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Beyond exclusive leptonic resonances with the ATLAS detector

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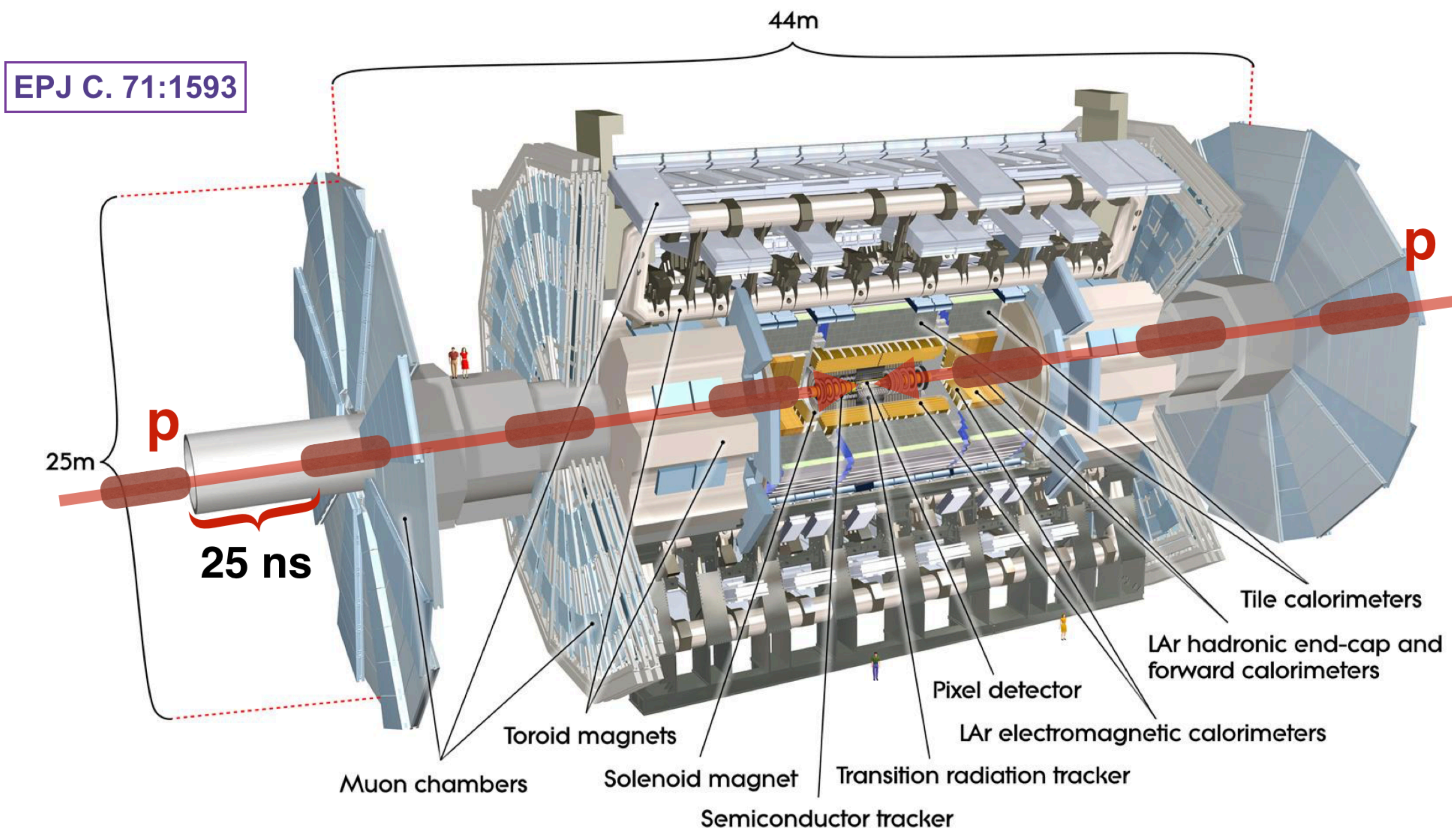
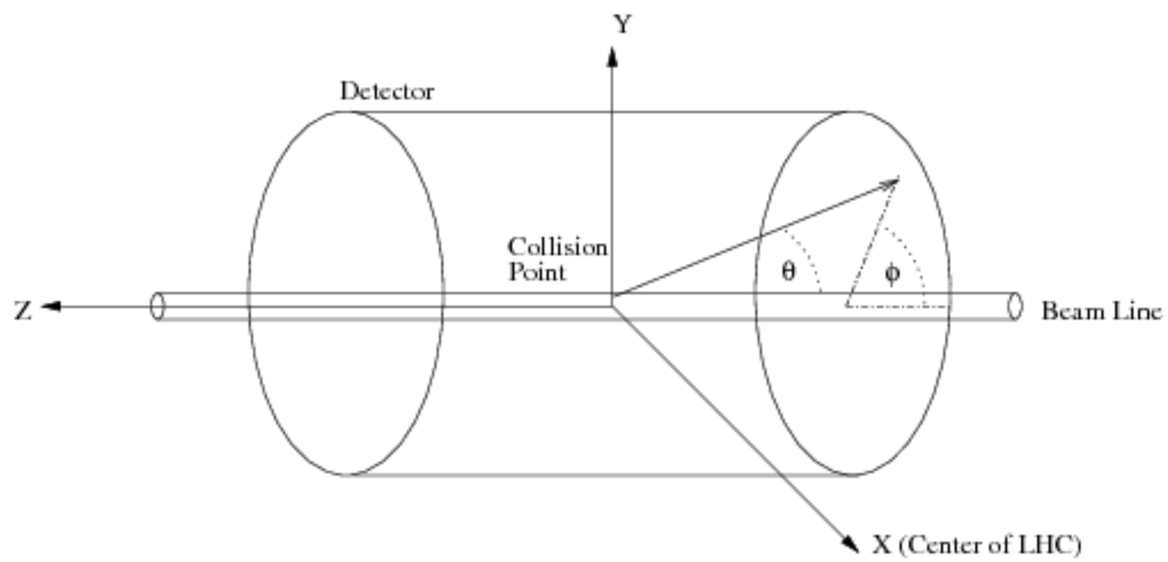
ATLAS detector @ LHC





Cylindrical coordinates (r, φ) are used in the transverse plane:

- φ azimuthal angle around the beam pipe
- θ polar angle $\eta = -\ ln[\tan(\theta/2)]$

Why beyond exclusive leptonic resonances

High-mass resonances have been already searched using the full data recorded by the ATLAS experiment (139 fb^{-1})

- **observable:**

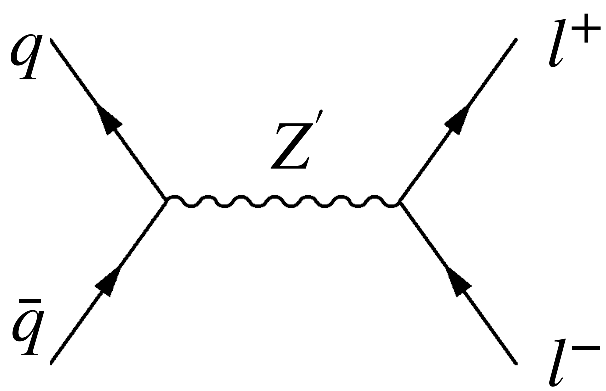
  dilepton (m_{ll}) invariant mass, l = **e** , μ

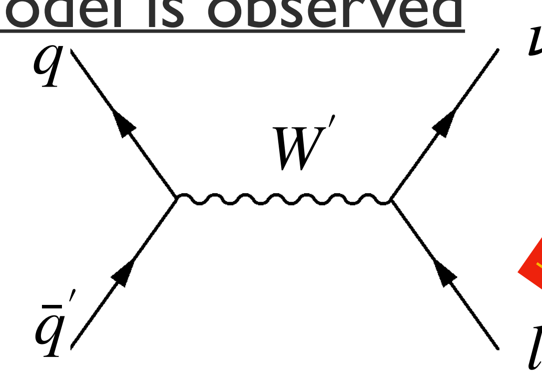
  transverse mass

- **signature:**

  bump on smoothly-falling background

No significant deviation from the standard model is observed





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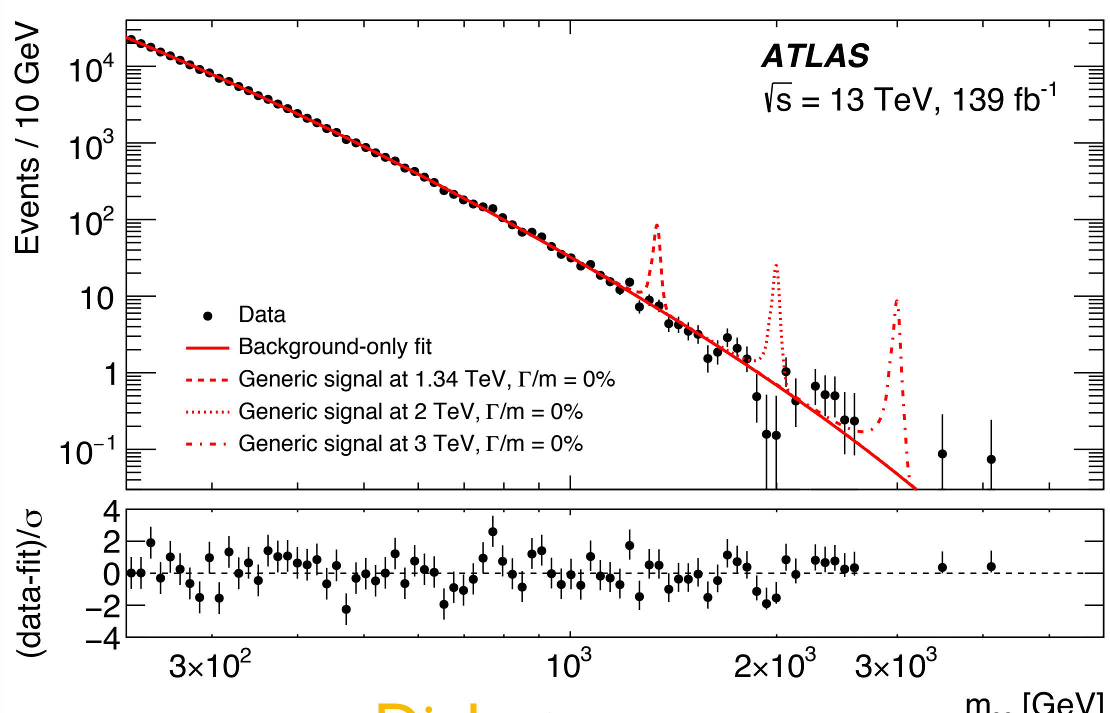
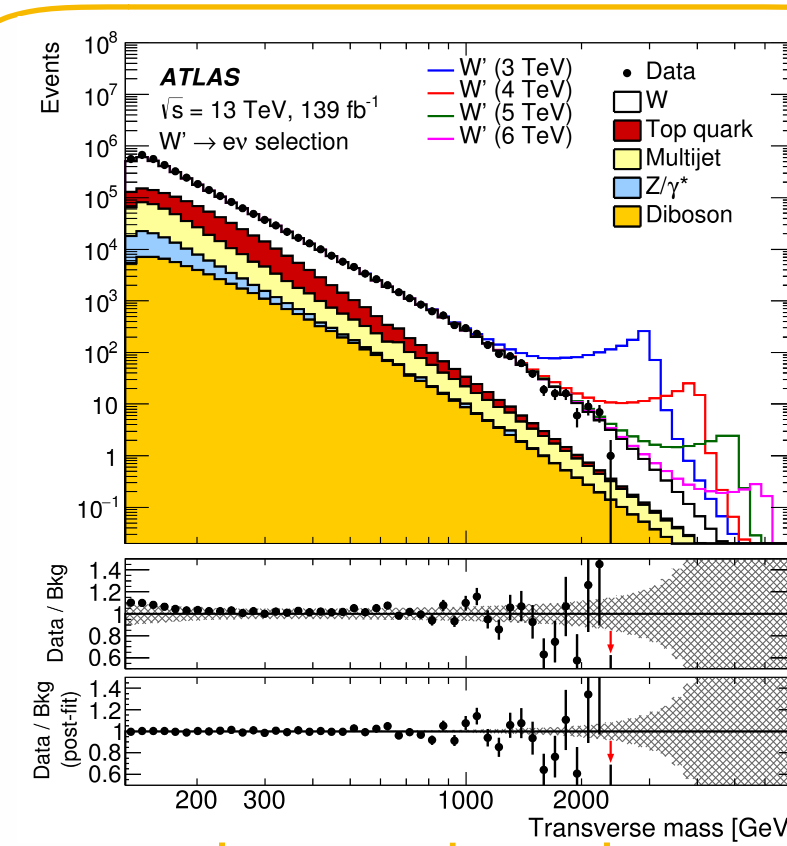


