How to Learn about Polarized Lambda-Baryon Fragmentation Functions?

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We study the inclusive production of Λ $(\bar{\Lambda})$ in several high energy collision processes (e^+e^-, $e^{\pm}p$, $\nu(\bar{\nu})p$, pp), in view of an accurate determination of the polarized fragmentation functions of a quark into a Λ $(\bar{\Lambda})$. We will recall that present data are unable to distinguish between various theoretical models, in particular for the spin transfer mechanisms and we will indicate how future measurements will provide ways to discriminate between them and also how to achieve a necessary quark flavor separation.

The usual parton ($f = q, \bar{q}, g$) distribution functions $f_H(x, Q^2)$ of a hadron H, which are extracted from Deep Inelastic Scattering (DIS) for a space-like energy scale ($Q^2 \leq 0$), have counterparts in the time-like region ($Q^2 \geq 0$), which are the hadron fragmentation functions $D_f^H(z, Q^2)$. They represent the probability to find the hadron H with a fraction z of the momentum of the parent parton ($f = q, \bar{q}, g$), at a given value of Q^2. Like distribution functions, fragmentation functions are *universal* , that is process-independent, and likewise, their Q^2 dependence is fully predicted by the QCD evolution equations. They can be measured in various high energy collision processes namely, e^+e^- annihilation, $e^+e^- \to (\gamma, Z) \to HX$, semi-inclusive DIS, $lp \to l'HX$ and single-inclusive pp collisions, $pp \to HX$. So far, the best known fragmentation funtions are D_f^{π} and D_f^K, corresponding to the most copiously produced light mesons π and K. Our purpose here is to consider the baryon fragmentation functions and more specifically to examine the case of Λ $(\bar{\Lambda})$. The self-analyzing properties of Λ $(\bar{\Lambda})$ make this spin-half baryon particularly interesting to study spin transfer mechanisms. The fragmentation of a longitudinally polarized parton into a longitudinally polarized Λ will be described in terms of

$$\Delta D_f^{\Lambda}(z, Q^2) = D_{f(+)}^{\Lambda(+)}(z, Q^2) - D_{f(+)}^{\Lambda(-)}(z, Q^2) \ , \quad (1)$$

where $D_{f(+)}^{\Lambda(+)}(z, Q^2)$ $[D_{f(+)}^{\Lambda(-)}(z, Q^2)]$ is the probability to find a Λ with positive [negative] helicity in a parton f with positive helicity. Clearly one obtains the unpolarized fragmentation function D_f^{Λ} by taking in (1), the sum instead of the difference. For the fragmentation of a transversely polarized parton into a transversely polarized Λ, one uses (1) to define $\Delta_T D_f^{\Lambda}(z, Q^2)$ in complete analogy with $\Delta D_f^{\Lambda}(z, Q^2)$.

The production of Λ $(\bar{\Lambda})$ in e^+e^- annihilation can be used to determine $D_f^{\Lambda}(z, Q^2)$ using a standard parametrization, at initial scale μ^2

$$D_f^{\Lambda}(z, \mu^2) = N_f z^{\alpha_f}(1-z)^{\beta_f} \ . \quad (2)$$

To reduce the number of free parameters occuring above, one must make some simplifying assumptions based on, *e.g.* $SU_f(3)$ arguments. The *ten* free parameters, needed to include light quarks, heavy quarks and gluons, were obtained by fitting the world data for $14 GeV \leq \sqrt{s} \leq 91.2 GeV$, in a leading and next-to-leading order (LO and NLO) QCD analysis [1]. In order to construct ΔD_f^{Λ}, one usually makes the assumption

$$\Delta D_f^{\Lambda}(z) = C_f^{\Lambda}(z) D_f^{\Lambda}(z) \ , \quad (3)$$

at a given scale, where $C_f^{\Lambda}(z)$ are the spin transfer coefficients, for which several models can be found in the literature. In ref.[1], ΔD_f^{Λ} was neglected for heavy quarks and gluon and they take the following simple parametrization

$$\Delta D_u^{\Lambda} = \Delta D_d^{\Lambda} = N_u \Delta D_s^{\Lambda} \ \textit{and} \ \Delta D_s^{\Lambda} = z^{\alpha} D_s \ , \quad (4)$$

in terms of *two* new parameters α and N_u at a given scale. To cover a wide range of plausible models, they consider three different scenarios:

1) In the non-relativistic quark model, only

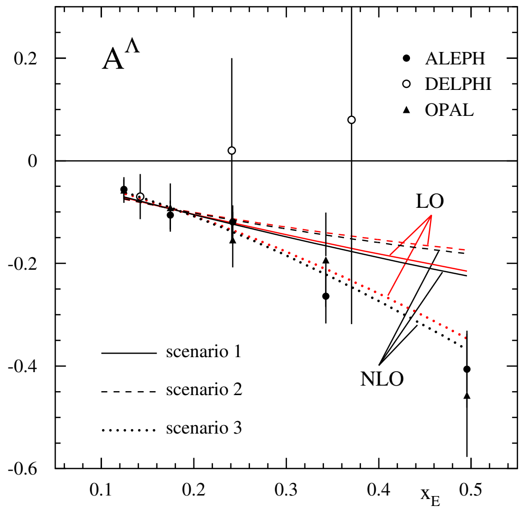

Figure 1. Comparison of the LEP data for A^Λ, versus $x_E = 2E_\Lambda/\sqrt{s}$, and the LO and NLO results using different scenarios described in the text (Taken from ref.[1]).

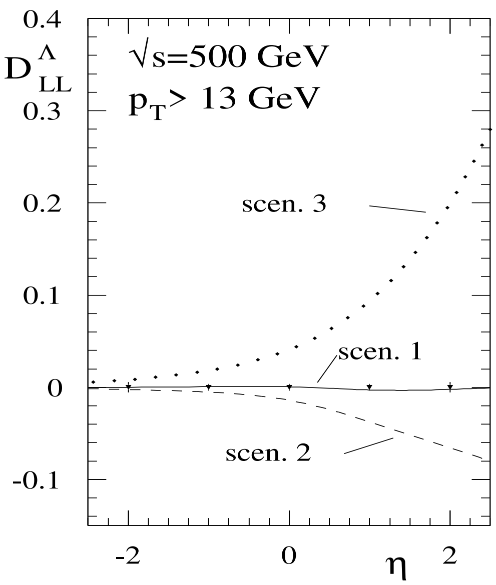

Figure 2. The helicity transfer parameter D^Λ_{LL}, versus the rapidity of the Λ at RHIC maximum energy, using different scenarios described in the text (Taken from ref.[4]).

strange quarks can contribute, therefore $N_u = 0$.
2) By transposing the estimate of ref.[2] for the polarized u and d quark distributions in a Λ, to the polarized fragmentation functions, one gets $N_u = -0.2$.
3) By assuming that all polarized fragmentation functions are equal, which is an extreme case, one gets $N_u = 1$.
The longitudinal Λ polarization A^Λ, which can be directly expressed in terms of the ΔD^Λ_f $'s$ (see ref.[1]), has been measured at LEP by several experiments and is shown in Fig.1. The results of the theoretical calculations for the three scenarios are also displayed. We note a small difference between LO and NLO and, although data are not accurate enough to allow a clean discrimination between these three scenarios, it seems that scenario 3) is a bit favored in the large x_E region.

One can then use these results to make predictions for Λ production in semi-inclusive DIS, with only the electron beam longitudinally polarized. The Λ polarization P^Λ is again driven by the ΔD^Λ_f $'s$, since one has

$$P^\Lambda \sim \sum_q e_q^2 q(x) \Delta D^\Lambda_q(z) / \sum_q e_q^2 q(x) D^\Lambda_q(z) \ . \quad (5)$$

From the values of N_u, one anticipates that P^Λ will be small for 1), negative for 2) and large and positive for 3) and the exact results can be found in ref.[1]. Another set of predictions, using a different approach without QCD evolution, is given in ref.[3] and it will be interesting to compare them with data from future polarized DIS experiments.

