

Resonance Searches with an Updated Top Tagger

G. Kasieczka, T. Plehn, T.S., T. Strebler, G. P. Salam [arXiv:1503.05921]

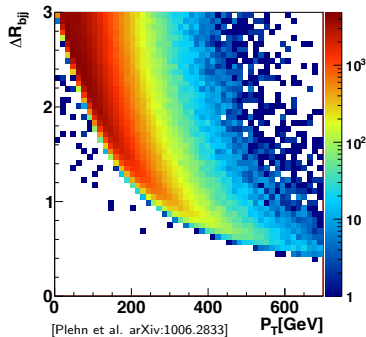
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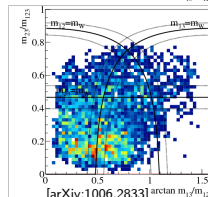
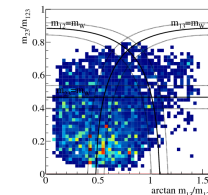
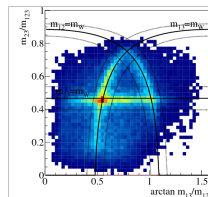
HEPTopTagging

- reconstruction of boosted hadronic tops
- collimated decay products
 - fat jets
 - reduced combinatorial problems
- SM: number of top quarks vs. collimation
- substructure analysis based on subjet masses



HEPTOPTAGGER – Algorithm

- 1 **fat jet:** $C/A R = 1.5$, $p_T > 200$ GeV
- 2 **hard substructures:**
mass drop $f_{\text{drop}} = 0.8$, $m_i < m_{\text{sub}} = 30$ GeV
- 3 **filtering:**
filter triplets of hard substructures \rightarrow 3 jets (j_1, j_2, j_3)
 $150 \text{ GeV} < m_{123} < 200 \text{ GeV}$
- 4 **mass plane cuts:** $0.85 \frac{m_W}{m_t} < \frac{m_{ij}}{m_{123}} < 1.15 \frac{m_W}{m_t}$
 $m_{23} \approx m_W$: $0.2 < \arctan \frac{m_{13}}{m_{12}} < 1.3$; else $\frac{m_{23}}{m_{123}} > 0.35$
- 5 **triplet selection:** choose triplet closest to m_t
- 6 **consistency:** $p_T^{(\text{tag})} > 200$ GeV



Resonance Reconstruction

Heavy neutral Z' -gauge bosons decaying to top quarks at LHC run II

Event generation:

- Pythia8, LHC $\sqrt{s} = 13$ TeV
- signal: $Z' \rightarrow t_h \bar{t}_h$, $m_{Z'} = 1500$ GeV, $\Gamma(Z') = 65$ GeV
- background: QCD-dijet & $t_h \bar{t}_h$, both $p_T > 400$ GeV
- no detector simulation

Event selection:

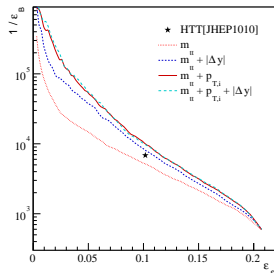
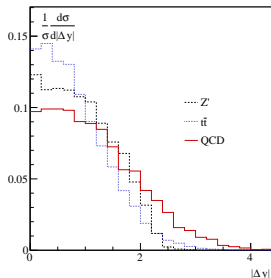
- 2 hardest C/A, $R = 1.5$ fat jets (FASTJET)
- require $p_{T,\text{fat}} > 400$ GeV and $|y_{\text{fat}}| < 2.5$

