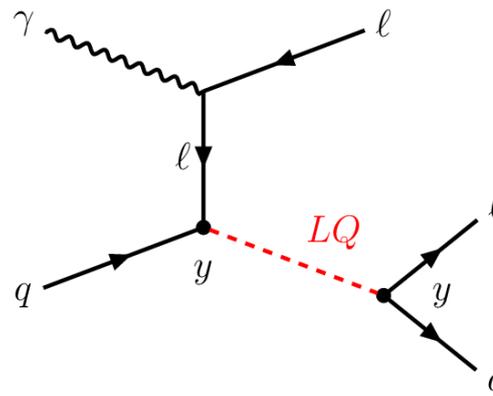
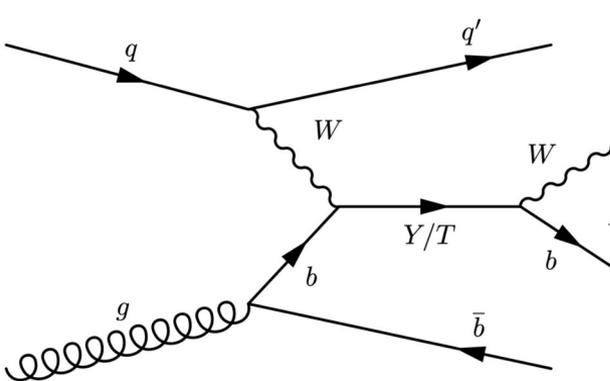


Searches for VLQs and LQs from the ATLAS Experiment

Elin Bergeaas Kuutmann, Uppsala University
obo the ATLAS experiment



Physics beyond the Standard Model

- Could more generations of matter exist?
- Not with light neutrinos
(LEP experiments, Phys.Rept.427:257-454,2006, arXiv:hep-ex/0509008)
- Not with a fourth generation that couples to the Higgs boson like the existing ones
(Phys.Rev.Lett. 109 (2012) 241802, arXiv:1209.1101)
- If new matter-like particles exist, they must be different from the SM
- **Vector-like quarks (VLQ)** and **leptoquarks (LQ)** are possible (still) allowed extensions

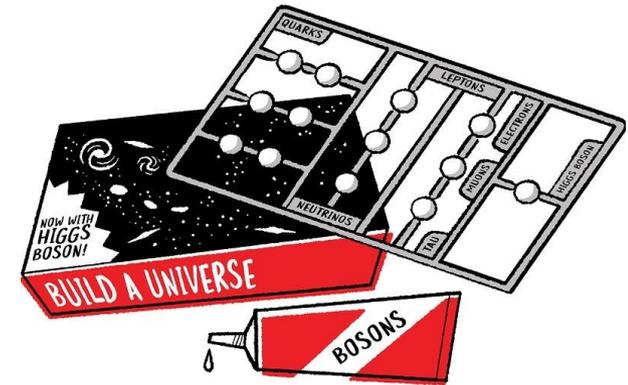


Image from iop.org

Vector-like quarks (VLQs)

What are VLQs?

- carry colour charge
- spin 1/2
- their right and left components have the same quantum numbers: “vector-like”, i.e. not chiral.
(This also means they don't have to get their mass via the Higgs mechanism)

Why VLQs?

- Arise in Composite Higgs models and little Higgs models – can explain the fine-tuning of the mass of the Higgs boson.

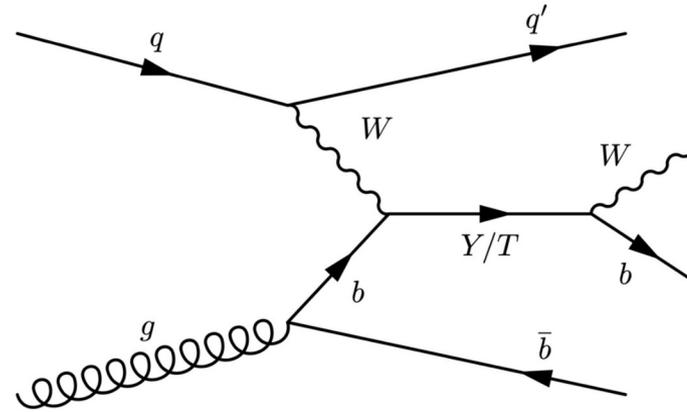
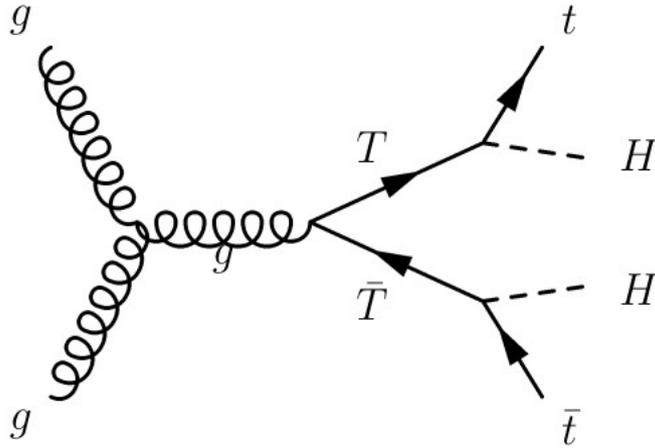
- Higgs potential: $V = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$

