FNAL Experimental
Proposal 377
Spokesman: Elizabeth S. Hafen

# A PRECISION STUDY OF LEADING PARTICLE AND DIFFRACTIVE EFFECTS IN $\pi^- p$ INTERACTIONS AT 300 GeV/c

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# SUMMARY

We propose a 200,000 picture exposure in the FNAL 30" proportional wire chamber hybrid bubble chamber system to a 300 GeV/c $\pi^-$ beam. We expect to use the high precision of this system to make a significant contribution to the following topics:

(1) Leading particle effects and diffraction phenomena

(2) Charged particle multiplicity moments

(3) Production spectra for charged and neutral particles

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

(5) Total cross section for $K^-$ interactions

(6) Semi-inclusive distributions for interactions with an associated forward $\pi^0$.

We expect a yield of about 40,000 interactions for our study. The rough breakdown by prong topology (based on a linear extrapolation from 147 GeV/c [1] and 205 GeV/c [2] is:

| Type | Number of events | Events with leading p | Events with leading $\pi^-$ |
|---|---|---|---|
| total | 40,000 | 2,400 | 2,400 |
| 2 prong elastic | 5,000 | | |
| 2 prong inelastic | 2,000 | 800 | 800 |
| 4 prong | 4,000 | 1,000 | 1,000 |
| 6 prong | 4,000 | 400 | 400 |
| 8 prong | 7,000 | | |
| 10 prong | 7,000 | | |
| 12 prong | 5,000 | | |
| 14 prong | 4,000 | | |
| 16 prong | 1,000 | | |
| ≥18 prong | 1,000 | | |

In addition, we expect to use the Čerenkov tagging system to detect and measure about 800 $K^-p$ and 300 $\bar{p}p$ interactions, assuming beam contaminations of 2% and 0.6%, respectively.

Data taking should require about 2 weeks.

Physics Justification

I. Introduction

(1) Purpose of the experiment

To date a wide range of exploratory experiments carried out in the Proportional Wire Hybrid System 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 ( $\leq 8$ charged particles)[1, 2, 3];

(ii) the essentially short-range nature of particle-particle correlations in the high multiplicity component, which accounts for the bulk of particle production;[4]

(iii) the rapid rise of neutral particle production ($\pi^0$, $K^0$, $\Lambda$, $\bar{\Lambda}$) through the FNAL energy range.[5]

High precision experiments at a range of energies need to be done in order to further extend our understanding of the production mechanisms underlying these phenomena.

We propose here an exposure of adequate statistics and resolution to study these phenomena in a way not previously possible. We propose 200,000 pictures of incident 300 GeV/c $\pi^-$ mesons. The Čerenkov tagging facility will allow us to obtain at least a total cross section measurement of $K^-p$ interactions at 300 GeV/c as well.

(2) Unique features of the experiment

The FNAL Proportional Wire Hybrid System provides enhanced momentum resolution for fast secondary tracks leaving the bubble chamber; to wit, $\frac{\Delta p}{p} \sim .05\ p\ \%$, or $\frac{\Delta p}{p} \sim 15\%$ at 300 GeV/c. At 147 GeV/c, this resolution enabled the PHS Consortium to measure the leading $\pi^-$ cross section as well as the leading proton cross section as a function of topology [1] and thus study the diffraction dissociation of the target as well as of the beam, whereas without the downstream spectrometer system, only the leading proton and diffraction dissociation of the beam can be directly measured[6]. See Fig. 1. In addition, we can study in detail the properties of the beam breakup such as to what extent particular meson resonances contribute to it. For example, we can study $\pi^- \rho^0$ diffractive enhancements with this increased resolution. Fig. 2 shows evidence for diffractive production of $\rho^0$'s in 8 GeV/c $\pi^- p$ reactions[7a] and in 11.2 GeV/c $\pi^- p$ reactions.[7b] Fig. 3 shows the measurement at 205 GeV/c, [7c] with the error on the effective mass of the $\pi^+\pi^-$ system indicated for the target fragmentation, pionization, and beam diffraction regions. For the Proportional Wire Hybrid System at 147 GeV/c, those errors are $\sim$ 20 MeV, 50 MeV, and 50 MeV, respectively. [8] If the mass resolution scales like $\frac{\Delta p}{p}$ , we might expect errors of 20 MeV, 50 MeV, and 100 MeV, respectively, at 300 GeV/c incident momentum.

