CP Violation in $B^0_s$ mesons
Results from flavor tagged analyses of $B^0_s \rightarrow J/\psi \, \phi$

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A very brief abstract of this talk first. The following topics will be developed:

CDF and D0 use $B_0^s \rightarrow J/\psi \phi$ to measure CKM phases. We determine from this decay the quantity $\beta_s$.

This is in exact analogy to B factory measurement of the $\beta$, an angle of the unitarity triangle.

The standard model makes very precise predictions for both angles.

But other new particles & processes, lurking potentially in quantum mechanical loops such as box diagrams and penguin diagrams can change the prediction.
Example of new physics: a fourth generation quark that contributes to the mixing phase

Would have other measurable consequences: e.g., an impact on direct CP violation in \( B^0 \to K^+\pi^- \) and \( B^+ \to K^+\pi^0 \)

\[ B^0_s \rightarrow J/\psi \, \phi \]

* \( B^0_s \rightarrow J/\psi \, \phi \) is two particles decaying to three final states.

Two particles:
\[
\begin{align*}
|B^0_{S,L}\rangle &= p|B^0_S\rangle + q|\bar{B}^0_S\rangle \\
|B^0_{S,H}\rangle &= p|B^0_S\rangle - q|\bar{B}^0_S\rangle
\end{align*}
\]
Light, CP-even, shortlived in SM
Heavy, CP-odd, longlived in SM

Three final states:
- \( J/\psi \, \phi \) in an S wave, CP Even
- \( J/\psi \, \phi \) in a D wave, CP Even
- \( J/\psi \, \phi \) in a P wave, CP Odd

Manifestations of CP violation in \( B^0_s \rightarrow J/\psi \, \phi \)

A supposedly CP even initial state decays to a supposedly CP odd final state.... like the neutral kaons

Measurement needs \( \Delta \Gamma \neq 0 \) but not flavor tagging.

The polarization of the two vector mesons in the decay evolves with a frequency of \( \Delta m_s \)

Measurement needs flavor tagging, resolution, and knowledge of \( \Delta m_s \)
Time dependence of the angular distributions: use a basis of linear polarization states of the two vector mesons

\{ S, P, D \} \rightarrow \{ P_{\perp}, P_{\parallel}, P_0 \}

CP odd states decay to \( P_{\perp} \)
CP even states decay to \( P_{\parallel}, P_0 \)

If \([H,CP] \neq 0\)
Then \[ \frac{d}{dt} \langle CP \rangle \neq 0 \]
\[ \Delta m_s \sim 17.77 \text{ ps}^{-1}. \]

• The polarization correlation depends on decay time.
• Angular distribution of decay products of the \( J/\psi \) and the \( \phi \) analyze the rapidly oscillating correlation.

The measurement is an analysis of time-dependent angular distributions

\[ \hat{n} = (\sin \theta \cos \phi, \sin \theta \sin \phi, \cos \theta) \]

\[ \vec{A} = (A_0(t) \cos \psi, \frac{-A_\parallel(t) \sin \psi}{\sqrt{2}}, i \frac{A_\perp(t)}{\sqrt{2}}) \]

\[ P(\theta, \phi, \psi, t) = \frac{9}{16\pi} |\vec{A}(t) \times \hat{n}|^2 \]

... formula suggests an analysis of an oscillating polarization.

This innocent expression hides a lot of richness:

* CP Asymmetries through flavor tagging.
* Sensitivity to CP without flavor tagging.
* Sensitivity to both \( \sin(2\beta_s) \) and \( \cos(2\beta_s) \) simultaneously.
* Width difference
* Mixing Asymmetries
CP Violation in the interference of mixing and decay for the $B^{0_s}$ system

Take: \( q/p \) from the mixing of $\bar{B}^{0_s} - B^{0_s}$

Take: $\bar{A}/A$ from the decay into \{ $P_{\perp}, P_{\parallel}, P_0$ \}

Form: the (phase) convention-independent and observable quantity:

$$\lambda = \frac{q}{p} \frac{\bar{A}}{A}$$

This number is real and unimodular if $[H, CP] = 0$
Very famous measurement of CP Asymmetries in $B^0 \rightarrow J/\psi K^0_s$

$|B^0 \rangle \rightarrow |J/\psi K^0_s \rangle$

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

BABAR, BELLE have used this decay to measure precisely the value of $\sin(2\beta)$ an angle of the $bd$ unitarity triangle.

