Preliminary results on the production of $b$-jets and pairs of $b$-jets with associated jets at the CMS experiment at $\sqrt{s} = 13$ TeV

DPG annual meeting

Patrick L.S. Connor    Paolo Gunnellini    Hannes Jung

Deutsches Elektronen-Synchrotron

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### Standard Model

- **bottom** or **beauty** quark
- heaviest quark that hadronises
- mostly in $B$-mesons

<table>
<thead>
<tr>
<th>Meson</th>
<th>Content</th>
<th>$M$ [MeV $c^{-2}$]</th>
<th>$\tau$ [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^{\pm}$</td>
<td>$ub$</td>
<td>$5279.29 \pm 0.15$</td>
<td>$1.638 \pm 0.004$</td>
</tr>
<tr>
<td>$B^{0}$</td>
<td>$db$</td>
<td>$5279.61 \pm 0.16$</td>
<td>$1.520 \pm 0.004$</td>
</tr>
<tr>
<td>$(B^{+}_c)$</td>
<td>$cb$</td>
<td>$6275.1 \pm 1.0$</td>
<td>$0.507 \pm 0.009$</td>
</tr>
<tr>
<td>$(B^{0}_s)$</td>
<td>$sb$</td>
<td>$5366.79 \pm 0.23$</td>
<td>$1.510 \pm 0.005$</td>
</tr>
</tbody>
</table>

$\Rightarrow \lambda \approx 2$ mm at CMS for heavily boosted $B$’s
Motivation

1. **background** in many (B)SM processes
   \[ \rightarrow H\bar{b}b, \ Z\bar{b}b, \ tt, \ etc. \]

2. **signal** where
   - \( m_b \gg \lambda_{\text{QCD}} \)
     \( \Rightarrow \) avoid non-perturbative effects
   - typical two-scale process
     \( \Rightarrow \) investigation of *Transverse-Momentum-Dependent* PDFs
As a function of \( p_T \) in bins of rapidity:

- ratio data/MC
- fraction of \( b \)-jets in the inclusive jet production

\[ b \text{-inclusive production} \]

\[ \Rightarrow \text{textbook measurements par excellence!} \]
Leading and subleading $b$-jet production

$\Rightarrow$ start investigation of $b\bar{b}$ pairs
Particle reconstruction

- bunch crossing at LHC
- Pythia 8
- Geant 4
- hits + energy deposits

**Reconstruction**
- Particle-Flow

**Jet clustering**
- anti-kt algorithm
- jets

**Jet calibration**
- corrected jets

**b-tagging**
- CSV
- b-jets
Machine acceptance

Rapidity

\[ |y_{b\text{-jet}}| < 2.5 \]

Jet transverse momentum

<table>
<thead>
<tr>
<th>trigger threshold [GeV]</th>
<th>effective threshold [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>114</td>
</tr>
<tr>
<td>80</td>
<td>133</td>
</tr>
<tr>
<td>140</td>
<td>220</td>
</tr>
<tr>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>260</td>
<td>430</td>
</tr>
<tr>
<td>320</td>
<td>507</td>
</tr>
<tr>
<td>400</td>
<td>638</td>
</tr>
<tr>
<td>450</td>
<td>737</td>
</tr>
</tbody>
</table>

Trigger strategy \[ p_\perp > 114 \text{ GeV} \]
Jet clustering

anti-$k_\perp$ algorithm ($R = 0.4$ at CMS)

\[ d_{iB} = \frac{1}{k_{\perp i}} \]  
\[ d_{ij} = \min \left( \frac{1}{k_{\perp i}^2}, \frac{1}{k_{\perp j}^2} \right) \frac{\Delta R_{ij}^2}{R^2} \]  
where \[ \Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2 \]

→ any two particles and pseudojets $i$ and $j$ must satisfy $d_{ij} < d_{iB}$ to belong to the same jet
Jet Energy Correction

- (L1) event pile-up
- (L2-3) non-uniformities in the detector response
- Residuals (only for data): discrepancies between data and MC

Charged-Hadron Subtraction

- To a given jet is associated the vertex that mostly contributes to its $p_\perp$
- Hadrons from other vertices are removed from the jet.
$b$ and $\bar{b}\bar{b}$

Patrick Connor

Introduction
Motivation
Goals of the analysis
Measurement
Event reconstruction
Jet reconstruction
$b$-tagging

Results
Conclusions

Work in progress

Jet $p_\perp$ spectrum

$\Rightarrow$ except in second bin, the agreement looks alright
**Combined Secondary Vertex**

Result of a MVA combining

1. **Track-Counting**: reject secondary vertices whose tracks are to close to the primary vertex
2. **Simple-Secondary-Vertex-Mass**: reject other meson candidates than $B$-mesons
3. **Soft-Lepton-Tag**: look for a non-isolated lepton in the jet

⇒ medium working point at 0.679
Application on the $p_{\perp}$ spectrum

anti-$k_{\perp}$ (R = 0.4)

CMS Data

Pythia 8
Early results

Selection

- $p_{\perp} > 114$ GeV
- $|y| < 2.5$
- CSV > 0.679
- anti-$k_{\perp}$ with $R = 0.4$

Caution
Results at detector level, without treatment of systematic and model uncertainties yet!
Ratio data over Monte Carlo

anti-$k_T$ ($R = 0.4$) \[ \int L \, dt = 575 \text{ pb}^{-1} \]

- CSV $> 0.679$
  - $b$-jets
  - Jets

$|y| < 0.5$
$0.5 < |y| < 1.0$
$1.0 < |y| < 1.5$
$1.5 < |y| < 2.0$
$2.0 < |y| < 2.5$

$p_T$ [GeV]

⇒ SF for $b$-jets to be applied, otherwise good agreement

Work in progress
Fraction of $b$-jets among jets

\[ \text{Fraction of } b\text{-jets among jets} \]

\[ \frac{b\text{-jet}}{\text{inclusive jet}} \]

\[ |y| < 0.5 \]

\[ 0.5 < |y| < 1.0 \]

\[ 1.0 < |y| < 1.5 \]

\[ 1.5 < |y| < 2.0 \]

\[ 2.0 < |y| < 2.5 \]

\[ p_T \geq 200 \text{ GeV}, 1000 \text{ GeV} \]

\[ CMS \text{ Data}, \text{Pythia 8} \]

\[ \Rightarrow \text{same conclusion} \]
Leading and subleading $b$-jets

\(\text{anti-}k_{\perp} \ (R = 0.4)\)
\[\int L \, dt = 575 \text{ pb}^{-1}\]
\[\text{CSV} > 0.679\]

\[\begin{array}{c}
\text{CMS Data / Pythia 8} \\
\text{leading jet} \\
\text{subleading $b$-jet} \\
\text{third jet}
\end{array}\]

\[\Rightarrow \text{enough statistics for at least 2-}$b$-jet studies\]
Conclusions

Summary

- $b$’s can help study two-scale effects of the evolution.
- Previous measurements can already be reproduced at the TeV scale.
- The CMS experiment will soon provide enough luminosity to have a sufficient resolution to study two-scale effects.

Outline

- Improvement of the detector simulation in the MC (correction scale factors for $b$-jets).
- Correction of the detector effects on the data (unfolding).
- Improvement of the pile-up treatment using data-driven methods.
- Treatment of model and systematic uncertainties.
References

anti-$k_{\perp}$ algorithm The anti-$k_t$ jet clustering algorithm, Matteo Cacciari and Gavin P. Salam, [arXiv:0802.1189v2]

Jet calibration CMS Performance note CMS DP-2-1012/012


TMDs http://tmdplotter.desy.de