



Searches for new physics with leptons using the ATLAS detector

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on behalf of the ATLAS Collaboration

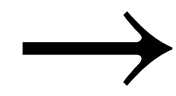


BoostDiscovery

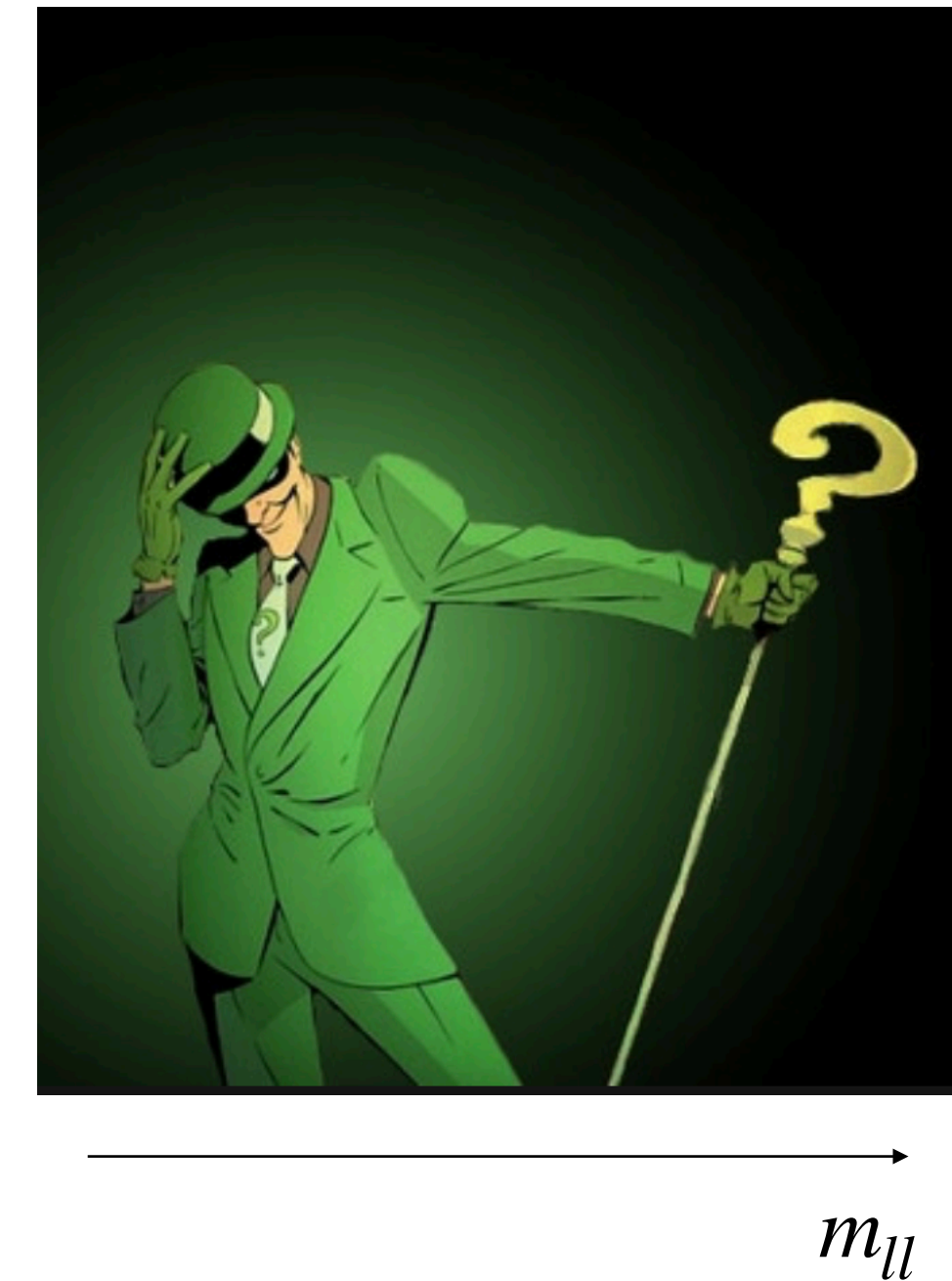
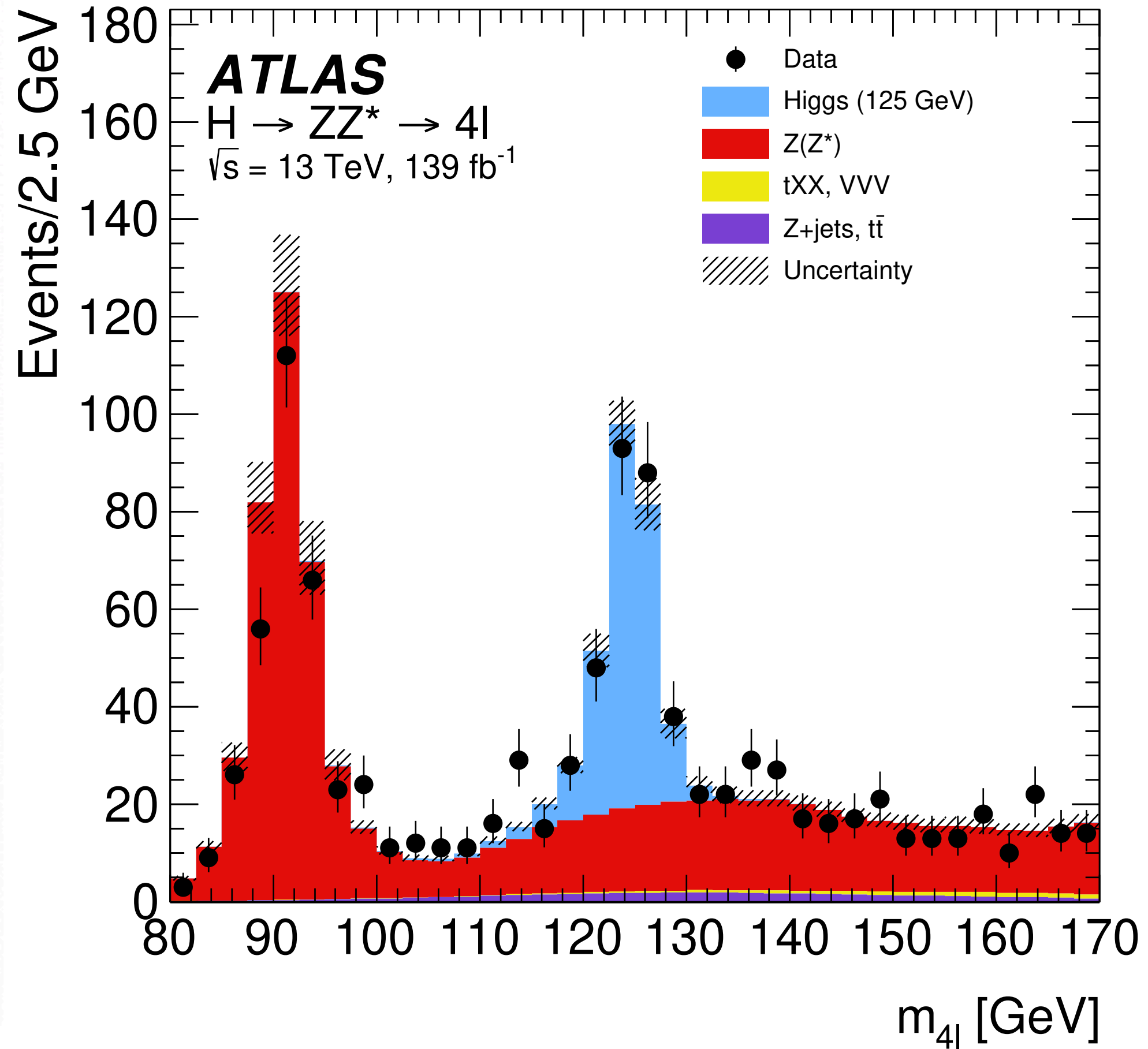
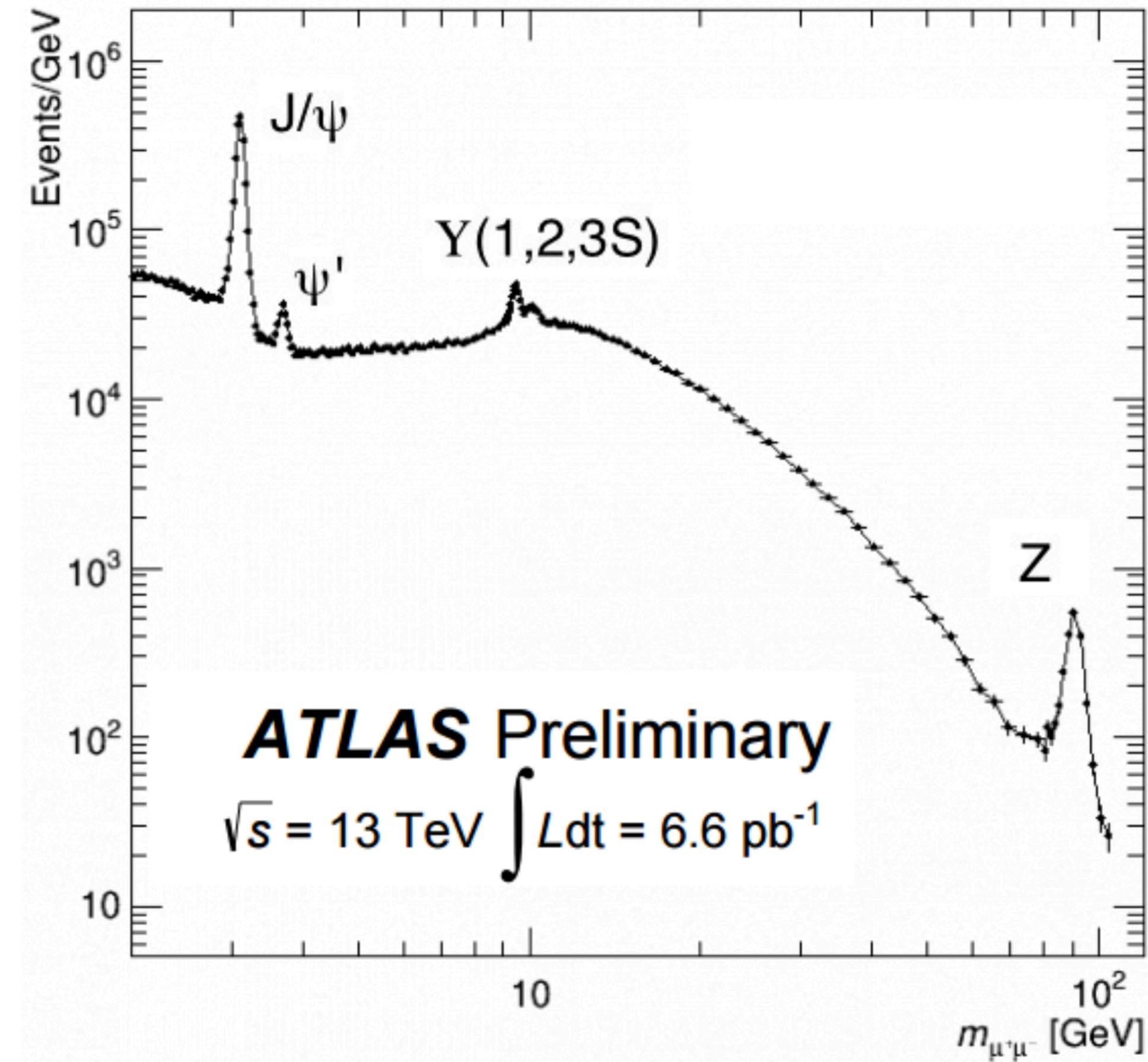


Why leptons?

very clean signature



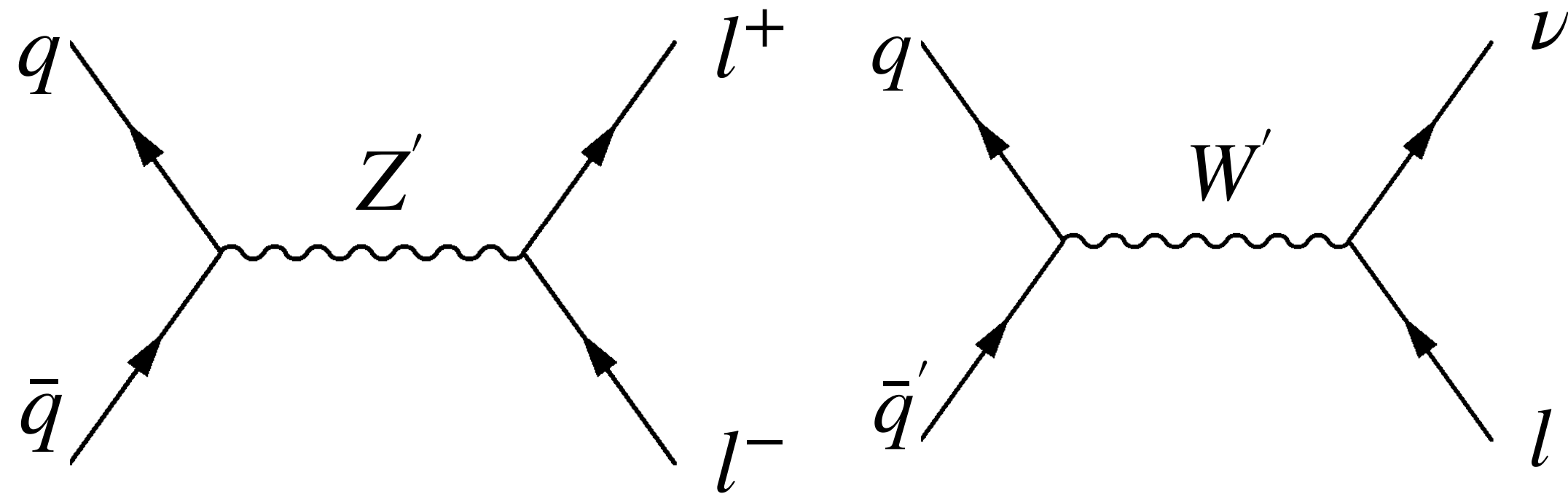
precision measurements
new physics searches



Searches for New High-mass phenomena

Search for resonant features :

