Recent B Physics
Results at the Tevatron

Gavril Giurgiu, Johns Hopkins University
on behalf of CDF and DØ collaborations

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Outline

- Introduction
  - Tevatron, CDF and DØ detectors
  - B Physics at the Tevatron

- Recent results
  - lifetime, lifetime difference and CP violation in neutral $B_s$ system
  - charge asymmetry in semileptonic $B_s$ decays
  - CP asymmetry in $B^+ \to J/\Psi K^+$ and $\Lambda_b \to p \pi(K)$ decays
  - $\Xi_b$ baryons
  - $B_c$ mass and lifetime
  - Rare decays
  - $D^0$ mixing

- Topics not covered

- Conclusions
Tevatron

- p\(\bar{p}\) collisions at 1.96 TeV

Close to 3 fb\(^{-1}\) data on tape

Initial instantaneous luminosity \(3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}\)

- Buffalos are doing well, they don’t know about the Fermilab budget cuts...

Delivered 3.46 fb\(^{-1}\)
Recorded 2.96 fb\(^{-1}\)
CDF II Detector

- Central tracking: - silicon vertex detector
  - drift chamber
  \[ \delta p_T/p_T = 0.0015 \, p_T \]
  \[ \rightarrow \text{excellent mass resolution} \]
- Particle identification: \( dE/dX \) and TOF
- Good electron and muon ID by calorimeters and muon chambers

DØ Detector

- Excellent tracking and muon coverage
- Excellent calorimetry and electron ID
- 2 Tesla solenoid, polarity reversed weekly
  \[ \rightarrow \text{good control of charge asymmetry systematic effects} \]
- Silicon layer 0 installed in 2006 improves track parameter resolution
B Physics at the Tevatron

- Mechanisms for $b$ production in $p\bar{p}$ collisions at 1.96 TeV

![Diagrams]

- At Tevatron, $b$ production cross section is much larger compared to B-factories
  $\rightarrow$ Tevatron experiments CDF and DØ enjoy rich B Physics program

- Plethora of states accessible only at Tevatron: $B_s$, $B_c$, $\Lambda_b$, $\Xi_b$, $\Sigma_b$...
  $\rightarrow$ complement the B factories physics program

- Total inelastic cross section at Tevatron is $\sim 1000$ larger than $b$ cross section
  $\rightarrow$ large backgrounds suppressed by triggers that target specific decays
CP Violation in $B_s$ System

- Standard Model CP violation occurs through complex phases in the unitary CKM quark mixing matrix:

\[
\begin{pmatrix}
    d' \\
    s' \\
    b'
\end{pmatrix} = \begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
    d \\
    s \\
    b
\end{pmatrix}
\]

- Expanded in $\lambda = \sin(\theta_{\text{Cabibbo}}) \approx 0.23$:

\[
\begin{pmatrix}
    1 - \frac{1}{2} \lambda^2 - \frac{1}{8} \lambda^4 \\
    -\lambda + \frac{1}{2} A^2 \lambda^5 [1 - 2 (\rho + i \eta)] \\
    A \lambda^2 [1 - (1 - \frac{1}{2} \lambda^2) (\rho + i \eta)]
\end{pmatrix}
\]

Highly suppressed CP violation $\sim \lambda^5$

Large CP violation $\sim \lambda^3$

Unitarity relations:

$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

$B_d$ unitarity triangle

$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$

$B_s$ unitarity triangle

- Unitarity triangles
Neutral $B_s$ System

- Time evolution of $B_s$ flavor eigenstates described by Schrodinger equation:

$$i \frac{d}{dt} \left( \begin{array}{c} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{array} \right) = \left( M - \frac{i}{2} \Gamma \right) \left( \begin{array}{c} |B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle \end{array} \right)$$

- Diagonalize mass ($M$) and decay ($\Gamma$) matrices
  $\rightarrow$ mass eigenstates

$$|B_s^H\rangle = p |B_s^0\rangle - q |\bar{B}_s^0\rangle \quad |B_s^L\rangle = p |B_s^0\rangle + q |\bar{B}_s^0\rangle$$

where $q/p = \frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}}$

- Flavor eigenstates differ from mass eigenstates and mass eigenvalues are different ($\Delta m_s = m_H - m_L \approx 2|M_{12}|$)
  $\rightarrow$ $B_s$ oscillates with frequency $\Delta m_s$
  precisely measured by

CDF: $\Delta m_s = 17.77 \pm 0.12$ ps$^{-1}$

DØ: $\Delta m_s = 18.56 \pm 0.87$ ps$^{-1}$

- Mass eigenstates have different decay widths

$$\Delta \Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}| \cos(\Phi_s) \quad \text{where} \quad \phi_s^{SM} = \arg \left( -\frac{M_{12}}{\Gamma_{12}} \right) \approx 4 \times 10^{-3}$$
CP Violation in $B_s \to J/\Psi \Phi$ Decays

- Analogously to the neutral $B^0$ system, CP violation in $B_s$ system occurs through interference of decay with and without mixing:

\[
\begin{align*}
B^0 & \to J/\Psi K^0_s & B_s^0 & \to J/\Psi \phi \\
\bar{B}^0 & \to \bar{J}/\Psi K^0_s & \bar{B}_s^0 & \to \bar{J}/\Psi \phi \\
\Rightarrow \sin(2\beta) & & \Rightarrow \sin(2\beta_s)
\end{align*}
\]