There was a fourfold ambiguity

http://ckmfitter.in2p3.fr/
Babar, Belle resolve an ambiguity in $\beta$ by analyzing the decay

$$B^0 \rightarrow J/\psi K^{0*}$$ which is $B \rightarrow V V$ and measures $\sin(2\beta)$ and $\cos(2\beta)$

This involves angular analysis as described previously.


\[|B^0\rangle \rightarrow J/\psi K^{0*} \rightarrow |\mathcal{P}\rangle > \rightarrow \mu^+ \mu^- K_0^0 \pi^0 > \rightarrow |\mathcal{P}_0\rangle > \rightarrow |\mathcal{P}_\perp\rangle >\]
Today I will tell you about an analysis of an almost exact analogy, 
$|B_s^0> \rightarrow J/\psi \phi$ (but I think that in the $B_s^0$ system the phenomenology
is even richer! Because of the width difference! )
The decay $B^0_s \rightarrow J/\psi \phi$ obtains from the decay $B^0 \rightarrow J/\psi K^{0\ast}$ by the replacement of a $d$ antiquark by an $s$ antiquark.

We are measuring then not the $(bd)$ unitarity triangle but the $(bs)$ unitarity triangle:
The analysis of $B^0_s \rightarrow J/\psi \phi$ can extract these physics parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_s$</td>
</tr>
<tr>
<td>$\Delta \Gamma = \Gamma_H - \Gamma_L$</td>
</tr>
<tr>
<td>$\tau = 2/(\Gamma_H + \Gamma_L)$</td>
</tr>
<tr>
<td>$A_\perp$ (phase $\delta_\perp$)</td>
</tr>
<tr>
<td>$A_\parallel$ (phase $\delta_\parallel$)</td>
</tr>
<tr>
<td>$A_0$ (phase 0)</td>
</tr>
</tbody>
</table>

The measurement of $\beta_s$ and $\Delta \Gamma$ are correlated; from theory one has the relation $\Delta \Gamma = 2|\Gamma_{12}|\cos(2\beta_s)$ with $|\Gamma_{12}| = 0.048 \pm 0.018$ and


The exact symmetry...

... is an experimental headache.
2019 ± 73 events

1967 ± 65 events
Flavor Tagging

SST + OST: $\varepsilon D^2 = 4.68 \pm 0.54\%$

SST: $\varepsilon D^2 \approx 3.6\%$
OST: $\varepsilon D^2 \approx 1.2\%$

Each tag decision comes with an error estimate validated:

1. Using $B^\pm$ (OST)

2. In the $B^0_s$ mixing (SST)
CDF Untagged Analysis (1.7 fb⁻¹)


Feldman-Cousins confidence region in the space of the parameters $2\beta_s$ and $\Delta \Gamma$

CDF II

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

$ct_{s} = 456 \pm 13 \pm 7 \, \mu m$

$\Delta \Gamma = 0.076^{+0.059}_{-0.063} \pm 0.006 \, ps^{-1}$

$|A_0|^2 = 0.530 \pm 0.021 \pm 0.007$

$|A_\parallel|^2 = 0.230 \pm 0.027 \pm 0.009$

HQET: $ct(B_s^0) = (1.00 \pm 0.01) \, ct(B^0)$

PDG: $ct(B^0) = 459 \pm 0.027 \, \mu m$
Tagged analysis: likelihood contour in the space of the parameters $\beta_s$ and $\Delta \Gamma$


One ambiguity is gone, now this one remains.

\[
\begin{align*}
\beta_s &\rightarrow \frac{\pi}{2} - \beta_s, \\
\Delta \Gamma &\rightarrow -\Delta \Gamma, \\
\delta_{||} &\rightarrow 2\pi - \delta_{||}, \\
\delta_{\perp} &\rightarrow \pi - \delta_{\perp}.
\end{align*}
\]
A frequentist confidence region in the $\beta_s-\Delta \Gamma$ including systematic errors is the main result. This interval is based on p-values obtained from Monte Carlo and represents regions that contain the true value of the parameters 68% (95%) of the time.

