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Electron Identification with upgraded VENUS Detector

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Abstract

We describe a new method of electron identification using a large cylindrical transition radiation detector together with Central Drift Chamber and Lead Glass Calorimeter in the VENUS detector system. With this method we have obtained a pion suppression factor of 3600 and an electron efficiency of about 70% for isolated tracks. For pions in hadronic jets the suppression factor is 135 $\sim$ 700 with the electron efficiency of about 60%.

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1 Introduction

The VENUS detector is located at the TRISTAN e^+e^- - storage ring in KEK. TRISTAN is running in high luminosity mode with center of mass (cms) energy $\sqrt{s} = 58 GeV$ and provides an integrated luminosity of about $0.8 pb^{-1}$ per day.

Electron identification of high quality is indispensable in various physics analyses of e^+e^- collision experiments. For example, it enables us to measure forward-backward-asymmetry (A_{FB}) of heavy quark productions in e^+e^- annihilation, using prompt electrons from their semileptonic decay [1]. The asymmetry of b - or c -quark production is expected to reach its maximum at the TRISTAN energy region. Due to hard fragmentation and large mass of the b -quark, leptons originating from b -quark decay have large momenta and large transverse momenta p_T , with respect to the quark direction, while c -quark has a lower mass and therefore the resulting leptons have lower p_T . In general, the c -quark is harder to tag in hadronic jets. With a reliable detection of decay electrons whose momenta are as low as $0.8 GeV/c$, it is possible to separate and measure charm production process event in two photon collisions [2].

To meet requirements of these physics analyses, the VENUS detector system was upgraded by installing a cylindrical transition radiation detector (TRD), which started operation in October 1991. TRD improves our electron identification capability by an order of magnitude. Along with the new detector we have developed a new algorithm to identify electrons. In this article we describe the method used for TRD in conjunction with a lead glass calorimeter (LG) in VENUS to identify electrons. We report first on the performance of each of these components separately and then on the combined ability to identify electrons.

2 The Detector

Components of the VENUS detector (Fig.1) are described in detail elsewhere [3-12]. Three of these which play important roles for electron identification are briefly recalled here. The VENUS coordinate system is defined as usual. Positive z corresponds to the e^- beam direction, φ is the azimuthal angle and ϑ is the polar angle.

Trajectories of charged particles are measured by a central drift chamber (CDC) [3]. CDC has a cylindrical shape with inner radius of 25 cm, outer radius of 126 cm and a length of 300 cm. Its 7104 drift cells are ar-

ranged in 20 axial layers and 9 stereo layers, with stereo angle of $\pm 3.3^\circ$. The magnetic field inside CDC has strength of $0.75 T$. CDC is operated with argon/ethane, 50%/50% mixture and provides us momentum resolution of $\Delta p_t/p_t = \sqrt{(0.008p_t)^2 + (0.013)^2}$ (in GeV/c).

CDC is surrounded by TRD [10,11,12]. The VENUS-TRD is the largest of its type ever performed in a collider experiment. Its inner and outer radius are 127 cm and 158 cm, respectively, with the total length of 296 cm. TRD consists of eight identical sectors, each of which has four layers. One layer consists of a radiator and a 2 cm thick x-ray chamber. The transition radiation produced by electrons is detected by the chamber, operated with xenon/methane mixture in proportional mode. The wire configuration is in a longitudinal drift cell, where the sense wires are located closer to the radiator shell, than to the window, which separates the radiator and the x-ray chamber (Fig.3).

LG [4] consists of 5160 lead glass counters. They are located between the coil and its return yoke, covering the angle region from -37° to 143° in ϑ . One counter has a cross section of $12 \times 11.6 \text{ cm}^2$ and has a length of 30 cm, which corresponds to 18 radiation length. The energy resolution of the calorimeter can be represented as $\sigma/E = 5.4\%/\sqrt{E} + 2.8\%$ (in GeV). Performance of LG is fully described in Ref. [5].

In the following sections, all estimations are made for particles in $|\cos \vartheta| < 0.68$, where either of the detectors described above has a uniform acceptance.

3 Data Sample

Data sample used for the present analysis corresponds to $75 \pm 2 \text{ pb}^{-1}$ with $\sqrt{s} = 58 \text{ GeV}$. The data were taken from October 1991 to July 1992. We have selected following data samples, to evaluate the electron identification ability.

