Hadronic Event Selection in the First R Scan Between 2-5 GeV

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January 16, 1999

Abstract

BES performed a scan of R measurement in the Spring '98 at center-of-mass energy 2.6, 3.2, 3.4, 3.55, 4.6 and 5.0 GeV. The total number of hadronic events is one of the key factors to determine R value. Hadronic event selection criteria are presented in this memo, and the hadronic event numbers at all the six energy points are also given.

1 Introduction

The value of R is determined from the number of observed hadronic events (N_{had}^{obs}) by the relation

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

where N_{bg} is the number of beam associated background events; $\sum_l N_{ll}$, $(l=e,\mu,\tau)$ and $N_{\gamma\gamma}$ are the numbers of misidentified lepton-pair and two-photon processes events; L is the integrated luminosity; δ is the correction for initial state radiation; and ε_{had} and ϵ_{trg} represent the detection and trigger efficiency for the hadronic events. Here we report the method to select hadronic events, and observed hadron events number N_{had}^{obs} and beam associated background events number N_{bg}.

2 Hadronic Event Selection Strategy

Hadronic events are produced from single virtual photon annihilation. The goal of event selection is to efficiently select hadronic events, and at the same time to suppress the background events as much as possible. The main sources of background are cosmic rays, lepton pair production from $e^+e^-\to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$, final states produced from two photon processes and the beam associated processes, i.e. interactions of beam particles with the residual gas (beam-gas events) or the walls of the vacuum chamber (beam-wall events).

To improve the statistics, we try to increase the solid angle acceptance, up to $| cos\theta | < 0.84$. To make the work simpler and easier, for the first stage work we require only events with at least 3 charged tracks; then, we pay extra effort to 2-prong events.

That is to say, the final R value will be obtained from both $\geq$ 2-prong events and $\geq$ 3-prong events. The results are expected to be consistent with each other. Since it is clean in multi-prong events, the corresponding result should be more close to real value, provided that the statistics is good enough.

For multi-prong events, the background from cosmic ray and lepton pair production is not a problem; but it is not the case to 2-prong events, since there exists huge contamination from all kinds of background. Generally speaking, for the tracks with good MDC fits, cosmic rays are rejected on the basis of their momentum and vertex position. Bhabha events are removed by utilizing the information of the deposited energy in the barrel ECAL, and the measured momentum, and dE/dx. Dimuon events are rejected by the response of the muon counters together with shower energy and momentum cuts. Pair production of $\tau^+\tau^-$ leptons (when E_{cm} is greater than the tau pair production threshold) are difficult to separate directly from the hadronic event sample because of their hadronic decay modes and short life time. Final states produced via two-photon processes are characterized by low momentum tracks that tend to be directed near the beam direction. These are quite distinct and, therefore, relatively easy to reject. The level of the $\tau\tau$ pair and residual two-photon backgrounds are determined by means of a Monte Carlo simulation. According to the production cross section and selection efficiency of hadron and $\tau\tau$ pair, the contribution from $\tau\tau$ pair to hadron sample is about 6%-8%. Two-photon interaction contribution, however, is very small, and thus can be neglected.

The most serious source of background in the hadronic event sample are beam-gas and beam-wall interactions. Most of the beam-gas and beam-wall background events are rejected by energy and vertex cut. The salient feature of the beam associated background are that their tracks are very much along the beam pipe direction, the energy deposited in ECAL is small, and most of the tracks are protons. The same hadronic event selection criteria are applied to the separated-beam data, and the number of separated-beam events N_{sep} surviving these criteria are obtained. The number of the beam associated background events N_{bg} in the corresponding hadronic event sample is given by

$$N_{bg} = f \cdot N_{sep} \tag{2}$$

where f can be determined by the ratio of the products of the pressure P at the collision region times the integrated beam currents I, i.e.

$$f = \frac{\int_{run} P_{run} \cdot I_{run}\, dt}{\int_{sep} P_{sep} \cdot I_{sep}\, dt} \tag{3}$$

So, number of hadron candidates after subtracting beam associated backgrounds can be expressed as,

$$N_{had}^{candi} = N_{had}^{obs} - N_{bg} \tag{4}$$

The ratio of $\tau\tau$ pair contribution can be obtained from Monte Carlo simulation,

$$r_\tau = \frac{\sigma_\tau \varepsilon_\tau}{\sigma_h \varepsilon_h + \sigma_\tau \varepsilon_\tau} \tag{5}$$

Finally, we get the hadrons number,

$$N_{had} = N_{had}^{candi} \cdot (1 - r_\tau) \tag{6}$$

3 Hadronic Events Selection Criteria

The event selection criteria are listed here briefly, and will be discussed in detail later. First, apparent Bhabha events are rejected. Since Bhabha event has some clear characteristics to be recognized, it will be efficient to remove them as an event. The method to select Bhabha is described in Ref. [1], only information from shower counter are used. And then the track level selection, at last the event level selection. The flow chart of events selection is shown in Fig. 1.

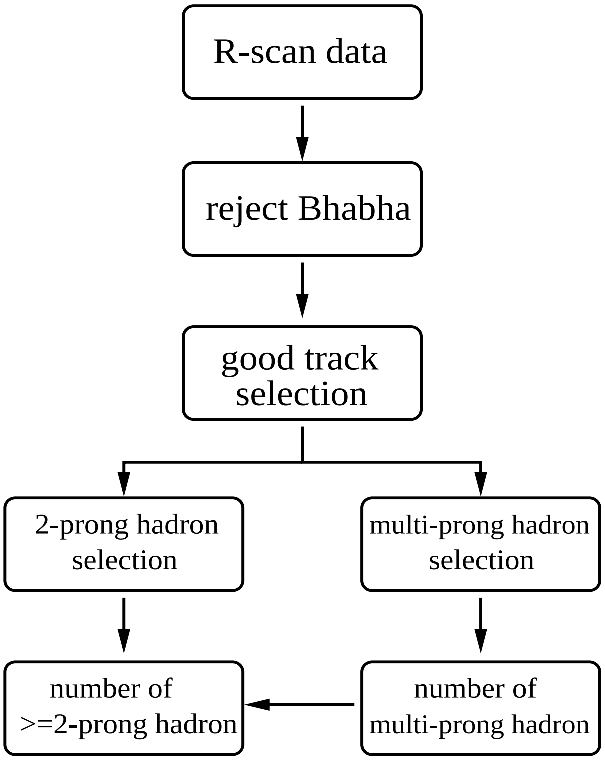

Figure 1: hadron event selection procedure

Charged tracks which fulfills the following criteria are regarded as good ones:

