Signals of NP in exclusive Radiative B-decays

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Outline: The incredible power of Radiative B’s

1) Rate for $b \rightarrow s$ ...over a decade of constraining NP!
2) Rate for $b \rightarrow d$ (excl. and incl.) for $|V_{td}|/V_{ts}$
3) Dir CP $b \rightarrow s$ and $b \rightarrow d$ in SM and extensions; valuable tests of SM
4) Mixing induced & dir. CP clean tests of SM using exclusive B-decays…
   a) ags(97)...$B \rightarrow V\gamma$
   b) aghsl...$B \rightarrow P_1 P_2 \gamma$; enhanced sensitivity to NP
   c) aghslII...$B \rightarrow PV\gamma$; SM pollution drastically reduced
5) Summary and Outlook

REMINDER: $(\varphi_1, \varphi_2, \varphi_3) = (\beta, \alpha, \gamma)$
Twin Problems of SM

- **Hierarchy Problem** → strongly suggests threshold for NP cannot be too far from the EW scale
- **Coincidence Problem** → experimental searches apparently show no sign of NP
- A possible resolution: signals are hiding beneath the error bars
- Since none of the tests that have been done so far is better than around 10%, this possibility should be taken seriously.
- More sensitive tests are needed → requires higher luminosities and also improvement in our calculational prowess
“COINCIDENCE”
Types of CP

- CPV in Mixing (a la neutral K)
- CPV in interference of mixing and decays
- Direct CPV
- Uniqueness of B...In the SM – CKM paradigm implies that only in B CPV effects are large. In K’s they are miniscule, also extremely small in charm, and vanishingly small in t-physics. Thus it is extremely important that we explore all types of CPV effects in B as that’s the only place where SM effects are expected to be largest to allow us to precisely nail down CKM-parameters
Should 10% tests be good enough?

Vital Lessons from our past

• **LESSON # 1: Remember $\varepsilon_K$**

• Its extremely important to reflect on the severe and tragic consequences if Cronin et al had decided in 1963 that $O(10\%)$ searches for $\varepsilon$ were good enough! Imagine what an utter disaster for our field that would have been.

Note also even though CKM-CP-odd phase is $O(1)$ (as we now know) in the SM due to this $O(1)$ phase only in B-physics we saw large effects... in $K$ (miniscule), $D$ (very small), $t$ (utterly negligible).

*Understanding the fundamental SM parameters to accuracy only of $O(10\%)$ would leave us extremely vulnerable .....Improvement of our understanding should be our crucial HOLY GRAIL!*
Lesson #2

*Remember* $m_\nu$

Just as there was never any good reason for $m_\nu = 0$
there is none for BSM-CP-odd phase not to exist
$\Delta m^2 \sim 1\text{eV}^2 \sim 1980 \Rightarrow \Delta m^2 \sim 10^{-4}\text{eV}^2 \cdots 97$

Osc. Discovered. . . .

Similarly for BSM-CP-odd phase, we may need to look for much smaller deviations than the current $O(10\%)$
Illustrative Examples of constraints on models from $B \rightarrow X_s \gamma$

Direct and indirect lower bounds on $M_{H^+}$ from different processes in the 2HDM of Type II as a function of $\tan\beta$. See Gambino and Misiak, hep-ph/0104034.
Direct CP-asymmetry

- As testing the SM with measurement of inclusive Br is now becoming less effective improved determination of the (inclusive) direct CP asymmetry is gaining in sensitivity. Recall, in the SM,
  - \( A_{CP} (B \rightarrow X_s \gamma) \sim 0.6\% \quad \text{SM} \)
  - BaBar (89X10^6 ) =0.025+-0.05+-0.015
  - Belle (152X10^6 ) =0.002+-0.05+-0.030
  - -> Precise measurement & test of SM will require \( \sim 10^{10} \) B’s; i.e a SUPER-B-Factory…
  - With improved measurement of \( A_{CP} (B \rightarrow X_s \gamma) \) should provide powerful (perhaps even better than Br) constrain on NP models.
\[ A_{CP} (B \rightarrow X_d \gamma) \]

