Strategies For The Determination of ϕ_3 (γ) In $B^- \to DK^-$

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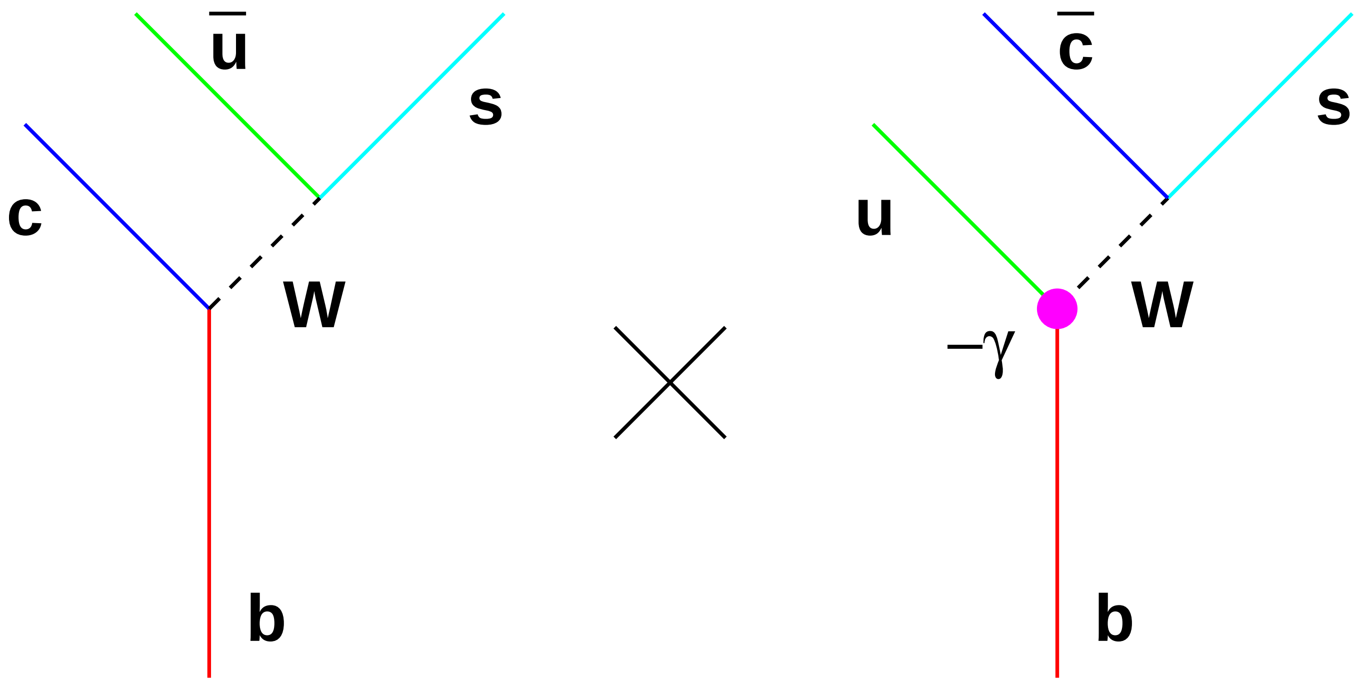
Outline

- What are we Measuring?
- The Basic Idea
- Methods to Extract γ: How well can we do?
  - A Single Two Body Mode
  - Two or More Two Body Modes
  - A Single Three Body Mode
- Impact of $D\overline{D}$ oscillations.
- Conclusions

What are We Measuring?

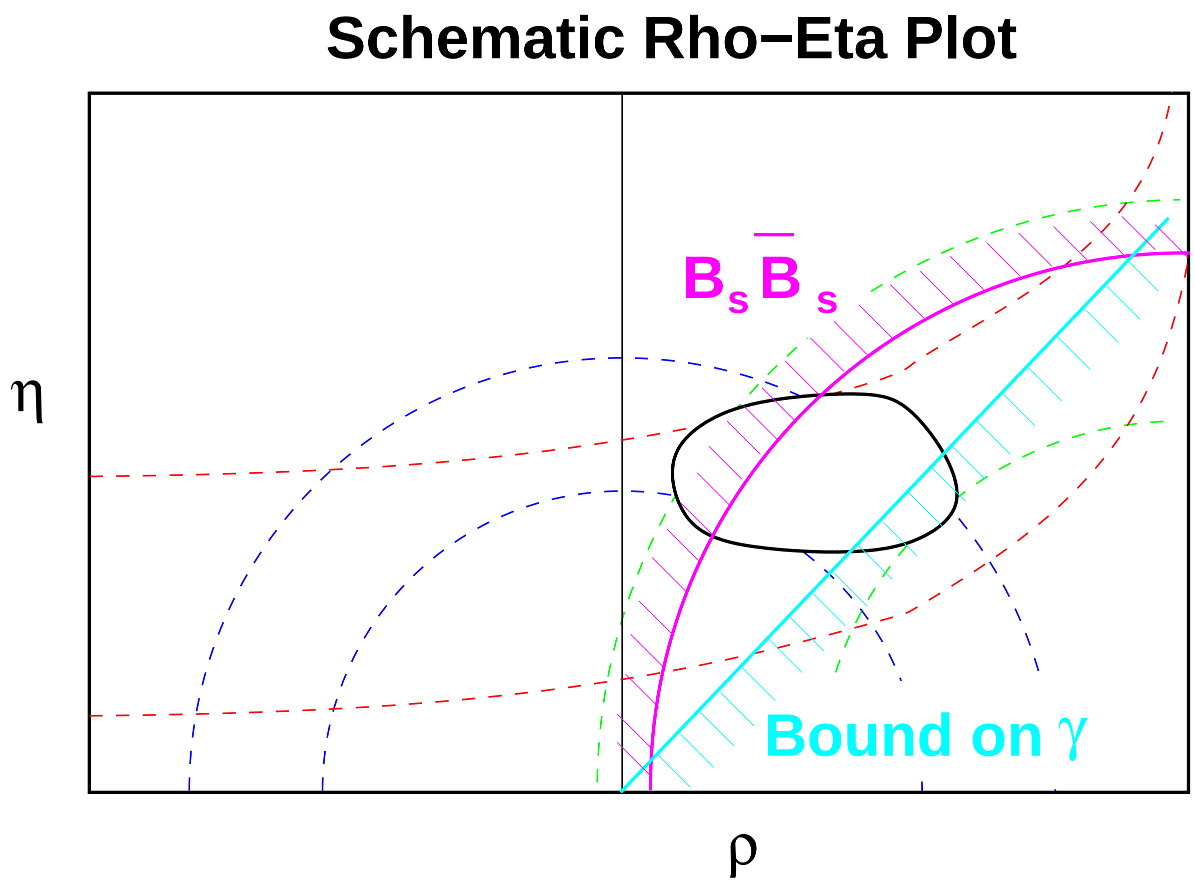
- We want to measure the CP odd phase difference between between $b \to \overline{u}cs$ and $b \to u\overline{c}s$.
- In the standard model, this phase is γ.
- For interference to occur:
  - Some trick must be used to match the initial and final states.
  - There must be a strong phase difference to produce manifest CP violation.



