



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

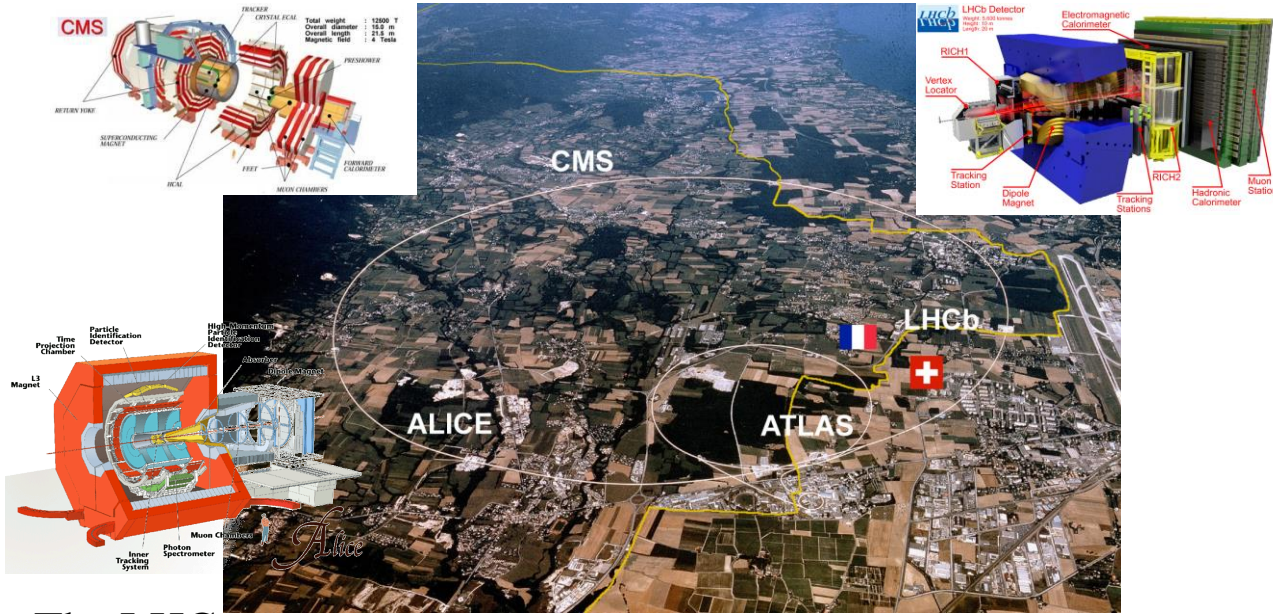
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on behalf of the ATLAS Collaboration

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Introduction to the LHC and ATLAS

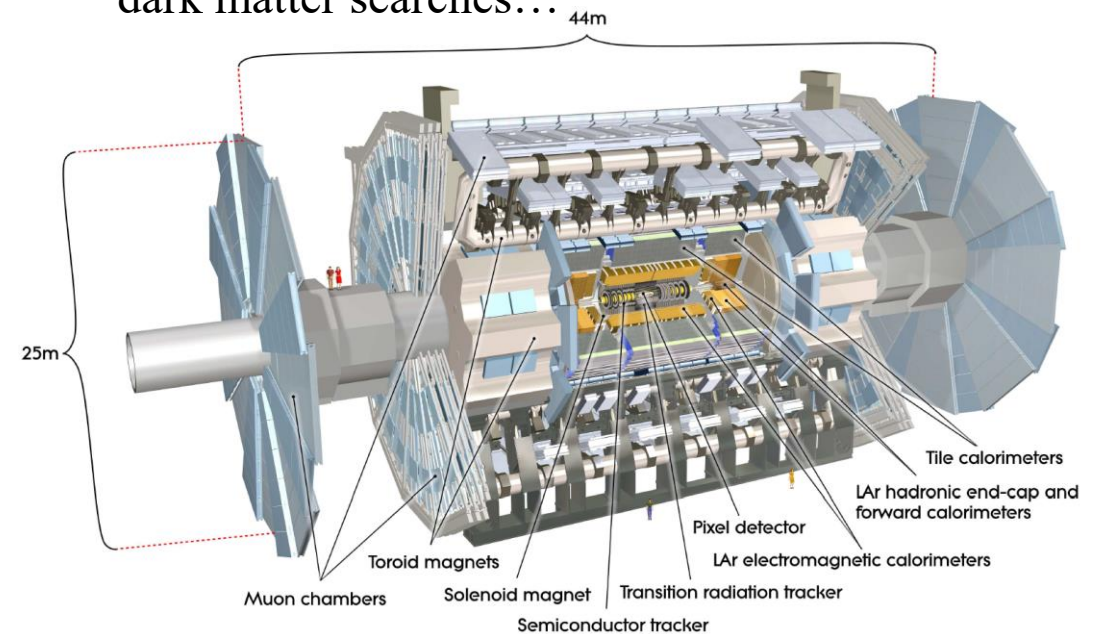


The LHC:

- The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator.
- Proton-Proton collision at a center-of-mass energy $\sqrt{s} = 13$ TeV.
- Four large detectors: ATLAS, CMS, LHCb and Alice.

The ATLAS detector:

- One of the two general-purpose detectors at the LHC.
- Collecting the collision data generated by the LHC (Full Run 2, 2015-2018, 139fb^{-1}).
- General purpose: Higgs, extra dimensions, SUSY, dark matter searches...