Why this μ value? (Only SM constant with dimension mass)

Vector-like quarks (VLQs)

By convention, T has charge $+2/3$, B has charge $-1/3$, Y has charge $-4/3$ (depending on model there could also be $X_{5/3}$, $Y_{8/3}$...)

VLQs can be produced in pairs (QCD cross section) or singly (EW, model-dependent)



Summary of exclusions limits, VLQs

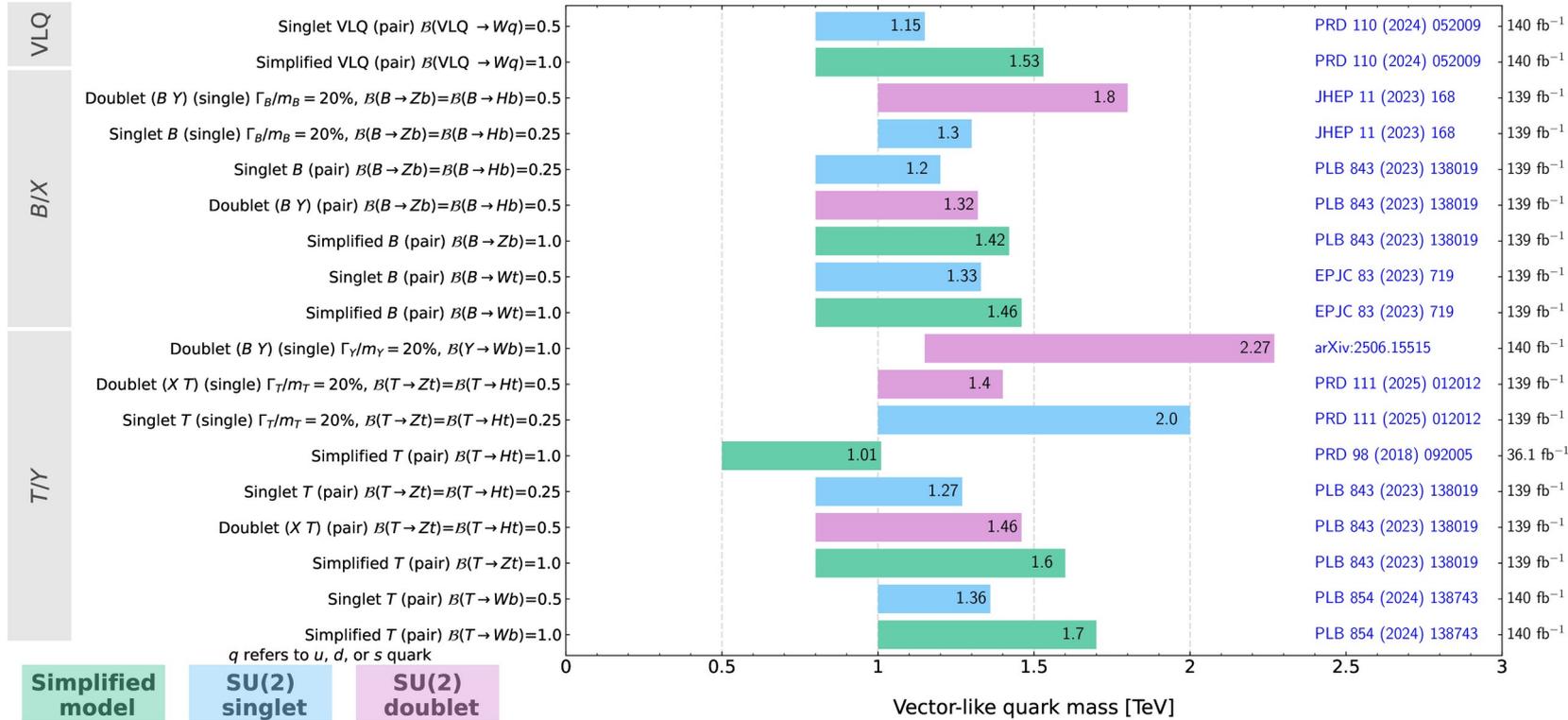
ATL-PHYS-PUB-2025-030

ATLAS vector-like quark searches - 95% CL exclusion

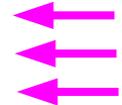
Status: June 2025

ATLAS Preliminary

$\sqrt{s}=13$ TeV, 36.1 fb^{-1} - 140 fb^{-1}



Caveat: all analyses listed here assume decay into SM particles only

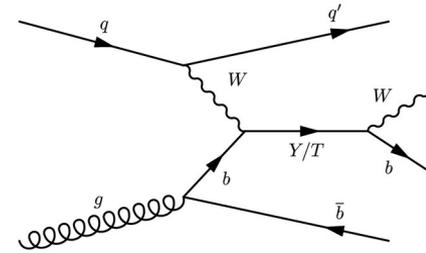


$\Gamma/m = 20\%$ for single prod