- CP violation phase $\beta_s$ in SM is predicted to be very small:

\[
\beta_s^{SM} = \arg(-V_{ts}^* V_{tb}^*/V_{cs}^* V_{cb}^*) \approx 0.02
\]

- New Physics affects the CP violation phase as:

\[
2\beta_s = 2\beta_s^{SM} - \phi_s^{NP}
\]

- If NP phase $\phi_s^{NP}$ dominates

\[
2\beta_s = -\phi_s^{NP}
\]
**B_s → J/ΨΦ Phenomenology**

- Extremely physics rich decay mode

- Can measure lifetime, decay width, and, using known $\Delta m_s$, CP violating phase $\beta_s$

- The decay of $B_s$ (spin 0) to $J/Ψ$(spin 1) $Φ$(spin 1) leads to three different angular momentum final states:
  - $L = 0$ (s-wave), $2$ (d-wave) → CP even $\Phi_s \approx 0 |B_s^L\rangle$
  - $L = 1$ (p-wave) → CP odd $\Phi_s = 0 |B_s^H\rangle$

- three decay angles $\overrightarrow{\rho} = (\theta, \phi, \psi)$ describe directions of final decay products
$B_s \rightarrow J/\Psi \Phi$ Phenomenology (2)

- Three angular momentum states form a basis for the final $J/\Psi \Phi$ state

- Use alternative “transversity basis” in which the vector meson polarizations w.r.t. direction of motion are either:
  - longitudinal (0) → CP even
  - transverse (∥ parallel to each other) → CP even
  - transverse (⊥ perpendicular to each other) → CP odd

- Corresponding decay amplitudes: $A_0$, $A_\parallel$, $A_\perp$

- At good approximation ($\Phi_s \approx 0$), mass eigenstates $|B^L_s\rangle$ and $|B^H_s\rangle$ are CP eigenstates
  → use angular information to separate heavy and light states
  → determine decay width difference
  $\Delta \Gamma = \Gamma_L - \Gamma_H$
  → some sensitivity to CP violation phase $\beta_s$

- Determine $B_s$ flavor at production (flavor tagging)
  → improve sensitivity to CP violation phase $\beta_s$
$B_s \rightarrow J/\Psi\Phi$ Phenomenology (3)

- $B_s \rightarrow J/\Psi\Phi$ decay rate as function of time, decay angles and initial $B_s$ flavor:

$$\frac{d^4 P(t, \rho)}{dt d\rho} \propto |A_0|^2 T_+ f_1(\rho) + |A_\parallel|^2 T_+ f_2(\rho)$$

$$+ |A_\perp|^2 T_- f_3(\rho) + |A_\parallel||A_\perp| U_\perp f_4(\rho)$$

$$+ |A_0||A_\parallel|\cos(\delta_\parallel)T_+ f_5(\rho)$$

$$+ |A_0||A_\perp| U_\perp f_6(\rho),$$

- $T_\pm = e^{-i\Gamma t} \times [\cosh(\Delta \Gamma t/2) \mp \cos(2\beta_s) \sin(\Delta \Gamma t/2)$

$$+ \eta \sin(2\beta_s) \sin(\Delta m_s t)],$$

- $U_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel) \cos(\Delta m_s t)$

$$\mp \cos(\delta_\perp - \delta_\parallel) \cos(2\beta_s) \sin(\Delta m_s t)$

$$\pm \cos(\delta_\perp - \delta_\parallel) \sin(2\beta_s) \sinh(\Delta \Gamma t/2)]$. 'strong' phases:

$$\delta_\parallel \equiv \arg(A_\parallel^* A_0)$$

$$\delta_\perp \equiv \arg(A_\perp^* A_0)$$

- Tagging $\rightarrow$ better sensitivity to $\beta_s$
**B_s Lifetime in B_s → J/ΨΦ Decays**

- Most precise B_s lifetime measurements from B_s → J/ΨΦ decays:
  (assuming no CP violation, β_s = 0)

  - **CDF**
    ~2500 signal events in ~1.7 fb^{-1}

  - **DØ**
    ~1040 signal events in ~1.1 fb^{-1}

\[ \tau_s = 1.52 \pm 0.04 \text{ (stat)} \pm 0.02 \text{ (syst)} \text{ ps} \]

Best measurement

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**arXiv:0712.2348**

**PRL 98, 121801 (2007)**
**B_s Decay Width**

CDF

CDF II Preliminary

\[ L = 1.7 \text{ fb}^{-1} \]

- Data
- Fit
- Signal
- Background
- CP-even
- CP-odd

DØ

\[ \Delta \Gamma = 0.08 \pm 0.06 \text{ (stat)} \pm 0.01 \text{ (syst)} \text{ ps}^{-1} \]

\[ 0.12 \pm 0.08 - 0.10 \text{ (stat)} \pm 0.02 \text{ (syst)} \text{ ps}^{-1} \]

