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

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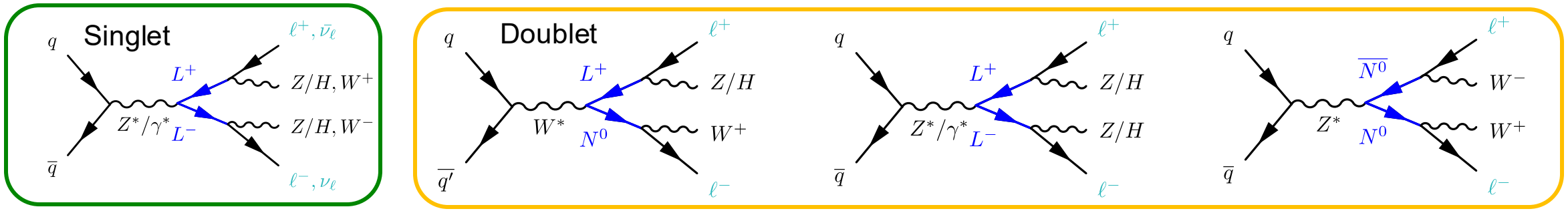
On behalf of the ATLAS collaboration

Overview

- Emphasis on new analyses
  - Vector-like leptons (VLL)
  - Vector-like quarks (VLQ)
  - Leptoquarks (LQ)
- All results use ~140 fb^{-1} of data from Run-2 with one very new results which also uses full Run-2 and partial Run-3 data
- This talk excludes leptonic final states from long-lived particles
  - See talk on Searches for unusual signatures in leptonic/missing energy channels with the ATLAS detector by E. Woodward in T09 session on Monday afternoon
- Many more results to be found in ATLAS public pages

Search for VLL in 1st and 2nd generation SM leptons

- Search for pair-produced VLLs
  - Model: SU(2) singlet or doublet extension of SM, coupling to 1st/ 2nd generation SM leptons

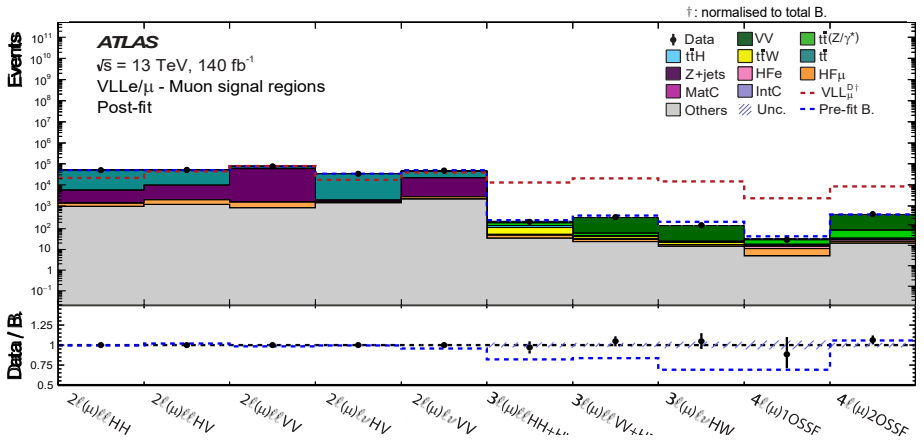


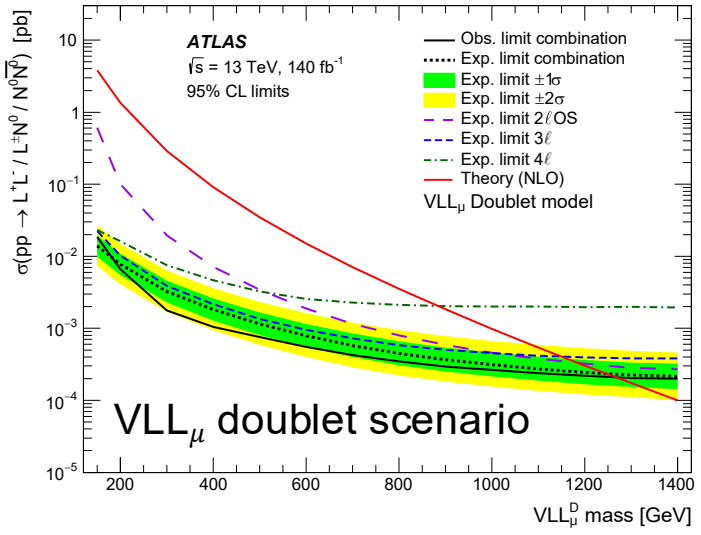
- Search in final states with 2 opposite-sign leptons (e or μ), possibly 1 or 2 additional leptons in VLL mass range between 150 GeV and 1600 GeV
  - $2\ell/3\ell$: neural network multi-class DNN classifier
  - 4ℓ: cut-and-count analysis
  - Plus, selections based on E_T^{miss} and number of b/light jets
- Main SM backgrounds: $t\bar{t}$, Z+jets, $t\bar{t}$ W, $t\bar{t}$ Z, ZZ

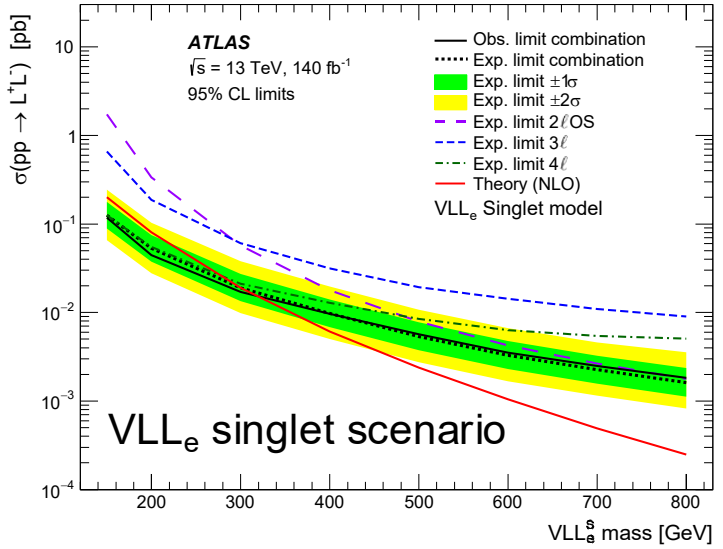
Search for VLL in 1st and 2nd generation SM leptons