Dielectron

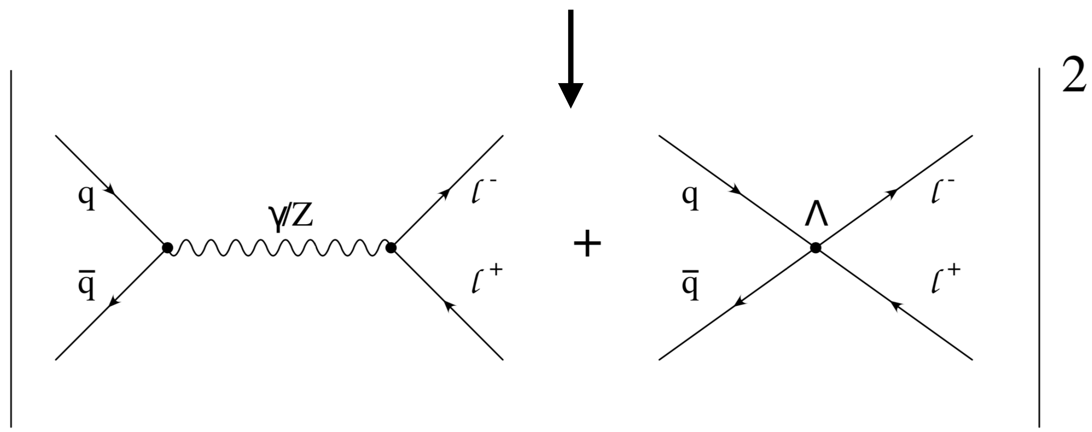


electron channel

Beyond exclusive leptonic resonances

Search for non-resonant features in dilepton mass spectra:

Resonance **above the scale of direct detection** at the LHC



High energy Λ ⟶ **Interference at lower mass**

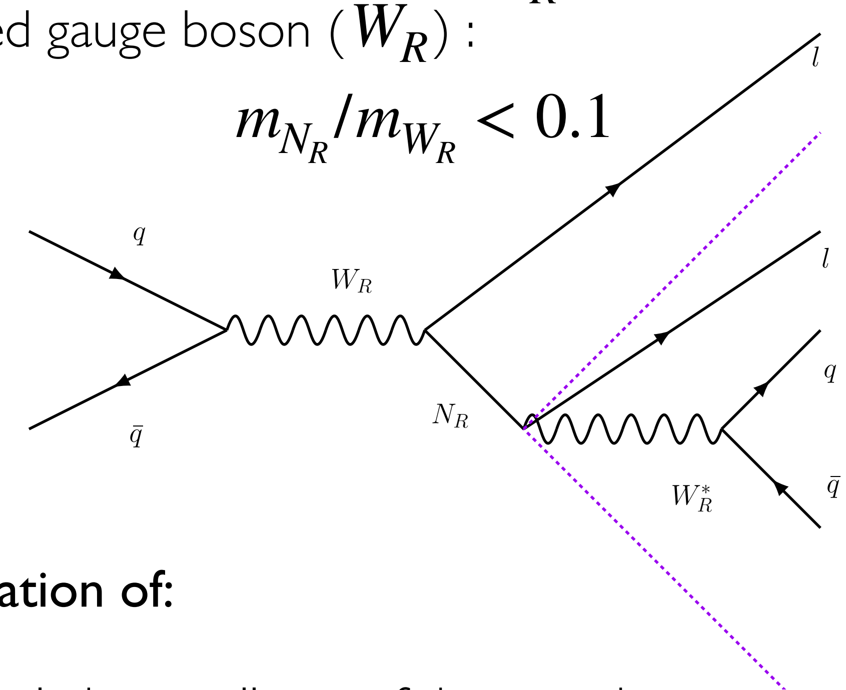
$$\sigma_{tot}(m_{ll}) = \sigma_{DY}(m_{ll}) - n_{ij}\frac{F_I(m_{ll})}{\Lambda^2} + \frac{F_C(m_{ll})}{\Lambda^4}$$

Indication of:
- massive mediator boson
- quark/leptons compositeness

Search for a right-handed gauge boson decaying into a high-momentum heavy neutrino and a charged lepton

Based on Left-Right Symmetric Model (LRSM) theory with right handed Neutrino (N_R) mass smaller than right handed gauge boson (W_R) :

$$m_{N_R}/m_{W_R} < 0.1$$



Explanation of:

- the relative smallness of the neutrino masses
- parity violation in the SM
- existence of the right-handed charged current

Non-resonant features in dilepton mass spectra

Contact interaction

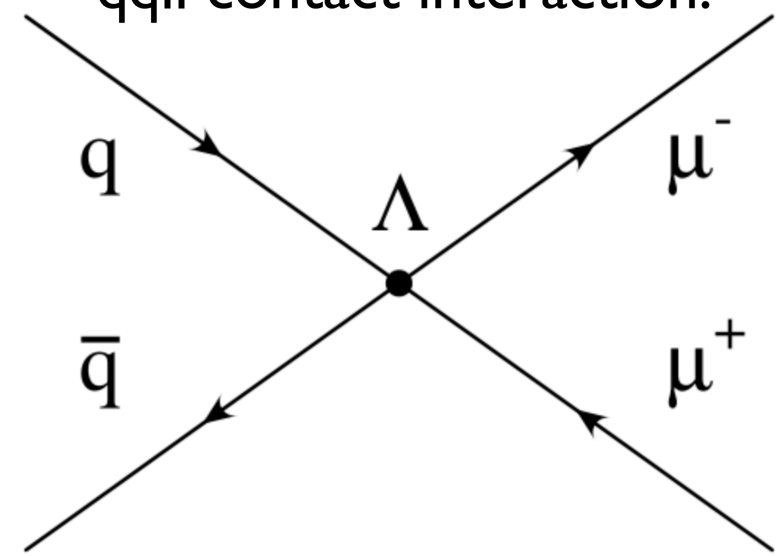
Contact Interaction (CI) scale leads to interference at lower masses

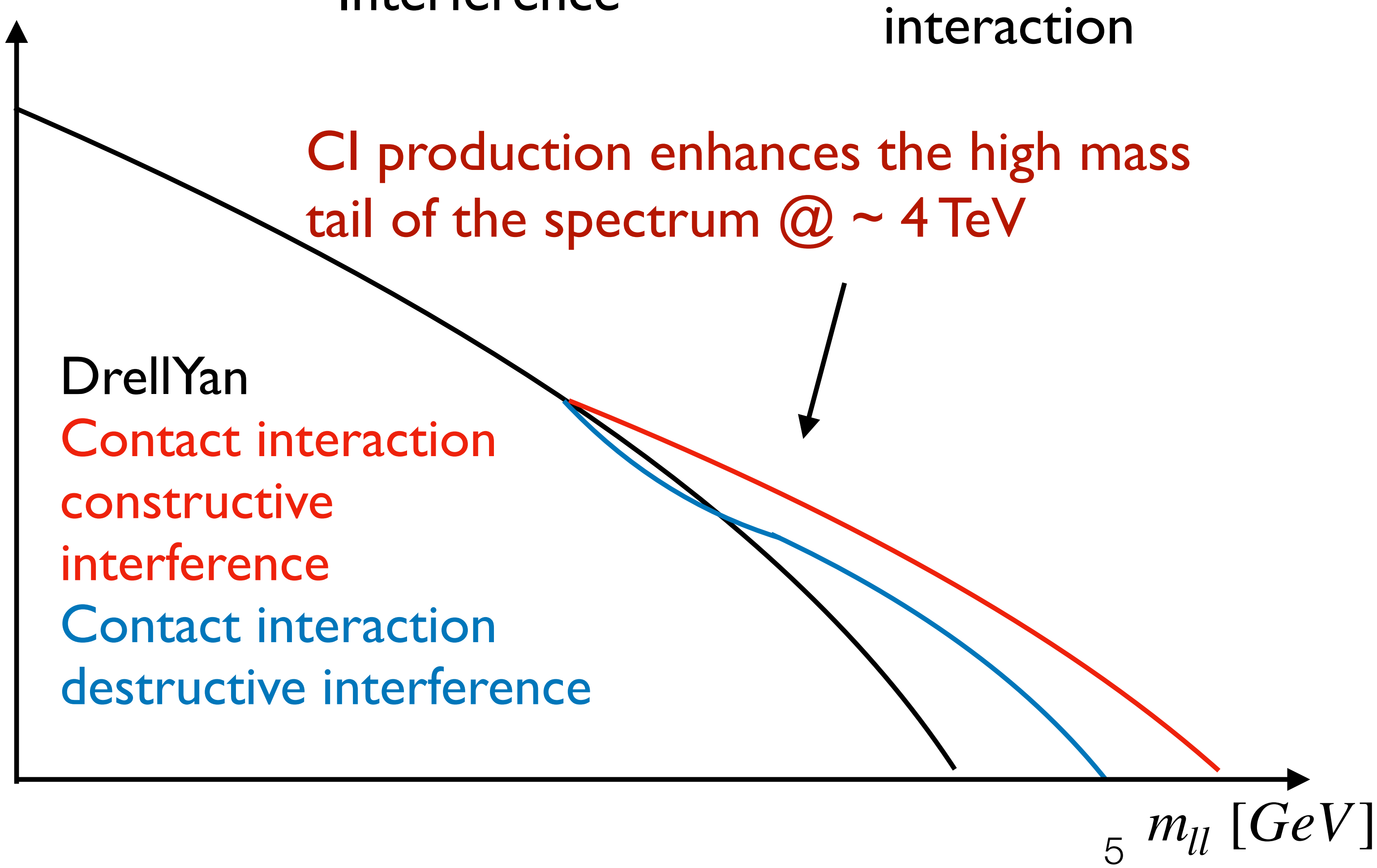
$$\sigma_{tot}(m_{ll}) = \sigma_{DY}(m_{ll}) - n_{ij}\frac{F_I(m_{ll})}{\Lambda^2} + \frac{F_C(m_{ll})}{\Lambda^4}$$

