Searches for W' and Z' in leptonic final states using 139 fb^{-1} of pp collision data collected at $\sqrt{s} = 13$ TeV with the ATLAS detector

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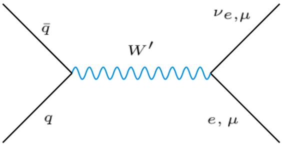
Epiphany 2021

Introduction

- I am going to present an overview of searches for new heavy gauge bosons at the ATLAS detector
- We will focus on dilepton final states ($\ell\nu$ and $\ell\ell$, excluding τ), looking at searches for:
  - Resonantly produced W' bosons decaying to an $\ell\nu$ pair
    https://arxiv.org/abs/1906.05609
  - Resonantly produced Z' bosons decaying to an $\ell\ell$ pair
    https://arxiv.org/abs/1903.06248
  - Non-resonant phenomena in $\ell\ell$ final states
    https://arxiv.org/abs/2006.12946
- All of these searches use the full Run-2 139 fb^{-1} *pp* dataset recorded at $\sqrt{s} = 13$ TeV

$W' \to \ell\nu$ search

- A search for a new heavy charged gauge boson (W') with high-p_T leptons and large missing energy in the final state



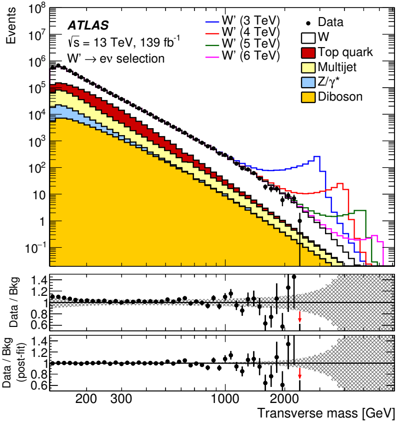
- Monte Carlo used to model all backgrounds except for Multijet
  - use data-driven method
- Backgrounds extrapolated into low stats region

Dominant uncertainties

Channel	Low-m_T	High-m_T
$W' \to e\nu$	jet uncertainties	background extrapolation
$W' \to \mu\nu$	jet uncertainties	p_T resolution

$$m_T = \sqrt{2 p_T^{\ell} E_T^{miss} (1 - cos(\phi_{\ell, E_T^{miss}}))}$$

https://arxiv.org/abs/1906.05609

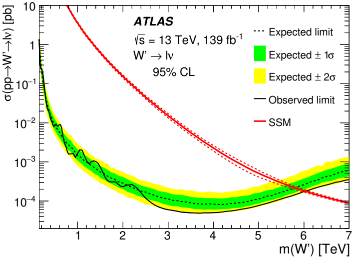


- The main signal hypothesis assumes SM-like couplings, but other model independent interpretations are provided

- Unfortunately, no statistically significant excesses were found

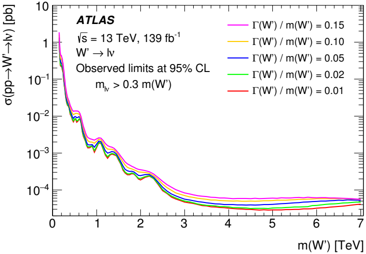
- Limits set on the assumption of a heavy W' with SM-like couplings
- Mass limits in the combined channel now extend to 6 TeV!
- Upper limits on the cross section go all the way down to 50 *ab*

https://arxiv.org/abs/1906.05609



- Model independent fiducial cross-section limits for different Breit-Wigner width assumptions
- Can be interpreted in the context of any given model

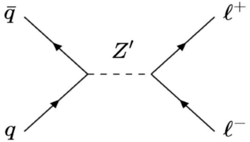
https://arxiv.org/abs/1906.05609



- Also provide completely model independent visible cross-section limits in single-bin signal regions (backup)

