LaMET 2023

Monday, 24 July 2023 - Wednesday, 26 July 2023

Book of Abstracts

Contents

2

Matching Factors for Quasi-GPDs with Hybrid Renormalization

Author: Jiunn-Wei Chen[None]

Corresponding Author: jwc@phys.ntu.edu.tw

I will present the one-loop result of the matching kernels between the quasi-GPDs in hybrid renormalization and GPDs in the MS-bar scheme. We will also show the effect of the matching to modeled functions of GPDs.

3

Factorization for lattice qTMD distributions at NNLO

Authors: Óscar del Río García[1]; Alexey Vladimirov[2]

[1] *Complutense University of Madrid*

[2] *Universidad Complutense de Madrid*

Corresponding Authors: alexeyvl@ucm.es, oscgar03@ucm.es

The determination of parton distributions with lattice simulations is a promising and rapidly growing direction in the physics of strong interactions. In particular, TMD factorization can be applied to a certain class of operators that can be computed within the lattice QCD approach. These are equal-time correlators usually called quasi-transverse-momentum dependent (qTMD) distributions. In this talk, I discuss the factorization theorem for qTMD distributions in terms of physical TMD-PDFs and soft factors and present the computation of the next-to-next-to-leading order coefficient function.

4

TMDs and Quasi PDFs in Parton Model Approach

Authors: Fatma Aslan[1]; Peter Schweitzer[None]; Asli Tandogan[1]

[1] *University of Connecticut*

Corresponding Author: peter.schweitzer@uconn.edu

The parton model is a well-known intuitive framework for first, exploratory studies of hadronic high energy reactions. The parton model can also be used to study nonperturbative properties of hadrons like structure functions and PDFs. The Wandzura-Wilczek relation is an example for that. The parton model approach has been (under the name "covariant parton model") extended to describe TMDs and recently also quasi PDFs and some of the gravitational form factors of the proton. We review the recent progress with focus on the field theoretical foundations and the pure-spin vs mixed-spin state versions of the model. We also discuss the theoretical consistency of the approach, and demonstrate the validity of sum rules for quasi PDFs in this approach.

5

Ultraviolet renormalized quasi PDFs

Authors: Fatma Pinar Aslan[None]; Jianwei Qiu[1]

[1] *Jefferson Lab*

Corresponding Authors: fpaslan@gmail.com, jqiu@jlab.org

Parton distribution functions (PDFs), $f(x)$, encode important nonperturbative information on the hadron structure as a function of light-cone momentum fraction x which can be extracted from experimental measurements of cross sections. The quasi parton distribution functions (qPDFs) of hadron momentum P_z, $\tilde{f}(\tilde{x}, P_z)$, introduced in the large-momentum effective field theory (LaMET) approach, provide an alternative method to access the same nonperturbative information from lattice QCD calculations. PDFs and qPDFs could be related through an infra-red, collinear and ultraviolet (UV) safe matching coefficient that is calculable perturbatively with the corrections suppressed by the inverse power of P_z. However, there are challenges that must be overcome to uniquely determine such a matching coefficient. Although, PDFs and qPDFs contain the same nonperturbative physics at the leading power in $1/P_z$, the perturbative UV divergences of the qPDFs are different from that of PDFs, and more explicitly, the integration of $\tilde{x}$ of $\tilde{f}(\tilde{x}, P_z)$ or the first $\tilde{x}$-moment of qPDFs could lead to a divergence with a UV origin. To address this issue, we introduce a UV renormalization scheme for qPDFs so that the first moment of qPDFs is finite and the $\tilde{x}$-dependence of the matching coefficient is well defined for all values of $\tilde{x}$.

