Constraining New Physics with Fake Triple Products in B Decays

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Outline of Talk

- Over the past 10-15 years, there have been many measurements of CP violation in the B system with the majority of these being of direct and indirect CP asymmetries in B decays.
- The goal is to find a discrepancy with the predictions of the standard model (SM).
- To date, the measurements are generally in agreement with the SM. However, there are some small hints of disagreements in some rare $\bar{b} \to \bar{s}$ decays - exactly where new physics(NP) might show up.
- In this talk I will concentrate on Triple Product Asymmetry- an observable in $B \to V_1 V_2$ decays which can be sensitive to NP.
- Conclusions.

Triple Product Correlations

- In the B rest frame we can construct T.P
$$T.P = \vec{p}.(\vec{\epsilon}_1 \times \vec{\epsilon}_2).$$
- We can define a T-odd asymmetry
$$A_T = \frac{\Gamma[T.P>0]-\Gamma[T.P<0]}{\Gamma[T.P>0]+\Gamma[T.P<0]}.$$
- For true CP violation, we need to compare A_T and $\bar{A}_T$
$$A_{T.P}^{true} = A_T + \bar{A}_T \propto \sin\phi\cos\delta$$
$$A_{T.P}^{fake} = A_T - \bar{A}_T \propto \cos\phi\sin\delta.$$
- If the NP has a different weak phase than SM then the true T.P in non zero. If NP and SM weak phase are the same the fake T.P can yeild information about NP.

- The T.P appear in the angular distribution of $B \to V_1 V_2$.
- We can define two T.P's

$$A_T^{(1)} \equiv \frac{\mathrm{Im}(A_\perp A_0^*)}{A_0^2 + A_\parallel^2 + A_\perp^2} \;, \qquad A_T^{(2)} \equiv \frac{\mathrm{Im}(A_\perp A_\parallel^*)}{A_0^2 + A_\parallel^2 + A_\perp^2} \;.$$

- The amplitudes are longitudinal (A_0), or transverse to their directions of motion and parallel ($A_\parallel$) or perpendicular ($A_\perp$) to one another.
- For the CP conjugate decay one defines two T.P's

$$\bar{A}_T^{(1)} \equiv -\frac{\mathrm{Im}(\bar{A}_\perp \bar{A}_0^*)}{\bar{A}_0^2 + \bar{A}_\parallel^2 + \bar{A}_\perp^2} \;, \qquad \bar{A}_T^{(2)} \equiv -\frac{\mathrm{Im}(\bar{A}_\perp \bar{A}_\parallel^*)}{\bar{A}_0^2 + \bar{A}_\parallel^2 + \bar{A}_\perp^2} \;.$$

NP: $B \to \phi K^*$ Polarization puzzle

- $B \to \phi K^*$ is a $b \to s$ transition has 3 amplitudes: $A_L(A_0), A_-, A_+(A_\perp, A_\|)$
- Consider $b \to f\bar{q}q$ where $f = s, d$ and $q = u, d, s$. Weak interactions are $(V - A)$ and so the weak transition is

$$b_L \quad \to \quad f_L \bar{q}_R q_L$$

- Helicity A_0 no helicity flip $\sim O(1)$
  A_- one helicity flip $\sim O(m_V/m_B)$. $m_V = m_{\phi,K^*}$.
  A_+ two helicity flips $\sim O(m_V^2/m_B^2)$.
- For $B \to V_1 V_2$ where $V_{1,2}$ are light:

$$f_L >> f_- >> f_+$$

$$f_i = \frac{\Gamma_i}{\Gamma_{total}}$$

where $i = 0, -, +$.

