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Study of the Baryon - Anti-Baryon Decays of the J/ψ*

Mark III Collaboration

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Abstract

The Mark III collaboration presents results on the decays $J/\psi \to B_8\bar{B}_8$, and $J/\psi \to B_8\bar{B}_{10}$ using 5.8×10^6 produced J/ψ's collected at SPEAR. Branching ratios have been determined for the decays $J/\psi \to \Sigma^+\bar{\Sigma}^-(1385)$ + *c.c.*, $J/\psi \to \Xi^-\bar{\Xi}^+(1530)$ + *c.c.* and $J/\psi \to \Xi^-\bar{\Xi}^+$. An upper limit on the branching ratios for the decay $J/\psi \to \Xi^0\bar{\Xi}^0(1530)$ + *c.c.* has also been determined. These indicate large isospin violation in the decay patterns for $J/\psi \to \Xi\bar{\Xi}^*$.

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1. Introduction

The J/ψ, with its many decay modes and copious production, has proven to be a fertile field to test our understanding of hadronic decays. The mesonic decay patterns for $J/\psi \to VP$, and $J/\psi \to PP$ have already yielded insight into the $SU(3)_f$ structure of the lowest lying pseudoscalar multiplet, the pseudoscalar form factors, and the contributions of electromagnetic and $SU(3)_f$-violating effects to charm annihilation.[1,2] Previous observation of the $SU(3)_f$-violating decay $J/\psi \to \Sigma^+\bar{\Sigma}^-(1385)$ [3] suggests that the study of 2-body baryonic decays of the J/ψ could yield insight into the charm annihilation Hamiltonian. The Mark III collaboration presents results on the baryonic decays:

$$J/\psi \to \Sigma^+\bar{\Sigma}^-\ (1385)\ +\ c.c. \tag{1}$$
$$J/\psi \to \Xi^-\bar{\Xi}^+\ (1530)\ +\ c.c. \tag{2}$$
$$J/\psi \to \Xi^0\bar{\Xi}^0\ (1530)\ +\ c.c. \tag{3}$$
$$J/\psi \to \Xi^-\bar{\Xi}^+ \tag{4}$$

The first three decays are of the type $B_8 \otimes \bar{B}_{10}$. Since the J/ψ is an isosinglet, these decays are $SU(3)_f$-violating. The fourth mode is $SU(3)_f$-allowed and is used as a monitor reaction. Comparison of the rates of decays (2) with (3) also tests the isospin symmetry of J/ψ decays.

2. The Mark III Detector

The Mark III detector at SPEAR is a conventional general purpose solenoidal magnetic spectrometer. An axial cross-section of the detector is shown in Fig. 1. A detailed description of the Mark III detector has been previously published.[4] Relevant features of the Mark III detector for this analysis are the following.

- The central drift chamber has a resolution

$$\frac{\delta p}{p} = \sqrt{1.5^2 + (1.5\ p)^2}\quad \%\ (p \text{ in GeV}/c)$$

  over a solid angle of 85%.
- The time-of-flight (TOF) system covers 80% of the solid angle and has a resolution $\sim$ 200 ps for hadrons.

- The shower counter has a solid angle coverage of 94%. The shower counter energy resolution for photons is

$$\frac{\delta E}{E} = \frac{17\%}{\sqrt{E}} \qquad (E \text{ in GeV}).$$

It has greater than 75% detection efficiency for photon energies above 100 Mev.

3. Data Analysis

The data sample consists of 5.8×10^6 produced J/ψ's collected by Mark III in three running periods from 1982 to 1985. The following are basic features of all the analyses.

1) All charged tracks are required to be reconstructed, and the total charge must be zero.
2) All candidate events are required to have both a TOF identified proton and anti-proton where

$$m^2_{TOF} > 0.4 \quad (\mathrm{GeV}/c^2)^2$$

3) Other charged tracks are assumed to be pions.
4) $p\pi^-(\bar{p}\pi^+)$ is identified as a $\Lambda(\bar{\Lambda})$ if

$$1.100 \quad \mathrm{Gev}/c^2 < m_{p\pi} < 1.127 \quad \mathrm{GeV}/c^2$$

5) The acceptance is determined by Monte Carlo simulation.

The Ξ Channels

We first consider the decay channels (2),(3), and (4) involving a Ξ. Since $\Xi \to \Lambda\pi$ and $\Xi(1530) \to \Xi\pi \to \Lambda\pi\pi$ we start with a sample of events of the type

$$J/\psi \to \Lambda\pi^-\bar{\Lambda}\pi^+ \; + X$$

where X may be missing neutrals. In Fig. 2 the invariant mass for either the $\Lambda\pi^-$ or the $\bar{\Lambda}\pi^+$ is plotted. A clear $\Xi^-(\bar{\Xi}^+)$ can be seen at a mass of 1.320 GeV/c^2. The smaller peak corresponds to the $\Lambda\pi^-$ $(\bar{\Lambda}\pi^+)$ decay mode of the $\Sigma^-(1385)$ and its charge conjugate. The Ξ^- $(\bar{\Xi}^+)$ is identified by requiring

$$1.280 \ \mathrm{GeV}/c^2 \; < \; m_{\Lambda\pi^-,\bar{\Lambda}\pi^+} \; < \quad 1.360 \quad \mathrm{GeV}/c^2$$

$\underline{J/\psi \rightarrow \Xi^- \bar{\Xi}^+(1530) + c.c.}$

The $\Xi^-(1530)$ has two isotopic decays to $\Xi\pi$. We now consider the decay $\Xi^-(1530) \rightarrow \Xi^0\pi^-$ which is twice as copious as the decay $\Xi^-(1530) \rightarrow \Xi^-\pi^0$. Using the above sample we require either a Ξ^- or $\bar{\Xi}^+$. In Fig. 3 we show the recoil mass against the $\Xi^-\pi^+$ ($\bar{\Xi}^+\pi^-$) system. The prominent peak at the Λ mass (1.115 GeV/c^2) is the result of the decay:

$$J/\psi \rightarrow \Xi^-\bar{\Xi}^+ \rightarrow \Xi^-\bar{\Lambda}\pi^+ + c.c.,$$

and the smaller peak at the Ξ^0 mass (1.320 GeV/c^2) corresponds to the decay

$$J/\psi \rightarrow \Xi^-\bar{\Xi}^0\pi^+ + c.c.$$

To determine resonance formation of the $\bar{\Xi}^0\pi^+$ system we plot the momentum of the $\Xi^-(\bar{\Xi}^+)$ in Fig. 4, where we have required a 'detected' $\bar{\Xi}^0(\Xi^0)$ with an invariant mass 1.280 GeV/c^2 $< m_{\Xi\pi\ recoil} <$ 1.360 GeV/c^2.