Resonance in the dilepton mass range of TeV

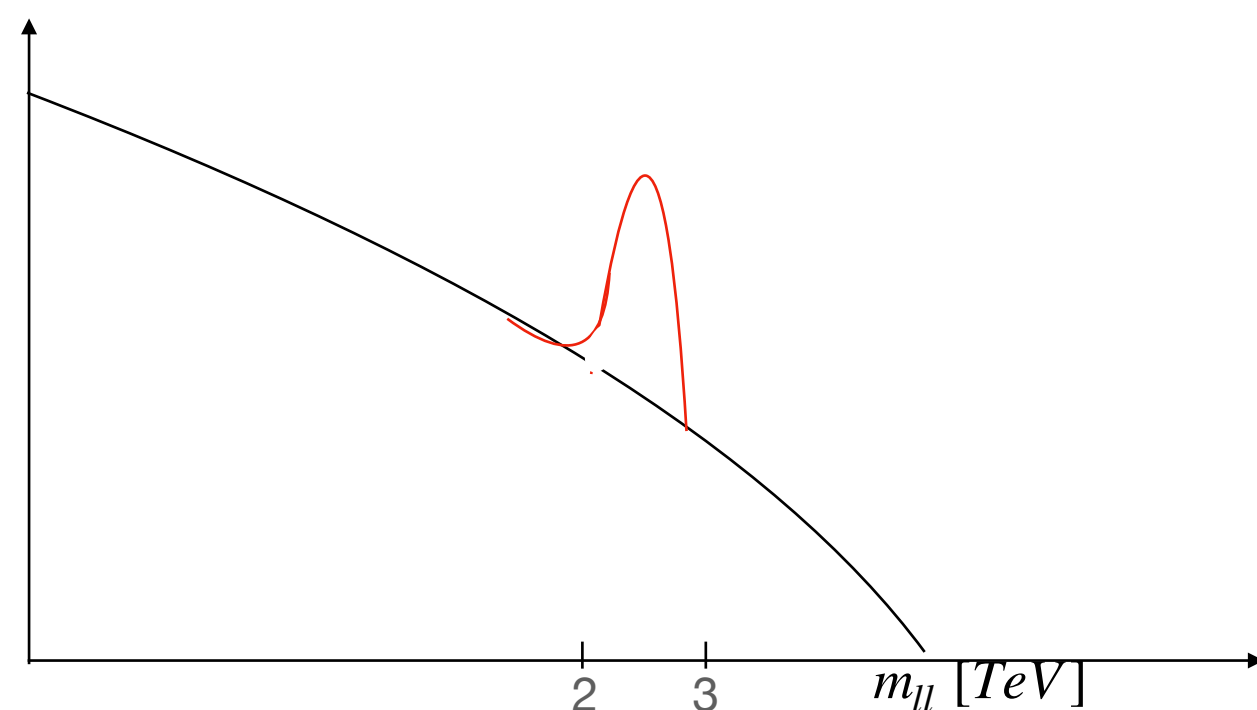


Signature: **bump** over a smoothly-falling background

Observable: invariant mass m_{ll} and transverse mass m_T

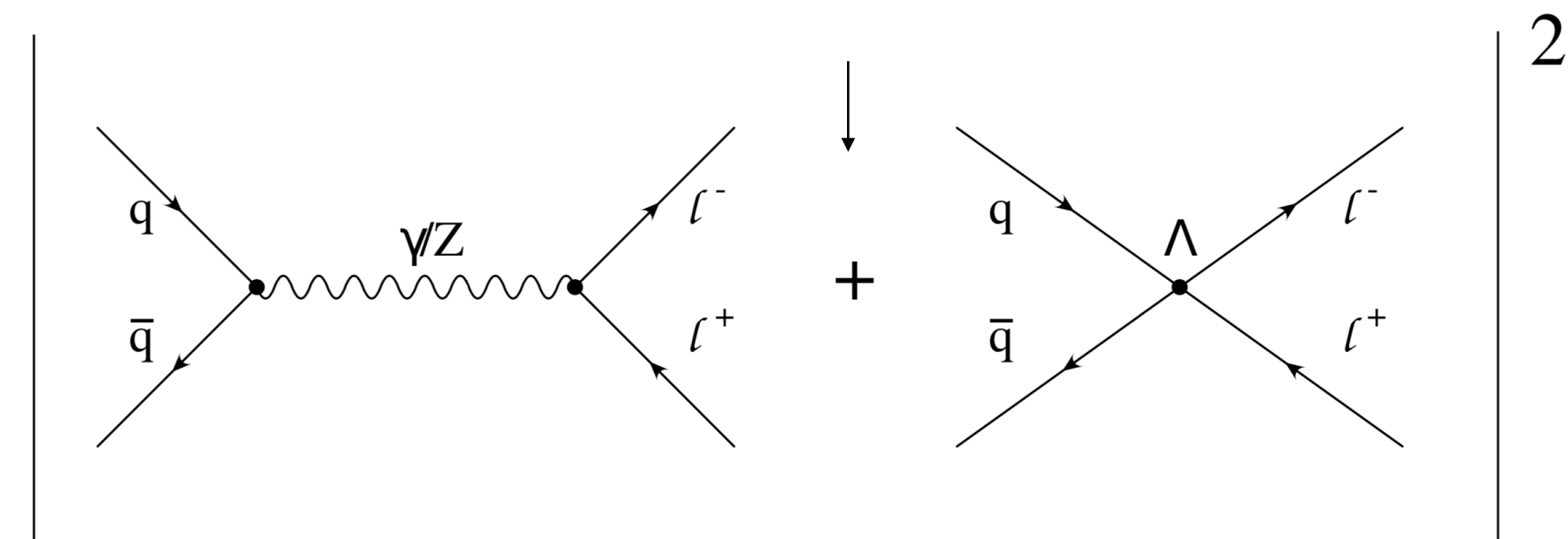
DrellYan

Generic signal



Search for non-resonant features:

Resonance above the scale of direct detection at the LHC



High energy \longrightarrow Interference at lower mass

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

Signature: **excess** over a smoothly-falling background

DrellYan

Contact interaction

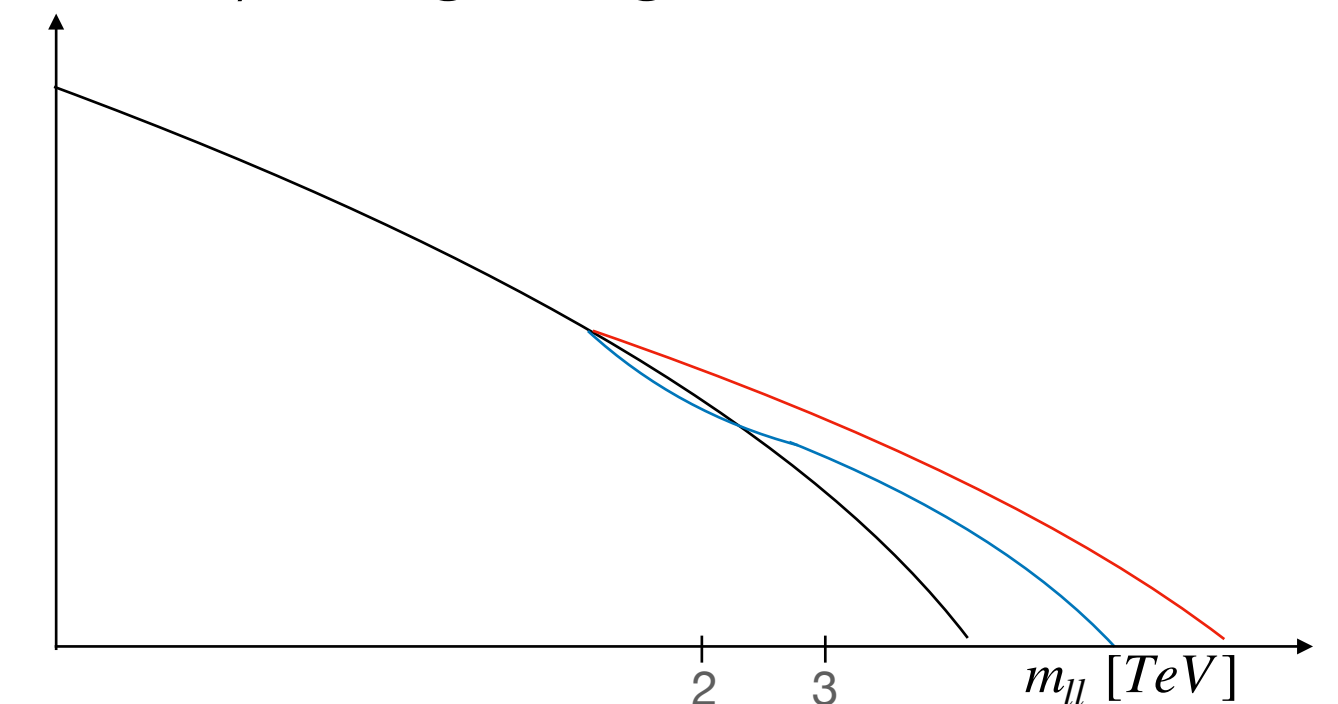
constructive

interference

Contact interaction

destructive

interference



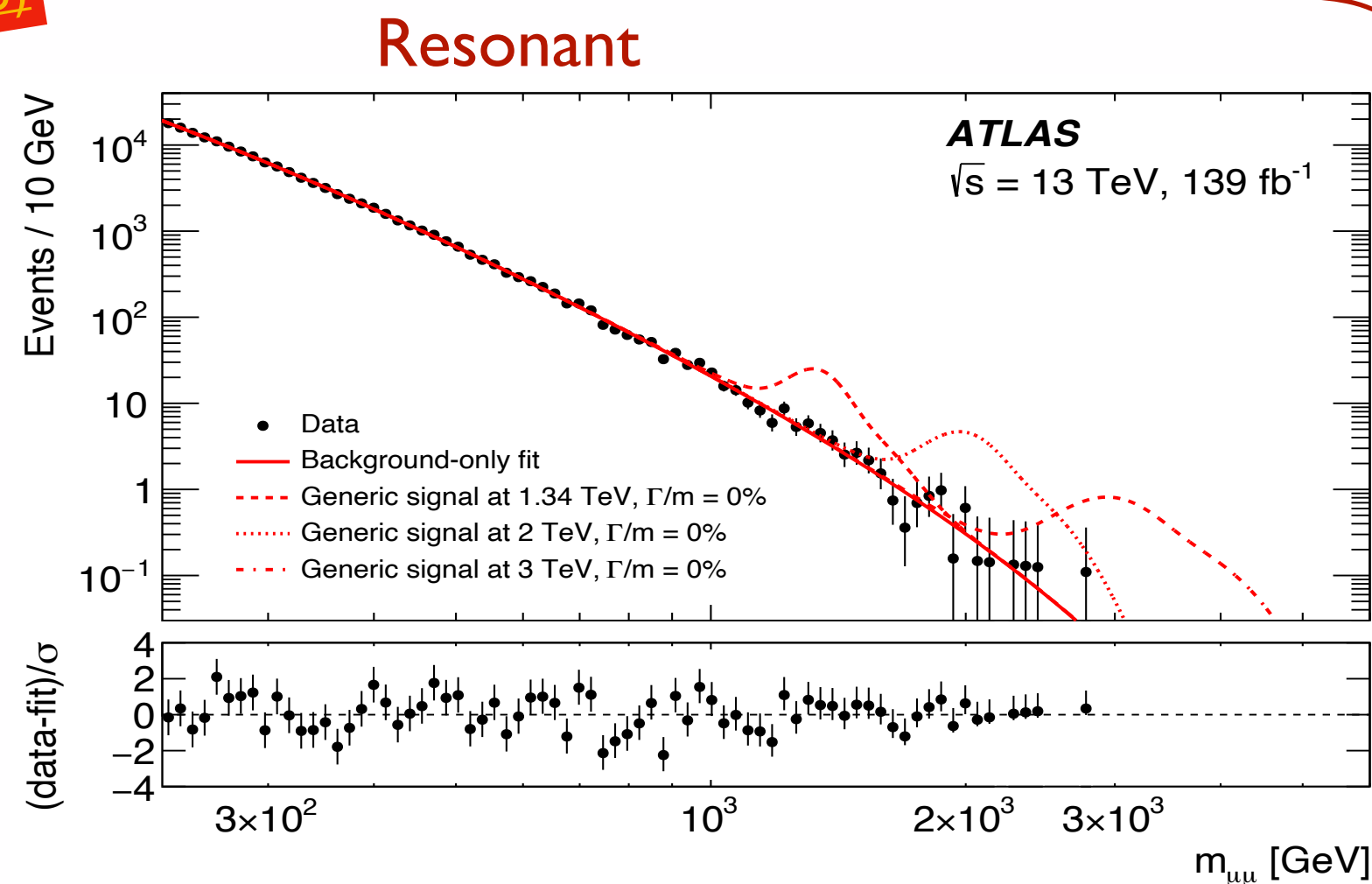
Search for resonant and non resonant features in dilepton mass spectra

- The search in these analyses is carried out entirely in a data-driven way
- Fit function choice based on smaller spurious signal result : SS/σ_{SS}

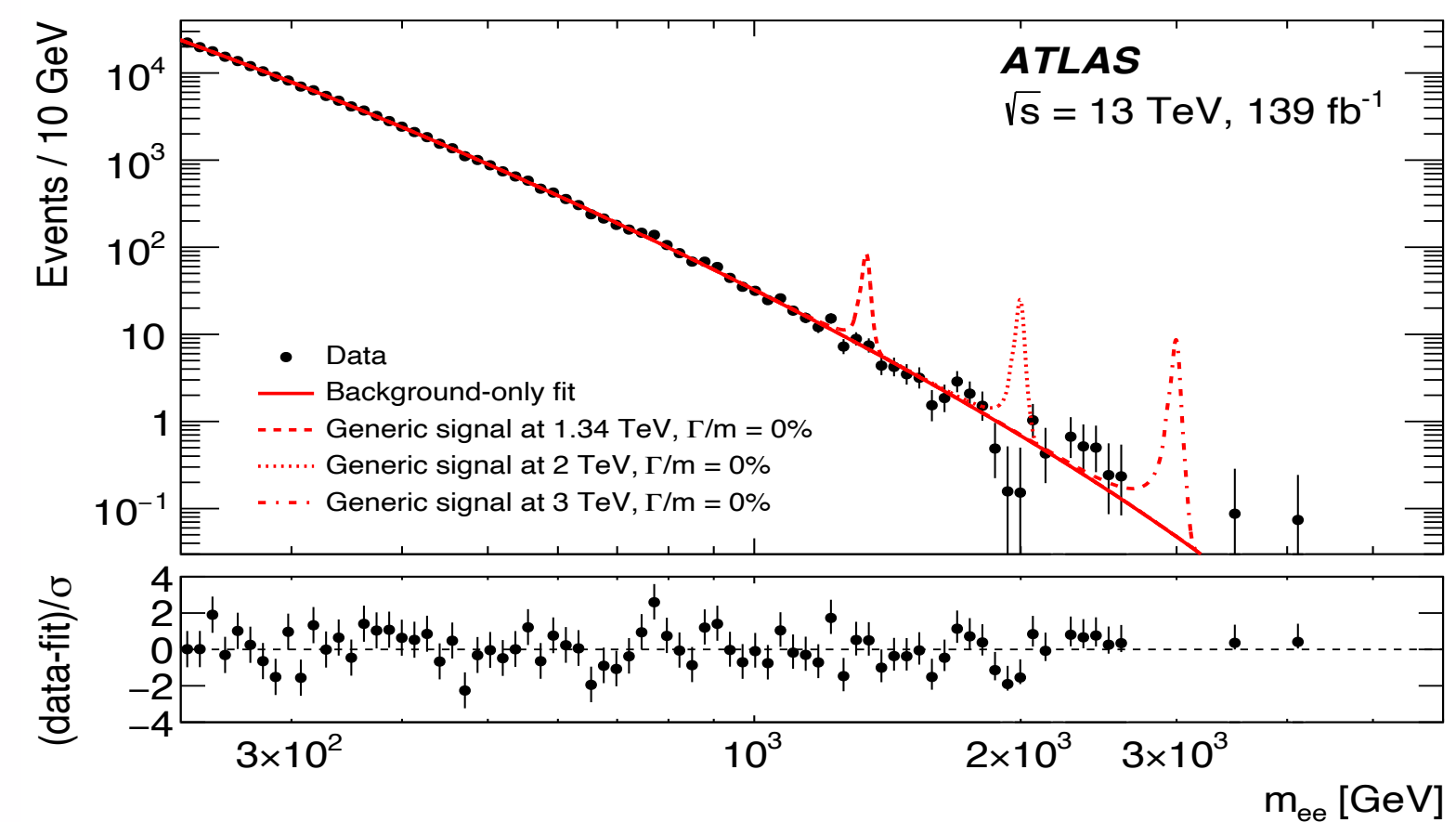
No significant deviation from the standard model is observed

