New Physics in Penguin $B \to VV$ *Decays*

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Dedicated to Patrick J. O'Donnell

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 $\bar{b} \to \bar{s}$, $\bar{b} \to \bar{d}$ decays - exactly where new physics(NP) might show up.
- $\bar{b} \to \bar{s}$ transitons are interesting as the SM CP violation in these decays are tiny. Hence good places to search for NP
- In this talk I will concentrate on the rare processes $b \to s\bar{q}q$ to VV final states.

$B \to V_1 V_2$ Decays

- $B \to V_1 V_2$ decays are really three transitions because there are 3 polarization states for the final state.

- Besides the direct CP violation(DCPV) one can have another measurement of CP violation which is called the triple product asymmetry (TPA).

- DCPV $\sim \sin\phi \sin\delta$ while TPA $\sim \sin\phi \cos\delta$. Hence DCPV and TPA complement each other. If the strong phases are small then TPA are maximized.

- There is another measurement whis is not CPV. Fake TP which go as $\sim\sim \cos\phi \sin\delta$. This observable can constrain NP if the NP has the same weak phase as the SM. In this case DCPV and TPA vanish.

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 $\bar{A}_T$
$$A^{true}_{T.P} = A_T + \bar{A}_T \propto \sin\phi\cos\delta$$
$$A^{fake}_{T.P} = A_T - \bar{A}_T \propto \cos\phi\sin\delta.$$

Measuring T.P

- The T.P appear in the angular distribution of $B \to V_1 V_2 -> (V_1 \to P_1 P_1')((V_2 \to P_2 P_2')$.
- We can define two T.P's

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

- 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

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

NP in $B \to V_1 V_2$: Polarization puzzle

- To motivate NP in $B \to V_1 V_2$ decays let us look at the polarization puzzle which could be indication of NP. (Note there are SM explanations of the polarization puzzles- so they may not be puzzles.)

- The puzzle is: In the SM, naively $B \to V_1 V_2$ decays, where the final states are light, should be dominated by the longitudinal polarization. Experiments find it to be true for tree dominated decays but not for penguin dominated decays which show large transverse polarization. Could be NP or some new SM effects.

- Further puzzle: Not all penguin dominated modes have large transverse polarizations: $B_d \to K^{0*} \bar{K}^{0*}$ has $f_L \sim 80$ % while $B_s \to K^{0*} \bar{K}^{0*}$ has $f_L \sim 30$ %, $B \to VT$ dominated by penguins do not show large transverse polarization. Could be NP as NP will affect certain decays and not affect others.

$B_d \to \phi K^*$: *Polarization puzzle*

- $B \to \phi K^*$ is a $b \to s$ transition has 3 amplitudes: $A_L(A_0), A_-, A_+($ $A_\perp, A_\parallel)$

- 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

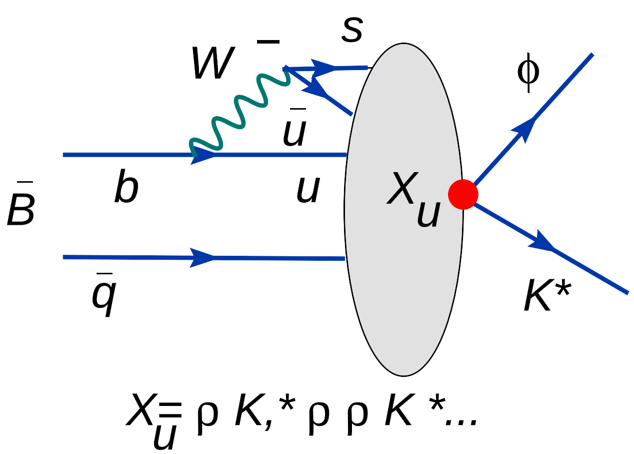
Decay	Final State	f_L
$B \to \phi K^*$	ϕK^{*0}	0.480 ± 0.030
	ϕK^{*+}	0.50 ± 0.05
$B_s \to \phi\phi$	$\phi\phi$	$0.348 \pm 0.18(stat) \pm 0.82$
$B \to \rho K^*$	$\rho^0 K^{*0}$	0.57 ± 0.12
	$\rho^+ K^{*0}$	0.48 ± 0.08
$B_d \to K^* \bar{K}^*$	$K^{*0} \bar{K}^{*0}$	$0.80^{+0.12}_{-0.13}$
	$K^{*+} \bar{K}^{*0}$	$0.75^{+0.16}_{-0.26}$
$B_s \to K^* \bar{K}^*$	$K^{*0} \bar{K}^{*0}$	$0.31 \pm 0.12 \pm 0.04$
$B \to \rho\rho$	$\rho^+ \rho^-$	$0.978^{+0.025}_{-0.022}$
	$\rho^0 \rho^0$	$0.75^{+0.12}_{-0.15}$
	$\rho^+ \rho^0$	0.950 ± 0.016

