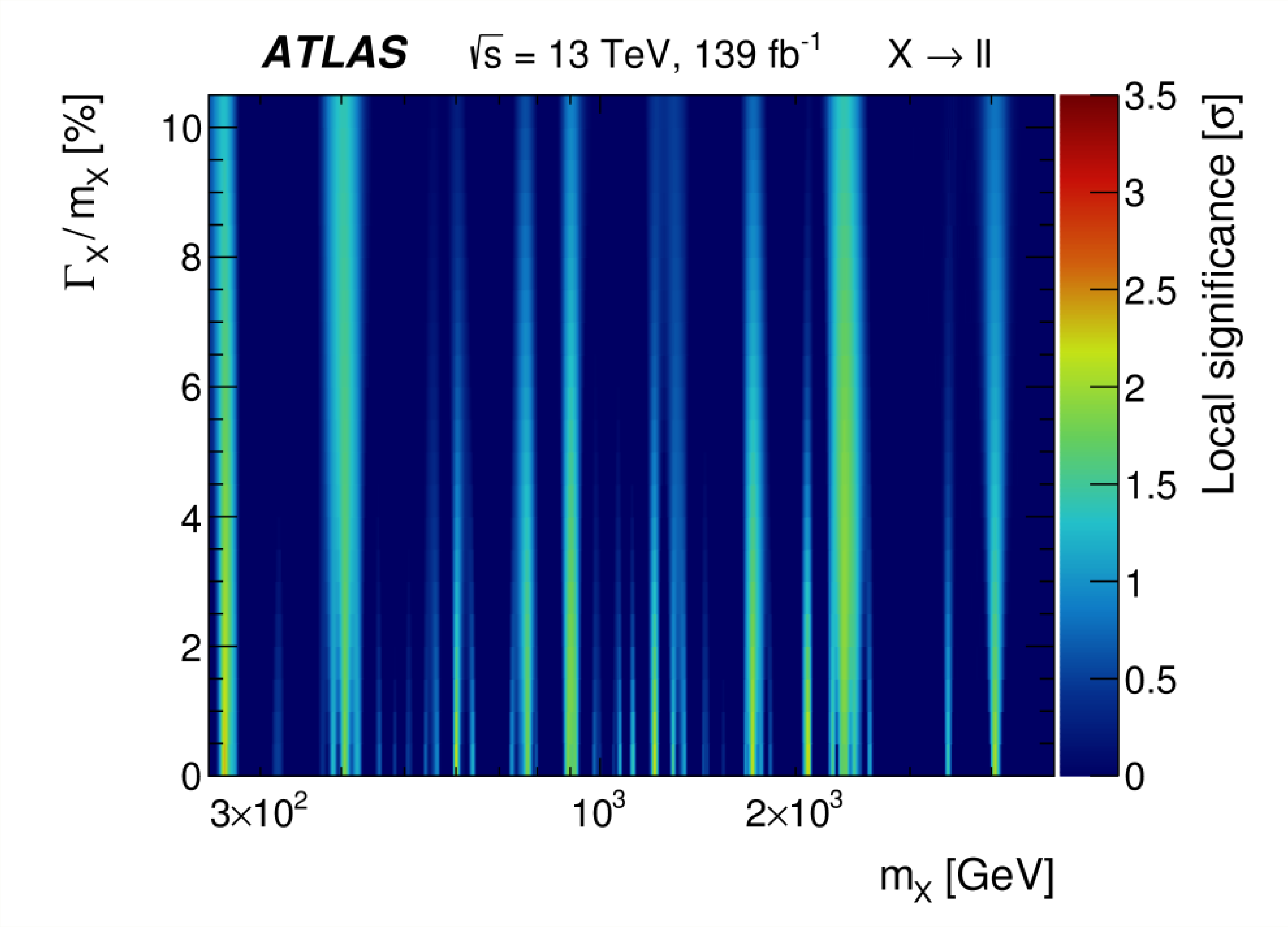
Dilepton Search: Results



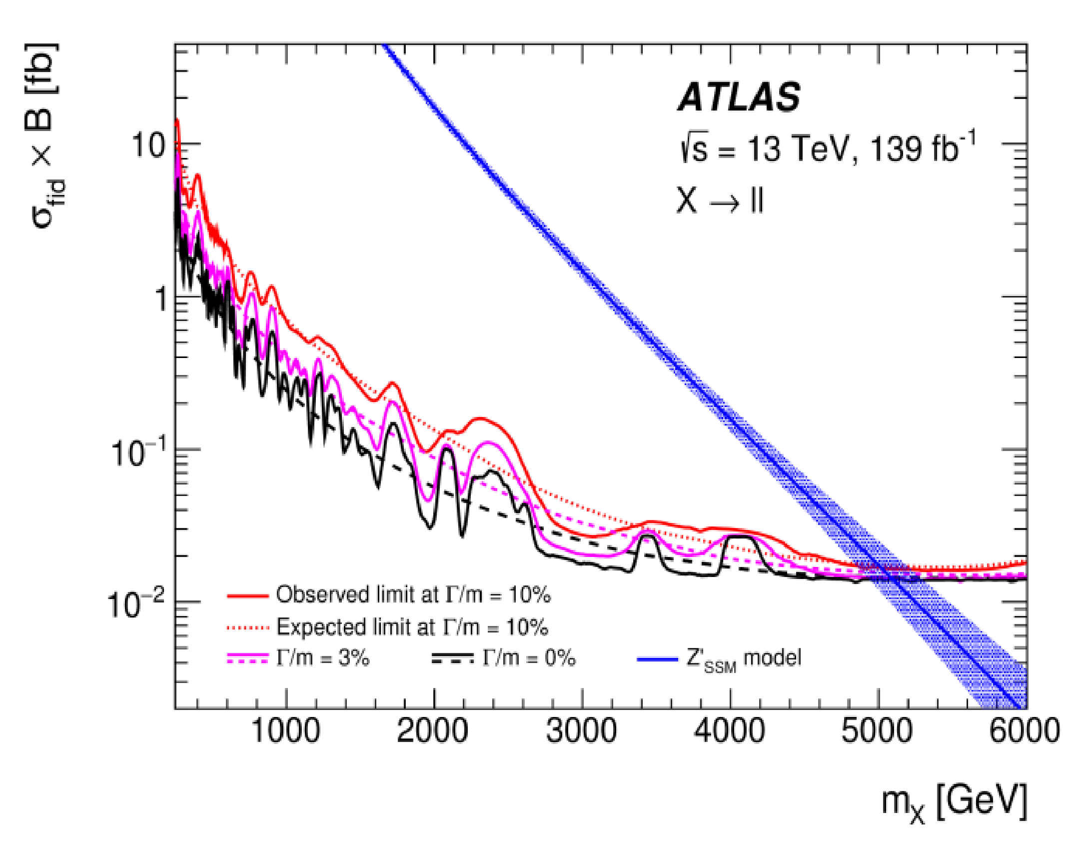


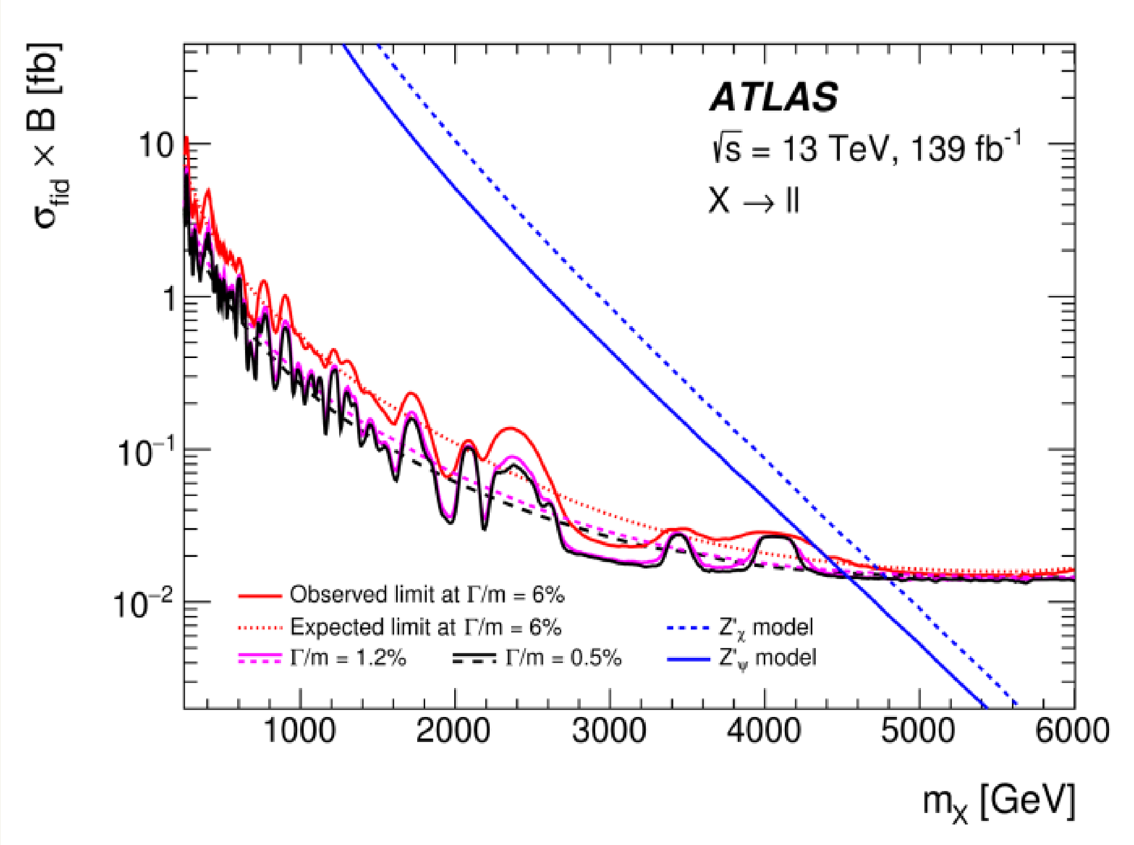
- Largest excess found at 264 GeV for 0-width with a local significance of 2.3σ for the combination of the dielectron and dimuon channels (assuming lepton flavor universality)
- No significant deviations for larger widths

