Polarized ^{3}He target and final state interactions in SiDIS

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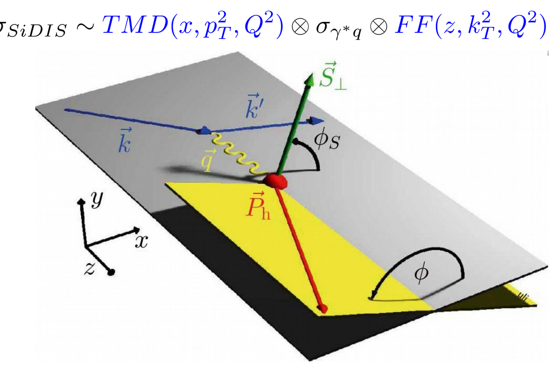
Abstract

At JLab is starting a wide program to study the neutron's structure, for instance by extracting the parton transverse-momentum distributions (TMDs) through polarized Semi-inclusive deep-inelastic scattering (SIDIS) experiments on ^{3}He. This will provide, together with proton and deuteron data, a sound flavour 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.
We present, in this contribution, the study of the Final State Interaction (FSI) in the standard SiDIS, where a pion (or a Kaon) is detected in the final state.
This study will be very useful for the JLab experiments on ^{3}He.

Neutron structure

$\sigma_{SiDIS} \sim TMD(x, p_T^2, Q^2) \otimes \sigma_{\gamma^* q} \otimes FF(z, k_T^2, Q^2)$



The measured quantity is the Single Spin Asymmetry:

$$A_{UT} \equiv \frac{1}{|S_T|}\frac{d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi)}{d\sigma(\phi,\phi_S) + d\sigma(\phi,\phi_S+\pi)}$$

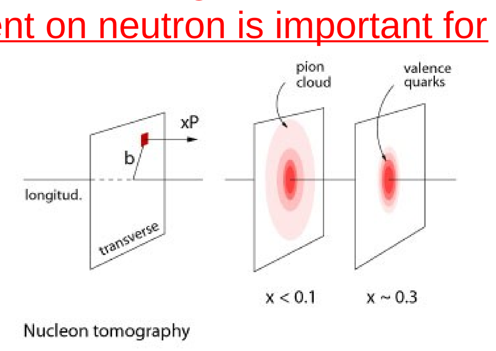
The Transverse Momentum dependent Distributions (TMDs) functions are embedded in the SSA together with a corresponding Fragmentation Function (FF).

They provide Informations on the dynamics of quark and gluons in the nucleons.

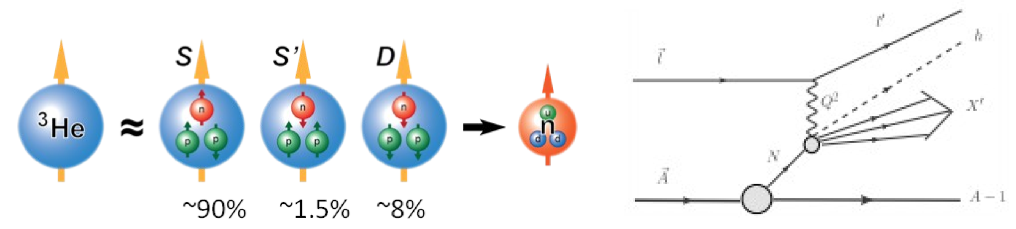
By multidimensional fits of the measured A_{UT} the so called Sivers and Collins TMDs can be extracted.

A_{UT} on proton measured in HERMES and COMPASS, and on deuteron in COMPASS. The data show a strong flavour dependence. A precise measurement on neutron is important for the flavour decomposition!

Wide program on nucleon tomography @JLab12



$^3\vec{He} \simeq \vec{n}$



Polarized ^{3}He is an effective neutron!

The first idea (Ciofi degli Atti et al .,PRC48(1993)R968), the Plane Wave Impulse Approximation:

- The virtual photon interacts with a single nucleon. The FSI's among the hadron, the nucleon and the (fully interacting) spectator nuclear system is disregarded,
- The internal structure of the bound nucleon is the same as the free one.

