Search for $W' \to tb$ in the all-hadronic final state with the ATLAS detector

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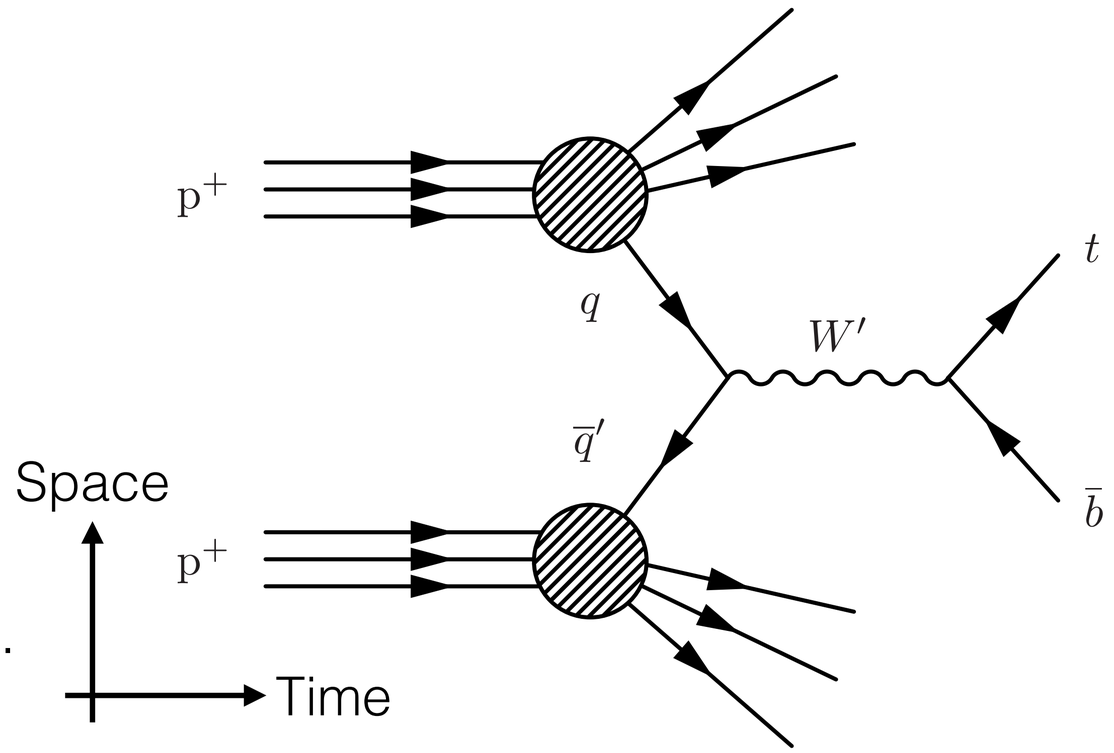
Search for the W'

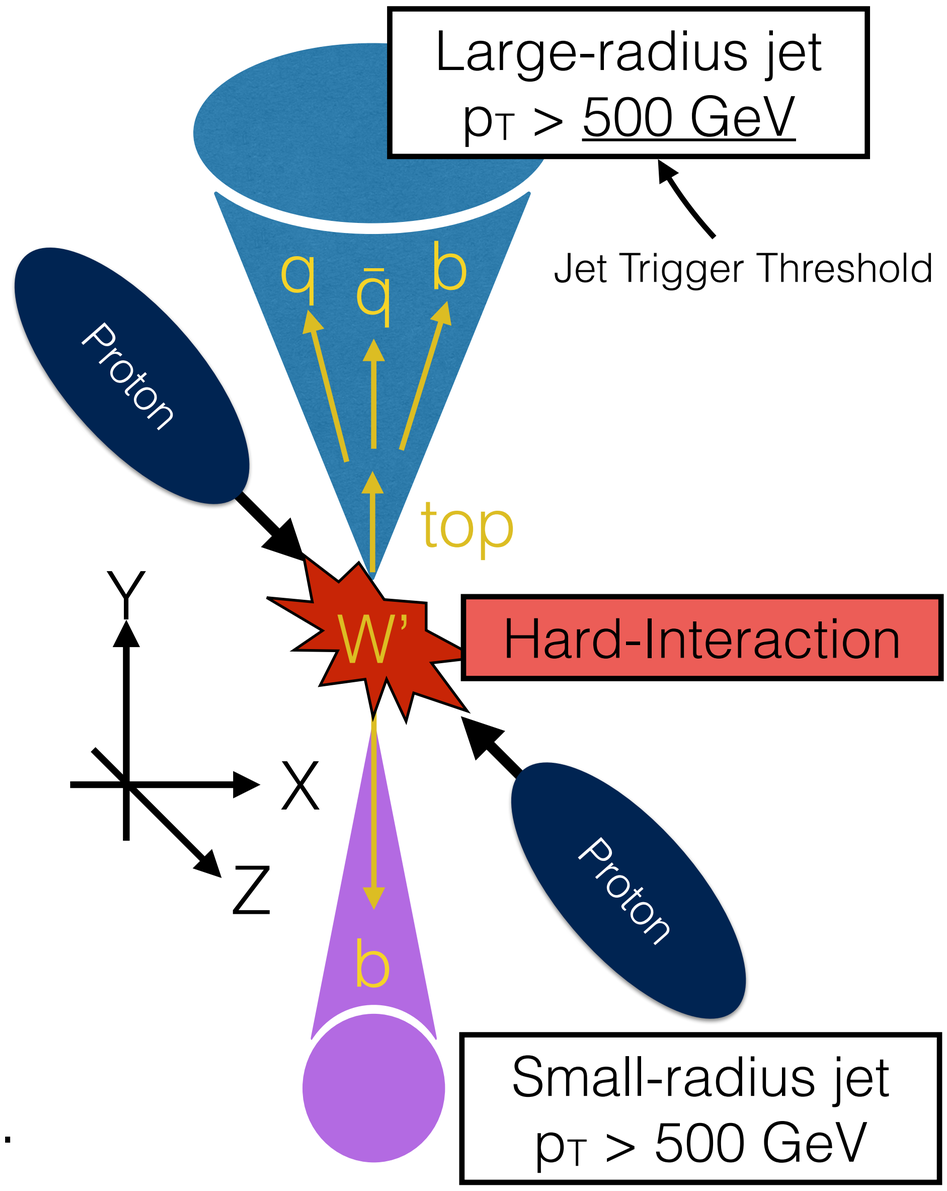
- Several new physics models predict new charged gauge bosons W':
  - Models: extra-dimension KK excitation, Little-Higgs, top-flavors (third generation favored).
  - Like a heavier brother of the SM W boson, but coupling and chirality are free parameters.
  - Two chiral states are possible: left (W'_L), right (W'_R). Focus on W'_R same coupling const. as the SM W.
  - Also assume $m_{\nu_R} > m_{W'_R}$



