NAL PROPOSAL No. 299

Scientific Spokesman:

Irwin A. Pless
Laboratory for Nuclear Science
Massachusetts Institute of Technology
575 Technology Square
Cambridge, Massachusetts 02139

PRECISION STUDY OF HIGH ENERGY COLLISIONS INDUCED BY INCIDENT 150 GeV/c PIONS AND PROTONS

Brown Univ.: D. Fong, M. Heller, A. Shapiro, M. Widgoff
I.I.T.: R. A. Burnstein, C. Fu, D. V. Petersen, M. Robertson, H. S. Rubin
Univ. of Illinois: R. D. Sard, A. Snyder, J. Tortora
Indianna Univ.: D. Alyea
Johns Hopkins Univ.: C-Y Chien, P. Lucas, A. Pevsner, R. A. Zdanis
M.I.T.: E. Hafen, V. Kistiakowsky, R. I. Hulsizer, A. Levy, I. A. Pless J. Wolfson, R. K. Yamamoto
Rutgers Univ. - Stevens Institute - SUNY at Albany: R. J. Plano, T. L. Watts, M. D. Jones, P. Jacques, T. C. Ou - E. L. Koller, E. B. Brucker, S. Taylor, P. Stamer - C. R. Sun
Univ. of Tenn. - ORNL - Univ. of Cincinnati: W. Bugg, G. Condo, E. Hart - H. Cohn - M. Nussbaum
Yale Univ. - NAL: W. Barletta, H. Kraybill, T. Ludlam, H. Taft - D. Bogert

11 May 1974

NAL Experimental
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SUMMARY

The PHSC is proposing a 1. 2 x 10^6 picutre exposure at 150 GeV/c in the NAL 30" proportional wire chamber hybrid bubble chamber system to be split equally between protons, π^- mesons, and π^+ mesons. The purpose of the experiment is to study, with good precision, high energy interaction induced by the three different projectiles. Due to improved instrument resolution and higher statistics we expect to make a significant contribution to the following topics:

(1) Charged Particle Multiplicity Moments

(2) Production Spectra for charged and neutral particles.

(3) Leading Particle and Diffraction Phenomena

(4) Correlating in momentum and rapidity among the produced particles

(5) Factorization of production amplitudes with respect to the quantum numbers of the incident particle.

In addition we expect to make a preliminary study of $K^{\pm}p$ and $\bar{p}p$ interactions

We expect an overall yield of about 170, 000 measured interactions for our study. The rough breakdown according to prong topology is as follows:

$\pi^{\pm}$ interactions (800, 000 pictures)

Type	Number of events
2 prong elastic	12, 000
2 prong total	19, 200
4 prong	15, 200
6 prong	18 000
8 prong	16, 800
10 prong	12, 400
12 prong	7, 600
14 prong	3 720
16 prong	1, 520
18 prong	800
20 prong	240
> 20 prong	200

PP interactions (400,000 pictures)

Type	Number of events
2 prong elastic	13,800
2 prong total	21,700
4 prong	13,600
6 prong	14,400
8 prong	11,600
10 prong	8,200
12 prong	5,000
14 prong	2,400
16 prong	1.000
18 prong	300
20 prong	180

In addition, we expect to detect and measure with the aid of the Čerenkov tagging system, about 1,200 each of K^+p and K^-p interactions and about 600 $\bar{p}p$ interactions.

DATA TAKING should require of the order of 12 weeks.

PHYSICS JUSTIFICATION

Precision Study of High Energy Collisions
Induced by Incident
150 GeV/c Pions and Protons

I. INTRODUCTION

(1) Purpose of the Experiment

To date a wide range of exploratory experiments carried out in the NAL 30-inch bubble chamber have revealed a great number of important characteristics of high energy collisions. These experiments have focused attention on such general properties as

(i) the predominance of diffractive processes in final states of small multiplicity ($\lesssim$ 8 charged particles)

(ii) the essentially short-range nature of particle-particle correlations in the high multiplicity component, which accounts for the bulk of particle production

(iii) the rapid rise of neutral particle production (π^0, K^0, Λ, $\bar{\Lambda}$) through the NAL energy range.

It is our belief that in order to extend further the present state of our understanding of the production mechanisms underlying these phenomena, the versatality of the bubble chamber should be brought to bear with more accurate experiments.

We propose here an exposure which constitutes a logical second generation experiment for this chamber; an exposure of relatively high statistics utilizing the enhanced analyzing power of the proportional wire hybrid system to study the incident momentum of 150 GeV/c. We propose 400,000 pictures each of incident 150 GeV/c protons, π^+ mesons and π^- mesons. In addition we propose a study of the interactions of the tagged $K^\pm$ meson and $\bar{p}$ component of the beam, which provides a first study of the interactions of these particles at this high energy in a bubble chamber.

(2) The Hybrid System

The NAL proportional wire hybrid system is now operational at the 30-inch bubble chamber, and its unique features are of central importance for the proposed exposure.

Of primary interest is the enhanced momentum resolution provided by the system for fast secondary tracks leaving the bubble chamber. In test exposures analyzed to date the hybrid system has performed up to its design expectations in this regard, yielding an average value of $\frac{\Delta P}{P}$ which is linear with momentum above ~20 GeV/c and approximately equal to ±15% for 150 GeV/c secondaries. This is to be contrasted with the bare bubble chamber measurements, from which useful momentum information cannot be gleaned for $P \gtrsim 50$ GeV/c (see Fig. 1).

A second feature is the angular accuracy of the system. The upstream system, with a flight path of 200 meters, measures beam track angles with an accuracy which is limited only by multiple scattering in the bubble chamber ($\sim$.05 milliradian), for the downstream portion of the system the angular resolution for high momentum secondaries is of the order of 0.1 milliradian.

This precision in the measurement of angles and momenta has yielded the following results, as observed in a 150 GeV/c test exposure:

(i) A very clean separation of elastic and inelastic 2-pronged events, (Fig. 2,3). We estimate a contamination of less than 10% in the inelastic 2-prong sample, as compared with typical estimates of 30-40% in bare chamber experiments.

(ii) A missing mass resolution of a few pion masses for missing masses near zero (Fig. 3). This is roughly a factor of 10 improvement over the bare chamber results.

(iii) Transverse momentum measurements accurate to $\pm$ 80 Mev, or about $\frac{1}{4}$ the average pion transverse momentum, for 150 GeV/c secondary tracks (Fig. 4).

These capabilities, and the presence of a downstream γ-ray counter (subtending an angle of $\pm 2^0$) will make possible clean samples of constrained fits for events with no missing neutrals, and will allow more detailed examination of multiparticle correlations than can be made with rapidity (or lab angle) measurements using the bubble chamber alone.

Finally, we cite the high duty cycle of the external proportional wire planes. Each sense wire is connected to a 16 bit shift register whose cycle time is 100 nanoseconds. Hence, information on each incident particle can be recorded, particle by particle, without any need for trigger selection. The system, like the bubble chamber itself, is essentially a DC device. External information, such as Čerenkov signals, can also be stored on a particle-by-particle basis, making it possible to tag incident particles as protons, pions, K mesons and anti protons.

