Flavor Physics Program at Tevatron Has Been Tremendously Successful!

- Complements excellent programs of BABAR and Belle experiments at the B-factories
  - $e^+e^-$ colliders produce B’s at the $\Upsilon(4S)$ and $\Upsilon(5S)$
- Many unique measurements made at Tevatron
  - Observation of $B_s$ mixing
  - CP violation in $B_s \rightarrow J/\psi\phi$
  - Discovery of b-baryons
- Several measurements in $B^0$ and $B^+$ systems are approaching sensitivity of BABAR and Belle
  - e.g. lifetimes, direct CPV
A Special Time for TeV(atron)

- Tevatron can contribute uniquely to flavor physics for the next few years
  - Transition between first run of B factories, LHC experiments
- Consider Tevatron flavor physics program present and future
  - Highlight recent results (from 2008 & 2009)
  - Anticipate results to come
    - Significant statistics can be added to many existing measurements before the end of Run II!
Tevatron Performance Has Been Excellent!

- Delivered $> 6$ fb$^{-1}$ of integrated luminosity
  - CDF and D0 experiments have collected $> 5$ fb$^{-1}$ each
- Expect $\sim 9$ fb$^{-1}$ delivered integrated luminosity through 2010
CDF and D0 Detectors Have Different Strengths in Detecting B Hadrons

Strong tracking system, ability to trigger on displaced tracks
⇒ Good mass resolution, high statistics in non-leptonic decays

Excellent calorimetry, muon id, reverse direction of B field
⇒ Large samples of semi-leptonic and forward decays, good direct CPV res.
Main Categories of Flavor Physics Results Discussed Today

- Production
  - Birth of B hadrons
- Lifetimes
  - Death of B hadrons
- CP Violation & Rare Decays
  - The curious things in between
Sandro Botticelli
The Birth of Venus
c. 1482-1486
Search for New Particles and Measure Production Rates of Known Particles

- Look for things that we think should be there and also for things that shouldn’t
  - Can find some surprises
    - e.g. $\chi$, $\Lambda$, $Z$ charm states
  - Many $b$-baryons have not been observed until Run II!
    - Observed $\Sigma_b^{\mp}$ (2006), $\Xi_b^-$ (2007) and recently $\Omega_b^-$ (2008)
  - Measure production rates and cross-sections
    - Rel. fragmentation fractions, $\sigma(B^+)$, $\sigma(B_c^+)$×$BR(B_c^+)/\sigma(B^+)\times BR(B^+)$
Evidence for New Y(4140) State

- Find evidence for new state Y(4140) in 2.7 fb⁻¹ of int. lumi.
  - Observed in
    \[ B^+ \rightarrow Y(4140)K^+ \]
    \[ Y(4140) \rightarrow J/\psi \phi \]
    - \( J/\psi \rightarrow \mu^+\mu^- \)
    - \( \phi \rightarrow K^+K^- \)

- Builds on previous discoveries of charm-like states at Belle/BaBar
  - e.g. X(3872), Y(3930)
  - D*D molecule? 4-quark state?

\[ N(B^+) \sim 75 \]

CDF II Preliminary, 2.7 fb⁻¹

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

arXiv:0903.2229, submitted to PRL
Observe 3.8σ Significant Excess

- Observe 14±5 events
  - Calculate significance to be 3.8σ
- Near J/ψφ threshold
  - Similar to Y(3930)→J/ψω

\[ \Delta M = M(\mu^+\mu^-K^+K^-) - M(\mu^+\mu^-) \Rightarrow \text{within } \pm 3\sigma \text{ of } m(B^+) \]

Assuming S-wave Breit-Wigner

\[ m = 4143.0 \pm 2.9 \text{ (stat)} \pm 1.2 \text{ (syst)} \text{ MeV/c}^2 \]
\[ \Gamma = 11.7^{+8.3}_{-5.0} \text{ (stat)} \pm 3.7 \text{ (syst)} \text{ MeV/c}^2 \]
Many b-baryons Have Been Observed Since the Beginning of Run II!
Observation of $\Omega_b^-$ Baryon