Phenomena in leptonic final states

➤ List of publications:

- Vectorlike taus [ATLAS-CONF-2022-044](#)
- Type-III seesaw heavy leptons [submitted to EPJC](#)
- Search for an unexpected asymmetry of $e\mu$ [Physics Letters B 830 \(2022\) 137106](#)
- W' to lepton + MET [ATLAS-CONF-2021-025](#)
- New phenomena in final states with two leptons and one/no b-tagged jets [Phys. Rev. Lett. **127**, 141801](#)

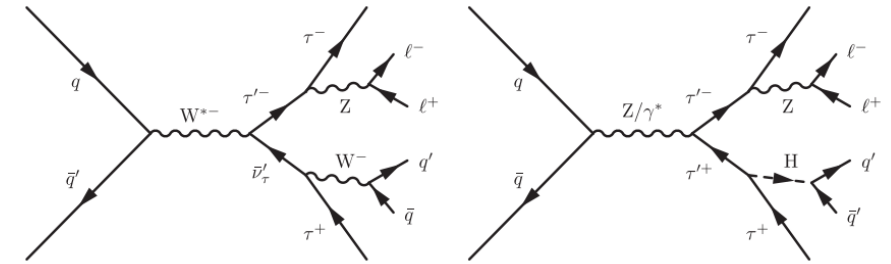
Vectorlike Taus

NEW!

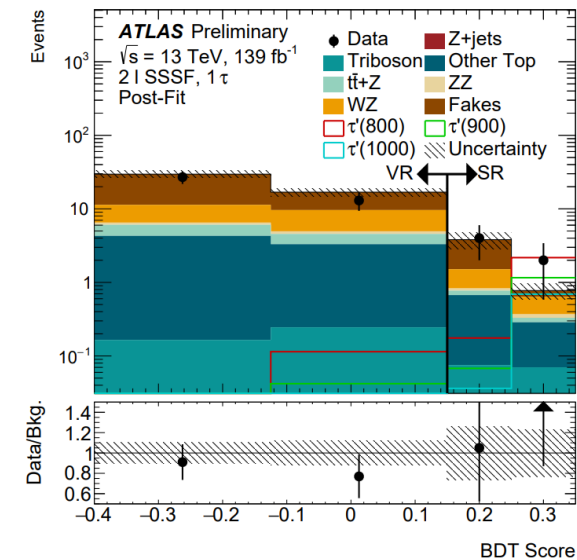
- Search for Third-Generation Vectorlike Leptons (VLL) with the full Run 2 ATLAS dataset (139 fb⁻¹).
- Production process: $pp \rightarrow \nu'_\tau \tau'$ (dominant), $pp \rightarrow \tau'^+ \tau'^-$ and $pp \rightarrow \nu'_\tau \bar{\nu}'_\tau$
- Event selection: at least two light leptons, zero or more hadronic taus
- Definition of Signal Regions:

Variables	Signal Regions						
N_ℓ	2	2	2	2	2	3	≥ 4
Charge/Flavor	SSSF	SSOF	OSSF	OSOF	-	-	-
N_τ	1	1	1	1	≥ 2	≥ 1	≥ 0
N_{jet}	> 0	> 0	> 0	> 0	> 0	> 0	> 0
E_T^{miss} [GeV]	≥ 120	≥ 90	≥ 60	≥ 100	≥ 60	≥ 90	≥ 60
BDT Score	≥ 0.15	≥ 0.1	≥ 0.1	≥ 0.1	≥ -0.11	≥ 0.08	≥ 0.08

- Background estimation: dominated by $t\bar{t}$, diboson and QCD.
 - MC simulation + fake-factor method.
- Boosted Decisions Tree (BDT) algorithm is utilized as an event classifier.



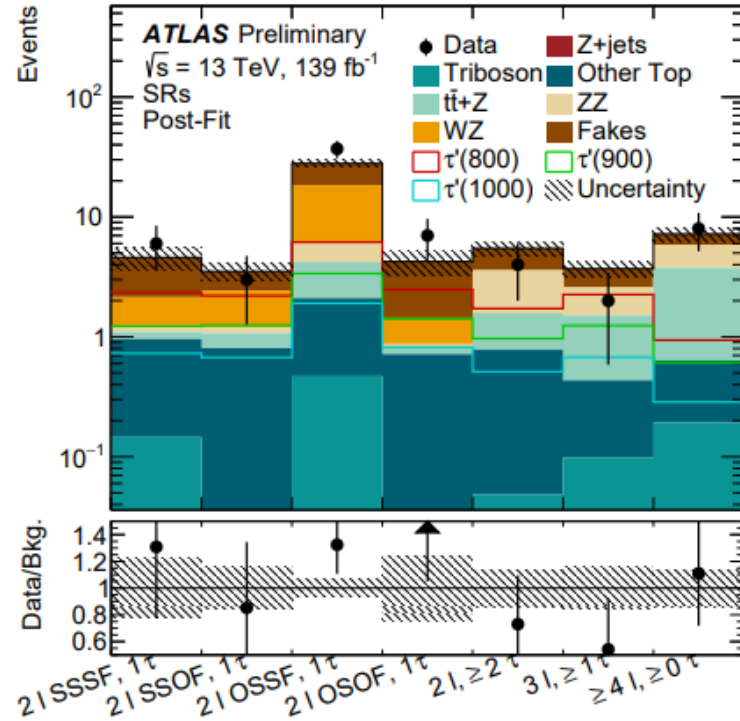
LO Feynman diagrams for VLL production and decay



