

Probing Flavor Asymmetry of Anti-quarks in Proton by Drell-Yan Experiment SeaQuest at Fermilab

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The proton and neutron contain a substantial number of anti-quarks which arise from dynamical interactions of gluons such as gluon dissociation. The E906/SeaQuest experiment will take place at the Fermi National Accelerator Laboratory (Fermilab). We will investigate the light anti-quark (\bar{u} , \bar{d}) distributions in the proton using Drell-Yan process. In the process, a quark and an anti-quark annihilate into a virtual photon and then it decays to a lepton pair. The SeaQuest experiment uses a 120-GeV proton beam extracted from the Fermilab main injector. A two-month commissioning run took place in spring 2012. This run confirmed the functionality of all the detector elements. A preliminary di-muon mass distribution was extracted as a result of the run. A two-year physics run started in November 2013. In this paper, the physics motivation of the SeaQuest experiment, the result of the commissioning run and the upgrade for the physics run are described.

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1. Flavor Asymmetry in Light Quark Sea

The proton consists of three valence quarks and sea of quarks and anti-quarks. Under a simple assumption where sea quarks are generated from gluon dissociation, the flavor symmetry is expected between \bar{u} and \bar{d} . However the asymmetry between \bar{u} and \bar{d} in the proton was discovered by NMC at CERN[1, 2]. They observed a violation of the Gottfried sum rule by deep inelastic muon scattering on the proton and neutron. This result showed that there are more \bar{d} than \bar{u} in the proton. The E866/NuSea experiment measured the ratio of \bar{d}/\bar{u} as a function of the nucleon momentum fraction, Bjorken x , over a range of $0.015 < x < 0.35$ with a 800-GeV proton beam [3, 4]. The experiment used the Drell-Yan process that is described by the annihilation process of a quark and an anti-quark: $q + \bar{q} \rightarrow \gamma^* \rightarrow \mu^+ + \mu^-$. This process is an ideal method to measure the anti-quark distributions because an anti-quark is always involved in the process.

Fig. 1 shows the result of E866, \bar{d}/\bar{u} vs Bjorken x , where the ratio is as large as 1.7 at $x \simeq 0.2$, and seems to be reversed at $x \simeq 0.3$. Several models of the proton structure were proposed to reproduce this behavior. In one such model known as the pion cloud model, the proton is assumed to be a superposition of a bare proton, pion-nucleon and pion-delta states: $|p\rangle \rightarrow |p_0\rangle + |N\pi\rangle + |\Delta\pi\rangle$ [5]. The pion is produced in the following way in the proton: $u \rightarrow \pi^+ + d$, $d \rightarrow \pi^- + u$. Since the amount of u in the proton is more than that of d , the probability of π^+ creation is higher than that of π^- in the model. The larger \bar{d} contribution to the proton sea can then be interpreted as a result of the abundance of π^+ , because π^+ consists of \bar{d} and u . However, this model cannot reproduce the E866/NuSea result at higher Bjorken x ($x > 0.3$) where the ratio becomes smaller than 1. Therefore, it is important to measure the ratio in the high x region with a high precision.

