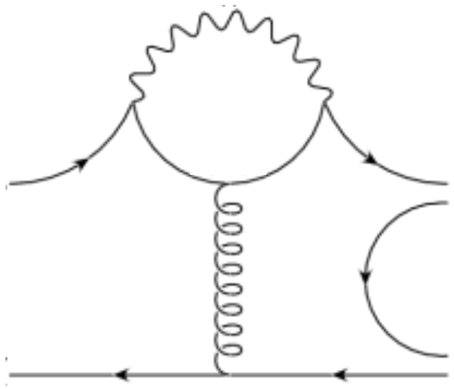

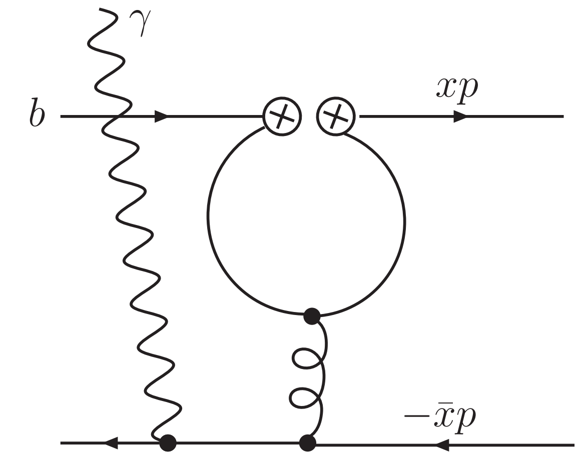

Hunting for Charming Penguins

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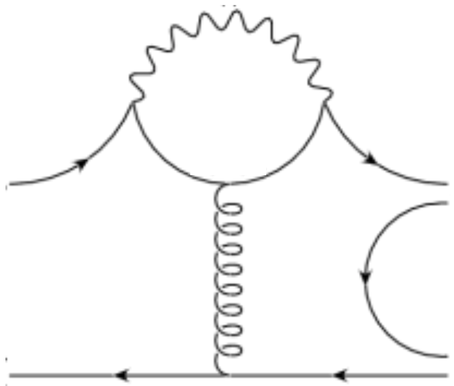

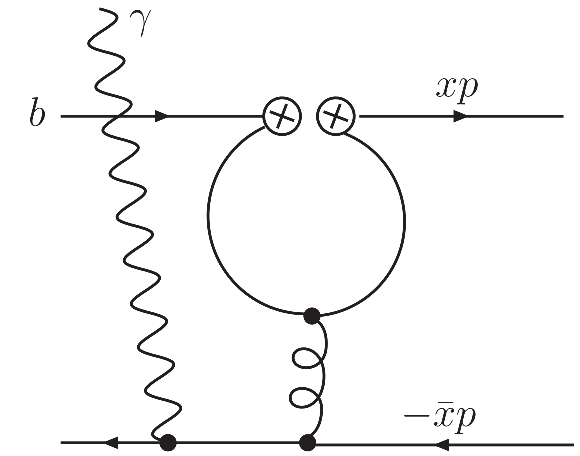

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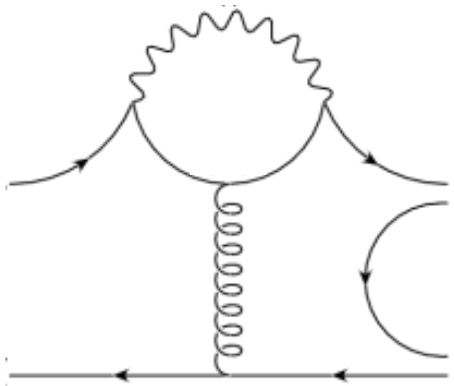

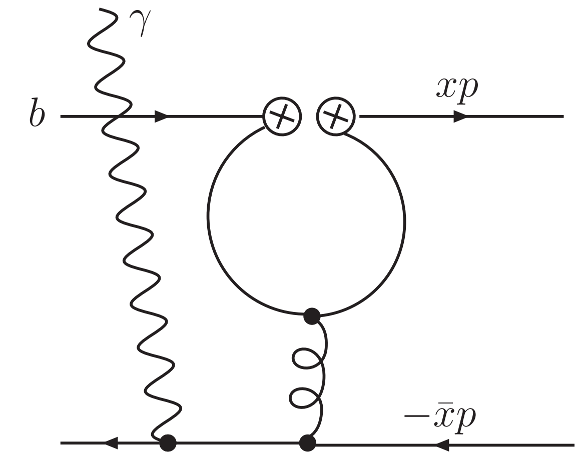

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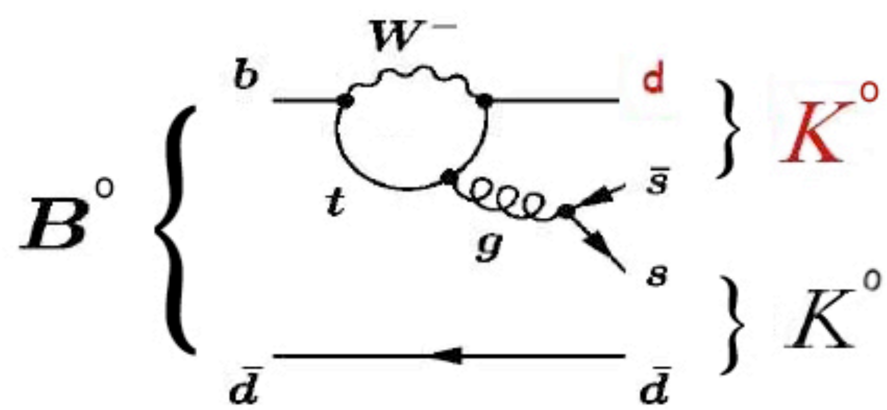
Outline

- Charming penguins: what and why?
- Review of SCET
- Semi-inclusive hadronic *B* decay
- Isospin asymmetries in radiative *B* decay

What are penguin diagrams?

Penguins are loop diagrams, with gauge field emission



Important for B decays, CP violation, $b \to s\gamma, \ldots$

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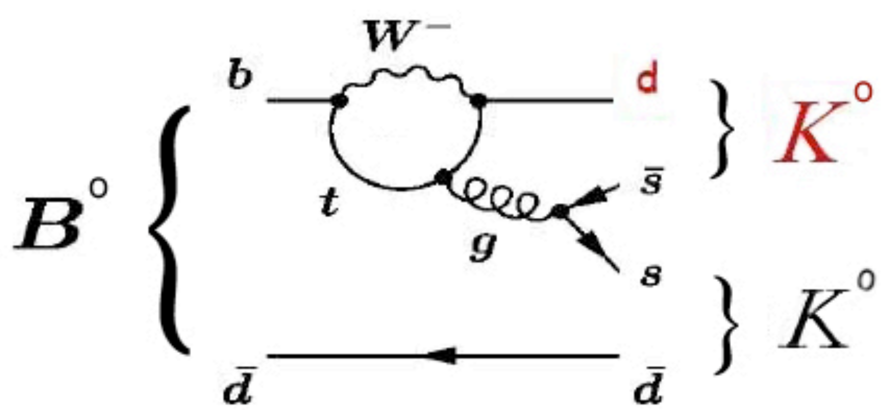

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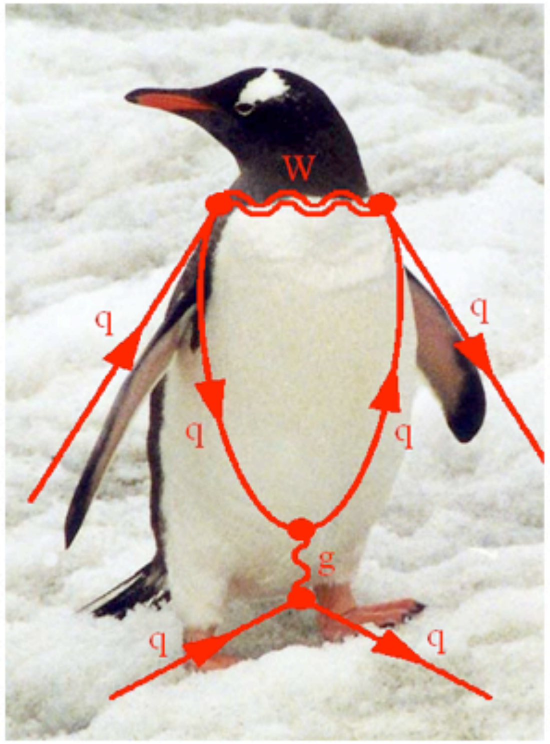

The Problem with Penguins

Can sometimes calculate effects of penguins

however

Charming penguins can be nonperturbative

Ciuchini, et al

The Problem with Penguins

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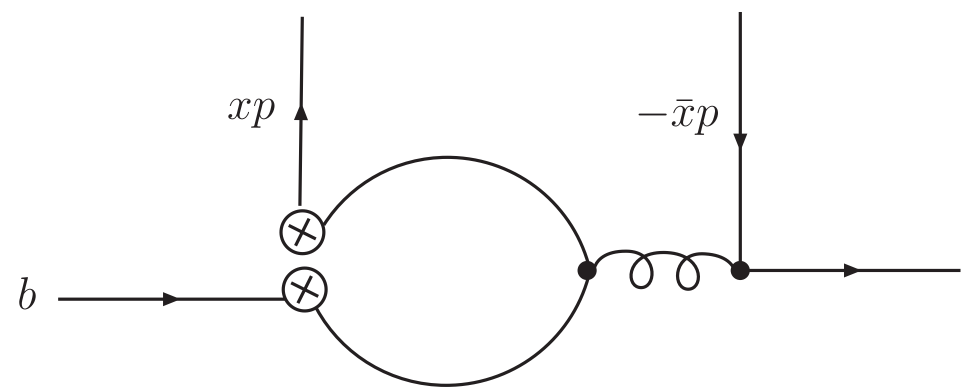
Charming penguins can be nonperturbative