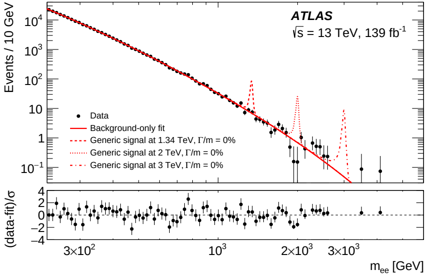
$Z' \to \ell\ell$ resonant search

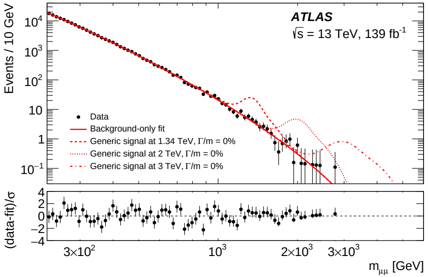
- Resonant search for heavy neutral gauge boson (Z') decaying to a dilepton pair



- A new approach to background estimation was performed, using a functional fit to the data to describe the SM background
  - Large MC stat. uncertainties + too CPU intense to generate more events
  - Hence, data-driven method is used with Monte Carlo used to optimise the fitting functions
- Generic signal model used:
  - Non-relativistic Breigt-Wigner convolved with a Gaussian and crystal ball function

https://arxiv.org/abs/1903.06248

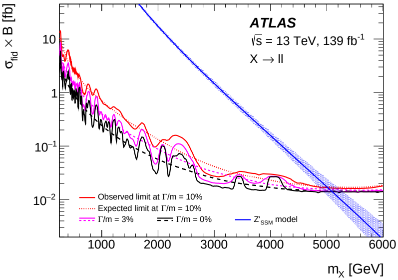


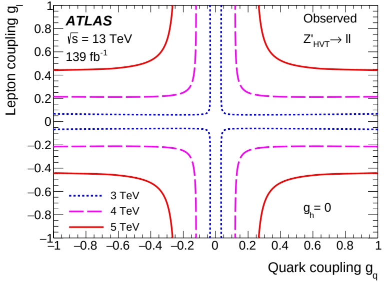


$Z' \to \ell\ell$ resonant search - statistical interpretation

- The two benchmark models presented here:
  - SSM: same couplings as SM Z
  - HVT: Z' is neutral component of new SU(2) triplet state
- Cross section limits:
  - Limits set on generic signal templates over a range of mass and width assumptions
  - SSM limits on Z' mass set to 5.1 TeV
- HVT interpretation:
  - Exclusion contours in the HVT model coupling space
  - g_ℓ and g_q correspond to the coupling strength between the triplet field and leptons/quarks
  - These limits are only slightly weaker than the 36 fb^{-1} combination of the W' and Z' channels here
  - 139 fb^{-1} combination with other HVT final states is ongoing

https://arxiv.org/abs/1903.06248





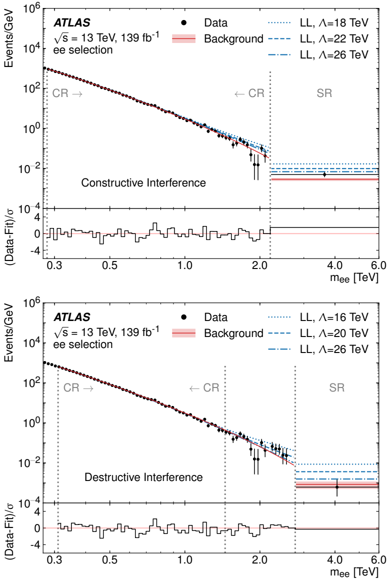
Non-resonant phenomena in dilepton final states

- The signal manifests itself as a broad tail in the $m_{\ell\ell}$ spectrum
- Same background procedure used as the resonant search
  - Fit in control region, extrapolate into signal region
- Focuses on the contact interaction interpretation
  - Composite quarks/leptons leads to effective four-fermion interaction
  - This process can interfere either constructively or destructively with the SM Drell-Yan process

$$\sigma_{tot}(m_{ll}) = \sigma_{DY} - \eta_{ij}\frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$

