Heavy quark impact factor

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Why heavy quark impact factor?

Theoretical motivation:

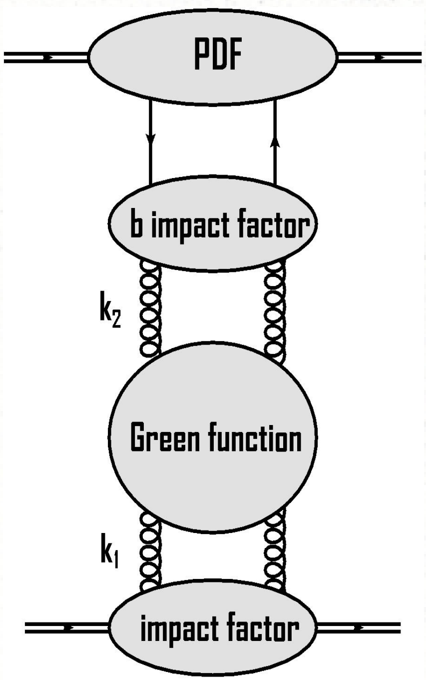
- A missing piece in small-x physics
- Open questions of phenomenology

Experimental motivation:

- A tagged heavy-quark in various processes
- Large rapidity coverage

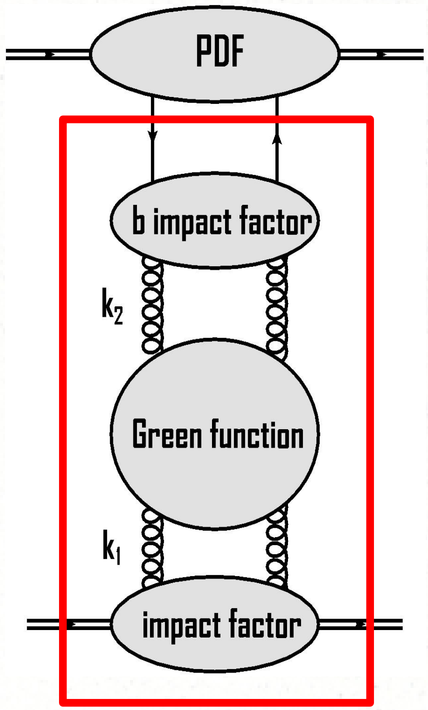
Framework

- Diagrams and cross sections



Framework

- Diagrams and cross sections

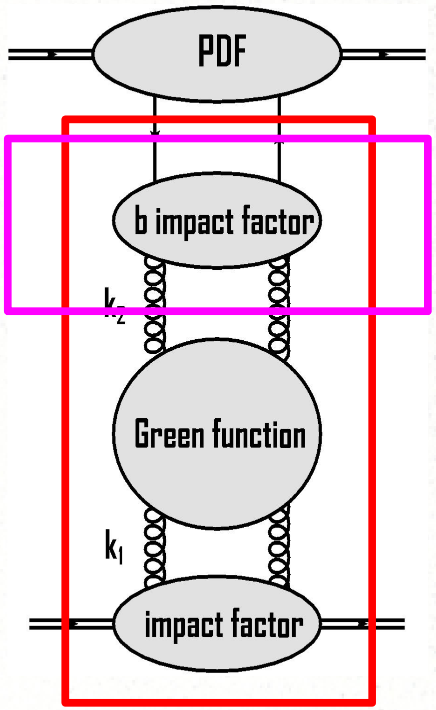


$$\frac{d\sigma_{\mathsf{ab}}}{d[\boldsymbol{k}_1]\,d[\boldsymbol{k}_2]} = \int \frac{d\omega}{2\pi i\omega} h_{\mathsf{a}}(\boldsymbol{k}_1)\mathcal{G}_\omega(\boldsymbol{k}_1,\boldsymbol{k}_2) \times \\ \times h_{\mathsf{b}}(\boldsymbol{k}_2)\left(\frac{s}{s_0(\boldsymbol{k}_1,\boldsymbol{k}_2)}\right)^{\omega}$$

