# Interesting Signals in B and Tau Decays

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# Outline

- Standard Model( SM) Signals:
- The $B_d \to K^0 \bar{K}^0$ decays and measuring $\alpha$.
- Polarization Puzzles and testing explanations of the puzzles using $b \to d$ penguin dominated processes.
- Large Triple Products in $B_d \to K^{0*} \bar{K}^{0*}$ and other $b \to d$ penguin dominated processes.

- New Physics( NP) Signals:
- The $B \to K\pi$ decays and fitting NP parameters.
- The $B \to \rho K^*$ decays and polarization predictions. $B \to VT$ Decays.

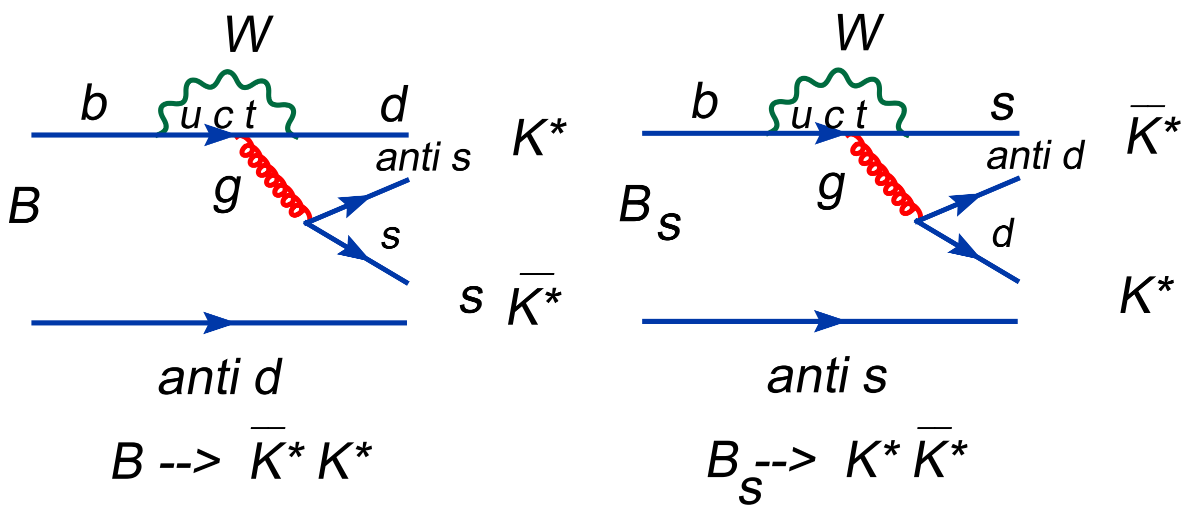
# Outline

- $b \to s$ Penguin/ Penguin Dominated $B \to VV$ Decays and measuring NP parameters.

- CP violation with hadronic tau decays.

- Conclusions.

# $B_d \to K^0 \bar{K}^0$ Decays




- This is a pure penguin process and hence sensitive to new physics.

- In general there are contributions from each of the internal quarks $u$, $c$ and $t$. However, using the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, one can eliminate the $c$-quark contribution and write

$$\mathcal{A} \equiv \mathcal{A}(B_d^0 \to K^0 \bar{K}^0) = V_{ub}^* V_{ud}[(P_u - P_c)] + V_{tb}^* V_{td}[(P_t - P_c)] \, .$$

# $B_d \to K^0\bar{K}^0$ Decays

$$\mathcal{A} \equiv \mathcal{A}(B_d^0 \to K^0\bar{K}^0) \;=\; V_{ub}^* V_{ud}[(P_u - P_c)] + V_{tb}^* V_{td}[(P_t - P_c)] \; .$$

• The amplitude $\bar{A}$ describing the conjugate decay $\bar{B}_d^0 \to K^0\bar{K}^0$ can be obtained from the above by changing the signs of the weak phases.

•The amplitudes $\mathcal{A}$ and $\bar{\mathcal{A}}$ thus depend on four unknown parameters:

$$\mathcal{P}_{tc} \equiv |[(P_t - P_c)]V_{tb}^* V_{td}|,$$

$$\mathcal{P}_{uc} \equiv |[(P_u - P_c)]V_{ub}^* V_{ud}|,$$

and the relative strong phase $\Delta \equiv \delta_{uc} - \delta_{tc}$, and the weak phase $\alpha$.

# $B_d \to K^0 \bar{K}^0$ Decays

• There are three measurements which can be made of $B_d^0 \to K^0 \bar{K}^0$: the branching ratio, and the direct and mixing-induced CP-violating asymmetries. These yield the three observables

$$
\begin{aligned}
X &\equiv \frac{1}{2}\left(|A|^2 + |\bar{A}|^2\right) = \mathcal{P}_{uc}^2 + \mathcal{P}_{tc}^2 - 2\mathcal{P}_{uc}\mathcal{P}_{tc}\cos\Delta\cos\alpha ~, \\
Y &\equiv \frac{1}{2}\left(|A|^2 - |\bar{A}|^2\right) = -2\mathcal{P}_{uc}\mathcal{P}_{tc}\sin\Delta\sin\alpha ~, \\
Z_I &\equiv \mathrm{Im}\left(e^{-2i\beta}A^*\bar{A}\right) = \mathcal{P}_{uc}^2\sin 2\alpha - 2\mathcal{P}_{uc}\mathcal{P}_{tc}\cos\Delta\sin\alpha ~.
\end{aligned}
$$

• One can partially solve the equations to obtain

$$
\begin{aligned}
\mathcal{P}_{tc}^2 &= \frac{Z_R\cos 2\alpha + Z_I\sin 2\alpha - X}{\cos 2\alpha - 1}, \\
Z_R^2 &= X^2 - Y^2 - Z_I^2.
\end{aligned}
$$

• Hence we need a theory input to solve for $\alpha$. We will discuss 2 possible theory inputs to solve for $\alpha$.

# Theory Input 1

• Using flavor SU(3) $\mathcal{P}_{tc}$ can be obtained from $B_s \to K^0 \bar{K}^0$. The amplitude for $B_s \to K^0 \bar{K}^0$ is given by

$$\begin{aligned} \mathcal{A}(B_s \to K^0 \bar{K}^0) &= V_{ub}^* V_{us} (P'_u - P'_c) \\ &\quad + V_{tb}^* V_{ts} (P'_t - P'_c) \ , \\ &\approx V_{tb}^* V_{ts} (P'_t - P'_c), \end{aligned}$$

where the prime indicates a $\bar{b} \to \bar{s}$ transition.

• The decay $B_s \to K^0 \bar{K}^0$ thus basically involves only $P'_{tc} \equiv |(P'_t - P'_c) V_{tb}^* V_{ts}|$, and this quantity can be obtained from its branching ratio.

• In the limit of perfect flavor SU(3) symmetry, $P'_{tc} = \mathcal{P}_{tc}$, apart from known CKM matrix elements. Thus, the measurement of $P'_{tc}$ gives the necessary theory input for extracting $\alpha$ from $B_d^0 \to K^0 \bar{K}^0$.

# Theory Input 2

• Rewrite amplitude - eliminate the $t$-quark contribution from the penguin amplitude

$$\mathcal{A}(B_d^0 \to K^0 \bar{K}^0) \quad = \quad V_{ub}^* V_{ud} T + V_{cb}^* V_{cd} P \ ,$$

where $P \equiv (P_c - P_t)$ and $T = (P_u - P_t)$ are complex quantities.

• Compared to the previous parameterization

$$\begin{aligned} |P \, V_{tb}^* V_{td}| &= \mathcal{P}_{tc} \\ |(T - P) V_{ub}^* V_{ud}| &= \mathcal{P}_{uc} \end{aligned}$$

• Using experimental input,

$$\mathcal{P}_{uc}^2 \quad = \quad \frac{Z_R - X}{\cos 2\alpha - 1} \ .$$

• We need a theory input for $\mathcal{P}_{uc}$.

• In factorization approaches like QCDf, pQCD etc the difference $\Delta_d \equiv T - P$ is a well defined calculable quantity free of these dangerous IR divergences.

$$|\Delta_d| = (2.96 \pm 0.97) \times 10^{-7}\ \mathrm{GeV}\ .$$

• The errors in $|\Delta_d|$ can be reduced with further improvements in theory like better estimate of $m_c$, form factors(lattice) etc.