Phys. Lett. B 796 (2019 68)

$$Z' \rightarrow \mu^+ \mu^-$$



$$Z' \rightarrow e^+ e^-$$

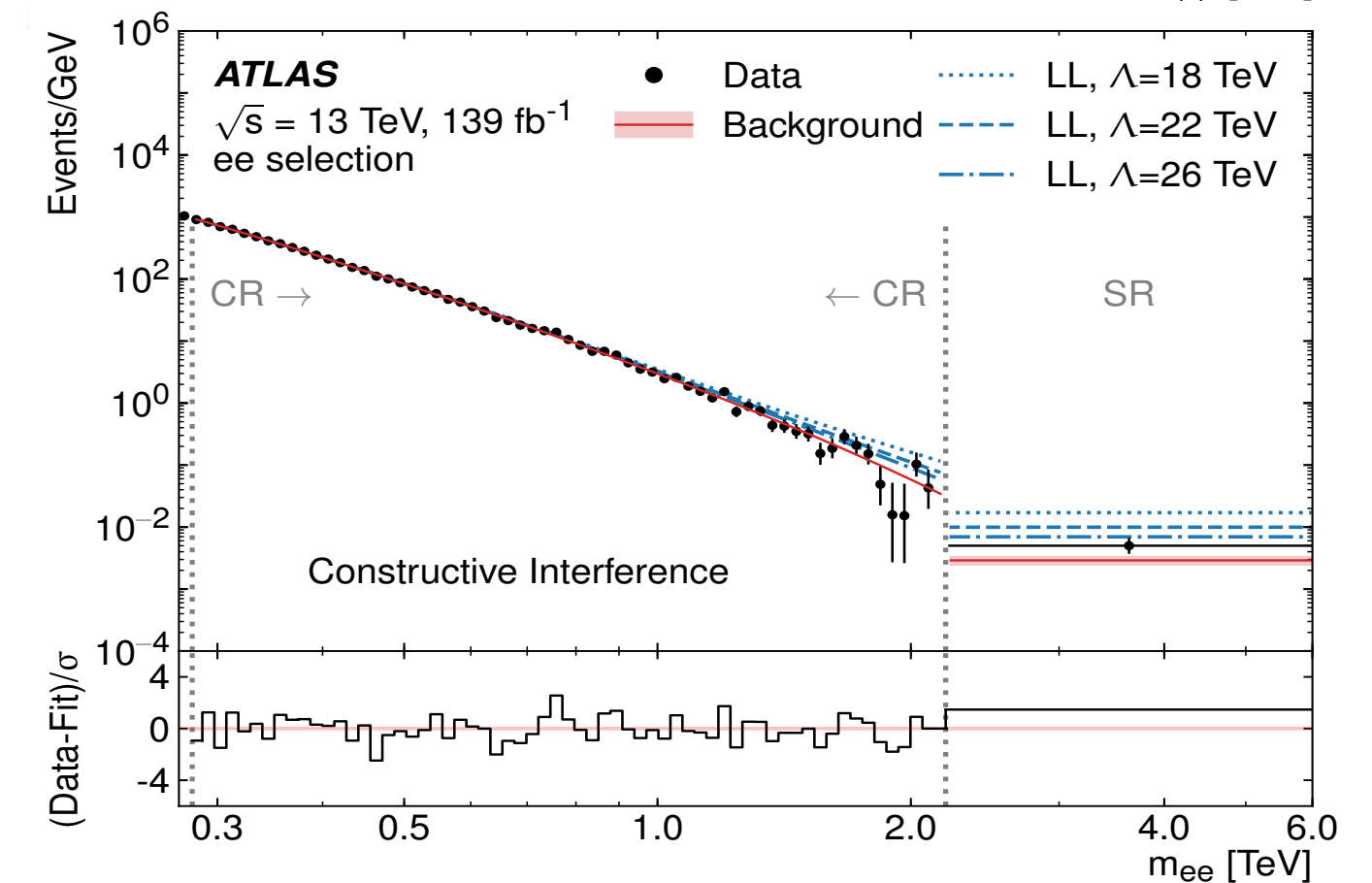
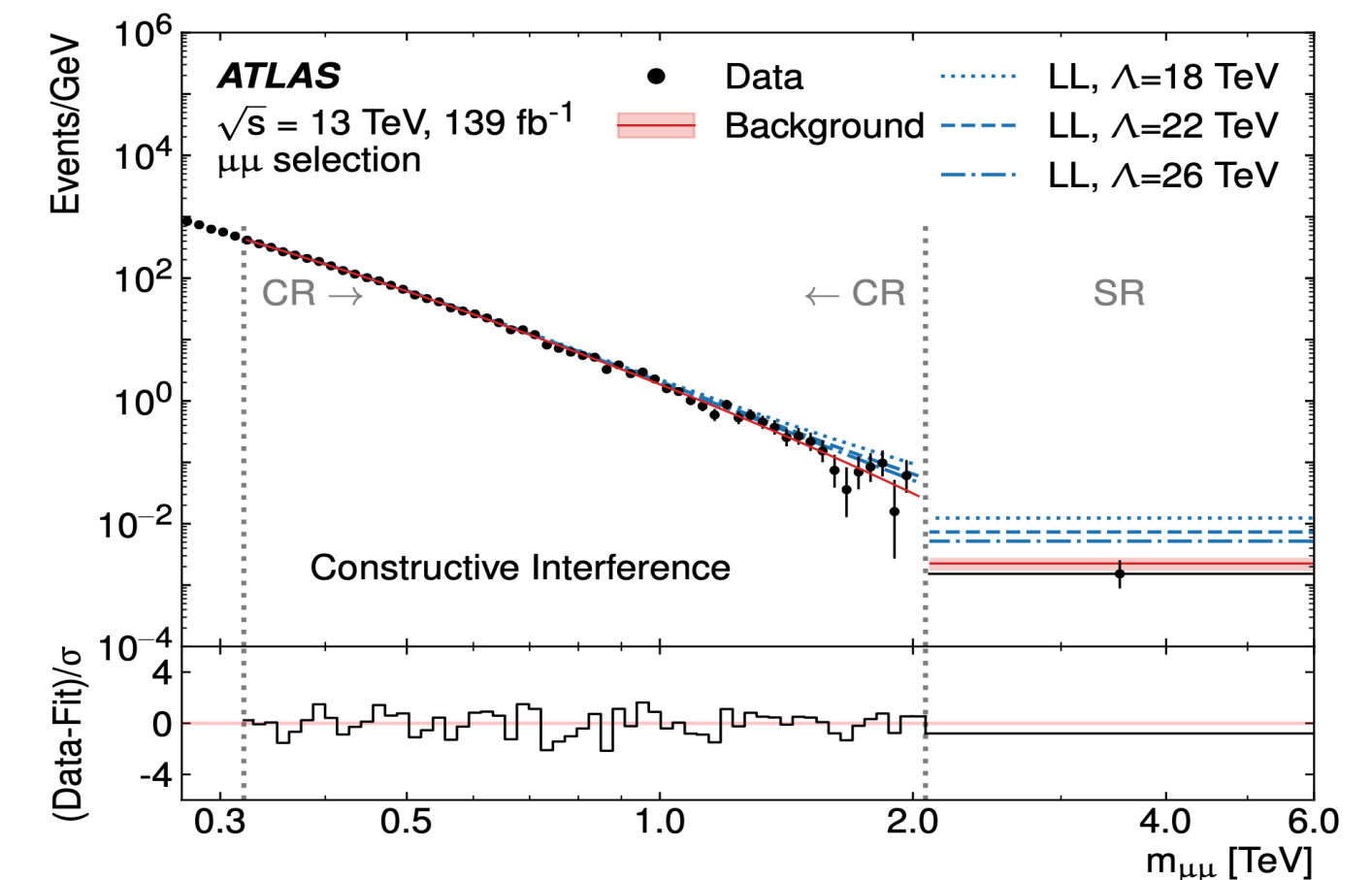


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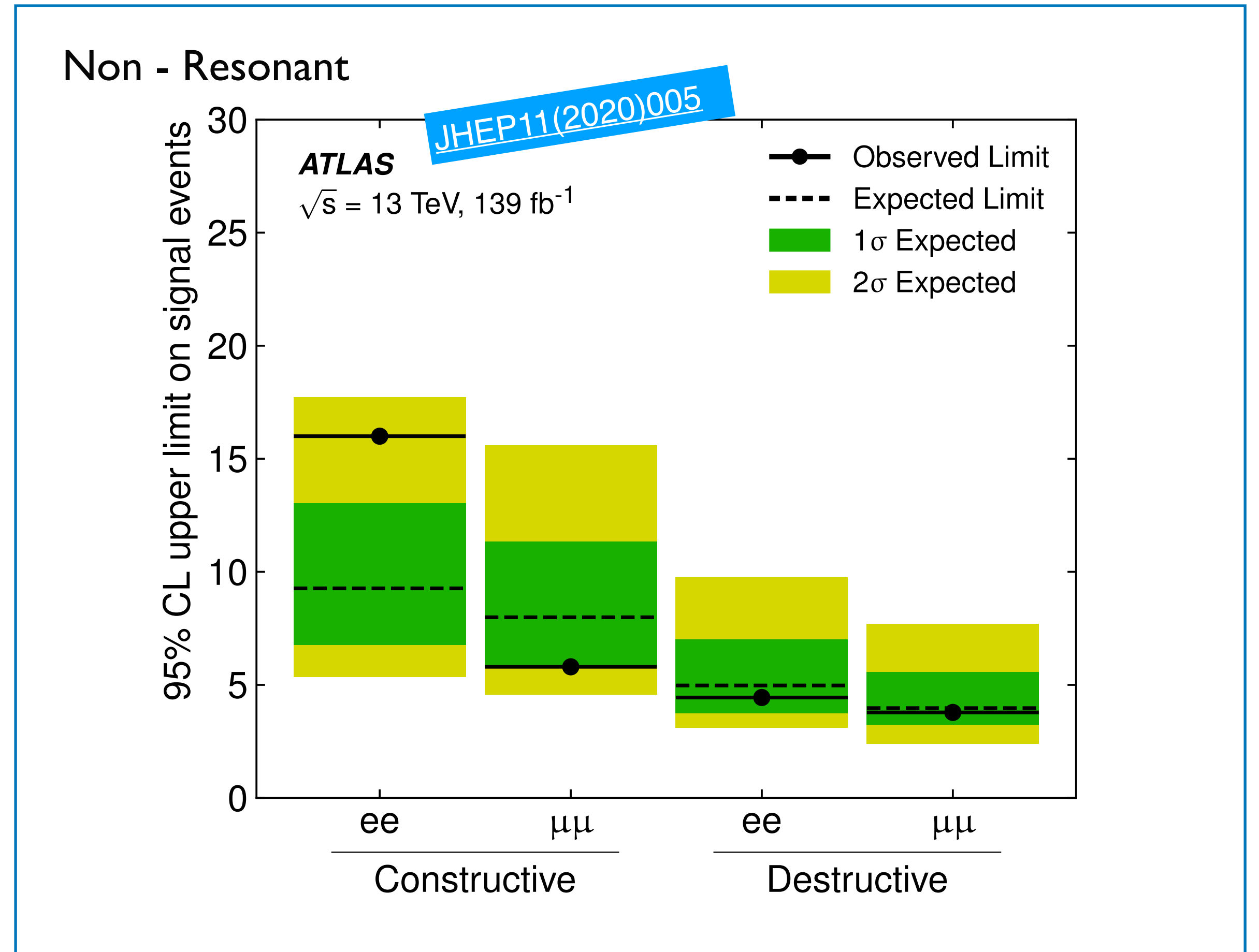
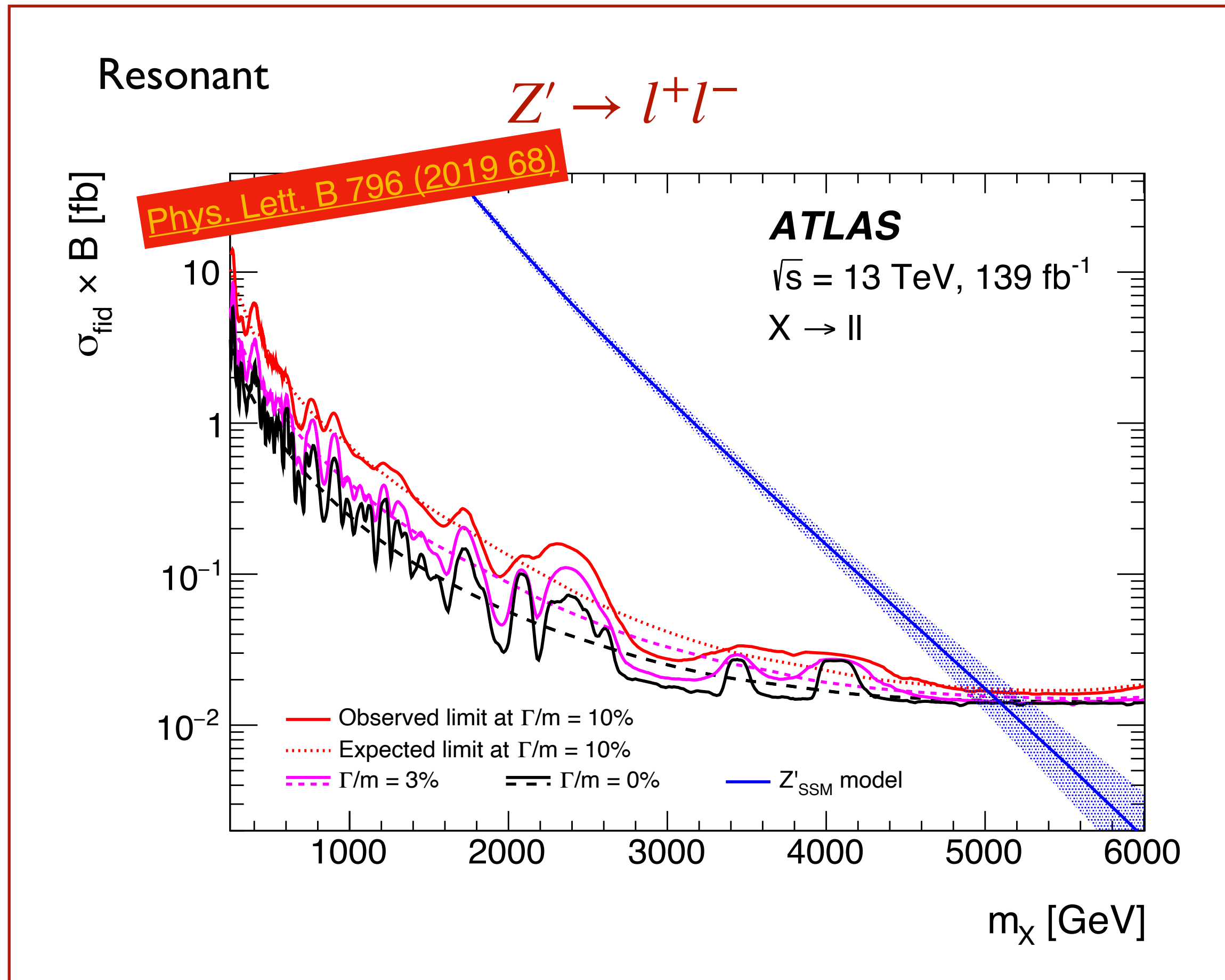
$$Z' \rightarrow \mu^+ \mu^-$$

