Low $P_T$ heavy flavour production at CMS and ZEUS

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ZEUS results

- selection algorithm
- inclusive production $ep \rightarrow e^\prime b \bar{b} \rightarrow e^\prime \mu \mu X$

CMS results

- charm study: $D^0, D^*\,\text{mesons}$
- beauty study: non-prompt $J/\psi\,\text{mesons}$

Now focusing on the ZEUS analysis

Continue Danny Bot analysis

Using secondary vertices

More statistics in HERA II

CMS-BPH-11-022

LHCb paper: arXiv:1306.3663
DATA: \( ep \) all HERA II

Energy CAL: \( E_T \geq 8 \) GeV

**Muon selection:**
- \( N_\mu \geq 2 \)
- \( p_{t\mu} > 0.75 \) GeV (\( \mu_{\text{qual}} \geq 5 \))
- \( p_{t\mu} > 1.5 \) GeV (\( \mu_{\text{qual}} = 4 \))

**DL significance distribution** give us additional tool for the separation beauty signal

- clear visible that distribution is antisymmetric
- beauty signal is dominating on the right part
Differential cross section in $P_{t\mu}$ bins (ZEUS)

Comparison with MC predictions

- Differential CS shape is in good agreement with QCD predictions.
- Scale factor for theory is 1.9

For both $\mu$:
- $p_{T\mu} > 1.5$
- $-2.2 < \eta < 2.5$
- $N_\mu > 2$ (for each event)

$p_T$ shape by LO+PS
MC well described
**Algorithm description (CMS)**

**ZEUS like** track based and low $P_T$ algorithm description:

- Works well for ZEUS → use it for CMS studies
- Select all tracks from the PV (with Beam Spot constraint)
- Select high $P_T$ separated (axis) tracks
- For each axis select closest track collection with $P_T > 0.5$ GeV/c
- Fit vertex candidate (ZEUS, CMS vertex fitter)
- Decay Length calculation (projection on the axis in XY plane)
- Extract beauty signal

**Event display:** algorithm example, one event

**CMS event display:**

**Formulas:**

\[
\cos (\vec{L}_{xy}, \vec{P}_{Taxis}) = \frac{(\vec{L}_{xy} \cdot \vec{P}_{T})}{|\vec{L}_{xy}| |\vec{P}_{T}|}
\]

\[
L_{xy}^{axis} = \cos (\vec{L}_{xy}, \vec{P}_{Taxis}) |\vec{L}_{xy}| = \frac{(\vec{L}_{xy} \cdot \vec{P}_{T})}{|\vec{P}_{T}|}
\]

\[
dL_{xy}^{axis} = \vec{P}_{T} \cdot (M_{PV}^{cov} + M_{SV}^{cov}) \cdot \vec{P}_{T}
\]
$b \rightarrow B \rightarrow D^{*+}$

$D^{*+} \rightarrow D^{0} \pi^{+}_{s}$

$c \rightarrow D^{*+}$

$D^{0} \rightarrow K^{-} \pi^{+}$

$D^{*+} \rightarrow K^{-} \pi^{+} \pi^{+}_{s}$

**DATA sample:**
- 2010 Open Data
- MinBias sample

**Selection cuts:**

**General requirements:**
- 3 tracks

**Pt cuts:**
- $P_{T}(D^{*}) > 3.5$ GeV/c
- $K(D0), \pi(D0) : P_{T} > 1$ GeV/c
- $\pi^{+}(D^{*}) : P_{T} > 0.25$ GeV/c
- $z = P_{T}(D^{*})/\Sigma P_{T}(tracks) > 0.05$

**Mass cuts:**
- $| M(D^{*}) - M(D^{0}) - 0.1454 \text{ (PDG)} | < 0.001$ GeV/c$^{2}$

**Similar to ATLAS paper:**
- arXiv:1512.02913
Decay Length calculation (CMS)

- Decay length for D0 candidates calculated
- Mirrored left part and normalized side bands of the D\(^0\) peak are in good agreement
- Visible possibility to introduce new DL cut: 0.2 mm
Mass distribution shows strong background reducing.

In the same time signal decreased in 2 times.

