Extraction of γ from three-body B decays

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arXiv:1303.0846 with M. Imbeault and D. London.

Outline

- Motivation
- Theory
- Experiment
- Results
- Summary and Conclusions

Motivation

Conventional γ extraction methods: GLW, ADS, GGSZ ($B^{\pm} \to DK^{\pm}$)

- Clean weak phase information
- Sensitive to a small ratio of interfering amplitudes.
- Large error bars $\sim 10^{\circ}$

Can we do any better with three-body B decays?

Independent γ extraction : cross check!

Obstacles:

- Final CP eigenstate $\to$ Indirect CPV measurement!
  3-body final states such as $K_S\pi^+\pi^-$ are not CP eigenstates.
- How to treat decay amplitudes with two different weak phase terms?

These issues can be overcome: D. London & N. Rey Le Lorier, 1109.0881

Which decays to consider?

- Three-body $\overline{b} \to \overline{s}$ transitions : $B^{0,+} \to K(\pi\pi, KK)$
- Ignore final states with multiple neutral pions
- Ignore B^+ decays $\to$ No indirect CP Asymmetry
- Flavor-SU(3) symmetry : relate amplitudes, eliminate redundancy

Three-body transitions with available data: (from *BaBar*)

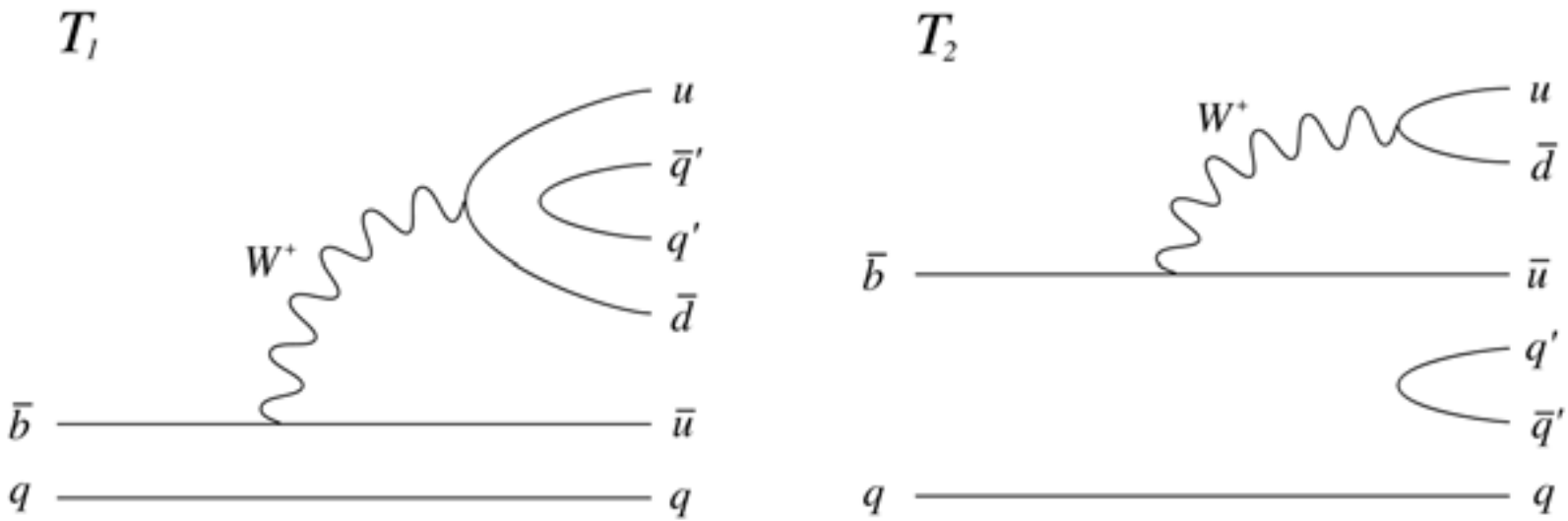
- $B^0 \to K_S\pi^+\pi^-$: *PRD* **80**, *112001 (2009)*
- $B^0 \to K^+\pi^-\pi^0$: *PRD* **83**, *112010 (2011)*
- $B^0 \to K_S K^+ K^-$: *PRD* **85**, *112010 (2012)*
- $B^0 \to K_S K_S K_S$: *PRD* **85**, *054023 (2012)*
- $B^+ \to K^+\pi^+\pi^-$: To estimate SU(3) breaking