Dilepton Search: 2-D width & mass scan



Dilepton Search: Exclusion Limits

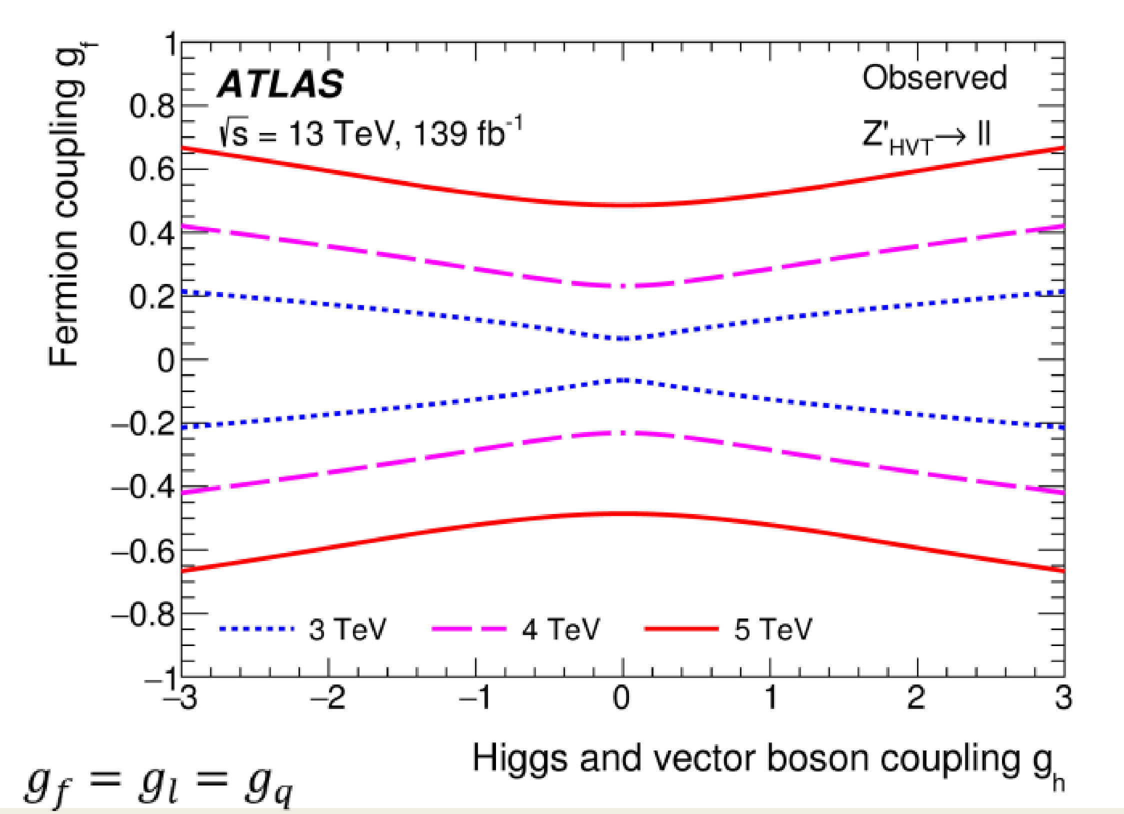


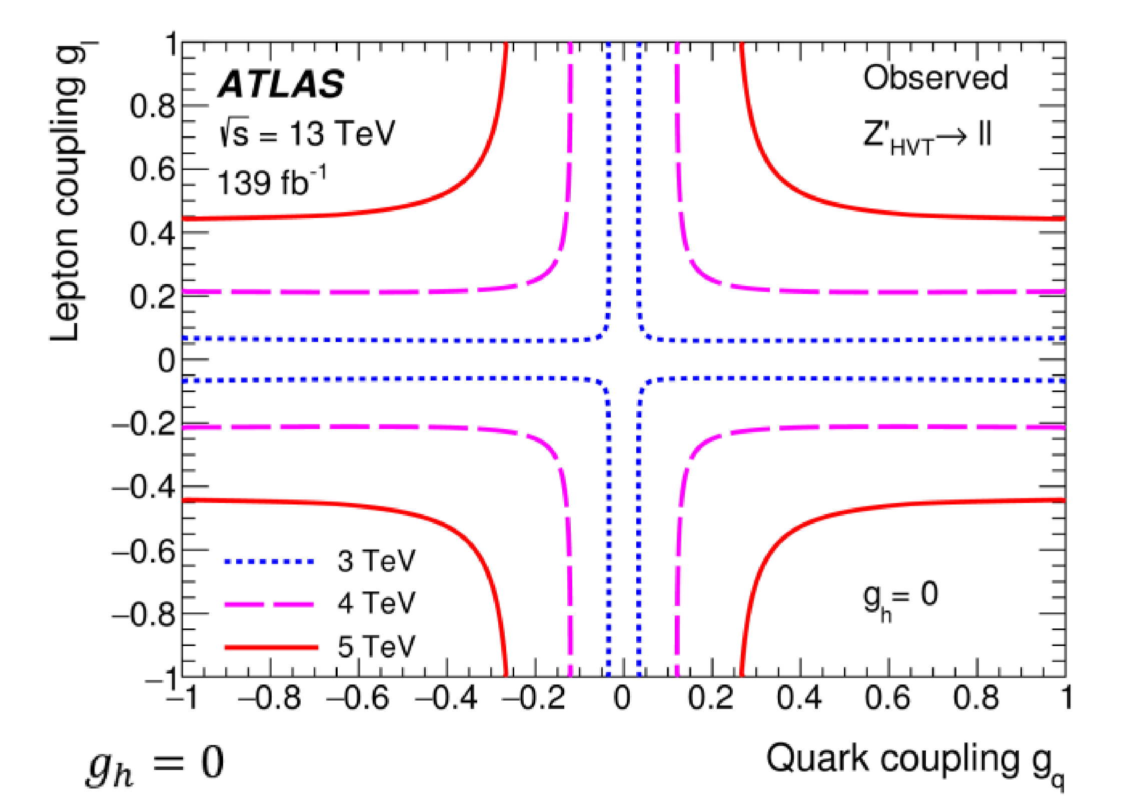


- Model-independent calculated for various width scenarios
- Limits can be re-interpreted for specific models
- Results re-interpreted in terms of Heavy Vector Triplet (HVT) couplings