- Announced by D0 on Aug. 29, 2008
- Observation made with 1.3 fb$^{-1}$ of data
  - Builds on previous observation of $\Xi_b^-$

Observe Significant $\Omega_b^-$ Signal

- Observe $17.8 \pm 4.9$ (stat) $\pm 0.8$ (syst) events

- $m = 6.165 \pm 0.010$ (stat) $\pm 0.013$ (syst) GeV/c$^2$

Expect $5.94$–$6.12$ GeV/c$^2$ from theory

Calculate significance of $5.4\sigma$

$$\frac{f(b \rightarrow \Omega_b^-) Br(\Omega_b^- \rightarrow J/\psi \Omega^-)}{f(b \rightarrow \Xi_b^-) Br(\Xi_b^- \rightarrow J/\psi \Xi^-)} = 0.80 \pm 0.32 \text{(stat)}^{+0.14}_{-0.22} \text{(syst)}$$
Have Observed Most Single b-baryons!

\[ J = 1/2 \ b \text{ Baryons} \]

\[ \Omega_b^\pm (2008) \]
\[ \Sigma_b^\pm (2006) \]
\[ \Xi_b^- (2007) \]

Have yet to observe double b-baryon states!
Measurement of Relative $B_c^+$ Cross Section Updated to 1 fb$^{-1}$

- **Measure**

\[
\frac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \rightarrow J/\psi \mu^+ \nu)}{\sigma(B^+) \times \mathcal{B}(B^+ \rightarrow J/\psi K^+)}
\]

- Need to model $B^+$, $B_c^+$ $p_T$ spectrum to calculate relative efficiency between decays
Find Good Agreement with Previous

B⁺𝑐 Cross-section Measurement

<table>
<thead>
<tr>
<th>Final results</th>
<th>pₜ(B) &gt; 4 GeV/c</th>
<th>pₜ(B) &gt; 6 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(B⁺𝑐 → J/ψ + μ⁺ + ν)</td>
<td>117.6 ± 17.2 (stat) ±⁸.⁹⁺⁻⁶.⁴ (sys)</td>
<td>107.1 ± 16.7 (stat) ±⁷.⁹⁺⁻⁶.¹ (sys)</td>
</tr>
<tr>
<td>N(B⁺ → J/ψ + K⁺)</td>
<td>2333 ± 55 (stat)</td>
<td>2299 ± 53 (stat)</td>
</tr>
<tr>
<td>ε_{rel}</td>
<td>5.867 ± 0.068 (stat) +⁰.⁵⁵⁴⁻⁰.⁴⁵⁰ (sys) ±⁰.⁷₂⁰ (spectrum)</td>
<td>4.872 ± 0.060 (stat) +⁰.⁴²⁰⁻⁰.²⁷⁸ (sys) ±⁰.₂⁹⁸ (spectrum)</td>
</tr>
<tr>
<td>σ(B⁺𝑐⁺BR(B⁺𝑐⁺→J/ψ+μ⁺+ν))/σ(B⁺⁺BR(B⁺⁺→J/ψ+K⁺⁺))</td>
<td>0.295 ± 0.040 (stat) +⁰.⁰⁳³⁻⁰.⁹²⁶ (sys) ±⁰.⁰³⁶ (spectrum)</td>
<td>0.227 ± 0.033 (stat) +⁰.⁰²⁴⁻⁰.⁰¹⁷ (sys) ±⁰.⁰¹⁴ (spectrum)</td>
</tr>
</tbody>
</table>

- Agrees well with previous results
- Systematic uncertainty is significantly improved

<table>
<thead>
<tr>
<th>Result</th>
<th>pT(B)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>B⁺𝑐⁺→J/ψe⁺νX (Run ll, 360 pb⁻¹)</td>
<td>&gt;6 GeV/c</td>
<td>0.245 ±0.045 (st) ±0.066 (sys) +⁰.⁰⁸⁰⁻⁰.⁰³² (lt)</td>
</tr>
<tr>
<td>B⁺𝑐⁺→J/ψμ⁺νX (Run ll, 360 pb⁻¹)</td>
<td>&gt;4 GeV/c</td>
<td>0.282 ±0.038 (st) ±0.035 (y) ±0.065 (a)</td>
</tr>
</tbody>
</table>
Jacques-Louis David
Death of Marat
c. 1793
Why Measure Lifetimes?

