Heavy quark impact factor and the single bottom production at the LHC

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- **Heavy quark production at large rapidities interesting:**

Experiment

- Tagged heavy quark
- Suitable detectors – large rapidity coverage

Theory:

- Phenomenology beyond the standard model
- Probing QCD – small *x* physics

In high enrgy regime - $\Lambda^2_{QCD} \ll |t| \ll s$ (where *t* and *s* are the usual Mandelstam variables) - the cross section factorises into two impact factors h_1, h_2 – describing the coupling of the colliding particles wiith the gluon ladder - and Green function *G* – describing the gluon ladder itself. The single heavy quark cross section will be a convolution of the *Qp* collision cross section and a parton density function of the heavy quark *Q*.

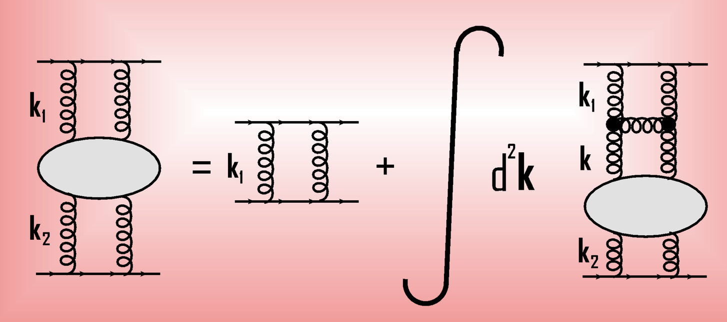
Parton distribution function of the heavy quark

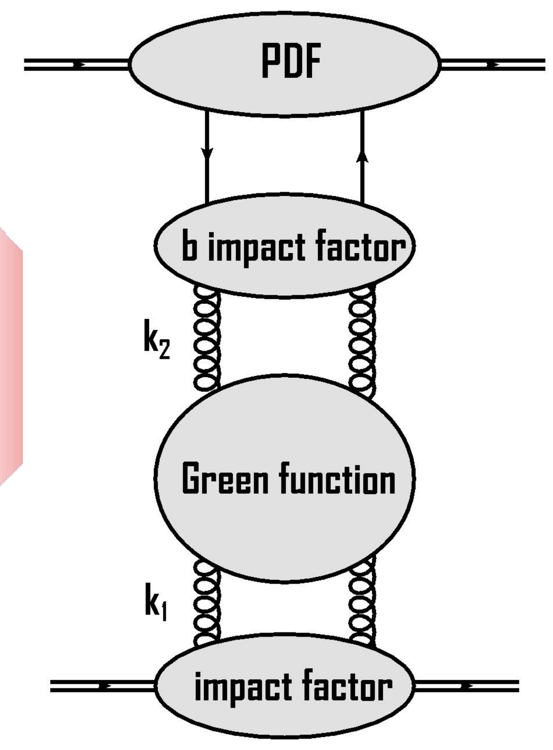
In high energy factorisation:

$$\Lambda^2_{QCD} \ll |t| \ll s$$

Resummation of $\alpha_S^n (\log s/|t|)^n$ via the BFKL equation

Green function – BFKL equation





Massless impact factor

LO impact factor

$$h^{(0)}(\boldsymbol{k}) = \sqrt{\frac{\pi}{N_c^2-1}}\,\frac{2C_F\alpha_s N_\varepsilon}{\boldsymbol{k}^2\,\mu^{2\varepsilon}}\,, \quad N_\varepsilon = \frac{(4\pi)^{\varepsilon/2}}{\Gamma(1-\varepsilon)}$$

Cross section

$$\frac{\mathrm{d}\sigma_{\mathsf{ab}}}{\mathrm{d}[\boldsymbol{k}_1]\,\mathrm{d}[\boldsymbol{k}_2]} = \int \frac{\mathrm{d}\omega}{2\pi i\omega}\, h_{\mathsf{a}}(\boldsymbol{k}_1)\mathcal{G}_\omega(\boldsymbol{k}_1,\boldsymbol{k}_2)h_{\mathsf{b}}(\boldsymbol{k}_2)\left(\frac{s}{s_0(\boldsymbol{k}_1,\boldsymbol{k}_2)}\right)^\omega$$