The standard model agrees with the data at the 15% CL
There is no way that this measurement can remove the remaining ambiguity alone. External constraints on the phases, from B factories, can do, but they may not be applicable:

Constrain strong phases $\delta_{||}$ and $\delta_{\perp}$ to BaBar Values (for $B^0 \rightarrow J/\psi K^*$)  
Constrain $\tau_s$ to PDG Value for $B^0$  
Apply both constraints.

using values reported in:

The D0 Result is a confidence interval using an external constraint:

Strong phases varying around the world average values (for $B^0 \rightarrow J/\psi \ K^*$); Gaussian constraint with $\sigma=\pi/5$ is applied.

D0 Result

$\phi_s = -2 \beta_s$

arXiv:0802.2255
Prev result: PRD 76, 057101 (2007)

Contours are 68% CL and 90% CL.

TABLE I: Summary of the likelihood fit results for three cases:
free $\phi_s$, $\phi_s$ constrained to the SM value, and $\Delta \Gamma_s$ constrained by the expected relation $\Delta \Gamma_s^{SM} \cdot |\cos(\phi_s)|$.

<table>
<thead>
<tr>
<th></th>
<th>free $\phi_s$</th>
<th>$\phi_s \equiv \phi_s^{SM}$</th>
<th>$\Delta \Gamma_s^{th}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_s$ (ps)</td>
<td>1.52±0.06</td>
<td>1.53±0.06</td>
<td>1.49±0.05</td>
</tr>
<tr>
<td>$\Delta \Gamma_s$ (ps$^{-1}$)</td>
<td>0.19±0.07</td>
<td>0.14±0.07</td>
<td>0.083±0.018</td>
</tr>
<tr>
<td>$A_\perp(0)$</td>
<td>0.41±0.04</td>
<td>0.44±0.04</td>
<td>0.45±0.03</td>
</tr>
<tr>
<td>$</td>
<td>A_0(0)</td>
<td>^2 -</td>
<td>A_\parallel(0)</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>-0.52±0.42</td>
<td>-0.48±0.45</td>
<td>-0.47±0.42</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>3.17±0.39</td>
<td>3.19±0.43</td>
<td>3.21±0.40</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>-0.57±0.30</td>
<td>$\equiv -0.04$</td>
<td>-0.46±0.28</td>
</tr>
<tr>
<td>$\Delta M_s$ (ps$^{-1}$)</td>
<td>$\equiv 17.77$</td>
<td>$\equiv 17.77$</td>
<td>$\equiv 17.77$</td>
</tr>
</tbody>
</table>

and $0.06 < \Delta \Gamma_s < 0.30$ ps$^{-1}$. To quantify the level of agreement with the SM, we use pseudo-experiments with the “true” value of the parameter $\phi_s$ set to $-0.04$. We find the probability of $6.6\%$ to obtain a fitted value of $\phi_s$ lower than $-0.57$. 
1 D Contours & Confidence Intervals

Likelihood contours for just $\Delta \Gamma$ and for just $\phi_s = -2\beta_s$.

- $\Delta \Gamma = 0.19 \pm 0.07$ ps$^{-1}$
- $\phi_s = -0.57^{+0.24}_{-0.30}$

Assuming $|\Gamma_{12}| = 0.048 \pm 0.018$ and the relation $\Delta \Gamma = 2|\Gamma_{12}| \cos(2\beta_s)$:

1. $2\beta_s \in [0.32, 2.82]$ at the 68% CL.
2. $2\beta_s \in [0.24, 1.36]$ U $[1.78, 2.90]$ at the 68% CL.

Constrain $\delta_{||}$ and $\delta_{\perp}$ to the results from $B^0 \rightarrow J/\psi K^0$ decays & $\tau_s = \tau_d$:

3. $2\beta_s \in [0.40, 1.20]$ at 68% CL.

Joe Boudreau HQL Melbourne June 5-9 2008
Note $\phi_s = -2\beta_s$

- Fluctuation or something more, it does go in the same direction.
- CDF estimates a p-value of 15% for the standard model, using Monte Carlo
- D0 estimates a p-value of 6.6% using Monte Carlo
UTFit group has made an “external” combination.