- Test HQE predictions
  - Have previously seen 1-2\sigma discrepancies between lifetime predictions and measurements in $B_s^0, \Lambda_b^0$
    - Expect $\tau(B^+) > \tau(B^0) \approx \tau(B_s^0) > \tau(\Lambda_b^0) \gg \tau(B_c^+)$

- Because they’re there?
  - Fundamental quantity, give complete picture of B’s
  - Useful for other measurements (e.g. b-tagging)
$B_s^0$ Lifetime Now Agrees with HQE

$\tau(B_s^0) = 455 \pm 12$ (stat.) $\pm 7$ (syst.) $\mu$m

Compatible with HQE predictions that $\tau(B^0) \approx \tau(B_s^0)$

$c\tau(B^0) = 458.7 \pm 2.7$, PDG 2008

Data collected with displaced track trigger

⇒ must correct for trigger bias (use Monte Carlo)

www-cdf.fnal.gov/physics/new/bottom/080207.blessed-bs-lifetime/
$B_c^+$ Lifetime Agrees with Theoretical Predictions

CDF: $\tau(B_c^+) = 142 \pm 15 \text{ (stat)} \pm 6 \text{ (syst)} \mu m$

D0: $\tau(B_c^+) = 134.3 \pm 11 \text{ (stat)} \pm 10 \text{ (syst)} \mu m$

Phys. Rev. Lett. 102, 092001 (2009)
$\Lambda_b^0$ Lifetime Question Closer to Resolution

Measure lifetime in displaced track sample

www-cdf.fnal.gov/physics/new/bottom/080703.blessed-lblcpi-ct/
New Measurements Are in Good Agreement with Predicted Lifetimes

New measurements of lifetime are in good agreement with theoretical predictions!
CP Violation & Rare Decays

Francisco Goya
The Third of May 1808
1814
CP Violation

- CP violation is the non-conservation of charge and parity quantum numbers

![Image of two Hello Kitty cats](image1) \(\neq\) ![Image of two Hello Kitty cats](image2)
Known Amount of CP Violation is Unable to Explain Matter-Antimatter Asymmetry

- Present sources of CP violation can’t account for the amount of matter we observe in the universe!
- Important to search for new sources of CP violation in places we don’t expect
  - Can indicate presence of new particles or forces
    - Maybe with much higher masses than we can observe directly at LHC!

Where’s the anti-matter?
There Are Three Types of CP Violation That Can Be Investigated

- Decay of hadrons ↔ direct CPV
  - Only type of CPV for charged mesons

- Mixing of neutral mesons ↔ indirect CPV
  - Semi-leptonic decays of neutral meson

- Interference between decays with and without mixing
  - $B^0 \rightarrow J/\psi K_s^0 \Rightarrow \sin 2\beta$
  - $B_s^0 \rightarrow J/\psi \phi \Rightarrow \sin 2\beta_s$

Use flavor tagging for more powerful measurement of CP phases!
Mixing and Decay in $B_s^0$

Mixing between particle and anti-particle occurs through the loop processes

Oscillations are very fast—\( \sim 3 \) trillion times per second!

New particles can contribute to box diagram!
Mixing and Decay in $B_s^0$

Mixing of $B_s^0$ mesons is governed by Schrodinger eqn.

