Left-right asymmetry of transverse densities from chiral dynamics

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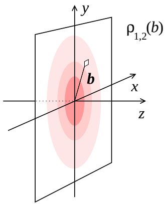
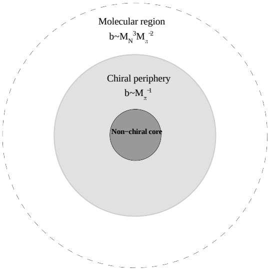
Transverse Densities





M.Strikman, C.Weiss PRC82(2010)

CG, C.Weiss JHEP 1401 (2014)

Connect Form Factors and GPDs to nucleon intrinsic spacial structure

$$F_{1(2)}(-\Delta_T^2) = \int d^2 b e^{i\boldsymbol{\Delta}_T\cdot\boldsymbol{b}} \rho(b)_{1(2)}$$

$$\rho_1(b) = \int dx \frac{d^2\Delta_T}{(2\pi)^2} e^{-i\boldsymbol{\Delta}_T\cdot\boldsymbol{b}} H(x, -\Delta_T^2)$$

G.A. Miller,ARNPS 60 (2010)

M.Burkardt,PRD62(2000)

Parametrize the light front electromagnetic current density

$$\frac{J^+(b)}{2p^+} = \underbrace{\rho_1(b)}_{spin-ind.} + 2\underbrace{\boldsymbol{S}_T \cdot (e_z \times e_b)\widetilde{\rho}_2(b)}_{spin-dep.}$$

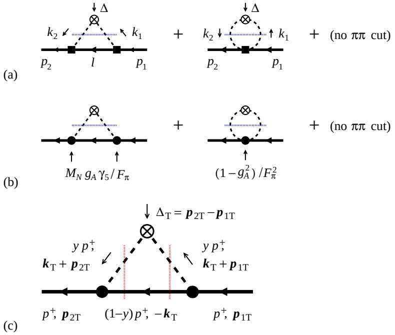
with

$$\widetilde{\rho}_2(b) = \frac{1}{2M_N}\frac{\partial \rho_2(b)}{\partial b}$$

Boost invariants; structure of the nucleon as a relativistic multiparticle systems.

Nucleon transverse profile; Define dynamical regions in impact parameter space; e.g., non chiral, chiral $[M_\pi^{-1}]$, and molecular $[M_N^2 M_\pi^{-3}]$

Pion loops in Light-front PT



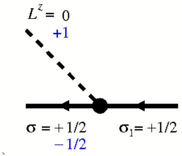
Chiral dynamics in the nucleon's periphery; Defines structure at $b \sim \frac{1}{M_\pi}$. Dominated by the behavior of spectral functions near the 2π threshold ($k_\pi \sim M_\pi$, already relativistic pions).

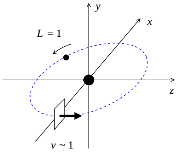
Pion current contributions: from Chiral Lagrangian with axial vector πN coupling ($\gamma_5 \not{k}_\pi$) + contact term to pseudoscalar coupling + modified contact term ($\sim 10\%$ contribution)

In LF variables ($v^\pm = v^0 \pm v^z$),

$$\frac{J^+}{2p^+} = \frac{1}{2\pi}\int \frac{dy}{y(\bar{y} = 1-y)} \frac{d^2 k_T}{(2\pi)^2} \Psi^\dagger(y, k_T, \boldsymbol{p}_{2T})\Psi(y, k_T, \boldsymbol{p}_{1T}) + \underbrace{(1-g_A)\delta(y)[\ldots]}_{\text{contact term}}$$

Light front wave functions





Eigenfunctions of LF Hamiltonian.

Allow quantum mechanical description of peripheral dynamics.