• Note that this method does not require the $B_s \to K^0 \bar{K}^0$ decays.

# The Polarization puzzle

• $B \to V_1 V_2$ has 3 amplitudes: $A_L(A_{00}), A_{--}, A_{++}$( $A_\perp, A_\parallel$)

• 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

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

Helicity $\Rightarrow A_L$ no helicity flip $\sim O(1)$
$A_{--}$ one helicity flip $\sim O(m_V/m_B)$. $m_V = m_{V_1,V_2}$.
$A_{++}$ two helicity flips $\sim O(m_V^2/m_B^2)$

For $B \to V_1 V_2$ where $V_{1,2}$ are light:

$$f_L >> f_{--} >> f_{++}$$

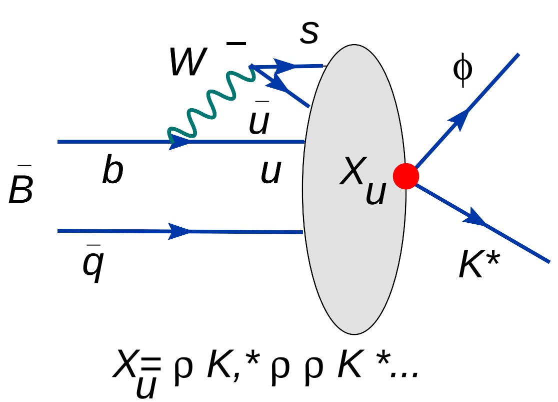
$$f_i = \frac{\Gamma_i}{\Gamma_{total}}$$

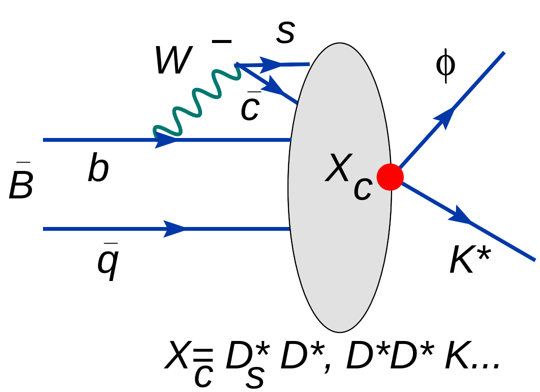
where $i = L, --, ++$.

•Expt: $f_L(B \to \rho\rho) = 1$ to a very good approximation.
$f_L(B \to \phi K^*) = 0.49 \pm 0.04 \Rightarrow f_T$ is large.

•Two main explanations have been put forward for the large $f_T$- Rescattering and Penguin Annihilation.

• RESCATTERING: rescattering is important for penguin decays and helicity arguments do not apply. Note $B \to \rho\rho$ is a tree dominated decay and rescattering is small.

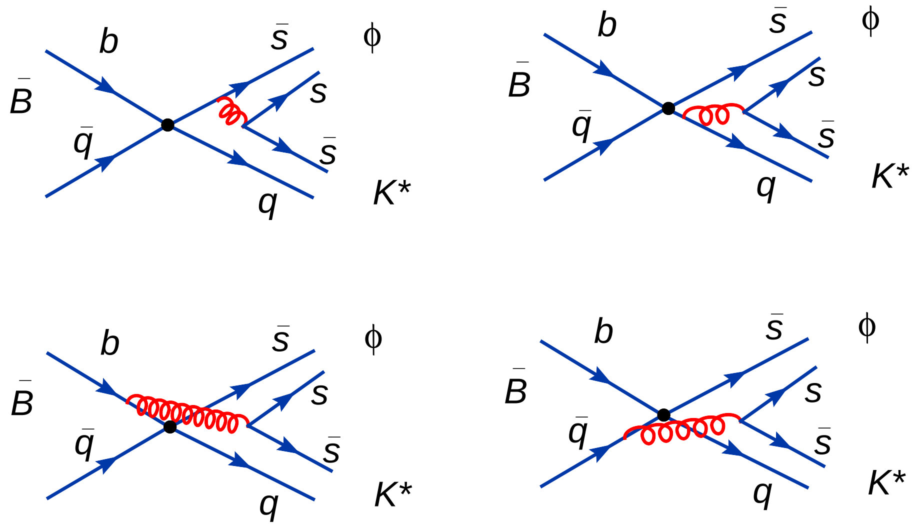



•But rescattering calculations predict: $f_{++} \sim f_{--}$ but experiments give $f_{--} >> f_{++}$.

# Penguin Annihilation

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




•Controversial: 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.

•Generic prediction -For penguin/penguin dominated decays to light final states $\frac{f_T}{f_L}$ is large.

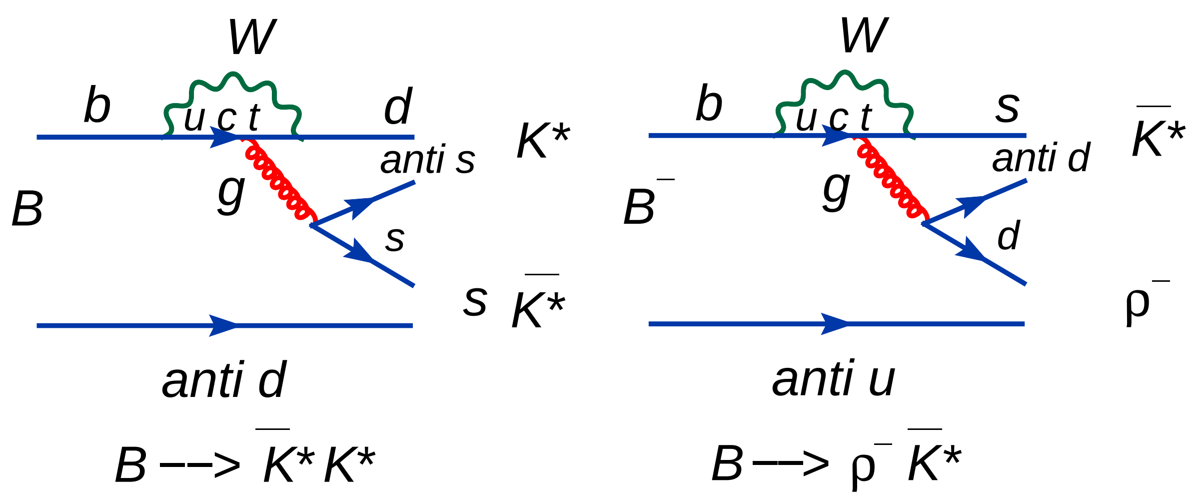
| Mode | $\mathcal{B}(10^{-6})$ | $f_L$ | $f_\perp$ |
|---|---|---|---|
| $\phi K^{*0}$ | $9.5 \pm 0.9$ | $0.49 \pm 0.04$ | $0.27^{+0.04}_{-0.03}$ |
| $\phi K^{*+}$ | $10.0 \pm 1.1$ | $0.50 \pm 0.05$ | $0.20 \pm 0.05$ |
| $\phi K_2^{*0}$ | $7.8 \pm 1.1 \pm 0.6$ | $0.853^{+0.061}_{-0.069} \pm 0.036$ | $0.045^{+0.049}_{-0.040} \pm 0.013$ |
| $\rho^+ K^{*0}$ | $9.2 \pm 1.5$ | $0.48 \pm 0.08$ | – |
| $\rho^0 K^{*0}$ | $5.6 \pm 1.6$ | $0.57 \pm 0.12$ | - |
| $\rho^- K^{*+}$ | $< 12.0$ | – | |
| $\rho^0 K^{*+}$ | $(3.6^{+1.9}_{-1.8})$ | $(0.9 \pm 0.2)$ | – |
| $K^{*0}\bar{K}^{*0}$ | $(0.49^{+0.16}_{-0.13} \pm 0.05)$ | $0.81^{+0.10}_{-0.12} \pm 0.06$ | – |

$$E_T = \frac{f_T^+ \mathrm{BR}^+ - 2 f_T^0 \mathrm{BR}^0}{f_T^+ \mathrm{BR}^+} \approx 0 \, .$$

# $b \to d$ Transitions

- So far large $f_T$ has been observed in $b \to s$ transitions.

$A_T \sim V_{cb} V_{cs}^* P_c$ ( Rescattering)
$A_T \sim V_{tb} V_{ts}^* P_t$ ( PA)
At present cannot distinguish PA from rescattering




- $f_T$ in penguin dominated $b \to d$ transitions should also be large in the SM.

