Neutron spin structure from DVCS and SIDIS on ^{3}He

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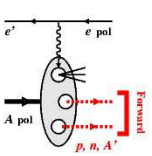


January 21^{st}, 2020

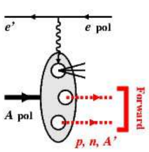
Outline

Selected topics:

- Coherent DVCS off ^3He in Impulse Approximation (more, on thursday):
  - * **today: extraction of neutron GPDs;**
    M. Rinaldi, S.S. PRC 85, 062201(R) (2012); PRC 87, 035208 (2013)
- SIDIS (quickly): beyond the impulse approximation.
  Final state interactions (FSI) and the distorted spectral function.
  - * **SIDIS $^3\vec{H}e(\vec{e}, e'\pi)X$ and the extraction of neutron SSAs;**
    (A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S.S., PRC 96 (2017) 065203)
  - * **spectator SIDIS $^3\vec{H}e(\vec{e}, e'd)X$ and the spin dependent EMC effect.**
    (L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206)

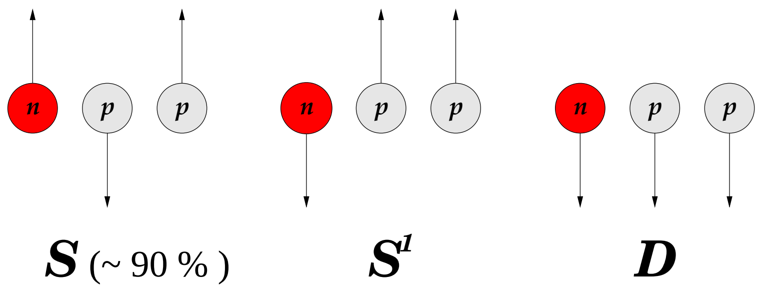
Relevant new calculations to be performed and proper measurements to check theoretical methods, thinking to the EIC, will be addressed.

Our calculations are valid in the valence region. Coherent effects at low x, relevant for the EIC, not implemented yet. (**See F. Bissey, V. Guzey, M. Strikman and A. Thomas, PRC 65 (2002) 064317; L. Frankfurt, V. Guzey, M. Strikman, Phys. Rep. 512 (2012) 255**)



The neutron information from ^{3}He

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



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

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

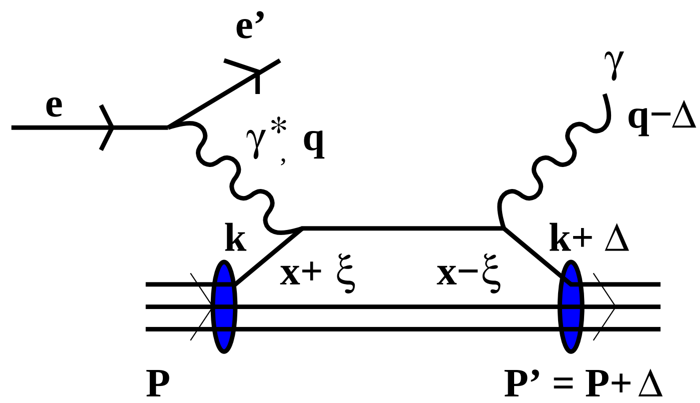
- Examples: SIDIS regime, @JLAB 12:
  H. Gao et al, PR12-09-014 (Rating A): Target Single Spin Asymmetry in SIDIS $(e, e'\pi^{\pm})$ Reactions on a Transversely Polarized ^{3}He Target
  J.P. Chen et al, PR12-11-007 (Rating A): Asymmetries in SIDIS $(e, e'\pi^{\pm})$ Reactions on a Longitudinally Polarized ^{3}He Target

- Widely used: DIS: the Bjorken Sum Rule studied considering also ^{3}He data; used even to constrain $\alpha_s(Q^2)$ (**see, e.g., A. Deur et al, Prog.Part.Nucl.Phys. 90 (2016) 1)...**
  HERE: DVCS, SIDIS, SIDIS with spectator tagging...
  In ^{3}He conventional nuclear effects under control... Exotic ones disentangled

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

DVCS and GPDs: Definitions (X. Ji PRL 78 (97) 610)

For a $J = \frac{1}{2}$ target,
in a hard-exclusive process,
(handbag approximation)
such as (coherent) DVCS:

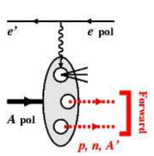


the GPDs $H_q(x, \xi, \Delta^2)$ and $E_q(x, \xi, \Delta^2)$ are introduced:

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P' | \bar{\psi}_q(-\lambda n/2) \quad \gamma^\mu \quad \psi_q(\lambda n/2) | P \rangle = H_q(x, \xi, \Delta^2) \bar{U}(P') \gamma^\mu U(P)$$

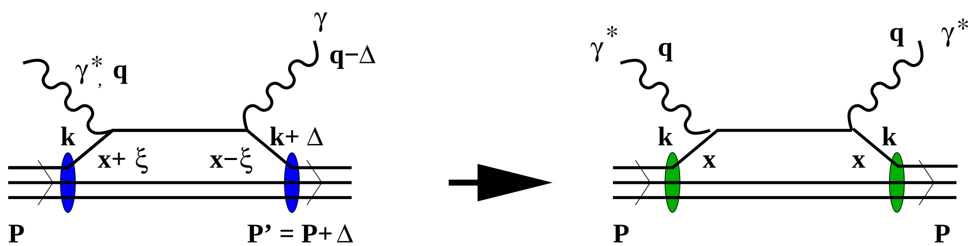
$$+ \quad E_q(x, \xi, \Delta^2) \bar{U}(P') \frac{i\sigma^{\mu\nu}\Delta_\nu}{2M} U(P) + \ldots$$

- $\Delta = P' - P$, $q^\mu = (q_0, \vec{q})$, and $\bar{P} = (P + P')^\mu / 2$
- $x = k^+/P^+$; ξ = "skewness" = $-\Delta^+/(2\bar{P}^+)$
- $x \leq -\xi \longrightarrow$ GPDs describe $antiquarks$;
  $-\xi \leq x \leq \xi \longrightarrow$ GPDs describe $q\bar{q}$ $pairs$; $x \geq \xi \longrightarrow$ GPDs describe $quarks$



GPDs: constraints

- when $P' = P$, i.e., $\Delta^2 = \xi = 0$, one recovers the usual PDFs:



$$H_q(x,\xi,\Delta^2) \Longrightarrow H_q(x,0,0) = q(x); \quad E_q(x,0,0) \; unknown$$

- the x–integration yields the q-contribution to the Form Factors (ffs)

$$\int dx \int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P' | \bar{\psi}_q(-\lambda n/2) \gamma^\mu \psi_q(\lambda n/2) | P \rangle =$$

$$\int dx\, H_q(x,\xi,\Delta^2) \bar{U}(P') \gamma^\mu U(P) + \int dx\, E_q(x,\xi,\Delta^2) \bar{U}(P') \frac{\sigma^{\mu\nu}\Delta_\nu}{2M} U(P) + ...$$

$$\Longrightarrow \int dx\, H_q(x,\xi,\Delta^2) = F_1^q(\Delta^2) \qquad \int dx\, E_q(x,\xi,\Delta^2) = F_2^q(\Delta^2)$$

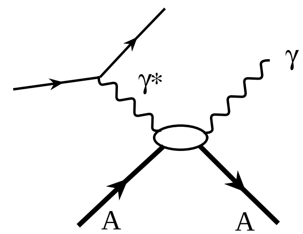
$\Longrightarrow$ Defining $\boxed{\tilde{G}_M^q = H_q + E_q}$ one has $\int dx\, \tilde{G}_M^q(x,\xi,\Delta^2) = G_M^q(\Delta^2)$

GPDs: a unique tool for many aspects...

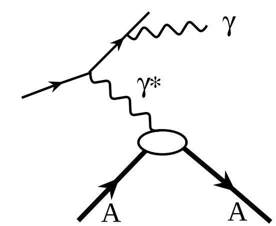
- Here: contribution to the solution to the "Spin Crisis" (**J.Ashman et al., EMC, PLB 206, 364 (1988)**); parton total angular momentum J through the Ji sum rule:

$$\boxed{\int_{-1}^{1} dx\, x\,(H_q + E_q)(x,0,0) = J_q^z}$$

... but also an experimental challenge:



DVCS



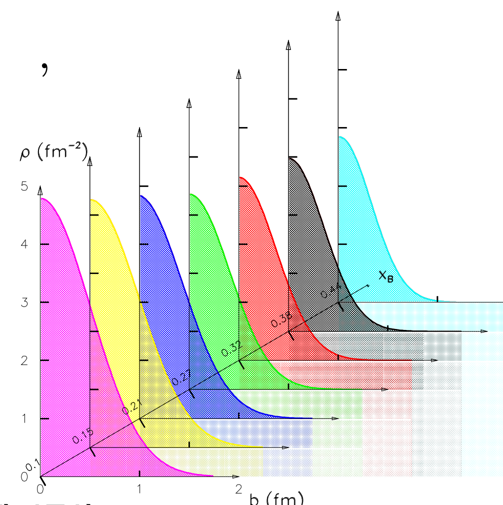
BH

- Hard exclusive process $\longrightarrow$ small σ;
- Difficult extraction:

$$T_{\mathbf{DVCS}} \propto CFF \propto \int_{-1}^{1} dx \frac{H_q(x,\xi,\Delta^2)}{x-\xi+i\epsilon} + \ldots \quad ,$$