Ciuchini, et al

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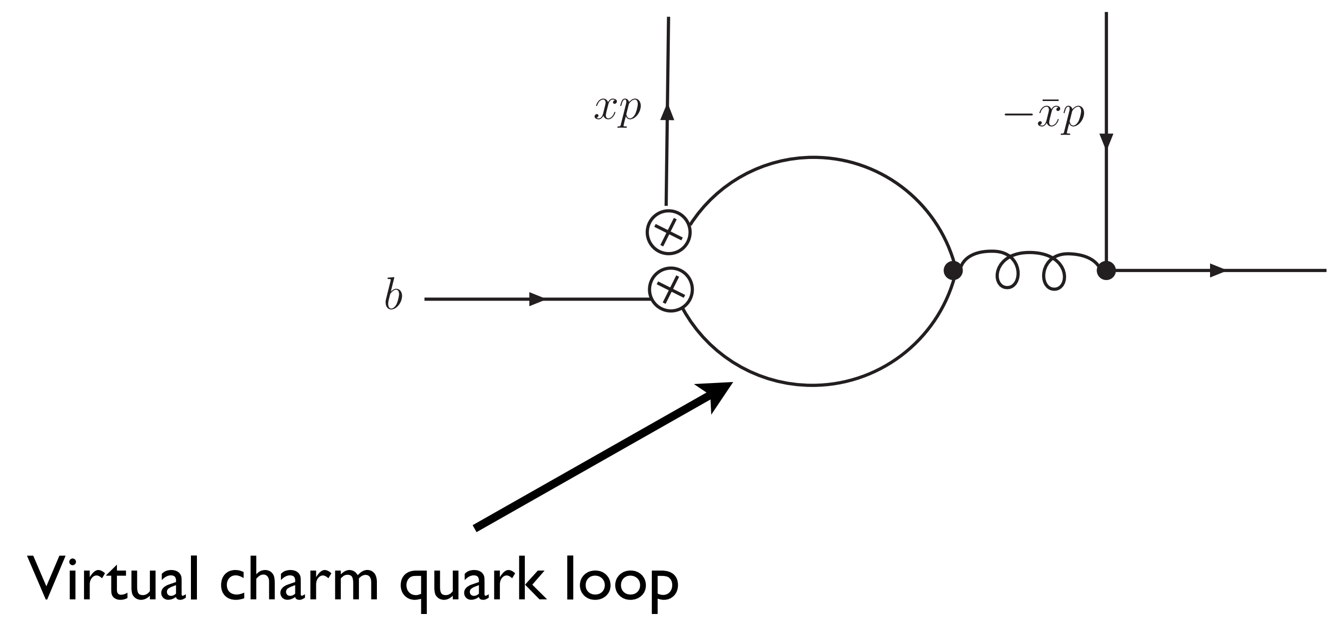

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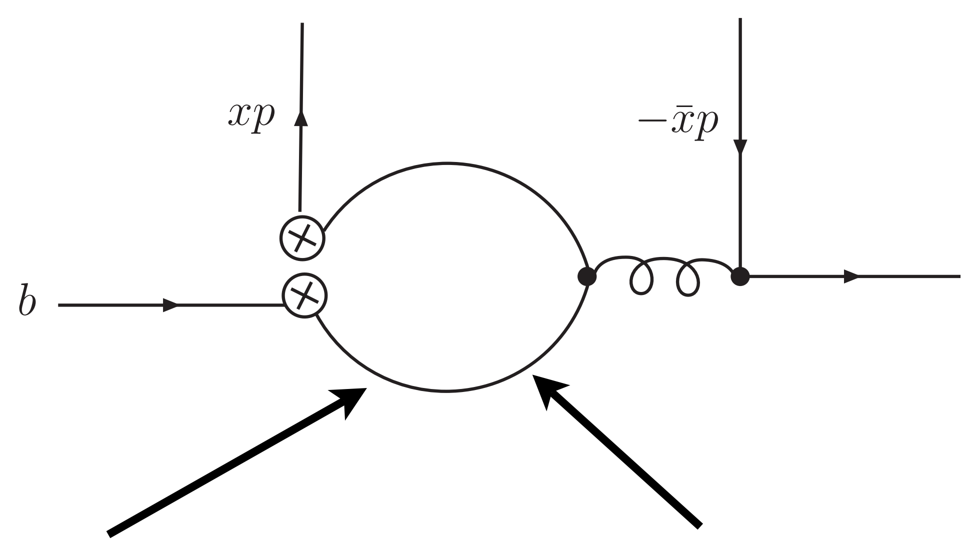

Virtual charm quark loop

For particular final state kinematics charm pair can be close to on-shell

A Charming Controversy

Charming penguins are present for $B \to \pi\pi$, important for CP violation studies.

How big are charming penguins?

Beneke, Buchalla, Neubert, Sachrajda

Charming penguins factorize at leading order in $1/m_b$

Bauer, Pirjol, Rothstein, Stewart

Charming penguins are only suppressed by

$$\alpha_s(2m_c) f\left(\frac{2m_c}{m_b}\right) v$$

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$$\alpha_s(2m_c) f\left(\frac{2m_c}{m_b}\right) v$$

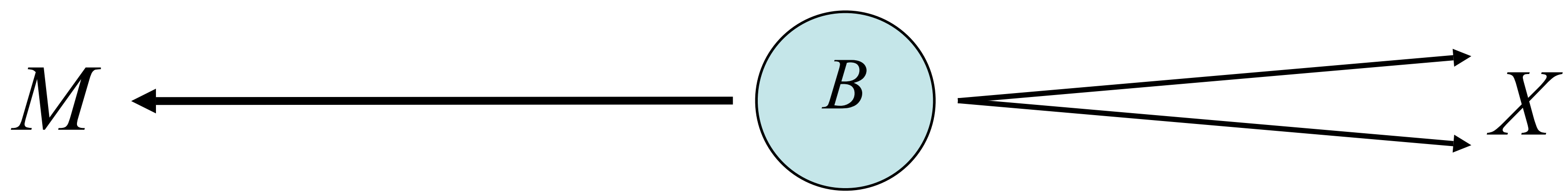
Our goal is to try to measure the size of (different) charming penguins, using data

The Plan

- Look at decays where charming penguins can contribute
    - Semi-inclusive hadronic B decays
    - Isospin asymmetries in radiative B decays
- Calculate the rates (using SCET)
- Parametrize charming penguin effects
- Extract the charming penguin contribution from data

Semi-inclusive hadronic decays?

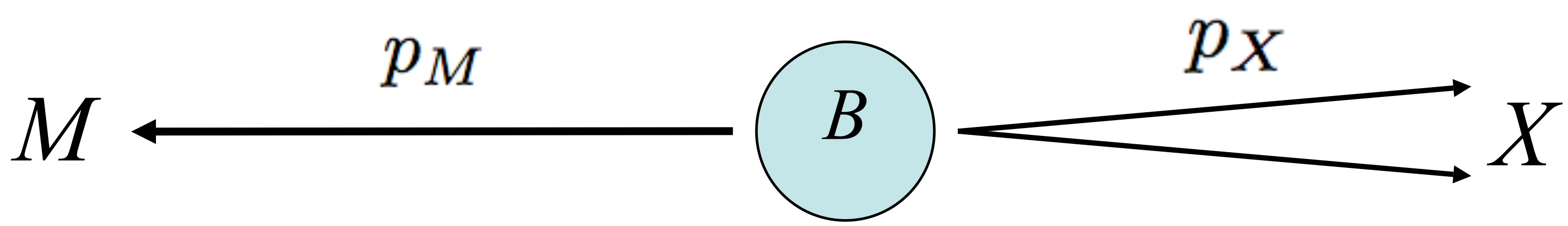
B decaying to light meson *M* recoiling against hadronic jet *X*



- Potentially large data sets
- SCET allows for factorization of rate
- The *B* to *X* part same as in $B \to X_s\gamma$
- Simpler than two-body exclusive decays
  - Spectator interactions suppressed
- Possible handle on charming penguins

Need for SCET

B decaying to light meson *M* recoiling against hadronic jet *X*



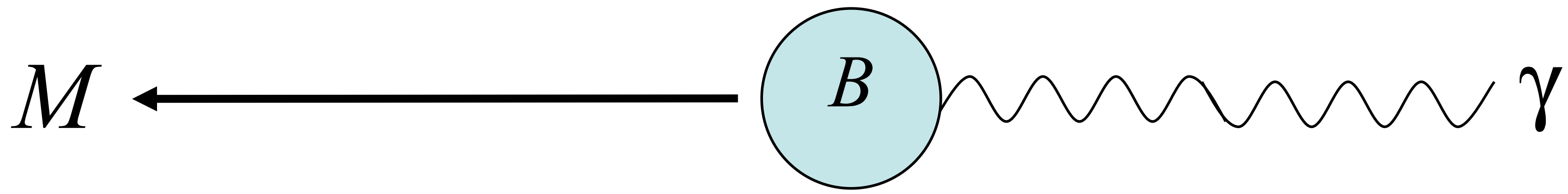
- Investigate in the endpoint region
  - Jet *X* is jet of collinear particles

$$p_M^2 \sim \Lambda_{\mathrm{QCD}}^2, \quad p_X^2 \sim \Lambda_{\mathrm{QCD}} m_b = \lambda^2 m_b^2$$

  - New small scale in the problem λ
- SCET is effective theory coupling collinear and soft particles together

Radiative decays

B decaying to light meson *M* recoiling against photon

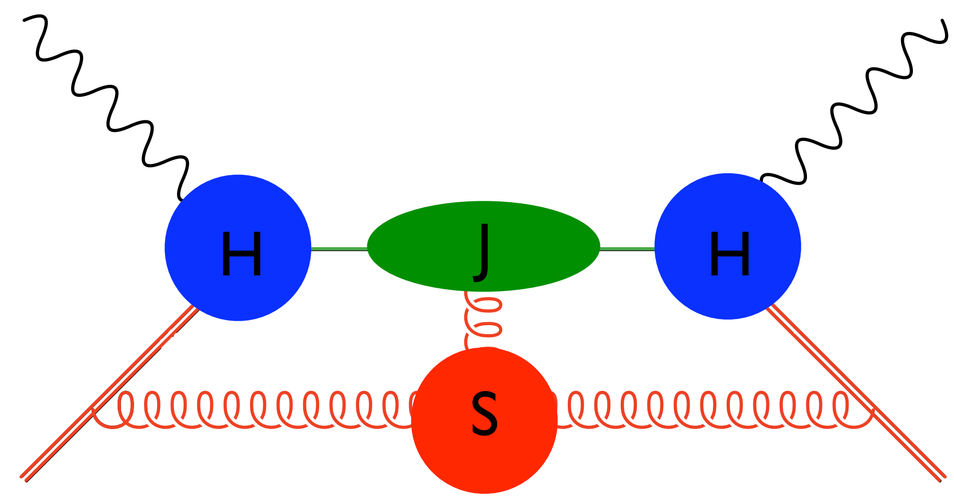


- Currently have data (with large uncertainties)
- SCET allows for factorization of rate
- Possible handle on charming penguins

