Measurement of the Total Cross Section for the Hadronic Production by e^+e^- Annihilation at $\sqrt{s} = 2 - 5$ GeV

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Motivation

- R value in the lowest order

$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)} = 3\sum_q Q_q^2 \quad (1)$$

A measurement of R directly counts the number of quarks, their flavor and colors.

- R with higher order QCD correction:

$$R = 3\sum_q Q_q^2[1 + (\frac{\alpha_s(s)}{\pi}) + 1.411(\frac{\alpha_s(s)}{\pi})^2 - 12.8(\frac{\alpha_s(s)}{\pi})^3 + \ldots] \quad (2)$$

Measure $R \to \alpha_s(s)$.

A precision measurement of R

- Reduce the uncertainty of $\alpha(M_z)$: essential for any precision test of the SM.

$$\alpha(s) \equiv \frac{\alpha}{1+\prod_{\gamma\gamma}}, Im\prod_{\gamma\gamma}(s) = -\frac{\alpha}{3}R_{had}(s) \tag{3}$$

$$Re\prod_{\gamma\gamma}(s) = \frac{\alpha s}{3\pi}P\int_{4m_\pi^2}^{\infty} ds' \frac{R(s')}{s'(s'-s)} \tag{4}$$

- narrow the mass window of the Higgs boson

$$X \equiv f^{SM}(\alpha, G_F, m_Z, \alpha_s, m_t, m_H) \tag{5}$$

Indirectly determination of M_H depends critically on $\alpha(M_Z)$.

- Contribution to the interpretation of a_μ

$$a_\mu^{the} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had} \tag{6}$$

$$a_\mu^{had} = (\frac{\alpha m_\mu}{3\pi})^2 \int_{4m_\pi^2}^{\infty} ds' \frac{\hat{K}(s')}{s'^2} R(s') \tag{7}$$

Current status of R value

R has been measured in the energy region from hadron production threshold to the Z^0 pole.

Table 1: Uncertainties of R in different energy region

$E_{cm}(GeV)$	$\Delta R/R(\%)$
$E_{cm} < 5$	$15-20$
$5 < E_{cm} < 10$	$5-10$
$10 < E_{cm} < m_Z$	$2-7$

Present $\Delta R/R$ below 5 GeV $\sim 15\%$.

Experimental expression

Experimentally,

$$R = \frac{\sigma^0_{had}}{\sigma^0_{\mu\mu}} = \frac{N_{obs} - N_{bg}}{\sigma^0_{\mu\mu} \cdot \overline{\varepsilon}_{had} \cdot \varepsilon_{trg} \cdot (1+\delta) \cdot L} \qquad (8)$$

Where,

N_{obs} : the observed hadronic events

N_{bg} : background

L : integrated luminosity

$(1+\delta)$: radiative correction

$\overline{\varepsilon}_{had}$: detection efficiency

ε_{trg}: trigger efficiency

$\sigma^0_{\mu\mu}$: the calculated lowest QED cross section of $e^+e^- \to \mu^+\mu^-$

$$\sigma^0_{\mu\mu}(s) = 4\pi\alpha^2/3s.$$

Apparatus and Measurements

- **Upgraded BES detector (BESII):**

- Vertex chamber : spatial resolution $\sim 80\mu m$;

- New Main Drift Chamber : momentum resolution $\sim 1.7\%\sqrt{1+p^2}$ (P in GeV);

- Time Of Flight counters : time resolution $\sim 180ps$;

- Shower Counters : energy resolution $\sim 22\%/\sqrt{E}$ (E in GeV);

- Muon chamber : position resolution 3cm and 5.5cm in $r\phi$ and z direction respectively.

- **1998 Spring Run :**

- Trigger criteria;

- Background subtraction;

- Detector performance.

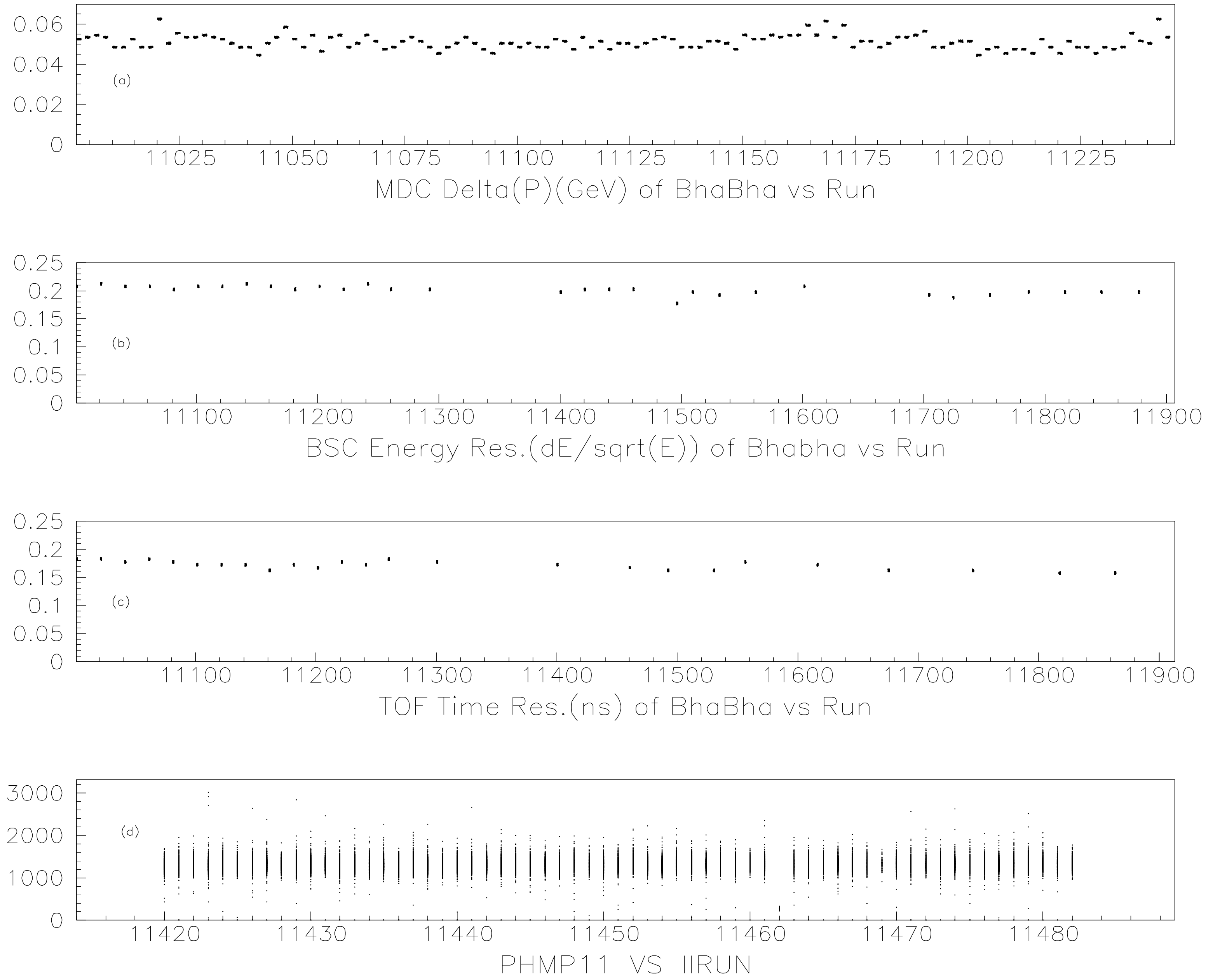

Figure 1: Plots showing the stable performance of BESII. (a) MDC momentum resolution; (b) ECAL energy resolution; (c) time resolution of BTOF; (d)MDC $dE/dx(\propto PHMP)$ of the R scan data. (a)-(c) are based on J/Ψ data collected before taking R scan data for the calibration of BESII. All the plots are produced using Bhabha events.

