2024 Meeting on Lattice Parton Physics from Large Momentum Effective Theory (LaMET2024)

Sunday, 11 August 2024 - Wednesday, 14 August 2024

University of Maryland, College Park

Book of Abstracts

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Exploring the heavy meson distribution amplitudes from lattice QCD

Author: Qi-An Zhang[None]

Corresponding Author: zhangqa@buaa.edu.cn

We present a method to compute lightcone distribution amplitudes (LCDAs) of heavy meson within heavy quark effective theory (HQET). Our method utilizes quasi distribution amplitudes (quasi-DAs) with a large momentum component P^z. We point out that by sequentially integrating out P^z and m_H, one can disentangle different dynamical scales. Integrating out P^z allows to connect quasi-DAs to QCD LCDAs, and then integrating out m_H enables to relate QCD LCDAs to HQET LCDAs. To verify this proposal, we make use of lattice QCD simulation on a lattice ensemble with spacing $a = 0.05187$fm. The preliminary findings for HQET LCDAs qualitatively align with phenomenological models. Using a recent model for HQET LCDAs, we also fit the first inverse moment λ_B^{-1} and the result is consistent with the experimentally constrain from $B \to \gamma \ell \nu_\ell$. This agreement demonstrates the promise of our method in providing first-principle predictions for heavy meson LCDAs.

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The Baryon LCDA from Lattice QCD

Author: Jun Hua[None]

Corresponding Author: ickeshill@gmail.com

The baryon light-cone distribution amplitudes(LCDAs) are critical inputs for hard exclusive reactions involving large momentum transfer between the initial and final state hadron. We present a lattice calcuation for the entire x dependent baryon LCDA under large momentum effective theory. The numerically simulation is based on emsembles with 2+1 flavor stout smeared clover fermions and Symanzik gauge action at 0.077fm. Our studies provide a first attempt of a entire two dimensional but one direction light cone distribution with unique matching and other procedures.

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Light-cone distribution amplitudes of a light baryon in large-momentum effective theory

Authors: Jia-Lu Zhang[1]; Jun Zeng[1]; Wei Wang[None]; Zhi-Fu Deng[1]; chao han[None]

[1] *Shanghai Jiao Tong University*

Corresponding Authors: qietuanzhang@gmail.com, elpsycongr00@sjtu.edu.cn, chaohan@sjtu.edu.cn, dengzhifu@sjtu.edu.cn, wei.wang@sjtu.edu.cn

Momentum distributions of quarks/gluons inside a light baryon in a hard exclusive process are encoded in the light-cone distribution amplitudes (LCDAs). In this work, we point out that the leading twist LCDAs of a light baryon can be obtained through a simulation of a quasi-distribution amplitude calculable on lattice QCD within the framework of the large-momentum effective theory. We calculate the one-loop perturbative contributions to LCDA and quasi-distribution amplitudes and explicitly demonstrate the factorization of quasi-distribution amplitudes at the one-loop level. Based on the perturbative results, we derive the matching kernel in the $\overline{\text{MS}}$ scheme and regularization-invariant momentum-subtraction scheme. Our result provides a first step to obtaining the LCDA from first principle lattice QCD calculations in the future.

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Lightcone and quasi distribution amplitudes for light octet and decuplet baryons

Authors: Jialu Zhang[1]; Jun Zeng[1]; Wei Wang[None]; Yushan Su[2]; chao han[None]

[1] *Shanghai Jiao Tong University*

[2] *University of Maryland*

Corresponding Authors: ysu12345@umd.edu, elpsycongr00@sjtu.edu.cn, qietuanzhang@gmail.com, wei.wang@sjtu.edu.cn, chaohan@sjtu.edu.cn

We present a comprehensive investigation of leading-twist lightcone distribution amplitudes (LCDAs) and quasi distribution amplitudes (quasi-DAs) for light octet and decuplet baryons within large momentum effective theory. In LaMET, LCDAs can be factorized in terms of a hard kernel and quasi-DAs that are defined as spatial correlators and calculable on Lattice QCD.
To renormalize quasi-DAs and eliminate the singular terms $\ln(\mu^2 z_i^2)'s$ in them, which undermine the efficacy in perturbative expansion, we adopt a hybrid renormalization scheme that combines the self-renormalization and ratio scheme. Through self-renormalization, we eliminate UV divergences and linear divergences at large spatial separations in quasi distribution amplitudes without introducing additional nonperturbative effects. By taking a ratio with respect to the zero-momentum matrix element, we effectively remove UV divergences at small spatial separations.
Under the hybrid renormalization scheme, we calculate the hard kernels up to one-loop accuracy. It turns out that only four different hard kernels are needed for all leading-twist LCDAs of octet and decuplet baryons. These results are crucial for the lattice-based exploration of the LCDAs of a light baryon from the first principle of QCD.