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

\[
|B_s^H\rangle = p |B_s^0\rangle - q |\bar{B}_s^0\rangle
\]

\[
|B_s^L\rangle = p |B_s^0\rangle + q |\bar{B}_s^0\rangle
\]

$\Delta m_s = m_H - m_L \approx 2 |M_{12}| \ [\text{ps}^{-1}]$

$\Delta \Gamma_s = \Gamma_L - \Gamma_H \approx 2 |\Gamma_{12}| \cos(\phi_s)$

$\phi_s = \text{arg}(-M_{12}/\Gamma_{12}) \sim 0.004$ in SM
$B_s^0 \rightarrow J/\psi\phi$ Decays Are A Good Place to Look for New Physics

- Decays of $B_s^0 \rightarrow J/\psi\phi$ gives access to CP violating phase predicted to be nearly zero in Standard Model

$$\beta_s^{J/\psi\phi} = \arg\left( - \frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right) \approx 0.02$$

- Large phase in $b \rightarrow s$ transition could lead to significant non-zero CP phase

New physics could produce large CP phase!

- G. Hou et al suggest that $t'$ quark w/mass $\sim 300$ GeV/c$^2 - 1$ TeV/c$^2$ would give $\beta_s \sim 0.5$
CDF Observes Discrepancy with SM in Flavor-Tagged $B_s^0 \rightarrow J/\psi \phi$

- Find $1.8\sigma$ ($p$-value = 7%) discrepancy with SM prediction for $\beta_s^{J/\psi \phi} = 0.02$, $\Delta \Gamma_s = 0.096$
- Expect further improvement in statistical precision shortly!
Similar Discrepancy Observed by D0 in Flavor-Tagged $B_s^0 \rightarrow J/\psi \phi$

- D0 result very similar to CDF’s!
  - Discrepancy w/SM is $1.7\sigma$, p-value = 0.085

Trend is identical, $\varphi_s^{J/\psi\phi} \equiv -2\beta_s$

D0 finds agreement in strong phase between $B_s^0 \rightarrow J/\psi \phi$ (assuming $\varphi_s^{J/\psi\phi} = 0$) and $B^0 \rightarrow J/\psi \ K^*0$

$\Rightarrow$ Use phases in $B^0 \rightarrow J/\psi \ K^*0$ to choose one of two solutions?

arXiv:0808.1297v1
More Significant Discrepancy in Combined $B_s^0 \rightarrow J/\psi \phi$ Result

New CDF result not included in combination!

Expect updates to both CDF and D0 results soon!
\( \mathcal{B}(B_s^0 \rightarrow D_s^{(*)} + D_s^{(*)}) \) Also Gives Access to CP-even Width Difference

- Measure branching ratio to determine \( \Delta \Gamma_s^{CP} (2.8 \text{ fb}^{-1}) \)
- Search for one \( D_s \rightarrow \phi \pi \), other to \( D_s \rightarrow \phi \mu \nu \)

\[
2 \mathcal{B}(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}) \simeq \Delta \Gamma_s^{CP} \left[ \frac{1}{2} \frac{1-2x_f}{2\Gamma_L} + \frac{1}{2\Gamma_H} \right] + \frac{1}{2} \frac{1-2x_f}{2} \cos \phi_s
\]
\( \Delta \Gamma_s^{CP} / \Gamma_s \) Measured in \( B_s^0 \rightarrow D_s^{(*)} + D_s^{(*)} \) - Consistent with World Average

- **Measure**

\[
\mathcal{B}(B_s^0 \rightarrow D_s^{(*)}D_s^{(*)}) = 0.035 \pm 0.010(stat) \pm 0.008(syst) \pm 0.007(\mathcal{B})
\]

with 3.2\( \sigma \) significance (p-value = 0.0012)

Assuming \( x_f = 0 \) and \( \varphi_s = 0 \)

\[
\frac{\Delta \Gamma_s^{CP}}{\Gamma_s} \approx \frac{2\mathcal{B}(B_s^0 \rightarrow D_s^{(*)}D_s^{(*)})}{1 - \mathcal{B}(B_s^0 \rightarrow D_s^{(*)}D_s^{(*)})} = 0.072 \pm 0.021(stat) \pm 0.022(syst)
\]

Consistent with WA (2007)
\( \Delta \Gamma / \Gamma = 0.096^{+0.048}_{-0.053} \)

*Phys. Rev. Lett. 102, 091801 (2009)*
Updated Measurement of $B_s^0$ Semileptonic Asymmetry