- CP violation implies lower bound on γ

Why is γ Important?

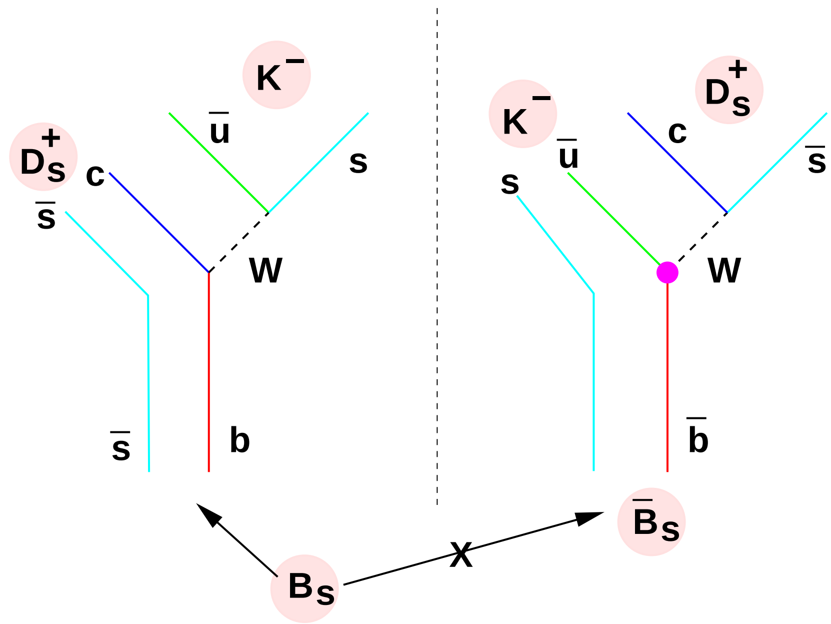
- Confirm or refute the standard model: The Standard Model predicts that all the CKM phases and magnitudes fit consistently into an unitary matrix. If this fails, the Standard Model with three generations must be extended.
- Observed CP violation will imply a lower bound on γ.
- Within the unitary triangle picture a **lower bound** on γ will be complimentary to the information from B_s oscillations.


Schematic Rho−Eta Plot
η
ρ
$B_s \bar{B}_s$
Bound on γ

The Basic Idea

- We need to dress up final and/or initial states to allow interference.
- There are two possible ways to do this
  1. $B_s/\overline{B}_s \to D_s^+ K^-$: Here B_s oscillation does the job.
  2. $B^- \to D^0/\overline{D}^0 K^-$: Interference will occur if a common D^0, $\overline{D}^0$ final state is observed (eg. $\pi^+\pi^-$). (**This talk**)

[Gronau, London, Wyler 91; DA Dunietz Soni 97]



K−
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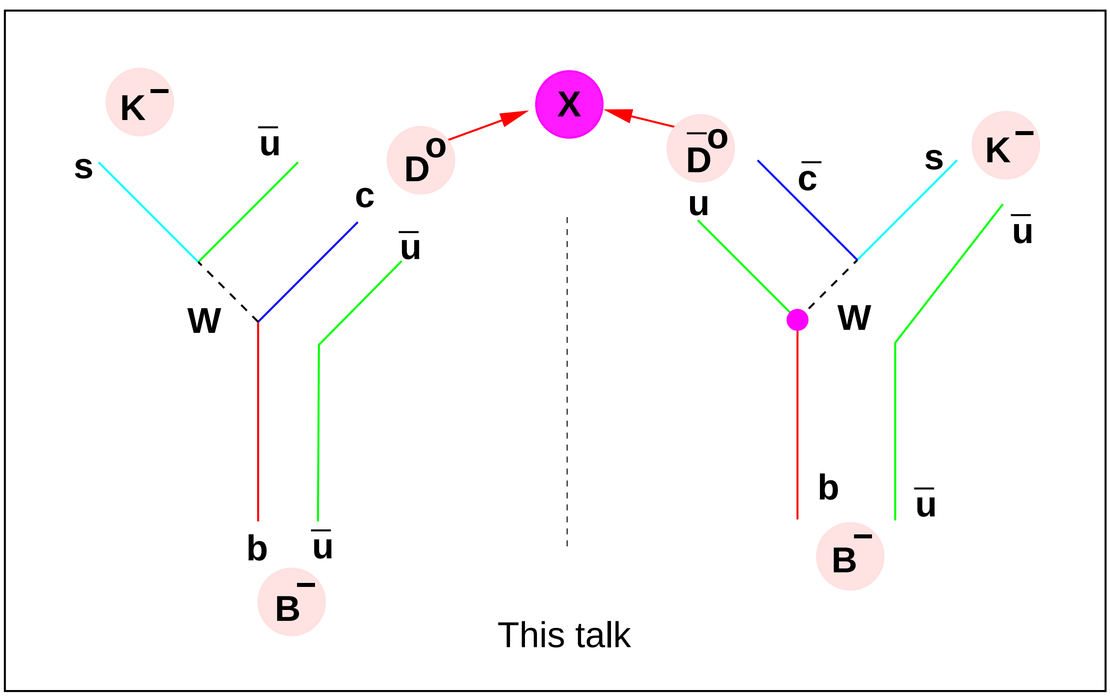

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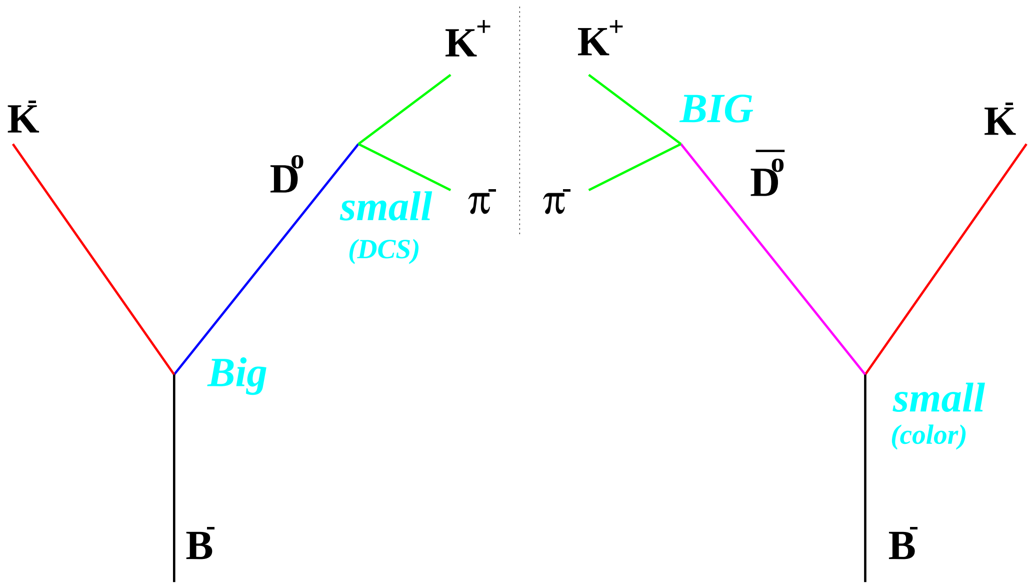
This talk

