The Boer-Mulders effect in polarised charmonium production within Soft Gluon Resummation approach

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Outline

- Hadronisation model: NRQCD & ICEM
- TMD factorisation and Soft Gluon Resummation approach
- InEW, matching of factorisation theorems
- Charmonium production at small and large p_T within current data
- Prediction of J/ψ and η_c production at SPD NICA
- Boer-Mulders effect in polarised J/ψ production within NRQCD & SGR
- Summary

Introduction

- J/ψ production as a tool to study gluon PDF in proton
  - In the small-p_T region, TMD PM and TMD PDFs
  - In the large-p_T region, CPM and Collinear PDFs
- Hadronisation approaches: NRQCD and ICEM
- Leptonic decay of J/ψ provides access to its polarisation

- V. Saleev, K. Shilyaev, «Production of S-wave charmonia in the Soft Gluon Resummation approach using the NRQCD», Mod. Phys. Lett. A 40 (2025) 32, 2550145.
- V. Saleev, K. Shilyaev, «Small-p_T production of η_c mesons within the Soft Gluon Resummation approach», Phys. Atom. Nucl. 88 (2025) 2, 338-341.
- V. Saleev, K. Shilyaev, «Small-p_T production of polarised J/ψ mesons within the Soft Gluon Resummation approach», Phys. Part. Nucl. Lett. 22 (2025) 5, 989-991.

Motivation

- Previous task:
  - leading contributions in TMD factorisation — unpolarised partons (PDFs) within NRQCD and ICEM for unpolarised and polarised J/ψ and η_c production
- Current & forthcoming work:
  - estimation of contribution of Boer-Mulders PDFs — BM PDFs, i.e. linearly polarised partons within protons, for J/ψ and η_c production
  - impact of Boer-Mulders PDFs on the polarisation observables and angular asymmetries for heavy quarkonium production

Hadronisation model: NRQCD

- J/ψ wave function as a series with respect to relative constituent quarks velocity v:

$$|J/\psi\rangle = \mathcal{O}(v^0)\,|c\bar{c}[^3S_1^{(1)}]\rangle + \mathcal{O}(v^1)\,|c\bar{c}[^3P_J^{(8)}]g\rangle + \mathcal{O}(v^2)\,|c\bar{c}[^3S_1^{(1,8)}]gg\rangle + \\ + \mathcal{O}(v^2)\,|c\bar{c}[^1S_0^{(8)}]g\rangle + \mathcal{O}(v^2)\,|c\bar{c}[^1D_J^{(1,8)}]gg\rangle + \dots$$

- Approximate v-scaling due to $v^2 \approx 0.2$
- Hard cross section factorisation:

$$d\hat{\sigma}(ab \to \mathcal{C}X) = \sum_n d\hat{\sigma}(ab \to c\bar{c}[n]X)\langle\mathcal{O}^{\mathcal{C}}[n]\rangle$$

- Nonperturbative (hadronisation) factors:

$\langle\mathcal{O}^{\mathcal{C}}[n]\rangle$ – long-distance matrix elements (LDME):

color singlet LDMEs — potential models, data for leptonic decay

color octet LDMEs — lattice QCD calculation or experimental data fitting

Improved Color Evaporation model

- Improved Color Evaporation Model, scale hierarchy $m_c \gg \lambda \gg \Lambda_{\mathrm{QCD}}$ [Y.-Q. Ma, R. Vogt (2016)]:
  - $c\bar{c}$-pair production on $\mathcal{O}(m_c)$ scale
  - soft gluon exchange and emission on $\mathcal{O}(\lambda)$ scale
  - $\lambda \sim q_T$, q_T is intrinsic transverse momentum of parton
- Momentum shift for $c\bar{c} \to J/\psi$ transition (with invariant mass $M_{c\bar{c}}$ of the produced $c\bar{c}$-quark pair):

$$\langle p^{J/\psi} \rangle = \frac{M_{J/\psi}}{M_{c\bar{c}}}\, p^{c\bar{c}} + \mathcal{O}\left(\lambda^2/m_c\right)$$

