Resonance Searches with an Updated HEPTopTagger

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

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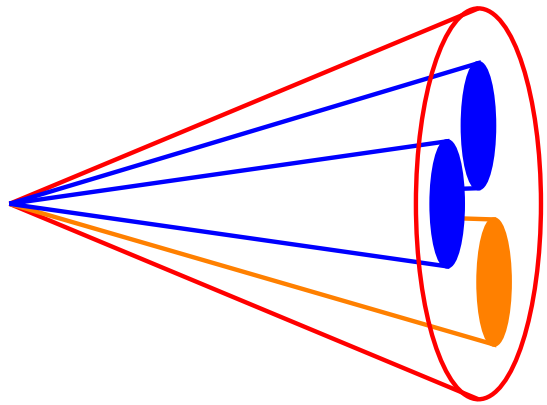
August 11, 2015

HEPTopTagging

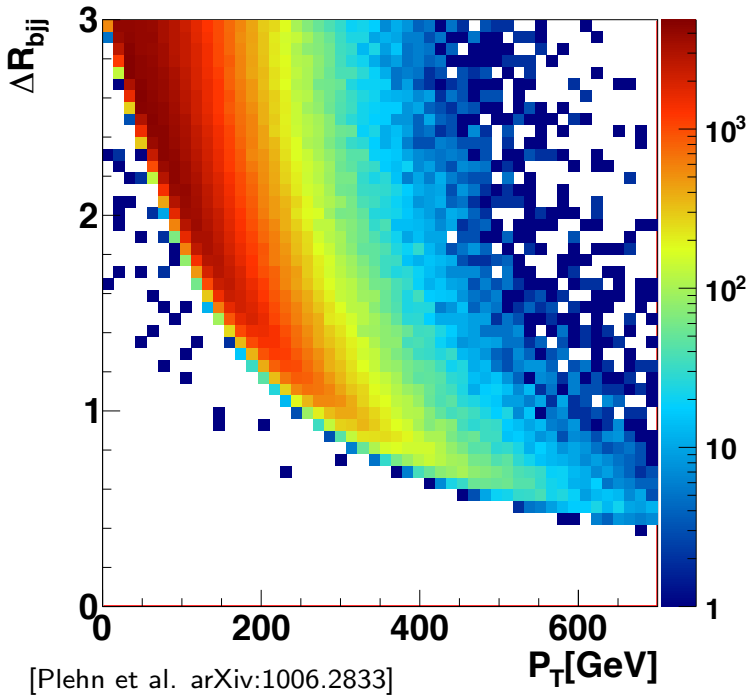
- reconstruction of boosted hadronic tops

- collimated decay products
  → fat jets
  → reduced combinatorial problems



HEPTopTagging

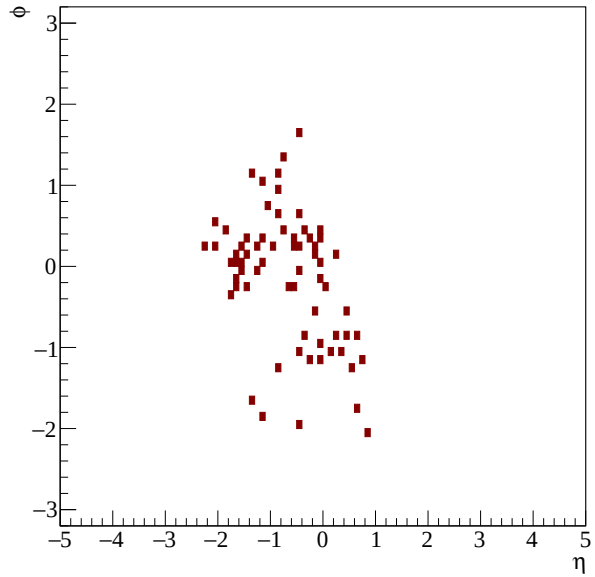
- reconstruction of boosted hadronic tops
- collimated decay products
  → fat jets
  → reduced combinatorial problems
- SM: number of top quarks vs. collimation
- substructure analysis based on subjet masses



[Plehn et al. arXiv:1006.2833]

HEPTopTagger – Algorithm

0. **fat jet**: C/A $R = 1.5$, $p_T > 200$ GeV



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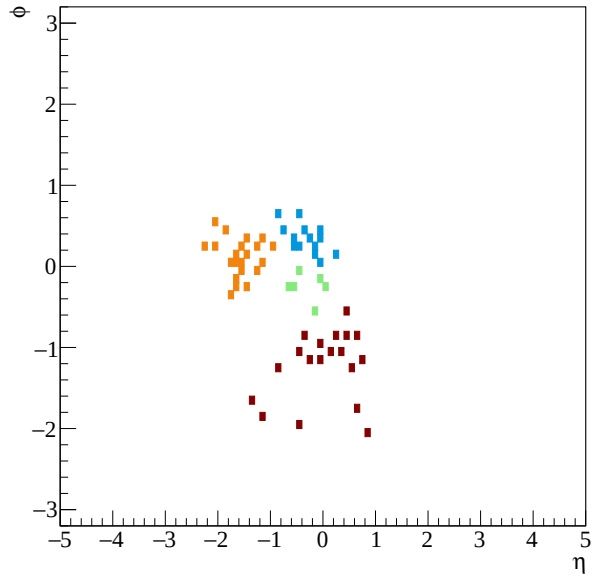

