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A MULTI-REGGE MODEL APPLIED TO HIGH-ENERGY INCLUSIVE PHOTOPRODUCTION*

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ABSTRACT

We compare inclusive photoproduction data in the energy range E_γ = 9.0 - 18.0 GeV to the multi-Regge model. The model incorporates vector-dominance coupling of the photon, the Chew-Pignotti algorithm for charge assignment, and correct treatment of n-body phase space. A technique of ordering the particles according to longitudinal momentum is used to enhance features of the data and provide a more sensitive test of the model. We compare the model to mass distributions, separation of particles in rapidity, longitudinal momentum distributions, topological cross-sections and charge orderings of secondaries. A reasonable description of the data is achieved, using parameters derived from pp and K^+p experiments.

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At high accelerator energies, where collision cross sections are dominated by high-multiplicity events, one cannot hope to comprehend interactions in terms of specific exclusive processes as has been widely and successfully attempted at lower energies. The suggestions of Feynman(1) and Yang(2) that these processes be studied through their inclusive characteristics then become appealing. By summing over many exclusive processes, one loses specific details about each individual process; but the compensating hope is that one may thus observe aggregate features(3) which arise from underlying dynamics, and which may not be apparent in specific channels.

This paper applies this approach to a high-energy photoproduction experiment performed using the SLAC 2-meter streamer chamber with hydrogen target.(4) An 18-GeV bremsstrahlung beam is usec and at these energies a majority of events (about 5/6) have neutral pai ticles. Thus the photon energy E_γ is unknown for most events. For each event we therefore calculate a surrogate "visible" photon energy $E_{vis} \equiv |\Sigma \vec{P}_i|$, where the index i refers to charged tracks. For the comparison described here we accept events having $E_{vis} \geqq 9.0$ GeV. The events retained for this study are produced by photons in the rang $E_\gamma = 9 - 18$ GeV (3075, 5205, 1151, and 160 of 3, 5, 7, and 9-prong events, respectively). The events are weighted to account for different film samples and individual geometrical configuration. We have arbitrarily normalized the data presented here such that 5-prong events have unit average weight.

The multi-Regge model we use is similar to that used earlier tc compare to high-energy K^+p and pp experiments.(5) However, the coupling of the photon to the multi-Regge chain requires particular

tention. The "elastic" process $\gamma p \to \rho^0 + p$ makes an important con-
ibution to the cross section. It has been extensively studied and
scribed in terms of the vector-dominance model represented by the
agram of Fig. 1a.(6) This suggests that the coupling of the γ to a
ulti-Regge chain might take the form of Fig. 1b. Here a ρ^0 is dif-
actively excited, in accordance with the vector-dominance picture,
id the exchanged Pomeron then ties onto the multi-Regge chain. This
iain is characterized by an "effective meson" m which propagates to
e target proton sequentially emitting produced pions, in the spirit of
e multi-Regge model of Chew and Pignotti.(7)

Finally, we include a "background" term to the ρ^0, characterized
r Fig. 1c. We do not expect this diagram to accurately describe all
spects of the coupling of the γ other than through the ρ^0, but, within
e multi-Regge framework, to dualistically represent the many other
pes of processes that can occur at the "photon end" of this chain.

To keep the model as simple as possible, we have not included
the present comparison a diagram involving baryon exchange (Fig.
1). We have found that the net effect of such diagrams is to increase
e cross section for high-multiplicity events relative to those of lower
ultiplicity, and also to increase the contribution of backward charged
econdaries. In the present analysis, these effects are relatively
nall.

The matrix-element squared for the diagram of Fig. 1c is given
y

$$|A|^2 = (g^2)^{N-2} \prod_{i=1}^{N-1} \left[\frac{s_i + b}{b}\right]^{2\alpha(t_i)} \beta^2(t_i) = (g^2)^{N-2} \prod_{i=1}^{N-1} P_i(s_i, t_i) \qquad (1)$$

ere s_i, t_i are the invariant sub-energy and momentum transfer
ɹared for the i-th link, $\alpha(t)$ and $\beta(t)$ are the trajectory and residue of
: exchanged Reggeon, g^2 is the coupling constant and b is a constant
osen to be equal to one so that the matrix-element approaches phase
ace at low subenergies. The matrix-element squared for Diagram
is given by

$$BW(M,\Gamma) \cdot \sin^2\theta_H \cdot \left[\frac{M(\rho)}{M(\pi\pi)}\right]^{n(t)} \cdot e^{At} \cdot (s+1)^{2\alpha_P(t)}, \qquad (2)$$

