Chicago Flavor seminar
Fermilab

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Angle γ from $B \to D^0 X$ decays

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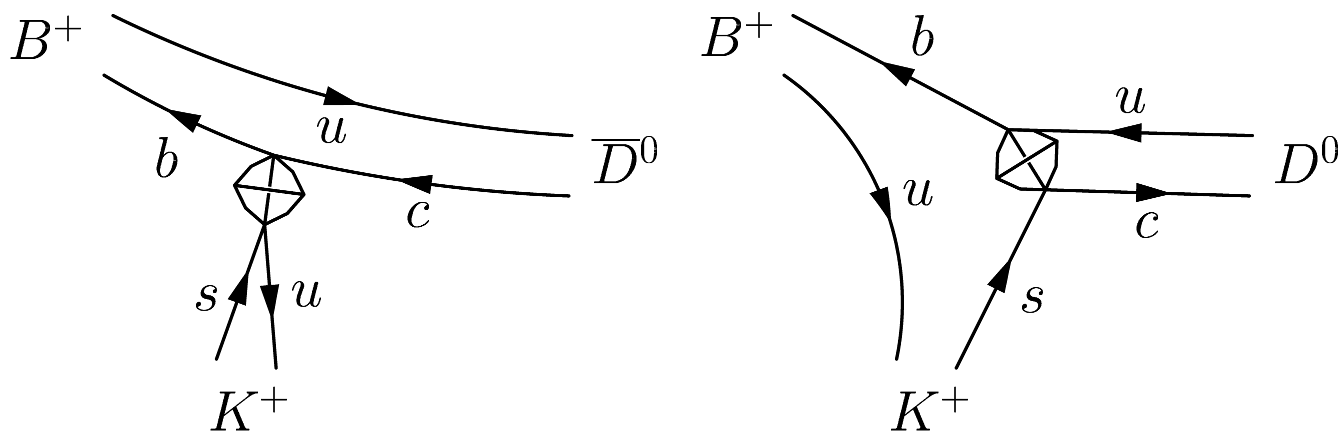
γ from tree-tree interference

Basic idea: Use interference of the two tree amplitudes $b \to c\bar{u}q$ and $b \to u\bar{c}q$ (with $q = d$ or $q = s$) to get $\gamma = \arg V_{ub}^*$.

Prototype: Gronau-London-Wyler (GLW) method:



Interference if both $D^0 \to f$ and $\overline{D^0} \to f$ are allowed,
e.g. if f is a CP eigenstate: $\overset{(-)}{D^0} \to K^+K^-$ or $\overset{(-)}{D^0} \to \pi^+\pi^-$.
Then view final state as

$$D_{CP+} \equiv \frac{D^0 - \overline{D^0}}{\sqrt{2}}.$$

On the other hand, flavor-specific $\overset{(-)}{D^0} \to f$ decays with i.e. either $D^0 \to f$, $\overline{D^0} \not\to f$ or $\overline{D^0} \to f$, $D^0 \not\to f$ only probe either the $b \to u\bar{c}s$ or the $b \to c\bar{u}s$ amplitude.

$\Rightarrow$ Combine branching fractions from $B \to \overset{(-)}{D^0}[\to f]X$ decays with different f to eliminate the hadronic parameters of $B \to \overset{(-)}{D^0}X$.

Important: Need to measure branching fractions only!

Remarks:

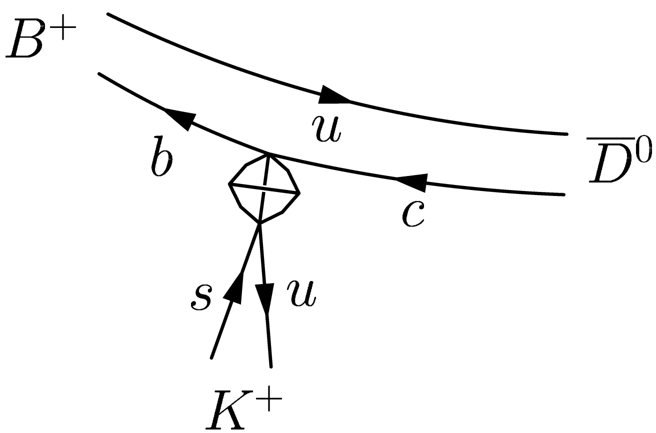
Works with $B \to X D^{0*}$ as well, because $D^{0*} \to D^0\pi^0, D^0\gamma$ only.

Likewise one can substitute the K^+ by K^{+*}.