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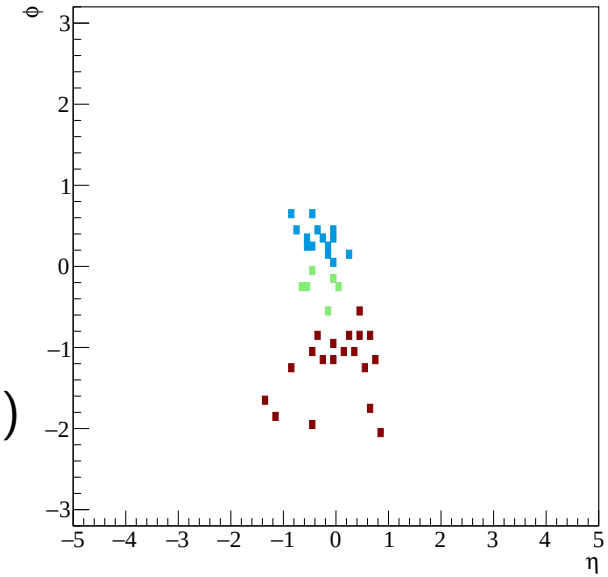

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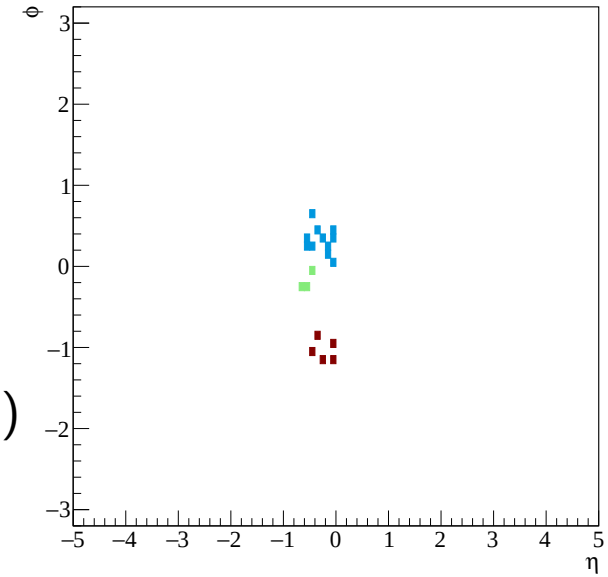

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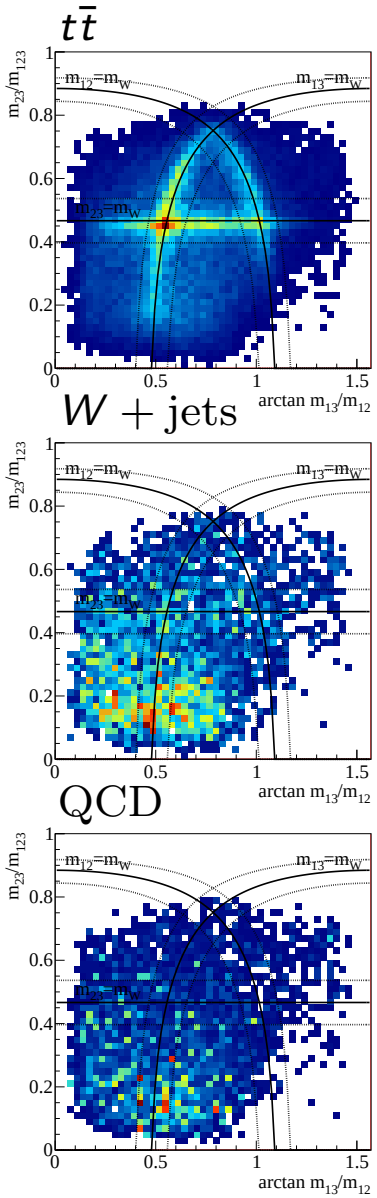

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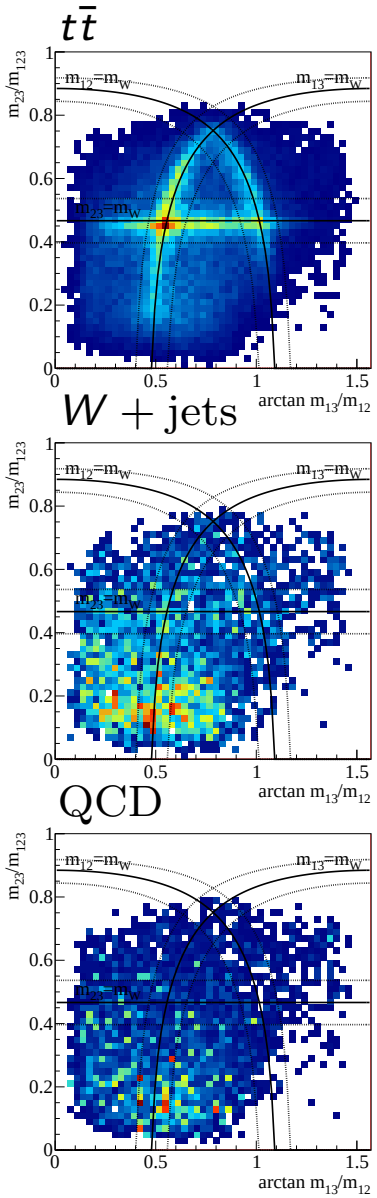

