Abstract} Jefferson Lab (JLab) is starting a wide experimental program aimed at studying the neutron’s structure, with a great emphasis on the extraction of the parton transverse-momentum distributions (TMDs). To this end, Semi-inclusive deep-inelastic scattering (SiDIS) experiments on polarized $^3$He will be carried out, providing, together with proton and deuteron data, a sound flavor decomposition of the TMDs. Given the expected high statistical accuracy, it is crucial to disentangle nuclear and partonic degrees of freedom to get an accurate theoretical description of both initial and final states. In this contribution, a preliminary study of the Final State Interaction (FSI) in the standard SiDIS, where a pion (or a Kaon) is detected in the final state is presented, in view of constructing a realistic description of the nuclear initial and final states.

1 Introduction

In order to extend our knowledge of the nucleon structure, we need to access the three-dimensional picture of neutron and proton in terms of the degrees of freedom of their constituents. Information on the three-dimensional momentum space of the nucleon can be obtained extracting the quark transverse momentum distributions (TMDs) \cite{1} from the so-called single spin asymmetries (SSAs), which can be measured in polarized semi-inclusive deep inelastic scattering (SiDIS). Indeed, by exploiting SiDIS off transversely polarized target the Sivers and Collins contributions can be selected \cite{1}, showing from the present data on $\bar{p}(e,e'\pi)x$ \cite{2} and $\bar{D}(e,e'\pi)x$ \cite{3} a strong flavor dependence of TMDs. To extend such a study, measurements with a $^3$He target become compelling (see Ref. \cite{4}, for the first data at 6 GeV) and, in the close future, highly accurate experiments are planned at 12-GeV Jlab \cite{5}. The neutron data will be extremely important to achieve the flavor separation of the TMDs \cite{6}; therefore to obtain a reliable information one has to take into account the nuclear structure of $^3$He considering also the final

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state interaction (FSI) between the detected pion and the remnant debris. In the following we report our preliminary results on this issue.

2 The polarized $^3$He nucleus as an effective neutron target

A polarized $^3$He nucleus is an ideal target to study the neutron, since at a 90% level it is equivalent to a polarized neutron. For disentangling the nucleon structure from the dynamical nuclear effects, one can adopt an approach primarily based on the spin-dependent spectral function of $^3$He, $P_{\sigma,\sigma'}(p,E)$, (see, e.g. [7]) that yields the probability distribution to find a nucleon with given missing energy (the spectator pair is interacting), three-momentum and polarization inside the nucleus. By using this formalism, known as Plane Wave Impulse Approximation (PWIA), one can safely extract [8] the neutron longitudinal asymmetry, $A_n$, from the corresponding $^3$He observable, $A_3^{exp}$, obtained from the reaction $^3$He($e,e'\pi$) in DIS regime, i.e.

$$A_n \simeq \left( A_3^{exp} - 2p_fn_f A_2^{exp} \right) / (p_n f_n) \quad (1)$$

with $p_n(p)$ the neutron (proton) effective polarization inside the polarized $^3$He, and $f_{p(n)}$, the dilution factor. Realistic values of $p_n$ and $p_p$ are $p_p = -0.023$, $p_n = 0.878$ (see, e.g., [8;9]). In [8], an analogous extraction was applied to the SSA of a transversely polarized $^3$He target, obtained from the process $^3$He($e,e'\pi$), in order to obtain the SSA of a transversely polarized neutron. In PWIA and adopting the Bjorken limit, the SSAs of $^3$He are a convolution of $P_{\sigma,\sigma'}(p,E)$, and the nucleon SSAs, that in turn are convolutions of suitable TMDs and fragmentation functions (FF), phenomenologically describing the hadronization of the hit quark. The same extraction procedure has been also applied in combination with a Monte Carlo simulating the kinematics of the experiment E12-09-018 [10]. The main ingredients for the extraction were: i) a realistic $P_{\sigma,\sigma'}(p,E)$ for the $^3$He, obtained using the AV18 interaction; ii) parametrizations of data for TMDs and FFs, whenever available; iii) models for the unknown TMDs and FFs. Within this framework, the extraction formula (1) works well even in the case of SiDIS, at least at the present statistical accuracy of the existing data. Indeed Eq. (1) has been used by the JLab Hall A Collaboration to extract, for the first time, the Collins and Sivers moments from a transversely polarized $^3$He target [4]. It is important to point out that the existing measurements are limited in statistical accuracy and kinematics coverage, therefore an extensive program of high precision measurements of SiDIS off $^3$He will be part of the JLab program at 12 GeV [5].

The expected statistical accuracy is of the order of percent in a wide range of multi-dimensional kinematical binning; for this reason the PWIA could be no longer sufficient and the FSI, (not considered in PWIA) may have a non-negligible role. Our aim is to add this effect to the formalism, obtaining a distorted spin-dependent spectral function of the $^3$He.

