Fermi National Accelerator Laboratory

FERMILAB-Pub-89/144-E
[E-691]

A Study of Decays of the Λ_c^+ *

J. C. Anjos[3], J. A. Appel[5], A. Bean[2], S. B. Bracker[8], T. E. Browder[1,a], L. M. Cremaldi[4,b], J. E. Duboscq[1], J. R. Elliott[4,c], C. O. Escobar[7], P. Estabrooks[2], M. C. Gibney[4], G. F. Hartner[8], P. E. Karchin[9], B. R. Kumar[8], M. J. Losty[6], G. J. Luste[8], P. M. Mantsch[5], J. F. Martin[8], S. McHugh[1], S. R. Menary[8], R. J. Morrison[1], T. Nash[5], U. Nauenberg[4], P. Ong[8], J. Pinfold[3], G. Punkar[1], M. V. Purohit[5,d], J. R. Raab[1,e], A. F. S. Santoro[3], J. S. Sidhu[2,f], K. Sliwa[5,f], M. D. Sokoloff[5,g], M. H. G. Souza[3], W. J. Spalding[5], M. E. Streetman[5], A. B. Stundžia[8], M. S. Witherell[1]

(1) *University of California, Santa Barbara, California 93106*
(2) *Carleton University, Ottawa, Ontario, Canada K1S5B6*
(3) *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
(4) *University of Colorado, Boulder, Colorado 80309*
(5) *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
(6) *National Research Council, Ottawa, Ontario, Canada K1A0R6*
(7) *Universidade de Saõ Paulo, 01000 Saõ Paulo, Brazil*
(8) *University of Toronto, Toronto, Ontario, Canada M5S1A7*
(9) *Yale University, New Haven, Connecticut 06511*

June 1989

*Submitted to Phys. Rev. Lett.

Operated by Universities Research Association, Inc., under contract with the United States Department of Energy

A STUDY OF DECAYS OF THE Λ_c^+

J.C. Anjos[(3)], J.A. Appel[(5)], A. Bean[(1)], S.B. Bracker[(8)], T.E. Browder[(1),(a)], L.M. Cremaldi[(4),(b)], J.E. Duboscq[(1)], J.R. Elliot[(4),(c)], C.O. Escobar[(7)], P. Estabrooks[(2)], M.C. Gibney[(4)], G.F. Hartner[(8)], P.E. Karchin[(9)], B.R. Kumar[(8)], M.J. Losty[(6)], G.J. Luste[(8)], P.M. Mantsch[(5)], J.F. Martin[(8)], S. McHugh[(1)], S.R. Menary[(8)], R.J. Morrison[(1)], T. Nash[(5)], U. Nauenberg[(4)], P. Ong[(8)], J. Pinfold[(2)], G. Punkar[(1)], M.V. Purohit[(5),(d)], J.R. Raab[(1),(e)], A.F.S. Santoro[(3)], J.S. Sidhu[(2),†], K. Sliwa[(5),(f)], M.D. Sokoloff[(5),(g)], M.H.G. Souza[(3)], W.J. Spalding[(5)], M.E. Streetman[(5)], A.B. Stundžia[(8)], M.S. Witherell[(1)]

(1) *University of California, Santa Barbara, California*, 93106
(2) *Carleton University, Ottawa, Ontario, Canada* K1S5B6
(3) *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
(4) *University of Colorado, Boulder, Colorado*, 80309
(5) *Fermilab National Accelerator Laboratory, Batavia, Illinois*, 60510
(6) *National Research Council, Ottawa, Ontario, Canada* K1A0R6
(7) *Universidade de São Paulo, São Paulo, Brazil*
(8) *University of Toronto, Toronto, Canada*, M5S1A7
(9) *Yale University, New Haven, CT* 06511

ABSTRACT

We report measurements of the decays $\Lambda_c^+ \to p\overline{K^0}$, $\Lambda_c^+ \to p\overline{K^0}\pi^+\pi^-$, $\Lambda_c^+ \to \Lambda^0\pi^+$, and $\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-$ from Fermilab photoproduction experiment E691. We have measured the relative branching ratios; $\mathrm{Br}(\Lambda_c^+ \to p\overline{K^0})/\ \mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) = 0.55 \pm 0.17 \pm 0.14$, $\mathrm{Br}(\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-)/\ \mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) = 0.82 \pm 0.29 \pm 0.27$, $\mathrm{Br}(\Lambda_c^+ \to \Lambda^0\pi^+)/\ \mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) < 0.33$@90% confidence level, and $\mathrm{Br}(\Lambda_c^+ \to p\overline{K^0}\pi^+\pi^-)/\ \mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) < 1.7$@90% confidence level.