- Expected to be much bigger (opp. sign)
- In principle may be accessible with fewer # of B’s as # of B’s needed scales
- \[ \sim \frac{Br}{(A_{CP})^2} \]
**Direct CP violation in Radiative B decays in and beyond the SM**

Kiers, Soni and Wu hep-ph/0006280 (some input from refs. below)

<table>
<thead>
<tr>
<th>Model</th>
<th>$A^{B \rightarrow X_s \gamma}_{CP}$(%)</th>
<th>$A^{B \rightarrow X_d \gamma}_{CP}$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>0.6</td>
<td>-16</td>
</tr>
<tr>
<td>2HDM (Model II)</td>
<td>$\approx 0.6$</td>
<td>$\approx -16$</td>
</tr>
<tr>
<td>3HDM</td>
<td>-3 to +3</td>
<td>-20 to +20</td>
</tr>
<tr>
<td>T2HDM</td>
<td>$\approx 0$ to +0.6</td>
<td>$\approx -16$ to +4</td>
</tr>
<tr>
<td>Supergravity[*]</td>
<td>$\approx -10$ to +10</td>
<td>-(5 - 45) and (2)</td>
</tr>
<tr>
<td>SUSY with squark mixing[+*]</td>
<td>$\approx -15$ to +15</td>
<td></td>
</tr>
<tr>
<td>SUSY with R-parity violation[+*]</td>
<td>$\approx -17$ to +17</td>
<td></td>
</tr>
</tbody>
</table>

Salvaging exclusive modes for precision tests

• Prior to ~97, exclusive modes remain unexploited for precision tests…
• This is quite unfortunate as experimentally exclusive modes are far more straightforward compared to inclusive ones
• Precision tests of the SM using time dependent or direct CP involving
  • I. \(B^0 \rightarrow K^*(\rho)\gamma\); Atwood, Gronau and A. S.; PRL’97
  • II. \(B^0 \rightarrow \{K_S\pi^0(\eta',\eta),\pi\pi\ldots\}\gamma\); Atwood, Gershon, Hazumi & AS, PRD’05
  • III \(B^{+\circ}, B_s \rightarrow \{K\phi(\omega,\rho),\eta'(\pi)\phi(\omega,\rho), \ldots\}\gamma\); Atwood, Gershon, Hazumi & AS… WIP
Mixing Induced CP in Radiative B-decays

Key point: $\gamma$ in $b$ decays is predominantly LH whereas $\gamma$ in $\bar{b}$ decays
is predominantly RH

$\Rightarrow$ esp. sensitive to presence of RH currents due BSM

In the SM TDCP in $B \rightarrow \gamma[\rho, \omega, K^*, ..] \propto m_d/m_b$ or $m_s/m_b$.

BSM [e.g. LRSM, SUSY...] can cause large asymmetries

See: Atwood, Gronau and A. S. PRL, '97; recent ext. to several
Gronau and Pirjol hep-ph/0205065.. In General, (for $q = s, d$)

$$H_{\text{eff}} = -\sqrt{8} G_F \frac{e m_b}{16 \pi^2} F_{\mu \nu} \left[ \frac{1}{2} F^q_{L} \bar{q} \sigma^{\mu \nu} (1 + \gamma_5) b + \frac{1}{2} F^q_{R} \bar{q} \sigma^{\mu \nu} (1 - \gamma_5) b \right]$$

In the SM, $\frac{F^q_R}{F^q_L} \approx \frac{m_d}{m_b}$ Mixing induced CP asymmetry in $B - \bar{B}$
decay requires both $B$ and $\bar{B}$ be able to decay to the same final state
i.e. a state with the same photon helicity $\propto \frac{F^q_R}{F^q_L} \rightarrow m_d/m_b \rightarrow 0$.

