Effective Field Theory

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Outline

Lecture I

- Principles, Operators, Power Counting , Matching, Loops,
  Using Equations of Motion, Renormalization and Decoupling

Lecture II

- Summing Logarithms, α_s matching, HQET

Weak Interactions at low energy, [power counting velocity NRQCD]

Lecture III

Soft - Collinear Effective Theory

An effective field theory for energetic hadrons & jets

$$E \gg \Lambda_{\text{QCD}}$$

Non-relativistic QCD

Systems with Two Heavy Particles

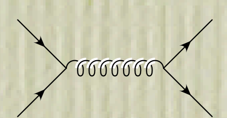
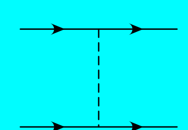
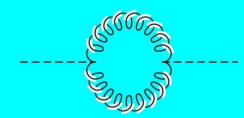
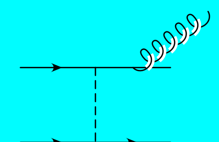
eg.

e^+e^-	$\rightarrow$	positronium	(NRQED)
pe^-	$\rightarrow$	Hydrogen	(NRQED)
$b\bar{b}, c\bar{c}$	$\rightarrow$	$\Upsilon, J/\Psi$	(NRQCD)
$t\bar{t}$	$\rightarrow$	$e^+e^- \rightarrow t\bar{t}$	(NRQCD)
NN	$\rightarrow$	deuteron	(few nucleon EFT)

- $E = p^2/(2m) \sim v^2$, count powers of v $\quad$ (and α_s)

treat $mv^2 \gg \Lambda_{\rm QCD}$

Momentum Regions

	k^0	**k**			
hard:	m	m		integrate these out	
potential:	mv^2	mv		ptnl gluons are not propagating	ψ, χ
soft:	mv	mv		radiative corrections, binding	A_s^μ, q_s
ultrasoft:	mv^2	mv^2		need multipole expansion	A_{us}^μ

Simplify p.c. and Implement multipole expansion

▷ $P = (m, \mathbf{0}) + \mathbf{p} + k$

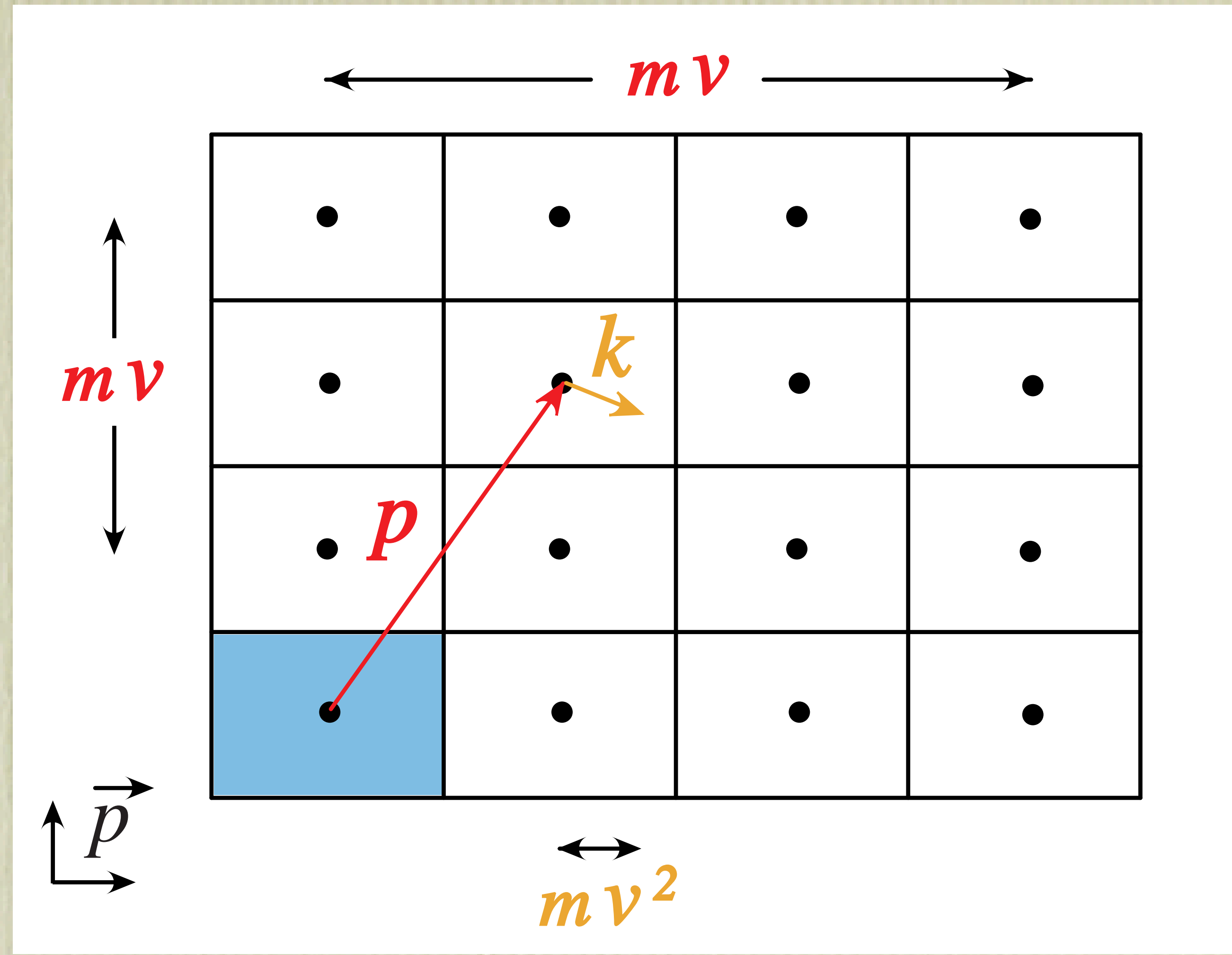
$\quad\quad m \quad\quad mv \quad\quad mv^2$

▷ $\mathbf{p}$ index

▷ $k = (k^0, \mathbf{k})$ continuous

$$\psi(x) = \sum_{\mathbf{p}} e^{i\mathbf{p}\cdot\mathbf{x}} \psi_{\mathbf{p}}(x)$$

$$i\partial^\mu \psi_{\mathbf{p}}(x) \sim (mv^2)\psi_{\mathbf{p}}(x)$$



$\mathcal{O}(v^0)$ Kinetic Terms give

potential quarks	$\psi, \chi \sim v^{3/2}$	
soft gluons	$A_s^\mu \sim v$	(scale μ_S)
ultrasoft gluons	$A_{us}^\mu \sim v^2$	(scale μ_U)

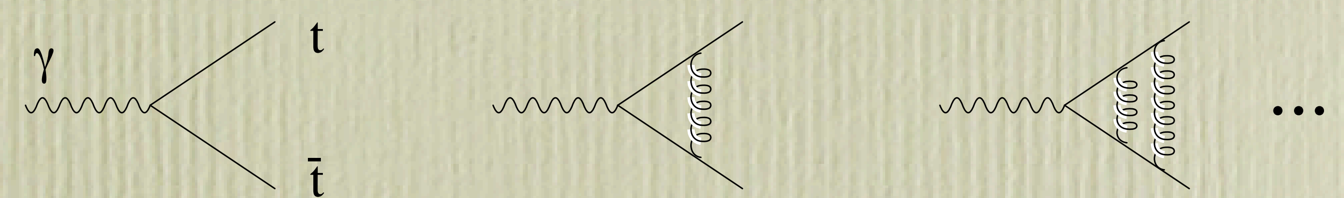
(board)

