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

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Standard Model

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

### Meson Content

<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>$(B_s^0)$</td>
<td>$sb$</td>
<td>$5366.79 \pm 0.23$</td>
<td>$1.510 \pm 0.005$</td>
</tr>
</tbody>
</table>

$\Rightarrow \lambda \approx 2\text{ mm at CMS for heavily boosted } B$'s
Motivation

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

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

\[ p^2 = 25 \text{ GeV}^2 \quad x = 0.1 \]
b-inclusive production

As a function of $p_\perp$ in bins of rapidity:

- ratio data/MC
- fraction of $b$-jets in the inclusive jet production

⇒ textbook measurements *par excellence*!
Leading and subleading $b$-jet production

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

- bunch crossing at LHC
- Pythia 8
- Geant 4

Reconstruction:
- hits + energy deposits

Jet clustering:
- anti-kt algorithm
  - jets

Jet calibration:
  - corrected jets

b-tagging:
  - CSV
  - b-jets
**Introduction**

**Motivation**

**Goals of the analysis**

**Measurement**

**Event reconstruction**

**Jet reconstruction**

**b-tagging**

**Results**

**Conclusions**

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**Machine acceptance**

**Rapidity**

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

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**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)

\[ d_{iB} = \frac{1}{k_{\perp i}} \]  

\[ d_{ij} = \min \left( \frac{1}{k_{\perp i}^2}, \frac{1}{k_{\perp j}^2} \right) \Delta R_{ij}^2 \frac{R^2}{\Delta R^2} \]  

where \[ \Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2 \]

\[ \rightarrow \] 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.
Jet $p_\perp$ spectrum

Work in progress

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

Work in progress

\[ \Rightarrow \text{medium working point at } 0.679 \]
Application on the $p_\perp$ spectrum

Work in progress

anti-$k_\perp$ (R = 0.4)
CMS Data
Pythia 8

CMS Data
Pythia 8
mind the scale!
Early results

Selection

- $p_{\perp} > 114 \text{ GeV}$
- $|y| < 2.5$
- 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

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

\[\text{CSV} > 0.679\]

⇒ SF for \(b\)-jets to be applied, otherwise good agreement
Fraction of $b$-jets among jets

$$\text{anti-}k_\perp (R = 0.4) \quad \int \mathcal{L} \, dt = 575 \text{ pb}^{-1}$$

CMS Data

Pythia 8

$|y| < 0.5$

$0.5 < |y| < 1.0$

$1.0 < |y| < 1.5$

$1.5 < |y| < 2.0$

$2.0 < |y| < 2.5$

$\Rightarrow$ same conclusion
Leading and subleading $b$-jets

\begin{align*}
\text{anti-}k_\perp \ (R = 0.4) & \quad \int L \ dt = 575 \ \text{pb}^{-1} \\
\text{CSV} > 0.679 & \quad \bullet \ b\text{-jets} \quad \triangle \ \text{jets}
\end{align*}

![Graph showing CMS Data / Pythia 8 comparison for leading and subleading $b$-jets.]

⇒ 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

**b-tagging** Identification of b-quark jets with the CMS experiment, CMS Collaboration, [arXiv:1211.4462v2]

Performance of b-tagging algorithms at the CMS experiment with pp collision data at $\sqrt{s} = 8$ TeV [arXiv:1409.0251v1]

**TMDs** http://tmdplotter.desy.de