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OMEGA PRODUCTION IN $pp \to pp\,\pi^+\pi^-\pi^0$ AT 6.6 GeV/c *

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ABSTRACT

We present a study of the 3π system in $pp \to pp\,\pi^+\pi^-\pi^0$ at 6.6 GeV/c. Both $\eta(549)$ and $\omega(783)$ production are observed. The Dalitz plot is displayed for the $pp\omega$ events, in addition to several other experimental distributions. There is no evidence for $p\omega$ resonances. The $pp\omega$ events have been assigned separately to the six possible multiperipheral diagrams on the basis of criteria in the four-momentum transfers and c.m. longitudinal momenta, respectively. In addition we discuss the means of achieving an effective diagram separation.

I. INTRODUCTION

We have analyzed 6098 events of the type

$$p + p \to p + p + \pi^+ + \pi^- + \pi^0 \qquad (1)$$

at a laboratory momentum of 6.6 GeV/c. The data were obtained in the Lawrence Radiation Laboratory's 72-inch liquid-hydrogen bubble chamber. The experimental details can be found elsewhere.[1,2] The cross section for reaction (1) is found to be 2.15±0.13 mb at 6.6 GeV/c. Reaction (1) is dominated by $\Delta(1238)$ production[3] and, to a lesser extent, by vector-meson production. Vector-meson production has been reported in proton-proton collisions for beam momenta between 4 and 10 GeV/c.[4-10]

In this work we present a study of $\omega(783)$ production. Since little data on ω production in proton-proton interactions has been reported in the intermediate-energy range, we present the data with the hope that they will supply some understanding of the production mechanisms responsible for the $pp\omega$ intermediate state.

In Section II we discuss the 3π system and the vector-meson production in reaction (1). In Section III we present our conclusions.

II. DISCUSSION

The spectrum of 3π effective mass for the 6098 examples of reaction (1) is displayed in Fig. 1. Both $\eta(549)$ and $\omega(783)$ meson production are observed. We have performed a fit of the $M^2(\pi^+\pi^-\pi^0)$ spectrum to Gaussians for the η and ω resonances, plus a slowly varying background, in order to determine the respective cross sections. The cross sections for $pp\eta$ and $pp\omega$ are presented in Table I along with those values determined from other experiments.[4-10] The tabulated results refer only to the $pp\pi^+\pi^-\pi^0$ final state. Above 5 GeV/c the $pp\eta$ and $pp\omega$ cross sections appear relatively constant if the different methods of determination are considered.

The 3π mass spectra for events occurring in the three denoted regions of 3π c.m. longitudinal momenta are given in Figs. 2(a-c). Figures 2(a-c) indicate that the ω signal/noise ratio increases with the magnitude of the 3π c.m. longitudinal momenta. Another enhancement is present in Fig. 2(b) in the region of 1000 MeV. We estimate by eye that no more than 100 events or 35 μb is represented in this enhance-

ment. However, the maximum cross section to be expected for $\phi(1019)$ production in this final state[11] is no more than 3 or 4 μb so the major part of this effect must be due to other causes.[12]

The high background present under all of the peaks occurring in Figs. 1 and 2 precludes any further analysis of the smaller effects, so we restrict ourselves henceforth to a study of ω production in the reaction.

$$p + p \rightarrow p + p + \omega \qquad (2)$$
$$\omega \rightarrow \pi^+ + \pi^- + \pi^0$$

We define the ω events to be those 671 events with $0.76 < M(\pi^+\pi^-\pi^0) < 0.82$ GeV. The non-ω background in this mass slice is roughly 40% and does contain $\Delta^{++}p\pi^-\pi^0$ events.[13] The ppω Dalitz plot is presented in Fig. 3. The Dalitz plot is not uniformly populated: the points tend to cluster along the boundaries of low $M^2(p\omega)$. The projection of pω mass is given in Fig. 4. Two combinations are plotted for each event. There does not appear to be any significant evidence for resonances in the pω system. The single particle four-momentum transfer distributions for the ppω events are given in Fig. 5. Figure 5(a) is the distribution of the lower of the two possible values of t (we define t to be positive in the physical region) from the beam or target proton to an outgoing proton. Two combinations are plotted for each event. This distribution peaks at low values of t. Figure 5(b) is the distribution of t from the beam proton to the ω. Although Fig. 5(b) does peak at low values of t it is not exemplary of a very peripheral t distribution.

The peripheral nature of the ppω data at 6.6 GeV/c and the apparent absence of resonances in the pω system, in addition to the character of the ppω Dalitz plot, suggest that ω production is proceeding via some multiperipheral process [see Fig. 6(a)]. We would expect the dominant process to involve production of peripheral protons at each outer vertex of Fig. 6(a). Figure 7 displays a t_1 vs t_2 scatter plot where t_i is the lower of the two possible momentum transfers from the beam or target proton to the ith outgoing proton. The multiperipheral nature of some of the ppω events is clearly seen in Fig. 7 in the region of simultaneously small values of t_1 and t_2.

