R Scan Between $2 - 5$ GeV with BESII

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OUTLINE

Introduction

"The uncertainty [in $\alpha(M_Z)^{-1}$], due to the low energy hadronic contribution to vacuum polarization, is the dominant theoretical uncertainty in the interpretation of precision data. . . . Further improvement will require better measurements of the cross section for $e^+e^- \rightarrow$ hadrons at low energy"

— PDG98, page 90

Motivation

- R value in the lowest order

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

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

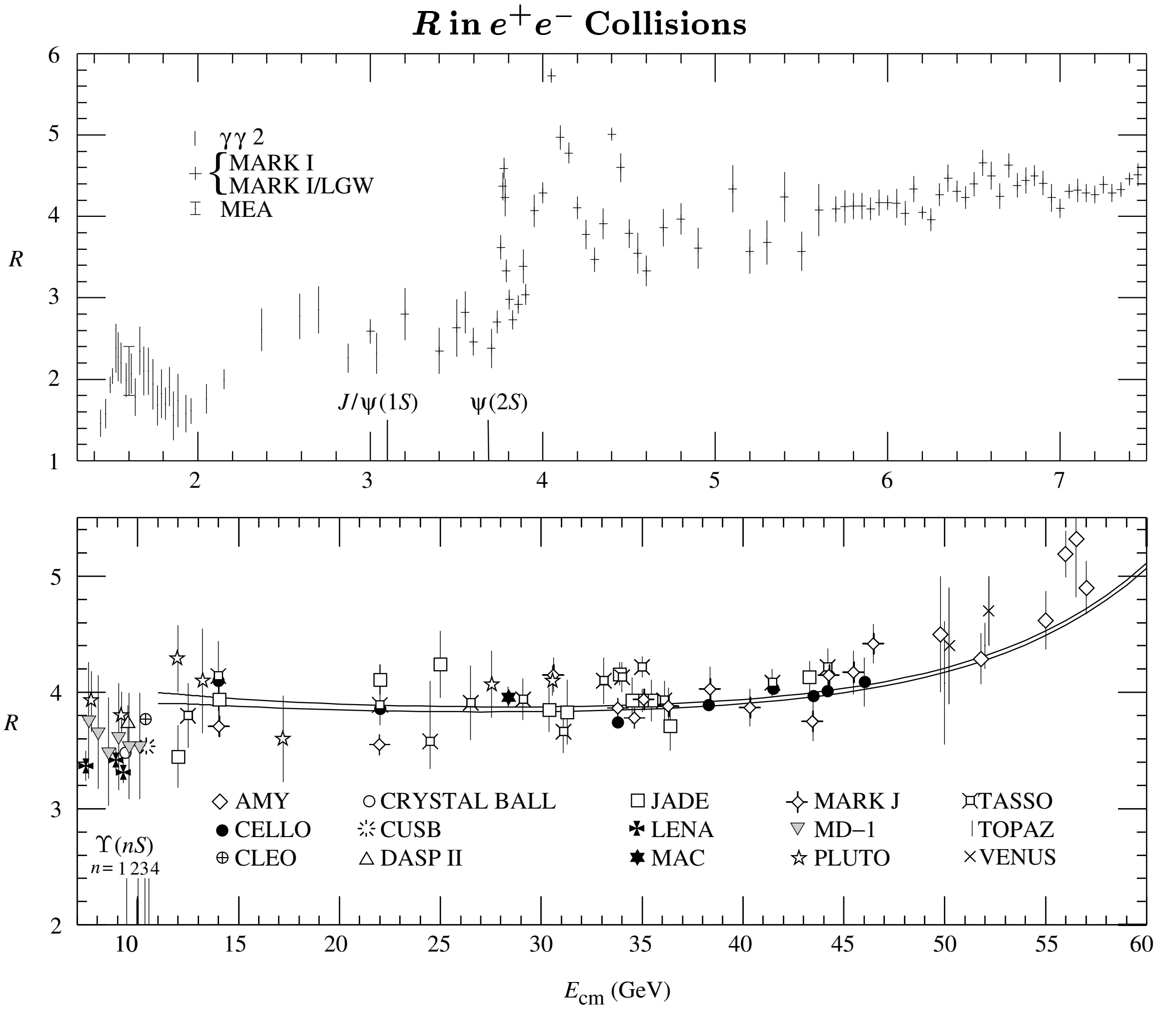
- R with higher order QCD correction:

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

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

Current status of R value

Previous R Experiments



- Consistent with theoretical predictions
- Latest Exp. in 1982, uncertainties $\sim 15\%$

Measurement of R at BESII

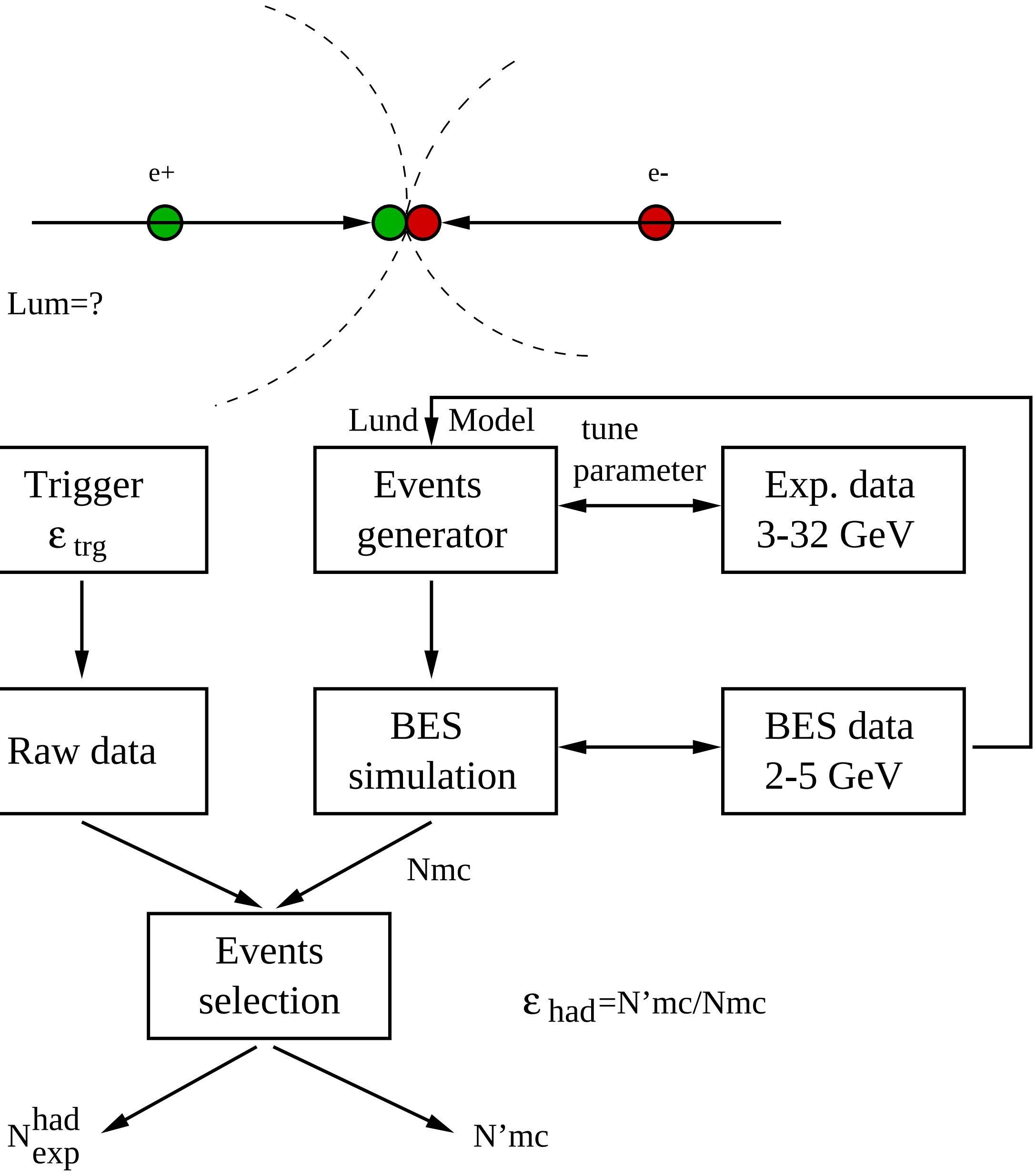


Figure 1: Outline of experiment and data analysis

R measurement

$$R = \frac{\sigma^0_{had}}{\sigma^0_{\mu\mu}} = \frac{N^{obs}_{had} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma^0_{\mu\mu} \cdot \varepsilon_{had} \cdot \varepsilon_{trg} \cdot (1+\delta) \cdot \mathcal{L}} \qquad (3)$$

Where,

N_{obs} : the observed hadronic events

N_{bg} : beam-associated backgrounds

N_{ll} : lepton pair backgrounds

$N_{\gamma\gamma}$: two-photon process events

$\mathcal{L}$: integrated luminosity

$(1+\delta)$: radiative correction

ε_{had}: detection efficiency

ε_{trg}: trigger efficiency

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

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

The First Run

- 6 energy points scaned, large sample @2.6 and 3.55 GeV to tune LUND parameters
- Paper published in PRL 84(2000)594-597

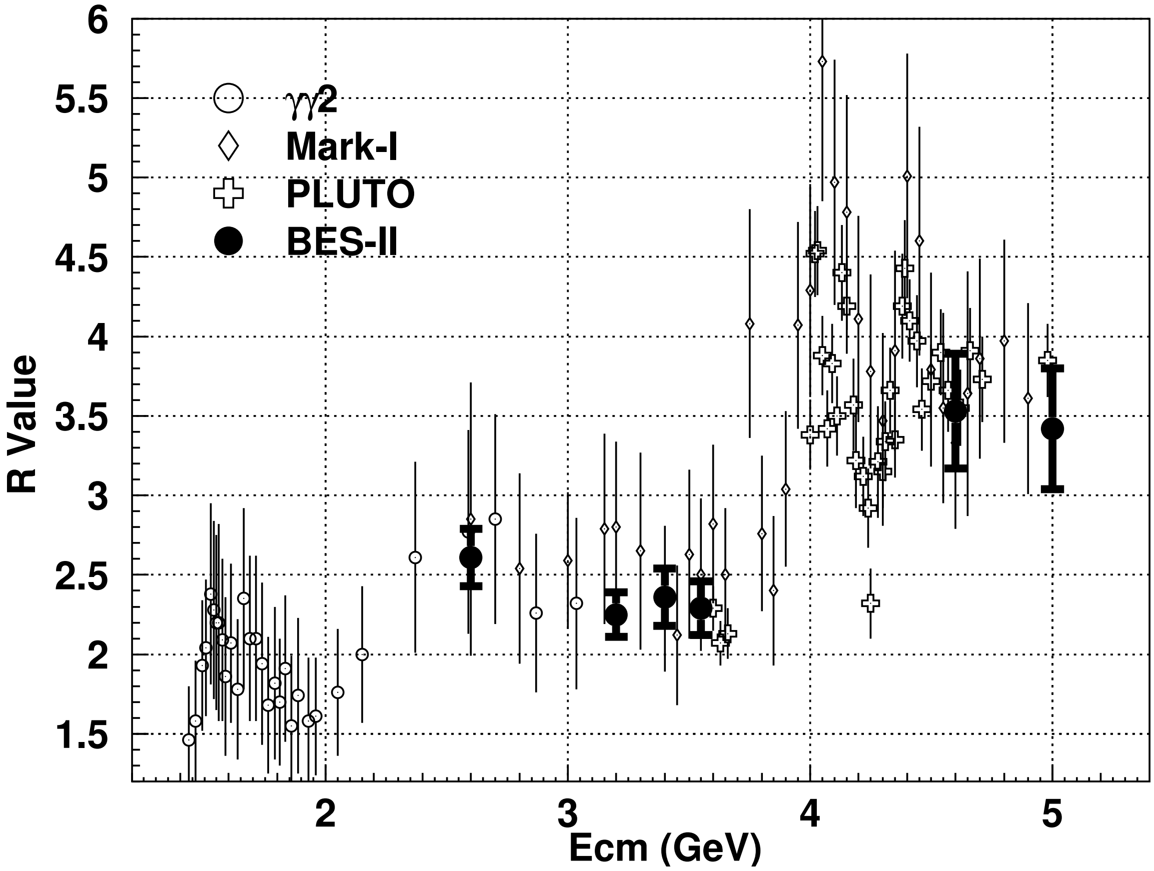


Figure 2: Plot of R values vs E_{cm}.

