Measurement of ψ' Resonance Parameters

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1. Motivation of ψ' Scan

Since the discovery of ψ' particle in 1974,a few measurements for its decay width have been carried out.The results show the big deviation of their central values ranging from 202KeV to 306KeV. Also their relative errors are rather large ranging from 13% to 28%.The branching ratio of $\psi' \to \pi^+\pi^- J/\psi$ is of particular importance because of its easy tagging and large fraction.However,its central value has been ranged from 0.283 to 0.36, by a factor of 27%.And its relative error is not sufficiently accurate ranging from 0.10 to 0.17.Due to the measurement of this branching ratio by E760 collaboration,its PDG value varied from 0.324 ± 0.026 (yr.1996) to 0.302 ± 0.019 (yr.1998).In the branching ratio measurement of any ψ' decay channel,the total number of produced ψ' events are usually calculated based on the number $\psi' \to \pi^+\pi^- J/\psi$ events and its branching ratio,therefore its relative error will be directly accounted into the error of the branching ratio of any being studied channel.

Similar situation happened for the branching ratios of $\psi' \to J/\psi X(anything)$ and $\psi' \to \mu^+\mu^-$. The central value of $B(\mu\mu)$ ranges from 0.0077 to 0.0099 and its relative error ranges from 0.17 to 0.32. For the $B(J/\psi X)$, the central value ranges from 0.51 to 0.57 and its relative error ranges from 0.14 to 0.24.

Table 1.1 ψ' decay width and some branching ratios

Group	yr.	$\Gamma(KeV)$	$B(\mu\mu)(10^{-3})$	$B(\pi^+\pi^- J/\psi)$	$B(J/\psi X)$
MARK I	75	$228 \pm 56(0.25)$	$9.3 \pm 1.6(0.17)$	$0.32 \pm 0.04(0.13)$	$0.57 \pm 0.08(0.14)$
SPEC	75		$7.7 \pm 1.7(0.22)$		
DASP	79	$202 \pm 57(0.28)$	$9.9 \pm 3.2(0.32)$	$0.36 \pm 0.06(0.17)$	$0.51 \pm 0.12(0.24)$
E760	92	$306 \pm 39(0.13)$			
	97			$0.283 \pm 0.029(0.10)$	
PDG	96	$277 \pm 31(0.11)$		$*0.324 \pm 0.026(0.08)$	$*0.57 \pm 0.08(0.14)$
PDG	98	$277 \pm 31(0.11)$		$*0.302 \pm 0.019(0.063)$	$*0.542 \pm 0.030(0.055)$

note:numbers in parenthesis denote the relative error $*$[1]

Table 1.1 summarizes the results of these measurements together with corresponding values of PDG96 and PDG98.It is certainly interesting to measure the total decay width of ψ'

[1] fit value

and the branching ratios to $\pi^+\pi^- J/\psi$,$J/\psi X$,$\mu^+\mu^-$ decay channels with better accuracy.We made ψ' scan in the vicinity of its peak value.

2. ψ' Scan Data Taking

ψ' peak was scanned by BES at BEPC.The data were taken at 24 center-of-mass energies ranging from 3.67 GeV to 3.71 GeV.In addition, 6 hours of separated-beam-data were taken at the first and the last points separately for background study.The measurement of every energy point was almost finished within one injection,with beam intensity about 45 mA and typical life time about 8 hours.Averagely it took 3 or 4 hours to complete one point data taking.Accumulately 115.4 hours,or about 4.8 days was used to finish the whole experiment and the total integrated luminosity is 1149 nb^{-1}.

From online event number and the corresponding luminosity, we can get online cross sections.The main results were listed in the table 2.1 and a graph was given for intuition.

Generally speaking, during ψ' scan period, the working of accelerator is stable and the running of spectrometer is smooth.

