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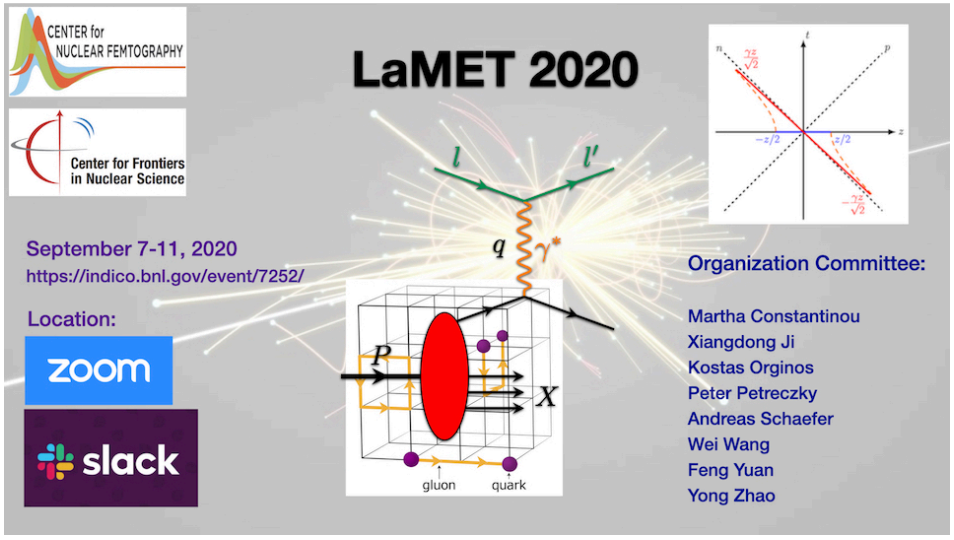
Center for Nuclear Femtography (SURA) and Center for Frontiers in Nuclear Science (SBU/BNL)



Book of Abstracts

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Welcome

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Session II / **8**

B-meson distribution amplitude

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We propose the approach for lattice investigation of light-cone distribution amplitudes of heavy-light mesons, such as B-meson, using both the formalism of quasi- and pseudo-distributions. We discuss the multiplicative renormalizability of the off-light-cone HQET operator with the aid of auxiliary field approach, and determine the perturbative matching coefficient entering the hard-collinear factorization formula at the one-loop accuracy within the large momentum effective theory. We further explore the short distance behavior of B-meson Ioffe-time distribution amplitude (ITDA) and construct an ultraviolet finite reduced ITDA of B-meson, which guarantees that the continuum limit exists on the lattice.

Session II / **17**

Gluon pseudo-distributions at short distances: Forward case

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We present the results that are necessary in the ongoing lattice calculations of the gluon parton distribution functions (PDFs) within the pseudo-PDF approach. We give a classification of possible two-gluon correlator functions and identify those that contain the invariant amplitude determining the gluon PDF in the light-cone $z^2 \to 0$ limit. One-loop calculations have been performed in the coordinate representation and in an explicitly gauge-invariant form. We made an effort to separate ultraviolet (UV) and infrared (IR) sources of the $\ln(-z^2)$-dependence at short distances z^2. The UV terms cancel in the reduced Ioffe-time distribution (ITD), and we obtain the matching relation between the reduced ITD and the light-cone ITD. Using a kernel form, we get a direct connection between lattice data for the reduced ITD and the normalized gluon PDF. We also show that our results may be used for a rather straightforward calculation of the one-loop matching relations for quasi-PDFs.

Session II / **18**

Decomposing the proton spin to quark and gluon contributions

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We will present results on the spin decomposition and the momentum distribution among quarks and gluons in the proton. Techniques for lattice QCD simulations at the physical pion mass applied for the computation of sea-quark and gluon contributions will be presented. We will discuss several challenges and perspectives for future developments.

