Looking for Large CP Violation in $B_s^0 \rightarrow J/\psi \phi$ Decays

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Overview

• *CP* Violation:
  – Standard model
  – $B^0_s \rightarrow J/\psi \phi$

• Measurement:
  – CDF Detector
  – Data Sample & Selection
  – Angular Analysis
  – Flavor Tagging
  – Likelihood

• Results
  – Untagged Analysis
  – Tagged Analysis
Quark weak flavor eigenstates related to mass eigenstates by CKM Matrix:

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

Wolfenstein parametrization expanded in $\lambda \approx 0.23$, up to $\lambda^5$, $V_{CKM} =$

\[
\begin{pmatrix}
    1 - \frac{1}{2} \lambda^2 - \frac{1}{8} \lambda^4 & \lambda & A\lambda^3 (\rho - i\eta) \\
    -\lambda + \frac{1}{2} A^2 \lambda^5 [1 - 2(\rho + i\eta)] & 1 - \frac{1}{2} \lambda^2 - \frac{1}{8} \lambda^4 (1 + 4A^2) & A\lambda^2 \\
    A\lambda^3 [1 - (1 - \frac{1}{2} \lambda^2)(1 - \rho - i\eta)] & -A\lambda^2 + \frac{1}{2} A\lambda^4 [1 - 2(\rho + i\eta)] & 1 - \frac{1}{2} A^2 \lambda^4
\end{pmatrix}
\]

$CP$ violation enters into elements in red. Controlled by one parameter in SM, $\eta$
Unitarity Triangles

... or how to get from one SM parameter to a very rich phenomenology.

\[ B_d^0 : \quad V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\[ B_s^0 : \quad V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0 \]

- Sides & interior angles can be independently measured
- Goal: to “overconstrain” the triangles
- Hope: that no single choice of CKM parameters will fit all measurements
Selective Review of CP Violation Measurements

Discovery of CP violation:

• 1964: $K_L^0 \to 2\pi$ decay, asymmetry in $K^0 - \bar{K}^0$ mixing

Since then, the standard model description has been (too) successful:

<table>
<thead>
<tr>
<th>Year</th>
<th>Process</th>
<th>Description</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988, ’99</td>
<td>$K_{S/L}^0 \to 2\pi^0, \pi^+\pi^-$</td>
<td>Direct CPV in decay</td>
<td>NA31/48, KTeV</td>
</tr>
<tr>
<td>2001</td>
<td>$B_d^0 \to J/\psi K_S^0$</td>
<td>CPV in $B_d^0 - \bar{B}_d^0$ mixing</td>
<td>BaBar, Belle</td>
</tr>
<tr>
<td>2005, ’06</td>
<td>$B^+ \to K^+ \rho^0$</td>
<td>Direct CPV in decay</td>
<td>BaBar, Belle</td>
</tr>
<tr>
<td>2004, ’05, ’07</td>
<td>$B_d^0 \to K^+\pi^-$</td>
<td>Direct CPV in decay</td>
<td>BaBar, Belle, CDF</td>
</tr>
<tr>
<td>2007</td>
<td>$B^+ \to J/\psi K^+$</td>
<td>Direct CPV in decay</td>
<td>DZERO</td>
</tr>
</tbody>
</table>

• Success of CKM both from precise determination & agreement, or calculational limitations

“Last hope” for new physics in beauty system: $B_s^0$ decays

• CP violation predicted to be very small in Standard Model
• If measured to be otherwise: unambiguous signal for new physics
"Mixing" of $B_s^0$ meson refers to $B_s^0 - \overline{B_s^0}$ oscillation, e.g.:

\[ i \frac{\partial}{\partial t} \begin{bmatrix} |B_s^0(t)\rangle \\ |\overline{B_s^0}(t)\rangle \end{bmatrix} = \left( M - \frac{i}{2} \Gamma \right) \times \begin{bmatrix} |B_s^0(t)\rangle \\ |\overline{B_s^0}(t)\rangle \end{bmatrix} \]

\[ |B_{L,H}(t)\rangle = p|B_s^0\rangle \pm q|\overline{B_s^0}\rangle, \quad q/p = \frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}} \]

