Measurement of the Inclusive Semi-electronic Decay Branching Fractions of D Mesons (Preliminary Version 1.0)

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Abstract

A measurement of the branching fractions of the inclusive semi-electronic decay of D mesons with the data collected using the BES detector at $\sqrt{s} = 4.03\, GeV$ is presented. We used a "method of combining D^+ and D^0 double tags together" to solve the D^0 and D^+ pollution in the recoil side against the D tags for the measurement of the branching fractions. We obtained $BF(D^+ \to e^+X) = (17.9 \pm 4.7^{+1.8}_{-1.7})\%$, $BF(D^0 \to e^+X) = (7.0 \pm 1.4^{+0.8}_{-0.9})\%$, the ratio $\frac{BF(D^+ \to e^+X)}{BF(D^0 \to e^+X)} = 2.6 \pm 0.8 \pm 0.5$ and an avarage inclusive semi-electronic decay branching fraction for the mixture of the D^+ and D^0 at $\sqrt{s} = 4.03 GeV$ to be $BF(D \to eX) = (9.7 \pm 1.5 \pm 2.2)\%$.

1 Introduction

The measurement of inclusive semi-electronic decay branching fraction of D^0 and D^+ mesons provides an important tool to study the weak decay mechanism of c quark. If isospin symmetry is preserved, the Cabbibo-Favored inclusive semi-electronic decay widths should be equal for the charged and neutral D mesons. If the Cabbibo-Suppressed inclusive semi-electronic decay width can be ignored, the ratio of the inclusive semi-electronic decay branching fractions of D^+ and D^0 should be equal to the ratio of D^+ and D^0 lifetimes.[1] Thus measurement of the inclusive semi-electronic decay branching fractions and the ratio of the branching fractions of the D mesons can provide useful information for one to understand the weak decay mechanism of charm mesons.

This MEMO reports a measurement of the inclusive D^+ and D^0 semi-electronic decay branching fractions with data collected at $\sqrt{s} = 4.03\, GeV$ using BES detector. The total data set used in the analysis corresponds to an integrated luminosity $22.3pb^{-1}$. By using the "Method of combining D^+ and D^0 double tags together"[2] to solve D^0 and D^+ pollution problem in the recoils, we obtained the decay branching fractions of:

$$BF(D^+ \to e^+X) = (17.9 \pm 4.7^{+1.8}_{-1.7})\%,$$

$$BF(D^0 \to e^+X) = (7.0 \pm 1.4^{+0.8}_{-0.9})\%,$$

and the ratio of branching fractions of

$$\frac{BF(D^+ \to e^+X)}{BF(D^0 \to e^+X)} = 2.6 \pm 0.8 \pm 0.5.$$

At $\sqrt{s} = 4.03GeV$, we measured an avarage inclusive branching fraction for a mixture of D^+ and D^0 to be

$$BF(D \to eX) = (9.7 \pm 1.5 \pm 2.2)\%.$$

2 Method of combining D^+ and D^0 double tags together[2]

At $\sqrt{s} = 4.03\,GeV$, D can be produced in e^+e^- annihilation via the following modes:

- $D^0\overline{D}^0$, D^+D^-
- $D^{*0}\overline{D}^0(\overline{D}^{*0}D^0)$, $D^{*+}D^-(D^{*-}D^+)$
- $D^{*0}\overline{D}^{*0}$,$D^{*+}D^{*-}$

Because $D^{*+}(D^{*-})$ can decay to both charged and neural D, it is impossible to know whether there is a charged or neutral D meson in the recoil side against a tagged D meson. But if we combine the neutral and charged D meson double tags together to measure inclusive particle "P" decay branching fractions, we can solve the pollution problem.

