

Exploiting the finite width in

$$B_s \rightarrow \phi\gamma$$

Overview:

- Observables $B \rightarrow V\gamma$ (status)
- Hierarchy photon helicity test SM
- t-dep CP probe
- Theory prediction - Experimental prospects
- Hadronic corrections



ROMAN ZWICKY
DURHAM UNIVERSITY IPPP

FLAVOUR THEORY INSTITUTE, CERN, 6 JUNE 2008

$B \rightarrow K^*\gamma$ observables (rough status)

- $B(4\Upsilon)$ -factories: $B_d \rightarrow K^*\gamma$ Cabibbo favoured ($b \rightarrow s$)
- LHCb: $B_s \rightarrow \phi\gamma$ Cabibbo favoured ($b \rightarrow s$)

$B \rightarrow (\rho, \omega)\gamma$ Cabibbo suppressed ($b \rightarrow d$) mainly Super-B factory

observable	Experiment	Theory
\mathcal{B}	$\sigma \sim 5\%$	form factor $T_1(0)^2 \rightarrow \sigma \sim 30\%$
$B \rightarrow K^*\gamma$	$A_{isospin}$	$5.4(1.4)\%$
	A_{CP}^{dir}	$-5(5?)\%$
	S_{CP}^{mix}	$-2.2(1)(1)\%$

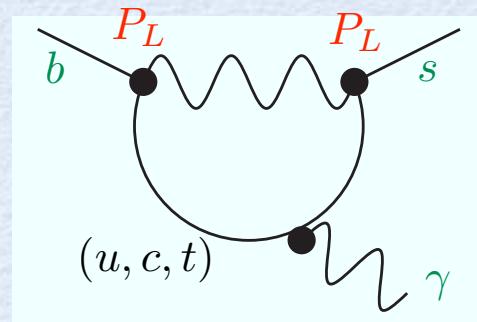
\Rightarrow mainly S_{CP}^{mix} is promising

Detour to understand significance of $S_{V\gamma}$

Weak-interaction are chiral

Gronau,Atwood & Soni 97

- look at Q_7 leading operator (single weak phase)
- $b \rightarrow s\gamma$ necessitates helicity flip on external quarks
strong hierarchy $\mathcal{A}(B \rightarrow V\gamma_{L(R)})$ for heavy-light decay



$$\epsilon_R \equiv \frac{\mathcal{A}(\bar{B} \rightarrow K^* \gamma_R)}{\mathcal{A}(B \rightarrow K^* \gamma_L)} = \frac{m_s}{m_b} + \text{long-dist(charm)}$$

BSM-probe!

Comments:

1. "room" for R since hidden in $\mathcal{B}(b \rightarrow s\gamma) \sim L^2 + R^2 = L^2(1 + \epsilon_R^2)$
2. photon polarization hard to measure directly ...

...indirect: t-dep CP asymmetry

t-dep CP-asymmetry for sizable $\Delta\Gamma$ and $|p/q| = 1$; general parametrisation

$$\mathcal{A}_{\text{CP}}(B_s \rightarrow \phi\gamma)[t] = \frac{S \sin(\Delta m_s t) - C \cos(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s}{2}t) - H \sinh(\frac{\Delta\Gamma_s}{2}t)}$$

$$B \xrightarrow{m_b} V\gamma_L \xleftarrow{m_s} \bar{B}$$

⇒ 'interference' of left and right handed amplitude (quantities odd t)

$$S[H] \sim \text{Im}[\text{Re}] \left(\frac{q}{p} \bar{\mathcal{A}}_L \mathcal{A}_L^* + (L \leftrightarrow R) \right)$$

ν CP-eigenstate

In both $B \rightarrow K^*\gamma$ and $B_s \rightarrow \phi\gamma$..

$$1. S_{K^*\gamma}^{SM} = -\sin(2\beta) \frac{m_s}{m_b} + ..$$

$$2. H \text{ out of question } \left(\frac{\Delta\Gamma}{\Gamma}\right)_{B_d} = 4 \cdot 10^{-3}$$

