Heavy Quark Production at the Tevatron

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On behalf of the D0 & CDF Collaborations

Heavy Quarks and Leptons, Puerto Rico, June 2004
In this talk…

A lot of analyses are in progress at the Tevatron, here not at all exhaustive summary!

• Cross-section measurements:
  • Prompt charm meson
  • Inclusive J/ψ
  • b → J/ψ X
  • γ + b/c

• Exclusive measurements:
  • B hadron masses
  • CP asymmetries and decay rate ratios
  • Observation of narrow D** states in semileptonic B decays
  • B⁰ mixing
  • Search for pentaquarks

• Not included:
  • B lifetimes (discussed in other sessions)
  • BR(B⁺ → ϕ K⁺)
  • Bc→J/ψ μ X search
  • ………

• Not included, but available in the back up slides:
  • Bₛ → μ μ search (discussed in other sessions)
  • X(3872) → J/ψ π π state (discussed in other sessions)
  • Two body charmless decays studies
  • Bₛ mixing sensitivity
Tevatron Performance

• The Tevatron is working quite well this year

• Record Initial luminosity = $7.4 \times 10^{31}$ sec$^{-1}$ cm$^{-2}$

• Detector efficiency $\sim 85-90\%$

$\sim 300$ pb$^{-1}$ on tape per experiment
Both detectors
Silicon microvertex tracker
Axial solenoid
Central tracking
High rate trigger/DAQ
Calorimeters and muons

CDF
L2 trigger on displaced vertexes
Particle ID (TOF and dE/dx)
Excellent tracking resolution

DØ
Excellent muon ID and acceptance
Excellent tracking acceptance $|\eta| < 2-3$
L3 trigger on impact parameter/L2 impact parameter trigger being commissioned
Heavy Flavor Physics at the Tevatron

B Bbar production mechanics in hadron collider:

- Huge Charm and Bottom cross-sections
- All B species produced:
  - $B_u, B_d, B_s, B_c, \Lambda_b, \ldots$

**BUT** $\sigma(bb) << \sigma(pp)$  $\Rightarrow$ B/C events have to be selected with specific triggers...

Trigger requirements: large bandwidth, background suppression, deadtimeless
Heavy Flavor Triggers

- **Single/di-lepton (CDF/D0)**
  - High $p_T$ lepton or two leptons with lower $p_T$
  - $J/\psi$ modes, masses, lifetime, x-section
  - Yields higher than Run I (low Pt threshold, increased acceptance)

- **lepton + displaced track - semileptonic sample (CDF)**
  - $p_T(e/\mu) > 4$ GeV/c, $120 \mu m < d0(Trk) < 1mm$, $p_T(Trk) > 2$ GeV/c
  - Semileptonic decays, Lifetimes, flavor tagging
  - $B$ Yields 3x Run I

- **Two displaced vertex tracks - hadronic sample (CDF)**
  - $p_T(Trk) >2$ GeV/c, $120 \mu m < d0(Trk) < 1mm$, $\Sigma p_T > 5.5$ GeV/c
  - X-section, branching ratios, $B_s$ mixing…
INCLUSIVE CROSS-SECTION MEASUREMENTS
Prompt Charm Meson X-Section

- Measure prompt charm meson production cross section using the CDF Two Track Trigger
- Large and clean signal Measurement not limited by statistics

Separate prompt and secondary charm based on their impact parameter distribution

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

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

\[
\sigma(D^0, p_T \geq 5.5\text{GeV}, |Y| \leq 1) = 13.3 \pm 0.2 \pm 1.5 \mu b
\]
\[
\sigma(D^{*+}, p_T \geq 6\text{GeV}, |Y| \leq 1) = 5.2 \pm 0.1 \pm 0.8 \mu b
\]
\[
\sigma(D^+, p_T \geq 6\text{GeV}, |Y| \leq 1) = 4.3 \pm 0.1 \pm 0.7 \mu b
\]
\[
\sigma(D_s^+, p_T \geq 8\text{GeV}, |Y| \leq 1) = 0.75 \pm 0.05 \pm 0.22 \mu b
\]
Inclusive $J/\psi$ X-Section