6

A novel approach for calculating GPDs from asymmetric frames

Authors: Shohini Bhattacharya[None]; Krzysztof Cichy[None]; Martha Constantinou[None]; Xiang Gao[1]; Andreas Metz[None]; Joshua Miller[2]; Swagato Mukherjee[None]; Fernanda Steffens[None]; Yong Zhao[None]

[1] *Argonne National Lab*

[2] *Temple University*

Corresponding Authors: tug23108@temple.edu, swagato@bnl.gov, joshua.miller0007@temple.edu, fsteffens@uol.com.br, metza@temple.edu, krzysztof.cichy@gmail.com, yong.zhao@anl.gov, marthac@temple.edu, gaox@anl.gov

Recently, significant progress has been made in improving the efficiency and computational speed of lattice QCD calculations associated with Generalized Parton Distributions (GPDs). These advancements are a result of employing asymmetric frames, which differ from the commonly used symmetric frames, and introducing flexibility in the distribution of transferred momentum. A key element of our approach involves utilizing a Lorentz covariant parameterization for the matrix elements in terms of Lorentz-invariant amplitudes. This enables us to establish connections between matrix elements in different frames. Furthermore, we utilize the amplitude-based approach to propose an alternative definition of quasi-GPDs. This alternative definition not only maintains frame independence but also holds the potential for reduced power corrections when matching with light-cone GPDs. We thoroughly explore the interpretations of these new definitions, carefully examining the intricacies involved, and addressing the important issue of uniqueness/non-uniqueness in their formulation. In this presentation, we discuss these theoretical advancements, focusing specifically on the axial-vector GPDs $\widetilde{H}$ and $\widetilde{E}$.

7

Progress in Lattice calculations for the Boer-Mulders function of the pion

Author: Lisa Walter[None]

Corresponding Author: lisa.walter@physik.uni-regensburg.de

We focus on the Boer-Mulders function of the pion and for now use the CLS ensemble X650 (a = 0.098 fm, m_π = 338 MeV) to study this quantity. Here, preliminary results of the ongoing work are shown, including extractions of the bare matrix elements and the rectangular Wilson loop. A main goal of the current work is to determine the largest momentum P^z at which we still see a sufficient signal.

8

Unpolarized Transverse-Momentum-Dependent Parton Distributions of the Nucleon from Lattice QCD

Author: Qi-An Zhang[None]

Corresponding Author: zhangqa@buaa.edu.cn

We present a first calculation of the unpolarized proton's isovector transverse-momentum-dependent parton distribution functions (TMDPDFs) from lattice QCD, which are essential to predict observables of multi-scale, semi-inclusive processes in the standard model. We use a $N_f = 2+1+1$ MILC ensemble with valence clover fermions on a highly improved staggered quark sea (HISQ) to compute the quark momentum distributions in large-momentum protons on the lattice. The state-of-the-art techniques in renormalization and extrapolation in correlation distance on the lattice are adopted. The one-loop contributions in the perturbative matching kernel to the light-cone TMDPDFs are taken into account, and the dependence on the pion mass and hadron momentum is explored.
Our results are qualitatively comparable with phenomenological TMDPDFs, which provide an opportunity to predict high energy scatterings from the first principles.

9

Quasi PDFs in the Covariant Parton Model

Authors: Asli Tandogan[1]; Fatma Aslan[1]; Peter Schweitzer[None]

[1] *University of Connecticut*

Corresponding Authors: peter.schweitzer@uconn.edu, asli.tandogan_kunkel@uconn.edu

The Covariant Parton Model is an appealing quark model framework that has been applied successfully to the description of structure functions, PDFs, and TMDs at the leading and subleading twist levels. In this contribution, the first application of the covariant parton model to quasi-PDFs is presented. Numerical results are presented and compared to lattice QCD results.

10

Transversity PDFs of the proton from lattice QCD with physical quark masses

Authors: Xiang Gao[1]; Andrew Hanlon[2]

Co-authors: Nikhil Karthik [2]; Swagato Mukherjee ; Peter Petreczky ; Qi Shi ; Sergey Syritsyn [3]; Yong Zhao

[1] *Argonne National Lab*

[2] *Brookhaven National Laboratory*

[3] *Stony Brook University*

Corresponding Authors: nkarthik@bnl.gov, gaox@anl.gov, qshi1@bnl.gov, yong.zhao@anl.gov, syritsyn@gmail.com, petreczk@bnl.gov, swagato@bnl.gov, ddhanlon@gmail.com

We present a lattice QCD calculation of the transversity isovector- and isoscalar-quark parton distribution functions (PDFs) of the proton utilizing a perturbative matching at next-to-leading-order (NLO). Additionally, we determine the isovector and isoscalar tensor charge for the proton. The calculations are performed using a single ensemble of $N_f = 2 + 1$ highly-improved staggered quarks simulated with physical-mass quarks and a lattice spacing of $a = 0.076$ fm. The Wilson-clover action, with the gauge links after one iteration of HYP smearing and physical quark masses, is used in the valence sector. The leading-twist OPE approximation is then utilized to extract the lowest four Mellin moments and the PDFs.