- In SM $(f_T/f_L)_{\bar{K}^* K} \sim (f_T/f_L)_{\bar{K}^* \rho^-}$ and large.

# $B \to V_1 V_2$ Decays

- Time dependent angular analysis give,

$$\Gamma(\overset{(-)}{B}(t) \to V_1 V_2) = e^{-\Gamma t} \sum_{\lambda \leq \sigma} \Big( \Lambda_{\lambda\sigma} \pm \Sigma_{\lambda\sigma} \cos(\Delta M t) \mp \rho_{\lambda\sigma} \sin(\Delta M t) \Big) g_\lambda g_\sigma \, .$$

$$\Lambda_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 + |\bar{A}_\lambda|^2), \qquad \Sigma_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 - |\bar{A}_\lambda|^2),$$

$$\Lambda_{\perp i} = -\mathrm{Im}(A_\perp A_i^* - \bar{A}_\perp \bar{A}_i^*), \qquad \Lambda_{\|0} = \mathrm{Re}(A_\| A_0^* + \bar{A}_\| \bar{A}_0^*),$$

$$\Sigma_{\perp i} = -\mathrm{Im}(A_\perp A_i^* + \bar{A}_\perp \bar{A}_i^*), \qquad \Sigma_{\|0} = \mathrm{Re}(A_\| A_0^* - \bar{A}_\| \bar{A}_0^*),$$

$$\rho_{\perp i} = \mathrm{Re}\Big( e^{-i\phi_M^q} [A_\perp^* \bar{A}_i + A_i^* \bar{A}_\perp] \Big), \qquad \rho_{\perp\perp} = \mathrm{Im}\Big( e^{-i\phi_M^q} A_\perp^* \bar{A}_\perp \Big),$$

$$\rho_{\|0} = -\mathrm{Im}\Big( e^{-i\phi_M^q} [A_\|^* \bar{A}_0 + A_0^* \bar{A}_\|] \Big), \qquad \rho_{ii} = -\mathrm{Im}\Big( e^{-i\phi_M^q} A_i^* \bar{A}_i \Big),$$

where $i = \{0, \|\}$ and $\phi_M^q$ is the weak phase factor associated with $B_q^0$–$\bar{B}_q^0$ mixing.

# PA or Rescattering

•We can distinguish PA from rescattering by measuring the weak phase of the transverse amplitudes- possible in $B_d^0 \to K^{*0}\bar{K}^{*0}$ through time dependent angular analysis.

•Measurement of $\frac{\rho_{aa}}{\Lambda_{aa}}$ where $a = \|, \perp$ give the weak phases of the transverse amplitudes. The strong phases cancel!

$A_T \sim V_{cb}V_{cd}^* P_c$. No weak phase ( Rescattering).

$A_T \sim V_{tb}V_{td}^* P_t$. Weak phase is $\beta$ (PA).

•If non SM weak phase $\Rightarrow$ New physics! in $b \to d$ transitions.

# Triple Products

• 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: $t \to -t$
T.P $\to$ -T.P

• In $B \to V_1 V_2$ decays we can construct the T.P

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

# How to Measure T-violation

- We can define a T-odd asymmetry

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

- $\tilde{A}_T$ is not a measure of true T-violation: $\tilde{A}_T \neq 0$ with strong phases and no weak phase.

- For true T violation we need to compare $\tilde{A}_T$ and $\overline{\tilde{A}}_T$(T-odd asymmetry for the C.P conjugate process.

# Triple Products

•The Triple Product Asymmetries (TPA) can be measured by a time independent angular analysis through,

$$\mathcal{A}_{\mathcal{T}} = \frac{\Lambda_{\perp i}}{\sum_\lambda \Lambda_{\lambda\lambda}} = \frac{-\mathrm{Im}(A_\perp A_i^* - \bar{A}_\perp \bar{A}_i^*)}{\sum_\lambda \Lambda_{\lambda\lambda}}$$

where $i = \{0, \|\}$.

•These are T-odd CP violating quantities.

•TPA vanish if a decay is dominated by a single amplitude like $B \to \phi K^*$. However in $b \to d$ transitions like $B_d^0 \to K^{*0}\bar{K}^{*0}$ there are two amplitudes with a relative large weak phase in the SM.

•Hence if $(f_T/f_L)$ is large in these decays then we expect O(1) T.P asymmetries in the SM- new large CP violating effects in the SM !!

# NEW PHYSICS

# New Phases from New Physics

- CPV in the SM is large.

- All CPV in SM $\propto \eta \sim O(1)$.

- $V_{CKM}$ is unitary: $V^\dagger_{CKM} V_{CKM} = 1 \Rightarrow$ 3 angles and 6 phases.

- Weak Interactions couple only to LH quarks: Can reabsorb 5 phases in quark field definitions.
- Only one weak phase $\eta$.

- Consider a NP scenario, e.g. Left-Right Symmetric Models:

- New phases associated with the RH mixing matrix, $V_R$.

- Can no longer absorb the phases of $V_R$: 6 new phases.

# Bottom line

• CPV in the SM is large: CP is not a symmetry or approximate symmetry of Nature.

• Any New Physics will have new CP phases.

• No reason to expect the new CP phases are small $\Rightarrow$ it is likely we will see deviations from the SM.

• Study of CPV is a good place to look for NP.

# Flavor Problem

The important question: NP at what scale ?

The contribution of NP operators to meson mixing can be represented by higher dimension operators:

$$c_{NP}(\bar{d}q)^2/\Lambda^2$$

where $q = s, b$.
The measurement of the K and the $B_d$ system tell us that $\Lambda \geq 100$ TeV !!! if $c_{NP} \sim 1$

Note $K(B)$ mixing in SM is small because of loop and small parameters like $\lambda = 0.22$

For e.g. $B$ mixing $\sim$ Loop $\times V_{td}^2$ and $V_{td} \sim \lambda^3$

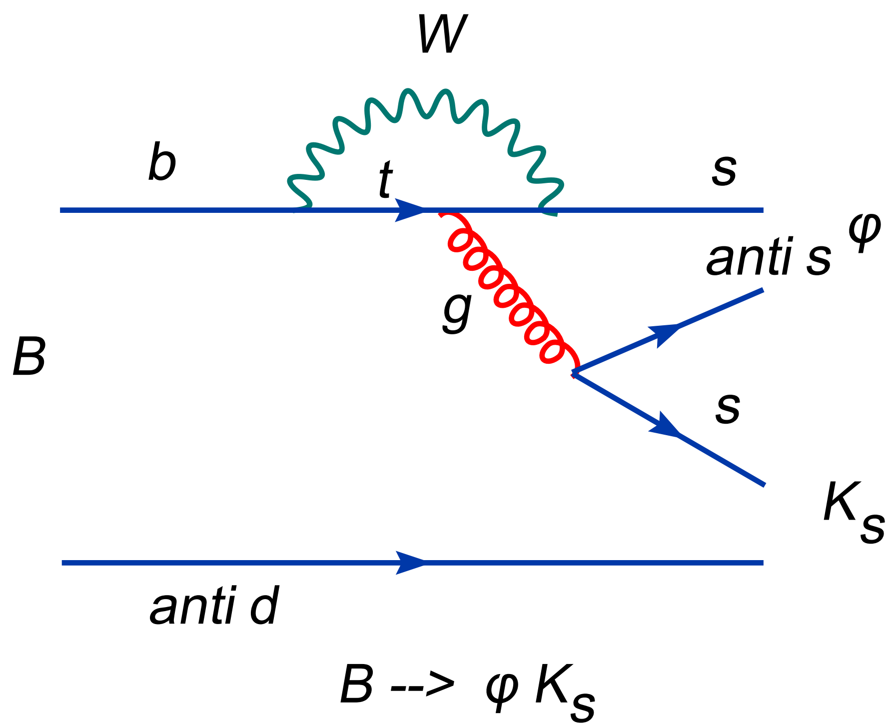
• But we expect $\Lambda \sim TeV$ to stabilize the Higgs mass!

• $c_{NP}$ has the same suppression as in the SM so $\Lambda \sim$ TeV $\Rightarrow$ strong constraints on the flavor structure of NP expected to be revealed at LHC.
or
if $c_{NP} \sim 1$ then flavor physics probes physics at scales way beyond the reach of present or future experiments.