The prominent peak at 0.598 GeV/c is the momentum one would expect from the two-body decay $J/\psi \rightarrow \Xi^-\bar{\Xi}^+(1530)$. The curve through the data is the result of a fit using a quadratic background and a Breit-Wigner function. The mean and half-width are fixed at 598 MeV/c and Γ = 11 MeV/c, respectively. The resulting parameters of the fit are:

136 ± 13 $\Xi^-\bar{\Xi}^+(1530) + c.c.$ events

$\chi^2 = 20$ for 18 degrees of freedom and four parameters

$\sigma = 30 \pm 4$ MeV/c

The resolution σ is consistent with the Monte Carlo simulation. The acceptance is determined by Monte Carlo and yields the following branching ratio:

$$BR(J/\psi \rightarrow \Xi^-\bar{\Xi}^+(1530) + c.c.) = (8.8 \pm 0.8 \text{ stat}) \times 10^{-4}$$

We next turn to the decay mode where $\bar{\Xi}^+(1530) \rightarrow \bar{\Xi}^+\pi^0$. To measure this channel we first require both an identified Ξ^- and an identified $\bar{\Xi}^+$ from the sample of events $J/\psi \rightarrow \Lambda\pi^-\bar{\Lambda}\pi^+ + X$. We now have the decays

$$J/\psi \rightarrow \Xi^-\bar{\Xi}^+ + X$$

where X consists of only neutral particles and is 'missing'. The recoil mass against the $\Xi^-(\bar{\Xi}^+)$ is plotted in Fig. 5. There is a large peak at the Ξ^- invariant mass due to the decay $J/\psi \to \Xi^-\bar{\Xi}^+$, and a smaller peak at a mass of 1.535 GeV/c^2 corresponding to the decay

$$J/\psi \to \Xi^-\bar{\Xi}^+(1530) \to \Xi^-\bar{\Xi}^+\pi^0 \quad + \quad c.c.$$

The curve through the data is the result of a fit over the region from 1.430 GeV/c^2 to 1.730 GeV/c^2 using a cubic polynomial background and a Breit-Wigner function with a width $\Gamma = 10$ MeV/c^2 convoluted with a gaussian. The fitted parameters follow.

$$\begin{aligned} &69 \pm 18\ \Xi^*(1530)\ \text{events} \\ \chi^2 =&11.8 \text{ for 8 degrees of freedom and 5 parameters} \\ m_{\Xi^*} =&1530 \pm 3\ \text{MeV}/c^2 \\ \sigma =&10.5 \pm 4.5\ \text{MeV}/c^2 \end{aligned}$$

The measured resolution σ is consistent with the results of the Monte Carlo. Using the acceptance determined by the Monte Carlo yields the following branching ratio.

$$BR(J/\psi \to \Xi^-\bar{\Xi}^+(1530) \ + \ c.c.) = (7.3 \pm 1.9 \text{ stat}) \times 10^{-4}$$

Averaging the two channels we find:

$$BR(J/\psi \to \Xi^-\bar{\Xi}^+(1530) \ + \ c.c.) = (8.6 \pm 0.7 \pm 2.2) \times 10^{-4}$$

The two-body decays are generated in the Monte Carlo with isotropic angular distributions. With little q^2 available for production, the angular distributions should be nearly flat.[5] Since the production angle distribution cannot be measured, the largest part of the systematic errors for this and the following measurements reflect this uncertainty.

$J/\psi \to \Xi^- \bar{\Xi}^+$

To measure the mode $J/\psi \to \Xi^-\bar{\Xi}^+$, we require from the sample of events

$$J/\psi \to \Xi^-\bar{\Xi}^+ \ + X$$

which we used in the previous analysis, that each Ξ has a recoil mass 1.119 Gev/c^2 $< m_{\Xi\ recoil} <$ 1.442 Gev/c^2. We find:

$$BR(J/\psi \to \Xi^-\bar{\Xi}^+) = (0.86 \pm 0.05 \pm 0.2) \times 10^{-3}$$

This result is consistent with the previous Mark II[3] result of $(1.14 \pm 0.08 \pm 0.2) \times 10^{-3}$.

$\underline{J/\psi \rightarrow \Xi^0\bar{\Xi}^0(1530) + c.c.}$

We search for the decay sequence

$$J/\psi \rightarrow \Xi^0\bar{\Xi}^0(1530) + c.c.$$
$$\hookrightarrow \bar{\Xi}^+ \pi^-$$

Starting with the sample of events $J/\psi \rightarrow \Xi^-\bar{\Xi}^0\pi^+$ from the first analysis we further require the momentum of the Ξ^- ($\bar{\Xi}^+$) to be less than 0.5 GeV/c. This criterion results in a 66% loss of acceptance, but eliminates the background from $J/\psi \rightarrow \Xi^-\bar{\Xi}^+(1530) \rightarrow \Xi^-\bar{\Xi}^0\pi^+$. The resulting momentum spectrum of the $\bar{\Xi}^+\pi^-$ ($\Xi^-\pi^+$) system is shown in Fig. 6. Assuming a conservative background of 4 events in the region 0.56 Gev/c < $p_{\Xi^\mp\pi^\pm}$ < 0.64 Gev/c we obtain the following 90% C.L. upper limit.

$$BR(J/\psi \rightarrow \Xi^0\bar{\Xi}^0(1530) + c.c.) < 4.1 \times 10^{-4}$$

$\underline{J/\psi \rightarrow \Sigma^+ \bar{\Sigma}^-(1385) + c.c.}$

Proceeding to the Σ channels, we consider the decay sequence

$$J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-(1385)$$
$$\hookrightarrow p\pi^0 \; \bar{\Lambda} \; \pi^-$$
$$\hookrightarrow p\,\pi^0\bar{p}\pi^+\pi^-$$

We start with a sample of events of the type:

$$J/\psi \rightarrow p\,\bar{\Lambda}\pi^- X + c.c.$$

where X is the 'unseen' mass of all neutral particles in the event. In addition the following selection criteria are applied.

1) The π^- (π^+) which is not the daughter of the $\Lambda(\bar{\Lambda})$ is required to be identified by TOF: -1.0 (Gev/c^2)^2 < m_π^2 < 0.1 (GeV/c^2)^2.

