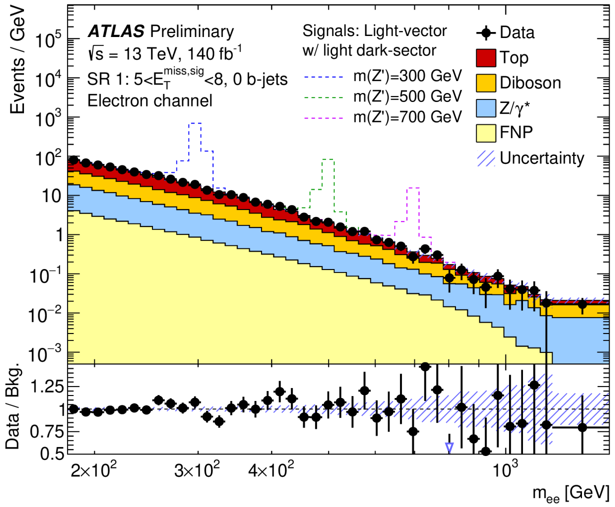
Searches for Exotic Heavy Resonances with the ATLAS detector

Marija Marjanović
University of Oklahoma
On behalf of ATLAS Collaboration

Lake Louise Winter Institute 2024

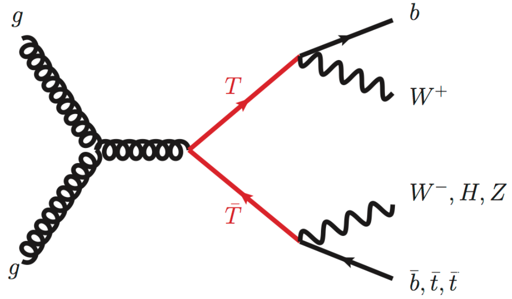
Heavy resonances at the LHC

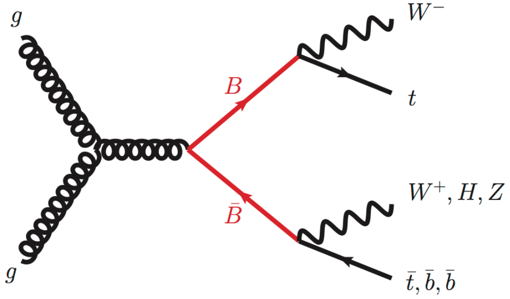
- Many Beyond Standard Model theories predict the existence of additional particles
- Heavy resonances are predicted in many new physics models
  - Heavy vector triplet (W', Z')
  - Vector like quarks
- Would appear as a bump on flat Standard Model (SM) prediction
  - Indicates an unknown resonance particle
- LHC allows to explore ever higher masses

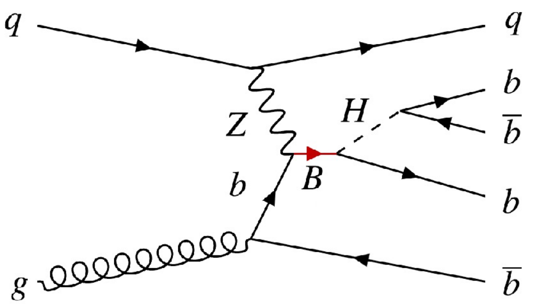


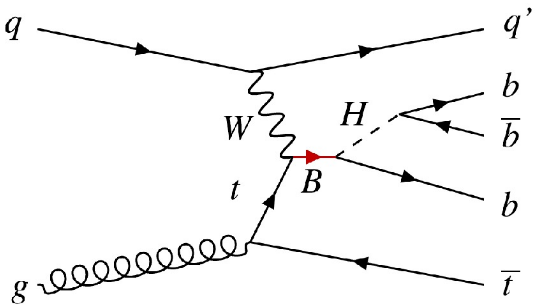
VLQ at the LHC

- Vector Like Quarks (VLQ) are predicted to be spin-1/2 particles that transform as a triplet under color gauge symmetry and whose left- and right-handed components both have the same electroweak quantum numbers
- Couple to the SM fermions via Yukawa couplings
  ➔ Interact principally with the third-generation SM quarks
- Vector-like T and B quarks
  - Vector-like equivalents of the third-generation SM quarks
  - Electric charge $Q(T)$ = 2/3 and $Q(B)$ = −1/3,
  - Can exist as singlets, doublets or triplets
- X and Y VLQs
  - Charges $Q(X)$ = 5/3 and $Q(Y)$ = −4/3 respectively
  - Can exist either in gauge doublets along with a T or B quark or in gauge triplets along with both the T and B quarks
- At the LHC, VLQs are expected to be produced either in pairs, via the strong interaction, or singly, via the exchange of an intermediate electroweak gauge boson



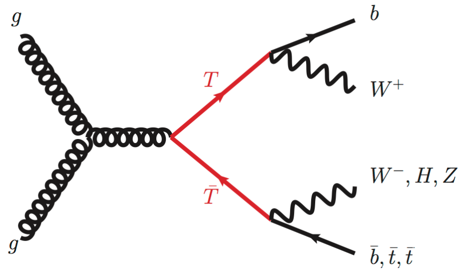


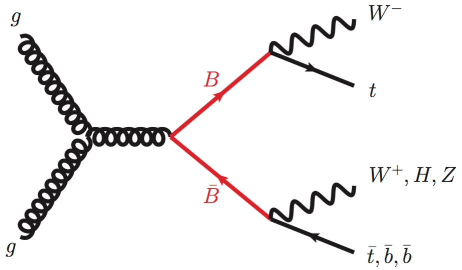




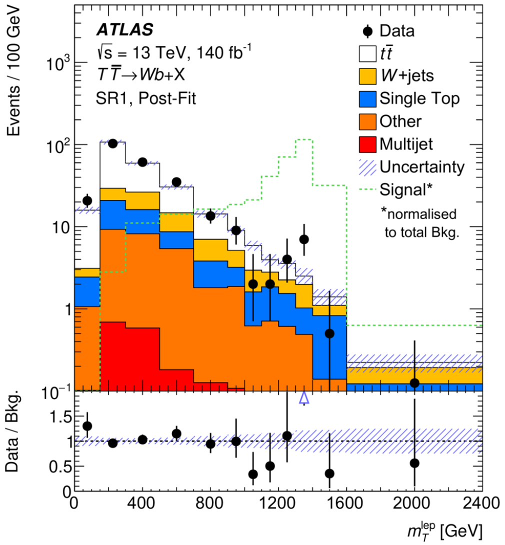
VLQ pair production search in the Wb+X final state

