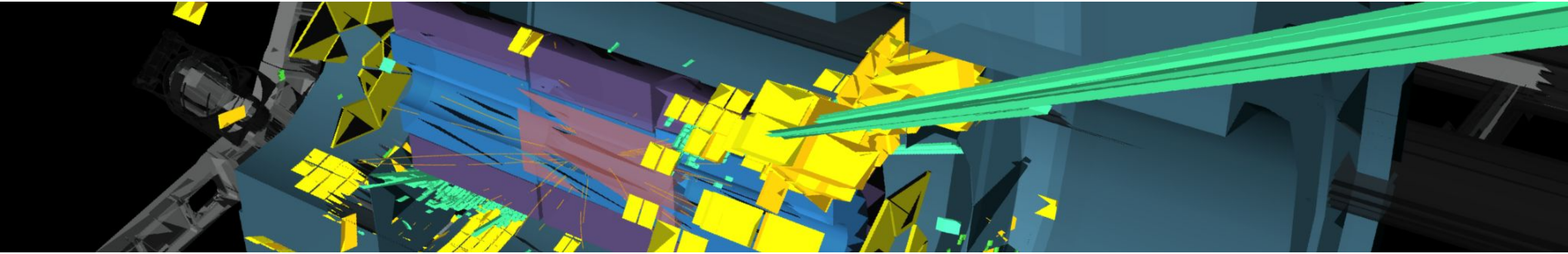
Searches for new phenomena in final states with 3rd generation quarks using the ATLAS detector

The XXIX International Conference on Supersymmetry
and Unification of Fundamental Interactions

University of Ioannina
1 July 2022



Patrick Rieck
New York University

on behalf of the ATLAS collaboration

ATLAS EXPERIMENT

NYU

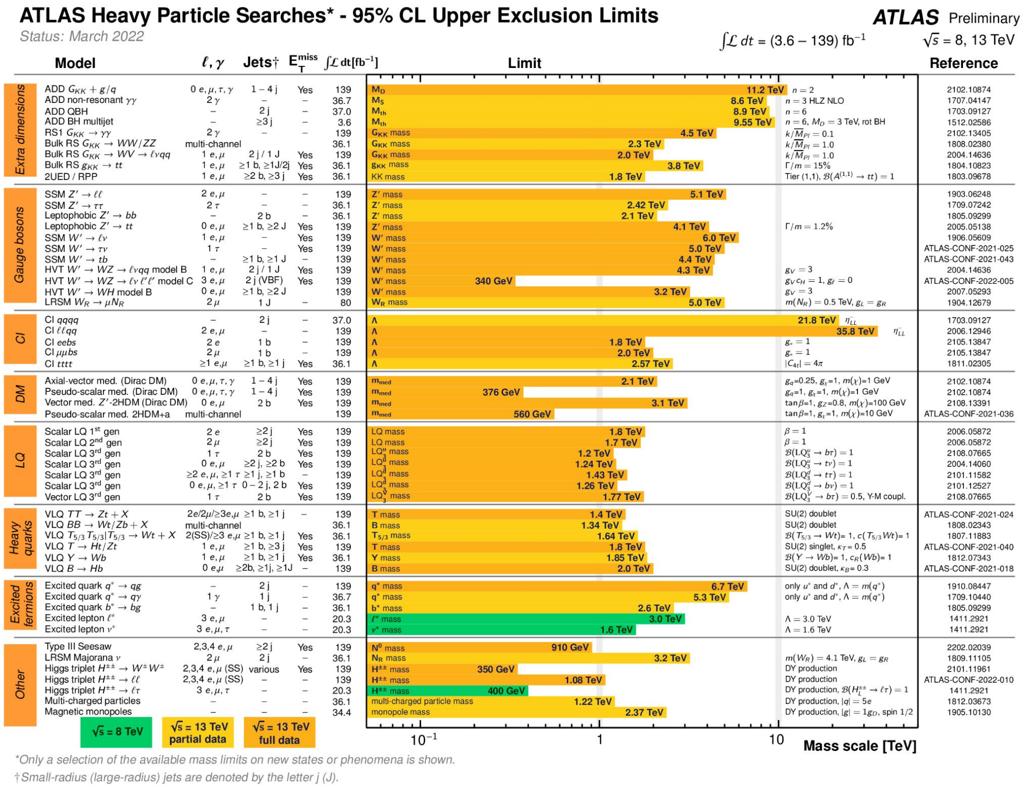
Overview

- Numerous reasons to search for new physics but no clear target
- Overwhelmingly large theory landscape

  ⇒ How to shape our search program?

- Peculiarity of the 3rd generation of fermions: strong couplings
  - Higgs physics
  - B-Meson decay anomalies ?

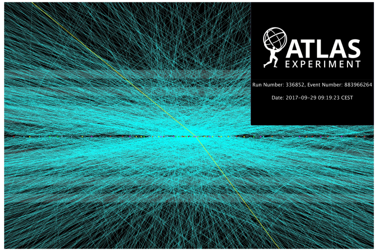
  ⇒ Searches with emphasis on 3rd generation quarks (and leptons)



