NAL PROPOSAL No. 204

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# Proposal for a pd 200 GeV/c Bubble Chamber Experiment at NAL

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## 1.0 Purpose

(a) Study of particle production in pp and pn collisions and testing the duality predictions for these reactions.

(b) Study of the fragmentation of the neutron in pn collisions.

(c) Study of particle production and multiplicity distribution in diffractive processes by measuring coherent pd collisions.

## 2.0 Specifications

(1) 200 GeV protons in the 30 in. bubble chamber filled with deuterium.

(2) 60,000 pictures with 6 protons per picture.

(3) Pictures photographed on 35 mm film.

(4) Magnetic field desired: 27 KG.

## 3.0 Yield estimates

Based upon existing NAL exposures[1-3], it would seem that an average of 6 protons per frame, in the 30" HBC is a reasonable flux. Assuming $\sigma_T(pd)$ of about 80 mb this would yield, in a fiducial volume of 50 cm along the beam, an average of about 1 interaction per picture, inside the fiducial volume. With a Poisson distribution about 1/3 of the pictures would yield no interactions or more than 3 interactions, which we assume to be then un-analyzable. Thus, in 60,000 pictures we expect about 40,000 good events, namely about 500 events/mb.

## 4.0 Introduction

Recent pp experiments at 100[1], 200[2] and 300[3] GeV/c in the 30 inch hydrogen bubble chamber at the National Accelerator Laboratory yielded interesting and important results. Moreover, they demonstrated the possibility of studying production of slow charged and neutral particles in bubble chamber at these energies. Following these experiments we propose a pd experiment at 200 GeV/c.

One of the main purposes of the proposed pd experiment is to study and compare the single particle spectra of slow charged and neutral particles in pp and pn collisions. There are several predictions for these spectra(4) and, for example, those of Tye and Veneziano(4), which generalize to inclusive spectra the well known predictions of two-component duality (Harari-Freund, $\sigma(K^+p)=\sigma(K^+n)$ and $\sigma(pp)=\sigma(pn)$), are summarized in table I. Glauber corrections and possible experimental biases are greatly reduced if one considers normalized spectra for inclusive reactions:

$$\rho_p(c) = \sigma(pp \to c) \,/\, \sigma_T(pp) \quad \text{and} \quad \rho_n(c) = \sigma(pn \to c) \,/\, \sigma_T(pn)$$

where $\sigma(pp \to c)$ and $\sigma(pn \to c)$ are the differential spectra of particle $c$ in a given $x$ and $P_T$ range and the $\sigma_T(pp)$ and $\sigma_T(pn)$ respectively are the total pp and pn cross-sections (How pp and pn cross-sections are measured in the pd experiment is described and discussed in the next section).

Table 1: relations predicted by Tye and Veneziano(4)

(1) $\rho_p(\pi^0) = \rho_n(\pi^0)$

(2) $\rho_p(\pi^+) + \rho_p(\pi^-) = \rho_n(\pi^+) + \rho_n(\pi^-)$

(3) $\rho_p(\pi^+) + \rho_p(\pi^-) = 2\rho_p(\pi^0)$

(4) $\rho_p(\bar{p}) = \rho_n(\bar{p})$

(5) $\rho_p(K^-) = \rho_n(K^-)$

(6) $\rho_p(K^+) + 2\rho_p(K^0_{s,L}) = \rho_n(K^+) + 2\rho_n(K^0_{s,L})$

(7) $\rho_p(\Lambda^0) = \rho_n(\Lambda^0)$

(8) $\rho_p(\Sigma^0) = \rho_n(\Sigma^0)$

The fragmentation of protons into neutrons in pp collisions was not measured so far. We propose to study the fragmentation of neutrons into protons and to measure the inclusive spectrum of the protons in pn collisions. Comparing this with $p \to p$ might provide an estimate of triple Pomeron and Regge-Regge-Pomeron couplings[5] in inclusive reactions. We shall also study the reaction $pn \to (p\pi^-) + x$ and attempt to observe inclusive production of the $N^*(1470)$ isobar.

We shall also attempt to study the production of particles in the coherent reaction $pd \to$ (fast prongs) + d. In this reaction the incident proton is fragmented presumably by diffraction dissociation into fast particles with no isospin exchange. It will be very interesting to study the multiplicity distribution of this diffractive reaction and thus test the current two-component description of multi-particle production at high energies.