3 Beyond PWIA: the generalized eikonal approximation

The JLab SiDIS experiments will exploit an electron beam at 8.8 and 11 GeV off $^3$He polarized gaseous target; the relative energy between the $(A-1)$ system and the system of the detected pion and the remnant (see Fig. 1) is a few GeV therefore the FSI can be treated within a generalized eikonal approximation framework (GEA). The GEA was already successfully applied to unpolarized SiDIS [11], and in a recent paper the distorted spin-dependent spectral function has been calculated for the spectator SiDIS, where a slow $(A-1)$ system nucleon system, acting as a spectator of the photon-nucleon interaction, is detected, while the produced fast hadron is not [12]. In the following we are going to report preliminary results for the usual SiDIS, where all the possible state of the two-nucleon spectator system have to be considered. The distorted spin-dependent

![Fig. 1 Interaction between the $(A-1)$ spectator system (fully interacting) and the debris produced by the absorption of a virtual photon by a nucleon in the nucleus.](image-url)
spectral function for a polarized $^3$He target can be written as

$$S^{N,S}_{\lambda\lambda'}(E, p_{\text{mis}}) =$$

$$= \sum_{f_2} \sum_{e_2^*} \rho(e_2^*) \hat{O}^{N,S}_{\lambda\lambda'} f_2(e_2^*, p_{\text{mis}}) \delta(E + M_3 - m_N - m_2^* - T_2)$$

with the product of distorted overlaps defined by

$$\hat{O}^{N,S}_{\lambda\lambda'} f_2(e_2^*, p_{\text{mis}}) =$$

$$= \langle \lambda, \phi^{e_2^*}_{f_2}(r)e^{-ip_{\text{mis}}P}\hat{G}(r, \rho)|\Psi^3_{3}(r, \rho)\rangle\langle\Psi^3(r', \rho')|\lambda', \hat{G}(r', \rho')\phi^{e_2^*}_{f_2}(r')e^{-ip_{\text{mis}}P}\rangle.$$ (3)

where i) $\rho(e_2^*)$ is the density of the spectator pair with intrinsic energy $e_2^*$, ii) $|\Psi^3_{3}(r, \rho)\rangle$ is the ground state of the 3-nucleon system with polarization $S_3$ iii) $E$ is the usual missing energy $E = e_2^* + B_3$, if the kinetic energy $T_2$ of the spectator pair is disregarded and $p_{\text{mis}}$ is the three momentum of the spectator pair.

The Glauber operator in Cartesian coordinates is given by

$$G(r_1, r_2, r_3) = G(r, \rho) = \prod_{i=2,3} \left[1 - \theta(r_{i||} - r_{i||})\Gamma(r_{i\perp} - r_{1\perp}, r_{i||} - r_{i||})\right],$$ (4)

where $r_{i\perp}$ and $r_{i||}$ are the perpendicular and the parallel components of $r_i$ with respect to the direction of the debris. The profile function

$$\Gamma(r_{i\perp}, r_{i||}) = \left(1 - \frac{i\eta}{2}\right) \frac{\sigma_{\text{eff}}(r_{i||})}{4\pi b_0^2} \exp\left[-\frac{r_{i\perp}^2}{2b_0^2}\right],$$ (5)

unlike the standard Glauber approach depends not only on the impact parameter but also on the longitudinal separation through an effective cross section. This expression has been already used in our previous works (for details on the model see Ref. \[12; 13\]). To recover the PWIA formulation one has simply to put $G \equiv 1$. In Fig. 2 a preliminary plot of the $^3$He distorted and undistorted spectral function, for the neutron, in the unpolarized case is shown.

### 4 Good news on the extraction of the neutron’s SSAs

The relevant part in the extraction of the transversely polarized neutron’s SSAs is the transverse spectral function, given by

$$S^{N,\perp}(E, p_{\text{mis}}) = S^{N,\perp}_{\frac{1}{2}\frac{1}{2}}(E, p_{\text{mis}}) + S^{N,\perp}_{\frac{1}{2}\frac{3}{2}}(E, p_{\text{mis}})$$

In general $S^{\perp(PWIA)}$ and $S^{\perp(FSI)}$ can be quite different and the effective polarizations are respectively $p^{\text{PWIA}}_p = -0.023$ and $p^{\text{FWIA}}_p = 0.878$; $p^{\text{FSI}}_p = -0.026$ and $p^{\text{FSI}}_n = 0.760$. Then $p_{p(n)}$ with and
without FSI differ by 10-15%. Nevertheless, in Eq. (1) the effective polarizations occur in products with the dilution factor and to a large extent \( p_{FWIA} p_{FWIA} \approx p_{FSI} p_{FSI} \), \( p_{FWIA} p_{FWIA} \approx p_{FSI} p_{FSI} \)\[15\]. Such a fortunate case allows one to safely adopt the usual extraction, as shown by the preliminary results in Fig. 3 and therefore the goal of a sound flavor decomposition of TMDs seems quite affordable.

As a next step, we plan to include the FSI in our Light-Front relativistic description of the \(^3\)He, already employed to evaluate the relativistic effects in SIDIS processes in PWIA (see [16]).

**Fig. 3** Neutron asymmetries extracted trough Eq. (1) from the Sivers (Left panel) and Collins (Right panel) asymmetries with and without FSI, in actual kinematics of JLab at 12 GeV [3]. Preliminary results to appear in [15].

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