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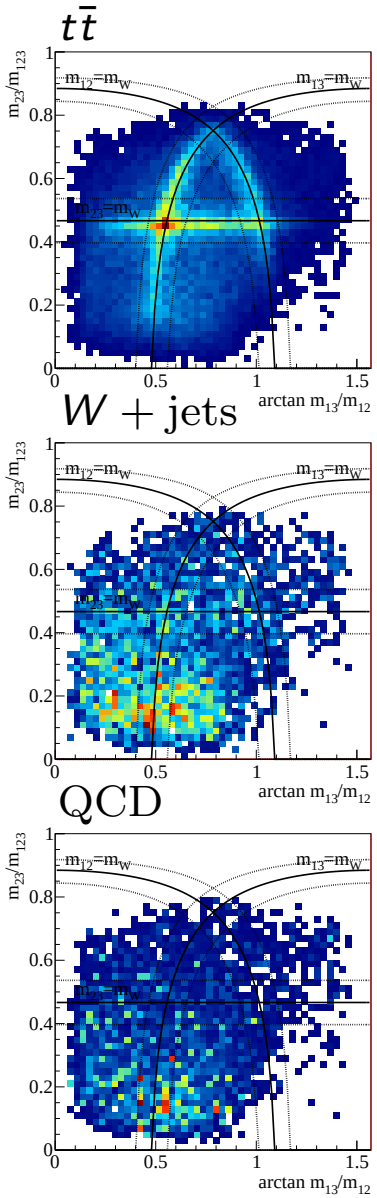

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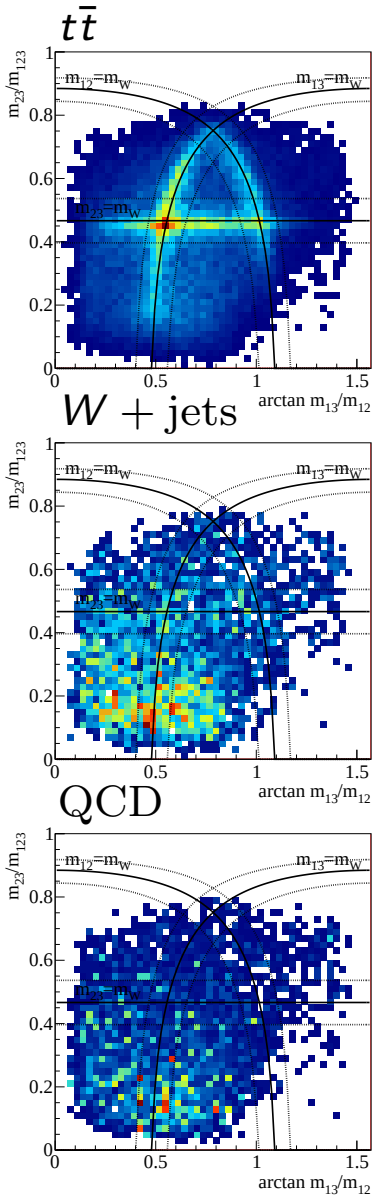

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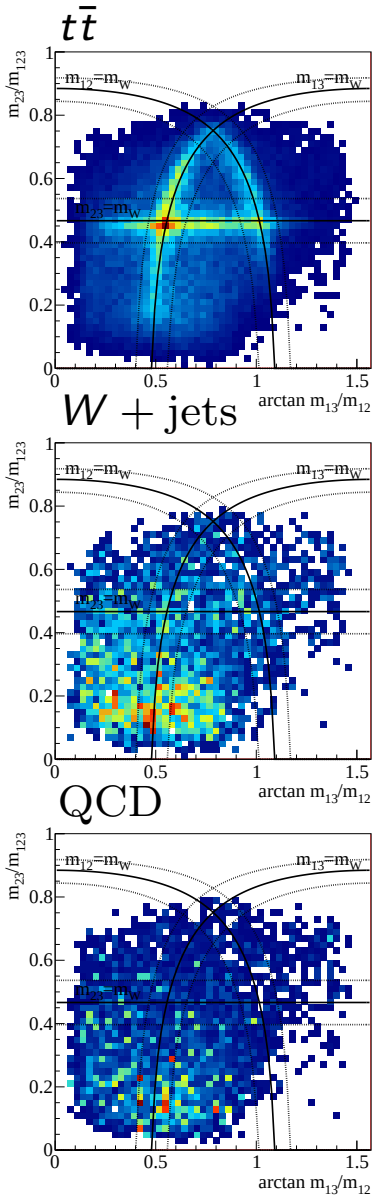

