Dynamical observables for a J=1/2 system within a fully Poincaré-covariant framework

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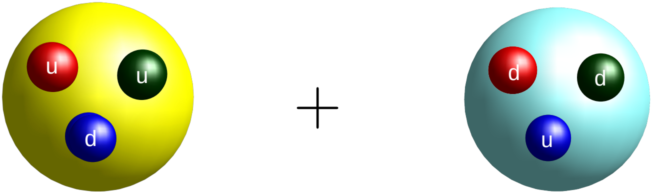
A Poincarè covariant spectral function for ^{3}He within the light-front (LF) dynamics
Del Dotto, Pace, Salmè, Scopetta, Physical Review C 95, 014001 (2017)
E. Pace., A. Del Dotto, L. Kaptari, M. Rinaldi, G. Salmè, S. Scopetta
Few Body Syst. 54 (2013) 1079; Few Body Syst. 56 (2015) 425; Few-Body Syst. 57 (2016) 601

Outline

Motivations

The quest of a reliable flavor decomposition needs sound information on the neutron dynamical observables (GPDs, TMDs).



A great motivation for very accurate and long-lasting experimental efforts in developing effective neutron targets to investigate the electromagnetic responses of the neutron

$\Rightarrow$ the polarized $^3\mathrm{He}$ target, 90% neutron target

(e.g. H. Gao et al, PR12-09-014; J.P. Chen et al, PR12-11-007, @JLAB12)

Bonus: mirror nuclei, $^3\mathrm{He}$ and $^3\mathrm{H}$, play a pivotal role for stringent checks of the model dependence, upon the nuclear description, in extracting the neutron information ($\Rightarrow$ G. Petratos, MARATHON @ JLAB12, for unpolarized DIS)

On the theory side, we need to implement the nuclear description and hence to validate a sound extraction procedure of dynamical information on the neutron

The main quantity to pursue such a programme is the

Nuclear Spectral Function (⇒ nucleon Green's function in the medium)

$$P_{\sigma'\sigma}(k,E) = -\frac{1}{\pi}\Im m\left\{\langle\Psi_{gr}|a^{\dagger}_{\mathbf{k},\sigma'}\ \frac{1}{E-H+i\epsilon}\ a_{\mathbf{k},\sigma}|\Psi_{gr}\rangle\right\}$$

with

$$H = \sum_{\alpha,\beta}\langle\alpha|H_1|\beta\rangle\ a^{\dagger}(\alpha)\ a(\beta) + \frac{1}{2}\sum_{\alpha,\beta,\gamma,\eta}\langle\alpha\gamma|H_2|\beta\eta\rangle\ a^{\dagger}(\alpha)\ a^{\dagger}(\gamma)a(\beta)\ a(\eta) + \ldots\ \ldots$$

Probabilistic interpretation: the diagonal terms give the probability distribution to find a constituent with given spin, momentum and removal energy in the ground state of the interacting system, $|\Psi_{gr}\rangle$.

This quantity is quite familiar in nuclear physics, less in hadron physics (hadronization of the constituent) where the QFT framework is needed → correlator, $\langle\Psi_{gr}|\psi(x)\psi(y)|\Psi_{gr}\rangle$.

Where we are for $^3\mathrm{He}$ (and $^3\mathrm{H}$)?

- Accurate description of the initial state within 'a non relativistic framework (cf Kievsky,Pace, G.S. Viviani PRC **56**, 64 (1997))
- Realistic description of the final state, as needed for SiDIS experiments (!!): besides the fully interacting spectator pair, the generalized eikonal approximation has been introduced for describing (knocked out nucleon + debris from hadronization) (cf Del Dotto et al PRC **96**, 065203 (2017))

The Relativistic Hamiltonian Dynamics framework

Why a relativistic treatment ?

General answer: to develop a more advanced theory, appropriate for JLAB12 and (future) EIC kinematics

- The Standard Model of Few-Nucleon Systems, where nucleon and pion degrees of freedom are taken into account, has achieved a very high degree of sophistication.
- Nonetheless, one should try to fulfill, as much as possible, the relativistic constraints, dictated by the covariance with respect the Poincaré Group, $\mathcal{G}_P$, when processes involving nucleons with high 3-momentum are considered and a high precision is needed.
  This is the case if one studies, e.g., i) the nucleon structure functions (unpolarized and polarized cases); ii) the nucleon TMDs, iii) signatures of short-range correlations; iv) exotics (6-bag quarks etc).
- At least, one should carefully deal with the boosts of the nuclear states, $|\Psi_{init}\rangle$ and $|\Psi_{fin}\rangle$!