•Hence new Super B factories will help us understand the flavor structure of new physics at a TeV or probe new physics effects at much higher scale( 10-100 TeV) beyond the reach of existing and upcoming colliders.

# NP- Where?

FCNC are very rare in SM and only arise as quantum corrections or Loops. E.g. $B \to \phi K_s$ ( $b \to sg$)

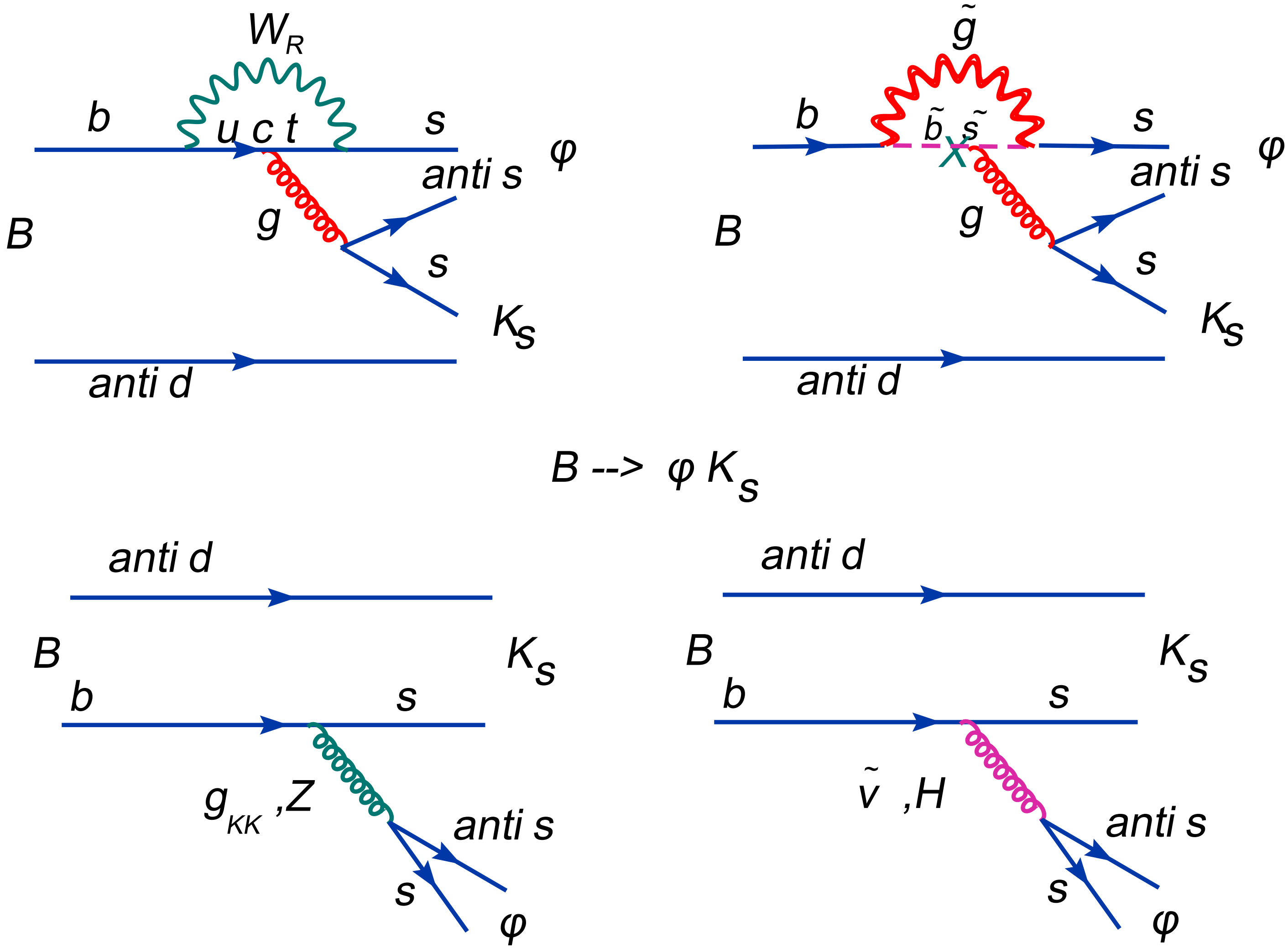



Beyond the SM FCNC may occur at tree level or loops and compete with the SM contribution.

Hence these decays are excellent probes of beyond the SM physics.

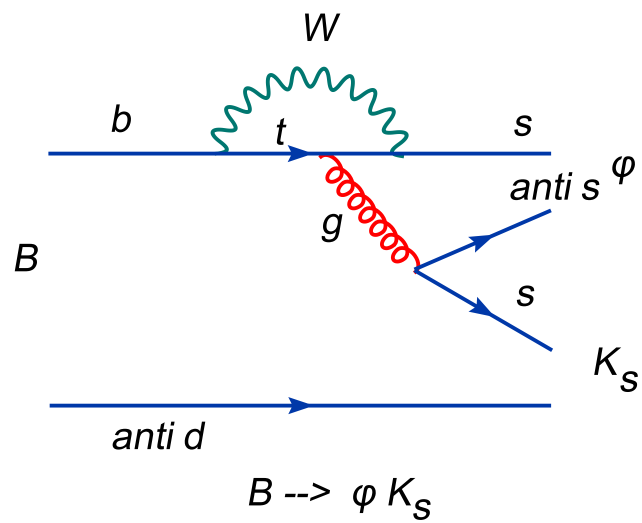
# $B \to \phi K_s$-NP models

- Many NP models can produce deviation from the SM for $B \to \phi K_s$



# $B \to \phi K_s$- Mixing CP

$B \to \phi K_s$ is a pure penguin process dominated by single amplitude




$A(B \to \phi K_s) = (P_t - P_c)V_{tb}V_{ts}^* + (P_u - P_c)V_{ub}V_{us}^* \approx (P_t - P_c)V_{tb}V_{ts}^*$
and so in SM

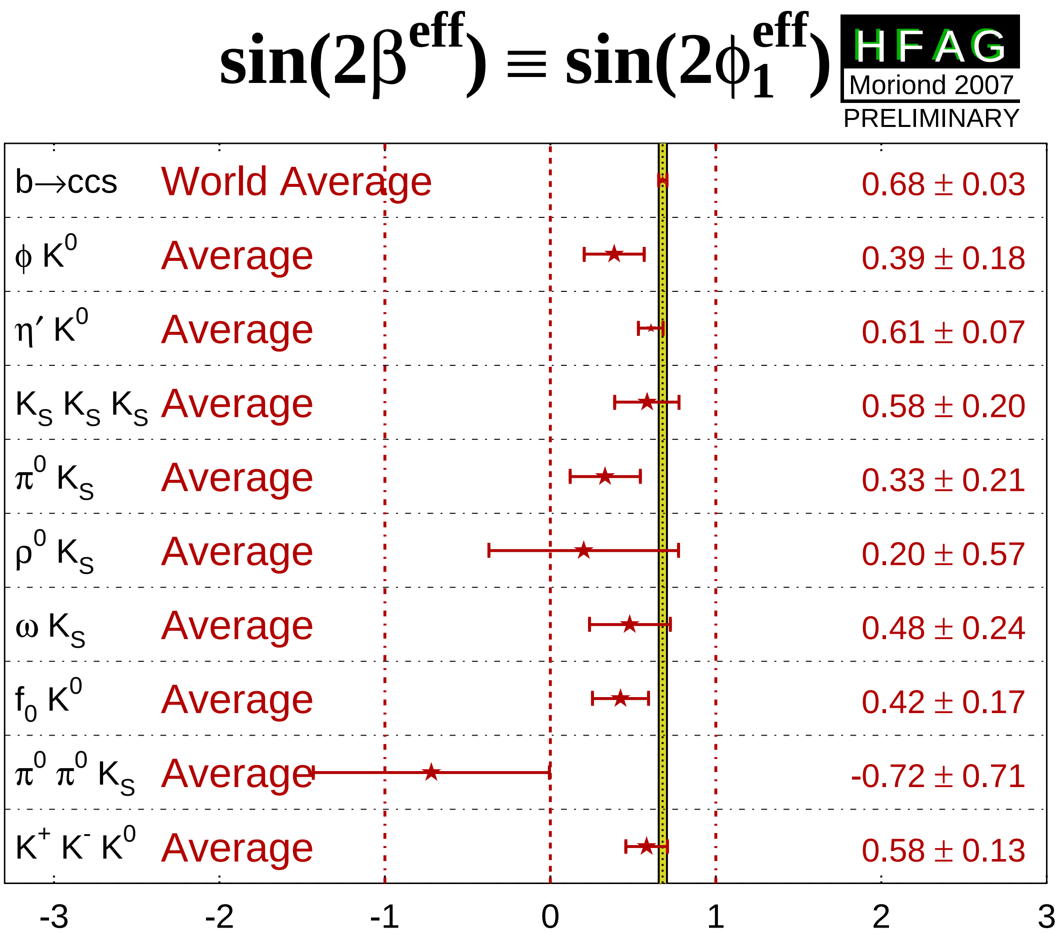
$$a_{mix}(B \to \phi K_s) = \sin 2\beta = 0.678 \pm 0.026 \ .$$

but Expt:$a_{mix}(B \to \phi K_s) = 0.39 \pm 0.18$ .

