Measurement of Beauty production at HERA
Using Events with Muons and Jets

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Apr 29, 2005
DIS2005 Conference, Madison
**Beauty production at HERA**

**Key questions/points:**

- Are available pQCD calculations in Next-to-leading order good enough?

- Multi-hard scale problem in pQCD: 
  \[ [\alpha_s \ln(Q^2/m_b^2)]^n \text{ terms} \]
  → pQCD approximations: Massive and Massless schemes (and variable s.)

- Probe hard scales over wide range:

<table>
<thead>
<tr>
<th>Kinematic region</th>
<th>Hard scales</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma p$: $Q^2 &lt; 1 \text{ GeV}^2$</td>
<td>$m_b, p_T^b$</td>
</tr>
<tr>
<td>DIS: $Q^2 &gt; 1 \text{ GeV}^2$</td>
<td>$m_b, Q^2, p_T^b$</td>
</tr>
</tbody>
</table>
Production rates at HERA

Total production rates at HERA:

\[ \sigma_{uds} : \sigma_{charm} : \sigma_{beauty} \sim 2000 : 200 : 1 \]

Main reason for Beauty suppression: phasespace!

**Kin. Threshold:**

\[ X_g \geq \frac{m_Q^2}{E_\gamma \cdot 920 \text{ GeV}} \]

- **c:** \( X_g \geq 10^{-4} \)
- **b:** \( X_g \geq 10^{-3} \)
Beauty Tag with muon and jets

Separate Beauty from c and uds:

- Large b mass $\rightarrow$ Large Muon $p_T^{rel}$
- Long b lifetime $\rightarrow$ Large Muon Impactpar. $\delta$
In the following focus on results from the new H1 paper hep-ex/0502010

This measurement covers both $\gamma p$ and DIS
$\delta$ and $p_t^{rel}$ in $\gamma p$ sample ($\approx 1750$ events)

Likelihood fit to 2-dimensional $(\delta, p_T^{rel})$ distribution:

$\rightarrow f_b \sim 30\%$
Beauty in $\gamma p$: vs muon pseudorapidity

\[ d\sigma/d\eta_\mu \ (ep \rightarrow eb\bar{b}X \rightarrow ejj\mu X) \]

- $Q^2 < 1$ GeV$^2$
- $0.2 < y < 0.8$
- $p_T^\mu > 2.5$ GeV
- $p_T^{\text{jet1(2)}} > 7(6)$ GeV
- $|\eta^{\text{jet}}| < 2.5$

H1

Data

NLO QCD $\otimes$ Had

NLO QCD

$\Rightarrow$ Flat distribution

Massive NLO (FMNR):

- somewhat too low
- describes shape
Beauty in $\gamma p$: vs $p_t^\mu$

$\frac{d\sigma}{dp_t^\mu}(ep \to e\bar{b}X \to ejj\mu X)$

- **Data**
- **NLO QCD $\otimes$ Had**
- **NLO QCD**

- $Q^2 < 1 \text{ GeV}^2$; $0.2 < y < 0.8$
- $p_{t,\text{jet}(1)} > 7(6) \text{ GeV}$; $|\eta_{\mu}| < 2.5$
- $-0.55 < \eta^\mu < 1.1$

⇒ Steep drop-off

⇒ NLO too low at low $p_t^\mu$
Comparison of H1 and ZEUS $\gamma p$ results

Good agreement
H1 vs ZEUS

ZEUS: No excess at low $p_t^\mu$
Beauty in DIS: vs. Muon $p_T$ and $\eta$

$Q^2 > 2$ GeV$^2$, $0.1 < y < 0.7$

$p_t^\mu > 2.5$ GeV

$p_{t,\text{jet}}^{\text{Breit}} > 6$ GeV

Massive NLO (HVQDIS): Too low at low $p_T^\mu$

Massive NLO: Too low in forward direction
**Beauty in DIS: Compare H1 and ZEUS results**

