Searches with jet substructure in ATLAS.

CMS B2G Workshop

Hamburg, 23 May 2018

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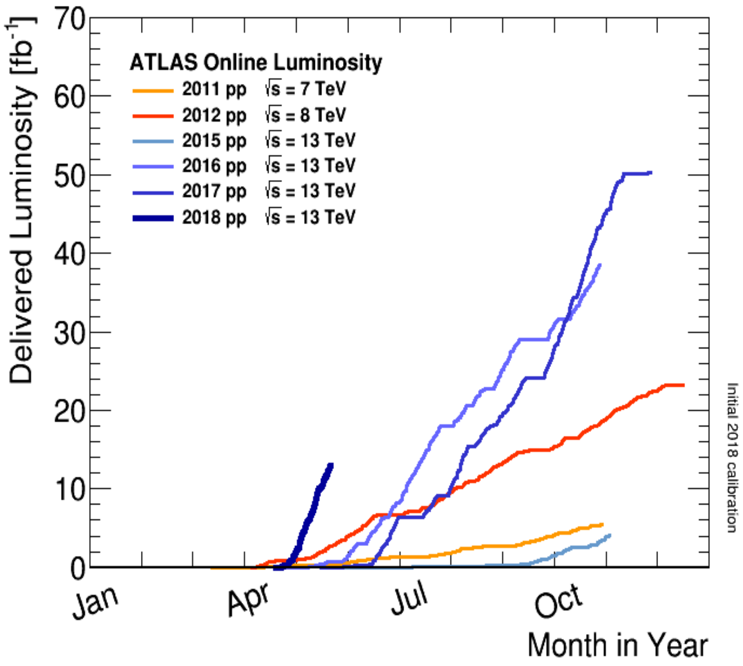
HELMHOLTZ ASSOCIATION

ATLAS EXPERIMENT

DESY

Where do we stand?



> LHC Run 2 in full swing: exciting times for searches!

- Recorded ~80 fb^{-1} of 13 TeV data...
- ... 140 fb^{-1} expected by the end of this year
- No BSM signal observed so far*
  ***but have not analysed all recorded data**

> **Most current public results based on 36 fb^{-1} of 2015+2016 data**

- **Important input to define strategies for full Run 2 searches**

> BSM physics may not be easy to spot

- Rare processes
- Challenging kinematics
- Non-trivial signal (e.g. due to interference)

> **Disclaimer**: many more interesting results in both experiments than shown here!

- Picked examples that illustrate new trends/methods
- Favoured newer results and those available from both experiments

Substructure in ATLAS

The Ingredients

Jets, grooming, discriminating variables

> Typical starting point: anti-k_t R=1.0 jets [CMS: anti-k_t R=0.8 jets]

> Widely used grooming approach: trimming [CMS: soft-drop filtering]
  – Remove all k_t R=0.2 subjets carrying less than 5% of the large-R jet p_T
  – Alternative grooming techniques investigated in [ATL-PHYS-PUB-2017-020]

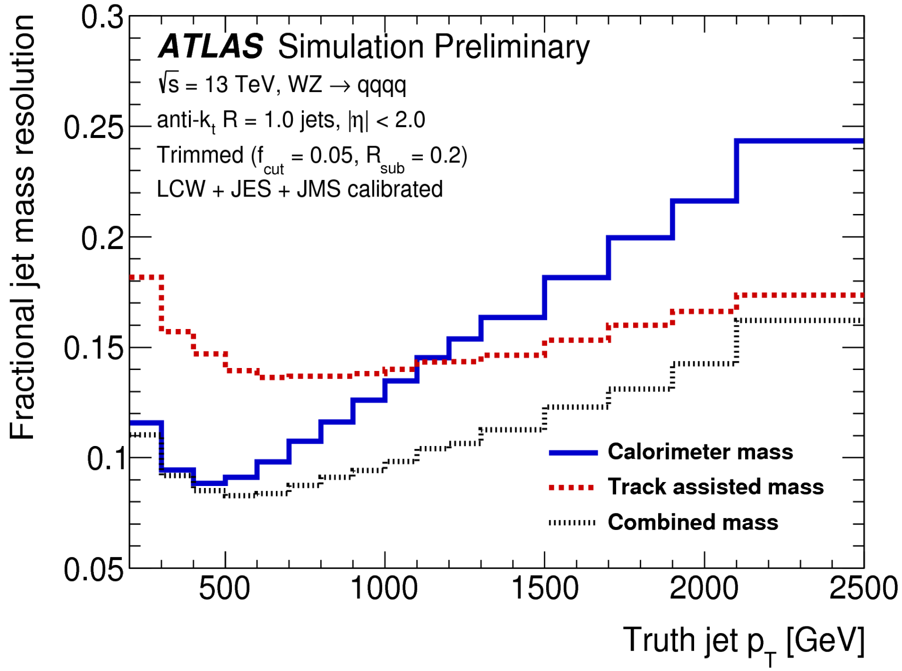
> **Discriminating variables**

– **Jet combined mass** [ATLAS-CONF-2016-035]

- Replaces calorimeter mass
  (= mass of sum of the (massless) 4-vectors corresponding calorimeter cells)
- Weighted average of calorimeter and track-assisted mass

$$m^{\mathrm{TA}} = \frac{p_{\mathrm{T}}^{\mathrm{calo}}}{p_{\mathrm{T}}^{\mathrm{track}}} \times m^{\mathrm{track}},$$

- Significantly improved mass resolution at large jet p_T



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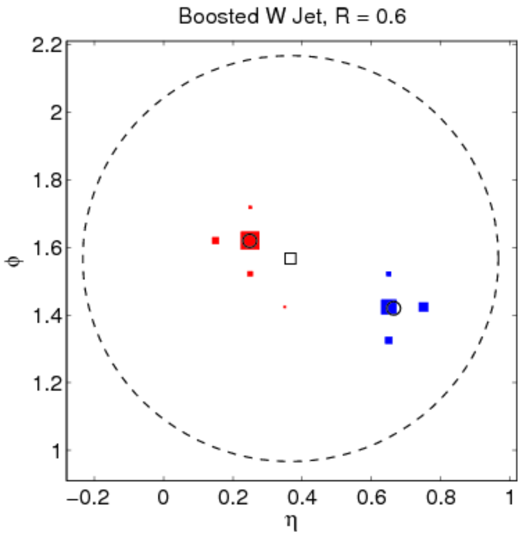
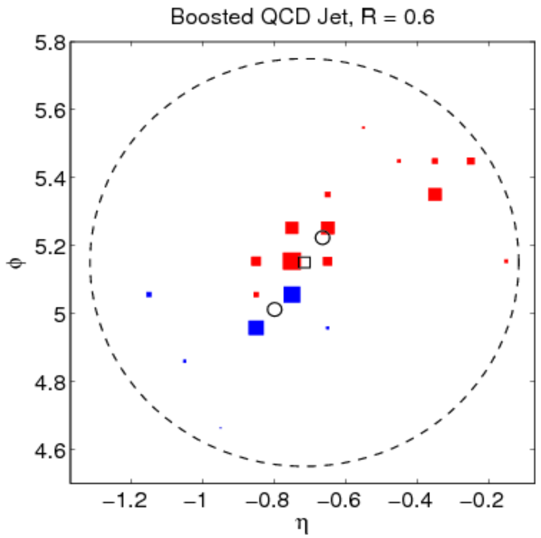
- **Discriminating variables**
  - Jet combined mass
  - n-subjettiness ratios τ_{ij}: "How compatible is the jet structure with the 'n-subjets' hypothesis?"





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> **Discriminating variables**

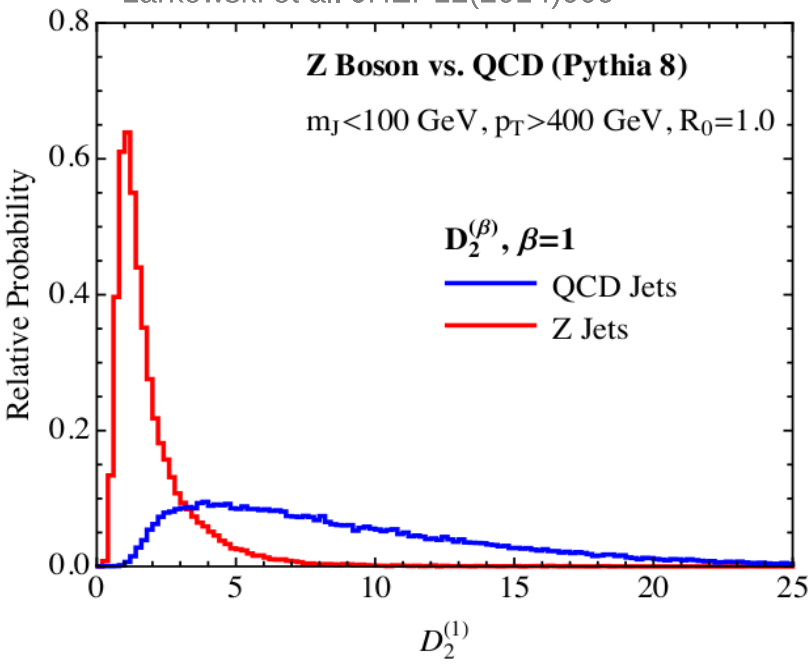
  – Jet combined mass

  – n-subjettiness ratios τ_{ij}

  – Ratios of n-point correlation functions

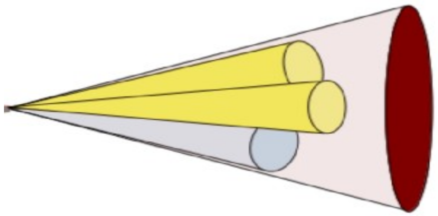
    • In particular: D_2

Larkowski et al. JHEP12(2014)009



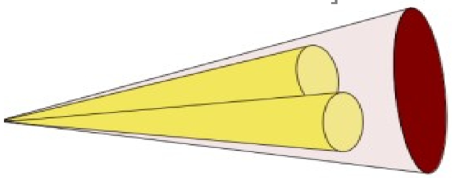
The Baseline Taggers

Tops, Higgs, W/Z Bosons



> **Simple baseline taggers** defined in early Run 2

- **Top tagging**: m, τ_{32} [ATL-PHYS-PUB-2015-053]
- **W/Z tagging**: m, τ_{21} or D_2 [ATL-PHYS-PUB-2015-033]
- **Higgs tagging**: m (, τ_{21} or D_2) + b-tagged subjets [ATLAS-PHYS-PUB-2015-035]



> **More complex, alternative taggers available**

- Shower deconstruction [ATLAS-CONF-2014-003,ATLAS-CONF-2017-064]
- HEPTopTagger [JHEP 06 (2016) 093,ATLAS-CONF-2017-064]
- Variable-R jets [ATL-PHYS-PUB-2016-013]
- Jet reclustering [ATLAS-CONF-2017-062]
- Machine learning based taggers [ATL-PHYS-PUB-2017-004]

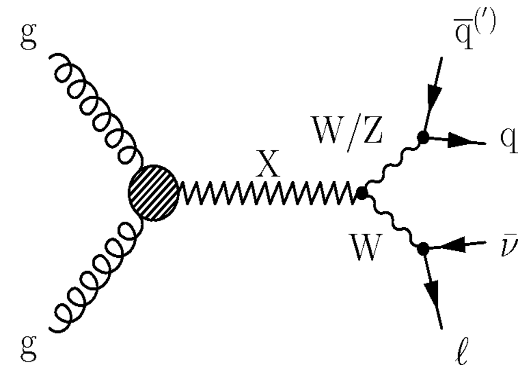
Searches with boosted bosons

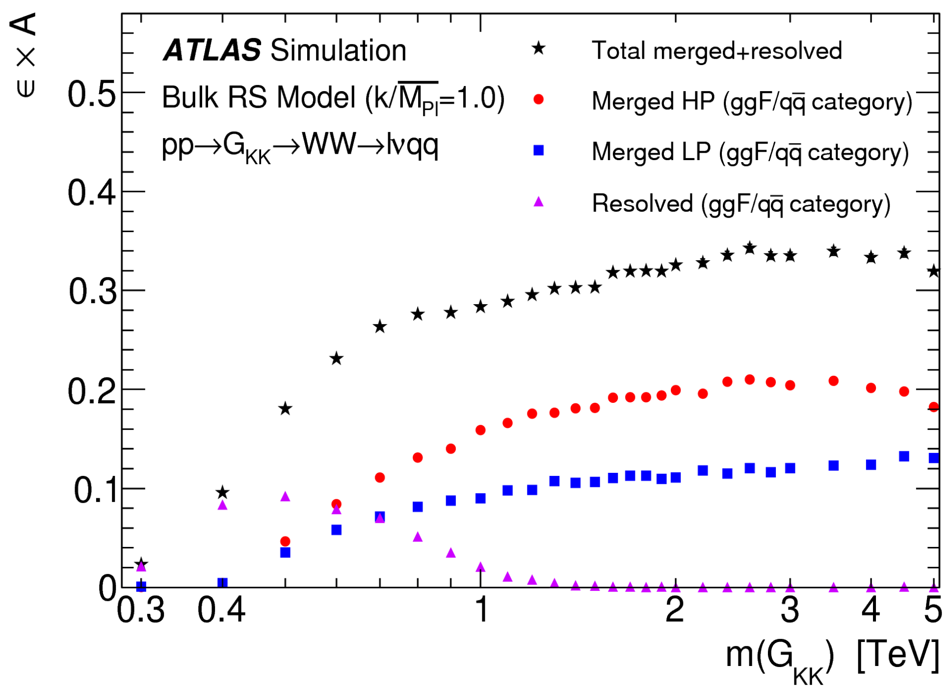
Search for resonances decaying to vector bosons

Single lepton + jets

[JHEP 03 (2018) 042]

- Focus on *WW* and *WZ* resonances with *W* ⟶ *l ν*
- Optimised for both VBF production and ggF/qq
- **Benchmark models**
  - Heavy vector triplets
  - Heavy Higgs boson (e.g. in a 2HDM)
  - Bulk Randall-Sundrum model
- Both merged and resolved regimes
- **Merged boson candidate**
  - Anti-k_t R=1.0 jet, p_T>200 GeV
  - Combined mass m_J>50 GeV
  - n-subjettiness ratio τ_{21} (high- and low-purity regions)



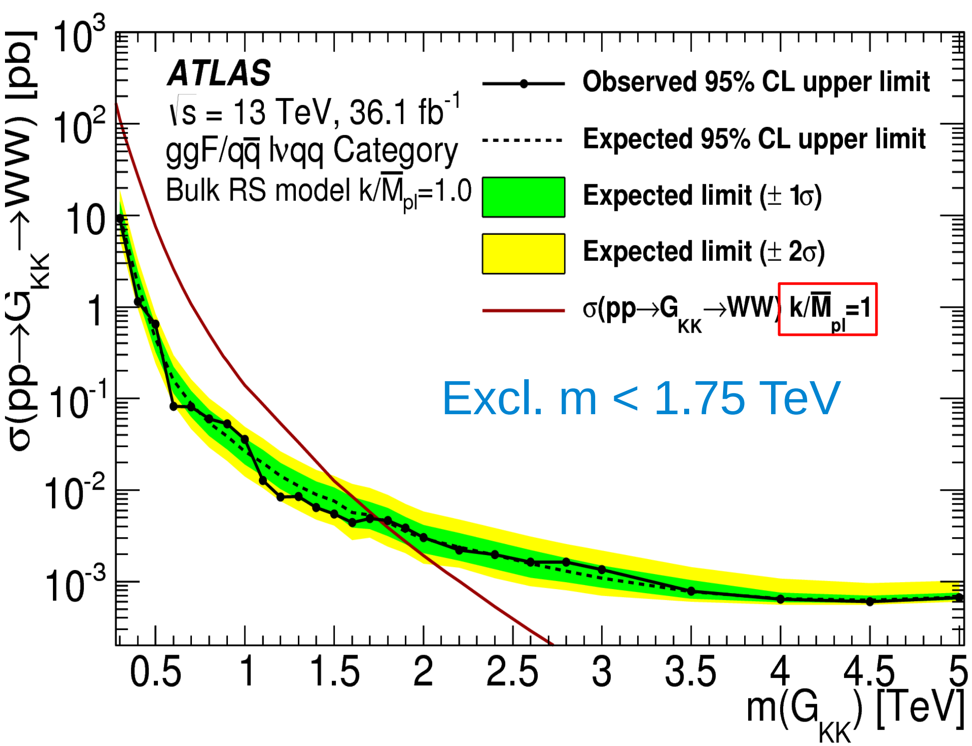


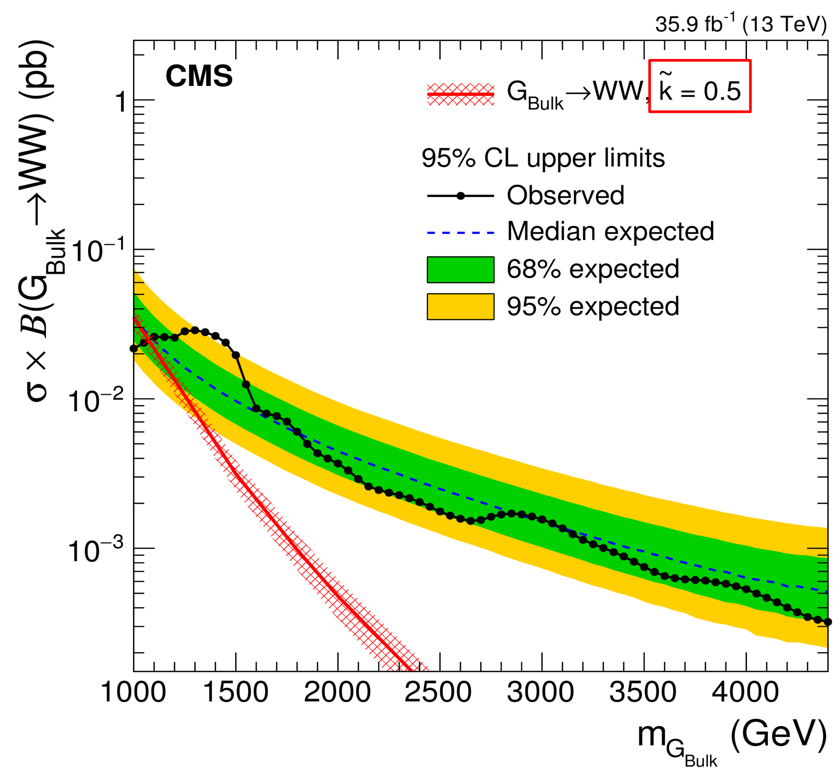
Search for resonances decaying to vector bosons

Single lepton + jets

[JHEP 03 (2018) 042]

- Results using 36.1 fb^{-1} of 13 TeV data (summary of all diboson channels in the backup)
- Comparison with **CMS-B2G-16-029** (comparable dataset)
  - Merged regime only
  - Boson candidate: anti-k$_t$ R=0.8 jet with p_T>200 GeV
  - **Tagger**: soft-drop mass and n-subjettiness ratio τ_{21} (high- and low-purity regions)





Search for Higgs boson pair production

4 b-jets

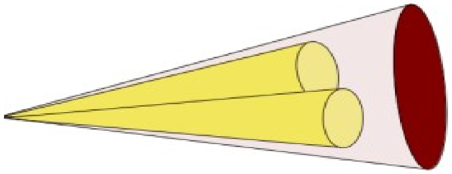
[arXiv:1804.06174]

> Challenging decay mode due to large multi-(b-)jet backgrounds

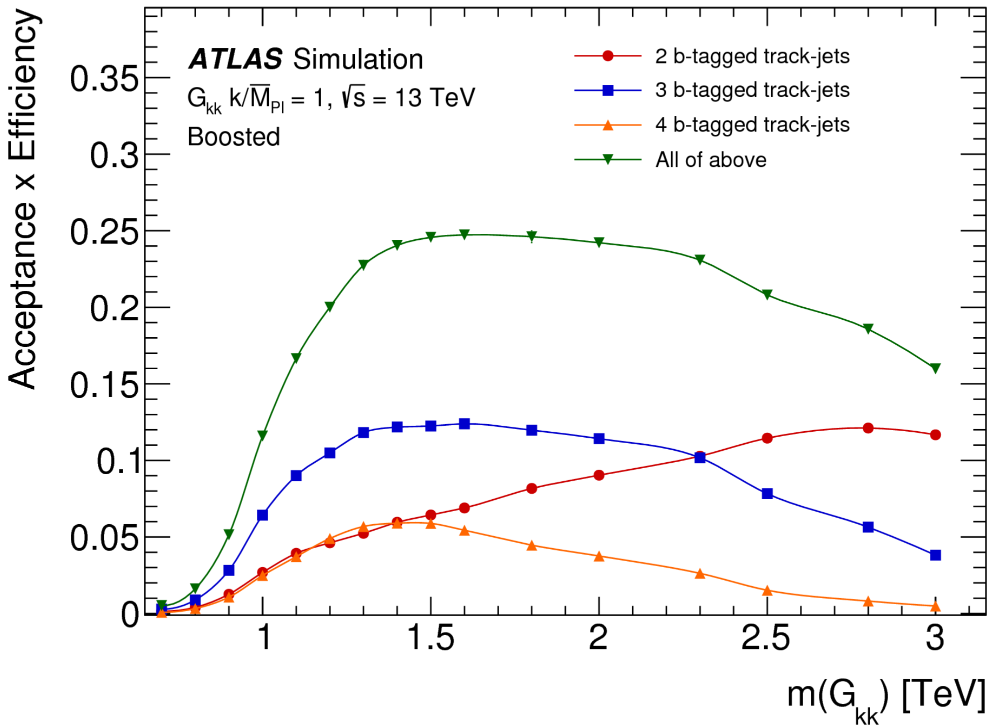
> **Benchmark models**
- Heavy Higgs boson (e.g. in a 2HDM)
- Bulk Randall-Sundrum model
- SM non-resonant production