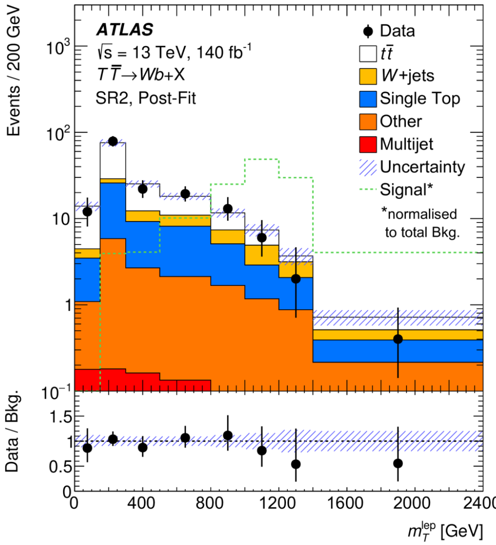
- Optimised for vector-like T-quarks that decay into a W-boson and a b-quark
  - One W-boson decaying leptonically and the other hadronically
- Also considered models
  - Vector-like B-quark
  - Vector-like Y-quarks, which decay exclusively into a W boson and a b-quark
- Event selection:
  - High p_T electron or muon
  - Large E_T^{miss}
  - Large radius jet identified as W-boson
  - Multiple small radius jets: at least one of them is b-tagged
- Important discriminant used to define Signal Region and Control Region, S_T: scalar sum of the p_T of the selected small-radius jets, the lepton p_T and the E_T^{miss}





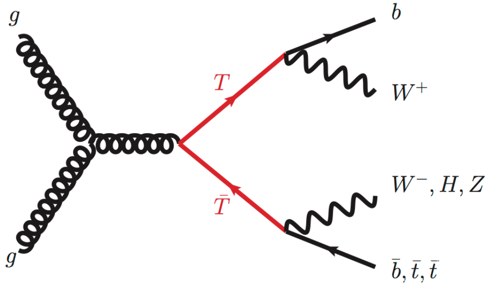
arxiv:2401.17165



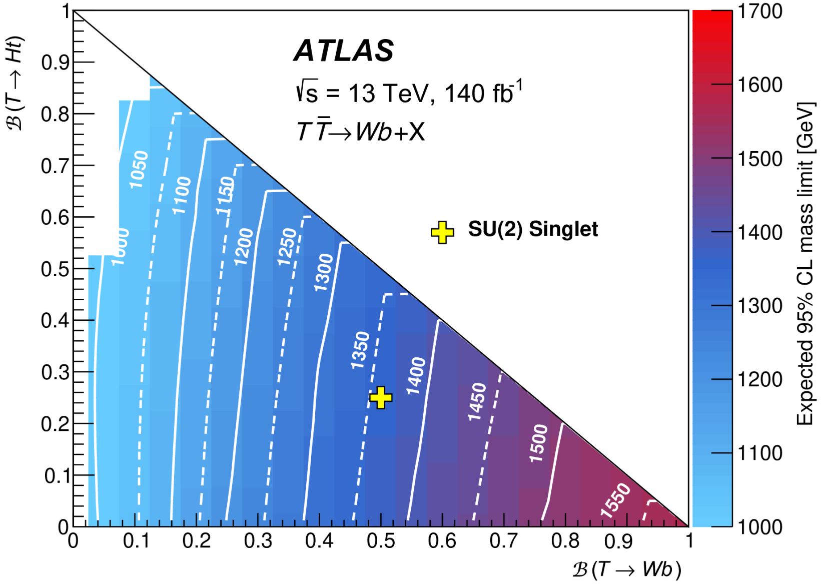


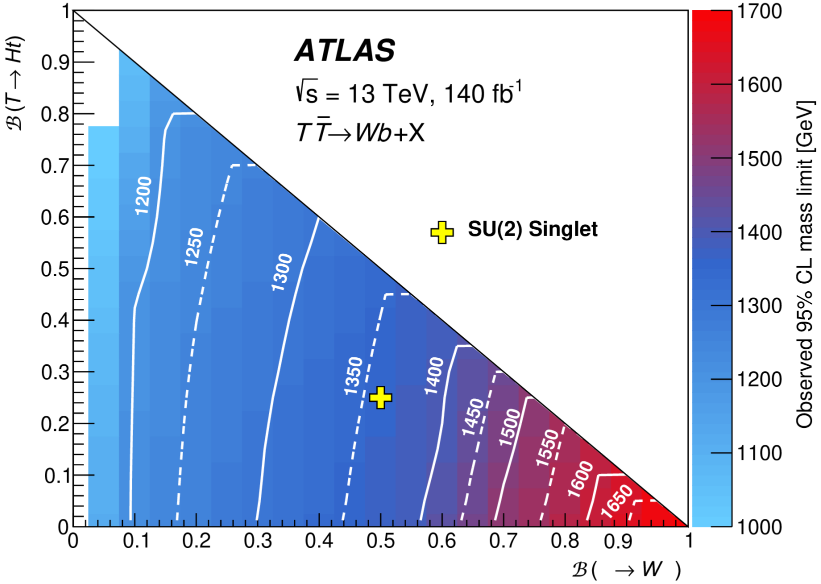
VLQ pair production search in the Wb+X final state

- VLQs can decay via a flavor-changing neutral current or a charged current
  - ➔ T has three possible decays: $T \rightarrow Wb/Zt/Ht$
- Expected and observed 95% CL lower limits on the mass of the T-quark in the branching-ratio plane of B($T \rightarrow Wb$) versus B($T \rightarrow Ht$)



arxiv:2401.17165

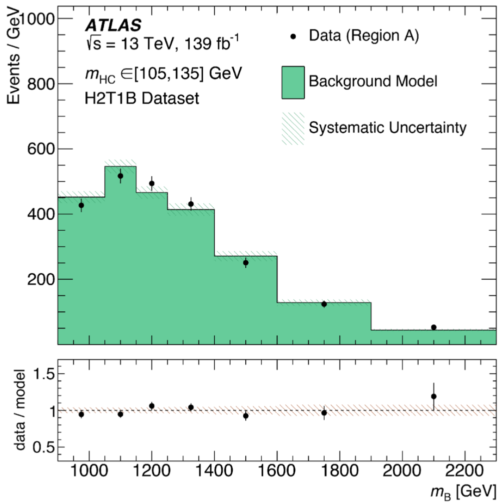


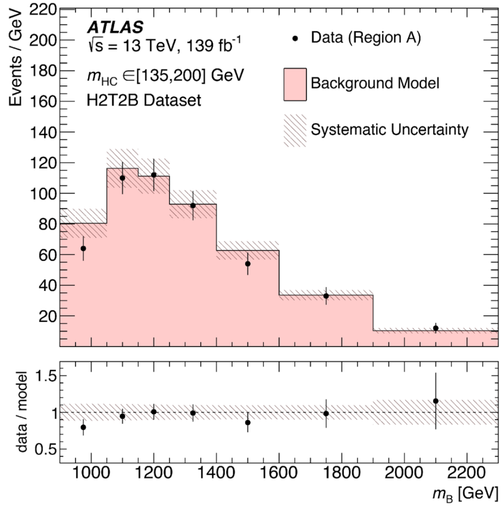


Search for vector-like $B \to bH$ with $H \to bb$

- Vector-like B quark can be produced in the resonant s-channel
  - Either the electroweak interaction of an initial-state b-quark and a Z boson (leading production mode for a vector-like B singlet)
  - Or of an initial-state t-quark and a W boson
- Strongly non-resonant single vector-like B quark production arises through t-channel processes
  - Mostly results in low-mass off-shell B quarks falling well outside the acceptance of the trigger selection employed by the analysis
- Event preselection:
  - At least 1 large-R jet, pT > 480 GeV
  - No leptons & no $\gamma\gamma$ pairs with $m_{\gamma\gamma} \in [105, 160]$ GeV
  - At least 2 track-jets associated with the large-R jet, at least one of them b-tagged
  - At least 1 small-R jet with $p_T > 300$ GeV
  - ΔR(small-R jet, large-R jet) > 2.0
- Data-driven background estimate