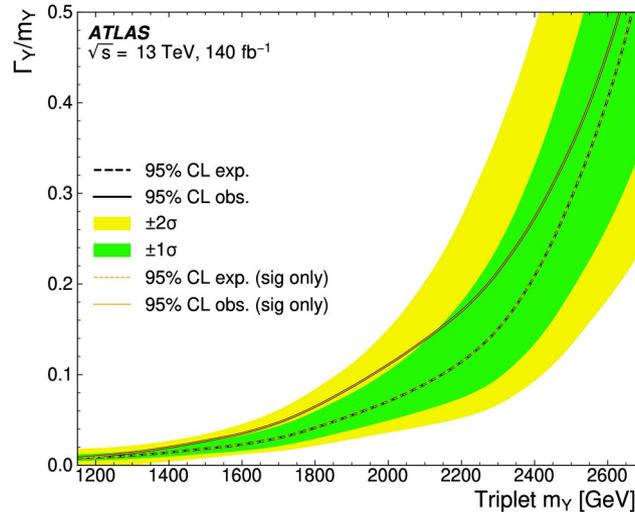
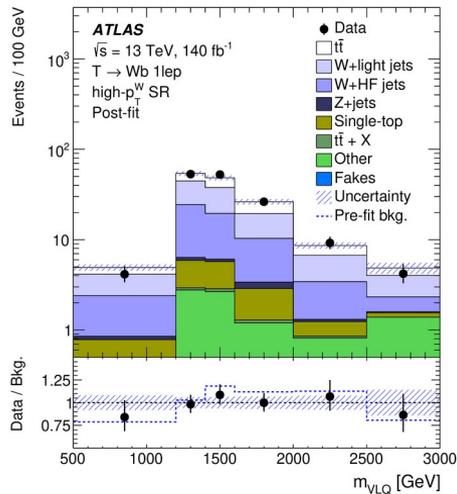


Search for singly produced $T/Y \rightarrow Wb$ (1L)

arXiv:2506.15515



- Search for SU(2) singlet T or a Y from the SU(2) (T, B, Y) triplet, $W(e/\mu+\nu)b$ final state.
- Single lepton triggers.
- Signature: e/μ , E_T^{miss} , hard b -jet, forward jet. m_{VLQ} from lepton, E_T^{miss} , b -jet.



Limits in terms of the coupling constant κ :
Singlet T : κ limit between 0.22 and 0.52
for m_T 1150 – 2300 GeV.

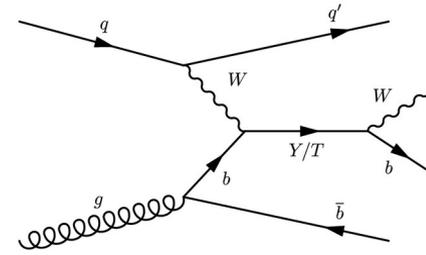
Triplet Y : κ limit between 0.14 and 0.46
for m_Y 1150 to 2600 GeV.

Effects of interference with the SM
background: negligible effect for Y limit.

The limits reinforce and extend the mass
coverage of the single VLQ upper limits
from ATLAS.