Polarization Puzzle

Decay	Final State	f_L
$B \to \phi K^*$	ϕK^{*0}	0.480 ± 0.030
	ϕK^{*+}	0.50 ± 0.05
$B \to \rho K^*$	$\rho^0 K^{*0}$	0.57 ± 0.12
	$\rho^+ K^{*0}$	0.48 ± 0.08
$B \to K^* \bar{K}^*$	$K^{*0} \bar{K}^{*0}$	$0.80^{+0.12}_{-0.13}$
	$K^{*+} \bar{K}^{*0}$	$0.75^{+0.16}_{-0.26}$
$B \to \rho\rho$	$\rho^+ \rho^-$	$0.978^{+0.025}_{-0.022}$
	$\rho^0 \rho^0$	$0.75^{+0.12}_{-0.15}$
	$\rho^+ \rho^0$	0.950 ± 0.016

Table: Longitudinal polarization fraction f_L for various $B \to V_1 V_2$ decays

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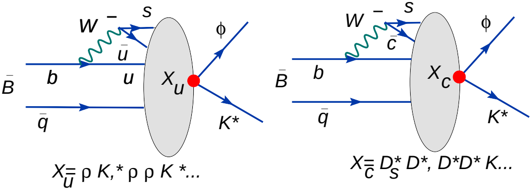
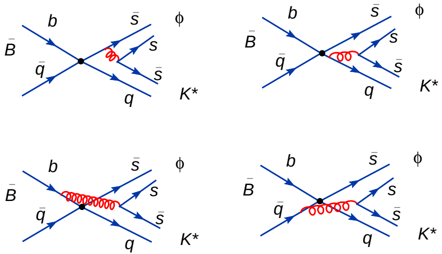
Solutions to the Polarization puzzle

- Non standard SM effects: Rescatering, Penguin Annhilation or New Physics(NP)
- Rescattering can be important for penguin decays and helicity arguments do not apply. Note $B \to \rho\rho$ is tree and rescattering



  is small.
- But rescattering calculations predict: $f_+ \sim f_-$ but experiments give $f_- >> f_+$.

- Annihilation topologies generated by the top penguin operator (PA) may cause large transverse polarization



- Subleading effect: PA is higher order in $\frac{\Lambda_{QCD}}{m_b}$ and expected to be small. No evidence of PA is decays like $B_d \to K^{+*} K^{-*}$.
- PQCD PA contributions cannot explain the data. QCDF PA are divergent- parameterize by unknown parameters- fit parameters to the data.

New Physics

- Suppose there is a new-physics (NP) contribution to the $\bar{b} \to \bar{s} s \bar{s}$ quark-level amplitude.
- If the NP operators have the structures

$$ST_{LL} = (1-\gamma_5) \otimes (1-\gamma_5) \quad or \quad \sigma(1-\gamma_5) \otimes \sigma(1-\gamma_5)$$
$$ST_{LL} = (1+\gamma_5) \otimes (1+\gamma_5) \quad or \quad \sigma(1+\gamma_5) \otimes \sigma(1+\gamma_5),$$

  then these operators contribute dominantly to f_T in $B \to \phi K^*$ and not to f_L
- The scalar operators are prefered if considering both $B_d \to \phi K^*$ and $B_d \to \rho K^*$(A. Datta et.al.)

Testing the Explantions

- SM: $b \to s$ transitions
  Rescattering:
  $A_T \sim V_{cb} V_{cs}^* P_c$
  PA:
  $A_T \sim V_{tb} V_{ts}^* P_t$
  At present cannot distinguish PA from rescattering as
  $V_{tb} V_{ts}^* \approx -V_{cb} V_{cs}^*$
- SM: $b \to d$ transitions
  $A_T \sim V_{cb} V_{cd}^* P_c$
  No weak phase (Rescattering)
  $A_T \sim V_{tb} V_{td}^* P_t$. Weak phase is β (PA)
- We can distinguish PA from rescattering by measuring the weak phase- possible in $B \to \bar{K}^* K^*$ through time dependent angular analysis. (Datta et.al 2007)
- Measurement of the fake T.P can strongly constain the SM as well as NP explanations.