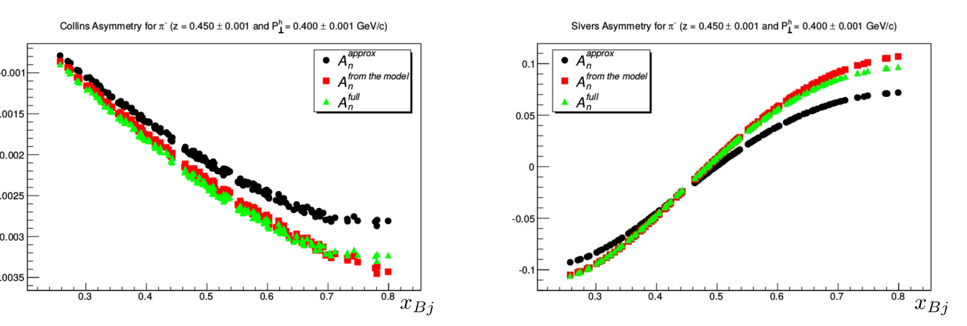
The key quantity is the ^{3}He Spectral Function (it appears in several processes i.e. DIS, SIDIS, DVCS), it encodes the informations on the nuclear structure through the effective polarizations $p_p = -0.023$ $p_n = 0.878$ entering the SSAs extraction formula:

$$A_n \simeq \frac{1}{p_n f_n}\left(A_3^{exp} - 2 p_p f_p A_p^{exp}\right) \qquad (f_{p(n)} \simeq 0.2)$$

Application of existing results

The extraction procedure has been applied to the existing result for the SSAs on ^{3}He polarized target. (JLab@6GeV, PRL 107, 072003 (2011)).

In view of JLab@12 GeV, it has been embedded in a Monte Carlo of the planned E12-19-018 experiment.



Red: Neutron asymmetry model;
Black: Neutron asymmetry extracted neglecting the proton effective polarization;
Green: Extracted using the whole formula.

$$A_n \simeq \frac{1}{p_n f_n}\left(A_3^{calc} - 2 p_p f_p A_p^{model}\right)$$

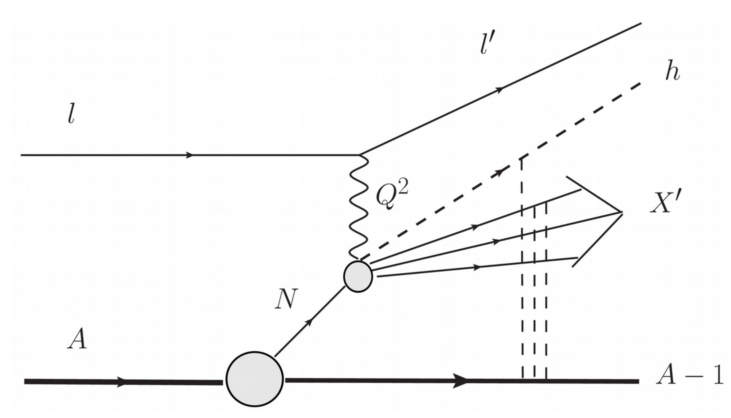
We need to be really confident on our extraction method!
A tremendous reduction of the statistical error is expected!

Does nuclear FSI have an effect on the extraction?

Final State Interaction

Generalized Eikonal Approximation (GEA)

The relative energy between the A-1 system and the remnants is ~ GeV therefore the Eikonal Approximation can be applied to evaluate the nuclear Final State Interaction.

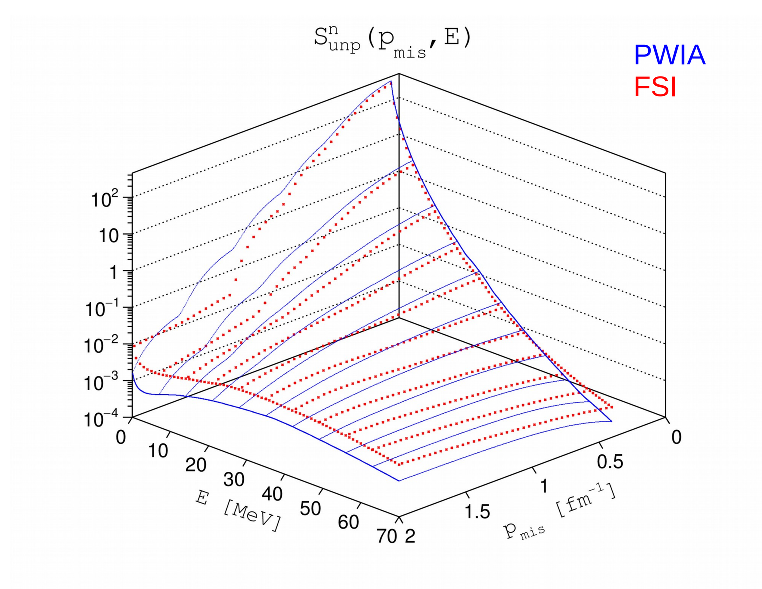


The quantity encoding the nuclear structure informations: the distorted spin-dependent Spectral Function