- General cross-section expression:

$$d\sigma(p^{J/\psi}) = F^{J/\psi} \times \int_{M_{J/\psi}}^{2m_D} dM_{c\bar{c}} \int d^4 p^{c\bar{c}}\, \frac{d\sigma\left(p^{c\bar{c}}\right)}{dM_{c\bar{c}}}\, \delta^{(4)}\left(p^{J/\psi} - \frac{M_{J/\psi}}{M_{c\bar{c}}} p^{c\bar{c}}\right) + \mathcal{O}\left(\lambda^2/m_c^2\right)$$

with $F^{J/\psi}$ as a hadronisation factor assumed to be independent on the factorisation approach.

TMD factorisation and initial parton transverse momenta

- **Transverse Momentum Dependent (TMD) factorisation**: $q_T, k_T \ll \mu_F \sim M$
- TMD parton distribution functions $F(x, \boldsymbol{q_T}, \mu_F, \zeta) \Rightarrow$ two-scale **Collins-Soper** equations:

$$\begin{cases} \dfrac{\partial \ln \hat{F}(x, \boldsymbol{b_T}, \mu_F, \zeta)}{\partial \ln \sqrt{\zeta}} = \tilde{K}(b_T, \mu_F) & \text{with CS kernel } \tilde{K}(b_T, \mu_F) \\ \dfrac{\partial \tilde{K}(b_T, \mu)}{\partial \ln \mu} = -\gamma_K[\alpha_s(\mu_F)] & \text{with anomalous dimension } \gamma_K[\alpha_s(\mu_F)] \end{cases}$$

- Partons' momenta decomposition:

$$q_1^\mu = x_1 p_1^\mu + y_1 p_2^\mu + q_{1T}^\mu, \qquad q_2^\mu = x_2 p_2^\mu + y_2 p_1^\mu + q_{2T}^\mu$$

  - preserving $\mathcal{O}(q_T/M)$ terms, neglecting $\mathcal{O}(q_T^2/M^2)$ terms and, therefore, assuming $y_{1,2} \to 0$:

$$q_1 \approx \left(\frac{x_1\sqrt{s}}{2}, \boldsymbol{q_{1T}}, \frac{x_1\sqrt{s}}{2}\right), \quad q_2 \approx \left(\frac{x_2\sqrt{s}}{2}, \boldsymbol{q_{2T}}, -\frac{x_2\sqrt{s}}{2}\right)$$

- Relevant $2 \to 2$ subprocesses:
  - gluon-gluon fusion $g + g \to c + \bar{c}$ and quark-antiquark annihilation $q + \bar{q} \to c + \bar{c}$

TMD factorisation and TMD PDFs

- General formula of TMD factorisation:

$$d\sigma = \frac{1}{2s}\frac{d^3p}{(2\pi)^3\,2p^0}\int dx_1\,dx_2\,d\boldsymbol{q}_{1T}\,d\boldsymbol{q}_{2T}\,\delta^{(4)}(q_{1T}+q_{2T}-p_T)\,\Phi_g^{\mu\nu}(x_1,\mathbf{q}_{1T})\Phi_g^{\rho\sigma}(x_2,\mathbf{q}_{2T})\overline{\mathcal{M}_{\mu\rho}\mathcal{M}^*_{\nu\sigma}}$$

  with $\Phi_g^{\mu\nu}(x,\mathbf{q}_T)$ being the correlator of gluon field strengths:

$$\Phi_g^{\mu\nu}(x,\mathbf{q}_T) = -\frac{1}{2x}\left[g_T^{\mu\nu}f_1^g(x,\mathbf{q}_T) - \left(\frac{q_T^\mu q_T^\nu}{M_h^2} + g_T^{\mu\nu}\frac{\mathbf{q}_T^2}{2M_h^2}\right)h_1^{\perp g}(x,\mathbf{q}_T)\right]$$