Common Final States

- In principle, any hadronic state is common to D^0 and $\overline{D}^0$.
- Each strategy to determine γ, needs overcome the following difficulties:
  1. $B^- \to D^0 K^-$ is about $100\times$ bigger than $B^- \to \overline{D}^0 K^-$
  2. It is probably not possible to measure $Br(B^- \to \overline{D}^0 K^-)$ independently.
- In all cases, one has to worry about the possibility of $D^0\overline{D}^0$ oscillations.

Why can't we measure Br($B^- \to \overline{D}^0 K^-$)?

- If the $\overline{D}^0$ decays hadronically, it will interfere quantum mechanically with the same decay mode of the D^0. (impossible)



- If the $\overline{D}^0$ decays semi-leptonically, it is subject to a $O(10^5)$ background from the direct semi-leptonic decay of the parent B^- to the same sign lepton. (difficult)

$$B^- \to K^-[\overline{D}^0 \to e^-\overline{\nu}_e + X]$$

versus

$$B^- \to e^-\overline{\nu}_e + X$$

Methods to Extract γ

- In this section, I will discuss the extraction of γ by using the following types of $D^0/\overline{D}^0$ decay modes:

  1. $D^0/\overline{D}^0$ to a single two body mode.
  2. $D^0/\overline{D}^0$ to two or more two body modes.
  3. $D^0/\overline{D}^0$ to a single three body final state.

$D^0/\overline{D}^0$ To A Single Two Body Mode.

- If only one $D^0/\overline{D}^0$ decay modes is observed, there is not enough information to determine γ, however if there is large CP violation, a restrictive lower bound may be placed on $\sin^2\gamma$.
- To enhance CP violation, it is best to consider states where $D^0 \to X$ is DCS and $\overline{D}^0 \to X$ is CA.

  [DA Dunietz Soni 1997, 2000]

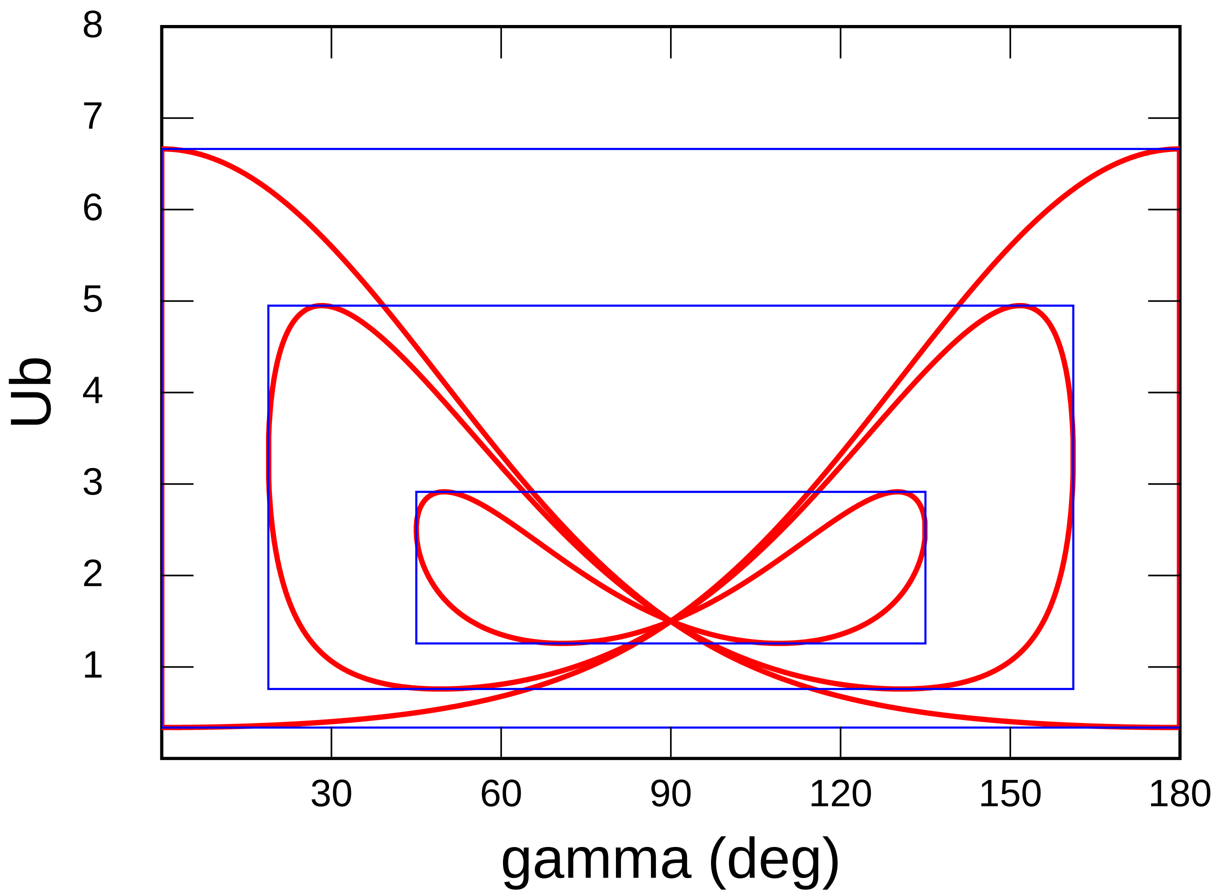
- In this case, the two channels have roughly equal magnitude giving potentially large CP asymmetries.

