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PROTON-DEUTERON INTERACTIONS IN THE BARE THIRTY-INCH BUBBLE CHAMBER

R. Edelstein, A. Engler, J. G. Fetkovich, G. Keyes,
R. Kraemer, C. Meltzer, C. T. Murphy*, J. Russ, and S. Toaff
Carnegie-Mellon University

J. W. Chapman, B. P. Roe, A. Seidl,
D. Sinclair, and J. C. Vander Velde
The University of Michigan

Abstract

We propose an exposure of 50,000 pictures in the bare thirty-inch chamber filled with deuterium, using protons of 100 GeV/c, and an average of 5 incident protons per picture. We plan to study numerous properties of p-n interactions, most notably the odd-prong multiplicity cross section, single and double dissociation, inclusive pion production, correlations, and the total cross section for deuteron final states.

We also propose a similar exposure at 400 GeV at a later date.

*Scientific Spokesman

**Replaces proposal # 173

I. Physics Justification.

There is currently great interest, but very little data, in high-multiplicity hadron interactions above 70 GeV. It is important to compare p-n interactions with the studies now underway of p-p and π-p interactions using the same techniques. In addition there are several features unique to high energy p-d interactions. Moreover, p-d interactions are of particular present interest for NAL since it is not likely that they will be studied at the ISR or in Mirabel in the near future.

We propose to study all interactions in this exposure, not merely the obvious (by virtue of a slow spectator proton) pure p-n interactions. The study of all interactions is necessary to unravel the p-n cross sections from the observed p-d cross sections via comparison with p-p cross sections measured in the same chamber filled with hydrogen. The experiment is proposed as a collaboration between two laboratories, one of which already has p-p film at 100 GeV, in order to maximize the reliability of the comparison of p-p and p-n data at the same energy. Should the Michigan and Rochester groups also obtain p-p film at 400 GeV (an approved NAL experiment), we will then submit a joint proposal for pd pictures at 400 GeV, in order to obtain consistent energy-dependent data.

Details of the main topics of interest in these exposures are as follows:

A. Odd-prong Multiplicities

Current bubble chamber data on charged multiplicity cross sections, $\sigma_m(E)$, from p-p interactions are shown in Figure 1. The following questions are of particular interest.

(1) What are the ratios of the various σ_m at a given E? For example, the Hwa-Jacob-Slansky (HJS) type models predict $\sigma_m \propto m^{-2}$. Clearly such ratios must be tested at energies where cross sections (at least for lower m values) have already reached their limiting values and this apparently requires NAL energies. It also requires <u>at least two energies</u> in order to see to what extent limits have been reached.

(2) In what manner are limits approached and what happens after that? There is some evidence already that σ_4 and σ_6 are decreasing with E. (See Fig. 1). It is important to measure the rate of decrease. The present experiment will allow us to investigate the other low-m cross sections, σ_3 and σ_5, for such behavior.

(3) HJS models predict that $\langle m^2 \rangle$ grows as $\sqrt{s}$ whereas other models predict a slower (ℓn s) dependence. p-n interactions give <u>independent</u> evidence to compare with p-p and π-p data on all of these questions.

We expect to be able to study the odd-prong multiplicities up to about m = 15. For example, we expect about 4500 3-prong and 100 15-prong events in the proposed run.

<u>A comment on the second scattering problem</u>

For much of the physics of this proposal, we can obtain reliable p-n data by restricting ourselves to those events in which the spectator proton range is less than a few millimeters in the bubble chamber. Including the unseen spectators, this should comprise about 75% of the p-n interactions. Lower energy data indicate that such protons are truly Hulthén-like.

However, multiplicity cross sections, if based on the same sample of events, require correction for the events in which a final state particle rescatters off the spectator proton. This correction is known to increase with multiplicity, being, for example, about 25% for m = 6 at 3.6 GeV/c. Working purely with the deuterium film, these corrections could be approximately determined by a study of the "long" spectator events, using a model to account for the multiplicity-changing rescatters. However, by tabulating all interactions in the film and using the hydrogen-determined multiplicities as a constraint on the model, these corrections can be made with much greater certainty. In this connection, coordination of pp and pd scan rules and cuts can be important.