To measure inclusive particle P decay branching fractions of the D^+ and D^0, the number of the particle P appeared in the recoiling side against the tagged D^+ and D^0 can be counted as $N^P_{D^+_{tag}}$ and $N^P_{D^0_{tag}}$. The $N^P_{D^+_{tag}}$ is related to $N^{D^-}_{D^+_{tag}}$ and $N^{\overline{D}^0}_{D^+_{tag}}$; $N^P_{D^0_{tag}}$ is related to $N^{D^-}_{D^0_{tag}}$ and $N^{\overline{D}^0}_{D^0_{tag}}$ which respectively are number of D^- and $\overline{D}^0$ produced in the recoil side against the tagged D^+ or D^0 by

$$N^P_{D^+_{tag}} = \epsilon_1 \times N^{D^-}_{D^+_{tag}} \times BF(D^- \to PX) + \epsilon_2 \times N^{\overline{D}^0}_{D^+_{tag}} \times BF(\overline{D}^0 \to PX), \quad (1)$$

and

$$N^P_{D^0_{tag}} = \epsilon_1 \times N^{D^-}_{D^0_{tag}} \times BF(D^- \to PX) + \epsilon_2 \times N^{\overline{D}^0}_{D^0_{tag}} \times BF(\overline{D}^0 \to PX) \quad (2)$$

where ϵ_1 and ϵ_2 are detection efficiencies for the particle P , $BF(D^- \to PX)$ and $BF(\overline{D}^0 \to PX)$ are decay branching fractions to be measured. *Monto Carlo* study shows that the detection efficiencies are almost the same, which allow to take $\epsilon_1 = \epsilon_2 = \epsilon$. The $N^{D^-}_{D^+_{tag}}$ and $N^{\overline{D}^0}_{D^+_{tag}}$ are the numbers of D^- and $\overline{D}^0$ produced in the recoiling system against the tagged D^+.

Using the numbers $N_{D^0_{tag}}$ and $N_{D^+_{tag}}$ of the D^0 and D^+ single tags, the numbers of $\overline{D}^0$ and D^- produced in the recoiling side against the single tags can be calculated as following

$$N^{\overline{D}^0}_{D^0_{tag}} = (1-\eta)N_{D^0_{tag}},\ N^{D^-}_{D^0_{tag}} = \eta N_{D^0_{tag}}$$

$$N^{\overline{D}^0}_{D^+_{tag}} = \beta N_{D^+_{tag}},\ N^{D^-}_{D^+_{tag}} = (1-\beta)N_{D^+_{tag}}$$

Where η and β are the probabilities of D^- and $\overline{D}^0$ appearing in the recoiling side against the tagged D^0 and D^+, respectively.

By using the values of $D^*\overline{D}^*$ and $\overline{D}^*D(\ D^*\overline{D})$ production cross section measured by the BES experiment, the probabilities are obtained to be $\eta = 0.1768 \pm 0.0175$ and $\beta = 0.546 \pm 0.0622$.

Combining the equation 1 and 2 together by inserting the $N^{\overline{D}^0}_{D^0_{tag}}$, $N^{D^-}_{D^0_{tag}}$, $N^{\overline{D}^0}_{D^+_{tag}}$, and $N^{D^-}_{D^+_{tag}}$ into them, the inclusive particle 'P' decay branching fractions of D^0 and D^- are given by

$$BF(D^0 \to PX) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\beta)\frac{N^{PX}_{D^0_{tag}}}{N_{D^0_{tag}}} - \eta\frac{N^{PX}_{D^+_{tag}}}{N_{D^+_{tag}}}) \quad (3)$$

and

$$BF(D^+ \to PX) = \frac{1}{\epsilon(1-\beta-\eta)}((1-\eta)\frac{N^{PX}_{D^+_{tag}}}{N_{D^+_{tag}}} - \beta\frac{N^{PX}_{D^0_{tag}}}{N_{D^0_{tag}}}) \quad (4)$$

3 Data Analysis

3.1 Event selection

The charged tracks are required to be well reconstructed in MDC with good helix fits. Each track should have impact parameter less than 1.2 cm in the xy plane and 15.0 cm in the Z direction. Further more, the track is required to have a normalized chisquare of less than 9 per degree of freedom. In order to optimize the momentum resolution and charged particle identification, a geometry cut $|\cos(\theta)| < 0.8$ (θ is the polar angle of the track) is applied to the tracks for the single tags or $|\cos(\theta)| < 0.85$ for the tracks in the recoil side.

For the K,π identification, one (or two) level(s) of particle identification is (are) applied. First a combined particle confidence level calculated using the dE/dx and TOF measurements is required to be greater than 1% for π/K hypothesis; then a normalized likelihood ratio $LR(K) > 50\%$ is required for the K hypothesis.

To identify e, K, π appearing in the recoil side of each single tag mode, another combined particle confidence level calculated using the dE/dx, TOF, and Barrel Shower Counter measurement is used. For $e/\pi/K$ hypothesis, it is required to be greater than 1% and also greater than the confidence level calculated using the $\pi\, or\, K/e\, or\, K/e\, or\, \pi$ hypothesis. The relative confidence level $CL(e)/(CL(e)+CL(\pi)+CL(K))$ is required to be greater than 0.95 for e hypothesis. Under these selection criteria, the identification efficiencies and misidentification rates are obtained based on real e, π and *Monto Carlo* K sample.

3.2 Single tag of $D^0(\overline{D}^0)$ and $D^\pm$

Making the different combinations of K and π tracks to do D single tag and applying about $3\sigma_p$ cuts (σ_p is the standard derivation of the neutral and charged D momentum distributions)for D momentum to each single tag mode to suppress combinational background, we got 2311 ± 78 $D^\pm$ and 7064 ± 130 $D^0(\overline{D}^0)$ events.

The distributions of invariant masses of $Kn\pi$ (where $n = 1, 2$ or 3) for the three single tag modes are shown in fig1.

3.3 Double tagged events

For each single tag mode, we search for electron in the recoil side. If it has the same charge as the K in the tagged D, it is called a right sign electron, otherwise called a wrong sign electron. In order to remove gamma conversion background, it is required that the angle between the electron candidate track and anyone of the anticharged track respect to the electron charge is greater than $20°$(the opening angle cut). It is also required that the invariant mass of the combination of the electron with anyone of the anticharged track which is also assigned the mass of electron to be greater than $140MeV$. The distance along the Z direction between the vertex of electron and any of the single tagged D tracks is required to be less than $2cm$. To further reduce gamma conversion electrons which haven't been removed totally by the opening angle cut, the number of wrong sign electron candidate events can be subtracted from the right sign electron candidate events. The invariant mass distributions of the single tagged D of which the electron candidates are observed in the recoil side for the net number of events are shown in fig 2.

Because e, π, K can be misidentified into each other, the same process is carried out for both recoil side π and K to unfold the number of electrons coming from D decays. The invariant mass distribution for the single tagged D mesons of which the π and K candidates are observed in the recoil side for the "net" number of events are also shown in fig 2. The figure for K observed in the recoil side is got by subtracting the right sign from wrong sign because there is more wrong signs K than right signs K due to Cabbibo-Favored decay of D mesons. Fit the histograms with an gaussian plus polynomial background, the net event numbers are obtained and the results are shown in table 1.

The particle detection efficiency and the misidentification rates are obtained based on a pure e and π sample selected from real data and pure K sample generated with *Monto Carlo* method. The identification efficiencies and misidentification rates are shown in table 2.

Requiring a $3\sigma_m$ invariant mass cut (σ_m is the standard derivation of the invariant mass distribution of each single tag mode.) on the tagged D we got

Table 1: Number of Recoil Events (right sign - wrong sign)

D tag mode	recoil e	recoil π	recoil K
$D^0 \to K^-\pi^+$	145±12	894±30	-629±25
$D^0 \to K^-\pi^+\pi^+\pi^-$	115±11	548±24	-425±27
$D^+ \to K^-\pi^+\pi^+$	113±13	613±37	-270±17

Table 2: Particle identification efficiency

	identified as		
Particle Type	e	π	K
e	0.641 ± 0.015	0.045 ± 0.004	0.038 ± 0.004
π	0.014 ± 0.001	0.840 ± 0.005	0.087 ± 0.002
K	0.0041 ± 0.0003	0.130 ± 0.002	0.821 ± 0.004

the momentum distributins of the right sign and wrong sign electrons in the recoil side. Subtracting the wrong sige electron momentum distribution from the right sign and adding the the momentum distributions of three single tag modes together, we obtained the net momentum distribution of the electrons coming from the $D \to eX$ process in the laboratory frame. If we assume that the momentum of the recoiling D equals the momentum of the single tagged $\overline{D}$ neglecting the soft π or γ, we can also got the momentum distribution of the electron coming from the $D \to eX$ process in the center of mass frame of the D. The two distributions are shown in fig3. The identification efficiencies of electrons at different momentum have been taken into account.

4 Result

If we make a 3×3 matrix with its columns and rows labled as e, π, K in turn and its element $\mathrm{M_{ab}}$ is assigned the ratio of type b particle identified as type a, from table 2, we can construct this particle identification efficiencies and misidentification rates matrix :

$$M = \begin{pmatrix} 0.641 & 0.014 & 0.004 \\ 0.045 & 0.840 & 0.131 \\ 0.038 & 0.087 & 0.821 \end{pmatrix}, \, and \, M^{-1} = \begin{pmatrix} 1.56 & -0.025 & -0.004 \\ -0.073 & 1.21 & -0.193 \\ -0.064 & -0.128 & 1.24 \end{pmatrix}$$

The number of observed e, π,K is related to the number of real e, π,K via the following relation:

$$\begin{pmatrix} N_e^{obs} \\ N_\pi^{obs} \\ N_K^{obs} \end{pmatrix} = M \cdot \begin{pmatrix} N_e^{real} \\ N_\pi^{real} \\ N_K^{real} \end{pmatrix} \Longrightarrow \begin{pmatrix} N_e^{real} \\ N_\pi^{real} \\ N_K^{real} \end{pmatrix} = M^{-1} \begin{pmatrix} N_e^{obs} \\ N_\pi^{obs} \\ N_K^{obs} \end{pmatrix},$$

so the real number of $D \to eX$ events produced in the recoil side of each single tag mode can be calculated. We obtain

$$N^e_{D^0_{tag}(K\pi)} = 206 \pm 19$$

$$N^e_{D^0_{tag}(K\pi\pi\pi)} = 168 \pm 17$$

$$N^e_{D^+_{tag}(K\pi\pi)} = 162 \pm 21$$

A *Monto Carlo* study shows that the efficiency ϵ for $D \to eX$ is 0.60. Using equations 3 and 4, we obtained the inclusive semi-electronic decay branching fractions of

$$BF(D^+ \to e^+X) = (17.9 \pm 4.7^{+1.8}_{-1.7})\%,$$

and

$$BF(D^0 \to e^+X) = (7.0 \pm 1.4^{+0.8}_{-0.9})\%.$$

We measured the ratio of the decay branching fractions of

$$\frac{BF(D^+ \to e^+X)}{BF(D^0 \to e^+X)} = 2.6 \pm 0.8 \pm 0.5.$$

In the values, the first error is statistical and the second systematic. The systematic error arise from some uncertainties in the measured values due to variations of the MC efficiency, particle identification efficiency, the probabilities β and η, the fit range, background function, and the analysis cuts.

Weighting the inclusiv semi-electronic decay branching fractions of D mesons by the charged and neutral D production cross sections at $\sqrt{s} = 4.03GeV$, we obtained the average inclusive semi-electronic decay branching fraction of

$$BF(D \to eX) = \frac{\sigma_{D^+} * Br(D^+ \to e^+X) + \sigma_{D^0} * Br(D^0 \to e^+X)}{\sigma_{D^+} + \sigma_{D^0}} = (9.7 \pm 1.5 \pm 2.2)\%$$

at $\sqrt{s} = 4.03GeV$. (The σ_{D^+} and σ_{D^0} are the total D^+ and D^0 production cross sections at $\sqrt{s} = 4.03GeV$ measured by L.Blum of BES Collaboration[3]). This may be useful to make a comparision with that measured by other experiments at higher center-of-mass energy.[4][5][6]

5 Discussion and Comparision of our result with that measured by other experiments

Table 3 and table 4 summarize several measured values of the inclusive semi-electronic decay branching fractions of the D mesons, which were used to calculate the world average (PDG96) by Particle Data Group[7] in 1996. Comparing our measured values of the branching fractions with the individuals in the tables, we find that the precision of our measurement of the decay branching fractions for $D^+ \to e^+X$ and $D^0 \to e^+X$ are better than that measured by HYBR[8] and MarkII[9]. Table 5 shows a comparision of Mark3 result on a measurement of $R = \frac{BF(D^+ \to eX)}{BF(D^0 \to eX)}$ with our result. When we combine the two results together, we obtained $R = 2.4 \pm 0.4$. By combining the PDG96 and our results together,

