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

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on behalf of the ATLAS collaboration

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HELMHOLTZ

ATLAS EXPERIMENT

DESY.

New phenomena

can be probed in final states with top and bottom quarks. Talk covers:

Vector like quarks (VLQ): new colour-triplet fermions whose both chiralities transform the same under SM gauge groups („vector-like“), could cancel quadratic divergence in Higgs mass.

Z‘ and W‘ heavy vector bosons: new gauge bosons, could explain recently observed lepton-flavor universality deviations.

Leptoquarks (LQ): new colour-triplet bosons with both lepton and quark quantum numbers, could explain anomalies in decays of B mesons and the discrepancy between measured and predicted muon anomalous magnetic moment.

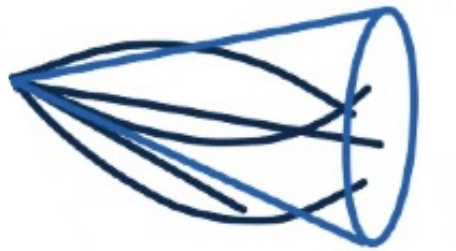
Why perform searches with 3rd generation quarks?

- among the heaviest Standard Model particles: very large Yukawa coupling.
- great potential to reduce the Standard Model background due to unique signature.

Detecting 3rd generation quarks

Identification of bottom quarks

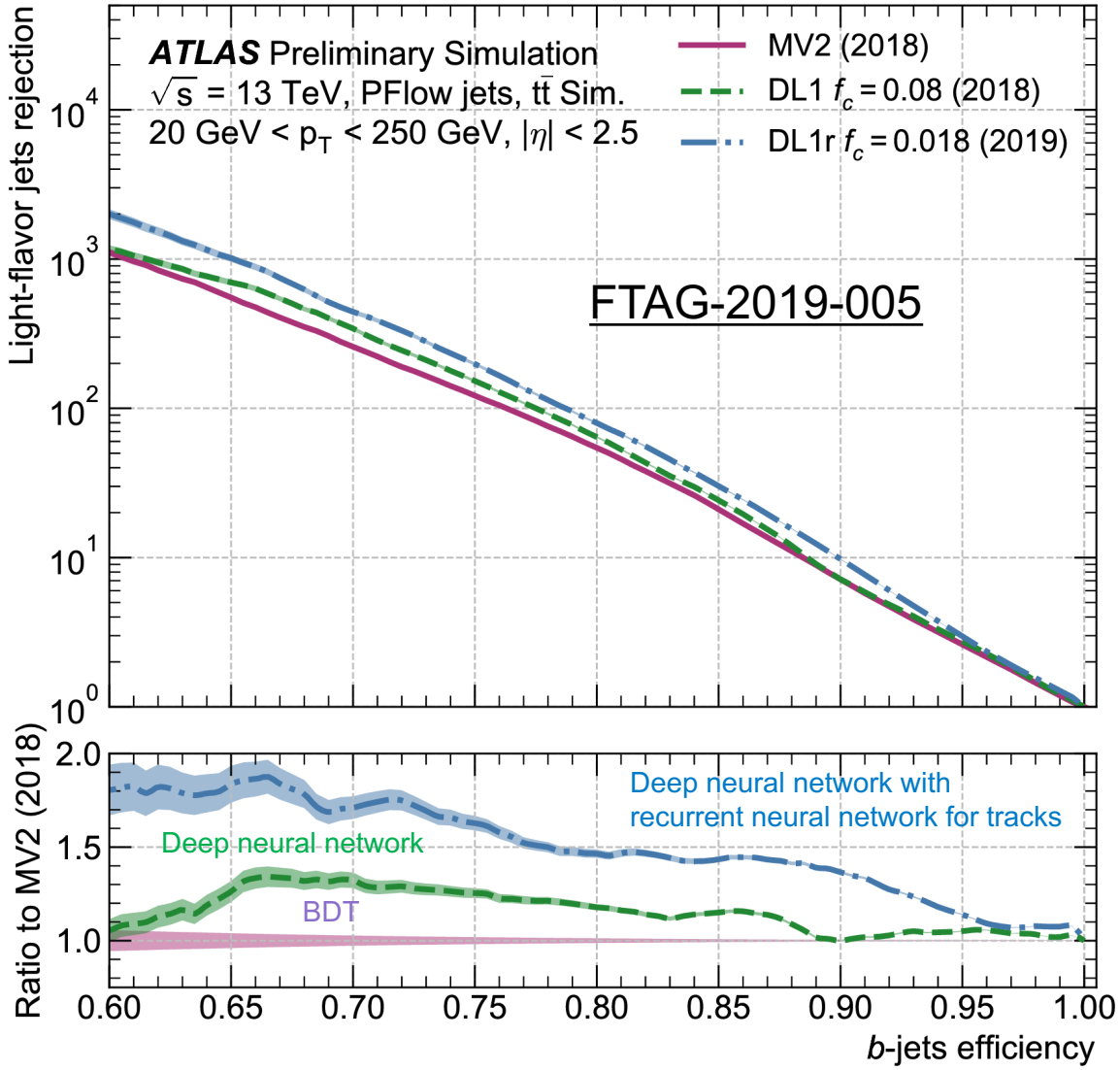
bottom quark



initiates formation of sprays of particles reconstructed as jets from particle flow objects.

Unique features of *b*-jets…
(displaced secondary vertex, high mass and track multiplicity)

… allow for their identification using multi-variate machine learning algorithms.



