Mixings, Lifetimes, Spectroscopy and Production of $b$-quarks

(mostly hadron collider results)

Kevin Pitts
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Outline

- Introduction - B physics at hadron machines
- Heavy flavor production
  - charm cross section
- Lifetimes
- B hadron masses
- Branching ratios
  - $B_s \rightarrow K^+K^-$, $\Lambda_b \rightarrow \Lambda_c \pi^-$, $B_s \rightarrow D_s \pi^+$
- Mixing
  - $B_d$, $B_s$
- Summary

Notation:

$B_d = B^0 = |\bar{b}d\rangle$
$B_u = B^+ = |\bar{b}u\rangle$
$B_s = |\bar{b}s\rangle$
$B_c = |\bar{b}c\rangle$
$\Lambda_b = |udb\rangle$
**Pros**

- Enormous cross-section
  - $\sim$100 $\mu$barn total
  - $\sim$3-5 $\mu$barn “reconstructable”
  - At $4 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$ $\Rightarrow \sim$150Hz of reconstructable $\bar{B}B!!$

- All $B$ species produced
  - $B_u, B_d, B_s, B_c, \Lambda_b, \ldots$

- Production is incoherent
  - Measure of $B$ and $\bar{B}$ not required

**Cons**

- Large inelastic background
  - Triggering and reconstruction are challenging

- Reconstruct a $B$ hadron, $\sim$20-40% chance 2$^\text{nd}$ $B$ is within detector acceptance

- $p_T$ spectrum relatively soft
  - Typical $p_T(B)$ $\sim$10-15 GeV for trigger+reconstructed $B$’s
  - …softer than $B$’s at LEP!

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Disclaimer: acceptance comments relevant to “central” detectors like DØ and CDF
Detectors

- Both detectors
  - silicon microvertex detectors
  - axial solenoid
  - central tracking
  - high rate trigger/DAQ system
  - calorimeter & muon systems

DØ fiber tracker installation

CDF silicon detector installation

- DØ
  - Excellent electron & muon ID
  - Excellent tracking acceptance

- CDF
  - Silicon vertex trigger
  - Particle ID (TOF and dE/dx)
  - Excellent mass resolution
Typical detector efficiency \(~85-90\%\)

Luminosity used for HF analyses 6–140 pb\(^{-1}\)

Collider Run IIA Integrated Luminosity

- April 2001
- Feb 2002
- Jul 2002

\(~220\) pb\(^{-1}\) on tape per experiment

Data for physics

First data for analyses

Commissioning

Luminosity used for HF analyses 6–140 pb\(^{-1}\)
Heavy Flavor Cross Sections

- Tevatron $B$ Cross sections measured at $\sqrt{s}=1.8$TeV (1992-1996) consistently higher than NLO calculation

- Theoretical work is ongoing
  - Fragmentation effects
  - Small $x$, threshold effects
  - Proposed beyond SM effects

- What can experiments do?
  - Measure more cross sections
    - $\sqrt{s}=1.96$ TeV
    - go to lower $p_T(B)$
  - Look at $b\bar{b}$ correlations
  - Measure the charm cross section
CDF Silicon Vertex Tracker (SVT)

- SVT incorporates silicon info in the Level 2 trigger... select events with large impact parameter!

- Uses fitted beamline
- impact parameter per track
- System is deadtimeless:
  - ~25 µsec/event for readout + clustering + track fitting

$P_T(B) \geq 5$ GeV
$L_{xy} \geq 450 \mu m$

$35 \mu m \oplus 33 \mu m$ resol $\oplus$ beam $\Rightarrow \sigma = 48 \mu m$
CDF charm yields

- Trigger on displaced tracks, accepts both bottom & charm.
- Reconstruct large samples of charm hadrons
  >85% prompt charm!