3. LHCb not feasible; recall V CP-eigenstate

$K^* \rightarrow K_s (\pi_0 \rightarrow \gamma\gamma)$ too difficult for hadron collider

		from 1st slide	
observable	Experiment	Theory	
$S_{B \rightarrow K^*\gamma}$	-19(23)%	-2.2(1)(1)%	

- $B_s \rightarrow \phi\gamma$ is experimentally easier $\phi \rightarrow KK$ is CP-eigenstate!
- copious production of B_s at LHCb

$$S_{B_s \rightarrow \phi\gamma}^{SM\dagger} = \sin(\phi_s - \phi_s) \frac{m_s}{m_b} \simeq 0 \quad H_{B_s \rightarrow \phi\gamma}^{SM\dagger} = \cos(\phi_s - \phi_s) \frac{m_s}{m_b} \simeq \frac{m_s}{m_b}$$

⇒ Enhancement of right-handed currents:
 'impossible' to see in S but very good H !

+ charm neglected
 ↙ 'footnote': situation changes
 new weak phases ϕ_{weak}^{new}

$H, S, C(B_s \rightarrow \phi\gamma)$ from the experiment

t-dep rate:

$$\bar{\mathcal{B}}(t) = \mathcal{B}_0 e^{-\Gamma_d t} [\cosh(\frac{\Delta\Gamma_s}{2}t) - H \sinh(\frac{\Delta\Gamma_s}{2}t) \pm C \cos(\Delta M_s t) \pm S \sin(\Delta M_s t)]$$

No tagging!!
for H

Theory (SM) :

$$\begin{aligned} H_{\phi\gamma} &= 4.5(25)(15)\% \\ S_{\phi\gamma} &= 0(0.2)\% \end{aligned}$$

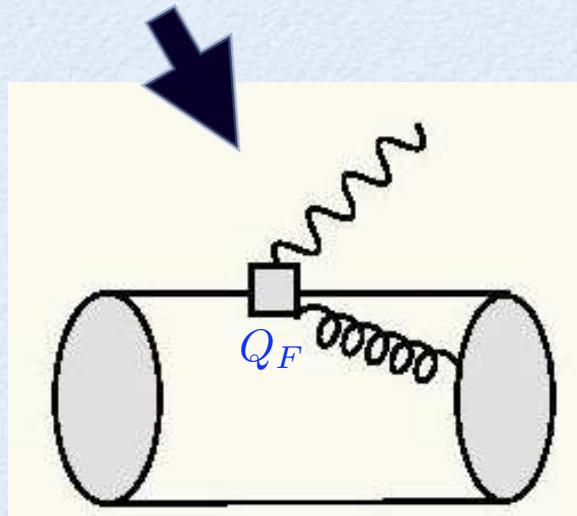
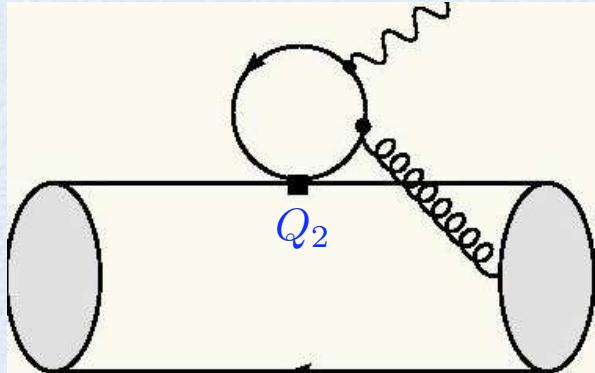
Muheim Xie RZ
PLB644(3) '08

Experiment:

$$\begin{aligned} \Delta C, \Delta S, \Delta H &\simeq 15\% \\ @ 2fb^{-1} (1 \text{ year LHCb}) \& \& \frac{\Delta\Gamma_s}{\Gamma_s} = 0.15 \end{aligned}$$

	HFAG	Lenz & Nierste
$\left(\frac{\Delta\Gamma}{\Gamma}\right)_s$	0.147(60)	0.133(74)

Corrections?



