SLAC-PUB-1716
February 1976
(T/E)

Diffractive Production of Nucleon Resonances at 14 GeV and at ISR Energies*

J. Ballam, J. Carroll, G. Chadwick, P. Herquet,†
D. Linglin,†† K. Moffeit†††

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

V. Davidson, A. Firestone,≠ F. Nagy, C. Peck

California Institute of Technology
Pasadena, California 91109

R. Ely, D. Grether, P. Oddone

Lawrence Berkeley Laboratory
Berkeley, California 94720

ABSTRACT

In a 14 GeV/c hybrid bubble chamber experiment studying the reactions $\pi^{\pm}p \to \pi^{\pm}(n\pi^{+})$ and $\pi^{\pm}p \to \pi^{\pm}(p\pi^{+}\pi^{-})$ we observe marked similarities in the shapes of the recoiling mass spectra to those found in $pp \to p(n\pi^{+})$ and $pp \to p(p\pi^{+}\pi^{-})$ at ISR energies. We discuss these similarities as well as absolute cross sections in terms of factorization.

*Work supported by U.S. Energy Research and Development Administration.
†Present address: Mons University, Mons, Belgium
††Present address: CERN, Geneva, Switzerland
†††Present address: DESY, Hamburg, Germany
≠Present address: Iowa State University, Ames, Iowa

(Submitted for Publication)

Present ideas of high energy scattering suggest that in the hadronic process

$$A + B \rightarrow A + B^* \tag{1}$$

where B^* is any state diffractively produced from B, the cross section should be a constant fraction of the elastic reaction at all energies where diffraction dominates. This follows if the diffractive amplitude factorizes into the form $g^{AA\mathbb{P}} s^{\alpha} g^{BB^*\mathbb{P}}$, where the g's are vertex residues describing coupling to the Pomeron trajectory and s^{α} gives the energy dependence (s is the C.M. energy squared). Then $\sigma_{B^*}/\sigma_{el} = (g^{BB^*\mathbb{P}}/g^{BB\mathbb{P}})^2$, independent of the incoming particle A.

This form of factorization was checked by Anderson <u>et al.</u>,[1] for $\pi^- p \rightarrow \pi^- N^*_{1700}$ at 16 GeV/c and $pp \rightarrow pN^*_{1700}$ at 15 GeV/c, using a missing mass technique. Here N^*_{1700} is the well-documented[2] mass enhancement at ~1700 MeV. It is usually identified with the F_{15} nucleon resonance, although the actual spin states involved have never been verified. They found $(\sigma_{1700}/\sigma_{el})$ to be the same in both reactions to ~10%, using one-half the observed N^*_{1700} cross section in the pp case because of particle symmetry (we shall refer to this as the <u>single vertex</u> cross section). This observation allows us to relate πp and pp diffractive reactions at different energies to study the s-dependent part of the amplitude.

We have obtained data on the reactions

$$\pi^{\pm} p \rightarrow \pi^{\pm}(n\pi^+) \tag{2}$$

and

$$\pi^{\pm} p \rightarrow \pi^{\pm}(p\pi^+\pi^-) \tag{3}$$

at 14 GeV/c in a hybrid bubble chamber experiment in which the camera flash lamps were triggered when a fast forward pion scatter corresponding to an

inelastic event was detected in a downstream magnetic spectrometer. The SLAC 40" hydrogen bubble chamber was run at up to 12 expansions/sec for about the equivalent of 95 and 70 event/μb exposures to π^+ and π^- beams, respectively. Further details of the apparatus may be found in Ref. 3.

In the off-line data analysis we combined the spark chamber measurements with those from the film, using a modified form of the TVGP-SQUAW analysis system. The resulting sample of events of reaction (2) have less than 10% contamination from wrong mass hypotheses and a mass resolution for the $(n\pi^+)$ system which varied between 10 and 30 MeV.

In Fig. 1 we compare the recoil mass spectrum (weighted for geometrical acceptance) found from our data at 14 GeV/c ($\sqrt{s}$ = 5.3 GeV) to that reported by E. Nagy et al.,[4] for the reaction

$$pp \rightarrow p(n\pi^+) \tag{4}$$

at $\sqrt{s}$ = 53 GeV. We plot the average $d\sigma/dM$ for π^+p and π^-p data in order to remove interference terms from I = 1 exchange and show the total $d\sigma/dM$ for reaction (4) (broken histogram), which is twice the single-vertex cross section. The πp data are selected for $0.05 < |t| < 0.5$ GeV^2 while the pp data have $0.05 < |t| < 0.8$ GeV^2. There are only a few events in πp for $|t| > 0.5$ GeV^2. In addition, we divide the data into forward ($\cos\theta_J > 0$. Fig. 1b) and backward ($\cos\theta_J < 0$, Fig. 1a) decay angles in the Gottfried-Jackson system.[5]

Figure 1 shows what we feel to be a remarkable similarity in spectral shapes in two different reactions at widely separated energies. In the forward hemisphere (Fig. 1b) we see the same slow rise to a sharp drop at ~1700 MeV, while in the backward hemisphere (Fig. 1a) peaks and valleys develop.[6] Detailed differences in the latter are probably due to statistics.[7]

The comparison strongly suggests that the same interfering resonances are present at both energies.

To test the factorization hypothesis, we define, for the pp reaction at C.M. energy $\sqrt{s}$, a cross section $d\sigma_N/dM$ normalized to the 14 GeV/c πp reaction

$$\frac{d\sigma_N}{dM} = \frac{\sigma(\pi p \text{ elastic}, \sqrt{s} = 5.3 \text{ GeV})}{2\ (\text{pp elastic}, \sqrt{s})} \times \frac{d\sigma}{dM}(\text{pp inelastic}, \sqrt{s}) \tag{5}$$

which should be identical to the spectrum of the πp reaction for any components obeying factorization as described previously. We use an average total elastic $\pi^{\pm}p$ cross section[3,8] of 4.1 ± 0.4 mb and a pp elastic cross section[9] of 7.8 ± 0.6 mb. The normalized spectra are shown in Fig. 1 as solid histograms. It is clear that the overall pp normalized spectrum is significantly lower in cross section than that of πp. Nagy et al.[4] compared their data with pp reactions at lower energies and also noted that the pp cross section integrated over all t and for M < 2 GeV fell like $\sigma = ap_{lab}^{-n}$ with n = 0.4 ± 0.1.

The prominence of peaks in the ISR data leads us to explore whether the resonance components alone obey factorization, as analysis of other data has suggested.[10] To do this, we require an estimate of the resonance cross section integrated over all decay angles, since the peaks for $\cos\theta_J < 0$ are most probably an interference phenomenon. In an attempt to isolate resonance contributions in our data we plotted the moments of the decay angular distributions,

$$Y_\ell^m = \frac{1}{f} \sum_{\text{events}} w_i Y_\ell^m(\theta_i, \phi_i), \tag{6}$$

where f is the beam flux in events/μb, w_i is the inverse of the geometrical acceptance for event i, θ_i the polar, and ϕ_i the azimuthal angle of the neutron with respect to target proton in the $n\pi^+$ rest frame.[5] Figure 1c-g

shows the moments with m = 0 for the average π^+ and π^- data, for $0.05 < |t| < 0.5\ \mathrm{GeV}^2$.

In Fig. 1e we observe that Y_2^o shows a well-defined two-peaked structure on a smooth background although the mass spectrum (Fig. 1c) does not. Rapid variations with $M_{n\pi^+}$ in the other moments are indicative of resonance behavior at about 1400, 1500, and 1700 MeV.

Although the identification and cross section determination require a full partial wave analysis, we can estimate a cross section for the contribu- of $J \geqslant 3/2$ resonances if we assume the Y_2^o peaks result from two such states. From the expected decay angular distributions[11] we observe that for $J \geqslant 3/2$ a <u>maximum</u> Y_2^o signal results if helicity is conserved in the analyzing system, e.g., for $J = 3/2$, $Y_2^o/Y_o^o = 1/\sqrt{5}$, for $J = 5/2$, $Y_2^o/Y_o^o = 8/7\sqrt{5}$, the ratio increasing slowly for higher spins. We fit the Y_2^o spectrum to a smooth background plus two Breit-Wigner forms to obtain an integrated resonance signal and, by using the $J = 3/2$ ratio, obtain what should be a <u>minimum</u> **cross section** $\sigma_{res} = \sqrt{4\pi}\int\sqrt{5}\, Y_2^o\, dM = 80 \pm 10\ \mu b$ in the region $1.4 < M_{n\pi^+} < 1.8$ GeV.[12] The result of one such fit is shown superimposed on the Y_2^o spectrum of Fig. 1e. In order to demonstrate that σ_{res} is a reasonable estimate of the $J \geqslant 3/2$ cross section, we subtracted the implied Y_o^o contribution for $J \geqslant 3/2$ resonances from the overall Y_o^o spectrum, and obtained the "background" superimposed as a broken line in Fig. 1c. Note such a background can contain any $J = 1/2$ wave contribution plus that from waves of any spin which do not peak strongly. Finally, we have added $\langle Y_o^o \rangle\, d\sigma_{res}/dM$ to the derived smoothed background. The result is the solid curve shown in Fig. 1c, which gives a perfectly reasonable description of the data. We conclude that σ_{res} therefore is not far from the true cross section for $J \geqslant 3/2$ resonances.

To complete the comparison, we obtain $\sigma_{MAX,ISR}$ by summing all ISR events in the same interval (using the normalized spectra of Fig. 1a and b). We find $\sigma_{MAX,ISR}$ = 25 μb (with 50% error),[7] which is about a factor 3 below the minimum factorization prediction. This discrepancy appears to be large enough to exclude its being due to experimental uncertainty or to the approximations used.

We can also compare our data on reaction (3) with those from the reaction

$$pp \rightarrow p(p\pi^+\pi^-). \tag{7}$$

In Fig. 2a we first show our data for $0.01 < |t| < 0.6$ GeV^2 compared with pp data of Rushbrooke et al.[13] at 16 GeV/c and all t. The latter is normalized by Eq. (5). The spectra agree reasonably well, giving rough confirmation of the conclusion of Anderson et al.,[1] mentioned previously. In Fig. 2b we compare our data to the normalized ISR pp result of Webb et al.[14] ($\sqrt{s}$ = 45 GeV), both samples having $0.1 < |t| < 0.6$ GeV^2. Except for a possible mass shift, the two spectra appear to differ only in scale in the resonance region, which tends to confirm our previous observations.

In comparing their data with the pp missing-mass measurements of Edelstein et al.,[15] at lower energies, Webb et al.[14] concluded that their 1700 MeV enhancement was consistent with being equal in cross section to that at 30 GeV/c. That analysis required that backgrounds at both energies, as well as the 1700 MeV branching ratio to $p\pi^+\pi^-$, be known. The comparison of reactions (2) and (4) does not require knowledge of the branching ratio to the $n\pi^+$ final state.

In conclusion, we have presented evidence that the "diffractive region" in πp and pp inelastic scattering shows similar mass distributions over a factor 10 in CMS energy, but the overall cross sections fall slightly faster with s than that of the elastic reaction. Whether this is from an inadequacy

of factorization as expressed in Eq. (5) or is indicative of the presence of non-diffractive processes will require further precise data at these and intermediate energy points.

We wish to thank the SLAC BC Operations Group, under R. Watt, the Experimental Facilities Group, under L. Keller, and our Data Analysis staffs, particularly J. Brown, D. Feick, and R. Aintablian for their willing help. In addition, we thank J. Murray for the beam design.

REFERENCES

1. E. W. Anderson et al., Phys. Rev. Lett. 25 (1970) 699.

2. Many results are tabulated by K. Boesebeck et al., Nucl. Phys. B33 (1971) 445. More recent observations above 10 GeV/c are (a) π-nucleon: R. Morse et al., Phys. Rev. D4 (1971) 133; Y. Oh et al., Phys. Lett. 42B (1972) 497; R. Harris et al., VTL-PUB-22 (1975), University of Washington preprint; (b) nucleon-nucleon: J. Allaby et al., Nucl. Phys. B52 (1973) 316; D. Hochman et al., Nucl. Phys. B80 (1974) 45.

3. A. R. Dzierba et al., Phys. Rev. D7 (1973) 725.

4. E. Nagy et al., Contribution No. 489 to the XVIIth International Conference on High Energy Physics, London (1974).

5. J. D. Jackson, Rev. Mod. Phys. 37 (1965) 484.

6. G. Berlad et al., Phys. Lett. 56B (1975) 297, have found that their 3.9 GeV/c $\pi^- p \to \pi^- (n\pi^+)$ data show the same general shape as that of Ref. 4, but in their case the N*(1700) peak was not observed.

7. Newer data and analysis of the experiment of Ref. 4 indicate less strong peaks in the backward hemisphere, which should strengthen this and later conclusions. However, an uncertainty of about 50% is suggested for the pp data in Fig. 1a and b. (K. Winter, private communication.)

8. K. J. Foley et al., Phys. Rev. 181 (1969) 1775.

9. U. Amaldi et al., Phys. Lett. 44B (1973) 112.

10. See, e.g., H. I. Miettinen, Plenary Session Talk at the EPS International Conference on High Energy Physics, Palermo, June 1975, and CERN preprint TH. 2072 - CERN, August 1975.

11. W. Ochs *et al.*, Nucl. Phys. *B86* (1975) 253.

12. Cross sections derived for each individual resonance depended strongly on the spape assumed, but the sum of the resulting cross sections remained within the error quoted. We therefore chose a mass interval which contained both Y_2^o peaks.

13. J. G. Rushbrooke *et al.*, Phys. Rev. *D4* (1971) 3273.

14. R. Webb *et al.*, Phys. Lett. *55B* (1975) 331.

15. R. M. Edelstein *et al.*, Phys. Rev. *D5* (1972) 1073.

FIGURE CAPTIONS

Figure 1. a) $n\pi^+$ invariant mass distribution in the backward hemisphere of the Jackson frame. The data points show the average of $\pi^+ p \to \pi^\pm (n\pi^+)$ data at $\sqrt{s} = 5.3$ GeV and for $0.05 < |t_{\pi\to\pi}| < 0.5$ GeV^2. The broken histogram shows $pp \to p(n\pi^+)$ data at $\sqrt{s} = 53$ GeV and $0.05 < |t_{p\to p}| < 0.8$ GeV^2. The solid histogram is the latter normalized to 14 GeV/c π data by Eq. (5).

b) As above but for the forward decay hemisphere.

c - g) Unnormalized moment distributions for $\pi^\pm p \to \pi^\pm (n\pi^+)$ average at 14 GeV/c and $0.05 < |t| < 0.5$ GeV^2. The curves on Y_0^0 and Y_2^0 show the results of the procedures described in the text.

Figure 2. a) $p\pi^+\pi^-$ invariant mass distributions for the average of $\pi^\pm p \to \pi^\pm (p\pi^+\pi^-)$ at 14 GeV/c, $0.01 < |t| < 0.6$ GeV^2 (data points), and for $pp \to p(p\pi^+\pi^-)$ at 16 GeV/c and all t (Ref. 13) normalized to 14 GeV/c πp data by Eq. (5).

b) Same for our data in the interval $0.1 < |t| < 0.6$ GeV^2, but now compared to pp at an equivalent momentum of 1030 GeV/c ($\sqrt{s} = 45$ GeV) normalized as above, and in the same t interval.

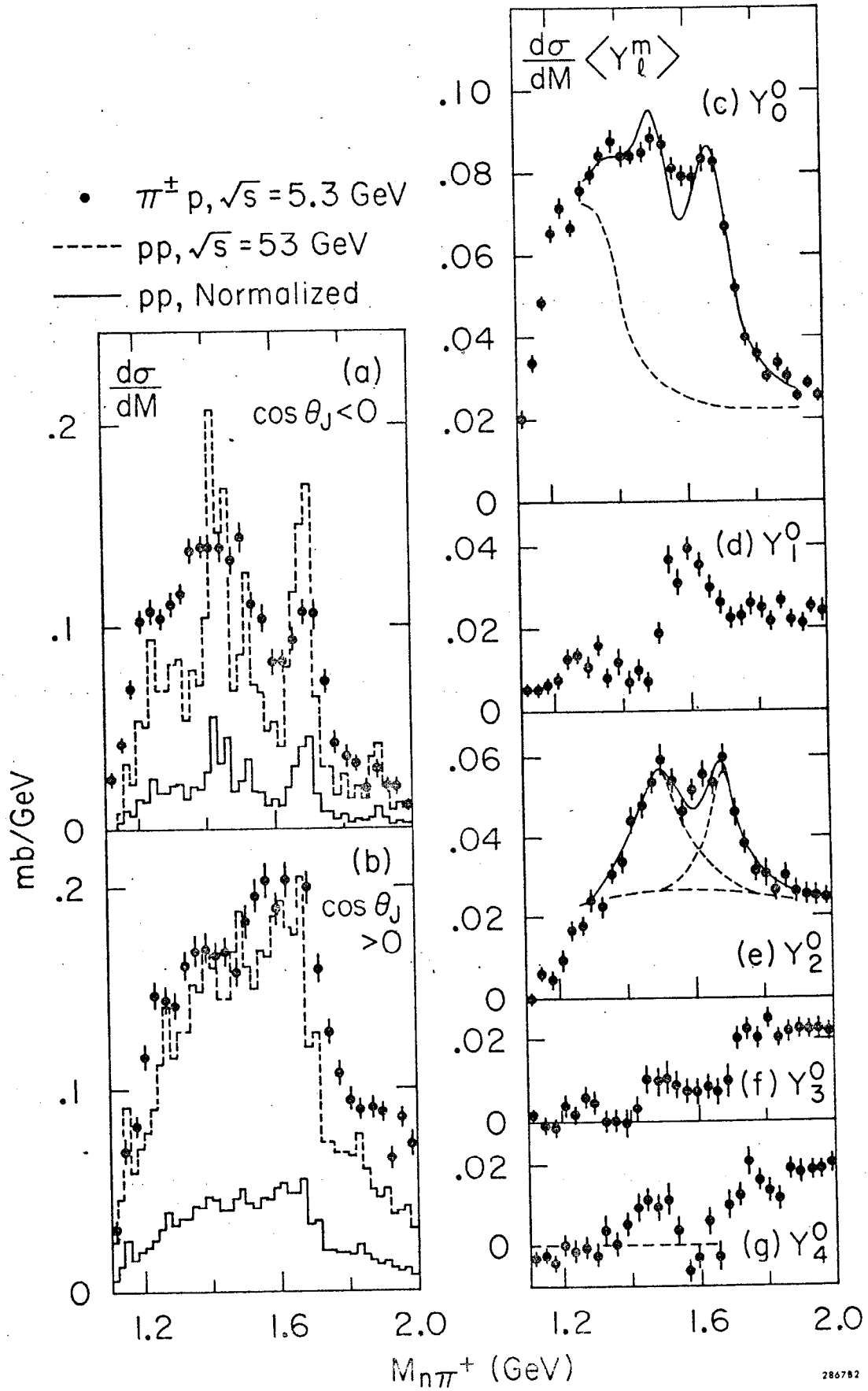
• $\pi^{\pm}$ p, $\sqrt{s}$ = 5.3 GeV
----- pp, $\sqrt{s}$ = 53 GeV
—— pp, Normalized
$\frac{d\sigma}{dM}$
(a) $\cos\theta_J < 0$
(b) $\cos\theta_J > 0$
mb/GeV
$\frac{d\sigma}{dM}\langle Y_\ell^m \rangle$
(c) Y_0^0
(d) Y_1^0
(e) Y_2^0
(f) Y_3^0
(g) Y_4^0
$M_{n\pi^+}$ (GeV)
286782

Fig. 1

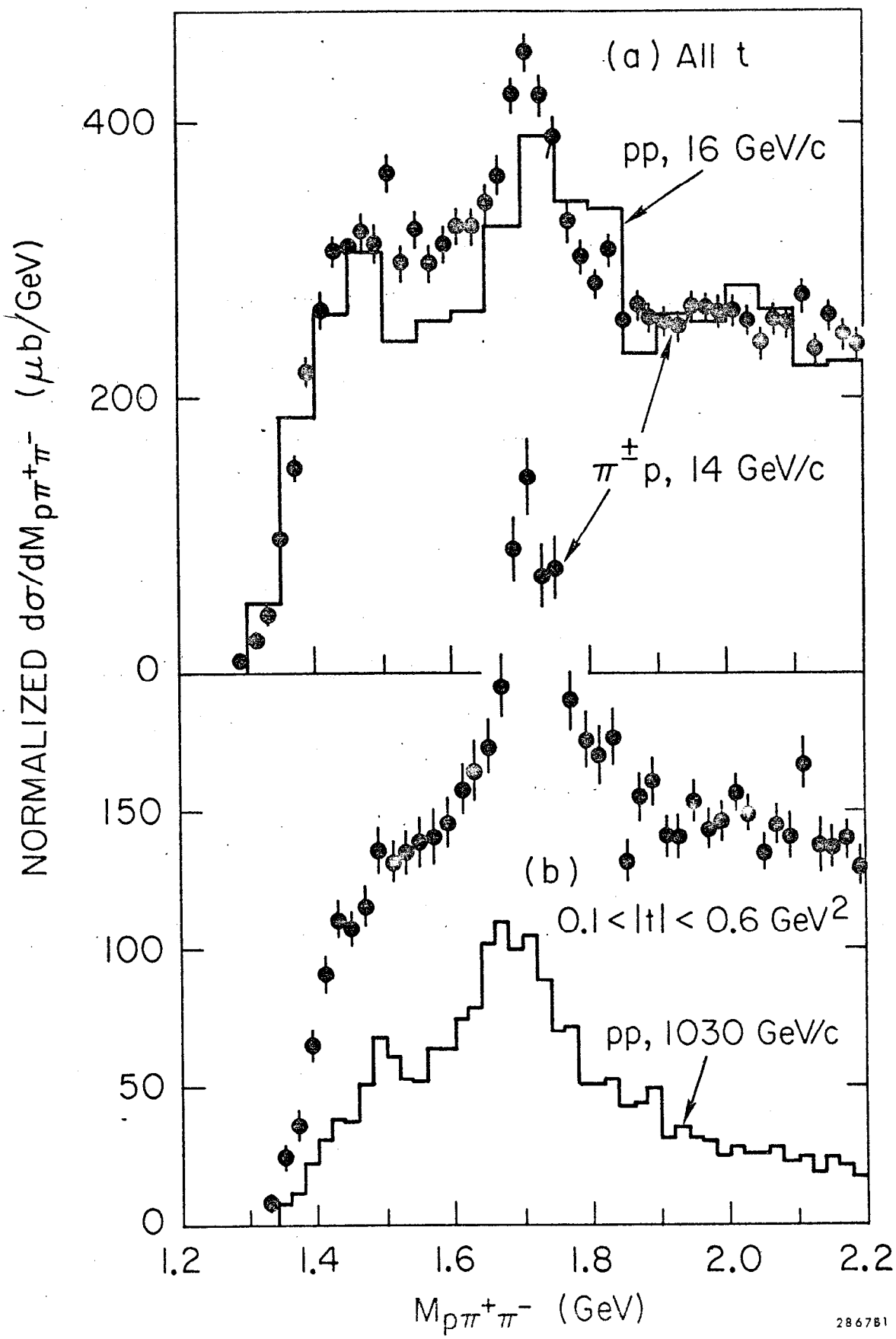
(a) All t
pp, 16 GeV/c
$\pi^{\pm}$p, 14 GeV/c
(b)
0.1 < |t| < 0.6 GeV^2
pp, 1030 GeV/c
NORMALIZED $d\sigma/dM_{p\pi^+\pi^-}$ (μb/GeV)
$M_{p\pi^+\pi^-}$ (GeV)
400
200
0
150
100
50
0
1.2
1.4
1.6
1.8
2.0
2.2
286781

Fig. 2