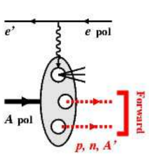
- Competition with the **BH** process! (σ asymmetries measured).

$$d\sigma \propto |T_{\mathbf{DVCS}}|^2 + |T_{\mathbf{BH}}|^2 + 2\,\Re\{T_{\mathbf{DVCS}} T^*_{\mathbf{BH}}\}$$

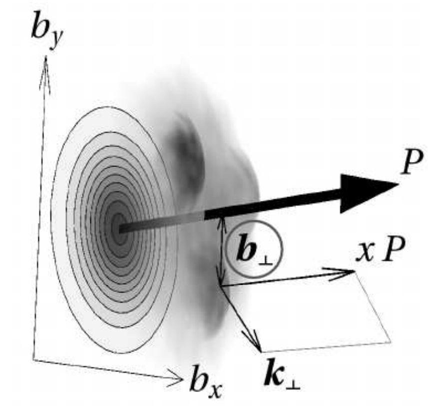


Nevertheless, for the proton, we have results:

(see, e.g., Dupré, Guidal, Niccolai, Vanderhaeghen Eur.Phys.J. A53 (2017) 171)



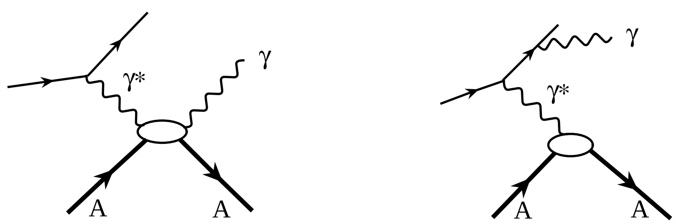
Nuclei and DVCS tomography



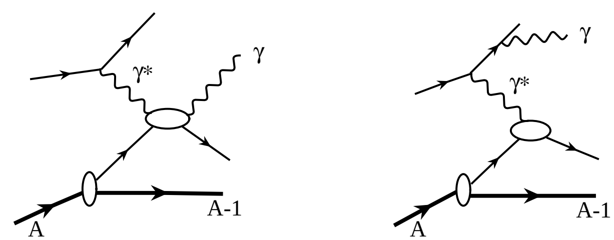
In impact parameter space, GPDs are *densities*:

M. Burkardt, PRD 62 (2000) 07153

$$\rho_q(x, \vec{b}_\perp) = \int \frac{d\vec{\Delta}_\perp}{(2\pi)^2} e^{i\vec{b}_\perp \cdot \vec{\Delta}_\perp} H^q(x, 0, \Delta^2)$$



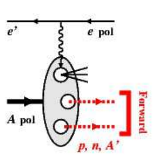
Coherent DVCS: nuclear tomography



Incoherent DVCS: tomography of bound nucleons, realization of the EMC effect; **FSI?**

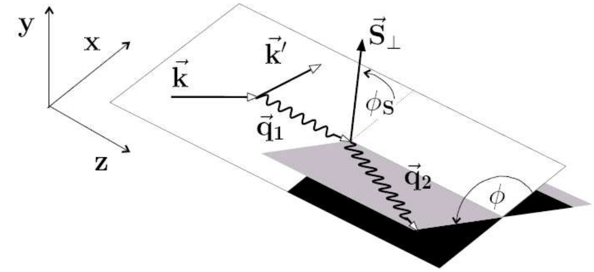
^{3}He is a unique target for GPDs studies. Examples:

- **HERE: access to the neutron in coherent processes (complementary to incoherent)**
- **heavier targets do not allow refined theoretical treatments. Test of the theory**
- **Between ^{2}H ("not a nucleus") and ^{4}He (a true one).** Not isoscalar!



Extracting GPDs: ^{3}He $\simeq p$

One measures asymmetries: $A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$



- Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \simeq \sin\phi \left[F_1\mathcal{H} + \xi(F_1 + F_2)\tilde{\mathcal{H}} + (\Delta^2 F_2/M^2)\mathcal{E}/4\right] d\phi \quad \Longrightarrow \quad H$$

- Unpolarized beam, longitudinally polarized target:

$$\Delta\sigma_{UL} \simeq \sin\phi \left\{F_1\tilde{\mathcal{H}} + \xi(F_1 + F_2)\left[\mathcal{H} + \xi/(1+\xi)\mathcal{E}\right]\right\} d\phi \quad \Longrightarrow \quad \tilde{H}$$

- Unpolarized beam, transversely polarized target:

$$\Delta\sigma_{UT} \simeq \cos\phi \sin(\phi_S - \phi) \left[\Delta^2(F_2\mathcal{H} - F_1\mathcal{E})/M^2\right] d\phi \quad \Longrightarrow \quad E$$

To evaluate cross sections, e.g. for experiments planning, one needs H, $\tilde{H}$, E

This is what we have calculated for ^{3}He . H alone, already very interesting.

GPDs of ^{3}He in IA (more, on thursday...)

H_q^A can be obtained in terms of H_q^N (**S.S. PRC 70, 015205 (2004), PRC 79, 025207 (2009)**):

$$H_q^A(x,\xi,\Delta^2) = \sum_N \int dE \int d\vec{p}\,\overline{\sum_S}\sum_s P^N_{SS,ss}(\vec{p},\vec{p}\,',E)\frac{\xi'}{\xi}H_q^N(x',\Delta^2,\xi')\ ,$$

and $\tilde{G}_M^{3,q}$ in terms of $\tilde{G}_M^{N,q}$ (**M. Rinaldi, S.S. PRC 85, 062201(R) (2012); PRC 87, 035208 (2013)**):

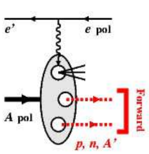
$$\tilde{G}_M^{3,q}(x,\Delta^2,\xi) = \sum_N \int dE \int d\vec{p}\left[P^N_{+-,+-} - P^N_{+-,-+}\right](\vec{p},\vec{p}\,',E)\frac{\xi'}{\xi}\tilde{G}_M^{N,q}(x',\Delta^2,\xi')\ ,$$

where $P^N_{SS,ss}(\vec{p},\vec{p}\,',E)$ is the one-body, spin-dependent, off-diagonal spectral function for the nucleon N in the nucleus,

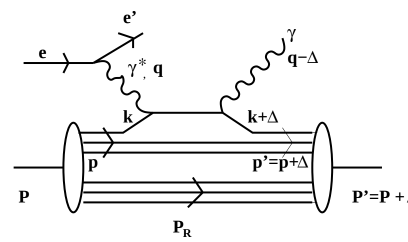
$$P^N_{SS',ss'}(\vec{p},\vec{p}\,',E) = \frac{1}{(2\pi)^6}\frac{M\sqrt{ME}}{2}\int d\Omega_t \sum_{s_t}\langle \vec{P}'S'|\vec{p}\,'s',\vec{t}s_t\rangle_N \langle \vec{p}s,\vec{t}s_t|\vec{P}S\rangle_N\ ,$$

evaluated by means of a realistic treatment based on Av18 wave functions (**"CHH" method in A. Kievsky** *et al* **NPA 577, 511 (1994); Av18 + UIX overlaps in E. Pace** *et. al*, **PRC 64, 055203 (2001)**).

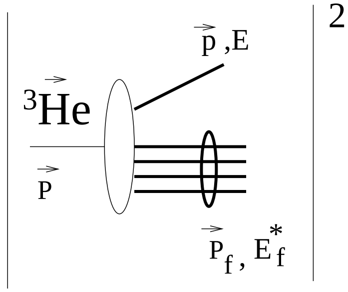
Nucleon GPDs given by an old version of the VGG model (VGG 1999, $x-$ and Δ^2- dependencies factorized)



The spectral function (Impulse Approximation)

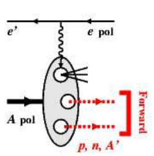


$$\mathbf{P}^N_{\mathcal{M}\sigma\sigma}(\vec{p},,E) = \sum_f \left| \quad \right|^2 =$$



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

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



Extracting the neutron - I:

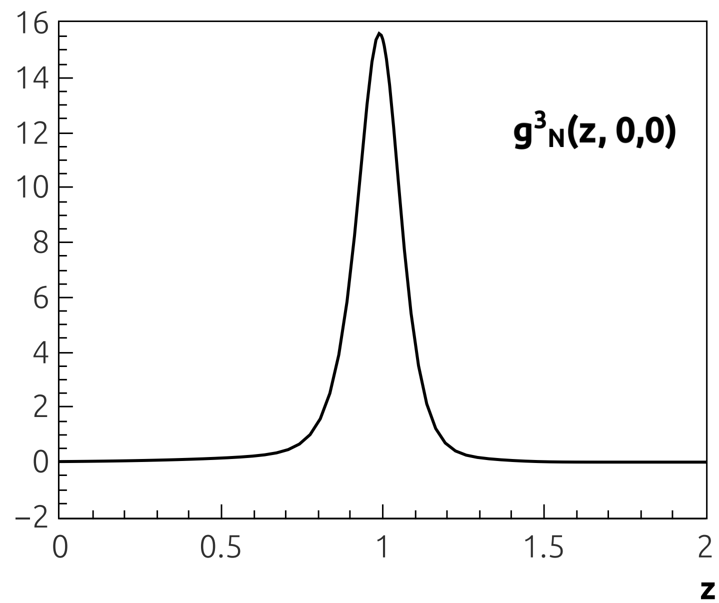
The convolution formula can be written as