- Can associate all powers of v with vertices

$$\delta = 5 + \sum_k (k-5)V_k^P + (k-8)V_k^U + (k-4)V_k^S - N_s$$

- Power counting of operators implies power counting of states

Coulombic Singularities $\Longrightarrow$ sum insertions of V_c



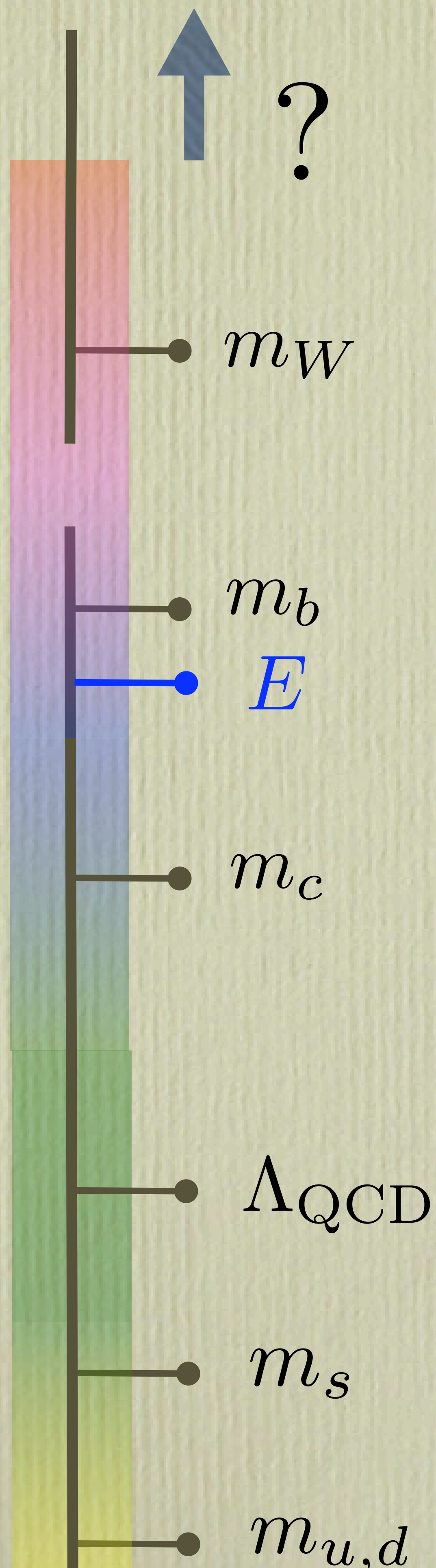
1 $\quad (\alpha_s/v) \quad (\alpha_s/v)^2$

Coulombic: $v \sim \alpha_s$

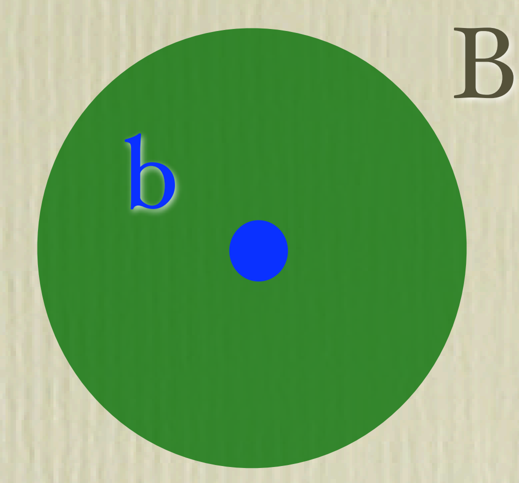
The rest of the NRQCD discussion can be found at the end of Lecture II on the website

Lecture III Outline

- d.o.f., SCETI & SCETII, Lagrangians
- Label Operators, Gauge Invariance, Wilson Lines, RPI, multipole expansion
- Hard-Collinear and Ultrasoft-Collinear Factorization
- IR divergences, Running
- $B \to X_s \gamma$



SCET can be used for:



B - decays by weak interactions:

$B \to X_u \ell \bar{\nu}$ $\quad B \to D\pi$ $\quad B \to K^* \gamma$

$B \to \pi \ell \bar{\nu}$ $\quad B \to X_s \gamma$ $\quad B \to \rho\gamma$

$B \to D^* \eta'$ $\quad B \to \rho\rho$ $\quad B \to \pi\pi$ $\quad B \to K\pi$ $\quad B \to \gamma \ell \bar{\nu}$

The B is heavy, so many of its decay products are energetic, E

Any other QCD process with large energy transfer:

$e^- p \to e^- X$ $\quad p\bar{p} \to X \ell^+ \ell^-$

$e^- \gamma \to e^- \pi^0$ $\quad \gamma^* M \to M'$ $\quad \Upsilon \to X\gamma$

$e^+ e^- \to$ jets $\quad e^+ e^- \to J/\Psi X$

Degrees of Freedom

eg.

Pion has: $\quad p^\mu_\pi = (2.310\,\mathrm{GeV}, 0, 0, -2.306\,\mathrm{GeV}) = Q n^\mu$

$$Q \gg \Lambda_{\mathrm{QCD}} \qquad n^\mu = (1, 0, 0, -1)$$

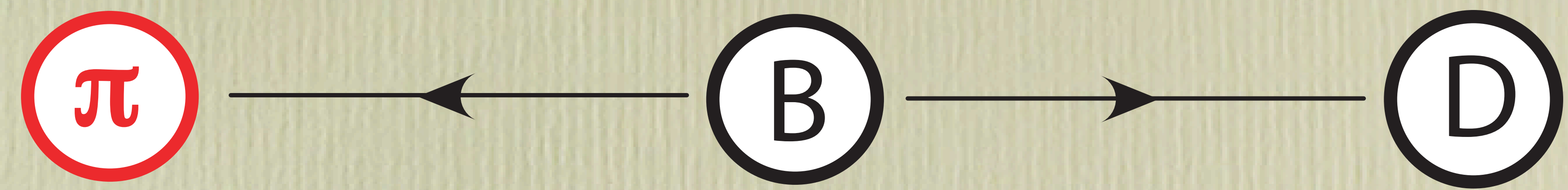
Light - Cone coordinates: $\quad$ Basis vectors n^μ, $\bar{n}^\mu$ with $n^2 = 0$, $\bar{n}^2 = 0$, $n\cdot\bar{n} = 2$

$$p^\mu = \frac{n^\mu}{2}\bar{n}\cdot p + \frac{\bar{n}^\mu}{2} n\cdot p + p^\mu_\perp \qquad p^+ \equiv n\cdot p, \qquad p^- \equiv \bar{n}\cdot p$$

$$g^{\mu\nu} = \frac{n^\mu \bar{n}^\nu}{2} + \frac{\bar{n}^\mu n^\nu}{2} + g^{\mu\nu}_\perp$$

eg. $\bar{n}^\mu = (1, 0, 0, 1)$

eg.

