New Measurement of the $\mathcal{B}_s$ mixing phase at CDF II

Martin Heck, for the CDF II collaboration

KIT

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Outline

• Motivation
• Analysis Strategy
• Results
• Other CDF flavor results
• Conclusions and Outlook
Motivation

- One possible way of CP violation:
  - Interference of decays with and without mixing
  - Only for channels that are accessible for both particle/antiparticle
  - CP violation comes in phase $\beta_s$

- In SM $\beta_s$ is predicted to be small
  
  $$\beta_s^{SM} = \arg \left( -V_{ts} V_{tb}^* / V_{cs} V_{cb}^* \right) \approx 0.02$$

$\beta_s$ value in SM indistinguishable from 0 for us.

Significant measurement of phase $\Rightarrow$ New Physics!

Top quark dominant contribution.
Are there SuSy particles in the loop, too?
Status with 2.8 fb\(^{-1}\) of Tevatron data

Looked promising...

Confidence region instead of value + uncertainty, because of non-Gaussian uncertainty behavior

- β\(_s\) analysis often cited by SuSy papers, random examples:
  - Biggio, Calibbi, arXiv 1007.3750
  - Wang, Zu, Li, arXiv:1007.2944
  - Kubo, Lenz, arXiv:1007.0680
  - Altmannshofer et. al., arXiv:0909.1333

See [http://tevbwg.fnal.gov/](http://tevbwg.fnal.gov/)

Combination of

Abazov et al. D0 Collaboration

PRL 101, 241801 (2008)

CDF public note 9458
Analysis Strategy

- Measure
  - $B_s$ life time
  - Decay width $\Delta \Gamma$ difference between CP even and odd $B_s$
  - CP violation phase $\beta_s$

CDF public note 10206

Di-muon Trigger

NN Selection

CDF Run II Preliminary $L=5.2 \text{ fb}^{-1}$

Candidates per 0.02

Network output
multidimensional likelihood-fit

\[
f_s P_s(m | \sigma_m) P_s(t, \rho, \xi | D, \sigma_t) P_s(\sigma_t) P_s(D)
\]

Angles separate CP even and odd final states

\[
\rho = (\theta, \varphi, \psi)
\]

tagging flavour of initial $B_s$ state

Mass discriminate signal/background

Lifetime lifetime of each mass eigenstate

\[
\xi = \begin{cases} +1 & \text{for } B_s^+ \\ -1 & \text{for } B_s^- \end{cases} \text{ at production time}
\]
Reconstruct $B_s$ candidates in 5.2 fb$^{-1}$ of data triggered on a dimuon pattern with $J/\psi$ characteristics.

Combine kinematic and particle ID variables in neural network to enrich signal.

Chose cut based on simulation in such a way, that uncertainty on $\beta_s$ is minimized.

~6500 $B_s$ mesons compared with ~3150 in old analysis.
- Propagating $B_s$ mesons are almost CP eigenstates.
- This dominates the lifetime difference (think as well $K_{short}^-$, $K_{long}^+$)
- CP violation means, sometimes dominantly CP even decays in CP odd final state and vice versa (like $K_{long}^-$ decaying into 2 pions)

$\Rightarrow$ necessary to know CP value of final state.

CP even (light if no New Physics) states decay in S- or D-waves
CP odd (heavy) states decay in P-waves

This allows statistical discrimination by measuring the angular distribution ($\rho = (\theta, \phi, \psi)$)

$\Psi$: K angle in $\Phi$ rest frame

$\phi$: $\mu$ angle of projection to $\Phi$ plane in $J/\psi$ rest frame

$\theta$: $\mu$ angle relative to $z$ direction in $J/\psi$ rest frame
We are searching for effect in mixing. Tagging production flavor tells us, if mixing happened or not.

Tagging is possible due to two effects
1. dominant $b$ production is in bottom anti-bottom pairs
   -> find flavour of “opposite side” bottom
2. fragmentation means, the strange quark has usually a nearby kaon partner
   -> find the fragmentation partner on the “same side”

Output of flavour tagger
- flavour decision
- probability that the decision is correct

For the first time the CDF II same side kaon Tagger has been calibrated on data for this analysis.