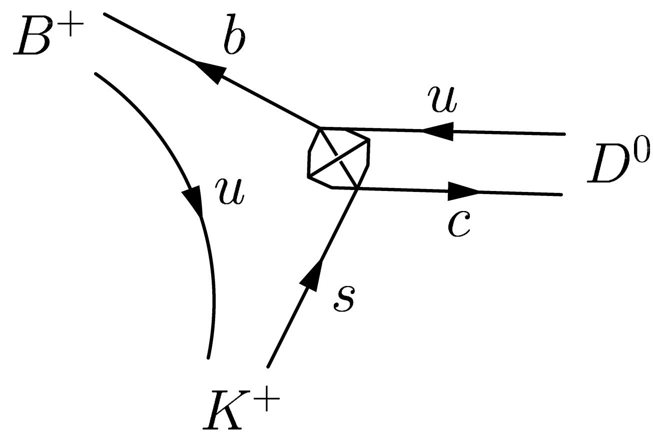
GLW method

Count factors of Wolfenstein parameters, $\lambda = 0.22$, and $R_u = \sqrt{\overline{\rho}^2 + \overline{\eta}^2} = 0.4$ (omitting factor of $A\lambda^2$ common to all decays) and color suppression factor $1/N_c = 1/3$:

λN_c



$R_u \lambda$



Ideally: Measure

- $\Gamma(B^+ \to D^0 K^+) \propto |A(b \to u)|^2$,
- $\Gamma(B^+ \to \overline{D}^0 K^+) \propto |A(b \to c)|^2$,
- $\Gamma(B^+ \to D_{CP+} K^+) \propto |A(b \to c) + e^{-i\gamma} A(b \to u)|^2$ and
- $\Gamma(B^- \to D_{CP+} K^-) \propto |A(b \to c) + e^{i\gamma} A(b \to u)|^2$,

form three ratios and solve for

$$r_B \equiv \left| \frac{\langle D^0 K^+ | B^+ \rangle}{\langle \overline{D}^0 K^+ | B^+ \rangle} \right| = \left| \frac{A(b \to u)}{A(b \to c)} \right|,$$

the relative strong phase δ between $A(b \to u)$ and $A(b \to c)$ and the desired weak phase γ.

Drawbacks:

- r_B is small, of order $R_u/N_c \sim 0.1$. $\Rightarrow$ Interference is small.
- $\Gamma(B^+ \to D^0 K^+) \propto |\langle\, D^0 K^+ \,|B^+\rangle|^2$ is practically unmeasurable: $D^0 \to K^- \ell^+ \nu_\ell$ is too difficult and $B^+ \to D^0[\to K^- \pi^+] K^+$ is polluted from $B^+ \to \overline{D}^0 [\to K^- \pi^+] K^+$.

  $\Rightarrow$ Include $B^\pm \to D_{CP_-} K^\pm$

Some CP-even final states of $\overset{(-)}{D^0}$ decays: K^+K^-, $\pi^+\pi^-$. Some CP-odd final states of $\overset{(-)}{D^0}$ decays: $K_S \pi^0$, $K_S \phi$, $K_S \omega$, $K_S \rho^0$.

Maybe best: Full Dalitz analysis of $B^\pm \to \overset{(-)}{D^0} [K_S \pi^+ \pi^-] K^\pm$, performed by BELLE and BaBar.

$$R_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{2\Gamma(B^- \to D^0 K^-)} = 1 \pm r_B \cos\gamma \cos\delta + r_B^2$$

$$A_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)} = \pm 2 r_B \sin\gamma \sin\delta / R_{CP\pm}$$

BaBar finds (ICHEP 2004):

$r_B < 0.18$ at 90% CL from $B^\pm \to \overset{(}{\overline{D^0}}\overset{)}{} K^\pm$

$r_B^* < 0.24$ at 90 % CL from $B^\pm \to \overset{(}{\overline{D^0}}\overset{)}{}{}^* K^\pm$

and

$$\gamma = (88 \pm 41 \pm 19 \pm 10)^\circ$$

plus a solution with $\gamma \to \gamma + 180^\circ$, the last error is from the Dalitz model.

ADS method

Atwood, Dunietz, Soni proposed a method which overcomes the problem for small r_B: Observe that $\overline{D^0} \to K^+\pi^-$ is CKM-favored, while $D^0 \to K^+\pi^-$ is $\mathcal{O}(\lambda^2)$. I.e. compensate the smallness of r_B by the smallness of

$$r_D \equiv \left| \frac{\langle K^+\pi^- | D^0 \rangle}{\langle K^-\pi^+ | \overline{D^0} \rangle} \right| = \left| \frac{A(c \to d u \overline{s})}{A(c \to s u \overline{d})} \right| = 0.060 \pm 0.003.$$