Interference

Pure contact interaction

Physics target: qqll contact interaction:





Signal model parameters:

- Sign of the interference (constructive or destructive)
- Chirality of the fermions (LL, LR, RL, RR)
- Energy scale Λ

Data and event selection

Analysis with ATLAS run 2 data (2015/2016) corresponding to 36 fb^{-1}

Electron selection

- electron candidates identified through:
  - Tracker
  - Electromagnetic calorimeter
- required to have:
  - transverse energy (E_T) > 30 GeV
  - $0 < |\eta| < 1.37$ or $1.52 < |\eta| < 2.47$

high efficiency selection ~95% ⟶ E_T @ 1.5 TeV

Muon selection

- muon candidates required to have :
  - Transverse momentum (p_T) > 30 GeV
  - $|\eta| < 2.5$
  - a cut based on the charge over momentum measurement

efficiency selection ~ 70% ⟶ p_T @1 TeV

leading E_T (p_T) electron(muon) pair is selected

Invariant mass distribution

- The primary background is Drell-Yan production (DY)
- Additional backgrounds from top and diboson production, and multi-jet events
- Functional fit to Drell Yan MC to take into account low MC stat

No significant deviation has been observed

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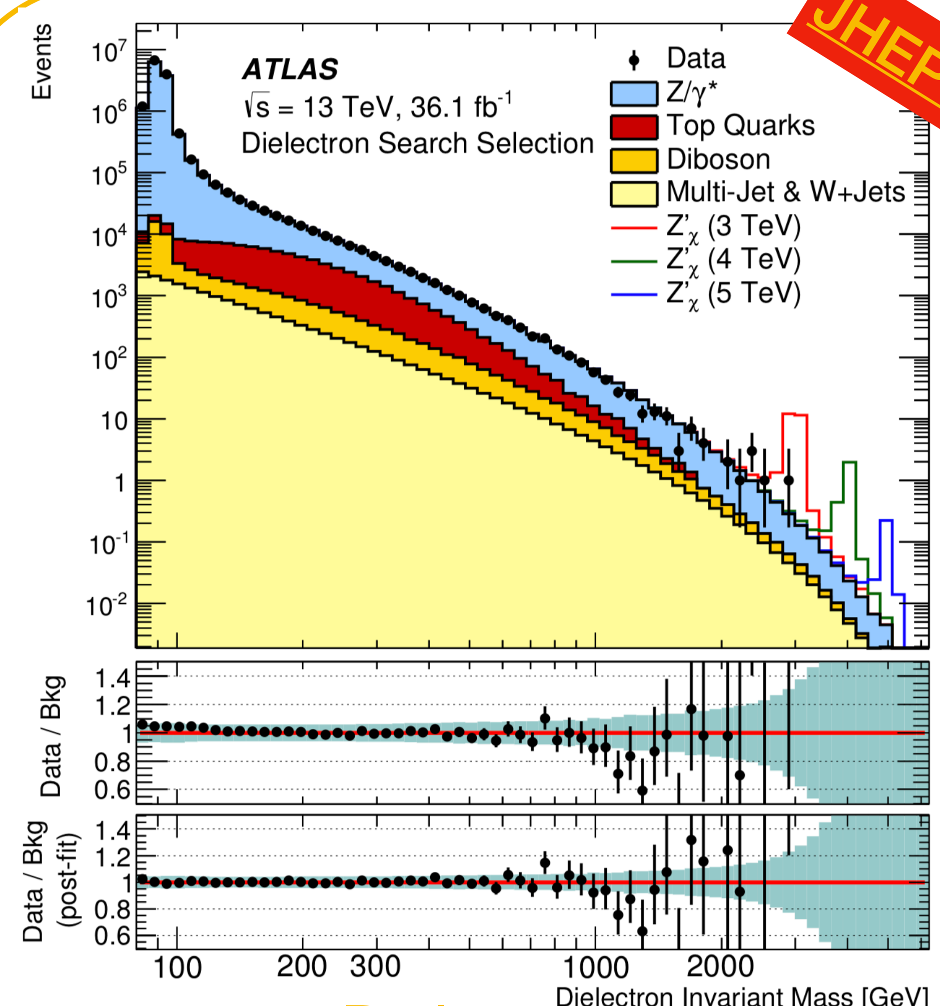
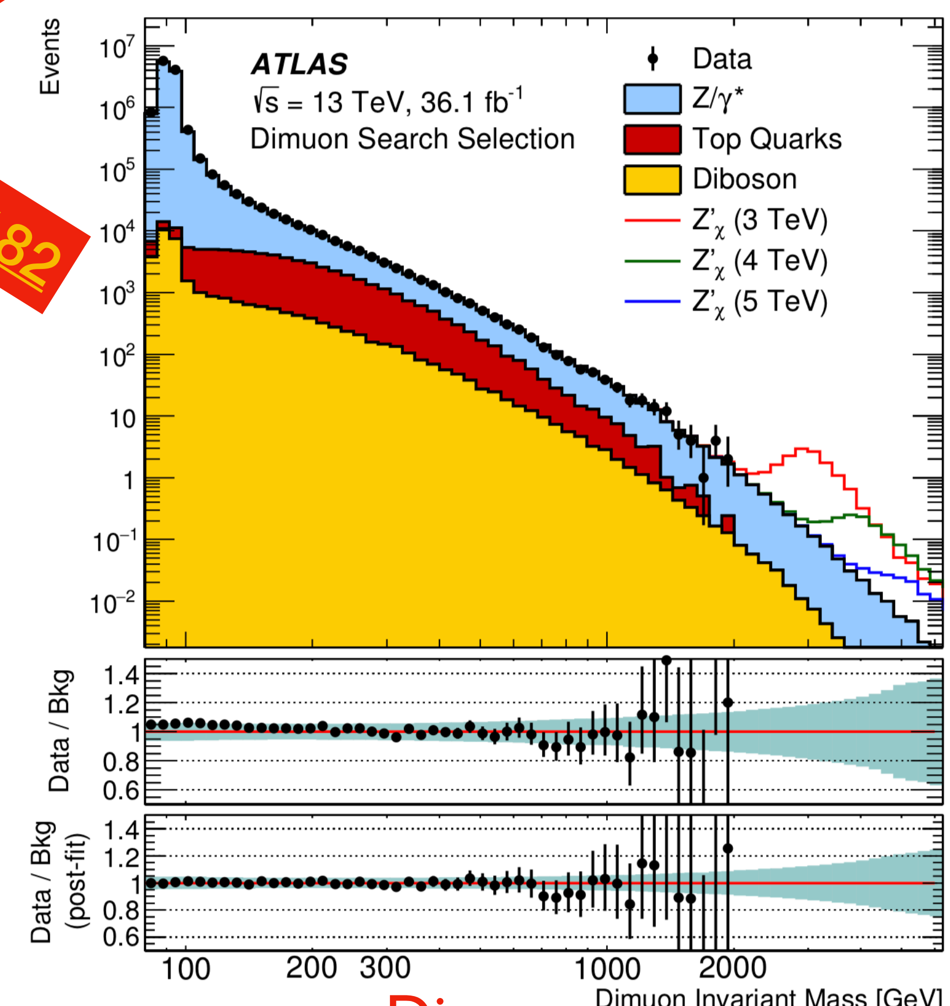


