New Methods for getting at Alpha and Gamma

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Outline

- What are we Measuring
- Gamma – Tree-Tree Interference
- Alpha – Tree-Penguin Interference
- Conclusions

What are we Measuring

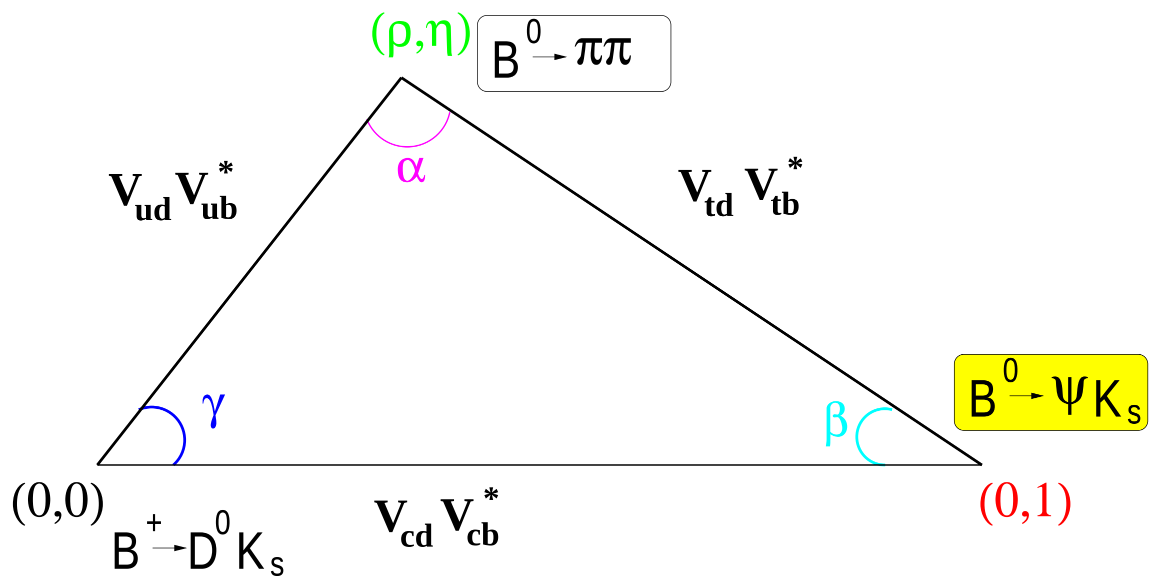
- The Standard Model predicts that V is unitary.

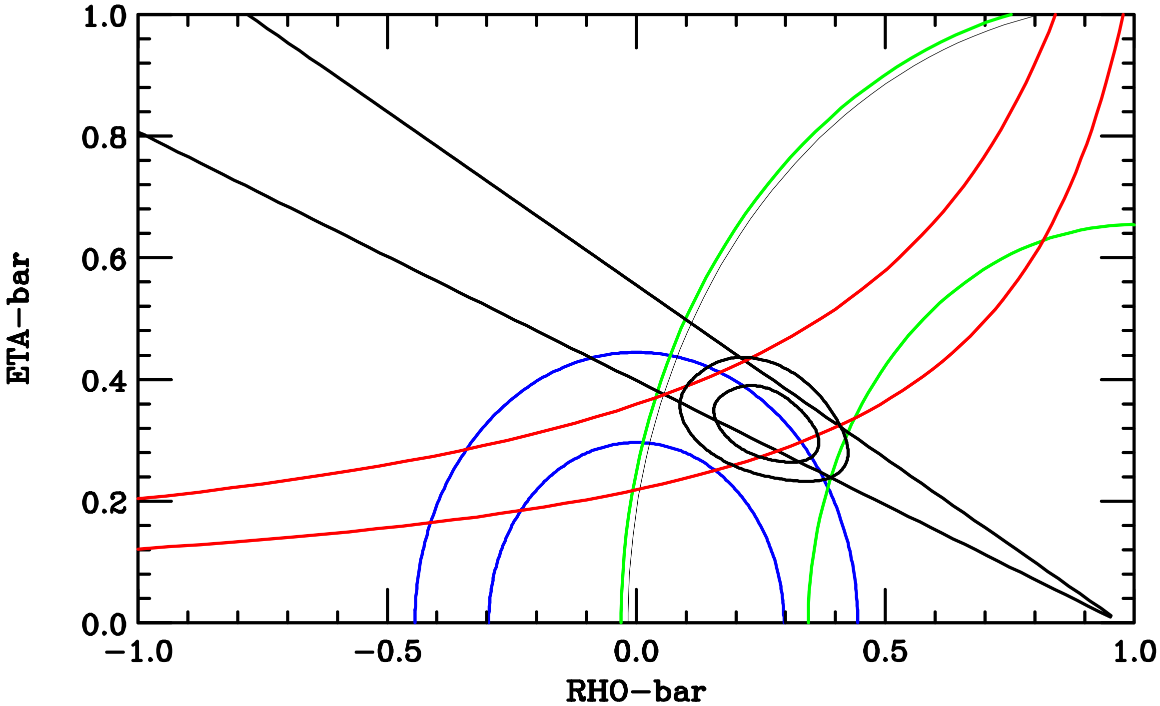
$$V = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$\begin{array}{c} V_{ud}V_{ub}^* \\ V_{cd}V_{cb}^* \\ \underline{V_{td}V_{tb}^*} \\ 0 \end{array}$$

