

New Physics from $B \rightarrow VV$ Decays

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Introduction:

- Hints of Deviation from SM in several decays
 - $B \rightarrow \phi K_S$, $B \rightarrow \phi K^*$, $B \rightarrow K\pi \dots$
- Question: If effects are real
 - Can we identify nature of N.P
 - Can we measure ^{effective} parameters of the N.P

Ans : Yes - specially with $B \rightarrow VV$ Decays

- $B(p) \rightarrow V_1(k_1, \epsilon_1) V_2(k_2, \epsilon_2) (\phi K^*)$

$$M = a \epsilon_1^* \cdot \epsilon_2^* + \frac{b}{m_B^2} (p \cdot \epsilon_1^*)(p \cdot \epsilon_2^*)$$

$$+ i \frac{c}{m_B^2} \epsilon_{\mu\nu\rho\sigma} p^\mu q^\nu \epsilon_1^{*\rho} \epsilon_2^{*\sigma}$$

$$q = k_1 - k_2$$

$\sim \vec{q} \cdot (\vec{\epsilon}_1 \times \vec{\epsilon}_2)$
rest frame of B

- Three partial waves: c is P wave, a and b are combination of S and D.

- T.P: $A_T \sim Im(bc^*)$ and $\sim Im(ac^*)$: Interference between P-even and P-odd amplitudes

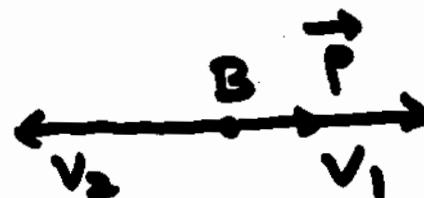
$$\bar{A}_T \sim Im(\bar{b}\bar{c}^*) \text{ and } \sim Im(\bar{a}\bar{c}^*)$$

T-violation- Another Probe of CP(T) violating NP phases (Datta and London)

- If CPT is conserved (local and Lorentz invariant field theory) then
CP violation implies T violation .
- T-violation in B decays can be measured via Triple Product Correlations(TP)
- Triple Products are products of vectors of the type
 $T.P = \vec{v}_1 \cdot (\vec{v}_2 \times \vec{v}_3)$
 \vec{v}_i are spin or momentum vectors.
- Under time reversal T: $t \rightarrow -t$
 $T.P \rightarrow -T.P$
- In $B \rightarrow V_1 V_2$ decays we can construct the T.P

$$T.P = \vec{p} \cdot (\vec{\epsilon}_1 \times \vec{\epsilon}_2)$$

$B \rightarrow \text{spin } 0$



- We can define a T-odd asymmetry

$$A_T = \frac{\Gamma[T.P > 0] - \Gamma[T.P < 0]}{\Gamma[T.P > 0] + \Gamma[T.P < 0]}$$

- A_T is not a measure of true T-violation: $A_T \neq 0$ with strong phases and no weak phase.
- For true T violation we need to compare A_T and \bar{A}_T (T-odd asymmetry for the C.P conjugate process)

eg:

$$A_T (B \rightarrow \Phi K^*)$$

$$\bar{A}_T (\bar{B} \rightarrow \bar{\Phi} \bar{K}^*)$$

$\neq \Rightarrow A_T$ and \bar{A}_T disagree

$$\propto \text{Cos}(\delta_1 - \delta_2) \text{Sin}(\phi_1 - \phi_2)$$

N.B: Direct CP $\propto \text{Sin}(\delta_1 - \delta_2) \text{Sin}(\phi_1 - \phi_2)$

$B \rightarrow \phi K^*$ (Pol Puzzles)

$B \rightarrow VV$ 3 amp S, P, D

$$\text{Helicity: } (0,0) \quad (+,+), (-,-) \quad \underbrace{\qquad}_{A_L} \quad A_T \equiv A_{\perp}, A_{||}$$

$$A_L \qquad \qquad \qquad A_{\perp} \sim P$$

$$m_V \ll m_B \quad \epsilon_L^V \sim p_V/m_V \quad E_T \sim O(1)$$

SM ($V-A$)

$$A_L \sim \epsilon_L^1 \cdot \epsilon_L^2 \sim \frac{p_1 \cdot p_2}{m^2} \sim \frac{m_B^2}{m^2}$$

$$A_T \sim \epsilon_T^1 \cdot \epsilon_T^2 \sim 1$$

$$A_L = -(2a+b) \frac{E^2}{m_1 m_2}$$

$$f_L = \frac{\Gamma_L}{\Gamma_L + \Gamma_T} \sim 1$$

$$\begin{cases} A_{||} \sim \sqrt{2} a \\ A_{\perp} \sim \sqrt{2} c \end{cases}$$