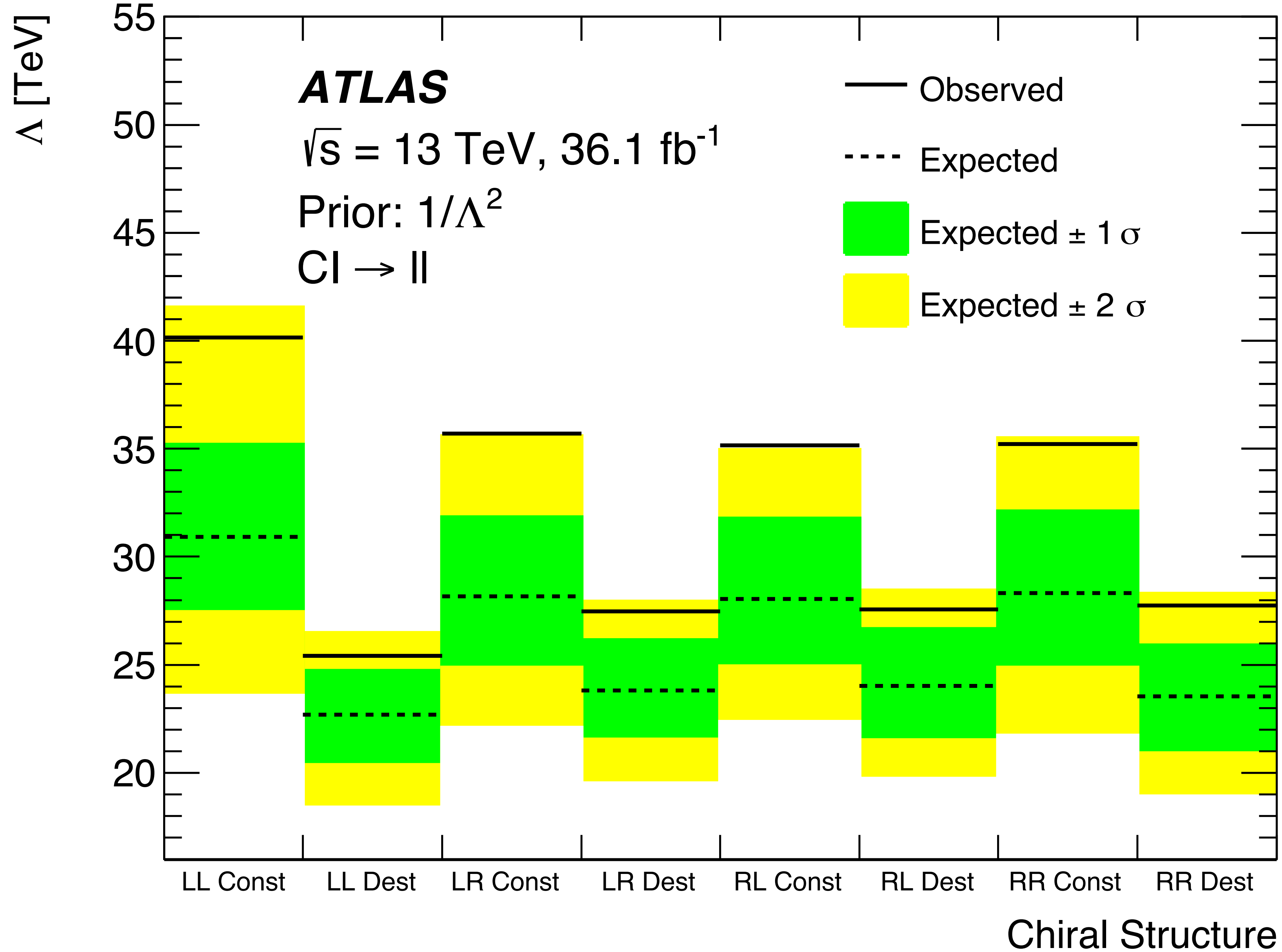
Dielectron



Dimuon

Combined *ll* limits on Λ

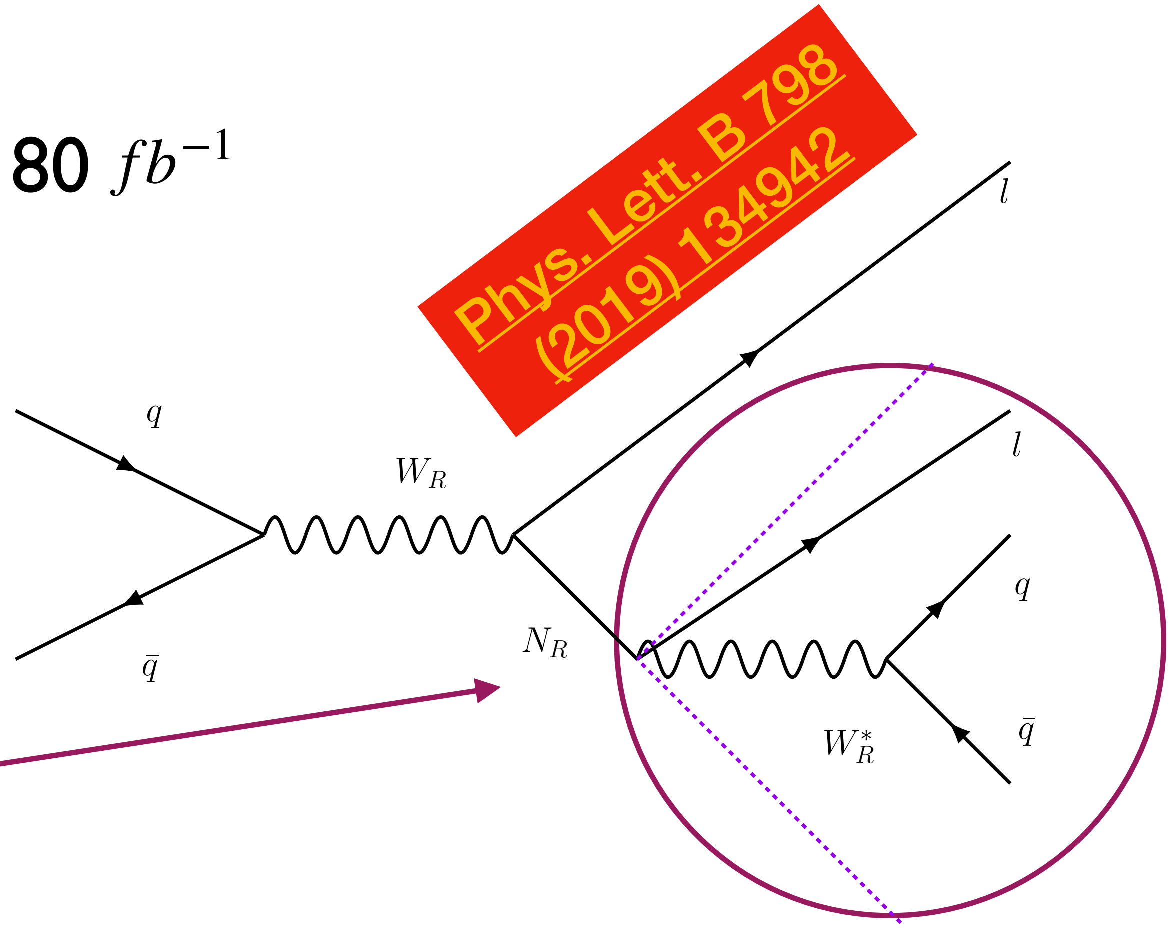
- The **ee** and **μμ** results are combined statistically to set limits on Λ
- highest expected limit for the constructive hypothesis is 31 TeV
- highest expected limit for the destructive hypothesis is 24 TeV



W_R into a high-momentum N_R and a charged lepton

Analysis with ATLAS run 2 data (2015-2017) 80 fb^{-1}

- two same-flavour leptons (no charge requirement)
- Isolated leading lepton
- at least 1 trimmed large jet , p_T > 200 GeV, $|\eta|$ < 2
- Leading lepton - large jet, $\Delta\phi$ > 2
- Sub-leading lepton contained inside the large jet
- m_{ll} > 200 GeV, l = e, μ



Electron selection

- electron candidates identified by:
  - tracker
  - Electromagnetic calorimeter
- required to have:
  - transverse energy (E_T) > 26 GeV
  - 0 < $|\eta|$ < 1.37 or 1.52 < $|\eta|$ < 2.47
  - large jet mass > 50 GeV

Muon selection

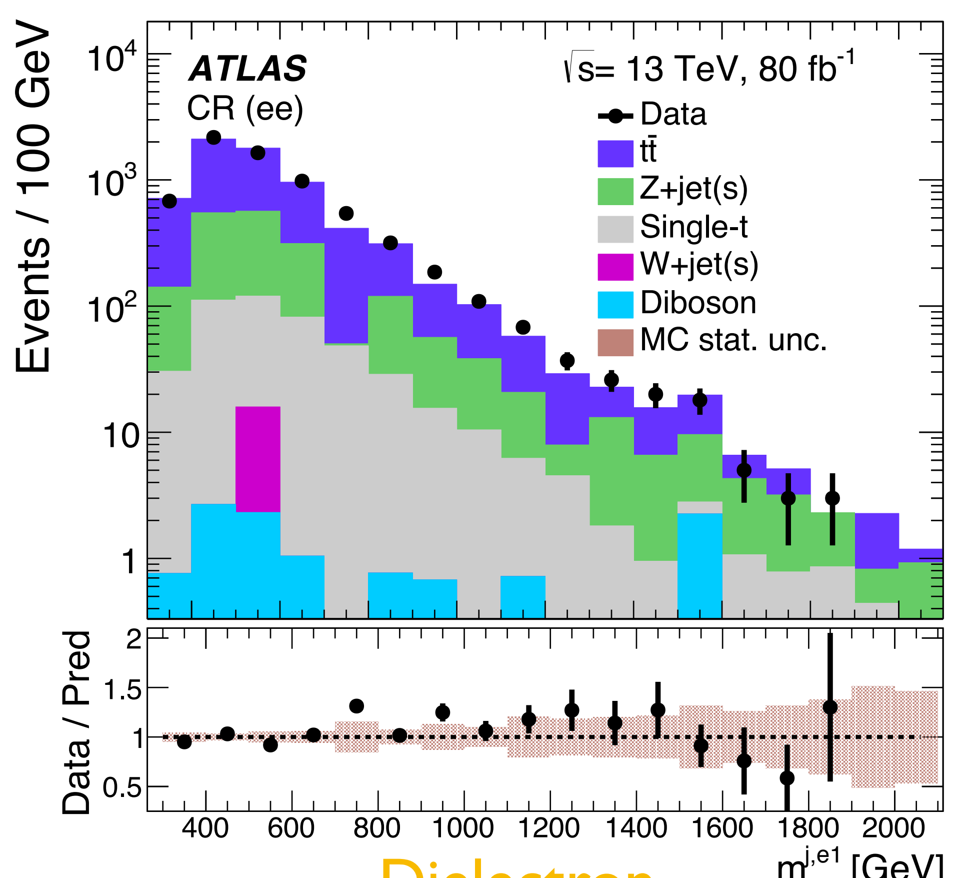
- muon candidates tracks from:
  - inner detector (ID)
  - muon spectrometer (MS)
- required to have:
  - Transverse momentum (p_T) > 28 GeV
  - $|\eta|$ < 2.5

Analysis strategy

Regions definition based on the observable: m_{W_R}

Region	Range of $m_{W_R}^{reco}$	Lepton flavour
Signal region (SR)	> 2 TeV	Same flavour
Control region (CR)	< 2 TeV	Same flavour
Validation region (VR)	All	Mixed flavour (leading: muon; subleading: electron)

- CR is dominated by $t\bar{t}$ events
- SR Z+jets events larger at higher masses
- W+jets, single-top-quark and multijet processes are negligible