.ere BW is a mass-dependent Breit-Wigner factor, θ_H is the ρ-decay
licity angle, n(t) pertains to the ρ-mass shift, and the last two fac-
:s are related to the exchanged Pomeron. Detailed formulae and
lues of parameters used can be found in the work of Moffeit[6]. The
ıtrix-element squared for the diagram of Fig. 1b is obtained by re-
ıcing the first two propagators P_1 and P_2 of Eq. 1 by the appropriate
rm of Eq. (2).

The parameters of the trajectory $\alpha(t)$, residue $\beta(t)$, and m-m-π
upling constant g^2 are all fixed in advance by previous multi-Regge
alyses of K^+p and pp reactions.[5] (See Table 1) Hence we have only three free
rameters: the overall normalizations of Diagrams 1(a, b, c). All
her features of the model predictions are then fixed. To evaluate
eir predictions, we sum incoherebtly over the diagrams of Fig. 1,
rforming the n-body phase space integrals with the LBL program
.GE.[8] Monte Carlo events in the energy range E_γ = 9.0 - 18.0 GeV
e generated in this manner. An event weight is calculated, based on
e matrix element corresponding to a diagram of Fig. 1, multiplied
· the bremsstrahlung shape. For each such simulated event, charges
e assigned by the Chew-Pignotti charge algorithm.[7]

An important advantage of this procedure is that we incorporat in the model the identical instrumental and programmed selections that the data contain. Specifically, the simulated events are treated as if neutral secondaries are unobserved and a selection on E_{vis} is imposed, as it is for the real events. The simulated events are ger erated with correct masses; in the comparison with data all charged particles are later assigned the mass of the charged pion, μ, both ir real and simulated events.

In an attempt to more sensitively examine the characteristics c secondaries presumed to emerge from various portions of the multi- Regge chain, we have ordered the charged secondaries according to P_L. Thus, we define: 1 ≡ particle with smallest P_L(lab), 2 ≡ particle with next smallest P_L, etc. Figure 2 (a-f) shows the invariant mass distributions of neighboring tracks which have been ordered in this fashion. Separate plots are shown for neighbors with equal and unequal charges. For three-prong events, invariant-mass distributions for the pair of "slowest" particles (1 and 2) are shown in Fig. and for the two fastest particles (2 and 3) in Fig. 2b. Most striking the peak near the ρ^0 mass in the M(2, 3) distribution for unlike charg As found elsewhere, the mass is shifted towards a value lower than the accepted ρ^0 mass. This is conveniently achieved in the model through the mass-dependent factor suggested by Ross and Stodolsky, included in Eq. (2).[9]

Note that the average values of the masses in Fig. 2a are larg a reflection of the small M(2, 3) mass and the presumed Pomeron li of Fig. 1a and 1b. The model underestimates the mass distributio for unlike charges in M(2, 3) at high mass and in M(1, 2) at low mass

These events could come from specific quasi-two processes that are not reproduced by our multi-Regge background.

In Fig. 2 (c-f), the corresponding mass plots for five-prong events are made. Here, the noticeable experimental feature is the pea in the M(4, 5) mass distribution near the ρ^0 mass. The theory over-estimates the distribution for unlike charges and underestimates tha for like charges. These discrepancies could be reduced by allowing charged mesons to be produced at the γ-end of Fig. 1c, a possibility arising naturally within the framework of the ABFST version of the multiperipheral model[12] (see Fig. 1e). The net effect is to in-crease the probability that the first two charged tracks emerging ha charges of the same sign. This detailed end-effect is perhaps the major inadequacy of the Chew-Pignotti model in our comparison.