B. Single and Double Dissociation

(1) A completely unanswered question at present is whether inelastic interactions can be described in terms of a "dissociation" or "fragmentation" of the beam and/or the target particles. If such a description is possible, it may occur with no quantum number exchange between beam and target clusters. In such fragmentation, the beam would produce m_1 particles and the target m_2 particles with the same net charge as the beam and target respectively. Such "allowed" values of m_1 and m_2 are listed in the table on p. 5.

m	$=m_1+m_2$ = number of charged prongs
2(pp)	1+1
3(pn)	3+0, 1+2
4(pp)	3+1
5(pn)	5+0, 3+2, 1+4
6(pp)	5+1, 3+3
7(pn)	7+0, 5+2, 3+4, 1+6
8(pp)	7+1, 5+3
9(pn)	9+0, 7+2, 5+4, 3+6, 1+8

As can be seen from the table, the study of p-n greatly enriches the possibility of finding ans studying such behavior. We note that σ_2 is difficult to measure in hydrogen because of the elastic background, so that the lowest multiplicity cross section to be studied occurs in pn scattering.

(2) The possible <u>independence</u> of m_1 from m_2 is also of importance. This can be tested by relations such as

$$\sigma_{2+5} \stackrel{?}{=} \frac{(\sigma_{2+3})(\sigma_{1+5})}{\sigma_{1+3}}$$

These relations can be tested with lower m values in p-n than in p-p. The cross-checks between p-p and p-n (such as above) are clearly of interest and, in fact, <u>necessary</u> if such relations are to be confirmed.

(3) $p + n \rightarrow p + p + \pi^-$ (one pion production). When this reaction proceeds via dissociation of the neutron, there is only one particle with unmeasurably high momentum, so the hypothesis is a "3C" fit. Our experience with the 100 GeV pp film suggests that three

constraints will be enough to isolate a clean sample of these events, so that one particular dissociation reaction can be completely studied. At 12 GeV, the cross section for this reaction is about 0.7 mb, which would imply 300 events in our experiment if the cross section is constant. This is probably not enough events to look for structure (i.e., isobars) in the $p\pi^-$ system.

When the π^- is produced at the proton vertex via charge exchange and is therefore fast in the laboratory, the reaction becomes a 2C fit. Whether the reaction can then be cleanly separated from the background reamins to be seen. One-pion production cannot possibly be isolated in the pp runs, as one particle is always neutral.

C. Inclusive nucleon production

To the best of our knowledge, there exists no data on the inclusive reaction, $p + p \rightarrow n$ + anything. This reaction is very difficult to study with either counter or visual chamber techniques. However, in deuterium we can study the corresponding $n \rightarrow p$ reaction via $p + d \rightarrow p_{spectator} + p_{slow}$ + anything. The identified slow protons ($P_{lab} < 1.2$ GeV/c) fall in the backward half of the backward CM hemisphere, ie., they have $x_{cm} < -0.5$ and $P_{\perp} < 1.0$ GeV/c. Their spectrum gives new and independent information with which to confront fireball models, Mueller-Regge theory, etc. It is also important to compare this spectrum with the spectrum from $p + p \rightarrow p$ + anything in order to extract the I = 0 and I = 1 components of the inclusive spectra.

D. Inclusive and Semi-inclusive $\pi^{\pm}$ Production

(1) If no-isospin-exchange between beam and target clusters is a valid concept then the following relations between neutron and proton fragmentation must hold:

$$(p \to \pi^+ + \text{anything}) = (n \to \pi^- + \text{anything})$$

$$(p \to \pi^- + \text{anything}) = (n \to \pi^+ + \text{anything})$$

We should be able to test these relations, at least for low-m events, to see if no-isospin-exchange is indeed valid, and in what kinematic regions.

