Preparation of Drift Chambers

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1. Abstract

This is a report of my time employed at DESY as a summer student with the OLYMPUS collaboration helping to prepare the drift chambers for the experiment.

2. Introduction

During my stay at DESY I worked with the OLYMPUS group. OLYMPUS is a fairly low energy fixed target experiment, elastically scattering electrons and positrons off a stationary unpolarised hydrogen target. The experiment will use the DORIS storage ring at DESY where the ARGUS experiment used to be placed. The centre of mass energies (Q^2) involved are ~ 0.6 -2.4 GeV. The purpose of the experiment is to investigate the electromagnetic form factors ($G(Q^2)$ where Q^2 is the centre of mass energy) of the proton to a precision of about 1%.

3. Form Factors

Simply put the form factors describe the distribution of electromagnetic charge in a nucleon. A full investigation of what form factors are was well beyond the scope of my work at DESY but they are worth considering at least at a fairly basic level. Studying the form factors allows one to learn a lot about the structure of nucleons and is therefore very important.

3.1 Rosenbluth Equation

One starts by considering the Feynman diagram for the elastic scattering of an electron off a proton involving the exchange of only one virtual photon and by treating the proton as a point particle (fig. 1).

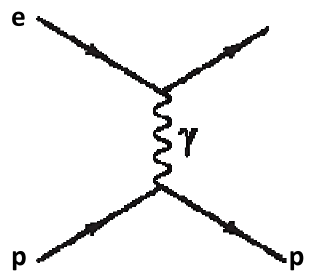

Fig. 1: Feynman diagram of elastic electron-proton scattering involving the exchange of one virtual photon.

At very low energies the differential cross section for this resembles that of Rutherford scattering. At higher energies relativistic effects and nucleon recoil need to be considered. Doing the necessary QED workings leads to the scattering formula [1];

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_1^2 sin^4\frac{\theta}{2}} \frac{E_3}{E_1} \left(cos^2\frac{\theta}{2} - \frac{Q^2}{2m_p^2} sin^2\frac{\theta}{2} \right) \quad (1)$$

m_p = proton mass
Θ = scattering angle
E_3 = Energy of scattered electron
E_1 = Energy of incident electron
Q^2 = 4-momentum change of electron

The first fraction involving α^2 corresponds to Rutherford scattering (the low energy limit). The cos^2 term represents the electromagnetic interaction of a spin $\frac{1}{2}$ charge in a static electric field (this is a relativistic effect). The sin^2 term accounts for the interaction of two spin $\frac{1}{2}$ magnetic moments. Finally the $\frac{E_3}{E_1}$ term takes into account the recoil of the target nucleon.

At high energies the wavelength of the incident electron will be of the same order as, or even smaller than the dimensions of the proton. Thus one then has to consider the distribution of charges and spins within the proton when writing the differential cross section. To take this into account one has to calculate the matrix element M_{fi} of first order perturbation theory for the electron interacting with a spatial potential $V(\mathbf{r})$.

$$M_{fi} = \langle \psi_f | V(\mathbf{r}) | \psi_i \rangle = \int e^{-\mathbf{p}_f \cdot \mathbf{r}} V(\mathbf{r}) e^{\mathbf{p}_i \cdot \mathbf{r}} d^3\mathbf{r} \tag{2}$$

Carrying the calculation through one finds that this is akin to adding a form factor term $F(Q^2)$ to the point like scattering formula.

$$\frac{d\sigma}{d\Omega} = \left.\frac{d\sigma}{d\Omega}\right|_{point} |F(Q^2)|^2 \tag{3}$$

After more work (again well beyond the scope of anything I considered in my time at DESY) one arrives at the Rosenbluth formula which takes account of the spatial distribution of the proton by introducing the factors $G_E(Q^2)$ and $G_M(Q^2)$. The first takes account of the electric charge distribution; the second describes the magnetic moment of the proton. The scattering cross section becomes:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_1^2 sin^4\frac{\theta}{2}} \frac{E_3}{E_1} \left(\frac{G_E^2 + \tau G_M^2}{1+\tau} cos^2\frac{\theta}{2} + 2\tau G_M^2\, sin^2\frac{\theta}{2}\right) \tag{4}$$

$\tau = \frac{-Q^2}{4m_p^2}$ Lorentz invariant.

It is important to note at this point that when applying QED to describe this scattering only the case of the exchange of one virtual photon has been taken into account.