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

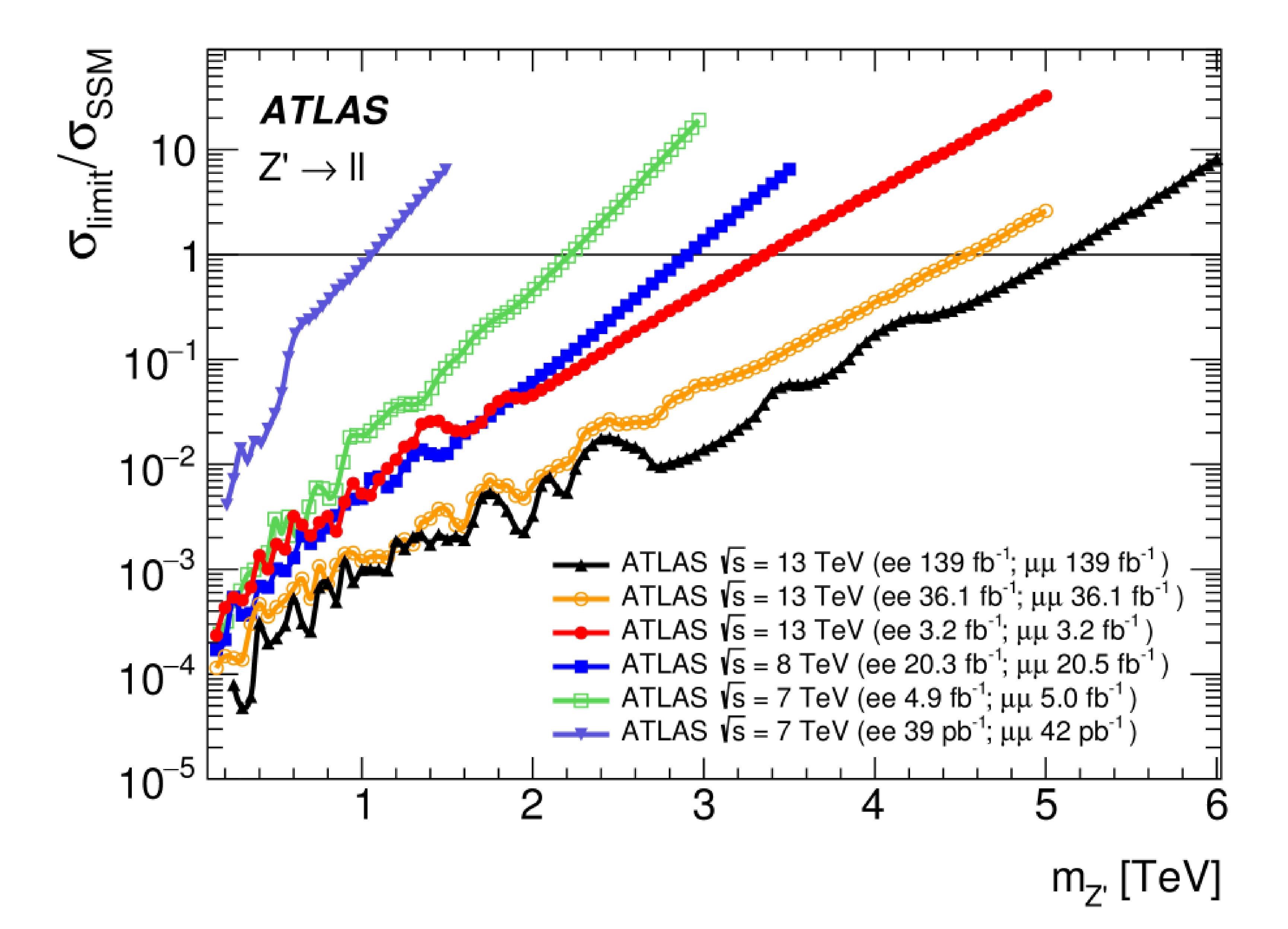
Dilepton Search: HVT Exclusion Contour



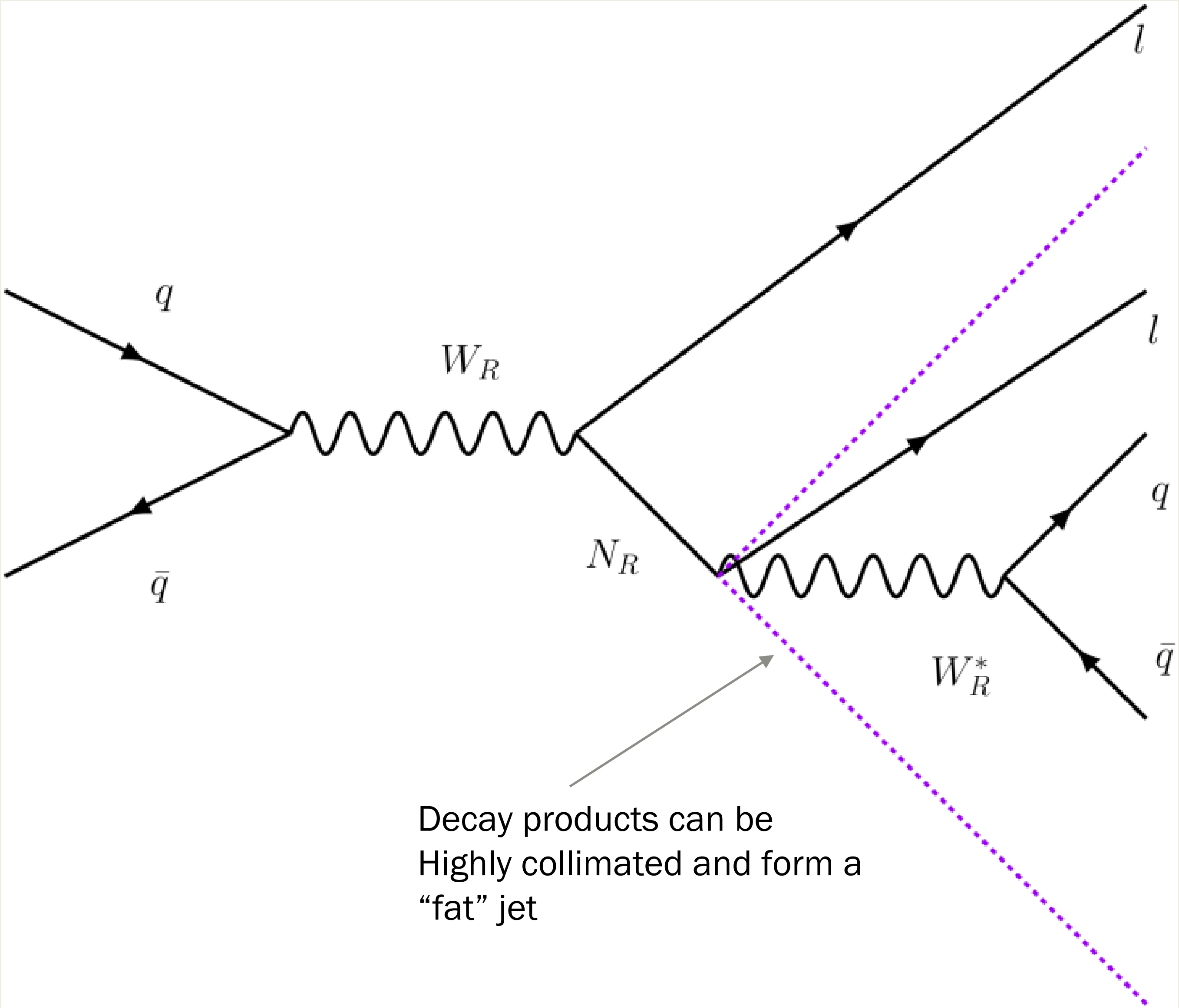


- Limits extracted on the Fermion-Higgs/Vector Boson and Quark-lepton coupling parameter space
- Area outside the curve is excluded
- HVT bosons can couple to fermions (f), leptons (l), and Higgs (h)

