# Polarized Lambda Production at HERA

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**Abstract**

We study the prospects for HERA with polarized electron and/or proton beams to determine the functions describing the fragmentation of a longitudinally polarized parton into a polarized $\Lambda$ baryon. We examine both semi-inclusive deep-inelastic scattering (SIDIS) and photoproduction of $\Lambda$.

## 1 Introduction

Measurements of rates for single-inclusive $e^+e^-$ annihilation (SIA) into a specific hadron $H$,

$$e^+e^- \to (\gamma,\, Z) \to H\; X \quad , \tag{1}$$

play a similarly fundamental role as those of the corresponding crossed 'space-like' deep-inelastic scattering (DIS) process $ep \to e'X$. Their interpretation in terms of scale-dependent fragmentation functions $D_f^H(z,Q^2)$, the 'time-like' counterparts of the parton distribution functions $f_H(x,Q^2)$ of a hadron $H$, hence provides a further important, complementary test of perturbative QCD.

The production of $\Lambda$ baryons appears to be particularly interesting, also from a different point of view. Contrary to spinless mesons like pions and kaons, the $\Lambda$ baryon offers the rather unique possibility to study for the first time spin transfer reactions. The self-analyzing properties of its dominant weak decay $\Lambda \to p\pi^-$ and the particularly large asymmetry of the angular distribution of the decay proton in the $\Lambda$ rest-frame allow for an experimental reconstruction of the $\Lambda$ spin. Such studies of $\Lambda$ polarization could provide a completely new insight into the field of spin physics whose theoretical understanding is still far from being complete despite of recent progress, and they might also yield further information on the hadronization mechanism.

In [1] a strategy was proposed for extracting in $e^+e^-$ annihilation the functions $\Delta D_f^\Lambda(z,Q^2)$ describing the fragmentation of a longitudinally polarized parton into a longitudinally polarized $\Lambda$ [2]. At high energies, such as at LEP, even *no* beam polarization is required since the parity-violating $q\bar{q}Z$ coupling automatically generates a net polarization of the quarks. Here, ALEPH [3], DELPHI [4] and OPAL [5] have recently reported first results for the polarization of $\Lambda$'s produced on the '$Z$-resonance'.

On the other hand, after the scheduled upgrade of the HERA electron ring with spin rotators in front of the H1 and ZEUS experiments, longitudinally polarized electrons will be also available for high-energy $ep$ collisions, and semi-inclusive DIS (SIDIS) or photoproduction measurements with polarized $\Lambda$'s in the final state could be carried out. Furthermore, having also a polarized proton beam available at HERA would allow the measurement of various different twist-2

asymmetries depending on whether the $e$ and/or the $p$ beam and/or the $\Lambda$ are polarized, i.e., $\vec{e}p \to \vec{\Lambda}X$, $e\vec{p} \to \vec{\Lambda}X$, and $\vec{e}\vec{p} \to \Lambda X$ (as usual, an arrow denotes a polarized particle).

So far estimates for future $\Lambda$ experiments have relied on simple models [6] or on Monte-Carlo simulations tuned with several parameters and parametrizations of scale-*in*dependent spin-transfer coefficients $C_f^\Lambda$ which link longitudinally polarized and unpolarized fragmentation functions via [7]

$$\Delta D_f^\Lambda(z) = C_f^\Lambda(z) D_f^\Lambda(z) \quad . \tag{2}$$

Of course, such relations cannot in general hold true in QCD. Due to the different $Q^2$-evolutions of $\Delta D_f^\Lambda$ and $D_f^\Lambda$ the assumed scale independence of $C_f^\Lambda$ in (2) cannot be maintained at different values of $Q^2$, and therefore one has to specify a scale at which one implements such an ansatz.

In the following we will address the issue of fragmentation into polarized $\Lambda$'s within a detailed QCD analysis. Here it will be possible for us to work even at next-to-leading order (NLO) accuracy, as the required spin-dependent 'time-like' two-loop evolution kernels were derived recently [8]. For the first time, we will provide some realistic sets of unpolarized and polarized fragmentation functions for $\Lambda$ baryons. Since there are hardly any data sensitive to the polarized fragmentation functions $\Delta D_f^\Lambda$, one has to rely on reasonable assumptions. A useful constraint when constructing models is provided by the positivity condition (similarly to the 'space-like' case), i.e.

$$\left|\Delta D_f^\Lambda(z,Q^2)\right| \leq D_f^\Lambda(z,Q^2) \quad . \tag{3}$$

The unpolarized $D_f^\Lambda(z,Q^2)$ will be taken from an analysis of the unpolarized case where several different and rather precise measurements already exist [9]. Of course, it will turn out that the available sparse data from LEP [3, 4, 5] are by far not sufficient to completely pin down the $\Delta D_f^\Lambda(z,Q^2)$. Our various proposed sets for $\Delta D_f^\Lambda$, which are all compatible with the LEP data [3, 4, 5], are particularly suited for estimating the physics potential of HERA to determine the polarized fragmentation functions more precisely. We hence present detailed predictions for future SIDIS and photoproduction measurements at HERA using our $\Delta D_f^\Lambda$.

The remainder of this contribution is organized as follows: in the next section we briefly sketch the required formalism for unpolarized SIA and discuss our analysis of unpolarized leading order (LO) and NLO $\Lambda$ fragmentation functions. In section 3 we turn to the case of longitudinally polarized $\Lambda$ production and present our different conceivable scenarios for the $\Delta D_f^\Lambda$. In section 4 we analyze in detail possible SIDIS and photoproduction measurements at HERA as a way to further discriminate between the different proposed sets of polarized fragmentation functions. Finally our results are summarized in section 5. Further details of our analysis will be published in [10].