Best measurement

- Cross check: CDF measures decay amplitudes and strong phases in high statistics
  \[ B^0 \rightarrow J/\Psi K^0 \text{ sample} \rightarrow \text{agreement and competitive with B factories} \]

\[ \arXiv:0712.2348 \]


PRL 98, 121801 (2007)
CP Violation Phase $\beta_s$ in Un-tagged $B_s \to J/\psi \phi$ Decays

- Without identification of the initial $B_s$ flavor still have sensitivity to $\beta_s$

- Due to irregular likelihood and biases in fit, CDF only quotes Feldman-Cousins confidence regions (Standard Model probability 22%)

- DØ quotes point estimate: $\Phi_s = -0.79 \pm 0.56$ (stat) $^{+0.14}_{-0.01}$ (syst)

- Symmetries in the likelihood → 4 solutions are possible in $2\beta_s$-$\Delta \Gamma$ plane

CDF: 90%, 95% C.L

DØ: 39% C.L.

PRL 98, 121801 (2007)
CP Violation Phase $\beta_s$ in Tagged $B_s \to J/\Psi\Phi$ Decays

- Likelihood expression predicts better sensitivity to $\beta_s$ but still double minima due to symmetry:
  \[ 2\beta_s \to \pi - 2\beta_s \]
  \[ \Delta\Gamma \to -\Delta\Gamma \]
  \[ \delta_{\parallel} \to 2\pi \quad \delta_{\parallel} \]
  \[ \delta_{\perp} \to \pi - \delta_{\perp} \]

- Study expected effect of tagging using pseudo-experiments

- Improvement of parameter resolution is small due to limited tagging power ($\varepsilon D^2 \sim 4.5\%$ compared to B factories $\sim 30\%$)

- However, $\beta_s \to -\beta_s$ no longer a symmetry
  $\to$ 4-fold ambiguity reduced to 2-fold ambiguity
  $\to$ allowed region for $\beta_s$ is reduced to half

\[ 2\Delta\log(L) = 2.3 \approx 68\% \text{ CL} \]
\[ 2\Delta\log(L) = 6.0 \approx 95\% \text{ CL} \]
CP Violation Phase $\beta_s$ in Tagged $B_s \rightarrow J/\Psi \Phi$ Decays (CDF, 1.4 fb$^{-1}$)

- First tagged analysis of $B_s \rightarrow J/\Psi \Phi$ (1.4 fb$^{-1}$)
- Signal $B_s$ yield $\sim$2000 events with S/B $\sim$ 1
- As in un-tagged analysis, irregular likelihood does not allow quoting point estimate
- Quote Feldman-Cousins confidence regions

- Confidence regions are underestimated when using $2\Delta \log L = 2.3$ (6.0) to approximate 68% (95%) C.L. regions
$\beta_s$ in Tagged $B_s \rightarrow J/\Psi \Phi$ Decays with External Constraints (CDF)

- Spectator model of B mesons suggests that $B_s$ and $B^0$ have similar lifetimes and strong phases
- Likelihood profiles with external constraints from B factories:

- External constraints on strong phases remove residual 2-fold ambiguity
\( \beta_s \) in Tagged \( B_s \rightarrow J/\Psi \Phi \) Decays Final Results (CDF)

- 1D Feldman-Cousins procedure without external constraints:
  \( 2\beta_s \) in \([0.32, 2.82]\) at the 68\% C.L.

- with theoretical input \( \Delta \Gamma = 0.096+/- 0.039 \)
  \( 2\beta_s \) in \([0.24, 1.36]\) U \([1.78, 2.90]\) at 68\% C.L.

- with external constraints on strong phases, lifetime and \( \Delta \Gamma \)
  \( 2\beta_s \) in \([0.40, 1.20]\) at 68\% C.L.

- \( \beta_s \) parameter space is greatly reduced when using flavor tagging:

- DØ results on \( \beta_s \) using flavor tagging expected soon
Charge Asymmetry in Semileptonic $B_s \rightarrow \mu D_s X$ Decays (DØ, 1.3 fb$^{-1}$)

- Study $B_s^0 \rightarrow \mu^+ D_s^- \nu X$ with $D_s^- \rightarrow \phi \pi^- \phi \rightarrow K^+ K^-$
- $L = 1.3$ fb$^{-1}$ with total signal yield $\sim 27K$ events
- Compare decay rates of $B_s$ and $\bar{B}_s$:

$$A_{SL}^{s, unt} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^+) + N(\mu^- D_s^-)} = [1.23 \pm 0.97 \text{(stat)} \pm 0.17 \text{(syst)}] \times 10^{-2}$$

- Suppressed systematic uncertainties due to regular change of magnet polarity at DØ
- Semileptonic charge asymmetry is related to $\phi_s^{SM} = \text{arg}(-\tilde{M}_{12}/\Gamma_{12})$

$$A_{SL}^{s, unt} = \frac{1}{2} \frac{\Delta \Gamma_s}{\Delta m_s} \tan \phi_s$$

- In SM $\Phi_s$ is predicted to be very small ($\approx 4 \times 10^{-3}$)
- NP can significantly modify SM prediction $\phi_s = \phi_s^{SM} + \phi_s^{NP}$
- If $\phi_s^{NP}$ dominates $2\beta_s = -\phi_s^{NP} = -\phi_s$
- Can combine this result with $\beta_s$ measurement in $B_s \rightarrow J/\Psi \Phi$ to constrain NP
Charge Asymmetry in Inclusive B_{s} Decays (DØ, CDF)

