Towards Polarized Hadroproduction of Heavy Quarks

I. Bojak[a]*

[a]Institut für Physik, Universität Dortmund, D-44221 Dortmund, Germany

Though leading order (LO) predictions for the hadroproduction of heavy quarks at RHIC look promising, next-to-leading order (NLO) corrections must be considered. First partonic NLO results are reported here.

1. NLO PHOTO- AND LO HADROPRODUCTION

The determination of the polarized gluon distribution Δg remains one of the most challenging goals of spin physics. The main difficulties are the limited kinematical range of the spin structure function g_1 measurements, the absence of a momentum sum rule and finally the lack of exclusive reaction measurements. It is the latter point which is or will be soon addressed experimentally [1–3], and thus requires improved theoretical understanding.

We have already explored the potential of polarized photoproduction of charm at COMPASS [2] in [4]. The range of explored x there is limited by the $\sqrt{S}$ of about 10 GeV. In Fig. 1 at the top we see the minimal x that can be probed for a given $\eta = s/(4m^2) - 1$ and the COMPASS range is indicated. Displayed in this plot are ratios of total *partonic* cross sections: on one hand for the gluonic part NLO divided by LO, and on the other hand in NLO the quark contribution divided by the gluon one. Here the cross sections for different helicity combinations are used for the ratios. Obviously in the COMPASS range one will not have to worry about the NLO photon-quark subprocess.

Also evident are the strong NLO corrections in the gluonic sector, which are well known in the unpolarized case, see for example [5]. They are due to new diagram topologies occuring for the first time at NLO, e.g., gluon t-channel exchange. But note that COMPASS does not probe the high energy enhancement, and the threshold enhancement is folded with the small gluon at large x, so that LO and NLO give similar predictions there.

For smaller x, one needs larger energies and thus the RHIC collider in its polarized proton collision mode [3]. Then one has to consider hadroproduction. In Fig. 2 a LO prediction for the total charm asymmetry $A^c_{pp} = \Delta\sigma^c_{pp}/\sigma^c_{pp}$ as a function of a p_T-cut $p_T^{\rm min}$ is displayed for two different center-of-mass energies ($\sqrt{S} = 200$ GeV with $\mathcal{L} = 240$ pb^{-1} as thick and $\sqrt{S} = 500$ GeV with $\mathcal{L} = 800$ pb^{-1} as thin lines). Several different parton distributions have been used [6,7] and a rough statistical error estimate using the formula

$$\delta A^c_{pp} \simeq \frac{1}{P_p^2}\frac{1}{\sqrt{\varepsilon_c \mathcal{L}\sigma^c_{pp}}} \qquad (1)$$

with a detection efficiency of $\varepsilon_c = 0.001$ is also displayed. The variable $x_T^{\rm min} = p_T^{\rm min}/p_T^{\rm max}$ with $p_T^{\rm max} = \sqrt{S/4 - m_c^2}$ is used in the plot to allow a better comparison between the different energies.

One can see that there is a range of p_T-cuts in which the expected asymmetry is much larger than the error. There cancelations between high and low p_T in the polarized cross section are cut out, whereas the error due to the reduced unpolarized cross section, see Eq. (1), has not increased too much. Even the small and oscillating GS C gluon [6] could be detected.

2. FIRST NLO RESULTS

But there are several problems with this LO prediction. It has a large dependence on the arbitrary choice of the renormalization μ_r and factorization μ_f scales. One can hope that the NLO corrections would cure this problem as in pho-

*Supported in part by the "Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie", Bonn.

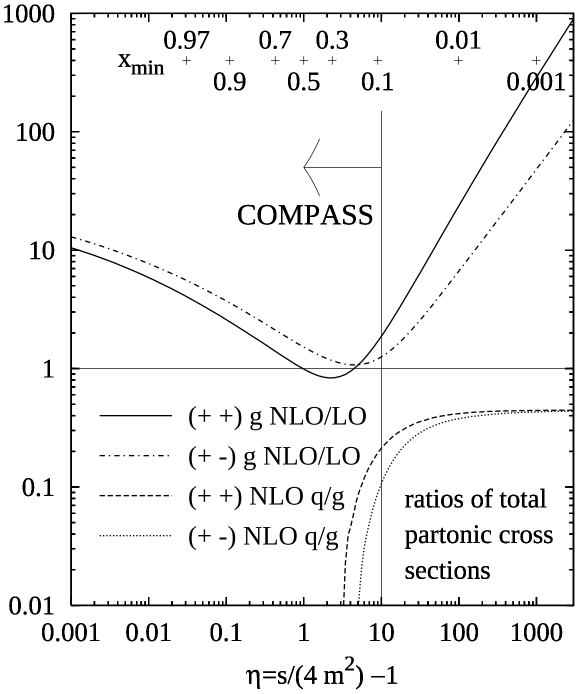

Figure 1. Partonic photoproduction ratios for the two helicity combinations, comparing NLO to LO $\vec{\gamma}\vec{g}$, and $\vec{\gamma}\vec{q}$ to $\vec{\gamma}\vec{g}$ in NLO. The $x_{\min}$ points indicate the minimal x for some η values.

