THE PRESTUDY OF THE R MEASUREMENT AT BES

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Jun 9, 1997

♣ The Qantities Related To R

I. Definition of R

R : The lowest order hadronic cross section of single-photon annihilation normalized by the same level $\mu^+\mu^-$ cross section in the e^+e^- colliding process.

• Theoretic Expression:

$$R = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to hadrons)}{\sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

• Experimental Expression:

$$R = \frac{\sigma^\circ_{had}}{\sigma^\circ_{\mu\mu}} = \frac{\sigma^{obs}_{had}}{\sigma^\circ_{\mu\mu} \cdot \bar{\varepsilon}_{had} \cdot (1+\delta)}$$

where,

$$\sigma^{obs}_{had} = \frac{N_{can} - N_{bg}}{L} - (\epsilon\sigma)_{ee} - (\epsilon\sigma)_{\tau\tau} epsilon\sigma)_{\mu\mu} - ((\epsilon\sigma)_{\gamma\gamma}$$

or,

$$N^{obs}_{had} = N_{can} - N_{bg} - L(\epsilon\sigma)_{ee} - L(\epsilon\sigma)_{\mu\mu} - L(\epsilon\sigma)_{\tau\tau} - L(\epsilon\sigma)_{\gamma\gamma}$$

Backgrounds in data:
(1) Cosmic-ray;
(2) Beam-gas/wall related background;
(3) $e^+e^- \Rightarrow e^+e^-(\gamma)$;
(4) $e^+e^- \Rightarrow \mu^+\mu^-(\gamma)$;
(5) $e^+e^- \Rightarrow \tau^+\tau^-(\gamma) \Rightarrow$ X;
(6) $e^+e^- \Rightarrow e^+e^-\gamma\gamma \Rightarrow e^+e^-X$.

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N_{can} : The number of candidate of hadronic events;
N_{bg} : The number of beam-gas/wall events in data;
L : The integrated luminosity of the data analysised;
$(1+\delta)$: The radiative corrections of hadronic process;
$L\sum_{BG}(\epsilon\sigma)_{BG}$: The remainant number of background events passing the hadronic criteria;
$\overline{\varepsilon}_{had}$: The detection efficiency of the hadronic events estimated by Monte Carlo;
$\sigma^{\circ}_{\mu\mu}$: The lowest QED cross section of $e^+e^- => \mu^+\mu^-$ process

$$\sigma^{\circ}_{\mu\mu}(s) = \frac{4\pi\alpha^2}{3s} \quad or \quad \sigma^{\circ}_{\mu\mu}(s) = \frac{4\pi\alpha^2}{3s}\cdot\beta(\frac{3-\beta^2}{2}) \quad (?)$$

II. Hadronic event selection

Hadronic events have not certain characteristic to follow, the way of statistical backgrounds subtraction was used. The applied critiaria of backgrounds depend on the observed topology.
(1). Principal characteristics of backgrounds
- low multiplicity;
- back-to-back topology;
- energy missing.

(2). 4 Common Conditions for good events
- Vertex locates at colliding region: $R_v \leq 1.5 \;\; cm, \quad |z_v| \leq 15 \;\; cm$;
- To ensure good $\vec{p}$ and $\vec{r}$ measurement: $|cos\theta| \leq 0.8$;
- In BSC, to ensure e and γ fully measured: $|cos\theta| \leq 0.75$;
- Track can go through MDC: $P_\perp \geq 0.08 \; GeV/c$;

(3). Event pre-judgement
judgement in following order,
- If Junk (?)
- If High-prong event (?)
  $\Rightarrow$ if background (?)
- If Two-prong event
  $\Rightarrow$ if e^+e^- event (?)
  $\Rightarrow$ if $\mu^+\mu^-$ event (?)
  $\Rightarrow$ if $\tau^+\tau^-$ event (?)
  $\Rightarrow$ if e^+e^-X event (?)
- Then hadronic candidate.

(4). High-prong ($N_{ch} \geq 3$) event
It is hadronic candidate, if
- fit convergence ($MFIT = 2$ or -9 or -19);
- low-energy loos;
- Energy-current asymmetry cut ($A_{LR}, A_{TB}, A_{FB} < 0.8$).

(5). Two prong event
- $Q_1 + Q_2 = 0$;
- track fit convergence;
- good TOF quality ($T_{qual} = 1, \; or \; 2, \; or \; 7$);

- $T = |T1 - T2| \leq 4 \quad ns$;
- $T2 = |T1 - Tc| \leq 3 \quad ns$.

it is back-to-back event, if

- $\theta_{acollinear}, \quad \theta_{acoplanar} \leq 10°$;
- total energy $E_{tot}/E_{beam} \leq 1.5$.