$$B \rightarrow gg \quad (b \rightarrow d) \quad f_L \sim 1$$

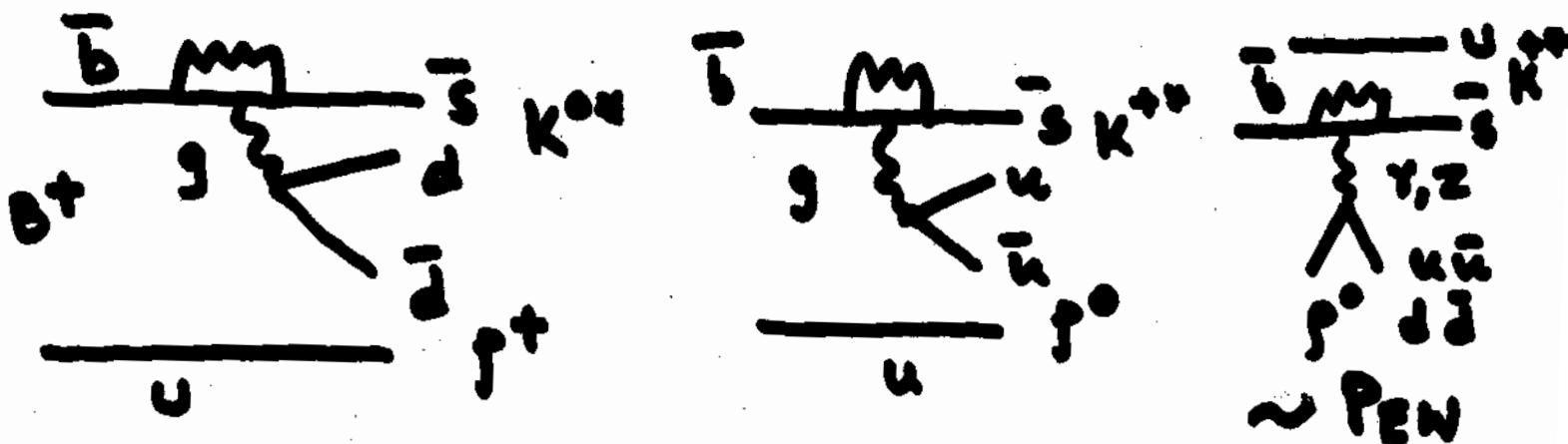
$$B \rightarrow \phi K^* \quad (b \rightarrow s \bar{s}) \quad f_L = 0.52 \pm 0.04$$

Resolution of Pol Puzzle

SM: Estimation of factorization
incorrect

- Large Rescattering
- Large Annihilation

Imp Question: What are the predictions for $B \rightarrow g K^{\ast\ast}$



NP fits to KIT suggest new physics
in PEW \Rightarrow NP couples to u and d differently

- Diff in measurement in $B^+ \rightarrow g^+ K^{*0}$
and $B^+ \rightarrow g^0 K^{*0}$ would be interesting!

Pol Puzzle :

Can be explained by N.P which is not SM like

$$\text{eg } \langle \Phi K^* | H_{V+A} | B \rangle \sim (-)^{L+1} \langle \Phi K^* | H_{V-A} | B \rangle$$

$$A_\perp = A_{SM}^+ + \text{NP}$$

$$A_0 = A_{SM}^0 - \text{NP}$$

$$\text{T.P.} \sim \langle \vec{\epsilon}_1 \times \vec{\epsilon}_2 \cdot \hat{P} \rangle$$

$$\text{T.P.} (B + \Phi K^*) = 0 \text{ (single amp)}$$

$$\text{T.P.} = \begin{matrix} 0.11 \pm 0.05 \pm 0.01 & (\text{BABAR}) \\ 0.07 \pm 0.11 \pm 0.04 & (\text{BELLE}) \end{matrix}$$

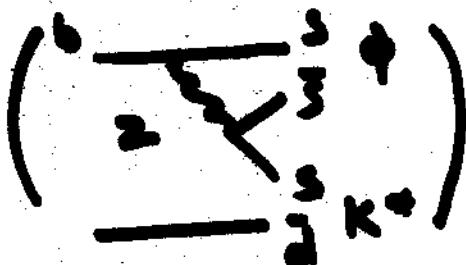
$$\text{Av: } 0.10 \pm 0.05 \sim 2\sigma$$