Hadronic event candidate

Charged track selection:

- good track in MDC : $N_{hits} > 16$;
- geometry acceptance : $|\cos\theta| < 0.84$;
- track vertex : $|v_{xy}| < 2.0cm$;
- momentum : $p < p_{beam} + 5 \times \sigma_{p_{beam}}$;
- time-of-flight : $2 < t < 20$ns;
- track energy : $E < 0.6E_{beam}$;
- remove any track with muon signal.

Event level selection:

- not all tracks carry positive charge($N_{chrg} > 2$);
- $\sum E_{sc} > 0.28E_{beam}$.

For $N_{chrg} = 2$, addiational requirements :

- reject back-to-back events:

$$| \theta_1 + \theta_2 - 180^\circ | > 10^\circ;$$
$$|| \phi_1 - \phi_2 | - 180^\circ | > 4^\circ.$$

- at least 2 isolated neutral tracks :

$$E_\gamma > 100MeV, \quad | \phi_\gamma - \phi_c | > 15^\circ.$$

- **geometry acceptance**

We check the momentum, dE/dx and deposited energy distribution of Bhabha events near $\mid cos\theta \mid = 0.84$.

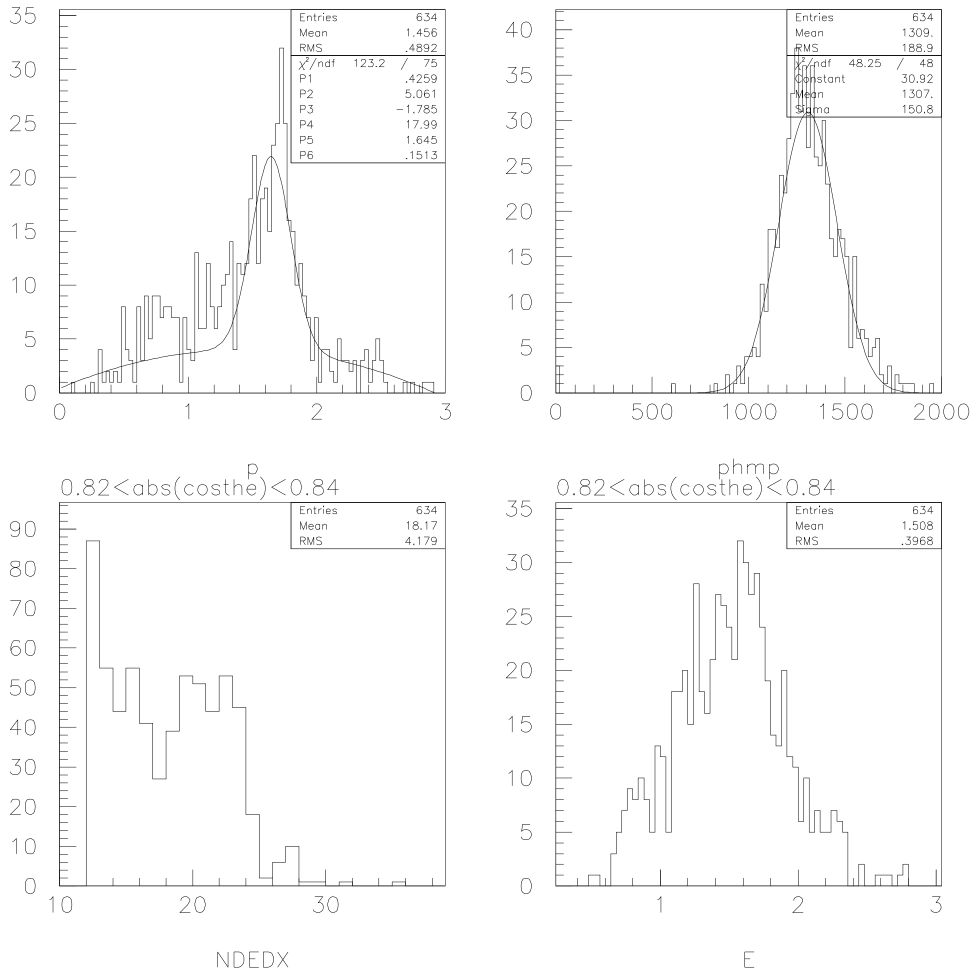

Figure 2: Several distribution of Bhabha events near $\mid cos\theta \mid = 0.84$ $(E_{cm} = 3.4GeV)$. The four figures represent track momentum, dE/dx pulse height, dE/dx hits number and deposited energy, respectively.

- **TOF information**

TOF of hadron track is required to be in a rather wide range from 2 to 20 ns.

- **track energy cut**

Hadron track deposites smaller energy than electron track. If a track has great energy deposit, it should not be a hadron.

- **vertex cut along the beam axis**

The distance of closest approach to the beam along the beam axis (V_z) should be less than 18cm.

- **vertex cut in the transverse plane**

The distance of closest approach to the beam in the transverse plane (V_r) should be less than 2.0cm.

- **total energy cut**

The good hadron event should not have too small energy, otherwise it probably is a background event.