## 2 Unpolarized $\Lambda$ Fragmentation Functions

The cross section for the inclusive production of a hadron with energy $E_H$ in SIA at a c.m.s. energy $\sqrt{s}$, integrated over the production angle, can be written in the following way [11]:

$$\frac{1}{\sigma_{tot}}\frac{d\sigma^H}{dx_E} = \frac{1}{\sum_q e_q^2}\left[2\,F_1^H(x_E,Q^2) + F_L^H(x_E,Q^2)\right] \ , \tag{4}$$

where $x_E = 2p_H \cdot k/Q^2 = 2E_H/\sqrt{s}$ ($k$ being the momentum of the intermediate boson, $k^2 = Q^2 = s$) and $\sigma_{tot}$ is the the total cross section for $e^+e^- \to \textit{hadrons}$. The sum in (4), runs over the $n_f$ active quark flavours $q$, and the $e_q$ are the corresponding appropriate electroweak charges.

The unpolarized 'time-like' structure function $F_1^H$ is in LO related to the fragmentation functions $D_f^H(z,Q^2)$ by

$$2\,F_1^H(x_E,Q^2) \;=\; \sum_q e_q^2\left[D_q^H(x_E,Q^2)+D_{\bar{q}}^H(x_E,Q^2)\right] \quad , \tag{5}$$

the $D_f^H(z,Q^2)$ obeying LO Altarelli-Parisi-type $Q^2$-evolution equations [11]. The corresponding NLO expressions for $F_1^H$ and $F_L^H$ which include the relevant NLO coefficient functions are too lengthy to be given here but can be found in [11]. Needless to say that when going to NLO, the $Q^2$-evolution of the $D_f^H$ also has to be performed to NLO accuracy. The unpolarized two-loop 'time-like' splitting functions required here have been published in [12, 13]. It should be mentioned that our NLO distributions refer to the $\overline{\rm MS}$ scheme.

In the last few years several experiments [9] have reported measurements of the unpolarized cross section for the production of $\Lambda$ baryons, which allows an extraction of the unpolarized $\Lambda$ fragmentation functions required for constructing the polarization asymmetries and as reference distributions in the positivity constraint (3). We emphasize at this point that the wide range of c.m.s. energies covered by the data [9] ($14 \le \sqrt{s} \le 91.2$ GeV) makes a detailed QCD analysis that includes the $Q^2$-evolution of the fragmentation functions mandatory. As pointed out in [1], the QCD formalism is strictly speaking only applicable to strongly produced $\Lambda's$. A certain fraction of the data [9] will, however, consist of secondary $\Lambda$'s resulting from $e^+e^- \to \Sigma^0 X$ with the subsequent decay $\Sigma^0 \to \Lambda\gamma$, not to be included in the fragmentation functions [1]. For simplicity, we will ignore this problem and (successfully) attempt to describe the full data samples by fragmentation functions that are evolved according to the QCD $Q^2$-evolution equations.

Unless stated otherwise, we will refer to both $\Lambda^0$ and $\bar{\Lambda}^0$, which are not usually distinguished in present $e^+e^-$ experiments [9], as simply '$\Lambda$'. As a result, the obtained fragmentation functions always correspond to the sum

$$D_f^{\Lambda}(x_E,Q^2) \equiv D_f^{\Lambda^0}(x_E,Q^2) + D_f^{\bar{\Lambda}^0}(x_E,Q^2) \quad . \tag{6}$$

This also considerably simplifies the analysis, since no distinction between 'favored' and 'unfavored' distributions is required. Since no precise SIDIS data are available yet, it is not possible to obtain individual distributions for all the light flavours separately, and hence some sensible assumptions concerning them have to be made. Employing naive quark model $SU_f(3)$ arguments and neglecting any mass differences between $u, d, s$, we *assume*[1] that all the light flavours fragment equally into $\Lambda$, i.e.

$$D_u^{\Lambda} = D_d^{\Lambda} = D_s^{\Lambda} = D_{\bar{u}}^{\Lambda} = D_{\bar{d}}^{\Lambda} = D_{\bar{s}}^{\Lambda} \equiv D_q^{\Lambda} \quad . \tag{7}$$

Needless to say that the $q$ and $\bar{q}$ fragmentation functions in (7) are equal due to eq. (6).

For our analysis, we choose to work in the framework of the radiative parton model which is characterized by a rather low starting scale $\mu$ for the $Q^2$-evolutions. The radiative parton model has proven phenomenologically successful in the 'space-like' case for both unpolarized [14] and polarized [15] parton densities, and also in the 'time-like' situation for photon fragmentation functions [13, 16].

At the initial scale ($\mu_{LO}^2 = 0.23\,\mathrm{GeV}^2$, $\mu_{NLO}^2 = 0.34\,\mathrm{GeV}^2$) we choose the following simple ansatz:

$$z\,D_f^{\Lambda}(z,\mu^2) = N_f\,z^{\alpha_f}(1-z)^{\beta_f} \;, \tag{8}$$

[1]Fits allowed to be more general do not significantly improve the final $\chi^2/d.o.f.$

