TRANSVERSE Λ POLARIZATION IN UNPOLARIZED SEMI-INCLUSIVE DIS *

M. ANSELMINO, D. BOER, U. D’ALESIO, F. MURGIA

Dipartimento di Fisica Teorica, Università di Torino, and INFN, Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy

RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA

INFN, Sezione di Cagliari, and Dipartimento di Fisica, Università di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

The long-standing problem of transverse Λ polarization in high-energy collisions of unpolarized hadrons can be tackled by considering new, spin and \( k_\perp \)-dependent quark fragmentation functions for an unpolarized quark into a polarized, spin-1/2 hadron. Simple phenomenological parameterizations of these new “polarizing fragmentation functions”, which describe quite well the experimental data on Λ and \( \bar{\Lambda} \) hyperons produced in \( p - A \) processes, are utilized and extended here to give predictions for transverse Λ polarization in semi-inclusive DIS.

1 Transverse Λ polarization in hadronic collisions

Transverse hyperon polarization in high-energy, unpolarized hadron collisions is a long-standing challenge for theoretical models of hadronic reactions. We have recently proposed an approach to this problem based on perturbative QCD and its factorization theorems, and including polarization and intrinsic transverse momentum, \( k_\perp \), effects. This approach was already applied to the study of transverse single spin asymmetries in inclusive particle production at large \( x_F \) and medium-large \( p_T \). It requires the introduction of a new class of leading-twist, polarized and \( k_\perp \)-dependent distributions and fragmentation functions (FF). These new functions can be extracted by fitting available experimental data and consistently applied to give predictions for other processes.

A large amount of data on transverse Λ polarization, \( P_\Lambda^T \), in unpolarized hadronic collisions is available; the main properties of experimental data at \( x_F \gtrsim 0.2 \) can be summarized as follows: 1) \( P_\Lambda^T < 0 \); 2) Starting from zero at very low \( p_T \), \( |P_\Lambda^T| \) increases up to \( p_T \sim 1 \text{ GeV} \), where it flattens to an almost constant value, up to the highest measured \( p_T \) of about 3 GeV; 3) The value of \( |P_\Lambda^T| \) in this plateau regime increases almost linearly with \( x_F \); 4) \( P_\Lambda^T \) is compatible with zero. In our approach, the transverse hyperon polarization in unpolarized hadronic reactions at large \( p_T \) can be written, e.g. for the \( pp \to \Lambda^+ X \) case, as follows.

*Talk delivered by F. Murgia at the IX International Workshop on Deep Inelastic Scattering (DIS2001), Bologna, 27 April - 1 May 2001.
We want now to extend our analysis to the case of Λ polarization in unpolarized semi-inclusive DIS (SIDIS), ℓp → ℓ'Λ↑ X. We neglect the intrinsic \( k_\perp \) effects in the unpolarized initial proton. Then, at leading twist and leading order, in the virtual boson-proton c.m. reference frame the virtual boson-quark scattering is collinear, and the intrinsic transverse momentum of the Λ with respect to the fragmenting quark and its observed transverse momentum \( p_T \) coincide. To study \( P_T^Λ(x_F, p_T) \) in the SIDIS case we then need the full \( k_\perp \) dependence of the polarizing FF. To this end we consider a simple gaussian parameterization, defining

\[
P_T^Λ(x_F, p_T) = \frac{dσ^{pp→Λ↑X} - dσ^{pp→Λ^+X}}{dσ^{pp→Λ↑X}}
\]

\[
= \sum \int dx_a dx_b \int d^2k_\perp f_{a/p}(x_a) f_{b/p}(x_b) d\hat{σ}(x_a, x_b; k_\perp) \Delta^N D_{Λ/c}(z, k_\perp),
\]

where \( dσ^{pp→ΛX} \) stands for \( E_Λ dσ^{pp→ΛX}/d^3p_Λ \); \( f_{a/p}(x_a) \) are the usual unpolarized parton densities; \( d\hat{σ}(x_a, x_b; k_\perp) \) is the lowest order partonic cross section with the inclusion of \( k_\perp \) effects; \( D_{Λ/c}(z, k_\perp) \) and \( Δ^N D_{Λ/c}(z, k_\perp) \) are respectively the unpolarized and the polarizing FF for the process \( c → Λ + X \).

