LFU violation searches in ATLAS

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on behalf of the ATLAS collaboration

Outline

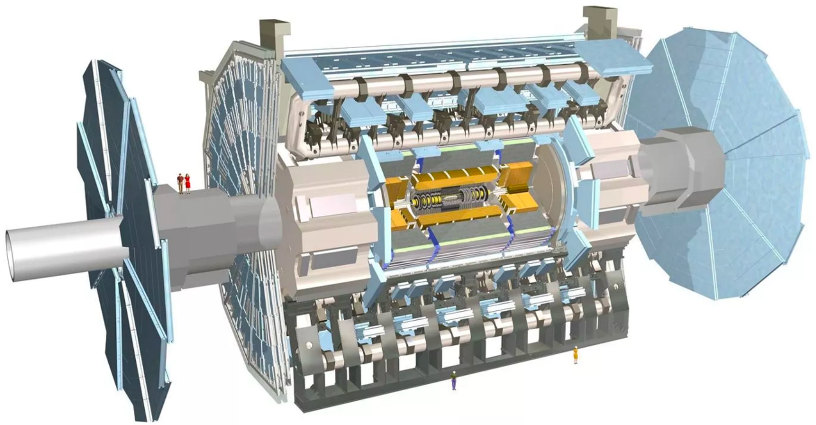
Motivation for Lepton Flavour Universality violation searches

Recent searches for:

- LeptoQuark $\rightarrow b\tau$
- Heavy resonance $\rightarrow ll'$
- Heavy Majorana neutrinos

All results use full Run 2 dataset.

Data is taken with the ATLAS experiment.



Motivation for searches

Lepton Number and Flavor are not related to a gauge symmetry=> why conserved?
Neutrinos already violate such assumption.

Important questions are:

do charged leptons violate lepton flavor conservation?

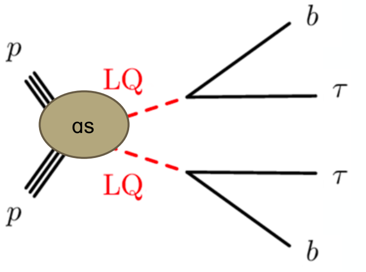
do processes show preference for one lepton flavour with respect to others?

These would be clear beyond SM effects.

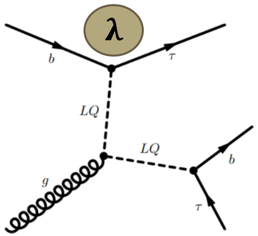
Searches for flavor-specific LQ or Z' final states (as those presented in this talk) can be combined to assess effects of lepton flavour universality violation.

Leptoquarks

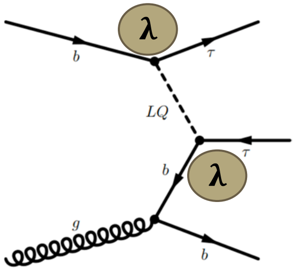
Pair production
σ ~independent of λ



Single production
$\sigma \sim \lambda^2$

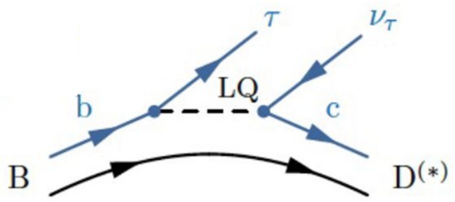


Non resonant production
$\sigma \sim \lambda^4$



λ , B (ratio of decay to ql vs qν) and m_{LQ} are free parameters

LQ are colour triplet bosons with a fractional electric charge. Invoked as explanation for B anomalies eg R(D*).

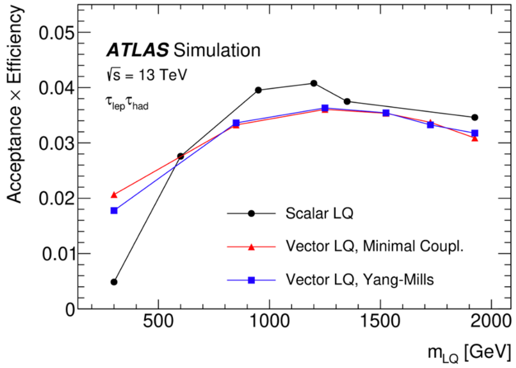


Two analyses probe all three processes depicted above, and are sensitive to scalar and vector (Yang-Mills and Minimal Coupling model) leptoquarks.