- The free parameters of the system are:
  1. γ, the total weak phase difference.
  2. ξ the total strong phase difference.
  3. The Branching ratio $a = Br(B^- \to K^- D^0)$.
  4. The branching ratio: $b = Br(B^- \to K^- \overline{D}^0)$.
  5. The branching Ratio $c = Br(D^0 \to X)$
  6. $\overline{c} = Br(\overline{D}^0 \to X)$
  7. The total rates $d = Br(B^- \to K^-[X])$ and $\overline{d} = Br(B^+ \to K^+[\overline{X}])$
- In addition d and $\overline{d}$ are each functions of $\{\gamma, \xi, a, b, c, \overline{c}\}$ so there are two equations in 3 unknowns $\to$ one parameter to nail down.
- Thus, given a set of observations, b is a function of γ (in fact $\sin^2\gamma$)

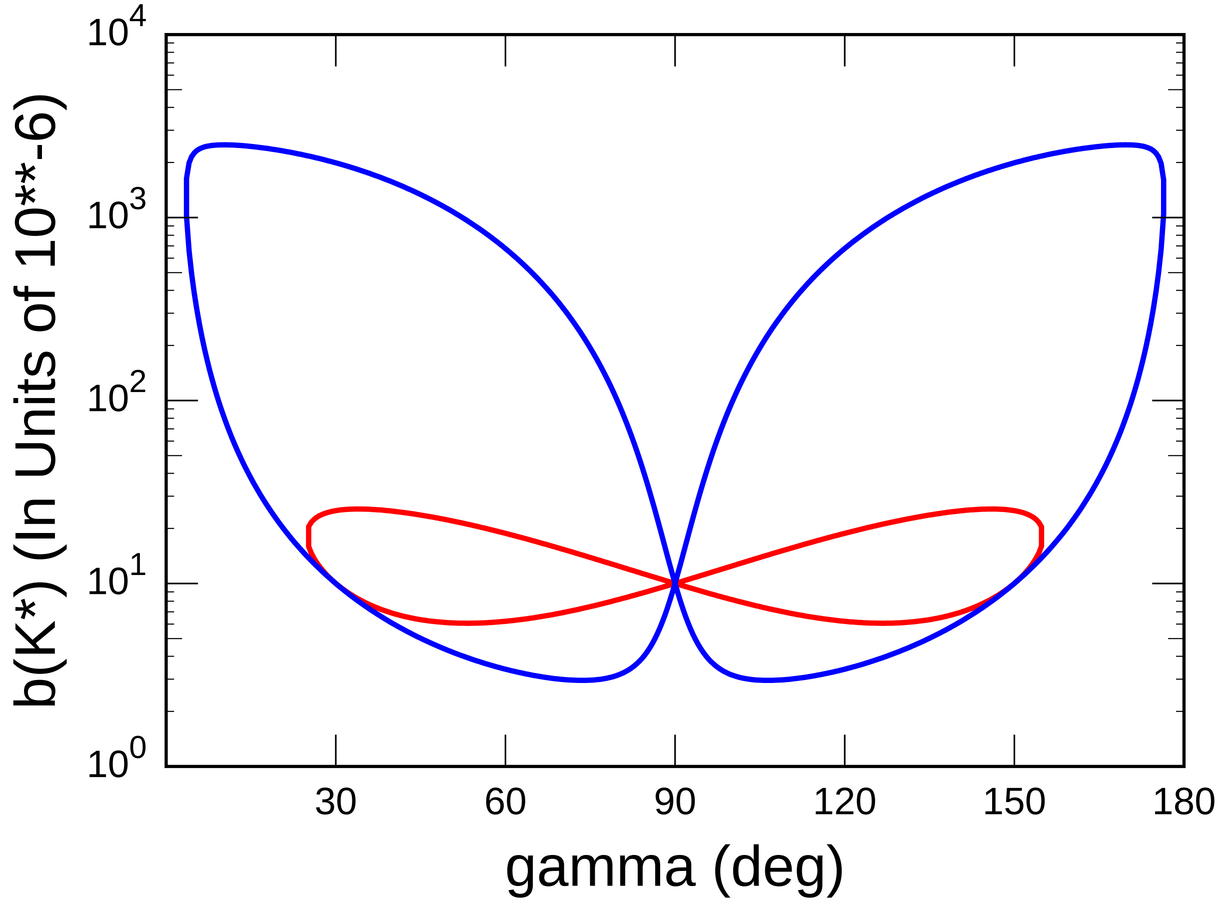
$$U^2 b^2 \sin^2\gamma - 2Ub(z + 2\cos^2\gamma)\sin^2\gamma + z^2\sin^2\gamma + y^2\cos^2\gamma = 0$$
$$U = (\overline{c}/ac); \qquad z = (d + \overline{d})/(2ac) - 1; \qquad y = (d - \overline{d})/(2ac).$$

- Larger CP violation results in a more restrictive lower bound on $\sin^2\gamma$ and more restrictive bounds on b:

$$\sin^2\gamma \geq \frac{1}{2}(1+z)(1 - \sqrt{1 - (y/(1+z))^2})$$
$$(1 - \sqrt{z + |y| + 1})^2 \leq u \leq (1 + \sqrt{z - |y| + 1})^2$$



- Here $z = 1.5$ while $y = 0,\ 1,\ 1.5$.
- Note that for a given value of b, the two angular branches are the strong phase and the weak phase.



- Numerical estimate for $B^- \to K^{*-}[D^0 \to X]$
  - Red is for $X = K^+\pi^-$
  - Blue is for $X = K_s\pi^0$

- Assuming:
  - $a(K^*) = 6.6 \times 10^{-4}$;
  - $b(K^*) = 1.0 \times 10^{-5}$
  - $\gamma = 90°$; $\xi = 30°$ for both modes.
  - Thus $d = 3 \times 10^{-7}$; $\bar{d} = 8.5 \times 10^{-7}$
  - $\alpha_{CP}(K^+\pi^-) = 0.47$ $\quad \alpha_{CP}(K_s\pi^0) = 0.12$

- In the above example, if $N_B/(acceptance) = 10^8$, then the 95% cl bound on γ is about $10°$ below the ideal bound.

$\xi°$	$\gamma°$	γ_{min} (95% cl)	γ_{min}
30	30	1.1	9.0
30	60	6.5	17.5
30	90	13.6	25.0
60	60	23.1	35.3
60	90	38.0	52.8
90	90	55.5	90

Possible methods to get around b

- Use many modes and take the best lower bound (see also 3 body case to follow)
- Use a model to estimate a range in b
- Check an analogous decay where cross channel interference is smaller: $\overline{B}^0 \to K^*[\overline{D}^0 \to K^+\pi^-]$; $\Lambda_b \to \Lambda[\overline{D}^0 \to K^+\pi^-]$ where the cross channel interference should only be $\sim 30\%$: can bound b to a possibly useful range.
- Use a two or more of quasi-two body modes simultaneously $\to$ see next.