Yields shown for 5.8pb⁻¹
CDF Prompt charm Cross Section

- Prompt charm cross section result submitted to PRL hep-ex/0307080
  ➔ See poster by Chunhui Chen
- Calculations shown are Cacciari & Nason hep-ph/0306212
- Observations:
  ➔ Data on the “upper edge” of theory for $D^0$ (shown), $D^+$ and $D^*$. 
  ➔ Trend similar to that seen in $B$ cross section measurements.
**Inclusive $J/\psi$**

Large yield, clean signals
- Acceptance down to $p_T=0$ GeV!
- $\chi_c$ signals also observed
- Inclusive lifetime shows $B \rightarrow J/\psi X$ fraction to be 15-20% (>80% direct charm)
- See Tomasz Skwarnicki’s quarkonia talk

Inclusive lifetime shows $B \rightarrow J/\psi X$ fraction to be 15-20% (>80% direct charm)

Inclusive lifetime also important for understanding lifetime systematics
**B Hadron Lifetimes**

- All lifetimes equal in spectator model.
  - Differences from interference & other nonspectator effects
- Heavy Quark Expansion predicts the lifetimes for different B hadron species
  \[ \tau(B^+) \geq \tau(B^0) \approx \tau(B_s) > \tau(\Lambda_b) \gg \tau(B_c) \]

- Measurements:
  - \(B^0, B^+\) lifetimes measured to better than 1%!
  - \(B_s\) known to about 4%
  - LEP/CDF (Run I) \(\Lambda_b\) lifetime lower than HQE prediction

- Tevatron can contribute to \(B_s, B_c\) and \(\Lambda_b\) (and other \(b\)-baryon) lifetimes.
Belle $B^+ \& B^0$ Lifetime

- 29 fb$^{-1}$ fully reconstructed decays
  - $7863$ $B^0$
  - $12047$ $B^+$
- Lifetime measured in $\Delta t$
  (see Tom Browder’s talk)

- Results:
  \[
  \tau(B^0) = 1.554 \pm 0.030 \text{(stat.)} \pm 0.019 \text{(syst.)} \text{ps}
  \]
  \[
  \tau(B^+) = 1.695 \pm 0.026 \text{(stat.)} \pm 0.015 \text{(syst.)} \text{ps}
  \]
  \[
  \frac{\tau(B^+)}{\tau(B^0)} = 1.091 \pm 0.023 \text{(stat.)} \pm 0.014 \text{(syst.)ps}
  \]

- Tails are well-modeled
Yields in $B\to J/\psi X$ Modes

- Trigger on low $p_T$ dimuons (1.5-2 GeV/µ)
- Fully reconstruct
  - $J/\psi, \psi(2S)\to\mu^+\mu^-$
  - $B^+\to J/\psi K^+$
  - $B^0\to J/\psi K^*, J/\psi K_S$
  - $B_s\to J/\psi \phi$
  - $\Lambda_b\to J/\psi \Lambda$
**B^+, B^0 Lifetimes in J/ψ Modes**

τ(B^0)

- **DØ**: 1.51 +0.19 \(-0.17\) (stat.) ± 0.2 (syst.) ps
- **CDF**: 1.51 ± 0.06(stat.) ± 0.02 (syst.) ps

**CDF Run II Preliminary**

- \(B^0 \rightarrow J/ψ K^0\)
- \(L = 138 \text{ pb}^{-1}\)
- \(\tau(B^+)\)

- **DØ**: 1.65 ± 0.08(stat.)\(^+0.10\)\(-0.12\) (syst.) ps
- **CDF**: 1.63 ± 0.05(stat.) ± 0.04 (syst.) ps

Proper decay length:

\[
ct = \frac{L_{xy}}{\beta \gamma} = \frac{L_{xy} m_B}{\beta \gamma p_T}
\]

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B BR, lifetimes, mixing
**$B_s$ Lifetime**

$B_s \rightarrow J/\psi \phi$, with $J/\psi \rightarrow \mu^+ \mu^-$ and $\phi \rightarrow K^+ K^-$

**DØ (115pb$^{-1}$): (shown here)**

$\tau(B_s) = 1.19^{+0.19}_{-0.16}$ (stat.) $\pm 0.14$ (syst.) ps

$\tau(B_s)/\tau(B^0) = 0.79 \pm 0.14$ (uncorrected for CP composition)

**CDF (138pb$^{-1}$):**

$\tau(B_s) = 1.33 \pm 0.14$ (stat.) $\pm 0.02$ (syst.) ps

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**Interesting $B_s$ physics:**

- Search for CPV in $B_s \rightarrow J/\psi \phi$
- ...sensitive to new physics
- Width difference $\Delta \Gamma$
- $B_s$ mixing (later in talk)
**$\Lambda_b$ Lifetime**