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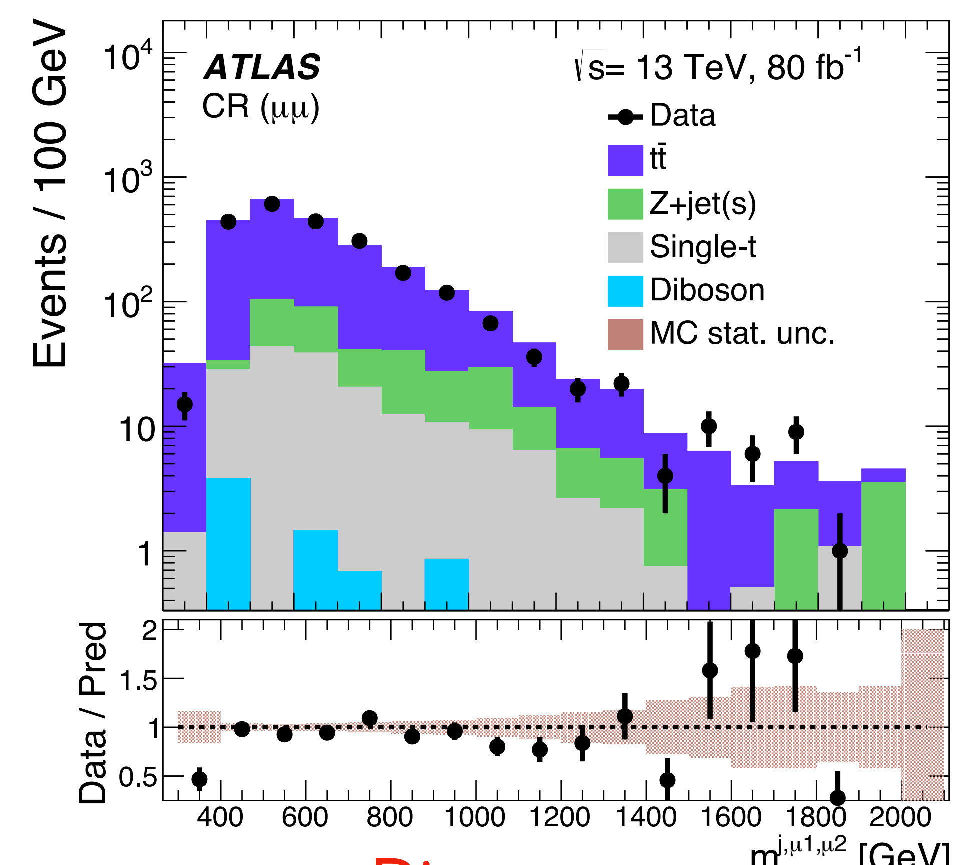
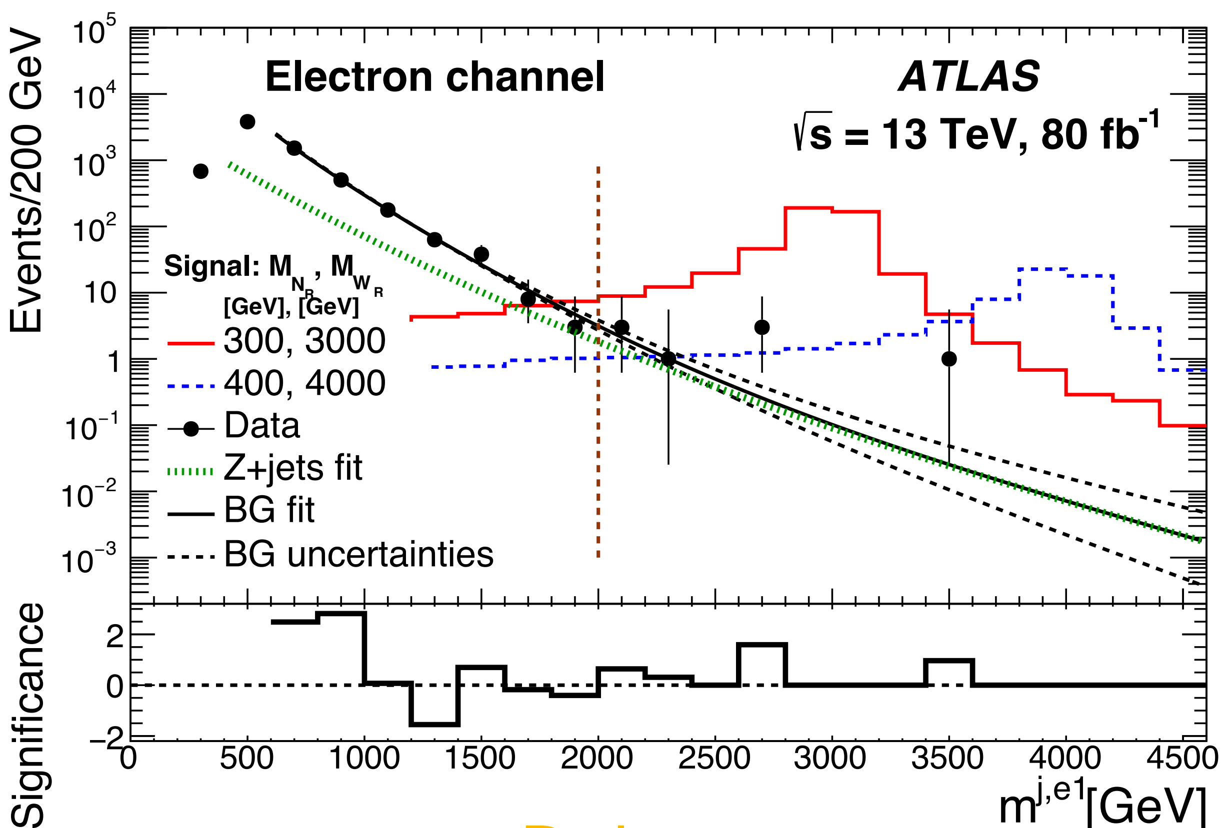


Dimuon

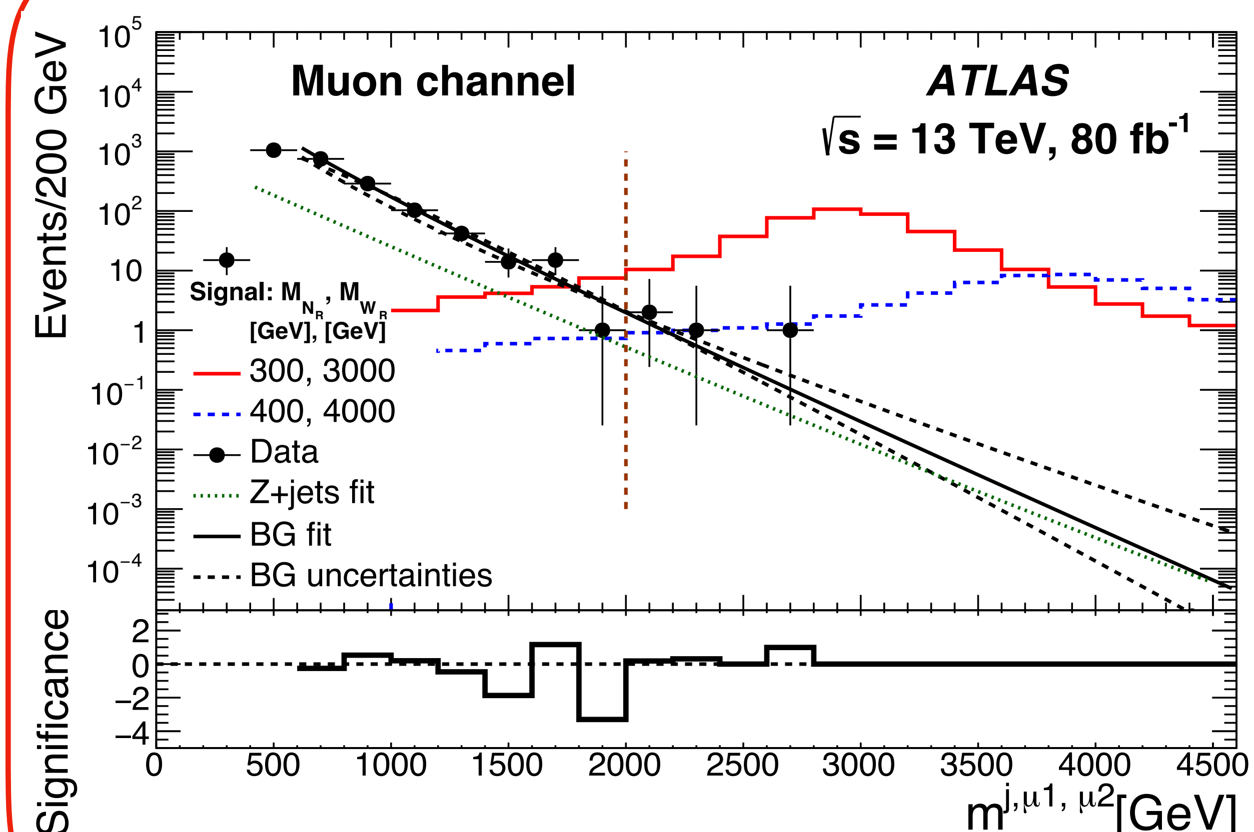
Background fit strategy

- $t\bar{t}$ background derived by a data-driven CR fit (400-1800 GeV) performed & extrapolated to SR

- **Zjets** dominates in higher mass range, Dilepton Zjets MC fit (400-4000 GeV) parameters also taken into account in resultant total fit to data



Dielectron



Dimuon

Results and limits

Expected background and observed events are reported in the table

No significance deviation is observed in the electron and muon channel

	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

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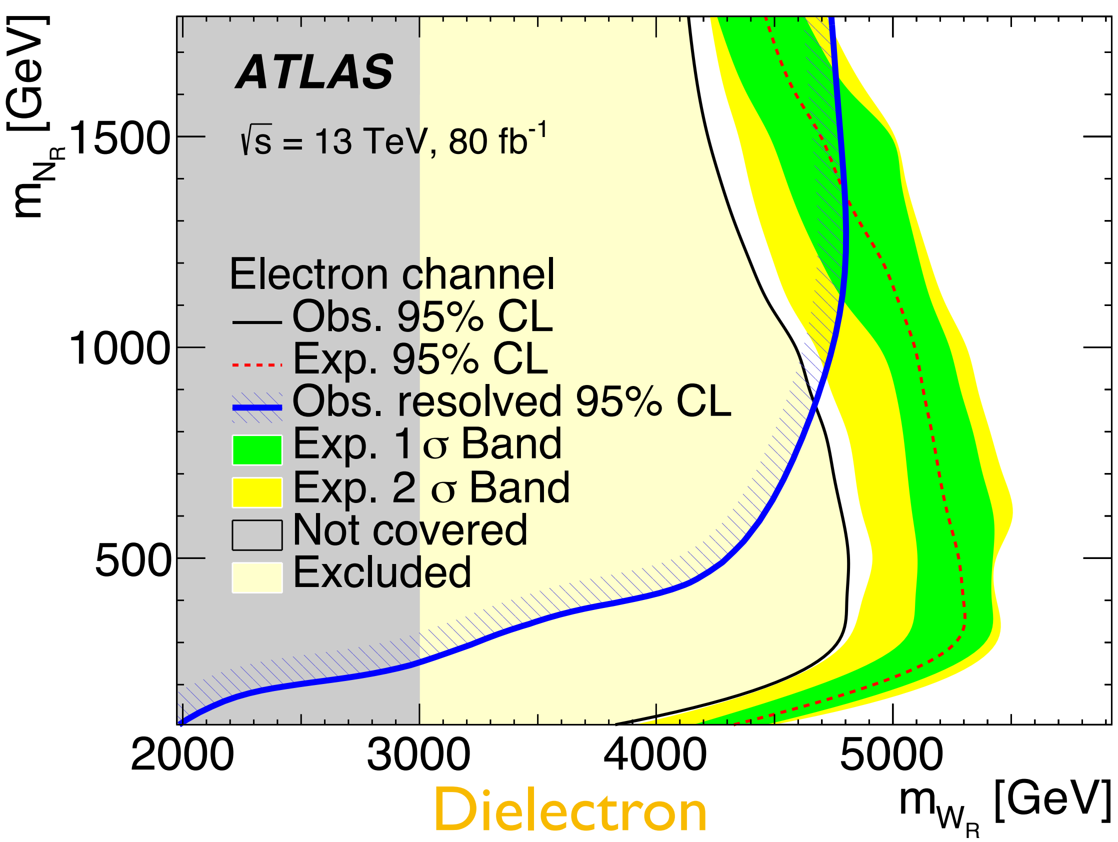