Pacs numbers: 13.30Eg, 14.20Kp

The Λ_c^+ charmed baryon decays weakly with a lifetime which is much shorter than the pseudoscalar charmed mesons. This supports the idea that, unlike the mesons, this baryon decays primarily by the W-exchange mechanism.[1] It is therefore interesting to investigate the pattern of exclusive Λ_c^+ decay modes to see if it is different from that observed in the decays of the charmed mesons. In this Letter, we present the results of a study of the four Λ_c^+ decay modes, p$\overline{K_0}$, p$\overline{K_0}\pi^+\pi^-$, $\Lambda^0\pi^+$, and $\Lambda^0\pi^+\pi^+\pi^-$, using data taken in a photoproduction experiment at the Fermilab Tagged Photon Spectrometer. The charge conjugate states are included in these analyses. The branching ratios of these decays were measured relative to the $\Lambda_c^+ \rightarrow pK^-\pi^+$ mode[2] for the momentum range 40 to 120 GeV, in which there is good acceptance for all channels.

The Λ_c^+ samples discussed in this study were obtained from a data sample of 10^8 events recorded at the Fermilab Tagged Photon Laboratory by experiment E691. The Tagged Photon Laboratory spectrometer is a two magnet spectrometer with large acceptance, good mass resolution, good particle identification using Cerenkov counters, muon detection, and electromagnetic and hadronic calorimeters, and precise vertex detection using silicon microstrip detectors. The spectrometer is described in detail elsewhere.[3,4] Bremsstrahlung photons with energies between 70 and 260 GeV impacted the 5 cm beryllium target, and events with greater than 2.2 GeV total transverse energy were recorded. The transverse energy requirement rejected 70% of the background hadronic interactions while keeping 80% of all charm events.

The initial task in the analyses of these modes was to isolate the neutral strange particle samples from the full data set. The neutrals were formed with tracks reconstructed only in the drift chamber system. Tracks found in the silicon microstrip detectors were not used because combinations containing these tracks generated most of the neutral particle background, while contributing only ~ 20% of the reconstructed Λ^0's and K_s's. The $\overline{K^0}$ sample was observed in the $K_s^0 \rightarrow \pi^+\pi^-$ decay channel by requiring that the decay position of the neutral vertex be greater than 5 cm downstream of the target, that the distance of closest approach of the decay products be less than .5 cm, and by applying a Cerenkov probability cut which eliminated candidate tracks with small pion probabilities. The efficiency for reconstructing K_s's with these cuts was 40%. The $\pi^+\pi^-$ invariant mass (shown in figure 1(a) for a small fraction of the data) was required to be between .486 and .510 GeV/c^2.

The Λ^0 sample was observed in the $\Lambda^0 \rightarrow p\pi^-$ decay channel by requiring that the decay position of the neutral be downstream of the target, that the distance of closest approach of the decay products be less than 1 cm, and by applying a cut on the product of the proton and pion Cerenkov probabilities that rejected $p\pi$ combinations for which either the proton or pion probability was small. The efficiency for reconstructing Λ^0's with these cuts was 30%. The $p\pi$ invariant mass (shown in figure 1(b) for a small fraction of the data) was required to be between 1.110 and 1.121 GeV/c^2.

The analyses of the $\Lambda^0\pi^+\pi^+\pi^-$ and $p\overline{K^0}\pi^+\pi^-$ decay modes proceeded as follows. In the $\Lambda^0\pi^+\pi^+\pi^-$ mode, we cut on the product of the Cerenkov probabilities of the three pions to reject tracks with low pion probability. In the $p\overline{K^0}\pi^+\pi^-$ analysis, a similiar cut on the $p\pi\pi$ product Cerenkov probability rejected low probability pion candidate tracks and ambiguous proton candidates. The charm decay vertex was then defined using the three pions from the $\Lambda^0\pi^+\pi^+\pi^-$ and the $p\pi\pi$ tracks from the $p\overline{K^0}\pi^+\pi^-$ decay. The neutral decay products were not used in this vertex because, as stated earlier, they were not reconstructed in the high resolution silicon microstrip detectors.

Tracks that were not used for the charm decay vertex but that were reconstructed in the silicon microstrip detector were used to form the set of possible production vertices. The vertex chosen from this set lay closest to the line-of-flight of the charm particle (defined by attaching the charm particle momentum vector to the charm decay vertex) and was required to be within $80\mu m$ of this line-of-flight. Furthermore, the position of the charm decay vertex was required to be at least a distance L_z downstream of the production vertex, where this distance is measured parallel to the beam direction. L_z was chosen in the analyses of both these charm decay modes to be $7\sigma_z$, where σ_z is the combination, in quadrature, of the errors on the secondary and production vertex positions ($\sigma_z \sim 300\mu m$). For the final vertex cut, we required that the three tracks in the charm vertex pass closer to that vertex than to the production vertex. These vertex cuts are similiar to those used in the $\Lambda_c^+ \to pK^-\pi^+$ mode.

