QWEAK: A SEARCH FOR NEW PHYSICS, REGION 3 VERTICAL DRIFT CHAMBER PROGRESS REPORT
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Abstract

The standard model of particle physics has been quite successful in the description of the electromagnetic, weak nuclear, and strong nuclear sectors of particle physics; however, it is known to be insufficient to completely describe nature. Qweak is an upcoming experiment at Thomas Jefferson National Accelerator Facility (JLAB) that will use high precision electron proton scattering to measure the weak nuclear charge of the proton. The measurement of the weak coupling will allow the effective probing of the 1.5 to 2.5 TeV region that is believed to contain new physics. To ensure accuracy, there will be tracking devices throughout the full apparatus to measure the positions and trajectories of the scattered electrons. The tracking device that will be further detailed in this report is known as a vertical drift chamber (VDC). All 5 of the VDCs have been built and tested and the resulting data will be presented.

Figure 1. Qweak Apparatus. The electron beam is incident from the left and scatters off a liquid hydrogen target. The electrons then pass through a series of collimators and a magnet to select only elastically scattered electrons and finally hit the quartz Cherenkov detectors. The electron's trajectories are measured by the region 1 gas electron multipliers (GEM), the region 2 horizontal drift chambers and the region 3 vertical drift chambers during calibration mode. The production mode will only use the target, collimators, QTOR, and the Cherenkov detectors.

The Qweak experiment will use parity-violating electron-proton scattering to determine the weak charge of the proton (Q^P_{weak}) and the running of the weak mixing angle sin^2(\theta_w). The full apparatus may be seen in Figure 1. The unique ability of Jefferson Lab to provide a high-quality highly polarized beam allows the probing of the weak nuclear force to a greater degree of accuracy than other facilities. The high statistics and resolving power that will be produced by the experiment will allow the search for particles beyond the Standard Model in the presently unexplored 1.5 to 2.5 TeV region as is seen in Figures 2 and 3. The experiment will utilize a large toroidal magnet to select scattered electrons with very low momentum transfer (Q^2 (<0.03)). This Q^2 will be determined in calibration mode using three sets of wire chambers to resolve the scattered electrons to a high degree of accuracy. At the end of the line are Cherenkov detectors that will allow for the collection of a large number of events. The GHz quantity of events is simply too much for wire chambers to monitor; therefore, the production run will not utilize the wire chambers. The difference between pure electromagnetic scattering and what will be observed is due to the weak nuclear force and will yield the value of Q^P_{weak}.
Fundamental particles have an intrinsic property known as chirality or handedness. The electromagnetic force interacts with left and right handed particles equally. The weak force interacts with left and right handed particles differently. If left and right handed particles are carefully identified and scattered, the difference between the two can be attributed to the weak force alone. Jefferson Lab can produce electrons with spin that are either aligned (right handed) or anti-aligned (left handed) with their momentum; this is known as positive and negative helicity, respectively. When the electrons have an energy of approximately 1 GeV, the difference between chirality and helicity is very small because the particles are moving very close to the speed of light. So in the experiment, we will scatter left-handed electrons and right-handed electrons separately and the difference between the two scattering rates is directly proportional to $Q_{\text{weak}}^p$.

**Figure 2. Regions of the Standard Model that will be explored by Qweak.** $A$ is the mass scale at which the new physics could exist, $g$ is the coupling constant of the SU(2) weak force, the ratio of the two is the model independent mass limit of new physics and $\theta_h$ is the flavor mixing angle or the amount of up and down quarks present in a proton. All of the region between the blue dashed line and the solid red line will be accessible to Qweak at the 95% confidence level. Qweak will extend the region of potential particles beyond the Standard Model to the blue dashed line. At some values of $\theta_h$ the blue line does not move; this occurs where the contributions of the two up quarks and one down quark identically cancel in the proton due to its composition. This extension may not seem significant; however, numerous theoretical models predict the existence of new particles within this region.\(^1\)

Currently my research focuses on construction and testing of the region 3 VDCs (as are shown in Figure 1). The chambers are 3’ x 8' and are constructed of G10 circuit board material. There are five total chambers, four for the experimental run, two on each side, which will be attached on both sides of a large rotator, and one spare. The heart of each chamber is a $u$ and a $v$ plane of 280 25 μm thick wires with positions known to tens of microns precision. The wires are held at a positive potential, ground, while foils above and below each of the planes of wires will be held at a negative potential. The chambers are filled with a 50/50 argon and ethane mixture that serves two purposes: the argon is a source for electrons that are ejected as energized electrons pass through and the ethane is a quenching agent to prevent too many electrons from remaining in the chamber after an electron has passed. As an electron traverses the chamber, electrons ejected from the argon will see the attractive potential and the repulsive potential of the foils and drift toward the wires as seen in Figure 4. When the electron is drifting, it will collide with other argon atoms and free more electrons. This occurs over and over as the electrons accelerate moving closer to the wire, due to the increasing electric field. Upon