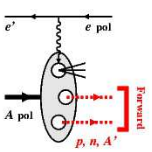
$$\tilde{G}_M^{3,q}(x_3,\Delta^2,\xi) = \sum_N \int_{x_3}^{\frac{M_A}{M}} \frac{dz}{z} g_N^3(z,\Delta^2,\xi) \tilde{G}_M^{N,q}\left(\frac{x_3}{z},\Delta^2,\frac{\xi}{z},\right) ,$$

where $g_N^3(z,\Delta^2,\xi)$ is a “light cone spin-dependent off-forward momentum distribution” and, since close to the forward limit it is strongly peaked around $z = 1$

$$g_N^3(z,\Delta^2,\xi) = \int dE \int d\vec{p}\, \tilde{P}_N^3(\vec{p},\vec{p}+\vec{\Delta},E)$$

$$\delta\left(z+\xi-\frac{M_A}{M}\frac{p^+}{\bar{P}^+}\right)$$





Extracting the neutron - I:

The convolution formula can be written as

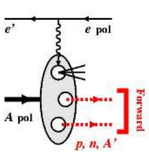
$$\tilde{G}_M^{3,q}(x_3, \Delta^2, \xi) = \sum_N \int_{x_3}^{\frac{M_A}{M}} \frac{dz}{z} g_N^3(z, \Delta^2, \xi) \tilde{G}_M^{N,q}\left(\frac{x_3}{z}, \Delta^2, \frac{\xi}{z},\right) ,$$

where $g_N^3(z, \Delta^2, \xi)$ is a "light cone spin-dependent off-forward momentum distribution" and, since close to the forward limit it is strongly peaked around $z = 1$

$$\begin{aligned}\tilde{G}_M^{3,q}(x_3, \Delta^2, \xi) &\simeq \quad low\,\Delta^2 \simeq \sum_N \tilde{G}_M^{N,q}\left(x_3, \Delta^2, \xi\right) \int_0^{\frac{M_A}{M}} dz g_N^3(z, \Delta^2, \xi) \\ &= \quad G_M^{3,p,point}(\Delta^2) \tilde{G}_M^{p,q}(x_3, \Delta^2, \xi) + G_M^{3,n,point}(\Delta^2) \tilde{G}_M^{n,q}(x_3, \Delta^2, \xi) .\end{aligned}$$

where, at $x_3 < 0.7$, the magnetic point like ff has been introduced

$$G_M^{3,N,point}(\Delta^2) = \int dE \int d\vec{p}\, \tilde{P}_N^3(\vec{p}, \vec{p} + \vec{\Delta}, E) = \int_0^{\frac{M_A}{M}} dz\, g_N^3(z, \Delta^2, \xi) .$$

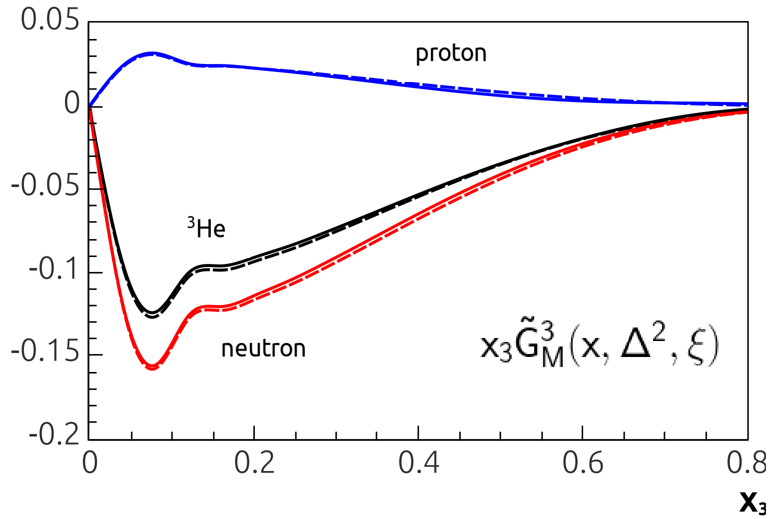


Extracting the neutron - II:

Validity of the approximated formula:

full: IA calculation, $\tilde{G}_M^3(x, \Delta^2, \xi)$ and proton and neutron contributions to it, at $\Delta^2 = -0.1$ GeV^2, $\xi = 0.1$;

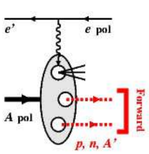
dashed: same quantities, with the approximated formula:



$$\tilde{G}_M^3(x, \Delta^2, \xi) \simeq G_M^{3,p,point}(\Delta^2)\tilde{G}_M^p(x, \Delta^2, \xi) + G_M^{3,n,point}(\Delta^2)\tilde{G}_M^n(x, \Delta^2, \xi)$$

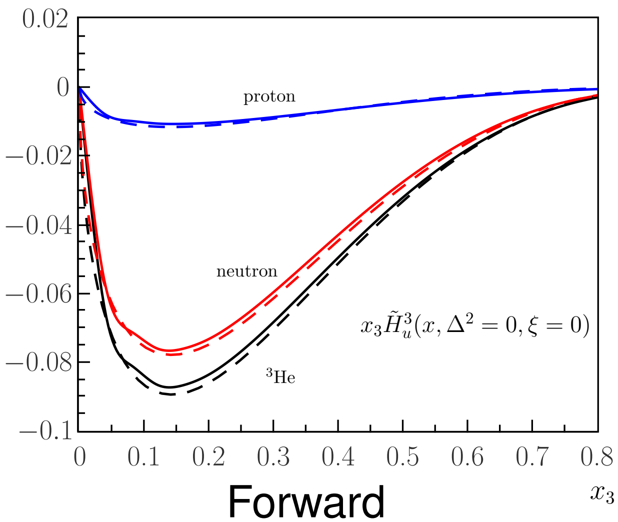
Impressive agreement! The only Nuclear Physics ingredient in the approximated formula is the magnetic point like ff, which is under good theoretical control:

Δ^2 [GeV^2]	$G_M^{3,p,point}$ Av18	$G_M^{3,p,point}$ Av14	$G_M^{3,n,point}$ Av18	$G_M^{3,n,point}$ Av14
0	-0.044	-0.049	0.879	0.874
-0.1	0.040	0.038	0.305	0.297
-0.2	0.036	0.035	0.125	0.119

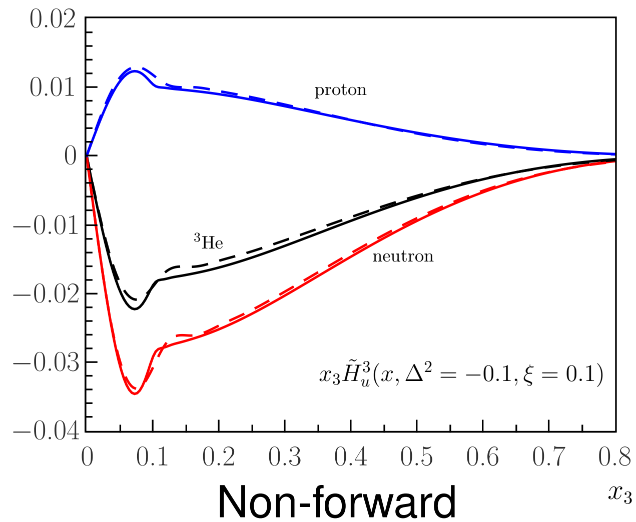


The GPD $\tilde{H}$: M. Rinaldi, S.S, Few-Body Systems 55, 861 (2014)

$\tilde{H}^{3,u}(x, \Delta^2, \xi)$ and proton and (dominant!) neutron contributions to it:



Forward

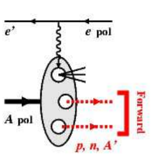


Non-forward

full: IA calculation; dashed: approximated formula:

$$\tilde{H}^{3,u}(x, \Delta^2, \xi) \simeq g_A^{3,p,point}(\Delta^2)\tilde{H}^{p,u}(x, \Delta^2, \xi) + g_A^{3,n,point}(\Delta^2)\tilde{H}^{n,u}(x, \Delta^2, \xi)$$

Good agreement! The only Nuclear Physics ingredient in the approximated formula is the axial point like ff, which is under good theoretical control.
One has $g_A^{3,N,point}(\Delta^2 = 0) = p_N$, nucleon effective polarizations (within AV18+ UIX, $p_n = 0.878$, $p_p = -0.024$), used in DIS for extracting the neutron information from ^{3}He (**C. Ciofi, S.S., E. Pace and G. Salmè, PRC 48 R968 (1993)**). Forward limit recovered!