Session II / **19**

Extraction of Next-to-Next-to-Leading-Order PDFs from Lattice QCD Calculations

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Quark correlation functions in position space are calculable in lattice QCD and factorizable into parton distribution functions with matching coefficients perturbatively calculable to all orders in QCD, which provides a way to extract PDFs from lattice QCD calculation. We present for the first time complete next-to-next-to-leading-order calculation of valence-quark matching coefficients. We find that theoretical uncertainties are improving with higher order contributions. Our method of calculations can be readily generalized to evaluate sea-quark matching coefficients and gluon correlation functions, putting the program to extract partonic structure of hadrons from lattice QCD calculations to be comparable with that from experimental measurements.

Session I / **20**

Lattice QCD calculations of TMD soft function through large-momentum effective theory

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The transverse-momentum-dependent (TMD) soft function is a key ingredient in QCD factorization of Drell-Yan and other processes with relatively small transverse momentum. We present a lattice QCD study of this function at moderately large rapidity on a 2+1 flavor CLS dynamic ensemble with $a = 0.098$ fm. We extract the rapidity-independent (or intrinsic) part of the soft function through a large-momentum-transfer pseudo-scalar meson form factor and its quasi-TMD wave function using leading-order factorization in large-momentum effective theory. We also investigate the

rapidity-dependent part of the soft function—the Collins-Soper evolution kernel—based on the large-momentum evolution of the quasi-TMD wave function.

Session I / **22**

Proton GPDs from lattice QCD

Authors: Constantia Alexandrou[1]; Krzysztof Cichy[2]; Martha Constantinou[3]; Kyriakos Hadjiyiannakou[4]; Karl Jansen[5]; Aurora Scapellato[2]; Fernanda Steffens[6]

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We will present new results of the proton unpolarized and helicity GPDs, within lattice QCD. Their x-dependence is extracted using the quasi-distribution method, which requires matrix elements of moving hadrons coupled with non-local operators. We use momentum boost up to 1.67 GeV, and momentum transfer squared up to 1 GeV^2. The calculation is performed on an Nf=2+1+1 ensemble of twisted mass fermions with a clover improvement, reproducing a pion mass of 260 MeV. The quasi-GPDs are matched to their light-cone counterparts using one-loop perturbation theory within Large Momentum Effective Theory (LaMET).

Session I / **23**

Transverse momentum dependent factorization for lattice observables

Author: Vladimirov Alexey[1]

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I present the derivation of the factorization theorem for the quasi-transverse-momentum-dependent (quasi-TMD) operator, within the soft collinear effective field theory framework. The factorized expression is built from the physical TMD distribution, and a nonperturbative lattice related factor. The lattice related functions cancel in appropriately constructed ratios. These ratios could be used to explore various properties of TMD distributions, for instance, the nonperturbative evolution kernel (Collins-Soper kernel). A discussion of such ratios and the related continuum properties of TMDs is presented.

Session I / **24**

NNLO Correction to Quark Quasi Distribution Functions

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We present the first next-to-next-to-leading order (NNLO) calculation of quark quasi parton distribution functions (PDFs) in the large momentum effective theory. The nontrivial factorization at this order is established explicitly and the full analytic matching coefficients between the quasi distribution and the lightcone distribution are derived for the first time. We demonstrate that the NNLO numerical contributions can improve the behavior of the extracted PDFs sizably.
With the unprecedented precision study of nucleon tomography at the planned electron-ion collider, high precision Lattice QCD simulations with our NNLO results implemented will enable to test the QCD theory and revolutionize our understanding of the fundamental structure of nucleon/nucleus.

Session I / 25

Matching for the twist-3 PDFs $g_T(x)$, $e(x)$ and $h_L(x)$: success or failure?

Authors: Shohini Bhattacharya[1]; Krzysztof Cichy[2]; Martha Constantinou[3]; Andreas Metz[3]; Aurora Scapellato[2]; Fernanda Steffens[4]

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The perturbative procedure of matching within Large Momentum Effective Theory connects the quasi-parton distributions to the light-cone distributions that enter physical processes. This procedure has demonstrated success in the extraction of the twist-2 PDFs from lattice QCD. We explore the formalism of matching, for the first time, for the twist-3 PDFs $g_T(x)$, $e(x)$ and $h_L(x)$. We make several non-trivial observations, all of which arise from the presence of singular zero-mode contributions in the perturbative results of the light-cone and quasi-PDFs. While matching seems possible for $g_T(x)$, zero-mode contributions could pose a challenge for the matching in the case of $e(x)$ and $h_L(x)$.