(6). Particle identification

Identifing in the order

$$p/\bar{p}(?) \Rightarrow \mu^{\pm}(?) \Rightarrow e^{\pm}(?) \Rightarrow K^{\pm}/\pi^{\pm}(?)$$

by the informations from MDC, TOF, BC, MUC.

- BC information : deposit energy of charged track, hit position.
- MUC information : μ hit;
- MDC information : $\chi^2_{dE/dx}(i) = \frac{(\frac{dE}{dx}_m - \frac{dE}{dx}_{it} - \delta\frac{dE}{dx})^2}{\sigma^2_{dE/dx}}$, (i=e,$\mu$,K,$\pi$,p);
- TOF information : $\chi^2_{TOF}(i) = \frac{(t_m - t_{it} - \delta t)^2}{\sigma^2_t}$;
- total $\chi^2 \; = \; \chi^2_{dE/dx} + \chi^2_{TOF}$.

III. Estimate of remaining backgrounds

$$e^+e^- \Rightarrow e^+e^-(\gamma), \mu^+\mu^-(\gamma), \tau^+\tau^-(\gamma), e^+e^-X$$

They are subtracted statistically by terms $-\sum(\epsilon\sigma)_{BG}$.

σ_{BG} : The background cross sections;

ϵ_{BG} : The detection efficiency of remaining backgrounds.

Accuracies of σ_{BG} (e.g. At $\sqrt{s} = 3.55396 \quad GeV$)

($\sigma_{e^+e^-X}$ is the no-tagging two-photon cross section)

PROCCESS	$\|cos\theta\|$	$\sigma_{BG}(nbar)$	$\delta\sigma_{BG}(nbar)$
e^+e^-	0.8	133.153	0.3001
$\mu^+\mu^-$	1.0	7.8261	0.0235
$\tau^+\tau^-$	1.0	0.12295	0.0003
e^+e^-X	0.8	240.035 ?	?

IV. The beam-gas/wall backgroud

The remainent number of beam-gas/wall background is estimated by the separated-beam data, in which the hadronic criteria are applied. The survived number N_{bg} is estimated by

$$N_{bg} = f_{PCT} \cdot N_{sep}$$

where, N_{sep} is the survived number in separated-beam experiment, and f may be determined by measuring PCT for both colliding- and separated- beam experiments,

$$f_{PCT} = \frac{PCT_{coll}}{PCT_{sep}}$$

where,

$$PCT_{coll} = \int_0^{T_{coll}} dt P_{coll}(t) \cdot (I_{e^+,coll}(t) + I_{e^-,coll}(t))$$

$$PCT_{sep} = \int_0^{T_{sep}} dt P_{sep}(t) \cdot (I_{e^+,sep}(t) + I_{e^-,sep}(t))$$

$P(t)$ is the presure of the beam-pipe. $I_e(t)$ is the single beam electric-current.

V. Luminosity Measurement

Using large angle Bhabha event
(1). Bhabha event selection : Selecting radiative Bhabha events
(2). Monte Carlo (by Berends etc.) gives

- the cross section $\sigma_{ee(\gamma)}$ in $0(\alpha^3)$ order;
- systematic error ~ 0.3 %;
- acception of Bhabha event $\epsilon_{e^+e^-}$.

(3). Integrad luminosity

$$L = \frac{N_{obs}^{e^+e^-}}{\sigma_{e^+e^-} \cdot \epsilon_{ee}}$$

VI. Radiative Corrections Of σ_{had}

Aim: to remove the contributions of all higher-order $0(\alpha^2)$ Feynman figures from σ_{had}^{obs}.
(1). Basic formula:
The cross section of order α^3

$$\begin{aligned}\sigma(s) &= \sigma_0(s)[1 + \delta_{vert} + \delta_{vac} - t\int_0^{E-m_e} \frac{dk}{k}(\frac{k}{E})^t \\ &+ t\int_0^{E-m_e} \frac{dk}{k}(\frac{k}{E})^t(1 - \frac{k}{E} + \frac{k^2}{2E^2})\frac{\sigma_0(s')}{\sigma_0(s)}]\end{aligned}$$

where, the equivalent radiator

$$t = \frac{2\alpha}{\pi}[ln\frac{s}{m_e^2} - 1]$$

E is the beam energy, k is the radiative energy, $s' = s(1 - k/E)$ is the e^+e^- squred c.m energy after radiation, and $(k/E)^t$ is the soft photon exponentiation.
(2). With detector factors:
In experiment analysis, the hadronic cross section is presented as

$$\sigma_{had} \Rightarrow \sigma_{had}^{obs} = \sigma_{had}^0 \cdot \overline{\varepsilon}_{had} \cdot (1 + \delta)$$