The definitely preferred framework for embedding the successful *non relativistic* phenomenology is given by the

Light-front Relativistic Hamiltonian Dynamics (fixed dof) + Bakamjian-Thomas construction of the *interacting* Poincaré generators.

One can address both Poincaré covariance and locality

General principles to be implemented

★ Extended Poincaré covariance - Commutation rules between the generators

$$[P^\mu, P^\nu] = 0, \quad [M^{\mu\nu}, P^\rho] = -\imath(g^{\mu\rho} P^\nu - g^{\nu\rho} P^\mu),$$

$$[M^{\mu\nu}, M^{\rho\sigma}] = -\imath(g^{\mu\rho} M^{\nu\sigma} + g^{\nu\sigma} M^{\mu\rho} - g^{\mu\sigma} M^{\nu\rho} - g^{\nu\rho} M^{\mu\sigma})$$

$\mathcal{P}$ and $\mathcal{T}$ have to be taken into account !

★ ★ Macroscopic locality ($\equiv$ cluster separability (relevant in nuclear physics)): i.e. observables associated with different space-time regions must commute in the limit of large spacelike separation (i.e. causally disconnected), rather than for arbitrary (μ-locality) spacelike separations (Keister-Polyzou, Adv. Nucl. Phys. **20**, 225 (1991)).

Physical motivation: When a system is separated into disjoint subsystems by a sufficiently large spacelike separation, then the subsystems behave as independent systems.

The Light-Front framework has several advantages:

- 7 Kinematical generators: i) three LF boosts (at variance with the dynamical nature of the Instant-form boosts), ii) $\tilde{P} = (P^+, \mathbf{P}_\perp)$, iii) Rotation around the z-axis.
- The LF boosts have a subgroup structure : then one gets a trivial separation of the intrinsic motion (as in the non-relativistic case). Separation of intrinsic and global motion is important to correctly treat the boost between initial and final states !)
- $P^+ \geq 0$ leads to a meaningful Fock expansion, once massless constituents are absent
- No square root in the dynamical operator P^-, propagating the state in the LF-time.
- The infinite-momentum frame (IMF) description of DIS is easily included.

Drawback: the transverse LF-rotations are dynamical
But within the Bakamjian-Thomas framework one can construct an intrinsic angular momentum fully kinematical!
Moreover the Mass Operator, developed within a *non relativistic framework*, is fully acceptable for a BT construction of the Poincaré generators

To complete the matter: the spin

- Coupling spins and orbital angular momenta is easily accomplished in the Instant Form of RHD (kinematical hyperplane t=0) through Clebsch-Gordan coefficients, since in this form the three rotation generators are independent of interaction.
- To embed this machinery in the LFHD one needs unitary operators, the so-called Melosh rotations that relate the LF spin wave function and the canonical one. For a particle of spin (1/2) with LF momentum $\tilde{\mathbf{k}} \equiv \{k^+, \vec{k}_\perp\}$

$$|\mathbf{k}; s, \sigma\rangle_c = \sum_{\sigma'} D^{1/2}_{\sigma',\sigma}(R_M(\tilde{\mathbf{k}}))\ |\tilde{\mathbf{k}}; s, \sigma'\rangle_{LF}$$

where

$D^{1/2}_{\sigma',\sigma}(R_M(\tilde{\mathbf{k}}))$ is the standard Wigner function for the $J = 1/2$ case ,

$R_M(\tilde{\mathbf{k}})$ is the rotation between the rest frames of the particle reached through a LF boost or a canonical boost, starting from the same Pauli-Lubanski vector.

$$D^{\frac{1}{2}}[\mathcal{R}_M(\tilde{\mathbf{k}})]_{\sigma\sigma'} = \chi^\dagger_\sigma \frac{m + k^+ - \imath\boldsymbol{\sigma}\cdot(\hat{z}\times\mathbf{k}_\perp)}{\sqrt{(m+k^+)^2 + |\mathbf{k}_\perp|^2}}\ \chi_{\sigma'} = {}_{LF}\langle\tilde{\mathbf{k}}; s\sigma|\mathbf{k}; s\sigma'\rangle_c$$

χ_σ is a two-dimensional spinor. To use the Clebsch-Gordan coefficients to couple angular momenta in LFHD one has to exploit the relation with the canonical spin.