Computable at leading order in chiral periphery

CG, C. Weiss, arXiv:1503.04839 [hep-ph]

$$\Psi(y, \widetilde{\boldsymbol{k}}_T = \boldsymbol{k}_T + y p_{1T}) \equiv \underbrace{\frac{\Gamma(y, \widetilde{\boldsymbol{k}}_T)}{\Delta\mathcal{M}^2(y, \widetilde{\boldsymbol{k}}_T)}}_{\text{Inv. Mass difference}}$$

$$\begin{aligned}\Gamma(y, \widetilde{\boldsymbol{k}}_T) &\approx \frac{g_A M_N}{F_\pi} \bar{u}(y, \boldsymbol{k}_T) i\gamma_5 u(p_{1T}) \\ &= \frac{2i g_A M_N^2}{F_\pi \sqrt{\bar{y}}} \left[y \boldsymbol{S}_z + \frac{\widetilde{\boldsymbol{k}}_T \cdot \boldsymbol{S}_T}{M_N} \right]\end{aligned}$$

while in transverse coordinate space,

$$\begin{aligned}\Phi(y, r_T) &= \int \frac{d^2\widetilde{\boldsymbol{k}}_T}{(2\pi)^2} e^{\widetilde{\boldsymbol{k}}_T \cdot \boldsymbol{r}_T} \Psi(y, \widetilde{\boldsymbol{k}}_T) \\ &= -2i \left[U_0(y, r_T) S^z + i \frac{U_1(y, r_T) \boldsymbol{r}_T \cdot \boldsymbol{S}_T}{r_T} \right]\end{aligned}$$

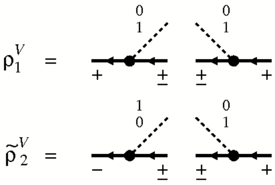
with radial functions,

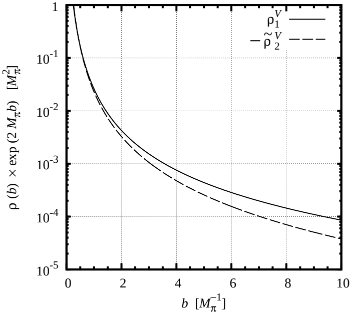
$$\left.\begin{array}{l} U_0(y, r_T) \\ U_1(y, r_T) \end{array}\right\} = \frac{g_A M_N\, y\sqrt{\bar{y}}}{2\pi F_\pi} \left\{ \begin{array}{l} y M_N \;\; K_0(M_T r_T) \\ M_T \;\; K_1(M_T r_T) \end{array}\right. ,$$

and transverse mass

$$M_T^2 = \bar{y}^2 M_\pi + y^2 M_N^2$$

Charge and magnetization densities





Light front current matrix as wavefunction overlap,

$$\frac{J(b)}{2p^+} = \frac{1}{2\pi}\int \frac{dy}{y\bar{y}}\Phi^\dagger\left(y, \frac{b}{\bar{y}}\right)\Phi\left(y, \frac{b}{\bar{y}}\right),$$

then in terms of radial functions

$$\left.\begin{array}{c}\rho_1^V(b)\\ \widetilde{\rho}_2^V(b)\end{array}\right\} = \frac{1}{2\pi}\int\frac{dy}{y\bar{y}^3}\left\{\begin{array}{c}[U_0(y, b/\bar{y})]^2 + [U_1(y, b/\bar{y})]^2\\ -2\,U_0(y, b/\bar{y})\;U_1(y, b/\bar{y})\end{array}\right\}.$$

Inequality and positive definiteness of light front current,

$$|\rho_1(b)| > \widetilde{\rho}_2(b) \Rightarrow J^+(b) > 0$$

weakly bound pions.

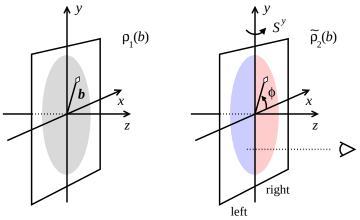
Near parametric equality,

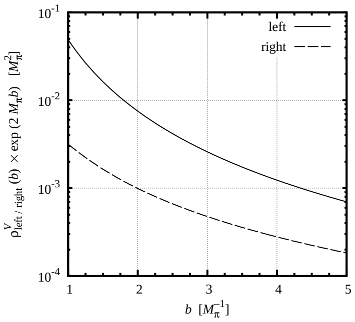
$\rho_1(b) \approx -\widetilde{\rho}_2(b) \Rightarrow$ relativistic pion-nucleon system

Explain through left right asymmetry in Transverse densities (See transverse polarization.)