- Search for a TeV-mass W' (resonance) via its decay to a (hadronically decaying) top quark and a bottom quark with full Run-2 ATLAS data

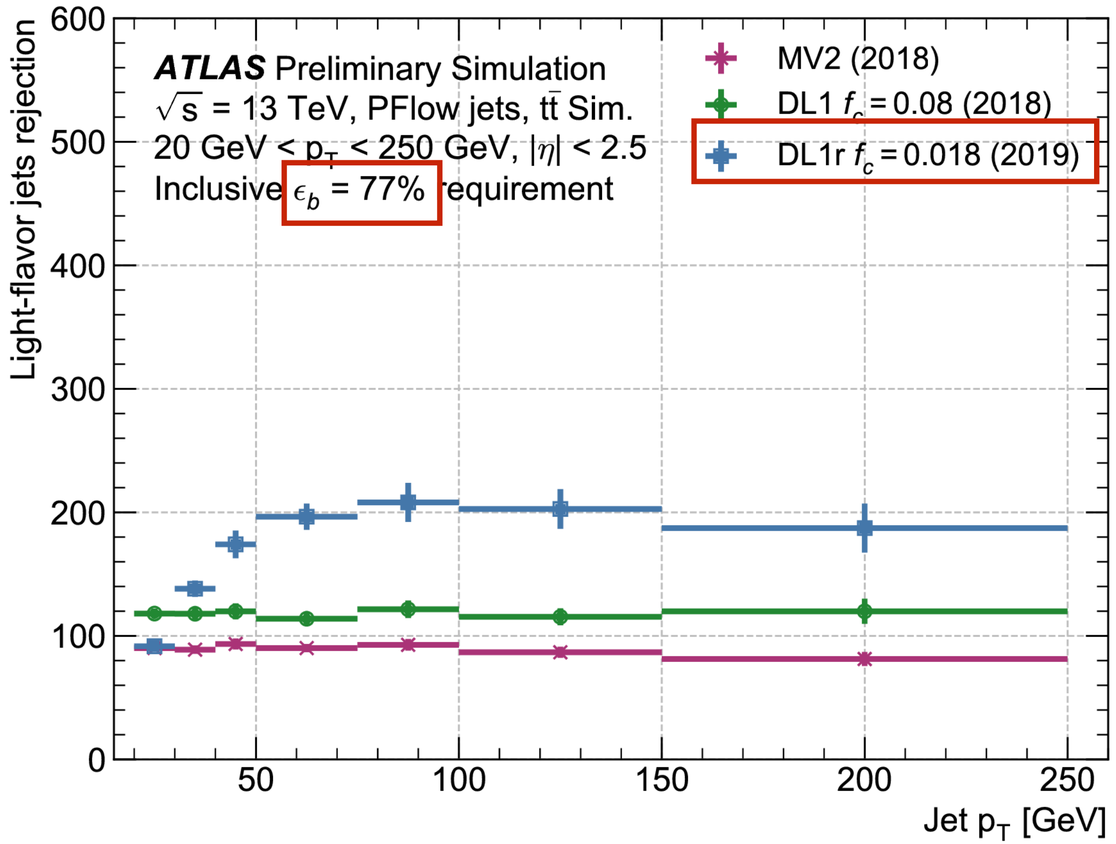
Reconstruct the W' Mass

- Jets are collimated hadrons originate from the high energy quarks or gluons produced in p-p collisions.
- The b-quark from W' is reconstructed by a **small-radius jet.**
- Hadronic top-quark decay has 2 light quarks + 1 bottom quark => Lorentz boosted => 3 quarks collimated.
- So the top-quark is clustered into a **large-radius jet.**
- Add large- and small-radius jet four-momenta to get reconstructed W' mass (M_{tb}).
- Search for a peak in a smoothly falling M_{tb} distribution.