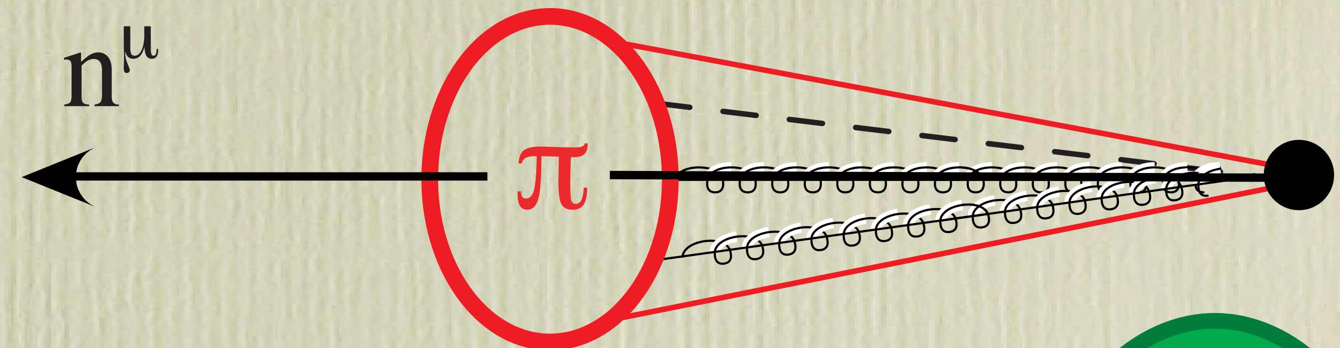


Collinear constituents:

$$p_c^\mu = (p^+, p^-, p^\perp) \sim \left(\frac{\Lambda^2}{Q}, Q, \Lambda\right) \sim Q(\lambda^2, 1, \lambda) \qquad \lambda = \frac{\Lambda}{Q}$$

Just a boost of

$$(p^+, p^-, p^\perp) \sim (\Lambda, \Lambda, \Lambda)$$



Soft Constituents

$$p_s^\mu = (p^+, p^-, p^\perp) \sim (\Lambda, \Lambda, \Lambda)$$

D and

$\mathrm{SCET_{II}}$ Energetic hadrons $\boxed{\lambda = \frac{\Lambda}{Q}}$

modes	$p^\mu = (+, -, \perp)$	p^2	fields
collinear	$Q(\lambda^2, 1, \lambda)$	$Q^2\lambda^2$	$\xi_n,\ A_n^\mu$
soft	$Q(\lambda, \lambda, \lambda)$	$Q^2\lambda^2$	$q_s,\ A_s^\mu$

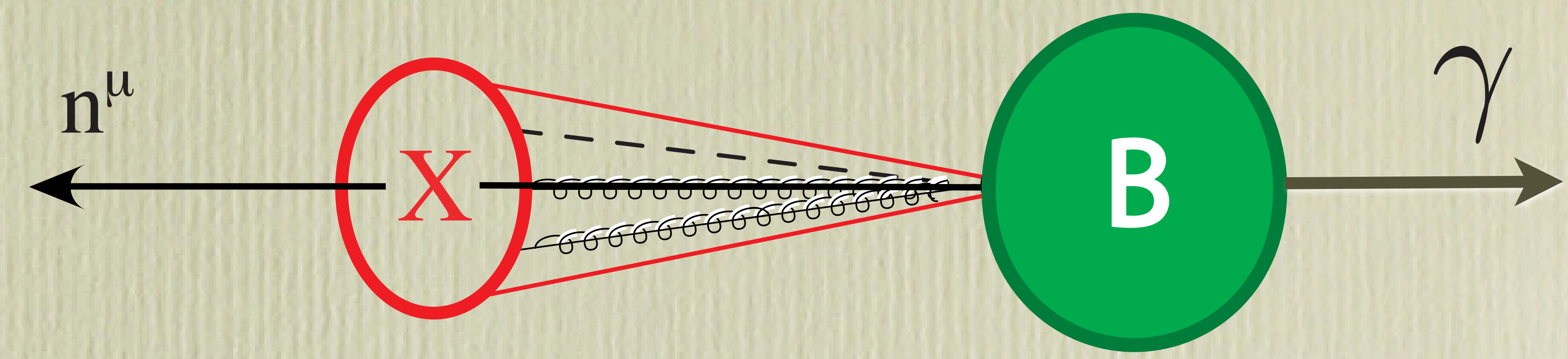
eg. $B \to X_s \gamma$

$m_X^2 \sim m_B^2$ OPE in $1/m_b$ (not SCET)

$m_X^2 \sim \Lambda^2$ not inclusive

$m_X^2 \sim \Lambda Q$

$\Lambda^2 \ll Q\Lambda \ll Q^2$



Jet constituents: $p^\mu \sim (\Lambda, Q, \sqrt{Q\Lambda}) \sim Q(\lambda^2, 1, \lambda)$

SCET$_\mathrm{I}$ Energetic jets

usoft $p^\mu \sim \Lambda$

collinear $p_c^2 \sim Q\Lambda$, $\boxed{\lambda = \sqrt{\Lambda/Q}}$

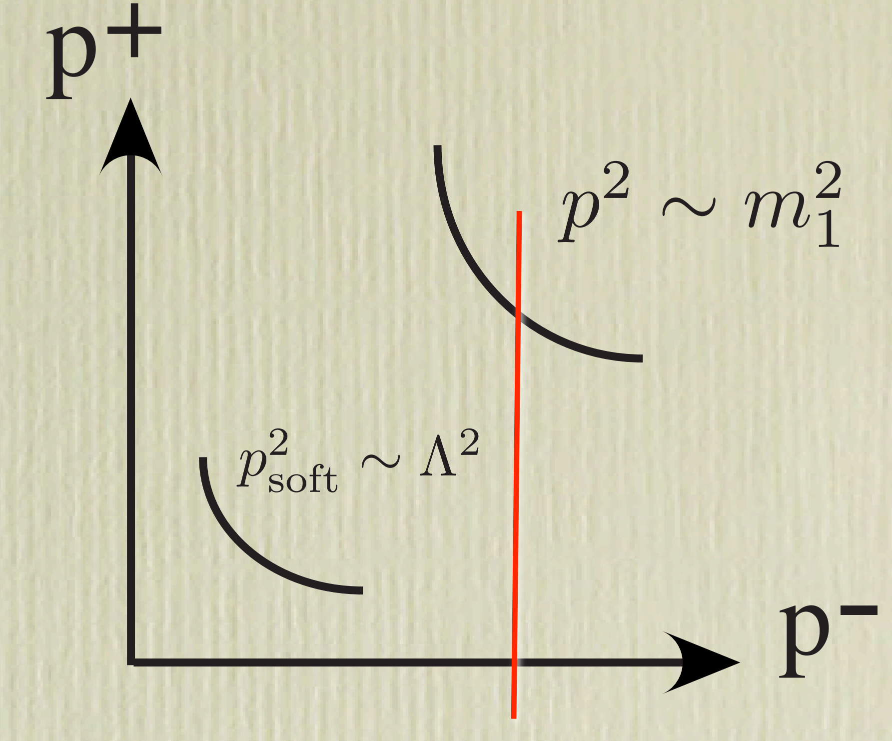
modes	$p^\mu = (+, -, \perp)$	p^2	fields
collinear	$Q(\lambda^2, 1, \lambda)$	$Q^2\lambda^2$	ξ_n, A_n^μ
usoft	$Q(\lambda^2, \lambda^2, \lambda^2)$	$Q^2\lambda^4$	q_{us}, A_{us}^μ