$$R_{ADS} \equiv \frac{\Gamma(B^- \to \overset{(}{\overline{D^0}}\overset{)}{}[K^+\pi^-]K^-) + \Gamma(B^+ \to \overset{(}{\overline{D^0}}\overset{)}{}[K^-\pi^+]K^+)}{\Gamma(B^- \to \overset{(}{\overline{D^0}}\overset{)}{}[K^-\pi^+]K^-) + \Gamma(B^+ \to \overset{(}{\overline{D^0}}\overset{)}{}[K^+\pi^-]K^+)}$$

$$= r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta + \delta_D) + r_B^2$$

$$A_{ADS} \equiv \frac{\Gamma(B^- \to \overset{(}{\overline{D^0}}\overset{)}{}[K^+\pi^-]K^-) - \Gamma(B^+ \to \overset{(}{\overline{D^0}}\overset{)}{}[K^-\pi^+]K^+)}{\Gamma(B^- \to \overset{(}{\overline{D^0}}\overset{)}{}[K^+\pi^-]K^-) + \Gamma(B^+ \to \overset{(}{\overline{D^0}}\overset{)}{}[K^-\pi^+]K^+)}$$

$$= 2 r_B r_D \sin\gamma \sin(\delta + \delta_D)/R_{ADS},$$

where δ_D is the strong phase difference between $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$.

No experimental results from ADS yet, $R_{ADS} < 0.030$ at 90 % CL.

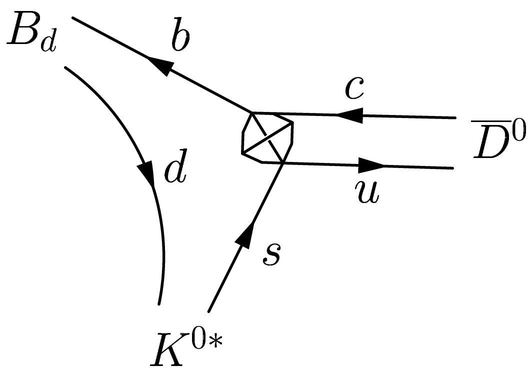
GLW: $R_{CP\pm} = 1 \pm \mathcal{O}(r_B)$, $A_{CP\pm} = \pm\mathcal{O}(r_B)$,

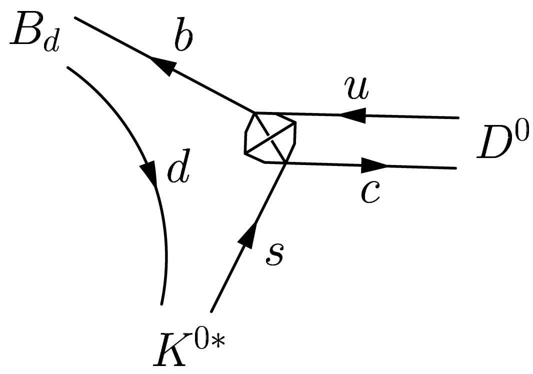
ADS: $R_{ADS} = \mathcal{O}(r_B^2)$, $A_{ADS} = \mathcal{O}(1)$,

B_d decays

Dunietz proposed to use $B_d \to \overset{(-)}{D^0} K^{0*}[\to K^+\pi^-]$:

λ $\qquad\qquad$ $R_u\lambda$





with flavor-specific D^0, $\overline{D^0}$ decays and $\overset{(-)}{D^0} \to f_{CP+}$. Here both amplitudes are color-suppressed and $r_B = \mathcal{O}(R_u) \sim 0.4$.

B_s decays

How about using the ADS idea in B_s decays?

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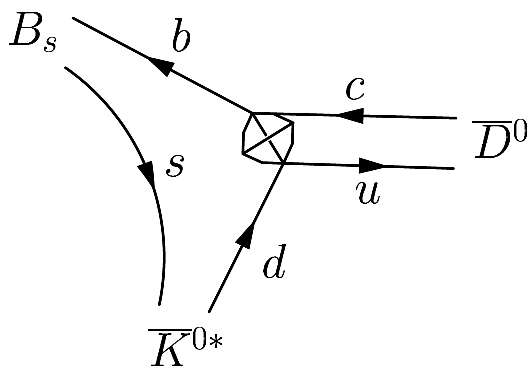
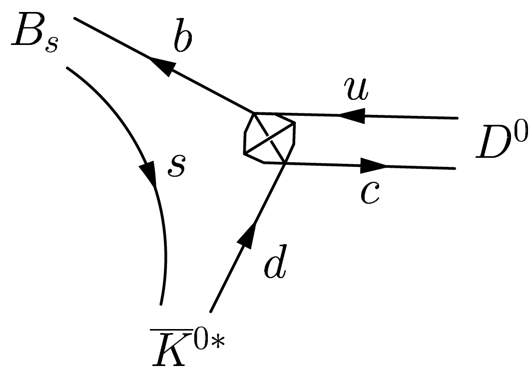