## 5.0 Discussion of the p and n interactions

### (a) pp and pn inclusive cross sections

We expect to have 40,000 good events in the 60,000 proposed pictures. We shall scan for all types of events and record in particular (1) the number of charged prongs, (2) associated stopper protons, (3) associated $V^o$ decays and $\gamma$ conversions, (4) charged decays of prongs from the primary vertex and (5) recognizeable Dalitz pairs. We shall measure all the low energy tracks ($p \lesssim 1.5$ GeV/c).

According to Charlton et al.[2] in their pp experiment they achieved a scanning efficiency of (99 ± 1)% and there were only 1.4% events with odd or unresolved prong count. We believe that we shall also be able to obtain a similar sample that will be classified as follows:

Class - (I) pp events: pd events with even number of charged prongs with no proton stopper of $P < 300$ MeV.

Class - (II) pn events: pd events with odd number of charged prongs with either (a) an unseen proton spectator or (b) an observed proton spectator i.e. a backward proton stopper ($p < 300$ MeV) in the laboratory system.

Class - (III) pN events: i.e. either pp or pn events - all the remaining events which are not included in (I) or (II), and are not coherent pd events. (The coherent events are discussed later).

More than 90% of the pp collisions in the proposed experiment will be found in class (I), and 15,000 good events are expected in this group (see table IV). Class (II) will include 80% of all pn collision with total of 13,000 expected events. About 5000 events are expected in class (III) of which about 80% are pn collisions and 20% are pp collisions.

Next we shall measure (whenever possible) the momentum and ionization of all slow particles associated with all the events in the three groups: (I) pp, (II) pn and (III) pN. The information about the measured particles is summarized in table II. In this table we used the results on charged and neutral particles obtained in the NAL pp experiments[2,3] and assumed that two particles with the same momentum and of different mass can be distinguished by ionization if $(I_1/I_2) = 1.5$. The expected number of particles was estimated from NAL[2,3] pp results. We expect similar measuring ability for pn events. It appears from table II that we shall be able to observe in a given $P_T$ and $x = \frac{2P_L}{\sqrt{s}}$ ranges the following particles: p, $\pi^+$, $\pi^-$, $\pi^o$, $K^o$, $\Lambda^o$ or $\Sigma^o$. We shall use these observations in both pp and pn events to measure the inclusive normalized spectra $\rho_p(c)$ and $\rho_n(c)$ of these particles, and to test the predictions of the various theories, i.e. some of those in Table I. We shall also use the results of the pp experiments[2,3] as another independent test of all available predictions.

(b) Fragmentation of the neutron

The pn events (class II) with measured slow protons ($E_p \leq 1.4$ GeV) will be used to study the inclusive spectrum of protons in the fragmentation region of the neutron: $-1.0 \leq x \leq -0.3$ . From cosmic ray estimates[6] one expects over 500 pn events with slow measurable proton in our sample. Furthermore pn events associated with both measurable protons and $\pi^-$ will be used to study the reaction $pn \to (p\pi^-)+x$ and to deduct possible inclusive production of the $N^*(1470)$ isobar in pn collisions.

Table II

Expected numbers of observed particles in pp collisions at 200 GeV/c, in 60,000 pd pictures (16,000 pp events)

| particle | Expected No. of Particles | $P_{max}$ GeV/c | $P_T$ GeV/c | $\frac{2P_L^*}{s}$ |
|---|---|---|---|---|
| $\pi^+$ (a) | 1550 | 1.4 | $\geq 0.1$ | $-1.0 \leq x \leq -0.04$ |
| p | 4500 | 1.4 | $\geq 0.1$ | $-1.0 \leq x \leq -0.3$ |
| $\pi^-$ (b) | $\geq 5000$ | 15 | 0-1.5 | $-1.0 \leq x \leq 0.07$ |
| $\pi^o$ | 800 | 20 | 0-0.6 | $-1.0 \leq x \leq 0.10$ |
| $K^o$ | 380 | 20 | 0-0.6 | $-1.0 \leq x \leq 0.09$ |
| $\Lambda$ | 160 | 20 | 0-0.6 | $-1.0 \leq x \leq 0.07$ |