We combine all the available experimental information on $B_s$ mixing, including the very recent tagged analyses of $B_s \rightarrow J/\Psi \phi$ by the CDF and DØ collaborations. We find that the phase of the $B_s$ mixing amplitude deviates more than $3\sigma$ from the Standard Model prediction. While no single measurement has a $3\sigma$ significance yet, all the constraints show a remarkable agreement with the combined result. This is a first evidence of physics beyond the Standard Model. This result disfavours New Physics models with Minimal Flavour Violation with the same significance.

• “re-introduces” the ambiguity into the D0 result.
• does so by symmetrizing.
• cannot fully undo the strong phase constraint.

• I am showing you this conclusion, but not endorsing it very enthusiastically.

D0 is now producing a result without the strong phase constraint.

HFAG is preparing to combine the two unconstrained results.
Further comments:

- We have assumed so far that:

\[ \lambda = \frac{q}{p} \overrightarrow{A} = e^{2i\beta_s} \]

and thus \(|\lambda| = 1\) .. To a very good approximation. In higher order however \(|q| \neq |p|\) and \(|\lambda| \neq 1\) (at the level of \(1-|\lambda| < 2.5 \times 10^{-3}\))

**Semileptonic asymmetry:**

\[ A_{SL}(t) = \frac{d\Gamma/dt[M_{\text{phys}}(t) \to \ell^+ X] - d\Gamma/dt[M_{\text{phys}}(t) \to \ell^- X]}{d\Gamma/dt[M_{\text{phys}}(t) \to \ell^+ X] + d\Gamma/dt[M_{\text{phys}}(t) \to \ell^- X]} = \frac{1 - |q/p|^4}{1 + |q/p|^4}. \]

**HQET:** \( \Gamma_{12}/M_{12}^s = (49.7 \pm 9.4) \pm 10^{-4} \)

- \( A_{SL}^s = 0.020 \pm 0.028 \) (CDF)

  http://www-cdf.fnal.gov/physics/new/bottom/070816.blessed-acp-bsemil/

- \( A_{SL}^s = 0.0001 \pm 0.0090 \) (stat) (D0)

Conclusion

• Towards the end of a 20-year program in proton-antiproton physics: some terribly interesting times for the physics of the b-quark.

• An anomaly from the B factories


• Are quantum loop corrections to the $b \rightarrow s$ transitions to blame?

• If so, precision measurements of the CP asymmetries in the $B^0_s$ system are a clean way to sort it out.

• D0 and CDF have just demonstrated the feasibility of doing those measurements; more work needed now to understand the true significance.

• Higher precision, higher statistics measurements could give us a even stronger hint as the LHC begins taking data.
FIN
Free Bonus Slides
An analysis of the decay can be done with either a mix of B and \( \bar{B} \) mesons (untagged) or with a partially separated sample (flavor tagged). Latter is more difficult and more powerful.

\[
\hat{n} = (\sin \theta \cos \varphi, \sin \theta \sin \varphi, \cos \theta)
\]

\[
\vec{A}(t) = (A_0(t) \cos \psi, -\frac{A_\parallel(t) \sin \psi}{\sqrt{2}}, i \frac{A_\perp(t)}{\sqrt{2}})
\]

\[
P(\theta, \varphi, \psi, t) = \frac{9}{16 \pi} |\vec{A}(t) \times \hat{n}|^2
\]

\[
A_i(t) = \frac{a_i e^{-i\Delta m t} e^{-\Gamma t/2}}{\sqrt{\tau_H + \tau_L \pm \cos 2\beta_s (\tau_L - \tau_H)}} \left[ E_+(t) \pm e^{i\beta_s} E_-(t) \right]
\]

\[
\bar{A}_i(t) = \frac{a_i e^{-i\Delta m t} e^{-\Gamma t/2}}{\sqrt{\tau_H + \tau_L \pm \cos 2\beta_s (\tau_L - \tau_H)}} \left[ \pm E_+(t) + e^{-2i\beta_s} E_-(t) \right]
\]

where \( i = 0, \text{para, perp and} \)

These expressions are:

* used directly to generate simulated events.

* expanded, smeared, and used in a Likelihood function.