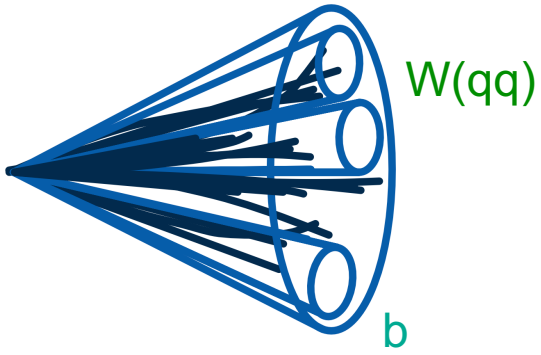
Eur. Phys. J. C 79 (2019) 970

Detecting 3rd generation quarks

Identification of top quarks

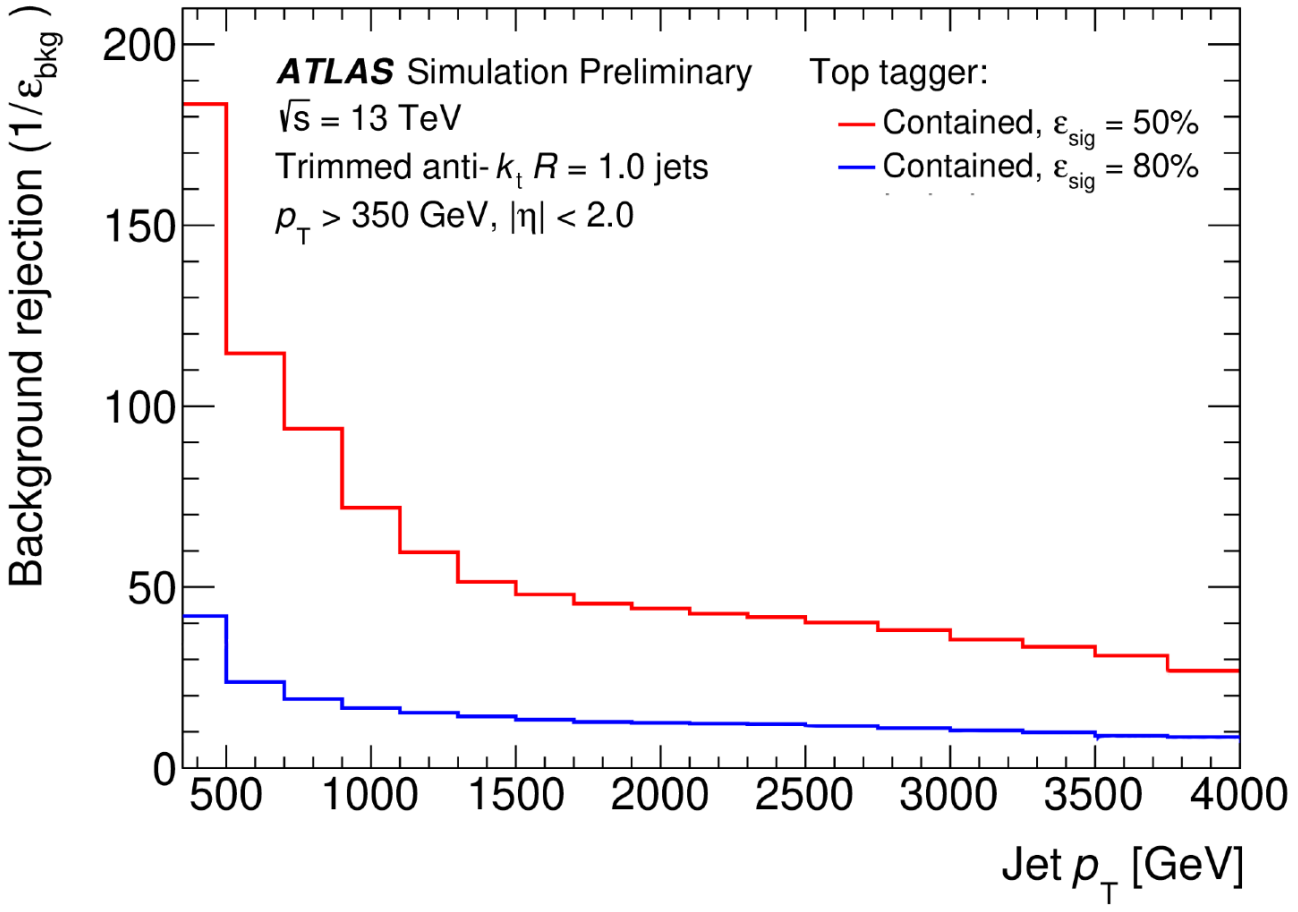
top quark

$t \rightarrow W + b$



reconstructed using jets with large-radius parameter (typical R=1) to **contain full top quark decay**.

often large-radius jets are not reconstructed from calorimeter energy deposits but from small-radius jets („jet reclustering“ , see JHEP 02 (2015) 075).



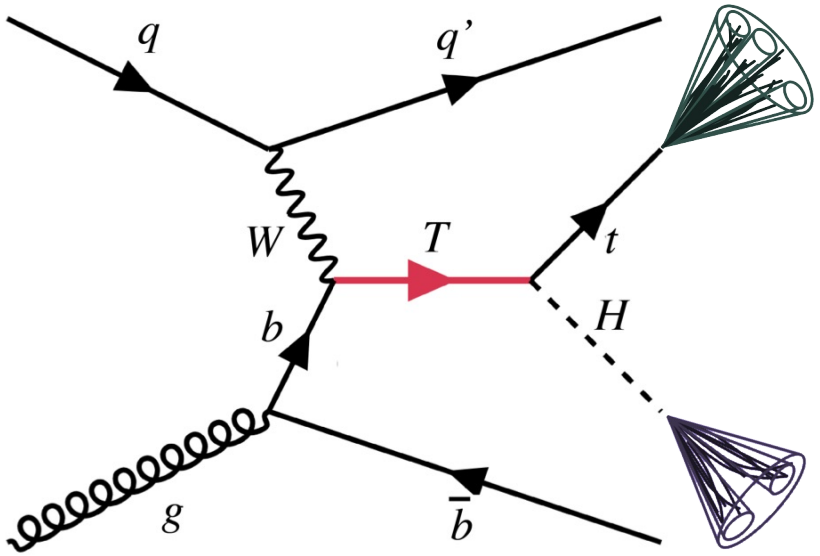
Deep neural network (DNN) top tagger
provides strong rejection of background processes.

Search for vector-like-quark T quarks decaying to Higgs + top

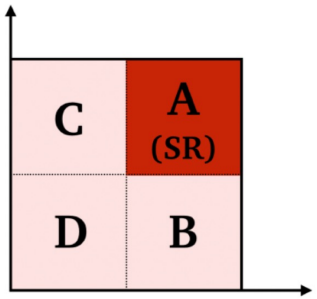
Analysis strategy

T→Ht with t→qqb and H→bb
- reconstructed as 2 large-radius jets with b-sub-jets
- no reconstructed leptons

Analysis regions defined by tagging of two large-radius jets:
- Higgs candidate / Top candidate / None
  - Higgs: 100 GeV < m_J < 140 GeV, two-prong jet substructure
  - Top: DNN top tagger with 80% efficiency working point
- Number of b-tagged sub-jets inside large-radius jets: 0 / 1 / 2+
  - sub-jets reconstructed from high-precision tracking information with variable p_T-dependent jet radius



Dominant background processes
- QCD multijet events: estimated in data using „ABCD“ method
- top quark pair production: MC simulation constrained by data in control regions enriched in top quark events

