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A NEW TECHNIQUE FOR DETERMINING CHARGE AND MOMENTUM OF ELECTRONS AND POSITRONS USING CALORIMETRY AND SILICON TRACKING*

Qun Fan & Arie Bodek
Department of Physics and Astronomy
University of Rochester
Rochester, NY 14627

UNIVERSITY OF ROCHESTER
DEPARTMENT OF PHYSICS AND ASTRONOMY
ROCHESTER, NEW YORK, 14627

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ABSTRACT

We describe the application of a new method for the determination of charge and track parameters for electrons and positrons in both central (pseudo-rapidity [1]) $0 < |\eta| < 1.2$) and forward (pseudo-rapidity $1.2 < |\eta| < 2.3$) regions at CDF. The method uses the shower centroid position in the calorimeter in combination with a track in the inner silicon vertex detector. The use of the central tracking chamber is not required. A comparison of the shower centroid in the calorimeter, with the extrapolated silicon vertex detector track determines the electron sign. This technique has been used to measure the W asymmetry in CDF in regions beyond the pseudo-rapidity coverage of the central tracking chamber. Application to other Physics analyses in current collider experiments at the Tevatron and in future high luminosity experiments at the LHC are discussed.

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1 Introduction

Charge and momentum of electrons and positrons are typically measured inside a central tracking device in a magnetic field. This is particularly the case in most large detector systems in colliding beam experiments. In the CDF experiment, for example, the central tracking chamber (CTC) plays an essential role in charge and momentum measurement of electrons. Figure 1 shows a cutaway view of CDF detector. In the central region, the CTC track momentum resolution is dP_T/p_T^2

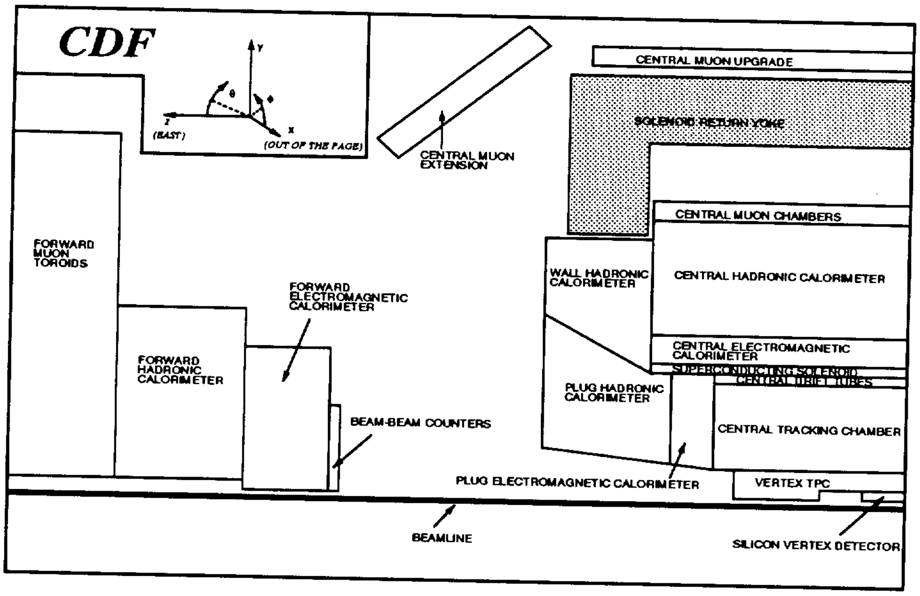

Figure 1: A cut away view of the CDF detector. Forward tracks($|\eta| > 1.1$) do not traverse the full tracking region of the CTC.

$\approx$0.001 $(GeV/c)^{-1}$, when the beam position constraint is included in the fit. The charge is determined from the bend direction of the the track.

While excellent momentum measurement is achieved in the central region, the CTC tracking in the forward/backward regions is compromised because the tracks traverse only a few CTC layers. The situation becomes worse at high instantaneous luminosity as the inner tracking layers suffer from higher occupancy due to increased number of soft tracks curling along the beam direction. Therefore, the central tracking chamber becomes inefficient for forward/backward electrons. Figure 2 shows that the CTC track finding efficiency falls as a function of pseudo-rapidity $|\eta|$, and is zero at $|\eta| = 1.8$.