The $\Lambda^0\pi^+\pi^+\pi^-$ and $p\overline{K^0}\pi^+\pi^-$ invariant mass distributions are shown in figure 2(a) and 2(b). A clear peak is evident for the $\Lambda^0\pi^+\pi^+\pi^-$ mode. Fitting this plot with a Gaussian plus a linear background, we obtain a signal of 44 ± 14 events over a background of $\sim$ 120 events. In this fit, the width is set to 12 MeV/c^2 as determined by the Monte Carlo, and the mass is measured to be 2.283 ± 0.003 GeV/c^2 which agrees well with the mass measurement made in the $pK^-\pi^+$ decay channel (2.286 ± 0.002 GeV/c^2).[2] The reconstruction efficiency for this mode, as determined by Monte Carlo simulation, is 1%. The $p\overline{K^0}\pi^+\pi^-$ mode is fit in the same manner and we obtain a signal of 9 ± 6 events over a background of ~ 15 events. The width is set to 10 MeV/c^2 as in the Monte Carlo and the mass is constrained to the mass value measured in the $pK^-\pi^+$ mode. The efficiency for this mode is .4%. The measured relative branching ratios for these two modes are given in Table 1 where both measurements are normalized to the $\Lambda_c^+ \rightarrow pK^-\pi^+$ mode. Uncertainties in neutral particle efficiencies[4] provide the main contribution to the systematic error in these measurements.

The two body states, $p\overline{K^0}$ and $\Lambda^0\pi^+$, differ from the four body states discussed above in that they have only one track (the bachelor pion or proton) which is reconstructed in the silicon microstrip detector. The charm decay vertex can not, then, be calculated with the small position errors characteristic of this detector and a modified analysis method must be employed.

In these analyses, the first step was to form the candidate production vertex set (as detailed above). The vector from each candidate production vertex to the bachelor track was then formed ($\overrightarrow{DMISS}$; shown in figure 3), in the plane perpendicular to the beam direction and containing the production vertex. This vector was resolved into two components; one contained in the plane defined by the charm decay products, the other perpendicular to this plane. The perpendicular component was required to be $< 80\mu m$, since, in the ideal case, the production vertex is found in the charm decay plane. The component contained in the charm decay plane was forced to be $> 30\mu m$, since the Λ_c^+ decay is expected to occur a significant distance downstream of the production vertex. If there were more than one possible production vertex, the candidate associated with the smallest perpendicular component was chosen.

The charm decay vertex was then formed between the charm momentum vector and the bachelor track, with the momentum vector secured to the production vertex. For the $\Lambda^0\pi^+$ decay mode, the position of this vertex had to be at least $2\sigma_z$ downstream of the production vertex, where σ_z is defined as before. The error on the charm decay vertex was parameterized by the inverse of the opening angle of the charm decay products times a constant, a choice supported by Monte Carlo studies. In the $p\overline{K^0}$ mode, the charm decay vertex position is compromised because the proton track carries most of the Λ_c^+ momentum and thus forms a small angle with the Λ_c^+ direction. For this mode, the decay position is required simply to be downstream of the production vertex.

The non-vertex cuts used in the p$\overline{K^0}$ and $\Lambda^0\pi^+$ analyses are as follows. First, the angle between the charm momentum vector and the bachelor track in the center of mass of the Λ_c^+ was calculated. The absolute value of the cosine of this angle was then restricted to be $< .8$ in the $p\overline{K^0}$ decay mode and $< .6$ in the $\Lambda^0\pi^+$ decay mode. In the $\Lambda^0\pi^+$ decay, this cut eliminated 60% of the background and kept 80% of the charm signal by excluding the high and low momentum bachelor tracks that were responsible for most of the background. A Cerenkov cut was also applied to the bachelor track in each of these modes, excluding ambiguous proton candidates ($p\overline{K^0}$) and low probability pion candidates ($\Lambda^0\pi^+$) from consideration.

