Construction of Drift Chambers for Drell-Yan Measurement by SeaQuest at FNAL

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The internal structure of the proton is one of the most vital topics in the present hadron physics. The SeaQuest experiment at Fermi National Accelerator Laboratory (FNAL) in USA is a Drell-Yan experiment. It uses a 120 GeV proton beam. The aim of this experiment is to measure the asymmetry between $\bar{u}$ and $\bar{d}$ distributions in the proton. This experiment measures the cross sections of the Drell-Yan process in a proton-proton reaction and proton-deuteron reaction. The ratio between $\bar{u}$ and $\bar{d}$ distributions can be derived from the cross section ratio. The Drell-Yan process in proton-proton collisions is the reaction in which a quark in one proton and an antiquark in the other proton annihilate into a virtual photon and then it decays to a muon pair: $q + \bar{q} \rightarrow \gamma^{*} \rightarrow \mu^{+} + \mu^{-}$. This process is suited to the study of antiquarks in the proton.

The physics run will start in spring 2013. We are constructing drift chambers for this physics run. In this paper, the structure and performance of the SeaQuest spectrometer and the status of the new chamber construction is described.

1. SeaQuest Spectrometer

We measure muons created by the Drell-Yan process, $q + \bar{q} \rightarrow \gamma^{*} \rightarrow \mu^{+} + \mu^{-}$ as shown in Fig. 1. The Drell-Yan process creates a lepton pair via a virtual photon from quark-antiquark pair annihilation. Antiquarks exist as sea quarks in the proton. Therefore, the Drell-Yan process can directly access antiquarks [1].

The SeaQuest spectrometer is shown in Fig. 2. The spectrometer has two magnets. The first one sweeps out low-momentum muons to collect high-momentum muons. The second one measures muon momenta. The spectrometer has 4 tracking stations for charged particles. Each of the first to third stations is composed of a plastic scintillator hodoscope and a drift chamber. The fourth station is composed of a hodoscope and a drift tube. The iron wall is installed between the third and fourth stations. All hadrons are stopped in the wall and only muons can pass through. The targets are liquid hydrogen, deuterium and solid materials. The beam is 120 GeV proton beam with a typical beam intensity of $10^{13}$ particles in a 5-second pulse.

2. Drift Chambers

The SeaQuest group constructs two drift chambers at Station 3: St. 3+ and St. 3−. The St. 3+ and St. 3− drift chambers cover the upper and lower halves of Station 3, respectively. There are two requirements on the performance of these chambers: position resolution and rate tolerance. The mass resolution of the dimuon is required to be ~0.8 GeV. This corresponds to the momentum resolution of ~0.2 GeV. Accordingly, the position resolution of the drift chambers must be better than 400 $\mu$m in the horizontal direction. The rate of the muons penetrating into the drift chambers is ~300 kHz/wire at maximum. This value has been evaluated with a GEANT simulation. The rate tolerance of the drift
chambers should be better than this value in order to observe them with high efficiency.

Figure 3 shows the front view of the chamber. The outer dimension of the chamber is 1.9 m × 3.4 m, and the active area is 1.7 m × 2.3 m. These chambers have 6 planes named as V′, V, X′, X, U′ and U. Wires of the V′ and V planes are tilted by −14° and wires of the U′ and U planes are tilted by +14° from the vertical direction. The gas for the both chambers is a mixture of argon (86%), methane (10%) and CF₄ (4%).

Figure 4 shows the cell structure of the chamber. One sense wire is placed at the center of each cell and is surrounded by six cathode wires and two field wires. The distances from a sense wire to the neighboring four wires are 1 cm. The size of one cell is 2 cm × 2 cm. The sense wire is Au-plated W, and its diameter is 30 μm. The cathode and guard wires are Au-plated CuBe, and their diameter is 80 μm. A high voltage of −2.4 kV is applied to the cathode and field wires, and −1.4 kV to guard wires.

3. Performance of St. 3+ Chamber

We have studied the performance of the St. 3+ chamber using a commissioning beam in March and April 2012 at FNAL. A test chamber at Tokyo Tech was also used in this study with Ar:CO₂ (80%:20%) gas and cosmic rays [2]. The test chamber has the same wire length as the St. 3+ chamber. The cosmic rays were detected as a coincidence of two scintillators covering an area of 10 cm × 18 cm.

3.1 Drift Property Studied with the Test Chamber

We evaluated the relation between the drift distance and the drift time, and the position resolution using the test chamber. The position resolution means an event-by-event drift-time deviation. The drift velocity was found to be approximately 30 μm/ns. The result is consistent with the Garfield simulation. The position resolution was found to be better than 500 μm.
3.2 Detection Efficiency Studied with the Test Chamber

We also evaluated the detection efficiency using the test chamber. The single-layer detection efficiency is defined as an efficiency of detecting one track by one layer. A layer in an event was regarded as efficient if at least one wire in the layer had a hit in the event. We evaluated that the efficiency is 100% within statistical uncertainty at sufficiently high voltage: $HV > 2.65 \, kV$.

3.3 Hit Distribution on the St. 3+ Chamber

We measured hit distributions at the St. 3+ chamber with the commissioning beam. We applied a hodoscope masking to chamber hits, which required that a chamber hit matched a hodoscope hit within \(~2\, cm\). It eliminated off-timing muons and electrical noises. Figure 5 shows results with and without the hodoscope masking. We also simulated hit distributions with GEANT4 (Fig. 6). We selected three different mass ranges. Dimuons form Drell-Yan process, $J/\psi$ and $\Upsilon$ were generated in the simulation. The distributions in Fig. 5 show increases at the both sides. The result with the hodoscope masking shows few events in the center. This doesn’t agree with that of the high-mass Drell-Yan events in Fig. 6. It indicates that the high-mass Drell-Yan event is not a dominant component in the data of the commissioning beam.

4. Construction of New St. 3– Chamber

A new St. 3– chamber is being constructed at FNAL toward the physics run which starts in spring 2013. From July to October 2012, we set up an optimized procedure for stretching wires. We completed 5,154 wires in 2 months, which means one wire in 2 minutes. The wire tension is 75 gf for sense wires and 130 gf for others. It was loaded by a weight of metal blocks hung. Its accuracy was required to be $< 10\%$ and achieved accuracy was 5%.
5. Summary

The SeaQuest experiment measures the Drell-Yan process, $q + \bar{q} \rightarrow \gamma^* \rightarrow \mu^+ \mu^-$, in the proton-proton collisions with the 120 GeV proton beam at FNAL. The SeaQuest group constructs two drift chambers at Station 3 (St. 3+ and St. 3−). We have tested the St. 3+ chamber with the commissioning beam at FNAL and also with the test chamber at Tokyo Tech. We are constructing the new St. 3− chamber at FNAL toward the physics run. We are upgrading the spectrometer now for the higher beam rate ($\times 10$) in the physics run. The beam time for physics will start in spring of 2013.

6. Acknowledgement

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References