There are many other final states, $\eta' K_s, \pi^0 K_s, f_0 K_s, ...$ for which $a_{mix} = \sin 2\beta$ in the SM.

Expt:$a_{mix}(combined) = 0.53 \pm 0.05$ .

# $a_{mix}$ for $b \longrightarrow s$ transitions



• Note that NP will effect different final states differently.

$$H_{NP} \sim \bar{s}\gamma_5 b \bar{s}\gamma_5 s$$

There can be a contribution to $B \to \eta' K_s$ but not to $B \to \phi K_s$ as

$$\bar{s}\gamma_5 b \to B \to K_s$$

$$\bar{s}\gamma_5 s \to \eta'$$

but not $\phi$.

• Hence by observing NP effects in different final states allows us to obtain information about the Lorentz structure of NP.

# NP in $b \longrightarrow s$ Decays

- If there is NP in $b \to s$ transitions then it should show up in many decays:
In $B \to \phi K(K^*)$ which is a $b \to s\bar{s}s$ transition.

- Decays with $b \to s\bar{q}q$ quark transition with $q = u, d$ should be affected like $B \to K\pi, \rho K^*$.

- Models that generate new $b \to sg \to s\bar{q}q$ penguins(SUSY, LR, extra dim) will produce same effect for $q = u, d, s$.

- Models that generate new electroweak terms will in general couple to $q = u, d, s$ differently.

- Hence a combined NP fit to all the decays where there are deviations

from SM will point to the flavor nature of NP.

# $B \to K\pi$ Decays

•Let $A^{i,j} = B \to K^i \pi^j =< K^I \pi^j | H_{eff} | B >$ then we have the following decays:

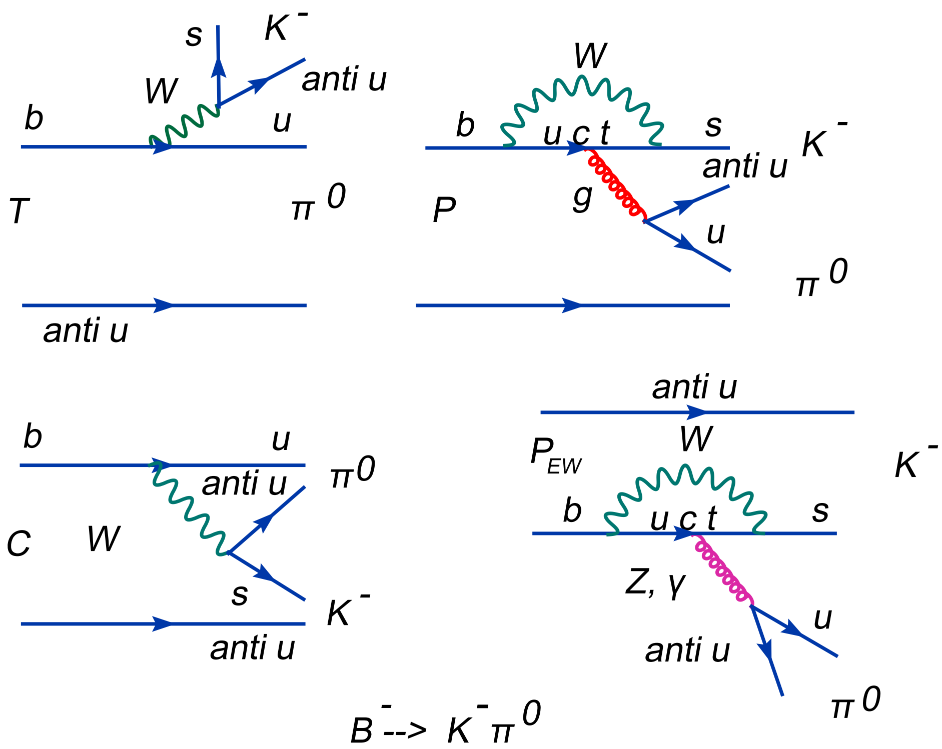
$B^+ \to \pi^+ K^0$ ($A^{+0}$)
$B^+ \to \pi^0 K^+$ ($A^{0+}$)
$B_d^0 \to \pi^- K^+$ ($A^{-+}$)
$B_d^0 \to \pi^0 K^0$($A^{00}$)

$$
\begin{aligned}
A^{+0} &= -P' + P'_{uc} e^{i\gamma} - \frac{1}{3} P'^{C}_{EW} \ , \\
\sqrt{2} A^{0+} &= -T' e^{i\gamma} - C' e^{i\gamma} + P' - P'_{uc} e^{i\gamma} \\
&\qquad - P'_{EW} - \frac{2}{3} P'^{C}_{EW} \ , \\
A^{-+} &= -T' e^{i\gamma} + P' - P'_{uc} e^{i\gamma} - \frac{2}{3} P'^{C}_{EW} \ , \\
\sqrt{2} A^{00} &= -C' e^{i\gamma} - P' + P'_{uc} e^{i\gamma} - P'_{EW} - \frac{1}{3} P'^{C}_{EW} \ .
\end{aligned}
$$

# $B \to K\pi$- SM

- In the SM the amplitudes for the four decays can be related by isospin.

The four decays can be represented by the following amplitudes:




- $\frac{|T|}{|P|} = \frac{V_{ub}V_{us}^*}{V_{cb}V_{cs}^*}\frac{c_1}{c_t} \sim 0.2, \quad \frac{|C|}{|P|} \sim \frac{1}{N_c}\frac{|T|}{|P|} \sim 0.04, \quad \frac{|P_{EW}|}{|P|} \sim 0.14.$

# $B \to K\pi$ puzzle

Table 1:

| Mode | $BR(10^{-6})$ | $A_{dir}$ | $A_{mix}(S)$ |
|---|---|---|---|
| $B^+ \to \pi^+ K^0$ | $23.1 \pm 1.0$ | $0.009 \pm 0.025$ | |
| $B^+ \to \pi^0 K^+$ | $12.9 \pm 0.6$ | $0.050 \pm 0.025$ | |
| $B_d^0 \to \pi^- K^+$ | $19.4 \pm 0.6$ | $-0.097 \pm 0.012$ | |
| $B_d^0 \to \pi^0 K^0$ | $9.9 \pm 0.06$ | $-0.14 \pm 0.11$ | $0.38 \pm 0.19$ |

•Puzzles:

Puzzle 1: $A_{dir}(B^+ \to \pi^0 K^+) = A_{dir}(B_d^0 \to \pi^- K^+)$ using isospin if electroweak penguins(EWP) are neglected. In the SM the EWP are not big enough to explain the data. Need new EWP to explain the data.

Puzzle 2: $B_d^0 \to \pi^0 K^0$ is dominated by a single amplitude and so in SM and hence,
$A_{dir} = 0$ and $A_{mix} = \sin 2\beta = 0.68 \pm 0.03$ in disagreement with data.
Again need new EWP to explain the data.

# $B \to K\pi$ puzzle

•BR( $R_{c,n}$) of the $K\pi$ modes are consistent with SM. The puzzles are in the CP measurements.

•Puzzle 1 can be resolved by an accidental equality of the strong phase in $(T+C)$ and $P$ amplitudes(PQCD). How stable is this equality to higher order corrections?