The Second Run

- 85 energy points, from which
  24 points with separated-beam data
  7 points with also single-beam data

- The scan lasted for near 5 months
  Total beam time: 113 days
  Pure data taking time: 50.3 days

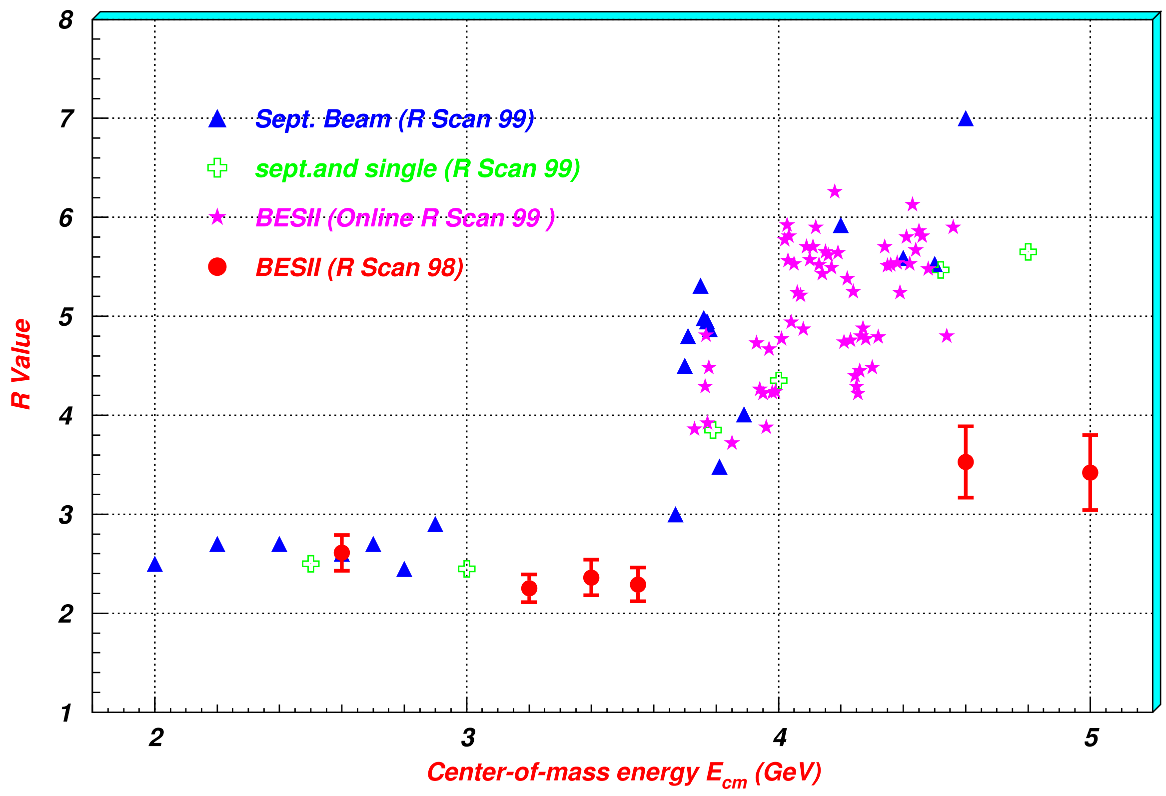


Figure 3: Data status of R scan ('98 and '99 runs)

Data quality check

- The noise problem successfully solved;
- The detector performance was stable;
- Data quality is good for R analysis.

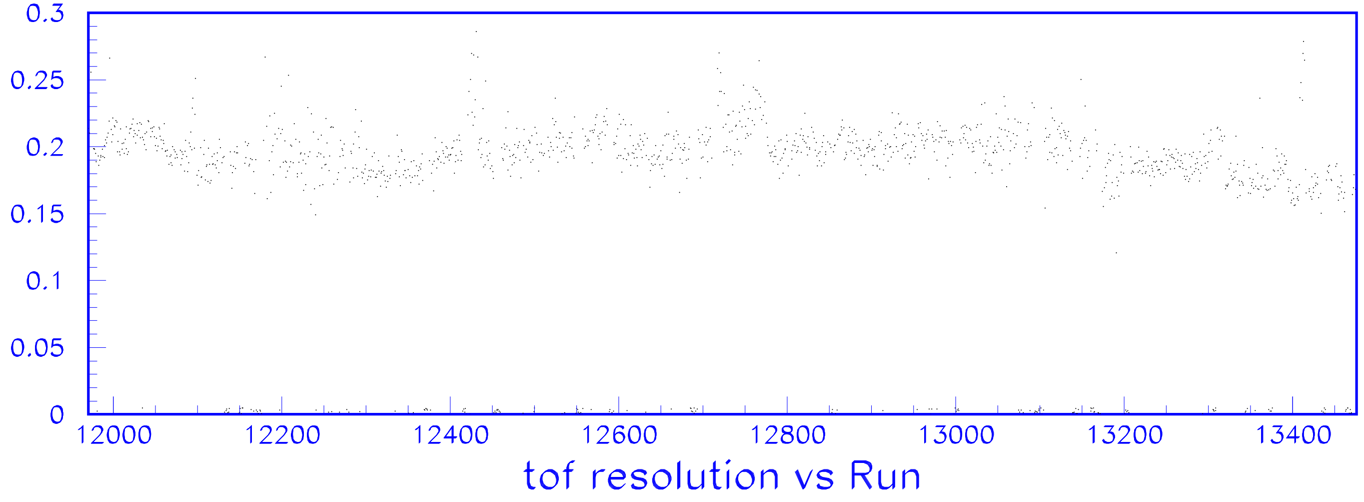


Figure 4: Variation of TOF time resolution with time.

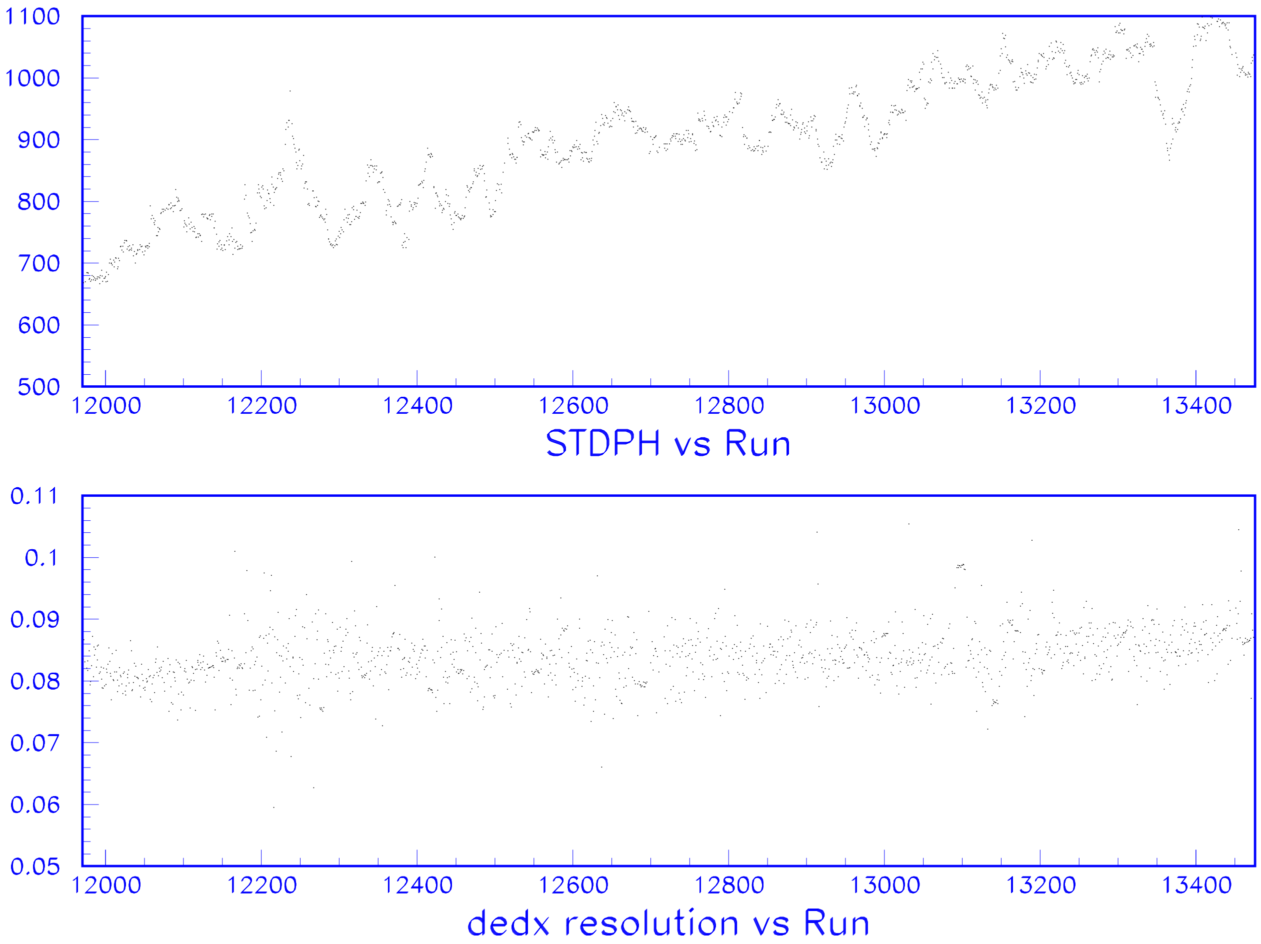


Figure 5: Variation of dE/dX before run correction with time, and dE/dX resolution with time.