- (i) $e^+e^- \rightarrow e^+e^-(\gamma)$ events: Electron sample. Due to hard gamma radiation in the initial or final state, spectrum of electron extends from $0.5 \text{ GeV}/c$ to $29 \text{ GeV}/c$.
- (ii) $e^+e^- \rightarrow q\bar{q}$ events: Multihadronic event sample [13]. Most of charged tracks in the events can be assumed as pions.
- (iii) Cosmic ray events: Muon sample covering the momentum range between 0.5 and $15 \text{ GeV}/c$.
- (iv) $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ events: Muon sample covering the momentum range between 10 and $29 \text{ GeV}/c$.

4 Electron Identification

4.1 Analysis and results of TRD

The performance of TRD itself is fully described in Ref. [11]. Only the features relevant to the present analysis are recalled here. Every track found in CDC is extrapolated to TRD (Fig.2). Deposited energy in TRD is calculated as follows. Pulse heights of the sense wires (j), for each of the four layers ($i = 1, 2, 3, 4$), whose drift cells are supposed to be crossed by the track (Fig.3), are summed up:

$$X_i = \sum_j A_j^i c_j^i(\varphi, z) g_i(t)/L.$$

Here A_j^i is a pulse height given by ADC modules and c_j^i is a gain correction factor given as a function of φ and z position of the hit. Furthermore, $g_i(t)$ corrects time dependent effects. The variable L stands for path length of the track in the chamber. If there are more than one track hits in a single cell the accumulated pulse height is divided among them, in proportion to the corresponding correction factors for their hit position and their path length. To calculate the deposited energy X_{TRD} of one track, we use truncated mean among X_i 's of the four layers by discarding the largest pulse height.

For tracks in $|\cos \vartheta| < 0.68$, an acceptance of TRD, which is slightly momentum dependent, is 92 % ($0.5 < p < 1 \text{ GeV}/c$) and 96 % ($p > 1 \text{ GeV}/c$). We estimated the efficiency of the connection between CDC tracks and hits in TRD by the sample (i). For about 1% of single electrons the connection fails due to hard photon emission in the shell of CDC or TRD.

To study e/π separation ability, we measure the pulse height of electrons in the sample (i). For pions we used the sample (iii) assuming that the energy deposits of muons can simulate those of pions. In Figure 4, we show X_{TRD} distributions for samples (i) and (iii).

We now apply a cut (X_{TRD}^{cut}) on the X_{TRD} spectra to separate electrons from pions. Since the pulse height for electrons increases with their momentum, we varied X_{TRD}^{cut} , depending on their momentum, which should give us nearly constant electron efficiency. The value of X_{TRD}^{cut} , which gives about 80% electron efficiency was found to be $X_{TRD}^{cut} = 9.8 + 0.97 p$ or $12.7 + 0.08 p \text{ (keV)}$ (p in GeV/c), whichever is smaller. The electron efficiency for X_{TRD}^{cut} cut is shown by squares in Figure 5. We see that the electron efficiency is nearly constant around 80 %. The pion efficiency is around 4% as shown in Figure 6.

4.2 Analysis and results of LG calorimeter

All tracks found in CDC are extrapolated through TRD and coil to LG. Clustering of hit blocks is done in the following way. We first identify a lead glass block to which the track is extrapolated using the CDC information. Around this block we build up a 3×3 array of nine lead glass blocks, which include the hit block in the center of the array. Figure 7 shows the numbering of the blocks with respect to the z - and φ -direction, where No.5 in the center corresponds to the one hit by the track.

In the next step, we sum up the energy of four different possible 2×2 block combinations. These four combinations correspond in Figure 7 to the block numbers (1,2,4,5); (2,3,5,6); (4,5,7,8) and (5,6,8,9). One out of these four combinations with maximum energy deposit is chosen as the cluster corresponding to the track.

We used the electrons in the sample (i) to estimate the efficiency for the connection between a CDC track and the cluster in LG. The connection efficiency was found to be $99.7 \pm 0.3\%$. The inefficiency results mainly from hard photon emission.

Using the distribution of $R = E/p$, the ratio of the energy deposited in a cluster to the corresponding momentum measured in CDC, which has a peak around unity for the electron track, we can discriminate electrons from other particles. Since $\text{mean} < R >$ and deviation σ_R of the R distribution for electrons are slightly dependent on their momentum, we define the following normalized variable

$$\mu = \frac{R - < R >}{\sigma_R},$$

where $< R >$ and σ_R are determined as functions of the electron momentum using sample (i). The resulting μ distribution, which has a gaussian shape with unit variance, is shown for electrons in Figure 8. We choose a cut value $\mu > -2.5$ to select electrons.

