Final state interactions and neutron SSAs from SIDIS by a transversely polarized ^{3}He target

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December 11^{th}, 2017

Why? 12 GeV Experiments @JLab, with ^{3}He

- DIS regime, e.g.

  Hall A, $http://hallaweb.jlab.org/12GeV/$
  MARATHON Coll. E12-10-103 (Rating A): MeAsurement of the F_{2n}/F_{2p}, d/u Ratios and A=3 EMC Effect in Deep Inelastic Electron Scattering Off the Tritium and Helium MirrOr Nuclei

  Hall C, $https://www.jlab.org/Hall-C/$
  J. Arrington, et al PR12-10-008 (Rating A$^-$): Detailed studies of the nuclear dependence of F_2 in light nuclei

- SIDIS regime, e.g.

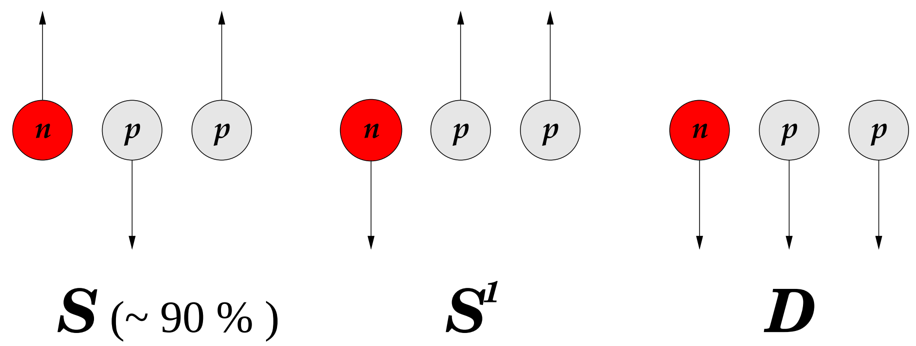
  Hall A, $http://hallaweb.jlab.org/12GeV/$
  H. Gao et al, PR12-09-014 (Rating A): Target Single Spin Asymmetry in Semi-Inclusive Deep-Inelastic $(e, e'\pi^{\pm})$ Reaction on a Transversely Polarized ^{3}He Target
  J.P. Chen et al, PR12-11-007 (Rating A): Asymmetries in Semi-Inclusive Deep-Inelastic $(e, e'\pi^{\pm})$ Reactions on a Longitudinally Polarized ^{3}He Target

- Others? DVCS, spectator tagging...

  In ^{3}He conventional nuclear effects under control... Exotic ones disentangled

The neutron information from ^{3}He

^{3}He is the ideal target to study the polarized neutron:



$\mu_{^3He} \simeq \mu_n$!

(deuteron: $\mu_{^2H} \simeq \mu_n + \mu_p$)

... But the bound nucleons in ^{3}He are moving! $\longrightarrow$ theoretical ingredient:
a realistic spin-dependent spectral function for $^3\vec{H}e$, $P_{\sigma,\sigma'}(\vec{p}, E)$.

Example: dynamical nuclear effects in inclusive DIS ($^3\vec{H}e(e,e')X$). The formula

$$A_n \simeq \frac{1}{p_n f_n} \left(A_3^{exp} - 2 p_p f_p A_p^{exp} \right) , \quad (Ciofi\ degli\ Atti\ et\ al.,\ PRC48(1993)R968)$$

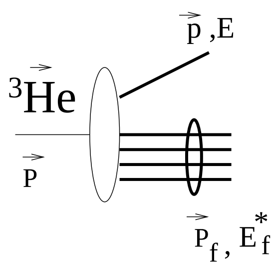
$$(f_p, f_n \quad dilution factors,\ from\ unpolarized\ data)$$

can be safely used $\longrightarrow$ widely adopted by experimental collaborations.

Nuclear effects hidden in the "effective polarizations", p_p and p_n, obtained from the nuclear w.f... But to proof this possibility, the spectral function had to be evaluated

The spectral function (Impulse Approximation)

$$\mathbf{P}^N_{\mathcal{M}\sigma\sigma}(\vec{p},,E) = \sum_f \left| \quad \right|^2 =$$



intrinsic overlaps

$$\sum_f \delta(E - E_{min} - E^*_f)\,\overbrace{{}_{S_A}\langle \Psi_A; J_A \mathcal{M} \pi_A | \vec{p}, \sigma; \phi_f(E^*_f)\rangle}\;\overbrace{\langle \phi_f(E^*_f); \sigma \vec{p} | \pi_A J_A \mathcal{M}'; \Psi_A\rangle_{S_A}}$$

- probability distribution to find a nucleon with given 3-momentum and removal energy E in the nucleus. It arises in q.e., DIS, SIDIS, DVCS...
- In general, if spin is involved, a 2x2 matrix, $\mathbf{P}^N_{\mathcal{M}\sigma\sigma'}(\vec{p},,E)$, not a density;
- the two-body recoiling system can be either the deuteron or a scattering state: when a deeply bound nucleon, with high $E = E_{min} + E^*_f$, leaves the nucleus, the recoiling system has high excitation energy E^*_f ;
- Realistic Spectral Function: 3-body bound state and 2-body final state evaluated within the same Realistic interaction (in our case, Av18, from the Pisa group **(Kievsky, Viviani)**). Extension to heavier nuclei very difficult

Status (Impulse Approximation and beyond)

	Impulse Approximation		including FSI	
	unpolarized	spin dep.	unpolarized	spin dep.
Non Relativistic	✓	✓	✓	✓
Light-Front	Def: ✓	Def: ✓		
	Calc: 🔧	Calc: 🔧		

Selected contributions from Rome-Perugia:

- Ciofi, Pace, Salmè PRC 21 (1980) 505 ...
- Ciofi, Pace, Salmè PRC 46 (1991) 1591: spin dependence
- Pace, Salmè, S.S., Kievsky PRC 64 (2001) 055203, first Av18 calculation
- Ciofi, Kaptari, PRC 66 (2002) 044004, unpolarized with FSI (q.e.)
- S.S. PRC 70 (2004) 015205, non diagonal SF for DVCS
- Kaptari, Del Dotto, Pace, Salmè, S.S., PRC 89 (2014), spin dependent with FSI
- LF, formal: Del Dotto, Pace, Salmè, SS, PRC 95 (2017) 014001; preliminary calc., S.S., Del Dotto, Kaptari, Pace, Rinaldi, Salmè, Few Body Syst. 56 (2015) 6

Outline

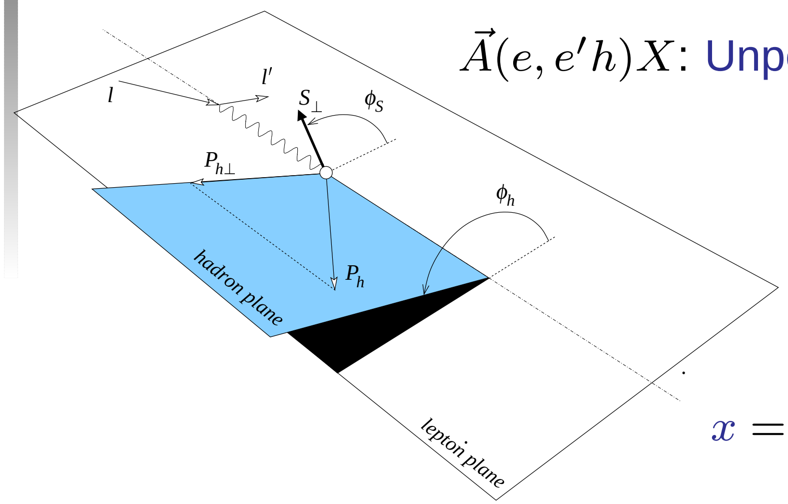
	Impulse Approximation		including FSI	
	unpolarized	spin dep.	unpolarized	spin dep.
Non Relativistic	✓	✓	✓	✓
Light-Front	Def: ✓	Def: ✓		
	Calc:	Calc:		