> Both merged and resolved regimes

> **Merged Higgs candidate**
- Anti-k_t R=1.0 jet, p_T>250 GeV
- Leading jet p_T> 450 GeV
- Combined mass m_J>50 GeV
- No n-subjettiness requirement
- *b*-tagging (70% WP)
  - anti-k_t R=0.2 track jets
  - matched to large-R jet



3 orthogonal signal regions: 2-, 3-, 4-b-tags



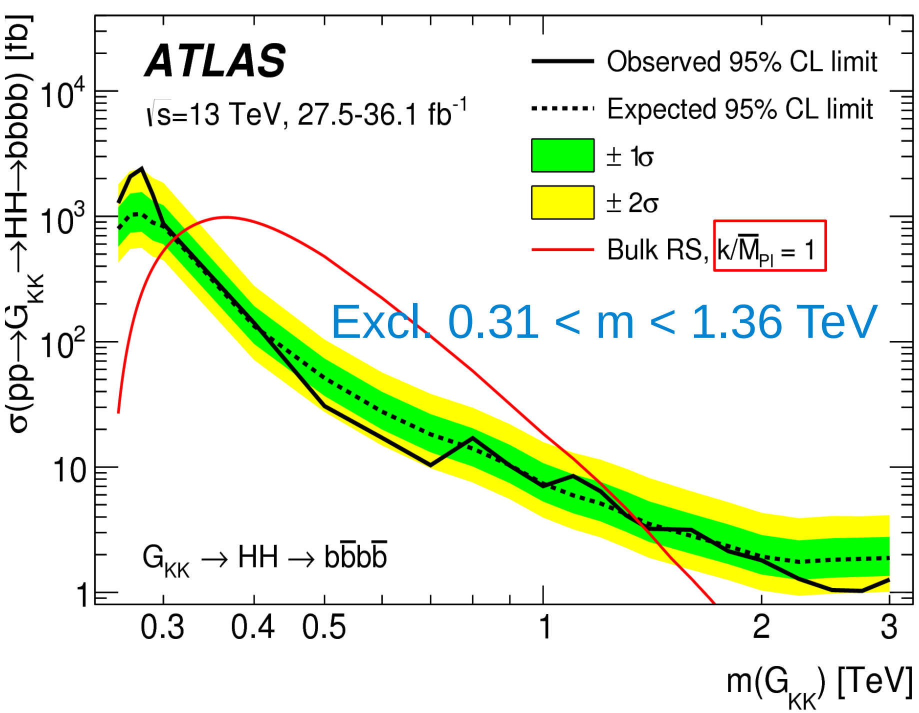
Search for Higgs boson pair production

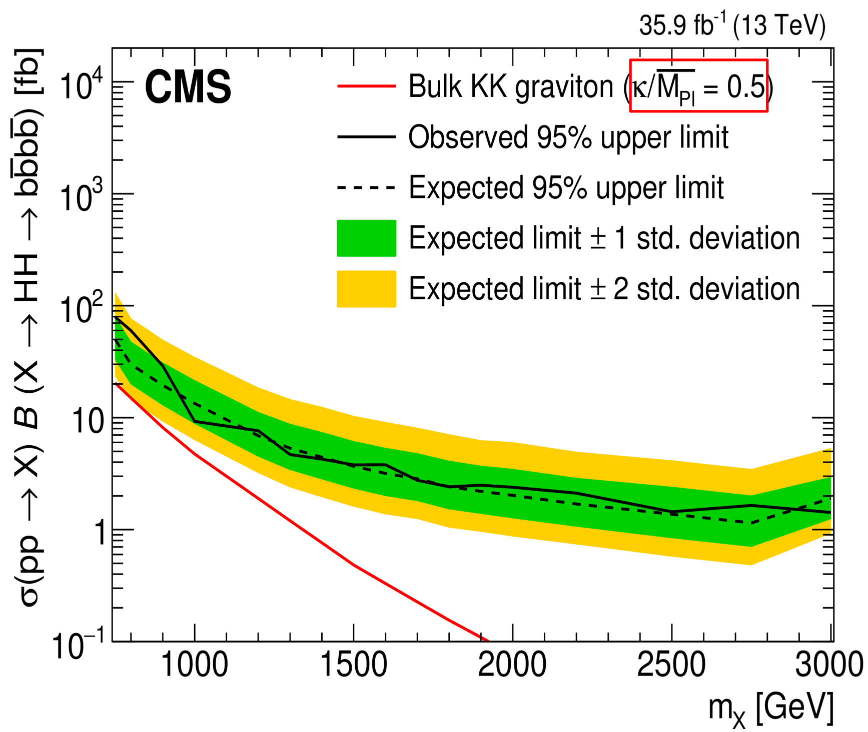
4 b-jets

[arXiv:1804.06174]

> Results using 36.1 fb^{-1} of 13 TeV data
  – Non-resonant production larger than 13*SM cross-section excluded at 95% CL

> Comparison with **CMS-B2G-16-029** (comparable dataset)
  – Merged regime only
  – Higgs candidate: anti-k_t R=0.8 jet with p_T>300 GeV (both leading and subleading Higgs)
  – **Tagger**: soft-drop mass and n-subjettiness ratio τ_{21} (high-purity region only)
  – Double b-tagger (MVA-based)





Searches with boosted top quarks

Search for heavy resonances decaying to top quarks

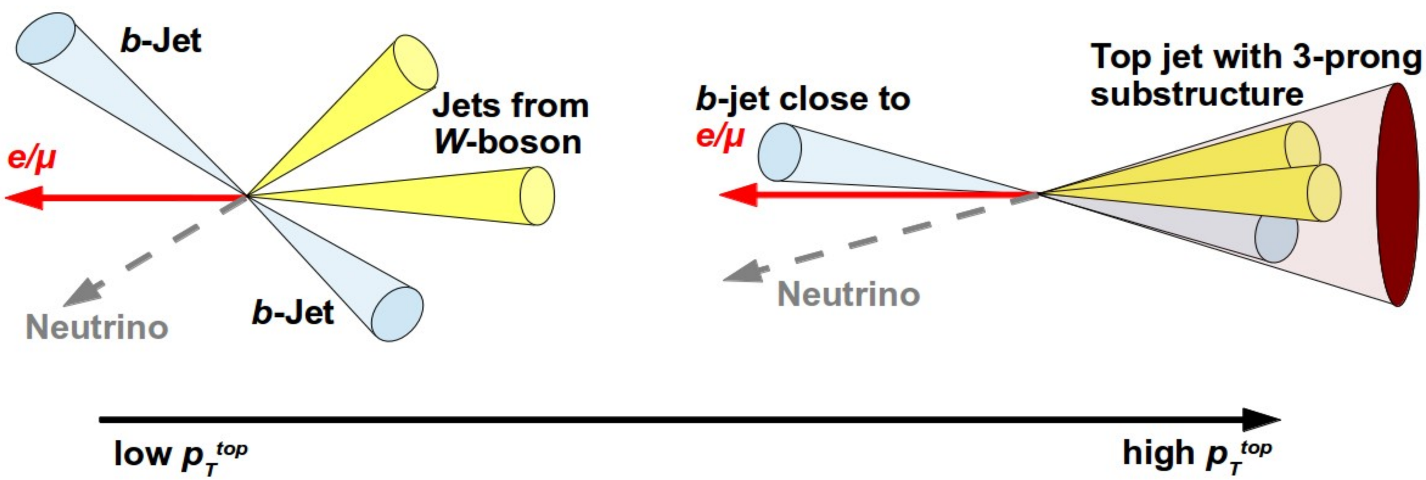
Single lepton+jets channel

[arxiv:1804.10823]

- Sensitive to a large range of BSM resonances
  - Spin-1 colour-singlet *Z′* (here: SSM *Z′*)
  - Spin-2 colour singlet: Kaluza-Klein graviton
  - Spin-1 colour octet: Kaluza-Klein gluon

- Two topologies: resolved and merged

- **Merged top candidate**
  - Anti-k_t R=1.0 jet, p_T>300 GeV
  - Combined mass and n-subjettiness ratio τ_{32} requirements
  - Top tagging efficiency WP: 80%
  - **b-tagging**: multivariate tagger with 70% efficiency on anti-k_t R=0.2 track jets

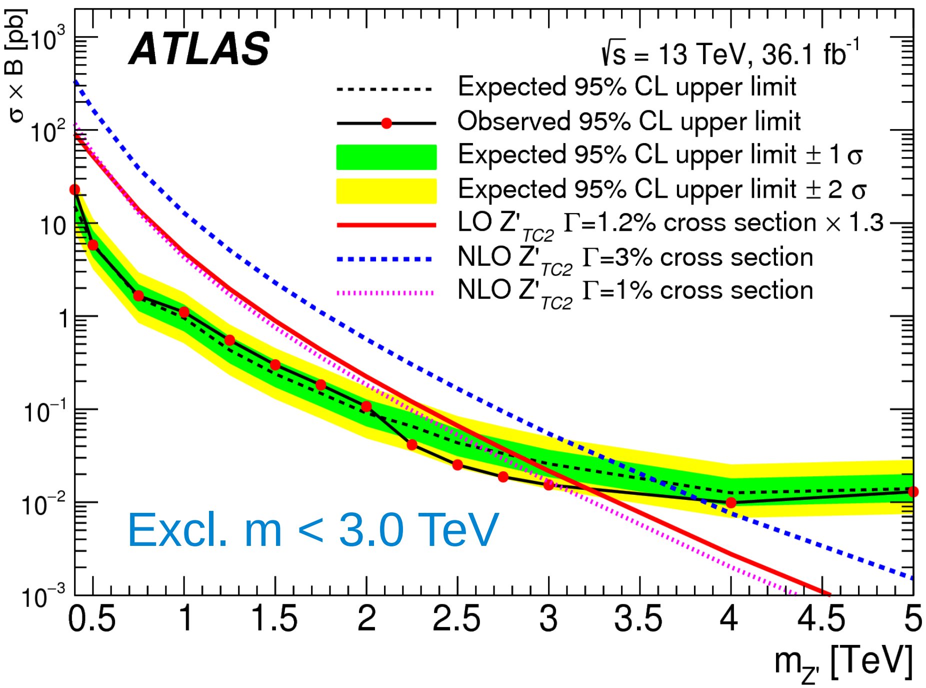


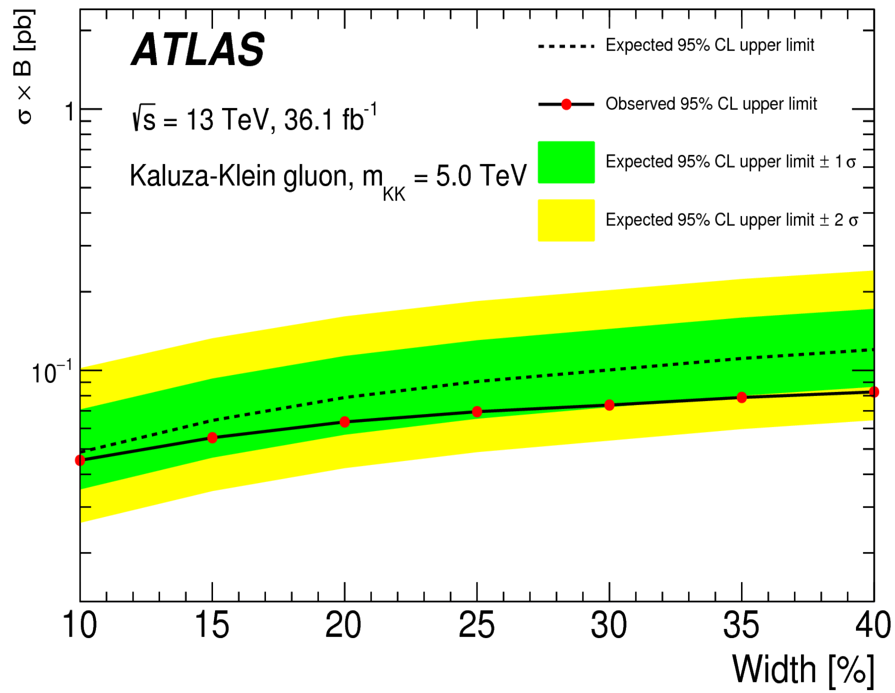
Search for heavy resonances decaying to top quarks

Single lepton+jets channel

[arxiv:1804.10823]

> Results using 36.1 fb^{-1} of 13 TeV data





> Comparison with JHEP 07 (2017) 001 (smaller dataset: 2.6 fb^{-1})
- Both lepton+jets and fully hadronic (merged only) final states
- Top candidates: anti-k_t R=0.8 jet with p_T>500 GeV
- **Tagger**: soft-drop mass and n-subjettiness ratio τ_{32}
- Exclude mass range 0.6 – 2.5 TeV for a Z' with 1% width

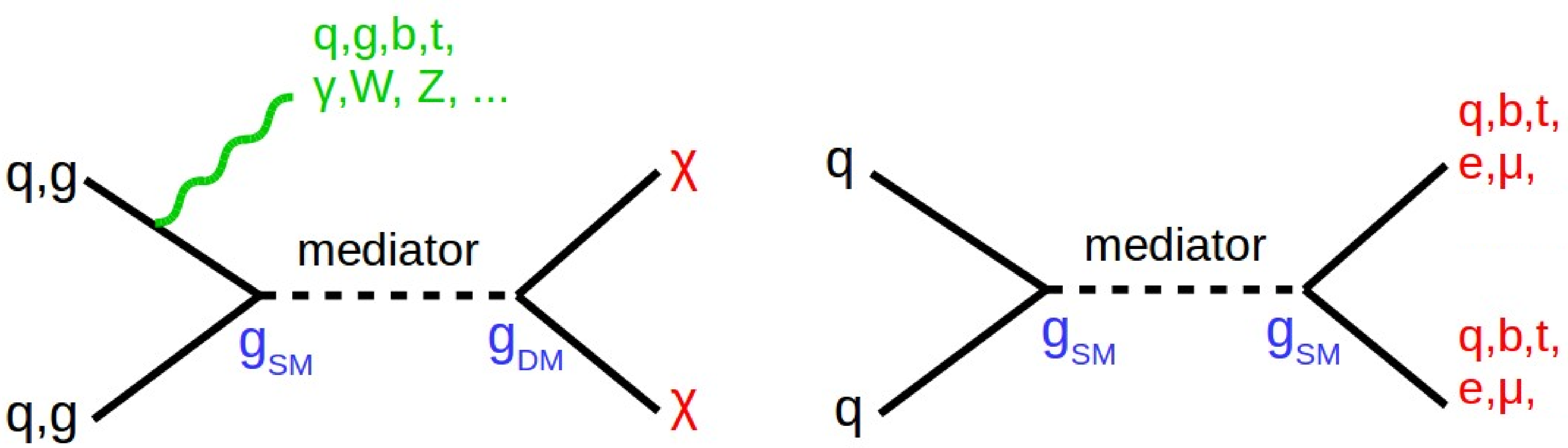
Search for heavy resonances decaying to top quarks

Dark Matter

[arxiv:1804.10823]

> Simplified model of dark matter
  – Contains a mediator *Z′* with (axial-)vector couplings to SM fermions and DM

> Common ATLAS/CMS benchmark model
  – LHC DM WG whitepapers [CERN-LPCC-2016-001,CERN-LPCC-2017-01]



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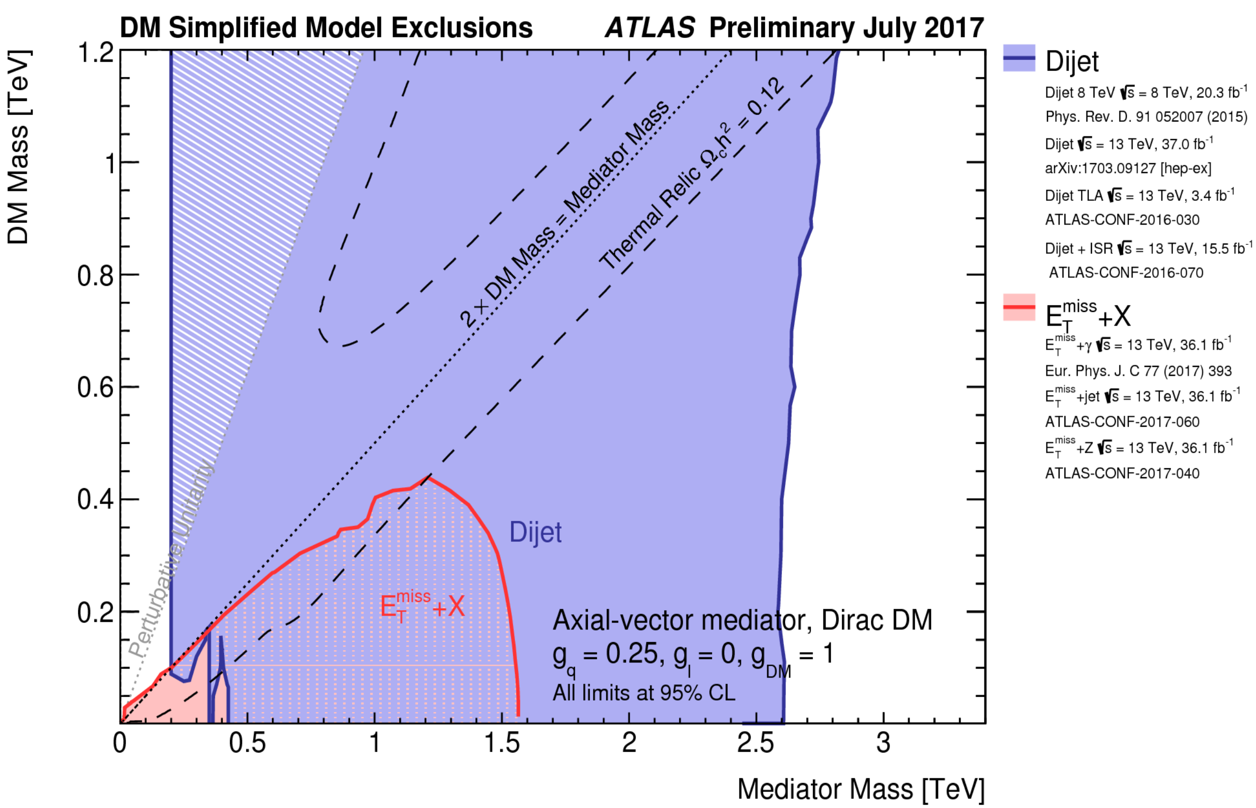
> Interplay between mono-X and resonance searches



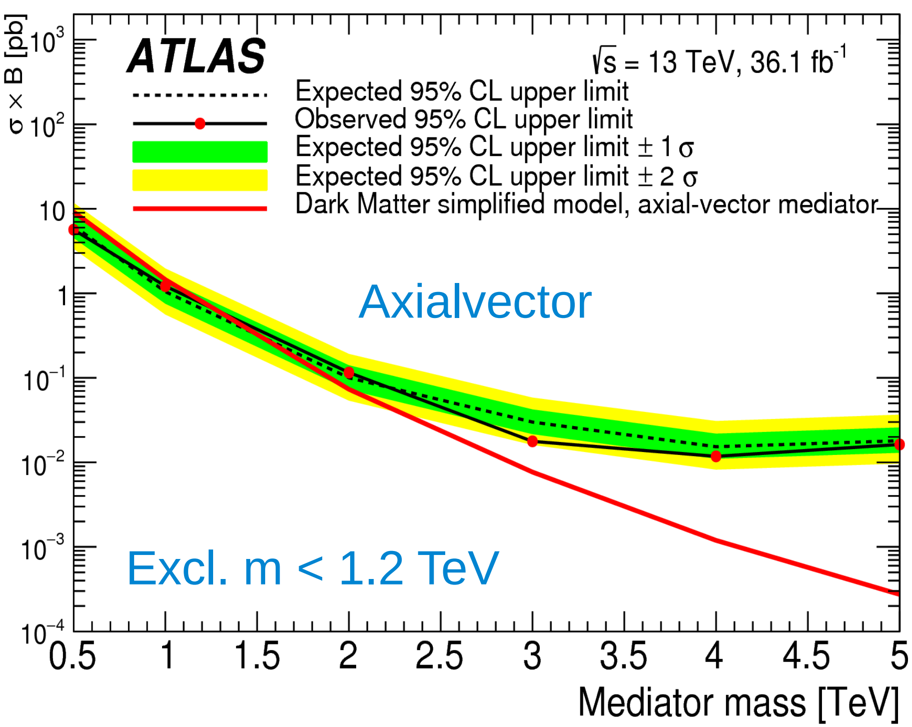
Search for heavy resonances decaying to top quarks

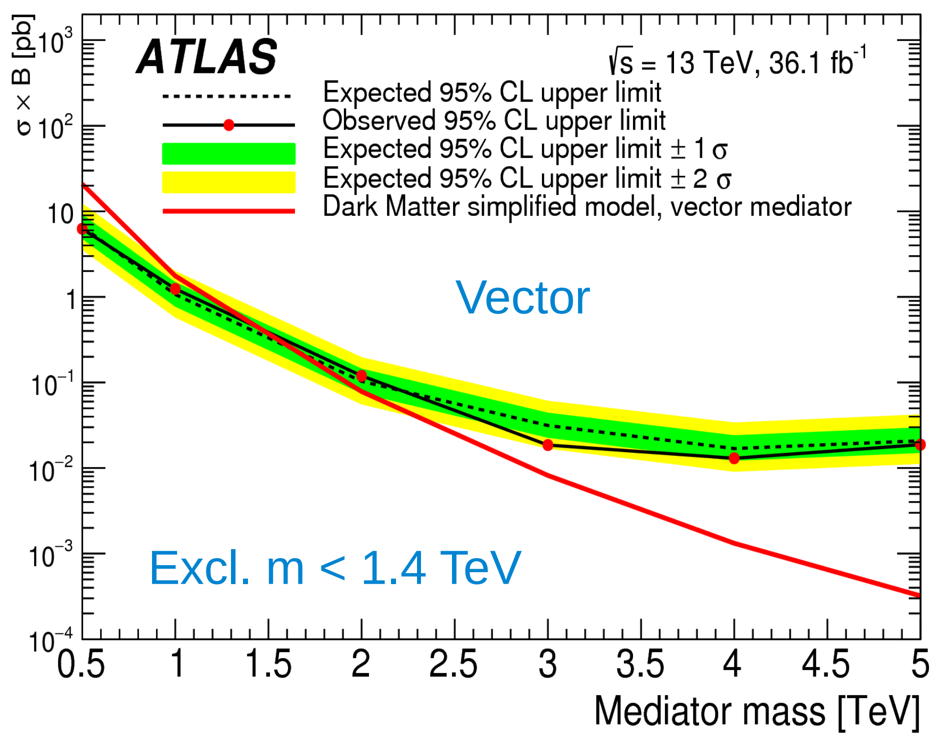
Dark Matter

[arxiv:1804.10823]

- Re-interpretation by **reweighting** existing SSM Z' samples
  - Weights obtained from ratio of m_{tt} distributions at truth level
- Exclusion limits on Z' with axialvector or vector couplings
- **Intermediate mass range is still interesting!**

NEW!