JHEP11(2023)168

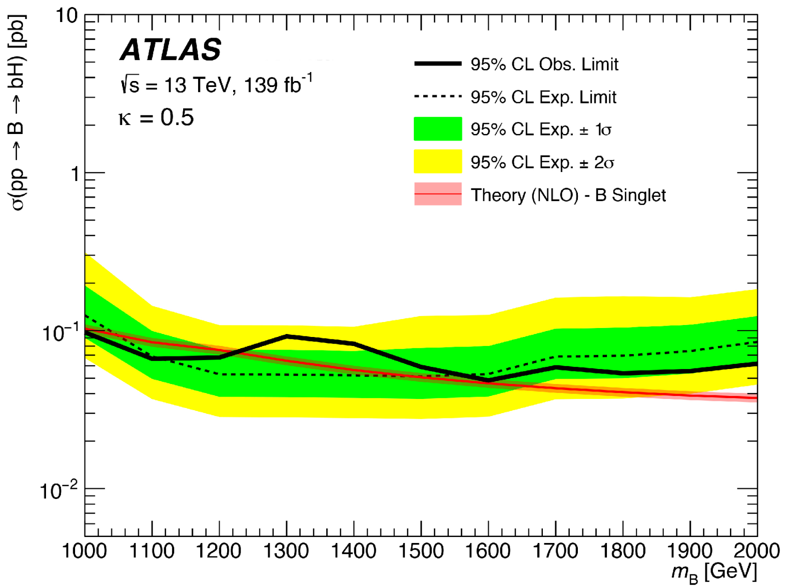


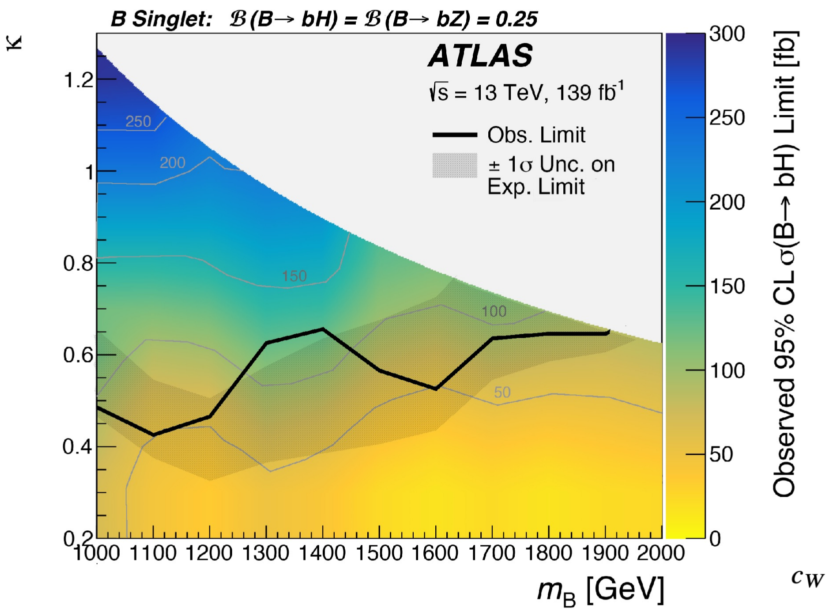


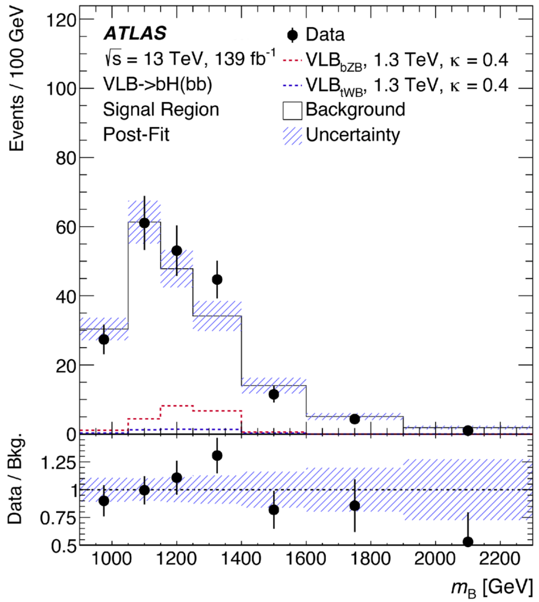
Search for vector-like $B \rightarrow bH$ with $H \rightarrow bb$

JHEP11(2023)168

- Results are interpreted as limits on the single-production cross-section
  - For fixed Κ = 0.5
  - Also as a function of the resonance mass and coupling strength κ







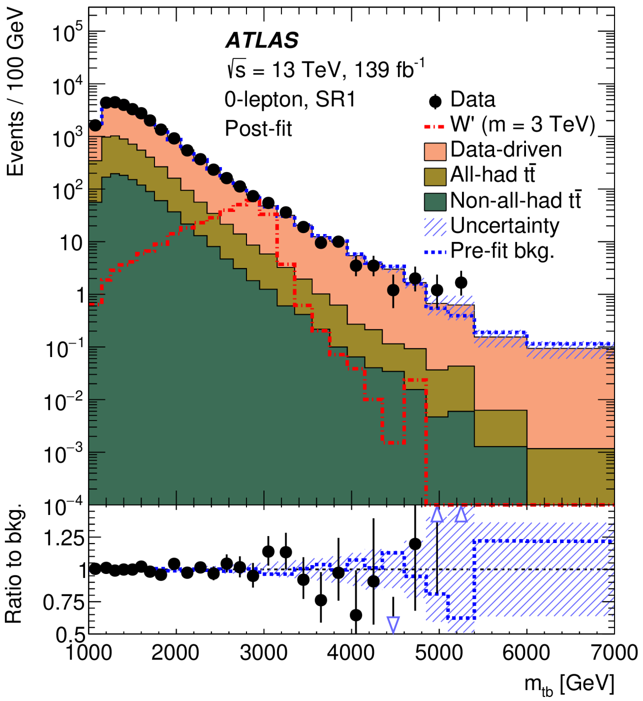
Theoretical scenarios determined by the couplings c_W, c_Z and c_H between the B quark and the SM W, Z and Higgs bosons

