Radiative Rare B Decays (Lecture # 2)

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Contents

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Interest in Rare B-Decays

- Rare B-Decays ($b \to s\gamma$, $b \to d\gamma$, $b \to s\ell^+\ell^-$, $b \to d\ell^+\ell^-$,...) are Flavour-Changing-Neutral-Current (FCNC) Processes ($|\Delta B| = 1$, $\Delta Q = 0$); In the SM, all electrically neutral particles (γ, Z^0, H^0, Gluons) have only diagonal couplings in the Flavour space; Hence, in the SM, FCNC transitions are not allowed at the Tree-Level

- ALL FCNC transitions (Rare decays and Particle-Antiparticle Mixings, such as the B^0 - $\overline{B^0}$ Mass Difference) are induced transitions requiring loops (Penguins, Boxes); They are governed by the GIM mechanism in the SM which imparts them sensitivity to higher scales (m_t, m_W)

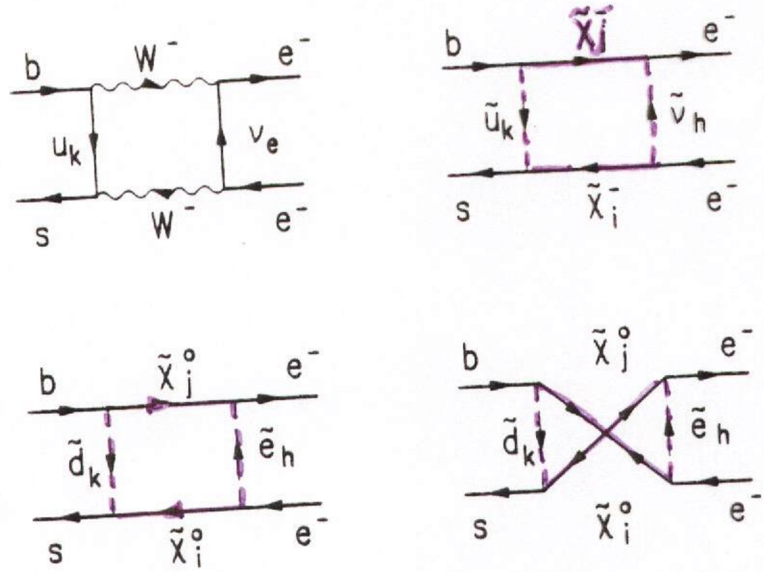
- FCNC Decays provide information on the top quark CKM couplings: V_{td}, V_{ts}, V_{tb} and they play a fundamental role in testing the CKM unitarity

- Rare Decays represent a popular area for the applications of QCD Technology (Heavy Quark Effective Theories, Lattice-QCD, QCD Sum Rules,...)

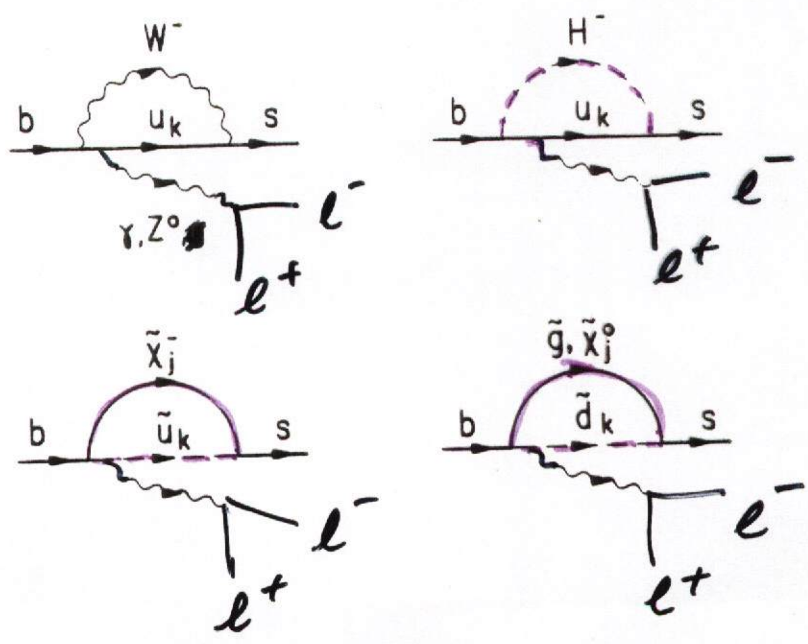
- They may reveal New Physics, such as supersymmetry if some of the supersymmetric particles are light

- Last but not least, Rare B-Decays enjoy great interest in the experimental search programmes (ARGUS, CLEO, LEP, Tevatron, BABAR, BELLE, BTeV, LHC-B, ATLAS, CMS)

$B_s \to \ell^+\ell^- + b \to s\ell^+\ell^-$ in SUSY

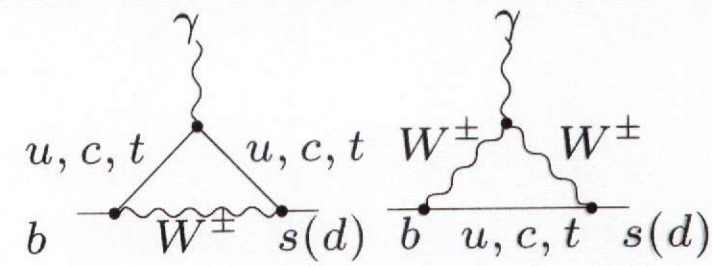


"$b \to s\gamma$" in SUSY



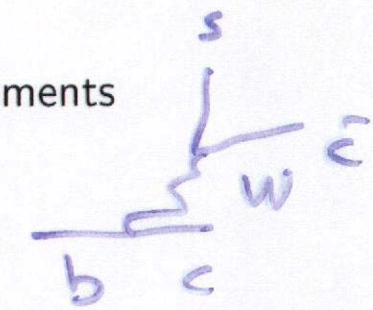
$B \to X_s(X_d)\gamma$ in the SM

Leading-Order Feynman diagrams for $b \to s(d)\gamma$ in the SM



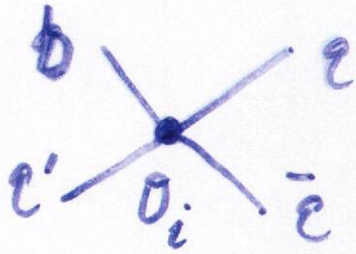
Effective Hamiltonian in the SM

$$\mathcal{H}_{\text{eff}}(b \to s\gamma) = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu)\, O_i(\mu)$$



- G_F: Fermi coupling constant, V_{ij}: CKM matrix elements
- $O_i(\mu)$: Dimension-six operators at the scale μ
- $C_i(\mu)$: Corresponding Wilson coefficients

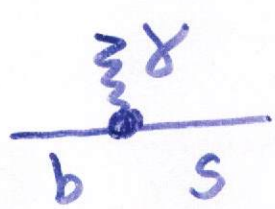
Four-Quark Operators O_i $(i = 1, \ldots, 6)$

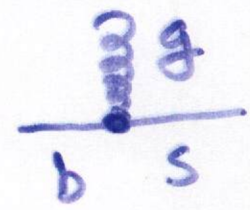


$$\begin{aligned}
\Rightarrow \quad O_1 &= (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L) \\
\Rightarrow \quad O_2 &= (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L) \\
O_3 &= (\bar{s}_L \gamma_\mu b_L) \textstyle\sum_q (\bar{q}\gamma^\mu q) \\
O_4 &= (\bar{s}_L \gamma_\mu T^a b_L) \textstyle\sum_q (\bar{q}\gamma^\mu T^a q) \\
O_5 &= (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} b_L) \textstyle\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q) \\
O_6 &= (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a b_L) \textstyle\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q)
\end{aligned}$$

Magnetic Moment Operators O_i $(i = 7, 8)$

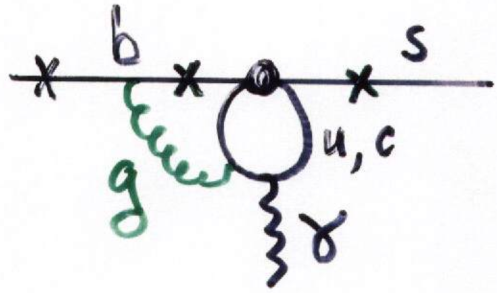
$$O_7 = \frac{e}{g_s^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}\,, \quad O_8 = \frac{1}{g_s} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}$$



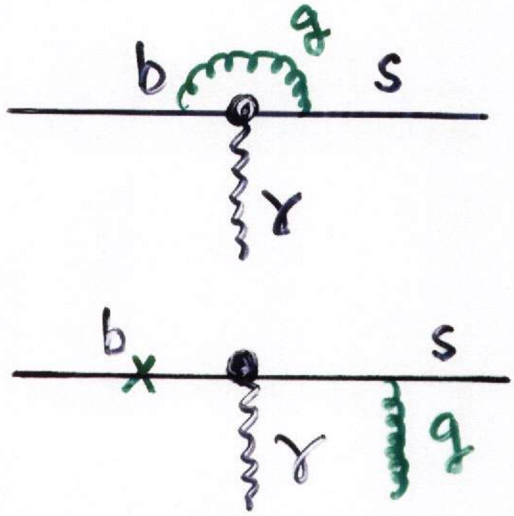


Typical $O(\alpha_s)$ Diagrams in $B \to X_s \gamma$

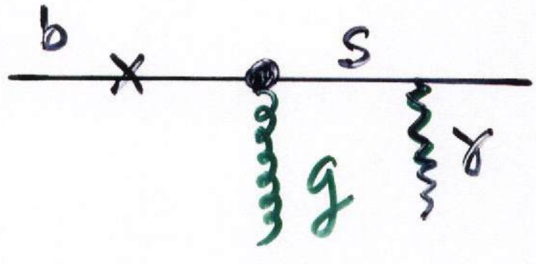
O_1, O_2 :



O_7 :

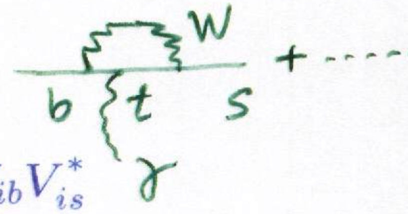


O_8 :



NLO $\mathcal{B}(B \to X_s\gamma)$ in the SM & Comparison with Data

- Unitarity of the CKM matrix



$$\sum_{u,c,t} \lambda_i = 0, \quad \text{with} \;\; \lambda_i = V_{ib}V_{is}^*$$

- $\lambda_u = V_{ub}V_{us}^* \simeq A\lambda^4(\bar{\rho} - i\bar{\eta}) \simeq O(10^{-2})$
- $\lambda_c \simeq -\lambda_t = A\lambda^2 + \ldots = (41.0 \pm 2.1) \times 10^{-3}$

- SM (pole quark masses) [Chetyrkin, Misiak, Münz]

$$\mathcal{B}(B \to X_s\gamma) = (3.35 \pm 0.30) \times 10^{-4}$$

- SM ($\overline{\text{MS}}$ quark masses) [Gambino, Misiak]

$$\mathcal{B}(B \to X_s\gamma) = (3.73 \pm 0.30) \times 10^{-4}$$

- Current Experimental World Average [CLEO, ALEPH, BABAR, BELLE]

$$\mathcal{B}(B \to X_s\gamma) = (3.43^{+0.42}_{-0.37}) \times 10^{-4}$$

$(3.48 \pm 0.36) \times 10^{-4}$ [HFAG '03]

- Experiment and SM are in accord in $B \to X_s\gamma$;
  Reduction of theory errors (mostly from the scheme-dependence of the quark masses) requires NNLO corrections
- $\mathcal{B}(B \to X_s\gamma)$ provides an indirect determination of λ_t (or V_{ts}), but currently limited in precision [Misiak, AA]

$$|1.69\lambda_u + 1.60\lambda_c + 0.60\lambda_t| = (0.94 \pm 0.07)|V_{cb}|$$

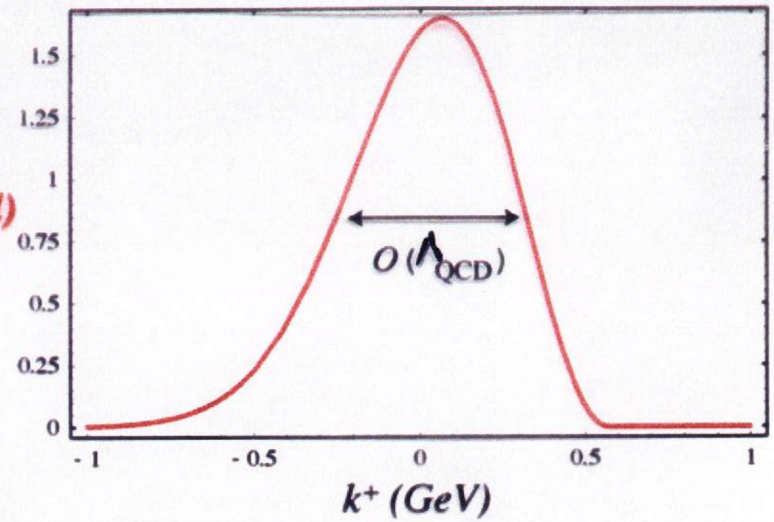
$$\Longrightarrow \boxed{\lambda_t = V_{ts} = (47 \pm 8) \times 10^{-3}}$$

- $A_{CP}(B \to X_s\gamma) \approx 0.5\,\%$ [SM]
- BELLE : $A_{CP}(B \to X_s\gamma) = 0.004 \pm 0.051 \pm 0.038$
  (90% CL) $\Longrightarrow$ $-0.107 < A_{CP}(X_s\gamma) < 0.099$

Theoretical Issues:

(i) Fermi motion:

Shapes of charged lepton spectrum, hadronic invariant mass spectrum and photon energy spectrum are ALL determined at leading order in $1/m_b$ by a UNIVERSAL parton distribution function



$$\boxed{f(\omega) = \frac{1}{2m_B}\langle B|\bar{b}\,\delta(\omega + i\hat{D}\cdot n)b|B\rangle}$$

$$\frac{1}{\Gamma_0}\frac{d\Gamma}{d\hat{E}_\gamma}(B\to X_s\gamma) = \quad d\omega\,\delta(1-2\hat{E}_\gamma-\omega)f(\omega)+\ldots$$

$$\frac{1}{2\Gamma_0}\frac{d\Gamma}{d\hat{E}_\ell}(B\to X_u\ell\bar{\nu}_\ell) = \quad d\omega\,\theta(1-2\hat{E}_\ell-\omega)f(\omega)+\ldots$$

$$\frac{1}{\Gamma_0}\frac{d\Gamma}{d\hat{s}_H}(B\to X_u\ell\bar{\nu}_\ell) = \quad d\omega\,\frac{2\hat{s}_H^2(3\omega-2\hat{s}_H)}{\omega^4}\theta(\omega-\hat{s}_H)f(\omega-\hat{\Lambda})+\ldots$$

S. Chen et al. (CLEO)
hep-ex/0108032

E_γ - Spectrum ($B \to X_s \gamma$)

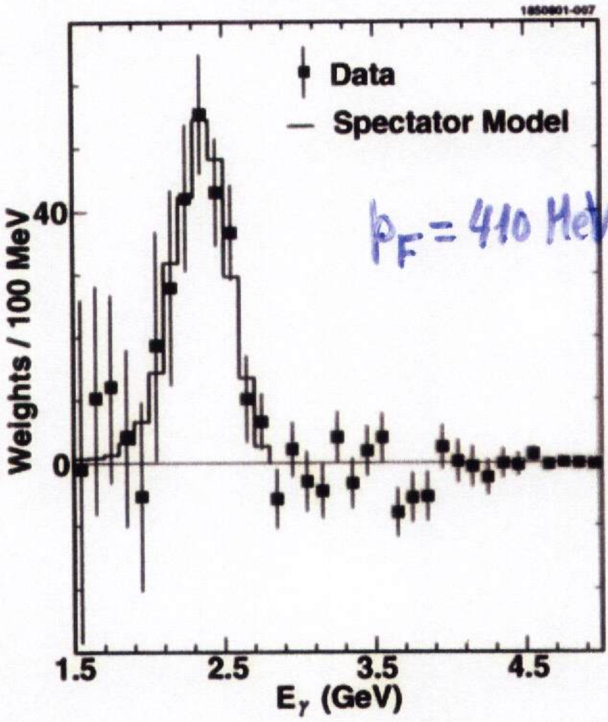
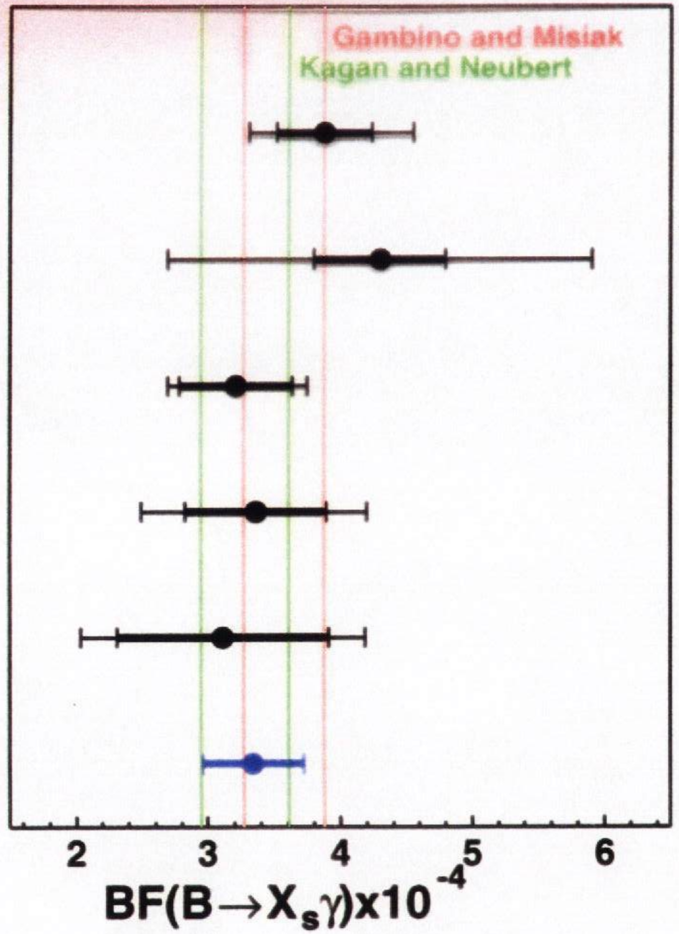


FIG. 2. Observed laboratory frame photon energy spectrum (weights per 100 MeV) for On minus scaled Off minus B backgrounds, the putative $b \to s\gamma$ plus $b \to d\gamma$ signal. No corrections have been applied for resolution or efficiency. Also shown is the spectrum from Monte Carlo simulation of the Ali-Greub spectator model with parameters $\langle m_b \rangle = 4.690$ GeV, $P_F = 410$ MeV/c, a good fit to the data.

$B \to X_s\gamma$ branching fractions

- **BaBar** hep-ex/0207076 [54.6 fb^{-1}] — $(3.88 \pm 0.36 \pm 0.37^{+0.43}_{-0.23}) \times 10^{-4}$
- **BaBar** hep-ex/0207074 [20.7 fb^{-1}] — $(4.3 \pm 0.5 \pm 0.8 \pm 1.3) \times 10^{-4}$
- **CLEO** PRL87,251807(2001) [9.1 fb^{-1}] — $(3.21 \pm 0.43 \pm 0.27^{+0.18}_{-0.10}) \times 10^{-4}$
- **Belle** PLB511,151(2001) [5.8 fb^{-1}] — $(3.36 \pm 0.53 \pm 0.42^{+0.50}_{-0.54}) \times 10^{-4}$
- **ALEPH** PLB429,169(1998) [4.1 MZ^0] — $(3.11 \pm 0.80 \pm 0.72) \times 10^{-4}$
- **Average** C.Jessop (SLAC-PUB-9610) — $(3.34 \pm 0.38) \times 10^{-4}$



$(3.48 \pm 0.36) \times 10^{-4}$
HFAG Update

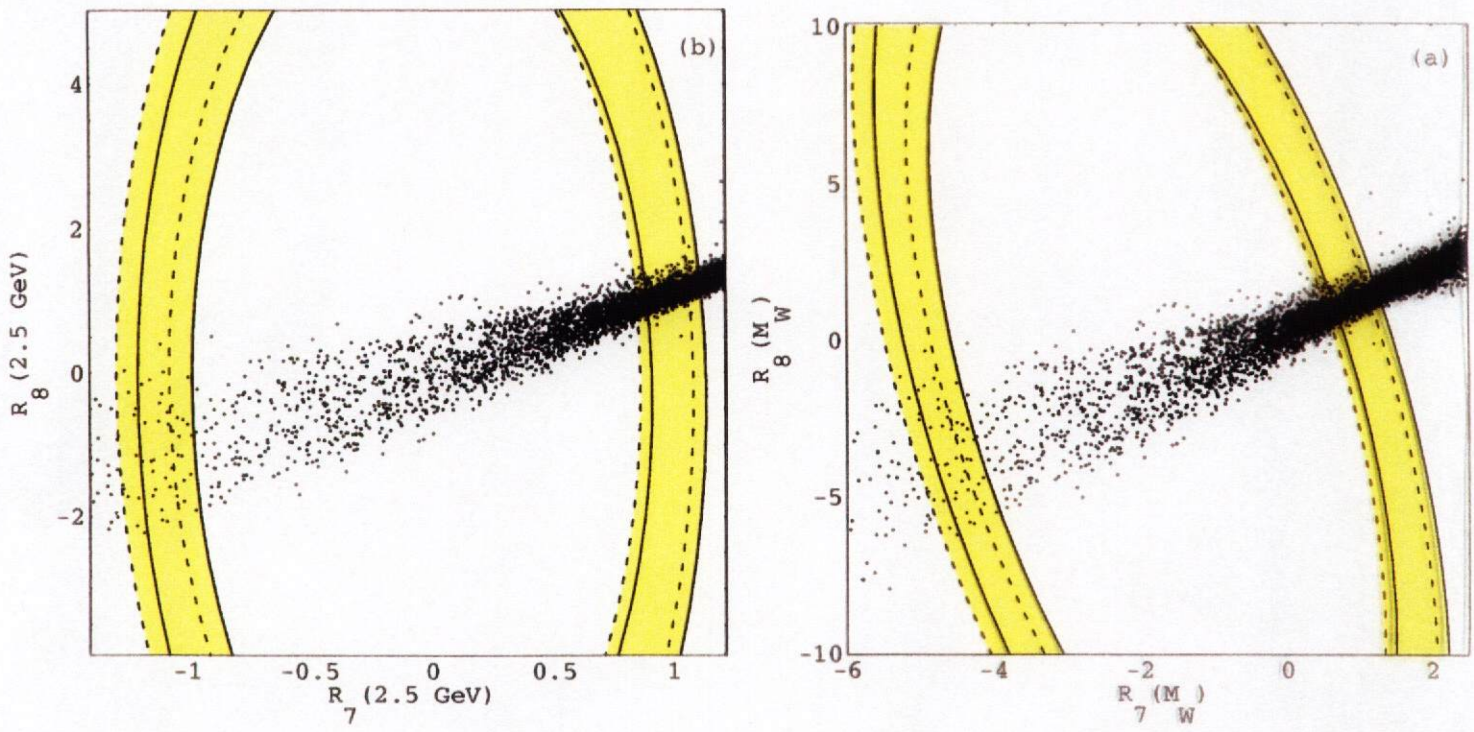
No deviation from SM — *many constraints on new physics*

To further reduce errors:
Theory — need to go from NLO to NNLO
Measurements — need to lower E_γ (more data)

A Model-independent Analysis of $B \to X_s\gamma$ & $B \to X_s\ell^+\ell^-$

- Assume $\mathcal{H}_{eff}^{\rm SM}$ a sufficient operator basis also for Beyond-the-SM physics
- Shifts due to Beyond-the-SM [BSM] physics only in $C_7(\mu_W)$,$C_8(\mu_W)$, $C_9(\mu_W)$, and $C_{10}(\mu_W)$
- BSM Coefficients: $R_7 - 1$, $R_8 - 1$, $C_9^{\rm NP}$, & $C_{10}^{\rm NP}$
- Define:
$$R_{7,8}(\mu_W) \equiv \frac{C_{7,8}^{\rm tot}(\mu_W)}{C_{7,8}^{\rm SM}(\mu_W)}$$
with $C_{7,8}^{\rm tot}(\mu_W) = C_{7,8}^{\rm SM}(\mu_W) + C_{7,8}^{\rm NP}(\mu_W)$
- Set the scale $\mu_W = M_W$, and use RGE to evolve $R_{7,8}(\mu_W) \to R_{7,8}(\mu_b) = \frac{A_{7,8}^{\rm tot}(\mu_b)}{A_{7,8}^{\rm SM}(\mu_b)}$
- RGE $\Longrightarrow$ modificications in $\tilde{C}_7^{eff}$, $\tilde{C}_9^{eff}$, $\tilde{C}_{10}^{eff}$
- Impose constraints from $R_7(\mu_b)$ and $R_8(\mu_b)$ from $B \to X_s\gamma$ Data
- Use Data on $B \to (X_s, K^*, K)\ell^+\ell^-$ BRs to constrain $C_9^{\rm NP}$ and $C_{10}^{\rm NP}$
- Two-fold ambiguity due to the sign of C_7^{eff}
$\Longrightarrow$ Two-fold ambiguity for $C_9^{\rm NP}$ and $C_{10}^{\rm NP}$

$B \to X_s\gamma$ bounds in the $[R_7, R_8]$ plane



[A. A., C. Greub, G. Hiller, E. Lunghi, hep-ph/0201049]

MFV Parameter space used in the scanning:

$$
\begin{aligned}
\mu &\in [-1000\ \text{GeV}, 1000\ \text{GeV}]\\
M_2 &\in [100\ \text{GeV}, 1000\ \text{GeV}]\\
M_{\tilde{t}} &\in [100\ \text{GeV}, 1000\ \text{GeV}]\\
M_{H^\pm} &\in [100\ \text{GeV}, 1000\ \text{GeV}]\\
\theta_{\tilde{t}} &\in [-\pi, \pi]\\
\tan\beta &\in [3, 30]
\end{aligned}
$$

@ 10^{36} $\mathcal{L}$-B Factory

Extrapolation ($B \to X_s \gamma$)

C. Jessop

Lumi ab-1	Stat %	Sys %	Model %	Total %
0.05 (2002)	9.2	9.4	8.5	15.8
0.1 (now)	7.6	6.4	5.0	11.2
0.5 (2005)	3.1	3.0	5.0	6.6
10.0	0.5	0.5	2.0	2.1

An educated guess, assuming improvements in understanding BB Background and photon systematics (but not improvements in purity)

Definitions

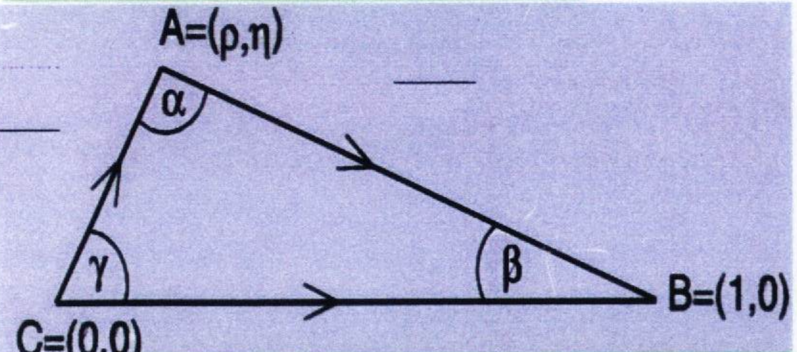
$\cancel{C}P$

$$V_{CKM} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda(1+iA^2\lambda^4\eta) & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2(1+i\lambda^2\eta) & 1 \end{pmatrix}$$