$^3\vec{He}$ & $^3\vec{H}$ at the EIC

From $^3\vec{He}$, neutron spin-dependent information I^n ($I^n = g_1^n, I^n_{GDH}, \tilde{H}^n ...$) is extracted using the free proton I^p according to (motivated within the IA)

$$I^n = \frac{1}{p_n}\left(I^{^3He} - 2p_p I^p\right) \tag{1}$$

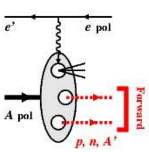
If one could use $^3\vec{H}$, the $proton$ I^p would be at hand:

$$I^p = \frac{1}{p_n}\left(I^{^3H} - 2p_p I^n\right) \tag{2}$$

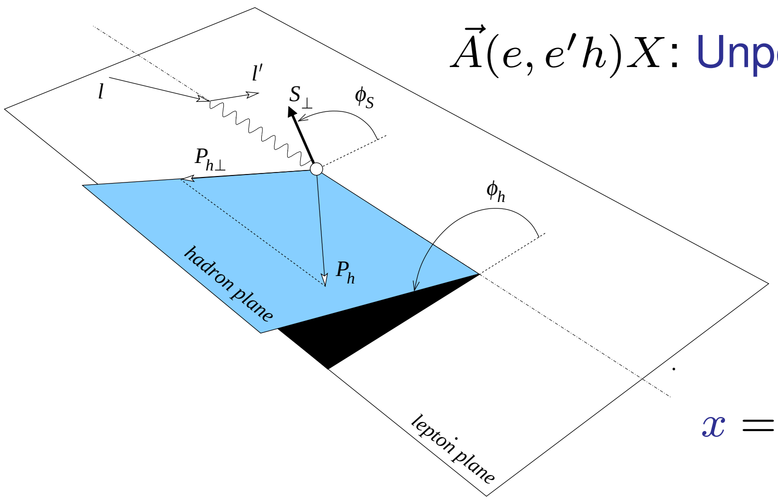
where $p_p = p_p^{^3He} = p_n^{^3H}$ and $p_n = p_n^{^3He} = p_p^{^3H}$ (Isospin symmetry assumed).

From Eqs. (1) and (2), I^n and I^p would be extracted from the measured $I^{^3He}$ and $I^{^3H}$, using $p_{p,n}$ as the only theoretical input.
The extraction does not require the knowledge of $I^{n,p}$ from other experiments!

If I^p extracted using Eq. (2) compared well with that of *free* protons, one could trust the extraction of I^n from $I^{^3He}$, Eq. (1); if not, interesting effects beyond IA, such as the effect of Δ's **(Frankfurt, Guzey, Strikman PLB 281, 379 (1996))**, would be exposed.



SIDIS off ^{3}He and neutron TMDs: Single Spin Asymmetries (SSAs) - 1



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

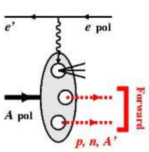
$$d^6\sigma \equiv \frac{d^6\sigma}{dxdydzd\phi_S d^2 P_{h\perp}}$$

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

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

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

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



SSAs - 2

SSAs in terms of parton distributions and fragmentation functions:

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

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

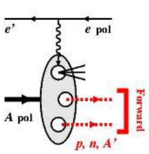
$$N^{Collins} \propto \sum_q e_q^2 \int d^2\kappa_{\mathbf{T}} d^2\mathbf{k_T} \delta^2(\mathbf{k_T} + \mathbf{q_T} - \kappa_{\mathbf{T}}) \frac{\hat{\mathbf{P}}_{\mathbf{h}\perp} \cdot \kappa_{\mathbf{T}}}{\mathbf{M_h}} h_1^q(x, \mathbf{k_T}^2) H_1^{\perp q,h}(z, (z\kappa_{\mathbf{T}})^2)$$

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

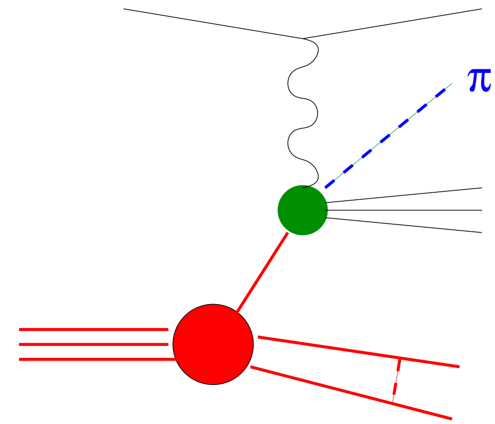
- LARGE A_{UT}^{Sivers} measured in $\vec{p}(e, e'\pi)x$ HERMES PRL 94, 012002 (2005)
- SMALL A_{UT}^{Sivers} measured in $\vec{D}(e, e'\pi)x$; COMPASS PRL 94, 202002 (2005)

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?

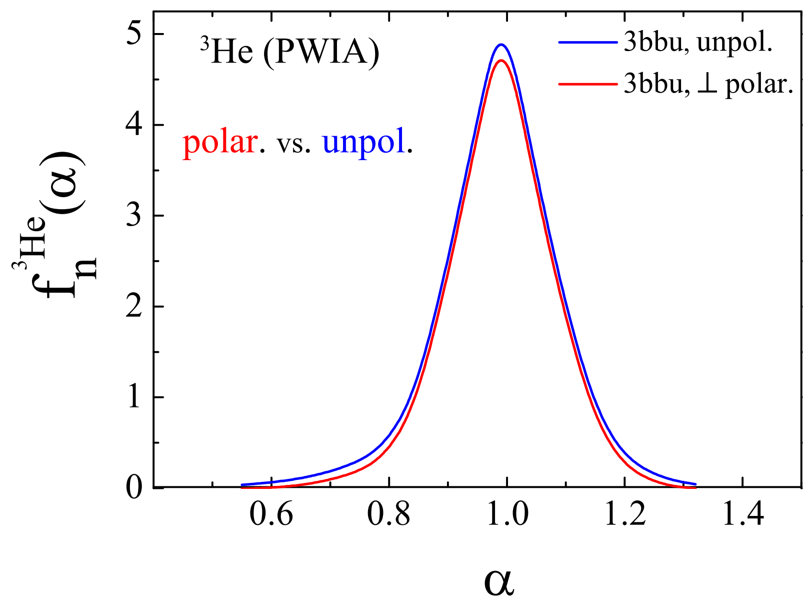
In a first paper on this subject,
(S.S., PRD 75 (2007) 054005)
the process $^3\vec{H}e(e,e'\pi)X$ has been evaluated :
* in the Bjorken limit
* in IA $\rightarrow$ no FSI between the measured fast, ultrarelativistic π
the remnant and the two nucleon recoiling system
$E_\pi \simeq 2.4\ GeV$ in JLAB exp at $6\ GeV$ - Qian et al., PRL 107 (2011) 072003

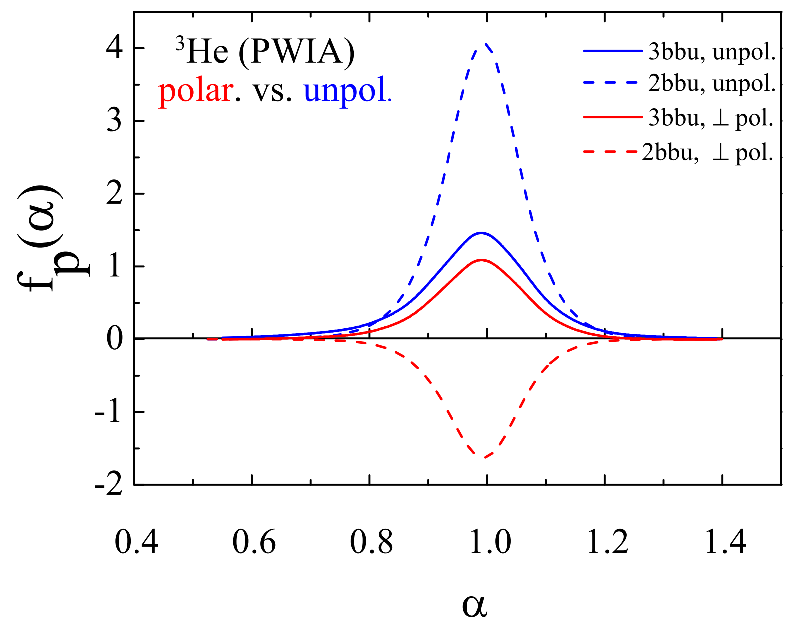
SSAs involve convolutions of the spin-dependent nuclear spectral function, $\vec{P}(\vec{p},E)$, with parton distributions and fragmentation functions