$$s_0 = \max(k_1, m_1)\max(k_2, m_2)$$

Framework

- Diagrams and cross sections



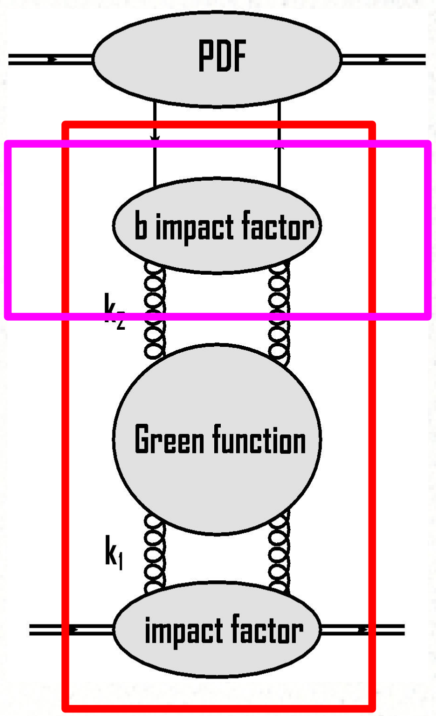
$$\frac{d\sigma_{ab}}{d[\boldsymbol{k}_1]\,d[\boldsymbol{k}_2]} = \int \frac{d\omega}{2\pi i\omega} \boxed{h_a(\boldsymbol{k}_1)} \mathcal{G}_\omega(\boldsymbol{k}_1, \boldsymbol{k}_2) \times \\ \times\, h_b(\boldsymbol{k}_2) \left(\frac{s}{s_0(\boldsymbol{k}_1, \boldsymbol{k}_2)}\right)^\omega$$

$$s_0 = \max(k_1, m_1)\max(k_2, m_2)$$

Framework

- Factorisation scheme: generalized CC scheme

Nucl.Phys. B538 (1999) 187-214



$$\mathcal{G}_\omega = (1+\overline{\alpha}_s H_L)\left[1-\frac{\overline{\alpha}_s}{\omega}(K_0+K_{NL})\right]^{-1}(1+\overline{\alpha}_s H_R)$$

In this scheme:

$$(H_R = H_L^\dagger = H)$$

$$H(\boldsymbol{k}_1,\boldsymbol{k}_2) = -\frac{1}{\boldsymbol{q}^2\Gamma(1-\varepsilon)\mu^{2\varepsilon}}\,\log\frac{q}{k_1}\,\Theta_{qk_1}$$

$$\boldsymbol{q} = \boldsymbol{k}_1 + \boldsymbol{k}_2$$

Heavy quark impact factor at NLO

Momentum space

- Single heavy quark production matrix element at NLO

JHEP **0005** (2000) 042 [hep-ph/0004033]

$$F_{\mathsf{q}}(z_1,\boldsymbol{k}_1,\boldsymbol{k}_2) = F_{\mathsf{q}}^{m=0}(z_1,\boldsymbol{k}_1,\boldsymbol{k}_2) + \Delta F_{\mathsf{q}}(z_1,\boldsymbol{k}_1,\boldsymbol{k}_2)$$