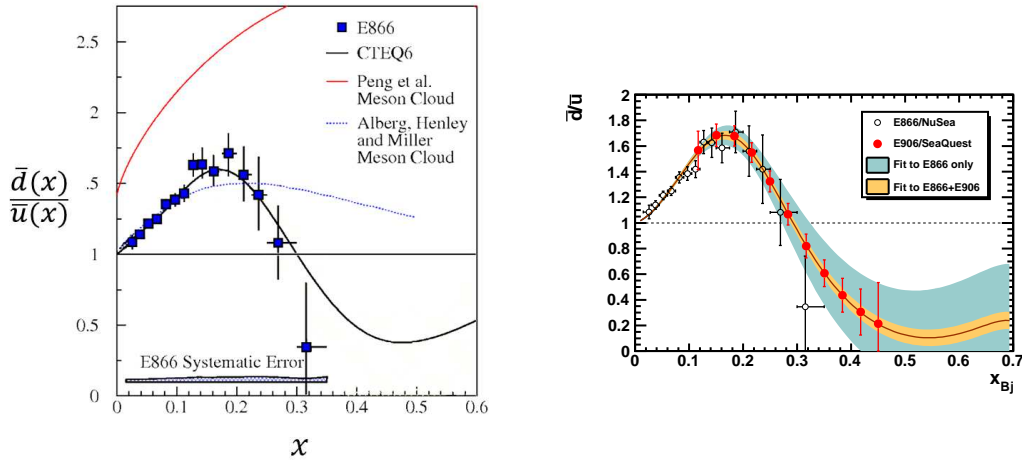


Figure 1: Both plots show the result of \bar{d}/\bar{u} vs Bjorken x obtained by E866/NuSea[6, 7]. The left plot shows also a curve by CTEQ6 taking into account the E866/NuSea results and expectations by the pion cloud model. In the right plot, the red error bars show anticipated uncertainties of SeaQuest. The central values are assumed to be on the MRST[8] curve in the plot. The blue and yellow bands are error bands of the result of the MSTW parametrization before and after the prospective results of SeaQuest is taken into account.

The SeaQuest experiment measures the ratio in the range $0.10 < x < 0.45$ with a 120-GeV proton beam. Because the beam energy is set lower than in E866/NuSea, the Drell-Yan cross section becomes larger and moreover the rate of background muons that come primarily from the J/ψ decay becomes smaller. Thus, we will obtain more statistics by a factor of ~ 50 compared to E866/NuSea. The accuracy is about 10 times better than that of E866/NuSea, as can be seen in the right plot of Fig. 1.

2. Experimental Setup

The SeaQuest spectrometer is designed to detect di-muons from the Drell-Yan process. It consists of the trigger system, two dipole magnets, and four detector groups, called “tracking stations”, as shown in Fig. 2. The targets used for the experiment are liquid hydrogen, liquid deuterium, carbon, iron, and tungsten. The first magnet is placed between the target system and the first tracking station. It focuses high transverse momentum muons into the spectrometer acceptance and bends low momentum muons out of the acceptance. The second magnet is used to measure the momenta of di-muons. Each tracking station is equipped with hodoscopes for trigger and drift chambers or drift tubes for tracking.

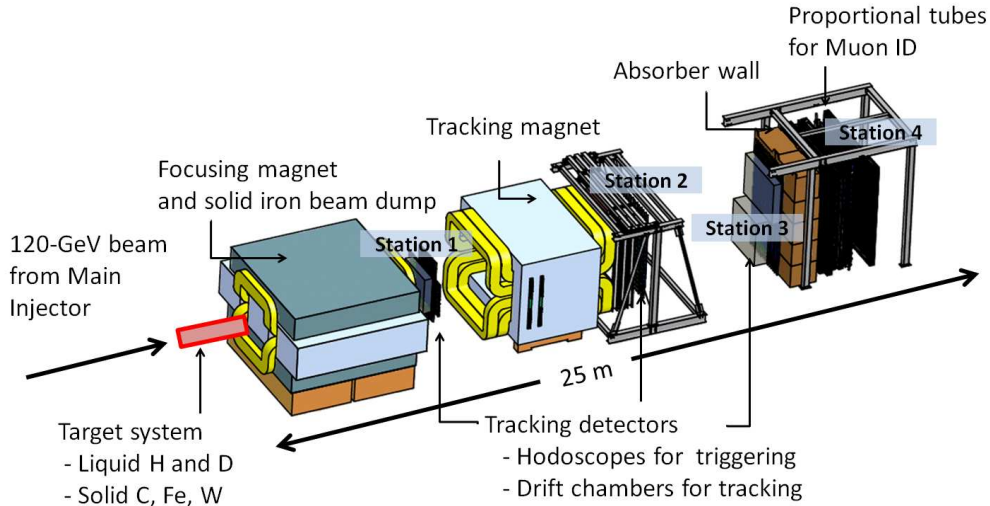


Figure 2: SeaQuest spectrometer. It contains a target system, a focusing magnet, a tracking magnet, and four groups of tracking detectors called “tracking stations”. Liquid hydrogen, liquid deuterium, carbon, iron, and tungsten are used as the targets. Each tracking station is equipped with hodoscopes for trigger and drift chambers or drift tubes for tracking.