Three-body Diagrammatics

- 2-body $\overline{b} \to \overline{s}$ transitions : T', C', P'_{tc}, P'_{uc}, P'_{EW} and P'^{C}_{EW}
- 2-body transition $\Rightarrow$ three-body transition : pop a $q\bar{q}$ pair

Two choices of popping :

- Subscript 1 : Between 2 non spectators
- Subscript 2 : Between spectator and a non spectator



Three-body topologies : T'_1, T'_2, C'_1, C'_2, ... (Now momentum dependent)

Effective diagrams

Effective diagrams : a, b, c, d; SU(3)-breaking parameter : $\alpha_{SU(3)}$

Neglect $P_{uc} \propto \lambda^2 \sim 0.04$; SU(3)-symmetric case : $|\alpha_{SU(3)}| = 1$

$$a \equiv -\tilde{P}'_{tc} + \kappa \left(\frac{2}{3} T'_1 + \frac{1}{3} C'_1 + \frac{1}{3} C'_2 \right) ,$$

$$b \equiv T'_1 + C'_2 , \quad c \equiv T'_2 + C'_1 , \quad d \equiv T'_1 + C'_1$$

$$\begin{aligned}
A(B^0 \to K^0 K^0 \overline{K}^0)_{\rm fs} &= \alpha_{SU(3)}\, a \\
\sqrt{2} A(B^0 \to K^+ K^0 K^-)_{\rm fs} &= \alpha_{SU(3)} \left(-a + \kappa\, b - c\, e^{i\gamma} \right) \\
2A(B^0 \to K^+ \pi^0 \pi^-)_{\rm fs} &= -\kappa\, c + b\, e^{i\gamma} \\
\sqrt{2} A(B^0 \to K^0 \pi^+ \pi^-)_{\rm fs} &= -a + \kappa\, d - d\, e^{i\gamma} \\
\sqrt{2} A(B^+ \to K^+ \pi^+ \pi^-)_{\rm fs} &= -a + \kappa\, b - c\, e^{i\gamma} \quad \texttt{(fs} \equiv \texttt{fully symmetric)}
\end{aligned}$$

For a given set of momenta $\to$ 8 unknowns (SU(3)-symmetric case)

Dalitz plots

Momentum dependent amplitudes $\leftrightarrow$ Dalitz plots

Isobar model : coefficients and phases from experiments $(s_{ij} = (p_i + p_j)^2)$

$$\mathcal{A}(s_{12}, s_{13}) = \mathcal{N} \sum_j c_j \; e^{i\theta_j} \; F_j(s_{12}, s_{23}) \; ; \qquad \sum_{i<j=1}^{3} s_{ij} = M_B^2 + \sum_{j=1}^{3} M_j^2$$

Fully symmetric amplitudes :

$$\mathcal{A}_{\rm fs}(s_{12}, s_{13}) = \frac{1}{\sqrt{6}} (\mathcal{A}(s_{12}, s_{13}) + \mathcal{A}(s_{13}, s_{12}) + \mathcal{A}(s_{12}, s_{23}) + \mathcal{A}(s_{23}, s_{12}) + \mathcal{A}(s_{23}, s_{13}) + \mathcal{A}(s_{13}, s_{23}))$$