$$S^{N S_A}_{\lambda\lambda'}(E, \mathbf{p}_{mis}) = \sum_{f_{A-1}} \sum_{\epsilon^*_{A-1}} \rho\left(\epsilon^*_{A-1}\right) \tilde{\mathcal{O}}^{N S_A f_{A-1}}_{\lambda\lambda'}\left(\epsilon^*_{A-1}, \mathbf{p}_{mis}\right) \delta\left(E + M_A - m_N - M^*_{A-1} - T_{A-1}\right)$$

The distorted spin-dependent Spectral Function

- While the PWIA Spectral Function is "universal", i.e. depends on ground state properties, **the distorted Spectral Function** is dynamical (hadronization eff. cross section) and process dependent.
- For each experimental point (x, Q^2,...) a different distorted spectral function has to be evaluated!
- A really cumbersome quantity, a very demanding evaluation (≈ 1 Mega CPU*hours @"Zefiro" INFN-farm in Pisa, "gruppo 4")



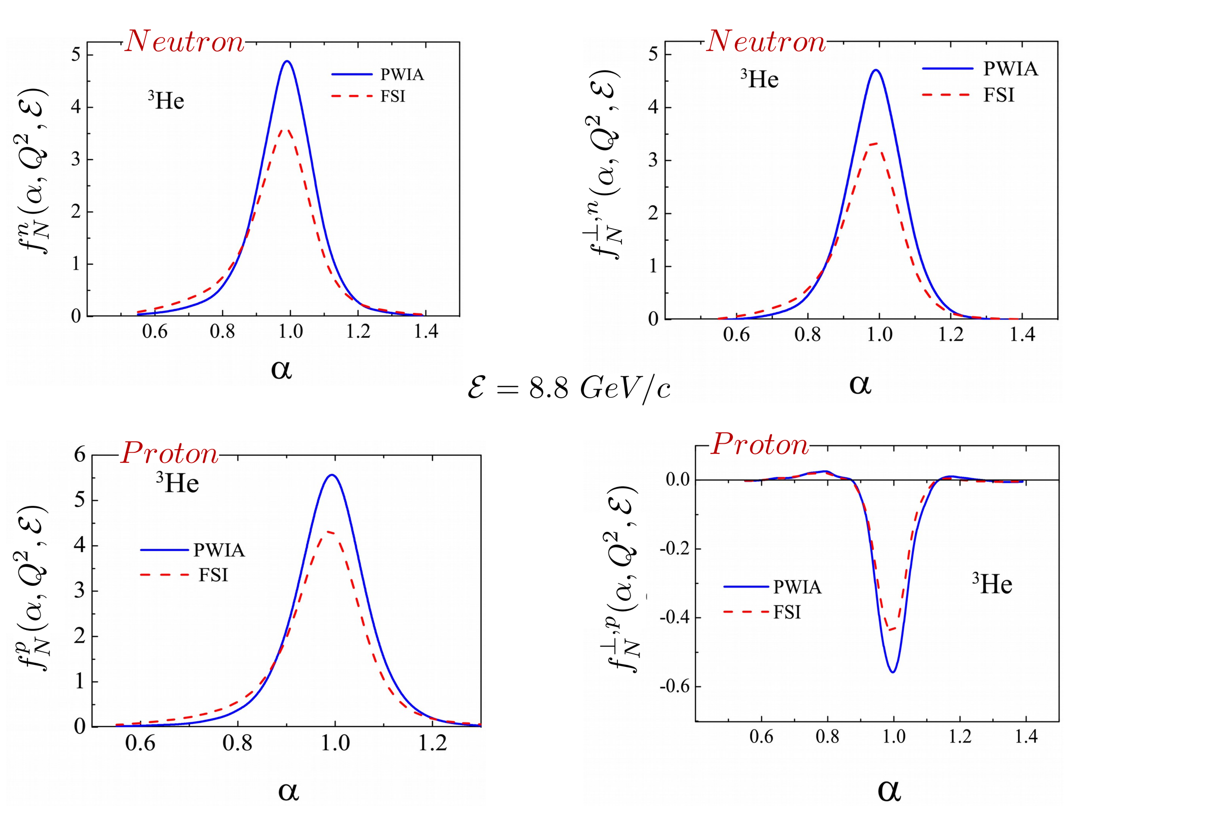
Good news from the GEA studies of FSI

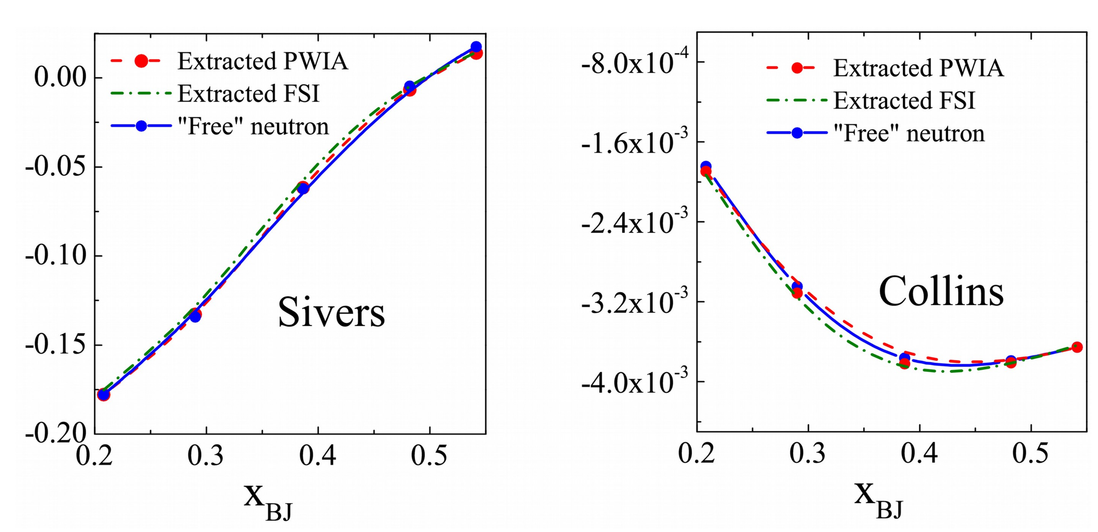
The convolution formula for a generic structure function can be cast in the form

$$\mathcal{F}^A(x_{Bj}, Q^2, \mathcal{E}) = \sum_N \int_{x_{Bj}}^A f_N^{i(\perp)}(\alpha, Q^2, \mathcal{E})\, \mathcal{F}^N(x_{Bj}/\alpha, Q^2, ...)\, d\alpha$$

where the Light-Front momentum distribution is

$$f_N^{i(\perp)}(\alpha, Q^2, \mathcal{E}) = \int dE \int d\mathbf{p}_{mis} \frac{\alpha m_N}{E_N} S^{Ni(\perp)}(E, \mathbf{p}_{mis}) \delta\left(\alpha - \frac{p_{mis} \cdot q}{m_N \nu}\right) \theta\left(W_Y^2 - (m_N + m_\pi)^2\right)$$





Effective polarizations (FSI/PWIA) differ for about 10-15%, but the products with the dilution factors change very little!