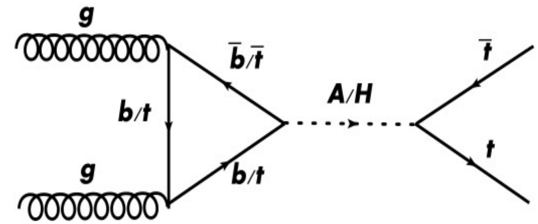


Search for heavy Higgs bosons decaying to top quarks

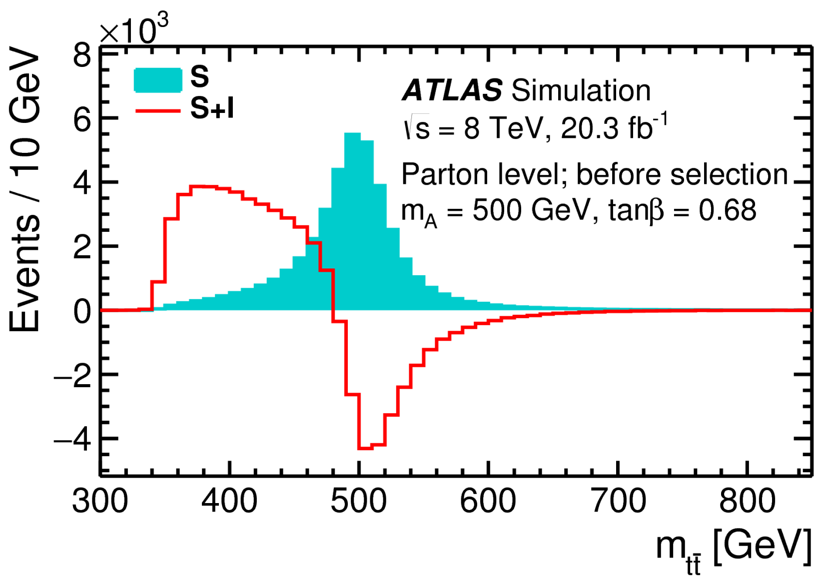
Including interference effects

[Phys. Rev. Lett. 119, 191803 (2017)]

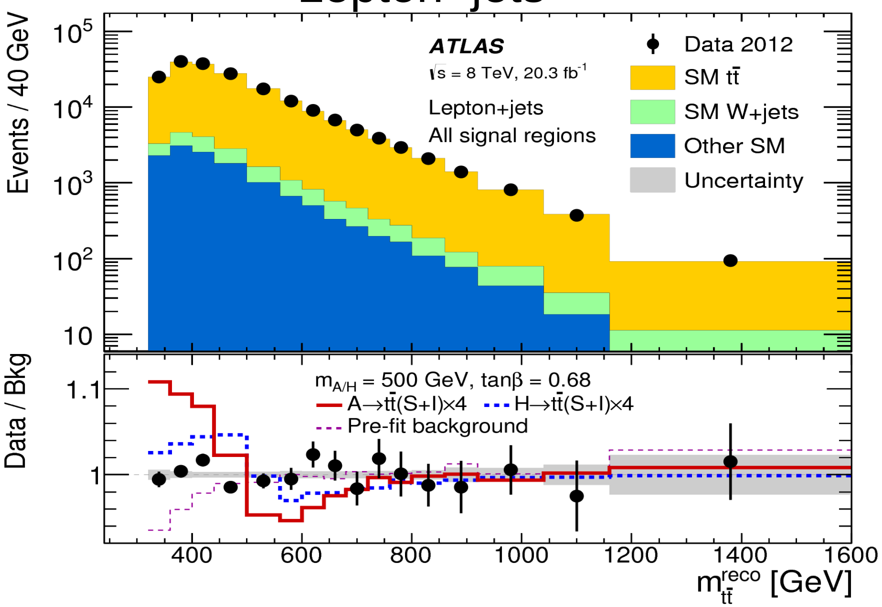
- Strong interference between $gg \to A/H \to t\bar{t}$ and background from $gg \to t\bar{t}$
- Complex signal shape: peak-dip structure
- Reduced sensitivity in traditional "bump hunts"
- **Challenges**: generating interference patterns, adapting statistical tools



- Search requires very well understood dataset
  - 2012 dataset: √s= 8 TeV, 20.3 fb^{-1}



Lepton+jets



Search for heavy Higgs bosons decaying to top quarks

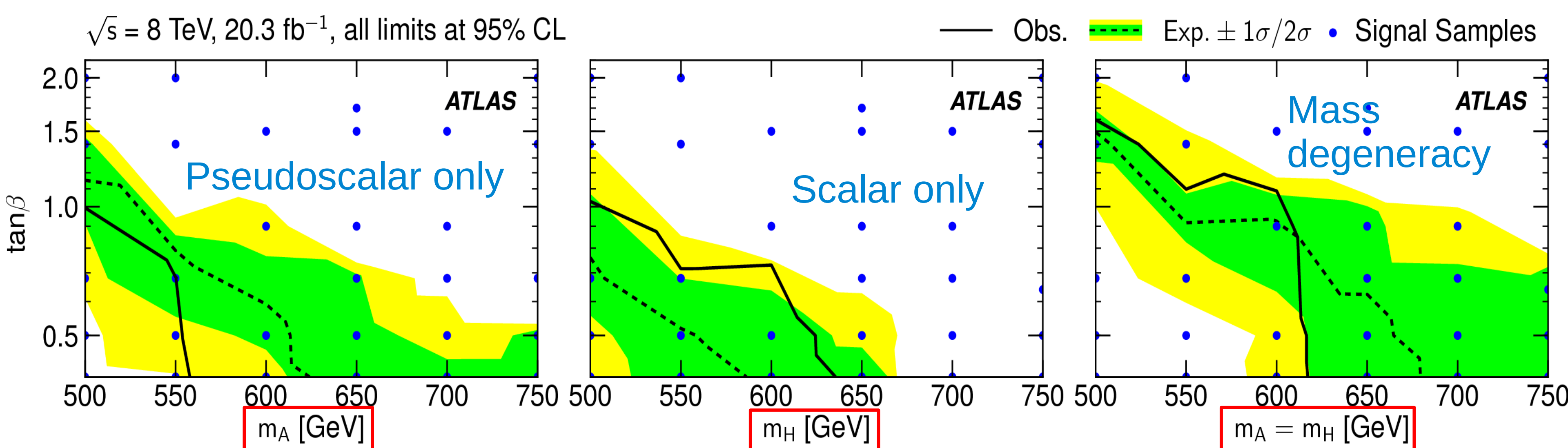
Including interference effects

[Phys. Rev. Lett. 119, 191803 (2017)]

NEW!

> Derive exclusion limits on type-II Two-Higgs-doublet model
  - **5 Higgs bosons**
    - Scalars h, H
    - Pseudoscalar A
    - Charged $H^{\pm}$
  - Alignment limit = lighter scalar *h* is SM Higgs boson
  - Interference pattern depends on mass and tanβ
  - **Reweighting** (based on matrix-element ratios) to obtain additional signal points

> **First direct limits in the high-mass, low-tanβ region**



Search for heavy Higgs bosons decaying to top quarks

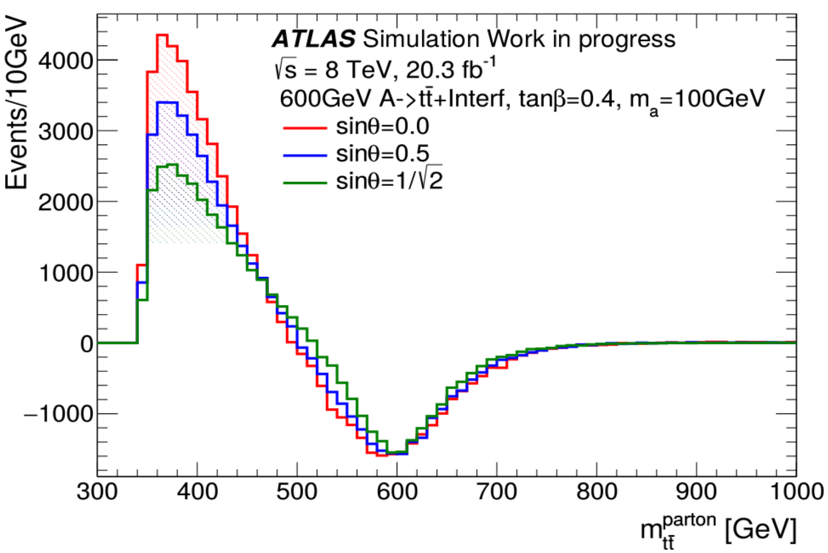
Dark matter

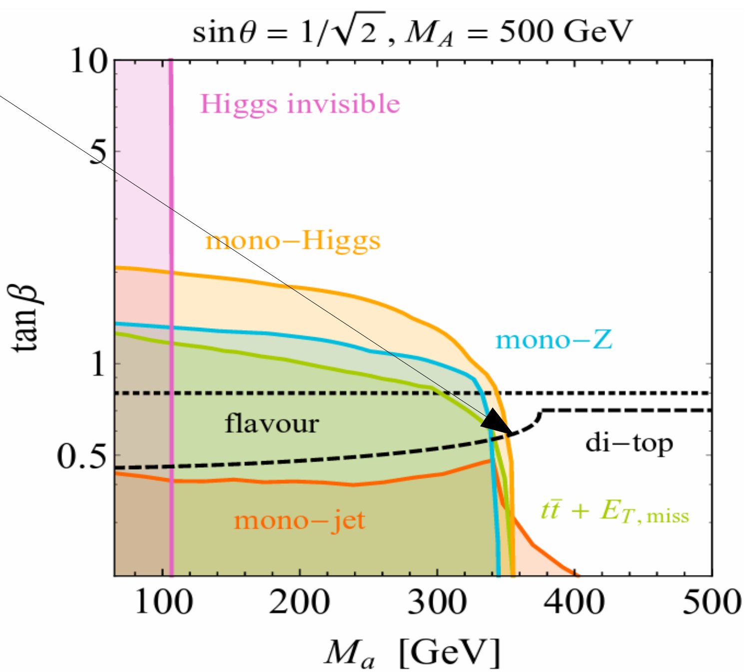
[LHC DM WG whitepaper in preparation]

> New benchmark model for dark matter
  – M. Bauer, U. Haisch, F. Kahlhoefer [JHEP 1705 (2017) 138]
  – Commonly studied by ATLAS and CMS via LHC DM WG

> 2HDM+pseudoscalar mediator a that mixes with pseudoscalar A of the 2HDM
  – Little constraints from direct detection
  – Rich collider phenomenology
  – Approximate constraints from $A/H \to t\bar{t}$

> Interference pattern depends on model parameters
  – E.g. a-A mixing angle



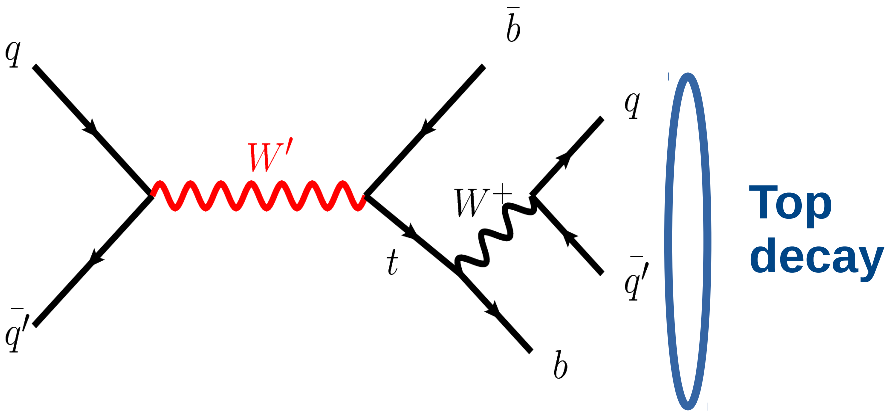


Search for *tb* resonances

Fully hadronic channel

[Phys. Lett. B 781 (2018) 327]

- Heavy *W′* predicted in various BSM scenarios
  - E.g. extra dimensions, composite Higgs
- **Benchmark model:** SSM *W′*
  - Right-handed W'_R [ATLAS: assume m(ν_R) >> m(W'_R)]
  - Left-handed W'_L



- Merged decay topology only
- Top quark candidate identified using **shower deconstruction**
- 0- and 1-b-tag event categories depending on whether top candidate has associated b-jet

Search for *tb* resonances

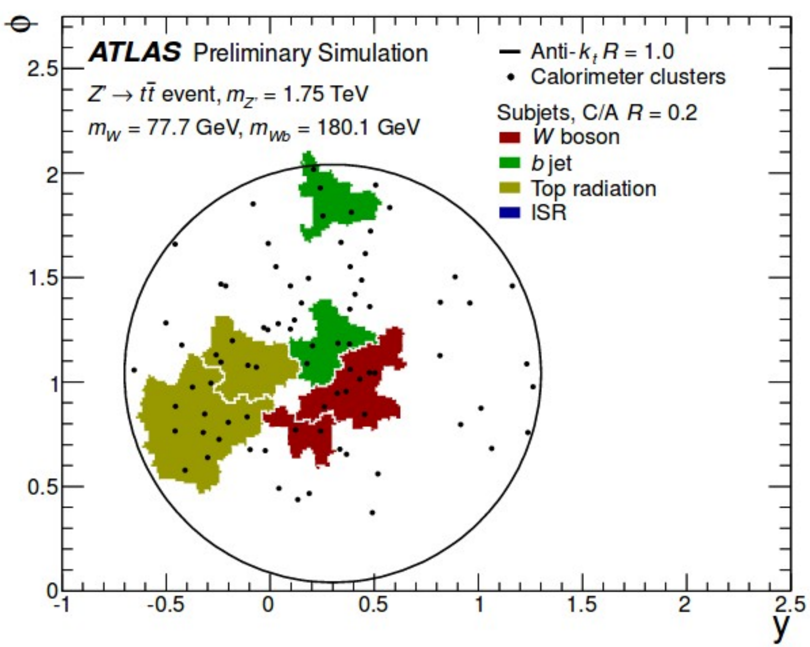
Shower deconstruction

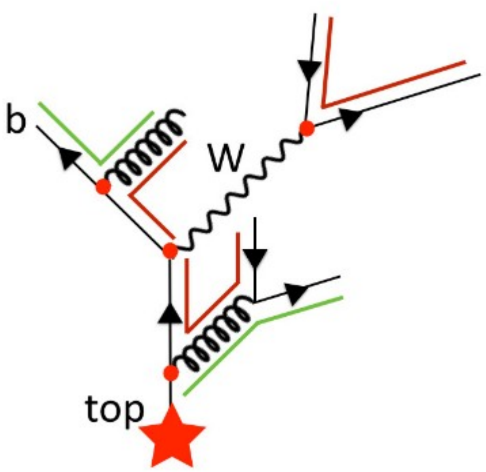
[Phys. Lett. B 781 (2018) 327]

> **Idea:** calculate likelihoods that jet originates from top quark or from a light quark or gluon

> **Input**: trimmed anti-k_t R=1.0 jets
  – Reclustered to find exclusive k_t subjets (better performance at high p_T)
    • Run 1: Cambridge-Aachen R=0.2 subjets
  – Apply loose pre-selection requirements

> Calculate all possible shower histories for signal (top) and background (light quark, gluon)
  – Using Sudakov factors and DGLAP splitting functions at each branching point





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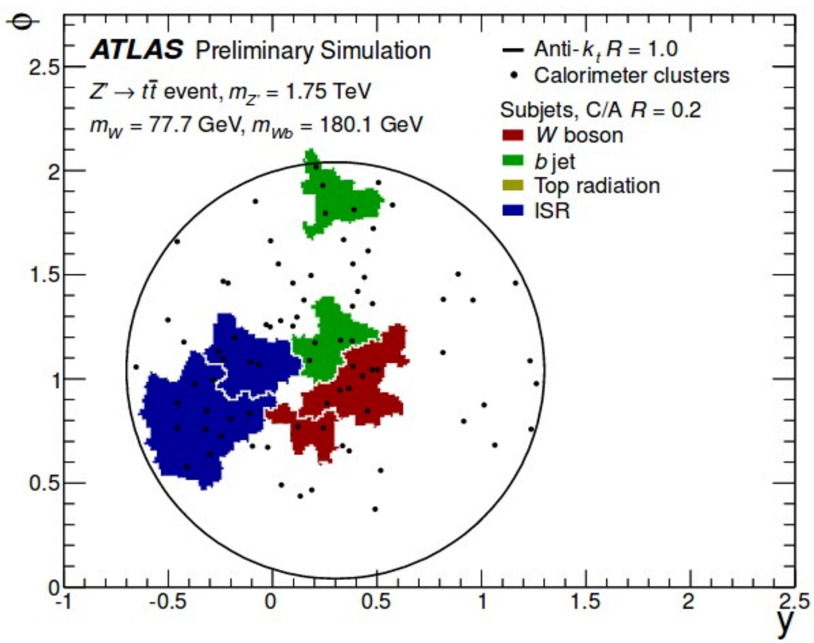

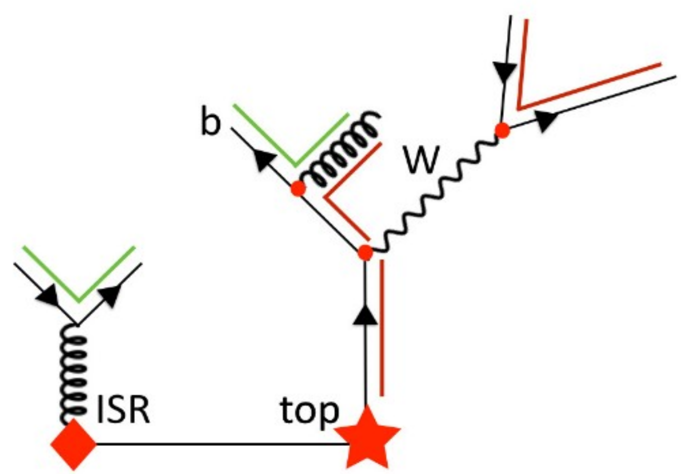

Search for *tb* resonances

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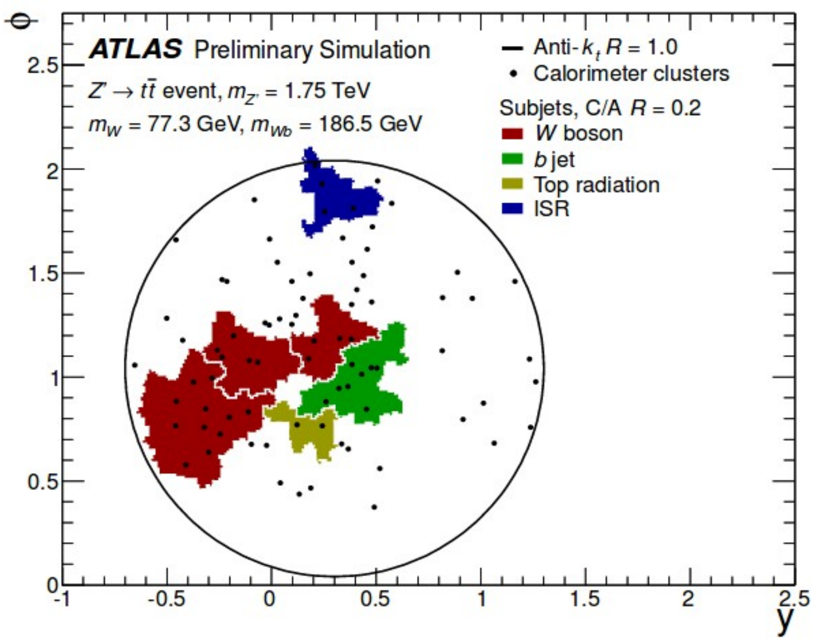
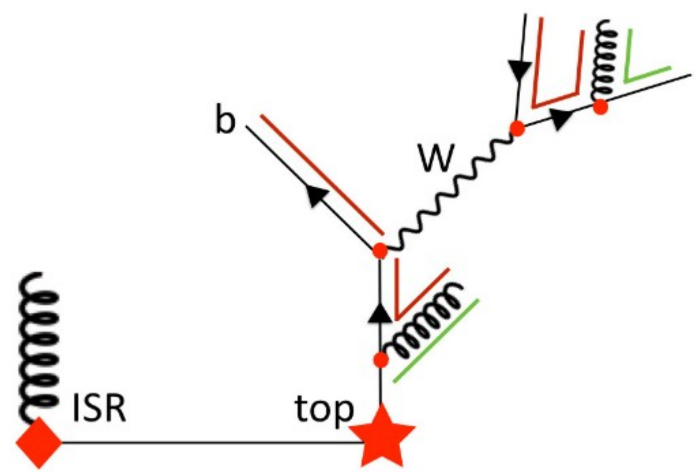




