Chapter 7: Conclusions and Future Work

Forward Muon Reconstruction

The forward muon reconstruction code, which is a part of the main H1REC program, has been described in detail. The performance of this code has been tested with a large number of simulated events with muon momenta in the range 5 - 250 GeV. The performance of the code on these single track events without noise gives the limit to what could be achieved in the real detector. The reconstruction performed well upon these tracks except that a systematic shift in the value of the reconstructed momentum was observed. This shift was as high as 10% for low values of momentum. The shift may be due to the approximate nature of the extrapolation used.

The momentum resolution achieved on this Monte Carlo data has been determined as 22.3±0.4% + (0.057±0.005%/GeV)p without the phi chambers and 23.4%±0.3% + (0.049%±0.004%/GeV)p with the phi chambers. The efficiency of track reconstruction was found to be 89%±1% over a wide range of momenta. The efficiency of reconstruction was found not to depend upon the position of the track within an octant and was not affected by the addition of the phi chambers.

The track θ angle was reconstructed with a resolution of 1.6×10^{-3} radians without the phi chambers and 1.1×10^{-3} radians with the phi chambers. The track angle ϕ was reconstructed with a resolution of 0.27 radians without the phi chambers and 2.7×10^{-3} radians with the phi chambers. The position of the track entry point was reconstructed with a resolution of 1 cm without the phi chambers and 0.17 cm with the phi chambers. The systematic variation of these quantities across an octant was understood by considering the relative mixture of drift and charge division co-ordinates used in the measurement.

It may therefore be concluded that the presence of the phi chambers improves the measurement of the ϕ angle, in agreement with expectation. With only the theta chambers installed, the precise drift measurement is only made in one direction. With the addition of the phi chambers, a precise determination is made in two perpendicular directions, resulting in a substantial improvement in the resolution of the track starting point in space.

The presence of the phi chambers has little effect on the momentum measurement. However, the Monte Carlo tracks used in this study were all radial and for this case the improvement was expected to be minimal. In the real data, where any muon coming from the centre of H1 will have passed through the instrumented iron, multiple scattering will have deflected the track from being exactly radial. In these circumstances, the presence of the phi chambers is expected to improve the momentum measurement. Further studies should quantify how the performance of the reconstruction varies as the tracks are deviated from radial.

In addition to making measurements of the five track parameters (p, θ, ϕ, x, y), the reconstruction code must supply an estimate of the errors on these quantities. Residual plots were used to show that the error analysis in the reconstruction code produced error estimates consistent with the observed spread in the reconstructed values.

Although the code has been shown to work well on Monte Carlo, there are still some studies that must be refined before a similar performance can be achieved on real data. Firstly, the detector must be aligned so that the positions of all the octants are well known. This will be done with a combination of beam halo muon tracks and physical survey of the detector. Secondly, the drift velocity and t_{zero} corrections must be determined, using beam halo tracks in the full detector and using cosmic ray test systems. Thirdly, studies must be made concerning how the drift velocity varies across a single drift cell and an isochrone map of the cell must be produced. This can be done using a special transparent test cell and an Ultraviolet laser, used to produce ionisation in the cell. Work is currently in progress in Manchester with such a set-up.

The information from all these studies must then be incorporated correctly into the reconstruction code and stringent performance tests must be made to ensure that the differences between the real detector and the simulation are correctly treated. Preliminary studies of all these problems have already been performed and further studies are currently in progress. It is hoped that the real detector will soon be delivering results in line with the design specifications.