Session I / 26

TMD parton densities from LaMET

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TMD parton densities are important for its theoretical value and for better understanding of Hadron structure. The first principle calculation of them from LaMET framework turns out to be non-trivial due to problems caused by soft function subtraction. In this talk I will talk about recent progress on lattice calculation of TMD soft functions and parton densities from the LaMET framework. I will show that the TMD soft function in off-light-cone regularization scheme can be extracted from heavy or light meson form factors, and with the help of the soft function, the universal scheme independent TMD-PDFs cane be obtained once combining them with lattice calculable quasi-TMD PDFs.

Session I / **27**

Connecting quasi and pseudo distributions in nongauge theories

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I explore the explicit relationship between the LaMET and pseudo-PDF approaches to collinear hadron structure in the context of a scalar theory, and demonstrate explicitly their equivalence at one loop in perturbation theory. Scalar field theory removes complications associated with gauge theories that enable complete calculations of all quantities, such as the Ioffe-time distribution at arbitrary field separation, and demonstrate explicitly their interrelationships. This provides the ideal playground for analysing and clarifying the main features of both quasi- and pseudo-PDFs.

Session II / **28**

Twist-3 PDFs from lattice QCD: g_T(x)

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We present a lattice exploration of the isovector flavor combination of the nucleon's twist-3 helicity PDF g_T(x), using twisted mass clover fermions. We employ the quasi-distribution approach at three values of the nucleon boost up to 1.7 GeV to connect the lattice-extracted matrix elements, renormalized in the RI/MOM scheme, to light-cone distributions, applying the matching procedure that we developed in parallel. We also calculate the twist-2 helicity distribution g_1(x) to test the Wandzura-Wilczek approximation for g_T(x) and find that it works well for a broad range of Bjorken-x.

Session II / **29**

Hadronic tensor with lattice QCD and elastic form factors

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We propose to study the hadronic tensor with lattice QCD, which works in all the energy ranges (from elastic scattering to inelastic scattering and on to deep inelastic scattering) and is related to many important physical problems. A challenge of this approach in the study of PDFs is to access high momentum and energy transfers, and numerical tests show that small lattice spacings are essential for this purpose. The need of fine lattices appear to be a common problem faced by the lattice PDF community. On the other hand, before lattices with very fine spacing are available, the hadronic tensor can be used to study the nucleon elastic form factors and low-energy scatterings such as the neutrino-nucleon scattering which is of significant physical importance. Numerically, the nucleon electric form factors (connected insertions only) calculated by means of 3-point functions for both u and d quarks are found to be consistent within errors with those deduced from the hadronic tensor.

Session II / **30**

Determining the Nonperturbative Collins-Soper Kernel From TMD Observables Using Lattice QCD

Author: Maximilian Schlemmer[1]

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I present the lattice calculation and results for the nonpertrubative Collins-Soper (CS) kernel, which describes the energy-dependence of the transverse momentum-dependent parton distribution functions (TMDPDFs). The CS kernel is extracted from the ratios of the quasi-TMD taken at different momenta.
The analysis is done with dynamical fermions for different polarization cases of quasi-TMD observables with staple shaped Wilson lines, for three different CLS ensembles at different lattice spacing and fixed pion mass.
The non-perturbative lattice CS kernel shows good agreement with an experimental extraction of the CS kernel. Furthermore a comparison with two previous explorative lattice studies is presented.

Session I / **31**

Collins-Soper Kernel for TMD Evolution from Lattice QCD

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The Collins-Soper kernel relates transverse momentum-dependent parton distribution functions at different energy scales. For small parton transverse momentum qT ~ ΛQCD, this kernel is nonperturbative and can only be determined with controlled uncertainties through experiment or first-principles calculations. I will describe an exploratory study using quenched lattice QCD to determine the Nf = 0 Collins-Soper kernel at scales in the range 250 MeV < qT < 2 GeV.