Eq. (1) is based on some simplifying conditions: 1) As suggested by experimental data, the Λ polarization is assumed to be generated in the fragmentation process; 2) Λ FF include also Λ’s coming from decays of other hyperon resonances. In order to reduce the number of parameters, as a first step the full integration over \( k_\perp \) is replaced by evaluation at an effective, average \( ⟨k_\perp^0(z)⟩ \); \( ⟨k_\perp^0(z)⟩ \) and \( Δ^N D_{Λ/c}(z, ⟨k_\perp^0⟩) \) are then parameterized by using simple expressions of the form \( Nz^a(1 - z)^b \). We impose appropriate positivity bounds on \( Δ^N D_{Λ/c} \) and consider only leading (or valence, \( q_v \)) quarks in the fragmentation process. In this way, a very good fit to experimental data for Λ and \( ̅Λ \) polarization, at \( p_T > 1 \) GeV, can be obtained. Moreover, it results that \( Δ^N D_{Λ/v,u,d} < 0 \), \( Δ^N D_{Λ/υ} > 0 \), and \( Δ^N D_{Λ/υ} > |Δ^N D_{Λ/v,u,d}| \). Notice that these general features are similar to those expected for the longitudinally polarized FF, \( Δ^N D_{Λ/q}(z) \), in the well-known Burkardt-Jaffe model.

### 2 \( P_T^Λ \) and \( P_T^Λ \) in semi-inclusive DIS at \( x_F > 0 \)

We want now to extend our analysis to the case of Λ polarization in unpolarized semi-inclusive DIS (SIDIS), ℓp → ℓ'Λ↑ X. We neglect the intrinsic \( k_\perp \) effects in the unpolarized initial proton. Then, at leading twist and leading order, in the virtual boson-proton c.m. reference frame the virtual boson-quark scattering is collinear, and the intrinsic transverse momentum of the Λ with respect to the fragmenting quark and its observed transverse momentum \( p_T \) coincide. To study \( P_T^Λ(x_F, p_T) \) in the SIDIS case we then need the full \( k_\perp \) dependence of the polarizing FF. To this end we consider a simple gaussian parameterization, defining

\[
D_{Λ/q}(z, k_\perp) = \frac{d(z)}{M^2} \exp\left[-\frac{k_\perp^2}{M^2 f(z)}\right],
\]

\[
Δ^N D_{Λ/q}(z, k_\perp) = \frac{δ(z) k_\perp}{M^2} \exp\left[-\frac{k_\perp^2}{M^2 φ(z)}\right] \sin φ,
\]
where $\phi$ is the azimuthal angle between the $\Lambda$ intrinsic transverse momentum and the polarization vector. We use the general relations $\int d^2k_\perp D_{\Lambda/q}(z, k_\perp) = D_{\Lambda/q}(z)$, $\int d^2k_\perp k_\perp^2 D_{\Lambda/q}(z, k_\perp) = \langle k_\perp^2(z) \rangle D_{\Lambda/q}(z)$. By imposing the positivity bound $|\Delta^N D_{\Lambda/q}(z, k_\perp)| / D_{\Lambda/q}(z, k_\perp) \leq 1 \forall z$ and $k_\perp$, and requiring full consistency with the approximations and parameterizations adopted in the fitting procedure to $pp \rightarrow \Lambda^\uparrow X$ data [that is, we require that, when appropriately used into Eq. (1), our parameterizations (2), (3) obey the simplifying assumption $\int d^2k_\perp F(k_\perp) \Rightarrow F(|k_\perp^0|)]$, we find:

$$D_{\Lambda/q}(z, k_\perp) = \frac{D_{\Lambda/q}(z)}{\pi(\frac{k_\perp^2}{2}(z))} \exp \left[ -\frac{k_\perp^2}{(\frac{k_\perp^2}{2}(z))} \right] , \quad (4)$$

$$\Delta^N D_{\Lambda/q}(z, k_\perp) = \Delta^N D_{\Lambda/q}(z, |k_\perp^0|) \frac{4\sqrt{2}}{\sqrt{\pi}} \frac{k_\perp}{(\frac{k_\perp^2}{2}(z))^{3/2}} \exp \left[ -2\frac{k_\perp^2}{(\frac{k_\perp^2}{2}(z))} \right] . \quad (5)$$

Notice that: 1) The factor 2 of difference in the exponential of $\Delta^N D_{\Lambda/q}$ w.r.t. $D_{\Lambda/q}$ is required by consistency with the approach in the $p - A$ case, and is by far more stringent than the most general bound ; 2) There is a simple relation between our “effective” $k_\perp^2(z)$ and the physical, observable $\langle k_\perp^2(z) \rangle$ of the $\Lambda$ inside the fragmenting jet: $\langle k_\perp^2(z) \rangle = 2 \langle |k_\perp^0(z)|^2 \rangle$. These relations are a very direct consequence of our approach and can be tested in SIDIS processes.