B-tagging

- Bottom quarks hadronize into B-hadrons travels few millimeters before decay.
- Charged particles decay from B-hadrons are tracked.
- These tracks intersect at the B-hadron decay vertex; secondary vertex separated from (hard-scatter) primary vertex.
- Deep Neural Network (DNN)-based b-tag algorithm to identify secondary vertices from tracks associated with small-radius jets.



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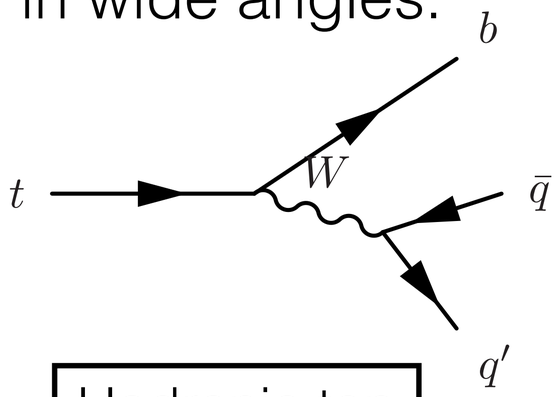
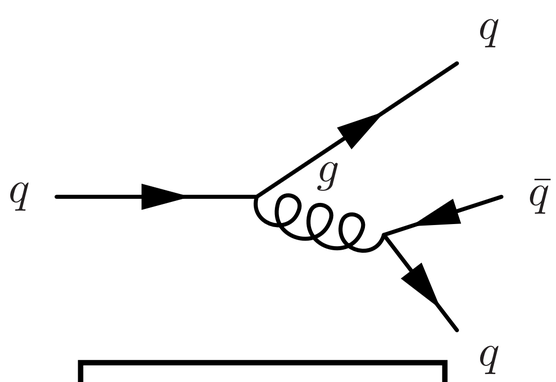
Top-tagging

- Large-radius jets cluster hadronic energy deposited into calorimeters.

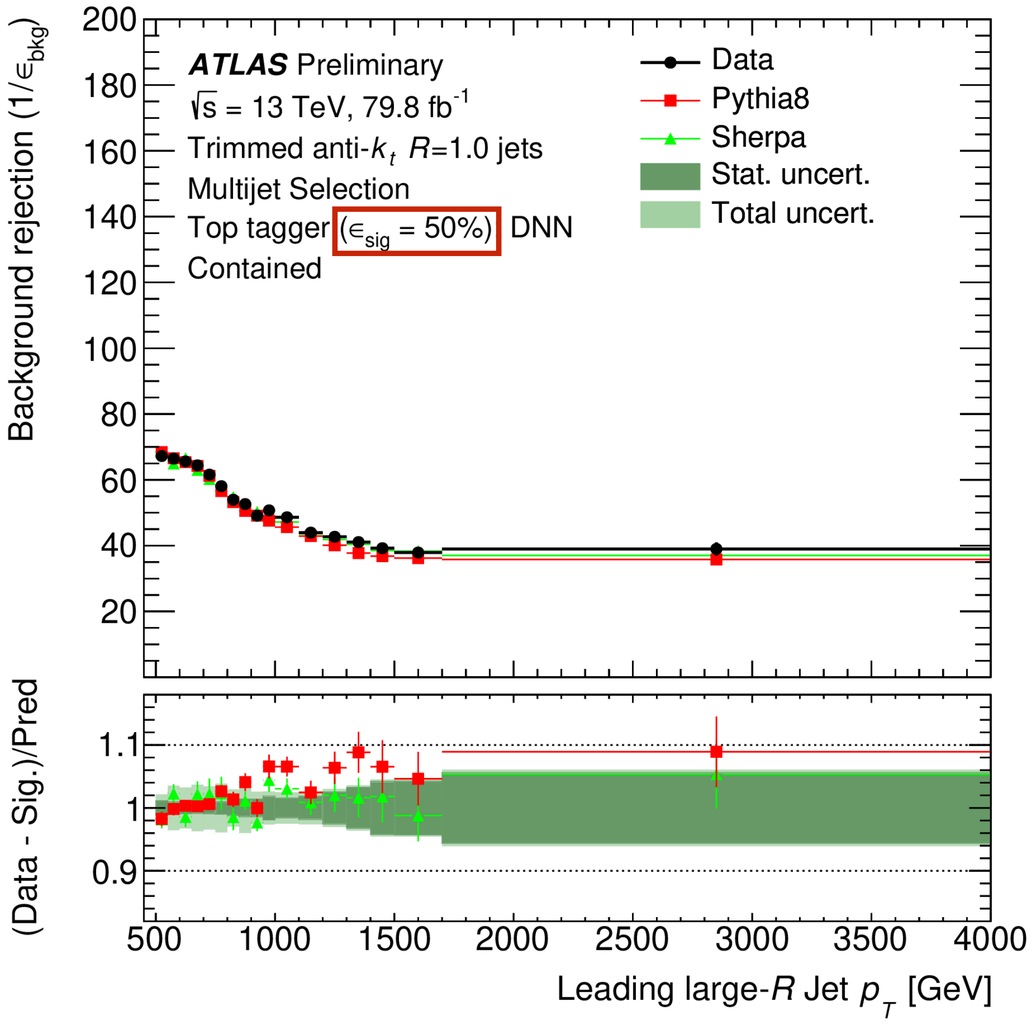
- A DNN-based top-tagger examine energy profile within in a jet to:
  - Find hadronic top quarks with three pongs from the 2 light & 1 bottom quarks
  - Reject lighte partons with parton showers in wide angles.