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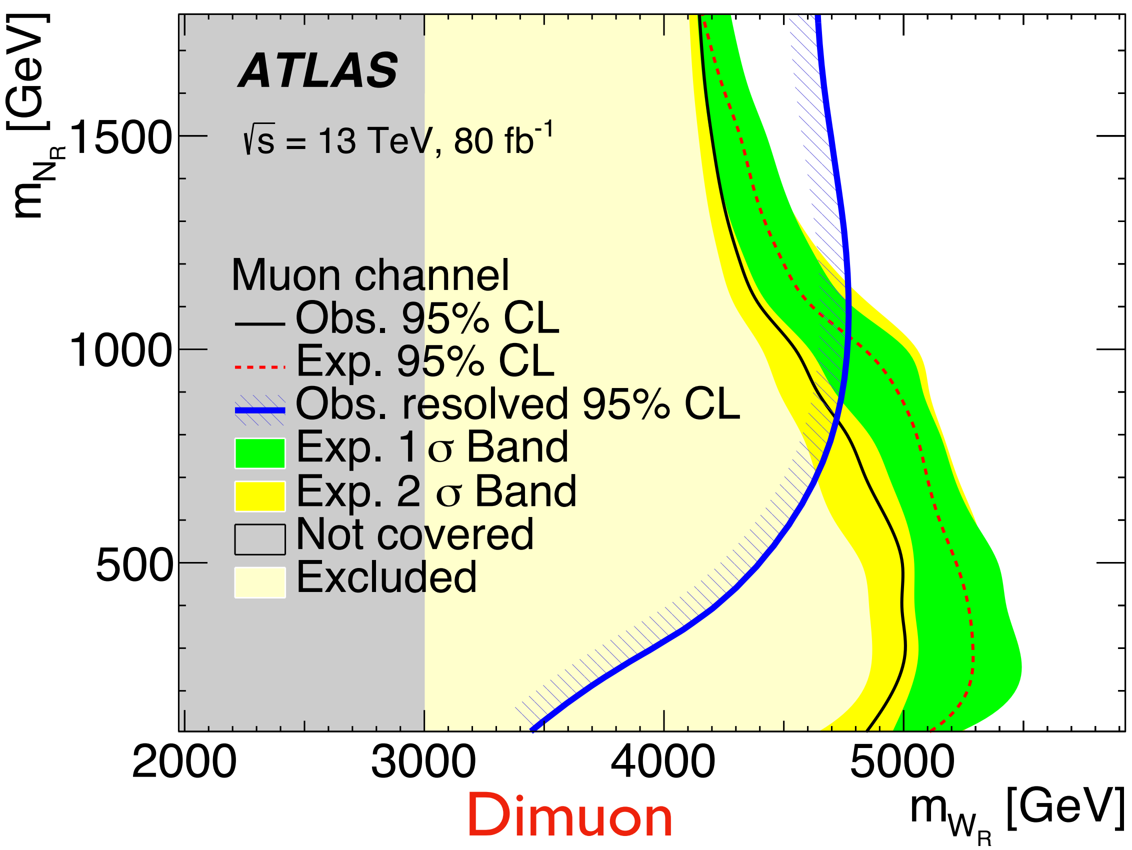


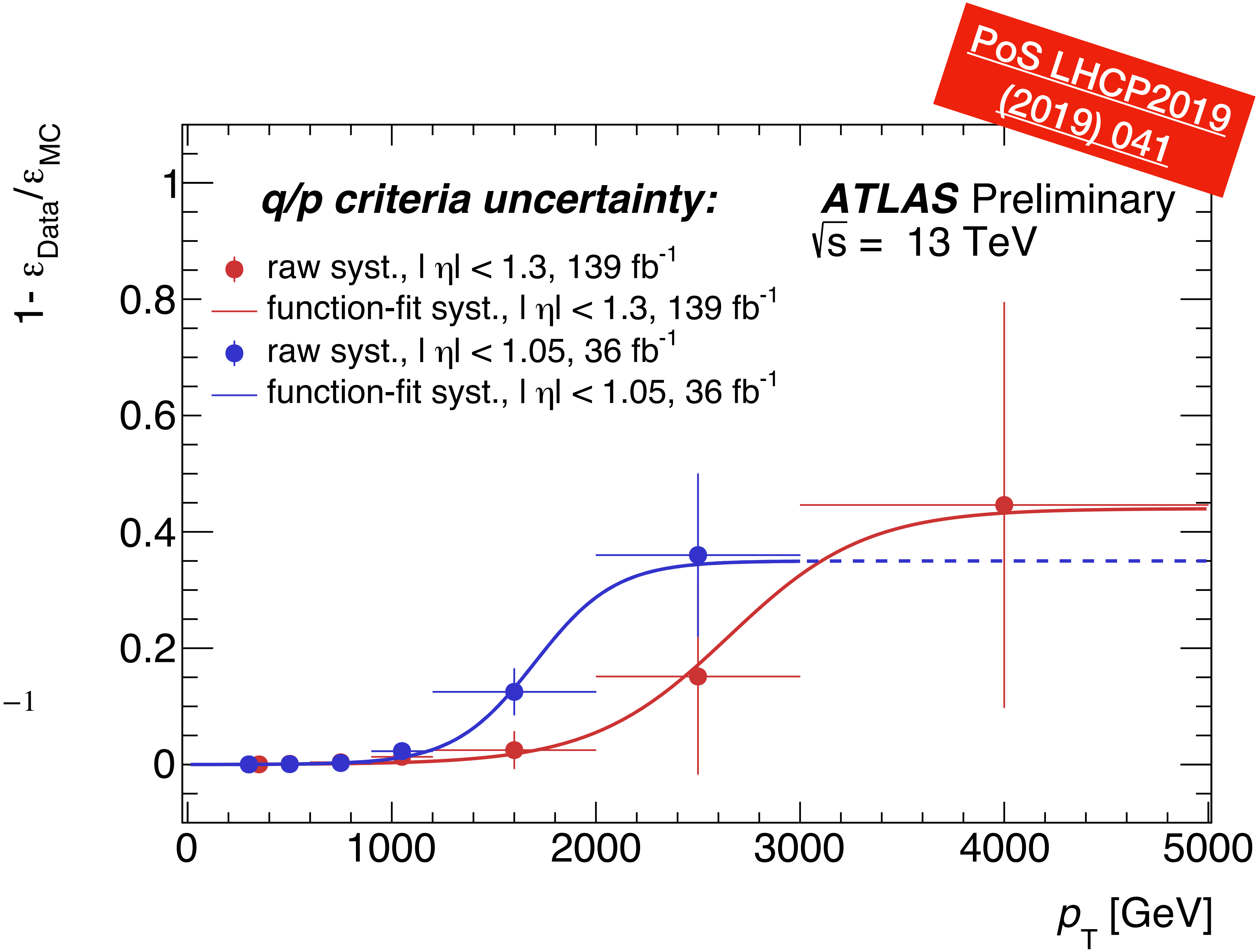
Dimuon

Performance study: new HighPt muon systematics :)

The goal of the q/p cut is to reject muons in the tails of the σ_{p_T}/p_T distributions

The selection is based on a cut on the relative uncertainty of the q/p measurement

Full ATLAS Run2 corresponding to 139 fb^{-1} data have been used for evaluating the new uncertainty



Summary

- Exclusive dilepton resonance in the mass range of 250 GeV to 6 TeV with the full run 2 data have been searched and no deviations from the SM have been observed

It is necessary to go beyond this paradigm:

- Search for new non-resonant high-mass phenomena in dielectron and dimuon final states with 36 fb^{-1} is presented
  - Lower limits on the qqll contact interaction scale are set between 2.4 TeV and 40 TeV
- Search for a right-handed gauge boson, decaying into a boosted right-handed heavy neutrino, in the framework of LRSM with 80 fb^{-1} is presented
  - Mass values of the W_R smaller than 3.8–5 TeV are excluded for N_R in the mass range 0.1–1.8 TeV

New ATLAS searches beyond exclusive leptonic resonances with the full run 2 data and several updates coming very soon :) !

