ALEPH 94-042
PHYSIC 94-038
J. Boucrot et al.
11.03.1994

# Search for Charmless b Decays

J. Boucrot, M–H Schune [*], D. E. Jaffe [†],
A. Litke, G. Taylor [‡], E. Simopoulou, K. Zachariadou [§]

March 10, 1994

## 1 Introduction

Decays of beauty hadrons into final states which do not contain a charmed quark can proceed via either a $V_{bu}$ transition or through penguin diagrams. The contribution from $V_{bu}$ is expected to dominate. Recent measurements [1] with the CLEO II detector have found the first evidence for hadronic charmless b decays. CLEO measure a combined branching ratio $B_d^0 \to \pi^+\pi^- + B_d^0 \to K^-\pi^+ = 2.4 \pm .8 \pm .2 \times 10^{-5}$ but are unable to obtain statistically significant signals in the two individual channels. With a data sample of 1.55 million hadronic Z decays one could expect around 7 decays of the type $B_d^0 \to \pi^+\pi^-, K^-\pi^+$ to be produced. Furthermore at LEP it is possible to look for charmless decays of both $\Lambda_b$ and $B_s^0$.

## 2 Summary of the Analysis Method

Charmless b decays may be identified by looking for two oppositely charged tracks, originating from a displaced vertex, which have an invariant mass above the kinematic limit for tracks coming from charmed b decays.

Such events were selected using a combination of cuts based on kinematics and topological vertexing.

Kinematic cuts

- Each track was required to have a momentum above 3 GeV

*Laboratoire de l'Accélérateur Linéaire, F-91405 Orsay Cédex, France.
†S.C.R.I., Florida State University, Tallahassee, FL 32306 USA
‡Institute for Particle Physics, University of California at Santa Cruz
§N.C.S.R. Demokritos, Athens, Greece

- Neither track was an identified lepton
- The momentum sum of the two tracks had to be at least 20 GeV

Topological Vertexing

- Each track was required to have at least one 3 dimensional coordinate in the vertex detector
- The three dimensional impact parameter of each track had to be inconsistent, by more than $3\sigma$, with the interaction point
- Each track had to cross the flight path of the b hadron candidate in front of the interaction point
- The two tracks had to form a consistent vertex with a probability $> 1\%$
- Their vertex had to be at least $6\sigma$ in front of the interaction point
- The b hadron candidate had to point back from its vertex to the interaction point with a probability $> 1\%$

Monte Carlo studies have shown that the maximum invariant mass for two tracks coming from a b meson decay involving charm, which pass the above kinematic cuts, is around 4.8 GeV. The corresponding limit from charmless b baryon decay is 5.0 GeV. A signal region was defined by requiring that the invariant mass of the two tracks, under the pion hypothesis, had to be at least $3\sigma$ above 5 GeV and when one track was given the proton hypothesis the mass had to be less than $3\sigma$ above the $\Lambda_b$ mass (the $\pm$ 50 MeV uncertainty [3] on the $\Lambda_b$ mass was added in quadrature). The efficiency of the above cuts was measured using Monte Carlo to be 27.5 $\pm$ .7 %.

# 3 Results

The above selection criteria were applied to a sample of just over 1.55 million hadronic Z decays. Each event was required to have a precisely determined 3 dimensional interaction point, obtained using QFNDIP [2]. The invariant mass distribution, under the pion hypothesis, is shown for both unlike-sign and like-sign pairs in Figure 1. In the unlike-sign pair sample there are 3 events which satisfy the selection criteria outlined above, with no events above 5.8 GeV. In the like-sign pairs there is one event with a mass of 5.73 GeV, under the pion hypothesis.