- Measure flavor-specific asymmetry, $a_{fs}$, in 5 fb$^{-1}$
  - Time-dependent
  - Flavor-tagged

- Reconstruct $B_s^0 \rightarrow \mu^+ D_s^- X$
  - $D_s^- \rightarrow \phi \pi^- \rightarrow (K^- K^+) \pi^-$
  - $D_s^- \rightarrow K^*0 K^-$

$$a_{fs}^s = \frac{\Gamma_{B_s^0 \rightarrow f} - \Gamma_{B_s^0 \rightarrow \bar{f}}}{\Gamma_{B_s^0 \rightarrow f} + \Gamma_{B_s^0 \rightarrow \bar{f}}}$$

arXiv:0904.3907
Measurement Improves Uncertainty by Factor of 2!

- Extract asymmetry with un-binned maximum likelihood fit

\[
\begin{align*}
\Gamma_{B_s^0 \rightarrow f} &= N_f \left| A_f \right|^2 \frac{1}{2} \left( 1 - a_{fs}^s \right) e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos(\Delta m_s t) \right] \\
\Gamma_{B_s^0 \rightarrow f} &= N_f \left| A_f \right|^2 \frac{1}{2} \left( 1 + a_{fs}^s \right) e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos(\Delta m_s t) \right]
\end{align*}
\]

- Find

\[
\alpha_{fs}^s = \left[ -1.7 \pm 9.1 \text{(stat)} +1.2 \text{(syst)} \right] \times 10^{-3}
\]

Uncertainties improved by factor of 2 over previous direct measurement!

Standard model prediction: \( \alpha_{fs}^s = (0.021 \pm 0.006) \times 10^{-3} \)
Rare Decays Help Search for Flavor Changing Neutral Currents

- Search for processes like:
  - $B^0 \rightarrow \mu^+ \mu^-$, $B^0_s \rightarrow \mu^+ \mu^-$
  - $D^0 \rightarrow \mu^+ \mu^-$

- Standard Model processes are extremely rare
  - $\mathcal{B} \sim 10^{-9} - 10^{-13}$

- New physics (e.g. SUSY) predicts new sources of FCNC

- Some processes are forbidden in SM
  - $B^0, B^0_s \rightarrow e^+ \mu^-$
  - $\Rightarrow$ leptoquarks
Examples of Rare Decay Processes

- **SM processes**
  - $B_s^0 \rightarrow \mu^+ \mu^-$
  - $D^0 \rightarrow \mu^+ \mu^-$

- **New physics processes**
  - $B_s^0 \rightarrow \mu^+ \mu^-$
  - $D^0 \rightarrow \mu^+ \mu^-$
  - $B_s \rightarrow \mu e$
$B_{(s)}^0 \rightarrow \mu^+ \mu^-$ Branching Ratios
Approaching SM Predictions!

- $B_s^0 \rightarrow \mu^+ \mu^- @ 95\%$ CL
  - CDF (2 fb$^{-1}$):
    $\mathcal{B} < 5.8 \times 10^{-8}$
  - D0 (5 fb$^{-1}$) expected:
    $\mathcal{B} < 5.3 \times 10^{-8}$

- $B^0 \rightarrow \mu^+ \mu^- @ 95\%$ CL
  - CDF (2 fb$^{-1}$):
    $\mathcal{B} < 1.8 \times 10^{-8}$
Other Rare Decays Are Limiting
New Physics Parameter Space

- $B_s^0 \rightarrow e^+ \mu^- @ 95\% \text{ CL}$
  - CDF (2 fb$^{-1}$):
    $\mathcal{B} < 2.6 \times 10^{-7}$
- $B^0 \rightarrow e^+ \mu^- @ 95\% \text{ CL}$
  - CDF (2 fb$^{-1}$):
    $\mathcal{B} < 7.9 \times 10^{-8}$

$\Rightarrow m(LQ, B_s^0) > 44.6 \text{ TeV}$
$\quad m(LQ, B^0) > 55.7 \text{ TeV}$

- $D^0 \rightarrow \mu^+ \mu^- @ 95\% \text{ CL}$
  - CDF (360 pb$^{-1}$):
    $\mathcal{B} < 5.3 \times 10^{-7}$
  - Predicted rate $\sim 10^{-13}$
Looking to the Future

Neo Rauch
The Next Move
2007
Many Interesting New and Updated Measurements to Come!

