Gold Mine for Heavy Flavor Physics

- **Mixing**: $B_s, B_d, D^0$
- **Lifetimes**: $\Delta \Gamma, \Lambda_b, B_s, B_c, B^+, B_d$ ...
- **New particles**: $X(3872), X_b$, Pentaquarks, ...
- **B and D Branching ratios**
- **Production properties**: $\sigma(b)$, $\sigma(J/\psi)$, $\sigma(D^0)$, ...
- **Mass measurements**: $B^{**}, D^{**}, B_c, \Lambda_b, B_s$, ...
- **CP Violation**: $A_{cp}(B \to hh), A_{cp}(D^0 \to K\pi)$, ...
- **Rare decay searches**: $B_s \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-$, ...
- **SURPRISES!?**

Exciting time at the Tevatron for heavy flavor physics!!!
• Tevatron is the highest energy collider in operation

• Collide proton – antiproton at c.m.s = 1.96 TeV

• Record luminosity
  \[ \sim 1.8 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]

• Delivered \( >1 \text{ fb}^{-1} \) of data since beginning of Run II
TEVATRON Projection

- Now in a 3 months shutdown for Tevatron upgrade
- Key is to improve antiproton stacking rate
- Expect to deliver at least 8fb\(^{-1}\) for the Run II program

Tevatron delivered: 1.6 fb\(^{-1}\)
CDF on tape: 1.4 fb\(^{-1}\)
Heavy Flavor Physics In Hadron Environment

$b$’s produced via strong interaction
decay via weak interaction

**Tevatron is great for heavy flavor:**
- Enormous $b$ production cross-section, x1000 times larger than $e^+e^-$ B factories
- All B species are produced ($B^0$, $B^+$, $\Lambda_b$, $B_s$, etc...)

**However,**
- Inelastic (QCD) background is about x1000 larger than $b$ cross-section
- Online triggering and reconstruction is a challenge: collision rate $\sim 1.7$MHz $\rightarrow$ tape writing limit $\sim 100$Hz
CDF Highlights:
- Excellent silicon vertex detector
- Particle identification (K,p)
- Good momentum and mass resolutions

Calorimeter
- CEM lead + scint 13.4%/\sqrt{E}\oplus2% 
- CHA steel + scint 75%/\sqrt{E}\oplus3%

Tracking
- \sigma(d0) = 40\mu m (incl. 30\mu m beam)
- \sigma(pt)/pt = 0.15 % pt
Reservoir Filters

Trigger is the Lifeline of Hadron Experiment

- Need sufficient buffer while filtering (overflow → deadtime)
- Volume is reduced at each stage which allows more refined filtering at subsequent stages
- If volume after filtering still exceeds the capacity of the subsequent stage:
  1. Add filters (tighter trigger cuts)
  2. Tighten the faucet (prescale)
  3. Buy better filters (upgrade)

Bottomline: store as many golden drops as possible
CDF Implementation

- CDF has implemented a 3-tier trigger

- Level-1 is a synchronous hardware trigger
  - Can process one event every 132ns
  - L1 decision always occurs at a fixed time (~5µs after beam collision)
  - Input rate = 1.7MHz (396ns 36x36 bunches)
    L1A rate ~ 30KHz (limited by L2)

- Level-2 is a combination of hardware and software trigger (asynchronous)
  - Average Level-2 processing time is ~30µs
  - L2A rate ~ 500Hz (limited by event-builder)

- Level-3 is purely a software trigger
  - Massive PC farm
  - L3A rate ~ 100Hz (limited by tape writing)

- Data reduction rate (L1+L2+L3) \(\rightarrow\) 1 : ~20000
B PHYSICS TRIGGERS AT CDF

Trigger provides basic objects (primitives): muon, tracks, jets, etc…

(1) Dimuon trigger:
   For triggering on $J/\Psi$ and rare B decays

(2) Two-track trigger (SVT):
   For triggering on hadronic B and charm decays. Both tracks are required to have an impact parameter $d_0 > 120\mu$m.
   New trigger for RunII!!

(3) Lepton+Displaced Track (SVT):
   For triggering on semileptonic B decays.
   New trigger for RunII!!
CDF is the first hadron collider experiment to be able to trigger on fully hadronic B events

- SVT links drift chamber tracks from Level-1 with silicon hits to compute the impact parameter of the track.

SVT $d_0$ resolution is $\sim 47 \mu m$ (35$\mu$m beamline $\oplus$ 33$\mu$m resol).