The second set of variables for our electron identification with LG, makes use of the fact, that lateral spread of the shower is narrower for electrons than for pions with their hadronic interactions. Therefore, the center of gravity of the shower coincides with the track impact point better for electron than for pions. We define the center of gravity $\bar{x}$, in our chosen four-block cluster.

$$\bar{x} = \frac{\sum E_i x_i}{\sum E_i}$$

The variable E_i stands for the energy of our chosen four blocks ($i = 1, 2, 3, 4$) and the position x_i is the center position of the corresponding lead glass

counter. We now define the variables $r\Delta\varphi$ and Δz as the distance between $\bar{x}$ and the impact point on the block surface, extrapolated from the track measured in CDC as illustrated in Fig. 2. The distribution of $r\Delta\varphi$ and Δz for electrons (sample (i)) is shown in Figure 9. We choose cut values of $r\Delta\varphi, \Delta z < 6.5 \text{ cm}$ to select electrons.

The resulting efficiency of isolated electrons for our cuts $\mu > -2.5$ and $r\Delta\varphi, \Delta z < 6.5 \text{ cm}$, is shown by circles in Figure 5. Since isolated pions are not available with the data taken in the e^+e^- annihilation, we only recall the efficiency for pions obtained in a beam test with $4 \text{ GeV}/c$ [5], where the efficiency of LG for isolated pions is given as 7×10^{-3} with the electron efficiency of 97 %.

If we take into account the isolated pion efficiency of about 4% for the TRD selection, we obtain an overall efficiency of 2.8×10^{-4} for isolated pions as a combined performance with both TRD and LG, while that for the electron is as large as 80% as shown by crosses in Figure 5.

4.3 Electron Identification in Jets

Since particles produced in high energy collision form jets, the electron track there may overlap with nearby hadron tracks. Thus the efficiency of electrons in hadronic jets is lowered comparing with the isolated case given in the previous section. The probability that an electron overlaps with other tracks becomes larger, if the electron is closer to a jet axis, where the hadronic tracks are crowded. Therefore, we have to give the electron efficiency in hadronic jets as functions of their momentum and transverse momentum (p_T) with respect to the jet axis.

To study the reduction in electron efficiency due to overlaps, we superimposed the samples (i) and (ii). This means, we simulated electrons in hadronic jets by superimposing the electron tracks taken from real events on hadronic events [14]. Then, we reconstructed this superimposed events and applied our electron identification.

From this study we found that the electron efficiency was reduced by about 10% in hadronic events, including the degradation of the track reconstruction efficiency in CDC which was estimated as $94 \pm 1\%$. The efficiency of electrons in hadronic jets is summarized in bins of p and p_T in Table 1. Besides the overall efficiency we show the following efficiencies separately: one that the superimposed electron passes the cuts with the given LG variables ($\mu > -2.5$); ($r\Delta\varphi, \Delta z < 6.5 \text{ cm}$) and that the electron passes the cuts on the truncated mean energy of TRD ($X_{TRD} > X_{TRD}^{\text{cut}}$). The errors in this table originate

from the limited statistics of our event sample.

The corresponding efficiencies of the electron identification for pions are given in Table 2, also in the same binnings of p and p_T . In determining the pion efficiencies in multihadronic events, we took the advantage of the fact, that we have two independent devices, LG and TRD to identify electrons. We now reverse the role of the cut to select electrons in a device to select a clean pion sample. This clean pion sample enables us to determine the efficiency of pions in another device.

In practice we selected pion tracks of high purity by TRD with the requirement of $X_{TRD} < 8keV$ (denoted hereafter as $\overline{TRD}$). This provides us an electron efficiency of 5%, while the pion efficiency is around 80%. Similarly an independent selection of very clean pion tracks was made with LG by requiring $\mu < -7$ (denoted hereafter as $\overline{LG}$), where the shower shape cut described in the previous chapter was also made. The pion efficiency for the electron identification in LG was evaluated by $\overline{TRD}$ and that in TRD by $\overline{LG}$. The overall efficiency for pions including TRD acceptance given in Chapter 4.1 is also summarized in Table 2. It is noted that the present LG clustering algorithm gives a better pion rejection in LG by about 10% than that using a simple 3×3 -block cluster described in the previous chapter in the whole region of p and p_T .