The efficiency for correctly reconstructing high momentum tracks in the downstream system (excepting those which scatter in the exit window of the bubble chamber) has been found to be essentially 100%. Some 10-12% of the fast tracks (pions) leaving the bubble chamber are lost to the downstream system

due to interactions in the liquid hydrogen and bubble chamber exit windows. Since no trigger is required, these are the only significant losses to the down stream system. Our studies of test exposures in 150 GeV/c and 200 GeV/c beams show that on the average there are about 1.5 produced tracks per event which lie within the acceptance of the downstream system ($P_{lab} \gtrsim 15$ GeV/c). Thus we can expect complete information, including downstream measurements, on greater than 80% of the events in our fiducial volume.

(3) Scope of the Experiment

(i) We will measure charged particle multiplicity moments with higher statistical accuracy than has previously been reported and with the improved accuracy afforded by a good measurement of the 2-prong inelastic cross sections.

(ii) We will study particle production spectra as a function of the C.M. momentum, as well as charged particle multiplicity with good resolution up to $x = +1^0$. With good momentum precision we will study correlations, including long range correlations, in both CM hemispheres.

(iii) With our 4π geometry, good momentum and angle resolution and relatively high statistical accuracy we will be able to perform detailed studies of leading particle effects and diffractive phenomena. This capability will accrue from our ability to isolate those particles which are truly beam-like ($x \simeq +1$) and to extract clean samples of constrained fits with reasonable statistics for many of the low-multiplicity channels in which diffractive phenomena are apparently the dominant production mechanism.

(iv) An important goal of this experiment will be to carry out programs of analysis which will probe the nature of the high multiplicity component of particle production. This will include measurements of 2 particle correlation functions with improved statistics over data presently available at NAL energies. In addition, with data from the hybrid system, the scope and sensitivity of such programs can be greatly enhanced in the following ways.

(a) We can determine correlations as a function of P_T as well as P_L.

(b) We can examine angular correlations in the CM frame of the collision, for events with and without leading particles.

(c) We can measure multiparticle in variant masses and momentum transfers among groups of particles over the full kinematic range, and can examine the "decay" correlations among groups of pions selected, for example, on their net charge and invariant mass, in the rest frame of the selected system.

(d) It is highly likely that we can provide useful data for new and more differential techniques of analysis as these are developed.

(e) We will analyze the interactions of the K^+, K^- and $\bar{p}$ component of the beam, making use of the particle by particle tagging information from the Čerenkov counter. The K^- beam has been measured to be 2% of the in cident π^- beam at the bubble chamber. The K^+ beam is estimated to be about 2% - 4% of the π^+ proton mixed beam used in the current π^+ exposures. The $\bar{p}$ component at the bubble chamber has been measured to be 6% of the incident π^- beam at the bubble chamber. Hence, we would expect about 1, 200 each of K^+ p and K^- p interactions and about 600 $\bar{p}$p interactions in this experiment.

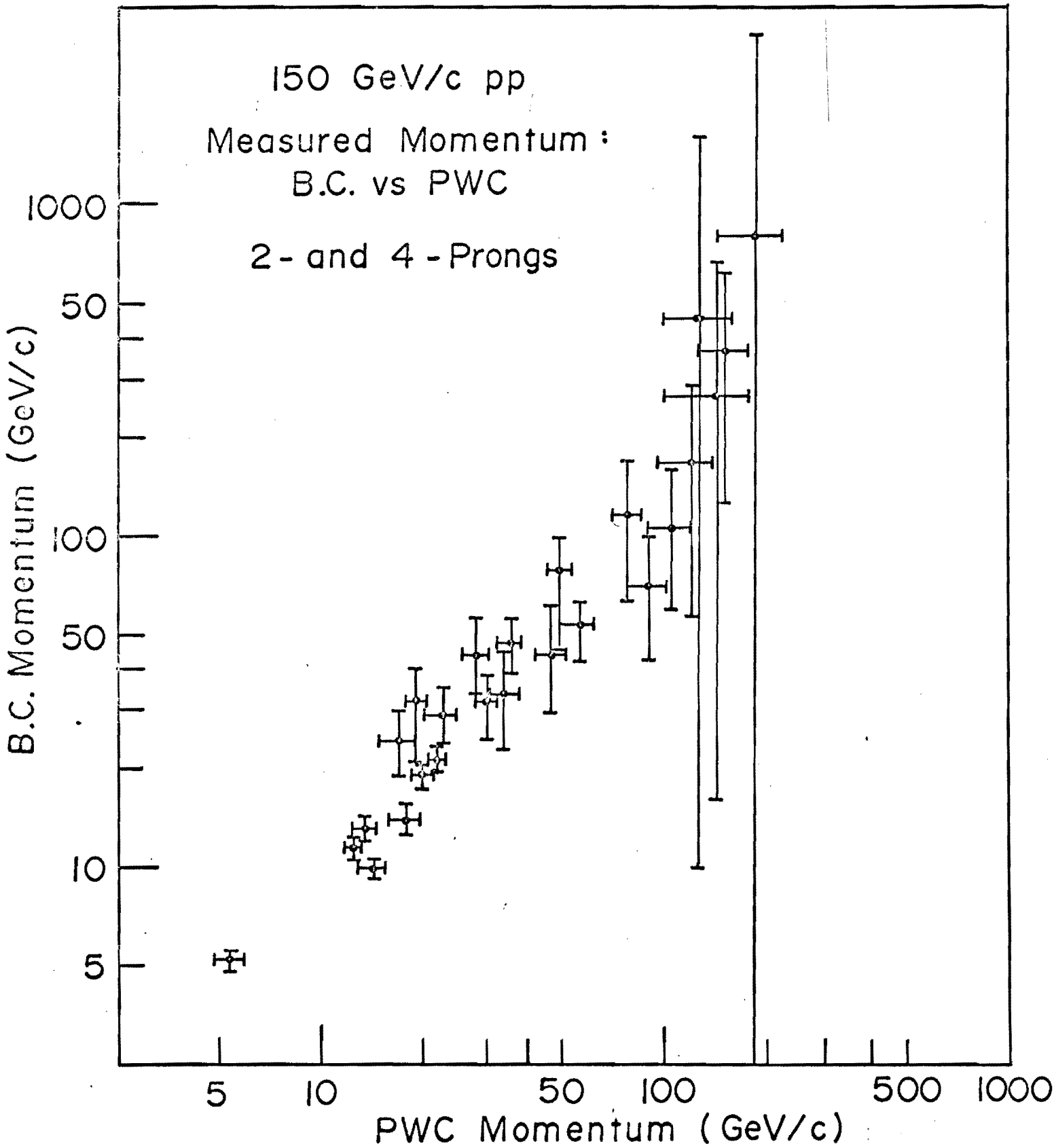

150 GeV/c pp
Measured Momentum:
B.C. vs PWC
2- and 4-Prongs
B.C. Momentum (GeV/c)
1000
50
100
50
10
5
5
10
50
100
500
1000
PWC Momentum (GeV/c)