Backup

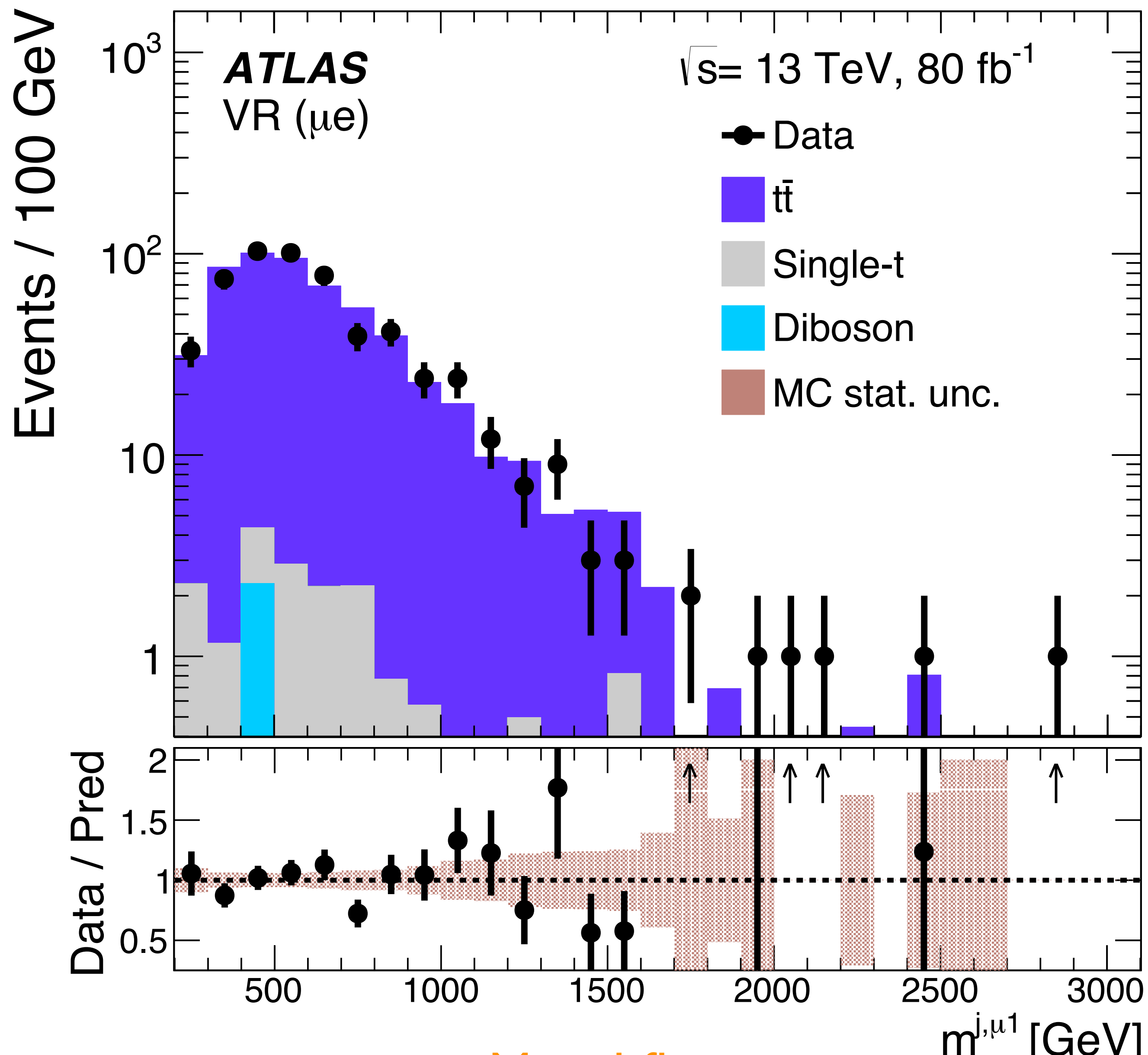
Systematic uncertainties

- Relative systematic uncertainties in the total expected number of events at a dilepton mass of 2TeV (4 TeV)
- Dielectron channel dominant uncertainty is due to isolation efficiency
- Dimuon channel dominant uncertainty is due to reconstruction efficiency

Source	Dielectron channel [%]		Dimuon channel [%]	
	Signal	Background	Signal	Background
Luminosity		3.2 (3.2)		3.2 (3.2)
MC statistical		<1.0 (<1.0)		<1.0 (<1.0)
Beam energy		2.0 (4.1)		1.9 (3.1)
Pile-up effects		<1.0 (<1.0)		<1.0 (<1.0)
DY PDF choice		<1.0 (8.4)		<1.0 (1.9)
DY PDF variation		8.7 (19)		7.7 (13)
DY PDF scales		1.0 (2.0)		<1.0 (1.5)
DY α_S		1.6 (2.7)		1.4 (2.2)
DY EW corrections		2.4 (5.5)		2.1 (3.9)
DY γ-induced corrections		3.4 (7.6)		3.0 (5.4)
Top quarks theoretical		<1.0 (<1.0)		<1.0 (<1.0)
Dibosons theoretical		<1.0 (<1.0)		<1.0 (<1.0)
Reconstruction efficiency		<1.0 (<1.0)		10 (17)
Isolation efficiency		9.1 (9.7)		1.8 (2.0)
Trigger efficiency		<1.0 (<1.0)		<1.0 (<1.0)
Identification efficiency		2.6 (2.4)		N/A
Lepton energy scale		4.1 (6.1)		<1.0 (<1.0)
Lepton energy resolution		<1.0 (<1.0)		<1.0 (6.7)
Multi-jet & W+jets		10 (129)		N/A
Total		18 (132)		14 (24)

Search for a right-handed gauge boson decaying into a high-momentum heavy neutrino and a charged lepton

Validation region



Mixed flavour

Search for a right-handed gauge boson decaying into a high-momentum heavy neutrino and a charged lepton

Systematic uncertainties

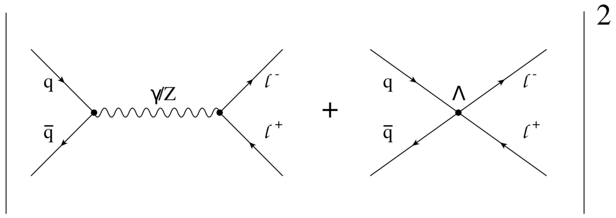
Component	Electron channel [%]	Muon channel [%]
Lepton identification	4–20	4–8
Lepton isolation	4–5	1.0–1.5
Lepton reconstruction	4–5	1–4
Lepton trigger	4–5	0.5
Pile-up	< 0.5	2–3
Luminosity	2	2
Theory	10	10

- Dominant uncertainty is related to the electron and muon identification
- The relative uncertainty of the background yield in the SR is about 25% for both channels
- Theory uncertainty of the signal yield is evaluated by varying the renormalisation and factorisation scales by factors of 2 and 0.5, and using alternative PDF sets

Beyond exclusive leptonic resonances

Search for non-resonant features in dilepton mass spectra:

Resonance above the scale of direct detection at the LHC →

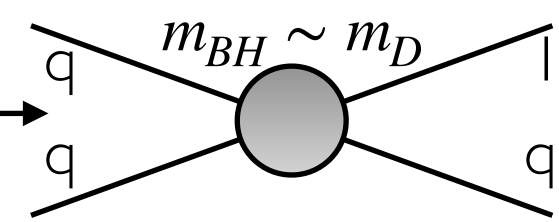


High energy Λ → Interference at lower mass

Indication of:
- massive mediator boson
- quark/leptons compositeness

Search for Quantum Black Holes in 1 lepton and 1 jet channel:

Quantum Black Holes (QBHs) detectable at LHC →



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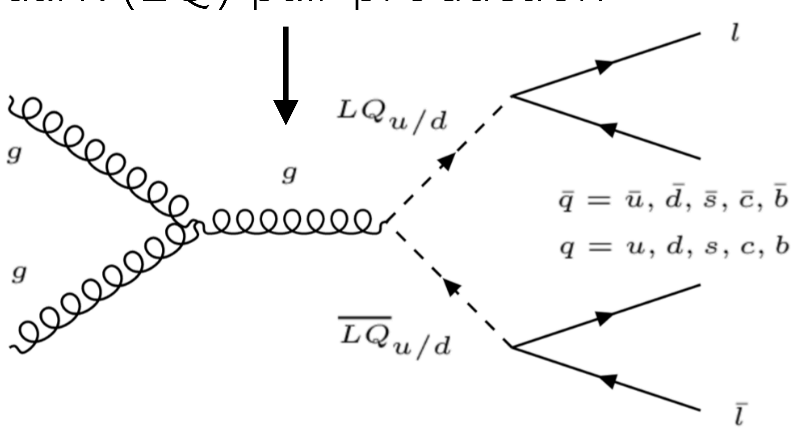
by lowering the scale of quantum gravity (M_D) to the TeV region

Solutions to:

the mass hierarchy problem

Search for leptoquark pair production:

Scalar leptoquark (LQ) pair production

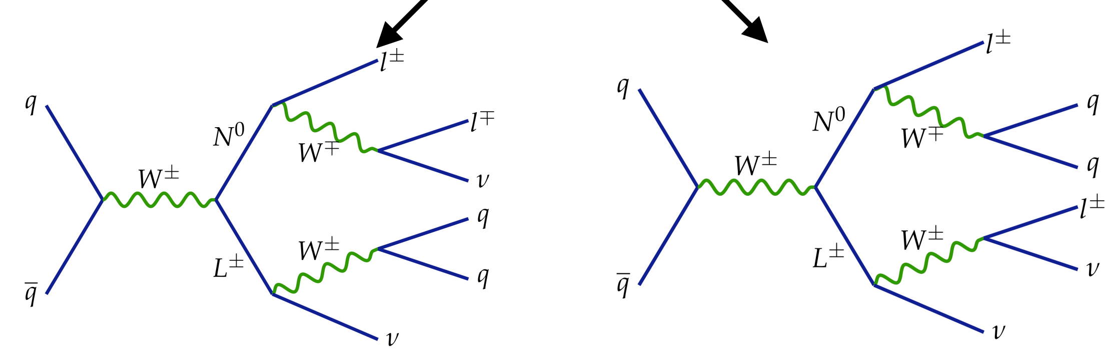


Can enable:

- violation of lepton flavour universality
- mediation of flavour changing neutral currents

Search for type-III seesaw heavy leptons:

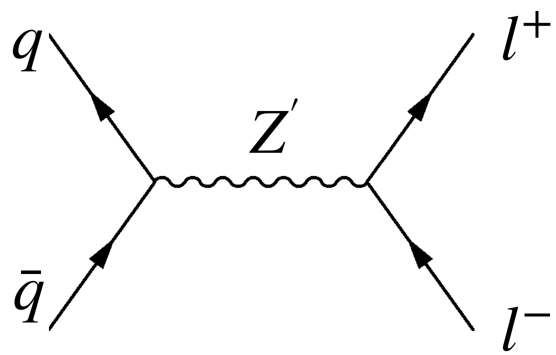
One neutral (N^0) and two oppositely charge leptons ($L^+ L^-$)



Explaining the relative smallness of the neutrino masses

Why beyond exclusive leptonic resonances

High-mass dilepton resonances have been already searched using the full data recorded by the ATLAS experiment (139 fb^{-1})