The six multiperipheral processes that can occur for $pp \rightarrow pp\omega$ are shown in Fig. 6(b): they are denoted by Roman numerals I to VI inclusive. Diagrams I and V are restricted to meson exchange, while the processes II, III, IV, and VI require both baryon and meson exchange. One difficulty with a multiperipheral analysis is the assignment of physical events to the correct diagram. The two current methods of diagram separation are the $|t_a + t_b|$ minimum[14] and the $P_{L3} > P_{L4} > P_{L5}$ criteria,[15] where $t_a = -(P_1 - P_3)^2$ and $t_b = -(P_2 - P_5)^2$ in the language of Fig. 6(a). The c.m. longitudinal momentum of the ith particle is denoted by P_{Li}. The results of the two methods of diagram separation as applied to the 671 ppω events are given in Table II for diagrams I through VI. The two different separation procedures yield results consistent with each other. The two diagrams representing only meson exchange (I,V) apparently account for 50-60% of the data.[16]

The interference between two amplitudes generally diminishes as one amplitude becomes weaker in comparison with the other. In Tables III [(A) and (B)] we attempt to indicate the magnitude of the interferences between different amplitudes (i.e., diagrams) as a function of the momentum transfers at the external vertices of Fig. 6(a) (t_a and t_b). Specifically, the events in Tables III[(A) and (B)] were assigned to the six processes by the $|t_a + t_b|$ minimum and $P_{L3} > P_{L4} > P_{L5}$ criteria, respectively. In addition, the numbers within the parentheses represent those events that had simultaneous momentum transfers t_a and t_b, corresponding to the accompanying processes (also in parenthesis), less than the maximum denoted value. For example, in Table III(A), of the 93 events assigned to diagram I with t_a and t_b both less than 0.5 GeV^2, seven events simultaneously had other t_a, t_b combinations corresponding to diagrams II and III, both less than 0.5 GeV^2. The overlapping events can be interpreted as an indication of possible interferences between processes I, II, and III to the tune of roughly 10% when $t < 0.5$ GeV^2. As we take events with higher and higher t values the interference or overlap becomes larger. From Tables III it appears that with enough events one could proceed with a noninterference analysis of ppω production by simultaneously requiring t_a and t_b to be less than 0.5 GeV^2.

III. CONCLUSIONS

At 6.6 GeV/c the cross section for ω meson production in the reaction $pp \rightarrow pp\,\pi^+\pi^-\pi^0$ is 180 ± 23 μb. The ω production systematically accounts for 6-10% of the cross section of the pp3π reaction from

4-10 GeV/c. In the $\pi^+\pi^-\pi^0$ mass spectrum the ω signal/noise ratio increases with the magnitude of the 3π c.m. longitudinal momentum. We have studied the reaction $pp \to pp\omega$ by just considering the 671 events in the 3π mass region of 0.76 - 0.82 GeV. The non-ω background in this mass slice is roughly 40% and does contain $\Delta^{++}p\pi^-\pi^0$ events. The $p\omega$ mass spectrum is peaked at low values and shows no evidence for $p\omega$ resonances.

The momentum transfer distributions of both protons and ω's are peaked at low values. In addition, many of the events are multiperipheral. As a first approximation at separation the 671 $pp\omega$ events were assigned to the six possible multiperipheral diagrams on the basis of the $|t_a + t_b|$ minimum and $P_{L3} > P_{L4} > P_{L5}$ criteria. The two diagrams requiring only meson exchange in both legs account for 50-60% of the $pp\omega$ events. However, an effective separation of diagrams with overlaps less than 10% of the time requires the momentum transfers in each leg to be simultaneously less than 0.5 GeV^2.

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FOOTNOTES AND REFERENCES

* Work supported by the U. S. Atomic Energy Commission.

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13. We find that $\Delta^{++}(1238)$ production accounts for approximately 60% of the $pp\pi^+\pi^-\pi^0$ final state.

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16. The reader should bear in mind that this percentage is only a first approximation. Detailed fits of the ppω data to specific multi-

peripheral models (e.g., Regge model) are necessary to ascertain the actual percentage of the data assigned to each diagram.

Table I. Experimental cross sections for resonance production in $pp \to pp\,\pi^+\pi^-\pi^0$ (in μb).

	Beam Momentum (GeV/c)							
Process	4[4]	4.95[5]	5.52[6]	6[7]	6[8]	6.6	6.92[9]	10[10]
$pp \to pp\eta$	40±20	28±9	20±10	70±50	28±5	29±9	40±10	36±15
$pp \to pp\omega$	80±30	152±18	110±20	180±50	104±12	180±23	140±40	145±30

Table II. Number of events assigned to each diagram illustrated in Fig. 6(b) for the 671 $pp \to pp\omega$ events at 6.6 GeV/c.

	Diagram					
Separation method [see Fig. 6(a)]	I	II	III	IV	V	VI
$\lvert t_a + t_b \rvert$ minimum	200	77	88	89	151	66
$P_{L3} > P_{L4} > P_{L5}$	221	68	79	65	182	56

Table III. Number of events assigned to each diagram [illustrated in Fig. 6(b)] with t_a, t_b both less than the maximum value listed in column 1. The numbers in parenthesis represent those events that also have t_a, t_b combinations, corresponding to the processes (also in parenthesis), both less than the same maximum value.