Figure 1

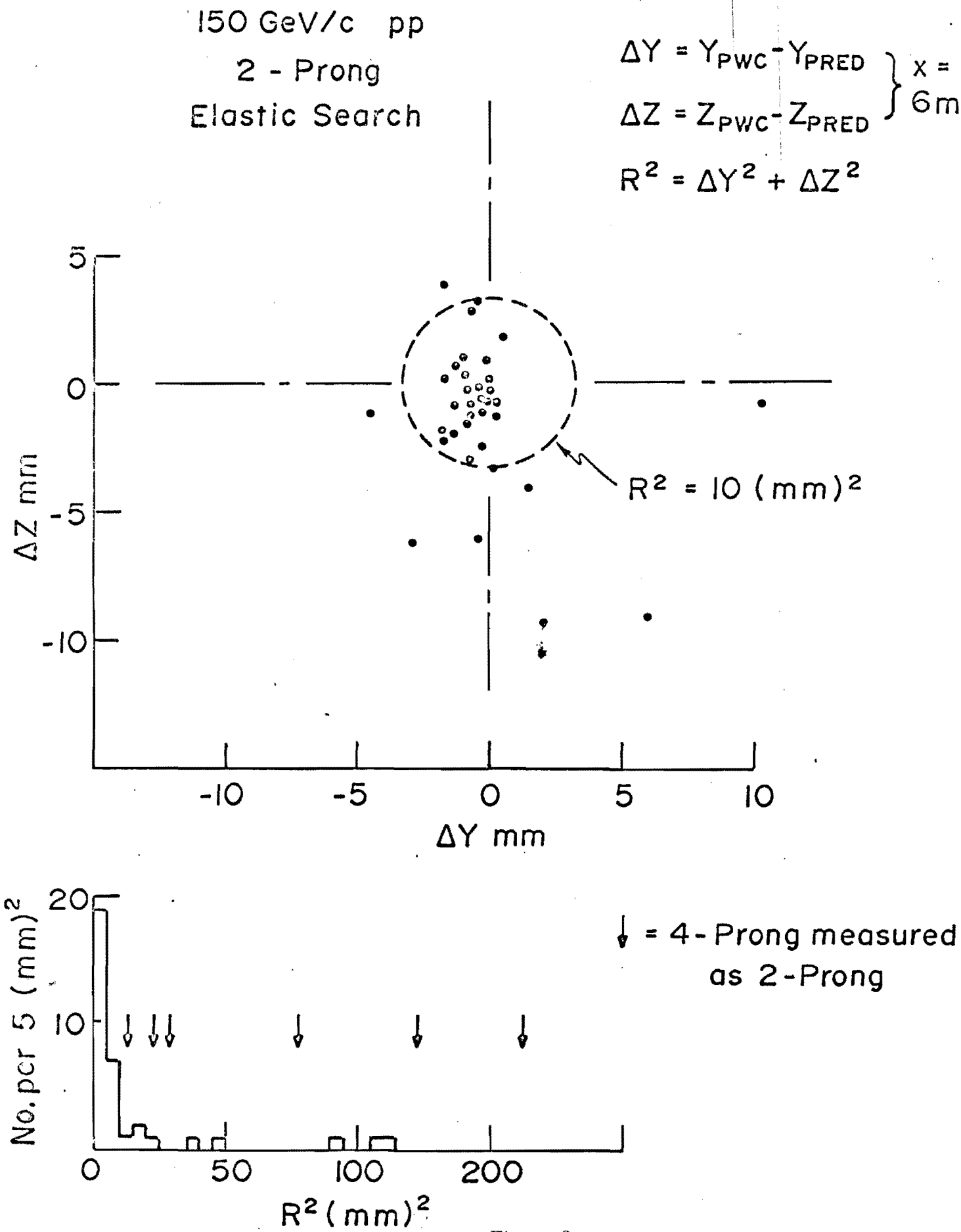

150 GeV/c pp
2 - Prong
Elastic Search
ΔY = Y_PWC - Y_PRED
ΔZ = Z_PWC - Z_PRED
x = 6m
R² = ΔY² + ΔZ²
R² = 10 (mm)²
ΔZ mm
ΔY mm
5
0
-5
-10
-10
-5
0
5
10
No. per 5 (mm)²
20
10
0
50
100
200
R² (mm)²
= 4-Prong measured as 2-Prong

Figure 2

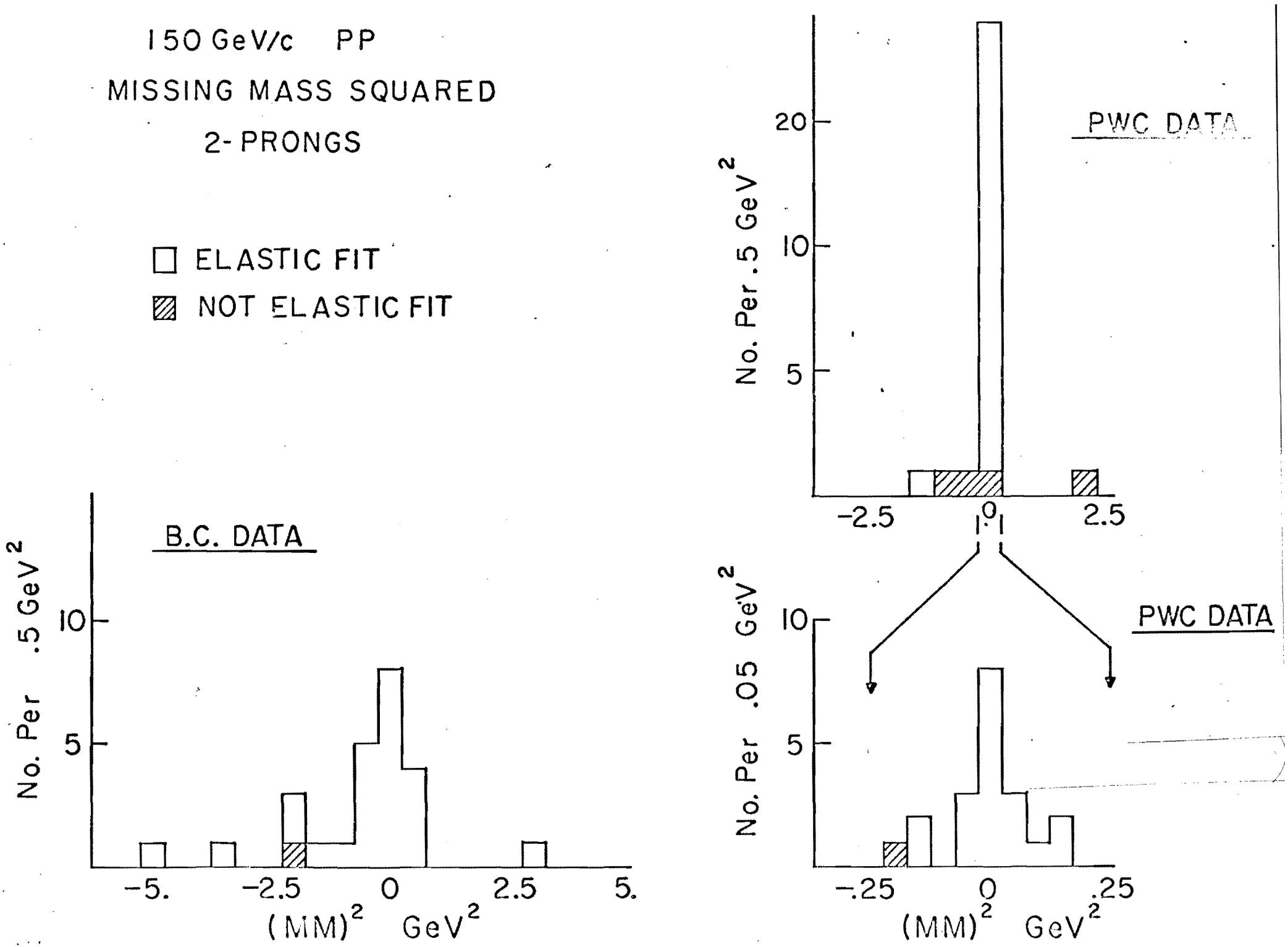
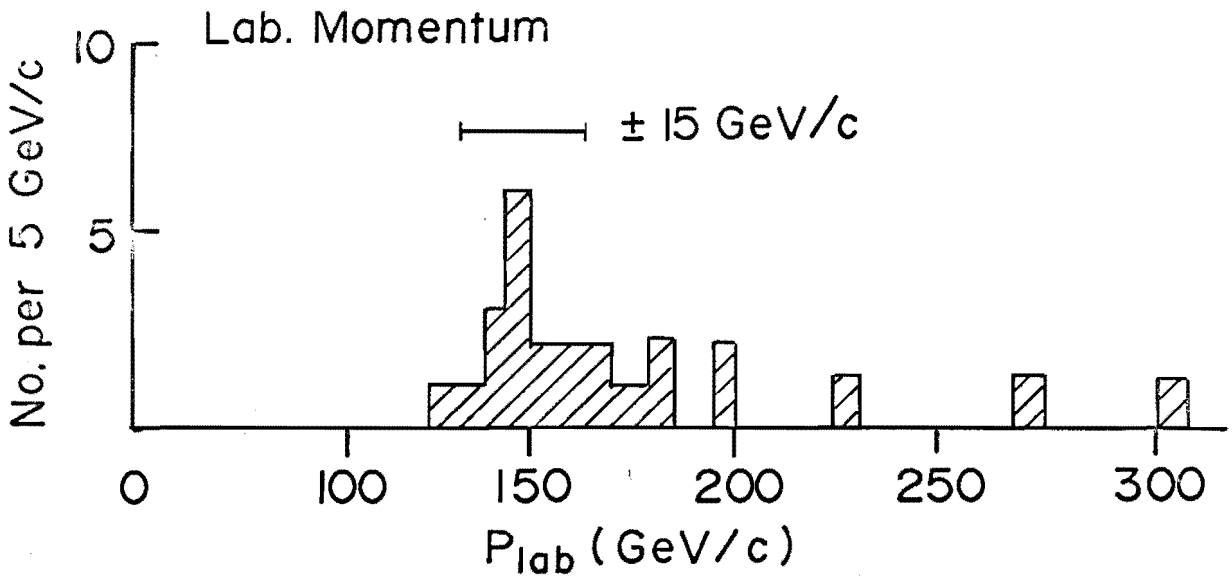