- SVT revolutionized B and Charm physics at CDF.
• SVT is performing extremely well

• Online reconstructed $D^0$ events are used as online monitoring of SVT trigger

• Many results that I will present today rely exclusively on SVT triggers

(Invariant mass computed using L3 track info)
**Λ_b Baryon Lifetime**

- Lifetime measurements are important tests of Heavy Quark Expansion (HQE)

- Long standing \( \sim 2\sigma \) effect between theory and experiment on \( \tau(\Lambda_b)/\tau(B^0) \). Experiment on the low side

- CDF has measured the \( \Lambda_b \) lifetime using fully reconstructed

\[
\Lambda_b \rightarrow J/\psi \Lambda
\]

\[
\mu^+\mu^- p\pi
\]

- Better proper time resolution than semileptonic mode

- Combine with \( \Lambda_c \pi \) channel, CDF has the largest fully reconstructed \( \Lambda_b \) sample in the world
Λ_b Candidate Event

CMU stubs

CMP stubs
"Proper decay length"

\[ PDL = \frac{L_{xy}^b \cdot c \cdot M_b}{P_T^b} \]

CDF (370 pb\(^{-1}\)):

\[ \tau(\Lambda_b) = 1.45^{+0.14}_{-0.13} (stat) \pm 0.02 (syst) \, ps \]
Active theoretical work to accommodate data
CDF's new result sits in the theory preferred region
Need more experimental inputs to resolve the issue

Updated CDF result with x2 data will be released in about 2 weeks
• $B_c$ has short lifetime and small production rate
• Full reconstruction allows for precise mass measurement
• New CDF analysis
  – Tune $B_c$ selection on reference $B^+ \rightarrow J/\psi K^+$ data
  – After selection cuts are fixed, “open box”
  – Wait for events to become a significant excess
  – Measure properties of the $B_c$
**B_c Mass Measurement**

Num(events)_{_{\text{FIT}}} = 38.9 \text{ sig} \ 26.1 \text{ bkg}

between 6.24-6.3

Significance > 6\sigma

over search area

**Mass(Bc) = 6275.2 +/- 4.3 +/- 2.3 \text{ MeV/c}^2**

Most precise measurement of B_c mass
Recent lattice calculations predict $B_c$ mass with ~20 MeV precision!!

$M(B_c)_{CDF} = 6275.2 \pm 4.3 \pm 2.3$ MeV/c$^2$ (hadronic)

$M(B_c)_{D0} = 5950 \pm 140 \pm 340$ MeV/c$^2$ (semileptonic)

$M(B_c)_{LAT} = 6304 \pm 12 \pm 18$ MeV/c$^2$

I.F. Allison et al., PRL 94 172001 (2005)
**$B_c$ Lifetime**

- $B_c$ lifetime extracted from $B_c \rightarrow J/\psi \ e \ \nu$ sample

- More stat than hadronic mode
- But also more background too
- Missing energy estimated from Monte Carlo simulation

- CDF $B_c$ lifetime measured with $J/\psi$+e channel (360pb$^{-1}$)
  
  $0.474 \ ^{+0.074/-0.066} \ ^{\pm 0.033}$ ps (**Best in the world**)

- Theoretical prediction: $0.55 \pm 0.15$ ps

V. Kiselev, hep-ph/0308214
Excited Charm Mesons

- Orbitally-excited charm mesons ($D^{**}$) are $P$-wave excitations of a system with a charm and a light quark.

- In HQ limit ($m_c \gg \Lambda_{QCD}$), the states $j_q = 1/2$ and $j_q = 3/2$ are fully degenerate.

- Finite $c$ mass introduces a calculable splitting among each doublet.

- $j_q = 3/2$ states ($D_1^0$, $D_2^{*0}$) are narrow states ($D$ wave decay).
  $j_q = 1/2$ states ($D_0^*$, $D_1^*$) are broad states ($S$ wave decay).
Theory and Previous Measurements

- A number of theory predictions for the \( D^{**} \) (no uncertainties)
- \( D^{**} \) states have been studied by various experiments, but (until recently) not at hadron colliders
- Generally good agreement between theory predictions and experiments
CDF Measurement

- CDF has a large sample of charm events from the SVT trigger. Perhaps even the largest sample of D** on tape

- This measurement was performed with 210 pb\(^{-1}\) (March 2001 to November 2003)