- Unitarity relation:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



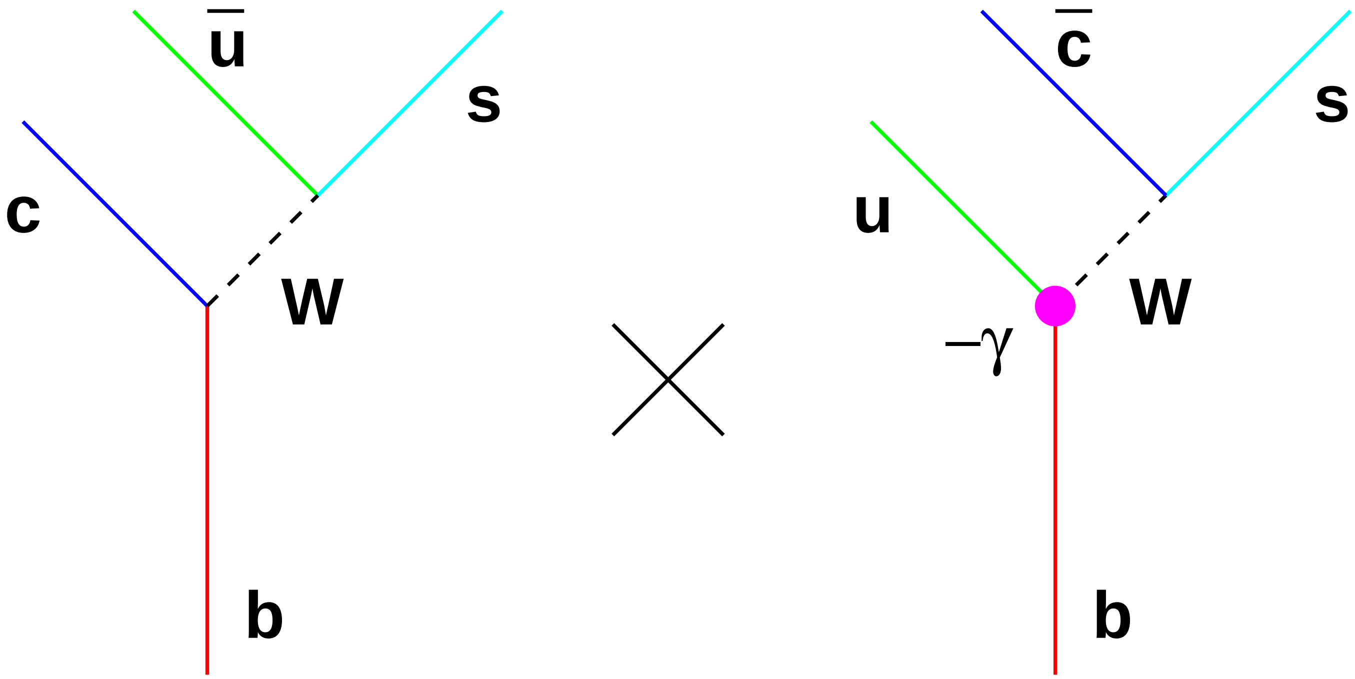


What do We Know so Far

- Experimental inputs:
    1. $K\bar{K}$ oscillation: ϵ_K.
    2. Rate of $b \to u$ transitions: V_{ub}/V_{cb}.
    3. The rate of $B\bar{B}$ oscillation.
    4. The lower bound on the rate of $B_s\bar{B}_s$ oscillation.
    5. Bound on $\sin 2\beta = 0.78 \pm .08$ from BaBaR and BELLE

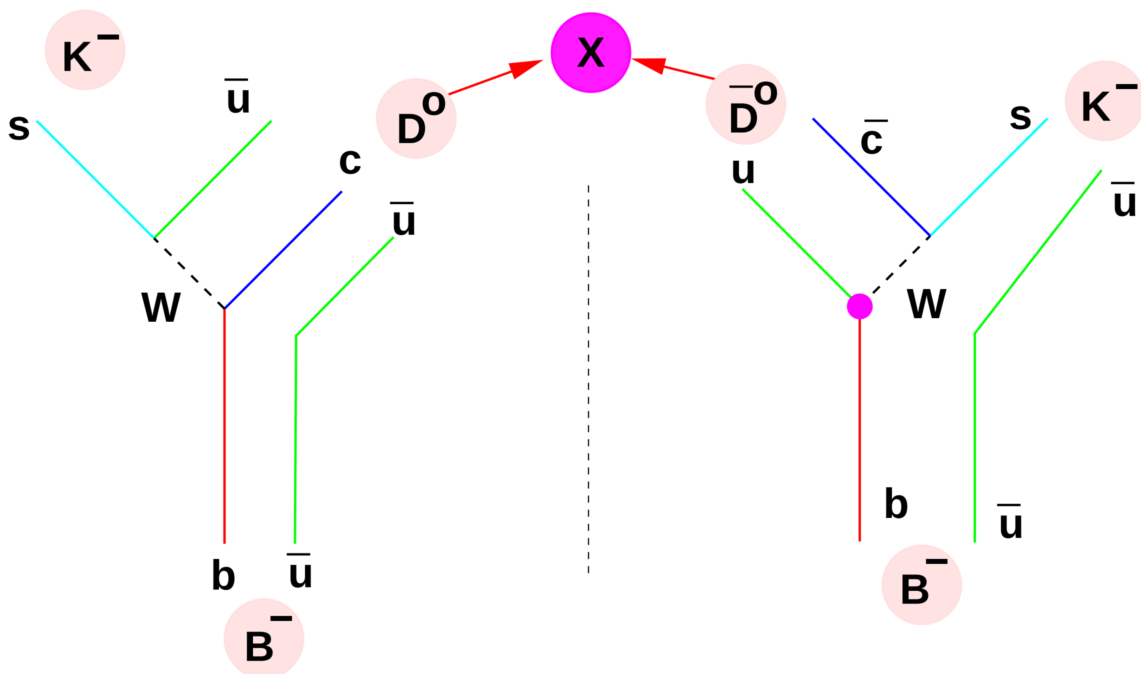
- 68% and 95% c.l. combined fit.

Tree-Tree Interference



- The interference of these two quark level diagrams is sensitive to the angle γ.
- In order for these two diagrams to interfere, the must be embedded in a meson level process with a common initial and final state.
- A determination of $B^- \to \bar{D}^0 K^-$ is hard. $B^- \to l^- \nu X$ is a background to $\bar{D}^0 \to l^- \nu + X$.
- Therefore at least two D^0 decay modes are required.