For multihadronic events, the number of pions remaining in the final electron sample can be evaluated reliably by scaling the μ spectra for $\overline{TRD}$ in the region $\mu < -7$ to that made with the electron selections other than the cut on μ as shown in Figure 10. The number of pions is represented by the number of entries in the region $\mu > -2.5$ of the scaled spectra indicated by the hatched area in Figure 10. Pion background is found to be $11 \pm 1\%$ in the final electron sample ($p > 1GeV/c$) including conversion electrons described later. In a similar manner, we can estimate it with X_{TRD} spectrum for $\overline{LG}$. Here we normalize it in the region below $8keV$ to that for the electrons selected with the LG information and count the number of entries in the region $X_{TRD} > X_{TRD}^{cut}$ of the normalized spectrum. Both of the estimations agree well within their statistical errors. The results given in Ref. [1], where the pion background is evaluated in a slightly different way, are also consistent with the present one.

5 Rejection of Electrons from Photon Conversions

The set of electron candidates, which fulfill the electron identification criteria described above, contains not only electrons from heavy quark decay, but also those from Dalitz decay of neutral pions or conversions of photons. Typically these pairs of opposite charged tracks have small invariant mass. A photon conversion candidate has to fulfill all four following criteria to be rejected.

- (1) Due to uncertainties in pattern recognition, the trajectories of both tracks do not meet exactly at a point. Most of them overlap or are separated by a minimum distance Δ . We choose $\Delta < 1.5 cm$ as a criterion.
- (2) The second criterion use the angle Θ_{conv} between the two tracks at the vertex point. The vertex point is defined as the crossing of the two tracks. If the two tracks are separated we assume the point of closest approach of these tracks as the vertex. If both tracks are reconstructed in three dimensions, we require $\cos \Theta_{conv} > 0.85$. If one of the two tracks is not reconstructed in three dimensions, we require $\cos \Theta_{conv} > 0.95$ in a $r - \phi$ plane, respectively.
- (3) We assume as the next criterion, that the angle α between the momentum sum vector of the track pair and the direction vector from the e^+e^- interaction point to the photon conversion point is small. We choose $\alpha < 0.15 rad$ as our criterion.
- (4) We calculate the invariant mass of the two opposite charged tracks, assuming the electron mass for both tracks. Its value below $M_{ee} < 200 MeV$ is assumed to come from photon conversions. Therefore we choose this value as a criterion.

Furthermore, electron candidates with a closest approach to the interaction point of $R_{min} < -0.3 cm$ (Figure 11) are regarded as electrons from photon conversions in the detector material.

A Monte Carlo simulation shows that the rejection efficiency for photon conversion electrons is $(88 \pm 1)\%$ including those from Dalitz decay of neutral pions, while the loss of prompt electrons is $(14 \pm 1)\%$ ($p > 1 GeV$). The rejection efficiencies are summarized in Table 3. Figure 12 shows a vertex distribution of the selected conversion candidates in comparison with the simulation. It is found that the simulation is reliable with better than 10% accuracy for the estimation of the rejection efficiency.

6 Summary

The new VENUS electron identification method presented here is a powerful tool to select isolated electrons and electrons in jets of hadronic events. TRD has been proven to be an excellent tool to identify electrons close to the jet axis, due to the fact that the TRD provides an uniform pion efficiency over the whole range of p and p_T . The final pion efficiency with LG and TRD is 7.4×10^{-3} to 1.4×10^{-3} keeping the efficiency for electrons around 60% in multihadronic events.

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Table 1: Efficiency for Electrons in Jets

Lead Glass Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	74.6 ± 1.6	82.7 ± 1.3	—
$1.0 < p < 2.0$	82.2 ± 1.3	87.2 ± 1.0	89.3 ± 1.2
$2.0 < p < 3.0$	84.0 ± 1.1		88.2 ± 1.0
$3.0 < p < 5.0$	88.6 ± 0.8		89.9 ± 0.7
$p > 5.0$	86.9 ± 1.2		86.5 ± 1.2

Table 2: Efficiency for Pions in Jets

Lead Glass Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	8.6 ± 0.3	7.7 ± 0.5	—
$1.0 < p < 2.0$	4.8 ± 0.2	2.5 ± 0.2	2.1 ± 0.3
$2.0 < p < 3.0$		5.6 ± 0.4	2.2 ± 0.4
$3.0 < p < 5.0$		5.6 ± 0.4	3.1 ± 0.4
$p > 5.0$		6.1 ± 0.5	2.4 ± 0.3

TRD Efficiency [%]