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

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

D0: Larger acceptance for $\mu$
Inclusive $J/\psi$ X-Section

$$\sigma(p\bar{p} \rightarrow J/\psi X, |y(J/\psi)| < 0.6) = 4.08 \pm 0.02^{+0.60}_{-0.48} \text{(stat)} \mu b$$

CDF: 39.7 pb$^{-1}$

D0: 4.8 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!
Inclusive b X-Section (CDF)

- RunI b cross-section \(\sim 3\times\) old NLO QCD
- Theoretical approaches: new physics, Next-to-Leading-log resummations, non perturbative fragmentation function from LEP, new factorization schemes…

- An unbinned maximum likelihood fit to the flight path of the J/\(\psi\) in the \(r-\phi\) plane to extract the b fraction

\[
\sigma(p\bar{p} \rightarrow bX)|_{|y|<1.0} = (29.4 \pm 0.6(\text{stat}) \pm 6.2(\text{sys})) \mu b
\]

**FONLL** \[
\sigma(p\bar{p} \rightarrow bX)|_{|y|<1.0} = (27.5^{+11}_{-8.2}) \mu b
\]
Using $\mu p_T$ spectrum to fit the b and non b content as a function of jet $E_T$
\( \gamma + b/c \) X-Section

- It probes the heavy flavor content of the proton, sensitive to new Physics
- Basic requirements:
  - One isolated and High \( E_T \) \( \gamma \) (> 25 GeV)
  - One jet with a secondary vertex (b/c “like” jet)
- Fit on the secondary vertex mass distribution of the tagged jets to determine the number of events containing b, c and uds quarks in the data

Cross-section measurements agree with the QCD predictions

\[
\sigma(b + \gamma) = 40.6 +/- 19.5 \text{ (stat.)} + 7.4 - 7.8 \text{ (sys.) pb} \\
\sigma(c + \gamma) = 486.2 +/- 152.9 \text{ (stat.)} + 86.5 - 90.9 \text{ (sys.) pb}
\]
Once the overall picture is under control, I will talk about some recent measurements from exclusive modes…

Results from ‘exclusive’ channels
Yields in Exclusive B Decays

**B^0**

\[ B^0 \rightarrow J/\psi + K^* \]

\[ N = 1857 \pm 72 \]

**B^+**

\[ B^+ \rightarrow J/\psi + K^* \]

\[ N = 4306 \pm 89 \]

---

CDF II Preliminary

361 ± 28 \( \Lambda_b \rightarrow \Lambda_c \pi \) candidates

- Four-prong B reflections
- Other B meson decays
- Other \( \Lambda_b \) decays
- \( \Lambda_b \rightarrow \Lambda_c K \)
- Combinatorial background

\( L \approx 180 \text{ pb}^{-1} \)

---

CDF Run II Preliminary

\( R_\phi \rightarrow \pi^+ D_s^- X \)

\[ N(D_{s0}^-) = 1400 \]
Mass measurements in fully reconstructed B decays:

- Small systematic uncertainties
- Best B$^+$ and B$^0$ single measurements
- Best $B_s$ and $Λ_b$ w.r.t the combined PDG

<table>
<thead>
<tr>
<th>Mass (Mev/c$^2$)</th>
<th>CDF preliminary</th>
<th>PDG value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+$</td>
<td>5279.10 ± 0.41 ± 0.34</td>
<td>5279.0 ± 0.5</td>
</tr>
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<td>$B^0$</td>
<td>5279.57 ± 0.53 ± 0.30</td>
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</tr>
<tr>
<td>$B_s$</td>
<td>5366.01 ± 0.73 ± 0.30</td>
<td>5369.6 ± 2.4</td>
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<tr>
<td>$Λ_b$</td>
<td>5619.7 ± 1.2 ± 1.2</td>
<td>5624 ± 9</td>
</tr>
</tbody>
</table>

To be reprocessed with extended tracking ⇒ improve yield by 50%
• The huge amount data collected by the CDF Two Track Trigger have been used for this analysis

Relative branching ratios:
\[ \frac{\Gamma(D^0 \rightarrow K^+K^-)}{\Gamma(D^0 \rightarrow K\pi)} \]
\[ \frac{\Gamma(D^0 \rightarrow \pi^+\pi^-)}{\Gamma(D^0 \rightarrow K\pi)} \]
\[ \frac{\Gamma(D^0 \rightarrow KK)}{\Gamma(D^0 \rightarrow \pi\pi)} \approx 2.8 \text{ (SM)} \]

