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

Corfu2022: Workshop on the Standard Model and Beyond

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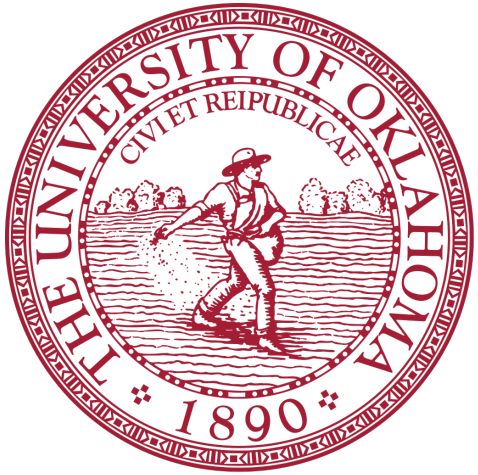
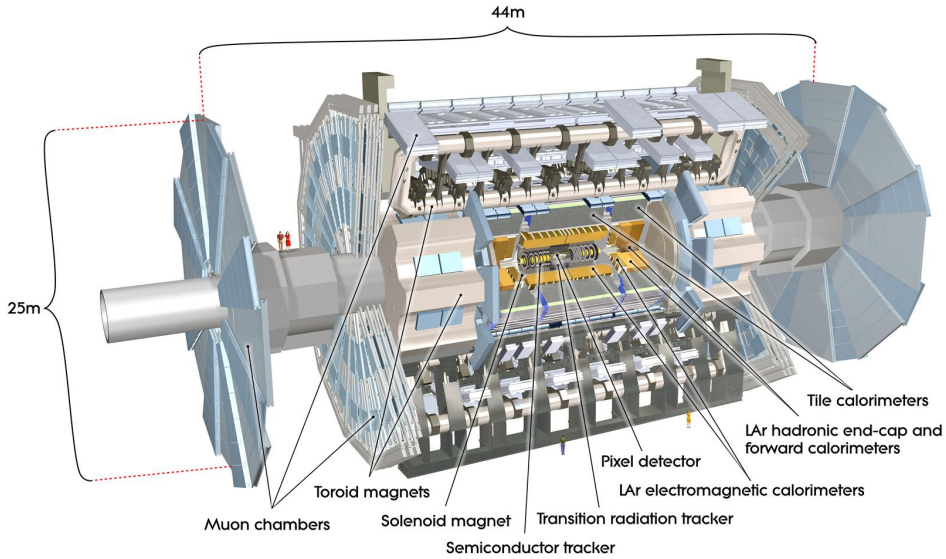
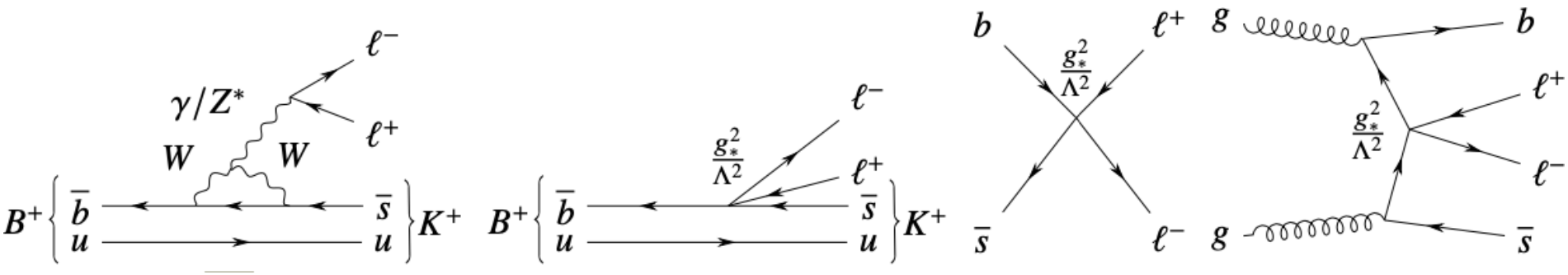


BSM physics in leptonic final states at ATLAS

- There are many interesting BSM scenarios to study with leptonic final states. To name a few:
  - Lepton flavor universality violation (LFV)
  - Enhancements to rare decays of B mesons
  - Seesaw mechanism to explain the origin of neutrino mass
- 2 strategies for BSM searches with the ATLAS experiment:
  - Direct searches for heavy resonances
    - Type-III seesaw mechanism
    - Vectorlike tau
    - Combination of searches for heavy resonances
    - Heavy resonances in $\tau + E_{\mathrm{T}}^{\mathrm{miss}}$
  - Precision measurements
    - $2\ell + 0$ or 1 b jet
    - $e^{\pm}\mu^{\mp}$ asymmetry

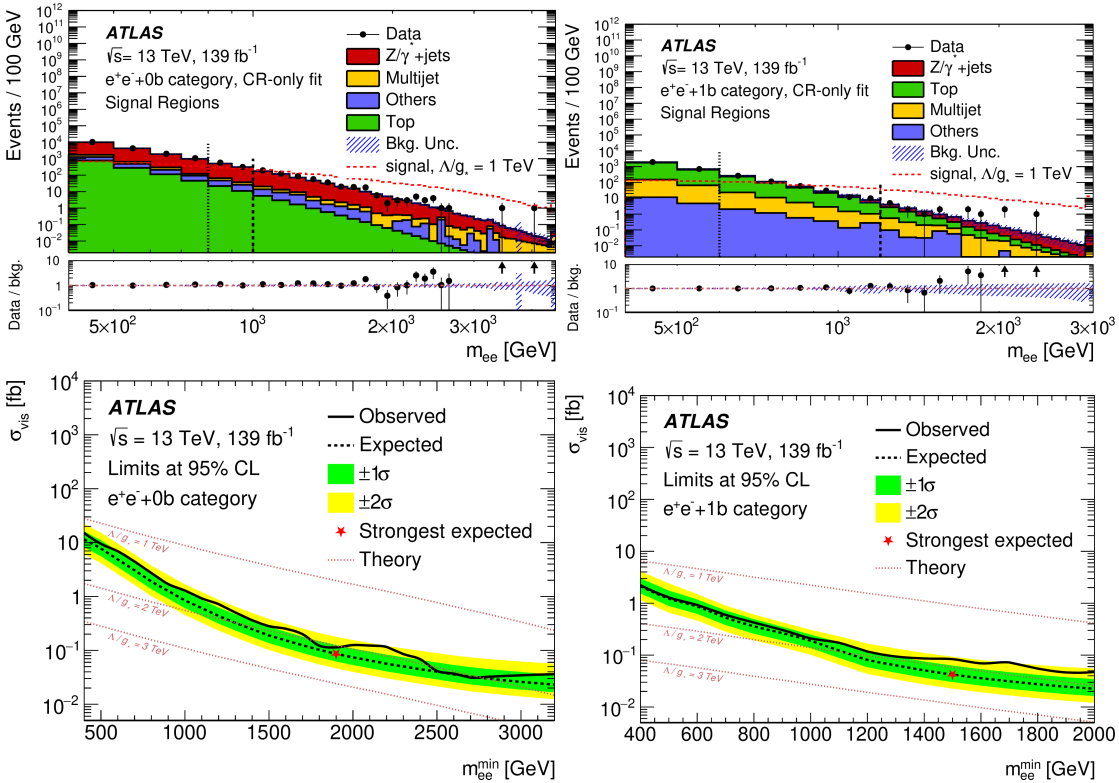


Two leptons, 0-1 b-jets



- Rare decays of B mesons, e.g. $bs\ell\ell$, may violate lepton flavor universality in BSM scenarios
- Recent results from LHCb suggest tension with the SM in rare B decays that can be explained by LFV
- BSM contribution to $bs\ell\ell$ was modelled by a 4-point EFT with two parameters: coupling g_* and BSM energy scale Λ
- Measurement of $\ell^{\pm}\ell^{\mp}$ (same-flavor light leptons) with 0 or 1 b jet
- Major backgrounds are Z+jets (0 b-jet channel) and top physics (1 b-jet channel)

