Experimental precision of $\sin 2\beta$ ($\sin 2\phi_1$) measurements

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What limits the precision of $\sin 2\beta$ measurements?

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What limits the precision of sin2β measurements?

*luminosity*

“*It’s the economy, stupid!*”

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James Carville
sin2\(\beta\) from charmonium modes

- **Extrapolation uncertainty**: asymptotic systematic error could be off by a factor of two either way (x0.5 or x2.0).

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\[ \sin^2 \beta_{\text{eff}} \text{ in } b \rightarrow s \text{ penguin modes} \]

- Uncertainty on CP of \( K^+K^-K_s \) included in statistical error.
- More difficult than charmonium to extrapolate systematic errors (next slide…)

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Limiting issues (?) for $b \to s$ penguin modes

- $\eta' K^0_S$ : Nothing special for this mode? Ultimate systematic error close to $J/\psi K_s$?

- $K^0_S K^0_S K^0_S$ : CP vertex measurement may suffer if machine backgrounds cause excessive occupancy in inner silicon? Efficiency will depend on design of detector…

- $\phi K^0_S$ and $K^+ K^- K^0_S$ : Dominant systematics are from uncertain CP content (S-wave contamination and average CP).
  - With super-B statistics, will do a time-dependent Dalitz analysis of the $K^+ K^- K_s$ system (e.g. $\rho \pi$). Systematic errors could reach 0.02 level?
Systematics common to all measurements

• **Beamspot location** \((\delta S \sim 0.01)\): Current techniques use constraint from (local) average beam position in \(\Delta t\) reconstruction.
  - *Essential for* \(K_s K_s K_s\) (theoretically pristine(?) mode) and single-track tag vertex events.
  - Unclear if this will improve in \(B \rightarrow \) super \(B\). May even get worse…

• **Silicon alignment and \(\Delta t\) resolution model** \((\delta S \sim 0.01)\):
  - Unlikely to improve much over today’s values
    - Randomness in tag vertex (long lived daughters) \(\rightarrow\) model dependence.
  - Si alignment depends on detector (and beam?) stability.
Another common systematic – Tag-side interference

• From $b \rightarrow c$ vs $b \rightarrow u$ interference on the tag side.

\[
\begin{align*}
&B^0 \quad \begin{array}{c}
\text{b} \\
\text{c}
\end{array} \quad D^+ \quad \pi^- \\
&\overline{A} \propto 1 \\
&B^0 \quad \begin{array}{c}
\bar{b} \\
\bar{u}
\end{array} \quad \pi^- \\
&A \propto r' \ e^{i(\gamma + \delta')}
\end{align*}
\]

• Small for sin2$\beta$ (S) due to 	extit{fortunately small} coefficient ($\delta S \ll 0.01$).

\[
S_{\text{fit}} \approx S_0 \left[ 1 - 2 \ r' \cos \delta' \left\{ \cos 2\beta \cos(2\beta + \gamma) + \mathcal{K} \sin 2\beta \sin(2\beta + \gamma) \right\} \right]
\]

\[
S_{\text{fit}} \approx S_0 \left[ 1 - 2 \ r' \cos \delta' \times (\approx -0.01) \right]
\]

• 	extit{Not} so small for direct CP term ($\delta A$ or $\delta C \sim 0.02$ to 0.03).

\[
C_{\text{fit}} \approx 2 \ r' \sin \gamma \sin \delta'
\]

\[
C_{\text{fit}} \approx 2 \ r' \sin \delta' \times (\approx 0.87)
\]

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Constraining tag-side interference

- Constrain the tag-side parameters with $D^*l \nu$
  - CP violation can only come from tag-side effect.
  - *Belle* $\sin(2\beta+\gamma)$ analysis already uses $D^*l \nu$ (PRL 93, 031802 (2004))

- Example of what could be done using $D^*l \nu$ constraint assuming measurements indicate $r' = 0$.

- Improvement of at least $x3$. Will probably go below $\delta C \sim 0.01$.

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Summary

• **sin2β from charmonium** will reach around $\sigma (\sin 2\beta) \approx 0.015$
  – Luminosity is *not* the limiting factor. Make life simple and work with the best events: $J/\psi K_s$ and lepton tags.

• **Control / understanding of beam position** should be kept in mind
  – Some modes could manage without beam constraint, for others it’s essential
  – We don’t want this to get significantly worse than current standards (~0.01)

• **b→s penguin modes** likely *will* be limited by statistics
  – Current major systematics should scale with statistics
  – Will the $KsKsKs$ mode suffer significantly in the new environment? Let’s hope not.

• **Tag-side interference** is an issue for the direct CP coefficient
  – Systematic can be significantly reduced by using constraints from $D^{*l}\nu$.

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