2) The neutral missing mass (i.e. the recoil mass against the $p\bar{\Lambda}\pi^-$ system) is shown in Fig. 7. The missing mass m_X is required to be loosely consistent with a π^0:

$$0.05 \text{ GeV}/c^2 < m_X < 0.21 \text{ GeV}/c^2$$

3) The recoil mass against the $\bar{\Lambda}\pi^-$ $(\Lambda\pi^+)$ is plotted in Fig. 8. This $\Lambda\pi$ mass is required to be consistent with a $\bar{\Sigma}^+(\Sigma^-)$:

$$1.15 \text{ GeV}/c^2 < m_{\Lambda\pi \ recoil} < 1.23 \text{ GeV}/c^2$$

The momentum spectrum of the final $\bar{\Lambda}\pi^-$ $(\Lambda\pi^+)$ system is shown Fig. 9. The peak at 861 MeV is the momentum one would expect from the two-body decay $J/\psi \to \Sigma^+\bar{\Sigma}^-(1385)$. The curve through the data is the result of a fit using a phase space background and a Breit-Wigner function convoluted with a gaussian. The results of the fit are:

$$126 \pm 12 \quad \Sigma^+\bar{\Sigma}^-(1385) + c.c. \text{ events}$$

$$\chi^2 = 51 \text{ for 40 degrees of freedom and 2 parameters}$$

The following branching ratio is obtained.

$$BR(J/\psi \to \Sigma^+\bar{\Sigma}^-(1385) + c.c.) = (3.7 \pm 0.4 \pm 0.9) \times 10^{-4}$$

This result is consistent with the previous measurement by the Mark II collaboration (see Table 1). Two of us (N.W.,G.E.) wishes to thank the Alexander von Humboldt

4. Summary

Table 1 contains results of this paper along with some additional results from the $B_8\bar{B}_8$ decays of the J/ψ. Included is the reduced branching ratio which is the branching ratio divided by a phase space factor $\frac{\pi p}{m_\psi}$. Clearly, $SU(3)_f$-violating effects are sizeable. The isospin-violating suppression of the $\Xi^0\bar{\Xi}^0(1530)$ in comparison to the $\Xi^-\bar{\Xi}^+(1530)$ indicate that electromagnetic interactions cannot be ignored. It has been suggested by Claudson, Glashow and Wise that isospin violations are sensitive probes of the baryon magnetic form factors.[5] Genz, Malvetti and Tatur have suggested that a comparison of the rates of $J/\psi \to \Sigma\bar{\Sigma}^*$ to $J/\psi \to \Xi\bar{\Xi}^*$ provides a test of octet dominance.[7] They suggest that pure octet dominance would lead to the ratio:

$$R = \frac{\Gamma(\psi \to \Xi^-(1530)\ \bar{\Xi}^+)}{\Gamma(\psi \to \Sigma^+(1385)\ \bar{\Sigma}^-)} = 0.7$$

whereas $R = 1.6$ for pure 27-plet dominance. We find $R = 2.4 \pm 1.57$.

In conclusion, our measurements of $J/\psi \to B_8\bar{B}_{10}$ indicate sizeable $SU(3)_f$ violations as well as isospin violations.

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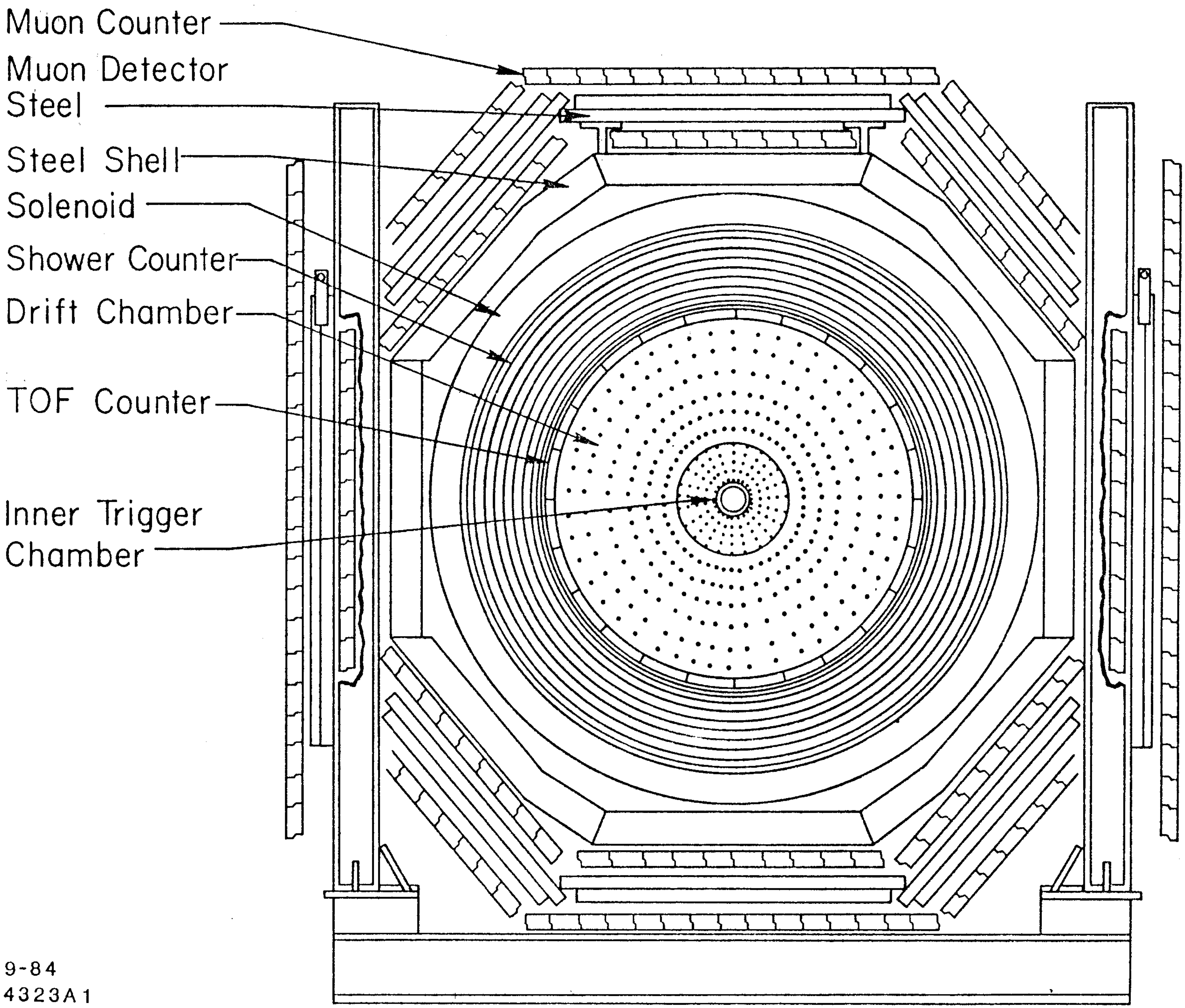
Table 1

