Inelastic x-section and its impact on L

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For joint CDF-D0 committee
(M. Begel, S. Klimenko, J. Konigsberg, T. Liss, H. Shellman,....)

- Tevatron Luminosity
- Reference process
- Problem with the value of the inelastic x-section
- Analysis of the CDF and E811 measurements
- Average x-section
- Impact on CLC luminosity
- Summary
Reference process: inelastic PPbar scattering

- Luminosity measurement

\[ R_{pp} = \mu_{pp} \cdot f_{BC} = \sigma_{\text{inel}} \cdot \varepsilon_{pp} \cdot \delta(L) \cdot L \]

- CLC established uncertainties of 
\[ \varepsilon_{pp}(4\%) \text{ and } R_{pp} (1.8\%) \]

- What is uncertainty on the inelastic x-section?
  - In Run I CDF used the CDF measurement of \( \sigma_{\text{in}} \).
ineelastic Ppbar x-section

- L independent measurement of total PPbar x-section
  
  \[(1 + \rho^2) \cdot \sigma_{tot} = 16\pi(\hbar c)^2 \frac{dN_{el} / dt|_{t\to0}}{N_{el} + N_{inel}}\]

- Inelastic cross-section @ 1.8TeV
  

  measured using the optical theorem, along with the total & elastic x-sections

What \(\sigma_{inel}\) to use? Run I: CDF(BBC), DØØ( world); Run II (CDF&E811 ?)

What is the error for \(\sigma_{inel}\)? CDF&E811 combined: ~4%

- "poor agreement" between all three measurements.
- For Run II CDF & DØ do not quote the error associated with \(\sigma_{inel}\) yet
- Joint committee is working on this issue
Do CDF and E811 disagree?

- \( \sigma_{in}(CDF) \) and \( \sigma_{in}(E811) \) are compatible at 2.3\( \sigma \).

\[
\sigma_{tot} = 16\pi(hc)^2 \frac{b}{1 + \rho^2} \frac{N_{el}}{N_{el} + N_{in}}
\]

\[
b = \frac{1}{N_{el}} \left. \frac{dN_{el}}{dt} \right|_{t \to 0}
\]

\[
\sigma_{in} = 16\pi(hc)^2 \frac{b}{1 + \rho^2} \frac{N_{el}N_{in}}{(N_{el} + N_{in})^2} = 16\pi(hc)^2 \frac{b}{1 + \rho^2} \frac{R}{(1 + R)^2}
\]

- E811 used the same value of \( b \)
- Therefore compare the ratio of the inelastic and elastic rates

<table>
<thead>
<tr>
<th></th>
<th>CDF</th>
<th>E811</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{el} )</td>
<td>78691 ± 1463</td>
<td>508.1K ± 3.5K</td>
</tr>
<tr>
<td>( N_{in} )</td>
<td>240982 ± 2967</td>
<td>1799.5K ± 57.2K</td>
</tr>
<tr>
<td>( R )</td>
<td>3.062 ± 0.068</td>
<td>3.542 ± 0.113</td>
</tr>
<tr>
<td>( b )</td>
<td>16.98 ± 0.25</td>
<td>16.98 ± 0.22</td>
</tr>
</tbody>
</table>

- Discrepancy for \( R \) at 3.6 standard deviations!
“Single diffractive rate problem”

- Rates measured by CDF:
  a) elastic-$N_{el}$, b) double_arm-$N_2$ c) single_arm $X p - N_{sd}$

- Rates measured by E811:
  a) elastic-$N_{el}$, b) double_arm-$N_2$ c) single_arm - $N_1$

\[ x = \frac{N_2}{N_{el}}, \quad y = \frac{N_1}{N_{el}}, \quad R = x + y \]

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<td>$x$</td>
<td>$2.638 \pm 0.058$</td>
<td>$2.657 \pm 0.023$</td>
</tr>
<tr>
<td>$y$</td>
<td>$0.424 \pm 0.021$</td>
<td>$0.885 \pm 0.115$</td>
</tr>
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</table>

“obvious” conclusion: “E811 measures too many single diffractive events”. Why? “E811 has a background of 93% in single arm rate. Quite possible it was incorrectly estimated” wrong conclusion, because CDF and E811 detector acceptances are different
What is the problem?