- Maximum likelihood fit performed across SRs simultaneously with CRs to constrain SM backgrounds
  - Main discriminant: H_T^{lep} + E_T^{miss}
  - Main systematics: Z+jets modelling, signal PDF and scale variations
  - Statistically limited analysis
- 95% CL exclusion limits
  - Doublet scenario
    - m(VLL_μ) < 1270 GeV
    - m(VLL_e) < 1220 GeV
  - Singlet scenario
    - m(VLL_μ) < 400 GeV
    - m(VLL_e) < 320 GeV

Post-fit event counts in VLL_μ SRs

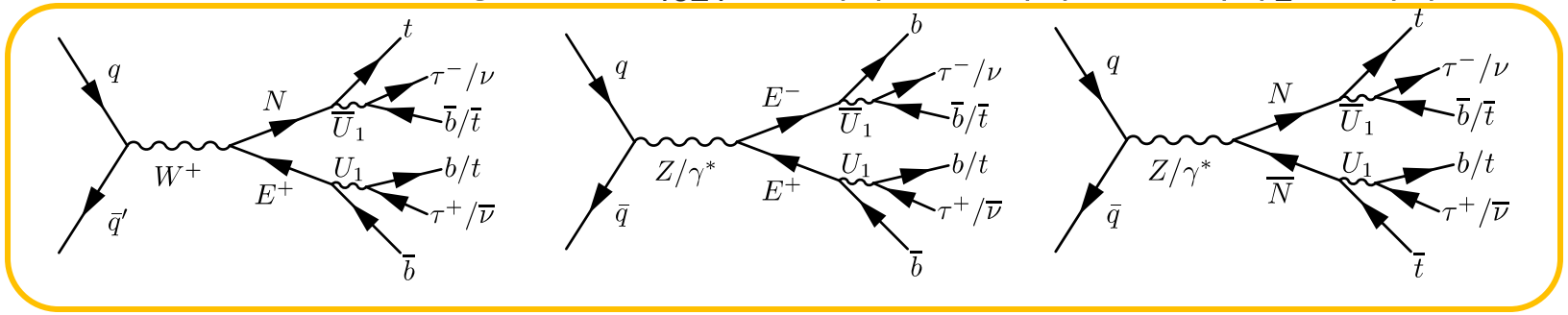






Search for VLL in 3rd generation SM leptons

- Search for pair-produced 3rd generation VLLs
  - **Model: '4321' UV complete model**
    - Model favours LQ and VLL decays into 3rd generation
    - Invariant under local group $G_{4321} \equiv SU(4) \times SU(3)' \times SU(2)_L \times U(1)'$



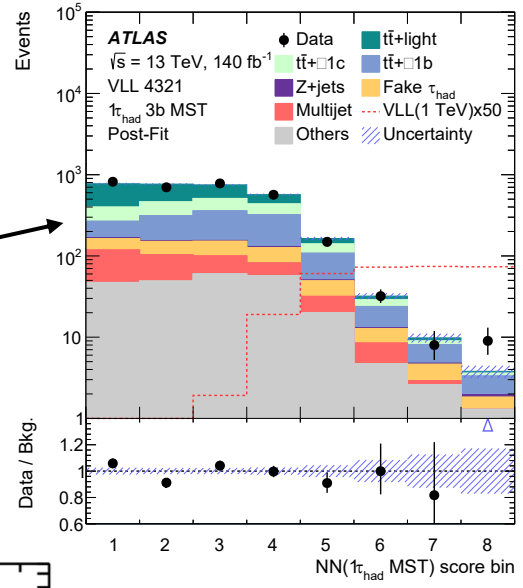
  - Interpretation for SUSY-RPV higgsino and wino scenarios
- Search in final states with $1\tau_{had}$ or $2\tau_{had}$, ≥3 b-jets and no other leptons in VLL mass range between 200 GeV and 1.5 TeV
  - 5 signal regions defined depending on n(τ) and n(b-jets)
  - Different p_T^τ bins defined depending on τ, E_T^{miss} and b-jet triggers used
  - Optimisation of signal classification using neural network
- Main SM backgrounds: $t\bar{t}$+jets (with real/misidentified τ's), multi-jets

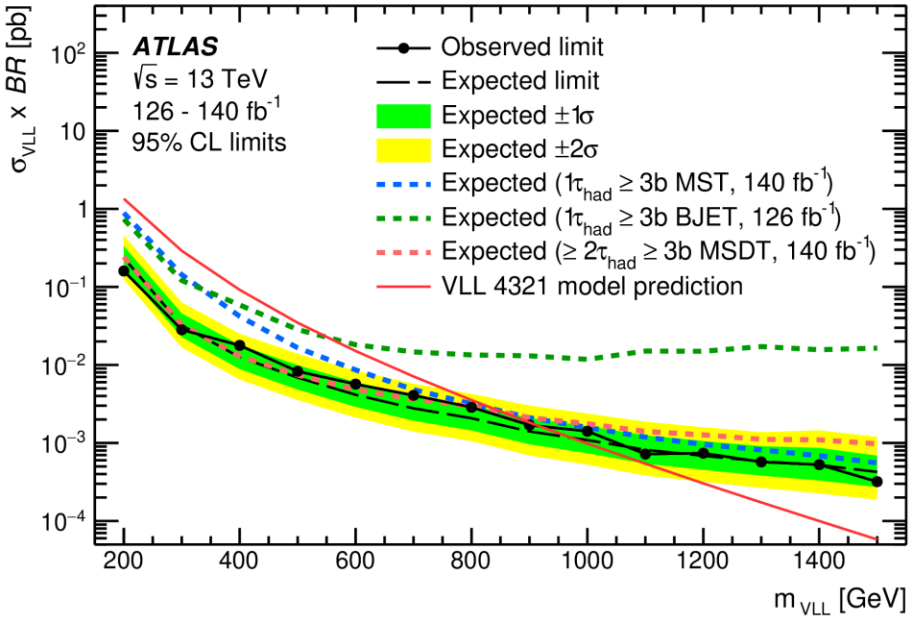
Search for VLL in 3rd generation SM leptons

arxiv:2303.22581

- Maximum likelihood fit performed for each signal hypothesis in all bins of SRs
  - Main discriminant: neural network score
  - Main systematics: $t\bar{t}$ modelling, data-driven bkd normalisations, QCD modelling, and data statistics
- 95% CL exclusion limits
  - m_{VLL} < 910 GeV (970 GeV) observed (expected)
  - m_{VLL}= 600 GeV region excluded, which is most compatible with 2.8σ excess seen in a similar search from CMS
    Phys. Lett. B 846 (2023) 137713

