Telescoping Jet Substructure

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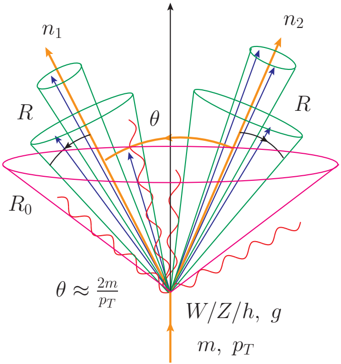
Outline

- Telescoping jets (T-jets)
- Telescoping X ($X =$ *essentially everything*)
- Preliminary results for W tagging
- Conclusions

Telescoping jets v1.0

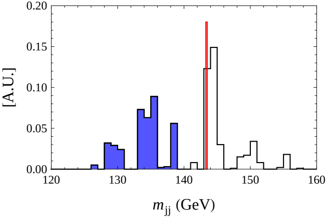
- Probe hadronic final states around dominant energy flows (axes $n_i's$) with multiple angular scales (radii R)
- Define exclusively the set of particles to evaluate the observables of interest, e.g. mass $m(R)$
- The dependence of the value of the observable on the particle sets can be measured by the volatility of the observable $\mathcal{V} = \Gamma/\langle m \rangle$
- Can be combined with cut-and-count, extended maximum likelihood fit and multivariate analysis. Significantly decreases background fluctuations and improves $S/\delta B$

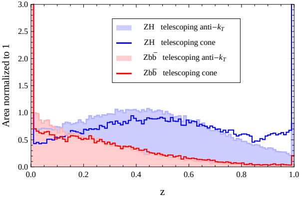


Zh with $h \to b\bar{b}$ (cut-and-count, Chien)

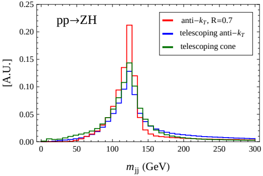
Moderately boosted higgs

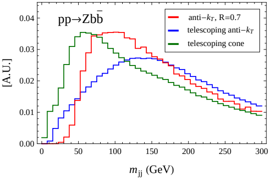
- $p_T^Z > 120\ GeV$
- $110\ GeV < m_{jj} < 140\ GeV$
- N R's with $R_{min} < R < R_{max}$





- Merged mass distributions



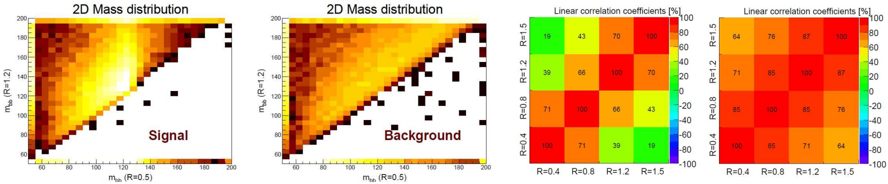


- Significance improvements

R range	N	algorithm	weight	$S/\delta B \uparrow$
0.4 and 1.0	2	cone	z	14%
0.4 to 1.0	7	cone	z	20%
0.4 to 1.5	12	cone	z	26%
0.2 to 1.5	100	anti-k_T	z	20%
0.2 to 1.5	100	cone	z	**28**%
0.4 to 1.5	12	cone	ρ_S/ρ_B	38%
0.2 to 1.5	100	cone	ρ_S/ρ_B	**46**%

Zh with $h \to b\bar{b}$ (EML and MVA, Chien et al)

- Explore the 2-D distributions of and the correlations between $m(R_i)$ and $m(R_j)$
- Extra information beyond the set of kinematics observables in a previous MVA study



Improvement (over R=0.5 only)	$p_T^Z < 120\ GeV$ xs-based	$p_T^Z < 120\ GeV$ EML	$p_T^Z > 120\ GeV$ xs-based	$p_T^Z > 120\ GeV$ EML
1 R, fraction in window	0.83	0.74	0.80	0.71
12 R's, fraction in window	0.98	0.97	0.92	0.88
1 R, $m_{b\bar{b}}$	1.00	1.00	1.00	1.00
5 R's, $m_{b\bar{b}}$ merged	0.94	1.08	0.94	1.06
4 R's, 3 bins	0.99	1.00	1.16	1.20
2 R's, full	1.10	1.14	1.35	1.38
2 R's, BDT	1.04	1.08	1.30	1.34
12 R's, BDT	1.19	1.30	1.52	1.41
12 kinematic	1.33	1.50	1.35	1.29
12 kinematic + 12 R's	1.39	1.68	1.67	1.55

