

Complementary Probes of Proton Structure at PANDA and CLAS12

(Dated: November 18, 2013)

PANDA at FAIR and CLAS12 at JLab have significant and complementary programs planned in nucleon structure physics. The common goal is to quantify the non-perturbative distributions that characterize the proton within various theoretical frameworks. These include the proton form factors (FFs), generalized parton distributions (GPDs), generalized distribution amplitudes (GDAs), transverse-momentum dependent distributions (TMDs), and transition distribution amplitudes (TDAs), which will be used to assemble multi-dimensional images of the position, momentum, and spin of the quarks in the proton. If these distributions are indeed universal, they could be measurable in both ep (CLAS12) and $p\bar{p}$ (PANDA) reactions. To successfully perform such experiments, both collaborations need to solve similar technical problems, such as creating high luminosity transversely polarized targets that operate inside solenoidal fields, accurately identifying electrons in an intense hadronic environment, and reconstructing π^0 s from two photons in a large electromagnetic background. Therefore, PANDA and CLAS12 will benefit greatly from a free exchange of ideas and personnel when mounting and executing our respective experiments.

Much remains to be learned about the proton. After two decades of studying its spin structure, we know that the contribution from quark spin is small and the contribution from gluon spin is likely small, but we are ignorant about the orbital angular momentum. The proton's rms charge radius was believed to be 0.88 fm from electron scattering experiments until recent muonic Lamb shift measurements obtained a value of 0.84 fm with high precision. We still do not know enough about the proton's gluon distribution to understand how light quarks make a heavy proton.

Experiments planned at the next-generation facilities such as FAIR and JLab will be able to address these puzzles. Details of the plans for using PANDA at FAIR and CLAS12 in Hall B at Jefferson Lab can be found in the corresponding proposals. In each of the topics summarized below, $p\bar{p}$ and ep reactions complement each other. If the distribution functions that each experiment explores are universal, direct comparisons and global fits of $p\bar{p}$ and ep data will help to demonstrate this. Furthermore, since these experiments measure cross sections that are differential in several variables, and each experiment has a limited kinematic reach, the two labs will contribute complementary kinematics. As with the case of the collinear parton distribution functions, our knowledge of the new distributions will come from global fits of many sets of experimental data within the framework of QCD. Therefore, we can anticipate sharing data between PANDA and CLAS12, both before and after publication, as we try to accurately pin down these distributions functions.

We outline, below, measurements from $p\bar{p}$ and ep reactions that highlight our common physics goals. These comprise inclusive, semi-inclusive, and exclusive reaction channels.

I. FORM FACTORS

Fig. 1 shows elastic scattering ($ep \rightarrow ep$) on the left and annihilation ($p\bar{p} \rightarrow e^+e^-$) on the right. The form factors (FFs) can be expressed in terms of electric and mag-

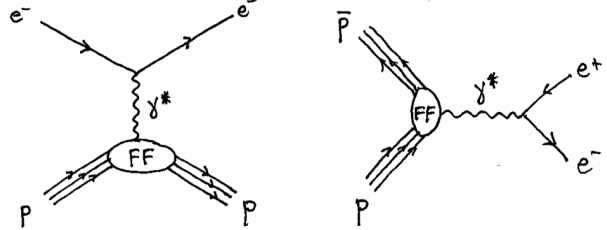


FIG. 1: Elastic electron scattering (left) and $p\bar{p}$ annihilation (right). These reactions are sensitive to space-like (left) and time-like (right) proton form factors.

netic pieces, $G_E(q^2)$ and $G_M(q^2)$, in which q^2 is the 4-momentum transfer squared of the virtual photon shown in the figure. Although Jefferson Lab has been very successful in determining G_E and G_M , separately, for space-like virtual photons, the jury is still out on the time-like case. PANDA will make a precise measurement of these time-like form factors. If all goes as predicted, the high- q^2 dependence of space-like and time-like form factors should be the same according to perturbative QCD. At what q^2 this will occur is unknown. Separation of G_E and G_M in the time-like case will require a transversely polarized target.

II. COMPTON SCATTERING

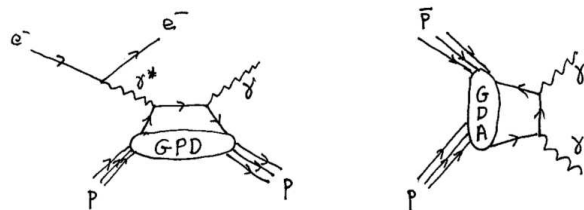


FIG. 2: DVCS (right) and WACS (left). These reactions are sensitive to GPDs and GDAs, respectively.