- Reconstruct fully-hadronic final states:
  - \( D_1^0, D_2^{*0} \rightarrow D^{*+} \pi^- \)
  - \( D^{*+} \rightarrow D^0 \pi^+ \)
  - \( D^0 \rightarrow K^+ \pi^- \)
  - \( D_2^{*0} \rightarrow D^+ \pi^- \)
  - \( D^+ \rightarrow K^- \pi^+ \pi^+ \)
Calibration Momentum Scale of Tracks Using J/Ψ Sample:
- dE/dx correction $\rightarrow$ tune GEANT material description to remove pT dependence on the J/Ψ mass,
- B field correction $\rightarrow$ apply magnetic field correction to shift the raw J/Ψ mass to the PDG value,
- Cross-checks $\rightarrow$ measure meson masses (Ks, D, $\Upsilon$, $\Psi'$, etc…).

<table>
<thead>
<tr>
<th></th>
<th>CDF mass</th>
<th>PDG mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Psi'$</td>
<td>$3685.80 \pm 0.12$</td>
<td>$3685.96 \pm 0.09$</td>
</tr>
<tr>
<td>$\Upsilon(1S)$</td>
<td>$9461.1 \pm 1.5$</td>
<td>$9460.30 \pm 0.26$</td>
</tr>
</tbody>
</table>
Event Selection

- 4 tracks with 0 total charge
  - 2 considered as “trigger tracks” (pT>2 GeV/c, |d₀|>100μm)
- D*π channel:
  - |M(Kπ)-M(D⁰)|<24 MeV
  - |M(Kππ)-M(D*)|<147 MeV with pT(π)>400 MeV/c
  - pT(track 4)> 400 MeV/c
- D⁺π channel:
  - 1.85 < M(Kππ) < 1.89 GeV/c² (2 trigger tracks, 1 with pT> 800 MeV/c)
  - These tracks originate from same secondary vertex with Lxy> 1 mm and X²_{3D}< 12.
  - pT(track 4)> 400 MeV/c

To improve resolution, we plot M(4 tracks) – M(3 tracks)
• 2 peaks for $D_1^0$ and $D_2^{*0}$ clearly visible
• Combinatorial background described as $\alpha(\Delta m - m_\pi)^\beta \times e^{-\gamma(\Delta m - m_\pi)}$
• Difficult to infer from these data the presence of the broad state $D_1^{0'}$, observed by other experiments; will be considered in systematics

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

CDF Preliminary $\int L = 210$ pb$^{-1}$

$\sim 7.5K D_1^0$
$\sim 5K D_2^*$
- D$_2^{0*}$ peak clearly visible
- Feed-downs from previous channel D$^{**} \rightarrow$ D$^*+\pi$ followed by D$^*+\rightarrow \pi^0 \pi^- D^+$ with undetected $\pi^0$.
- Also in this case, very marginal indication of broad state D$^0_0^{*0}$

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

CDF Preliminary
\[ \int L = 210 \text{ pb}^{-1} \]

\[ \sim 20K \ D_2^* \]
Likelihood Fit for D^+π^- Channel

- Signal term for each narrow state is a convolution of Breit-Wigner with resolution histogram taken from MC.
- Background term of the form $\alpha (\Delta m - m_\pi) \beta e^{-\gamma (\Delta m - m_\pi)} + \delta$.
- Broad state is convolution of Breit-Wigner and Gaussian.
- Feed-down term for second histogram uses masses and widths from first histogram with shift and smearing coming from Monte Carlo.
Systematic Uncertainties and Results

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta(M_{D^0})$</th>
<th>$\Delta(\Gamma_{D^0})$</th>
<th>$\Delta(M_{D^{*0}})$</th>
<th>$\Delta(\Gamma_{D^{*0}})$</th>
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</thead>
<tbody>
<tr>
<td>MC statistics</td>
<td>0.3</td>
<td>1.2</td>
<td>0.4</td>
<td>1.2</td>
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<tr>
<td>Broad State</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
<td>0.5</td>
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<td>Track Error scale</td>
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<td>—</td>
<td>0.1</td>
<td>—</td>
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<tr>
<td>Fit model</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
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<tr>
<td>Mass Calibration</td>
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<td>0.2</td>
<td>0.1</td>
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<tr>
<td>Total (Relative)</td>
<td>0.4</td>
<td>1.3</td>
<td>0.5</td>
<td>1.3</td>
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<tr>
<td>Reference mass</td>
<td>0.5</td>
<td>—</td>
<td>0.7</td>
<td>—</td>
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<tr>
<td>Total (Absolute)</td>
<td>0.6</td>
<td>1.3</td>
<td>0.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