$\delta\gamma \sim O(\lambda^2)$

The Unitarity Test

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$



$\phi_1=\beta \quad \phi_2=\alpha \quad \phi_3=\gamma$

$$\alpha = \arg\left(-\frac{V^*_{tb}V_{td}}{V^*_{ub}V_{ud}}\right)$$

$$\beta = \arg\left(-\frac{V^*_{cb}V_{cd}}{V^*_{tb}V_{td}}\right)$$

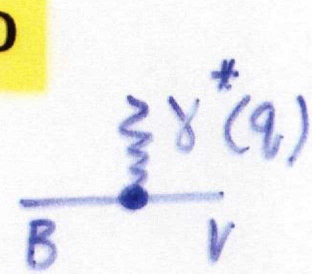
$$\gamma = \arg\left(-\frac{V^*_{ub}V_{cd}}{V^*_{cb}V_{cd}}\right)$$

Both involve V_{ub}

Exclusive Decays $B \to K^*\gamma$ in the SM

- Decay Rates
- Isospin Violation in $B \to K^*\gamma$ Decay Rates
- CP Asymmetry in $B \to K^*\gamma$ Decays
- Present Experimental Status

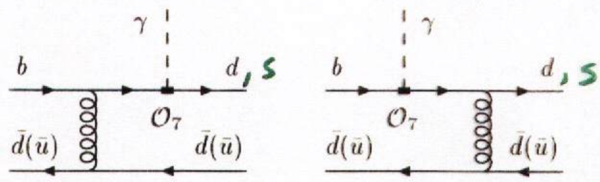
$B \to (K^*, \rho)\gamma$ Decay Rates in NLO



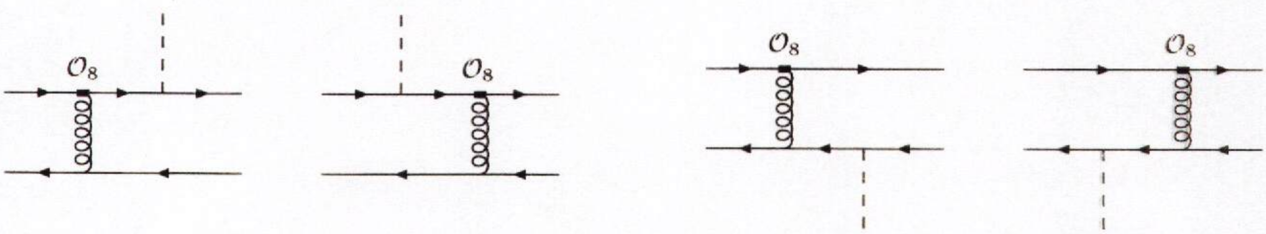
- Large Energy Effective Theory (LEET)
  [Dugan, Grinstein '91; Charles et al. '99]
  $$E_V = \frac{m_B}{2}\left(1 - \frac{q^2}{m_B^2} + \frac{m_V^2}{m_B^2}\right)$$
  For Large $E_V \sim m_B/2$, i.e., $q^2/m_B^2 \ll 1$; Symmetries in the Effective Theory $\Longrightarrow$ Relations among FFs:
  $$f_k(q^2) = C_{\perp k}\xi_\perp(q^2) + C_{\parallel k}\xi_\parallel(q^2)$$
- LEET-symmetries broken by perturbation theory
  Factorization Ansatz:
  [Beneke, Buchalla, Neubert, Sachrajda; Beneke & Feldmann]
  $$f_k(q^2) = C_{\perp k}\xi_\perp(q^2) + C_{\parallel k}\xi_\parallel(q^2) + \Phi_B \otimes T_k \otimes \Phi_V$$
  Perturbative Corrections:
  $$C_i = C_i^{(0)} + \frac{\alpha_s}{\pi} C_i^{(1)} + \ldots$$
- T_k: Hard Spectator Corrections
  $$\Delta\mathcal{M}^{(\mathrm{HSA})} = \frac{4\pi\alpha_s C_F}{N_c} \int_0^1 du \int_0^\infty dl_+ \, M_{jk}^{(B)} M_{li}^{(V)} T_{ijkl},$$
- $M_{jk}^{(B)}$ and $M_{li}^{(V)}$ B-Meson & V-Meson Projection Operators

Hard Spectator Contributions in $B \to (K^*, \rho)\gamma$

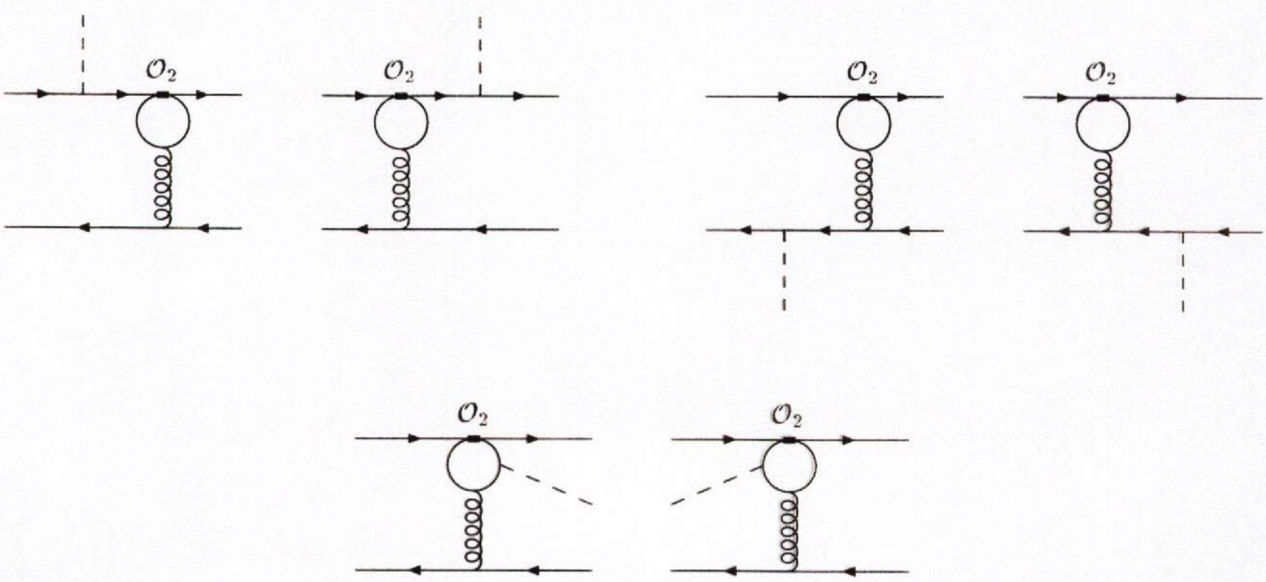
- Spectator corrections due to $\mathcal{O}_7$



- Spectator corrections due to $\mathcal{O}_8$



- Spectator corrections due to $\mathcal{O}_2$



$$\mathcal{B}_{\text{th}}(B \to K^*\gamma) = \tau_B \frac{G_F^2 \alpha |V_{tb}V_{ts}^*|^2}{32\pi^4} m_{b,\text{pole}}^2 M^3$$

$$\times \left[\xi_\perp^{(K^*)}\right]^2 \left(1 - \frac{m_{K^*}^2}{M^2}\right)^3 \left|C_7^{(0)\text{eff}} + A^{(1)}(\mu)\right|^2$$

$$K = \frac{\left|C_7^{(0)\text{eff}} + A^{(1)}(\mu)\right|^2}{\left|C_7^{(0)\text{eff}}\right|^2} \quad \text{with} \quad 1.5 \le K \le 1.7$$

[Beneke, Feldmann, Seidel; Bosch, Buchalla; Parkhomenko, A.A.]

$$\mathcal{B}_{\text{th}}(B^0 \to K^{*0}\gamma) \simeq (6.9 \pm 1.1) \times 10^{-5} \left(\frac{m_{b,\text{pole}}}{4.65\ \text{GeV}}\right)^2 \left(\frac{\xi_\perp^{(K^*)}}{0.35}\right)^2$$

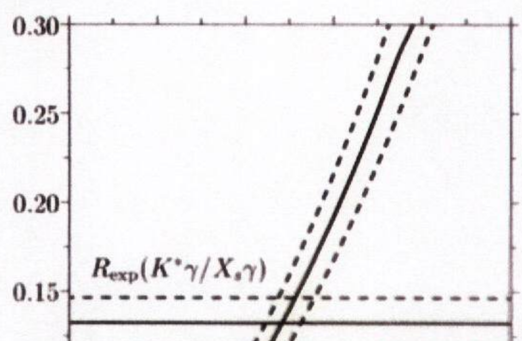
$$\mathcal{B}_{\text{th}}(B^\pm \to K^{*\pm}\gamma) \simeq (7.4 \pm 1.2) \times 10^{-5} \left(\frac{m_{b,\text{pole}}}{4.65\ \text{GeV}}\right)^2 \left(\frac{\xi_\perp^{(K^*)}}{0.35}\right)^2$$

motivated by QCD-SR

Current Experimental Average

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.14 \pm 0.26) \times 10^{-5}; \quad \mathcal{B}(B^\pm \to K^{*\pm}\gamma) = (3.98 \pm 0.35$$

HFAG update: 4.17 ± 0.23 $\quad$ 4.18 ± 0.32 $\quad \times 10^{-5}$



$\Rightarrow \xi_\perp^{K^*}(0) = 0.25 \pm 0.04$

- $\mathcal{B}(B_s^0 \to \varphi\gamma) \approx (4.5 - 5.0) \times 10^{-5}$

$$R(K^*\gamma/X_s\gamma) \equiv \frac{\mathcal{B}(B \to K^*\gamma)}{\mathcal{B}(B \to X_s\gamma)} = 0.13 \pm 0.02 \implies \bar{\xi}_\perp^{(K^*)}(0) = 0.25 \pm 0.04$$

Relation between HQET FF $\xi_\perp$ and QCD FF $T_1^{K^*}$

[Benke, Feldmann; hep-ph/0008255]

$$T_1^{K^*}(s) = \xi_\perp^{K^*}(s) \left(1 + \frac{\alpha_s C_F}{4\pi}[\ln\frac{m_b^2}{\mu^2} - L]\right) + \frac{\alpha_s C_F}{4\pi}\Delta T_1$$

$$L = -\frac{2E}{M-2E}\ln\frac{2E}{M}; \quad \Delta T_1 = \frac{M}{4E}\Delta F_\perp$$

Limiting case: $L \to 1$ for $E \to M/2$; $\Delta F_\perp$ a Non-pert. parameter

$$T_1^{(K^*)}(0, m_b) \simeq 1.08\xi_\perp(0) \implies \boxed{T_1^{(K^*)}(0, m_b) = 0.27 \pm 0.04}$$

$= 0.38 \pm 0.05$ [LC-QCD Sum Rules; Ball & Braun; AA, Ball, Handoko, Hiller]

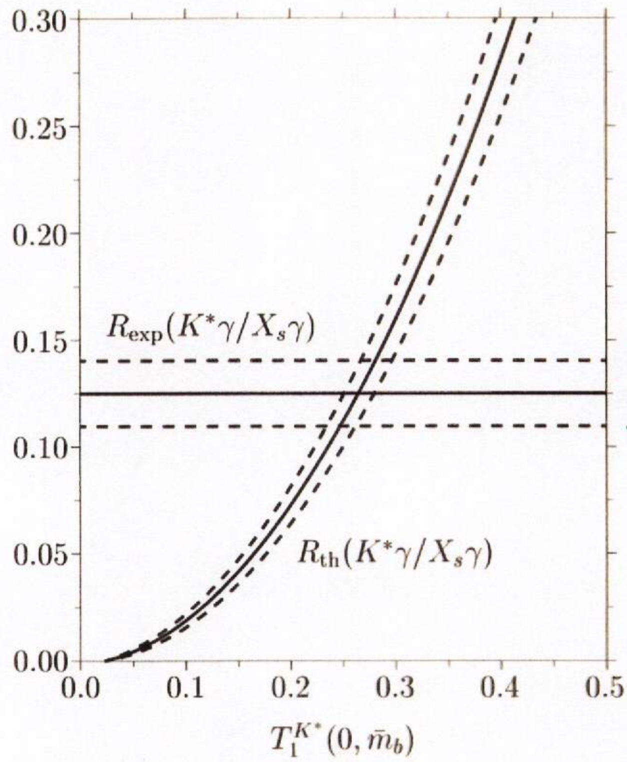
$= 0.32^{+0.04}_{-0.02}$ [Lattice-QCD; Del Debbio et al.]