In Fig. 2e, a small peak appears in the M(3, 4) data at the ρ^0 mass. To within the statistics of the Monte Carlo, this peak does no appear to arise from the "end" ρ^0 of Fig. 1b emerging slowly, but is instead produced "internally". Its source could be a coupling of the form $\gamma \rightarrow A_{1,2}$ (plus pions) $\rightarrow \rho^0$ (plus pions) or $\gamma \rightarrow \rho^0 \rightarrow \rho^0 \pi^+ \pi^-$.[10]

For each event, both in experiment and theory, we also plot th separation in rapidity between neighboring tracks (Fig. 2g). (We de-fine rapidity as $w \equiv (P_L - E)/\sqrt{P_T^2 + \mu^2}$.) The distributions seen ma be regarded as a reflection of the mass distributions of Fig. 2 (a-f). The noticeable features for three-prong events are the large separa-tion between 2 and 3 when they are of opposite charge. For five-pro events, the low subenergies result in small separations in rapidity. common feature of Fig. (2g) is that like-charged neighbors are alwa further separated than unlike-charged neighbors.

In Fig. 3 we show the longitudinal momentum distribution for positive and negative tracks for 3, 5, and 7 prong events, (Figs. ›, c) as well as summed over all events (Fig. 3d). We note that distributions of positive and negative tracks are very similar in high-momentum range. This is a consequence of the photon fragting into positive and negative secondaries with substantially the e probability. On the other hand, we note an essential difference veen the two distributions near $P_L = 0.0$, in that the positive tracks e a large peak. This effect is due to the high elasticity of the pro-, which leads to the proton emerging at P_L near zero in the lab-tory. (We remark that even at large P_L the positive distribution ls to remain somewhat larger than that for the negative secon-ies.)

As the multiplicity increases, (see Fig. 3b, 3c), the range of contracts as the energy is shared among an increasing number of ticles. Moreover, the difference to be seen between the positive negative distributions becomes smaller as the effect of the ident-proton charge is reduced by the presence of additional charged ondaries.

The model description of the data both in magnitude and shape quite good. In the multi-Regge model, the t - cut off in the prop-tors leads to a Poisson-type of multiplicity dependance, with the istant g^2 fixing the average. From Ref. 5, we have $g^2 = 7$ in ad-ice, and see from Fig. 3 that relative magnitudes of the various ologies is adequately described.(12) In addition, the shapes of the = distributions are accounted for except at $P_L \lesssim 0$. In the 3-prong tribution (Fig. 3a), the model underestimates the slow π^- distribugs. 2a, b. In the 7-prong distribution (Fig. 3c), the low predic- at $P_L \sim 0$ could be improved by including baryon exchange.

In Table 2, we present the relative topological cross sections. three-prong cross section is underestimated, a reflection of the of background in Fig. 2b. The 7-prong cross section is some- underestimated also, although this could be improved with the ısion of baryon exchange; the effect of baryon exchange would be ıise the higher-multiplicity cross sections through the inclusion ·w-Q resonances.

As still a further way of investigating the correlations among the ·ged secondaries, we have evaluated the probability for various igurations of the charged particles in the three-prong events. se data and the theoretical predictions are given in Table 3. Here seen that the configuration having the negative track as number 1 west) is greatly depressed, compared to the other possible con- rations. This of course reflects the γ-coupling to a neutral sys- and the proton's elasticity. The theory tends to exaggerate this ct, which is a reflection of our underestimation of the high-mass kground in Fig. 2a and our underestimation of the P_L distribution negative secondaries at small P_L (Fig. 3a).

The contributions of Diagrams of Fig. 1 to the total cross sec- ı (omitting strange-particle production) required are about 12 μb, ıb and 45 μb, respectively. These amounts refer to the sample ore the E_{vis} selection is made. Thus it would seem that Diagrams and 1c are of roughly comparable magnitude and that γ-($\rho \rightarrow 2\pi$) cou- ıg does not dominate higher multiplicity processes to the degree t it dominates the three-prong events.

A significant result of this study is that, using parameters $\alpha(t)$, provision for photon coupling, multibody photoproduction is reasonal described by the multi-Regge model. Thus the model suggests a co nection between these different experiments through their common parameters. This observation provides evidence that the underlying dynamics in γp, K^+p and pp multibody production may be fundamentally similar, except for the particular manner in which the beam particle couples onto the production mechanism.

The novel approach we have taken to compare this type of data with theory (namely, the ordering of tracks by longitudinal momenti and the event-by-event generation and handling of Monte-Carlo event exactly like the data) is a method that may be of great use in the analysis of similar experiments.