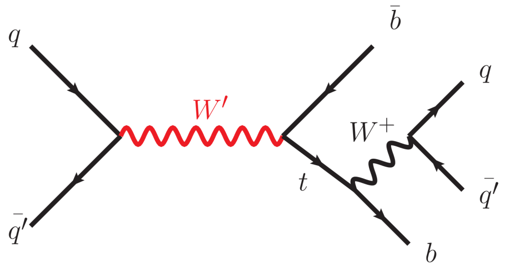
$$c_W = \kappa\sqrt{\frac{2\xi_W}{\rho_W}}, \qquad c_Z = \frac{m_Z}{m_W} \times \kappa\sqrt{\frac{2\xi_Z}{\rho_Z}}, \qquad c_H = \frac{1}{2}\frac{g_W m_B}{m_W} \times \kappa\sqrt{\frac{2\xi_H}{\rho_H}}$$

Search for W’ → tb in 0/1-lepton channel

JHEP12(2023)073

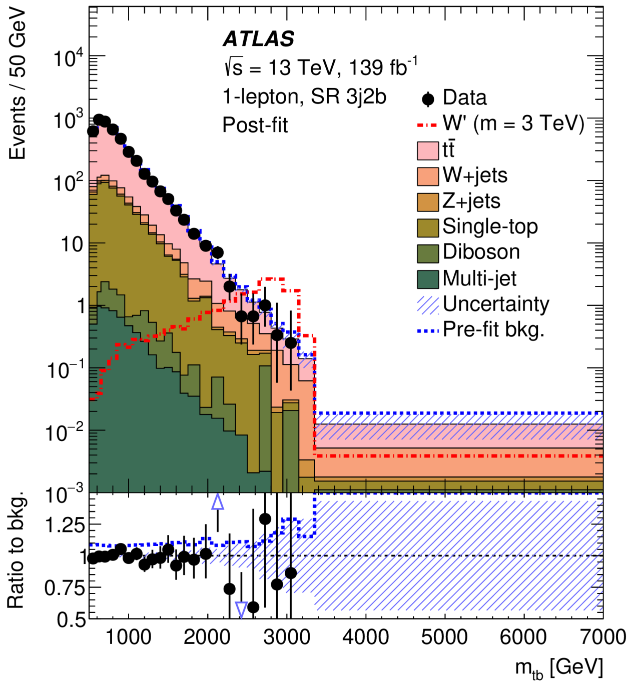
- Many models (extra dimensions, strong dynamics, or a composite Higgs boson), predict new vector charged-current interactions
  - Some models predict W' bosons that preferentially couple to third-generation particles

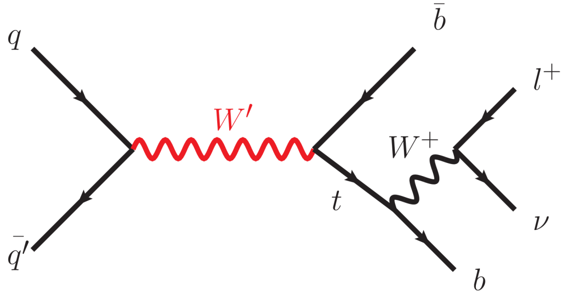




Hadronic channel

- One large-R jet that is top-tagged
- Small-R jet that is b-tagged
- Lepton (e, μ) veto