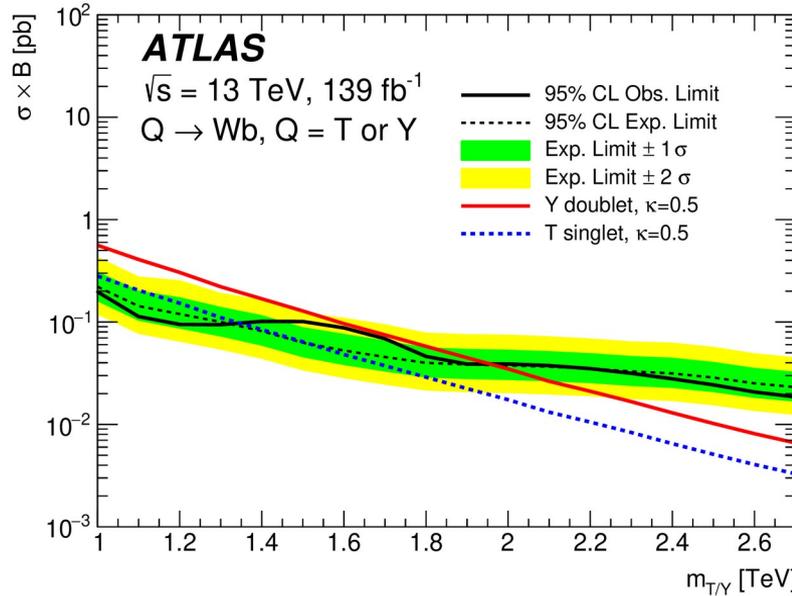
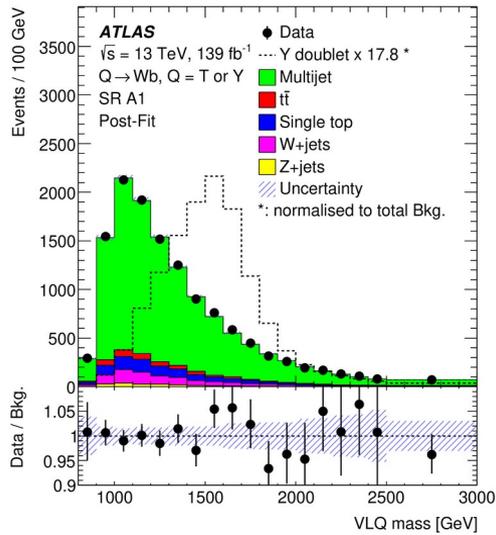
Search for singly produced $T/Y \rightarrow Wb$ (all-had)

JHEP 02 (2025) 075



Complementary to the previous analysis. Limits on a SU(2) singlet T , and a Y from the (B, Y) doublet, Wb all-hadronic final state.

Large R -jet trigger. Signature: W -tagged large- R jet, small- R b -jet. VLQ mass = $m(W, b)$.



Limits in terms of the κ coupling:

$Y, \kappa = 0.5$: 2.0 TeV

$Y, \kappa = 0.7$: 2.4 TeV

$T, \kappa = 0.5$: 1.4 TeV

$T, \kappa = 0.7$: 1.9 TeV.

Most stringent limits to date for this channel (dep. on coupling).

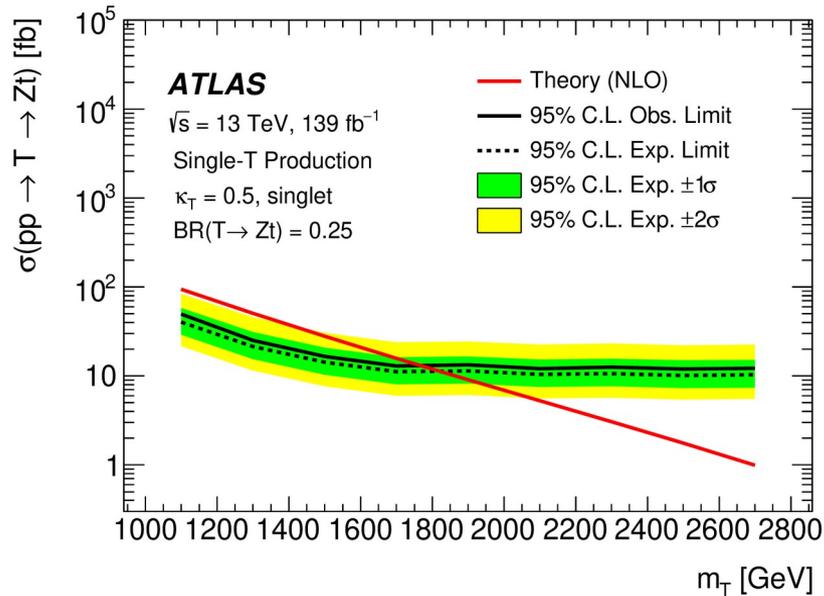
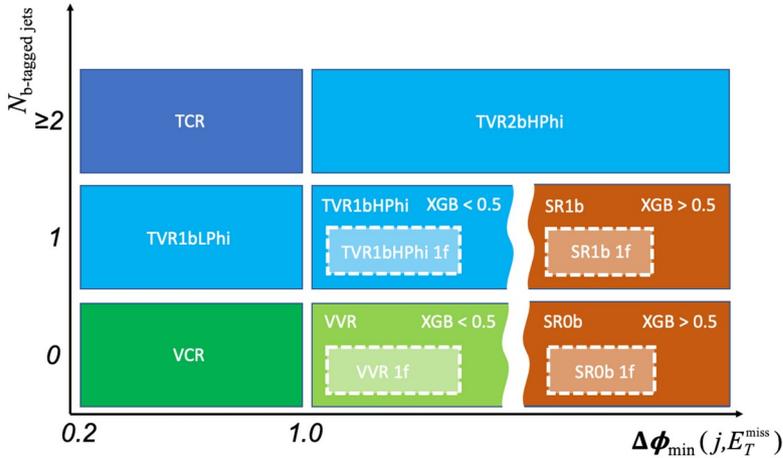
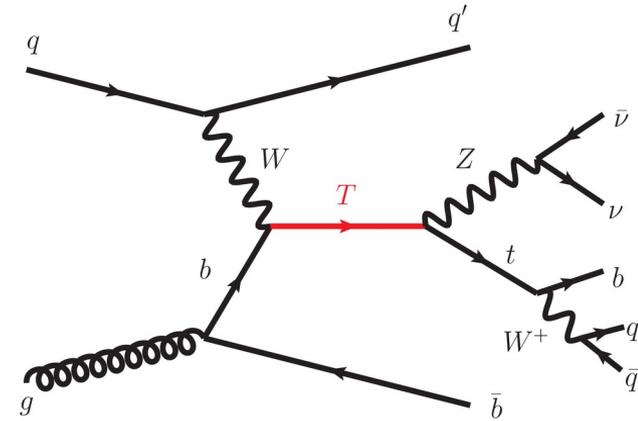
The mass limits on Y in the (B, Y) doublet improved w.r.t previous ATLAS results.