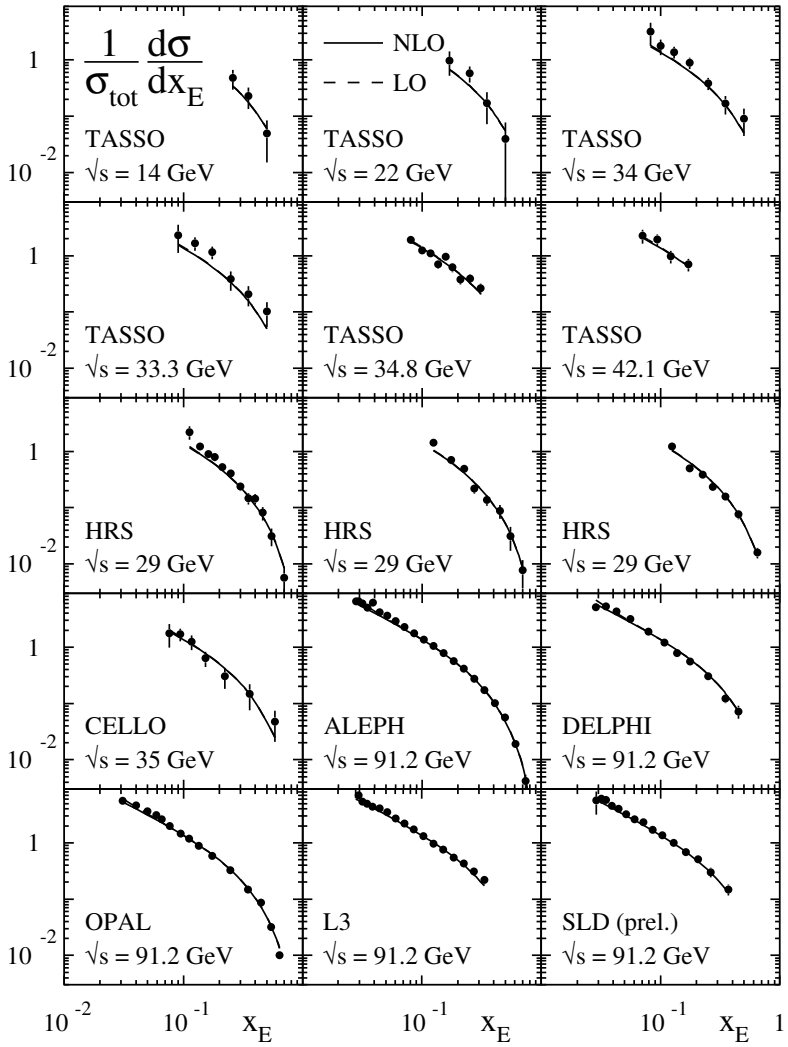


Figure 1: Comparison of LO and NLO results with all available data on unpolarized $\Lambda$ production in $e^+e^-$ annihilation [9]. Note that only data points with $x_E \geq 0.1$ have been included in our fit.

where $f = u, d, s$, and $g$. For details on the treatment of the heavy flavour contributions, i.e. by $c$ and $b$ quarks, which are of minor importance in our analysis, we refer to [10]. Utilizing eq. (7) a total of 10 free parameters remains to be fixed from a fit to the available 103 data points [9] (as usual, see, e.g. [17] for a recent analysis of pion and kaon data, we include only data with $x_E > 0.1$ in our fit to avoid possibly large non-perturbative contributions induced by finite-mass corrections). The total $\chi^2$ values are 103.55 and 104.29 in NLO and LO, respectively, and the optimal parameters in (8) can be found in [10].

A comparison of our LO and NLO results with the data is presented in fig. 1, where all the existing data [9] have been converted to the 'format' of eq.(4). One should note that the LO and the NLO results are almost indistinguishable, demonstrating the perturbative stability of the process considered. Furthermore, there is an excellent agreement between the predictions of our fits and the data even in the small-$x_E$ region which has not been included in our analysis.

# 3 Polarized Fragmentation Functions

Having obtained a reliable set of unpolarized fragmentation functions we now turn to the polarized case where unfortunately only scarce and far less precise data are available. In fact, no data at all have been obtained so far using polarized beams. The only available information comes from *un*polarized LEP measurements [3-5] profitting from the parity-violating electroweak $q\bar{q}Z$ coupling.

For such measurements, done at the mass of the $Z$ boson ('$Z$-resonance'), the cross section for the production of polarized hadrons can be written as [1, 18]

$$\frac{d\Delta\sigma^H}{d\Omega dx_E} = 3\frac{\alpha^2(Q^2)}{2s}\left[g_3^H(x_E,Q^2)(1+\cos^2\theta) - g_1^H(x_E,Q^2)\cos\theta + g_L^H(x_E,Q^2)(1-\cos^2\theta)\right] \ . \quad (9)$$

If, as for the quoted experimental results [3, 4, 5], the cross section is integrated over the angle $\theta$, the anyway small contribution from $g_1^H$ vanishes. One can then define the asymmetry

$$A^H = \frac{g_3^H + g_L^H/2}{F_1^H + F_L^H/2} \quad (10)$$

which corresponds to the '$\Lambda$-polarization' observable measured at LEP. The polarized *non*-singlet structure function $g_3^H$ is given at LO by

$$g_3^H(x_E,Q^2) = \sum_q g_q\left[\Delta D_q^H(x_E,Q^2) - \Delta D_{\bar{q}}^H(x_E,Q^2)\right] \quad , \quad (11)$$

where the $g_q$ are the appropriate effective charges (see, e.g., [10]). The complete NLO QCD corrections can be found in [10, 18]. Note that only the *valence* part of the polarized fragmentation functions can be obtained from the available LEP data [3-5], and that $\Lambda^0$'s and $\bar{\Lambda}^0$'s give contributions of opposite signs to the measured polarization and thus to $g_3^\Lambda$. Unfortunately, it turns out that with the available LEP data [3-5], all obtained on the $Z$-resonance, it is not even possible to obtain the valence distributions for all the flavours, so some assumptions have to be made here. Obviously, even further assumptions are needed for the polarized gluon and sea fragmentation functions in order to have a complete set of fragmentation functions suitable for predictions for other processes, in particular for those relevant for HERA.