In contrast, in a LR model as an example $\frac{F^q_R}{F^q_L}$ can be appreciably
bigger as presence of RH currents $\Rightarrow m_t/m_b$ enhancement for $\frac{F^q_R}{F^q_L}$
Limitation of inclusive measurements

• Though inclusive Br (B->X_s γ) measurement provides an excellent test of the SM (now to ~10% accuracy), it is rather insensitive to testing the presence of “forbidden” helicity (i.e. RH photons in b-quark decays)…
• {This is because rate monitors the incoherent sum of LH & RH}
• Monitoring polarization of the photon is crucial…
• THIS IS WHERE heretofore unexploited exclusive radiative decays come in handy.
Time Dependent CP Asymmetry in $B(t) \rightarrow M^0\gamma$

For a state tagged as a $B$ rather than a $\bar{B}$ at $t = 0$ and with

$CP|M^0 > = \xi |M^0 >$; with $\xi = \pm 1$:

\[
A(B \rightarrow M^0\gamma_L) = A \cos \psi e^{i\phi_L},
\]

\[
A(B \rightarrow M^0\gamma_R) = A \sin \psi e^{i\phi_R},
\]

\[
A(B \rightarrow M^0\gamma_R) = \xi A \cos \psi e^{-i\phi_L},
\]

\[
A(B \rightarrow M^0\gamma_L) = \xi A \sin \psi e^{-i\phi_R}.
\]

Here $\tan \psi = \frac{F_R^0}{F_L^0}$ and $\phi_{L,R}$ are CP-odd weak phases. Thus, with

$\phi_M$ as the mixing phase, $\Gamma(t) \equiv \Gamma(B(t) \rightarrow M^0\gamma),$

\[
\Gamma(t) = e^{-\Gamma t} |A|^2 [1 + \xi \sin(2\psi) \sin(\phi_M - \phi_L - \phi_R) \sin(\Delta mt)] .
\]

This leads to a time-dependent CP asymmetry,

\[
A(t) = \frac{\Gamma(t) - \Gamma(t)}{\Gamma(t) + \Gamma(t)} = \xi \sin(2\psi) \sin(\phi_M - \phi_L - \phi_R) \sin(\Delta mt). 
\]
Thus, in the SM:

for \( B^0 \) : \( \phi_M = 2\beta \),
for \( B_s \) : \( \phi_M = 0 \),

and

for \( b \to s\gamma \) : \( \sin(2\psi) \approx \frac{2m_s}{m_b} \), \( \phi_L = \phi_R \approx 0 \),
for \( b \to d\gamma \) : \( \sin(2\psi) \approx \frac{2m_d}{m_b} \), \( \phi_L = \phi_R \approx \beta \),

(4)

Thus as illustrative examples (in the SM):

\[ B^0 \to K^{*0}\gamma : A(t) \approx (2m_s/m_b)\sin(2\beta)\sin(\Delta mt) \, , \]
\[ B^0 \to \rho^0\gamma : A(t) \approx 0 \, , \]
\[ B_s \to \phi\gamma : A(t) \approx 0 \, , \]
\[ B_s \to K^{*0}\gamma : A(t) \approx -(2m_d/m_b)\sin(2\beta)\sin(\Delta mt) \, , \]

(5)

where \( K^{*0} \) is observed through \( K^{*0} \to K_S\pi^0 \).
LRSM: $G = SU(2)_L \times SU(2)_R \times U(1)$

$\begin{pmatrix}
  u \\
  d
\end{pmatrix}_{L,R}$

$\begin{pmatrix}
  \nu_e \\
  e
\end{pmatrix}_{L,R}$

Many attractive features, e.g. $\nu$ mass arises naturally. Using $K_L - K_S$ mass diff one gets a rather imposing bound $m_R \geq 1.5$TeV [Beall, Bander and A. S’82]. Given that $m_\nu \neq 0$ (and TeV no longer such an imposing scale) model ought to reconsidered as a nice effective low energy theory. Done recently [Kiers et al, hep-ph/0205082] Taking, $\langle \Phi \rangle = \begin{pmatrix}
  \kappa' \\
  0 \\
  0 \\
  \kappa
\end{pmatrix}$ and setting $|\kappa'/\kappa| = m_b/m_t$ leads to striking simplification:

$\Rightarrow$ CKM angle hierarchy arises

$\Rightarrow (CKM)_R = (CKM)_L$

$\Rightarrow \delta_R = \delta_L$

endowing the model with considerable predictive power.
The $W_L - W_R$ mixing is described by

$$
\begin{pmatrix}
W_1^+ \\
W_2^+
\end{pmatrix} =
\begin{pmatrix}
\cos \zeta & e^{-i\omega} \sin \zeta \\
-\sin \zeta & e^{-i\omega} \cos \zeta
\end{pmatrix}
\begin{pmatrix}
W_L^+ \\
W_R^+
\end{pmatrix}.
$$

Although $\zeta$ is small, $\leq 3 \times 10^{-3}$, [see Beall and A.S.'81; Wolfenstein '84] that’s considerably offset by helicity enhancement factor $m_t/m_b$.

Radiative B-decays previously examined in LRSM [see Fujikawa and Yamada, '94; Basu, Fujikawa, Yamada, '94; Cho and Misiak, '94]

$F_L \propto F(x) + \eta_{QCD} + \zeta m_t/m_b e^{i\omega} F(x)$; $F_R \propto \zeta m_t/m_b e^{-i\omega} F(x)$. where $x = (m_t/m_{W^\pm})^2$, $\eta_{QCD} = -0.18$. Also Assuming $BR(B \to X_s\gamma)_{exp} = 1.0 \pm 0.1 \Rightarrow |\sin(2\omega)| = 0.67$

<table>
<thead>
<tr>
<th>Process</th>
<th>SM</th>
<th>LRSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(B \to K^* + \gamma)$</td>
<td>$2 m_s/m_b \sin 2\beta \sin(\Delta m_t)$</td>
<td>$\sin 2\omega \cos 2\beta \sin(\Delta m_t)$</td>
</tr>
<tr>
<td>$A(B \to \rho \gamma)$</td>
<td>$\approx 0$</td>
<td>$\sin 2\omega \sin(\Delta m_t)$</td>
</tr>
</tbody>
</table>

$\Rightarrow$ whereas in the SM negligible asymmetries, in the LRSM can be $O(50\%)$ even if $BR(B \to X_s\gamma)$ is in very good agreement with the SM.
B-Factory Signals for a WED
(Agashe,Perez,Soni,hep-ph/0406101(PRL);0408134)

- RS1 with a WARPED EXTRA DIMENSION (WED) provides an elegant solution to the HP
- In this framework, due to warped higher-dimensional spacetime, the mass scales (i.e. flavors) in an effective 4D description depend on location in ED. Thus, e.g. the light fermions are localized near the Plank brane where the effective cut-off is much higher than TeV so that FCNC's from HDO are greatly suppressed. The top quark, on the other hand is localized on the TeV brane so that it gets a large 4D top Yukawa coupling.
Key features of WED

• **Amielorating the Flavor Problem.** This provides an understanding of hierarchy of fermion masses w/o hierarchies in fundamental 5D params. Thus “solving” the SM flavor problem.

**Flavor violations** Most flavor-violating effects arise due to the violation of RS-GIM mechanism by the large top mass. This originates from the fact that $\left( t, b \right)_L$ is localized on the TeV brane.
between the relevant models considered below. The basic set-up of our models is the RS1 framework [1]. The space time of the model is described by a slice of ADS$_5$ with curvature scale, $k \sim M_{Pl}$, the 4D Planck mass. The Planck brane is located at $\theta = 0$, where $\theta$ is the compact extra dimension coordinate. The TeV brane is located at $\theta = \pi$. The metric of RS1 can be written as:

$$\begin{align*}
(ds)^2 &= \frac{1}{(kz)^2} \left[ \eta_{\mu\nu} dx^\mu dx^\nu - (dz)^2 \right],
\end{align*}$$