Table 3: $BF(D^+ \to e^+X)$

	$BF(D^+ \to e^+X)$	Year	Relative Error
HYBR	$0.20^{+0.09}_{-0.07}$	87	42.5%
MRK3	$0.170 \pm 0.019 \pm 0.007$	85	11.9%
MRK2	0.168 ± 0.064	81	38.1%
PDG 96	0.172 ± 0.019	96	11.0%
Our Result	$0.179 \pm 0.047^{+0.018}_{-0.017}$	98	26.1%
World Average	0.173 ± 0.018	98	10.0%

Table 4: $BF(D^0 \to e^+X)$

	$BF(D^0 \to e^+X)$	Year	Relative Error
HYBR	0.15 ± 0.05	87	33.3%
MRK3	$0.075 \pm 0.011 \pm 0.004$	85	15.6%
MRK2	0.055 ± 0.037	81	67.3%
PDG 96	0.077 ± 0.012	96	
Our Result	$0.070 \pm 0.014^{+0.008}_{-0.009}$	98	19.7%
World Average	0.074 ± 0.010	98	14%

the relative error in the world average value can be further reduced. The world average computed from PDG96 and our result is also shown in table 3, 4, and 5.

Table 6 lists inclusive semi-electronic decay branching fractions of charm quark $c \to e^+\nu X$ for a mixture of charged and neutral D mesons measured by several experiment groups at different center of mass energe.

In calculating the momentum of the electrons comining from the $D \to eX$ process in the center of mass frame of the D mesons, we neglected the effect of soft π and γ coming from D^*. MC study shows that the angle between the momentum of the single tagged D and the $\overline{D}$ in the recoil side is around 170° and the magnitudes of the momentum of the single tagged D and the recoiling $\overline{D}$ are nearly equal.

Table 5: $R = \frac{BF(D^+ \to eX)}{BF(D^0 \to eX)}$

Exp	R	year	Relative Error
Mark3	2.3 ± 0.5	85	22%
Our Result	2.4 ± 0.4	98	37%
World Average	2.4 ± 0.4	98	17%

Table 6: $BF(c \to e^+\nu X)$

	$BF(c \to e^+\nu X)\%$	year	$\sqrt{s}$ GeV	Relative Error	Ref
MRK1	7.2 ± 2.8	1978	3.772	38.9%	[10],[5]
MRK3	$11.7 \pm 1.0 \pm 0.5$	1985	3.77	9.6%	[1]
TASSO	$9.2 \pm 2.2 \pm 4.0$	1984	34.6	49.6%	[6],[7]
TPC	$9.1 \pm 0.9 \pm 1.3$	1985	29	17.4%	[4],[7]
DELCO	$11.6^{+1.1}_{-0.9}$	1986	29	8.6%	[5],[7]
our result	$9.7 \pm 1.5 \pm 2.2$	1998	4.03	27.7%	

6 Conclusion

With 2311 ± 78 $D^\pm$ and 7064 ± 130 $D^0(\overline{D}^0)$ single tagged events, we obtained the inclusive semi-electronic decay branching fractions of D^+ and D^0 to be

$$BF(D^+ \to e^+X) = (17.9 \pm 4.7^{+1.8}_{-1.7})\%,$$

and

$$BF(D^0 \to e^+X) = (7.0 \pm 1.4^{+0.8}_{-0.9})\%.$$

Using the branching fractions, we obtain the ratio of the D^+ and D^0 inclusive semi-electronic decays branching fractions of

$$\frac{BF(D^+ \to e^+X)}{BF(D^0 \to e^+X)} = 2.6 \pm 0.8 \pm 0.5.$$

This result agrees with the results got by other experiment groups and the world average.

At $\sqrt{s} = 4.03GeV$, we measured an avarage inclusive semi-electronic decay branching fraction for the mixture of D^+ and D^0 to be

$$BF(D \to e^+X) = (9.7 \pm 1.5 \pm 2.2)\%.$$

The momentum distribution of the electrons coming from the $D \to eX$ process is also measured.