From the NR Nuclear Spectral Function to the LF one

$$P_{\sigma'\sigma}(k,E) = -\frac{1}{\pi}\Im m \left\{ \langle \Psi_{gr}| a^\dagger_{\mathbf{k},\sigma'} \ \frac{1}{E-H+i\epsilon} \ a_{\mathbf{k},\sigma}|\Psi_{gr}\rangle \right\}$$
$$= \sum_{f_{(A-1)}} \langle \vec{p},\sigma\tau;\psi_{f_{(A-1)}}|\psi^A_{J\mathcal{M}}\rangle \ \langle \psi^A_{J\mathcal{M}}|\psi_{f_{(A-1)}};\vec{p},\sigma'\tau\rangle \ \delta(E - E_{f_{(A-1)}} + E_A)$$

with $|\vec{p},\sigma\tau\rangle$ plane wave with momentum $\vec{p}$ in the system rest frame and spin along z equal to σ, and $|\psi_{f_{(A-1)}}\rangle$: a state of the $(A-1)$-particle spectator system: fully interacting !

The spin-dependent LF Nuclear Spectral Function can be defined through the **formal** relation between the overlaps $\langle \vec{p},\sigma\tau;\psi_{f_{(A-1)}}|\psi^A_{J\mathcal{M}}\rangle_{LF}$ in *Light-front HD* (hyperplane $x^+ = 0$) and the ones in *Instant-form* HD (hyperplane $t = 0$)

Then, by exploiting the Bakamjian-Thomas construction,one can approximates the *Instant-form* overlaps through the ones calculated within a *non relativistic approach*, still preserving the Poincaré covariance and taking benefit of the whole successful phenomenology. (A. Del Dotto, E. Pace, G. Salmè, S. Scopetta, PRC **95**, 014001 (2017))

For implementing the macrocausality, it is crucial to distinguish between the cluster $(1,23)$ reference frame and the one of the whole system (123). (At the present stage the packing operators (Sokolov, Theor. Mat. Fiz. 36 (1978) 355) are neglected).
The LF overlaps are

$$ {}_{LF}\langle T\tau;\alpha,\epsilon;JJ_z;\tau_1\sigma,\tilde{\boldsymbol{\kappa}}|j,j_z;\epsilon^3;\frac{1}{2}T_z\rangle = \sum_{\tau_2\tau_3}\int d\mathbf{k}_{23}\sum_{\sigma'_1} D^{\frac{1}{2}}[\mathcal{R}_M(\tilde{\mathbf{k}})]_{\sigma\sigma'_1} $$

$$ \sqrt{(2\pi)^3\ 2E(\mathbf{k})}\sqrt{\frac{\kappa^+E_{23}}{k^+E_S}}\sum_{\sigma''_2,\sigma''_3}\sum_{\sigma'_2,\sigma'_3}\mathcal{D}_{\sigma''_2,\sigma'_2}(\tilde{\mathbf{k}}_{23},\tilde{\mathbf{k}}_2)\ \mathcal{D}_{\sigma''_3,\sigma'_3}(-\tilde{\mathbf{k}}_{23},\tilde{\mathbf{k}}_3) $$

$$ {}_{NR}\langle T,\tau;\alpha,\epsilon;JJ_z|\mathbf{k}_{23},\sigma''_2,\sigma''_3;\tau_2,\tau_3\rangle\ \langle\sigma'_3,\sigma'_2,\sigma'_1;\tau_3,\tau_2,\tau_1;\mathbf{k}_{23},\mathbf{k}|j,j_z;B_3;\frac{1}{2}T_z\rangle_{NR} $$

$$ \mathcal{D}_{\sigma''_i,\sigma'_i}(\pm\tilde{\mathbf{k}}_{23},\tilde{\mathbf{k}}_i)=\sum_{\sigma_i} D^{\frac{1}{2}}[\mathcal{R}^\dagger_M(\pm\tilde{\mathbf{k}}_{23})]_{\sigma''_i\sigma_i}\ D^{\frac{1}{2}}[\mathcal{R}_M(\tilde{\mathbf{k}}_i)]_{\sigma_i\sigma'_i} $$

where the relevant LF momenta of the emitted constituent, in the two frames are
$\mathbf{k}_\perp=\boldsymbol{\kappa}_\perp$, $k^+=\xi\ M_0(123)=\kappa^+\ M_0(123)/\mathcal{M}_0(1,23)$