1. $\mid \cos\theta \mid < 0.84$, where θ is the track polar angle;
2. track should have good three-dimentional helix fit in MDC (MFIT =2), or not too bad (MFIT=-19);
3. for tracks with MFIT=2, distance of closest approach to the beam in the transverse plane and along the beam axis are less than 2.0 cm and 18 cm respectively;
4. for tracks with MFIT=-19, no vertex cuts are applied, but the number of dE/dx hits are required to be greater than 16;
5. $p < p_{beam} + 5 \times \sigma_{p_{beam}}$, where p and p_{beam} are the momenta of the track and the beam respectively, $\sigma_{p_{beam}}$ is the beam momentum resolution;
6. track should not have energy larger than $0.6E_{beam}$ or 1.0 GeV;

7. remove any track with muon signal;

8. $2 < t < t_p + 5 \times \sigma_t\ ns$, where t and σ_t are the measured time-of-flight of the track and the BTOF time resolution, t_p is the time-of-flight of proton assumption calculated for the track;

   And then, we come to event level selection:

9. at least 2 good charged tracks, and from which at least 1 track with MFIT=2;

10. the total deposited energy should be greater than $0.28E_{beam}$;

    Now, different requirements are applied to 2-prong and multi-prong hadron candidates. To multi-prong events,

11. the selected tracks should not be all positive charged ones;

    To 2-prong events, it is a little more complicated,

12. the two selected tracks should not be back-to-back:
    $$| \theta_1 + \theta_2 - 180^\circ | > 10^\circ, || \phi_1 - \phi_2 | -180^\circ | > 4^\circ;$$
    and, at least 2 isolated neutral tracks fulfill:
    $$E_\gamma > 100MeV, | \phi_\gamma - \phi_c | > 15^\circ.$$
    where ϕ_c represents ϕ angle of any of the two charged track.

3.1 geometry acceptance

The solid angle acceptance is set to $\mid cos\theta \mid < 0.84$. We check the momentum, dE/dx and deposited energy distribution of Bhabha events near $\mid cos\theta \mid = 0.84$. The resolution is not so good as large angle region, still they can be used, as the following figures show.

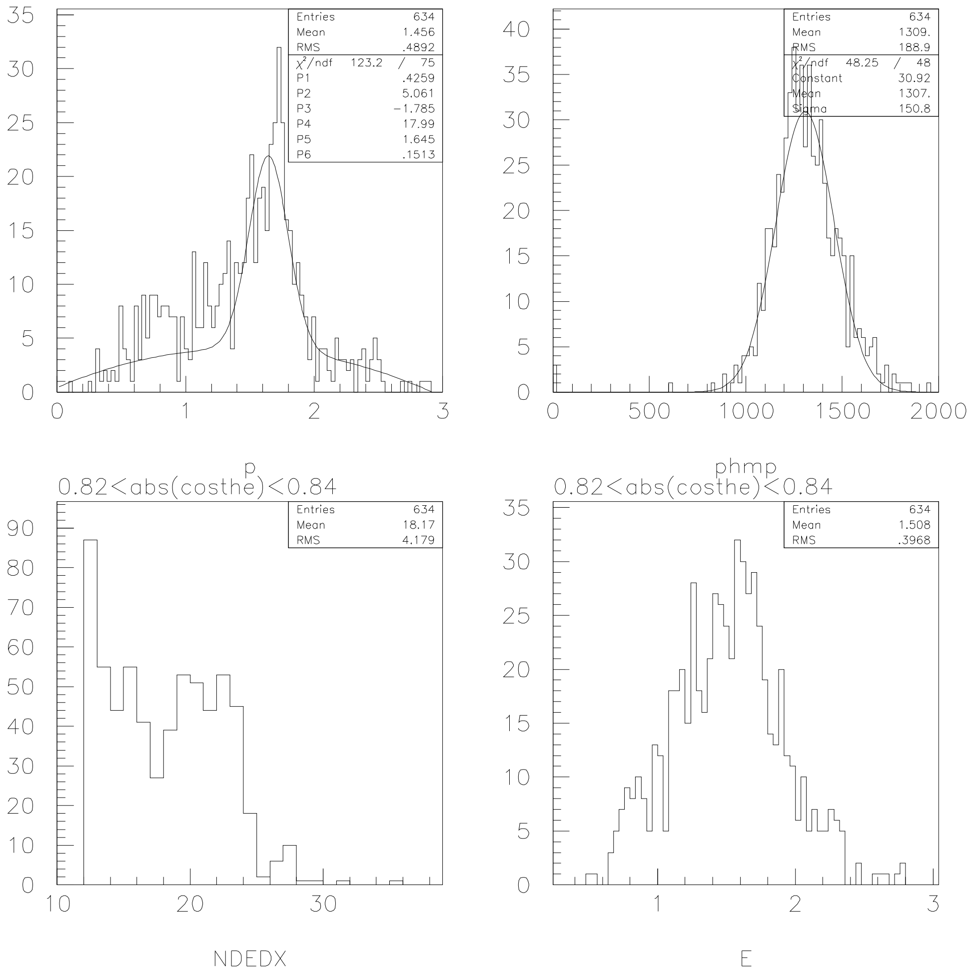

Figure 2: Several distribution of Bhabha events near $\mid cos\theta \mid = 0.84$ ($E_{cm} = 3.4GeV$). The four figures represent track momentum, dE/dx pulse height, dE/dx hits number and deposited energy, respectively.

3.2 vertex cut in the transverse plane

The distance of closest approach to the beam in the transverse plane (V_r) should be less than 2.0 cm for tracks with MFIT=2. The cut effect is shown in the following figures.