11

Proton GPDs from Lattice QCD

Authors: Andreas Metz[None]; Aurora Scapellato[None]; Fernanda Steffens[None]; Jack Dodson[None]; Joshua Miller[None]; Krzysztof Cichy[None]; Martha Constantinou[None]; Shohini Bhattacharya[None]; Swagato Mukherjee[None]; Xiang Gao[1]; Yong Zhao[None]

[1] *Argonne National Lab*

Corresponding Authors: aurora.scapellato@temple.edu, joshua.miller0007@temple.edu, swagato@bnl.gov, marthac@temple.edu, fsteffens@uol.com.br, tug76350@temple.edu, metza@temple.edu, krzysztof.cichy@gmail.com, gaox@anl.gov, yong.zhao@anl.gov, sbhattach@bnl.gov

The few calculations of x-dependent GPDs performed in lattice QCD use the symmetric frame, where the momentum transfer is evenly divided between the momentum of the initial and final hadron states. To obtain the GPDs for several values of the momentum transfer in a computationally efficient method, we employ an asymmetric frame developed in PRD 106 (2022) 11, 114512. The kinematic setup we use allows all momentum transfer to be assigned to the initial state. The calculation uses an $N_f = 2 + 1 + 1$ ensemble of twisted mass fermions with a clover improvement. The light quark masses provide a pion mass of about 260 MeV. This talk will cover the implementation of the asymmetric frame and the extraction of twist-2 GPDs for the proton with unpolarized quarks (H and E), as well as the helicity ($\widetilde{H}$) case, both at zero skewness.

12

Moments of proton GPDs from the OPE of nonlocal quark bilinears up to NNLO

Authors: Andreas Metz[None]; Fernanda Steffens[None]; Joshua Miller[1]; Krzysztof Cichy[None]; Martha Constantinou[None]; Peter Petreczky[None]; Shohini Bhattacharya[None]; Swagato Mukherjee[None]; Xiang Gao[2]; Yong Zhao[None]

[1] *Temple University*

[2] *Argonne National Lab*

Corresponding Authors: fsteffens@uol.com.br, metza@temple.edu, gaox@anl.gov, swagato@bnl.gov, joshua.miller0007@temple.edu krzysztof.cichy@gmail.com, petreczk@bnl.gov, marthac@temple.edu, yong.zhao@anl.gov, sbhattach@bnl.gov

We present a lattice QCD determination of Mellin moments of unpolarized generalized parton distributions (GPDs) of the proton from an analysis of the quasi-GPD matrix elements within the short-distance factorization framework. We perform our calculation on an N_f=2+1+1 twisted mass fermions ensemble with a clover improvement at lattice spacing $a = 0.093$ fm and a pion mass of $m_\pi = 260$ MeV. Focusing on the zero-skewness case, the quasi-GPDs are calculated from the γ_0 definition, as well as a recently proposed Lorentz-invariant definition. We utilize data on both symmetric and asymmetric kinematic frames, which allows us to obtain the Mellin moments for several

values of the momentum transfer, $-t$, in the range 0.17 to 2.77 GeV^2. We use the ratio scheme for GPDs, i.e. renormalization group invariant ratios with leading-twist factorization formula and perturbatively calculated matching coefficients up to the next-next-to-leading order (NNLO) to extract Mellin moments of GPDs.