Dilepton Search: Summary

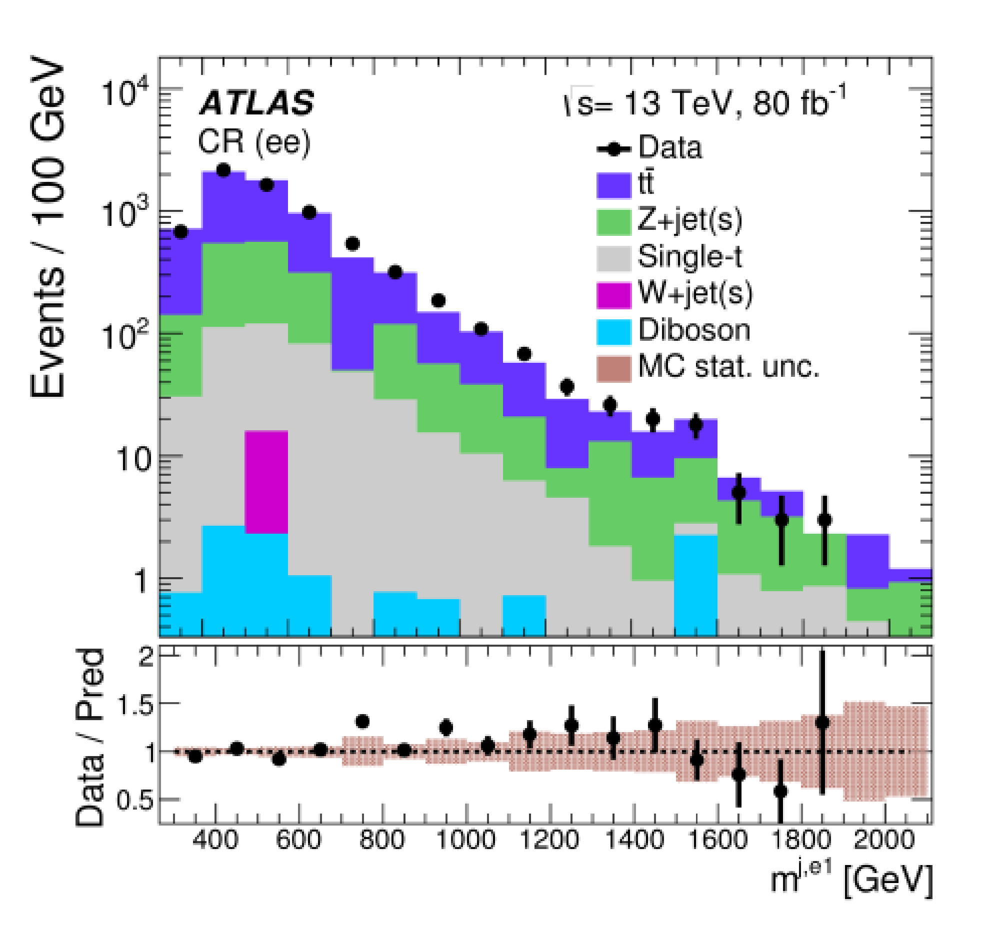


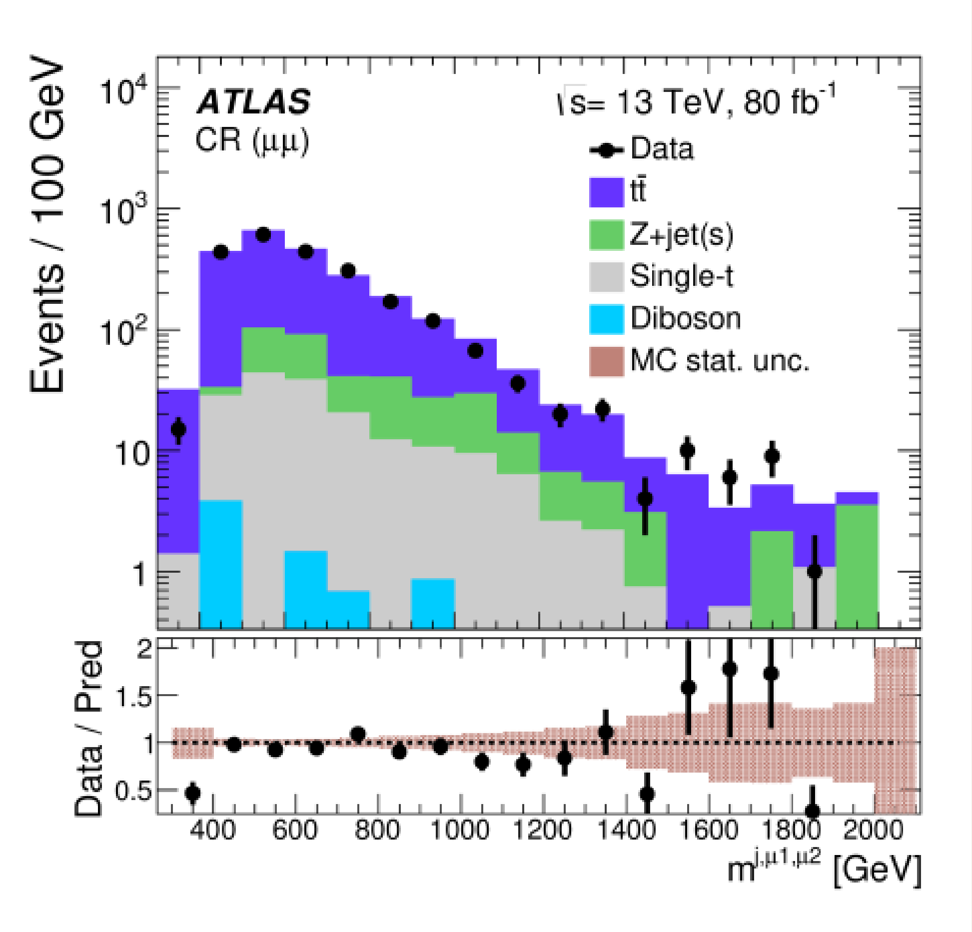
Heavy Neutrino search: arXiv 1904.12679



- Search for a right-handed gauge boson (W_R) decaying into a boosted right-handed heavy neutrino (N_R) together with a lepton
- Focused on the regime where the mass of the heavy neutrino is less than 10% of the right-handed gauge boson
- The decay products of the heavy neutrino can be found within a jet within a large-R jet
- For the electron channel the energy deposit is included in the large-R jet