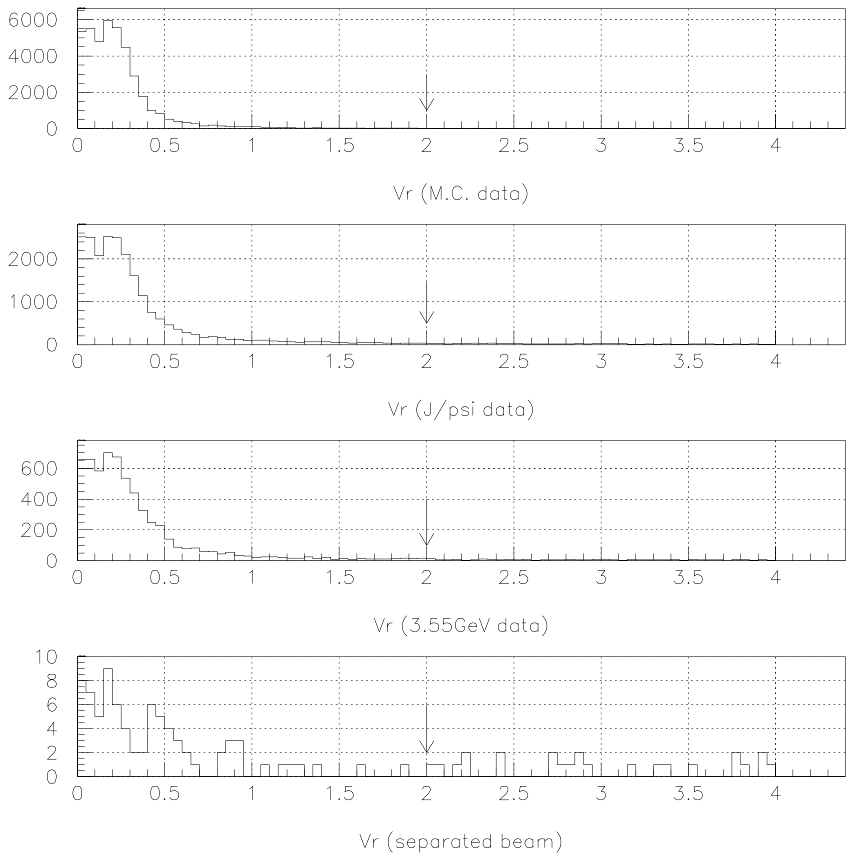

Figure 3: V_r cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data for tracks with MFIT=2

For tracks with MFIT=-19, since vertex distribution in the transverse plane is obviously broader, it is difficult to determine a suitable cut value. The beam pipe radius is 5.0 cm, but fitted V_r of quite a few tracks is much beyond this value, So we don't cut V_r in order not to lose real tracks.

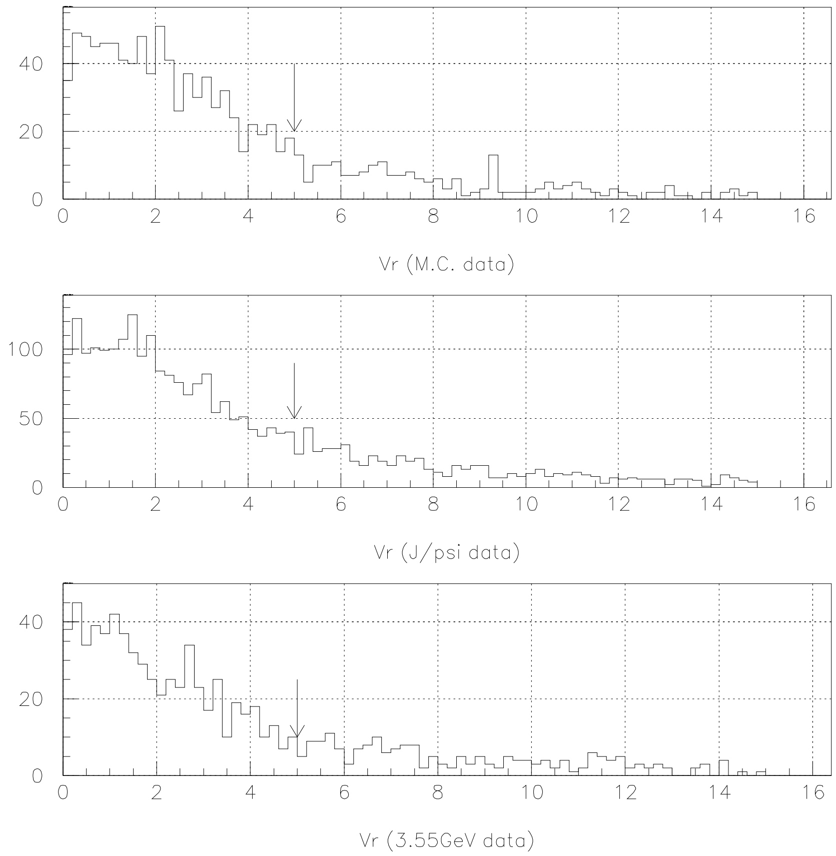

Figure 4: Vertex distribution in the transverse plane of M.C., J/ψ, and 3.55 GeV colliding data (tracks with MFIT=-19). Arrows indicate beam pipe radius.

3.3 vertex cut along the beam axis

The distance of closest approach to the beam along the beam axis (V_z) should be less than 18 cm for tracks with MFIT=2, but for tracks with MFIT=-19 no V_z cut is applied as bad V_z fit. The cut effect is shown in the following figures.

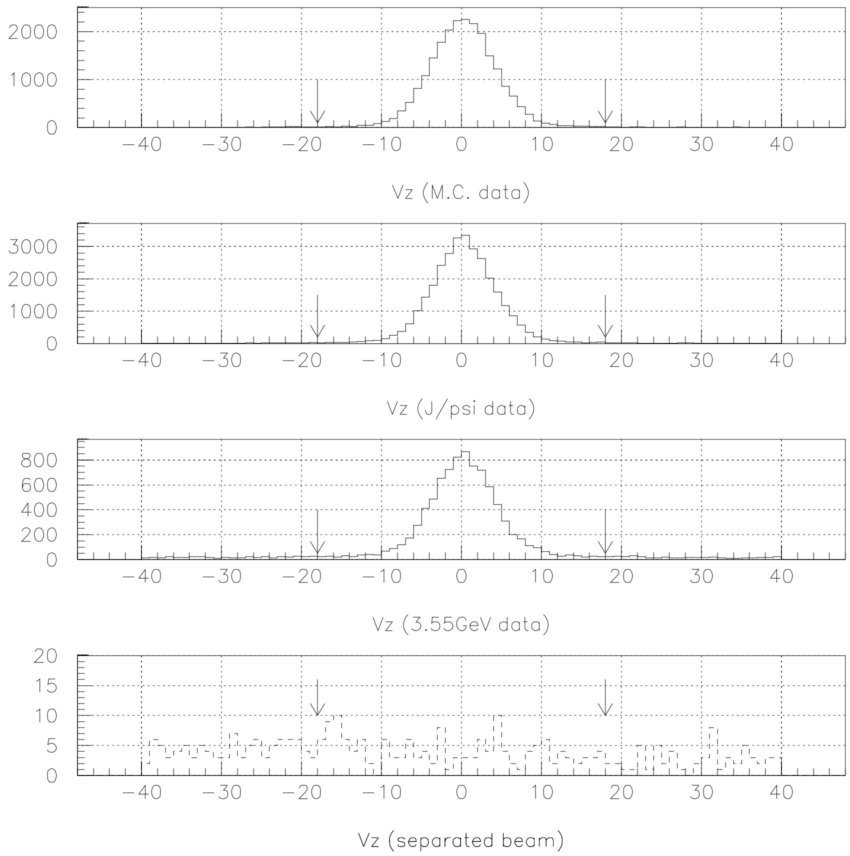

Figure 5: V_z cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data (tracks with MFIT=2)

