FRAGMENTATION IN QUARKONIUM HADROPRODUCTION

HEE SOK CHUNG
KOREA UNIVERSITY

Geoffrey T. Bodwin, HSC, U-Rae Kim, Jungil Lee, PRL113, 022001 (2014)

Geoffrey T. Bodwin, HSC, U-Rae Kim, Jungil Lee, Yan-Qing Ma, Kuang-Ta Chao, PRD 93, 034041 (2016)

Production at Large p_T

- Large p_T ($p_T >> m_H$) cross section of a hadron H is given in QCD factorization by

$$\frac{d\sigma_H}{dp_T^2} = \sum_{i=g,q,\bar{q}} \frac{d\sigma_i}{dp_T^2} \otimes D_{i\to H}(z,\mu) \qquad (\text{LP: } \sim 1/p_T{}^4)$$

Leading-power fragmentation

$$+\sum_n \frac{d\sigma_{Q\bar{Q}(n)}}{dp_T^2} \otimes D_{Q\bar{Q}(n)\to H}(z,\zeta_1,\zeta_2,\mu) \qquad (\text{NLP: } \sim 1/p_T{}^6)$$

Next-to-leading-power fragmentation

$$+O(1/p_T^8)$$

J.C.Collins and D.E.Soper, NPB194, 445 (1982)
Z.-B. Kang, J.-W. Qiu, G. Sterman, PRL108, 102002 (2012)
S. Fleming, A. K. Leibovich, T. Mehen, I. Z. Rothstein, PRD86, 094012 (2012)
Y.-Q. Ma, J.-W. Qiu, G. Sterman, H. Zhang, PRL113, 142002 (2014)

Fragmentation Production at Large p_T

- Leading-power fragmentation

Parton cross section

$$\left.\frac{d\sigma_H}{dp_T^2}\right|_{\text{LP}} = \sum_{i=g,q,\bar{q}} \frac{d\sigma_i}{dp_T^2}(z) \otimes D_{i\to H}(z,\mu)$$

Fragmentation function

- Compute parton cross sections in perturbative QCD

$$\sigma_{AB\to i} = \sum_{j,k=g,q,\bar{q}} \int_0^1 dx_1 dx_2 f_{j/A}(x_1) f_{k/B}(x_2) \hat{\sigma}_{jk\to i}$$

in collinear factorization

Available through NLO in α_s

- Determine fragmentation functions by perturbatively matching to NRQCD

$$D_{i\to H}(z,\mu) = \sum_N d_{i\to Q\bar{Q}(N)}(z,\mu)\langle\mathcal{O}^H(N)\rangle$$

Analytically available through order α_s^2,
order α_s^3 numerically available for some channels

NLP Corrections

- If needed, compute power-suppressed NLP corrections by either matching to fixed-order calculations,

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Bodwin, HSC, Kim, Lee, Ma, Chao, PRD 93, 034041 (2016)

$$\left.\frac{d\sigma_H}{dp_T^2}\right|_{\rm NLP} = \left.\frac{d\sigma_H}{dp_T^2}\right|_{\rm fixed\ order} - \left.\frac{d\sigma_H}{dp_T^2}\right|_{\rm LP}$$

or compute NLP fragmentation contributions

Y.-Q. Ma, J.-W. Qiu, G. Sterman, H. Zhang, PRL113, 142002 (2014)

$$\frac{d\sigma_H}{dp_T^2} = \sum_{i=g,q,\bar{q}} \frac{d\sigma_i}{dp_T^2} \otimes D_{i\to H}(z,\mu) \qquad (\sim 1/p_T{}^4)$$

Leading-power fragmentation

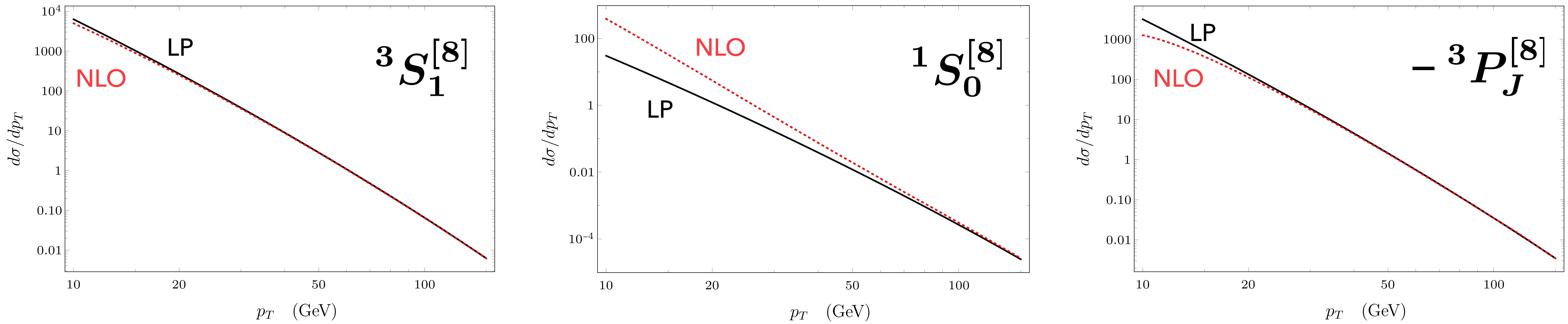
$$+\sum_n \frac{d\sigma_{Q\bar{Q}(n)}}{dp_T^2} \otimes D_{Q\bar{Q}(n)\to H}(z,\zeta_1,\zeta_2,\mu) \qquad (\sim 1/p_T{}^6)$$

Next-to-leading-power fragmentation

$$+O(1/p_T^8)$$

Matching Fragmentation and Fixed-order Calculations

- Comparison of LP fragmentation and NLO fixed-order calculation



- Difference between LP and NLO gives the power-suppressed corrections

Resummation of DGLAP Logarithms

- Logarithms of p_T/m can be resummed by implementing DGLAP evolution.

