An **EFT** approach to **Quarkonium** at small transverse momentum

Yiannis Makris
INFN (Pavia)

Istituto Nazionale di Fisica Nucleare

Supported by the FELLINI project and the European Commission

Fellowship for Innovation at INFN

Quarkonium and TMDs

Quarkonium production is considered as one of the most important processes to access unpolarized and polarized gluon TMDs. Some example of relevant processes are:

$$ep/pp \to \psi + X/\psi + \psi + X/\psi + \gamma + X/\ldots$$

arXiv:1202.6585 (S. J. Brodsky, F. Fleuret, C. Hadjidakis, J. P. Lansberg)

arXiv1208.3642 (D. Boer, C. Pisano)

arXiv:1401.7611 (W. J. den Dunnen, J.-P. Lansberg, C. Pisano, M. Schlegel)

arXiv:1406.5476 (G-P. Zhang)

arXiv:1809.02056 (A. Bacchetta, D. Boer, C. Pisano, P. Taels)

and many others

Quarkonium and TMDs

Many attempts that approach the problem in CEM and CSM: Cannot be improved the same way EFTs can. CEM and CSM fail in other regions/aspects of quarkonium production

arXiv:hep-ph/0404158 (E. L. Berger, J. Qiu, Y. Wang)

arXiv:hep-ph/0411026 (E. L. Berger, J. Qiu, Y. Wang)

NRQCD attempt (including evolution)*: Assumption: NRQCD factorization holds at low pT?

arXiv:1210.3432 (P. Sun, C-P. Yuan, and F. Yuan)

arXiv:1405.3373 (J.P. Ma, J.X. Wang, S. Zhao)

arXiv:1509.04421 (J.P. Ma, C. Wang)

*Plethora of other studies that use NRQCD factorization also make the same assumption.
Usually the CSS kernel is assumed to be sufficient for resummation and evolution.

CGC + NRQCD methods: small-x resummation/ NO pT/M resummation, sufficient for charmonium at LHC.

arXiv:1408.4075 (Y-Q. Ma, R. Venugopalan)

arXiv:1503.07772 (Y-Q. Ma, R. Venugopalan, and H-F. Zhang)

In this talk

NRQCD: a brief review

- Scales - soft modes
- Factorization conjuncture
- Factorization breakdown

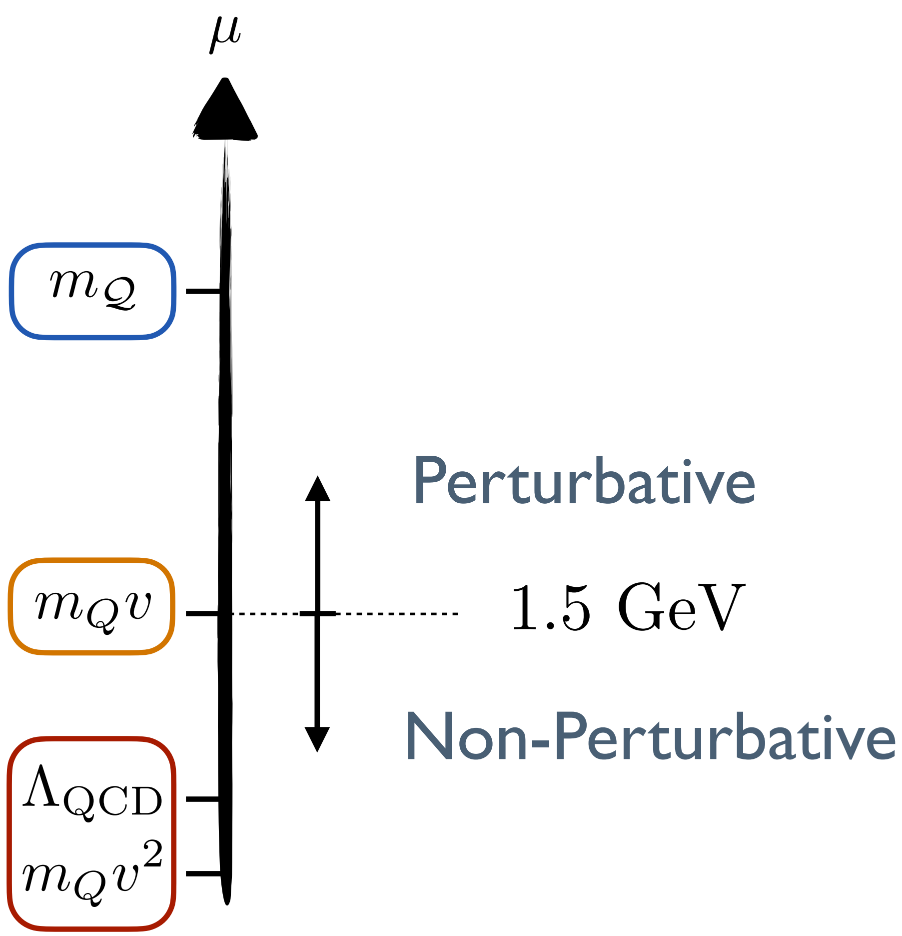
SCET-Q: a fusion of SCET and NRQCD

- New approach to deal with TMDs
- The operators
- Re-parameterization transformation

Case-Study: P wave

- Operators
- Factorization and Shape functions
- IR safety and channel mixing
- 2D-RG and resummation

NRQCD in brief (scales)



