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Electron Track-Cluster Matching in Neutral Current Events at the H1 Experiment

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Abstract

A study on optimizing the cut on the distance between electron track and cluster in neutral current events has been made using the 2006 $e^{-}p$ HERA data set at a luminosity of 54.98 pb^{-1}. The effect on the track finding and charge identification efficiencies are studied in both data and signal Monte Carlo. The corresponding effects on the measured cross section are also considered.

Contents

1 Theoretical Framework

The HERA accelerator has been in operation between 1994-2007, colliding electrons and protons at a center of mass energy of 319 GeV. In $e^{\pm}p$ collisions two kinds of processes can occur: neutral current processes (the exchanged particle is a Z boson or a photon) or charged current events (mediated by the $W^{\pm}$ boson). The Feynman diagrams for the two cases are shown in figure 1. In this project only neutral current events are considered.

The cross sections for the NC processes $e^{\pm}p \rightarrow e^{\pm}$ X are given by:

$$\frac{d^2\sigma_{NC}^{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\phi_{NC}^{\pm}(x, Q^2) \tag{1}$$

where

$$\phi_{NC}^{\pm} = Y_+\tilde{F}_2^{\pm}(x, Q^2) \mp Y_- x\tilde{F}_2^{\pm}(x, Q^2) - y^2\tilde{F}_L^{\pm}(x, Q^2) \tag{2}$$

and

$$Y_{\pm} = 1 \pm (1 - y)^2. \tag{3}$$

x is the Bjorken scaling variable, Q^2 is the negative four-momentum transfer squared, α - the electromagnetic coupling constant ($=e^2/4\pi$), y is the inelasticity. $\tilde{F}_2$, $x\tilde{F}_3$ and $\tilde{F}_L$ are the structure functions of the proton.

The structure functions can be separated into a purely electromagnetic part (γ exchange), a purely weak term (Z exchange) and an interference term (γ and Z). $\tilde{F}_L$ is known as the longitudinal structure function.

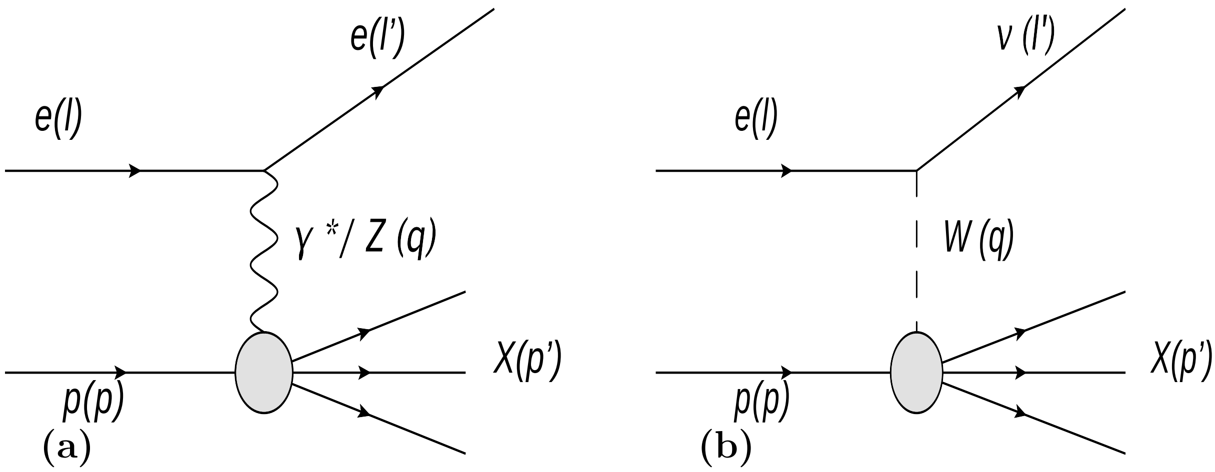

Figure 1: Feynman diagrams for (a) neutral current and (b) charged current processes. Indicated in brackets are the associated 4-momentum of each particle.

2 H1 Experiment

The H1 detector was one of the 4 experiments on the HERA ring. The Hadron Electron Ring Accelerator collided electrons or positrons at 27.6 GeV with protons at 920 GeV. The purpose of the H1 detector was to identify particles produced in $e^{\pm}p$ collisions and reconstruct their 4-momenta. This is achieved by surrounding the point of interaction with several subdetectors, each sensitive to energy deposited by the particles that pass through it.