In conclusion, we emphasize that the generally adequate descr tion of the data by this model arises from the model incorporating se eral characteristics of photoproduction–(1) elasticity of incident par ticles (as reflected in the P_L distributions of Fig. 3), (2) t cut-off (as reflected in the prong cross sections), (3) γ-ρ^0 coupling (as seen Fig. 2 and Fig. 3), (4) correct evaluation of n-body phase space (a prerequisite for any detailed comparison of a model to data), (5) and the bremsstrahlung spectrum and neutral pion production (which are features of this experiment). Quite likely, these characteristics car be built into other types of models, such as the thermodynamic and diffractive models.[13] While the present comparison does offer a theoretical framework for the nature of the underlying production mechanism, tests must be formulated that can distinguish between th features unique to multiperipheralism and those unique to the other models. Work on this will be reported elsewhere.

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12. In the present comparison, we have the magnitude of Fig. 1a t adjust in reproducing the three prong cross-section.

13. For single particle distributions, the t-cut off of multiperiphalism is equivalent to a P_T cut-off in these models.

Table 1. Parameters in the model

	Meson		Baryon	
$\beta(t)$	$e^{2.1t}$	$t > -0.3$	$e^{1.5t}$	$t > 0.2$
	$c\ e^{0.3t}$	$t < -0.3$	$c'\ e^{0.2t}$	$t < 0.2$
$\alpha(t)$	$t + 0.5$	$t > -0.6$	$t + \alpha_0$	$t > 0$
	$0.5t + 0.3$	$-2 < t < -0.6$	$0.5t + \alpha_0$	$-0.5 < t < 0$
	$0.25t - 0.2$	$t < -2.$	$0.2t + \alpha_0 - .15$	$t < 0.5$
			$\alpha_0 = -1$ if $s > 6$	
			$\alpha_0 = -2$ if $s < 6$	

The value of α_0 gives an adequate fit to a parametrization of the backward $\pi^- p$ elastic cross section, $d\sigma/du \sim (s/s_0)^{2\alpha_0 - 2}$ for $s < 8\ \text{GeV}^2$. It is not the intercept of the canonical Δ^{++} trajectory, which governs $d\sigma/du$ for $s \gtrsim 8\ \text{GeV}^2$. The constants c, c' simple ensure continuity In Eq. (1), we used $g^2 = 7$.

able 2. Relative topological cross sections for $E_{vis} > 9$ GeV.

Topology	Experiment	Theory
3-prong	7570	6008
5-prong	5205	5482
7-prong	2803	2254

le 3. Relative charge ordering of 3-prong events ($E_{vis} > 9$ GeV).

