DETERMINING THE SPIN STRUCTURE OF THE PHOTON
AT FUTURE COLLIDERS

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It is demonstrated that measurements of the spin asymmetry for di-jet production at future polarized colliders appear to be particularly suited for a first determination of the so far unmeasured parton densities of circularly polarized photons.

1 $\Delta f^\gamma$: Framework and Present Status

Nothing is known experimentally about the parton content of circularly polarized photons, defined by $\Delta f^\gamma(x, Q^2) \equiv f_{\gamma+}^+(x, Q^2) - f_{\gamma-}^-(x, Q^2)$, where $f_{\gamma+}^+(f_{\gamma-}^-)$ denotes the density of a parton $f$ with helicity `+' (`−') in a photon with helicity `+', and the next round of spin experiments, COMPASS and RHIC, is not sensitive to these distributions either. The $\Delta f^\gamma$ contain information different from that contained in the unpolarized ones, $f^\gamma$, and their measurement is vital for a complete understanding of the partonic structure of photons. It has been demonstrated that measurements of the structure function $g^\gamma_1$ and of di-jet spin asymmetries at a future polarized linear $e^+e^-$ collider can provide valuable information about $\Delta f^\gamma$. Di-jet spin asymmetries at HERA running in a polarized collider mode, appear to be equally promising. Here we will focus on two other recent proposals for a polarized $ep$ collider: eRHIC and THERA. As in previous work we will exploit the predictions of two very different models for the $\Delta f^\gamma$, and study the sensitivity of di-jet production to these unknown quantities. In the first case (`maximal scenario') we saturate the positivity bound $|\Delta f^\gamma(x, Q^2)| \leq f^\gamma(x, Q^2)$ at a low input scale $\mu \simeq 0.6$ GeV, using the unpolarized GRV densities $f^\gamma$. The other extreme input (`minimal scenario') is defined by a vanishing hadronic input at the scale $\mu$. We limit ourselves to leading order (LO) QCD, which is entirely sufficient for our purposes; however both scenarios can be straightforwardly extended to next-to-leading order.

2 $\Delta f^\gamma$: Tests and Signatures

The generic expression for polarized resolved photoproduction of two jets with laboratory system rapidities $\eta_1, \eta_2$ and transverse momentum $p_T$ reads in LO

$$\frac{d^3\Delta\sigma}{dp_Td\eta_1d\eta_2} = 2p_T \sum_{f^\gamma, f_p} x_{\gamma} \Delta f^\gamma(x_{\gamma}, \mu_T^2)x_{p_\gamma} \Delta f^p(x_p, \mu_T^2) \frac{d\Delta\hat{\sigma}}{dt},$$

(1)
where $x_e \equiv p_T/(2E_e)(e^{-\eta_1} + e^{-\eta_2})$ and $x_p \equiv p_T/(2E_p)(e^{\eta_1} + e^{\eta_2})$. The $\Delta f^p$ and $\Delta f^e$ in (1) denote the spin-dependent parton densities of the proton and electron, i.e., photon, respectively, see (3). The key feature of di-jet production is that a measurement of both jet rapidities allows for fully reconstructing the kinematics of the underlying hard subprocess and thus for determining $x_\gamma = x_e/y$ experimentally, with $y$ being the fraction of the electron’s energy taken by the photon. In this way it becomes possible to suppress the direct ($x_\gamma = 1$) contribution by, e.g., scanning different bins in $x_\gamma$, cf. (7).

Fig. 1 shows the di-jet spin asymmetries $A^{2-\text{jet}} \equiv d\Delta \sigma/d\sigma$ at eRHIC ($\sqrt{s} = 100$ GeV) and THERA ($\sqrt{s} = 950$ GeV) for three bins in $x_\gamma$, using $\mu_f = p_T$, $0.2 \leq y \leq 0.85$ and similar cuts for $|\eta_1 - \eta_2|$ and $(\eta_1 + \eta_2)/2$ as in (7).