- **Use fully reconstructed** $\Lambda_b \rightarrow J/\psi \Lambda$
  with $J/\psi \rightarrow \mu^+ \mu^-$ and $\Lambda \rightarrow p \pi^-$

  - Previous LEP/CDF measurements used **semileptonic** $\Lambda_b \rightarrow \Lambda_c \nu$
  - Systematics different

**CDF** 46±9 signal

Unbinned Likelihood Fit To $\Lambda_B$ Lifetime

- $\tau = 374 \pm 78 \text{(stat)} \pm 29 \text{(syst)}$ ps

CDF Run II Preliminary 65pb$^{-1}$

- $56 \pm 14$ signal

**DØ Run II Preliminary**

\[ \tau = 1.05^{+0.21}_{-0.18} \pm 0.12 \text{ ps} \]

CDF

\[ \tau (\Lambda_b) = 1.25 \pm 0.26 \text{(stat.)} \pm 0.10 \text{(syst.) ps} \]

DØ

\[ \tau (\Lambda_b) = 1.05^{+0.21}_{-0.18} \text{(stat.)} \pm 0.12 \text{(syst.) ps} \]
**B Hadron Masses**

- Measure masses using fully reconstructed $B \rightarrow J/\psi X$ modes
- High statistics $J/\psi \rightarrow \mu^+ \mu^-$ and $\psi(2s) \rightarrow J/\psi \pi^+ \pi^-$ for calibration.
- Systematic uncertainty from tracking momentum scale
  - Magnetic field
  - Material (energy loss)
- $B^+$ and $B^0$ consistent with world average.
- $B_s$ and $\Lambda_b$ measurements are world’s best.

CDF result: $M(B_s)=5365.50 \pm 1.60$ MeV  
World average: $M(B_s)=5369.6 \pm 2.4$ MeV

CDF result: $M(\Lambda_b)=5620.4 \pm 2.0$ MeV  
World average: $M(\Lambda_b)=5624 \pm 9$ MeV
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CDF $B \rightarrow h^+ h^-$

- charmless two-body decays
  - longer term $B_s$ modes help extract unitarity angle $\gamma$ (see Hassan’s talk)

- Signal is a combination of:
  - $B^0 \rightarrow \pi^+ \pi^- \quad BR \sim 5 \times 10^{-6}$
  - $B^0 \rightarrow K^+ \pi^- \quad BR \sim 2 \times 10^{-5}$
  - $B_s \rightarrow K^+ K^- \quad BR \sim 5 \times 10^{-5}$
  - $B_s \rightarrow \pi^+ K^- \quad BR \sim 1 \times 10^{-5}$

- Requirements
  - Displaced track trigger
  - Good mass resolution
  - Particle ID ($dE/dx$)

Did you ever think this physics could be done at a hadron collider?
**BR(\(B_s \rightarrow K^+K^-\))**

Simulation

- 320±60 events
  - \(\mu = 5.252(2)\) GeV/c²
  - \(\sigma = 41.1(1.9)\) MeV/c²

**Fitted contributions:**

<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±17(stat.)±17(syst)</td>
</tr>
<tr>
<td>(B^0 \rightarrow \pi\pi)</td>
<td>39±14(stat.)±17(syst)</td>
</tr>
<tr>
<td>(B_s \rightarrow KK)</td>
<td>90±17(stat.)±17(syst)</td>
</tr>
<tr>
<td>(B_s \rightarrow K\pi)</td>
<td>3±11(stat.)±17(syst)</td>
</tr>
</tbody>
</table>

**First observation of \(B_s \rightarrow K^+K^-\)!!**

Result:

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

includes error on \(f_s/f_d\)

see poster by Diego Tonelli
Reflections, Satellites and All That

Vertex trigger sample
reconstruct: $B^{-} \rightarrow D^{0} \pi^{-}$

*Clear peak seen, sidebands have interesting structure*

CDF Run II Preliminary, $L = 119 \text{ pb}^{-1}$

about 1900 $B^{+} \rightarrow \overline{D}^{0} \pi^{+}$

- "horns" coming from $D^{*}$
- Reflection from $B^{-} \rightarrow D^{0} K^{-}$
  (reconstruct $K$ as $\pi$)

CDF Run II Monte Carlo

Work in progress, must understand these contributions to extract BR
CDF $\Lambda_b \rightarrow \Lambda_c \pi$ with $\Lambda_c \rightarrow pK\pi$