Some relevant properties of these 4 events are given in Table 1. These events were scanned to try and identify any possible effects, such as pattern recognition

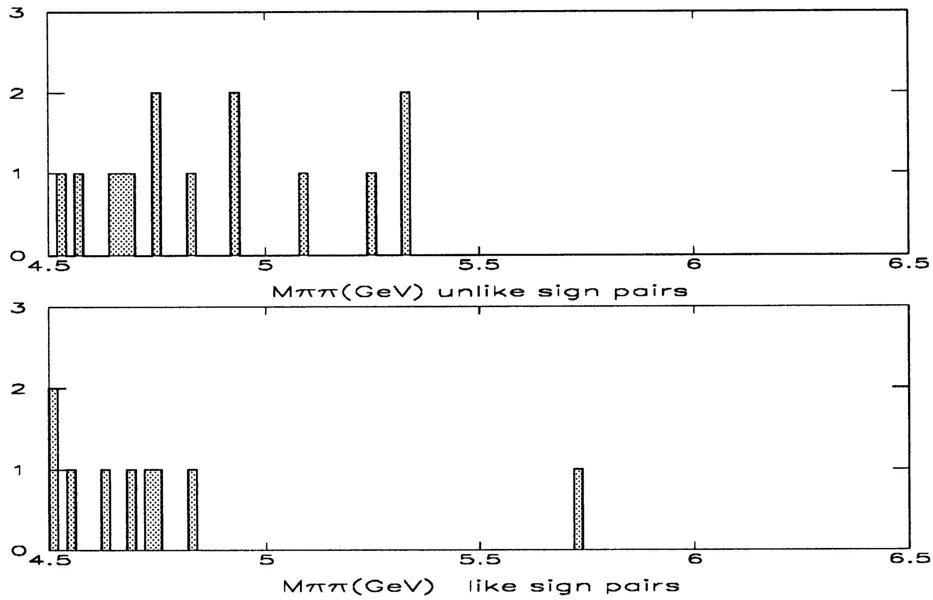


Figure 1: Invariant mass distribution, under the pion hypothesis, for both unlike-sign and like-sign candidates.

mistakes or pinholes, which could cause the vertex properties of the events to be mismeasured.

Event 13366/1385 is shown in Figure 3. The b candidate tracks each have at least one 3-D VDET hit in each layer and form a consistent vertex, well displaced from the interaction point. In the hemisphere defined by the b candidate there is an unambiguous $K_s^0$ which is consistent with originating from the interaction point. There is also an unambiguous pair conversion, where the photon is also consistent with originating from the interaction point. For the pair conversion the standard reconstruction has been modified to use only the unambiguous vertex detector hits. The two other tracks in the same hemisphere have a momentum below 250 MeV and one of them is reconstructed only in the ITC.

Event 16396/312 is shown in Figure 4. The b candidate tracks each have at least one 3-D VDET hit in each layer and form a consistent vertex, well displaced from the interaction point. The hemisphere containing the b candidate is dominated by a low momentum spiraling track. There is however no ambiguity in the assignment of coordinates to the two tracks forming the b candidate. In the other hemisphere there is evidence for a displaced secondary vertex.

Event 22026/6311 is shown in Figure 5. The b candidate tracks again have at least one 3-D VDET hit in each layer and form a consistent vertex, well displaced from the interaction point. The hemisphere contains two other charged tracks, which both have low momentum and are consistent with coming from the reconstructed interaction point.

None of these three unlike-sign events were consistent with background created

| Sign | Run | Event | $M_{\pi\pi}$ | $P_b$ | $P_1$ | $P_2$ | $\sigma_1$ | $\sigma_2$ | $D_{decay}$ | $\sigma_{decay}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| + - | 13366 | 1385 | 5.34 ± .04 | 38 | 9 | 30 | 38 | 14 | .60 | 40 |
| + - | 16936 | 312 | 5.25 ± .04 | 24 | 21 | 3 | 6 | 15 | .23 | 17 |
| + - | 22026 | 6311 | 5.34 ± .05 | 40 | 10 | 30 | 67 | 27 | .95 | 73 |
| - - | 17600 | 3034 | 5.73 ± .03 | 23 | 5 | 18 | 13 | 3 | .12 | 11 |

Table 1: Some properties of the 4 events with $M_{\pi\pi}$ significantly above 5 GeV. The masses ($M_{\pi\pi}$) and momenta of the b candidates ($P_b$) and individual tracks ($P_1$,$P_2$) are given in GeV, $\sigma_1$ and $\sigma_2$ are the impact parameter significances of the two tracks. The decay length ($D_{decay}$) is given in cm together with its significance ($\sigma_{decay}$).

by pattern recognition mistakes.