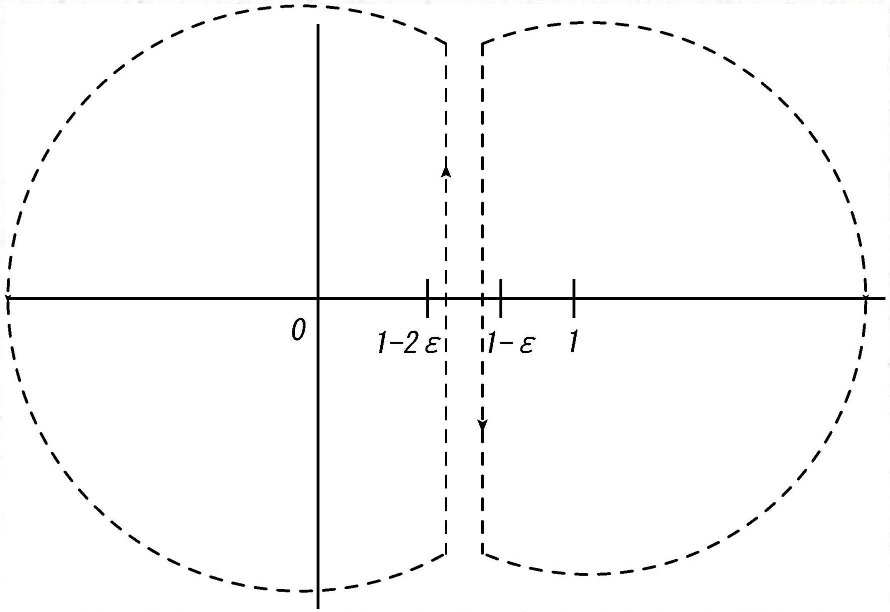
$$\begin{aligned}\Delta F_{\mathsf{q}}(\boldsymbol{k}_2) &= \Delta F_{\mathsf{q},\mathrm{real}}(\boldsymbol{k}_2) + \Delta F_{\mathsf{q},\mathrm{virt}}(\boldsymbol{k}_2)\\ &= A_\varepsilon\left[\frac{\Gamma(-\varepsilon)}{2(1+2\varepsilon)}\frac{(m^2)^\varepsilon}{\boldsymbol{k}_2^2} + \frac{\Gamma(1-\varepsilon)}{2}\left\{\int_0^1\int_0^1 \mathrm{d}z_1\,\mathrm{d}x\left(\frac{1-z_1}{z_1}+\frac{1+\varepsilon}{2}z_1\right)\times\right.\right.\\ &\qquad\times\left[\frac{1}{\left[x(1-x)\boldsymbol{k}_2^2+m^2z_1^2\right]^{1-\varepsilon}} - \frac{1}{\left[x(1-x)\boldsymbol{k}_2^2\right]^{1-\varepsilon}}\right]+\\ &\qquad\left.\left.+\frac{2m^2}{\boldsymbol{k}_2^2}\int_0^1\int_0^1\frac{z_1(1-z_1)\,\mathrm{d}z_1\,\mathrm{d}x}{\left[x(1-x)\boldsymbol{k}_2^2+m^2z_1^2\right]^{1-\varepsilon}}\right\}\right]\end{aligned}$$

- Integrals over *x* and *z* - <u>finite</u>

Some technical aspects

- Sum of residua – picture

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



Some technical aspects

- Sum of residua – picture

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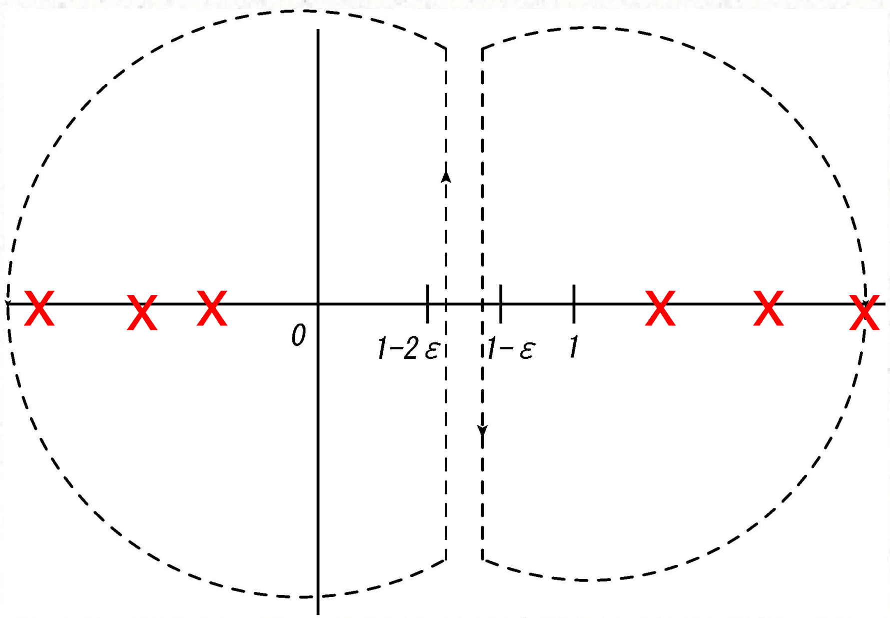