3. Commissioning Run

A two-month commissioning run was successfully carried out in spring 2012. The provided beam intensity was approximately 1×10^{11} protons per second on average. At the beginning of the run, we observed unexpected variations in the beam intensity over several orders of magnitude. The spectrometer was highly occupied with hits due to the beam with high instantaneous intensity. The

high multiplicity in the spectrometer would in turn make track reconstruction difficult. SeaQuest developed a veto trigger system in order to filter out the high instantaneous intensity parts of the beam. Using the veto system, SeaQuest succeeded in collecting valuable data. During the last two weeks of the run, the experiment ran in a stable condition and approximately 1.5 million events were recorded. We have achieved the reconstruction of di-muon tracks and the extraction of the preliminary di-muon mass distribution. A cross-check of the reconstruction of the mass distribution was done by two independent tracking algorithms and their results agreed. Fig. 3 shows an example of the reconstructed di-muon event.

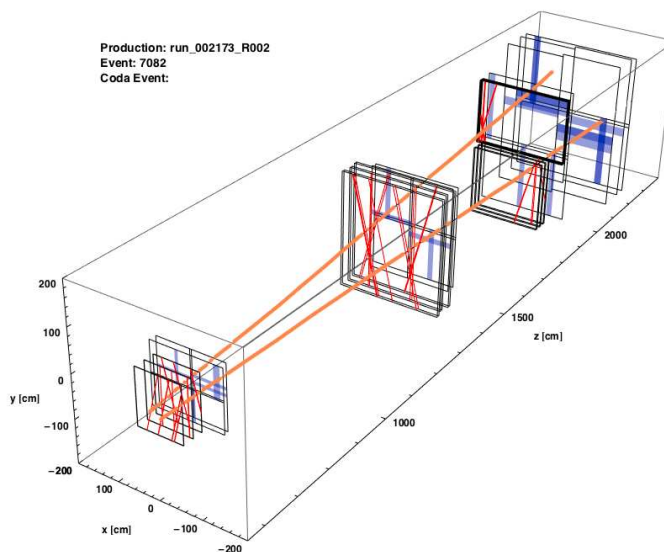


Figure 3: Event display of the SeaQuest. A reconstructed di-muon event is shown. The 120-GeV proton beam comes from the left in this figure. The red lines and the blue rectangles indicate the chamber wires and the hodoscope paddles fired by muons. The orange lines show the reconstructed di-muon.

4. Physics Run Starting Fall 2013

A two-year physics run started in November 2013. The optimization of each component toward the stable data accumulation is ongoing. Several upgrades were completed since the commissioning run. In the beam line, a Cherenkov detector was placed to measure the beam intensity at the 53 MHz RF frequency. This allows the experiment to generate a veto to avoid the high instantaneous intensity RF buckets of the beam, and also to measure the absolute value of the cross-section of the Drell-Yan process. In the spectrometer, an improvement of the hodoscopes and wire chambers was done. For the hodoscopes, we upgraded the existing PMT bases with a new circuit board to achieve higher rate capabilities. For drift chambers, one new drift chamber was installed at the bottom half of the third station to improve the acceptance of the spectrometer. It was constructed at Fermilab last year. About 5,300 wires were strung by SeaQuest collaborators. One more new drift chamber will be installed at the first tracking station. This chamber also improves the acceptance of the spectrometer.

5. Summary

The SeaQuest experiment will investigate anti-quark distributions in the proton using the Drell-Yan process. It uses the 120-GeV proton beam extracted from the Fermilab main injector. The Drell-Yan process is an ideal method for studying the anti-quark distributions in the proton because an anti-quark is always involved in this process. The SeaQuest spectrometer is optimized to detect di-muons from the Drell-Yan process. It consists of several targets, two magnets, and four tracking stations. A two-month commissioning run was successfully carried out in spring 2012. All the system worked well, and a preliminary di-muon mass distribution was extracted. A two-year physics run started in November 2013 and will help us to understand deeply the sea structure of the nucleon.

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