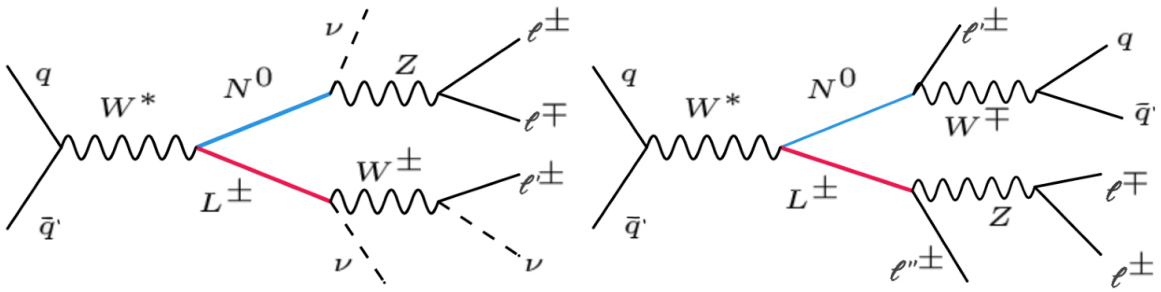
Two leptons, 0-1 b-jets results



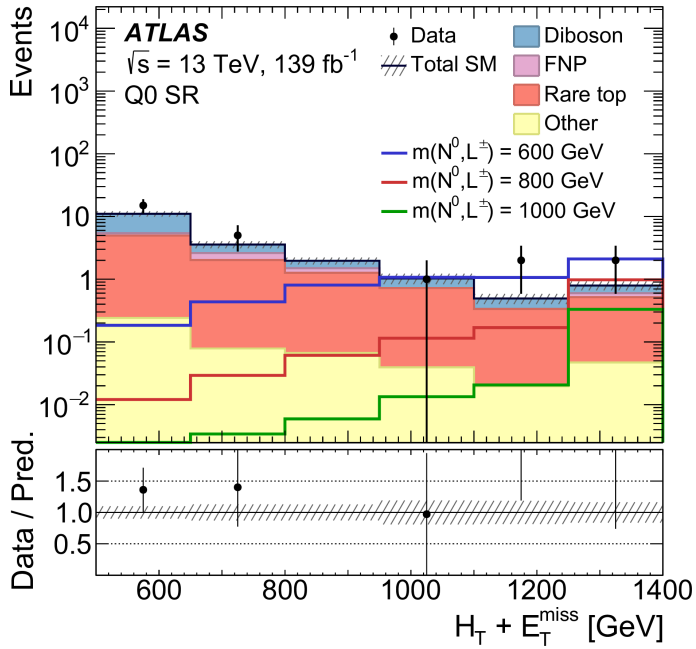
- No significant deviation from SM expectations was observed
- Upper limits for the $bs\ell\ell$ EFT model were determined separately in e and μ channels:
  - Observed limit for electron channel is $\Lambda/g_* < 2.0$ TeV at the 95% CL
  - Observed limit for muon channel is $\Lambda/g_* < 2.4$ TeV at the 95% CL
- Recent results from LHCb indicate tension with SM in $bs\ell\ell$ corresponding to $\Lambda/g_* \approx 30$ TeV

Search for type-III seesaw

- Search for a triplet under $SU(2)_{\mathrm{L}}$ of charged heavy leptons $L^{\pm}$ and a neutral Majorana neutrino N^0 coupled to EW gauge bosons
- Combination of 5 signal regions with 3 or 4 leptons
- Major backgrounds are from top physics, diboson, and misidentified photons (estimated with fake factor method)
- Likelihood fit to $m_{\mathrm{T},3\ell}$ in 3 lepton regions and $H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$ in 4 lepton regions ($H_{\mathrm{T}} \equiv \sum p_{\mathrm{T}}(\ell)$)



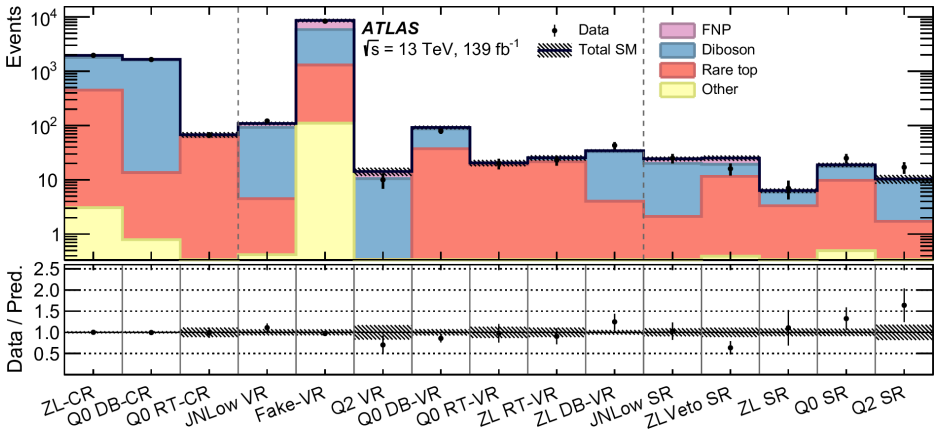
Production modes for 3 and 4 lepton channels

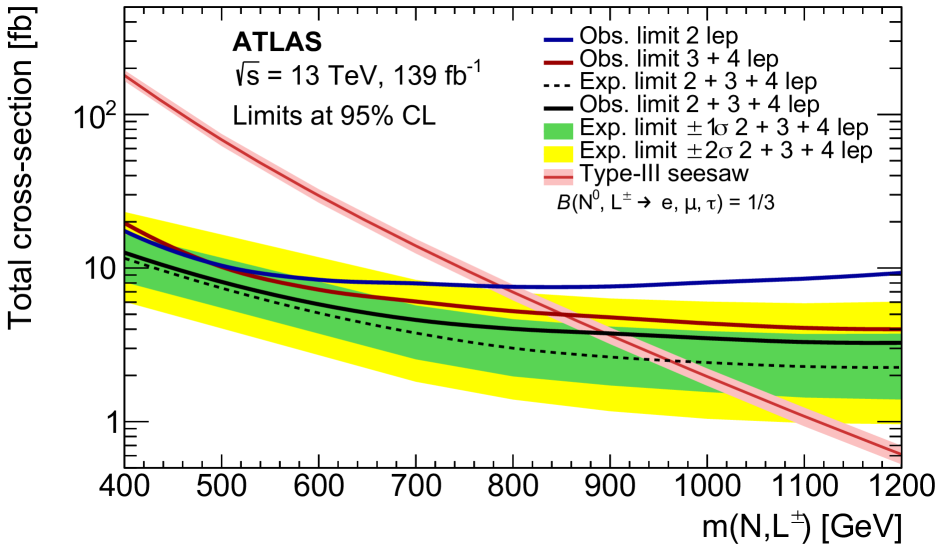


$H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$ in 4ℓ channel with $\sum_{i=1}^{4} Q(\ell_i) = 0$