SR with $1\tau_{had}$ and 3 b-jets using 1τ or E_T^{miss} triggers



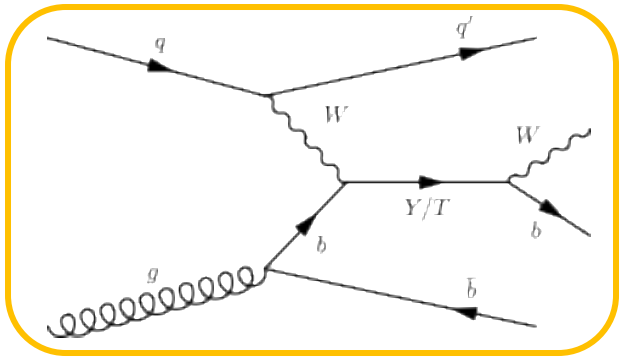


Search for VLQ: T/Y → Wb decays

New

arXiv:2506.15515

- Search for single production of T or Y VLQ → Wb
  - Model-independent simplified Lagrangian used
    - $\mathcal{L} = \sum_{Q,q,\zeta} \left[\frac{g_w}{\sqrt{2}} \kappa_\zeta^{Qq} \bar{Q} \not{W} P_\zeta q + \frac{g_w}{2c_W} \tilde{\kappa}_\zeta^{Qq} \bar{Q} \not{Z} P_\zeta q + \hat{\kappa}_\zeta^{Qq} H \bar{Q} P_\zeta q \right] + \text{h.c.}$
    - T (Y) belongs to singlet ({T, B, Y} triplet)
    - Interference effects taken into account



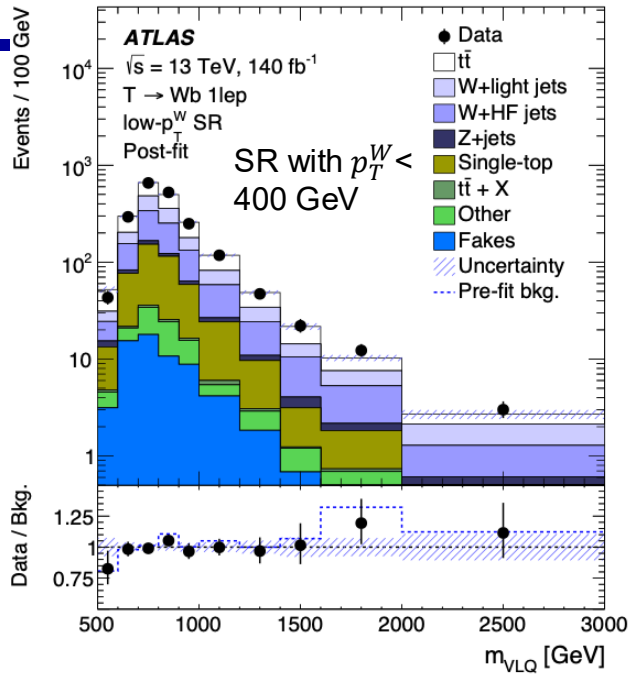
- Search in final states with W→e/μ ν
  - Exactly 1 e/μ, ≥3 jets with ≥1 forward jet and ≥1 high-p_T b-jet, significant E_T^{miss}
  - Complementary to similar search with W→hadrons JHEP 02 (2025) 075
- Main SM backgrounds: W+jets, $t\bar{t}$, single t, multi-jet (estimated using Matrix method)
- Use binned profile-likelihood in 3 bins of p_T^W
  - W+jets, $t\bar{t}$ CRs included in fit to constrain SM background normalisations
  - Main discriminant: m_{VLQ}
  - Main systematics: $t\bar{t}$ and single-top MC generators, $t\bar{t}$ and W+jets reweighting procedure, jet flavour composition