The heavy flavour contributions to polarized $\Lambda$ production are neglected, and $u$ and $d$ fragmentation functions are taken to be equal in this analysis. Furthermore, polarized unfavored distributions, i.e. $\Delta D_{\bar{u}}^{\Lambda^0} = \Delta D_u^{\bar{\Lambda}^0}$, etc., and the gluon fragmentation function $\Delta D_g^\Lambda$ are assumed to be negligible at the initial scale $\mu$, an assumption which of course might deserve a further scrutiny in the future. The remaining fragmentation functions are parametrized in the following simple way

$$\Delta D_s^\Lambda(z,\mu^2) = z^\alpha D_s^\Lambda(z,\mu^2) \ , \ \Delta D_u^\Lambda(z,\mu^2) = \Delta D_d^\Lambda(z,\mu^2) = N_u\,\Delta D_s^\Lambda(z,\mu^2) \quad (12)$$

and are subject to the positivity constraints (3). These input distributions are then evolved to higher $Q^2$ via the appropriate Altarelli-Parisi equations. For the NLO evolution one has to use for this purpose the spin-dependent 'time-like' two-loop splitting functions as derived in [8] in the $\overline{\rm MS}$ scheme.

Within this framework we try three different scenarios for the polarized fragmentation functions at our low initial scale $\mu$ to cover a rather wide range of plausible models:
**Scenario 1** corresponds to the expectations from the non-relativistic naive quark model where only $s$-quarks can contribute to the fragmentation processes that eventually yield a polarized $\Lambda$,

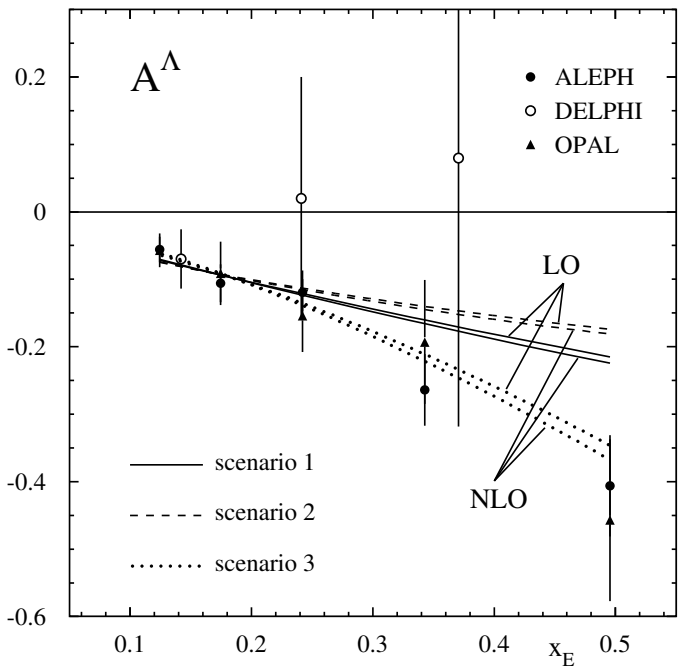


Figure 2: Comparison of LEP data [3, 4, 5] and our LO and NLO results for the asymmetry $A^\Lambda$, using the three different scenarios (see text).

even if the $\Lambda$ is formed via the decay of a heavier hyperon. We hence have $N_u = 0$ in (12) for this case.

**Scenario 2** is based on estimates by Burkardt and Jaffe [1, 19] for the DIS structure function $g_1^\Lambda$ of the $\Lambda$, predicting sizeable negative contributions from $u$ and $d$ quarks to $g_1^\Lambda$ by analogy with the breaking of the Gourdin-Ellis-Jaffe sum rule [20] for the proton's $g_1^p$. Assuming that such features also carry over to the 'time-like' case [19], we simply impose $N_u = -0.20$ (see also [7]).

**Scenario 3:** All the polarized fragmentation functions are assumed to be equal here, i.e. $N_u = 1$, contrary to the expectation of the non-relativistic quark model used in scen. 1. This rather 'extreme' scenario might be realistic if, e.g., there are sizeable contributions to polarized $\Lambda$ production from decays of heavier hyperons who have inherited the polarization of originally produced $u$ and $d$ quarks.

Our results for the asymmetry $A^\Lambda$ in (10) within the three different scenarios are compared to the available LEP data [3-5] in fig. 2. The optimal parameters in (12) for the three models can be found in [10]. As can be seen, the best agreement with the data is obtained within the (naively) most unlikely scen. 3. The differences occur mainly in the region of large $x_E$, where scen. 1 and 2 cannot fully account for the rather large observed polarization due to the positivity constraints (3). For instance, in the case of scen. 1, the asymmetry behaves asymptotically roughly like $-\Delta D_s^\Lambda / 3 D_s^\Lambda$, and even when saturating the positivity constraint (3) at around $x_E = 0.5$ it is not possible to obtain a polarization as large as the one required by the LEP data. Of course, such an argument still depends strongly on the assumed $SU(3)_f$ symmetry for the *un*polarized fragmentation functions, which could be broken. The situation concerning the $\Lambda$ fragmentation functions can only be further clarified by future precise SIDIS and photoproduction measurements for unpolarized *and* polarized beams.

Finally, in fig. 3 we show the LO and NLO partonic fragmentation asymmetries for each flavour distribution separately, i.e., $A_f \equiv \Delta D_f^\Lambda / D_f^\Lambda$. A rather large polarized gluon fragmentation function has built up in the $Q^2$-evolution in spite of the vanishing input at $\mu^2$.