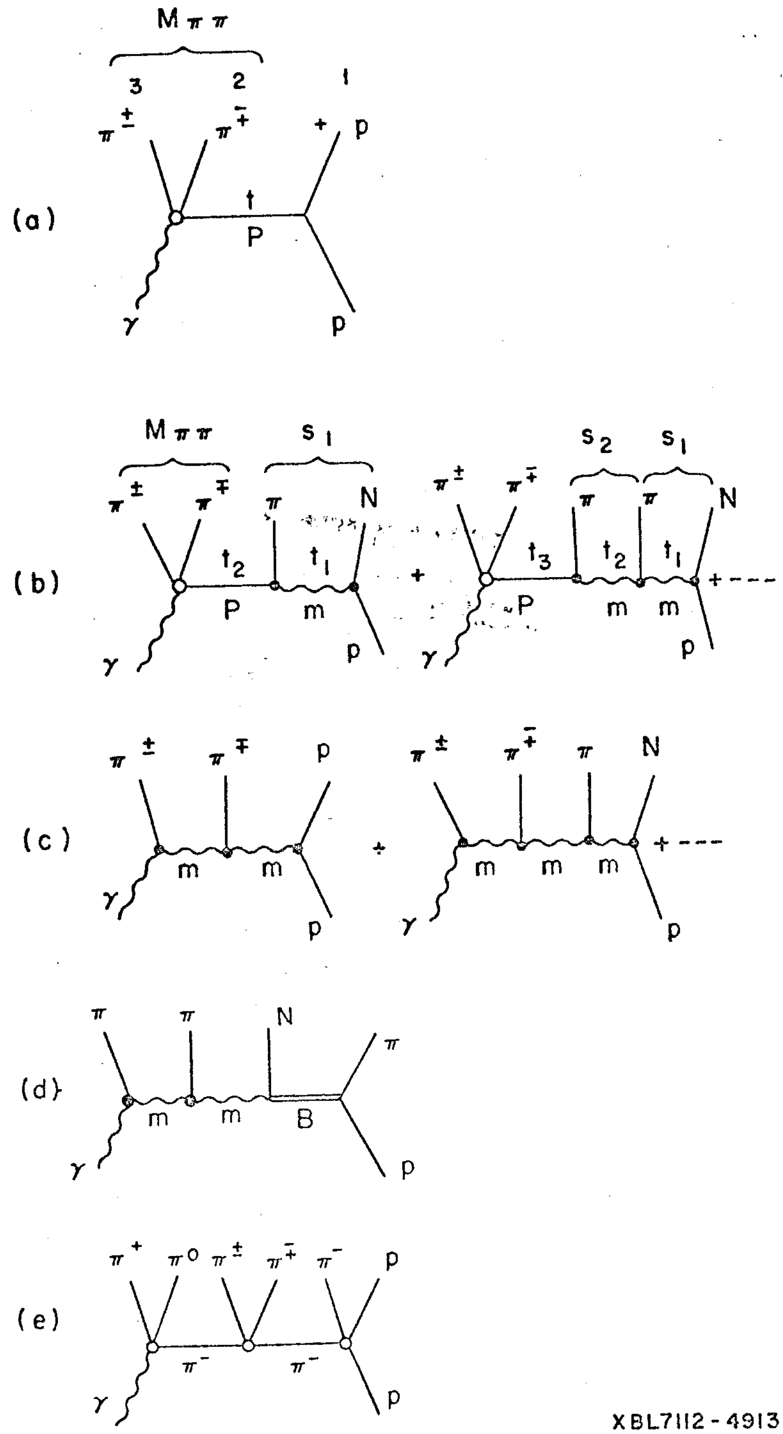
Track ordering 1 2 3	Experiment	Theory
- + +	10%	3%
+ - +	48%	47%
+ + -	42%	50%

FIGURE CAPTIONS

1. Multi-peripheral diagrams for photoproduction: (a)-(c) Multi-e diagrams used in this report; (d) baryon exchange; (e) A BFST am.

2. (a)-(f) Invariant-mass distributions of two-particle combina-. All particles are assumed to be pions and are ordered accord-ɔ laboratory longitudinal momentum (1 = smallest P_L, etc.). ɔinations of adjacent tracks are shown. Possible neutral particles gnored. In each panel (a)-(f) the upper distribution contains neu-dipions, and the lower (shaded) doubly charged (++ or --). Curves he multi-Regge model described in the text. Panels (a) and (b) 3-prong events; (c) - (f) show 5-prongs. (g) Average spacing pidity $\Delta w_{i,i+1}$ of adjacent charged particles. See text for def-ɔn of rapidity used. The error bar in Fig. (e) shows a typical r in the Monte Carlo calculation. Normalization discussed in text.

3. Longitudinal momentum distributions in 3-, 5-, a 7-prong ts and in all events for positive tracks (solid lines) and negative ks (dashed lines). Histograms–experimental data; curves–retical predictions. Normalization discussed in text.