Many physics analyses require a charge determination of electrons and positrons. In the W lepton charge asymmetry measurement [2)], about half of the overall sensitivity is in the forward/backward regions. Similarly, in the dilepton analyses, e.g. Drell-Yan and Z forward-backward asymmetry, the determination of the sign of each lepton is required. The dilepton signal events are opposite sign, and the backgrounds from QCD jets are determined from the rate of same sign events. The top analysis can be also extended to forward region if a forward electron charge information becomes available for use in reducing backgrounds. Even in the central region where the CTC already provides charge determination, an independent way of determining the charge of electrons can serve as a check of central tracking efficiency

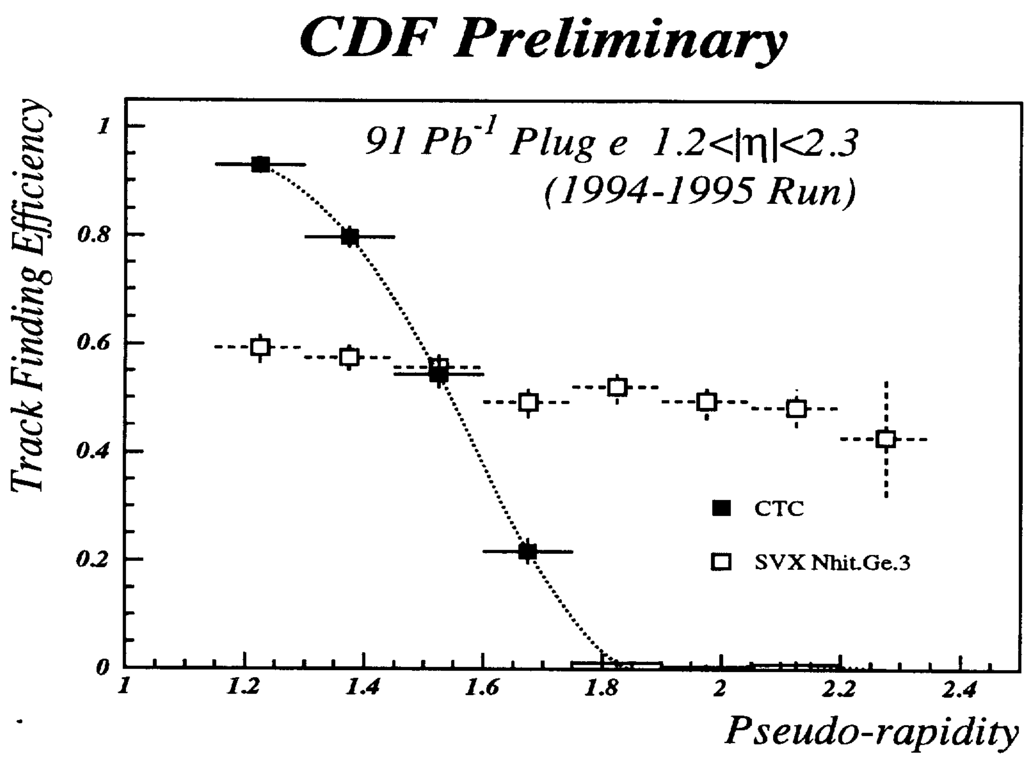

Figure 2: The track-finding efficiencies as a function of pseudo-rapidity.

at high luminosity. This will be even more important at the Large Hadron Collider (LHC) where even central tracking will be difficult at high luminosity. Therefore, an additional method for charge determination both in the central and forward direction is needed.

2 The Technique

At CDF, positively (negatively) charged particles bend toward increasing (decreasing) ϕ. The track ϕ direction can be measured near the primary vertex using silicon tracking (SVX), and at the Electromagnetic (EM) shower maximum using the shower centroid position measurement of EM detectors. By comparing two measurements, the charge of the track is determined.