Backgrounds: real $B$ decays
Reconstruct $\pi$ as $p$: $B_d \rightarrow D^-\pi^+ \rightarrow K^+\pi^-\pi^-\pi^+$

- Use MC to parametrize the shape.
- Data to normalize the amplitude
- Dominant backgrounds are real heavy flavor
- Proton particle ID ($dE/dx$) improves S/B

Fitted signal:
$$N_{\Lambda_b} = 96 \pm 13\,(stat.)^{+6}_{-7}\,(syst.)$$

Measure:
$$\frac{\sigma_b \times f_{\text{baryon}} \times BR(\Lambda_b \rightarrow \Lambda_c^{\mp} \pi^\mp)}{\sigma_b \times f_d \times BR(\Lambda^0 \rightarrow D^-\pi^+)}$$

New Result!
$$BR(\Lambda_b \rightarrow \Lambda_c \pi^{\pm}) = (6.0 \pm 1.0\,(stat) \pm 0.8\,(sys) \pm 2.1\,(BR)) \times 10^{-3}$$
**$B_d$ Mixing**

$B_d$ mixing measured with great precision

$\rightarrow$ World average now dominated by Babar and Belle

$B_d$ fully mixes in about $4.1$ lifetimes

---

**Babar $\Delta m_d$ result using hadronic $B$ decays**

$V_{tb} \sim 1$

$Re(V_{td}) \approx 0.0071$

$B_d$ fully mixes in about $4.1$ lifetimes

---

**$B_d$ Mixing Diagram**

- $B_d$ mixing
- $V_{tb} \sim 1$
- $Re(V_{td}) \approx 0.0071$

---

**Babar $\Delta m_d$ result using hadronic $B$ decays**

$A_{mix}$

$B_A B A R$

$\Delta m_d$ (ps$^{-1}$)

- $0.44 \pm 0.026 \pm 0.019$ ps$^{-1}$
- $0.519 \pm 0.018 \pm 0.011$ ps$^{-1}$
- $0.444 \pm 0.028 \pm 0.028$ ps$^{-1}$
- $0.479 \pm 0.018 \pm 0.015$ ps$^{-1}$
- $0.495 \pm 0.033 \pm 0.027$ ps$^{-1}$
- $0.500 \pm 0.008 \pm 0.006$ ps$^{-1}$
- $0.506 \pm 0.006 \pm 0.008$ ps$^{-1}$
- $0.502 \pm 0.007$ ps$^{-1}$
- $0.493 \pm 0.032$ ps$^{-1}$
- $0.502 \pm 0.006$ ps$^{-1}$

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**Main Points**

- $B_d$ mixing measured with great precision.
- World average now dominated by Babar and Belle.
- Babar $\Delta m_d$ result using hadronic $B$ decays.
- $V_{tb} \sim 1$ and $Re(V_{td}) \approx 0.0071$.
- $B_d$ fully mixes in about $4.1$ lifetimes.
Towards $B_S$ Mixing

- Measurement of $\Delta m_s$ helps improve our knowledge of CKM triangle.
- Combined world limit on $B_S$ mixing
  \[ \Delta m_S > 14.4\text{ps}^{-1} @ 95\% CL \]
  \[ B_S \text{ fully mixes in <0.15 lifetime!!!} \]
- $B_S$ oscillation much faster than $B_d$ because of coupling to top quark:
  \[ \text{Re}(V_{ts}) \approx 0.040 > \text{Re}(V_{td}) \approx 0.007 \]

Combining limit comes from 13 measurements from LEP, SLD & CDF Run I
Measuring Mixing

- $B_s$ or $\bar{B}_s$ at the time of production?
  - Initial state flavor tagging
  - Tagging “dilution”: $D=1-2w$
  - Tagging power proportional to: $\varepsilon D^2$

- $B_s$ or $\bar{B}_s$ at the time of decay?
  - Final state flavor tagging
  - Can tell from decay products (e.g. $B_s \rightarrow D_s^- \pi^+$)

- Yields
  - Need lots of decays (because flavor tagging imperfect)

- Proper decay time
  \[ ct = \frac{L_{xy}}{(\beta \gamma)} = \frac{L_{xy} m_B}{p_T} \]
  - Need decay length ($L_{xy}$) and time dilation factor ($\beta \gamma = p_T/m_B$)
  - Crucial for fast oscillations (i.e. $B_s$)

Typical power (one tag):
$\varepsilon D^2 = O(1\%)$ at Tevatron
$\varepsilon D^2 = O(10\%)$ at PEPII/KEKB
Flavor Tagging

- Strategy: use data for calibration (e.g. $B^\pm \rightarrow J/\psi K^\pm$, $B \rightarrow$lepton)
  - “know” the answer, can measure right sign and wrong sign tags.