- $B^- \to D^0 K^-$ can interfere with $B^- \to \overline{D^0} K^-$ if the D^0 and $\overline{D^0}$ decay to a common final state (eg $K^+\pi^-$). [Gronau; DA Soni and Dunietz]

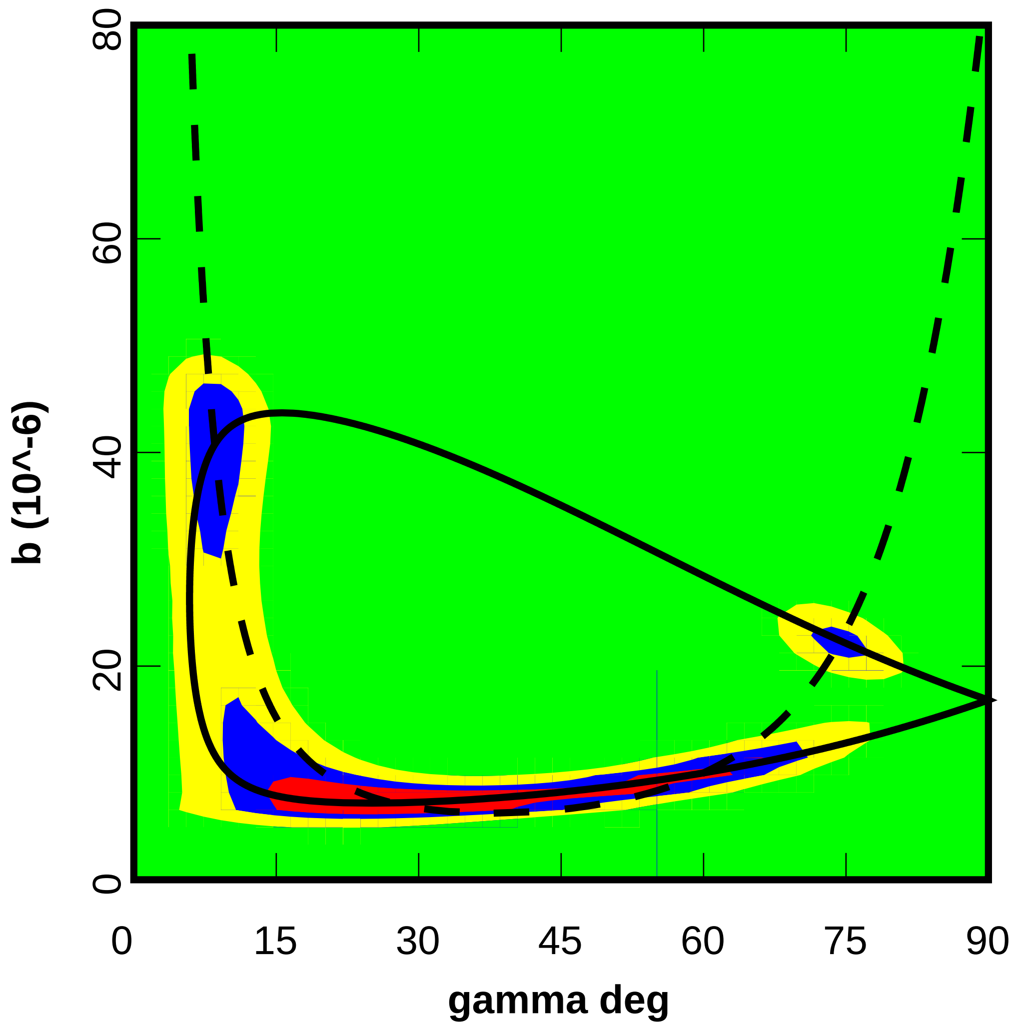


- Note, the CP asymmetries are expected to be large (O(100%): (color allowed)(DCS)≈(color suppressed)(CA)
- The same principle can be used in $B^0 \to D^0 K^0$. Here there is also oscillation.

