Transverse Double-Spin Asymmetries for Dimuon Production in pp Collisions

O. Martin[a]*

[a]Institut für Theoretische Physik, Universität Regensburg,
D-93040 Regensburg, Germany

We calculate the transverse double-spin asymmetry for the production of dimuons in pp collisions as function of the dimuon rapidity and mass to next-to-leading order accuracy in the strong coupling constant. Predictions for BNL-RHIC and HERA-$\vec{N}$ are made by assuming a saturation of Soffer's inequality at a low hadronic input scale. Is seems unlikely that transversity can be measured in dimuon production at RHIC.

1. TRANSVERSITY

The transversity distribution $\delta q(x,\mu^2)$ counts the number of quarks in a transversely polarized proton weighted with their transverse polarization [1]. As a twist-2 distribution function it is, at least theoretically, as important as the unpolarized and helicity weighted quark distributions $q(x,\mu^2)$ and $\Delta q(x,\mu^2)$ [2]. All three objects are related by Soffer's inequality [3] which states that for quarks and antiquarks

$$|\delta q(x,\mu^2)| \leq \frac{1}{2}\left[q(x,\mu^2)+\Delta q(x,\mu^2)\right] . \qquad (1)$$

This relation is preserved by next-to-leading order (NLO) evolution which means that it will be valid for all $\mu > \mu_0$ in case it is fulfilled at the scale μ_0 [4]. This is demonstrated in Fig. 1 where we assume that Soffer's inequality is saturated at the hadronic scale of $\mu_0 \approx \mathcal{O}(0.6\text{ GeV})$. Due to lack of data on $\delta q(x,\mu^2)$ all predictions in this work are based on this assumption. We use the unpolarized GRV 95 HO and the GRSV standard helicity weighted parton distributions.

2. MUON PAIR PRODUCTION

As usual, the polarized cross section for the production of dimuons is given by a convolution of a partonic cross section $\mathrm{d}\delta\hat{\sigma}$ with polarized parton densities [5]:

$$\frac{\mathrm{d}\delta\sigma}{\mathrm{d}M\,\mathrm{d}y\,\mathrm{d}\phi} = \int_{x_1^0}^1 \mathrm{d}x_1 \int_{x_2^0}^1 \mathrm{d}x_2 \frac{\mathrm{d}\delta\hat{\sigma}}{\mathrm{d}M\,\mathrm{d}y\,\mathrm{d}\phi} \times \sum_q \bar{e}_q^2 \left[\delta q(x_1,\mu_F^2)\delta\bar{q}(x_2,\mu_F^2) + 1 \leftrightarrow 2\right] . \qquad (2)$$

The dimuon mass M and rapidity y are related to the integration limits by $x_{1,2}^0 = (M/\sqrt{S})\exp(\pm y)$, where S is the hadronic center-of-mass (cm) energy. At leading order (LO), $x_{1,2}^0$ are just the momentum fractions of the interacting (anti-)quarks so that the y-dependent cross section is sensitive to the shape of the transversity densities. We calculated the partonic cross section to NLO ($\mathcal{O}(\alpha_s)$) in the $\overline{\mathrm{MS}}$-scheme by transformation of the results of [5] which were previously calculated in a massive gluon scheme. The partonic cross section retains its $\cos(2\phi)$-dependence also at NLO with ϕ being the azimuthal angle of one of the outgoing muons. So in order to maximize statistics we define the transverse double-spin asymmetry as [6]

$$A_{TT}(M,y) \equiv \frac{\int_0^{2\pi}\mathrm{d}\phi\ \mathrm{d}\delta\sigma(\cos 2\phi \to |\cos 2\phi|)}{\int_0^{2\pi}\mathrm{d}\phi\ \mathrm{d}\sigma} .$$