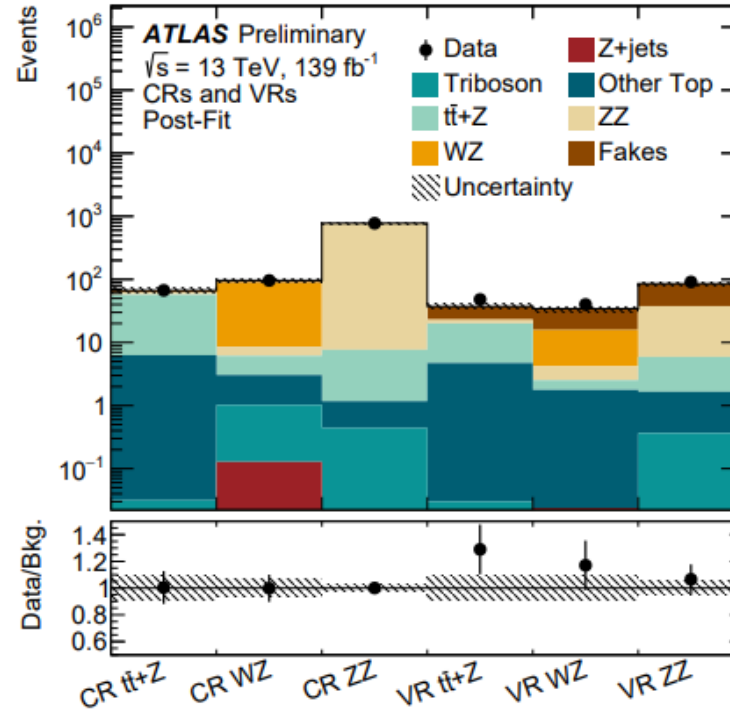
BDT score of one SR and VR as example.

Vectorlike Taus (results)

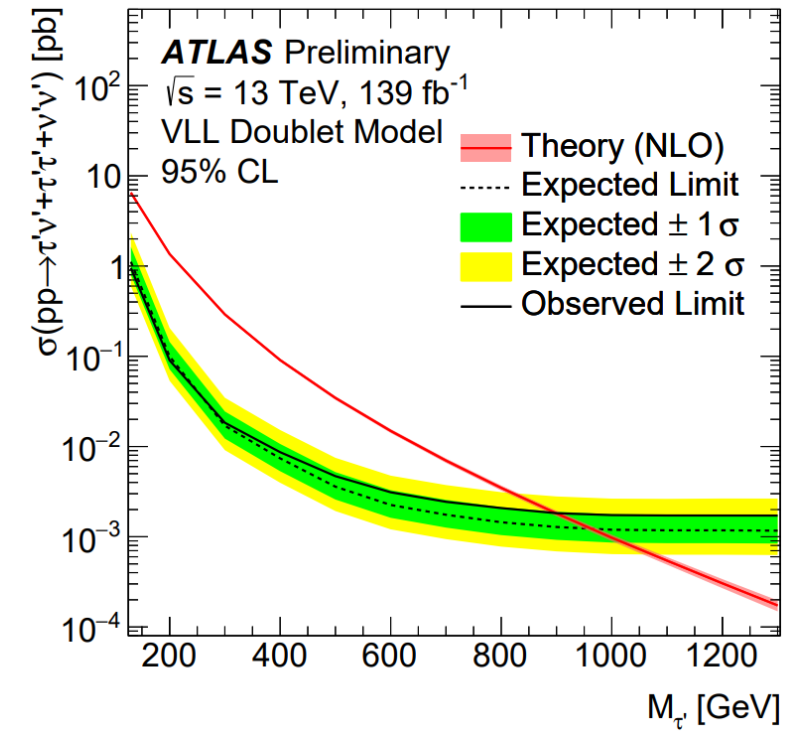
NEW!



Signal Regions



Control and validation Regions

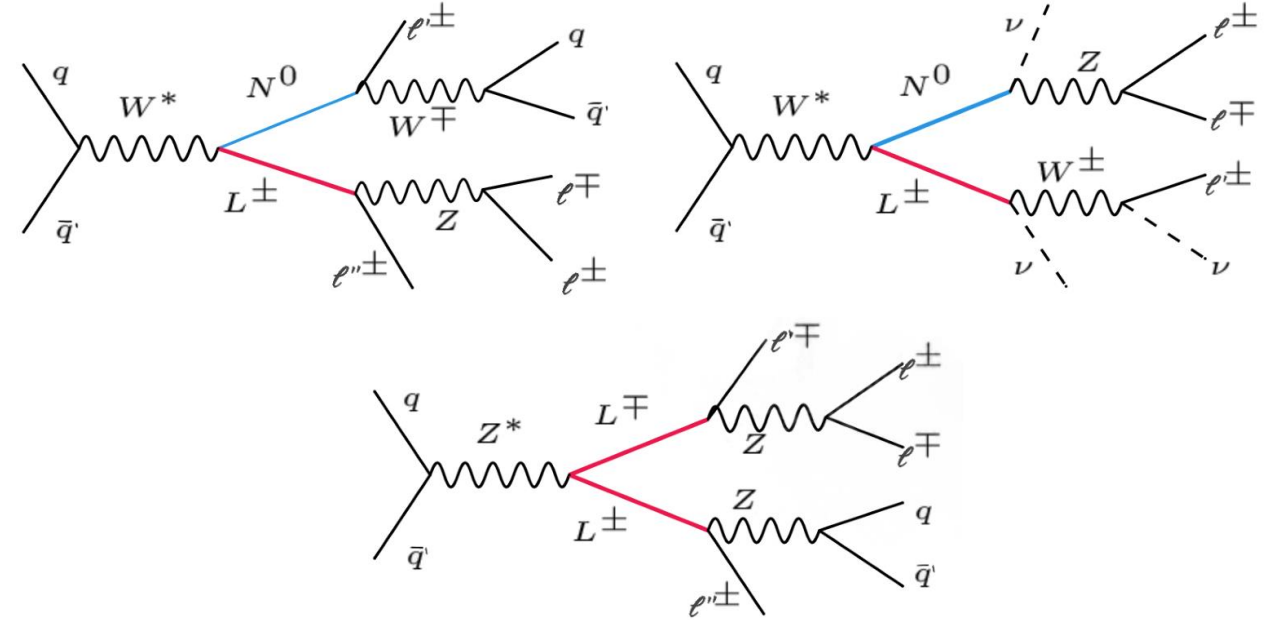


Limit setting

- No excess of events above SM expectation.
- The expected excluded upper mass is 970 GeV.
- The observed mass range 130 GeV to 900 GeV is excluded at the 95% CL.

