A Drift Chamber for a Muon Spectrometer and Measurement of Sea Quark Flavor Asymmetry in the Proton at E906/SeaQuest Drell-Yan Experiment

Florian Sanftl and Toshi-Aki Shibata
Department of Physics, Tokyo Institute of Technology, 2-12-1, Ohokayama, Meguro-ku, Tokyo, 152-8551, Japan
E-mail: florian.sanftl@nucl.phys.titech.ac.jp

Abstract. Fermilab E-906/SeaQuest is a particle physics experiment which will use Drell-Yan process to measure the contributions of antiquarks to the structure of the proton or neutron and how this structure is modified when the proton or neutron is included within an atomic nucleus. It is part of a series of fixed target Drell-Yan experiments. The Drell-Yan process occurs in high energy hadron–hadron scattering. It takes place when a quark of one hadron and an antiquark of another hadron annihilate, creating a virtual photon which then decays into a pair of oppositely-charged muons. The kinematics of these muons allow a direct relation to the antiquark structure of the proton. In addition the E-906/SeaQuest experiment can also examine the modifications to the antiquark structure of the proton from nuclear binding or access transverse momentum dependent parton distribution functions. The E906/SeaQuest experiment will use a 120 GeV proton beam extracted from the Fermilab Main Injector. This beam energy provides a tremendously increasing cross section compared to past Drell-Yan experiments. Taking the reduction of background events due to $J/\Psi$ decays into account a gain in statistics by a factor of 50 compared to the latest Drell-Yan experiments is expected. The spectrometer is currently being assembled at Fermilab. It is expected to be commissioned in spring 2011 and collect data for two years. The group of Tokyo Institute of Technology is among Japanese collaborators in charge of the tracking stations in the E-906/SeaQuest experiment. In this report we will give an overview and a status report of the ongoing commissioning of the Drift Chambers (DC).

1. Introduction

E906/SeaQuest is a fixed-target experiment that is currently being installed at Fermilab in USA. For its measurements it is using the 120 GeV proton beam extracted from the Fermilab Main Injector. The E906/SeaQuest detector is a forward spectrometer and is designed to be sensitive to the Drell-Yan process, $q\bar{q} \rightarrow \gamma^* \rightarrow \mu^+\mu^-$, in proton-nucleon reactions by detecting the final-state muon pair. The main goal of this experiment is to investigate the flavor asymmetry of light sea quarks ($\bar{u}$ and $\bar{d}$) in the proton[1]. Particularly it focuses on the asymmetry at larger $x_{Bj}$ of sea quarks ($\geq 0.25$), where $x_{Bj}$ is the momentum fraction carried by the scattered quark with respect to the target nucleon.
2. The E906/SeaQuest Detector
The E906/SeaQuest spectrometer is designed to be capable of not only detecting muon pairs from the Drell-Yan process but also eliminating a huge number of low-momentum charged particles, particularly muons that come mainly from $J/\Psi$ decays.

Figure 1. Schematic drawing of detector setup in side-top view.

Figure 1 shows the setup of the E906/SeaQuest detector, where the proton beam comes from the left side. The target materials will be liquid-hydrogen, liquid-deuterium and several solid targets, like Carbon, Calcium or Tungsten, stored in a cryogenic target cell. A focusing magnet labeled as “Solid Iron” in Fig. 1 condenses especially high-$p_T$ muons into the detector acceptance and sweeps out low-momentum background muons. A large iron block is placed inside the focusing magnet, and serves both as a hadron absorber and also as a beam dump. Station 1, 2 and 3 are multi-wire drift chambers (MWDC). Station 3 consists of two different chambers, the Top and the Bottom chamber. They measure hit positions of passing muons in order to reconstruct their tracks and momenta. The momenta are determined with an analyzing magnet labeled as “KTeV Magnet” in Fig. 1 that bends muons in the horizontal direction. Station 4 consists of alternating layers of drift tubes and iron absorbers. It identifies high-momentum muons by only being sensitive to particles that penetrate the complete spectrometer including its absorbers due to its far back position in the overall detector setup. Each station is sandwiched by hodoscope arrays to trigger di-muon events.

The proton beam becomes available in spring 2011. Data will be taken intermittently for the next three years. The E906 Japanese group designed and constructed the Station 3 Top DC and is in charge of the operation of all Station 3 drift chambers. This article reports on the commissioning status of the new Station 3 Top DC at Fermilab. Throughout this report we refer to the new Station 3 Top DC by Station 3 DC.