3. RESULTS

Fig. 2 shows the y-dependence of A_{TT} for HERA-$\vec{N}$ at $\sqrt{S} \approx 40$ GeV and RHIC at $\sqrt{S} = 200$ GeV integrated over a suitable dimuon mass range. QCD corrections to the asymmetry are

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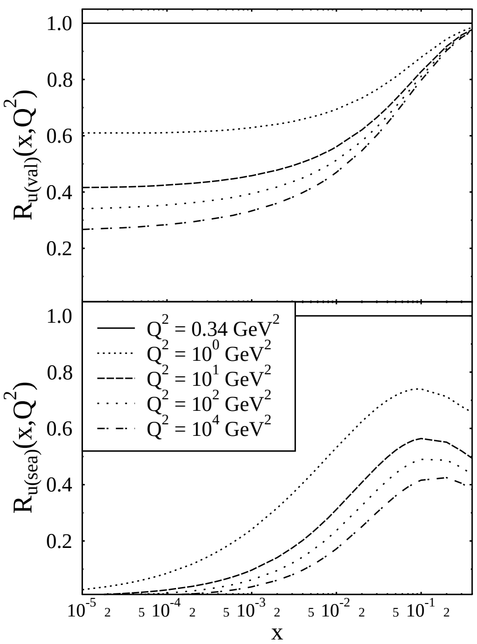

Figure 1. Preservation of Soffer's inequality by NLO evolution. R is defined as $R(x,\mu^2) = 2|\delta q(x,\mu^2)|/\left[q(x,\mu^2)+\Delta q(x,\mu^2)\right]$.

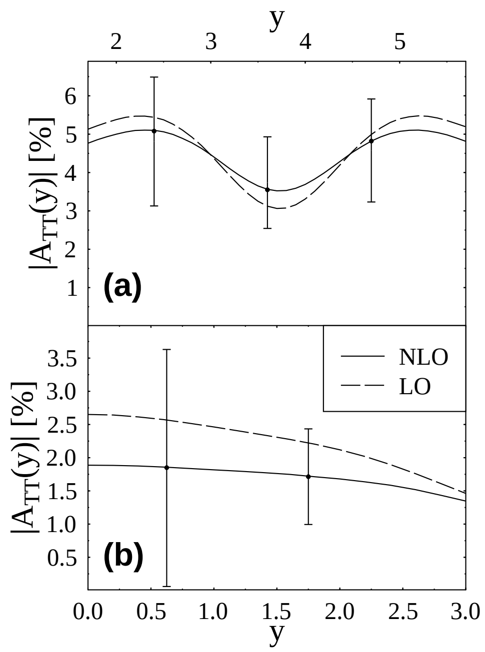

Figure 2. Rapidity dependence of A_{TT} for (a) HERA-$\vec{N}$ (E_{beam} = 820 GeV, $M = 4-9$ GeV) [7] and (b) PHENIX at RHIC ($\sqrt{S}$ = 200 GeV, $M = 5-9$ GeV) [8].

obviously larger for higher cm-energies while the opposite is true for the polarized cross sections [6]. What is actually shown is the maximal absolute A_{TT} which is consistent with the validity of Eq. (1) at $\mu \approx 0.6$ GeV. If the inequality is not saturated at this scale, then the resulting asymmetry will be smaller. The statistical errors shown in Fig. 2 are based on an integrated luminosity of $\mathcal{L} = 240\,\text{pb}^{-1}$ for HERA-$\vec{N}$, $\mathcal{L} = 320\,\text{pb}^{-1}$ for RHIC and a beam and target polarization of $\mathcal{P} = 70\%$. Furthermore we also took the limited geometrical acceptance ϵ and $\delta\epsilon$ of the detectors into account (cf. Fig. 3). For their calculation the momenta of the outgoing muons must be known which can not be inferred from the variables M, y and ϕ of Eq. (2). Actually, only the square root of the acceptance enters the expression for the statistical error