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Quarks and Glue inside Hadrons in the Instanton Vacuum

Authors: Edward Shuryak[None]; Wei-yang Liu[1]; ismail zahed[1]

[1] *Stony Brook University*

Corresponding Authors: edward.shuryak@stonybrook.edu, ismailzahed@gmail.com, wei-yang.liu@stonybrook.edu

We discuss a general framework for the evaluation of the parton distribution, distribution amplitudes as well as the form factors in light hadrons in the QCD vacuum. At medium resolution of the order of the inverse mean instanton size, the glue is mostly localized in single or pair of pseudoparticles, and globally constrained by the fluctuations of their topological charges. These pseudoparticles trap light quarks, giving rise to emerging multiflavor 't Hooft interactions. In this approach the quantum breaking of conformal symmetry and U(1) chiral symmetry is encoded in the form of stronger-than-Poisson fluctuations in the number of instantons and gaussian fluctuations in the topological charge. The spontaneous chiral symmetry breaking emerges naturally by the interaction between instantons and quarks, forming the light mesons.

For partonic structures, this framework is used to estimate the distribution amplitudes and parton distributions for pion, kaon and rho mesons.

For hadronic form factors, this framework is used to estimate pion and rho electromagnetic form factors, gluonic scalar, pseudoscalar and energy-momentum tensor (EMT), the leading C-odd and C-even three gluons hadronic form factors, as well as the proton and neutron electric dipole moment induced by a small CP violating θ at low resolution.

The ILM results compare well with those of recent lattice QCD calculations as well as the experimental analysis. Our results for the mass and spin composition of the nucleon are also shown to be in good agreement with the recently reported lattice results at higher resolution.

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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 use the CLS ensembles X650 (a = 0.098 fm), H102 (a = 0.085 fm) and N203 (a = 0.064 fm) to study this quantity and later allow for a controlled continuum extrapolation. The pion masses of these ensembles are approximately equal, as they range between 338 and 354 MeV. Here, preliminary results of the ongoing work are shown, including extractions of the bare matrix elements, determination of the short distance renormalization factors Z_O, and matching to the light-cone. A main goal of the current work is to determine the largest momentum P^z at which we still see a sufficient signal.

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Transverse Momentum Distributions from Lattice QCD without Wilson Lines

Author: Yong Zhao[None]

Corresponding Author: yong.zhao@anl.gov

The transverse-momentum-dependent distributions (TMDs), which are defined by gauge-invariant 3D parton correlators with staple-shaped lightlike Wilson lines, can be calculated from quark and gluon correlators fixed in the Coulomb gauge on a Euclidean lattice. These quantities can be expressed gauge-invariantly as the correlators of Coulomb-gauge-dressed fields, which reduce to the standard TMD correlators under principal-value prescription in the infinite boost limit. In the framework of Large-Momentum Effective Theory, a quasi-TMD defined from such correlators in a large-momentum hadron state can be matched to the TMD via a factorization formula, whose exact form is derived using Soft Collinear Effective Theory and verified at one-loop order. Compared to the currently used gauge-invariant correlators, this new method can substantially improve statistical precision and simplify renormalization for the time-reversal-even TMDs, which will greatly enhance the predicative power of lattice QCD in the non-perturbative region.