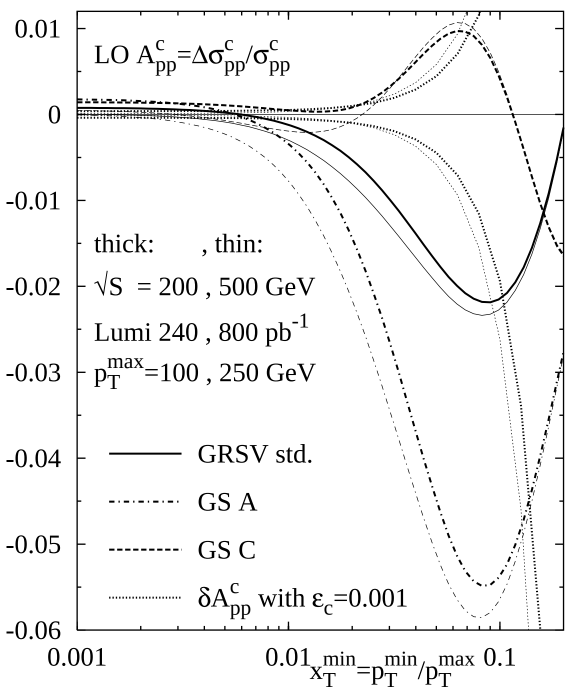

Figure 2. Total LO charm asymmetry at RHIC [3] for $\sqrt{S} = 200,\ 500$ GeV (thick, thin lines) for different parton sets [6,7] as function of a p_T-cut. An estimate of δA^c_{pp} by Eq. (1) is also shown.

toproduction [4]. Also we expect NLO logarithmic enhancements at threshold and for high energies like in photoproduction. Furthermore the new NLO gluon-quark process could be relevant at these high energies, as seen for photon-quark. Finally the cutting of p_T-cancelations, used in Fig. 2, is of course sensitive to shifts of the zeroes in the polarized cross section.

Thus a calculation of the NLO corrections is mandatory for a meaningful analysis of the experimental results. The calculation proceeds similarly to that of [4] and will be described in detail in a future paper. Currently the gluon-quark and quark-quark subprocesses have been calculated, while for the gluon-gluon part the virtual contributions remain to be done. After integrating the double differential results[2], the resulting total partonic cross section scales in $\eta = s/(4m^2) - 1$:

$$\Delta\sigma_{ij}(s, m^2, \mu_f, \mu_r) = \frac{\alpha_s^2(\mu_r^2)}{m^2}\Big[\Delta f^{(0)}_{ij}(\eta) + 4\pi\alpha_s(\mu_r^2)\left(\Delta f^{(1)}_{ij}(\eta) + \Delta\overline{f}^{(1)}_{ij}(\eta)\ln\frac{\mu_f^2}{m^2}\right)\Big], \quad (2)$$

with $i, j = g, q, \overline{q}$.

The scaling functions according to (2) for the gluon-quark process can be found in Fig. 3. The abelian and non-abelian contributions to $\Delta f^{(1)}_{gq}$ are displayed separately. Note that the abelian part equals our previous result for the photoproduction gluon-quark subprocess divided by $2N_C = 6$. Also shown for comparison is the unpolarized $f^{(1)}_{gq}$ scaled down by a factor 20.

Finally the scaling functions for the quark-quark part are displayed in Fig. 4. Here the hard

[2]Ignoring $\ln \mu_r^2/\mu_f^2$ terms, which only shift α_s [4], for now.