Puzzle 1 can be resolved including $\frac{\Lambda_{QCD}}{m_b}$ corrections- General Parameterization( Silvestrini).

In units of $10^{-2}$

| | PQCD | GP | exp |
|---|---|---|---|
| $S_{\pi^0 K_S}$ | $74^{+2}_{-3}$ | $74.3 \pm 4.4$ | $38 \pm 19$ |
| $S_{\phi K_S}$ | $71^{+1}_{-1}$ | $71.5 \pm 8.7$ | $39 \pm 18$ |

•Puzzle 2(central value) remains unresolved. A precise measurement of S is crucial. Many NP models can solve Puzzle 1 but not Puzzle 2( e.g. MSUGRA).

# $B \to K\pi$ puzzle- all data

$$
\begin{aligned}
A^{+0} &= -P' + P'_{uc} e^{i\gamma} - \frac{1}{3} P'^{C}_{EW} \,, \\
\sqrt{2} A^{0+} &= -T' e^{i\gamma} - C' e^{i\gamma} + P' - P'_{uc} e^{i\gamma} \\
&\qquad\qquad - P'_{EW} - \frac{2}{3} P'^{C}_{EW} \,, \\
A^{-+} &= -T' e^{i\gamma} + P' - P'_{uc} e^{i\gamma} - \frac{2}{3} P'^{C}_{EW} \,, \\
\sqrt{2} A^{00} &= -C' e^{i\gamma} - P' + P'_{uc} e^{i\gamma} - P'_{EW} - \frac{1}{3} P'^{C}_{EW} \,.
\end{aligned}
$$

•Keep all amplitudes- no assumption about their sizes. We now have eight theoretical parameters: $|P|$, $|P_{uc}|$, $|T|$, $|C|$, $\gamma$, and three relative strong phases. With nine pieces of experimental data, we can perform a fit.

•However fit gives $|C/T| = 1.6 \pm 0.3$ about 10 times bigger than expected size. Such large $|C/T|$ are not seen in other decays including decays like $B \to \pi\pi$ which are related to $B \to K\pi$ by SU(3) symmetry.

# New Physics- General

The low energy structure of new physics( $b \to s$) can have the general form

$$
\begin{aligned}
H_{NP} &= \sum_{ij} c_{ij} \mathcal{O}_{NP}^{ij,q} + \sum_{ij} d_{ij} \mathcal{O}_{NPC}^{ij,q}, \\
\mathcal{O}_{NP}^{ij,q} &\sim \bar{s}_\alpha \Gamma_i b_\alpha \, \bar{q}_\beta \Gamma_j q_\beta, \\
\mathcal{O}_{NPC}^{ij,q} &\sim \bar{s}_\alpha \Gamma_i b_\beta \, \bar{q}_\beta \Gamma_j q_\alpha,
\end{aligned}
$$

where the $\Gamma_{i,j}$ represent Lorentz structures. There are a total of 20 possible NP operators.

•Define

$$
\begin{aligned}
\sum \langle f | \, \mathcal{O}_{NP}^{ij,q} \, | B \rangle &= \mathcal{A}^q e^{i\Phi_q}, \\
\sum \langle f | \, \mathcal{O}_{NPC}^{ij,C,q} \, | B \rangle &= \mathcal{A}_{NP}^{C,q} e^{i\Phi_q^C}.
\end{aligned}
$$

# New Physics- $K\pi$

$$
\begin{aligned}
A^{+0} &= -P' + \mathcal{A}'^{C,d} e^{i\Phi_d'^C} , \\
\sqrt{2}A^{0+} &= P' - T' e^{i\gamma} - P'_{EW} \\
&\quad + \mathcal{A}'^{,comb} e^{i\Phi'} - \mathcal{A}'^{C,u} e^{i\Phi_u'^C} , \\
A^{-+} &= P' - T' e^{i\gamma} - \mathcal{A}'^{C,u} e^{i\Phi_u'^C} , \\
\sqrt{2}A^{00} &= -P' - P'_{EW} + \mathcal{A}'^{,comb} e^{i\Phi'} + \mathcal{A}'^{C,d} e^{i\Phi_d'^C} ,
\end{aligned}
$$

$\mathcal{A}'^{,comb} e^{i\Phi'} \equiv -\mathcal{A}'^{,u} e^{i\Phi'_u} + \mathcal{A}'^{,d} e^{i\Phi'_d}$.

- The best fit is obtained for models with

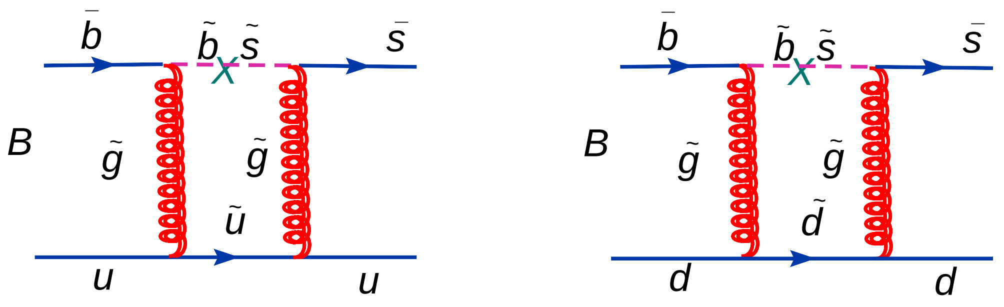
$A_{comb} = A_{NP}, \quad A_C^u \sim A_C^d \sim 0$.

This can come from NP that is not isospin conserving.

This points to electroweak penguins(EWP) and to certain color structures of the NP operators- color allowed EWP ($c_{ij} \neq 0, d_{ij} \sim 0$).

# NP Models that might work

- For models that produce new QCD penguins (LR models, SUSY with squark mixing, extra dim) the NP is isospin conserving and $A_{comb} = 0, \quad A_C^u = A_C^d = A_{NP}$- do not work but




$\bar{b} \dashrightarrow \bar{s} q\bar{q}$

- SUSY with different up and down squark masses(Trojan penguins).

- FCNC with $Z$ or $Z'$.

- FCNC through scalar exchange- colored scalar not allowed.

# $B \to \rho K^*$

- Can we understand the polarization data with new physics?

| Mode | $\mathcal{B}(10^{-6})$ | $f_L$ | $f_\perp$ |
|---|---|---|---|
| $\phi K^{*0}$ | $9.5 \pm 0.9$ | $0.49 \pm 0.04$ | $0.27^{+0.04}_{-0.03}$ |
| $\phi K^{*+}$ | $10.0 \pm 1.1$ | $0.50 \pm 0.05$ | $0.20 \pm 0.05$ |
| $\phi K_2^{*0}$ | $7.8 \pm 1.1 \pm 0.6$ | $0.853^{+0.061}_{-0.069} \pm 0.036$ | $0.045^{+0.049}_{-0.040} \pm 0.013$ |
| $\rho^+ K^{*0}$ | $9.2 \pm 1.5$ | $0.48 \pm 0.08$ | – |
| $\rho^0 K^{*0}$ | $5.6 \pm 1.6$ | $0.57 \pm 0.12$ | - |
| $\rho^- K^{*+}$ | $< 12.0$ | – | |
| $\rho^0 K^{*+}$ | $(3.6^{+1.9}_{-1.8})$ | $(0.9 \pm 0.2)$ | – |
| $K^{*0} \bar{K}^{*0}$ | $(0.49^{+0.16}_{-0.13} \pm 0.05)$ | $0.81^{+0.10}_{-0.12} \pm 0.06$ | – |

- Note $K\pi$ Puzzle allows

$$\frac{4G_F}{\sqrt{2}} \sum_{A,B=L,R} \left\{ f_q^{AB}\, \bar{b}\gamma_A s\, \bar{q}\gamma_B q + g_q^{AB}\, \bar{b}\gamma^\mu \gamma_A s\, \bar{q}\gamma_\mu \gamma_B q \right\} \ .$$

- Can these operators explain the polarization pattern in $B \to \rho K^*$ ?

