Heavy Flavor Production and Cross Sections at the Tevatron
(Run II results only)

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Outline

• Tevatron and CDF/D0 upgrade
• Prompt charm meson production cross section
• Inclusive J/Ψ cross section
• b cross section
• b-jet cross section
• Conclusion
The Tevatron is a proton-antiproton collider with 980 GeV/beam

1.80 TeV in Run I

36 bunches $p \times 36$ bunches $\bar{p}$

6x6 in Run I

396 ns bunch crossing time

3.5 $\mu$s in Run I

Tevatron Performance:

$L \sim 5.0 \times 10^{31}$ cm$^{-2}$s$^{-1}$ 9 pb$^{-1}$/week

$L_{int} \sim 300$ pb$^{-1}$ delivered by Tevatron

Goal: $L \sim 10^{32}$ cm$^{-2}$s$^{-1}$
The upgraded detectors

- New silicon detector
- New drift chamber
- Upgraded calorimeter, $\mu$
- Upgraded DAQ/trigger, esp. displaced-track trigger
- New TOF PID system

- New tracking: silicon and fibers in magnetic field
- Upgraded muon system
- Upgraded DAQ/trigger (displaced track soon)

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B cross section measured from Run I at Tevatron is consistently higher than NLO QCD

Theoretical development still ongoing.
Ex: fragmentation effect ……

**Experimental Approaches:**

- More cross section measurement
  - energy at 1.96TeV
  - lower $p_T(B)$
- Study $b\bar{b}$ correlation
- Measure charm production cross section

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CDF Silicon Vertex Trigger (SVT)

- Read out Silicon information and reconstruct tracks online at ~10’s KHz
- Using track impact parameter information to make trigger decision
- Tracks from B, D displaced from primary vertex

Tracks from B, D displaced from primary vertex:
- $L_{xy} \geq 450 \mu m$
- $P_T(B) \geq 5 \text{ GeV}$
- $d = \text{impact parameter}$

$35 \mu m \oplus 33 \mu m \oplus \text{resol} \oplus \text{beam} \Rightarrow \sigma \approx 48 \mu m$

Collect large amount and fully reconstructed B, D Hadrons:

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Measure prompt charm meson production cross section

Data collected by SVT trigger from 2/2002-3/2002

Large and clean signal
Measurement not limited by statistics

\[
\begin{align*}
D^0 & \to K\pi^+ \\
D^{*+} & \to D^0\pi^+_s \text{ with } D^0 \to K\pi^+ \\
D^+ & \to K\pi^+\pi^+ \\
D_s^+ & \to \phi\pi^+ \text{ with } \phi \to K^+K
\end{align*}
\]

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Separate Prompt/Secondary Charm

Separate prompt and secondary charm based on their impact parameter distribution.

Need to separate direct D and B→D decay
- Direct D point back to collision point I.P. = 0
- Secondary D not point back to PV I.P. ≠ 0

Detector I.P. resolution Measured from data

Direct Charm Meson Fraction:
- \( D^0 \): \( f_D = 86.5 \pm 0.4 \pm 3.5\% \)
- \( D^{*+} \): \( f_D = 88.1 \pm 1.1 \pm 3.9\% \)
- \( D^+ \): \( f_D = 89.1 \pm 0.4 \pm 2.8\% \)
- \( D^{+}_s \): \( f_D = 77.3 \pm 4.0 \pm 3.4\% \)

Most reconstructed charm mesons are direct

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Prompt Charm Meson X-Sections

Determine trigger and reconstruction efficiency from data and MC
Measure charm meson $p_T$ spectrum

Integral cross section: ($|Y| \leq 1$)

\[
\begin{align*}
\sigma(D^0, p_T \geq 5.5\text{GeV}, |Y| \leq 1) &= 13.3 \pm 0.2 \pm 1.5 \mu b \\
\sigma(D^{*+}, p_T \geq 6\text{GeV}, |Y| \leq 1) &= 5.2 \pm 0.1 \pm 0.8 \mu b \\
\sigma(D^+, p_T \geq 6\text{GeV}, |Y| \leq 1) &= 4.3 \pm 0.1 \pm 0.7 \mu b \\
\sigma(D_s^+, p_T \geq 8\text{GeV}, |Y| \leq 1) &= 0.75 \pm 0.05 \pm 0.22 \mu b \\
\sigma(B^+, p_T \geq 6\text{GeV}, |Y| \leq 1) &= 3.6 \pm 0.6 \mu b
\end{align*}
\]

Prompt charm cross section result submitted to PRL hep-ex/0307080
Calculation from M. Cacciari and P. Nason: Resummed perturbative QCD (FONLL)

CTEQ6M PDF
$M_c=1.5\text{GeV}$,
Fragmentation: ALEPH measurement
Renorm. and fact. Scale: $m_T=(m_c^2+p_T^2)^{1/2}$
Theory uncertainty: scale factor 0.5-2.0