A Detailed description of the CDF detector can be found elsewhere [3]. Starting at the collision points, the detector's tracking components are the Inner Silicon Vertex detector (SVX), the Vertex Tracking Chamber (VTX), and the Central Tracking Chamber (CTC). The Central and Plug Electromagnetic Calorimeters (CEM, PEM) yield both energy and also a measurement of the shower centroid position . The SVX is a four layer, single sided device from $r \approx 3cm$ to $\approx 8cm$, with $\approx 10\mu m$ position resolution in the $r - \phi$ plane. Inside the CEM, the EM shower centroid is measured using strip chamber placed near the shower maximum at $r \approx 184cm$. The position measurement in the PEM is done using both the strip detector at shower maximum, and the calorimeter tower information (needed for $|\eta| > 1.8$ where there is no strip coverage).

3 SVX Tracking

The track ϕ direction at SVX is measured by a standalone trackfinding using only SVX hits. A ϕ road to search for track stubs with SVX hits is defined from the electron cluster, and the collision point. The precise position resolution of the SVX device ensures low background arising from wrong combinations of hits. At least three hits are required for a stub. As shown in Figure 2, the SVX track finding efficiency in the plug region is relatively flat in contrast to the quickly falling CTC efficiency. The $\approx 60\%$ level results from the fact that SVX device is 50 cm long in z while the primary interaction has a rms $\sigma \approx 30cm$ spread in z direction. A ϕ resolution of $\approx 0.3mrad$ can be achieved from the SVX track stub. This corresponds to $\approx 550\mu m$ in position uncertainty when extrapolated to the shower maximum at the CEM, and between $120\mu m$ ($|\eta| = 2.3$) and $400\mu m$ ($|\eta| = 1.2$) at the location of the shower maximum inside the PEM. These uncertainties are small compared to the position resolution of the CEM and PEM shower centroid measurements which are described below.

4 EM Shower Centroid Measurement

The second measurement of the track direction ϕ comes from the EM shower centroid measurement. The detailed structure of the CEM is described elsewhere [4]. In the central region, the shower centroid is determined from the central strip chamber at the shower maximum. A strip cluster corresponding to each electron is formed and shower centroid is calculated from a fit using shower shape data from test beam measurements.

In the forward region, the position measurement is made using a combination of a strip detector at the shower maximum for $|\eta| < 1.8$ where it is available, and in addition the calorimeter pad information at the larger rapidities. The PEM detector is described in detail elsewhere [5]. It consists of two 2.8 m diameter and 50 cm deep round disc-shaped lead sampling calorimeters. Each is constructed using resistive plastic gas proportional tube arrays sandwiched with lead absorber panels. These are finely segmented into projective tower geometry using cathode readout based on pads and strips etched on printed circuit board in the chambers, with a precise positioning of strips and pads to $0.1mm$. The chamber high voltage is controlled from feedback of gas pressure and temperature. The gas gain is moni-