The form factors can be measured using the “Rosenbluth Separation Technique”. From the above formula one notes that the cross section is dependent upon the electron beam energy, the scattering angle and the 4-momentum transfer Q^2 (from the form factors). The Rosenbluth equation is manipulated to get the reduced cross section [2]

$$\sigma_{red} = (1+\tau) \frac{d\sigma}{d\Omega} / \left.\frac{d\sigma}{d\Omega}\right|_{Mott} = G_E^2 + \frac{\tau}{\epsilon} G_M^2 \tag{5}$$

$\left.\frac{d\sigma}{d\Omega}\right|_{Mott}$ = Mott scattering cross section

$\varepsilon = [1 + 2(1+\tau)tan^2\left(\frac{\theta}{2}\right)]^{-1}$

By doing a simple elastic scattering experiment of an unpolarised electron beam on a stationary proton one can measure the cross section at constant Q^2 but differing ε by changing the beam energy and measured scattering angle. Fitting $\varepsilon\sigma_{red}$ against ε will then allow the electric and magnetic form factors to be determined. The Rosenbluth method suffers from large inaccuracies at larger interaction energies.

3.2 Recoil Polarisation Measurement

Recent progress in accelerator technology has produced well polarised electron beams. This allows for an alternative measurement of the form factors. One uses a beam of longitudinally polarised electrons incident on an unpolarised target. One then measures the longitudinal and transverse polarisation of the recoiling protons. Since these polarisation quantities are dependent upon the electric and magnetic form factors one has instant access to the form factor values without having to calculate cross sections from a scattering experiment. This method of measurement has the advantage of being much more accurate at larger energies than the Rosenbluth method.

For a more complete overview of these two methods for measuring form factors please see [2].

3.3 Motivation for OLYMPUS

The two methods described to measure the proton electromagnetic form factors have produced dramatically differing results. If one considers the ratio G_E/G_M this discrepancy can be made clear. The Rosenbluth results suggest a roughly constant ratio (corresponding to the total magnetic moment of the proton) up to energies of roughly 8GeV. Results using the recoil polarisation method (particularly recent ones from Jefferson Laboratory (JLab) in America) show this ratio dropping off dramatically at energies over 1 GeV. The graph below (fig. 2) shows clearly the discrepancy.

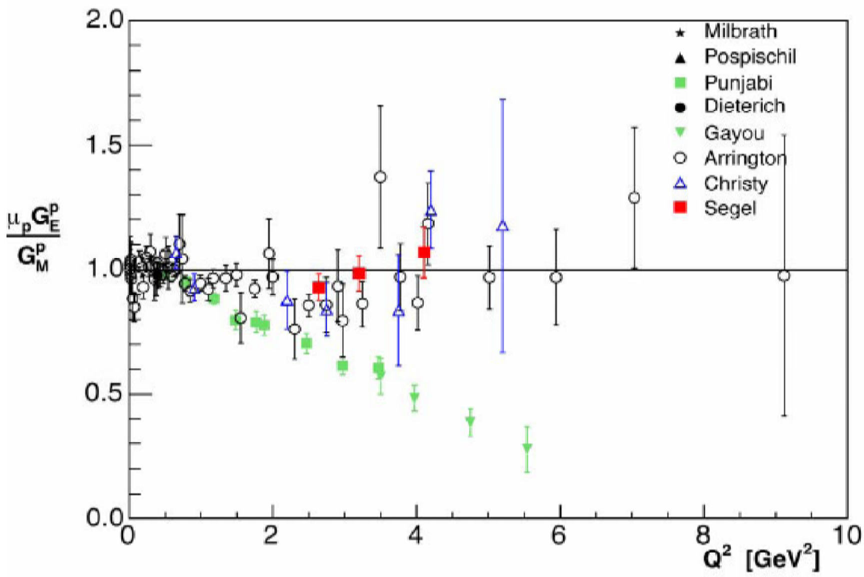

Fig. 2: Ration of electromagnetic form factors of the proton. The points in green are data from the recent experiment at JLab; those in black are the Rosenbluth results. Taken from [3]

The results in green are from the recoil polarisation experiments completed recently at JLab. They show a clear divergence from the previous Rosenbluth data in black and blue. It is worth noting the large errors on the Rosenbluth data compared with the recoil technique. The discrepancies between the two, however, are too large to be accounted for by error analysis [4].

It has been postulated that this discrepancy arises due to the contribution of multiple photon exchange in the scattering experiments (fig. 3); recall that when the Rosenbluth formula was derived it was done by approximating the interaction to one involving only a single virtual photon. OLYMPUS aims to investigate this possibility by performing a scattering experiment involving both electrons and positrons.