Some technical aspects

- Sum of residua
- $R=\boldsymbol{k}_2^{\,2}/(4m^2)$

$$h_{1-2\varepsilon}(\boldsymbol{k}_2) = -\frac{1+5\varepsilon-2\varepsilon^2}{2(1+2\varepsilon)} - \log(4R) + \psi(1-\varepsilon) - \psi(1) - 2\psi(\varepsilon) + 2\psi(2\varepsilon)\ ,$$

$$h_{1/2-2\varepsilon}(\boldsymbol{k}_2) = \sqrt{R}\,\frac{(3+4\varepsilon)\,\Gamma(1+2\varepsilon)\,\pi\tan(\pi\,\varepsilon)}{4^{1+\varepsilon}(1+\varepsilon)\,\Gamma^2(1+\varepsilon)}\ ,$$

$$h_{-2\varepsilon}(\boldsymbol{k}_2) = R\,\frac{1+\varepsilon}{1+2\varepsilon}\ ,$$

$$h_{-n-\varepsilon}(\boldsymbol{k}_2) = (-1)^{1+n}\,(4R)^{1+n-\varepsilon}\,\frac{\varepsilon\,\Gamma(1+2\varepsilon)\Gamma(1+n)\,\Gamma(1+n-\varepsilon)}{4\,\Gamma(1-\varepsilon)\,\Gamma^2(1+\varepsilon)\,\Gamma(2+2n)} \times\left[\frac{1+\varepsilon}{\varepsilon-n}+\frac{2}{1+2n-2\varepsilon}\left(\frac{1}{1+n-\varepsilon}-\frac{1}{3+2n}\right)\right]\ ,$$