Search for *tb* resonances

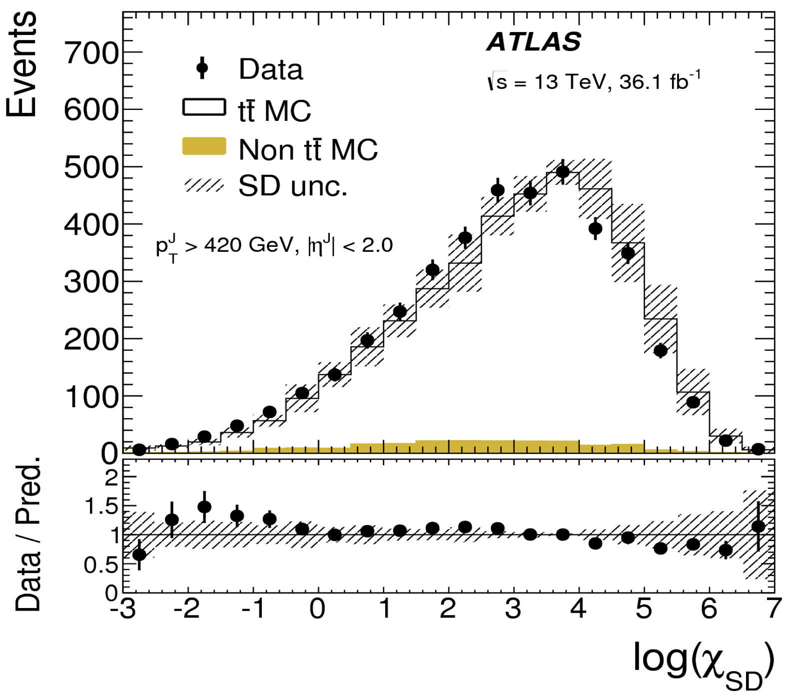
Shower deconstruction

[Phys. Lett. B 781 (2018) 327]

- **Idea:** calculate likelihoods that jet originates from top quark or from a light quark or gluon
- **Input**: trimmed anti-k_t R=1.0 jets
  - Reclustered with Cambridge-Aachen algorithm to obtain exclusive R=0.2 subjets
  - Apply loose pre-selection requirements
- Calculate all possible shower histories for signal (top) and background (light quark, gluon)
  - Using Sudakov factors and DGLAP splitting functions at each branching point
- Discriminating variable:

$$\chi(\{p\}_N) = \frac{\sum_{\text{histories}} P(\{p\}_N|S)}{\sum_{\text{histories}} P(\{p\}_N|B)}$$

- Requirements on log(X) to obtain WPs with 50% and 80% efficiency

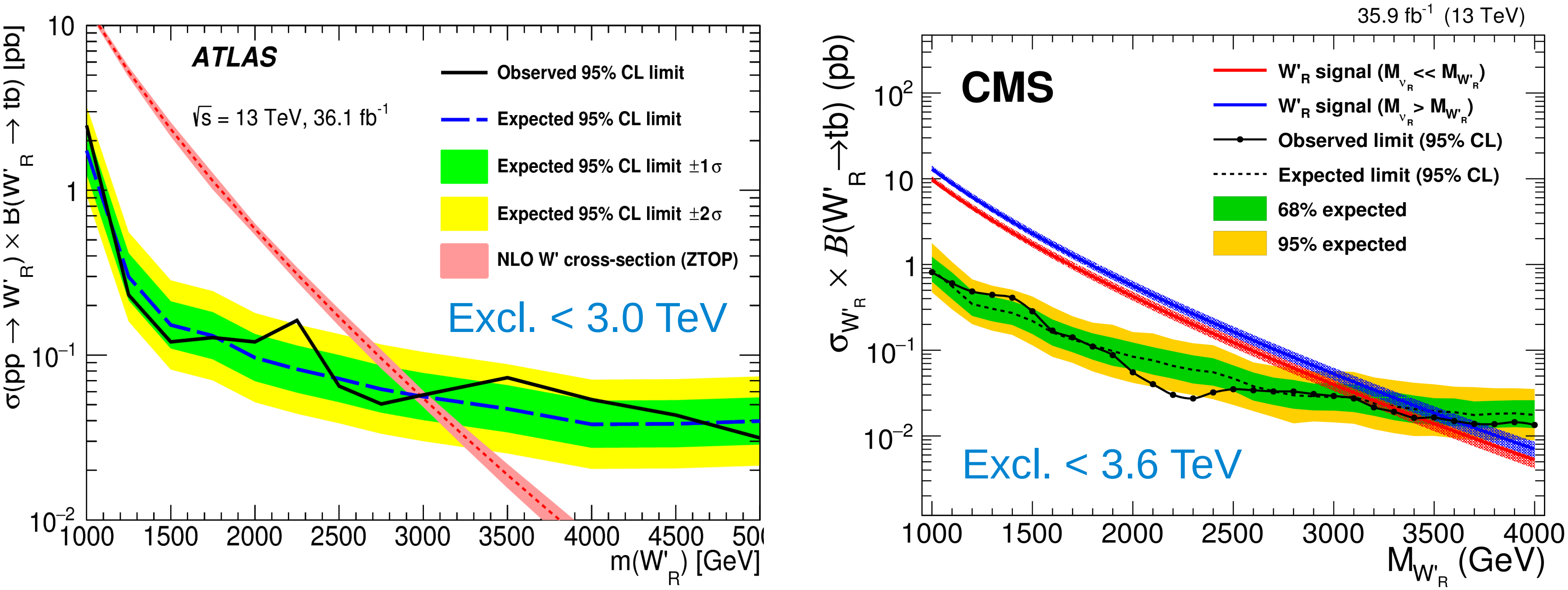


Search for *tb* resonances

Fully hadronic channel

[Phys. Lett. B 781 (2018) 327]

- Results using 36.1 fb^{-1} of 13 TeV data
- Comparison with **Phys. Lett. B 777 (2017) 39**
  - Lepton+jets final state, comparable dataset
- Compare only results for W'_R as those for W'_L are presented differently in ATLAS and CMS

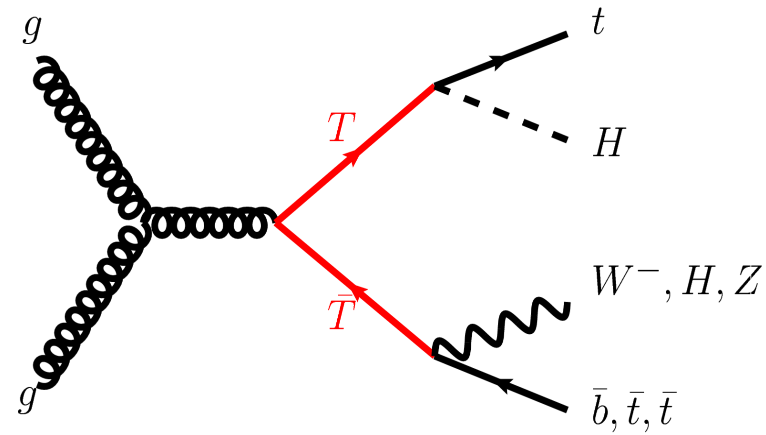


Searches for vector-like quarks

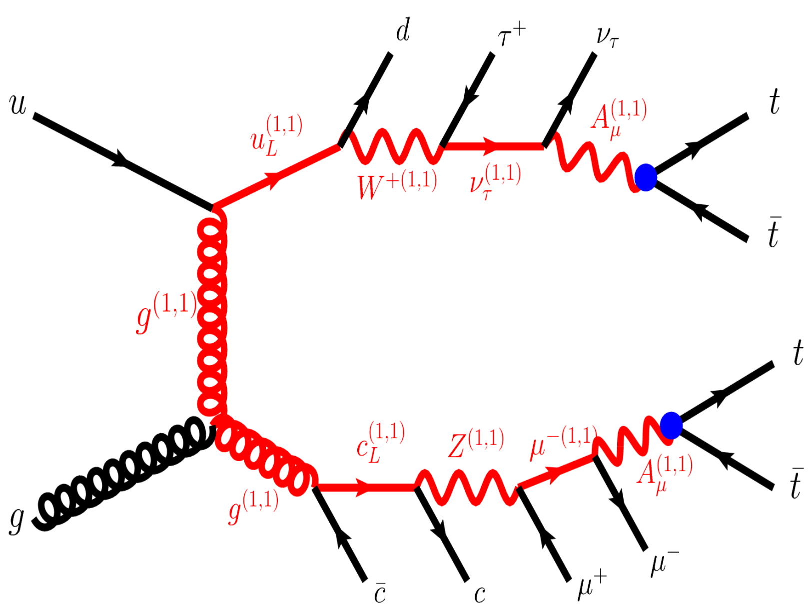
Search for pair production of vector-like T-quarks

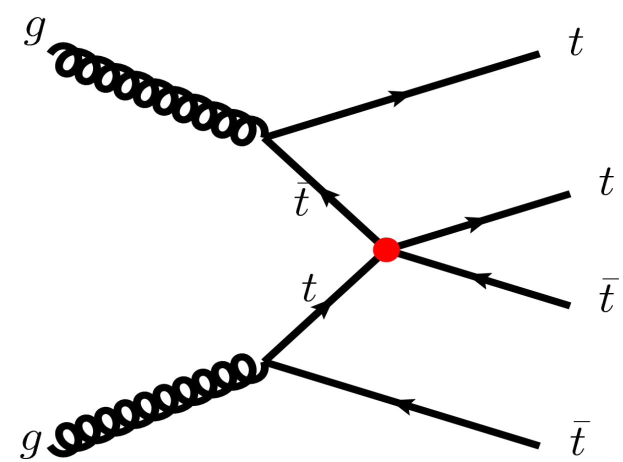
HT+X search

[arxiv:1803.09678]



- Various different interpretations
  - Pair production of VLT
  - 4-top production in EFTs
  - Cascade decays of KK excitations
- Note: not optimised for SM 4-top production





Search for pair production of vector-like T-quarks

HT+X search

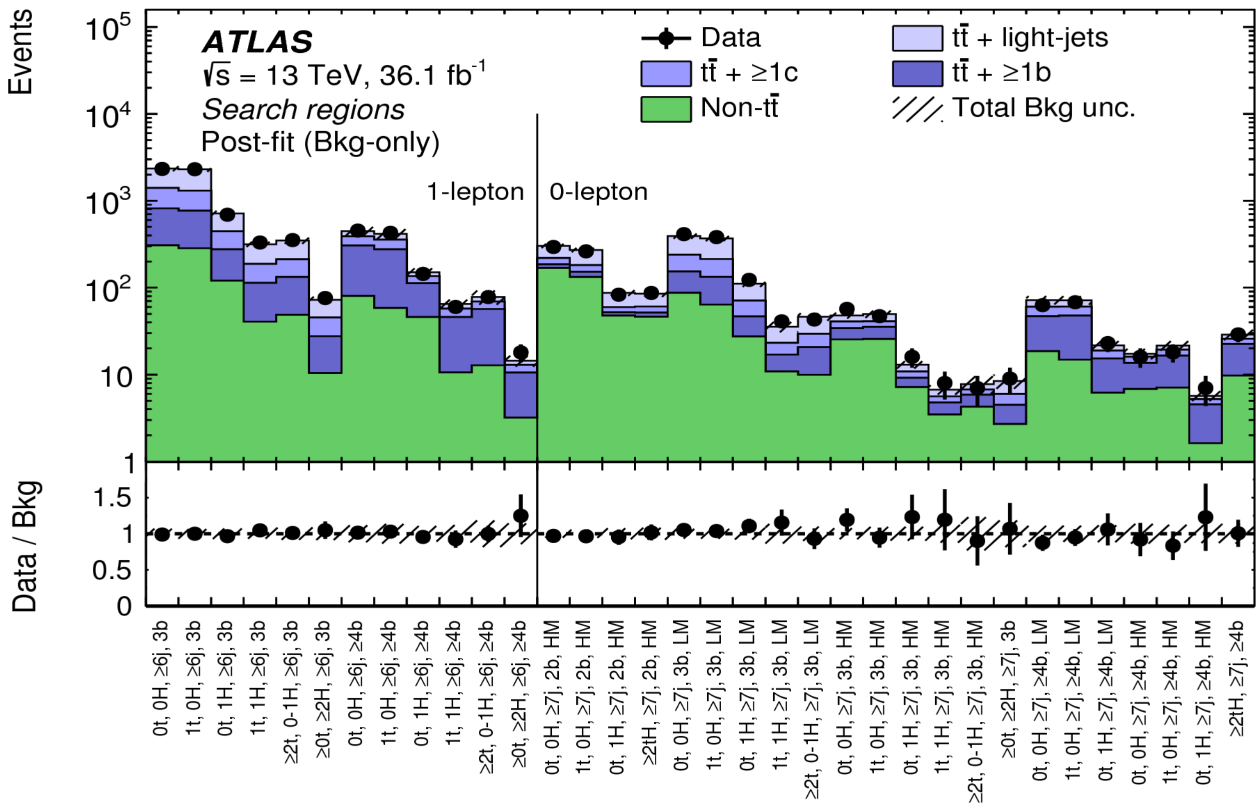
[arxiv:1803.09678]

> Search optimised for TT--> HtHt, HtZt, HtWb but some sensitivity for ZtZt,ZtWb with Z-->bb

> High jet and b-tag multiplicities!

> 34 signal regions (22 regions for 0-lepton, 12 regions for 1-lepton) divided according to
  - Jet multiplicity
  - b-tag multiplicity
  - Top-tags
  - Higgs-tags

> Shape fit in each region

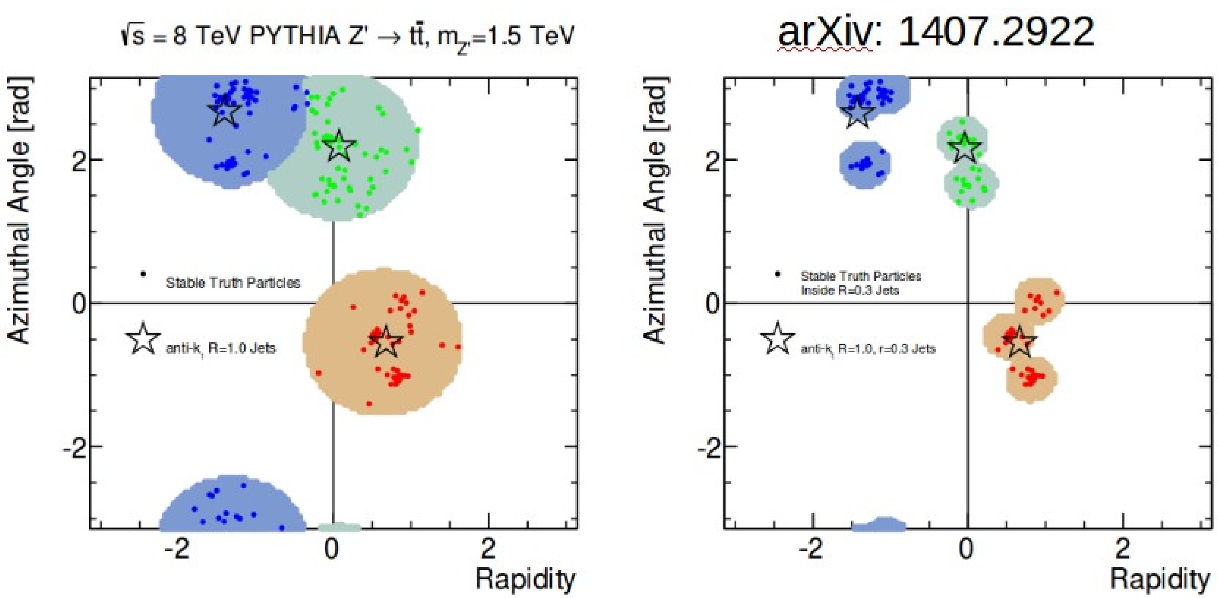


Search for pair production of vector-like T-quarks

HT+X search

[arxiv:1803.09678]

> Top- and Higgs-tagged jets reconstructed via **jet reclustering**
  - Anti-k_t R=1.0 jets build from calibrated anti-k_t R=0.4 jets



> **Top-candidate jets**
  - p_T> 300 GeV
  - m> 140 GeV
  - ≥ 2 subjets

> **Higgs-candidate jet**
  - p_T> 200 GeV
  - 105 < m < 140 GeV
  - Exactly 2 subjets (p_T< 500 GeV)
  - 1 or 2 subjets (p_T> 500 GeV)

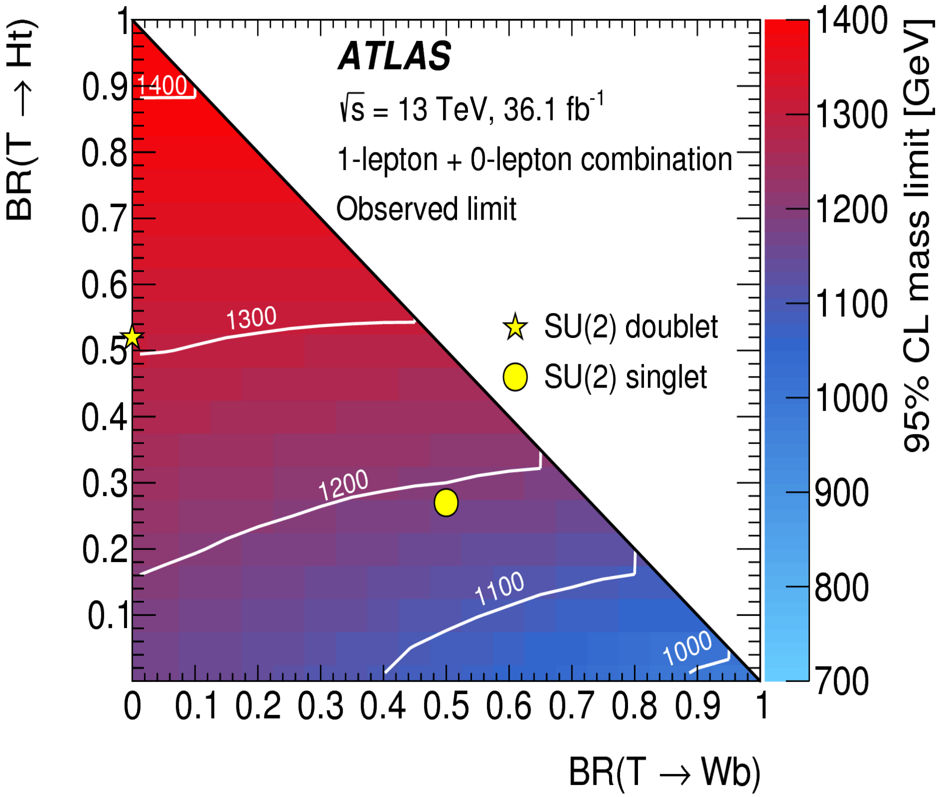
> Note aside: reclustering used also in many ATLAS SUSY searches

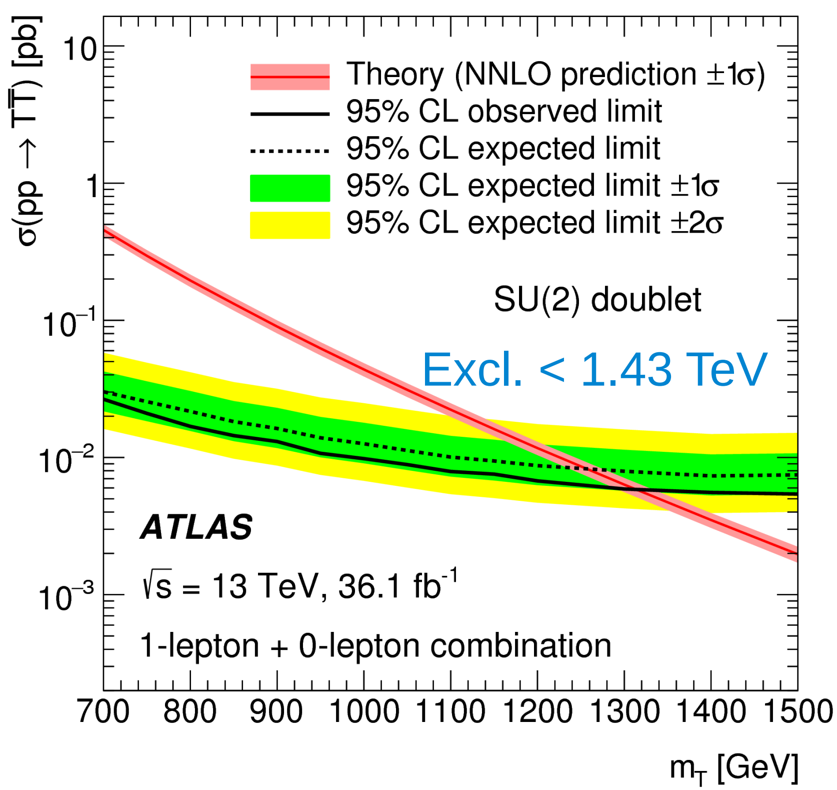
Search for pair production of vector-like T-quarks

HT+X search

[arxiv:1803.09678]