The main parts of the H1 detector were: the trackers (Central Track Detector and Forward Track Detector), calorimeters (Liquid Argon calorimeter for the central and forward region and the Lead-Fiber Spaghetti calorimeter (SPACAL) for the backward region) and muon detectors. A superconducting solenoid surrounds the calorimeters, producing a magnetic field of 1.15T.

In the tracker hits are collected by various subdetectors and are used as input into the track-fitting procedure. Track segments are then built using these hits. These segments are then constrained to an interaction vertex. Only charged particles will leave tracks in the detector. The curvature of these reconstructed tracks can be used to determine their charge.

Both calorimeters (LAr and SPACAL) are made of two parts: electromagnetic part and hadronic part. The signature of a neutral current event is a compact electromagnetic energy deposition (cluster) coming from the scattered electron as well as a track associated with the cluster.

3 Distance of closest approach (DCA) between electron track and cluster

The DCA is the distance of closest approach between the electron track and the cluster and is a good variable to use for background removal. The main source of background in $e^{\pm}p$ interactions is photoproduction. In this case the electron is scattered at a very low angle and goes down the beam pipe but it is faked by the hadronic final state. When looking at the distribution of the signal and photoproduction events with respect to the DCA one can observe that the distribution of signal events has a peak at low DCA and decreases toeards higher values of DCA, while the photoproduction distribution is flat.

The background can be estimated using the sign of the track linked to the scattered electron candidate. For example, if we are looking at an e^-p process and we find a track with a positive charge, we can consider the event as background. This means that we can estimate the number of background events in our e^-p sample as being equal to the number of events with a positive track (we assume a symmetric charge distribution of background events):

$$N^{bg}_{e^-p} = N^{+}_{e^-p} \tag{4}$$

Where $N^{bg}_{e^-p}$ is the number of background events in the e^-p process and $N^{+}_{e^-p}$ indicates the number of events with positively charged tracks.

Equation 4 can be rewritten as equation 5 if there is a charge assymmetry in the background (denoted as k). k is defined as the ratio of negative to positive background (equation 6)

$$N_{e^-p}^{bg} = kN_{e^-p}^{+} \tag{5}$$

$$k \equiv \frac{N_{bg}^{-}}{N_{bg}^{+}} \tag{6}$$

The background correction is made by statistically subtracting the background which is estimated by the number of wrongly charged tracks from the sample. This is called "wrong charged background subtraction" and is applied both to data and MC. Using this procedure we can express the background corrected number of events (N') as :

$$N' = N^{-} - kN^{+} \tag{7}$$

and

$$N' = N^{+} - \frac{N^{-}}{k} \tag{8}$$

where + and − indicate the sign of the tracks. Equation 7 is for the e^-p sample while equation 8 is valid for the e^+p.

4 Method

In order to study the efficiency of finding tracks at DCA's of 6 and 12 cm, the track requirement must be removed. This would lead to a sample with a large background contribution. A clean sample has to be obtained in order to get an accurate measurement of the efficiency. Such a background free sample is obtained by applying a series of cuts wich are listed in detail in the "Event Selection" section. From the clean sample, the track-finding and charge identification efficiencies in data and signal MC can be measured and compared.

5 Event Selection

The selection of the events for the clean sample is made by applying the following cuts on the 2006 e^-p data. The kinematic requirements are $Q^2 \leqslant 2000$ GeV^2 and $y \geq 0.3$.

Other cuts:

- Trigger Requirement : s67 or s77 subtriggers
- z_{vertex} within 0 ± 35 cm. Requiring the z_{vertex} between these limits plays a significant role in limiting the amount of non e^-p background.
- The fiducial volume cut removes regions of significant inefficiency that appear due to trigger cells switched of because of high noise or malfunctioning hardware.
- $\theta \geq 60^0$. For very forward θ the tracker efficiency in both data and simulations decreases and the level of agreement worsens.
- Timing and Topological cuts designed to remove non-ep background.

Tight physics cuts:

- E_e'$\geq$ 18 GeV.
- 45 $\leq$ E-P_z $\leq$ 65 GeV.
- 0.5 $\leq$ P_{tbal} $\leq$ 1.4

E_e' is the energy of the scattered electron,E -P_z is the total longitudinal momentum of all final state particles and P_{tbal} represents the ration between the transverse momenta of the hadronic final state and the electron respectively. By limiting the electron energy and ensuring a tight balance in longitudinal and transverse momenta a sample with negligible background is obtained.