Heavy neutrino search: m_{W_R}

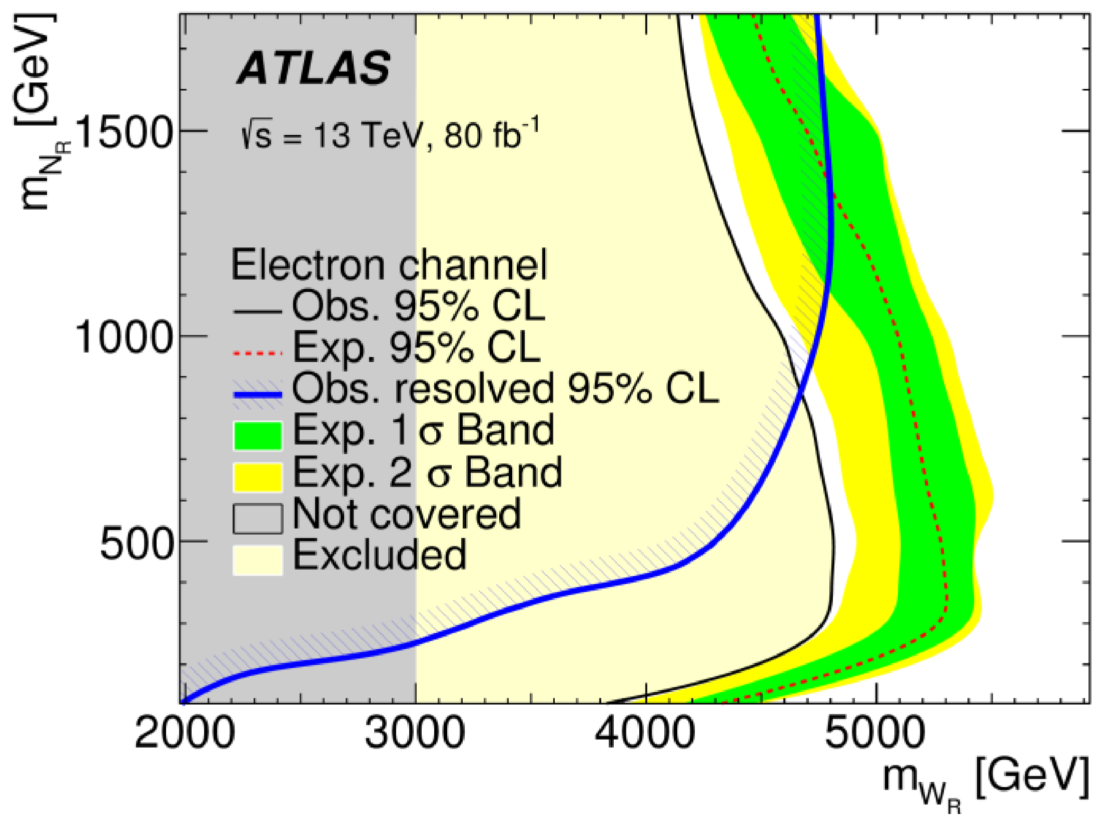


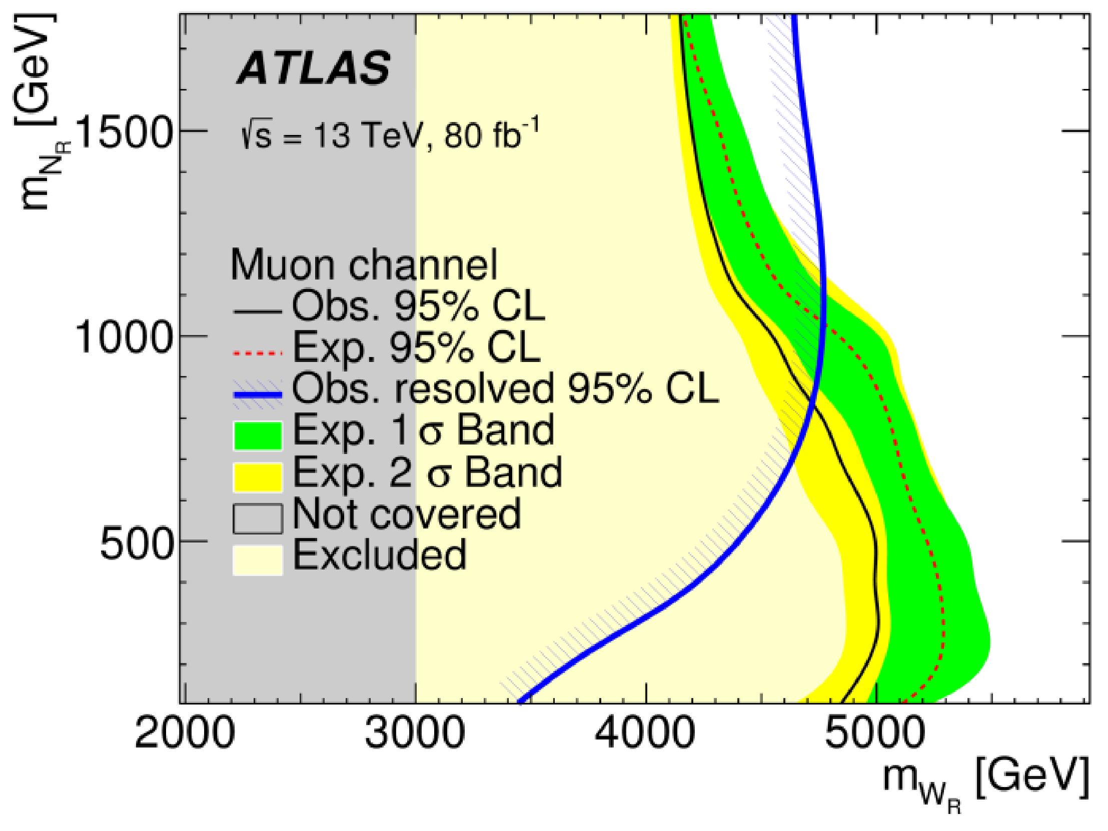


	Electron Channel	Muon Channel
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 150$ GeV)	346^{+48}_{-75}	411^{+36}_{-48}
Signal ($m_{W_R} = 3$ TeV, $m_{N_R} = 300$ GeV)	471^{+42}_{-69}	429^{+29}_{-40}
Signal ($m_{W_R} = 4$ TeV, $m_{N_R} = 400$ GeV)	66^{+6}_{-10}	57^{+4}_{-4}
Expected background	$2.8^{+0.5}_{-0.7}$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

Good agreement found between data and expectation

Heavy neutrino search: Exclusion contour

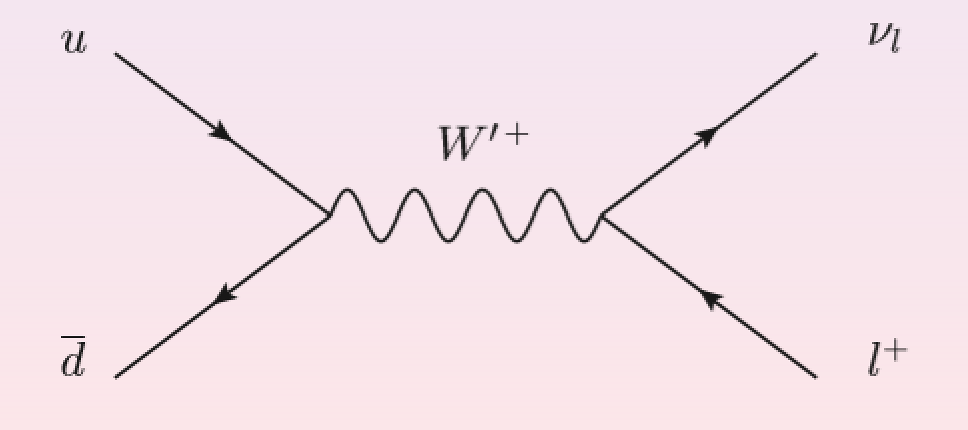




- Limits extracted in the m_{N_R}-m_{w_R} plane
- Slightly worse limits for the muon channel at high mass due to worse resolution
- Observed limits also shown for the resolved topology, where heavy neutrino is produced with large p_T and their decay products are very collimated. A large-R jet can reconstruct the N_R

Lepton+MET: Analysis Strategy

ATLAS-CONF-2018-017



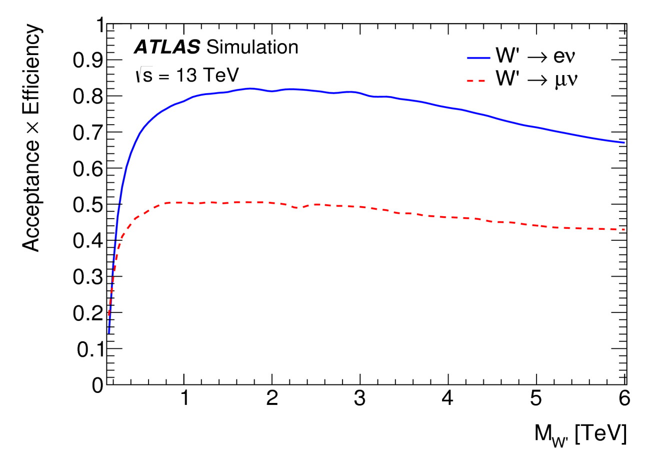
- Possible additional charged gauge bosons
- Its decay would produce a signature with a lepton and missing transverse energy coming from the neutrino
- Benchmark model used is the Sequential Standard Model
- No interference between W and W' considered