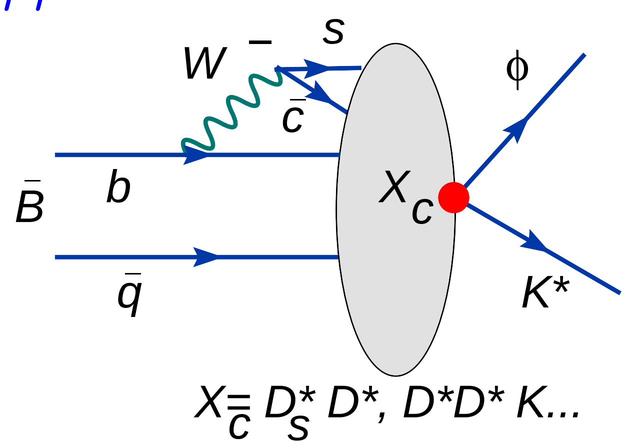
Table: Longitudinal polarization fraction f_L for various $B \to V_1 V_2$ decays

.

Solutions :Polarization puzzle

- Non standard SM effects: Rescattering, 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.

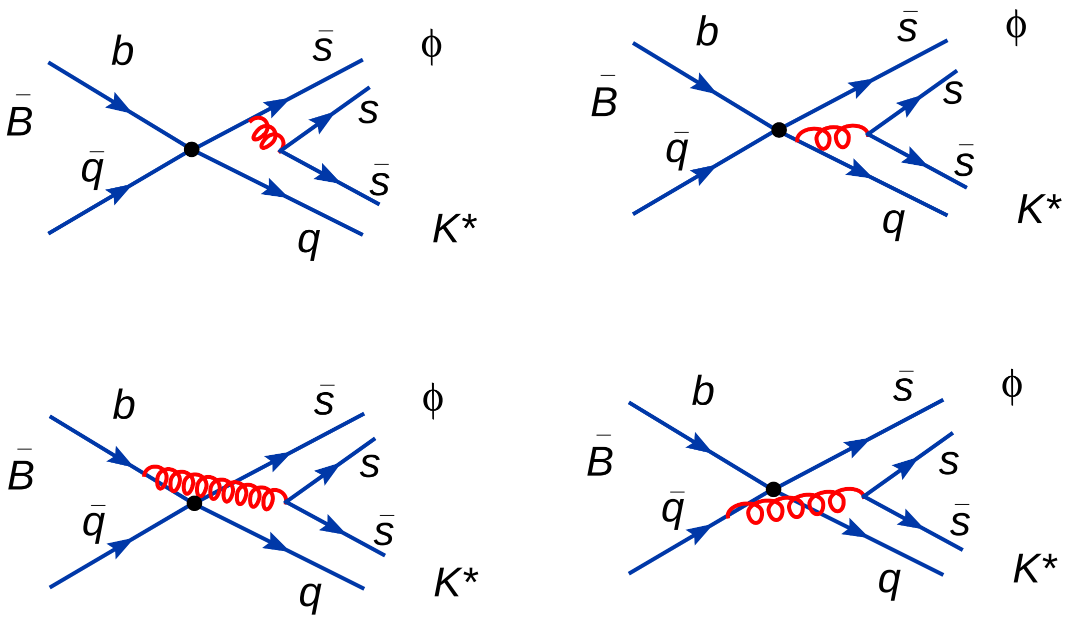




- But rescattering calculations predict: $f_+ \sim f_-$ but experiments give $f_- >> f_+$.

Penguin Annihilation

- 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.
- 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

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

  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 constrain the SM as well as NP explanations.

T.P and New Physics

- The transverse amplitudes are written in terms of helicity amplitudes