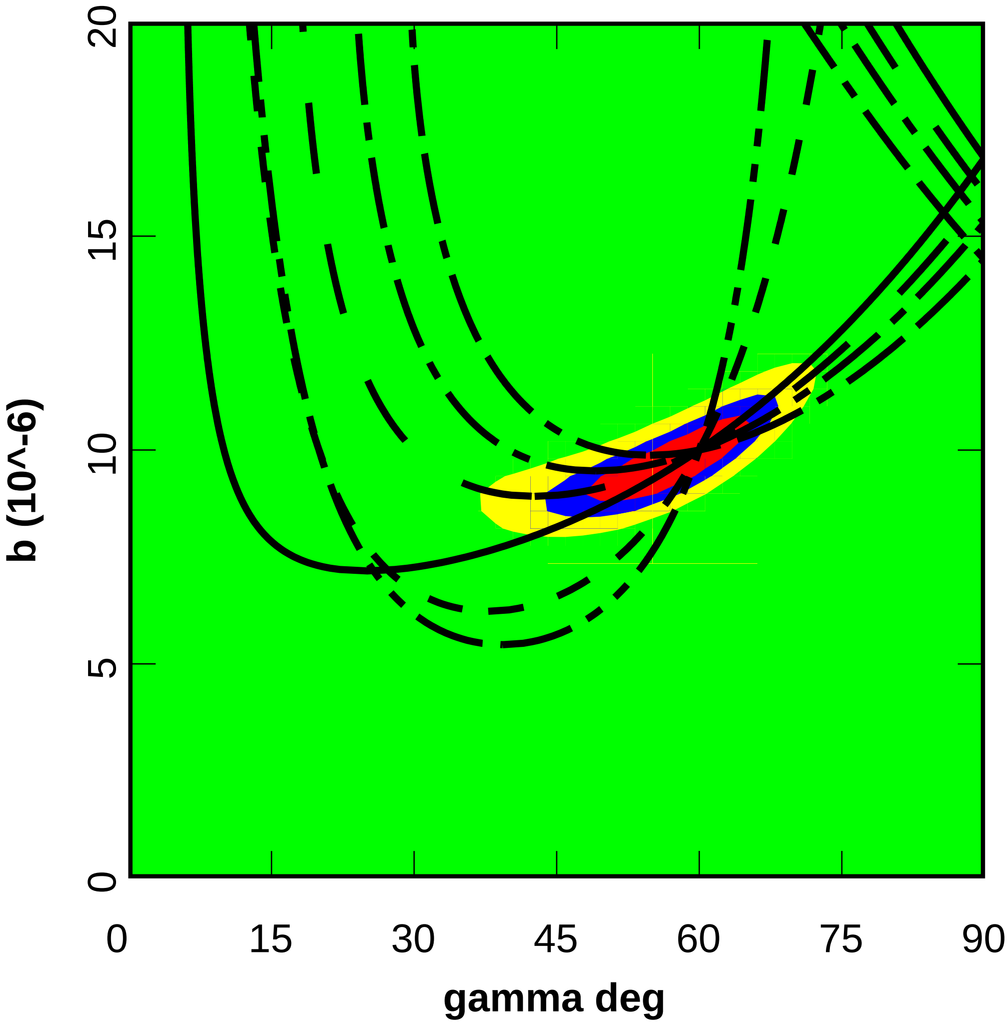
$B^- \to D^0 K^-$

- The key is to consider common decay mode of D^0 and $\overline{D^0}$ to allow interference. For instance $D^0 \to K^+\pi^-$ and $D^0 \to K_s\pi^0$.
- What you measure:
  - The base rate $B^- \to D^0 K^-$
  - The relevant D^0 branching ratios
  - The four rates
    - $B^- \to K^-(D^0 \to K^+\pi^-)$
    - $B^+ \to K^+(D^0 \to K^-\pi^+)$
    - $B^- \to K^-(D^0 \to K_s\pi^0)$
    - $B^+ \to K^+(D^0 \to K_s\pi^0)$
- What you need to solve for
  - The base rate $B^- \to \overline{D^0} K^-$
  - The net strong phases in each channel
  - The weak phase γ
- With two modes there is discrete ambiguity in γ, this is reduced if multiple modes are considered.

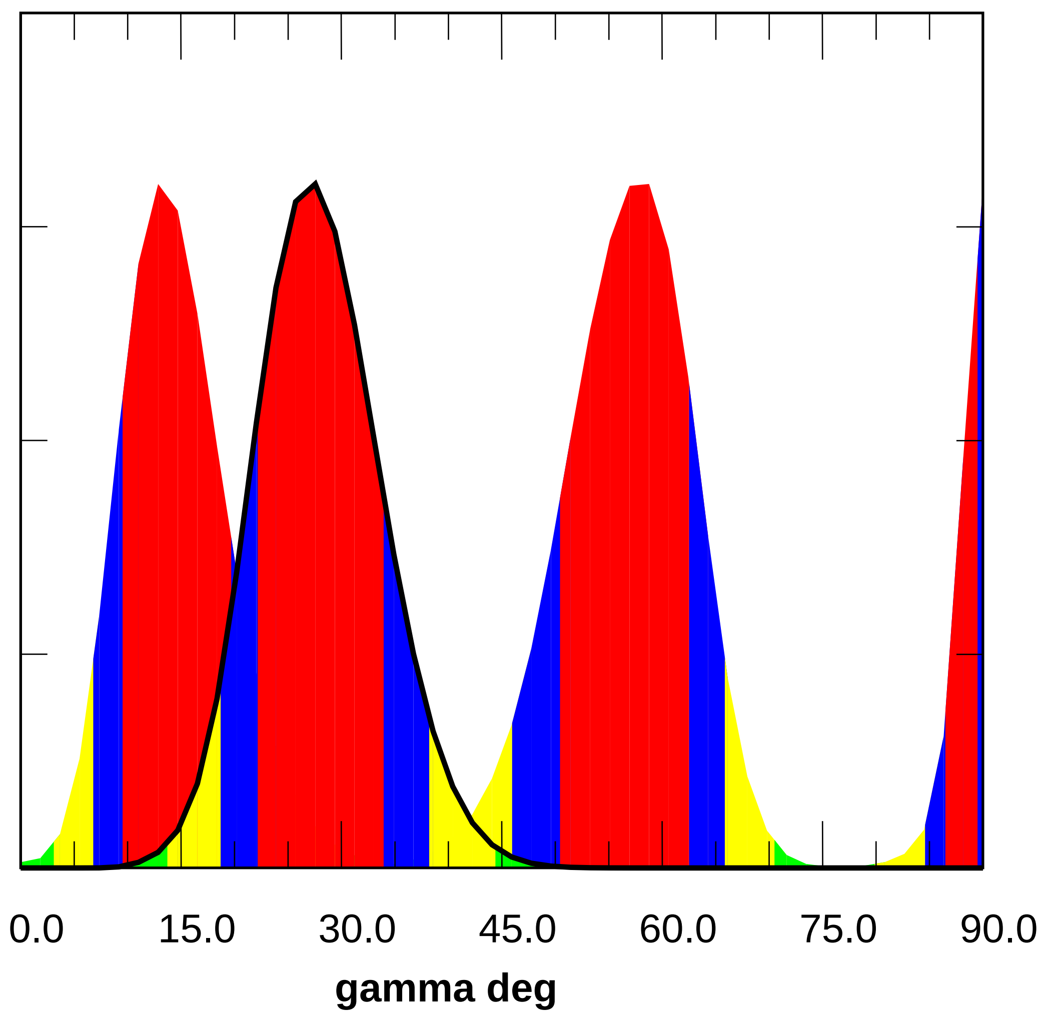
- Just two modes used:
  - $K^+\pi^-$ (solid)
  - $K_s\pi^0$ (short dashes)
- Confidence regions assuming that $N_B(acceptance) = 10^8$:
  99%; 90%; 68%



- All the modes used:
- $K^+\pi^-$ (solid) $K_s\pi^0$ (short dashes)
  $K^+\rho^-$ (long dashes) $K^+a_1^-$ (dash-dot)
  $K_s\rho^0$ (dash-dot-dot) $K^{*+}\pi^-$ (dash-dash-dot)
- Confidence regions assuming that $N_B(acceptance) = 10^8$:
  99%; 90%; 68%