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Non-perturbative Collins-Soper kernel from a Coulomb-gauge-fixed quasi-TMD

Authors: Dennis Bollweg[None]; Xiang Gao[1]; Swagato Mukherjee[None]; Yong Zhao[None]

[1] *Argonne National Lab*

Corresponding Authors: swagato@bnl.gov, gaox@anl.gov, yong.zhao@anl.gov, dbollweg@physik.uni-bielefeld.de

We present the first lattice QCD calculation of the rapidity anomalous dimension of transverse-momentum-dependent distributions (TMDs), i.e. the Collins-Soper (CS) kernel, employing the recently proposed Coulomb-gauge-fixed quasi-TMD formalism as well as a chiral-symmetry-preserving lattice discretization. This unitary lattice calculation is conducted using the domain wall fermion discretization scheme, a fine lattice spacing of approximately 0.08 fm, and physical values light and strange quark masses. The CS kernel is determined analyzing the ratios of pion quasi-TMD wave functions (quasi-TMDWFs) at next-to-leading logarithmic (NLL) perturbative accuracy. We observe significantly slower signal decay with increasing quark separations compared to the established

gauge-invariant method with a staple-shaped Wilson line. This enables us to determine the CS kernel at large nonperturbative transverse separations and find its near-linear dependence on the latter. Our result is consistent with the recent lattice calculation using gauge-invariant quasi-TMDWFs, and agrees with various recent phenomenological parametrizations of experimental data.

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LCDA moments of meson

Authors: Ji-Hao Wang[1]; Mengchu Cai[1]; Yi-Bo Yang[2]

[1] *Institute of Theoretical Physics, Chinese Academy of Sciences*

[2] *CAS*

Corresponding Authors: ybyang@itp.ac.cn, wangjihao@itp.ac.cn

We calculate the leading-twist light-cone distribution amplitude (LCDA) moments of mesons on MILC ensembles using the hyp-smeared clover action. For pseudoscalar mesons, we compute the first moments of the K meson and the second moments of the π and K mesons. For vector mesons, we compute the first moments of the K^* meson and the second moments of the ρ, K^*, and ϕ mesons.

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Impact of gauge fixing precision on the continuum limit of non-local quark-bilinear lattice operators

Authors: Kuan Zhang[1]; Yi-Bo Yang[1]

[1] *ITP/CAS*

Corresponding Author: pcewilos@gmail.com

We analyze the gauge fixing precision dependence of some non-local quark-blinear lattice operators interesting in computing parton physics for several measurements, using 5 lattice spacings ranging from 0.032 fm to 0.121 fm. Our results show that gauge dependent non-local measurements are significantly more sensitive to the precision of gauge fixing than anticipated. The impact of imprecise gauge fixing is significant for fine lattices and long distances. For instance, even with the typically defined precision of Landau gauge fixing of 10^{-8}, the deviation caused by imprecise gauge fixing can reach 12 percent, when calculating the trace of Wilson lines at 1.2 fm with a lattice spacing of approximately 0.03 fm. Similar behavior has been observed in ξ gauge and Coulomb gauge as well. For both quasi PDFs and quasi TMD-PDFs operators renormalized using the RI/MOM scheme, convergence for different lattice spacings at long distance is only observed when the precision of Landau gauge fixing is sufficiently high. To describe these findings quantitatively, we propose an empirical formula to estimate the required precision.

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Systematic Uncertainties from Gribov Copies in Lattice Calculation of Quasi-distributions in the Coulomb gauge

Author: Jinchen He[1]

[1] *University of Maryland, College Park*

Corresponding Author: jinchen@umd.edu

Recently, it is proposed to compute Parton distribution in fixed Coulomb gauge without Wilson line, which could greatly improve the efficiency of lattice calculations. However, there are some concerns about the systematic uncertainties from Gribov copies, which correspond to the ambiguity in the nonperturbative gauge fixing, is not controlled. This work gives an assessment on the systematic uncertainties in the lattice QCD calculation of quasi-distributions from Gribov copies in the Coulomb gauge. We tested two different strategies for choosing Gribov copies in the calculation of pion quasi-PDF and quark spatial propagators, the systematic uncertainties from Gribov copies are not significant compared with the statistical uncertainties.