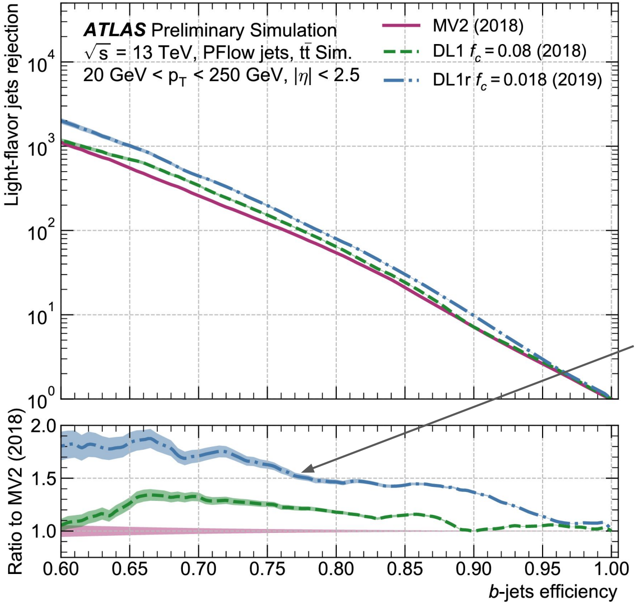
B-Tagging

ATLAS-FTAG-2019-005

- 3rd generation charged fermions: short-lived with complex decays ⇒ sophisticated event re-construction and detailed detector understanding required
- Key technique: identification of *b*-quark induced jets
  - Recurrent, deep neural networks mapping tracks to a *b*-jet score
- Ongoing development with further significant improvements (graph neural networks most recently)



Vertex identification in busy environments



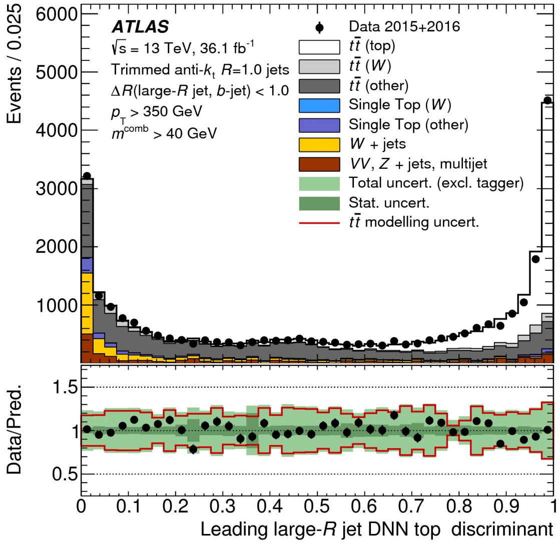
Early Run 2 vs. end of Run 2: 50 % improvement

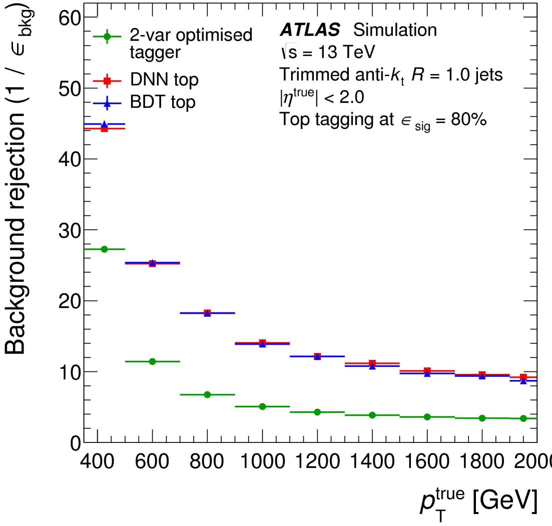
Boosted Top-Quark Tagging

arxiv 1808.07858

- Building R = 1.0 anti-k_T jets from clusters of calorimeter cells, removing lower p_T contributions from soft QCD physics

- Deep Neural Network* tagging algorithm
  - Input: Jet mass, p_T and substructure variables (constituent p_T correlations, e.g. as indicator of a 3-body-decay)
  - Training with a flat p_T-spectrum for true top-quark jets



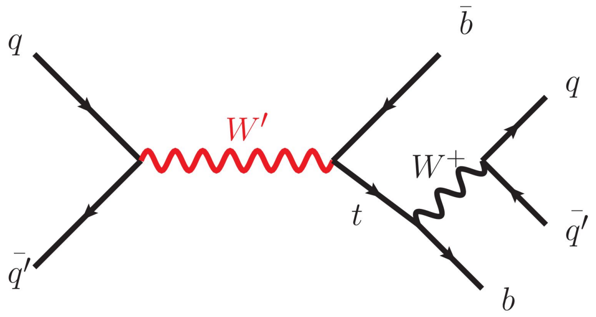


Outcome: binary classifier, cut decision giving ≈ 80 % efficiency ∀ jet p_T

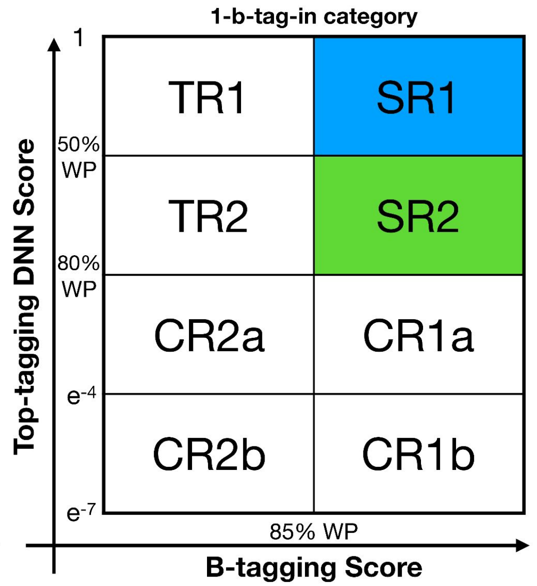
* Fully connected, feed forward architecture

Top + Bottom Resonance Search (W')