Two or More Two Body Modes

- The data from two different modes will in general intersect in 4 points in the $\gamma - b$ plane.
- Three or more modes will, in general, intersect only at the correct point — the strong phases can be read off of the other branches of the curves.
- For a sample calculation I will feed in the following randomly selected strong phases:

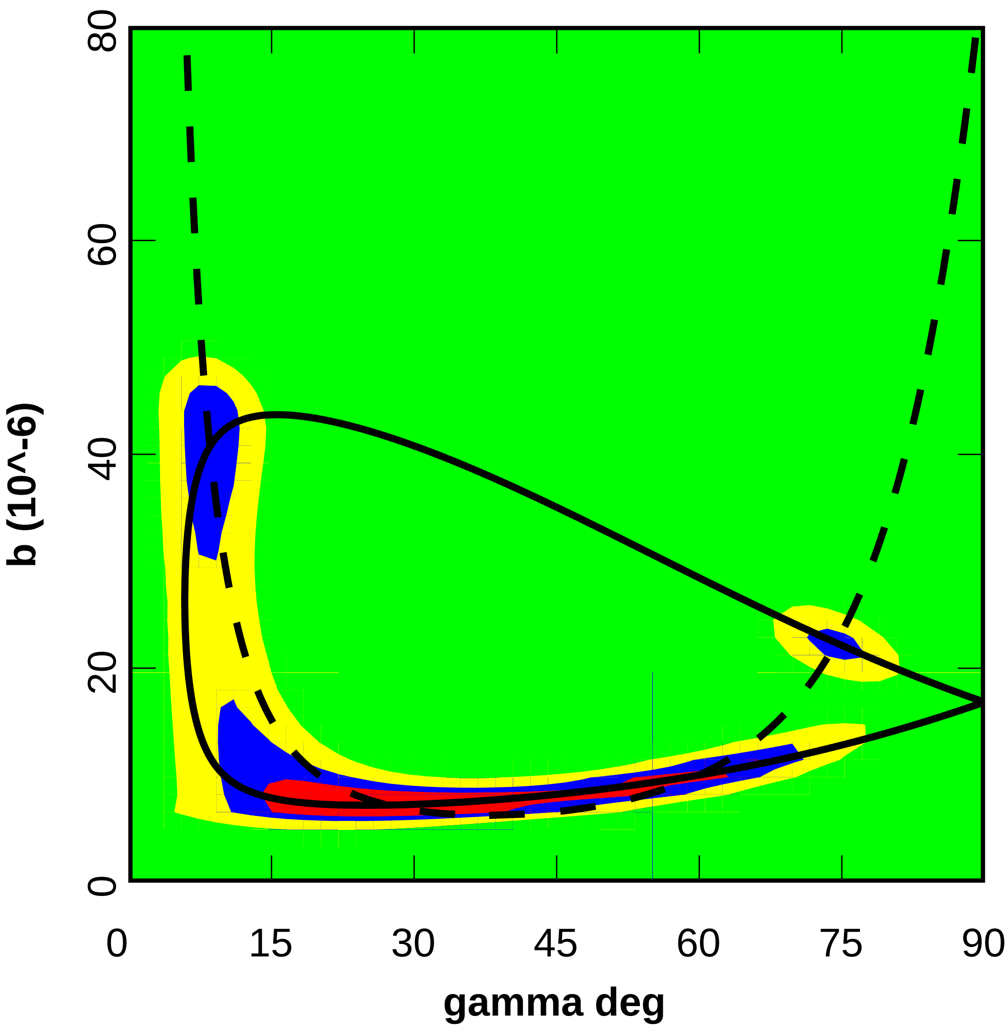
$a(K^*) = 6.6 \times 10^{-4}$ $b(K^*) = 1.0 \times 10^{-5}$

Mode	$Br(D^0 \to \text{final state})$	$Br(\overline{D}^0 \to \text{final state})$
$K^+\pi^-$	$(2.9 \pm 1.4) \times 10^{-4}$	3.83×10^{-2}
$K^+\rho^-$	3.8×10^{-4}	10.8×10^{-2}
$K^+a_1^-$	7.0×10^{-5}	7.3×10^{-2}
$K^{*+}\pi^-$	8.3×10^{-4}	5.0×10^{-2}

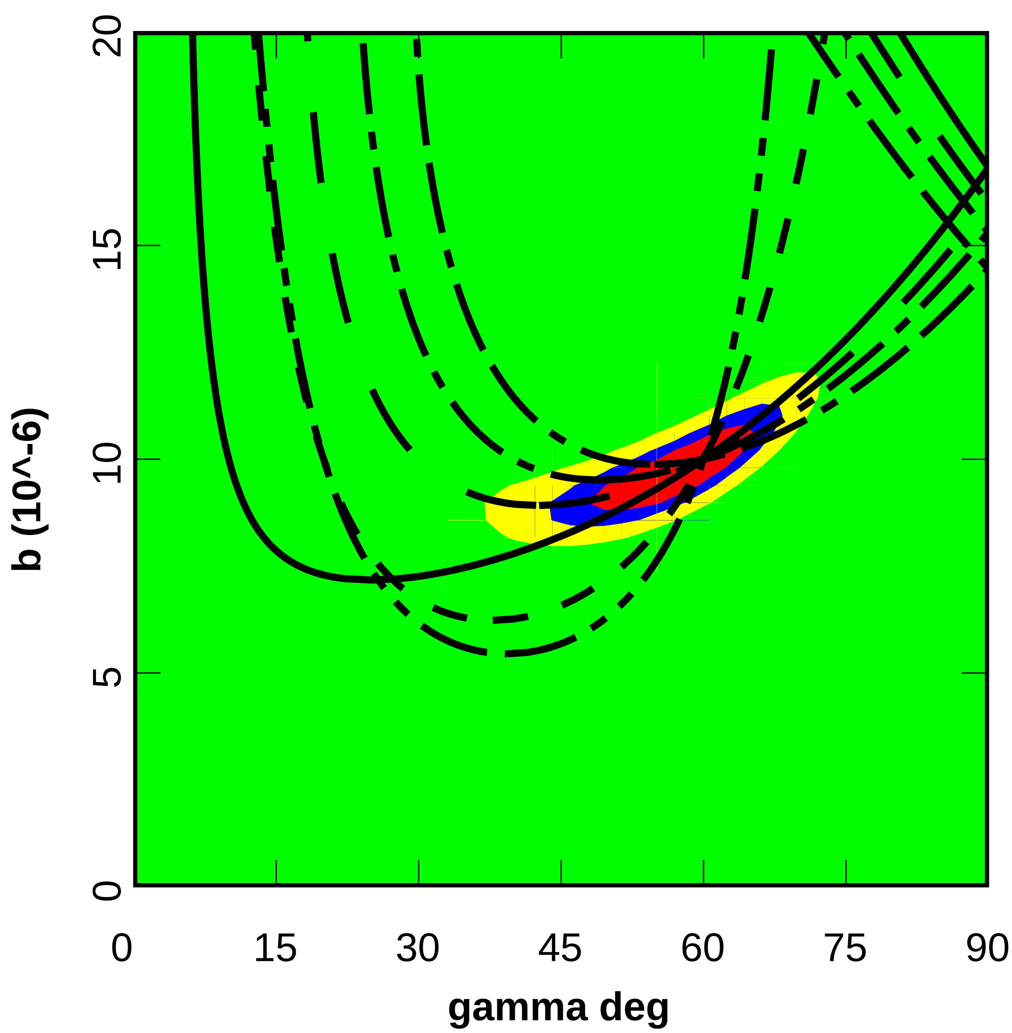
Branching ratios in units of 10^{-8}

Mode	d_i	$\overline{d_i}$	$\frac{1}{2}(d_i + \overline{d_i})$	α'	ξ_i
$K^+\pi^-$	91	75	83	0.096	10
$K_s\pi^0$	842	740	791	0.064	20
$K^+\rho^-$	289	159	224	0.288	30
$K^+a_1^-$	203	90	146	0.383	40
$K_s\rho^0$	333	391	362	0.081	200
$K^{*+}\pi^-$	97	34	65	0.477	50