* summed over B and \( \bar{B} \) (untagged analysis only)
\[ \mathbf{A}(t) = \mathbf{A}_+(t) + \mathbf{A}_-(t), \quad \bar{\mathbf{A}}(t) = \bar{\mathbf{A}}_+(t) + \bar{\mathbf{A}}_-(t) \]

\[ \mathbf{A}_+(t) = \mathbf{A}_+ f_+(t) = (a_0 \cos \psi, -\frac{a_0 \sin \psi}{\sqrt{2}}, 0) \cdot f_+(t) \]

\[ \bar{\mathbf{A}}_+(t) = \bar{\mathbf{A}}_+ \bar{f}_+(t) = (a_0 \cos \psi, -\frac{a_0 \sin \psi}{\sqrt{2}}, 0) \cdot \bar{f}_+(t), \]

\[ \mathbf{A}_-(t) = \mathbf{A}_- f_-(t) = (0, 0, i \frac{a_0 \sin \psi}{\sqrt{2}}) \cdot f_-(t) \]

\[ \bar{\mathbf{A}}_-(t) = \bar{\mathbf{A}}_- \bar{f}_-(t) = (0, 0, i \frac{a_0 \sin \psi}{\sqrt{2}}) \cdot \bar{f}_-(t). \]

obtain the overall time and angular dependence

\[
P(\theta, \phi, \psi, t) = \frac{9}{16\pi} \left\{ |\mathbf{A}_+(t) \times \hat{n}|^2 + |\mathbf{A}_-(t) \times \hat{n}|^2 + 2 \text{Re}((\mathbf{A}_+(t) \times \hat{n}) \cdot (\mathbf{A}_+(t) \times \hat{n})) \right\}
= \frac{9}{16\pi} \left\{ |\mathbf{A}_+ \times \hat{n}|^2 |f_+(t)|^2 + |\mathbf{A}_- \times \hat{n}|^2 |f_-(t)|^2 + 2 \text{Re}((\mathbf{A}_+ \times \hat{n}) \cdot (\mathbf{A}_+ \times \hat{n}) \cdot f_+(t) \cdot f^*_+(t)) \right\}
\]

and

\[
P(\theta, \phi, \psi, t) = \frac{9}{16\pi} \left\{ |\bar{\mathbf{A}}_+(t) \times \hat{n}|^2 + |\bar{\mathbf{A}}_-(t) \times \hat{n}|^2 + 2 \text{Re}((\bar{\mathbf{A}}_+(t) \times \hat{n}) \cdot (\bar{\mathbf{A}}_+(t) \times \hat{n})) \right\}
= \frac{9}{16\pi} \left\{ |\mathbf{A}_+ \times \hat{n}|^2 |\bar{f}_+(t)|^2 + |\mathbf{A}_- \times \hat{n}|^2 |\bar{f}_-(t)|^2 + 2 \text{Re}((\mathbf{A}_+ \times \hat{n}) \cdot (\mathbf{A}_+ \times \hat{n}) \cdot \bar{f}_+(t) \cdot \bar{f}^*_+(t)) \right\}.
\]
Explicit time dependence is here:

where the diagonal terms are:

\[
|\tilde{f}_+(t)|^2 = \frac{1}{2} \frac{(1 \pm \cos 2\beta_s)e^{-\Gamma_L t} + (1 \mp \cos 2\beta_s)e^{-\Gamma_R t} \pm 2 \sin 2\beta_se^{-\Gamma_t} \sin \Delta mt}{\tau_L(1 \pm \cos 2\beta_s) + \tau_H(1 \mp \cos 2\beta_s)},
\]

\[
|\tilde{f}_-(t)|^2 = \frac{1}{2} \frac{(1 \pm \cos 2\beta_s)e^{-\Gamma_L t} + (1 \mp \cos 2\beta_s)e^{-\Gamma_R t} \mp 2 \sin 2\beta_se^{-\Gamma_t} \sin \Delta mt}{\tau_L(1 \pm \cos 2\beta_s) + \tau_H(1 \mp \cos 2\beta_s)}.
\]

and the cross-terms, or interference terms, are: \(f_+(t)f_-^*(t)\). For \(\bar{B}\) and \(B\), those terms are