$b\bar{b}: \quad v^2 \sim 0.1$ bottomonium

$c\bar{c}: \quad v^2 \sim 0.3$ charmonium

Relative velocity of the heavy quark and antiquark in the quarkonium

typical momentum of heavy quark: $|\mathbf{p}_Q| \sim m_Q v$ (soft)

typical kinetic energy of heavy quark: $K_Q \sim m_Q v^2$ (ultra-soft)

NRQCD in brief (Lagrangian)

arXiv:hep-ph/9910209 (M. E. Luke, A.V. Manohar, I. Z. Rothstein)

soft: $p_s^\mu \sim m_Q v(1,1,1,1)$

ultra-soft: $p_{us}^\mu \sim m_Q v^2(1,1,1,1)$

subleading

ultra-soft

$$\mathcal{L} = \sum_{\mathbf{p}} \psi_{\mathbf{p}}^\dagger \left\{ iD^0 - \frac{(\mathbf{p} - \boxed{i\mathbf{D}})^2}{2m} \right\} \psi_{\mathbf{p}}$$

$$-4\pi\alpha_s \sum_{q,q'\mathbf{p},\mathbf{p}'} \left\{ \frac{1}{q^0} \psi_{\mathbf{p}'}^\dagger \left[A_{q'}^0, A_q^0 \right] \psi_{\mathbf{p}} + \frac{g^{\nu 0}(q'-p+p')^\mu - g^{\mu 0}(q-p+p')^\nu + g^{\mu\nu}(q-q')^0}{(\mathbf{p}'-\mathbf{p})^2} \psi_{\mathbf{p}'}^\dagger \left[A_{q'}^\nu, A_q^\mu \right] \psi_{\mathbf{p}} \right\}$$

soft

$$+ \sum_{\mathbf{p},\mathbf{q}} \frac{4\pi\alpha_s}{(\mathbf{p}-\mathbf{q})^2} \psi_{\mathbf{q}}^\dagger T^A \psi_{\mathbf{p}} \chi_{-\mathbf{q}}^\dagger \bar{T}^A \chi_{-\mathbf{p}} + \ldots$$

NRQCD in brief (factorization)

arXiv:hep-ph/9407339 (G.T. Bodwin, E. Braaten, G. P. Lepage)

LDME: Long Distance Matrix Elements

$$d\sigma(a+b\to\mathcal{Q}+X)=\sum_n \boxed{d\sigma(a+b\to Q\overline{Q}(n)+X)}\boxed{\langle\mathcal{O}_n^{\mathcal{Q}}\rangle}$$

Perturbative expansion in the strong coupling.

NRQCD Scaling Rules

$$\boxed{d\sigma_0(1+\alpha_s C_1+\alpha_s^2 C_2+\ldots)} \quad \boxed{\langle\mathcal{O}({}^{2S+1}L_J^{[1,8]})\rangle\sim v^{3+2L+2E+4M}}$$

$$Q\bar{Q}(n)\xrightarrow{\langle\mathcal{O}_n^{\mathcal{Q}}\rangle}\mathcal{Q}$$

NRQCD is an expansion of QCD in the relative velocity of the heavy quark pair

$$\mathcal{O}_n^{\mathcal{Q}}=\mathcal{O}_2^{n\dagger}\left(\sum_X|X+\mathcal{Q}\rangle\langle X+\mathcal{Q}|\right)\mathcal{O}_2^n$$

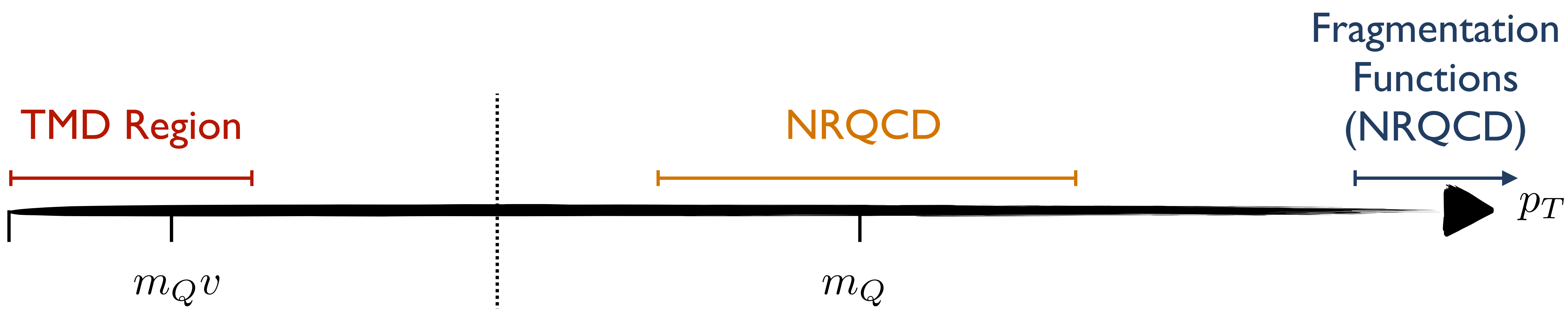
ultra-soft + soft

$$\mathcal{O}_2^n=\psi^\dagger\mathcal{K}^n\chi$$

$$n={}^{2S+1}L_J^{[c]}$$

NRQCD in brief (regimes)