Again, kinematics necessitate the use of SCET

Building the EFT

- Want SCET to describe relevant physics (long distance, IR)
- Need degrees of freedom for each type of on-shell mode



➡ Will have collinear and soft d.o.f.

$$\frac{E+p_3}{2} \sim O(m), \frac{E-p_3}{2} \sim O(m(1-x))$$

$$p = (p^+,\ p^-,\ p_\perp) = (n \cdot p,\ \bar{n} \cdot p,\ p_\perp)$$

$$\bar{n}^\mu = (1,0,0,1) \qquad n^\mu = (1,0,0,-1)$$

$\lambda \sim p_\perp / \bar{n} \cdot p$

Collinear	$p \sim M(\lambda^2,\ 1,\ \lambda)$	
Soft	$p \sim M(\lambda,\ \lambda,\ \lambda)$	$p^2 \lesssim M^2\lambda^2$
Ultrasoft	$p \sim M(\lambda^2,\ \lambda^2,\ \lambda^2)$	

Need systematic expansion in λ.

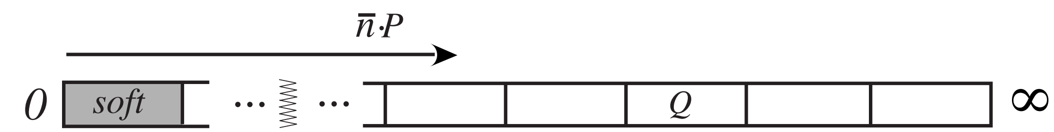
Building the EFT

Collinear particles: remove "large" components of momentum

$$p^\mu = \bar{n}\cdot p\frac{n^\mu}{2} + p_\perp^\mu + n\cdot p\frac{\bar{n}^\mu}{2}$$

$O(Q)$ $O(Q\lambda)$ $O(Q\lambda^2)$

Take partial Fourier transform:



$$\psi(x) = \sum_p \psi_{n,p}(x) e^{-ip\cdot x}$$

Derivatives scale as $O(Q\lambda^2)$

Split spinor into "large" and "small" components:

$$\psi_{n,p} = \frac{\not{n}\not{\bar{n}}}{2}\psi_{n,p} + \frac{\not{\bar{n}}\not{n}}{2}\psi_{n,p} = \xi_{n,p} + \xi_{\bar{n},p}$$

Building the EFT

- Scaling (from kinetic term)

	Collinear Quark	Usoft gluon	Collinear gluon		
Field	$\xi_{n,p}$	A^{μ}_{us}	$\bar{n}\cdot A_{n,p}$	$A^{\perp}_{n,p}$	$n\cdot A_{n,p}$
Scaling	λ	λ^2	λ^0	λ^1	λ^2

- Plug into the (massless) QCD Lagrangian $\mathcal{L} = \psi\, i\not{D}\, \psi$

$\psi_{n,p} = \xi_{n,p} + \xi_{\bar{n},p}$

giving

$$\mathcal{L} = \sum_{p,p'} e^{-i(p-p')\cdot x} \Big[\bar{\xi}_{n,p'} \frac{\not{\bar{n}}}{2} (in\cdot D)\, \xi_{n,p} + \bar{\xi}_{\bar{n},p'} \frac{\not{n}}{2} (\bar{n}\cdot p + i\bar{n}\cdot D)\, \xi_{\bar{n},p}$$
$$+ \bar{\xi}_{n,p'} (\not{p}_\perp + i\not{D}_\perp)\, \xi_{\bar{n},p} + \bar{\xi}_{\bar{n},p'} (\not{p}_\perp + i\not{D}_\perp)\, \xi_{n,p} \Big]$$

$D = \partial - igA_{n,p} - igA_{us}$

Building the EFT

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$$\mathcal{L} = \sum_{p,p'} e^{-i(p-p')\cdot x}\Big[\bar{\xi}_{n,p'}\frac{\bar{\not{n}}}{2}(in\cdot D)\,\xi_{n,p} + \bar{\xi}_{\bar{n},p'}\frac{\not{n}}{2}(\bar{n}\cdot p + i\bar{n}\cdot D)\,\xi_{\bar{n},p}$$

$$+\,\bar{\xi}_{n,p'}(\not{p}_\perp + i\not{D}_\perp)\,\xi_{\bar{n},p} + \bar{\xi}_{\bar{n},p'}(\not{p}_\perp + i\not{D}_\perp)\,\xi_{n,p}\Big]$$

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$$\left. + \bar{\xi}_{n,p'}\,(\not{p}_\perp + i\not{D}_\perp)\,\xi_{\bar{n},p} + \bar{\xi}_{\bar{n},p'}\,(\not{p}_\perp + i\not{D}_\perp)\,\xi_{n,p}\right]$$

$D = \partial - igA_{n,p} - igA_{us}$

No kinetic term for $\xi_{\bar{n},p}$

Building the EFT

- $\xi_{\bar{n},p}$ not dynamical

$$(\bar{n}\cdot p + \bar{n}\cdot iD)\xi_{\bar{n},p} = (\not{p}_\perp + i\not{D}_\perp)\frac{\not{\bar{n}}}{2}\xi_{n,p}$$

substituting

$$\mathcal{L} = \sum_{p,p'} e^{-i(p-p')\cdot x}\bar{\xi}_{n,p'}\left[n\cdot iD + (\not{p}_\perp + i\not{D}_\perp)\frac{1}{\bar{n}\cdot p + \bar{n}\cdot iD}(\not{p}_\perp + i\not{D}_\perp)\right]\frac{\not{\bar{n}}}{2}\xi_{n,p}$$

Building the EFT

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Imposes label conservation

Simplify by always imposing label conservation

Building the EFT

- $\xi_{\bar{n},p}$ not dynamical

$D = \partial - igA_{n,p} - igA_{us}$

$$(\bar{n}\cdot p + \bar{n}\cdot iD)\xi_{\bar{n},p} = (\not{p}_\perp + i\not{D}_\perp)\frac{\not{\bar{n}}}{2}\xi_{n,p}$$

substituting

$$\mathcal{L} = \bar{\xi}_{n,p'}\left[n\cdot iD + (\not{p}_\perp + i\not{D}_\perp)\frac{1}{\bar{n}\cdot p + \bar{n}\cdot iD}(\not{p}_\perp + i\not{D}_\perp)\right]\frac{\not{\bar{n}}}{2}\xi_{n,p}$$

$\bar{n}\cdot A_{n,p} \sim O(1), \bar{n}\cdot\partial = \bar{n}\cdot A_{us} = O(\lambda^2)$

At this point, not uniform in the power counting

Need to expand in λ

Introduce label operator $\mathcal{P}^\mu \xi_{n,p} = p^\mu \xi_{n,p}$

Introduce Wilson line

$$W_n(x) = \mathrm{P}\exp\left(-ig\int_{-\infty}^{x} ds\,\bar{n}\cdot A_n(s\bar{n})\right)$$

Building the EFT

Expanding gives

$$\mathcal{L} = \bar{\xi}_{n,p'} \left[n \cdot iD + gn \cdot A_{n,q} + (\not{\mathcal{P}}_\perp + g\not{A}^\perp_{n,q}) W \frac{1}{\bar{\mathcal{P}}} W^\dagger (\not{\mathcal{P}}_\perp + g\not{A}^\perp_{n,q'}) \right] \frac{\not{\bar{n}}}{2} \xi_{n,p}$$

Only contains ultrasoft A_{us}

$$iD = i\partial + gA_{us}$$

$$\bar{\mathcal{P}} \equiv \bar{n} \cdot \mathcal{P}$$

- Leading order collinear quark Lagrangian
- Only coupling to ultrasoft through one term

(Will come back to this)

Gauge invariance

- Gauge invariance is very useful constraint
- Have multiple gluons modes: How does it work?

Only QCD gauge transformation that are relevant have support over collinear, soft or usoft momenta

Usoft gauge transformation has $V_{us}(x) = \exp[i\beta^A_{us}(x)T^A]$
with $\partial^\mu V_{us}(x) \sim Q\lambda^2$

Collinear gauge transformation has $U(x) = \exp[i\alpha^A(x)T^A]$
with $\partial^\mu U(x) \sim Q(\lambda^2, 1, \lambda)$

Gluon fields are gauge fields associated with these

Usoft act as a background field for collinear fields

(Local for residual x dependence)

Usoft fields invariant under collinear transformation

Gauge invariance

- Under a collinear gauge transformation

$$_{n,p} \qquad \mathbf{U}_n \;\; _{n,p}, \mathbf{W}_n \qquad \mathbf{U}_n \mathbf{W}_n$$

- Collinear gauge invariant can be constructed

$$W_n^\dagger(x)\xi_{n,p}$$

- Still transforms under ultrasoft gauge transformation

$$W_n^\dagger \xi_{n,p} \to V_{us} W_n^\dagger \xi_{n,p}$$

Integrating out hard fluctuations gives Wilson coefficients

Gauge invariance restricts form $C(\bar{\mathcal{P}}, \bar{\mathcal{P}}^\dagger)$

Sometimes useful to introduce $\chi^{(i)}_{n,}$ $\quad [\delta(\omega - \bar{\mathrm{P}}) W_n^\dagger \xi^{(i)}_{n,p}]$

Decoupling the Ultrasofts

$$\mathcal{L} = \bar{\xi}_{n,p'} \left[n\cdot iD + gn\cdot A_{n,q} + (\not{\mathcal{P}}_\perp + g\not{A}^\perp_{n,q}) W \frac{1}{\bar{\mathcal{P}}} W^\dagger (\not{\mathcal{P}}_\perp + g\not{A}^\perp_{n,q'}) \right] \frac{\not{\bar{n}}}{2} \xi_{n,p}$$

