

Observation of Semileptonic Decays of Charmed Baryons \*

E. Vella, G. H. Trilling,<sup>(1)</sup> G. S. Abrams, M. S. Alam,<sup>(2)</sup> C. A. Blocker,<sup>(3)</sup>  
A. Blondel,<sup>(4)</sup> A. M. Boyarski, M. Breidenbach, D. L. Burke, W. C. Carithers,  
W. Chinowsky, M. W. Coles,<sup>(5)</sup> S. Cooper,<sup>(6)</sup> W. E. Dieterle, J. B. Dillon,  
J. Dorenbosch,<sup>(7)</sup> J. M. Dorfan, M. W. Eaton, G. J. Feldman,  
M. E. B. Franklin, G. Gidal, G. Goldhaber, G. Hanson, K. G. Hayes,<sup>(7)</sup>  
T. Himel,<sup>(7)</sup> D. G. Hitlin,<sup>(8)</sup> R. J. Hollebeek, W. R. Innes, J. A. Jaros,  
P. Jenni,<sup>(7)</sup> A. D. Johnson, J. A. Kadyk, A. J. Lankford, R. R. Larsen,  
V. Lüth, R. E. Millikan, M. E. Nelson, C. Y. Pang, J. F. Patrick, M. L. Perl,  
B. Richter, A. Roussarie,<sup>(9)</sup> D. L. Scharre, R. H. Schindler,<sup>(7)</sup>  
R. F. Schwitters,<sup>(3)</sup> J. L. Siegrist,<sup>(7)</sup> J. Strait, H. Taureg,<sup>(7)</sup>  
M. Tonutti,<sup>(10)</sup> R. A. Vidal, I. Videau,<sup>(4)</sup> J. M. Weiss, and H. Zaccane<sup>(9)</sup>

Stanford Linear Accelerator Center  
Stanford University, Stanford, California 94305

Lawrence Berkeley Laboratory and Department of Physics  
University of California, Berkeley, California 94720

Abstract

Direct electrons are observed in baryon events produced in  $e^+e^-$  annihilation at center-of-mass energies above the  $\Lambda_c\bar{\Lambda}_c$  threshold. These events are attributed to charmed baryon pair production and subsequent  $\Lambda_c$  semileptonic decay. Various semileptonic branching ratios of the  $\Lambda_c$  are determined, including  $BR(\Lambda_c \rightarrow e^+ X) = (4.5 \pm 1.7) \%$ .

Submitted to Physical Review Letters

---

\* Work supported by the Department of Energy,  
contracts DE-AC03-76SF00515 and W-7405-ENG-48.

- (1). Miller Professor, Miller Institute for Basic Research in Science, University of California, Berkeley, CA, 1980-81
- (2). Present address: Vanderbilt University, Nashville, TN
- (3). Present address: Harvard University, Cambridge, MA
- (4). Present address: LPNHE, Ecole Polytechnique, Palaiseau, France
- (5). Present address: Carnegie-Mellon University, Pittsburgh, PA
- (6). Present address: DESY, Hamburg, F. R. Germany
- (7). Present address: CERN, CH-1211 Geneva 23, Switzerland
- (8). Present address: California Institute of Technology, Pasadena, CA
- (9). Present address: CEN Saclay, F-91190 Gif-sur-Yvette, France
- (10). Present address: Universitat Bonn, D-53 Bonn, F. R. Germany

The production of the  $\Lambda_c$  charmed baryon in  $e^+e^-$  annihilation and its decay into several hadronic modes have been clearly established.<sup>1</sup> In the present paper, the first evidence for the observation of  $\Lambda_c$  semileptonic decay is reported. This evidence is based on measurements of direct electron production in baryon events at center-of-mass energies above and below the threshold for charmed baryon pair production.

The Mark II detector at the SLAC  $e^+e^-$  colliding beam facility SPEAR has been described elsewhere,<sup>2</sup> and we mention here only those elements essential to the present analysis. A cylindrical drift chamber (DC) system in an axial magnetic field is used to reconstruct and measure the momenta of charged tracks within a solid angle of 85% of  $4\pi$  sr. Charged particle identification is obtained with a system of time-of-flight (TOF) counters covering 75% of  $4\pi$  sr. The TOF timing resolution of 300 ps provides  $1\sigma$  separation of protons from kaons up to 2 GeV/c and  $1\sigma$  separation of electrons from pions up to 300 MeV/c. A lead - liquid argon (LA) electromagnetic calorimeter, covering 64% of  $4\pi$  sr, is used to measure the energy deposited by electrons and to separate electrons from pions at momenta above 300 MeV/c.