- **QCD Factorization & Current Data $\Longrightarrow$ smaller value for the FF $T_1^{K^*}$ than the LC-QCD Sum Rules or the Lattice QCD**

- **The consistency of the QCD Factorization theory has to be checked by independent measurements, such as $\mathcal{B}(B \to \rho\gamma)$ and $d\mathcal{B}(B \to K^*\ell^+\ell^-/ds)$** + improved Calculations of FFs

Parkhomenko, A.A

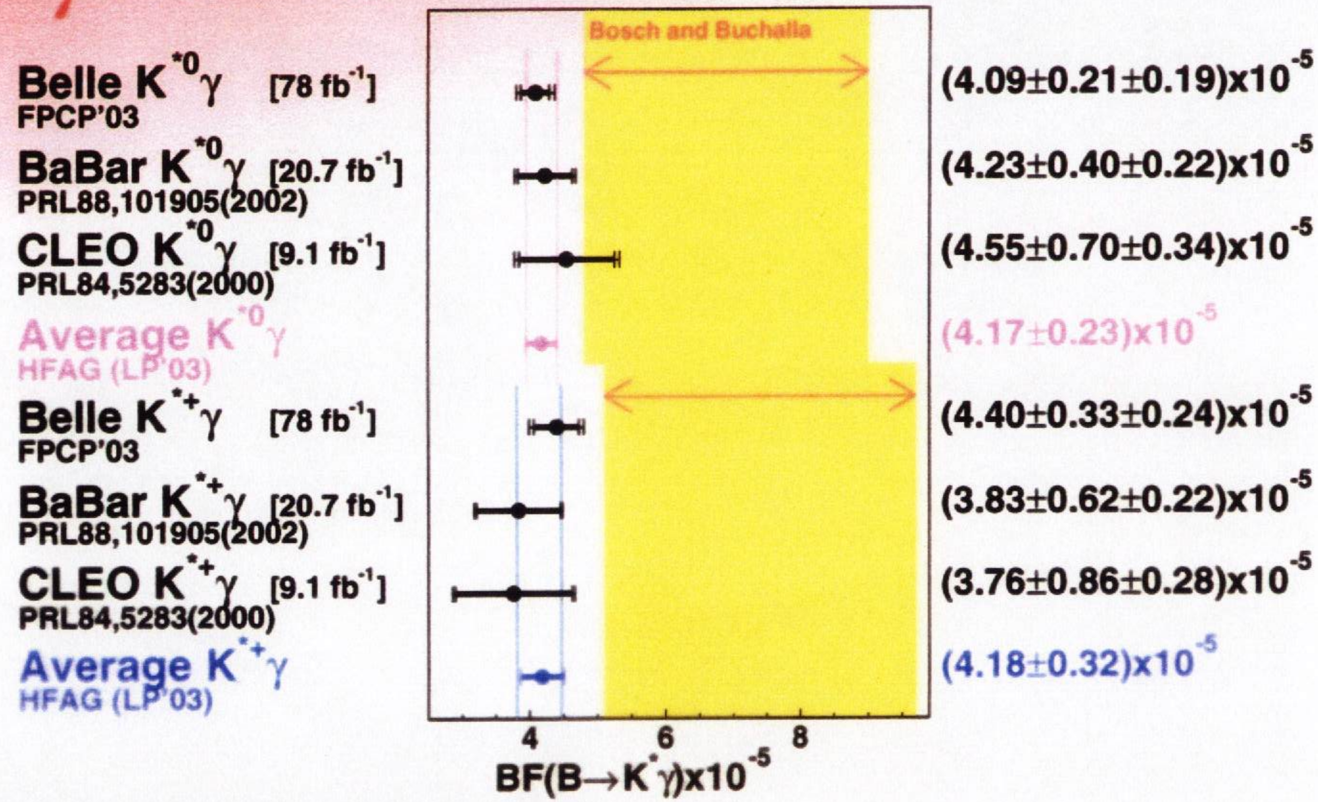
$R(K^*\gamma/X_s\gamma)$



$\} \; 0.125 \pm 0.015$

$$\Rightarrow \; T_1^{K^*}(0) = 0.27 \pm 0.02$$

$B \to K^* \gamma$ results



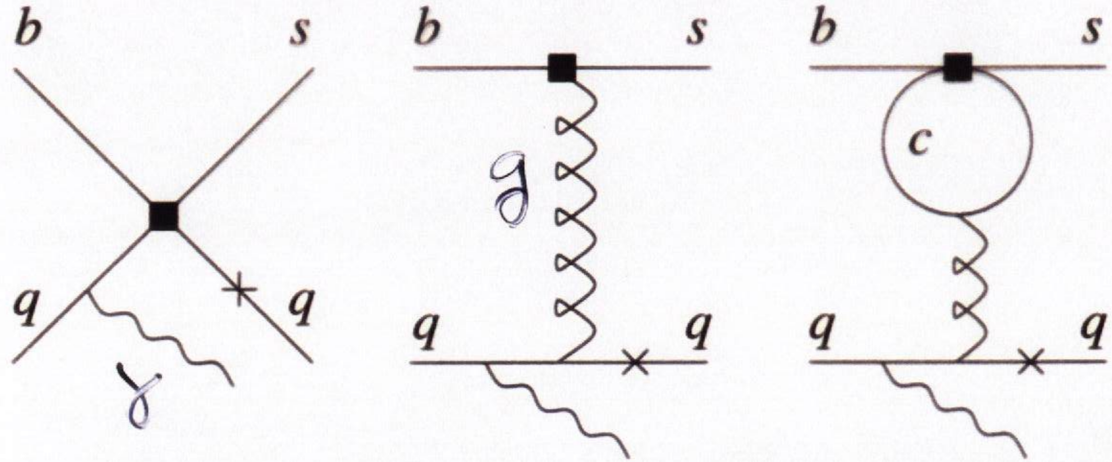
- All measurements agree
- Some theoretical debate on the $B \to K^*$ form factor
  - Light-cone sum rule (LCSR): $F_7^{B\to K^*}(0) = 0.38 \pm 0.05$
  - Extracted from measurements: $F_7^{B\to K^*}(0) = 0.27 \pm 0.04$
  - New preliminary Lattice: $F_7^{B\to K^*}(0) = 0.25 \pm 0.04$ (!?) [Becirevic et al.]

Isospin Violation in QCD Factorization - Standard Model

A.K. and M. Neubert

(Alex Kagan's Talk)
at SLAC, May 2003

- Due to annihilation, exchange graphs with photon radiated off of spectators of different charge

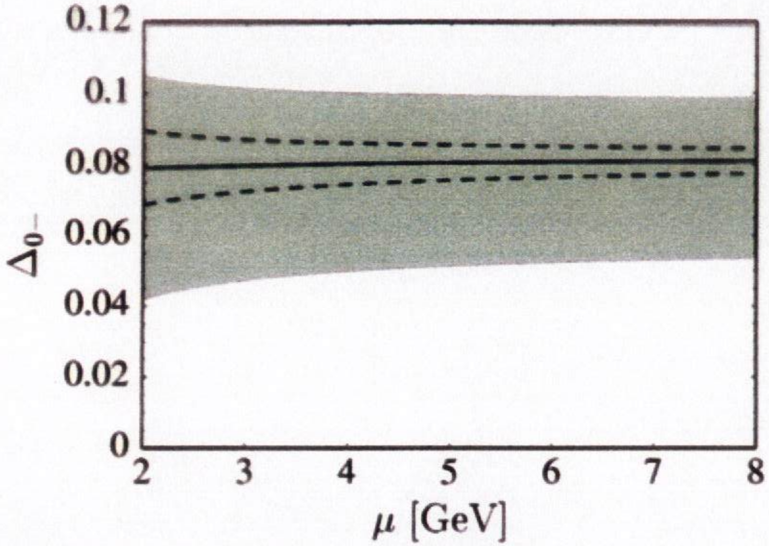


- Subleading $\mathcal{O}(\Lambda_{QCD}/m_b)$ effects, but the dominant contributions are calculable, factorizable
- Parametrize isospin breaking contributions as $A_q = b_q A_{\text{lead}}$, $q = u$ for B^-, $q = d$ for $\bar{B}^0$.

$$\Rightarrow \quad \Delta_{0-} = \text{Re}(b_d - b_u)$$

Isospin Breaking: Numerical Results

Predictions for Δ_{0-} as a function of renormalization scale μ, assuming $F_{K^*} = .3$. Dark lines refer to variation in estimate of residual NLO contributions. The band shows the theoretical uncertainty



Kagan, Newbert

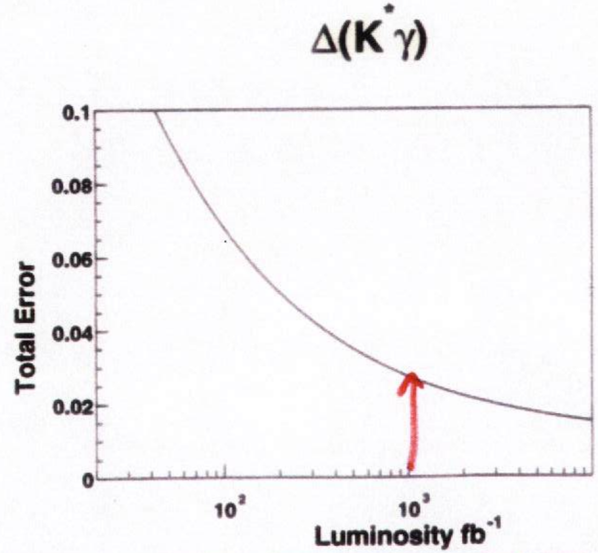
- Combining uncertainties $\Rightarrow \Delta_{0-} = (8.0^{+2.1}_{-3.2})\% \times \frac{0.3}{F_{K^*}}$
- The largest uncertainties: λ_B $(^{+1.0}_{-2.5}\%)$, the divergent integral $X_\perp$ $(\pm 1.2\%)$, the decay constant f_B $(\pm 0.8\%)$
- The sign of Δ_{0-} predicted unambiguously

$B \to K^*\gamma$ Isospin Violation

- Standard Model prediction from Kagan: (hep-ph 0201313)

$$\Delta_{0-} \equiv \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to \bar{K}^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to \bar{K}^{*-}\gamma)} = (8.0^{+2.1}_{-3.2})\% \times \frac{0.3}{T_1^{B\to K^*}}$$

- Experimentally, many systematics cancel out
- For K^{*+} use both $K^{*+} \to K^+\pi^0$ and $K^{*+} \to K_s^0\pi^+$
- Asymptotic systematic error $\approx< 1\%$.
- Significant result possible with $\approx 1ab^{-1}$



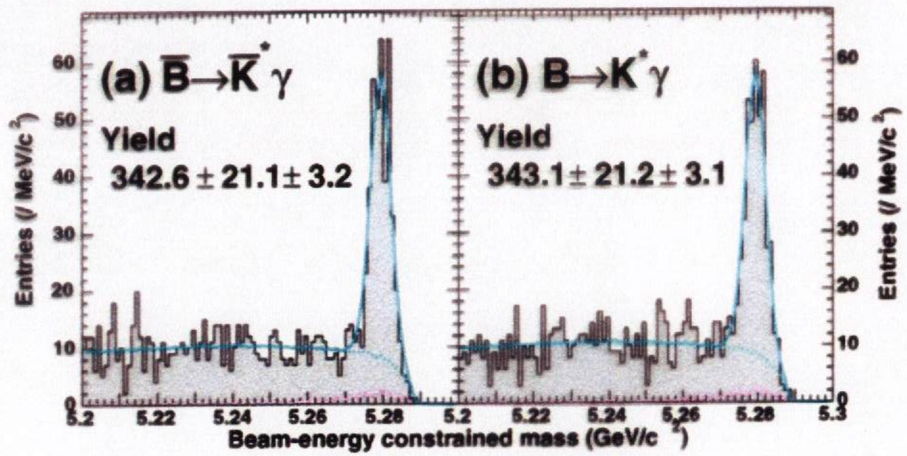
~3%

$1ab^{-1}$

Direct CP asymmetry in $B \to K^*\gamma$

[Belle FPCP'03 78 fb^{-1}]

- $B \to K^*\gamma$ is the easiest way to find a direct CP asymmetry in $B \to X_s\gamma$, if any exists
- Wrong-tag fraction is very small ($w = 0.9\%$ for Belle)

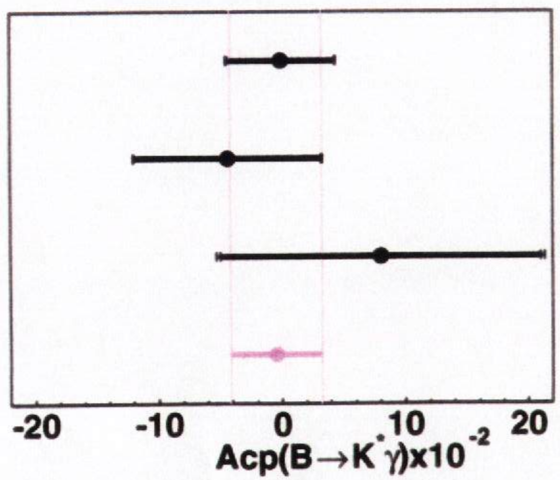


Belle [78 fb^{-1}] FPCP'03 — $(-0.1\pm4.4\pm0.8)\times10^{-2}$

BaBar [20.7 fb^{-1}] PRL88,101905(2002) — $(-4.4\pm7.6\pm1.2)\times10^{-2}$

CLEO [9.1 fb^{-1}] PRL84,5283(2000) — $(8\pm13\pm3)\times10^{-2}$

Average HFAG (LP'03) — $(-0.5\pm3.7)\times10^{-2}$



$$A_{CP} \equiv \frac{1}{1-2w}\frac{N(\overline{B})-N(B)}{N(\overline{B})+N(B)}$$

$\overline{B} = \overline{B}^0$ or B^-

$B = B^0$ or B^+

- No deviation from zero: $A_{CP}(B \to K^*\gamma) = (-0.5 \pm 3.7)\%$

Summary of Results on BRs & A_{CP} in $B \to K^*\gamma$ Decays
(Averages taken from HFAG (Summer 2003))

Experiment	$B^0 \to K^{*0}\gamma$ $[10^{-5}]$	$B^- \to K^{*-}\gamma$ $[10^{-5}]$	$A_{CP}(K^*\gamma)$
CLEO	$4.55 \pm 0.7 \pm 0.34$	$3.76 \pm 0.86 \pm 0.28$	$-0.08 \pm 0.13 \pm 0$
BABAR	$4.23 \pm 0.4 \pm 0.22$	$3.83 \pm 0.62 \pm 0.22$	$-0.044 \pm 0.076 \pm$ 0.012
BELLE	$4.09 \pm 0.21 \pm 0.19$	$4.40 \pm 0.33 \pm 0.24$	$(-0.1 \pm 4.4 \pm 0.8)\times 1$ ~~$-0.022 \pm 0.048 \pm$ 0.017~~
Average	4.17 ± 0.23	4.18 ± 0.32	~~-0.03 ± 0.04~~ $(-0.5 \pm 3.7)\times 1$

(Nakao LP '03)

Isospin-Violation in $B \to K^*\gamma$

$$\Delta_{0-} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

- **SM Predictions:** $\Delta_{0-} = (8.0^{+2.1}_{-3.2})\%$ [Kagan, Neubert]

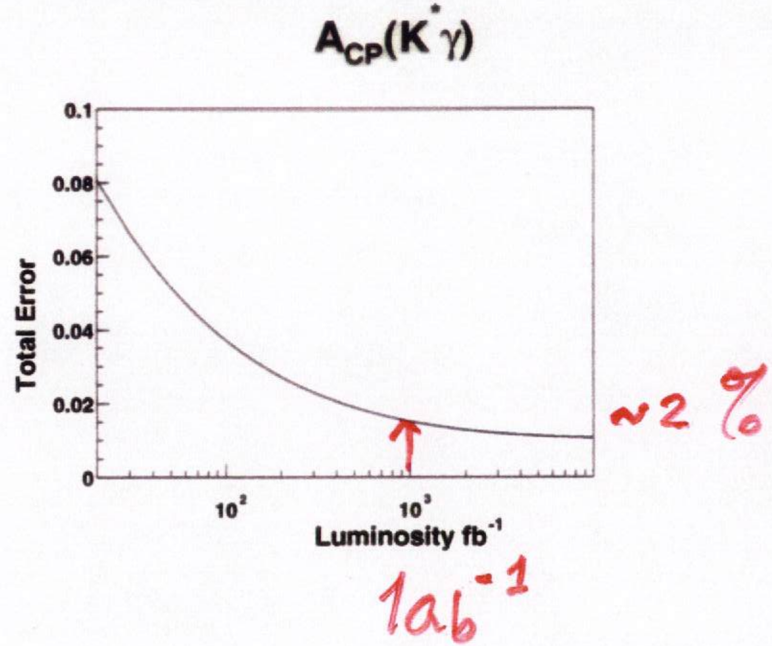
$\Delta_{+0} = (+0.003 \pm 0.045 \pm 0.018)$

- ~~$\Delta_{0-} = (4 \pm 8.0)\%$~~; in agreement with SM

- $|\mathcal{A}_{CP}(B \to K^*\gamma)| < 0.07$; **in agreement with SM predictions** (~ 0.005); **but leaves room for small** $\mathcal{O}(5\%)$ **new phases**

$B \to K^* \gamma$ CP Violation

- Standard Model predction $A_{CP} < 0.01$
- Systematics already $\approx 1\%$
- Can the be improved further?