Analysis Strategy



- Benchmark model: new charged mediator W' coupling to right-handed top and *b*-quarks
- Selecting events with a top-tagged large-radius jet and a separate *b*-jet
- Signal and control regions defined by top-tag and *b*-tag scores
- Major background: multijet production, data-driven estimation

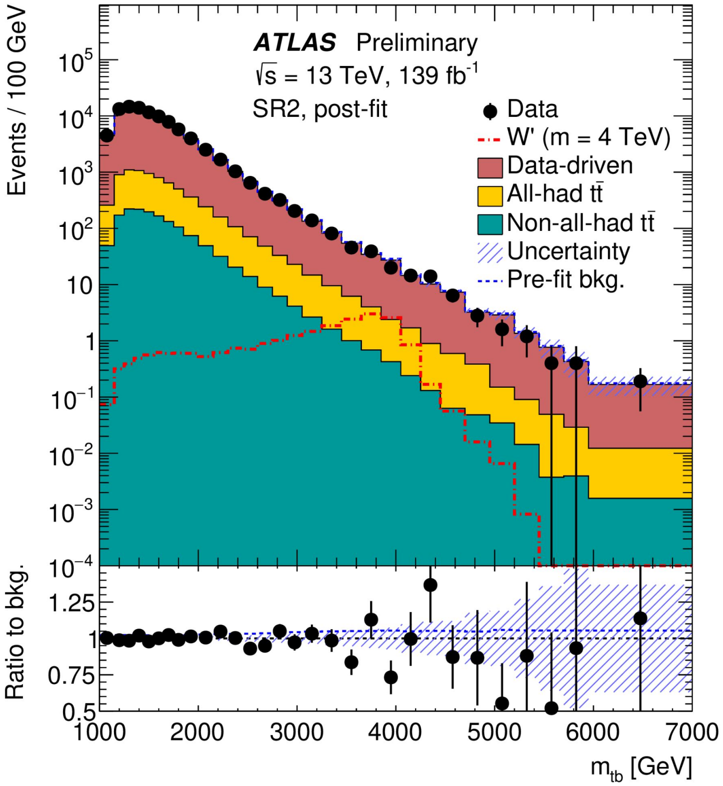


$$N_{TR} \frac{N_{CR1}}{N_{CR2}} = N_{SR}$$

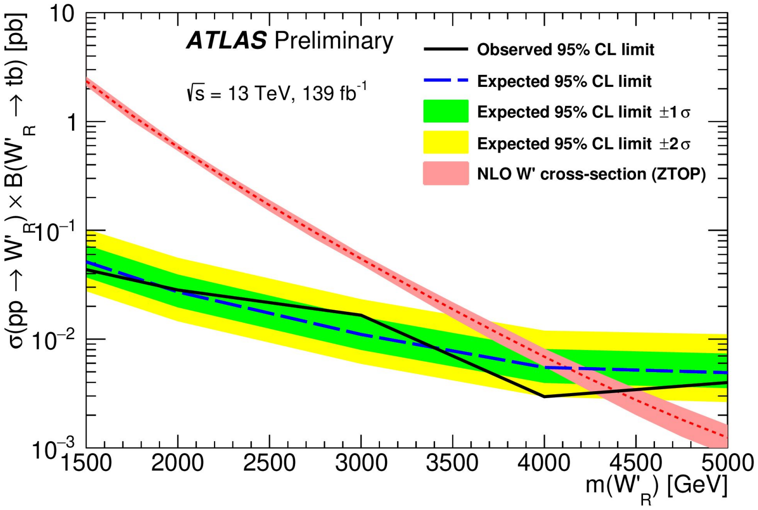
Top + Bottom Resonance Search (W')

Results

ATLAS-CONF-2021-043



- Fit of the dijet mass distribution in the signal regions ⇒ W' mass exclusion limit, $m_{W'_R} > 4.4$ TeV

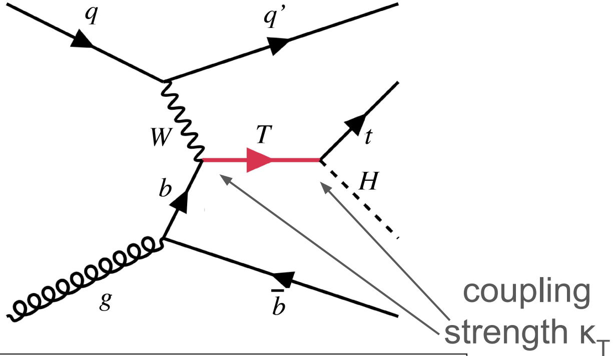


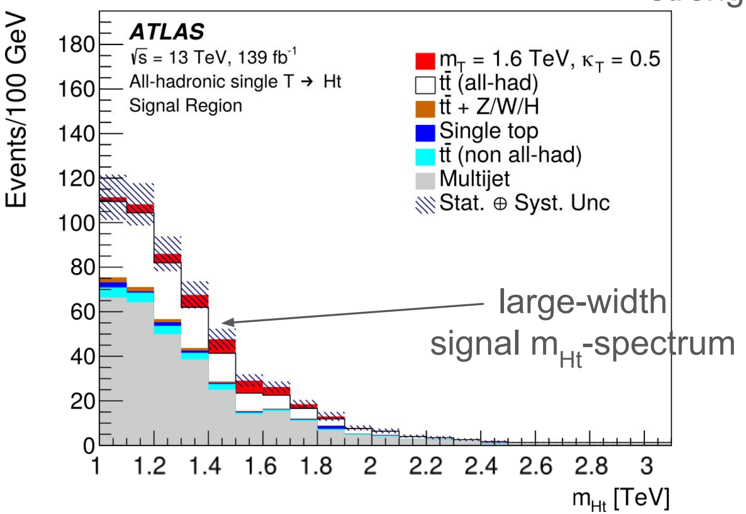
Single Vector-Like Quark T

Analysis Strategy

[arXiv:2201.07045](https://arxiv.org/abs/2201.07045)