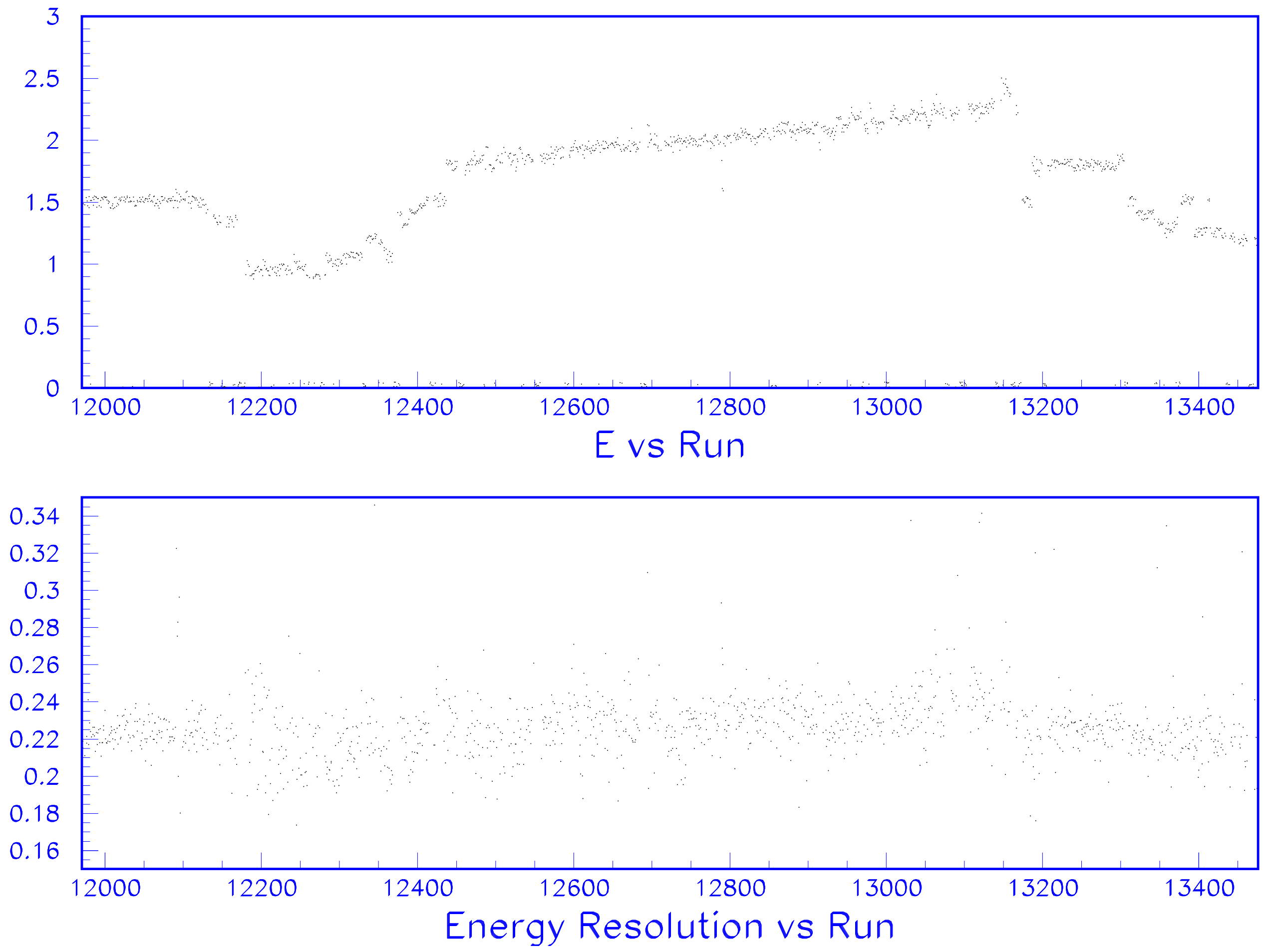
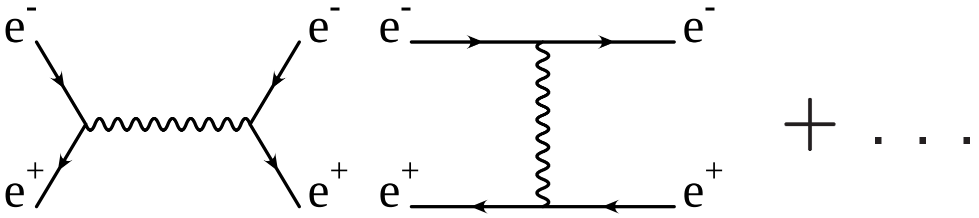
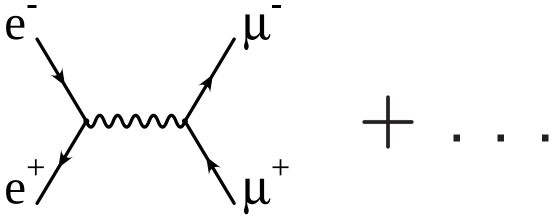
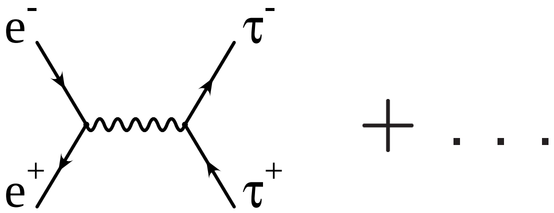


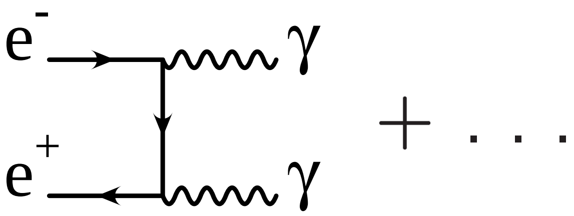
Figure 6: Variation of BSC energy and energy resolution with time.

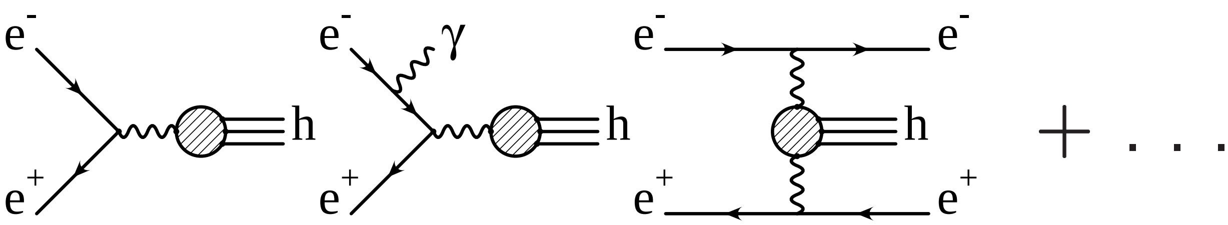
Events collected at BES











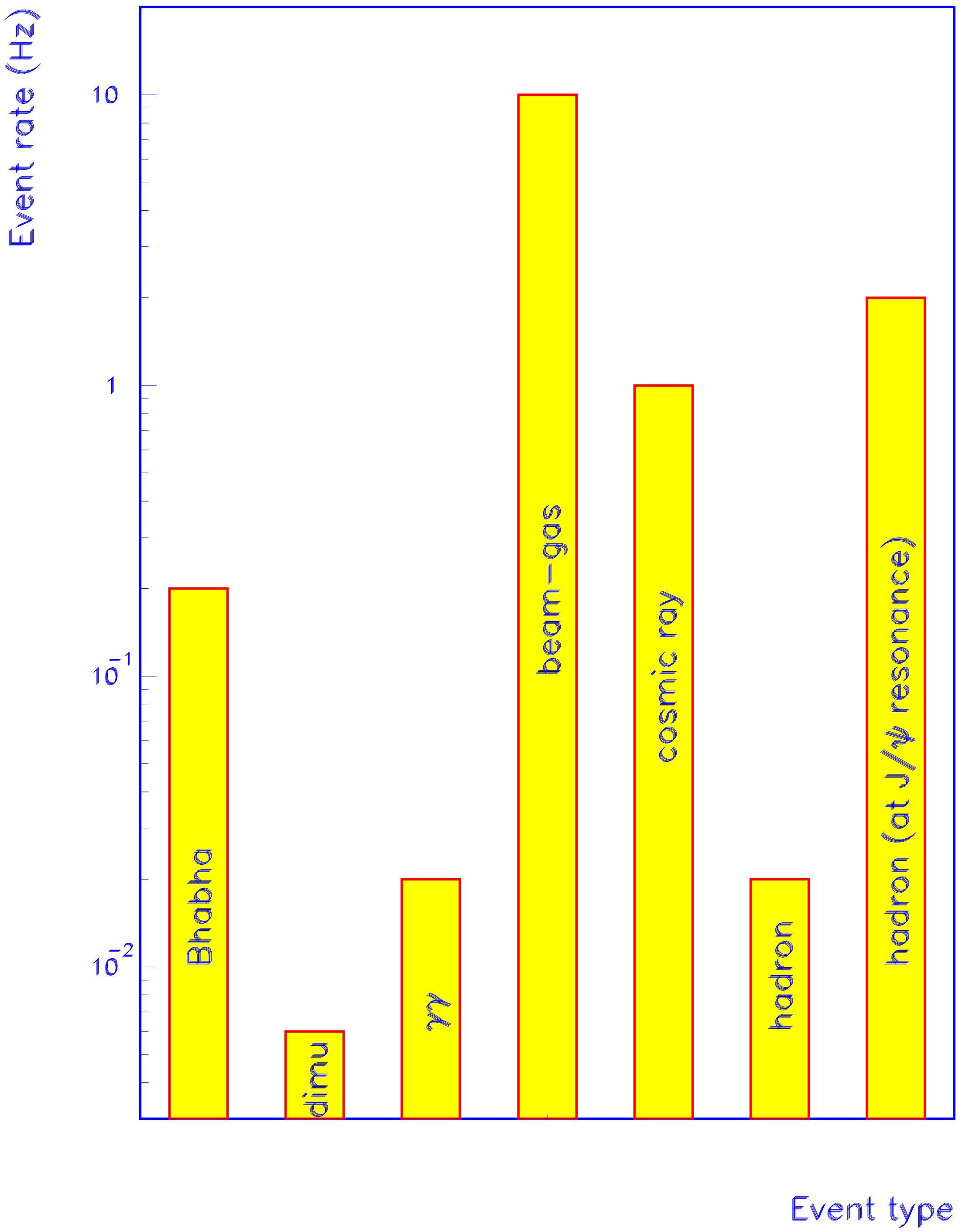


Figure 7: Typical event rates

Hadronic event selection

According to particle's $(t, \vec{r})$ and $(E, \vec{P})$

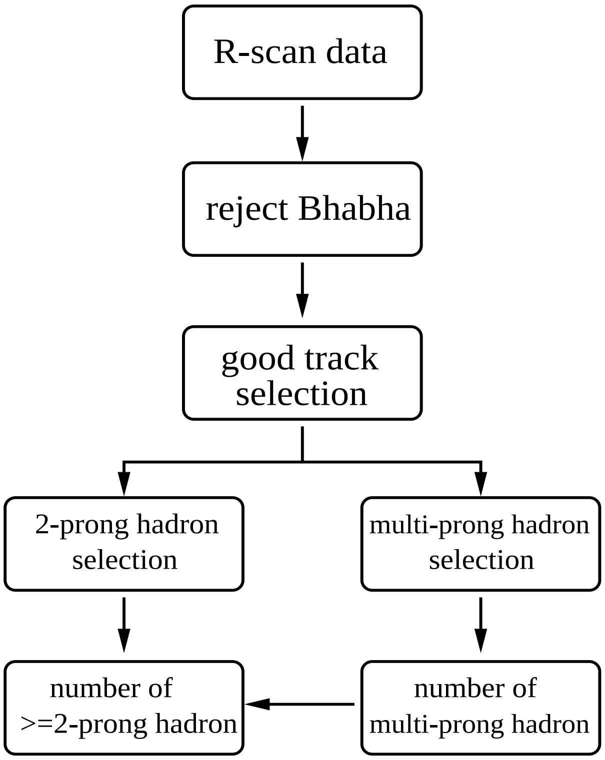


Figure 8: hadron event selection procedure

- Remove apparent Bhabha
  - Large energy deposite; back to back
  - Cut criteria

    $E_1 + E_2 + E_3 \geq 1.15E_{\text{beam}}$

    $E_1 \geq 0.6E_{\text{beam}}$

    $E_2(+E_3) \geq 0.45E_{\text{beam}}$

    $|\Sigma\theta - 180| \leq 10^o; \Delta\phi \leq 25^o$

- Track level
  Select track to remove cosmic rays, beam-gas, and ensure the geometry acceptance, . . .