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

- 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.

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

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

  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.

Corrections to the heavy quark limit in QCDF

- There is a constraint:

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

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

- Note $\frac{f_\perp}{f_\|} = 1$ 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

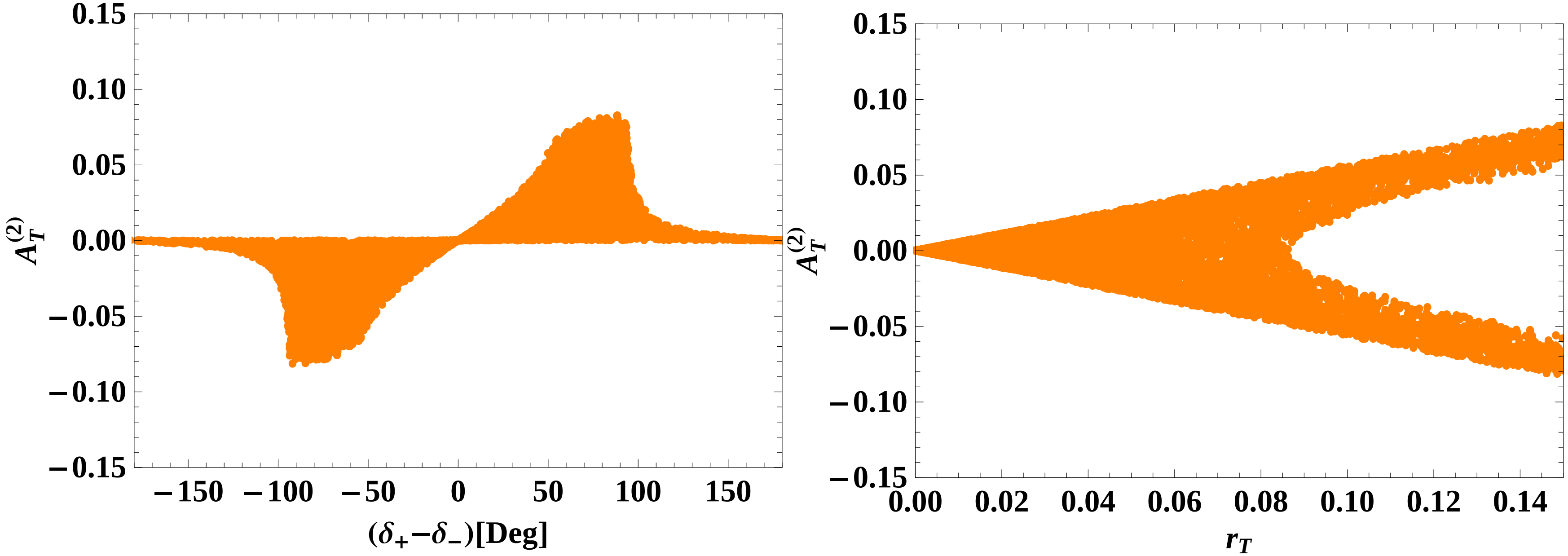


Figure: The left (right) panel of the figure shows $A_T^{(2)}$ for the decay $B_d \to \phi K^{*0}$ as a function of $(\delta_+ - \delta_-)$ and r_T.