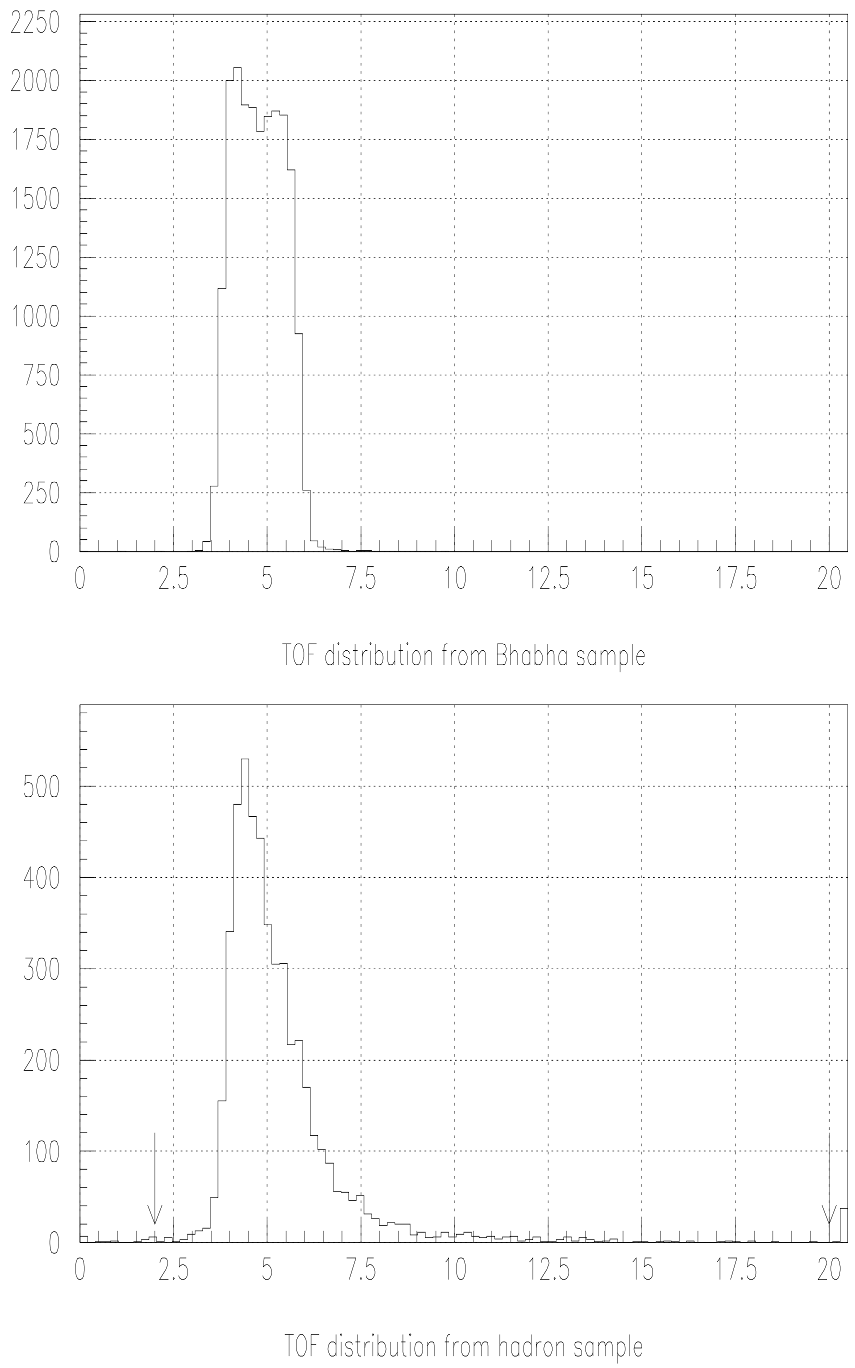

Figure 3: TOF at 3.4 GeV

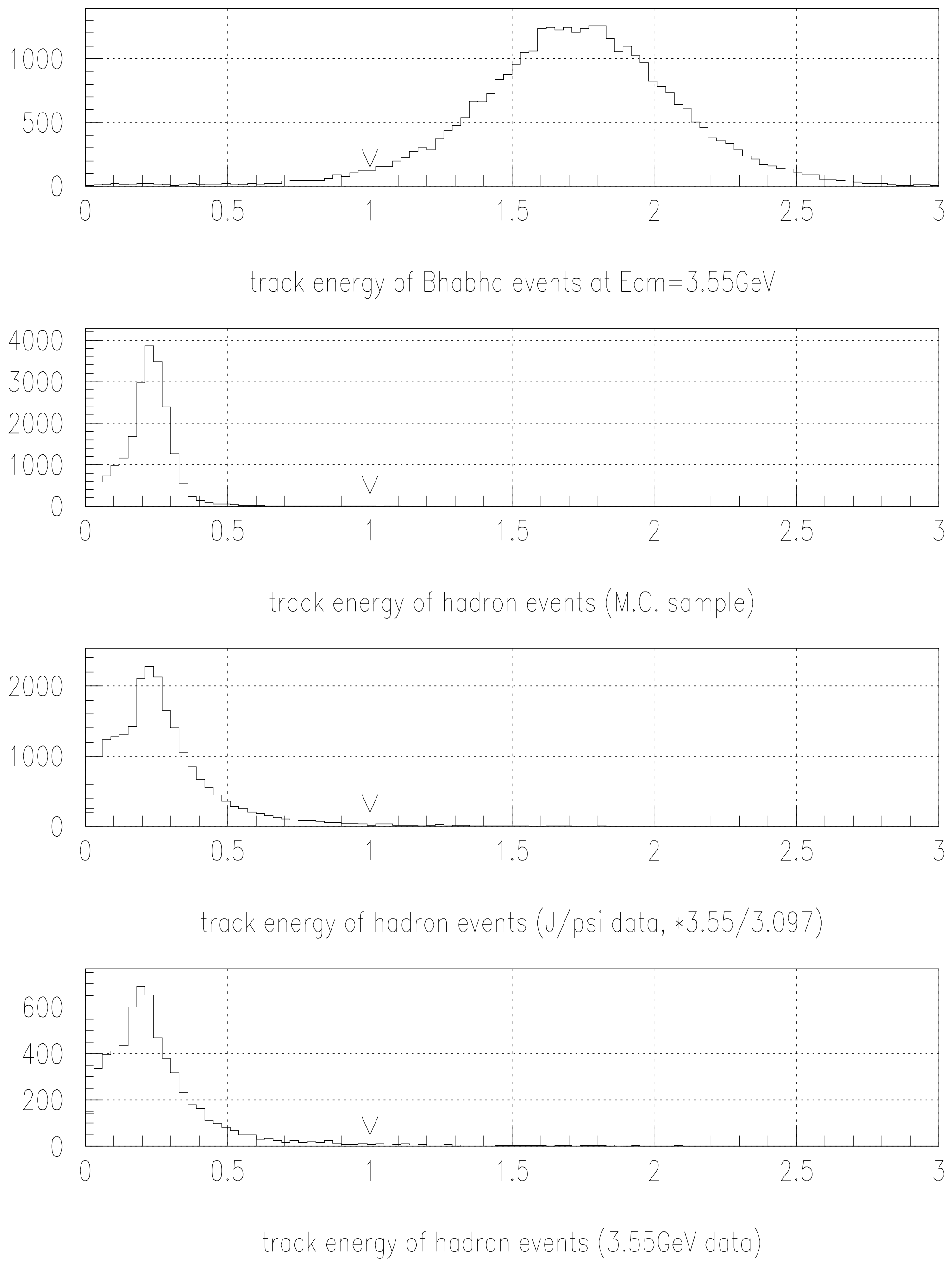

Figure 4: Track energy of Bhabha and hadron events

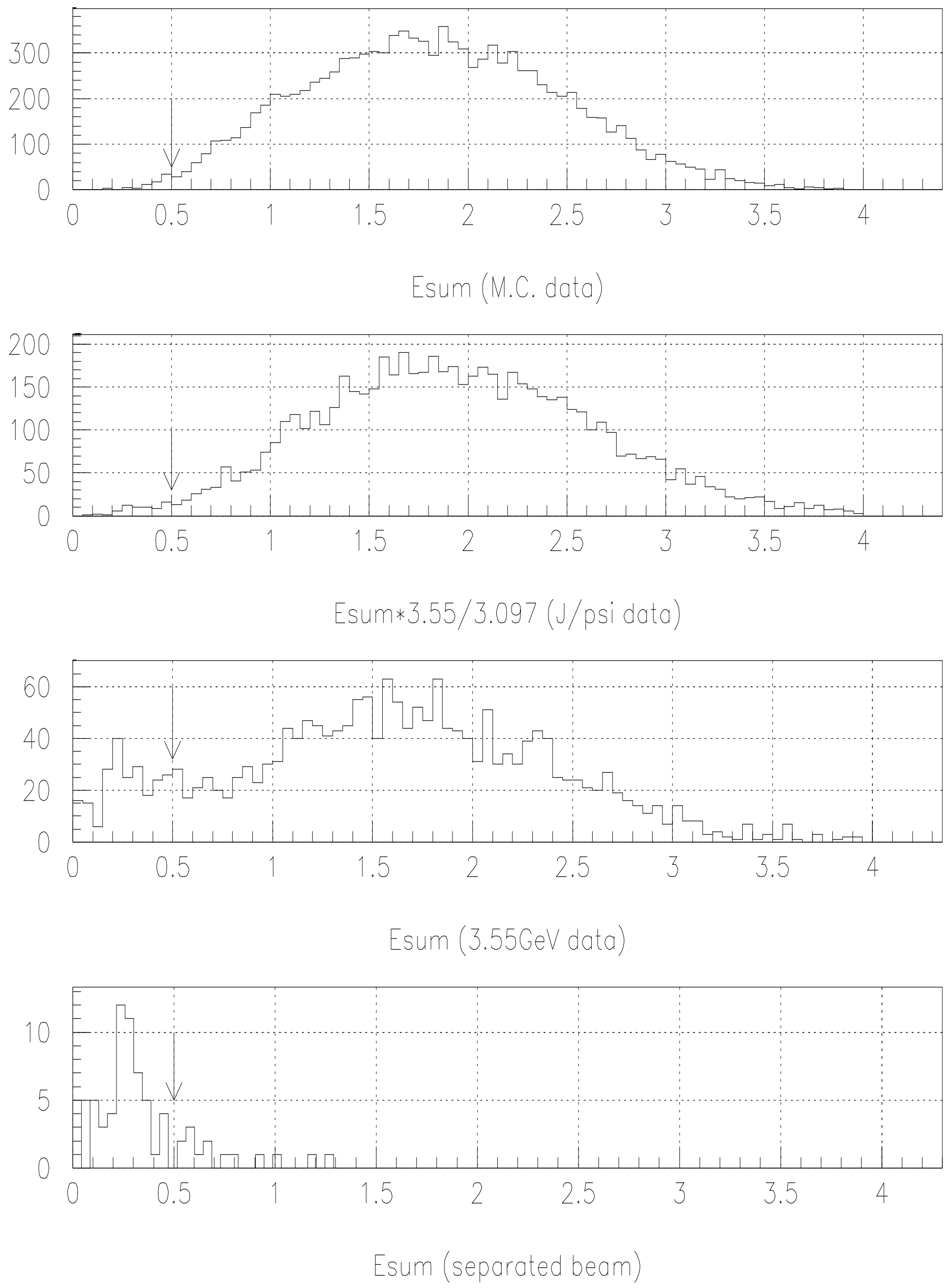