Search for type-III seesaw results

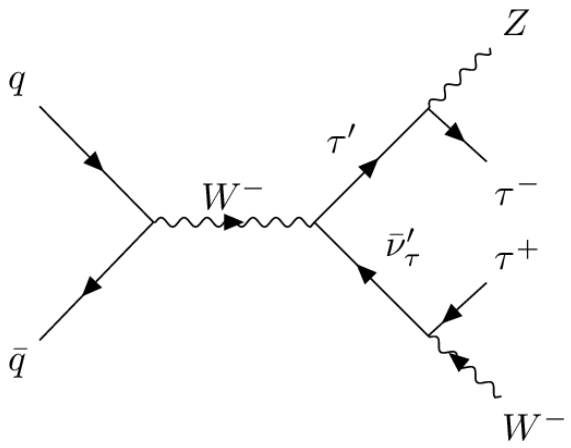
- No significant deviation from the SM was observed
- Expected upper mass limit on $L^{\pm}$ mass is 900 $\pm$ 80 GeV at the 95% CL
- Observed upper mass limit on $L^{\pm}$ mass is 870 GeV at the 95% CL



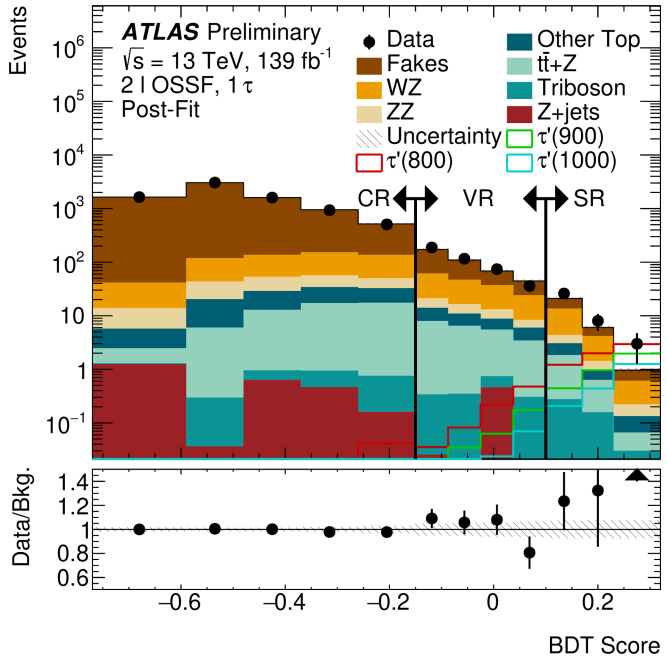


Search for vectorlike taus

- Search for vectorlike leptons τ', ν' (mass-degenerate) having large mixing with third generation leptons τ, ν_τ
- Vectorlike taus appear in many BSM theories including rare B meson decay anomalies
- Combination of 7 signal regions with at least 2 light leptons and 0 or 1 hadronic τ
- Major backgrounds are from top physics, diboson, and misidentified leptons/taus (estimated with fake factor method)
- Vectorlike signal separated from SM backgrounds using boosted decision trees (BDT)