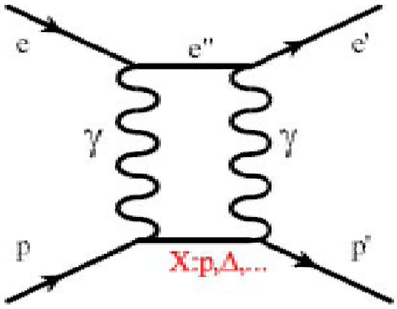

Fig. 3: Feynman diagram of elastic electron-proton scattering involving two virtual photons.

4. The OLYMPUS Experiment

OLYMPUS will elastically scatter unpolarised electrons and positrons off a stationary hydrogen target to measure the electromagnetic form factor ratio for each case. By comparing the ratio for each (electrons and positrons) one can investigate the effect of multiple photon interactions in the scattering as it will affect the electron and its antiparticle differently.

4.1 The Detector

The detector being used for OLYMPUS is the former Bates Large Acceptance Spectrometer Toroid (BLAST) from MIT. The BLAST experiment was also designed to measure the ratio of electromagnetic form factors of the proton. It did this using a polarised electron beam incident upon a polarised hydrogen target and measuring the spin dependent elastic scattering asymmetries. The energy range BLAST measured was for $Q^2$of less than 1GeV. The experiment was designed to complement recoil polarisation measurements for that range. For a more in depth description of BLAST see [5, 6, 7]. The detector was taken apart at MIT and shipped to DESY. There it has to be reassembled ready to be placed around the target.

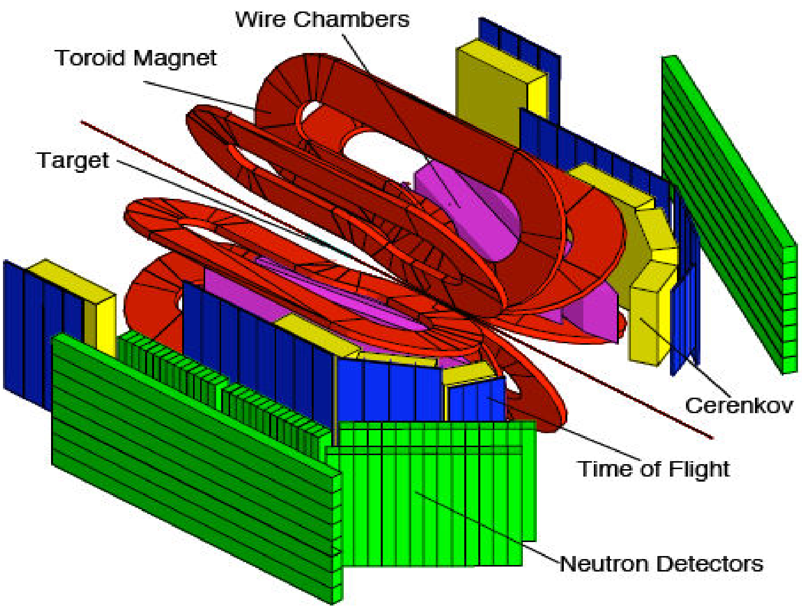

Fig. 4: The BLAST detector. Picture taken from [6].

For a complete technical profile of the BLAST detector I point you in the direction of [6], which also contains a brief description of the experiment. The OLYMPUS detector is essentially the same, although there are a few modifications. The essential features of the BLAST detector are the magnetic coils, drift chambers, Cerenkov counters, neutron detectors and scintillators. The OLYMPUS detector will not incorporate the neutron detectors or Cerenkov counters. It will feature certain improvements to luminosity measurements and time of flight detection. There will also be additional tracking capabilities provided by a Gas Electron Multiplier (GEM) surrounding the target chamber. My work at DESY only concerned the drift chamber, so this is all I shall consider henceforth.

4.2 Drift Chambers

The drift chambers allow for the path of charged particles to be tracked. Thus one can determine the particle momenta and charges by examining their paths through the toroidal magnetic field produced by the coils. Additionally the particle scattering angles and the vertex of the interaction are determined by following their paths through the drift chamber. Any decent particle or nuclear physics textbook will include a brief description of how drift chambers function. For the sake of completeness a quick overview follows.