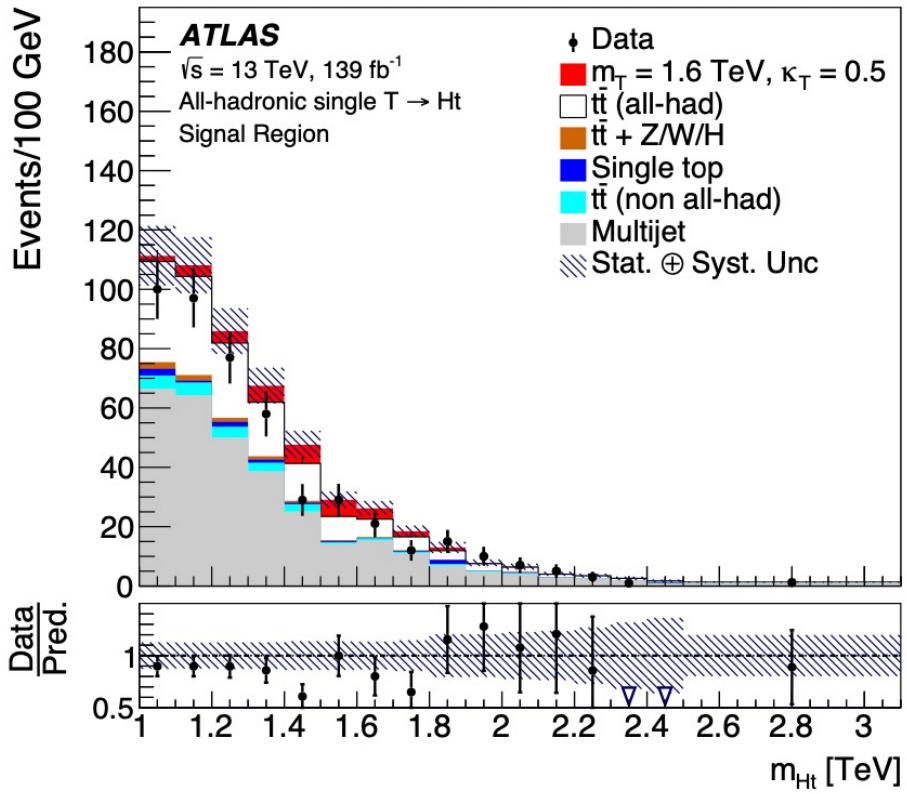


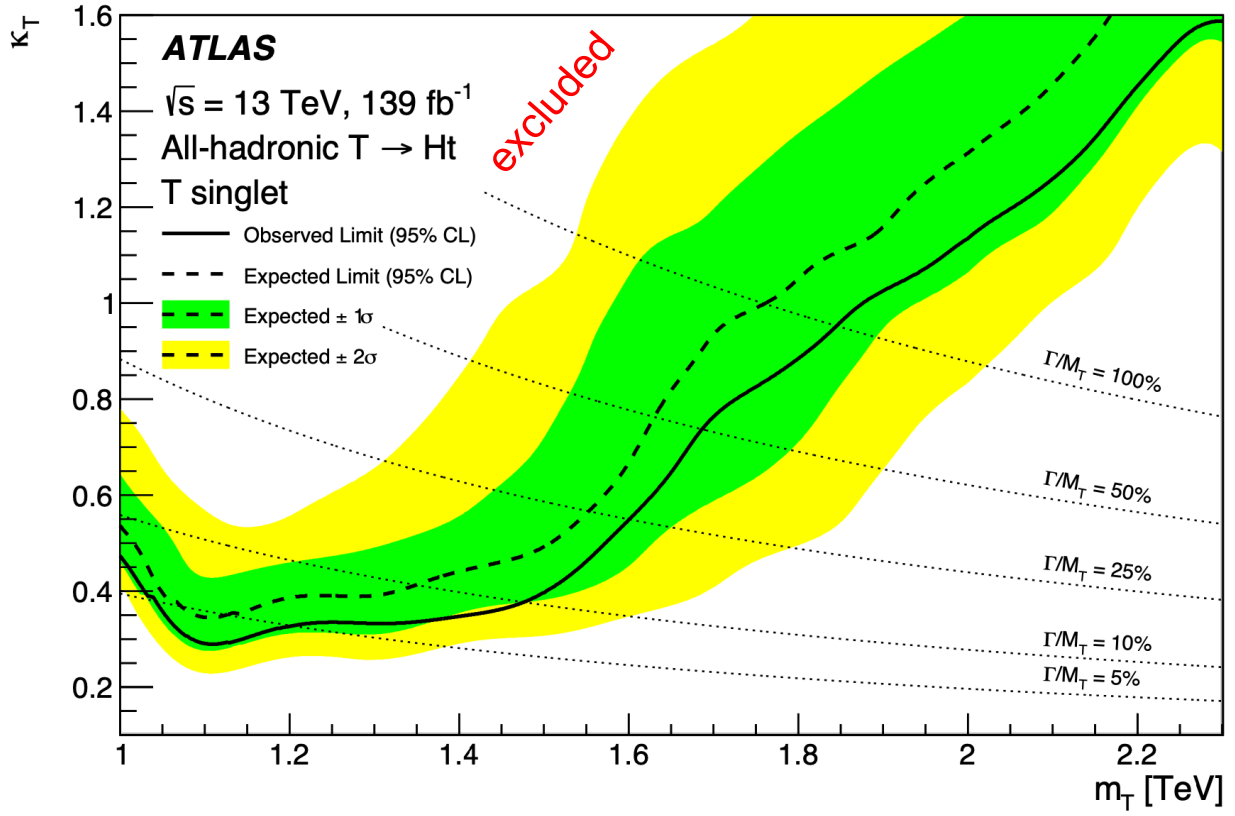
$$N_A = N_B \times \frac{N_C}{N_D}$$

arXiv:2201.07045
(submitted to Physical Review D)

Search for vector-like-quark T quarks decaying to Higgs + top

Results





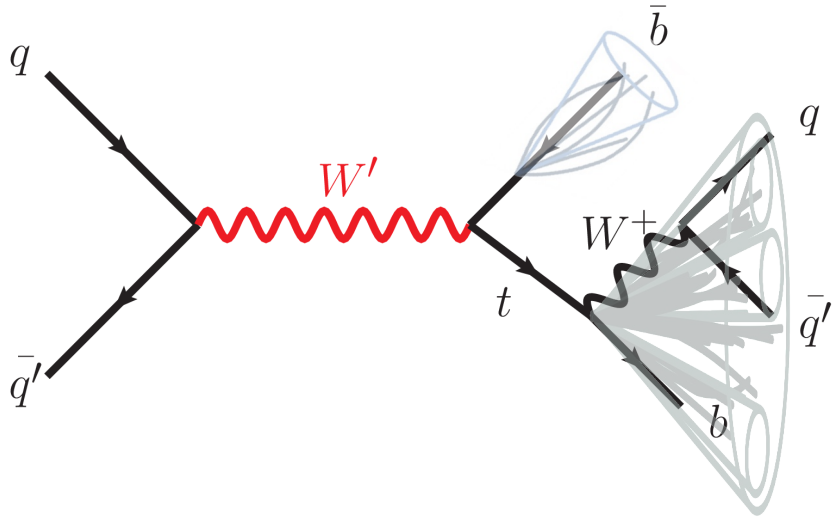
Simultaneous fit of dijet mass distribution in SR and NR to extract signal cross-section and top quark background normalisation.

No excess in data: set limits as function of T mass and coupling κ.

arXiv:2201.07045
(submitted to Physical Review D)

Search for heavy W' resonances in top + bottom final states

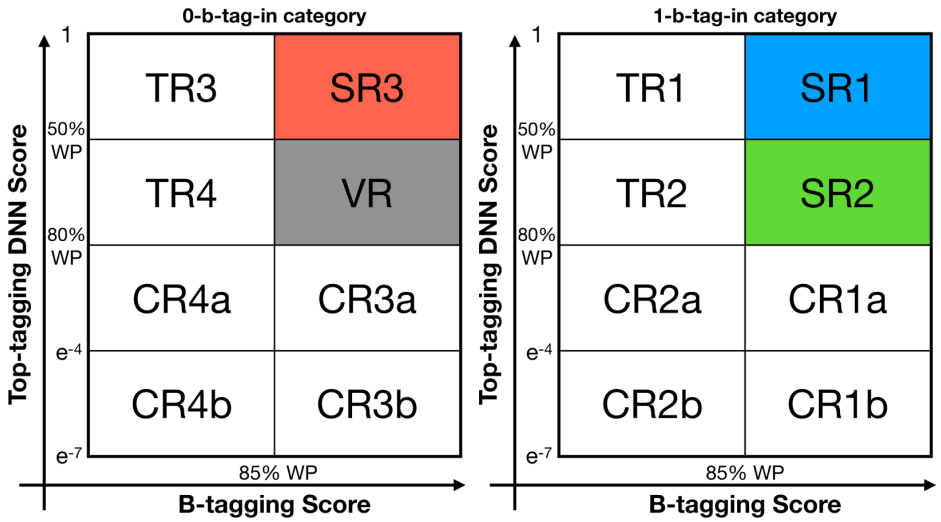
Analysis strategy



W'→tb with high-p_T top and bottom quarks:
- top-tagged large-radius jet (DNN) and b-tagged small-radius jet (*DL1r*)

Analysis regions defined by tagging of two large-radius jets:
- Regions split in 0-b-tag-in (ΔR(j,J)>1.0) and 1-b-tag-in (ΔR(j,J)<1.0)

Dominant background processes
- QCD multijet events estimated with data-driven method using template and control regions
- Top quark pair production estimated with simulation



VR = validation region
TR = template region
CR = control region
SR = signal region

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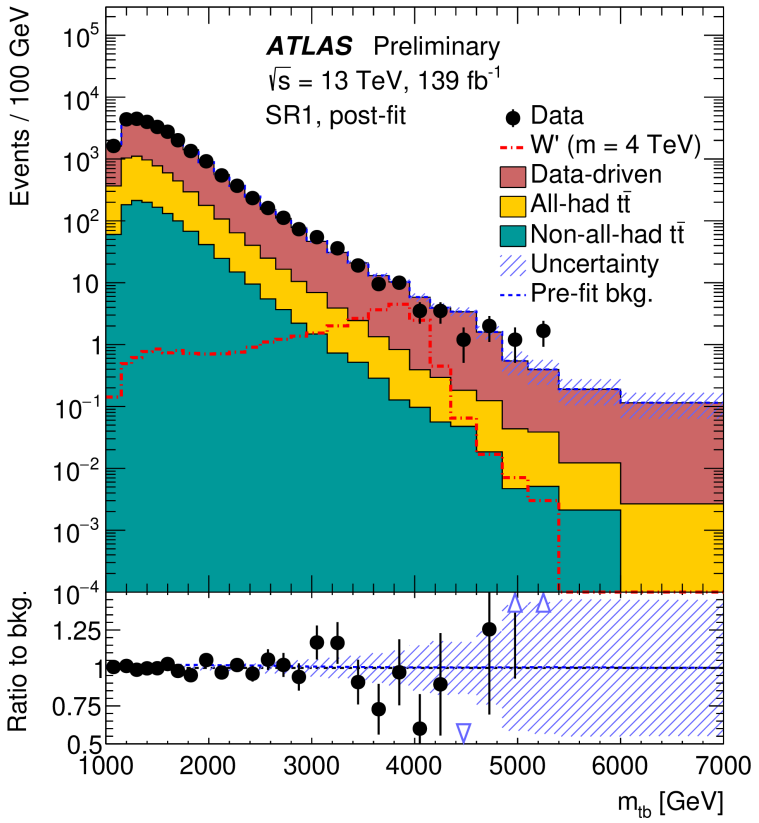
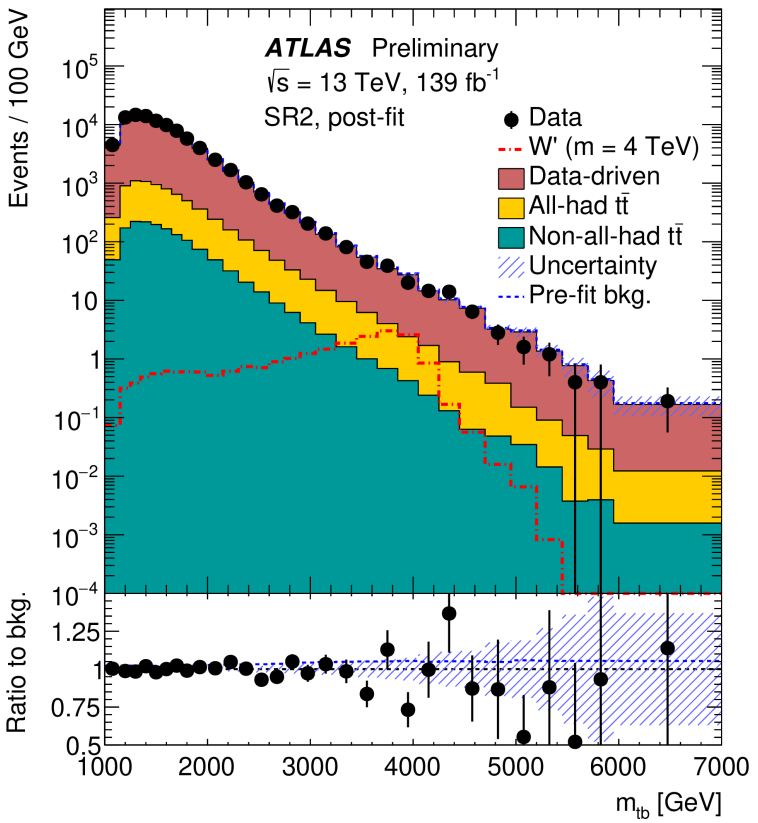
Search for heavy W' resonances in top + bottom final states