The data sample was taken at center-of-mass energies from 4.5 to 6.8 GeV and represents an integrated luminosity of  $13700 \text{ nb}^{-1}$ . Data taken at lower energies (primarily at the  $\psi'$  (3685)), representing an integrated luminosity of  $4300 \text{ nb}^{-1}$ , are used to verify the absence of baryon associated direct electrons below the  $\Lambda_c$  threshold. Two separate baryon event samples are used - events containing an antiproton and events containing a  $\Lambda$  or  $\bar{\Lambda}$ . Events containing a proton and not an antiproton are excluded to reduce the background from beam - gas interactions. The  $p$  and  $\bar{p}$  are identified by TOF, with a some-

what looser cut for those baryons which are  $\Lambda$  or  $\bar{\Lambda}$  decay products. The background of pions and kaons misidentified as baryons is estimated to be less than 5%. The  $\Lambda$  ( $\bar{\Lambda}$ ) are identified from reconstruction of their  $p\pi^-$  ( $\bar{p}\pi^+$ ) decay modes. Background under the  $\Lambda$  peak due to beam - gas protons is reduced to the 20% level with a cut ( $Q \leq 0$ ) on the total charge of those  $\Lambda$  events which do not contain an identified  $\bar{p}$ . The background under the  $\bar{\Lambda}$  peak is very small. The overall  $\bar{p}$  and  $\Lambda, \bar{\Lambda}$  detection efficiencies are 60% and 15% (including the  $p\pi$  branching ratio) respectively.

Electrons are identified by TOF in the momentum range 100-300 MeV/c, by TOF and LA in the range 300-500 MeV/c, and by LA alone in the range 500-1200 MeV/c. The electron selection criteria are chosen to give clean electron identification, with as little contamination by misidentified pions as possible, at the expense of a relatively low electron detection efficiency. This efficiency is deduced in two independent ways: (1) from a sample of real electrons arising from photon pair conversion, and (2) from a sample of Monte Carlo generated electron showers. The results are in reasonable agreement and lead to an efficiency versus momentum dependence shown in figure 1(a). The fractional uncertainty in the electron detection efficiency is estimated to be less than 5%.

The major background is the misidentification of charged pions as electrons. Samples of real pions, taken from reconstructed  $\psi$  and  $\psi'$  events ( $\psi' \rightarrow \psi\pi^+\pi^-$  and  $\psi \rightarrow 2(\pi^+\pi^-)\pi^0$  or  $3(\pi^+\pi^-)\pi^0$ ), are used to determine the momentum dependent probabilities of misidentifying  $\pi^+$  and  $\pi^-$  as electrons. These probabilities, shown in figure 1(b), are used to calculate the number of misidentified pions included in the electron sample. The  $\pi^+ \pi^-$  difference in fig-

ure 1(b) is due to misidentifications arising from  $\pi^+n$  and  $\pi^-p$  charge exchange in the LA calorimeter lead plates, which contain more neutrons than protons. Uncertainties in the pion misidentification probabilities are estimated at 7% overall, based on the statistics of the samples of known pions from which they are determined.

The only other significant background arises from electron - positron pairs, produced either by photon conversions in the material between the beam and the drift chamber or by Dalitz decays of  $\pi^0$ s. Most  $e^+e^-$  pairs are easily identifiable, either from their small invariant mass or by a visual scan if one of the electrons was detected but not tracked by the drift chamber. These electrons are removed on an event by event basis. A statistical subtraction is necessary to correct for the remaining  $e^+e^-$  pairs in which one electron is completely undetected. The number of electrons from this source was calculated by Monte Carlo, with the  $\pi^0$  population taken as half of the  $\pi^\pm$  population at each momentum. Unidentified  $e^+e^-$  pairs are the dominant background at very low electron momenta, but are a negligible background above 300 MeV/c.