- $\Gamma(D_1^{0}) = 20.0 \pm 1.7 \pm 1.3 \text{ MeV/c}^2$
- $\Gamma(D_2^{0*}) = 49.2 \pm 2.3 \pm 1.3 \text{ MeV/c}^2$
- $M(D_1^{0}) - M(D^{*+}) = 411.7 \pm 0.7 \pm 0.4 \text{ MeV/c}^2$
- $M(D_2^{0*}) - M(D^+) = 593.9 \pm 0.6 \pm 0.5 \text{ MeV/c}^2$
Comparison with the Rest of the World

Using PDG values for $D^*$ and $D^+$ masses
- $M(D_{10}^-) = 2421.7 \pm 0.7 \pm 0.6$ MeV/c$^2$
- $M(D_{20}^{*+}) = 2463.3 \pm 0.6 \pm 0.8$ MeV/c$^2$

This is the best single measurement of these quantities, in line with previous measurements and allowing to further discriminate among various HQET calculations.
Double-Cabibbo-Suppressed $D^0$ Decays

Right-Sign (RS) -

CF decay $D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^- \pi^+$

Wrong-Sign (WS) -

DCS decay $D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^+ \pi^-$

Measure time integrated ratio:

$$R_D = Br(D^0 \rightarrow K^+ \pi^-) / Br(D^0 \rightarrow K^- \pi^+)$$

First step to time-dependent $D^0$ mixing
## Results

### Analysis

<table>
<thead>
<tr>
<th>Analysis</th>
<th>WS D0s</th>
<th>Stat. Error</th>
<th>Significance</th>
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<tbody>
<tr>
<td>CDF</td>
<td>2005</td>
<td>104</td>
<td>19.2</td>
</tr>
<tr>
<td>BABAR</td>
<td>430</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Belle</td>
<td>845</td>
<td>40</td>
<td>21</td>
</tr>
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</table>

### Analysis

<table>
<thead>
<tr>
<th>Analysis</th>
<th>WS/RS ratio</th>
<th>Stat.</th>
<th>Systematic</th>
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<tr>
<td>CDF</td>
<td>4.05</td>
<td>0.21</td>
<td>0.12</td>
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<tr>
<td>BABAR</td>
<td>3.57</td>
<td>0.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Belle</td>
<td>3.81</td>
<td>0.17</td>
<td>+ 0.08</td>
</tr>
</tbody>
</table>

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**CDF Run II**  
$L dt \sim 350 \text{pb}^{-1}$

**CDF Run II**  
Preliminary  
$L = 350 \text{pb}^{-1}$

**CDF Run II**  
2005 +/- 104

**CDF Run II**  
Wrong-Sign $m_{K\pi} - m_{K\ell} - m_{\pi}$ (MeV)

**CDF Run II**  
2005 +/- 104

**CDF Run II**  
Wrong-Sign $m_{K\pi} - m_{K\ell} - m_{\pi}$ (MeV)

---

**CDF Run II**  
491165.29 +/- 988.51

**CDF Run II**  
Right-Sign $M_{K\pi} - M_{K\ell} - M_{\pi}$ (MeV)
R_D Comparisons

CDF II Preliminary L ≈ 350 pb^{-1}

CLEO

FOCUS

BABAR

Belle

CDF II

D^0 WS/RS Ratio x10^{-3}

PDG average not including CDF II
• In the $B^0$ system: physical mass eigenstates ≠ flavor eigenstates

\[ |B_L\rangle = |B^0\rangle + |\bar{B}^0\rangle \]

\[ |B_H\rangle = |B^0\rangle - |\bar{B}^0\rangle \] (ignoring CP violation)

• Time evolution of the two states is governed by the time-dependent Schrödinger equation and in the limit $\Delta \Gamma \ll \Delta m$:

\[
\begin{align*}
\text{Pr} &\ \text{ob} \ (B^0 \rightarrow B^0) = \frac{1}{2} e^{-\Gamma t} (1 + \cos \Delta m t) \\
\text{Pr} &\ \text{ob} \ (B^0 \rightarrow \bar{B}^0) = \frac{1}{2} e^{-\Gamma t} (1 - \cos \Delta m t)
\end{align*}
\]

where: $\Delta \Gamma = \Gamma_H - \Gamma_L$ (lifetime difference)

\[ \Gamma = (\Gamma_H + \Gamma_L)/2 \]