Only one term
couples to ultrasofts

Decoupling the Ultrasofts

$$\mathcal{L} = \bar{\xi}_{n,p'} \left[n \cdot iD + g n \cdot A_{n,q} + (\not{\mathcal{P}}_\perp + g \not{A}^\perp_{n,q}) W \frac{1}{\bar{\mathcal{P}}} W^\dagger (\not{\mathcal{P}}_\perp + g \not{A}^\perp_{n,q'}) \right] \frac{\not{\bar{n}}}{2} \xi_{n,p}$$

$$i\partial + g A_{us}$$

Only one term couples to ultrasofts

Decoupling the Ultrasofts

$$\mathcal{L} = \bar{\xi}_{n,p'} \left[n \cdot iD + g n \cdot A_{n,q} + (\not{\mathcal{P}}_\perp + g \not{A}^\perp_{n,q}) W \frac{1}{\bar{\mathcal{P}}} W^\dagger (\not{\mathcal{P}}_\perp + g \not{A}^\perp_{n,q'}) \right] \frac{\not{\bar{n}}}{2} \xi_{n,p}$$

$$i\partial + g A_{us}$$

Only one term couples to ultrasofts

Can remove by introducing ultrasoft Wilon line

$$Y(x) = \mathrm{P} \exp \left(ig \int_{-\infty}^{x} ds\, n \cdot A_{us}(sn) \right)$$

Important: $Y^\dagger n \cdot iD Y = n \cdot i\partial$

Do field redefinition

$$\xi_{n,p} = Y \xi^{(0)}_{n,p} \qquad A^\mu_{n,p} = Y A^{(0)\mu}_{n,p} Y^\dagger$$

Decoupling the Ultrasofts

$$\mathcal{L} = \bar{\xi}^{(0)}_{n,p'} \left[n \cdot i\partial + g n \cdot A^{(0)}_{n,q} + (\not{\mathcal{P}}_\perp + g \not{A}^{(0)\perp}_{n,q}) W \frac{1}{\bar{\mathcal{P}}} W^\dagger (\not{\mathcal{P}}_\perp + g \not{A}^{(0)\perp}_{n,q'}) \right] \frac{\not{\bar{n}}}{2} \xi^{(0)}_{n,p}$$

No term
couples to ultrasofts (at leading order)

At leading order, collinear particles do not interact with ultrasoft particles!

Effects of ultrasoft incorporated by ultrasoft Wilson lines appearing in operators

(See this in a second)

This will get us the factorization theorems

Familiar Objects

Need to define some objects in the effective theory

Heavy-to-light current $J(x) = \bar{q}\,\Gamma b(x)$

Match onto effective fields $J_{\rm eff}(x) = \bar{\xi}_{n,p}\Gamma h_v(x)$

Appears to not be gauge invariant - build up Wilson line

Want $J_{\rm eff}(x) = \bar{\xi}_{n,p} W \Gamma h_v(x)$

Familiar Objects

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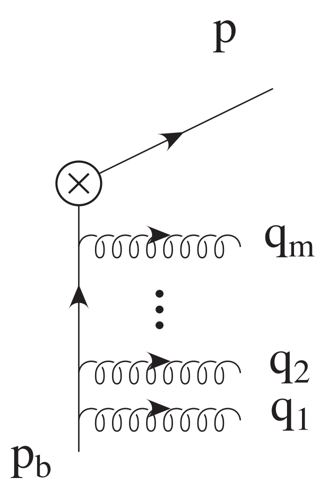
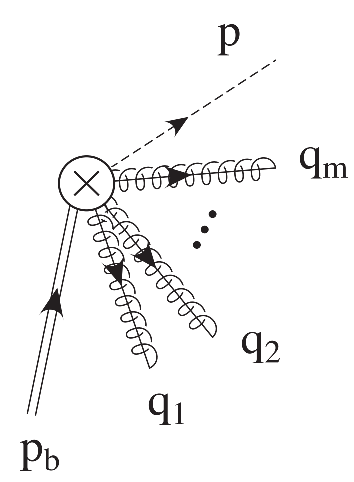


+ perms $\longrightarrow$



$J_{\rm eff}(x) = \bar{\xi}_{n,p} W \Gamma h_v(x)$

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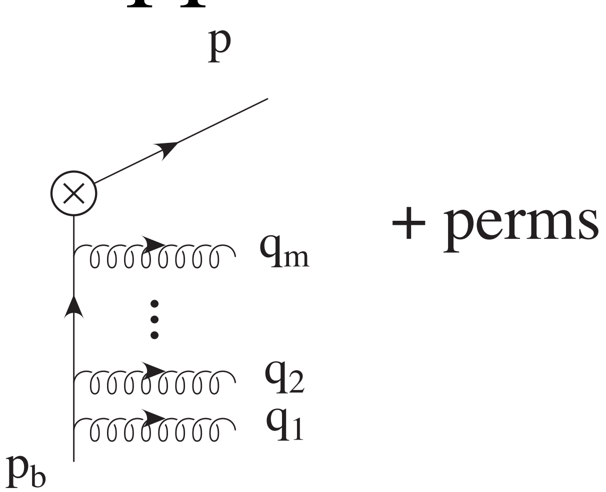
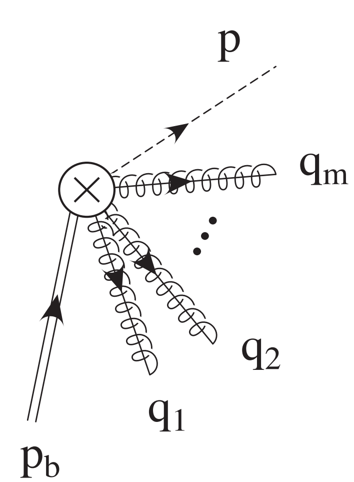


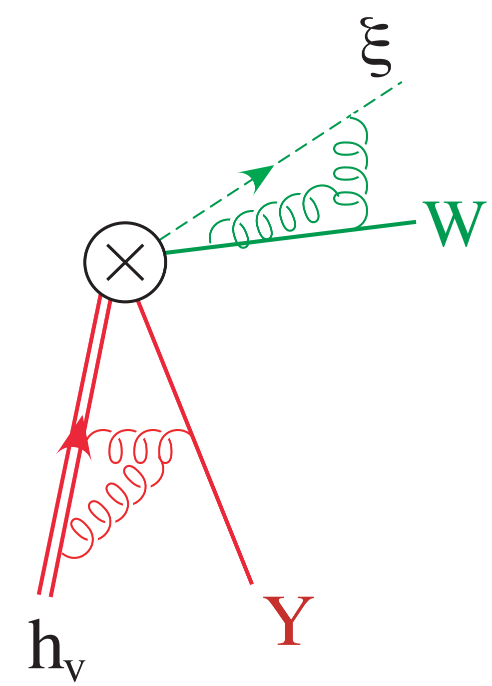
$\longrightarrow$



$J_{\rm eff}(x) = \bar{\xi}_{n,p} W \Gamma h_v(x)$

If we now decouple ultrasofts

$$J_{\rm eff}(x) = \bar{\xi}^{(0)}_{n,p} W^{(0)} \Gamma Y^\dagger h_v(x)$$



Familiar Objects

Need to define some objects in the effective theory

- Pion light-cone amplitude

$$\pi^a(p)|\,\bar{\ }(y)\ {}^{\mu}\ {}^{5}\frac{b}{\sqrt{2}}Y(y,x)\ (x)|0 = -if_\pi\ {}^{ab}p^\mu\ {}_0^1 dz\, e^{i[zp\cdot y+(1-z)p\cdot x]}\ {}_\pi(\mu,z)$$

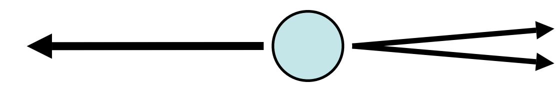
In SCET, write in terms of effective fields

$$\langle\pi^a_{n,p}(p)|\bar{\xi}_{n,y}\bar{\not{n}}\gamma^5\frac{\tau^b}{\sqrt{2}}W(y,x)\xi_{n,x}|0\rangle = -if_\pi\delta^{ab}\bar{n}\cdot p\ {}_0^1 dz\, e^{i\bar{n}\cdot p[zy+(1-z)x]}\phi_\pi(\mu,z)$$

Schematic of Calculation

Semi-inclusive hadronic *B* decays

- Match QCD onto SCET_I $\overline{}$/Q



$$H_W \to H_I = \frac{2G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p^{(q)} \sum_{i=1}^{6} C_i^p \otimes \mathcal{O}_i$$