Direct CP-violating decay rate asymmetries:
\[ A_{CP} = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)} \approx 0 \text{ (SM)} \]

• Candidates selected as: \( D^{*+/0} \rightarrow D^0 \pi \) (unbiased tag of the \( D^0 \) flavor)

\( \sim 2 \times 90000 \ D^{*+/0} \) !!!
CP Asymmetries and Decay Rate Ratios

CDF Run II Preliminary

$L = 123 \pm 7 \text{ pb}^{-1}$

$D^{+} \rightarrow D^{0} \pi^{+} \rightarrow [K^{-} K^{+}] \pi^{+}$

$N_{D^{0}} = 8190 \pm 140$

$D^{+} \rightarrow D^{0} \pi^{+} \rightarrow [\pi^{-} \pi^{+}] \pi^{+}$

$N_{D^{0}} = 3660 \pm 69$

$D^{*+} \rightarrow D^{0} \pi^{+} \rightarrow [K^{+} K^{-}] \pi^{-}$

$N_{D^{0}} = 8030 \pm 140$

$D^{*+} \rightarrow D^{0} \pi^{+} \rightarrow [\pi^{+} \pi^{-}] \pi^{+}$

$N_{D^{0}} = 3674 \pm 68$
CP Asymmetries and Decay Rate Ratios

Very important to understand the asymmetry of the CDF detector!!!

Results are computed after applying a correction for the intrinsic charge asymmetry of the detector response and tracking algorithms

<table>
<thead>
<tr>
<th>Ratio</th>
<th>CDF</th>
<th>FOCUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi)$</td>
<td>(9.96 +/- 0.11 +/- 0.12)%</td>
<td>(9.93 +/- 0.14 +/- 0.14)%</td>
</tr>
<tr>
<td>$\Gamma(D^0 \to \pi\pi)/\Gamma(D^0 \to K\pi)$</td>
<td>(3.608 +/- 0.054 +/- 0.040)%</td>
<td>(3.53 +/- 0.12 +/- 0.06)%</td>
</tr>
<tr>
<td>$\Gamma(D^0 \to KK)/\Gamma(D^0 \to \pi\pi)$</td>
<td>(2.762 +/- 0.040 +/- 0.034)%</td>
<td>(2.81 +/- 0.10 +/- 0.06)%</td>
</tr>
</tbody>
</table>

$A(D^0 \to KK) = (2.0 +/- 1.2 \text{ (stat.)} +/- 0.6 \text{ (syst.)})\%$

$A(D^0 \to \pi\pi) = (1.0 +/- 1.3 \text{ (stat.)} +/- 0.6 \text{ (syst.)})\%$

$A(D^0 \to KK) = (0.0 +/- 2.2 \text{ (stat.)} +/- 0.8 \text{ (syst.)})\%$

$A(D^0 \to \pi\pi) = (1.9 +/- 3.2 \text{ (stat.)} +/- 0.8 \text{ (syst.)})\%$
Observation of $B \rightarrow \mu \nu D^{**} X$

Start from “$B \rightarrow \mu \nu D^{*-} + X$” sample, and “reconstruct another $\pi^+$”. Look at mass of $D^{*-} \pi^+$ system.

Excess in right-sign combinations can be interpreted as combined effect of $D_1^0$ and $D_2^{*0}$

From topological analyses at LEP we know:

$\text{Br}(B \rightarrow D^{*-} \pi^- \mu \nu X) = 0.48 \pm 0.10 \%$

DØ’s preliminary result constrains the resonant contribution

$\text{Br}(B \rightarrow \{D_1^0, D_2^{*0}\} \mu \nu X) \cdot \text{Br}(\{D_1^0, D_2^{*0}\} \rightarrow D^{*-} \pi^-) = 0.280 \pm 0.021 \text{ (stat)} \pm 0.088 \text{ (syst)} \%$
The $B^0/B^0$ mixing frequency $\Delta m_d$ has been measured with high precision, most recently at the B factories. Measurements of $\Delta m_d$ constrain $|V_{td}|$, but current limitations are due to theoretical inputs.