At least one tau decaying hadronically.

LQ pair production-optimised analysis

arXiv:2303.01294



signal region selection

split by tau decays (lep-had or had-had)
⩾ 2 jets
⩾ 1 b jet
p_T^{miss} > 100 GeV
S_T>600 GeV

Variable	$\tau_{lep}\tau_{had}$ channel	$\tau_{had}\tau_{had}$ channel
$\tau_{\text{had-vis}}$ p_T^0	✓	✓
s_T	✓	✓
$N_{b\text{-jets}}$	✓	✓
$m(\tau,\text{jet})_{0,1}$		✓
$m(\ell,\text{jet})$, $m(\tau_{\text{had}},\text{jet})$	✓	
$\Delta R(\tau,\text{jet})$	✓	✓
$\Delta\phi(\ell, E_T^{\text{miss}})$	✓	
E_T^{miss} ϕ centrality	✓	✓

PNN parametrized in mLQ for signal extraction

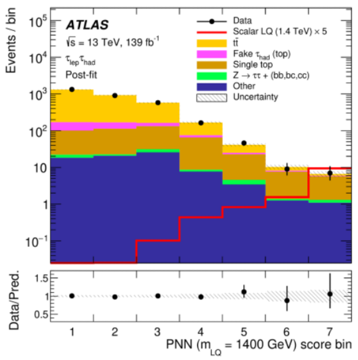
Scenario used for signal optimisation and observation/limit is:

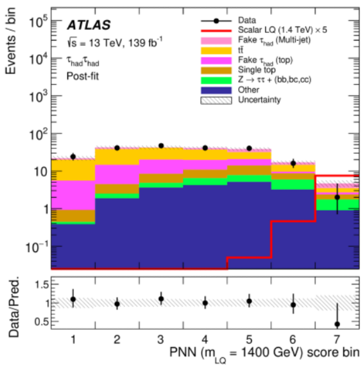
Third generation LQ pair production (coupling only to b,t,τ,ν) .

Q=2/3e. Scalar type LQ^{up}, Vector type U1.

LQ measurement done via a multivariant discriminant (PNN), trained on LQ^{up} signal with B (ratio of decay to ql vs qν)=1 where ql = bτ.

LQ pair production-optimised analysis





leptonic and hadronic tau decays equally relevant

	$\tau_{lep}\tau_{had}$ channel	$\tau_{had}\tau_{had}$ channel
$t\bar{t}$	2420 ± 90	93 ± 9
single-top	355 ± 27	20 ± 4
Fake τ_{had} (top)	170 ± 90	43 ± 18
$Z\to\tau\tau$ + (bb, bc, cc)	13.9 ± 2.4	10.3 ± 1.4
Multi-jet	–	22 ± 11
Other	78 ± 7	19 ± 5
Total Background	3040 ± 60	207 ± 13
Data	3031	211

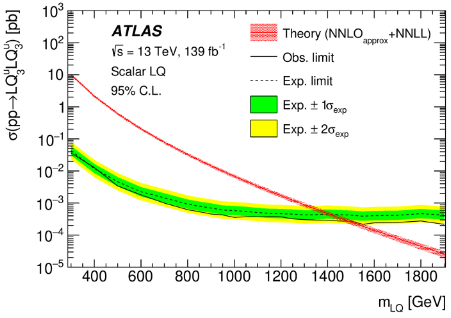
taken from simulation and scaled from data in control regions

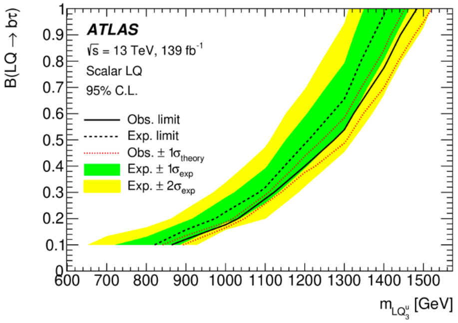
fully data-driven

	Obs. limit [GeV]	Exp. limit [GeV]
Scalar LQ	1490	1410
Vector LQ (minimal-coupling)	1690	1600
Vector LQ (Yang–Mills)	1960	1840