(a) $K^+$ are neglected

(b) $K^-$ are neglected

## 6.0 The Diffractive Component

### (a) Inelastic Coherent Part

Currently there are several fits(7-10) to the high energy multiplicity distribution in which the two component model(11) is being utilized. The various approaches emphasize different theoretical aspects - however practically all of them assume that the diffractive part is energy independent. If such a component indeed exists, measurements of the coherent diffractive D cross-section in the reaction:

$$pD \rightarrow D + \text{anything} \quad (1)$$

could reveal it. Thus, the yield of coherent D events due to this component should remain constant with energy, for each multiplicity separately. The following table III summarizes the expected yields (in mb):

Table III

| cross section inelastic | Quigg Jackson(7) | Fialkowski & Miettinen(8) | Frazer et al(9) | Harari & Rabinovici(10) |
|---|---|---|---|---|
| $\sigma_2$ | (2.5)* | 2.3 | 2.0 | 2.0 |
| $\sigma_4$ | 2.4 | 3.1 | 2.7 | 2.2 |
| $\sigma_6$ | 1.1 | 1.7 | 1.7 | 0.9 |
| $\sigma_8$ | 0.6 | 0.6 | 0 | 0.1 |
| $\sigma_{10}$ | 0.4 | - | - | - |
| $\sigma_{D(tot)}$ | 8.5 | 7.0 | 6.4 | 5.2 |

(*) In the original calculation $\sigma_{2(elastic)} \simeq 7$ mb was added to $\sigma_2$

Tests in some of our current deuterium experiments (pd at 12 GeV/c) have indicated to us that one can distinguish <u>reliably</u> between short proton recoils and deuterons, if the particles have a range of $\geq$ 6 cm in the bubble chamber. This range deuteron corresponds to a momentum transfer of $-t = 0.16\ \mathrm{GeV}^2$. Assuming the diffractive inelastic part to behave like:

$$\frac{d\sigma}{dt} = A\ e^{Bt} \qquad (2)$$

with $B \simeq 6\ \mathrm{GeV}^{-2}$, we obtain for the coherent deuterium cross section in the single[12] scattering region ($|t| \lesssim 0.4$) :

$$\frac{d\sigma}{dt} = 4\cdot A\ e^{Bt}\ [F(\tfrac{1}{4}\,t)]^2 + \text{(d. scatt. corrections)} \qquad (3)$$

The form factor F(t) can be[12] approximated here by:

$$F(t) \simeq \frac{1}{1+60|t|} \cdot \frac{1}{1+5|t|} \qquad (4)$$

The double scattering region ($|t| \gtrsim 0.5$), where the interaction occurs on one of the nucleons and the diffractively dissociated projectile ($N^*$'s (?)) subsequently scatters elastically on the other nucleon of the deuterium, is characterized by a much flatter[12] $d\sigma/dt$. Roughly, the slope here becomes about half the corresponding slope in pp collision, namely about B/2. At NAL energies the $N^*$ would behave like a stable particle and thus estimates of the double scattering effect can be gotten from $\pi^+d$ scattering[12]. It is worth pointing out that in principle the double scattering term could lead to determination of the $N^*$-N scattering, as was done by Anderson et al.[12] in $\rho^0 N$ photoproduction.

<u>Expected yield</u>

From table III we take 7 mb as an estimate of the total cross-section in the diffractive component in p-p collisions. Assume the above expression (2) to get $A \simeq \sigma \cdot B \simeq 40$ mb$\cdot$GeV$^{-2}$. Utilizing now (3) we get about 0.3-0.4 mb for the integrated coherent total cross section for $|t| \geq 0.16$ (namely, deuterons with range $\geq$ 6 cm in the bubble chamber). In an experiment with 500 event/mb this would yield about 150-200 events. Comparison with other energies would give the diffractive multiplicity energy dependence. With this number of events some information on the double scattering region might be gotten ($\sim$ 50 events).

Missing Mass distribution:

The typical errors at 205 GeV/c lead to a resolution of $\delta_{mm^2} = \pm 1.5$ GeV$^2$ for masses around 1 GeV[2], based on measurements of the recoil particle only. This should enable us to study further the coherent events and to examine if in general they are associated with low missing masses.

(b) Elastic Coherent $pd \rightarrow pd$.