150 GeV/c PP
MISSING MASS SQUARED
2-PRONGS
ELASTIC FIT
NOT ELASTIC FIT
B.C. DATA
No. Per .5 GeV²
10
5
-5.
-2.5
0
2.5
5.
(MM)² GeV²
PWC DATA
No. Per .5 GeV²
20
10
5
-2.5
0
2.5
PWC DATA
No. Per .05 GeV²
10
5
-.25
0
.25
(MM)² GeV²

Figure 3

Reconstructed Momenta : Tracks at x = +1.

$pp \rightarrow pp$

$pp \rightarrow pp\pi^+\pi^-$



Transv. Momentum : Recons. – True

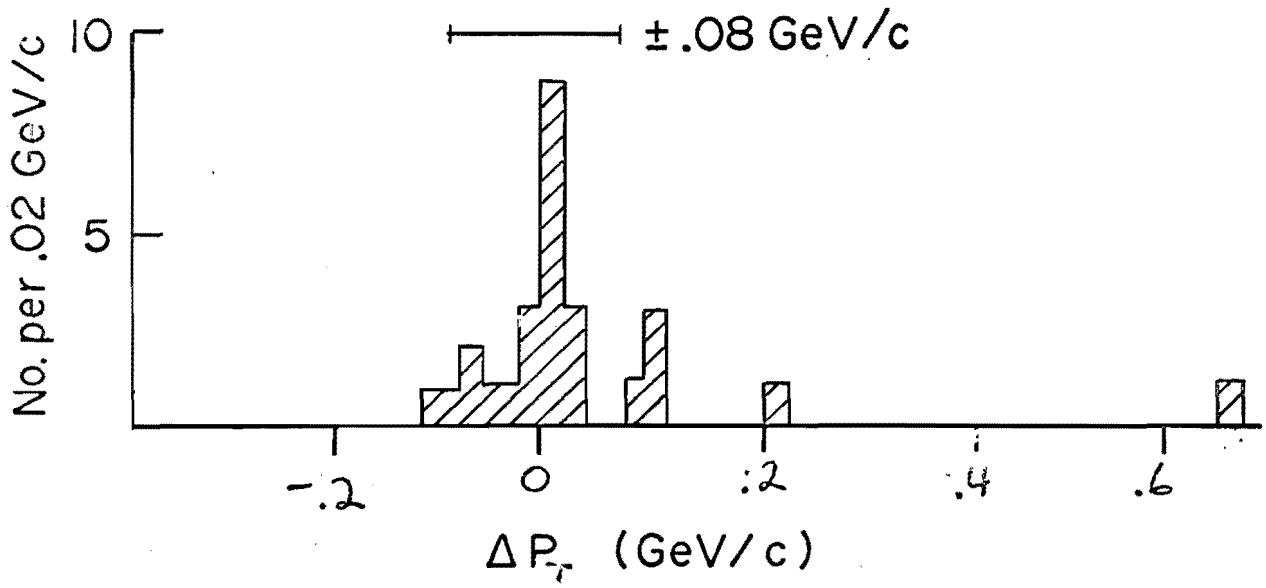


Figure 4

II. LEADING PARTICLE STUDIES AND DIFFRACTION DISSOCIATION PHENOMENA

An important component of high energy interactions is an s independent peak near $x = +1$ in the cross section $E \frac{d^3\sigma}{d\vec{p}}$. This peak is interpreted by essentially everyone as a diffractive phenomenon. It is of great interest to study this diffractive peak in 150 GeV/c π p interactions. Our ability to measure single particles with x close to 1 will allow us to make a quantitative study of this process. For a given x of the leading particle, we will be able to answer the following questions:

1. What is $\frac{d^3\sigma}{d\vec{p}}$ for the other particles produced?
2. What is the charged multiplicity of the other particles produced?
3. What is the charged multiplicity of the other particles produced as a function of the recoiling invariant mass?
4. What are the invariant masses of the other particles produced? Do they contain Δ^{++} or ρ^0 predominantly?

The above questions are relevant for $x > 0.8$. Hence, we are examining in detail the diffraction dissociation of the target proton.

One can also look at a "leading particle" effect when the target proton has $x \sim -1$. ($x_p < -0.8$). In this case, it is the pion or projectile proton which is diffractively dissociating. The ability of the hybrid spectrometer to measure secondary momenta up to about 200 GeV/c permits analysis of reactions such as:

$$\pi^{\pm} p \rightarrow \pi^{\pm} \pi^{+} \pi^{-} p$$

$$\pi^{\pm} p \rightarrow \pi^{\pm} \pi^{+} \pi^{-} \pi^{+} \pi^{-} p$$

in which the incident pion "fragments" into a fast forward multipion system with small momentum transfer to the target proton. We expect to be able to reduce the

π^0 contamination in our fits to < 10% by balancing transverse momentum. We can also study the proton diffraction dissociation into a YK system.