Hadronic top



Light parton



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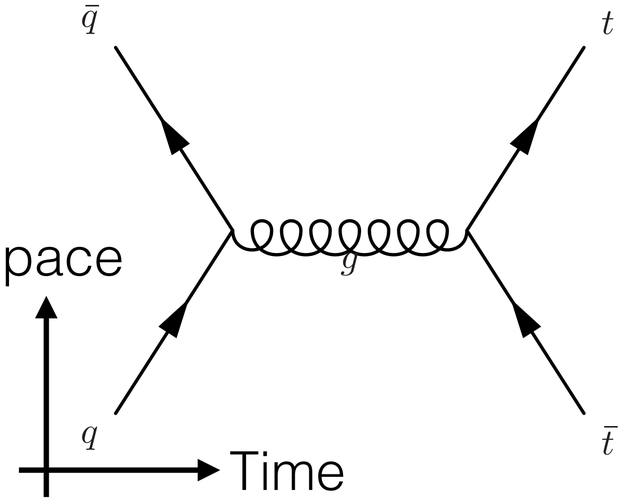
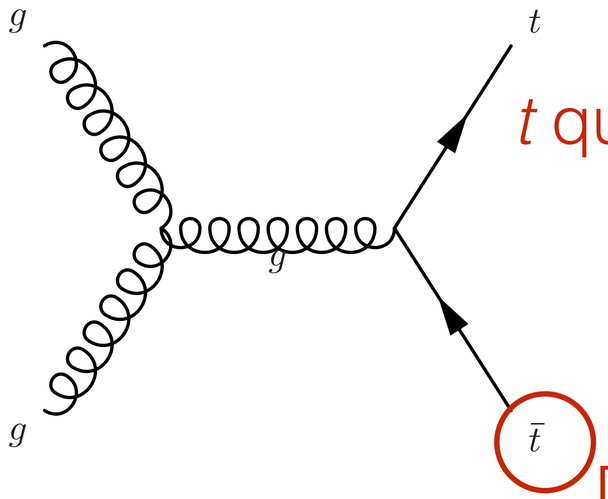
Main Backgrounds

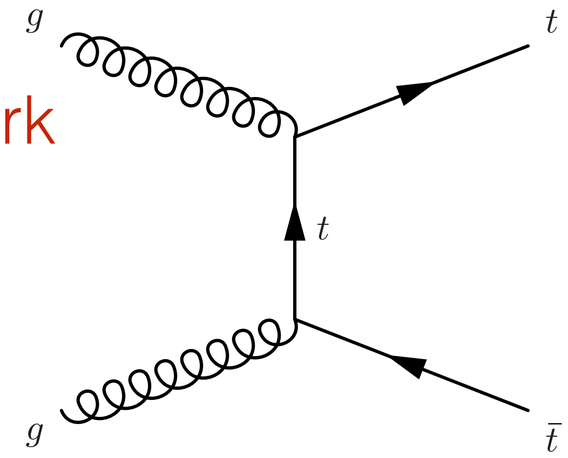
$t\bar{t}$

(MC estimate)