Finally, the positivity bound reads now

$$\frac{|\Delta^N D_{\Lambda/q}(z, |k_\perp^0|)|}{D_{\Lambda/q}(z)/2} \leq \frac{\sqrt{\pi}}{2\sqrt{\pi}} \simeq 0.465 . \quad (6)$$

This bound is consistently satisfied by the original parameterizations obtained for the $p A \rightarrow \Lambda^\uparrow X$ case.

Choosing the $\hat{z}$-axis along the virtual boson direction, the $\hat{x}$-axis along the $\Lambda$ transverse momentum $p_T$, the transverse $\uparrow$ direction results along the positive $\hat{y}$-axis, and $\phi = \pi/2$. In this configuration, $P^A_T$ is given, in the $\ell p \rightarrow \ell' \Lambda^\uparrow X$ case (HERMES, H1, ZEUS, COMPASS, E665, etc.) with e.m. contributions only, by

$$P^A_T(x, y, z, p_T) = \sum_q e_q^2 f_{q/p}(x) \frac{d\hat{\sigma}^q}{dy} |\Delta^N D_{\Lambda/q}(z, |p_T^0|)| \frac{d\hat{\sigma}^N D_{\Lambda/q}(z, |p_T^0|)}{D_{\Lambda/q}(z, |p_T^0|)} . \quad (7)$$

In the case of weak CC processes, $\nu \mu p \rightarrow \mu^- \Lambda^\uparrow X$ (NOMAD, $\nu$-factories, etc.) one finds ($f_{u/p}(x) = u$, etc.)

$$P^A_T(x, y, z, p_T) = \frac{(d + R s) N D_{\Lambda/q} + \bar{u} \left( \Delta^N D_{\Lambda/q} + R \Delta^N D_{\Lambda/q} \right) (1 - y)^2}{(d + R s) N D_{\Lambda/q} + \bar{u} \left( \Delta^N D_{\Lambda/q} + R D_{\Lambda/q} \right)(1 - y)^2} , \quad (8)$$

3
where $R = \tan^2 \theta_c \simeq 0.056$; notice that at large $x$ and $z$ $P^\Lambda_T \simeq \Delta N_D^\Lambda / u / D^\Lambda / u$, and one may have a direct access to the polarizing FF. Analogous expressions hold for the $\bar{\Lambda}$ case, by interchanging $D_q$ with $D_{\bar{q}}$ into (7), (8), and for the $\bar{\nu}$ case by interchanging $q, D_q$ with $\bar{q}, D_{\bar{q}}$ into (8).

As an example, we present in Fig. 1 some preliminary predictions for $P^\Lambda_T$ and $P^\Lambda_T$ vs. $z$ and $p_T$ for kinematical configurations typical of HERMES and NOMAD experiments. Our results are compatible with present NOMAD data for $P^\Lambda_T$ in CC interactions; however, only few points with large error bars are available. More precise data, for different kinematical configurations and at larger energies, are required for a detailed test of our model and its predictions, and for more refined parameterizations of the $\Lambda$ polarizing FF. We hope that these data will be soon available from running or proposed experiments.

References

1. M. Anselmino, D. Boer, U. D’Alesio, F. Murgia, Phys. Rev. D 63, 054029 (2001).
2. M. Anselmino, M. Boglione, F. Murgia, Phys. Lett. B 362, 164 (1995); M. Anselmino, F. Murgia, Phys. Lett. B 483, 74 (2000).
3. P.J. Mulders, R.D. Tangerman, Nucl. Phys. B 461, 197 (1996); B 484, 538(E) (1997); D. Boer, P.J. Mulders, Phys. Rev. D 57, 5780 (1998).
4. M. Burkardt, R.L. Jaffe, Phys. Rev. Lett. 70, 2537 (1993).
5. NOMAD Collaboration, P. Astier et al., Nucl. Phys. B 588, 3 (2000).