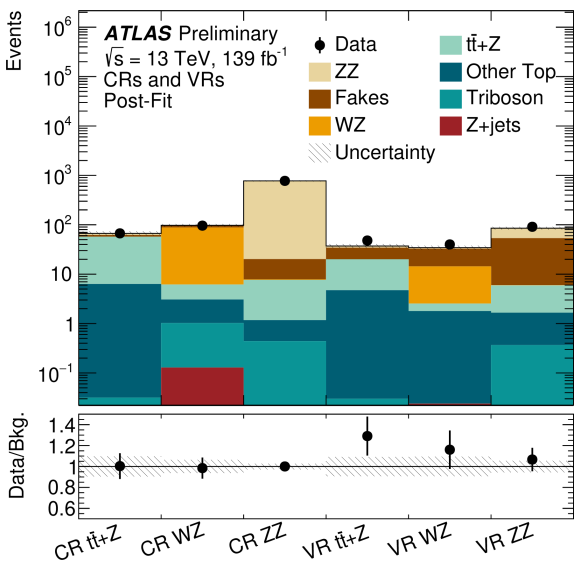


Dominant production mode $pp \to \tau'\nu'$

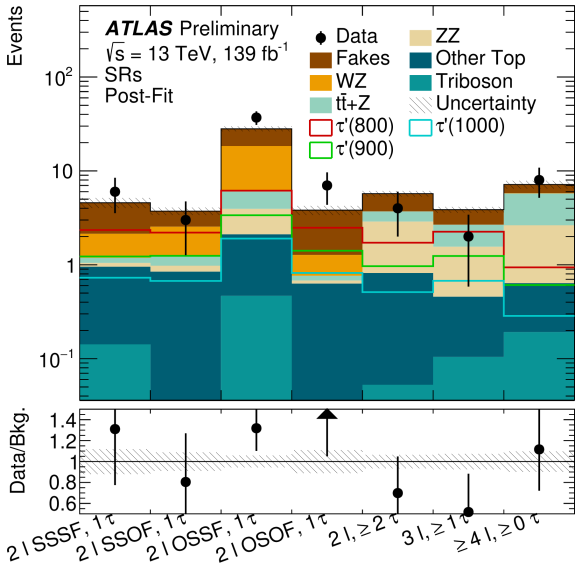


BDT score for 2ℓ OSSF + τ_{had} events

Search for vectorlike taus results

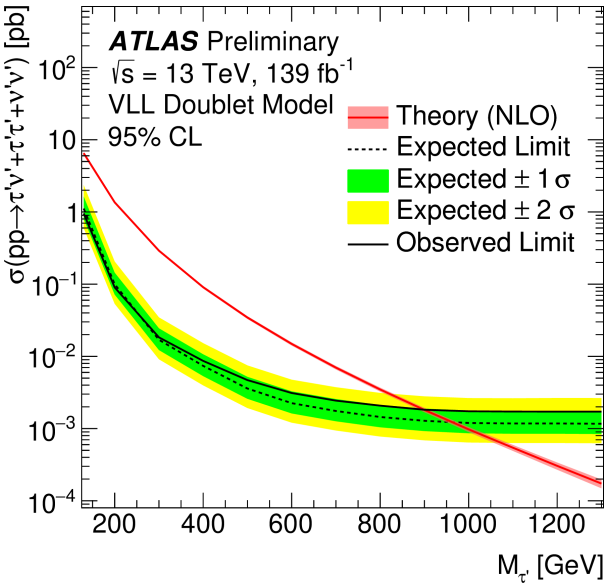


Control+validation regions



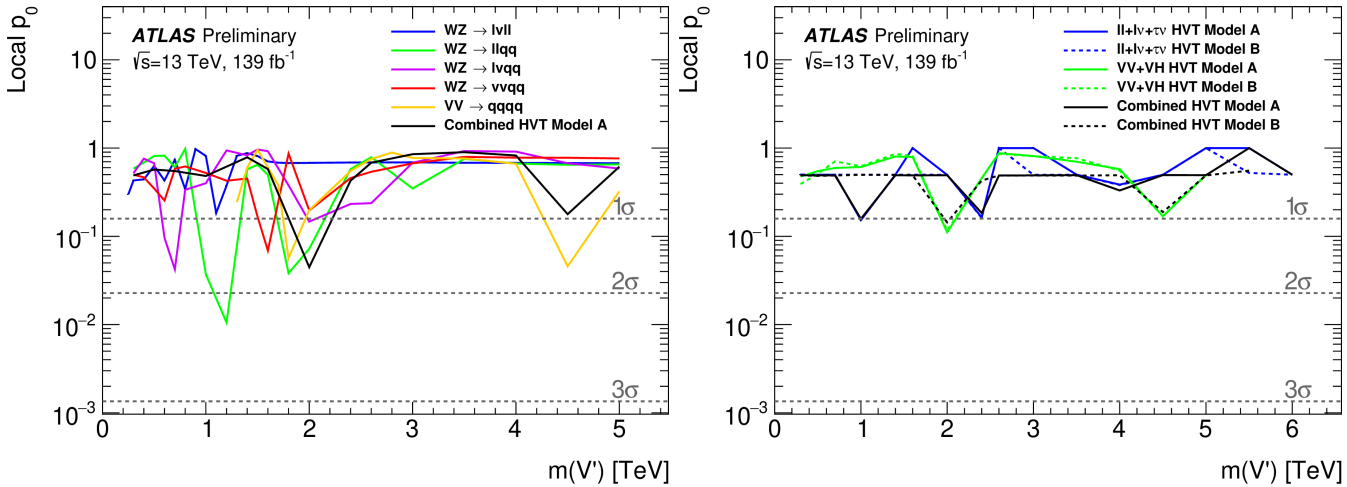
Signal regions

- No significant deviation from the SM was observed
- 970 GeV expected upper limit on τ', ν' mass at the 95% CL
- 130 - 900 GeV mass range excluded by observed limits at the 95% CL

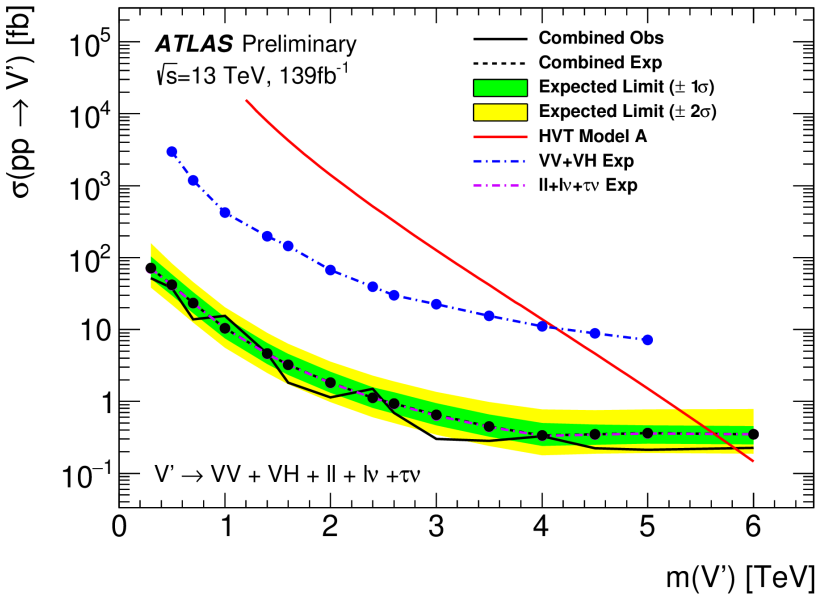


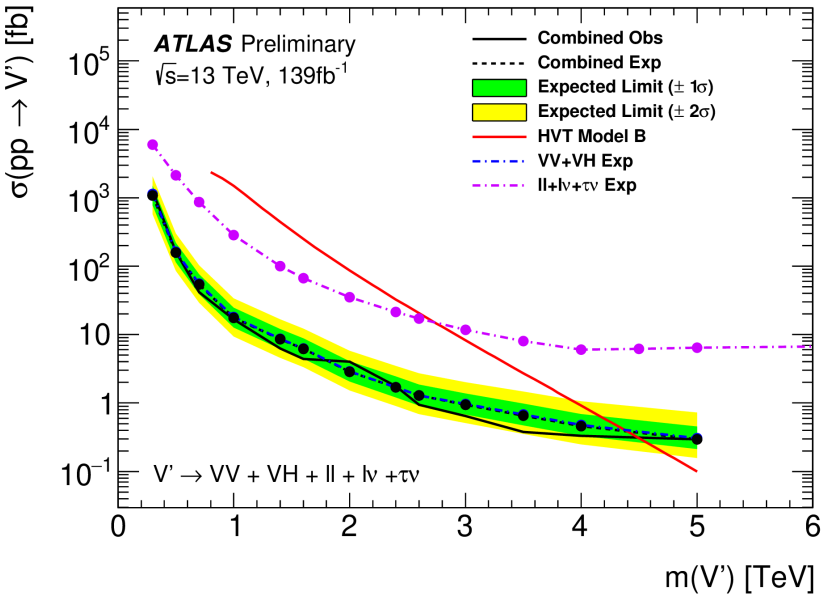
Combination of searches for heavy resonances

- Direct searches for high mass resonances are a staple of the LHC physics program
- Results from orthogonal ATLAS analyses in the following channels are statistically combined:
  - $WZ \to qqqq, \nu\nu qq, \ell\nu qq, \ell\ell qq, \ell\nu\ell\ell$
  - $WH \to qqbb, \ell\nu bb$
  - $ZH \to \nu\nu bb, \ell\ell bb$
  - $\ell\ell, \ell\nu, \tau\nu$
- Interpretation with spin-1 mass-degenerate heavy vector triplet model ($W'^{\pm}, Z'$)
  - Weakly-coupled model (model A): couplings $g_H = -0.56$, $g_f = -0.55$
  - Strongly-coupled model (model B): couplings $g_H = -2.9$, $g_f = 0.14$