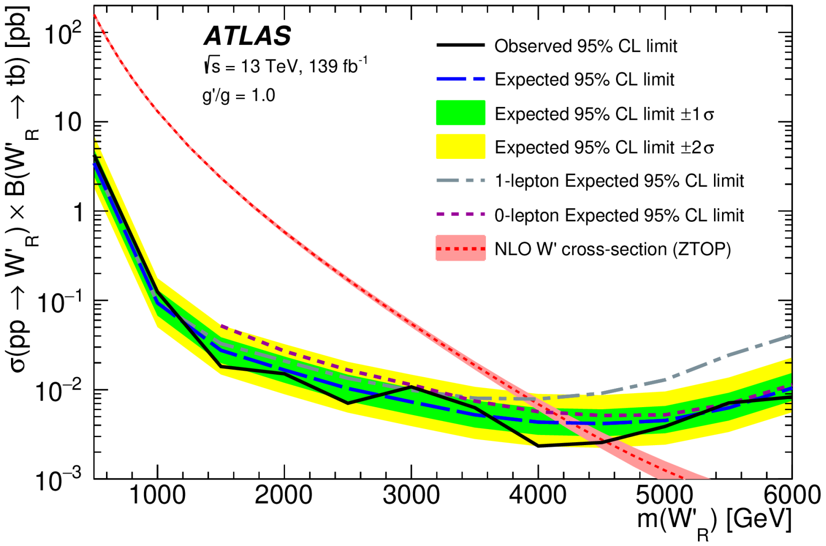


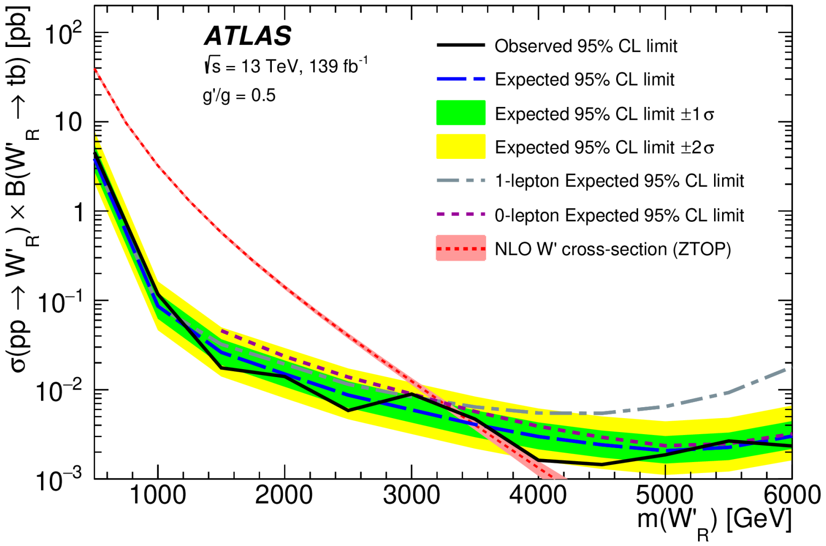
Single lepton channel

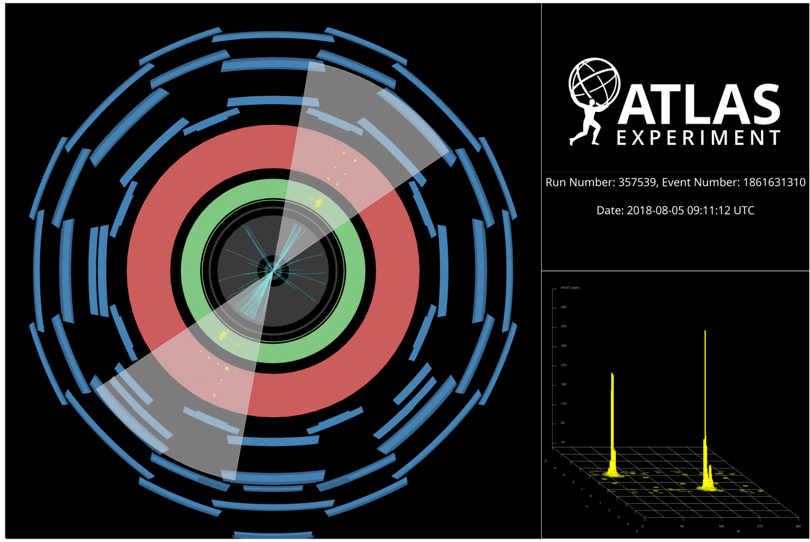
- One lepton (e, μ)
- Large E_T^{miss}
- Neutrino reconstruction
- W-boson is reconstructed as the sum of the lepton and the neutrino
- Top quark is reconstructed by combining the W boson with one of the jets, without considering b-tagging

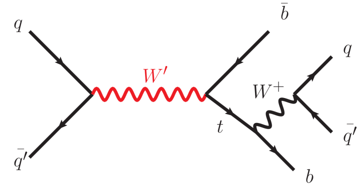
Search for W' to tb 0/1-lepton

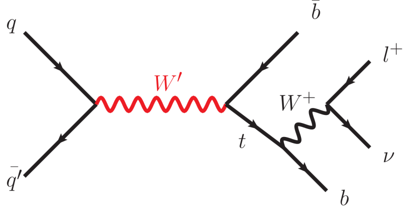
- Good agreement between the background prediction and data observed in all regions
- Results interpreted as limits on W’ mass









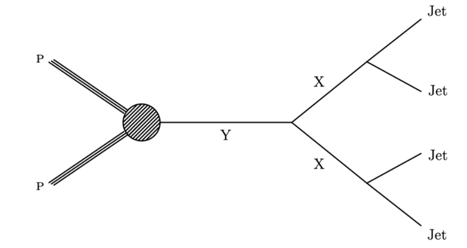


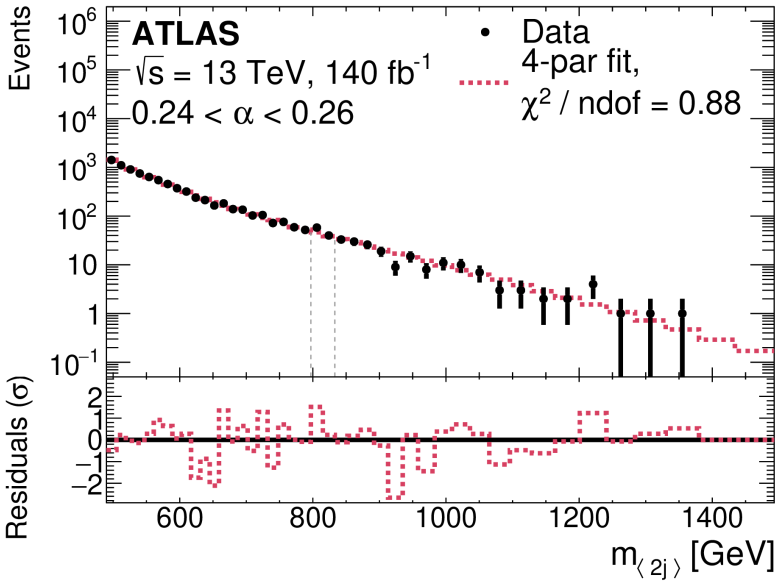
JHEP12(2023)073

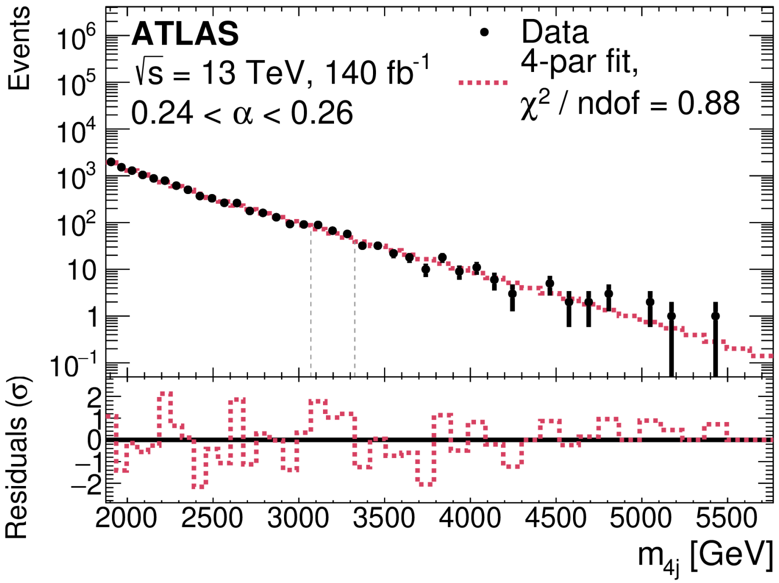
Paired dijet resonance

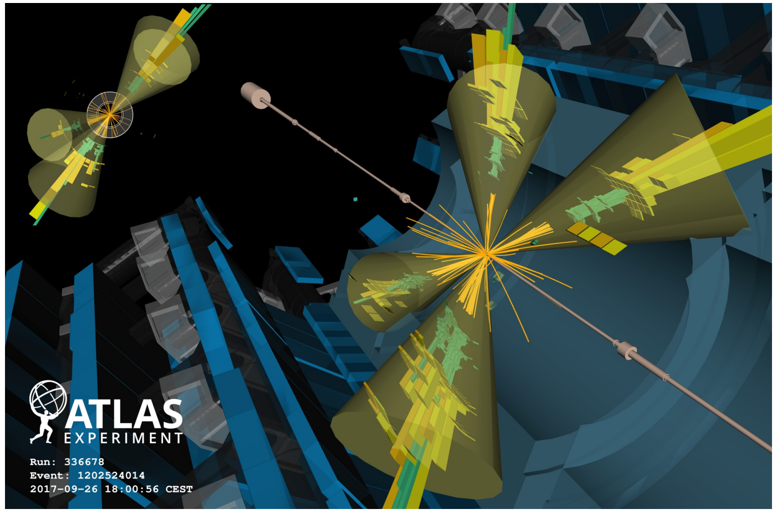
Phys. Rev. D 108 (2023) 112005

- Generic massive resonance Y that decays into two pairs of intermediate resonances X with the same mass, each decaying into two partons and so typically producing a pair of dijet system
- Resonances are searched for in the invariant mass of the tetrajet system, and in the average invariant mass of the pair of dijet systems
- Data-driven background estimate is obtained by fitting the tetrajet and dijet invariant mass distributions with a four-parameter dijet function