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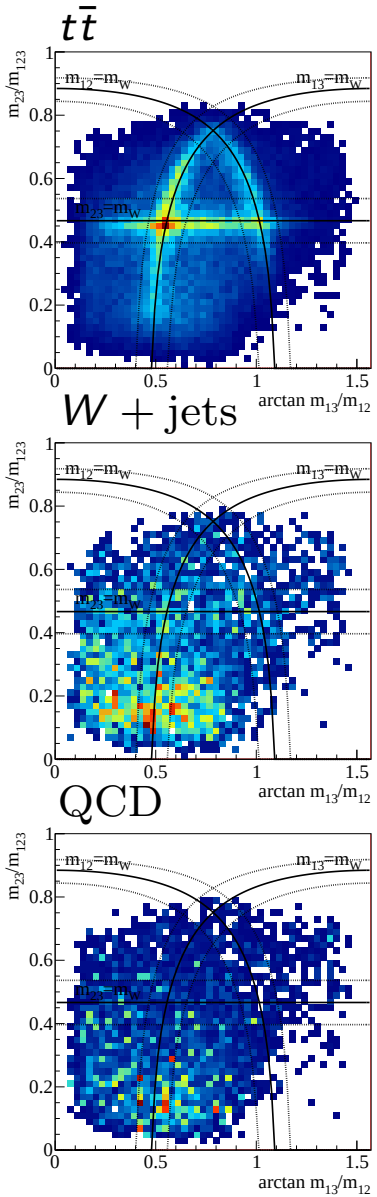
5. **consistency**: $p_T^{(\text{tag})} > 200 \text{ GeV}$



Resonance Reconstruction

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

Event generation:

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

Event selection:

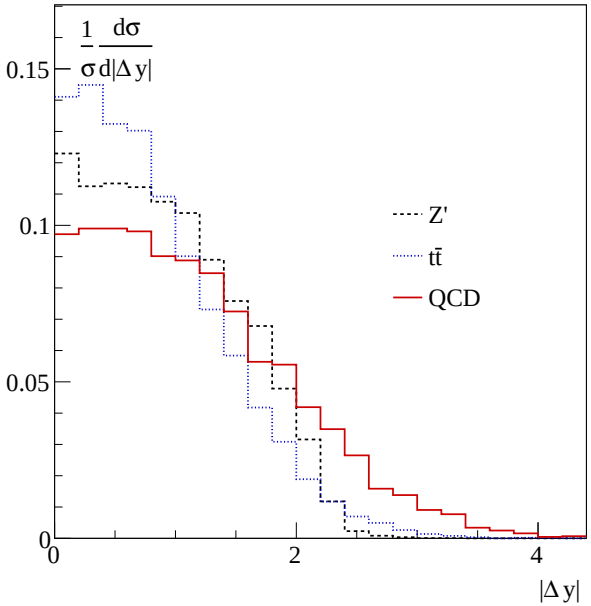
- 2 hardest C/A, $R = 1.5$ fat jets (FastJet)
- require $p_{T,\text{fat}} > 400$ GeV and $|y_{\text{fat}}| < 2.5$

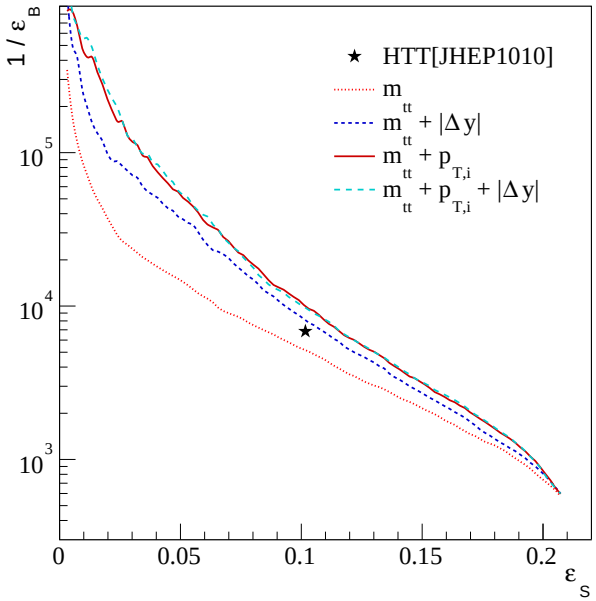
Decay Kinematics

- HTT working point + m_{tt} window

	$Z' \to t\bar{t}$	$t\bar{t}$	QCD
generator level	10^5	10^5 (1.76 pb)	$8 \cdot 10^6$ (1.93 nb)
$\geq$ 2 fat jets with $p_T > 400$ GeV and $\lvert y \rvert < 2.5$	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)

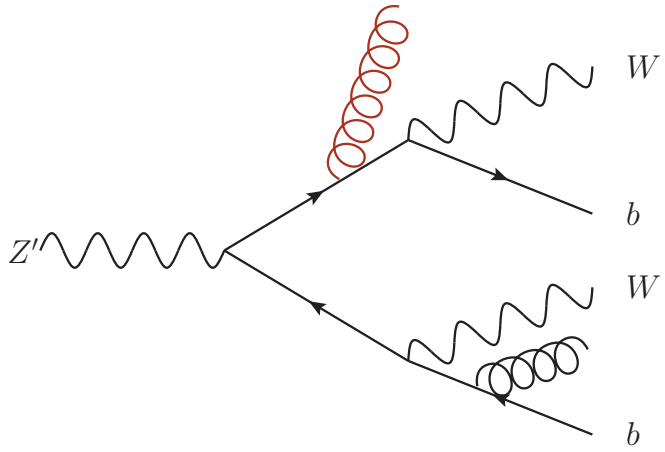
- include additional kinematic variables in BDT analysis
- decay kinematics well described by $\{ m_{tt}, p_{T,j} \}$