Quarkonium spectrum vs EFT regions



Expansion in v and in λ

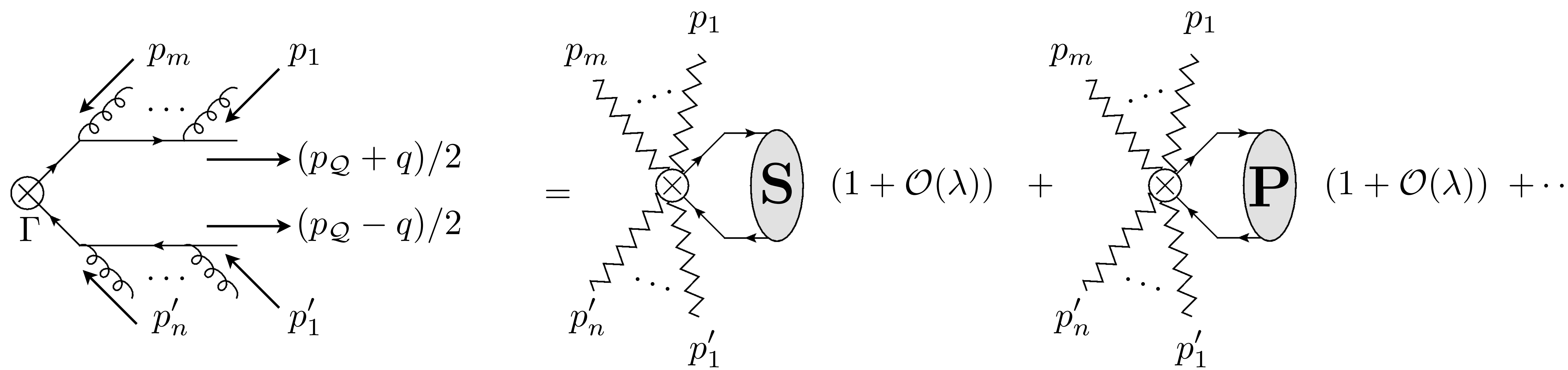
$\lambda = q_\perp / M$

will properly incorporate quarkonium recoiling against soft radiation

Expansion in the relative velocity

Note: it is possible to probe TMDs in this region as well but the additional measurement introduces a new soft scale which changes the factorization: e.g., TMD fragmentation

Diagrammatic analysis at tree level



$$d_\Gamma(m,n) = d_\Gamma^{(0)}(m,n)\ (1+\mathcal{O}(\lambda)) + d_\Gamma^{(1)}(m,n)\ (1+\mathcal{O}(\lambda)) + \cdots$$

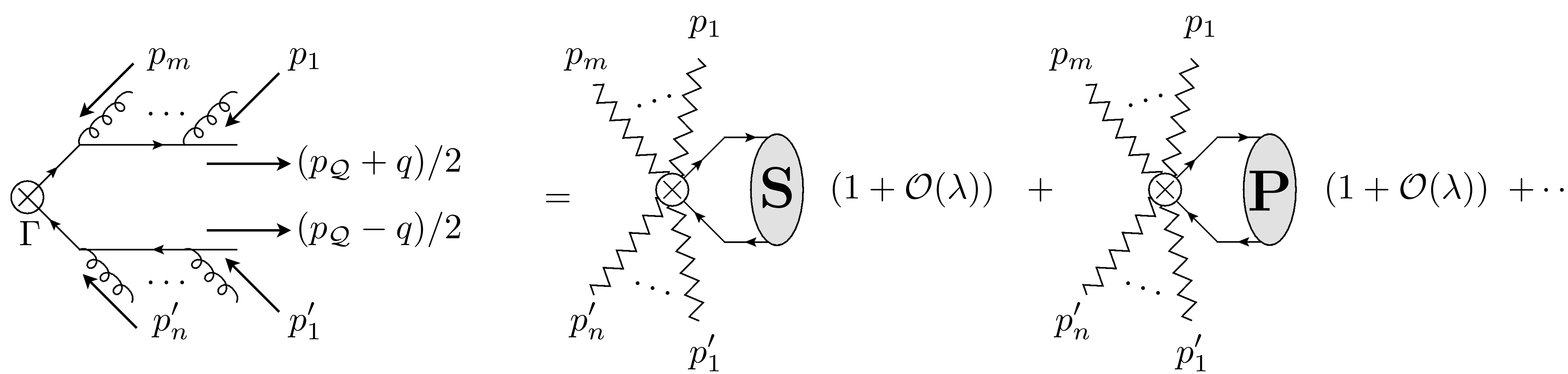
S-wave:
simple result

$$\boxed{d_\Gamma^{(0)} = \left(u^{(0)}\right)^\dagger S_v^\dagger\, \Gamma^{(0)}\ S_v v^{(0)}}$$

$$S_v = \sum_n \sum_{\text{perms}} \frac{g^n}{n!} \prod_{s=1}^{n} \left[\frac{A^0_{n+1-s}}{p_t^0(s)}\right]$$

$$S_v(x,-\infty) = \mathrm{P}\Big[\exp\Big(-ig\int_{-\infty}^{0} d\tau\ v\cdot A_{soft}(x^\mu + v^\mu \tau)\Big)\Big]$$

Diagrammatic analysis at tree level



$$d_\Gamma(m,n) \quad = \quad d_\Gamma^{(0)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \ d_\Gamma^{(1)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \cdots$$

