The Measurement of $Br(\psi' \to \tau^+\tau^-)$

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BES99

1 Introduction

1.1 The physics significance

Up to now, experimental evidence suggests that the τ particle is a conventional lepton, which behaves itself like other two charged leptons — electron and μ, obeying the rule of the $e-\mu-\tau$ universality hypothesis. In the $c\bar{c}$ system, the ψ' provides an unique opportunity to compare the three generation leptons by studying its leptonic decay. According to the theory, the relations between the branching ratios of the decay modes $\psi' \to e-, \mu-$ and $\tau-pair$, $Br_{ee}, Br_{\mu\mu}$ and $Br(\psi' \to \tau\tau)$ are given by

$$\frac{Br(\psi' \to \tau\tau)}{0.3885} \approx Br_{\mu\mu} \approx Br_{ee} \qquad (1)$$

Previous experiments have yielded the measurements of Br_{ee} and $Br_{\mu\mu}$, but no $Br(\psi' \to \tau\tau)$. By use of the 93/94 ψ' data, we have measured the value of the $Br(\psi' \to \tau\tau)$, which was reported in the BES Annual Meeting, the HEP-Glasgow in 1994 and so on. But before formal publication, the measurement of the $Br_{\tau\tau}$ must be checked.

1.2 Our main task

This memo will clarify and solve some important problems as follows:

In the previous measurement of the total $\tau-pair$ event number $N_{\tau\tau}$, we used

a. the 93/94 ψ' filtered data collected by BES, which place a restriction on the tracks in the SC. We worry about that might result in the loss of the $N_{\tau\tau}$;

b. the 92 Ds data collected by BES, used as determining the detection efficiency;

c. four topologies, $e\mu$ eh μh and ee, were used.

Our way to deal with the above problems is

a. using the 93/94 ψ' unfiltered data reconstructed by USA instead of the filtered data and Bill, Xinhua's PID correction will be uesd; For comparing with 93/94 data and decreasing the statistical error, 95 data will be used and analysised independently first and then put them together. All runs which status > 0 will be used .

b. using MC to determine the detection efficiency directly, do not use the Ds data any more.

c. because we think there are some problems for the TOF and BSC simulation for hadrons, or say it's hard for us to get a correct efficiency from MC for eh and μh channels. For the ee channel, the background (especially from double photon process) is big and it is hard to estimate. So, only the $e\mu$ channel will be used.

2 Formulae used in the measurement

2.1 The formula for measuring $Br(\psi' \to \tau\tau)$

$$Br(\psi' \to \tau\tau) = \frac{N_{\tau\tau} - \sigma_{Q+I} \bullet L}{N_{\psi'}} \tag{2}$$

where $N_{\tau\tau}$ is the total τ-pair event number; σ_{Q+I} is the sum of the cross section of the QED generating τ-pair and that of the interference part; L is the integrated luminosity at the ψ' resonance; $N_{\psi'}$ is the number of the produced ψ' events.

From the theory analysis, σ_{Q+I}=2.237nb; L,$N_{\psi'}$ have been determined by other people from ψ' group. So, the left problem is to get the $N_{\tau\tau}$.

2.2 The formula for measuring $N_{\tau\tau}$

The $\tau\tau$ events are identified by means of the $e\mu$ topology because this channel's background is very small. $N_{\tau\tau}$ is expressed as

$$N_{\tau\tau} = \frac{n - n_{bg}}{B \bullet \varepsilon_d \bullet \varepsilon_t} \simeq \frac{n - n_{bg}}{B \bullet \varepsilon_d} \tag{3}$$

where n is observed $e\mu$ events from real data; n_{bg} is the relevant background; B is the branching ratio of $\tau\tau$ decay to $e\mu$; ε_d is the detection efficiency; ε_t is the trigger efficiency and $\varepsilon_t \simeq 100\%$.

3 PID correction

3.1 dE/dX and TOF

These 2 items have been corrected by Bill and Xinhua. We checked the Xse (dE/dX separation assuming the electron hypothesis) and Tse (TOF separation assuming the electron hypothesis) both for real data and MC, they are all agreed with the standard normal distribution, N(0,1), shown as Figure 1 .

$$Xs(i) = \frac{(\frac{dE}{dx})_{meas} - (\frac{dE}{dx})^i_{exp}}{\sigma_{dE/dX}} \tag{4}$$

$$Ts(i) = \frac{TOF_{meas} - TOF^i_{exp}}{\sigma_{TOF}} \tag{5}$$

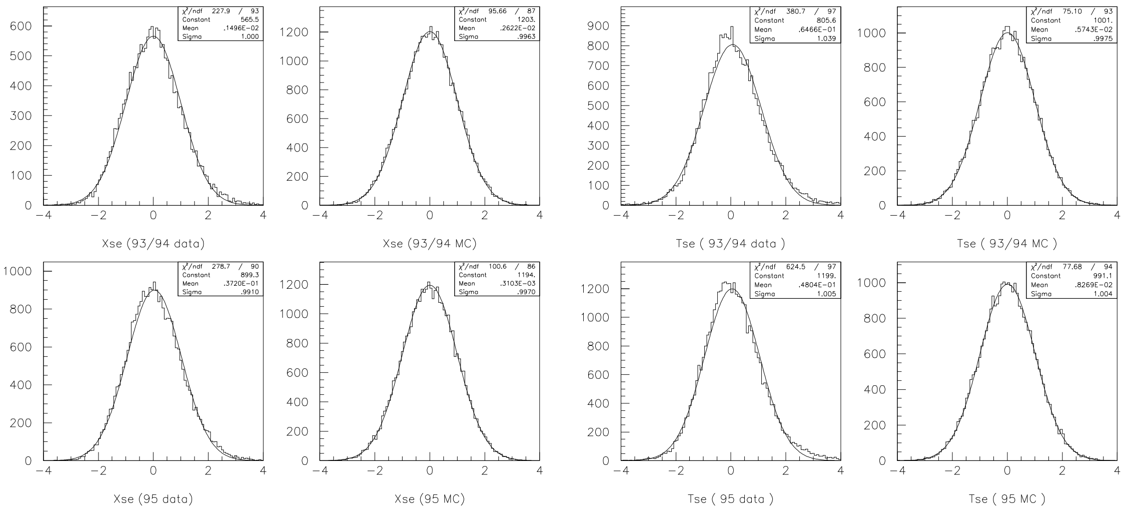

Figure 1: Xse and Tse distribution of electron

3.2 BSC

3.2.1 The introdution of Sse

To identify electron, we usually use E or E/p, where E is the energy deposit in the shower calorimeter and p is momentum. When we make correction, we only try to let the mean value of E/p equal to 1 and don't care about the sigma. But if we don't make any correction on the sigma of E/p, typically, the sigma of MC is smaller than the real data, for example, about 0.2 for MC but 0.25 for real data. So, despite we have made the mean value of E/p equal to 1, when we cut E/p $\geq$ 0.8, we get different efficiency, 84% for MC and 79% for real data. So we need another method to identify electron by the information from SC .

Similar to dE/dX and TOF, we introduce Sse (Energy separation assuming the electron hypothesis) as

$$Sse = \frac{E - E^{exp}}{\sigma_E} = \frac{E - p}{a \bullet \sqrt{E}}$$

where, E is the energy deposit in the SC;
p is the momentum of the track;
E^{exp} is expected energy deposit in the SC. for electron, E^{exp}=p ;
σ_E is energy resolution of SC, $\sigma_E = a \bullet \sqrt{E}$. typically, a=0.25

Sse should be a standard normal distribution. But, as we know, there will be a little difference both for MC and real data before correction .

3.2.2 Correction of Sse

- The selection of data sample

  - For real data, we use the wide angle radiative bhabha events:
    1) have two opposite charged tracks
    Mfit=2, Pxy$\geq$0.07Gev, $|\cos\theta| \leq 0.75$
    2) The track which momentum is bigger shoud be a electron
    1.65$\leq$P$\leq$2.0GeV, E$\geq$0.8GeV, -1.5$\leq$Xse$\leq$3
    Then the other untaged track will also be a electron and it has a wide momentum distribution. We use it to correct the Sse.

  - For MC, we use the electron from $\tau\tau \to e\mu$.

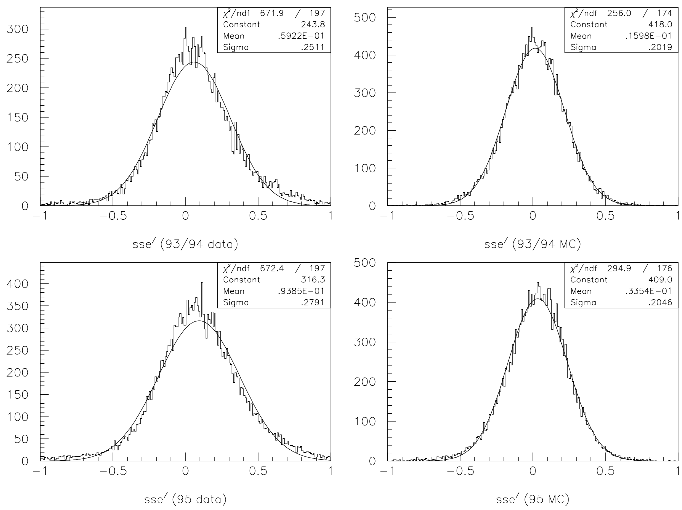

Figure 2: $\text{Sse}' = \frac{E-p}{\sqrt{E}}$ for electron

- correction
  We use the electrons which satisfy
  0.04$\leq$ $|Zsc|$ $\leq$0.8 .or. 1.0$\leq$ $|Zsc|$ $\leq$1.25, 0.35$\leq$P$\leq$1.2 GeV .

to get the distribution of $\text{Sse}' = \frac{E-p}{\sqrt{E}}$ (Figure 2) and fit it with gaussian function, get the result as Table 1. Where Eoff is the mean value and σ is the standard deviation.

Table 1: Sse′ for electron

	ψ' 93/94 data	ψ' 93/94 MC	ψ' 95 data	ψ' 95 MC
Eoff	0.059	0.016	0.094	0.034
σ	0.251	0.202	0.279	0.205

Then, Sse=$\frac{E-p-Eoff}{\sigma \bullet \sqrt{E}}$ will be a standard normal distribution, N(0,1)

3.3 MUON

We usually use Av and Az to identify a muon. Here Av and Az are the difference between the real muon hit in muon counter and the projected position from MDC in v-plane and z axis. As they are normalized by resolution, they also should be a standard normal distribution, N(0,1).

Similar to the correction of Sse, we get the distribution of Av and Az in three muon layers. Figure 3 is the distribution for 1st layer. We find that for μ^+ and μ^-, the mean value of Av has the same shift from the expected value 0, but they shift to different side. Such thing doesn't happen to Az. Both the real data and MC data are the same. So we make

$Av' = Av * Ichg$ (Ichg is the charge of the μ)

$Az' = Az$

distribution in three muon layers shown as Figure 4. After fitting with gaussian function, we get the mean value and sigma (Av^i_{off}, σ^i_v) , (Az^i_{off}, σ^i_z) $i = 1, 2, 3$ shown as Table 2.

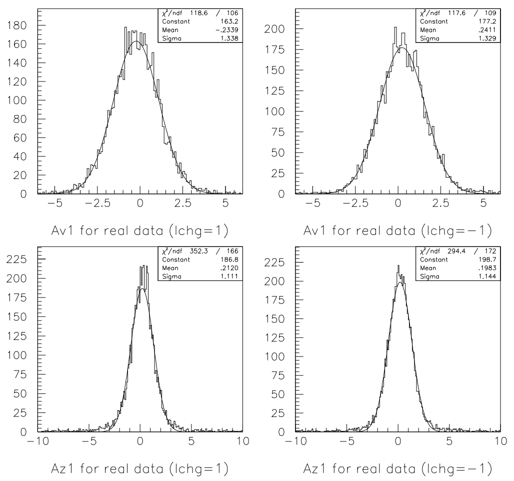

Figure 3: Av,Az distribution of μ^+, μ^- in 1st layer

Table 2: The correction parameter of Av, Az

		real data			MC data		
Layer i		1	2	3	1	2	3
Av	Av^i_{off}	-0.24	-0.16	-0.07	-0.24	0.16	0.25
	σ^i_{off}	1.34	1.20	1.11	1.14	0.92	0.94
Az	Az^i_{off}	0.20	0.24	0.17	0.03	0.01	0.02
	σ^i_z	1.14	1.23	1.20	1.02	0.89	0.93