Type	**Cuts**
Time	$2 < t < t_P + 5\sigma_{\text{TOF}}$
Space	$\begin{cases} r_0 < 2.0\text{cm}, \\ \lvert z_0 \rvert < 18\text{cm}, \end{cases}$ MFIT=2 $NHIT_{dE/dx} > 16,$ MFIT=-19
Energy	$E < 0.6E_{\text{beam}}$
Momentum	$\begin{cases} p < E_{\text{beam}} + 5\sigma_p \\ \lvert\cos\theta\rvert < 0.84 \end{cases}$

- Event level
  Remove beam-gas, two-photon, ee, $\mu\mu$, . . .
  - Kick out events with all tracks in the same side
  - Good tracks ≥ 2, from which $N_{MFIT=2} \geq 1$
  - $\Sigma E > 0.28E_{\text{beam}}$
  - for 2-prong candidate:
    Not back-to-back .AND. ≥ 2 isolatd γ's

Beam associated background

- Method A: Scale separated-beam data

  events survived in separated-beam data, N_{sep}

  The number of the beam associated background events in the corresponding normal data run,

$$N_{bg} = f \times N_{sep} \tag{4}$$

where

$$f = \frac{\int_{run} P_{run} \cdot I_{run}\, dt}{\int_{sep} P_{sep} \cdot I_{sep}\, dt} \tag{5}$$

So,

$$N_{had}^{candi.} = N_{had}^{obs.} - N_{bg} \tag{6}$$

♠ cross checked by single-beam data

- Method B: Fit z component of event vertex

  fitting by Gaussian + polynomial of degree 2

  Gaussian peak area represents number of hadrons.

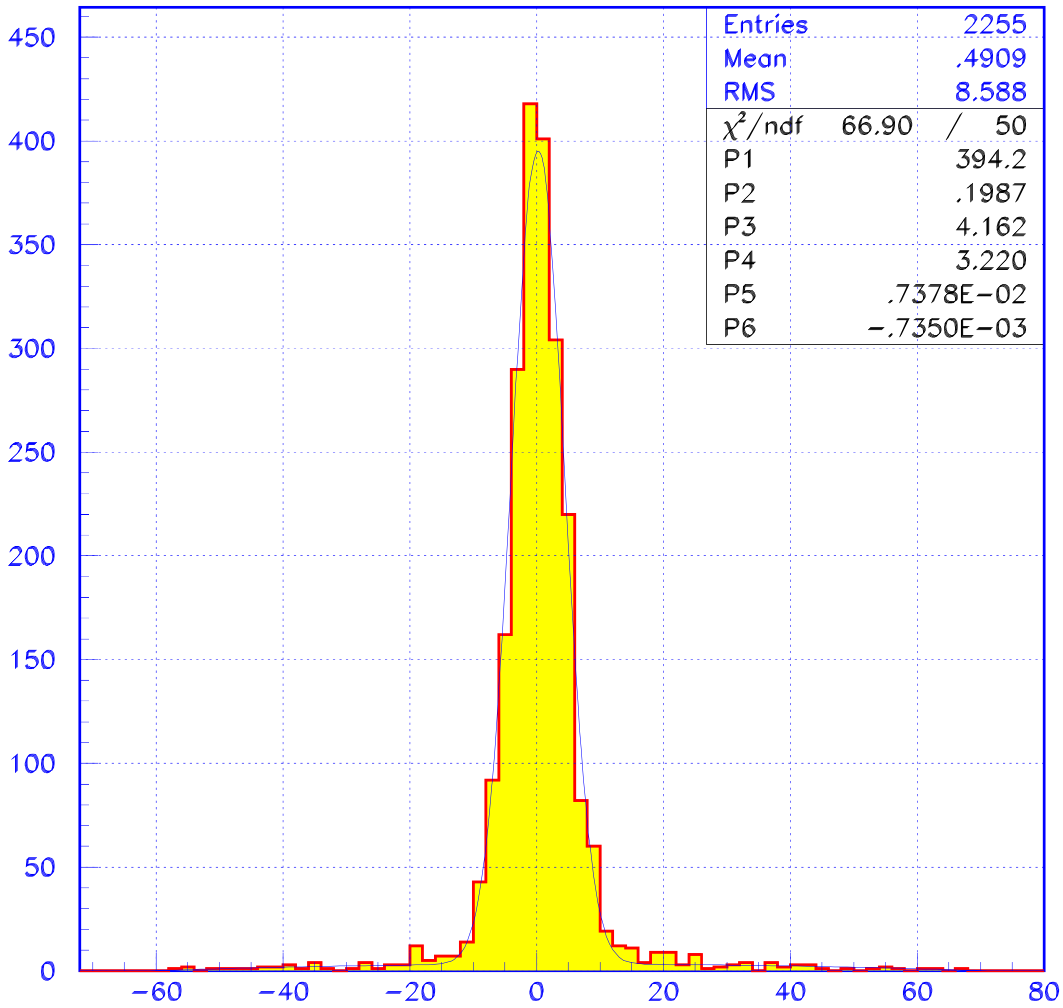


Figure 9: Event V_z distribution at Ecm=3.0GeV

Table 1: Comparison between Mathod A and B

E_{cm}(GeV)	3.2	3.4	3.55	4.6	5.0
$\Delta N_{had}/N_{had}$ (%)	-2.3	-3.3	-3.1	-4.1	+2.5
$\Delta\varepsilon/\varepsilon$ (%)	-4.5	-2.7	-2.1	-1.4	-2.0
$\Delta R/R$ (%)	+2.2	-0.6	-1.0	-2.7	+4.5
$\Delta(\Delta R/R)_{sys}$ (%)	$\pm$1.1	$\pm$0.3	$\pm$0.5	$\pm$1.4	$\pm$2.3

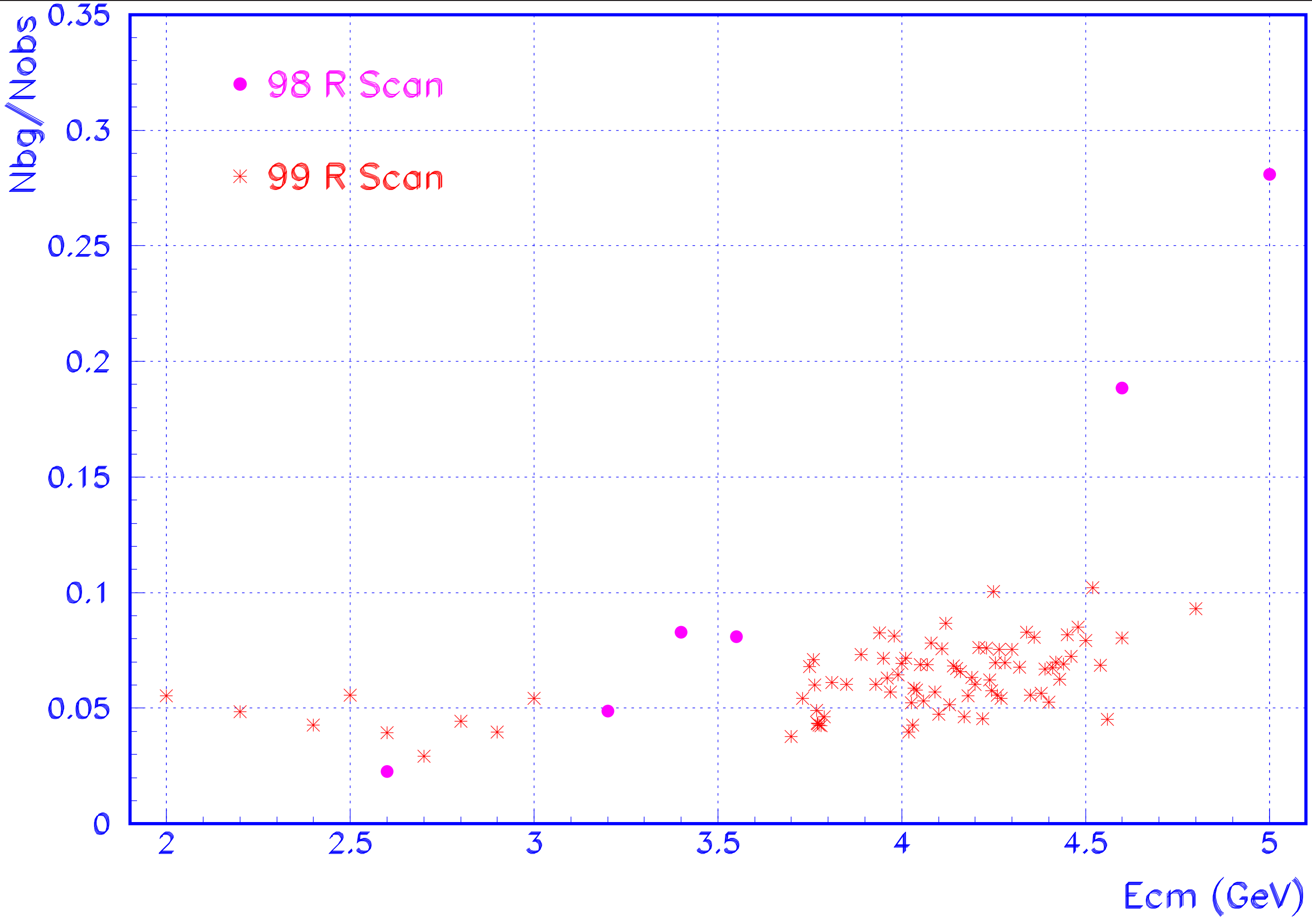


Figure 10: Ratio of beam-associated backgrounds

Detection Efficiency

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

- **Determination of detection efficieccy**

—– new generator based on Area Law to describe few-body states, extremely necessary in low energy region ($\leq$ 3GeV)

—– LUND Model (JETSET74)
$E_{cm} > 4$GeV, default parameters
$E_{cm} \leq 4$GeV, tuned parameters:

$$a = 0.3 \rightarrow 1.5,\ b = 0.58 \rightarrow 0.78,$$
$$w = 0.8 \rightarrow 0.5,\ \sigma = 0.36 \rightarrow 0.45.$$

—– mixing with DD events, in the resonance region ($3.72 < E_{cm} < 5.0$GeV), the fractions given by Eichten model.