- Updates to CP violation measurements
  - Expect 2-4x higher yield depending on measurement
  - More flavor-tagged CP violation results

- Updated lifetimes with higher statistics
  - Updated $B \to J/\psi X$ lifetimes with 2x more data
    - Will give most precise $B^+$, $\Lambda_b^0$ lifetimes to date

- Observation of new states?
Valuable Contributions to Study of Bottom and Charm Hadrons Made at Tevatron

- Exciting time for flavor physics at the Tevatron!
  - Many significant contributions to knowledge of B hadrons has been made
  - Expect many interesting, important updates in the next few years!
Back-up
Y(4140) Selection

- Optimize $S/\sqrt{(S+B)}$
  - $L_{xy}(B^+) > 500 \mu m$
  - Log likelihood ratio of kaon $> 0.2$
- Observe clear sideband subtracted $\phi$ signal
  - Fit with P-wave relativistic Breit-Wigner
- Require events to have $K^+K^-$ mass consistent with $\phi$
  - $|m(K^+K^-) - m(\phi)| < 7 \text{ MeV}/c^2$
Y(4140) Events Are Evenly Distributed in Phase Space

- See uniform distribution in Dalitz decays
- All events are within kinematically allowed region determined from MC simulation
Investigate Properties of X(3872)

- First observed by Belle collaboration in 2003
- Observed in decay $X(3872) \rightarrow J/\psi \pi^+ \pi^-$
  - Nature of particle is still unknown
    - D*D “molecule”? 4-quark state?
- Search for mass splitting, measure absolute mass
  - Observation of mass splitting offers evidence of tetra-quark
  - No mass splitting makes absolute mass interesting
    - Checks possibility of bound-state D*D

No Mass Splitting Observed in X(3872)

- Fit mass with Breit-Wigner convolved with resolution
  - Result consistent with no mass splitting
  - Assign upper limit CL

\[ \Delta m(X(3872)) < 3.2 (3.6) \text{ MeV/c}^2 \text{ at 90\% (95\%) C.L.} \]
**Most Precise Measurement of X(3872) Mass**

\[
m(X(3872)) = 3871.61 \pm 0.16 \text{ (stat)} \pm 0.19 \text{ (syst)} \text{ MeV/}c^2
\]

Measured mass is below D*D threshold, although uncertainties are within threshold

\[\Rightarrow \text{ D*D bound state is still a possibility}\]
Selection of $X(3872)$

- Use ANN to select events
  - Optimize selection on Monte Carlo (signal) and mass sidebands (background)

![Graphs showing network output vs. candidates and significance vs. cut on network output.](image-url)
Mass Splitting of $X(3872)$

- Model resolution with Monte Carlo simulation
  - Width scale floats freely in fit

![Graphs showing mass splitting with Monte Carlo simulation](image)

- $\Delta m = 3.2 \text{ MeV/c}^2$
  - $f_1 = 0.5$
  - Measured Value
  - 90% confidence level

- $\Delta m = 3.6 \text{ MeV/c}^2$
  - $f_1 = 0.5$
  - Measured Value
  - 95% confidence level
In 2007, both CDF and D0 observed the $\Xi_b^-$ and made a precise determination of its mass:

$\Xi_b^- \rightarrow J/\psi \Xi^- \rightarrow [\mu^+ \mu^-][\Lambda^0 \pi^-]$, $\Lambda^0 \rightarrow p\pi^-$
Use boosted decision tree (BDT) to improve identification of $\Omega^-$ signal

Re-process data with higher IP req. to increase $\Xi^-/\Omega^-$ acceptance!
Cross-Checks of $\Omega_b^-$ Signal (1)