$$Z' \rightarrow e^+ e^-$$

Non Resonant



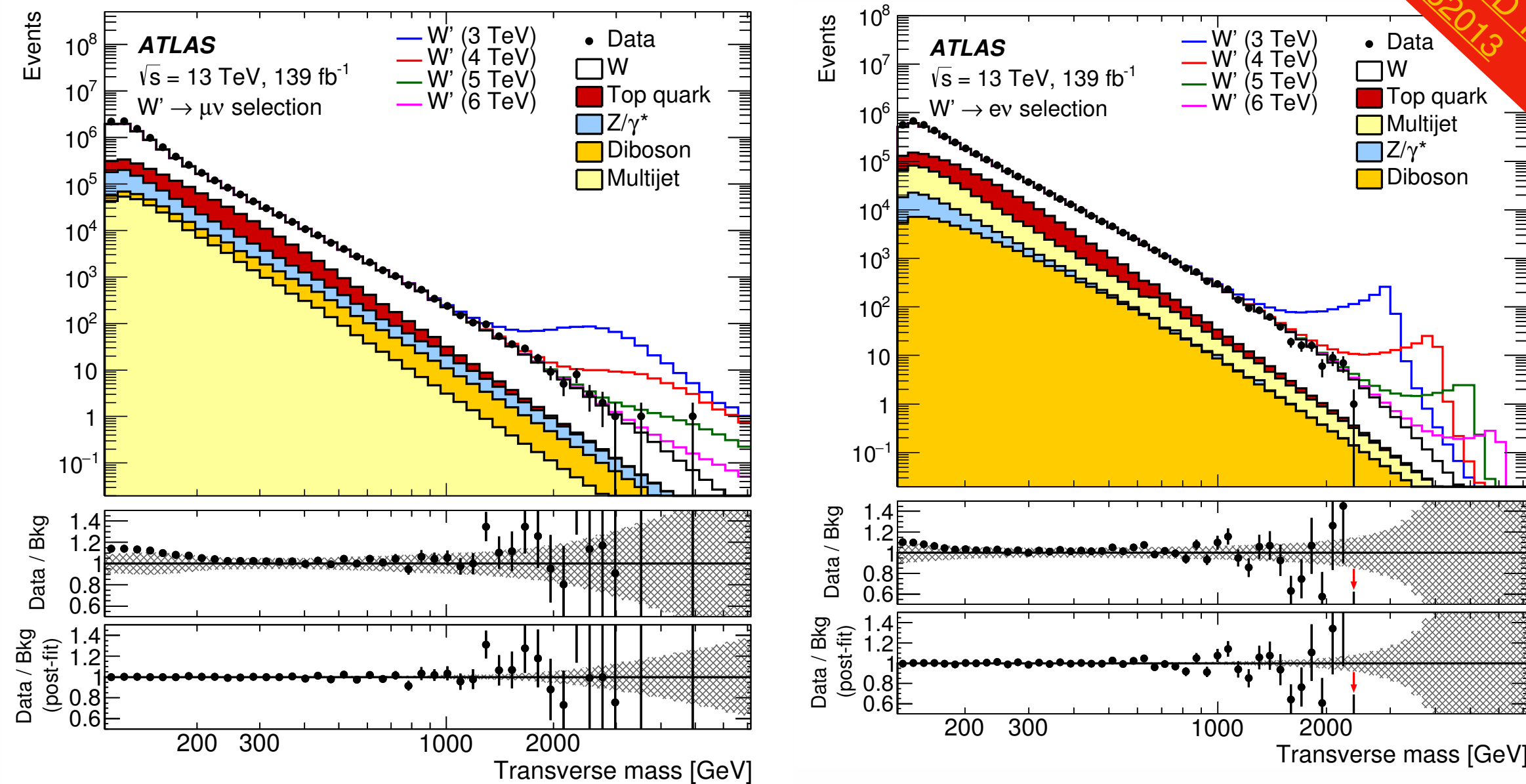
Upper Limits @ 95% CL



Search for a heavy charged boson

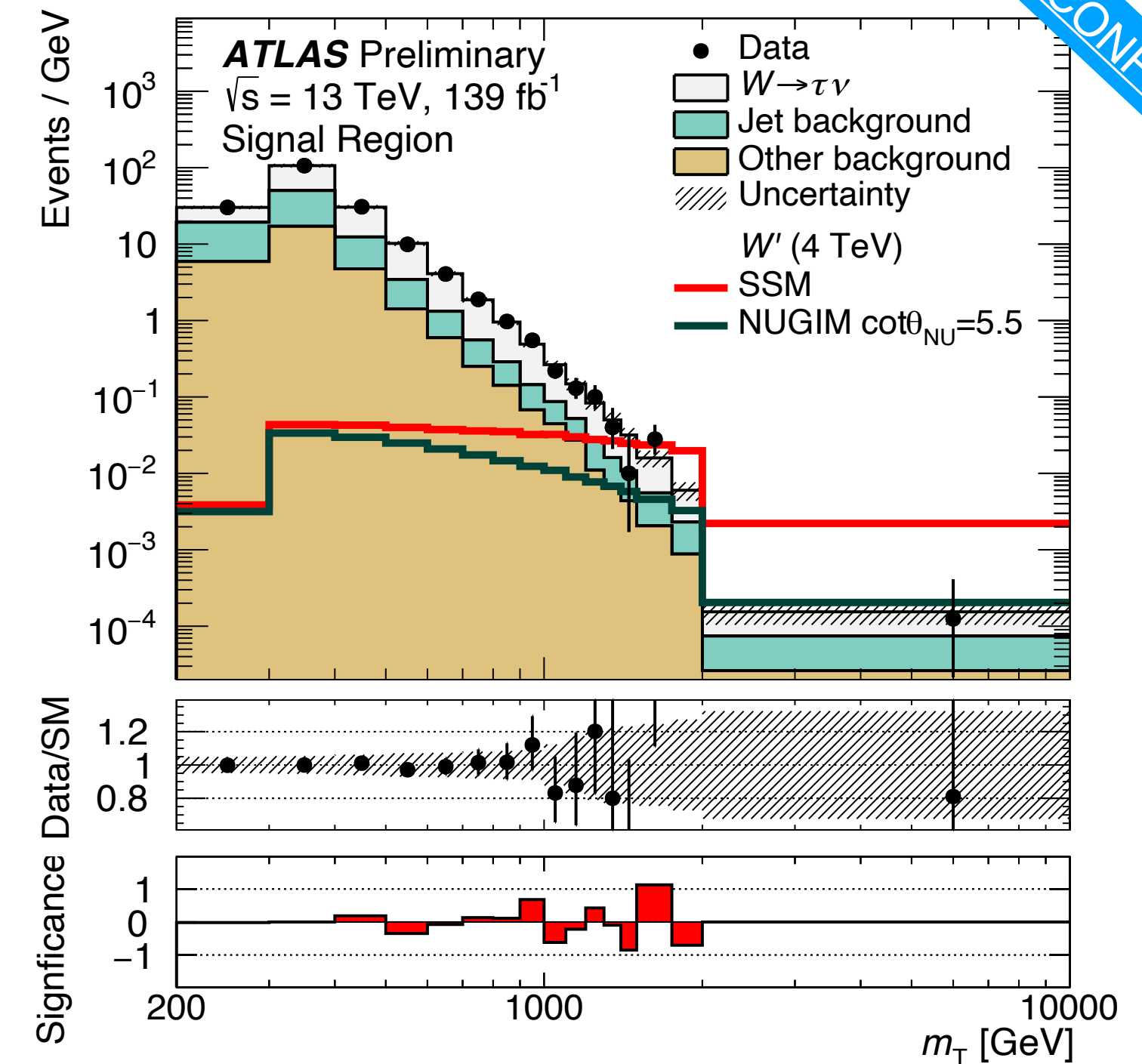
$$W' \rightarrow l\nu, l = e, \mu$$

- Background estimation from MC
- $t\bar{t}$, WW MC distribution fitted at low m_T value and extrapolated at higher m_T
- Fakes electrons and muons evaluated from data



$$W' \rightarrow \tau_{had}\nu$$

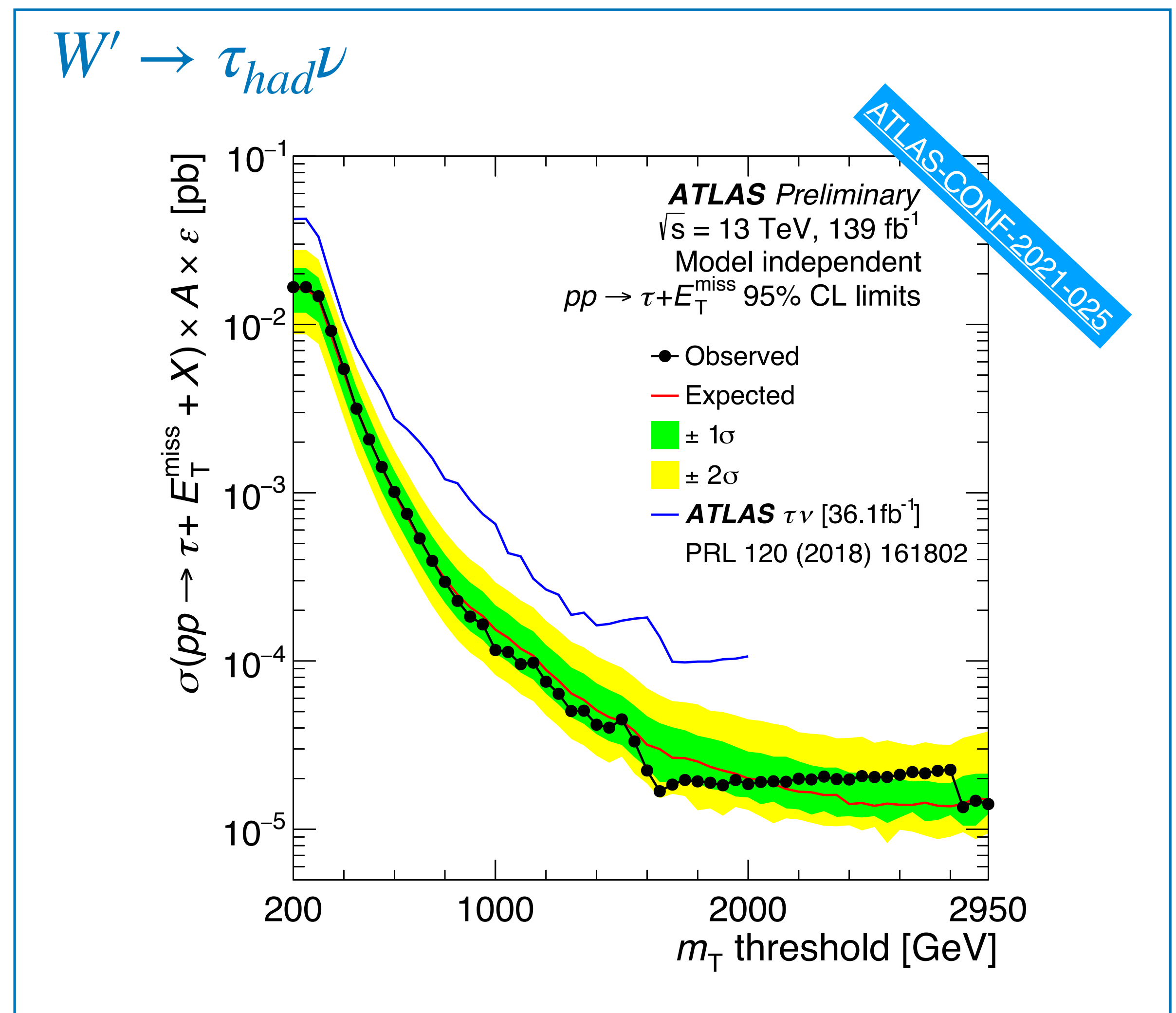
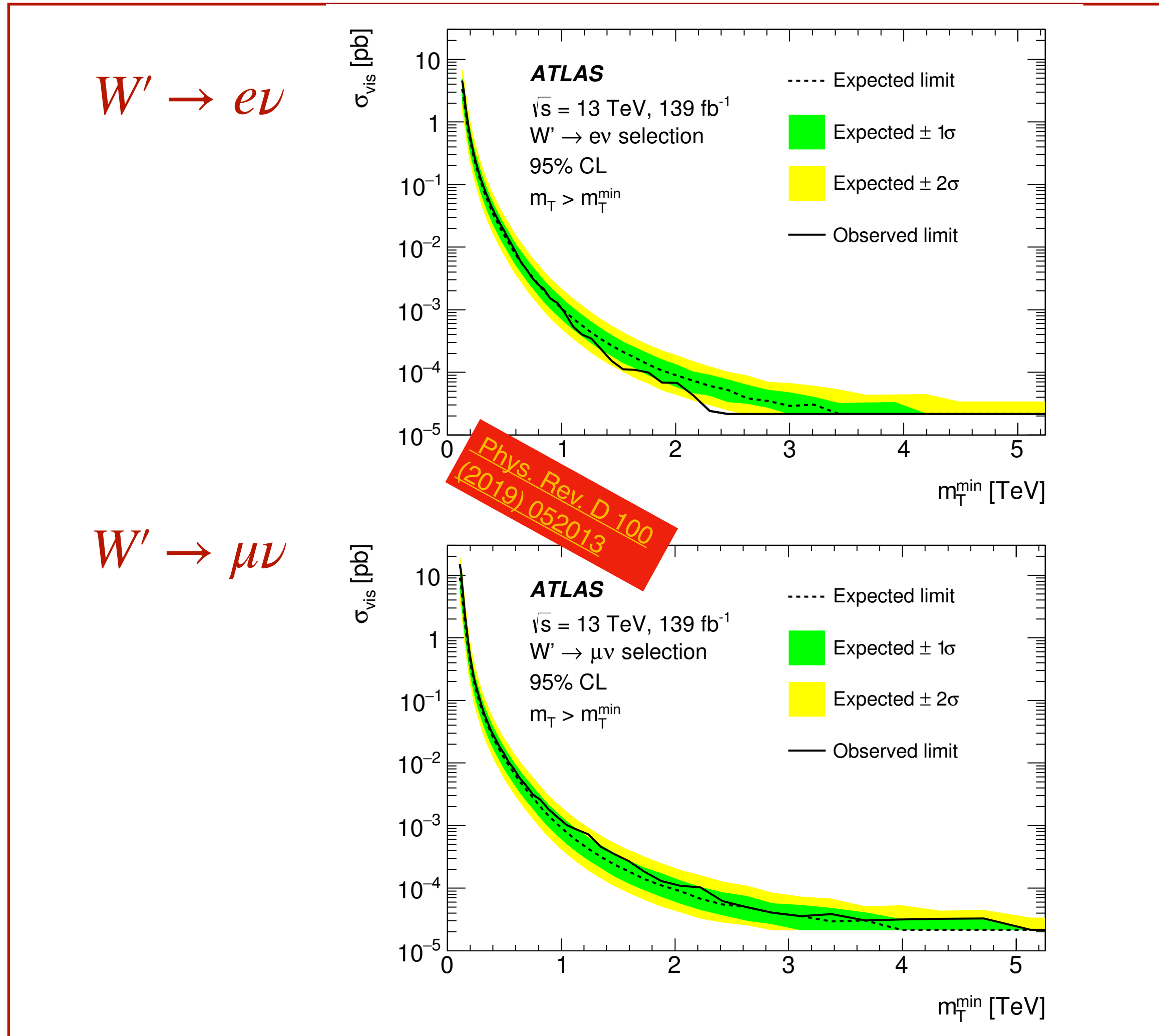
- Jet background estimated from data
- CRs defined by τ identification criteria
- Other background estimate from simulation



ATLAS-CONF-2021-025

No significant deviation from the standard model is observed

Upper Limits @ 95% CL



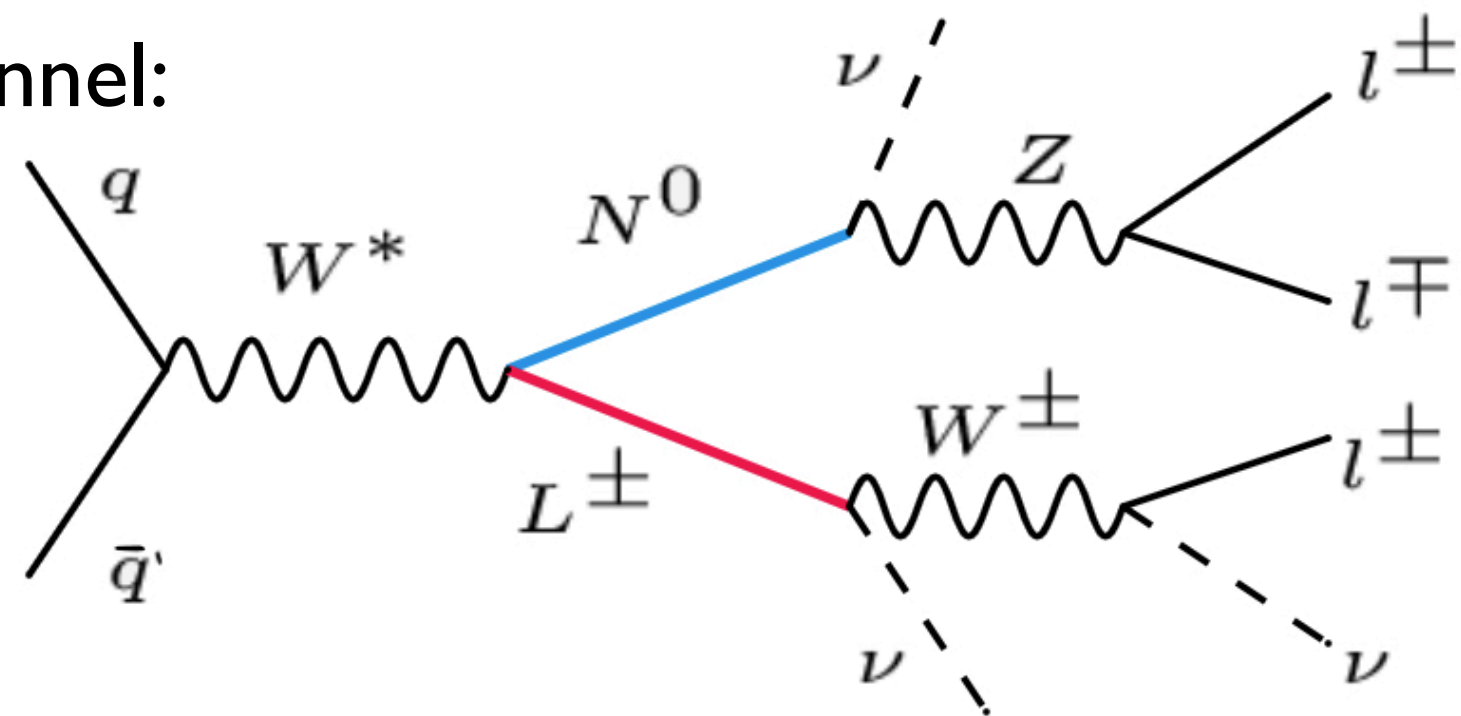
Search for type-III seesaw heavy leptons in leptonic final states