Heavy quark – Regge gluon vertex in transversal momentum space at NLO level known in integral form

Function of

$$R = \frac{\boldsymbol{k}_2^2}{4m^2}$$

Mellin transform

In Mellin space the integrals simplify

$$\tilde{h}_{\mathsf{q}}(\gamma) = \int \mathrm{d}[\boldsymbol{k}_2]\left(\frac{\boldsymbol{k}_2^2}{m^2}\right)^{\gamma-1} h_{\mathsf{q}}(\boldsymbol{k}_2)$$

Inverse Mellin transform

To calculate the integral inverse Mellin transform we use the Cauchy theorem. We can close the contour on the left of the complex plane or on the right of the complex plane – corresponding to γ<0 and γ>0 -- which gives us two different expansions in *R* – when **k>m** and **k<m**.

$$h_{\mathsf{q}}(\boldsymbol{k}_2) = \int_{1-2\varepsilon<\mathrm{Re}\,\gamma<1-\varepsilon} \frac{\mathrm{d}\gamma}{2\pi i}\left(\frac{\boldsymbol{k}_2^2}{m^2}\right)^{-\gamma-\varepsilon}\tilde{h}_{\mathsf{q}}(\gamma,\varepsilon)$$

$$h^-(R) = \sum_{\gamma<1-\varepsilon} \mathrm{Res}\left\{(4R)^{1-\gamma-\varepsilon}\tilde{h}_{\mathsf{q}}(\gamma,\varepsilon)\right\}$$

$$h^+(R) = \sum_{\gamma>1-2\varepsilon} \mathrm{Res}\left\{(4R)^{1-\gamma-\varepsilon}\tilde{h}_{\mathsf{q}}(\gamma,\varepsilon)\right\}$$

Cauchy theorem

Sum of residua

Taylor expansion in R

The heavy quark impact factor hq depends on ε due to dimensional regularisation. For the inverse Mellin transform we have to choose a special integration region due to convergence (indicated in the formula above).

One can define a ε finite and a singular part of the impact factor:

$$h_{\mathsf{q}}(\boldsymbol{k}_2) = h_{\mathsf{q}}^{(1)}(\boldsymbol{k}_2)|_{\mathrm{sing}} + h_{\mathsf{q}}(\boldsymbol{k}_2)|_{\mathrm{finite}}$$

$$R = \frac{\boldsymbol{k}_2^2}{4m^2} \qquad R_1 = (\sqrt{R}+\sqrt{1+R})^{-1}$$

The final result for the finite part of the heavy quark impact factor.

$$\begin{aligned} h_{\mathsf{q}}(\boldsymbol{k}_2)|_{\mathrm{finite}} = & h_{\mathsf{q}}^{(0)}(\alpha_s(\boldsymbol{k}_2))\Bigg\{1+\frac{\alpha_S N_C}{2\pi}\Bigg[\mathcal{K}-\frac{\pi^2}{6}+1-\log(R_1)\,(1+2R)\sqrt{\frac{1+R}{R}} \\ & -2\log^2(R_1) - 3\sqrt{R}\left(\mathrm{Li}_2(R_1)-\mathrm{Li}_2(-R_1)+\log(R_1)\,\log\left(\frac{1-R_1}{1+R_1}\right)\right) \\ & +\mathrm{Li}_2(4R)\,\Theta_{m\,k_2} + \left(\frac{1}{2}\log(4R)+\frac{1}{2}\log^2(4R)+\mathrm{Li}_2\left(\frac{1}{4R}\right)\right)\Theta_{k_2\,m}\Bigg]\Bigg\} \end{aligned}$$

First time in a compact explicit formula.

References:
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M. Ciafaloni and D. Colferai, Nucl. Phys. B **538**, 187 (1999) [hep-ph/9806350]
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