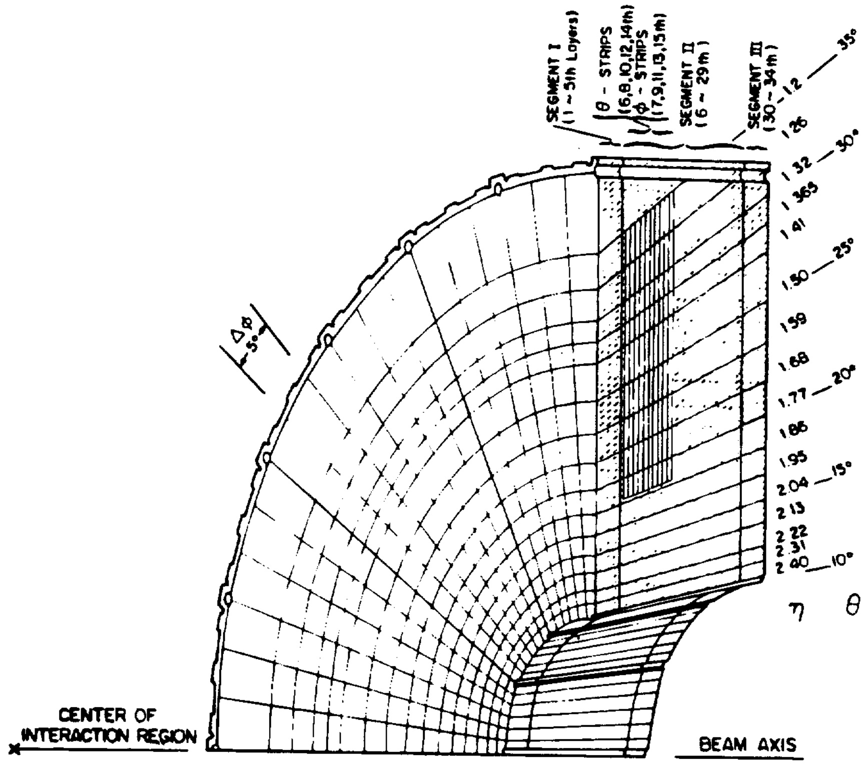

Figure 3: View of a PEM quadrant. Pads are segmented in 5 degree unit in ϕ and strips in 1 degree unit covering $1.2 < |\eta| < 1.8$.

tored by proportional tubes mounted with Fe^{55}. The gain variation is controlled to within 1% . The energy resolution (pad) is 2.8% for 100 GeV electrons. Figure 3 shows a PEM quadrant. Strips segments are 1 degree in ϕ covering $1.2 < |\eta| < 1.8$, and pads have a 5 degree segmentation. Table 1 lists the physical dimensions of the PEM detector.

The transverse shape of EM showers are very stable at high energies ($E > 20GeV$). Therefore, the fit function for the CEM electromagnetic shower shape from test beam can be tunned to match the data. In the plug strip case, we use similar clustering and fitting method as for the CEM strips to extract the shower transverse

Table 1: Summary of PEM position resolution. For electrons with $|\eta| > 1.8$, $1mm$ position resolution is achieved using $4.7cm$ wide towers (bend is at mean Pt of 40 GeV).

	η Range	Segmentation in ϕ	Bend	σ_{pos}
Strips	1.2-1.8	2.2-1.1 cm (1.7 cm)	0.51 cm	0.15 cm
Pads	1.8-2.3	5.6-3.4 cm (4.7 cm)	0.16 cm	0.10 cm

position. For electron clusters with $|\eta| > 1.8$, a 5x5 energy cluster is formed with the biggest energy tower in the center. To determine the ϕ position, energy is summed in η blocks. The expected energy fraction for each η block is calculated and normalized to the total measured energy. In the fit, the center tower energy fraction is not used since it does not contain position information. For electrons with $|\eta| > 1.8$, $1mm$ position resolution is achieved using $4.7cm$ wide towers.

We differntiate between positively and negatively charged tracks by comparing the extrapolated SVX track position at EM shower maximum and the position measured by the EM calorimeter. The bending is a function of track transverse momentum P_T and the radii at shower maximum. For electrons from W decays with average $P_T = 40GeV/c$, the bending is on average $20mm, 5mm$, and $1.6mm$ for the $|\eta| < 1.2$, $1.2 < |\eta| < 1.8$, and $|\eta| > 1.8$ regions, respectively.

We take the ratio of $\delta\phi_{measured}/\delta\phi_{expected}$ where $\delta\phi$ is defined as $\phi_{PEM} - \phi_{SVX}$. The $\delta\phi_{expected}$ can be calculated using the calorimeter E_T and the radial distance that the electron travels inside magnetic field. For electrons and positrons, the average ratio peaks at -1 and $+1$ separately. Figure 4 shows the $\delta\phi_{measured}/\delta\phi_{expected}$ distribution as measured from an electron sample.

The charge misidentification rates are 0.40% and 5.0% for low and high η electrons, respectively.