**Why is $B^0$ Mixing analysis so important?:**
- Benchmark the initial state flavor tagging
- A step toward $B_s$ Mixing

**Semileptonic B decays ($D0$, CDF analysis in progress)**
**Fully reconstructed B decays (CDF)**
“Ingredients” to get a $B_{(d,s)}$ mixing measurement:

- Measure proper decay time:
  \[ c\tau = \frac{L_{xy}}{\beta\gamma} = \frac{L_{xy} m(B)}{P_T(B)} \rightarrow \sigma_{cl} = \frac{m(B)}{P_T(B)} \sigma_{Lxy} \oplus c\tau \left( \frac{\sigma_{P_{T}(B)}}{P_T(B)} \right) \]

- Identify B flavor at decay:
  Reconstruct the final state with good S/B
  (precise tracking, vertexing, particle ID)

- Identify the flavor of B at production:
  B - flavor tagging algorithms
B^0 yields
Mixing and Flavor Tagging

Figure of merit: \( \epsilon D^2 \)

- \( \epsilon \): tag efficiency
- \( D \): dilution

\[
A(t) \equiv \frac{N_R(t) - N_W(t)}{N_R(t) + N_W(t)} = D \cos(\Delta m t)
\]
\[
A \equiv \frac{N_R - N_W}{N_R + N_W} = D = 1 - 2 P_{Tag}
\]

- **Strategy:**
  - use data for calibration (e.g., \( B^\pm \rightarrow J/\psi K^\pm, B^\pm \rightarrow D^0 \pi^\pm, B \rightarrow \text{lepton} \ldots \))
  - allow to measure \( \epsilon, D \) and \( \epsilon D^2 \) in data and optimize the taggers
  - can then apply them in any sample without bias

\[
\Delta m_d (\text{ps}^{-1})
\]

**High precision measurement in \( B_d \) mixing**

- **ALEPH** (3 analyses)
- **DELPHI** * (5 analyses)
- **L3** (3 analyses)
- **OPAL** (5 analyses)
- **CDF** * (4 analyses)
- **BABAR** * (3 analyses)
- **BELLE** * (4 analyses)

- **ARGUS+CLEO** (\( \chi^2 \) measurements)

- **World average**

- **Working group average without adjustments**

- **Average of above after adjustments**
Flavor Tagging algorithms

**OST (Opposite Side Tagging):**

B’s are produced in pairs → measure flavor of opposite B

- **JETQ**: sign of the weighted average charge of opposite B-Jet
- **(*) SLT**: identify the soft lepton from semileptonic decay of opposite B
- **Opposite Side K**: due to $b \rightarrow c \rightarrow s$ it is more likely that a $B$ meson will contain in final state a $K^+$ than a $K^-$. Identify $K^-$ in the opposite side

**SST (Same Side Tagging):**

- **(*) SS pion T**: $B^0$ is likely to be accompanied close by a $\pi^+$ from fragmentation
- **SS Kaon T**: $B_s$ is likely to be accompanied close by a $K^+$ from fragmentation
B^0 mixing results from CDF

CDF uses fully reconstructed B^0 decays to measure $\Delta m_d$:

- This analysis uses Same-Side Pion Tag
- Preliminary results:
  $\Delta m_d = 0.55 \pm 0.10 \text{ (stat.)} \pm 0.01 \text{ (syst.)} \text{ ps}^{-1}$

Work in progress:
- improve SST
- other tagging methods:
  - JQT, SMT, SET
- add more fully reconstructed decay channels
- use semileptonic B decays!
$B^0$ mixing results from DØ

DØ uses a large sample of semileptonic $B^0$ decays to measure $\Delta m_d$:

- This analysis uses Opposite-Side Muon tag
- Preliminary results:
  
  $\Delta m_d = 0.506 \pm 0.055 \text{ (stat.)} \pm 0.049 \text{ (syst.)} \text{ ps}^{-1}$

- Consistent with world average:
  
  $0.502 \pm 0.007 \text{ ps}^{-1}$

- Tagging efficiency: $4.8 \pm 0.2 \%$
- Tagging purity, $N_R/(N_R+N_W) = 73.0 \pm 2.1 \%$

Work in progress:

- other tagging methods: JQT, SST
- add more decay channel
- add fully reconstructed decays
Pentaquarks searches

Summary of the new CDF results on the search for Pentaquarks:
CDF has looked at all known channels and has nothing so far