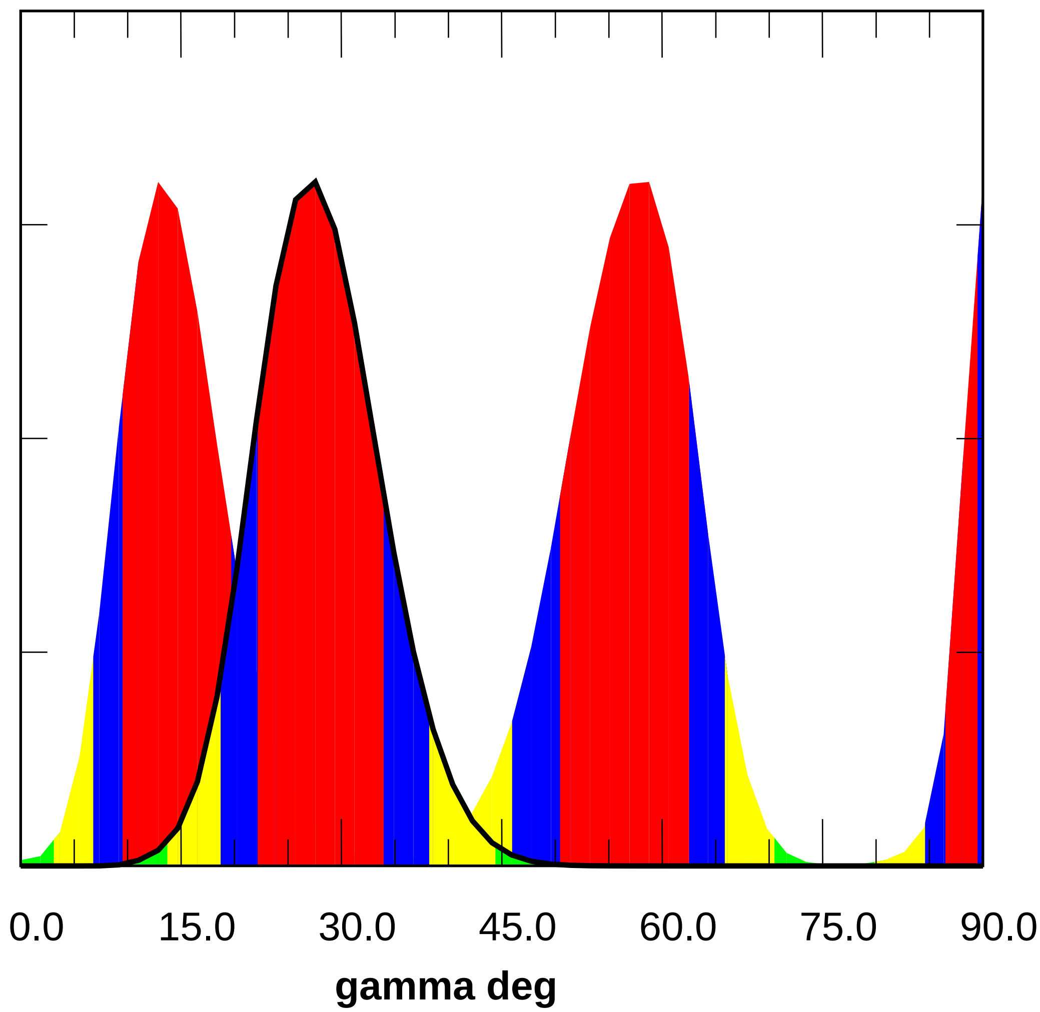
- Just two modes used:
  - $K^+\pi^-$ (solid)
  - $K_s\pi^0$ (short dashes)
- Confidence regions assuming that $N_B/acceptance = 10^8$: 99%; 90%; 68%



- All the modes used:
- $K^+\pi^-$ (solid) $\quad$ $K_s\pi^0$ (short dashes)
  $K^+\rho^-$ (long dashes) $\quad$ $K^+a_1^-$ (dash-dot)
  $K_s\rho^0$ (dash-dot-dot) $\quad$ $K^{*+}\pi^-$ (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%



What States Can be Used?

- One can change D^0 to any excited D^{0*} state
- One can change K^{-*} to any excited K^{-*} state
- The same analysis applies if there is only one amplitude.
- If there are multiple amplitudes (D^*K^*) one can consider angular momentum analysis of the decay. [Sinha and Sinha 98]
- Each combo must be placed on a separate $\gamma - b$ plot.
- If you assume that $Br(B^- \to \overline{D}^0 K^{*-}) = Br(\overline{B}^0 \to \overline{D}^0 K^{*0})$ then we can also include B^0 decays on the same $\gamma - b$ plot.

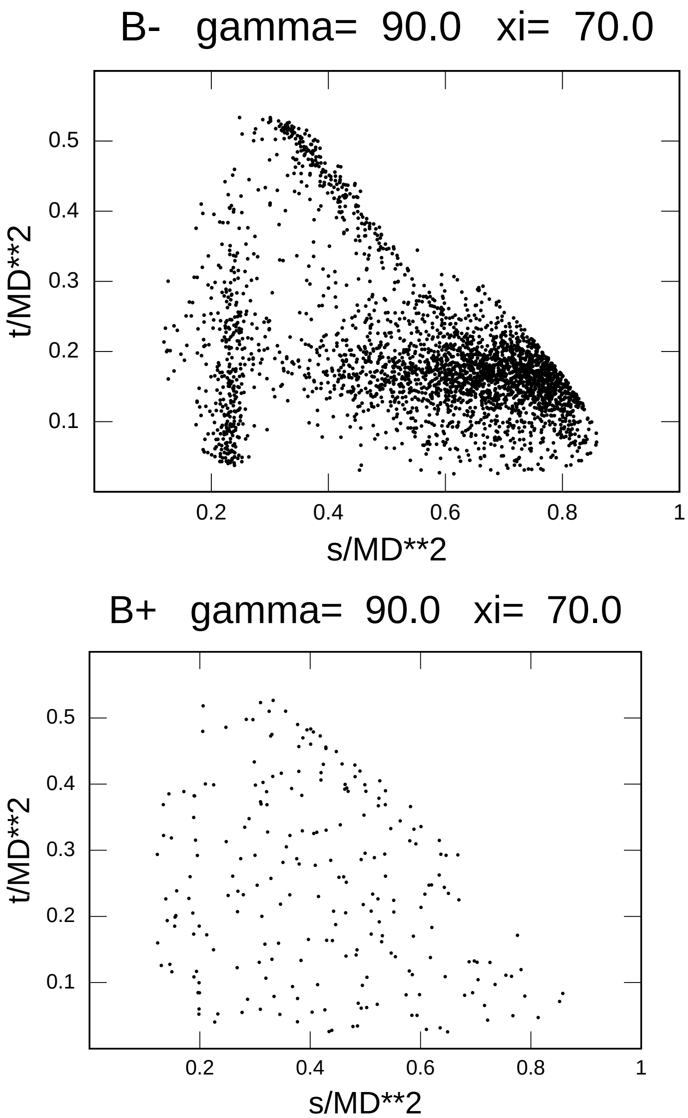
  [DA in progress]
- Likewise, given $Br(\Lambda_b \to \Lambda K^-) = Br(B^- \to \overline{D}^0 K^-)$ then we can also include Λ_b decays on the same $\gamma - b$ plot.
- Phase information from a charm factory could also be used to provide additional constraints to a global fit.

