

1 - 8 Exploring Photon Using Basis Light-front Quantization Approach*

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The distinctive characteristic of the photon is that its partonic content can be calculated using leading-order perturbative QED^[1,2]. While our understanding of the photon's parton distributions (PDFs) is now well-established both theoretically and experimentally^[3], we have less knowledge about its Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent distributions (TMDs). We derive the photon's light-front wave functions (LFWFs) from the eigenvectors of the light-front QED Hamiltonian, aiming to identify its bare photon and electron-positron Fock components. Using these LFWFs, we calculate the photon's TMDs and GPDs^[4]. At a fixed light-front time, the photon state can be depicted through photon, electron- positron, and other Fock components $|\Psi_\gamma\rangle = \psi_{(\gamma)}|\gamma\rangle + \psi_{(e\bar{e})}|e\bar{e}\rangle + \dots$. In this study, we focus on the photon and electron-positron Fock sectors, using the light-front QED \hat{P}_{QED}^- which includes interactions pertinent to the photon's primary two Fock components.

$$\hat{P}_{\text{QED}}^- = \int dx^- d^2x^\perp \left\{ \frac{1}{2} \bar{\Psi} \gamma^+ \frac{m_e^2 + (i\partial^\perp)^2}{i\partial^+} \Psi + \frac{1}{2} A^j [m_{0\gamma}^2 + (i\partial^\perp)^2] A^j + e \bar{\Psi} \gamma^\mu \Psi A_\mu \right\}, \quad (1)$$

where $\Psi(x)$ and $A_\mu(x)$ are the fermion and the gauge boson fields, respectively, and $\gamma^+ = \gamma^0 + \gamma^3$, where γ^μ are the Dirac matrices. The first and second terms in Eq. (1) correspond to the kinetic energies of the electron and the photon with bare mass m_e and $m_{\gamma 0}$, respectively and the third term represents their interaction with coupling e .

In our Basis Light-Front Quantization (BLFQ) computation, we use three parameters set to the electron mass (m_e): electron/positron mass, the $\gamma \rightarrow e^+e^-$ vertex coupling constant (e), and the 2D HO scale (b). We set m_e to 0.51 MeV and e to 0.3, aligning with the QED fine structure constant α , and the real photon's mass (M_γ) to zero. These parameters allow us to present photon observables. Our TMD result align excellently with the lowest-order perturbative results, as do the GPD, validating the BLFQ approach(Fig. 1). The main goal is to establish a foundation for studying the nonperturbative structure of QCD systems like vector mesons.

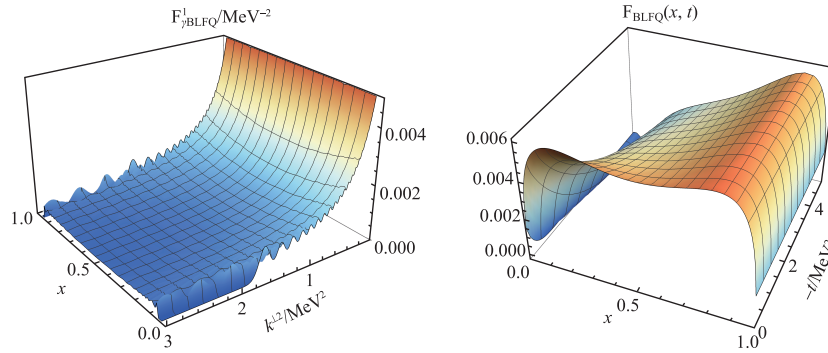


Fig. 1 (color online) Left: 3D plots of the BLFQ results for $f_\gamma^1(x, \mathbf{k}^{\perp 2})$ TMD of the photon. The results are obtained by averaging over the BLFQ computations at $N_{\text{max}} = \{100, 102, 104\}$ and $K = 104$. Right: 3D plots of the BLFQ results for $F(x, t)$ GPDs of the photon. The results are obtained at $N_{\text{max}} = K = 100$.

References

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* Foundation item: S. N and C. M. thank the Chinese Academy of Sciences Presidents International Fellowship Initiative for support (2021PM0021 and 2021PM0023). C. M. is supported by new faculty start up funding by the Institute of Modern Physics, Chinese Academy of Sciences (E129952YR0), X. Z. is supported by new faculty startup funding by Institute of Modern Physics, Chinese Academy of Sciences, by Key Research Program of Frontier Sciences, Chinese Academy of Sciences (ZDB-SLY-7020), by Natural Science Foundation of Gansu Province, China (20JR10RA067) and by Strategic Priority Research Program of Chinese Academy of Sciences (XDB34000000). A. M. thanks SERB for support through POWER Fellowship (SPF/2021/000102). J. P. V. is supported in part by Department of Energy (DE-FG02-87ER40371, DE-SC0018223 (SciDAC4/NUCLEI)). A portion of the computational resources were also provided by Gansu Computing Center