Event 17600/3034 is shown in Figure 6. This event has two track pairs which have ambiguous assignments of vertex detector hits in the $z$ direction. With the original assignment of hits there are 7 tracks in the event with significant impact parameters. By swapping the hit assignment of the two pairs of tracks, increasing in one case the chi-squared by .3 and in the other by 1.8 for an extra degree of freedom (an unassigned hit is now used), all tracks become consistent with the interaction point.

# 4 Background Estimation

A Monte Carlo estimation of the background to the above signal was obtained by selecting events which passed a slightly loosened version of the kinematic cuts at the generator level. The tracks were required to be hadrons with a momentum of at least 2.8 GeV. The b candidate was required to have a momentum of at least 18 GeV and have an invariant mass, under the pion hypothesis, of at least 4.9 GeV. These events were subsequently passed through the full simulation program and the final selection criteria were applied. Three background events, one like-sign and two unlike-sign, were observed in the mass region between 5.0 and 6.5 GeV in a sample equivalent to 36 million hadronic Z decays. It is expected that the Monte Carlo should reproduce reasonably accurately the background caused by occupancy effects. This would, for example, include effects such as the swapping of hits between two tracks which pass nearby in the VDET. There are, however, some potential sources of background which are not properly modeled in the simulation of the vertex detector. For example, pinholes and the suppression of the signals from noisy strips could cause the coordinates in the vertex detector to be displaced by up to 50 $\mu m$, which given a 12 $\mu m$ coordinate error, could move the track by as much as $4\sigma$. The ability of the Monte Carlo to reproduce accurately

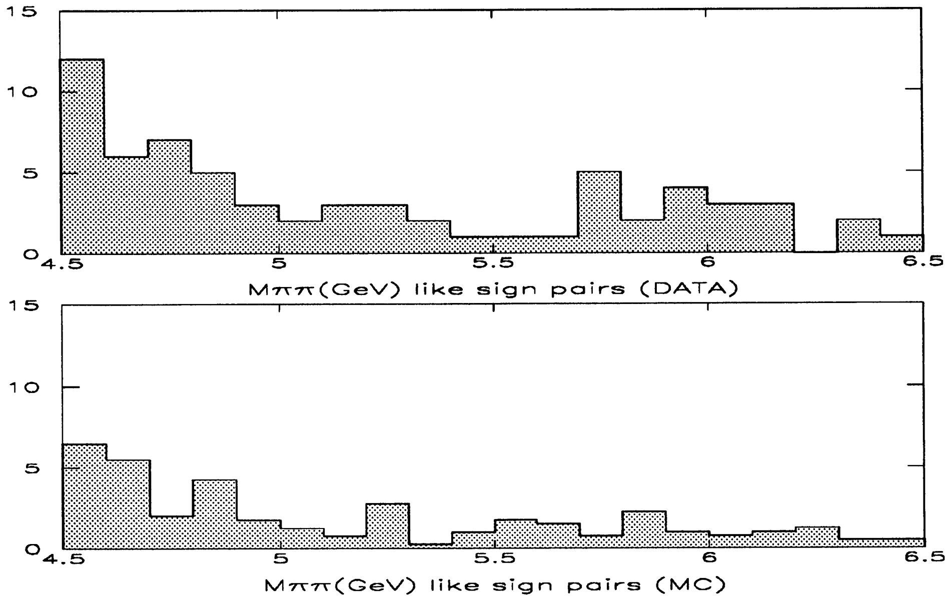


Figure 2: Invariant mass distribution with relaxed cuts for both data and Monte Carlo .

