Exploiting the width difference in $B_s \to \phi \gamma$

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$b \to s\ell\ell$

workshop

1. Introduction

(A) Basics of $B_s \to \phi\gamma$ TDCP

(B) Helicity hierarchy leading twist-2 at $q^2=0$ all orders PT

(C) LER by Charles et al '98 viewpt of LCSR

(D) Corrections to TDCP $B_s \to \phi\gamma$ $\begin{cases} \frac{m_s}{m_b} \text{ quark masses} \\ \text{charmloop higher twist} \end{cases}$

End

Ⓐ $B_s \to \phi\gamma$

$$B_s \to \underbrace{\phi\,\gamma_{L(R)}}_{\text{CP-eigenstate}} \leftarrow \overline{B}_s$$

CP-eigenstate
(pure no dilution of effect)

Basic idea: • V–A interaction prefers one helicity over other
• difficult to test since rate superselection rule

$$\Gamma(B_s \to \phi\gamma) \propto |\underset{\uparrow\,\text{large}}{A_L}|^2 + |\underset{\nearrow\,\text{small}}{A_R}|^2$$

▷ test in interference through time dependent
CP asymmetry. $B_s \to \overline{B}_s$, $L \to R$

... next slide

Testing photon polarisation in time dependent CP-asymmetries

Atwood, Gronau, Soni '97

$$A_{CP} = \frac{\Gamma(\bar{B}_s \to \phi\gamma) - \Gamma(B_s \to \phi\gamma)}{+} = \frac{S \sin \Delta m_s t - C \cos(\Delta m_s t)}{\mathrm{ch}\left(\frac{\Delta\Gamma_s}{2} t\right) - H \,\mathrm{sh}\left(\frac{\Delta\Gamma}{2} t\right)}$$

C: direct CP-violation even t

S, H: indirect CP-violation (mixing) odd in t

$$S\,(H) \propto \mathrm{Im}\,(\mathrm{Re}) \left[\frac{q}{p} \left(\bar{A}_L A_L^* + \bar{A}_R A_R^* \right) \right]$$

$\bar{A}_{L(R)} \equiv A(\bar{B}_s \to \phi \gamma_{L(R)})$ helicity hierarchy $|A_L| \gg |\bar{A}_L|$

▷ test for effect in interference!

Almost null test for the SM! The topic rest of the talk.

First "understand" and quality helicity hierarchy

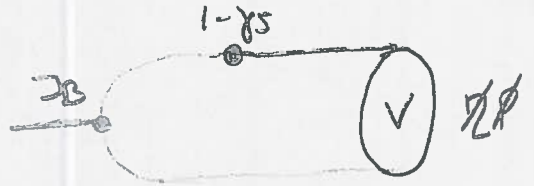
(B) Helicity hierarchy $B \to V\gamma$ et al leading twist-2

Dimou, Lyon
RZ PRD'13

$$B(p+q) \to V(p,\eta)\ \gamma(q,\varepsilon)$$

(pol. vectors)

twist-2 DA: $\langle V(p,\eta)|\bar q_1(0)\,\sigma_{\mu\nu}\,q_2(x)|0\rangle = -i f_V^{\perp}(\eta^*_{[\mu}\,p_{\nu]})\int_0^1 \phi_\perp e^{iupx}\,du$



$$A(B\to V\gamma) = \varepsilon_\mu A^\mu$$

$$A^\mu|_{\text{twist-2}} \propto \mathrm{tr}(\not\eta\not p\, I^\mu)$$

(projector: $\not\eta\not p$)

$$I^\mu|_{\substack{\text{ansatz}\\ \text{Lorentz-covariance}}} \doteq \left(I_0^\mu + I_1\not p\gamma^\mu + I_2\not q\gamma^\mu + I_3\not q\not p\right)(1-\gamma_5)$$

(V-A: $(1-\gamma_5)$)

$$= I_2\,\mathrm{tr}(\not\eta\not p\not q\gamma^\mu(1-\gamma_5))$$ only one structure remains

$$\Rightarrow \boxed{X_2 + \frac{q^2}{m_B^2}X_3 = X_1}$$

all orders in α_s

X_i $i=1..3$ same projection T_i = $i=1..3$ form factors

▷ Any local operator $\mathcal{O}_X$

$$X^{\lambda} = \langle V(\eta(\lambda))\gamma(\varepsilon(\lambda))|\mathcal{O}_X|B\rangle$$

helicity

$$X^{+} = \frac{1}{\sqrt{2}}(X_1 - X_2) = \mathcal{O}(q^2) \ll X^{-} = \frac{1}{\sqrt{2}}(X_1 + X_2) \qquad (*)$$

at leading twist-2

N.B. ① For $\mathcal{O}_{T}^{\mu} = (\bar{q}_1 \sigma_{\mu\nu} q_2) q^{\nu}$ we have $T^{+}(0) = \frac{1}{\sqrt{2}}(T_1(0) - T_2(0)) = 0$ purely on grounds of kinematics (special, more constraining case)

② Result valid in any light-cone DA approach < LCSR, QCDF *

* presumably same/similar Jäger, Camalich had in JHEP '13 and Charles et al '98

type A ③ Subject to $\mathcal{O}(m_q)$ - corrections] - corrections to (*)

type B ④ Higher twist corrections

(C) Digression (on popular implicite demand)

- Related (essentially same) as Charles et '98 $\xi^{\parallel}, \xi^{\perp}$ Form factor
  ↑ the one we have found

- Why no $\xi^{\parallel,\perp}$ vector-current .. $\xi^{\parallel,\perp}$ tensor current