- Need to compare the number of “non-diffractive” and single diffractive events corrected for acceptances.

\[ \varepsilon_2(CDF) \approx 98.7\%, \quad \varepsilon_2(E811) = 88.85 \pm 2.0\% \]

- The E811 single-arm rate had a lot of “non-diffractive” events missed by the two-side inelastic trigger

\[ N_{nd} = N_2 / \varepsilon_2, \quad N_{sd} = N_2 (r + \delta - \frac{1-\varepsilon_2}{\varepsilon_2}). \]

\( r \) and \( \delta \) were measured in a special run

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<td>( N_{nd} )</td>
<td>203200 \pm 2558</td>
<td>1519.7K \pm 34.9K</td>
</tr>
<tr>
<td>( N_{sd} )</td>
<td>37782 \pm 1770</td>
<td>279.8K \pm 36.3K</td>
</tr>
<tr>
<td>( N_{nd}/N_{el} )</td>
<td>2.582\pm0.058</td>
<td>2.991\pm0.069</td>
</tr>
<tr>
<td>( N_{sd}/N_{el} )</td>
<td>0.480\pm0.029</td>
<td>0.551\pm0.072</td>
</tr>
<tr>
<td>( N_{sd}/N_{nd} )</td>
<td>0.186\pm0.009</td>
<td>0.184\pm0.024</td>
</tr>
</tbody>
</table>

Conclusion: the E811 single diffractive rate seems to be O’K. We can’t isolate the problem.
How to average the x-section?

- To average two incompatible measurements we have to ignore the accurate error analysis done by both experiments and inflate the systematic error.

- Procedure:
  - Find average value: $\bar{R} = fR_1 + (1 - f)R_2$
  - by minimization of its variance: $\text{var}(\bar{R}) = FCF^T$, $F = (f, 1 - f)$
  - covariance matrix: $C = \begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\alpha \\ \sigma_1\sigma_2\alpha & \sigma_2^2 \end{bmatrix}$
  - Calculate $\chi^2$: $\chi^2 = R_1^2 / \sigma_1^2 + R_2^2 / \sigma_2^2$
  - If $\chi^2$ indicates disagreement $\Rightarrow$ inflate the average variance $\text{var}(\bar{R}) \Rightarrow \text{var}(\bar{R}) \cdot \chi^2$
Averaging of $R$

- Average $R$ and calculate x-sections using
  \[ \sigma_{in} = 16\pi(hc)^2 \frac{b}{1 + \rho^2} \frac{\bar{R}}{(1 + \bar{R})^2} \]

- Method A: ignore correlation between $b$ and $R$ \(\Rightarrow \alpha = 0\).
  
  average $R = 3.19 \pm 0.06$, \(\chi^2 = 13.2 \Rightarrow \) average $R = 3.19 \pm 0.21$
  
  \[ \overline{\sigma}_{in} \cdot (1 + \rho^2) = 60.4 \pm 2.3mb \]

- Method B: estimate $\alpha$ from simulation assuming gaussian errors and
  \[ R = \frac{N_{in}}{n_{el}} \left( \exp(-bt_{\min}) - \exp(-bt_{\max}) \right) \]

  $\alpha = -0.09$, average $R = 3.20 \pm 0.06$, \(\chi^2 = 12.3 \Rightarrow \) average $R = 3.20 \pm 0.20$
  
  \[ \overline{\sigma}_{in} \cdot (1 + \rho^2) = 60.3 \pm 2.2mb \]
Averaging of x-sections itself

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<tr>
<td>Quoted $\sigma_{tot}$, mb</td>
<td>80.03 ± 2.25</td>
<td>71.71 ± 2.02</td>
</tr>
<tr>
<td>Derived $\sigma_{tot}(R,b)$ mb</td>
<td>80.03 ± 2.17</td>
<td>71.70 ± 1.90</td>
</tr>
<tr>
<td>Quoted $\sigma_{irr}$ mb</td>
<td>60.33 ± 1.40</td>
<td>55.92 ± 1.19</td>
</tr>
<tr>
<td>Derived $\sigma_{irr}(R,b)$ mb</td>
<td>60.32 ± 1.34</td>
<td>55.90 ± 1.15</td>
</tr>
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- Method C: Average total and inelastic x-sections using their functional dependence on b for estimation of non-diagonal covariance term.