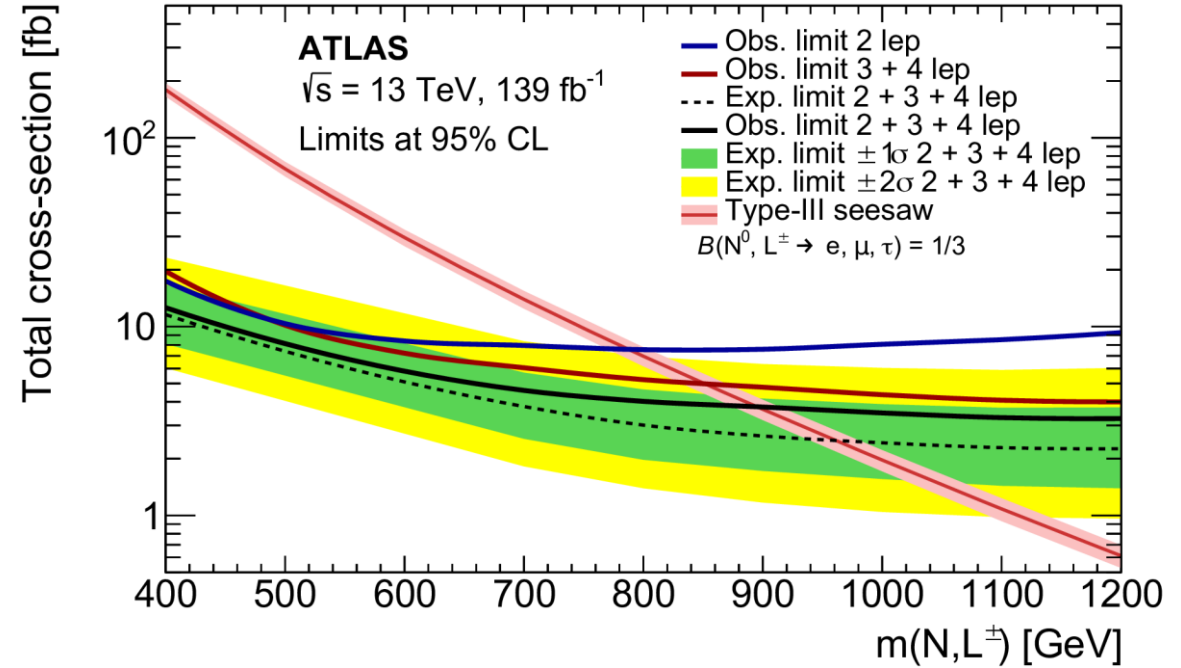
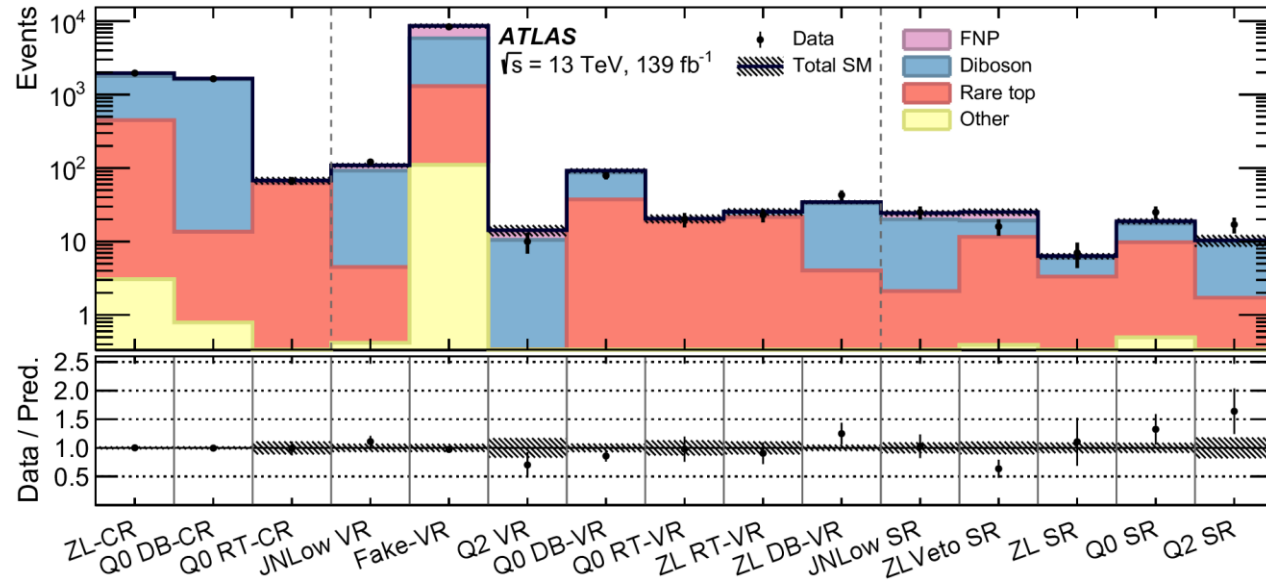
Type-III seesaw heavy leptons

- Search for type-III seesaw heavy leptons in leptonic final states
- Pair production of the neutral Majorana (N^0) and charged (L^\pm) heavy leptons proceeds via the s -channel production of virtual EW gauge bosons.
- Region definition in Three-lepton channel and four-lepton channel.
 - Control regions, validation regions and signal regions are defined based on invariant mass, sum of charge and many other key parameters.
- Background estimation:
 - The background estimation combined simulations and data-driven methods common to all channels.