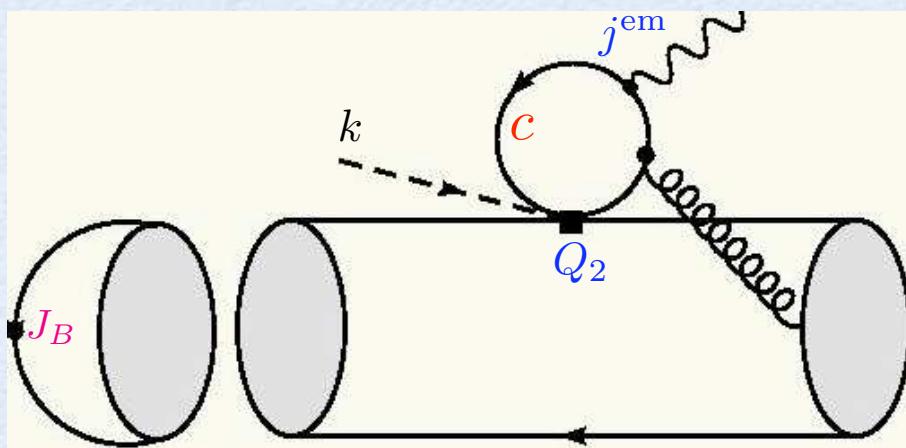
Grinstein, Grossman, Ligeti, Pirjol '04

- QCD is not chiral
- Q_2 sizable Wilson coefficient $|C_2| \sim 3|C_7|$
- resort dim. estimate matrix element
 $\Rightarrow |S_{K^*\gamma}^{C_2}| \simeq 6\%$ & uncertainty large

- Context $\mathcal{B}(b \rightarrow s\gamma)_{incl}^{excl}$ expand $1/m_c^2$ '97
exclusive Khodjamirian, Rückl, Stoll, Wyler '97
 $\Rightarrow Q_F \sim [\bar{s}\gamma_\alpha(\tilde{G} \cdot D_\alpha F) b_L]$, estimate QCDSR
- Context of $S_{K^*\gamma}^{C_2}$ (same $1/m_c^2$ expansion)
estimate $\langle K^* | Q_F | B \rangle$ with LCSR Ball RZ 06

$$\Rightarrow S_{K^*\gamma}^{C_2} \simeq 0.5 \pm 1\%$$

Refrain from $1/m_c^2$ expansion



Extended $B \rightarrow V\gamma$

- u-loop Ball, Jones RZ '06
- c-loop RZ '08 to appear

- analogous problem in $B \rightarrow \pi\pi$
u-loop $q^2 \ll -\Lambda_{\text{QCD}}^2$ project on π
- main difficulty avoid parasitic cuts
spurious momentum k Khodjamirian '00
(eliminated end suitable analytic cont.)

large strong phase $\delta \sim 90^\circ$ typical
 B decays with intermediate charm config.

$$\Rightarrow H = 0.047(1 \pm 17\%_{ms} \pm 10\%_{LD} \pm 14\%_{\delta} \pm 5\%_{Abs} \pm 30\%_{\alpha m_s})$$

The End ...

- B physics potential in asymmetries (hadronic uncertainties often cancel)
(K physics rates, free hadronic uncertainties, talks Haisch, Buras)
- CP-violation in S, H possible without new phases
(CP-violation consistent with MFV) !
- right-handed currents $B \rightarrow V\gamma$
 $B_s \rightarrow \phi\gamma$ promising LHCb ($B \rightarrow K^*\gamma$ good Super-B)
- method c-loops applied $B \rightarrow K^*\mu\mu$ LHCb
(rich angular kinematics \Rightarrow many new observables!)

Exploiting finite width !!!

Thanks for your attention!