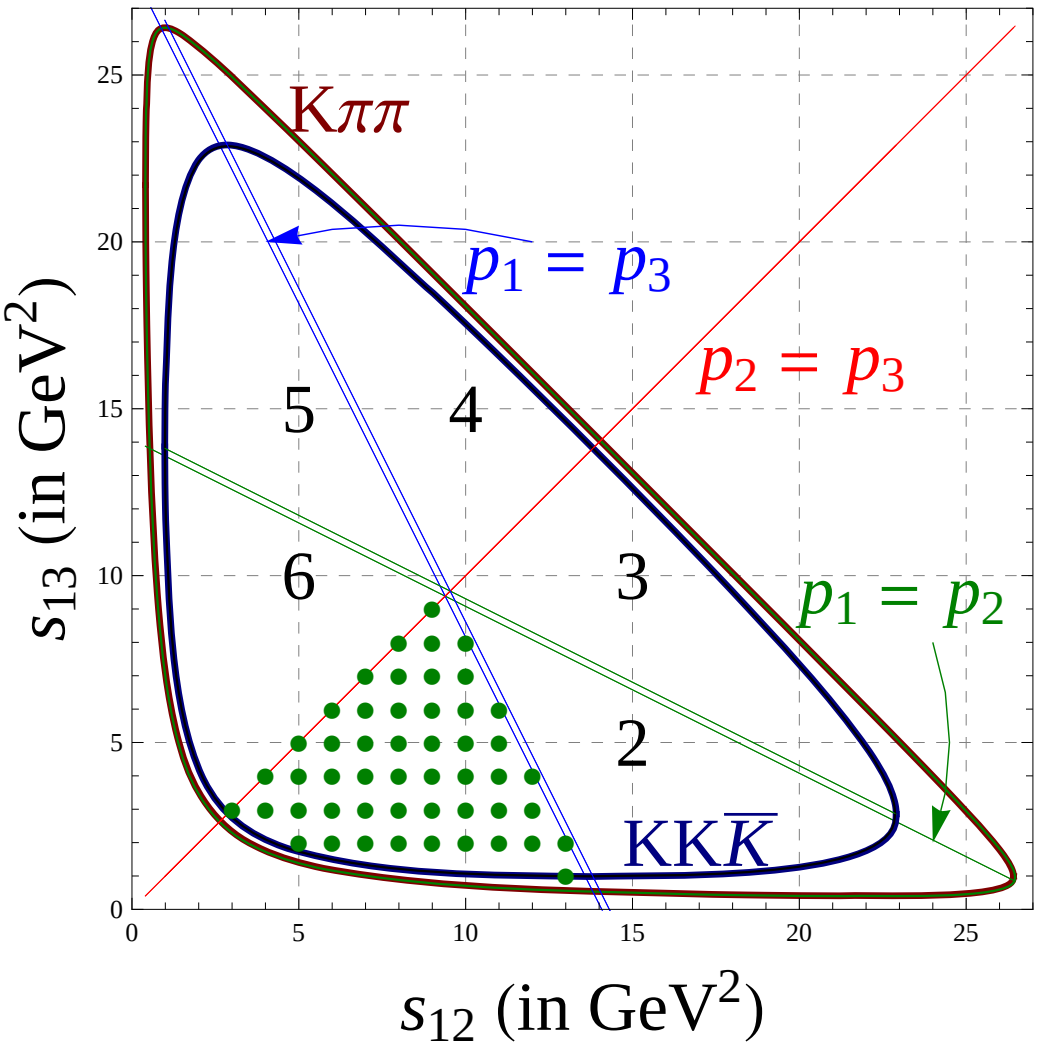
Observables constructed for a χ^2 fit :

$$X(s_{12}, s_{13}) = |\mathcal{A}_{\rm fs}(s_{12}, s_{13})|^2 + |\overline{\mathcal{A}}_{\rm fs}(s_{12}, s_{13})|^2 \quad \textit{CP averaged branching fraction}$$

$$Y(s_{12}, s_{13}) = |\mathcal{A}_{\rm fs}(s_{12}, s_{13})|^2 - |\overline{\mathcal{A}}_{\rm fs}(s_{12}, s_{13})|^2 \quad \textit{Direct CP asymmetry}$$

$$Z(s_{12}, s_{13}) = {\rm Im}\left(\mathcal{A}^*_{\rm fs}(s_{12}, s_{13}) \, \overline{\mathcal{A}}_{\rm fs}(s_{12}, s_{13})\right) \quad \textit{Indirect CP asymmetry}$$