# $B \to \rho K^*$

Taking into account also all polarization data in $B_d^0 \to \rho K^*$

| Operator | $A_0$ | $A_\parallel$ | $A_\perp$ |
|---|---|---|---|
| $f_d^{RR}$ | $O(m_V/m_B)$ | $2\sqrt{2}\zeta_{\perp\rho}Z_d^{RR}$ | $2\sqrt{2}\zeta_{\perp\rho}Z_d^{RR}$ |
| $f_d^{LL}$ | $O(m_V/m_B)$ | $-2\sqrt{2}\zeta_{\perp\rho}Z_d^{LL}$ | $2\sqrt{2}\zeta_{\perp\rho}Z_d^{LL}$ |
| $f_d^{RL}$ | $-2\zeta_{\parallel\rho}(g_{K^*}/g_{K^*}^T)Z_d^{RL}$ | $O(m_V/m_B)$ | $O(m_V/m_B)$ |
| $f_d^{LR}$ | $2\zeta_{\parallel\rho}(g_{K^*}/g_{K^*}^T)Z_d^{LR}$ | $O(m_V/m_B)$ | $O(m_V/m_B)$ |
| $g_d^{RR}$ | $\frac{1}{N_c}\zeta_{\parallel\rho}(g_{K^*}/g_\rho)X_d^{RR}$ | $O(m_V/m_B)$ | $O(m_V/m_B)$ |
| $g_d^{LL}$ | $-\frac{1}{N_c}\zeta_{\parallel\rho}(g_{K^*}/g_\rho)X_d^{LL}$ | $O(m_V/m_B)$ | $O(m_V/m_B)$ |

•A low energy theory that contains operators $O_{AA} \sim \bar{b}\gamma_A s \bar{q}\gamma_B q$ with $A = L, R$ and $q = d, s$ are allowed. NP couples dominantly to down type quarks.

•These operators produce large $f_T$ in $\rho^+ K^{*0}$ and $\rho^0 K^{*0}$ but NOT in $\rho^0 K^{*+}$. Assuming SU(3) symmetry of the NP the $\phi K^*$ and the $\phi K_2^*$ data can also be explained.

# NP with $B \to VV$ Decays

- In penguin/ penguin dominated $b \to s$ processes we can measure NP parameters and weak phases.
- From a time dependent angular analysis we get,

$$\Gamma(\overset{(-)}{B}(t) \to V_1 V_2) = e^{-\Gamma t} \sum_{\lambda \le \sigma} \Big( \Lambda_{\lambda\sigma} \pm \Sigma_{\lambda\sigma} \cos(\Delta M t) \mp \rho_{\lambda\sigma} \sin(\Delta M t) \Big) g_\lambda g_\sigma \ .$$

- There are 18 observables and 11 are independent.

We can write the general amplitude including NP as,

$$\begin{aligned} A_\lambda \equiv Amp(B \to V_1 V_2)_\lambda &= a_\lambda e^{i\delta_\lambda} + \mathcal{A}_\lambda^q e^{i\Phi_q} \ , \\ \bar{A}_\lambda \equiv Amp(\bar{B} \to V_1 V_2)_\lambda &= a_\lambda e^{i\delta_\lambda} + \mathcal{A}_\lambda^q e^{-i\Phi_q} \ . \end{aligned}$$

- There are 10 unknowns which can be determined from the 11 observables- so we can measure both the SM and NP amplitudes !

•To be specific,

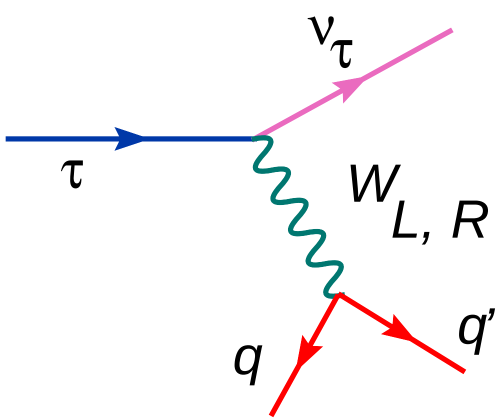
•$\mathcal{A}_\lambda^s$ and $\Phi_s$ can be extracted from $B_d^0 \to \phi K^{*0}$ or $B_s \to \phi\phi$( $b \to s\bar{s}s$).

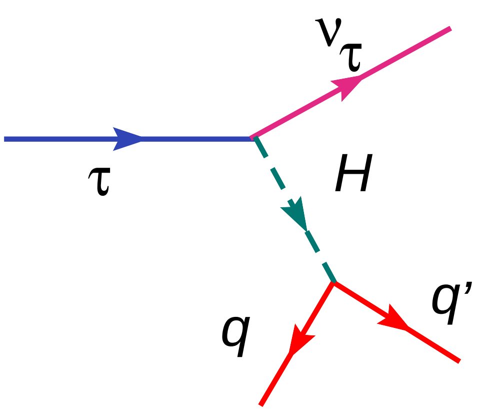
•$B_d^0 \to K^{*0}\rho^0$ and $B_s \to K^{*0}\bar{K}^{*0}$ can be used to measure $\mathcal{A}_\lambda^d$ and $\Phi_d$ ( $b \to s\bar{d}d$).

•Finally, measurements of the decay $B_s \to D_s^{*+}D_s^{*-}$ can be used to obtain $\mathcal{A}_\lambda^c$ and $\Phi_c$( $b \to s\bar{c}c$).

# CPV with Tau Decays

# CPV with Tau Decays




- There can be new physics contribution to $\tau \to f \nu_\tau$ through a $W_R$ exchange or a charged Higgs exchange. The SM contribution is through a $W_L$ exchange. CPV requires interference of SM with NP.

- The $W_L - W_R$ interference is tiny, proportional to $m_{\nu_\tau}$ or $W_L - W_R$ mixing and so neglected. Hence the NP we consider is a charged Higgs exchange.

$$H = \frac{G_F}{\sqrt{2}} \cos\theta_c \left( L_\mu H^\mu + L_0 H_0 \right) + h.c. \; ,$$

where the first and second pieces correspond to $W_L$ and $H$ exchange.

•We have

$$L_\mu = \bar{\nu}\gamma_\mu(1-\gamma_5)\tau \quad , \quad H^\mu = \bar{d}\gamma^\mu(1-\gamma_5)u$$
$$L_0 = \bar{\nu}(1+\gamma_5)\tau \quad , \quad H_0 = \bar{d}\,(a + b\gamma_5\,)\,u\,.$$

•The part in $L_0$ given by $\bar{\nu}(1-\gamma_5)\tau$ has tiny interference with the SM is neglected.

•We concentrate on $\Delta S = 0$ decays of the type $\tau \to N\pi\nu_\tau$ where N=3,4. For N=2 there is no coupling to the Higgs boson because of isospin symmetry.

•The decay $\tau \to N\pi\nu_\tau$ proceeds through $\tau \to V\pi\nu_\tau$ where $V$ is a vector meson with $V = \rho, a_1, \omega$.

•Consider the decay $\tau(l) \to V(q_1)\pi(q_2)\nu_\tau(l')$, where $V$ is a vector or axial-vector meson.

•The general structure for the SM current $J^\mu = \langle V(q_1)\pi(q_2)|H^\mu|0\rangle$ is

$$J^\mu = F_1(Q^2)\left(Q^2\epsilon_1^\mu - \epsilon_1\cdot q_2 Q^\mu\right) + F_2(Q^2)\,\epsilon_1\cdot q_2\left(q_1^\mu - q_2^\mu - Q^\mu\frac{Q\cdot(q_1-q_2)}{Q^2}\right)$$
$$+iF_3(Q^2)\,\varepsilon^{\mu\alpha\beta\gamma}\epsilon_{1\alpha}q_{1\beta}q_{2\gamma} + F_4(Q^2)\,\epsilon_1\cdot q_2 Q^\mu\ ,$$

where $Q^\mu \equiv (q_1+q_2)^\mu$ and $\epsilon_1$ denotes the polarization tensor of the $V$.

•For $\rho,\omega$, $F_{1,2}$ are small. $F_3$ vanishes for $\rho$.