AIM

Search for deviations from Standard Model predictions in the m_T distribution

EVENT SELECTION

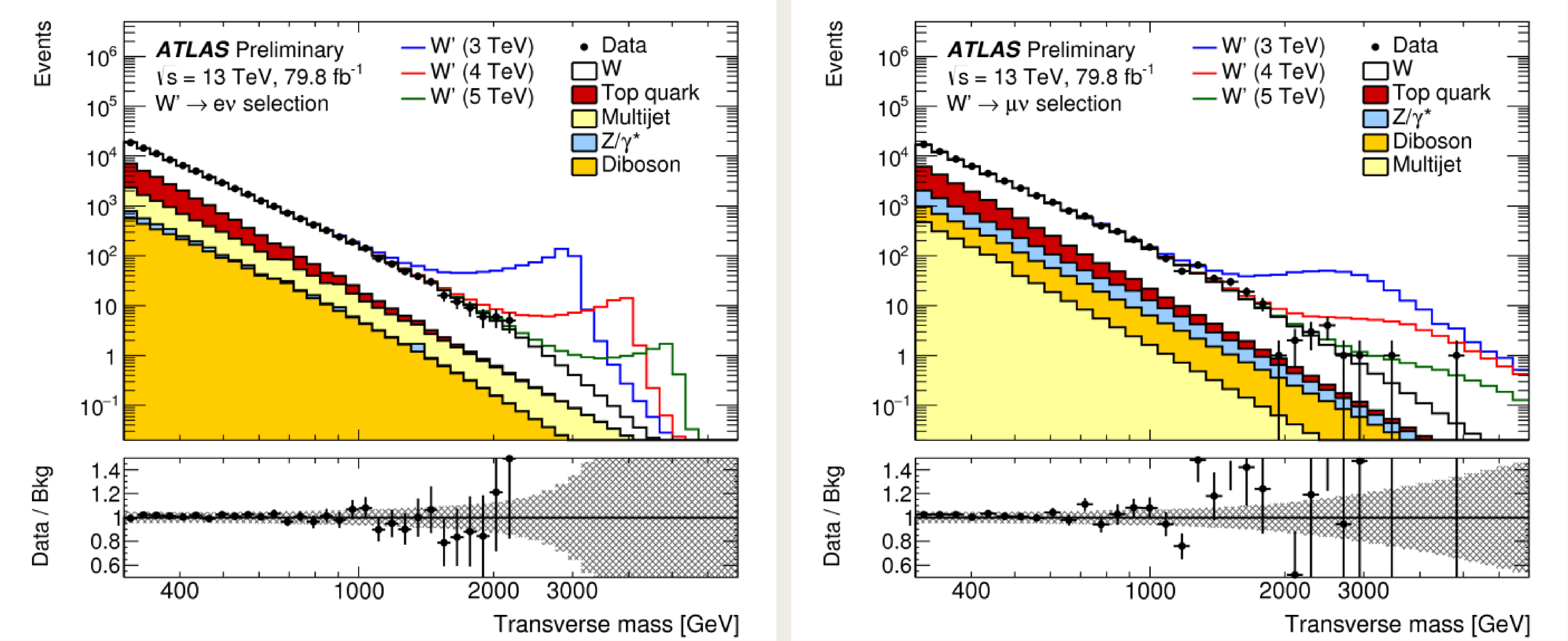
Identify events with one high-pT lepton and large missing transverse energy



BACKGROUND ESTIMATION

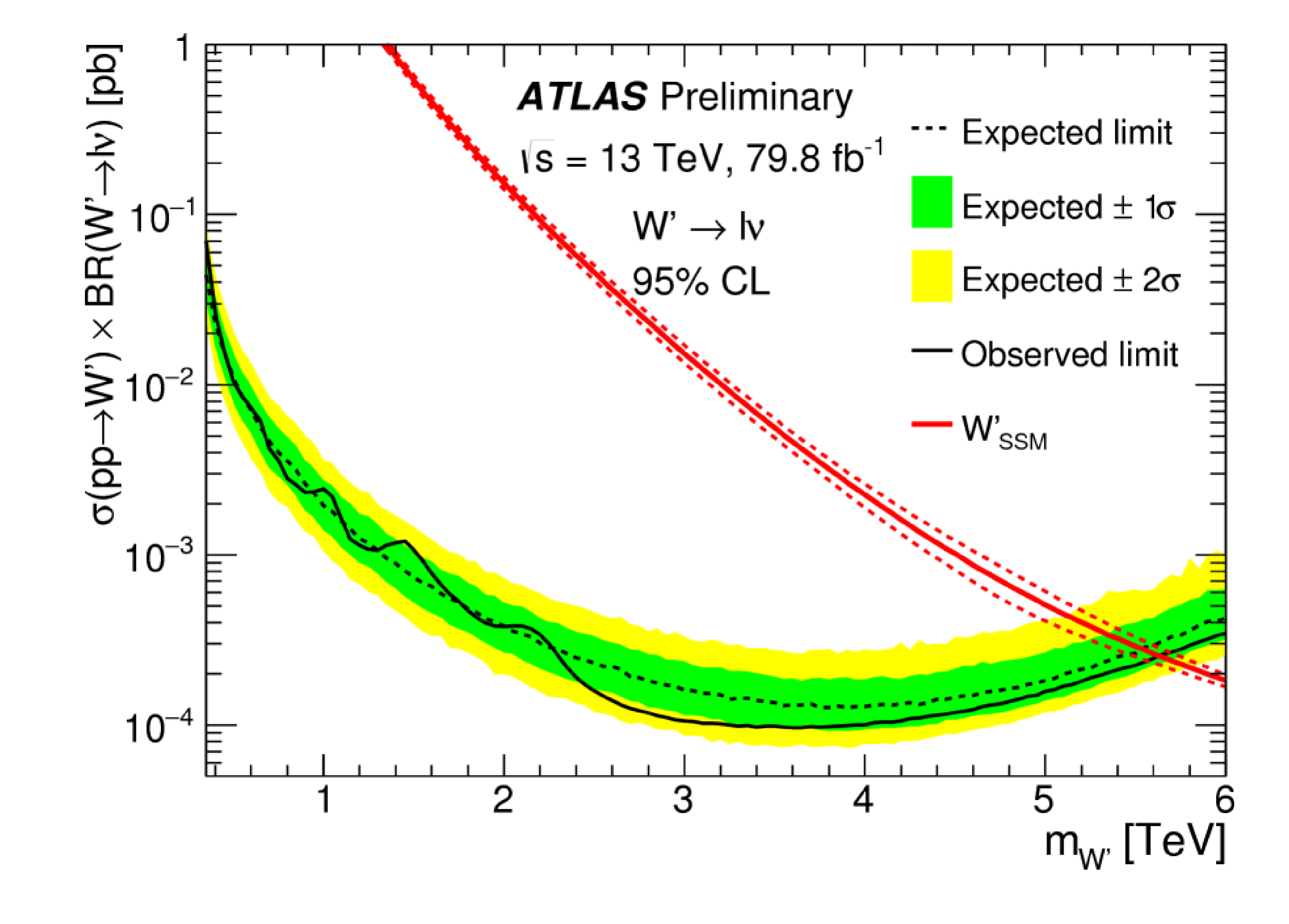
- Events with prompt leptons are estimated through the use of Monte Carlo simulation
- Backgrounds coming from non-prompt leptons are estimated through data-driven methods

Lepton+MET: m_T spectrum



- No significant deviations found from Standard Model expectation
- Largest local significance in the muon channel (2.2 σ) for $m_{w'} = 1.55$ TeV
- Extract limits on the Sequential Standard Model