Non zero TP \Rightarrow NP and new weak phase
 \Rightarrow non-SM like physics

New Physics in $B \rightarrow \phi K^*$

- Suppose there is a new physics contribution which is SM like- involving new left-handed coupling of the b quark.

$$A \sim g_\phi \langle K^* | V - A | B \rangle X_{SM} + g_\phi \langle K^* | V - A | B \rangle X_{NP}$$



- We can combine X_{SM} and X_{NP} - still only one phase here $X = X_{SM} + X_{NP}$ and so $A_T = 0$. In other words

$$a \sim g_\phi A_1 [X_{SM} + X_{NP}]$$

$$b \sim g_\phi A_2 [X_{SM} + X_{NP}]$$

$$c \sim g_\phi V [X_{SM} + X_{NP}]$$

a and b are proportional to the axial vector form factors $A_{1,2}$ while c is proportional to vector form factor V

- $A_T \sim \text{Im}(bc^*) = \text{Im}(|X|^2) = 0 = \text{Im}(ac^*)$

No T-violation even with N.P if N.P is SM type(LH interaction)!

Even though there is N.P it is kinematically similar to SM

New Physics in $B \rightarrow \phi K^*$

- Suppose there is a new physics contribution which is not SM like- e.g involving new right-handed coupling of the b quark.

$$A \sim g_\phi \langle K^* | V - A | B \rangle X_{SM} + g_\phi \langle K^* | V + A | B \rangle X_{NP}$$

$$a \sim (X_{SM} - X_{NP})$$

$$b \sim (X_{SM} - X_{NP})$$

$$c \sim (X_{SM} + X_{NP})$$

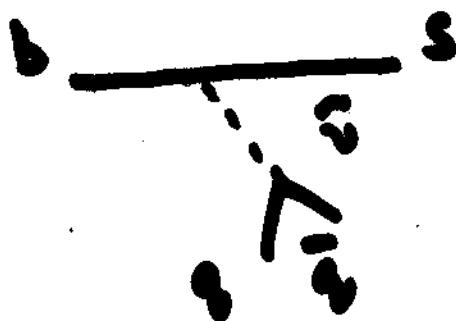
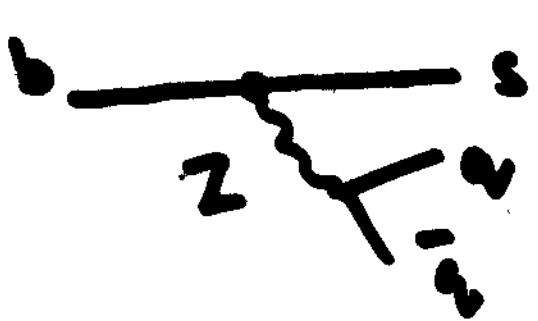
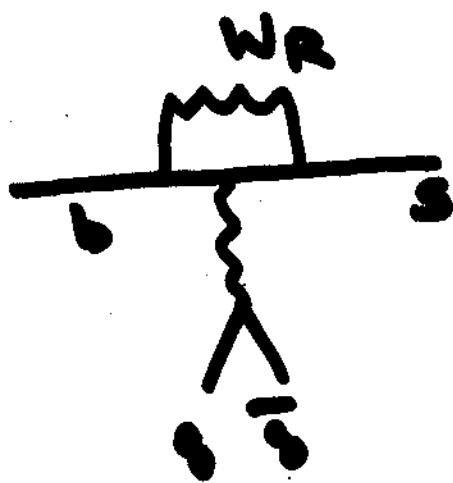
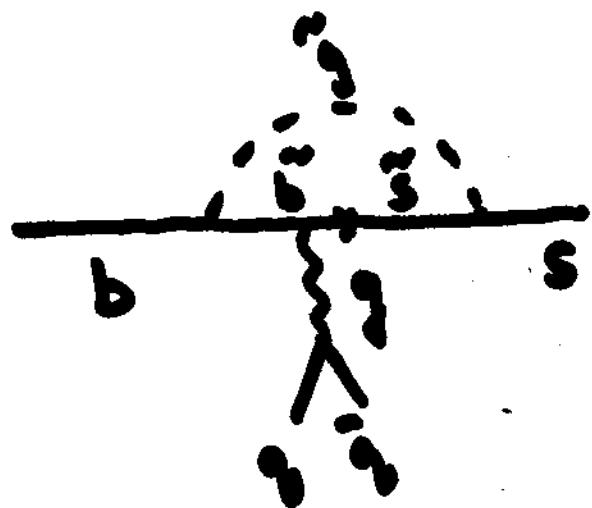
- Clearly now $A_T \sim \text{Im}(X_{SM} X_{NP}^*) \neq 0$

$$A_T \sim \text{Im}(bc^*)$$

- Hence non zero measurement of T violation in $B \rightarrow \phi K^*$ not only indicates presence of new physics but also yields information (partially) about the nature of new physics. — RH b coupling