Photoproduction At HERA

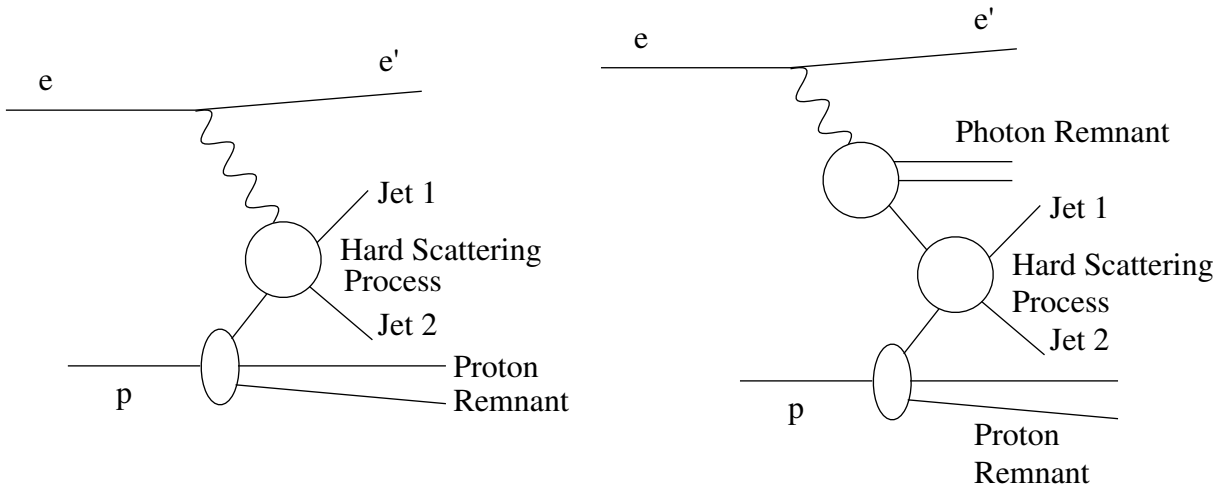
In Autumn 1992, H1 took 23.8±1.5 nb^{-1} of electron-proton data compared with a design goal of 200 pb^{-1} per year of running. The analysis possible on such a small data sample was necessarily limited. However, the total cross section for photoproduction at HERA was measured to be 159±7±20 μb in a previous publication [75], suggesting that meaningful studies could be made in this area. A decision was therefore made to trigger on photoproduction events where the scattered electron was detected in the electron tagger. Insisting that the electron be tagged allowed the four-momentum of the photon to be reconstructed using the electron information only but limited the accessible kinematic range to Q^2<0.01 GeV^2 and 0.2< y <0.8.

H1 therefore collected photoproduction events with the ETAG*t0 trigger. These events were then passed through a set of cuts to reduce the contribution from random hits in the electron tagger in coincidence with proton beam induced interactions in the H1 detector. The events so selected were compared with theoretical predictions using the PYTHIA Monte Carlo program and the H1SIM detector simulation program. The photon structure function parameterisation used was that of Gluck, Reya and Vogt. The events were also re-weighted with the LACIII structure function parameterisation to compare the predictions of the two. The Monte Carlo events were passed through the same cuts as the data sample.

After the imposition of these cuts, 4354 events remained in the data sample. A selection of proton pilot bunch events was used to tune the cuts and it was estimated that only 11±2 such background events remained in the data after cuts. The Monte Carlo predictions were 5957 events using the GRV structure function and 10915 events using the LACIII structure function. It was therefore concluded that a significant number of photoproduction events were observed at HERA even with the small integrated luminosity collected in 1992. The number of events collected was broadly in line with theoretical predictions. Distributions of the energy of the tagged electron, y calculated by the Jacquet-Blondel method and the z position of the reconstructed vertex were examined and reasonable agreement between the data and the Monte Carlo predictions was observed.

Photoproduction events fall into two classes, shown in figures 7.1(a) and 7.1(b). In

direct events, figure 7.1(a), the whole photon interacts with a parton from the proton, producing two jets and a proton remnant in the final state. In resolved events, figure 7.1(b), some parton from the photon interacts with a parton from the proton, producing two jets, a proton remnant and a photon remnant.



A) Direct B) Resolved

Figure 7.1: Photoproduction events at HERA. a) Direct, b) resolved.

The LUCELL jet finding algorithm was used in order to find jets in the events. The parameters used were an initiator transverse energy requirement of 0.2 GeV and a cone size of 1.0 unit in $\eta-\phi$ space. The cone was accepted as a jet if the transverse energy contained within it exceeded a threshold. A value of E_{Tmin}=5 GeV was chosen for this threshold. Normally, higher values are chosen (the H1 paper on jet rates in photoproduction used 7 GeV [64]) but with the small data sample available it was necessary to go down to 5 GeV in order to be able to tag two jet events. Scanning Monte Carlo events visually led to the conclusion that at least one reconstructed jet could clearly be related back to the parton in approximately 90% of events but that the second jet could only be related back clearly in half the events.