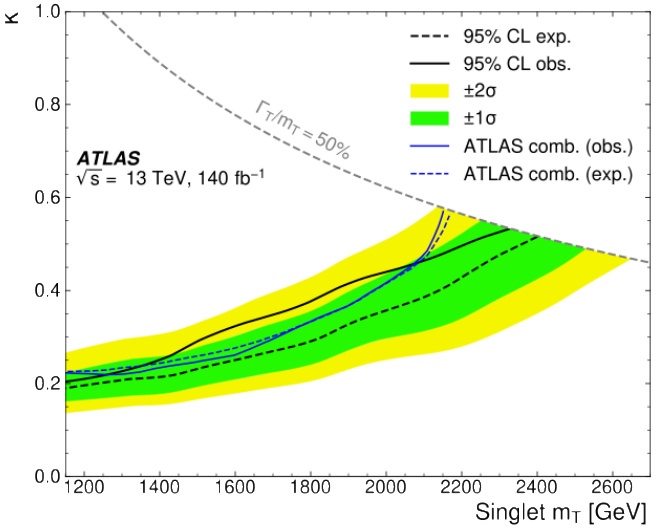
Search for VLQ: T/Y → Wb decays

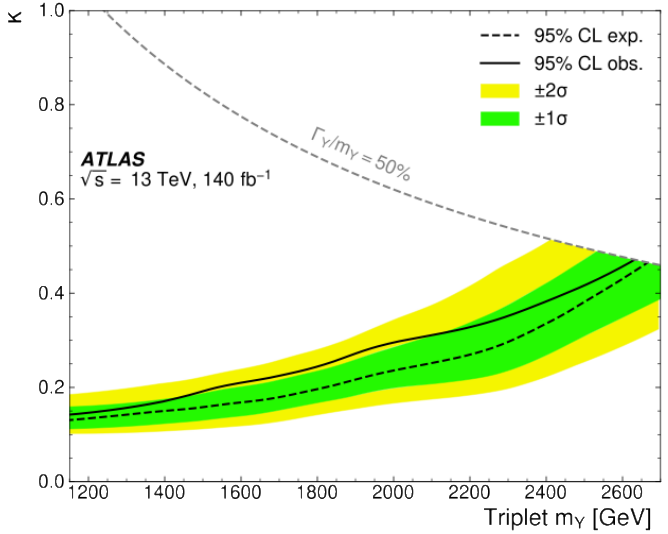
New

arXiv:2506.15515

- Good data-MC agreement in SRs and VRs
- 95% CL exclusion limits
  - κ < 0.22 to 0.52 with 1150 < m_{VLQ} < 2300 GeV for T-singlet model
    - Extends limits for κ >0.45 wrt T→Ht & T →Zt ATLAS *combination* PRD 111 (2025) 012012
  - κ < 0.14 to 0.46 with 1150 < m_{VLQ} < 2600 GeV for Y-triplet model
  - Most sensitive single analysis to date, similar sensitivity to previous ATLAS combination







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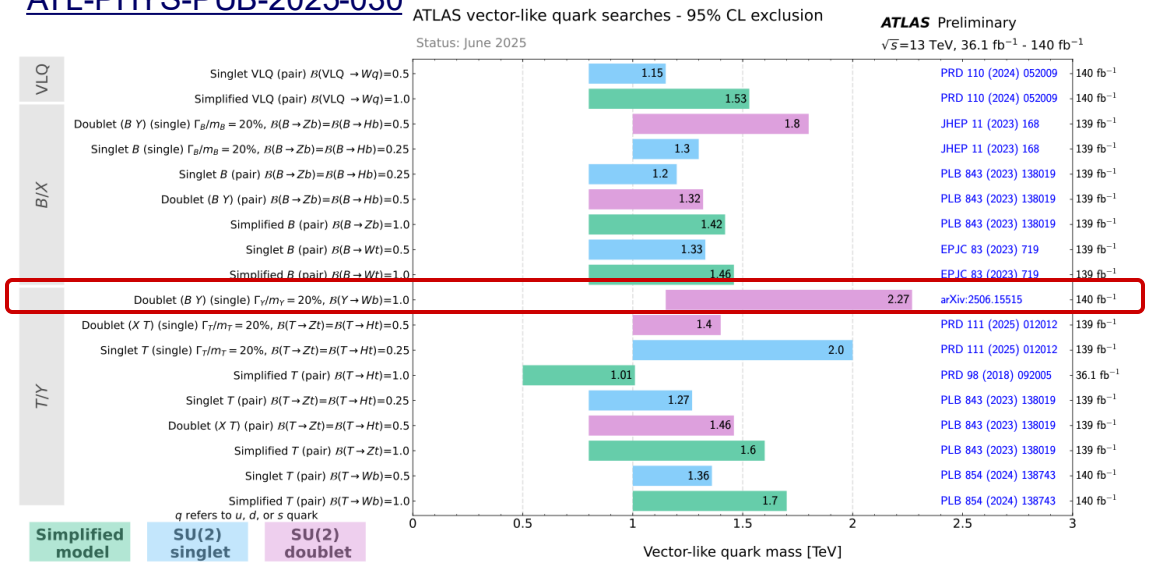


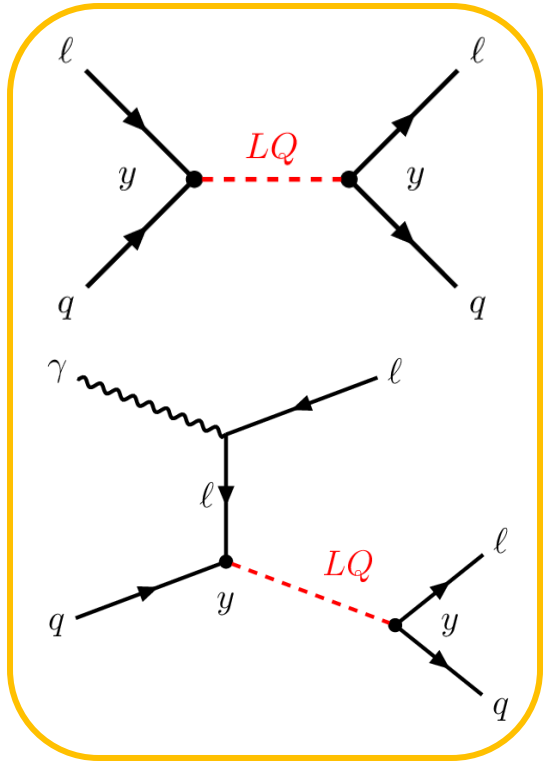
09/07/2025

Resonant 1st and 2nd generation LQ production

New

arXiv:2507.03650

- Search for resonant single LQ production in new production mode using Run-2 and 58 fb^{-1} Run-3 data
  - 1st ATLAS analysis for LQ production exploiting lepton+photon PDFs
    - Possible now due to advancements in understanding of lepton content of protons
    - Photon PDF less suppressed than lepton PDF → contributions roughly on “equal footing”
  - Use scalar $\tilde{S}_1$ LQ with q=-4/3e as benchmark signal
- Search in final states with 1 or 2 leptons and a jet
  - 1e or 1μ + 1 light jet; 1e or 1μ + 1 b-jet
  - 2e or 2μ + 1 light jet; 2e or 2μ + 1 b-jet
    - LQ sensitivity also from non-resonant production to dilepton production via t-channel (DY)
- Main SM backgrounds
  - W+jets, Z+jets, $t\bar{t}$ (in b-jet channels)
  - Jets mis-identified as leptons or non-prompt leptons