\[
\tilde{f}_+(t)\tilde{f}_-^*(t) = \frac{-e^{-\Gamma_t} \cos \Delta mt - i \cos 2\beta_se^{-\Gamma_t} \sin \Delta mt + i \sin 2\beta_se^{-\Gamma_L t} - e^{-\Gamma_R t} / 2}{\sqrt{[(\tau_L - \tau_H) \sin 2\beta_s]^2 + 4\tau_L\tau_H}},
\]

\[
\frac{e^{-\Gamma_t} \cos \Delta mt + i \cos 2\beta_se^{-\Gamma_t} \sin \Delta mt + i \sin 2\beta_se^{-\Gamma_L t} - e^{-\Gamma_R t} / 2}{\sqrt{[(\tau_L - \tau_H) \sin 2\beta_s]^2 + 4\tau_L\tau_H}}.
\]

... then, replace \(\exp, \sin^*\exp, \cos^*\exp\) with smeared functions.
Curiosity #1: $\cos(2\beta_s)$ is easier to measure than $\sin(2\beta_s)$. It can be done in the untagged analysis for which the PDF contains time dependent terms:

\[
|f_\pm(t)|^2 = \frac{1}{2} \left( 1 \pm \cos 2\beta_s \right) e^{-\Gamma_L t} + \left( 1 \mp \cos 2\beta_s \right) e^{-\Gamma_H t} \pm 2 \sin 2\beta_s e^{-\Gamma t} \sin \Delta m t \frac{\tau_L (1 \pm \cos 2\beta_s) + \tau_H (1 \mp \cos 2\beta_s)}{\tau_L (1 \pm \cos 2\beta_s) + \tau_H (1 \mp \cos 2\beta_s)},
\]

Physically this is accessible because one particular lifetime state (long or short) decays to the “wrong” angular distributions. Needs $\Delta \Gamma \neq 0$; no equivalent in $B^0 \to J/\psi K^{0*}$.

Some fine print: in the interference term, in an untagged analysis, there is a term including $\sin(2\beta_s)$; however this term does not determine the sign of $\sin(2\beta_s)$ so it does not solve any ambiguity.
Curiosity #2:

Sensitivity to $\Delta m_s$ (tagged analysis only; even in the absence of CP)

\[ \bar{f}_+(t)f^-_+(t) = \frac{-e^{-\Gamma t} \cos \Delta mt - i \cos 2\beta_s e^{-\Gamma t} \sin \Delta mt + i \sin 2\beta_s (e^{-\Gamma L t} - e^{-\Gamma H t})/2}{\sqrt{[(\tau_L - \tau_H) \sin 2\beta_s]^2 + 4\tau_L \tau_H}}, \]

\[ f_+(t)f^+_+(t) = \frac{e^{-\Gamma t} \cos \Delta mt + i \cos 2\beta_s e^{-\Gamma t} \sin \Delta mt + i \sin 2\beta_s (e^{-\Gamma L t} - e^{-\Gamma H t})/2}{\sqrt{[(\tau_L - \tau_H) \sin 2\beta_s]^2 + 4\tau_L \tau_H}}. \]

How much sensitivity? Well, we did not exploit it yet but it could be important news at the LHC!
\[ V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \]

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

\[ V_{ub} V_{ud} = O(\lambda^3) \]
\[ V_{tb} V_{td} = O(\lambda^3) \]
\[ V_{cb} V_{cd} = O(\lambda^3) \]
\[ V_{cb} V_{cs} = O(\lambda^2) \]
\[ V_{ub} V_{us} = O(\lambda^4) \]
\[ V_{tb} V_{ts} = O(\lambda^2) \]

With \( \lambda = 0.2272 \pm 0.0010 \)
\( A = 0.818 \ (+0.007 - 0.017) \)
\( \rho = 0.221 \ (+0.064 - 0.028) \)
\( \eta = 0.340 \ (+0.017 - 0.045) \)

One easily obtains a prediction for \( \beta_s \):
\[ 2\beta_s = 0.037 \pm 0.002 \]
Elsewhere there is another anomaly that may also have to do with $b \to s$

* Direct CP in $B^+ \to K^+ \pi^0$ and $B^0 \to K^+\pi^-$ are generated by the $b \to s$ transition. These should have the same magnitude.