- LHC Run 1 / 2: lower mass limits on Vector-Like Quarks (VLQ) beyond 1 TeV
  ⇒ Higher rates of single VLQ production
  - Here: $Wb \rightarrow T \rightarrow Ht$
- H-boson and top-quark reconstructed as large-R jets with corresponding substructure, including *b*-tagging
  - Signal region: large-R jets pass H and top-Tagging requirements, resp.
  - Control regions with two top-tags for $t\bar{t}$ normalisation
- Major background: multijet production, data-driven estimation



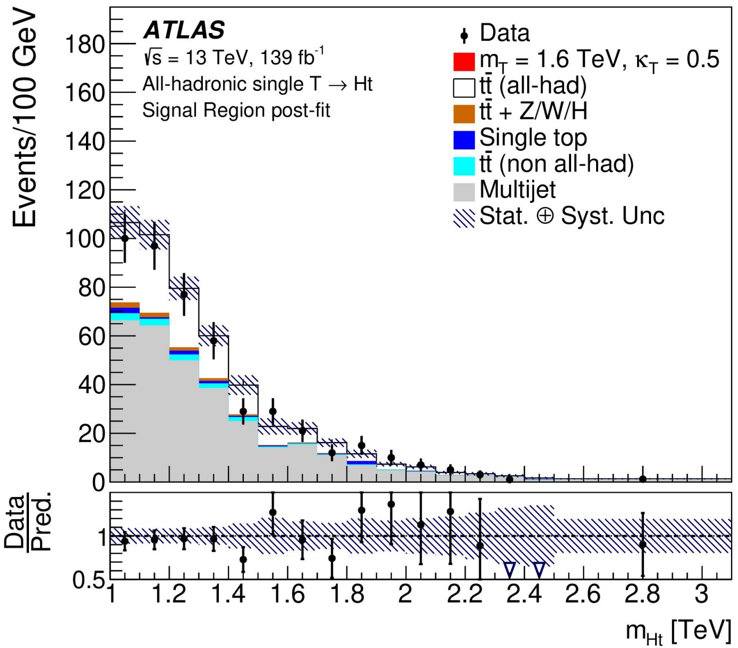


Single Vector-Like Quark T

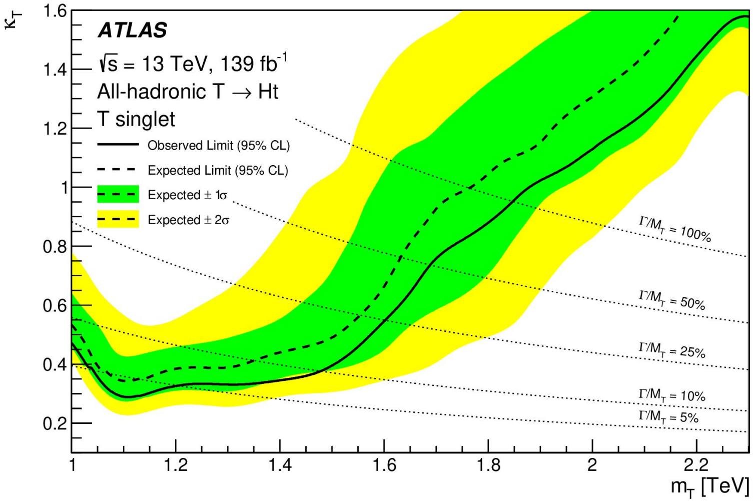
Results

arXiv:2201.07045

- Combined fit of signal and control region dijet invariant mass spectra



- Exclusion limits on the T-quark mass, depending on κ_T

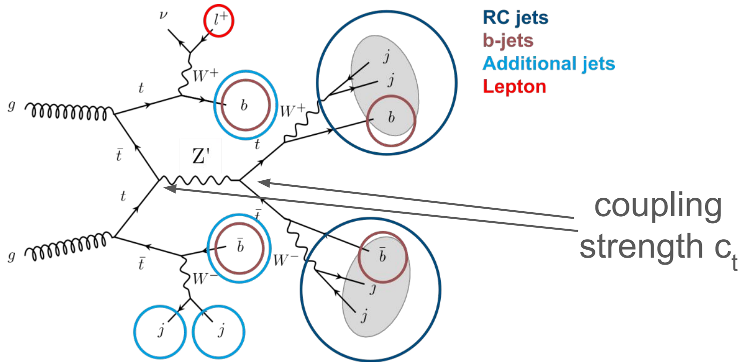


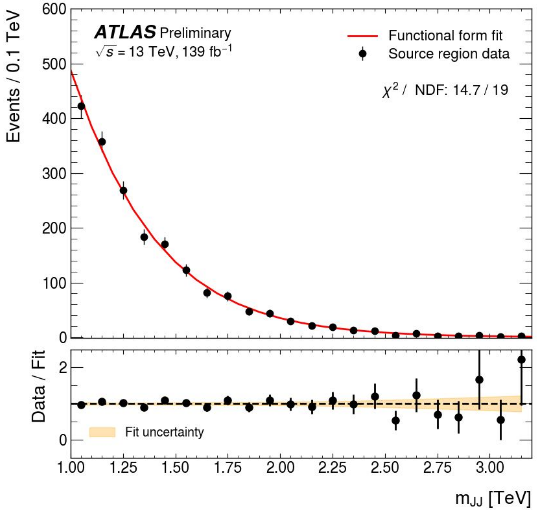
Resonances in 4-top-quark events

ATLAS-CONF-2021-048

Analysis Strategy

- Search for new resonances coupling only to top-quarks
- Target signature:
  - Single lepton events: e or μ from associated top-quark decay
  - Resonance mass reconstruction from two fully hadronic top-quark decays → discriminating variable m_{JJ}
- Data-driven background estimation ($t\bar{t}$ events)
  - Control region with fewer *b*-tagged jets
  - Fitting a smoothly falling function of m_{JJ}
  - Extrapolation to the signal region using simulations