D** also include calculation from B.A. Kniehl
(private communication)
Comparison with Theory

Ratio of the measured to the predicted cross section

Not incompatible with uncertainties

$p_T$ shape consistent for D mesons

Measured cross section higher : similar to B

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CDF: Lower $p_T$ trigger threshold for $\mu$: $p_T(\mu) \geq 1.5\text{GeV}$

$J/\Psi$ acceptance down to $p_T = 0$

D0: Larger $y$ acceptance for $\mu$

$114 \text{ pb}^{-1}$

$0 < p_T(J/\Psi) < 0.25\text{GeV}$

39.7$\pm$2.3 pb$^{-1}$
\[ \sigma(p\overline{p} \rightarrow J/\Psi X, |y(J/\Psi)| < 0.6) = 4.08 \pm 0.02(\text{stat})^{+0.60}_{-0.48}(\text{syst}) \mu b \]

CDF: 39.7\pm 2.3 pb\(^{-1}\)  

D0: 4.74 pb\(^{-1}\)
The $J/\Psi$ inclusive cross section includes contribution from

- Direct production of $J/\Psi$
- Decays from excited charmonium: $\Psi(2S) \rightarrow J/\Psi \pi^+ \pi^-$, 
- Decays of $b$-hadrons: $B \rightarrow J/\Psi X$, 

$b$ hadrons have long lifetime,
$J/\Psi$ decayed from $b$ hadrons
Will be displaced from primary vertex
A unbinned maximum likelihood fit to the flight path of the $J/\Psi$ in the $r\phi$ plane to extract the $b$ fraction.

- $1.25 < p_T < 1.5\text{GeV}$
  \[ f_b = 0.097 \pm 0.010^{+0.012}_{-0.010} \]

- $5.0 < p_T < 5.5\text{GeV}$
  \[ f_b = 0.143 \pm 0.005^{+0.006}_{-0.006} \]

- $10 < p_T < 12\text{GeV}$
  \[ f_b = 0.279 \pm 0.012^{+0.008}_{-0.007} \]
$d\sigma(\bar{p}p \rightarrow H_b X, H_b \rightarrow J/\Psi X) \cdot Br(J/\Psi \rightarrow \mu\mu) / dp_T(J/\Psi)$

$H_b$ denote both $b$ hadron and anti $b$ hadron $|Y(H_b)| < 0.6$

**But:**

We can not extract $b$ fraction when $b$ hadron is at rest

We want total $b$ hadron cross section

We want $b$ cross section as a function of $b$ hadron transverse momentum

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Bottom decays transfer about 1.7 GeV $p_T$ to the $J/\Psi$.

We can probe $b$ near $p_T=0$ if we can measure $b$ fraction of $J/\Psi$ with $p_T$ below this value.

Assume a $b$-hadron $p_T$ spectrum

Unfold $p_T(H_b)$ from $p_T(J/\Psi)$ using MC

$b$-hadron X-section $d\sigma/dp_T(H_b)$

New $b$-hadron $p_T$ spectrum

Iterate to obtain the correct $p_T$ spectrum

$b$-hadron differential and total X-section

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b Hadron Differential X-Section

\[ d\sigma(p\bar{p} \rightarrow H_b X, H_b \rightarrow J/\Psi X) \cdot Br(J/\Psi \rightarrow \mu\mu)/dp_T(H_b) \]
Total $b$ Quark Production X-Section

\[
d\sigma(p\bar{p} \to H_b X, |y| \leq 0.6) \cdot Br(H_b \to J/\Psi X) \cdot Br(J/\Psi \to \mu\mu) = 24.5 \pm 0.5(stat) \pm 4.7(syst)\text{nb}
\]

\[
d\sigma(p\bar{p} \to \bar{b} X, |y| \leq 0.6) = 18.0 \pm 0.4(stat) \pm 3.8(syst)\mu\text{b}
\]

MC extract to high $Y$ region

\[
d\sigma(p\bar{p} \to \bar{b} X, |y| \leq 1.0) = 29.4 \pm 0.6(stat) \pm 6.2(syst)\mu\text{b}
\]
b-jet X-Section

μ + jet sample → Using μ p_T spectrum to fit the b and non b content as a function of jet E_T

DØ Run 2 Preliminary

R = 0.5 Cone Jets
|η_{jet}| < 0.6
p_T^μ > 4 GeV/c
|η_μ| < 0.8
δR(jet, μ) < 0.7

DØ: 4.8 pb^{-1}

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Conclusion

- Large amount data collected by both CDF and D0 already surpass the run I statistics
- New Charm, Bottom cross section results
- Lots of analysis in progress:
  - $J/\Psi$, $\Psi(2S)$ cross section and polarization
  - Upsilon cross section and polarization
  - Updated $b$ cross section …
- Tevatron will contribute the knowledge of heavy flavor production
- Stay tuned