Contribution ID: **40** Type: **30 min.**

# Exploring Higher-Twist Hadron Structure in Light-Front QCD

*Monday 15 September 2025 14:00 (30 minutes)*

Understanding the internal structure of hadrons beyond the leading-twist approximation is essential for probing the non-perturbative dynamics of QCD. While high-$Q^2$ processes are dominated by gluon and sea quark dynamics, the low-$Q^2$ region requires non-perturbative modeling to capture the role of valence quarks and confinement. To address this, I investigate a wide range of distribution functions up to twist-4 within the light-front quark-diquark model (LFQDM).

I present a detailed analysis of higher-twist TMDs, emphasizing model-dependent predictions and structural relations. A complete set of linear, quadratic, and inequality relations is derived at both intra-twist and inter-twist levels. A helicity-based parameterization framework is introduced, along with a classification table that allows the identification of spin-$1/2$ TMDs by parton and parent helicities. Model-specific amplitude matrices for each diquark configuration are also constructed. The results are compared with other models (e.g., LFCQM, bag model) and CLAS data.

Additionally, I report the first model calculations of higher-twist chiral-even GPDs at zero skewness for the proton, along with their spatial distributions. Results on higher-twist GTMDs at zero skewness are also discussed. Preliminary findings for pion and kaon GTMDs are presented as a step toward extending the analysis to mesonic systems.

The results are most relevant at low-to-moderate scales ($Q \sim$ 1-3 GeV, $\sqrt{s} \sim$ 10-30 GeV), where higher-twist effects are enhanced. These results can be beneficial for facilities operating in this energy region, such as SPD at NICA, COMPASS, and JLab, by providing input for parametrizations of twist-3 and twist-4 distributions. While evolution equations for these functions remain incomplete, modeling them at low scales remains essential for interpreting data and guiding future theoretical developments.

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**Session Classification:** Quantum chromodynamics at large distances

**Track Classification:** Structure functions of hadrons and nuclei