$\Delta m_s \approx 2 |M_{12}|$

$\Delta \Gamma_s \approx 2 |\Gamma_{12}| \cos(\phi_s)$

$\phi_s^{SM} = \arg(-M_{12}/\Gamma_{12}) \approx 4 \times 10^{-3}$
\( CP \) Violation in \( B_S^0 \rightarrow J/\psi\phi \)

- From above diagrams, phase \( \beta_{SM} = \arg(-V^*_{ts}V_{tb}/V^*_{cs}V_{cb}) \approx 0.02 \)
- \( CP \) violation occurs in the interference of mixing and decay
- This is in analogy to the well-studied case of \( B_d^0 \rightarrow J/\psi K_S^0 \)

\[
\begin{align*}
B^0 & \rightarrow J/\Psi K_S^0 \\
\overline{B}^0 & \rightarrow J/\Psi K_S^0 \\
B_S^0 & \rightarrow J/\Psi \phi \\
\overline{B}_S^0 & \rightarrow J/\Psi \phi
\end{align*}
\]

\( \Rightarrow \sin(2\beta) \)

\( \Rightarrow \sin(2\beta_S) \)
\[ B_s^0 \rightarrow J/\psi\phi \text{ Vs. } B_d^0 \rightarrow J/\psi K_S^0 \]

- Oscillation frequency \( \Delta m_s \approx 35 \times \Delta m_d \rightarrow \text{need vertex resolution} \)
- \( J/\psi\phi \) admixture of \( CP \)-even and odd \( \rightarrow \text{need angular analysis} \)
- \( \sin(2\beta_s) \approx 0.05 \times \sin(2\beta) \) from SM \( \rightarrow \text{much smaller effect} \)

Unitarity triangles to common scale:

- a: \( V_{id} V_{is}^* \)
- b: \( V_{is} V_{ib}^* \)
- c: \( V_{id} V_{ib}^* \)
\[ \beta_s, \phi_s \text{ Notation} \]

- \[ \beta_s^{SM} = \arg(-V_{ts}^* V_{tb}/V_{cs}^* V_{cb}) \approx 0.02 \]
  - phase of the \( b \rightarrow c\bar{c}s \) transition that accounts for mixing & mixing + decay

- \[ \phi_s^{SM} = \arg(-M_{12}/\Gamma_{12}) \approx 0.004 \]
  - \( \arg(M_{12}) = \arg[(V_{tb} V_{ts}^*)^2] \): connecting \( B_s^0 \) to \( \bar{B}_s^0 \) through oscillation
  - \( \arg(\Gamma_{12}) = \arg[(V_{cb} V_{cs}^*)^2 + V_{cb} V_{cs}^* V_{ub} V_{us}^* + (V_{ub} V_{us}^*)^2] \): width of matter and antimatter into common final states

Both SM values too small for current experimental sensitivity (assumed zero). If new physics occurs in mixing:

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

Standard shorthand \( \rightarrow \phi_s = -2\beta_s \)
Measurement

• \( CP \) Violation:
  – Standard model
  – \( B^0_S \rightarrow J/\psi \phi \)

• Measurement:
  – CDF Detector
  – Data Sample & Selection
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  – Flavor Tagging
  – Likelihood

• Results
  – Untagged Analysis
  – Tagged Analysis
CDF Detector, B Physics Focus

- **Silicon SVXII + Layer00:**
  - B physics triggers
  - Vertex Resol $\approx 25 \mu m$

- **COT drift chamber:**
  - Momentum resolution $\sigma_p/p^2 < 0.1\%$
  - $dE/dx$ for particle ID (selection, tagging)

- **Time-Of-Flight:**
  - Particle ID (selection, tagging)

- **Muon det., EM cal:**
  - Lepton triggers
  - Lepton ID: tagging
Data Sample and Selection

- Data with 1.35 fb$^{-1}$ (1.7)
- Di-muon trigger
- Soft precuts followed by neural network selection
- NN Trained on:
  - Simulated events for signal
  - $B_s^0$ mass sidebands for bkg
- Selection maximizes $S/\sqrt{S+B}$ in signal peak
- $S \approx 2000$ $B_s^0 \rightarrow J/\psi \phi$ signal evts
  $S/B \approx 2$ in signal peak
General Analysis Strategy