	Three-lepton signal regions			Four-lepton signal regions		
	ZL SR	ZLveto SR	JNLow SR	Q0 SR	Q2 SR	
Data	7	16	25	25	17	
Total background	6.25 \pm 0.52	25.2 \pm 2.8	24.4 \pm 2.3	19.0 \pm 1.6	10.3	\pm 1.9
Diboson	2.62 \pm 0.27	7.64 \pm 0.95	18.0 \pm 2.1	7.70 \pm 0.78	8.5	\pm 1.6
Rare top	3.2 \pm 0.5	11.2 \pm 1.7	1.82 \pm 0.32	9.4 \pm 1.4	1.63	\pm 0.35
Fakes	0.29 \pm 0.05	5.98 \pm 0.85	4.3 \pm 0.5	1.37 \pm 0.36	0.07	\pm 0.37
Other	0.113 \pm 0.015	0.36 \pm 0.12	0.33 \pm 0.03	0.49 \pm 0.04	0.1001 \pm 0.0098	

Type-III seesaw heavy leptons (result)



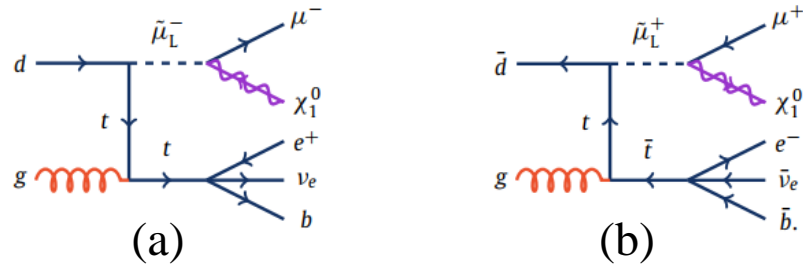
- No significant deviation from SM expectations.
- The observed (expected) exclusion limit on the heavy-lepton mass is 870 GeV (900^{+80}_{-80} GeV) at the 95% CL.
- In the full combination, heavy leptons with masses below 910 GeV are excluded at the 95% CL, while the expected lower limit on the mass is 960^{+90}_{-80} GeV.

$e\mu$ asymmetry

- Comparison of the production cross sections for $e^+\mu^-$ and $e^-\mu^+$ pairs to constrain physics process beyond the Standard Model with the full Run 2 ATLAS dataset (139 fb^{-1}).

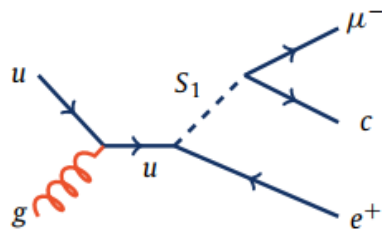
- Ratio to be measured: $\rho = \frac{\sigma(pp \rightarrow e^+\mu^- + X)}{\sigma(pp \rightarrow e^-\mu^+ + X)}$
- Model-independent and two BSM:

- RPV supersymmetry:

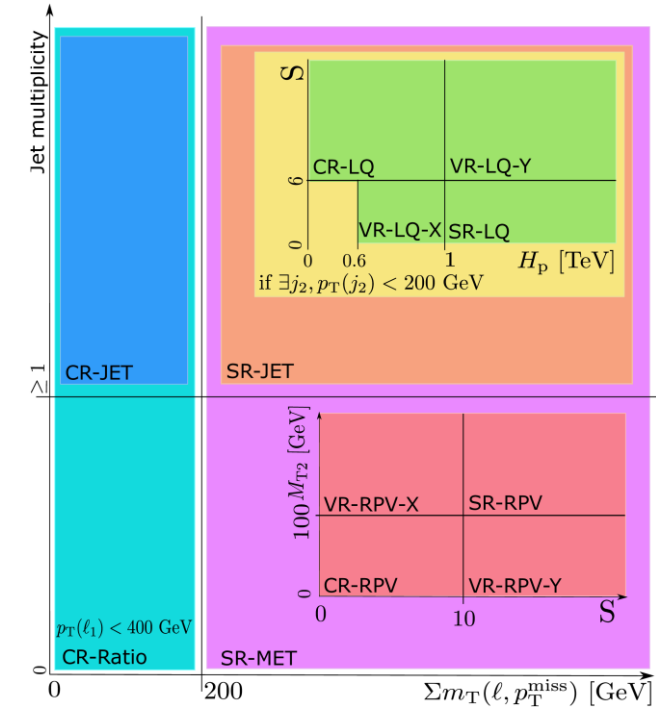


The cross-section of process 1 is larger than process 2.

