Recent results on Charmonium production at HERA

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Outline

- HERA and ZEUS
- Diffractive vector meson production at HERA
- Data selection and signal extraction
- Results
HERA and ZEUS

**HERA:** ep collider

- Colliding beams:
  - 920 GeV $p$ and 27.5 GeV $e^\pm$
  - $\sqrt{s} = 318$ GeV
- Data taking: 1992 - 2007

**ZEUS** – hermetic multipurpose detector
- Total collected luminosity: $\sim 0.5$ fb$^{-1}$
Diffractive vector meson (VM) production at HERA

elastic (exclusive)

proton-dissociative

\[ Q^2 \text{ — photon virtuality} \]
\[ Q^2 < 1 \text{ GeV}^2 — \gamma p \]
\[ Q^2 \geq 1 \text{ GeV}^2 — \text{DIS} \]

\[ W \text{ — photon-proton CMS energy} \]

\[ t \text{ — 4-mom. transfer squared at proton vertex} \]

\[ Q^2 = - q^2 = - (k - k')^2 \]

\[ W^2 = (q + P)^2 \]

\[ t = (P - P')^2 \]
Measurement of the cross-section ratio $\frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi(1S)}}$ in DIS gives information about the dynamics of hard process sensitive to radial wave function of charmonium.

\[ R = \frac{\sigma_{\gamma p \rightarrow \psi(2S)p}}{\sigma_{\gamma p \rightarrow J/\psi(1S)p}} \] 

\[ \psi(2S) \text{ wave function different from } J/\psi(1S) \text{ wave function:} \]

- Has a node at $\approx 0.35$ fm
- $\langle r^2 \rangle_{\psi(2S)} \approx 2 \langle r^2 \rangle_{J/\psi(1S)}$

pQCD model calculations predicts $R \sim 0.17$ (PhP) and rise of $R$ with $Q^2$ (DIS)
Investigated channels and samples

\[ \psi(2S) \rightarrow J/\psi \pi^+ \pi^-; \ J/\psi \rightarrow \mu^+ \mu^- \]

\[ \psi(2S) \rightarrow \mu^+ \mu^- \]

\[ J/\psi(1S) \rightarrow \mu^+ \mu^- \]

Data samples

HERA II data (2003 — 2007)
Integrated luminosity: 354 pb\(^{-1}\)

MC-data samples

**Signal MC:** DIFFVM for exclusive VM production

**Background MC:** GRAPE for Bethe–Heitler mu-pair production
\[ \psi(2S) \rightarrow \mu^+\mu^- \text{ and } J/\psi(1S) \rightarrow \mu^+\mu^- \]

- Scattered e with \( E > 10 \text{ GeV} \) reconstructed in CAL
- Scattered \( p \) undetected
- Two reconstructed tracks identified as muons
  
  \[ \text{and for } \psi(2S) \rightarrow J/\psi \, \pi^+\pi^- \text{ additionally two pion tracks from } \mu\mu \text{ vertex} \]
- Nothing else in detector (above noise)

30 \leq W \leq 210 \text{ GeV}  
5 \leq Q^2 \leq 70 \text{ GeV}^2  
|t| \leq 1 \text{ GeV}^2
Background subtraction

Sideband of the signal: $2 < M_{\mu\mu} < 2.62$ GeV and $4.05 < M_{\mu\mu} < 5$ GeV

fitted by straight line
\( \psi(2S) \rightarrow J/\psi(1S) \pi^+ \pi^- \)

- ZEUS (prel.) 354 pb\(^{-1}\)

\[ \Delta M = M_{\mu\mu\pi\pi} - M_{\mu\mu} \]

\[ 3.02 < M_{\mu\mu} < 3.17 \text{ GeV} \]

\[ 0.5 < \Delta M < 0.7 \text{ GeV} \]

After cut on \( M_{\mu\mu} \)

\[ \leq 3 \text{ events background} \]
Data-MC comparison for $J/\psi(1S)$

Good description of the data by the weighted Monte Carlo

- $J/\psi(1S) \rightarrow \mu^+ \mu^-$
- ZEUS (prel.) 354 pb$^{-1}$
- DIFFVM + BH
- BH