Combination of searches for heavy resonances 1D limits

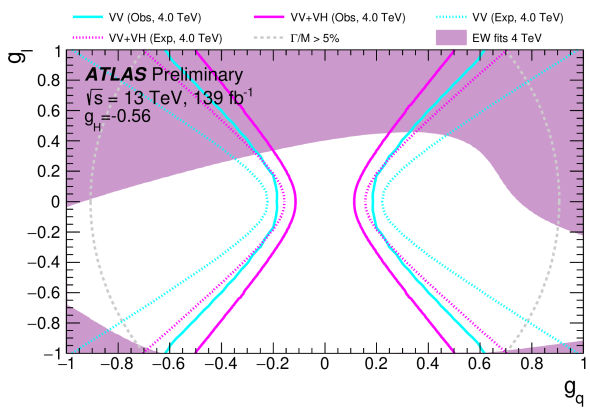


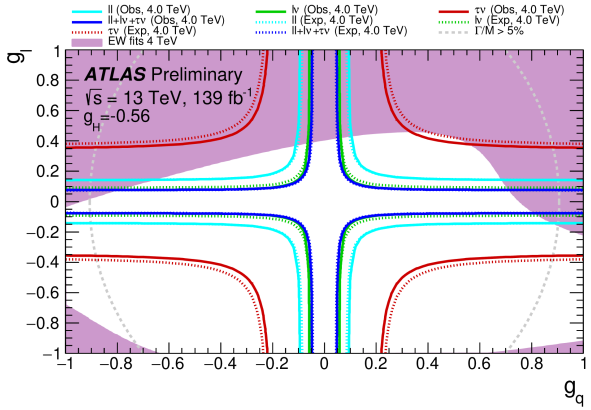


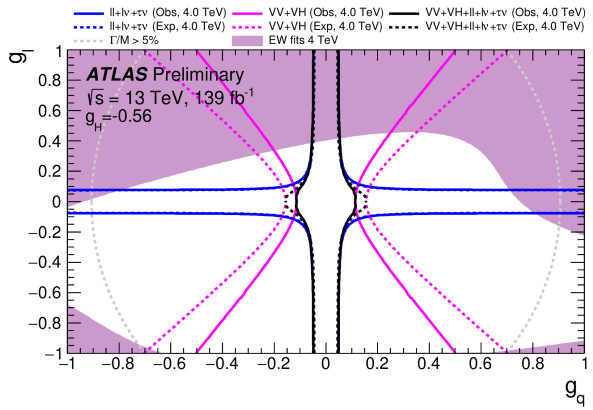
- No significant deviation from the SM is observed
- Observed limits at the 95% CL on V' mass are 4.5 TeV for a weakly-coupled HVT model and 5.8 TeV strongly-coupled HVT model

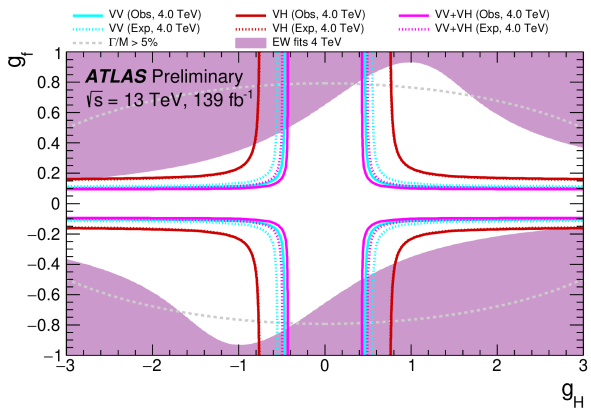
Combination of searches for heavy resonances 2D limits

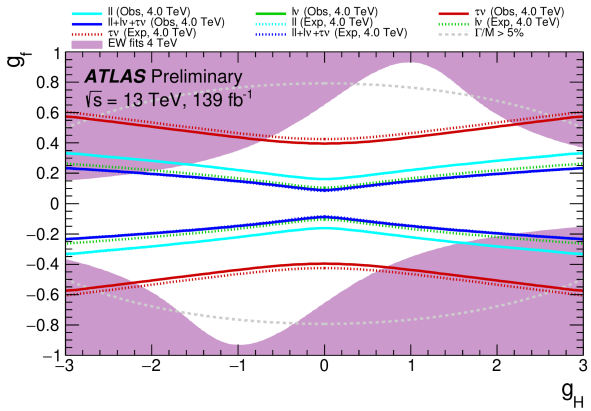
- No significant deviation from the SM (i.e. $g_f = g_q = g_l$) is observed
- Limits on combinations of V' couplings g_f, g_H, g_l, g_q are derived for individual channels and combinations

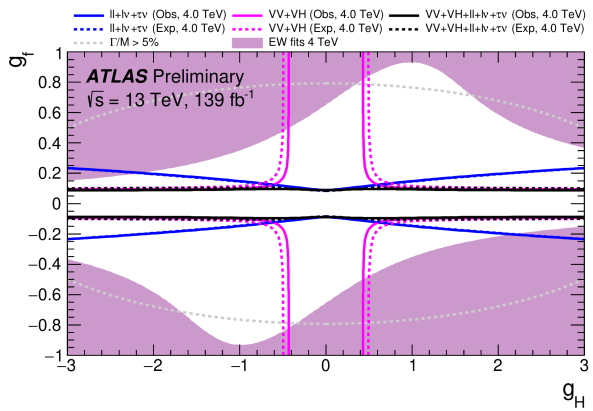






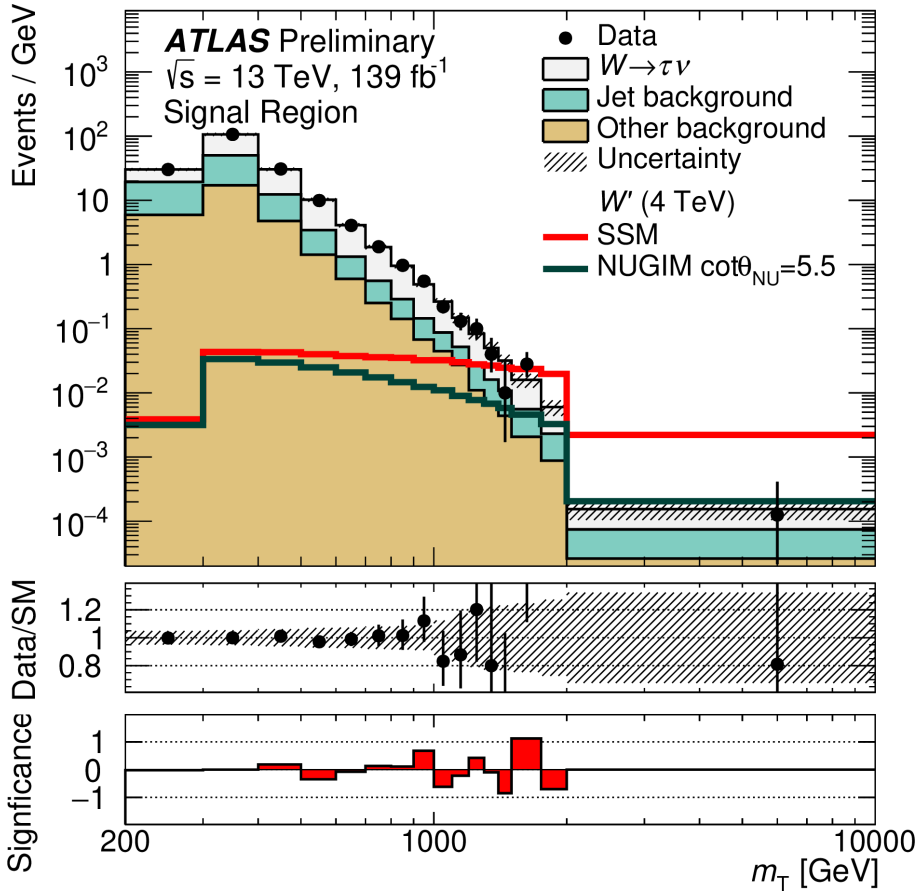






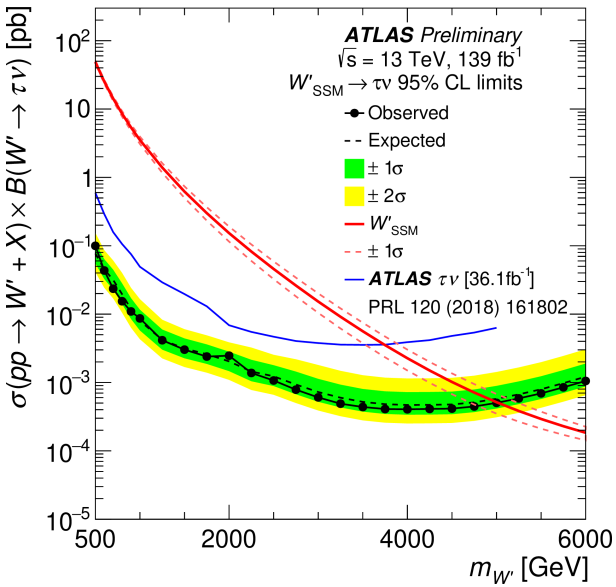
High-mass resonances with $\tau + E_{\mathrm{T}}^{\mathrm{miss}}$