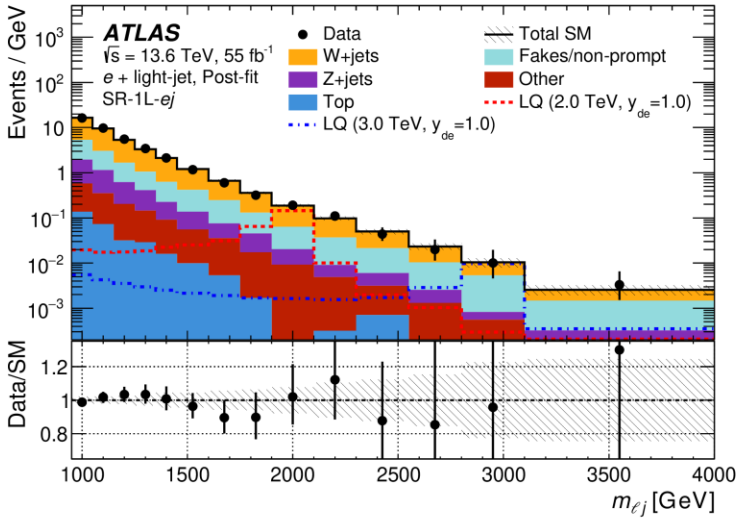
Resonant 1st and 2nd generation LQ production

New

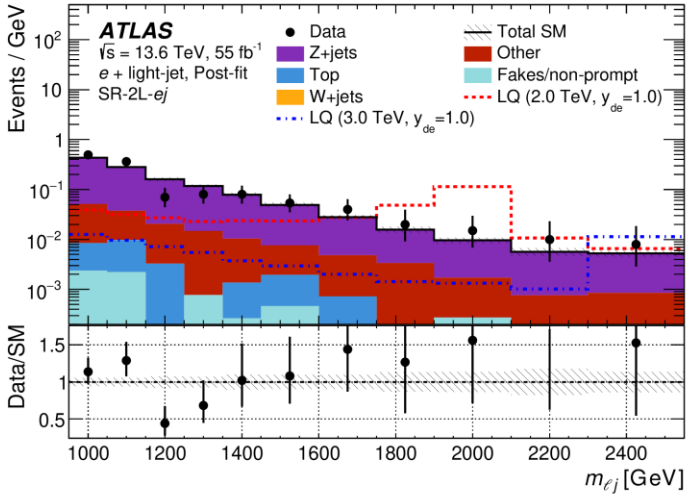
arXiv:2507.03650

- Profile likelihood fit performed with simultaneous fit of SR + CRs
  - Main discriminant: $m_{\ell j}$
  - Systematics: theory and modelling, experimental, fakes/non prompt determination uncertainties all contribute
  - Statistically limited analysis

1e + 1 light jet SR, Run-3



2e + 1 light jet SR, Run-3



2ℓ channel more sensitive to possible signal due to lower bkgs

- Data-SM predictions agree with each other in all channels within uncertainties (both for Run-2 and Run-3)

Resonant 1st and 2nd generation LQ production

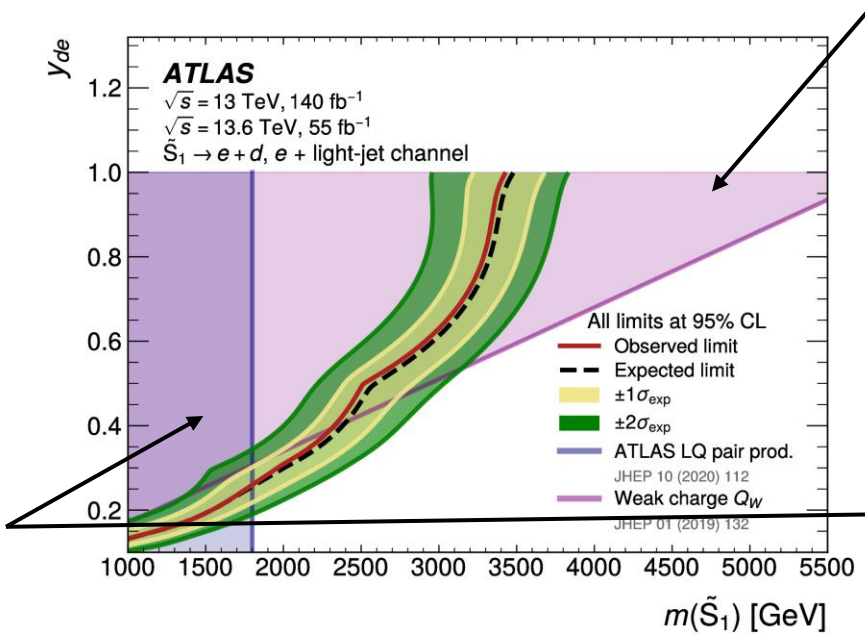
New

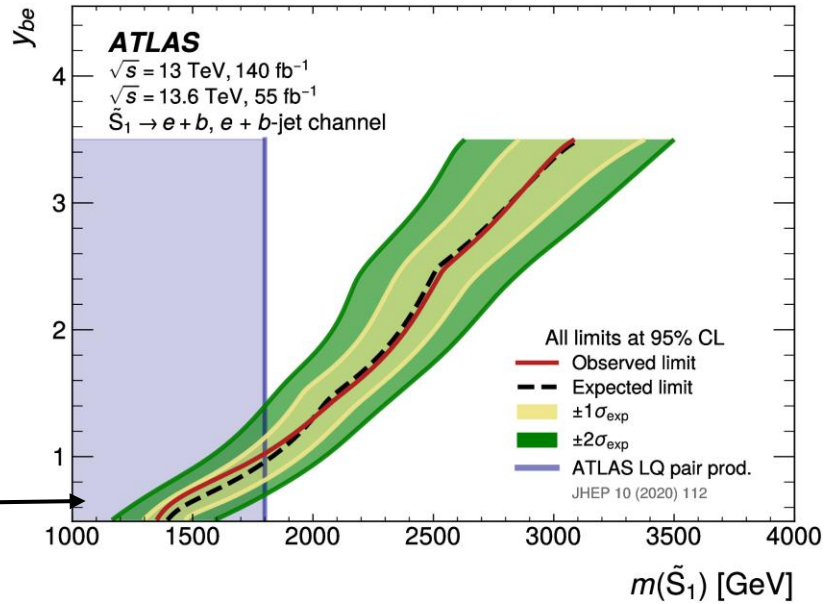
arXiv:2507.03650

- 95% CL exclusion limits

Constraints from low energy experiments on y_{de} couplings (weak charge measurements) JHEP 01(2019) 132