(2) The beam energy dependence of π^- production for each m value is straightforward and of great importance. In particular, the study of single charged pion production is much easier in $n \to \pi^- p$ than in $p \to \pi^+ n$, because of the ambiguity between the fast π^+ and protons in the latter case.

E. Correlations

One wants to measure, for example, $\pi_1^- \pi_2^-$ transverse and longitudinal correlations as a function of $\Delta y = y_1 - y_2$. Do correlations fall as $\exp(-\Delta y/2)$ as some theories suggest? For this purpose, one wants as many events as possible at large Δy. A reaction like

$$pn \to (p\pi^+\pi^-) + (p\pi^-)$$

requires one less pion than the p-p reaction

$$pp \to (p\pi^+\pi^-) + (p\pi^+\pi^-)$$

Phase space considerations suggest that the above pn reaction will produce a greater fraction of events at large Δy than the analogous pp reaction.

We should be able to measure the y and ϕ_{lab} distributions of the fast π^- with sufficient accuracy to make such tests.

F. Deuteron Final States

We expect to be able to identify pd elastic scattering by kinematic fitting. Inelastic reactions p+d → X+d will be difficult to fit (at least using just bubble chamber measurements) on an individual event basis. However, we expect to be able to measure the cross section $d\sigma/dt$ for such processes by making use of the steep t slope and elastic-like behavior of the recoiling deuteron for small M_X. We will be able to classify the state X by an approximate measure of its mass ($\delta M_X^2 \simeq \pm 0.8$ GeV^2) and by seeing how many charged prongs it decays into. (X → 1 prong will probably not be feasible because of the large background from elastic pd and pp scattering.)

Such coherent inelastic pd reactions single out the I = 0 exchange process and are therefore clearly of great importance to our understanding of the mechanism for diffraction dissociation. Similar reactions can be studied in hydrogen, but there one is faced with the ambiguity that the slow proton in many cases can be either a true recoil <u>or</u> a proton from the decay of a state X which was produced at the target vertex. This ambiguity does not exist for p+d → X+d. The identification of these reactions is discussed in more detail in the Appendix.

G. Miscellany

We mention here two other minor topics which are possible.

1. $pd \rightarrow pp$ + all neutrals. Low momentum-transfer charge exchange reactions such as this one (in which only two slow protons are observed) are easy to recognize. It is important to measure the energy dependence of such processes.

2. Neutral strange particle production and π° production. It will be possible to measure the cross section for slow K° and $(\Lambda^\circ, \Sigma^\circ)$ production, and therefore perhaps possible to learn something about strange particle production at the lower vertex, i.e., produced at the neutron vertex in an exchange process. Fast K° and Λ° will be ambiguous with converted γ rays. Preliminary estimates indicate that there might be roughly equal numbers of converted γ rays and fast strange particle decays, a few thousand of each.

II. Film Analysis

We point out that much of this physics requires no measuring and can be done quickly. Both laboratories are well equipped to scan and measure 30-inch chamber film, and are experienced with the chamber. Because of a slightly greater wealth of equipment which handles the 70 mm MURA film format, and the conservative desire to take no chances with resolution problems, we request 70 mm film. We are sufficiently staffed that the scanning could be completed within three months after determing scan criteria.

Both institutions have POLLY systems which will become operational during 1973, which may turn out to be very useful in extracting more detailed information from the film at a later stage.

We believe that this experiment should be given as high priority as the other approved bare chamber p-p exposures and we would hope to obtain film soon enough so that it can be more-or-less concurrently analyzed with the Michigan-Rochester p-p exposures.

III. Special Equipment

The physics outlined above can be done using the "bare" 30-inch chamber and the emphasis for these exposures should be to operate in the normal bubble chamber mode. However it is possible that certain features of the data could be improved and additional useful information obtained by the simultaneous use of down-stream spark chambers. The usefulness of such additional data is yet to be determined, but if the equipment is available we would, of course, like to consider making use of it.