The work of Charlton[2] *et al.*, has shown that separating elastic events from inelastic is possible and reliable in the $|t|$ range $|t| \gtrsim 0.05$ GeV$^2$, for P = 200 GeV/c. This t corresponds to proton recoil momentum of about 220 MeV/c, or range of 5 cm. The coplanarity and angle vs. P(recoil) tests should be reliable in deuterium also and thus we shall be able to measure elastic coherent $pd \rightarrow pd$ for events with $R_d \geq 4 - 5$ cm, or $|t| \geq 0.12$ GeV$^2$. Utilizing expressions (2)-(4) above, for $\sigma_{pp}^T(el) \simeq 7$ mb and $B = 10.1$ GeV$^{-2}$, one has $A \simeq 70$ mb GeV$^{-2}$ and we get $\sigma_{pd}^T(el) \simeq 8$ mb, of which we shall reliably measure about 0.5 mb ($|t| \geq 0.12$ GeV$^2$), corresponding to 250 events. Estimates of $\sigma_T(pd)$ and, by subtraction, also $\sigma_T(pn)$ will thus be possible. This work would extend therefore the small angle pd scattering measurements at NAL[11] to higher $|t|$ - regions.

## 7.0 The Weizmann Institute Bubble Chamber Group

Our group has been active in bubble chamber work for about 12 years and we have been engaged in many experiments. We are particularly active in deuterium work and have conducted several $K^-d$, $\gamma d$, and pd experiments in the energy range of 3-12 GeV/c. Thus our entire personnel is used to working with deuterium and well prepared to handle deuterium problems.

The group at present is composed of 10 physicists, 7 programmers, 6 engineers and technicians and about 20 scanners. Most of our people are experienced and participated already in many experiments.

Our measuring equipment is composed of a Spiral Reader system and 3 film plane manual digitizers. Our measuring capacity is over 300,000 events per year. Thus the relatively small number of measurements involved in the NAL experiment should be completed in a short time, of the order of a few months.

The Institute owns an IBM 370/165 computer and 30-40% of its time is used by the High Energy group. Also, we have worked already with the MURA 30" HBC in the past and thus all the desired programs are readily available.

## 8.0 Time table and collaboration

The proposed experiment can be done by our group alone in 6-12 months. If it will turn out to be successful and yield important information as outlined in the proposal, we think that it should be repeated at a higher energy and eventually supplemented by measurements of the fast particles in one of the hybrid systems currently under consideration at NAL in conjunction with the 30" HBC. We shall be interested to collaborate with other interested groups in the continuation of such experiments at NAL.

Table IV. Cross-sections and yields estimates

| | σ(mb) | No. of events in Fiducial Volume |
|---|---|---|
| Total pd cross section | 80 | 40,000 |
| Elastic scattering, pd → pd (all) | 8 | 4,000 |
| Inelastic, coherent d (all) | 6 | 3,000 |
| d Break-up events: | | |
| p-p interactions(all) | 33 | 16,500 |
| p-n interactions(all) | 33 | 16,500 |
| pn → $p_s$(visible) + odd | 10 | 5,000 |
| pn → ($p_s$ - visible, backwards in Lab) + odd | 5 | 2,500 |
| d Coherent events: | | |
| Elastic with $\|t\| \geq 0.12$ ($R_d > 4.5$ cm) | 0.5 | 250 |
| inelastic, $\|t\| > 0.16$ ($R_d > 6$ cm) | 0.4 | 200 |

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Supplement 1 March, 1973

# Proposal for a pd 200 GeV/c BC Experiment at NAL

(Weizmann Institute High Energy Group)

## Estimates of the expected differences in the inclusive p and n spectra.

In general, the single particle inclusive spectra on protons and neutrons are expected to be different. Typical order of magnitude of the p-n differences can be gotten from total cross-sections differences, $\sigma_T(pp) - \sigma_T(pn)$, $\pi^+p$ and $\pi^-p$, etc. Using recent Serpukhov results[14] and compilations[15] one can extrapolate the effects to 200 GeV/c to find that the expected differences are about 1-2 mb, namely of the order 2-5%. These could barely be detected in the main channels of the present experiment, namely p, $\pi^+$, $\pi^-$ (see table II), because of limited statistics. One can be less certain about the expected inclusive difference ($p \rightarrow K^-$) vs. ($n \rightarrow K^-$), in the target nucleon fragmentation regions. These could be larger and therefore easier and interesting to test in the present experiment. A difference of about 10% in this inclusive spectra could already be detected. Thus some tests of the duality predictions will be possible in our experiment and this would help the planning of more detailed and accurate future experiments, along similar lines.

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Supplement 2

NAL PROPOSAL No. 204
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Proposal for a pd 200 GeV/c BC

Experiment at NAL

(Weizmann Institute High Energy Group)

Identification of coherent d events from recoil particle measurements.

In standard bubble-chamber experiments at a few GeV/c the identification of coherent d-events is usually achieved via complete kinematical solutions of individual events (4c or 1c solutions). Thus in true d-events, for example, $pd \rightarrow pd\pi^+\pi^-$, the spurious (1c) solution $pp_s n\pi^+\pi^-$ usually yields a very narrow d spike in the invariant mass distribution $M(p_s+n)$. At NAL energies complete kinematical solutions are almost impossible and one has to utilize the measurements of the slow particle alone in order to isolate the coherent d-events. We wish to demonstrate that by such measurements one can unambigously identify deuterons in the momentum region of 0.4 - 3.0 GeV/c.

A. Region $p_d$ = 0.8 - 3.0 GeV/c. In this region deuterons will have specific ionization less than 6 time minimum ionization and will not stop in the 30" bubble chamber. However, ionization measurements can easily be carried out here and since for the same ionization the d-momenta will be twice the corresponding proton momentum, the particle identification is easy and possible. Note that $p \geq .8$ GeV corresponds to $|t| \gtrsim 0.6$ GeV$^2$ and thus only very few events are expected in this energy region.

B. Region $p_d$ = 0.4 - 0.8 GeV/c. This region corresponds to $|t|$ = 0.16-0.6 $GeV^2$ and should contain most of our identifiable d-events. The technique that we shall use here is momentum vs. range measurements, which we find reliable down to d-ranges of 6 cm in the bubble chamber. Because of the extremely steep t-distribution of the coherent d-events it is important to estimate reliably the smallest t value for which deuterium identification is possible. Thus we tested this point experimentally in the following ways:

(1) Reliability of rejection of protons. From a high statistics $\pi^+ p$ experiment in the SLAC 82" HBC stopping protons produced in the reaction $\pi^+ p \rightarrow \pi^+ p \pi^+ \pi^-$ where selected and measured on our Spiral Reader. Each track yields 4 "measured" momenta values: $p_p(R)$ and $p_p(C)$, momenta determined from range and curvature respectively, assuming the stopping particle to be a proton, and $p_d(B)$, $p_d(C)$ - the corresponding quantities for a deuteron hypothesis. The errors on p(R) are usually extremely small and thus the quantity

$$x = \frac{p(R) - p(C)}{\delta p(C)}$$

where $\delta p(C)$ is the error of p(C), should have a normal distribution with a mean of zero and unit variance. The distribution of x for the proton hypothesis ($x_p$) and the deuteron ($x_d$) are shown in fig. 1, for all events having a range R $\geq$ 6 cm. Clearly a reliable separation is observed and one concludes that very few protons could be mis-identified as deuterons. In Fig. 2(a) and 2(b) we give actual distributions of $p_p(C)$ vs. R and $p_d(C)$ vs. R, assuming the protons to be deuterons. Again, clearly the protons sit nicely on the range-energy proton curve whereas the deuteron hypothesis does not agree with its curve, for R $\geq$ 6 cm.