XBL7112-4913

Fig. 1

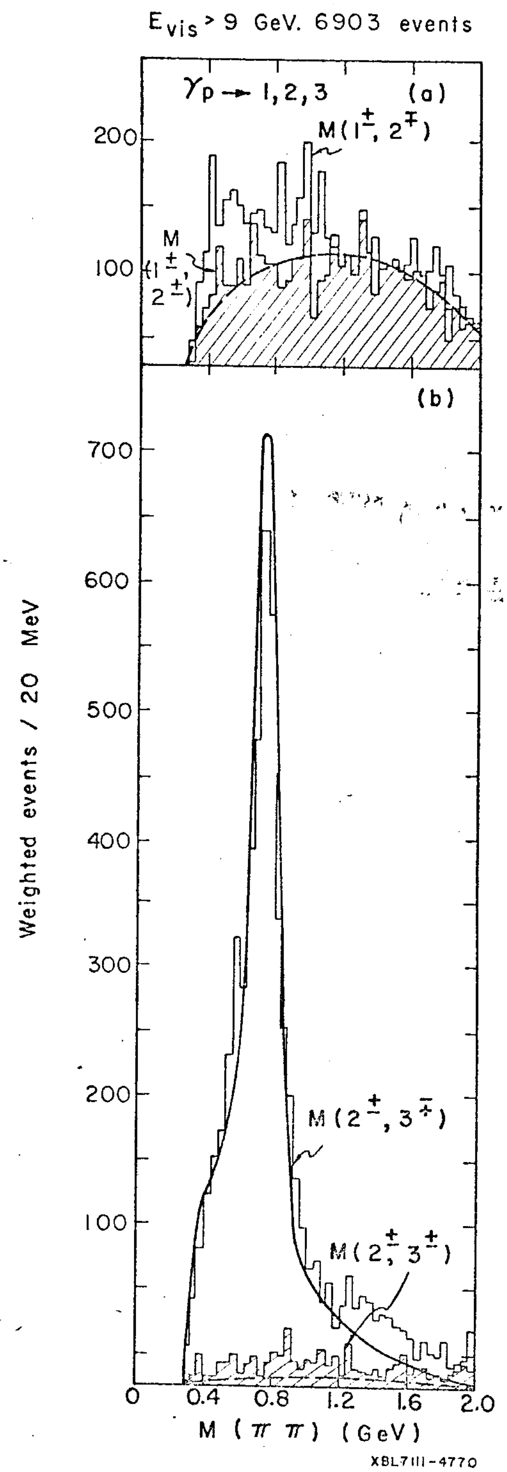

E$_{vis}$ > 9 GeV. 6903 events
γp → 1,2,3
(a)
M(1±, 2∓)
M (1±, 2±)
(b)
M(2±, 3∓)
M(2±, 3±)
Weighted events / 20 MeV
M (ππ) (GeV)
XBL7111-4770

Fig. 2 a-b

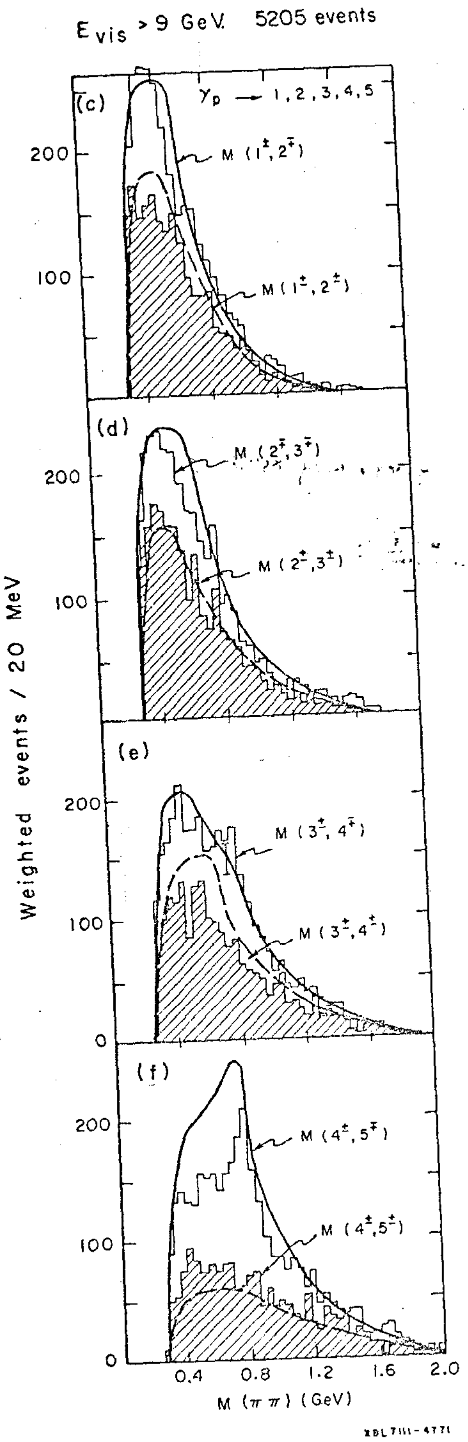

E vis > 9 GeV 5205 events
(c)
γp → 1, 2, 3, 4, 5
M (1±, 2∓)
M (1±, 2±)
(d)
M (2±, 3∓)
M (2±, 3±)
(e)
M (3±, 4∓)
M (3±, 4±)
(f)
M (4±, 5∓)
M (4±, 5±)
Weighted events / 20 MeV
0
100
200
0.4
0.8
1.2
1.6
2.0
M (π π) (GeV)
XBL 7111-4771