- Extracting the neutron information from SiDIS off $^3\vec{He}$.
  Basic approach: Impulse Approximation in the Bjorken limit
  (S.S., PRD 75 (2007) 054005)

- **Main topic:**
  - **Evaluation of Final state interactions (FSI): distorted spectral function and spectator SIDIS**
    (L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206)
  - **Evaluation of FSI: distorted spectral function and full treatment of SIDIS**
    (A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S.S., PRC (2017) in press, arXiv:1704.06182 [nucl-th])

- Conclusions

Single Spin Asymmetries (SSAs) - 1



$\vec{A}(e,e'h)X$: Unpolarized beam and T-polarized target $\rightarrow \sigma_{UT}$

$$d^6\sigma \equiv \frac{d^6\sigma}{dx\,dy\,dz\,d\phi_S\,d^2P_{h\perp}}$$

$$x = \frac{Q^2}{2P\cdot q} \quad y = \frac{P\cdot q}{P\cdot l} \quad z = \frac{P\cdot h}{P\cdot q} \quad \boxed{\hat{q} = -\hat{e}_z}$$

The number of emitted hadrons at a given ϕ_h depends on the orientation of $\vec{S}_\perp$!

In SSAs 2 different mechanisms can be experimentally distinguished

$$A_{UT}^{Sivers(Collins)} = \frac{\int d\phi_S d^2P_{h\perp} \sin(\phi_h - (+)\phi_S) d^6\sigma_{UT}}{\int d\phi_S d^2P_{h\perp} d^6\sigma_{UU}}$$

with $\quad d^6\sigma_{UT} = \frac{1}{2}(d^6\sigma_{U\uparrow} - d^6\sigma_{U\downarrow}) \qquad d^6\sigma_{UU} = \frac{1}{2}(d^6\sigma_{U\uparrow} + d^6\sigma_{U\downarrow})$

SSAs - 2

SSAs in terms of parton distributions and fragmentation functions:

- $A_{UT}^{Sivers} = N^{Sivers}/D \qquad A_{UT}^{Collins} = N^{Collins}/D$

$$N^{Sivers} \propto \sum_q e_q^2 \int d^2\kappa_{\mathbf{T}} d^2\mathbf{k_T} \delta^2(\mathbf{k_T} + \mathbf{q_T} - \kappa_{\mathbf{T}}) \frac{\hat{\mathbf{P_{h\perp}}} \cdot \mathbf{k_T}}{\mathbf{M}} f_{1T}^{\perp q}(x, \mathbf{k_T}^{\mathbf{2}}) D_1^{q,h}(z, (z\kappa_{\mathbf{T}})^{\mathbf{2}})$$

$$N^{Collins} \propto \sum_q e_q^2 \int d^2\kappa_{\mathbf{T}} d^2\mathbf{k_T} \delta^2(\mathbf{k_T} + \mathbf{q_T} - \kappa_{\mathbf{T}}) \frac{\hat{\mathbf{P_{h\perp}}} \cdot \kappa_{\mathbf{T}}}{\mathbf{M_h}} h_1^q(x, \mathbf{k_T}^{\mathbf{2}}) H_1^{\perp q,h}(z, (z\kappa_{\mathbf{T}})^{\mathbf{2}})$$

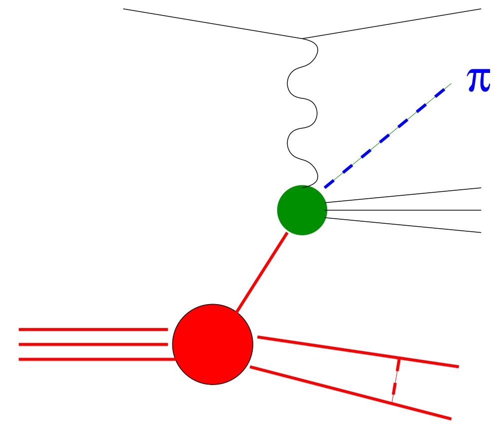
$$D \propto \sum_q e_q^2 f_1^q(x) D_1^{q,h}(z)$$

- LARGE A_{UT}^{Sivers} measured in $\vec{p}(e,e'\pi)x$ HERMES PRL 94, 012002 (2005)
- SMALL A_{UT}^{Sivers} measured in $\vec{D}(e,e'\pi)x$; COMPASS PRL 94, 202002 (2005)

A strong flavor dependence

Importance of the neutron for flavor decomposition!

$\vec{n}$ from $^3\vec{H}e$: SIDIS case, IA



Is the extraction procedure tested in DIS valid also for the SSAs in SIDIS?

In a first paper on this subject,

(S.Scopetta, PRD 75 (2007) 054005)

the process $^3\vec{H}e(e, e'\pi)X$ has been evaluated :

* in the Bjorken limit
* in IA $\rightarrow$ no FSI between the measured fast, ultrarelativistic π the remnant and the two nucleon recoiling system

  $E_\pi \simeq 2.4\ GeV$ in JLAB exp at $6\ GeV$ - Qian et al., PRL 107 (2011) 072003

SSAs involve convolutions of the spin-dependent nuclear spectral function, $\vec{P}(\vec{p}, E)$, with parton distributions and fragmentation functions

$$A \simeq \int d\vec{p}\, dE .... \vec{P}(\vec{p}, E)\ f_{1T}^{\perp q}\left(\frac{Q^2}{2p \cdot q}, \mathbf{k_T^2}\right)\ D_1^{q,h}\left(\frac{p \cdot h}{p \cdot q}, \left(\frac{p \cdot h}{p \cdot q}\kappa_{\mathbf{T}}\right)^2\right)$$

Specific nuclear effects, new with respect to the DIS case, can arise and have to be studied carefully