(A) Diagram separation by $|t_a+t_b|$ minimum criteria.

Maximum t_a,t_b value (GeV^2)	Diagram I	II	III	IV	V	VI
0.3	33(0)	16(0)	16(0)	11(0)	23(0)	9(0)
0.5	93(7,II,III)	33(4,I)	35(4,I)	41(4,V)	68(8,IV,VI)	25(2,V)
0.7	126(24,II,III)	48(13,I)	47(10,I)	48(12,V)	93(26,IV,VI)	39(7,V)
1.0	154(74,II,III)	54(24,I)	69(28,I)	58(28,V)	125(52,IV,VI)	45(22,V)

(B) Diagram separation by $P_{L3}>P_{L4}>P_{L5}$ criteria.

Maximum t_a,t_b value (GeV^2)	Diagram I	II	III	IV	V	VI
0.3	33(0)	16(0)	16(0)	11(0)	23(0)	9(0)
0.5	97(13,II,III)	29(2,I)	32(0)	32(0)	74(21,IV,VI)	21(0)
0.7	132(39,II,III)	39(10,I)	41(7,I)	37(7,V)	101(43,IV,VI)	33(4,V)
1.0	164(91,II,III)	44(18,I)	62(24,I)	44(18,V)	141(73,IV,VI)	38(16,V)

FIGURE CAPTIONS

Fig. 1. $\pi^+\pi^-\pi^0$ invariant mass for the 6098 pp → pp $\pi^+\pi^-\pi^0$ events at 6.6 GeV/c.

Fig. 2. $\pi^+\pi^-\pi^0$ invariant mass subject to selection on the 3π c.m. longitudinal momentum:

(a) $P_L < 0.3$ GeV/c

(b) $0.3 < P_L < 0.6$ GeV/c

(c) $P_L > 0.6$ GeV/c.

Fig. 3. ppω Dalitz plot for the 671 events with $0.76 < M(\pi^+\pi^-\pi^0) < 0.82$ GeV.

Fig. 4. The pω invariant mass for the 671 pp → ppω events at 6.6 GeV/c. Two combinations are plotted for each event.

Fig. 5. Four-momentum transfer distributions for the 671 pp → ppω events at 6.6 GeV/c:

(a) The lower of the two possible values of t from the beam or target proton to an outgoing proton. Two combinations are plotted for each event.

(b) t from the beam proton to the ω.

Fig. 6. (a) Double peripheral diagram. (b) The six possible multiperipheral diagrams for the reaction pp → ppω.

Fig. 7. t_1 vs t_2 scatter plot for the 671 pp → ppω events at 6.6 GeV/c. t_i is the lower of the two possible momentum transfers from the beam or target proton to the i outgoing proton.

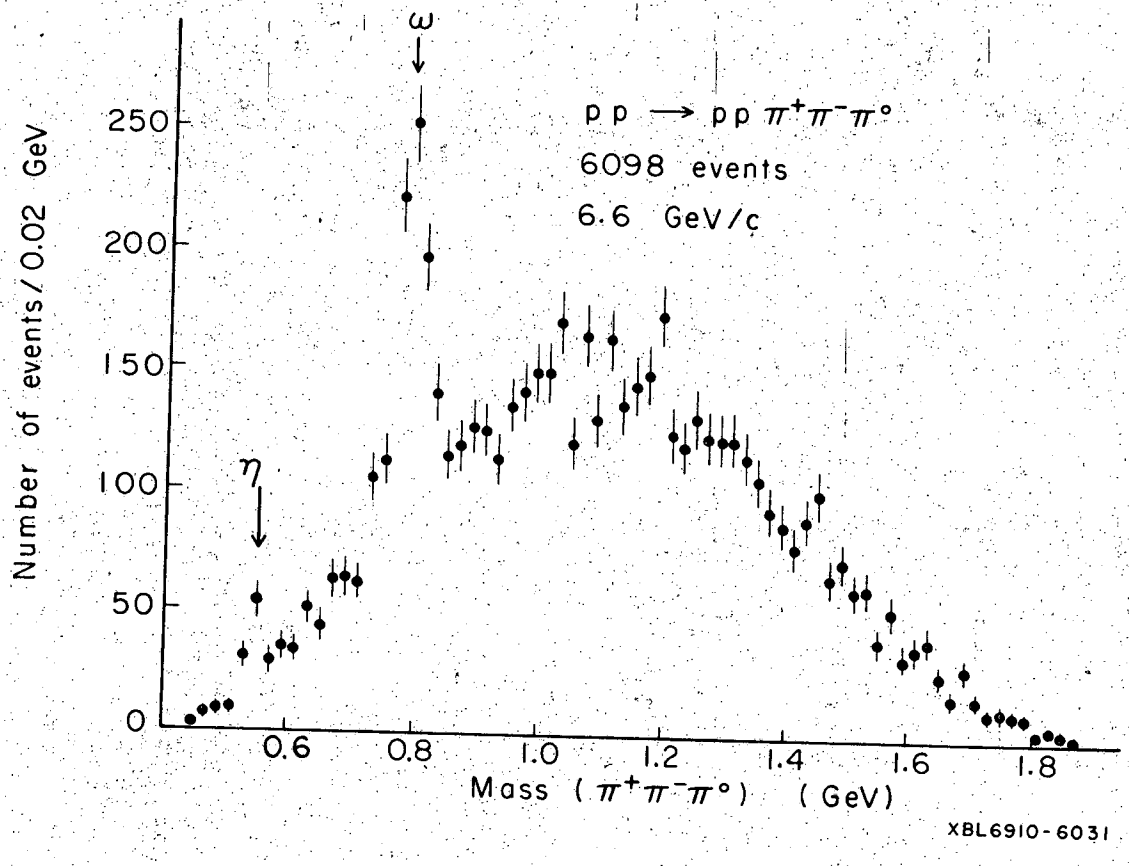
ω
η
pp → pp π⁺π⁻π°
6098 events
6.6 GeV/c
Number of events/0.02 GeV
0
50
100
150
200
250
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Mass (π⁺π⁻π°) (GeV)
XBL6910-6031