the level of background observed in the data was tested by removing some of the selection criteria. The invariant mass distribution of like sign track pairs which passed the kinematic cuts, had a 3-D vertex detector hit and a significant positive impact parameter is shown for both data and Monte Carlo in Figure 2. In the mass region between 5.0 and 6.5 GeV there are 33 $\pm$ 6 events observed in the data compared with a Monte Carlo prediction of 17 $\pm$ 3. This underestimate of the background in the Monte Carlo, by a factor of two, was confirmed with more statistics by including also tracks with significant negative impact parameters. To be conservative it was assumed that the probability to observe a background event in the data was two times higher than in the Monte Carlo. It was also assumed that the background is roughly flat in the above mass region (see Figure 2), and that like-sign and unlike-sign background events are equally produced (this is true in both data and Monte Carlo for the loose cuts described above). With these assumptions the corresponding binomial probability for observing 3 or more background events in the data in the signal region, when 3 background events have been observed in the Monte Carlo sample, is 1.8 $\times 10^{-4}$. The corresponding binomial probability for observing one or more background events in the data is .22, indicating consistency between data and Monte Carlo background estimates. With somewhat less statistical power, the data itself was used to estimate the background probability. The binomial probability of observing 3 or more events in the signal region, when a total of 4 events is observed, is .05.

| | 13366 1385 | 16396 312 | 22026 6311 | Total > .1 | 90 % Confidence Level Upper Limit |
|---|---|---|---|---|---|
| $B_d \to \pi\pi$ | .57 | .20 | .06 | 2 | 7.5 $\times 10^{-5}$ |
| $B_d \to K\,\pi$ | .03 | .80 | .20 | 2 | 7.5 $\times 10^{-5}$ |
| $B_s \to K\,\pi$ | .18 | .05 | .80 | 2 | 2.5 $\times 10^{-4}$ |
| $B_s \to K\,K$ | $< .01$ | .02 | $< .01$ | 0 | 1.1 $\times 10^{-4}$ |
| $\Lambda_b \to p\,h$ | .01 | .01 | .06 | 0 | 1.6 $\times 10^{-4}$ |

Table 2: Consistency of the candidate events with the different hypotheses together with the 90 % confidence level upper limits obtained for the corresponding branching ratios.

# 5 Upper Limits on Exclusive Final States

The event sample selected above was used to set branching ratio upper limits for exclusive decays of beauty hadrons into two charged hadrons. For each individual final state a probability was obtained from the invariant mass of the system and the dE/dx values of the two tracks, if available. This probability was required to be greater than .1 for the corresponding hypothesis. The consistency of the 3 candidate events with each given exclusive final state is shown in Table 2. From the total number of events consistent with each final state, the 90 % confidence level upper limits for the individual branching ratios were obtained. These limits were obtained assuming that the Br($Z \to b\bar{b}$) is 0.217 and that the fraction of b quark fragmenting into $B_d$ , $B_s$ and $\Lambda_b$ are .40, .12 and .08 respectively

# 6 Conclusions

In a sample of 1.55 million hadronic Z decays three candidates for charmless b decay have been observed. The probability that these events come from background sources has been estimated from Monte Carlo to be 1.8 $\times 10^{-4}$, a significance of over $3.5\sigma$. Upper limits, of order $10^{-4}$, have been obtained for a variety of exclusive final state involving charmless decays of b hadrons.