We are considering the possibility of installing a thin, opaque screen in the downstream part of the chamber (positioned roughly like the lead plate of earlier years) in order to ease the track-matching problem in the reconstruction program. In the upstream pair of cameras, track endings on the screen would give corresponding-point end points. No volume would be lost, as the downstream cameras could measure momentum over the full chamber length. The technical problems of this suggestion must be discussed.

The installation of a beam "kicker" in the incident beam would be useful, but not essential. It would allow us to run at a constant 8 tracks per picture, which we believe to be manageable, instead of an average of 5.

Appendix

We believe that we can identify deuteron final states by making use of two of their prominent features.

(1) The sharp t slope. Typical reactions with a final state deuteron have $d\sigma/dt \sim e^{35t}$. At 12.5 GeV/c for $pd \rightarrow (p\pi^+\pi^-)d$ the Michigan group finds a slope of (34.5 ± 1.5) GeV^2 and a cross section of 0.36 mb. It is therefore reasonable to expect a cross section of 0.5 mb at 100 GeV for $p+d \rightarrow d + (X \rightarrow 3 \text{ prongs})$, with $M_X < 3$ GeV. The corresponding reaction on hydrogen should be approximately the same size. (With 100 GeV pp the Michigan-Rochester group finds 0.5 ± 0.1 mb for this.) For a given topology one measures all stopping deuteron-like tracks with range > 0.2 cm. This sample will contain about 50% of the deuteron events. It will also contain spectator protons from states produced diffractively off the neutron and recoil protons from similar states produced off the proton, i.e, diffractive deuteron break-up reactions. Only about 25% of the spectator protons have range > 0.2 cm and these can be subtracted out, making use of their isotropic angular distribution in the lab. The recoil protons can be identified by range vs. curvature if their range is $\gtrsim$ 4 cm.

(Only ~ 1% of the deuterons have range > 4 cm). If one assigns a t value to all stopping tracks based on the deuteron range-energy relation then the false t value for the proton is ~ 2.6 times its true value. For example, a proton cross section of $d\sigma/dt = 9\ e^{9t}$ takes the form $d\sigma/dt_{false} = 1.7\ e^{3.5t_{false}}$ when plotted vs. t_{false}. This data can be extrapolated under the deuteron peak and the deuteron cross section can then be extracted. An approximation of what the data should look like is shown in Fig. (2). We hope to obtain a ±(10-20)% measurement of the deuteron cross section by this technique.

(2) The angular correlation.

For the reaction $p+d \rightarrow d+X$ the deuterons appear quite elastic-like for low M_X and high beam momentum. At 100 GeV, for $M_X < 3$ GeV, virtually all of the deuterons with range > 0.2 cm will have angles (θ) within 77° - 87° of the beam direction (see Fig.3). Recoil protons from reactions with the same M_X and t values tend to fall in the same region on a t vs. θ plot, provided they were at rest before the collision. However, in deuterium the Fermi momentum of the protons smears out this correlation since the Fermi momentum is not small compared to the recoil momentum we are talking about (100-200 MeV/c).