- The cross section as convolutions of TMD PDFs in transverse momentum:

$$d\sigma = \sigma_0\left(\mathcal{C}[f_1^g(x_1,\boldsymbol{q}_{1T})f_1^g(x_2,\boldsymbol{q}_{2T})] + \mathcal{C}[w(\boldsymbol{q}_{1T},\boldsymbol{q}_{2T})h_1^{\perp g}(x_1,\boldsymbol{q}_{1T})h_1^{\perp g}(x_2,\boldsymbol{q}_{2T})]\right)$$

$$w(\boldsymbol{q}_{1T},\boldsymbol{q}_{2T}) = \frac{(\boldsymbol{q}_{1T}\cdot\boldsymbol{q}_{2T})^2 - \frac{1}{2}\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2}{2M_h^2}$$

TMD factorisation and TMD PDFs

- To implement **Collins-Soper** evolution, the transfer to impact parameter $\boldsymbol{b_T}$ space by 2D Fourier transform is done:

$$\frac{d\sigma}{d\boldsymbol{p_T}} = \sigma_0 \int \frac{d\boldsymbol{b_T}}{(2\pi)^2}\, e^{i\boldsymbol{p}_T\boldsymbol{b}_T} \Big(\hat{f}_1^g(x_1, \boldsymbol{b}_T, \mu_F, \zeta_1)\, \hat{f}_1^g(x_2, \boldsymbol{b}_T, \mu_F, \zeta_2) + \\ + \hat{h}_1^{\perp g}(x_1, \boldsymbol{b}_T, \mu_F, \zeta_1)\, \hat{h}_1^{\perp g}(x_2, \boldsymbol{b}_T, \mu_F, \zeta_2) \Big)$$

- Definition of Fourier transformed PDFs:

$$\hat{f}_1^g(x, \boldsymbol{b_T}, \mu_F, \zeta) = \int d\boldsymbol{q}_T e^{-i\boldsymbol{q}_T\boldsymbol{b}_T} f_1^g(x, \boldsymbol{q}_T, \mu_F, \zeta)$$

$$\hat{h}_1^{\perp g}(x, \boldsymbol{b_T}, \mu_F, \zeta) = \int d\boldsymbol{q}_T \frac{(\boldsymbol{b}_T \cdot \boldsymbol{q}_T)^2 - \frac{1}{2}\boldsymbol{b}_T^2\boldsymbol{q}_T^2}{\boldsymbol{b}_T^2 M_h^2} e^{-i\boldsymbol{q}_T\boldsymbol{b}_T} h_1^{\perp g}(x, \boldsymbol{q}_T, \mu_F, \zeta)$$

Soft Gluon Resummation approach, perturbative evolution

- Soft and collinear gluon resummation approach by [J. Collins, D. Soper (1981)]:
  - with $\hat{F}(x, \mu'_{b^*}, b_T^*) \equiv \hat{f}_1^g(x, \mu'_{b^*}, b_T^*)$ or $\hat{h}_1^{\perp g}(x, \mu'_{b^*}, b_T^*)$

$$\frac{d\sigma(J/\psi)}{d\boldsymbol{p_T}} = \sigma_0 \int_0^\infty db_T\, b_T\, J_0(p_T b_T)\; e^{-S_P(b_T,\mu_F,Q)}\; e^{-S_{NP}(b_T,Q)}\; \hat{F}(x_1, \mu'_{b^*}, b_T^*)\, \hat{F}(x_2, \mu'_{b^*}, b_T^*)$$

- Sudakov factor in LL–LO perturbative calculations [J. Collins, D. Soper (1982)]:

$$S_P(b_T, \mu_F, Q) = \frac{C_A}{\pi} \int_{\mu_b^2}^{Q^2} \frac{d\mu'^2}{\mu'^2} \alpha_s(\mu') \left[\ln \frac{Q^2}{\mu'^2} - \left(\frac{11 - 2N_f/C_A}{6} + \frac{1}{2} \right) \right] + \mathcal{O}(\alpha_s)$$