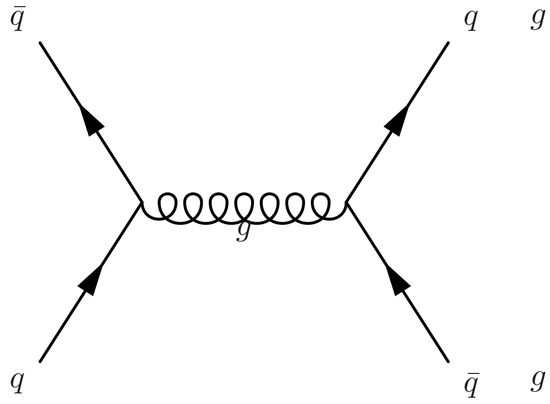
t quark

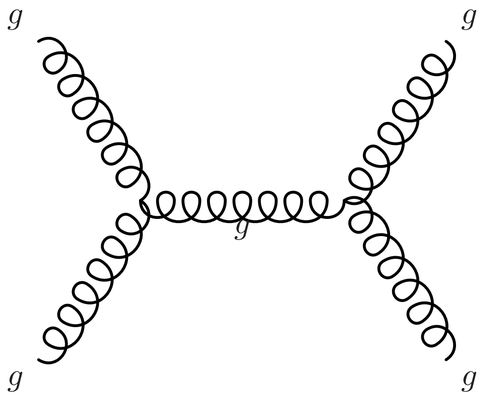


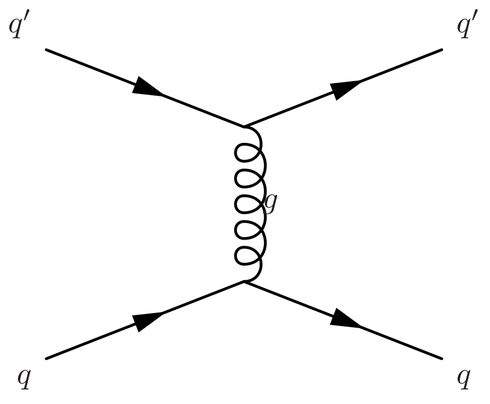
Decay has a *b* quark

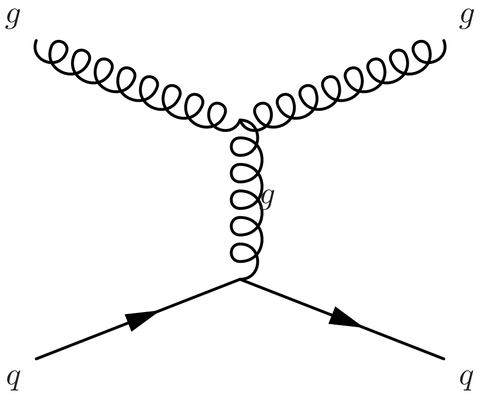
QCD jets

(Data-driven)









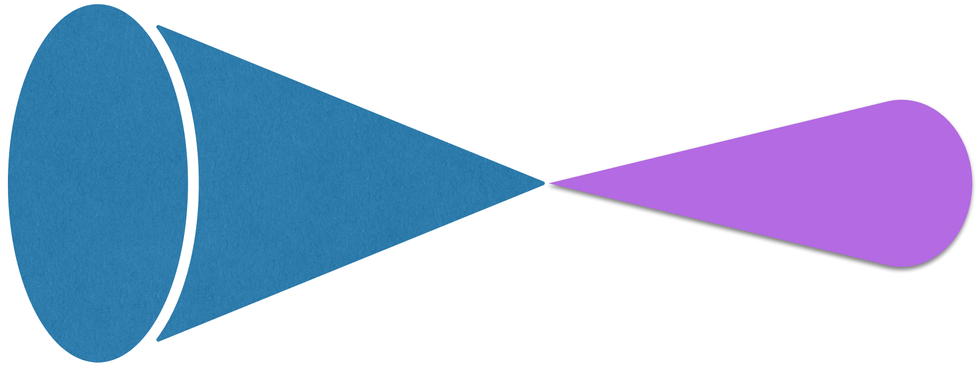
Quark/gluon mis-tagged as a *t* or *b* quark

Data-driven Background Estimate

- QCD jets can be estimated by data in side-band regions defined by reversing large-radius jet top-tagging & back-to-back small-radius jet b-tagging.
  - **Assumption**: the two tagging outcomes are uncorrelated.
  - And the signal insignificant except in the signal region (SR).
  - Then the background in the SR = N_A = $N_B \times N_C / N_D$

Y-axis: large-radius jet top-tagged?

X-axis: small-radius jet b-tagged?