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Figure 1: Invariant Mass Distribution of Single Tagged D

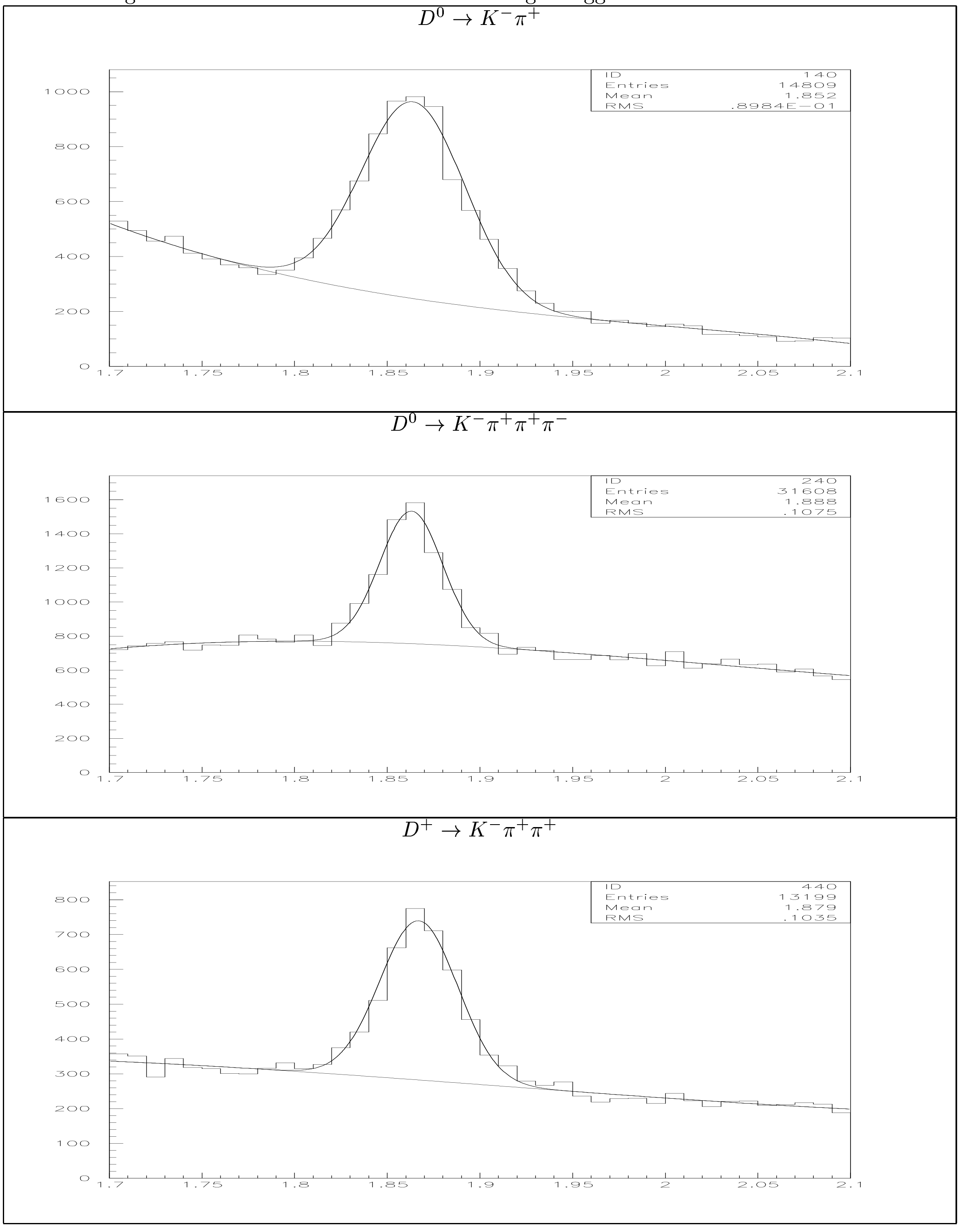


Figure 2: The invariant mass distribution of the single tagged D with right sign and wrong sign e in the recoil side