Decay Modes	B. R. (%)	Reduced B. R. (%)	Source
$p\bar{p}$	$0.22 \pm .02$	0.18 ± 0.02	Particle Data Group[6]
$n\bar{n}$	$0.18 \pm .09$	0.14 ± 0.07	Particle Data Group
$\Sigma^+\ \bar{\Sigma}^-$	$0.24 \pm .26$	0.24 ± 0.26	Particle Data Group
$\Sigma^0\ \bar{\Sigma}^0$	$0.13 \pm .04$	0.13 ± 0.04	Particle Data Group
$\Lambda\ \bar{\Lambda}$	$0.11 \pm .02$	0.10 ± 0.02	Particle Data Group
$\Xi^-\ \bar{\Xi}^+$	$0.086 \pm .005 \pm .02$	$0.104 \pm 0.006 \pm 0.02$	Mark III *this paper*
	$0.114 \pm .008 \pm .02$	$0.139 \pm .026$	Mark II[3]
$\Sigma^+\ \bar{\Sigma}^-(1385)$	$0.037 \pm .0.004 \pm 0.009$	$0.042 \pm 0.005 \pm 0.01$	Mark III *this paper*
	$0.031 \pm .011 \pm 0.11$	$0.037 \pm .020$	Mark II[3]
$\Sigma^-\ \bar{\Sigma}^+(1385)$	$0.029 \pm .011 \pm .010$	$0.039 \pm .020$	Mark II[3]
$\Xi^-\ \bar{\Xi}^+(1530)$	$0.086 \pm .008 \pm .022$	$0.14 \pm 0.01 \pm 0.036$	Mark III *this paper*
$\Xi^0\ \bar{\Xi}^0(1530)\ +\ c.c.$	$<\ .041$	$<\ 0.066$	Mark III *this paper*

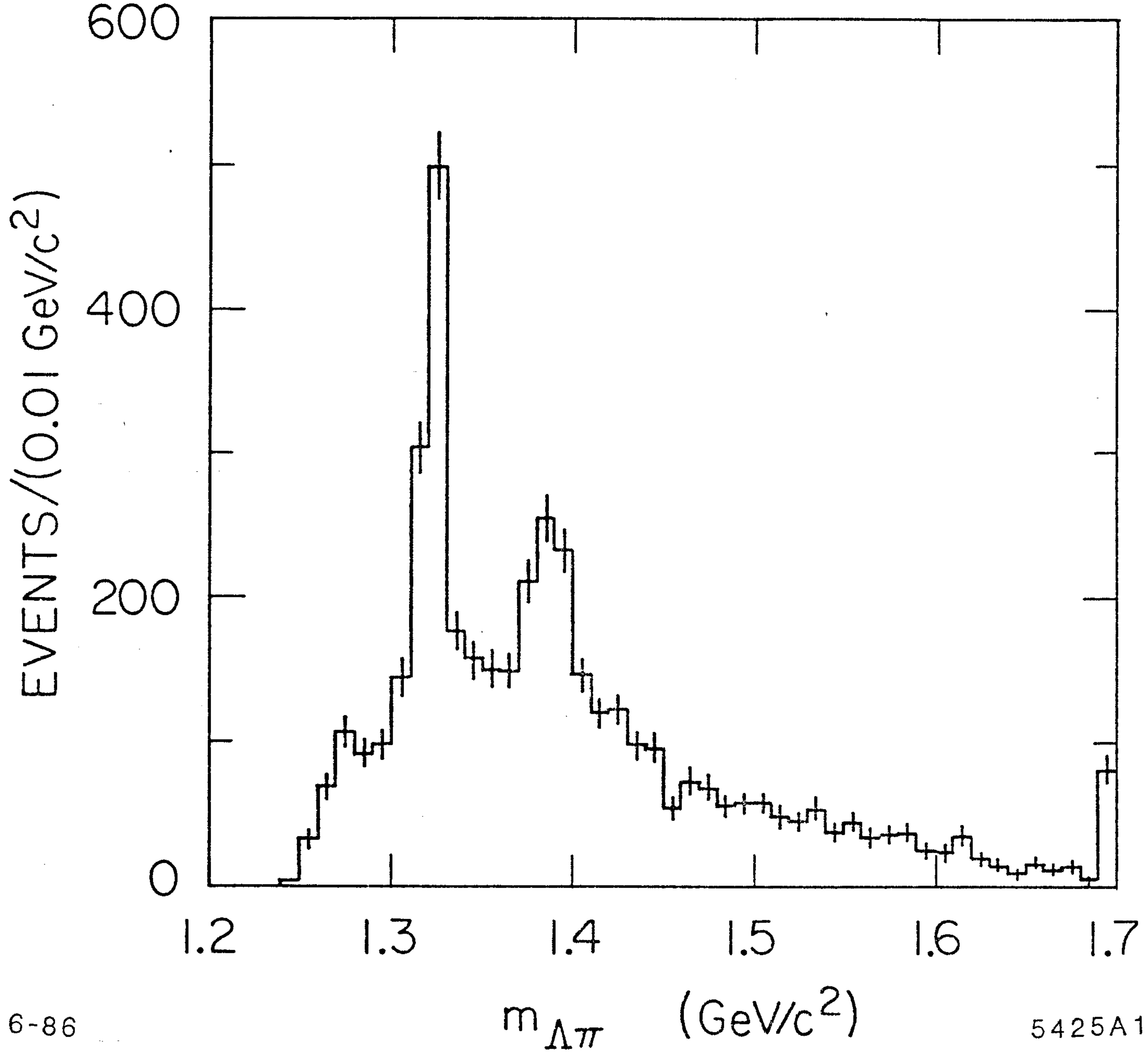
Figure Captions

1. An axial view of the Mark III detector.
2. The $\Lambda\pi^-$ and $\bar{\Lambda}\pi^+$ invariant mass spectrum.
3. Recoil mass against $\Xi^-\pi^+$ ($\bar{\Xi}^+\pi^-$) system.
4. Momentum of Ξ^- ($\bar{\Xi}^+$) requiring an identified $\bar{\Xi}^0$ (Ξ^0). The curves through the data are the fitted background and signal.
5. Recoil mass against the Ξ^- or $\bar{\Xi}^+$.
6. $\bar{\Xi}^+\pi^-$ and $\Xi^-\pi^+$ momenta after requiring $p_{\Xi^-,\bar{\Xi}^+} < 0.5$ GeV/c.
7. Recoil mass against the $p\bar{\Lambda}\pi^-$ system.
8. Recoil mass against $\Lambda\pi^-$ and $\bar{\Lambda}\pi^+$.
9. Momenta of $\bar{\Lambda}\pi^-$ and $\Lambda\pi^+$. The curves through the data are the fitted background and signal.