The type-III seesaw introduces at least one extra fermionic SU(2)_L triplet field coupled to EW gauge bosons :

The neutral Majorana (N^0) and charged (L^\pm) heavy leptons;

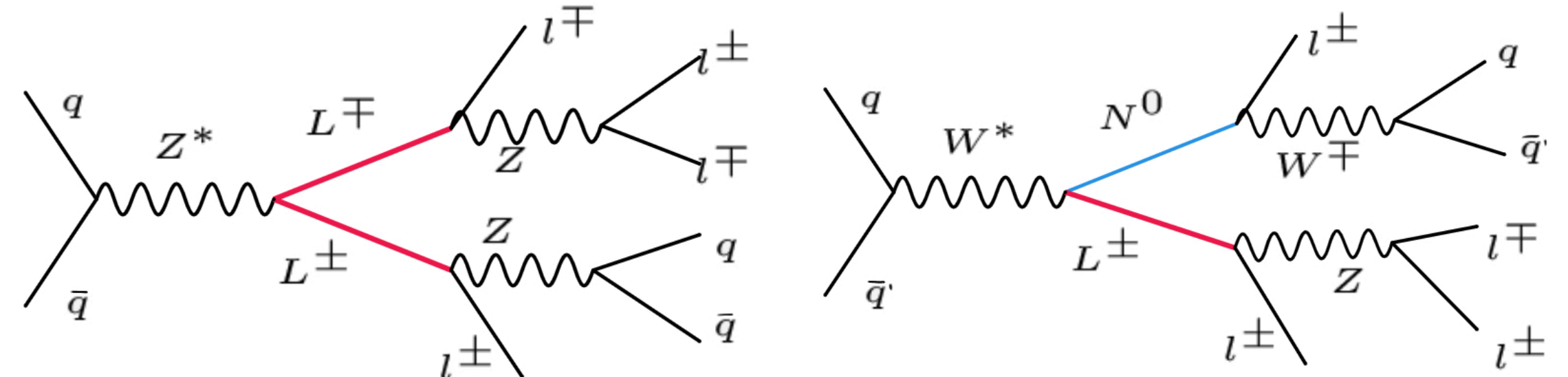
$$L^\pm \rightarrow Hl^\pm, Zl^\pm, W^\pm\nu \quad ; \quad N^0 \rightarrow Z\nu, H\nu, W^\pm l^\mp, \quad l = e, \mu, \tau$$

Three lepton channel:



Observable: $m_{T,3l} = \left| \sum_i^{3l} \vec{p}_{T,i} + \vec{p}_T^{miss} \right|$

Four lepton channel:



Observable: $H_T + E_T^{miss}$

$H_T \rightarrow$ the scalar sum of pT of all the selected objects in the event

Analysis strategy

Three lepton channel:

Signal Region (SR) \rightarrow ZL, ZL Veto, JNLow

$$80 < m_{t\bar{t}}(\text{GeV}) < 100 \quad m_{t\bar{t}}(\text{GeV}) > 115 \quad N_{\text{jet}} < 2$$

Control Region (CR) \rightarrow ZL

Four lepton channel:

SR \rightarrow Q0, Q2

$$\sum_i^{4l} q_l = 0 \quad \left| \sum_i^{4l} q_l \right| = 2$$

CR \rightarrow Q0 DiBoson (DB), Q0 RareTop (RT)

Validation region (VR) \rightarrow kinematically close to SR

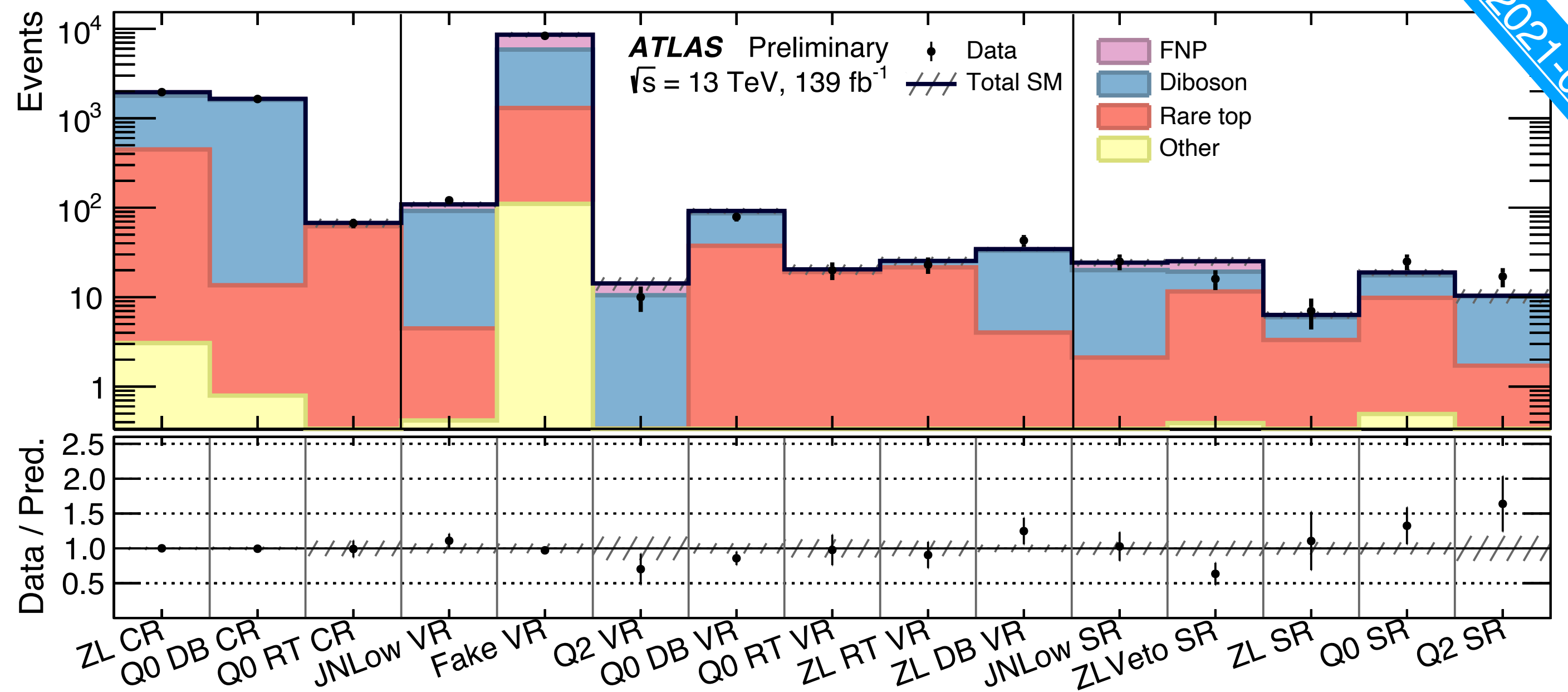
Main Background:

Reducible - Irreducible

Fake non-prompt (FNP)

Diboson- $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}H$

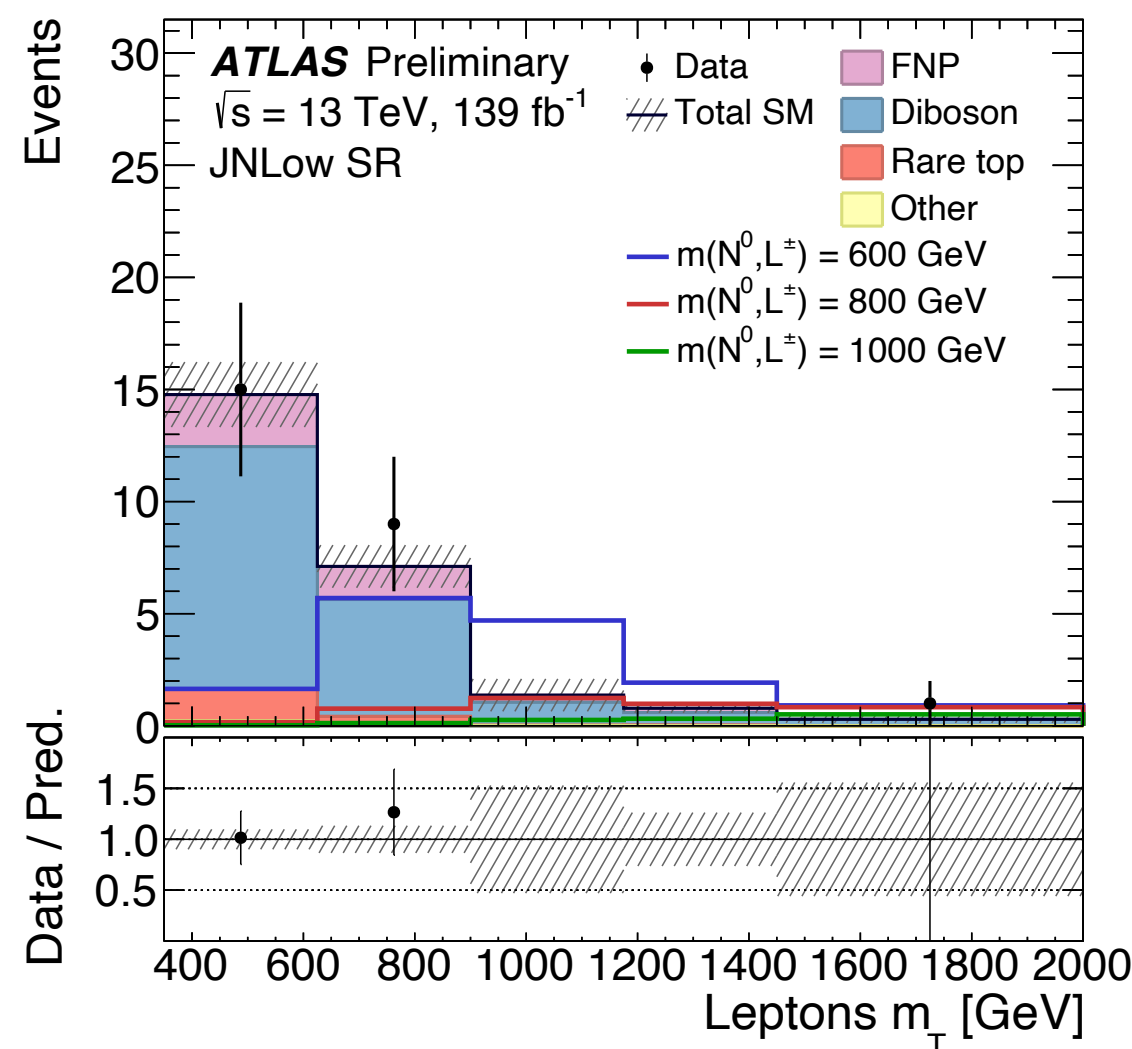
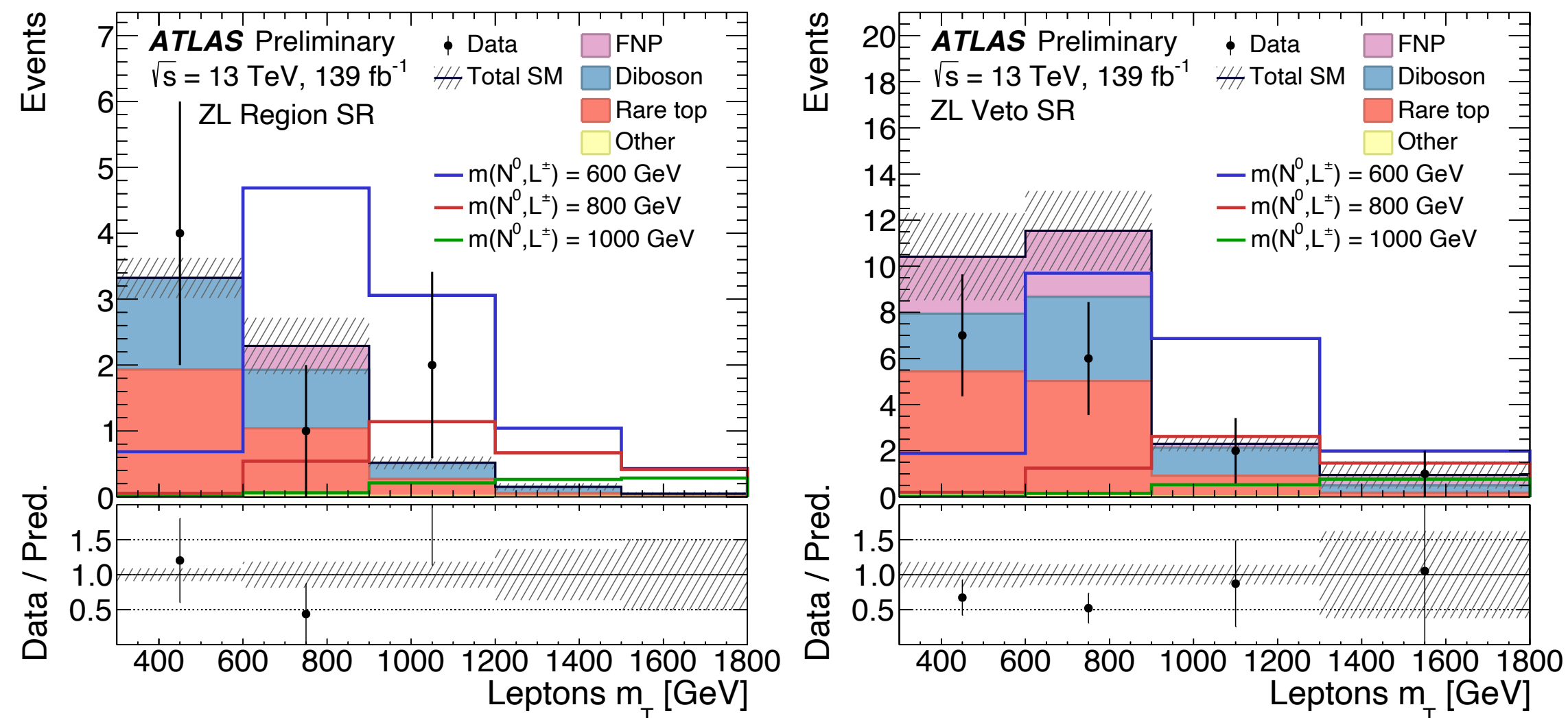
ATLAS-CONF-2021-023



