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OBSERVATION OF A NEW Ω^{*-} AT 2.47 GeV/c^2 IN K$^-$p INTERACTIONS AT 11 GeV/c*

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ABSTRACT

Clear evidence is presented for an Ω^{*-} resonance of mass 2474 ± 12 MeV/c^2 and width 72 ± 33 MeV/c^2 in K^-p interactions at 11 GeV/c. The state is observed in the $\Omega^-\pi^+\pi^-$ decay mode, and the corresponding inclusive cross section, corrected for $\Omega^-\pi^0\pi^0$ decay, is estimated to be 290 ±90 nb.

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Data demonstrating the existence of excited baryons with strangeness -3 have become available only recently [1–3]. Such data require the use of K^- or hyperon beams in fixed target experiments involving large electronic spectrometers. These must be capable of acquiring and processing large data samples, and must also be able to deal efficiently with the complex topologies that events involving such particles entail. In addition, good particle identification capability is necessary to the identification of the relevant final states. To date, these criteria have been met by only two experiments [1–3].

The observed Ω^{*-} states are seen to couple strongly to the $\Xi^- K^- \pi^+$ system. The $\Omega^{*-}(2250)$ decays predominantly to $\Xi^{*\circ}(1530)K^-$ [1–3]. A second Ω^{*-}, at $\sim$2.38 GeV/c^2 [2], is reported to decay directly to $\Xi^- K^- \pi^+$ and also to $\overline{K^{*\circ}}(892)\Xi^-$. There is no evidence in the present experiment for Ω^{*-} decaying directly to $\Xi^- K^- \pi^+$ [3].

In this paper, we present evidence for a third state which is observed in the $\Omega^- \pi^+ \pi^-$ system produced inclusively in the reaction

$$\begin{array}{ll} K^- p \rightarrow & \Omega^{*-} + \text{anything} \\ & \;\lfloor\!\rightarrow \Omega^- \pi^+ \pi^- \end{array} \quad . \tag{1}$$

The data derive from a 4.1 event/nb exposure of the LASS spectrometer [4] to an 11 GeV/c K^- beam. A total of 1.13×10^8 K^- induced event triggers was accumulated, from which a subsample containing approximately 650 Ω^- events was extracted for analysis.

The beam, the LASS spectrometer and the trigger are described in detail in ref. [4]. The vertex detector consisted of a superconducting, solenoidal magnet which produced an axial field of 22.4 kG, and which was instrumented with cylindrical and planar proportional wire chambers (PWC's). These were used not only for momentum measurement of the produced charged tracks, but also served to define a cylindrical box surrounding the liquid hydrogen target which played a crucial role in defining the event trigger. More precise measurement of high momentum, low angle charged tracks was accomplished by means of a conventional dipole spectrometer located downstream of the solenoid. The event trigger required at least two outgoing charged tracks in the cylindrical box in addition to an incoming K^-, with the result that a very high triggering efficiency was attained for the complex Ω^- topologies of relevance to the present analysis.

Particle identification was achieved by means of a time-of-flight (TOF) scintillation counter hodoscope, and a threshold Cherenkov counter with pion threshold at 2.6 GeV/c, both located at the downstream end of the solenoid. Further information was obtained from a second threshold Cherenkov counter, with pion threshold at 2.8 GeV/c, located behind the dipole spectrometer. In addition, the cylindrical PWC's surrounding the target provided dE/dx information for large angle tracks with momenta less than ~1 GeV/c.

The entire event sample was processed through track reconstruction, and events consistent with the $\Omega^- \rightarrow \Lambda K^-$ decay topology were identified. A p and π^- track pair were required to meet with separation less than 8 mm, and to yield an effective mass within 8 MeV/c^2 of the nominal Λ mass. The Λ momentum vector was required to point back to within 5 mm of a K^- candidate track, and to be such that the ΛK^- effective mass lay within 35 MeV/c^2 of the Ω^- mass. The negative track formed from the ΛK^- combination was, in turn, required to have length $\geq$4 cm, and to extrapolate to within 1 cm of a primary vertex whose position was determined by a fit to the incoming beam and the other primary charged track candidates in the event. Particle identification information was used to reject events inconsistent with the Ω^- interpretation [4,5], and misidentified γ's were removed from the Λ sample by eliminating events having $|\cos\theta_{\rm H}| \geq 0.98$, where $\theta_{\rm H}$ is the Λ decay helicity angle. At this point there remained a significant contamination due to Ξ^- events which fell within the Ω^- mass window when the decay π^- was interpreted as a K^-. This was removed by eliminating Ω^- candidates for which the $\Lambda\pi^-$ mass was within ±30 MeV/c^2 of the nominal Ξ^- mass. Additional technical details of the Ω^- selection process are to be found in ref. [5].