• Channels:
  • $\Theta^+ \rightarrow p K_s \rightarrow p \pi^+ \pi^-$
  • $\Xi^0_{3/2} \rightarrow \Xi^- \pi^+ \rightarrow \Lambda \pi^+ \pi^-$
  • $\Xi^-_{3/2} \rightarrow \Xi^- \pi^- \rightarrow \Lambda \pi^- \pi^-$
  • $\Theta_c \rightarrow D^*^- p \rightarrow D^0 \pi^- p$
Search for $\Theta^+ \rightarrow p K_s$

- Use 2 energy ranges (min bias and jet20)
- Identify protons using TOF

No evidence for narrow resonance

CDF is working on limit for $s$ ($\Theta^+/\Lambda(1520)$)
Search for $\Xi^0/^{--}_{3/2} \rightarrow \Xi \pi$

- CDF has developed tracking of long lived hyperons in the SVX detector
- Silicon tracking of hyperons improves momentum and impact parameter resolution as well as background reduction

No excess is observed in the CDF data

<table>
<thead>
<tr>
<th>Channel (TTT)</th>
<th># of events</th>
<th>$R(\Xi_{1860}/\Xi_{1530})$ U. L. 95% C.L.</th>
<th>$R(\Xi_{1860}/\Xi_{1530})$ NA49</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^-\pi^+$</td>
<td>57 +/- 51</td>
<td>0.07</td>
<td>$\sim 0.21$</td>
</tr>
<tr>
<td>$\Xi^-\pi^-$</td>
<td>-54 +/- 47</td>
<td>0.04</td>
<td>$\sim 0.24$</td>
</tr>
<tr>
<td>$\Xi^-\pi^{+-}$</td>
<td>47 +/- 70</td>
<td>0.08</td>
<td>$\sim 0.45$</td>
</tr>
</tbody>
</table>
Search for $\Theta_c \rightarrow D^- p$

- Identify protons using TOF ($p < 2.75$ GeV/c) or dEdx ($p > 2.75$ GeV/c)
- Large sample of $D^-$ (0.5M)

- No evidence of charmed Pentaquark seen
- Combined upper limit: < 29 events (90% C.L.)
Summary

• Inclusive cross-section measurements agree, within the errors, with the theoretical expectations

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• Charm Physics:
  • A(D^0 → KK) = (2.0 +/- 1.2 (stat.) +/- 0.6 (syst.))%
  • A(D^0 → ππ) = (1.0 +/- 1.3 (stat.) +/- 0.6 (syst.))%
  • Observation of narrow D** states in semileptonic B decays

• B^0 Mixing measurement already established in both experiments, another step toward B_s mixing

• No evidence of Pentaquarks in the Tevatron data so far

Work in progress, stay tuned!
Backup Slides...
Rare B decays: $B_{s(d)} \rightarrow \mu^+\mu^-$ from CDF

- No excess has been found unfortunately
- Limits on the Branching fractions have been set

(Expected/Observed) **BR limits vs. luminosity**

**Already Submitted to PRL!**

<table>
<thead>
<tr>
<th></th>
<th>$B_{s} \rightarrow \mu^+\mu^-$</th>
<th>$B_{d} \rightarrow \mu^+\mu^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>$1.05 \pm 0.30$</td>
<td>$1.07 \pm 0.31$</td>
</tr>
<tr>
<td>Data</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BR limit @95% C.L.</td>
<td>$7.5 \times 10^{-7}$</td>
<td>$1.9 \times 10^{-7}$</td>
</tr>
<tr>
<td>BR limit @90% C.L.</td>
<td>$5.8 \times 10^{-7}$</td>
<td>$1.5 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

Best world result

Slightly better results than Belle and BaBar

$1.6 \times 10^{-7}$

$2.0 \times 10^{-7}$
$B_s \rightarrow \mu^+ \mu^-$ sensitivity study from D0

Optimised cuts using Random Grid Search [Prosper, CHEP’95; Punzi, CSPP’03] based on the mass sidebands

After optimisation:

expect $7.3 \pm 1.8$ background events in signal region

Expected limit (Feldman/Cousins):

\[
\text{Br}(B_s \rightarrow \mu^+ \mu^-) < 9.1 \times 10^{-7} \ @ \ 95 \% \ CL \quad (\text{stat only}) \\
\text{Br}(B_s \rightarrow \mu^+ \mu^-) < 1.0 \times 10^{-6} \ @ \ 95 \% \ CL \quad (\text{stat + syst}) \\
\text{(expected signal has been normalised to } B^\pm \rightarrow J/\Psi K^\pm) 
\]