- Total x-section: $\alpha=0.23$, $\chi^2 = 8.6 \rightarrow \bar{\sigma}_{tot} \cdot (1 + \rho^2) = 76.8 \pm 4.7 mb$

- Inelastic x-section: $\alpha=0.41$, $\chi^2 = 6.6 \rightarrow \bar{\sigma}_{in} \cdot (1 + \rho^2) = 58.8 \pm 2.7 mb$

→ Poor agreement for inelastic x-section with CL=1%
→ require estimation of $\alpha$, which is not quoted anywhere.
Conclusion on the value of inelastic x-section

<table>
<thead>
<tr>
<th>Method</th>
<th>$\sigma_{in} \cdot (1 + \rho^2)$</th>
<th>$\sigma_{tot} \cdot (1 + \rho^2)$</th>
</tr>
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<tr>
<td>Method A</td>
<td>60.4 ± 2.3 mb</td>
<td>79.3 ± 4.2 mb</td>
</tr>
<tr>
<td>Method B</td>
<td>60.3 ± 2.2 mb</td>
<td>79.1 ± 4.0 mb</td>
</tr>
<tr>
<td>Method C</td>
<td>58.8 ± 2.7 mb</td>
<td>76.8 ± 4.7 mb</td>
</tr>
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- Use method A (simple average of the rate ratios)
- most straightforward, averages are actually measured numbers
- agrees with method B
- based on quoted numbers only

$\sigma_{in} = 59.3 ± 2.3 mb$ for $\rho = 0.135$ and @1.8 TeV

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Extrapolation to 1.96 TeV

- Energy dependence
  - prediction for inelastic x-section: $\sim \ln^2(s)$
  - prediction for diffractive x-section: $\sim \ln(s)$
  - E710 and E811 favor: $\sim \ln(s)$
  - best fit for total x-section: $\sim \ln^{2.2}s$

- Assuming $\ln^2(s)$ dependence and additional 1% systematic error due to uncertainty of the inelastic x-section energy dependence, the inelastic x-section at 1.96 TeV is

$$\bar{\sigma}_{in} = 60.7 \pm 2.4 \text{mb} \text{ @ 1.96 TeV}$$
Impact on the CLC acceptance?

- Inelastic x-section @ 1.8 TeV (CDF only)
  \[ \sigma_{inel} \sim 60.4 \, mb \]  
  \[ \sigma_h = 43.95 \, mb \quad \text{hard core} \]  
  \[ \sigma_{dd} = 7.0 \pm 2.0 \, mb \quad \text{double diffractive (PRL 87, 141802 (2001))} \]  
  \[ \sigma_d = 9.46 \pm 0.44 \, mb \quad \text{single diffractive (CDF)} \]

- Inelastic x-section used for CLC L @ 1.96 TeV
  \[ \sigma_{inel} \sim 61.7 \, mb \]  
  \[ \sigma_h = 44.4 \, mb \quad \text{hard core} \]  
  \[ \sigma_{dd} = 7.0 \, mb \quad \text{double diffractive} \]  
  \[ \sigma_d = 10.3 \, mb \quad \text{single diffractive} \]

- CLC acceptance
  \[ \mathcal{E}_{CLC} = \frac{\mathcal{E}^h \cdot \sigma_h + \mathcal{E}^d \cdot \sigma_d + \mathcal{E}^{dd} \cdot \sigma_{dd}}{\sigma_{inel}} \]
  \[ \mathcal{E}_{CLC}(\text{@1.96TeV}) = 60.2\%, \quad \mathcal{E}_{CLC}(\text{@1.8TeV}) = 60.8\% \quad (\pm 4\% \text{ error}) \]

At the first approximation the acceptance doesn’t depend on the absolute value of the inelastic cross-section.

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Impact on the CLC luminosity?

- Assuming
  - the $ln^2s$ extrapolation
  - the same CLC acceptance

**luminosity “inflation”**

\[
\frac{\delta L}{L} = 1 - \frac{\sigma_{in}(CDF)}{\bar{\sigma}_{in}} = 1 - \frac{60.41}{59.3} = +1.9\%
\]

**luminosity “sales price”**

\[
\sigma_L = \sigma_{in} \oplus \varepsilon_{clc} \oplus \sigma_{R_{pp}} = 3.9\% \oplus 4.0\% \oplus 1.8\% = $5.99 \approx 6\%
\]

Blessed