Reconstruct decays from stable products:

- \( B^{0}_{S} \rightarrow J/\psi [\mu^{+}\mu^{-}]\phi[K^{+}K^{-}] \)
- \( B^{0}_{d} \rightarrow J/\psi [\mu^{+}\mu^{-}]K^{*}[K^{+}\pi^{-}] \)
- \( B^{0}_{d} \rightarrow J/\psi K^{*} \): control sample

Identify \( B^{0}_{S}/\bar{B}^{0}_{S} \)

- Flavor tagging

Event variables:

- Mass
- Lifetime \( ct = m_{B}L_{xy}/p_{T} \)
- \( \vec{\rho} \equiv \theta_{T}, \phi_{T}, \psi_{T} \)
- Tag decision \( \xi \)

Perform maximum likelihood fit:

- Likelihood in \( m, ct, \vec{\rho}, \xi \)
\( B_s^0 \rightarrow J/\psi \phi \) Angular Analysis

**Angular momentum:**
- \( P \rightarrow VV \) decay:
  - \( L = 0 \)
  - \( L = 1 \)
  - \( L = 2 \)

**Transversity Basis:**
- 3 Angles:
  - \( \theta_T \) (\( J/\psi \) frame)
  - \( \phi_T \) (\( J/\psi \) frame)
  - \( \psi_T \) (\( \phi \) frame)

- Since \( J/\psi \phi \) is C-odd, parity determines CP
- In Transversity basis, polarization of \( VV \):
  - longitudinal (0), transverse and parallel (\( \parallel \)) \( \rightarrow \) \( CP \)-even
  - transverse and perpendicular (\( \perp \)) \( \rightarrow \) \( CP \)-odd
$B_d^0 \rightarrow J/\psi K^*$ Angular Analysis

Similar Angular Decay:

- $P \rightarrow VV$
- Similar phase space available

Control:

- Detector efficiency in $\vec{\rho}$
- Measure $|A_0|$, $|A_\parallel|$, $|A_\perp|$
Flavor Tagging

- 2 independent methods of tagging: same and opposite side
- Opposite Side Tagger is calibrated using data (high stat $B^+, B^0_d$)
- Same Side Tagger is calibrated on Monte Carlo
- Efficiency $\varepsilon = P(\text{tag decision})$
- Dilution $D = 1 - 2q$, $q$ is mistag probability
Opposite Side Flavor Tagging

Exclusive algorithms:

Soft Lepton Tagger
- look for semileptonic B decay on OS
- lepton charge indicates $b$-flavor
- $\mu, e$ tagger

Jet Charge Tagger
- look for jet or secondary vertex on OS
- jet charge indicates $b$-flavor

Performance
- Efficiency: $\varepsilon = 0.96 \pm 0.01$
- Avg Dilution: $D = 0.11 \pm 0.02$
Same Side Flavor Tagging

Most Powerful Tagger:

Fragmentation Track
- Look for Kaon assoc. w/ $B^0_s$ production
- Use TOF & COT for $\pi - K$ separation

Calib using Monte Carlo
- $B^0_s$, $B^0_d$, $B^+$ different
- Use PYTHIA simulation

Performance
- Efficiency: $\varepsilon = 0.50 \pm 0.01$
- Avg Dilution: $\mathcal{D} = 0.27 \pm 0.04$

$\rightarrow$ SST + OST Total $\varepsilon\mathcal{D}^2 \approx 4\%$
Likelihood for Decay to $J/\psi\phi$: Overview

$B^0_s/\bar{B}^0_s \rightarrow J/\psi\phi$ differential decay rates depend on 4 event variables:

- $ct$: Proper decay length
- $\vec{\rho}$: vector formed by the 3 angles that characterize the decay
- $\xi$: tag decision ($+1 \rightarrow B^0_s$, $-1 \rightarrow \bar{B}^0_s$, $0 \rightarrow$ no tag)

... and quite a few parameters describing the physics

- $|A_\alpha|, \alpha = 0, ||, \perp$: amplitudes for decay to longitudinal, parallel (both $CP$-even), or perpendicular ($CP$-odd) polarizations of $J/\psi, \phi$