Results

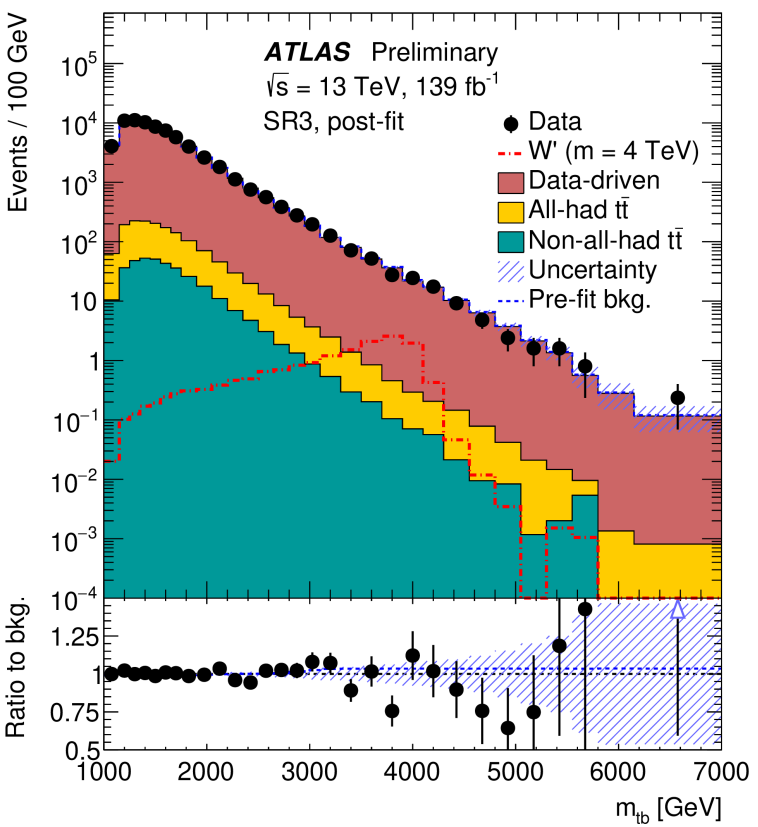
SR1



SR2



SR3



most sensitive signal region → least sensitive signal region

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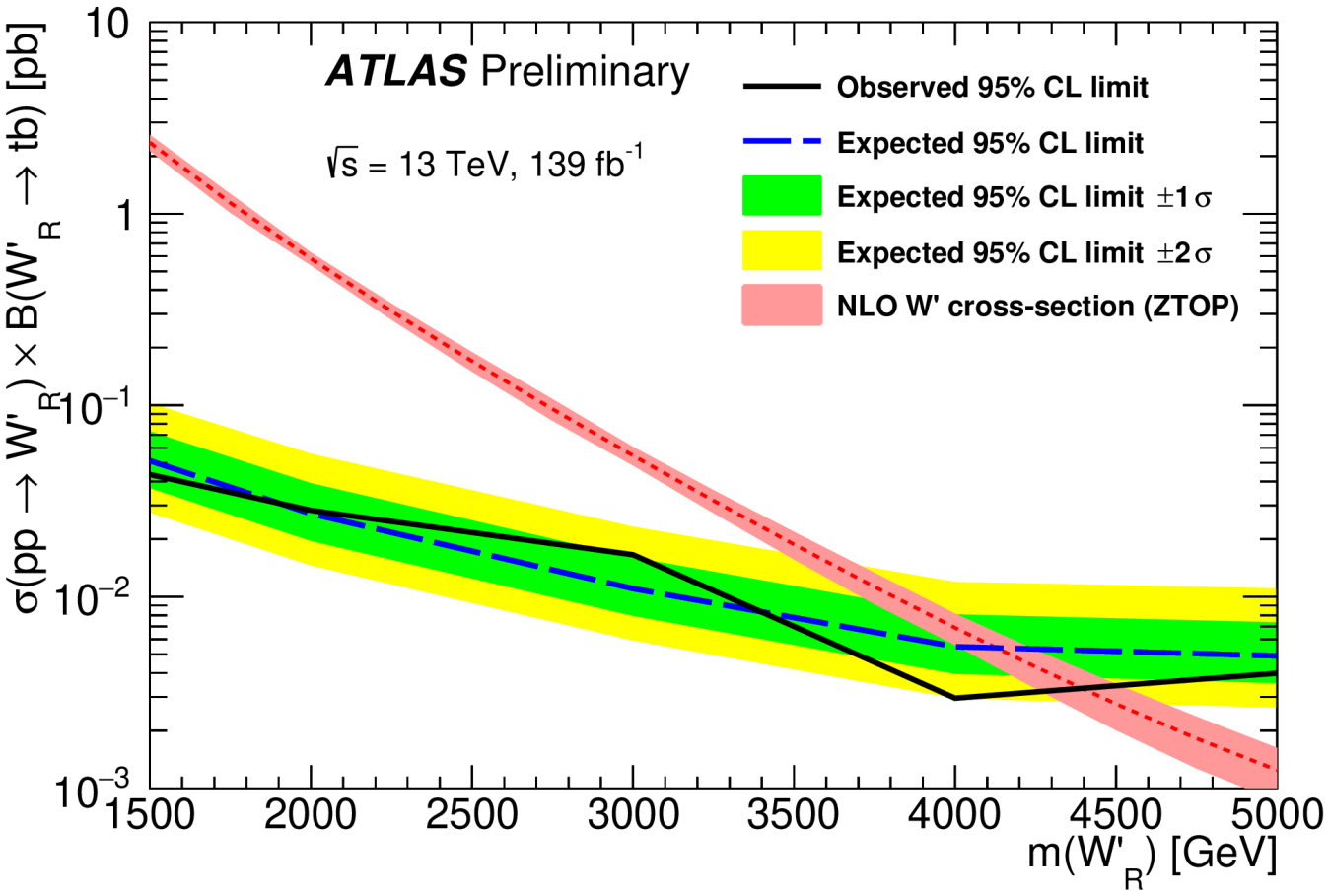
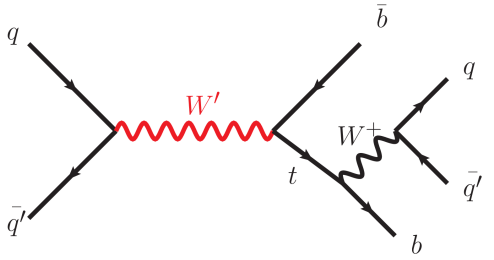
Search for heavy W' resonances in top + bottom final states

Results





W'_R vector bosons with $m_{W'} < 4.4$ TeV are observed to be excluded.