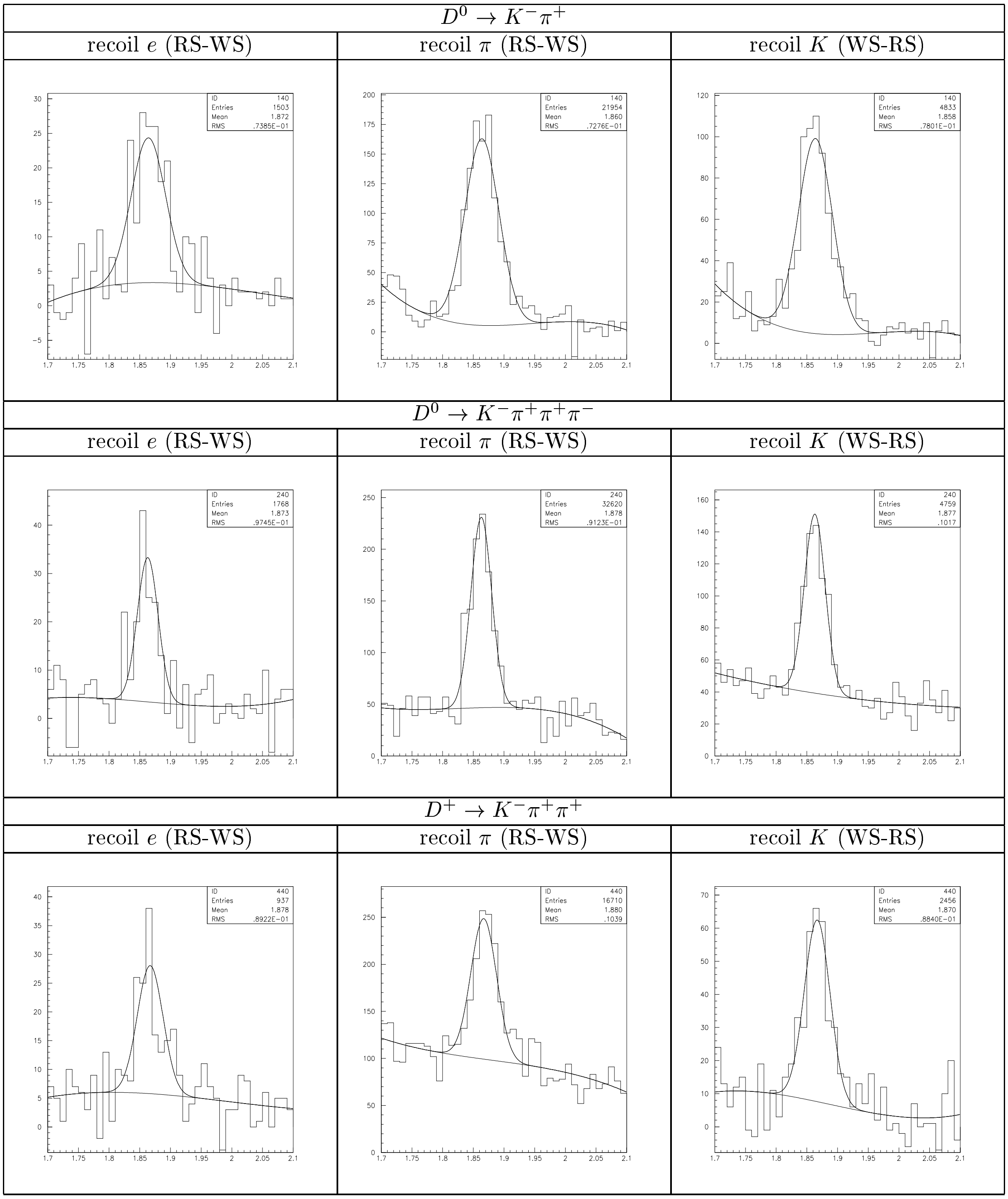
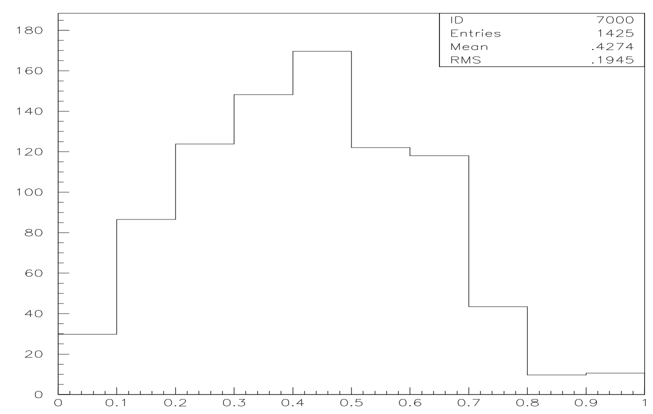


Figure 3: The momentum distribution of electron coming from recoil D

Momentum distribution in the laboratory frame



Momentum distribution in the recoil D frame