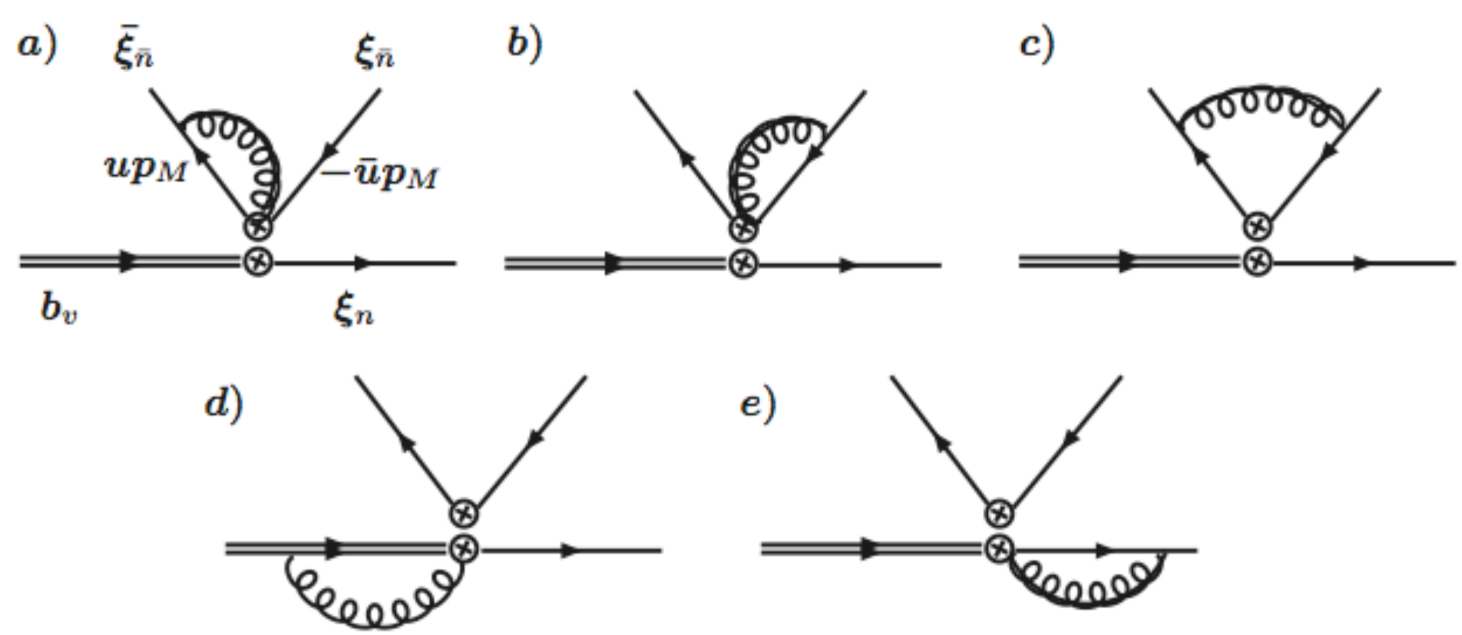
– Operators look like $\mathcal{O}_1 = \left[\bar{u}_n \bar{\not n} P_L Y_n^\dagger b_v\right]\left[\bar{q}_{\bar{n}} \not n P_L u_{\bar{n}}\right]$

- Run down to SCET_II scale /Q

Factorization makes running simple

Brodsky-Lepage kernel for $\bar{n}$ direction

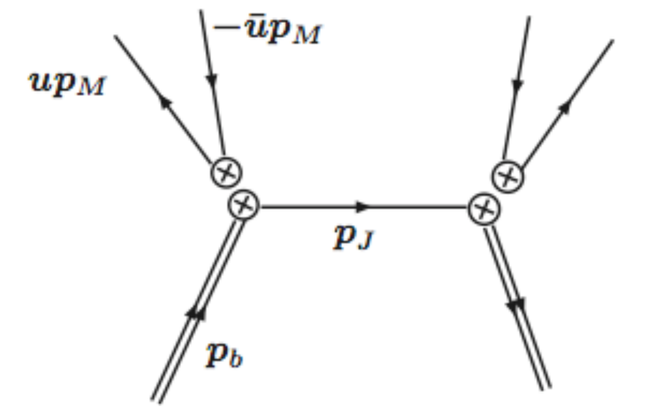
Heavy-to-light for rest



Schematic of Calculation, cont

Semi-inclusive hadronic *B* decays

- Situation where spectator from *B* ends up in *M* suppressed



- Decay amplitude looks like

$$\langle XM|H_I|B\rangle = \frac{2G_F}{\sqrt{2}}\int_0^1 du\, T_M^{(q)}(u,\mu)\ \langle M|\left[\bar{q}'_{\bar{n}}\not{\bar{n}}P_L q''_{\bar{n}}\right]_u|0\rangle\langle X|\bar{q}_n\not{\bar{n}}P_L Y_n^\dagger b_v|B\rangle$$

Gives lightcone amplitude

Gives jet function convoluted with shape function

- Use Optical Theorem to relate decay rate to imaginary part of forward scattering

Schematic of Calculation, cont

Semi-inclusive hadronic *B* decays

- Decay rate is

$$\frac{d}{dE_M}(B \quad X M) = \frac{G_F^2}{8\pi} m_b^2 x_M^3 S(x_M, \mu_0) \; h_M^{(q)} \;\; ^2$$

where

B shape function

Light quark jet function

$$S(x_M, \mu_0) = m_b \int_{-m_b+2E_M}^{\bar{\Lambda}} dl_+ f(l_+) \left[-\frac{1}{\pi} \mathrm{Im} J_P \left(m_b - 2E_M + l_+ + i \right) \right]$$

$$h_M^{(q)} = f_M \int_0^1 du \quad _M(u) \quad _u^{(q)} T_{M,u}^{(q)}(u) + \quad _c^{(q)} T_{M,c}^{(q)}(u)$$

Lightcone amplitude

Perturbative

$$_p^{(q)} = V_{pb} V_{pq}$$

Compare with $B \to X_s \gamma$

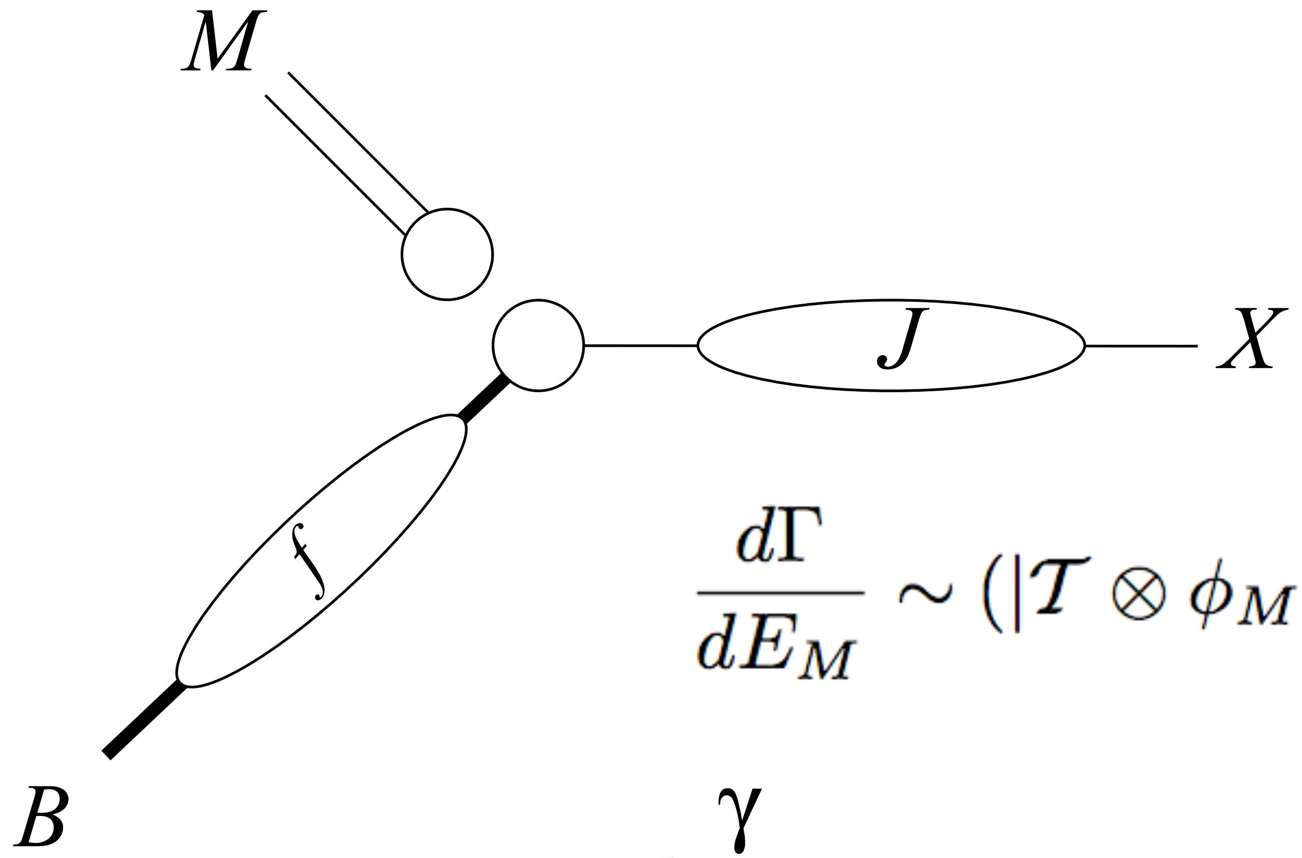
$$\frac{d}{dE}(\bar{B} \quad X_s \;\;) = \frac{G_F^2 m_b^4}{16\pi^4} x^3 \quad H \;\; (m_b, \mu_0) S(x \;\; , \mu_0)$$