- There we see that $|A_T^{(2)}| \leq 9\%$ 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.

Corrections to the heavy quark limit

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

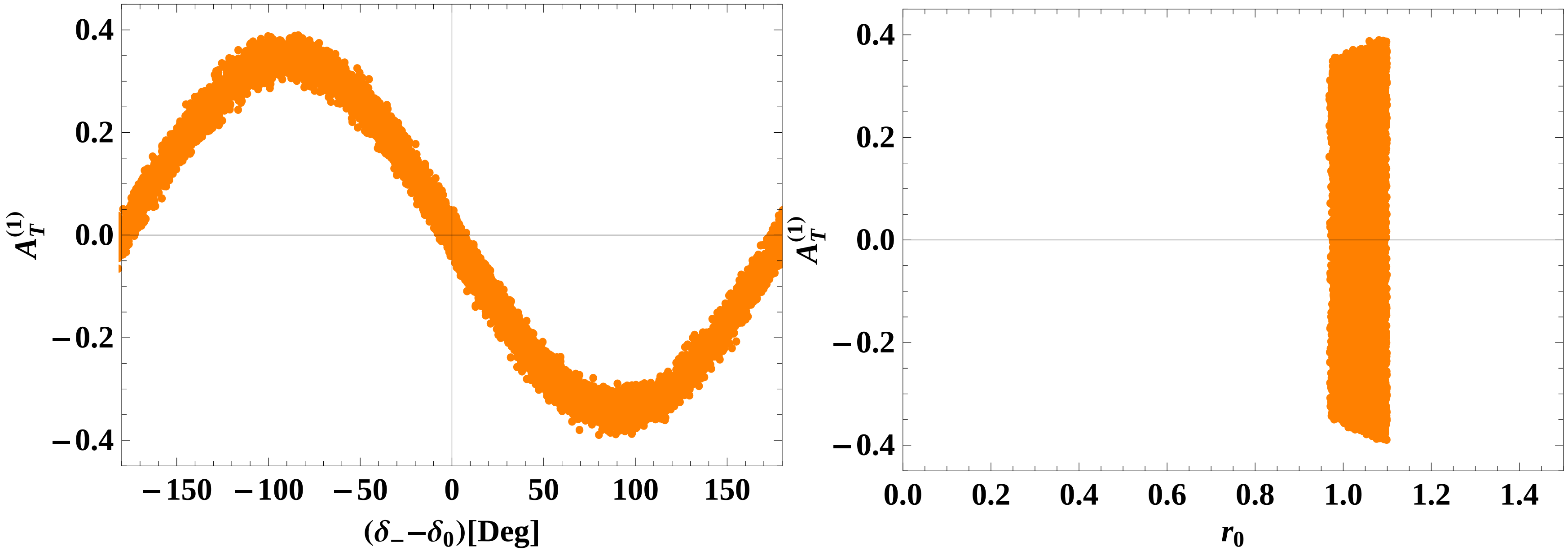


Figure: The left (right) panel of the figure shows $A_T^{(1)}$ for the decay $B_d \to \phi K^{*0}$ as a function of $(\delta_+ - \delta_-)$ (r_T).

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

Experiments

- The relevant $B_d \to \phi K^{*0}$ polarization observables are shown in Table below.
-

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 .

- 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 large f_T.