The IA @ JLab kinematics: a few words more

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

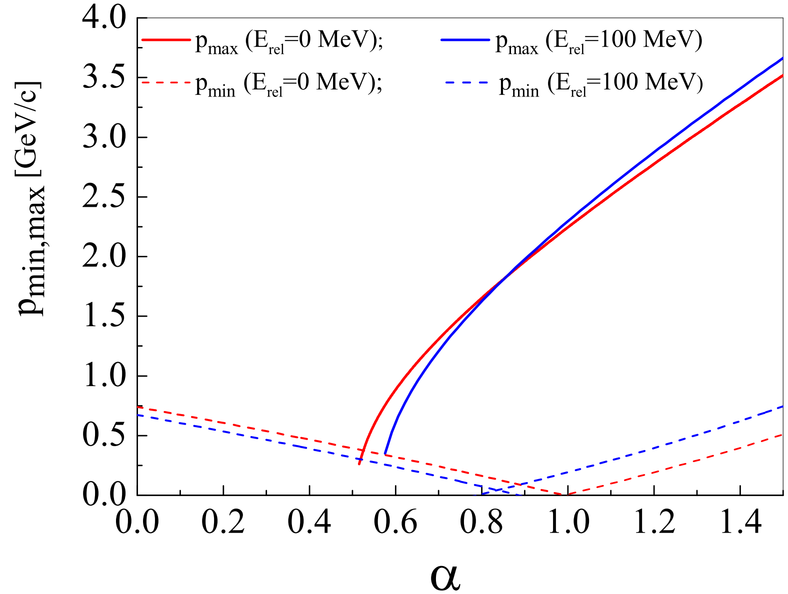
$$\mathcal{F}^A(x_{Bj}, Q^2, ...) = \sum_N \int_{x_{Bj}}^{A} f_N^A(\alpha, Q^2, ...)\, \mathcal{F}^N(x_{Bj}/\alpha, Q^2, ...)\, d\alpha$$

with the light-cone momentum distribution:

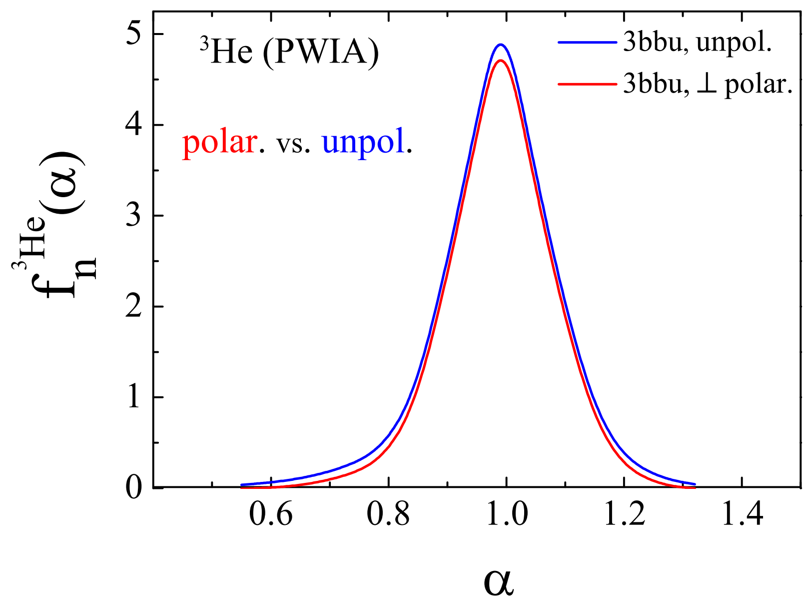
$$f_N^A(\alpha, Q^2, ...) = \int dE \int_{p_{min}(\alpha,Q^2,...)}^{p_{max}(\alpha,Q^2,...)} P_N^A(\mathbf{p}, \mathbf{E})\, \delta\left(\alpha - \frac{\mathbf{pq}}{\mathbf{m}\nu}\right)\, \theta\left(\mathbf{W_x^2} - (\mathbf{M_N} + \mathbf{M}_\pi)^\mathbf{2}\right) \mathbf{d^3p}$$

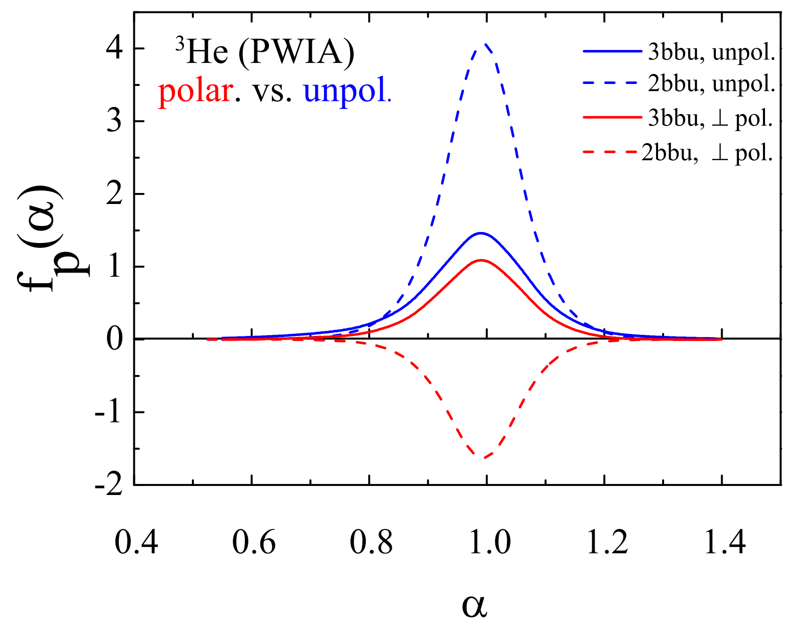
- Bjorken limit:
  $p_{min,max}$ not dependent on Q^2, x:
  $f_N^A(\alpha)$ depends on α only,
  $0 \leq \alpha \leq A$

- @ JLab kinematics,
  ($E = 8.8$ GeV, $E' \simeq 2 \div 3$ GeV,
  $\theta_e \simeq 30^o$) $q \neq \nu$ and $\alpha_{min} \neq 0$



Light-cone momentum distributions in IA

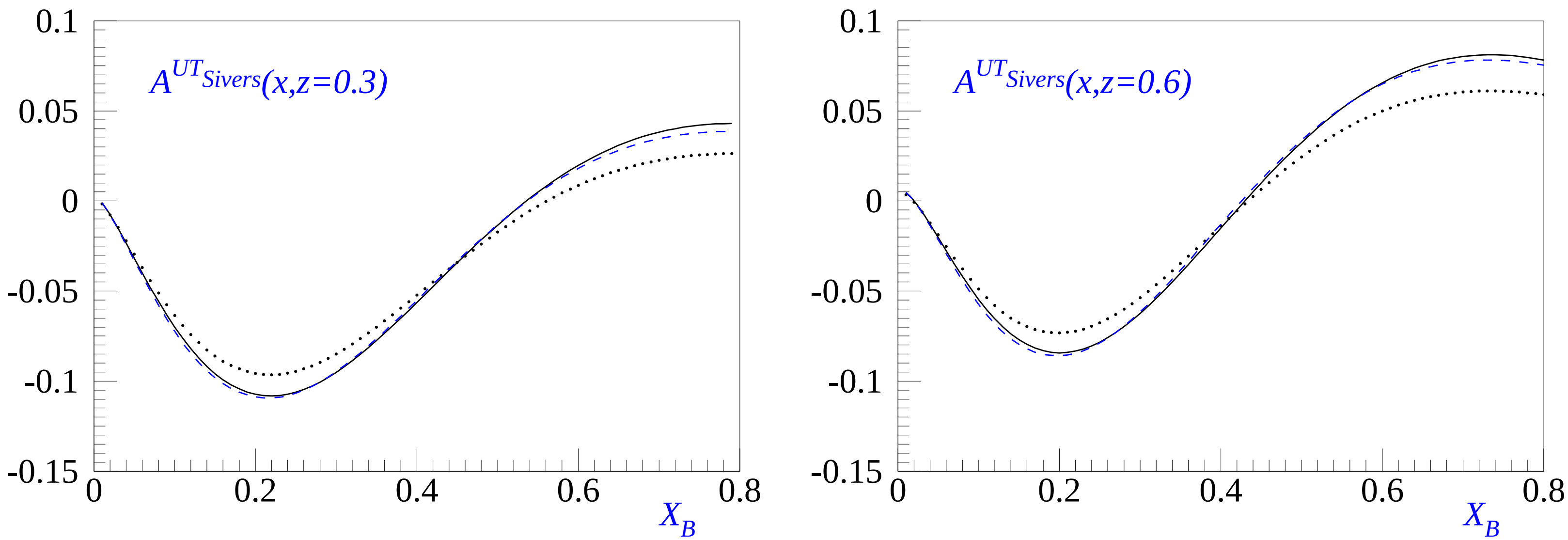




Calculation within the **Av18** interaction:

- weak depolarization of the neutron, $p_n = \int d\alpha\, f_n^{^3He}(\alpha) = 0.878$
- strong depolarization of the protons, $p_p = \int d\alpha\, f_p^{^3He}(\alpha) = -0.023$
  (cancellation between contributions in the 2-body and 3-body channels)

Results: $\vec{n}$ from $^3\vec{He}$: A_{UT}^{Sivers}, @ JLab, in IA



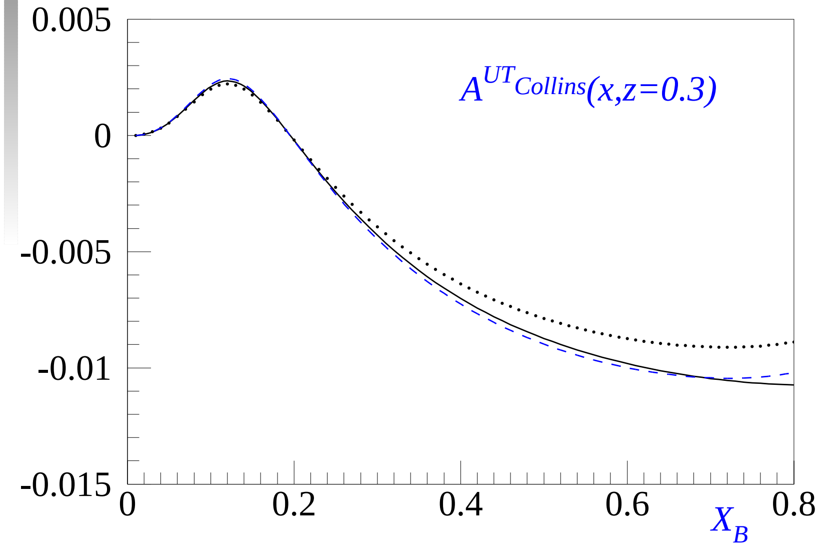
FULL: Neutron asymmetry (model: from parameterizations or models of TMDs and FFs)

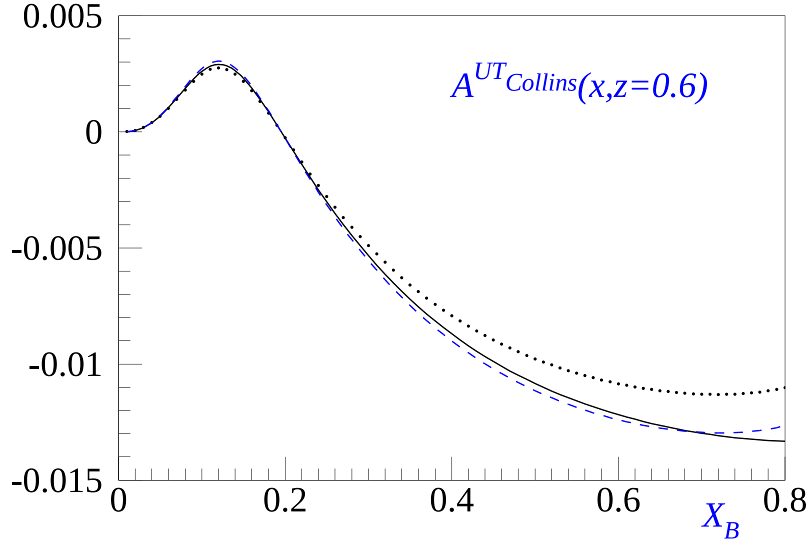
DOTS: Neutron asymmetry extracted from ^3He (calculation) neglecting the contribution of the proton polarization $\bar{A}_n \simeq \frac{1}{f_n} A_3^{calc}$

DASHED : Neutron asymmetry extracted from ^3He (calculation) taking into account nuclear structure effects through the formula:

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

Results: $\vec{n}$ from $^3\vec{He}$: $A_{UT}^{Collins}$, @ JLab





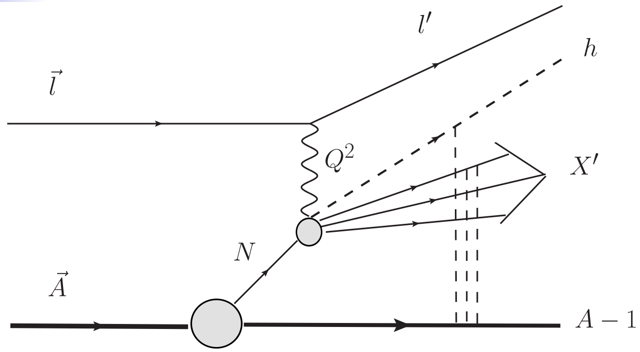
In the Bjorken limit the extraction procedure successful in DIS works also in SiDIS, for both the Collins and the Sivers SSAs !

What about FSI effects ?

(thinking to E12-09-018, A.G. Cates et al., approved with rate A @JLab 12)

FSI: Generalized Eikonal Approximation (GEA)

L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206



Relative energy between $A-1$ and the remnants: a few GeV
$\longrightarrow$ eikonal approximation.

$$d\sigma \simeq l^{\mu\nu} W^A_{\mu\nu}(S_A)$$

$$W^A_{\mu\nu}(S_A) \approx \sum_{S_{A-1},S_X} J^A_\mu J^A_\nu \qquad J^A_\mu \simeq \langle S_A \mathbf{P} | \hat{\mathbf{J}}^{\mathbf{A}}_\mu(\mathbf{0}) | \mathbf{S_X}, \mathbf{S_{A-1}}, \mathbf{P_{A-1}} \mathbf{E^f_{A-1}} \rangle$$

$$\langle S_A \mathbf{P} | \mathbf{r_1 r_2 r_3} \rangle = \mathbf{\Phi_{3_{He}}}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) = \mathcal{A}\, \mathbf{e^{iPR}} \mathbf{\Psi_3^{S_A}}(\rho, \mathbf{r})$$

$$\langle \mathbf{r_1 r_2 r_3} | S_X, S_{A-1} \mathbf{P_{A-1}} \mathbf{E^f_{A-1}} \rangle = \Phi^*_f(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \approx \hat{S}_{Gl}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \mathbf{\Psi}^{*\mathbf{f}}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3})$$

$$\hat{S}_{Gl} = Glauber\ operator \qquad \approx \hat{S}_{Gl}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \sum_{\mathbf{j>k}} \chi^+_{\mathbf{S_X}} \phi^*(\xi_{\mathbf{x}}) \mathbf{e}^{-\mathbf{ip_X r_i}} \mathbf{\Psi}^{*\mathbf{f}}_{\mathbf{jk}}(\mathbf{r_j}, \mathbf{r_k}),$$

$$J^A_\mu \approx \int d\mathbf{r_1} d\mathbf{r_2} d\mathbf{r_3} \Psi^{*f}_{23}(\mathbf{r_2}, \mathbf{r_3}) e^{-i\mathbf{p}_X \mathbf{r_i}} \chi^+_{S_X} \phi^*(\xi_x) \cdot \hat{S}_{Gl}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \hat{j}_\mu(\mathbf{r_1}, X) \vec{\Psi}_3^{\mathbf{S}_A}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3})$$