Fig. 1



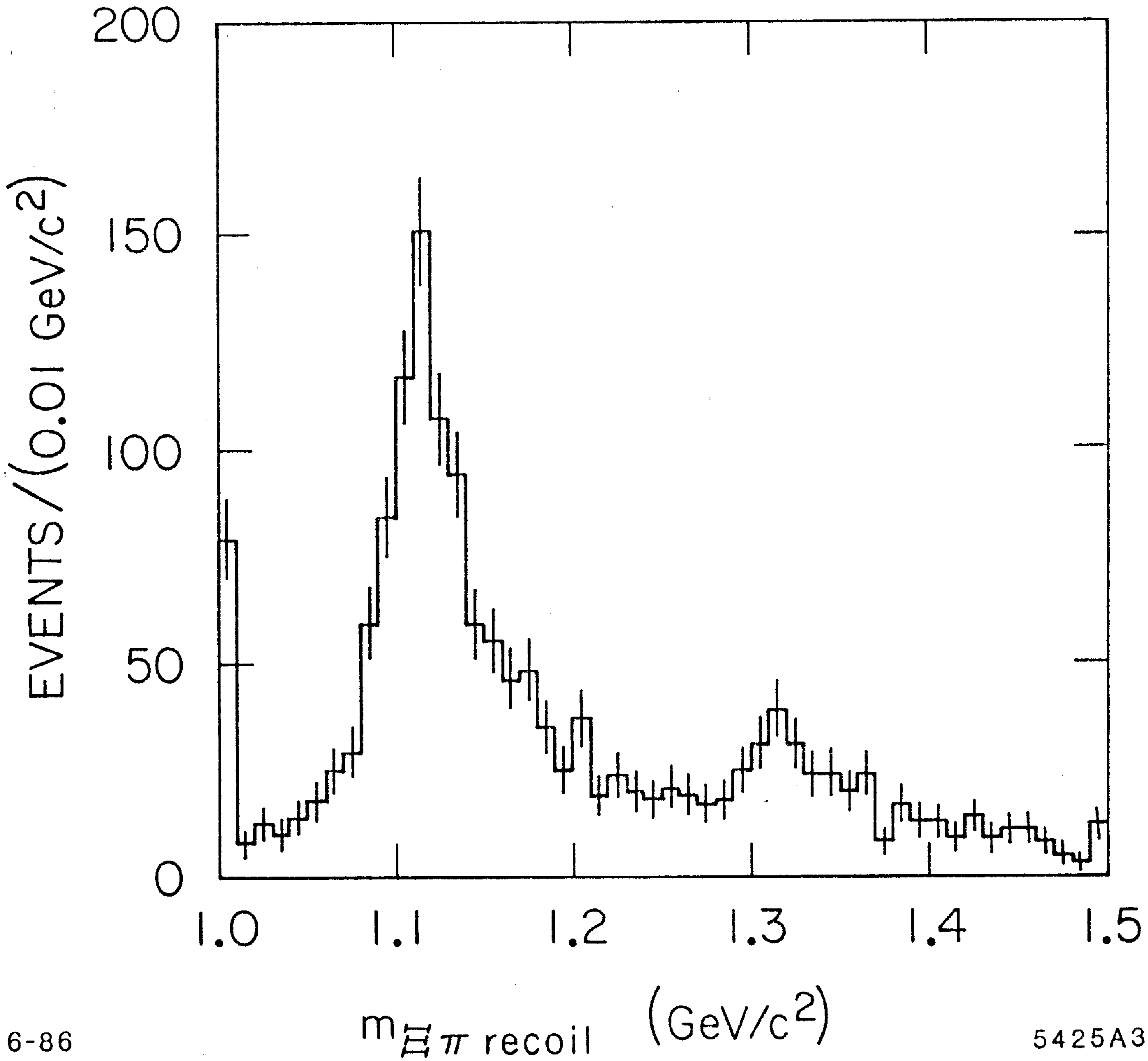
9-84
4323A1



600
400
200
0
EVENTS/(0.01 GeV/c²)
1.2
1.3
1.4
1.5
1.6
1.7
6-86
m Λπ (GeV/c²)
5425A1