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

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

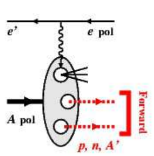
Light-cone momentum distributions in IA





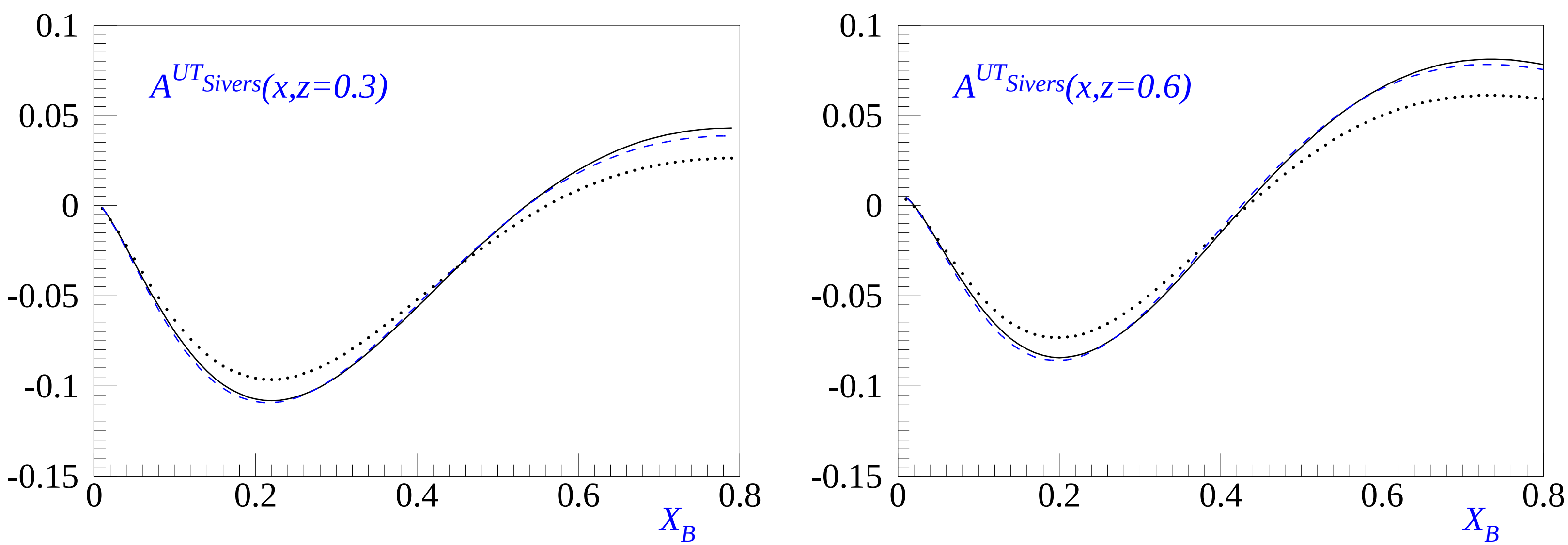
Calculation within the **Av18+UIX** interaction:

- 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)



January 21^{st}, 2020

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

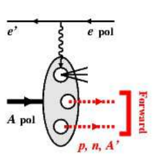


FULL: Neutron asymmetry (model: from parameterizations or models of TMDs and FFs)

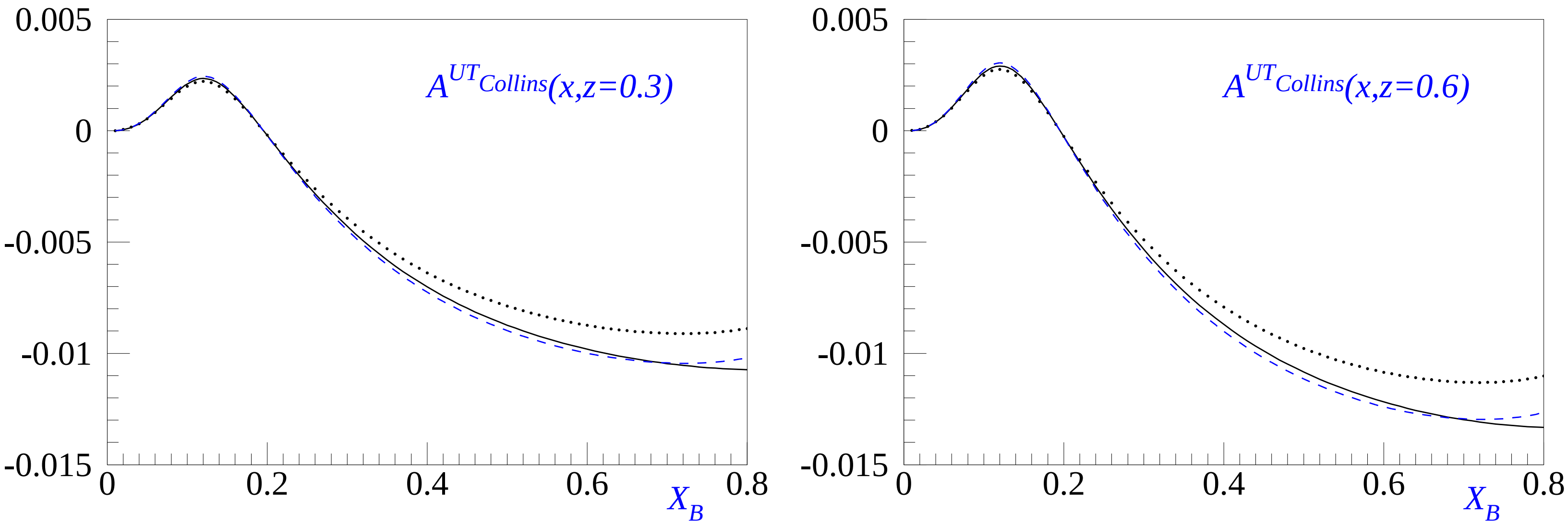
DOTS: Neutron asymmetry extracted from ${}^3He$ (calculation) neglecting the contribution of the proton polarization $\bar{A}_n \simeq \frac{1}{f_n} A_3^{calc}$

DASHED : Neutron asymmetry extracted from ${}^3He$ (calculation) taking into account nuclear structure effects through the formula (f_n, f_p = "dilution factors"):

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



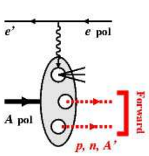
Results: $\vec{n}$ from $^3\vec{He}$: $A_{UT}^{Collins}$, @ JLab



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

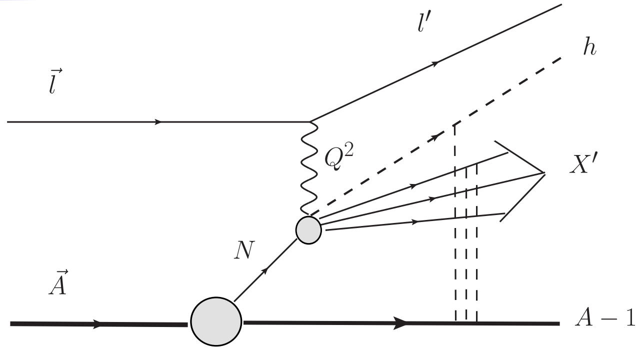
What about FSI effects ?

(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.

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

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

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

$$\begin{aligned} \langle \mathbf{r_1 r_2 r_3} | S_X, S_{A-1} \mathbf{P_{A-1}} \mathbf{E^f_{A-1}} \rangle &= \Phi^*_f(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \approx \hat{S}_{Gl}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \mathbf{\Psi^{*f}}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \\ \boxed{\hat{S}_{Gl} = Glauber\ operator} \quad &\approx \hat{S}_{Gl}(\mathbf{r_1}, \mathbf{r_2}, \mathbf{r_3}) \sum_{\mathbf{j>k}} \chi^+_{\mathbf{S_X}} \phi^*(\xi_\mathbf{x}) \mathbf{e^{-ip_X r_i}} \mathbf{\Psi^{*f}_{jk}}(\mathbf{r_j}, \mathbf{r_k}) \ , \end{aligned}$$

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

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:

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

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

$$\langle (\hat{S}_{Gl}) \{\Phi_{\epsilon^*_{A-1}}, \lambda, \mathbf{p}_N\} | S_A, \mathbf{P_A} \rangle \delta\left(E - B_A - \epsilon^*_{A-1}\right).$$

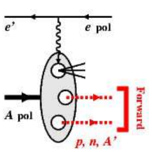
Glauber operator: $\hat{S}_{Gl}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3) = \prod_{i=2,3}\left[1 - \theta(z_i - z_1)\Gamma(\mathbf{b}_1 - \mathbf{b}_i, z_1 - z_i)\right]$

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

GEA (Γ depends also on the longitudinal distance between the debris and the scattering centers z_{1i}!) very successful in q.e. semi-inclusive and exclusive processes off ^{3}He

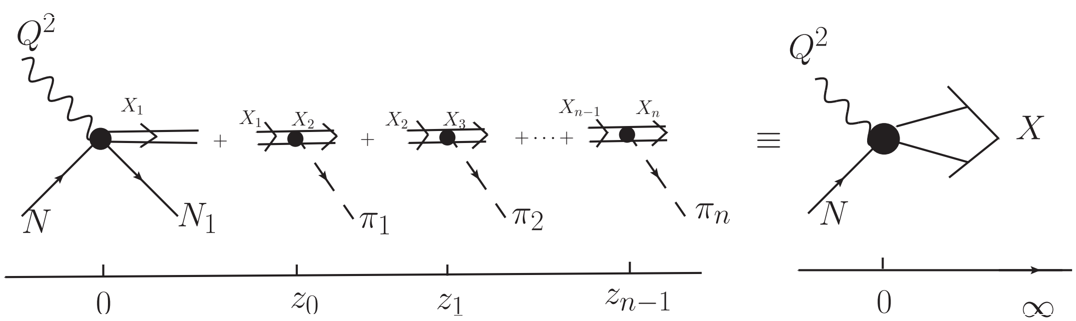
see, e.g., Frankfurt, Sargsian, Strikman PRC 56 (1997) 1124; Alvioli, Ciofi & Kaptari PRC 81 (2010) 02100 and references there in

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).