Table 2: ε comparison between AreaLaw and Jetset

E_{cm}(GeV)	3.0	4.6	4.8
ε(JETSET)	0.6733	.8628	.8796
ε(AreaLaw)	0.6969	.8757	.8664
diff. (%)	3.5	1.5	1.5

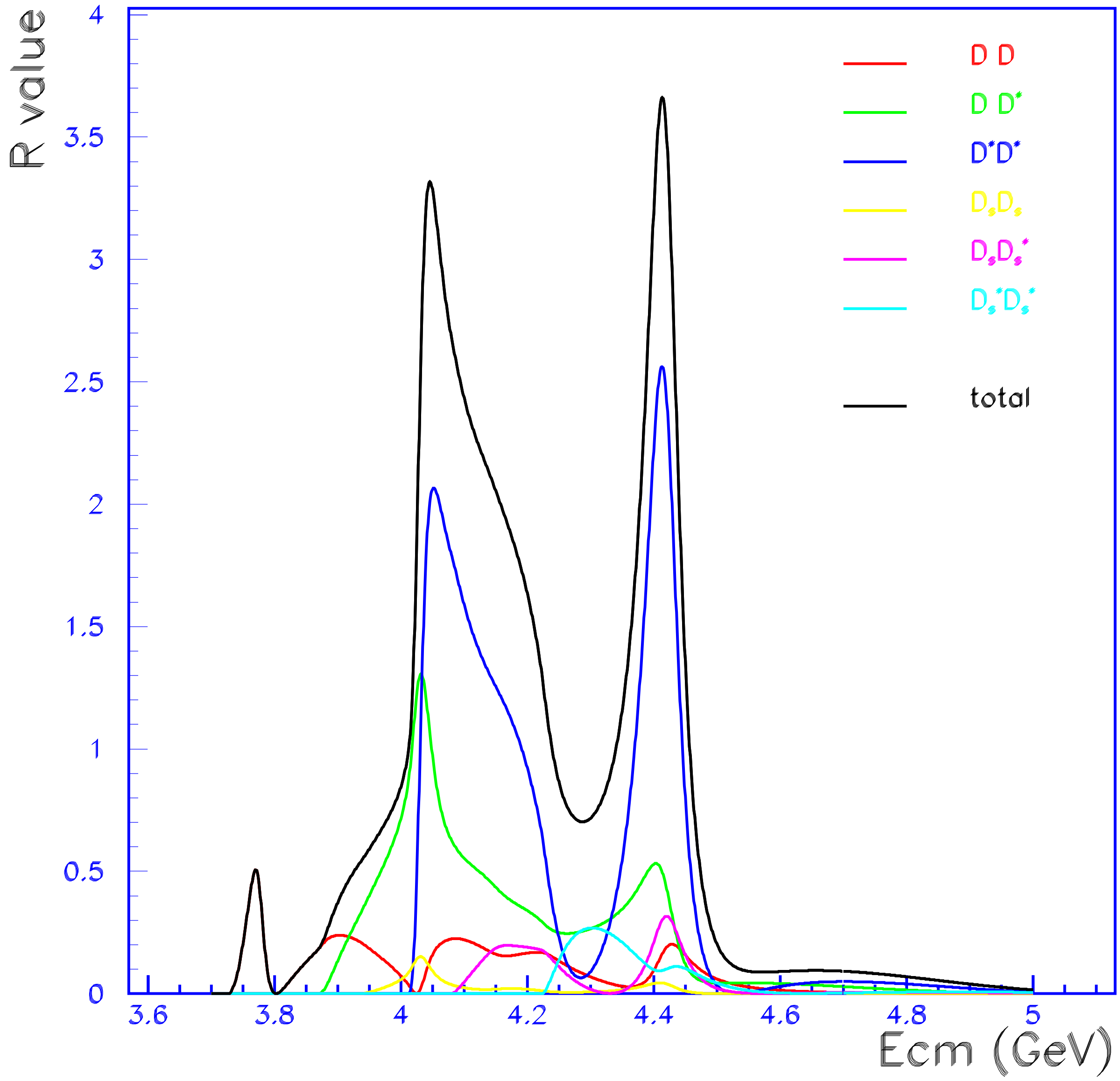


Figure 11: DD channel ratios is given by Eichten model, which describes DD mesons production in the resonant region. The contribution from continuum part is assumed to be R=2.5.