Fig. 2

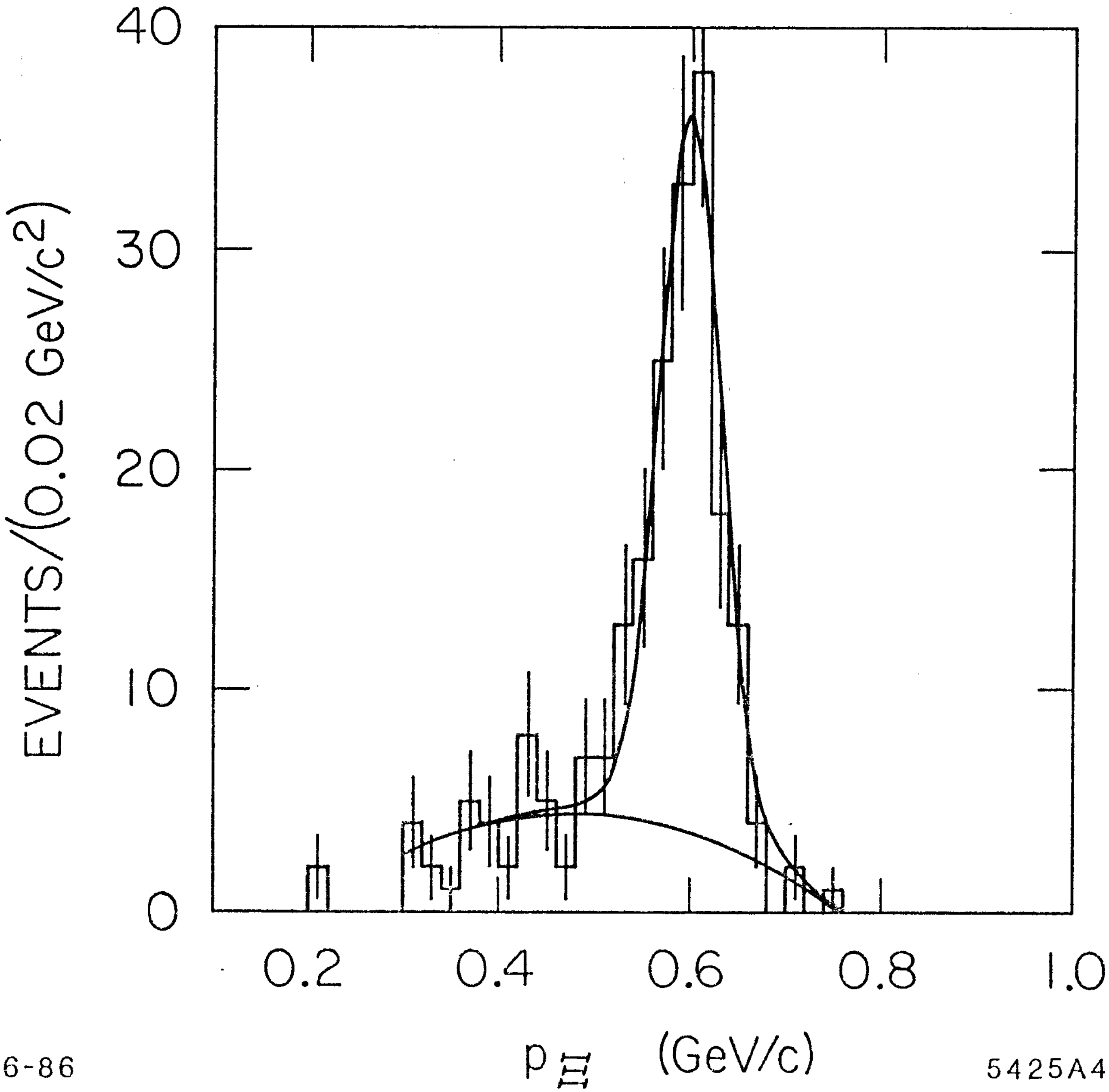
Fig. 3



6-86

5425A3

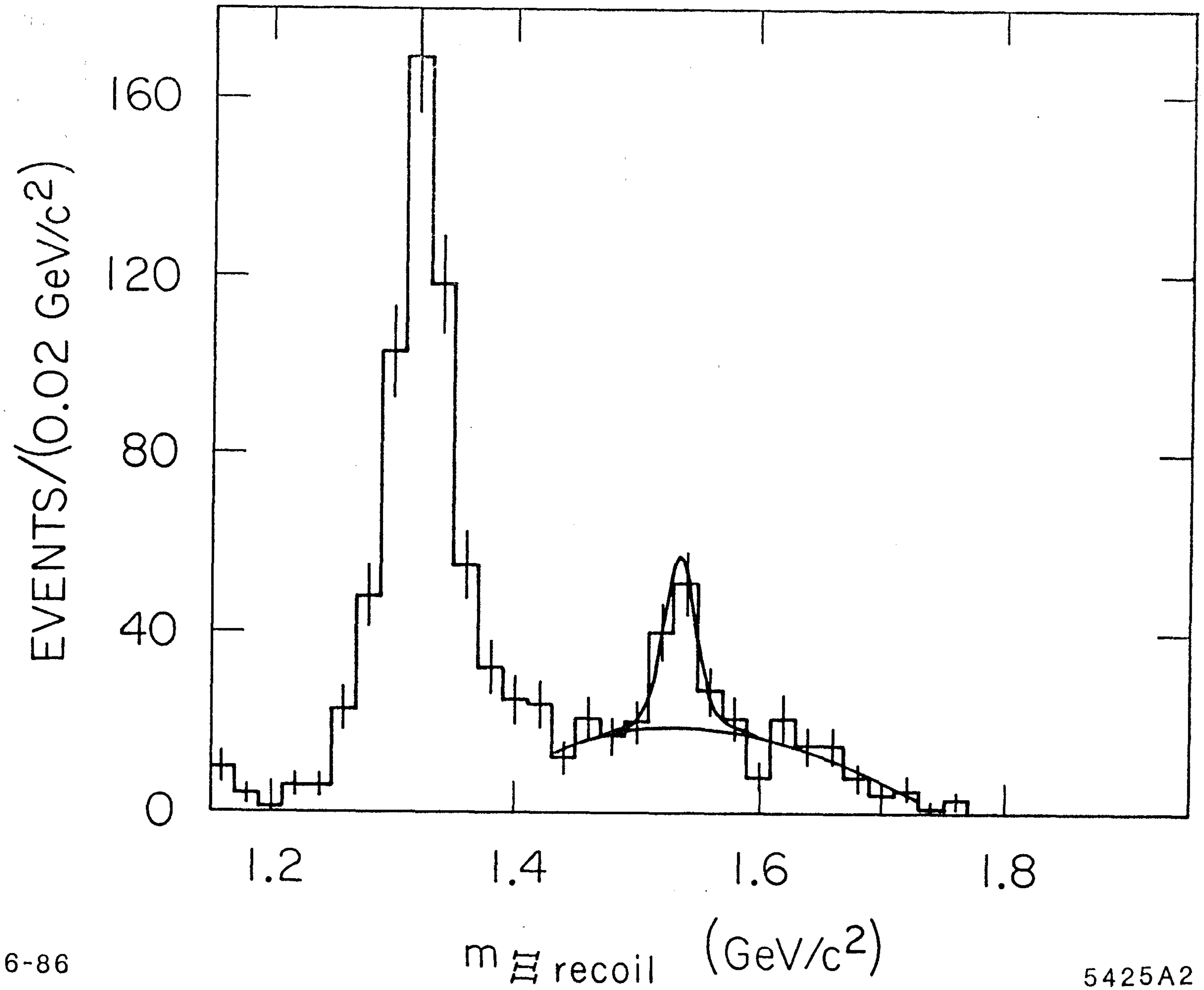
Fig. 4



6-86

5425A4