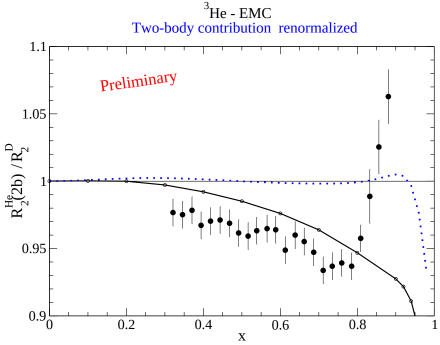
$$ \mathcal{M}^2_0(1,23)=\frac{m^2+|\boldsymbol{\kappa}_\perp|^2}{\xi}+\frac{M^2(23)+|\boldsymbol{\kappa}_\perp|^2}{(1-\xi)} $$

N.B. within LFHD, normalization and momentum sum rule are automatically fulfilled !!

Preliminary Results for EMC effect in $^3\mathrm{He}$:

$$R_2^A(x) = \frac{A\ F_2^A(x)}{Z\ F_2^p(x) + (A - Z)\ F_2^n(x)}$$

Two-body channel, only (the spectator pair is in a deuteron state)



- Solid line: calculation with the LF Nuclear Spectral Function.
- Dotted line: convolution formula with a momentum distribution as in Oelfke, Sauer, Coester, Nucl. Phys. A 518, 593 (1990) - only two-body contribution

The next step will be the full calculation including the exact 3-body contribution.

Within the LFHD and exploiting the BT construction ($M_{free} \to M_{int}$), the LF spin-dependent spectral function for a system polarized along **S**, can be decomposed in terms of available vectors,

- the unit vector $\hat{n}$, $\perp$ to the hyperplane $n \cdot x = 0$. Our choice is $n^\mu \equiv \{1, 0, 0, 1\}$
- the polarization vector **S**
- the transverse (with respect to the $\hat{n}$ axis) momentum component $\mathbf{k}_\perp = \mathbf{p}_\perp = \boldsymbol{\kappa}_\perp$ of the 3-momentum **p** of one of the constituents,

$$\boldsymbol{\mathcal{P}}^\tau_{\mathcal{M},\sigma'\sigma}(\tilde{\boldsymbol{\kappa}}, \epsilon, S) = \frac{1}{2}\left[\mathcal{B}^\tau_{0,\mathcal{M}} \; + \; \boldsymbol{\sigma} \cdot \boldsymbol{\mathcal{F}}^\tau_{\mathcal{M}}(\tilde{\boldsymbol{\kappa}}, \epsilon, \mathbf{S})\right]_{\sigma'\sigma}$$

The scalar $\mathcal{B}^\tau_{0,\mathcal{M}} \; = \; Tr\left[\mathcal{P}^\tau_{\mathcal{M},\sigma'\sigma}(\tilde{\boldsymbol{\kappa}}, \epsilon, S)\right]$ yields the unpolarized spectral function ; the pseudovector $\boldsymbol{\mathcal{F}}^\tau_{\mathcal{M}}(\tilde{\boldsymbol{\kappa}}, \epsilon, \mathbf{S}) = \; Tr\left[\hat{\boldsymbol{\mathcal{P}}}^\tau_{\mathcal{M}}(\tilde{\boldsymbol{\kappa}}, \epsilon, S) \; \boldsymbol{\sigma}\right]$ can be written as a linear combination of the available pseudovectors,