The remaining sample was subjected to a multi-vertex fitting procedure in which the appropriate geometrical and kinematical vertex constraints were simultaneously imposed in re-fitting the found tracks to their measured coordinates. Events yielding a fit with acceptable χ^2 probability and having an Ω^- candidate track of length greater than 3 cm were retained. The resulting ΛK^- effective mass distribution contains 970 events, and is shown in fig. 1. A strong Ω^- signal is evident above a rather small background. The shaded histogram corresponds to the 680 events having at least one pair of oppositely-charged primary vertex tracks consistent with a $\pi^+\pi^-$ interpretation. Monte Carlo studies yield an Ω^- resolution function which has full width at half-maximum of 7 MeV/c^2. The curve superimposed on the shaded histogram of fig. 1 is obtained from a fit to the data using this resolution function plus a constant background term. The resulting Ω^- mass value is 1671.8 ± 0.3 MeV/c^2; there is an additional systematic uncertainty of 0.3 MeV/c^2. The interval within ±10 MeV/c^2 of the nominal Ω^- mass contains 425 events, of which $\sim$ 86% are Ω^-'s; these events are selected for further study.

Figure 2a shows the $\Omega^-\pi^+\pi^-$ invariant mass distribution corresponding to this sample of Ω^- candidates; a clear peak is observed at $\sim$2.47 GeV/c^2. Although the plot contains an average of 2.3 combinations per event, no event has more than one combination in the peak region. The $\Omega^-\pi^+\pi^-$ mass distribution for the events from fig. 1 differing in mass by more than 10 MeV/c^2 from the nominal Ω^- value shows no signal at $\sim$ 2.47 GeV/c^2. This demonstrates that the signal is indeed associated with Ω^- production.

An estimate of the background level in the vicinity of the peak may be obtained from the wrong-sign combinations, viz. $\Omega^-\pi^\pm\pi^\pm$. Each such combination is given weight 1.56+0.31(M-2.23) in order to reproduce the correct normalization outside the peak region. The resulting mass distribution is shown as the dashed histogram of fig. 2a; no signal is observed at $\sim$ 2.47 GeV/c^2, and a background level of $\sim$40 events per 50 MeV/c^2 is estimated.

The interpretation of the peak at $\sim$2.47 GeV/c^2 as an Ω^{*-} depends critically upon the identification of the charged particle pair as pions. Strangeness, energy and baryon number conservation make it highly improbable that the negative track could be a K^- or $\overline{p}$; similarly, the positive track would not be expected to be a proton. However, overall strangeness conservation implies that a positive particle produced in conjunction with an Ω^- is quite likely to be a K^+. It follows that the peak at $\sim$2.47 GeV/c^2 might be due to the decay of a Ξ^{*-} into $\Omega^-K^+\pi^-$. That this is not the case is shown by the $\Omega^-K^+\pi^-$ mass distribution of fig. 2b; this is obtained from fig. 2a by changing the π^+ mass to the K^+ mass in each combination and re-calculating the three-body effective mass. Clearly, no evidence for peak structure exists when these combinations are treated as $\Omega^-K^+\pi^-$. In a similar way, interpretations of the $\pi^+\pi^-$ pair as e^+e^-, π^+K^- or K^+K^- fail to yield any narrow structure in the corresponding mass spectrum.

It is desirable to have more direct evidence that the signal in fig. 2a is indeed associated with π^+ tracks. In this regard, it should be noted that the detection of the Ω^{*-}(2250) depended crucially on the Cherenkov identification of the final state K^- [1–3]. Unfortunately, very few of the π^+ candidates for reaction (1) have momentum above Cherenkov threshold. This is indicated explicitly in fig. 2a, where combinations involving a Cherenkov-identified π^+ are shown shaded; obviously they have no bearing on the interpretation of the signal in the present analysis.

A significant number of the charged tracks produced in conjunction with the Ω^- have TOF or dE/dx measurements available. The momentum dependence of such information for charged kaons is illustrated in fig. 3 using events from the reaction

$$K^- p \to K^- K^+ \Lambda \tag{2}$$

in the present experiment. The events chosen correspond mainly to baryon exchange production of Ξ^{*-} (1830). Consequently, they yield a small, but very clean, sample of K^-'s with TOF measurement (fig. 3a), and a somewhat larger, high purity sample of K^+'s having dE/dx information (fig. 3d).