5 Alignment of the EM Calorimeters

The alignment of the EM calorimeters is important for the shower position measurement. Although the internal alignment of each quadrant is controlled to within $0.1mm$, the positioning of the EM calorimeters usually have on the order of $\approx 1cm$ mechanical allowance in $r - \phi$ plane. Each time the EM calorimeter is pulled out for shutdown maintenance and put back in, it ends up in a different $r - \phi$ position. Therefore, in situ position alignment calibration is necessary in order for this technique to work. The PEM position in $r - \phi$ plane can be described by three parameters: off-centerness in δx and δy directions and a rotation $\delta\phi_o$. The actual ϕ_{cor} and local ϕ are related in the following formula:

$$\phi_{cor} = \phi - \frac{\delta\, x}{R} sin\phi - \frac{\delta\, y}{R} cos\phi - \delta\phi_o, \qquad (1)$$

This technique is self-calibrating in that for each local ϕ bin ϕ_{cor} corresponds to center position of two peaks (e.g. Figure 4) and is easily determined. A sample of electrons and positrons are employed for the calibration. Figure 5 shows $(\phi_{cor} - \phi)$ as a function of ϕ for west and east PEM separately. The dashed lines are fits to the data. Using this alignment technique, the position of calorimeters is known to better than $0.5mm$.