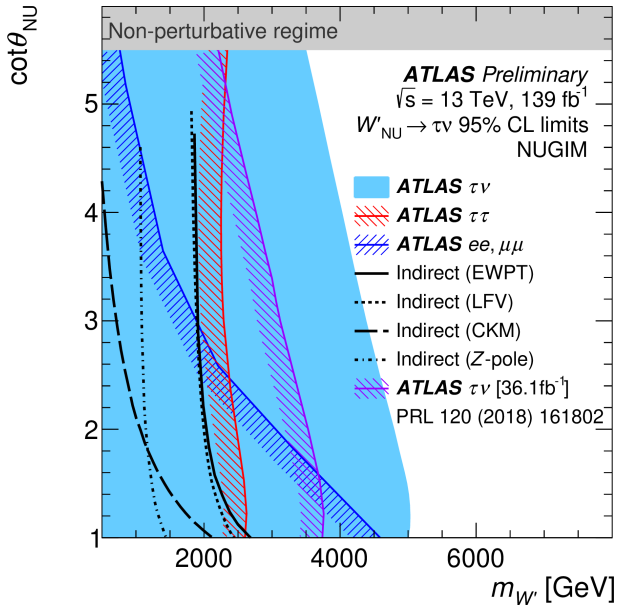
- Undiscovered heavy gauge bosons may be a source of lepton flavor universality violation
- Searches for various heavy gauge boson models decaying to tau leptons
  - Sequential Standard Model (SSM): W', Z' couplings to fermions are identical to those of SM W, Z
  - Non-universal gauge interaction models (NUGIM): W', Z' couplings to fermions vary across the three lepton generations
- One signal region with $E_{\mathrm{T}}^{\mathrm{miss}} < 150$ GeV and $0.7 < p_{\mathrm{T}}(\tau)/E_{\mathrm{T}}^{\mathrm{miss}} < 1.3$
- Major backgrounds are $W \to \tau\nu$ and multijet (estimated using events that fail τ ID requirements)

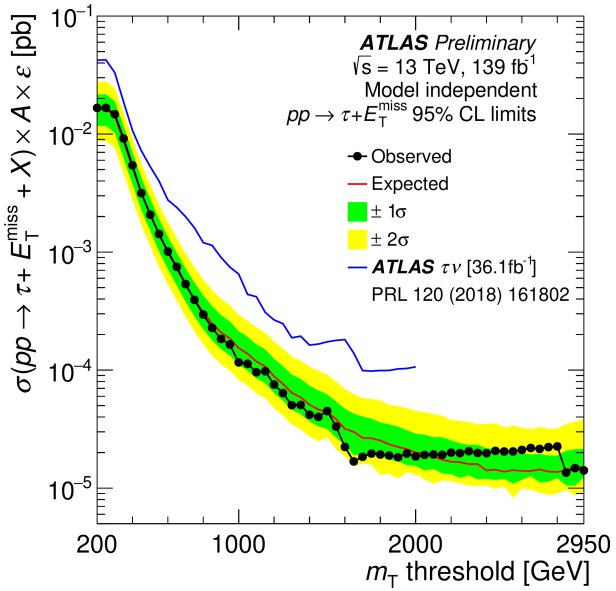


High-mass resonances with $\tau + E_{\mathrm{T}}^{\mathrm{miss}}$ results

- No significant deviation from the SM was observed
- Observed upper limit on W' mass under the SSM is 5.0 TeV at the 95% CL
- Observed upper limits on W' mass under NUGIM are 3.0-5.0 TeV (depending on model parameters) at the 95% CL
- Model-independent observed upper limits on the visible cross section for $\tau + E_{\mathrm{T}}^{\mathrm{miss}}$ production range from 0.0141-16.7 fb depending on the transverse mass threshold





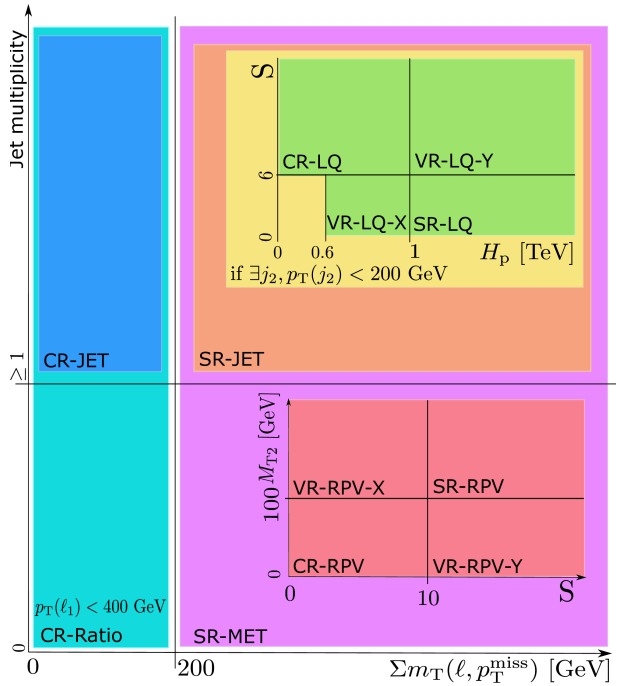


$e^{\pm}\mu^{\mp}$ asymmetry

- Measurement of

$$\rho = \frac{\sigma(pp \to e^+\mu^-)}{\sigma(pp \to e^-\mu^+)}$$

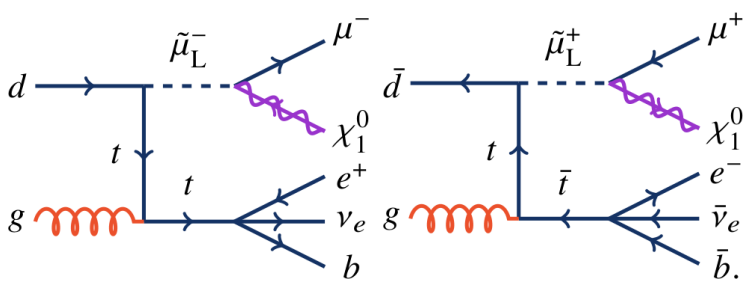
  as a test of lepton universality
- Major backgrounds are top physics, diboson, and fake leptons (estimated with matrix method)
- Signal region definitions are based on flavor-symmetric variables $\mathcal{S}$, M_{T2}, and H_{P}