$$\text{stat. error} = \frac{1}{\mathcal{P}^2\sqrt{\mathcal{L}\int \epsilon \mathrm{d}\sigma}} \quad , \tag{3}$$

and so we just restricted ourselves to a LO calculation since here the transverse momenta k_T of both outgoing muons are the same (with opposite direction). Therefore, we only need the differential cross section $\mathrm{d}(\delta)\sigma^{\mathrm{LO}}/\mathrm{d}M\mathrm{d}y\mathrm{d}\phi\mathrm{d}k_T$ which can be easily obtained [6]. Note, that Eq. (3) gives the statistical error on the measured asymmetry, which is not the same as the theoretical asymmetries shown in Figs. 2 and 4 since usually $\delta\epsilon/\epsilon \neq 1$ (cf. Fig. 3). Fig. 4 shows A_{TT} as a function of the dimuon mass M. Just like for $A_{TT}(y)$, the expected statistical errors are sizable for both experiments but HERA-$\vec{N}$ is again in somewhat better shape. Considering the fact that we assumed a saturation of Eq. (1) is seems unlikely that a measurement of $\delta q(x,\mu^2)$ with dimuon production at RHIC is possible.

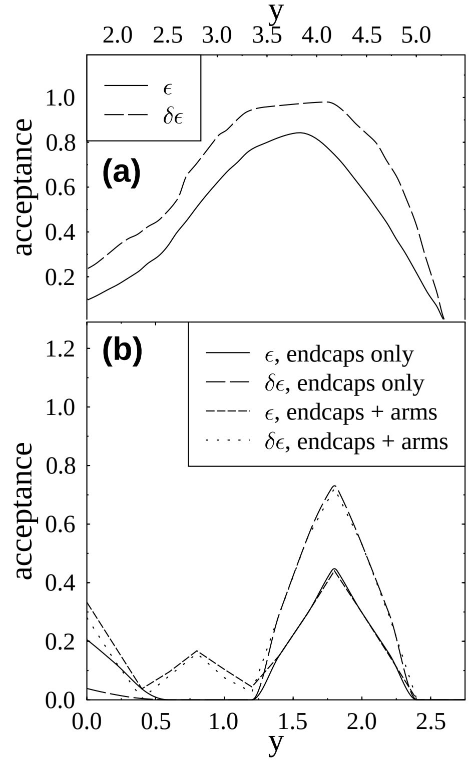

Figure 3. Unpolarized and polarized acceptance ϵ and $\delta\epsilon$ as function of dimuon rapidity for (a) HERA-$\vec{N}$ and (b) PHENIX at RHIC (same parameters as in Fig. 2). For the geometrical and kinematical cuts see [6].

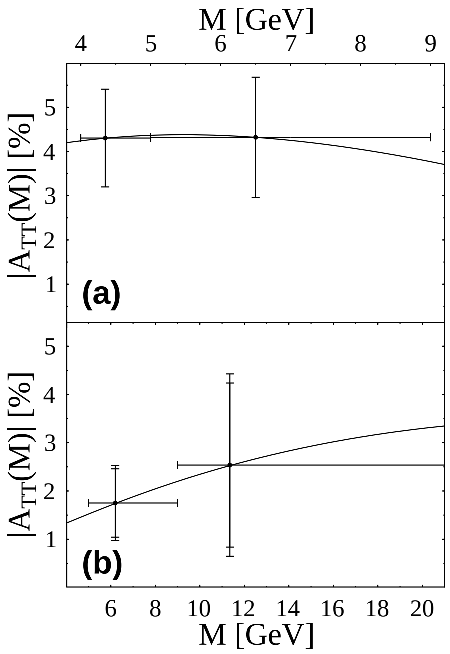

Figure 4. $A_{TT}(M)$ for (a) HERA-$\vec{N}$ and (b) RHIC (same parameters as in Fig. 2). The two error bars in (b) correspond to PHENIX with or without muon detection in the central arms.

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