In fig. 3a, the abscissa is the difference (in standard deviations) between the TOF calculated under the kaon mass assumption, $\mathrm{t}^K_{\mathrm{calc}}$, and the measured value, $\mathrm{t}_{\mathrm{meas}}$. The observed distribution is, to a good approximation, a vertical band localized within $\sim \pm 2\sigma$ of the origin, as would be expected for a pure K^- sample. In fig. 3d, the abscissa is the natural logarithm of the kaon to pion probability ratio, $\mathrm{P}_K/\mathrm{P}_\pi$, as derived from the induced cathode pulse height signals in the cylindrical PWC's [4]. For momenta less than ~0.4 GeV/c, the kaon interpretation is clearly preferred; at higher momentum, the distribution is a vertical band centered at the origin.

The corresponding TOF distributions for the negatively and positively charged tracks produced in association with an Ω^- are shown in figs. 3b and 3c, respectively. The distribution of fig. 3b is confined almost entirely to the region of positive abscissa, in contrast to that observed in fig. 3a. Furthermore, when the TOF is re-calculated using the pion mass, the distribution of fig. 3b becomes a narrow vertical band centered at the origin, demonstrating that the negative tracks are almost entirely π^-'s, as expected. In contrast, the distribution of fig. 3c appears to be a superposition of those in figs. 3a and 3b, i.e., the positive track sample contains both π^+'s and K^+'s, again as expected. However, it is clear from figs. 3a and 3b that the sample having positive abscissa in fig. 3c should contain almost all of the π^+'s together with approximately half the K^+'s, whereas that with negative abscissa should also contain approximately half the K^+'s but only a small fraction of the π^+'s.

In fig. 2c, the solid histogram corresponds to those $\Omega^-\pi^+\pi^-$ combinations for which the positive track has positive abscissa in fig. 3c; the dashed histogram represents those for which it has negative abscissa. A signal similar in position, shape and significance to that of fig. 2a, is observed in the solid histogram; no signal is observed in the dashed histogram. This demonstrates that the signal is associated with genuine $\pi^+\pi^-$ pairs. Furthermore, in the difference between the solid and dashed histograms of fig. 2c, the contribution from mis-identified K^+'s should cancel, within statistics, thereby yielding a "net TOF-identified π^+" distribution. This distribution constitutes one contribution to the histogram of fig. 2d.

A second contribution to fig. 2d is obtained by following a similar procedure with regard to the distributions of figs. 3e and 3f. These correspond, respectively, to negatively and positively charged tracks with dE/dx information produced in conjunction with an Ω^-. The distributions of figs. 3d and 3e are quite different, and again indicate that the negative tracks are almost all π^-'s. The positive track distribution (fig. 3f) appears to have π^+ and K^+ components, as expected. If tracks with momentum $\leq$ 0.4 GeV/c and positive abscissa are removed, the residual K^+ component should be approximately symmetric about the origin (cf., fig. 3d). For the remaining tracks, the difference between the $\Omega^-\pi^+\pi^-$ distributions for those having negative and those having positive abscissae in fig. 3f then constitutes a "net dE/dx-identified π^+" distribution. This contains a signal of about 10 events at $\sim$ 2.47 GeV/c^2, and has been added to that obtained on the basis of the TOF information to form the "net identified π^+" distribution of fig. 2d; in this regard it should be noted that none of the positive tracks has both TOF and dE/dx information. A signal estimated as ~ 60% of that in fig. 2a, and of similar significance, is observed at ~2.47 GeV/c^2.

It follows from the above that the signal observed in fig. 2a is indeed associated with genuine $\pi^+\pi^-$ pairs, and thus constitutes the observation of a new Ω^{*-} resonant state. The distribution of fig. 2a has been fit by a phase-space term multiplying an S-wave Breit-Wigner line shape [3] plus a fifth-order polynomial background. The result, shown by the solid curve in fig. 4, has a χ^2 of 15 for 20 degrees of freedom, and gives mass and width parameter values

$$M_0 = 2474 \pm 12 \quad \mathrm{MeV/c^2}$$

$$\Gamma_0 = \quad 72 \pm 33 \quad \mathrm{MeV/c^2} \quad .$$

The corresponding signal is estimated to contain 59 events over a background of 71 in the mass interval 2.43–2.53 GeV/c^2, and thus represents a seven standard deviation effect. The mass scale uncertainty is less than 1 MeV/c^2; furthermore the $\Omega^-\pi^+\pi^-$ mass resolution function has full width at half-maximum ~22 MeV/c^2 at ~ 2.47 GeV/c^2, so that resolution effects are negligible compared to the uncertainty of the width measurement.