- Sudakov factor expression is valid only on region $b_0/Q \leqslant b_T \leqslant b_{T,\,\mathsf{max}}$ which is being controlled with [D. Boer, W. J. den Dunnen (2014); J. Collins, D. Soper, G. Sterman (1985)]

$$\mu_b \to \mu'_b = \frac{Q b_0}{Q b_T + b_0} \quad \text{and} \quad b_T^*(b_T) = \frac{b_T}{\sqrt{1 + (b_T/b_{T,\,\mathsf{max}})^2}}$$

Soft Gluon Resummation approach, nonperturbative content

- Master formula for soft gluon resummation:
  - with $\hat{F}(x,\mu'_{b^*},b_T^*) \equiv \hat{f}_1^g(x,\mu'_{b^*},b_T^*)$ or $\hat{h}_1^{\perp g}(x,\mu'_{b^*},b_T^*)$

$$\frac{d\sigma(J/\psi)}{d\boldsymbol{p_T}} = \sigma_0 \int_0^\infty db_T\, b_T\, J_0(p_T b_T)\; e^{-S_P(b_T,\mu_F,Q)}\; e^{-S_{NP}(b_T,Q)}\; \hat{F}(x_1,\mu'_{b^*},b_T^*)\, \hat{F}(x_2,\mu'_{b^*},b_T^*)$$

- **Nonperturbative** quark factor obtained in SIDIS data fitting [S. Aybat, T. Rogers (2011)]:

$$S_{NP}(b_T,Q) = \left[g_1 \ln\frac{Q}{2Q_{NP}} + g_2 \left(1 + 2g_3 \ln\frac{10 x x_0}{x_0 + x}\right)\right] b_T^2$$

  - it should be Casimir-scaled by C_A/C_F for initial gluons

- In the leading order of α_s, the perturbative tail of TMD PDF is expressed with collinear PDF [P. Sun, B.-W. Xiao, F. Yuan (2011)]:

$$\hat{f}_1^g(x,\mu'_{b^*},b_T^*) = f(x,\mu'_{b^*}) + \mathcal{O}(\alpha_s) + \mathcal{O}(b_T\Lambda_{\text{QCD}})$$

Matching of small-p_T and high-p_T regions within Inverse-Error Weighting Scheme

- Matched cross-section as a weighted sum of CPM and TMD terms [M. Echevarria, T. Kasemets, J.-P. Lansberg, C. Pisano, A. Signori (2018)]:

$$d\sigma = \mathcal{W}\, d\sigma^{\mathsf{TMD}} + \mathcal{Z}\, d\sigma^{\mathsf{CPM}}$$

- Normalised weights for each of the two terms:

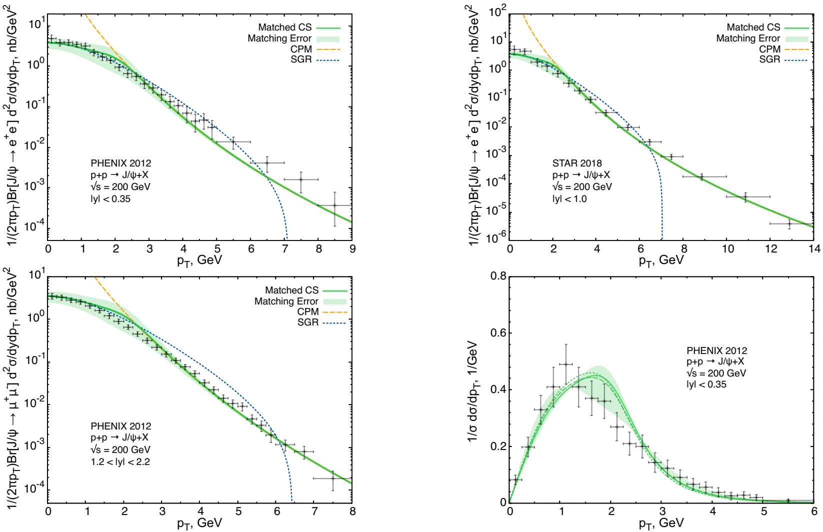
$$\mathcal{W} = \frac{\Delta\mathcal{W}^{-2}}{\Delta\mathcal{W}^{-2} + \Delta\mathcal{Z}^{-2}}, \qquad \mathcal{Z} = \frac{\Delta\mathcal{Z}^{-2}}{\Delta\mathcal{W}^{-2} + \Delta\mathcal{Z}^{-2}}$$