A. $\pi^{\pm} p \rightarrow \pi^{\pm} \pi^{+} \pi^{-} p$

On the basis of the results of the Berkeley - NAL 205 GeV/c $\pi^- p$ exposure [1]; we expect about 1200 events of this kind in 400,000 pictures of which about 2/3 will be beam dissociation. With a 3π mass resolution of about 5%, we expect to see A_1-A_2 bump (1.0 - 1.4 GeV) if it continues the slow fall observed between 25 and 40 GeV/c [2], but cannot expect to determine the A_2 cross section unless a partial wave analysis [3] proves possible. The A_3 should also be observable.

We can investigate the decay modes of the 3π system to see whether the $\rho\pi$ channel continues to predominate.

With a sample of this size we could begin to investigate the dependence of the cross section on s, M and t, for comparison with the data found at Sepukhov at 25 and 40 GeV/c [2].

We can determine the complete energy and angle distribution for each event. Sorting out the distributions in 3π mass bins, we can compare them with those found at 40 GeV/c and lower. If, as expected, the shapes are essentially the same, we can assume the same spin-parity-polarization composition as at the lower energies [3], and extract, for example, the A_1 cross section from the data. The energy dependence of this cross section is of great interest as a test of its "diffractive" character. We expect the band $M_{3\pi}$ = 1.0 - 1.4 GeV to contain about 200 A_1 events, 30 A_2. Comparison with the equal π^+ exposure will permit comparison of the positive and negative cross sections to check the isospin character of the produced 3π systems.

While similar analyses are being made of the bare bubble chamber data obtained at near-by energies, we would have the advantage of a cleaner sample resulting from better momentum resolution and better statistics.

B. $\pi^{\pm} p \rightarrow \pi^{\pm} \pi^{+} \pi^{-} \pi^{+} \pi^{-} p$

We expect to find in a total of 400,000 pictures about 8,000 six-prong events, of which probably 10% fit this channel. We can look at the differential cross section as a function of $M_{5\pi}$ and t.

III. SINGLE PARTICLE DISTRIBUTIONS

An important feature of the proposed experiment is the measurement of the single particle differential cross sections for final state pions

$$f(\vec{p}) = E \frac{d^3\sigma}{d\vec{p}}$$

as a function of the momentum, $\vec{p}$, over the full kinematic range, with complete information on the charged prong multiplicity for each event. This will allow several important measurements to be made which are not possible either in the bare 30" bubble chamber or with single-arm spectrometers.

The following reactions will be examined in this complete manner:

$p + p \rightarrow \pi^{\pm}$ anything (1)

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

$\pi^{\pm} + p \rightarrow K^0$ + anything (3)

$\pi^{\pm} + p \rightarrow \Lambda$ + anything (4)

In addition, the following reactions can be examined in the target fragmentation region where the final state protons may be examined by ionization:

$\pi^{\pm} p \rightarrow p$ + anything (5)

$p\,p \rightarrow p$ + anything, (6)

The measurement of $f(\vec{p})$ for reaction (1) and (2) with sufficient precision to resolve the leading particle peak should provide new and extremely valuable information on the character of pp, $\pi^{\pm} p$ collisions in this energy regime. Among the results of particular interest from the pion-induced reactions are:

(i) The distributions $f(x) = \int f(x), d P_T^2$ and the semi-inclusive distributions $f_n(x)$, where x is the Feynman scaling variable and n is the number of charged prongs.

(ii) The cross section for quasi-elastic pion production as a function of the charged prong multiplicity.

(iii) The π^+ / π^- ratio as a function of x.

(iv) The average transverse momentum as a function of x and of rapidity.

These measurements will, at the very least, provide more powerful tests of the data fitting capabilities of various models than are presently available. Point ii), along with measurements of the slow proton spectrum, will allow estimates of the diffractive component of the inelastic cross section for $\pi^{\pm}p$ collisions in a manner comparable with those which now exist for pp collisions at NAL and ISR energies.

Measurements of the semi-inclusive distributions $f_n(x, p_T)$ for $\pi^{\pm}p$ collisions may provide sensitive tests of the validity of models based on the assumption of short-range order in the central region. These models presuppose a very weak dependence of the behavior in the central region on the incident particles. At lower energies (< 30 GeV) the distributions of pions produced near $x = 0$ show rather strong dependence on the incident particle: One such effect is the so-called quark-frame result[4], in which pions produced in $\pi^{\pm}p$ collisions fall off more sharply in $f_n(x)$ for $x < 0$ than for $x > 0$ where, in pp collisions, the pion distributions are necessarily symmetric about $x = 0$. Further, in $\pi^{\pm}p$ collisions at 16 GeV/c[5], it is observed that the average transverse momentum behaves quite differently in the central region of rapidity depending on whether or not the observed particle has the same charge as the incident pion. [Fig. 5]

A well known phenomenon of pion production at low energies is the fact that the differential cross section $f(x, p_T^2)$ does not factorize into the form $g(x)\, h(p_T^2)$: the average transverse momentum is smaller at $x = 0$ than at larger values of x. It has been shown[6] that this so-called "sea gull effect" is only partially accounted for by phase space effects. The distribution $f(y, p_T^2)$, where y is the rapidity, apparently does factorize in the central region for the reactions $\pi^{\pm}p \rightarrow \pi^{\pm}$+anything (see Figure 5)

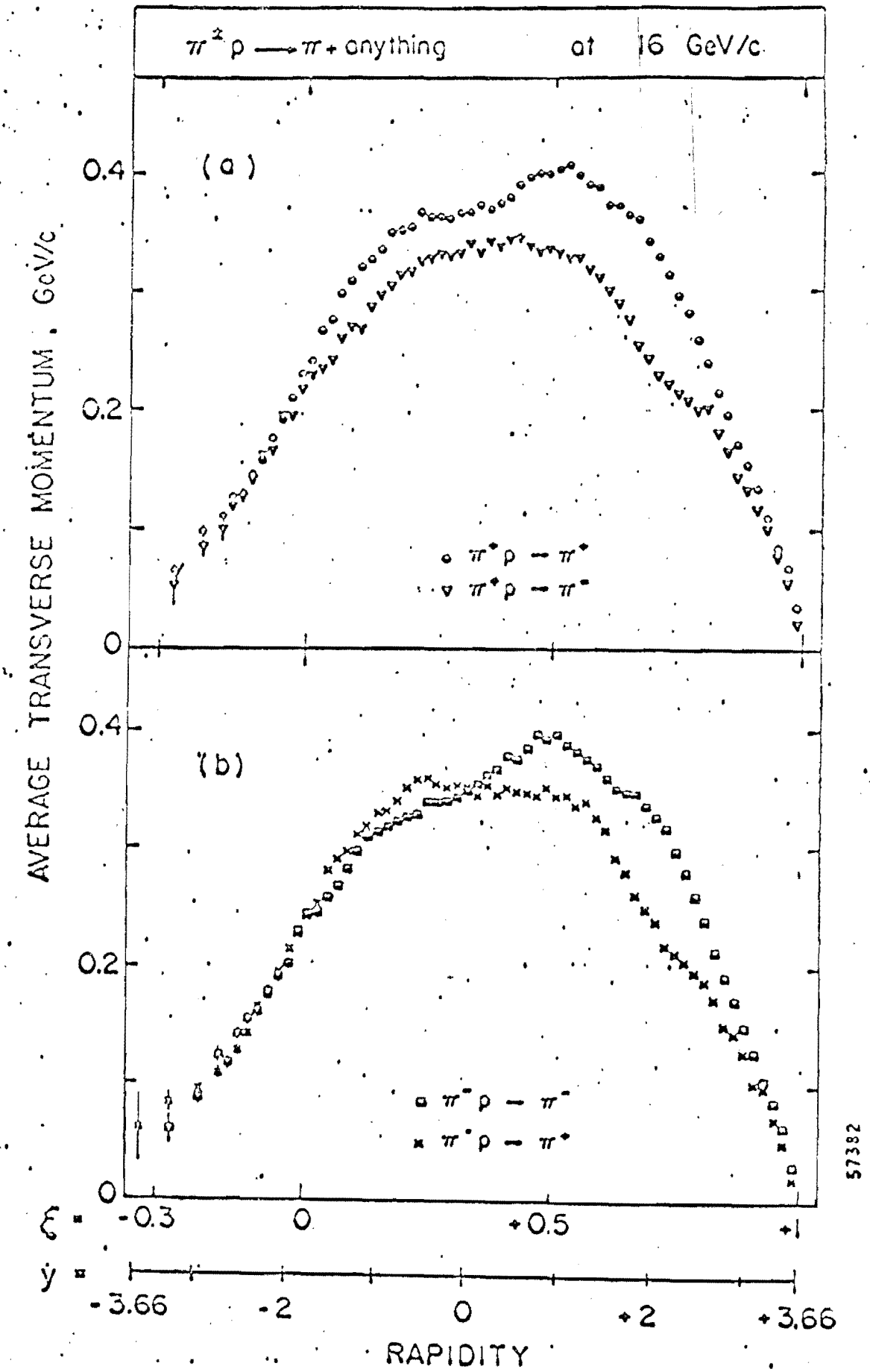
and for pions produced in pp collisions at ISR energies.[7]

A study of these effects for reactions (1) and (2) at 150 GeV/c should bear sensitively on the scaling properties of the single particle distribution and on the character of particle production in the central region.

Predictions for the energy dependence of the approach to scaling in single particle distributions for reactions of the type

$$a + b \rightarrow c + \text{anything} \qquad (5)$$

depend on the kinematic region in which the produced particle is observed and on the quantum numbers of the incident and observed particles. Thus, Mueller's generalized optical theorem[8] with further assumptions from Regge theory, predicts an $s^{-1/4}$ dependence for reaction (9) near $x = 0$, and an approach to limiting fragmentation (x near ± 1) as $s^{-1/2}$. Additional assumptions regarding finite energy sum rules lead to scaling in the fragmentation regions at very low energies if some (or all) of the combinations a, b, c have exotic quantum numbers.[9] In this experiment, data with good statistics from reactions (1) and (2), in comparison with the large body of existing data at lower energies, will provide detailed checks for such predictions and will extend considerably the range of energies over which these checks can be made for $\pi^{\pm}p$ collisions.



ξ = REDUCED RAPIDITY.

Figure 5

IV. MOMENTUM AND ANGLE CORRELATIONS IN INCLUSIVE REACTIONS

1. The Particle Correlations

Any experiment, such as this one, with 4π geometry for detecting charged particles is capable of measuring very complex correlations among the produced particles in multiparticle final states. At the moment, the types of correlations which can be meaningfully analyzed are still relatively simple. There is considerable interest in two-particle correlations of the type

$$C(y_1, y_2) = \frac{1}{\sigma\,\text{inel.}} \frac{d^2\sigma}{dy_1\,dy_2} - \frac{1}{\sigma\,\text{inel.}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}$$

where y is the rapidity. A good deal of data now exists from NAL and ISR experiments [10], [11] for an empirically normalized variant of this two-particle correlation function in proton-proton collisions:

$$R_{12}(\eta_1\,\eta_2) = \frac{\sigma_{\text{inel.}} \dfrac{d^2\sigma}{d\eta_1\,d\eta_2}}{\dfrac{d\sigma}{d\eta_1} \dfrac{d\sigma}{d\eta_2}} - 1$$

where $\eta = -\ln(\tan\frac{\theta}{2})$.

These measurements indicate that collisions from 200 to 1500 GeV/c are characterized by relatively short-range, positive correlations among particle pairs for the bulk of the produced particles. Although the correlation data presently available exhibit considerable structure, much of this structure follows directly from the shapes and magnitudes of the single-particle, semi-inclusive distributions upon which are superimposed the "interesting" dynamical correlations. (12)

A crucial question with regard to the observed short-range correlations is whether or not this behavior indeed results from short-range order in the production mechanism (in which the observed hadrons are produced independently, e.g., along a multiperipheral chain,) or whether the particles are being produced in kinematically related groups or clusters.

Evidence for clustering effects certainly exists (13), (14) although existing 2-particle correlation measurements do not offer definitive conclusions regarding the existance of such effects. Correlation measurements of high precision and good statistical accuracy are needed in order to confront such questions.

This experiment, with the hybrid system, has two advantages over the existing bare bubble chamber data: (1) We can measure the true rapidity, y, as well as η. (2) We can determine the distributions and correlations as a function of P_T as well as P_L. The proposed experiment will provide such measurements for pions as well as protons incident, and with sufficient by high statistical precision to examine two-particle correlations for the following configurations:

i) y_1, and/or y_2 both inside and outside the central plateau region.

ii) Correlations between like charges (++ and -- correlations). as well as for all charged particles.

iii) Correlations within specific final state charge multiplicities

More searching tests of the various models for high-energy reactions can be made by sorting out the events according to number of charged prongs (n). Study of the semi-inclusive correlation function

$$\text{e.g. } f_n(y_1, y_2) = \frac{1}{\sigma_n} \frac{d^2\sigma_n}{dy_1\, dy_2} - \frac{n-1}{n} \frac{1}{\sigma_n^2} \frac{d\sigma_n}{dy_1} \frac{d\sigma_n}{dy_2}$$

The last-mentioned measurements are of particular importance in view of the fact that the semi-inclusive single particle distributions in pp collisions are found to be markedly narrower in the high multiplicity channels than at low multiplicity. [12] This fact, by itself, can account for a positive correlation in the central region when all multiplicities are included in the empirically determined correlation function.

Correlations between the transverse momenta of particle pairs will also be measured for the configurations listed above, and these may provide useful new physics information in this energy range. [15] In particular, for both c and c_n sorting of the particles according to transverse momentum (p_T) and charge will permit sharper tests of specific models.

With 400,000 pictures of incident π^+ or π^- we expect a total of about 35,000 events with four or more prongs and we therefore expect about 150,000 tracks of each sign. For estimating densities in rapidity space we assume (for ease of computation) a flat distribution of $\frac{d\sigma}{dy}$ over a range of $\Delta y = 4$.

This corresponds to the centrally peaked distribution for pp interactions [11]. If we use a bin width of $\Delta y = 0.25$, a plateau of 4 units of y can be represented by 16 x 16 squares. From the 150,000 tracks of the same sign we expect about 285,000 pairs. In the 35,000 events we expect 715,000 pairs of tracks of opposite sign. This will give us about 1,100 pairs of the same sign per bin on the y_1 y_2 plot. We also expect about 2,800 pairs of tracks per bin of opposite sign for the y_1 y_2 plot. We can breakdown the y_1 y_2 distribution according to multiplicity and transverse momentum. There are roughly equal numbers of events for h = 4, 6, 8, 10 and ≧ 12.