Fig. 2 c - f

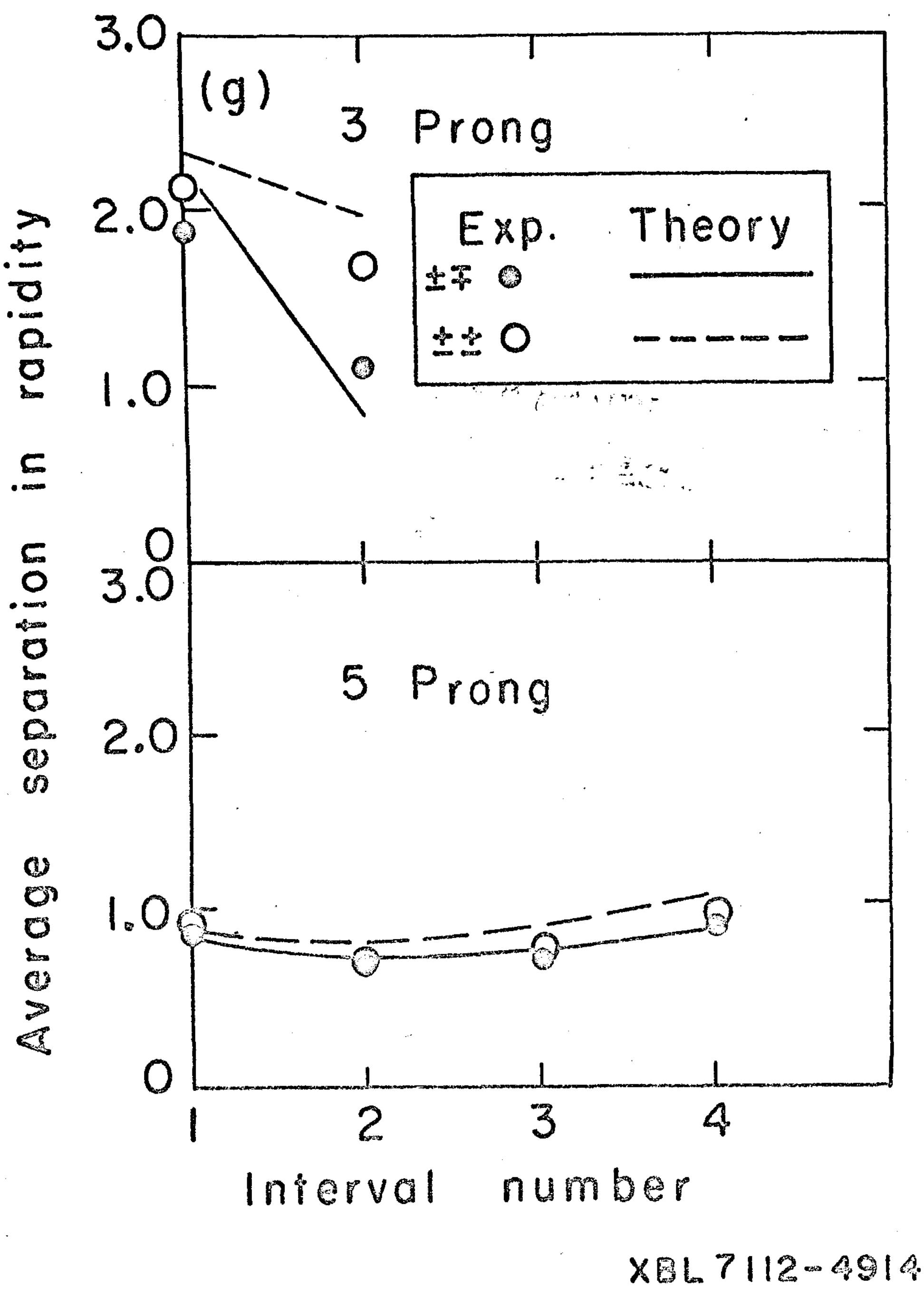
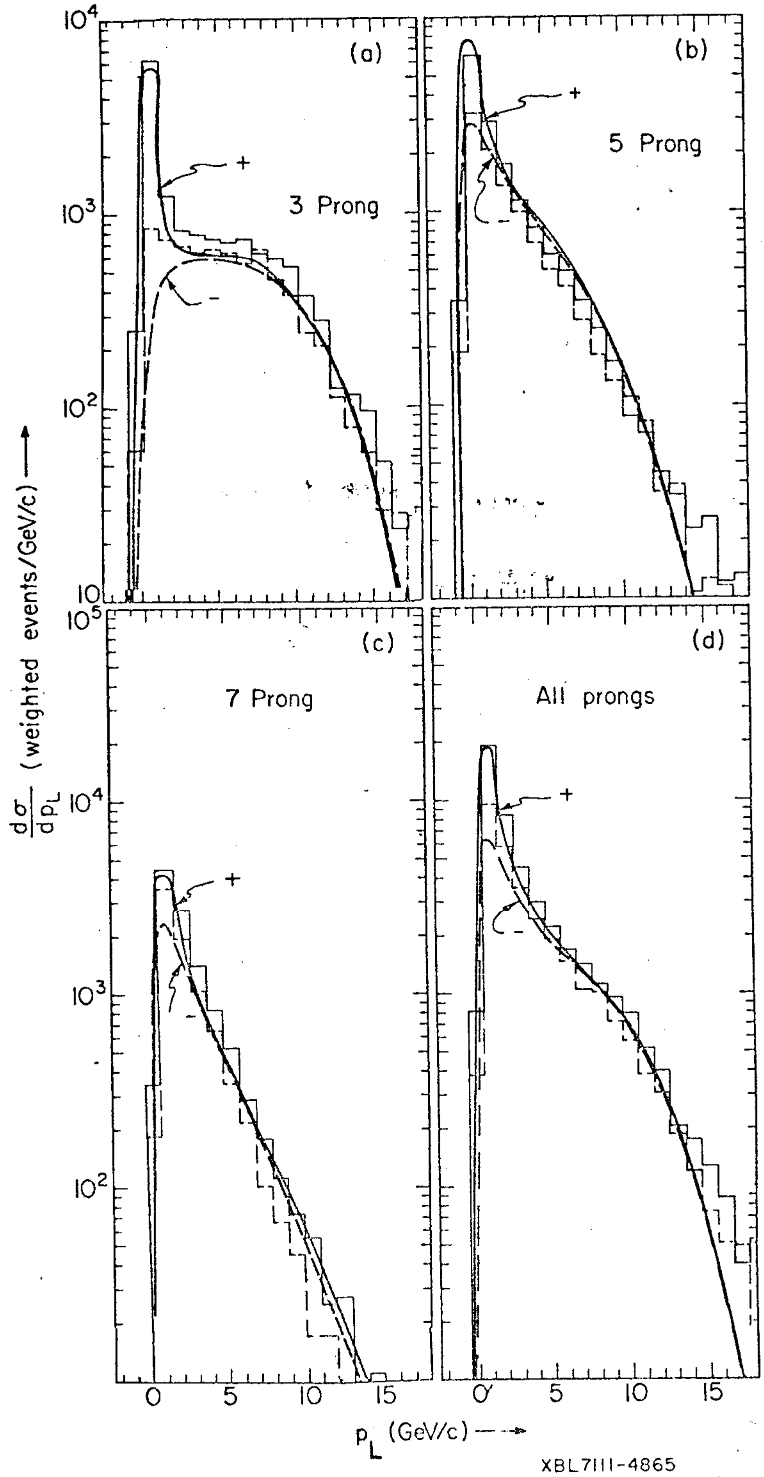

(g)
3 Prong
Exp.
Theory
±∓
±±
5 Prong
3.0
2.0
1.0
0
1
2
3
4
Average separation in rapidity
Interval number
XBL 7112-4914

Fig. 2 g



(a)
3 Prong
+
−
(b)
5 Prong
+
(c)
7 Prong
+
(d)
All prongs
+
−
10^4
10^3
10^2
10
10^5
$\frac{d\sigma}{dp_L}$ (weighted events/GeV/c)
0
5
10
15
p_L (GeV/c)
XBL7111-4865

Fig. 3