6 Results

6.1 Tracker requirement efficiency

The dependence of the tracker requirement efficiency with respect to the distance between track and cluster (DCA) has been studied. When changing the cut on DCA from 6 to 12 cm we gain 2% events in data and 1% in MC (figure 2). Figure 3 shows a level of agreement between efficiencies in data and MC of approximately 2% and is consistent to previous studies. This systematic error leads to a 2% relative error on the cross section.

6.2 Charge Identification Efficiency

The charge identification efficiency is taken as the fraction of events from the clean sample with a charge matching the beam lepton charge.

The charge identification efficiencies have been studied in both data and MC for different DCA's. As can be seen in figure 4 the efficiencies have similar values in data and MC for DCA's limited to 6 and 12 cm. The level of agreement between data and MC is approximately 0.5 % figure 5.

In figure 6 the efficiency of data and MC is shown exclusively for tracks with DCA's between 6 and 12 cm. In figure 7, for a DCA less than 6 cm a level of agreement in the range of 1 $\pm$ 0.05 % is found. This worsens considerably for a distance between track and cluster between 6 and 12 cm, the systematic error in this case being approximately 10 %.

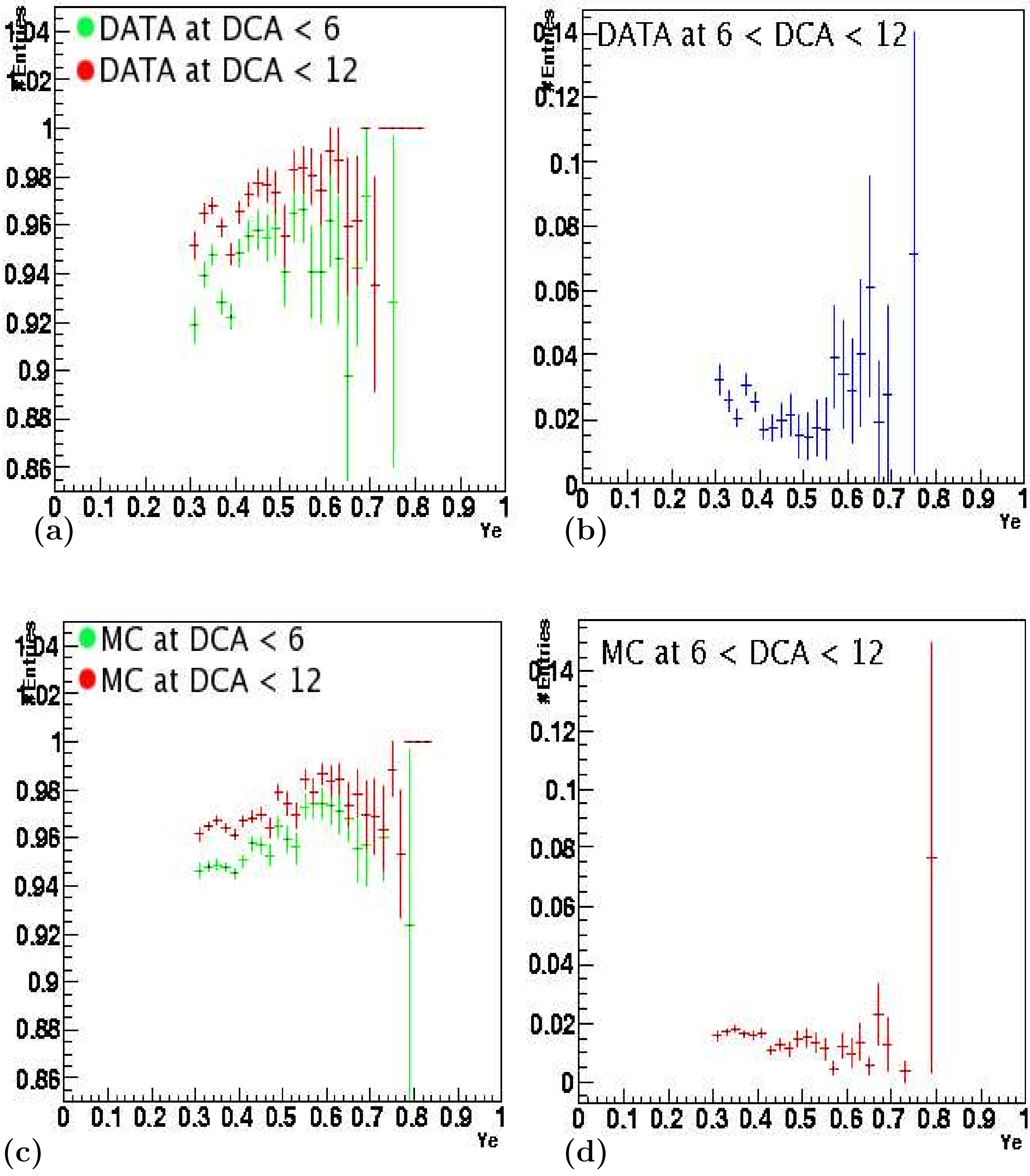

Figure 2: (a) Tracking efficiency in data for DCA less than 6 cm and DCA less than 12 cm. (b) Tracking eficiency in data for DCA between 6 and 12 cm. (c) Tracking efficiency in MC for DCA less than 6 cm and DCA less than 12 cm. (d) Tracking efficiency in MC for DCA between 6 and 12 cm.

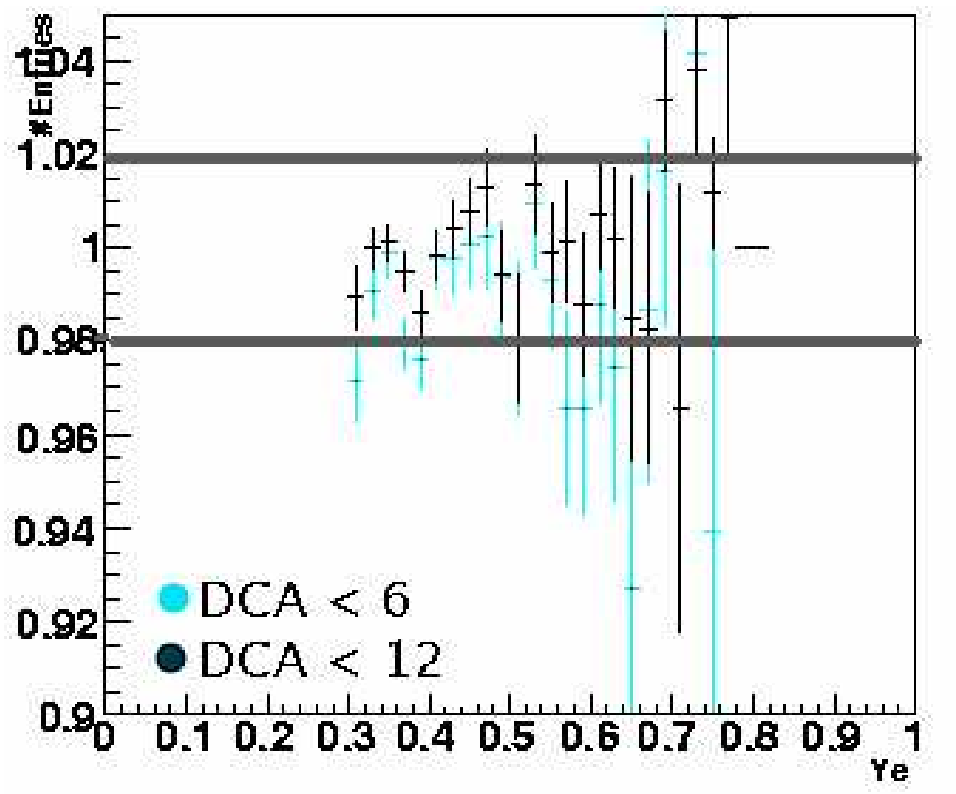

Figure 3: Level of agreement between tracking efficiencies in data and MC for distances between track and cluster less than 6 and 12 cm.

7 Conclusions

Efficiencies for the tracker requirement and charge identification have been measured using the 2006 e^-p data set.

Changing the DCA cut from 6 cm to 12 cm brings a gain of 2% events in data and 1% in signal MC. The level of agreement between data and MC is approximately 2%, which leads to a 2% relative error on the cross section.

From the charge identification efficiency study we can conclude that with a track-cluster distance between 6 and 12 cm the relative error on the cross section is about 20% due to a 10% level of agreement between data and signal MC, while for a DCA less than 6 cm the error is 1%. Overall, choosing a DCA $\leq$12 cm leads to a relative uncertainty on the cross section of about 1.4%.