$\overline{D^0} \to K^- \pi^+$

λ^2

$R_u \lambda^2$



$D^0 \to K^- \pi^+$

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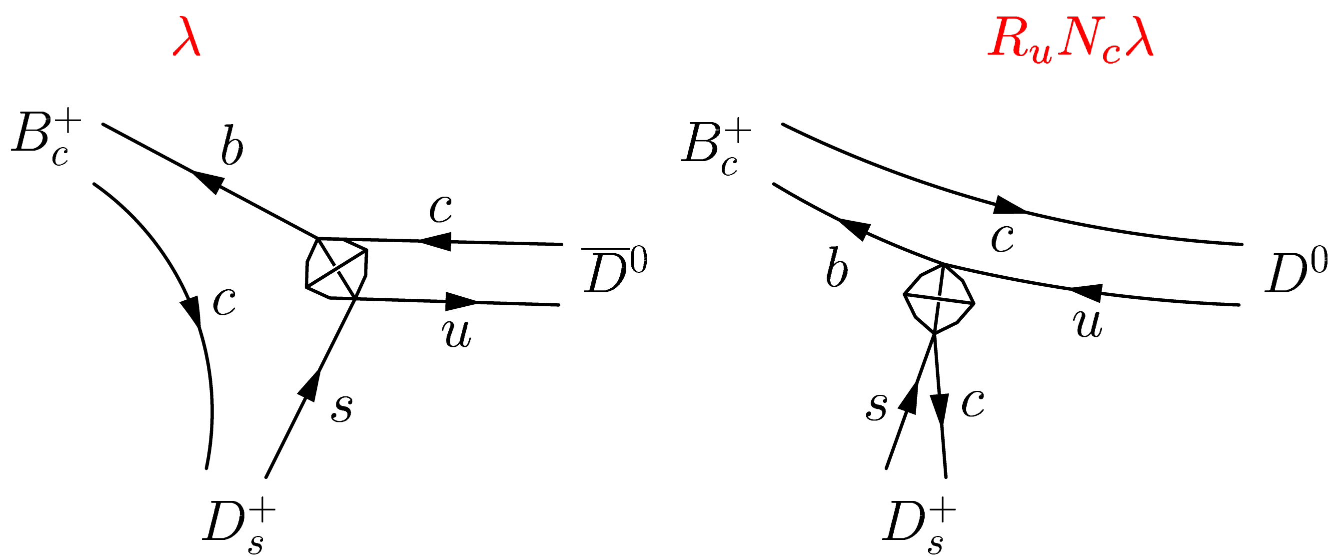
B_c and Λ_b decays

Fleischer-Wyler: Best ratio of $b \to u$ and $b \to c$ amplitudes:



The baryonic version of the interference of $b \to u\bar{c}s$ and $b \to c\bar{u}s$ decays is $\Lambda_b \to \Lambda \overset{(}{\overline{D^0}}\overset{)}{}$ and was proposed by Dunietz.

Three-body decays

The GLW method comes with the drawback that the smaller $A(b \to u)$ amplitude has an extra $1/N_c$ suppression.

In certain three-body decays both $A(b \to u)$ and $A(b \to c)$ are color-favored. Aleksan, Petersen, Soffer proposed $B^+ \to \overset{(-)}{D^0} K^+ \pi^0$. One can easily extend their findings to decay modes which are better suited for the Tevatron:

$B^+ \to \overset{(-)}{D^0} K^+ \rho^0$, $B_d \to \overset{(-)}{D^0} K^+ \pi^-$, $B_s \to \overset{(-)}{D^0} K^- \pi^+, \ldots$

Non-flavor-specific decays

Final states like $D^0 K_S$ are accessible to both B_d and $\overline{B}_d$. Still one can solve for γ from untagged $\overset{(-)}{B}_d$ decays as observed by Gronau et al.:

Measurements of the $\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to f_i] K_S$ and $\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to \overline{f}_i] K_S$ branching fractions, where $i = 1, \ldots N$, $\overline{f}_i = CP f_i$ (and the f_i's are not CP eigenstates), give $2N$ measurements for $N+3$ unknowns.

$\Rightarrow$ Need to study $N \geq 3$ different $\overset{(-)}{B}_d \to \overset{(-)}{D^0}[\to f_i] K_S$ decays.

Needless to say that one can adapt this method to other decay modes accessible at the Tevatron. $\overset{(-)}{B}_s \to \overset{(-)}{D^0}\phi$ comes to mind!

Conclusions

The determination of γ from $B \to \overset{(-)}{D^0} X$ and $B \to \overset{(-)}{D^0}{}^* X$ decays can be done from the measurements of branching fractions alone. It is possible with all weakly decaying b-flavored hadrons. It is well possible that this measurement is a "world effort", with both B factories and the Tevatron contributing to the measurements of the needed branching ratios and with the study of many different decay modes.