T-jets generalized

It is important to realize that R is just an artificial *parameter* in *observable* definitions

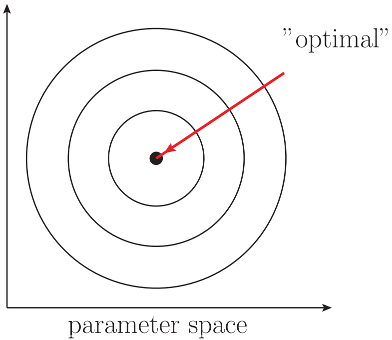
- Different parameters correspond to different observables (however within the same class) probing different regions of phase space
- Since observables are probing phase spaces, the parameters associated with the observable definitions are either constraining *energy* or *angle* in some way
- Energy and angle are correlated

More generally, all analysis procedures and operations have artificial parameters

- jet grooming, cuts, taggers, ...

Conventionally, we tend to optimize an analysis or find the best discriminating observable by coming up with a single choice of parameter sets

- Let's telescope around it

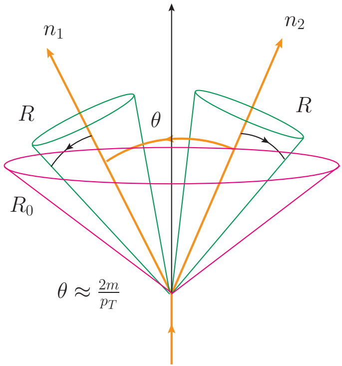


Telescoping X

- T-pruning
  - `pruner(jet algorithm, zcut, Rcut factor)`
  - soft and wide angle radiation is pruned away
- T-trimming
  - `trimmer(Rfilt, SelectPtFractionMin(fcut))`
  - soft subjets are trimmed away
- T-reclustering
  - `jet def(jet algorithm, Rsub)`
  - leading subjets of size `Rsub` are kept
- T-subjet
  - `Tsubjet(axes, Rsub)`
  - radiation within `Rsub` around `axes` are kept
- T-subjettiness
  - `nSub(onepass kt axes, para(beta,1.0,1.0))`
  - `beta` is the angular weighting

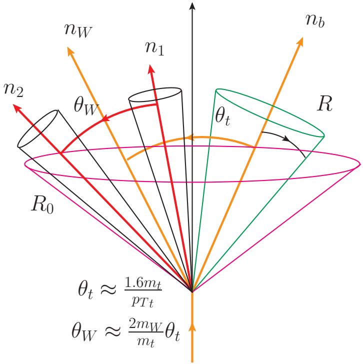
Boosted W/Z/h tagging

- There are at least three relevant angular scales to think about
- Boson masses m set the intrinsic angular scale $\theta \approx 2m/p_T$ resulting in the 2-pronged structure
- Cluster particles with $R_0 > \theta$ large enough to capture most of the boson decay products but small enough to avoid contamination
    - R_0 fixed or variable-R_0
- To resolve the 2-pronged structure, the angular resolution R should satisfy $\theta > R$
- In highly boosted regimes, detector resolutions will come into play



Boosted top tagging

- There are at least four relevant angular scales to think about
- The top mass sets the first intrinsic angular scale θ_t in top decay
  - W is massive
- The W mass sets the second intrinsic angular scale θ_W in the subsequent W decay
  - Accidentally, $\theta_t \approx \theta_W$, resulting in the generic 3-pronged structure
- Again, $R_0 > \theta_t \approx \theta_W > R$

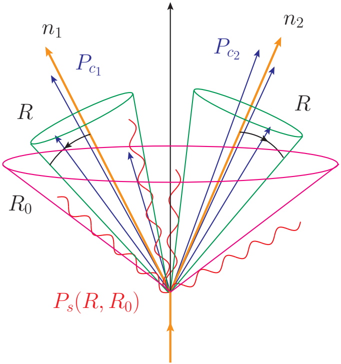


Volatility of T-jet masses

- Use volatility as a simple evaluation of the performance of T-jets
- Let's analyze a closely related observable $\Delta m^2 = m^2(R_1) - m^2(R_2)$