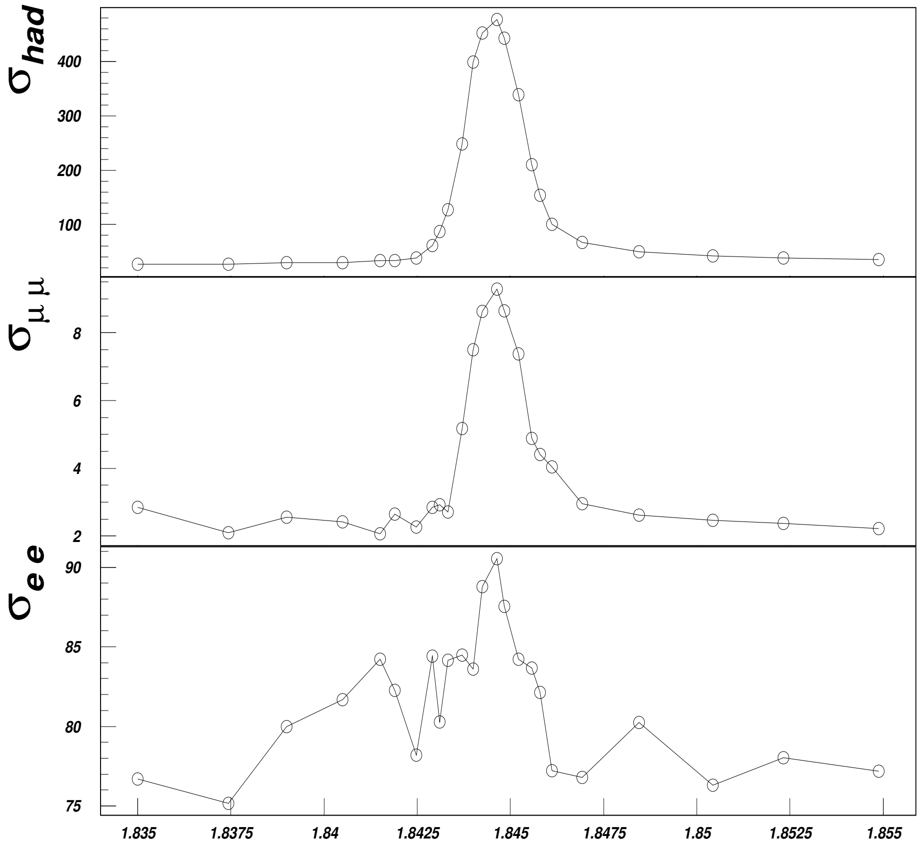

Figure 1: Online cross sections

Table 2.1 Online Results

E_{beam}		online number			Average online cross section			run number
planned	Injected	$N_{e^+e^-}$	$N_{Hadrons}$	$N_{\mu^+\mu^-}$	$\sigma_{e^+e^-}$	$\sigma_{Hadrons}$	$\sigma_{\mu^+\mu^-}$	*begin ~ end*
1.8350	1.8350	3664	1294	134	76.708	26.977	2.844	13196-13199
1.8350	1.8350	separated beam						13200-13205
1.8375	1.83743	3525	1273	100	75.174	27.040	2.105	13206-13208
1.8390	1.8390	3623	1350	116	79.972	29.821	2.562	13209-13211
1.8405	1.8405	3721	1342	110	81.667	29.838	2.415	13212-13217
1.8415	1.8415	3690	1455	92	84.213	33.569	2.070	13218-13221
1.8420*1[1]	1.8419	3195	1289	98	82.257	33.243	2.642	13223-13225
1.8425	1.84248	3664	1774	104	78.194	38.723	2.267	13226-13229
1.8428*2[2]	1.84286	1752	1246	52	81.880	58.890	2.500	13230-13231
1.8428	1.8429	3763	2709	131	84.428	61.365	2.850	13232-13235
1.8432	1.8431	3792	4107	137	80.289	86.977	2.927	13236-13239
1.8434	1.84332	3920	5930	122	84.168	127.34	2.716	13244-13247
1.8437	1.8437	3674	10606	216	84.485	248.05	5.179	13240-13243
1.8440	1.8440	3945	18698	374	83.609	399.18	7.497	13248-13251
1.8443	1.84425	3681	18876	350	88.780	452.390	8.631	13252-13255
1.8446	1.84464	3704	19615	381	90.541	476.742	9.288	13256-13259
1.8449	1.84483	3757	18995	388	87.553	442.976	8.649	13260-13263
1.8452	1.84522	3682	14739	322	84.225	338.622	7.373	13264-13267
1.8455	1.84557	3628	9251	220	83.672	210.068	4.890	13268-13271
1.8458	1.8458	3607	6752	191	82.123	153.533	4.408	13272-13275
1.8462	1.84612	3848	5033	210	77.223	100.658	4.044	13276-13280
1.8470	1.84693	3670	3156	135	76.793	66.902	2.953	13281-13284
1.8485	1.84845	4101	2580	120	80.232	49.975	2.612	13285-13289
1.8505	1.85043	3909	2149	133	76.290	41.948	2.459	13290-13294
1.8525*3[3]	1.85259	1228	612	33	77.652	38.700	2.087	13295
1.8525	1.85232	3939	1926	114	78.024	38.789	2.379	13296-13299
1.8550	1.85488	4040	1830	125	77.175	35.131	2.218	13300-13304
1.8550	1.85488	separated beam						13305-13309

*1[1] *2[2] *3[3]

3. Event Seletion

3.1 Lepton-paired-event selection

Table 3.1 shows the cuts we used for lepton-paired-events selection. First we select two tracks with maximum momenta,they must meet the demands listed in the table 3.1.

Esc, shorting for the energy deposit in BSC, is a powerful variable to tell electrons from muons.Time-of-flight($t_1 for\ \ particle_1, t_2 for\ \ particle_2$) cut is used to eliminate cosmic-ray contamination. According to the solid angle coverage of sub-detectors, angle-cut is applied

[1] VME crash,no Run-Summary for about 8 hours at this point.
[2] For beam lost,another injection Ebeam is a bit different
[3] Only one RUN was taken for machine study.

for both tracks. For e^+e^- events we require the charges of two tracks must be plus and minus respectively. But this requirement is too strict for dimuon events to be demanded. For $\mu^+\mu^-$ events we adopt a noncollinear-angle requirement which has little effect for bhabha events. The last cut, involving the momenta of two tracks, is the same for both e^+e^- and $\mu^+\mu^-$ states and mainly used to get ride of J/ψ-included-events which are annoying background channels.

Table 3.1 cut-conditons for lepton pair final states

demand	e^+e^- *final state*	$\mu^+\mu^-$ *final state*
cut-1	$\sqrt{(Esc_1-1.85)^2+(Esc_2-1.85)^2}<1.2$	$\sqrt{Esc_1{}^2+Esc_2{}^2}<1.0$
cut-2	$\sqrt{(t_1^f-5)^2+(t_2^f-5)^2}<4, f=e,\mu$	
cut-3	$\lvert cos\theta^f\rvert<0.75, f=e,\mu$	
cut-4	$Q_1\&Q_2\ must\ \ be+\&-$	
cut-5		$\alpha_{acol}<5^0$
cut-6	$(p_1^f>1.75)\cup(p_2^f>1.75)\cup\sqrt{(p_1^f-1.85)^2+(p_2^f-1.85)^2}<0.25\ f=e,\mu$	

3.2 Hadron event selection

Cuts are listed firstly and explains are given afterwards.

- Track level

  1. MFIT $=2$ & $R_{xyz}<0.1$ or MFIT $=-19$ & $N_{dE/dx}\geq 16$,
     where $R_{xyz}=\sqrt{V_x^2+V_y^2+V_z^2}$;
  2. $\delta_{tof}^e<6$ & $\delta_{tof}^e>-0.5$,
     where $\delta_{tof}^e=t-l/p*\sqrt{p^2+m_e^2}$, m_e electron mass;
  3. $|cos\theta|<0.85$ when MFIT=2.

- Event level

  1. Good tracks[1] number $N_{good}\geq 2$;
  2. The sum of good tracks and real photons $N_{good}+N_{real\gamma}>4$;
  3. Total (charged and neutral) energy deposit $E_{sum}>0.6$,
     total neutral energy deposit $E_{tot-neutral}<2.5$;
  4. The difference of time-of-flight of any two tracks i and j,
     $|t_i-t_j|<6\ or\ >12$;
  5. For any two tracks of events with $N_{good}\leq 3$,
     $\sqrt{(p_i^2-1.85)^2+(p_j^2-1.85)^2}\geq 0.25\&|p_i-1.85|>0.15$
     where $i,j=1,2,3\ and\ i\neq j$.

[1] the tracks passing the track-level-conditions

As we want to collect all events containing hadrons in final states and there is no peculiar event topology, therefore we have to try our best to clear out all possible background events, such as e^+e^-,$\mu^+\mu^-$, $radiative\ \ Bhabha\ \ (e^+e^-\gamma\ final\ state)$, $cosmic-ray$, $beam-gas$ and so on events. A little complex problem is that sometimes one background needs more than one cut to clear it off but sometimes one cut plays a role in more than one background-clear-off.To be distinct,the background events and cuts used to eliminate them are given in table 3.2. The symbol "Y" means that the cut play important role in eliminating the corresponding background event and the symbol "-" means that this cut can not distinguish the background events from the hadron events effectively.

Table 3.2 the relation between background and cut

cut condition	$beam-gas$	$cosmic-ray$	e^+e^-	$\mu^+\mu^-$	$\gamma\gamma$
$mfit=2\&R_{xyz}<0.1\ or$ $mfit=-19\&N_{dedx}\geq 16$	Y	-	-	-	-
$-0.5<\delta^e_{tof}<6$	Y	Y	-	-	-
$N_{good}\geq 2$	Y	-	-	-	-
$N_{good}+N_{real\gamma}>4$	Y	-	-	-	Y
$E_{sum}>0.6$	Y	-	-	Y	-
$E_{tot-neutral}<2.5$	-	-	-	-	Y
$\|t_i-t_j\|<6\ \ or\ \ >12$	-	Y	-	-	-
$\sqrt{(p_i^2-1.85)^2+(p_j^2-1.85)^2}\geq 0.25$ $\&\|p_i-1.85\|>0.15$	-	-	Y	Y	-

3.3 Analysis result

According to the above selection rules,we analyze approximate 3 million experimental data and list the results in table 3.3.

4 Experiment Acceptance

4.1 Trigger efficiency

The trigger of BES is implemented through a trigger table [1] which includes 8 channels and 15 conditions for each channel.The logic relation between conditions is "and" that means the trigger efficiency of a channel is the product of several trigger conditions you use ,while the logic relation among channels is "or" that means the events would be recordered if they satisfy any channel trigger.In the trigger table,the letter "Y" means the corresponding condition has to be satisfied ,letter "N" means the condition must not be satisfied and symbol

[1]whose first row,or that begin with **active ?**,indicates which channels will be used or not ,denoting by "Y" or "N".

"-" means the condition can be ignored.

In fact each condition is related with BES different sub-detectors' information or event topology,more concrete information has been given in table 4.2.

A carefully studied trigger table, printed in table 4.1, was used for ψ' scan. Totally 4 channels and 10 trigger conditions was set for the data taking. As we mainly concern with barrel detectors information, only 3 channels and 8 conditions play important roles in our experiment. Accordering to relations of trigger conditions, we have

$$\varepsilon_{charged} = \epsilon_{Ntof\geq 1} \bullet \epsilon_{Nvc\geq 1} \bullet \epsilon_{Ntrk\geq 1} \bullet \epsilon_{Etot.l}$$

$$\varepsilon_{char2} = \epsilon_{Ntof\geq 2} \bullet \epsilon_{Nvc\geq 1} \bullet \epsilon_{Ntrk\geq 2}$$

$$\varepsilon_{neutral} = \epsilon_{RADIAL} \bullet \epsilon_{Etot.h}$$

Based on specially selected samples which use certain detectors' information, we can determine the efficiencies for each sub-detector's trigger condition about different type events, such as $hadron, e^+e^-, \mu^+\mu^-$.

Table 3.3 Offline Analysis recorder

E_{beam}		Luminosity	Selected Events Number			RUN number
ordinal	Injected(GeV)	$L_{ee}(nb^{-1})$	$N_{e^+e^-}$	$N_{\mu^+\mu^-}$	$N_{Hadrons}$	$begin \sim end$
1	1.83500	31.282169	2284	158	498	13196~13199
2	1.83743	30.374100	2210	134	465	13206~13208
3	1.83900	30.287910	2203	159	503	13209~13211
4	1.84050	31.316971	2273	141	514	13212~13217
5	1.84150	31.036110	2249	92	549	13218~13221
6	1.84190	34.030258	2466	136	670	13222~13225
7	1.84248	31.704130	2292	116	858	13226~13229
8	1.84290	31.842840	2309	114	1742	13232~13235
9	1.84310	32.362350	2352	110	2995	13236~13239
10	1.84332	33.541359	2439	120	4669	13244~13247
11	1.84370	32.369530	2354	126	9018	13240~13243
12	1.84400	35.248402	2562	176	16122	13248~13251
13	1.84425	33.097210	2410	187	16566	13252~13255
14	1.84464	33.414509	2434	255	17273	13256~13259
15	1.84483	33.586861	2447	227	16648	13260~13263
16	1.84522	32.483231	2358	223	12799	13264~13267
17	1.84557	32.640041	2361	228	7738	13268~13271
18	1.84580	31.636530	2287	171	5461	13272~13275
19	1.84612	39.410271	2850	238	4387	13276~13280
20	1.84693	31.855400	2296	153	2102	13281~13284
21	1.84845	35.628521	2565	147	1560	13285~13289
22	1.85043	34.046009	2446	163	1209	13290~13294
23	1.85232	33.542610	2403	149	990	13296~13299
24	1.85488	34.685009	2477	167	895	13300~13304

Table 4.1 Trigger condition table for ψ' scan

Channel Condition	BHAHBA	CHARGED	2-MU	CHAR2	NEUTRAL	Eneutral	ESC	BB2
Active?	N	Y	N	Y	Y	N	Y	N
$TOFB-B$	-	-	Y	-	-	-	-	Y
$Ntof \geq 1$	-	Y	Y	-	-	-	-	-
$Ntof \geq 2$	-	-	-	Y	-	-	-	Y
$RADIAL$	-	-	-	-	Y	-	-	-
$Nvc \geq 1$	-	Y	Y	Y	-	Y	Y	-
$Eradial$	Y	-	-	-	-	-	-	-
$ETOFBB$	-	-	-	-	-	-	Y	-
$Ntrk \geq 1$	-	Y	-	-	-	-	-	Y
$Ntrk \geq 2$	-	-	-	Y	-	-	-	-
$Ntrk \geq 4$	-	-	-	-	-	-	-	-
$MUON-OR$	-	-	-	-	-	-	-	-
$Etrk$	-	-	-	-	-	Y	-	-
$ESC-Etot$	-	-	-	-	-	-	Y	-
$Etot.l$	-	Y	-	-	-	-	-	Y
$Etot.h$	-	-	-	-	Y	-	-	-

Table 4.2 Sub-detectors and Trigger conditions

relevant sub-detector	trigger conditions and their meanings
MDC (Main Drift Chamber)	$Ntrk \geq 1, Ntrk \geq 2, Ntrk \geq 4$ (at least 1,2 or 4 tracks in MDC found by trigger tracking system
TOF (Time of Flight)	$TOFB-B$ (back-to-back hits found in TOF) $Ntof \geq 1, Ntof \geq 2$ (at least 1 or 2 hits found in TOF)
ETOF (Endcap Time of Flight)	$ETOFB-B$ (back-to-back hits found in ETOF)
BSC (Barrel Shower Chamber)	$RADIAL$ (total radial energy deposited in BSC) $Etot.l, Etot.h$ (low or high threshold of energy deposited in BSC)
ESC (Endcap Shower Chamber)	$Eradial$ (total radial energy deposited in ESC) $ESCEtot$ (low threshold of energy deposited in ESC)
VC (Vertex Chamber)	$Nvc \geq 1$ (at least 1track found in VC)

Note: in our experiment $Etot.l(8) \approx 90MeV, Etot.h(25) \approx 750MeV, ESCEtot \approx 220MeV$

For example, in the channel ESC of table 4.1 the condition of track number $Ntrk$ in MDC is not applied.Defining the number of e^+e^-events triggered through channel ESC as N,and the number of events satisfying the condition $Ntrk \geq 1$ as n, then the trigger efficiency for the condition $Ntrk \geq 1$ for e^+e^-events is $\epsilon_{Ntrk\geq 1} = n/N$.In a similar way, the other sub-detectors' trigger efficiencies can be determined for certain kinds of events. From the product of the efficiencies of the sub-detectors trigger conditions in the trigger table with which the data were taken,we obtain the efficiencies of different channels and from the channel-efficiencies, using probability theory[1], with some physical consideration, we can calculate the overall trigger efficiency as follow

$$\varepsilon = \epsilon_{Ntof\geq1} \bullet \epsilon_{Nvc\geq1} \bullet \epsilon_{Ntrk\geq1} \bullet (\epsilon_{Etot.l} - \epsilon_{Etot.h} \bullet \epsilon_{RADIAL})$$

$$+\epsilon_{Ntof\geq2} \bullet \epsilon_{Nvc\geq1} \bullet \epsilon_{Ntrk\geq2} \bullet (1 - \epsilon_{Etot.l})$$

$$+\epsilon_{RADIAL} \bullet \epsilon_{Etot.h}$$

Doctor Huang Guangshun and Doctor Li Zhongchao have made expert studies about the efficiencies of the sub-detectors' trigger conditions. Using their results we work out the efficiencies needed. All involved data are given in table 4.3.

Table 4.3 efficiency

efficiency	Bhabha efficiency	Dimuon efficiency	Hadron efficiency
$Ntof \geq 1$	0.9986600	0.9946710	0.9981700
$Ntof \geq 2$	0.9304000*	0.9113000*	0.9904000*
$Nvc \geq 1$	0.9985500	1.0000000	0.9998300
$Ntrk \geq 1$	1.0000000	1.0000000	0.9996200
$Ntrk \geq 2$	0.9963900	0.9964790	0.9906600
$RADIAL$	0.9944300	0.2673720	0.4080700
$Etot.l$	1.0000000	0.9864050	0.9984000
$Etot.h$	0.9990700	0.0785500	0.9029800
$\varepsilon_{charged}$	0.9972119	0.9811484	0.9960249
ε_{char2}	0.9256970	0.9080913	0.9809829
$\varepsilon_{neutral}$	0.9935052	0.0210021	0.3684790
ε	0.9999819	0.9936059	0.9984710

*[1]

4.2 Reconstruction and selection efficiency

The event reconstruction and selection efficiencies are usually determined by Monte Carlo simulation. First the physical events data are produced by Monte Carlo generator;then after passing the BES detectors' simulation program SOBER, the Monte Carlo data are obtained; after that the reconstruction data are gained by events reconstruction program DRUNK. At last we use the selection criteria which are adopted for the real or experimental selection, to get selected events. If the selected events number is written as n and those produced by generator as N, the reconstruction and selection efficiency is $\varepsilon_{rs} = n/N$.

For different processes,the corresponding generators would be used. Table 4.4 summarizes the generators we used. Concretely speaking,for e^+e^- and $\mu^+\mu^-$ final states,the efficiencies of QED process are acquired by RADEE and RADMU generators respectively while these of resonance by special generator V2LL which was written by Doctor Wang Ping. As to the hadronic process, LUND-MODEL is used to get the efficiencies for both QCD process and resonance one, only with different parameters.

[1]more concretely speaking, we use the formula
$P(A_1 \cup A_2 \cup A_3) = P(A_1) + P(A_2) + P(A_3) - P(A_1A_2) - P(A_1A_3) - P(A_2A_3) + P(A_1A_2A_3)$

[1]the number with $*$ come from Li Zhongchao's report **"Trigger Efficiency Study for R Scan"** and others from Huang Guangshun's doctoral thesis .

Table 4.4 generators

Type	lepton-pair				Hadron
	QED process		resonance		resonance
	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$	& continuum
Generator	RADEE	RADMU	V2LL		LUND-MODEL

4.3 Acceptance

The acceptance of i type event is defined as :

$$A(i) = \varepsilon_{trg}(i) \bullet \varepsilon_{rs}(i)$$

From efficiencies of trigger and those of reconstruction and selection, we get acceptances. All results are listed in table 4.5. It should be pointed that the acceptance of e^+e^- final states listed in table 4.5 are for events within a restricted solid angle ($|cos\theta| < 0.75$ for e^+e^- events),whereas those of the hadron and dimuon final states spread all solid angles. Therefore some factors are used to modify the original efficiency. Some relevant factors are in table 4.6

Table 4.5 Acceptance and efficiency of trigger, reconstruction and selection

process	trigger efficiency (ε_{trg})	reconstruction and selection efficiency (ε_{rs})	acceptance (A)	$\frac{\Delta A}{A}$ (%)
$1.e^+e^- \to e^+e^-$	0.9999819	0.80083	0.80082	
$2.e^+e^- \to \psi(2S) \to e^+e^-$		0.8431	0.8431	
$3.e^+e^- \to \mu^+\mu^-$	0.9936059	0.55656	0.55300	
$4.e^+e^- \to \psi(2S) \to \mu^+\mu^-$		0.6282	0.6242	
$5.e^+e^- \to hadrons$	0.9984710	0.75373	0.75258	
$6.e^+e^- \to \psi(2S) \to hadrons$		0.7949	0.7937	

Table 4.6 Revised Efficiency

Type	State	Monte Carlo produce scope	Reconstruction and Selection scope	Efficiency	Revised factor	Revised Efficiency
Hadron	*Resonance*	*all*	$\|cos\theta\| \le 0.75$	0.7949	1	0.7949
	Continuum	*space*		0.75373		0.75373
Dimuon	*Resonance*	*all*	$\|cos\theta\| \le 0.75$	0.6282	1	0.6282
	Continuum	*space*		0.55656		0.55656
Bhabha	*Resonance*	*all space*	$\|cos\theta\| \le 0.75$	0.5859	0.6949	0.8431
	Continuum	$\|cos\theta\| \le 0.80$		0.62913	0.7856	0.80083

5. Fitting of the Observed Cross Section

5.1 The observed cross section of $e^+e^- \to R \to f$

The cross section of the process $e^+e^- \to R \to f$ can be described by Breit-Wigner formula

$$\sigma_0(W) = \frac{4\pi(2J+1)\Gamma_e\Gamma_f}{(W^2-M^2)+\Gamma^2M^2}$$

where W is the center-of-mass energy,J the angular momentum of the resonance R, Γ_e and Γ_f the width of R's decaying into e^+e^- and f, Γ the total width, M the mass of R.Taking the initial radiative correction of e^+e^- into consideration, the cross section become

$$\sigma(W) = \int_0^1 dx\{\sigma_0(W)[W^2(1-x)]B(x,W)\}$$

where $x = k/E_b$, k is the energy of radiative photon,$B(x,W)$ the spectrum of radiative photon. In our case, the energy spread Δ is much larger than the nature width of ψ', therefore the effect of Δ must be taken into consideration. Δ can be treated as Gaussian function

$$G(W,W') = \frac{1}{\sqrt{2\pi}\Delta} exp[\frac{-(W-W')^2}{2\Delta^2}]$$

then the experimental resonance cross section become

$$\sigma^R(W) = \int_0^\infty \{\sigma(W')G(W,W')dW'\}$$

5.2 Approximation

In order to get calculable formula,some approximation must be applied. In the above theoretical formula ,$B(x,W)$ describes the spectrum of radiative photon,using **Kuraev and Fadin** structure function method,we get a complex analytical expression. With some physical consideration and approximation,we can get the cross section formula for our fitting.

$$\sigma^R(W) = 12\pi\Gamma_e\Gamma_f \int_0^\infty dW' \bullet G(W,W') \bullet \frac{1}{W'^4}$$

$$\bullet\{(1+\delta)a^{\beta-2}\phi(cos\theta,\beta) + (\frac{3}{4}\beta^2-\beta)a^{\beta-1}\phi(cos\theta,\beta+1)\}$$

where the variables are defined as follow:

$$a^2 = (1-\frac{M^2}{s})^2 + \frac{M^2\Gamma^2}{s^2}$$

$$cos\theta = \frac{1}{a}(\frac{M^2}{s}-1)$$

$$\phi(cos\theta,\beta) = \frac{\pi\beta sin[\theta(1-\beta)]}{sin\theta sin\pi\theta}$$

$$(\sqrt{s} = W \ \ is \ \ center-of-mass)$$

According to the study of Prof. Y.S.Zhu and Dr. P.Wang, for the radiatively corrected cross section, the description accuracy of the above approximate analytical expression can come up to the order of 0.1% .

5.3 The observed cross section

Besides the resonance cross section, the observed cross section includes the continuous cross section and that comes from interference between resonance and continuum.So we should write the observed cross sections as

$$\sigma_h^{obs}(W) = \sigma_h^R(W)A_h^R + \sigma_h^C(W)A_h^C + \sigma_h^I(W)A_h^I$$

$$\sigma_e^{obs}(W) = \sigma_e^R(W)A_e^R + \sigma_e^{QED}(W)A_e^{QED} + \sigma_e^I(W)A_e^I$$

$$\sigma_\mu^{obs}(W) = \sigma_\mu^R(W)A_\mu^R + \sigma_\mu^{QED}(W)A_\mu^{QED} + \sigma_\mu^I(W)A_\mu^I$$

where A_f is the experimental acceptance for the process $e^+e^- \rightarrow f, f = e, \mu, h$ and C indicates continuum, R resonance, I interference.For hadronic final states, the continuous cross section comes from QCD process and the interference cross section is small enough to be negligible, so $\sigma_h^I(W) \approx 0$. For e^+e^- final states,the interference term A_e^I can be get from QED and resonance terms $A_e^I = \sqrt{A_e^R \bullet A_e^{QED}}$. Similarly for $\mu^+\mu^-$ final states, $A_\mu^I = \sqrt{A_\mu^R \bullet A_\mu^{QED}}$.Then the observed cross section can be written as

$$\sigma_h^{obs}(W) = \sigma_h^R(W)A_h^R + \sigma_h^C(W)A_h^C$$

$$\sigma_e^{obs}(W) = \sigma_e^R(W)A_e^R + \sigma_e^{QED}(W)A_e^{QED} + \sigma_e^I(W)\sqrt{A_e^R \bullet A_e^{QED}}$$

$$\sigma_\mu^{obs}(W) = \sigma_\mu^R(W)A_\mu^R + \sigma_\mu^{QED}(W)A_\mu^{QED} + \sigma_\mu^I(W)\sqrt{A_\mu^R \bullet A_\mu^{QED}}$$

From above formulae,we know, to get ψ' decay width from fitting of the observed cross sections, only six experimental acceptances need to be known, are $A_h^R, A_h^C, A_e^R, A_e^{QED}, A_\mu^R, A_\mu^{QED}$.