Session II / **33**

Nucleon Ioffe-time Pseudo-distributions from Distillation

Authors: Colin Egerer[None]; Christos Kallidonis[1]

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The pseudo-distribution formalism is one such lattice methodology capable of extracting light-cone distributions from matrix elements of suitably constructed Euclidean non-local operators of a space-like extent. Leveraging the distillation spatial smearing program, we extract the unpolarized isovector quark distribution of the nucleon via a direct 1-loop matching of the Ioffe-time pseudo-distribution and model PDFs. We benchmark the efficacy and systematics inherent to this choice by also extracting the PDF from the matched light-cone Ioffe-time distribution. The tempering of excited-states and improved spatial sampling afforded by distillation is likewise seen to allow for a meaningful simultaneous determination of the isovector quark and sea-quark distributions. Comparisons with phenomenological determinations are made.

Session II / **34**

Pion and Kaon Distribution Amplitudes in Large-Momentum Effective Theory

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We present a lattice-QCD calculation of π, K distribution amplitudes using large-momentum effective theory (LaMET). Our results are calculted at 130-MeV pion mass with three different lattice spacing: 0.06, 0.09 and 0.12 fm, using 2+1+1 flavors of highly improved staggered quarks (HISQ) ensembles generated by MILC collaboration. We use the hybrid renormalization scheme for quasi light-front correlations to properly renormalize both linear and logarithmic divergences in correlation functions at lattice spacing a. The light-cone distribution amplitude (LCDA) of π, K are finally derived by inverse one-loop mathching from quasi distribution amplitude .

Session II / **35**

Hybrid Renormalization for Quasi Light-Front Correlations in Large-Momentum Effective Theory

Author: Jianhui Zhang[1]

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In large-momentum effective theory (LaMET), the quasi light-front correlations calculated on lattice contain both linear and logarithmic divergences in the lattice spacing, and thus need to be properly renormalized. The commonly used renormalization strategy in the literature has the problem of introducing extra non-perturbative effects at large distance. In this talk, I present a hybrid renormalization procedure that avoids this problem and is well-suited for matching the lattice correlations to

those in the continuum MSbar scheme. Also addressed are several other issues that are important in extracting parton physics using LaMET.

Session II / **36**

Nucleon Gluon Distribution Function from 2+1+1-Flavor Lattice QCD

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The parton distribution functions (PDFs) provide process-independent information about the quarks and gluons inside hadrons. Although the gluon PDF can be obtained from a global fit to experimental data, it is not constrained well in the large-x region. Theoretical gluon-PDF studies are much fewer than those of the quark PDFs. In this work, we present the first lattice-QCD results that access the x-dependence of the gluon unpolarized PDF of the nucleon. The lattice calculation is carried out with nucleon momenta up to 2.16~GeV, lattice spacing $a \approx 0.12$~fm, with valence pion masses of 310 and 690~MeV.
We use reduced Ioffe-time distributions to cancel the renormalization and implement a one-loop perturbative pseudo-PDF matching to the lightcone distribution. Our matrix element results in coordinate space are consistent with those obtained from the global PDF fits of CT18 NNLO and NNPDF3.1 NNLO. Our fitted gluon PDF extrapolated to the physical pion mass gives consistent results in the $x > 0.3$ region.

Session I / **37**

Direct computation of light quarks and strange helicity PDFs with lattice QCD

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We present the first lattice QCD computation of the light quarks and strange helicity PDFs. We used a $N_f = 2 + 1 + 1$ lattice ensemble generated by the Extended Twisted Mass collaboration (ETMC), with pion mass $M_\pi \approx 250$ GeV, $M_\pi L \approx 3.8$ and lattice spacing $a = 0.0938(2)(3)$ fm. Momentum smearing is employed in order to improve the signal-to-noise ratio, allowing for the computation of the matrix elements up to nucleon boost momentum $P_3 = 1.24\,\mathrm{GeV}$.