In order to estimate systematic effects due to the assumed background form, the mass spectrum of fig. 4 was re-fit in the restricted range 2.23–2.78 GeV/c^2 using a background having a linear mass dependence. The resonance mass and width parameters obtained, viz. 2477 ± 10 and 22 ± 57 MeV/c^2, indicate corresponding systematic uncertainties ~5 MeV/c^2 and ~25 MeV/c^2, respectively; the significance of the signal is slightly reduced, but remains at the 5.5 σ level. Finally, it should be noted that even the dashed histogram of fig. 2a, which provides a further estimate of the background level in the interval 2.43–2.53 GeV/c^2, results in a signal of ~5.5 σ significance in this range.

The $\Omega^-\pi^+\pi^-$ distribution observed in a hyperon beam experiment at 116 GeV/c exhibits no clear signal at ~2.47 GeV/c^2 [6]. However, the great differences in beam momentum, $\Omega^-\pi^+\pi^-$ production environment and acceptance limitations make direct comparison difficult.

The acceptance for an Ω^{*-} of mass 2474 MeV/c^2 decaying to $\Omega^-\pi^+\pi^-$ was estimated using a Monte Carlo generated sample. Events with distributions in missing mass squared, primary particle multiplicity and x (Feynman) similar to the data were generated, and the particles projected through the LASS spectrometer to simulate PWC, Cherenkov and TOF data, etc.. These were then submitted to the same analysis chain and event selection criteria as the real data, and a data summary tape of Monte Carlo events was written. In this way, the average overall acceptance was found to be ~22 %; this yields an estimated inclusive cross section of 290 ±90 nb for production of $\Omega^{*-}(2474)$, with isotropic decay to $\Omega^-\pi^+\pi^-$ or $\Omega^-\pi^0\pi^0$.

The recoil dipion system in the $\Omega^{*-}(2474)$ decay is required to have isospin zero to be consistent with the Ω^{*-} interpretation. The dipion mass and angular distributions for events in the $\Omega^-\pi^+\pi^-$ peak and sideband regions have been examined. There is no evidence for ρ^0 ($I = 1$) in the mass plots, and all distributions are quite consistent with the corresponding Monte Carlo distributions resulting from pure s-wave (isotropic) dipion generation.

Existing predictions for Ω^{*-} states at masses up to $\sim$ 2380 MeV/c^2 [7,8] have been summarized in ref. [3]. The states in this mass range have spins up to 7/2, and both odd and even parity, but predictions for radially excited Ω^{*-} states have not been made. It follows that the $\Omega^{*-}(2474)$ lies beyond the range of current theoretical prediction.

In conclusion, evidence has been presented for the existence of a new Ω^{*-} resonance with mass 2474±12 MeV/c^2 and width 72±33 MeV/c^2. The signal, which has at least

5.5 σ significance, has been observed in the $\Omega^-\pi^+\pi^-$ decay mode, and is estimated to have an inclusive production cross section (after correction for $\Omega^-\pi^0\pi^0$ decay) of 290 ±90 nb in K^-p interactions at 11 GeV/c.

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REFERENCES

[1] D. Aston et al., Contributed talk given by B. Ratcliff in session P09 at the *International Europhysics Conference on High Energy Physics,* Bari, Italy, July 1985. See S. Cooper, Rapporteur Talk in these conference proceedings, p. 947 and SLAC–PUB–3819.

[2] S. F. Biagi et al., Zeits. Fur Physik, **C31** (1986) 33.

[3] D. Aston et al., Phys. Lett. **B194** (1987) 579.

[4] D. Aston et al., SLAC–REP–298; J. P. Sinervo, Ph.D. Thesis, SLAC–REP–299, May 1986, N. Awaji, Ph.D. Thesis, Nagoya University (Jan. 1987) [unpublished].

[5] J. D'Amore, Ph.D. Thesis, University of Cincinnati (1988) [unpublished].

[6] P. Rosselet, *Proceedings of the Second International Conference on Hadron Spectroscopy*, KEK, Tsukuba, Japan, April 1987.

[7] J. M. Richard, Phys. Lett. **100B** (1981) 515.

[8] N. Isgur and G. Karl, Phys. Rev. **D19** (1979) 2653.

FIGURE CAPTIONS

1. The ΛK^- mass distribution for the inclusive Ω^- events; the shaded histogram corresponds to those events having at least one pair of oppositely-charged primary vertex tracks consistent with a $\pi^+\pi^-$ interpretation; the curve is described in the text.

2. (a) The inclusive $\Omega^-\pi^+\pi^-$ mass distribution for those events within ± 10 MeV/c^2 of the nominal Ω^- mass in the shaded histogram of fig. 1; for the $\pi^\pm$ tracks, any available particle identification information must be consistent with the pion mass assignment. The shaded histogram corresponds to Cherenkov-identified π^+'s. The dashed histogram represents the $\Omega^-\pi^\pm\pi^\pm$ distribution weighted as described in the text. (b) The mass distribution obtained from the solid histogram of fig. 2a when the π^+ track is given the K^+ mass. (c) The $\Omega^-\pi^+\pi^-$ mass distribution corresponding to those π^+ tracks having TOF information such that $t^K_{\text{calc}} \geq t_{\text{meas}}$; the dashed histogram is for those having $t^K_{\text{calc}} \leq t_{\text{meas}}$. (d) The $\Omega^-\pi^+\pi^-$ mass distribution for the " net identified π^+ " sample described in the text.

3. (a)–(c) The momentum dependence of the difference between time-of-flight calculated on the assumption of the kaon mass (t^K_{calc}) and the measured value: (a) for K^-'s from reaction (2); (b) for negative, and (c) for positive primary tracks produced in association with an Ω^-. (d)–(f) The momentum dependence of the natural logarithm of the kaon to pion probability ratio for tracks having dE/dx information from the cylindrical PWC package surrounding the target: (d) for K^+'s from reaction (2); (e) for negative, and (f) for positive primary tracks produced in association with an Ω^-.

4. The histogram is the solid histogram of fig. 2a; the curve is obtained from a fit using an s-wave Breit-Wigner line shape plus a polynomial background (dashed curve); the resulting mass and width values are as indicated.

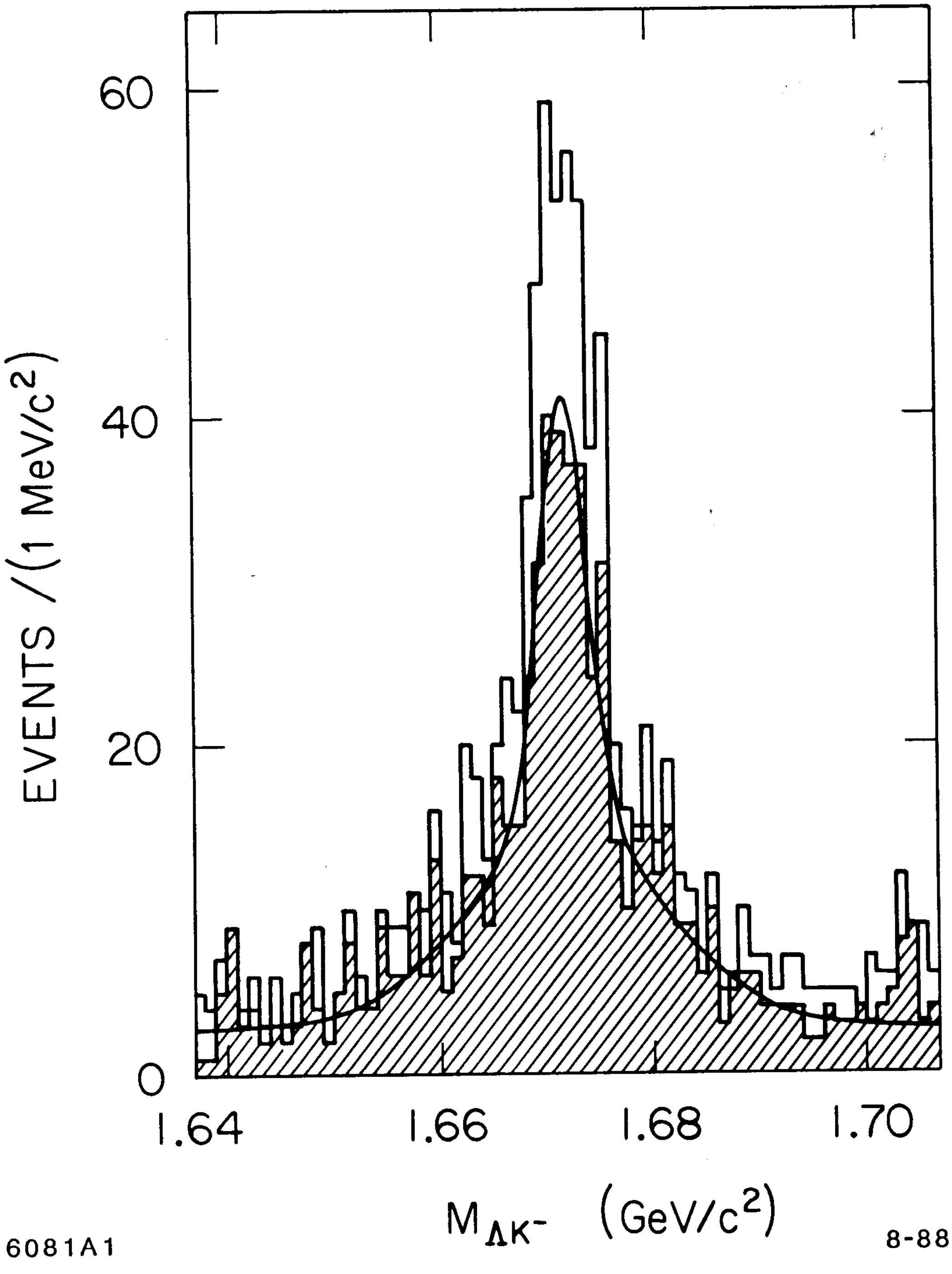
60
40
20
0
EVENTS /(1 MeV/c^2)
1.64
1.66
1.68
1.70
$M_{\Lambda K^-}$ (GeV/c^2)
6081A1
8-88

