Boosted W-Boson Identification at $\sqrt{s} = 8$ TeV with the ATLAS Detector

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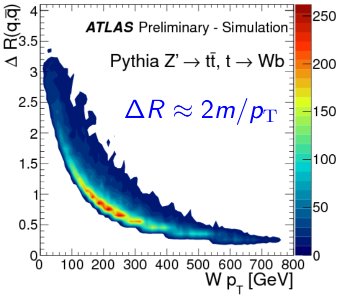
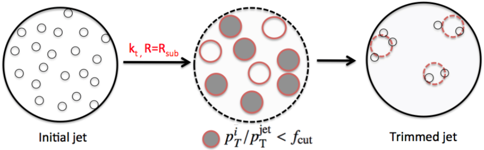
Motivation

- W-bosons produced in Standard Model processes and decay of exotic particles (technicolor, extra dimensions ...)
- Hadronic decay modes have large branching ratio
- At high p_{T}, signal over background ratio generally increases
  $\rightarrow$ the W-boson decay products are boosted
  $\rightarrow$ reconstruction as one single large-radius jet



Need to distinguish between large-R jets from boosted bosons and quarks/gluons

1. **Grooming techniques**
   - Clean the large-R jet from soft gluon radiation and pile-up effects that diminish jet mass resolution
   - Techniques: **trimming**, BDRS (mass-drop/filtering), pruning (see backup)



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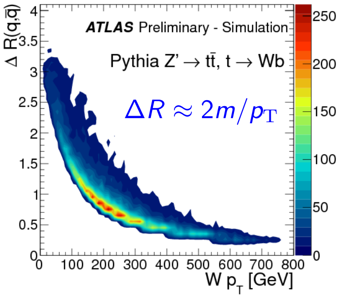

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2. **Substructure information**
   - Use hard substructure of jet (not present in e.g. gluon jet) to improve signal efficiency and background rejection

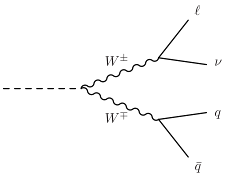
W-tagging Overview

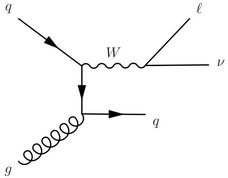
Three different steps are considered to define a W-tagger:

1. Compare jet groomer performance based on the jet mass
2. Use substructure information to increase the background rejection
3. How well are the substructure variables modeled?
   (Using boosted W-bosons from $t\bar{t}$ enriched events)

What do we want to distinguish:

- Signal: KKG $\rightarrow$ W($\ell\nu$)W(qq)
- Background: $W(\ell\nu)$+jets





Jet Selection:

- The leading jet of each considered groomed jet collection is used and has to be matched to the leading C/A R =1.2 truth jet (allows for an unbiased comparison)
- Groomers: Trimmed, BDRS, BDRS-A, C/A-pruned and k_{t}-pruned

Step 1 - Jet Mass

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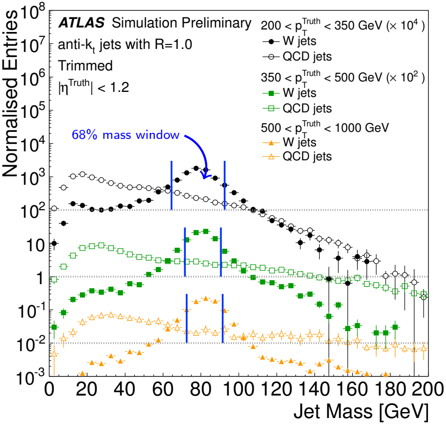
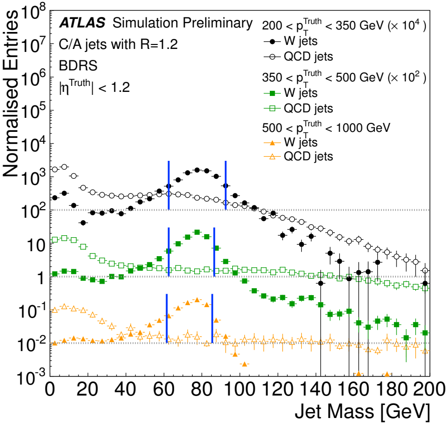
Good groomer requires:

- Most probable value of mass distribution close to m_W
- Minimal background efficiency in window containing 68% of the signal events
- Good signal jet mass resolution

Trimmed



BDRS



Step 2 - Substructure Information

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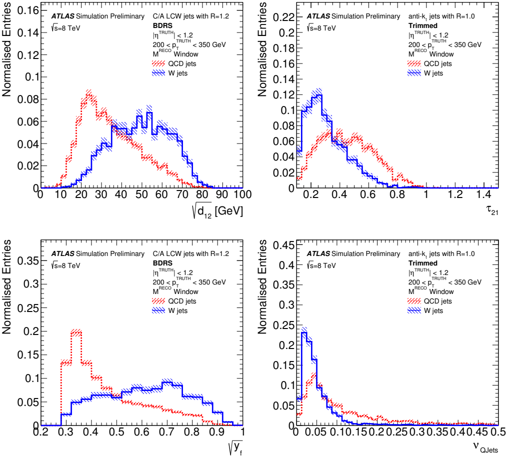
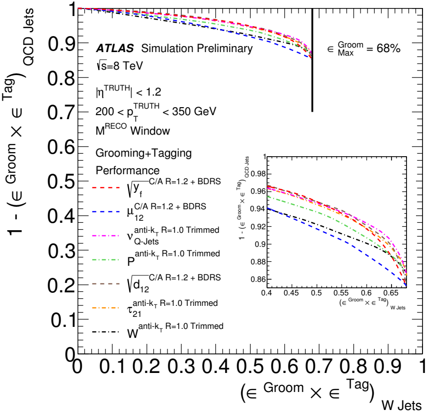
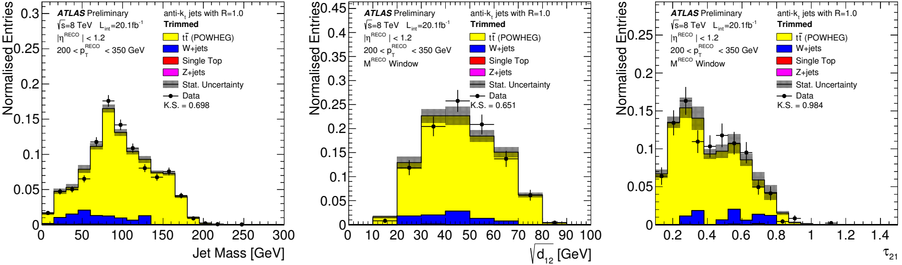
- In addition to mass window use single-sided cut on substructure variable
- ϵ^{Tag}: efficiency of cut on substructure variable
- ϵ^{Groom}: efficiency of mass window cut





Step 3 - Data/MC Comparison

- Good tagger also needs good modeling of substructure variables
- Studies performed using boosted W-bosons from lepton+jets $t\bar{t}$ events



- Good data/MC agreement for studied variables

Summary

- Performance of boosted W-boson identification was studied at $\sqrt{s} = 8$ TeV
- With the Run-II of the LHC at $\sqrt{s} = 13$ TeV, the identification of boosted bosons will become more important
- Focus here on W-bosons, Z-boson tagging similar but using a different mass window criterion $\rightarrow$ will need W/Z discrimination
- Grooming techniques are a powerful tool to discriminate between the hard substructure of a signal jet and a quark/gluon jet
- The background rejection can be increased using further substructure information
- Variables with good MC modeling and large background rejection to be used
- New physics might be just around the corner and could be discovered using these techniques

Backup

References

W-Boson Identification:

- The ATLAS Collaboration *"Performance of Boosted W Boson Identification with the ATLAS Detector"* ATL-PHYS-PUB-2014-004

Substructure performance at 7 TeV:

- The ATLAS Collaboration, *"Performance of jet substructure techniques for large-R jets in proton-proton collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector"* JHEP 09(2013) 076