Leading logarithm: $$\frac{d}{d\log\mu_f^2}\begin{pmatrix} D_S(\mu_f) \\ D_g(\mu_f)\end{pmatrix} = \frac{\alpha_s(\mu_f)}{2\pi}\begin{pmatrix} P_{qq} & 2n_f P_{gq} \\ P_{qg} & P_{gg}\end{pmatrix} \otimes \begin{pmatrix} D_S(\mu_f) \\ D_g(\mu_f)\end{pmatrix}$$

- DGLAP evolution for fragmentation available through NLL accuracy

- NRQCD results for fragmentation functions singular at $z{=}1$, requires care.

  Numerical procedure for distributions singular at $z{=}1$:

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$$\begin{aligned}\int_0^1 dz\,\hat{\sigma}(z)D(z) &= \int_0^{1-\epsilon} dz\,\hat{\sigma}(z)D(z) + \int_{1-\epsilon}^1 dz\,\hat{\sigma}(z)D(z) \\ &\approx \int_0^{1-\epsilon} dz\,\hat{\sigma}(z)D(z) + \hat{\sigma}(z=1)\int_{1-\epsilon}^1 dz\,z^N D(z)\end{aligned}$$

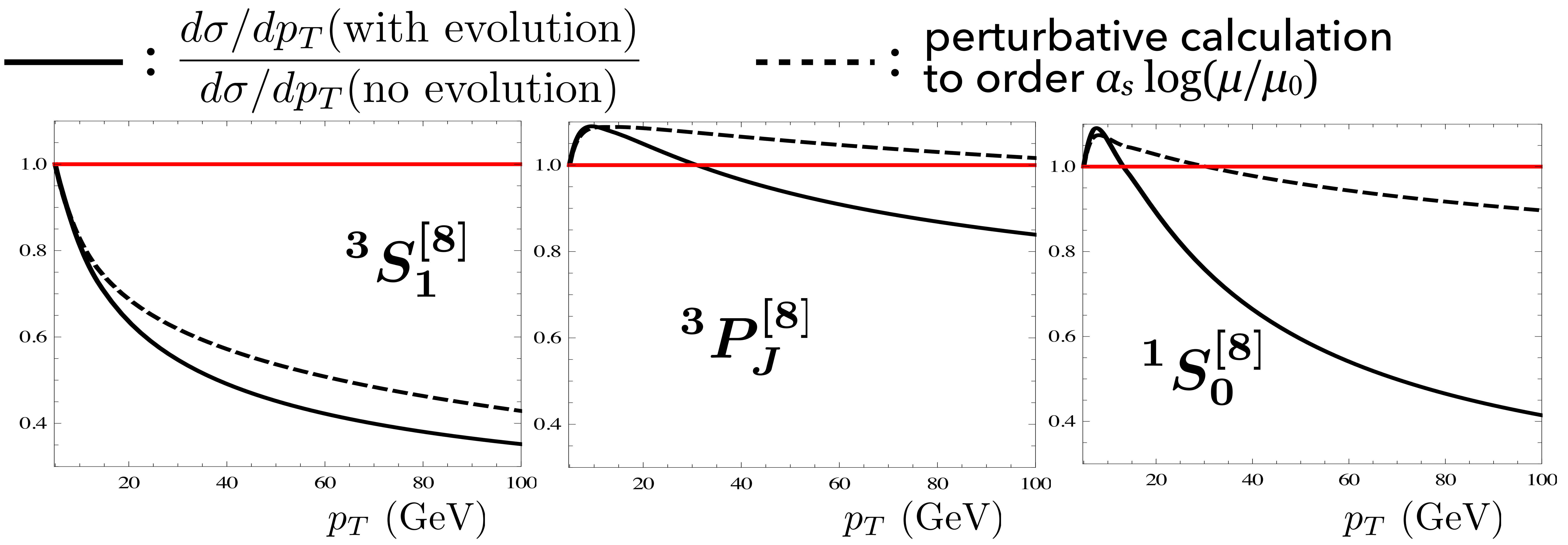
$$\int_{1-\epsilon}^1 dz\,z^N D(z) = \int_0^1 dz\,z^N D(z) - \int_0^{1-\epsilon} dz\,z^N D(z)$$

Well defined in Mellin space

Well behaved numerically

Resummation of DGLAP Logarithms

- Modification of p_T-shape by evolution from μ_0=3 GeV to μ=p_T :
  Resummation modifies the shape differently for each channel.



- When μ is not too large, numerical results agree well with perturbative calculation of DGLAP evolution to order $\alpha_s \log(\mu/\mu_0)$

Quarkonium Production in LP Fragmentation

- To obtain $\frac{d\sigma}{dp_T dy}$,
- Compute NLO parton cross sections

  Aversa, Chiappetta, Greco, Guillet, NPB 327, 105 (1989)
- Compute DGLAP evolution of fragmentation functions (LL, NLL)
- Fortran and Mathematica versions
- PDFs can be swapped
- To change initial state, swap parton cross sections e.g. use photoproduction parton cross sections to compute photoproduction

  Fontannaz, Guillet, Heinrich, EPJC 21, 303 (2001), EPJC 22, 303 (2001), EPJC26, 209 (2002), EPJC34, 191 (2004)

  Bodwin, HSC, Kim, Lee, PRD 92, 074042 (2015)

Computing time on a laptop:

~5 min per p_T and y

~5-10 min per p_T and y for 10 polarized & unpolarized channels