Impact factor results

- The finite part ($O(\varepsilon^0)$) of the heavy quark impact factor

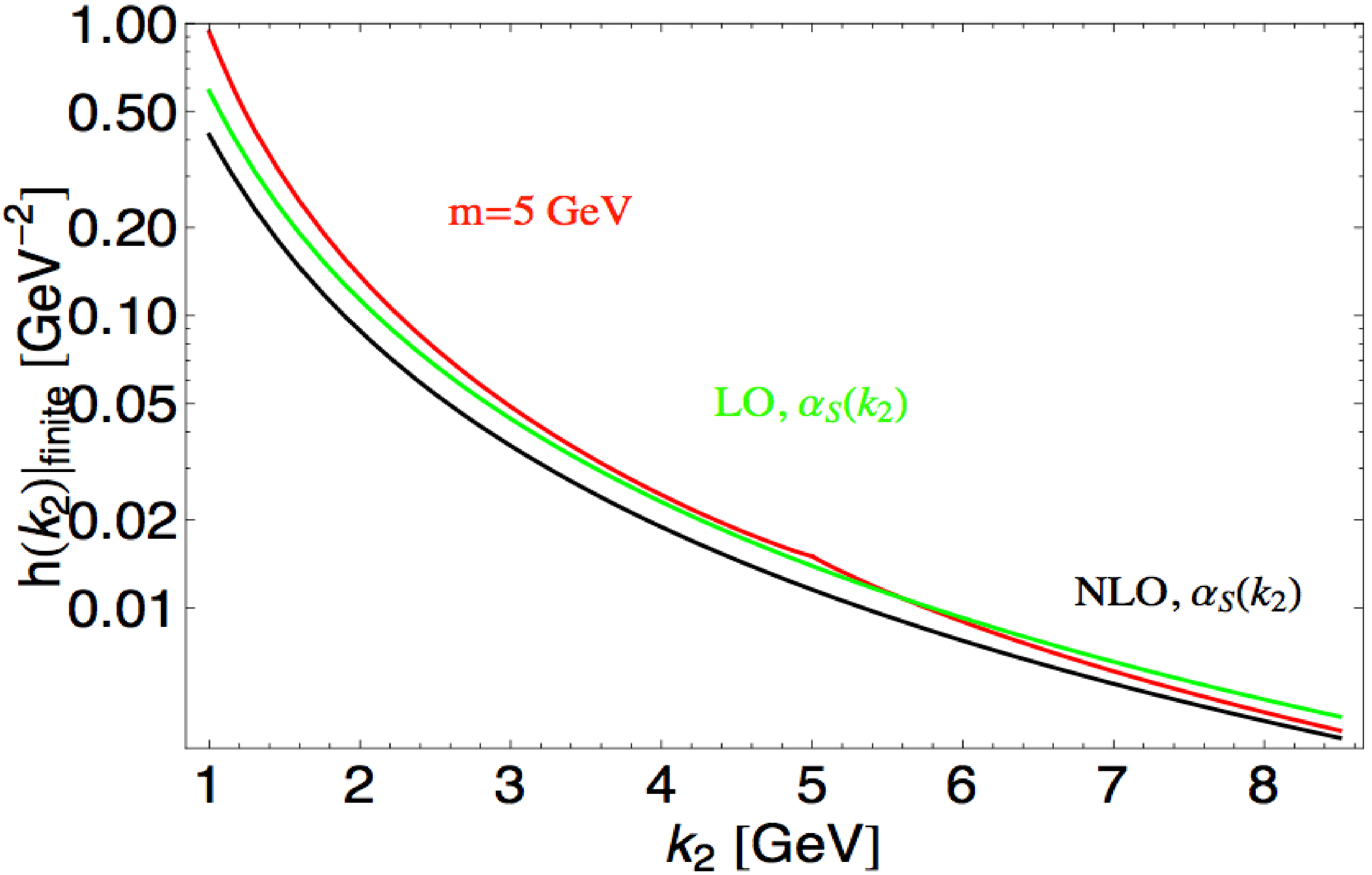
$$h_{\mathsf{q}}(\mathbf{k}_2)|_{\text{finite}} = h_{\mathsf{q}}^{(0)}(\alpha_s(\mathbf{k}_2))\left\{1+\frac{\alpha_s N_c}{2\pi}\left[\mathscr{K}-\frac{\pi^2}{6}+1-R\log(4R)-\log(Z)\,(1+2R)\sqrt{\frac{1+R}{R}}\right.\right.$$
$$-2\log(Z)^2-3\sqrt{R}\left(\mathrm{Li}_2(Z)-\mathrm{Li}_2(-Z)+\log(Z)\log\left(\frac{1-Z}{1+Z}\right)\right)$$
$$\left.\left.+\mathrm{Li}_2(4R)\,\Theta_{mk_2}+\left(\frac{1}{2}\log(4R)+\frac{1}{2}\log^2(4R)+\mathrm{Li}_2\left(\frac{1}{4R}\right)\right)\Theta_{k_2 m}\right]\right\}.$$