Sorting the data into five multiplicity bins ($n = 4, 6, 8, 10 \geqq 12$) and three transfer momentum bins will result in about 10% statistical error. Hence we should have enough data to explore correlation lengths much smaller than 2 units in rapidity.

For each charge we expect roughly equal numbers--about 8k-of events with 4, 6, 8, 10 prong topology; thereafter a rapid fall, by about a factor of 2 for every increment of n by 2 is expected [10]. Some sorting according to n will be possible, but again with coarser binning.

2. Many-Particle Correlations

The availability of good momentum information for even the fastest tracks in this experiment will allow not only a detailed study of those low-multiplicity events which constitute the so-called "diffractive" (Sec. II) component of particle production, but will also make possible more differential and more sophisticated techniques of analysis in studying the many-particle events ($\gtrsim 6$ charged prongs) which contribute the bulk of particle production at these energies. These events populate mainly the central region of the rapidity scale, and are characterized by short-range correlations among particle pairs. An important goal of this expriment will be to carry out programs of analysis which will probe the nature of the production mechanism in this component. For example, we would like to distinguish between the predictions of a short-range-order, multiperipheral picture and one in which relatively heavy states are formed which decay to large numbers of particles in the central region.

Such analysis requires the 4π solid angle of a bubble chamber. With the bare 30" bubble chamber the available data for these studies at NAL energies consist of rapidity (or lab angle) measurements with which one can study charged prong correlations or gap distributions. There is ample evidence that such measurements do not provide sufficient sensitivity to push our understanding of multiparticle production mechanisms much further than it stands now with existing bare chamber data. With data from the hybrid system the scope and sensitivity of such programs are greatly enhanced.

1) We can distinguish beamlike (fast) leading-particles from those particles which, although their rapidity may be very large, do not carry a significant fraction of the beam momentum.

2) We can examine angular correlations in the CM frame of the collision, for events with and without leading particles.

3) We can examine the "decay" correlations among groups of particles selected, for example, on their net charge and invariant mass, in the rest frame of the selected system.

4) We can study two -body factorization. The physical idea behind two-body factorization is simply stated by saying that, if two particles come one from the target fragmentation and the other from the projectile fragmentation, then the cross section should factorize. This can be stated as follows:

$$F_{ab}^{cd}(p_T^c, p_T^d, X^c, X^d, \phi^{cd} =$$

$$F_{ab}^{c}(P_T^c, X^c) \cdot F_{ab}^{d}(P_T^d, X^d)$$

where ϕ^{cd} is the angle between $\vec{p}_T^{\,c}$ and $p_T^{\,d}$ and $x^c \cdot x^d < 0$. In practice, one must choose x^c close to -1 and x^d close to +1 to ensure that particle c is in the fragmentation region of the target and particle d is in the fragmentation region of the projectile.

5) If the idea of factorization is valid, the mean multiplicity in the target fragmentation region should be independent of the x value of a particle measured in the projectile fragmentation region. This prediction is only poorly and inconclusively measured at the ISR for proton projectiles and obviously not at all for pion projectiles. A study of these correlations, especially at $x \simeq +1$ will help shed light on the applicability of the currently popular "two component" theories.

6) Neutral Strange Particle Production:

Cross sections for the production of K^0, Λ and $\bar{\Lambda}$ are rising rapidly in the NAL energy range, as is the cross section for $\bar{p}$. Presumably $\bar{p}$ and $\bar{\Lambda}$ result from particle-antiparticle pair production. This need not be the case for the K's and Λ's, which may result from $K\bar{K}$ or $Y\bar{Y}$ pair production internally on a multiperipheral chain, or they may be primarily due to $p \rightarrow \Lambda K$ (diffractive processes). In this experiment we will have sufficient statistics to examine a reasonable sample of events in which two (or more) neutral strange particle decays are observed. We can determine the realtive rates for ΛK, $K\bar{K}$, $\Lambda\bar{\Lambda}$ and can examine the correlations between such pairs (effective mass, rapidity difference, etc.). On the basis of a rough calculation, we expect to see the following number of events in our total sample.

K^0	7000
Λ	3600
$2V^0$ events	400

Fully differential analysis programs, applied to completely specified inelastic channels are feasible for, at best, only a very small fraction of the inelastic cross section at these energies. New techniques for analyzing more global information from the total sample than is given by the two-particle correlation functions are being developed.[16, 17] Such analyses will ultimately demand a knowledge of momentum as well as angle for both fast and slow tracks in the laboratory. This is certainly true of any extension of the longitudinal phase space analyses to partially determined multiparticle final states,[16] and the statistical analysis of Ref. 17 is considerably enhanced in sensitivity if momentum as well as angular information is available over the full kinematic range.

V. TOPOLOGICAL CROSS SECTIONS AND MULTIPLICITY MOMENTS

Measurement of the total charge multiplicity, n_c, of inelastic final states have been of major importance in the development of phenomenological regarding multiparticle production in hadron collisions. The simplest of multiperipheral pictures, in which secondaries are produced uniformly in rapidity with zero-range correlations, predicts a poisson distribution in n_c for produced particles in the asymptotic limit, with $\langle n_c \rangle \sim \ln s$. [18] Existing measurements of the multiplicities and their moments rule out this simple behavior: the moment

$$f_2 = \langle n_c \ (n_c - 1) \rangle - \langle n_c \rangle^2,$$

which is zero for a poisson distribution, is found to be rising with energy, crossing zero for pp collisions with beam momenta ~ 50 GeV/c. Nonetheless, detailed information on the charged prong multiplicities and their moments allows direct confrontation with rather sensitive predictions of specific models.

Diffractive excitation models predict $f_2 \sim \ln s$.

The KNO scaling law, [19]

$$\sigma_n(s) = \frac{\sigma \text{ inel. } (s)}{\langle n_c \rangle} \ \psi\left(\frac{n_c}{\langle n_c \rangle}\right)$$

which is derived from the hypothesis that the semi-inclusive distributions all scale at $x = 0$, has been shown to give a good empirical description of existing data from 50 - 300 GeV/c [20], despite the fact that scaling in the single-particle distributions at $x = 0$ is not observed in this energy range. The KNO law implies $\frac{\langle n^k \rangle}{\langle n \rangle^k} = c_k$,

where c_k is independant of onergy. A question of current interest is whether KNO scaling is approximate, and will eventually break down, as advocated by proponents of short-range order models.

Two-component models, involving both long- and short-range correlations give specific predictions for, and are constrained by, the charged prong multiplicities.

In this experiment we will obtain the topological cross sections, σ_{n_c} and the multiplicity distributions with good statistics. The electronic information accompanying the bubble chamber pictures should serve to minimize the scanning losses for low-multiplicity events. In particular, the higher moments of the multiplicity distributions are extremely sensitive to the two-prong inelastic cross section, where scanning losses are particularly difficult to overcome under ordinary circumstances.