The distribution along the beam axis of the tracks with MFIT=-19 is quite broad. To these tracks, it is difficult to use V_z cut, because the value can not be trusted in. The ratio of tracks with MFIT=-19 among total selected tracks in hadron sample is about 4.6% in Monte Carlo, and 9.2% in real data. As a comparison, the ratios in Bhabha sample are 2.1% and 1.6% respectively. Both in Monte Carlo and real data, the ratio of tracks with MFIT=2 or -19 to total tracks in hadron sample is about 92.0%.

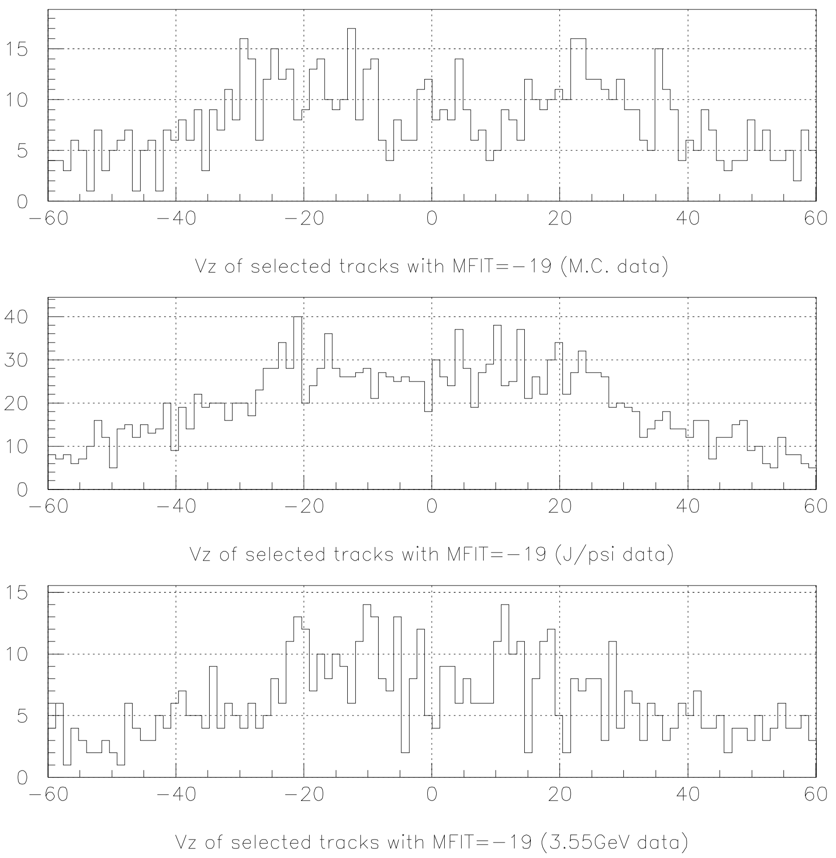

Figure 6: Vertex distribution along beam axis of tracks with MFIT=-19

3.4 number of dE/dx hits

Tracks with MFIT=-19 pass both circle and helix fitting, but the fit quality is not good. So most cuts are not applied to these tracks, and thus after track selection, tracks with MFIT=-19 are not as clean as those with MFIT=2. However, dE/dx hits number of tracks with MFIT=-19 is fewer than that of MFIT=2. In order to remove those most possible bad tracks, the hits number is required to be greater than 16 for tracks with MFIT=-19.

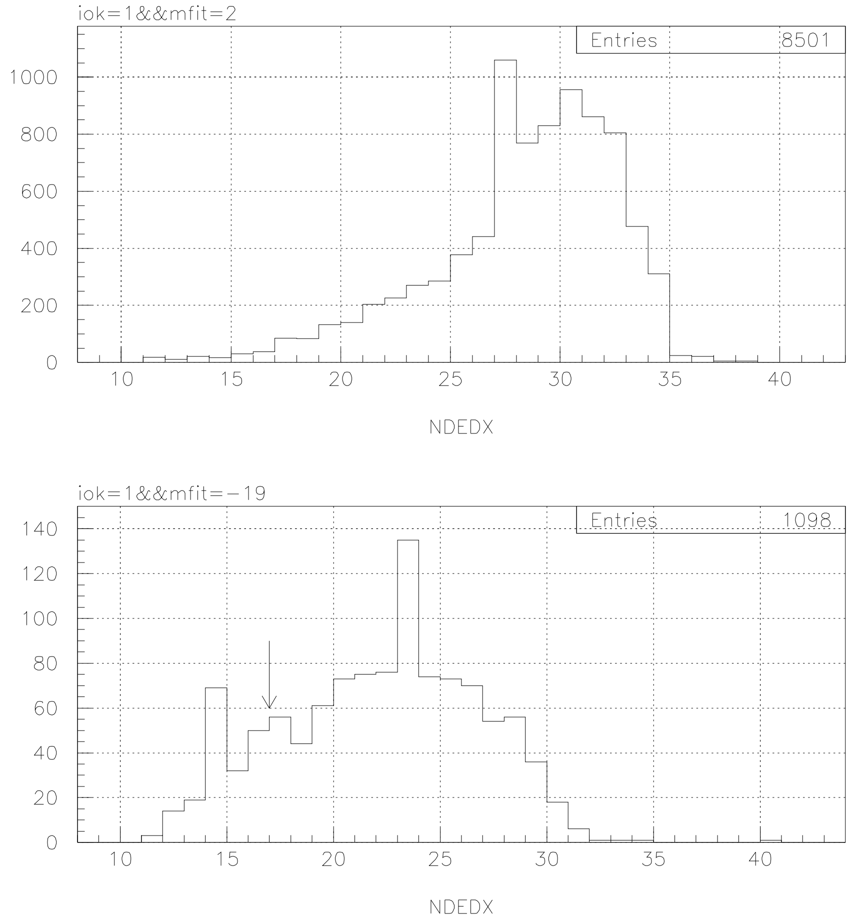

Figure 7: Number of dE/dx hits of tracks with MFIT=2 and -19

3.5 track energy cut

Hadron track deposites smaller energy than electron track. If a track has energy larger than $0.6 \cdot E_{beam}$ or 1.0 GeV, it should not be regarded as that of hadron.

