Inelastic x-section and its impact on L

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For joint CDF-D0 committee

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- 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

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

σ_{LM}

L – luminosity
f_{bc} – Bunch Crossing rate
μ_a – # of pp / BC

σ_{inel} – inelastic x-section
ε_{pp} – acceptance for a single pp
$\delta(L)$ – detector non-linearity

- CLC established uncertainties of

  ε_{pp}(4%) and R_{pp} (1.8%)

- What is uncertainty on the inelastic x-section?
  - In Run I CDF used the CDF measurement of σ_{in}.

inelastic Ppbar x-section

- L independent measurement of total PPbar x-section

$$(1+\rho^2)\cdot\sigma_{tot} = 16\pi(\hbar c)^2 \frac{dN_{el}/dt|_{t\to 0}}{N_{el}+N_{inel}}$$

ρ=0.135

- Inelastic cross-section @ 1.8TeV
  - ✓ ***55.50 ± 2.20* mb (E710: Phys.Rev.Let, 68, p2433, 1992)**
  - ✓ ***60.33 ± 1.40* mb (CDF: Phys.Rev.D, 50, p5550, 1994)**
  - ✓ ***55.92 ± 1.19* mb (E811: Phys.Let.B, 445, p419, 1999)**

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

What σ_{inel} to use? Run I: CDF(BBC), DØ($\overline{\text{world}}$); Run II $\overline{\text{(CDF\&E811}}$?)

What is the error for σ_{inel}? CDF&E811 combined: ~4%

→ "poor agreement" between all three measurements.
→ For Run II CDF & **DØ do not quote the error associated with** σ_{inel} yet
→ **Joint committee is working on this issue**

Do CDF and E811 disagree?

- σ_{in}(CDF) and σ_{in}(E811) are compatible at 2.3σ.

$$\sigma_{tot} = 16\pi(hc)^2 \frac{b}{1+\rho^2} \frac{N_{el}}{N_{el}+N_{in}} \qquad b = \frac{1}{N_{el}} \frac{dN_{el}}{dt}\Big|_{t\to 0}$$

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

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

	CDF	E811
N_{el}	78691 ± 1463	$508.1\text{K} \pm 3.5\text{K}$
N_{in}	240982 ± 2967	$1799.5\text{K} \pm 57.2\text{K}$
R	3.062 ± 0.068	3.542 ± 0.113
b	16.98 ± 0.25	16.98 ± 0.22

- 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

$$x = \frac{N_2}{N_{el}}, \qquad y = \frac{N_1}{N_{el}}, \qquad R = x + y$$

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	CDF	E811
x	2.638 ± 0.058	2.657 ± 0.023
y	0.424 ± 0.021	0.885 ± 0.115

"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.

$$\varepsilon_2(CDF) \approx 98.7\%, \qquad \varepsilon_2(E811) = 88.85 \pm 2.0\%$$

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

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

r and δ were measured in a special run

	CDF	E811
N_{nd}	203200 ± 2558	$1519.7K \pm 34.9K$
N_{sd}	37782 ± 1770	$279.8K \pm 36.3K$
N_{nd}/N_{el}	2.582±0.058	2.991±0.069
N_{sd}/N_{el}	0.480±0.029	0.551±0.072
N_{sd}/N_{nd}	0.186±0.009	0.184±0.024

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: $$\overline{R} = fR_1 + (1-f)R_2$$
    by minimization of its variance: $$\mathrm{var}(\overline{R}) = FCF^T, \quad F = (f, 1-f)$$
    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 → inflate the average variance

$$\mathrm{var}(\overline{R}) \Rightarrow \mathrm{var}(\overline{R}) \cdot \chi^2$$

Averaging of R

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

- Method A: ignore correlation between *b* and *R* → α=0.

average R = 3.19 ± 0.06, χ2 = 13.2 → average R = 3.19 ± 0.21

$$\overline{\sigma}_{in} \cdot (1+\rho^2) = 60.4 \pm 2.3mb$$

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- Method B: estimate α from simulation assuming gaussian errors and

$$R = \frac{N_{in}}{n_{el}} \left(\exp\left(-bt_{\min}\right) - \exp\left(-bt_{\max}\right) \right)$$

α=-0.09, average R = 3.20 ± 0.06, χ2 = 12.3 → average R = 3.20 ± 0.20

$$\overline{\sigma}_{in} \cdot (1+\rho^2) = 60.3 \pm 2.2mb$$

Averaging of x-sections itself

	CDF	E811
Quoted σ_{tot}, *mb*	80.03 ± 2.25	71.71 ± 2.02
Derived $\sigma_{tot}(R,b)$ *mb*	80.03 ± 2.17	71.70 ± 1.90
Quoted σ_{in}, *mb*	60.33 ± 1.40	55.92 ± 1.19
Derived $\sigma_{in}(R,b)$ *mb*	60.32 ± 1.34	55.90 ± 1.15

- **Method C: Average total and inelastic x-sections using their functional dependence on b for estimation of non-diagonal covariance term.**

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

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

→Poor agreement for inelastic x-section with CL=1%

→require estimation of α , which is not quoted anywhere.

Conclusion on the value of inelastic x-section

	$\overline{\sigma}_{in} \cdot (1+\rho^2)$	$\overline{\sigma}_{tot} \cdot (1+\rho^2)$
Method A	60.4 ± 2.3 mb	79.3 ± 4.2 mb
Method B	60.3 ± 2.2 mb	79.1 ± 4.0 mb
Method C	58.8 ± 2.7 mb	76.8 ± 4.7 mb

- 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***

$$\overline{\sigma}_{in} = 59.3 \pm 2.3 mb \quad \text{for } \rho = 0.135 \text{ and } @ 1.8\,\text{TeV}$$

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**

$$\overline{\sigma}_{in} = 60.7 \pm 2.4 mb \; @ \; 1.96\ \mathrm{TeV}$$

Impact on the CLC acceptance?

- Inelastic x-section @ 1.8 TeV (CDF only)

$$\sigma_{inel} \sim 60.4\,\mathrm{mb} \begin{cases} \nearrow \sigma_h = 43.95 & \text{hard core} \\ \rightarrow \sigma_{dd} = 7.0 \pm 2.0 mb & \text{double diffractive (PRL 87, 141802 (2001))} \\ \searrow \sigma_d = 9.46 \pm 0.44\mathrm{mb} & \text{single diffractive (CDF)} \end{cases}$$

- Inelastic x-section used for CLC L @ 1.96 TeV

$$\sigma_{inel} \sim 61.7\,\mathrm{mb} \begin{cases} \nearrow \sigma_h = 44.4 mb & \text{hard core} \\ \rightarrow \sigma_{dd} = 7.0 mb & \text{double diffractive} \\ \searrow \sigma_d = 10.3\mathrm{mb} & \text{single diffractive} \end{cases}$$

MBR

- CLC acceptance $$\varepsilon_{CLC} = \frac{\varepsilon^h \cdot \sigma_h + \varepsilon^d \cdot \sigma_d + \varepsilon^{dd} \cdot \sigma_{dd}}{\sigma_{inel}}$$

ε_{CLC}(@1.96TeV) = 60.2%, ε_{CLC}(@1.8TeV) = 60.8% ($\pm$ 4% error)

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

Impact on the CLC luminosity?

- Assuming
  - the $ln^2 s$ 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"

$$\sigma_L = \sigma_{in} \oplus \underbrace{\varepsilon_{clc} \oplus \sigma_{R_{p\bar{p}}}}_{\text{Blessed}} = 3.9\% \oplus 4.0\% \oplus 1.8\% = \$5.99 \approx 6\%$$