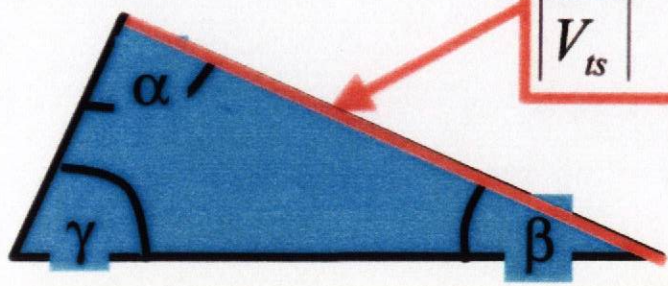


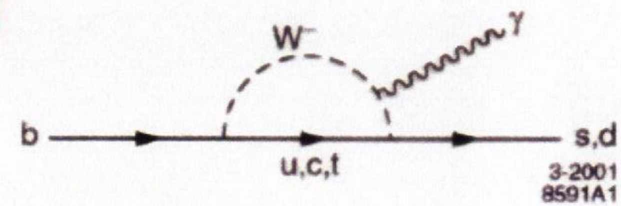
$\alpha = 10^{--}$ Workshop (SLAC)

Libby

Rare Penguins B -> $\rho,\omega\gamma$

$$\left|\frac{V_{td}}{V_{ts}}\right|^2 \propto \frac{B(B \to X_d \gamma)}{B(B \to X_s \gamma)}$$





Penguin analog of ΔMs/ΔMd B-mixing to over-constrain CKM ◣

Extensive effort to do this with exclusive modes (see Convery talk)

Exclusive Penguins (15-35% theory error)

ΔMs/ΔMd B-mixing 7-15% theory error

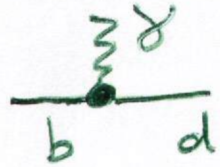
Inclusive Penguins (< 10% - from discussion ~~no~~ on rigorous theory)

Effective Hamiltonian for Radiative $B \to X_d$ Decays

$$\mathcal{H}_{\text{eff}}(b \to d\gamma) = \frac{G_F}{\sqrt{2}} \Big\{ V_{ub}V_{ud}^* \left[C_1^{(u)}(\mu)\, \mathcal{O}_1^{(u)}(\mu) + C_2^{(u)}(\mu)\, \mathcal{O}_2^{(u)}(\mu) \right]$$

$$+ V_{cb}V_{cd}^* \left[C_1^{(c)}(\mu)\, \mathcal{O}_1^{(c)}(\mu) + C_2^{(c)}(\mu)\, \mathcal{O}_2^{(c)}(\mu) \right]$$

$$- V_{tb}V_{td}^* \left[C_7^{\text{eff}}(\mu)\, \mathcal{O}_7(\mu) + C_8^{\text{eff}}(\mu)\, \mathcal{O}_8(\mu) \right] + \ldots \Big\},$$



$\simeq$ 

$q = u, c, t$

- Dominant Four-quark Operators ($q = u, c$)

$$\mathcal{O}_1^{(q)} = (\bar{d}_\alpha \gamma_\mu (1-\gamma_5) q_\beta)\, (\bar{q}_\beta \gamma^\mu (1-\gamma_5) b_\alpha) \qquad (\underset{\sim}{8})$$
$$\mathcal{O}_2^{(q)} = (\bar{d}_\alpha \gamma_\mu (1-\gamma_5) q_\alpha)\, (\bar{q}_\beta \gamma^\mu (1-\gamma_5) b_\beta) \qquad (\underset{\sim}{1})$$

- Electromagnetic & Chromomagnetic Penguin Operators

$$\mathcal{O}_7 = \frac{e m_b}{8\pi^2} (\bar{d}_\alpha \sigma^{\mu\nu} (1+\gamma_5) b_\alpha)\, F_{\mu\nu}$$
$$\mathcal{O}_8 = \frac{g_s m_b}{8\pi^2} (\bar{d}_\alpha \sigma^{\mu\nu} (1+\gamma_5) T^a_{\alpha\beta} b_\beta)\, G^a_{\mu\nu}$$

- $F_{\mu\nu}$ ($G_{\mu\nu}$) Electromagnetic (Chromomagnetic) field-strength tensor
- $C_i(\mu)$ are Wilson Coefficients; $C_7^{\text{eff}}(\mu)$ and $C_8^{\text{eff}}(\mu)$ include the effects of the operators O_5 and O_6

$B \to X_d\gamma$ Decay

[Soares; Wolfenstein, Soares; Asatrian, Greub, AA;...]

- **Branching Ratio:**

$$\mathcal{B}(\overline{B} \to \overline{X_d} + \gamma) = \frac{|\xi_t|^2}{|V_{cb}|^2} D_t + \frac{|\xi_u|^2}{|V_{cb}|^2} D_u + \frac{Re(\xi_t^* \xi_u)}{|V_{cb}|^2} D_r + \frac{Im(\xi_t^* \xi}{|V_{cb}|^2}$$

- $R(d\gamma/s\gamma) = \frac{\Gamma(B \to X_d\gamma)}{\Gamma(B \to X_s\gamma)}$ $\quad \xi_i = V_{ib} V_{id}^* \; ; \; i = u, t$

$$R(d\gamma/s\gamma) = \frac{|\xi_t|^2}{|\lambda_t|^2} + \frac{D_u}{D_t}\frac{|\xi_u|^2}{|\lambda_t|^2} + \frac{D_r}{D_t}\frac{Re(\xi_t^* \xi_u)}{|\lambda_t|^2} \sim \frac{|V_{td}|}{|V_{ts}|}$$

$R(d\gamma/s\gamma)$ **provides complementary constraints on the CKM Unitarity triangle;** Similar to $\Delta M_d/\Delta M_s$

Typically: $R(d\gamma/s\gamma) \simeq 0.04$

m_c/m_b CKM param.   scal

$$= \left(3.86^{+0.11}_{-0.18} \pm 0.43 \pm 0.09 \pm 0.15\right) \times 10$$

- **CP Asymmetry**

Hurth, Lunghi, Porod
hep-ph/0312260

$$a_{CP}(B \to X_d + \gamma) = \frac{D_i \bar{\eta}}{D_t^{(0)} \left[(1-\bar{\rho})^2 + \bar{\eta}^2\right]} \simeq \frac{0.4\bar{\eta}}{(1-\bar{\rho})^2 + \bar{\eta}^2}$$

$a_{CP}(B \to X_d + \gamma)$ **a sensitive measure of** $\bar{\eta}$;

Typically: $a_{CP}(B \to X_d + \gamma) \simeq 0.15$

$$= \left(10.2^{+2.4}_{-3.7} \pm 1.0^{+2.1}_{-4.4}\right)\%$$

(Hurth, Lunghi, Porod)

[Asatrian, Greub, AA]

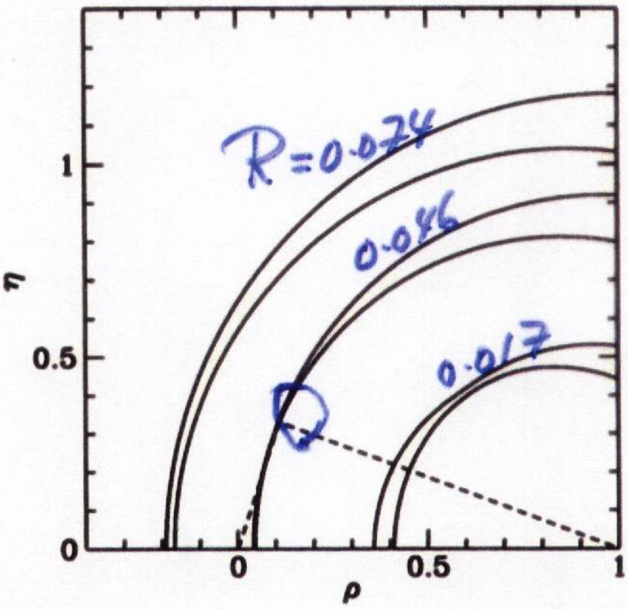


Figure 1: Fixed-R contours in the (ρ, η) plane, corresponding to $R = 0.017$ (bottom), $R = 0.046$ (middle) and $R = 0.074$ (top)

Scale dependence

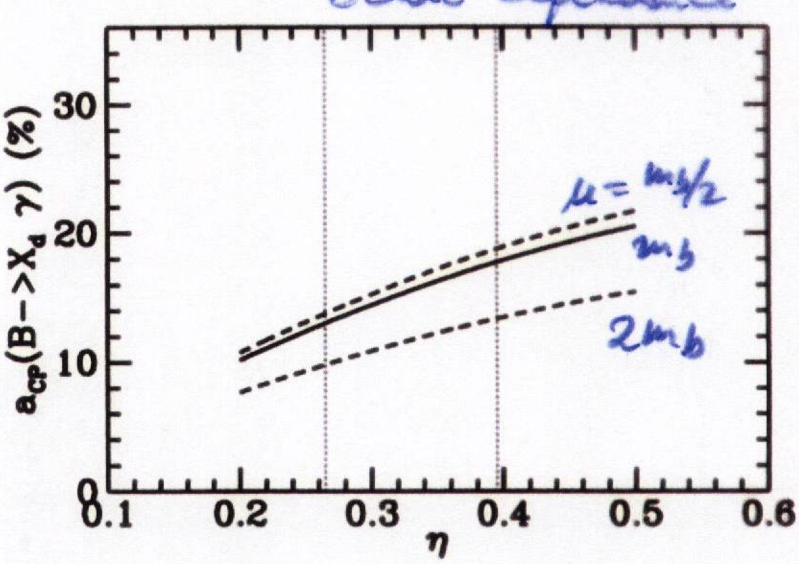
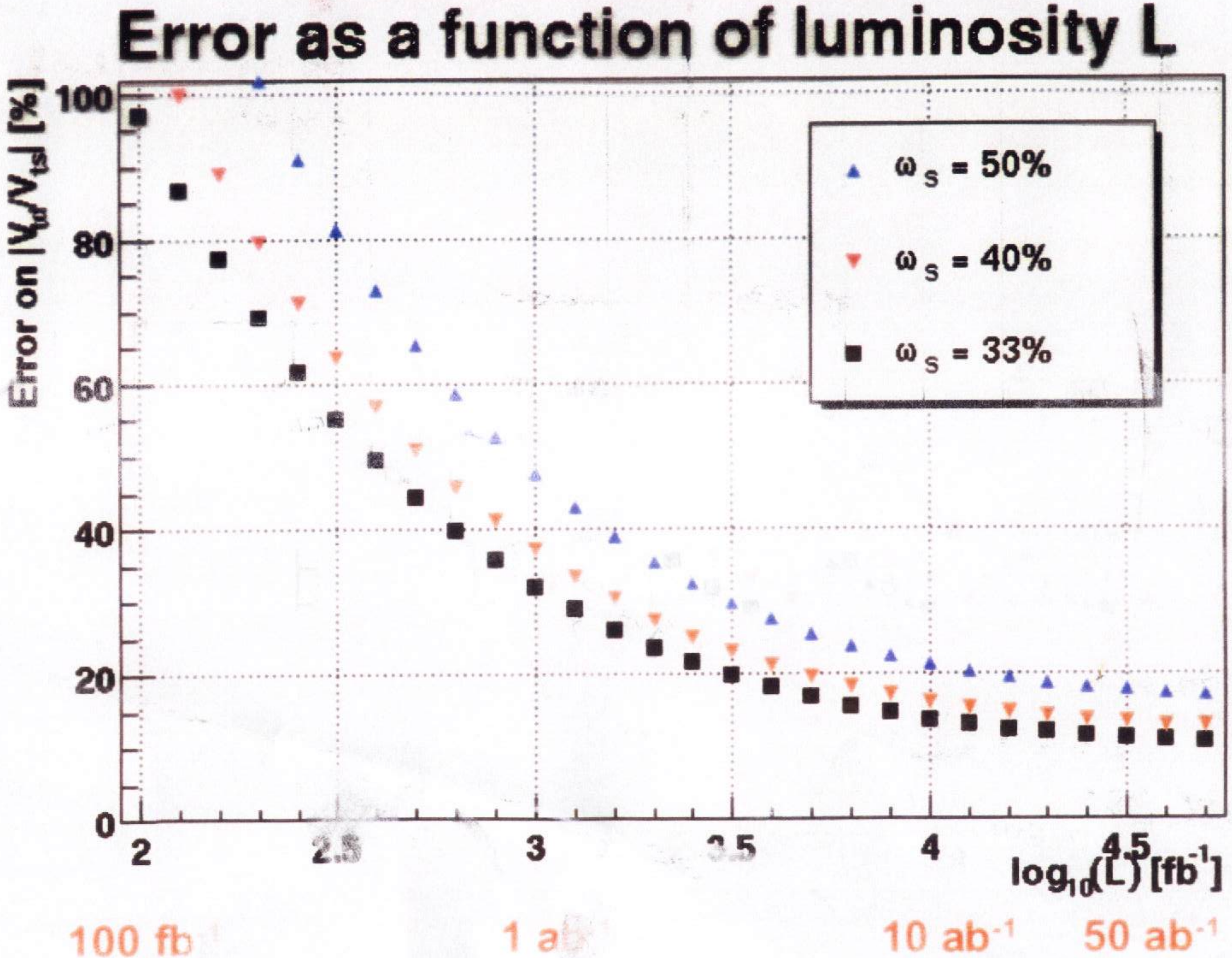