13

x-dependence of nucleon PDFs from two-current matrix elements

Author: Christian Zimmermann[None]

Corresponding Author: christian.zimmermann@univ-amu.fr

We use the operator product expansion (OPE) to relate hadronic Euclidean two current matrix elements to parton distribution functions (PDFs) resolving the dependence on the parton momentum fraction x. We are following the ansatz proposed by [arXiv:1709.03018]. In our calculation, we consider the valence quark PDFs for the proton. This requires the evaluation of a connected proton four-point function for small quark distances. Our simulation is performed on $n_f = 2+1$ CLS gauge ensemble with extension $32^3 \times 96$, coupling $\beta = 3.4$, and pseudo-scalar masses $m_\pi = 355$ MeV and $m_K = 441$ MeV, where we include proton momenta up to $|\vec{p}| = 1.57$ GeV. The results are converted to the $\overline{\mathrm{MS}}$-scheme at the scale $\mu = 2$ GeV. In order to extract the PDF, the data is fitted in Fourier space based on a standard parameterization of the PDF.

15

Parton Distributions from Boosted Fields in the Coulomb Gauge

Authors: Wei-yang Liu[1]; Xiang Gao[2]; Yong Zhao[None]

[1] *Stony Brook University*

[2] *Argonne National Lab*

Corresponding Authors: wei-yang.liu@stonybrook.edu, gaox@anl.gov, yong.zhao@anl.gov

In this talk, we will discuss a new method to calculate parton distribution functions (PDFs) from correlations of boosted quarks and gluons in the Coulomb gauge.
Compared to the widely used quasi-PDFs defined from gauge-invariant Wilson-line operators, such correlations offer advantages including absence of linear power divergence, enhanced long-range precision, and accessibility to larger off-axis momenta. We verify the validity of this method at next-to-leading order in perturbation theory and use it to calculate the pion valence quark PDF on a lattice with spacing $a = 0.06$ fm and valence pion mass $m_\pi = 300$ MeV.
Our result agrees with that from the gauge-invariant quasi-PDF at similar precision, achieved with only half the computational cost through a large off-axis momentum $|\vec{p}| \sim 2.2$ GeV.

16

Connecting Euclidean to lightcone correlations: From forward to non-forward kinematics

Authors: Fei Yao[1]; Jianhui Zhang[2]; Yao Ji[3]

[1] *BNU*

[2] *CUHK-shenzhen*

[3] *TUM*

Corresponding Authors: yao.ji@tum.de, 202131140015@mail.bnu.edu.cn, zhangjianhui@cuhk.edu.cn

According to large momentum effective theory (LaMET), the parton observables can be extracted from lattice calculations of quasi-observables through a perturbative matching relation. In this talk, I present a unified framework for the perturbative factorization connecting Euclidean correlations to light-cone correlations. We derive the flavor singlet and non-singlet matching kernel for the generalized distribution functions (GPDs), parton distribution functions (PDFs) and distribution amplitudes (DAs) at one-loop level,including the unpolarized, longitudinally and transversely polarized cases. Our results provide a manual for extracting all leading-twist GPDs,PDFs as well as DAs from lattice simulations of Euclidean correlations, following the state-of-the-art renormalization and matching strategy, either in coordinate or in momentum space factorization approach.

17

Leading Power Accuracy in Lattice Calculations of Parton Distributions

Author: Rui Zhang[1]

Co-authors: Jack Edward Holligan ; Xiangdong Ji ; Yushan Su [1]

[1] *University of Maryland*

Corresponding Authors: zhangrui9308@gmail.com, xji@umd.edu, holligan@msu.edu, ysu12345@umd.edu

In lattice-QCD calculations of parton distribution functions (PDFs) via large-momentum effective theory, the leading power (twist-three) correction appears as $calO(\Lambda_{\rm QCD}/P^z)$ due to the linear-divergent self-energy of Wilson line in quasi-PDF operators. For lattice data with hadron momentum P^z of a few GeV, this correction is dominant in matching, as large as 30\% or more. We show how to eliminate this uncertainty through choosing the mass renormalization parameter consistently with the resummation scheme of the infrared-renormalon series in perturbative matching coefficients. An example on the lattice pion PDF data at $P^z = 1.9$ GeV shows an improvement of matching accuracy by a factor of more than $3 \sim 5$ in the expansion region $x = 0.2 \sim 0.5$.