(1)

where $kz = e^{kr_c \theta}$. We assume that $k\pi r_c \sim \log (M_{Pl}/\text{TeV})$ to solve the hierarchy problem,

$$\begin{align*}
\left( z_h \equiv \frac{1}{k} \right) &\leq z \leq \left( z_v \equiv \frac{e^{k\pi r_c}}{k} \right),
\end{align*}$$

(2)

where $z_v \sim \text{TeV}^{-1}$.

The gauge group of the models under study is given by [9, 10] $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$. The gauge symmetry is broken on the Planck brane down to the SM gauge group and in the TeV brane it is broken down to $SU(3)_c \times SU(2)_{D} \times U(1)_{B-L}$. $SU(2)_{D}$ is the diagonal subgroup of the two $SU(2)$'s present in the bulk.
Contrasting B-Factory Signals from WED with those from the SM

<table>
<thead>
<tr>
<th></th>
<th>$\Delta m_{B_s}$</th>
<th>$S_{B_s \to \phi \psi}$</th>
<th>$S_{B_d \to \phi K_s}$</th>
<th>$Br[b \to s l^+ l^-]$</th>
<th>$S_{B_{d,s} \to K^* \phi \gamma}$</th>
<th>$S_{B_{d,s} \to \rho K^* \gamma}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS1</td>
<td>$\Delta m_{B_s}^{SM}[1 + O(1)]$</td>
<td>$O(1)$</td>
<td>$\sin 2\beta \pm O(2)$</td>
<td>$Br^{SM}[1 + O(1)]$</td>
<td>$O(1)$</td>
<td>$O(1)$</td>
</tr>
<tr>
<td>SM</td>
<td>$\Delta m_{B_s}^{SM}$</td>
<td>$\lambda_c^2$</td>
<td>$\sin 2\beta$</td>
<td>$Br^{SM}$</td>
<td>$\frac{m_s}{m_b} \left( \sin 2\beta, \lambda_c^2 \right)$</td>
<td>$\frac{m_d}{m_b} \left( \lambda_c^2, \sin 2\beta \right)$</td>
</tr>
</tbody>
</table>

**NOT A Precise Model**
Exploring flavor structure of supersymmetry breaking from rare $B$ decays and unitarity triangle

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(Dated: 12/8/2003)

Abstract

We study effects of supersymmetric particles in various rare $B$ decay processes as well as in the unitarity triangle analysis. We consider three different supersymmetric models, the minimal supergravity, SU(5) SUSY GUT with right-handed neutrinos, and the minimal supersymmetric standard model with U(2) flavor symmetry. In the SU(5) SUSY GUT with right-handed neutrinos, we consider two cases of the mass matrix of the right-handed neutrinos. We calculate direct and mixing-induced CP asymmetries in the $b \to s\gamma$ decay and CP asymmetry in $B_d \to \phi K_S$ as well as the $B_s - B_s$ mixing amplitude for the unitarity triangle analysis in these models. We show that large deviations are possible for the SU(5) SUSY GUT and the U(2) model. The patterns and correlations of deviations from the standard model will be useful to discriminate the different SUSY models in future $B$ experiments.

PACS numbers: 12.60.Jv, 14.40.Nd, 12.15.Hh, 11.30.Er
FIG. 6: (a) The direct CP asymmetry in $b \rightarrow s\gamma$, and (b) the mixing-induced CP asymmetry in $B_d \rightarrow M_{s\gamma}$ as functions of the gluino mass.
TAMING OF the higher order corrections

- Practically decade after AGS’97 observation, Grinstein, Grossman, Ligeti and Pirjol (PRD’05), examined higher order corrections and identified a potentially important source for “wrong” helicity photons.