Fig. 1.

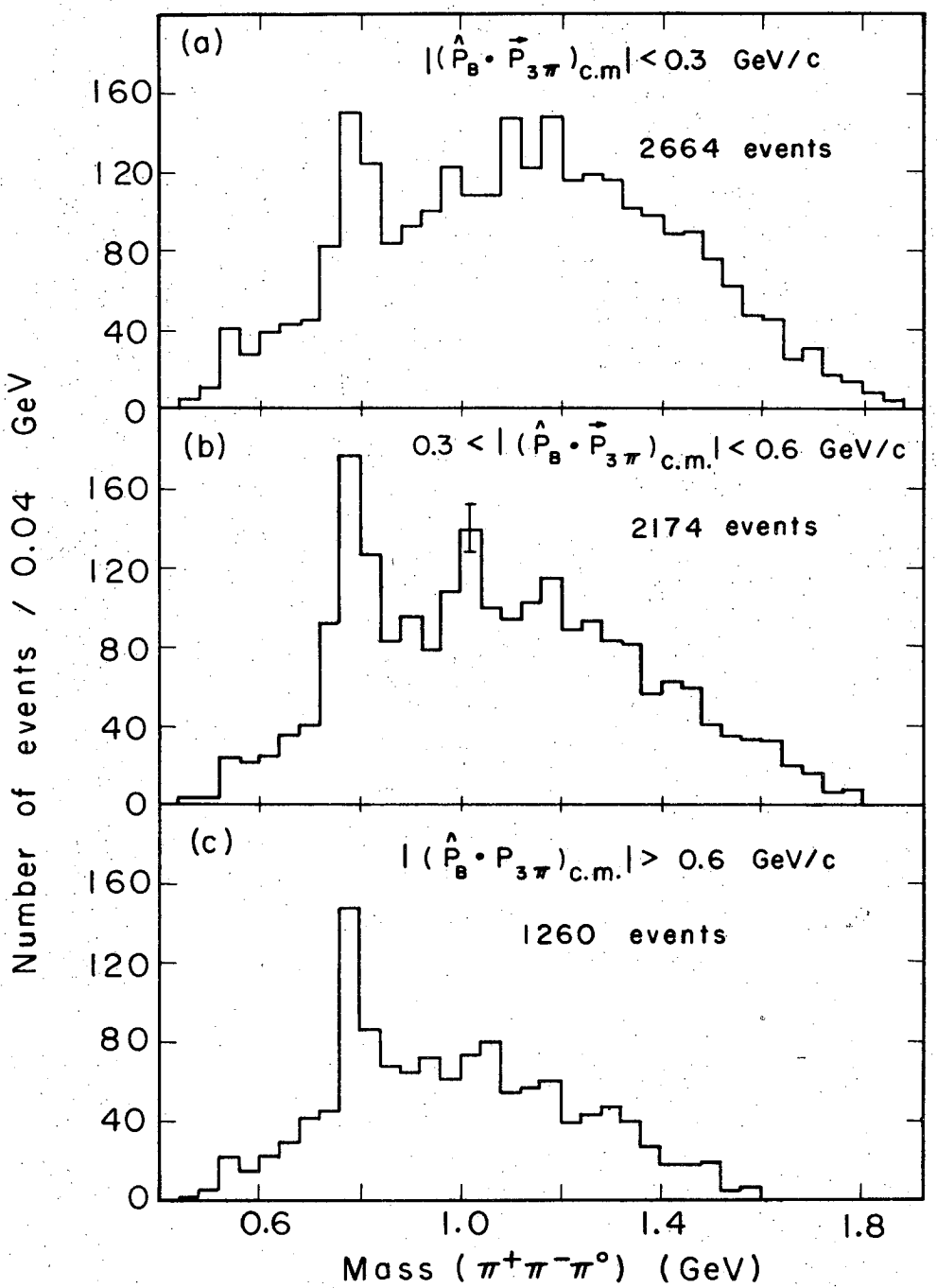
(a)
$|(\hat{P}_B \cdot \vec{P}_{3\pi})_{c.m}| < 0.3$ GeV/c
2664 events
(b)
$0.3 < |(\hat{P}_B \cdot \vec{P}_{3\pi})_{c.m.}| < 0.6$ GeV/c
2174 events
(c)
$|(\hat{P}_B \cdot P_{3\pi})_{c.m.}| > 0.6$ GeV/c
1260 events
Number of events / 0.04 GeV
Mass ($\pi^+\pi^-\pi^0$) (GeV)
0
40
80
120
160
0.6
1.0
1.4
1.8
XBL6910-6032

Fig. 2.