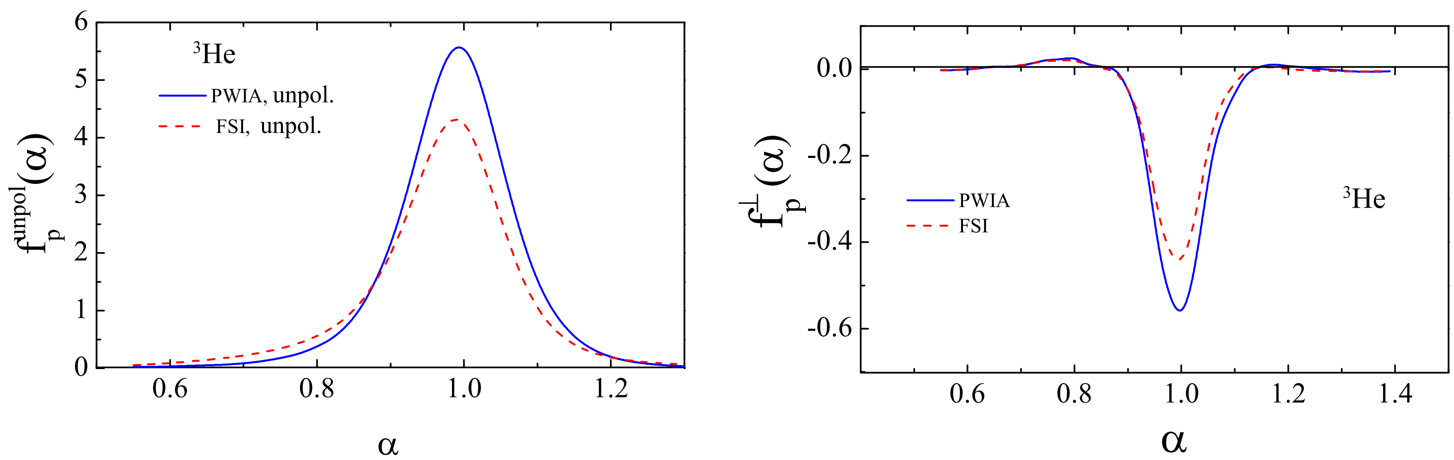
$$\sigma_{eff}(z) = \sigma_{tot}^{NN} + \sigma_{tot}^{\pi N}\,[n_M(z) + n_g(z)]$$

- 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**)

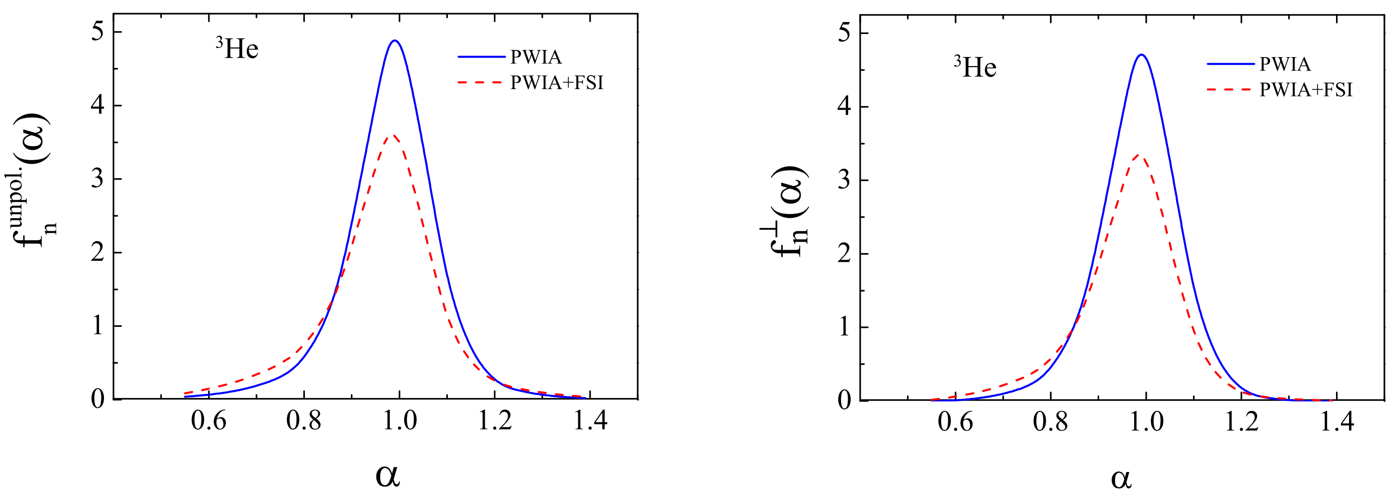
light-cone momentum distributions with FSI:

Del Dotto, Kaptari, Pace, Salmè, S.S., PRC 96 (2017) 065203

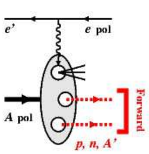
PROTON @ E_i = 8.8 GeV



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

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

PWIA:

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

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

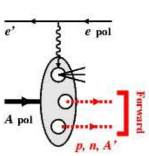
FSI:

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

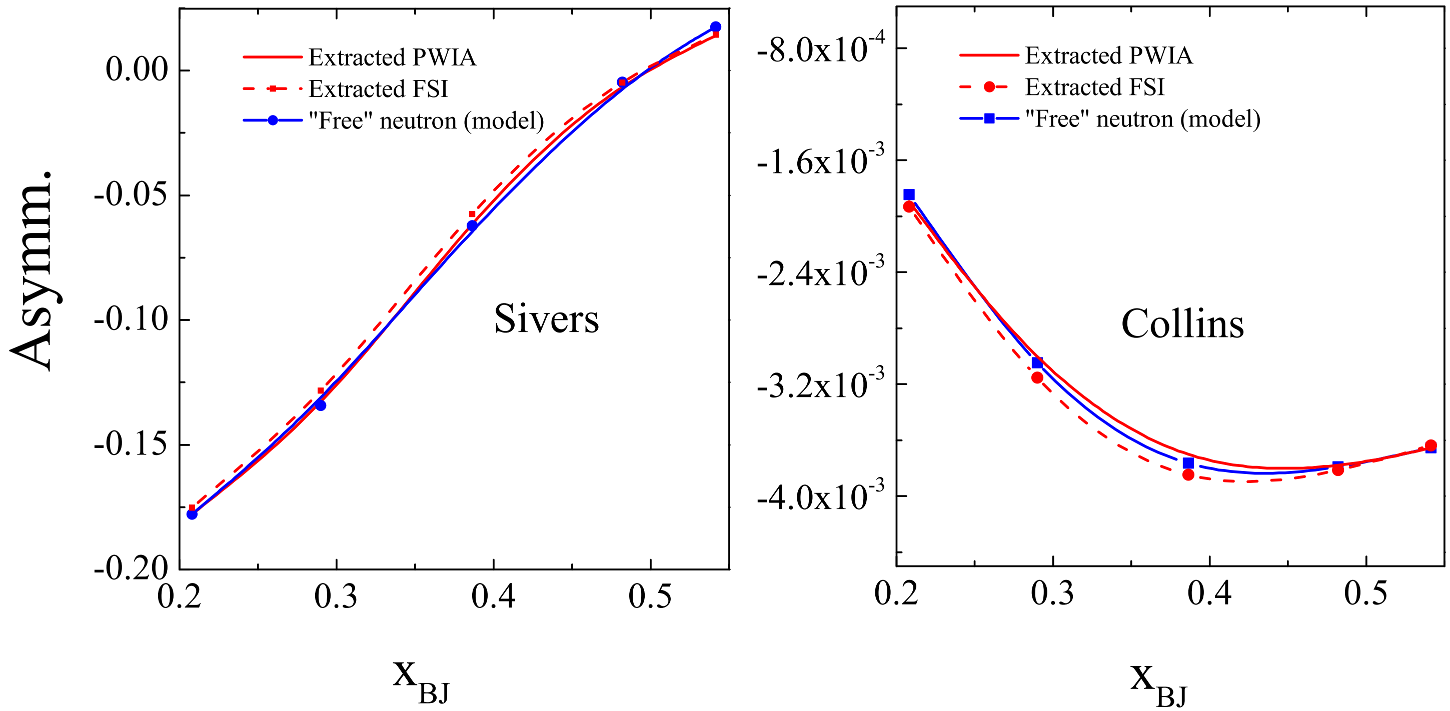
$$\Longrightarrow \quad \mathbf{f_{n,(p)}^{FSI}(x,z)} = \frac{\sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,n(p)}(x) D_1^{q,h}(z)}}{\sum_\mathbf{N}\langle \mathbf{N}\rangle \sum_\mathbf{q} \mathbf{e_q^2 f_1^{q,N}(x) D_1^{q,h}(z)}}$$

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

2

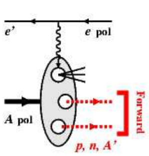


Good news from GEA studies of FSI!



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!