- Check WS events and mass sidebands for spurious excesses
  - None observed!
Cross-Checks of $\Omega_b^-$ Signal (2)

- Check lifetime distribution of $\Omega_b^-$ candidate events
  - Consistent with B hadron lifetime

[Graph showing the distribution of proper decay length with data, MC signal, and background]
Cut-based Analysis of $\Omega_b^-$

- Alternatively, try using simpler cut-based analysis
  - Find $15.7 \pm 5.3$ (stat) events
  - $m = 6.177 \pm 0.015$ GeV/c$^2$
  - Signal significance is $3.9\sigma$
$\Omega_b^-$ Significance Calculation

- Evaluate significance from likelihood ratio of background only hypothesis ($L_B$) to signal + background hypothesis ($L_{S+B}$)

$$ \sqrt{-2\Delta \ln L} = \sqrt{-2 \ln \left( \frac{L_B}{L_{S+B}} \right) }$$
New Technique Used to Measure $B^+$ Lifetime

- Measured in displaced track sample
- Novel method for correcting for trigger bias without using Monte Carlo

$\tau(B^+) = 498.2 \pm 6.8\ (\text{stat.}) \pm 4.5\ (\text{syst.}) \ \mu m,$
$\tau(B^+) = 491.1 \pm 3.3\ \mu m, \ \text{PDG 2008}$

Use acceptance function to correct for trigger bias on event-by-event basis

www-cdf.fnal.gov/physics/new/bottom/080612.blessed-MCfree_Blifetime/
Perform simultaneous unbinned maximum likelihood fit to mass and lifetime

- Use partially reconstructed decays to double statistics
  - e.g. $B_s^0 \rightarrow D_s^- \rho^+ (\rightarrow \pi^0 \pi^+)$
  - $\sim 2200$ $B_s^0$ candidates
### Comparison of $B_s^0$ Lifetime with Prev. Results

- **$B_s^0$ lifetime is higher than recently measured $B_s^0$ lifetimes in flavor-specific decay modes**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mean Lifetime ($\mu$s) ± Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH (1996)</td>
<td>$1.54^{+0.14}_{-0.13} \pm 0.04$</td>
</tr>
<tr>
<td>OPAL (1998)</td>
<td>$1.5^{+0.16}_{-0.15} \pm 0.04$</td>
</tr>
<tr>
<td>CDF (1999)</td>
<td>$1.36 \pm 0.09^{+0.06}_{-0.05}$</td>
</tr>
<tr>
<td>DELPHI (2000)</td>
<td>$1.42^{+0.14}_{-0.13} \pm 0.03$</td>
</tr>
<tr>
<td>D0 (2006)</td>
<td>$1.398 \pm 0.044^{+0.028}_{-0.025}$</td>
</tr>
<tr>
<td>PDG 2007</td>
<td>$1.41 \pm 0.04$</td>
</tr>
</tbody>
</table>

CDF (Prelim.) $D_s(\phi\pi)X$

- $1.518 \pm 0.041 \pm 0.025$

**CDF Mean Lifetime (ps)**

- 0.6
- 0.8
- 1
- 1.2
- 1.4
- 1.6

**CDF Mean Lifetime (ps)**

- $B_s^0$
$B_c^+$ Lifetime Agrees with Theoretical Predictions

Simultaneously fit mass and lifetime

$\text{c}\tau(B_c^+) = 134.3 \pm 11 \text{ (stat)} \pm 10 \text{ (syst) \mu m}$

arXiv:0805.2614, submitted to PRL
$B_c^+$ Lifetime Agrees with Theoretical Predictions and D0

- Fit $e$, $\mu$ channels separately, combine $\mathcal{L}$ afterwards

$$c\tau(B_c^+) = 142 \pm 15 \text{ (stat)} \pm 6 \text{ (syst)} \mu\text{m}$$

www-cdf.fnal.gov/physics/new/bottom/080327.blessed-BC_LT_SemiLeptonic/
Measurement of $B_c^+ \rightarrow J/\psi e^+ X$ Lifetime