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Three-dimensional Imaging of Pion using Lattice QCD: Generalized Parton Distributions

Author: Qi Shi[None]

Co-authors: Heng-Tong Ding [1]; Peter Petreczky ; Sergey Syritsyn [2]; Swagato Mukherjee ; Xiang Gao [3]; Yong Zhao

[1] *CCNU*

[2] *Stony Brook University*

[3] *Argonne National Lab*

Corresponding Authors: yong.zhao@anl.gov, gaox@anl.gov, qshi1@bnl.gov, syritsyn@gmail.com, swagato@bnl.gov, hengtong.ding@mail.ccnu.edu.cn, petreczk@bnl.gov

We report a lattice calculation of x-dependent valence pion generalized parton distributions (GPDs) at zero skewness with multiple values of the momentum transfer $-t$. The calculations are based on an $N_f = 2 + 1$ gauge ensemble of highly improved staggered quarks with Wilson-Clover valence fermion. The lattice spacing is 0.04 fm, and the pion valence mass is tuned to be 300 MeV. We determine the Lorentz-invariant amplitudes of the quasi-GPD matrix elements for both symmetric and asymmetric momenta transfers with similar values and show the equivalence of both frames. Then, focusing on the asymmetric frame, we utilize a hybrid scheme to renormalize the quasi-GPD matrix elements obtained from the lattice calculations. After the Fourier transforms, the quasi-GPDs are then matched to the light-cone GPDs within the framework of large momentum effective theory with improved matching, including the next-to-next-to-leading order perturbative corrections, and leading renormalon and renormalization group resummations. We also present the 3-dimensional image of the pion in impact-parameter space through the Fourier transform of the momentum transfer $-t$.

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Collins-Soper kernel from lattice QCD

Authors: Artur Avkhadiev[None]; Michael Wagman[None]; Phiala Shanahan[1]; Yang Fu[1]; Yong Zhao[None]

[1] *MIT*

Corresponding Authors: yong.zhao@anl.gov, aavkhadi@mit.edu, phiala.shanahan@gmail.com, mwagman@fnal.gov, yangfu@mit.edu

This work presents a determination of the quark Collins-Soper kernel from quasi-TMD wavefunctions using lattice QCD and LaMET. This is the first such determination with systematic control

of quark mass, operator mixing, and discretization artifacts. Furthermore, this work also achieves systematic control over the imaginary part of the LaMET matching coefficients at small transverse momentum scales by including a leading infrared renormalon subtraction. In addition to the results on the quark Collins-Soper kernel, preliminary results of the ongoing lattice QCD calculation of the gluon Collins-Soper kernel will also be discussed.

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Factorization of quasi GPD and the ambiguity in the mixing channel

Author: Zhuoyi Pang[1]

[1] *The Chinese University of Hong Kong, ShenZhen*

Corresponding Author: pangzhuoyi@cuhk.edu.cn

In this talk, I'll report our earlier work on the factorization of quasi GPD based on collinear expansion. Using ward identity and BRST symmetry, we show how to get a gauge-invariant factorization form. We also discuss the inconsistency of the mixing channel results in literature: its origin and possible solutions.

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Towards Unpolarized GPDs from Pseudo-Distributions

Authors: Hadstruc Collaboration[None]; Herve Dutrieux[1]

[1] *William and Mary*

Corresponding Author: hldutrieux@wm.edu

I will present the recent lattice calculation of the unpolarized generalized form factors by the Hadtruc collaboration. We use the pseudo-distribution formalism with an extended kinematic domain in (ξ, t). I will discuss the limitations and improvement perspectives of this study.

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Lattice QCD calculation of the pion distribution amplitude with domain wall fermions at physical pion mass

Authors: Peter Boyle[None]; Rui Zhang[None]

Co-authors: Dennis Bollweg ; Ethan Baker ; Ian Cloet ; Peter Petreczky ; Swagato Mukherjee ; Xiang Gao [1]; Yong Zhao

[1] *Argonne National Lab*

Corresponding Authors: gaox@anl.gov, icloet@anl.gov, swagato@bnl.gov, yong.zhao@anl.gov, dbollweg@physik.uni-bielefeld.de, petreczk@bnl.gov, pboyle@bnl.gov, ruizhang@anl.gov