- Measure same sign muon charge asymmetry at DØ with 1 fb-1:
  \[ A = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1}{4f} \left[ A_{B^0} + \frac{f_s \chi_s}{f_d \chi_d} A_{B_s^0} \right] \]
  \[ f \cdot A = -0.0023 \pm 0.0011 \text{ (stat)} \pm 0.0008 \text{ (syst)} \]

- With knowledge of fragmentation fractions f_s and f_d, the integrated oscillation probabilities \( \chi_d \) and \( \chi_s \) and known \( B^0 \) semileptonic asymmetry from B factories:
  \[ A_s = -0.0064 \pm 0.0101 \text{ (stat+syst)} \]
  [PRD 74, 092001 (2006)]

- Similar measurement at CDF with 1.6 fb-1:
  \[ A_s = 0.020 \pm 0.021 \text{ (stat)} \pm 0.016 \text{ (syst)} \pm 0.009 \text{ (inputs)} \]
  [http://www-cdf.fnal.gov/physics/new/bottom/070816.blessed-acp-bsemil/]

- These measurements can be combined with asymmetries in \( B_s \rightarrow \mu D_s X \) to further constrain CP violation phase
Combined DØ Constraints on $\Delta \Gamma$ and $\Phi_s$

- Combine width difference and CP violation phase from time dependent angular analysis $B_s \rightarrow J/\Psi \Phi$ with measurements from charge asymmetry in semileptonic decays
- Contours indicate 39% C.L. regions:
  - Final combined DØ results with $\sim 1$ fb$^{-1}$:
    \[
    \Delta \Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1} \\
    \phi_s = -0.70^{+0.47}_{-0.39}.
    \]
- From tagged $B_s \rightarrow J/\Psi \Phi$ analysis, CDF excludes $\sim$half available space in $\Phi_s$-$\Delta \Gamma$ plane (two LHS solutions)
- Assuming same lifetime and strong phases for $B^0$ and $B_s$, CDF constrains strong phases to B factories measurements $\rightarrow$ bottom – right solution is suppressed as well
- Expect tagged $B_s \rightarrow J/\Psi \Phi$ analysis from DØ soon
- Expect updated analyses with 2x data from both experiments soon
CDF Impact on $\Phi_s$ World Average

- Overlay CDF result on UT world average which includes DØ combined result

http://www.utfit.org/

- CDF 68% CL no constraints
- CDF 68% CL with constraints on strong phases, lifetime and $\Delta \Gamma$

- CDF measurement suppresses large fraction of CP violation parameter space!
Direct CP Violation in $B^+ \rightarrow J/\Psi K^+$ Decays (DØ, 1.6 fb$^{-1}$)

- SM predicts small (~1%) direct CP violation in $B^+ \rightarrow J/\Psi K^+$
- Due to interference between direct and annihilation amplitudes

- Signal yield ~28K $B^+ \rightarrow J/\Psi K^+$ decays
- DØ reverses magnet polarities frequently → good control of systematic uncertainties in charge asymmetry measurements
- Correct for $K^+/K^-$ asymmetry

\[
A = \frac{N(B^- \rightarrow J/\psi K^-) - N(B^+ \rightarrow J/\psi K^+)}{N(B^- \rightarrow J/\psi K^-) + N(B^+ \rightarrow J/\psi K^+)} = +0.0067 \pm 0.0074(stat) \pm 0.0026(syst)
\]

- Consistent with world average: $A_{CP}(B^+ \rightarrow J/\psi K^+) = +0.015 \pm 0.017$
but factor of two better precision → best measurement

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B49/B49.pdf
Branching Fractions and CP Asymmetry in $\Lambda_b \rightarrow p \pi(K)$ (CDF, 1 fb$^{-1}$)

- First study of CP asymmetry in b baryon decays (SM prediction $\sim 10\%$)
- Use large sample collected by two displaced track trigger

- Different states that contribute to $\pi^+\pi^-$ invariant mass are not separated in mass
- Use additional kinematic and dE/dx information to achieve better statistical separation

Branching Fractions and CP Asymmetry in $\Lambda_b \rightarrow p\pi(K)$ (CDF, 1 fb$^{-1}$)

- Results:

$$A_{CP}(\Lambda_b^0 \rightarrow p\pi^-) = \frac{B(\Lambda_b^0 \rightarrow p\pi^-) - B(\overline{\Lambda}_b^0 \rightarrow \overline{p}\pi^+)}{B(\Lambda_b^0 \rightarrow p\pi^-) + B(\overline{\Lambda}_b^0 \rightarrow \overline{p}\pi^+)} = 0.03 \pm 0.17 \text{ (stat.)} \pm 0.05 \text{ (syst.)}$$

$$A_{CP}(\Lambda_b^0 \rightarrow pK^-) = \frac{B(\Lambda_b^0 \rightarrow pK^-) - B(\overline{\Lambda}_b^0 \rightarrow \overline{p}K^+)}{B(\Lambda_b^0 \rightarrow pK^-) + B(\overline{\Lambda}_b^0 \rightarrow \overline{p}K^+)} = 0.37 \pm 0.17 \text{ (stat.)} \pm 0.03 \text{ (syst.)}$$