Backup

Formulas for TDCP asymmetries

General amplitude

$$\mathcal{A}_L = A_L^t e^{i\phi_L^t} e^{i\delta_L^t} + A_L^t e^{i\phi_L^u} e^{i\delta_L^u} + \{t \rightarrow c\} + \{t \rightarrow u\}$$

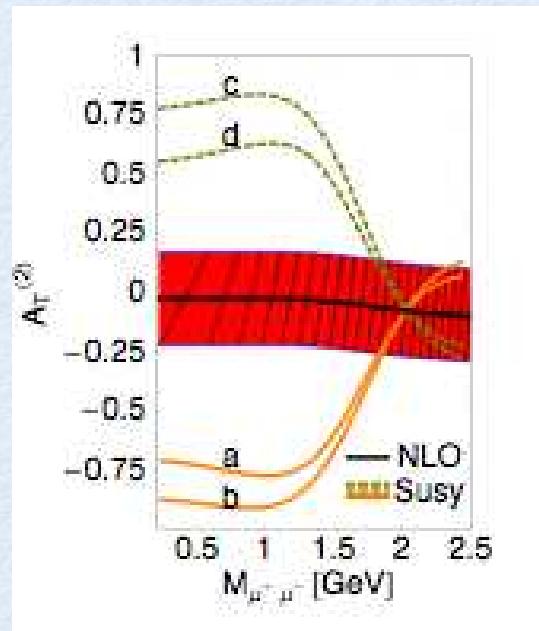
eliminate charm contribution with $\lambda_u + \lambda_c + \lambda_t = 0$ unitarity condition

$$\begin{aligned} H \sim & (A_L^t A_R^t \cos(\delta_L^t - \delta_R^t) \cos(\phi_s - \phi_L^t - \phi_R^t) \\ & + A_L^t A_R^u \cos(\delta_L^t - \delta_R^u) \cos(\phi_s - \phi_L^t - \phi_R^u) + \{u \leftrightarrow t\}) \end{aligned}$$

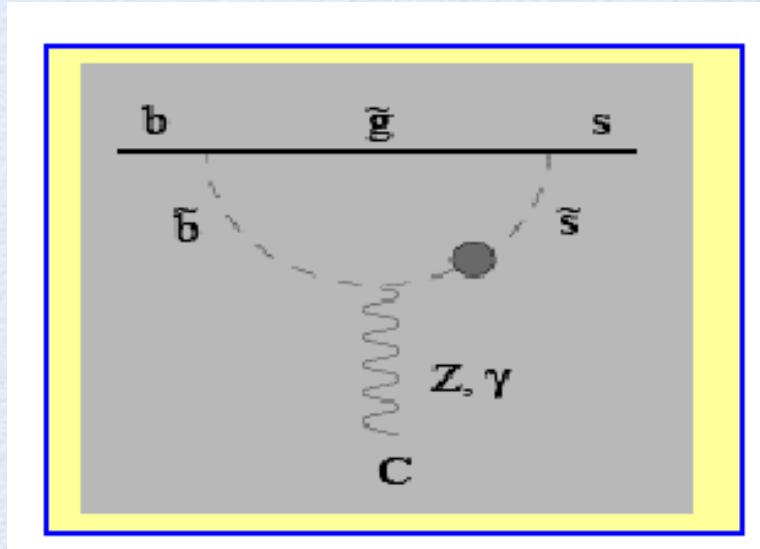
S like $H \cos(\phi..) \rightarrow \sin(\phi..)$

Ex: MSSM non-MFV

- LR-models
- Randall-Sundrum (Soni et al)



main contribution (mass insertion)



Lunghi & Matias 06

$$C_7 = \frac{\sqrt{2}}{M_{sq}^2 G_F} \frac{1}{3} \frac{N_c^2 - 1}{2 N_c} \frac{\pi \alpha_s}{K_{ts}^* K_{tb}} \left[\left((\delta_{32}^d)_{LL} + (\delta_{32}^d)_{RR} \frac{m_s}{m_b} \right) \frac{1}{4} P_{132}(x, x) + (\delta_{32}^d)_{RL} P_{122}(x, x) \frac{M_{gl}}{m_b} \right]$$

$$C'_7 = \frac{\sqrt{2}}{M_{sq}^2 G_F} \frac{1}{3} \frac{N_c^2 - 1}{2 N_c} \frac{\pi \alpha_s}{K_{ts}^* K_{tb}} \left[\left((\delta_{32}^d)_{RR} + (\delta_{32}^d)_{LL} \frac{m_s}{m_b} \right) \frac{1}{4} P_{132}(x, x) + \textcircled{(} (\delta_{32}^d)_{LR} P_{122}(x, x) \frac{M_{gl}}{m_b} \textcircled{)} \right]$$