Fig. 1

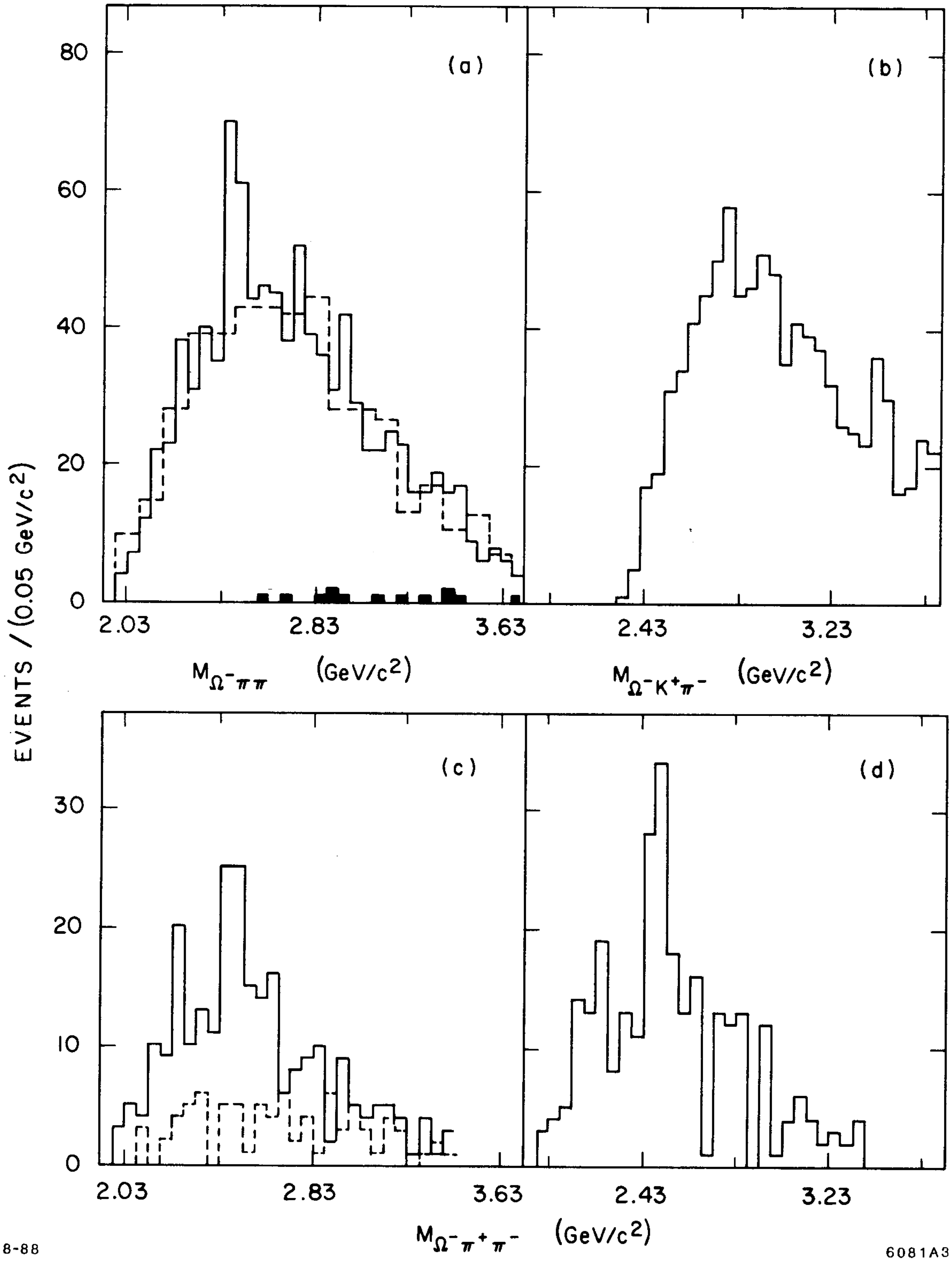

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Fig. 2

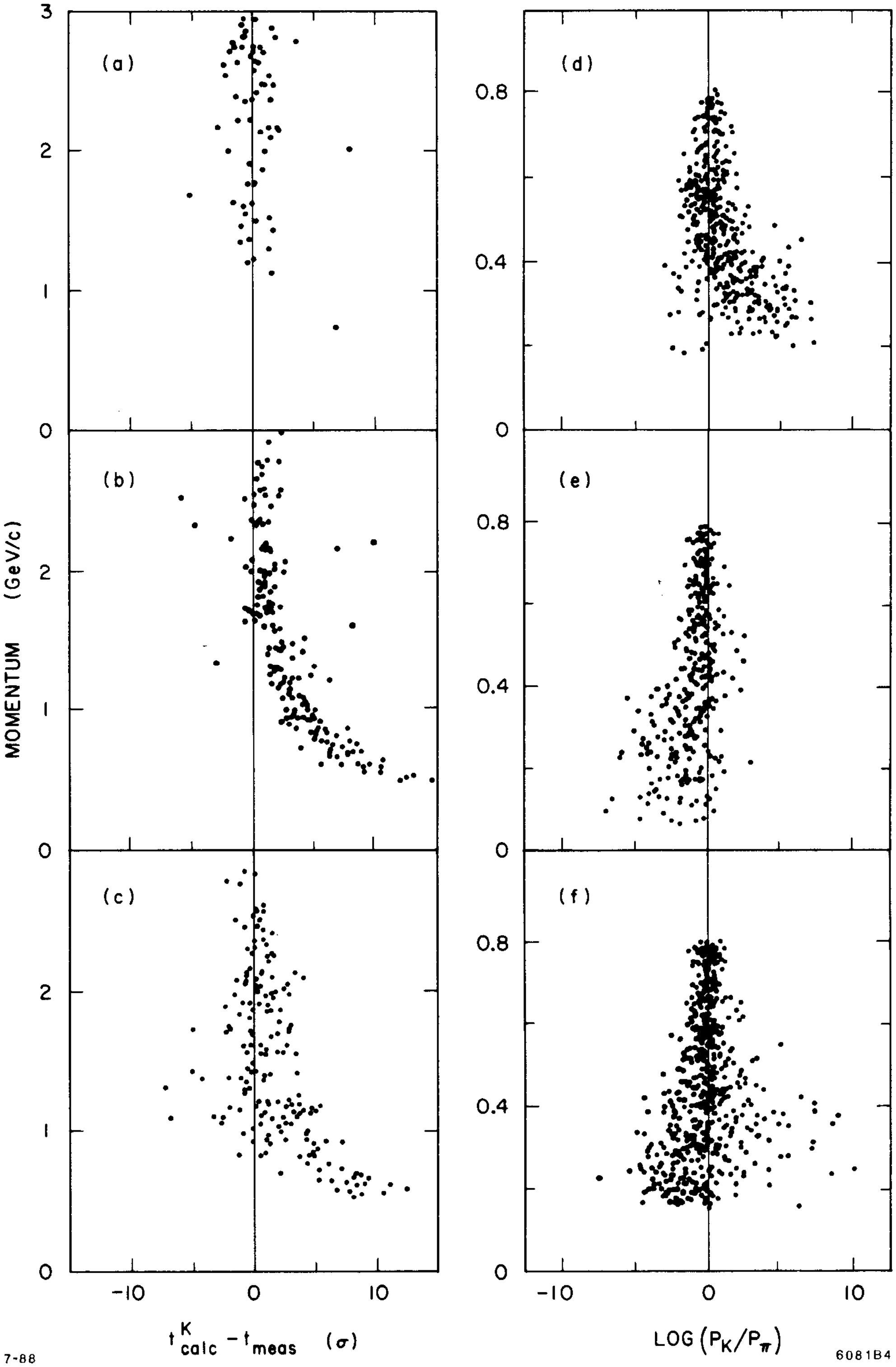
(a)
(b)
(c)
(d)
(e)
(f)
MOMENTUM (GeV/c)
0
1
2
3
0
0.4
0.8
-10
0
10
$t^K_{calc} - t_{meas}$ (σ)
LOG (P_K/P_π)
7-88
6081B4

Fig. 3

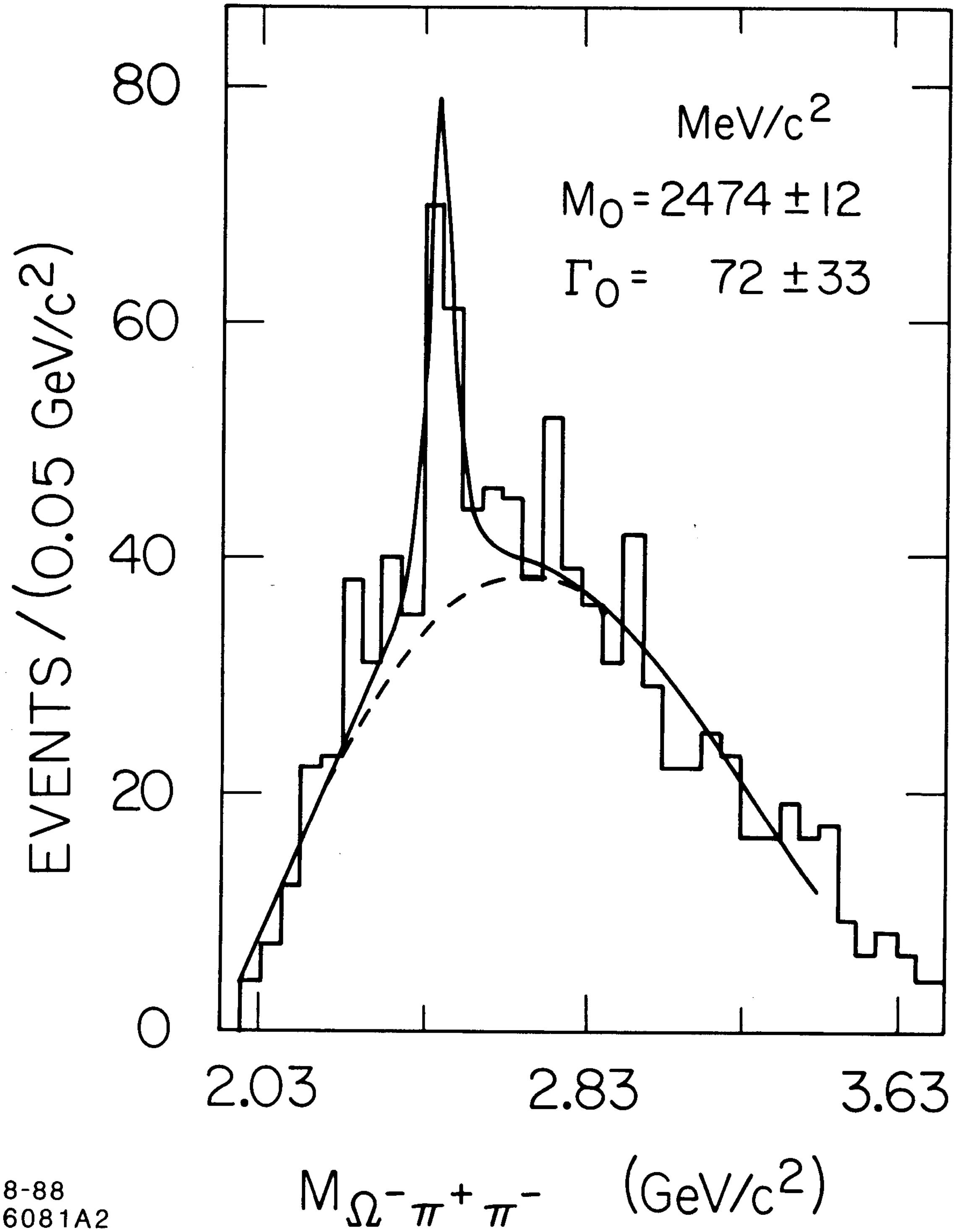

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Fig. 4