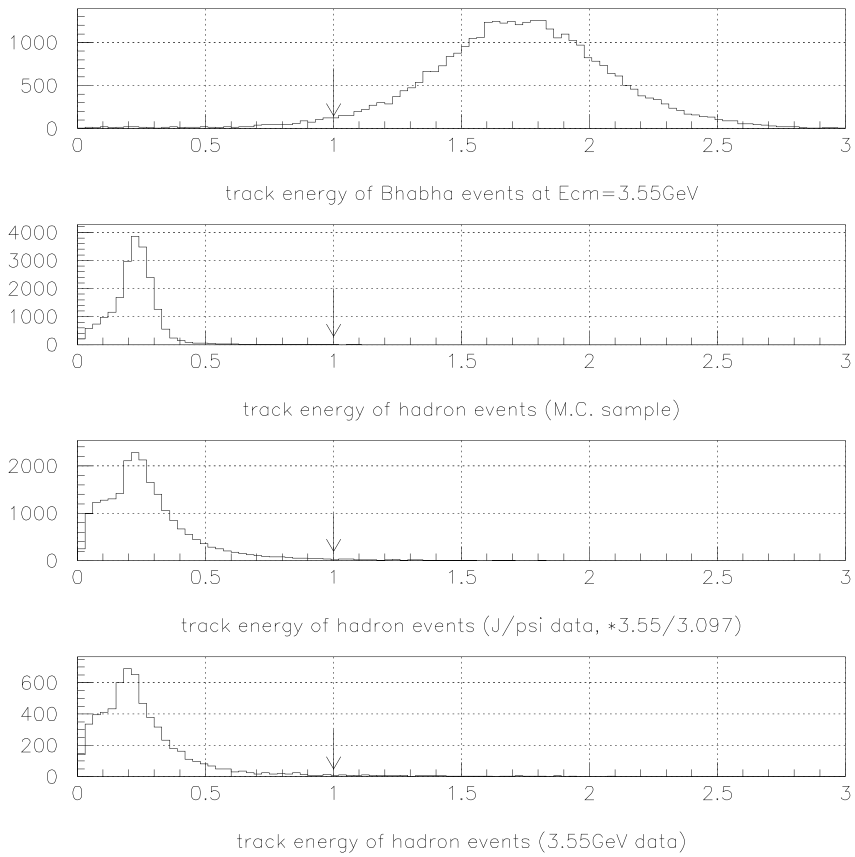

Figure 8: Track energy of Bhabha and hadron events

3.6 remove muon track

Any track with 5 or 6 hits in muon counter is removed as muon track, whereas track with fewer hits might be of hadron punching through. A good muon hit fullfills: the distance in the transverse plane between hit in muon counter and projected position from MDC track fitting is less than $20 + 5 \cdot layer$ cm; and if two-tube hits in a layer, the hits number is regarded as 2.

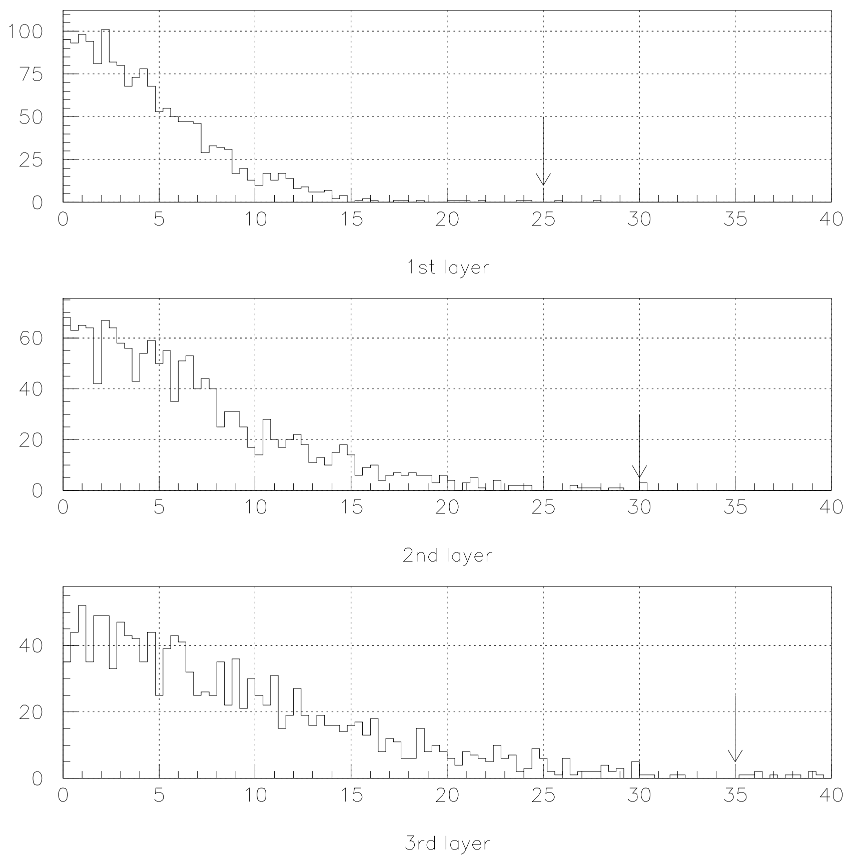

Figure 9: $| \vec{r}_{hit} - \vec{r}_{proj.} |$ in transverse plane in 3 layers of muon counter (unit in cm)

3.7 TOF information

Generally, TOF information is useful to reject cosmic ray events. Unfortunately, we don't have good TOF information at some points in the first R scan. The most severe case is at 4.6 GeV, as online TOF calibration was not passed, there are many online dead channels. Similar problem also exists at 5.0 GeV; and at 3.55 GeV counter 21 has single-end output which can not give reliable information. If TOF cut is used, then many good events will be lost. So we don't use TOF information at these 3 points. Then, how about cosmic ray events? As multi-prong requirement, and vertex, total energy, momentum and muon track cut, there are hardly any cosmic ray events survived. The selection criteria are applied to 5.9 hours cosmic ray data, and only 1 event (2-prong) left. The normal data collection duration at 2.6 GeV is about 160 hours, and at other 5 points is from 30 to 53 hours. So we needn't worry about it.