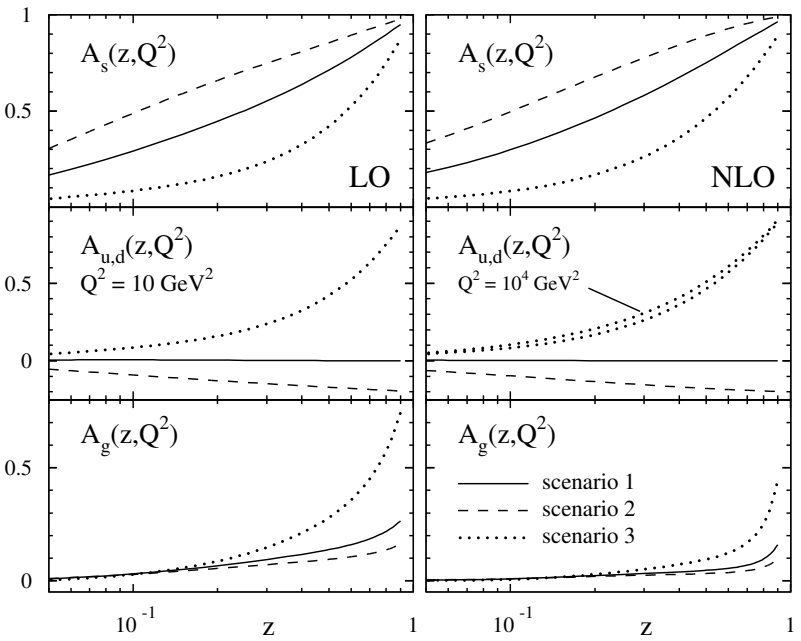


Figure 3: LO and NLO partonic fragmentation asymmetries $A_f \equiv \Delta D_f^\Lambda / D_f^\Lambda$ for $f = s$, $u = d$, and $g$ at $Q^2 = 10\,\mathrm{GeV}^2$. For the NLO $A_{u,d}$ we also show the results for $Q^2 = 10^4\,\mathrm{GeV}^2$.

# 4 SIDIS and Photoproduction Signatures at HERA

Equipped with various sets of polarized fragmentation functions, let us now turn to other processes that might further probe our distributions.

The SIDIS process $eN \to e'HX$ is also very well suited to give information on fragmentation functions. In this case, the cross section is proportional to a combination of both the parton distributions of the nucleon $N$ and the fragmentation functions for the hadron $H$. The latter thus automatically appear in a constellation different from the one probed in $e^+e^-$ annihilation.

In this work, we will only refer to the current fragmentation region by implementing a cut $x_F > 0$ on the Feynman-variable. Target fragmentation can be accounted for by the introduction of 'fracture functions' [21], but is beyond the scope of this analysis [22].

In the particular case where both nucleon and hadron are unpolarized, the cross section can be written in a way similar to the fully inclusive DIS case:

$$\frac{d\sigma^H}{dx\,dy\,dz} = \frac{4\,\pi\alpha^2 xs}{Q^4}\left[(1+(1-y)^2)F_1^{N/H}(x,z,Q^2) + \frac{(1-y)}{x}F_L^{N/H}(x,z,Q^2)\right] \tag{13}$$

with the structure function $F_1^{N/H}$ given at LO by

$$2\,F_1^{N/H}(x,z,Q^2) = \sum_{q,\overline{q}} e_q^2\, q(x,Q^2) D_q^H(z,Q^2)\ . \tag{14}$$

The corresponding NLO corrections can be found in [23, 11]. As already mentioned in the introduction, three other possible cross sections can be defined when the polarization of the lepton, the initial nucleon and the hadron are taken into account. If both nucleon and hadron are polarized and the lepton is unpolarized, the expression is similar to eqs. (13),(14) above with, however, the unpolarized parton distributions *and* the fragmentation functions to be replaced by their polarized counterparts. In the case that the lepton and either the nucleon or the hadron

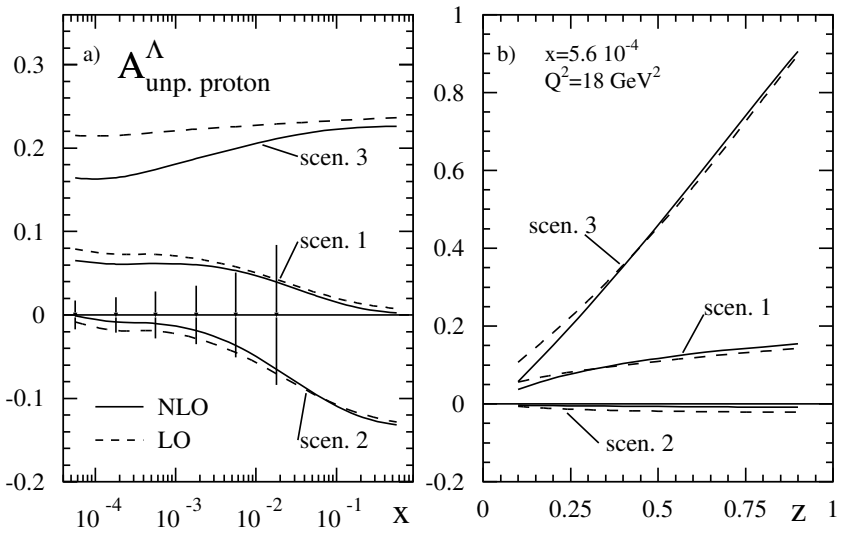


Figure 4: LO and NLO predictions for the SIDIS asymmetry for unpolarized protons and polarized $\Lambda$'s and leptons (see text) for our three distinct scenarios of polarized fragmentation functions. In **a)** we also show the expected statistical errors for such a measurement at HERA.

are polarized, the expression for the cross section is given as in the fully inclusive case by a single structure function $g_1^{N/H}(x, z, Q^2)$:

$$\frac{d\Delta\sigma^H}{dx\,dy\,dz} = \frac{8\pi\alpha^2 xys}{Q^4}\left[(2-y)\,g_1^{N/H}(x,z,Q^2)\right] \ . \tag{15}$$

Here the polarized structure function $g_1^{N/H}$ can be written as [24, 25]

$$2\,g_1^{N/H}(x,z,Q^2) = \sum_{q,\overline{q}} e_q^2\,(\Delta)q(x,Q^2)(\Delta)D_q^H(z,Q^2)\ , \tag{16}$$

the position of the $\Delta$ depending on which particle is polarized. The corresponding NLO corrections for the various polarized cross sections can be found in [24-26, 10].

