LA-UR- 09-04001

Approved for public release; distribution is unlimited.

Title: Access quark information in semi-inclusive deep inelastic scattering at JLab-12 GeV

Author(s): Xiaodong Jiang

Intended for: Jefferson Lab 12GeV workshop, talks.

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

Accessing Quark Information Through Semi-Inclusive Deep-Inelastic Production at JLab-12 GeV

Xiaodong Jiang

MS H846, Los Alamos National Laoratory, Los Alamos, NM 87545.

Abstract. We outline a plan for a detailed study of SIDIS hadron-multiplicities (pion and kaon). The goal of this plan is to firmly establish the kinematic region over which SIDIS reactions can be reliably interpreted to the next-to-leading-order QCD in terms of parton distributions and fragmentation functions.

Keywords: parton distribution, fragmentation function, JLab-12GeV.
PACS: xxx.xx.xx

INTRODUCTION

Jefferson Lab's 12 GeV energy upgrade will provide high intensity electron beam as a probe for a detailed study of quark's behavior inside a nucleon. Especially, the new facility will offer unique physics opportunities for investigations of quark transverse spin and angular momentum (via Sivers function) through semi-inclusive deep-inelastic scattering experiments (SIDIS).

In SIDIS experiments, one of the leading hadrons in addition to the scattered lepton is detected. Since the leading hadrons from the remnant of the quark fragmentation carry information about the struck quark's flavor, detection of the leading hadron effectively "tags" the flavor of the struck quark. For example, the detection of a high momentum π^+ in the final state effectively tags a u-quark. Therefore, SIDIS offers a unique opportunity for determining the quark-flavor and quark-spin contents of the nucleon.

The most recent DOE's nuclear physics long range plan highlighted the study of quark distribution, transversity and transvers momentum dependent parton distributions (TMD) through SIDIS reactions. JLab-12 GeV, especially with the large acceptance CLAS12 detector, will provide many of these unique opportunities, among them are:

- Transverse target single spin asymmetry measurements A_{UT} (on polarized proton, deuteron and ^{3}He) to provide constrain on quark transversity, the T-odd Collins fragmentation functions and the Sivers distributions for u and d-quarks.
- Longitudinal double-spin asymmetry measurements A_{LL} (on polarized proton, deuteron and ^{3}He) to constrain quark helicity distribution for each quark flavor and to access polarized sea asymmetry $\Delta\bar{u} - \Delta\bar{d}$.
- Measurements of hadron azimuthal distribution ($cos(2\phi)$) on unpolarized targets to access quark spin-orbit correlation through the so-called Boer-Mulders functions.

- Measurements of other azimuthal distributions in single-spin and double-spin asymmetry to extract TMDs and access quark spin-orbit correlations, for example: $\cos(\phi_h - \phi_S)$ in A_{LT} and $\sin(2\phi_h)$ in A_{UL} etc.
- Measurements of unpolarized SIDIS cross sections to access unpolarized sea asymmetry $\bar{u} - \bar{d}$.
- Measurements of fragmentation functions of quark to $\pi, K, \omega, \rho, K_s^0$ and ϕ.

The first step toward realizing this SIDIS program at JLab-12 GeV is to firmly establish the evidences that SIDIS reactions at JLab kinematics can be reliably interpreted in terms of parton distributions and fragmentation functions. Experimental evidences should be presented to address the following questions:

- How do we know that the hard probe hit a quark ?
- How do we know that the quark information is preserved through the fragmentation ?

A particle identification detector in CLAS12 designed to provide π/K separation to a momentum of 5 GeV/c will help us in the following ways in SIDIS:

- to cover a wide kinematics range in z_h to the exclusive limit.
- to have the pion physics clearly identified without kaon contaimination.
- to have the kaon physics isolated from that of the pion.
- to provide clean accesses to other SIDIS channels, such as $\rho, \omega, K_s^0, \phi$ etc.

A MONTE CARLO STUDY: SIDIS WITH CLAS12.

A detailed Monte Carlo simulation has been developed based on the LEPTO program and the HERMES simulation code with modifications corresponding to the CLAS12 detector. The simulation is performed in two steps. First, for each beam energy and target, different reaction products are generated. Second, the events are read back by an analyzer which adds on smearing effects on momentum and angular directions to produce histograms for each hadron species within the acceptances of CLAS12.

SIDIS cuts are taken as $Q^2 > 1$ GeV^2, $W > 2GeV$ and $x_F > 0$. The momentum for hadrons are required to be at least 1.0 GeV/c. For the invariant mass of the undetected system, $W' > 2.0$ GeV is required.

The estimation of SIDIS coincidence rates has the following inputs:

- Inclusive $N(e,e')$ cross sections.
- A nominal luminosity of 10^{35} cm^{-2}s^{-1}.
- A LEPTO based Monte Carlo simulation which includes hadron decays.