- Notice that: at JLab12 we are dealing with extremely small statistical errors in a multidimensional binning!
- We have the ^{3}He Spectral Function for different typical JLab12 SiDIS kinematics!
- **The extraction procedure can be carefully tested in MC simulating the phase space of the JLab ^{3}He target dedicated experiments.**

Conclusions & perspectives

- We are studying SiDIS processes off ^{3}He beyond the NR, PWIA approach.
We have encouraging results concerning:

- FSI effects evaluated through the Generalized Eikonal Approximation: a distorted spin dependent spectral function has been studied (still NR);
- Relativistic effects (in PWIA) through an analysis of the LF spectral function (not presented here, see [2])

- Next step:
  - relativistic FSI
  - interaction with the JLab12 MonteCarlo community to merge the distorted spectral function in the JLab12 SiDIS MC

Our works:

[1] L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S. Scopetta, "Distorted spin-dependent spectral function of an A=3 nucleus and semi-inclusive deep-inelastic scattering processes", Phys. Rev. C 89, (2014), 035206.

[2] E. Pace, A. Del Dotto, L. Kaptari, M. Rinaldi, G. Salmè, S. Scopetta, "Light-Front Dynamics and the ^{3}He Spectral Function", Few-Body Systems , 57, 601-606 (2016)

[3] A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S. Scopetta, "Final state interactions in deep inelastic meson electroproduction off transversely polarized ^{3}He and the extraction of neutron single spin asymmetries", in preparation