The most interesting observable at HERA with respect to the determination of the polarized $\Lambda$ fragmentation functions is of course the asymmetry for the production of *polarized* $\Lambda$'s from an unpolarized proton, defined by $A^{\Lambda} \equiv g_1^{p/\Lambda}/F_1^{p/\Lambda}$ [19]. Such a measurement would be particularly suited to improve the information on polarized fragmentation functions. In fig. 4a), we show our LO and NLO predictions for HERA with polarized electrons and *un*polarized protons using the GRV parton distributions [14], integrated over the measurable range $0.1 \leq z \leq 1$. The values for $Q^2$ that correspond to each $x$ have been chosen as in [27]. Good perturbative stability of the process is found. As can be seen, the results obtained using the three distinct scenarios for polarized fragmentation functions turn out to be completely different. Since the asymmetry at small $x$ is determined by the proton's sea quarks, its behaviour can be easily understood: in scen. 1 only $s$ quarks fragment to polarized $\Lambda$'s, giving an asymmetry which is positive but about three times smaller than the one of scen. 3 where all the flavours contribute. In the case of scen. 2 the positive contribution from $s$-quark fragmentation is cancelled by a negative one from $u$ and $d$, resulting in an almost vanishing asymmetry. The interpretation is similar for the region of large $x$, where only the contribution involving $u_v$ is sizeable and the asymmetry asymptotically goes to $\int dz\Delta D_u^{\Lambda} / \int dz D_u^{\Lambda}$ for each scenario.

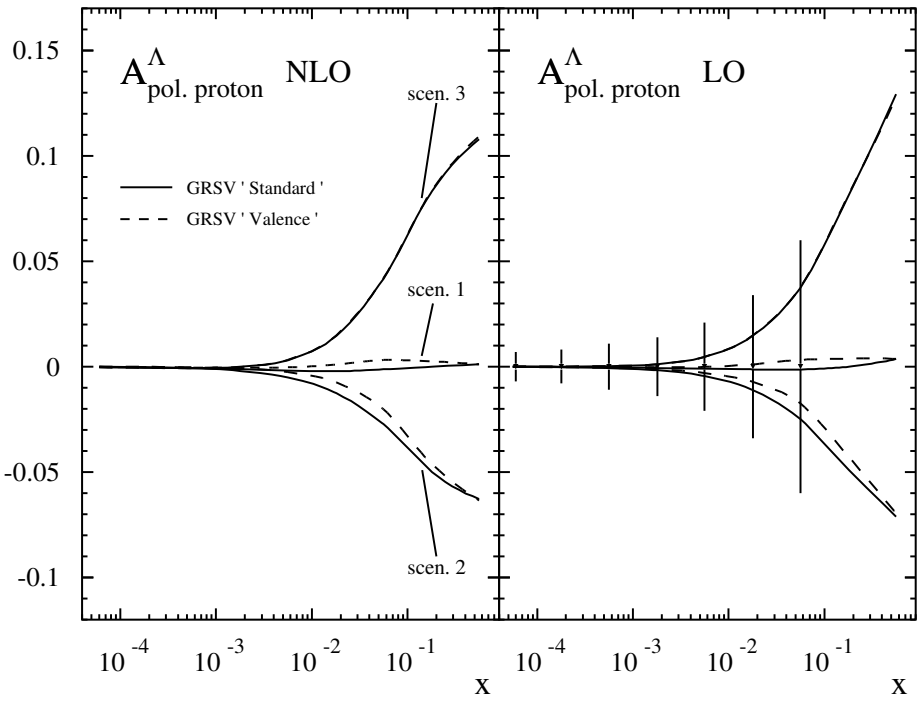


Figure 5: LO and NLO predictions for the SIDIS asymmetry for polarized protons but unpolarized leptons for two different sets of polarized parton distributions taken from [15]. Also shown are the expected statistical errors for such a measurement at HERA assuming again a luminosity of $100\,\text{pb}^{-1}$ and a $\Lambda$ detection efficiency of 0.1.

We have included in fig. 4a) also the expected statistical errors for HERA, computed assuming an integrated luminosity of 500 $\text{pb}^{-1}$ and a realistic value of $\epsilon = 0.1$ for the efficiency of $\Lambda$ detection [28]. Comparing the asymmetries and the error bars in fig. 4a) one concludes that a measurement of $A^{\Lambda}$ at small $x$ would allow a discrimination between different conceivable scenarios for polarized fragmentation functions. Fig. 4b) shows our results vs. $z$ for fixed $x = 5.6 \cdot 10^{-4}$. Again, very different asymmetries are found for the three scenarios.

The particular case of both target and hadron being polarized was originally proposed as a very good way to obtain the $\Delta s$ distribution [29]. The underlying assumption here was that only the fragmentation function $\Delta D_s^{\Lambda}$ is sizeable (as realized, e.g. in our scenario 1), and that therefore the only contribution to the polarized cross section has to be proportional to $\Delta s \Delta D_s^{\Lambda}$. In order to analyse the sensitivity of the corresponding asymmetry to $\Delta s$, we compute it using the two different GRSV sets of polarized parton densities of the proton [15], which mainly differ in the strange distribution: the so-called 'standard' set assumes an unbroken $SU(3)_f$ symmetric sea, whereas in the 'valence' scenario the sea is maximally broken and the resulting strange quark density quite small.

The results are shown in fig. 5. Unfortunately – and not unexpectedly – it turns out that the differences in the asymmetry resulting from our different models for polarized $\Lambda$ fragmentation are far larger than the ones due to employing different polarized proton strange densities. In addition, a distinction between different $\Delta s$ would remain elusive even if the spin-dependent $\Lambda$ fragmentation functions were known to good accuracy, as can be seen from the error bars in fig. 5 which were obtained using the same parameters as before.