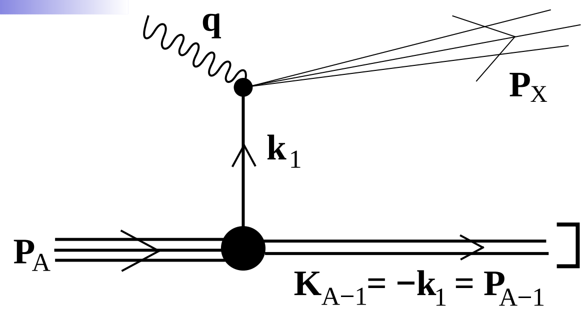
$$A_n \approx \frac{1}{p_n^{FSI} f_n^{FSI}} \left(A_3^{exp} - 2{p_p}^{FSI} f_p^{FSI} A_p^{exp} \right) \approx \frac{1}{p_n f_n} \left(A_3^{exp} - 2p_p f_p A_p^{exp} \right)$$



A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S.S., PRC 96 (2017) 065203

Now: *spectator* SIDIS...

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



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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[2] Departament de Fìsica Teòrica, Universitat de València, E-46100 Burjassot, València, Spain

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

In this process, in IA, no convolution!

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

for the deuteron: Simula PLB 1997;

Melnitchouk, Sargsian, Strikman ZPA 1997; BONUS@JLab

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!

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

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(Dated: November 24, 2010)

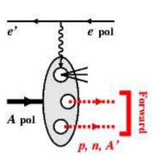
Abstract

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.

new perspectives: loi to the JLab PAC, already in November 2010;

now: approved experiments at JLab!

ALERT run group, arXiv:1708.00891 [nucl-ex], for ^{4}He...



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

Kaptari, Del Dotto, Pace, Salmè, 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 $\hat{z} \equiv \hat{\mathbf{q}}$)

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

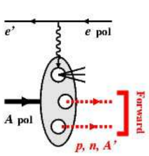
$$\approx 4\frac{\alpha_{em}^2}{Q^2 z_N \mathcal{E}} \frac{m_N}{E_N}\, g_1^p\left(\frac{x}{z}\right)\mathcal{P}_{||}^{\frac{1}{2}}(\mathbf{p}_{mis})\mathcal{E}(2-y)\left[1 - \frac{|\mathbf{p}_{mis}|}{m_N}\right] \qquad \textit{Bjorken limit}$$

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

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

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

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



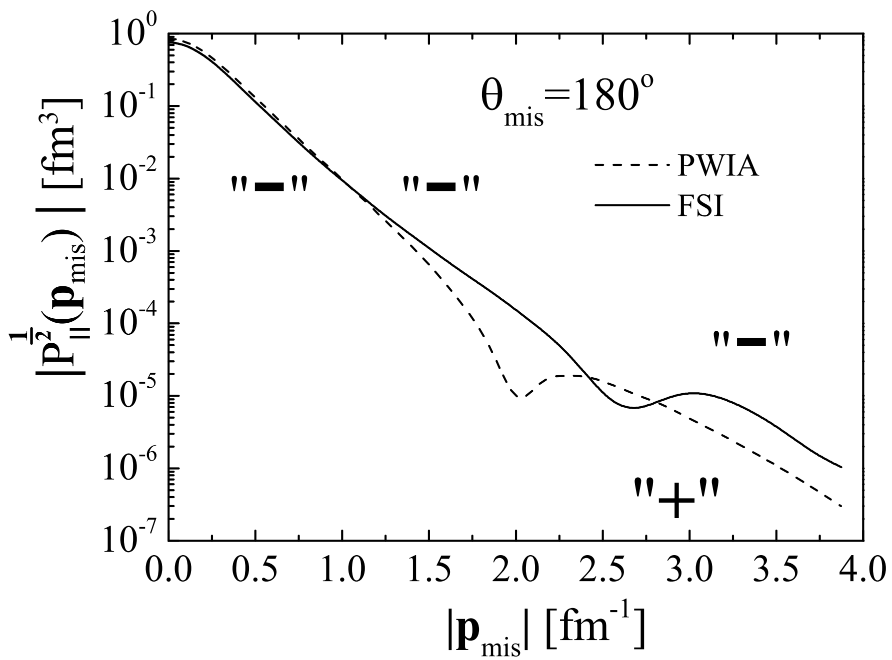
Spectator SIDIS ${}^3\vec{\mathrm{H}}\mathrm{e}(\vec{e}, e'\, {}^2\mathrm{H})X \to g_1^p$ for a bound proton

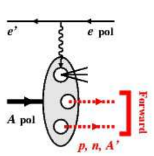
Kaptari, Del Dotto, Pace, Salme', Scopetta PRC 89, 035206 (2014)

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 $g_1^N(x_N)$.

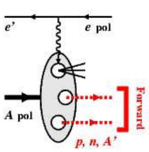
At JLab, $\mathcal{E} = 12\ GeV$, $-\mathbf{p}_{mis} \parallel \mathbf{q}$:



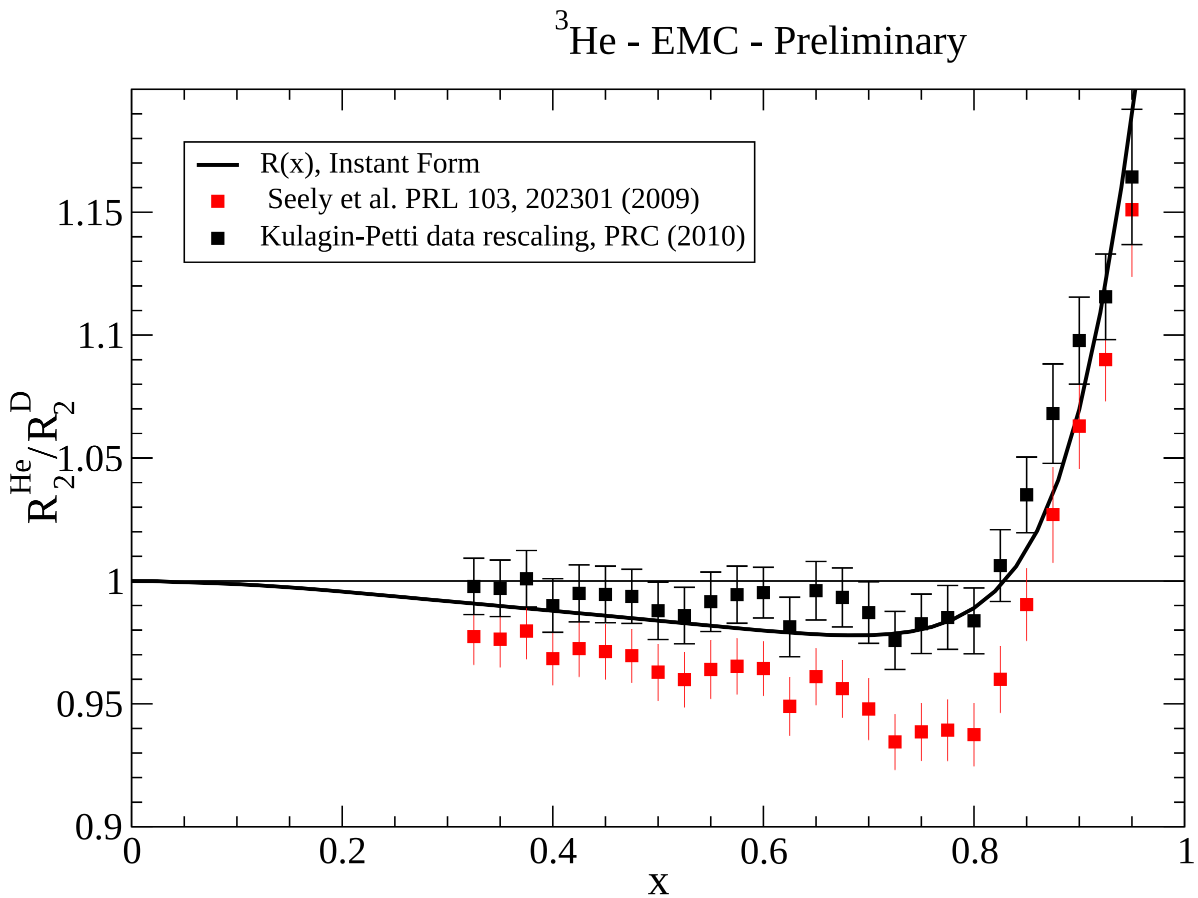


Perspectives

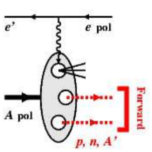
- **Further calculations to support DIS EIC measurements:**
  * Calculations with a Light-Front spectral function (in IA);
    LF, formal: Del Dotto, Pace, Salmè, SS, PRC 95 (2017) 014001. Relativistic FSI?
  * Importance of inputs by the low energy (few- and many-body) nuclear Physics community;
  * Extension to low x kinematics (shadowing effects)
- **Contribution of EIC to validate underlying assumptions**
  * Provide also absolute cross sections, not only asymmetries!
  * Spectator tagging with polarization (very difficult to observe slow recoils in a polarized environment with fixed targets): off-shell effects, validity of the impulse approximation, incoherent DVCS, SIDIS $^3\vec{H}e(\vec{e}, e'd)X$ and polarized EMC effect;
  * Even better with $^3\vec{H}$ beams: direct access to g_1^n; check of IA and extraction formulae (even the inclusive measurement is sufficient for this)
  * **More, on thursday**: even unpolarized ^3H very interesting (DVCS) for isospin dependent nuclear effects and the possible breaking of IA; DVCS off ^{3}He, even unpolarized: onset of nuclear effects, great theoretical control



