Light-front Spectral-function of $^3\mathrm{He}$

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A. Del Dotto, E. Pace, G. S., S. Scopetta, *Light-front spin-dependent spectral function and nucleon momentum distributions for a three-body system,* PRC 95 (2017) 014001.

LF Nucleon Spectral Function for ^3He

To construct a relativistic description with a fixed number of constituents, besides the Poincaré covariance, one has to take into account

Macrocausality

i.e. if the subsystems which compose a system are brought far apart, the Poincaré generators of the system have to become the sum of the Poincaré generators corresponding to the subsystems in which the system is asymptotically separated.
We implement macrocausality in the tensor product of a plane wave for the knocked out constituent times a fully interacting intrinsic state for the spectator pair.

Starting point:

The non relativistic three-body mass operator fully complies the requirements (rotational invariance) for a Bakamijan-Thomas construction of interacting Poincaré generators.

LF Nucleon Spectral Function for ^3He

$$\mathcal{P}^{\tau}_{\sigma'\sigma}(\kappa^+, \boldsymbol{\kappa}_\perp, \epsilon_S, S_{He}) = \rho(\epsilon_S) \sum_{J_S J_{zS} \alpha} \sum_{T_S \tau_S} {}_{LF}\langle \tau_S, T_S, \alpha, \epsilon_S J_S J_{zS}; \tau\sigma', \tilde{\boldsymbol{\kappa}} | \Psi_0 S_{He} \rangle$$
$$\langle S_{He}, \Psi_0 | \tilde{\boldsymbol{\kappa}}, \sigma\tau; J_S J_{zS} \epsilon_S, \alpha, T_S, \tau_S \rangle_{LF}$$

- $\tilde{\boldsymbol{\kappa}} \equiv \{\kappa^+, \boldsymbol{\kappa}_\perp\}$
- $\kappa^+ = \xi \mathcal{M}_0(1,23)$ and

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

  $\mathcal{M}_0(1,23)$="free mass", value of the total P^+ in the LF intrinsic frame of the (1,23) cluster, in terms of which the spectral function is defined
- $M_S = 2\sqrt{m^2 + m\epsilon_S}$
- $\rho(\epsilon_S) \equiv$ density of the two-body states (1 for the bound state, and $m\sqrt{m\epsilon_S}/2$ for the excited ones)
- Automatically fulfilled both normalization and momentum sum rule !!

What about the overlap $_{LF}\langle \tau_S, T_S, \alpha, \epsilon_S J_{zS} J_S; \tau\sigma', \tilde{\boldsymbol{\kappa}} | \Psi_0 S_{He}\rangle$?

LF overlaps for ^3He from the Instant-form RHD ones

$$_{LF}\langle \tau_S, T_S, \alpha, \epsilon_S J_S J_{zS}; \tau\sigma, \tilde{\boldsymbol{\kappa}} | \Psi_0 S_{He}\rangle =$$

$$= \sum_{\tau_2,\tau_3} \sum_{\sigma'_1} D^{\frac{1}{2}}[\mathcal{R}^\dagger_M(\tilde{\boldsymbol{\kappa}})]_{\sigma\sigma'_1} \int d\mathbf{k}_{23} \sum_{\sigma_2,\sigma_3} \sqrt{\frac{\kappa^+ E_{23}}{k^+ E_S}} \sqrt{(2\pi)^3 \ k^+ \frac{\partial k_z}{\partial k^+}} \ \times$$

$$_{IF}\langle \tau_S, T_S, \alpha, \epsilon_S J_S J_{zS} | \mathbf{k}_{23}; \sigma_2, \sigma_3; \tau_2, \tau_3\rangle \langle \tau_3, \tau_2, \tau_1; \sigma_3, \sigma_2, \sigma'_1; \mathbf{k}, \mathbf{k}_{23} | \Psi_0 S_{He}\rangle_{IF}$$