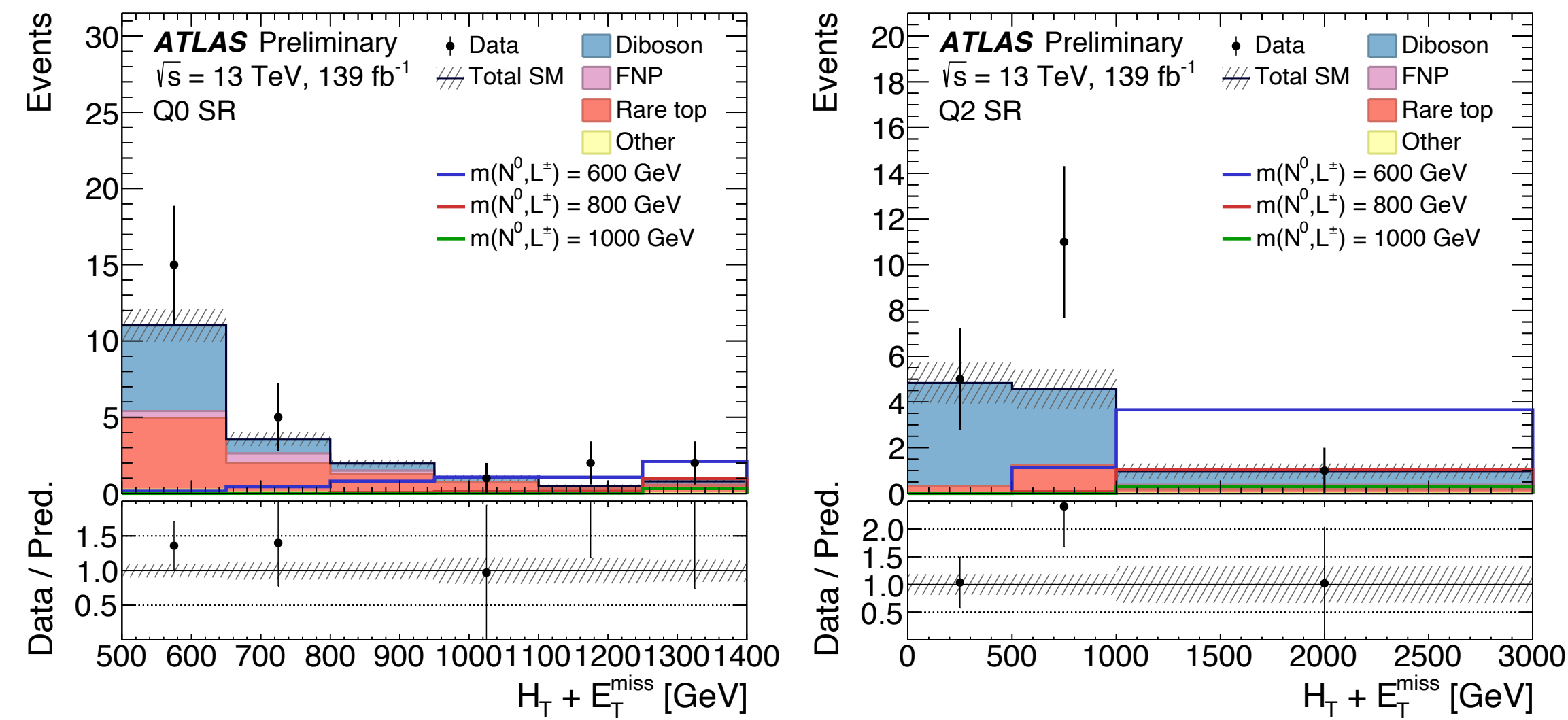
Analysis Results

ATLAS-CONF-2021-023

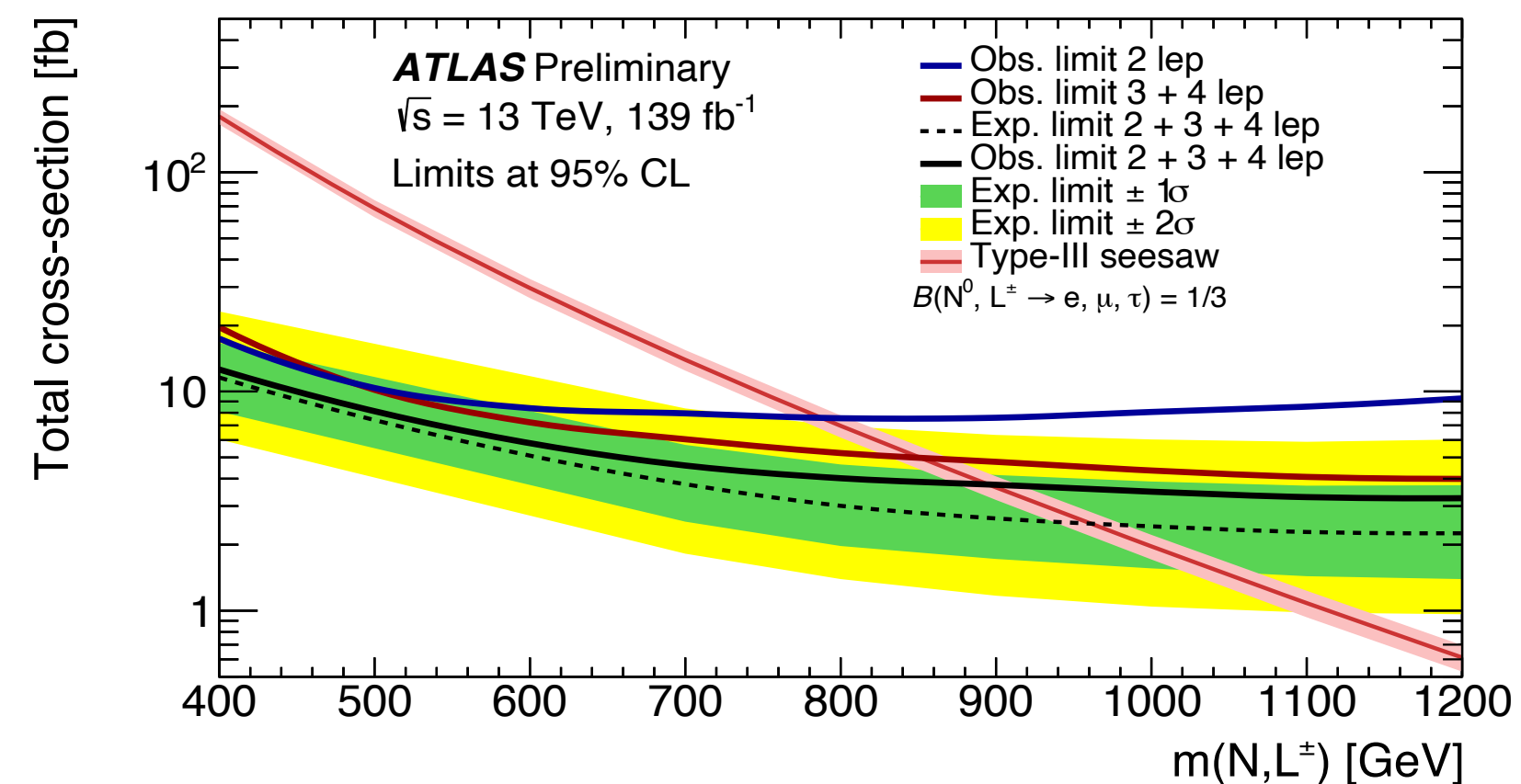
Three lepton channel:



Four lepton channel:



Upper limit @ 95% CL:

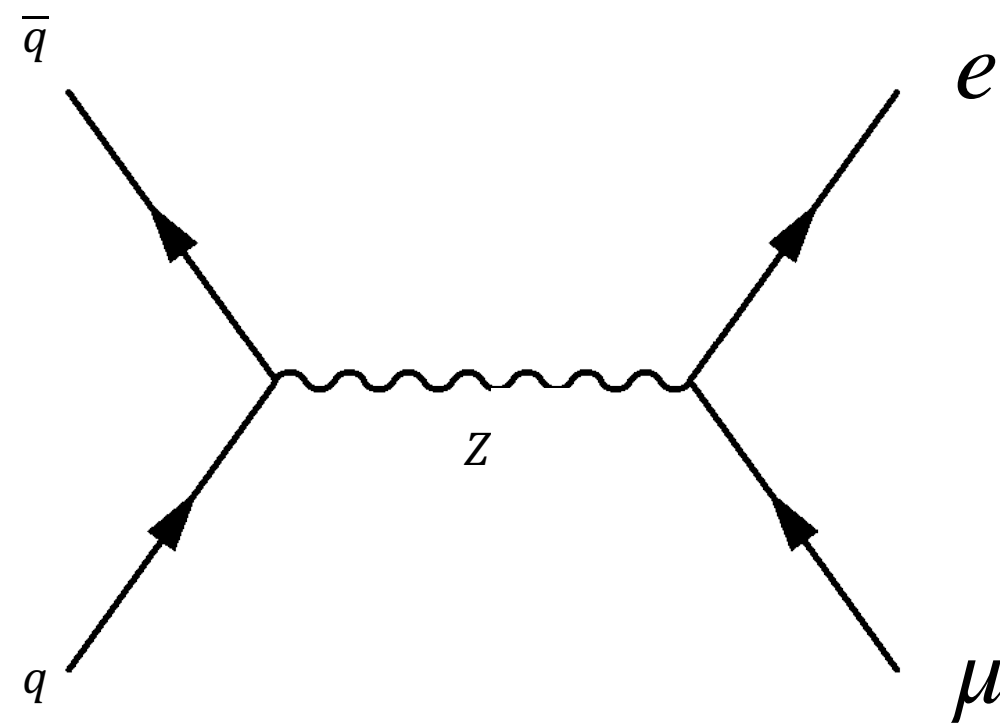


N^0, L^\pm
 Limit exclusion
 @ 870 GeV

Search for lepton-flavor-violation in Z-boson decays

Search for resonant features in $e\mu$ mass spectra:

Resonance search around the Z boson mass GeV

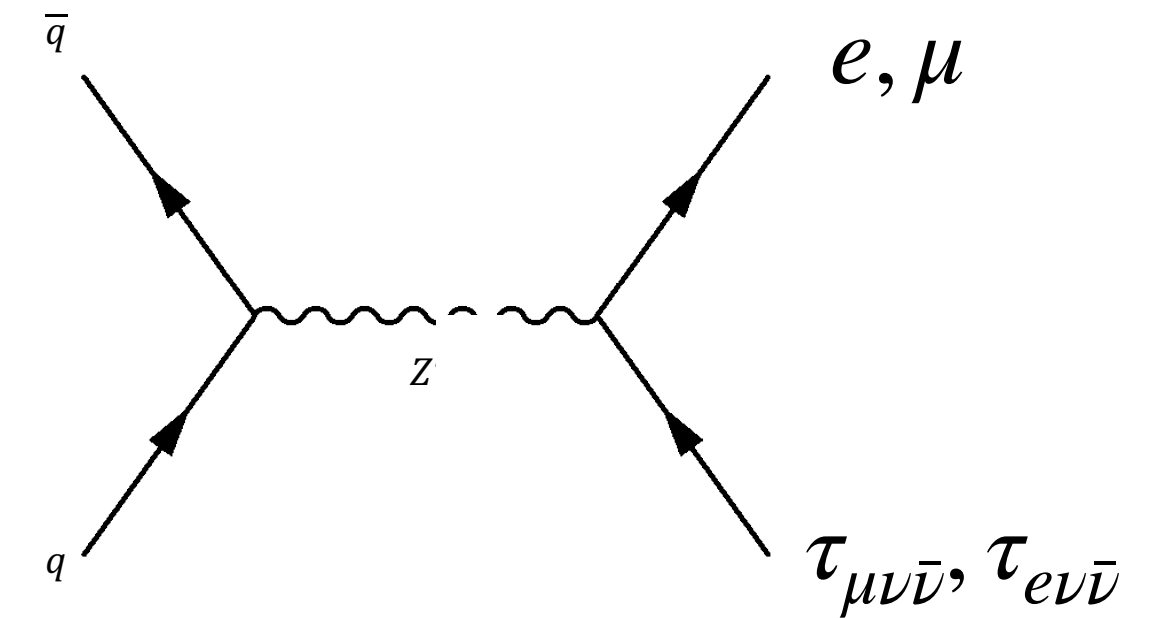


Signature: **bump** over a smoothly-falling background

Observable: dilepton ($m_{e\mu}$) invariant mass

Search for lepton-flavor-violation in Z-boson decays with τ -leptons

Resonance search around the Z boson mass GeV

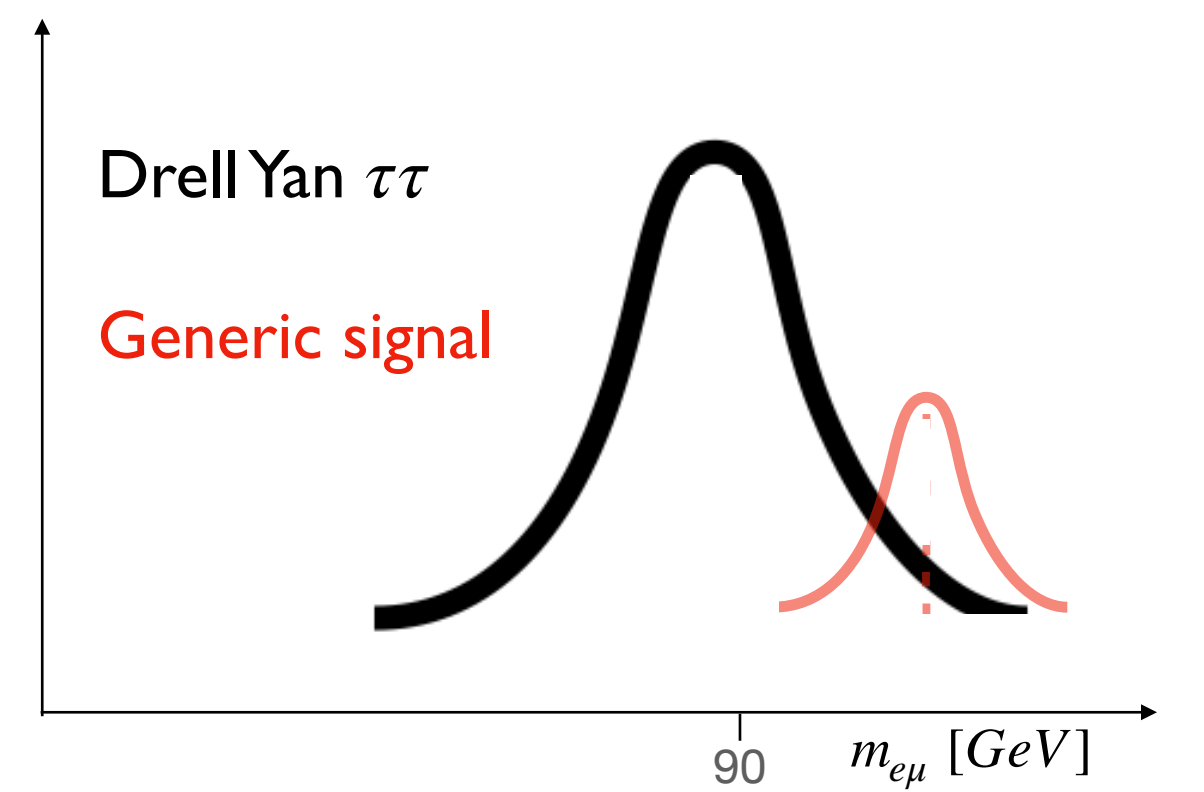


Signature: **excess** over the background expectation

Observable: $m_{e\mu}^{coll}$ and Neural Network score invariant mass

New searches of charged-lepton-flavor violation :