- First CP asymmetry measurement in b baryon decays

- Additionally, first measurement of branching fraction relative to $B^0 \rightarrow K\pi$ decays:

$$\frac{\sigma(pp \rightarrow \Lambda_b^0 X, p_T > 6 \text{ GeV/c})}{\sigma(pp \rightarrow B^0 X, p_T > 6 \text{ GeV/c})} \frac{B(\Lambda_b^0 \rightarrow p\pi^-)}{B(B^0 \rightarrow K^+\pi^-)} = 0.0415 \pm 0.0074 \text{ (stat.)} \pm 0.0058 \text{ (syst.)}$$

$$\frac{\sigma(pp \rightarrow \Lambda_b^0 X, p_T > 6 \text{ GeV/c})}{\sigma(pp \rightarrow B^0 X, p_T > 6 \text{ GeV/c})} \frac{B(\Lambda_b^0 \rightarrow pK^-)}{B(B^0 \rightarrow K^+\pi^-)} = 0.0663 \pm 0.0089 \text{ (stat.)} \pm 0.0084 \text{ (syst.)}$$

$\Lambda_b$ Lifetime (DØ, 1.3 fb⁻¹)

- Important test of models that describe interactions between heavy and light quarks within bound states
- HQET + Lattice QCD predicts: $\tau(\Lambda_b)/\tau(B^0) = 0.88 \pm 0.05$  
- DØ measures $\Lambda_b$ lifetime in two decay modes:

  $\Lambda_b \rightarrow J/\psi \Lambda$
  1.2 fb⁻¹, ~170 signal events

  $\Lambda_b^0 \rightarrow \mu\bar{\nu}\Lambda^+_c X$
  1.3 fb⁻¹, ~4400 signal events

\[
\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115}\text{(stat)} \pm 0.042\text{(syst)} \text{ ps} \quad \tau(\Lambda_b^0) = 1.290^{+0.119}_{-0.110}\text{(stat)}^{+0.087}_{-0.091}\text{(syst)}
\]
\[
\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.811^{+0.096}_{-0.087}\text{(stat)} \pm 0.034\text{(syst)}
\]
Λ_b Lifetime Current Status

- DØ measurements are in agreement with the theoretical predictions and with the world average \( \tau(Λ_b^0) = 1.230 \pm 0.074 \) ps.

- CDF measurement in \( Λ_b \to J/\psi Λ \) is ~3σ high w.r.t world average [arXiv:hep-ex/0609021v1]

- Expect CDF measurement in hadronic mode soon

<table>
<thead>
<tr>
<th>decay mode</th>
<th>CDF lifetime (ps), 1 fb-1</th>
<th>DØ lifetime (ps), 1.3 fb-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Λ_b \to J/\psi Λ )</td>
<td>( 1.593^{+0.083}_{-0.078} ) (stat.) \pm 0.033 (syst.)</td>
<td>( 1.218^{+0.130}_{-0.118} ) (stat.) \pm 0.042 (syst.) ps</td>
</tr>
<tr>
<td>( Λ_b^0 \to μνΛ^+_c X )</td>
<td>x</td>
<td>( 1.290^{+0.119}_{-0.110} ) (stat.) \pm 0.087 (syst)</td>
</tr>
<tr>
<td>( Λ_b^0 \to Λ_c^+ π^- )</td>
<td>expected soon</td>
<td>x</td>
</tr>
</tbody>
</table>
**Ξ_b Baryons (DØ, 1.3 fb⁻¹)**

- **Ξ_b** (quark content: *bds*) → third observed *b* baryon after *Λ_b* and CDF’s recent discovery of *Σ_b*
- Study *b* baryons → great way to test QCD which predicts \( M(Λ_b) < M(Ξ_b) < M(Σ_b) \)
- Predicted mass: 5805.7 ± 8.1 MeV
- Discovery decay mode at DØ:

\[
Ξ_b^- \rightarrow J/ψ Ξ^-, \text{ with } J/ψ \rightarrow μ^+ μ^-, \text{ and } Ξ^- \rightarrow Λπ^- \rightarrow pπ^- π^-
\]

Run 179200, Event 55278820, \( M(Ξ_b) = 5.788 \text{ GeV} \)
$\Xi_b$ Mass Measurement (DØ, 1.3 fb$^{-1}$)

- Clear excess in $\Xi_b$ invariant mass distribution
- Significance $\sim 5.5\sigma$

Number of signal events: $15.2 \pm 4.4\,\text{(stat)} \pm 1.9_{-0.4}\,\text{(syst)}$
Mass: $5.774 \pm 0.011\,\text{(stat)} \pm 0.015\,\text{(syst)}$ GeV (prediction $5805.7 \pm 8.1$ MeV)