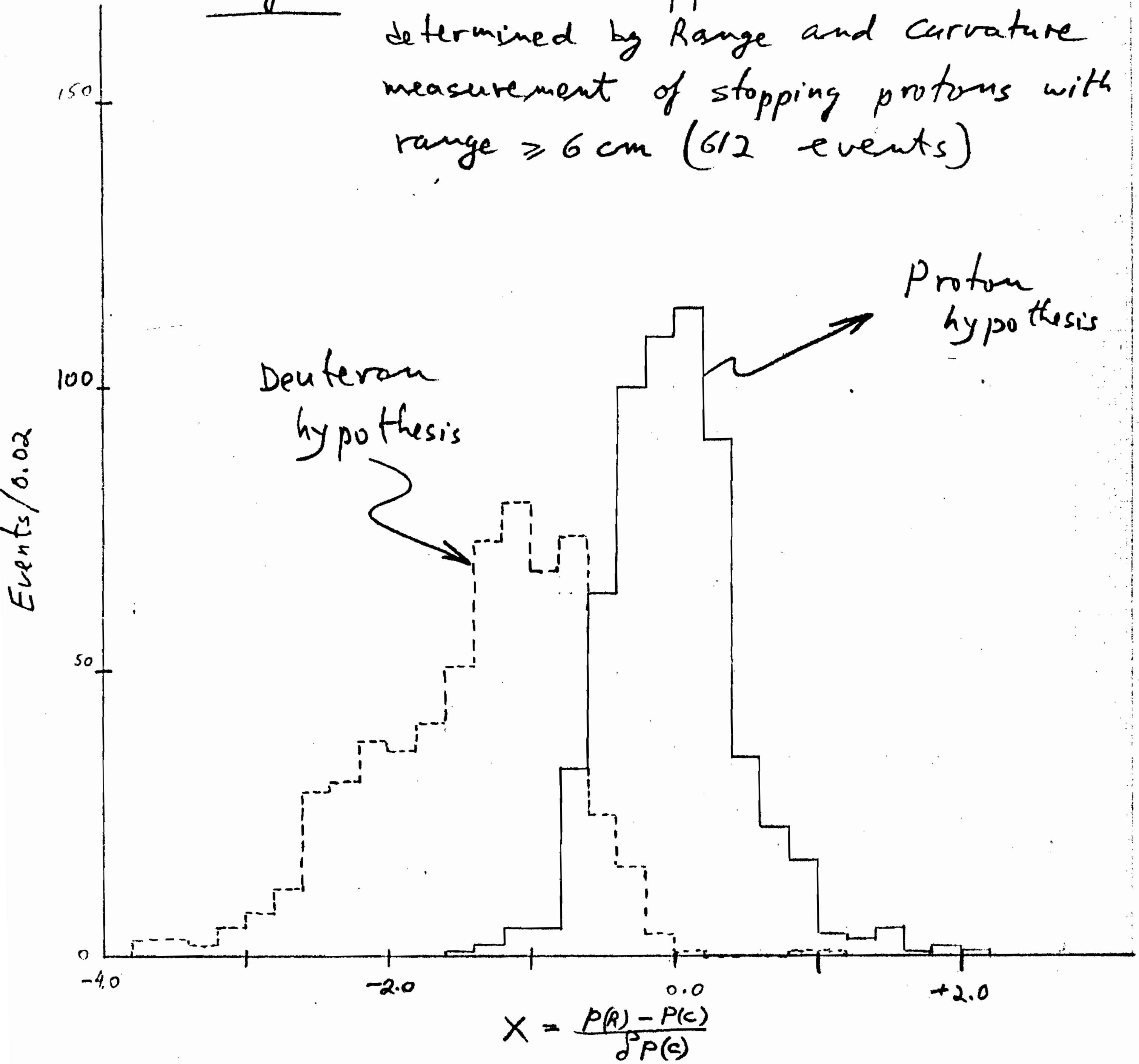
(2) Reliability and efficiency of deuteron detection. From another exposure (pd at 12 GeV/c, BNL) we selected coherent d-events by conventional kinematical methods. These events should be mostly true d-events. We computed also here $p_d(C)$ and $p_p(C)$ and show in Fig. 3 $p_d(C)$ and $p_p(C)$ vs. the true range R. Each event is entered twice in Fig. 3 assuming it to be a proton and deuteron. Again we see from Fig. 3 that for ranges over 5-6 cm in the bubble chamber, reliable and efficient identification of the deuterons is possible and the events scatter nicley around the expected range-energy curve of the deuteron.

## Conclusions

We conclude that practically all deuterons having a range $\geq$ 6 cm can be positively and unambiguously identified in the bubble chambers by measurements performed on the slow particle alone. This would include coherent events with $|t| \gtrsim 0.16$ GeV$^2$. By extra demands on coplanarity and range vs. angle relations, coherent elastic d-events with $|t| \gtrsim 0.12$ GeV$^2$ could also be identified.