  $m^2(R) = 2P_{c_1} \cdot P_{c_2} + P_{c_1}^2 + P_{c_1}^2 + 2P_c \cdot P_s(R)$

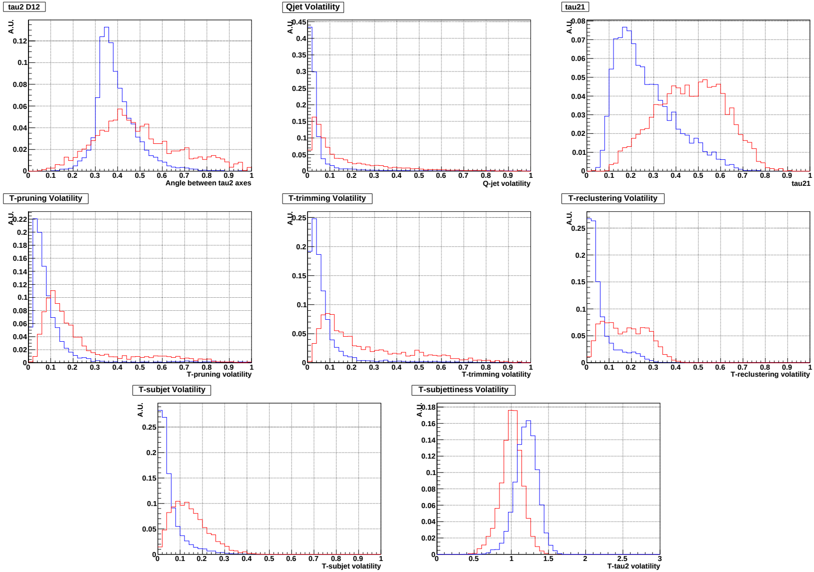
  - So $\Delta m^2 = 2P_c \cdot P_s(R_1, R_2)$
- Volatility probes the soft radiation around subjets and should be directly sensitive to subjet flavors and color connections



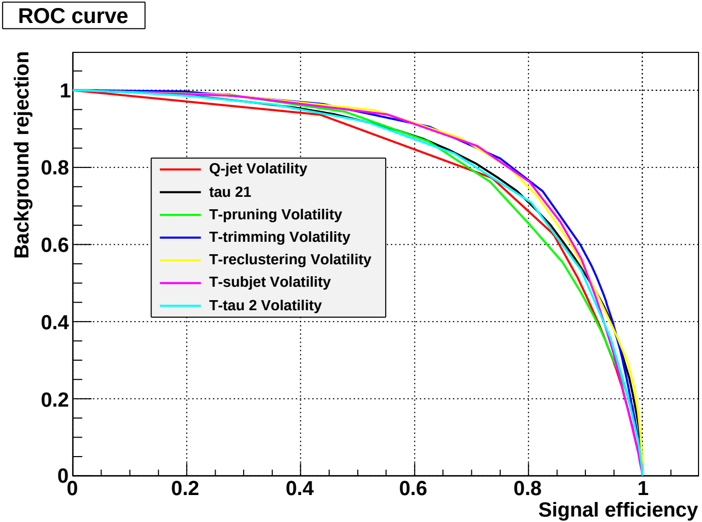
Telescoping X setup

- Samples
  - W: 1 and 2 TeV $W' \to WZ$, anti-k_T $R_0 = 1.0$
  - t: 1 and 2 TeV $Z' \to t\,\bar{t}$, anti-k_T $R_0 = 1.0$
  - 300 GeV $< p_T < 500$ GeV and 800 GeV $< p_T < 1000$ GeV, $|\eta| < 1.2$
  - For W, 70 GeV $< m_{trim} < 90$ GeV with `Rfilt = 0.3` and `fcut = 0.05`
- T- specifics
  - 20 values in the parameter ranges below
  - T-pruning
    - `zcut = 0.1, 0.1 < Rcut factor < 2.0 (2m/pt)`
  - T-trimming
    - `Rfilt = 0.1 or 0.2, 0.0 < fcut < 0.1`
  - T-reclustering
    - `anti-kt, 0.05 or 0.1 < Rsub < 0.6`
  - T-subjet
    - `tau2 axes, 0.05 or 0.1 < Rsub < 0.6`
  - T-subjettiness
    - `onepass kt axes, 1.0 < beta < 3.0`