3. The new Station 3 Drift Chamber
The dimensions of the Station 3 DC are 3.2 m in height × 2.2 m in width. In order to maximize the acceptance its position in the overall spectrometer has been determined to be 19 m from the target. The required position resolution at Station 3 is supposed to be less than 400$\mu$m. It is required to provide a very high (above 98%) muon pair detection efficiency at background rates which correspond to 5kHz/cm$^2$ at the spectrometer location of Station 3. The background rate has been evaluated using the GEANT detector simulator[2].
sense wire (φ 30 µm)  
field wire (φ 80 µm)  
guard wire (φ 80 µm)  
cell height (20 mm)  
cell width (20 mm)  
cathode wire (φ 80 µm)  
cathode-to-guard gap (10 mm)  
cathode-wire space (10 mm)  
guard-wire space (10 mm)  

Figure 2. Cell structure (unit cell in blue boxes) of the Station 3 DC.

Figure 2 shows the cell structure of Station 3 DC. It consists of six layers labeled as U, U’, X, X’, V and V’. All wires are vertically arranged, whereas the wires of the U’- and V’-layers are tilted by 14°. In total, the number of sense wires, and thus of readout channels, is 768, and the number of field and guard wires is 4368.

The construction of the Station 3 DC was finalized in February 2010. After basic operational tests at RIKEN during spring and summer 2010 it was shipped to Fermilab in July 2010.

4. Commissioning - The first Steps
We present the first performance studies of the Station 3 DC. All measurements have been performed since August 2010 at Fermilab. For all studies, only eight neighboring sense wires were read out in an Argon:CO₂ (80%:20%) gas mixture.

As a first step, the gas amplification gain for different high voltage (HV) values was measured. Raw signals caused by cosmic rays were recorded and the corresponding gas gain was evaluated. A Garfield simulation [3] predicted the gas amplification gain to be \( O(10^5) \). The gas gain was obtained by dividing the charge output by the predicted ionization deposit. As seen in Fig. 3, the simulation and measurement differ by about a factor of 2. Further studies have to investigate the ionization process in a more detailed way.

| HV [kV] | Gas Gain |
|---------|----------|
| 2.15    | 1.0      |
| 2.2     | 1.0      |
| 2.25    | 1.0      |
| 2.3     | 1.0      |
| 2.35    | 1.0      |
| 2.4     | 1.0      |
| 2.45    | 1.0      |
| 2.5     | 1.0      |
| 2.55    | 1.0      |
| 2.6     | 1.0      |
| 2.65    | 1.0      |

Figure 3. Measured (red line) and simulated (blue line) gas gain for Argon:CO₂ (80%:20%).

Furthermore, the one-layer efficiency curve was determined. Two plastic scintillators served as cosmic ray triggers for the measurement. Figure 4 shows the efficiency curve for two different discriminator thresholds. For the high threshold 98 ± 1%-detection efficiency is reached at a HV of \( \approx 2.5 \text{kV} \). This turns out to be sufficient considering that the future nominal operational HV of the Station 3 DC lies at 2.8 kV.
Finally, a preliminary TDC distribution was measured with a common-stop trigger signal. Considering only single hit events (red line in Fig. 5) the measurement is in good agreement with our Garfield simulations. The width of the TDC distribution is 150 TDC channels, which corresponds to 300 ns. The right side of the TDC distribution corresponds to a shorter drift time and has more hits by a factor of 3 compared to the left part. According to our simulation, this can be explained by the non-linear drift velocity being faster near the sense wire than at the cell edge by a factor between $2 - 3$.

Figure 5. Integrated TDC distributions for multiple (black line) and single hits (red line).

5. Conclusion, Outlook and Acknowledgments

We reported on preliminary performance measurements of the Station 3 DC. The operation and behaviour of the chamber are well understood and match our expectations. At the moment we are optimizing the future read-out electronics. More detailed performance measurements will be possible as soon as the setup of the full read-out electronics is finished.

The collaboration of the E906/SeaQuest members is acknowledged. In particular, I would like to thank the group of Tokyo Institute of Technology and all Japanese members of E906/SeaQuest who built the Station 3 DC with me. The support of the Global Center of Excellence "Nanoscience and Quantum Physics" at Tokyo Institute of Technology is highly acknowledged.

References

[1] J. Arrington et al., Proposal of E906 Experiment, http://www.phy.anl.gov/mep/drell-yan/proposals/
[2] CERNLIB Webpage, http://cernlib.web.cern.ch/cernlib/
[3] Garfield Webpage, http://garfield.web.cern.ch/garfield/