- The transverse amplitudes are written in terms of helicity amplitudes

$$A_{\|} = \frac{1}{\sqrt{2}}(A_+ + A_-) \, ,$$
$$A_{\perp} = \frac{1}{\sqrt{2}}(A_+ - A_-) \, .$$

- Due to the fact that the weak interactions are left-handed, the helicity amplitudes obey the hierarchy

$$\left|\frac{A_+}{A_-}\right| = \frac{\Lambda_{QCD}}{m_b} \, .$$

Thus, in the heavy-quark limit, $A_{\|} = -A_{\perp}$ which means $A_T^{(2)}$, which is proportional to $\mathrm{Im}(A_{\perp} A_{\|}^*)$, vanishes.

T.P and New Physics

- This means that if the large f_T/f_L observed in several $B \to V_1 V_2$ decays is due to the SM, $A_T^{(2)} = 0$ should be found.
- On the other hand, suppose that the large f_T/f_L is due to NP which contains RH couplings then $A_T^{(2)}$ is non zero.
- If the new interactions have a different weak phase from the SM, they can be detected using the true TP's (of $A_T^{(1)}$ or $A_T^{(2)}$).
- However, the NP could have the same weak phase as the SM (~ 0) for the $b \to s$ ransitions, so that the true TP's vanish. The fake TP can then provide useful information about NP.

Corrections to the heavy quark limit

- There are corrections to the prediction that $A_T^{(2)} = 0$, since the heavy-quark limit is just an approximation.
- We take $A_\lambda = |A_\lambda| e^{i\delta_\lambda}$ $(\lambda = 0, \pm)$, and define $r_T \equiv |A_+/A_-|$. $A_T^{(2)}$ is then given by

$$A_T^{(2)} = \frac{r_T f_T}{(1 + r_T^2)} \sin(\delta_+ - \delta_-) ,$$

  with $f_T = f_\perp + f_\parallel$.
- In the SM, in pure-penguin $\bar{b} \to \bar{s}$ decays there is effectively only one weak amplitude and $(\delta_+ - \delta_-)$ is purely a strong phase. Thus, $A_T^{(2)} = -\bar{A}_T^{(2)}$ and so $A_T^{(2)}$ is by itself a fake TP.

- There is a constraint:

$$\frac{[(1-r_T^2)^2 + 4r_T^2 \sin^2(\delta_+ - \delta_-)]^{1/2}}{1 + r_T^2 + 2r_T \cos(\delta_+ - \delta_-)} = \sqrt{\frac{f_\perp}{f_\parallel}} \,.$$

  Given the experimental values for $f_\perp$ and $f_\parallel$, the above equation provides a constraint on r_T and the phase $(\delta_+ - \delta_-)$.

- Note $\frac{f_\perp}{f_\parallel} = 1$ does not mean $r_T = 0$. It is possible to have $(\delta_+ - \delta_-) = \pi/2$ in which case $A_T^{(2)}$ is non zero.
- In QCD factorization, without PA $r_T \lesssim 4$ % but with PA r_T is increased to lie in the range 5%-15%. We vary the phase $(\delta_+ - \delta_-)$ between $-\pi$ to π.

Corrections to the heavy quark limit

- We begin with $B \to \phi K^*$. The estimate for $A_T^{(2)}$ is

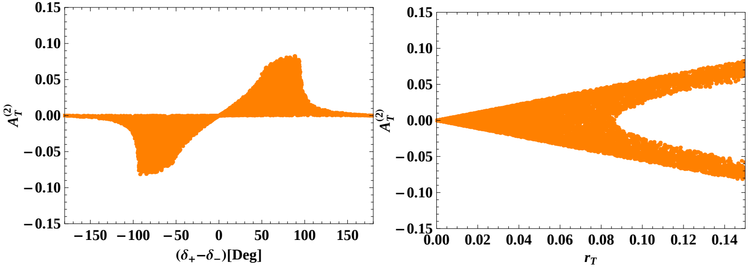


Figure: The left (right) panel of the figure shows $A_T^{(2)}$ for the decay $B_d \to \phi K^{*0}$ as a function of $(\delta_+ - \delta_-)$ (r_T).

- There we see that $|A_T^{(2)}| \le 9\%$ is predicted.
  This prediction can be compared with the experimental result.
  $A_T^{(2)}$ has not been explicitly measured, but its value can be deduced using other measurements.