Statistical wise, due to the relatively high luminosity, every two hours of CLAS12 data is equivalent to the HERMES 1996-2002 data sample. We can afford to bin data into a $10 \times 10 \times 10$ 3D-grid in (x, Q^2, z) with $\Delta x = 0.05$, $\Delta Q^2 = 0.5$ GeV^2 and $\Delta z = 0.1$. Physics production with a beam energy of 11.0 GeV (1000 hours), 8.8 GeV (250 hours) and 6.6 GeV (250 hours) each on unpolarized liquid hydrogen and deuterium targets are assumed.

In Fig. 1, pion multiplicities off proton and deuteron targets at one Q^2 bin, $Q^2 = 2.5$ GeV^2, are shown as functions of z for four x-bins corresponding to $E_0 = 11$ GeV together with the predictions of NLO QCD calculation [1]. The decreases along z are caused by the z-dependence of fragmentation functions.

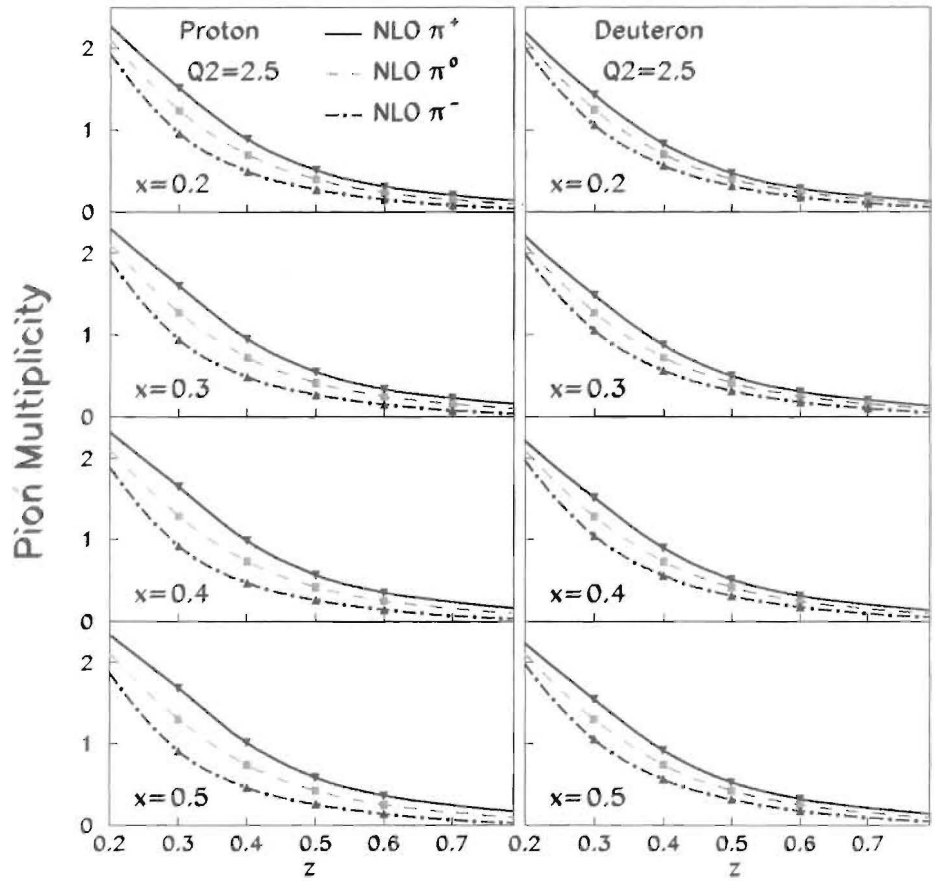

FIGURE 1. One example of z-dependence of pion multiplicities for bin $Q^2 = 2.5$ GeV^2, E_0=11 GeV.

The expected precision for measurements of the Q^2-dependency of pion multiplicities in the $x = 0.4$ bin are shown in Fig. 2 with data points from $E_0 = 11, 8.8$ and 6.6 GeV. Data from the overlapping region, at the same x, z and Q^2, will be extremely powerful in identifing effects from beyond NLO contributions thus quantify the "unexplained" parts of the SIDIS cross sections at JLab kinematics.

With a reliable PID detector, charged kaon multiplicities (thus fragmentation functions) and their x, Q^2 and z-dependence can be studied in detail. An example of z-dependency, in one Q^2-bin, is shown in Fig. 3 in which a limit of $p_K < 3.0$ GeV/c has been applied. If a PID detector can provide a clean π/K separation up to 5.0 GeV/c, such as the RICH detector discussed in this workshop, the avialable z range can be expanded by $\sim 60\%$ covering the kinematics limit of the $K\Lambda$ production.