> Exclusion limits derived as function of mass and branching ratios



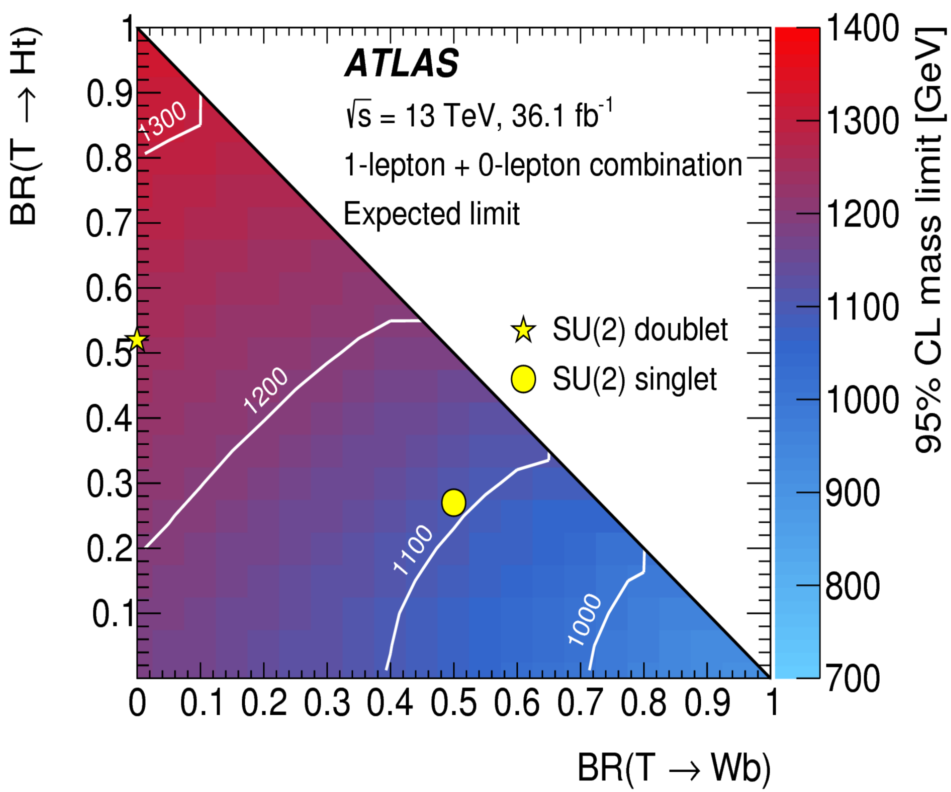


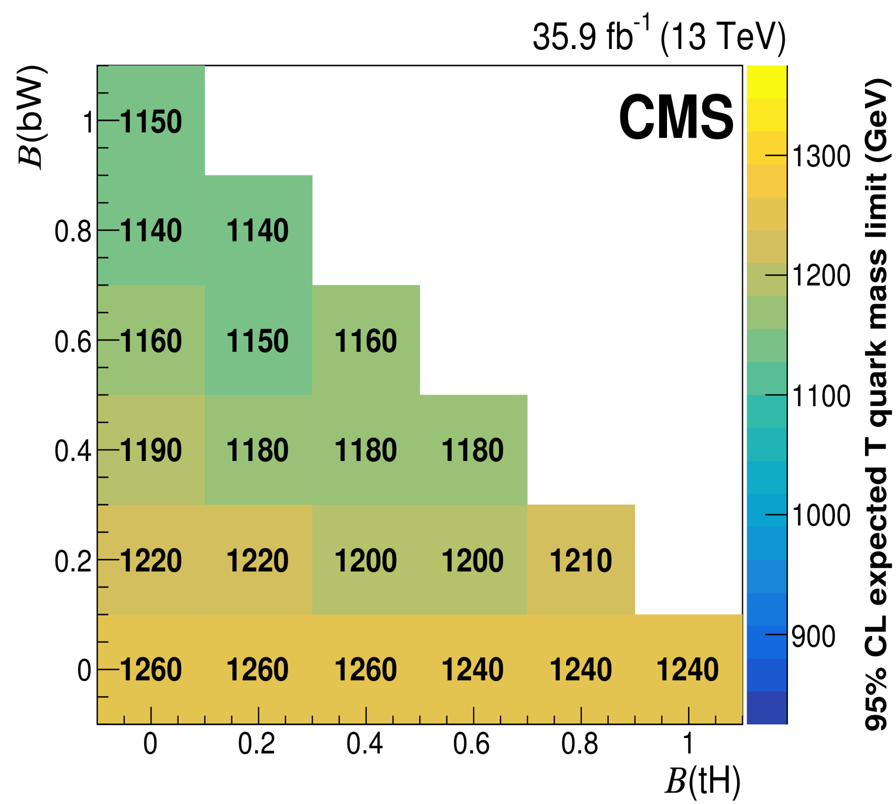
Search for pair production of vector-like T-quarks

HT+X search

[arxiv:1803.09678]

- Comparison with **CMS-B2G-17-011**, targetting leptonic final states
  - Single lepton, same-sign dileptons, at least three leptons





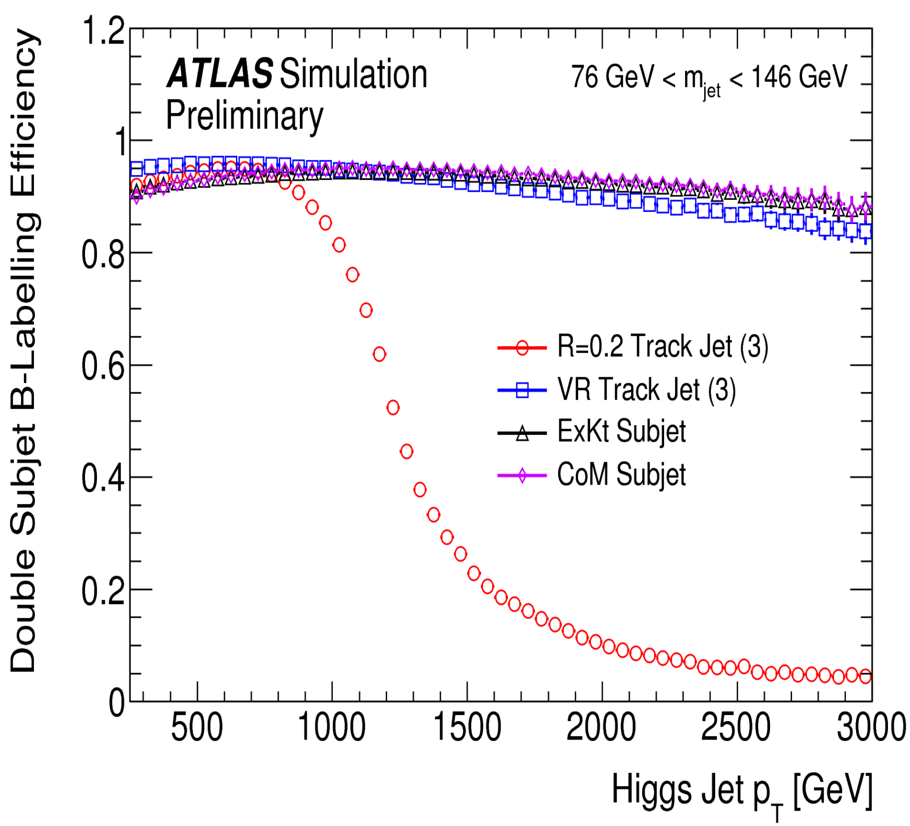
Tools for future searches

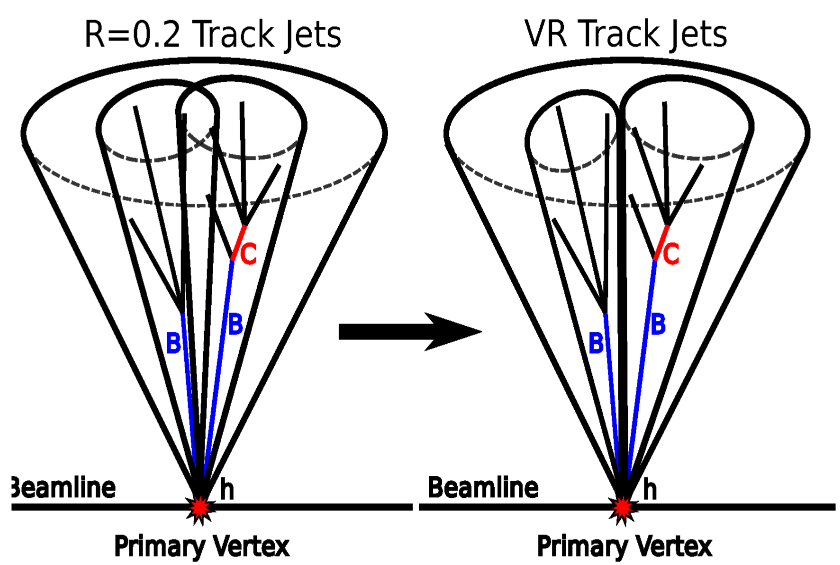
Improvements in h(bb) tagging

Alternative subjets

[ATL-PHYS-PUB-2017-010]

- Current taggers based on anti-k_t R=0.2 track jets limited at high jet-p_T due to jet merging
- **Solution**: variable-R jets
  - Effective jet radius shrinks with jet transverse momentum: $R_{eff} \sim 1/p_T$





Improvements in top- and W-tagging

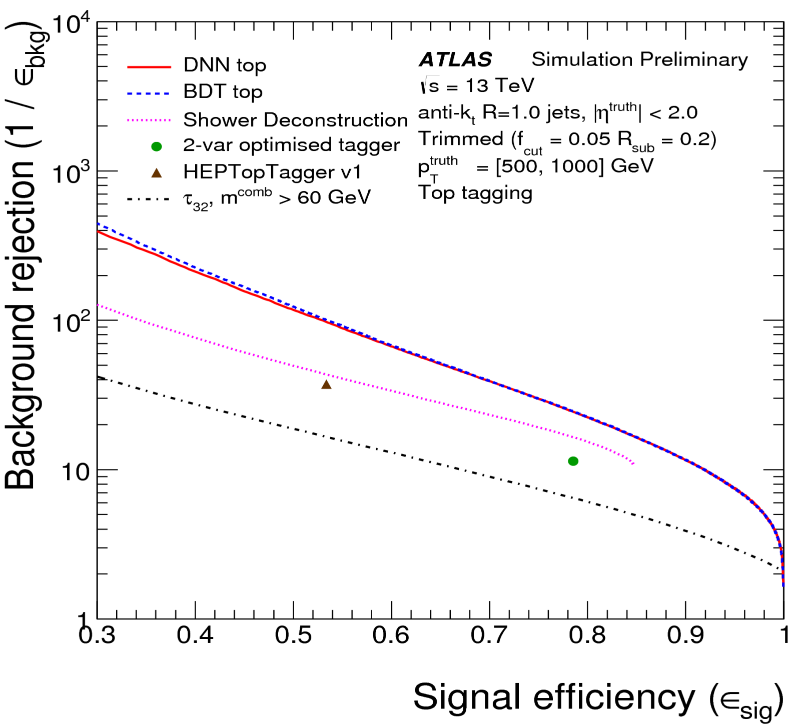
Multivariate methods

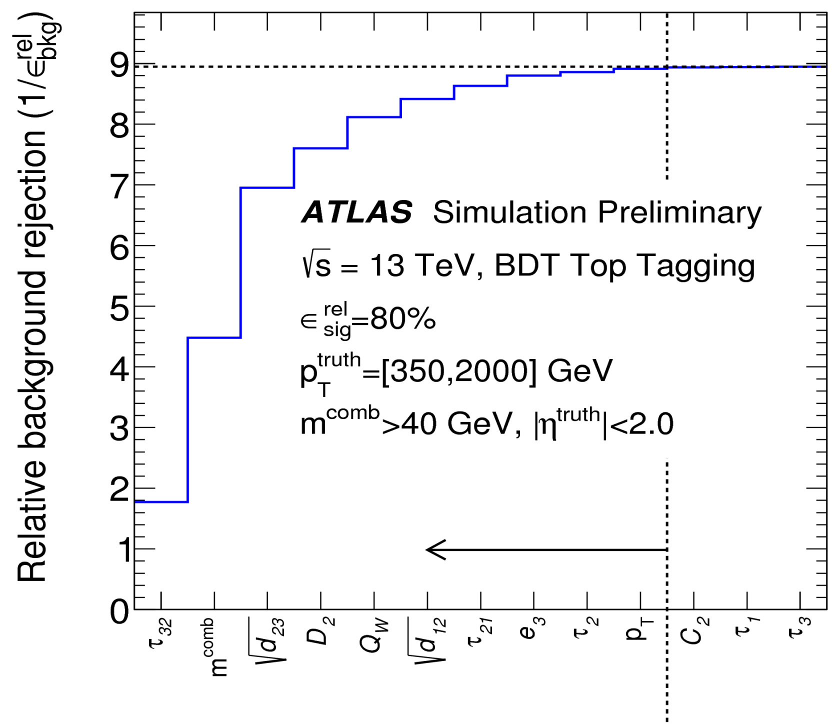
[ATL-PHYS-PUB-2017-004, ATLAS-CONF-2017-064]

- Studied boosted decision trees (BDTs) and deep neural networks (DNN)
  - Exploit correlation of input variables

- **Input**: various substructure variables
  - BDT: add sequentially variable that gives largest performance improvement
  - DNN: test different groups of input variables

- Significant performance improvements compared to single-variable taggers





A few general observations...

- Substructure techniques well established by now
  - Many analyses in ATLAS and CMS rely on simple 1- or 2-variable taggers

  - Various new/alternative taggers investigated in both experiments
  - Significant efficiency boost from machine learning techniques

  - Track-assisted techniques increasingly used in ATLAS
    - Combined mass
    - Jets built from Track-CaloClusters **[ATL-PHYS-PUB-2017-004]**

- b-tagging efficiency at high momenta a limiting factor for many searches
  - New algorithms targetting dense topologies

- Interference effects are becoming more relevant as precision/scope of searches increases
  - *A/H-->tt*
  - Single VLQ production
  - ...

- Increasing interest in re-interpretations/new benchmark models
  - E.g. use *Z'-->tt* and *A/H-->tt* searches to constrain DM models

  - Signal interpolation techniques (reweighting, morphing, ...) become important!

Extra Material

Track-CaloCluster (TCC) Jets

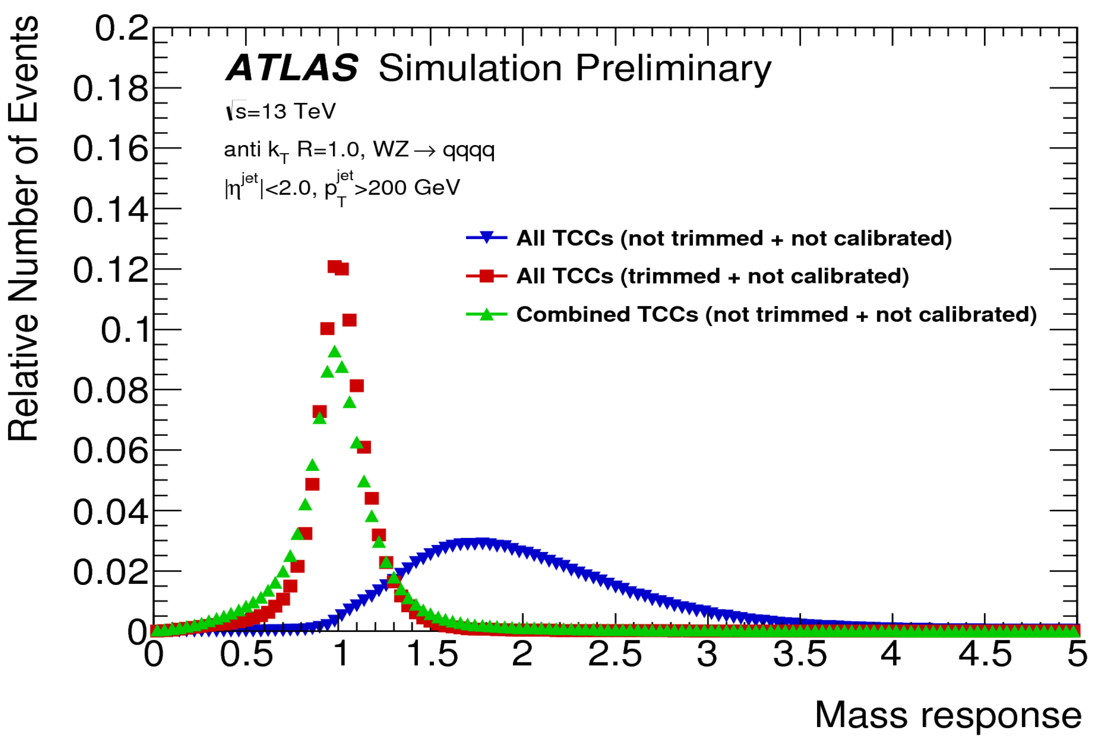
Track-assisted substructure

[ATL-PHYS-PUB-2017-004]

> Combine tracking and calorimeter information at the low level of jet inputs
  – New Track-CaloCluster objects as input to jet clustering

> Different from track-assisted mass/substructure where tracks are matched to a calorimeter jet

> Type of particle flow approach
  – Main difference: angular information taken from track, energy from calorimeter
  – Track 4-vector is NOT used to correct the full 4-vector of the TCC object



Track-CaloCluster (TCC) Jets

Combining calorimeter and tracking information

[ATL-PHYS-PUB-2017-004]

- Combine tracking and calorimeter information at the low level of jet inputs
  - New Track-CaloCluster objects as input to jet clustering
- Different from track-assisted mass/substructure where tracks are matched to a calorimeter jet
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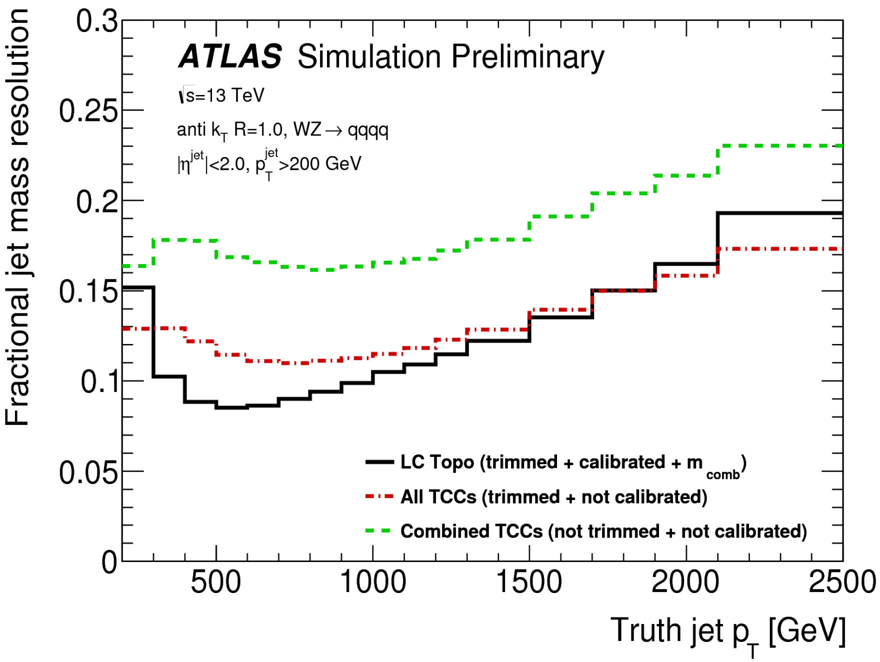
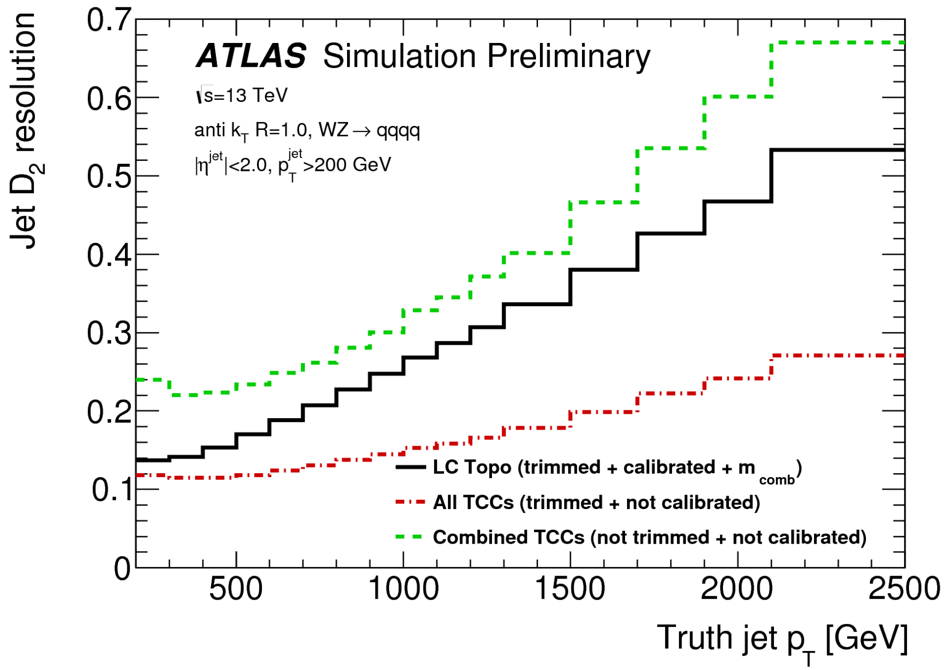
  - Main difference: angular information taken from track, energy from calorimeter
  - Track 4-vector is NOT used to correct the full 4-vector of the TCC object





Alternative jet inputs and grooming

W-tagging

[ATL-PHYS-PUB-2017-020]

> Lists of constituent-level pile-up mitigation techniques and grooming algorithms

Input Type	Name	Parameter Values
Uncorrected LC topoclusters	LCTopo	-
Voronoi subtraction with negative suppression	VorSupp	-
Voronoi subtraction with negative spreading	VorSpread	-
Constituent Subtraction	CS	$\Delta R_{\mathrm{max}} = 0.25$
SoftKiller	SK	$\ell = 0.6$
Constituent Subtraction + SoftKiller	CS+SK	$\Delta R_{\mathrm{max}} = 0.25$, $\ell = 0.6$
Voronoi Suppression + SoftKiller	VorSupp+SK	$\ell = 0.6$

