Some thoughts on making a White Paper for NREC

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On behalf of the organizing committee

Workshop on NREC 2024
in cooperation with PREN 2024 and µASTI

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Motivation

- In recent years, people from various collaborations or initiatives wrote their white papers or similar documents

- For instance:
  - Hot QCD White Paper
  - The Present and Future of QCD
    QCD Town Meeting White Paper – An Input to the 2023 NSAC Long Range Plan
  - Fundamental Symmetries, Neutrons, and Neutrinos (FSNN):
    Whitepaper for the 2023 NSAC Long Range Plan
  - CFNS Ad-Hoc meeting on Radiative Corrections Whitepaper
  - Snowmass 2021 whitepaper: Proton structure at the precision frontier
  - The Solenoid Large Intensity Device (SoLID) for JLab 12 GeV
  - The case for an EIC Theory Alliance: Theoretical Challenges of the EIC

Motivation

- Science white papers are generally designed to inform readers on
  - specific plans for studying certain important topics
  - identifying possible challenges/problems
  - how to solve those issues
  - promoting and/or highlighting the features of possible solutions
  - giving also prospects for future developments
- Physics white papers may have similar as well as additional priorities

Motivation: three examples

- SoLID white paper summarizes
  - rich physics program to be realized with the SoLID apparatus
  - how the SoLID will be able to overcome challenging requirements for having high-precision measurements on nucleon structure

- Snowmass proton structure white paper summarizes
  - status and future prospects for determination of high-precision PDFs applicable in a wide range of energies and experiments
  - various synergies between experimental and theoretical studies of hadron structure

- EIC Theory Alliance white paper
  - outlines physics opportunities provided by the Electron Ion Collider
  - reviews present status and future challenges in EIC theory that have to be addressed
  - discusses scientific goals and scope of such an EIC Theory Alliance

White paper structure: one example

The case for an EIC Theory Alliance: Theoretical Challenges of the EIC

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White paper structure: one example

CONTENTS

White paper structure: one example

IV. TRANSVERSE MOMENTUM DISTRIBUTIONS

At the frontier of hadron structure studies is the three-dimensional (3D) structure of the nucleon. Both the confined motion and the spatial distribution (see Section III) of quarks and gluons inside a bound nucleon characterize its 3D internal structure, which is an immediate consequence of QCD dynamics. To probe such 3D internal structure one utilizes physical observables with *two-scales*; a large momentum transfer Q that ensures localization of the probe and manifestation of the particle nature of quarks and gluons, plus an additional well-measured soft momentum scale q_T associated, for instance, with the transverse motion of quarks and gluons. Such two scale measurements provide much more sensitivity to the details of hadron's internal structure and to details of the inner mechanism of confinement in QCD. The distributions that encode both the longitudinal momentum fraction carried by the parton, x, and the transverse motion, k_T are called Transverse Momentum Dependent distribution (TMD PDFs) and fragmentation functions (TMD FFs), or collectively TMDs [113–115].

Recently a great deal of progress was made in understanding the properties of TMDs from both the theoretical advances [116–123] and phenomenological studies from global fits [124–132]. A crucial ingredient in our exploration of hadron structure are experimental measurements provided by various facilities around the world [133], such as Tevatron at Fermilab [134], HERMES at DESY [135], the LHC at CERN with its collider and fixed target [136, 137], COMPASS experiments [138], RHIC at BNL [139, 140], Jefferson Lab [141], BELLE at KEK [142], Electron-ion collider in China [143],etc. The EIC will provide essential information, with the promise to dramatically improve the precision of various measurements, and to enable the exploration of the role of the sea quarks and the gluons in a polarized nucleon [33, 144–146].

Guiding and understanding the future experimental measurements will require a laborious and meticulous analysis of the data, new approaches and new methods in the theoretical treatment and in the phenomenological extraction of TMDs. The EIC Theory Alliance will provide an essential framework for guiding and organizing the broad theoretical and phenomenological efforts needed to tackle the challenges and opportunities provided by the future EIC. Research directions supported by the EIC Theory Alliance will also ensure that US remains at the forefront in studies of the inner 3D structure of matter.