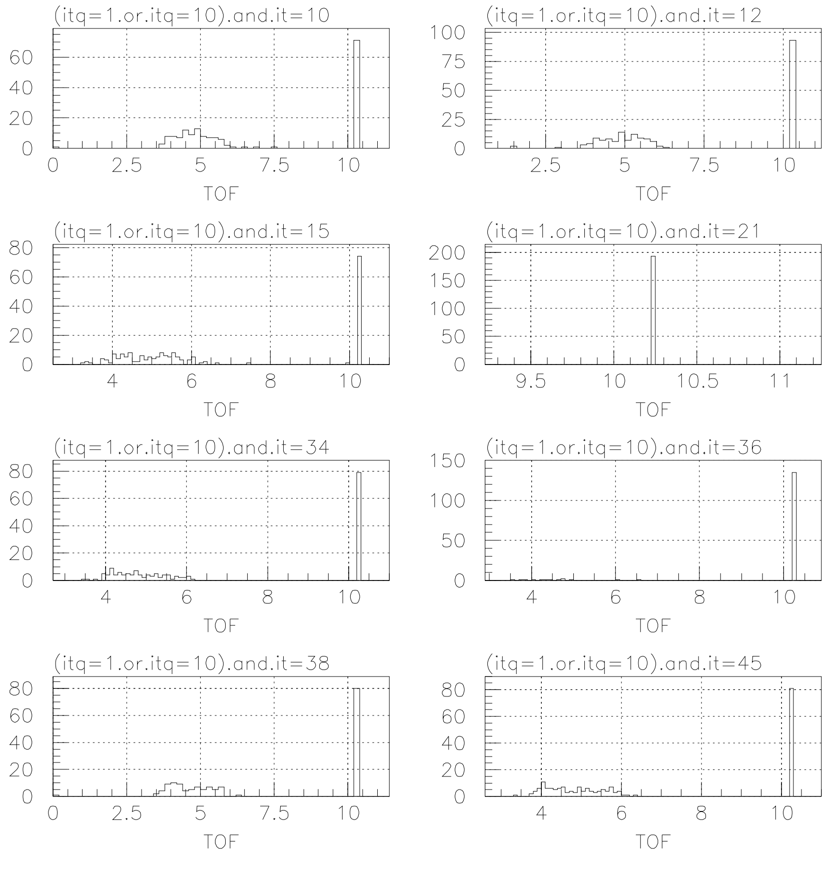

Figure 10: Bad TOF information at 4.6 GeV. The distribution is from Bhabha events with good TOF hit quality (1 or 10), but most TOF values are meanless 999 at counter 10, 12, 15, 21 34, 36, 38 and 45. (note that TOF values which populate at 10.2 in the histograms represent 999 in fact)

On the other hand, we don't find any TOF problem at 2.6, 3.2 and 3.4 GeV. To these 3 points, we can still use TOF cut to remove cosmic ray events. At first, TOF of hadron track is required to be in a rather wide range from 2 to 20 ns; and then, assuming the track as a proton which is the heaviest and so the slowest particle, TOF is calculated according to the flight path length and track momentum, if the measured value is greater than calculated one plus 2 ns (about 5 times of BTOF resolution), that is to say, the track is even slower than slowest proton, obviously it is not the expected good track.

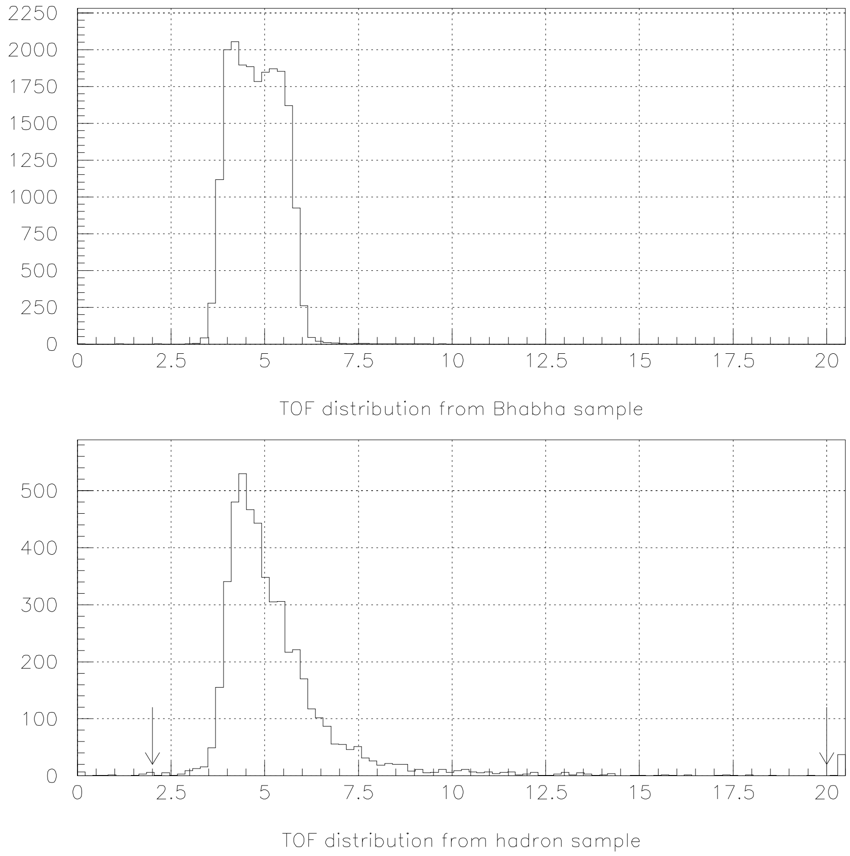

Figure 11: TOF at 3.4 GeV

3.8 total energy cut

The good hadron event should not have too small energy, otherwise it probably is a background event. The total deposited energy is required to be greater than $0.28E_{beam}$. From M.C. sample and J/ψ data, very few hadronic events are cut off, whereas beam-gas events can be effectively suppressed by this cut, as the following figure shows.