Figure 5: E_{sum} cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data

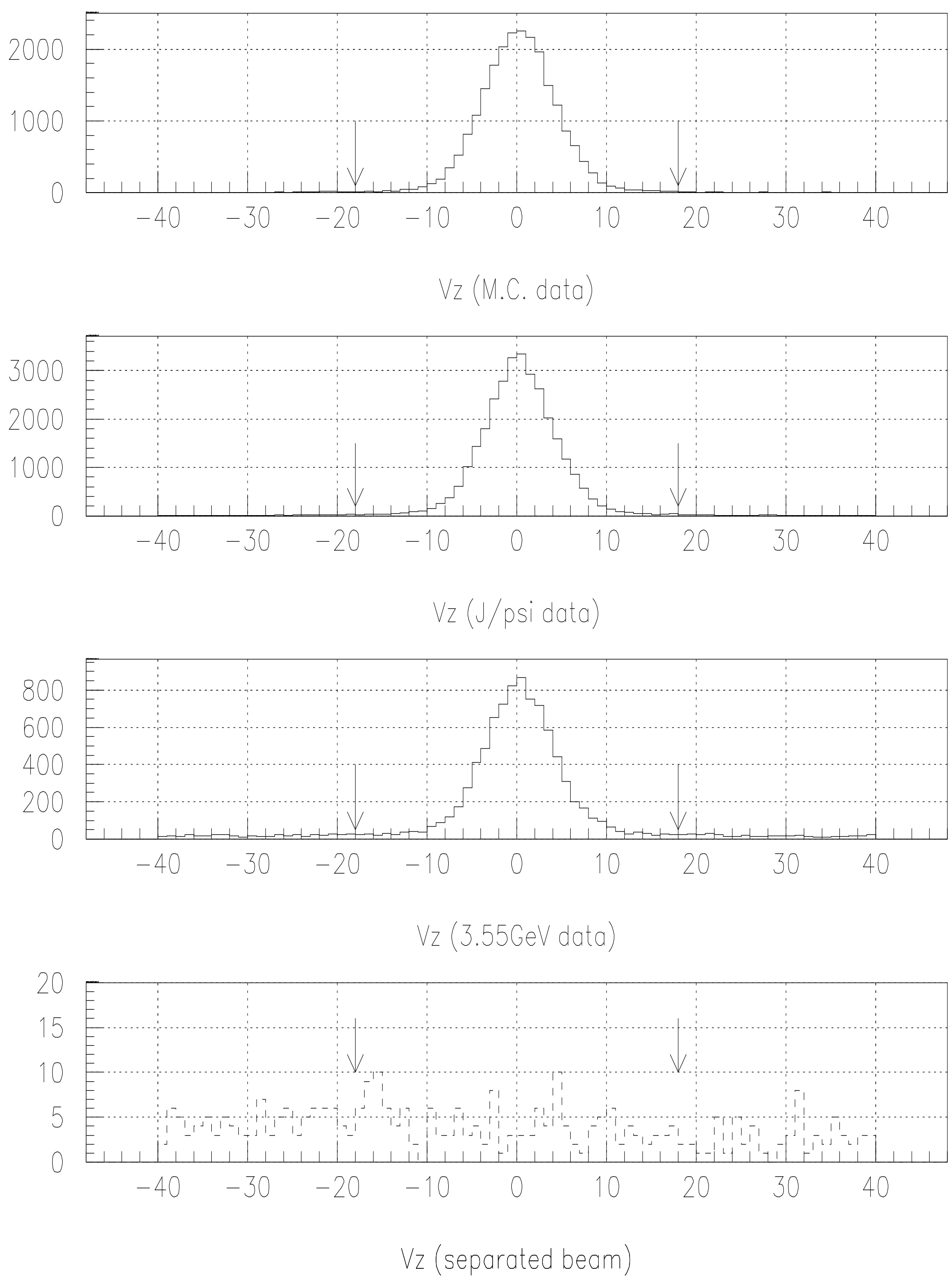

Figure 6: V_z cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data (tracks with MFIT=2)