$$\Delta\mathcal{W} = \left(\frac{p_T}{Q}\right)^2 + \left(\frac{m}{Q}\right)^2, \qquad \Delta\mathcal{Z} = \left(\frac{m}{p_T}\right)^2 \left(1 + \ln^2 \frac{\sqrt{Q^2 + p_T^2}}{p_T}\right)$$

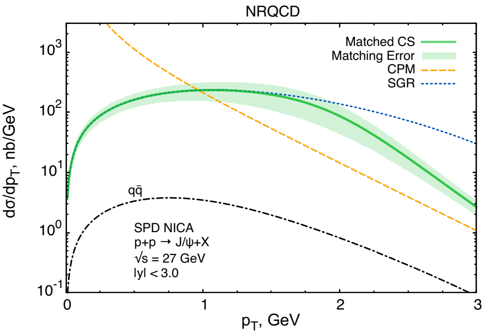
- Uncertainty due to the matching procedure:

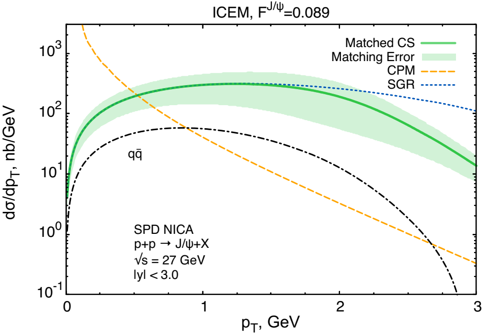
$$\Delta d\sigma = \frac{d\sigma}{\sqrt{\Delta\mathcal{W}^{-2} + \Delta\mathcal{Z}^{-2}}} = \frac{\Delta\mathcal{W}\cdot\Delta\mathcal{Z}}{\sqrt{\Delta\mathcal{W}^2 + \Delta\mathcal{Z}^2}} d\sigma$$