Jet Grooming in a Nutshell

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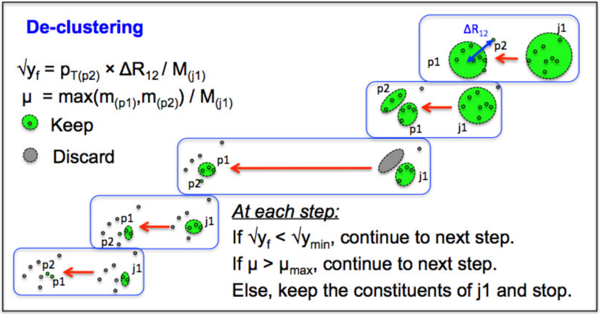
1. **Mass drop/filtering** (http://arxiv.org/abs/0802.2470)
   - Splitting: use substructure of jet: $\sqrt{y_s}$ and mass drop
   - Filtering: remove soft radiation



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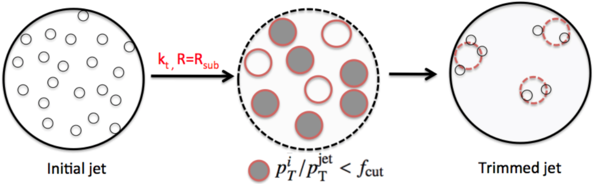

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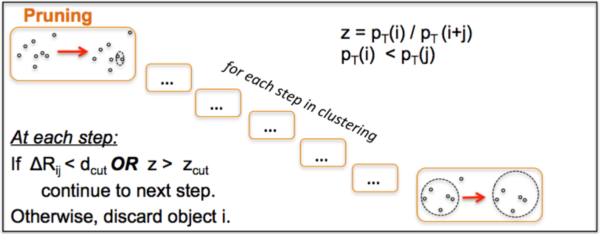
3. **Pruning** http://arxiv.org/abs/0912.0033
   - For each jet in reclustering, remove softer constituent from jet if
     - wide-angled: $\mathrm{R_{12} > R_{cut} \cdot 2m/p_T}$ or
     - soft: $\frac{\min(p_{T,1},p_{T,2})}{p_{T,1}+p_{T,2}} < Z_{cut}$



Event Selection for W-tagging Studies

- KKG $\rightarrow$ W($\ell\nu$)W(qq) vs. $W(\ell\nu)$+jets
- Events need to contain a truth W-boson decaying to $\mu + \nu$
- W-boson defined as the generator-level vector sum of the muon and neutrino
- $|\eta_{\mathrm{W}}| < 2.0$ and $p_{\mathrm{T}} > 160$ GeV
- One reconstructed muon
- $E_{\mathrm{T,miss}} > 20$ GeV
- C/A R $=$ 1.0 truth jet with $p_{\mathrm{T}} > 100$ GeV, $|\eta| < 2.0$
- For each groomer, the leading calorimeter jet must be within $0.75 \cdot R$ of the leading C/A R $=$ 1.2 truth jet

Definition of Substructure Variables

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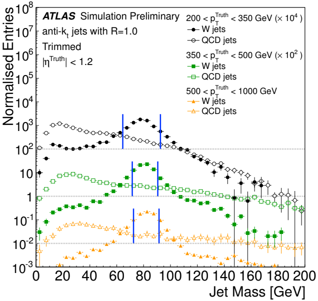
- **Splitting scale** Phys. Rev. D65 (2002) 096014
  - k_t distance between the two proto-jets of the final clustering step:
  $$\sqrt{d_{12}} = \min(p_{\mathrm{T}1}, p_{\mathrm{T}2}) \times \Delta R_{12}$$
  - Hardest proto-jets are combined in last step of reclustering for k_t algorithm
  - Symmetric energy distribution for W-jets, asymmetric for QCD jets