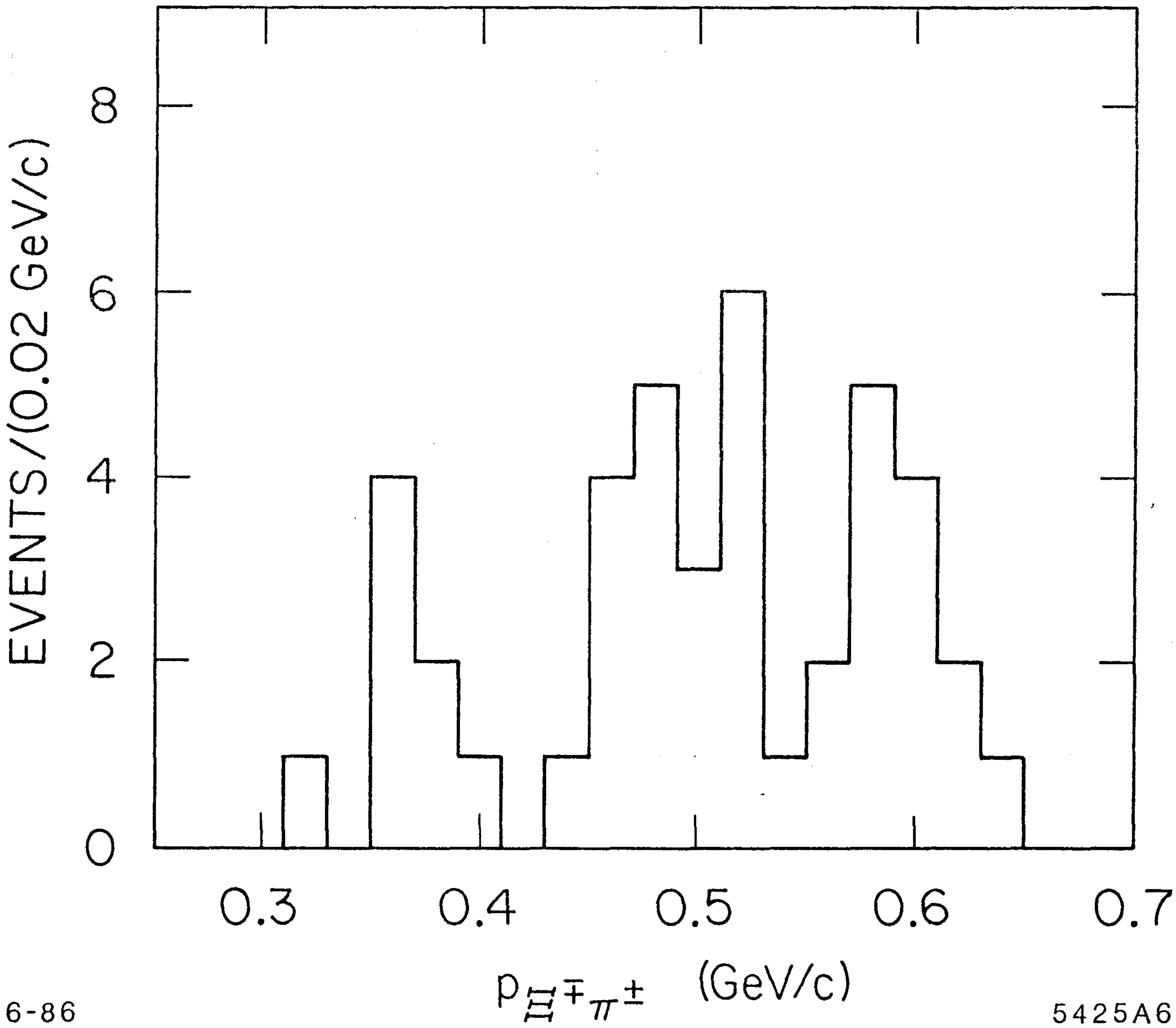
Fig. 5



6-86

5425A2

Fig. 6



EVENTS/(0.02 GeV/c)
0
2
4
6
8
0.3
0.4
0.5
0.6
0.7
$p_{\Xi^{\mp}\pi^{\pm}}$ (GeV/c)
6-86
5425A6