Top-tagged	B	A (Signal region)
Loose top-tagged	D	C
	Not b-tagged	**B-tagged**

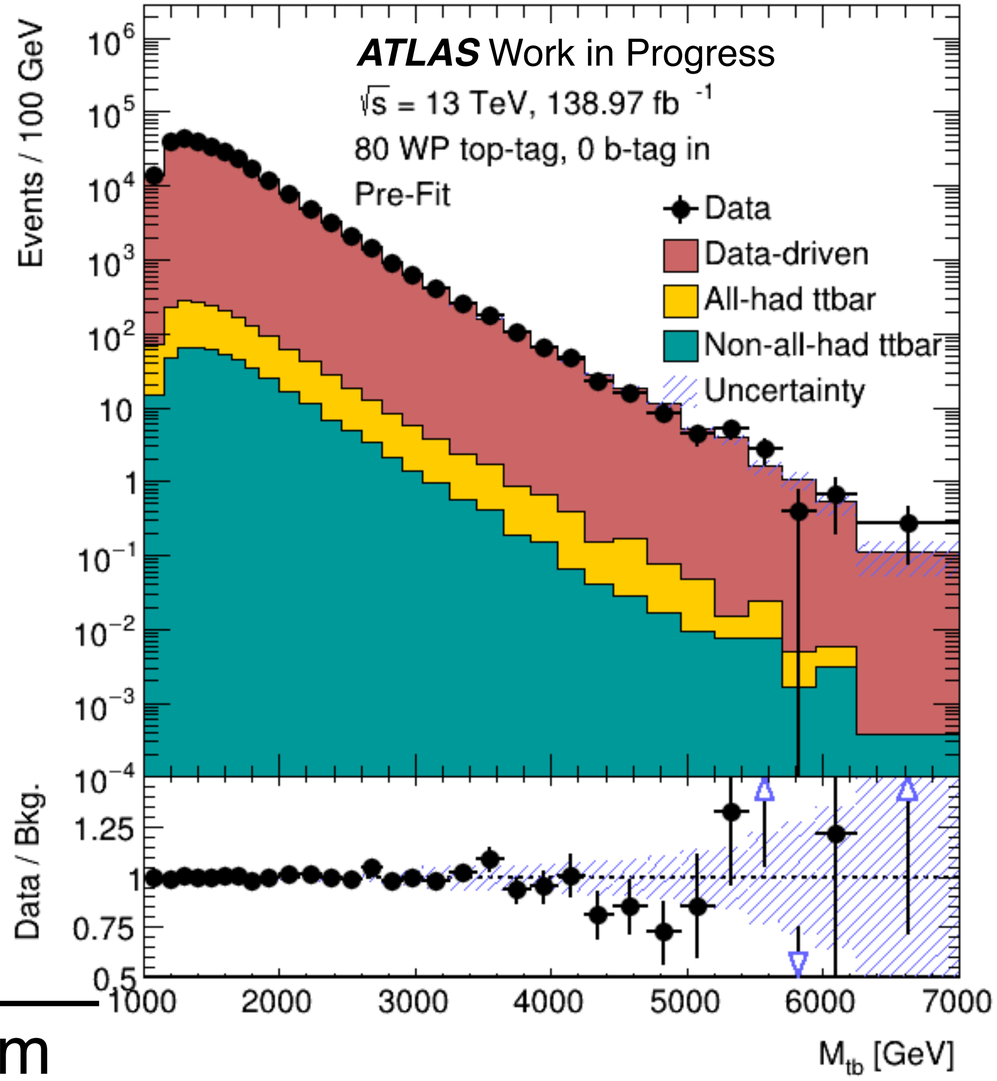
Data-driven Background Systematics

- The hypothesis of no correlation means $(N_A/N_B)/(N_C/N_D) = 1$.
- Using extended sidebands with large-R jets less “top-quark” like:
  - $(N_C/N_D)/(N_E/N_F)$ measures the correlation in data and serve as a systematic uncertainty

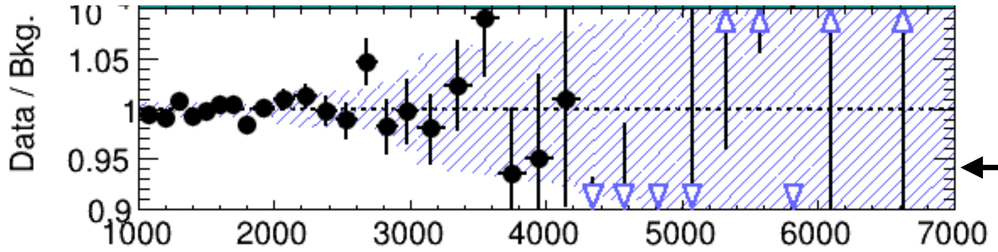
Top-tagged	B	A (Signal region)
Loose top-tagged	D	C
Even looser top-tagged	F	E
	Not b-tagged	**B-tagged**

Validation Region

- Validation region has a mildly tight top-tagged large-radius jet which contains no b-tagged small-radius jet to suppress signals.
- Uncertainty band: systematic and statistical uncertainties of backgrounds.