Grooming Algorithm	Name	Parameters Tested
Modified Mass Drop	mMDT	$(z_{\mathrm{cut}}, n_{\mathrm{filt}}) \in [0.05, 0.1, 0.15, 0.2] \times [3]$
Soft Drop	SD	$(z_{\mathrm{cut}}, \beta) \in [0.05, 0.1, 0.15, 0.2, 0.25] \times [0, 0.5, 1, 1.5, 2]$
Pruning	Pruned	$(z_{\mathrm{cut}}, R_{\mathrm{cut}}) \in [0.10, 0.15, 0.20] \times [0.12, 0.25, 0.5]$
Trimming	Trimmed	$(f_{\mathrm{cut}}, R_{\mathrm{sub}}) \in [5, 7, 9, 11, 13, 15]\% \times [0.1, 0.2, 0.3]$
Reclustering	RC	$(R_{\mathrm{small}}, f_{\mathrm{cut}}) \in [0.2, 0.3, 0.4] \times [5\%]$

Alternative jet inputs and grooming

W-tagging

[ATL-PHYS-PUB-2017-020]

- Lists of best performing combinations

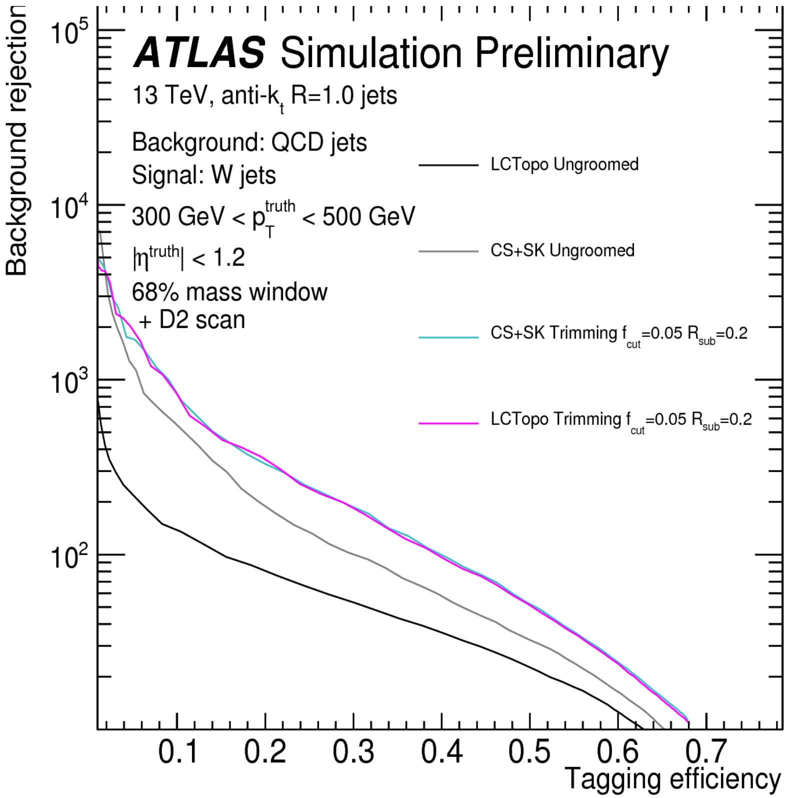
Constituent Type	Grooming Algorithm	Parameter Choice
CS+SK	Soft Drop	$z_{\mathrm{cut}} = 0.1,\ \beta = 0$
CS+SK	Pruning	$z_{\mathrm{cut}} = 0.15,\ R_{\mathrm{cut}} = 0.25$
CS+SK	Trimming	$R_{\mathrm{sub}} = 0.1,\ f_{\mathrm{cut}} = 9\%$
LCTopo	Trimming	$R_{\mathrm{sub}} = 0.2,\ f_{\mathrm{cut}} = 5\%$
EMTopo	Reclustering	$R(small{-}\mathrm{R}) = 0.4,\ f_{\mathrm{cut}} = 5\%$

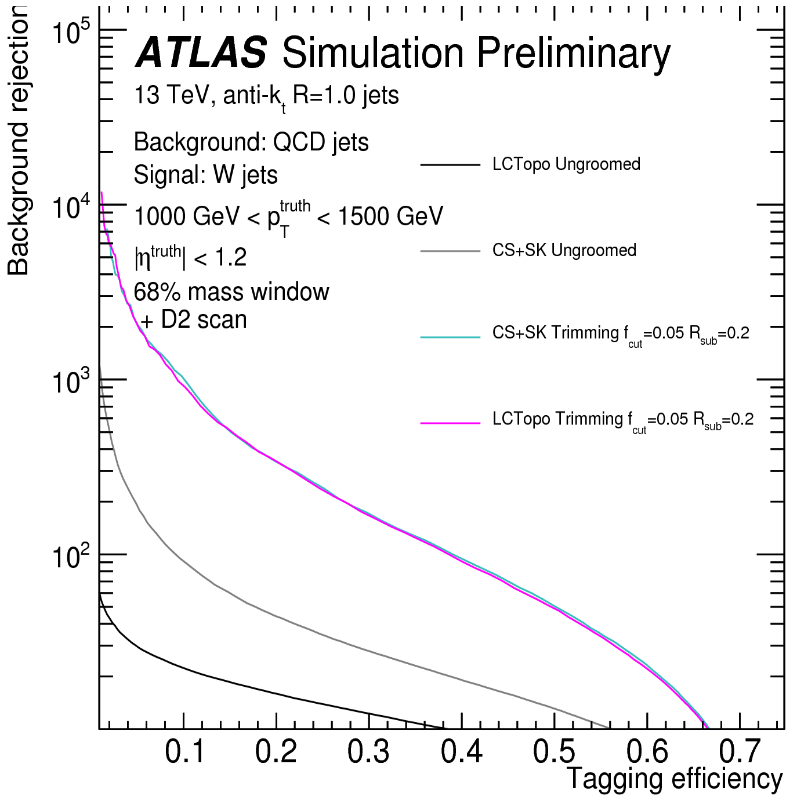
Alternative jet inputs and grooming

W-tagging

[ATL-PHYS-PUB-2017-020]

> ROC curves for $m+D_2$ tagger
> Comparing ungroomed and trimmed jets



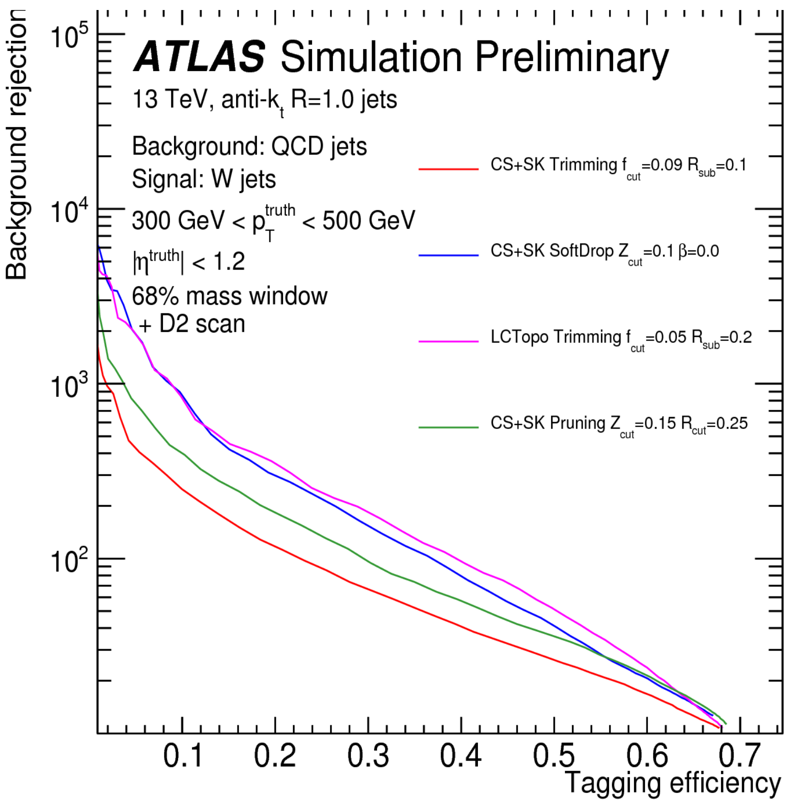


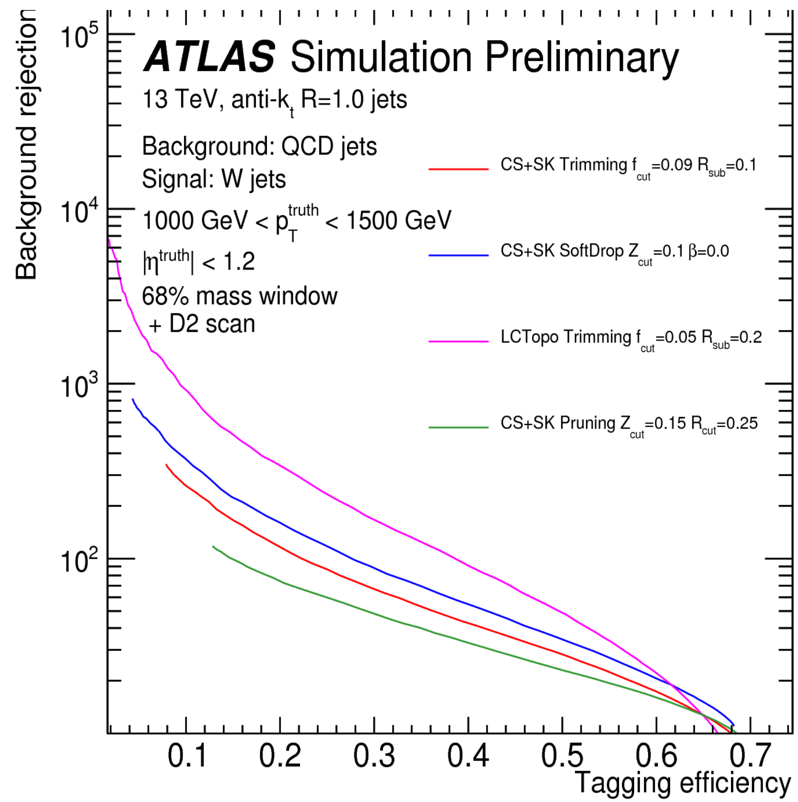
Alternative jet inputs and grooming

W-tagging

[ATL-PHYS-PUB-2017-020]

- ROC curves for m+D_2 tagger
- Comparing trimmed jets with pruned and soft-drop filtered jets
- Too aggressive grooming reduces discrimination power of D_2 variable



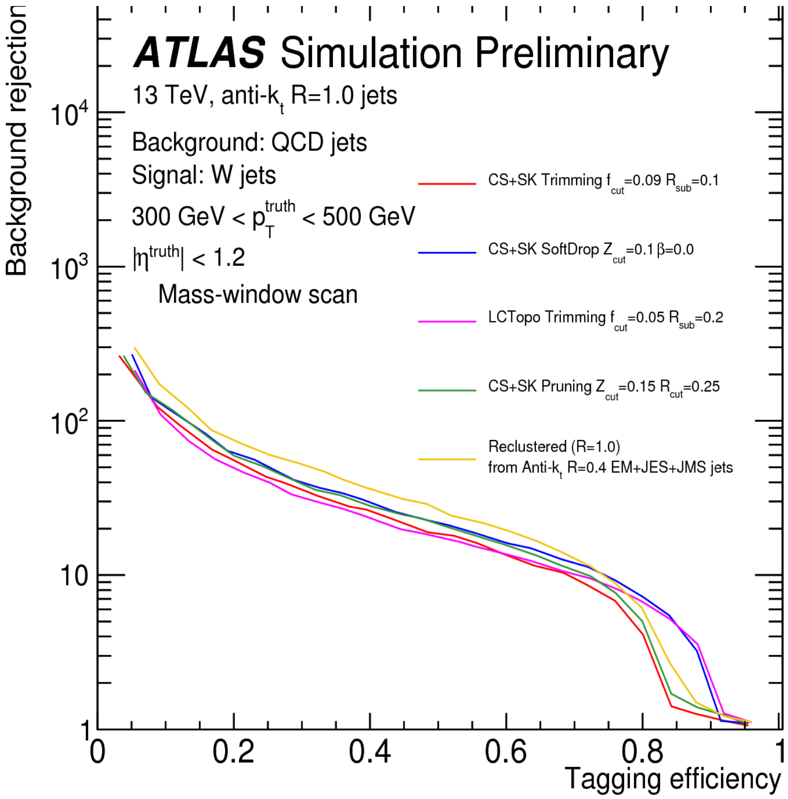


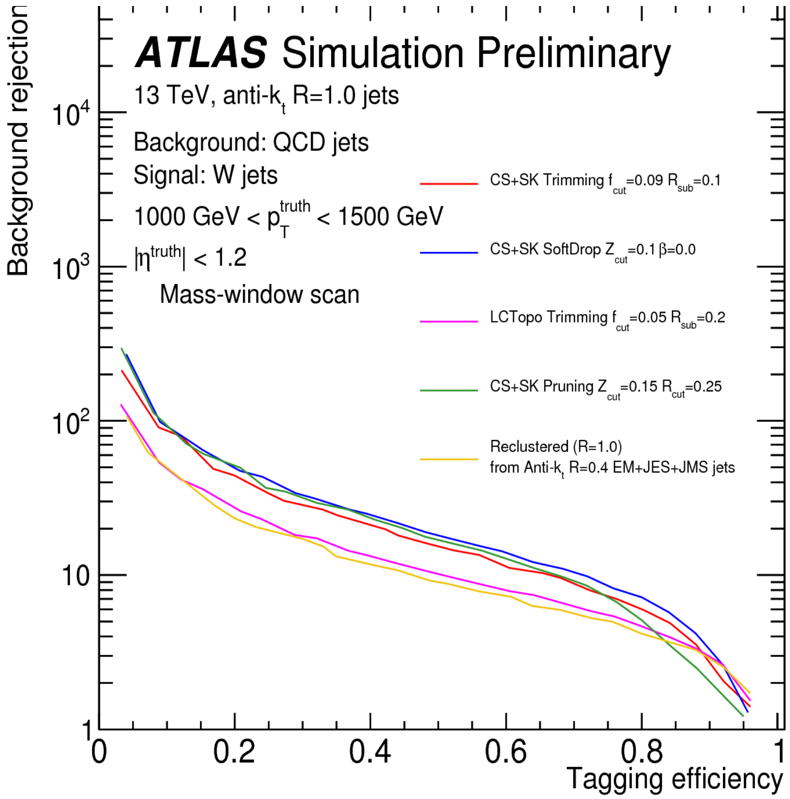
Alternative jet inputs and grooming

W-tagging

[ATL-PHYS-PUB-2017-020]

> ROC curves for mass-window tagger
> Comparing trimmed jets with pruned and soft-drop filtered jets



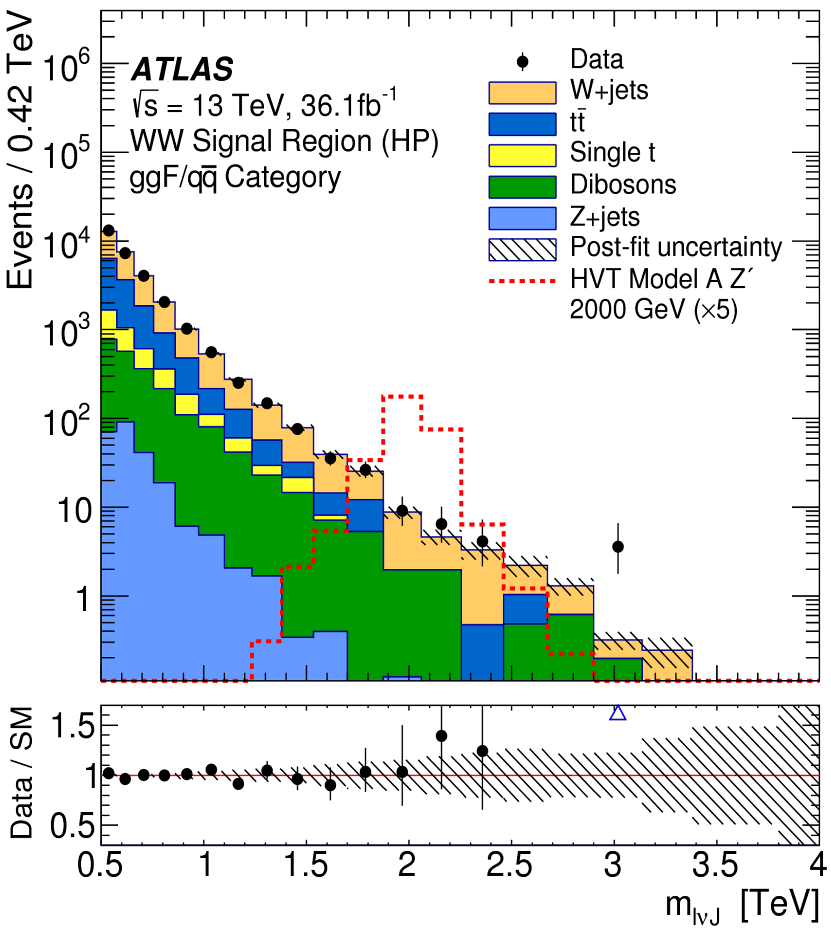


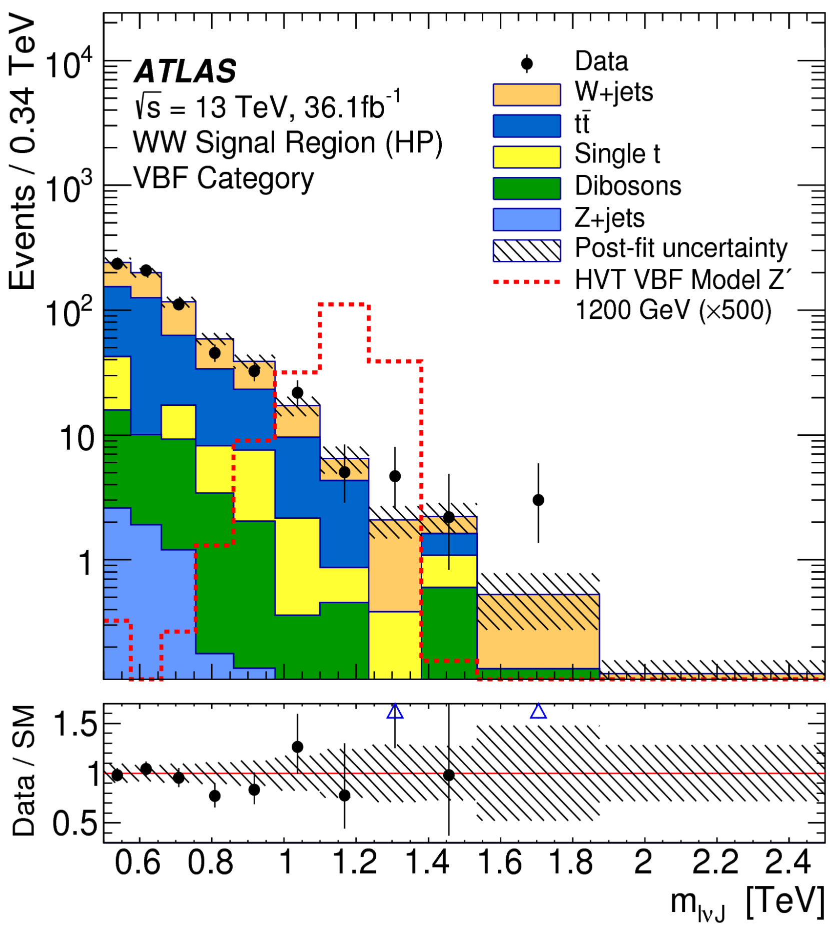
Search for resonances decaying to vector bosons

Single lepton + jets

[JHEP 03 (2018) 042]

- Results using 36.1 fb^{-1} of 13 TeV data
- Post-fit plots for the merged HP region



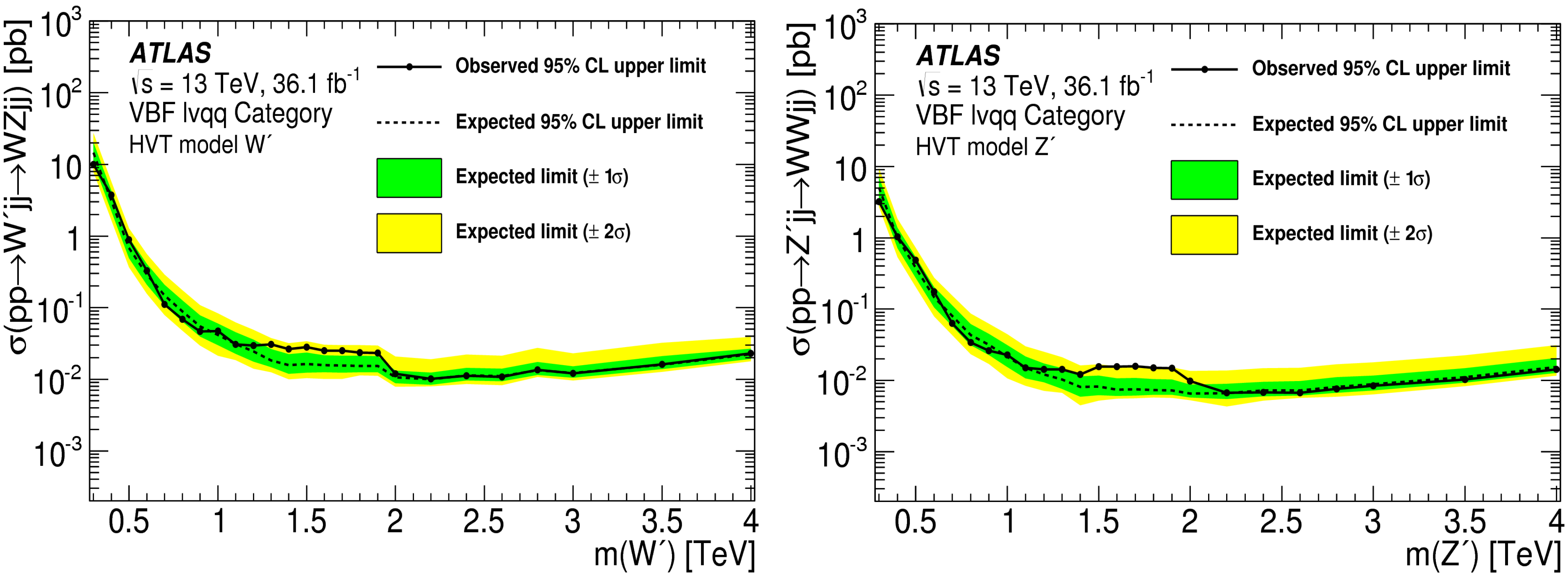


Search for resonances decaying to vector bosons

Single lepton + jets

[JHEP 03 (2018) 042]