Published CDF Run I result (98 pb$^{-1}$):

\[
\text{Br}(B_s \rightarrow \mu^+ \mu^-) < 2.6 \times 10^{-6} \ @ \ 95 \% \ CL 
\]

The analysis has not been unblinded yet (signal region still hidden)
Branching ratio for $B_s \rightarrow \mu^+\mu^-$ as a function of $m_{1/2}$ for $m_0 = 300, 500$ and $800$ in R-parity violation SUSY scenario. Other mSUGRA parameters are fixed to be $\tan\beta = 10$, $A_0 = 0$ and $m > 0$.

Dashed lines are to indicate the models that are excluded via $b \rightarrow s\gamma$ constraints.
Exotic State: $X(3872) \rightarrow J/\psi \pi^+ \pi^-$

$\Delta M = 774.9 \pm 3.1 \text{(stat)} \pm 3.0 \text{ (sys)} \text{ MeV/c}^2$

$\Delta M + M(J/\psi) = 3871.8 \pm 4.3 \text{ MeV/c}^2$

Belle: $M_X = 3872.0 \pm 0.6 \text{ (stat)} \pm 0.5 \text{ (sys)} \text{ MeV/c}^2$
lepton + displaced track trigger provides high statistics sample

**Analysis:**

- Trigger lepton used to estimate B flavor at production
- Identify $\mu$ charge on opposite side
- Cross check consistency with partially reconstructed lepton+$D^{+,0}$
- **Remainder:** this number is UNBIASED since we are using an independent (and high statistics) control sample

**Detailed sample composition studies:**

- Mass cut removes $D$ decays: $2 < M(\ell + \text{track}) < 4\,\text{GeV/c}^2$
- Background subtraction variable separates $B$’s from background: signed IP of displaced track

$\varepsilon D^2 (SMT) = (0.7 \pm 0.1)\%$
Jet Charge Tag in Semileptonic Sample at CDF

- This work starts from the high-Pt version of the Run I Jet Charge Tagging algorithm.
- The algorithm is applied to and calibrated on the inclusive semileptonic events from the $e^{+}\text{svt}$ and $\mu^{+}\text{svt}$ trigger.

<table>
<thead>
<tr>
<th>Jet type</th>
<th>$\epsilon$, %</th>
<th>D at $Q_{\text{jet}}=1$, %</th>
<th>$\epsilon D^2$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^{-}\text{SVT}$ sample with $\mu^{-}\text{SVT}$ tuning:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SecVtx jets</td>
<td>9.9±0.1%</td>
<td>36.7±3.1%</td>
<td>0.226±0.016%</td>
</tr>
<tr>
<td>non-SecVtx jets</td>
<td>68.8±0.2%</td>
<td>12.0±1.2%</td>
<td>0.193±0.018%</td>
</tr>
<tr>
<td>combined</td>
<td>78.6±0.2%</td>
<td></td>
<td>0.419±0.024%</td>
</tr>
</tbody>
</table>

- First step on JQT
- Work in progress to improve it
CPV - Two body charmless decays $B \rightarrow h^+h^-$

- Time dependent asymmetry $B_d \rightarrow \pi\pi$ ($\alpha$ angle) and $B_s \rightarrow KK$ ($\gamma$ angle)
- Direct CP asymmetry of the self tagging modes $B_d \rightarrow \pi K$ and $B_s \rightarrow K\pi$

1. extracting the signal

Online hadronic selection
+ $B$ pointing prim. vertex, displaced & isolated

2. Separation of the components

- $dE/dx \sim 1.3s$ for $K/\pi$ separation
- Statistical separation is still possible
- Unbinned log-likelihood fit defined including
  - Kinematical variables $M(\pi\pi)$ and $a=\frac{1-p1/p2}{q1}$
  - $dE/dx$