Figure 1: Dominant contribution to $b \rightarrow s \gamma g$. A second diagram with photon and gluon vertices exchanged is implied.
higher order corrections

- Their (SCET) analysis, confirming earlier work, showed these corrections are $1/m_b$ suppressed. Grinstein and Pirjol did a dimensional analysis (not an actual computation of the ME), PRD’06, claimed corrections could be rather sizeable, rendering,
- $S(t) \sim \sin 2\varphi_1 \times O(0.1)$. Since an extra gluon is involved it requires either suppression also by $\alpha_s$ (hard glue) or participation by (suppressed) higher Fock states…..

**THEREFORE IN ALL LIKELIHOOD, GP’S RESULT IS A GENEROUS OVERESTIMATE**
EXPLICIT CALCULATIONS

- Already two very important explicit computations of these higher order corrections have recently become available:
  - I. M. Matsumori and A. I. Sanda, PRD’06
    use pQCD and find \( S(t) = (3.5\pm 1.7)\% \)
  - P. Ball and R. Zwicky, hep-ph/0609037,
    In another very commendable study use QCDSR and find
    \( S(t) = [2.2\pm 1.2(\pm 0.1)]\% \)

BOTH THESE STUDIES SHOW GRINSTEIN et al.
CORRECTION IS ACTUALLY VERY SMALL and they
largely substantiate original AGS estimate confirming the
cleanliness of this test of the SM
**Important Generalizations to AGS**

- **I.** $B^0 \rightarrow \{K_S\pi^0(\eta',\eta),\pi\pi\ldots\}\gamma$; Atwood, Gershon, Hazumi & AS; PRD’05. Not on only this is a very important generalization to AGS, It also develops a DATA DRIVEN method for separating (unwanted) effects of higher order corrections ....thus their rendering their precise numerical value quite irrelevant.

- **II** $B^{\pm,0}, B_s \rightarrow \{K\phi(\omega,\rho),\eta'(\pi)\phi(\omega,\rho), \ldots\}\gamma$; Atwood, Gershon, Hazumi and AS...WIP

- This generalization is now to FS that are VECTOR + Scalar (+photon)...Presence of the vector enhances the sensitivity to NP significantly and renders it essentially a PERFECT NULL TEST..(i.e. SM pollution virtually zero)

Now also Dir. CP opens up possibilities e/LHC6.
Current experimental status & outlook for Super-B

- $S (K^*\gamma) = -0.32\pm0.36\pm0.05$ Belle (535M B’s)
- $-0.21\pm0.40\pm0.05$ BaBar (232M B’s)
- HFAG $-0.28\pm0.26$

- SUPER-B Projections by BABAR & BELLE:
  - Luminos. $10^{35}$ -> $S \sim 0.07$
  - $5\times10^{35}$ -> $S \sim 0.04$
In this case there is potentially additional information from the angular distribution of the two mesons.

There are two different cases of how the angular information enters:

1) $P_1 = P_2$ e.g. $B^0 \to \pi^+\pi^-\gamma$. In this case the angular distribution gives you the information to calculate $\sin(2\psi)$ and $\sin(\phi_L + \phi_R + \phi_M)$ separately.

2) $P_1$ and $P_2$ are C eigenstates e.g. $B^0 \to K_s\pi^0\gamma$. In this case you can obtain no additional information from angular distributions but you can add all the statistics (as unlike AGS $K\pi$ need not be resonant) and thereby it allows a more stringent test for NP, that is, a more accurate value of the NP phase.

In both cases the variation with $E_\gamma$ tests whether dipole emission is an accurate model.

For details see Atwood, Gershon, Hazumi & AS, PRD’05.
Intuitive elaboration of why/how AGHS idea works

In AGS eq.3, strong interaction (meaning leaving out weak phase) info is in \((A \sin \psi)\).

For 3-body modes of AGHS interest, such quantities, in general,

become functions of Dalitz variables, \(s_1\) and \(\cos \Theta = z\):

\[
S_1 = (p_1 + p_2)^2; \quad S_2 = (p_1 + k)^2; \quad S_3 = (p_2 + k)^2
\]

\(k\) is photon momentum, so \(z = (S_2 - S_3)/(S_2 + S_3)\).