Session I / **38**

Hadron structure from current-current correlation functions in lattice QCD

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We present how partonic structure of hadrons can be extracted from matrix elements of two spatially-separated currents, which are computable directly in lattice QCD and can be factorized into parton distribution functions with calculable hard coefficients. We demonstrate the recently derived one-loop matching coefficient has a well-controlled behavior in Ioffe-time, for example, in a specific calculation of pion valence quark distribution. We discuss issues in obtaining PDFs from the factorized matrix elements which involve an inverse problem - common to the extraction of PDFs from lattice QCD calculations or experimental data and what would require in a lattice calculation to discriminate between different large x behaviors of pion valence PDF.

Session I / **39**

Ioffe time pseudo-distributions from Lattice QCD

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In this presentation, we focus on the pseudo-PDF method of calculating parton distributions. We use a Euclidean space matrix element, called the Ioffe-time pseudo distribution, and Short Distance Factorization, which allows data from all momenta to contribute in the analysis, to obtain parton distributions. We present the latest lattice results from the HadStruc collaboration, discuss several lattice systematics, discuss the inverse problem universal to PDF determinations, and perform a comparison with the pertinent phenomenological determinations.

Session II / **40**

One-Loop Matching for Spin-Dependent Quasi-TMDs

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Transverse-momentum-dependent parton distribution functions (TMDPDFs) provide a unique probe of the three-dimensional spin structure of hadrons. We construct spin-dependent quasi-TMDPDFs that are amenable to lattice QCD calculations and that can be used to determine spin-dependent TMDPDFs. We calculate the short-distance coefficients connecting spin-dependent TMDPDFs and quasi-TMDPDFs at one-loop order. We find that the helicity and transversity distributions have the same coefficient as the unpolarized TMDPDF. We also argue that the same is true for pretzelosity and that this spin universality of the matching will hold to all orders in α_s. Thus, it is possible to calculate ratios of these distributions as a function of longitudinal momentum and transverse position utilizing simpler Wilson line paths than have previously been considered.

Session II / **42**

UV divergence of the quasi-PDF operator under the lattice regularization

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Even since the quasi parton distribution function (PDF) was proposed within the large-momentum effective theory (LaMET) framework, its renormalization under lattice regularization has been a central challenge due to the existence of linear divergences. Previous theoretical studies have shown that the quasi-PDF operator is multiplicatively renormalizable and the linear divergence comes from the gauge link in the Wilson line only. Thus, we can extract the linear divergence from various quantities, e.g., the Wilson loop or the off-shell quark matrix element using the regularization independent momentum subtracted (RI/MOM) schemes. In this talk, we discuss and compare the linear divergence extracted from different methods, with the calculation being carried out using the MILC configurations with the lattice spacing from 0.03 fm to 0.12 fm.

Session I / **45**

Extraction of PDF with the Hybrid Renormalization Scheme

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Recently, a hybrid scheme was proposed by the author and company to renormalize the quasi light-front correlations in the LaMET calculation of the PDFs. The hybrid scheme reduces the systematic uncertainty in the renormalization at distances where the leading-twist expansion or perturbation theory is expected to fail, so that one can have a better-controlled Fourier transform to the momentum space, and reliably extract the PDF through a large-momentum expansion in LaMET. In this talk, I will show the results from the analysis of existing lattice data with this hybrid scheme, and compare it to other schemes. We found that without making model assumptions of the PDF, the result is consistent with previous analyses in the moderate-x region, but have different qualitative behaviors in the small- and large-x regions, which is where the models are most sensitive to.

Session II / **46**

Valance parton distribution of pion from fine lattices

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We present a high-statistics lattice QCD determination of the valence parton distribution function (PDF) of pion, with a mass of 300 MeV, using HISQ gauge ensambles with two very fine lattice spacings of a = 0.06 fm and 0.04 fm. Our analysis use both RI-MOM and ratio-based schemes to renormalize the equal-time bi-local quark-bilinear matrix elements of pions boosted up to 2.4 GeV momenta. We reconstruct the x-dependent PDF, as well as infer the first few even moments of the PDF using the 1-loop perturbative LaMET framework. We also present preliminary results for pion PDF with physical mass from DWF calculations. This talk is based on arXiv: 2007.06590.

Welcome / **47**

Welcome