We present a direct lattice QCD calculation of the x-dependence of the pion distribution amplitude (DA), which is performed using the quasi-DA in large momentum effective theory on a domain-wall fermion ensemble at physical quark masses and spacing $a \approx 0.084$ fm. The bare quais-DA

matrix elements are renormalized in the hybrid scheme and matched to $\overline{\mathrm{MS}}$ with a subtraction of the leading renormalon in the Wilson-line mass. For the first time, we include threshold resummation in the perturbative matching onto the light-cone DA, which resums the large logarithms in the soft gluon limit at next-to-next-to-leading log. The resummed results show controlled scale-variation uncertainty within the range of momentum fraction $x \in [0.25, 0.75]$ at the largest pion momentum $P_z \approx 1.85$˜GeV. In addition, we apply the same analysis to quasi-DAs from a highly-improved-staggered-quark ensemble at physical pion mass and $a = 0.076$ fm. By comparison we find with 2σ confidence level that the DA obtained from chiral fermions is flatter and lower near $x = 0.5$.

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Threshold resummation for computing large-x PDF under LaMET

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

[1] *Jagiellonian University*

[2] *University of Maryland*

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

Parton distribution functions (PDFs) at large x are difficult to be extracted from experimental data, but are extremely important in understanding hadron structures as well as searching for new physics beyond the Standard Model. We study the large x PDFs under the framework of large momentum P^z expansion of lattice quasi-PDFs. In the threshold limit, the matching kernel of quasi-PDF can be factorized into the heavy light Sudakov hard kernel and space-like jet function, and their renormalization group equations allow us to resum the threshold logarithms regarding the spectator momentum. The pion valence PDFs calculated with the resummed matching kernel clearly expose the breaking down of perturbative matching for the spectator momentum $(1-x)P^z \sim \Lambda_{\mathrm{QCD}}$, and at the same time validate the perturbative matching if both spectator and active quark momenta $(1-x)P^z, xP^z$ are much larger than Λ_{QCD}, where a good perturbative convergence is observed after the implementation of threshold resummation with leading renormalon resummation.

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Proton Transversity GPDs from Lattice QCD

Author: Joshua Miller[None]

Corresponding Author: joshua.miller0007@temple.edu

The x-dependence of GPDs is still relatively unknown, but recent developments from lattice QCD with a new approach (PRD 106 (2022) 11, 114512) produce promising results from matrix elements calculated from any kinematic frame. Traditionally, GPDs are calculated in the symmetric frame, where the momentum transfer is evenly split between the initial and final states. In this talk, we present the first twist-2 GPDs for the tensor operator in the asymmetric frame; H_T, $\widetilde{H}_T$, E_T, $\widetilde{E}_T$. The calculation uses an $N_f = 2{+}1{+}1$ ensemble of twisted mass fermions with a clover improvement. The quarks mass values give a pion mass of roughly 260 MeV.

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Progress toward Moments of Light-Cone Distribution Amplitudes from a Heavy-Quark Operator Product Expansion

Authors: Alex Chang[1]; Anthony Grebe[None]; C.-J. David Lin[None]; Issaku Kanamori[2]; Robert Perry[None]; William Detmold[None]; Yong Zhao[None]

[1] *NYCU*

[2] *R-CCS, RIKEN*

Corresponding Authors: agrebe@mit.edu, perryrobertjames@gmail.com, wdetmold@mit.edu, s44930e0@gmail.com, kanamori-i@riken.jp, yong.zhao@anl.gov, dlin@nycu.edu.tw

The pseudoscalar meson light-cone distribution amplitudes (LCDAs) are essential non-perturbative inputs for a range of high-energy exclusive processes in quantum chromodynamics. I will discuss progress towards determination of the low Mellin moments of pion and kaon LCDAs – including the fourth moment of the pion LCDA – by the HOPE Collaboration.

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Off-lightcone Wilson-line operators in gradient flow

Author: Xiangpeng Wang[1]