- Fit lifetime only, use mass as cross-check
- Determine all background shapes and normalizations from data if possible, MC otherwise $\Rightarrow$ constrain in fit

$$c\tau(B_c^+ \rightarrow J/\psi e^+ X ) = 122^{+18}_{-16} \text{ (stat)} \, \mu m$$
Fit lifetime only, use mass as cross-check

Determine all background shapes and normalizations from data if possible, MC otherwise ⇒ constrain in fit

\[
\text{ct}(B_c^+ \rightarrow J/\psi \mu^+ X) = 179^{+33}_{-27} \text{ (stat)} \text{ \mu m}
\]
Combination of Semilep. $B_c^+$ Lifetimes

- Combine $-2\ln L_e$, $-2\ln L_\mu$

CDF Run II Preliminary: $\sim 1 \text{ fb}^{-1}$

- $-2\log(L_\mu)$
- $-2\log(L_e)$

$$c\tau = 142.5^{+15.8}_{-14.8} \text{ (stat.) \mu m}$$
Unitarity Relations in $B^0/B_s^0$

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

\[V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0\]
\[V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0\]
New Physics in $B_s^0$ Decays

- $B_s^0 - \overline{B_s}^0$ oscillations observed by CDF
  - Mixing frequency $\Delta m_s$ now very well-measured
  - Precisely determines $|M_{12}|$ - in good agreement w/SM pred.

- Phase of mixing amplitude is still very poorly determined!

$$M_{12} = |M_{12}|e^{i\phi_m},$$
where $\phi_m = \text{arg}(V_{tb}V_{ts}^*)^2$

New physics could produce large CP phase!
\[ \Delta \Gamma / \Gamma \text{ Measured in } B_s^0 \rightarrow D(\ast)_s^0 + D(\ast)_s^{-} \]

Consistent with World Average

- Measure branching ratio to determine \( \Delta \Gamma \) (2.8 fb\(^{-1}\))
- Search for one \( D_s \rightarrow \phi \pi \), other to \( D_s \rightarrow \phi \mu \nu \)

Under certain theoretical assumptions, \( B_s^0 \rightarrow D(\ast)_s^0 + D(\ast)_s^{-} \) is nearly CP even

\[
2Br(B_s \rightarrow D(\ast)_s^0 D(\ast)_s^0) \approx \Delta \Gamma_s^{CP} \left[ \frac{1 + \cos \phi_s}{2\Gamma_L} + \frac{1 - \cos \phi_s}{2\Gamma_H} \right]
\]

Find

\[
Br(B_s^0 \rightarrow D(\ast)_s^0 D(\ast)_s^0) = 0.042 \pm 0.015 \text{(stat)} \pm 0.017 \text{(syst)}
\]

Assuming SM, \( \phi_s = 0 \), \( \Delta \Gamma_s^{CP} = \Delta \Gamma \)

\[
\frac{\Delta \Gamma_s}{\Gamma_s} = 0.088 \pm 0.030 \text{(stat)} \pm 0.036 \text{(syst)}
\]

Consistent with

WA (2007)
\( \Delta \Gamma / \Gamma = 0.096 \pm 0.048 \pm 0.053 \)

www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B53/
New Measurement of Direct CPV in $B^+ \rightarrow J/\psi K^+ (\pi^+)$

\[ A_{CP}(B^+ \rightarrow J/\psi K^+ (\pi^+)) = \frac{N(B^- \rightarrow J/\psi K^-(\pi^-)) - N(B^+ \rightarrow J/\psi K^+(\pi^+))}{N(B^- \rightarrow J/\psi K^-(\pi^-)) + N(B^+ \rightarrow J/\psi K^+(\pi^+))} \]

$A_{CP}(B^+ \rightarrow J/\psi K^+)$ = $+0.0075 \pm 0.0061$ (stat) $\pm 0.0027$ (syst)

$A_{CP}(B^+ \rightarrow J/\psi \pi^+)$ = $-0.09 \pm 0.08$ (stat) $\pm 0.03$ (syst)