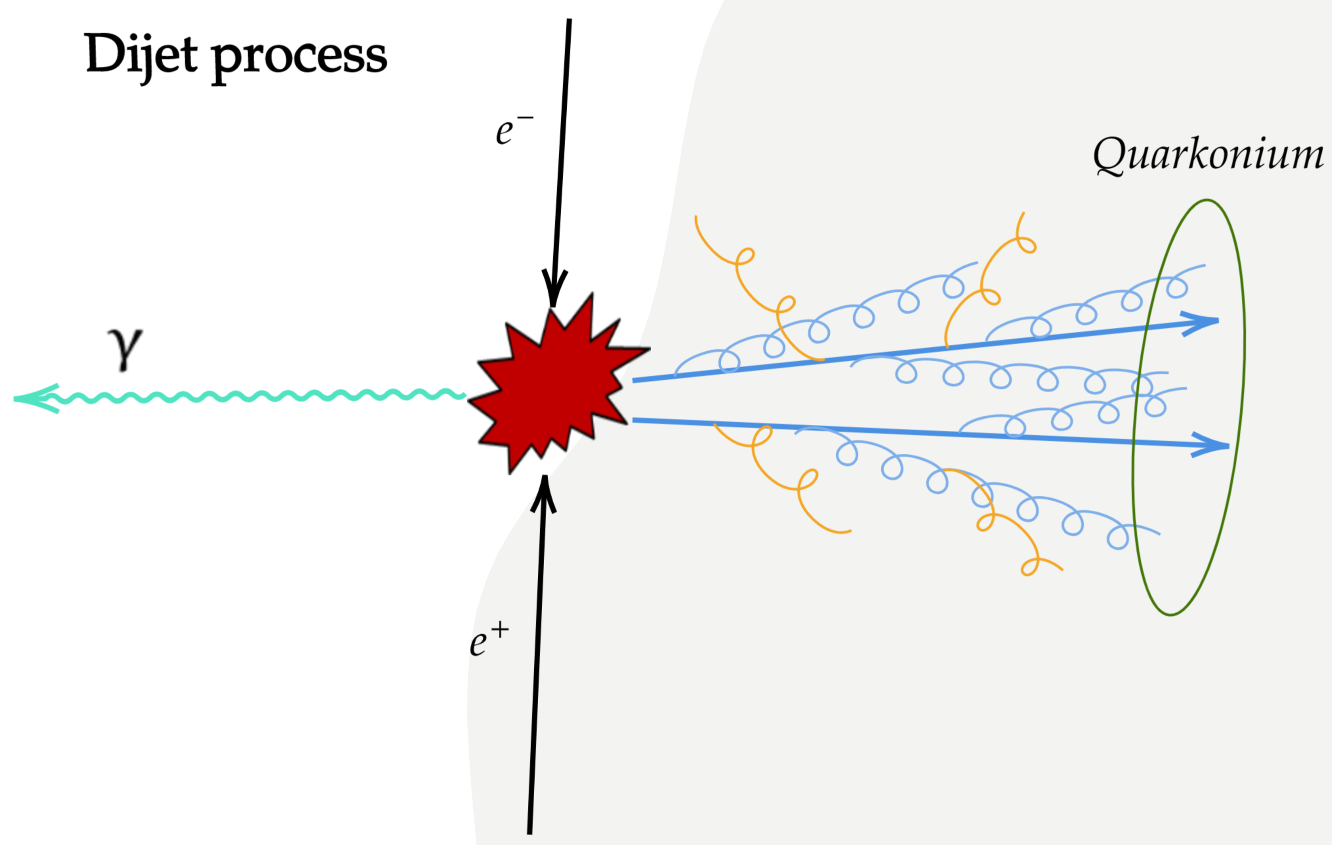
Toward understanding of exclusive heavy-quarkonium production at subleading power using soft-collinear theory

Yunlu Wang, June-Haak Ee, Daekyoung Kang
Fudan University, Shanghai, China

Background

➢The quarkonium H in $\gamma * \to \gamma H$ is produced at $Q \gg m_q$.



➢Higgs Yukawa couplings in Higgs/Z to Upsilon(J/psi)+ gamma

➢studied as a background channel in XYZ searches.

Effective field theory approach

hierarchy of scales:

$$\mu_h \sim Q = \sqrt{s} \qquad \vec{p} \sim m_q v$$
$$\mu_c \sim \mu_s \sim m_q \qquad E \sim m_q v^2$$

➢The energetic back-to-back photon and heavy quarks can be described by Soft-Collinear Effective Theory systematically,

$$p_q^\mu \sim Q(\lambda^2, 1, \lambda) \qquad \lambda = \frac{m_q}{Q} <<1$$
$$\chi_n \sim \lambda,\ \mathcal{A}_{n\perp} \sim \lambda$$

➢The core step is doing factorization of amplitude at leading power [3]

$$i\mathcal{M} \sim C_h \otimes \varphi_\gamma \otimes \varphi_H \otimes f_H$$

- φ_γ: anti-collinear photon part.
- C_h: short-distance coefficient.
- φ_H : collinear matrix element called Light-cone distribution amplitude
- f_H: non-perturbative NRQCD matrix element
- soft sector cancelled at leading power but may appear at subleading power.

➢That theory assists to resum large logs Log(Q/m_q)

$$\sum_k \alpha_s^i L(\alpha_s L)^k \qquad \alpha_s L\sim 1$$

➢Similar factorization in SCET frame at subleading power and next-to-leading order.