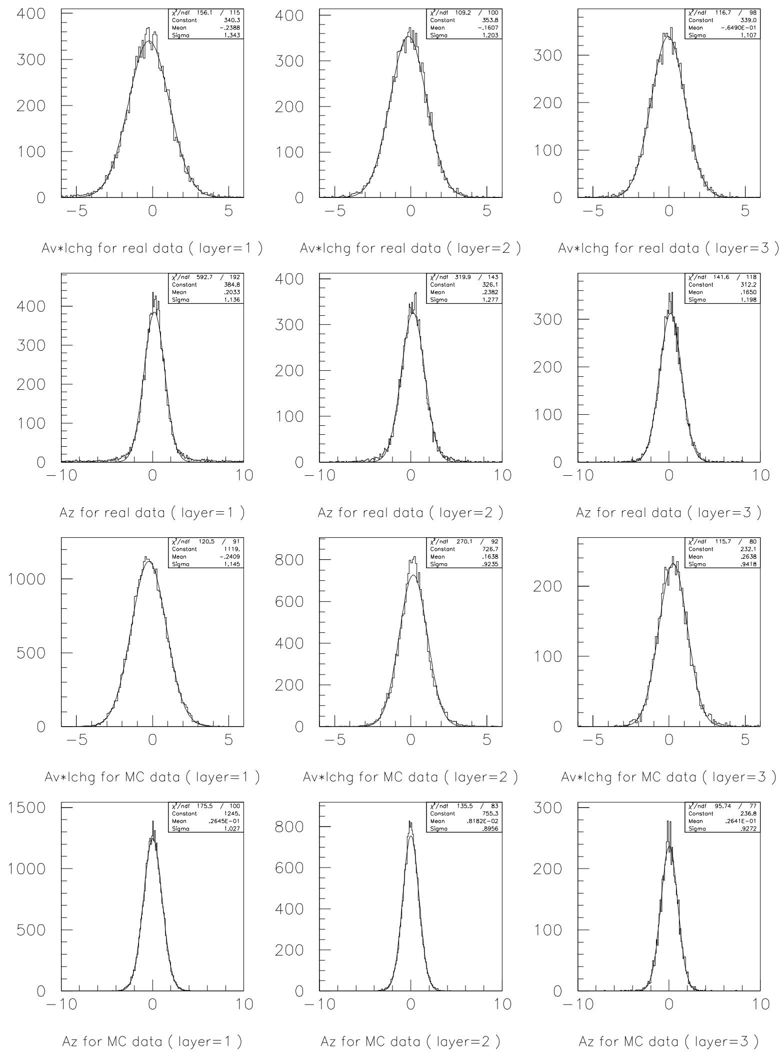

Figure 4: Av and Az distribution for real and MC data

So,

$$\begin{aligned} Av'' &= \frac{Av - Av_{off} * Ichg}{\sigma_v} \\ Az'' &= \frac{Az - Az_{off}}{\sigma_z} \end{aligned} \tag{6}$$

will be a standard normal distribution, N(0,1)

4 Event selection

4.1 The selection criteria of $e\mu$ events

- have and only have 2 good charged tracks:
  Mfit = 2 or -19, $|x| \leq 1.5cm, |y| \leq 1.5cm, |z| \leq 15cm$;
  $\sum Q_i = 0$;
- one track is e :
  a) $0.2 \leq p \leq Pmax = 1.2$ GeV
  b) $|\cos\theta| \leq 0.65$
  c) when $0.2 \leq p < 0.35$ GeV, according to Figure 5, we need
  $-4 \leq Tse \leq 0.5, -1 \leq Xse \leq 2, -4 \leq Sse \leq 4$
  d) when $0.35 \leq p < 0.7$ GeV, according to Figure 6, we need
  $-4 \leq Tse \leq 1.5, -2 \leq Xse \leq 2, -1.5 \leq Sse \leq 4$
  e) when $0.7 \leq p \leq 1.2$ GeV, according to Figure 7, we need
  $-4 \leq Tse \leq 4, -1.5 \leq Xse \leq 2, -2 \leq Sse \leq 4$
- another track is μ :
  a) $0.6 \leq p \leq Pmax = 1.2$ GeV
  b) having at least 1 layer μ-hit with two tube hits, or
  having at least 2 layers μ-hit .
  here μ-hit means $|Av| \leq 4$.
- $10° \leq acol \leq 170°$; $acop \geq 20°$;
- no isolated photon
  The isolated photon is: $E \geq 60MeV$, the angle between it and the charged track nearest to it $\geq 12°$;