  [Soffer 98]

A Single Three Body Final States

- Many of the quasi-two body states are channels in the same three body final state, for instance: $D^0 \to K^{*0}\pi^0$; $K^{*+}\pi^-$; $K^+\rho^-$; $\to K^+\pi^-\pi^0$
- Each point in the Dalitz plot may be thought as a separate "mode" so in principle, such a system offers an infinitude of "modes" so there is enough information in such a final state to determine both γ and b.
  [DA Dunietz Soni 2000]
- To extract the amplitude, one can fit the distribution to a resonance channel model.
- We can also construct the lower bound on $\sin^2\gamma$ for each point on the Dalitz plot.
- Generally, the lest lower bound is exactly $\sin^2\gamma$.
- The same is true for both lower and upper bounds on b.
- Let us define $f(q)$ as the fraction of the dalitz plot where the bound on $\sin^2\gamma$ is better than q.
- Using the phenomenological model from E687 for the CA decay and SU(3) for the DCS decay ...

Figure 5a

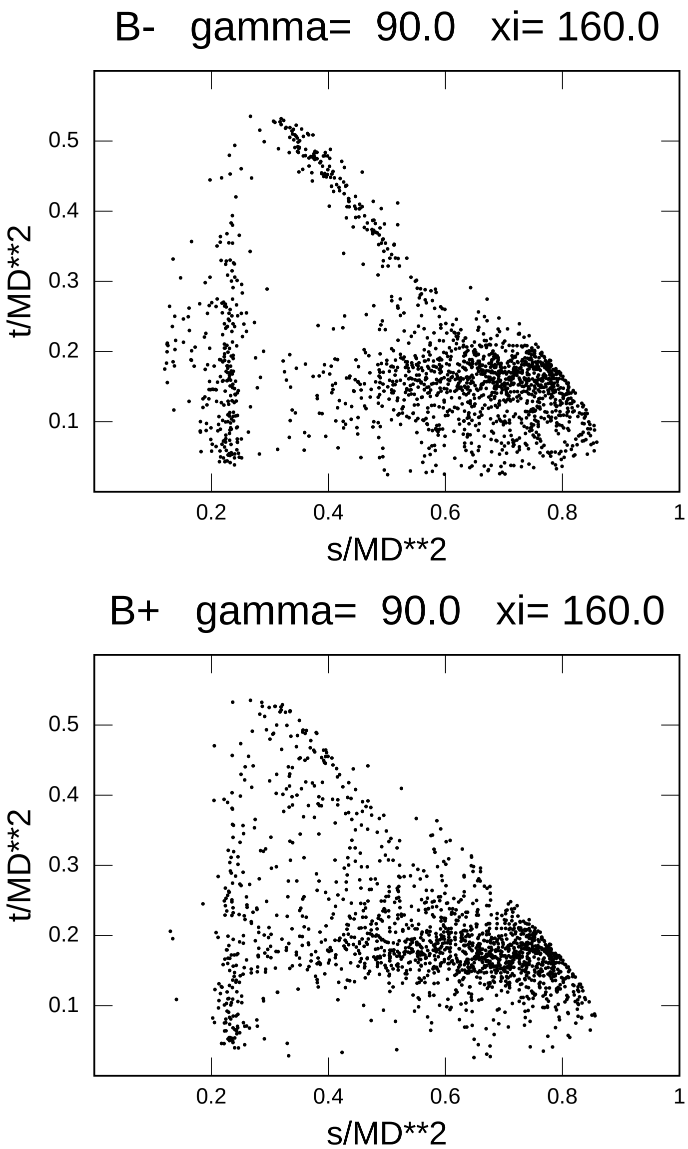


With $10^{10}/acceptance\ B's$!!!!

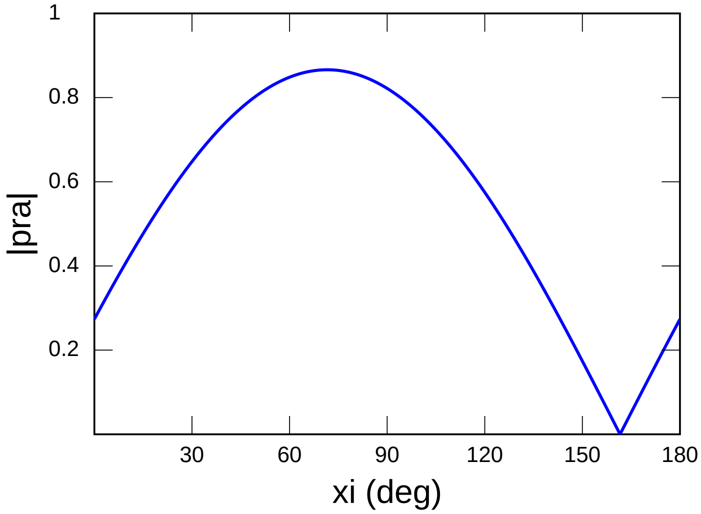
$s = (p_{\pi-} + p_{K+})^2$ and $t = (p_{\pi 0} + p_{\pi-})^2$