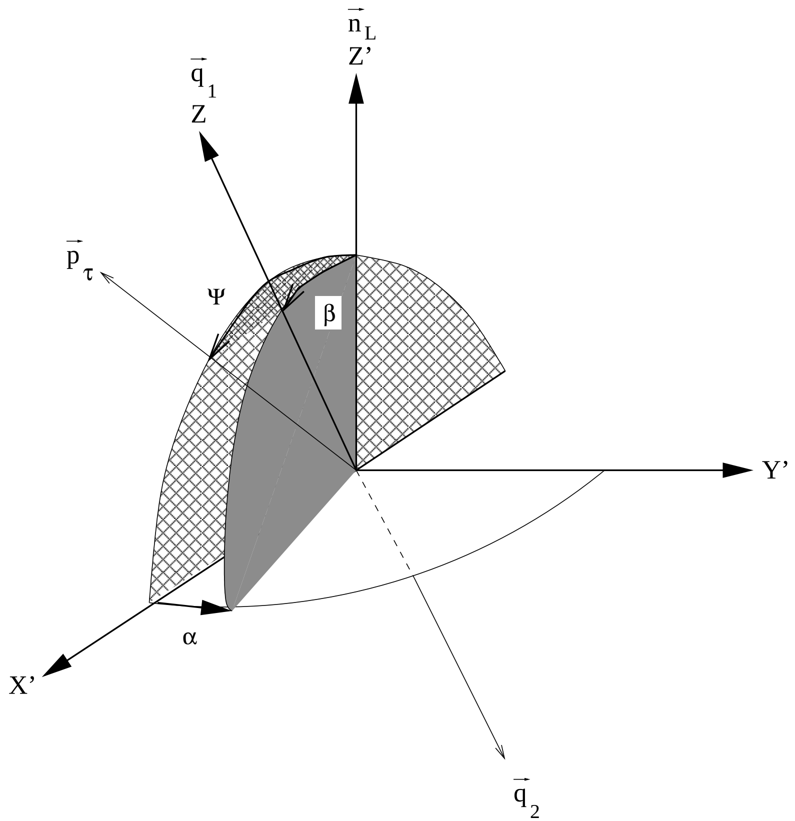
•For $a_1$ $F_3$ is small but $F_{1,2}$ can be large.

•$F_4$ is small in the SM for all the final states.

•The effect of the charged Higgs contribution can be absorbed by the redefinition

$$\widetilde{F}_4(Q^2) = F_4(Q^2) + (bf_H/m_\tau) \quad V : vector,$$
$$= F_4(Q^2) + (af_H/m_\tau) \quad V : axial - vector.$$

# CP Asymmetries




$$d\Gamma = \frac{|\vec{q_1}|}{2m_\tau(4\pi)^3}\left(\frac{m_\tau^2 - Q^2}{m_\tau^2}\right)\frac{dQ^2}{\sqrt{Q^2}}\frac{d\cos\theta}{2}\frac{d\cos\beta}{2}|\mathcal{A}|^2 \ .$$

- From the distribution we can construct various CPV asymmetries.

- We will normalize the distribution to width for $\tau \to e\nu\bar{\nu}(\Gamma_e)$

# CP Asymmetries

- Rate Asymmetries:

$$A_{CP} = \frac{\Delta\Gamma}{\Gamma_{\text{sum}}} \ ,$$

where $\Delta\Gamma$ is the difference of the widths for the process and the anti-process (normalized to $\Gamma_e$),

$$\begin{aligned}\Delta\Gamma &= \int \left[ \frac{d\Gamma}{\Gamma_e \, dQ^2} - \frac{d\overline{\Gamma}}{\Gamma_e \, dQ^2} \right] dQ^2 \\ &\simeq \int \frac{3\cos^2\theta_c}{2\left(Q^2\right)^{3/2} m_\tau^6} \left(m_\tau^2 - Q^2\right)^2 |q_1^z| \left(W_{SA} - \overline{W}_{SA}\right) \, dQ^2 \ ,\end{aligned}$$

$$W_{SA} - \overline{W}_{SA} = 4 \frac{Q^4 \left(q_1^z\right)^2}{m_V^2} \frac{|F_4 f_H b|}{m_\tau} \sin\left(\delta_4 - \delta_H\right) \sin\phi_b$$

- The rate asymmetries are proportional to $F_4$ which is tiny and hence the asymmetries are small.

•Weighted Rate Asymmetry:We weight the differential width by $\cos\beta$ when performing the integration over $\cos\beta$.

$$A_{CP}^{\langle\cos\beta\rangle} = \frac{\Delta\Gamma_{\langle\cos\beta\rangle}}{\Gamma_{\text{sum}}} \ ,$$

where $\Delta\Gamma_{\langle\cos\beta\rangle}$ is the difference of the widths for the process and the anti-process:

$$\Delta\Gamma_{\langle\cos\beta\rangle} \quad = \quad \int\left[\frac{d\Gamma}{\Gamma_e\, dQ^2 d\cos\beta} - \frac{d\overline{\Gamma}}{\Gamma_e\, dQ^2 d\cos\beta}\right] dQ^2 \cos\beta\, d\cos\beta$$

•The Asymmetry is proportional to $F_{1,2}$ and hence can be large for $V = a_1$.Need to measure $\beta$- the angle between the $a_1$ momentum in the hadronic rest frame and the direction of the lab. Need to reconstruct the $a_1$ for its momentum which could be a problem as $a_1$ is wide.

# Triple Products

•If the momentum of the $\tau$ can be determined experimentally, the polarization of the $V$ is measured we can construct a triple-product CP asymmetry.

$$|Amp|^2\big|_{\text{TP}} \;=\; \frac{8m_\tau Q^2}{E_1}\text{Im}\,(b f_H F_3^*)\,(\vec{\epsilon}_1\cdot\vec{q}_1)\,\vec{\epsilon}_1\cdot\left(\vec{l}\times\vec{q}_1\right)\;,$$

where $l, q_1$ are the $\tau$ and $V$ momenta.

$$A_{CP}^{\text{TP}} = \frac{\Delta\Gamma_{\text{TP}}}{\Gamma_{\text{sum}}}\;,$$

$$\begin{aligned}\Delta\Gamma_{\text{TP}} \;&=\; \int\left[\frac{d\Gamma}{\Gamma_e\,dQ^2} - \frac{d\overline{\Gamma}}{\Gamma_e\,dQ^2}\right]_{\text{TP}} dQ^2 \\ &\simeq\; (\vec{\epsilon}_1\cdot\vec{n}_1)\,(\vec{\epsilon}_1\cdot\vec{n}_2)\int\frac{3\pi\cos^2\theta_c}{2\,m_\omega m_\tau^6\sqrt{Q^2}}\left(m_\tau^2 - Q^2\right)^2|q_1^z|^3 \\ &\quad\times |b f_H F_3|\cos\left(\delta_3 - \delta_H\right)\sin\phi_b\,dQ^2.\end{aligned}$$

$$\vec{n}_1 = \frac{\vec{q}_1}{|\vec{q}_1\,|}\frac{m_\omega}{E_1}\,, \quad \vec{n}_2 = \frac{\vec{l}\times\vec{q}_1}{\left|\vec{l}\times\vec{q}_1\right|} = \frac{\vec{l}\times\vec{q}_1}{\left|\vec{l}\right|\,|\vec{q}_1\,|\sin\zeta}\,, \quad \vec{n}_3 = \frac{\left(\vec{l}\times\vec{q}_1\right)\times\vec{q}_1}{\left|\left(\vec{l}\times\vec{q}_1\right)\times\vec{q}_1\,\right|}\,.$$

•The T.P asymmetry is proportional to $F_3$ and so can be significant for $V=\omega$.

•Many models have two Higgs doublets, which give mass to the fermions. In such models, the coupling of the charged Higgs boson to first-generation final states is generally proportional to $m_u$ and $m_d$, which are tiny. As a result, any CP violation which is due to charged-Higgs exchange is correspondingly small. If CP violation is to be observed in $\tau$ decays, the charged-Higgs coupling must be large. Thus, $\tau$ decays probe non-“standard” NP CP violation.

# Conclusions

•In a future Super B factory there are many interesting signals.

•We discussed $B_d^0 \to K\bar{K}^0$, $B_d^0 \to K^{*0}\bar{K}^{*0}$. In the VV modes we can test SM explanation of the polarization puzzles and potentially measure large Triple product asymmetries.

•There are many hints of new physics in $b \to s$ transitions. If present, the new physics can be measured by a fit to the $B \to K\pi$ data. Combined with the $\rho K^*$ data we can construct the low energy structure of the new physics. NP parameters can be measured in $b \to s$ penguin $B \to VV$ decays.

•There are various asymmetries that one can construct in hadrronic tau decays $\tau \to V\pi\nu_\tau \to N\pi\nu_\tau$. These decays probe nonstandard Higgs boson interactions.