It is convenient, from the view-point of experiment, to make the replacement

$$\overline{\varepsilon}_{had}(1 + \delta) => \varepsilon^{eff}(0)(1 + \delta_{obs})$$

then the radiative effect in $\overline{\varepsilon}_{had}$ is moved into δ_{obs}.
$\varepsilon^{eff}(k)$ is the efficiency with radiative energy k, δ_{obs} the radiative correction,

$$\delta_{obs} = \delta_{ver} + \delta^{e}_{vac} + \delta^{\mu}_{vac} + \delta^{\tau}_{vac} + \delta^{res}_{vac} + \delta^{con}_{vac} + \delta_{\gamma obs}$$

(3) Calculated value of radiative correction (at $\sqrt{s} = 3.55396\ GeV$)

δ_{ver}	δ^{e}_{vac}	δ^{μ}_{vac}	δ^{τ}_{vac}	δ^{res}_{vac}	δ^{con}_{vac}	$\delta_{\gamma obs}$	δ_{obs}
0.0646	0.0243	0.0083	-0.0004	0.0123	0.0105	0.0319	0.1478

♡ MC Simulation And BES Data

BEPC energy region lies at the lower end of high energy region, which crosses several resonances production thresholds, and appears the complex production properties. There is no specialized Monte Carlo generator in this region.

I. Hadronization Model

In Mote Carlo, $e^+e^- \Rightarrow$ hadrons is modeled in several steps:
- Electroweak interaction phase;
- Perturbative QCD phase;
- Hadronization phase;
- Unstable particle deacy.

JETSET74 & HERWIG59 are designed to simulate the hadronic event production in high energy ($\sqrt{s} > 5GeV$) continuum region. The used hadronization schame
- In JETSET : string formation and fragmentation;
- In HERWIG : cluster formation and decay.

II. JETSET/HERWIG and BES data

Having a good Hadronic generator is very important to R measurement. In order to learn how well the LUND and HERWIG model simulate the BEPC/BES events, several final state spectra were calculated.
(1). Multiplicity comparison of data with MC (e.g. at $\sqrt{s} = 3.55396\ GeV$)

by JETSET74 $\Rightarrow$ SOBER $\Rightarrow$ DRUNK + HADSEL
(No lossing-tracks compensation)

prong	JETSET74 (%)	BES MC (%)	BES data (%)
0	2.36	-	-
1	-	-	-
2	28.04	8.28	12.33
3	-	22.18	28.16
4	49.12	42.08	38.90
5	-	13.47	10.74
6	18.86	11.28	0.22
7	-	1.63	0.99
8	1.54	0.75	0.60
9	-	0.19	0.05
≥ 10	0.06	0.07	0.0

(2). Final state spectra
In the flowing spectra, the all distributions were not recovered to the physical events level. In order to display the influence of the remainent leptonic backgrounds in the spectra, the JETSET74$\bigoplus$BGGEN (including 4 background generators) was used to simulate hadronic-leptonic mixed Monte Carlo samples, which may compare with BES data, HERWIG59 was used to simulate pure hadronic process. We can see the remainent backgrounds are clear.
(3). Based on the comparison and the consideration in physics, we will try adjusting some model parameters and to see if the models may be cosistant with the data better.

III. Detection efficiency ε

(1). Definition : Probability that handronic events observed in detector and passed all selection criteria, which can be determined by MC simulation.
(2). ϵ estimation

At $\sqrt{s} = 3.5529 \quad GeV$

GENERATOR	PROCESS	$\bar{\epsilon}$
JETSET74	$e^+e^- \Rightarrow$ hadrons	0.464
HERWIG59	$e^+e^- \Rightarrow$ hadrons	0.470
BHAGEN	$e^+e^- \Rightarrow e^+e^-(\gamma)$	0.1262
RADMUMU	$e^+e^- \Rightarrow \mu^+\mu^-(\gamma)$	0.0658
BHAGEN	$e^+e^- \Rightarrow \tau^+\tau^-(\gamma)$	0.1726
GAMMA2	$e^+e^- \Rightarrow e^+e^-X$	0.1744

The systematic error of $\bar{\epsilon}_{had}$ may be estimated as

$$\frac{\delta\bar{\epsilon}_{had}}{\bar{\epsilon}_{had}} \sim 0.01285$$

(3). Hadronic efficiency with certain radiation
$\epsilon(k)$: the hadronic efficiency with a emission of photon energy k at $\sqrt{s} = 3.55396 \ GeV$

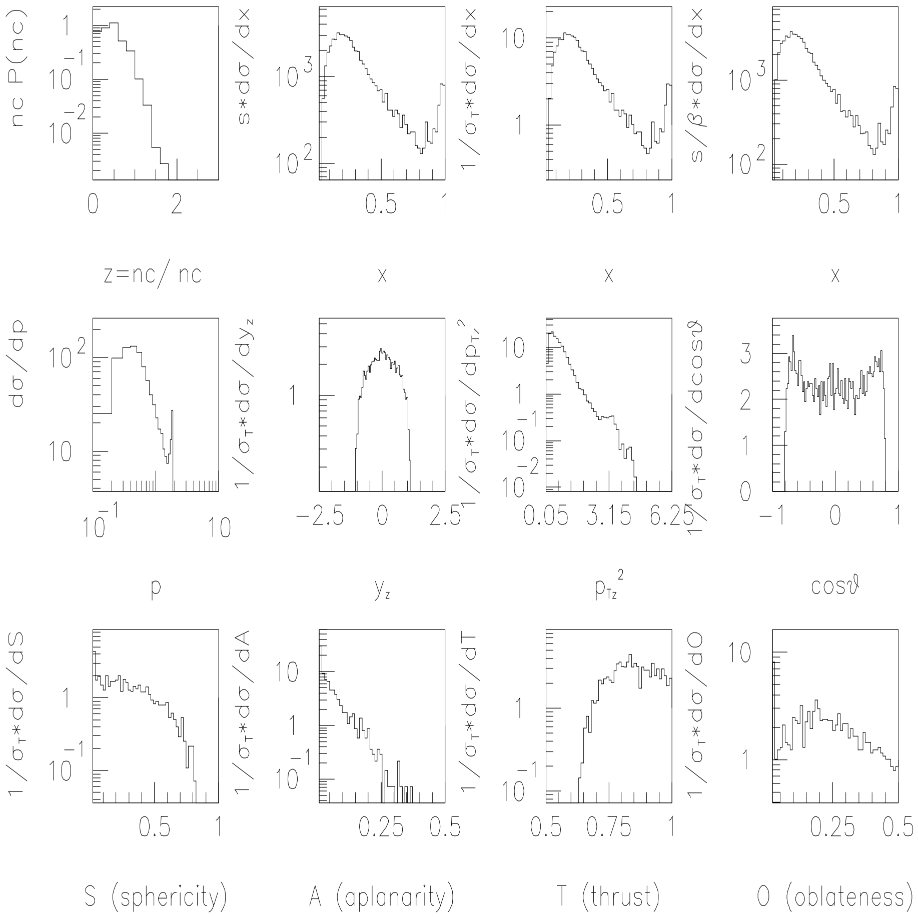

Figure 1: Some final-state spectra of hadronic process by JETSET74$\bigoplus$BGGEN $\Rightarrow$ SOBER $\Rightarrow$ DRUNK (with hadonic criteria) at $\sqrt{s} = 3.55396\ GeV$. The upward-tail at large x is caused by the remainent leptonic events

k/E	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
$\epsilon(k)$	0.496	0.4704	0.4630	0.4286	0.3866	0.3498	0.2846	0.1828	0.0820	0.03020

(4). $\bar{\epsilon}$ changes with E_{cm}

$\sqrt{s}$ (GeV)	2.5	3.0	3.5	4.0	4.5	5.0
$\bar{\epsilon}$	0.3342	0.3858	0.4590	0.4608	0.4630	

♡ Error Estimation Of R

By the experimental expression of R, an estimation of errors is given (no corelation between values measured is assumed)

$$\frac{\delta R}{R} \quad = \quad \{[\frac{N_{can}}{N_{can} - N_{bg} - L\sum_{x}(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta N_{can}}{N_{can}}]^2$$