for B($b\tau$)=1

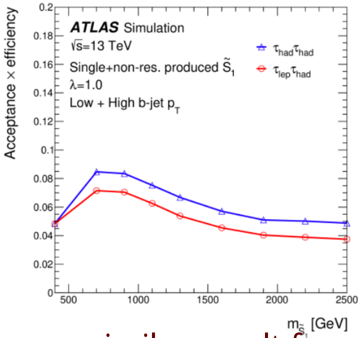
for B=1

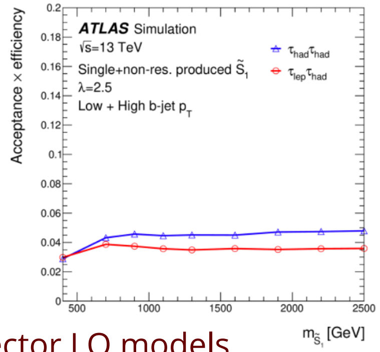




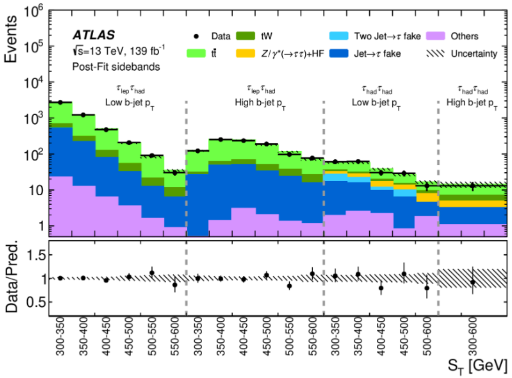
LQ single production-optimised analysis

arXiv:2305.15962





similar result for vector LQ models



Process	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
$t\bar{t}$	764 ± 82	9.9 ± 2.6
Single top	65 ± 35	3.9 ± 1.0
Jet→ τ *fake*	215 ± 79	3.9 ± 1.0
Two jet→ τ *fake*	–	1.34 ± 0.27
$Z(\rightarrow\tau\tau)$+HF jets	5.5 ± 0.4	4.6 ± 1.1
Others	9.7 ± 1.0	1.75 ± 0.30
Total	1059 ± 51	25.4 ± 4.9
Data	1053	29

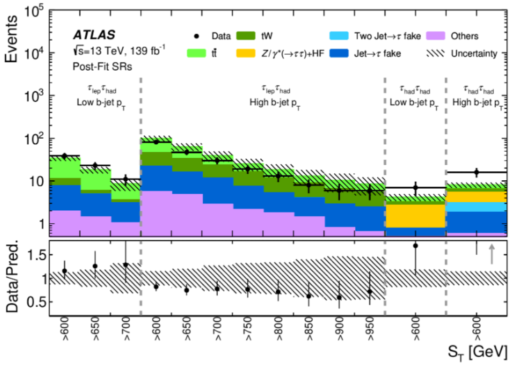
high bjet p_T Signal Region

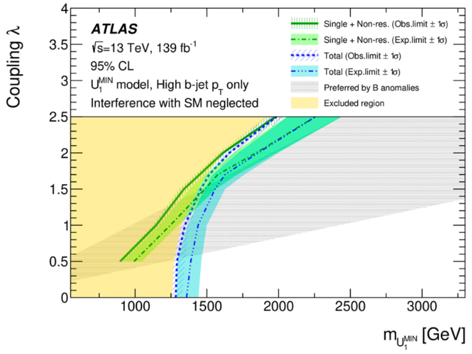
Scenario used for signal optimisation and observation/limit is:

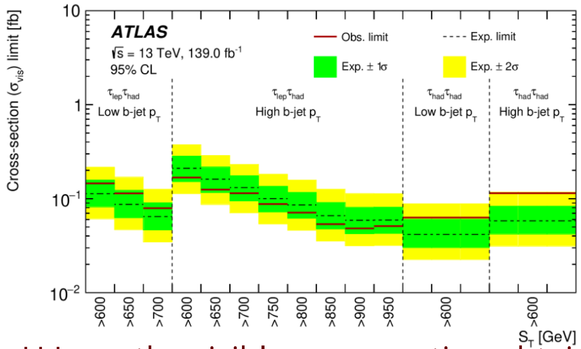
Third generation LQ single production. Vector type U1 , Q=2/3e; Scalar type LQ^{down}, Q=4/3e. B (relative coupling ql to qν)=0.5 or 1 for bτ respectively. Consider LQ pair production and non resonant in interpretation.

LQ measurement via fit to S_T variable. Main backgrounds: single top, tt, Z/W + jet faking tau decay.