What makes this EFT different?

$$p^2 = p^+ p^- + p_\perp^2$$

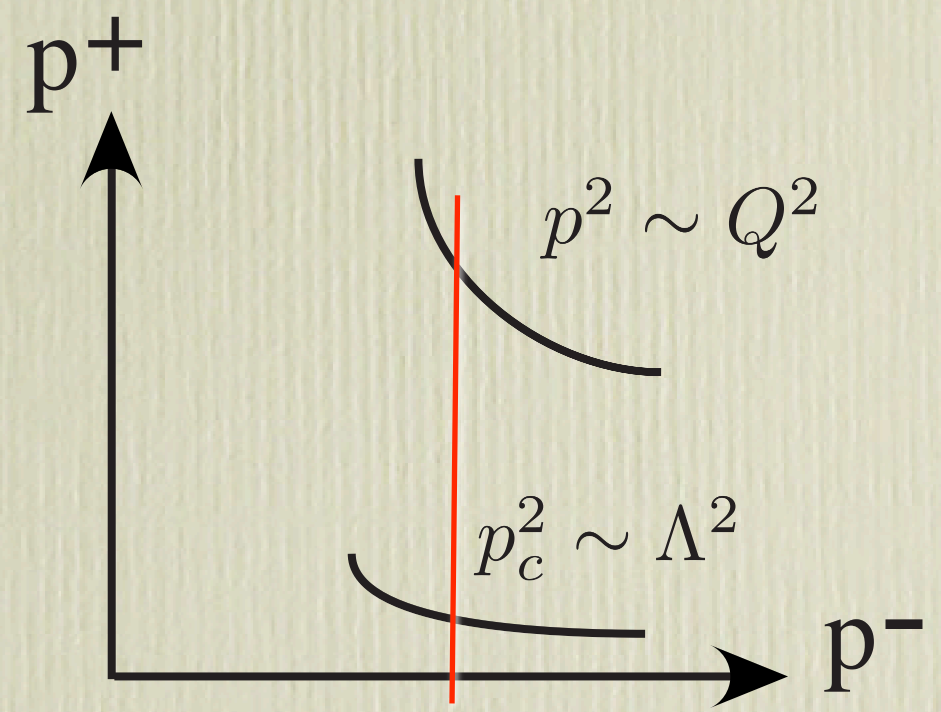
- Usually $m_1 \gg \Lambda$

$$\sum_{i=1}^{n} C_i(\mu, m_1)\, O_i(\mu, \Lambda)$$



- In SCET constituent $p^- \sim m_b \sim E_\pi$

$$\int d\omega\; C(\omega)\, O(\omega)$$



Collinear Propagator

(board)

Power Counting for Collinear Fields

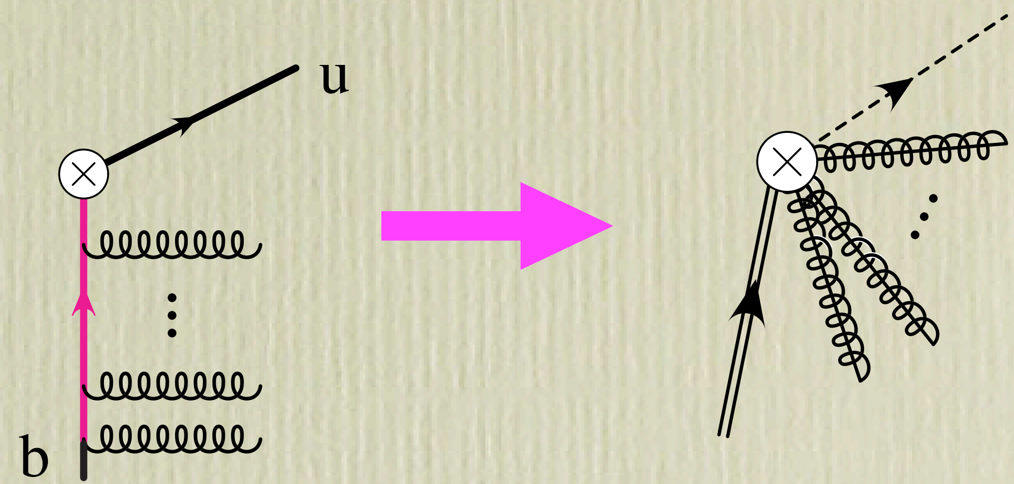
(board)

Currents

eg. $\bar{u}\,\Gamma\,b$ involves both collinear and ultrasoft objects

(board)

$\bar{u}\,\Gamma\,b$ ⟶ $\bar{\xi}_n W\ \Gamma\ h_v$



$$W = P\exp\left(ig\int_{-\infty}^{y} ds\,\bar{n}\cdot A_n(s\bar{n}^\mu)\right)$$

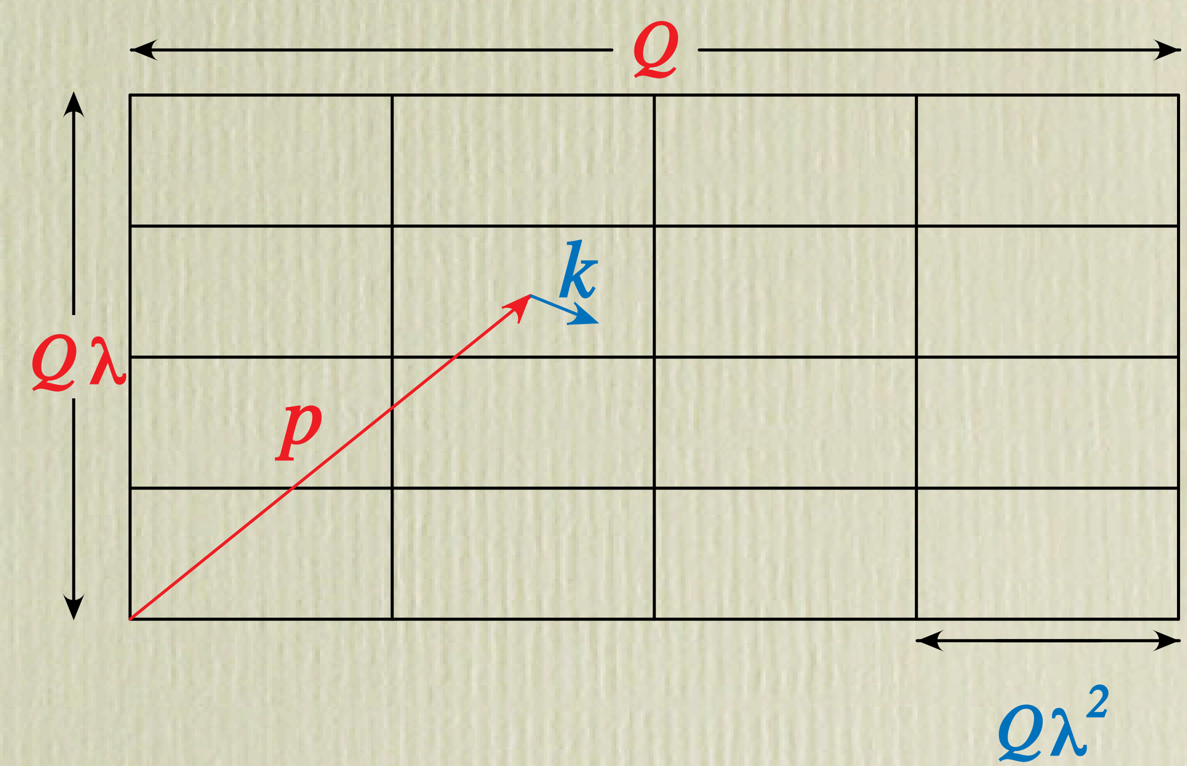
Interaction of modes: Offshell versus Onshell