Unpolarised J/ψ production at $\sqrt{s} = 200$ GeV, unpolarised PDFs only



Prediction for unpolarised J/ψ production at SPD NICA, unpolarised PDFs only

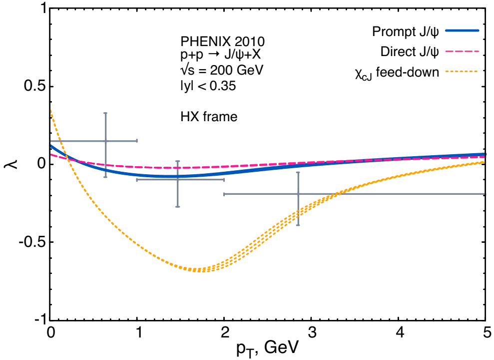




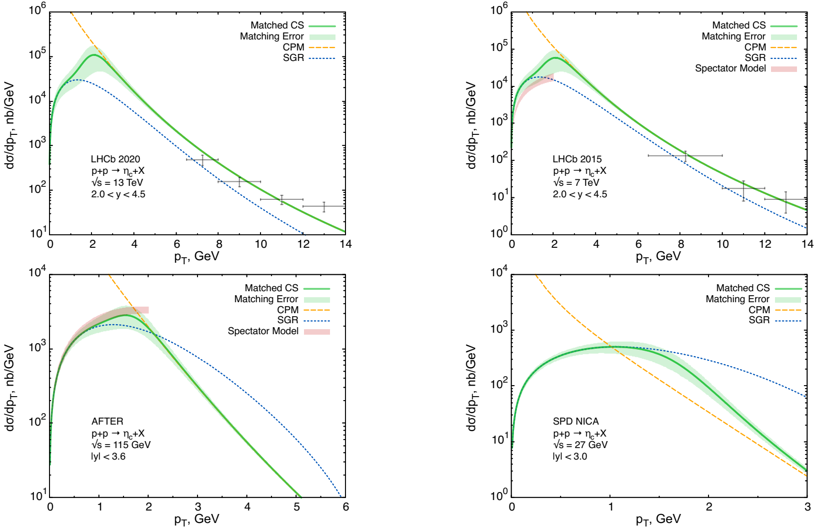
$\langle\mathcal{O}^{J/\psi}[^1S_0^{(8)}]\rangle$, GeV^3	$(9.66 \pm 0.52)\cdot 10^{-2}$	$\langle\mathcal{O}^{J/\psi}[^3S_1^{(8)}]\rangle$, GeV^3	$(1.95 \pm 1.59)\cdot 10^{-3}$
$\langle\mathcal{O}^{J/\psi}[^3P_0^{(8)}]\rangle$, GeV^5	$(1.29 \pm 0.19)\cdot 10^{-2}$	$\langle\mathcal{O}^{\chi_{c0}}[^3S_1^{(8)}]\rangle$, GeV^3	$(8.55 \pm 2.91)\cdot 10^{-3}$
χ^2/n.d.f.		0.76	

Estimation of J/ψ polarisation within SGR, CPM & InEW

$$\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{3+\lambda}\left(1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\varphi + \nu\sin^2\theta\cos 2\varphi\right)$$



η_c production, unpolarised PDFs only



Boer-Mulders PDFs

- Correlator of gluon field strengths:

$$\Phi_g^{\mu\nu}(x,\mathbf{q}_T) = -\frac{1}{2x}\left[g_T^{\mu\nu} f_1^g(x,\mathbf{q}_T) - \underline{\left(\frac{q_T^\mu q_T^\nu}{M_h^2} + g_T^{\mu\nu}\frac{\mathbf{q}_T^2}{2M_h^2}\right) h_1^{\perp g}(x,\mathbf{q}_T)}\right]$$

- Perturbative tail for gluon Boer-Mulders PDF within the SGR approach:

$$\hat{h}_1^{\perp g}(x,\mu'_{b^*},b_T^*) = -\frac{C_A\alpha_s(\mu'_{b^*})}{\pi}\int_x^1 \frac{dx'}{x'}\left(\frac{x'}{x}-1\right) f(x',\mu'_{b^*}) + \mathcal{O}(\alpha_s^2) + \mathcal{O}(b_T\Lambda_{\mathrm{QCD}})$$

- Definition of convolution of PDFs:

$$\begin{aligned}
\mathcal{C}[wff] &= \int d\boldsymbol{q}_{1T}\, d\boldsymbol{q}_{2T}\, \delta(\boldsymbol{q}_{1T}+\boldsymbol{q}_{2T}-\boldsymbol{p}_T)\, w(\boldsymbol{q}_{1T},\boldsymbol{q}_{2T})\, f(x_1,\boldsymbol{q}_{1T})\, f(x_2,\boldsymbol{q}_{2T}) = \\
&= \frac{1}{(2\pi)^2}\int d\boldsymbol{b}_T e^{i\boldsymbol{p}_T\boldsymbol{b}_T}\hat{f}(x_1,\boldsymbol{b}_T)\hat{f}(x_2,\boldsymbol{b}_T) = \\
&= \frac{1}{2\pi}\int db_T b_T J_0(p_T b_T)\hat{f}(x_1,\boldsymbol{b}_T)\hat{f}(x_2,\boldsymbol{b}_T)
\end{aligned}$$

Estimation of Boer-Mulders contribution

- Therefore, the following ratio of PDF convolutions can be introduced and investigated [D. Boer, C. Pisano (2012); J. Bor, D. Boer (2022)]:

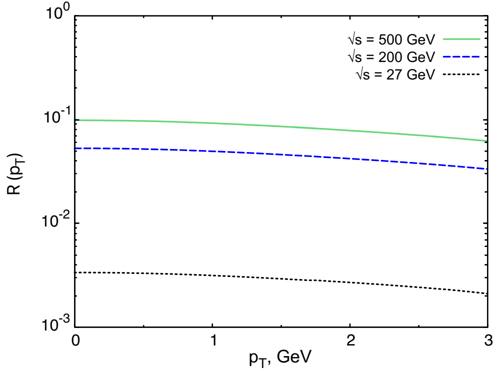
$$R(\boldsymbol{p}_T^2) = \frac{\mathcal{C}[w h_1^{\perp g} h_1^{\perp g}]}{\mathcal{C}[f_1^g f_1^g]}$$

- It can be directly investigated, for example, in unpolarised η_c production, where Color Singlet Model is sufficient approximation for description of quarkonium hadronisation:

$$\frac{d\sigma(\eta_c)}{dy d\boldsymbol{p}_T^2} = \frac{2\pi^2\alpha_s^2}{9sM^3} \langle \mathcal{O}^{\eta_c}[^1S_0^{(1)}]\rangle \, \mathcal{C}[f_1^g f_1^g] \left(1 - R(\boldsymbol{p}_T^2)\right)$$

$$\frac{d\sigma(\chi_{c0})}{dy d\boldsymbol{p}_T^2} = \frac{8\pi^2\alpha_s^2}{3sM^5} \langle \mathcal{O}^{\chi_{c0}}[^3P_0^{(1)}]\rangle \, \mathcal{C}[f_1^g f_1^g] \left(1 + R(\boldsymbol{p}_T^2)\right)$$

$$\frac{d\sigma(\chi_{c2})}{dy d\boldsymbol{p}_T^2} = \frac{32\pi^2\alpha_s^2}{9sM^5} \langle \mathcal{O}^{\chi_{c2}}[^3P_2^{(1)}]\rangle \, \mathcal{C}[f_1^g f_1^g]$$



Polarisation of J/ψ in NRQCD

- Angular distribution of leptonic decay of quarkonia [C. S. Lam, Wu-Ki Tung (1978)]:

$$\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{3+\lambda}\left(1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\varphi + \nu\sin^2\theta\cos 2\varphi\right)$$

$$\lambda = \frac{\sigma_1 - 2\,\sigma_0}{\sigma_1 + 2\,\sigma_0} \qquad \mu = \frac{2\sqrt{2}\,\mathrm{Re}\,\sigma_{01}}{\sigma_1 + 2\,\sigma_0} \qquad \nu = \frac{2\,\mathrm{Re}\,\sigma_{1-1}}{\sigma_1 + 2\,\sigma_0}$$

- NQRCD-structure of polarised J/ψ cross-section which is necessary for λ calculation (only valid and non-zero subprocesses for TMD-factorisation in leading twist are shown):
  - Boer-Mulders effect is expected to impact little on λ

$$\sigma_0^{J/\psi} = \sigma_0({}^3S_1^{(8)}) + \underline{\frac{1}{3}\sigma({}^1S_0^{(8)}) + \frac{1}{3}\sigma({}^3P_0^{(8)})} + \frac{2}{3}\sigma_0({}^3P_2^{(8)}) + \frac{1}{2}\sigma_1({}^3P_2^{(8)})$$

$$\frac{d\sigma({}^1S_0^{(8)})}{dy\,d\boldsymbol{p}_T^2} = \frac{5\pi^2\alpha_s^2}{12sM^3}\,\langle\mathcal{O}^{J/\psi}[{}^1S_0^{(8)}]\rangle\,\mathcal{C}[f_1^g f_1^g]\,\left(1 - R(\boldsymbol{p}_T^2)\right)$$

$$\frac{d\sigma({}^3P_0^{(8)})}{dy\,d\boldsymbol{p}_T^2} = \frac{5\pi^2\alpha_s^2}{sM^5}\,\langle\mathcal{O}^{J/\psi}[{}^3P_0^{(8)}]\rangle\,\mathcal{C}[f_1^g f_1^g]\,\left(1 + R(\boldsymbol{p}_T^2)\right)$$