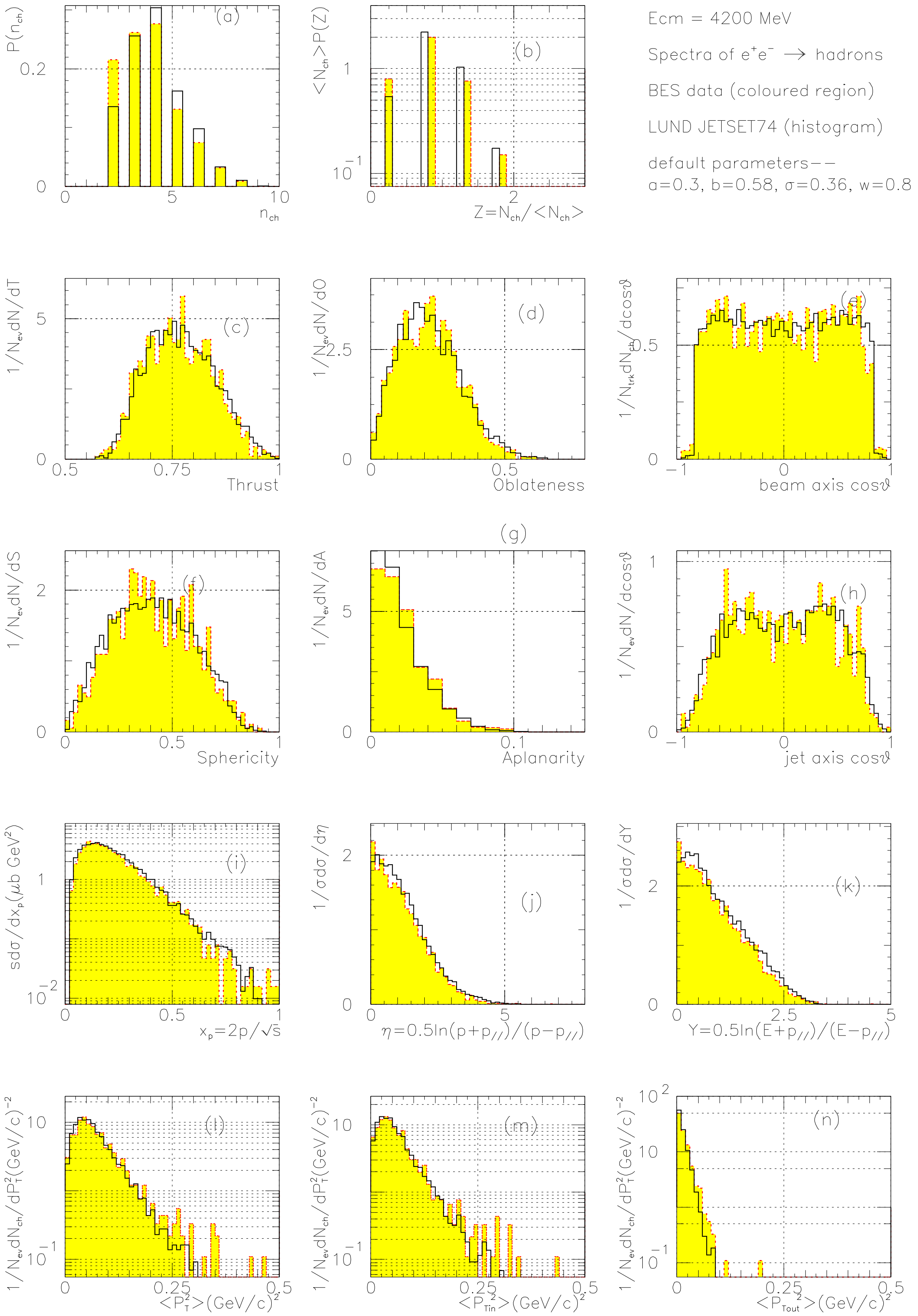


Figure 12: Event shapes at 4.2 GeV, default parameters

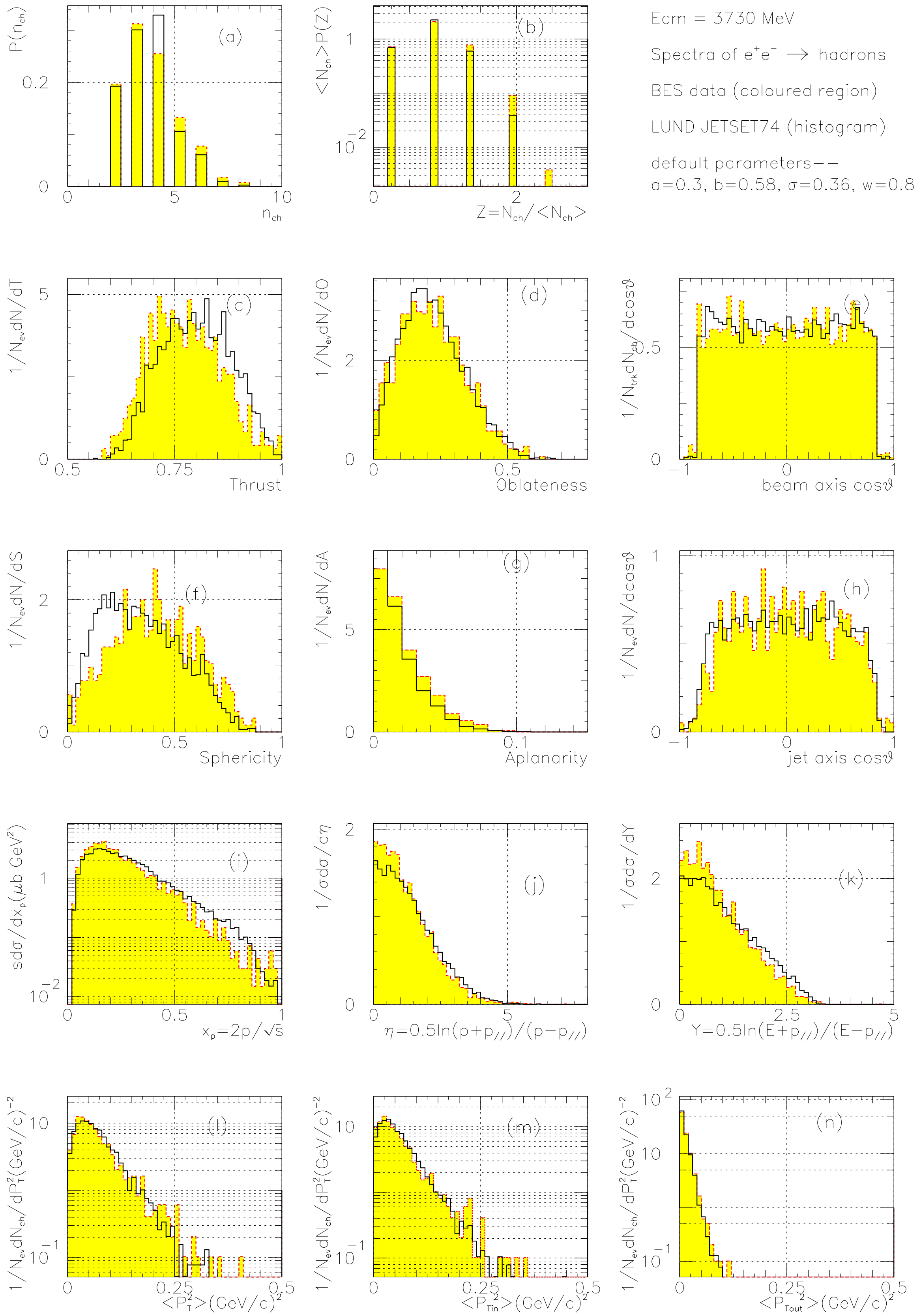


Figure 13: Event shapes at 3.73 GeV, default parameters

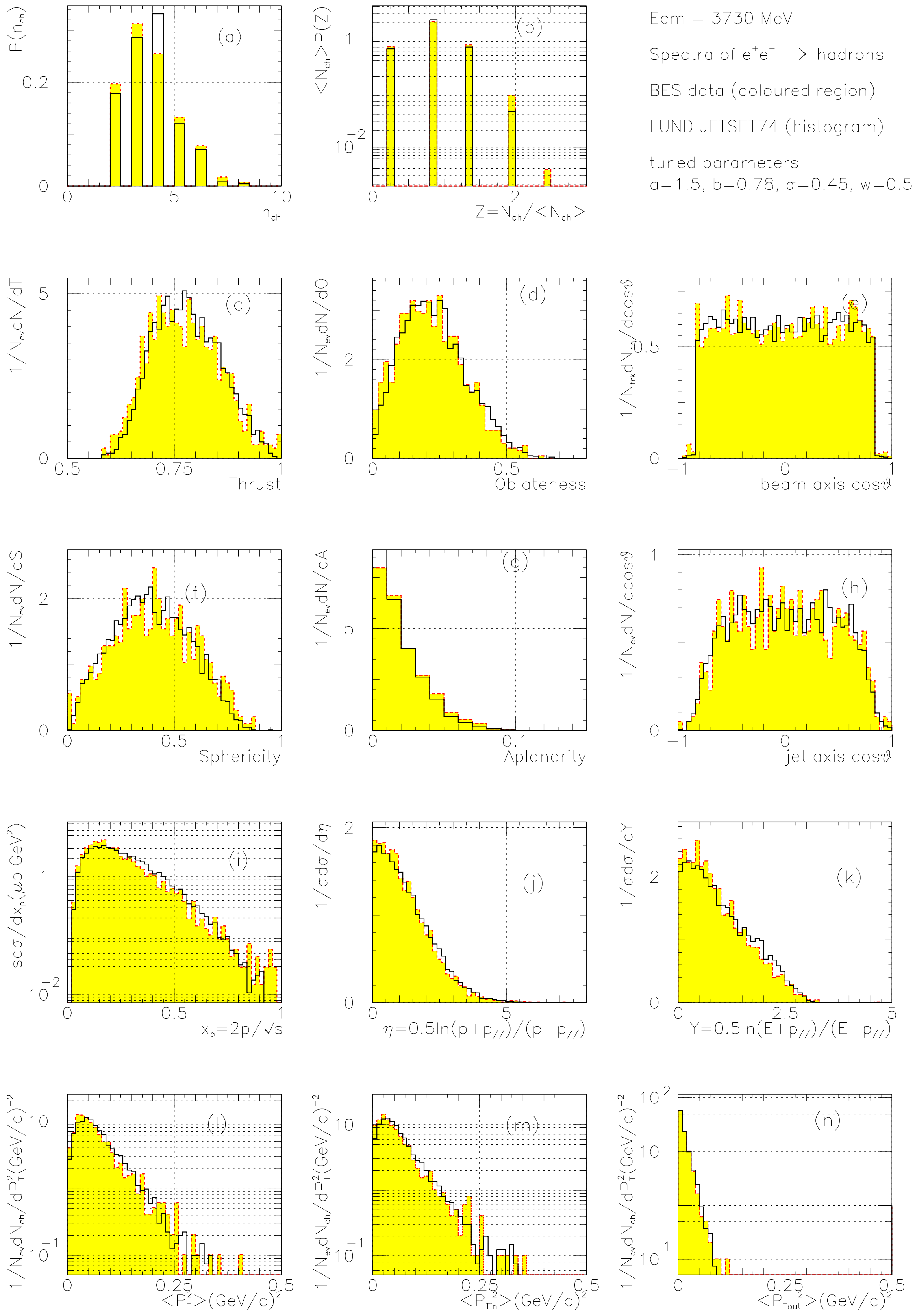


Figure 14: Event shapes at 3.73 GeV, tuned parameters

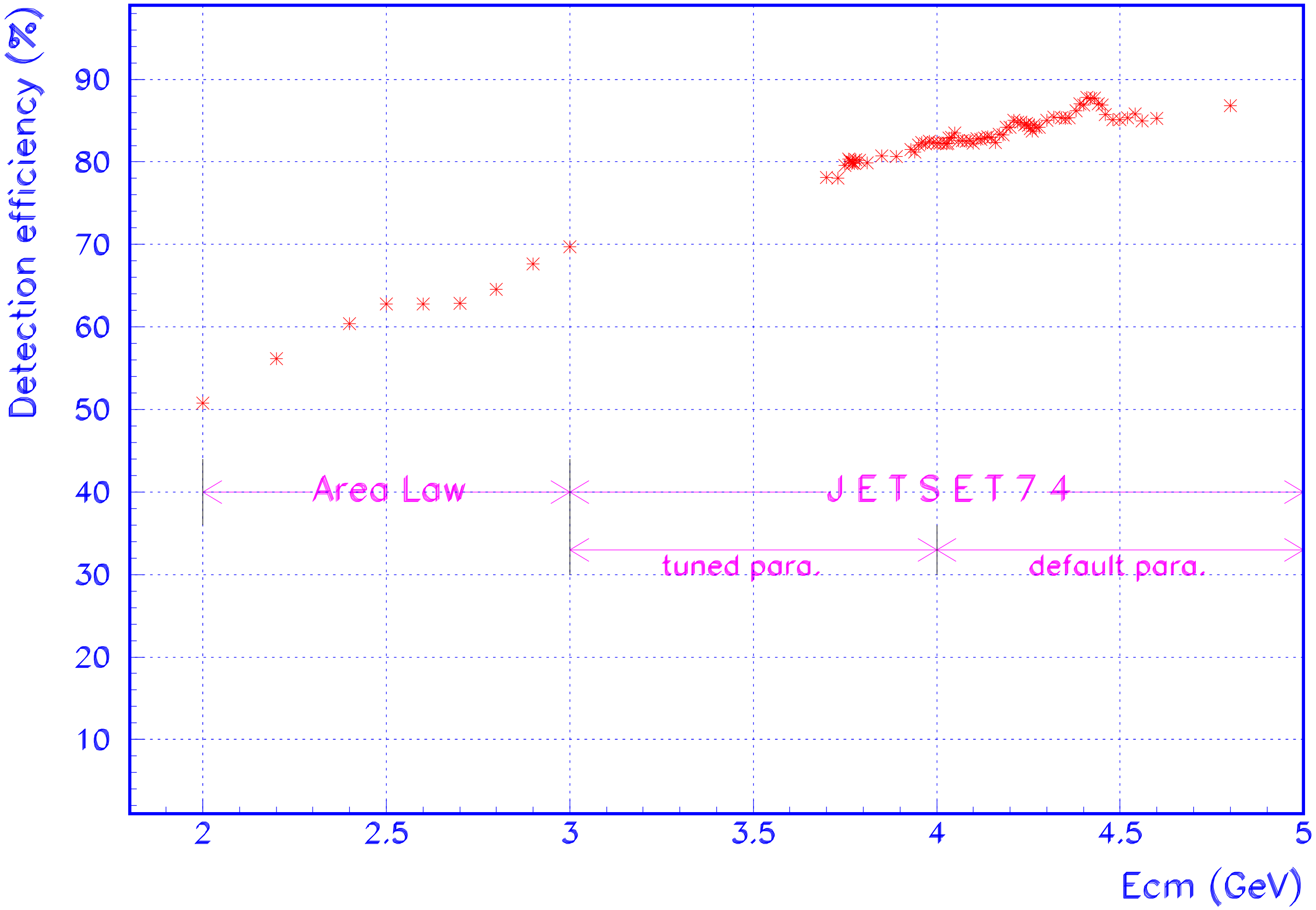


Figure 15: Detection efficiencies in '99 R scan

Luminosity Measurement

The integrated luminosity is given by

$$L = \frac{N_{obs}}{\sigma \cdot \varepsilon \cdot \varepsilon_{trg}} \tag{7}$$

N_{obs}: number of events observed,
σ: M.C. production cross section,
ε_{trg}: trigger efficiency,
ε: detection efficiency, given by

$$\varepsilon = N_{mc}^{obs} / N_{mc}^{total} \tag{8}$$

Possible channels to determine luminosity:

- $e^+e^- \to e^+ \ e^-(\gamma)$
- $e^+e^- \to \mu^+\mu^-(\gamma)$
- $e^+e^- \to \gamma \ \ \gamma \ \ (\gamma)$

- small angle monitor unreliable
- large angle Bhabha analysis applied
- dimuon and diphoton used for cross check

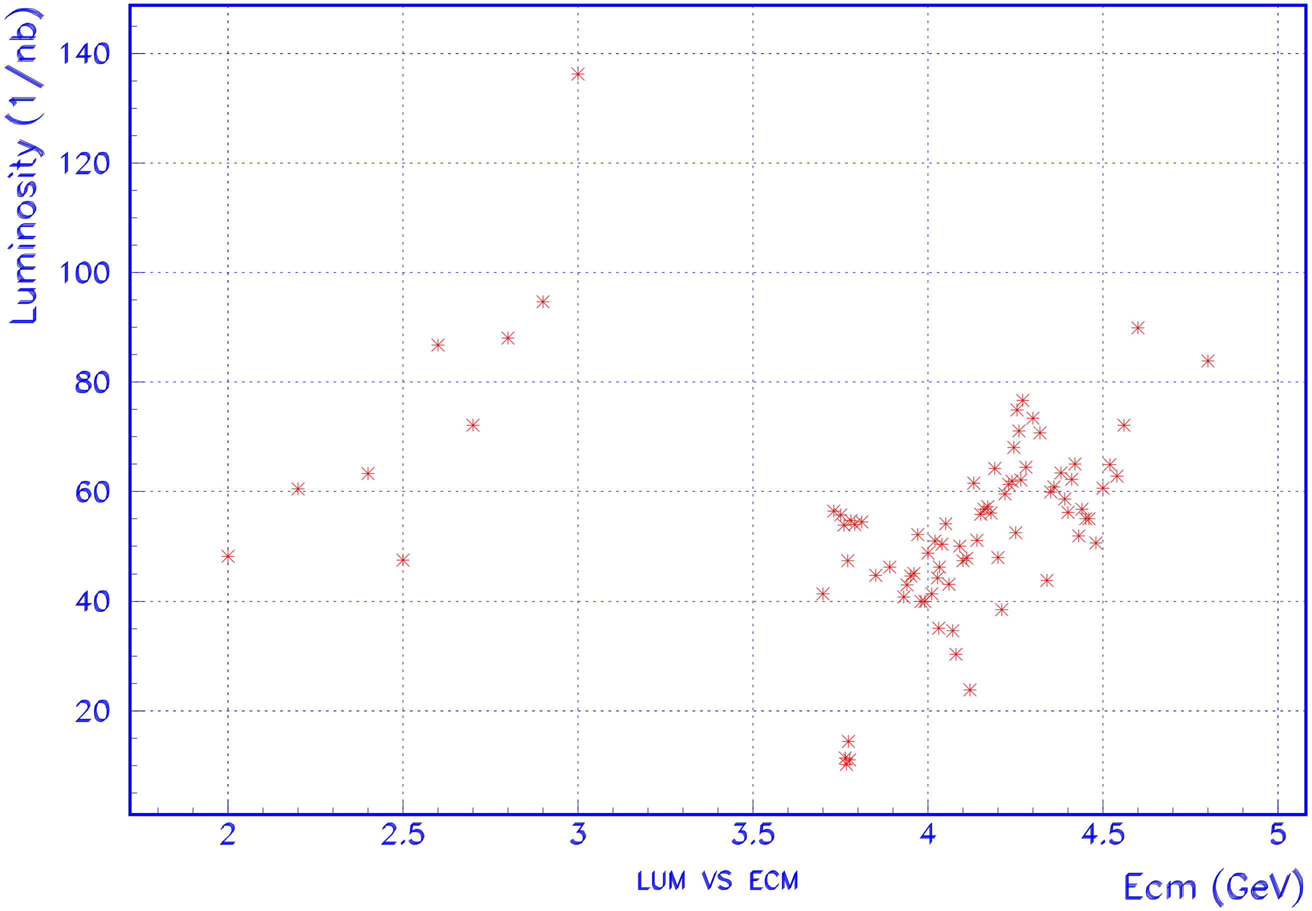


Figure 16: Integrated luminosity values in '99 R scan

Initial State Radiative Correction

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

$$\sigma_{had}^{obs} = \sigma_{had}^{0} \cdot \epsilon_{had} \cdot (1+\delta) \tag{9}$$