(board)

Separate Momenta (multipole expansion)

		label	residual	
HQET	$P^\mu =$	$m_b v^\mu$	$+\ k^\mu$	$h_v(x)$
SCET	$P^\mu =$	p^μ	$+\ k^\mu$	$\xi_{n,p}(x)$

$(1, \lambda)$



Collinear Quarks

▷ $\psi(x) \to \sum_p e^{-ip\cdot x} \xi_{n,p}(x)$

▷ $\not{n}\, \xi_{n,p} = 0$

▷ $\partial^\mu\, \xi_{n,p} \sim (Q\lambda^2)\, \xi_{n,p}$

usual derivative

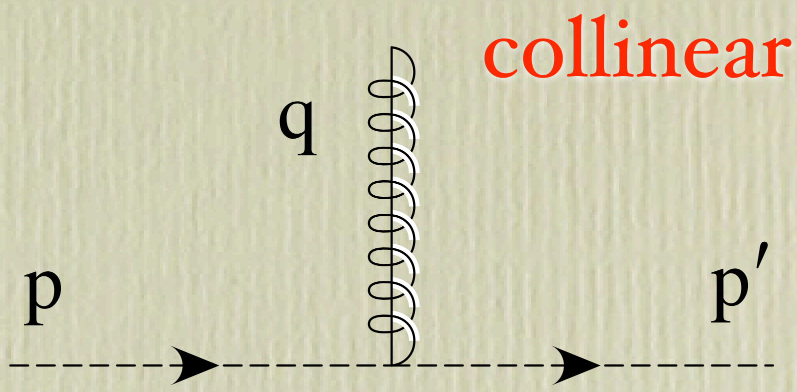
Introduce Label Operator

$$\mathcal{P}^\mu \big(\phi^\dagger_{q_1} \cdots \phi_{p_1} \cdots \big) = (p_1^\mu + \ldots - q_1^\mu - \ldots)\big(\phi^\dagger_{q_1} \cdots \phi_{p_1} \cdots \big)$$

derivative for labels

$$i\partial^\mu e^{-ip\cdot x}\, \phi_p(x) = e^{-ip\cdot x}(\mathcal{P}^\mu + i\partial^\mu)\phi_p(x)$$

- Labels are changed by collinear interactions



- Labels are preserved by ultrasoft interactions

Power Counting Summary

Type	$(p^+, p^-, p^\perp)$	Fields	Field Scaling
collinear	$(\lambda^2, 1, \lambda)$	$\xi_{n,p}$	λ
		$(A^+_{n,p}, A^-_{n,p}, A^\perp_{n,p})$	$(\lambda^2, 1, \lambda)$
soft	$(\lambda, \lambda, \lambda)$	$q_{s,p}$	$\lambda^{3/2}$
		$A^\mu_{s,p}$	λ
usoft	$(\lambda^2, \lambda^2, \lambda^2)$	q_{us}	λ^3
		A^μ_{us}	λ^2

Make kinetic terms order λ^0 $\quad \int d^4X \quad \bar{\xi}_{n,p'} \, \frac{\bar{n}\!\!\!/}{2} \Big(in\cdot\partial + \ldots \Big) \, \xi_{n,p}$

$$\lambda^0 = \quad \lambda^{-4} \quad \lambda \quad \lambda^2 \quad \lambda$$

- At leading power only λ^0 interactions are required

Power counting can be assigned to vertices

$$\delta = 4 + \sum_k (k-4)(V_k^c + V_k^s + V_k^{sc}) + (k-8)V_k^{us}$$

LO SCET Lagrangian

$$\mathcal{L}_{\rm QCD} = \bar{\psi}\, i\not{D}\psi \qquad \text{Write } \psi = \xi_n + \chi_{\bar{n}} \qquad \xi_n = \frac{\not{n}\not{\bar{n}}}{4}\,\psi$$

$$\chi_{\bar{n}} = \frac{\not{\bar{n}}\not{n}}{4}\,\psi$$

$$\mathcal{L} = (\bar{\chi}_{\bar{n}} + \bar{\xi}_n)\Big[i\frac{\not{\bar{n}}}{2}\, n\cdot D + i\frac{\not{n}}{2}\,\bar{n}\cdot D + i\not{D}_\perp\Big](\xi_n + \chi_{\bar{n}})$$

$$= \Big(\bar{\xi}_n\,\frac{\not{\bar{n}}}{2}\, in\cdot D\,\xi_n\Big) + \Big(\bar{\chi}_{\bar{n}}\,\frac{\not{n}}{2} i\bar{n}\cdot D\,\chi_{\bar{n}}\Big) + \Big(\bar{\xi}_n\, i\not{D}_\perp\,\chi_{\bar{n}}\Big) + \Big(\bar{\chi}_{\bar{n}}\, i\not{D}_\perp\,\xi_n\Big)$$

e.o.m: $\dfrac{\delta}{\delta\bar{\chi}_{\bar{n}}}$: $\quad i\bar{n}\cdot D\chi_{\bar{n}} + \dfrac{\not{n}}{2}\, i\not{D}_\perp\xi_n = 0 \qquad \chi_{\bar{n}} = \dfrac{1}{i\bar{n}\cdot D}\, i\not{D}_\perp\dfrac{\not{n}}{2}\,\xi_n$

$$\mathcal{L} = \bar{\xi}_n\,\Big(i\bar{n}\cdot D + i\not{D}_\perp\,\frac{1}{i\bar{n}\cdot D}\, i\not{D}_\perp\Big)\frac{\not{\bar{n}}}{2}\,\xi_n$$

(board)

$$\mathcal{L}_c^{(0)} = \bar{\xi}_n\Big\{n\cdot iD_{us} + gn\cdot A_n + i\not{D}_\perp^c\,\frac{1}{i\bar{n}\cdot D_c}\, i\not{D}_\perp^c\Big\}\frac{\not{\bar{n}}}{2}\,\xi_n$$

That was tree level.

Use Symmetries — Power counting, Gauge symmetry, Discrete, Lorentz invariance (?)