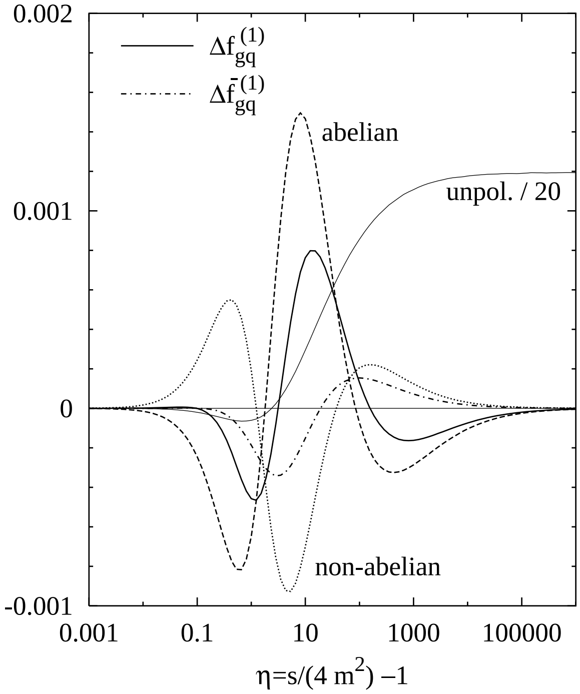

Figure 3. NLO gluon-quark scaling functions. (Non-)abelian contributions to $\Delta f_{gq}^{(1)}$ and the unpolarized $f_{gq}^{(1)}$ divided by 20 are also shown.

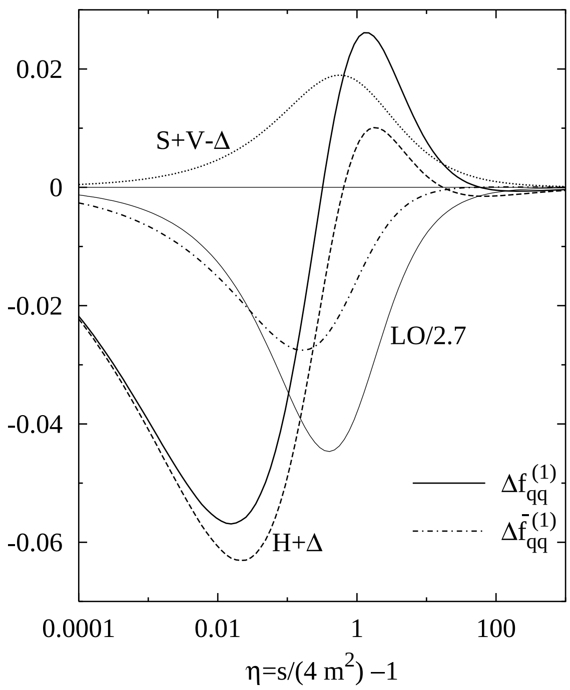

Figure 4. NLO quark-quark scaling functions. "Hard+Δ" and "soft+virtual-Δ" parts of $\Delta f_{qq}^{(1)}$, and the LO $\Delta f_{gq}^{(0)}$ divided by 2.7, are also shown.

and soft plus virtual contributions to $\Delta f_{qq}^{(1)}$ are also shown separately. To obtain finite results for the parts, one has to shift $\ln \Delta/m^2$ terms from the soft plus virtual to the hard part. Δ is a small auxiliary parameter used in the phase space slicing for extracting the soft singularities. The hard part is dominating the behaviour close to the production threshold. Also shown for comparison is the LO $\Delta f_{gq}^{(0)}$. It is scaled down by a factor of $4\pi\alpha_s(m_c^2 \ldots 4m_c^2) \simeq 2.7$, so that a direct comparison of the LO and NLO size is meaningful. Obviously the NLO corrections have a significant impact over the whole η range.

Acknowledgements. I am grateful to M. Stratmann for the fruitful collaboration on this and previous work.

REFERENCES

1. HERMES Collab., K. Ackerstaff et al., Nucl. Instrum. Meth. **A417** (1998) 230; HERMES Collab., internal notes 97-003 and 97-004.
2. COMPASS Collab., G. Baum et al., CERN/SPSLC-96-14 and CERN/SPSLC-96-30.
3. RHIC Spin Collab., D. Hill et al., RHIC-SPIN-LOI-1991, updated 1993.
4. I. Bojak and M. Stratmann, Phys. Lett. **B433** (1998) 411 and Nucl. Phys. **B540** (1999) 345.
5. J. Smith and W.L. van Neerven, Nucl. Phys. **B374** (1992) 36.
6. M. Glück et al., Phys. Rev. **D53** (1996) 4775; T. Gehrmann and W.J. Stirling, Phys. Rev. **D53** (1996) 6100.
7. M. Glück et al., Z. Phys. **C67** (1995) 433.