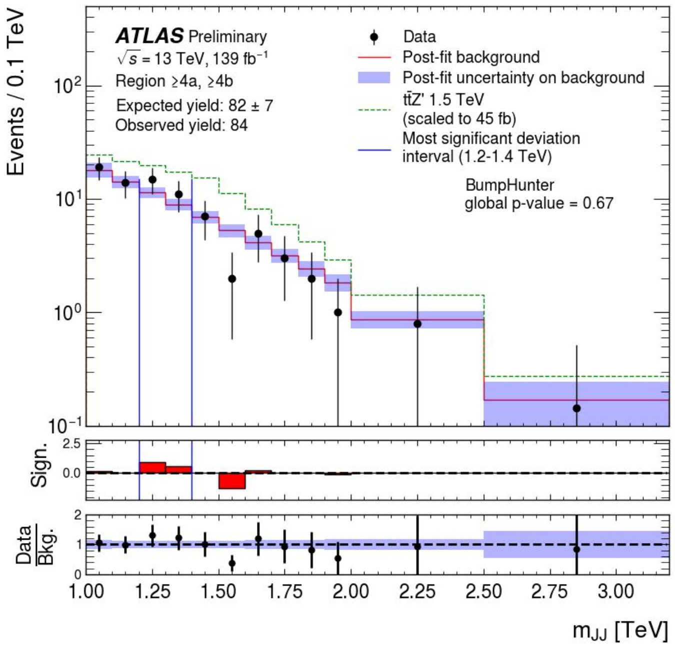


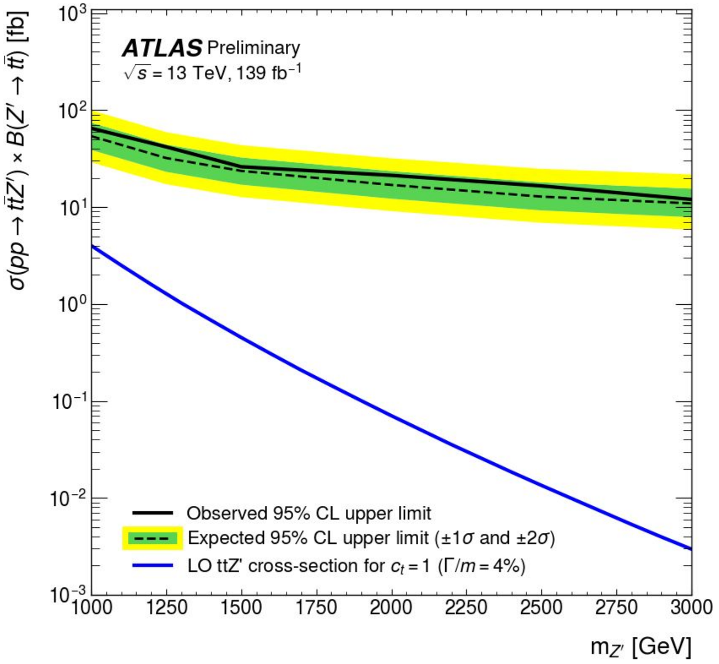


Resonances in 4-top-quark events

ATLAS-CONF-2021-048

Results

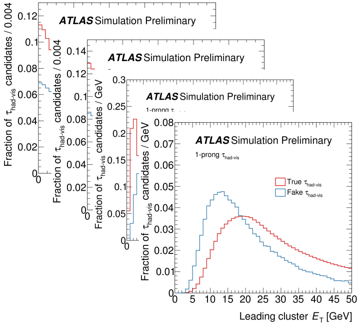


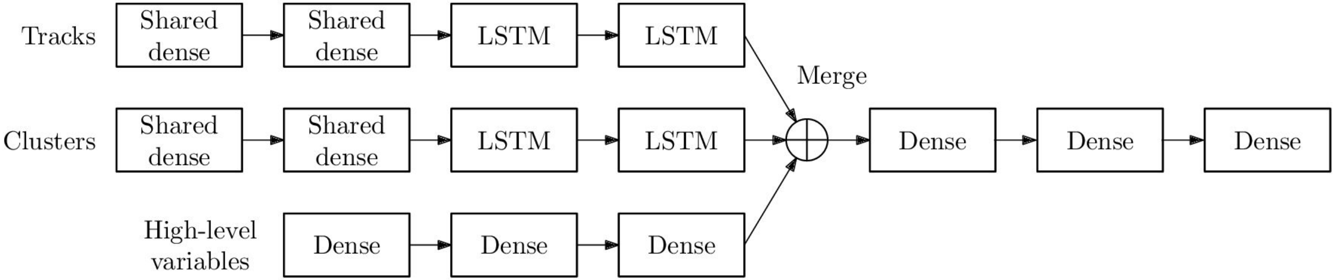


- No mass exclusion for Z'-top coupling strength $c_t = 1$

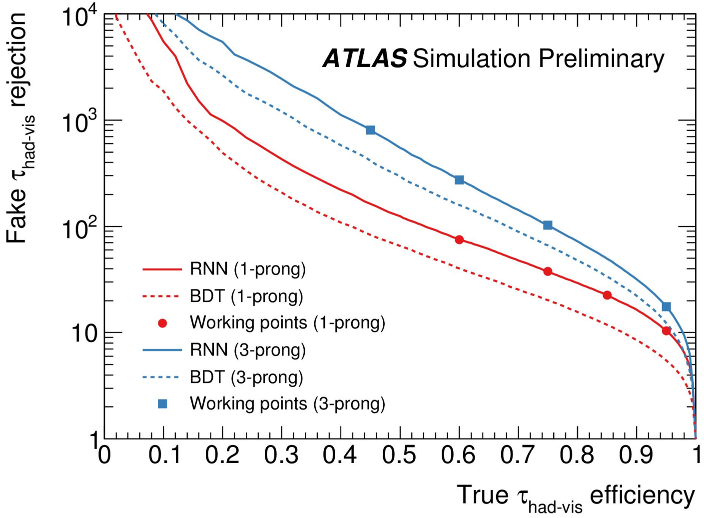
Tau Lepton Identification

ATL-PHYS-PUB-2019-033





- Recurrent neural network used to distinguish τ-leptons from jets
  - Trained on di-τ and di-jet MC samples, same p_T^{τ} distribution after reweighting
- Charged particle tracks, calorimeter cell topological clusters and variables derived from them as input
- Considerable improvement compared to previous approach with fewer input variables