- $\mathbf{k}_\perp = \boldsymbol{\kappa}_\perp$, since the ^3He transverse momentum is $\mathbf{P}_\perp = 0$, by choice
- $k^+ = \xi \ M_0(123) = \kappa^+ \ M_0(123)/\mathcal{M}_0(1,23)$

$$\text{with} \qquad M_0^2(123) = \frac{m^2 + |\boldsymbol{\kappa}_\perp|^2}{\xi} + \frac{M_{23}^2 + |\boldsymbol{\kappa}_\perp|^2}{(1-\xi)}$$

  and $M_{23}^2 = 4(m^2 + |\mathbf{k}_{23}|^2)$ the mass of the spectator pair without interaction !
  Recall that in $\mathcal{M}_0(1,23)$ the spectator pair is interacting, $M_{23} \to M_S$
- $k_z = \frac{1}{2}\left[k^+ - \frac{m^2 + |\boldsymbol{\kappa}_\perp|^2}{k^+}\right]$, $E_{23} = \sqrt{M_{23}^2 + |\mathbf{k}|^2}$ and $E_S = \sqrt{M_S^2 + |\boldsymbol{\kappa}|^2}$
- In the preliminary results, $\mathcal{M}_0(1,23) = M_0(123)$

In the actual calculations, we have identified the IF overlaps with the NR ones

- Ground state:

$$\langle \tau_3, \tau_2, \tau_1; \sigma_3, \sigma_2, \sigma_1'; \mathbf{k}, \mathbf{k}_{23} | \Psi_0 S_{He} \rangle_{IF} \Rightarrow \langle \tau_3, \tau_2, \tau_1; \sigma_3, \sigma_2, \sigma_1'; \mathbf{k}, \mathbf{k}_{23} | \Psi_0 S_{He} \rangle_{NR}$$

- Final state:

$$_{IF}\langle \tau_S, T_S, \alpha, \epsilon_S J_S J_{zS} | \mathbf{k}_{23}; \sigma_2, \sigma_3; \tau_2, \tau_3 \rangle \Rightarrow_{NR} \langle \tau_S, T_S, \alpha, \epsilon_S J_S J_{zS} | \mathbf{k}_{23}; \sigma_2, \sigma_3; \tau_2, \tau_3 \rangle$$

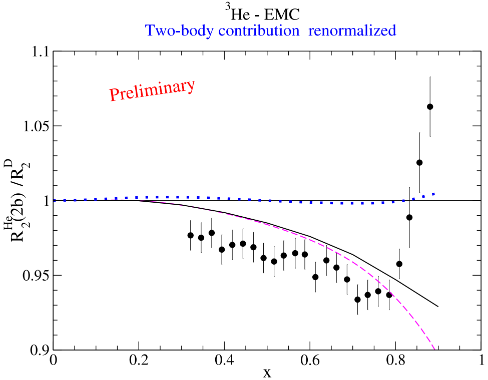
Let us stress two important features of our LF spectral function:

★ the definition of the nucleon momentum $\tilde{\kappa}$ in the intrinsic frame of the cluster $(1, 23)$

★★ the use for the calculation of the LF spectral function of the tensor product of a plane wave of momentum $\times$ the state which describes the intrinsic motion of the fully interacting spectator subsystem

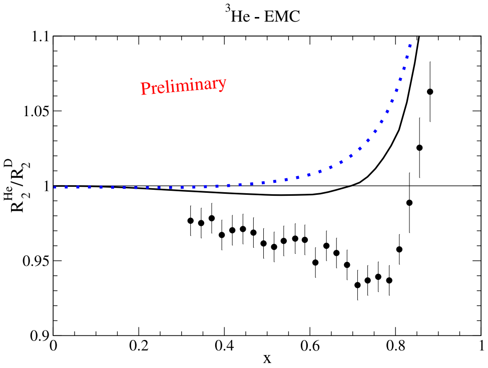
These new features allows one to take care of macrocausality and to introduce a new effect of binding in the Spectral Function

Preliminary Results for ^{3}He EMC effect We have first calculated the contribution from the 2B channel, with the spectator pair in a deuteron state



- Solid line: calculation with the LF Spectral Function.
- Dashed line: as the solid line, but with $\sqrt{\bar{k}^2_{23}} =$ 136.37 MeV for D (AV18).
- Dotted line: LF Momentum Distribution with only two-body contribution

Calculation of $R_2^{He}(x)/R^D(x)$: 2-body and 3-body contributions



- Solid line: LF Spectral Function, with the exact calculation for the 2-body channel, and an average energy in the 3-body contribution: $<\bar{k}_{23}>=$ 113.53 MeV (proton), $<\bar{k}_{23}>=$ 91.27 MeV (neutron).
- Dotted line: LF momentum distribution U. Oelfke, P. Sauer and F. Coester, NPA **518**, 593 (1990)

Within the LF framework normalization and momentum sum rule are fulfilled automatically. $\Rightarrow$Big difference from the IF approach !