Cancel in the ratio

Schematic of Calculation, cont

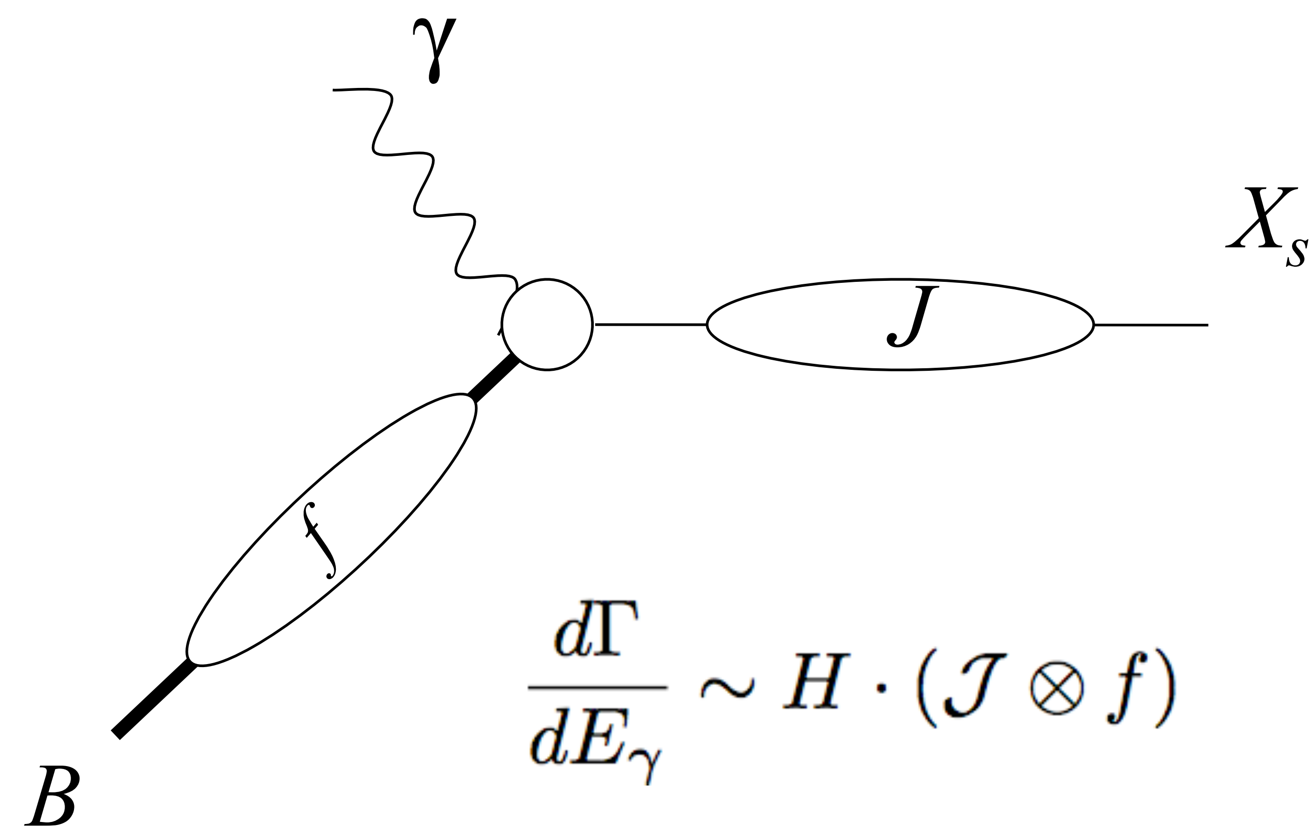
Semi-inclusive hadronic *B* decays

In a picture



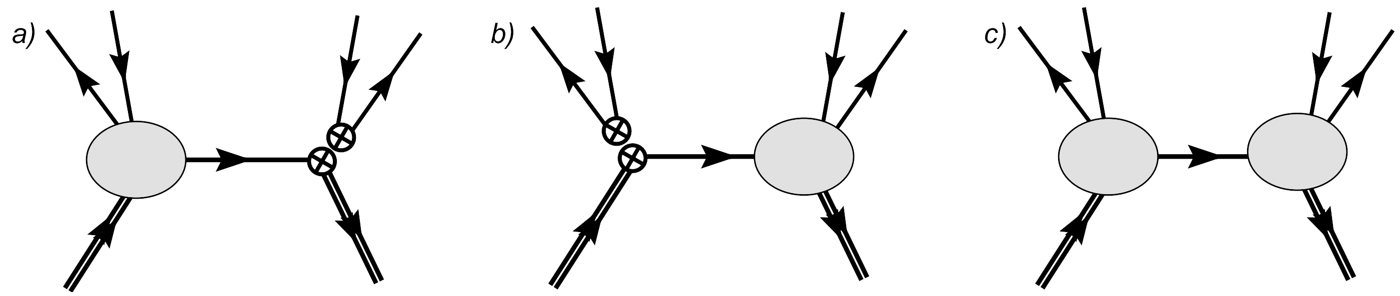
$$\frac{d\Gamma}{dE_M} \sim (|\mathcal{T} \otimes \phi_M|^2) \cdot (\mathcal{J} \otimes f)$$

Compare to

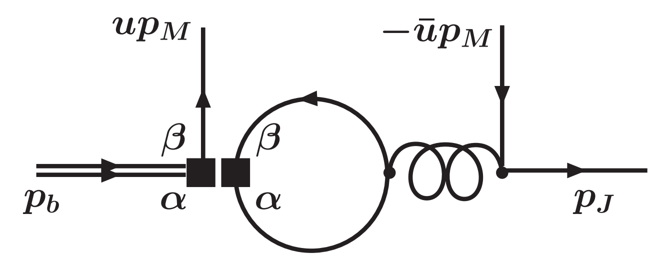


$$\frac{d\Gamma}{dE_\gamma} \sim H \cdot (\mathcal{J} \otimes f)$$

Charming Penguin?



Can include effects



$$\frac{\mathbf{d}\ \ (\mathbf{B}\qquad \mathbf{M}\,\mathbf{X})/\mathbf{dE}_M}{\mathbf{d}\ \ (\bar{\mathbf{B}}\qquad \mathbf{X}_s\ \ )/\mathbf{dE}_\gamma} = \frac{2\pi^3}{\mathbf{m}_b^2\mathbf{H}_\gamma}\left(\left|\mathbf{h}_M^{(q)}\right|^2 + 2\mathrm{Re}\left[\ {}_c^{(q)}\mathbf{c}_{cc}\,\mathbf{p}_{cc}^M\left(\mathbf{h}_M^{(q)}\right)^*\right] + \left|\ {}_c^{(q)}\mathbf{c}_{cc}\right|^2\mathbf{P}_{cc}^M\right)$$

Unknown pieces

Charming penguin adds new terms to rate

Strategy for Charming Penguin

- Look at decays without it
  - Example: $\bar{B} \to \phi X^0$
  - Test method, within errors?
- Look at decays with it
  - Example: $\bar{B} \to K^- X^+$
  - Is term from charming penguin necessary?

$$\frac{d\Gamma}{dE_M}(B \to X M) = \frac{G_F^2}{8\pi} m_b^2 x_M^3 S(x_M, \mu_0) \left| h_M^{(q)} \right|^2 + \cdots$$

Uncertainties

Lots of higher order corrections

- Higher order *B* shape function: Mostly cancel in ratio
- New subleading function enter due to correction to collinear currents: Could be large for some modes
- "Chirally enhanced" terms: Unknown size
- *SU*(3) breaking: For *M* of order 20% (small for *B*)

Also have uncertainty in parameters
(ie, lightcone amplitudes)

Phenomenology

- Put cut on invariant mass $m_X < 2$ GeV
- Normalize rate to $B_{\bar{q}} \quad X_{s\bar{q}}$ in endpoint
- Lightcone amps from QCD sum rules
- Calculate CP asymmetry

$$A_{CP} = \frac{d\Gamma(\overline{B} \to XM)/dE_M - d\Gamma(B \to XM)/dE_M}{d\Gamma(\overline{B} \to XM)/dE_M + d\Gamma(B \to XM)/dE_M}$$

- Look at as many decays as possible, assuming charming penguin is small

Some Results

Have rates for 60 different channels

Some are listed below (without NPCP)

Mode	Br/Br(B X_s)	Exp. (2 body)	A_{CP}
$\bar{B}$ $K^- X^+$	$0.17 \pm 0.09 \pm 0.05$	***	$0.30 \pm 0.16 \pm 0.01$
B_s $K^- X_s^+$	$0.17 \pm 0.09 \pm 0.05$	-	$0.30 \pm 0.16 \pm 0.01$
B $\pi^- X^+$	$0.67 \pm 0.37 \pm 0.14$	> 0.038	$-0.040 \pm 0.021 \pm 0.004$
B $^- X^+$	$1.76 \pm 0.97 \pm 0.35$	> 0.10	$-0.039 \pm 0.021 \pm 0.004$
B^- $K^0 X^-$	$0.20 \pm 0.11 \pm 0.06$	***	$(9.7 \pm 4.8 \pm 0.6) \times 10^{-3}$
B^- X_s^-	$0.22 \pm 0.13 \pm 0.03$	> 0.035	$(8.9 \pm 5.0 \pm 1.6) \times 10^{-3}$
B X_s^0	$0.22 \pm 0.13 \pm 0.03$	> 0.034	$(8.9 \pm 5.0 \pm 1.6) \times 10^{-3}$

*** wait for it

Got Data?

$$\frac{(\mathbf{B}^-/\overline{\mathbf{B}}^0 \quad \mathbf{K}^-\mathbf{X})}{(\mathbf{B} \quad \mathbf{X}_s \quad)} = 1.13 \pm 0.30$$

$$\frac{(\mathbf{B}^-/\overline{\mathbf{B}}^0 \quad \overline{\mathbf{K}}^0\mathbf{X})}{(\mathbf{B} \quad \mathbf{X}_s \quad)} = 0.89 \pm 0.42$$

from BaBar
hep-ex/0607053

The prediction again were

$$\left.\frac{(\mathbf{B}^-/\overline{\mathbf{B}}^0 \rightarrow \mathbf{K}^-\mathbf{X})}{(\mathbf{B} \rightarrow \mathbf{X}_s \quad)}\right|_{\text{no NPCP}} = 0.17 \pm 0.09 \pm 0.06$$

$$\frac{\Gamma(B^-/\overline{B}^0 \rightarrow \overline{K}^0 X)}{\Gamma(B \rightarrow X_s\gamma)} = 0.20 \pm 0.11 \pm 0.06$$

no NPCP

Charming penguins?

$$\frac{\mathbf{d} \ (\mathbf{B} \quad \mathbf{M}\,\mathbf{X})/\mathbf{dE}_M}{\mathbf{d} \ (\overline{\mathbf{B}} \quad \mathbf{X}_s \ )/\mathbf{dE}_\gamma} = \frac{2\pi^3}{\mathbf{m}_b^2 \mathbf{H}_\gamma}\left(\left|\mathbf{h}_M^{(q)}\right|^2 + 2\mathrm{Re}\left[\ {}_c^{(q)}\mathbf{c}_{cc}\,\mathbf{p}_{cc}^M \left(\mathbf{h}_M^{(q)}\right)^*\right] + \left|\ {}_c^{(q)}\mathbf{c}_{cc}\right|^2 \mathbf{P}_{cc}^M\right)$$

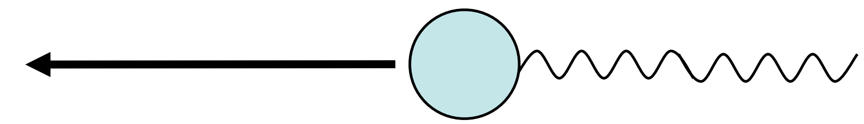
$$\left|\frac{\lambda_c^{(s)} p_{cc}^K}{h_K^{(s)}}\right| = \begin{cases} 2.2 \pm 1.1 & : K^+X \\ 2.0 \pm 1.5 & : K^0X \end{cases}$$

Outlook for Semi-inclusive hadronic *B* decays

- With future measurements, could constrain charming penguin better
- Error estimates could be done better

Isospin Asymmetries in Radiative *B* Decays

Begin with data



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

$$\Delta_{0-}^{\rho} = \frac{2\Gamma(\overline{\mathbf{B}}^0 \quad {}^0) - \Gamma(\mathbf{B}^- \quad {}^-)}{2\Gamma(\overline{\mathbf{B}}^0 \quad {}^0) + \Gamma(\mathbf{B}^- \quad {}^-)}$$

Recent data from BaBar:

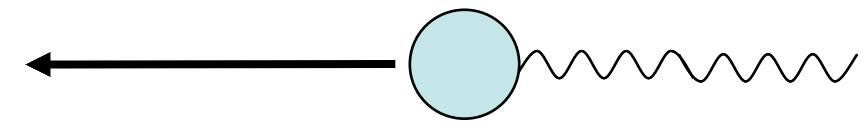
$$\Delta_{0-}^{K} = 0.03 \pm 0.04$$

$$\Delta_{0-} = 0.26 \pm 0.14$$

without NPCP,
order few percent.