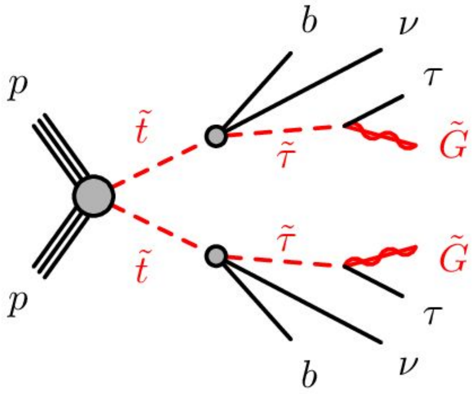


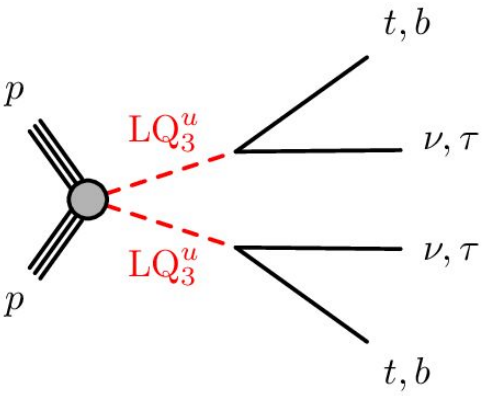
Search with τ-leptons, b-quarks and MET

Analysis Strategy

arXiv:2108.07665

- Search for pair production of new particles via strong interactions:
    1. SUSY: stop-quark pair production and decays to stau leptons
    2. Leptoquarks: spin ∈ {0, 1}, |Q| ∈ {⅓, ⅔} , decays ∈ { {$t\nu$, $b\tau$}, {$b\nu$, $t\tau$} }
- MET triggered events, 1 or 2 τ-leptons (hadronic decays) and b-tagged jets
    - Require large momentum transfer collisions, e.g. $S_T = \sum p_T(\tau, \text{jets}) > 800$ GeV
- Main background: $t\bar{t}$ events ($W \to \tau\nu$ decays), estimated from control regions, e.g. with lower S_T