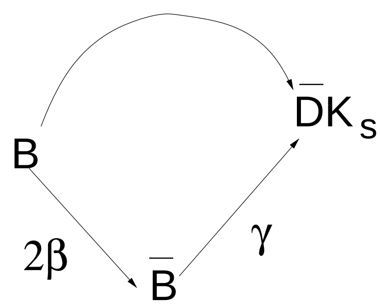


- Projecting the normalized likelihood distribution onto the γ axis in the cases where $\gamma = 15°; 30°; 60°$ and $90°$.
- Confidence regions assuming that $N_B(acceptance) = 10^8$: 99%; 90%; 68%

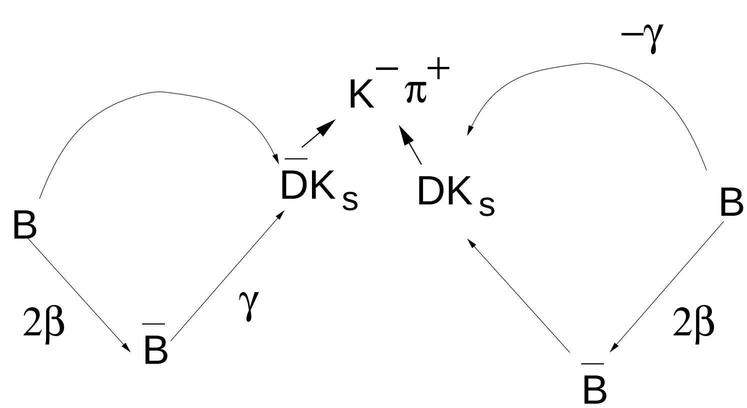


$B^0 \to D^0 K$ Case

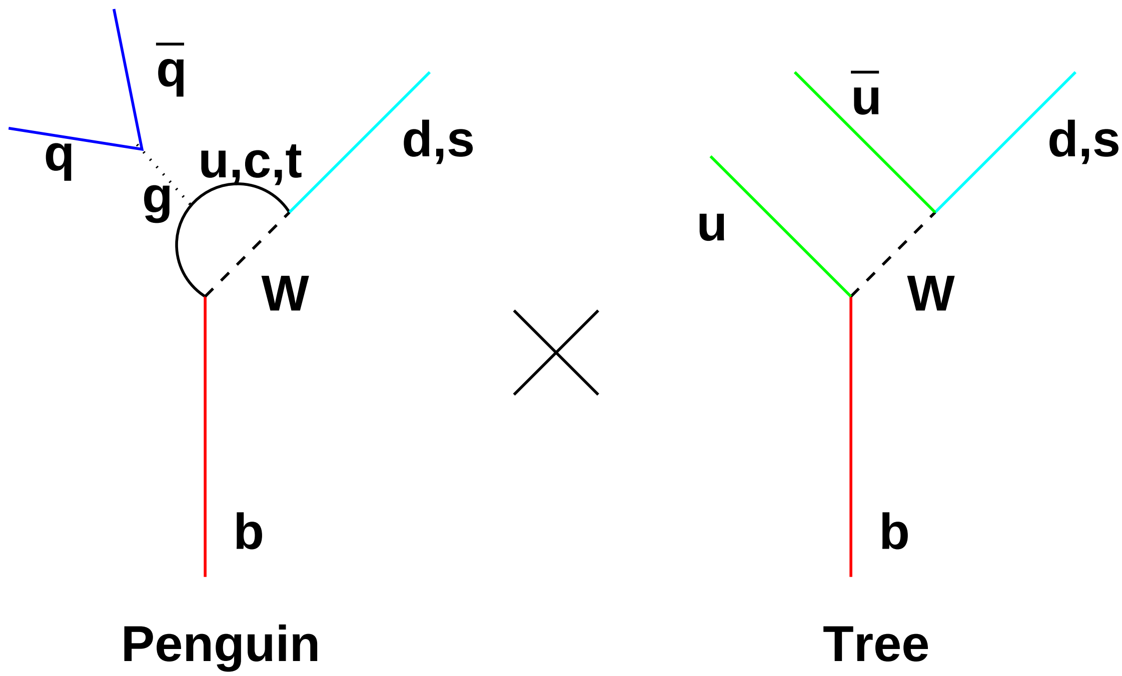
- The same method as above can be used in $B^0 \to D^0 K^{0*}$ if $K^{0*} \to K^+\pi^-$ (self tagging) [Dunietz].
- In the case $B^0 \to D^0 K_s$, the oscillation is proportional to $\sin(\beta - \alpha)$ [Bigi and Sanda; London and Kayser], however the D must be flavor tagged:
  - $D \to l\nu + X$: background
  - $D^{**} \to D^+\pi^-$: need to distinguish D_1 from D_2.
  - $D^0 \to K^-\pi^+$: quantum interference.



- However in the case of $D^0 \to K^-\pi^+$ both β and γ can in principle be extracted from the same data set [London Kayser]