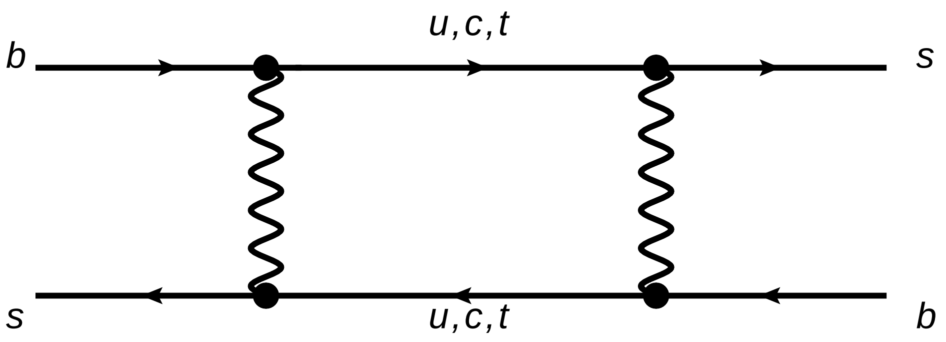
- NP: Assume $f_T^{SM} = 0$. In the heavy-quark limit, $A_+ = 0$ in the ST_{LL} scenario, so that $A_\| = -A_\perp$ (as in the SM) and $A_T^{(2)} = 0$.
  Similarly, ST_{RR} predicts that $A_- = 0$, so that $A_\| = A_\perp$ and $A_T^{(2)} = 0$.

- 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.

Angular Distribution with $B_{s,d}$ mixing

- Can we use additional measurements to constrain the NP scenarios? We can use decays like $B_s \to \phi\phi(\bar{b} \to \bar{s}s\bar{s}), K^*\bar{K}^*(\bar{b} \to \bar{s}d\bar{d})$. Here the final state can be reached by both B_s and $\overline{B}_s$ decays so mixing effects have to be included

- Focussing on B_s: In the SM, $B_s^0 - \overline{B_s^0}$ mixing occurs at one-loop level by flavor-changing box diagram



- The phase of B_s mixing in the SM comes from $V_{ts}V_{tb}^*$ and is tiny $(\phi_s = -2\beta_s^{SM} = -0.04)$.

- Latest, LHCb measured ϕ_s in radian from $B_s(t) \to J/\psi\phi$

$$\phi_s = 0.001 \pm 0.101(stat) \pm 0.027(syst)$$

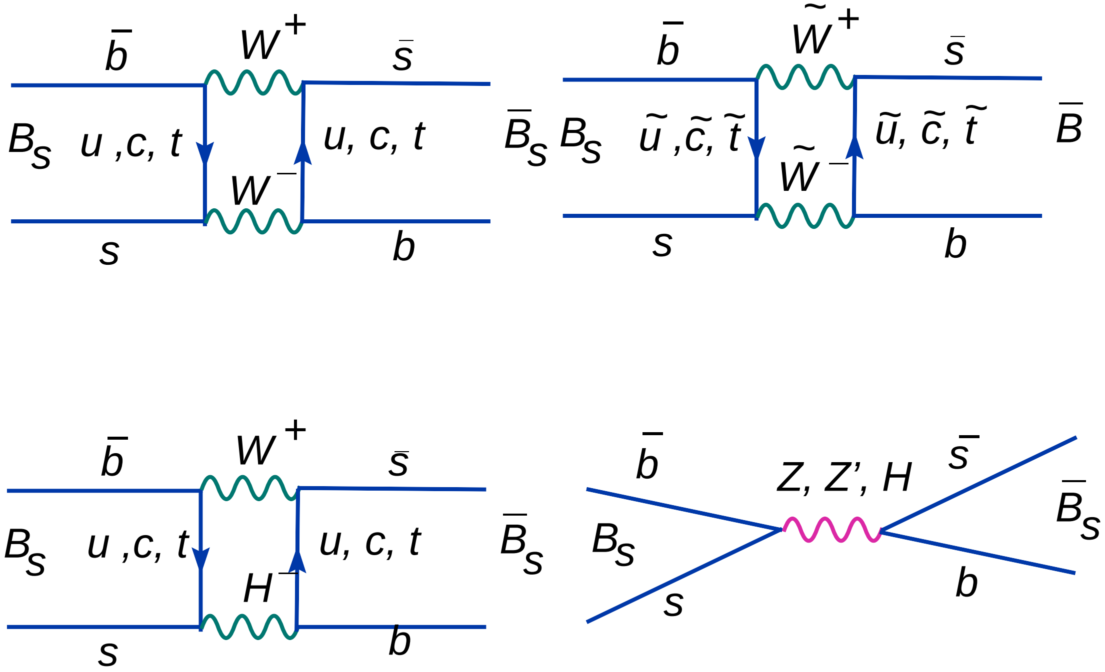
$$\Gamma_s = 0.6580 \pm 0.0054(stat) \pm 0.0066(syst) psinverse$$