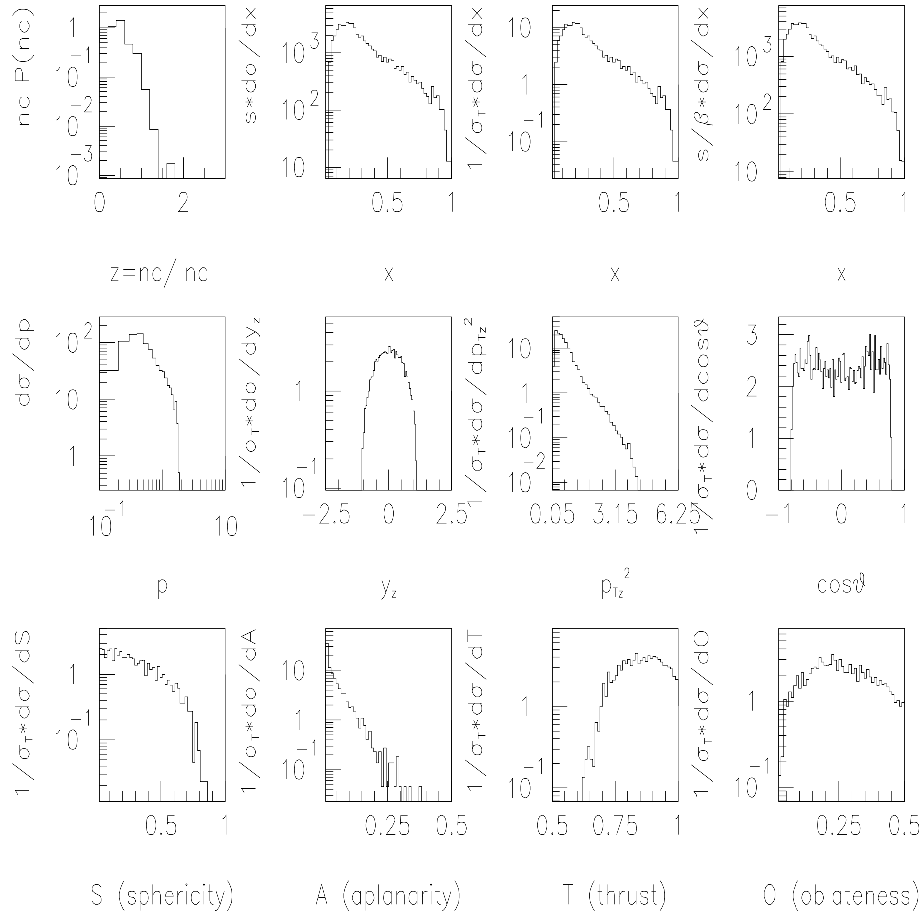

Figure 2: Some final-state spectra of hadronic process by HERWIG59 $\Rightarrow$ SOBER $\Rightarrow$ DRUNK at $\sqrt{s} = 3.55396\ GeV$

$$
\begin{aligned}
+ & \quad [\frac{N_{bg}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta N_{bg}}{N_{bg}}]^2 \\
+ & \quad [\frac{L(\epsilon\sigma)_{ee}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta(\epsilon\sigma)_{ee}}{(\epsilon\sigma)_{ee}}]^2 \\
+ & \quad [\frac{L(\epsilon\sigma)_{\mu\mu}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta(\epsilon\sigma)_{\mu\mu}}{(\epsilon\sigma)_{\mu\mu}}]^2 \\
+ & \quad [\frac{L(\epsilon\sigma)_{\tau\tau}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta(\epsilon\sigma)_{\tau\tau}}{(\epsilon\sigma)_{\tau\tau}}]^2 \\
+ & \quad [\frac{L(\epsilon\sigma)_{\gamma\gamma}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta(\epsilon\sigma)_{\gamma\gamma}}{(\epsilon\sigma)_{\gamma\gamma}}]^2 \\
+ & \quad [\frac{N_{can} - N_{bg}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x}]^2 \cdot [\frac{\delta L}{L}]^2
\end{aligned}
$$