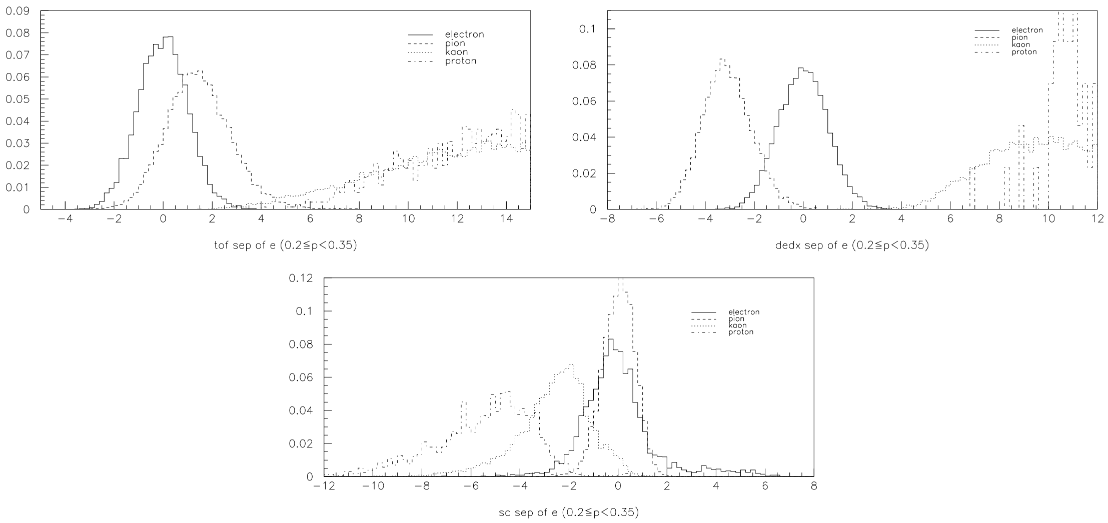

Figure 5: The distribution of Tse, Xse, Sse ($0.2 \leq p < 0.35$GeV, MC data)

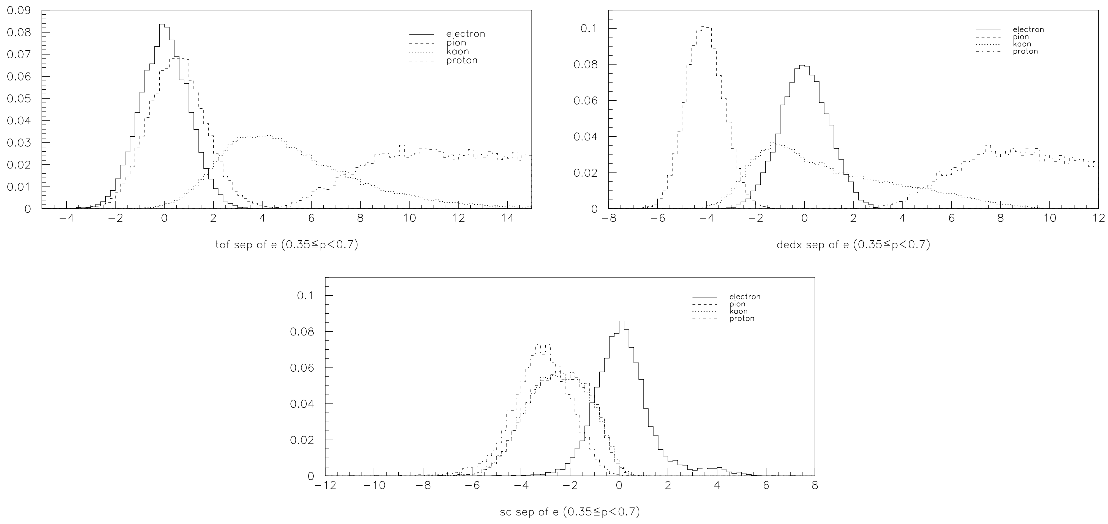

Figure 6: The distribution of Tse, Xse, Sse ($0.35 \leq p < 0.7$GeV, MC data)