A total of 467 data events were left after requiring two jets, corresponding to 10.8% of the original sample. In the GRV Monte Carlo, only 277 events remained, corresponding to 4.7% of the original. When the Monte Carlo events were reweighted with the LACIII structure function, 728 events remained, corresponding to 6.7% of the original sample. It may therefore be

concluded that the number of events with two or more jets in the data was between the two Monte Carlo predictions. However, the fraction of events with at least two jets was found to be higher for the data than for either Monte Carlo prediction.

The distributions of these jets as a function of energy (E), pseudo-rapidity (η), phi (ϕ) and transverse momentum (p_T) were then examined. The data and Monte Carlo predictions were found to agree well in shape for E, ϕ and p_T. However, a discrepancy was found in the η distribution. In the forward region, $\eta>1$, significantly more jets were observed in the data than predicted by either Monte Carlo. A similar effect was observed using tracks reconstructed by the H1 central tracking detector.

The jet profiles, plots of transverse energy flow relative to the axis of the found jets, were then examined. It was observed that the jet energy was well contained within a cone of radius 1.0 in $\eta-\phi$ space. It was found that the observed shape agreed with the Monte Carlo prediction in ϕ, but that there was more energy in the forward jet tail in the data than predicted by the Monte Carlo. This effect has also been reported in [64].

It is currently suggested that the data and Monte Carlo predictions match well except in the forward region. It is therefore also suggested that there is some physical effect spraying particle into the forward region. This difference in energy flow is thought to account for the higher fraction of data events having two or more jets and for the discrepancies observed in the jet and charged track distributions. No firm conclusions could be drawn regarding the possibility of distinguishing between different parameterisations of the photon structure function because of this forward energy flow difference. Studies are in progress at DESY to understand and reproduce the forward energy flow using both the 1992 data and the new 1993 data, in which the forward tracker is fully operational and well reconstructed, which should greatly aid the investigation of this problem.

The value of x_γ, the fraction of the photon four-momentum taken by the interacting parton, was calculated using the reconstructed jet information. As a greater fraction jets were found in the forward region in the data, it was expected that a greater fraction of events would have a low value of x_γ than predicted by the Monte Carlo. It was observed that the data had a

much larger fraction of events in the region x_γ<0.3 but that above this the data and GRV Monte Carlo distributions matched well. The LACIII re-weighted Monte Carlo predicted significantly more events than were observed.

The Photon Remnant

As discussed above, two classes of photoproduction event were expected at HERA: direct and resolved. A previous Monte Carlo study by D'Agostini and Monaldi [74] had indicated that a separation between direct and resolved events may be performed by looking for the photon remnant, expected to be present in resolved events only as shown in figure 7.1. The algorithm used in their study examined the energy contained within a cone one unit in η behind the backwards-most jet. If this energy exceeded 3 GeV, the event was labelled as resolved.

In addition to searching for the presence of a photon remnant to distinguish between direct and resolved events, the properties of the photon remnant itself are of interest. In order to examine these properties, an algorithm was used to sum those particle believed to have originated from the photon remnant parton. Two such algorithms were presented, the first based on the cone used by D'Agostini and Monaldi, the second collecting all energy deposited behind the forward-most jet and at least 1.5 units away from the axis of any jet as well as the cone behind the backwards-most jet.

It was observed that 79±2% of events with two or more jets in the data had a photon remnant using the D'Agostini/Monaldi based algorithm. With the new algorithm this rose to 96±2%, but the new algorithm was thought to be very sensitive to the presence of noise or particles from jet pedestals. To reduce this sensitivity, a requirement was made that the found photon remnant should have an energy of at least 3 GeV. Imposing this requirement, 55±2% of data events remained when using the original algorithm, rising to 69±2% with the new algorithm.