**DØ Results:**
- Jet charge $\varepsilon D^2 = (3.3 \pm 1.1)\%$
- Muon tagging $\varepsilon D^2 = (1.6 \pm 0.6)\%$

**CDF Results:**
- Same-side ($B^+$) $\varepsilon D^2 = (2.1 \pm 0.7)\%$
  ($B^+/B^0/B_s$ correlations different)
- Muon tagging $\varepsilon D^2 = (0.7 \pm 0.1)\%$
**$B_s$ Yields:** CDF $B_s \to D_s \pi^+$

CDF Run II Preliminary, $L = 119 \text{ pb}^{-1}$

- About 100 $B_s^0 \to D_s^- \pi^+$

$B_s \to D_s \pi^-$ with $D_s \to \phi \pi^+$ and $\phi \to K^- K^+$

\[
BR(B_s \to D_s \pi^\pm) = (4.8 \pm 1.2 \pm 1.8 \pm 0.8 \pm 0.6) \times 10^{-3}
\]

New measurement!

Previous limit set by OPAL: BR ($B_s \to D_s \pi^\pm$) < 13%

BR result uses less data than shown in plot.
Semileptonic $B_S$ Yields

Plots show: $B_S \rightarrow D_s l^- \nu$ with $D_s \rightarrow \phi \pi^+$ and $\phi \rightarrow K^- K^+$

(will also reconstruct $D_s \rightarrow K^{*0} K^+$ and $D_s \rightarrow Ks K^+$)
**DØ B Semileptonic Lifetime**

$B \rightarrow \mu^- \nu_\mu D^0 X$ with $D^0 \rightarrow K^- \pi^+$

12pb$^{-1}$ of data taken with single muon trigger.

**D$^0$ Mass**

<table>
<thead>
<tr>
<th>Event/C(18 GeV/c$^2$)</th>
<th>1000</th>
<th>800</th>
<th>600</th>
<th>400</th>
<th>200</th>
<th>100</th>
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<tbody>
<tr>
<td>1.65</td>
<td>0.81</td>
<td>0.35</td>
<td>0.15</td>
<td>0.07</td>
<td>0.03</td>
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<tr>
<td>1.7</td>
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<td>0.02</td>
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<tr>
<td>1.75</td>
<td>0.89</td>
<td>0.41</td>
<td>0.18</td>
<td>0.09</td>
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<td>0.02</td>
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<tr>
<td>1.8</td>
<td>0.94</td>
<td>0.44</td>
<td>0.20</td>
<td>0.10</td>
<td>0.06</td>
<td>0.03</td>
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<td>1.85</td>
<td>0.99</td>
<td>0.48</td>
<td>0.22</td>
<td>0.11</td>
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<tr>
<td>1.9</td>
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<td>0.51</td>
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<td>1.95</td>
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<td>0.08</td>
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<td>2.05</td>
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<td>0.19</td>
<td>0.12</td>
<td>0.10</td>
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<tr>
<td>2.1</td>
<td>1.24</td>
<td>0.66</td>
<td>0.36</td>
<td>0.21</td>
<td>0.14</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Signal fraction = 0.155**

**DØ Run II Preliminary**

<table>
<thead>
<tr>
<th>$\chi^2$ / ndf</th>
<th>16.68 / 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prob</td>
<td>0.6739</td>
</tr>
<tr>
<td>Nevents</td>
<td>1276 ± 102.9</td>
</tr>
<tr>
<td>Mean</td>
<td>1.857 ± 0.002202</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.02937 ± 0.002627</td>
</tr>
<tr>
<td>Norm</td>
<td>616.6 ± 6.659</td>
</tr>
<tr>
<td>Slope</td>
<td>1.439 ± 0.064</td>
</tr>
</tbody>
</table>