- Single leptoquark production:



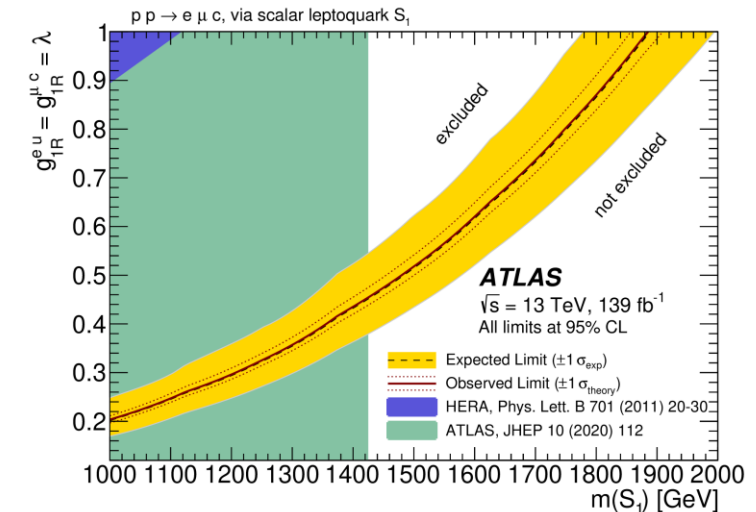
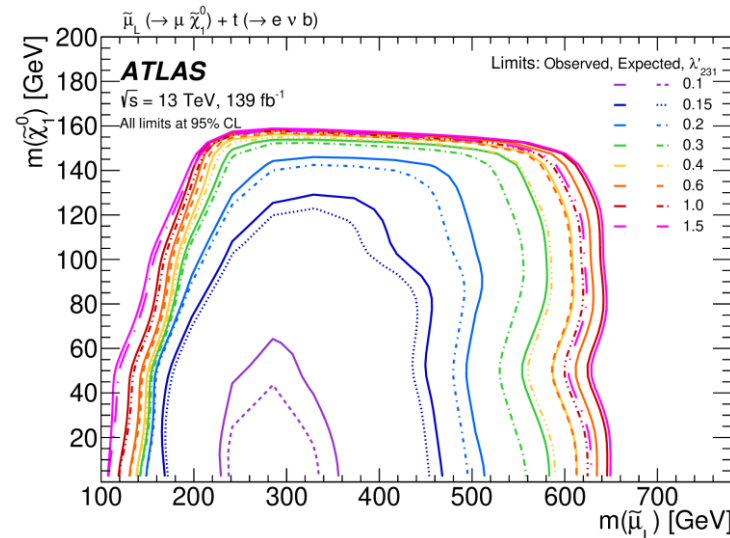
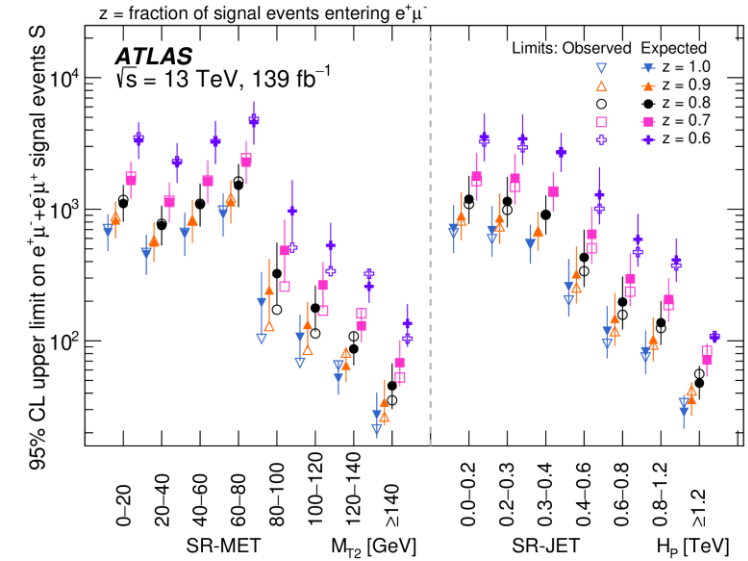
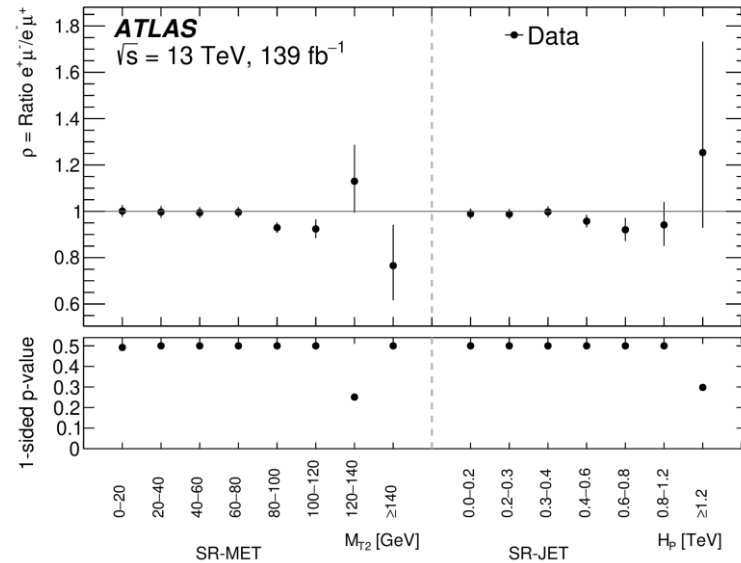
This process would be favoured over charge conjugates.



- Background: dominated by top and diboson.
 - The fake-lepton background estimation is determined using a Likelihood Matrix Method.

$e\mu$ asymmetry (result)

- No significant model-independent evidence for $\rho > 1$.
- Dependent on the existence of λ'_{231} R -parity-violating couplings, singly produced smuons in certain models are excluded.
- Scalar leptoquarks with $g^{eu}_{1R} = g^{\mu c}_{1R} \leq 1$ were excluded for masses below 1880 GeV. This value reduces to $g^{eu}_{1R} = g^{\mu c}_{1R} = 0.46$ for 1420 GeV.