Decay Kinematics

- HTT working point + m_{tt} window

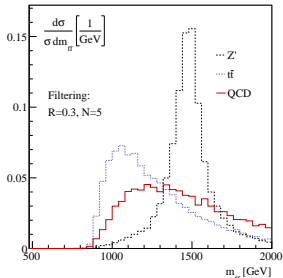
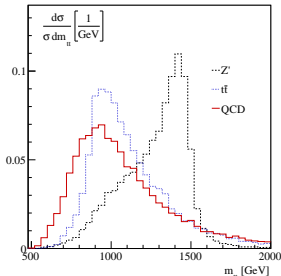
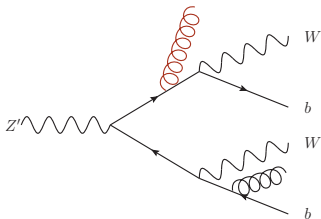
	$Z' \rightarrow t\bar{t}$	$t\bar{t}$	QCD
generator level	10^5	10^5 (1.76 pb)	$8 \cdot 10^6$ (1.93 nb)
≥ 2 fat jets with $p_T > 400$ GeV and $ y < 2.5$	69142	85284 (1.50 pb)	$6.7 \cdot 10^6$ (1.62 nb)
hardest 2 fat jets HTT [JHEP1010] tagged	9679	11706 (0.21 pb)	4426 (1.07 pb)
$m_{tt} \in [1200, 1600]$ GeV	7031	2817 (0.05 pb)	978 (0.24 pb)

- include additional kinematic variables in **BDT** analysis
- decay kinematics** well described by $\{ m_{tt}, p_{T,j} \}$



Final State Radiation

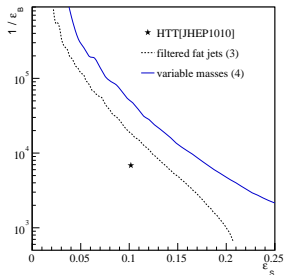
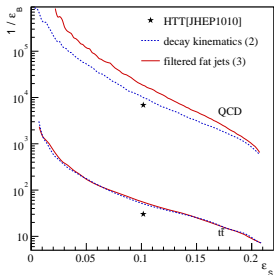
- HTT reconstructs on-shell tops
 - misses **final state radiation**
 - sizeable tail in m_{tt} distribution
- consider HTT tagged fat jets



Final State Radiation & Variable Masses

- filtered fat jet momenta instead of reconstructed tops \rightarrow no improvement
- add **filtered fat jet** information: $\{ m_{tt}, p_{T,j}, m_{ff}^{(filt)}, p_{T,f_j}^{(filt)} \}$
- going beyond HTT working point:
variable masses in HTT cuts + corresponding variables in BDT

$$\{ m_{tt}, p_{T,j}, m_{ff}^{(filt)}, p_{T,f_j}^{(filt)}, m_{rec}^{min}, m_{rec}^{max}, f_{rec}^{max} \}, \quad f_{rec} = \min_{ij} |(m_{ij}/m_{rec})/(m_W/m_t) - 1|$$

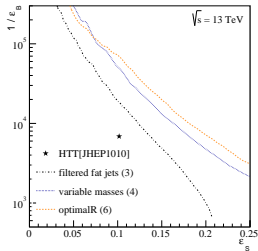
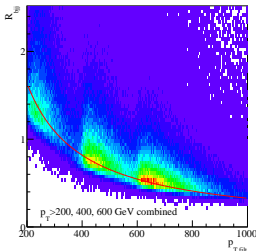


OptimalR Mode

- there is an optimal fat jet size R_{opt}
- reduce R until leaving top mass plateau

$$|m_{\text{rec}}^{(R)} - m_{\text{rec}}^{(R_{\text{opt}})}| < 0.2 m_{\text{rec}}^{(R_{\text{opt}})} \rightarrow R_{\text{opt}}$$

- estimate as $R_{\text{opt}}^{(\text{calc})} \rightarrow$ additional variable $R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}$
- **OptimalR** $\{ m_{tt}, p_{T,j}, m_{ff}^{(\text{filt})}, p_{T,f_j}^{(\text{filt})}, m_{\text{rec}}^{\text{min}}, m_{\text{rec}}^{\text{max}}, f_{\text{rec}}^{\text{max}}, \max(R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}) \}$