<table>
<thead>
<tr>
<th>Mode</th>
<th>Yield (65 pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow K\pi$</td>
<td>$148\pm17$(stat.) $\pm 17$(syst)</td>
</tr>
<tr>
<td>$B^0 \rightarrow \pi\pi$</td>
<td>$39\pm14$(stat.) $\pm 17$(syst)</td>
</tr>
<tr>
<td>$B_s \rightarrow KK$</td>
<td>$90\pm17$(stat.) $\pm 17$(syst)</td>
</tr>
<tr>
<td>$B_s \rightarrow K\pi$</td>
<td>$3\pm11$(stat.) $\pm 17$(syst)</td>
</tr>
</tbody>
</table>
CPV - Direct $A_{CP}$ Selftagging Modes - Projections

- First observation $B_s \rightarrow KK$
- Direct $A_{CP}$ violation $\sim 0$

\[
\frac{BR(B_s \rightarrow K^\pm K^\mp)}{BR(B_d \rightarrow K^\pm \pi^\mp)} = 2.71 \pm 1.15
\]

\[
A_{CP}(B^0 \rightarrow K^- \pi^+) = 0.02 \pm 0.15 \text{ (stat)} \pm 0.02 \text{ (syst)}
\]

\[
A_{CP}(B^0) = A_{CP}^{dir} \cos \Delta m_d t + A_{CP}^{mix} \sin \Delta m_d t
\]

\[
A_{CP}(B_s) = A_{CP}^{dir} \cos \Delta m_s t + A_{CP}^{mix} \sin \Delta m_s t
\]

![CDF Run II Preliminary](image1.png)

A factor of 4 below Yellow Book

![CDF Run II Preliminary](image2.png)

$B_S \rightarrow KK$

$\in D^2 = 5\%$

$\sigma_t = 50 \text{ fs}$

$x_S = 50$

$x_S = 30$

$x_S = 20$
Towards $B_s$ Mixing

- Measurement of $\Delta m_s$ helps improve our knowledge of CKM triangle
  - $\Delta m_s > 14.4 \text{ps}^{-1}$ @95% C.L.
  - $B_s$ fully mixes in < 0.15 lifetime!
- $B_s$ oscillation much faster than $B_d$ because of coupling to top quark

$V_{tb} \sim 1$, $\text{Re}(V_{td}) \approx 0.0071$

$V_{tb} \sim 1$, $\text{Re}(V_{ts}) \approx 0.04$

$B_d$ Mixing

$B_s$ Mixing
B$_s$ Mixing sensitivity

- D0: 2 fb$^{-1}$, $\Delta m_s = 15$ and $s_t = 150$ fs
  - Please, be careful with these numbers!
  - Single muon trigger:
    - $B_s \rightarrow D_s \mu X (3.5 \, \sigma)$
    - $B_s \rightarrow D_s e X (3.5 \, \sigma)$
    - $B_s \rightarrow D_s \pi (2.2 \, \sigma)$, $\mu$ in the other side
  - Dimuon trigger:
    - $B_s \rightarrow D_s \mu X (3.0 \, \sigma)$, $\mu$ in the other side
- CDF:
  - $\Delta m_s = 15$, $2 \, \sigma$ limit with 0.5 fb$^{-1}$
  - $\Delta m_s = 18$, discovery with 1.7 fb$^{-1}$
  - $\Delta m_s = 24$, discovery with 3.2 fb$^{-1}$

**Semileptonic decays:**
- Very good statistics, but poorer time resolution
- If $\Delta m_s \approx 15$ ps$^{-1}$ expect a 1-2 $\sigma$ measurement with 500 pb$^{-1}$
CDF Trigger System Overview

- Crossing: 396 ns, 2.5 MHz
  - Level 1: hardware
    - Electron, Muon, track, missing $E_t$
    - 15-20kHz (reduction $\sim$x200)
  - Level 2: hardware
    - Cal. Cluster, jet finding, Silicon track
    - 300-350 Hz (reduction $\sim$x5)
  - Level 3: Linux PC farm
    - \(~\) Offline quantities
    - 50-70 Hz (reduction $\sim$ x6)
**b Hadron Differential Cross Section**

\[
d\sigma(p\bar{p} \rightarrow H_b X, H_b \rightarrow J/\Psi X) \cdot Br(J/\Psi \rightarrow \mu\mu) / dp_T(J/\Psi)
\]

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
b Hadron Differential X-Section

Bottom decays transfer about 1.7GeV $p_T$ 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