18

A journey through the heavy-light Sudakov universality class in LaMET: from quasi-TMDPDF at large Pz to quark quasi-PDF in the threshold limit

Authors: Xiangdong Ji[None]; Yizhuang Liu[1]; Yushan Su[2]

[1] *Jagiellonian University*

[2] *University of Maryland*

Corresponding Authors: ysu12345@umd.edu, xji@umd.edu, namgunzitsau@gmail.com

In this talk we will provide a survey of three fundamental objects: quasi-TMDPDF, quasi-LFWF amplitudes and perturbative quark quasi-PDF that appears naturally in the application of LaMET to lattice calculation of various parton distribution functions. We demonstrate how factorization works for the three objects in the corresponding scaling limits, in a way that shares the common maximally-conformal ingredient (or hard kernel): the ***universal*** heavy-light Sudakov form factor. We show how the physical TMDPDF/LFWF amplitudes can be extracted by combining the quasi-TMD quantities together with an auxiliary space-like form factor. Finally, we explain how the NNLO

heavy-light Sudakov form factor can be extracted through the threshold limit of quasi-PDF matching kernel (or perturbative quark quasi-PDF).

19

Multiparton distributions from lattice QCD

Author: Jianhui Zhang[None]

Corresponding Author: zhangjianhui@bnu.edu.cn

Multiparton distributions, among which the double parton distributions (DPDs) are the simplest and most important ones, play an important role in describing multiparton scattering processes in hadron collisions. In this talk, I'll discuss how they can be directly computed from correlations of equal-time nonlocal Euclidean operators on the lattice in the large hadron momentum limit.

20

Collins-Soper kernel from lattice QCD with NNLO and NNLL LaMET matching

Authors: Artur Avkhadiev[None]; Michael Wagman[None]; Phiala Shanahan[None]; Yong Zhao[None]

Corresponding Authors: aavkhadi@mit.edu, pshana@mit.edu, yong.zhao@anl.gov, mwagman@fnal.gov

This work presents a determination of the quark Collins-Soper kernel from quasi-TMDs using lattice QCD and LaMET. The kernel is extracted in the range of transverse momentum scales $240\,\mathrm{MeV} < q_T < 1.6\,\mathrm{GeV}$ for hadron momenta $P < 2.2\,\mathrm{GeV}$, using quark masses corresponding to a close-to-physical value of the pion mass. An analysis of LaMET matching, including for the first time next-to-next leading order accuracy and next-to-next leading logarithmic resummations, indicates perturbative convergence for q_T
$lesssim 550\,\mathrm{MeV}$ and increasing sensitivity to the associated power corrections in q_T at larger transverse momenta.

21

Perturbative study of renormalization and mixing for asymmetric staple-shaped Wilson-line operators on the lattice

Authors: Gregoris Spanoudes[1]; Haralambos Panagopoulos[1]; Martha Constantinou[None]

[1] *University of Cyprus*

Corresponding Authors: marthac@temple.edu, haris@ucy.ac.cy, gspano01@ucy.ac.cy

We present one-loop perturbative results of the renormalization functions for a complete set of non-local quark bilinear operators containing an asymmetric staple-shaped Wilson line, using a family of improved lattice actions. This study is relevant for the nonperturbative investigations regarding the renormalization of the unpolarized, helicity and transversity transverse-momentum dependent parton distribution functions (TMDPDFs) in lattice QCD. We employ a number of different versions of regularization-independent (RI′) renormalization prescriptions which address the power and logarithmic divergences of such non-local operators, the pinch-pole singularities at infinite Wilson-line lengths, as well as the mixing among operators of different Dirac structures, as dictated by discrete symmetries. All cancelations of divergences and admixtures are confirmed by our results at one-loop level. We compare all the different prescriptions and we provide the conversion matrices

at one-loop order which relate the matrix elements of the staple operators in RI′ to the reference scheme $\overline{\text{MS}}$.