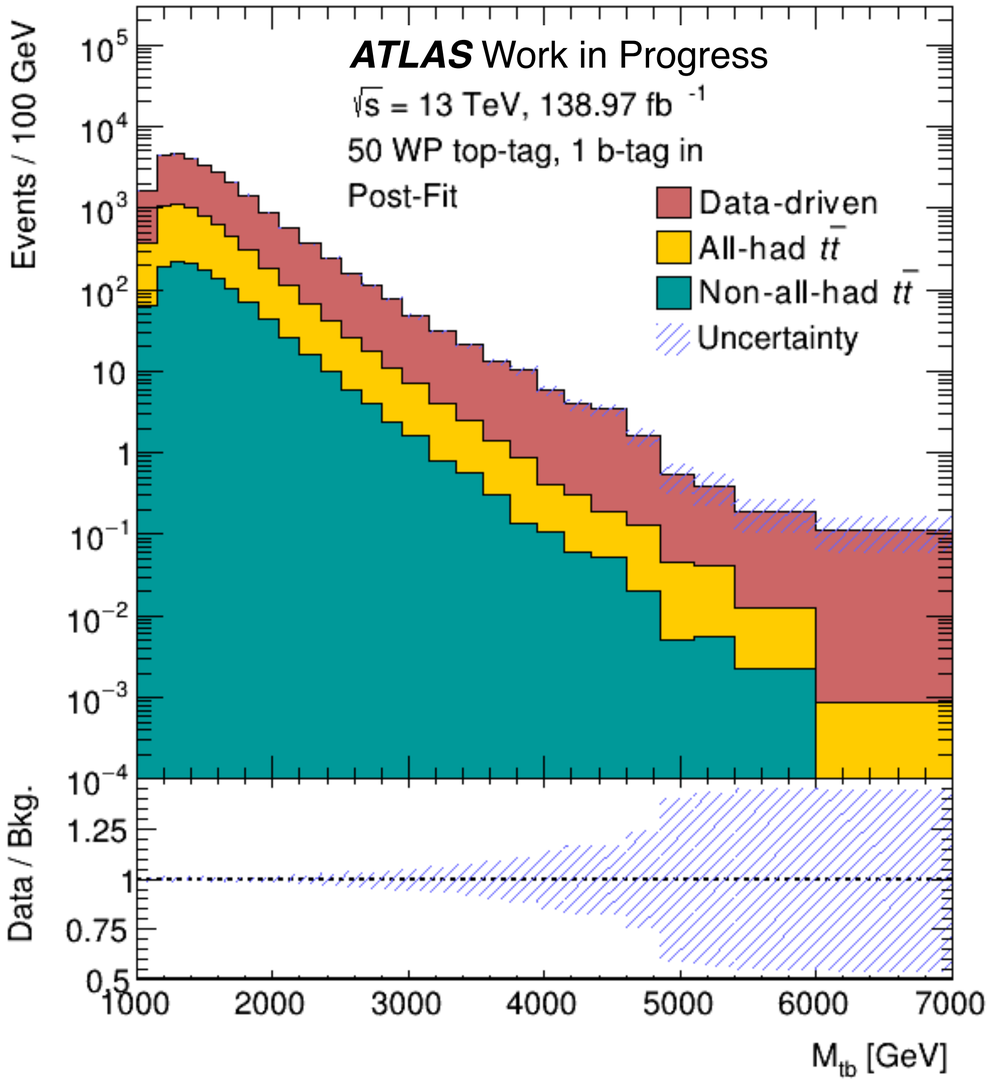


Zoom



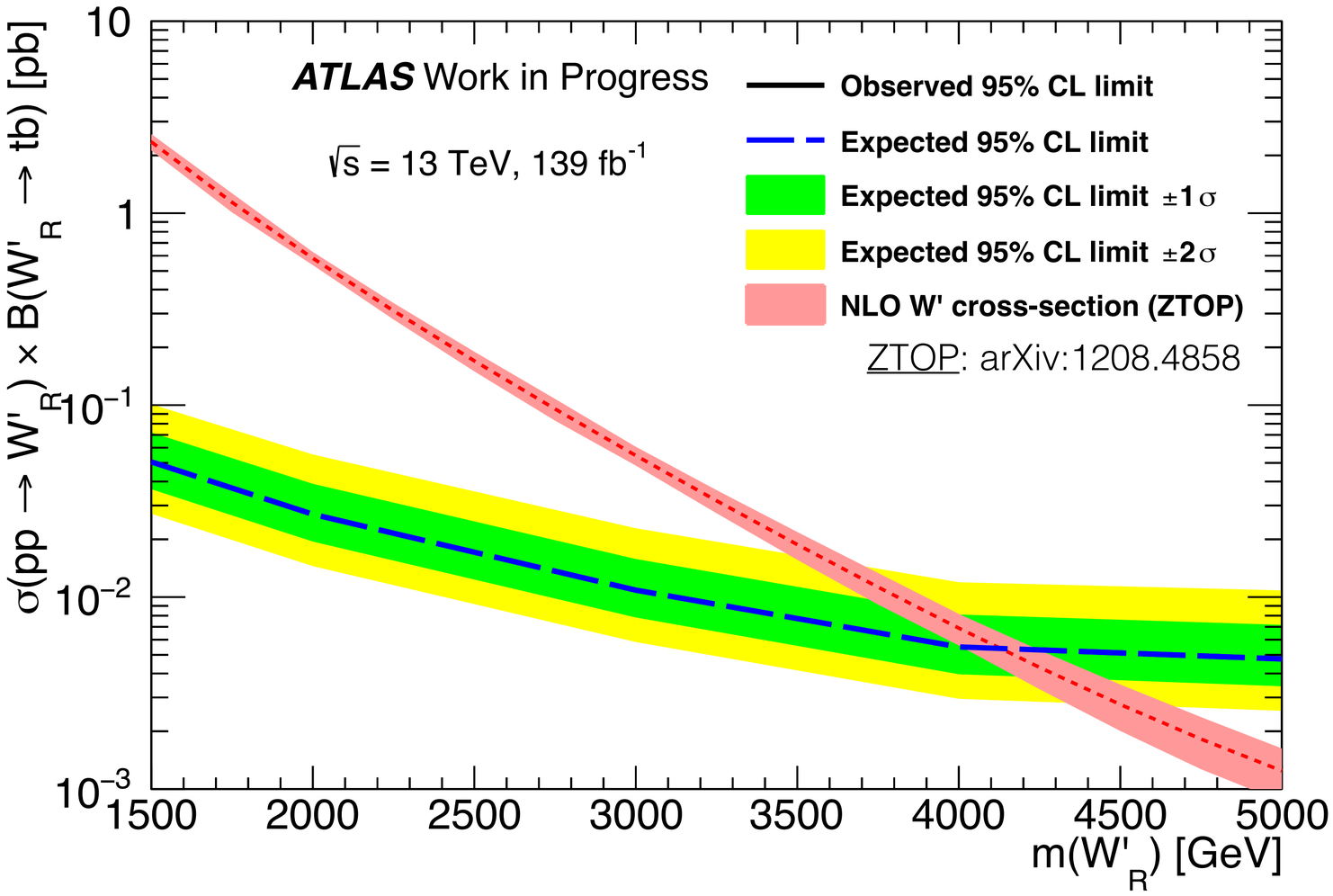
Statistical Analysis

- Profile-likelihoods with nuisance parameters for systematic uncertainties from jet energy/mass measurements, **top/b-tag calibrations**, **background modeling**…
  - Constrained by fit to data.
  - If no excess is found, exclude signals too large to be compatible with data.
- Right: Test the fit with pseudo-data made up by predicted backgrounds.