Gauge symmetry $U(x) = \exp\left[i\alpha^A(x)T^A\right]$

need to consider U's which leave us in the EFT

collinear $i\partial^\mu \mathcal{U}_c(x) \sim p_c^\mu \mathcal{U}_c(x) \leftrightarrow A^\mu_{n,q}$

usoft $i\partial^\mu U_{us}(x) \sim p_c^\mu U_{us}(x) \leftrightarrow A^\mu_{us}$

Object	Collinear $\mathcal{U}_c$	Usoft U_{us}
ξ_n	$\mathcal{U}_c\, \xi_n$	$U_{us}\, \xi_n$
gA_n^μ	$\mathcal{U}_c\, gA_n^\mu\, \mathcal{U}_c^\dagger + \mathcal{U}_c\big[i\mathcal{D}^\mu, \mathcal{U}_c^\dagger\big]$	$U_{us}\, gA_n^\mu\, U_{us}^\dagger$
W	$\mathcal{U}_c\, W$	$U_{us}\, W\, U_{us}^\dagger$
q_{us}	q_{us}	$U_{us}\, q_{us}$
gA_{us}^μ	gA_{us}^μ	$U_{us} gA_{us}^\mu U_{us}^\dagger + U_{us}[i\partial^\mu, U_{us}^\dagger]$
Y	Y	$U_{us}\, Y$

reconsider current (board)

Reparameterization Invariance (RPI)

$n\ ,\ \ \bar{n}$ break Lorentz invariance, restored within collinear cone by RPI, three types

$$\text{(I)}\begin{cases} n_\mu \to n_\mu + \Delta_\mu^\perp \\ \bar{n}_\mu \to \bar{n}_\mu \end{cases} \qquad \text{(II)}\begin{cases} n_\mu \to n_\mu \\ \bar{n}_\mu \to \bar{n}_\mu + \varepsilon_\mu^\perp \end{cases} \qquad \text{(III)}\begin{cases} n_\mu \to (1+\alpha)\, n_\mu \\ \bar{n}_\mu \to (1-\alpha)\, \bar{n}_\mu \end{cases}$$

eg. rules out $\bar{\xi}_n iD_\perp^\mu \dfrac{1}{i\bar{n}\cdot D}\, iD_\mu^\perp \dfrac{\bar{\not n}}{2}\xi_n$

$$\Rightarrow \quad \mathcal{L}_c^{(0)} = \bar{\xi}_n \Big\{ n\cdot iD_{us} + g n\cdot A_n + i\not{D}_\perp^c \frac{1}{i\bar{n}\cdot D_c} i\not{D}_\perp^c \Big\} \frac{\bar{\not n}}{2}\xi_n$$

Wilson Coefficients and Hard - Collinear Factorization

$C(\bar{\mathcal{P}},\mu)$: they depend on large momenta picked out by $\bar{\mathcal{P}} = \bar{n}\cdot\mathcal{P} \sim \lambda^0$

eg. $$C(-\bar{\mathcal{P}},\mu)\,(\bar{\xi}_n W)\Gamma h_v = \underbrace{(\bar{\xi}_n W)}_{\text{only the product is gauge invariant}}\Gamma h_v\, C(\bar{\mathcal{P}}^\dagger,\mu)$$

Write

$$(\bar{\xi}_n W)\Gamma h_v\, C(\bar{\mathcal{P}}^\dagger,\mu) = \int d\omega\, C(\omega,\mu)\Big[(\bar{\xi}_n W)\delta(\omega-\bar{\mathcal{P}}^\dagger)\Gamma h_v\Big] = \int d\omega\, C(\omega,\mu) O(\omega,\mu)$$

In general:

$$\begin{aligned} f(i\bar{n}\cdot D_c) &= W f(\bar{\mathcal{P}}) W^\dagger \\ &= \int d\omega\ f(\omega)\ [W\delta(\omega-\bar{\mathcal{P}})W^\dagger] \end{aligned}$$

hard coefficient $p^2 \sim Q^2$

in collinear operator $p^2 \sim Q^2\lambda^2$

hard-collinear factorization follows from properties of SCET operators

Multipole Expansion and Ultrasoft - Collinear Factorization

Multipole Expansion:

$$\mathcal{L}_c^{(0)} = \bar{\xi}_n \Big\{ n\cdot iD_{us} + g n\cdot A_n + i\not{D}_\perp^c \frac{1}{i\bar{n}\cdot D_c} i\not{D}_\perp^c \Big\} \frac{\not{\bar{n}}}{2} \xi_n$$

(board)

usoft gluons have eikonal Feynman rules
and induce eikonal propagators

Field Redefinition: (board)

$$\xi_n \to Y\xi_n \quad , \quad A_n \to Y A_n Y^\dagger$$

$$Y(x) = P\exp\Big(ig\int_{-\infty}^0 ds\, n\cdot A_{us}(x+ns)\Big)$$

$$n\cdot D_{us} Y = 0,\ Y^\dagger Y = 1$$

gives:

$$\mathcal{L}_c^{(0)} = \bar{\xi}_n \Big\{ n\cdot iD_{\rm us} + \ldots \Big\} \frac{\not{\bar{n}}}{2} \xi_n \to \bar{\xi}_n \Big\{ n\cdot iD_c + i\not{D}_\perp^c \frac{1}{i\bar{n}\cdot D_c} i\not{D}_\perp^c \Big\} \frac{\not{\bar{n}}}{2} \xi_n$$

Moves all usoft gluons to operators, simplifies cancellations

Field Theory gives the same results pre- and post- field redefinition, but the organization is different

Ultrasoft - Collinear Factorization:

eg1. $J = (\bar{\xi}_n W)_\omega \Gamma h_v \to (\bar{\xi}_n Y^\dagger Y W Y^\dagger)_\omega \Gamma h_v = (\bar{\xi}_n W)_\omega \Gamma (Y^\dagger h_v)$

note: not upset by hard-collinear mometum fraction since ultrasoft gluons carry no hard momenta

(board)

so usoft-collinear factorization is also simply a property of SCET

eg2. No ultrasoft fields

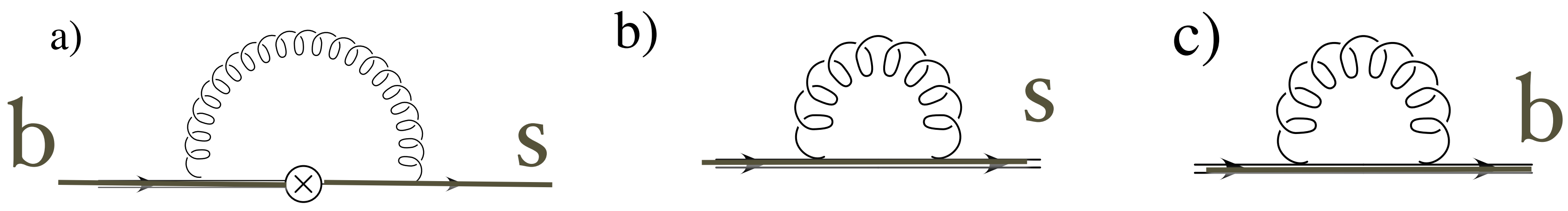
$$J = (\bar{\xi}_n W)_{\omega_1} \Gamma (W^\dagger \xi_n)_{\omega_2} \to (\bar{\xi}_n W)_{\omega_1} Y^\dagger Y \Gamma (W^\dagger \xi_n)_{\omega_2} = (\bar{\xi}_n W)_{\omega_1} \Gamma (W^\dagger \xi_n)_{\omega_2}$$

color transparency

IR divergences, Matching, & Running

$$J^{\mathrm{QCD}} = \bar{s}\,\Gamma\, b \qquad J^{\mathrm{SCET}} = (\bar{\xi}_n W)_\omega \Gamma h_v \qquad \Gamma = \sigma^{\mu\nu}$$

