TOP TAGGING

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TT RESONANCES

$\frac{d\sigma}{dm(t\bar{t})}$ (pb/GeV)

- SM bgd.
- basic RS $t\bar{t}$
- SO(5) $N=0$ $t\bar{t}$
- SO(5), $N=1$ $t\bar{t}$
- SM $t\bar{t}$
- LH $t\bar{t}$

$pp \rightarrow t\bar{t} \rightarrow l\bar{\nu} + n$ jets
$\sqrt{s} = 14$ TeV
reconstr. $m(t\bar{t})$

$m(t\bar{t})$ (GeV)

2000 2500 3000 3500 4000
KK GLUONS

Lillie et al., hep-ph/0701166

$M_{tt}$ (GeV)

$\sigma_{t\bar{t}}$ (pb/GeV)

SM $t\bar{t}$

$2$ TeV
$3$ TeV
$5$ TeV
$7$ TeV
BG
BACKGROUND IS HUGE

SM dijets
**FINDING TOPS**

- **Difficult** to use electrons – at high $p_T$ not isolated
- Branching ratio with one muon is 10% – lose a lot of signal
- Branching ratio to two muons is 1% – lose most of signal

- At high $p_T$, jets from hadronic decays are not isolated

- Require 1 or 2 **b-tags**
  - b-tagging efficiency degrades at high $p_T$

\[ = 2 \text{b-jets} + 2 \text{jets} + \mu + E_T \]
B-TAGGING

B-tagging efficiency degrades at high $p_T$

And high luminosity (pileup)

However...

- ATLAS can get 70% b-tagging efficiency at high $p_T$
- B-tagging will improve with time
All-hadronic $tt$ events at high $p_T$ look just like dijets!

Or do they...?
TYPICAL TOP JETS

$P_T > 500$ GeV

dijet with $P_T=500$ GeV

dijet with $P_T=500$ GeV

dijet with $P_T=500$ GeV

dijet with $P_T=500$ GeV

dijet with $P_T=500$ GeV

TYPICAL BACKGROUND JETS
TYPICAL TOP JETS

$P_T > 1500 \text{ GeV}$

TYPICAL BACKGROUND JETS
How can we tag the all-hadronic $tt$ events at high $p_T$?

1. Look for subjets
2. Cut on top mass
3. Cut on $W$ mass
4. Cut on helicity angle

D. Kaplan, K. Rehermann, MDS, and B. Tweedie
SUBJET DECOMPOSITION

1. Find fat jets first
   - We use geometric Cambridge-Aachen algorithm
   - Fat jet size $R = 0.4-0.8$

2. Reverse clustering steps
   - Clean out soft radiation
   - Clean out collinear radiation
   - Tops should have a 3 (or 4) subjets

Fat jet size $R=0.4-0.8$
Varies with jet $p_T$
DEMANDING 3 SUBJETS

- **Fat jet** has 3 or 4 **hard** \((\delta_p)\) **separated** \((\delta_r)\) **subjets**
EFFICIENCY FOR SUBJET CUT

Keeps 60% tops

Rejets 90% of jets
• After **subject** requirement
• Cut on **fat jet** mass
CUT ON TOP MASS

- After subjet requirement
- Cut on fat jet mass

145 GeV < M_t < 205 GeV
EFFICIENCIES

*subject cut only*
EFFICIENCIES

subject + $M_{\text{top}}$ cut

$\epsilon_f$

$\epsilon_{\text{miss}}$

+ $M_{\text{top}}$
W MASS

- After **subjett** requirement
- After **top mass** requirement
- Cut on 2 subjets closest to W mass

\[ M_W = \text{pair whose mass is closest to } M_W \]  
(keeps the most signal)
CUT ON W MASS

- After *subjet* requirement
- After *top mass* requirement
- Cut on 2 subjets closest to W mass

65 GeV < M_W < 105 GeV

M_W = pair whose mass is closest to M_W
(keeps the most signal)
EFFICIENCIES

\[ \text{subj} + M_{\text{top}} \text{ cut} \]
EFFICIENCIES

\(\text{subj} + M_{\text{top}} + M_{W} \) cut
- $W$ decays basically isotropically
- Can be used to measure $W$ helicity

Intermediate **off-shell massless** parton
- Helicity angle **strongly peaked**
- Divergent in perturbation theory (soft divergence)

\[
\frac{d\sigma}{dM_{12} d\cos\theta_h} = 2 \frac{M_{12}^2}{M_{123}^2} \frac{2M_{123}^2}{M_{12}^2} \frac{1}{1 - \cos(\theta_h)} + \ldots
\]
• After **subjet** requirement
• After **top mass** requirement
• After **W mass** requirement
• Exclude small \( \cos(\theta_h) \)
CUT ON HELICITY ANGLE

- After **subjet** requirement
- After **top mass** requirement
- After **W mass** requirement
- Exclude small $\cos(\theta_h)$

$\cos(\theta_h) < 105 \text{ GeV}$
EFFICIENCIES

\[ \text{subj} + M_{\text{top}} + M_{W} \text{ cut} \]
For $p_T > 1000$ GeV
- Keep 40% tops
- Reject 99% of light jets

Numbers get squared for dijet events
DIJET CROSS SECTION

\[ \frac{d\sigma}{dM} \text{ (fb/100 GeV)} \]

- dijets (SM)
- \texttt{ttbar} (SM)
DIJET CROSS SECTION

dijets (SM – after cuts)

\[ \text{dijet/tt} \text{ invariant mass } M \text{ (GeV)} \]

\[ \text{d} \sigma / \text{d}M \text{ (fb/100 GeV)} \]

\[ \text{ttbar} \text{ (SM – after cuts)} \]
• Lillie et al, hep-ph/0701166, p.10
  “extraction of signal will require a background rejection of about a factor of 10”

• We have a rejection factor of 10,000!
KK GLUON

Before top-tagging

$\sigma \times BR = 10 \text{ pb}$
After top-tagging

100 pb$^{-1}$

$\sigma = 10 \text{ pb}$
New CMS study (Rappoccio & Maksimovic)

Top $p_T = 600$ GeV: \[
\begin{align*}
46\% \text{ top-tagging efficiency} \\
98.5\% \text{ background rejection}
\end{align*}
\]

- With full simulation, similar efficiencies
- With 100 pb$^{-1}$ at 10 TeV, can rule out 2 TeV KK gluons (95% c.l.)
Explored jet algorithm dependence
RECLUSTERING

But using anti kT and reclustering with C-A works great
Top tagging works:
1. Look for subjets
   - Clean up soft and collinear radiation
2. Cut on top mass
3. Cut on W mass
4. Cut on helicity angle

- No b-tagging required
- Can use all-hadronic channel
- Works great after full simulation (CMS)
- Can use any jet algorithm
- Top-tagging better than b-tagging at high $p_T$