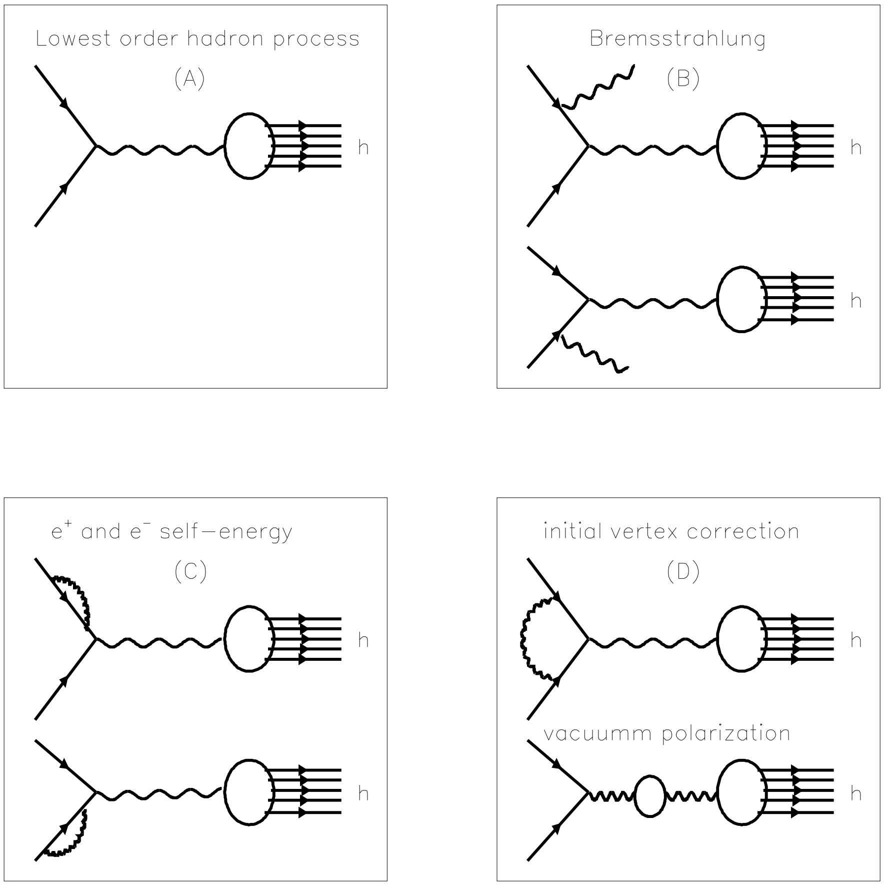


Figure 17: Feynman diagrams of $e^+e^- \to$ hadrons processes. (A) is the lowest order electromagnetic process, and (B), (C) and (D) are the higher order ones, whose contributions are represented by initial state radiative correction factor δ.

$$\delta_{obs} = \delta_{vert} + \delta_{vac}^{e} + \delta_{vac}^{\mu} + \delta_{vac}^{\tau} + \delta_{vac}^{had} + \delta_{\gamma obs} \quad (10)$$

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

Four different schemes investigated:

- Berends and Kleiss (1981)
- Bonneau and Martin (1971)
- Edwards, et al (Crystal Ball) (1990)
- Kureav and Fadin (1985) / Alexander (1989)

The radiative correction $(1 + \delta)$ calculated by these methods are all consistent to within 1% for off-resonance points.

Bonneau and Martin scheme selected.

Improvements in '99 R scan:
1. contribution of wide resonances;
2. beam energy spread simulation.