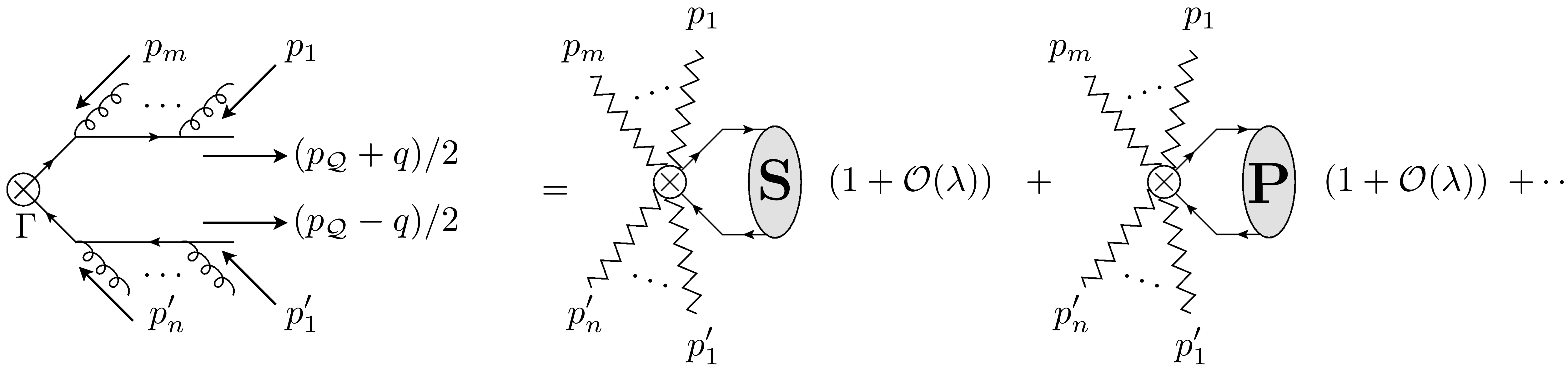
S-wave:
simple result

$$\boxed{d_\Gamma^{(0)} = \left(u^{(0)}\right)^\dagger S_v^\dagger\, \Gamma^{(0)}\ S_v v^{(0)}}$$

For S-wave, color-singlet heavy quark pair the soft gluon contribution, at leading order, cancels.

For color-octet contributions the net effect is similar to jet and top-pair productions: new soft wilson-lines enter the soft matrix element.

Diagrammatic analysis at tree level



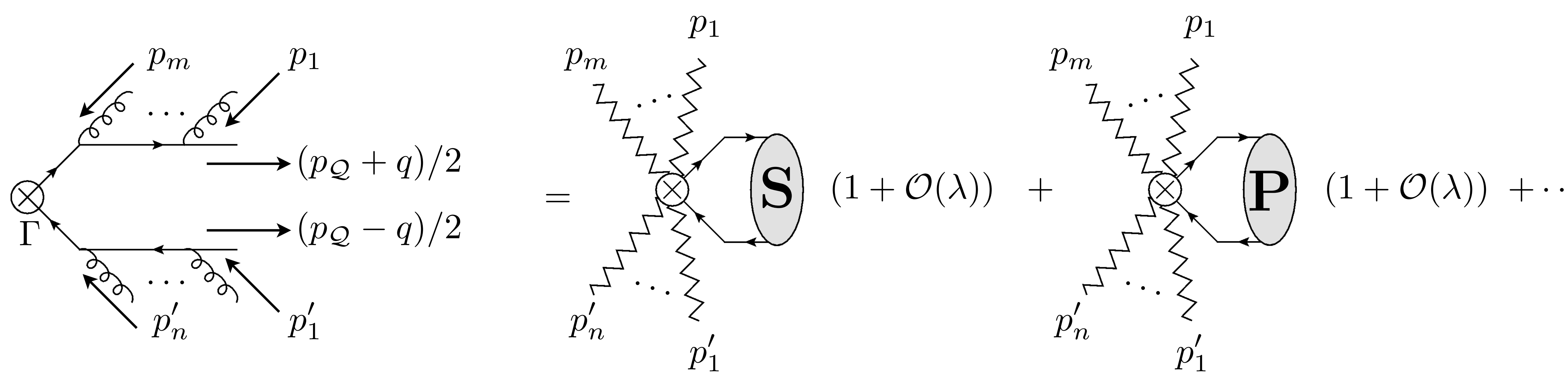
$$d_\Gamma(m,n) \quad = \quad d_\Gamma^{(0)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \ d_\Gamma^{(1)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \cdots$$

P-wave: Not so simple result

$$B_s^\mu = -\frac{1}{g} S_v^\dagger\Big[(\mathcal{P}^\mu - gA^\mu)S_v\Big]$$

$$d_\Gamma^{(1)} = \boxed{\frac{g}{2m}\left(u^{(0)}\right)^\dagger\left\{S_v^\dagger\Gamma^{(0)}S_v,\left[\frac{1}{v\cdot\mathcal{P}}\mathbf{q}\cdot\mathbf{B}_s\right]\right\}v^{(0)}} + \left(u^{(0)}\right)^\dagger S_v^\dagger\, \mathbf{q}\cdot\left(\boxed{\mathbf{\Gamma}^{(1)}} - \boxed{\frac{1}{4m}\left\{\Gamma^{(0)},\gamma\right\}}\right)S_v v^{(0)}$$

Diagrammatic analysis at tree level



$$d_\Gamma(m,n) \quad = \quad d_\Gamma^{(0)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \ d_\Gamma^{(1)}(m,n)\ (1+\mathcal{O}(\lambda)) \quad + \cdots$$

P-wave: Not so simple result

Also through RPI transformations

$$d_\Gamma^{(1)} = \boxed{\frac{g}{2m}\left(u^{(0)}\right)^\dagger\left\{S_v^\dagger\Gamma^{(0)}S_v,\left[\frac{1}{v\cdot\mathcal{P}}\mathbf{q}\cdot\mathbf{B}_s\right]\right\}v^{(0)}} + \left(u^{(0)}\right)^\dagger S_v^\dagger\,\mathbf{q}\cdot\left(\boxed{\mathbf{\Gamma}^{(1)}} - \boxed{\frac{1}{4m}\left\{\Gamma^{(0)},\gamma\right\}}\right)S_v v^{(0)}$$