- The estimate for $A_T^{(1)}$ is

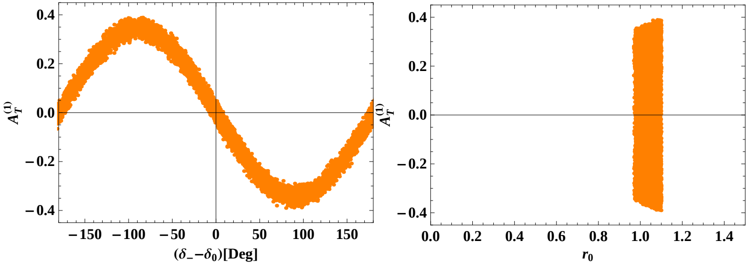


Figure: The left (right) panel of the figure shows $A_T^{(1)}$ for the decay $B_d \to \phi K^{*0}$ as a function of $(\delta_+ - \delta_-)$ (r_T).

- There we see that $|A_T^{(1)}| \leq 40\%$ is predicted. This prediction is not unexpected given the large size of the transverse amplitudes.

- The relevant $B_d \to \phi K^{*0}$ polarization observables are shown in Table below.
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Polarization fractions	
$f_L = 0.480 \pm 0.030$	$f_\perp = 0.241 \pm 0.029$
Phases	
$\phi_\parallel(rad) = 2.40^{+0.14}_{-0.13}$	$\phi_\perp(rad) = 2.39 \pm 0.13$
$\Delta\phi_\parallel(rad) = 0.11 \pm 0.13$	$\Delta\phi_\perp(rad) = 0.08 \pm 0.13$
CP asymmetries	
$A^0_{CP} = 0.04 \pm 0.06$	$A^\perp_{CP} = -0.11 \pm 0.12$

Table: $B_d \to \phi K^{*0}$ polarization observables .

Experimental T.P's

- Using the numbers above we can calculate $A_T^{(2)}$:

$$A_T^{(2)} = \frac{1}{2}(A_{T,B}^{(2)} - \bar{A}_{T,\bar{B}}^{(2)}) = 0.002 \pm 0.049 \ .$$
$$A_T^{(1)} = \frac{1}{2}(A_{T,B}^{(1)} - \bar{A}_{T,\bar{B}}^{(1)}) = -0.23 \pm 0.03 \ ,$$

- The measured value of $A_T^{(2)}$ is therefore in agreement with the SM prediction in the heavy quark limit. Indeed, it is consistent with zero. What does this say about the SM NP explanations of the large observed value of f_T/f_L?
- The actual T.P are

$$A_T^{(2)} = \frac{1}{2}(A_{T,B}^{(2)} + \bar{A}_{T,\bar{B}}^{(2)}) = -0.004 \pm 0.025$$
$$A_T^{(1)} = \frac{1}{2}(A_{T,B}^{(1)} + \bar{A}_{T,\bar{B}}^{(1)}) = 0.013 \pm 0.053$$

Hence consistent with SM or with NP with same weak phase as the SM.

Constraints on SM and NP

- SM: Rescattering and PA have to be constrained to produce $A_T^{(2)} \approx 0$ or $A_+ << A_-$. Hence in the PA case heavy quark effects must be small in r_T but large enough to produce larfe f_T.
- NP: In the heavy-quark limit, $A_+ = 0$ in the ST_{LL} scenario, so that $A_\parallel = -A_\perp$ (as in the SM) and $A_T^{(2)} = 0$.
  Similarly, ST_{RR} predicts that $A_- = 0$, so that $A_\parallel = A_\perp$ and $A_T^{(2)} = 0$.
- However both ST_{LL} and ST_{RR} cannot be present.
  If the SM produces a large f_T from PA and rescattering(which is left handed) then ST_{RR} cannot be present. Thus, the measurement of $A_T^{(2)} \simeq 0$ rules out ST_{RR}, or at least strongly constrains it.

Conclusions

- Triple products, both fake and real, are good probes of new physics.
- Present measurements of triple products in certain B decays strongly constrain non- standard explanation of the polarization puzzle and also new physics.