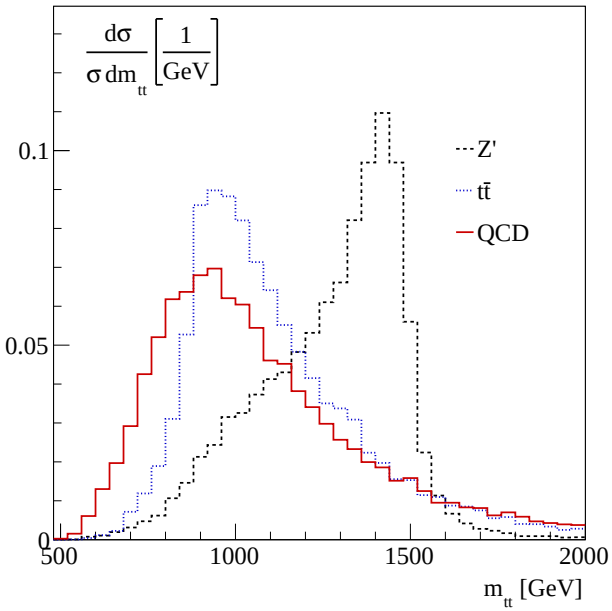




Final State Radiation

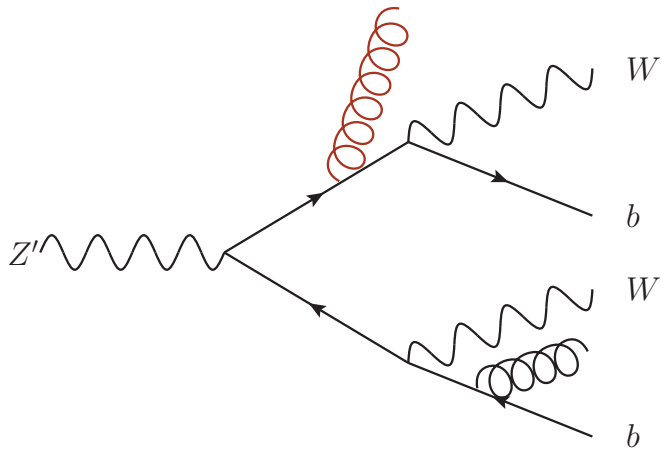
- HTT reconstructs on–shell tops
  $\rightarrow$ misses final state radiation
  $\rightarrow$ sizeable tail in m_{tt} distribution

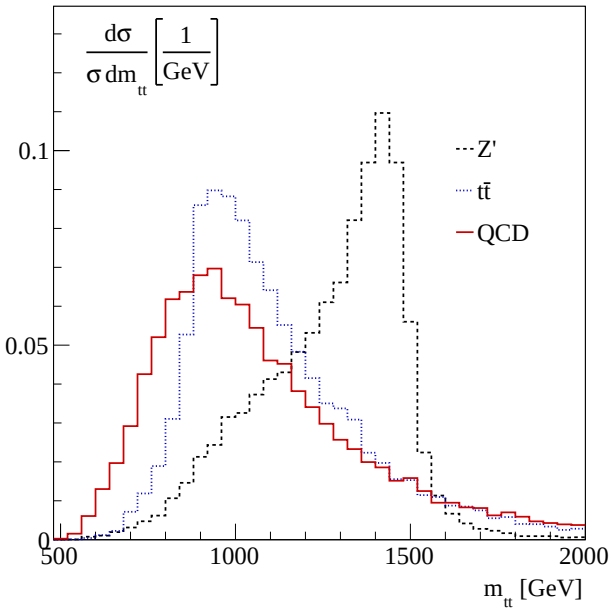


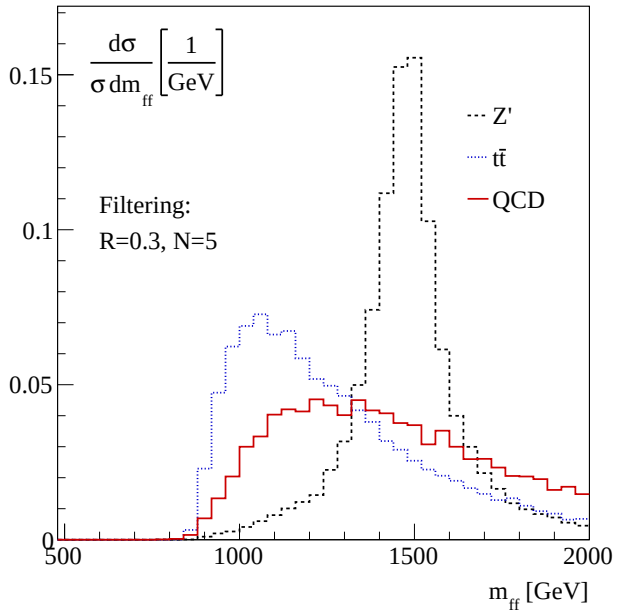


Final State Radiation

- HTT reconstructs on–shell tops
  → misses final state radiation
  → sizeable tail in m_{tt} distribution
- consider HTT tagged fat jets
  → Breit–Wigner shaped signal
  but shifted backgrounds
  m_{ff} instead of m_{tt} → no improvement