Isospin Asymmetries in Radiative B Decays

Begin with data



$$\Delta^{K}_{0-} = \frac{(\overline{B}^0 \to \overline{K}^{\,0}\gamma) - (B^- \to K^-\gamma)}{(\overline{B}^0 \to \overline{K}^{\,0}\gamma) + (B^- \to K^-\gamma)}$$

$$\Delta^{\rho}_{0-} = \frac{2\Gamma(\overline{\mathbf{B}}^0 \quad {}^0\ ) - \Gamma(\mathbf{B}^- \quad {}^-\ )}{2\Gamma(\overline{\mathbf{B}}^0 \quad {}^0\ ) + \Gamma(\mathbf{B}^- \quad {}^-\ )}$$

Recent data from BaBar:

$$\Delta^{K}_{0-} = 0.03 \pm 0.04$$

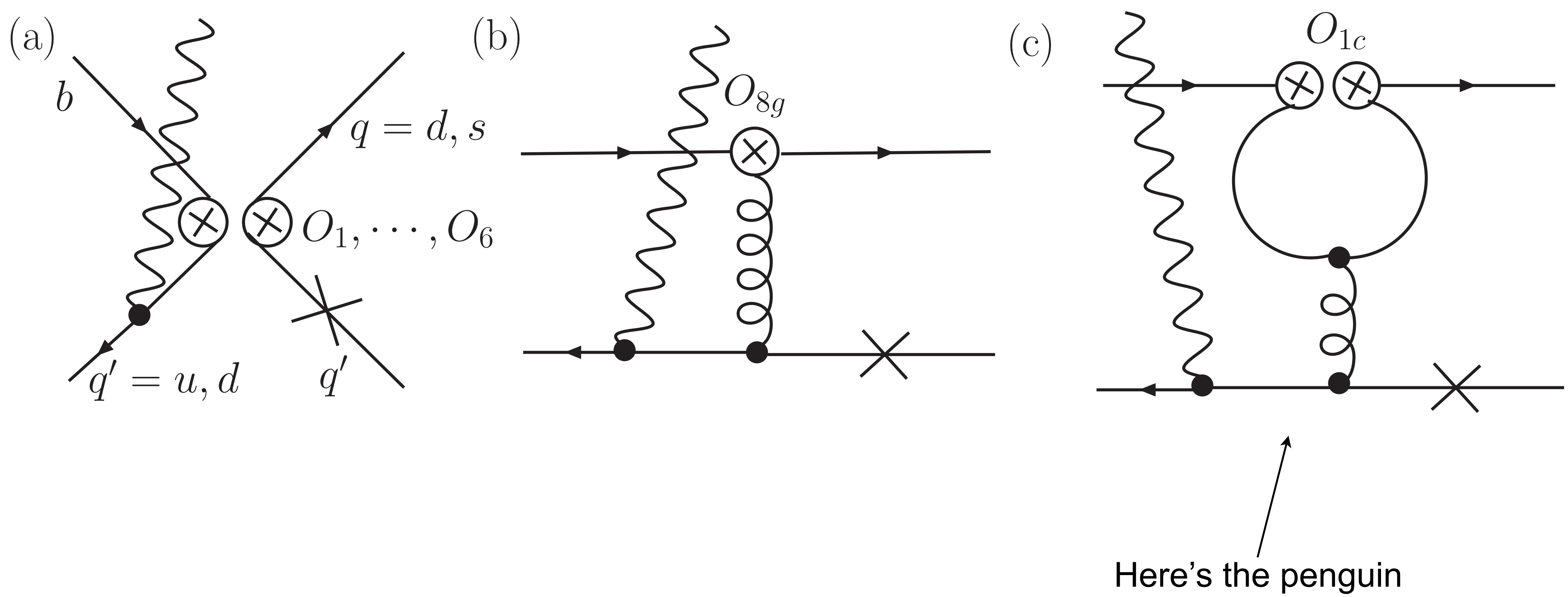
$$\Delta_{0-} = 0.26 \pm 0.14$$

Why so much bigger?

without NPCP,
order few percent.

Various contributions

- Mass difference of spectator $O[(m_u - m_d)/ \quad _{\mathrm{QCD}}]$
- Dominant contribution from EM interaction with spectator quark

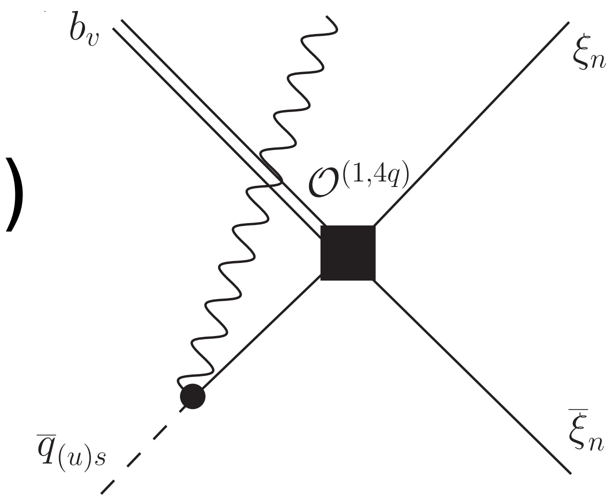


$\lambda_p^{(q)} = V_{pb}V_{pq}$

Schematic of Calculation

Isospin Asymmetries in Radiative *B* Decays

- Match QCD onto $\mathrm{SCET_I}$ p^2 m_b



$$H^{(1,4\mathbf{q})}_{\mathbf{W},\mathrm{SCET}} = \frac{G_F}{\sqrt{2}} \sum_{\mathbf{p}} \lambda_{\mathbf{p}}^{(\mathbf{q})} \sum_{\mathbf{i}=1}^{6} \int_0^1 dx\, \mathbf{B}_{\mathbf{i}}^{\mathbf{p}}(x,\mu)\, \mathbf{O}_{\mathbf{i}}^{(1,4\mathbf{q})}(x,\mu)$$

–Operators look like

$$O_1^{(1,4q)} = \bar{u}_{\bar{n}} W_{\bar{n}} \gamma_\mu (1-\gamma_5) Y_{\bar{n}}^\dagger b_v \; \bar{q}_{\bar{n}} W_n \gamma^\mu (1-\gamma_5) W_n^\dagger u_n + \bar{q}_n W_n \gamma^\mu (1-\gamma_5) W_n^\dagger u_{\bar{n}} \quad x$$

- Take time-ordered product with

$$L_{EM}^{(1)} = e_q \bar{q}_{us} Y_{\bar{n}} A\!\!\!/ \; W_{\bar{n}}^\dagger q_{\bar{n}} + \mathrm{h.c.}$$

- Match onto $\mathrm{SCET_{II}}$ p^2 ^{2}

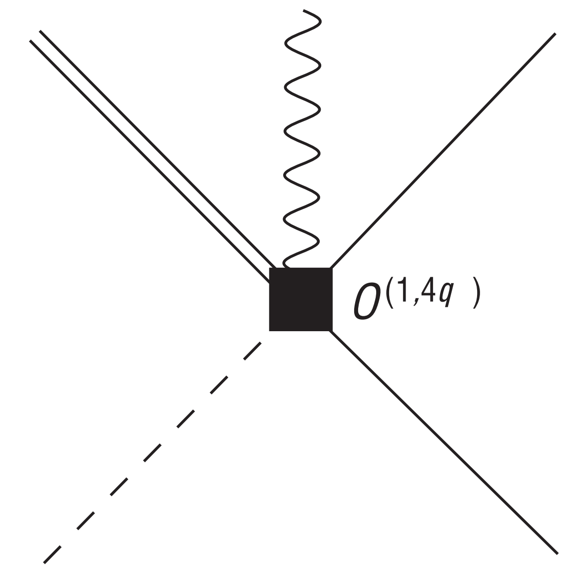
–get jet function

Schematic of Calculation, cont

Isospin Asymmetries in Radiative *B* Decays

- OR Match QCD onto $\mathrm{SCET_I}$ p^2 m_b

$$H^{(1,4q\ \ )}_{W,SCET} = \frac{G_F}{\sqrt{2}} \ {}_{p} \ {}^{(q)}_{p} \ {}^{2}_{i=1} \ {}^{1}_{0} dx\, A_i^p(x,\mu)\, O_i^{(1,4q\ \ )}(x,\mu)$$



– Operators look like

$$O^{(1,4q\ \ )}_{\{1,2\}}(x) = \sum_{q'=u,d,s} e_{q'} \bar{q}\, Y_n \{\bar{n}\!\!\!/, n\!\!\!/\}(1 + \ {}_5) Y_n^\dagger b_v \left[{}^{-q}_{n} W_n \bar{n}\!\!\!/ 2 A\!\!\!/ \ \ (1 + \ {}_5) \frac{1}{\bar{P}} W_n^\dagger \ {}^{q'}_{n} \right]_x$$