Finally, let us examine the case of photoproduction of $\Lambda$'s at HERA. We can be very brief here and refer the reader to the dedicated report on photoproduction for this workshop [30],

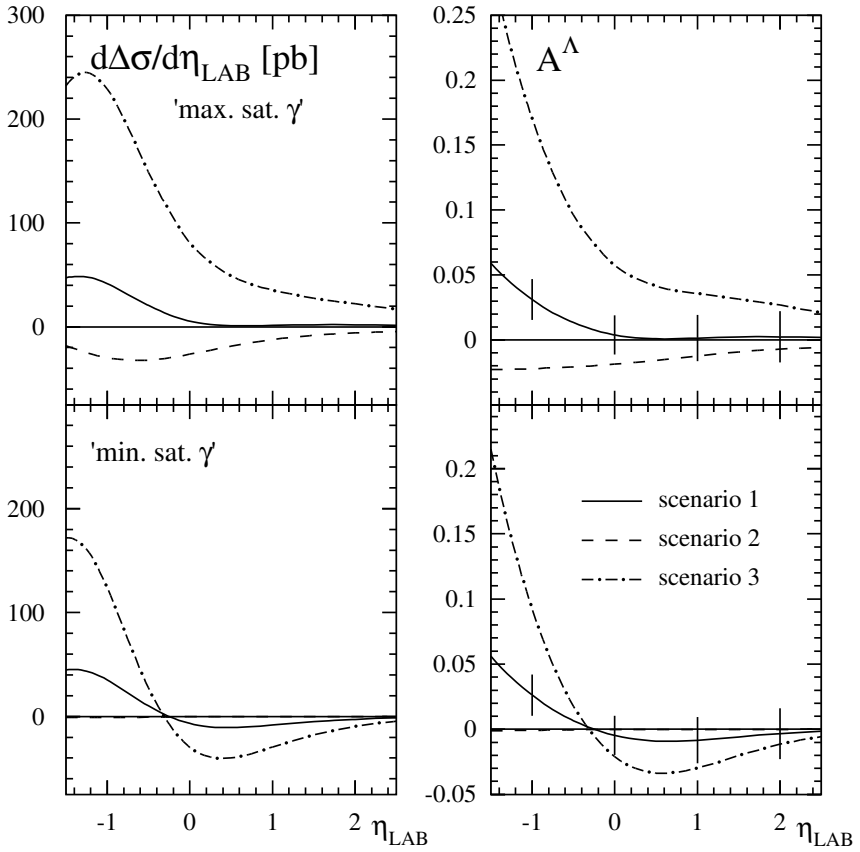


Figure 6: $\eta_{LAB}$-dependence of the polarized single-inclusive $\Lambda$ photoproduction cross section and of the corresponding asymmetry $A^\Lambda$ at HERA, integrated over $p_T^\Lambda > 2\,\mathrm{GeV}$. The renormalization/factorization scale was chosen to be $p_T^\Lambda$. In the upper part the resolved contribution to the cross section has been calculated with the 'maximally' saturated set of polarized photonic parton distributions whereas the 'minimally' saturated one was used in the lower half [30]. Also shown are the expected statistical errors for such a measurement at HERA assuming a luminosity of $100\,\mathrm{pb}^{-1}$ and a $\Lambda$ detection efficiency of 0.1.

where all details like, e.g. the polarized parton distributions of the photon and the kinematical cuts suitable for photoproduction, are discussed.

Here it appears very promising to study the $\eta_{LAB}$-distribution of the photoproduction cross section for $\Lambda$'s and the corresponding asymmetry, where $\eta_{LAB}$ is the laboratory frame rapidity defined to be positive in the proton forward direction. Fig. 6 shows our results for such a calculation where we have integrated over $p_T^\Lambda > 2\,\mathrm{GeV}$. To calculate the resolved photon contribution to the cross section we have used two conceivable, extreme scenarios for the experimentally completely unknown parton distributions of a longitudinally polarized photon $\Delta f^\gamma$ (see [30] for details). As can be inferred from fig. 6 there is a strong sensitivity to our proposed different scenarios for the $\Delta D_f^\Lambda$, but a comparison of the upper and lower parts of fig. 6, which have been calculated for different assumptions for the resolved contribution, also reveals that our ignorance concerning the $\Delta f^\gamma$ sets a potential limitation to an extraction of the fragmentation functions. The $\Delta f^\gamma$ can of course be further constrained in other conceivable photoproduction measurements in polarized $ep$ collisions at HERA like dijet production [30]. Finally it should be stressed that due to the small $Q^2$, photoproduction benefits from larger rates, and hence reasonable measurements can be performed at even rather low luminosities of about $100\,\mathrm{pb}^{-1}$.

# 5 Summary and Conclusions

We have analyzed HERA's capability of pinning down the spin-dependent fragmentation functions for $\Lambda$ baryons via semi-inclusive deep-inelastic scattering or photoproduction of $\Lambda$'s.

Working within the framework of the radiative parton model, our starting point has been a fit to unpolarized data for $\Lambda$ production taken in $e^+e^-$ annihilation, yielding a set of realistic unpolarized fragmentation functions for the $\Lambda$. We have then made simple assumptions for the relation between the spin-dependent and the unpolarized $\Lambda$ fragmentation functions at the input scale for the $Q^2$ evolution. Taking into account the sparse LEP data on $\Lambda$ polarization, we were able to set up three distinct 'toy scenarios' for the spin-dependent $\Lambda$ fragmentation functions. We emphasize that our proposed sets can by no means cover all the allowed possibilities for the polarized fragmentation functions, the main reason being that the LEP data are only sensitive to the valence part of the polarized fragmentation functions. Thus, there are still big uncertainties related to the 'unfavored' quark and gluon fragmentation functions, making further measurements in other processes indispensable.

Under these premises, we have considered $\Lambda$ production at HERA, both in a situation with polarized electrons scattered of unpolarized protons and vice versa. It turns out that SIDIS measurements in the first case should be particularly well suited to yield further information on the $\Delta D_f^\Lambda$: differences between the asymmetries obtained when using different sets of $\Delta D_f^\Lambda$ are usually larger than the expected statistical errors. In contrast to this, having a polarized proton beam does not appear beneficial in any way as far as $\Lambda$ production at HERA is concerned. Finally, we found that also photoproduction of $\Lambda$'s in scattering of polarized photons off the unpolarized proton beam at HERA shows strong sensitivity to the $\Delta D_f^\Lambda$, even though here the unknown contribution from resolved photons will set limitations to an extraction of the polarized fragmentation functions.