Figure 2: η dependence of the CP rate asymmetry $a_{CP}(B \to X_d + \gamma)$ for fixed $\rho = 0.11$

Variation with ω_s

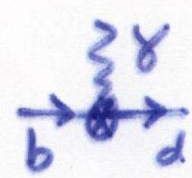
C. Jessop
$\mathcal{L} = 10^{36}$ Workshop
(SLAC)



$\omega_s \equiv$ Dilution
(Mistagging in $B \to X_s \gamma$)

$\sim \mathcal{O}(10\,\%)$

$B \to \rho\gamma$ Decay

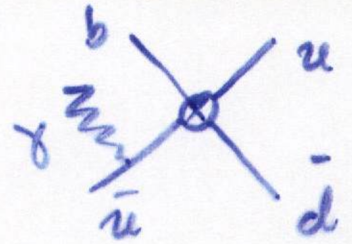


Penguin Amplitude $\mathcal{M}_{\rm P}(B \to \rho\gamma)$

$$-\frac{G_F}{\sqrt{2}} V_{tb} V_{td}^* C_7 \frac{e m_b}{4\pi^2} \epsilon^{(\gamma)\mu} \epsilon^{(\rho)\nu} \left(\epsilon_{\mu\nu\alpha\beta} p^\alpha q^\beta - i[g^{\mu\nu}(q.p) - p^\mu q^\nu] \right) T_1^{(\rho)}(0)$$

Annihilation Amplitude $\mathcal{M}_{\rm A}(B^\pm \to \rho^\pm\gamma)$

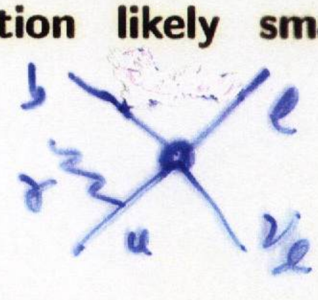
$$e\frac{G_F}{\sqrt{2}} V_{ub} V_{ud}^* a_1 m_\rho \epsilon^{(\gamma)\mu} \epsilon^{(\rho)\nu} \left(\epsilon_{\mu\nu\alpha\beta} p^\alpha q^\beta F_A^{(\rho);\rm p.v.}(0) - i[g^{\mu\nu}(q.p) - p^\mu q^\nu] F_A^{(\rho);\rm p.c}\right.$$



- $F_A^{(\rho);\rm p.v.}(0) \simeq F_A^{(\rho);\rm p.c.}(0) = F_A^{(\rho)}(0)$
  [more recently Byer, Melikhov, Stech]

$\frac{A}{P}$:
$$\epsilon_{\rm A}(\rho^\pm\gamma) = \frac{4\pi^2 m_\rho a_1}{m_b C_7^{eff}} \frac{F_A^{(\rho)}(0)}{T_1^{(\rho)}} = 0.30 \pm 0.07$$

- **Holds in factorization approximation**
- **$O(\alpha_s)$ corrections to annihilation amplitude $\mathcal{M}_{\rm A}(B^\pm \to \rho^\pm\gamma)$: Leading-twist contribution vanishes in the chiral limit [Grinstein, Pirjol]; non-factorizing annihilation contribution likely small; testable in $B^\pm \to \ell^\pm \nu_\ell \gamma$**



Annihilation Amplitude $\mathcal{M}_{\rm A}(B^0 \to \rho^0\gamma)$

- **Suppressed due to the electric charges ($Q_d/Q_u = -1/2$) and colour factors (BSW Parameters: $a_2/a_1 \simeq 0.25$)**
  $$\Longrightarrow \epsilon_{\rm A}(\rho^0\gamma) \simeq 0.05$$

$\frac{A}{P}(\rho^0\gamma) \ll 1$

$B \to \rho\gamma$ Decay Rates

[Parkhomenko,A.A.; Bosch, Buchalla]

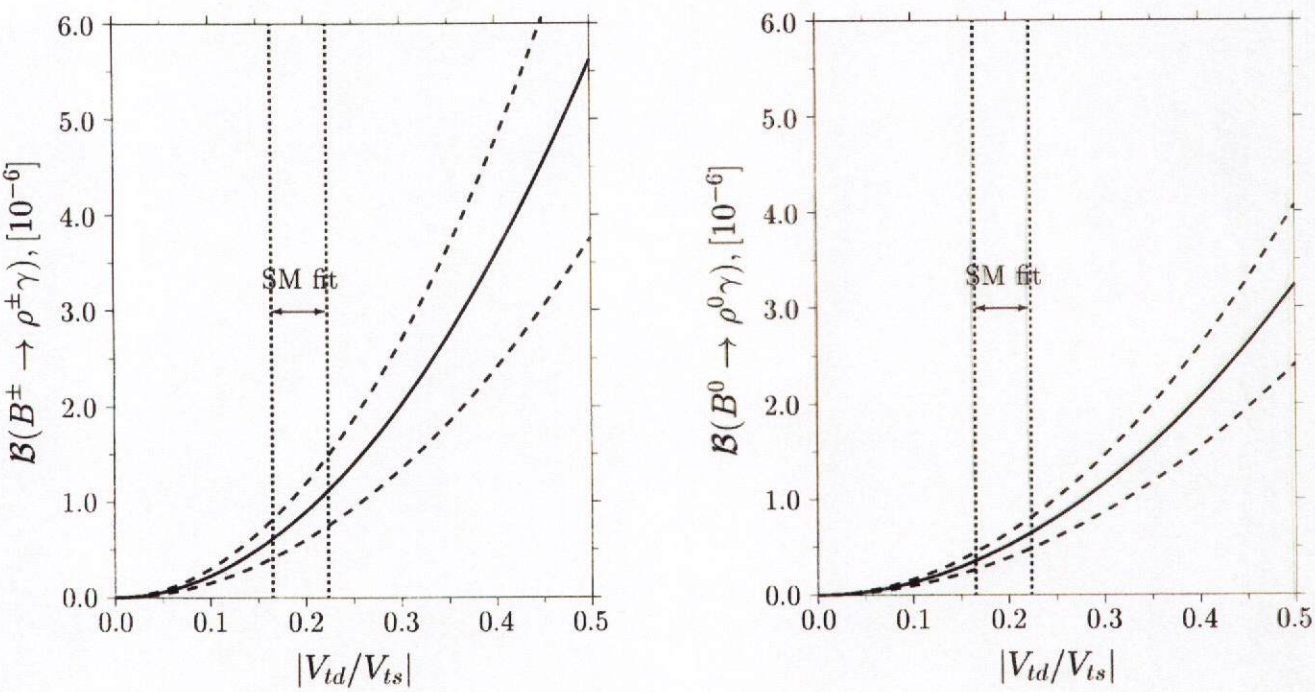
$$\frac{\overline{\mathcal{B}}_{\rm th}(B \to \rho\gamma)}{\overline{\mathcal{B}}_{\rm th}(B \to K^*\gamma)} = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(1 - m_\rho^2/M^2)^3}{(1 - m_{K^*}^2/M^2)^3} \zeta^2 \left[1 + \Delta R(\rho/K^*)\right]$$

$$S_\rho = 1 \ \text{ for } B^\pm \to \rho^\pm\gamma; \quad = 1/2 \ \text{ for } \ B^0 \to \rho^0\gamma$$

$\zeta = \dfrac{T_1^{(\rho)}(0)}{T_1^{(K^*)}(0)} \simeq 0.76 \pm 0.10$ [Braun, Simma, AA.; Khodjamirian et al.; Narisor

$$\Delta R(\rho^\pm/K^{*\pm}) = 0.06 \pm 0.13; \quad \Delta R(\rho^0/K^{*0}) = 0.02 \pm 0.11$$

[Parkhomenko,A.A. '01; Lunghi,A.A. '02]



$\mathcal{B}_{\rm SM}(B^\pm \to \rho^\pm\gamma) = (0.90 \pm 0.33) \times 10^{-6}$ [Expt. : $< 2.1 \times 10^{-6}$ (BABA

$\mathcal{B}_{\rm SM}(B^0 \to \rho^0\gamma) = (0.49 \pm 0.18) \times 10^{-6}$ [Expt. : $< 1.2 \times 10^{-6}$ (BABAI

$\mathcal{B}_{\rm SM}(B^0 \to \omega\gamma) \simeq \mathcal{B}_{\rm SM}(B^0 \to \rho^0\gamma)$ [Expt. $< 1.0 \times 10^{-6}$ (BABAR)]

$R(\rho\gamma/K^*\gamma) \equiv \dfrac{\mathcal{B}(B \to \rho\gamma)}{\mathcal{B}(B \to K^*\gamma)} = 0.01 - 0.04$ [Expt. < 0.047 (BABAR)]

- BELLE: $\mathcal{B}(\rho^+\gamma) < 2.7 \times 10^{-6}$
  $\mathcal{B}(\rho^0\gamma) < 2.6 \times 10^{-6}$
  $\mathcal{B}(\omega\gamma) < 4.4 \times 10^{-6}$

The Function $\Delta R(\rho/K^*)$

$$\Delta R(\rho/K^*) = 2\epsilon_A F_1 + \epsilon_A^2 (F_1^2 + F_2^2)$$

$$+ \frac{2}{C_7^{(0)}} Re\Big[A_{sp}^{(1)\rho} - A_{sp}^{(1)K^*}$$

$$+ F_1 (A^u + \epsilon_A A^{(1)t})$$

$$+ \epsilon_A (F_1^2 + F_2^2) A^u \Big]$$

where

$$F_1 = \left|\frac{V_{ub}}{V_{td}}\right| \cos\alpha$$

$$F_2 = \left|\frac{V_{ub}}{V_{td}}\right| \sin\alpha$$

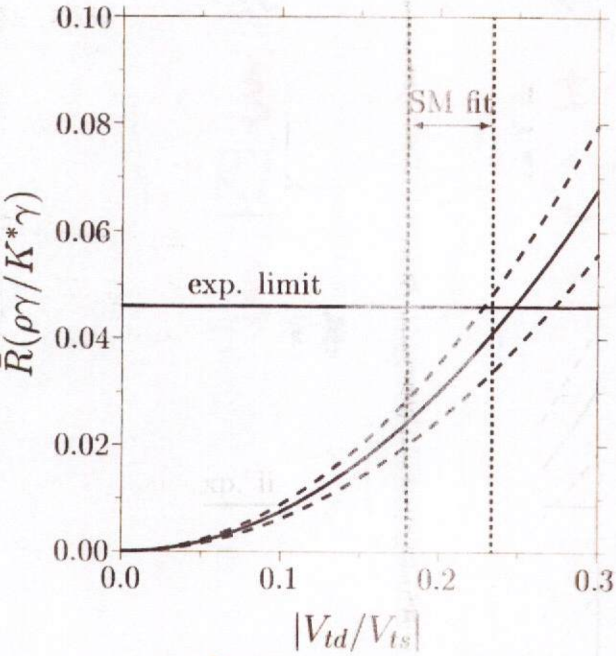
$$F_1^2 + F_2^2 = \left|\frac{V_{ub}}{V_{td}}\right|^2$$

Theoretical Update

Parkhomenko, A.A.

Experiment: $\bar{R}(\rho\gamma/K^*\gamma) < 0.047$ @ 90% C.L.

- $\xi = 0.85 \pm 0.10$



$\Rightarrow \left|\frac{V_{td}}{V_{ts}}\right| < 0.28$

- $\lambda_B^{-1} = \int_0^\infty \frac{dk}{k} \phi_+(k,\mu) = (2.15 \pm 0.50)\,GeV^{-1}$

(Braun, Korchimsky

$\Rightarrow \Delta R^{\pm} = 0.056 \pm 0.10$

$\Delta R^{0} = -0.01 \pm 0.064$

includes variations in $(\bar{\rho}, \bar{\eta})$

$\Rightarrow R^{\pm}(\rho\gamma/K^*\gamma) = 0.033 \pm 0.012$

$R^{0}(\rho\gamma/K^*\gamma) = 0.016 \pm 0.006$

SM Estimates:

$\mathcal{B}(B^{\pm} \to \rho^{\pm}\gamma) = (1.36 \pm 0.50) \times 10^{-6}$

$\mathcal{B}(B^{0} \to \rho^{0}\gamma) = (0.64 \pm 0.23) \times 10^{-6}$

$\mathcal{B}(B^{0} \to \omega\gamma) \simeq \mathcal{B}(B^{0} \to \rho^{0}\gamma)$

CKM unitarity triangle fits (95% C.L.) [Lunghi, Parkhomenko, A.A.]