The results of the search for direct electrons below and above the  $\Lambda_c$  threshold are shown in table 1. The raw  $e^\pm$  count excludes those electrons from recognized  $\gamma$  conversions and  $\pi^0$  Dalitz decays. The backgrounds from misidentified pions and from unidentified electron pairs are listed separately. The net electron signals, after efficiency corrections, are shown in figure 2 as a function of center-of-mass energy. Table 1 and figure 2 show the electron rate in baryon events to be consistent with zero below the  $\Lambda_c$  threshold. Above threshold, independent signals are present at the  $2.6 \sigma$  level in both the  $\bar{p}$  and the  $\Lambda, \bar{\Lambda}$  samples. The probability of obtaining such

signals if there is actually no direct electron contribution is less than  $10^{-4}$ .

The measured rates of production of electrons in association with baryons, averaged over energies between 4.5 and 6.8 GeV, are as follows:

$$N(\bar{p}e^+) / N(\bar{p}) = (1.9 \pm 0.9) \%$$

$$N(\bar{p}e^-) / N(\bar{p}) = (1.4 \pm 0.6) \%$$

$$[N(\bar{\Lambda}e^+) + N(\Lambda e^-)] / [N(\bar{\Lambda}) + N(\Lambda)] = (3.2 \pm 1.8) \%$$

$$[N(\bar{\Lambda}e^-) + N(\Lambda e^+)] / [N(\bar{\Lambda}) + N(\Lambda)] = (3.8 \pm 2.0) \%$$

where  $\bar{p}$  from  $\bar{\Lambda}$  decay are included in the first two entries.

We attribute the baryon - electron events to charmed baryon pair production and subsequent semileptonic decay. Charmed baryon - charmed meson associated production is assumed to be negligible.<sup>3</sup> Events with misidentified baryons in which the electrons actually arise from charmed meson semileptonic decay contribute at most 10% of the observed signal in the  $\bar{p}$  events, and much less in the  $\Lambda, \bar{\Lambda}$  events.

Since charmed baryons emit positrons, the inclusive branching ratio  $BR(\Lambda_c \rightarrow eX)$  can be obtained from baryon - electron events, with the observed baryon serving only as a tag for a charmed baryon event. Semi-inclusive branching ratios  $BR(\Lambda_c \rightarrow peX)$  and  $BR(\Lambda_c \rightarrow \Lambda^0 eX)$  can be obtained from baryon - positron events. The same statements apply to the charge conjugate combinations.

The branching ratio determinations require estimates of the charmed baryon content of the proton and lambda data samples. These estimates are provided by previous measurements of inclusive p and  $\Lambda$  production,  $R(p)$  and  $R(\Lambda)$ , as

functions of energy,<sup>4</sup> which show definite steps near the charmed baryon threshold. The fraction of p or  $\Lambda$  events due to charmed baryon production is taken as the increase in  $R(p)$  or  $R(\Lambda)$  relative to the base value of  $R(p)$  or  $R(\Lambda)$  below the charmed baryon threshold. Averaged over the center-of-mass energy distributions of the baryon data samples, the resulting fractions are  $\Delta R(p) / R(p) = 0.45 \pm 0.07$  and  $\Delta R(\Lambda) / R(\Lambda) = 0.57 \pm 0.14$ . The fraction of charmed baryon decays leading to a proton (rather than a neutron) in the final state is taken to be  $F(p) = 0.6 \pm 0.1$ .<sup>5</sup> The fraction of charmed baryon decays leading to a lambda in the final state is then  $F(\Lambda) = [\Delta R(\Lambda) / \Delta R(p)] F(p) = 0.17 \pm 0.06$ . The above numbers are based on the assumption that the observed increases in  $R(p)$  and  $R(\Lambda)$  above the charmed baryon threshold are due entirely to charmed baryon production. If part of the increases are unassociated with charm, the true branching ratios will be correspondingly larger than those calculated below.

The calculations of the various semileptonic branching ratios of the charmed baryon proceed as follows:

$$BR(\Lambda_c \rightarrow e^+ X) = \frac{N(\bar{p}e^+)}{N(\bar{p})} \left[ \frac{\Delta R(p)}{R(p)} \right]^{-1} = (4.2 \pm 2.0) \%$$

$$BR(\Lambda_c \rightarrow e^+ X) = \frac{N(\bar{\Lambda}e^+) + N(\Lambda e^-)}{N(\bar{\Lambda}) + N(\Lambda)} \left[ \frac{\Delta R(\Lambda)}{R(\Lambda)} \right]^{-1} = (5.5 \pm 3.5) \%$$