**Figure 3. Experimental data on $Q_{\text{weak}}^p$.** $C_{1u} + C_{1d}$ and $C_{1u} - C_{1d}$ are the isoscalar and isovector couplings of the up and down quarks, respectively. These quantities can be thought of as the weak charge of the up and down quarks together. The current world data on $Q_{\text{weak}}^p$ is represented by the large grey oval with the Standard Model prediction in red. The Qweak experiment will narrow the error on the measurement to the small black oval. (The location of Qweak’s blue line was chosen arbitrarily to agree with the Standard Model.\(^1\))

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arrival to the wire, the single liberated electron is now $10^6$ to $10^7$ electrons, a measurable pulse. The signal travels through the wires that are all connected to readout cards, after which they are sent along chains of delay chips which allow the signals to be multiplexed to reduce the number of readout components and yet preserve single wire timing information. In other words, multiple wires are connected to the same electronics; however, the arrival time of each signal is unique so as to distinguish it from wire to wire. With the comparison of known trajectories and simulations through the planes, two from each chamber, the track of the electron can be resolved to better than 190μm.

**Figure 4. Cross section of VDC.** The green path is that of a scattered electron, the red lines are the paths of drifting freed electrons, the blue circles are grounded sense wires and the grey bars are HV foils.

**VDC Chamber Construction and Status**

The current status of the VDC’s is discussed in this section. I have assembled the frames of all five chambers. A stringing jig has been aligned along with a rigid support structure to hold the frames in place while the wires are attached. Once a wire is put into the correct location using the jig, it was glued at one end while a 90 g weight was placed on the opposite end and then the wire was glued in place. 30 g of tension is lost because of friction leaving a remaining tension of 60g. Once correctly positioned and tensioned, the wire was epoxied to the G10 frame. The epoxy was allowed to cure for 24 hrs. With the wires secured to the frame, their tensions and positions were both measured. The position of each wire was measured using a CCD camera mounted to a stepper motor with a linear encoder to give an absolute position. The camera was then connected to a PC that fit a Gaussian curve to the image identifying the center of a wire and recording its absolute position relative to the first wire measured. The tension was measured by sending an AC signal through each wire and placing a magnet with field aligned perpendicular to the wire. For a harmonic frequency of a wire, the tension is proportional to the harmonic frequency squared. We watched for the wire to move as the frequency of the signal was adjusted. Once a harmonic was located, the wire would oscillate several millimeters. After the technique was perfected, the wires were strung to have a tension of $58 \pm 6$ g and a position standard deviation of 76 μm as desired. All 10 of the wire planes have been strung and stored. A plane of 279 wires was strung in 1 week.

**Figure 5. Foil stretching and holding jigs.** The foil stretching jig is the outer component with the copper pipe in the “u” shaped groove and the holding jig is the inner aluminum plates. Both devices are used to stretch foils and secure them to G10 frames as well as to the outer aluminum plates.

The chambers use aluminized Mylar foils for the cathode planes and as the outer gas seal on the aluminum plates. The cathode planes provide the repulsive potential to push the electrons toward the wires. A foil stretching jig and holding jig have been designed and built as may be seen in Figures 5 and 6. The device works by wrapping the edges of the foil around the copper pipes and clamping them in place. There are screws that are attached to a “u” shaped groove that holds the copper pipe that drives the pipe in or out as the screws are turned. After a foil is appropriately tensioned, the jig is raised and a frame with epoxy in place is slid underneath the jig and it is then lowered down onto the frame so the foil is resting on the G10. Once seated correctly, a stamp is placed on the foil to ensure contact between the foil and the epoxy along the inner perimeter of a frame. All 15 of the high voltage foil planes have been stretched and glued. The outer aluminum plates that provide support to the structure have been designed and delivered. Each outer plate also receives a foil using the same procedure as with the G10; however, the purpose of this foil is to provide an outer gas seal, no HV is applied. Overall, the major components of all five chambers have been completed and stored.
Figure 6. Foil stretching jig in operation. The foil stretching jig is holding a foil in place. It is perfectly flat and looks like a mirror.

A gas handling system to provide gas flow to the chambers has been designed and tested. The gas mixture being used is 50 % argon and 50 % ethane. This mixture comes in premixed bottles and requires no further treatment. A flowmeter is used to regulate the volume of gas entering the chamber and a bubbler is used to maintain pressure in the chamber. A bubbler is a device that is used to prevent the back flow of air into the chamber and provide enough resistance to the argon mixture to place the chamber’s pressure slightly over atmospheric pressure. The chambers leak rate has been measured to be no more than 10 l/hr.