Now for L,R helicities particle and antiparticle decays we have 4 amplitudes so we have 4 such quantities now: \(f_L\), \(f_R\) and similar 2 for anti-particle. Each is now a function of \(s_1\) and \(z\). But QCD respects P, C and therefore for (I) the case of \(K_s \pi^0\) all 4 become identically the same upto a sign.

Thus time-dependent CP asymmetry \(A(t)\) becomes independent of Dalitz variables.

\(\Rightarrow\) Expression for \(A(t)\) holds whether \(K_s \pi^0\) are resonant or not or from more than one resonance, in fact!

\(\Rightarrow\) Since \(A(t)\) is independent of \(s_1\) all points in Dalitz plot can be added.

\(\Rightarrow\) Significant improvement in statistics and in implementation.

Combining the data together one gets significantly improved info on \(\sin(\psi) \sin(\Phi)\) ...the product of strong and weak phase which allows putting lower bound on each.
AGHS for $\pi^+ \pi^- + \gamma$

This is the generalization for $b \rightarrow d$ penguin of the rho gamma case...Since $\pi^+ \pi^-$ are now antiparicles. Therefore, under C, S2 and S3 get interchanged and as a result $z\rightarrow-\gamma$. So angular distribution becomes non-trivial. Once again, resonant and non-resonant info can be combined but now additional angular info becomes available to allow a separate determination of the strong and the weak phase (up to dis. Ambig)!
Some Details

- Usual Expt. Cuts to ensure underlying 2 body $b \rightarrow s(d) + \gamma$ is necessary...that is, HARD PHOTON...in particular to discriminate against Brehmms
- Departure from that will show up as smears around a central value on the Dalitz plot
- In principle, annihilation graph is a dangerous contamination, due to enhanced emission of (LD) photons off of light (initial) quark leg (see Atwood,Blok and A.S). This is relevant only to $b \rightarrow d$ case. Fortunately, can prove that these photons dominantly have same helicity as from the penguin. See AGHS for details.
Implications for B -> K $\eta(\eta)\gamma$
of AG’HS

- AG’HS not only allows $K\pi\gamma$ from all Kaonic resonances (irrespective of $J^{CP}$) as well as from non-resonant continuum to be included even a more important repercussion of AG’HS is that $K\eta(\eta)\gamma$ can be used. For these reasons expect AG’HS to allow improvement over AGS (resonance only) by factor $O(2-5)$ so that with current $O(10^{8.5})$ luminosities asymmetries $O(0.20)$ may become accessible. With a SBF may be able to get down to $O$(few%)
New physics signals in $B \to \Phi K \gamma$
{Atwood, Gershon, Hazumi, AS; WIP}

- Presence of a Vector in the FS allows many useful observables to be constructed, in particular, triple correlations.
- A highly distinctive FS: $B^{+} \to \Phi K^{+} \gamma$; ($\Phi \to K^{+} K^{-}$)
- Sizeable BR: $(3.4 \pm 0.9 \pm 0.4) \times 10^{-6}$; see A. Drutskoy et al (Belle), PRL '04 {Used 90M B’s}
  Babar {hep-ex/0607037; 207M B’s} also finds:
  I. $Br(B^+) = [3.46 \pm 0.57 \pm 0.39] \times 10^{-6}$
  II. $A_{CP}(B^+) = [-26.4 \pm 14.3 \pm 4.8] \%$ ....NEEDS ATTENTION
  III. $Br(B^0) < 2.71 \times 10^{-6}$
Rich plethora of measurable observables in $B \to \Phi K\gamma$

\[
F = |F_L|^2 + |F_R|^2 + \overline{|F_L|^2} + \overline{|F_R|^2}
\]