Averaging these two results gives  $BR(\Lambda_c \rightarrow e^+ X) = (4.5 \pm 1.7) \%$ .

$$BR(\Lambda_c \rightarrow p e^+ X) = \frac{N(\bar{p}e^-)}{N(\bar{p})} F(p) \left[ \frac{\Delta R(p)}{R(p)} \right]^{-1} = (1.8 \pm 0.9) \%$$

$$BR(\Lambda_c \rightarrow \Lambda^0 e^+ X) = \frac{N(\bar{\Lambda}e^-) + N(\Lambda e^+)}{N(\bar{\Lambda}) + N(\Lambda)} F(\Lambda) \left[ \frac{\Delta R(\Lambda)}{R(\Lambda)} \right]^{-1} = (1.1 \pm 0.8) \%$$

Protons from  $\Lambda^0$  decay are included in  $BR(\Lambda_c \rightarrow peX)$ , and lambdas from  $\Sigma^0$  decay are included in  $BR(\Lambda_c \rightarrow \Lambda^0 eX)$ . The Cabibbo favored semileptonic charm decay has the isospin selection rule  $|\Delta I| = 0$ , and hence the hadronic decay products are expected to have isospin 0. The simplest way in which this might occur, namely through the mode  $\Lambda^0 e^+ \gamma$ , does not seem to be dominant.

The inclusive semileptonic branching ratio of the  $\Lambda_c$  can be related to the  $\Lambda_c$  lifetime if the  $\Lambda_c$  semileptonic decay rate is known. A theoretical calculation of the semileptonic width of charmed particles gives  $\Gamma_{sL} = (1.9 \pm 0.5) 10^{11} \text{ sec}^{-1}$ .<sup>6</sup> Combined with the present inclusive semileptonic branching ratio measurement, this leads to a lifetime  $\tau(\Lambda_c) = BR(\Lambda_c \rightarrow e X) / \Gamma_{sL} = (2.4 \pm 1.1) 10^{-13} \text{ sec}$ . This value is in good

agreement with recent direct measurements of the  $\Lambda_c$  lifetime,<sup>7</sup> which give  $\tau(\Lambda_c) = (2.3^{+1.1}_{-0.7}) 10^{-13}$  sec.

#### REFERENCES

<sup>1</sup> G. S. Abrams et al., Phys. Rev. Lett. 44, 10 (1980).

<sup>2</sup> W. Davies-White et al., Nucl. Inst. Methods 160, 227 (1979); G. S. Abrams et al., IEEE Trans. Nucl. Sci. NS-25, 309 (1978).

<sup>3</sup> M. W. Coles, Ph.D. Thesis, University of California, Berkeley, LBL-11513 (1980). Searches for  $\Lambda_c \bar{D}^0 \bar{p}$  associated production have yielded negative results. An associated production rate of 20% (near the present upper limit), combined with an average D semileptonic branching ratio of 8%, would reduce the calculated  $\Lambda_c$  inclusive semileptonic branching ratio from 4.5% to 3.6%.

<sup>4</sup> E. N. Vella, Ph.D. Thesis, University of California, Berkeley, LBL-13845 (1981). This thesis contains tables of  $R(p)$  and  $R(\Lambda)$  from which the ratios  $\Delta R(p)/R(p)$ ,  $\Delta R(\Lambda)/R(\Lambda)$ , and  $\Delta R(\Lambda)/\Delta R(p)$  are derived. The values of  $R(\Lambda)$  used here are 20% lower than the previously published values<sup>1</sup>; this corrects an error in the previous calculation of  $R(\Lambda)$  caused by the use of an incorrect  $\Lambda^0$  detection efficiency.

<sup>5</sup> This value is based on a simple isospin statistical model.

<sup>6</sup> N. Cabibbo and L. Maiani, Phys. Lett. 79B, 109 (1978); A. Ali and E. Pietarinen, Nucl. Phys. B154, 519 (1979); N. Cabibbo, G. Corbo, and L. Maiani, Nucl. Phys. B155, 93 (1979). The semileptonic width and error quoted here are based on a charmed quark mass  $m_c = (1.75 \pm .10) \text{ GeV}/c^2$ .

<sup>7</sup> W. N. Reay, Invited Paper at the San Francisco Meeting of the American Physical Society (January 1982).



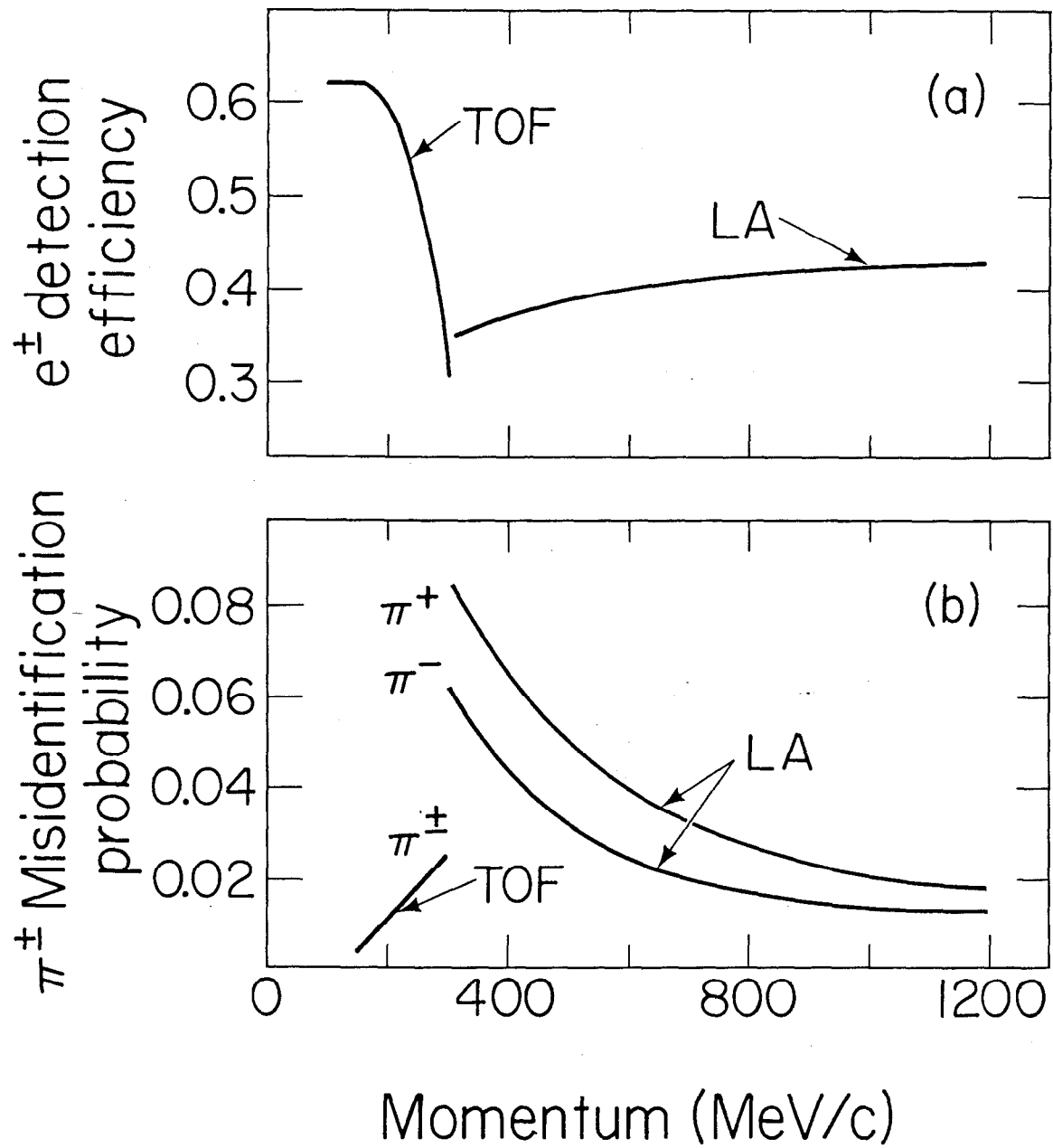
Table 1. Direct electron signal in baryon events

	$E_{cm} < 4.5 \text{ GeV}$		$E_{cm} > 4.5 \text{ GeV}$	
	9992 $\bar{p}$	1499 $\Lambda, \bar{\Lambda}$	5209 $\bar{p}$	757 $\Lambda, \bar{\Lambda}$
raw $e^\pm$	613±25	58±8	440±21	73±9
$\pi^\pm$ bgnd	424±22	51±3	287±14	39±2
$e^\pm$ bgnd	144±16	19±2	84±8	12±1
net $e^\pm$	45±37	-12±8	69±26	22±9
corrected $e^\pm$	105±86	-32±23	170±64	52±21

