Jet substructure at the LHC

New Physics - new methods - new results

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Shower deconstruction
- a new method to search New Physics -

signal

background

\( H \)

\( g \)

\( g \)

\( b \)

\( \bar{b} \)

Terascale workshop                Oregon
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Event selection cuts

- Cluster hadrons to 'detector cells' 0.1 x 0.1, ET > 0.5 GeV
- lepton pT > 15 GeV
- two hardest leptons mZ +- 10 GeV
- at least 1 fat jet (anti-kT, R=1.2, pT>200 GeV)

Normalize signal/background cross section to the NLO results obtained from MCFM

\[
\begin{align*}
\sigma_{MC}(S) &= 1.48 \text{ fb} \\
\sigma_{MC}(B) &= 2610 \text{ fb} \\
\frac{\sigma_{MC}(S)}{\sigma_{MC}(B)} &= \frac{1}{1760}
\end{align*}
\]
Recombine fat jet's constituents to microjets
\[(kT, R=0.15, pT > 1 \text{ GeV})\]

\[b\text{-tag if among hardest 3 AND } pT > 15 \text{ GeV}\]
Fat jet: $R=1.2$, anti-$kT$

microjets
$R=0.15$, $kT$

Build all possible shower histories
signal vs background hypothesis based on:

- Emission probabilities
- Color connection
- Kinematic requirements
- $b$-tag information
Fat jet: $R=1.2$, anti-$kT$

**microjets**

$R=0.15$, $kT$

**ISR/UE**

**hard interaction**

Build all possible shower histories

signal vs background hypothesis based on:

- Emission probabilities
- Color connection
- Kinematic requirements
- $b$-tag information
Figure 5: A shower history for a background event in which a high pT "any" parton treated as a gluon splits to a b̅b pairs. The QCD shower splitting of a b quark is to a b quark plus a gluon. The b and b̅ quarks radiate gluons and one of the gluons splits into two "any" partons treated as gluons. Let the label of the daughter that carries the 3 color of the mother parton J be A. We draw this daughter parton on the left in our diagram. Let the label of the daughter parton that carries the 3 color of parton J be B. We draw this daughter parton on the right in our diagram. We track the angle variables of two color connected partner partons to parton J. Parton k m J n L carries the 3 color that is connected to the 3 color line of parton J. Parton k m J n R carries the 3 color that is connected to the 3 color line of parton J. The labels k m J n L and k m J n R specify lines in the shower history diagram not necessarily final microjets. Given the labels of the color connected partners to the mother parton J, we assign the color connected partons of the daughter partons. The two daughter partons are color connected partners of each other and each inherits one of the color connected partners of the mother's. That is:

\[ k_m J_n L = k_m J_n R, \]

and

\[ k_m J_n R = B, \]

\[ k_m J_n L = A, k_m J_n R = k_m J_n R. \]

If parton J is a b quark, then it has a color connected partner k m J n R that carries the 3 color connected to the quark's 3 colors. There is no k m J n L partners. The b quark can split into daughter b and a daughter gluon B which we draw on the right because it carries the 3 color of the mother b quarks. The color connected partners of the daughter partons are then:

\[ k_m A_n R = B, \]

and

\[ k_m B_n L = A, k_m B_n R = k_m J_n R. \]

Similarly, if parton J is a b̅ quark, then it has a color connected partner k m J n L that carries the 3 color connected to the b̅ quark's 3 colors. There is no k m J n R partners. The b̅ quark can split into daughter b̅ and a daughter gluon B which we draw on the right because it carries the 3 color of the mother b̅ quarks. The color connected partners of the daughter partons are then:

\[ k_m A_n R = B, \]

and

\[ k_m B_n L = A, k_m B_n R = k_m J_n R. \]

Fat jet: R=1.2, anti-kT

Build all possible shower histories signal vs background hypothesis based on:

- Emission probabilities
- Colour connection
- Kinematic requirements
- b-tag information

microjets
R=0.15, kT
Results of shower deconstruction (SD)

\[ \chi\left(p, t\right) = \frac{P\left(p, t \mid S\right)}{P\left(p, t \mid B\right)} \]

Graphs showing the distribution of signal and background with imperfect b-tagging.
Results of shower deconstruction (SD)

imperfect b-tagging -- 2 positively tagged microjets

\[
\frac{d\sigma_{MC}}{d\log \chi} \quad \text{(fb)}
\]

\[
\frac{s^2}{b} \quad \text{(fb)}
\]

| \( \sigma_{BDRS}(S) \) | \( 0.22 \text{ fb} \) |
| \( \sigma_{BDRS}(B) \) | \( 0.44 \text{ fb} \) |
| \( \sigma_{MC}(S) \) | \( 0.34 \text{ fb} \) |
perfect b-tagging -- 2 positively tagged microjets

\[ \sigma_{\text{BDRS}}(B) = 1.02 \text{ fb} \quad \sigma_{\text{BDRS}}(S) = 0.65 \text{ fb} \quad \sigma_{\text{MC}}(S) = 1.48 \text{ fb} \]
Lots of room for improvement:

- FSR simulation
- ISR simulation
- Matrix element
- UE simulation
- Simulation of experimental issues, e.g. b-tagging

Modular build \(\rightarrow\) improvements are additive
Targeted scenarios:

- Busy final states -- e.g. tth, susy cascades

- Difficult processes with low stat. significance
Conclusions

- SD realization of ‘maximal information approach’
- In simple HZ final state not as good as BDRS
- Theoretical Systematic uncertainty similar to BDRS
- Profits more from information than BDRS, e.g. b-tagging
- Might be useful for busy final states
- Modular set-up -> parts can be improved independently