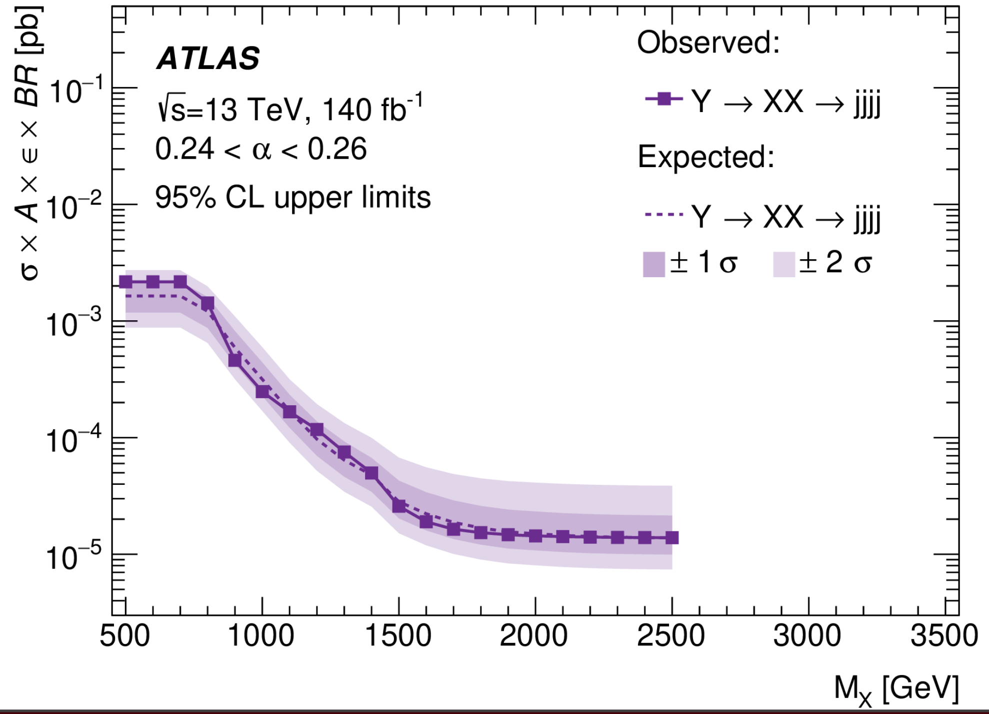


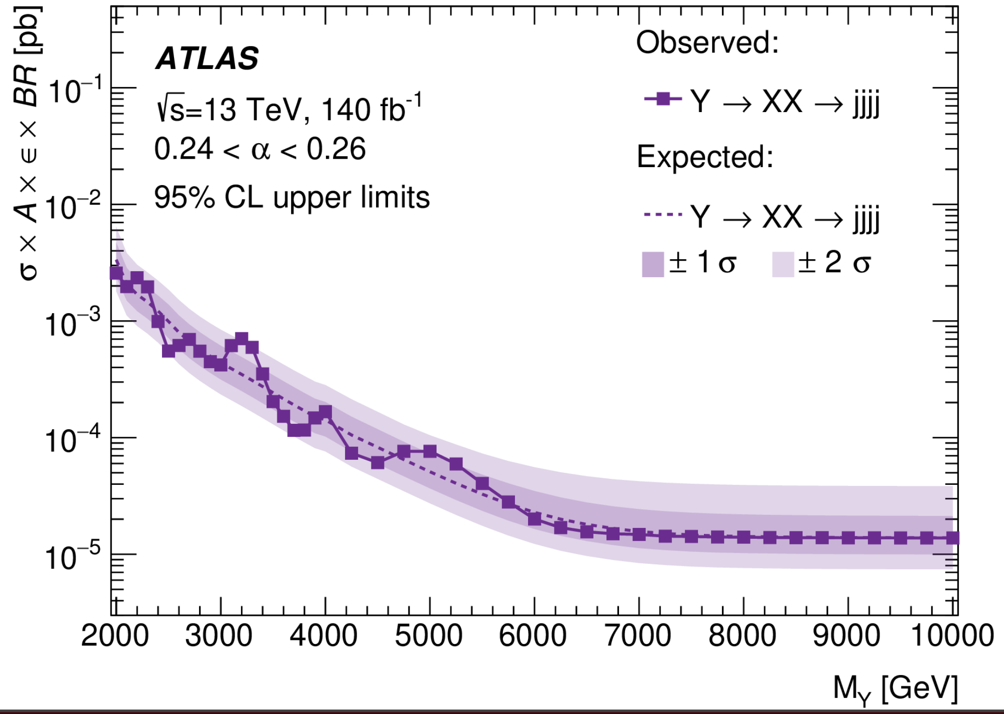


Paired dijet resonance

- 95% CL upper limits on the allowed cross-sections of these particles as a function of their mass
- Several representative $\alpha = \langle m_{2j} \rangle / m_{4j}$ regions