As expected with new DL cut, Signal/BG ratio in much higher.
Follow the publication:
CMS-BPH-10-002

**DATA sample:**
- 2010 Open Data
- Muonia sample

**General requirements:**
- 2 tracks
- Valid hits > 11, PixelHits > 1
- Track \( \chi^2/\text{ndof} < 4 \)
- IsGoodMuon
- IsTrackerMuon

**Muon momentum cuts:**
- \(|\eta| > 1.3, P_T > 3.3 \text{ GeV/c}\)
- \(1.3 < |\eta| < 2.2, P > 2.9 \text{ GeV/c}\)
- \(2.2 < |\eta| < 2.4, P_T > 0.8 \text{ GeV/c}\)

- for this analysis we are interested in non-prompt \(J/\psi\)-mesons.
- \(b\)-hadrons could produce one and it is possible to separate them from prompt using decay length distribution.
Decay length calculated in *two rapidity* bins with *different* $P_T$ cut:

- Decay length for $J/\psi$ candidates calculated
- Distributions are in good agreement with distributions from the publication
- Analysis prepared with higher statistic
- Observe indication of $J/\psi$ from the $b$ hadrons

**Work in progress**

2010 Open Data

**CMS-BPH-10-002:**
Conclusions:

- the technique which allow us to go to the minimal threshold in $P_T$ introduced
- results from ZEUS experiment presented
- CMS open data have been used. Anyone can use it!
- charm contribution studied on $D^0, D^*$ examples (CMS)
- beauty contribution study is in progress (CMS)
  - non-prompt $J/\psi$ candidates studied
  - good agreement with the public results
- clear possibility to use DL significance distribution down to low $P_T$ for the S/BG separation
- the technique allows us to extend any heavy flavour analysis correspondingly

Plans: (CMS)

- use the ZEUS technique to extract $b$ events from minBias-like event sample
- add the use of MC
- measure total and differential beauty cross section down to $P_T \sim 0$ GeV

Thanks for your attention!
**ZEUS event selection**

- **DATA:**
  
  V02e : 0304p, 05e, 06e, 0607  \((376 \pm 6.5) \text{ pb}^{-1}\)

- **MC samples:**
  
  Inclusive Charm and Beauty (PYTHIA)
  
  Inelastic J/\(\psi\) and \(\psi'\) (HERWIG), inelastic \(\Upsilon\) (PYTHIA)
  
  Elastic quarkonia – DIFFVM. BH processes – GRAPE

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**Event selection:**

- Energy CAL: \(E_T \geq 8 \text{ GeV}\)
- \(|z_{vtx}| < 30 \text{ cm and } \sqrt{x_{vtx}^2 + y_{vtx}^2} < 3 \text{ cm; }\)

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**Muon selection:**

- \(N_\mu \geq 2\)
- \(p_t^{\mu} > 0.75 \text{ GeV } (\mu_{\text{qual}} \geq 5)\)
- \(p_t^{\mu} > 1.5 \text{ GeV } (\mu_{\text{qual}} = 4)\)
- Difference in \(\eta\): \(|\eta^{\mu_1} - \eta^{\mu_2}| < 3.0\)
- Invariant mass: \(m_{\mu\mu_{\text{inv}}} > 1.5 \text{ GeV}\)
- Muon \(E_T\) fraction cuts

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**Background cuts (cosmic rejection):**

- \(T_{\text{CAL}} < 10 \text{ ns}\)
- \(E_{\text{BAC}} < 100 \text{ GeV or } N^{\mu}_{\text{BAC}} < 15\)
- \(|\phi^{\mu_1} - \phi^{\mu_2} - \pi| < \pi/200\)
- \(|\theta^{\mu_1} - (\pi - \theta^{\mu_1})| < \pi/200\)
-- at least 3 tracks;
-- Kaon(D0), Pt > 0.5 GeV/c;
-- Pion(D0), Pt > 0.5 GeV/c;
-- D0 (Kaon and Pion) come from cylinder, R = 0.1 cm, L = 0.1 cm;
-- |D0 mass calculated - 1.9| < 0.3 ;
-- D* (D0 and SlowPion) come from cylinder, R = 0.1 cm, L = 0.1 cm;
-- D*-D0 mass < 0.17 GeV/c2
-- all tracks from D* cylinder : get Sum Pt; z = D*pt/SumTracksPt;
-- z > 0.05;

* ATLAS cuts:
-- D*pt > 3.5 GeV/c
-- Kaon(D0), Pt > 1 GeV/c;
-- Pion(D0), Pt > 1 GeV/c;
-- SlowPion (D*), Pt > 0.25 GeV/c;
-- |dM(D0 and D*) - 0.1454 (PDG)| <0.001 GeV/c2;

* D0 regions with 0.05 GeV/c2 width:
-- peack : |dM(D0 and D0pdg )| < 0.025 GeV/c2
-- left : |dM(D0 and D0pdg )| < 1.8 && > 1.75 GeV/c2;
-- right : |dM(D0 and D0pdg )| < 1.98 && > 1.93 GeV/c2;

\[
D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow K^- \pi^+ \pi_s^+ \\
\]

\[
D^* \left\{ \begin{array}{c}
\bar{d} \\
\bar{u} \\
\end{array} \right\} \pi^+ \\
D^0 \left\{ \begin{array}{c}
c \\
u \\
\end{array} \right\} \pi^+ \\
2 \\
D^0 \left\{ \begin{array}{c}
d \\
s \\
\end{array} \right\} K^- 
\]