TRD Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	71.8 ± 1.6	72.8 ± 1.5	—
$1.0 < p < 2.0$	76.3 ± 1.5	77.3 ± 1.2	77.9 ± 1.6
$2.0 < p < 3.0$	78.6 ± 1.2		80.6 ± 1.2
$3.0 < p < 5.0$	79.8 ± 1.0		79.6 ± 0.9
$p > 5.0$	76.4 ± 1.6		77.8 ± 1.5

Overall Efficiency [%]

Overall Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	50.9 ± 1.6	57.4 ± 1.6	—
$1.0 < p < 2.0$	56.7 ± 1.6	59.9 ± 1.4	62.1 ± 1.8
$2.0 < p < 3.0$		60.9 ± 1.3	64.1 ± 1.3
$3.0 < p < 5.0$		65.3 ± 1.1	65.4 ± 1.0
$p > 5.0$		60.3 ± 1.8	62.8 ± 1.6

TRD Efficiency [%]

TRD Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	9.8 ± 0.8	8.5 ± 1.1	—
$1.0 < p < 2.0$	9.4 ± 0.5	7.7 ± 0.5	7.2 ± 0.7
$2.0 < p < 3.0$		9.7 ± 0.6	8.0 ± 0.8
$3.0 < p < 5.0$		8.0 ± 0.6	7.1 ± 0.7
$p > 5.0$		10.8 ± 0.9	9.1 ± 0.7

Overall Efficiency [%]

Overall Efficiency [%]			
p, p_T [GeV/c]	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$
$0.5 < p < 1.0$	0.74 ± 0.08	0.53 ± 0.12	—
$1.0 < p < 2.0$	0.40 ± 0.06	0.16 ± 0.06	0.14 ± 0.08
$2.0 < p < 3.0$		0.48 ± 0.11	0.16 ± 0.09
$3.0 < p < 5.0$		0.38 ± 0.10	0.20 ± 0.10
$p > 5.0$		0.57 ± 0.14	0.19 ± 0.09

Figure Captions:

Figure – 1 : A cut-through one quadrant of the VENUS detector.

Figure – 2 : A cross sectional view of the VENUS system perpendicular to the beam line. Tracks of a hadronic event extrapolated to TRD and LG are shown.

Figure – 3 : Cell structure of X-ray chamber. Effective cells are tilted by magnetic field. S, P and G stand for sense, potential and grid wire, respectively. In this example, pulse heights from S_{j-1}, S_j and S_{j+1} are added to calculate a total charge.

Figure – 4 : Truncated mean energy measured in TRD (X_{TRD}) for electrons and pions ($1 < p < 3 \text{ GeV}/c$).

Figure – 5 : Electron efficiencies for isolated tracks. TRD efficiency, LG efficiency and combined efficiencies of both components are shown.

Figure – 6 : Pion efficiency of TRD for isolated tracks.

Figure – 7 : Example for 4-block clustering method. Numbering of the 3×3 array of lead glass blocks with respect to the z - and φ - direction.

Figure – 8 : μ spectrum for electrons. We choose the cut value $\mu > -2.5$ for the electron identification.

Figure – 9 : $\tau\Delta\varphi$ (solid line), Δz (broken line) distribution for electrons. We choose the cut value $\tau\Delta\varphi, \Delta z < 6.5 \text{ cm}$.

Figure – 10 : μ spectrum for $\overline{TRD}$ (shaded histogram), which is scaled in $\mu < 7$ to the solid histogram representing the spectrum for the final electron sample. The hatched area indicates the remaining hadronic background.

Figure – 11 : Schematic illustration of definition of the variables used in the rejection of the photon conversions.

Figure – 12 : Vertex distribution of photon conversion candidates, selected by the present algorithm. R_{vertex} is the distance from the interaction

Table 3: Conversion Rejection efficiency

$p, p_T \text{ [GeV}/c]$	Rejection efficiency [%]			
	$0.0 < p_T < 0.5$	$0.5 < p_T < 1.0$	$p_T > 1.0$	
$0.5 < p < 1.0$	95 ± 1	87 ± 3	–	66 ± 8
$1.0 < p < 2.0$	90 ± 2	83 ± 3		78 ± 9
$2.0 < p < 3.0$	90 ± 3			79 ± 9
$3.0 < p < 5.0$	86 ± 4			83 ± 9
$p > 5.0$	60 ± 8			

tion point to the conversion vertex. The data are taken from multihadronic events, histogram shows Monte-Carlo prediction, normalized by luminosity. Peaks correspond to the beam pipe, trigger chamber and inner wall of CDC

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12