$$\begin{aligned}\boldsymbol{\mathcal{F}}_{\mathcal{M}}(\xi, \mathbf{k}_\perp; \epsilon, \mathbf{S}) = \mathbf{S}\; \mathcal{B}_{1,\mathcal{M}} \; + \; \hat{\mathbf{k}}_\perp \; (\mathbf{S} \cdot \hat{\mathbf{k}}_\perp) \; \mathcal{B}_{2,\mathcal{M}} \; + \; \hat{\mathbf{k}}_\perp \; (\mathbf{S} \cdot \hat{n}) \; \mathcal{B}_{3,\mathcal{M}} \\ + \; \hat{n} \; (\mathbf{S} \cdot \hat{\mathbf{k}}_\perp) \; \mathcal{B}_{4,\mathcal{M}} \; + \; \hat{n} \; (\mathbf{S} \cdot \hat{n}) \; \mathcal{B}_{5,\mathcal{M}} \; + \; \left(\hat{\mathbf{k}}_\perp \times \hat{n}\right) \left[\left(\hat{\mathbf{k}}_\perp \times \hat{n}\right) \cdot \mathbf{S}\right] \; \mathcal{B}_{6,\mathcal{M}}.\end{aligned}$$

where any angular dependence is explicitly given.
The seven scalar quantities $\mathcal{B}_{i,\mathcal{M}}$ ($i = 0, 1, ..., 6$) can depend on the possible scalars, i.e., $|\mathbf{k}_\perp|, \; \xi, \; \epsilon, \; (\mathbf{S} \cdot \hat{\mathbf{k}}_\perp)^2, \; (\mathbf{S} \cdot \hat{n})^2$.

By integrating the LF SF on *the minus component* of the constituent 4-momentum, that amounts to integrate on the internal energy of the spectator system, one straightforwardly gets the LF spin-dependent momentum distribution

$$n^{\tau}_{\sigma'\sigma}(x, \mathbf{k}_\perp; \mathcal{M}, \mathbf{S}) = \frac{1}{2} \left\{ b_{0,\mathcal{M}} + \boldsymbol{\sigma} \cdot \mathbf{f}_{\mathcal{M}}(x, \mathbf{k}_\perp; \mathbf{S}) \right\}_{\sigma'\sigma}$$

$\mathbf{f}_{\mathcal{M}}(x, \mathbf{k}_\perp; \mathbf{S})$ is a pseudovector

$$\mathbf{f}_{\mathcal{M}}(x, \mathbf{k}_\perp; \mathbf{S}) = \mathbf{S}\ b_{1,\mathcal{M}} \ + \ \hat{\mathbf{k}}_\perp\ (\mathbf{S} \cdot \hat{\mathbf{k}}_\perp)\ b_{2,\mathcal{M}} \ + \ \hat{\mathbf{k}}_\perp\ (\mathbf{S} \cdot \hat{n})\ b_{3,\mathcal{M}}$$
$$+ \ \hat{n}\ (\mathbf{S} \cdot \hat{\mathbf{k}}_\perp)\ b_{4,\mathcal{M}} \ + \ \hat{n}\ (\mathbf{S} \cdot \hat{n})\ b_{5,\mathcal{M}} \ + \ \left(\hat{\mathbf{k}}_\perp \times \hat{n}\right) \left[\left(\hat{\mathbf{k}}_\perp \times \hat{n}\right) \cdot \mathbf{S}\right]\ b_{6,\mathcal{M}}$$

The decomposition follows from the corresponding one of the SF, and the seven **scalar functions** $b_{i,\mathcal{M}}$ are properly integrals over the spectator energy, ϵ, present in the functions $\mathcal{B}_{i,\mathcal{M}}$

The valuable content of such a decomposition is to make explicit the interplay relations among constituent longitudinal/transverse variables and spin dofs.
This can be usefully exploited in determining *relations* for the so-called Transverse-momentum Distributions (TMDs) in the *valence sector*.
N.B.the above decomposition is built considering a fixed number of constituents inside the *interacting system*.