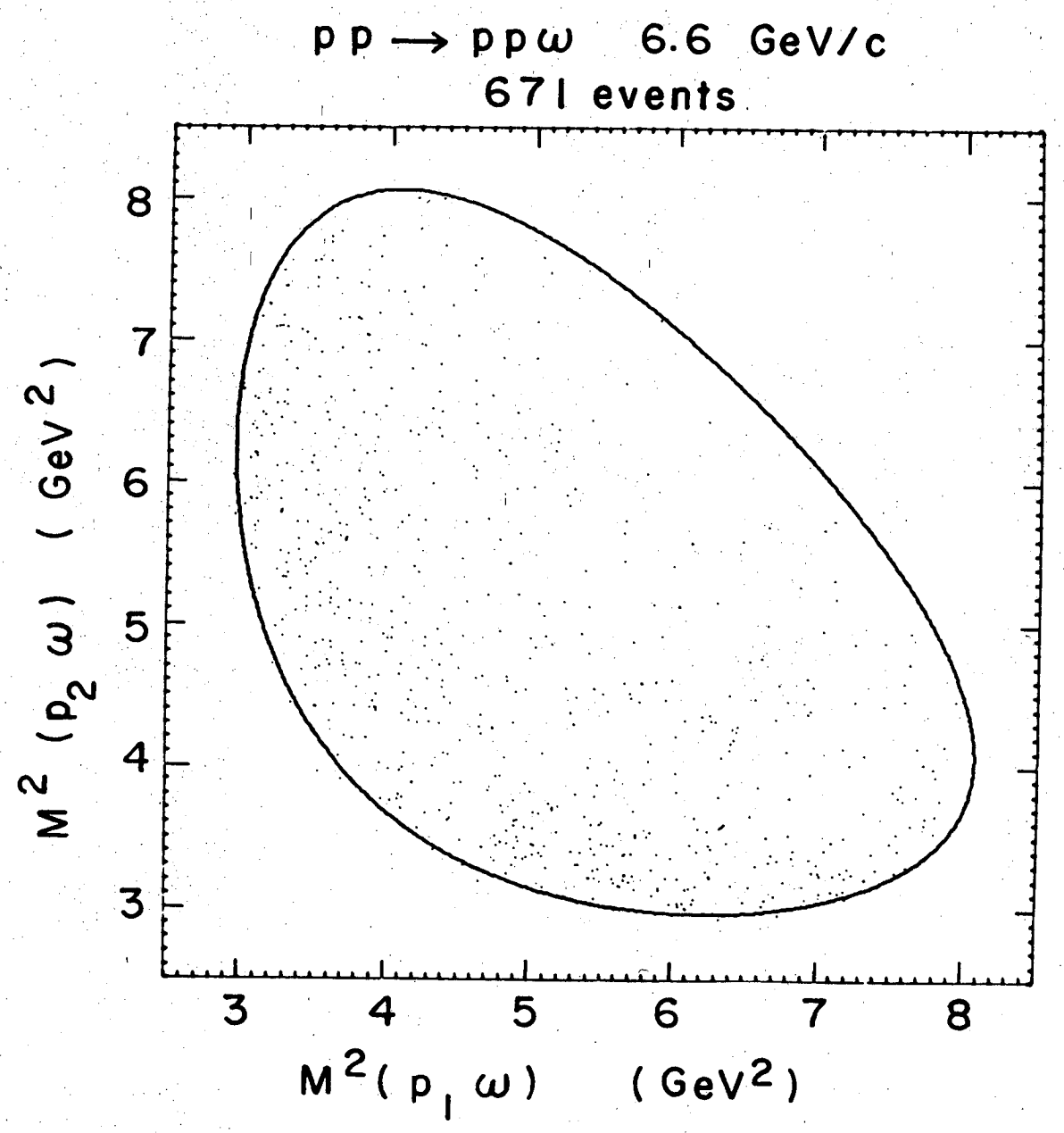

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Fig. 3.

