Title

DIFFRACTION DISSOCIATION, PION EXCHANGE, AND DIP STRUCTURES IN p + p->X + p

Author

Bishari, Mordechai.

Publication Date

1973-07-01

LBL-2066
UC-34d-Physics
Particles and Fields
TID-4500-R60

DIFFRACTION DISSOCIATION, PION EXCHANGE, AND DIP STRUCTURES IN $p + p \to X + p$

Mordechai Bishari

July 3, 1973

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA • BERKELEY •

DISCLAIMER

DIFFRACTION DISSOCIATION, PION EXCHANGE, AND DIP STRUCTURES IN $p + p \rightarrow X + p$ *

Mordechai Bishari†

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

July 5, 1973

ABSTRACT

A recent NAL experiment, by Sannes et al., on charge exchange dissociation of the proton, namely $p + n \rightarrow X + p$, is shown to be crucial for the understanding of the structure of the diffractive inclusive process $p + p \rightarrow X + p$. It is anticipated that the shallow dip observed in $p + p \rightarrow X + p$ (at $x \approx 0.87$ and $t \approx -0.2$ GeV^2) will considerably move toward $x = 1$ for $|t|$ comparable with the pion mass squared (e.g., $t \approx -0.03$ GeV^2). We point out the implications for a recent NAL experiment, at very small $|t|$ values, by Childress et al. The importance of the dip structure in $p + p \rightarrow X + p$ for the high mass diffraction dissociation mechanism is also discussed.

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

† On leave from the Weizmann Institute of Science, Rehovoth, Israel (also address from August 21, 1973).

Remarkable measurements have been recently performed at NAL, by Sannes et al.,[1,2] resulting with data on $p + p \rightarrow X + p$ and $p + D \rightarrow X + p$ from which an information on $p + n \rightarrow X + p$ has been extracted. The last charge exchange inclusive reaction is extremely useful since it directly measures nondiffractive contributions that must be included in $p + p \rightarrow X + p$. It is then evident that the reaction $p + n \rightarrow X + p$ is important for a better understanding of the structure of $p + p \rightarrow X + p$ and in particular the diffraction mechanism into high masses.

We shall present here a semiquantitative analysis of $p + p \rightarrow X + p$ and $p + n \rightarrow X + p$ (see Fig. 1) near the end of the kinematic boundary. We shall emphasize only features which do not depend on the precise description of the experimental data. Specifically it will be shown that the dip observed by Sannes et al., at $x \approx 0.87$ (here x is Feynman's variable) and momentum transfer $|t|$ much larger than the pion mass squared ($\mu^2 \approx 0.02$ GeV^2), will appreciably move toward $x = 1$ when $|t|$ is comparable with μ^2. The location, shape, and depth of the dip, especially at $t \approx -\mu^2$, depend on the relative strength of the pion and diffractive dissociation mechanisms.

In fact a preliminary data by Childress et al.[3] indeed indicate that for $t \approx -0.03$ GeV^2 ($s \approx 377$ GeV^2) the dip is located at $x \approx 0.96$. What we present here is a simple and natural explanation, based on the smallness of the pion mass, for the motion of the dip position as a function of t. As mentioned above, the detailed structure of the dip will provide a direct information on the nature of high mass diffraction dissociation mechanism.

It has been already known[4] that the charge exchange inclusive reaction, $p + p \to X + n$, is essential for a correct interpretation of the observed $p + p \to X + p$ spectra. The experiment[5] $p + p \to X + n$ is being carried out at CERN and a preliminary data is available (at 24 GeV/c) with, however, a large quoted[5] uncertainty in the overall normalization. Nevertheless the shape of the $p + p \to X + n$ spectrum is sufficient for a guess of the underlying dominant mechanism.

Fortunately the theoretical questions, that can be resolved by the $p + p \to X + n$ data, are equally clarified from recent NAL measurements which are experimentally completely different from the CERN experiment. Explicitly the NAL experiment[1,2] involves very accurate measurements of $p + p \to X + p$ and $p + D \to X + p$, where slow protons are detected, from which $p + n \to X + p$ is extracted.[6]

Since we are interested in the spectrum near the phase-space boundary (Fig. 1), the forthcoming analysis is presented in the language of triple-Regge couplings.