MC weighted in $Q^2$, $|t|$ and $J/\psi(1S)$ decay angles to match the data
Data-MC comparison for $\psi(2S) \rightarrow \mu^+ \mu^-$

Good description of the data by the weighted Monte Carlo

$\psi(2S) \rightarrow \mu^+ \mu^-$
- ZEUS (prel.) 354 pb$^{-1}$
- DIFFVM + BH
- BH

MC weighted in $Q^2$, $|t|$ and $\psi(2S)$ decay angles using $J/\psi(1S) \rightarrow \mu^+ \mu^-$ weights
Data-MC comparison for 
\( \psi(2S) \rightarrow J/\psi \, \pi^+ \pi^- \)

Good description of the data by the weighted Monte Carlo
σ(ψ(2S))/σ(J/ψ(1S))
in full kinematic range

<table>
<thead>
<tr>
<th>ψ(2S) decay mode</th>
<th>σ(ψ(2S))/σ(J/ψ(1S))</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ J/ψ(→ µ⁺µ⁻)π⁺π⁻</td>
<td>0.29 ± 0.04^{+0.02}_{-0.01}</td>
</tr>
<tr>
<td>→ µ⁺µ⁻</td>
<td>0.25 ± 0.05^{+0.04}_{-0.02}</td>
</tr>
<tr>
<td>combined</td>
<td>0.28 ± 0.03^{+0.02}_{-0.01}</td>
</tr>
</tbody>
</table>

Both ratio measurements agree

30 ≤ W ≤ 210 GeV
5 ≤ Q^2 ≤ 70 GeV^2
|t| ≤ 1 GeV^2

Method

\[ R_{\psi(2S)→J/ψπ^+π^-} = \frac{\sigma_{\psi(2S)}}{\sigma_{J/ψ(1S)}} = \frac{N_{\psi(2S)}}{N_{J/ψ(1S)}} \cdot \frac{Acc_{J/ψ(1S)→µ^+µ^-}}{Acc_{ψ(2S)→J/ψπ^+π^-}} \cdot \frac{1}{BR_{ψ(2S)→J/ψπ^+π^-}} \]

\[ R_{\psi(2S)→µ^+µ^-} = \frac{\sigma_{\psi(2S)}}{\sigma_{J/ψ(1S)}} = \frac{N_{\psi(2S)}}{N_{J/ψ(1S)}} \cdot \frac{Acc_{J/ψ(1S)→µ^+µ^-}}{Acc_{ψ(2S)→µ^+µ^-}} \cdot \frac{1}{BR_{ψ(2S)→µ^+µ^-}} \]

BR(ψ(2S)→J/ψπ⁺π⁻) = (33.6 ± 0.4) %
BR(J/ψ→µ⁺µ⁻) = (5.93 ± 0.06)%

\[ Acc_i = \frac{N_i^{reco}}{N_i^{true}} \]
\[ \frac{\sigma(\psi(2S))/\sigma(J/\psi(1S))}{Q^2, W \text{ and } |t|} \]

**ZEUS**

- Indication of an increase with \(Q^2\)
- Independent of \(W\)
- Independent of \(|t|\)
• ZEUS data analysed in $Q^2$ bins used by H1
  ($Q^2$: 5 — 12 and 12 — 80 GeV$^2$)

Results agree - $\sigma(\psi(2S))/\sigma(J/\psi(1S))$ increases with $Q^2$

Significantly improved accuracy thanks to increased integrated luminosity

H1 collaboration:
Summary and outlook

- Using HERA II data $\sigma(\psi(2S))/\sigma(J/\psi(1S))$ in exclusive DIS has been measured for the first time by ZEUS in the kinematic range: $30 \leq W \leq 210$ GeV, $5 \leq Q^2 \leq 70$ GeV$^2$, $|t| \leq 1$ GeV$^2$

- The accuracy has been improved compared to the H1 HERA I results

- $\sigma(\psi(2S))/\sigma(J/\psi(1S))$: increases with $Q^2$ and independent of $W$ and $|t|$
Thank you very much for your attention!