$$Z=(\sqrt{1+R}+\sqrt{R})^{-1}$$

$R=k_2^2/(4m^2)$

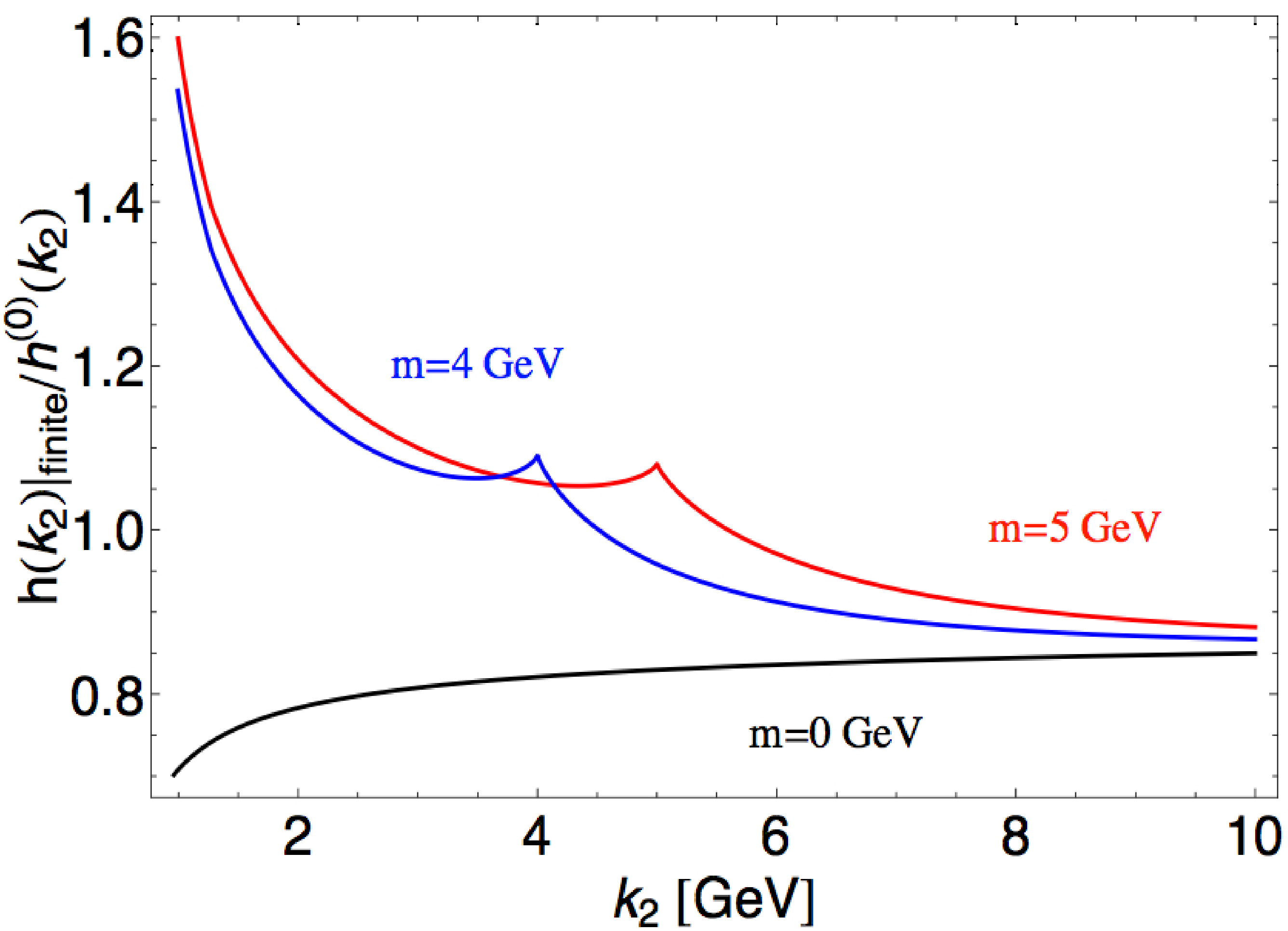
Impact factor results

- NLO m = 5 GeV vs. LO and NLO massless



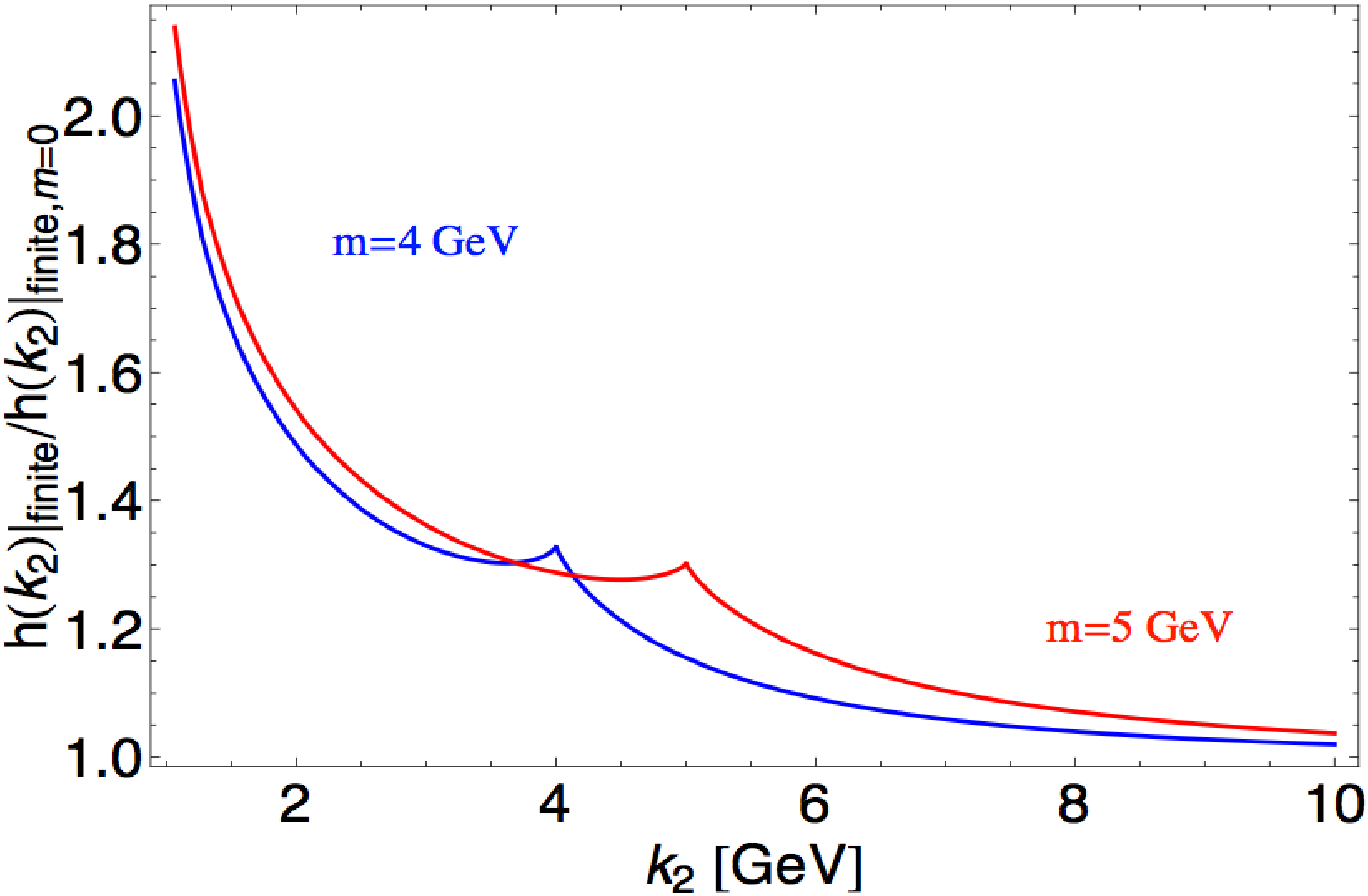
Impact factor results

- Size of the NLO corrections: 4 and 5 GeV
- Ratio



Impact factor results

- Size of the mass correction
- Ratio



Summary and Outlook

- Numerical results for heavy quark impact factor at NLO obtained in numerically suitable form

Next steps:

- Convolution with the gluon Green function and heavy quark PDFs
- Cross section for single and two heavy quark production at large rapidities