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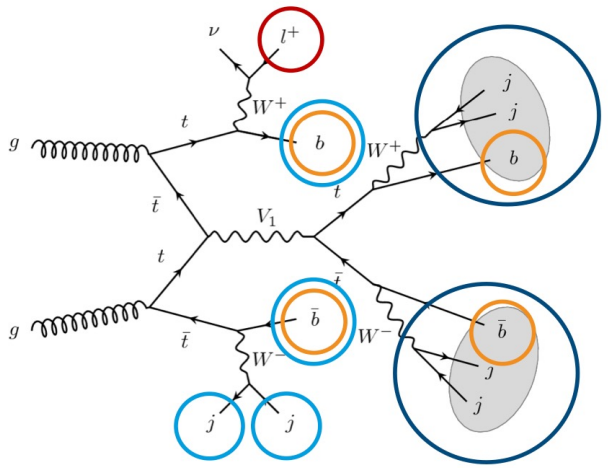
Search for heavy Z' resonances in four-top-quark final states

Analysis strategy

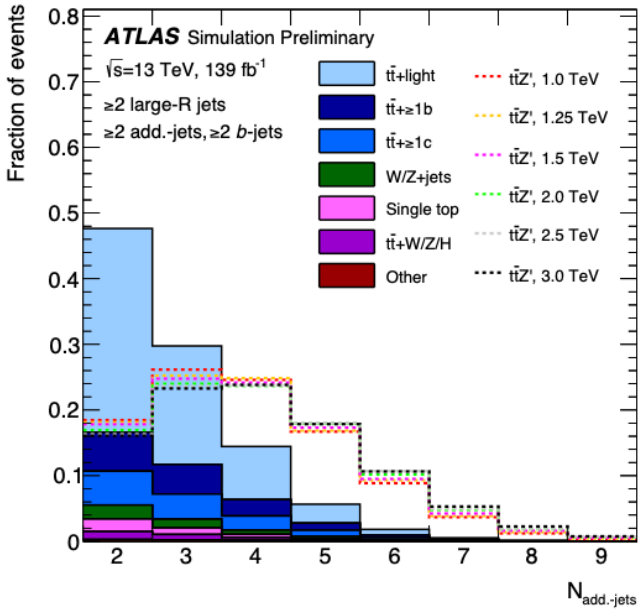
ttZ'→tttt in 1 lepton final state with

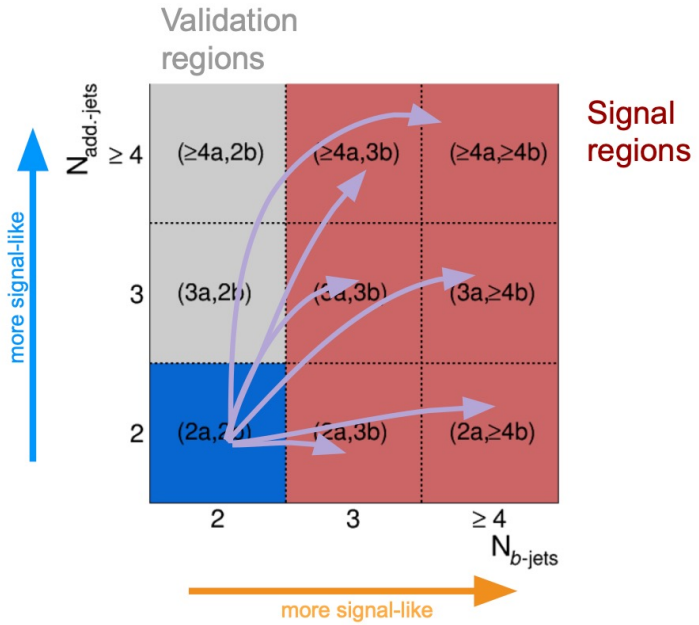
- Z' resonance decay reconstructed using large-radius reclustered jets with b-tagged sub-jets
- top quarks from associated production reconstructed as additional small-radius jets which can be b-tagged

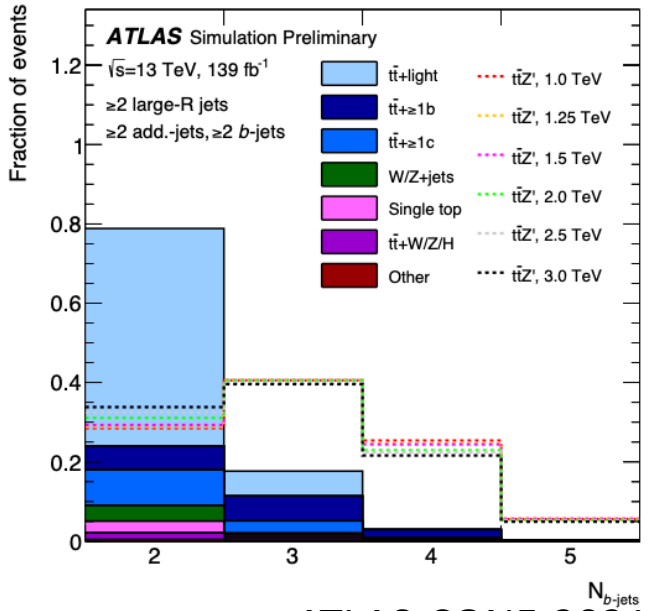


Analysis regions defined by number of additional jets and number of b-jets.

Background prediction from functional form fit to source region data and MC-based extrapolation.