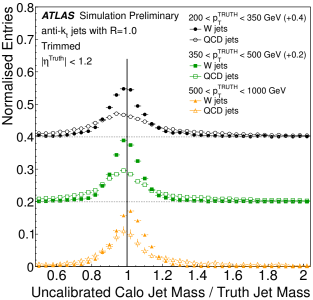
- **Momentum balance** Phys. Rev. Lett. 100 (2008) 24200
  $$\sqrt{y_f} = \frac{\min(p_{\mathrm{T}1}, p_{\mathrm{T}2})}{m_{12}} \times \Delta R_{12}$$

- **N-subjettiness** JHEP 03 (2011) 015
  - Describes how likely it is that a jet is composed out of N subjets:
  $$\tau_N = \frac{\sum_k p_{\mathrm{T,k}}(\min(\Delta R_{1,k}, R_{2,k}, \ldots, R_{N,k}))^\beta}{\sum_k p_\mathrm{T}(R_0)^\beta}$$
  - Powerful discrimination using the ratio: τ_2/τ_1

- **Q-jets mass volatility** Phys.Rev.Lett. 108 (2012) 182003
  - Q-jets technique reclusters the jet many times with a degree of randomness.
  - Jet observables have a distribution for a given jet
  - W-jets: mass persists during re-clustering
  - QCD-jet mass fluctuates
  $$\nu_\mathrm{QJets} = \frac{\sqrt{<m^2> - <m>^2}}{<m>}$$

Jet Mass Distribution and Mass Responses - I





Jet Mass Distribution and Mass Responses - II

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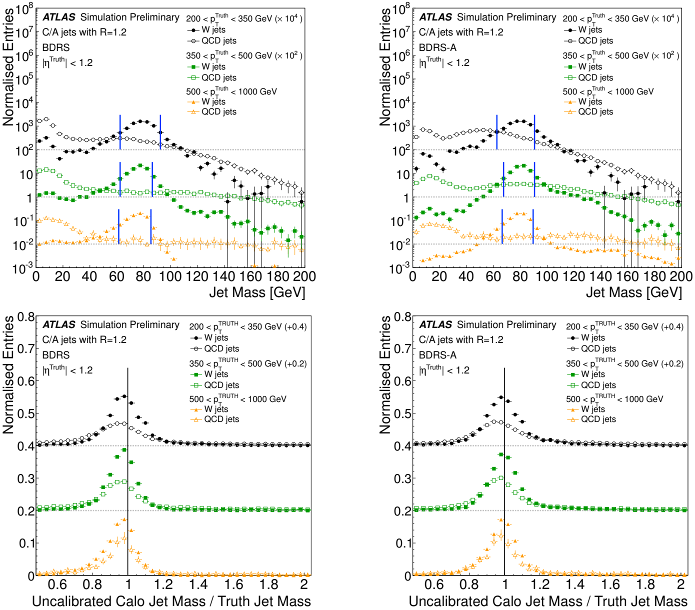
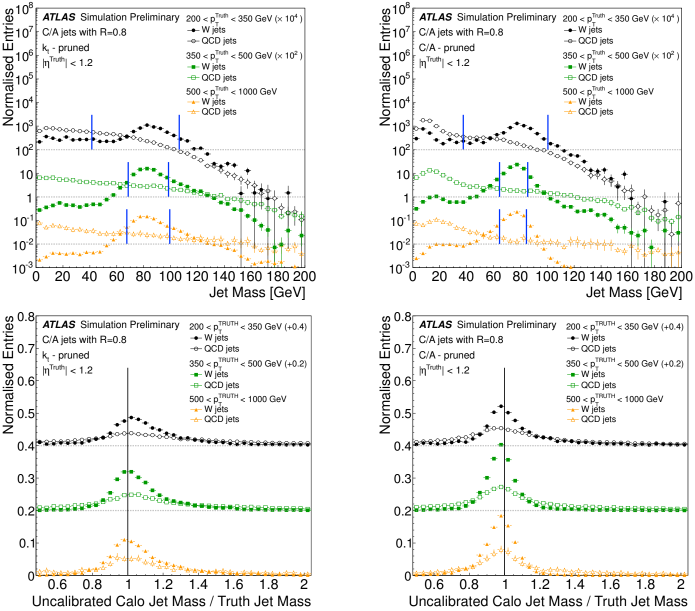
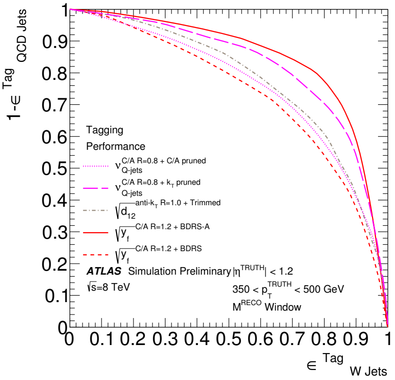