Parametrizing NP

Many models of NP contribute
to rare B decays



- At m_b scale effect of NP

$$H_{NP} \sim \sum \bar{s}_i P_i \cdot g \bar{s}_i P_i \cdot b + \text{color}$$

↳ 4 quark operator

$$H = H_{SM} + H_{NP}$$

- 20 new operators

For each process $B \rightarrow f$

$$\langle f | \sum O_i^{NP} | B \rangle = \sum A_i e^{i \Phi_i^{NP}} e^{i \delta_i^{NP}}$$

Φ_i^{NP} → process independent (weak phase)

A_i, δ_i^{NP} → process dependent

- Argue $\delta_i^{NP} \sim \text{small}$
- δ_i^{SM} may be large

{ Delta London
PLB }

{ Delta et al
PRD
PRD }

$$\langle f | \sum O_i^{NP} | B \rangle = \sum A_i e^{i \Phi_i^{NP}}$$

$$= A_{NP} e^{i \sum \Phi_i^{NP}}$$

can measure
 A_{NP}, Φ^{NP}

$$\tan \bar{\Phi}^{NP} = \frac{\sum A_i \sin \Phi_i^{NP}}{\sum A_i \cos \Phi_i^{NP}}$$

$B \rightarrow V_1 V_2$

- Consider decays with quark level transitions

$$\bar{B} \rightarrow \bar{c} c \bar{s}, \bar{B} \rightarrow \bar{s} s \bar{s}, \bar{B} \rightarrow \bar{s} d \bar{d}$$

- In SM dominated by single amp
 - weak phase ~ 0

$$A_\lambda (B \rightarrow V_1 V_2) = \underbrace{g_\lambda e^{i\delta_\lambda}}_{SM} + A_\lambda^q e^{i\phi_q^\lambda} \quad \text{NP}$$

$$\bar{A}_\lambda (\bar{B} \rightarrow V_1 V_2)_\lambda = g_\lambda e^{i\delta_\lambda} + A_\lambda^q e^{-i\phi_q^\lambda}$$

$$q = s \quad (\bar{B} \rightarrow \bar{s} s \bar{s} \text{ etc.}) \quad \lambda \rightarrow \text{ helicity}$$

Time dependent angular analysis

$$\Gamma [B(t) \rightarrow V_1 V_2] = e^{-pt} \sum_{\lambda \leq r} [\Lambda_{\lambda r} \pm \sum_{\lambda r} (n(4mt) \\ \mp p_{\lambda r} \sin(4mt)) j_\lambda] r$$

• $\Lambda, \Sigma, p \rightarrow 18$ obs

$$\Lambda_{\perp i} = -\text{Im} (A_{\perp} A_i^* - \bar{A}_{\perp} \bar{A}_i^*) \rightarrow \text{T.P}$$
$$i = \{0, 11\}$$

• $A(B \rightarrow V_1 V_2) \rightarrow 3$ amp

$A(\bar{B} \rightarrow V_1 V_2) \rightarrow 3$ amp

11 independent obs = 6 amp + 5 relative phases.

(count # unknowns: $a_\lambda(3), \delta_\lambda(2)$
 $A_\lambda^*(3), \Phi_q^\lambda(3), \Phi_{\text{mixing}}(\text{known}) = 12$

12 unknowns 11 obs = cannot
solve

Many classes of NP have

- one dominant weak phase
- or universal weak phase

$$\Rightarrow \Phi_q^\lambda = \Phi^0 \text{ (helicity independent)}$$

Now 10 unknowns, 11 obs

- can solve (fit)

A_λ^s, Ξ_s measured from $B \rightarrow \phi K^*$

$$B_S \rightarrow \phi \phi$$

A_λ^d, Ξ_d " " $B \rightarrow K^{0*} \rho^0$

$$B_S \rightarrow K^{0*} \bar{K}^{0*}$$

A_λ^c, Ξ_c " " $B \rightarrow D_S^{*+} \bar{D}_S^{*-}$

Conclusion s

- Hints of NP in several decays
- In $B \rightarrow VV$ polarization and T.P may reveal sign and nature of N.P
- Full time dependent angular analysis can be used to measure "effective" parameters of N.P