22

TMDPDFs in twisted mass lattice QCD

Authors: Aniket Sen[None]; Chuan Liu[1]; Constantia Alexandrou[None]; Fernanda Steffens[None]; Gregoris Spanoudes[2]; Jacopo Tarello[None]; Karl Jansen[3]; Krzysztof Cichy[None]; Martha Constantinou[None]; Simone Bacchio[None]; Xu Feng[None]

[1] *Peking University*

[2] *University of Cyprus*

[3] *DESY*

Corresponding Authors: krzysztof.cichy@gmail.com, marthac@temple.edu, sen@hiskp.uni-bonn.de, pkufengxu@gmail.com, karl.jansen@desy.de, gspano01@ucy.ac.cy, j.tarello@cyi.ac.cy, liuchuan@pku.edu.cn, fsteffens@uol.com.br, s.bacchio@gmail.com, alexand@ucy.ac.cy

Advancements in LaMET have made it possible to extract the transverse momentum dependent parton distribution functions (TMDPDFs) from first principles calculations. In this work, we calculate the two main ingredients necessary, the quasi-beam function and the soft function. We investigate the non-perturbative renormalization of these objects. Finally, we present results for the TMDPDF in twisted mass lattice QCD.

23

Toward a precision calculation of generalized parton distribution functions.

Authors: Huey-Wen Lin[None]; Jack Edward Holligan[None]

Corresponding Authors: hueywen@msu.edu, holligan@msu.edu

Generalized parton distribution functions (GPDs) describe the longitudinal momentum distribution within a hadron among its constituent partons as well as information about the momentum in the transverse direction. We calculate unpolarized and helicity GPDs using 2+1+1 flavors of highly improved staggered quarks in ensembles generated by the MILC collaboration at a=0.09 fm with a physical pion mass using the method of large-momentum effective theory (LaMET). We use boosting momentum ~ 1.7 GeV for multiple $\xi = 0$ and $\xi = 0.25$ with multiple transfer momenta renormalized in the hybrid scheme. In addition, we study the effects of systematic errors by applying leading renormalon resummation and renormalization group resummation in the matching process.

24

Moments from local and non-local operators

Author: Xiangdong Ji[None]

Co-author: Yushan Su [1]

[1] *University of Maryland*

Corresponding Author: xji@umd.edu

I will discuss the relation between lattice computation of PDF moments from local and non-local operators. Consistency between the two approaches provide important constraints on LaMET calculations of partons on lattice.

25

Chiral-even axial twist-3 GPDs of the proton from lattice QCD

Authors: Shohini Bhattacharya[None]; Krzysztof Cichy[None]; Martha Constantinou[None]; Jack Dodson[None]; Andreas Metz[None]; Aurora Scapellato[None]; Fernanda Steffens[None]

Corresponding Authors: sbhattach@bnl.gov, metza@temple.edu, marthac@temple.edu, aurora.scapellato@temple.edu, krzysztof.cichy@gmail.com, fsteffens@uol.com.br, tug76350@temple.edu

We present the first lattice-QCD calculation of the proton's twist-3 axial quark GPDs using the LaMET approach. The lattice computation is performed using one ensemble of $N_f = 2 + 1 + 1$ maximally twisted mass fermions with a clover term at a single lattice spacing of 0.093 fm and a pion mass of 260 MeV, employing three proton boosts up to 1.67 GeV. The light-cone GPDs are defined in the symmetric frame, at $-t = 0.69, 1.38$ and 2.76 GeV^2 and at zero skewness. We extract the leading combinations with twist-2 helicity GPDs, $\widetilde{H} + \widetilde{G}_2$ and $\widetilde{E} + \widetilde{G}_1$. We also isolate $\widetilde{G}_2$ and calculate the suppressed GPD $\widetilde{G}_4$, while $\widetilde{G}_3$ is confirmed to vanish at zero skewness. We also present several consistency checks, including the local limit of the twist-3 GPDs and the Burkhardt-Cottingham-type and Efremov-Teryaev-Leader-type sum rules.