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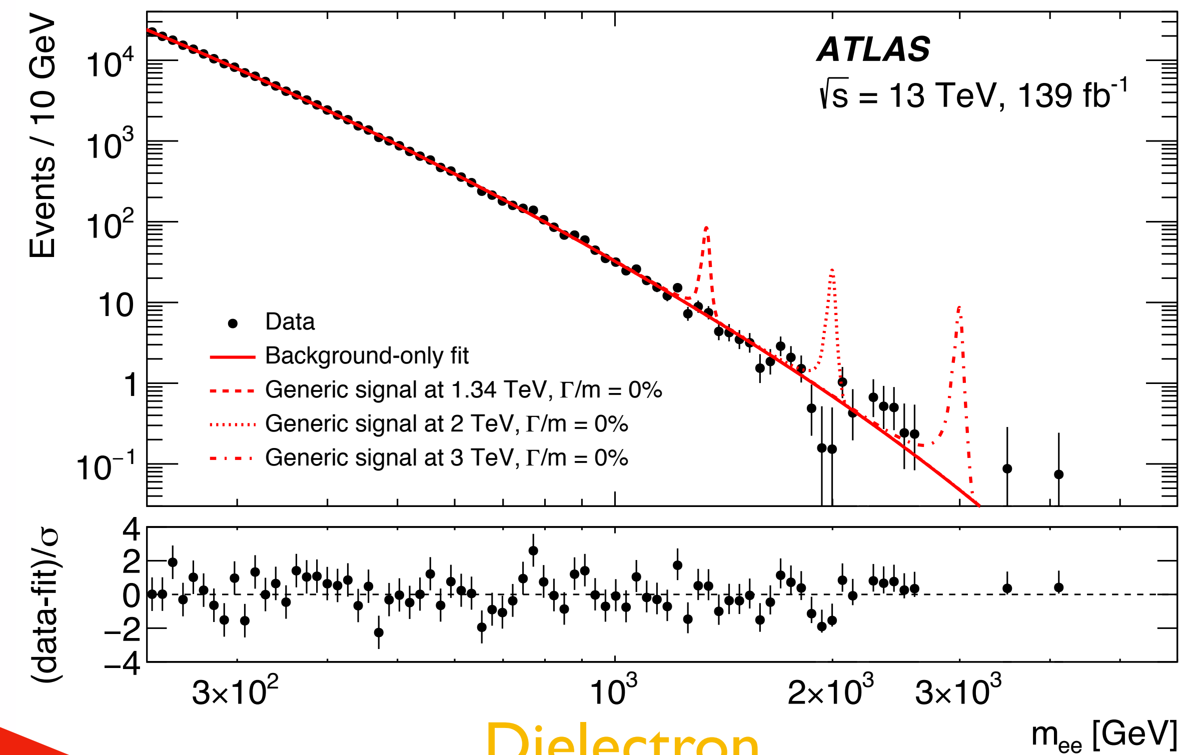
- **signature:**
  bump on smoothly-falling background

<ins>No significant deviation from the standard model is observed</ins>



Dielectron

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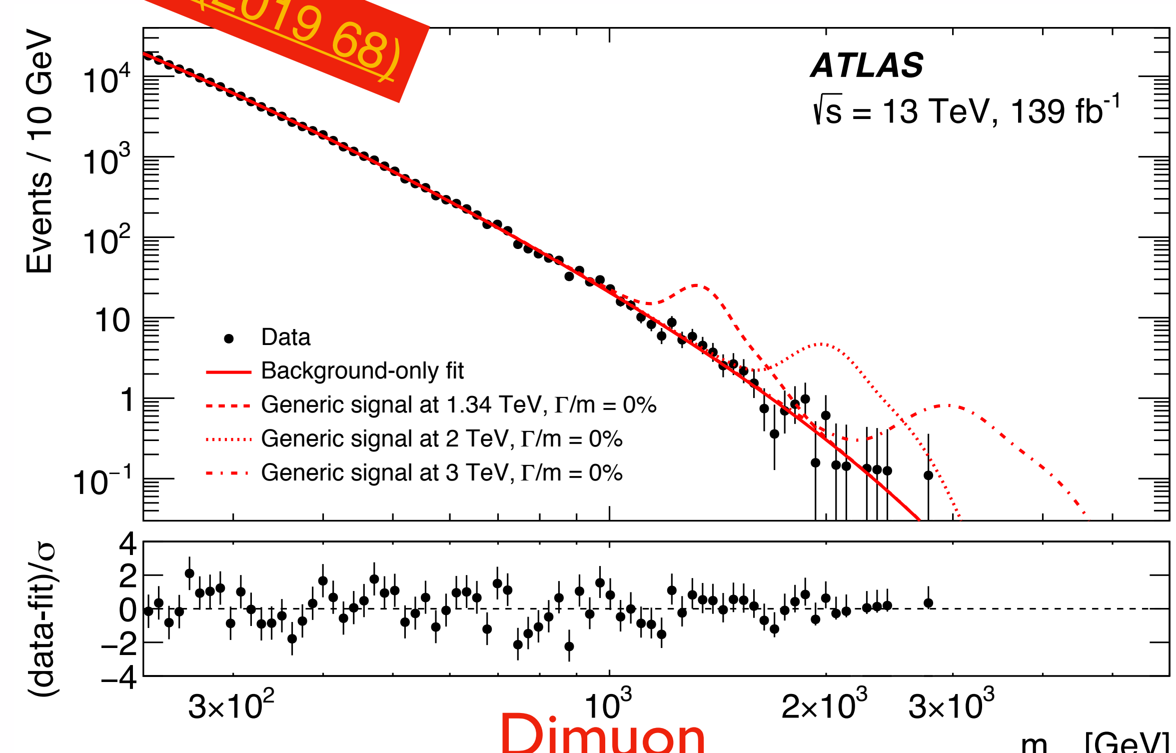
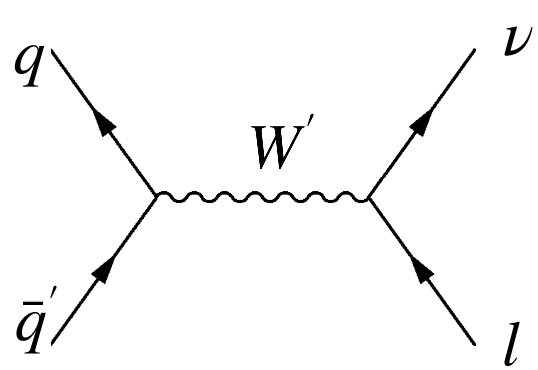


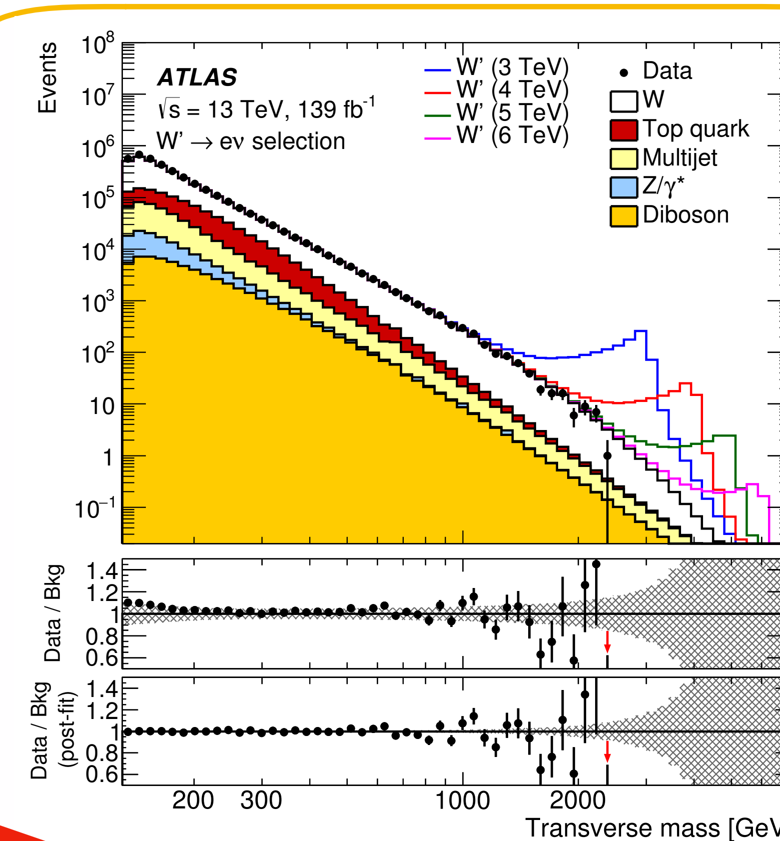
Dimuon

Why beyond exclusive leptonic resonances II

heavy charged boson in events with a charged lepton and missing transverse momentum have been already searched using the full data recorded by the ATLAS experiment (139 fb^{-1})



- **observable:**
  Transverse mass
- **signature:**
  bump on smoothly-falling background



electron channel

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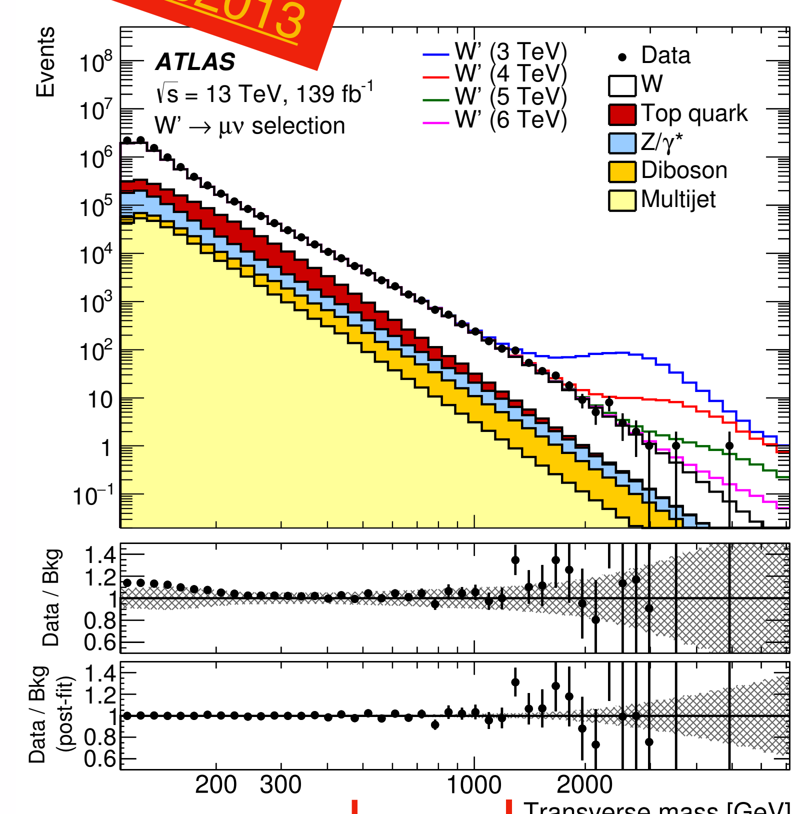

muon channel

<u>No significant deviation from the standard model is observed</u>