The search regions for Y and the T singlet have been extended.

Search for boosted top + E_T^{miss}

JHEP 05 (2024) 263

- Interpreted as a search for singly produced $T \rightarrow Z(\nu\nu)t$
- E_T^{miss} triggers
- Signature: top-tagged large- R jet, E_T^{miss}
- Using XGBoost classifier to suppress background

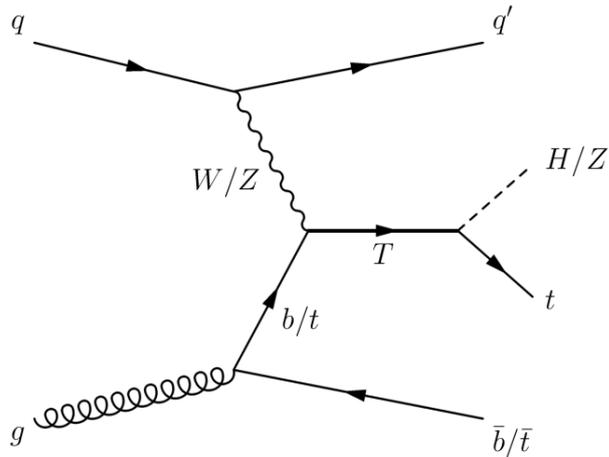


Mass limit
 SU(2) singlet T :
 $m < 1.8$ TeV
 $\kappa_T = 0.5$,
 $BR(Zt) = 25\%$.

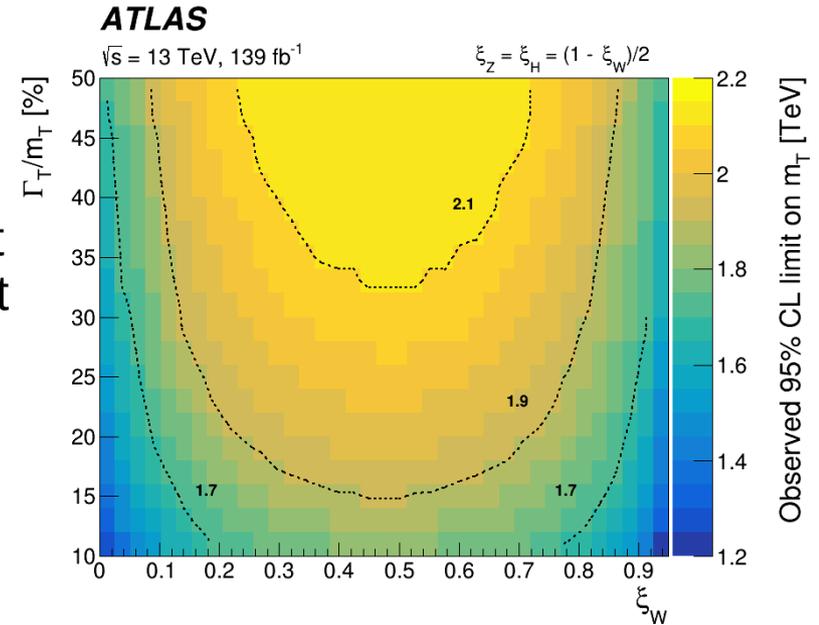
Single T combination

PRD 111 (2025) 012012

- Combination of several ATLAS analyses searching for $T \rightarrow H/Z+t$ (including the one from previous slide, boosted top + E_T^{miss})
- Results shown as a function of decay width and BR into W, H, Z - approximately the $\xi_{W,Z,H}$ parameters (PRD 101 (2020) 115027)



