New Approach to Identify Boosted Hadronically Decaying Particle using Jet Substructure in its Centre of Mass Frame

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Many NP models predict heavy resonance decay into W/Z/Top:

- Boosted (high $p_T$) jets in the final decay states
- Problem with traditional jet reconstruction
  - Jet merging, overlapping

Solution:

- Jet algorithm with large cone-size
- Reconstruct boosted particle in a single jet

\[ \Delta R \approx \frac{2m}{p_T} \]
How to identify boosted W/Z/top

- Jet mass tells the origin of the jet
  - QCD jet: originated from non-top quark or gluons

- Problem: QCD jet production a few orders magnitude higher
- Jet mass alone not enough discriminating power
Jet substructure for additional discriminating power
Traditional method to identify boosted hadronic W/Z/top

- Jet grooming, trimming etc
- Shape variables:
  - Jet width, eccentricity, aplanarity etc
  - Using energy clusters in the ($\eta$, $\phi$) plane

Our proposal: shape variable/reclustering in jet rest frame:

- Jet CM frame: jet 4 momentum = (0,0,0,$m_{jet}$)
- Similar technique used at LEP and B-factory
- Better discriminating power against QCD background
- Using full momentum information of the energy clusters
Jet substructure in the jet CM Frame

- Distribution of jet clusters in hadron collider:
  - W/Z→jj
  - t→Wb→jjj
  - QCD

- Lesson learned from e⁺e⁻ collider: event topology → jet topology
MC: pythia generator level study,
Particles in 0.1x0.1 cell group as a single cluster,
jet $p_T>$300GeV $|\eta|<2.5$
AntiKt algorithm, R=0.6
Correlation of shape variable & jet mass

- Large correlation between eccentricity and jet mass
  - Eccentricity: a jet shape in lab frame used

- Small correlation for variables in CM frame
  - Sphericity, Aplanarity and Thrust_minor slightly better

- Better background rejection power for shape variables in CM

Distribution of the jet mass of QCD jets after cutting on each individual variable to reject 90% QCD jets
Using W ID to search for X→WW

- Heavy resonance decaying into diboson:
  - Using X→WW as example
    - One W decay leptonically,
    - The other decay hadronically
    - Full reconstruction of m_X
      - One neutrino in the event
      - Reconstruction using miss E_T & W mass constraint
  - Assuming production effective cross section : 20fb
Reclustering in the rest frame

- W/Z->jj
- t->Wb->jjj
- QCD

Rerun the jet finding algorithm on the clusters in the CM frame
- Fastjet
- Jet algorithm similar (not identical) to e^+e^- experiments
  - Tradition jet algorithm based on \( \eta \) and \( \theta \) not appropriate
  - Combine 2 clusters in \( \Delta \Theta < 0.6 \)
  - Angle \( \Theta \): angle between 2 clusters
Subjets of boosted top in its CM frame

- $p_T(\text{top}) > 600\text{GeV}, W$ decay hadronically
- At least 3 subjets with $E > 10\text{GeV}$

- Many jet substructure variables are correlated
- Multi variable approach to combine different variables
  - Energies of 3 leading jets, mass combinations ......
Identify $b$ quark inside boosted top

- Top quark decays to $Wb$ almost 100%
- Identify $b$ quark ($b$-tagging) based on its long lifetime

Problem of direct application of $b$-tagging for boosted top jet:
Difficult to disentangle tracks originated by $b$ decays from tracks originated from $W$ decay
Identify b quark inside boosted top

- Boost charged tracks back into jet rest frame
- Associate tracks with subjets
- Separate tracks originated from different partons: b or W->qq'
- Comparing to direct application of b-tagging
  - Studies done using impact parameter algorithm b-tagging
  - Better performance using CM b-tagging
- Combine b-tagging with jet substructure

\[ t \rightarrow Wb \rightarrow j jj \]
Using Top ID to search for $X \rightarrow t\bar{t}b\bar{b}$

- Heavy resonance decaying into a top pair
- Both top decay hadronically: hadronic $W$
  - Dominant bg: SM mutijet production, top pair production
- Choose 2 leading jets as top candidate to form a $X$ candidate
- Assuming effective production cross section of $X$: 10 fb

$M_C$
Propose a new approach to identify boosted particle
   ✓ Based on shape variables/reclustering in jet CMS frame

Show its application to identify boosted hadronic W/Z/top

Improved b-tagging performance in boosted top quark

Improve search sensitivities for heavy resonance decaying
to final states containing W/Z bosons or top quarks

Details in Reference: