Chapter 5

Determination of $b\bar{b}$ event fraction

The amount of $b\bar{b}$ events in the data sample is estimated using the p_T^{rel} and the impact parameter distributions. Both distributions are fitted to a four components sum of the hadron, the conversion, the $c\bar{c}$ and the $b\bar{b}$ templates. The results described the previous chapter are used as constraints on non-heavy flavor background fraction when we make this fit.

In this chapter, we started with the control samples to obtain the templates for the fit of the p_T^{rel} and the impact parameter distributions.

5.1 Control samples for p_T^{rel} and impact parameter fit

Monte Carlo sample for $b\bar{b}$ and $c\bar{c}$

In order to obtain the templates for the $b\bar{b}$ and $c\bar{c}$ events, we use the `PYTHIA 5.7` Monte Carlo simulator. We use the tuned `PYTHIA 5.7` which was modeled to reproduce the underlying multiplicity of $l + D^0$ sample [31]. The b-quarks and c-quarks are generated with p_T above 12 GeV/c so as to produce a high p_T electron through its decay. In order to reduce the CPU time for the event generation, both b and c quarks are forced to decay into an electron plus anything with the `QQ` Monte Carlo program which deal with b and c hadron decays developed by the CLEO group [32]. The $\bar{b}$ and $\bar{c}$ quarks generated at the same time are not forced so as to keep the right branching ratio of their decay. A generator-level filter simulates the effect of the Level-2 trigger. The following p_T dependent trigger efficiency is used in the trigger simulation,

$$\epsilon(p_T) = 0.927 \times F\left(\frac{p_T - 6.18}{4.20}\right) \times F\left(\frac{p_T - 7.48}{0.504}\right).$$

where F represents the normal frequency function,

$$F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{1}{2}t^2}\, dt.$$

The kinematical cuts of $p_T > 8$ GeV/c and $|\eta| < 1.2$ are also applied to the electron in the generator-level filter. The events satisfying the generator level selection are processed by the fast CDF detector simulation (QFL). After the detector simulation, the Monte Carlo events are treated as if they were real data. Finally the events passing the selection criteria composes the samples for the $b\bar{b}$ and the $c\bar{c}$ events.

Sequential $b \to c \to e$ decay

The real data contains not only the electrons from direct $b \to e$ decays but also the electrons from sequential $b \to c \to e$ decays. The fraction of sequential $b \to c \to e$ decays in the electron sample is studied using the Monte Carlo simulation without forcing to the semi-leptonic decay. Table 5.1 gives the fractions of electrons from the direct $b \to e$ decay and the sequential $b \to c \to e$ decays.

The fraction of sequential $b \to c \to e$ decays in all $b\bar{b}$ events is found to be 4.5±0.4%($stat$). We use this event fraction to make the more precise template for the $b\bar{b}$ events than with only the direct $b \to e$ decays.

In order to generate the sequential $b \to c \to e$ decay events, we force all c hadrons with the parent of the b hadrons to decay semileptonically. The event sample of this sequential $b \to c \to e$ decay is obtained in the same way as stated above.

b-hadrons	$B^{\pm}$	B^0	B_s	Λ_b	–
$95.5 \pm 0.2(\%)$	38.0 ± 1.3	40.4 ± 1.3	8.8 ± 0.6	8.4 ± 0.5	–
c-hadrons	$D^{\pm}$	D^0	J/ψ	D_s	Λ_c
$4.5 \pm 0.4(\%)$	1.5 ± 0.2	1.3 ± 0.2	1.1 ± 0.2	0.5 ± 0.1	0.1 ± 0.1

Table 5.1: Sources of the trigger electron in the $b\bar{b}$ Monte Carlo simulation data.

Hadron sample with a SVX track

A hadron sample with a SVX track is selected with the following selection criteria:

- Apply all electron identification cuts shown in Table 3.1 except for the requirements of the HAD/EM and the CPR
- HAD/EM>0.04 for one track or HAD/EM>0.10 for more than one track
- CPR charge < 2.0
- (Energy measured in the CES strip)/p < 0.5
- Require the measured Q_{CTC} for the track to be smaller than the predicted value for electron

Photon conversion sample with a SVX track

A photon conversion sample with a SVX track is selected with the following selection criteria:

- Apply all electron identification cuts shown in Table 3.1 except for the requirements of the conversion rejection
- Identify a conversion using the conversion finding method: $|\delta S| < 0.2$(cm) and $|\delta \cot\theta| < 0.06$

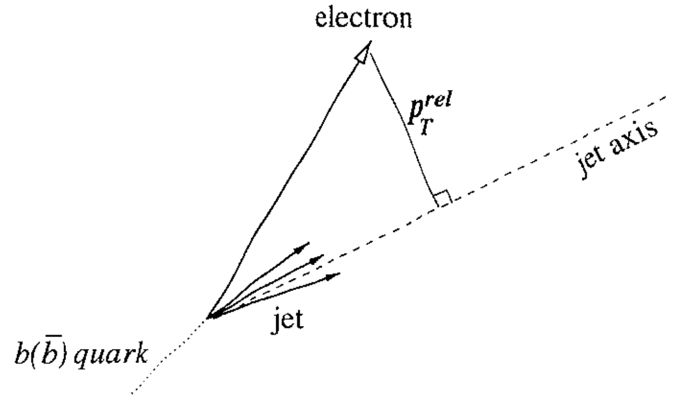

Figure 5.1: Definition of the p_T^{rel}.

- Require the measured Q_{CTC} for the conversion partner track to be larger than the predicted value for electron by one sigma

5.2 Results of ${p_T}^{rel}$ fit

The ${p_T}^{rel}$ is the transverse momentum of the electron relative to the associating jet axis as shown in Fig. 5.1. It clearly reflects the mass of the parent particle. The jet is reconstructed using the track information with the CTC using the algorithm described in Sec. 3.1.1. In the ${p_T}^{rel}$ calculation, the associating jet axis is determined by subtracting the electron momentum vector from the jet momentum vector so as to define the jet excluding the electron.

The ${p_T}^{rel}$ templates of $b\bar{b}$, $c\bar{c}$, hadron fakes and conversions are made using the samples described in the previous section. Figures 5.2(a)-(d) show the ${p_T}^{rel}$ distributions for the samples. The templates are obtained by fitting the distributions to the following empirical function [33],

$$f(x) = P_1 x^{P_2} exp\left[P_3 x^{P_4}\right] + \frac{P_5}{P_7} exp\left[-\frac{1}{2}\left(\frac{x-P_6}{P_7}\right)^2\right].$$

The templates for the $b\bar{b}$ events shown in Fig. 5.2(d) are obtained by studying the two kinds of the b-quark decay modes, the direct $b \to e$ decay and the sequential $b \to c \to e$ decay. The ${p_T}^{rel}$ distributions of the direct $b \to e$

decay and the sequential $b \to c \to e$ decay are shown in Figs. 5.3(a) and (b). The distribution for the sequential $b \to c \to e$ decay shows softer spectrum than for the direct $b \to e$ decay. We mix both templates for the direct and sequential decays with a ratio of 95.5:4.5 to obtain the whole $b\bar{b}$ event templates as shown in Fig 5.2(d).

We fit the p_T^{rel} distribution for the whole electron sample to a sum of the templates for the $b\bar{b}$, $c\bar{c}$, conversion and hadron with the maximum binned likelihood method described in Appendix D.1. In the likelihood function, Gaussian terms are introduced to constrain the contribution of the conversions and hadron faking electrons according to the results of the independent analysis described in the previous chapter. The ${p_T}^{rel}$ distribution for the whole electron sample is shown in Fig. 5.4 together with a fitted curve. The fit yields the $b\bar{b}$ fraction of 42.9 ± 0.4(stat)% for the whole electron sample.

The p_T^{rel} distribution for the diffractive candidates is also fitted to a sum of the four templates with the maximum likelihood method (Appendix D.2). The Gaussian terms are also introduced to constrain the contribution of the conversions and hadron faking electrons. The ${p_T}^{rel}$ distribution for the diffractive candidates is shown in Fig. 5.5 together with a fitted curve. We obtain 38.1 ± 13.5(stat) $b\bar{b}$ events in 100 diffractive candidates by this fit.

The fit results of the ${p_T}^{rel}$ distribution are summarized in Tables 5.2 and 5.3.

	hadron	conversion	$c\bar{c}$	$b\bar{b}$
input from CPR	41489±1063	4924±172	–	–
and ε_{conv}	(25.6±0.7)%	(3.0±0.1)%	–	–
outputs	43554±931*	5000±168*	43668±726	69165±724
	(27.0±0.6)%*	(3.1±0.1)%*	(27.1±0.4)%	(42.9±0.4)%

Table 5.2: The number of hadron faking electrons, photon conversion, $c\bar{c}$ and $b\bar{b}$ events in the **whole electron sample** obtained with the p_T^{rel} distribution fit. *Fit is constrained to the inputs.

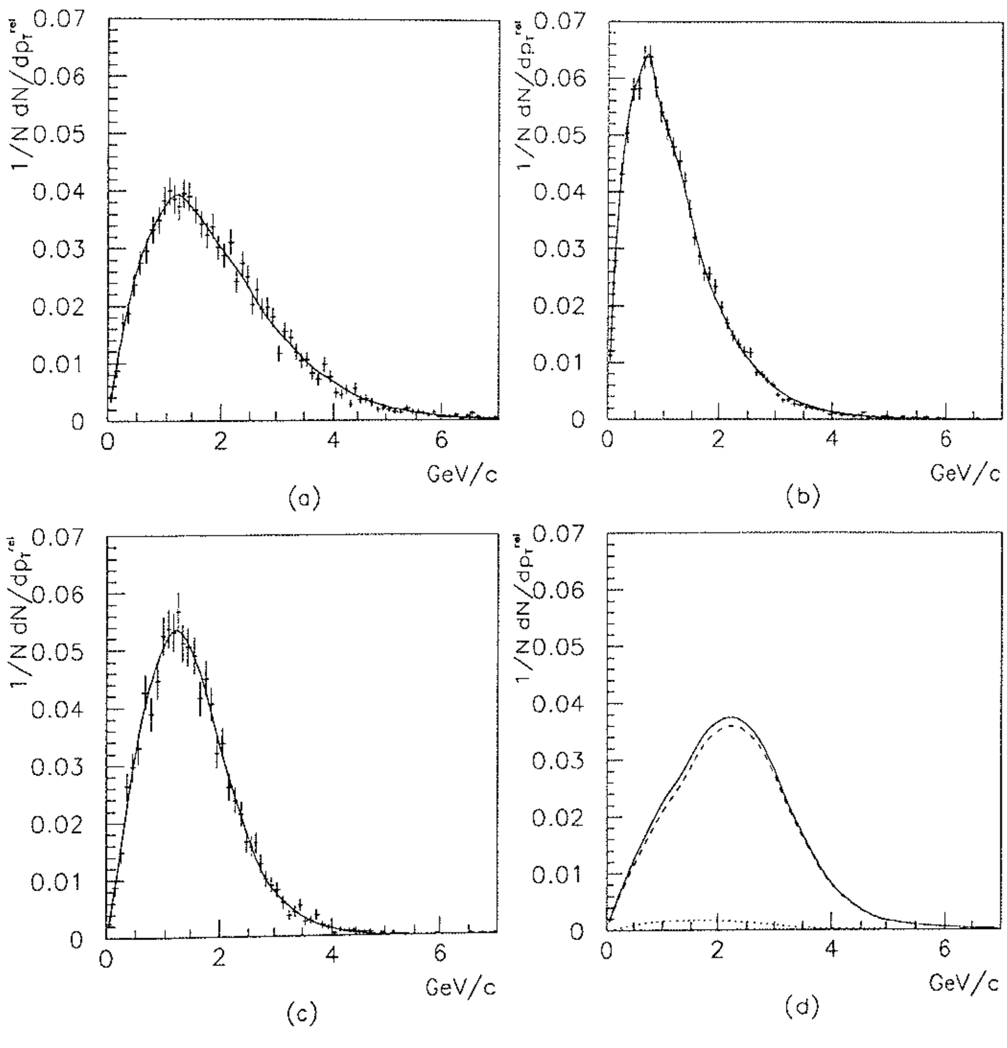

Figure 5.2: The p_T^{rel} distribution for (a) hadron faking electrons, (b) photon conversions, (c) $c\bar{c}$ Monte Carlo, and (d) $b\bar{b}$ Monte Carlo (dashed curve:direct $b \to e$ decays, dotted curve:sequential $b \to c \to e$ decays).

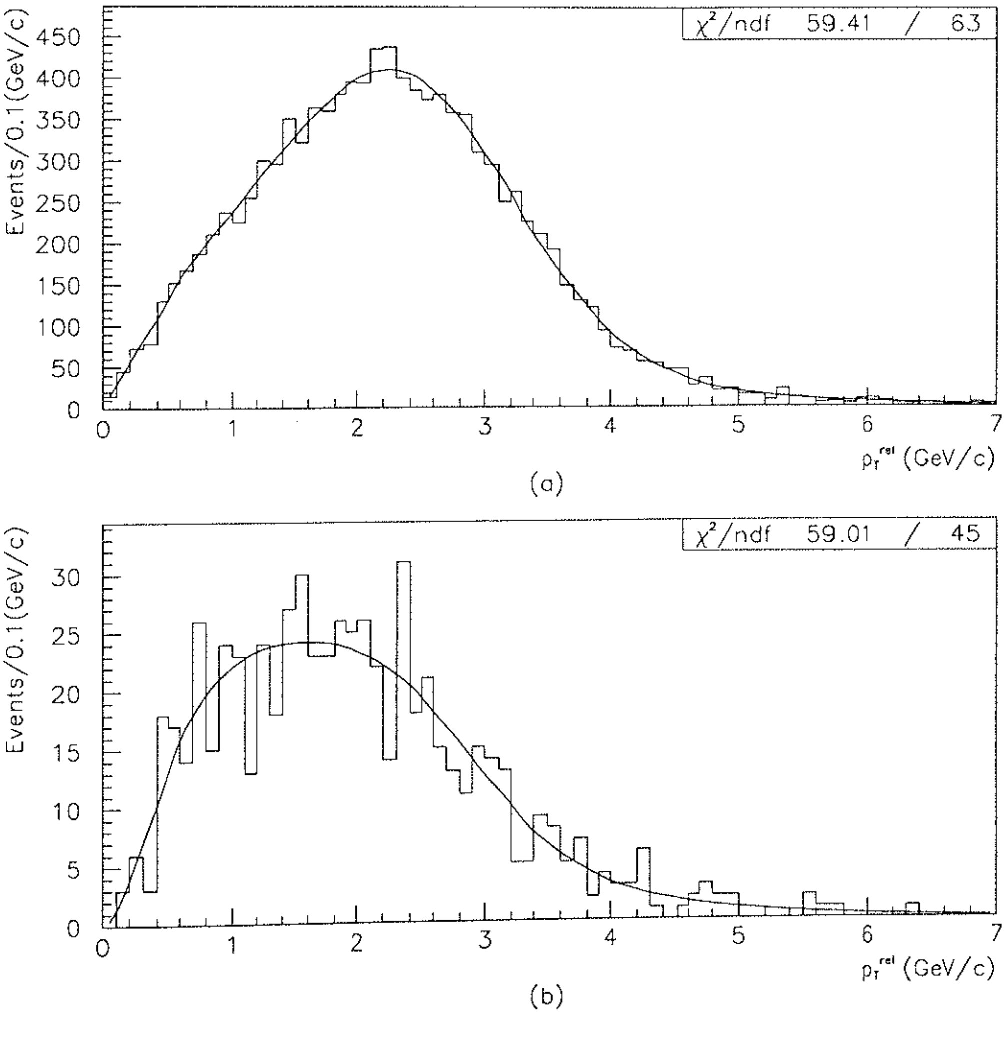

Figure 5.3: The p_T^{rel} distribution for the Monte Carlo samples. (a) Direct $b \to e$ decays (b) Sequential $b \to c \to e$ decays

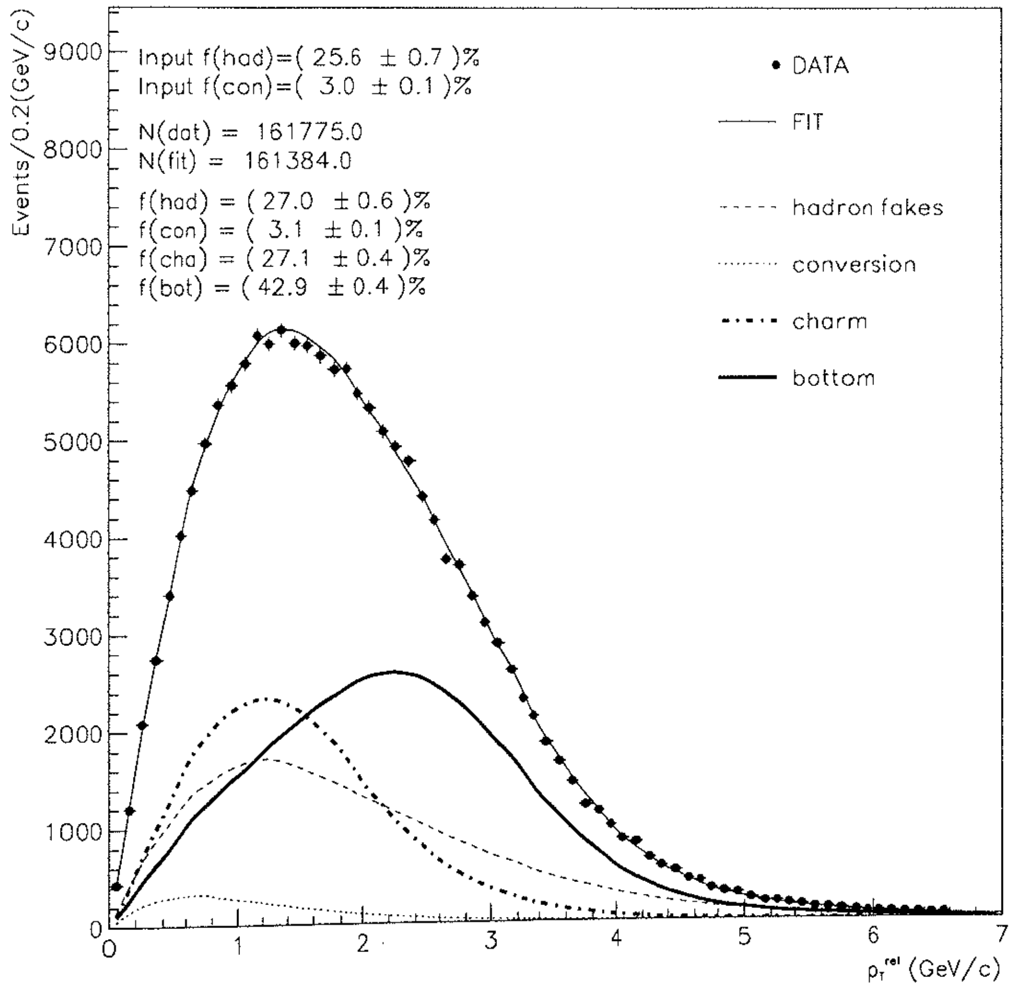

Figure 5.4: The p_T^{rel} distribution for the whole electron sample. The results of the four-component fit are also shown. Dashed curve shows hadron faking electrons, dotted curve shows conversions, thick dashed curve shows $c\bar{c}$ and thick solid curve shows $b\bar{b}$.

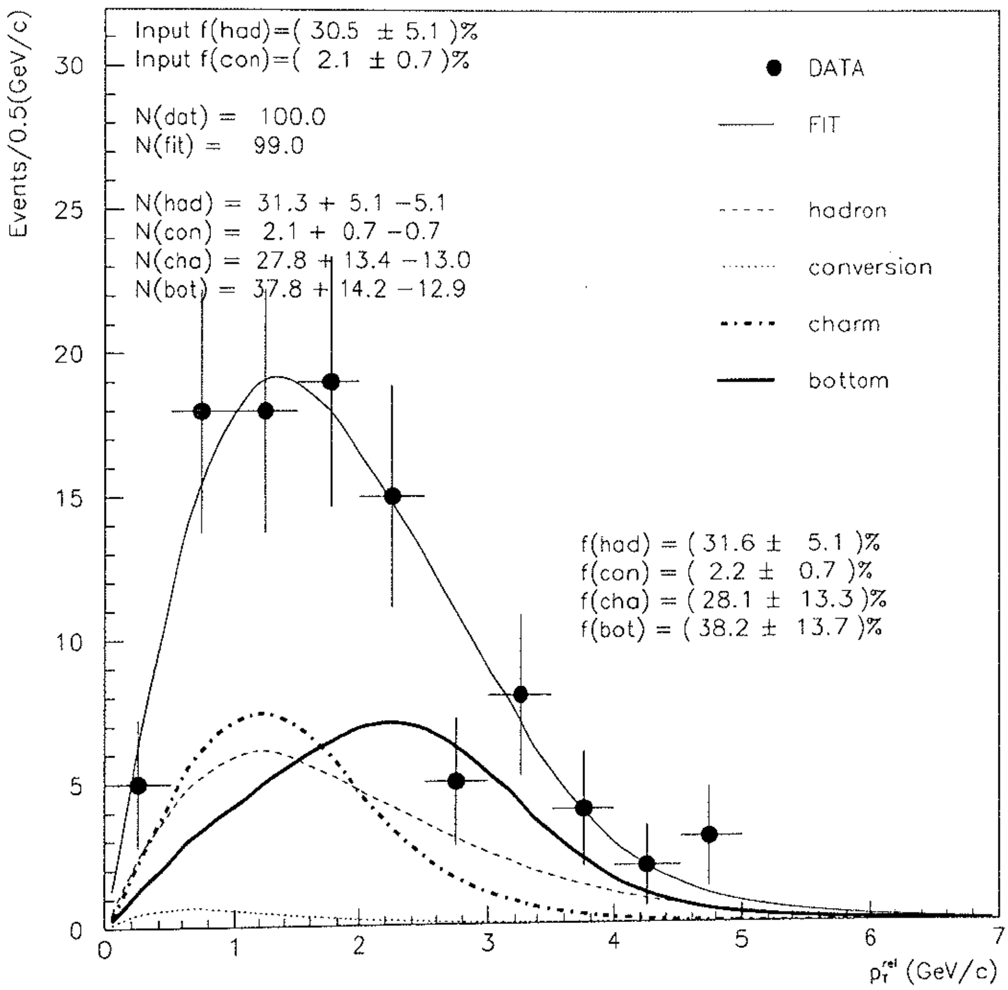

Figure 5.5: The p_T^{rel} distribution of the diffractive candidates. The results of the four-component fit are also shown. Dashed curve shows hadron faking electrons, dotted curve shows conversions, thick dashed curve shows $c\bar{c}$ and thick solid curve shows $b\bar{b}$.

	hadron	conversion	$c\bar{c}$	$b\bar{b}$
inputs from CPR	30.5±5.1	2.1±0.7	—	—
and ε_{conv}	(30.5±5.1)%	(2.1±0.7)%	—	—
outputs	31.3±5.1*	2.1±0.7*	27.8±13.2	37.8±13.6
	(31.6±5.1)%*	(2.2±0.7)%*	(28.1±13.3)%	(38.2±13.7)%

Table 5.3: The number of hadron, conversion, $c\bar{c}$ and $b\bar{b}$ events in the **diffractive candidates** obtained with the p_T^{rel} distribution fit. *Fit is constrained to the inputs.

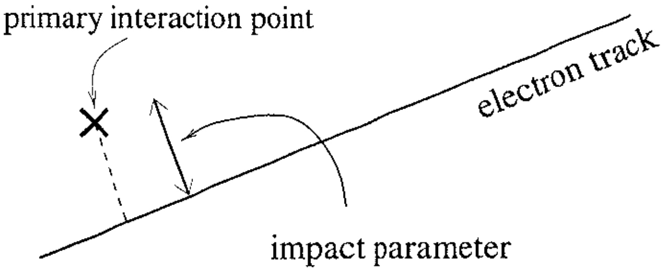

Figure 5.6: Definition of the impact parameter.

5.3 Results of impact parameter fit

The impact parameter is defined as a minimum distance between a primary vertex and the electron track in a r-ϕ plane as shown in Fig. 5.6.

The impact parameter reflects the mass and the lifetime of the parent particle according to the following expression [34];

$$\delta = \frac{c\tau_b}{k}, \quad k \equiv \frac{1+\beta\cos\theta^*}{\beta\sin\theta^*}$$

where $c\tau_b$ is a proper decay length of the parent particle, β is a velocity of the parent particle and θ^* is an angle in space between the direction of the parent particle and the electron track in the rest frame of the parent particle.

The impact parameter distribution for each control sample is shown in Figs. 5.7(a)-(d).

The template for the hadrons faking electrons is obtained by fitting the impact parameter distribution for the hadron sample to a sum of two functions, Gaussian and exponential.

$$f(x) = P_1 \frac{2}{\sqrt{2\pi}P_2} exp\left[-\frac{1}{2}\left(\frac{x}{P_2}\right)^2\right] + P_3 e^{P_4 x}$$

Since most hadrons are produced directly at a primary interaction point, the impact parameter distribution for the hadrons can be fit to a Gaussian function which represents a detector resolution for the measurement. The exponential function represents a small contamination of electrons from heavy flavor decay in the hadron sample. Only the Gaussian term is used for a template for hadrons. We also use this Gaussian as a resolution function to make templates for the $b\bar{b}$ and $c\bar{c}$ events as described below.

The impact parameter distribution for the conversion sample is parameterized by

$$f(x) = P_1 \frac{1}{\sqrt{2\pi}P_2} exp\left[-\frac{1}{2}\left(\frac{x}{P_2}\right)^2\right] + P_3 e^{P_4 x} + P_5 e^{P_6 x}.$$

The Gaussian term is a resolution function for the electrons from π^0 Dalitz decay. The exponential terms comes from the conversion electrons produced in the material inside the detector.

In order to obtain the templates for electrons from heavy flavor decay, we perform the following steps. At first we parameterize the impact parameter distribution for the sample at a generator level. Next we smear the fit function according to the resolution function measured for the hadron sample.

Figures 5.8(a)-(c) show the impact parameter distributions for the Monte Carlo sample of the direct $b \to e$ decays, the sequential $b \to c \to e$ decays and the $c\bar{c}$ events at a generator level. These distributions are parameterized by

$$f(x)_{gen} = P_1 e^{P_2 x} + P_3 e^{P_4 x} (+P_5 e^{P_6 x})$$

where the last term is only used for the $b \to e$ sample. The $b\bar{b}$ template is made by adding the direct and sequential decay samples with a ratio of 95.5:4.5. Final templates for the $c\bar{c}$ and $b\bar{b}$ events are made by smearing the parameterized functions using the resolution function.

We fit the impact parameter distribution for the whole electron sample to a sum of the above templates with a maximum binned likelihood method described in Appendix D.1. In the likelihood function, Gaussian terms are introduced to constrain the contribution of the conversions and hadron faking electrons in the same way as in the p_T^{rel} fit. The impact parameter distribution for the whole electron sample is shown in Fig. 5.9 together with a fitted curve. The fit yields the $b\bar{b}$ fraction of 47.7 ± 0.4% in the whole electron sample.

The impact parameter distribution for the diffractive candidates is fitted to a sum of above templates with a maximum likelihood method described in Appendix D.2. The contributions of conversions and hadrons are also constrained to the results described in Chapter 4. The fit yields 50.7 ± 14.9(stat) $b\bar{b}$ events in 100 diffractive candidates.

The fit results of the impact parameter distribution are are summarized in Tables 5.4 and 5.5.

	hadron	conversion	$c\bar{c}$	$b\bar{b}$
inputs from CPR	41489±1063	4924±172	–	–
and ε_{conv}	(25.6±0.7)%	(3.0±0.1)%	–	–
outputs	48398±852*	5160±171*	30538±1306	76792±653
	(30.1±0.5)%*	(3.2±0.1)%*	(19.0±0.8)%	(47.7±0.4)%

Table 5.4: The number of hadron faking electron, conversion, $c\bar{c}$ and $b\bar{b}$ in the **whole electron sample** obtained with the impact parameter fit. *Fit is constrained to the inputs.

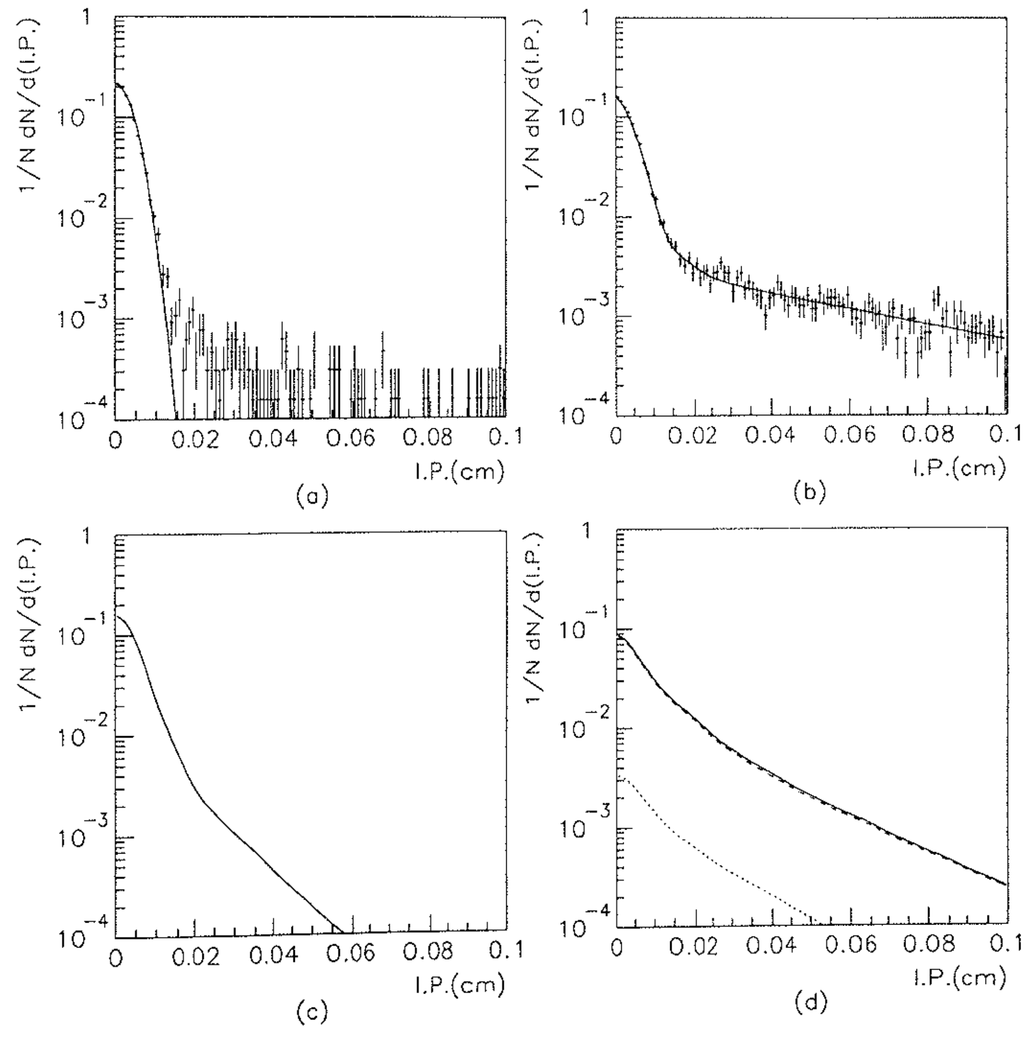

Figure 5.7: The impact parameter distributions for (a) hadron faking electrons, (b) photon conversions, (c) $c\bar{c}$ Monte Carlo, and (c) $b\bar{b}$ Monte Carlo (dashed curve:direct $b \to e$ decays, dotted curve:sequential $b \to c \to e$ decays).

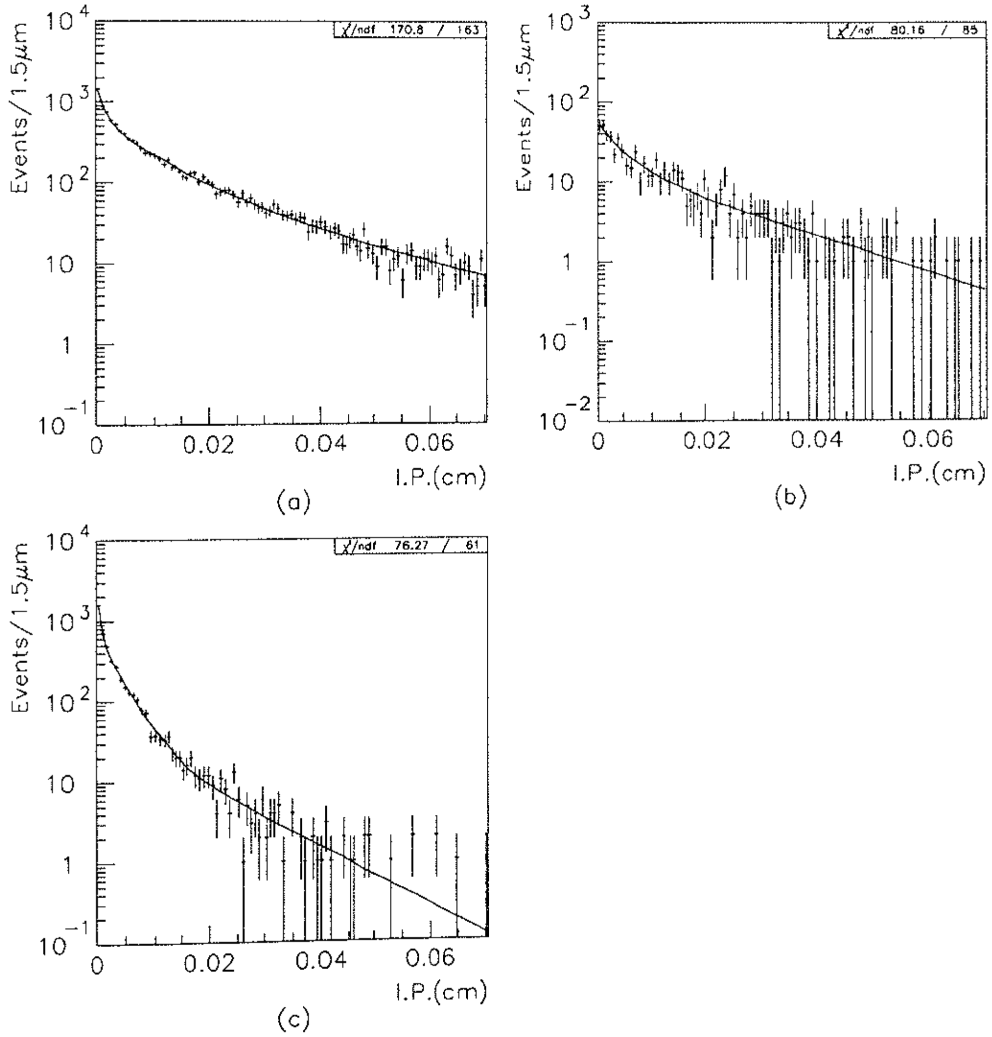

Figure 5.8: The impact parameter distributions without detector resolution. (a) Direct $b \to e$ decays (b) Sequential $b \to c \to e$ decays (c) $c \to e$ decays

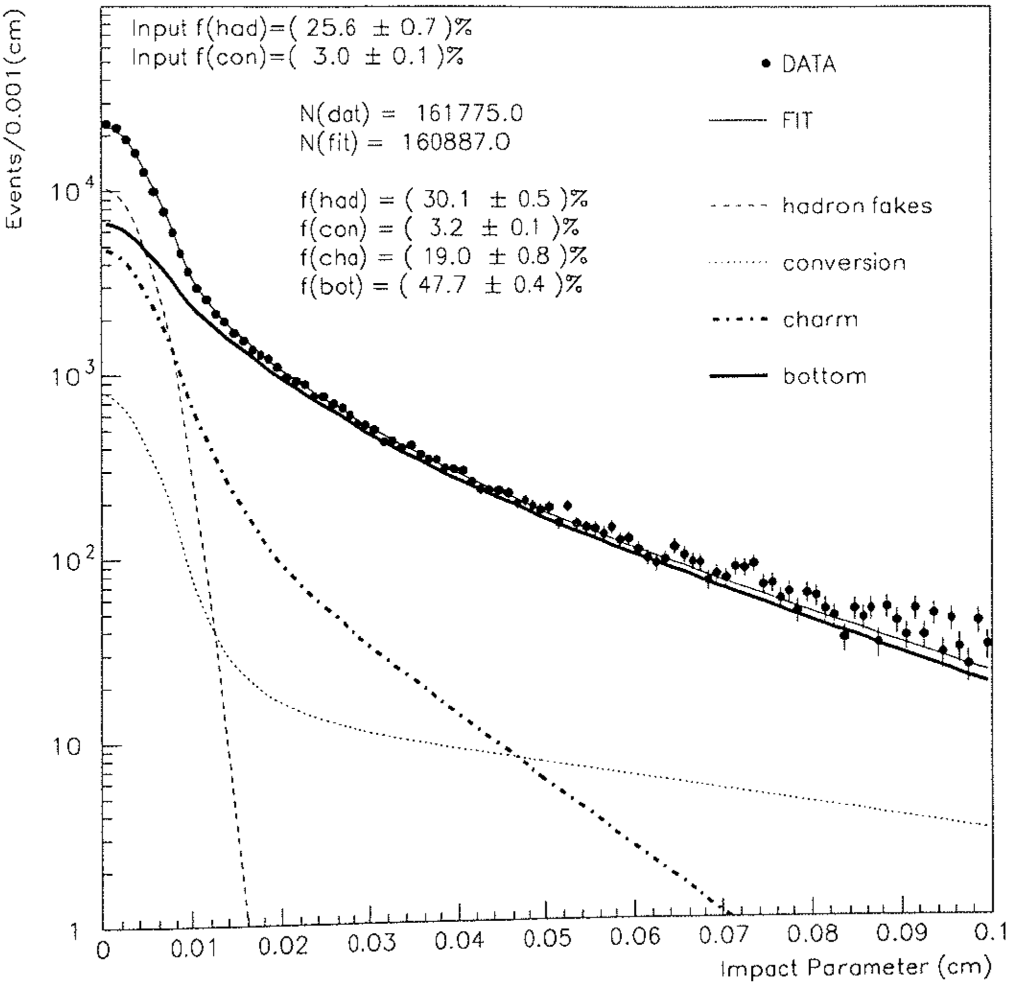

Figure 5.9: The impact parameter distribution for the whole electron sample. Results of the four-component fit are also shown. Dashed curve shows hadron faking electrons, dotted curve shows conversions, thick dashed curve shows $c\bar{c}$ and thick solid curve shows $b\bar{b}$.

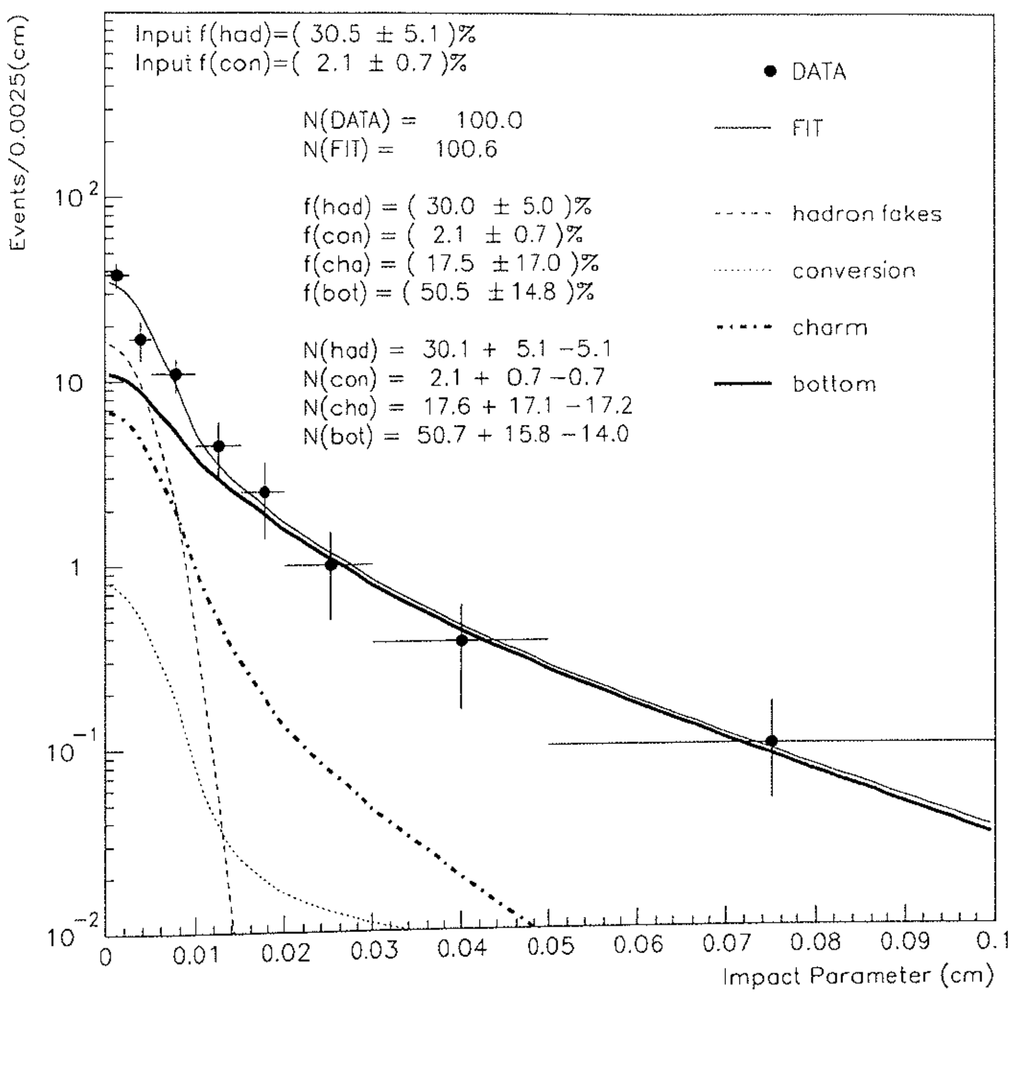

Figure 5.10: The impact parameter distribution for the diffractive candidates. Results of the four-component fit are also shown. Dashed curve shows hadron faking electrons, dotted curve shows conversions, thick dashed curve shows $c\bar{c}$ and thick solid curve shows $b\bar{b}$.

	hadron	conversion	$c\bar{c}$	$b\bar{b}$
inputs from CPR	30.5±5.1	5.4±1.8	–	–
and ε_{conv}	(30.5±5.1)%	(2.1±0.7)%	–	–
outputs	30.1±5.1*	2.1±0.7*	17.6±17.1	50.7±14.9
	(30.0±5.0)%*	(2.1±0.7)%*	(17.5±17.0)%	(50.5±14.8)%

Table 5.5: The number of hadron faking electron, conversion, $c\bar{c}$ and $b\bar{b}$ in the **diffractive candidates** obtained with the impact parameter fit. *Fit is constrained to the inputs.

5.4 Combined results

For the whole electron sample, the number of $b\bar{b}$ events is estimated to be 69165 ± 931(stat) and 76792 ± 653(stat) by the ${p_T}^{rel}$ and the impact parameter fits, respectively. We combine two results by taking a weighted mean and obtain 73371 ± 485(stat) $b\bar{b}$ events in the whole electron sample. The corresponding $b\bar{b}$ fraction is 45.4±0.3(stat)%.

For the diffractive candidates, we fit both ${p_T}^{rel}$ and impact parameter distribution simultaneously with a maximum likelihood method. The fit results are shown in Fig. 5.11. We estimate that the number of $b\bar{b}$ events in diffractive candidates to be 44.4±10.2(stat).

The fit results are summarized in Tables 5.6 and 5.7.

	hadron	conversion	$c\bar{c}$	$b\bar{b}$
input from CPR	41489±1063	4924±172	–	–
and ε_{conv}	(25.6±0.7)%	(3.0±0.1)%	–	–
output by	43554±931*	5000±168*	43668±726	69165±742
p_T^{rel} fit	(27.0±0.6)%*	(3.1±0.1)%*	(27.1±0.4)%	(42.9±0.4)%
output by impact	48398±852*	5160±171*	30538±1306	76792±653
parameter fit	(30.1±0.5)%*	(3.2±0.1)%*	(19.0±0.8)%	(47.7±0.4)%

Table 5.6: The number of hadron faking electrons, conversion, $c\bar{c}$ and $b\bar{b}$ in the **whole electron sample** by the p_T^{rel} and impact parameter fit. *Fit is constrained to the inputs.

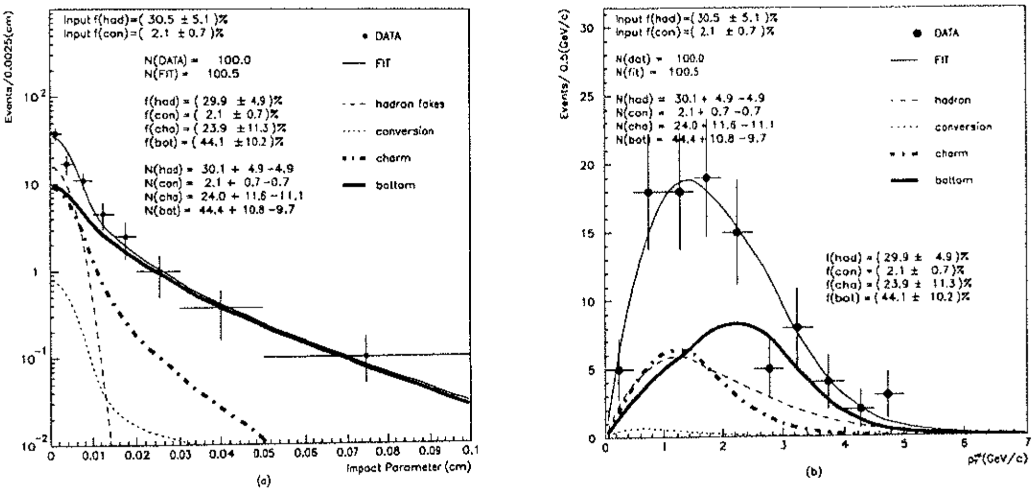

Figure 5.11: The impact parameter distribution and the p_T^{rel} distribution of the diffractive candidates. The results of the four-component fit to the combined two distributions are also shown. Dashed curve shows hadron faking electrons, dotted curve shows conversions, thick dashed curve shows $c\bar{c}$ and thick solid curve shows $b\bar{b}$.

	hadron	conversion	$c\bar{c}$	bb
inputs from CPR and ε	30.5±5.1 (30.5±5.1)%	2.1±0.7 (2.1±0.7)%	– –	– –
output by p_T^{rel} fit	31.3±5.1* (31.6±5.1)%*	2.1±0.7* (2.2±0.7)%*	27.8±13.2 (28.1±13.3)%	37.8±13.6 (38.2±13.7)%
output by impact parameter fit	30.1±5.1* (30.0±5.0)%*	2.1±0.7* (2.1±0.7)%*	17.6±17.1 (17.5±17.0)%	50.7±14.9 (50.5±14.8)%
output from combined i.p.+p_T^{rel}	30.1±4.9* (29.9±4.9)%*	2.2±0.7* (2.1±0.7)%*	24.0±11.3 (23.9±11.3)%	44.4±10.2 (44.1±10.2)%

Table 5.7: The number of hadron faking electrons, conversion, $c\bar{c}$ and $b\bar{b}$ in the **diffractive candidates** by the p_T^{rel} and impact parameter fit. *Fit is constrained to the inputs.