Backup: ^{3}He EMC effect IF - preliminary



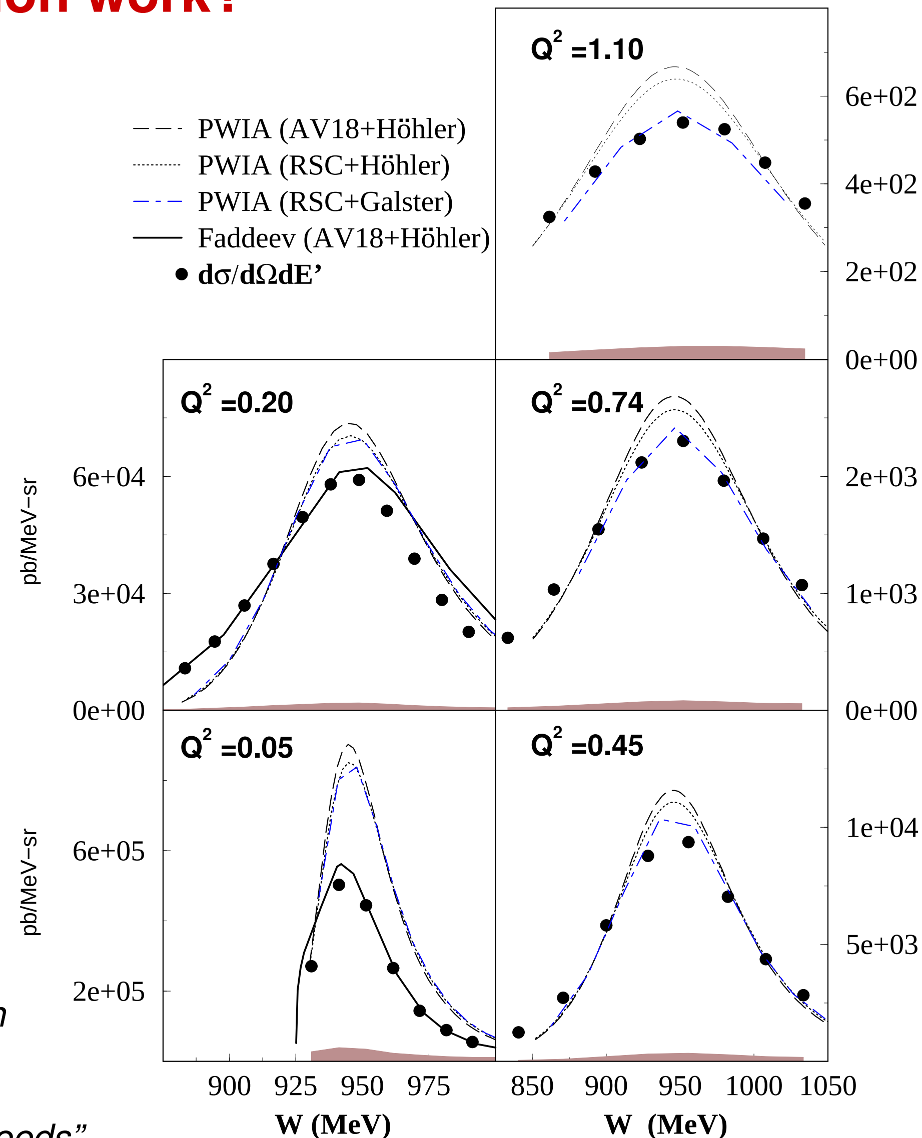
- Red squares: **Seely et al. (E03103), Hall A JLab, PRL 103 (2009) 202301**
- Black squares: reanalysis (currently accepted) **Kulagin and Petti, PRC 82 (2010) 054614**
- particle SR fulfilled; momentum SR violated by 2 %



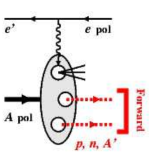
Backup: Is the spectral function useful? Does the Impulse Approximation work?

The answer in the data.

Example: ${}^3\vec{H}e(\vec{e},e')X$ in q.e. kinematics
(**K. Slifer et al, PRL 101 (2008) 022303**)



- Faddeev calc. at low Q^2
  J. Golak et al. Phys. Rept. 415 (2005) 89
- PWIA (Av18) calc.
  E. Pace et al, PRC 64 (2001) 055203
- Conclusion of the Slifer et al. paper:
  “A full three-body Faddeev calculation agrees well with the data but starts to exhibit discrepancies as the energy increases, possibly due to growing relativistic effects. As the momentum transfer increases, the PWIA approach reproduces the data well, but there exists an intermediate range where neither calculation succeeds”
- caveat: always check kinematics and set-up (this is q.e., inclusive)

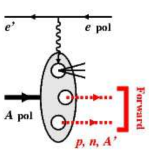


Status (Backup: Impulse Approximation and beyond)

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

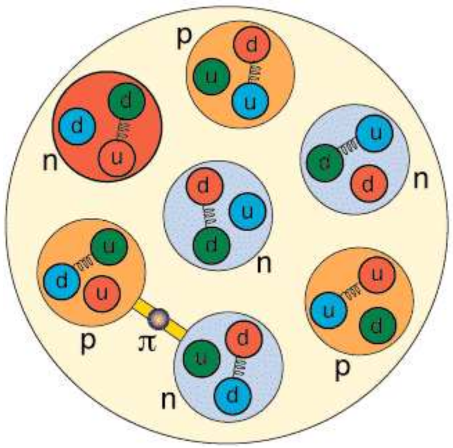
Selected contributions from Rome-Perugia:

- 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



Backup: DVCS off ^{3}He and neutron GPDs (a fast look)

Question: **Which of these transverse sections is more similar to that of a nucleus?**

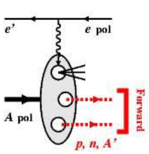


To answer, we should perform a *tomography...*

We can! M. Burkardt, PRD 62 (2000) 07153

Answer: Deeply Virtual Compton Scattering & Generalized Parton Distributions (GPDs)

For ^{4}He, recent data (M. Hattawy et al., PRL 119, (2017) 20204) and new experiments approved (ALERT coll., e-Print: arXiv:1708.00888 [nucl-ex])



Backup: JLab kinematics: a few words more

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

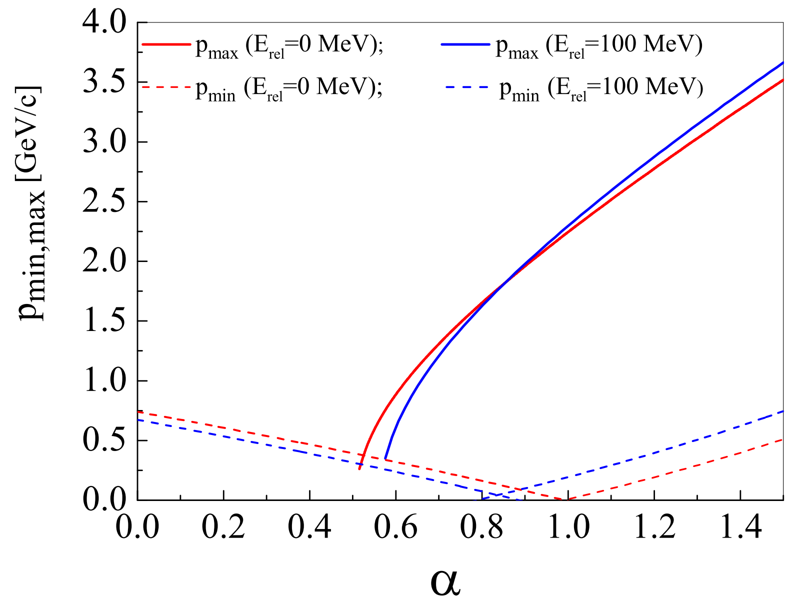
$$\mathcal{F}^A(x_{Bj}, Q^2, \ldots) = \sum_N \int_{x_{Bj}}^{A} f_N^A(\alpha, Q^2, \ldots)\, \mathcal{F}^N(x_{Bj}/\alpha, Q^2, \ldots)\, d\alpha$$

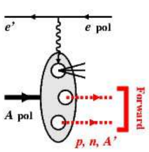
with the light-cone momentum distribution:

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

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

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





Backup: Example: 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

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

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

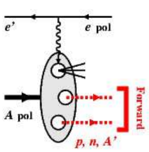
- While P^{IA} is "static",i.e. depends on ground state properties, P^{FSI} is dynamical ($\propto \sigma_{eff}$) and process dependent;
- For each experimental point (given x, Q^2...), a different spectral function has to be evaluated!
- Quantization axis (w.r.t. which polarizations are fixed) and eikonal 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:

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



SIDIS off ^{3}He and neutron TMDs

	Impulse Approximation		including FSI	
	unpolarized	spin dep.	unpolarized	spin dep.
Non Relativistic	$\surd$	$\surd$	$\surd$	$\boxed{\surd}$
Light-Front	Def: $\surd$ Calc: 🔧	Def: $\surd$ 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 SIDIS**
    (A. Del Dotto, L. Kaptari, E. Pace, G. Salmè, S.S., PRC 96 (2017) 065203)
  - * **Evaluation of FSI: distorted spectral function and spectator SIDIS**
    (L. Kaptari, A. Del Dotto, E. Pace, G. Salmè, S.S., PRC 89 (2014) 035206)