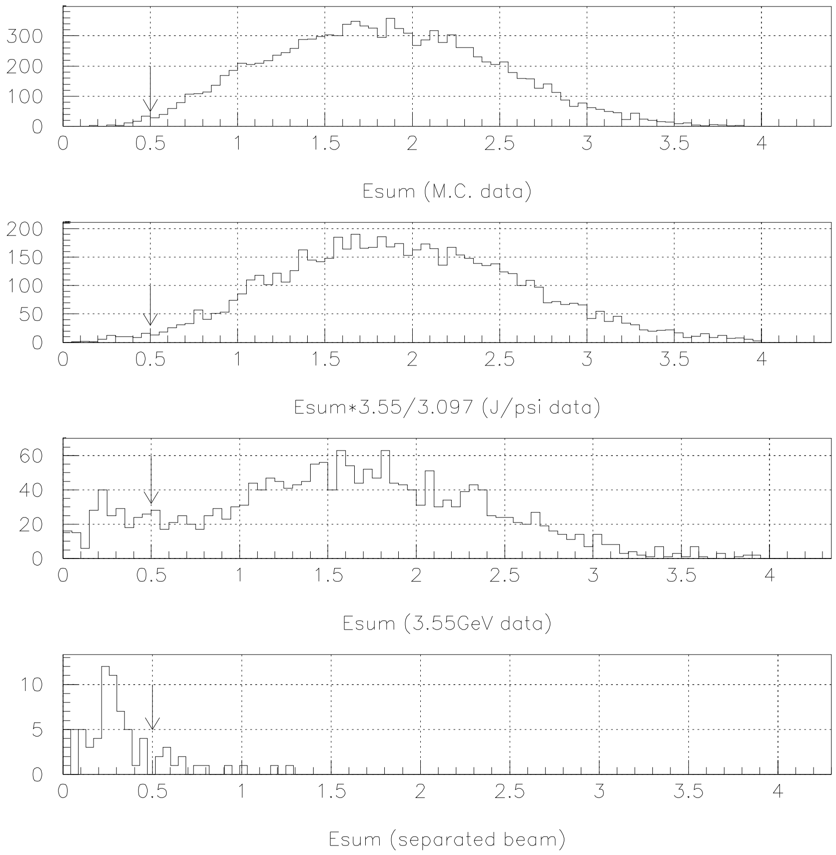

Figure 12: E_{sum} cut to M.C., J/ψ, 3.55 GeV colliding data and separated beam data

3.9 net charge requirement

To multi-prong events, the selected tracks should not all carry positive charge. Since beam-gas events often have several positive tracks, and most of them are roughly identified to be protons. 2-prong events, however, maybe come from multi-prong events with one or more tracks missing, so any combination of the two tracks is acceptable.

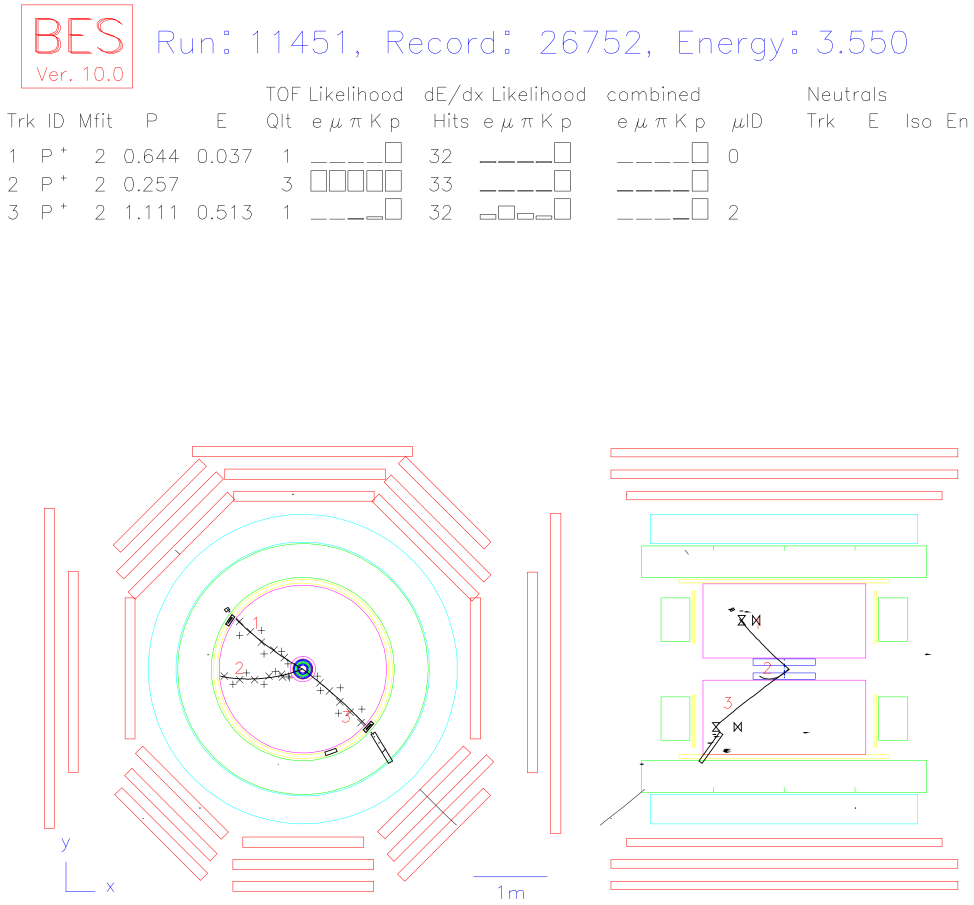

Figure 13: A typical beam-gas event found from 3.55 GeV data

3.10 special treatments to 2-prong events

As mentioned above, 2-prong events have much more severe backgrounds. All our efforts described here is try to remove backgrounds from cosmic rays and lepton pairs produced via e^+e^- annihilation.

3.10.1 discard back-to-back events

Since cosmic ray and lepton pair events are characterized by two back-to-back tracks, and the cross section of lepton pair is much larger than that of hadron, we had to discard back-to-back events to reduce these contaminations. Fig. 14 shows back-to-back in θ and ϕ of Bhabha events, we cut $10°$ in θ and $4°$ in ϕ direction.

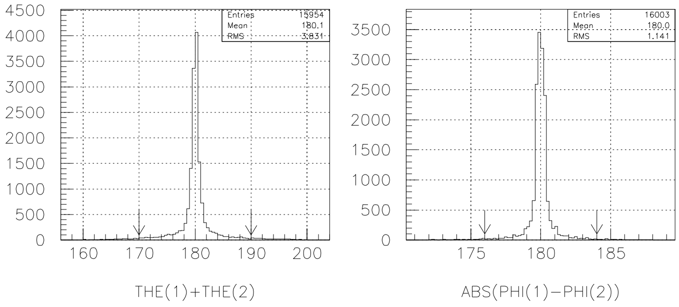

Figure 14: back-to-back of Bhabha events

3.10.2 reject radiative photon

Radiative Bhabha or radiative dimu events often have one photon near charged track. But an event with more than two good isolated neutral tracks is most likely a hadron. Fig. 15 shows the distribution of separation angle between radiative photon and charged track of Bhabha events. If the angle is less than $15°$ in ϕ direction, then the neutral track is regarded as radiative photon, otherwise, it is counted as a good isolated photon. Since there are many fake photons with small energy, the good isolated photon should have energy larger than 100 MeV.

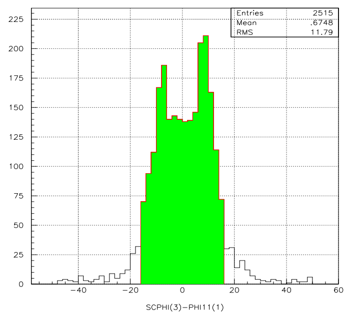

Figure 15: separation angle between radiative photon and charged track of Bhabha events

4 Preliminary Results

Hadronic event numbers at all 6 energy points are listed in the following table, and beam-gas events number and the f factor are also given. TOF cut is applied at 2.6, 3.2 and 3.4 GeV, not at 3.55, 4.6 and 5.0 GeV. The distributions of β versus track momentum and dE/dx pulse height versus track momentum are shown in Fig. 16, from which one can see clear bands of different kinds of particles, indicating that the selection criteria is reliable. As a comparison, the polar angle distribution of Monte Carlo, J/ψ data and 3.55 GeV data is shown in Fig. 17.

Table 1: Hadron numbers at 6 energy points (≥ 2 prong)

$E_{cm}(GeV)$	N_{had}^{obs}	N_{sep}	f	$r_\tau(\%)$
2.6	5884	11	15.84	-
3.2	2076	10	10.24	-
3.4	2165	48	3.86	-
3.4(I)	1212	48	2.62	-
3.4(II)	953	48	1.24	-
3.55	2676	50	4.31	-
4.6	1497	48	5.88	7.9
5.0	1649	26	17.81	8.1

Table 2: Hadron numbers at 6 energy points (≥ 3 prong)

$E_{cm}(GeV)$	N_{had}^{obs}	N_{sep}	f	$r_\tau(\%)$
2.6	4216	6	15.84	-
3.2	1621	8	10.24	-
3.4	1660	31	3.86	-
3.4(I)	910	31	2.62	-
3.4(II)	750	31	1.24	-
3.55	2071	28	4.31	-
4.6	1163	24	5.88	5.9
5.0	1291	14	17.81	6.0

References

[1] Huang Guangshun, Luminosity Calculation in R Measurement at 3.55 GeV, BES'98 Annual Meeting

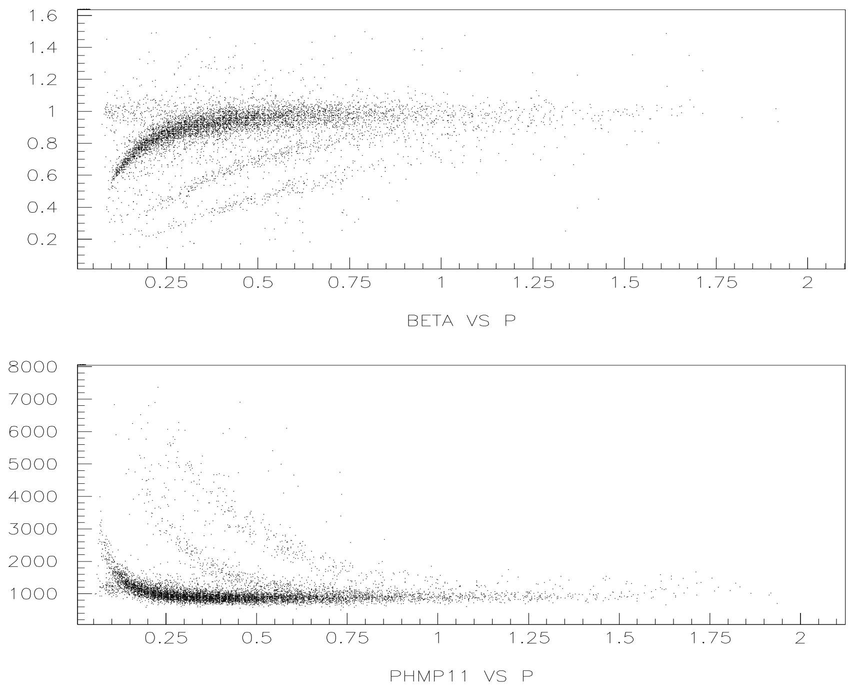

Figure 16: $\beta - p$ and $dE/dx - p$ distributions of final selected hadrons

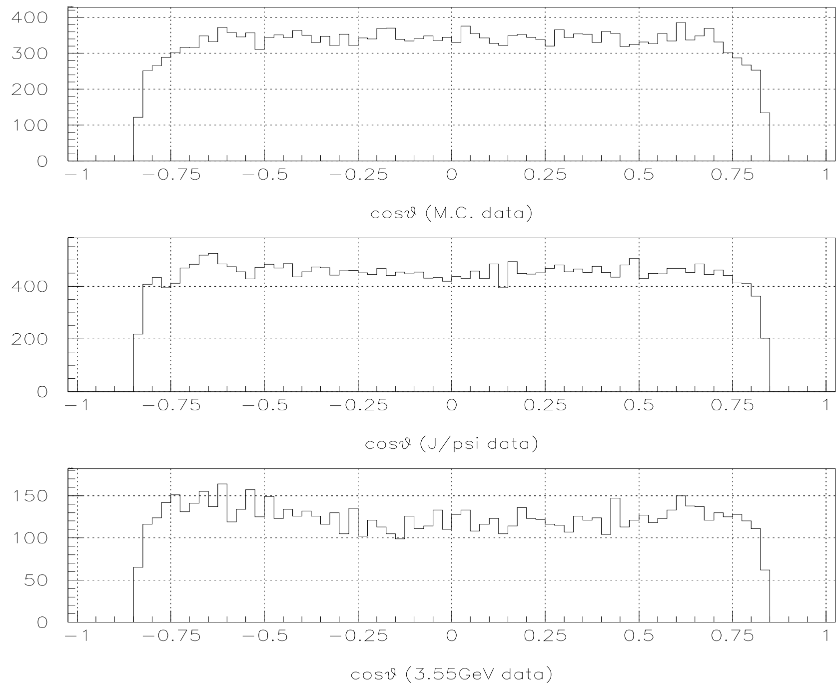

Figure 17: Polar angle distribution of hadronic tracks