For the $\pi^- p$ reaction, it is very hard to detect with a bare bubble chamber the 0-prong topological cross-sections; i. e., $\pi^- p \rightarrow$ neutrals. However, because of our special experimental setup, we can easily obtain a reliable measure of this cross section. It has been studied at low momenta where it was found to decrease with energy. In general, it can be shown model independantly that [21]

$$\sigma_0 / \sigma_T = \exp \{ - [\langle n_{ch} \rangle + \tfrac{1}{2} f^{(2)}_{ch} + 0 \; (f^{(n \geqq 3)})] \}$$

where $f^{(n)}$ are the integrated inclusive correlations. Assuming that the integrated correlation functions are not too large, this can be approximated by

$$\frac{\sigma_0}{\sigma_{T^-}} = e^{- \langle n_{ch} \rangle}$$

For the 150 GeV/c $\pi^- p$ collisions, $\langle n_{ch} \rangle \cong 8$. Thus, we expect to detect 5-10 zero-prong events.

VI CROSS SECTIONS

A. Total Cross Section σ_T

We will be able to measure the total cross sections to an accuracy of about 1% - 2%. This accuracy makes it possible to testablish the energy behavior of σ_T ($\pi^- p$) with respect to lower and higher energy measurements. For the π p interactions we will be able to determine whether σ_T continues to be energy independent as indicated by its values as measured at Serpukhov above 30 GeV/c, (σ_T ($\bar{p}$ P) ~ 24.5 mb) or whether there is a possible convergence of the cross section toward a common Pomeranchuck limit. We should also obtain about a 5% measurement on $K^- p$, $K^+ p$ and $\bar{p}p$ total cross sections.

B. Elastic Cross Sections

The measurement of the elastic differential cross sections near $t = 0$, as a function of beam energy, will determine the slope parameter b for $\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{bt}$. Assuming that the elastic and total cross sections stay constant from their values at 30 GeV/c, then we would expect to have about 10,000 elastic events with $|t| \geqq 0.05$ $(\mathrm{GeV/c})^2$ which is the region where we expect to be able to resolve the elastic events with very good efficiency.

With these statistics we expect to be able to measure this slope to better than ± 0.30 $(\mathrm{GeV/c})^2$ which represents a 3% measurement. This accuracy will allow a reasonable check on "shrinkage" of the elastic peak and, incidentally, check early counter data.

In addition, we can measure the total elastic cross section, correcting in the normal way, for the loss of events at very small t. The energy dependence of this total elastic cross section is of current interest. Although these checks will not be definitive when compared to counter data, they will be of interest.

VII COMPARISON OF THE THREE BEAM PARTICLES

The availability of $\pi^+ p$, $\pi^- p$ and pp data from the hybrid system at 150 GeV/c will allow detailed comparisons among these three beams which will enlarge considerably the scope of the physics programs discussed in the preceeding sections. We will also, with much poorer statistics, be able to include in our comparison information about $K^{\pm} p$ and PP interactions.

A comparison of the differential cross sections for pion production for these three beams,

$$\pi^{\pm} p \rightarrow \pi^{\pm} + \text{anything}$$

$$p p \rightarrow \pi^- + \text{anything}$$

as a function of x will be of particular interest, especially in the "intermediate" x region ($0 \leq x \leq +1$) where these distributions offer the greatest sensitivity to model predictions. This is also true of the ratio of π^+ to π^- production as a function of x.

For those events which are attributed, by their kinematic behavior, to diffraction production mechanisms a comparison of cross sections and momentum transfer distributions among the three beam particles will be an essential part of the detailed analysis of this phenomenon. Checks of factorization and of isospin relations predicted by Pomeranchuk exchange will be of primary interest.

We refer here specifically to reactions like

$$\pi^{\pm} p \rightarrow A^{\pm} p \qquad (1)$$

$$\pi^{\pm} p \rightarrow \pi^{\pm} p^* \qquad (2)$$

$$p p \rightarrow p^* p \qquad (3)$$

where $A^{\pm}$ and p^* are low-mass, peripherally produced objects.

Factorization of the amplitudes for beam and target excitation implies, for example:

$$\frac{\sigma(2)}{\sigma_{el}(\pi^{\pm} p)} = \frac{\sigma(3)}{\sigma_{el}(pp)}$$

This relation cannot be checked to better than ~ 30% accuracy with the bare bubble chamber, owing to the contamination of misidentified elastic events in the inelastic 2-prong sample and the difficulty of excluding unseen neutrals in events of higher multiplicity . Much more precise results will be afforded by the present experiment.

In the low-multiplicity events for which the dominant production mechanism is apparently a diffractive or quasi-elastic process we have, if not a complete theory, at least a well-developed framework of phenomenological ideas in which to view the data, and we can enumerate in a proposal such as this a very specific set of measurements to make,and analysis programs to carry out. This is not the case for the high multiplicity component, which is not so well understood and is certainly more complex in its kinematic specification. The dominant characteristic of this component is the short-range nature of correlations among particle pairs, suggestive of a multiperipheral picture. This, however, allows for a wide range of specific production models. We have outlined in previous sections of this proposal the means by which this experiment should contribute to a sharpening of this picture. We have pointed out in Sec. IV that in any single experiment the two-particle correlation functions are not terribly sensitive to the underlying dynamical processes encompassed by such a picture. However, a study of charged particle correlations in the central region as a function of the quantum numbers of the incident channel may in fact provide very useful information, particularly if clustering processes are important, and if the cluster sizes are relatively large.

FIGURE CAPTIONS

Fig. 1 Reconstructed momenta from a sample of 2- and 4- pronged events obtained in a test exposure of the Proportional Hybrid System to 150 GeV/c protons. The vertical axis gives the momentum, with its error, obtained using only the bare bubble chamber information. The horizontal axis gives the momentum and error reconstructed in the downstream portion of the hybrid system.

Fig. 2 Illustrating a technique for isolating elastic scattering events with the hybrid system, using a sample of 54 2-prong events (many of which fall off-scale) from a 150 GeV pp test exposure. The scatter plot displays the difference between the measured coordinates of the outgoing fast track at the last downstream proportional wire chamber and that predicted on the basis of the bubble chamber measurements of the slow particle in the bubble chamber. The elastic signal clusters about the origin. The radial distribution is plotted in the lower histogram. The arrows on this histogram show the positions of a sample of 12 four-constraint 4-pronged events (6 are off-scale) which were treated as 2-prongs after removing two slow pions. This gives some measure of the discrimination of the technique against two prongs with two neutral pions.

Fig. 3 Missing mass recoiling against the two charged outgoing particles in 2-pronged events in a 150 GeV/c test exposure of the hybrid system to a proton beam. The lower left histogram gives the result of using the bubble chamber measurements alone. The upper right shows the result using the full hybrid system to measure the fast track. The lower right hand histogram shows the same plot, with the horizontal scale expanded a factor of 10.

Fig. 4 Reconstructed momenta of fast (150 GeV/c) outgoing tracks from fitted elastic and quasi-elastic events in a test exposure of the hybrid system. The corner histogram compares the reconstructed transverse momentum with the "true" transverse momentum obtained from measurements of the slow recoil tracks in the bubble chamber.

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APPARATUS NEEDED

I. HYBRID Proportional wire chamber NAL 30 inch bubble chamber system.

II. 150 GeV/c π^+, π^-, and proton beams.

III. ON SITE computer facility to calculate survey parameters.

No new equipment is anticipated.

SCOPE OF THE EXPERIMENT

This experiment will be accomplished by use of the proportional wire chamber NAL 30 inch bubble chamber system. A total of 1.2×10^6 pictures are requested equally divided between incident π^+, π^- and protons at 150 GeV/c. The film will be scanned and measured by the groups forming the Proportional Hybrid System Collaboration (PHSC). The time required for film acquisition should be about twelve weeks.