LQ single production-optimised analysis







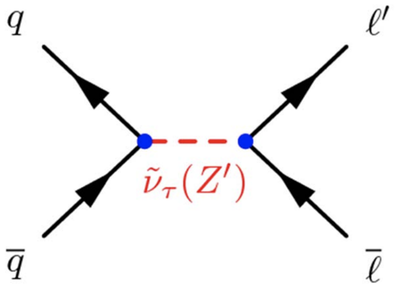
U.L. on the visible cross-section obtained from the model-independent search

Signal regions: split by tau decays (lep-had or had-had) and b jet p_T (more or less than 200 GeV). All: S_T>600 GeV. In high bjet p_T can neglect interference of non-resonant prod. with SM backgrounds.

Control regions: used to normalise top/single top and Z+HF and to measure tau (had) fake factor.

Validation regions : 300 <S_T< 600 GeV. Additional validation for multi-jets and Z+HF for had-had.

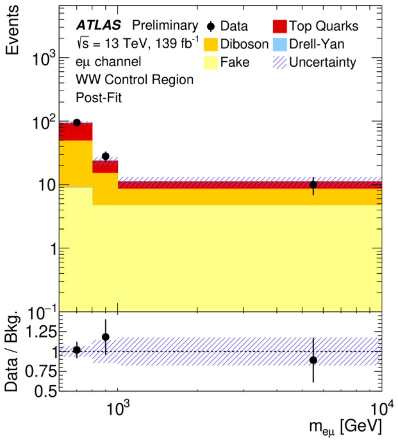
Heavy resonance →ll’

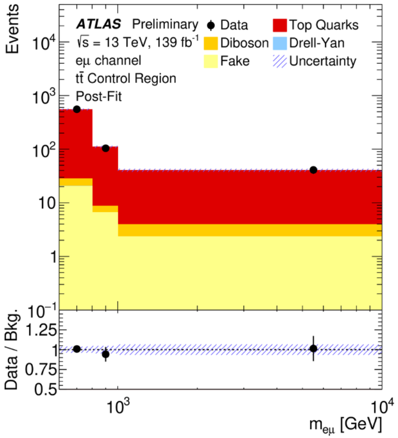


Region	Channels	Requirements
	Nominal $\Delta\phi_{\ell\ell'}$	
SR	$e\mu$, $e\tau$ and $\mu\tau$	$\Delta\phi_{\ell\ell'} > 2.7$, no b-jet, $m_{\ell\ell'} > 600$ GeV
$t\bar{t}$ CR	$e\mu$, $e\tau$ and $\mu\tau$	$\Delta\phi_{\ell\ell'} > 2.7$, at least one b-jet, $m_{\ell\ell'} > 600$ GeV
	Reversed $\Delta\phi_{\ell\ell'}$	
Low $\Delta\phi_{\ell\ell'}$ $t\bar{t}$ CR	$e\mu$	$\Delta\phi_{\ell\ell'} < 2.7$, at least one b-jet, $m_{\ell\ell'} > 600$ GeV
WW CR	$e\mu$	$\Delta\phi_{\ell\ell'} < 2.7$, no b-jet, $m_{\ell\ell'} > 600$ GeV

correction factors for simulated WW and top backgrounds measured in CR

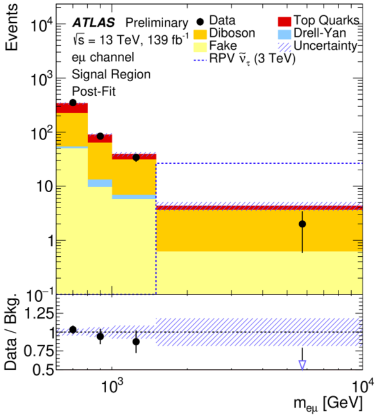
Process	$e\mu$ channel	$e\tau$ channel	$\mu\tau$ channel
Top Quarks	151±15	114±10	79.4±6.4
Diboson	246±28	125±27	94±20
Fake	66±11	172±34	67±25
Drell–Yan	8.62±0.45	76.1±8.9	78.0±7.9
Total background	471±21	488±21	319±16
Data	470	499	319