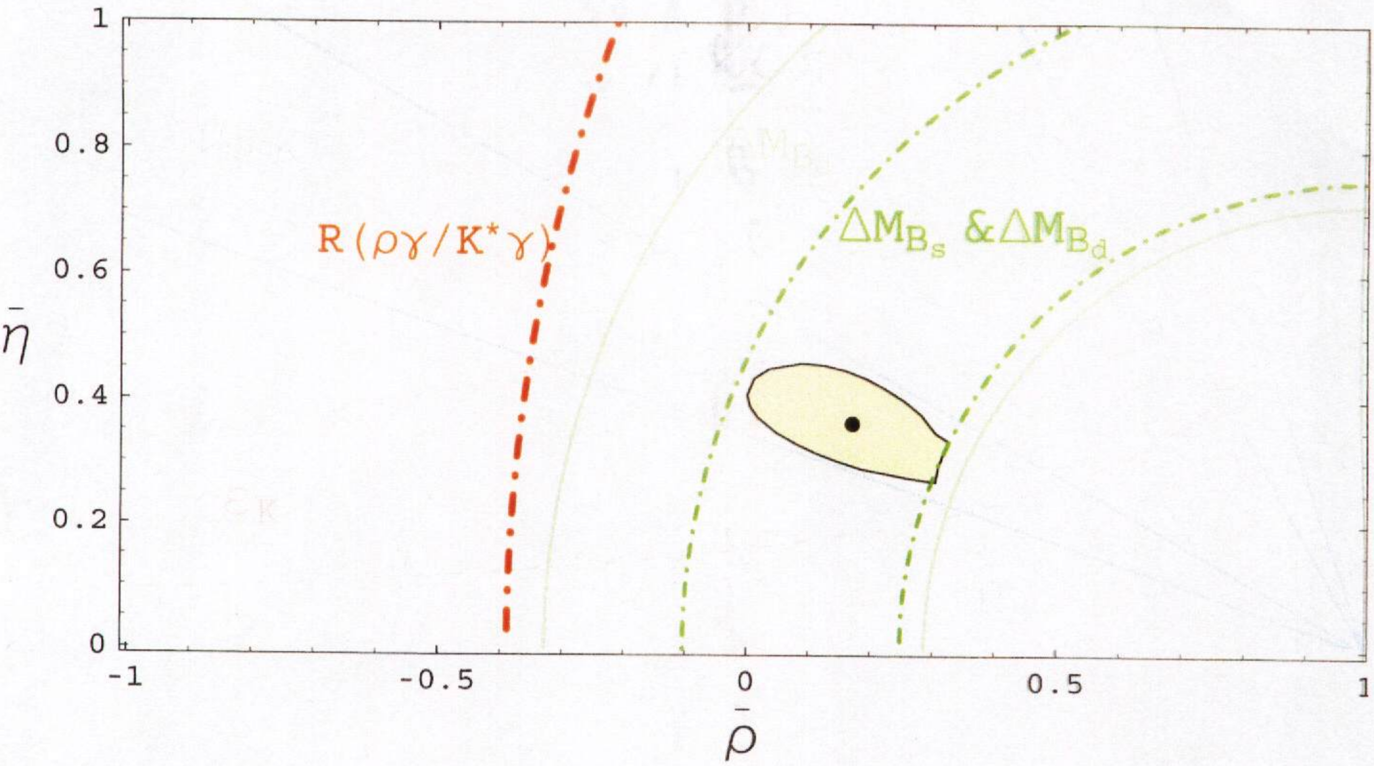


Table 1: 68% C.L. ranges for the Wolfenstein parameters, CP-violating phases and ΔM_{B_s} from the CKM-unitarity fits.

Parameter	68% C.L. Range
$\bar{\rho}$	0.11 - 0.23
$\bar{\eta}$	0.32 - 0.40
A	0.79 - 0.86
$\sin 2\phi_1$	0.68 - 0.78
ϕ_1	21.6° - 25.8°
$\sin 2\phi_2$	-0.44 - 0.30
ϕ_2	81° - 103°
$\sin 2\phi_3$	0.49 - 0.95
ϕ_3	53° - 75°
ΔM_{B_s}	14.4 - 20.5 $(\mathrm{ps})^{-1}$

Asymmerties in $B \to \rho\gamma$ Decays

[Parkhomenko,A.A.; Bosch, Buchalla; Handoko, London, A.A.]

- Isospin-Violating Ratios $\Delta^{\pm 0}$

$$\Delta = \frac{1}{2}\left[\Delta^{+0} + \Delta^{-0}\right], \qquad \Delta^{\pm 0} = \frac{\Gamma(B^{\pm} \to \rho^{\pm}\gamma)}{2\Gamma(B^0(\bar{B}^0) \to \rho^0\gamma)} - 1$$

- $\Delta_{\rm LO} \simeq 2\epsilon_A \left[F_1 + \frac{\epsilon_A}{2}(F_1^2 + F_2^2)\right]$ $\quad \propto \epsilon_A \cos\alpha + \cdots$

- $\Delta_{\rm NLO} \simeq \Delta_{\rm LO} - \frac{2\epsilon_A}{C_7^{(0)\rm eff}}\left[F_1 A_R^{(1)t}\right.$

$$\left. + (F_1^2 - F_2^2)A_R^u + \epsilon_A(F_1^2 + F_2^2)(A_R^{(1)t} + F_1 A_R^u)\right]$$

$$\frac{V_{ub}V_{ud}^*}{V_{tb}V_{td}^*} = -\left|\frac{V_{ub}V_{ud}^*}{V_{tb}V_{td}^*}\right| e^{i\alpha} = F_1 + iF_2$$

$$F_1 \simeq \left|\frac{V_{ub}}{V_{td}}\right| \cos\alpha$$

$$F_2 \simeq \left|\frac{V_{ub}}{V_{td}}\right| \sin\alpha$$

$B^{\pm} \to \rho^{\pm}\gamma: \quad \epsilon_A = +0.3 \pm 0.03; \quad B^0 \to \rho^0\gamma: \quad \epsilon_A \simeq 0.05$

[Braun,AA; Khodjamirian, Stoll, Wyler; Pirjol, Grinstein; Byer, Melikhov, Stech]

- **Sign of ϵ_A alternates in literature! Recent calculations in the QCD Factorization framework now agree on the sign**

  [Bosch, Buchalla; Kagan, Neubert; Parkhomenko, AA]

$$\underline{\Delta(\rho\gamma)}$$

$$\Delta(\rho\gamma)_{\rm SM} = 0.035^{+0.14}_{-0.07}$$

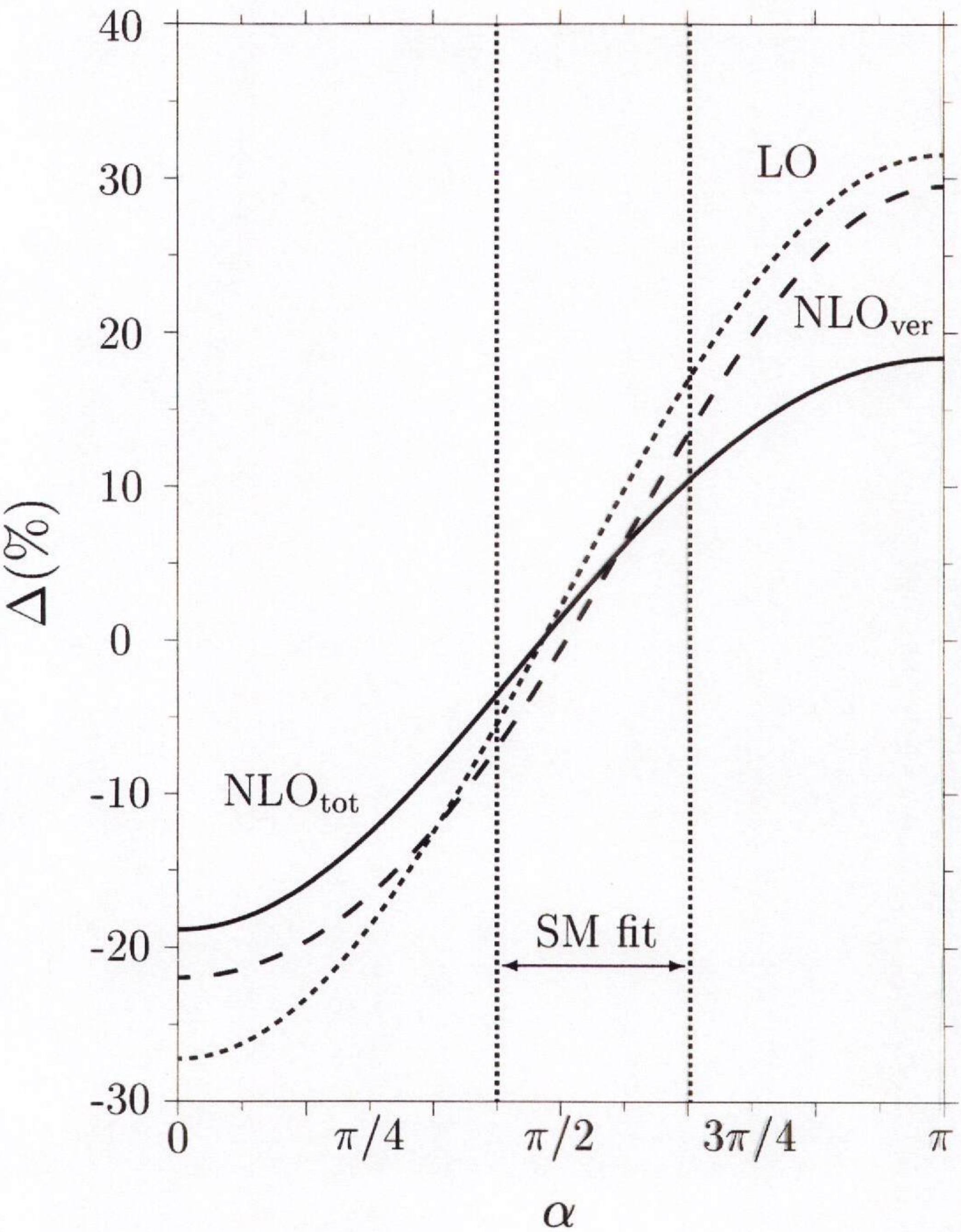
reflects poor knowledge of α

[Parkhomenko; A.A.; in agreement with Bosch & Buchalla]

$\underline{\Delta(\rho\gamma)}$

$\Delta(\rho\gamma)_{\mathrm{SM}} = 0.035^{+0.14}_{-0.07}$

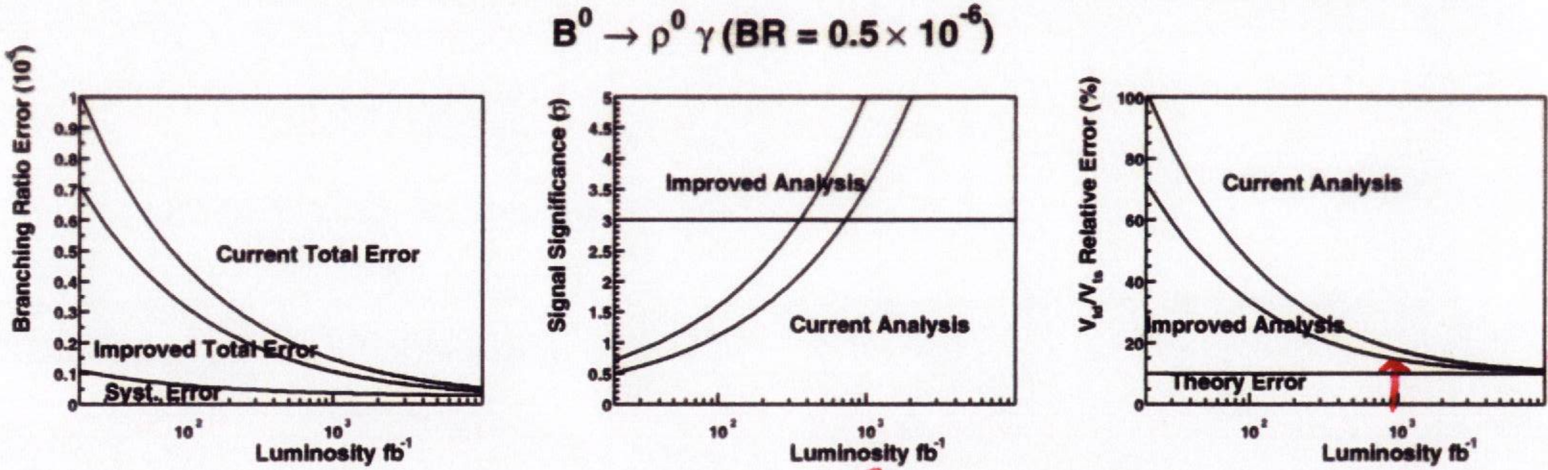
[Parkhomenko; A.A.; in agreement with Bosch & Buchalla]



$\mathcal{B}(B \to \rho\gamma)$ Extrapolation to Higher Luminosity

- Scale statistical error by $\mathcal{L}^{-1/2}$
- Scale systematic error by $A/\mathcal{L}^{-1/2} + B$. $B \approx 5\%$
- What if we could improve continuum background rejection by a factor of 2?