$\Delta m = m_H - m_L$ (mass difference)

oscillation frequency

$(B_d \Rightarrow \Delta m_d, B_s \Rightarrow \Delta m_s)$

\[ \Delta m_s = 10 \text{ps}^{-1} \]
D0 and CDF measure $B_s$ lifetime in semileptonic decay: $B_s \rightarrow l^+ \nu D_s^- X$

**D0:**

$\tau(B_s) = 1.420 \pm 0.043 \text{(stat)} \pm 0.057 \text{(syst)} \text{ ps}$

(Best in the world)

**CDF:**

$\tau(B_s) = 1.381 \pm 0.055 \text{(stat)} \pm 0.052 \pm 0.046 \text{(syst)} \text{ ps}$
Extract $\Delta \Gamma$ from $B_s \rightarrow K^+ K^-$ Lifetime

- Measurement of $B_s \rightarrow K^+ K^-$ lifetime ($= \tau_L$) in $360 \text{pb}^{-1}$
- Mass fit as in BR and CP measurements
- Lifetime fit:
  - Extraction of $\Delta \Gamma_{\text{CP}}/\Gamma_{\text{CP}}$
  - This measurement gives $c\tau_L = 458 \pm 53 \pm 6 \, \mu\text{m}
  - HFAG average gives weighted average: $(\tau_L^2 + \tau_H^2) / (\tau_L + \tau_H)$
  - Extract $\tau_H$
  - Thus derive $\Delta \Gamma/\Gamma = -0.080 \pm 0.23 \, \text{(stat)} \pm 0.03 \, \text{(syst)}$
Summary of $\Delta \Gamma_s / \Gamma_s$ Measurements

- **CDF** $B_s \rightarrow K^+ K^-$ (measure $\tau_L$): $360\text{pb}^{-1}$
  \[ \Delta \Gamma / \Gamma = -0.080 \pm 0.23 \text{ (stat)} \pm 0.03 \text{ (syst)} \]

- **D0** $B_s \rightarrow J/\psi \phi$ (measure $\tau_H, \tau_{B_s}$): $220\text{pb}^{-1}$
  \[ \Delta \Gamma / \Gamma = 0.24 \pm 0.28 \text{ (stat)} \pm 0.04 \text{ (syst)} \]
  (PRL 95 171801 (2005))

- **CDF** $B_s \rightarrow J/\psi \phi$ (measure $\tau_L$ and $\tau_H$): $210\text{pb}^{-1}$
  \[ \Delta \Gamma / \Gamma = 0.65 \pm 0.25 \text{ (stat)} \pm 0.01 \text{ (syst)} \]
  (PRL 94 102001 (2005))

Both CDF and D0 have $>\times 2$ more data to analyze
In the Standard Model $B$ mixing occurs via the box diagram:

\[ \begin{array}{c}
  b & \rightarrow & t & V_{td,ts} & d,s \\
  \bar{d},\bar{s} & \rightarrow & \bar{t} & W & \bar{b} \\
  \end{array} \]

Study of $B^0$ oscillation provides an important test of SM and probes the origin of CP violation.

A measurement of $B^0$ oscillation frequency, specifically $\Delta m_d$, is the most direct way to extract $|V_{td}|$.
• $\Delta m_d$ has been measured to within $\sim 1\%$ ($\Delta m_d = 0.507 \pm 0.004 \text{ps}^{-1}$, HFAG2005)

However, extraction of $|V_{td}|$ is severely limited by theoretical uncertainties:

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) B_{B_d} f_{B_d}^2 \eta_{QCD} \left| V_{tb}^* V_{td} \right|^2$$

$\sim 15\%$ uncertainty on $\sqrt{B_{B_d} f_{B_d}}$

• The problem can be circumvented by measuring $B_s$ mixing. Dominant theoretical uncertainties cancel in the ratio:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \frac{f_{B_s}^2}{f_{B_d}^2} \frac{B_{B_s}}{B_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2 = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

(assume $V_{ts} = V_{cb}$)

New lattice result $\xi = 1.21^{+0.041}_{-0.026}$ ($\sim 3\%$ uncertainty)

• Sounds like a good approach to measure $|V_{td}|$, but…

$\Delta m_s$ is expected to be large (much larger than $\Delta m_d$)
Key Ingredients of Bs Mixing Analysis