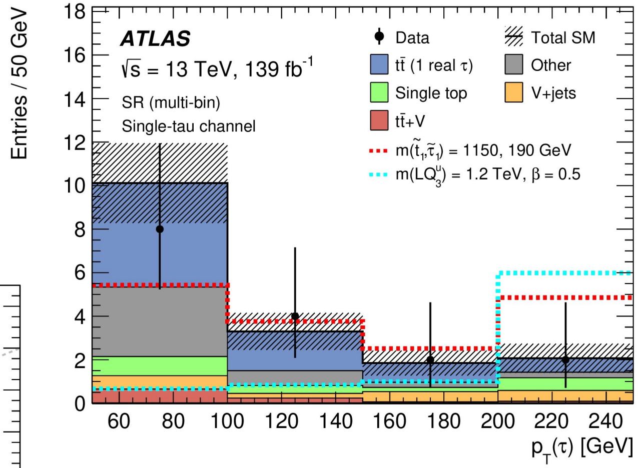


Search with τ-leptons, b-quarks and MET

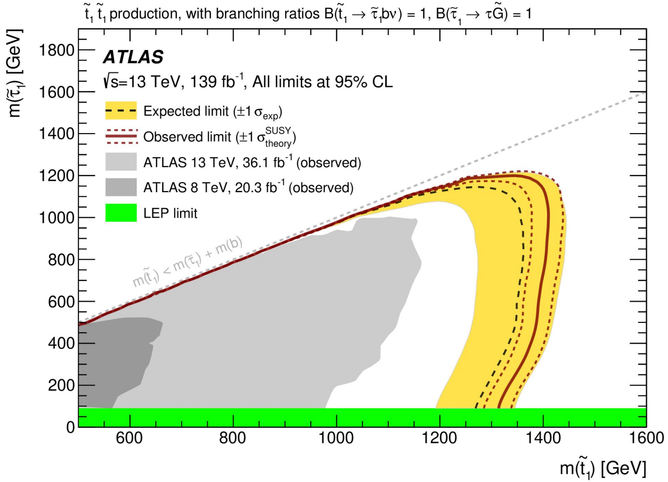
arXiv:2108.07665

Results

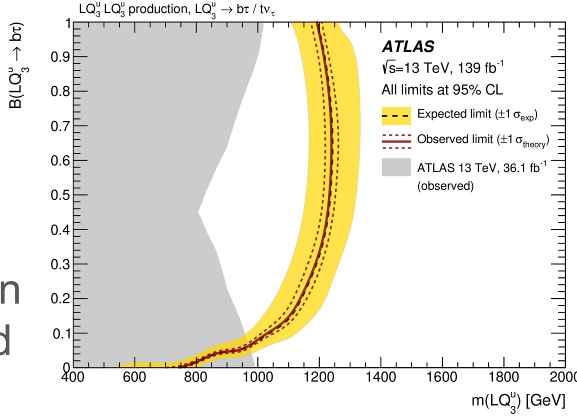
- Combined control and signal region fit, also using the τ-lepton p_T distribution
  - Multijet background negligible thanks to the good τ-lepton identification



- SUSY: stop-quark and stau-lepton mass exclusion



- Leptoquarks
  - Spin 0: mass and branching fraction exclusion
  - Spin 1, SU(2) singlet : m < 1.77 TeV excluded



Leptoquarks with cross-generational couplings

ATLAS-CONF-2022-009

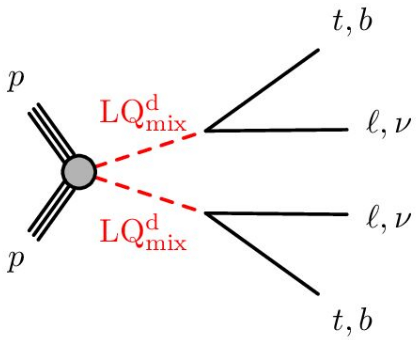
Analysis Strategy

- Selecting events with MET > 250 GeV, $N_{e/\mu} = 1$, $N_{jets} \geq 4$, $N_{b\text{-}jets} \geq 1$

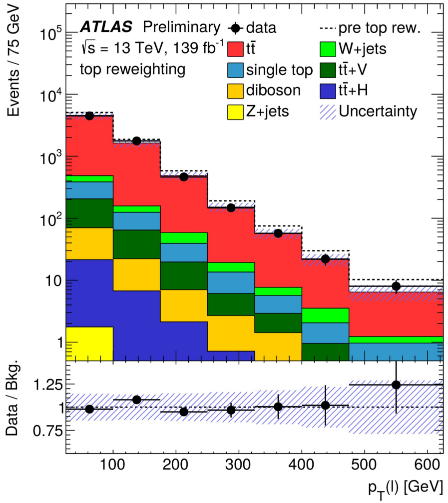
  ⇒ Challenging phase space, need for reweighting of top-quark background prediction from simulations using a dedicated control region

- W+jets and single top-quark control regions

- Neural network for signal distrimination
  - Dedicated networks for various signal hypotheses



Targeting final States with t, ν, b and e or μ

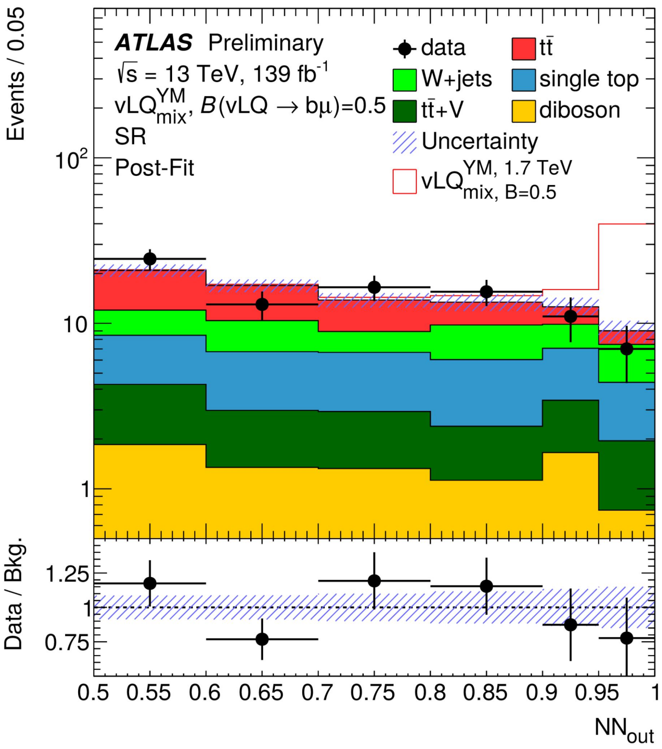


Necessity of top-quark back-ground reweighting

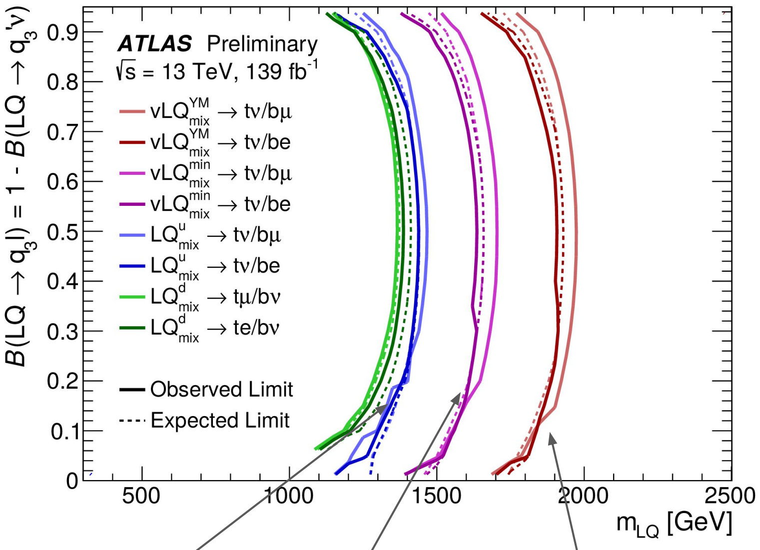
Leptoquarks with cross-generational couplings