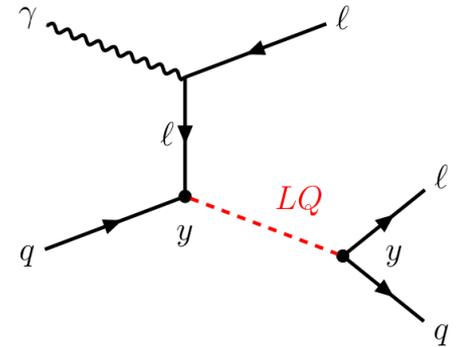
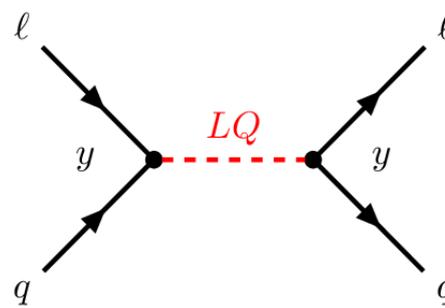
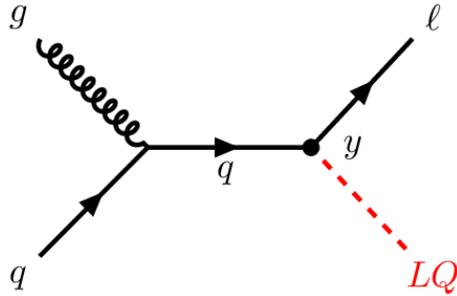
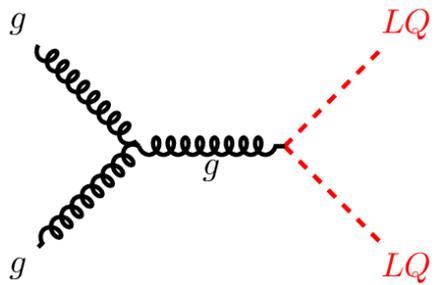
$\xi_W=0.5 \iff$ SU(2) singlet
 $\xi_W=0.0 \iff$ SU(2) doublet
under the assumption that
only decays into W, Z, H
are allowed.



Leptoquarks (LQ)

LQs can

- arise in GUT models with extended gauge groups
- carry both lepton and baryon numbers, as well as electric charge and colour
- decay into a lepton-quark pair
- be scalar (spin 0) or vector (spin 1)
- lead to lepton flavour universality violations
- be produced in pair or singly