**H1**
- **Data**
- **NLO QCD ⊗ Had**
- **NLO QCD**

**ZEUS**
- **ZEUS 99-00**
- **NLO QCD ⊗ Had.Corr.**
- **NLO QCD (HVQDIS)**

- $0.05 < y < 0.7$
- $-0.9 < \eta^\mu < 1.3$, $p_T^\mu > 2$ GeV
- $1.6 < \eta^\mu < -0.9$, $p_T^\mu > 2$ GeV
- $E_{T,jet} > 6$ GeV, $-2 < \eta_{jet} < 2.5$

$\Rightarrow$ Good agreement
Recent HERA beauty results vs. $Q^2$

Ratio Data/Massive NLO

$\sigma^{b\bar{b}} / \sigma_{\text{NLO QCD}}$

**H1 and ZEUS:**
Muon + Jets

**H1:**
incl. Lt-Tag

$\Rightarrow$ Data syst. above massive NLO
First HERA beauty results (Situation in 2001)

\[ \sigma^\text{vis} (\text{ep} \rightarrow b \ X) \]

- H1 \( \mu \) \( p_T^{\text{rel}} \)
- H1 \( \mu \) impact param. (prel.)
- ZEUS \( e^- p_T^{\text{rel}} \)

Why is the excess larger for the first H1 measurements???

For the first H1 measurements:

- Data were extrapolated from the Muon+jets level to the Muon level using leading order AROMA MC and then compared to NLO. Reinvestigation \( \rightarrow \) LO and NLO extrapolation consistent, no problem

- Softer \( p_T^{\text{Jet}} \) and \( p_T^\mu \) cuts applied (e.g. \( p_T^\mu > 2 \text{ GeV} \) instead of \( 2.5 \text{ GeV} \)) \( \rightarrow \) different kinematic phasespace!
NLO calculations: How it is done today to compare with HERA data: Example: HVQDIS

- Apply purely longitudinal Peterson fragmentation to b-quark
- Fragmented b-quark is ‘decayed’ using muon decay spectrum (e.g. from JETSET)
- Apply hadronisation corrections for parton jets using MC

⇒ Kniehl et al.: Fragmentation is arbitrary → what is the uncertainty?
⇒ Fragm., Muon-decay and Hadronisation corr. for parton jets → All sources for considerable syst. uncertainties of calculation!
Improved NLO calculations available with e.g. more consistent
treatment of fragmentation

\[ |y(J/\psi)| < 0.6 \]

Points: CDF
Curves: FONLL
Dashed: MC@NLO

⇒ Much improved description!
We want to have the improved models for HERA too!
Conclusions

- Recent results on B-production at HERA with Muons and Jets:
  - Generally good agreement between H1 and ZEUS data
  - Data are systematically above predictions from Massive NLO
  - Trend: Data above NLO at small hard scales $p_t^b$, $Q^2$ and in forward direction
  - Need for improved models: Theoreticians: Please provide them, e.g. MC@NLO!
Backup slides
## Beauty with muon and jets: Theory models

### Leading order +P.S. MC’s

<table>
<thead>
<tr>
<th></th>
<th>PYTHIA</th>
<th>RAPGAP</th>
<th>CASCADE</th>
<th>FMNR</th>
<th>HVQDIS</th>
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<tbody>
<tr>
<td><strong>Version</strong></td>
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<td>2.8</td>
<td>1.00/09; 1.2</td>
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<td><strong>Proton PDF</strong></td>
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<td>$\Lambda_{QCD}^{(4)}$ [GeV]</td>
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<td>0.326</td>
<td>0.309</td>
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<tr>
<td><strong>Renorm. scale</strong> $\mu_r^2$</td>
<td>$m_q^2 + p_{iqq}^2$</td>
<td>$Q^2 + p_{iqq}^2$</td>
<td>$\hat{s} + p_{iqq}^2$</td>
<td>$m_b^2 + p_{tbb}^2$</td>
<td>$m_b^2 + p_{tbb}^2$</td>
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<tr>
<td><strong>Factor. scale</strong> $\mu_f^2$</td>
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<td>$\hat{s} + Q_f^2$</td>
<td>$m_b^2 + p_{tbb}^2$</td>
<td>$m_b^2 + p_{tbb}^2$</td>
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<tr>
<td>$m_b$ [GeV]</td>
<td>4.75</td>
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<td>Peterson $\epsilon_b$</td>
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### Massive NLO