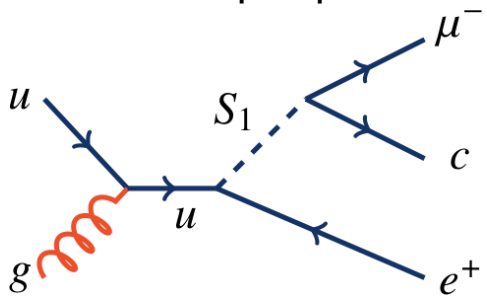
Region definitions in phase space

Two BSM models considered to give $\rho \neq 1$:

- *R*-parity violating supersymmery

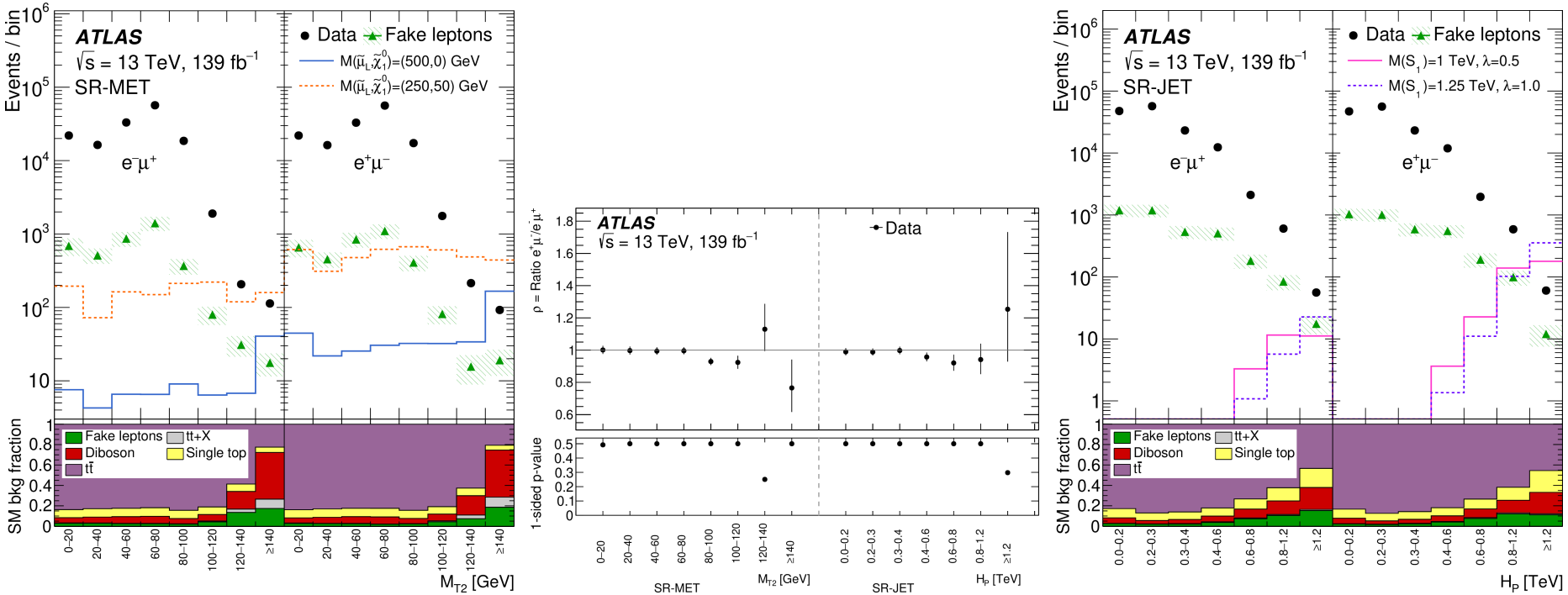


- Scalar leptoquarks with $g_{1R}^{e\mu} = g_{1R}^{\mu c} \leq 1$

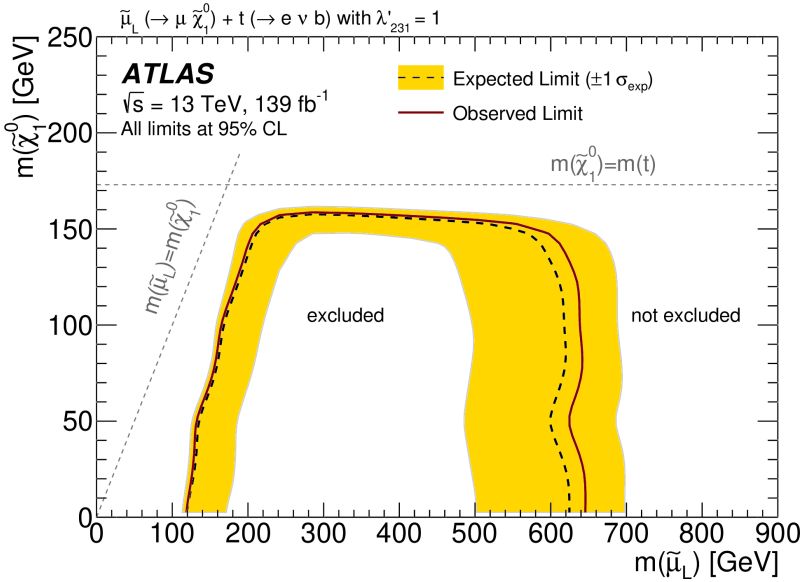


$e^{\pm}\mu^{\mp}$ asymmetry results

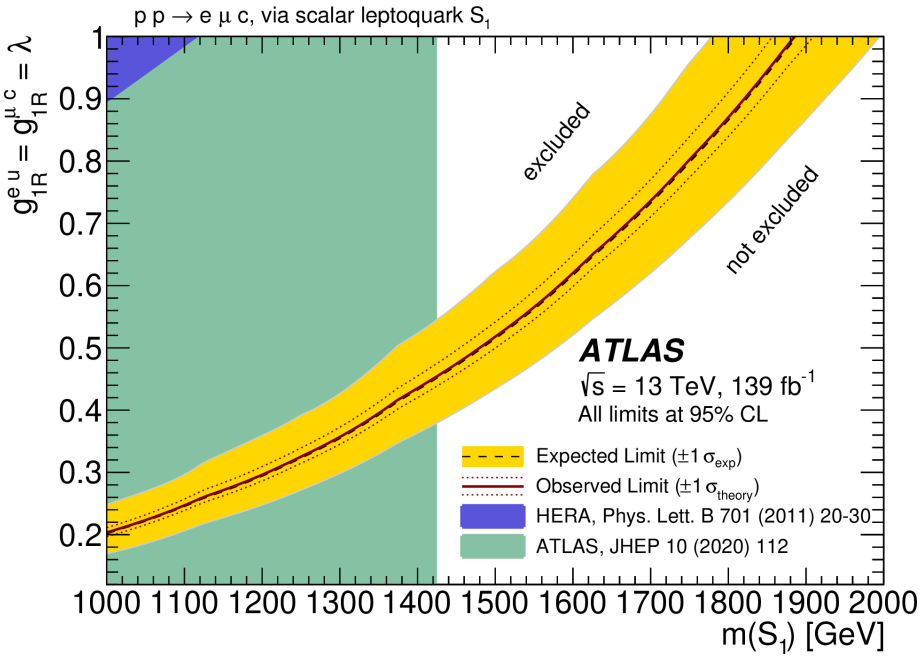
- No significant deviation from the SM (i.e. $\rho = 1$) was observed