Fig. 7

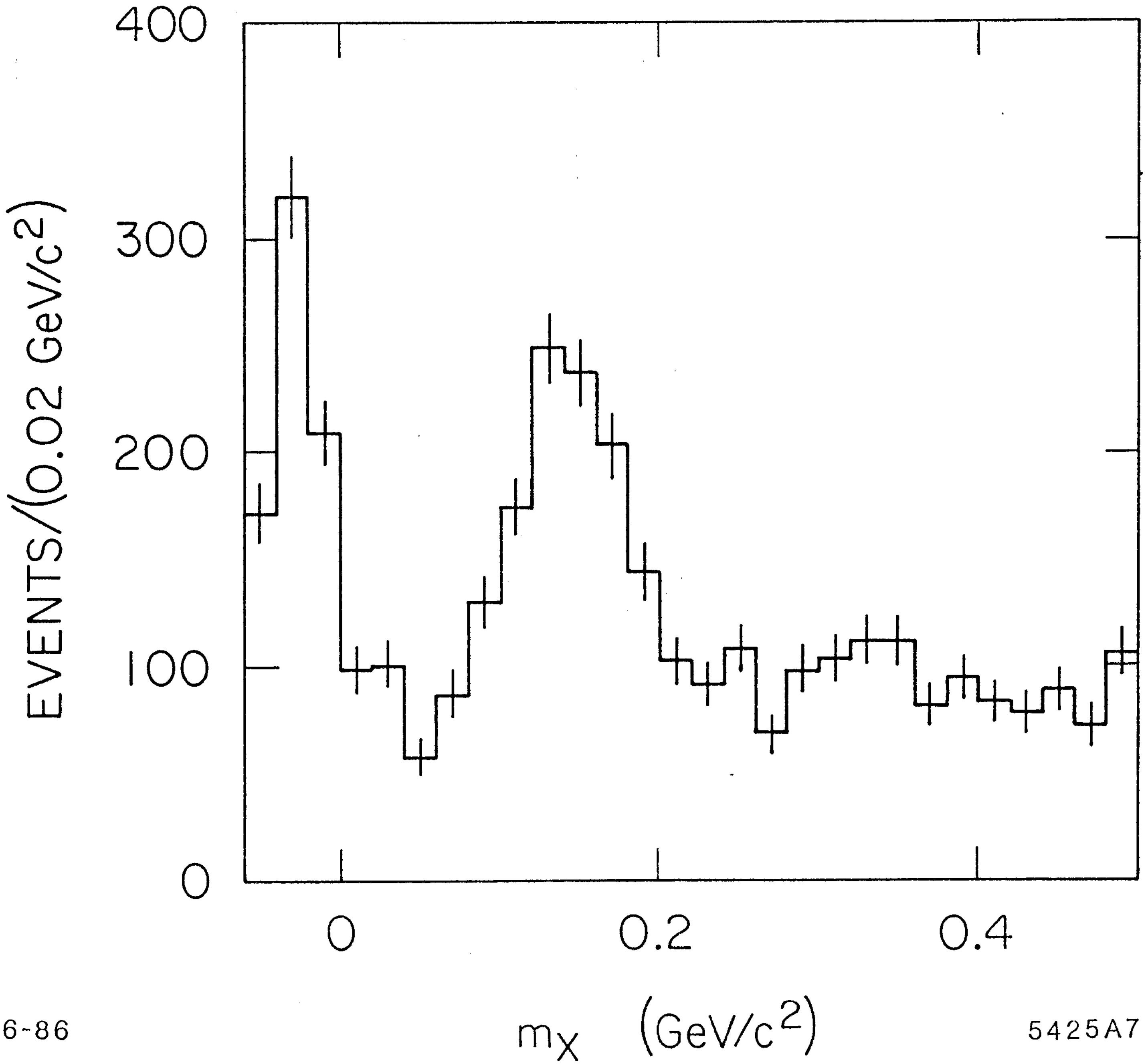
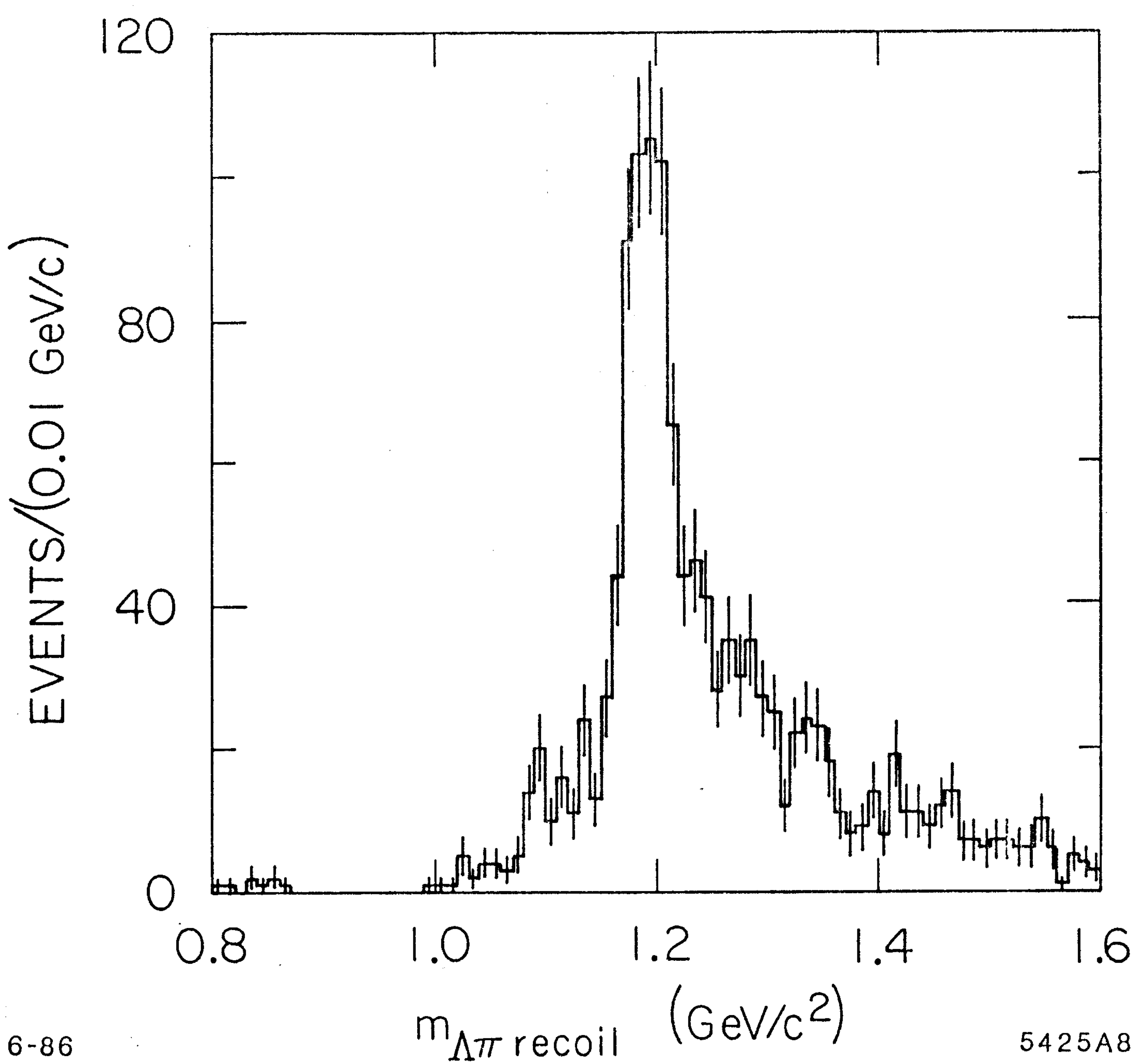
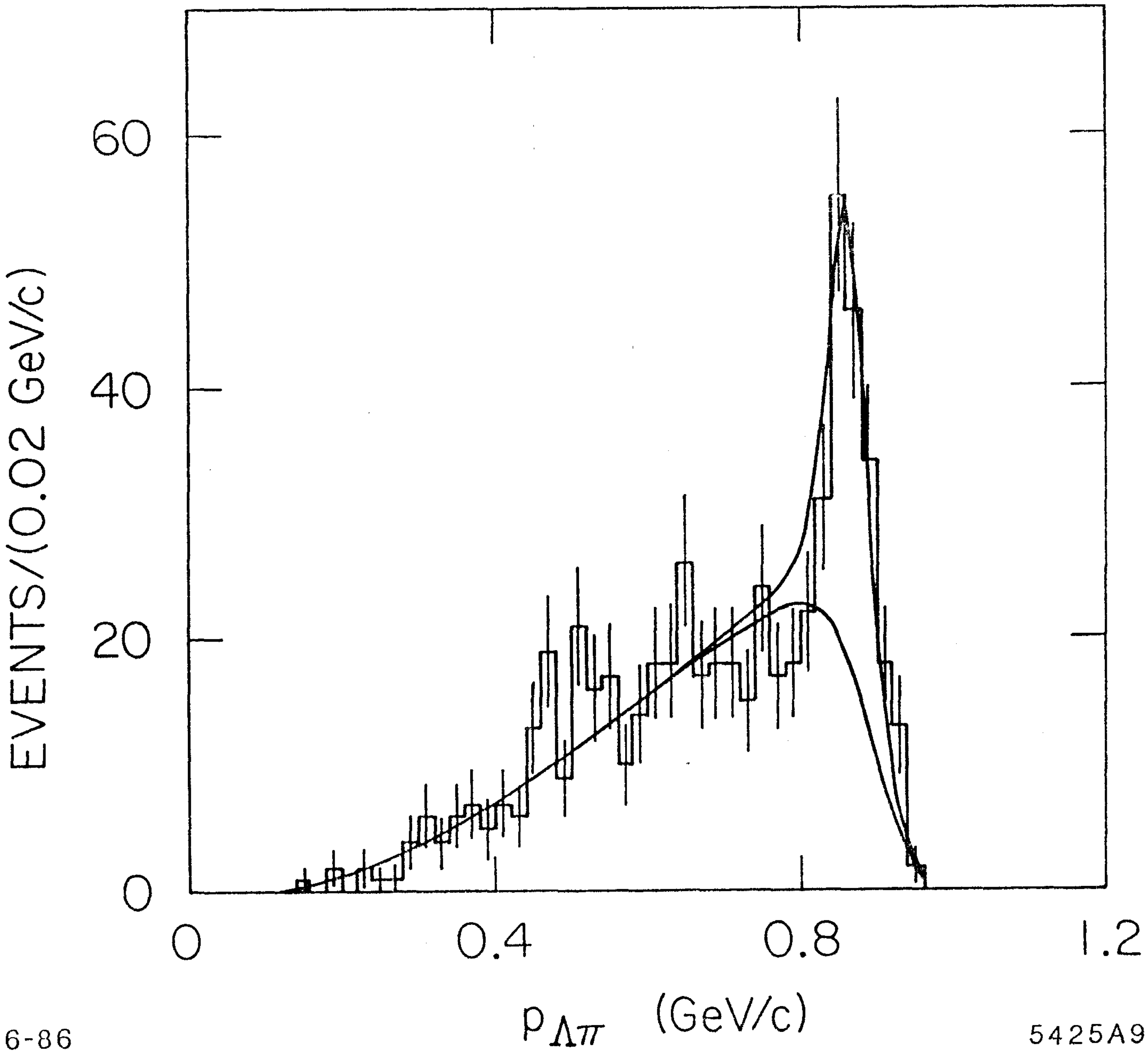


Fig. 8



120
80
40
0
EVENTS/(0.01 GeV/c)
0.8
1.0
1.2
1.4
1.6
$m_{\Lambda\pi\ recoil}$ (GeV/c^2)
6-86
5425A8

Fig. 9



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5425A9