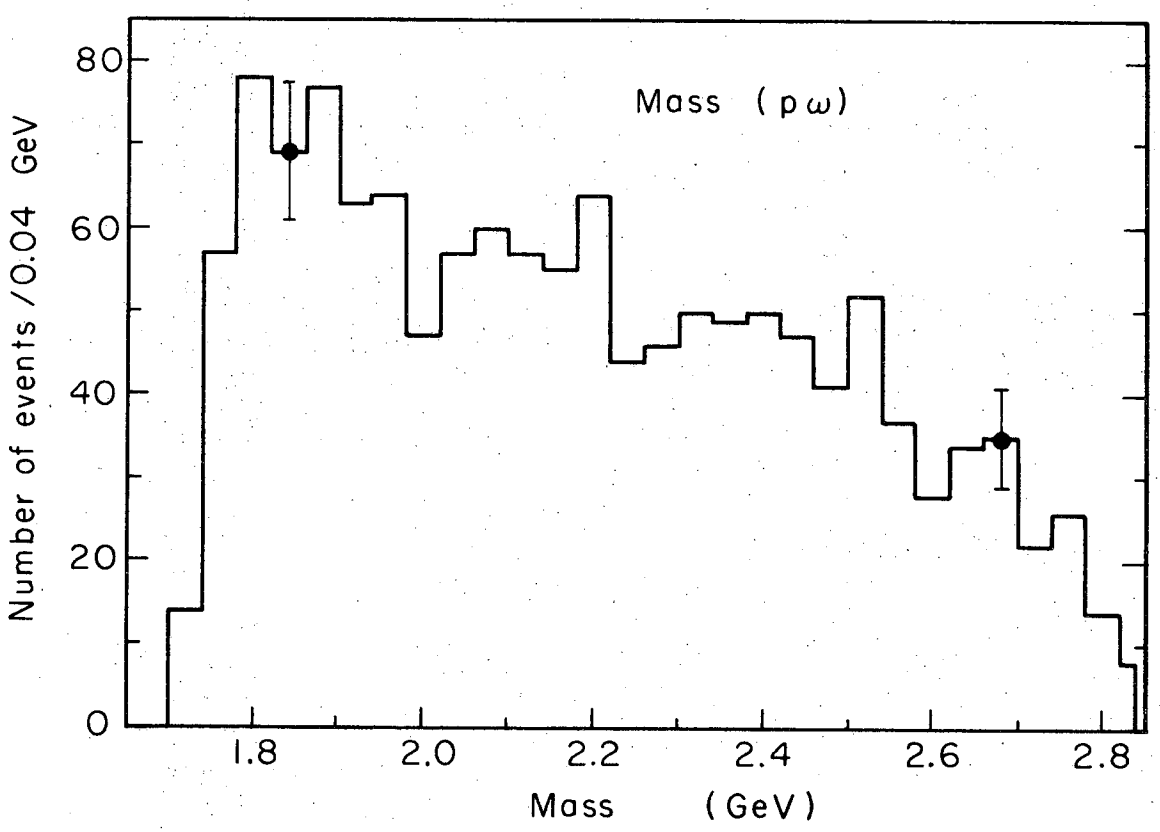

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Fig. 4.