$\pi^+ p \rightarrow \pi^+ p \, \pi^+ \pi^-$

Fig. 1: Normalized Differences between momenta determined by Range and Curvature measurement of stopping protons with range ≥ 6 cm (612 events)



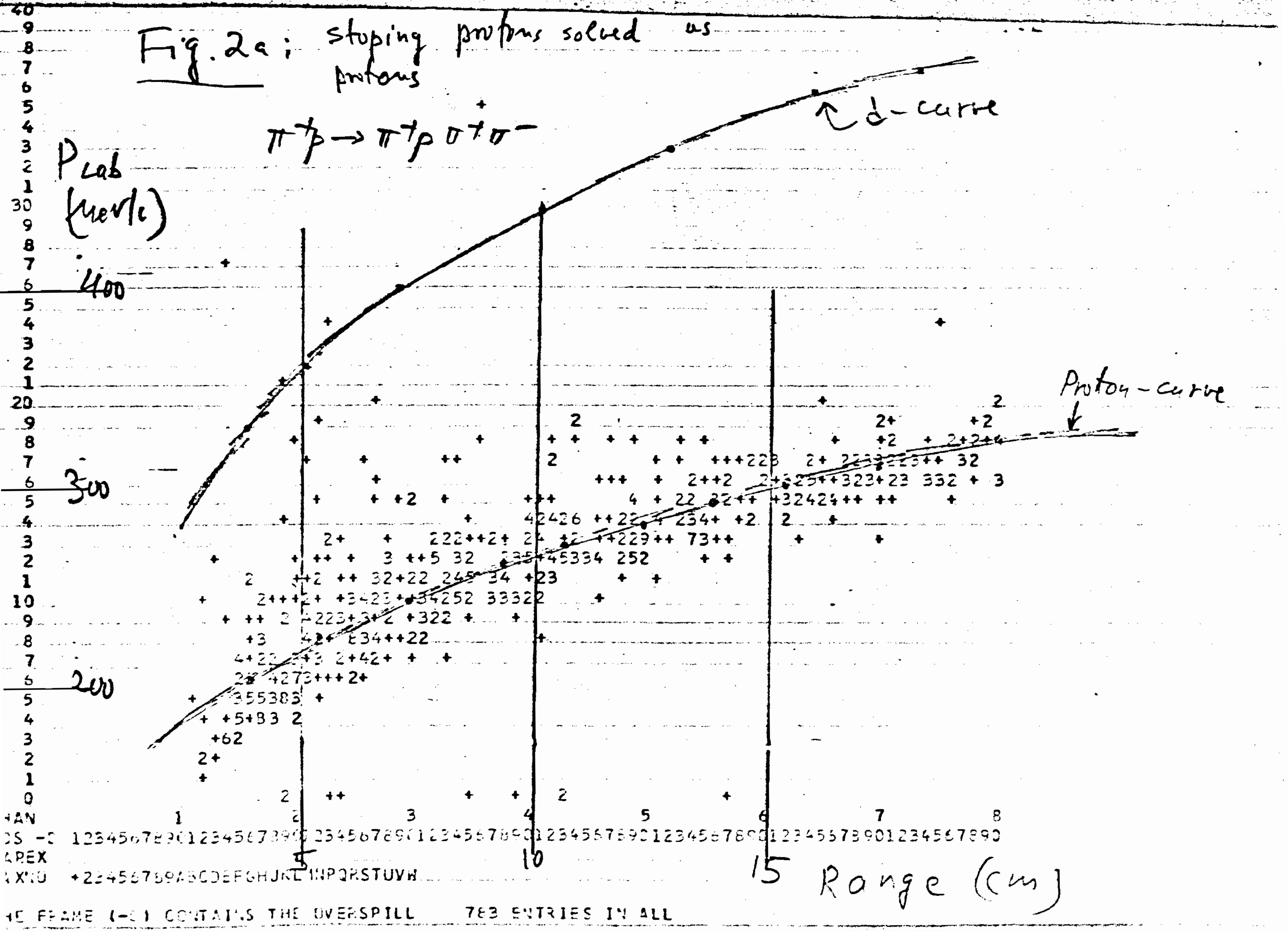
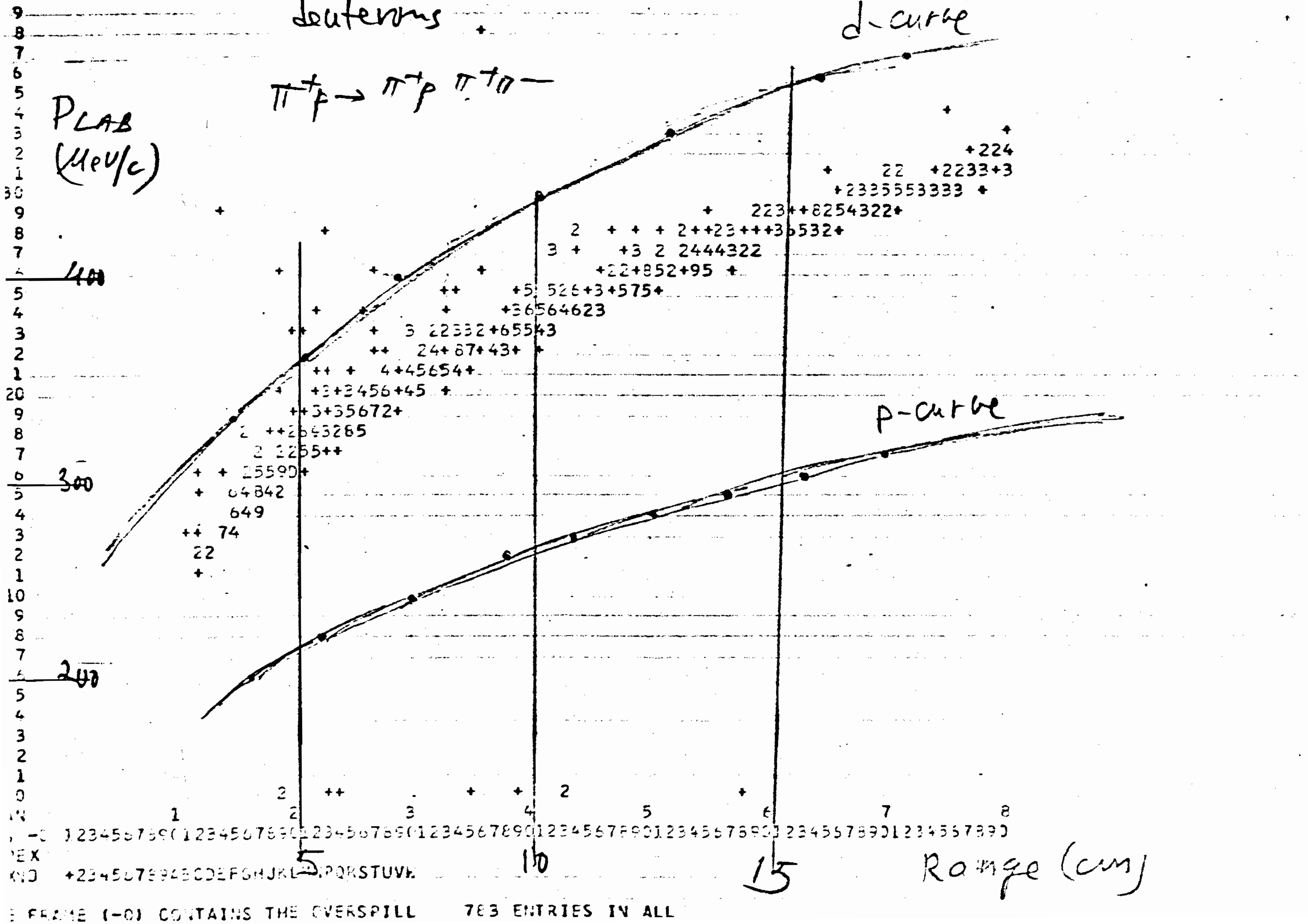


Fig. 2a: stoping protons solved as protons
π+p → π+pπ+π−
Plab (MeV/c)
400
300
200
d-curve
Proton-curve
5
10
15
Range (cm)
THE FRAME (-C) CONTAINS THE OVERSPILL 783 ENTRIES IN ALL

2b: Stopping protons solved as deuterons



$pd \rightarrow pd\,\pi^+\pi^-$

Fig. 3: Measured momenta vs. Range for stopping deuterons