Transverse-momentum distributions are obtained within a field-theoretical framework, when the the virtual-photon scattering by a J=1/2 target is analyzed.
The basic quantity for elaborating the analysis is the Correlator (e.g. [Barone, Drago, Ratcliffe, Phys. Rep. 359, 1 (2002))

$$\Phi^{\tau}_{\alpha,\beta}(p,P,S) = \int d\xi \; e^{ip\dot{\xi}} \langle P,S,A|\bar{\psi}^{\tau}_{\beta}(0)\psi^{\tau}_{\alpha}(\xi)|A,S,P\rangle$$

$$\Rightarrow \; \Phi(p,P,S) = \frac{1}{2}\, \not{P}\, A_1 + \frac{1}{2}\, \gamma_5\, \not{P} \left[A_2\, S_z + \frac{1}{M}\, \widetilde{A}_1\, \mathbf{p}_{\perp}\cdot\mathbf{S}_{\perp}\right] +$$

$$+\frac{1}{2}\, \not{P}\, \gamma_5 \left[A_3\, \not{S}_{\perp} + \widetilde{A}_2\, \frac{S_z}{M}\, \not{p}_{\perp} + \frac{1}{M^2}\, \widetilde{A}_3\, \mathbf{p}_{\perp}\cdot\mathbf{S}_{\perp}\, \not{p}_{\perp}\right]$$

where $|A,S,P\rangle$ is the A-particle state and $\psi^{\tau}_{\alpha}(\xi)$ the fermionic field (e.g. a nucleon of isospin τ in a nucleus, or in valence approximation a quark in a nucleon).

From the above decomposition, one introduces the TMDs, that yield insights in the possible correlations involving both kinematical variables and spin degrees of freedom, .

To match the description in terms of SF, with fixed number of particles, the particle contribution to the correlation function from on-mass-shell fermions, has to be singled out

$$\Phi^{\tau}_{val}(p,P,S) = \frac{(\not{p}_{on} + m)}{2m}\, \Phi^{\tau}(p,P,S)\, \frac{(\not{p}_{on} + m)}{2m} =$$

TDMs in the valence sector I

By using the proper traces one finds for a $J = 1/2$ target the following relations between the six T-even, twist-2 TMDs, and the seven scalar functions b_i, defining the spin-dependent constituent LF momentum distribution (recall: within the Bakamjian-Thomas framework)

$$f(x, |\mathbf{p}_\perp|^2) = b_0$$

$$\Delta f(x, |\mathbf{p}_\perp|^2) = \left\{ b_{1,\mathcal{M}} + \ b_{5,\mathcal{M}} \right\}$$

$$g_{1T}(x, |\mathbf{p}_\perp|^2) = \frac{M}{|\mathbf{p}_\perp|} \ b_{4,\mathcal{M}}$$

$$\Delta_T' f(x, |\mathbf{p}_\perp|^2) = \frac{1}{2} \ \left\{ 2 \ b_{1,\mathcal{M}} + \ b_{2,\mathcal{M}} + \ b_{6,\mathcal{M}} \right\}$$

$$h_{1L}^\perp(x, |\mathbf{p}_\perp|^2) = \frac{M}{|\mathbf{p}_\perp|} \ b_{3,\mathcal{M}}$$

$$h_{1T}^\perp(x, |\mathbf{p}_\perp|^2) = \frac{M^2}{|\mathbf{p}_\perp|^2} \ \left\{ \ b_{2,\mathcal{M}} \ - \ b_{6,\mathcal{M}} \right\}$$

In the case of $^3\mathrm{He}$ the Nuclear TMDs could be obtained through measurements of appropriate spin asymmetries in $^3He(e, e'p)$ experiments at high momentum transfer. In the hadronic case SiDIS reactions are the golden door to access TMDs.

Let us remind that

$$n^{\tau}_{\sigma\sigma'}(x, \mathbf{k}_\perp; \mathcal{M}, \mathbf{S}) = \frac{2(-1)^{\mathcal{M}+1/2}}{(1-x)} \sum_{L=0,2} \int dk_{23}\ \mathcal{Z}^{\tau}_{\sigma\sigma'}(x, \mathbf{k}_\perp, k_{23}, L, \mathbf{S})$$

L is the orbital angular momentum of the one-body off-diagonal density matrix. Non relavistically...

$$\int d^3k\ e^{i\mathbf{k}\cdot(\mathbf{r}-\mathbf{r}')}\ \rho(\mathbf{r}, \mathbf{r}')e^{i\mathbf{k}\cdot(\mathbf{r}-\mathbf{r}')} = \sum_{L,\lambda} \mathcal{Y}^{\lambda}_{L}(\hat{k})......$$

Summarize: from the general principles implemented in the SF, TMDs receive contributions from both $L = 0$ and $L = 2$.