Let us now move to another area where we can test these polarized fragmentation functions, namely spin transfer in pp collisions. The forthcoming polarized pp collider at BNL RHIC will allow to undertake a vast spin physics programme at center of mass energies up to $\sqrt{s} = 500 GeV$. We are interested in the reaction $\vec{p}p \to \vec{\Lambda}X$,

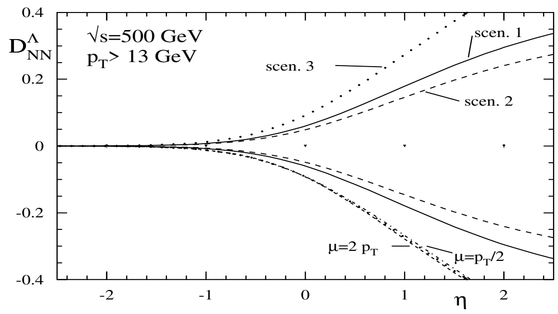

Figure 3. Upper and lower bounds for the spin-transfer parameter D^{Λ}_{NN}, versus the rapidity of the Λ at RHIC maximum energy, using saturated positivity bounds and different scenarios described in the text. For scenario 3) we show the uncertainty induced by the variation of the hard scale μ from $p_T/2$ to $2p_T$ (Taken from ref.[6]).

where both the initial p and the produced Λ are longitudinaly polarized and we consider the helicity transfer parameter D^{Λ}_{LL} defined as follows

$$D^{\Lambda}_{LL}(\eta, p_T) = (d\sigma_{++} - d\sigma_{+-})/(d\sigma_{++} + d\sigma_{+-}) \ ,(6)$$

where η and p_T are the rapidity and the transverse momentum of the outgoing Λ. $d\sigma_{++}$ $[d\sigma_{+-}]$ denotes the cross section where the p and Λ helicities have the same [opposite] sign. η is positive for a Λ in the direction of $\overrightarrow{p}$ and p_T is large. D^{Λ}_{LL} is directly related to the ΔD^{Λ}_{f} *'s*, whose exact expression can be found in ref.[4] and it is possible to make predictions which are shown in Fig.2. Again we see that the sign and magnitude of D^{Λ}_{LL} are strongly correlated to the values of N_u and given the smallness of the expected statistical errors, it will be now rather easy to pin down the right mechanism.

We can also consider the case where both p and Λ are transversely polarized and the corresponding spin-transfer parameter D^{Λ}_{NN}, is defined as in eq.(6), where helicity is replaced by transverse polarization. This spin observable is related to the quark transversity distributions, so called $h_1^q(x, Q^2)$ and to the transversity fragmentation functions $\Delta_T D^{\Lambda}_f(z, Q^2)$ mentioned earlier. Needless to say that we have no experimental information on these quantities, however we can derive some bounds on D^{Λ}_{NN}, using positivity arguments. We recall that positivity leads to the inequality [5]

$$2|h_1^q(x, Q^2)| \leq q(x, Q^2) + \Delta q(x, Q^2) \qquad (7)$$

and a similar constraint holds for hadron fragmentation functions [6],namely

$$2|\Delta_T D_q^H(z, Q^2)| \leq D_q^H(z, Q^2) + \Delta D_q^H(z, Q^2) \ .(8)$$

By saturating the above inequalities, we get an estimate for an upper and lower bounds for D^{Λ}_{NN} which are displayed in Fig.3. The larger allowed region corresponds to scenario 3), due to the value of N_u and from the expected statistical accuracy we get rather small error bars.

Finally it is important to mention that Λ ($\bar{\Lambda}$) production in ν and $\bar{\nu}$ DIS will allow a clean quark flavor separation for unpolarized and polarized fragmentation functions [7]. This is due to the fact that $\nu(\bar{\nu})$ DIS provides a source of polarized quarks with specific flavor.

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