Summary of exclusions limits, LQs

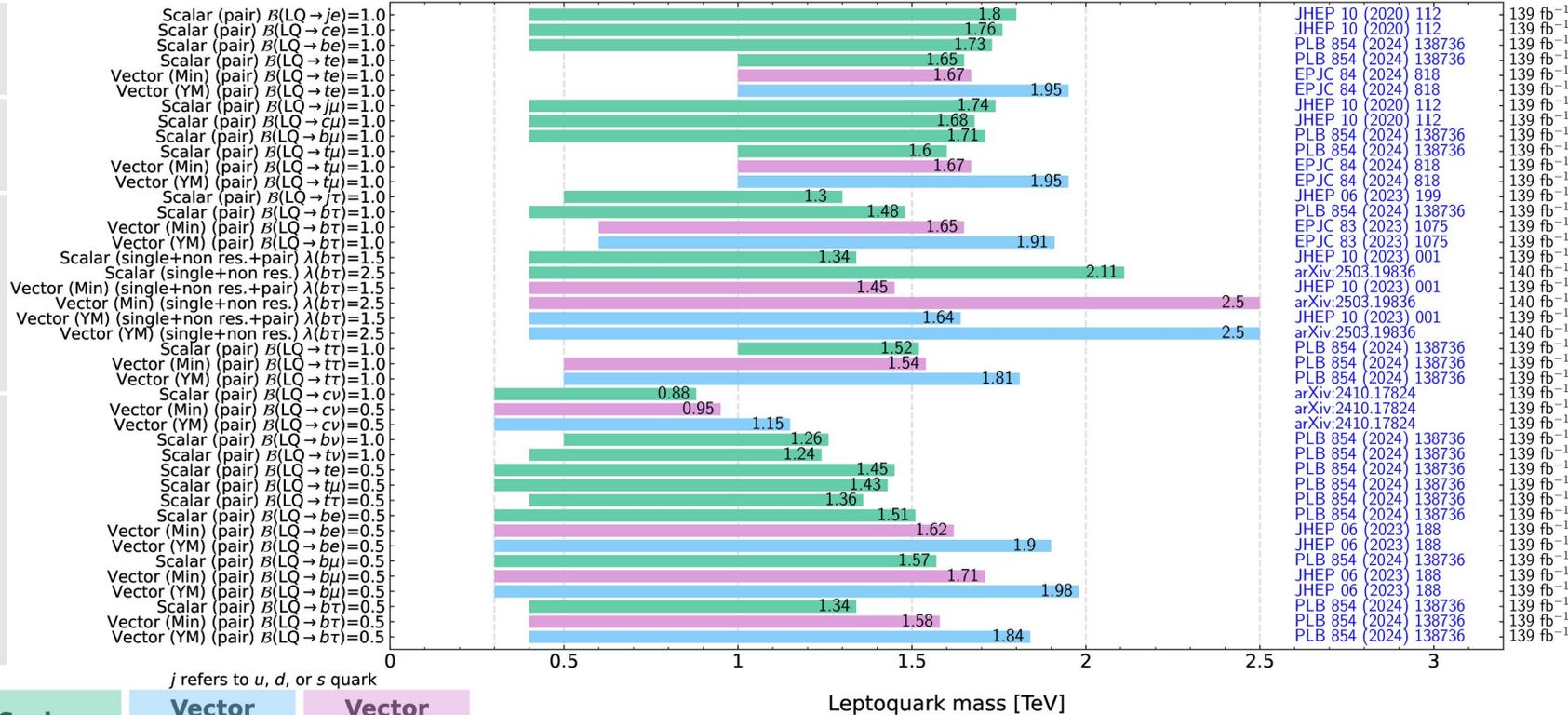
ATL-PHYS-PUB-2025-013

ATLAS leptoquark searches - 95% CL exclusion

ATLAS Preliminary

Status: March 2025

$\sqrt{s}=13$ TeV, 139 fb^{-1} - 140 fb^{-1}



Status March 2025

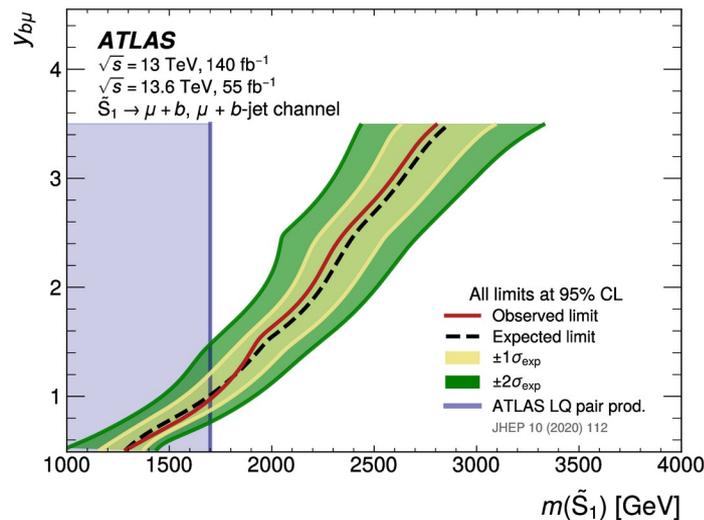
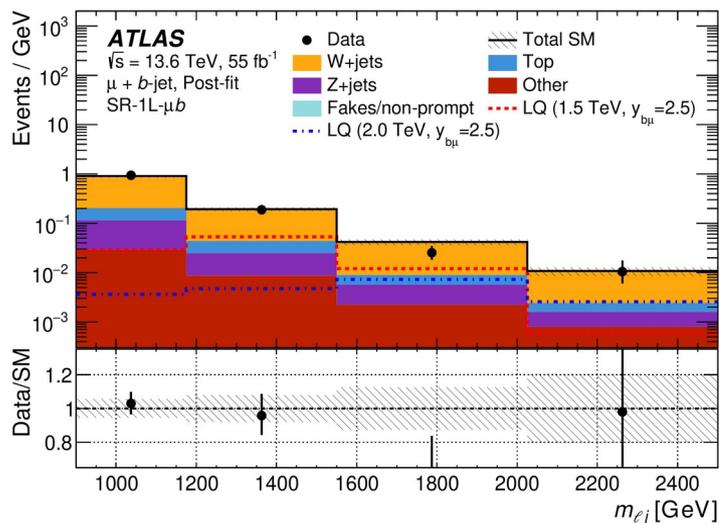
Vector LQ:
with Yang-Mills
couplings (to
gluons)
or minimal



Search for lepton-jet resonance

arXiv:2507.03650

Search for a single scalar LQ, resonant production, which couples to charged leptons and down-type quarks in $\sqrt{s} = 13, 13.6$ TeV data. Complementary to pair-prod searches.



y : coupling
 LQ ℓq

Mass exclusions (dep. on coupling): 3.4 TeV for $y_{de}=1.0$,
 4.3 TeV for $y_{s\mu}=3.5$, 3.1 TeV for $y_{be}=3.5$, 2.8 TeV for $y_{b\mu}=3.5$ (shown in figure).
 Extends previous limits.