Constraints from ATLAS LQ pair production JHEP 10(2020) 112





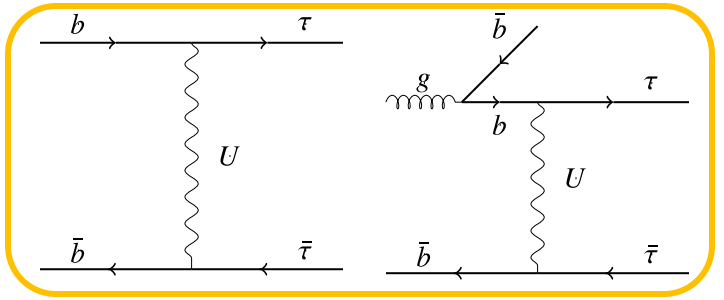
- e+light-jet channel: $m_{LQ} < 3.4$ TeV with $y_{de}=1.0$
- e+b-jet channel: $m_{LQ} < 3.1$ TeV with $y_{be}=3.5$
- μ+light-jet channel: $m_{LQ} < 4.3$ TeV with $y_{s\mu}=3.5$
- μ+b-jet channel: $m_{LQ} < 2.8$ TeV with $y_{b\mu}=3.5$
- Access new phase space (high coupling+high mass)

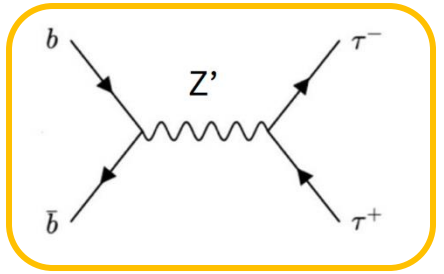
- More information in poster shown tonight by D. Buchin

High-mass $\tau\tau$ production

arxiv:2503.19836

- Measurement of
  - $\tau\tau$ fiducial cross section as function of visible mass
  - Search for deviation in high mass tail
    - Non-resonant production of Z' bosons
    - Non-resonant production of **Leptoquarks**
      - $\Delta\mathcal{L} = U^{\mu}(\beta_L^{i3}\bar{q}_L^i\gamma_\mu\ell_L^3 + \beta_R^{i3}\bar{q}_R^i\gamma_\mu\tau_R)/\sqrt{2} + h.c.$
    - EFT interpretation
- Look at events with $2\tau_{had}$ and ≤2 b-jets in 1.5 TeV < m_{LQ} < 3 TeV
  - Best sensitivity for searches is 1 b-jet final state
- Main Backgrounds
  - τ's from Drell-Yan (DY) and $t\bar{t}$ production
  - Jets misidentified as τ's
- Profile likelihood fit to the data performed
  - Main systematics: Drell-Yan modelling, $t\bar{t}$ normalisation/modelling