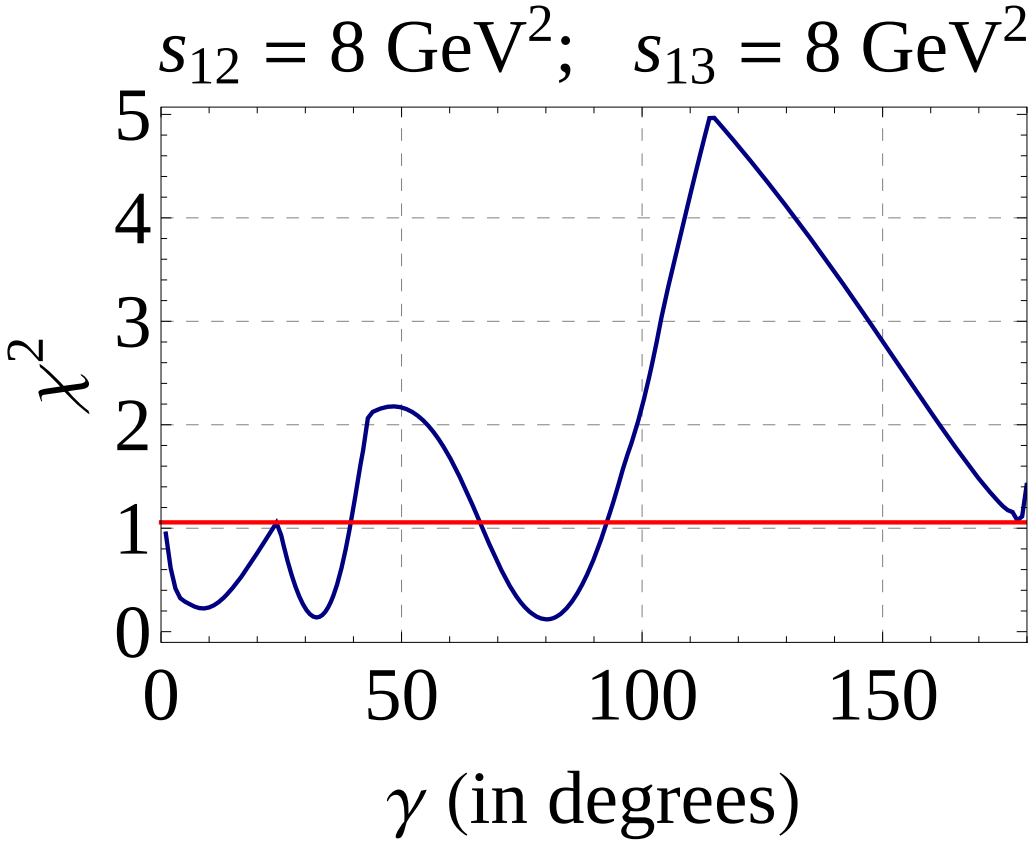
Dalitz plots



- Use $\frac{1}{6}$ of Dalitz plot
- 9 observables per point :
  $B^0 \to K^0\pi^+\pi^- : X, Y, Z$
  $B^0 \to K^0K^+K^- : X, Y, Z$
  $B^0 \to K^+\pi^-\pi^0 : X, Y$
  $B^0 \to K^0K^0\overline{K}^0 : X, \cancel{Y}, \cancel{Z}$
- 8 unknowns :
  4 magnitudes, 3 phases, γ
- χ^2_{min} fit to extract γ
- 50 points $\Rightarrow$ 50 independent γ measurements
- Combined likelihood maximization gives best fit value(s) of γ