Transverse polarization and asymmetry

CG, C. Weiss, arXiv:1503.04839 [hep-ph]





LFWF components of a transversely polarized nucleon,

$$
\begin{aligned}
\Phi_{\rm tr}(+,+) &= \sin\alpha\, U_1, \\
\Phi_{\rm tr}(-,-) &= -\sin\alpha\, U_1, \\
\Phi_{\rm tr}(+,-) &= U_0 + \cos\alpha\, U_1, \\
\Phi_{\rm tr}(-,+) &= -U_0 + \cos\alpha\, U_1,
\end{aligned}
$$

Define Left and Right transverse densities from LFWF at $\alpha = 0$,

$$
\left.\begin{array}{l} \rho^V_{\rm left}(b) \\ \rho^V_{\rm right}(b) \end{array}\right\} = \int_0^1 dy\, \frac{|\Phi_{\rm tr}(y, \mp r_T \boldsymbol{e}_x; -,+)|^2}{2\pi y \bar{y}^3}
$$

$$[r_T = b/\bar{y}]$$

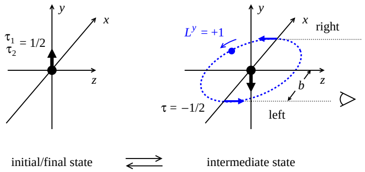
to find for the charge and magnetization densities that

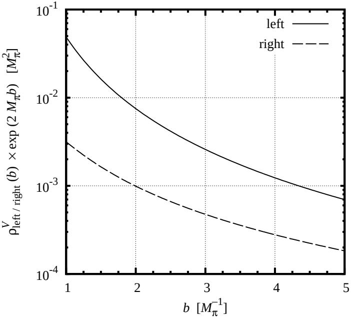
$$
\left.\begin{array}{l} \rho^V_1(b) \\ \widetilde{\rho}^V_2(b) \end{array}\right\} = \frac{1}{2}[\pm \rho^V_{\rm left}(b) + \rho^V_{\rm right}(b)].
$$

-$\widetilde{\rho}_2$ measures Left-Right asymmetry of LF currents in the nucleon.
Strikingly large in the chiral periphery, generates the near equality $\rho_1 \approx -\widetilde{\rho}_2$.

Quantum Mechanical Picture

CG, C. Weiss, arXiv:1503.02055 [hep-ph]





For a nuleon to pion-nucleon transition with $J_y = +1/2$,

$$\Phi_{\mathrm{tr}}(-,+)$$

is the only contribution in x-z plane and classically represents its $L^y = +1$ state. Then,

$$\langle J^+(\pm b\boldsymbol{e}_x)\rangle = \rho_{\mathrm{r(l)}}(b)$$

Peripheral pions are weakly bound,

$$\begin{aligned} J^+ &= 2k^+ \\ &\approx 2(\sqrt{\boldsymbol{k}^2 + M_\pi^2} + k_z) \end{aligned}$$

Then

$$J^+ > 0$$

as shown by the inequality $|\rho_1| > |\widetilde{\rho}_2|$.

For non relativistic pion

$$\frac{\rho_{\mathrm{left}}}{\rho_{\mathrm{right}}} = \frac{E_\pi + k^z}{E_\pi - k^z} = 1 + O(v)$$

while for peripheral pions $k_z \sim M_\pi$, then

$$\frac{\rho_{\mathrm{left}}}{\rho_{\mathrm{right}}} >> 1$$

Summary and Outlook

Trensverse densities computable in Chiral EFT were used in a model independent approach to describe features of the long distance structure of the nucleon.

The light front formulation reveals how general properties of chiral transverse densities are connected to a mechanical picture of the nucleon's periphery.

- Inequality and thus positive definiteness of J^{+} tied to the onset of quasi-free pions.
- Near equality $\rho_1 \approx \widetilde{\rho}_2$ originated by large asymmetry evidencing the relativistic dynamics dominating the periphery. Potentially observable in form factor extractions at low momentum transfer.

This new framework opens the possibility of fully exploring the role that chiral dynamics plays constraining the nucleons internal structure.

- Expand on different intermediate baryons. Ongoing work on intermediate Δ probes large Nc limit properties of LCWF and allows the study of higher orbital modes
- Transverse densities associated with form factors of the energy momentum tensor.Distributions of matter and OAM in impact parameter space.