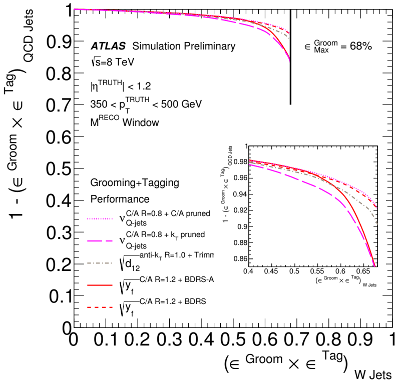
Jet Mass Distribution and Mass Responses - III



Signal Efficiency vs. Background Rejection

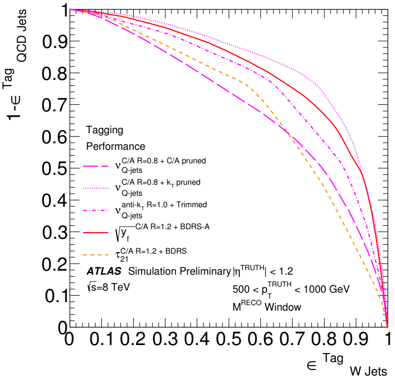
- $350 < p_{\mathrm{T}}^{\mathrm{C/A\ R=1.2\ truth}} < 500$ GeV

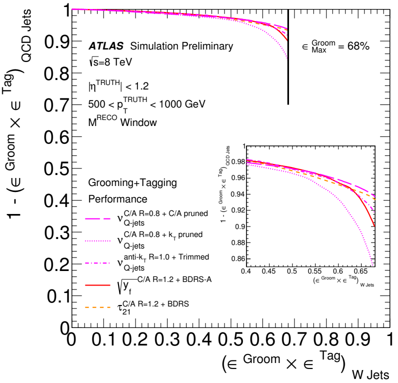




Signal Efficiency vs. Background Rejection

- $500 < p_T^{\mathrm{C/A\ R=1.2\ truth}} < 1000$ GeV





Event Selection for Data/MC Studies

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- W-boson taken from enriched $t\bar{t}$ events with $t\bar{t} \rightarrow W(\rightarrow \mu\nu)W(\rightarrow qq)b\bar{b}$
- HEPTopTagger algorithm is used to find hadronically-decaying W-bosons
- Single muon trigger , muon in event is required to be isolated
- $E_{\mathrm{T,miss}} > 20$ GeV and $E_{\mathrm{T,miss}} + m_{\mathrm{W,T}} > 60$ GeV

HEPTopTagger:

- C/A R = 1.5 jets are decomposed into substructure objects using the iterative mass-drop procedure until $m_{\mathrm{subjet}} < 50$ GeV
- Filter jet using $R_{\mathrm{sub}} = 0.3$ and the five hardest subjets are kept
- Constituents of five hardest subjets are clustered with the C/A algorithm into three substructure objects.
- Compability of substructure objects with top quark decay topology is tested
- Invariant mass of one pair of substructure to be within 15% of W mass

References for HEPTopTagger

- T. Plehn, G. P. Salam, and M. Spannowsky, *Fat Jets for a Light Higgs*, Phys. Rev. Lett. 104 (2010) 111801
- T. Plehn et al., *Stop Reconstruction with Tagged Tops*, JHEP 10 (2010) 078

HEPTopTagger

JHEP09 (2013) 076