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# References

[1] M. Burkardt and R.L. Jaffe, *Phys. Rev. Lett.* **70** (1993) 2537.

[2] R.L. Jaffe and X. Ji, *Phys. Rev. Lett.* **71** (1993) 2547; X. Ji, *Phys. Rev.* **D49** (1994) 114; W. Lu, X. Li and H. Hu, *Phys. Rev.* **D53** (1996) 131.

[3] D. Buskulic et al., ALEPH collab., *Phys. Lett.* **B374** (1996) 319; paper submitted to the XVIII International Symposium on Lepton Photon Interactions, 1997, Hamburg, Germany, paper no. **LP279**.

[4] DELPHI collab., DELPHI 95-86 PHYS 521 (paper submitted to the EPS-HEP 95 conference, Brussels, 1995).

[5] K. Ackerstaff et al., OPAL collab., `CERN-PPE/97-104`, `hep-ex/9708027`.

[6] I. Bigi, *Nuovo Cim.* **41A** (1977) 43, 581; G. Gustafson and J. Häkkinen, *Phys. Lett.* **B303** (1993) 350; M. Nzar and P. Hoodbhoy, *Phys. Rev.* **D51** (1995) 32.

[7] A. Bravar, A. Kotzinian, and D. von Harrach, `hep-ph/9701384`.

[8] M. Stratmann and W. Vogelsang, *Nucl. Phys.* **B496** (1997) 41.

[9] G. Alexander et al., OPAL collab., *Z. Phys.* **C73** (1997) 569; M. Acciarri et al., L3 collab., *Phys. Lett.* **B407** (1997) 389; K. Abe et al., SLD collab., SLAC-PUB-7571, paper submitted

to the XVIII International Symposium on Lepton Photon Interactions, 1997, Hamburg, Germany, and to the International Europhysics Conference on High Energy Physics, 1997, Jerusalem, Israel; For a compilation of the previously published $e^+e^-$ data see: G.D. Lafferty, P.I. Reeves, and M.R. Whalley, *J. Phys.* **G21** (1995) A1.

[10] D. de Florian, M. Stratmann and W. Vogelsang, CERN-TH/97-286 *(in preparation)*.

[11] G. Altarelli, R.K. Ellis, G. Martinelli and S.Y. Pi, *Nucl. Phys.* **B160** (1979) 301; W. Furmanski and R. Petronzio, *Z. Phys.* **C11** (1982) 293; P. Nason and B. Webber, *Nucl. Phys.* **B421** (1994) 473; **B480** (1996) 755 (E).

[12] G. Curci, W. Furmanski and R. Petronzio, *Nucl. Phys.* **B175** (1980) 27; W. Furmanski and R. Petronzio, *Phys. Lett.* **97B** (1980) 437; L. Beaulieu, E.G. Floratos and C. Kounnas, *Nucl. Phys.* **B166** (1980) 321; P.J. Rijken and W.L. van Neerven, *Nucl. Phys.* **B487** (1997) 233; J. Binnewies, B.A. Kniehl and G. Kramer, `hep-ph/9702408`.

[13] M. Glück, E. Reya and A. Vogt, *Phys. Rev.* **D48** (1993) 116; **D51** (1995) 1427 (E).

[14] M. Glück, E. Reya and A. Vogt, *Z. Phys.* **C67** (1995) 433.

[15] M. Glück, E. Reya, M. Stratmann and W. Vogelsang, *Phys. Rev.* **D53** (1996) 4775.

[16] K. Ackerstaff et al., OPAL collab., `CERN-PPE/97-086`, `hep-ex/9708020`.

[17] J. Binnewies, B.A. Kniehl and G. Kramer, *Phys. Rev.* **D52** (1995) 4947.

[18] V. Ravindran, *Nucl.Phys.* **B490** (1997) 272; *Phys.Lett.* **B398** (1997) 169.

[19] R.L. Jaffe, *Phys. Rev.* **D54** (1996) 6581.

[20] M. Gourdin, *Nucl. Phys.* **B38** (1972) 418; J. Ellis and R.L. Jaffe, *Phys. Rev.* **D9** (1974) 1444; **D10** (1974) 1669 (E).

[21] L. Trentadue and G. Veneziano, *Phys. Lett.* **B323** (1993) 201.

[22] For a study on polarized $\Lambda$ production in the target fragmentation region of DIS see: J. Ellis, D. Kharzeev and A. Kotzinian, *Z. Phys.* **C69** (1996) 467.

[23] D. Graudenz, *Nucl. Phys.* **B432** (1994) 351.

[24] D. de Florian, C. García Canal and R. Sassot, *Nucl. Phys.* **B470** (1996) 195.

[25] D. de Florian and R. Sassot, *Nucl. Phys.* **B488** (1997) 367.

[26] M. Stratmann, Ph.D. Thesis, Univ. Dortmund report DO-TH 96/24 (unpublished).

[27] R.D. Ball, A. Deshpande, S. Forte, V.W. Hughes, J. Lichtenstadt and G. Ridolfi, proceedings of the 1995/96 workshop on 'Future Physics at HERA', Hamburg, Germany, eds. G. Ingelman, A. De Roeck and R. Klanner, p. 777.

[28] A. De Roeck, private communication.

[29] W. Lu and B.-Q. Ma, *Phys. Lett.* **B357** (1995) 419; W. Lu, *Phys. Lett.* **B373** (1996) 223.

[30] J.M. Butterworth, N. Goodman, M. Stratmann and W. Vogelsang, these proceedings.