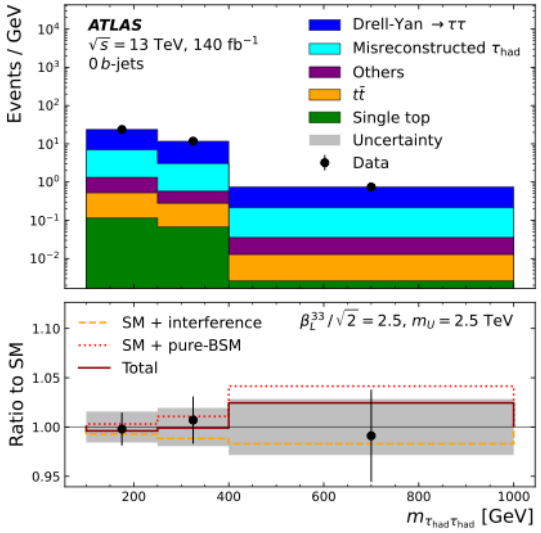


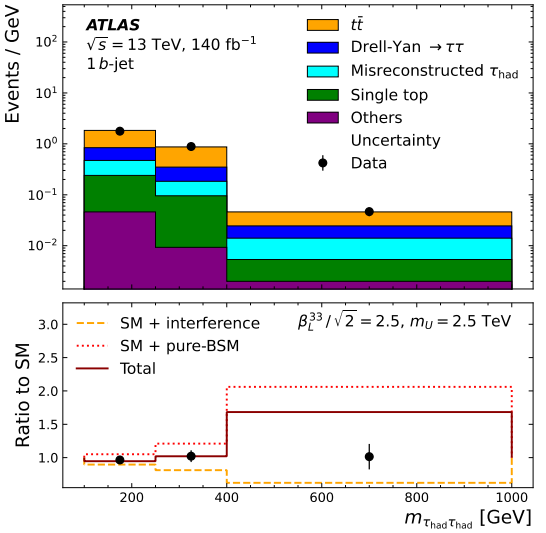


Search for 3rd generation Leptoquarks

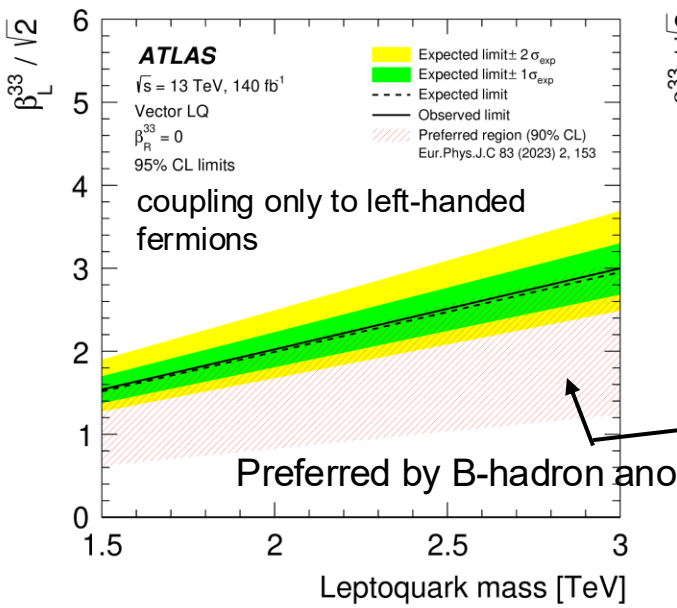
arxiv:2503.19836

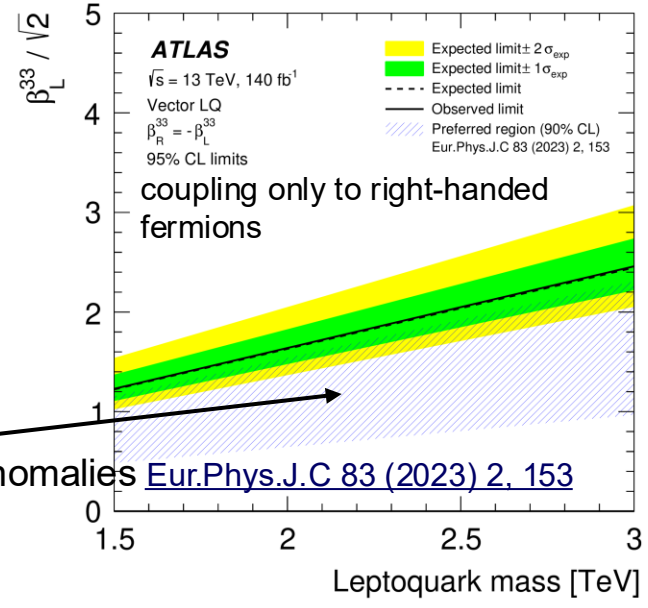
- Good data-MC agreement in SRs





- 95% CL exclusion limits
  - Excellent constraints on LQ searches in 1.5 TeV < m_{LQ} < 3 TeV ATL-PHYS-PUB-2025-013
    - Small part excluded of preferred region by B-hadron anomalies
  - Excludes m(LQ) =2 TeV, λ=2.5, in which CMS observed local excess of 2.8σ JHEP 05 (2024) 311



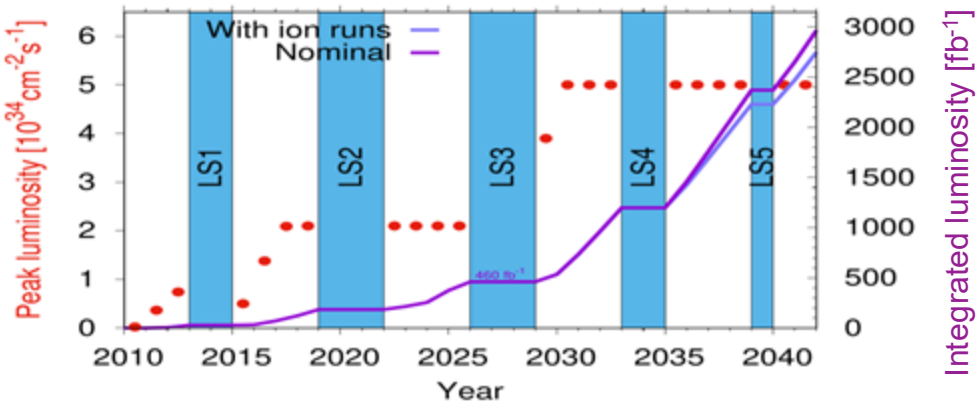


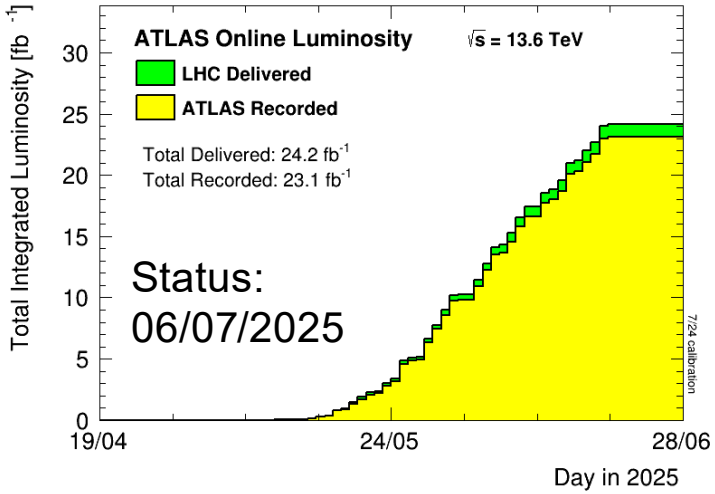
Preferred by B-hadron anomalies Eur.Phys.J.C 83 (2023) 2, 153

- More information in poster shown tonight by G. Padovano!

Summary

- New exotics results with leptons in final state presented
  - More to come using full Run-2 statistics
  - No sign yet of new BSM phenomena
- Run-3 data taken at √s = 13.6 TeV will further increase our physics potential
  - Already ~180 fb^{-1} collected in 2022 - 2024, with more to come
- And after this: HL-LHC running





Backup

Vector like quarks summary for scalar or vector models (status 06/25)