Polarisation of J/ψ in NRQCD

- NQRCD-structure of polarised J/ψ cross-section which is necessary for μ calculation (only valid and non-zero subprocesses for TMD-factorisation in leading twist are shown):

$$\sigma_{01}^{J/\psi} = \sigma_{01}(^3S_1^{(8)}) - \underline{\frac{1}{3}\sigma(^1S_0^{(8)}) - \frac{1}{3}\sigma(^3P_0^{(8)})} + \underline{\underline{\sqrt{\frac{2}{3}}\sigma_{02}(^3P_2^{(8)}) + \frac{1}{3}\sigma_{00}(^3P_2^{(8)})}}$$

- Matrix elements and weights by the Boer-Mulders terms:

$$\sigma_{02}(^3P_2^{(8)}) = \frac{1}{\sqrt{6}}\frac{2\pi^2\alpha_s^2}{3M^3}\left(\frac{\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2 - (\boldsymbol{q}_{1T}\boldsymbol{q}_{2T})^2}{2M_h^4}\right)$$

$$\sigma_{00}(^3P_2^{(8)}) = \frac{1}{3}\frac{2\pi^2\alpha_s^2}{3M^3}\left(\frac{\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2 - (\boldsymbol{q}_{1T}\boldsymbol{q}_{2T})^2}{2M_h^4}\right)$$

Polarisation of J/ψ in NRQCD

- NQRCD-structure of polarised J/ψ cross-section which is necessary for ν calculation (only valid and non-zero subprocesses for TMD-factorisation in leading twist are shown):

$$\sigma_{1-1}^{J/\psi} = -\sigma_{1-1}({}^3S_1^{(8)}) + \underline{\frac{1}{3}\sigma({}^1S_0^{(8)}) + \frac{1}{3}\sigma({}^3P_0^{(8)})} +$$
$$+ \underline{\underline{\frac{1}{\sqrt{6}}\sigma_{20}({}^3P_2^{(8)}) + \sigma_{2-2}({}^3P_2^{(8)}) + \frac{1}{6}\sigma_{00}({}^3P_2^{(8)}) + \frac{1}{\sqrt{6}}\sigma_{0-2}({}^3P_2^{(8)})}}$$

- Matrix elements and weights by the Boer-Mulders terms:

$$\sigma_{20}({}^3P_2^{(8)}) = \frac{1}{\sqrt{6}}\frac{2\pi^2\alpha_s^2}{3M^3}\left(\frac{\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2 - (\boldsymbol{q}_{1T}\boldsymbol{q}_{2T})^2}{2M_h^4}\right)$$

$$\sigma_{00}({}^3P_2^{(8)}) = \frac{1}{3}\frac{2\pi^2\alpha_s^2}{3M^3}\left(\frac{\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2 - (\boldsymbol{q}_{1T}\boldsymbol{q}_{2T})^2}{2M_h^4}\right)$$

$$\sigma_{2-2}({}^3P_2^{(8)}) = \frac{1}{2}\frac{2\pi^2\alpha_s^2}{3M^3}\left(\frac{\boldsymbol{q}_{1T}^2\boldsymbol{q}_{2T}^2}{2M_h^4}\right)$$

Summary

- We have used the Soft Gluon Resummation approach to calculate small-p_T J/ψ and η_c production in the TMD factorisation
- Unpolarised J/ψ and η_c production can be described within NRQCD and CSM, respectively, in Soft Gluon Resummation approach
- We estimate decreasing contribution of BM PDFs with decrease of $\sqrt{s}$
- Polarisation observables can be considered as important for access to BM PDFs
- Extra access to BM PDFs can be provided with pair production of J/ψ-mesons and D-mesons production, where azimuthal asymmetries can be observed

THANK YOU FOR ATTENTION!