FIGURE CAPTIONS

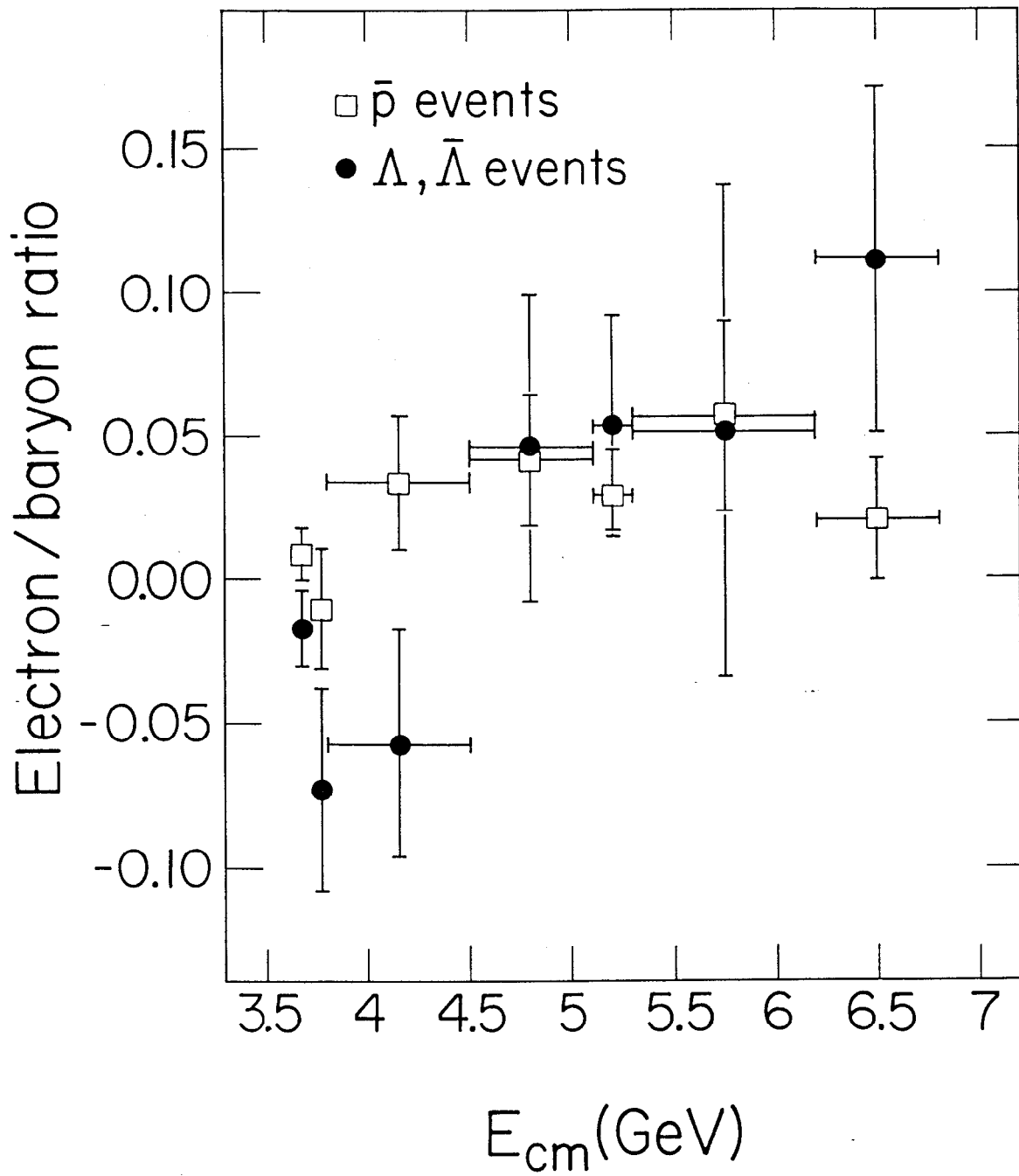
Figure 1: (a) electron detection efficiency  
 (b) pion misidentification probability

Figure 2: electron signal vs.  $E_{cm}$



XBL 823-274

Fig. 1



XBL 823-273

Fig. 2