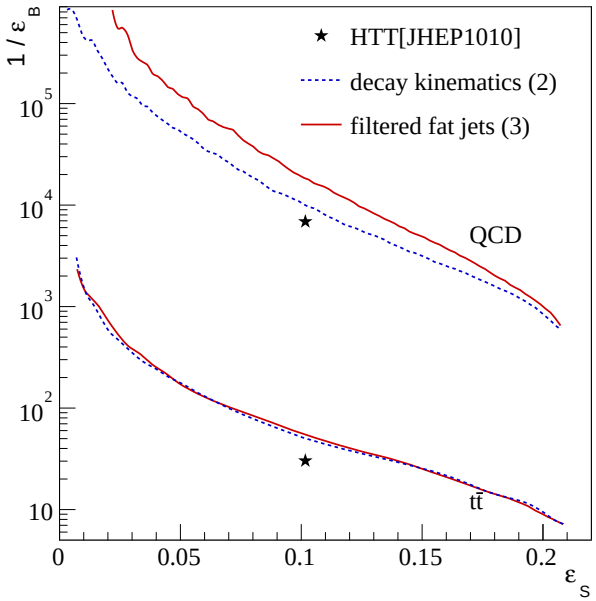






Final State Radiation & Variable Masses

- add filtered fat jet information: $\{ m_{tt}, p_{T,j}, m_{ff}^{(\text{filt})}, p_{T,f_j}^{(\text{filt})} \}$

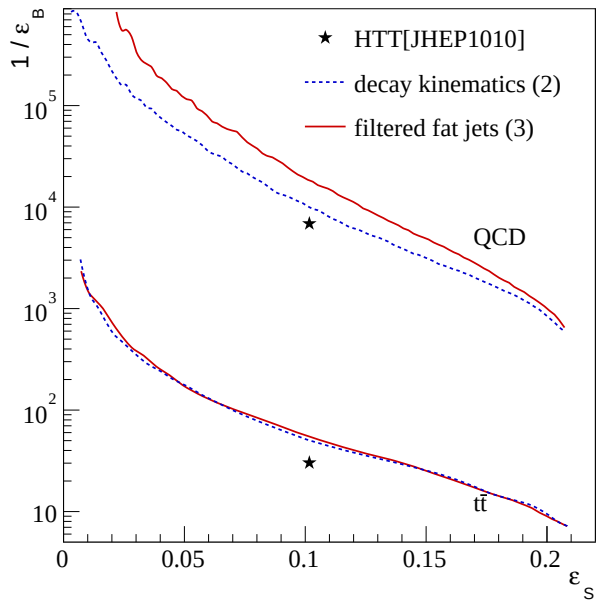


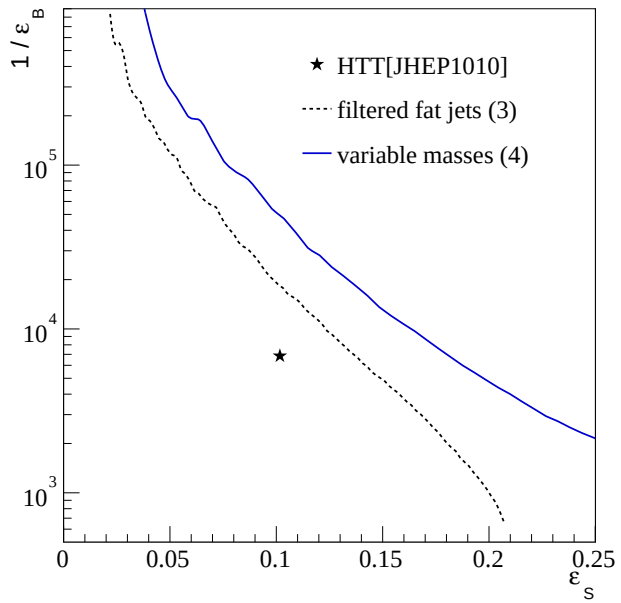
Final State Radiation & Variable Masses

- add filtered fat jet information: $\{\ m_{tt}, p_{T,j}, m_{ff}^{(\text{filt})}, p_{T,f_j}^{(\text{filt})}\ \}$

- going beyond HTT working point:
  variable masses in HTT cuts + corresponding variables in BDT