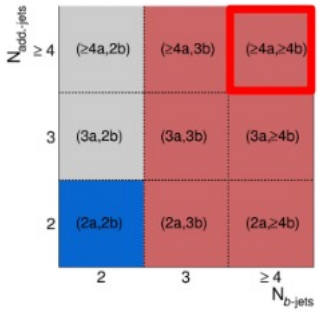


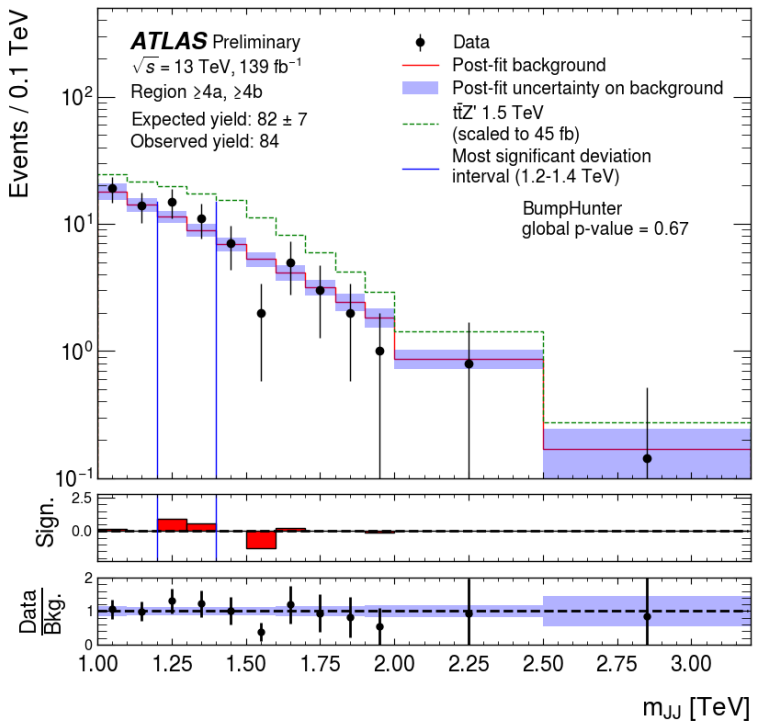


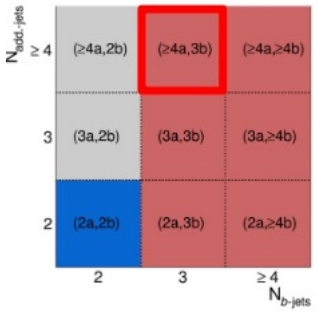
ATLAS-CONF-2021-048

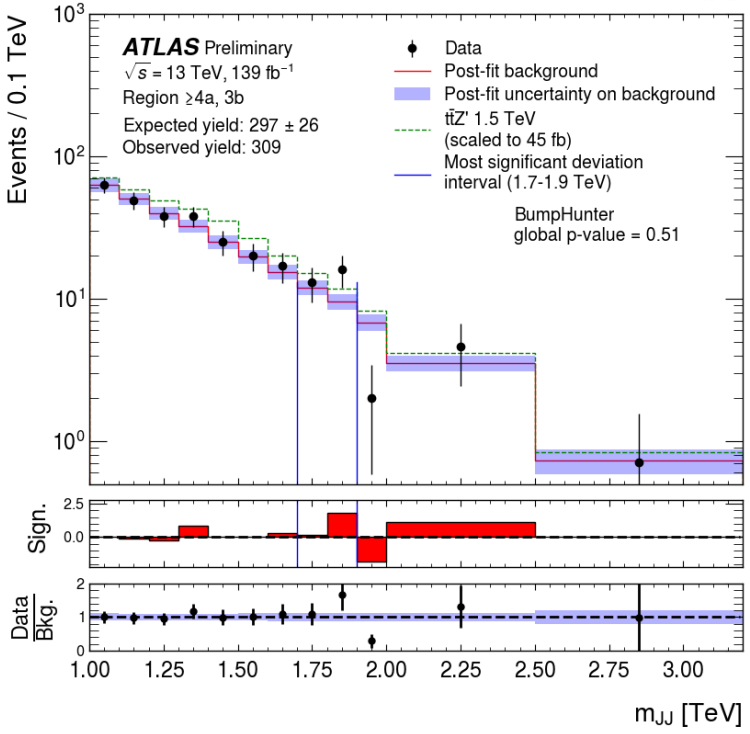
Search for heavy Z' resonances in four-top-quark final states

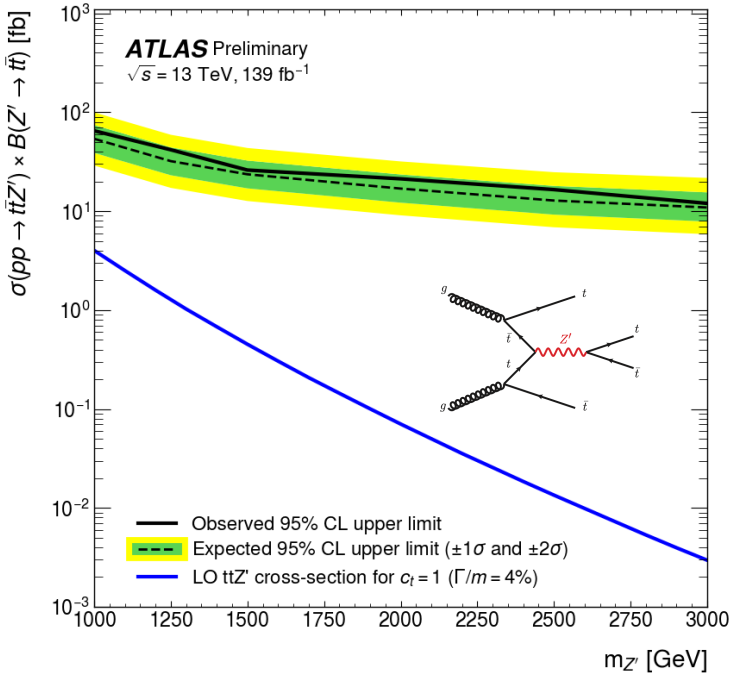
Results











Limits on simplified top-philic Z' phenomenological model for fixed coupling c_t=1 (narrow width Γ/m = 4%).

Ready for interpretation in terms of other models and coupling scenarios.

First ATLAS exploration of the four-top-quark final state for resonances as a „bump-hunt".

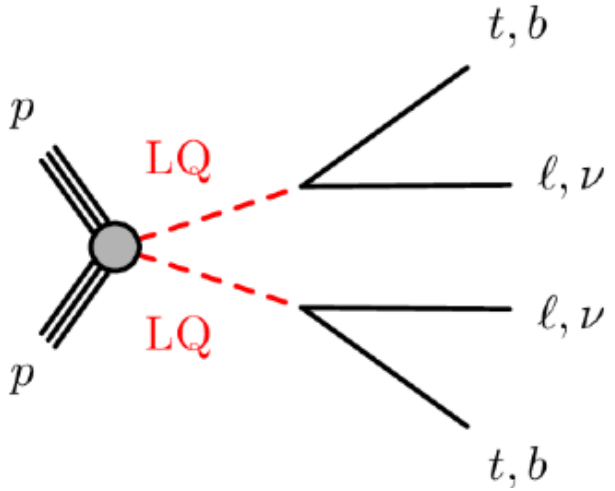
ATLAS-CONF-2021-048

Search for leptoquark pairs decaying to 3rd gen quarks + 1st / 2nd gen leptons

Analysis strategy

Scalar and vector pair-produced leptoquarks (LQ) decaying to 3rd generation quarks t/b and 1st/2nd generation leptons e/μ/ν in final states with

- 1 lepton, substantial missing transverse momentum
- top / bottom quark candidate jets (at least 4 jets)



Dominant background processes

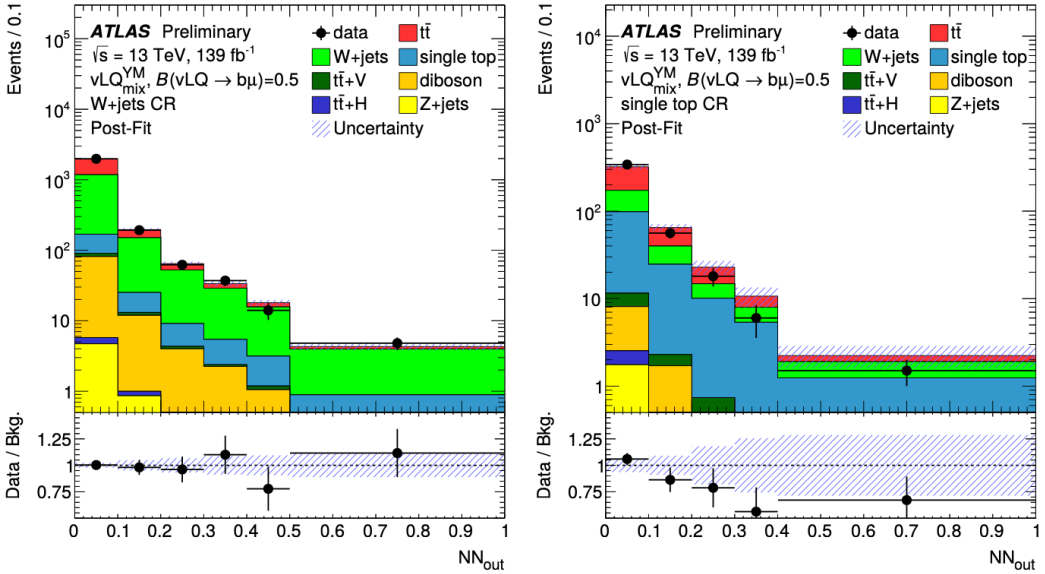
- top quark pairs: MC simulation with corrections from data for high momenta
- W+jets, single-top quark production: MC simulation with control regions

Several models for leptoquarks considered:

- scalar (LQ): up type (charge 2/3e), down-type (-1/3e)
- vector (vLQ): aimed explaining B-anomalies

Signal vs background discrimination with neural network

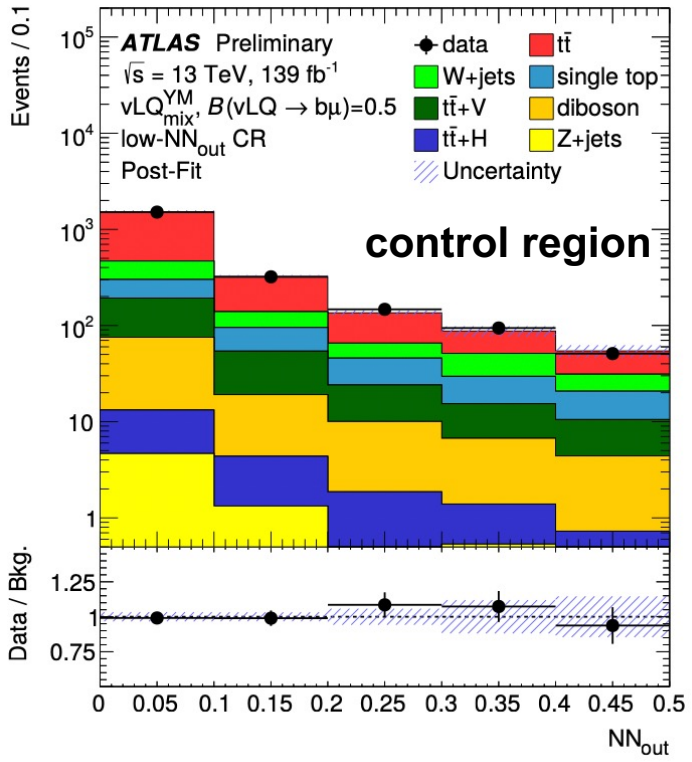
- dedicated networks for each of the 8 LQ signal models
- neural network score defines signal and control regions, additional control regions for W+jets and single top quarks.