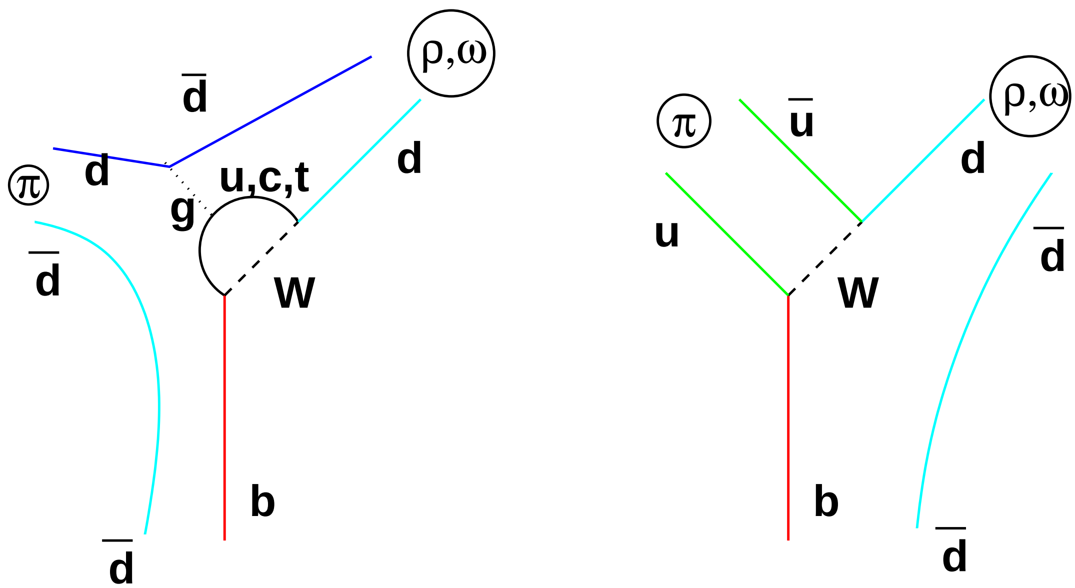
Tree-Penguin Interference



- The interference of these two quark level diagrams is sensitive to either α $(b \to d)$ or γ $(b \to s)$.
- Generally, some theoretical input is needed.
- ElectroWeak Penguins (i.e. Z or γ penguins) are also a danger. They have the weak phase of the penguin but the isospin properties of the tree.

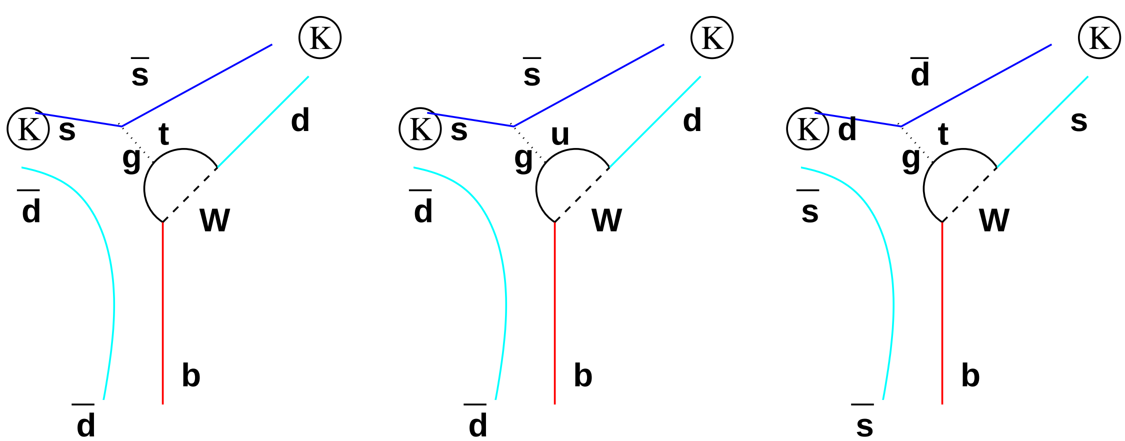
- Some Examples

  – Comparison of $B^0 \to \rho P$ with $B^0 \to \omega P$



  – Comparison of B_u, B_d and $B_s \to VV$ with pure penguin.

  – Comparison of $B^0 \to K\overline{K}$ versus $B_s \to K\overline{K}$ (see next talk)



$B^0 \to \rho/\omega \quad P$

- In this case, we need to use indirect CP violation in order to obtain enough information to solve for α.
- For a given final state f, the time dependent decay rate is:

$$\frac{1}{\Gamma_{B^0}}\frac{d\Gamma(f)}{d\tau} = \frac{1}{2}e^{-|\tau|}\left(X_f + bY_f\cos x_b\tau - bIm(Z_f)\sin x_b\tau\right)$$

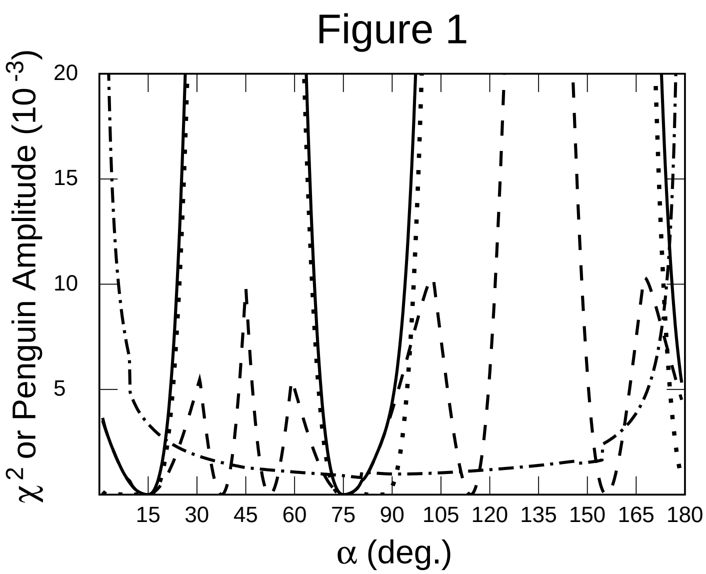
- $\tau = t\Gamma$, b=+1 (-1) for B^0 ($\overline{B^0}$) and $Re(Z_f)^2 = X_f^2 - Y_f^2 - Im(Z_f)^2$

$$\begin{aligned} X_f &= (|A_f|^2 + |\overline{A}_f|^2)/2 \\ Y_f &= (|A_f|^2 - |\overline{A}_f|^2)/2 \\ Z_f &= e^{-2i\beta}A_f^*\overline{A}_f \end{aligned}$$