Re-parameterization transformations

$$\psi_{\mathbf{p}}^\dagger S_v^\dagger \, \Gamma^{(0)} \, S_v \chi_{\mathbf{p}} \longrightarrow \psi_{\mathbf{p},+}^\dagger S_{v_+}^\dagger \, \Gamma^{(0)} \, S_{v_-} \chi_{\mathbf{p},-}$$

$$\begin{aligned} v_\pm^\mu &= \left(\sqrt{1 + \frac{\mathbf{q}^2}{4m^2}}, \pm \frac{\mathbf{q}}{2m} \right) \\ &= v^\mu + \frac{q^\mu}{2m} + O\left(\frac{q^2}{m^2}\right) \end{aligned}$$

$$\not{v}_\pm \psi_{\mathbf{p},\pm} = \psi_{\mathbf{p},\pm}$$

$$\not{v}_\pm \chi_{\mathbf{p},\pm} = -\chi_{\mathbf{p},\pm}$$

$$\left(v + \frac{q}{2m}\right) \cdot (\mathcal{P} - gA)(S_v + \delta S_v) = 0$$

$$\psi_{\mathbf{p},\pm} = \psi_{\mathbf{p}} \pm \frac{\not{q}}{4m} \psi_{\mathbf{p}} \qquad \chi_{\mathbf{p},\pm} = \chi_{\mathbf{p}} \mp \frac{\not{q}}{4m} \chi_{\mathbf{p}}$$

$$\begin{aligned} S_{v,+} &= S_v + \frac{1}{2m} \frac{1}{v \cdot (\mathcal{P} - gA)} q \cdot (\mathcal{P} - gA) S_v \\ &= S_v + \frac{1}{2m} S_v \frac{1}{v \cdot \mathcal{P}} S_v^\dagger q \cdot (\mathcal{P} - gA) S_v \\ &= S_v - \frac{g}{2m} S_v \frac{1}{v \cdot \mathcal{P}} q \cdot B \,. \end{aligned}$$

HQET:

arXiv: hep-ph/9205228 (M. E. Luke and A.V. Manohar)

SCET:

arXiv: hep-ph/0204229 (A.V. Manohar, T. Mehen, D. Pirjol and I.W. Stewart)

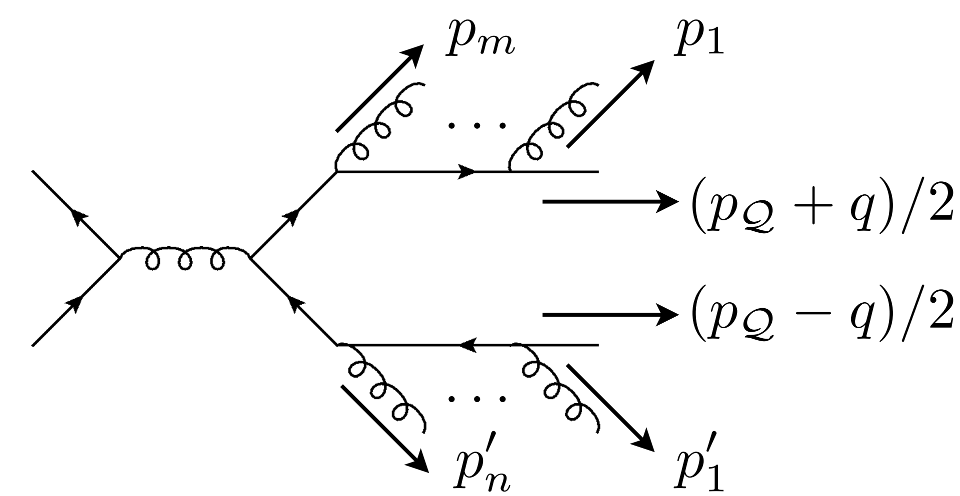
Case studies

Next in this talk

	Case-1	Case-2	Case-3
Process:	P-wave decay to light quarks	Photo-production of S-wave	TMD-Fragmentation
Partonic process:	$Q\bar{Q}[n] \to i + j + X$	$\gamma g \to Q\bar{Q}[n] + X$	$q \to Q\bar{Q}[n] + X$
Mechanisms involved:	$n \in \{^3P_J^{[1]}, {^3S_1^{[8]}}\}$	$n \in \{^1S_0^{[8]}, {^3P_J^{[8]}}, {^3S_1^{[1]}}\}$	$n \in \{^3S_1^{[8]}, {^3S_1^{[1]}}\}$
Challenge:	channel mixing	sub-leading factorization	competing the LO result
	arXiv:1910.03586 (S. Fleming, Y. Makris, and T. Mehen)	In progress: (S. Fleming, Y. Makris, T. Mehen, and J. Lieffers)	arXiv:2007.05547 (M. G. Echevarria, Y. Makris, and I. Scimemi)

Case study: P-wave Decay

Decay to light quarks nice example that exhibits operator mixing
as well as color-octet modification of the CSS kernel:



S-wave octet: $^3S_1^{(8)}$

$$\mathcal{S}_v^{cd}\left(\psi^\dagger \sigma^i T^d \chi\right) \times \left(\bar{\chi}_{\bar{n}} \gamma^i S_{\bar{n}}^\dagger T^c S_n \chi_n\right) \xrightarrow{\text{LO matching}} C_{q\bar{q}}({}^3S_1^{[8]}) = \alpha_s \frac{\pi}{m^2}$$