6. Result and Discussion

6.1 Result

The three data sets for $e^+e^- \rightarrow hadrons, e^+e^-\ and\ \mu^+\mu^-$ were fitted simultaneously to obtain the partial widths of ψ' to hadrons, electrons, muons, and the total width is assumed to be the sum of four partial widths.

$$\Gamma_{total} = \Gamma_h + \Gamma_\mu + \Gamma_e + \Gamma_\tau,$$

$$(with\ assumption\ \Gamma_e = \Gamma_\mu = \Gamma_\tau/0.38847)$$

During the fit, the following parameters are allowed to vary:
$M(mass), \Gamma_h\ and\ \Gamma_\mu(partial\ widths)$,
$\Delta(the\ energy\ spread\ of\ the\ machine)$,
$\sigma_{nr}(the\ nonresonant\ hadronic\ cross\ section)$.

The fitting curves are shown with the scan points in figure 2 and the final results given in table 6.1.

Table 6.1 Fit results

Γ	237.492 $\pm ??keV$
Γ_h	231.687 $\pm ??keV$
Γ_μ	2.3414 $\pm ??keV$
Γ_h/Γ	0.97556 $\pm ?$
Γ_μ/Γ	0.01023 $\pm ?$

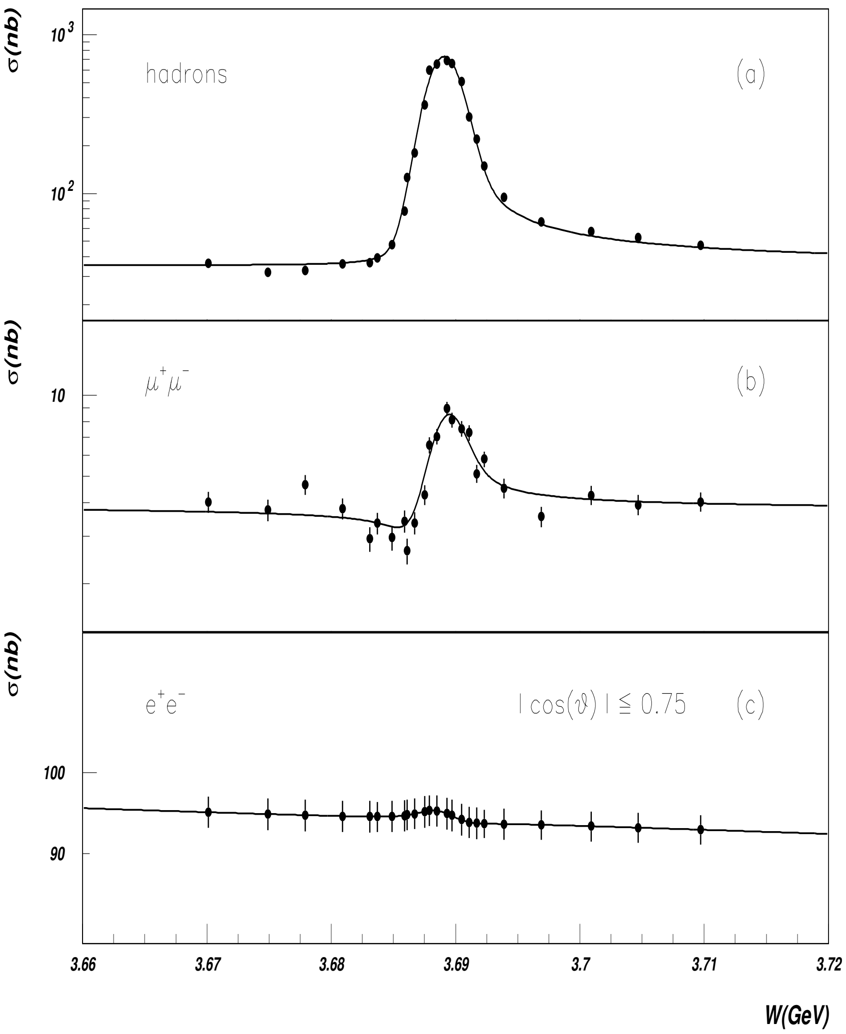

Figure 2: (a) The total cross section for $e^+e^- \rightarrow hadrons$, (b) the total cross section for $e^+e^- \rightarrow \mu^+\mu^-$, and (c) the total cross section for $e^+e^- \rightarrow e^+e^-$ integrated over the range $|cos\theta| \leq 0.75$ versus center-of-mass energy. The solid curves represent the results of the fit to the data.

6.2 Discussion

At last I will say a few words about some works to be done.

- Event selection re-examination and systematic error study.
- Measurement of $B(\psi' \rightarrow \pi^+\pi^- J/\psi)$
- Some other branching ratios can be studied:
  - $B(\psi' \rightarrow J/\psi\ anything)$
  - $B(\psi' \rightarrow J/\psi\ neutrals)$
  - $B(\psi' \rightarrow J/\psi\, \pi^0\, \pi^0)$

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