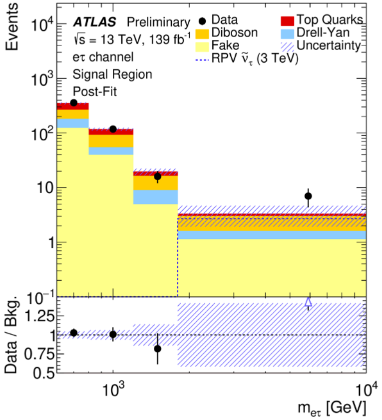


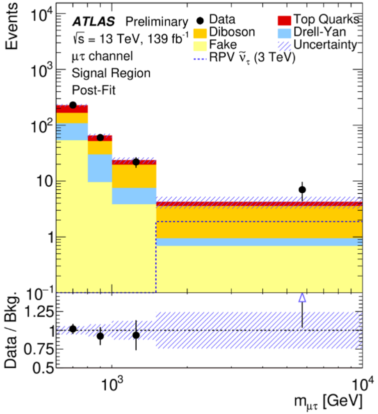


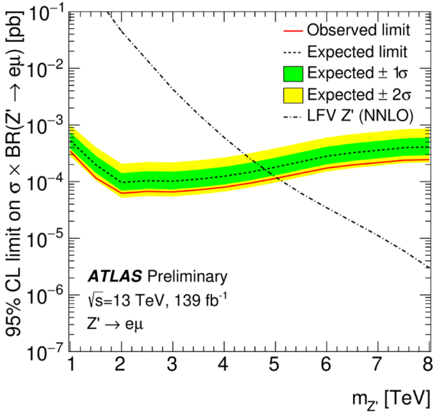
fake: multi-jet and W+jet. Data driven estimate using matrix method (eμ) or extrapolation from CR to SR.

Heavy resonance →ll’

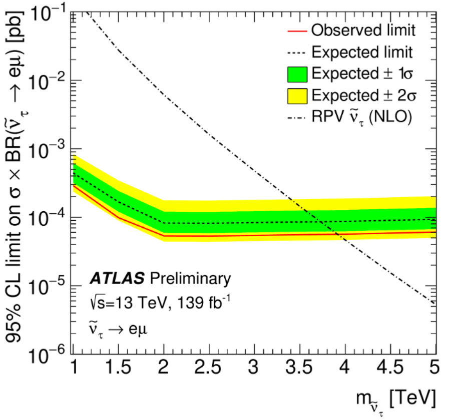






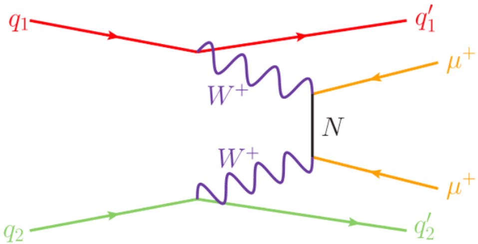


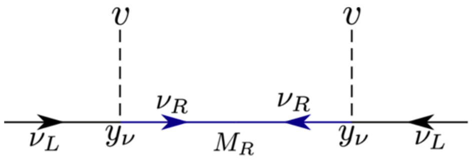
Model	Observed (expected) 95% CL lower limit [TeV]		
	$e\mu$ channel	$e\tau$ channel	$\mu\tau$ channel
LFV Z'	5.0 (4.8)	4.0 (4.3)	3.9 (4.2)
RPV SUSY $\tilde{\nu}_\tau$	3.9 (3.7)	2.8 (3.0)	2.7 (2.9)
QBH ADD $n = 6$	5.9 (5.7)	5.2 (5.5)	5.1 (5.2)
QBH RS $n = 1$	3.8 (3.6)	3.0 (3.3)	3.0 (3.1)