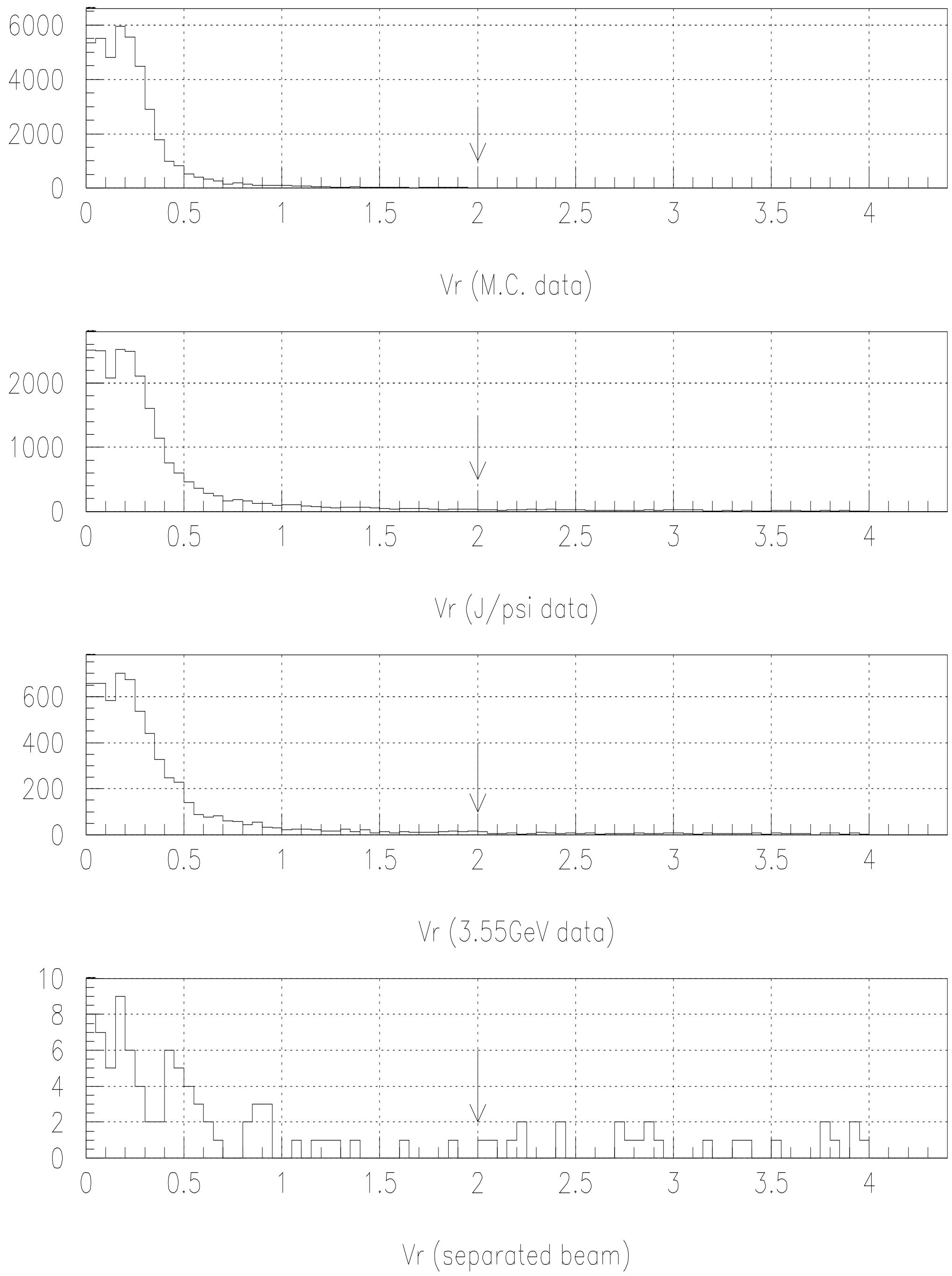

Figure 7: V_r cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data for tracks with MFIT=2

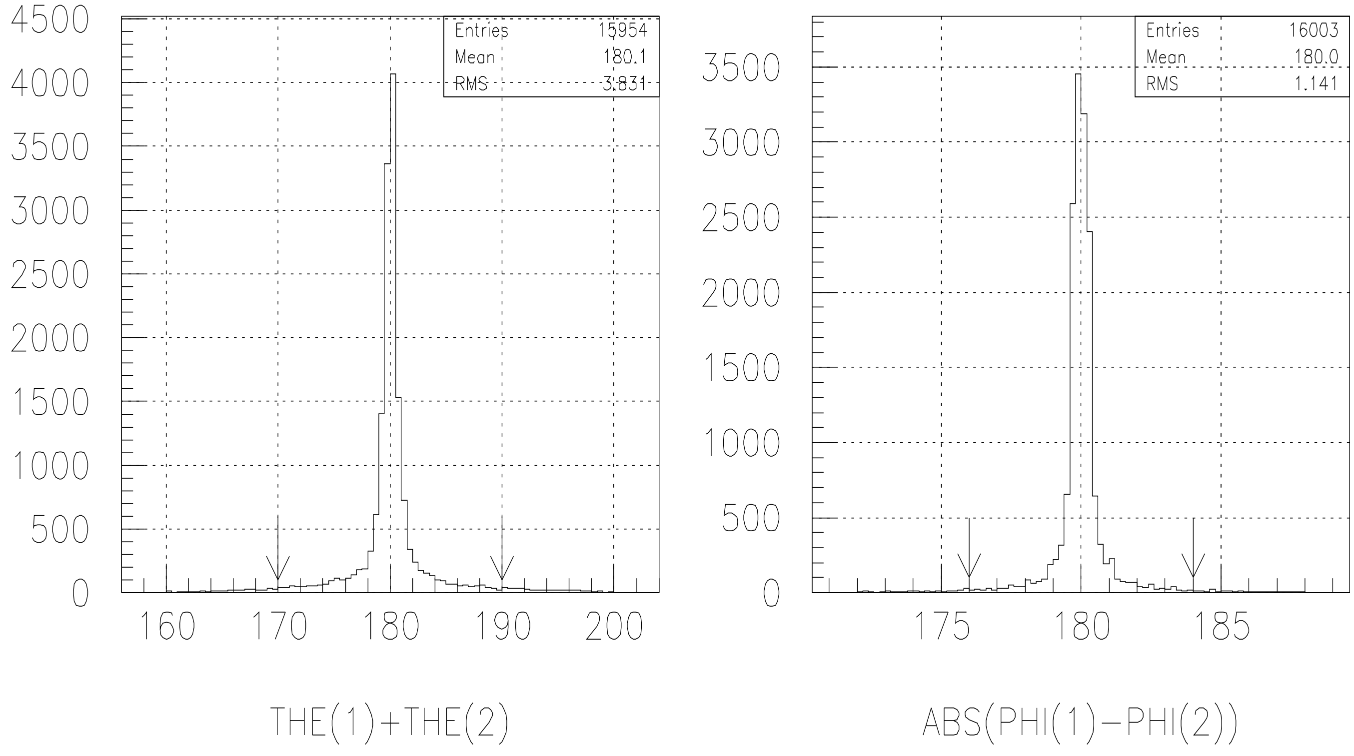

Figure 8: back-to-back of Bhabha events

Beam associated background

- vertex cut
- energy and momentum cut
- separated-beam data survived from event selection

$$N_{bg} = f \times N_{sep}$$

where,

$$f = \frac{\int\limits_{coll.} P_{coll.} \cdot I_{coll.} \, dt}{\int\limits_{sep} P_{sep} \cdot I_{sep} \, dt} \tag{9}$$

N_{sep} : The number of the separated-beam data survived after hadronic events selection;

N_{bg} : The number of the beam associated background events in the corresponding hadronic event sample.

Detection Efficiency

Hadronic events generator $\leftarrow$ **model dependent**

- **Determination of detection efficieccy**

1. LUND Model (JETSET74) & HERWIG

- Large hadronic events sample at 2.6, 3.55, 4.6 GeV ;

- Parameters tunning ;

- Cross check with HERWIG.

- **Systematic error estimation:**

1. Uncertainties from model (or pamarters) ($< 1.5\%$);

2. Uncertainties of Event selection ($< 4\%$);

3. Imperfection of simulation ($< 3.5\%$).

Luminosity Measurement

- Large-angle Bhabha Method

$$e^+e^- \to e^+e^-(\gamma) \tag{10}$$

$$e^+e^- \to \mu^+\mu^-(\gamma) \tag{11}$$

$$e^+e^- \to \gamma\gamma(\gamma) \tag{12}$$

- Event selection for Bhabha (BSC)

- two big clusters in BSC : $N_{chrg} \geq 2$;

- geometry acceptance : $|\cos\theta| < 0.7$;

- total energy :
$E1 + E2 + E3 > 1.15E_{beam}$,
$E_1 > 0.6E_{beam}$,
$E_2(+E_3) > 0.45E_{beam}$;

- back to back (largest two) :
$|\theta_1 + \theta_2 - 180°| < 10$,
$||\phi_1 - \phi_2| - 180°| < 20$;

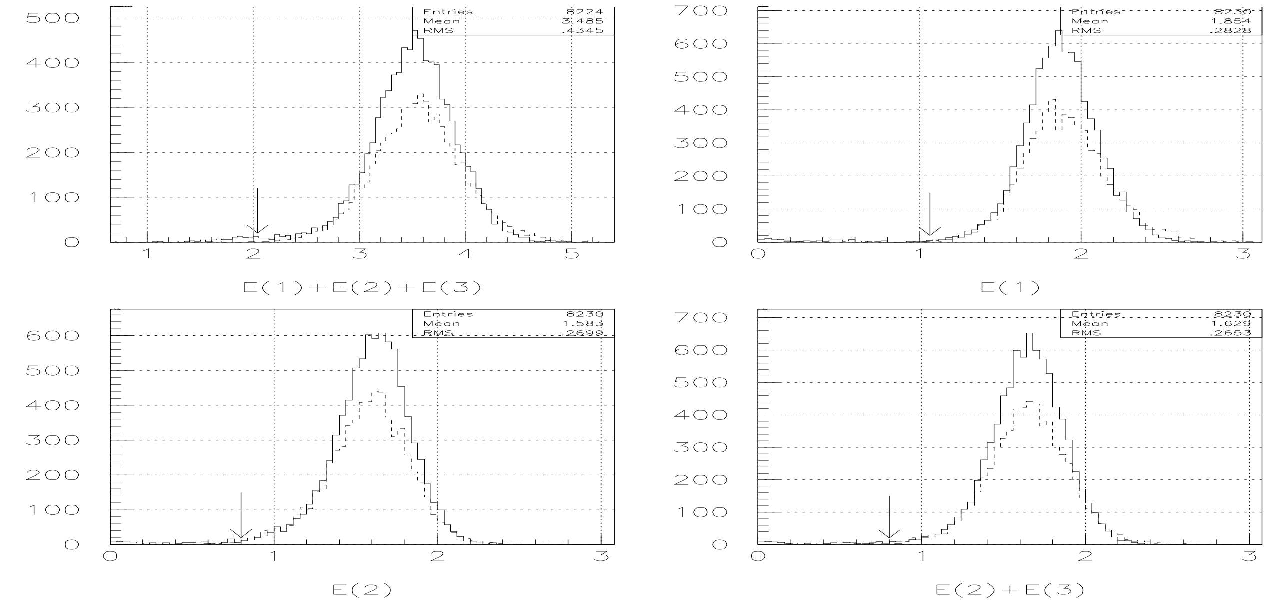

Figure 9: Energy cut to select Bhabha and $\gamma\gamma$, M.C.: solid line, data: dashed line

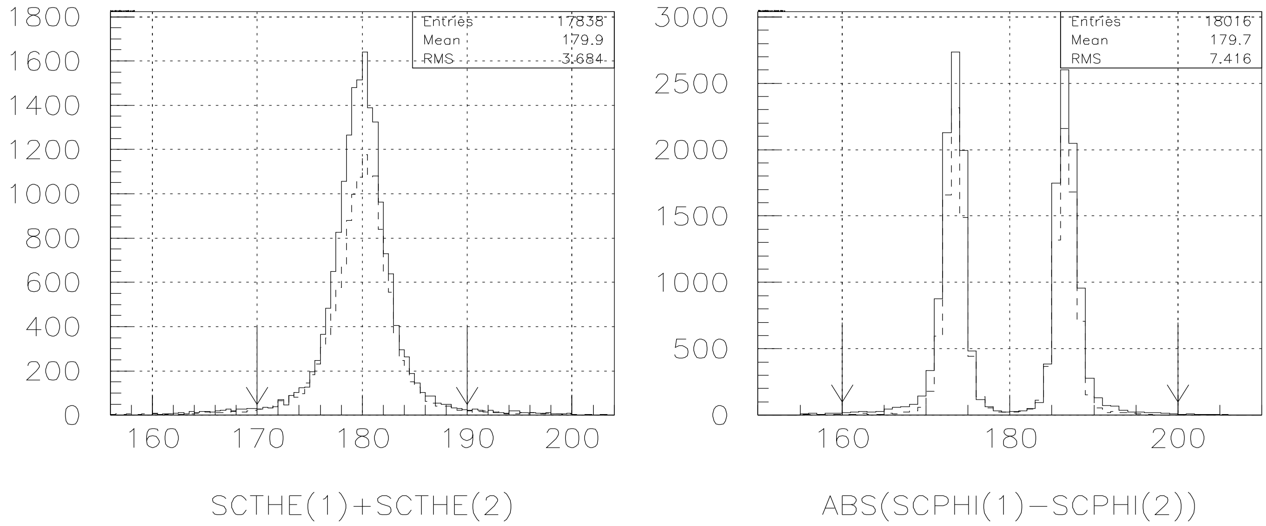

Figure 10: back-to-back cut to select Bhabha, M.C.: solid line, data: dashed line