Important theoretical topics for studies relevant to enabling the full potential of the EIC to be reached include:

- Rigorous theoretical exploration of bench mark TMD observables as well as new experimental observables related to TMD physics. This exploration includes studies of leading and sub-leading contributions to Semi-Inclusive Deep Inelastic Scattering process, individuation of the set of observables that allow precise extraction of the 3D structure for quarks and gluons.

- Theoretical and phenomenological exploration of QCD factorization theorems and expanding the region of their applicability, for instance by inclusion of power corrections in q_T/Q. A crucial ingredient will be matching collinear factorization ($\Lambda_{\mathrm{QCD}} \ll q_T \sim Q$) and TMD factorization ($\Lambda_{\mathrm{QCD}} \lesssim q_T \ll Q$) in the overlap region $\Lambda_{\mathrm{QCD}} \ll q_T \ll Q$ in a stable and efficient way. Such a matching is needed for our ability to describe the measured quantities, differential in transverse momentum, in the widest possible region of phase space. In turn, this will lead to a much more reliable understanding of both collinear and TMD related functions and uncertainties in their determinations.

White paper structure: one example

- Supporting long terms commitments in the analysis of large data sets from the existing experiments and facilities. Global QCD analyses of the experimental data are usually multi year efforts of relatively large collaborations. Encouraging theory participation in such efforts is very important for the future development of new QCD analyses, both to preserve knowledge and to utilize advanced methods.

- Encouraging calculations of higher order perturbative quantities, such as anomalous dimensions, spin-dependent cross-sections etc, needed for an accurate and precise extraction of 3D structure and for reliable predictions of future measurements.

- Supporting the experimental community with the development of Monte-Carlo event generators is an essential task [33] that requires a multi-year commitment. The alliance will support studies based on the conventional techniques that take into account radiative corrections, such as Ref. [154]; and new frameworks that incorporate TMD and QED physics, such as Ref. [155].

- Comprehensive analysis of the nonperturbative behaviour of TMDs. As TMDs encode the consequence of confinement, it is very important to understand better the nonperturbative structure of the nucleon as prototype of baryons, and of the pion as prototype of mesons [156, 157]. It can be done in model or ab-initio calculations, such as lattice QCD, and in the global QCD analyses. The combination of model, lattice QCD, and phenomenological results will allow for a better understanding of the nature of the extracted quantities and for a better precision of extractions in case the experimental measurements are scarce for some observables. For example, at present gluon TMDs are phenomenologically unknown and model calculations represent a useful tool to explore their features, confirm or falsify generally accepted assumptions, make reasonable predictions for experimental observables, and or guide the choice of functional forms in future gluon TMD fits [158, 159]. Explore in more detail the impact of the nonperturbative behavior of TMDs (in particular, their flavor dependence) on the determination of some crucial Standard Model parameters like the W boson mass [160].

- Understanding the flavor dependence of quark TMDs and the gluon sector of TMDs. Both quark and gluon TMDs present a vast field of exploration in terms of the TMDs that encode aspects of the internal structure, such as spin correlations, flavor dependence, etc. We know that there exist highly universal functions, such as Collins-Soper kernel [161–164] related to the properties of the vacuum of QCD, less universal non-perturbative functions that encode flavor or hadron dependence but not less interesting as they carry the footprint of the non-perturbative QCD interactions. Careful examination of the whole spectrum of TMDs is important for our final goal of understanding of the underlying 3D structure of hadrons.

- Understanding nuclear TMDs with the methods developed for the nucleon. Following the methodology of well-established nuclear collinear PDFs, Ref. [129] performed the first extraction of nuclear modified TMDs from the world set of data in semi-inclusive electron-nucleus deep inelastic scattering and Drell-Yan production in proton-nucleus collisions. It is important to advance and improve the methodology along this direction. The modification of TMDs in nuclei in comparison with those in the nucleon has important connections with the conventional transverse momentum broadening in nuclei, see e.g. [165–167] and [168–172] within different formalisms, and is highly relevant to the jet transport coefficient $\hat{q}$ in nuclei [173, 174]. In addition, the (non)universality of gluon TMDs [175–177] will also be studied within the context of small-x physics and nuclei structure in Sec. V and Sec. XI.