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



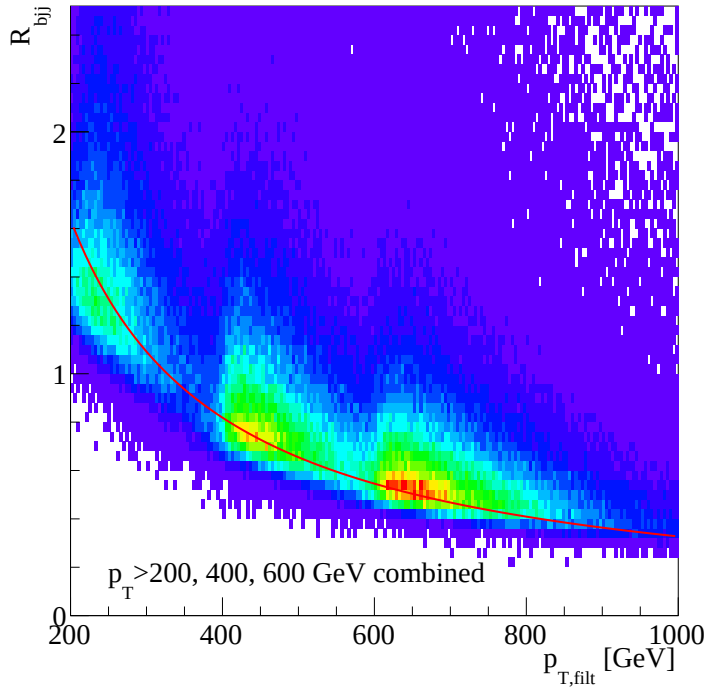


OptimalR Mode

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

$$m_{\text{rec}}^{(1.5)} - m_{\text{rec}}(R) > 0.2\ m_{\text{rec}}^{(1.5)} \Leftrightarrow R < R_{\text{opt}}$$

- estimate as $R_{\text{opt}}^{(\text{calc})}$ $\rightarrow$ additional variable $R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}$



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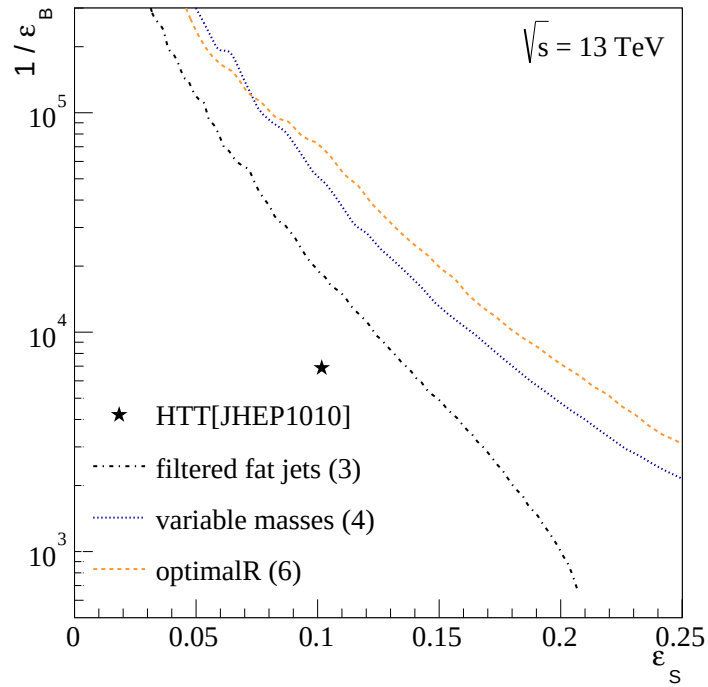
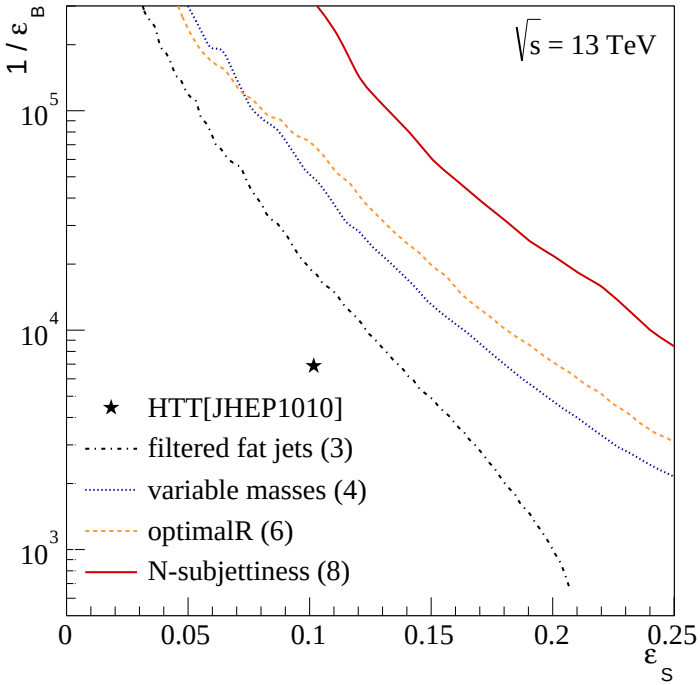


- OptimalR $\{ m_{tt}, p_{T,j}, m_{ff}^{(\text{filt})}, p_{T,f_j}^{(\text{filt})}, m_{\text{rec}}^{\text{min}}, m_{\text{rec}}^{\text{max}}, f_{\text{rec}}^{\text{max}}, \max(R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}) \}$