Figure 1: Predictions for $A^{2-\text{jet}}$ in LO (left: eRHIC, right: THERA) using the two scenarios for $\Delta f^\gamma$ as described above and the GRSV $\Delta f^p$ densities (8). Also shown are the expected statistical errors for such a measurement assuming 70% beam polarizations and $\mathcal{L} = 200$ pb$^{-1}$.

To actually unfold information on $\Delta f^\gamma$ it is useful to introduce the concept of ‘effective parton densities’ (9). Although $A^{2-\text{jet}}$ is dominated by $gg$ scattering, all QCD subprocesses contribute. In the unpolarized case it was shown that the ratios of dominant subprocesses are roughly constant, i.e., $qq'/qg \simeq qg/gg \simeq 4/9$, such that the jet cross section factorizes approximately into some effective parton densities times a single subprocess cross section. In the polarized case this factorization is slightly broken as $qq'/qg \neq qg/gg$. However, the approximation still works surprisingly well at a level of $5 - 10\%$.
accuracy, and the appropriate effective densities are given by (see also ref. 10)
\[
\Delta f^\gamma_{\text{eff}} = \sum_q (\Delta q^\gamma + \Delta\bar{q}^\gamma) + \frac{11}{4} \Delta g^\gamma
\]  
(2)
such that the polarized double resolved jet cross section can be expressed as
\[
\Delta \sigma^{2-\text{jet}} \simeq \Delta f^\gamma_{\text{eff}} \otimes \Delta f^p_{\text{eff}} \otimes \Delta \hat{\sigma}_{qq'\to qq'}. \tag{3}
\]
As can be inferred from the l.h.s. of Fig. 1, the effective parton density approximation (dotted lines) works very well indeed. It is only for large \(p_T\) that the deviations from the exact results become more pronounced.

Given the error bars shown in Fig. 1, the prospects for distinguishing between different scenarios for \(\Delta f^\gamma_{\text{eff}}\) are rather promising for eRHIC (but remote for THera where only luminosities of \(O(10 \text{ pb}^{-1})\) seem to be realistic) provided the \(\Delta f^p_{\text{eff}}\), also entering (3), are known fairly well, which is clearly not the case yet. However, our ignorance of the \(\Delta f^p\) will be vastly reduced by the upcoming polarized pp collider RHIC and ongoing efforts in the fixed target sector. It should be kept in mind that so far nothing at all is known about the \(\Delta f^\gamma\), and even to establish the very existence of a resolved component also in the spin-dependent case would be an important step forward.

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References
1. M. Stratmann and W. Vogelsang, *Nucl. Phys. B (Proc. Suppl.)* **82**, 400 (2000).
2. M. Stratmann and W. Vogelsang, *Z. Phys. C* **74**, 641 (1997); in *Future Physics at HERA*, G. Ingelman et al. (eds.), p. 815; J.M. Butterworth et al., in DESY-PROC-1998-01, p. 120 (hep-ph/9711250).
3. M. Stratmann, and W. Vogelsang, in DESY-PROC-1999-03, p. 324.
4. M. Glück and W. Vogelsang, *Z. Phys. C* **55**, 353 (1992); *ibid. C* **57**, 309 (1993); M. Glück et al., *Phys. Lett. B* **337**, 373 (1994).
5. M. Glück, E. Reya, and A. Vogt, *Phys. Rev. D* **46**, 1973 (1992).
6. M. Stratmann and W. Vogelsang, *Phys. Lett. B* **386**, 370 (1996).
7. H1 collab.: C. Adloff et al., *Eur. Phys. J. C* **1**, 97 (1998).
8. M. Glück et al., *Phys. Rev. D* **53**, 4775 (1996).
9. B.L. Combridge and C.J. Maxwell, *Nucl. Phys. B* **239**, 429 (1984).
10. D. Indumathi et al., *Z. Phys. C* **56**, 427 (1992).