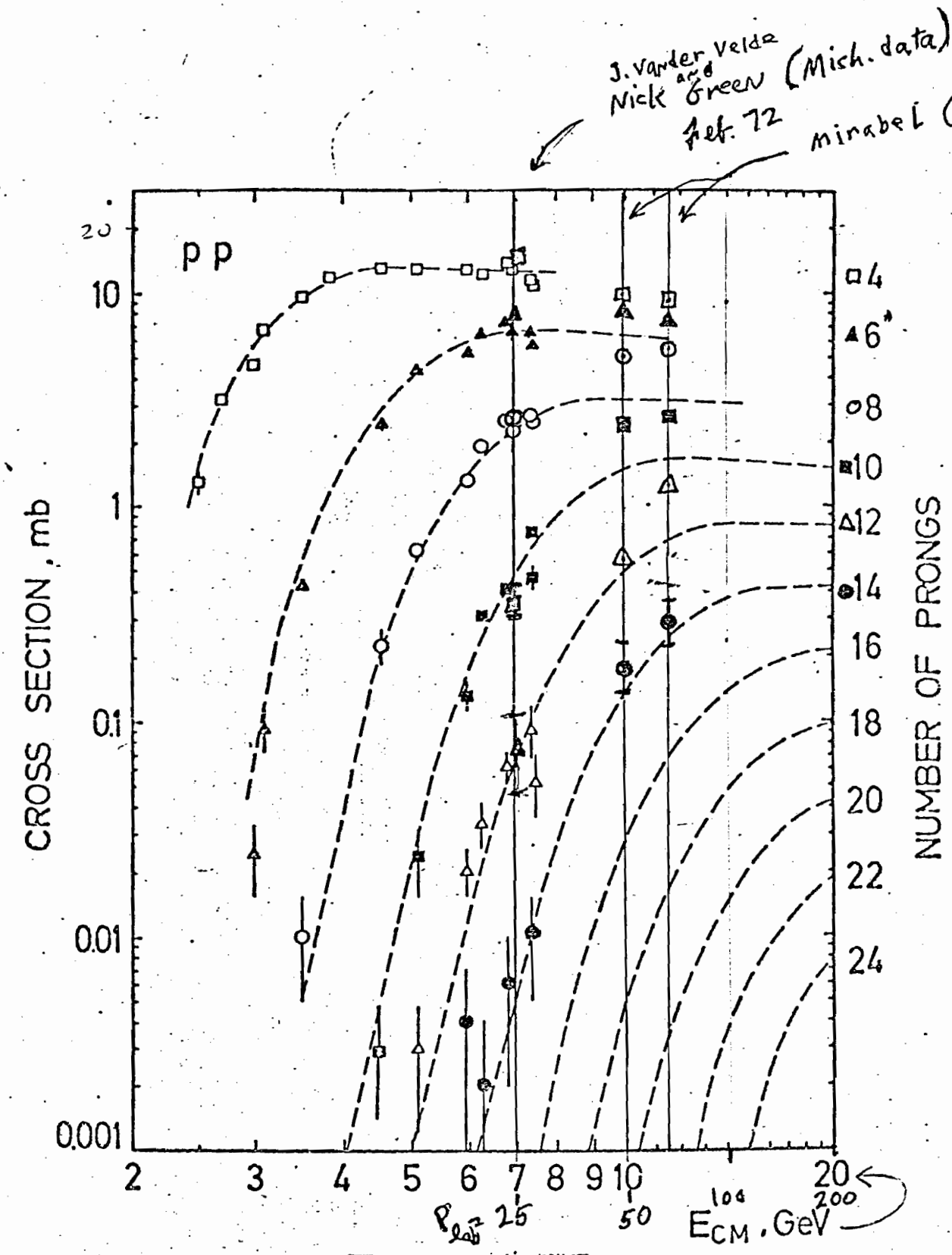
J. Vander Velde and Nick Green (Mich. data) Feb. 72
Minabel (Oxford CONF.) April '72.
p p
CROSS SECTION, mb
NUMBER OF PRONGS
4
6
8
10
12
14
16
18
20
22
24
20
10
1
0.1
0.01
0.001
2
3
4
5
6
7
8
9
10
20
P_{lab} 25
50
100
200
E_{CM}, GeV

Fig.1

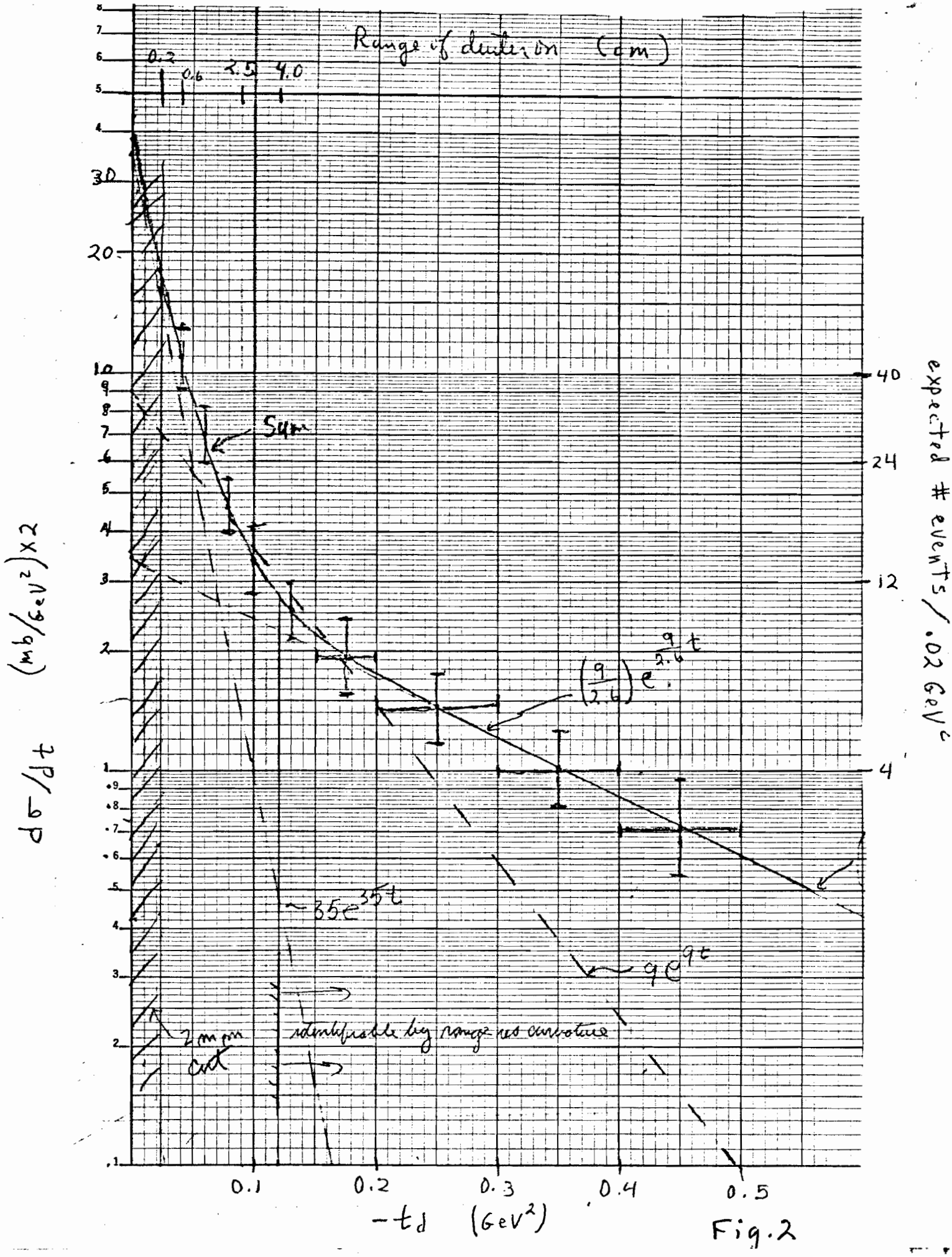
Range of deuteron (cm)
0.2
0.6
2.5
4.0
Sum
$\left(\frac{9}{2.6}\right) e^{\frac{9}{2.6}t}$
$\sim 35e^{35t}$
$\sim 9e^{9t}$
2 mm cut
identifiable by range not curvature
$d\sigma/dt$ (mb/GeV^2)x2
expected # events/.02 GeV^2
$-t_d$ (GeV^2)
0.1
0.2
0.3
0.4
0.5
40
24
12
4