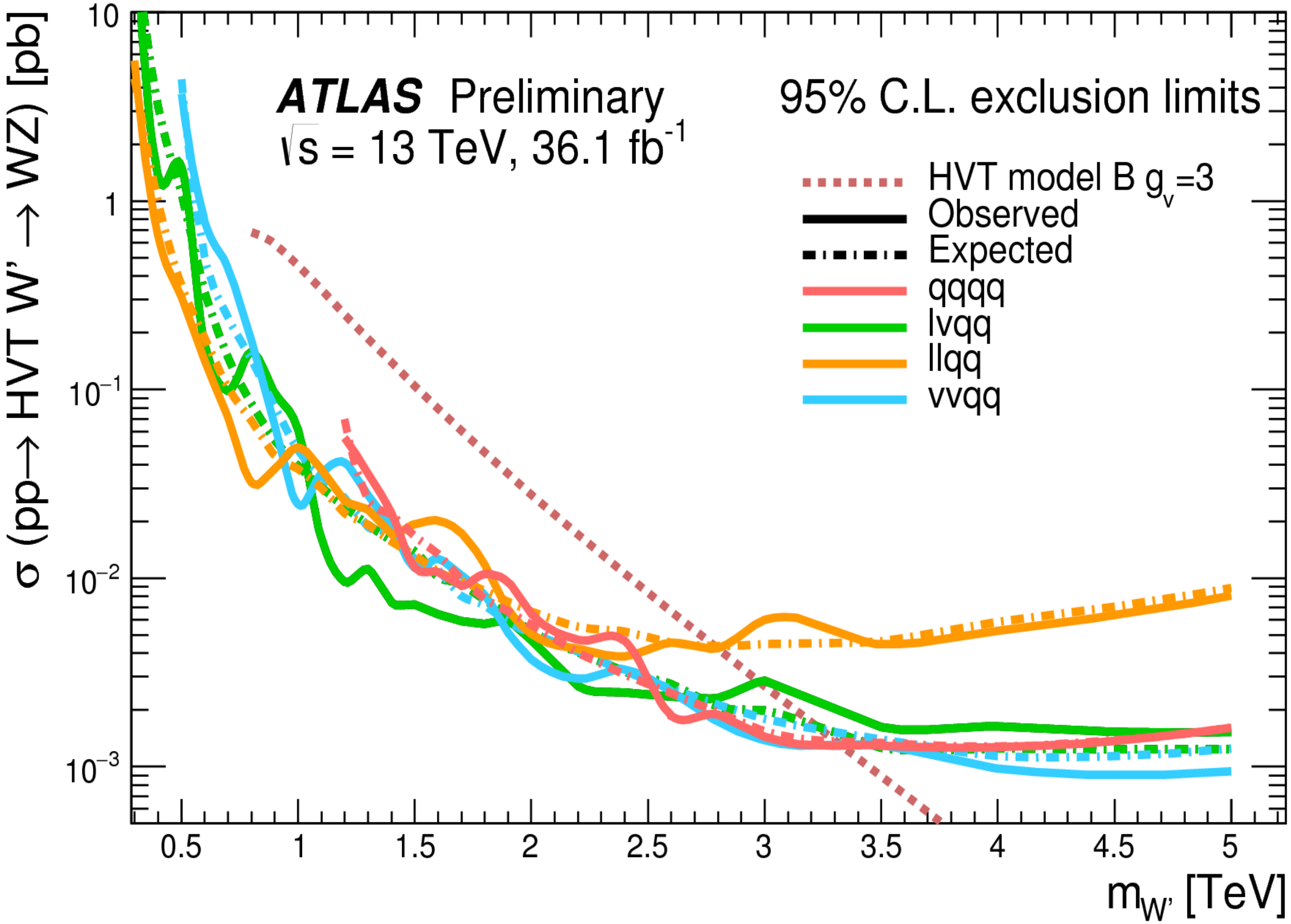
> Results using 36.1 fb-1 of 13 TeV data



Search for resonances decaying to vector bosons

Summary of all channels

> Results using 36.1 fb^{-1} of 13 TeV data



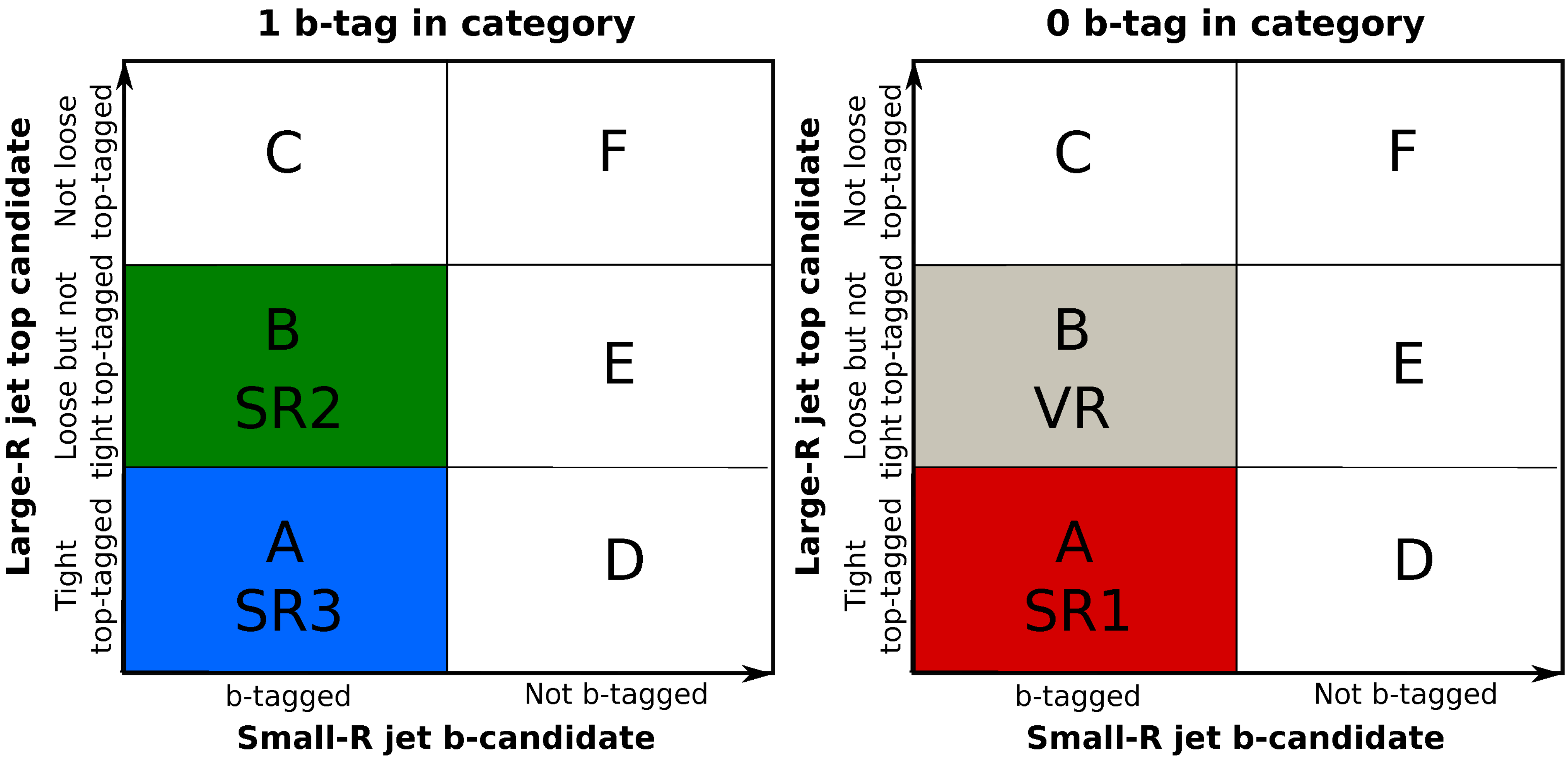
Search for *tb* resonances

Fully hadronic

[Phys. Lett. B 781 (2018) 327]

> Top quark candidate identified using **shower deconstruction**
  – Loose and tight WPs with 50% and 80% efficiency, respectively

> 0- and 1-b-tag event categories depending on whether top candidate has associated b-jet



Search for *tb* resonances

Fully hadronic

[Phys. Lett. B 781 (2018) 327]

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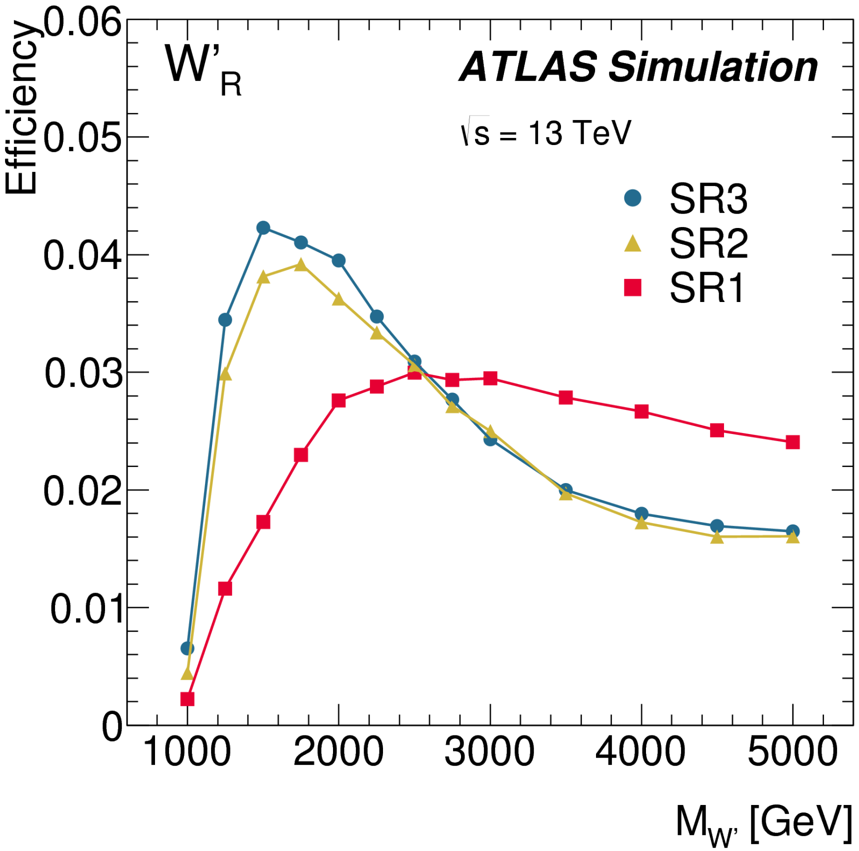
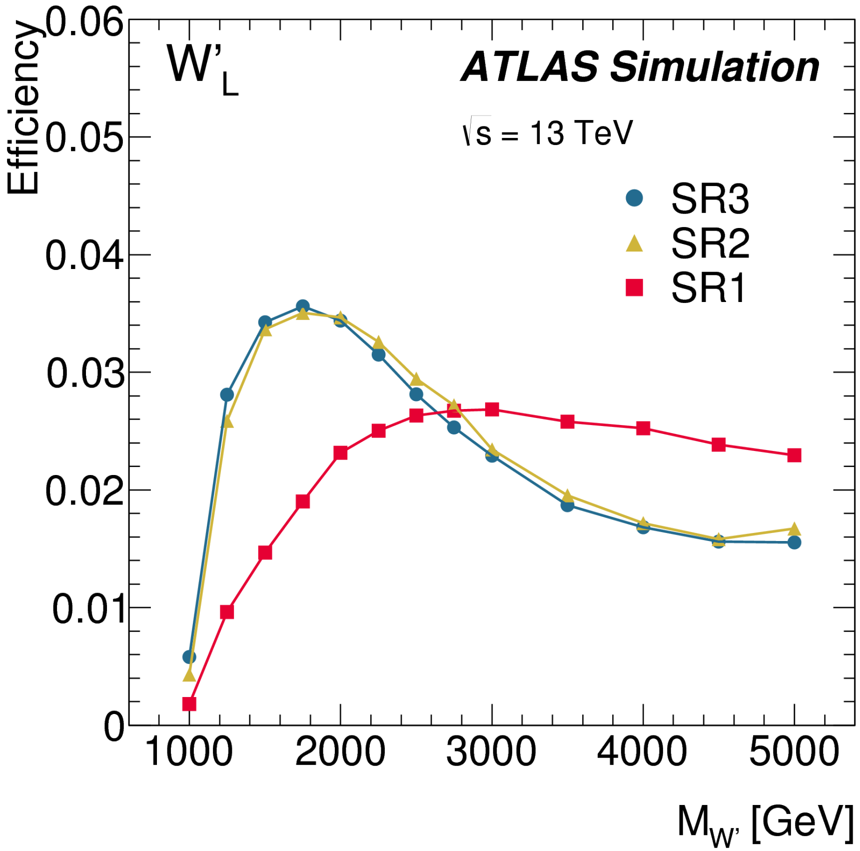
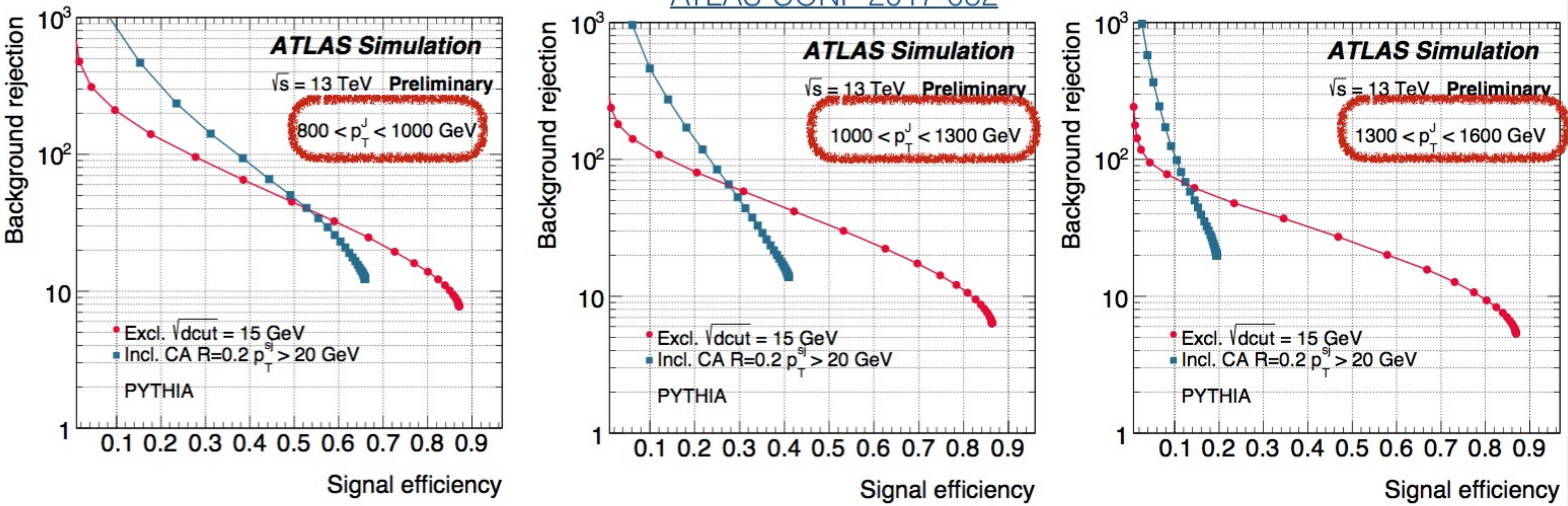




SD Update for high p_T NEW!

- So far used SD with C/A R=0.2 subjets, good proxies for partons with $\Delta R > 0.2$
- SD needs $n_{subjet} \geq 3$ to work (i.e. for three top decay partons)

ATLAS-CONF-2017-082



- New: At large p_T use exclusively k_T* clustered jets
- Provides more $n_{subjet} \geq 3$ large input jets to SD —> Larger efficiency at high p_T.

*Eur. Phys. J. C 72 (2012) 1896

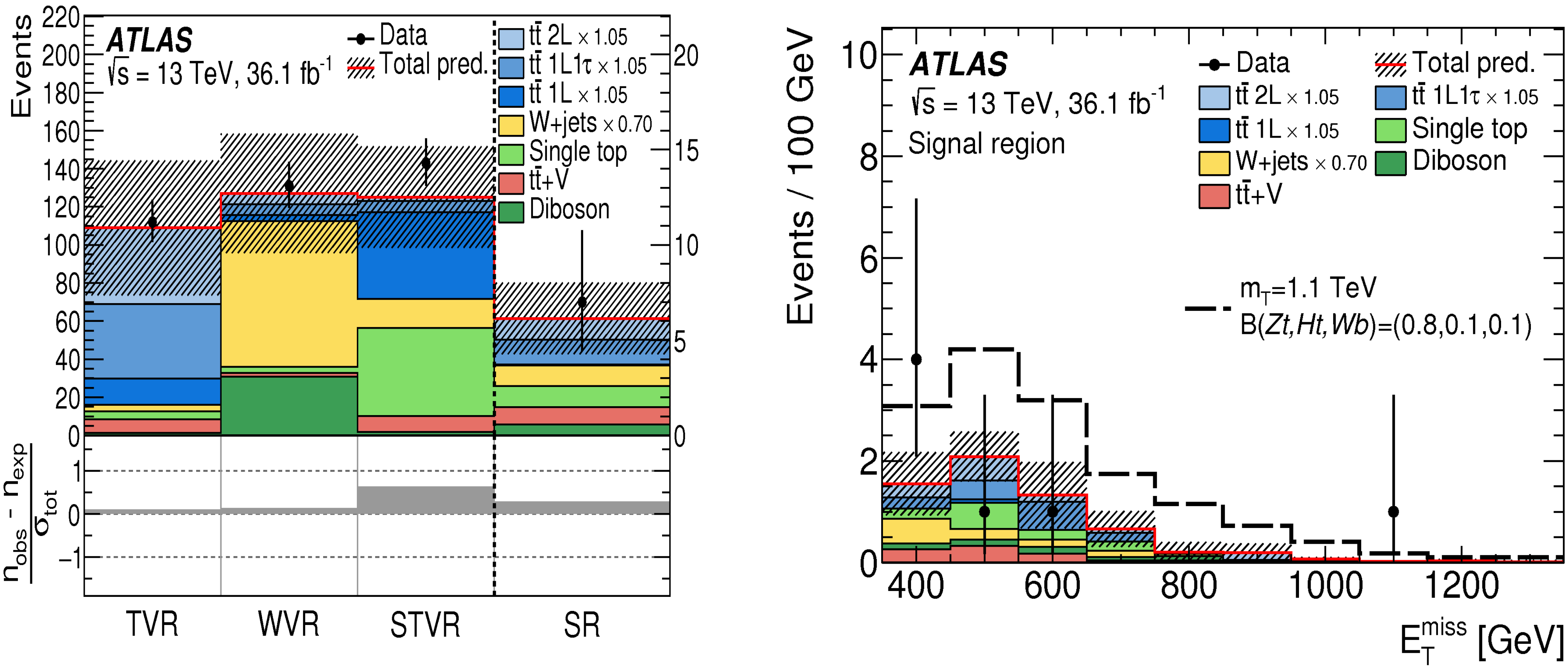
Search for pair production of vector-like T-quarks

Zt+X search

[JHEP 08 (2017) 052]

> Search optimised for TT--> Zt+X with Z-->νν

> Shape fit of MET distribution in signal region

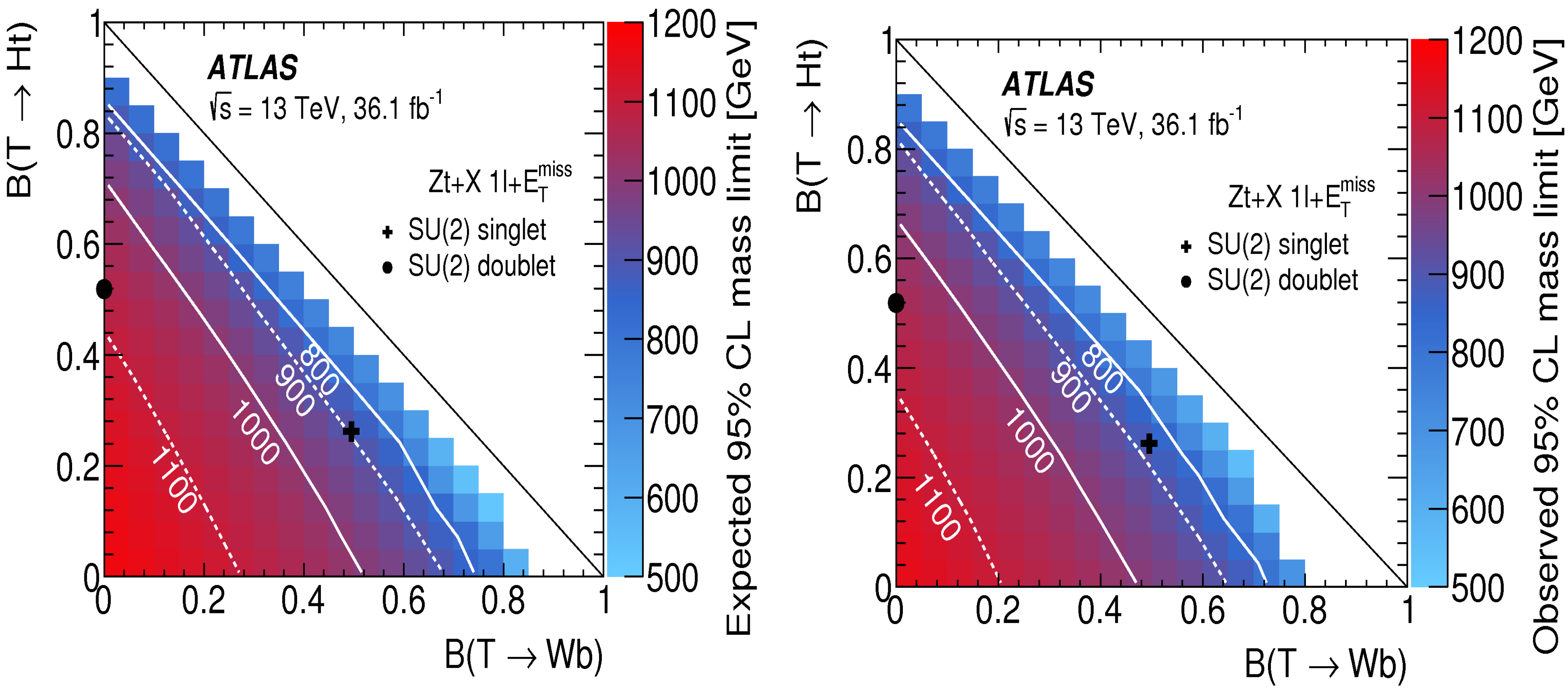


Search for pair production of vector-like T-quarks

Zt+X search

[JHEP 08 (2017) 052]