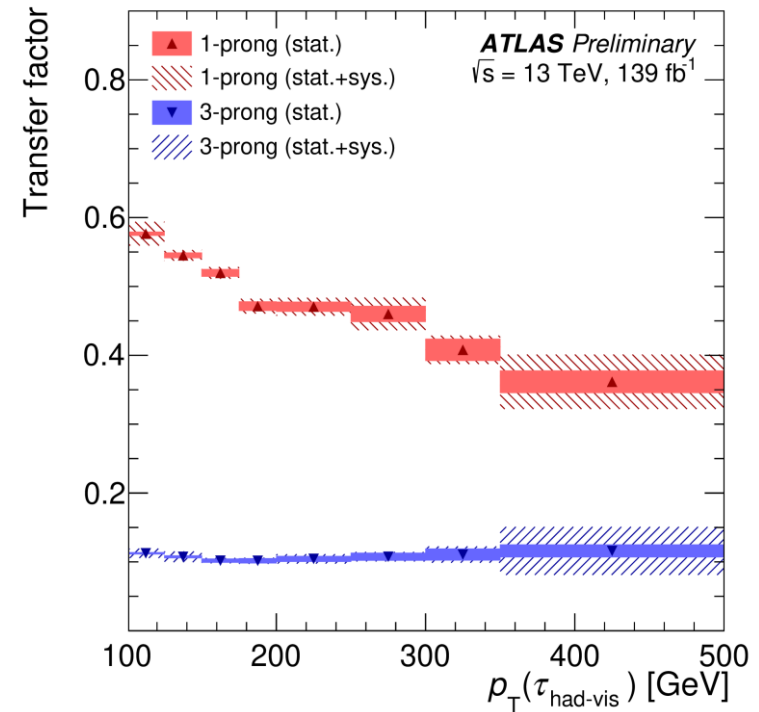
W' to $\tau\nu$

- Search for $W' \rightarrow \tau\nu$ with the full Run 2 ATLAS dataset (139 fb⁻¹).
- Resonance: W' in sequential standard model (SSM) and Non-universal Gauge Interaction Models (NUGIM).
- Final states: hadronic τ (one or three associated tracks) + E_T^{miss}
- One or three prong $\tau_{had-vis}$ with $p_T > 30$ GeV and $|\eta| < 2.4$ (excluding 1.37-1.52), and Recurrent Neural Network (RNN) algorithm used to identify Hadronic tau decays.
- Discrimination relies on the transverse mass (m_T):

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

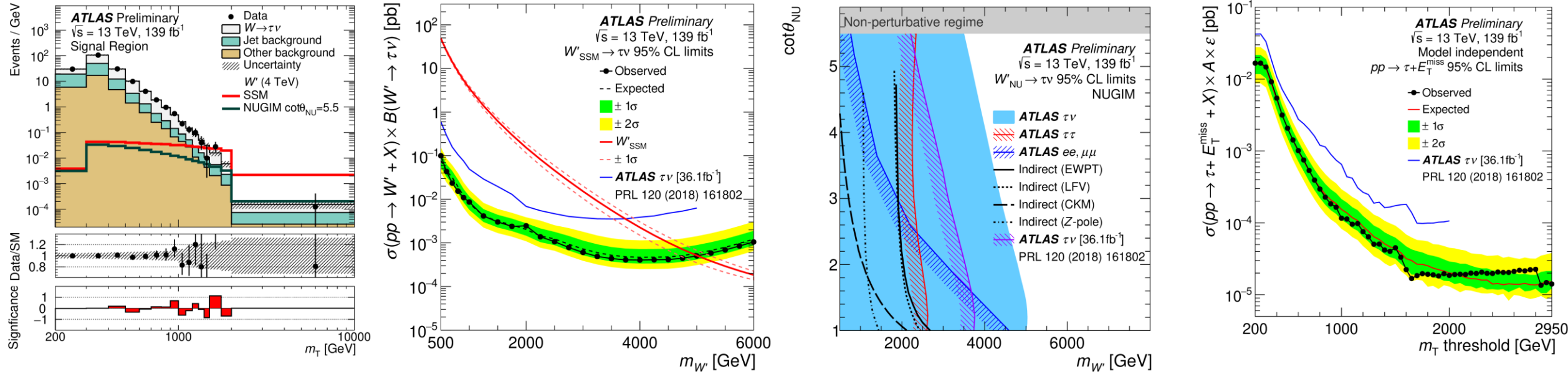
- Jet background estimation: data-driven + function ($f(m_T) = Am_T^B$) fit.

$$N_{SR}^{jet} = N_{CR1} F \equiv N_{CR1} \frac{N_{CR2}}{N_{CR3}}.$$



	Region requirements				
	SR	CR1	CR2	CR3	VR
Tau identification	L	VL \ L	L	VL \ L	L
E_T^{miss}	> 150 GeV	> 150 GeV	< 100 GeV	< 100 GeV	> 150 GeV
p_T/E_T^{miss}	∈ [0.7, 1.3]	∈ [0.7, 1.3]	–	–	< 0.7
m_T	–	–	–	–	> 240 GeV

W' to $\tau\nu$ (result)