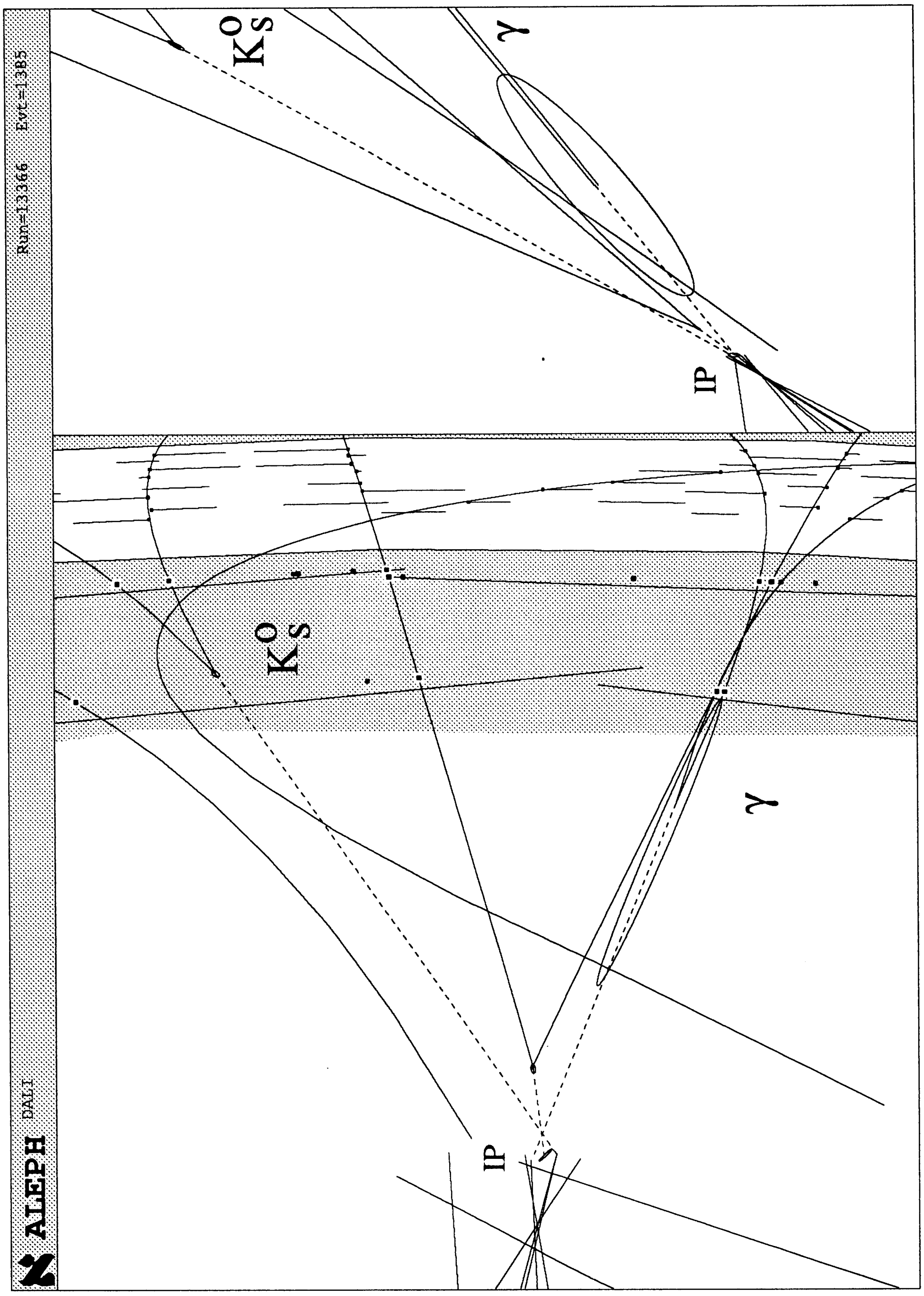


Figure 3: Two orthogonal views showing the region close to the interaction point for event 13366/1385. The displaced vertices due to the b candidate decay, the $K_s^0$ decay, and the pair conversion are indicated together with the interaction point (IP) by their $3\sigma$ error ellipses. There is evidence for a displaced vertex in the hemisphere opposite to the b meson candidate.