IF ($FACTORIZED$ FSI !) $\left[\hat{S}_{Gl}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3), \hat{j}_\mu(\mathbf{r_1})\right] = 0$ THEN:

$$W^A_{\mu\nu} = \sum_{N,\lambda,\lambda'} \int dE\, d\mathbf{p}\, w^{N,\lambda\lambda'}_{\mu\nu}(\mathbf{p})\, P^{FSI,A,N}_{\lambda\lambda'}(E, \mathbf{p}, ...) \qquad CONVOLUTION!$$

FSI: *distorted* spin-dependent spectral function of ^{3}He

L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206

Relevant part of the (GEA-distorted) spin dependent spectral function:

$$\mathcal{P}_{||}^{IA(FSI)} = \mathcal{O}_{\frac{1}{2}\frac{1}{2}}^{IA(FSI)} - \mathcal{O}_{-\frac{1}{2}-\frac{1}{2}}^{IA(FSI)}; \qquad \text{with:}$$

$$\mathcal{O}_{\lambda\lambda'}^{IA(FSI)}(p_N, E) = \sum\!\!\!\!\!\!\int_{\epsilon^*_{A-1}} \rho\left(\epsilon^*_{A-1}\right) \langle S_A, \mathbf{P_A}|(\hat{S}_{Gl})\{\Phi_{\epsilon^*_{A-1}}, \lambda', \mathbf{p}_N\}\rangle \times$$
$$\langle(\hat{S}_{Gl})\{\Phi_{\epsilon^*_{A-1}}, \lambda, \mathbf{p}_N\}|S_A, \mathbf{P_A}\rangle \delta\left(E - B_A - \epsilon^*_{A-1}\right).$$

Glauber operator: $\hat{S}_{Gl}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3) = \prod_{i=2,3}\left[1 - \theta(z_i - z_1)\Gamma(\mathbf{b}_1 - \mathbf{b}_i, z_1 - z_i)\right]$

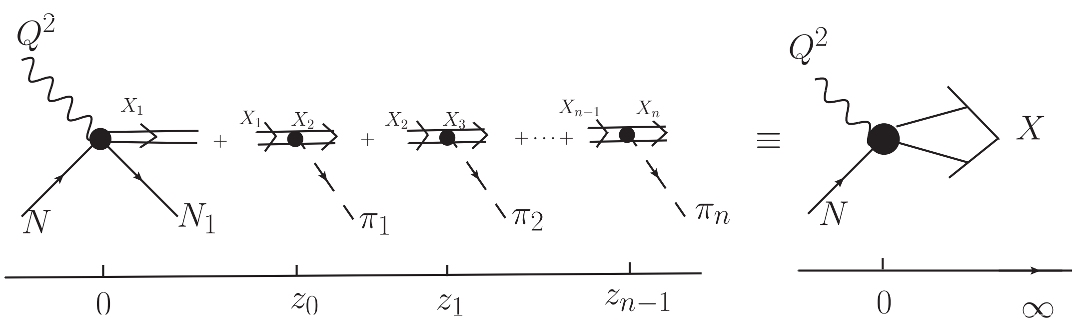
(generalized) profile function: $\Gamma(\mathbf{b}_{1i}, z_{1i}) = \frac{(1-i\,\alpha)\ \sigma_{eff}(z_{1i})}{4\,\pi\,b_0^2} \exp\left[-\frac{\mathbf{b}_{1i}^2}{2\,b_0^2}\right],$

GEA (Γ depends also on the longitudinal distance between the debris and the scattering centers z_{1i}!) very succesfull in q.e. semi-inclusive and exclusive processes off ^{3}He
see, e.g., Alvioli, Ciofi & Kaptari PRC 81 (2010) 02100

A hadronization model is necessary to define $\sigma_{eff}(z_{1i})$...

FSI: *the hadronization model*

Hadronization model **(Kopeliovich et al., NPA 2004)**
+ σ_{eff} model for SIDIS **(Ciofi & Kopeliovich, EPJA 2003)**
GEA + hadronization model succesfully applied to unpolarized SIDIS $^2H(e,e'p)X$
(Ciofi & Kaptari PRC 2011).



$$\sigma_{eff}(z) = \sigma_{tot}^{NN} + \sigma_{tot}^{\pi N}\left[n_M(z) + n_g(z)\right]$$

- The hadronization model is phenomenological: parameters are chosen to describe the scenario of JLab experiments (e.g., $\sigma_{NN}^{tot} = 40$ mb, $\sigma_{\pi N}^{tot} = 25$ mb, $\alpha = -0.5$ for both NN and πN...).
  According to high energy $N - N$ scattering data, $\sigma_{eff}(z)$ is taken spin-independent (see, e.g., **Alekseev et al., PRD 79 (2009) 094014**)

FSI: *distorted* spin-dependent spectral function of ^{3}He

L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206

- While P^{IA} is "static",i.e. depends on ground state properties, P^{FSI} is dynamical ($\propto \sigma_{eff}$) and process dependent;
- For each experimental point (given x, Q^2...), a different spectral function has to be evaluated!
- Quantization axis (w.r.t. which polarizations are fixed) and eikonal direction (fixing the "longitudinal" propagation) are different)... States have to be rotated...
- P^{FSI}: a really cumbersome quantity, a very demanding evaluation ($\approx$ 1 Mega CPU*hours @ "Zefiro" PC-farm, PISA, INFN "gruppo 4").