The $\Lambda^0\pi^+$ and p$\overline{K^0}$ invariant mass distributions are shown in figure 4(a) and 4(b). A clear peak is evident in the p$\overline{K^0}$ decay mode. Fitting this plot with a Gaussian plus a linear background, we obtain a signal of 45 ± 12 events over a background of ~ 100 events. In this fit, the width is set to 13 MeV/c^2, as determined by the Monte Carlo, and the mass is measured to be 2.283 ± 0.003 GeV/c^2 which again agrees with the $pK^-\pi^+$ mass measurement.[2] The reconstruction efficiency for this mode, as determined by Monte Carlo simulation, is 3%. The $\Lambda^0\pi^+$ mode is fit with a Gaussian plus a linear background as well. The width in this plot is set to 13 MeV/c^2, as indicated by Monte Carlo studies, and the mass is set to the value measured in the $pK^-\pi^+$ mode. With this fit, we obtain a signal of 28 ± 13 over a background of ~ 150 events. The efficiency for this mode is 3.4%. The relative branching ratios for these two modes are given in Table 1 and are normalized, as before, to the $pK^-\pi^+$ mode. The systematic errors assigned to these measurements are dominated by uncertainties in the neutral particle detection efficiencies.[4]

To summarize, we observed a 3.8σ signal in the $\Lambda_c^+ \to p\overline{K^0}$ decay channel and a 3.3σ signal in the $\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-$ channel. Significant signals were not observed for the $\Lambda_c^+ \to \Lambda^0\pi^+$ or the $\Lambda_c^+ \to p\overline{K^0}\pi^+\pi^-$ decays. The branching ratios for these decays were measured relative to the $\Lambda_c^+ \to pK^-\pi^+$ decay channel and are presented in Table 1. All these measurements are in agreement with results from the ARGUS[5,6] and CLEO[7] collaborations, also shown in Table 1.

We gratefully acknowledge the assistance of the staffs of Fermilab and of all the participating institutions. This research was supported by the U.S. Department of Energy, by the Natural Science and Engineering Research Council of Canada through the Institute of Particle Physics, by the National Research Council of Canada, and by the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico.

REFERENCES

† Deceased.

[a] now at Stanford Linear Accelerator Center, Stanford, CA 94309.

[b] Now at University of Mississippi, Oxford, MS 38677.

[c] Now at Electromagnetic Applications, Inc., Denver, CO 80226.

[d] Now at Princeton University, Princeton, NJ 08544.

[e] Now at CERN, Division EP, CH-1211 Genève, Suisse.

[f] Now at Tufts University, Medford, MA 02155.

[g] Now at University of Cincinnati, Cincinnati, OH 45221.

(1) M. Bander, D. Silverman, and A. Soni, Phys. Rev. Lett. **44**, 7 (1980); H. Fritzsch and P. Minkowski, Phys Lett. **90B**, 455 (1980).

(2) J.C. Anjos *et al.*, Phys. Rev. Lett. **60**, 1379 (1988).

(3) For details see J.C. Anjos *et al.*, Phys. Rev. Lett. **58**, 311 (1987); J. Raab, PhD thesis, University of California, Santa Barbara (1987, unpublished); T. Browder, PhD thesis, University of California, Santa Barbara (1988, unpublished).

(4) M. Gibney, PhD thesis, University of Colorado, Boulder (1989, unpublished).

(5) H. Albrecht *et al.*, Phys. Lett. **207B**, 109 (1988).

(6) ARGUS Collaboration: M. V. Danilov, in *XXIV International Conference on High Energy Physics, Munich*, 1988, edited by R. Kotthaus and J. H. Kühn (Springer-Verlag, Berlin, Heidelberg, 1989).

(7) CLEO Collaboration: M. S. Alam *et. al.*, in *Proceedings of the* 1987 *International Symposium on Lepton and Photon Interactions at High*

Energies, Hamburg, 1987, edited by W. Bartel and R. Rückl (North-Holland, Amsterdam, 1988).

TABLE 1. Λ_c^+ branching ratios (Br) relative to Br($\Lambda_c^+ \to pK^-\pi^+$).

Decay mode	E691	ARGUS	CLEO[7]
$\Lambda_c^+ \to \Lambda^0\pi^+\pi^+\pi^-$	$0.82 \pm 0.29 \pm 0.27$	$0.61 \pm 0.16 \pm 0.04$[5]	$0.80 \pm 0.19 \pm 0.22$
$\Lambda_c^+ \to p\overline{K^0}\pi^+\pi^-$	$< 1.7@90\%(CL)$	$1.0 \pm 0.3 \pm 0.3$[6]	$0.67 \pm 0.28 \pm 0.29$
$\Lambda_c^+ \to p\overline{K^0}$	$0.55 \pm 0.17 \pm 0.14$	$0.62 \pm 0.15 \pm 0.03$[5]	$0.66 \pm 0.20 \pm 0.19$
$\Lambda_c^+ \to \Lambda^0\pi^+$	$< 0.33@90\%(CL)$	$0.21 \pm 0.05 \pm 0.04$[6]	$0.22 \pm 0.07 \pm 0.06$

FIGURE CAPTIONS

1a. Invariant $\pi^+\pi^-$ mass spectrum. The signal was fit to a gaussian plus a linear background, giving 12700 ± 160 events for $\sim .5\%$ of our data sample.