- Width: $0.037 \pm 0.008$ GeV in good agreement with MC expectation $0.035$ GeV
- Production relative to $\Lambda_b \rightarrow J/\Psi \Lambda$

\[
\frac{f(b \rightarrow \Xi_b^-) \cdot B_r(\Xi_b^- \rightarrow J/\psi \Xi^-)}{f(b \rightarrow \Lambda_b) \cdot B_r(\Lambda_b \rightarrow J/\psi \Lambda)} = 0.28 \pm 0.09\,\text{(stat.)}^{+0.09}_{-0.08}\,\text{(syst.)}
\]

where $f(b \rightarrow X)$ : fraction of times $b$ quark hadronizes to $X$

**\( \Xi_b \) Mass Measurement (CDF, 1.9 fb\(^{-1} \))**

- \( \Xi \) tracked in silicon vertex detector for the first time at hadron collider
  → reduce background
  → improve secondary vertex precision

\[ \text{Yield} = 17.5 \pm 4.3 \]
\[ \text{M} = 5792.9 \pm 2.5 \text{ MeV/c}^2 \]

\[ M(\Xi_b^-) = (5.792.9 \pm 2.4\text{(stat.)} \pm 1.7\text{(syst.)}) \text{ MeV/c}^2 \]
most precise measurement at 7.8\( \sigma \) significance
- $\Xi_b$ can be measured in hadronic decays at CDF
- With more data will study other properties of $\Xi_b$
**$B_c$ Mass in $B_c \to J/\Psi \pi$ (CDF, 2.4 fb$^{-1}$)**

- $B_c$ contains both heavy quarks $b, c \to$ each quark can decay
- Mass predictions:
  - NR potential models 6247 - 6286 MeV
  - lattice QCD 6304 +/- 12 +18 -0 MeV
- Three decay possibilities:
  - $c$ quark decays: $B_c^+ \to B_s^0 \pi^+$, and $B_c^+ \to B_s^0 \ell^+ \nu$
  - $b$ quark decays: $B_c^+ \to J/\Psi \pi^+$, $B_c^+ \to J/\Psi D_s^+$, $B_c^+ \to J/\Psi \ell^+ \nu$
  - annihilation: $B_c^+ \to \ell^+ \nu$

- Best mass measurement:

\[
6275.6 \pm 2.9 \text{ (stat.)} \pm 2.5 \text{ (syst.) MeV/c}^2
\]
**B_c Lifetime in $B_c \rightarrow J/\Psi \mu X$ (DØ, 1.4 fb$^{-1}$)**

- Lifetime expected $\sim$1/3 of other B mesons
- Main challenge in partially reconstructed mode is understanding multiple backgrounds:
  - real $J/\Psi$ + fake muon
  - fake $J/\Psi$ + real muon
  - real $J/\Psi$ + real muon $\rightarrow$ from bb events
  - $B^+ \rightarrow J/\psi K^+$ where $K \rightarrow \mu \nu \nu$
  - prompt $J/\Psi$ + $\mu$

- Mass – lifetime simultaneous fit used to disentangle small signal fraction among large fraction of backgrounds

- Most precise $B_c$ lifetime measurement:

$$\tau(B^\pm) = 0.444^{+0.039}_{-0.038} \text{ (stat)} \pm 0.039 \text{ (sys)} \text{ ps.}$$

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B52/
**Rare Decays (DØ)**

- In SM FCNC processes are forbidden at tree level → only occur at higher order
- In many new physics models, decay rates of FCNC decays of b- or c-mesons are enhanced w.r.t. SM expectations
- $B_s \rightarrow \mu^+\mu^-$ theoretical SM prediction $\mathcal{B}(B_s \rightarrow \mu^+\mu^-) = (3.42 \pm 0.54) \cdot 10^{-9}$
- DØ limit with 2.0 fb$^{-1}$:

$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 7.5 \times 10^{-8} \text{ at } 95(90)\% \text{CL}$$

- In case of c-mesons branching fraction SM expectations are $\sim 10^{-9}$
- Reconstruct $D^+ \rightarrow \pi^+\mu^+\mu^-$ where muons come from $\Phi$

- First observation of $D_s^+ \rightarrow \phi\pi^+ \rightarrow \mu^+\mu^-\pi^+$
- First evidence for $D^+ \rightarrow \phi\pi^+ \times \mu^+\mu^-\pi^+$

- Search for FCNC $D^+ \rightarrow \pi^+\mu^+\mu^-$ outside $\Phi \rightarrow \mu\mu$ mass window
- No signal seen → set most stringent upper limit:

$$1.3 \text{ fb}^{-1}$$

$$\mathcal{B}(D^+ \rightarrow \pi^+\mu^+\mu^-) < 3.9 \times 10^{-6} \text{ at } 90\% \text{ CL}$$

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B48/

**μ+μ- invariant mass**

hep-ex/0708.2094
Rare Decays (CDF)