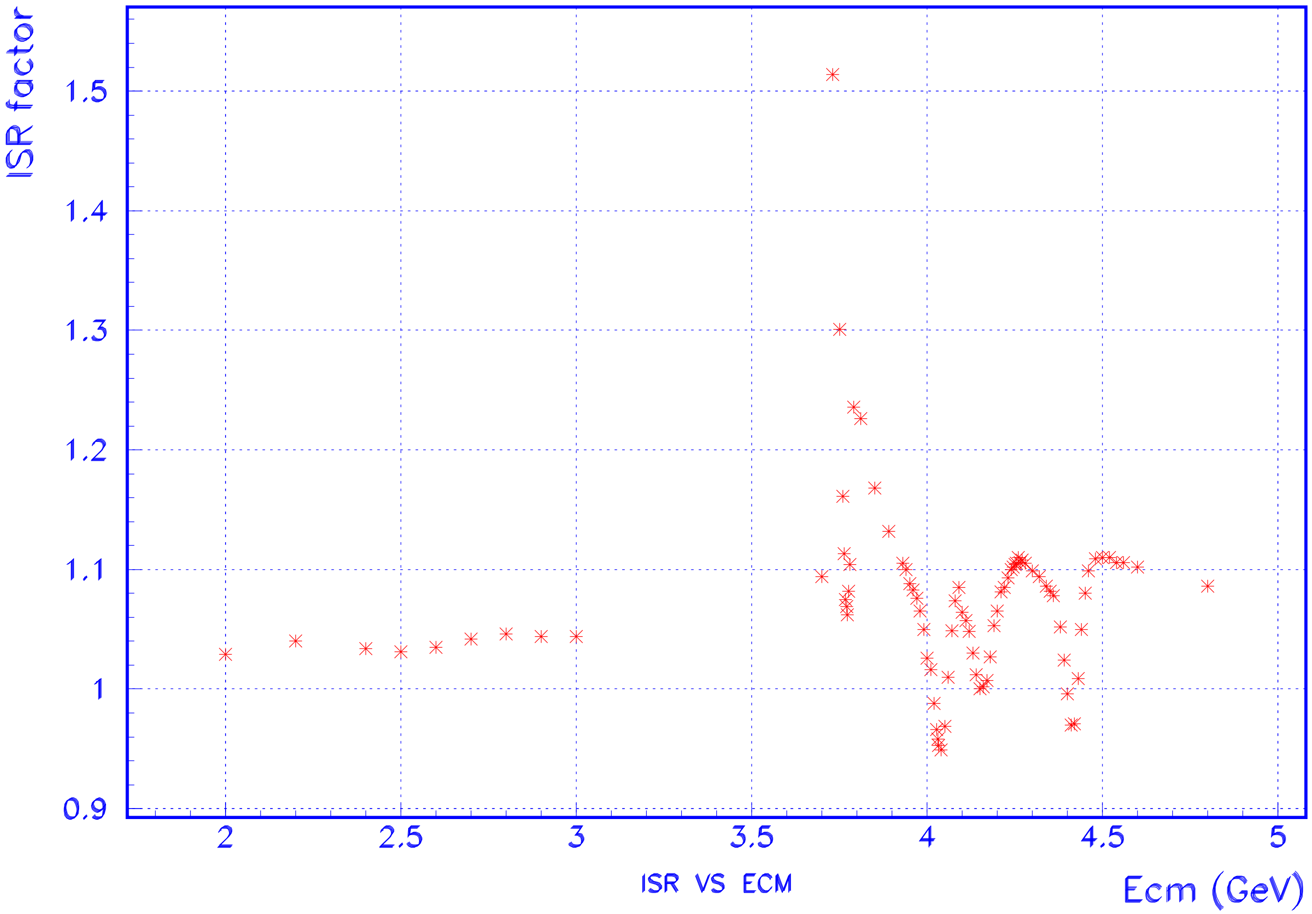


Figure 18: Initial state radiation correction factors in '99 R scan

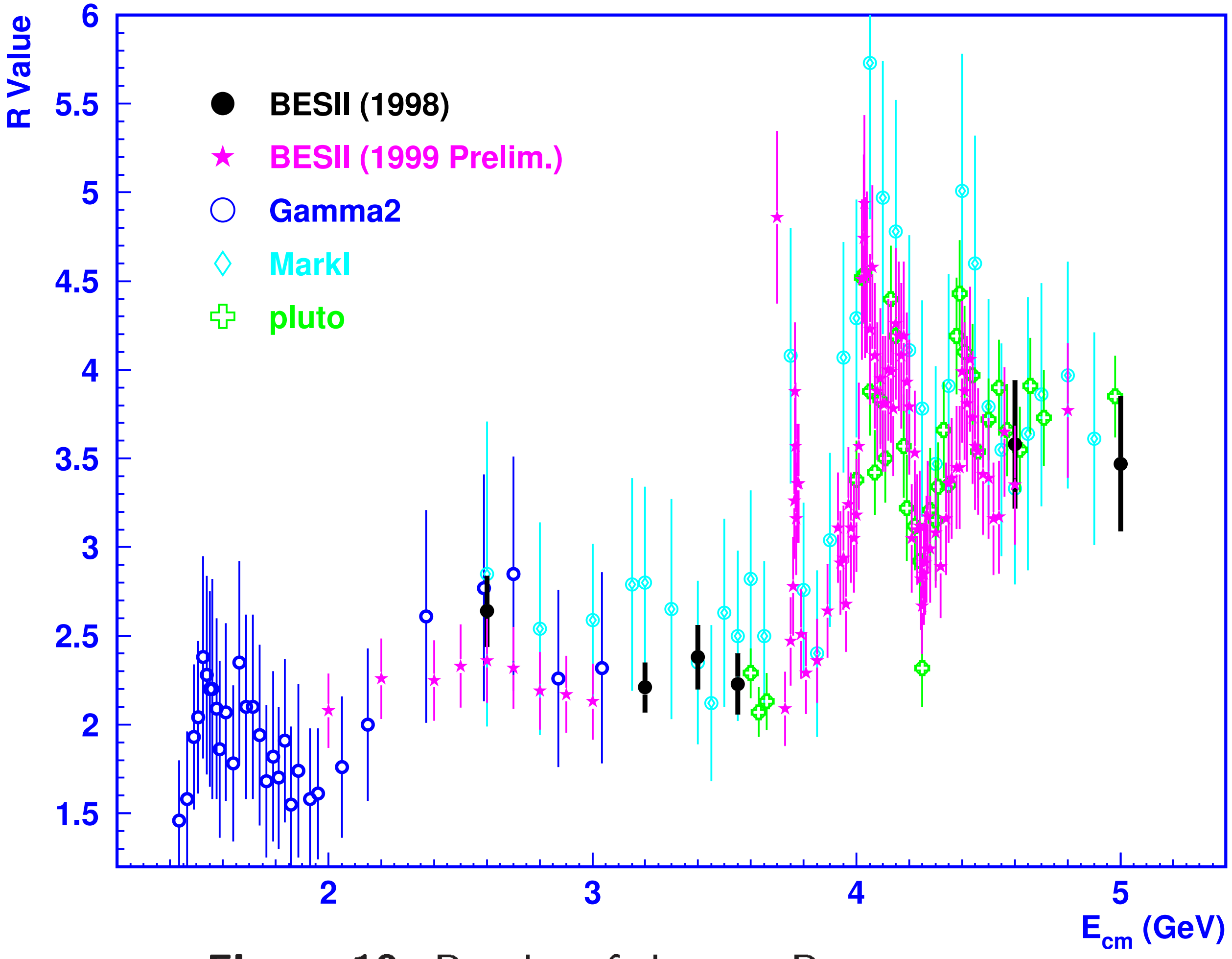


Figure 19: Results of the two R scan runs

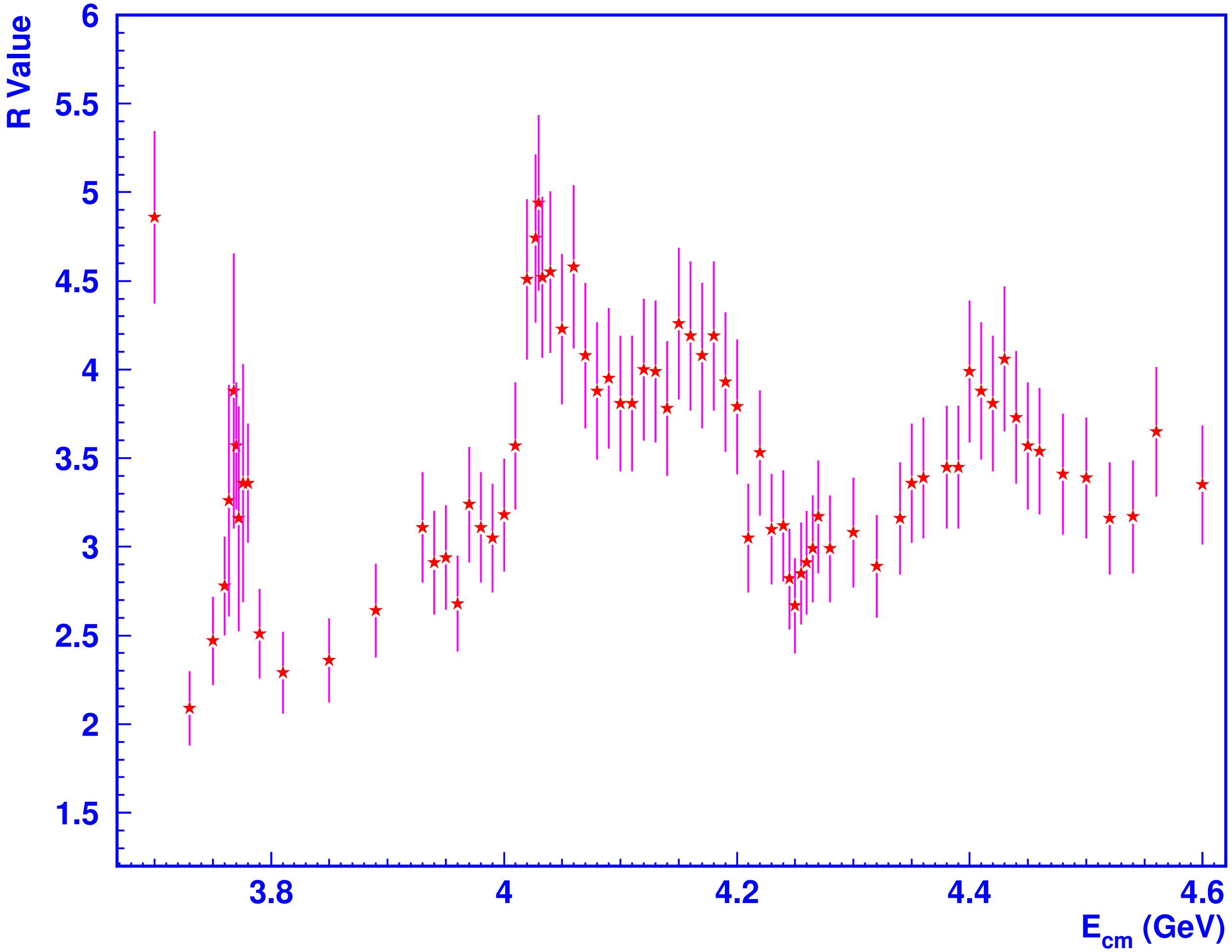


Figure 20: Resonance structure between $3.7 - 4.6$ GeV

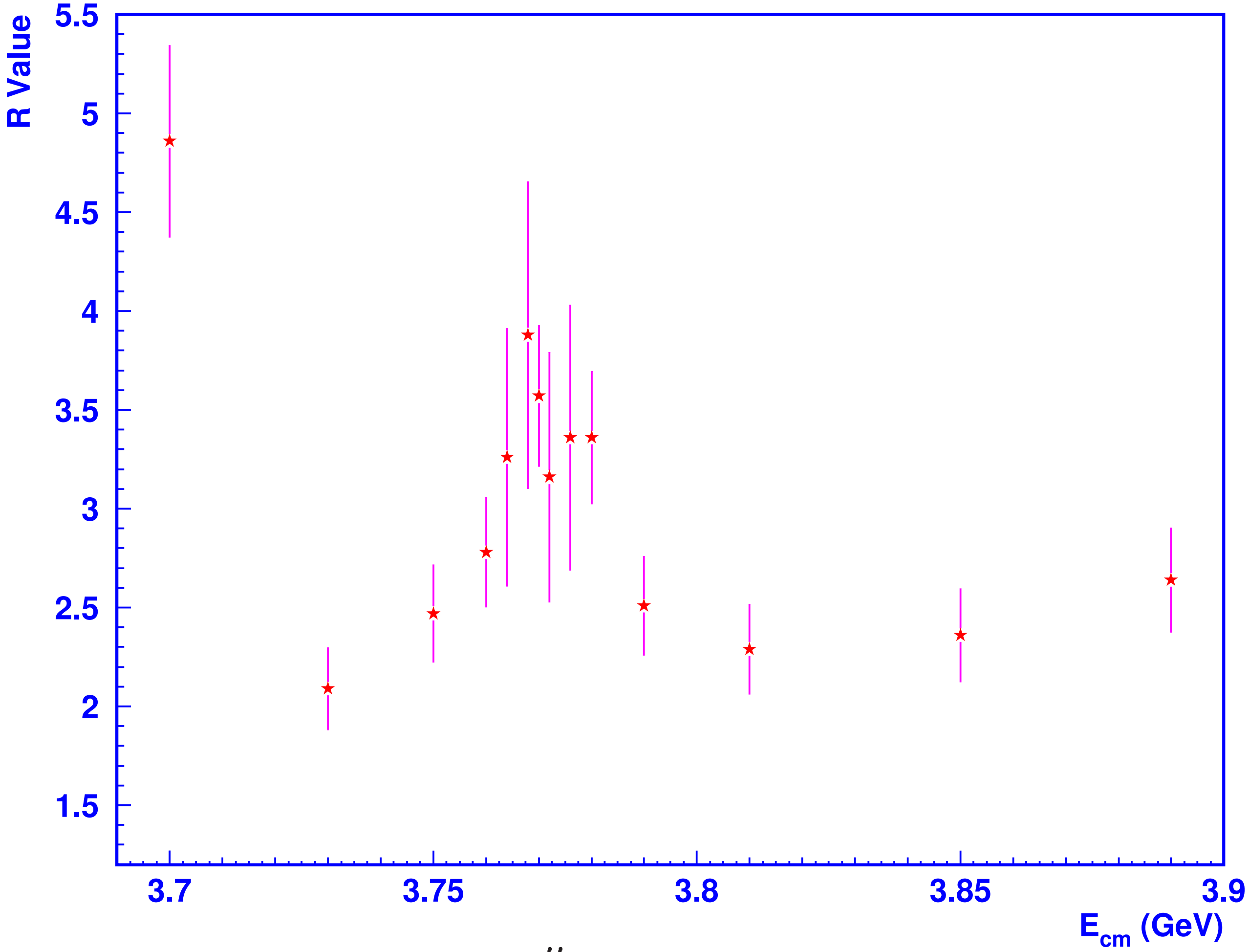


Figure 21: R values near ψ'', another detail scan is necessary?

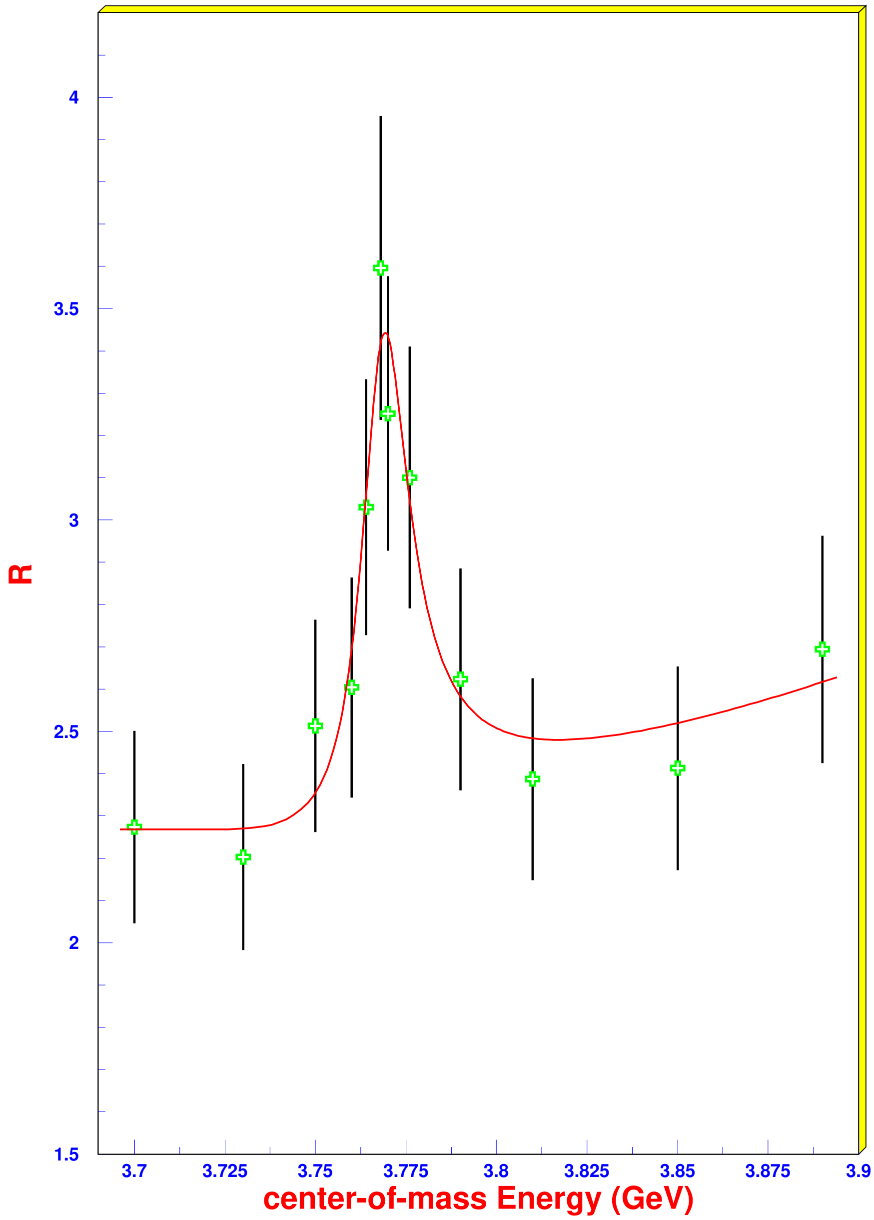


Figure 22: R vs E_{cm} after corrections for radiative effects

Table 3: Comparison of $\psi(3770)$ parameters

Experiment	$M_{\psi''}$(MeV)	Γ_{tot}(MeV)
MARK-I	3772 ± 6	28 ± 5
DELCO	3770 ± 6	24 ± 5
MARK-II	3764 ± 5	24 ± 5
BES-II	$3770.6 \pm ?$	$17.6 \pm ?$

Summary

- The 2 runs of R scan performed with good quality and stablity give satisfactory results;

- The first R scan: test run with 6 points, results published;

- The finer R scan: complete run with 85 points in 2-5 GeV, also successful;

- Further efforts:

– more study on detection efficiency;

– systematic error analysis;

– resonance parameters determination;

– final results $\rightarrow$ Conference $\rightarrow$ paper.