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

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

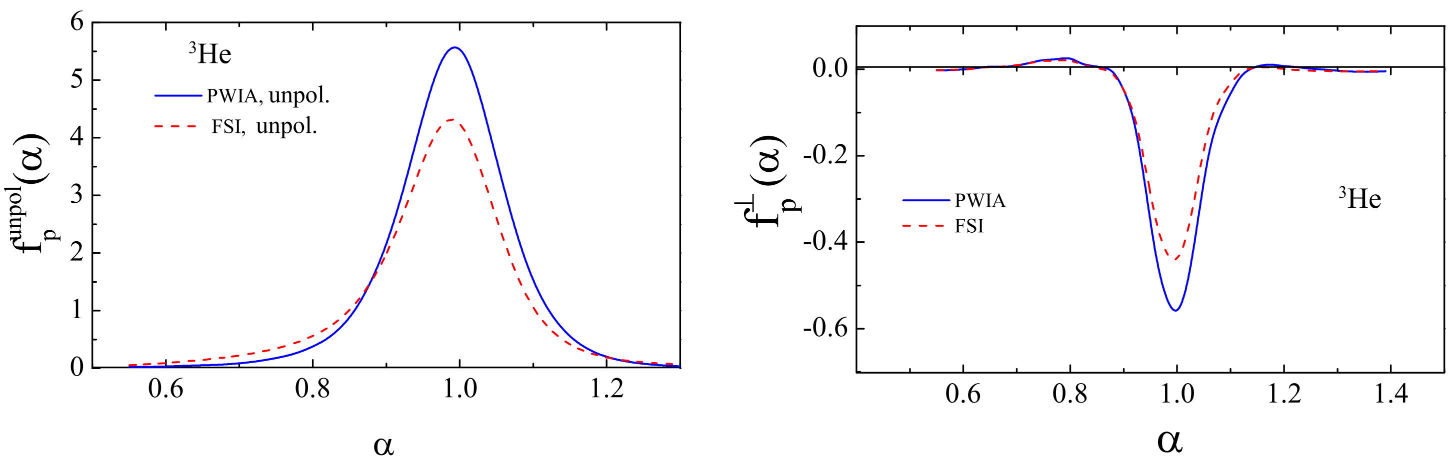
with the distorted light-cone momentum distribution:

$$f_N^A(\alpha, Q^2, ..) = \int dE \int_{p_m(\alpha, Q^2, ..)}^{p_M(\alpha, Q^2, ..)} P_N^{A,FSI}(\mathbf{p}, E, \sigma..)\, \delta\left(\alpha - \frac{pq}{m\nu}\right) \theta\left(W_x^2 - (M_N + M_\pi)^2\right) d^3\mathbf{p}$$

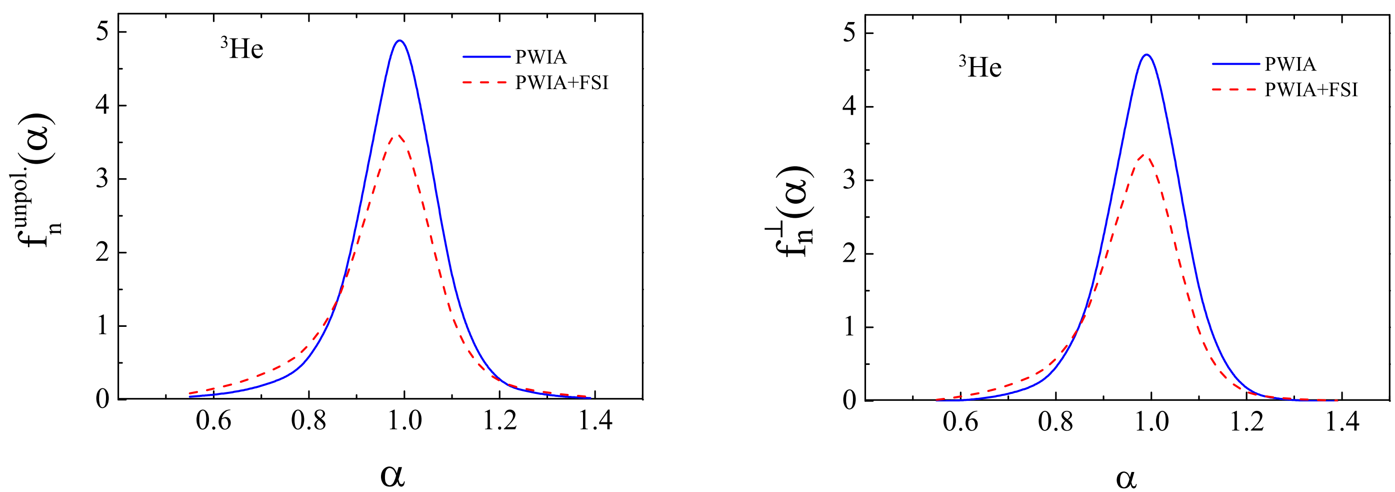
light-cone momentum distributions with FSI:

Del Dotto, Kaptari, Pace, Salmè, S.S., PRC (2017) in press, arXiv:1704.06182 [nucl-th]

PROTON @ E_i = 8.8 GeV



NEUTRON @ E_i = 8.8 GeV



Effective polarizations change...

Does the strong FSI effect hinder the neutron extraction?

Actually, one should also consider the effect on dilution factors f_N

DILUTION FACTORS

$$A_3^{exp} \simeq \frac{\Delta\vec{\sigma}_3^{exp.}}{\sigma_{unpol.}^{exp.}} \Longrightarrow \frac{\langle\vec{\mathbf{s}}_\mathbf{n}\rangle\boldsymbol{\Delta}\vec{\sigma}(\mathbf{n}) + \mathbf{2}\langle\vec{\mathbf{s}}_\mathbf{p}\rangle\boldsymbol{\Delta}\vec{\sigma}(\mathbf{p})}{\langle\mathbf{N_n}\rangle\sigma_{\mathbf{unpol.}}(\mathbf{n}) + \mathbf{2}\langle\mathbf{N_p}\rangle\sigma_{\mathbf{unpol.}}(\mathbf{p})} = \langle\vec{\mathbf{s}}_\mathbf{n}\rangle\mathbf{f_n}\mathbf{A_n} + \mathbf{2}\langle\vec{\mathbf{s}}_\mathbf{p}\rangle\mathbf{f_p}\mathbf{A_p}$$

PWIA:
$$\langle\vec{s}_{n(p)}\rangle = \int dE \int d^3p P_{||}(E,\mathbf{p}) = \mathbf{p_{n(p)}};$$
$$\langle N\rangle = \int dE \int d^3p P_{unpol.}(E,\mathbf{p}) = 1.$$

$$\mathbf{f_{n,(p)}}(\mathbf{x},\mathbf{z}) = \frac{\sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,n(p)}(x) D_1^{q,h}(z)}}{\sum_\mathbf{N}\sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,N}(x) D_1^{q,h}(z)}}$$