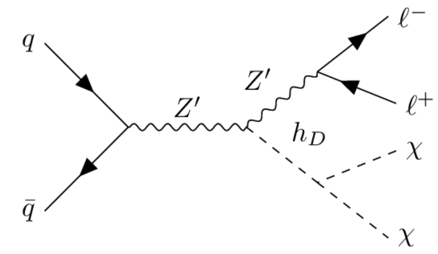
Phys. Rev. D 108 (2023) 112005

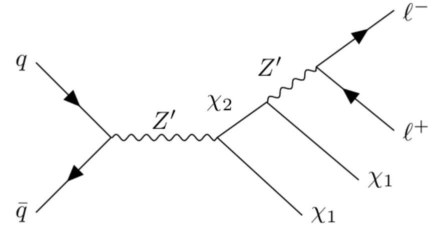


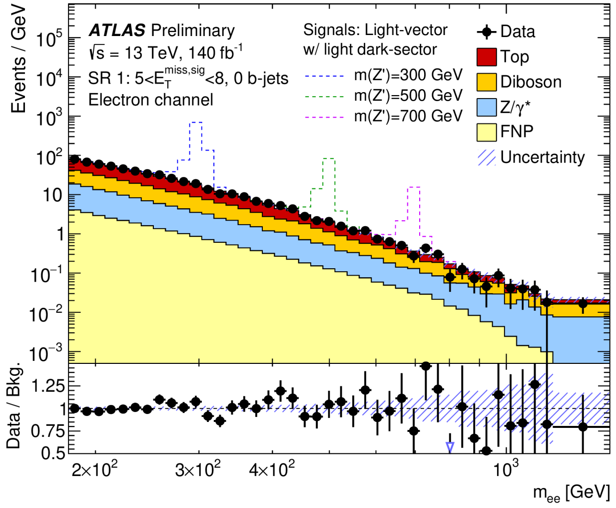


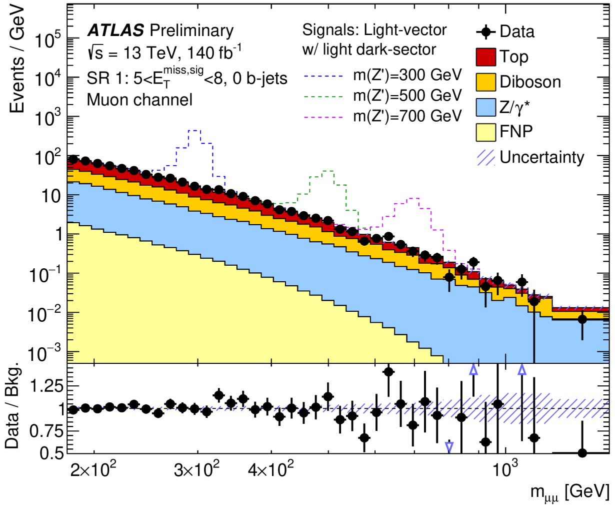
Exclusive dilepton + E_T^{miss}

- Dark matter particles produced in association with a new neutral vector boson
- Decays of the Z′ boson to same-flavor light leptons ($e^+e^-/\mu^+\mu^-$)
- Dark-Higgs model: a dark-sector Higgs boson h_D can be radiated from the Z' boson and decay to a pair of dark matter particles ($\chi\,\chi$)
- Light-vector case: the Z' boson has an off-diagonal coupling to the χ_1 and χ_2 dark-sector particles
    - Heavier state χ_2 decays to a lighter dark matter candidate χ_1 and a Z'









ATLAS-CONF-2023-045

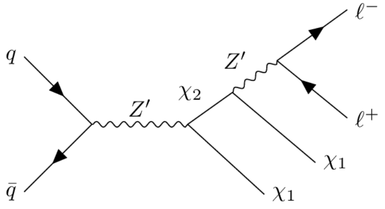
- Event selection:
    - Same flavor opposite sign leptons
    - Large E_T^{miss}
    - Three SR based on $E_T^{miss,sig}$

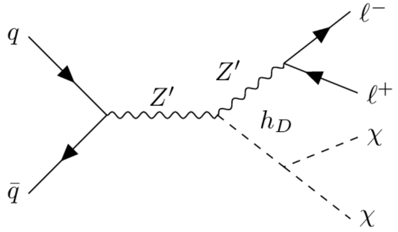
$$E_T^{miss,sig} = \frac{|\mathbf{p}_T^{miss}|}{\sqrt{\sigma_L^2(1-\rho_{LT}^2)}}$$

Exclusive dilepton + E_T^{miss}

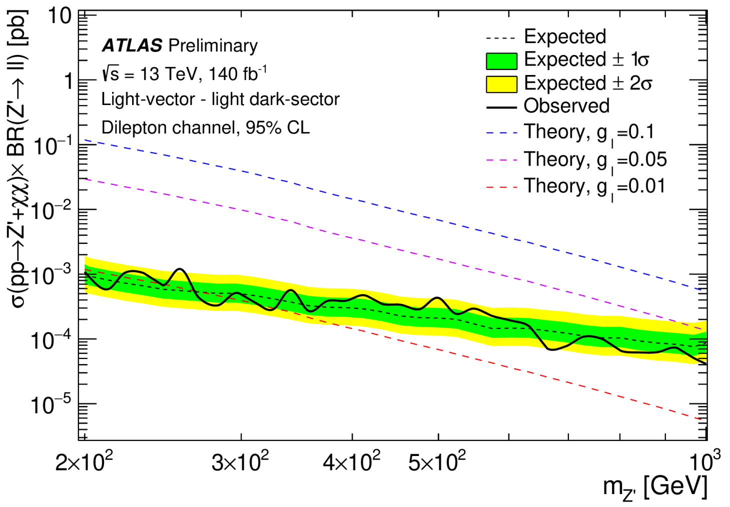
ATLAS-CONF-2023-045

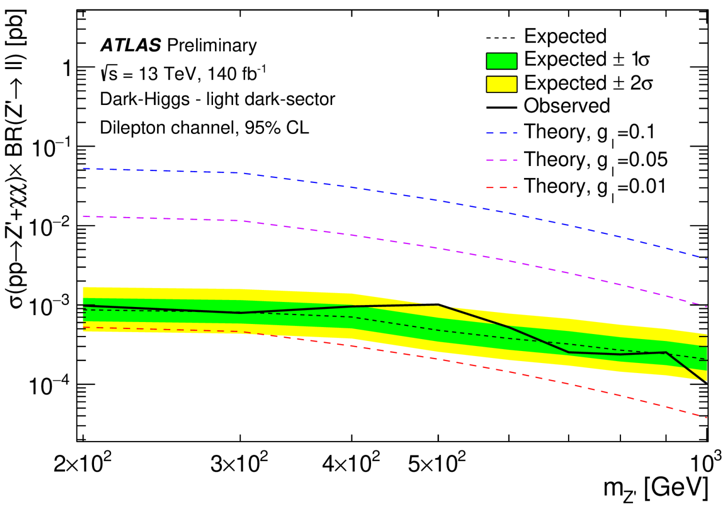
- No significant deviations from the SM are observed
  - ➔ Derive limits as a function of the Z' mass as well as limits on the Z' coupling to leptons





	Dark Higgs	Light Vector
Light dark-sector	$m_\chi = 5$ GeV	$m_{\chi_1} = 5$ GeV
	$m_{h_D} = 125$ GeV	$m_{\chi_2} = m_{\chi_1} + m_{Z'} + 25$ GeV
Heavy dark-sector	$m_\chi = 5$ GeV	$m_{\chi_1} = m_{Z'}/2$
	$m_{h_D} = m_{Z'}$	$m_{\chi_2} = 2m_{Z'}$