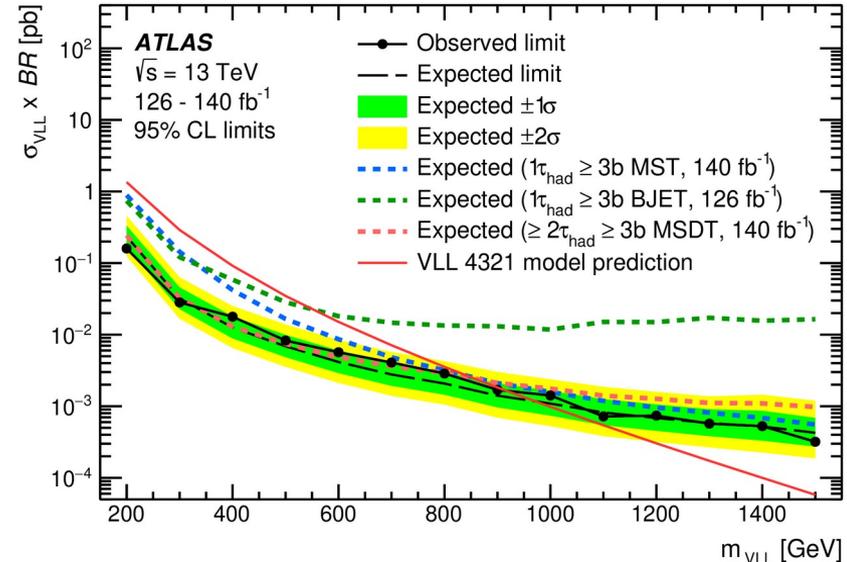
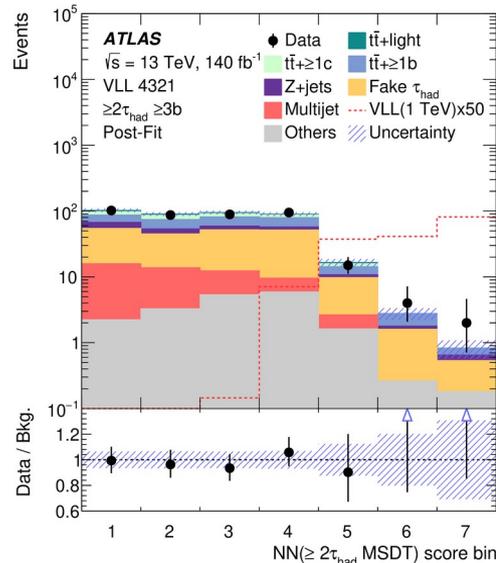
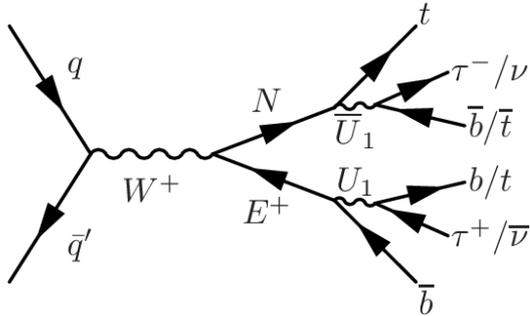
Also: LQ searches in $\tau\bar{\tau}$ production – **Simon Koch's talk in this session.**



Vector-like leptons (VLL) decaying to a LQ

arXiv:2503.22581

- If you have vector-like quarks, why not leptons? N like neutrino, E like electron.
- Ultraviolet-complete extension to SM, “4321” (DiLuzio et al, JHEP 11 (2018) 081), VLL decays into a vector LQ (U_1), in $\tau+b$ final state
- **More on Thursday** in Jack Harrison's talk “*Searches for new physics using leptons with the ATLAS detector*”



Summary and conclusions

- VLQs, VLLs and LQs are possible new particles beyond the Standard Model
- ATLAS has extensive programmes for searches for these particles.
- The recent results, mostly single production channels, exclude more regions than before

References:

- [ATL-PHYS-PUB-2025-030](#)
VLQ summary plot
- [EXOT-2018-60](#) arXiv:2505.15515
 $Y/T \rightarrow Wb$ (1L)
- EXOT-2022-43 JHEP02(2025) 075
 $Y/T \rightarrow Wb$ (0b)
- [EXOT-2022-40](#) JHEP05(2024) 263
boosted $t + E_T^{\text{miss}}$ with T interpretation
- [EXOT-2021-02](#) PRD 111 (2025) 012012
single T combination
- [ATL-PHYS-PUB-2025-013](#)
LQ summary plot
- [EXOT-2024-12/](#) arXiv:2507.03650
LQ pair to lepton + jet
- [EXOT-2022-27](#) arXiv:2503.22581
VLL pair to taus and jet