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References

[1] Shiraz Habib. Unpolarized neutral current $e^{\pm}p$ cross section measurements at the H1 experiment, HERA. PhD thesis. DESY-THESIS-2009-039

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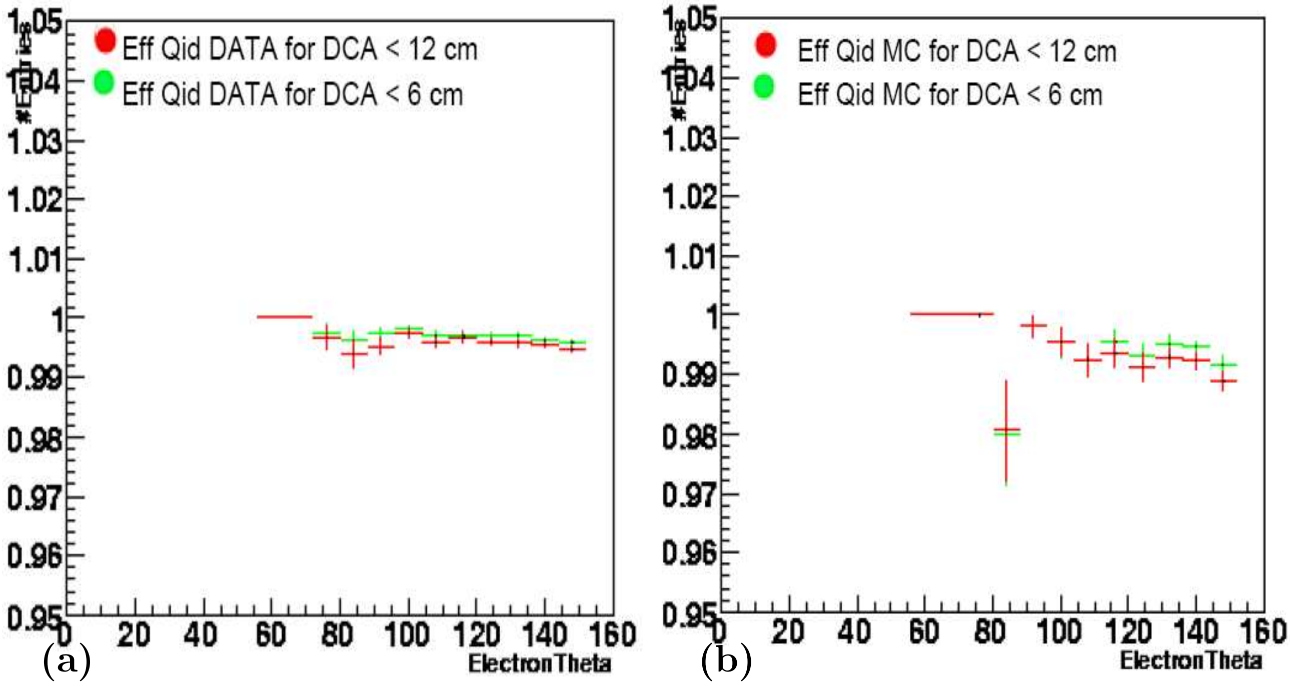

Figure 4: The charge identification efficiency in data (a) and MC (b) with DCA less than 6 cm and DCA less than 12 cm as a function of the electron polar angle.