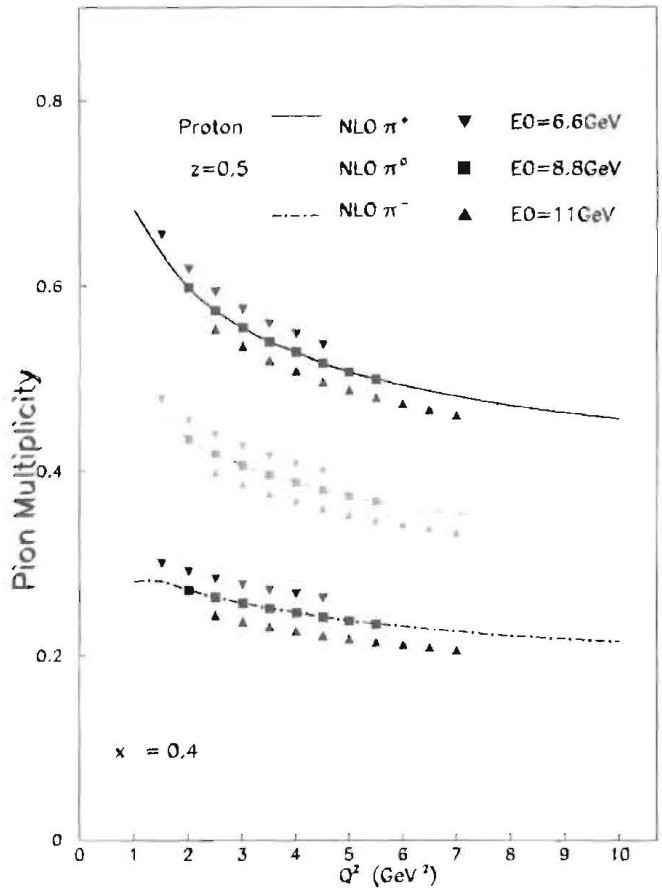

FIGURE 2. A zoomed-in view of Q^2 dependence of pion multiplicities for bin $z = 0.5$ and $x = 0.4$, E_0=11, 8.8 and 6.6 GeV.

CONSIDERATIONS FOR THE RICH DETECTOR

Based on our Monte Carlo simulations, a typical SIDIS π/K ratio is in the order of 10:1. In order to have the pion containmination supressed to the level of a few percent in the kaon sample, a minimum pion rejection factor of ~250:1 is required for the RICH detector. In our point of view, the most exciting physics topic associated with the RICH detector in CLAS12 is the target single-spin asymmetry measurement in the SIDIS kaon production channels. Recent data from the HERMES experiment has revealed a much unexpected behavior of kaon SSA, with K^- and K^+ having the same sign in SSA. Since target SSA is a correlation between the target transverse spin and the hadron azimuthal distribution, a minimum of two-sector RICH detector on the opposite side is needed in order to clearly identify a physics asymmetry among the false asymmetries generated by the detctor's response.

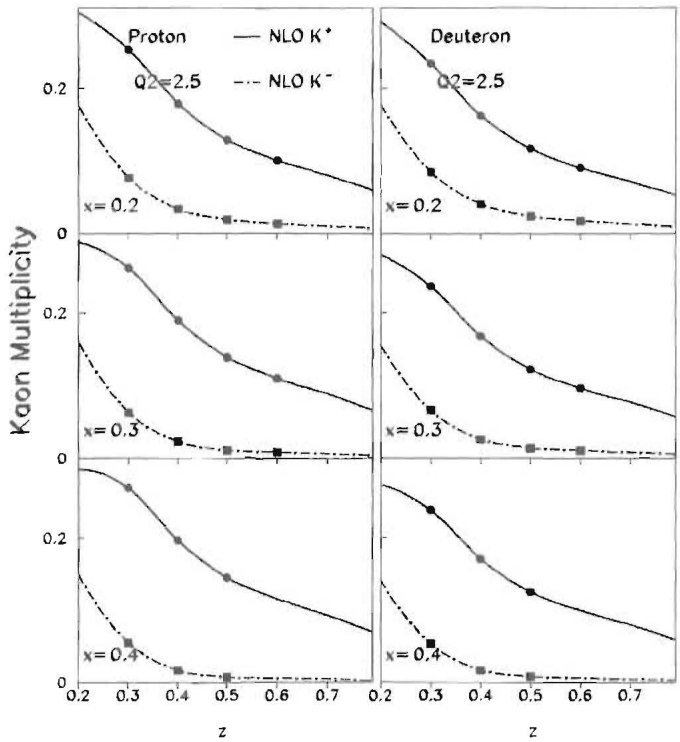

FIGURE 3. One example of z-dependence of kaon multiplicities for bin $Q^2 = 2.5$ GeV^2, E_0=11 GeV.

ACKNOWLEDGMENTS

We thank D. de Florian, R. Sassot and M. Stratmann for providing their NLO calculations.

REFERENCES

1. D. de Florian, R. Sassot and M. Stratmann, arXiv:hep-ph/0703242, and private communications (2007).