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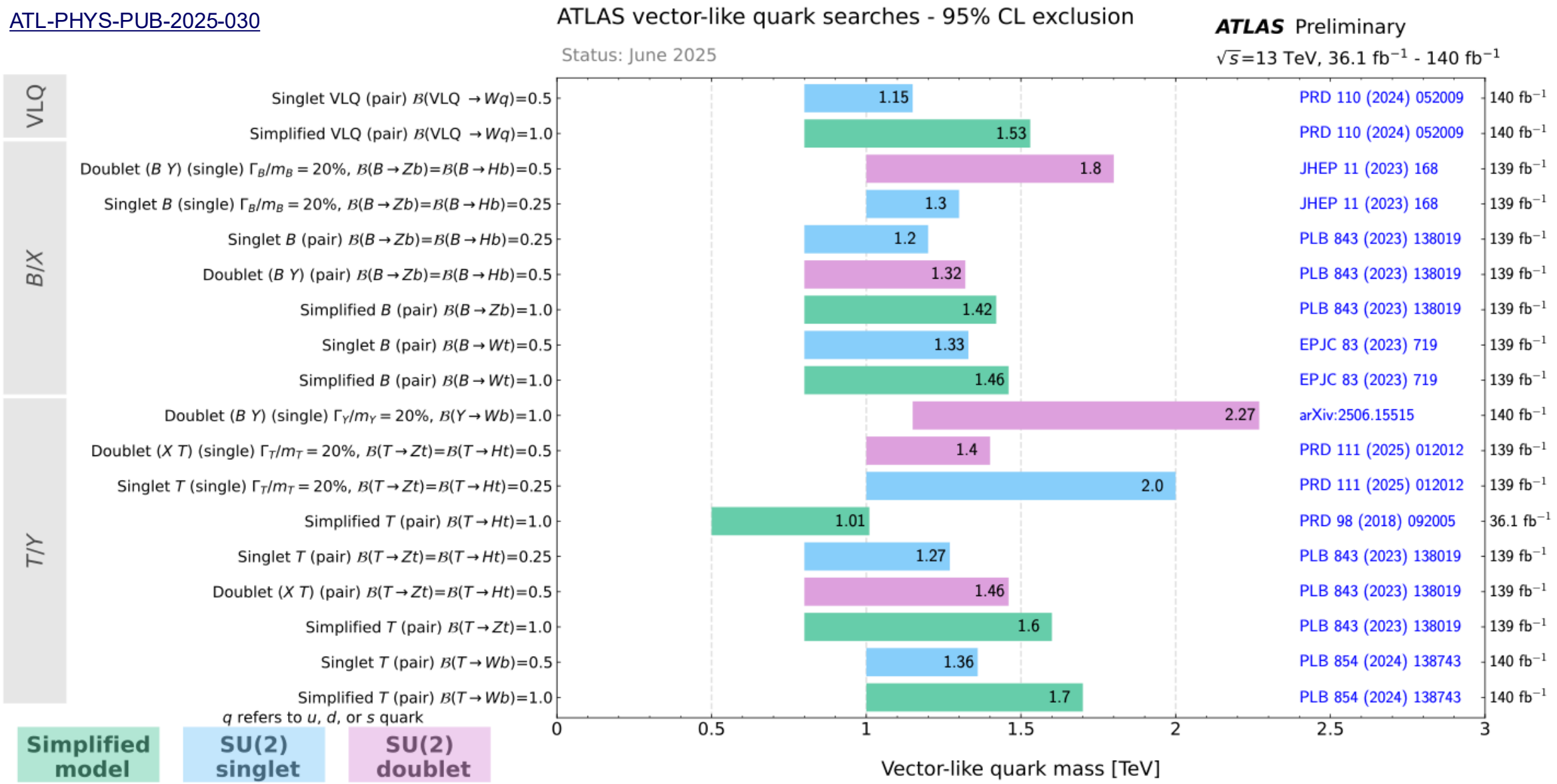

09/07/2025

Leptoquarks summary for scalar or vector models (status 07/24)

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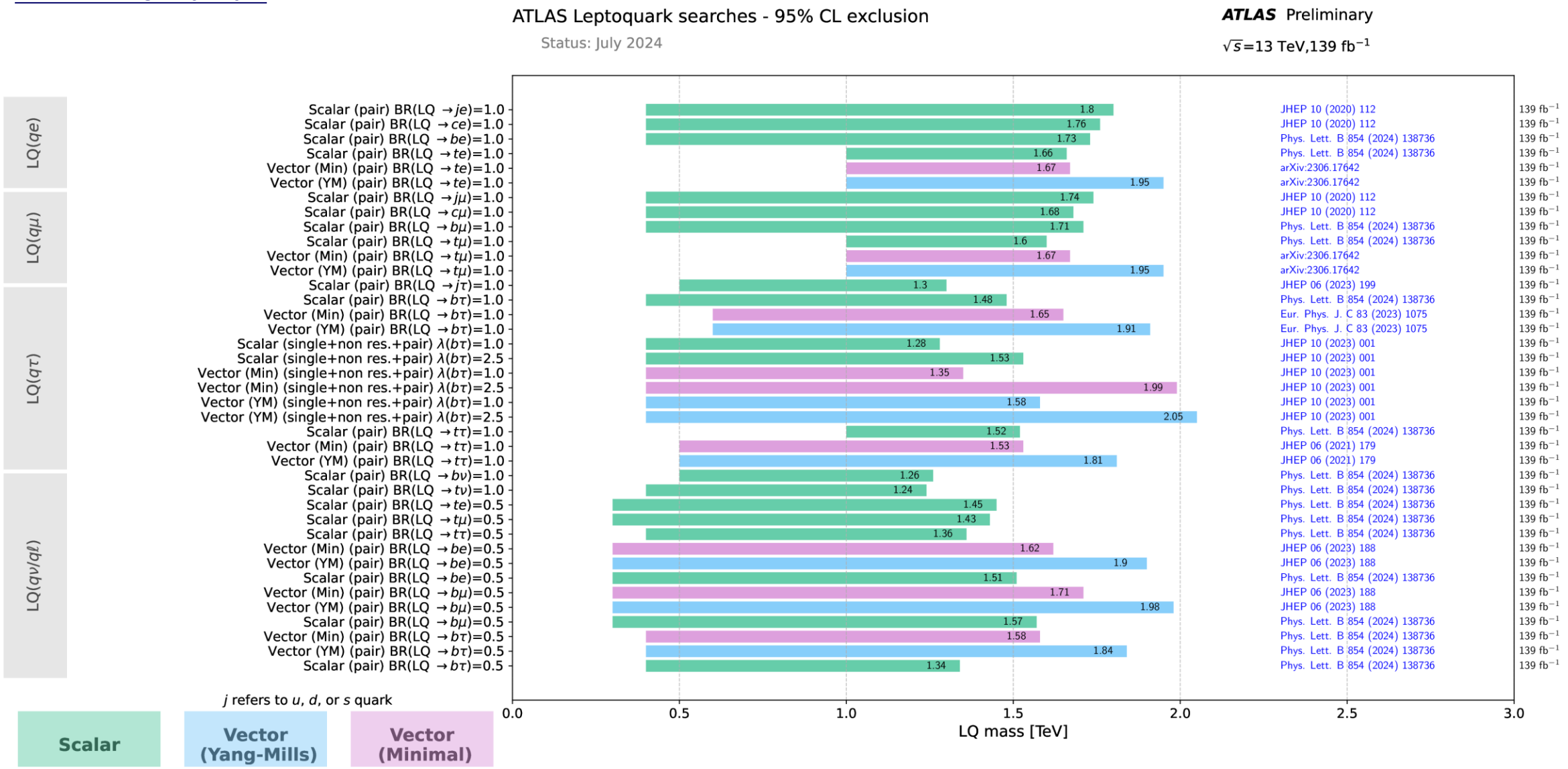

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