Drell-Yan Measurements of Light Antiquarks in the Nucleon and in Nuclei

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Abstract

Previous Drell-Yan and deep-inelastic lepton scattering experiments have established that the momentum and spin distributions of sea quarks in the nucleon are not simple, and exhibit unexpected structure. A new Drell-Yan experiment at Fermilab, E906, is being mounted to carry out precision measurements of the Drell-Yan cross sections on 1 H, 2 H and a collection of heavier nuclei. The main point of the physics program is the study of the anti-quark distribution in the middle range of Bjorken x in both the nucleon and in nuclei. In addition, the data can be used to study quark energy loss in nuclear matter.

Key words: Drell-Yan, antiquarks, PDFs, partonic energy loss

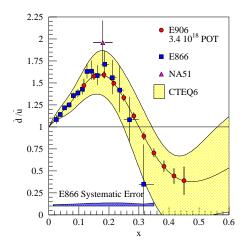
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The study of the quark and antiquark distributions of the proton is now entering a stage in which high precision is required in order to determine the small components of the nucleon structure. A recent phenomenological analysis[1] of the helicity dependent distributions suggests that gluons and some flavors of sea quarks at high Bjorken x may have opposite polarization to that at low x, implying that the sea/gluon structure of the nucleon is non-trivial. Understanding this structure in detail should help in elucidating the uniquely strong roles that the vacuum and confinement play in determining the nucleon's basic properties as well as the nucleon-nucleon force. A stringent test of our understanding of these effects is gained from further studies of how the parton distributions may change inside a nucleus, where the vacuum environment is presumably different; at the very least, one could expect significant changes when nucleons are close together and interacting with each other.

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 $^{^2}$ URL: http://www.phy.anl.gov/mep/drell-yan .



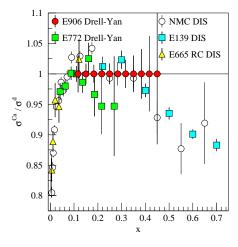


Fig. 1. Left panel: Projected statistical accuracy of the E906 measurement of the light sea ratio $\bar{d}(x_2)/\bar{u}(x_2)$ assuming the CTEQ6[3] quark distributions and 3.4×10^{18} protons on target. Results from the previous experiments NA51[4] and E866[2] are shown for comparison. Right panel: Projected statistical accuracy of the E906 measurement of the ratio of Drell-Yan cross sections of Ca and 2 H, compared with the previous experiments [5,7–9].

While deep inelastic scattering at high photon virtuality Q^2 has allowed the determination of the proton parton distribution functions (PDFs) over a broad range in x, the cross section itself is only sensitive to the sum of the different quark and antiquark distributions, weighted by the square of the charges. The antiquark distributions themselves are found by theoretical analysis, based on quantum chromodynamics (QCD), of the variation of the cross section with Q^2 at a given x. At x values less than about 0.1, where the sea quarks dominate and show large variation with Q^2 , this leads to a relatively precise determination of the \bar{u} and \bar{d} PDFs. However, at higher x additional experimental information is required from processes which are more directly sensitive to the antiquark distributions, such as charged current weak interactions or so-called "flavor-tagging" in semi-inclusive deep inelastic scattering. To date, the most precise information has come from measurements [2] of the Drell-Yan pp and pd cross section ratios with high incident proton energy (800 GeV) incident on hydrogen and deuterium targets (Fermilab experiment E866). In fixed target kinematics, forward di-muon pairs primarily result from beam quarks (with Bjorken x_1) annihilating with target antiquarks (with x_2); this allows an easier separation of beam and target parton structure.

In 2001 the Fermilab PAC approved a new experiment, E906, to extend the earlier Drell-Yan measurements using the high intensity 120 GeV beam from the main injector of the Tevatron. To carry out this experiment the collaboration will assemble a new di-muon spectrometer using many components from the previous E866 experiment. The planned design is very similar to that of E866, comprising a solid iron focusing dipole magnet containing the beam dump, followed by a large open aperture dipole for precise momentum determination. Multi-wire proportional and drift chambers between the first two magnets as well as after the second dipole provide tracking information, supplemented by scintillation hodoscopes used primarily for fast triggering. A final large iron absorber instrumented with proportional tubes provides muon identification.

The primary goal of the experiment is the precise determination of the light sea ratio, $\bar{d}(x_2)/\bar{u}(x_2)$, with a 1% systematic uncertainty. The ratio will be extracted using Drell-Yan absolute cross sections in pd and pp collisions, measured with absolute normalization uncertainty of 6.5% in the range of $0.3 < x_1 < 0.9$ and $0.05 < x_2 < 0.5$. Projections for the statistical accuracy of the light sea are shown in the left panel of Fig. 1 compared to earlier measurements and the prediction from the CTEQ6[3] quark distributions. It should be noted that no physical models at present are able to explain the drop in the ratio below 1 at high x, already observed in E866. In addition to the light sea ratio, these cross section will provide a strong constraint on the high x quark distributions.

Drell-Yan cross sections from nuclear targets, such as C, Ca, Fe, and W, will also be determined. These data will allow the comparison of the sea quark distribution in nuclei to that in the deuteron. Earlier measurements[5] of Drell-Yan in nuclei (Fermilab E772) saw essentially no significant modification of the nuclear cross section dependence on x_2 above 0.1, in contrast to that observed in deep inelastic scattering, originally by the EMC[6], and more thoroughly by later experiments[7–9]. The right panel of Fig. 1 shows the statistical precision that is expected from the E906 measurement of the ratio of Ca to ²H, compared to earlier deep inelastic experiments as well as the Drell-Yan measurement of E772. These data will be able to resolve the question of whether an anti-shadowing region exists in the Drell-Yan ratio, and moreover at the highest x, whether the so-called "EMC" effect around $x \sim 0.5$ is also seen by the Drell-Yan process. In addition to the nuclear sea ratio, the measurements on nuclear targets at high x_1 can strongly constrain models of fast quark energy loss in "cold" nuclear matter. The energy loss of a colored quark in the nucleus is not only a basic QCD process; its understanding is critical to the interpretation of results from the recent measurements at the relativistic heavy ion collider.

As of November 2008, Fermilab management and the US Dept. of Energy have agreed to provide the necessary support to carry out E906. In the present schedule, the spectrometer is expected to be completely installed in spring 2010, followed by commissioning and data collection soon after.

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