▷ QCD equation of motion

$$i\partial^\nu(\bar{s}\, i\sigma_{\mu\nu}(\gamma_5) q) = -(m_s \pm m_b)\, \bar{s}\gamma_\mu(\gamma_5) b + i\partial_\mu \bar{s}(\gamma_5) b - 2\bar{s}\, i\overleftarrow{D}_\mu (\gamma_5) b$$

↙ 0

apply $\langle V | \ldots | B \rangle$

schematic $\quad T_\lambda(q^2) = m_b V_\lambda(q^2) - \mathcal{D}_\lambda(q^2) \quad$ λ = helicity

high q^2 (low recoil) $\quad \mathcal{D}_\lambda \sim \mathcal{O}(1/m_b)$ Isgur-Wise relations

low q^2 (large recoil) $\quad$ Burdman, Donoghue '90 heuristic argument $\mathcal{D}$'s small

'98 Charles et al $\quad \mathcal{O}(\alpha_s^0)$ LCSR true

'00 Beneke & Feldman $\quad \mathcal{O}(\alpha_s^1)$ QCDF largely true

'04 Ball RZ $\quad \mathcal{O}(\alpha_s^1)$ LCSR idem

Consequences:

"known" ① LCSR obey to leading orders Large Energy Relations (known as SCET by now) by Charles et al '98 on grounds of a) QCD equation of motion
b) light-cone formalism

corrections in higher twist etc parametrise corrections to LER.
(N.B. not discussed twist-3 associated Feynman mechanism also obey LER)

⇒ correlations sensible

'additional bene fit' ②

Hambrock, Hiller, Schacht, RZ '13

- $T_\lambda = m_b V_\lambda - \mathcal{D}_\lambda$ ← small (up to irrelevant contact terms)
- same true correlation functions

▷ $s_0^T \approx s_0^V$, $M^T_{Borel} \approx M^T_{Borel}$ as otherwise gigantic violation of quark hadron duality (semi-global)

▷ strong correlation (reduction) of error between T's and V's!

(D) SM - value either driven by

back to time dep. CP-asymmetry

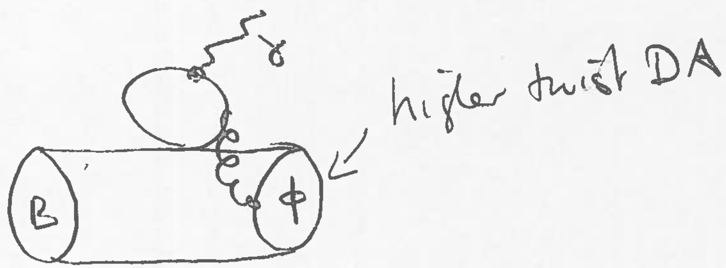
- Type A $\Theta(m_s)$ - correction ..... O' or form factor correction

$$S(H) = -2\frac{m_s}{m_b}\begin{smallmatrix}\sin\\ \cos\end{smallmatrix}(\phi_s - \phi_{decay})$$

$B_s \to \phi\gamma$; $\phi_{decay} = \phi_s$ $\Rightarrow$ $S \approx 0$

H large sensitive to right-handed current

- Type B higher twist correction of charmloop (sizeable Wilson coefficient)



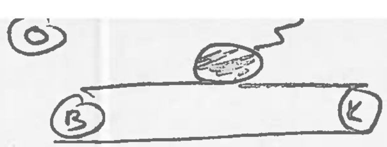
'04 Grinstein et al ... large $\Theta(10\%)$ to $S_{K^*\gamma}$ on grounds of $b \to s\gamma$ inc.

'06 Ball RZ small local operator $1/m_c^2$

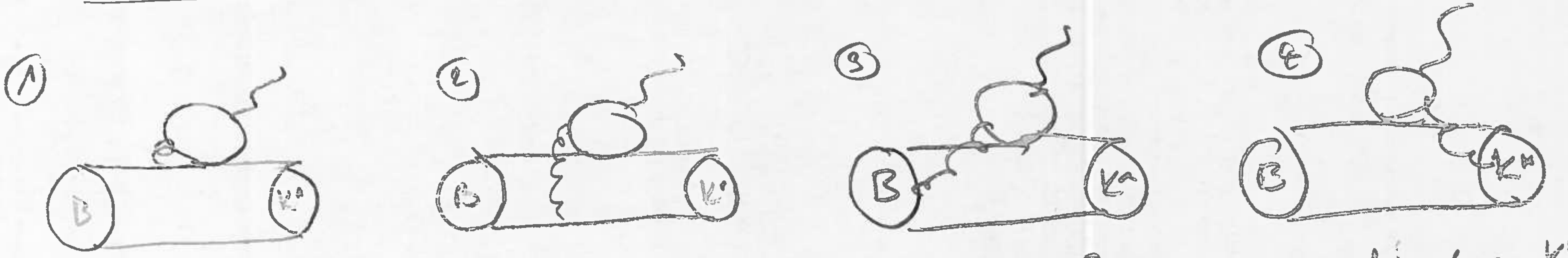
'08 Muheim, Xie, RZ do not expand in $1/m_c^2$ .. compute loop

Error budget: $H = 0.047\,(1 \pm 17\%_{m_s} \pm 15\%_{\text{charmloop}} \pm 10\%_{LD})$

General remark on charm loop



FACTORIZATION



vertex — Spectator — soft gluon B — soft gluon K*

respect helicity hierarchy twist-2 — breaks h.h. twist-3

<u>Message</u>: • Compute all of Kem in one approach (disentangle diff. approaches is ambiguous)

• Contr. (3) (only) evaluated Khodjamirian et al '10

Problem φ_{3B} 3-particle B-DA ... uncertainties

— End —