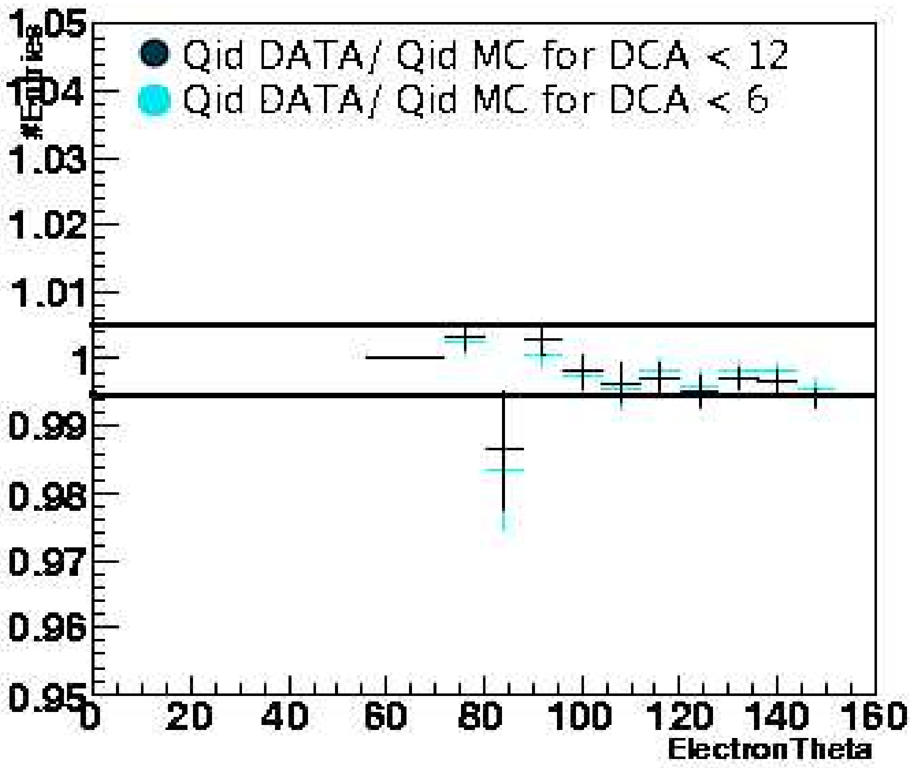

Figure 5: The ratio of the data to MC charge identification efficiency for DCA cuts at 6 and at 12 cm as a function of the electron polar angle together with lines at ± 1.005.

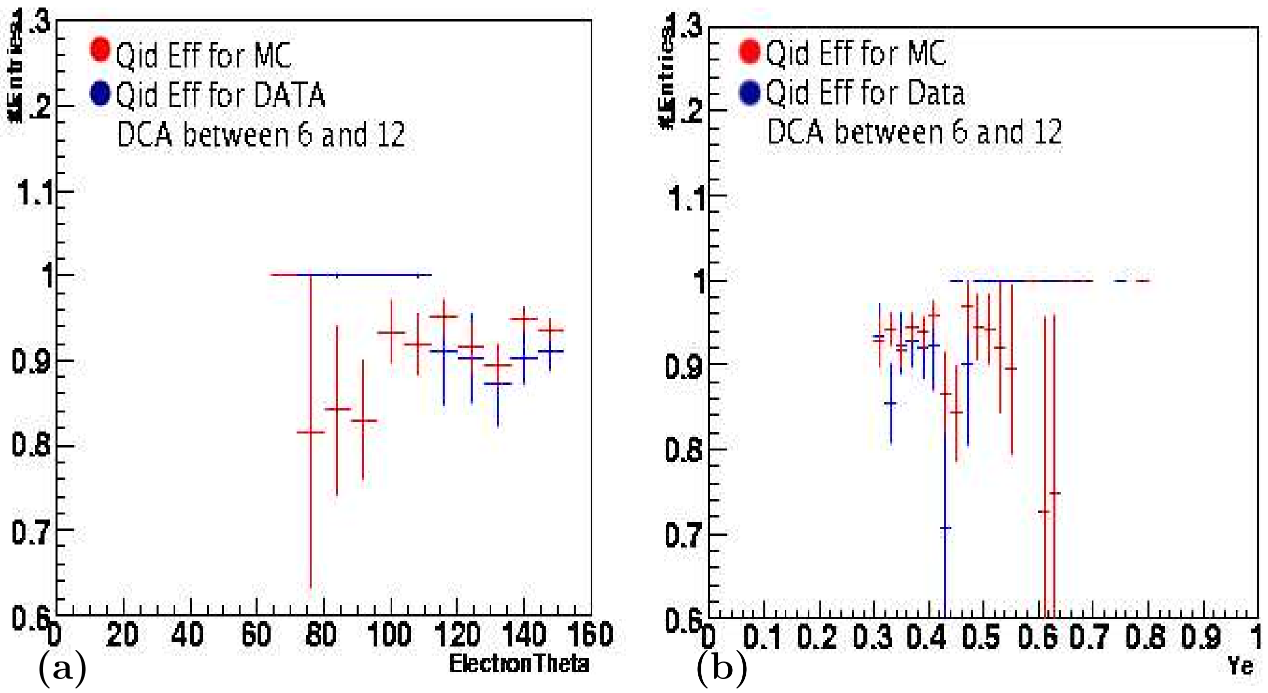

Figure 6: Charge identification efficiency in data and MC with DCA between 6 and 12 cm as a function of (a) electron polar angle and (b) y_e.