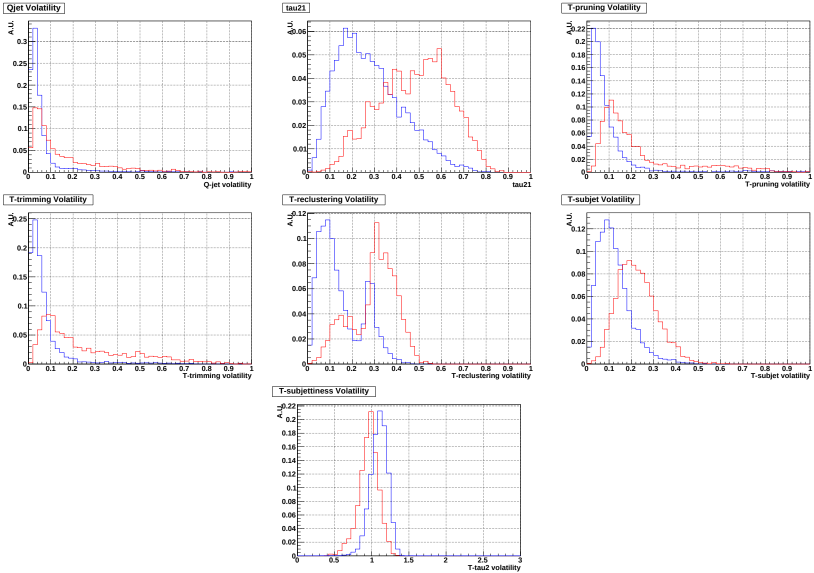
300 GeV $< p_T <$ 500 GeV, truth particles



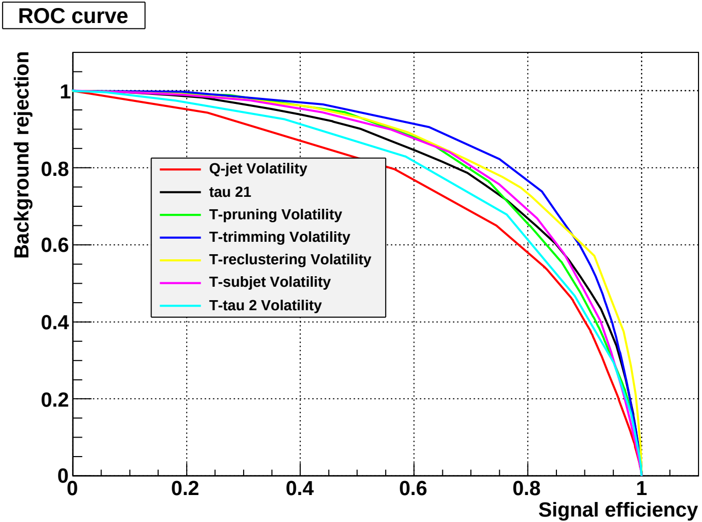
$300\ \text{GeV} < p_T < 500\ \text{GeV}$, truth particles, ROC curves



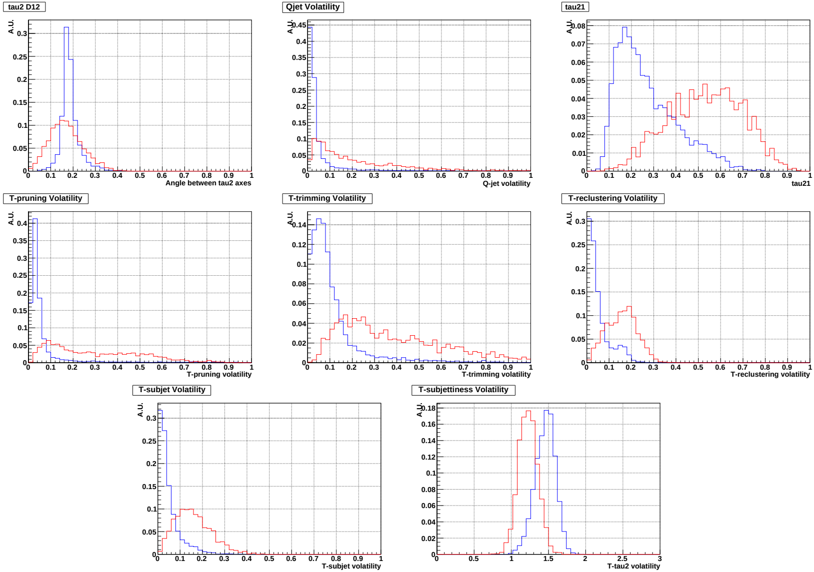
$300\ \text{GeV} < p_T < 500\ \text{GeV}$, pseudo calorimeter cell particles