- physics beyond the Standard Model
- Constrain for BSM theory



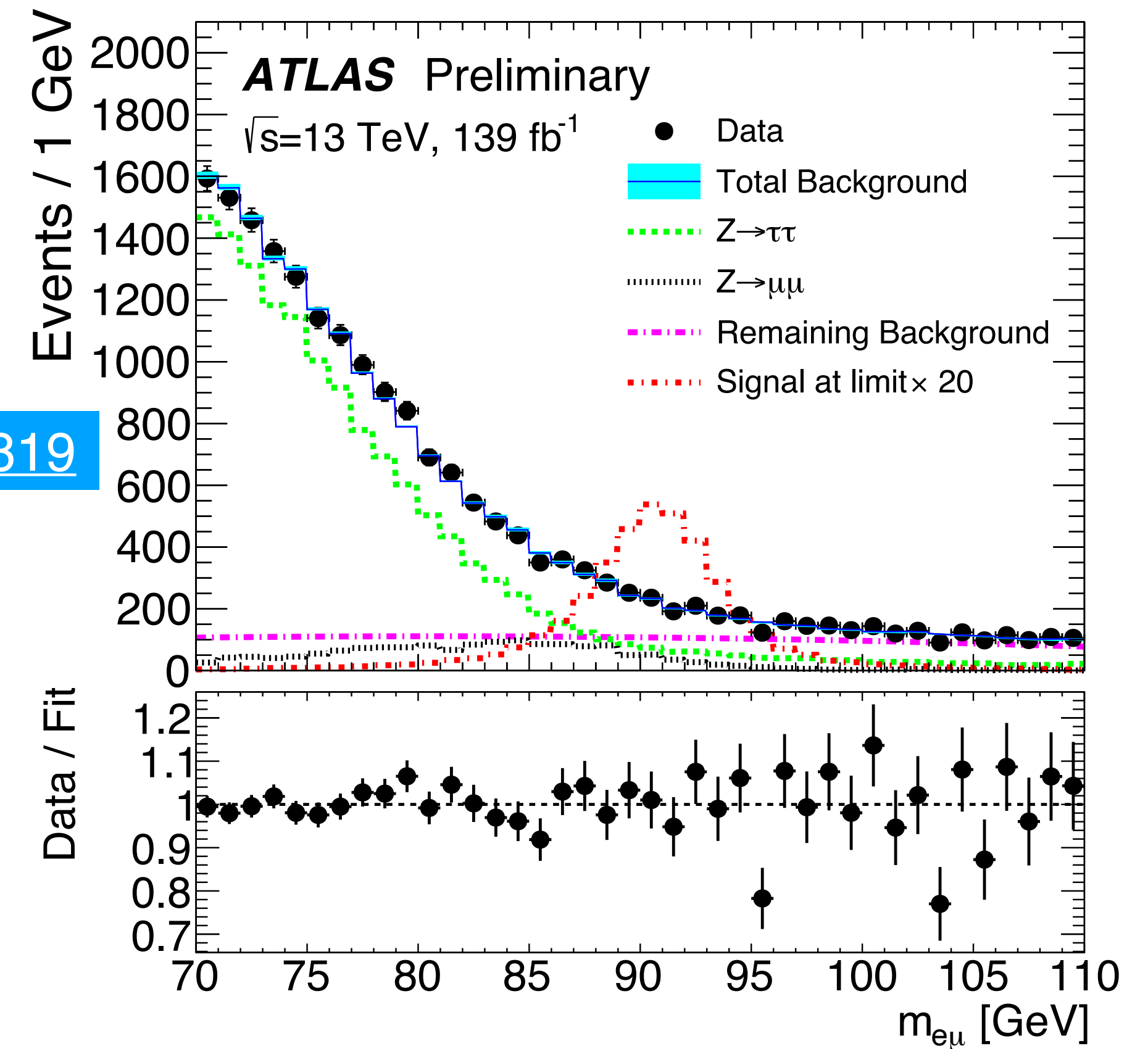
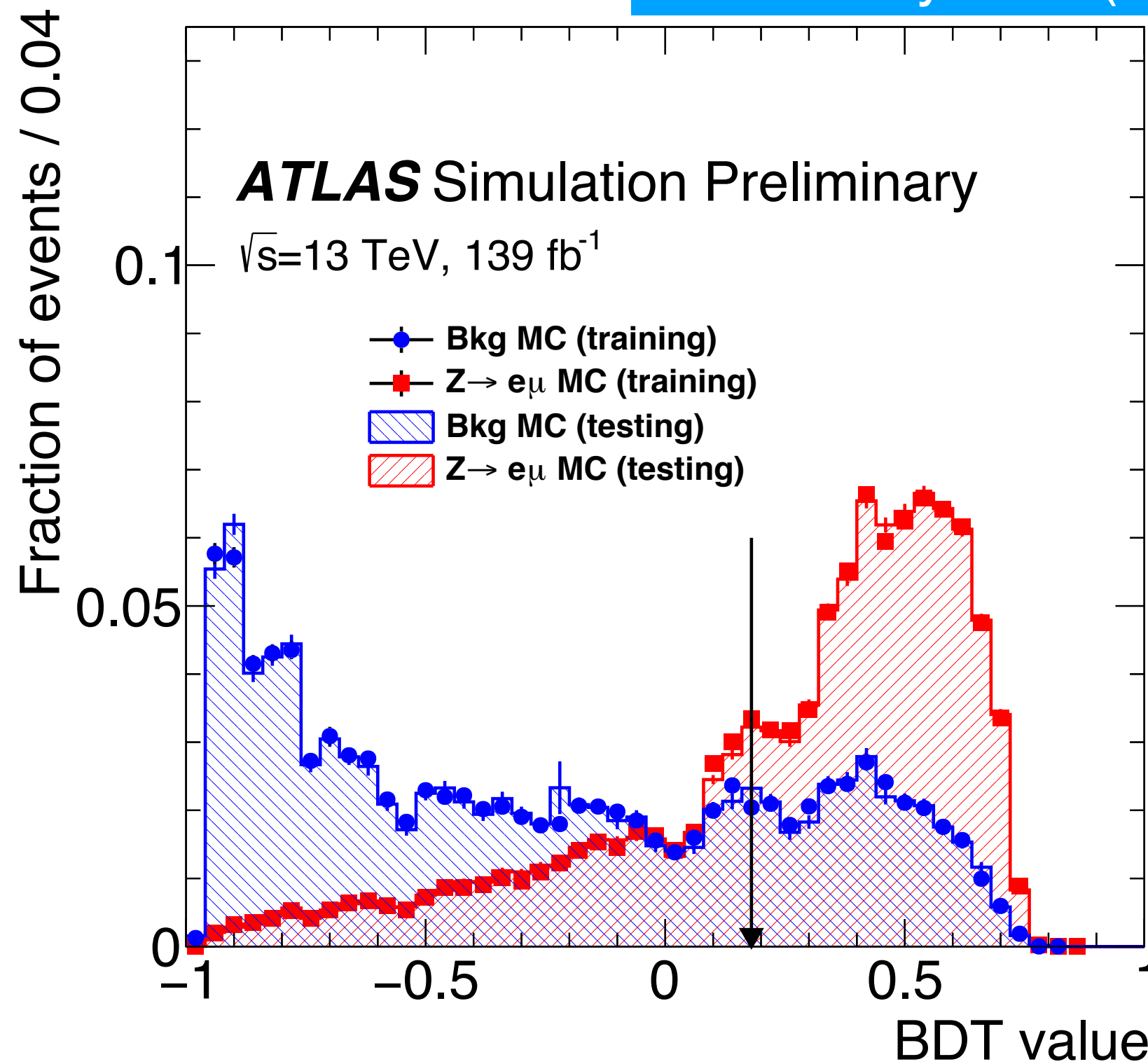
Search for the Charged-Lepton-Flavor Violating decay $Z \rightarrow e\mu$

Main background processes:

- $Z \rightarrow \tau\tau \rightarrow e\mu\bar{\nu}\nu\bar{\nu}$
 - $Z \rightarrow \mu\mu$, misidentified as an electron
 - $t\bar{t} \rightarrow e\mu\bar{\nu}b\bar{b}$
 - $WW \rightarrow e\mu\bar{\nu}$
- } → Estimated from MC
- } → Flat polynomial Fit

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- Little jet activity
- Little missing energy

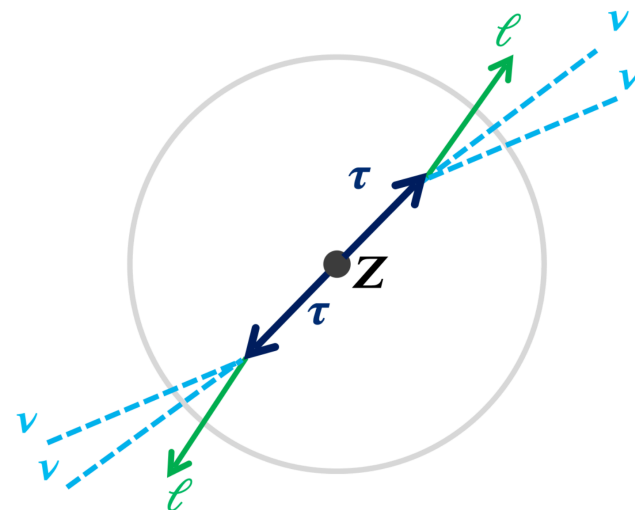


Upper limit @ 95% CL on the $B(Z \rightarrow e\mu)$

observed	3.04×10^{-7}
expected	2.75×10^{-7}

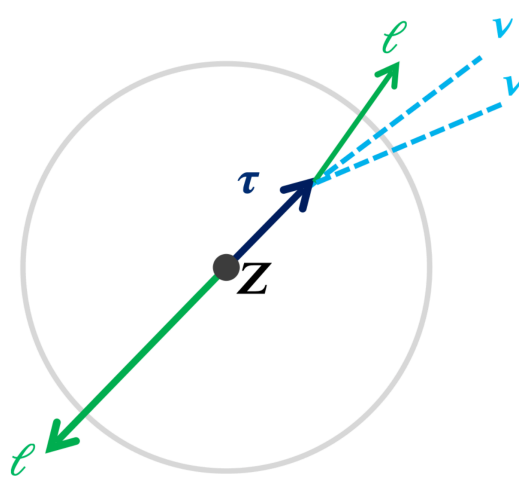
Search for lepton-flavor-violation in Z -boson decays with τ -leptons

Main background processes:

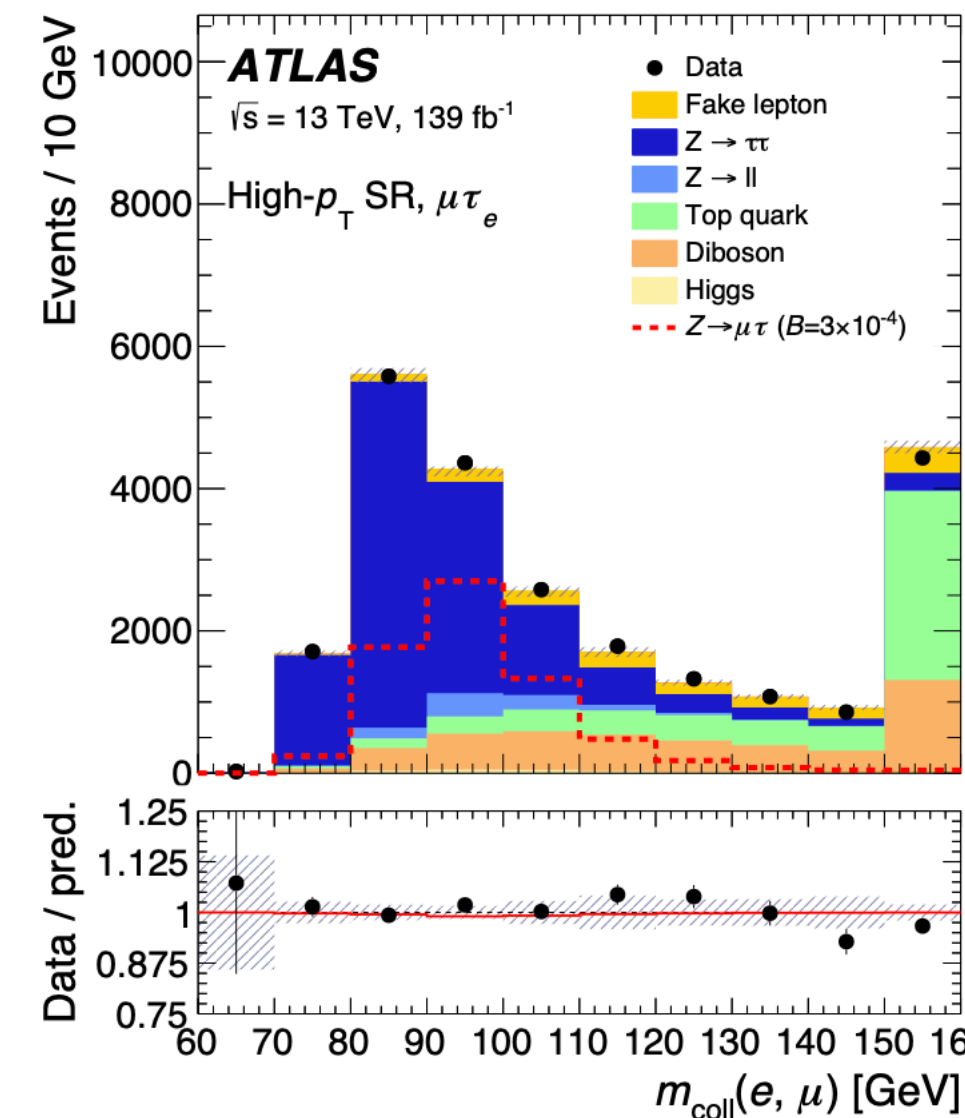
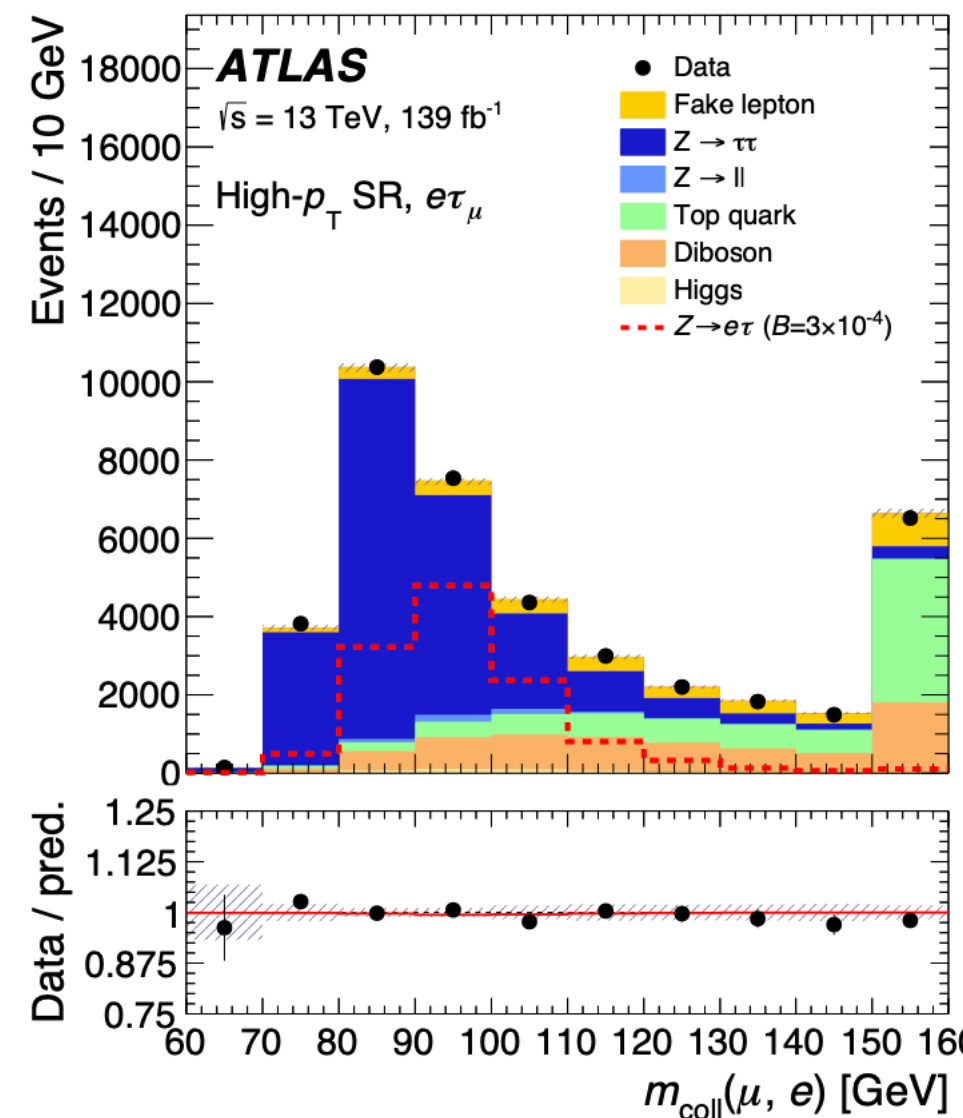