White paper structure: NREC

NREC white paper may have the following content (as an example)

1. Introduction

   1.1 NREC program overview

   1.2 Structure, operation and goals

2. Form factors of hadrons and light nuclei

   2.1 Electromagnetic

   2.2 Energy-momentum tensor (gravitational)

   2.3 Weak (axial & scalar & pseudoscalar)

3. Radii of nucleons and light nuclei

   3.1 Electric (charge), magnetic, Friar, Zemach and polarizability

   3.2 Gluon mass (scalar & tensor) and mechanical (D-term)

   3.3 Axial

White paper structure: NREC

4. Radii of various types of baryons and mesons
   - 4.1 electromagnetic and weak
   - 4.2 mass and strong

5. Radii of medium-sized & heavy nuclei (stable & short-lived isotopes)
   - 5.1 Charge and weak
   - 5.2 Shape deformations and geometric shape
   - 5.3 Neutron skin

6. Radiative corrections and two-photon exchange

7. Overview of current and upcoming experiments/measurements
   - 7.1 Lepton and neutrino scattering
   - 7.2 Atomic and muonic hydrogen spectroscopy
   - 7.3 Collinear laser and resonance ionization spectroscopy

8. Summary and outlook

White paper structure: NREC

- For instance, let's suppose we look at the section of

Radiative corrections and two-photon exchange

- An example of a contribution to this section by 1+ 3 NREC members may look like something like this:

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- One could think of uncertainty sources in radiative corrections that would not only lead to normalization errors but could also introduce Q^2 dependencies. Finding a fitter (mathematical fitting function) [43,44] robust against such processes will be important for lepton scattering experiments devoted to proton form-factor and radius extractions [45,46,47]. It is possible that predictive models or even more so physics-motivated models handle this issue not properly, as these systematics shift will violate the underlying assumptions of the motivation [48]. Thus, it could be quite relevant to study how the Q^2-dependent RC systematic effects would be reflected in the behavior of various fitters.

White paper structure: NREC

References

[43] X. Yan, D. W. Higinbotham, D. Dutta, H. Gao, et al.,
Phys. Rev. C 98, no.2, 025204 (2018)

[44] J. Zhou, V. Khachatryan, H. Gao, D. W. Higinbotham, et al.,
Phys. Rev. C 103, no.2, 024002 (2021)

[45] J. C. Bernauer, P. Achenbach, C. Ayerbe Gayoso, R. Bohm, et al. [A1],
Phys. Rev. Lett. 105, 242001 (2010)

[46] J. C. Bernauer, M. O. Distler J. Friedrich, Th. Walcher, et al. [A1],
Phys. Rev. C 90, no.1, 015206 (2014)

[47] W. Xiong, A. Gasparian, H. Gao, D. Dutta, et al. [PRad],
Nature 575, no. 7781, 147 (2019)

[48] S. K. Barcus, D. W. Higinbotham and R. E. McClellan,
Phys. Rev. C 102, no.1, 015205 (2020)

Potential outcomes and benefits for the collaboration

- If I write a funding/grant application, in that case I
  - may include the link to the white paper (published in archive and/or in a journal)
  - can specify the sections and subsections in which I am the leading author of a contribution(s) and/or a co-author of other contribution(s)
  - can show that the proposed project(s) is part of the global initiative: namely, NREC white paper
- As such, it is possible that NREC white paper may help in receiving some funding
- NREC white paper may also serve as
  - kind of handbook to obtain prompt information on all topics NREC will be studying in the future
- It may also attract other interested researchers to join the collaboration

Potential outcomes and benefits for the collaboration

We ask the collaboration members to think about making such a white paper

Please give us your ideas and suggestions !

We will be back to this discussion at the end of the workshop, on Friday

Thanks !