- $\delta_\alpha$: Phases associated with those amplitudes
- $\Gamma, \Delta \Gamma$: Average lifetime and lifetime difference

$$P(ct, \vec{\rho}|\xi) = \frac{1 + \xi \mathcal{D}}{1 + |\xi|} \cdot P_B(ct, \vec{\rho}) + \frac{1 - \xi \mathcal{D}}{1 + |\xi|} \cdot P_{\bar{B}}(ct, \vec{\rho})$$
Likelihood for Decay to $J/\psi \phi$: Time Dependence

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

$B^0_s$ term

\[
+ |A_\perp|^2 T_- f_3(\bar{\rho}) + |A_\parallel||A_\perp| U_+ f_4(\bar{\rho})
\]

\[
+ |A_0||A_\parallel| \cos(\delta_\parallel) T_+ f_5(\bar{\rho})
\]

\[
+ |A_0||A_\perp| V_+ f_6(\bar{\rho}),
\]

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

anti-$B^0_s$

\[
+ |A_\perp|^2 T_- f_3(\bar{\rho}) + |A_\parallel||A_\perp| U_- f_4(\bar{\rho})
\]

\[
+ |A_0||A_\parallel| \cos(\delta_\parallel) T_+ f_5(\bar{\rho})
\]

\[
+ |A_0||A_\perp| V_- f_6(\bar{\rho}),
\]

$A_0$, $A_\parallel$, $A_\perp$: transition amplitudes in a given polarization state

$f(\bar{\rho})$: angular distribution for a given polarization state
CP-Violating Terms

\[ T_\pm = e^{-\Gamma t} \times \left[ \cosh(\Delta \Gamma t/2) \pm \cos(2\beta_s) \sinh(\Delta \Gamma t/2) \right. \]

\[ \left. \mp \eta \sin(2\beta_s) \sin(\Delta m_s t) \right], \]

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

\[ \left. - \cos(\delta_\perp - \delta_\parallel) \cos(2\beta_s) \sin(\Delta m_s t) \right. \]

\[ \left. \pm \cos(\delta_\perp - \delta_\parallel) \sin(2\beta_s) \sinh(\Delta \Gamma t/2) \right] , \]

\[ V_\pm = \pm e^{-\Gamma t} \times \left[ \sin(\delta_\perp) \cos(\Delta m_s t) \right. \]

\[ \left. - \cos(\delta_\perp) \cos(2\beta_s) \sin(\Delta m_s t) \right. \]

\[ \left. \pm \cos(\delta_\perp) \sin(2\beta_s) \sinh(\Delta \Gamma t/2) \right] . \]

\[ \delta_\perp = \arg[A_\perp^* A_0] , \delta_\parallel = \arg[A_\parallel^* A_0] \]
Some sensitivity to $\beta_s$, but better suited to measure $\Delta \Gamma$, $c\tau$
• Monte Carlo study with $\Delta \Gamma - \beta_s$ generated at SM values
• Plotting results of 300 fits in 2D plane
Source of Problems in Straightforward Fit

Difficulties arise

- Likelihood exhibits symmetry to following transformation:
  - $2\beta_s \rightarrow \pi - 2\beta_s$
  - $\Delta \Gamma \rightarrow -\Delta \Gamma$
  - $\delta_\parallel \rightarrow 2\pi - \delta_\parallel$
  - $\delta_\perp \rightarrow \pi - \delta_\perp$

- Small $\beta_s \rightarrow$ effective loss of degrees of freedom
  - Biases in straightforward likelihood fit (parameter-dependent)
  - Irregular (non-elliptical) likelihood shape & uncertainties
  - $\rightarrow$ Undercoverage by likelihood profile

- These problems go away with very large statistics, but not for our sensitivity
Separate time evolution of mesons produced as $B_s^0$ or $\overline{B_s}$. Utility:

**Three ways to think of utility of flavor-tagging:**

- In short: $B_s^0/\overline{B_s}$ differential decay rates $\frac{dP}{dt\vec{\rho}}(t, \vec{\rho})$ dependent on $\beta_s$ differently