Co-author: Nora brambilla

[1] *Technische Universität München*

Corresponding Authors: xiangpeng.wang@tum.de, nora.brambilla@ph.tum.de

Off-lightcone Wilson-line operators are constructed using local operators connected by time-like or space-like Wilson lines, which ensure gauge invariance. Off-lightcone Wilson-line operators have broad applications in various contexts. For instance, space-like Wilson-line operators play a crucial role in determining quasi-distribution functions (quasi-PDFs), while time-like Wilson-line operators are essential for understanding quarkonium decay and production within the potential non-relativistic QCD (pNRQCD) framework. In this work, we establish a systematic approach for calculating the matching from the gradient-flow scheme to the MS scheme in the limit of small flow time for off-lightcone Wilson-line operators. By employing the one-dimensional auxiliary-field formalism, we simplify the matching procedure, reducing it to the matching of local current operators. We provide one-loop level matching coefficients for these local current operators. For the case of hadronic matrix element related to the quark quasi-PDFs, we show at one-loop level that the finite flow time effect is very small as long as the flow radius is smaller than the physical distance z, which is usually satisfied in lattice gradient flow computations. Applications include lattice gradient flow computations of quark/gluon quasi-PDFs, gluonic correlators related to quarkonium decay and production in pNRQCD, and spin-dependent potentials in terms of chromoelectric and chromomagnetic field insertions into a Wilson loop.

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The time-ordering issue of TMD soft factors

Author: Yizhuang Liu[1]

[1] *Jagiellonian University*

Corresponding Author: namgunzitsau@gmail.com

In this talk I revisit the time-ordering issue of TMD soft factors based on coordinate-space analyticity properties of Wightman functions in Wightman-Osterwalder-Schrader QFTs.

In particular, I show that the TMD soft factor for the DY process in three rapidity regularization schemes can be smoothly connected to each other in a way that maintain certain crucial (S=S_t type) equalities required for lattice applications.

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One loop matching for singlet quasi-parton distributions in the hybrid ratio scheme

Authors: Jiunn-Wei Chen[None]; Yi-Xian Chen[1]

[1] *National Taiwan university*

Corresponding Authors: jwc@phys.ntu.edu.tw, r11222036@ntu.edu.tw

We compute the matching kernel of singlet quasi-parton distributions in the hybrid ratio scheme. Momentum conservation of the quasi-distributions is observed. However, the renormalization condition is complicated by the quark and gluon mixing.

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Evolution of parton pseudo-distributions

Author: Joseph Karpie[None]

Co-authors: Chris Monahan [1]; Herve Dutrieux [2]; Kostas Orginos [3]; Savvas ZAFEIROPOULOS

[1] *William & Mary*

[2] *William and Mary*

[3] *William and Mary - Jlab*

Corresponding Authors: cjmonahan@wm.edu, jkarpie@gmail.com, kostas@wm.edu, savvas.zafeiropoulos@cpt.univ-mrs.fr, hldutrieux@wm.edu

Critical to the understanding of parton structure is the scale dependence of the distributions. By compared data at different scales one can test the validity of the factorization approximation. Typically the universal short distance scale dependence of the object is calculated in perturbation theory. We propose a method for calculating the scale dependence non-perturbatively from lattice QCD data. With this approach, the range of universal scaling can be studied without the limitations of perturbation theory at lower energy scales.

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Lattice QCD Predictions for Meson Electromagnetic Form Factors at High Momenta: Testing Factorization in Exclusive Processes

Author: Peter Petreczky[None]

Co-authors: Dennis Bollweg ; Qi Shi ; Rui Zhang ; Swagato Mukherjee ; Xiang Gao [1]; Yong Zhao

[1] *Argonne National Lab*

Corresponding Authors: ruizhang@anl.gov, yong.zhao@anl.gov, gaox@anl.gov, dbollweg@physik.uni-bielefeld.de, swagato@bnl.gov, qshi1@bnl.gov, petreczk@bnl.gov

We report the first lattice QCD computation of pion and kaon electromagnetic form factors, $F_M(Q^2)$, at large momentum transfer up to 10 and 28 GeV2, respectively. The calculations are performed using HISQ
action on fine lattices with physical quark massesi and Breit frame [1].
We test the QCD collinear factorization framework utilizing our high- Q^2 form factors at next-to-next-to-leading
order in perturbation theory, and lattice QCD results on the pion and kaon distribution amplituded calculated
within the LaMET approach using fine HISQ lattices with physical quark masses [2].
Within estimated uncertainties we find that QCD collinear factorization framework works [1].