- Event selection for Bhabha (dE/dx)

- vertex : $|V_{x,y}| < 2.0$cm, $|V_Z| < 20$ cm;
- good helix fit : mfit=2 ;
- time-of-flight : $2 < t < 8$ns;
- momentum and dE/dx : $p > 1.4$ GeV for any one track & $\chi_{se} > 0$, or
$P > 1.3GeV/c$ for both tracks, & $CL(\chi_{se1}, \chi_{se2}) > 0.317$.

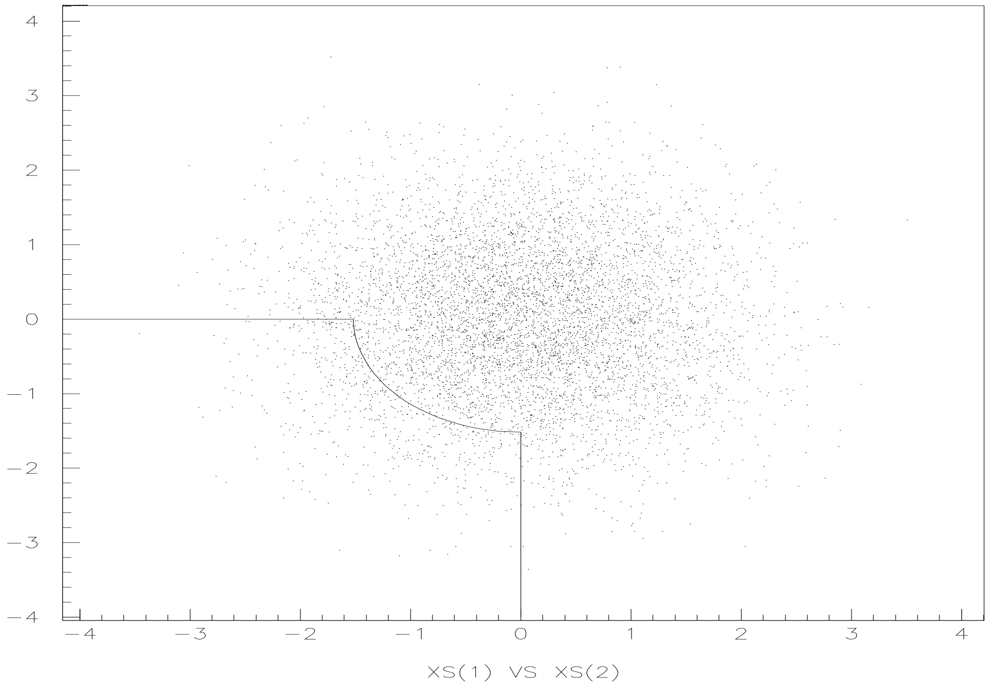

Figure 11: Two dimensional distribution of χ_{se}

- Systematic error ($< 3\%$)

- the selection of the cuts ($< 2.5\%$);

- the efficiency determination ($< 1\%$);

- the possible background contribution ($< 0.3\%$);

- uncertainty in calculation of the cross section ($< 0.3\%$);

- trigger efficiency of Bhabha (0.5%).

Initial State Radiative Correction

To remove high order effects from σ_{had}^{obs} :

$$\sigma_{had}^{obs} = \sigma_{had}^{0} \cdot \bar{\epsilon}_{had} \cdot (1 + \delta) \quad (13)$$

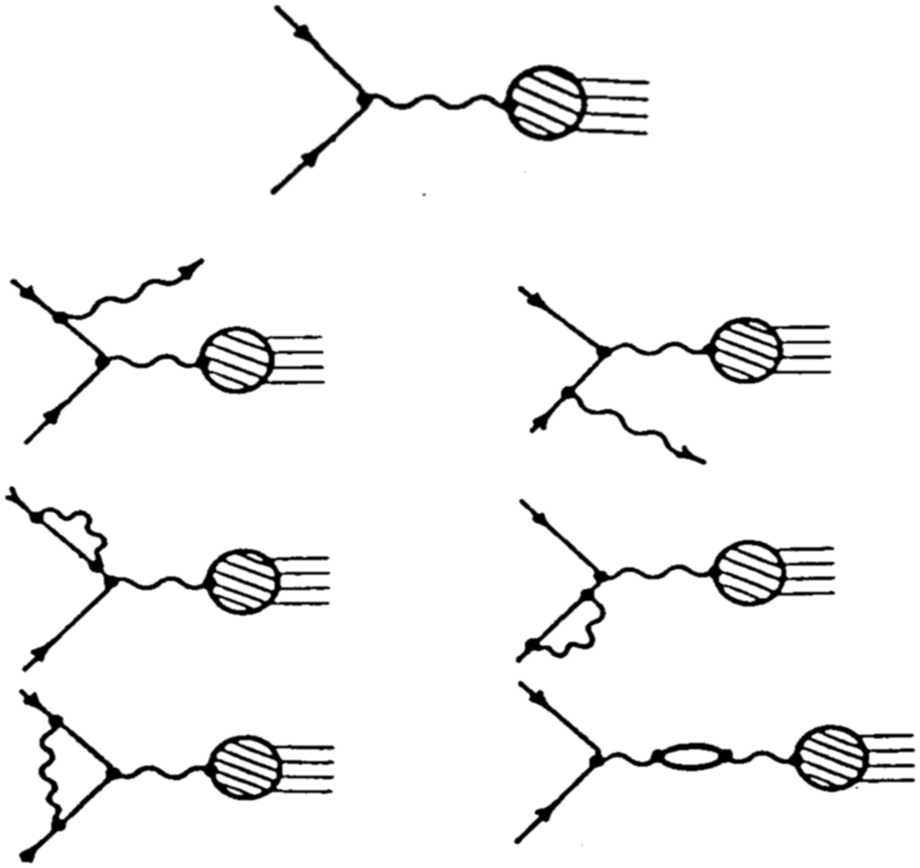

Figure 12: Feynman diagrams of $e^+e^- \rightarrow$ hadrons processes. They are the higher order electromagnetic processes, whose contributions are represented by radiative correction factor δ.

$$\delta_{obs} = \delta_{vert} + \delta^{e}_{vac} + \delta^{\mu}_{vac} + \delta^{\tau}_{vac} + \delta^{had}_{vac} + \delta_{\gamma obs} \quad (14)$$

δ_{vert} : the initial vertex correction;
δ_{vac} : the vacuum polarization ;
$\delta_{\gamma obs}$: the bremsstrahlung correction.