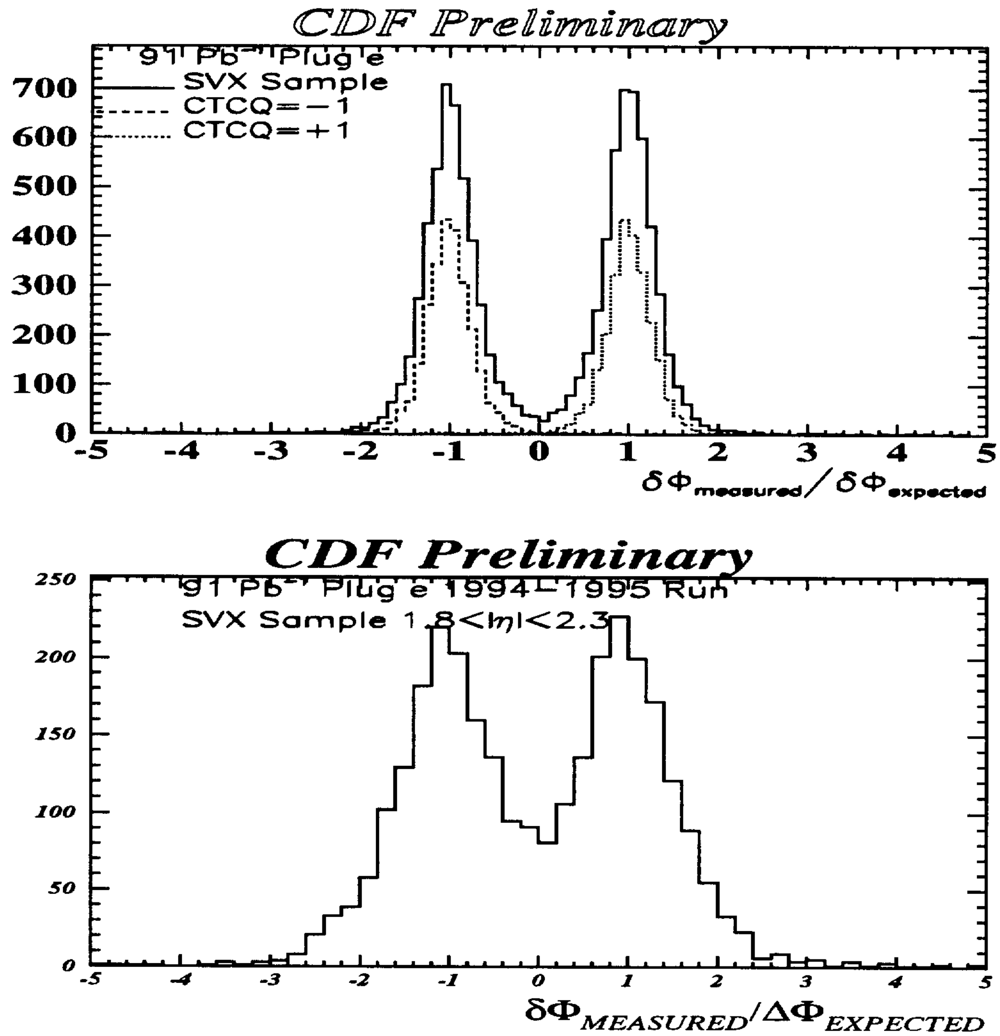

Figure 4: $\delta\phi_{measured}/\delta\phi_{expected}$ for a sample of electrons. The top and bottom plots show electrons from low η bin $(1.2 < |\eta| < 1.8)$ and high η bin $(1.8 < |\eta| < 2.3)$, respectively.

6 Conclusion and Outlook

We have described a new technique for charge determination of electrons in both the central and forward regions. This technique has enabled CDF to determine the charge for electrons in regions up to $|\eta| = 2.3$. As a result, the W lepton charge asymmetry measurement has been extended to high electron rapidity.

In principle a silicon vertex detector in conjunction with an electromagnetic calorimeter with good transverse segmentation can be used to do all of physics with electrons and positrons without the need for any additional tracking information either in the central or in the forward direction. This may be used at the LHC where the luminosity is high, and the central tracker is expected to have a very large number of tracks. Note that if the electromagnetic calorimeter has good transverse segmentation, the energy, η and ϕ of electrons and positrons are already well determined from the calorimetry information alone. In this technique, the sil-

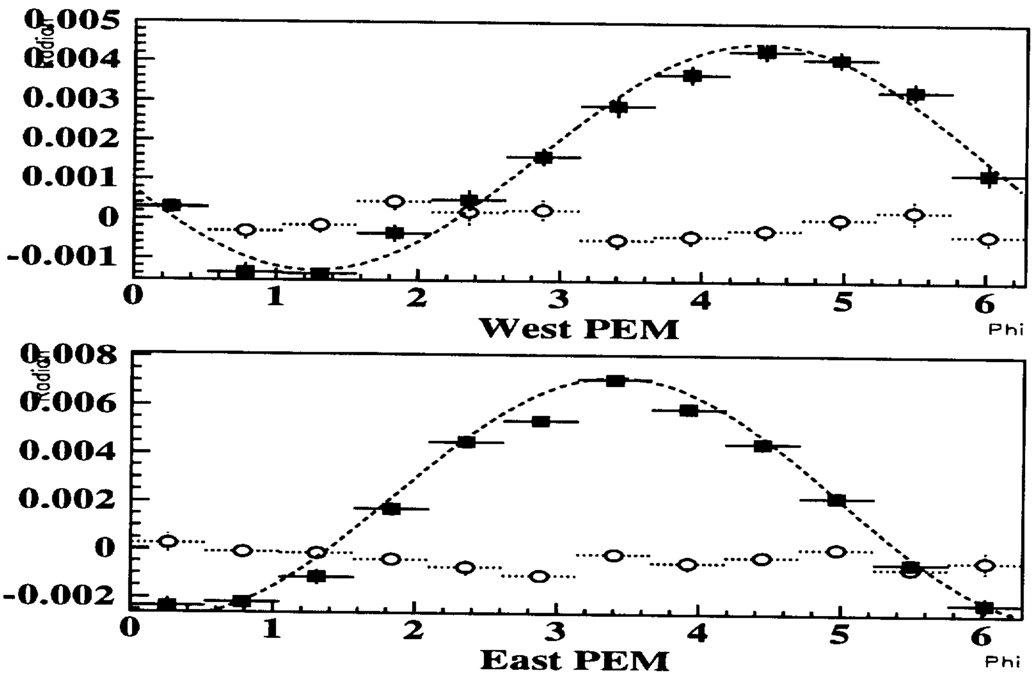

Figure 5: $(\phi_{cor} - \phi)$ as a function of ϕ for west and east PEM separately. Data points in open circles are after alignment corrections.

icon tracking is used only for the sign. Therefore, this use of technique should be kept in mind for future experiments, when the design of both silicon tracking and the EM calorimeters are done.

References

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