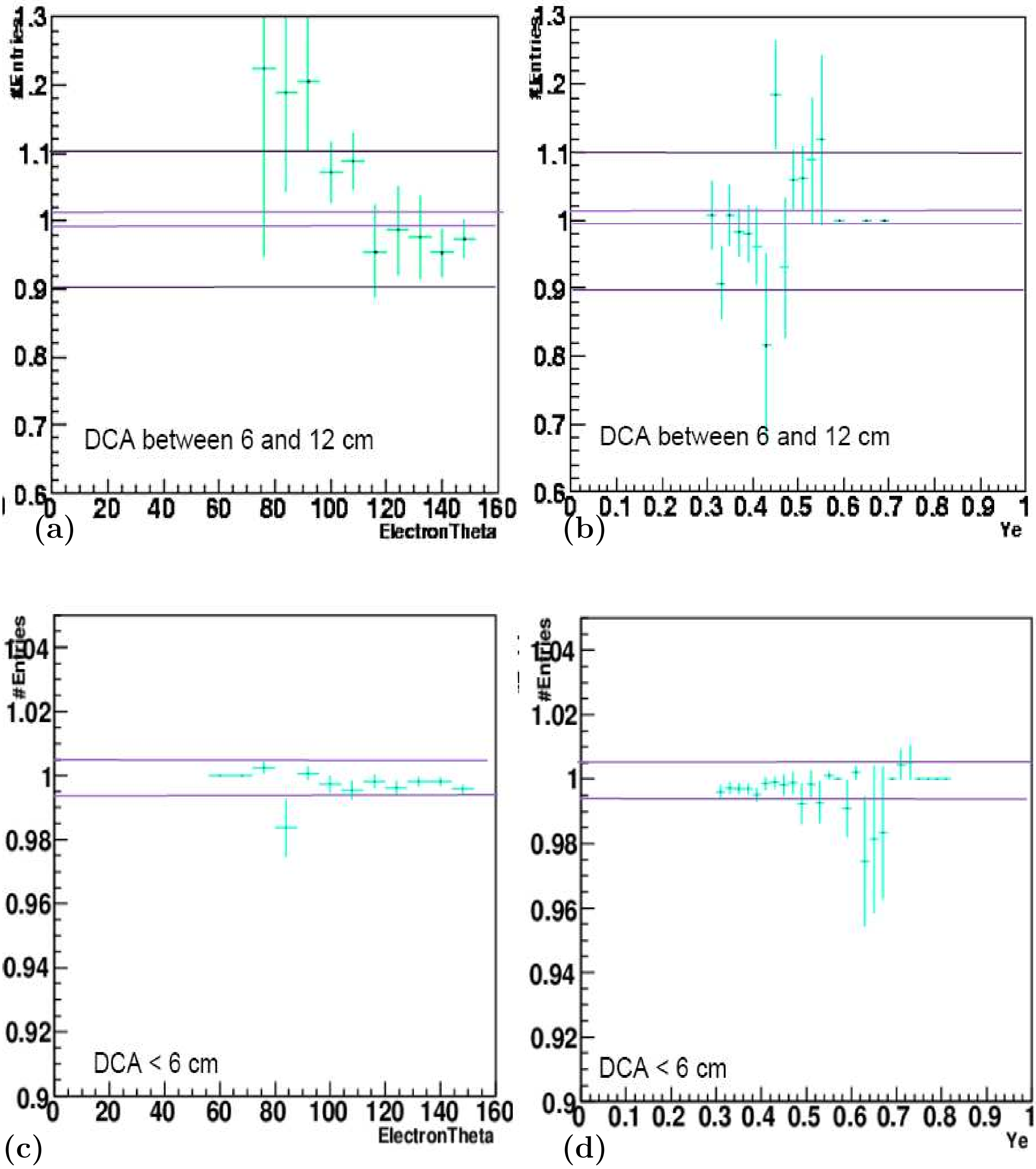

Figure 7: The ratio of the data to MC charge identification efficiency for (a) DCA between 6 and 12 cm and (c) DCA $\leq$ 6 cm as a function of the electron polar angle. The same ratio is plotted in (b) and (d) as a function of y_e.