N–Subjettiness

- optimalR working point

  $m_{\text{rec}} \in [150, 200]$ GeV, $\quad f_{\text{rec}} < 0.175$,
  $R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})} < 0.3$
  $\rightarrow$ two categories per fat jet



- two different filterings and BDT analyses

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

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

- N–Subjettiness [Thaler, Van Tilburg]

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

- BDTs: $\left\{m_{tt}, m_{\text{ff}}, p_{T,t_1}, p_{T,t_2}, p_{T,\text{f}_1}, p_{T,\text{f}_2}, m_{\text{rec}}^{\text{min}}, m_{\text{rec}}^{\text{max}}, f_{\text{rec}}^{\text{max}}, R_{\text{opt}} - R_{\text{opt}}^{(\text{calc})}, \tau_{f_i,N}, \tau_{f_i,N}^{(\text{filt})}\right\}$

QJETS

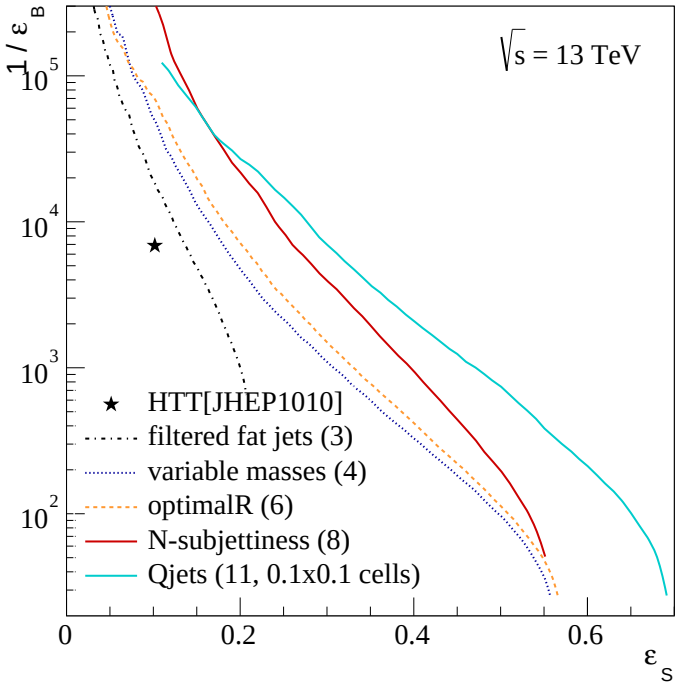
[Ellis, Hornig, Roy, Krohn, Schwartz]

- 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

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



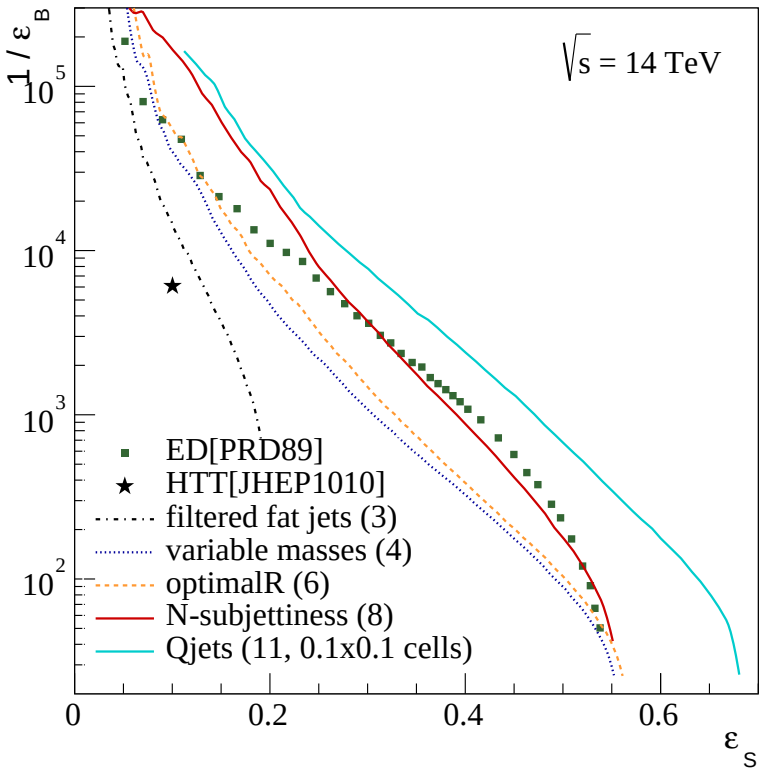
- use leading tagged QJETS history + statistical information from tagged histories

$$\{\, m_{tt},\, m_{\mathrm{ff}},\, p_{T,t_1},\, p_{T,t_2},\, p_{T,\mathrm{f}_1},\, p_{T,\mathrm{f}_2},\, m_{\mathrm{rec}}^{\min},\, m_{\mathrm{rec}}^{\max},\, f_{\mathrm{rec}}^{\max},\, R_{\mathrm{opt}} - R_{\mathrm{opt}}^{(\mathrm{calc})},\, \{\tau_N\},\, \varepsilon_{\mathrm{Qjets}}^{\min},\, \{m_{\mathrm{rec}}^{\mathrm{Qjets}}\} \,\}$$

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

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IMPRS PTFS