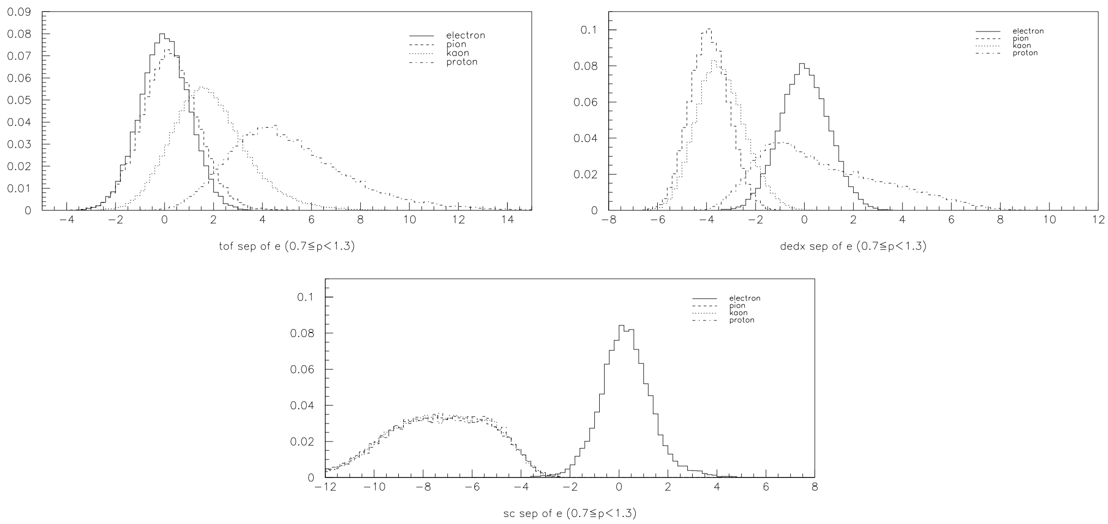

Figure 7: The distribution of Tse, Xse, Sse ($0.7 \leq p < 1.3$GeV, MC data)

4.2 Real data

There are total 77 and 140 events meet the criteria for $e\mu$ channel for 93/94 data set and 95 data set respectively, Some distributions of these events are compared to MC data shown as Figure 8 .

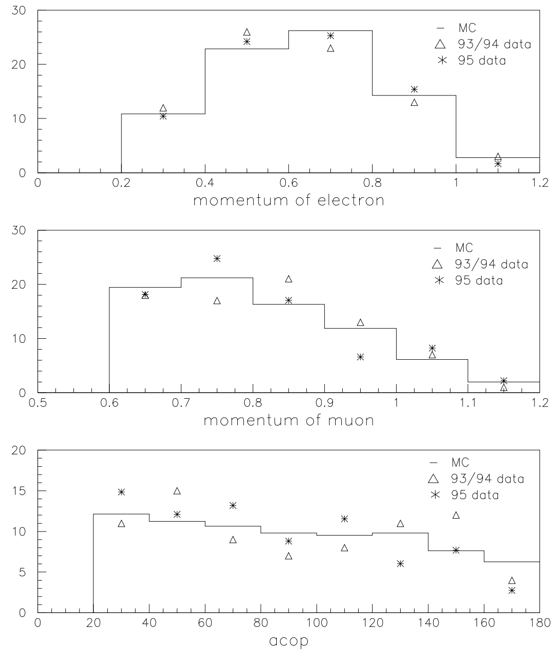

Figure 8: The distributions of the momentum, ACOP for the $\tau\tau \to e\mu$ candidate events (points) compared to that for the MC events subjected to the same selection criteria (histogram) and normalized to the 93/94 data.

4.3 Efficiency

400K τ pair events with version 153 and 154, corresponding to 93/94 ψ' data set and 95 data set, are generated respectively for determining the efficiency. The efficiency is 0.1449 for 93/94 data set and 0.1439 for 95 data set .

4.4 The background from $q\bar{q}$

The continuum background is estimated by use of the J/ψ data, which include three datasets, those runs from 1480 to 1616, from 1750 to 1940 and from 3579 to 3738, corresponding to 5 million $q\bar{q}$ events. Only 1 events meet the criteria for $e\mu$ channel, corresponding to 0.27 events for 93/94 ψ' data and 0.49 for 95 data, which are used to be subtracted from the selected events.