1. Enriched sample of $B_s^0$ decays
2. Determine the flavor of $B_s^0$ at production and decay
3. Reconstruct the decay length & boost of the $B_s^0 \rightarrow$ proper decay time ($t = \frac{L}{\beta \gamma c}$)

The significance of the analysis can be estimated using the Moser formula:

$$\text{Significance} = \sqrt{\frac{N \epsilon D^2}{2}} f_{B_s} e^{-\frac{1}{2}(\Delta m_s \sigma_t)^2}$$

- $N = \#$ of events
- $f_{B_s} = B_s$ fraction
- $\epsilon D^2 = \text{flavor tagging power}$
- $\sigma_t = \text{proper time resolution}$

Proper time resolution has contribution from decay length and boost

$$\sigma_t^2 = \left(\frac{\sigma_L}{\gamma \beta c}\right)^2 + \left(\frac{\sigma_p}{p} \frac{t}{\gamma \beta c}\right)^2$$

- constant
- grows linearly with proper time

Mixed Fraction = $N_{\text{mixed}} / (N_{\text{mixed}} + N_{\text{unmixed}})$

$\Delta m_s = 10 \text{ps}^{-1}$

$\sigma_L = 200 \mu m$

$\sigma_p / p = 0.10$

$f_{B_s} = 0.10$

mistag = 0.25
B_s \rightarrow D_s \mu \nu \ (where \ D_s \rightarrow \phi \pi, \ K^* \ K)

\sim 34K \ semileptonic \ B_s \ (610pb^{-1})

B_s \rightarrow D_s \pi \ (where \ D_s \rightarrow \phi \pi, \ K^* \ K, \ 3\pi)

B_s \rightarrow D_s \delta \ (where \ D_s \rightarrow \phi \pi, \ K^* \ K, \ 3\pi)

\sim 1100 \ fully \ reconstructed \ B_s

\sim 17K \ semileptonic \ B_s \ (350pb^{-1})
Amplitude Fit Primer

- A modified form of Fourier analysis is used to search for periodic signal
  ⇒ Amplitude Fit (NIM A384, 491 (1997))

- Amplitude fit:
  - Prob \((B_s^0 \rightarrow B_s^0) = \frac{1}{2} \Gamma e^{-\Gamma t} (1 + A \cos \Delta m_s t)\)
  - Prob \((\bar{B}_s^0 \rightarrow \bar{B}_s^0) = \frac{1}{2} \Gamma e^{-\Gamma t} (1 - A \cos \Delta m_s t)\)
  - Fit for oscillation amplitude “\(A\)” for a given \(\Delta m_s\) value
  - Expect “\(A\)” = 1 for frequency = true \(\Delta m_s\)
    Expect “\(A\)” = 0 for frequency \(\neq\) true \(\Delta m_s\)

- If no signal is observed:
  - Exclude \(\Delta m_s\) value at 95% C.L.
    in regions where \(A + 1.65 \sigma_A < 1\)
  - Sensitivity at 95% C.L. is at
    \(\Delta m_s\) value for which \(1.65 \sigma_A = 1\)
**DO Result:**
Sensitivity = 9.5 ps^{-1}
Exclusion: $\Delta m_s < 7.3$ ps^{-1} @95%CL

**CDF Result:**
Sensitivity = 13.0 ps^{-1}
Exclusion: $\Delta m_s < 8.6$ ps^{-1} @95%CL
New Tevatron results improved the world $\Delta m_s$ limit from 14.5 to 16.6 ps$^{-1}$ @ 95%CL
**B_s Mixing Projection**

CDF Projections :: Combined Analyses :: W05

- CDF projections were made ~ 1 year ago
- CDF has surpassed the baseline projection
- Goal is to reach “stretched” by Sum 2006:
  - Same-side kaon tag
  - Partially reconstructed B_s* \(\rightarrow\) B_s
- At “stretched”, CDF will be probing SM region at 3-sigma level this summer
• With 1 fb^{-1} of data, heavy flavor physics at CDF is in full swing. In this talk, I have only touched the “tip of the iceberg”

• CDF is entering precision era on measuring a broad spectrum of B and Charm properties. Many measurements are unique to Tevatron and some are complementary to the B-factory physics program

• One exciting prospect this summer: Tevatron will start probing the SM $\Delta m_s$ regions at 3-sigma level. Tevatron is finally “in the game”

• Stay tuned!!!