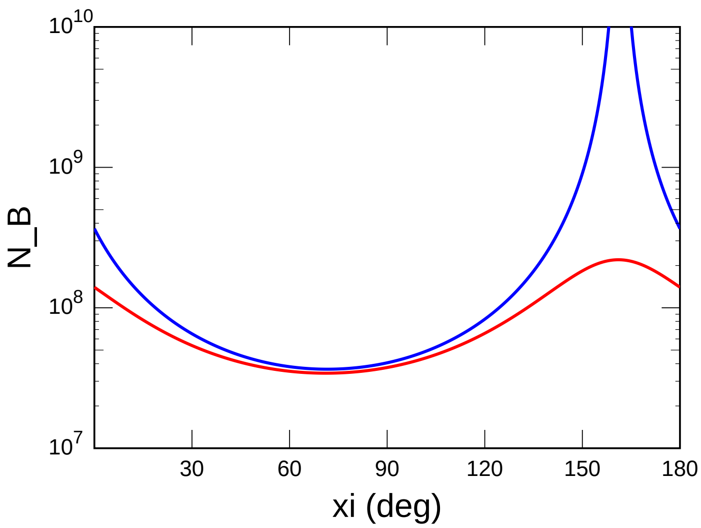
- Large partial rate asymmetry

Figure 3b



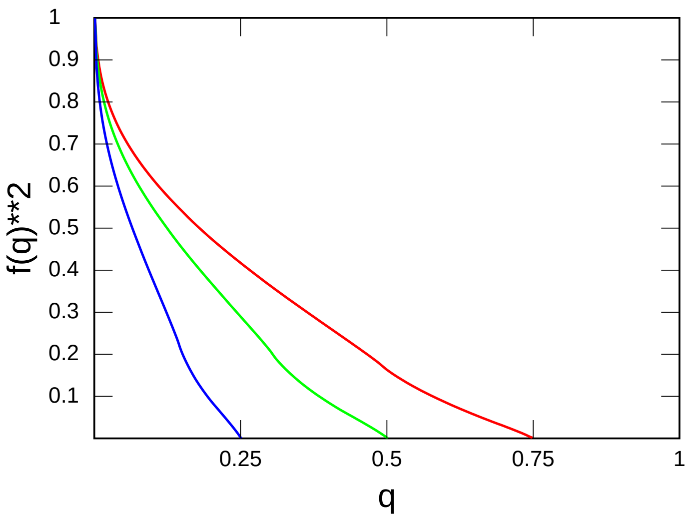
- Little partial rate asymmetry but difference in distribution

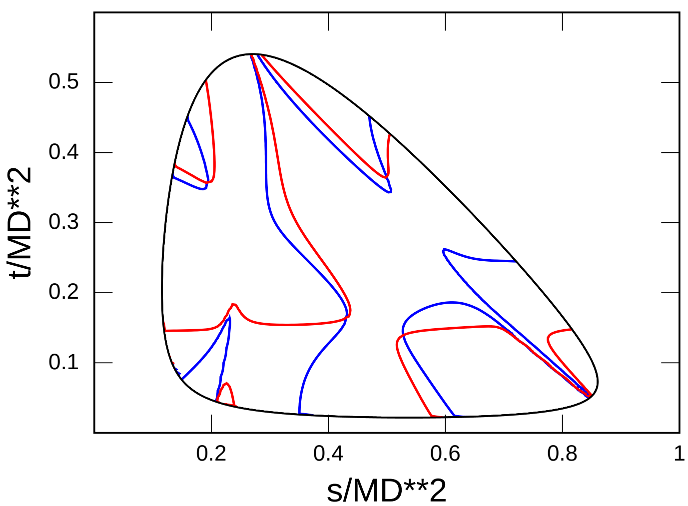




But what do you really need?

- Blue curve: $N_B^{3\sigma}$ to see CP violation using only PRA.
- Red curve: $N_B^{3\sigma}$ to see CP violation using the differences in distribution.





- $f(q)$ is the proportion of the Dalitz plot with $\sin^2\gamma > q$. Curves for $\sin^2\gamma = 0.25; 0.5; 0.75$.

The Impact of $D\overline{D}$ Oscillation

- It has been suggested that resonant effects can give a SM value of $y_D \sim .01$ while physics beyond the SM could give $x_D \sim .01$ [M Gronau 99; H Nelson 99]
- Consider $B^- \to K^-[D^0 \to K^+\pi^-]$ where the last step is DCS. If there is $O(1\%)$ chance of the D^0 oscillating to a $\overline{D}^0$, the CA decay $\overline{D}^0 \to K^+\pi^-$ will be comparable and disrupt the above analysis.
- To analyze the expected magnitude of mixing effects in this system, let us introduce an expansion parameter $\mu^2 = b/a$.
- Then, numerically $c/\overline{c} = O(\mu^2)$ and if mixing is near its maximum expected value, then $x_D = O(\mu^2)$ or $y_D = O(\mu^2)$ and $\mu \sim 0.1$.
- In this regime it is valid to approximate:

$$d(\tau) = (d_0 + d_1\tau)e^{-\tau}; \qquad \overline{d}(\tau) = (\overline{d}_0 + \overline{d}_1\tau)e^{-\tau};$$

  Where $\tau = \Gamma_D t$ and d_0 and $\overline{d}_0$ are the decay rates that would obtain absent mixing.
- Using the expansion in terms of μ, d_1/d_0 and $\overline{d}_1/\overline{d}_0$ are $O(\mu)$ thus mixing effects are expected to be $\sim 10\%$.

- Three ways to deal with mixing are:
  1. Determine the mixing parameters elsewhere and fold them into the analysis.
     - If the mixing parameters were known, the determination of $\{d_0, \overline{d}_0\ d_1, \overline{d}_1\}$ would give enough information to extract γ and b.
     - This is likely to be practical only if the mixing is very large.
  2. Include the possible mixing as a systematic error in your final result.

     [Soffer and Silva 2000]

     - An analysis of how the error propagates through estimates that a mixing bound of x_D, y_D $<$ .01 will result in a systematic error in γ of about $10°$

3. Use time dependent information to eliminate contamination due to mixing.

[DA Dunietz Soni 2000]

– If time dependent information is available, one can reduce to the unmixed case by convoluting the data with the weighting function $w = 2 - \tau$:

$$d_0 = \int_0^\infty d(\tau)\ w\ d\tau \quad \overline{d}_0 = \int_0^\infty \overline{d}(\tau)\ w\ d\tau$$

– The statistical cost of this approach is:

$$N_{mixing} = 2(1+\sigma^2)(1+d_1/d_0)^2 N_{no\ mixing}$$

– σ is the (detector time resolution)$\cdot\Gamma_D$.

– N_{mixing} is the number of B's required if mixing might be present, $N_{no\ mixing}$ would be the number of B's required if mixing is known to be absent.

Conclusions

- Decays of the form $B^- \to D^0 K^-$ allow the opportunity to measure γ through the interference of $b \to c$ and $b \to u$ transitions.

- All DCS decay modes of the D^0 should be checked for CP violation. If any are found, a bound on γ may be established.

- Data from at least three modes can be used to determine γ but as many modes as possible should be used.

- Three body modes contain additional phase information; potentially one mode alone could be used.

- Respectable measurements of γ may happen if $N_B/(accept) \sim 10^8$

- The potential for large (1%) $D\bar{D}$ oscillations introduces about $O(10^\circ)$ systematic uncertainty in γ. Time dependent information can eliminate this at the cost of a factor of ~ 2 in statistic.