26

Investigating nucleon's elastic, resonance, and DIS structures from hadronic tensor in lattice QCD

Author: Raza Sufian[1]

Co-authors: Bigeng Wang ; Jian Liang ; Keh-Fei Liu ; Tanjib Khan ; Yi-Bo Yang

[1] *Brookhaven National Lab*

Corresponding Author: gluon2025@gmail.com

The excitation of nucleons to resonance structures via electromagnetic interactions is crucial for enhancing our comprehension of strong interactions within the realm of quark confinement. Moreover, accurate characterization of various resonance structures is also essential for maximizing the discovery potential of neutrino oscillation experiments. In this presentation, we present preliminary determinations of the nucleon's elastic and transition form factors, utilizing the hadronic tensor. Furthermore, we discuss how the hadronic tensor formalism enables access to x-dependent structure functions and allows for the numerical investigation of higher-twist contributions in deep inelastic scattering.

27

Transverse-Momentum-Dependent Wave Functions of Pion from LaMET

Author: Jun Hua[1]

[1] *South China Normal University*

Corresponding Author: ickes_hill@163.com

We present a first lattice QCD calculation of the transverse-momentum-dependent wave functions (TMDWFs) of the pion using large-momentum effective theory. Numerical simulations are based on one ensemble with 2+1+1 flavors of highly improved staggered quarks action with lattice spacing $a = 0.121$˜fm from the MILC Collaboration, and one with 2 +1 flavor clover fermions and tree-level Symanzik gauge action generated by the CLS Collaboration with $a = 0.098$˜fm. As a key ingredient, the soft function
is first obtained by incorporating the one-loop perturbative contributions and a proper normalization. Based on this and the equal-time quasi-TMDWFs simulated on the lattice, we extract the light-cone TMDWFs. The results are comparable between the two lattice ensembles and a comparison with phenomenological parametrization is made. Our studies provide a first attempt of $ab\ initio$ calculation of TMDWFs which will eventually lead to crucial theory inputs for making predictions for exclusive processes under QCD factorization.

28

Double Parton Distributions off and on the lattice

Author: Andreas Schaefer[None]

Corresponding Author: andreas.schaefer@physik.uni-r.de

The HL-LHC program will be sensitive to significantly smaller effects
of BSM physics than probed so far. This implies that the quantitative understanding of non-perturbative Standard Model "backgrounds" has to be improved correspondingly. In this context Multiple Parton Interactions (MPIs) are a major concern. Theory efforts to improve their understanding focus on the simplest case, Double Parton Interactions, which are parameterized by Double Parton Distributions (DPDs) [1]. Jianhui Zhang
will present a talk on LaMET evaluations of DPDs [2], see also [3], while I plan to present some general introduction, analytic results [4] and lattice results for DPD moments [5].

[1] M. Diehl, D. Ostermeier and A. Schäfer, JHEP **03** (2012), 089, [arXiv:1111.0910]
[2] J. H. Zhang, [arXiv:2304.12481]
[3] M. Jaarsma, R. Rahn and W. J. Waalewijn, [arXiv:2305.09716]
[4] M. Diehl et al., Eur. Phys. J. C **80** (2020) 468 [arXiv:2001.10428]
[5] G. S. Bali, et al., JHEP **09** (2021), 106 [arXiv:2106.03451]

29

Lattice Constraints on the Fourth Mellin Moment of the Pion LCDA using the HOPE Method

Authors: Anthony Grebe[1]; Issaku Kanamori[2]; Robert Perry[3]; Will Detmold[4]; Yong Zhao[None]; C.-J. David Lin[5]

[1] *Fermilab*

[2] *R-CCS, RIKEN*

[3] *Univerisity of Barcelona*

[4] *Massachusetts Institute of Technology*

[5] *National Yang Ming Chiao Tung Univiersity*

Corresponding Authors: agrebe@mit.edu, kanamori-i@riken.jp, wdetmold@gmail.com, yong.zhao@anl.gov, perryrobertjames@gmail.com

The light-cone distribution amplitude (LCDA) of the pion carries information about the parton momentum distribution and is an important theoretical input into various predictions of exclusive measurements at high energy, including the pion electromagnetic form factor. We provide constraints on the fourth Mellin moment of the LCDA using the heavy quark operator product expansion (HOPE) method.