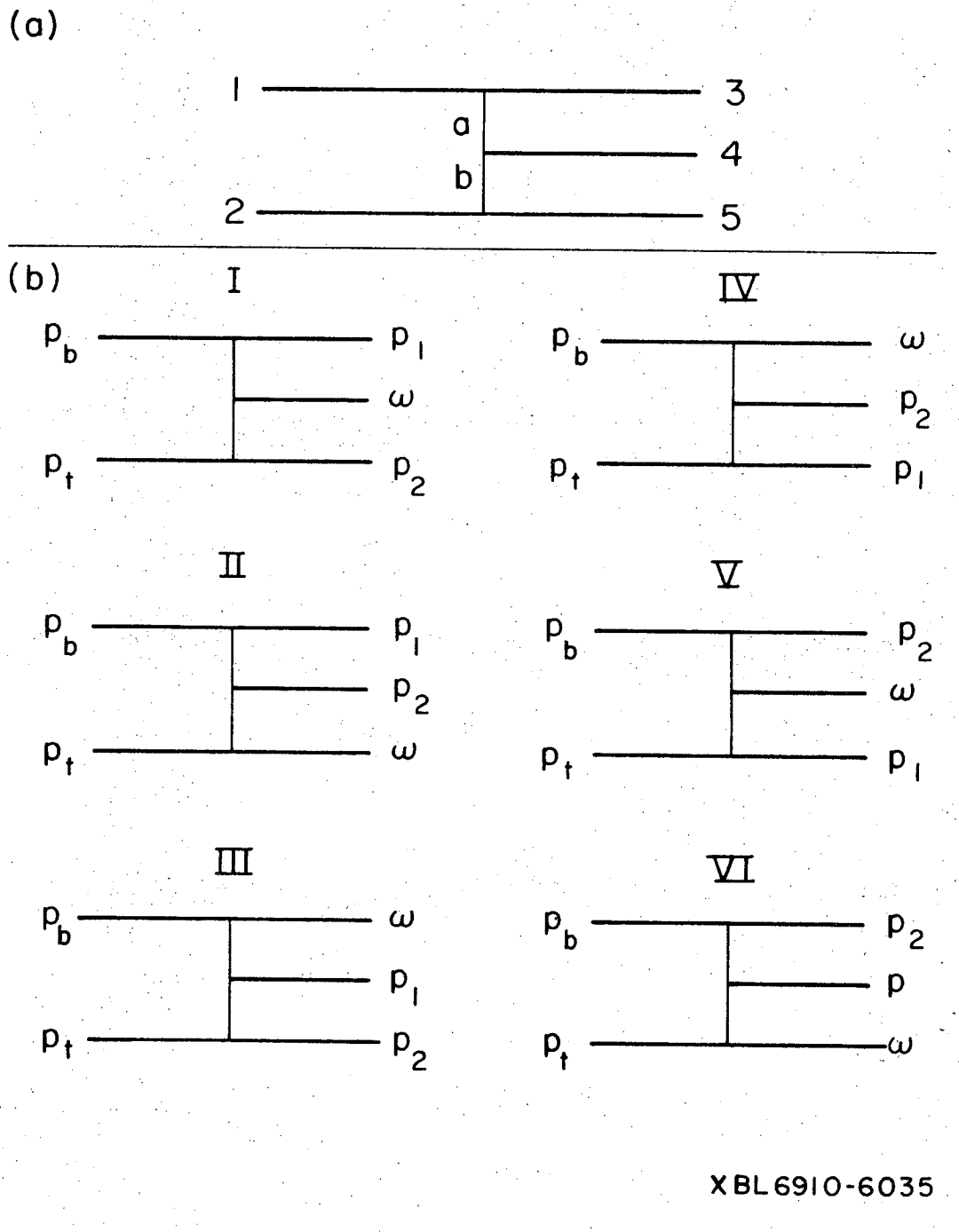

(a)
1
2
a
b
3
4
5
(b)
I
p_b
p_t
p_1
p_2
ω
II
p_b
p_t
p_1
p_2
ω
III
p_b
p_t
ω
p_1
p_2
IV
p_b
p_t
ω
p_2
p_1
V
p_b
p_t
p_2
ω
p_1
VI
p_b
p_t
p_2
p
ω
XBL6910-6035

Fig. 6.