$$\Delta\Gamma_s = 0.116 \pm 0.018(stat) \pm 0.006(syst) psinverse$$

$\Longrightarrow$ good agreement with the Standard Model prediction
One can have new physics in the mixing and in the decay. Measure ϕ_s using penguin decays: $B_s \to \phi\phi$, $B_s \to K^{0*}\bar{K^{0*}}$.

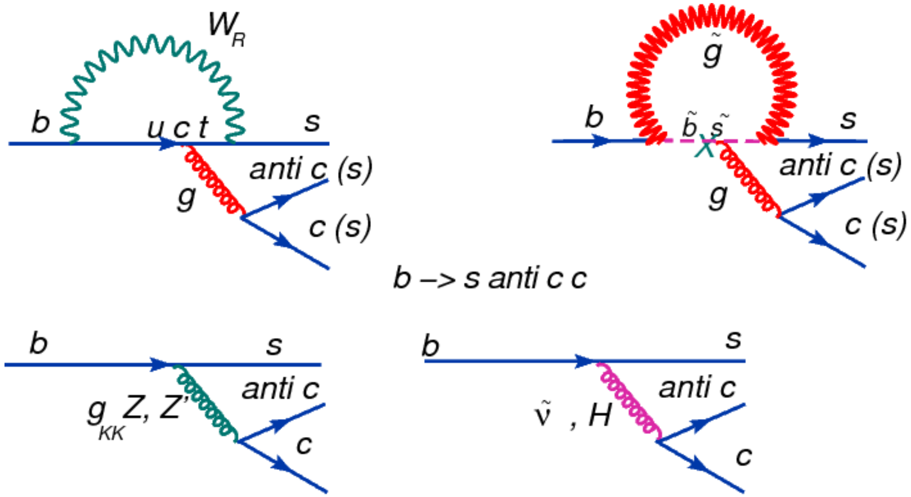
$\mathcal{NP}$ in B_s Mixing.

- Many New Physics models can contribute to the phase of $B_s^0 - \overline{B_s^0}$ mixing. Some at loop level and some even at tree level.



- However, most (if not all) New Physics models that contribute to B_s mixing also contribute to the $b \to s\bar{q}q$ decays and hence to $B_s \to \phi\phi$, $B_s \to K^{0*}\bar{K}^{0*}$.

- In general, new physics models that contribute to B_s mixing also contribute to the decay $\bar{b} \to \bar{s}s\bar{q}q$



- $B \to V_1 V_2$ are no longer dominated by a single amplitude. This changes the angular distribution of the decay and hence the interpretation of the $B_s^0 - \overline{B_s^0}$ mixing phase (β_s).

Time dependent AD: $B \to V_1 V_2$

- Due to B_q^0-$\bar{B}_q^0$ mixing, the amplitude for the decay is time dependent. Assuming that $V_{1,2}$ both decay into pseudoscalars (i.e. $V_1 \to P_1 P_1'$, $V_2 \to P_2 P_2'$), the angular distribution of the decay is then given in terms of the vector $\vec{\omega} = (\cos\theta_1, \cos\theta_2, \Phi)$:

$$\frac{d^3\Gamma(t)}{d\vec{\omega}} = \frac{9}{32\pi} \sum_{i=1}^{6} K_i(t) f_i(\vec{\omega}) \ .$$