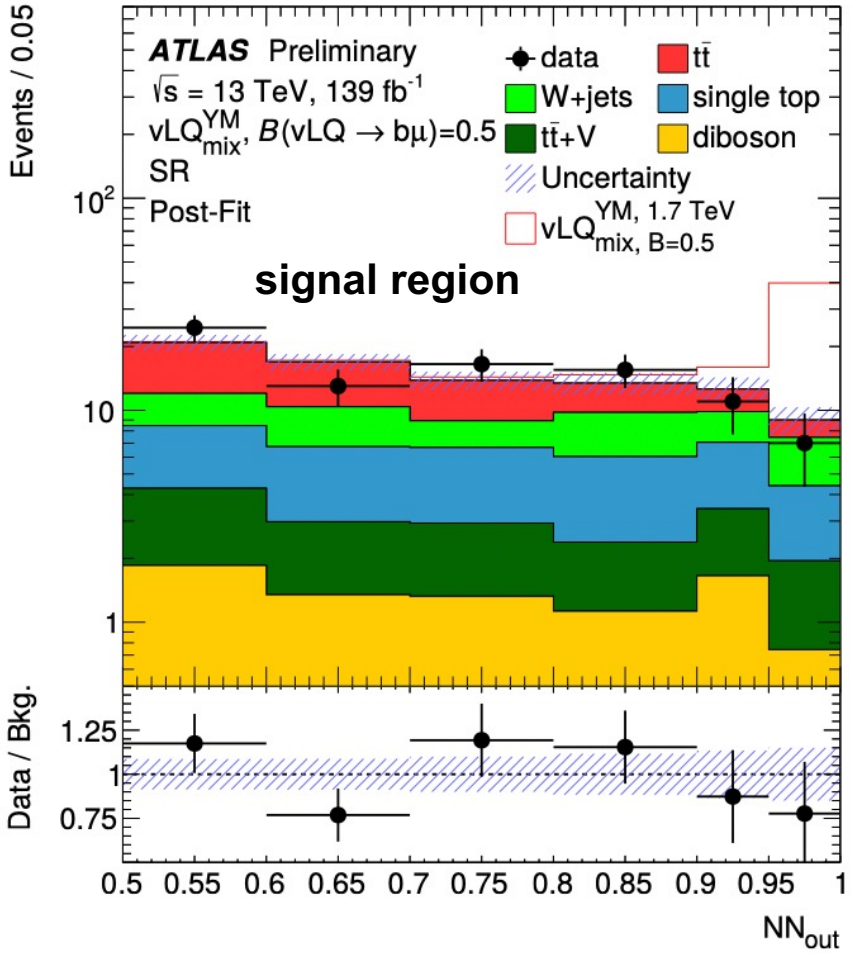
ATLAS-CONF-2022-009

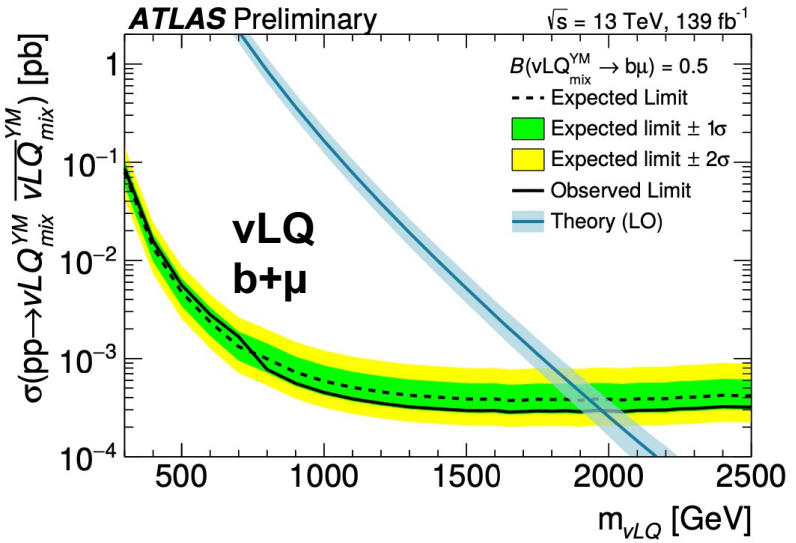
Search for leptoquark pairs decaying to 3rd gen quarks + 1st / 2nd gen leptons

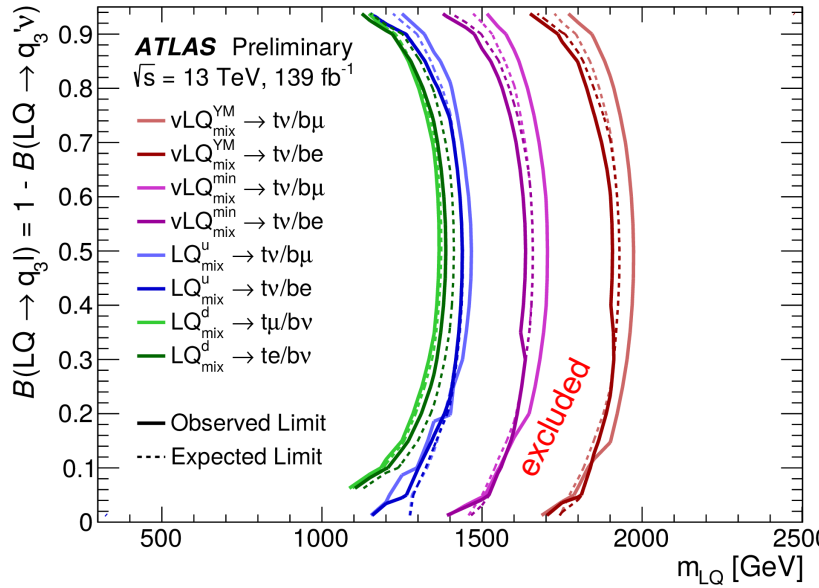
Results



showing NN trained for vector leptoquark.