- Prompt $e^\pm \mu^\mp$:
 $Z \rightarrow \tau\tau, t\bar{t}, WW$ and single top
- Misidentified l :
 $Z \rightarrow ll$

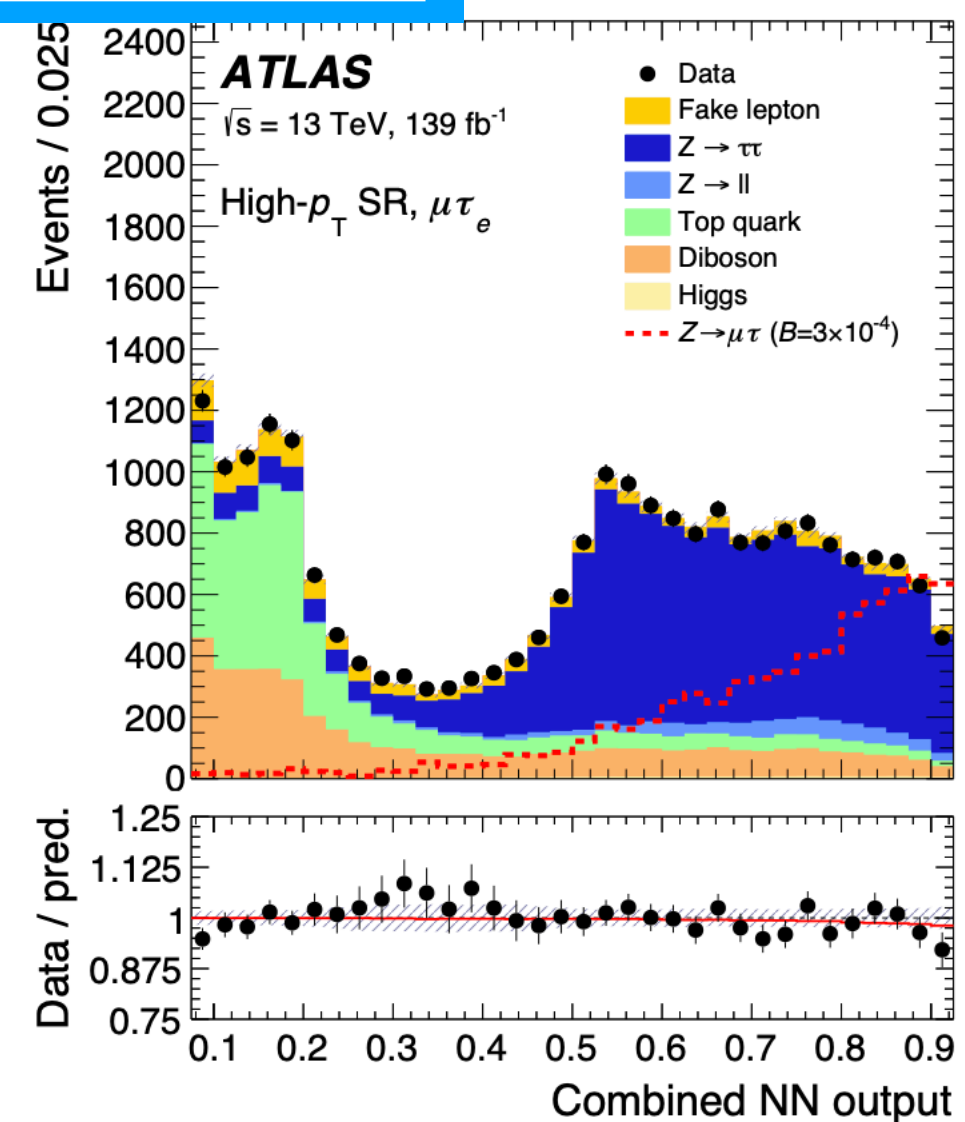
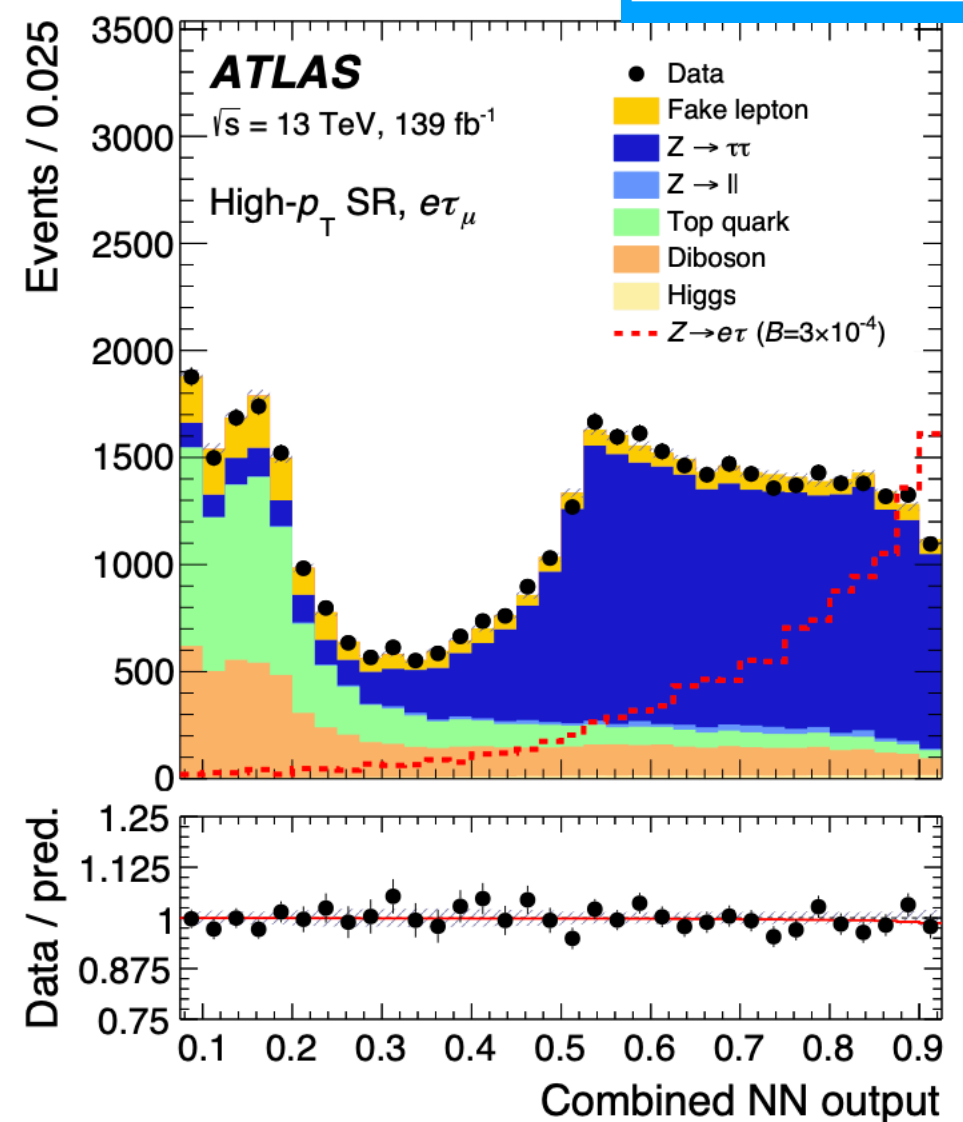
Signal:



- Two orthogonal channels:
 $Z \rightarrow e\tau_\mu$ and $Z \rightarrow \mu\tau_e$
- Leading p_T - l_1 from Z
- SubLeading p_T - l_2 from



arXiv:2105.12491



Upper limit @ 95% CL on:

$$B(Z \rightarrow e\tau_\mu)$$

observed 5.9×10^{-6}
 expected 7.5×10^{-6}

$$B(Z \rightarrow \mu\tau_e)$$

observed 5.7×10^{-6}
 expected 8.5×10^{-6}

Summary

Searches with leptons final states have a long history with the discovery of :

$J/\Psi, \Upsilon, Z, W, H \longrightarrow$ establishment of the Standard Model

- Searches with leptons final states could help to pave the way to a better understanding of the physics processes beyond it
- Searches with different leptonic final states investigating mass range from the Z mass up to TeV have been presented
- No deviation from the background expectation have been observed
- Upper and Lower limit at 95 % on the Cross Section and Branching fraction have been set

Be careful! It does not mean: “No new Physics with leptons.....”

.....It just means: “We have to push through our limits ”



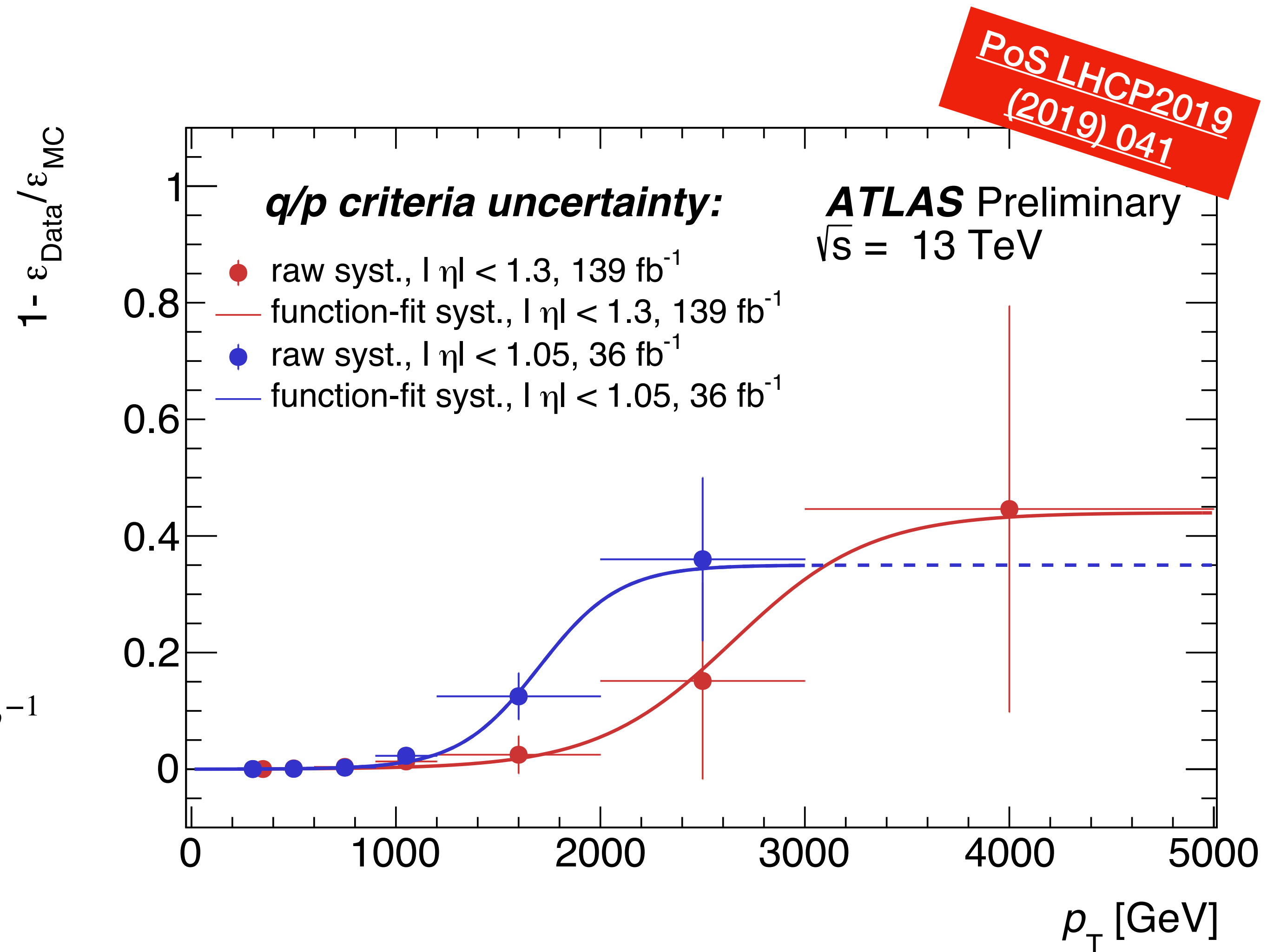
Back Up

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 measurement q/p

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



Search for resonant phenomena in dilepton mass spectra

Systematic uncertainties

Uncertainty source for m_X [GeV]	Dielectron			Dimuon		
	300	2000	5000	300	2000	5000
Spurious signal	± 12.5 (12.0)	± 4.6 (10.8)	± 0.1 (1.0)	± 11.7 (11.0)	± 3.8 (3.5)	± 2.1 (2.2)
Lepton identification	± 1.6 (1.6)	± 5.6 (5.6)	± 5.6 (5.6)	± 1.8 (1.8)	$^{+12}_{-10}$ ($^{+12}_{-10}$)	$^{+25}_{-20}$ ($^{+25}_{-20}$)
Isolation	± 0.3 (0.3)	± 1.1 (1.2)	± 1.1 (1.1)	± 0.4 (0.4)	± 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)	± 1.7 (1.7)	± 1.7 (1.7)
Electron energy scale	$^{-1.7}_{-4.0}$ ($^{+1.0}_{-1.8}$)	$^{-1.9}_{-6.0}$ ($^{+1.7}_{-2.9}$)	$^{+0.1}_{-0.4}$ (± 0.8)	-	-	-
Electron energy resolution	$^{+7.9}_{-8.3}$ ($^{+1.1}_{-0.9}$)	$^{+9.0}_{-11.8}$ ($^{+0.7}_{-0.5}$)	$^{+0.4}_{-0.9}$ (± 0.1)	-	-	-
Muon ID resolution	-	-	-	$^{+0.8}_{-2.3}$ ($^{+0.3}_{-0.8}$)	$^{+0.9}_{-1.3}$ ($^{+0.7}_{-1.1}$)	$^{+0.6}_{-0.4}$ ($^{+0.5}_{-0.3}$)
Muon MS resolution	-	-	-	$^{+2.8}_{-3.8}$ ($^{+1.0}_{-1.3}$)	$^{+3.2}_{-3.0}$ ($^{+2.6}_{-2.4}$)	± 2.4 (2.1)
'Good muon' requirement	-	-	-	± 0.6 (0.6)	$^{+9.0}_{-8.2}$ ($^{+9.0}_{-8.2}$)	$^{+55}_{-35}$ ($^{+55}_{-35}$)

Search for non-resonant phenomena in dilepton mass spectra

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

Channel	Interference	Background uncertainties			Signal uncertainties	
		σ_b^{Stat}	σ_b^{ISS}	σ_b^{CRB}	$\sigma_s^{\text{Experiment}}$	σ_s^{Theory}
e^+e^-	Constructive	14%	4%	2%	8%	+11% -10%
e^+e^-	Destructive	34%	7%	1%	8%	+14% -13%
$\mu^+\mu^-$	Constructive	21%	6%	2%	+20% -17%	+10% -9%
$\mu^+\mu^-$	Destructive	58%	24%	4%	+27% -22%	+13% -12%

Search for resonant phenomena in transverse mass spectra

Systematic uncertainties

Source	Electron channel		Muon channel	
	Background $m_T = 2$ (6) TeV	Signal $m_T = 2$ (6) TeV	Background $m_T = 2$ (6) TeV	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%)