- Functions $K_i(t)$ are expressed in terms of ϕ_q , Γ_q , $\Delta\Gamma_q$, the B_q^0 oscillation frequency Δm_q and transversity amplitudes $A_{i(=0,\|,\perp)}$

- In the presence of both standard model and NP contributions,the untagged time dependent angular distribution for $B \to V_1 V_2$ decay:

$$\frac{d^4(\Gamma^{B_s} + \Gamma^{\bar{B}_s})}{dt d\vec{\omega}} = \frac{9}{32\pi} \sum_{i=1}^{6} (K_i(t) + \bar{K}_i(t)) f_i(\vec{\omega})$$

Time dependent AD: $B \to V_1 V_2$

- $$\begin{aligned} K_1(t) + \bar{K}_1(t) &= e^{-\Gamma t}\Bigg[\cosh\left[\frac{\Delta\Gamma t}{2}\right]\left(|A_0|^2 + |\bar{A}_0|^2\right) \\ &\quad -2\mathrm{Re}[\bar{A}_0 A_0^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M \\ &\quad -2\mathrm{Im}[\bar{A}_0 A_0^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Bigg] , \\ K_2(t) + \bar{K}_2(t) &= e^{-\Gamma t}\Bigg[\cosh\left[\frac{\Delta\Gamma t}{2}\right]\left(|A_\|{}|^2 + |\bar{A}_\|{}|^2\right) \\ &\quad -2\mathrm{Re}[\bar{A}_\| A_\|^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M \\ &\quad -2\mathrm{Im}[\bar{A}_\| A_\|^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Bigg] , \end{aligned}$$

Time dependent AD: $B \to V_1 V_2$

- $$\begin{aligned}
K_3(t) + \bar{K}_3(t) &= e^{-\Gamma t}\Bigg[\cosh\left[\frac{\Delta\Gamma t}{2}\right]\left(|A_\perp|^2 + |\bar{A}_\perp|^2\right) \\
&\quad + 2\mathrm{Re}[\bar{A}_\perp A_\perp^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M \\
&\quad + 2\mathrm{Im}[\bar{A}_\perp A_\perp^*]\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Bigg]\ , \\
K_4(t) + \bar{K}_4(t) &= e^{-\Gamma t}\Bigg[\left(\mathrm{Im}[A_\perp A_\parallel^*] - \mathrm{Im}[\bar{A}_\perp \bar{A}_\parallel^*]\right) \\
&\quad \left(\cosh\left[\frac{\Delta\Gamma t}{2}\right] - \sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M\right) \\
&\quad - \left(\mathrm{Re}[A_\perp \bar{A}_\parallel^*] + \mathrm{Re}[\bar{A}_\perp A_\parallel^*]\right)\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Bigg]\ ,
\end{aligned}$$

- $$\begin{aligned} K_5(t) + \bar{K}_5(t) &= e^{-\Gamma t}\Big[\cosh\left[\frac{\Delta\Gamma t}{2}\right]\Big(\mathrm{Re}[A_{\|}A_0^*] + \mathrm{Re}[\bar{A}_{\|}\bar{A}_0^*]\Big) \\ &\quad -\Big(\mathrm{Re}[A_{\|}\bar{A}_0^*] + \mathrm{Re}[\bar{A}_{\|}A_0^*]\Big)\sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M \\ &\quad +\Big(\mathrm{Im}[A_{\|}\bar{A}_0^*] - \mathrm{Im}[\bar{A}_{\|}A_0^*]\Big)\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Big]~, \\ K_6(t) + \bar{K}_6(t) &= e^{-\Gamma t}\Big[\Big(\mathrm{Im}[A_{\perp}A_0^*] - \mathrm{Im}[\bar{A}_{\perp}\bar{A}_0^*]\Big) \\ &\quad \Big(\cosh\left[\frac{\Delta\Gamma t}{2}\right] - \sinh\left[\frac{\Delta\Gamma t}{2}\right]\cos\phi_M\Big) \\ &\quad -\Big(\mathrm{Re}[A_{\perp}\bar{A}_0^*] + \mathrm{Re}[\bar{A}_{\perp}A_0^*]\Big)\sinh\left[\frac{\Delta\Gamma t}{2}\right]\sin\phi_M\Big]~. \end{aligned}$$

Measurements.