Efficiency times Dilution$^2$ ($\varepsilon D^2$) is measured as $3.2 \pm 1.4\%$ (~reduced statistics)
Results

Lifetime and decay width difference

Assuming no CP violation, most precise single measurements

\[ \tau_s = 1.530 \pm 0.025 \text{ (stat)} \pm 0.012 \text{ (sys)} \text{ ps} \]

\[ \Delta \Gamma_s = 0.075 \pm 0.035 \text{ (stat)} \pm 0.01 \text{ (sys)} \text{ ps} \]
Polarization amplitudes

\[ |A_{\parallel}(0)|^2 = 0.231 \pm 0.014 \text{ (stat)} \pm 0.015 \text{ (syst)} \]

\[ |A_0(0)|^2 = 0.524 \pm 0.013 \text{ (stat)} \pm 0.015 \text{ (syst)} \]

\[ \Phi_\perp = 2.95 \pm 0.64 \text{ (stat)} \pm 0.07 \text{ (syst)} \]
CP violating phase

Allowed are $\beta_s$ [0.02, 0.52] or [1.08, 1.55] at 68% CL

Improvement in this analysis:
S-wave contributions with $B_s \to J/\psi K^+ K^-$ are included.

The effect of the contributions is as expected rather small, so old analysis still OK.

Improved agreement with standard model.
Other CDF Flavour Results

First measurement of polarization angles in $B_s \rightarrow \Phi\Phi$

Confirms puzzling behavior in $b \rightarrow s$ penguin polarizations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M \ [\text{GeV}/c^2]$</td>
<td>$5.3636 \pm 0.0012$</td>
</tr>
<tr>
<td>$\sigma \ [\text{GeV}/c^2]$</td>
<td>$0.0165 \pm 0.0011$</td>
</tr>
<tr>
<td>$f_b$</td>
<td>$0.381 \pm 0.030$</td>
</tr>
<tr>
<td>$b \ [c^2/\text{GeV}]$</td>
<td>$2.68 \pm 0.67$</td>
</tr>
<tr>
<td>$</td>
<td>A_0</td>
</tr>
<tr>
<td>$</td>
<td>A_\parallel</td>
</tr>
<tr>
<td>$\cos \delta_\parallel$</td>
<td>$-0.91^{+0.15}_{-0.13}$</td>
</tr>
<tr>
<td>$B$</td>
<td>$0.49^{+0.31}_{-0.26}$</td>
</tr>
</tbody>
</table>

CDF public note 10064
Updated measurement
B -> K^*\mu\mu
competitive B factory results

More details on this analysis and many more on

http://www-cdf.fnal.gov/physics/new/bottom/
Conclusion

- CP violation measurement updated with 5.2 fb\(^{-1}\)
- Tightened constraints in \(\beta_s\) space
  
  \([0.02, 0.52]\) or \([1.08, 1.55]\) at 68% CL
- Agreement with SM has increased
- Best measurement of
  - \(B_s\) life time
  - \(\Delta \Gamma_s\)
  - Polarization amplitudes

- Several other measurement
  - \(B_s \rightarrow \Phi \Phi\) polarization
  - \(B \rightarrow K^* \mu \mu\): \(A_{FB}(q^2 = 1 - 6\text{GeV}^2) = 0.43^{+0.36}_{-0.37}\) (stat) ± 0.06 (syst)
Outlook

- Possible further improvements with more data and channels: factor ~2-3

- $\beta_s$ measurement is one of the most promising B physics cases today (see as well D0 $A_{SL}$ measurement)
  
  => stay tuned for updates

- Update on $B_s \rightarrow \mu\mu$ is going to be ready soon.
Backup
One dimensional likelihood profile

CDF Run II Preliminary  
$L = 5.2 \text{ fb}^{-1}$

- **95% CL**
- **68% CL**
- SM prediction
Detector angular efficiency has to be taken into account to separate CP even and CP odd states by their decay angular distribution.

Use simulation to determine angular efficiency

Compare with background (expectation is flat primary distribution) 

==> simulation is in good agreement with background shape.