ATLAS-CONF-2022-009

Results



- Combined fit of control region event yields and neural network discriminant distribution



Scalar LQs

Vector LQs, minimal coupling

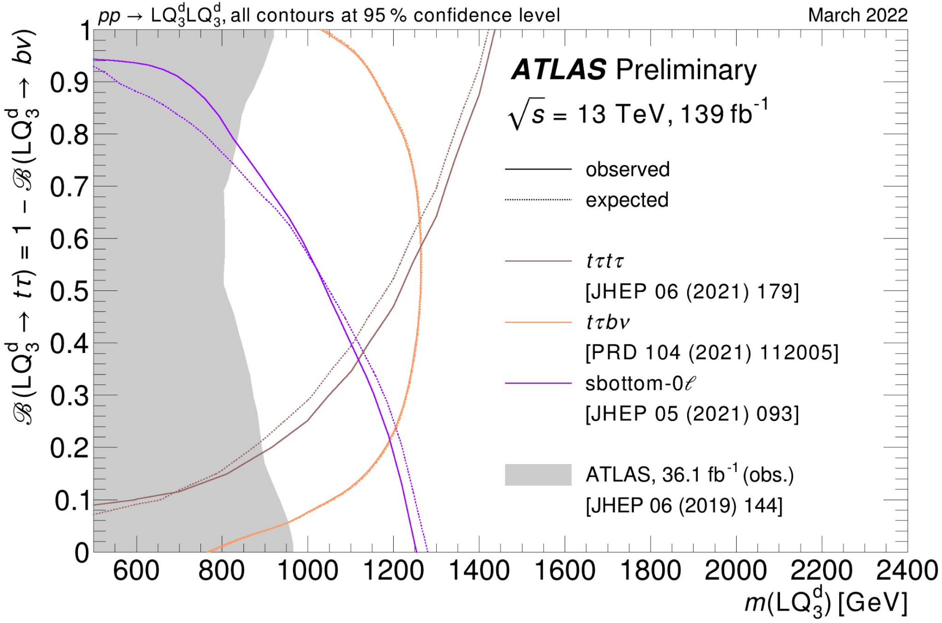
Vector LQs, Yang-Mills coupling

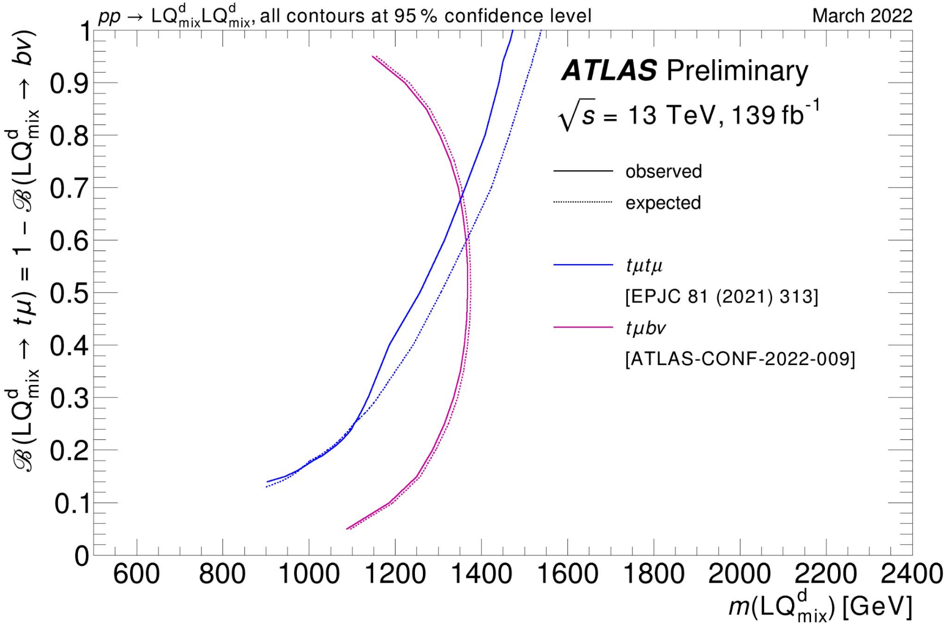
Leptoquark mass and branching fraction exclusion: Highest sensitivity for BR(ql) = BR(qν): most distinct final states

Leptoquark Exclusion Summaries

ATL-PHYS-PUB-2022-012

Examples





- Broad program of complementary leptoquark searches
- Run 2: shift from SUSY search reinterpretations to dedicated leptoquark searches

Summary

- Broad search program in ATLAS targeting new physics with couplings to 3rd generation quarks and leptons
- Searches empowered by sophisticated event reconstruction algorithms
  - Continued efforts providing improvements beyond the luminosity increase
- Increasing importance of searches motivated by B-meson decay anomalies, e.g. leptoquark searches
  - More final states to be covered in Run 3, providing further improvement beyond the luminosity increase