- CDF and LHCb have made measurements of the untagged time integrated quantities.
- Observe large f_T. The T.P are zero in the SM.
- The T.P terms have been measured. No tagging necessary. No time dependence is necessary.
- If we assume new physics we should use the correct angular distribution with NP.
- Can we fit to the NP and ϕ_s

Fit to new physics.

- Can we use these observables to fit to NP and ϕ_s ?
- Case1: If there is one new weak phase. The decay amplitude for each of the three possible helicity states in $B \to V_1 V_2$ decays may be written as,

$$
\begin{aligned}
A_\lambda \equiv Amp(B \to V_1 V_2)_\lambda &= a_\lambda e^{i\delta_\lambda^a} + b_\lambda e^{i\phi} e^{i\delta_\lambda^b} \ , \\
\bar{A}_\lambda \equiv Amp(\bar{B} \to (V_1 V_2)_\lambda &= a_\lambda e^{i\delta_\lambda^a} + b_\lambda e^{-i\phi} e^{i\delta_\lambda^b} \ ,
\end{aligned}
$$

- Here $a_\lambda \equiv$ SM and $b_\lambda \equiv$ NP.
- ϕ is the new CP violating phases and the δ's are the strong phases.

New Physics- one weak phase

- There are 6 magnitudes(3 SM, 3 NP), 5 relative phases, weak phase ϕ and the mixing phase ϕ_s making a total of 13 parameters.
- However for the SM we can use $a_\perp = -a_\parallel$ which we found to have small $1/m_b$ correction. This reduces the number of unknowns to 11.
- If NP is pure lefthanded or right handed then $b_\perp = \mp b_\parallel$. So there are 9 independent parameters.

New Physics- one weak phase

- With the time integrated quantities we have only 6 measurements to fit 9 parameters. Not possible for NP fit.
- If we can measure time dependent measuremenst and isolate the $\cosh \Delta\Gamma t/2$ and $\sinh \Delta\Gamma t/2$ then there are 12 measurements and a fit can be done.
- If ultimately a tagged distribution can be measured then we can fit to most general physics.

New Physics- more than one weak phase

- As shown in (Datta and London) to a first approximation we can ignore the NP strong phases if $|b_\lambda| < |a_\lambda|$.

$$A_\lambda \equiv Amp(B \to V_1 V_2)_\lambda = a_\lambda e^{i\delta^a_\lambda} + b_\lambda e^{i\phi^b_\lambda} ,$$

  There are 6 magnitudes(3 SM, 3 NP), 3 strong phases δ_λ, 3 weak phase ϕ_λ and the mixing phase ϕ_s making a total of 13 parameters. Cannot be determined from 9 measurements.

- However for the SM and NP we can use $a_\perp = -a_\parallel$, $b_\perp = \mp b_\parallel$. This reduces the number of unknowns to 9. So we can fit to the data.
- Nice to do the fit -need the data. Similar ideas can be applied to untagged $B_s \to \phi l^+ l^-$ decays

Conclusions

- $B \to V_1 V_2$ decays are good places to look for NP. In $\bar{b} \to \bar{s}$ transitions CPV in the SM is tiny but NP can produce measurable effects even with the present experimental constraints
- Present measurements already constrain the NP explanation of the polarization puzzle in $B \to V_1 V_2$ decays.
- Time dependent decays offer additional probes of NP. Untagged decays can measure T.P.A which are absent in the SM.
- The untagged distribution give us enough observables that can be used to fit to certain classes of new physics and measure ϕ_s.