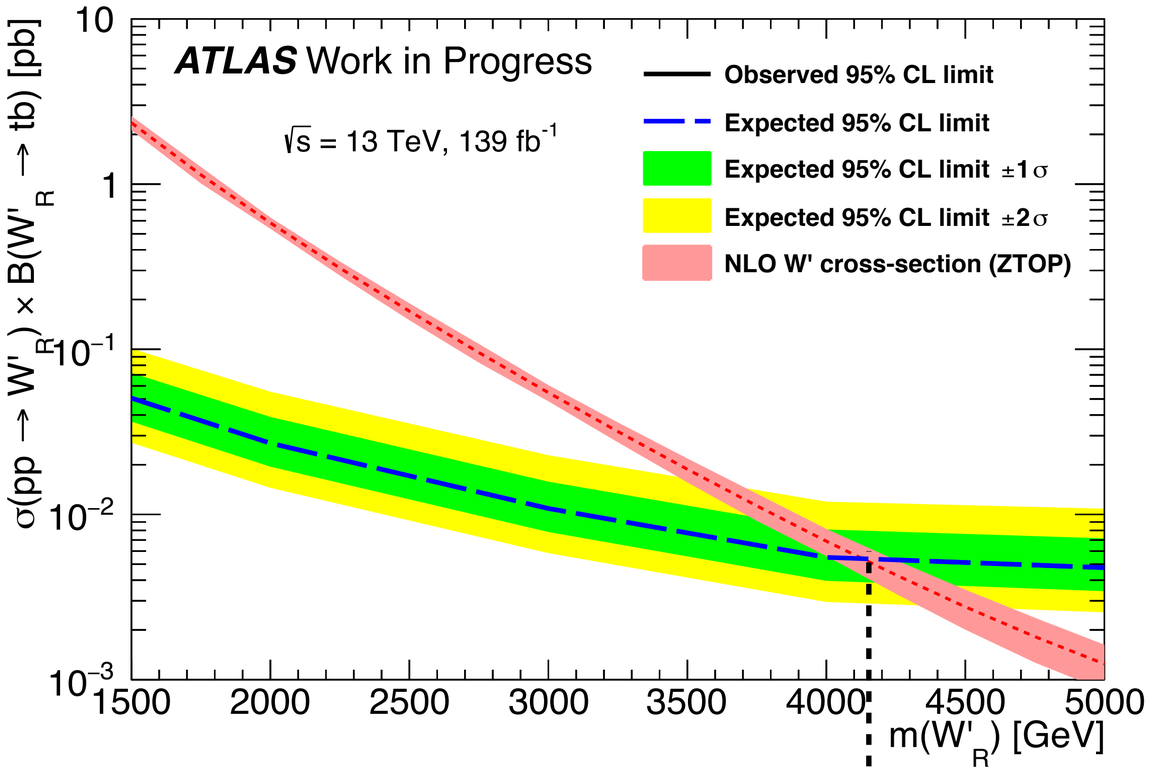
Expected Upper Limit

- Exclusion limit on right-handed W' production cross-section time Branching Ratio for different W' masses.
- Expected limit: pseudo-data with no signal present.
  - Systematic plus statistical uncertainty bands.



Conclusion

- Search for W' to tb in the all-hadronic final state with ATLAS full Run-2 dataset (139 fb^{-1}).
- Multivariate techniques identify top-quark-initiated large-radius jets and bottom-quark-initiated small-radius jets.
- Main background estimated with data by assuming no correlation between top- and b-tagging. Correlation uncertainty also estimated with data.
- Expected lower mass limit on right-handed W' with SM-W couplings at 4.15 TeV.



Back-up

Syst. vs. Stat. Uncertainties

	1.5 TeV W'_R	2 TeV W'_R	3 TeV W'_R	4 TeV W'_R	5 TeV W'_R
Systematic	51.8%	50.0%	45.0%	31.5%	20.2%
Background Statistical	13.6%	12.3%	13.4%	13.4%	11.9%
Poisson Statistical	34.6%	37.7%	41.6%	55.1%	67.9%

Top-3 systematics

	1.5 TeV W'_R	4 TeV W'_R
1	Top-tagging calibrations	Data-driven background estimate
2	Data-driven background estimate	B-tagging calibrations for high momentum jets
3	$t\bar{t}$ background modeling on parton showers	$t\bar{t}$ background modeling on parton showers

Ranked by impact of varying the nuisance parameters on fit to pseudo-data