1b. Invariant $p\pi^-$ mass spectrum. The signal was fit to a gaussian plus a linear background, giving 6350 ± 90 events for $\sim .5\%$ of our data sample.

2(a). Invariant $\Lambda^0\pi^+\pi^+\pi^-$ mass spectrum.

2(b). Invariant $p\overline{K^0}\pi^+\pi^-$ mass spectrum.

3. The vector distance between the production vertex and the impact point of the bachelor track is shown ($\overrightarrow{DMISS}$). The x-y laboratory plane is perpendicular to the beam direction, contains the production vertex, and is intersected by the charm decay plane as shown. The vector $\overrightarrow{DMISS}$ is decomposed into two parts; one parallel and one perpendicular to this line of intersection.

4(a). Invariant $\Lambda^0\pi^+$ mass spectrum.

4(b). Invariant $p\overline{K^0}$ mass spectrum.

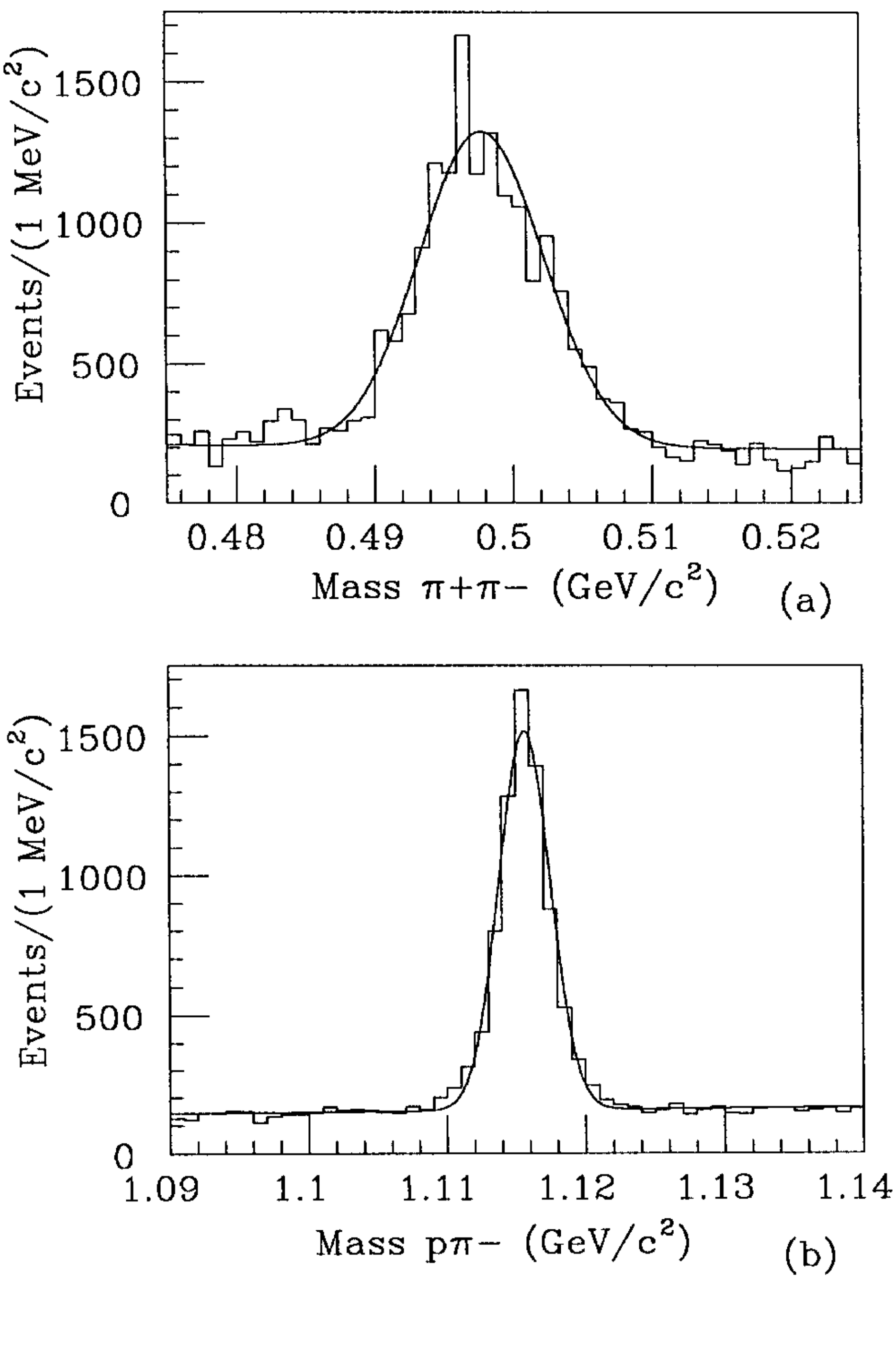

Events/(1 MeV/c²)
1500
1000
500
0
0.48
0.49
0.5
0.51
0.52
Mass π+π− (GeV/c²)
(a)
Events/(1 MeV/c²)
1500
1000
500
0
1.09
1.1
1.11
1.12
1.13
1.14
Mass pπ− (GeV/c²)
(b)

