Status of measurements of Drell–Yan process at FNAL SeaQuest

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The partonic structure of the proton is one of the most vital topics in the present study of hadron physics. The SeaQuest experiment is being carried out at Fermi National Accelerator Lab (FNAL) in USA to investigate the partonic structure with the Drell–Yan process. In the Drell–Yan process, a quark in one hadron and an anti-quark in another hadron annihilate into a virtual photon and then decay into a lepton pair as $q+\bar{q} \rightarrow \gamma^* \rightarrow l^+ + l^-$, as shown in Fig. 1. The cross section at the leading order of α_S is expressed as

$$\frac{d^2\sigma}{dx^{\mathrm{B}}dx^{\mathrm{T}}} = \frac{4\pi\alpha^2}{9x^{\mathrm{B}}x^{\mathrm{T}}}\frac{1}{s}\sum_i {e_i}^2 \cdot \left\{q_i^{\mathrm{B}}(x^{\mathrm{B}})\bar{q}_i^{\mathrm{T}}(x^{\mathrm{T}}) + \bar{q}_i^{\mathrm{B}}(x^{\mathrm{B}})q_i^{\mathrm{T}}(x^{\mathrm{T}})\right\}, \quad (1)$$

where x is the Bjorken scaling variable, s is the square of the center-of-mass energy of two interacting hadrons, $q_i(x)$ is the parton distribution function of a flavor i, and the superscripts "B" and "T" denote partons in the beam hadron and target hadron, respectively. When the process is measured at forward rapidity as SeaQuest does, the second term $\left(\bar{q}_i^{\mathrm{B}}(x^{\mathrm{B}})q_i^{\mathrm{T}}(x^{\mathrm{T}})\right)$ of Eq. (1) becomes negligible since $x_{\mathrm{B}} \gg x_{\mathrm{T}}$ and $\bar{q}(x^{\mathrm{B}}) \sim 0$ at large x^{B}. This implies that a quark mostly originates from the beam with x^{B} and an anti-quark from the target with x^{T}. Therefore, the Drell–Yan process at forward rapidity is directly proportional to the anti-quark distributions, $\bar{q}(x)$.

SeaQuest utilizes the proton beam extracted from the FNAL Main Injector with $E = 120$ GeV as well as several types of targets to cover wide physics topics. Liquid hydrogen (LH_2) and deuterium (LD_2) targets are used for the measurement of the Drell–Yan processes in $p + p$ and $p + d$ reactions. Carbon, iron, and tungsten targets are also used for the $p + A$ reaction. The SeaQuest spectrometer detects the final-state muon pair of the Drell–Yan process, the details of which were reported in the past.[2] 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 is actively analyzing approximately 40% of the recorded data.

The primary purpose of SeaQuest is to measure the flavor asymmetry of light anti-quarks ($\bar{u}$ and $\bar{d}$) in the proton. Since a large asymmetry has been observed by the NMC, NA51, and E866/NuSea experiments, various theoretical models are being examined to understand the origin of this flavor asymmetry.[1] SeaQuest analyzed high-mass Drell–Yan events in $p+p$ and $p+d$ reactions and obtained a preliminary result of $\bar{d}(x)/\bar{u}(x)$ at $0.10 < x < 0.58$, as reported last year.[3] Further analyses are being performed to improve the statistics and measurement accuracy.

Another purpose of SeaQuest with $p + p$ and $p + d$ reactions is to measure the angular distribution of final-state leptons in the Drell–Yan process. The angular distribution is theoretically predicted to satisfy the Lam-Tung relation but was found by several experiments to violate it. This violation can originate from, for example, QCD higher-order radiation and the Boer-Mulders effect.[4] It can be investigated further with high-precision data from SeaQuest. The angular dependence of the detection efficiency is being studied in detail by tuning detector responses and background distributions in simulation.[5]

SeaQuest also measures the nuclear effect via the Drell–Yan process in $p + A$ reactions. Approximately 1/5 of the beam protons were applied to the carbon, iron and tungsten targets. The nuclear effect is defined as the difference in per-nucleon cross sections between $p+A$ and $p+p$, namely $\frac{\sigma_{p+A}/A}{\sigma_{p+p}} \neq 1$. It involves various physics mechanisms and is widely examined by measurements and theories. SeaQuest is first focusing on the Drell–Yan process in the large-x^T region ($\gtrsim 0.2$) to extract the partonic energy loss in cold nuclear matter.[6] Background events in $p + A$ reactions are being identified in detail, where the rates of all background types are different from those in $p + p$.[7]

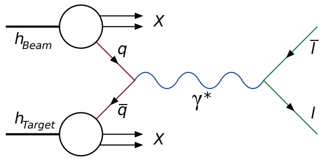

Fig. 1. Feynman diagram of the Drell–Yan process.

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