Lepton+MET: Exclusion Limits

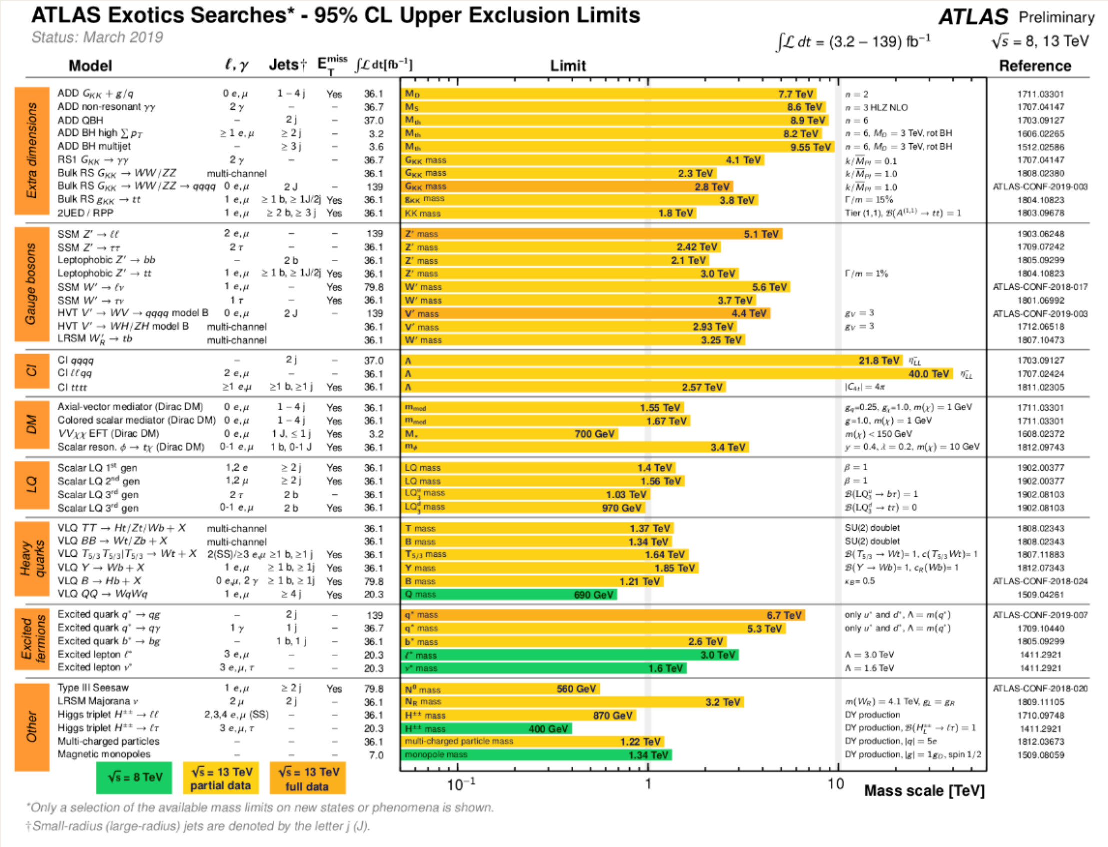


Decay	$m_{W'}$ lower limit [TeV] Expected	Observed
$W' \to e\nu$	5.4	5.7
$W' \to \mu\nu$	4.9	4.8
$W' \to \ell\nu$	5.5	5.6

- Bayesian Limits with flat prior on the signal cross-section
- Mass limits are increased by about half a TeV compared to the 2015+2016
- Results with the full Run-2 dataset coming in the next few months

Summary

- Searches with leptons provide a useful test of the Standard Model, with generally manageable backgrounds
- Still lots of data left to be analyzed!



Dilepton Search: Systematics

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)	$^{+55}_{-35}$ $\left(^{+55}_{-35}\right)$

Systematics for zero (10) % width

Lepton+MET: Systematics

Source	Electron channel Background	Electron channel Signal	Muon channel Background	Muon channel Signal
Trigger	negl. (negl.)	negl. (negl.)	1% (1%)	2% (2%)
Lepton reconstruction and identification	negl. (negl.)	negl. (negl.)	7% (21%)	5% (29%)
Lepton momentum scale and resolution	4% (3%)	4% (3%)	3% (12%)	7% (10%)
Multijet background	7% (113%)	N/A (N/A)	1% (1%)	N/A (N/A)
Top extrapolation	2% (5%)	N/A (N/A)	3% (3%)	N/A (N/A)
Top normalization	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)
Diboson extrapolation	2% (9%)	N/A (N/A)	3% (10%)	N/A (N/A)
PDF choice for DY	1% (14%)	N/A (N/A)	$< 0.5\%$ ($< 0.5\%$)	N/A (N/A)
PDF variation for DY	8% (12%)	N/A (N/A)	7% (11%)	N/A (N/A)
EW corrections for DY	4% (5%)	N/A (N/A)	4% (6%)	N/A (N/A)
Luminosity	2% (1%)	2% (2%)	2% (2%)	2% (2%)
Total	13% (115%)	4% (4%)	12% (29%)	9% (31%)

Dilepton Search: parametric function

The smooth functional form for the background is based on fit performance studies on a MC background template. The associated uncertainties are also estimated through these studies. In order to minimise the statistical uncertainties in this procedure, the background template for DY is produced from large-statistics samples simulated only at generator level and smeared by the experimental dilepton mass resolution, described in the previous section, with mass-dependent acceptance and efficiency corrections applied. A similar procedure is applied to the generator-level dilepton mass distribution in the $t\bar{t}$ sample exploiting the larger number of events from the generator-level mass distribution. The distributions from the diboson and single-top simulated samples and, in the electron channel, a template for multi-jet and W+jet processes are also considered. All MC-based contributions are scaled by their respective cross-sections.

In order to select the background functional form, a fit to the dilepton mass background template is performed, under the signal plus background hypothesis, for various functional forms, following the procedure outlined in Ref. [47]. The chosen functional form is the one with the smallest absolute number of fitted signal events ('spurious signal'), which are determined as as a function of $m_{\ell\ell}$:

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

where $x = m_{\ell\ell}/\sqrt{s}$ and parameters b and p_i with $i = 0, ..3$ are left free in the fit to data and independent for dielectron and dimuon channels. The parameter c is 1 for the dielectron and 1/3 for the dimuon channel. The function $f_{\mathrm{BW},Z}(m_{\ell\ell})$ is a non-relativistic Breit–Wigner function with $m_Z = 91.1876$ GeV and $\Gamma_Z = 2.4952$ GeV [48]. The normalisation of the background function is such that the integral a corresponds to the total number of background events. To further validate this functional form an extra degree of freedom ($i = 4$) is added to the fit function before the final data analysis, to check if it improves the likelihood value of the fit by more than 2σ. To check the fit stability in the high-mass region, signal injection tests are performed at various mass points. No significant bias in the number of extracted signal events is observed.