- With 2.0 fb⁻¹, best limit in:

\[
\begin{align*}
B(B_s^0 \rightarrow \mu^+ \mu^-) &< 5.8 \times 10^{-8} \ (4.7 \times 10^{-8}) \text{ at } 95(90)\%\text{CL} \\
B(B^0 \rightarrow \mu^+ \mu^-) &< 1.8 \times 10^{-8} \ (1.5 \times 10^{-8}) \text{ at } 95(90)\%\text{CL}
\end{align*}
\]

arXiv:0712.1708

- 0.9 fb⁻¹

\[
B(B^* \rightarrow \mu^+ \mu^- K^+) = (0.60 \pm 0.15 \pm 0.04) \times 10^{-6}, \\
B(B^0 \rightarrow \mu^+ \mu^- K^0) = (0.82 \pm 0.31 \pm 0.10) \times 10^{-6}
\]

consistent with world average and competitive with best measurements

\[
B(B_s \rightarrow \mu^+ \mu^- \phi)/B(B_s \rightarrow J/\psi \phi) < 2.61(2.30) \times 10^{-3} \text{ at } 95(90)\%\text{CL} \quad \text{best limit}
\]

http://www-cdf.fnal.gov/physics/new/bottom/061130.blessed_bnumuh/

- First observation of \( \overline{B}_s^0 \rightarrow D_s^{\pm} K^{\mp} \) in 1.2 fb⁻¹

109 +/- 9 signal events with ~8 sigma significance

Measure branching fraction relative to Cabibbo allowed mode:

\[
B(B_s^0 \rightarrow D_s^+ K^+) / B(B_s^0 \rightarrow D_s^- \pi^-) = 0.107 \pm 0.019 \text{ (stat)} \pm 0.008 \text{ (sys)}
\]

http://www-cdf.fnal.gov/physics/new/bottom/070524.blessed Bs-DsK/
D^0 Mixing

- After recent observation of fastest neutral meson oscillations in B_s system by CDF and DØ → time to look at the slowest oscillation of D^0 mesons 😊

- D^0 mixing in SM occurs through either:

![Diagram showing short range and long range processes](image)

<table>
<thead>
<tr>
<th></th>
<th>(\Delta M/\Gamma)</th>
<th>(\Delta \Gamma/\Gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K^0</td>
<td>0.474</td>
<td>0.997</td>
</tr>
<tr>
<td>B^0</td>
<td>0.77</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>B_s</td>
<td>27</td>
<td>0.15</td>
</tr>
<tr>
<td>D^0</td>
<td>&lt; few%</td>
<td>&lt; few%</td>
</tr>
</tbody>
</table>

- Recent D^0 mixing evidence ← different D^0 decay time distributions in

**Belle**

- \(D^0 \rightarrow \pi\pi, \, KK\) (CP eigenstates) compared to \(D^0 \rightarrow K\pi\)

**BaBar**

- Doubly Cabibbo suppressed (DCS) \(D^0 \rightarrow K^+\pi^-\) compared to Cabibbo favored (CF) \(D^0 \rightarrow K\pi^+\) (Belle does not see evidence in this mode)
Evidence for D$^0$ Mixing at CDF (1.5 fb$^{-1}$)

- CDF sees evidence for D$^0$ mixing at 3.8σ significance by comparing DCS D$^0 \rightarrow K^+\pi^-$ decay time distribution to CF D$^0 \rightarrow K^-\pi^+$ (confirms BaBar)

- Ratio of decay time distributions:

$$R(t/\tau) = R_D + \sqrt{R_D} y'(t/\tau) + \frac{x'^2}{4} (t/\tau)^2$$

where $x' = x \cos \delta - y \sin \delta$ and $y' = -x \sin \delta + y \cos \delta$

$\delta$ is strong phase between DCS and CF amplitudes.

Mixing parameters $x = \Delta M / \Gamma$, $y = \Delta \Gamma / 2\Gamma$ are 0 in absence of mixing.
Topics Not Covered

- Many other recent results not covered in this talk:
  
  - $B_s$ oscillations
  - $B_s \rightarrow D_s(*) D_s(*)$
  - $\Psi(2S)$ production,
  - $Y(1S), Y(2S)$ polarization
  - $B^0 \rightarrow J/\psi K^{*0}$ angular analysis
  - orbitally excited $B$ mesons
  - $b\bar{b}$ correlations
  - $CP$ asymmetry in $B^+ \rightarrow D^0 K^+$
Conclusions

- Very rich B physics program at the Tevatron

- Complementary and competitive with *Belle* and *BaBar*

- Great Tevatron performance
  → accumulate data fast
  → expect \( \sim 6 \text{ fb}^{-1} \) by the end of the run

- Expect updates of many analyses

- Exciting time to study CP violation and search for new phenomena in B physics at Tevatron!
Triggers

- Triggers designed to select events with topologies consistent with B decays:

  - single lepton (+ displaced track) (semileptonic decays) \(\leftarrow\) DØ (CDF)

  \[\begin{align*}
  &\text{P.V.} \quad \text{B} \quad \text{D} \\
  &\text{lepton} \quad \text{displaced track}
  \end{align*}\]

  - di-lepton (B \(\rightarrow\) J/\(\Psi\), B \(\rightarrow\) \(\mu\mu\), B \(\rightarrow\) \(\mu\mu\) + hadrom) \(\leftarrow\) both CDF and DØ

  \[\begin{align*}
  &\text{P.V.} \quad \text{B}_s \quad \Phi \rightarrow \text{KK} \\
  &\text{J/\(\Psi\)} \rightarrow \text{\(\mu\mu\)} \quad \text{\(\Phi\)} \rightarrow \text{KK}
  \end{align*}\]