NRQCD

SCET

P-wave singlet: $^3P_J^{(1)}$

Confirmed at LO:

$$\sqrt{\frac{2}{N_c}} \times \mathcal{S}_v^{cd}\left[\frac{g\, B_s^{d,j}}{m\, v \cdot \mathcal{P}}\right]\left[\psi^\dagger \frac{\sigma^i \overleftrightarrow{\mathcal{P}}^j}{2\sqrt{2N_c}}\chi\right] \times \left(\bar{\chi}_{\bar{n}} \gamma^i S_{\bar{n}}^\dagger T^c S_n \chi_n\right) \longrightarrow C_{q\bar{q}}({}^3P_J^{[1]}) = C_{q\bar{q}}({}^3P_J^{[8]}) = C_{q\bar{q}}({}^3S_1^{[8]})$$

Factorization

$$\frac{d\Gamma}{dz_1 dz_2 d\boldsymbol{q}_\perp} = \Gamma_0 \sum_{ij} H^{ij}_{{}^3S_1^8}\, D^\perp_{i/H_1}(b, z_1)\, D^\perp_{j/H_2}(b, z_2)\, S^\perp_{ij}(b)$$

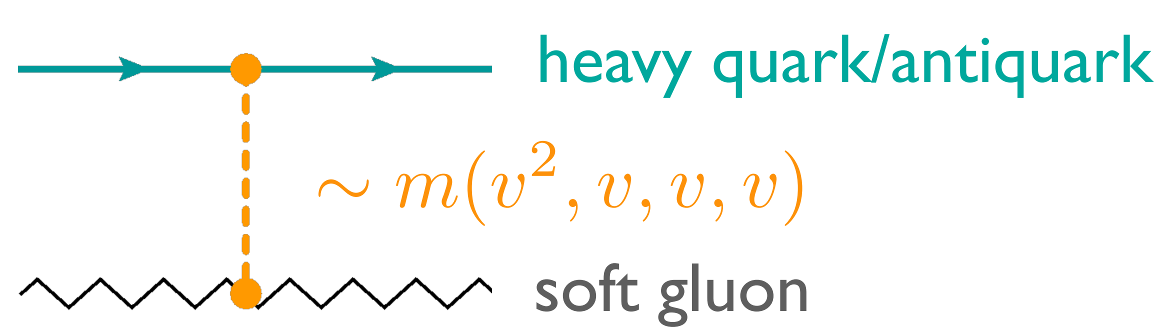
Hard function: The same for S and P wave mechanism for this process. Importance consequence for IR finiteness of the observable

Standard unsubtracted TMD fragmentation functions

Quarkonium shape functions

$$S^\perp_{ij}(b) = \sum_{n \in \{{}^3S_1^8, {}^3P_J^1\}} S^{[n]\perp}_{ij}(b)$$

Quarkonium TMD-shape functions* encode both soft and non-perturbative quarkonium related effects. Further factorization is not possible due to Coulomb-like interactions:



*See also: arXiv:1907.06494 (M. Echevarria)

TMD-shape functions

$$\frac{d\Gamma}{dz_1 dz_2 d\boldsymbol{q}_\perp} = \Gamma_0 \sum_{ij} H^{ij}_{^3S_1^8}\; D^\perp_{i/H_1}(b,z_1)\; D^\perp_{j/H_2}(b,z_2)\; S^\perp_{ij}(b)$$

Quarkonium shape functions

$$S^\perp_{ij}(b) = \sum_{n\in\{^3S_1^8,\,^3P_J^1\}} S^{[n]\perp}_{ij}(b)$$

S-wave octet:

$$S^\perp_{\chi_J\to{}^3S_1^{[8]}}(\mathbf{k}_\perp) = \frac{d-2}{(d-1)t_F}\mathrm{tr}\Big\langle \chi_J \Big| \psi^\dagger \sigma^i T^a \chi \mathcal{S}_v^{ba}(S_{\bar n}^\dagger T^b S_n)\delta^{(2)}(\mathbf{k}_\perp - \boldsymbol{\mathcal{P}}_\perp) \times (S_n^\dagger T^c S_{\bar n})\mathcal{S}_v^{dc}\chi^\dagger \sigma^i T^d \psi \Big| \chi_J \Big\rangle$$

Ultra-soft gluons (Wilson-lines) are not shown to keep the expressions simple

P-wave singlet:

$$S^\perp_{\chi_J\to{}^3P_J}(\mathbf{k}_\perp) = (2J+1)\frac{g^2}{N_c^2\, t_F}\,\mathcal{A}_J^{ij}\,\mathrm{tr}\Big\langle \chi_J \Big| \psi^\dagger \boldsymbol{\sigma}\cdot\overleftrightarrow{\boldsymbol{\mathcal{P}}}\,\chi \Big[\frac{B_s^{a,i}}{m\, v\cdot\mathcal{P}}\Big]\mathcal{S}_v^{ba}(S_{\bar n}^\dagger T^b S_n)$$
$$\times\;\delta^{(2)}(\mathbf{k}_\perp - \boldsymbol{\mathcal{P}}_\perp)(S_n^\dagger T^c S_{\bar n})\mathcal{S}_v^{dc}\Big[\frac{B_s^{d,j}}{m\, v\cdot\mathcal{P}}\Big]\chi^\dagger \boldsymbol{\sigma}\cdot\overleftrightarrow{\boldsymbol{\mathcal{P}}}\,\psi\Big|\chi_J\Big\rangle$$