- Likelihood: with tagging, gain sensitivity to both $|\cos(2\beta_s)|$ and $\sin(2\beta_s)$, rather than only $|\cos(2\beta_s)|$ and $|\sin(2\beta_s)|$ (note absolute value)

- Visually: MC study comparing 68%, 95% likelihood contours for tagged (thick line) / untagged (thin line) in $\Delta \Gamma - \beta_s$ plane
2D confidence Region Method

- Problems arise from limited sensitivity: biases observed in pseudo-experiments depending on input value of $\beta_s$

- We use a likelihood ordering suggested by Feldman and Cousins to estimate a confidence interval

- Calculate a p-value for each point on the $\Delta \Gamma - \beta_s$ plane

- Verify that we have proper coverage in the confidence region for alternative true values of the parameters

- Construct a confidence region rather than quote a point estimate
Systematic Effects

→ Important for measurement of $\Delta \Gamma$, $c\tau$:
  
  • $B_d^0 \rightarrow J/\psi K^*$ decays misreconstructed as $B_s^0$: $O(3\%)$ contamination
  • Signal mass model
  • Lifetime resolution model
  • Detector angular acceptance
  • Silicon detector alignement

Tagged $\beta_s$ result:

• Dilution scale factor
• Background angular distributions
• Lifetime resolution model/ bkg model

→ Contributed to 2% confidence region adjustment for $\Delta \Gamma - \beta_s$ result
Results

• *CP* Violation:
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**B^0_d Results: c\tau, Angular Parameters**

CDF Run II Preliminary \[ L = 1.3 \text{ fb}^{-1} \]

- **Param = Val ± Stat ± Syst**
  - \( c\tau = 456 \pm 6 \pm 6 \text{ \mu m} \)
  - \( |A_0|^2 = 0.569 \pm 0.009 \pm 0.009 \)
  - \( |A_\parallel|^2 = 0.211 \pm 0.012 \pm 0.006 \)
  - \( \delta_\parallel = -2.97 \pm 0.08 \pm 0.03 \)
  - \( \delta_\perp = +2.97 \pm 0.06 \pm 0.01 \)

BaBar 2007 (hep-ex 0704.0522)

- \( |A_0|^2 = 0.556 \pm 0.009 \pm 0.010 \)
- \( |A_\parallel|^2 = 0.211 \pm 0.010 \pm 0.006 \)
- \( \delta_\parallel = -2.93 \pm 0.08 \pm 0.04 \)
- \( \delta_\perp = +2.91 \pm 0.05 \pm 0.03 \)
$B^0_s$ UnTagged Results: $\Delta \Gamma$, $c\tau$

CDF II Preliminary  $L=1.7$ fb$^{-1}$

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

**Fixing $\beta_s$ to 0:**

Param = Val ± Stat ± Syst

- $c\tau = 456 \pm 13 \pm 7 \mu$m
- $\Delta \Gamma = 0.076^{+0.059}_{-0.063} \pm 0.006$ ps$^{-1}$

→ **Improved best measurement by 30 (50)%**
B^0_s Utagged Results: Angular Parameters

Fixing $\beta_s$ to 0:

- $|A_0|^2 = 0.531 \pm 0.020 \pm 0.007$
- $|A_\parallel|^2 = 0.239 \pm 0.029 \pm 0.011$
- $|A_\perp|^2 = 0.230 \pm 0.026 \pm 0.009$
Untagged Results: $\Delta \Gamma - \beta_s$ Confidence Region

**$\beta_s$ Floating:**

- Assuming the SM, the probability to observe a fluctuation as large or larger than the one observed in data: 22%
Tagged Results: $\Delta \Gamma - \beta_s$ F-C Confidence Region

- Main result w/ tagging

- Assuming the SM, the probability to observe a fluctuation as large as or larger than the one observed in data:
  
  $15\%$, ($\approx 1.5\sigma$)

- $\cos(\delta_\perp) < 0$
  $\cos(\delta_\perp - \delta_\parallel) > 0$
  in upper region

- $\cos(\delta_\perp) > 0$
  $\cos(\delta_\perp - \delta_\parallel) < 0$
  in lower region
Tagged Results: Likelihood & F-C Confidence Region