Fig. 2

SCATTERPLOT NUMBER 1 THETA VS. PR

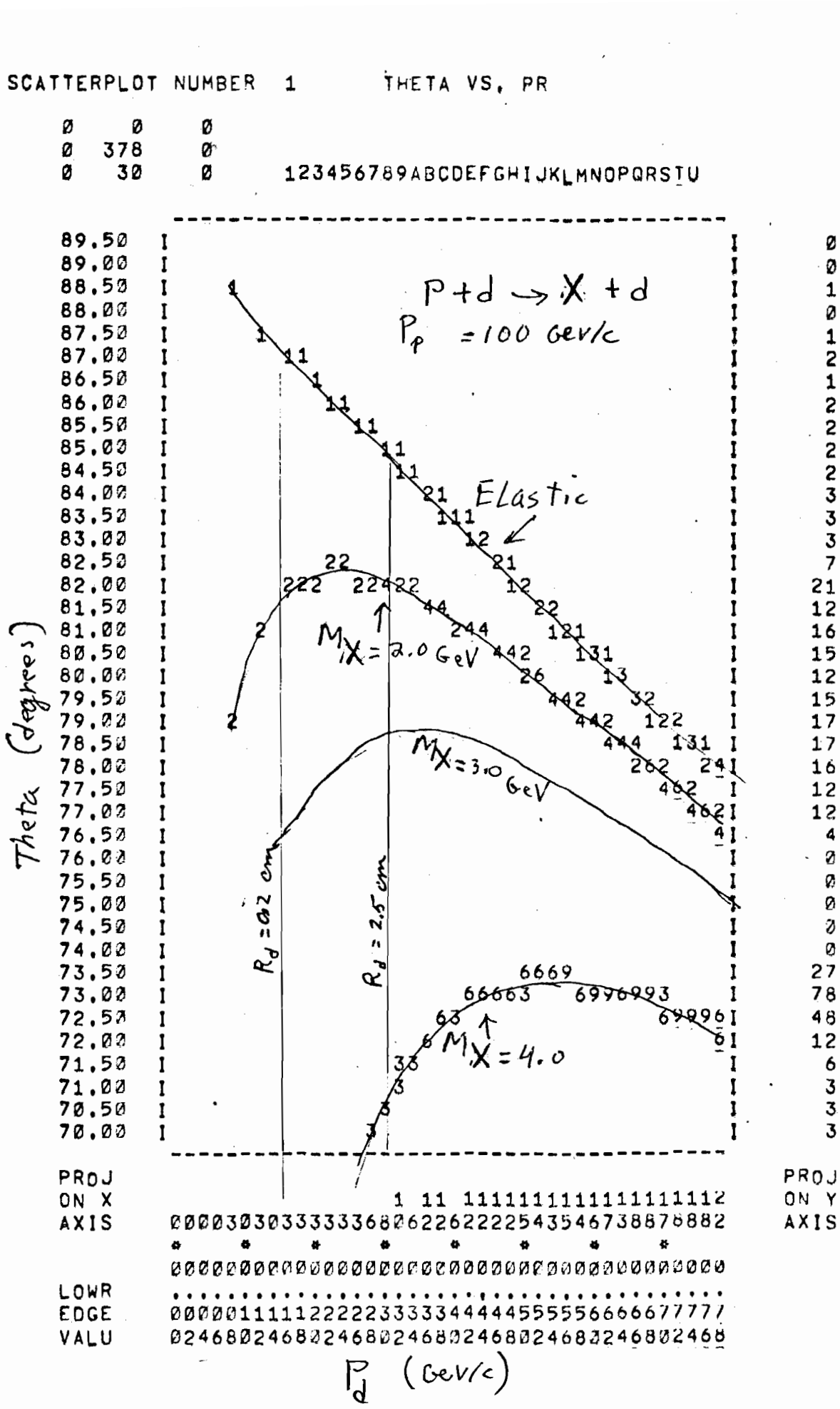

Fig. 3