Toward factorization: matching at tree-level

☐In general the matching includes α_s and λ expansion,

$$\mathcal{M}_{\text{QCD}} = \sum_{n,m} C_i^{(\alpha_s{}^n)} \mathcal{M}_{\text{eff},i}^{(\lambda^m)}$$

☐At tree-level, Wilson coefficient $C_h^{(0)} = 1$, and operators $O_{\chi\chi i}^{(k)} \sim \lambda^k$ are determined by

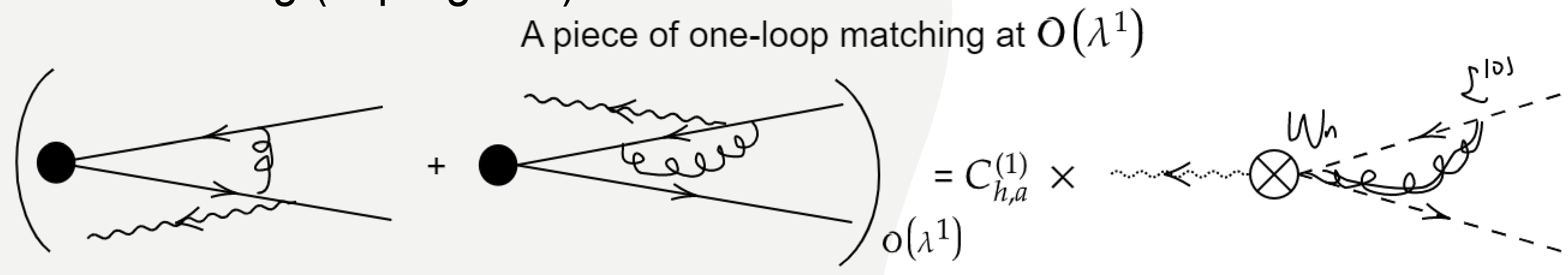
Tree-level matching between QCD and SCET partonic amplitudes at $O(\lambda^1)$

$$\mathcal{O}_{\chi\chi n1}^{(1)\mu} = -\frac{1}{\omega_1}\bar{\chi}_{n,\omega_1}\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\frac{\bar{n}\!\!\!/}{2}\Gamma^\mu\chi_{n,-\omega_2}\,,$$
$$\mathcal{O}_{\chi\chi n2}^{(1)\mu} = \frac{1}{\omega_2}\bar{\chi}_{n,\omega_1}\Gamma^\mu\frac{\bar{n}\!\!\!/}{2}\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\chi_{n,-\omega_2}\,.$$

$$\mathcal{O}_{\chi\chi n1}^{(2)\mu} = \frac{1}{\omega_1\omega_2}\bar{\chi}_{n,\omega_1}\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\frac{\bar{n}\!\!\!/}{2}\Gamma^\mu(\mathcal{P}\!\!\!/_\perp + m)\frac{\bar{n}\!\!\!/}{2}\chi_{n,-\omega_2} - \frac{2}{\omega_1\omega_3}\bar{\chi}_{n,\omega_1}\mathcal{P}_\perp^\dagger\cdot\mathcal{A}_{\perp\bar{n},\omega_3}\Gamma^\mu\chi_{n,-\omega_2} - \frac{1}{\omega_1\omega_3}\bar{\chi}_{n,\omega_1}\left[\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\mathcal{P}\!\!\!/_\perp^\dagger\right]\Gamma^\mu\chi_{n,-\omega_2}\,,$$
$$\mathcal{O}_{\chi\chi n2}^{(2)\mu} = \frac{1}{\omega_1\omega_2}\bar{\chi}_{n,\omega_1}\frac{\bar{n}\!\!\!/}{2}(\mathcal{P}\!\!\!/_\perp^\dagger + m)\Gamma^\mu\frac{\bar{n}\!\!\!/}{2}\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\chi_{n,-\omega_2} - \frac{2}{\omega_2\omega_3}\bar{\chi}_{n,\omega_1}\mathcal{A}_{\perp\bar{n},\omega_3}\cdot\mathcal{P}_\perp\Gamma^\mu\chi_{n,-\omega_2} + \frac{1}{\omega_2\omega_3}\bar{\chi}_{n,\omega_1}\Gamma^\mu\left[-\mathcal{P}\!\!\!/_\perp\mathcal{A}\!\!\!/_{\perp\bar{n},\omega_3}\right]\chi_{n,-\omega_2}$$

☐The next-to-leading order $C_h^{(1)}$ should be determined by one-loop matching (in progress)

A piece of one-loop matching at $O(\lambda^1)$



Effective operators with identical power and order		
order\power	λ^1	λ^2
$(\alpha_s)^0$	☑ $C_{h,0}^{(0)}O_{\chi\chi}^{(1)}$	☑ $C_{h,i}^{(0)}O_{\chi\chi i}^{(2)}$
$(\alpha_s)^1$	☑ $C_{h,0}^{(1)}(\alpha_s)O_{\chi\chi}^{(1)}$	$C_{h,i}^{(1)}(\alpha_s)O_{\chi\chi i}^{(2)}$

☐The coefficient $C_{h,i}^{(n)}$ is related with $C_{h,0}^{(n)}$ by reparametrization invariant (amplitudes do not depend on direction n).

$$\delta_{\text{RPI}}^{(\lambda^1)}\left(C_{h,0}^{(\alpha_s^n)}\mathcal{O}_{\chi\chi}^{(\lambda^1)}\right) + \delta_{\text{RPI}}^{(\lambda^0)}\left(C_{h,i}^{(\alpha_s^n)}\mathcal{O}_{\chi\chi i}^{(\lambda^2)}\right) = 0$$

Summary

➢ Exclusive quarkonium production at high energies can be factorized by using SCET.

➢ We like to understand factorization of γH process up to subleading power.

➢ From tree-level matching, operators at leading power and some operators at subleading power are obtained

➢ One-loop matching is required to complete factorization (in progress).

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Reference

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