- Single bin signal region, with control regions optimised separately for constructive/destructive interference
- RHS: di-electron invariant mass distribution (di-muon in backup)

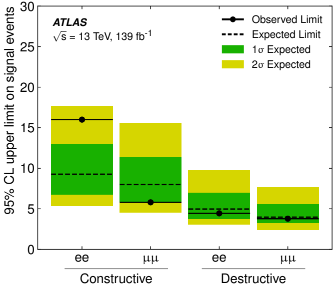
https://arxiv.org/abs/2006.12946

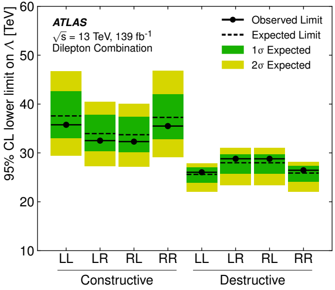


Statistical interpretation

- Top figure:
  - Limits are set on the integrated number of signal events (visible cross section) in each SR
  - Four SRs: di-electron & di-muon, constructive and destructive interference
  - Completely model independent
- Bottom figure:
  - Lower limits on Λ for constructive and destructive interference for all chirality options
  - Λ is the energy scale below which fermion constituents are bound
  - The observed lower limit on Λ ranges from 22.3 TeV to 35.8 TeV

https://arxiv.org/abs/2006.12946





Conclusion

- All three of these analyses are now complete and published
- Limits on resonant $W' \to \ell\nu$ now go up to 6 TeV, and 5.1 TeV for resonant $Z' \to \ell\ell$
- For non-resonant phenomena decaying to dilepton pairs, the observed lower limit on the compositeness scale (Λ) ranges from 22.3 TeV to 35.8 TeV
- The combination of the resonant W' and Z' signals is currently ongoing, following on from the 36 fb^{-1} analysis (https://arxiv.org/abs/1808.02380)

References

Slides 4-5:

ATLAS Collaboration, Search for a heavy charged boson in events with a charged lepton and missing transverse momentum from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys.Rev.D 100 (2019) 5, 052013, https://arxiv.org/abs/1906.05609.

Slides 7-8:

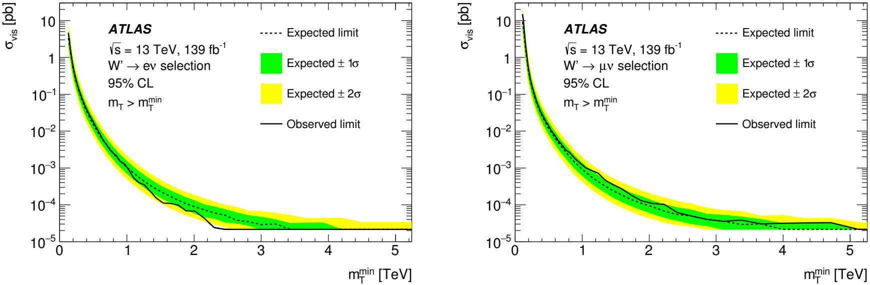
ATLAS Collaboration, Search for high-mass dilepton resonances using 139 fb^{-1} of pp collision data collected at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys.Lett.B 796 (2019) 68-87, https://arxiv.org/abs/1903.06248.

Slides 10-11:

ATLAS Collaboration, Search for new non-resonant phenomena in high-mass dilepton final states with the ATLAS detector, JHEP 11 (2020) 005, https://arxiv.org/abs/2006.12946.

Backup

Single-bin signal regions



- Model-independent upper limits are also provided for the number of signal events in single-bin signal regions
  - Defined by an increasing transverse mass threshold
- These limits are translated into limits on the visible cross section (number of signal events / luminosity)

Dimuon non-resonant invariant mass distribution