\[
A_{CP} = \frac{|F_L|^2 + |F_R|^2 - \overline{|F_L|^2} - \overline{|F_R|^2}}{|F_L|^2 + |F_R|^2 + \overline{|F_L|^2} + \overline{|F_R|^2}}
\]

\[
S_0 = \frac{1}{2} \frac{\text{Im}(F_L F_R^* + F_R F_L^*)}{|F_L|^2 + |F_R|^2 + \overline{|F_L|^2} + \overline{|F_R|^2}}
\]

\[
A_{RL} = \frac{|F_R|^2 - |F_L|^2}{|F_R|^2 + |F_L|^2}
\]

\[
\overline{A}_{RL} = \frac{|\overline{F_L}|^2 - |\overline{F_R}|^2}{|\overline{F_L}|^2 + |\overline{F_R}|^2}
\]

\[
\zeta_{RL} = \text{arg}(F_R F_L^*)
\]

\[
\overline{\zeta}_{RL} = \text{arg}(\overline{F_R^*} F_L)
\]
The general form of the angular distribution

\[
\frac{d\Gamma(B^- \rightarrow \gamma K^- \phi)}{d\eta d\theta d\Phi} = \lambda_0 \sin^2 \theta + \lambda_1 \sin^2 \theta \cos^2 \eta + \lambda_2 \sin^2 \theta \cos \eta \\
+ \lambda_3 \sin^2 \theta \cos(2\Phi) + \lambda_4 \sin^2 \theta \sin(2\Phi) + \lambda_5 \sin^2 \theta \cos \eta \cos(2\Phi) \\
+ \lambda_6 \sin^2 \theta \cos \eta \sin(2\Phi) + \lambda_7 \sin^2 \theta \cos^2 \eta \cos(2\Phi) + \lambda_8 \sin^2 \theta \cos^2 \eta \sin(2\Phi) \\
+ \lambda_9 \cos^2 \theta \sin^2 \eta + \lambda_{10} \sin 2\theta \sin \eta \cos \phi + \lambda_{11} \sin 2\theta \sin \eta \sin \phi \\
+ \lambda_{12} \sin 2\theta \sin 2\eta \cos \phi + \lambda_{13} \sin 2\theta \sin 2\eta \sin \phi 
\]
Null tested perfected

- $\sin \Phi$ terms in angular distribution are CP-odd, $T_N$ odd (so don’t require absorptive phase)…
  They go as $\sim (\text{CP-odd phase}) \times \frac{F_R}{F_L}$
  SM…CP odd phase is in $b \to s$ penguin $\sim O(\lambda)$
  SM…. $F_R/F_L \sim \{m_s/m_b + \text{hoc}\}$
- THUS dir CPV triple co-or is reduced to about 1/20 previous (already suppressed)!
  TDCP asy in $K^* \gamma$……i.e. well below 1%
- $\text{TRIPLE COR. Asy (TCA) in } \Phi K \gamma \text{ is an extremely clean null test of the SM}$
- For more details see Atwood, Gershon, Hazumi&AS (to be published)
Summary & Outlook

• Radiative B-decays one of the most important FS for exploring new phenomena at the SBF
• Though $\text{Br}(B\to X_s \gamma)$ unlikely to payoff more, precise determination of CP-asy ($B\to X_s \gamma$), $\text{Br}(B\to X_d \gamma)$, CPA ($B\to X_d \gamma$), CPA ($B\to X_{s+d} \gamma$), are vitally important goals at a SBF
• TDCPA in $B\to \gamma(K^*, K_1, ..., K_5 \pi(\eta, \eta') \rho, \rho' \pi \pi)$ & TCA in $\gamma \Phi(\omega, \rho)K$.. and many other VP$\gamma$ provide very clean null tests of the SM & very powerful probes of NP at the SBF...

• In particular, now also use dir CP for extremely precise tests of SM
• MAY ALSO BE DOABLE at LHCb
• Synergy: Such precision flavor studies help discriminate amongst NP scenarios @ LHC