> Results using 36.1 fb^{-1} of data



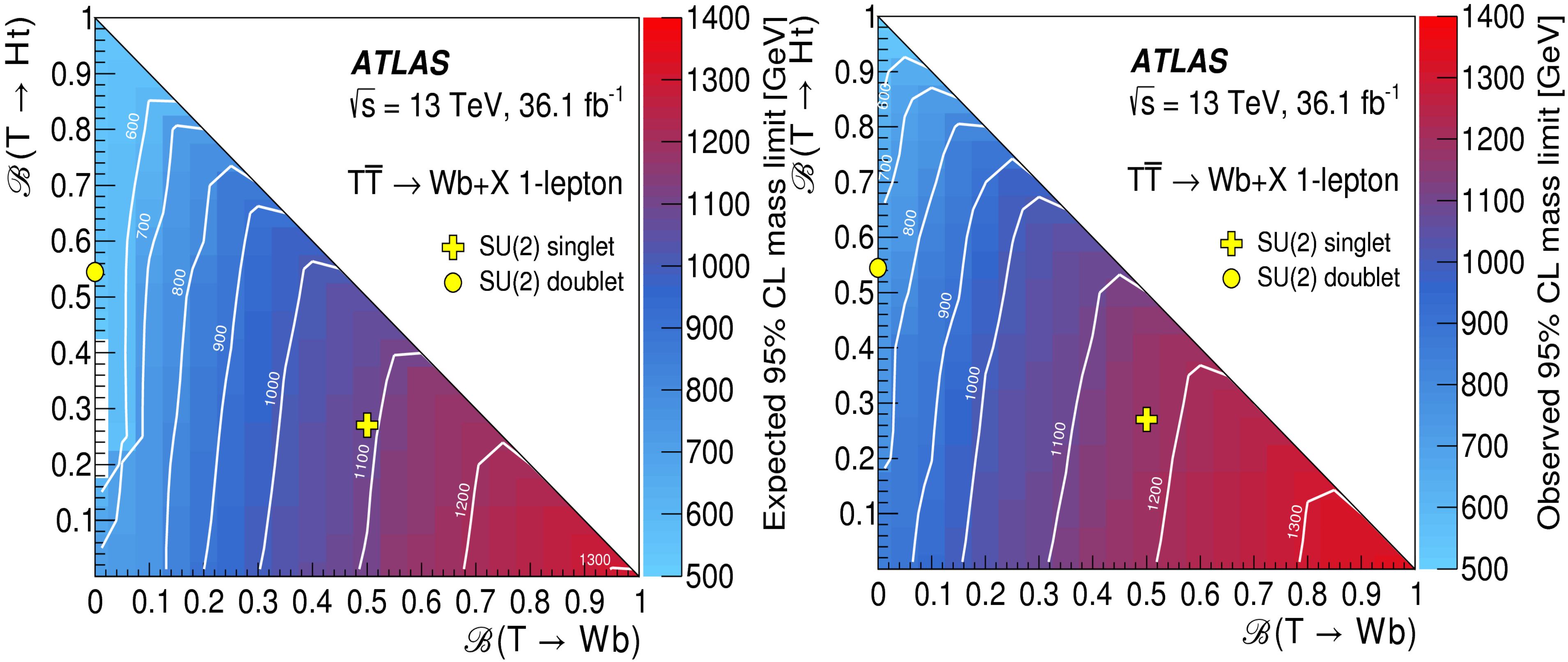
Search for pair production of vector-like T-quarks

Wb+X search

[JHEP 10 (2017) 141]

> Search optimised for TT--> Wb+X with a boosted W-boson decay
  – Some sensitivity to T-->Wt

> Results using 36.1 fb^{-1} of data

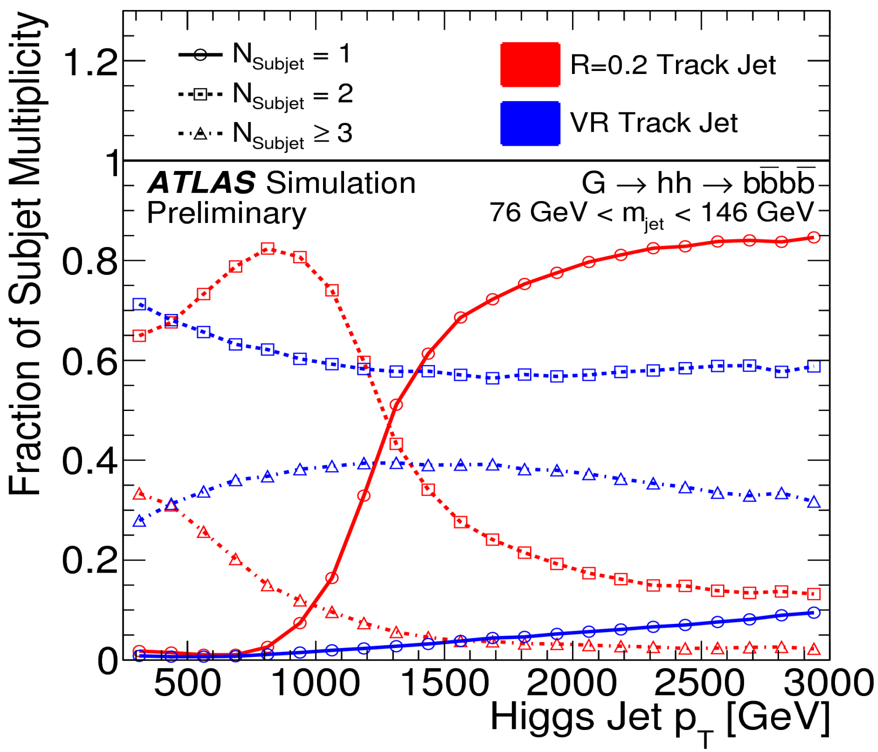


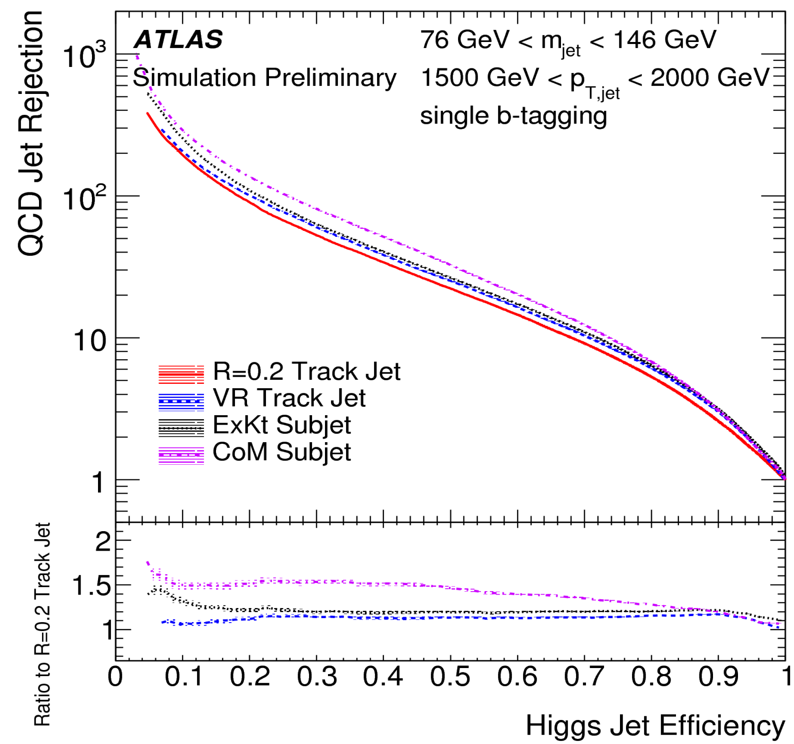
Improvements in h(bb) tagging

Alternative subjets

[ATL-PHYS-PUB-2017-010]

- Current taggers based on anti-k_t R=0.2 track jets limited at high p_T jet due to jet merging
- **Solution**: variable-R jets
  - Effective jet radius shrinks with jet transverse momentum: $R_{eff} \sim 1/p_T$





Improvements in top- and W-tagging

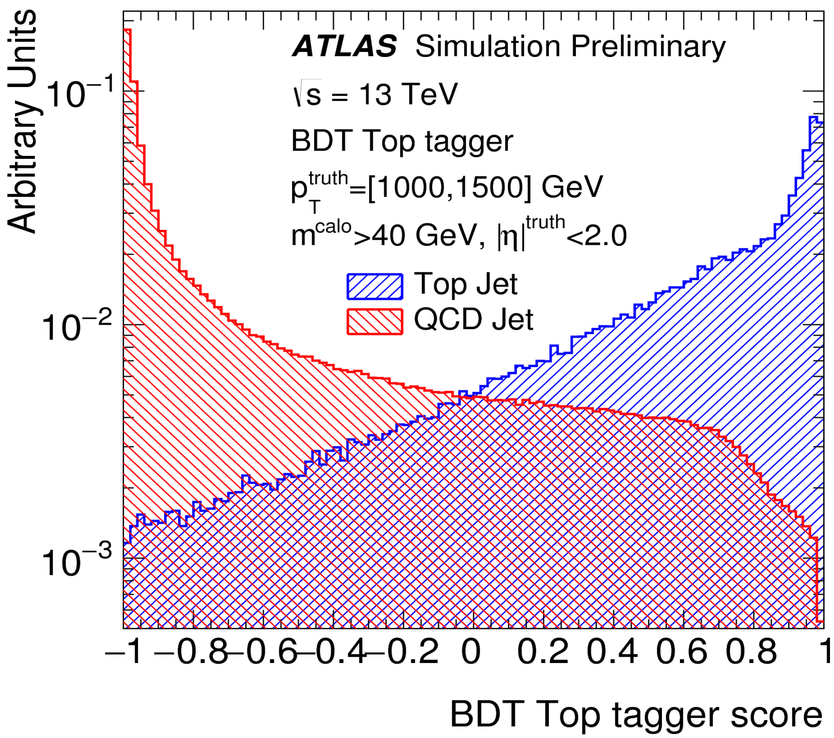
Multivariate methods

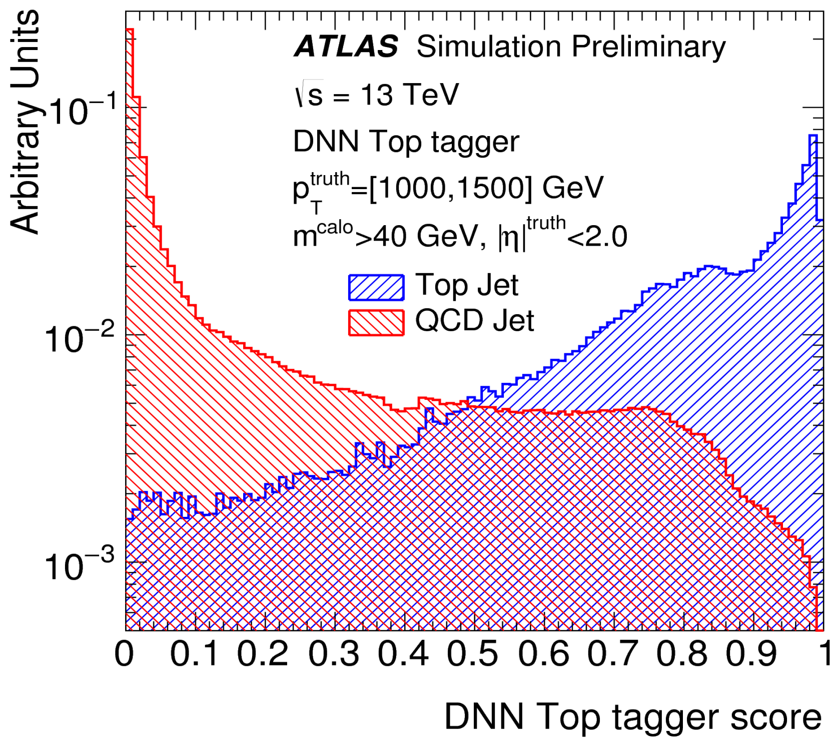
[ATL-PHYS-PUB-2017-004]

> Studied boosted decision trees (BDTs) and deep neural networks (DNN)

> **Input:** various substructure variables (not including m^{jet} or p_T^{jet})

> **Output:** scores between -1 and +1





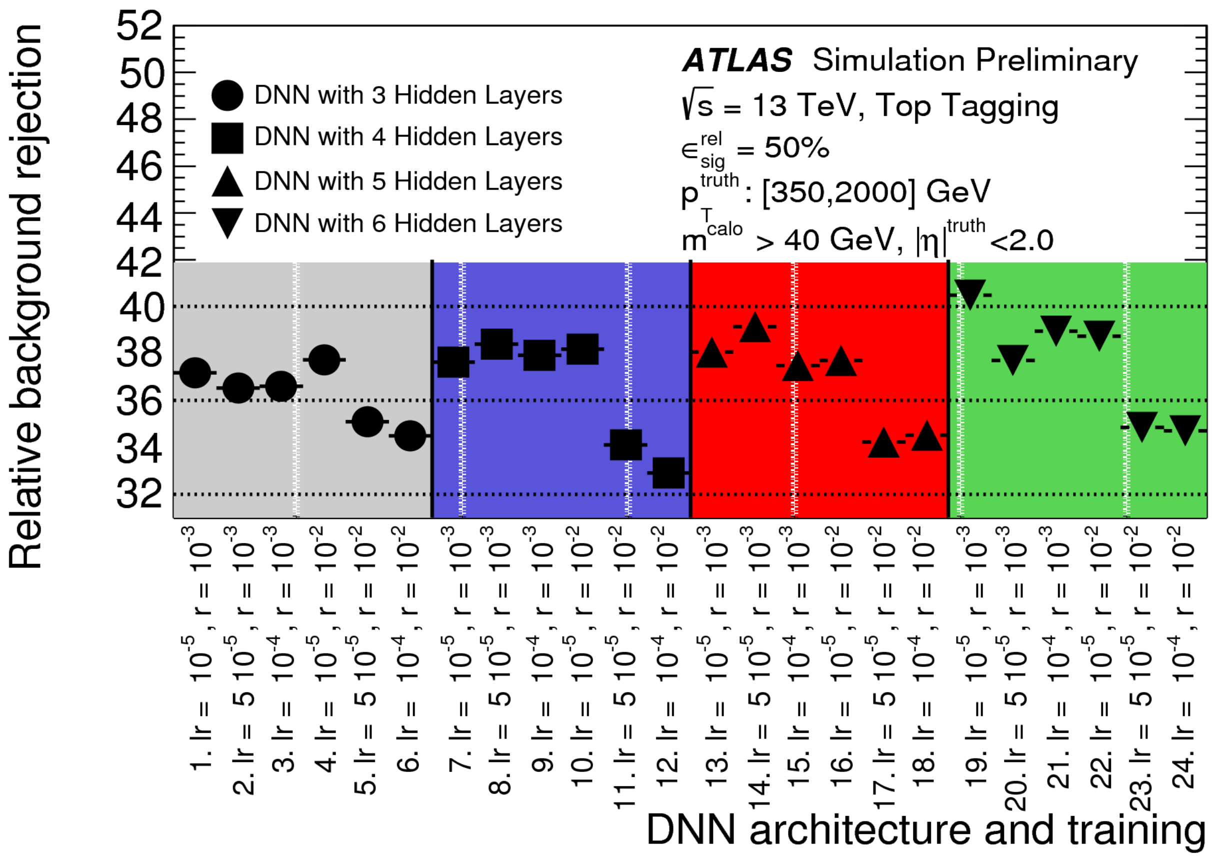
Improvements in top- and W-tagging

Multivariate methods

[ATL-PHYS-PUB-2017-004]

> Studied different DNN architectures

> Compared background rejection at given signal efficiency



Improvements in top- and W-tagging

Multivariate methods

[ATL-PHYS-PUB-2017-004]

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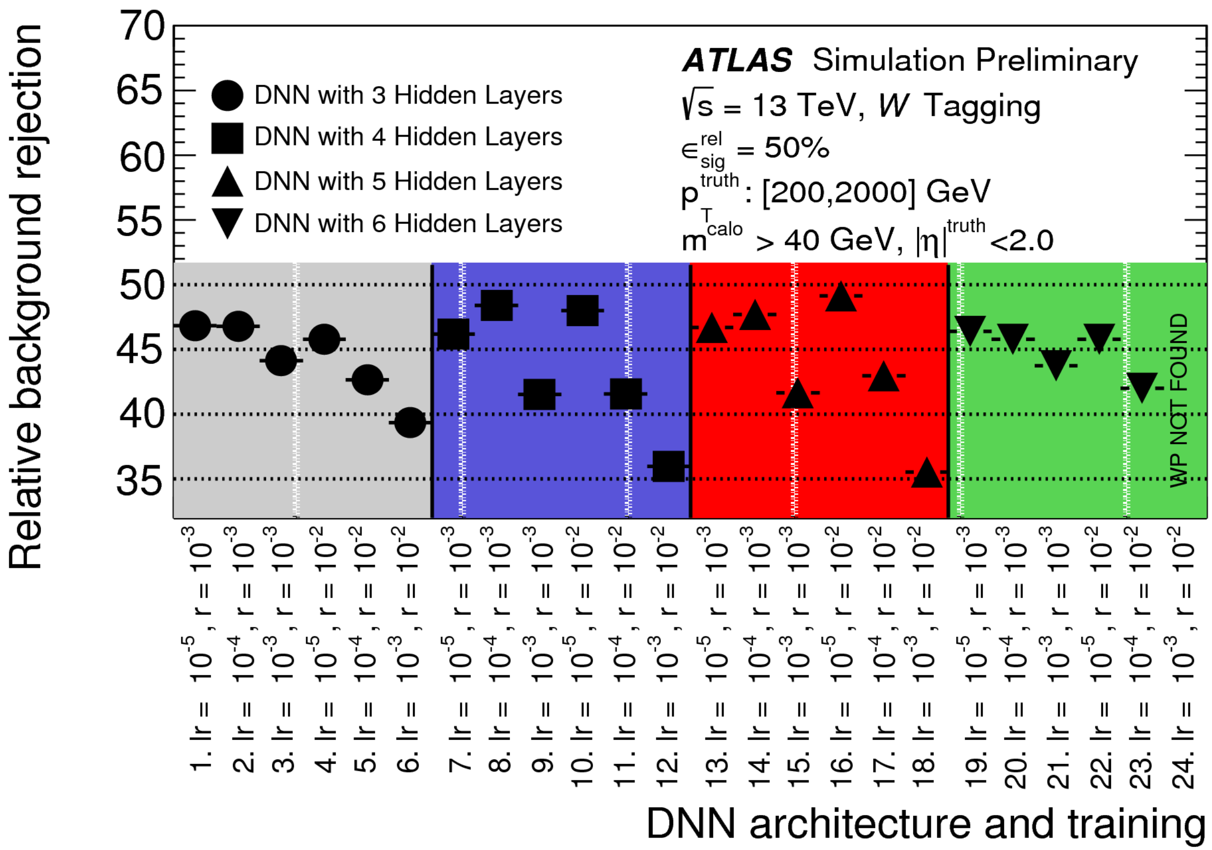

Improvements in top- and W-tagging

Multivariate methods

[ATL-PHYS-PUB-2017-004]

- Studied different DNN architectures
- Compared background rejection at given signal efficiency

	W-Boson Tagging Chosen	Top-Quark Tagging Chosen	Reference
Layer type	Dense	Dense	[24]
Number of hidden layers	5	5	[24]
Activation function	rectified linear unit (relu)	rectified linear unit (relu)	[41]
Learning rate	10^{-5}	5×10^{-5}	[43]
L1 Regularizer	10^{-2}	10^{-3}	[41]
NN weight initialization	Glorot uniform	Glorot uniform	[44]
Batch size	200	200	[41]
Batch normalization	Yes	Yes	[45]
Training groups	Group 5	Group 6	-
Architecture	18, 25, 22, 19, 14, 7, 1	13, 18, 16, 14, 10, 5, 1	-

Table 8: Chosen DNN parameters and architecture for W-boson and top-quark tagging.

Improvements in top- and W-tagging

Multivariate methods

[ATL-PHYS-PUB-2017-004]

>