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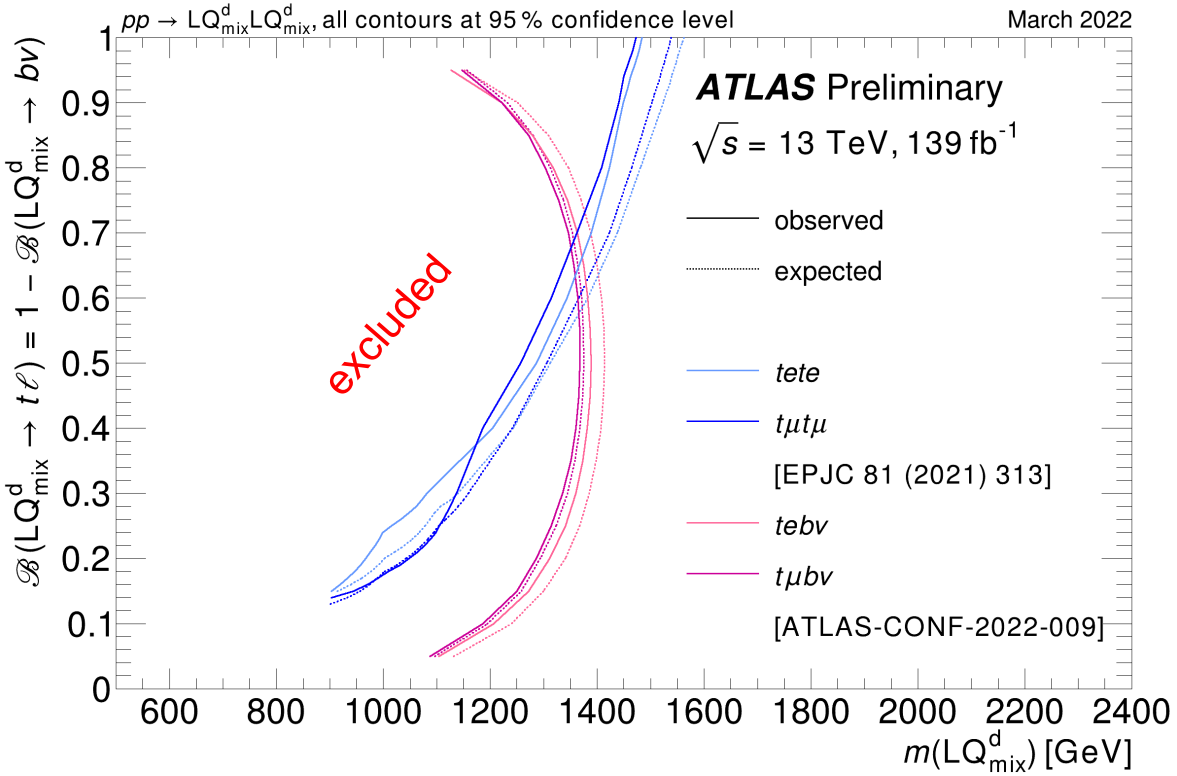
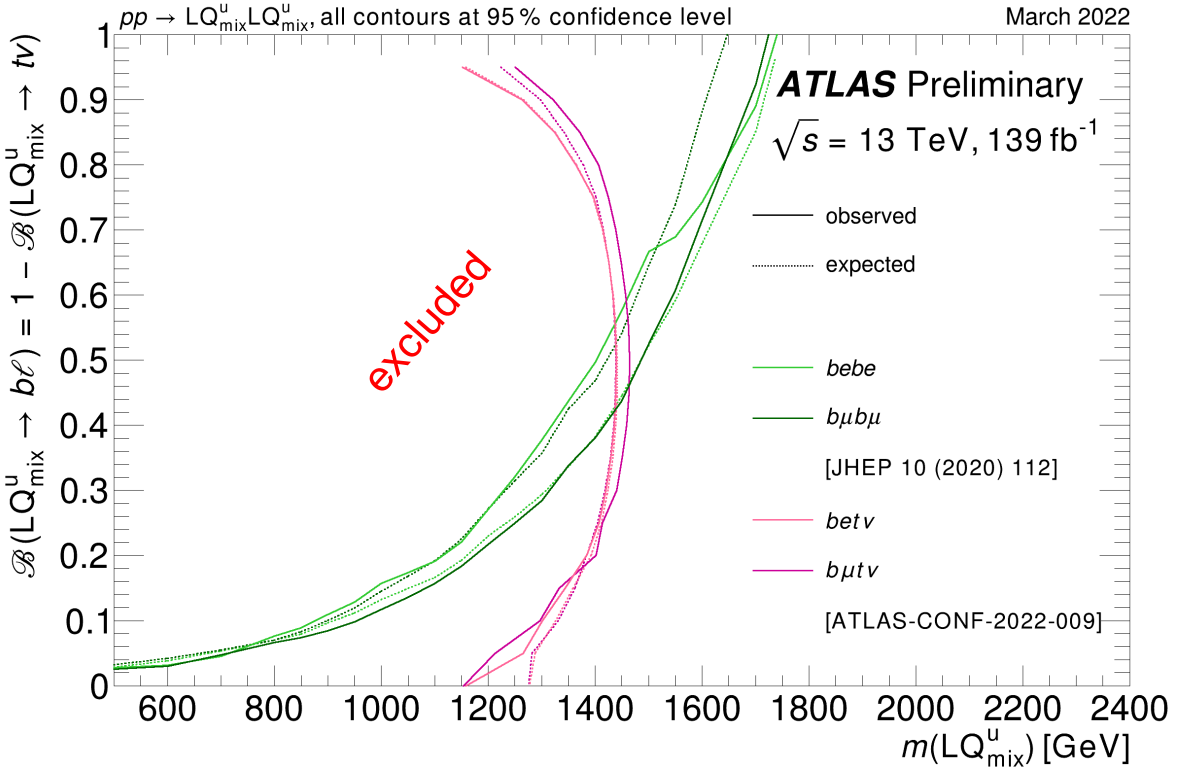
Summary of ATLAS leptoquark searches with 3rd gen quarks and 1st / 2nd gen leptons





For discussion of leptoquark searches involving 3rd gen quarks and tau leptons go to Bertrand Dit Latours talk „Searches for strong production of supersymmetric particles with the ATLAS detector“ [QCD&EWIII session]!

ATL-PHYS-PUB-2022-012

Conclusions

ATLAS probes various models predicting new phenomena by investigating final states with bottom and top quarks.

In all results, machine learning algorithms are used both for signal extraction and for identification of top + bottom candidates.

Presented **four searches** looking for:

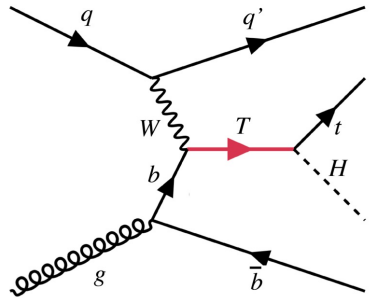
1. vector-like-quarks T → Higgs + top [ref]
2. heavy W' resonances → top + bottom [ref]
3. heavy Z' resonances ttZ'→ tttt [ref]
4. leptoquark pairs → 3rd gen quarks + 1st/2nd gen leptons [ref1] [ref2]

Many **other exciting searches** not covered here!

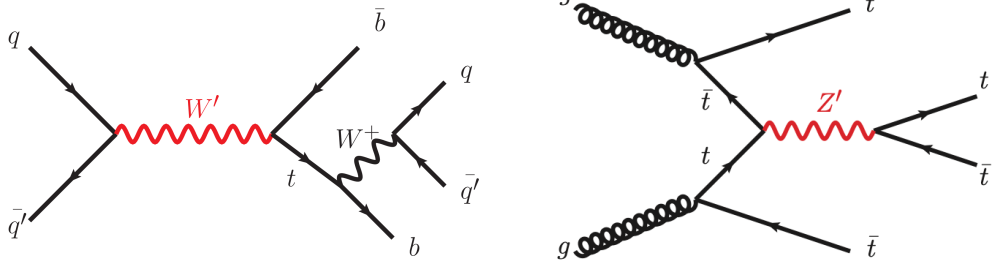
- challenging final states: ttA/H → tttt [ref]
- B-meson anomaly-inspired search: dilepton + b [ref]

Further improvements in analysis techniques and new data in Run-3 will provide access to yet more complicated and rare signatures.

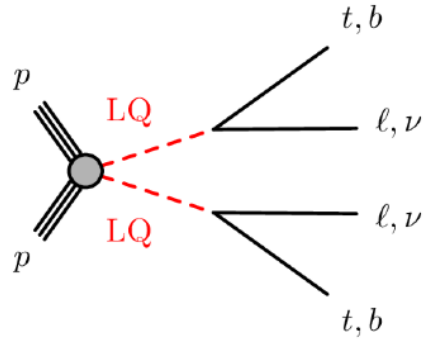
vector-like quarks



heavy vector bosons



leptoquarks



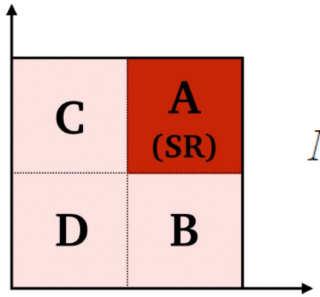
Thank you

Search for vector-like-quark T quarks decaying to Higgs + top

Analysis regions

Second-leading large-R jet tagging state \ Leading large-R jet tagging state	0t 0H 0b	0t 1H 0b	1t 0H 0b	0t 0H 1b	0t 1H 1b	1t 0H 1b	0t 0H ≥2b	0t 1H ≥2b	1t 0H ≥2b
1t 0H ≥2b				VR8		NR		SR	NR
0t 1H ≥2b			VR6			SR			SR
0t 0H ≥2b									
1t 0H 1b						NR		SR	NR
0t 1H 1b						VR1			
0t 0H 1b						VR2			VR7
1t 0H 0b						VR3		VR5	
0t 1H 0b						VR4			
0t 0H 0b									

multijet estimate:
used for „ABCD method“



$$N_A = N_B \times \frac{N_C}{N_D}$$

NR — top quark normalisation

VR1 — validation region to check background modelling

SR — signal regions

arXiv:2201.07045
(submitted to Physical Review D)

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