$\mathbf{B^0 \to \rho^0 \gamma\ (BR = 0.5 \times 10^{-6})}$



~ 15 %

1 ab^{-1} 1 ab^{-1}

Direct CP-Asymmetries $\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma)$ and $\mathcal{A}_{\mathrm{CP}}(\rho^{0}\gamma)$

- **Annihilation Contribution important in $\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma)$**

$$\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma) = \frac{\mathcal{B}(B^- \to \rho^-\gamma) - \mathcal{B}(B^+ \to \rho^+\gamma)}{\mathcal{B}(B^- \to \rho^-\gamma) + \mathcal{B}(B^+ \to \rho^+\gamma)}$$

$$\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma) = \frac{2F_2(A_I^u - \epsilon_A\, A_I^{(1)t})}{C_7^{(0)\mathrm{eff}}\,(1+\Delta_{\mathrm{LO}})} \quad \propto \sin\alpha$$

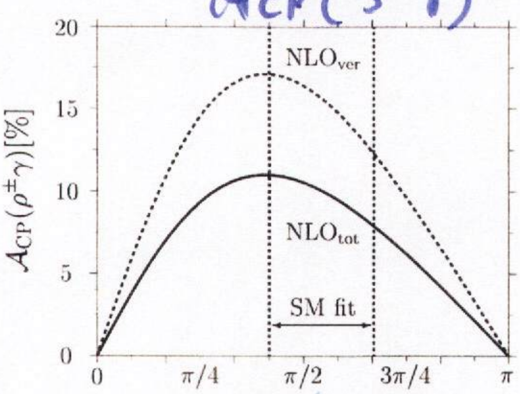
- **Annihilation Contribution small in $\mathcal{A}_{\mathrm{CP}}(\rho^{0}\gamma)$**

$$\mathcal{A}_{\mathrm{CP}}(\rho^{0}\gamma)(t) = a_{\epsilon'}\cos(\Delta M_d t) + a_{\epsilon+\epsilon'}\sin(\Delta M_d t)$$

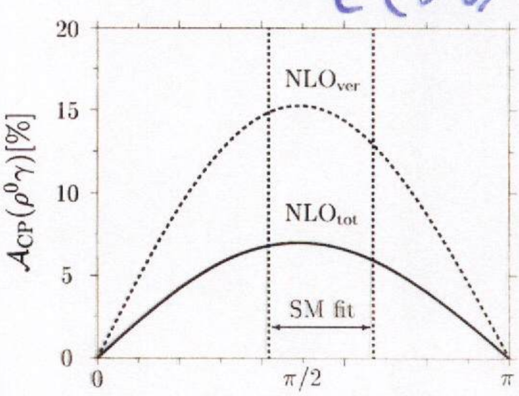
$$a_{\epsilon}'(\rho^{0}\gamma) = \frac{2F_2 A_I^u}{C_7^{(0)\mathrm{eff}}\,(1+\Delta_{\mathrm{LO}})}$$

[Parkhomenko;A.A.]; see, also Bosch & Buchalla

$\mathcal{A}_{CP}(\rho^{\pm}\gamma)$



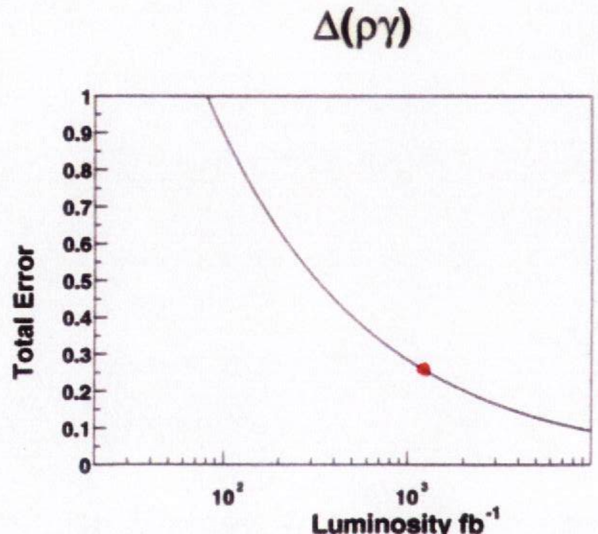
$a_{\epsilon}'(\rho^{0}\gamma)$



- **Hard Spectator Corrections reduce $\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma)$ and $\mathcal{A}_{\mathrm{CP}}(\rho^{0}\gamma)$**
- $\mathcal{A}_{\mathrm{CP}}(\rho\gamma)$ **sensitive to μ, m_c/m_b, and ϵ_A**
- **SM:** $\mathcal{A}_{\mathrm{CP}}(\rho^{\pm}\gamma) = 0.10 \pm 0.03$; $\mathcal{A}_{\mathrm{CP}}(\rho^{0}\gamma) = 0.06 \pm 0.02$

$B \to \rho\gamma$ Isospin violation

- $\Delta(\rho\gamma) \equiv \Gamma(B^+ \to \rho^+\gamma)/2\Gamma(B^0 \to \rho^0\gamma)$
- Ali et al. (hep-ph 0210183) $\Delta(\rho\gamma) = 0.04^{+0.14}_{-0.07}$
- Some of the major systematic errors cancel out
- Asymptotic systematic error $\approx< 2\%$.
- Probably requires $\approx 100ab^{-1}$ to measure deviation from zero.

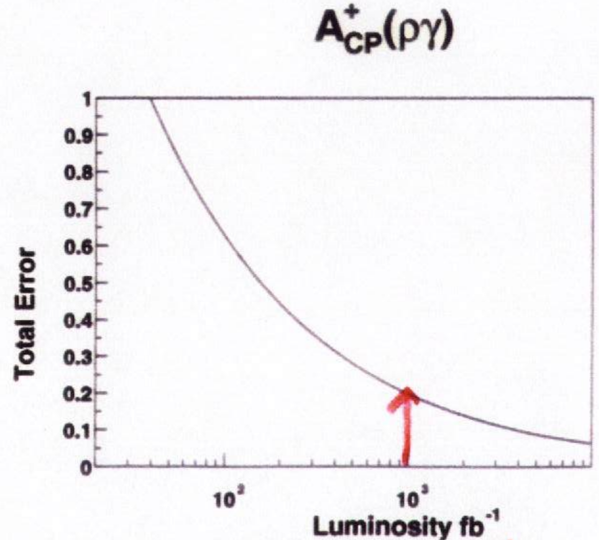


~ 20%

1 ab⁻¹

$B \to \rho\gamma$ Direct CP Violation

- $A^{+}_{CP}(\rho\gamma) \equiv \frac{\mathcal{B}(B^- \to \rho^- \gamma) - \mathcal{B}(B^+ \to \rho^+ \gamma)}{\mathcal{B}(B^- \to \rho^- \gamma) + \mathcal{B}(B^+ \to \rho^+ \gamma)}$
- Ali (hep-ph 0210183) $A^{\pm}_{CP} = 0.10^{+0.03}_{-0.02}$
- Most of the systematic errors cancel out
- Asymptotic systematic error $\approx < 1\%$.
- Interesting measurement possible with about 10 ab^{-1}



~ 20%

1 ab^{-1}

Isospin breaking ratio

$$\Delta^{\pm 0} = \frac{\mathcal{B}(B^{\pm} \to \rho^{\pm}\gamma)}{2\mathcal{B}(B^0 \to \rho^0\gamma)} - 1$$

$$\Delta^{SM} = \frac{\Delta^{+0} + \Delta^{-0}}{2}$$

$$\stackrel{\text{LO}}{=} 2\epsilon_A \left[F_1 + \frac{1}{2}(F_1^2 + F_2^2) \right]$$

CP asymmetry

$$A_{CP}^{SM} = \frac{\mathcal{B}(B^- \to \rho - \gamma) - \mathcal{B}(B^+ \to \rho^+\gamma)}{\mathcal{B}(B^- \to \rho - \gamma) + \mathcal{B}(B^+ \to \rho^+\gamma)}$$

$$= -\frac{2F_2(A_I^u - \epsilon_A A_I^{(1)t})}{C_7^{SM}(M_b)(1 + \Delta_{LO})}$$

$\epsilon_A = +0.3,\ A_I^u = 0.046,\ A_I^{(1)t} = -0.016,$

$F_1 = -\left| \frac{V_{ub}V_{ud}^*}{V_{tb}V_{td}^*} \right| \cos\alpha\ ,\ F_2 = -\left| \frac{V_{ub}V_{ud}^*}{V_{tb}V_{td}^*} \right| \sin\alpha.$

Extension to the SUSY case

$\alpha \to \alpha - \arg C_7^d(M_b)]$

$C_7^{SM}(M_b) \to |C_7^d(M_b)|$

Lunghi, A.A.

Analysis in the SM

- Experimental upper bound:

  $R\ (\rho\gamma) < 0.047$ at 90% C.L.

- SM predictions:

  $R^{\pm}(\rho\gamma) = 0.023 \pm 0.012$

  $R^{0}(\rho\gamma) = 0.011 \pm 0.006$

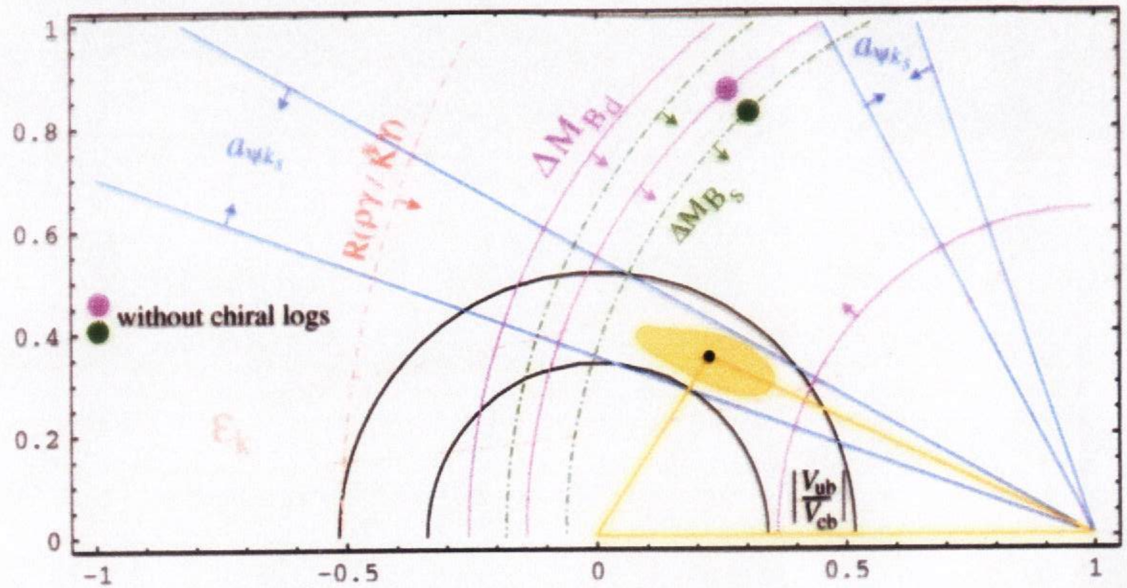
  $\Delta(\rho\gamma) = (3.5^{+1.4}_{-0.7})\%$

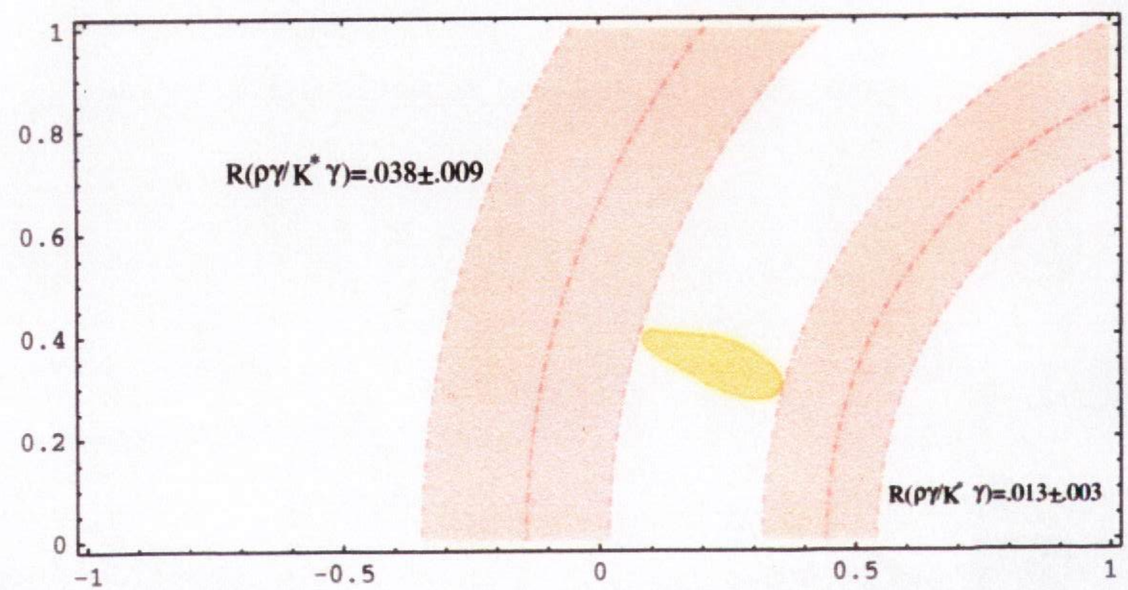
  $A^{\pm}_{CP}(\rho\gamma) = (10^{+3}_{-2})\%$

  $A^{0}_{CP}(\rho\gamma) = (6 \pm 2)\%$

- Compatibility with the SM:

  $R^{\pm}(\rho\gamma) \in [0.013, 0.038]$





Numerical Analysis

High statistic scanning

$\Downarrow\Downarrow$

$$\mu = (100 \div 1000)\ \mathrm{GeV}$$
$$M_2 = (100 \div 1000)\ \mathrm{GeV}$$
$$\tan\beta_S = 3 \div 35$$
$$M_{H^\pm} = (100 \div 1000)$$
$$M_{\tilde{t}_2} = (100 \div 600)$$
$$\theta_{\tilde{t}} = -0.3 \div 0.3$$

- $b \to s\gamma$ and δa_μ strongly favour $\mu > 0$
- Only the lower limit $\delta a_\mu > 0$ is imposed
- We impose the $b \to d\gamma$ requiring:
  $\left|\delta_{\tilde{u}_L \tilde{t}_2}\right| < \left(\sqrt{\frac{0.28}{R^{SM}}} - 1\right) \left|\frac{C_7^s(M_b)}{\eta^{\frac{16}{23}} \overline{C}_7^{MI}}\right|$

Analysis in supersymmetry

- Minimal Flavour Violation (MFV)
  - C_7 has the same value in the d and s sectors, hence the ratio R does not vary sizeably
  - The asymmetries can receive large corrections

- Models with extra sources of Flavour Changing (e.g. Extended-MFV, MIA)
  - Large deviations can be present in all the observables

Lunghi, AA