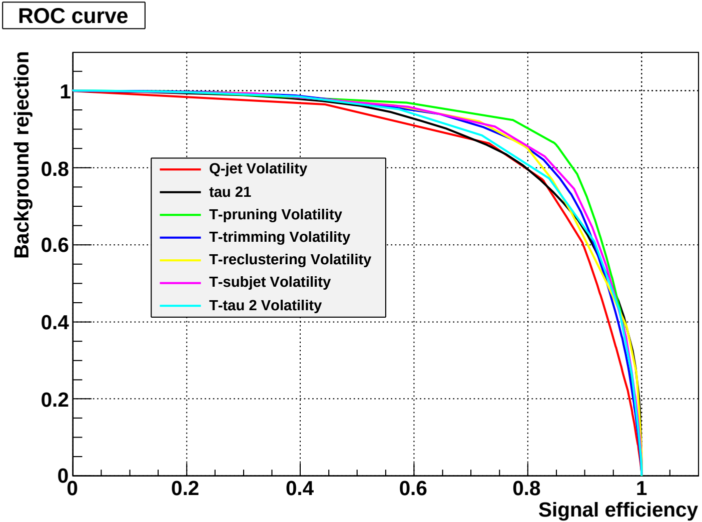
$300\ \mathrm{GeV} < p_T < 500\ \mathrm{GeV}$, pseudo calorimeter cell particles, ROC curves



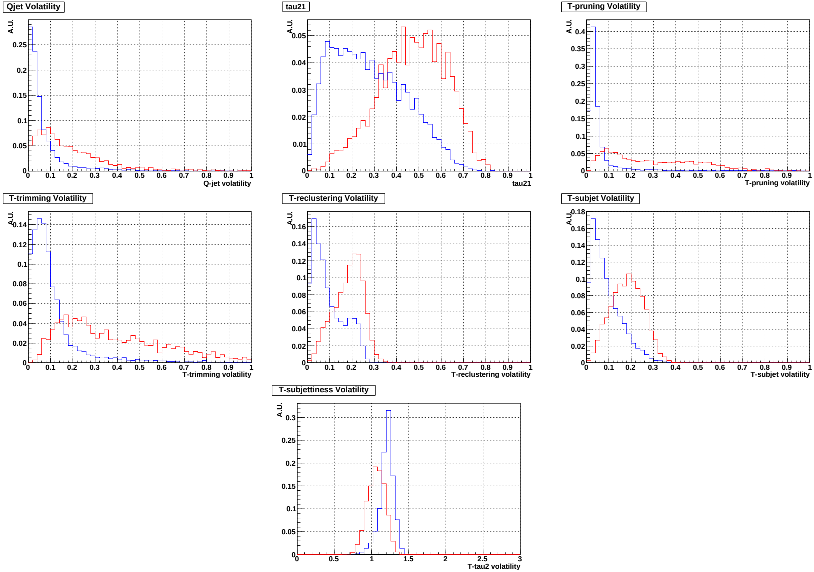
800 GeV $< p_T <$ 1000 GeV, truth particles



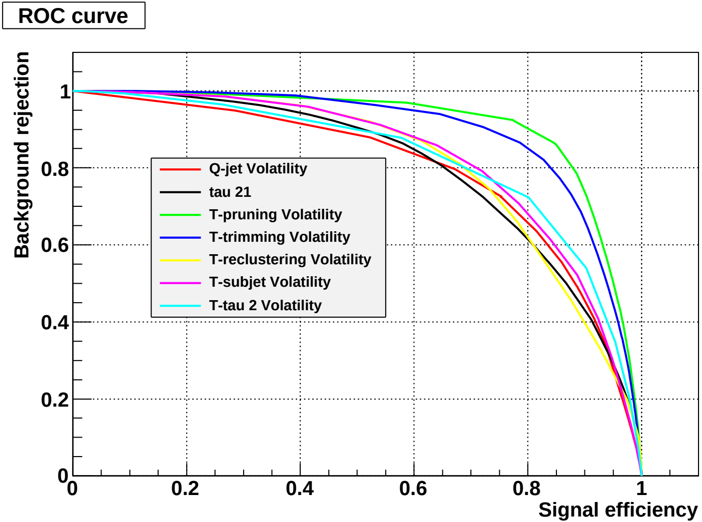
$800\ \mathrm{GeV} < p_T < 1000\ \mathrm{GeV}$, truth particles, ROC curves



800 GeV $< p_T <$ 1000 GeV, pseudo calorimeter cell particles



800 GeV $< p_T <$ 1000 GeV, pseudo calorimeter cell particles, ROC curves



Conclusions

- Telescoping jet substructure is a promising tool in boosted boson tagging
- There is a lot of information beyond the prong structure from hard splitting
- Volatility probes the components of soft radiation in exclusive angular regions
- Telescoping jets systematically deconstructs hadronic final states
- Future direction: subjet kinematics and telescoping deconstruction