Figure 1

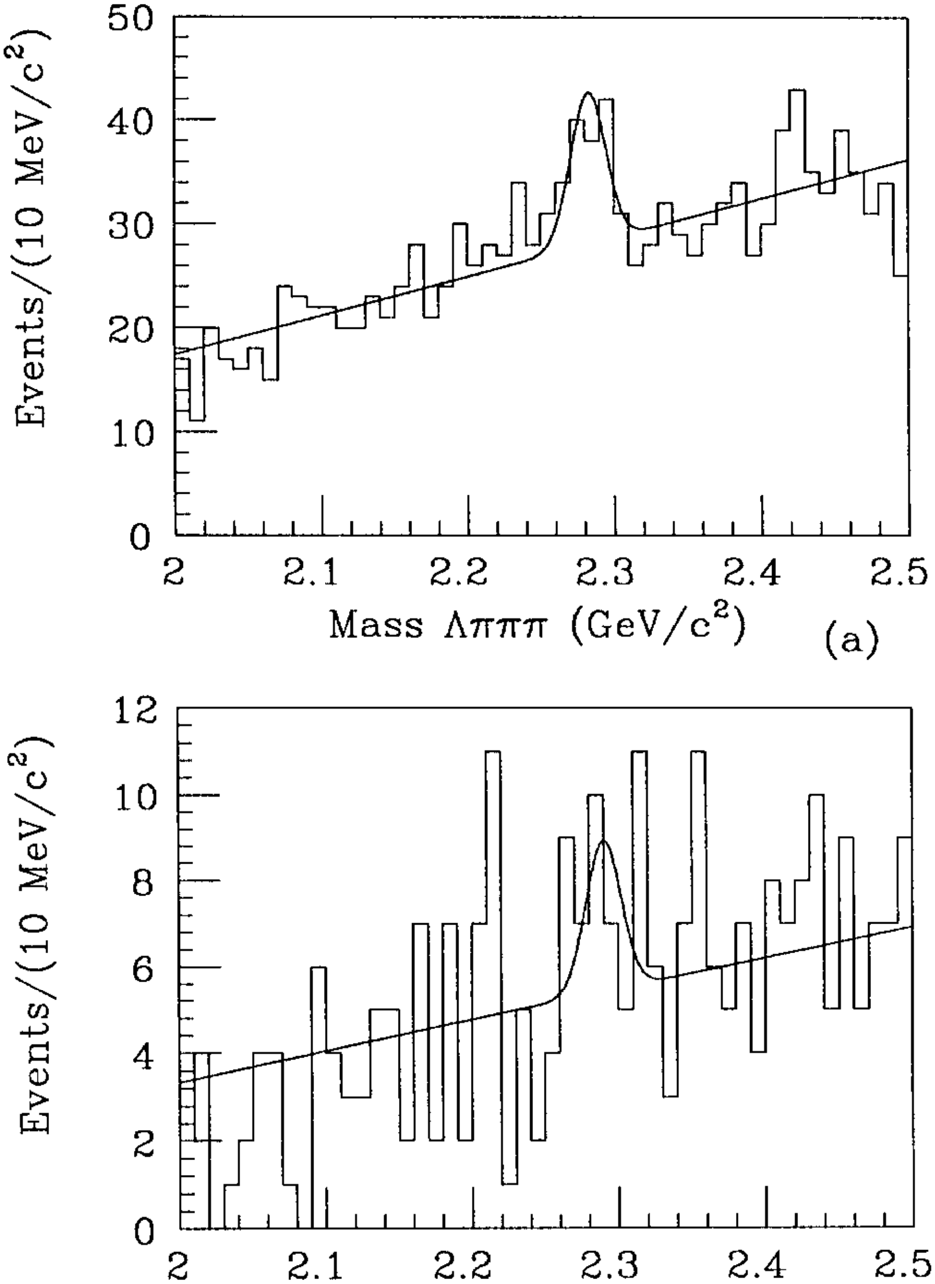
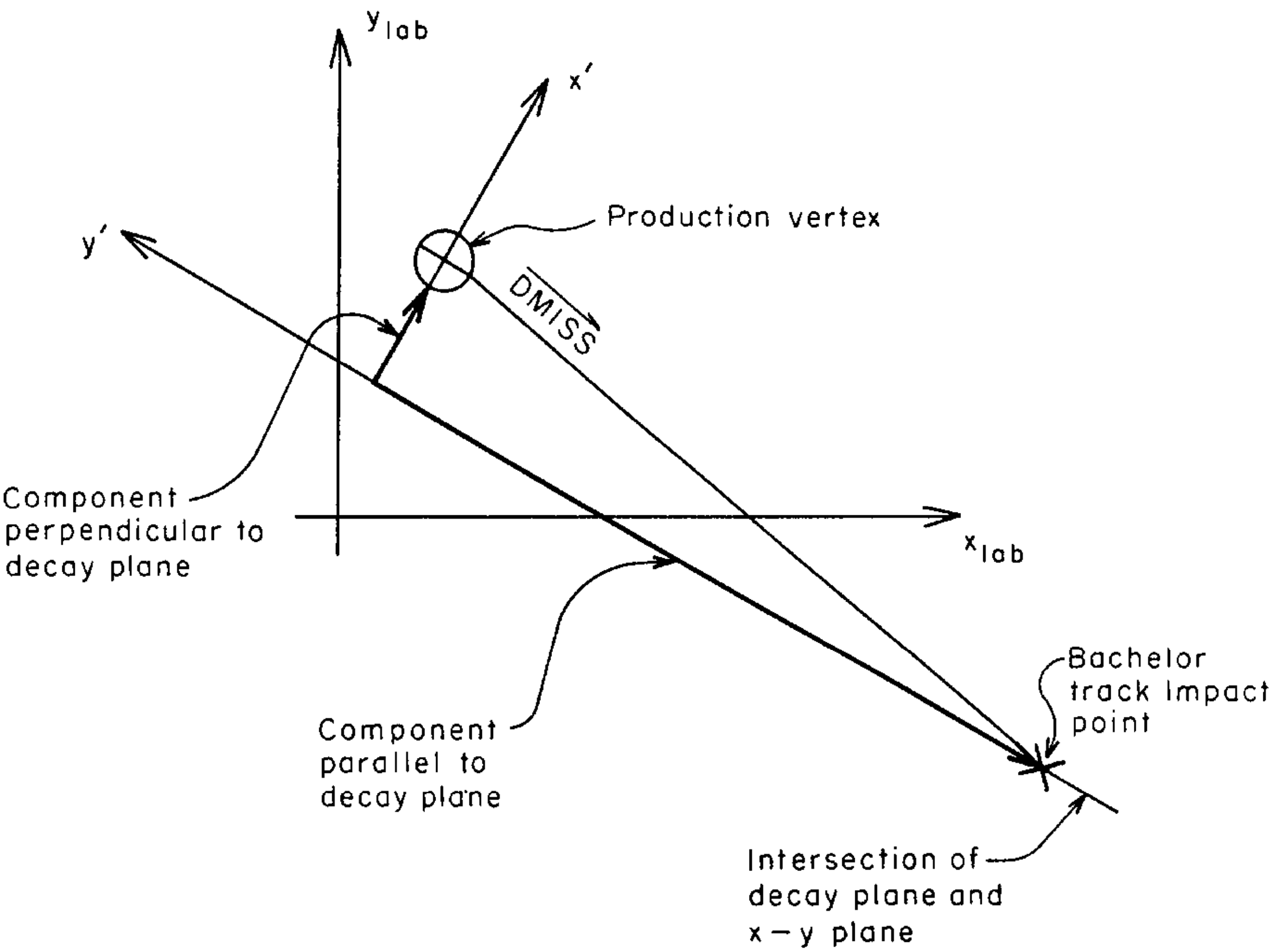
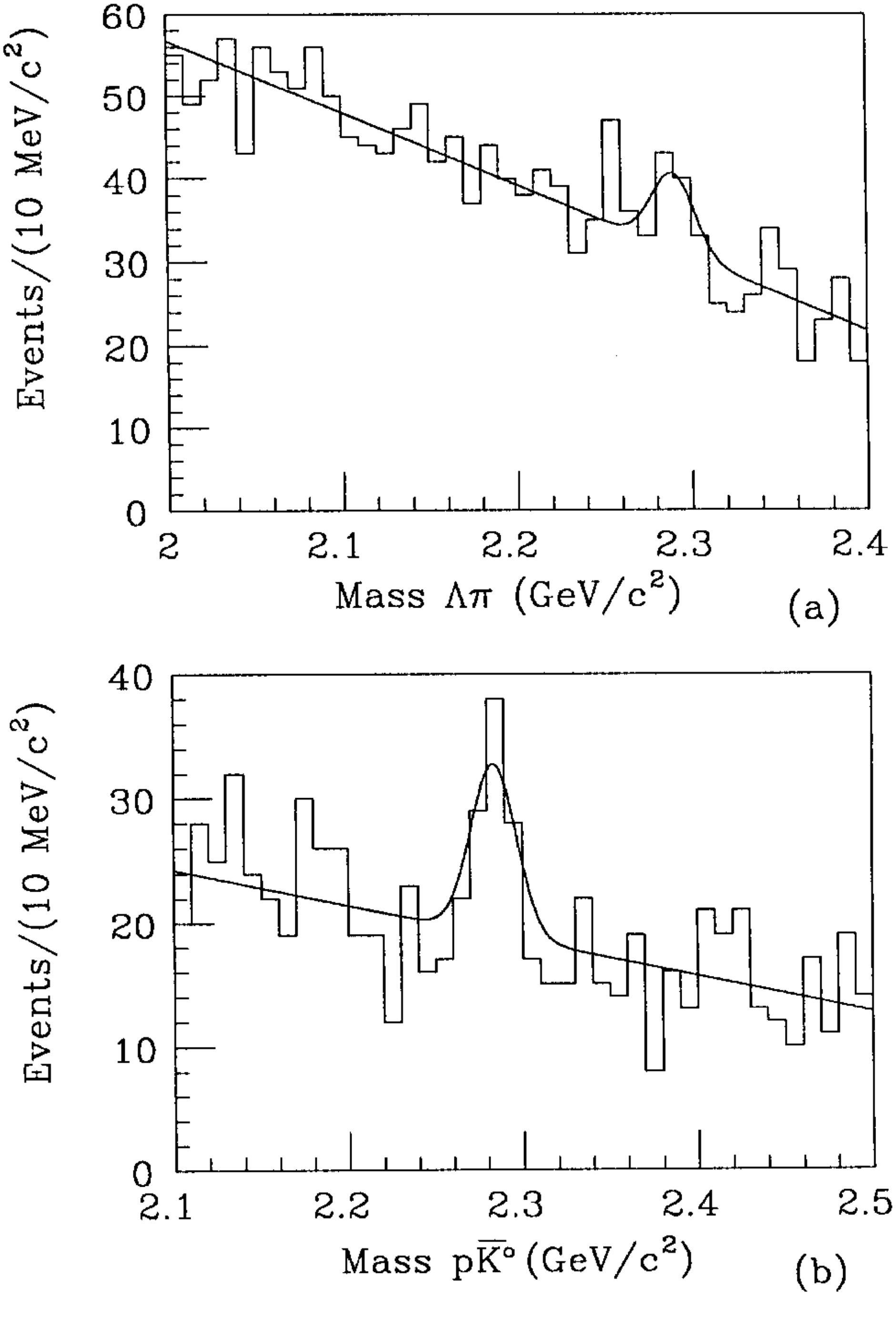

50
40
30
20
10
0
Events/(10 MeV/c^2)
2
2.1
2.2
2.3
2.4
2.5
Mass $\Lambda\pi\pi\pi$ (GeV/c^2)
(a)
12
10
8
6
4
2
0
Events/(10 MeV/c^2)
2
2.1
2.2
2.3
2.4
2.5
Mass $p\overline{K}^{\circ}\pi\pi$ (GeV/c^2)
(b)

Figure 2



y_{lab}
x′
y′
Production vertex
DMISS
Component perpendicular to decay plane
x_{lab}
Bachelor track impact point
Component parallel to decay plane
Intersection of decay plane and x − y plane

Figure 3



Events/(10 MeV/c²)
60
50
40
30
20
10
0
2
2.1
2.2
2.3
2.4
Mass Λπ (GeV/c²)
(a)
Events/(10 MeV/c²)
40
30
20
10
0
2.1
2.2
2.3
2.4
2.5
Mass pK̄° (GeV/c²)
(b)

Figure 4