* But Belle measures

\[ \Delta A = \mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = +0.164 \pm 0.037, \quad (4.4 \sigma) \]

* Including BaBar measurements: $> 5\sigma$


• The electroweak penguin can break the isospin symmetry

• But then extra sources of CP violating phase would be required in the penguin

Joe Boudreau HQL Melbourne June 5-9 2008
In general the most important components of a general purpose detector system, for B physics, is:

• tracking.
• muon [+electron] id
• triggering: B hadrons comprise is $O(10^{-3})$ of all events.

Charmless decay modes have branching fractions $O(10^{-6})$
The D0 Silicon tracker.....

• surrounded by a fibre tracker at a distance 19.5 cm < r < 51.5 cm

• now augmented by a high-precision inner layer ("Layer 0")
  • 71 (81) μm strip pitch
  • factor two improvement in impact parameter resolution
CDF Detector showing as seen by the B physics group.

Muon chambers for triggering on the $J/\psi \rightarrow \mu^+\mu^-$ and $\mu$ identification.

Strip chambers, calorimeter for electron ID

Central outer tracker
dE/dX and TOF system for particle ID
$r < 132$ cm $B = 1.4$ T for momentum resolution.
L00: 1.6 cm from the beam.
50 μm strip pitch
Low mass, low M-S.

*Uses precise impact parameter information at trigger level 2, to collect hadronic decays of $b$-hadrons.*
The extent to which these features show up depends upon numerical values of the constants governing mixing, decay, direct CP violation and CP asymmetries:

<table>
<thead>
<tr>
<th>Species</th>
<th>$x = \Delta m / \Gamma$</th>
<th>$y = \Delta \Gamma / \Gamma$</th>
<th>Striking feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^0$</td>
<td>0.474</td>
<td>0.997</td>
<td>Width difference</td>
</tr>
<tr>
<td>$B^0$</td>
<td>0.77</td>
<td>&lt;0.01</td>
<td>CP violation</td>
</tr>
<tr>
<td>$B^0_s$</td>
<td>27</td>
<td>0.15</td>
<td>Fast Oscillation</td>
</tr>
<tr>
<td>$D^0$</td>
<td>0.01</td>
<td>0.01</td>
<td>None</td>
</tr>
</tbody>
</table>

The $B^0_s$ system is characterized by the following standard model expectations:

- Very fast oscillation frequency.
- Small but observable (~10%) lifetime difference.
- Very small CP violation in the standard model.
Contrast this phenomenology with that of $B^0$ mesons.

$$\begin{align*}
|B^0\rangle &= |\bar{b}d\rangle \\
|\bar{B}^0\rangle &= |bd\rangle
\end{align*}$$

**Slow oscillation**

$\Delta m_d = 0.507 \pm 0.005$ ps$^{-1}$

$\Rightarrow$ Oscillation length $cT = 3.7$ mm

**Large Standard Model CP violation**

$$\beta = -\text{Arg} \left( \frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right)$$

$$\sin(2\beta) = 0.668 \pm 0.028$$

$$\begin{align*}
|B^0_s\rangle &= |\bar{b}s\rangle \\
|\bar{B}^0_s\rangle &= |bs\rangle
\end{align*}$$

**Fast oscillation**

$\Delta m_s \sim 18$ ps$^{-1}$

Oscillation length $cT = 110$ $\mu$m

**Zero Standard Model CP violation (almost)**

$$\beta_s = -\text{Arg} \left( \frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right)$$

$$\sin(2\beta_s) = 0.037 \pm 0.002$$

http://utfit.roma1.infn.it/
Tagger performance in $J/\psi\phi$ decays:

Dilution: $(27\pm4)\%$
Efficiency: $(50\pm1)\%$

Dilution: $(11\pm2)\%$
Efficiency: $(96\pm1)\%$
The quality of the Prediction of dilution Can be checked against the data:

We reconstruct a sample Of $B^\pm$ decays in which one knows the sign of the $B$ meson.

We then “predict” the sign of the meson and plot the predicted dilution vs the actual dilution.

Separately for $B^+$ and $B^-$

Scale (from lepton SVT this sample; take the difference $B^+/B^-$ as an uncertainty).