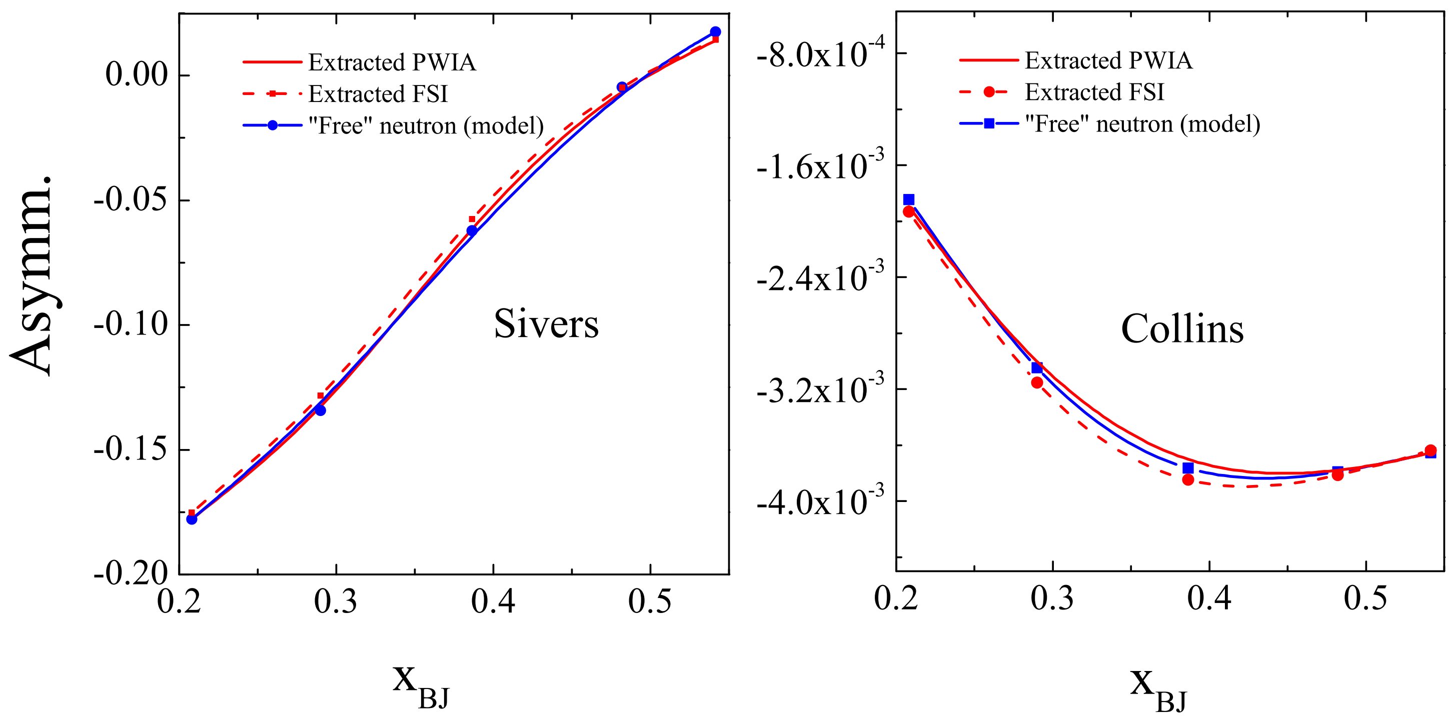
FSI:
$$\langle\vec{s}_{n(p)}\rangle = \int dE \int d^3p P_{||}^{FSI}(E,\mathbf{p}) = \mathbf{p_{n(p)}^{FSI}};$$
$$\langle N\rangle = \int dE \int d^3p P_{unpol.}^{FSI}(E,\mathbf{p}) < 1.$$

$$\mathbf{f_{n,(p)}^{FSI}}(\mathbf{x},\mathbf{z}) = \frac{\sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,n(p)}(x) D_1^{q,h}(z)}}{\sum_\mathbf{N}\langle\mathbf{N}\rangle\sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,N}(x) D_1^{q,h}(z)}}$$

$$A_n \approx \frac{1}{p_n^{FSI} f_n^{FSI}}\left(A_3^{exp} - 2{p_p}^{FSI} f_p^{FSI} A_p^{exp}\right) \approx \frac{1}{p_n f_n}\left(A_3^{exp} - 2p_p f_p A_p^{exp}\right)$$

2

Good news from GEA studies of FSI!



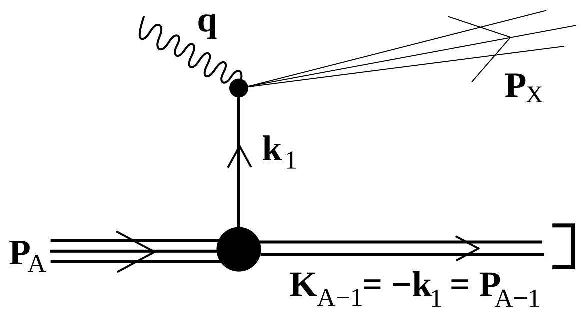
Effects of GEA-FSI (shown at $E_i = 8.8$ GeV) in the dilution factors and in the effective polarizations compensate each other to a large extent: the usual extraction is safe!

$$A_n \approx \frac{1}{p_n^{FSI} f_n^{FSI}} \left(A_3^{exp} - 2{p_p}^{FSI} f_p^{FSI} A_p^{exp} \right) \approx \frac{1}{p_n f_n} \left(A_3^{exp} - 2 p_p f_p A_p^{exp} \right)$$

A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S.S., PRC (2017) in press, arXiv:1704.06182 [nucl-th]

Now: *spectator* SIDIS...

We studied the process $A(e,e'(A-1))X$ many years ago



In this process, in IA,

$$d^2\sigma_A \propto F_2^N(x)$$

there is no convolution! **(nucl-th/9609062)**
Example: through ^{3}He(e,e'd)X, F_2^p, check of the reaction mechanism (EMC effect);
measuring ^{3}H(e,e'd)X, direct access to the neutron F_2^n!

new perspectives:
loi to the JLab PAC,
already in November 2010;
now: approved experiments at JLab!
ALERT coll., arXiv:1708.00891 [nucl-ex]
(For the moment, for ^{4}He)

Eur. Phys. J. A 5, 191–207 (1999)

THE EUROPEAN PHYSICAL JOURNAL A

Semi-inclusive deep inelastic lepton scattering off complex nuclei

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Received: 4 March 1999
Communicated by B. Povh

Abstract. It is shown that in semi-inclusive deep inelastic scattering (DIS) of electrons off complex nuclei, the detection, in coincidence with the scattered electron, of a nucleus $(A-1)$ in the ground state, as well as of a nucleon and a nucleus $(A-2)$, also in the ground state, may provide unique information on several long standing problems, such as: *i*) the nature and the relevance of the final state interaction in DIS; *ii*) the validity of the spectator mechanism in DIS; *iii*) the medium induced modifications of the nucleon structure function; *iv*) the origin of the *EMC* effect.

PACS. 13.40.-f Electromagnetic processes and properties – 21.60.-n Nuclear-structure models and methods – 24.85.+p Quarks, gluons, and QCD in nuclei and nuclear processes – 25.60.Gc Breakup and momentum distributions

Semi-inclusive Deep Inelastic Scattering from Light Nuclei by Tagging Low Momentum Spectators

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Abstract

We propose to measure the semi-inclusive deep inelastic scattering from light nuclei (D,^{3}He, ^{4}He). The detection of the low energy recoil nucleus in the final state will provide unique information about the nature of nuclear EMC effect and will permit to investigate the modifications of the nucleon structure functions in the nucleus. We propose to measure a set of observable by using the future 11 GeV electron beam in Hall B CLAS12. The baseline CLAS12 detector is suitable to detect electrons in the valence region, and a new low energy recoil detector with good performance is required to achieve the proposed physics goals.

Spectator SIDIS ${}^3\vec{\mathrm{He}}(\vec{e}, e'\, {}^2\mathrm{H})X \longrightarrow\ g_1^p$ for a bound proton

Kaptari, Del Dotto, Pace, Salme', Scopetta PRC 89, 035206 (2014)

The distorted spin-dependent spectral function with the Glauber operator $\hat{G}$ can be applied to the "spectator SIDIS" process, where a slow deuteron is detected.

Goal $\longrightarrow$ $g_1^N(x_N = \frac{Q^2}{2p_N q})$ of a bound nucleon.