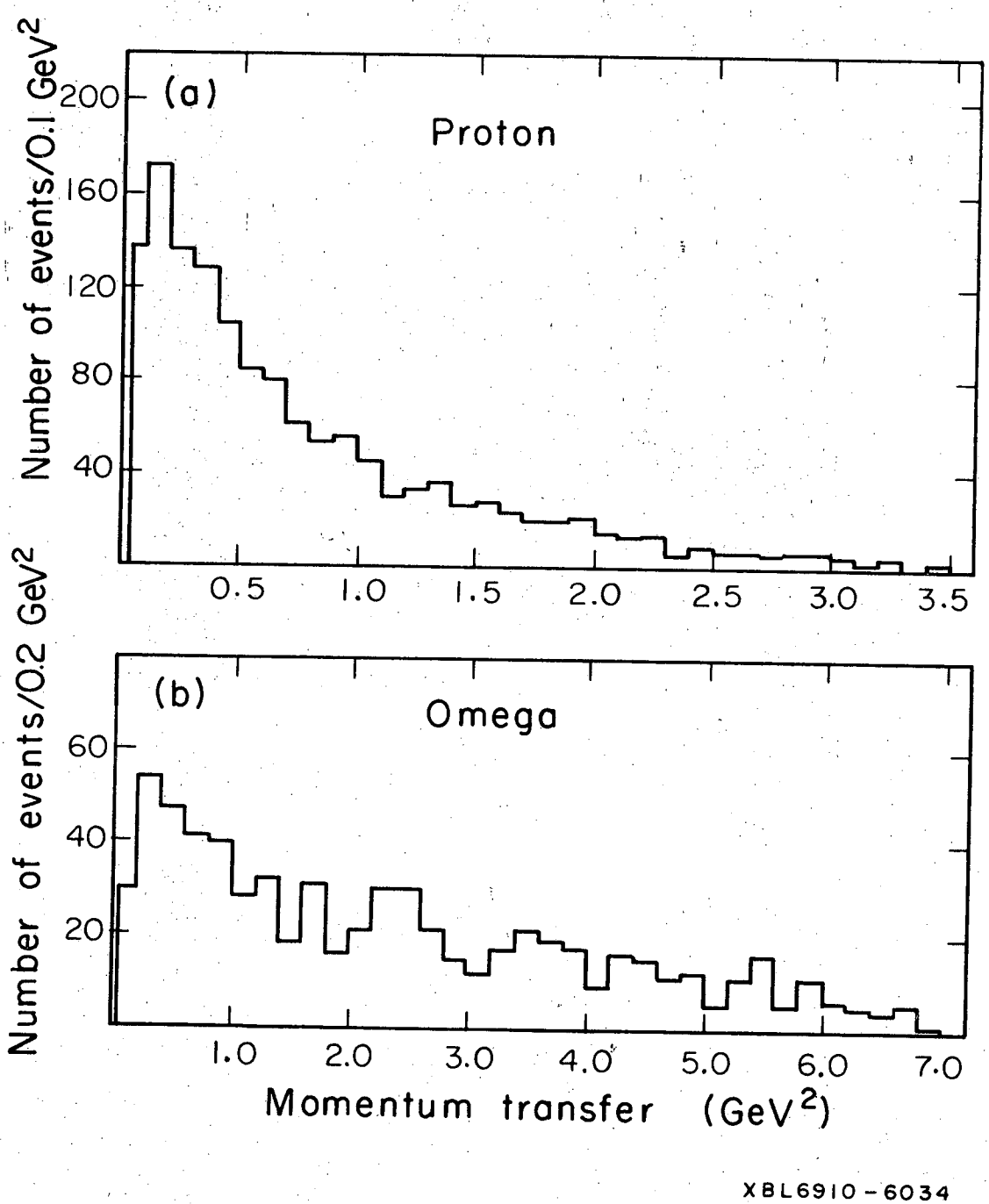
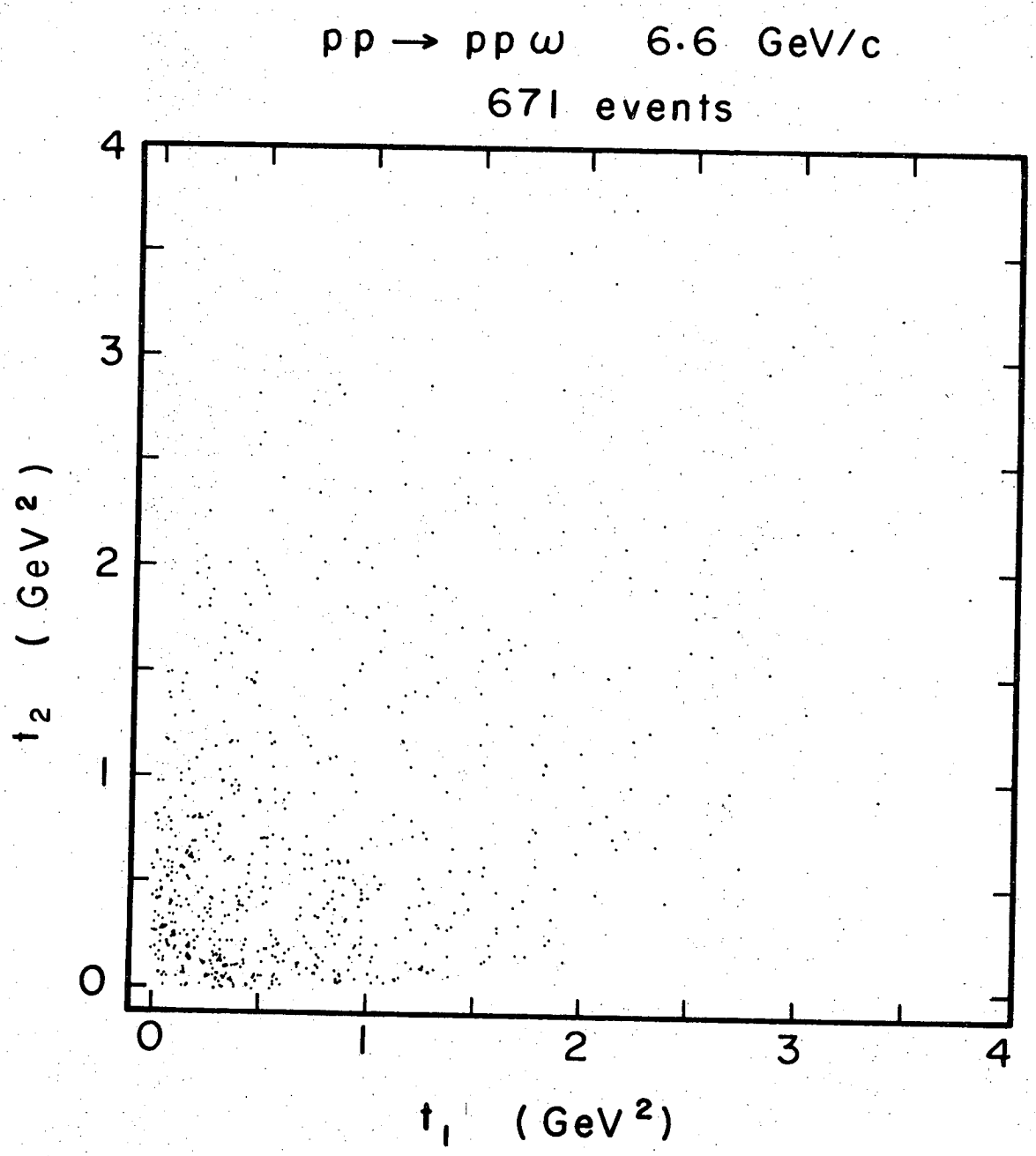

(a)
Proton
Number of events/0.1 GeV²
200
160
120
80
40
0.5
1.0
1.5
2.0
2.5
3.0
3.5
(b)
Omega
Number of events/0.2 GeV²
60
40
20
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Momentum transfer (GeV²)
XBL6910-6034

Fig. 5.



XBL6910 - 6036

Fig. 7.

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