Likelihood Profile:

- Similar shape with likelihood profile, but F-C region has proper coverage.
Tagged Results: $\beta_s$ with Experimental Constraints

Strong Phases Contrained:

Phases & Lifetime (to $B^0_d c\tau$):

- Constrained to BaBar results in $B^0_d \rightarrow J/\psi K^*$
Results for $\beta_s$: 1-D Confidence Interval, Constraints

If we seek no info on $\Delta \Gamma$, bounding $\beta_s$ in 1D:

- At 68% C.L. we find $2\beta_s \in [0.32, 2.82]$

Using a theoretical constraint on $|\Gamma_{12}|$:

- $2\beta_s \in [0.24, 1.36] \cup [1.78, 2.90]$ at 68% C.L.

Adding constraint on $\delta_\parallel, \delta_\perp$ from B factories:

- $2\beta_s \in [0.40, 1.20]$ at 68% C.L.

The latter range is the tightest constraint we can obtain on $\beta_s$ incorporating all available information.
Main result is point estimate with strong phases constrained. Best to compare to CDF's 1D confidence interval with similar constraint: \( 2\beta_s \in [0.40, 1.20] \) at 68% C.L.
Future Prospects

- Add +50% statistics from other triggers
- Improve tagging algorithms
- Better-behaved likelihood profile at high stat

This measurement will be a key component of the LHCb program. The Tevatron will have much more to say about it as well before “handing it over” to LHC.
Conclusion

Important result in $B$ physics:

- First flavor-tagged measurement of $CP$ violating phase in $B_s^0$ system: submitted to PRL arXiv:0712.2397 [hep-ex]
- Cut in half allowed space of parameters. Already 95% CL exclusion of a large portion of the NP-phase space as allowed by global fits. Large positive values of $\phi_s$ excluded
- World’s best determination of $B_s^0$ average lifetime and decay-width difference. Accepted by PRL arXiv:0712.2348 [hep-ex]
Additional Slides
Tagged Analysis: Sideband Subtracted Angular Distribution

\[ \text{Events per 0.20} \]

- \text{data}
- \text{fit}

\[ \cos(\psi_T) \]
Tagged Analysis: Sideband Subtracted Angular Distribution

![Graph showing data and fit for angular distribution](image)

- **Data**
- **Fit**

Events per 0.20

\[ \cos(\theta_T) \]
Tagged Analysis: Sideband Subtracted Angular Distribution

![Graph showing data and fit for events per 0.63 rad vs. $\phi_T$ (rad).](image)
Predicted Dilution: OST

CDF Run II Preliminary

L = 1.35 fb\(^{-1}\)

- Signal
- Background
Predicted Dilution: SST

CDF Run II Preliminary  \( L = 1.35 \text{ fb}^{-1} \)

- **Signal**
- **Background**

SST Predicted Dilution

K. Makhoul CDF/MIT – Feb 21, 2008
Measured vs. Predicted Dilution: $B^-$

CDF Run II Preliminary

$L = 1.35 \text{ fb}^{-1}$

B$^-$ only

Slope $= 1.09 \pm 0.13$
Measured vs. Predicted Dilution $B^+$

CDF Run II Preliminary

$B^+$ only

Slope $= 0.85 \pm 0.11$

$L = 1.35 \text{ fb}^{-1}$
Measured vs. Predicted Dilution $B^+ + B^-$

CDF Run II Preliminary $L = 1.35$ fb$^{-1}$

Combined $B^+/B^-$

Slope = 0.95 ± 0.09
Likelihood Profile w/ Additional Asymmetry

CDF Run II Preliminary

$L = 1.35 \text{ fb}^{-1}$

$\Delta \Gamma (\text{ps}^{-1})$ vs. $\beta_s (\text{rad})$

- SM prediction
- $+20\%$ dilution asymmetry:
  - $2\Delta \log(L) = 5.99$
  - $2\Delta \log(L) = 2.30$
- $-20\%$ dilution asymmetry:
  - $2\Delta \log(L) = 5.99$
  - $2\Delta \log(L) = 2.30$