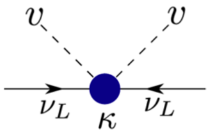
Heavy Majorana neutrinos

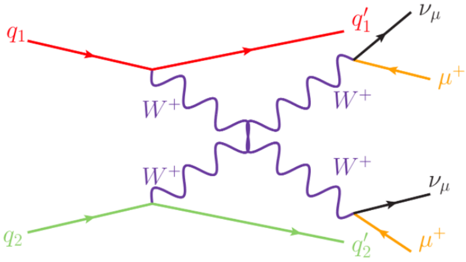
arXiv:2305.14931





νμ N νμ





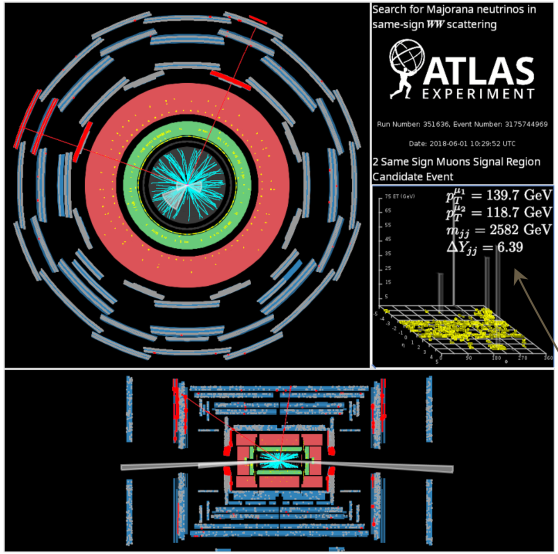
main background

Two benchmark scenarios:

- Phenomenological Type-I Seesaw model, heavy Majorana neutrino couples to SM particles through mass-mixing with light neutrinos ($V_{\mu N}$ or y_ν). two free parameters: M_R and y_ν.
- d=5 extension of the SM with coefficient $C^5_{\mu\mu}$ and scale Λ

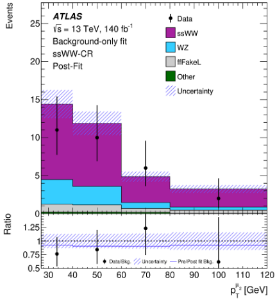
$$\mathcal{L}_5 = \frac{C_5^{\ell\ell'}}{\Lambda}[\Phi\cdot\overline{L}_\ell^c][L_{\ell'}\cdot\Phi],$$

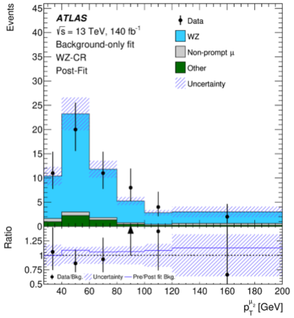
Heavy Majorana neutrinos

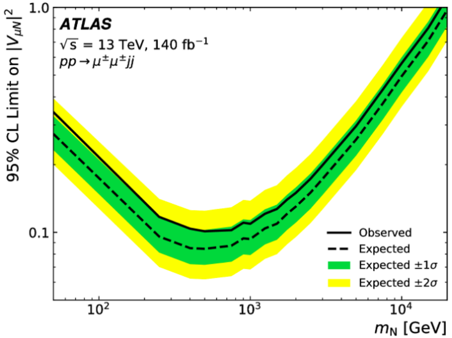


Observable	SR	ssWW-CR	WZ-CR
Same-sign muons	= 2 (signal μ)		
Number of b-jets	= 0		
m_{jj}	> 300 GeV		
$\lvert\Delta y_{jj}\rvert$	> 4		
Third lepton (OS)	= 0 (baseline)	= 0 (baseline)	= 1 (signal μ)
E_T^{miss} signif. $\mathcal{S}$	< 4.5	> 5.8	< 4.5
$m_{\ell\ell\ell}$	—	—	> 100 GeV
$p_T^{\mu_2}$	—	< 120 GeV	—

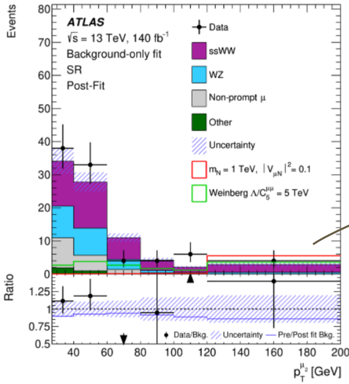
high p_T (μ_2) is the discriminant







accessible range
50 GeV - 20 TeV
via VBS process



4 observed
3 expected

Outlook

The Run 2 dataset allows us to test several models predicting lepton flavour universality violation.

More analyses have been released recently :

- search for heavy right-handed Majorana or Dirac neutrinos N_R and heavy right-handed gauge bosons W_R in left-right symmetric models [arXiv:2304.09553]
- first searches for tau lepton compositness:
  - excited τ leptons τ* [arXiv:2303.09444]
  - vector-like τ and ν_τ leptons [arXiv:2303.05441], excluded in the mass range from 130 GeV to 900 GeV

The LHC allows to test several BSM effects in the lepton sector and to challenge the SM assumptions.

Look forward to more results with more data from Run 3!