Measurement of nuclear effects on anti-quarks via Drell-Yan process at FNAL-SeaQuest

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The nuclear effects on the partonic structure of nucleons signify that the distribution of partons in a nucleon bound inside a heavy nucleus changes from that in a free nucleon. It was first discovered by the EMC collaboration in 1983[1)] and is being studied using various measurements and theories to understand its mechanism. Most measurements made use of deep inelastic scattering (DIS), which does not differentiate between quarks and anti-quarks. The E772 experiment utilized the Drell-Yan process to extract the nuclear effects on anti-quarks.[2)] It indicates that the effects are smaller than those observed in DIS, although the statistical precision was limited. If the difference between quarks and anti-quarks in the nuclear effects is confirmed, it will be a strong constraint in understanding the mechanism because it contradicts, for example, the conventional nuclear model.[3)] A number of theoretical models were proposed to reproduce the measured difference.[4)]

The E906/SeaQuest experiment at Fermilab aims to study the anti-quark distributions in the nucleon and nuclei. It utilizes the 120-GeV proton beam from the Fermilab Main Injector ($\sqrt{s} = 15$ GeV). It employs liquid hydrogen (LH_2), liquid deuterium (LD_2), carbon, iron, and tungsten as targets to measure the Drell-Yan process in $p + p$, $p + d$, and $p + A$ reactions. In the Drell-Yan process, a quark in one hadron and an anti-quark in the other hadron are annihilated to produce a virtual photon, which then decays into a lepton pair: $q + \bar{q} \to \gamma^* \to l^+ + l^-$. When it is measured at forward rapidity ($x_F \gg 0$), an anti-quark nearly always originates from the target-side hadron. Therefore, the ratios of per-nucleon cross sections of two targets, $R(A/D) \equiv (\sigma_{p+A}/A)\,/\,(\sigma_{p+d}/2)$, are sensitive to the nuclear effects on anti-quarks.

The SeaQuest spectrometer[5)] detects the final-state muon pair of the Drell-Yan process. SeaQuest acquired physics data from November 2013 to July 2017 with a summer accelerator shutdown each year. It has recorded 1.4×10^{18} beam protons on targets and analyzed approximately 40% of the recorded data. We selected dimuons with the invariant mass larger than 4.2 GeV, for which the Drell-Yan events are dominant. The dimuon yields have been corrected for track-reconstruction efficiency and background dimuons by using the extrapolation method.[6)]

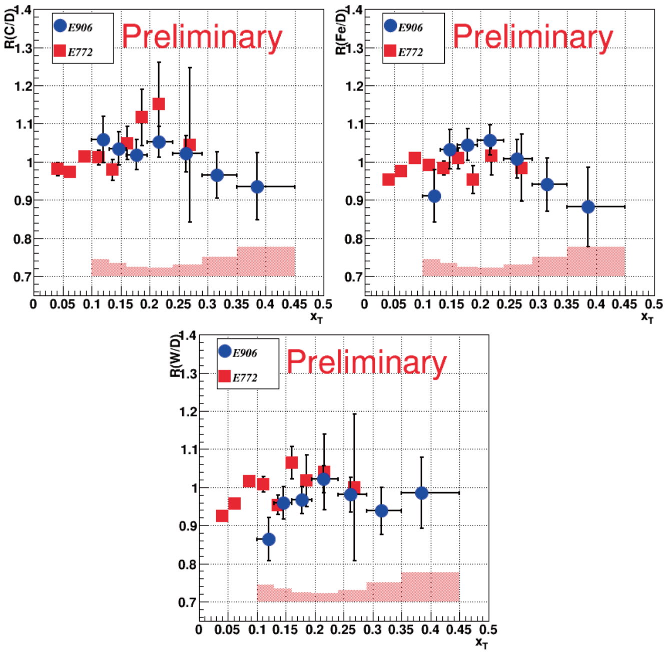

Fig. 1. Ratios of per-nucleon cross sections of C, Fe, and W to D versus the Bjorken x of target-side partons (x_T). The SeaQuest preliminary result is drawn with blue circles, and the E772 result is drawn with red squares.

Figure 1 shows the preliminary result of $R(A/D)$ measured using SeaQuest, together with the result obtained using E772 for comparison. The systematic uncertainty arises mostly from the fitting shape used in the extrapolation method. SeaQuest is consistent with E772 in the commonly measured region, $x_T \sim 0.2$, with better accuracy at higher x_T. It favors the observation by E772 that the nuclear effects on anti-quarks differ from those on quarks. Improvements in the measured precision and comparisons to theoretical models in order to finalize the result are ongoing.

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