The arguments[4] for the pion exchange dominance in $p + p \to X + n$ and $p + n \to X + p$ will not be repeated here. The predictions made on the basis of such a model are in agreement with available data. Indeed the CERN data[5] on $p + p \to X + n$ reveal, for $q_T \approx 0$, a rapid decrease toward $x = 1$ and a maximum at $x \approx 0.82$, as predicted in Ref. 4. These results are, of course, independent of the overall normalization.

Also the analysis, of the accurate NAL experiments,[2] indicates that the $p + n \to X + p$ spectrum considerably decreases towards $x = 1$. Moreover their data also show that the proton production in $p + p \to X + p$ and $p + n \to X + p$ can be comparable for $x \lesssim 0.82$.

This is also in accordance with the prediction in Ref. 4, which is based on the iso-spin enhancement of the pion coupling in $p + n \to X + p$.

As mentioned before the normalization, in the measurements by Sannes et al., is determined to a very good accuracy. Thus we are encouraged to describe the $p + n \to X + p$ data by a single π-exchange term. For simplicity we shall take a zero slope pion trajectory. We emphasize, however, that this does not imply a flat pion trajectory. Indeed one can fit the data with a finite slope if $\pi\pi R$ is included in addition to the scaling term $\pi\pi P$. Also other objects such as ρ and A_2 are expected to be present. However, since the discussion is confined to the small t region the above simplifications will not crucially affect the central results of this work.

The $p + n \to X + p$ data is satisfactorily described by (see Fig. 2)

$$\left(\frac{s d^2\sigma}{dt dM^2}\right)_{p+n\to X+p} = \frac{1}{4\pi}\frac{2g^2}{4\pi}\frac{-t}{(t-\mu^2)^2}\,\sigma_T(\pi p)\, e^{at}(1-x) \qquad (1)$$

with $a \approx 3.3\ \mathrm{GeV}^{-2}$, $\sigma_T(\pi p) \approx 25$ mb, and $g^2/4\pi \approx 15$.

Equation (1) represents a spectrum which is comparable, for $x \leq 0.85$,[2] with the $p + p \to X + p$ spectrum. Therefore one must realize that the hitherto overlooked π exchange term must be included in the analysis of $p + p \to X + p$. This is done below.

Two important features of the pion contribution will be mentioned; (i) the factor $-t/(t - \mu^2)^2$ grows rapidly when t varies from $t \approx -0.2\ \mathrm{GeV}^2$ (Sannes et al.[2]) to $t \approx -\mu^2 \approx -0.02\ \mathrm{GeV}^2$ (Childress et al.[3]); (ii) it vanishes at $x = 1$.

Thus for $t \approx -0.02\ \text{GeV}^2$ the pion term is proportional to $(1 - x)$ with a huge coefficient. Hence it will rapidly increase away from $x = 1$ and is already large at $x \lesssim 0.96$. This feature will be essential for explaining the dip structure in the NAL measurements.[2,3]

We shall now present a semiquantitative analysis of the above discussion. Diffraction dissociation in $p + p \to X + p$ is characterized, in the triple Regge scheme, by PPP and PPP' couplings. In addition to these couplings we also include the RRP (where $R = P'$ or ω) and $\pi\pi P$ contributions in order to describe the $p + p \to X + p$ data. It should be remarked that this is not the only possible parametrization of the data. However, the gross features emphasized here are presumably not crucially dependent on the details of the parametrization.

The various triple-Regge contributions are given by

$$\left(\frac{sd^2\sigma}{dtdM^2}\right)_{p+p\to X+p} = \frac{1}{16\pi s_0}\beta^2_{Ppp}(0)\, e^{Bt}\, g_{PPP}(t)\, \beta_{Ppp}(0) \times (1-x)^{1-2\alpha_P(t)} \tag{2a}$$

$$+ \frac{1}{16\pi s_0}\beta^2_{Ppp}(0)\, e^{Bt}\, g_{PPP'}(t)\, \beta_{P'pp}(0)\, \frac{(1-x)^{\alpha_{P'}(0)-2\alpha_P(t)}}{(s/s_0)^{1-\alpha_{P'}(0)}} \tag{2b}$$

$$+ \frac{1}{16\pi s_0}\beta^2_{Rpp}(0)\, e^{B_1 t}\, 2g_{RRP}(t)\, \beta_{Ppp}(0)(1-x)^{1-2\alpha_R(t)} \tag{2c}$$

$$+ \frac{1}{4\pi}\frac{g^2}{4\pi}\frac{-t}{(t-\mu^2)^2}\,\sigma_T(\pi p)\, e^{at}(1-x) \tag{2d}$$

where $R = P'$ or ω with the assumption of exchange degeneracy.

The factorization property of the exchanged objects has been used so as to isolate the couplings which are reaction independent. This is useful for theoretical investigations since the couplings g_{PPP} and $g_{PPP'}$ determine the leading singularities in the J plane.

It is self-explanatory that the couplings β_{Ppp} and β_{Rpp} are measurable from two-body scattering processes.

If one demands a pomeron with exactly unit intercept then g_{PPP} and $g_{PPP'}$ are constrainted to vanish at $t = 0$. The following forms are adopted;

$$g_{PPP}(t) = -a_1 t e^{b_1 t} \tag{3}$$

$$g_{PPP'}(t) = -a_2 t e^{b_2 t}\ . \tag{4}$$

Equations (3) and (4) will be used here although in reality the couplings may not vanish, e.g., become small but finite at $t = 0$.

We proceed now to relate the triple-Regge scheme, Eqs. (2a)-(2d), (3), and (4), to experimental data. The Sannes et al.[2] data can be reasonably well represented with the following parameters;[7]

$$a_1 \approx 1.2\ \text{mb/GeV}^2, \quad b_1 \approx 2\ \text{GeV}^{-2} \tag{3'}$$

$$a_2 \approx 3.6\ \text{mb/GeV}^2, \quad b_2 \approx 2\ \text{GeV}^{-2} \tag{4'}$$

and[8]

$$g_{RRP} \approx 1.15 \text{ mb} . \quad (5)$$

The various terms are displayed in Fig. 3 ($s = 110$ GeV^2 and $t = -0.16$ GeV^2) together with the total spectrum. A shallow dip is observed at $0.86 \leq x \leq 0.88$. The dip is essentially due to the falling PPP and PPP' terms and the rising $\pi\pi P$ term (also RRP rises slightly). Since for $t = -0.16$ GeV^2 the pion propagator is not so large the $\pi\pi P$ term has only a moderate increase and thus the observed dip is shallow [see discussion following Eq. (1)].

The characteristics of the pion exchange mechanism can be best studied at very small t values since for e.g., $t \approx -\mu^2$ the RRP term is almost constant with x. On the other hand, the pion propagator[9] is very large and thus the $\pi\pi P$ term has a very rapid increase. These features are exhibited in Fig. 4 ($s \approx 377$ GeV^2 and $t \approx -0.03$ GeV^2). With the falling PPP and PPR contributions one thus expects to observe a pronounced dip nearer to $x = 1$ than in Fig. 3. In Fig. 4 the PPP and PPR terms vanish at $t = 0$ [Eqs. (3), (4)] and hence high-mass diffraction is suppressed at $t \approx -0.03$ GeV^2 and a prominent dip is obtained located at $x \approx 0.95$, i.e., very near $x = 1$. Thus the details of the dip structure are determined also by the nature of the diffraction mechanism.

It is noted again that a qualitatively similar structure, namely a small high-mass diffraction production and a pronounced dip very near $x = 1$, had been observed by Childress et al.[3] for the same values of s and t as in Fig. 4. Although the errors in Childress et al. experiment are large we nevertheless believe that the interesting structure they observed is genuine.

To summarize, it has been shown that pion exchange is essential for a simple and natural interpretation of a dip structure in $p + p \rightarrow X + p$ especially for $|t|$ comparable with the pion mass squared.

Finally it is stressed that one can fit the available $p + n \rightarrow X + p$ and $p + p \rightarrow X + p$ data with more[10] triple-reggeon couplings, e.g., RRR and $\pi\pi R$ in addition to those in Eqs. (1) and (2a)-(2d). This, however, will not alter the aforementioned dip structure in $p + p \rightarrow X + p$ at least for $|t|$ comparable with the pion mass squared.

It is a pleasure to thank J. D. Jackson for many discussions on both theoretical and experimental aspects of this work. F. Sannes and R. McCarthy are gratefully acknowledged for communicating the results of their experiments prior to publication. Thanks are also due to R. Schopper from the CERN group for sending the preliminary results of their experiment.

REFERENCES

1. F. Sannes, T. De Lillo, M. Lieberman, J. Mueller, B. Robinson, I. Siotis, G. Cvijanovich, A. Pagnamenta, and R. Stanek, Phys. Rev. Letters 30, 766 (1973).

2. F. Sannes et al., preliminary results from Exp. 188 presented at NAL seminar 5/11/73, and to be published. Private communication from F. Sannes.

3. S. Childress, P. Franzini, J. Lee-Franzini, R. Mc Carthy, and R. Schamberger, Jr., submitted to Phys. Rev. Letters.

4. M. Bishari, Phys. Letters 38B, 510 (1972).

5. J. Engler, W. Flauger, B. Gibbard, F. Monnig, K. Pack, K. Runge, and H. Schopper, presented to the IV International Conference on High Energy Collisions, Oxford, April 1972.

6. In the process of extracting the reaction $p + n \to X + p$ there are some uncertainties for very slow final protons because of rescattering in the target deuteron. However, such corrections become less important when the final proton is less slower, namely when x is not very near one[2] ($x \lesssim 0.85$).

7. The other couplings and parameters appearing in Eqs. (2a)-(2d) are taken from two-body scattering data;

$$\beta^2_{Ppp}(0) \approx 100, \quad B \approx 5\ \text{GeV}^{-2}, \quad \beta_{Rpp}(0) \approx 7, \quad B_1 \approx 3\ \text{GeV}^{-2},$$

$$\alpha_R(t) = \tfrac{1}{2} + 0.9t \quad (R = P', \omega), \quad \alpha_P(t) = 1 + 0.25t, \quad \text{and} \quad s_0 = 1\ \text{GeV}^2.$$

8. A factor of 2 is associated with g_{RRP} in Eq. (2c) because both P' and ω contribute equally. Also the g_{RRP} in Eq. (5) is smaller than in previous fits, which ignore π exchange, because of the relatively large pion contribution.

9. It is an interesting question whether some sort of absorption will alter, at very small $|t|$, the expression $-t/(t - \mu^2)^2$ appearing in Eqs. (1) and (2d). It is hoped that future data will allow clarification of this point. For a related discussion see E. Gotsman and U. Maor, Nucl. Phys. (in press).

10. F. Sannes, private communication and in Ref. 1; Pham Xuan Yem, preprint, IPNO 73.015.

FIGURE CAPTIONS

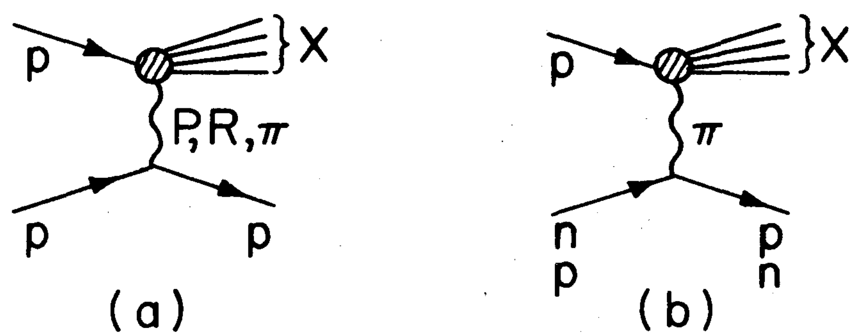
Fig. 1. (a) The process $p + p \to X + p$ with the various dominant exchanges near the end of phase space.

(b) The processes $p + n \to X + p$ (NAL) and $p + p \to X + n$ (CERN) with π-exchange dominance. In the NAL experiment the outgoing slow proton is a fragment of the "target" neutron. In the CERN experiment the detected neutron is fast and is a fragment of the projectile.

Fig. 2. The $\pi\pi P$ contribution [Eq. (1)] compared with a preliminary data on $p + n \to X + p$ by Sannes et al.[2]

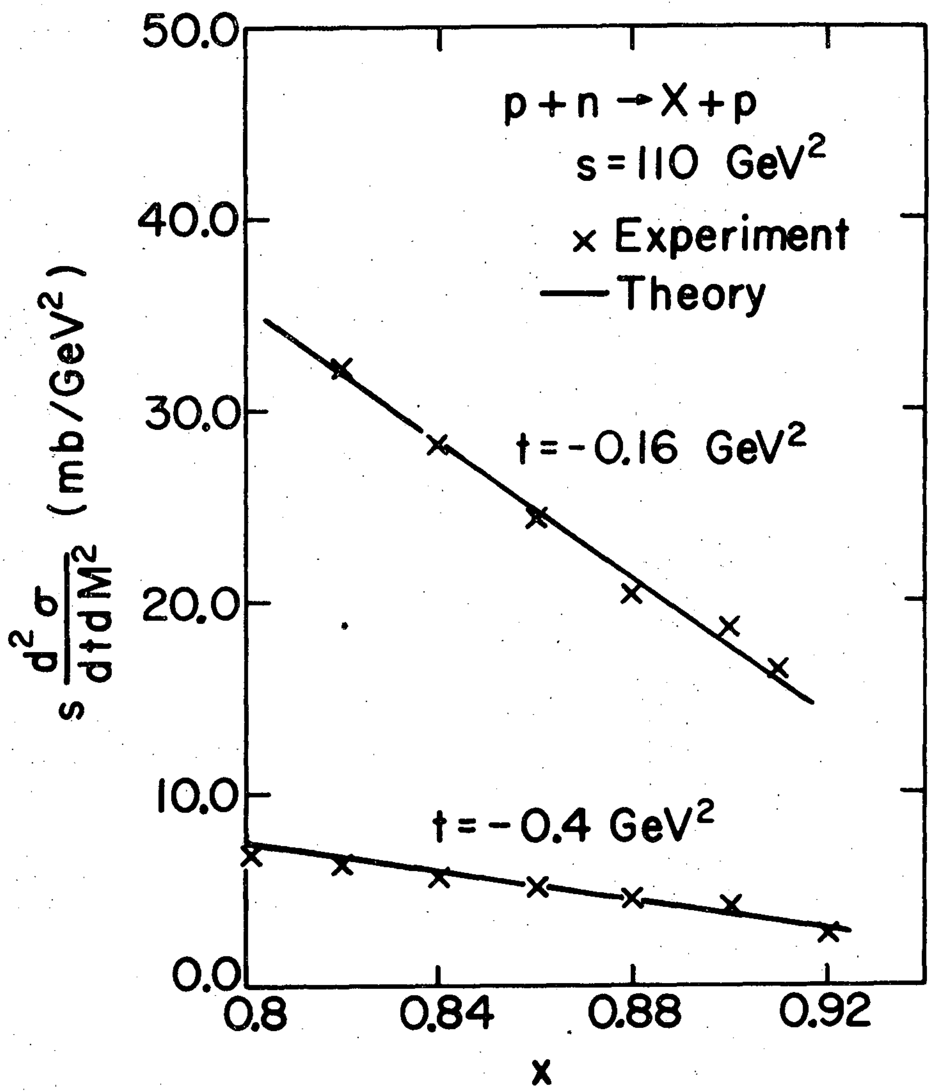
Fig. 3. A semiquantitative fit to the Sannes et al. data[2] on $p + p \to X + p$ for $t = -0.16\ \text{GeV}^2$ ($|t| \gg \mu^2 = 0.02\ \text{GeV}^2$). The contribution of each term [see Eqs. (2a)-(2d)] is also given.

Fig. 4. With the same parameters as in Fig. 3 a prediction is given for $s \approx 377\ \text{GeV}^2$ and $t \approx -0.03\ \text{GeV}^2$ ($|t| \approx \mu^2$), corresponding to the measurement of Columbia-Stony Brook collaboration.[3]



XBL738-3866

Fig. 1



XBL738-3867

Fig. 2

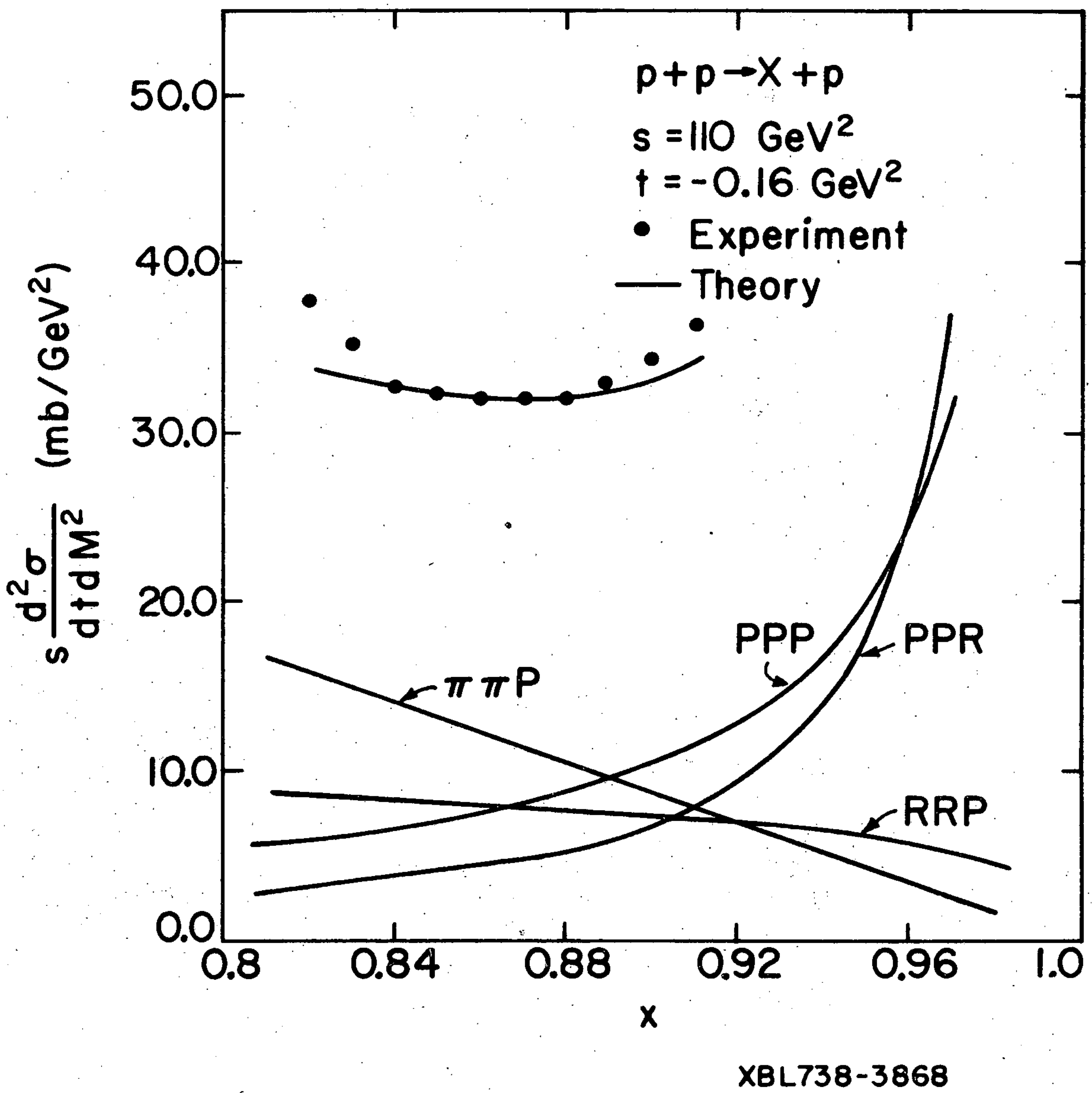
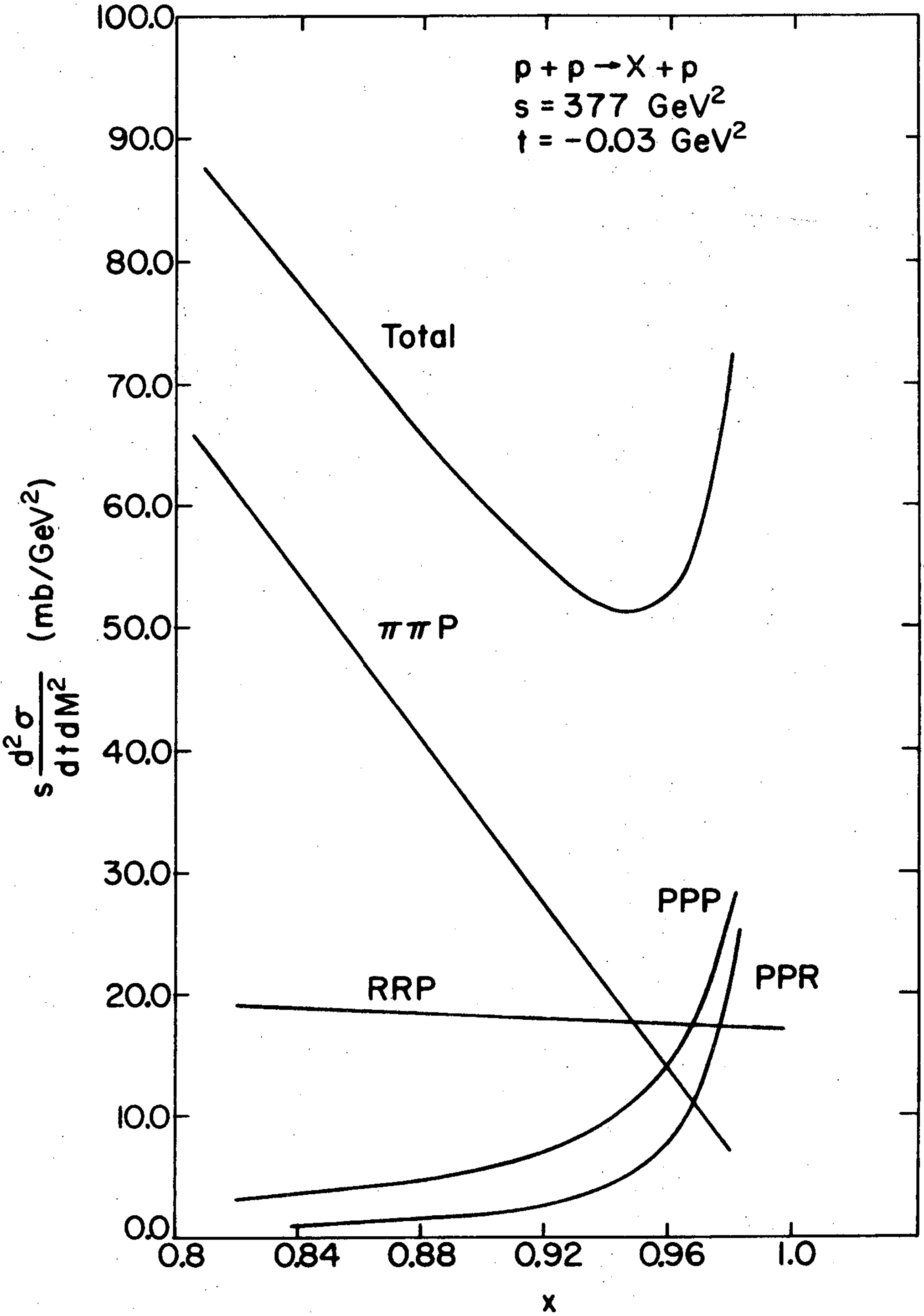

p+p→X+p
s =110 GeV²
t =-0.16 GeV²
Experiment
Theory
50.0
40.0
30.0
20.0
10.0
0.0
0.8
0.84
0.88
0.92
0.96
1.0
x
s d²σ/dtdM² (mb/GeV²)
PPP
PPR
ππP
RRP
XBL738-3868

Fig. 3



XBL 738-3869

Fig. 4

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720