χ^2 vs γ

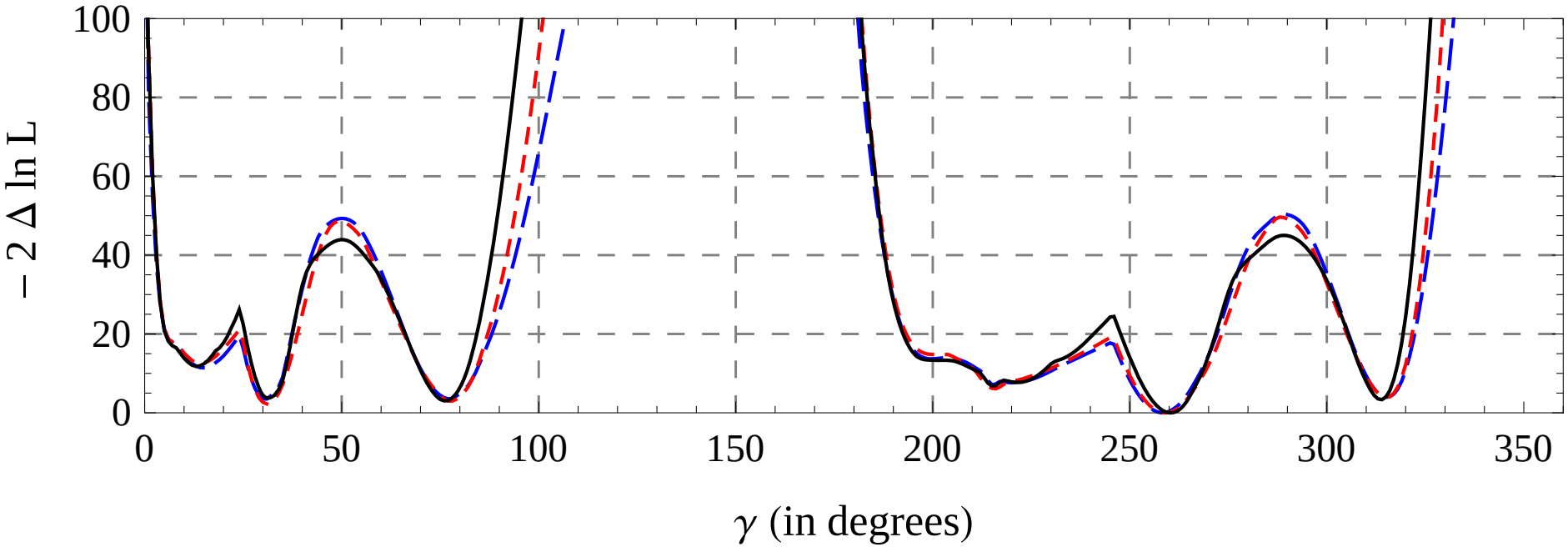
$\chi^2_{\rm min}$ as a function of γ for one of the Dalitz plot points:



- Multiple solutions for γ : discrete ambiguities
- Combine results from several points to remove discrete ambiguities

Maximum Likelihood

- 2 Δ ln L as a function of γ (all 50 points combined):



- 3 different maximum-likelihood fits:

  a) $|\alpha_{\mathbf{SU(3)}}| = \mathbf{1}$. b) $|\alpha_{SU(3)}|$ fixed at every point. c) Floating $|\alpha_{SU(3)}|$.

- Discrete ambiguity : $\left(31^{+2}_{-3}\right)^\circ, (\mathbf{77 \pm 3})^\circ, \left(258^{+4}_{-3}\right)^\circ, \left(315^{+3}_{-2}\right)^\circ$

- Most precise 2-body value from Belle (1301.2033) : $\left(68^{+\mathbf{15}}_{-\mathbf{14}}\right)^\circ$

Comments and caveats

- Errors quoted are statistical only; Systematic errors ~~large~~ small.
- Correlation between isobar coefficients may affect the error analysis
- M_π, M_K and other resonance masses break SU(3) : results from points near resonances or the boundary are susceptible to large SU(3) breaking
- $|\alpha_{SU(3)}|_{\rm avg} = 0.97 \pm 0.05 \Rightarrow$ SU(3) breaking is small
- 50 points chosen for fit. However, optimum number of points should be chosen depending on statistics available for the Dalitz plots
- An analysis of the complete experimental data set may be able to avoid many of these issues $\Rightarrow$ improve the analysis significantly and hopefully decrease the error bars on γ even further
- Successful in obtaining a modest value for γ using three-body B decays, but much work still remains to be done

Summary and Conclusions

- Combine multiple three-body B decays to extract γ with available data
  (Technique augments other independent ways of measuring γ)
- Each point on the Dalitz plot provides an independent γ measurement!
  Smaller statistical errors : Test for SM value of γ
- Solution consistent with GLW, ADS, GGSZ : $\gamma = (77 \pm 3)^\circ$
- Three others : $(31^{+2}_{-3})^\circ, (258^{+4}_{-3})^\circ, (315^{+3}_{-2})^\circ$
- SU(3)-breaking effects are small : $|\alpha_{SU(3)}|$ close to 1!
- Future Work :
  - How to distinguish between discrete ambiguities?
  - How to extend the technique to include non-fully-symmetric amplitudes?
  - Is there new physics in $b \to s$ transitions?