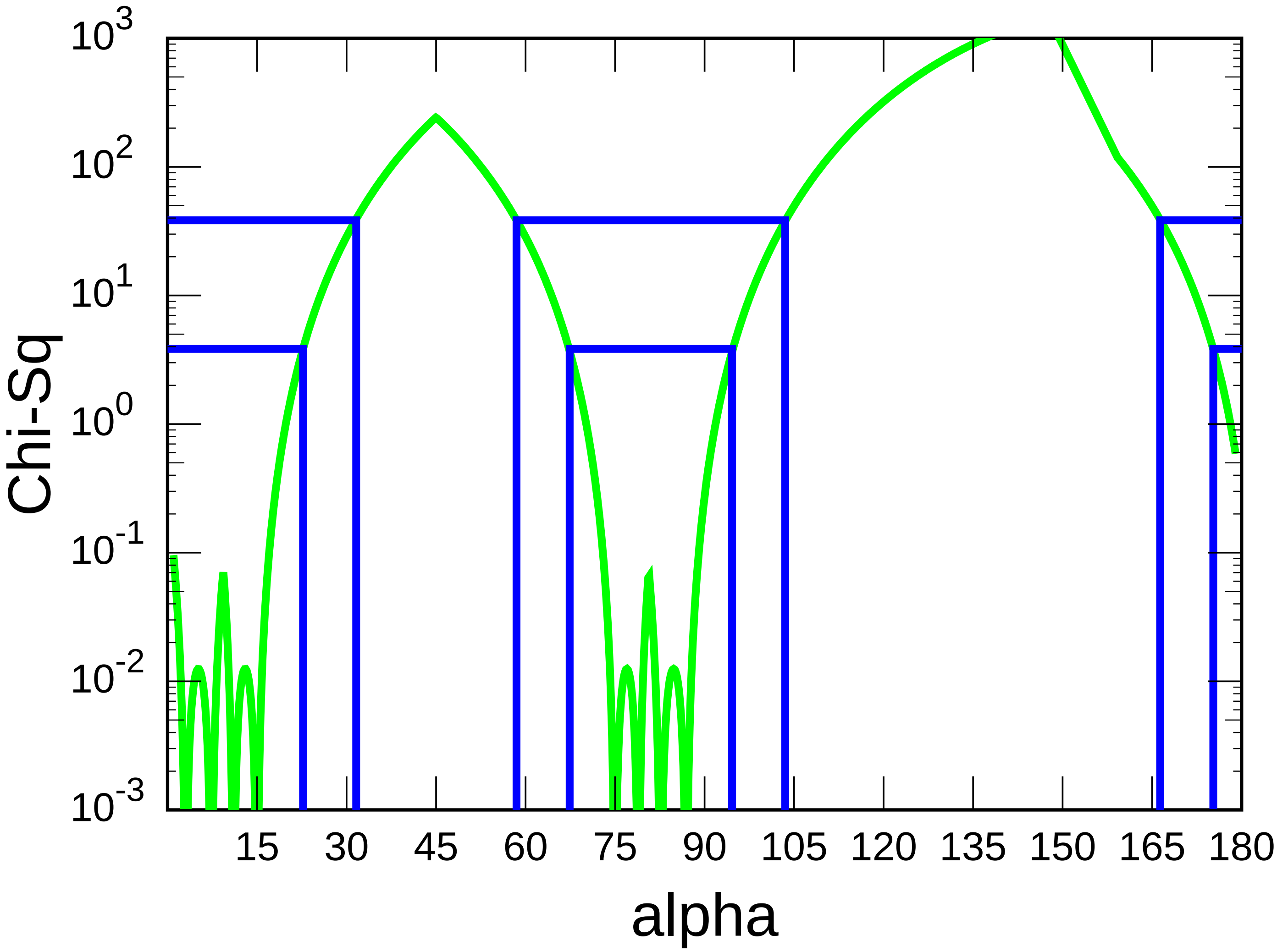
- If the ρP and ωP modes are measured, then one can eliminate the penguin and solve for α:

$$\alpha = \frac{1}{2}\left[\arg(Z_\rho - Z_\omega) \pm \cos^{-1}\left(\frac{X_\rho - X_\omega}{|Z_\rho - Z_\omega|}\right)\right] + \begin{cases} 0 \\ or \\ \pi \end{cases}$$