QCD



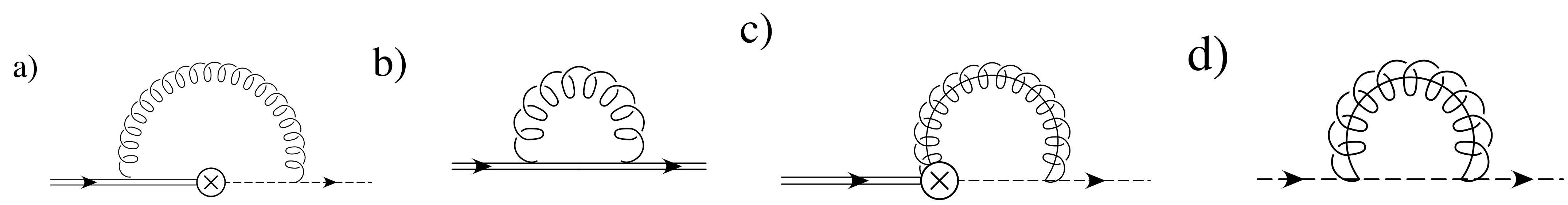
IR regulator

$p^2 \neq 0$ for s-quark

$1/\epsilon_{\mathrm{IR}}$ for b-quark

sum= $$-\frac{\alpha_s}{3\pi}\left[\ln^2\left(\frac{-p^2}{m_b^2}\right) + \frac{3}{2}\ln\left(\frac{-p^2}{m_b^2}\right) + \frac{1}{\epsilon_{\mathrm{IR}}} + 2\ln\left(\frac{\mu^2}{m_b^2}\right) + \text{constants}\right]$$

SCET



sum= $$-\frac{\alpha_s}{3\pi}\left[\ln^2\left(\frac{-p^2}{m_b^2}\right) + \frac{3}{2}\ln\left(\frac{-p^2}{m_b^2}\right) + \frac{1}{\epsilon_{\mathrm{IR}}} - \frac{1}{\epsilon_{\mathrm{UV}}^2} - \frac{5}{2\epsilon_{\mathrm{UV}}} - \frac{2}{\epsilon_{\mathrm{UV}}}\ln\left(\frac{\mu}{m_b}\right) - 2\ln^2\left(\frac{\mu}{m_b}\right) - \frac{3}{2}\ln\left(\frac{\mu^2}{m_b^2}\right) + \text{constants}\right]$$

same IR

Running

$$\int d\omega \; C(\omega)\, O(\omega)$$

$$\omega = m_b \text{ in } B \to X_s\gamma$$

counterterm

$$Z = 1 + \frac{\alpha_s}{3\pi}\left[\frac{1}{\epsilon^2} + \frac{2}{\epsilon}\ln\left(\frac{\mu}{\omega}\right) + \frac{5}{2\epsilon}\right]$$

RGE

$$\mu\frac{\partial}{\partial\mu}C(\mu) = -\frac{4\alpha_s(\mu)}{3\pi}\ln\left(\frac{\mu}{\omega}\right)C(\mu) + \ldots$$

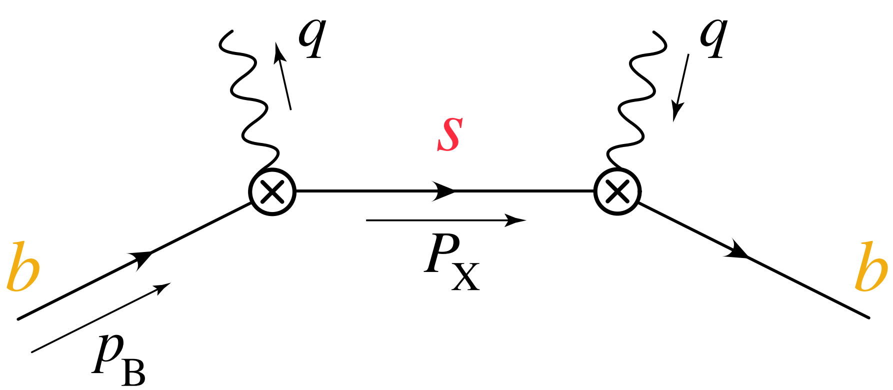
(board)

Endpoint $B \to X_s\gamma$

(board)

Endpoint $B \to X_s\gamma$

Optical Thm: $\Gamma \sim \mathrm{Im} \int d^4x\, e^{-iq\cdot x} \langle B | T\{J_\mu^\dagger(x) J^\mu(0)\} | B\rangle$



	$P_X^2 = m_B(m_B - 2E_\gamma)$
standard OPE	$\sim m_B^2$
endpoint region	$\sim m_B \Lambda_{QCD}$
resonance region	$\sim \Lambda_{QCD}^2$

For EndPoint: $E_\gamma \gtrsim 2.2\,\mathrm{GeV}$, X_s collinear, B usoft, $\lambda = \sqrt{\frac{\Lambda_{QCD}}{m_B}}$

Decay rate is given by factorized form

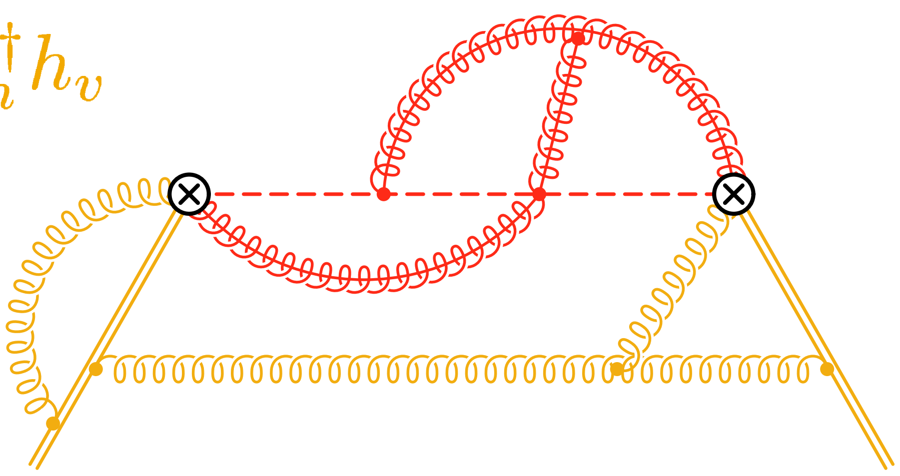
$$\frac{1}{\Gamma_0}\frac{d\Gamma}{dE_\gamma} = H(m_b,\mu) \int_{2E_\gamma - m_b}^{\bar\Lambda} dk^+\, S(k^+,\mu)\, J(k^+ + m_b - 2E_\gamma, \mu)$$