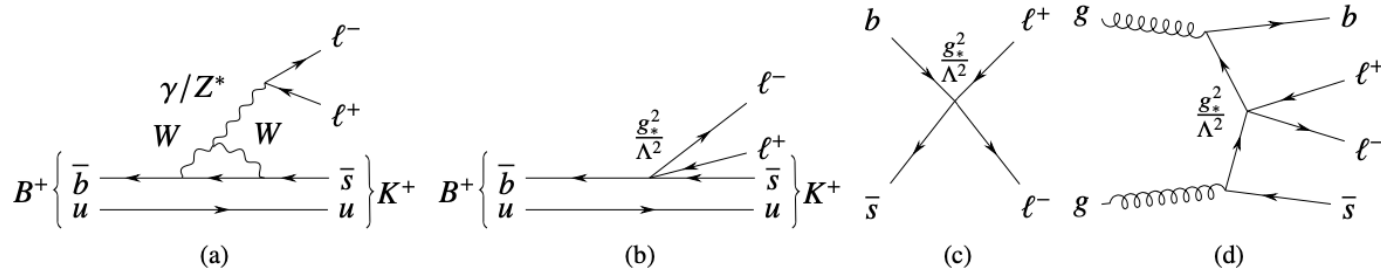


Selection	Data	$W \rightarrow \tau\nu$	Jet background	Other background	W'_{SSM} (5 TeV)
Preselection	3640749	101810	—	89460	18.463
Tau identification	1189863	84370	—	62770	16.804
$E_T^{\text{miss}} > 150 \text{ GeV}$	58528	13406	30760	12555	15.090
$0.7 < \frac{p_T}{E_T^{\text{miss}}} < 1.3$	18528	9662	5761	3348	13.810
$m_T > 1 \text{ TeV}$	58	51.1	9.96	12.0	7.236

- Sequential standard model W'_{SSM} with masses less than 5.0 TeV are excluded at 95% C.L.
- NUGIM W'_{NU} with masses less than 3.5–5.0 TeV are excluded depending on the coupling parameter $\cot\theta_{\text{NU}}$.
- Model-independent upper limits range from 16.7 fb for $m_T^{\text{thresh}} = 200 \text{ GeV}$ to 0.0141 fb for $m_T^{\text{thresh}} = 2.95 \text{ TeV}$

The search for new phenomena to two leptons and one/no b-jets

- The bsll EFT is considered as a benchmark model, and model-independent results are also presented.



- Final states: Two oppositely charged electrons or muons with either no b-tagged jets or exactly one b-tagged jets.
- Background estimation: dominated by Z+jets (0b category) and Top (1b category):
 - A fit-based extrapolation procedure is used to estimate the tails of the top m_{ll} distributions:

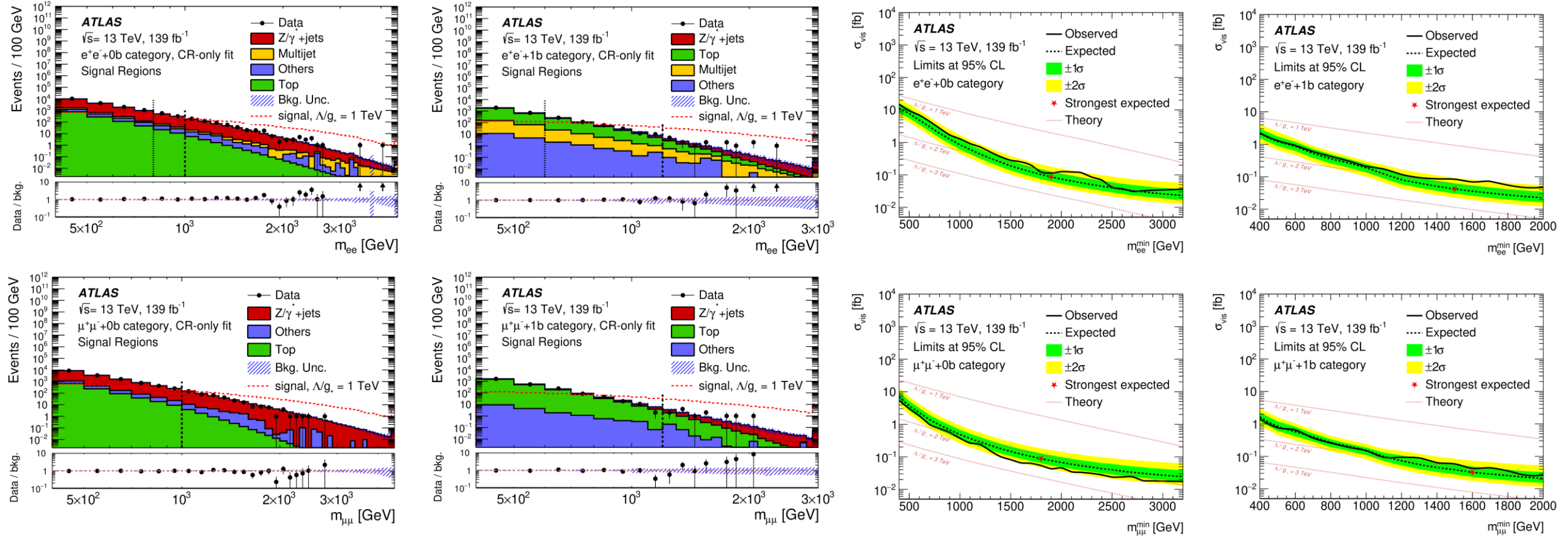
$$f^{\text{bkg1}}(m_{\ell\ell}) = e^{-a} m_{\ell\ell}^b m_{\ell\ell}^{c \log(m_{\ell\ell})}$$

- Multijet background:

$$f^{\text{bkg2}}(m_{\ell\ell}) = \frac{a}{(m_{\ell\ell} + b)^c},$$

- ✓ A data-driven approach in the electron channel.
- ✓ Negligible in the muon channel.

New phenomena to two leptons and one/no b-jets (result)



- No significant excess of events above the SM expectations.
- For electron channel, values of Λ/g_* smaller than 2.0 TeV are excluded using the observed limits at 95% C.L.
- For muon channel, values of Λ/g_* smaller than 2.4 TeV are excluded using the observed limits at 95% C.L.

Summary

- No evidence for New Phenomena yet.
- Limits are set for different theory models and model-independent searches.

Thanks!