Fig. 2 shows deeply virtual Compton scattering (DVCS) on the left and wide-angle Compton scattering (WACS) on the right. DVCS is optimally sensitive to the generalized parton distributions (GPDs), which hold the promise of showing us the spatial distributions of the various quark flavors. CLAS has already made measurements of DVCS for limited kinematics and plans to continue with greater energy and precision at 12 GeV. PANDA expects to be able to measure WACS, which tests the applicability of the hand-bag mechanism. WACS probes nucleon structure through a generalized distribution amplitude (GDA).

III. HARD EXCLUSIVE MESON PRODUCTION

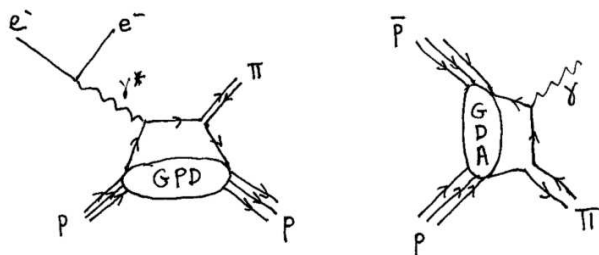


FIG. 3: DVMP (left) and hard exclusive meson production HEMP (right). DVMP is sensitive to GPDs, whereas HEMP is sensitive to GDAs.

Fig. 3 shows deeply virtual meson production (DVMP) on the left and hard exclusive meson production (HEMP) on the right. DVMP is very similar to DVCS, but with a meson taking the place of a real photon in the final state. Like in DVCS, a quark line is removed and then put back into the proton with a new momentum fraction, thereby probing the GPDs. HEMP, which also probes the GDAs, is analogously similar to WACS.

IV. TRANSITION DISTRIBUTION AMPLITUDES

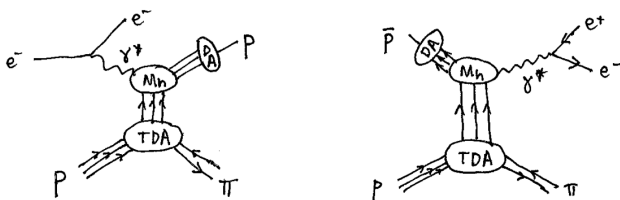


FIG. 4: Exclusive meson production with space-like (left) and time-like (right) virtual photons. These reactions both are sensitive to the TDAs.

Fig. 4 shows an exclusive process by which a baryon becomes a meson by emitting three perturbative quarks. This process is described by a transition distribution amplitude (TDA). CLAS has already begun work at 6 GeV to measure this process and will continue doing so at 12 GeV. The combined work of CLAS12 and PANDA is required to establish the validity of this framework and to quantify these amplitudes.

V. TRANSVERSE MOMENTUM DEPENDENT DISTRIBUTIONS

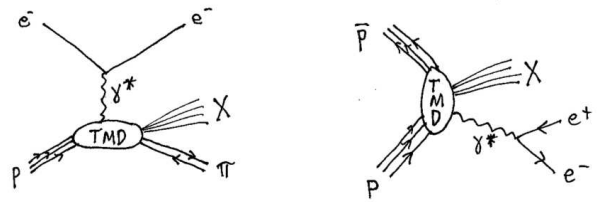


FIG. 5: Semi-inclusive deep-inelastic scattering (left) and Drell-Yan (right). These reactions are both sensitive to TMDs.

Fig. 5 shows semi-inclusive deep-inelastic scattering (SIDIS) on the left and Drell-Yan (DY) on the right. Both processes require polarized targets and measurements of asymmetries around the virtual photon's azimuth. In the electron scattering case, one measures hadronization products around the azimuth. In the $p\bar{p}$ case one measures the azimuthal angle of the e^+e^- plane. In each case the various Fourier components of these asymmetries can be related to the transverse momentum distributions (TMDs), which are sensitive to spin-orbit correlations in the proton. Understanding TMDs will help us to better determine the spin content of the proton. If theory is correct, the so-called Sivers TMD f_{1T}^\perp , which has been studied at CLAS, HERMES, and COMPASS in SIDIS, must be equal and opposite in sign to the equivalent DY Sivers TMD.

VI. HARDWARE

Currently there is ongoing R&D within both the PANDA and CLAS12 collaborations on how to shield a transversely polarized target from a strong solenoidal field. PANDA is exploring passive superconducting shields; CLAS12 is considering Helmholtz coils. This is an example of where cross-fertilization would be advantageous to both collaborations.