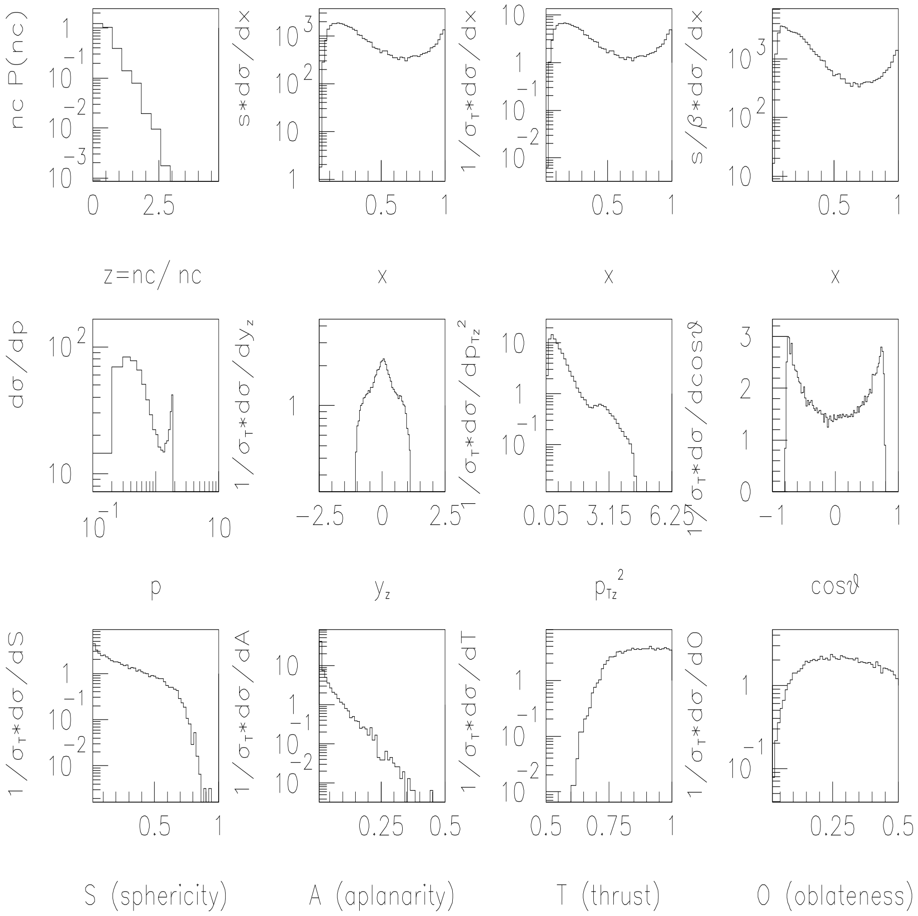

Figure 3: Some final-state spectra of hadronic process from BES data (τ mass scan data at $\sqrt{s} = 3.55396\ GeV$) and passing hadronic criteria. The clear upward-tail at large x is caused by the remainent leptonic events.

$$+ \quad [\frac{\delta\overline{\epsilon}_{had}}{\overline{\epsilon}_{had}}]^2 + [\frac{\delta(1+\delta)}{(1+\delta)}]^2\}^{1/2}$$

Table of systematic errors
The experimental data are taken from
the data summary of BES2
RUN 10692 $\quad E_{beam} = 1.547$ GeV $\quad$ Mar. 14, 1997

sourse	relative error (%)	contribution (%)
$\frac{\delta N_{can}}{N_{can}}$	3.0	6.1427 (!)
$\frac{\delta N_{bg}}{N_{bg}}$	2.0 (?)	1.9780(?)
$\frac{\delta(\epsilon\sigma)_{ee}}{(\epsilon\sigma)_{ee}}$	≤ 2.0	≤ 0.0332
$\frac{\delta(\epsilon\sigma)_{\mu\mu}}{(\epsilon\sigma)_{\mu\mu}}$	≤ 2.0	≤ 0.0010
$\frac{\delta(\epsilon\sigma)_{\tau\tau}}{(\epsilon\sigma)_{\tau\tau}}$	≤ 2.0	-
$\frac{\delta(\epsilon\sigma)_{\gamma\gamma}}{(\epsilon\sigma)_{\gamma\gamma}}$	3.0 (?)	0.0829
$\frac{\delta L}{L}$	5.0 (?)	5.2928 (?) (!)
$\frac{\delta\epsilon}{\epsilon}$	1.285	1.285
$\frac{\delta(1+\delta)}{(1+\delta)}$	≤ 1	≤ 1.0
total systematic error	-	8.3466

CONCLUSION

- Studied some BES1 data;
- Studied hadronization model JETSET74 & HERWIG59;
- A subroutine for J/ψ and ψ' thresholds production was added in JETSET74;
- HERWIG59/JETSET74 may be used to estimate hadronic efficiency for $\sqrt{s} > 3\ GeV$;
- Completed the programs for calculating hadronic radiative corrections;
- Completed the programs for removing backgropund and selecting hadronic event;
- Studied the scheme of calculating luminosity by large angle Bhabha event;
- estimated some systematic errors of R measurement;
- The dominant systematic errors come from event selection and the luminosity(!);
- It is expected that the error of R measurement may be reduced to 8% below.