N -Subjettiness

- optimalR working point

$$m_{\text{rec}} \in [150, 200] \text{ GeV}, \quad f_{\text{rec}} < 0.175,$$

$$R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})} < 0.3$$

- two different filterings and BDT analyses

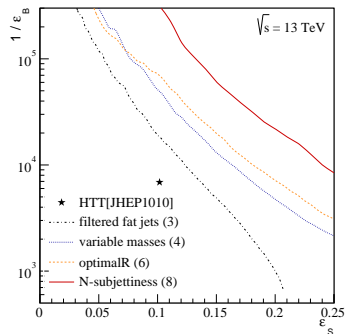
$$\text{passed: } R_{\text{filt}} = 0.3, N_{\text{filt}} = 3$$

$$\text{rejected: } R_{\text{filt}} = 0.2, N_{\text{filt}} = 5$$

- N -Subjettiness [Thaler, Van Tilburg]

$$\tau_N = \frac{1}{R_0 \sum_k p_{T,k}} \sum_k p_{T,k} \min(\Delta R_{1,k}, \dots, \Delta R_{N,k})$$

- BDTs: $\{m_{tt}, m_{ff}, p_{T,t_1}, p_{T,t_2}, p_{T,f_1}, p_{T,f_2}, m_{\text{rec}}^{\text{min}}, m_{\text{rec}}^{\text{max}}, f_{\text{rec}}^{\text{max}}, R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}, \tau_{f_i, N}, \tau_{f_i, N}^{(\text{filt})}\}$



QJETS

[Ellis, Hornig, Roy, Krohn, Schwartz]

- deterministic clustering \rightarrow set of weighted histories

- each possible merging (ij) gets a weight

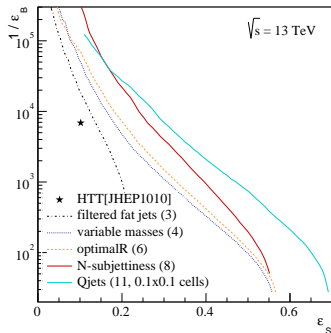
$$\omega_{ij}^{(\alpha)} = \exp\left(-\alpha \frac{d_{ij} - d_{ij}^{\min}}{d_{ij}^{\min}}\right)$$

- clustering history weight

$$\Omega^{(\alpha)} = \prod_{\text{mergings}} \omega_{ij}^{(\alpha)} = \left[\prod_{\text{mergings}} \exp\left(-\frac{d_{ij} - d_{ij}^{\min}}{d_{ij}^{\min}}\right) \right]^{\alpha}$$

- use leading tagged QJETS history + statistical information from tagged histories

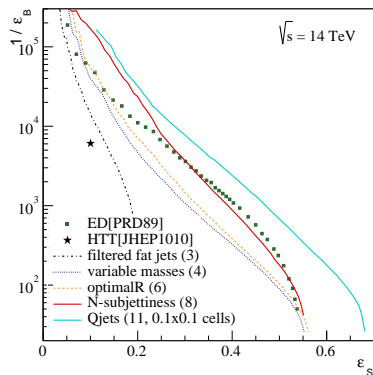
$$\{ m_{tt}, m_{ff}, p_{T,t_1}, p_{T,t_2}, p_{T,f_1}, p_{T,f_2}, m_{\text{rec}}^{\min}, m_{\text{rec}}^{\max}, f_{\text{rec}}^{\max}, R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}, \{ \mathcal{T}N \}, \varepsilon_{\text{Qjets}}^{\min}, \{ m_{\text{rec}}^{\text{Qjets}} \} \}$$



Comparison

Event Deconstruction [Soper, Spannowsky]

- likelihoods based on up to 9 C/A microjets per fat jet ($R = 0.2$ and $p_T > 10$ GeV)
- soft and/or collinear approximation of QCD
- event classification based on likelihood ratio



Summary

Resonance search with an updated HEPTOPTAGGER and additional kinematic variables:

- fat jet kinematics to account for **final state radiation**
- algorithmically optimized size of used fat jets and its prediction (**optimalR**)
- **N-subjettiness** probing more general substructures inside the fat jet
- **QJETS** with a global picture of the most likely clustering histories giving a top tag

→ factor 30 improvement compared to the previous HEPTOPTAGGER version

IMPRS
PTFS