Charged particles passing through a gas will cause the gas molecules to become ionised along its path. An electric field then sweeps the ionised electrons towards a sensor wire where they are collected and an electrical pulse produced which can be detected. By including many sensor wires in a confined area one can track the path of the particle through a given volume. Better resolution can be achieved by using a trigger to take note of when the particle enters the chamber. Using a suitable field ionised electrons can be moved to the sensor wire at a roughly constant speed. Therefore by taking the timing of electrons arriving at the sensor wires compared to the trigger one can determine the distance of the particle's path from the sensor. The position of the path longitudinally along the sensor wire can be determined from the difference in time it takes the electrical pulse to reach each end of the wire. Alternatively (and what is usually done) sensor wires are arranged in layers at angles to each other to provide three dimensional tracking.

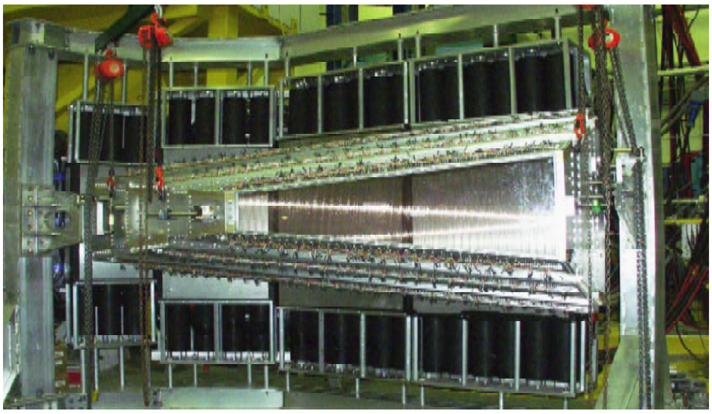

Fig. 5: A drift chamber installed in BLAST. Picture taken from [5]

The drift chambers in the OLYMPUS detector are unmodified from how they were in BLAST. For a complete technical description see [6]. Here are presented the essentials of the drift chamber configurations. OLYMPUS has the drift chamber split into two sections either side of the target chamber (left and right as shown by the purple features in fig. 4). In turn these have 3 smaller sections, giving a total of 6 regions in which the particle path can be traced. In each of the six small sections there are two layers of wires, arranged at an angle to each other, so that particles can be tracked in three dimensions.

Each layer of wires is further sub dived into square cells of 39 wires. In the middle of the cells lie 3 sensor wires that detect the ionised electrons. The other (field) wires are all used to shape the electric field to sweep the electrons to the sensor wires. This is achieved by the potentials (a few thousand volts) applied to each wire. The force on the electron is roughly constant until it is very close to the sensor wire at which point it becomes very large. There the electron acceleration leads to more ionisation of the gas, multiplying the signal into something detectable. In its travel from being ionised to the sensor wire, the electron periodically loses momentum through collision with gas molecules (over a length known as the collision length). By knowing the motility of the electron through the gas, one can easily work out the velocity of the ionised electron towards the sensor wire due to the force from the electric field. This is important when working out the distance of the particle path from the sensor wire. Finally it should be noted that the three sensor wires in a cell are slightly off centre from the surrounding field wires in order to determine whether the electrons have arrived from the left or the right of the wire. In total there are roughly ten thousand wires. Fig. 6 shows the arrangement of the wires in the two layers of a drift chamber section and the electric field in the chamber. Note that the field is shaped to concentrate onto the three sensor wires in the middle of each cell.