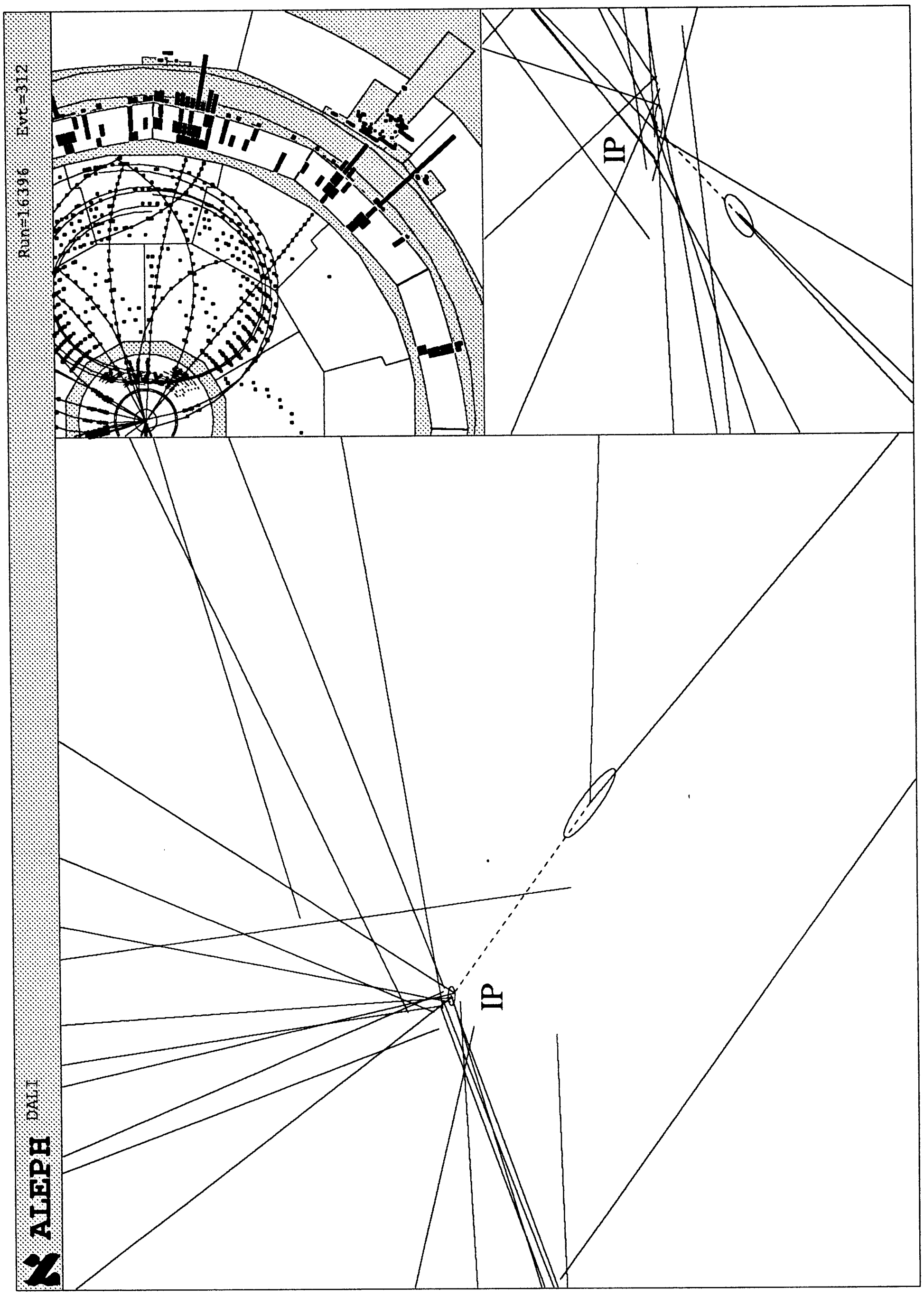


Figure 4: Two orthogonal views showing the region close to the interaction point and one $r - \phi$ view of the hemisphere for event 16396/312. The positions of the reconstructed vertex of the b candidate and the interaction point (IP) are indicated together with their $3\sigma$ error ellipses.

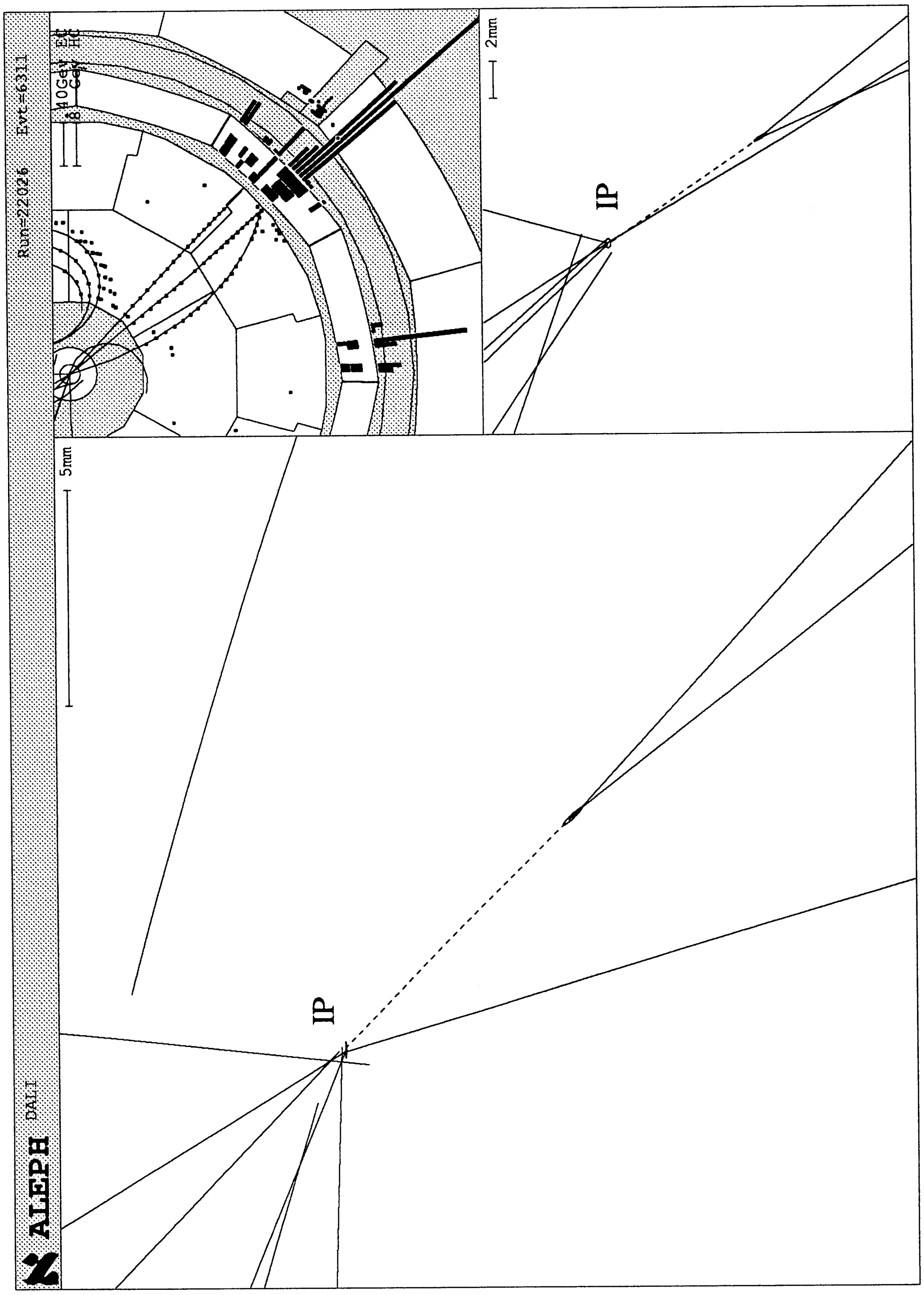


Figure 5: Two orthogonal views showing the region close to the interaction point and one $r - \phi$ view of the hemisphere for event 22026/6311. The positions of the reconstructed vertex of the b candidate and the interaction point (IP) are indicated together with their $3\sigma$ error ellipses.

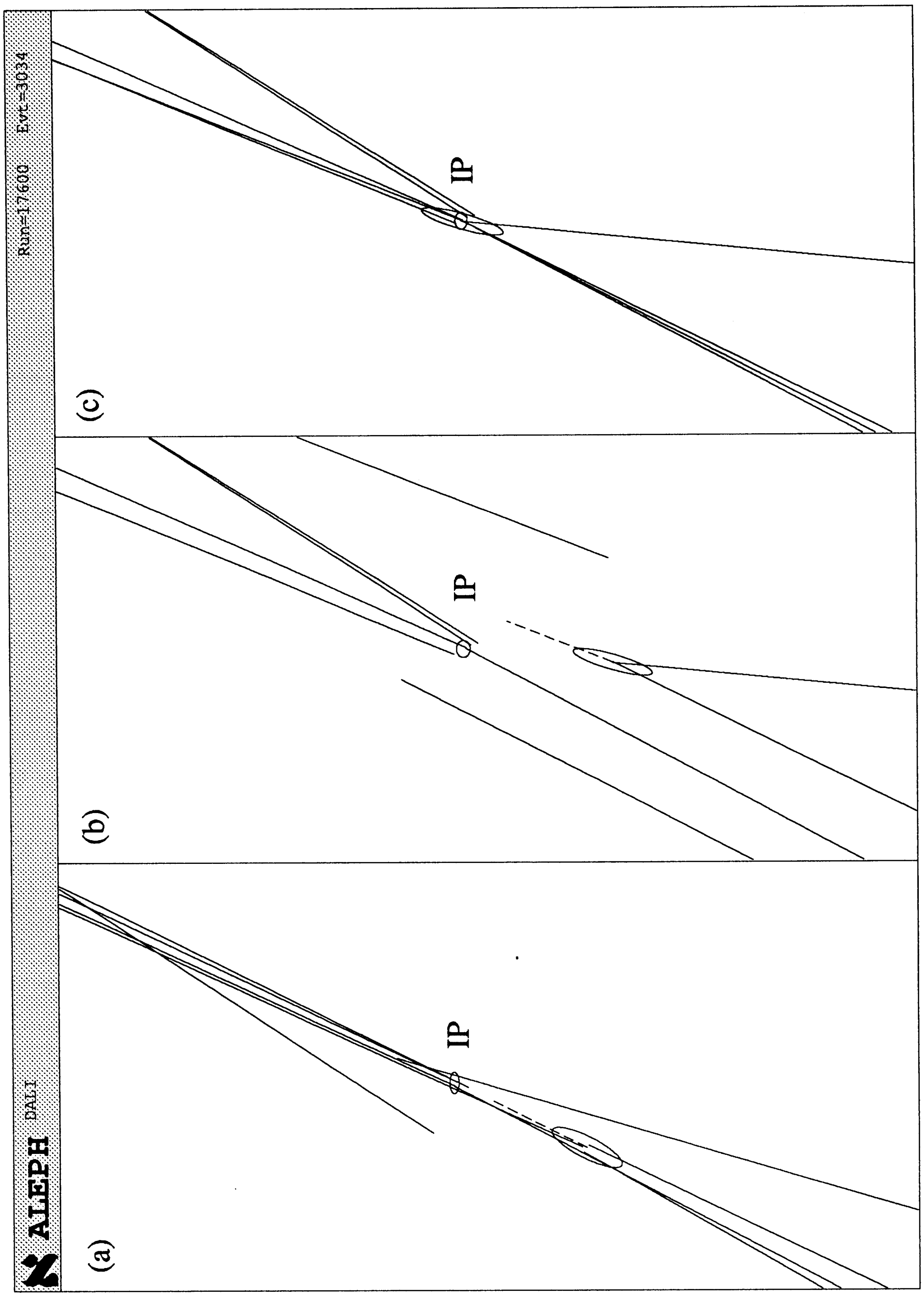


Figure 6: Three views showing the region close to the interaction point for event 17600/3034. The position of the b decay vertex and interaction point (IP) are indicated together with their $3\sigma$ error ellipses in the $r-\phi$ view (a) and in an orthogonal view (b) displaying the $z$ information. View (c) shows how view (b) looks after two ambiguities in the $z$ hit assignment have been interchanged.

# References


[1] The CLEO Coll., M. Battle *et al.*, Phys. Rev. Lett. 71, (1993) 3992

[2] The ALEPH Coll., D. Buskulic *et al.*, Phys. Lett. $B295$, (1992) 174

[3] Particle Data Group, Phys. Rev. D **45** (1992).