Match: $\bar{s}\Gamma_\mu b \to e^{i(m_b v-\mathcal{P})\cdot x} C(\bar{\mathcal{P}})\bar{\xi}_{n,p} W \gamma_\mu^\perp P_L h_v$

$$T_\mu^\mu = \int d^4x\, e^{i(m_b\frac{\bar{n}}{2}-q)\cdot x} \left\langle B \middle| T J_{\rm eff}^\dagger(x) J_{\rm eff}(0) \middle| B \right\rangle$$

label conservation
$\bar{\mathcal{P}} \to m_b$

Factor usoft: $\bar{\xi}_n W \Gamma_\mu h_v = \bar{\xi}_n^{(0)} W^{(0)} \Gamma_\mu Y_n^\dagger h_v$



$$T_\mu^\mu = |C(m_b)|^2 \int d^4x\, e^{i(m_b\frac{\bar{n}}{2}-q)\cdot x} \left\langle B \middle| T [\bar{h}_v Y](x)\ [Y^\dagger h_v](0) \middle| B \right\rangle$$
$$\times \left\langle 0 \middle| T [W^{(0)\dagger}\xi_n^{(0)}](x) [\bar{\xi}_n^{(0)} W^{(0)}](0) \middle| 0 \right\rangle \times [\Gamma_\mu \otimes \Gamma^\mu]$$

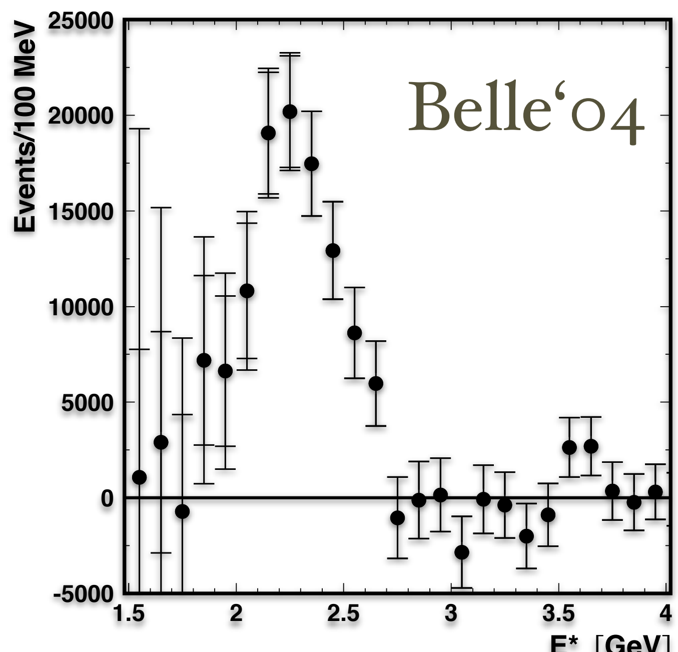
Convolution:

$$\langle 0|\cdots|0\rangle \longrightarrow J_P(k_+)$$

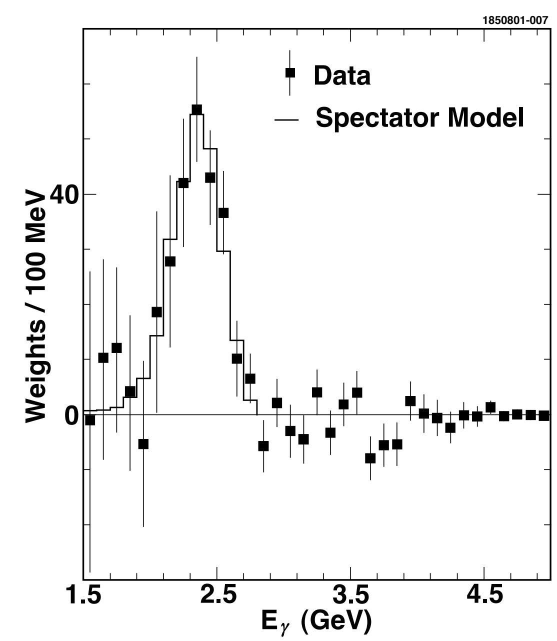
Define Fourier Transforms $\langle B|\cdots|B\rangle \longrightarrow S(l) \longrightarrow S(l^+)$

$$\mathrm{Im}\, T_\mu^\mu = |C(m_b)|^2 \int dl^+ S(l^+)\, \mathrm{Im}\, J_P(m_b - 2E_\gamma + l^+)$$

where $S(l^+) = \langle B|\bar{h}_v \delta(in\cdot D - l^+) h_v|B\rangle$



CLEO '01

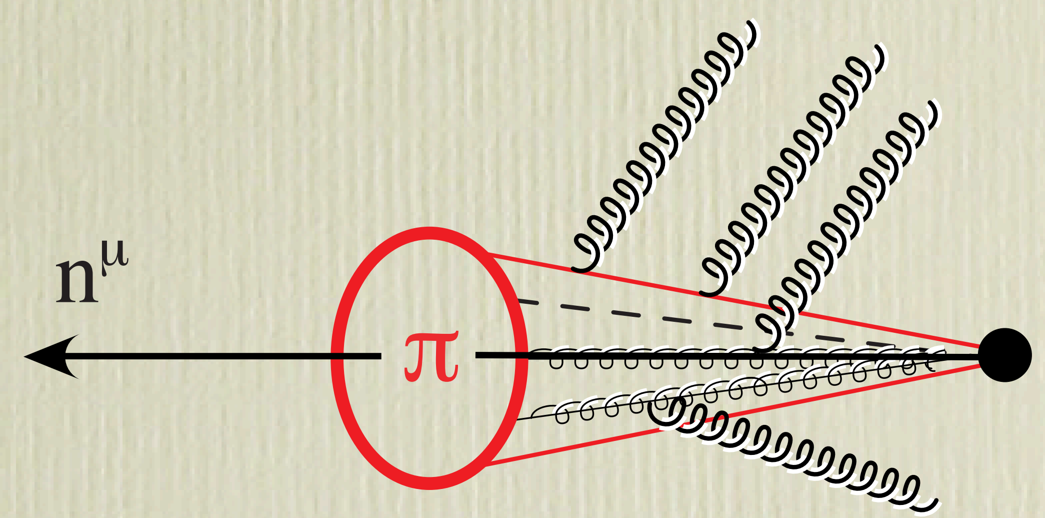


SCET is a field theory which:

- explains how these degrees of freedom communicate with each other, and with hard interactions
- organizes the interactions in a series expansion in $\dfrac{\Lambda_{\rm QCD}}{E}$
- provides a simple operator language to derive factorization theorems in fairly general circumstances

eg. unifies the treatment of factorization for exclusive and inclusive QCD processes

- new symmetry constraints
- scale separation & decoupling



How is SCET used?

- cleanly separate short and long distance effects in QCD
  - ➡ derive new factorization theorems
  - ➡ find universal hadronic functions, exploit symmetries & relate different processes
- model independent, systematic expansion
  - ➡ study power corrections
- keep track of μ dependence
  - ➡ sum logarithms, reduce uncertainties

The End