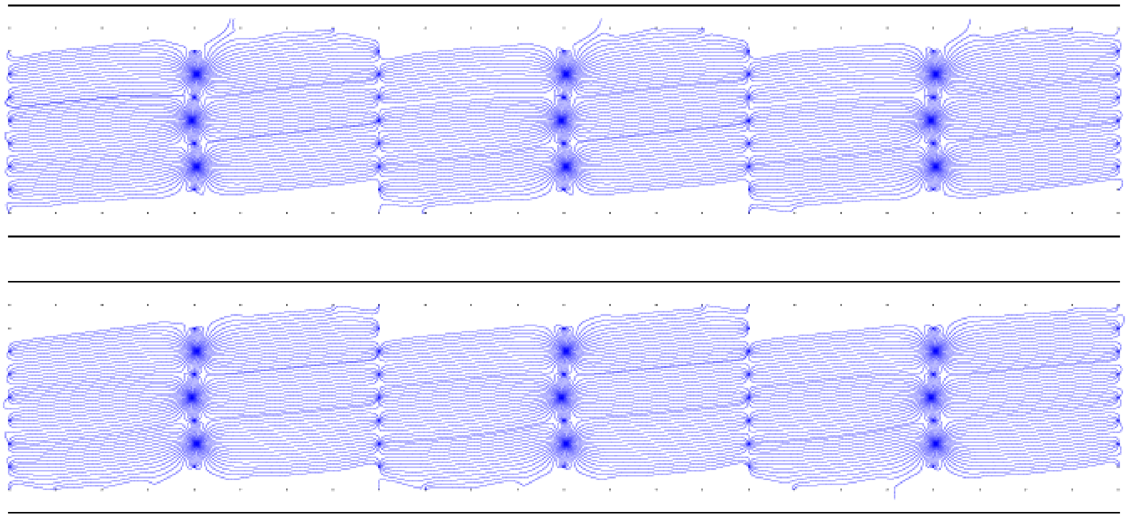

Fig. 6: The electric field in a section of the drift chamber. The three boldest blue spots at the middle of each cell show where the sensor wires are located as the field has been concentrated at these points. Picture taken from [6].

5. The Work

It was decided that upon shipping the drift chambers to DESY all of the wires should be replaced with new ones. This was scheduled to take place during the summer of 2010. Thus my work at DESY was to aid with the re-wiring of the drift chambers.

The wires all have to strung by hand in a clean room. Any dust in the chamber could potentially lead to shorts between the wires or interact with particles passing through. The wires are all under tension to prevent them sagging, which would alter the electric field shape and possibly lead to shorts. As the wire length increases so does the tension.

The actual process of stringing is very simple. A metal needle is passed through a hole on one side of the chamber to the corresponding hole on the other side. The wire to be strung is attached to the needle which is then pulled through. The wire is secured on one side by means of crimping a feed-through that has been pushed into the hole. The wire is then tensioned with a weight and pulley and secured on the other side by crimping another feed through. This has to be done for each of the ten thousand or so wires. The wires must all be tensioned properly and not cross each other. In transit from America the sides of the chambers were secured with piano wire tensioned so as to replicate the force of all the wires in order to prevent the chambers warping when the load had been removed.

Having inserted all of the wires they then have to be checked with a continuity tester to ensure none are broken or have been crossed with other wires.

When I arrived at DESY the process of stringing the chambers had just begun. Upon leaving the drift chamber for one side had been completed and tested and is awaiting the faults to be rectified. For the other the stringing is nigh on complete.

6. Conclusions

Stringing the drift chambers is a very laborious and repetitive process, but it is vital it is done with great care and attention for the success of the experiment. Despite the repetitive nature of the work I have really appreciated witnessing what goes into an experiment in terms of the effort and hours involved in its preparation. As a student one is rarely able to get an appreciation of how particle physics experiments come in to being.

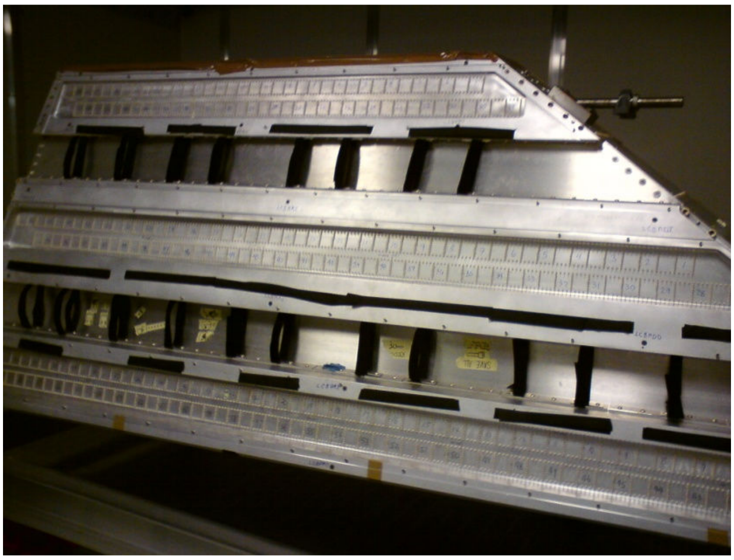

Fig. 7: The completed and tested chamber awaiting correction of faults.

I thank DESY, the OLYMPUS group, and the organisers of the Summer Student program for the opportunity to work at DESY and witness the effort that goes into bringing Physics experiments to life.

7. References

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[5] http://blast.lns.mit.edu/, website containing BLAST documentation

[6] D. Hasell et al., "The Blast Experiment", Nuclear Methods and Instruments A, July 2009

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