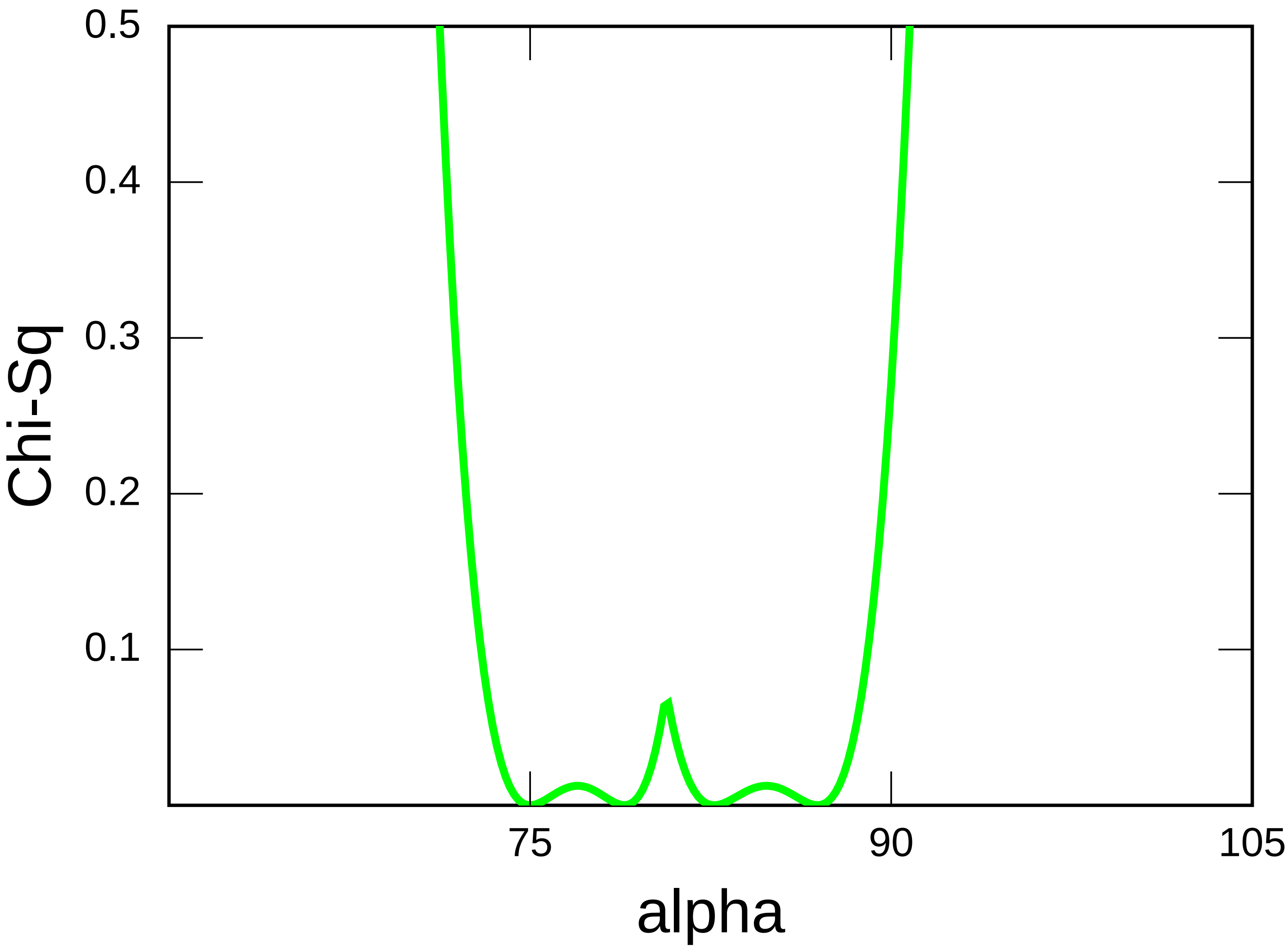
Figure 1: Using $N_B(acceptance) = 10^9$ The χ^2 function for the minimum χ^2 solution at various values of α is shown for the inputs given in eqn. (15) where the true value of $\alpha = 75°$. The $B^0 \to \rho/\omega\ \pi^0$ results are shown as a dashed curve, the $B^0 \to \rho/\omega\ \eta$ results are shown as a dotted curve while the sum is shown as a solid curve. The magnitude of the penguin for the minimum χ^2 solution is shown in units of 10^{-3} by the dot-dashed curve.



- As usual, multiple modes helps solve ambiguities.
- In this case, how well you can do depends crucially on how the ambiguous solutions are distributed.
- This method is complimentary to the $\rho\pi$ method of Quinn and Snyder.
  - Both involve the same amplitudes
  - ρ versus ω does not depend crucially on the phase structure of the Dalitz plot.
  - Snyder-Quinn provides a number of observables which can be important in resolving ambiguities

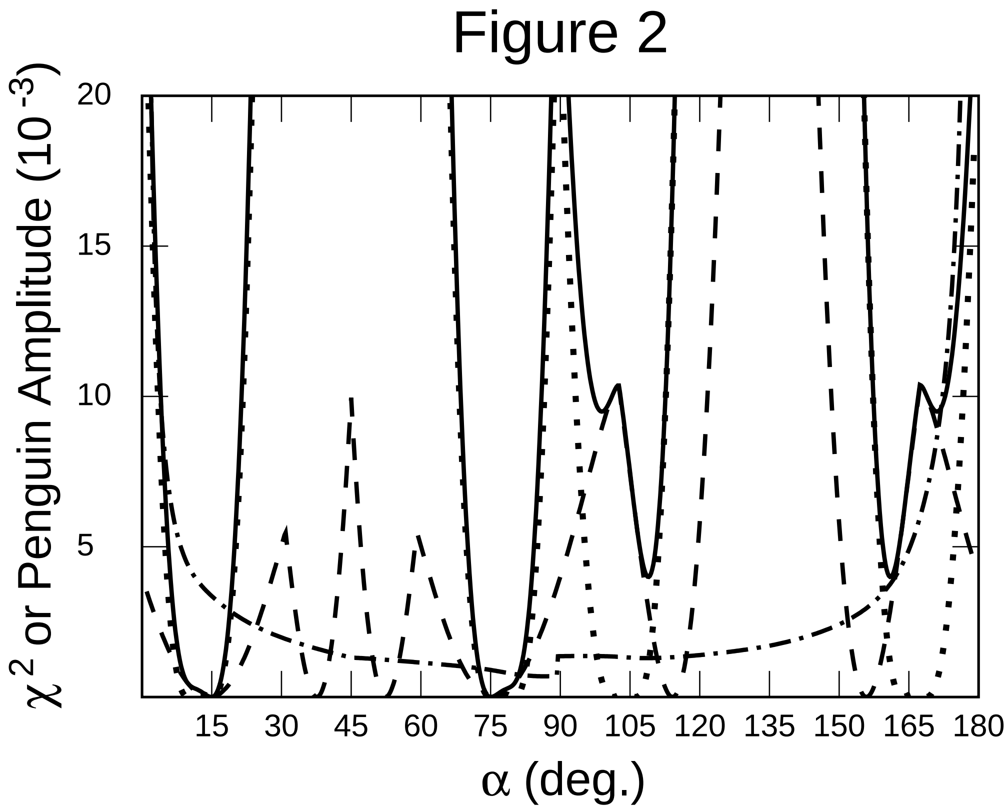


Chi-Sq
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
15
30
45
60
75
90
105
120
135
150
165
180
alpha



0.5
0.4
0.3
0.2
0.1
Chi-Sq
75
90
105
alpha

Figure 2: The χ^2 function and penguin amplitude as in Fig. 1 with $\alpha = 75°$ and the inputs as in eqn. (15) except with $\psi_p^\eta = 190°$.



Conclusions

- At $N_B \sim O(10^9)$, B factories can determine α and γ.
- It is crucial that the number of observables is greater than the number of parameters
- $B \to DK$
  - Free of Penguin Problems
  - Need several D decays
- $B \to \rho/\omega\ P$
  - Common penguin gives α
  - Time dependent
  - Several values of P need to be considered