References

[1] H.-T. Ding et al, arXiv:2404.04412 [hep-lat]
[2] I. Cloet et al, arXiv:2407.00206 [hep-lat]

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Obtaining the TMD Soft function and CS kernel from lattice QCD

Authors: Anthony Sebastian Francis[1]; C.-J. David Lin[None]; Issaku Kanamori[2]; Wayne Morris[3]; Yong Zhao[None]

[1] *Chiao Tung University (TW)*

[2] *R-CCS, RIKEN*

[3] *National Yang Ming Chiao Tung University*

Corresponding Authors: afrancis.heplat@gmail.com, yong.zhao@anl.gov, waynemorris@nycu.edu.tw, dlin@nycu.edu.tw, kanamori-i@riken.jp

The TMD soft function may be obtained by formulating the Wilson line in terms of auxiliary 1-dimensional fermion fields on the lattice. We take inspiration from heavy quark effective theory (HQET) in order to define the auxiliary field. Our computation takes place in the region of the lattice that corresponds to the "spacelike"region in Minkowski space in order to obtain the Collins soft function. The matching of our result to the Collins soft function is achieved through the mapping of the auxiliary field directional vector to the Wilson line rapidity. I present some exploratory numerical results of our lattice calculation, and discuss the methodology employed.

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Lanczos for spectroscopy

Author: Michael Wagman[None]

Corresponding Author: mwagman@fnal.gov

I will present a new method for determining the energy spectrum of lattice QCD using the Lanczos algorithm. The method provides faster ground-state convergence than standard energy estimators and rigorous two-sided error bounds, while avoiding the exponential signal-to-noise degradation present using standard methods.

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Lanczos for matrix elements

Authors: Daniel Hackett[None]; Michael Wagman[None]

Corresponding Authors: dhackett@fnal.gov, mwagman@fnal.gov

We present a new method for extracting hadronic matrix elements from simultaneous analysis of two- and three-point correlation functions, based on the Lanczos algorithm. In applications to both synthetic and lattice data, we demonstrate its advantages in both signal-to-noise and treatment of excited states over previous analysis approaches. We discuss the potential improvements for quasi-PDF calculations and what will be required to enable them.

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Extracting Meson Distribution Amplitudes from Lattice QCD at Next-to-Next-to-Leading Order

Authors: Fei Yao[None]; Jianhui Zhang[1]; Yao Ji[2]

[1] *CUHK-shenzhen*

[2] *TUM*

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

In this talk, I present the result of the next-to-next-to-leading order (NNLO) matching kernel for extracting light meson distribution amplitudes from lattice calculations of nonlocal Euclidean correlation functions. The renormalization is done in a state-of-the-art scheme. I also show some preliminary numerical test to demonstrate the impact of the NNLO matching.

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Towards Hybrid-Renormalized Gluon Parton Distribution Function from LaMET

Author: William Good[1]

Co-authors: Kinza Hasan [1]; Huey-Wen Lin

[1] *Michigan State University*

Corresponding Authors: hasankin@msu.edu, goodwil9@msu.edu, hueywen@msu.edu

We present the first attempt at using the hybrid-ratio renormalization scheme on gluon quasi-lightfront correlators from lattice quantum chromodynamics with $a \approx 0.12$ fm at pion masses $M_\pi \approx 310$ and 690 MeV. We measured over 1.2 million two-point correlators and used momentum smearing and aggressive gauge link smearing for the gluon operator to obtain a reasonable level of signal up to a hadron boost momentum of 2.14 GeV. We compare the gluon matrix elements to those reconstructed from the CT18 global fit gluon PDF using the hybrid-ratio matching kernel.

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LaMET and Weinberg's EFT

Corresponding Author: xji@umd.edu

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Some mathematical aspects on reconstructing GPDs through universal moment parameterization

We present some mathematical results for reconstructing the generalized parton distributions (GPDs) through the universal moment parameterization (GUMP) program. We elucidate several subtle issues observed in previous literature, particularly the relationship between formal summation and the Mellin-Barnes integral. Furthermore, we derive an asymptotic condition on the conformal moments of GPDs to ensure that GPDs vanish at \(|x|=1\) and subsequently develop an approximate formula for GPDs when \(x>\xi\). Additionally, we propose a method to handle double summations arising from the non-trivial conformal indices mixing in the NLO scale evolution kernel of DVCS and DVMP. This method converts the double summations into double Mellin-Barnes integrals, which will be beneficial for further studies in the GUMP program.