A_{LL} of electrons with opposite helicities scattered off a longitudinally polarized ^{3}He for parallel kinematics ($\mathbf{p}_N = -\mathbf{p}_{mis} \equiv -\mathbf{P}_{A-1} \parallel \hat{z}$, with $\hat{z} \equiv \hat{\mathbf{q}}$)

$$\frac{\Delta\sigma^{\hat{\mathbf{S}}_A}}{d\varphi_e\, dx\, dy\, d\mathbf{P}_D} \equiv \frac{d\sigma^{\hat{\mathbf{S}}_A}(h_e = 1) - d\sigma^{\hat{\mathbf{S}}_A}(h_e = -1)}{d\varphi_e\, dx\, dy\, d\mathbf{P}_D} =$$

$$\approx 4\frac{\alpha_{em}^2}{Q^2 z_N \mathcal{E}}\frac{m_N}{E_N}\, g_1^p\left(\frac{x}{z}\right)\mathcal{P}_{||}^{\frac{1}{2}}(\mathbf{p}_{mis})\mathcal{E}(2-y)\left[1 - \frac{|\mathbf{p}_{mis}|}{m_N}\right] \qquad \textit{Bjorken limit}$$

$$x = \frac{Q^2}{2m_N\nu}, \quad y = (\mathcal{E} - \mathcal{E}')/\mathcal{E}, \quad z = (p_N \cdot q)/m_N\nu$$

$$\mathcal{P}_{||}^{\frac{1}{2}}(\mathbf{p}_{mis}) = \mathcal{O}^{\frac{1}{2}\frac{1}{2}}_{\frac{1}{2}\frac{1}{2}} - \mathcal{O}^{\frac{1}{2}\frac{1}{2}}_{-\frac{1}{2}-\frac{1}{2}}$$ parallel component of the spectral function

$$\mathcal{O}_{\lambda\lambda'}^{\mathcal{M}\mathcal{M}'(FSI)}(\mathbf{P_D}, E_{2bbu}) = \left\langle \hat{G}\left\{\Psi_{\mathbf{P}_D}, \lambda, \mathbf{p}_N\right\}|\Psi_A^{\mathcal{M}}\right\rangle_{\hat{\mathbf{q}}} \left\langle \Psi_A^{\mathcal{M}'}|\hat{G}\left\{\Psi_{\mathbf{P}_D}, \lambda', \mathbf{p}_N\right\}\right\rangle_{\hat{\mathbf{q}}}$$

Using ^{3}H one would get the neutron!

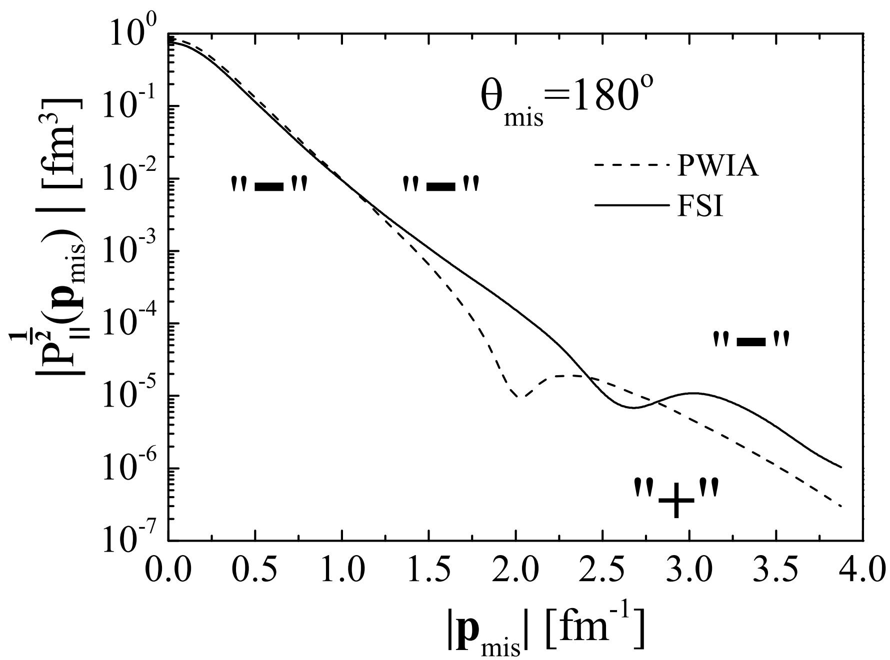
Spectator SIDIS $^3\vec{\mathrm{He}}(\vec{e}, e'\,^2\mathrm{H})X \rightarrow\ g_1^p$ for a bound proton

Kaptari, Del Dotto, Pace, Salme', Scopetta PRC 89, 035206 (2014)

The kinematical variables upon which $g_1^N(x_N)$ depends can be changed independently from the ones of the nuclear-structure $\mathcal{P}_{||}^{\frac{1}{2}}(\mathbf{p}_{mis})$. This allows to single out a kinematical region region where the final-state effects are minimized: $|\mathbf{p}_{mis} \equiv \mathbf{P}_D| \simeq 1 fm^{-1}$

Possible direct access to $g_1^N(x_N)$.

At JLab, $\mathcal{E} = 12\ GeV$, $-\mathbf{p}_{mis} \parallel \mathbf{q}$:



Spectator SIDIS $^3\vec{\mathrm{He}}(\vec{e}, e'\ ^2\mathrm{H})X$ and $^3\vec{\mathrm{H}}(\vec{e}, e'\ ^2\mathrm{H})X$

Summarizing:

- FSI under control in specific regions; they can be evaluted elsewhere
- g_1^p of bound protons from $^3\vec{\mathrm{He}}(\vec{e}, e'\ ^2\mathrm{H})X$:
  - * study of polarized EMC effect
  - * check of the extraction formula used in DIS for the neutron. Remember:
    the Bjorken Sum Rule obtained considering also ^{3}He data;
    the Bjorken Sum Rule is used even to obtain $\alpha_s(Q^2)$
- g_1^n of bound neutrons from $^3\vec{\mathrm{H}}(\vec{e}, e'\ ^2\mathrm{H})X$: direct measurement

I understand that at JLab the use of a recoil detector in a polarized set-up is difficult, and the use of ^{3}H targets complicated...

Actually none of these problems occur at the EIC

Conclusions

We are studying SIDIS off trinucleons, beyond the realistic, NR, IA approach in the Bjorken limit. We have results for:

- ${}^3\vec{H}e(e,e'\pi)X$: nuclear effects in the extraction of the neutron information are under control. **FSI effects** Evaluated through the GEA – a distorted spin dependent spectral function
- *Spectator* SIDIS: ${}^3\vec{H}e(\vec{e},e'(A-1))X$: nice possibilities towards the understanding of the structure of bound nucleons
- An analysis at finite Q^2 with a LF spectral function (in IA); (not discussed today)

  LF, formal: Del Dotto, Pace, Salmè, SS, PRC 95 (2017) 014001; preliminary calc., S.S., Del Dotto, Kaptari, Pace, Rinaldi, Salmè, Few Body Syst. 56 (2015) 6

Next steps: 1) complete this program! 2) relativistic FSI?
3) Towards 4-body systems: DVCS off ^{4}He (in collaboration with M. Viviani, Pisa), non diagonal spectral function...

Importance of a precise description of dynamics of light ions for the forthcoming EIC program