Systematic error estimation:

1. all uncertainties in the theoretical calculation ($< 1.5\%$);

2. uncertainties from detection efficiency ($< 3\%$).

Error estimation

The formula for the error of R :

$$
\begin{aligned}
(\frac{\delta R}{R})^2 &= (\frac{N_{can}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x} \cdot \frac{\delta N_{can}}{N_{can}})^2 \\
&+ (\frac{N_{bg}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x} \cdot \frac{\delta N_{bg}}{N_{bg}})^2 \\
&+ (\frac{L(\epsilon\sigma)_{ll}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x} \cdot \frac{\delta(\epsilon\sigma)_{ll}}{(\epsilon\sigma)_{ll}})^2 \\
&+ (\frac{L(\epsilon\sigma)_{\gamma\gamma}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x} \cdot \frac{\delta(\epsilon\sigma)_{\gamma\gamma}}{(\epsilon\sigma)_{\gamma\gamma}})^2 \\
&+ (\frac{N_{can} - N_{bg}}{N_{can} - N_{bg} - L\sum_x(\epsilon\sigma)_x} \cdot \frac{\delta L}{L})^2 \\
&+ (\frac{\delta\overline{\epsilon}_{had}}{\overline{\epsilon}_{had}})^2 + (\frac{\delta\overline{\epsilon}_{trg}}{\overline{\epsilon}_{trg}})^2 + (\frac{\delta(1+\delta)}{(1+\delta)})^2
\end{aligned}
$$

Table 2: Sources of error ($E_{cm} = 2.6GeV$)

Source	Error (%)	Project to R (%)
Event selection	5.50	7.98
Hadron efficiency	4.5	4.5
Luminosity	< 3.00	< 3.00
Radiative correction	3.50	3.50
Trigger efficiency	0.50	0.50
Total		~ 10.0

R at E_{cm}=2.6, 3.2, 3.4, 3.55, 4.6 and 5.0GeV

Table 3: R value with BESII data ($\geq$ 2prong)

E_{cm} (GeV)	N_{had}	L (nb^{-1})	ε_{had} (%)	$1+\delta$ (%)	σ	R
2.6	5884	292.9	55.90	1.009	12.840	2.69±
3.2	2076	109.3	64.69	1.447	8.477	2.28±
3.4	2165	135.3	69.91	1.173	7.509	2.38±
3.55	2676	200.2	68.64	1.125	6.888	2.31±
4.6	1497	87.7	81.82	1.079	4.102	3.45±
5.0	1649	102.3	84.34	1.068	3.472	3.29±

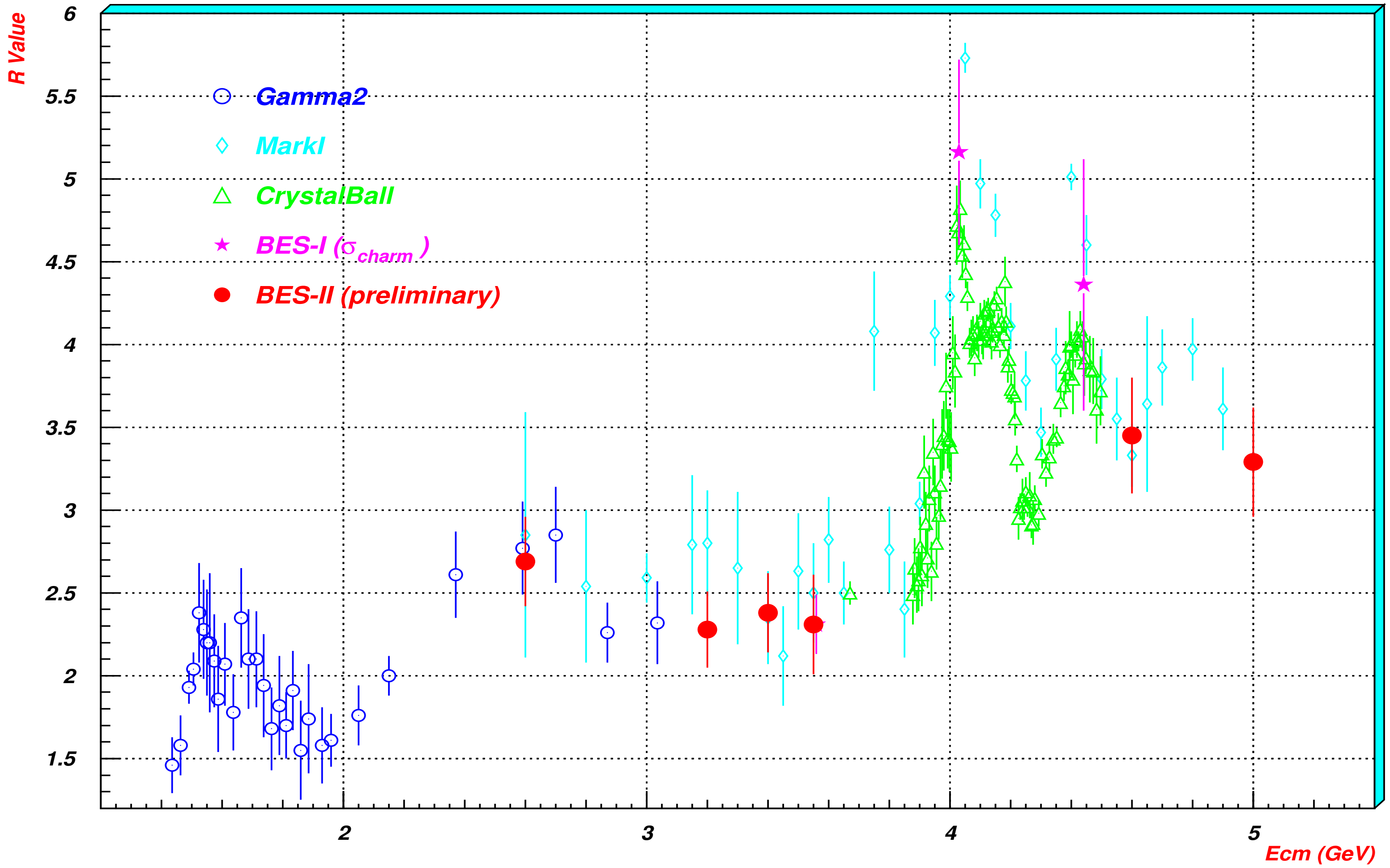

Figure 13: Preliminary results of R at BESII

Summary

- The first R scan performed with BESII at BEPC gives a promising preliminary results.

- A finer scan in 2-5 GeV is being carried out at BEPC/BES now.

- BES will reduce the present $\Delta R/R$ in 2-5 GeV region by a factor of two.

- The R scan data can serve for the other interesting physics topics:

- hadron production mechanism

- electromagnetic form factor, proton form factor

- Physicists who are interested in the work carrying out with BESII at BEPC are welcome to join BES collaboration.