  - displaced tracks (hadronic decays) \(\leftarrow\) CDF

  \[\begin{align*}
  &\text{P.V.} \quad \text{B} \quad \text{D} \\
  &\text{displaced track} \quad \text{displaced track}
  \end{align*}\]
Effect of Dilution Asymmetry on $\beta_s$

- Effect of 20% b-bbar dilution asymmetry is very small
Branching Fractions and CP Asymmetry in $B^+ \rightarrow D^0 K^+$ (CDF, 1 fb$^{-1}$)

- Measures quantities relevant for determination of the CKM angle

$$\gamma = \arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$$

$$A_{CP+} = \frac{BR(B^- \rightarrow D_{CP+}^0 K^-) - BR(B^+ \rightarrow D_{CP+}^0 K^+)}{BR(B^- \rightarrow D_{CP+}^0 K^-) + BR(B^+ \rightarrow D_{CP+}^0 K^+)}$$

$$R_{CP+} = \frac{R_+}{R} \quad \text{where:}$$

$$R = \frac{BR(B^- \rightarrow D^0 K^-) + BR(B^+ \rightarrow D^0 K^+)}{BR(B^- \rightarrow D^0 \pi^-) + BR(B^+ \rightarrow D^0 \pi^+)}$$

$$R_+ = \frac{BR(B^- \rightarrow D_{CP+}^0 K^-) + BR(B^+ \rightarrow D_{CP+}^0 K^+)}{BR(B^- \rightarrow D_{CP+}^0 \pi^-) + BR(B^+ \rightarrow D_{CP+}^0 \pi^+)}$$
Branching Fractions and CP Asymmetry in $B^+ \rightarrow D^0 K^+$ (CDF, 1 fb$^{-1}$)

- Discriminating variables used to disentangle decay modes:
  - $(D^0, \text{track})$ invariant mass
  - momentum imbalance: $p_{tr} < p_{D^0}$
    $$\alpha = 1 - \frac{p_{tr}}{p_{D^0}} > 0$$
  - total momentum $p_{tr} \geq p_{D^0}$
    $$\alpha = -(1 - \frac{p_{D^0}}{p_{tr}}) \leq 0$$
  - ‘kaonness’ contains $dE/dx$ information

of direct B track

\[ p_{tot} = p_t + p_{D^0} \]
Branching Fractions and CP Asymmetry in $B^+ \rightarrow D^0 K^+$ (CDF, 1 fb$^{-1}$)

- Results:
  - ratio of branching fractions:
    \[
    R = \frac{BR(B^+ \rightarrow D^0 K^-) + BR(B^+ \rightarrow D^0 \pi^-)}{BR(B^- \rightarrow D^0 \pi^+) + BR(B^- \rightarrow D^0 \pi^-)} = 0.0745 \pm 0.0043 \text{(stat.)} \pm 0.0045 \text{(syst.)}
    \]
    \[
    R_{CP^+} = \frac{BR(B^+ \rightarrow D_{CP+}^0 K^-) + BR(B^+ \rightarrow D_{CP+}^0 \pi^-)}{BR(B^- \rightarrow D^0 K^-) + BR(B^- \rightarrow D^0 \pi^-)} = 1.57 \pm 0.24 \text{(stat.)} \pm 0.12 \text{(syst.)}
    \]
  - direct CP asymmetry:
    \[
    A_{CP^+} = \frac{BR(B^+ \rightarrow D_{CP+}^0 K^-) - BR(B^+ \rightarrow D_{CP+}^0 \pi^-)}{BR(B^- \rightarrow D^0 K^-) + BR(B^- \rightarrow D^0 \pi^-)} = 0.37 \pm 0.14 \text{(stat.)} \pm 0.04 \text{(syst.)}
    \]
  - Quantities measured for the first time at hadron colliders
  - Results in agreement and competitive with B factories

**Graphs:**

- BABAR (arXiv:0708.1554)
  - BABAR (PRD 73, 031106(2006))
  - CDF II
  - Old AVG (Babar+BELLE)
  - New AVG (Babar+BELLE+CDF)

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  - CDF II
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  - New AVG (Babar+BELLE+CDF)
$\Xi_b$ Production (DØ, 1.3 fb$^{-1}$)

- Normalize $\Xi_b$ production to $\Lambda_b$ production
- Normalization mode $\Lambda_b \rightarrow J/\Psi \Lambda$

$$\Xi^-_b \rightarrow J/\psi \Xi^-$$

$DØ$, 1.3 fb$^{-1}$

- Data
- Fit

$$\frac{f(b \rightarrow \Xi^-_b) \cdot Br(\Xi^-_b \rightarrow J/\psi \Xi^-)}{f(b \rightarrow \Lambda_b) \cdot Br(\Lambda_b \rightarrow J/\psi \Lambda)} = 0.28 \pm 0.09 \text{ (stat.)}^{+0.09}_{-0.08} \text{ (syst.)}$$

where $f(b \rightarrow X)$ : fraction of times $b$ quark hadronizes to $X$