5 Result and discussion

According to Eq. (3), the items measured and the value of $N_{\tau\tau}$ obtained are listed in Table 3. Where the 2nd error of $N_{\tau\tau}$ is the systematic error and the detail is listed in Table 4 .

Table 3: the values of $N_{\tau\tau}$

Data	n	n_{bg}	ε_d	B	$N_{\tau\tau}$
93/94	77	0.27	0.1449		$8559 \pm 976 \pm 440$
95	140	0.49	0.1439	0.06187	$15670 \pm 1325 \pm 848$
93/94 + 95	217	0.76	0.1443		$24221 \pm 1645 \pm 1204$

Table 4: the systematic error of $N_{\tau\tau}$

cut	change	relative error (%)		
		93/94	95	93/94+95
Mfit	2,-19 $\rightarrow$ 2	1.03	3.47	2.60
Acop	$20^\circ \rightarrow 25^\circ$	1.05	1.86	1.57
E of photon	60Mev $\rightarrow$ 40Mev	1.62	1.87	1.78
$\lvert\cos\theta\rvert$	$0.65 \rightarrow 0.6$	0.62	1.96	1.48
PID of e	shift 1σ	2.76	0.44	1.27
PID of μ	shift 1σ	3.69	2.50	2.92
Total		5.14	5.41	4.97

According to Eq. (2), as the L, $N_{\psi'}$ have been measured by other people, we can get the the branching ratio of $\psi' \rightarrow \tau\tau$ listed as Table 5. The error source are listed in Table 6.

Table 5: the branching ratio of $\psi' \rightarrow \tau\tau$

Data	$N_{\tau\tau}$	L	$N_{\psi'}$	$Br(\psi' \rightarrow \tau\tau)(10^{-3})$
93/94	$8559 \pm 976 \pm 440$	$2123 \pm 15 \pm 51$	$1.325 \pm 0.005 \pm 0.109$	$2.88 \pm 0.76 \pm 0.58$
95	$15670 \pm 1325 \pm 848$	$3929 \pm 19 \pm 98$	$2.463 \pm 0.007 \pm 0.200$	$2.79 \pm 0.56 \pm 0.58$
93/94+95	$24221 \pm 1645 \pm 1204$	$6052 \pm 24 \pm 149$	$3.788 \pm 0.009 \pm 0.309$	$2.82 \pm 0.45 \pm 0.56$

The existing measurements of the leptonic decays of the ψ', the $Br_{ee}, Br_{\mu\mu}$ from PDG98 and our $Br_{\tau\tau}$ result from 93/94+95 ψ' data set, are listed in Table 7 . Our value $Br_{\tau\tau}$, corrected by a factor of 0.3885, as indicated by Eq.(1), agrees with the data Br_{ee} and $Br_{\mu\mu}$.

In conclusion, we have measured $Br_{\tau\tau}$. This results, along with the Br_{ee} and $Br_{\mu\mu}$, satisfy the relation predicted by the hypothesis of $e - \mu - \tau$ universality within the errors .

Table 6: the error source of $Br_{\tau\tau}(\%)$

error source	93/94		95		93/94+95	
	statistical	systematic	statistical	systematic	statistical	systematic
$N_{\tau\tau}$	25.6	11.5	19.3	12.3	15.4	11.3
$\sigma_{Q+I}L$	0.9	3.0	0.6	3.2	0.5	3.1
$N_{\psi'}$	0.4	8.2	0.3	8.1	0.2	8.2
$E, \triangle E$		11.0		11.0		11.0
Total	26.5	20.0	19.9	20.7	15.9	19.9

Table 7: the leptonic branching ratio of $\psi^{'}$

$Br(\psi^{'} \to ee)(10^{-3})$	$Br(\psi^{'} \to \mu\mu)(10^{-3})$	$Br(\psi^{'} \to \tau\tau)/0.3885(10^{-3})$
8.5 ± 0.7	7.7 ± 1.7	$7.26 \pm 1.16 \pm 1.44$

6 Acknowledgement

In this check, we obtain some useful helps and instructions from our colleagues at IHEP, we greatly acknowledge them. We also thank our colleagues in Hawaii University who provide us with the unfiltered reconstructed $\psi^{'}$ data.