$e^{\pm}\mu^{\mp}$ asymmetry BSM results



Limits on R-parity violating supersymmetry (λ'_{231} fixed at unity)



Limits on scalar leptoquark model

- Limits at 95% CL for R-parity violating SUSY model are reported for various values of coupling parameter λ'_{231}, smuon mass $m(\tilde{\mu}_L)$, and neutralino mass $m(\tilde{\chi}_1^0)$
- Observed upper limit on mass of scalar leptoquarks is 1880 GeV at 95% CL
- Other leptoquark analyses place limits near 1420 GeV, at which $g_{1R}^{e\mu} = g_{1R}^{\mu c}$ reduces to 0.46

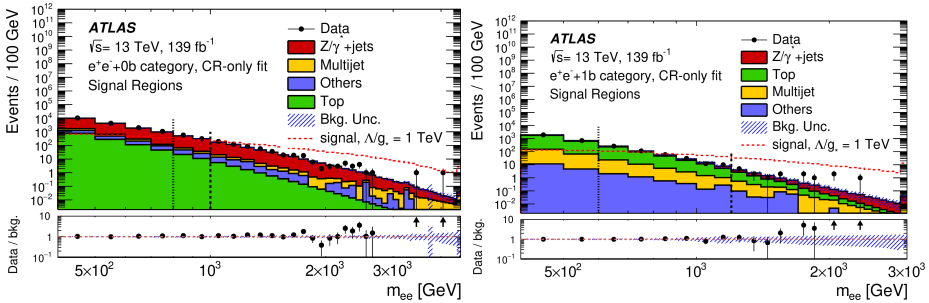
Summary

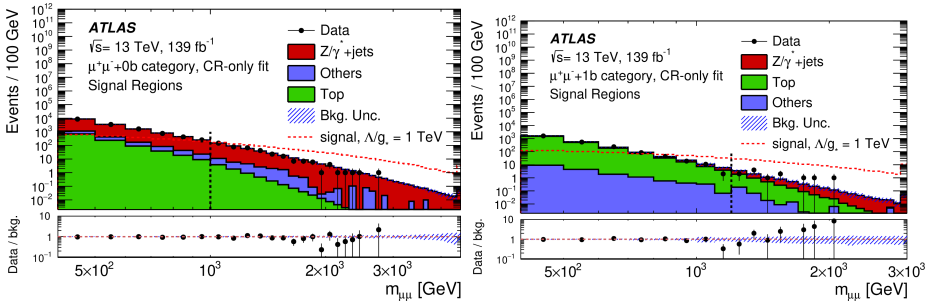
- No significant deviations from the SM were observed by ATLAS in leptonic channels
- Limits were set at the 95% CL for BSM models including:
  - Vectorlike tau
  - Type-III seesaw
  - R-parity violating SUSY
  - Scalar leptoquarks
  - Heavy vector triplet
  - Sequential Standard Model
  - Non-universal gauge interaction models
  - EFT enhancements to $bs\ell\ell$
- Check the ATLAS Exotics and HDBS public TWikis for more!

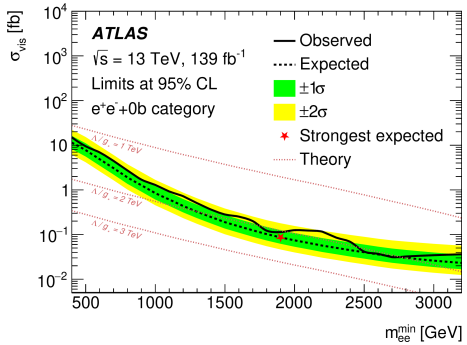
Thank you!

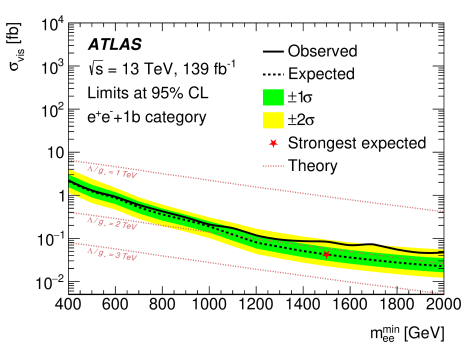
Backup

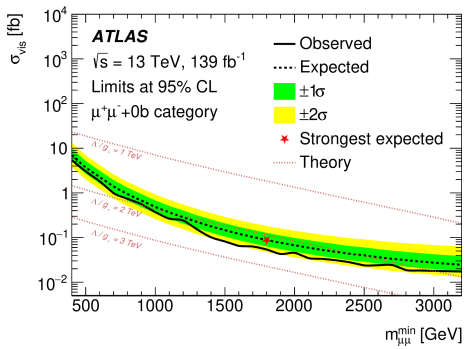
2 leptons + 0 or 1 b jet results

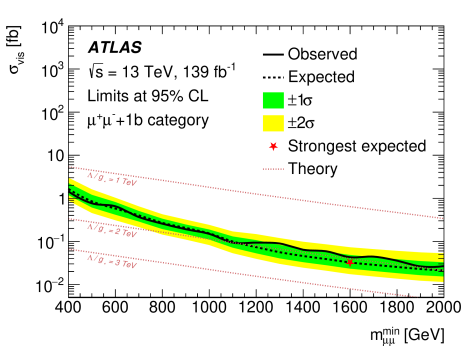












$e^{\pm}\mu^{\mp}$ asymmetry flavor-symmetric variables

- $\mathcal{S}$: "object-based $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$ significance" (see ATLAS-CONF-2018-038)

$$\mathcal{S}^2 = 2\ln\left(\frac{\max_{\mathbf{p}_{\mathrm{T}}^{\mathrm{invis}}\neq 0}\mathcal{L}(\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|\mathbf{P}_{\mathrm{T}}^{\mathrm{invis}})}{\max_{\mathbf{p}_{\mathrm{T}}^{\mathrm{invis}}=0}\mathcal{L}(\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|\mathbf{P}_{\mathrm{T}}^{\mathrm{invis}})}\right)$$

  where the likelihoods in the numerator and denominator are maximized w.r.t. the constraints $p_{\mathrm{T}}^{\mathrm{invis}} \neq 0$ and $p_{\mathrm{T}}^{\mathrm{invis}} = 0$ respectively

- $M_{\mathrm{T2}} = \min_{\vec{a}+\vec{b}=\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}} \max\left[m_{\mathrm{T}}(e,\vec{a}), m_{\mathrm{T}}(\mu,\vec{b})\right]$ where $\vec{a}$ and $\vec{b}$ represent the contributions to $p_{\mathrm{T}}^{\mathrm{miss}}$ from each semi-leptonic decay of a pair-produced particle

- $H_{\mathrm{P}} = |\vec{p}_{\mathrm{T}}^{\,e}| + |\vec{p}_{\mathrm{T}}^{\,\mu}| + |\vec{p}_{\mathrm{T}}^{\,j_1}|$

Other searches for scalar leptoquarks

- Some recent searches for leptoquarks by ATLAS:
  - ATLAS-CONF-2022-009: Scalar/vector leptoquarks decaying to 3rd generation quarks and light leptons
  - ATLAS-CONF-2022-037: Scalar leptoquarks in $b\tau\tau$ final states
  - ATLAS-CONF-2022-052: Leptoquark pairs decaying to $t\ell^{-}\bar{t}\ell^{+}$