Factorization@NLO

The NLO S-wave shape function:

$$S^{\perp,\mathrm{NLO}}_{\chi\to{}^3S_1^{[8]}}(\mathbf{k}_\perp;\mu,\nu) = \frac{d-2}{d-1}\left\{\left[S^{\perp}_{\mathrm{DY}}(\mathbf{k}_\perp) + \boxed{\frac{\alpha_s C_A}{2\pi}\left(\frac{1}{\epsilon}\delta^{(2)}(\mathbf{k}_\perp) - 2\mathcal{L}_0(\mathbf{k}_\perp^2,\mu^2)\right)}\right]\langle{}^3S_1^{[8]}\rangle_{\mathrm{LO}}\right.$$

$$\left. + \delta^{(2)}(\mathbf{k}_\perp)\left[\frac{4\alpha_s}{3\pi m^2}\left(C_F\sum_J\langle{}^3P_J^{[1]}\rangle_{\mathrm{LO}} + B_F\sum_J\langle{}^3P_J^{[8]}\rangle_{\mathrm{LO}}\right)\left(\frac{1}{\epsilon_{\mathrm{UV}}} - \frac{1}{\epsilon_{\mathrm{IR}}}\right)\right]\right\}$$

Divergence and logarithm associated with the color octet final state. An additional term in the anomalous dimension will thus change the evolution kernel

The hard function:

$$H(\mu) = 1 - \frac{\alpha_s C_F}{2\pi}\left\{\ln^2\left(\frac{\mu^2}{M^2}\right) + 3\ln\left(\frac{\mu^2}{M^2}\right) + \frac{\pi^2}{6} - 2B({}^3S_1^{[8]})\right\} \boxed{- \frac{\alpha_s C_A}{2\pi}\ln\left(\frac{\mu^2}{M^2}\right)}$$

arXiv:hep-ph/9707223 (A. Petrelli, M. Cacciari, M. Greco, F. Maltoni, M.L. Mangano)

Factorization@NLO

The NLO S-wave shape function:

$$S^{\perp,\mathrm{NLO}}_{\chi\to {}^3S_1^{[8]}}(\mathbf{k}_\perp;\mu,\nu) = \frac{d-2}{d-1}\left\{\left[S^\perp_{\mathrm{DY}}(\mathbf{k}_\perp) + \boxed{\frac{\alpha_s C_A}{2\pi}\left(\frac{1}{\epsilon}\delta^{(2)}(\mathbf{k}_\perp) - 2\mathcal{L}_0(\mathbf{k}_\perp^2,\mu^2)\right)}\right]\langle {}^3S_1^{[8]}\rangle_{\mathrm{LO}}\right.$$

$$\left. + \delta^{(2)}(\mathbf{k}_\perp)\left[\boxed{\frac{4\alpha_s}{3\pi m^2}\left(C_F\sum_J\langle {}^3P_J^{[1]}\rangle_{\mathrm{LO}} + B_F\sum_J\langle {}^3P_J^{[8]}\rangle_{\mathrm{LO}}\right)\left(\frac{1}{\epsilon_{\mathrm{UV}}}\right.} - \left.\frac{1}{\epsilon_{\mathrm{IR}}}\right)\right]\right\}$$

Mixing terms in the renormalization.
The same cancelation as in NRQCD.

The NLO P-wave shape function:

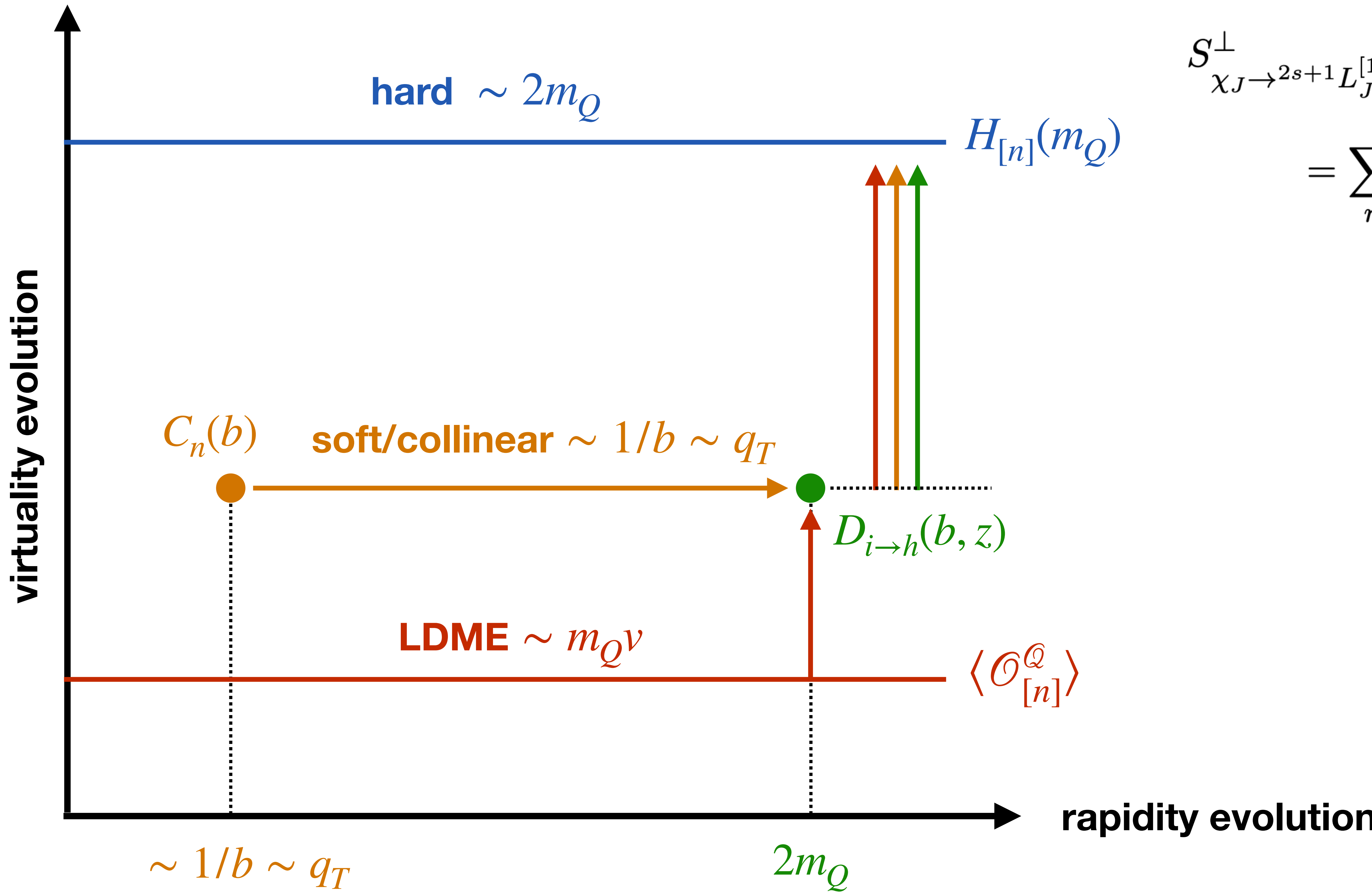
$$S^{\perp,\mathrm{NLO}}_{\chi\to {}^3P_J^{[1]}}(\mathbf{k}_\perp) = \boxed{\frac{8\alpha_s C_F}{9\pi m^2}\sum_J\langle {}^3P_J^{[1]}\rangle_{\mathrm{LO}}\left(\frac{1}{\epsilon}\delta^{(2)}(\mathbf{k}_\perp)\right.} - \left. 2\mathcal{L}_0(\mathbf{k}_\perp^2,\mu^2) + c_J\right)$$

The hard function:

$$H(\mu) = 1 - \frac{\alpha_s C_F}{2\pi}\left\{\ln^2\left(\frac{\mu^2}{M^2}\right) + 3\ln\left(\frac{\mu^2}{M^2}\right) + \frac{\pi^2}{6} - 2B({}^3S_1^{[8]})\right\}\boxed{-\frac{\alpha_s C_A}{2\pi}\ln\left(\frac{\mu^2}{M^2}\right)}$$

arXiv:hep-ph/9707223 (A. Petrelli, M. Cacciari, M. Greco, F. Maltoni, M.L. Mangano)

2-dimensional RG evolution



$$S^{\perp}_{\chi_J \to {}^{2s+1}L_J^{[1,8]}}(\mathbf{k}_\perp;\mu_0,\nu_0) = \sum_n C_n(\mathbf{k}_\perp;\mu_0,\nu_0,\mu) \times \langle \mathcal{O}^{[n]} \rangle^{\mu}_{\chi_J}$$

Summary

- Presence of TMD-shape functions reveals new NP-effects unique to quarkonium production

- New TMD evolution associated with the color-octet channels

- Operator mixing is necessary for the IR-safe definition of quarkonium production/decay of P-waves

Factorization in NR-SCET

Quarkonium at the kinematic end-point:

arXiv:hep-ph/9705286 (M. Beneke, I. Z. Rothstein, and M. B. Wise)
arXiv:hep-ph/0211303 (S. Fleming and A. K. Leibovich)
arXiv:hep-ph/010631 (C. W. Bauer, C-W Chiang, S. Fleming, A. K. Leibovich, and I. Low)
arXiv:hep-ph/0306139 (S. Fleming, A. K. Leibovich, and T. Mehen)
arXiv:hep-ph/0607121 (S. Fleming, A. K. Leibovich, and T. Mehen)
arXiv:0705.3230 (A. K. Leibovich and X. Liu)

Dark matter bound-state decay spectrum (NRDM-SCET):

arXiv:1409.4415 (M. Baumgart, I. Z. Rothstein, and V. Vaidya)
arXiv:1409.7392 (M. Bauer, T. Cohen, R. J. Hill, and M. P. Solon)
arXiv:1409.8294 (G. Ovanesyan, T. R. Slatyer, and I. W. Stewart)
arXiv:1412.8698 (M. Baumgart, I. Z. Rothstein, and V. Vaidya)
arXiv:1510.02470 (M. Baumgart and V. Vaidya)
arXiv:1612.04814 (G. Ovanesyan, N. L. Rodd, T. R. Slatyer, and I. W. Stewart)
arXiv:1712.07656 (M. Baumgart, T. Cohen, I. Moult, N. L. Rodd, T. R. Slatyer, P. Solon, I. W. Stewart, and V. Vaidya)
arXiv:1808.04388 (L. Rinchiuso, N. L. Rodd, I. Moult, E. Moulin, M. Baumgart, T. Cohen, T. R. Slatyer, I. W. Stewart, and V. Vaidya)
arXiv:1808.08956 (M. Baumgart, T. Cohen, E. Moulin, I. Moult, L. Rinchiuso, N. L. Rodd, T. R. Slatyer, I. W. Stewart, and V. Vaidya)