The discriminating power of this requirement was examined using the Monte Carlo predictions. It was found that between 38% and 47% of the resolved events had a photon remnant defined by the original algorithm with at least 3 GeV whereas only 6% of direct events

had such a remnant. For the new algorithm, between 56% and 62% of the resolved events and 44% of the direct events had a remnant with an energy of at least 3 GeV.

It was therefore concluded that the D'Agostini/Monaldi algorithm was capable of good discrimination between direct and resolved events and that the new algorithm did not perform as well. The observation that over 50% of the data events had a remnant with a energy of at least 3 GeV in the D'Agostini/Monaldi cone led to the conclusion that the data events were mostly resolved rather than direct, in line with theoretical expectations.

The distributions of the photon remnants in E, η, ϕ and p_T were then examined with the remnant defined by both the algorithms described above. As the remnant was found to be predominantly in the backwards region, $\eta<0.0$, the difference in forward energy flow between data and Monte Carlo was not expected to cause problems. The distributions were found to be in agreement within errors. The E, η, ϕ and p_T distributions of the charged tracks within the remnant were examined and good agreement was found between data and Monte Carlo, confirming that the description of the photon remnant in PYTHIA is reasonable.

The transverse energy flows about the found remnant axis in η and ϕ were examined using both calorimeter cells and tracks. These energy flow profiles were found to be peaked around the remnant axis, confirming that the found photon remnant corresponded to a real concentration of energy. The shape of the observed profiles agreed with the Monte Carlo predictions within errors. It was observed that the peaks in the remnant energy flow were broader than 1.0 unit in $\eta-\phi$, suggesting that the remnant jets were not as well collimated as the hard scattered parton jets.

A measurement was made of x_{rem}, the fraction of the photon's four-momentum taken by the photon remnant and the value of the checksum $x_\gamma+x_{rem}$ was plotted. Contrary to expectation, the peak of this distribution lay significantly below 1.0 for data and Monte Carlo. Comparisons between the generated and reconstructed parameters of the partons in the Monte Carlo sample indicated that the hard scattered parton jets were being well reconstructed but that the remnant reconstruction was relatively poor. It was therefore concluded that the remnant reconstruction algorithms were missing some energy (the original algorithm more than the new) and that this

was mainly responsible for the shortfall in the x_γ+x_{rem} checksum.

Three hypotheses were advanced to account for the poor correlation between the reconstructed and generated parameters of the photon remnant. This first hypothesis was that the remnant, where present, had already been labelled as a jet and the remnant formed by the algorithms was therefore the sum of noise in the event. The peaks in the energy flow profiles and a visual scan of the Monte Carlo events did not support this hypothesis. Second, it was thought that noise in the calorimeters might have been swamping the photon remnant signal, giving a poor relation back to the parton level. The observation that the reconstructed energy was too low rather than too high in the Monte Carlo did not support this explanation. It was therefore suggested that the poor hadronic calorimetry in the backward region of H1 might have limited how well the remnant could be reconstructed. Further studies should therefore include the instrumented iron behind the BEMC as this may improve matters. An upgrade to the backward calorimetry of H1 is also planned.

Future studies should also be carried out using different algorithms to gather the photon remnant. The broad collection algorithms described in this report have been shown to be capable of identifying that a remnant is present but to be poor at reconstructing the parameters of this remnant. It is therefore suggested that studies be carried out using event decomposition techniques such as the JADE algorithm [76] and DECO [77] where all particles in the detector are assigned to jets by minimisation of some quantity such as the invariant mass between the jets. Such algorithms are useful as they use all particles in the event and also use make good use of both the direction and energy information reconstructed by the detector.

It is further suggested on the basis of the observed remnant energy flow profiles that a cone algorithm of the LUCELL type may be capable of identifying and reconstructing the photon remnant. Future studies could investigate how best to modify the LUCELL algorithm for this purpose in order to provide a complimentary alternative to the event decomposition method.

Finally, it is suggested that more detailed studies should be made on the 1993 (and future) data as this will allow a much greater understanding of photoproduction at HERA than has been possible with the initial 1992 data.