**Time dilation factor ($\beta\gamma$) must be corrected for missing $\nu$**

$$\tau(B) = 1.46 \pm 0.08 \text{ (stat.) ps}$$
**$B_s$ Sensitivity**

- From data, now have some knowledge of the pieces that go into measuring $\Delta m_s$
  - **Yields** $S = \#$ signal events
  - **Flavor tagging** tagging power $= \varepsilon D^2$
  - **Signal-to-noise** $S/B = \text{signal/background}$
  - **Proper time resolution** $\sigma_t = \text{proper time resolution}$

- The sensitivity formula:

  \[
  \text{Significance} = \sqrt{\frac{S\varepsilon D^2}{2} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}}} \sqrt{\frac{S}{S + B}}
  \]

- Significance (in number of standard deviations) is “average significance”
**CDF $B_s$ Sensitivity Estimate**

- Current performance:  
  - $S=1600$ events/fb$^{-1}$ \( i.e. \sigma_{\text{effective}} \text{ for produce+trigger+recon} \)  
  - $S/B = 2/1$  
  - $\varepsilon D^2 = 4\%$  
  - $\sigma_t = 67$fs  
  
  \[2\sigma\] sensitivity for $\Delta m_s = 15$ps$^{-1}$ with $\sim 0.5$fb$^{-1}$ of data  
  - surpass the current world average  

---

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**CDF B_s Sensitivity Estimate**

- **Current performance:**
  - $S=1600$ events/fb$^{-1}$ *(i.e. $\sigma_{\text{effective}}$ for produce+trigger+recon)*
  - $S/B = 2/1$
  - $\varepsilon D^2 = 4\%$
  - $\sigma_t = 67$fs

  **2$\sigma$ sensitivity for $\Delta m_s=15$ps$^{-1}$ with ~0.5fb$^{-1}$ of data**
  - surpass the current world average

- **With “modest” improvements**
  - $S=2000$ fb *(improve trigger, reconstruct more modes)*
  - $S/B = 2/1$ *(unchanged)*
  - $\varepsilon D^2 = 5\%$ *(kaon tagging)*
  - $\sigma_t = 50$fs *(event-by-event vertex + L00)*

  **5$\sigma$ sensitivity for $\Delta m_s=18$ps$^{-1}$ with ~1.7fb$^{-1}$ of data**
  **5$\sigma$ sensitivity for $\Delta m_s=24$ps$^{-1}$ with ~3.2fb$^{-1}$ of data**

  $\Delta m_s=24$ps$^{-1}$ “covers” the expected region based upon indirect fits.

- **This is a difficult measurement.**

- **There are ways to further improve this sensitivity…**
Work In Progress

Estimates based current performance plus modest improvements. Further gain is possible on all of these pieces:

- $\sigma_t$
  - Event-by-event vertex
  - Layer 00
- Flavor tagging
  - Kaon tagging (same-side and opposite-side)
- Yields
  - Other $B_s$ modes (hadronic and semileptonic)
  - Other $D_s$ modes
  - Triggering
    - Improved use of available bandwidth
    - Improve available bandwidth
    - Improve SVT efficiency

Matters most for going to $\Delta m_s > 20 \text{ ps}^{-1}$

Trigger improvements matter most for yields

It’s doable! It will take time, luminosity and hard work!
Tevatron $B_s$ Sensitivity

- We know $B_s$ mixing is a difficult measurement.

- Estimate shown is based solely CDF sensitivity for the hadronic modes.
  - $D\emptyset$ will have sensitivity in hadronic mode (opposite muon)
  - Semileptonic modes important, especially at lower $\Delta m_s$
  - $D\emptyset$ and CDF will both contribute to $B_s \rightarrow$ lepton+$D_s$

- “This is a marathon, not a sprint.”

- SM expectation: $\Delta \Gamma_s \propto \Delta m_s$
  - Experiments will also attempt to measure $\Delta \Gamma_s$
    - in untagged samples
    - by extracting $CP$ even/odd components in $B_s \rightarrow J/\psi \phi$
Conclusion

- New cross sections, lifetime and branching ratio measurements from the Tevatron
  - Beginning to exploit high yields and upgraded detectors
    - DØ has a new spectrometer
    - CDF has a new impact parameter trigger
- Babar and Belle continue to provide an amazing breadth of $B^+$ and $B^0$ results
- Tevatron will contribute knowledge of heavier $B$ hadrons
  - Many technical challenges have been overcome
  - Lots of work to do
- Stay tuned!