N.B. for $L = 2 \Rightarrow b_{2,\mathcal{M}} = b_{5,\mathcal{M}} = 0$ and one can recover, in the valence sector we are, well-known linear equalities [Jacob, Mulders, Rodrigues, Nucl. Phys. A 626, 937 (1997) ; Lorcé, Pasquini, Phys. Rev. D 84, 034039 (2011)]

$$\Delta f(x, |\mathbf{p}_\perp|^2) = \Delta'_T f(x, |\mathbf{p}_\perp|^2) + \frac{|\mathbf{p}_\perp|^2}{2M^2}\ h^{\perp}_{1T}(x, |\mathbf{p}_\perp|^2)$$
$$g_{1T}(x, |\mathbf{p}_\perp|^2) = -h^{\perp}_{1L}(x, |\mathbf{p}_\perp|^2) \qquad (1)$$

As far as the quadratic relation discussed in the above papers is concerned

$$(g_{1T})^2 + 2\ \Delta'_T f\ \ h^{\perp}_{1T} = 0 \qquad (2)$$

in our approach it does not hold, even if the contribution from the angular momentum $L = 2$ is absent, because of the considered effects due to the interacting spectator pair.

TMDs in the valence sector II: T-even Twist-3 case

Extending our analysis to the T-even twist-3 TMDs, in the valence sector $\Rightarrow$ relations among twist-2 and twist-3 TMDs can be recovered (cf Bacchetta et al (JHEP02(2007)093) in the nucleon case, once the gluon contribution is dropped out i.e. Wandzura-Wilczek approximation), viz

$$e(x, |\mathbf{p}_\perp|^2) = \frac{m}{Mx}\ f(x, |\mathbf{p}_\perp|^2)$$

$$f^\perp(x, |\mathbf{p}_\perp|^2) = \frac{1}{x}\ f(x, |\mathbf{p}_\perp|^2)$$

$$g'_T(x, |\mathbf{p}_\perp|^2) = \frac{m}{Mx}\ h_{1T}(x, |\mathbf{p}_\perp|^2)$$

$$g_T^\perp(x, |\mathbf{p}_\perp|^2) = \frac{1}{x}\ \left[\frac{m}{M}\ h_{1T}^\perp(x, |\mathbf{p}_\perp|^2) + g_{1T}(x, |\mathbf{p}_\perp|^2)\right]$$

$$g_T(x, |\mathbf{p}_\perp|^2) = \frac{1}{x}\ \left[\frac{m}{M}\ \Delta'_T f(x, |\mathbf{p}_\perp|^2) + \frac{|\mathbf{p}_\perp|^2}{2M^2} g_{1T}(x, |\mathbf{p}_\perp|^2)\right]$$

$$g_L^\perp(x, |\mathbf{p}_\perp|^2) = \frac{1}{x}\ \left[\frac{m}{M}\ h_{1L}^\perp(x, |\mathbf{p}_\perp|^2) + \Delta f(x, |\mathbf{p}_\perp|^2)\right]$$

$$\cdots \quad \cdots \quad \cdots \quad \cdots$$

Conclusions & Perspectives

- **A Poincaré covariant description of nuclei, based on the light-front Hamiltonian dynamics, has been proposed.** The Bakamjian-Thomas construction of the Poincaré generators allows one to embed the successful phenomenology for few-nucleon systems in a Poincaré covariant framework. N.B. Normalization and momentum sum rule both automatically fulfilled.
- ★ Macrocausality can be implemented, as it must be (packing operator not yet included)

  ★★ A new effect of binding in the nuclear spectral function follows. This is seen in our preliminary (two-body channel only), calculation of $^3\mathrm{He}$ EMC effect.
- ★ Notably, the Spectral Function is related to the valence contribution to the correlator introduced for a QFT description of SiDIS reactions.

  ★★ General principles implemented in the LF Spectral function entail relations among T-even twist-2 and twist-3 valence TMDs, with interesting angular momentum dependence.
- Nuclear and hadronic applications of the LF Nuclear spectral function are in progress, in collaboration with L. Kaptari