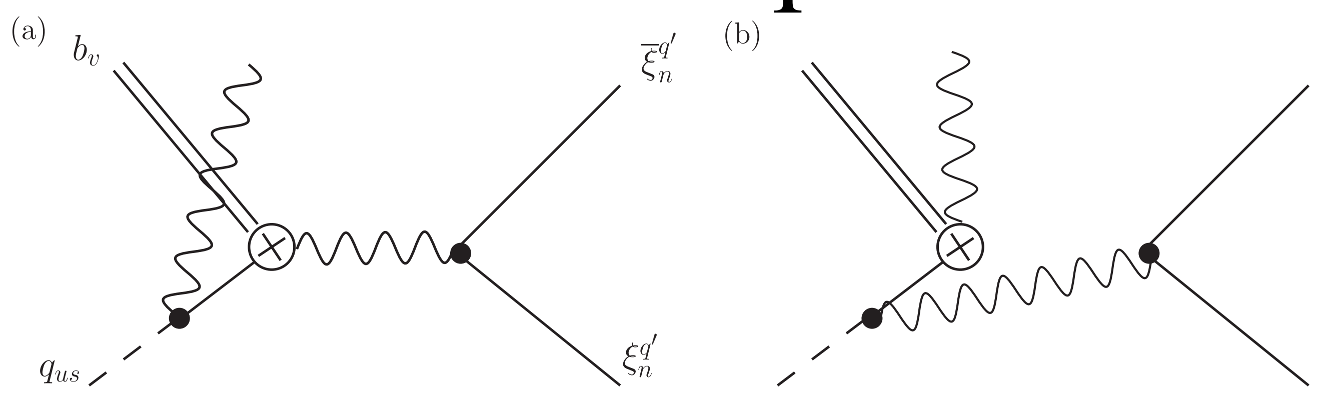
- Match onto $\mathrm{SCET_{II}}$ p^2 ^{2}

Schematic of Calculation, cont

Isospin Asymmetries in Radiative *B* Decays

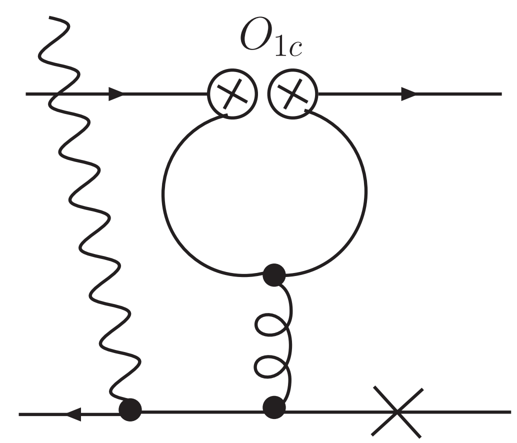
- In both cases, *B* to γ piece factorizes from light-meson production
  - $\bar{n}$- and n-collinear degrees of freedom decouple
  - both decouple from usoft (Same old field redefinition)
  - n-collinear piece describing vector meson production decouples from rest

- Can also treat "double photon" contribution



  - small correction

Charming Penguin?



- B to γ piece still factorizes

$$M^{c\bar{c}} = -\frac{G_F}{\sqrt{2}}\lambda_c^{(q)} e_q\, f_B\, f_V\, m_B^2\, A_L(\epsilon \quad , \eta \quad) \frac{\pi \alpha_s}{N} \quad {}_{c\bar{c}} \int_0^1 dx \frac{\phi \quad (x)}{\bar{x}} \delta(\bar{x} - 4s_c^2)\hat{H}_{c\bar{c}}(\bar{x})$$

Polarization factor

Also get right-handed, but doesn't enter into asymmetry

Parametrizes charming penguin

$$A_L = \quad \cdot \quad - i \quad {}^{\mu} \quad {}_{\mu}$$

$$^{\mu} = \quad ^{\mu} \quad n \quad \bar{n} \quad /2$$

$$\frac{m_B}{\quad {}_{c\bar{c}}} \quad \frac{(4s_c^2)}{4s_c^2} \quad \frac{v\, m_b}{\quad {}_{QCD}}$$

using power counting of BPRS

Combine everything

Huge mess

$$\Delta_{0-}^{V} = \frac{\mathrm{Re}(b_d^V - b_u^V) + R\,\mathrm{Re}(\bar{b}_d^V - \bar{b}_u^V)}{1+R}$$

$$b_d^V = \frac{A_0^V}{c_V L_V} \qquad b_u^V = \frac{A_-^V}{L_V}$$

Isospin violating

Isospin symmetric

$$R = |\bar{L}_V|^2/|L_V|^2$$

$$b_q^K = Q_q \frac{2\pi^2 f_B}{m_b a_{7,K}^c \quad K} \; 2\frac{f^K}{m_b} K_1^K + \frac{f_K \; m_K}{B \, m_b} K_{2q}^K$$

$$K_1^K = \int_0^1 dx \frac{(x)}{\bar{x}} - \frac{1}{2} \; A_1^c(x) + A_2^c(x) \; - C_1 \frac{\pi \quad s}{N} \frac{m_B}{c\bar{c}} \; (\bar{x} - 4s_c^2)$$

$$K_{2q}^K = \int_0^1 dx \left[g_\perp^{(v)} - \frac{\partial}{4\partial x} g_\perp^{(a)} \right](x) \left\{ \frac{u^{(s)}}{c^{(s)}} \left(C_1 + \frac{C_2}{N} \right) \; qu + \mathcal{B}_4^c(x, m_b) \right\}$$

Combine everything

Huge mess

$$\mathcal{A}_1^p(x,\mu) = C_6 + \frac{C_5}{N} + \frac{\alpha_s}{4\pi}\frac{C_F}{N}\left\{\frac{2C_1}{3}\left[1+\ln\frac{m_B^2}{\mu^2} - \frac{3}{2}G(s_p,x)\right] - 2C_{8g}\frac{m_b}{\bar{x} m_B}\right\}$$

$$\mathcal{A}_2^p(x,\mu) = C_6 + \frac{C_5}{N} + \frac{{}_s}{4\pi}\frac{C_F}{N}\quad \frac{C_1}{3}\quad 1+\ln\frac{m_B^2}{\mu^2} - \frac{3}{2}G(s_p,x)\quad - C_{8g}\frac{m_b}{m_B}$$

$$V\ (\quad)|\ \bar{}_{\bar n} W_n\ {}^{\mu} W_n^{\dagger}\ {}_{n} + \bar{}_{n} W_n\ {}^{\mu} W_n^{\dagger}\ {}_{\bar n}\ {}_{x}|0 = -i f_V m_V\ {}^{\mu} g^{(v)}(x)$$

$$V\ (\quad)|\ \bar{}_{\bar n} W_n\ {}^{\mu}\ {}_5 W_n^{\dagger}\ {}_{n} + \bar{}_{n} W_n\ {}^{\mu}\ {}_5 W_n^{\dagger}\ {}_{\bar n}\ {}_{x}|0 = -\frac{f_V}{4} m_V\ {}^{\mu}\quad \frac{\partial}{\partial x} g^{(a)}(x)$$

$$\overline{K}^{*0}\ |O_1^{(1,4q\gamma)}|\overline{B}^0 = \overline{K}^{*0}\ |O_2^{(1,4q\gamma)}|\overline{B}^0 = -\frac{e_d}{2} f_B f_{K^*}^{\perp} m_B A_L(\ {}^{*}_{\perp},\ {}^{*}_{\perp})\frac{{}_{\perp}(x,\mu)}{\bar{x}}$$

$$L_{K^*} = \frac{G_F}{\sqrt{2}}\frac{e}{4\pi^2} m_b^2 m_B A_L(\epsilon_\perp^*,\eta_\perp^*)\lambda_c^{(s)} a^c_{7,K^*}\zeta_\perp^{K^*}$$

$$a^p_{7,V} = C_7\ \ A_7^{(0)} + \frac{\alpha_s C_F}{4\pi}[C_1 G_1(s_p) + C_{8g} G_8(s_p)] + \pi\alpha_s\frac{C_F}{N}\frac{f_B f_V m_B}{m_b^2}\quad dl_+\frac{\phi_B^+(l_+)}{l_+}\int_0^1 dx\frac{\phi\ (x)}{\bar{x}}\ C_7\ + \frac{C_1}{6}H(x,s_p) + \frac{C_{8g}}{3}\ \frac{1}{\zeta^V}$$

$${}^{+}_{B}(l,\mu) = \frac{4\mu l}{\pi\ {}_B(l^2+\mu^2)}\ \frac{\mu^2}{l^2+\mu^2} - \frac{2(\ {}_B - 1)}{\pi^2}\ln\frac{l}{\mu}, \qquad {}_B^{-1} = \ dl\ {}^{+}_{B}(l)/l$$

$$\int_0^1 dx\frac{g_\perp^{(v)}(x)}{\bar{x}} \longrightarrow \int_0^1 dx\frac{g_\perp^{(v)}(x) - g_\perp^{(v)}(1)}{\bar{x}} \qquad \int_0^1 dx\frac{\ (x)}{\bar{x}^2} - \int_0^1 dx\frac{\ (x) + \bar{x}\ \ (1)}{\bar{x}^2}$$

Finally get numbers

Including CP asymmetry and branching ratio

	Exp	w/o NPCP	w/ NPCP
Δ^K_{0-}	0.03±0.04	0.04±0.02	0.10±0.05
Δ_{0-}	0.26±0.14	0.02±0.02	0.10±0.06
Δ_{+-}	0.11±0.33	0.08±0.02	0.07±0.13
$Br[B^{+} \quad ^{+} \ ] \times 10^6$	0.96±0.24	1.80±0.69	1.63±067

Finally get numbers

Including CP asymmetry and branching ratio

	Exp	w/o NPCP	w/ NPCP
Δ^K_{0-}	0.03±0.04	0.04±0.02	0.10±0.05
Δ_{0-}	0.26±0.14	0.02±0.02	0.10±0.06
Δ_{+-}	0.11±0.33	0.08±0.02	0.07±0.13
$Br[B^{+} \quad {}^{+}] \times 10^6$	0.96±0.24	1.80±0.69	1.63±067

Best fit NPCP contribution was

$$\mathrm{Re}\ \frac{m_B}{c\bar{c}} = -0.102 \pm 0.063 \quad \mathrm{Im}\ \frac{m_B}{\Lambda_{c\bar{c}}} = 0.022 \pm 0.255$$

Outlook for Radiative *B* decays

- Charming penguin can increase both isospin asymmetries together, but doesn't split them
- Errors are still large, will have to wait and see
- No obvious sign of charming penguin