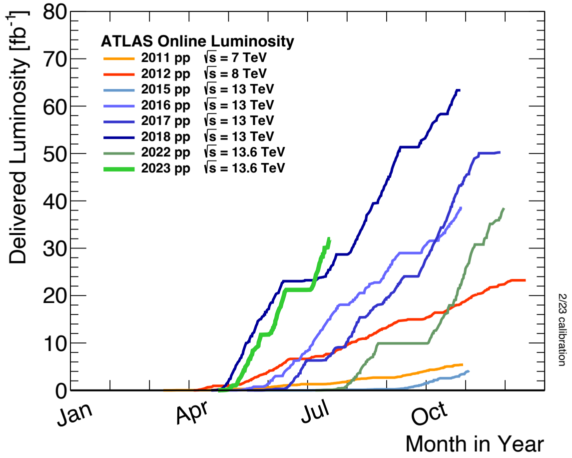


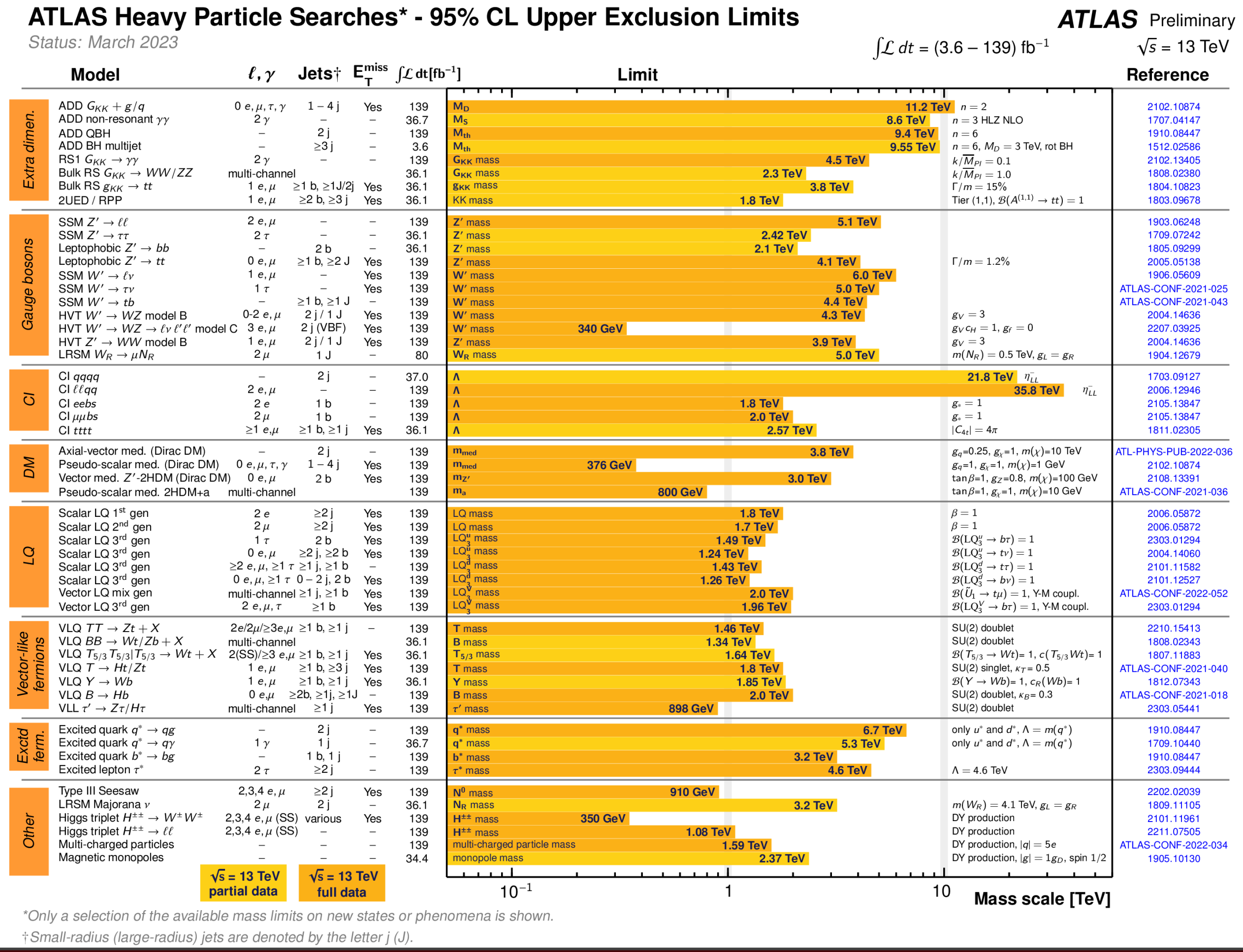


- Three coupling parameters considered in each model:
  - Coupling of the Z' to quarks (g_q)
  - Coupling of the Z' to leptons (g_l)
  - Coupling of the Z' to the dark-sector particles (g_{DM})
- In the dark-Higgs model the coupling g_{DM} is the coupling between the Z' and h_D
- In the light-vector model g_{DM} is the coupling between Z' and the dark-sector particles χ_1 and χ_2
- Couplings to quarks and leptons are assumed to be constant across generations
- Couplings considered for this search are $g_{DM} = 1$, $g_q = 0.1$, and $g_l = 0.01$
- Non-zero g_l introduced to allow the leptonic decay of the Z' boson

Conclusion and Outlook

- ATLAS performed many searches for heavy resonances
- Many more to come with $\sqrt{s}$ = 13.6 TeV





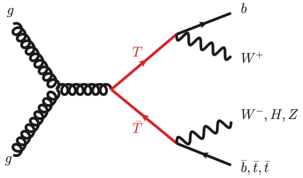
Back-up

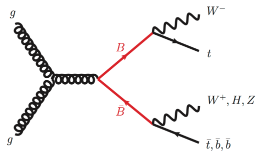
arxiv:2401.17165

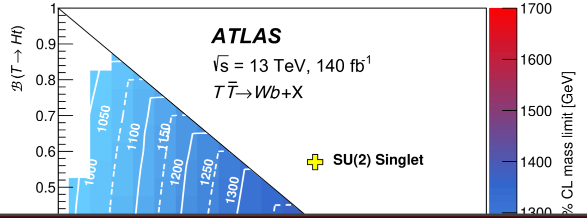
VLQ pair production search in the Wb+X final state

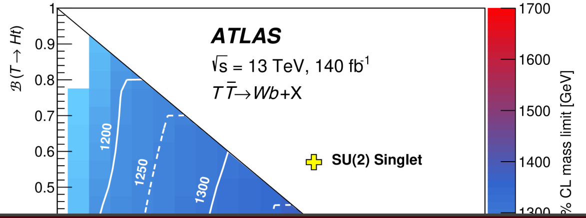
- VLQs can decay via a flavor-changing neutral current or a charged current
  - ➔ T and B to each have three possible decays: $T \rightarrow Wb/Zt/Ht$ and $B \rightarrow Wt/Zb/Hb$

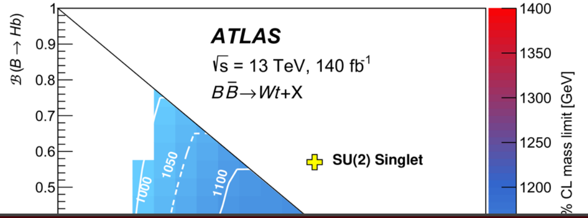
- Expected and observed 95% CL lower limits on the mass of the T-quark in the branching-ratio plane of B($T \rightarrow Wb$) versus B($T \rightarrow Ht$)

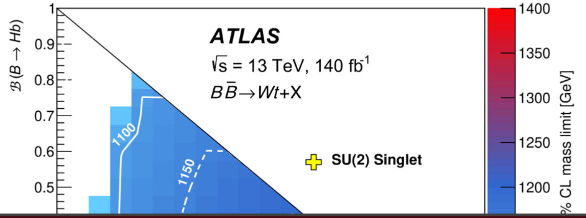












Search for dark jets

arxiv:2311.03944

- New Z' resonance
  - Decays into a pair of dark quarks which hadronise into dark hadrons before promptly decaying back as SM particles

- Selecting events containing large-R jets with high track multiplicity