Preliminary VDC testing began using a gas mixture that we determined was incompatible with our chamber design. During the summer, we switched to a different gas mixture that made all the difference. With the old mixture, we saw very poor efficiencies that were inconsistent. With the new mixture, it was a huge difference, the HV the chamber could hold went up 25 % causing the gas gain to increase; thus, making the chamber as efficient as it should be (97+ % efficient for a single wire). In addition, our software has progressed to the point where we can look at the chamber’s electron tracking resolution, which is presently 190 um (adequate for the experiment). We also began using the correct pre-amp discriminator known as a MAD card after several problems were solved (this amplifies the analog signals from the chamber and turns them into logic pluses). With a support structure in place for the electronics and with bus bars to power all 36 MAD cards, we were able to properly ground all of the wires with the correct resistance and receive signals from the whole chamber as seen in Figure 8. In order to read out the signals from the chamber, we have setup a complete data acquisition system (DAQ). The DAQ began with one single-hit V775 time to digital converter (TDC) reading out 4 MAD cards (64 wires). We have since progressed to two multi-hit F1 TDCs with the addition of a multiplexing crate (MUX) to read out an entire chamber at a time.

Figure 7. First assembled chamber. This is a picture of a complete chamber containing 2 wire frames, 3 HV frames, 3 spacing frames, and two outer aluminum frames. The red wires are the connection to the HV supply for each foil. There are no readout electronics connected. The dimensions of the chamber are 96.0” x 36.0” x 5.5” and it weights approximately 1000 lbs.

Figure 8. First chamber with electronics. This is a picture of a complete chamber containing all of the cables and electronics necessary to properly ground and receive signals from the wires. There is a piece of PVC on the top of the chamber for protection and a scintillator on top of that to tell us when a particle is inside the chamber.

The first chamber was assembled 1 year ago, refer to Figure 7, and the other four were completed throughout the past year. When a chamber is first assembled, the preliminary task is to see if the chamber will hold HV. All of the chambers can hold 4400 V
while drawing a reasonable 100 nA of current. With a stable HV, the next task is to look at single wire efficiency. This is done using a scintillator as a trigger to simply say that a particle should have just hit the chamber. With a signal from the scintillator I look at seven wires. I then require a signal from wires 1,2,3 and 5,6,7 as well as the scintillator to all be in coincidence within a microsecond window; meaning that all three signals came from the same particle. With a trigger set, I then compare the rate of wires 1,2,3 and 5,6,7 and the scintillator to wire 4. If wires 1,2,3 and 5,6,7 both fired for the same particle, wire 4 between wires 1,2,3 and 5,6,7 should have also seen the particle. The ratio of the 1·2·3·4·5·6·7 to 1·2·3·5·6·7 is the single wire efficiency. The chambers efficiency should rise with voltage until a plateau is reached when the chamber is close to 100 % efficient. All 5 chambers operate with a single wire efficiency of 97+ %. There is another measure of efficiency known as chamber efficiency. This efficiency simply asks do I get a hit in one plane if I got a hit in the other wire plane. The chamber efficiency for all 5 chambers is 99.5+ % as may be seen in Figure 9.

![Efficiency vs. Chamber Voltage at 2V Threshold Voltage](image)

**Figure 9. Chamber efficiency plot.** This is a typical plot of chamber efficiency vs HV for both wire planes. The efficiency increases to over 99 % and then plateaus between 4200 V and 4400 V for the 2 V threshold setting used in this test.

All five chambers are complete and two have already been shipped to JLAB. The remaining two needed chambers will be shipped to JLAB within a month with the fifth remaining at William and Mary as a spare. The installation of the experiment has already begun and will continue through May 2010. The VDCs are scheduled to install in April 2010. The experiment will undergo a commissioning phase to make sure all of the instrumentation is working properly this summer and will be followed by a longer data taking phase ending in May 2012. Over the next year I will begin to take shifts on the experiment, and then collect and analyze data.

**Importance of Nuclear Physics to the Aerospace Industry**

Nuclear physics is of critical importance to the success of the aerospace industry. Without a proper understanding of and prevention of exposure to galactic cosmic rays, damage to long-term instrumentation and astronauts may occur. Qweak will not only provide a better understanding of the nuclear structure of the proton, but will probe currently unexplored regions of nature in which new particles very possibly exist. The new knowledge of the proton alone could lead to the development of new materials and new methods of protection for electronics and personnel in space. The unique ability of Qweak to probe higher energy levels will serve to fill the present gap in knowledge of potentially different particles in the region. The study of nuclear physics, through precision experiments like Qweak, is vital to the success of the Human Exploration and Development of Space program in NASA. The full 93 page proposal including presentations and the full list of collaborators from all 25 institutions may be found at [http://www.jlab.org/qweak/](http://www.jlab.org/qweak/).

**References**


2. Importance of Nuclear Physics to NASA’s Space Missions, R.K. Tripathi, J.W. Wilson, and F.A. Cucinotta, 2001

References