In addition to the enhanced resolution, the presence of a downstream $\gamma$ ray vertex detector and calorimeter (subtending an angle of $\pm 5^0$ at 4m ) will make possible a study of the properties of $\pi^- p$ interactions with one or more forward $\pi^0$'s. The expected energy resolution is $\frac{\Delta E}{E} \sim 1\%$ for $\gamma$ rays above 5 GeV, and the vertex location is estimated at $\pm 3$ mm.[9]

(3) Details of the experiment

(i) We will measure charged particle multiplicity moments with higher accuracy than has been previously possible at this energy by obtaining a good separation of the 2-prong inelastic events from the 2-prong elastic events.

(ii) We will study particle production spectra as a function of the center of mass momentum, with good resolution up to x = + 1. We will study long and short range correlations in both center of mass hemispheres with good momentum precision.

(iii) With our $4\pi$ geometry and good momentum and angle resolution, we will be able to perform studies of leading particle effects and diffractive phenomena. This capability is due to our ability to identify beamlike particles near $x = 1$. We also expect to extract samples of constrained fits for many of the low-multiplicity channels in which diffractive phenomena are the dominant production mechanism. In particular, we should be able to obtain 1C fits to the channels with 1 missing forward $\pi^0$, using the information from the Forward Gamma Detector.

(iv) We will study 2-particle correlation functions in detail in the following ways.

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

(b) We can determine angular correlations in the center of mass frame for events with and without leading particles.

(v) We can measure multiparticle invariant masses and momentum transfers among groups of particles over the full kinematic range, and can examine "decay" correlations among groups of pions.

(vi) In conjunction with the earlier experiment at 147 GeV/c and another proposed experiment at 75 GeV/c, this experiment will contribute to an understanding of the energy dependence or lack thereof of the leading particle production mechanism.

(vii) We can measure the charged multiplicity moments of the semi-inclusive reaction $\pi^- p \rightarrow \pi^0 + X$, where the $\pi^0$ was detected in the Forward Gamma Detector.

## FIGURE CAPTIONS

Figure 1: Figure 1(a) shows the charged multiplicity distribution (all charged) and the multiplicities for pion single diffraction dissociation (leading proton) and for proton single diffraction dissociation (leading pion) as obtained by measurement of the leading p and $\pi^-$ peaks in the Feynman x distributions for $\pi^- p$ interactions at 147 GeV/c. Figure 1(b) shows the charged particle multiplicity distribution and the beam diffraction dissociation multiplicity distribution at 205 GeV/c, where the beam diffraction dissociation events were defined as $\pi^- p \rightarrow p + X$, with the momentum of the proton <1.4 GeV/c and the mass squared of X less than 32 $GeV^2$.

Figure 2: Figure 2(a) shows the x-distribution for inclusive $\rho^0$, $\pi^+$, and $\pi^-$ production in 8 GeV/c $\pi^- p$ interactions, and for inclusive $K^{*+}$ production in 8.2 GeV/c $K^+ p$ interactions. Figure 2(b) shows the x-distributions for all $\pi^\pm$ coming from $\rho^0$ decay in 8 GeV/c $\pi^- p$ interactions. Figure 2(c) shows the $\pi^+\pi^-$ mass distribution in $\pi^- p \rightarrow \pi^+\pi^- X$ at 11.2 GeV/c with both $\pi^+$ and $\pi^-$ forward in the center of mass. The dashed line is an estimate of the background in the $\rho^0$ region. The lower histogram has the restriction $-t\,(\text{beam}, \pi^+\pi^-) < 0.4\ GeV^2$.

Figure 3: Figure 3(a) shows the center of mass rapidity distribution for $\pi^+\pi^-$ combinations in $\pi^- p \rightarrow \pi^+\pi^- X$ reactions at 205 GeV/c. The $\pi^+\pi^-$ effective mass resolution is given for three rapidity regions. Figure 3(b) shows the $\rho^0$ production cross section for two of the regions.

## REFERENCES


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APPARATUS NEEDED

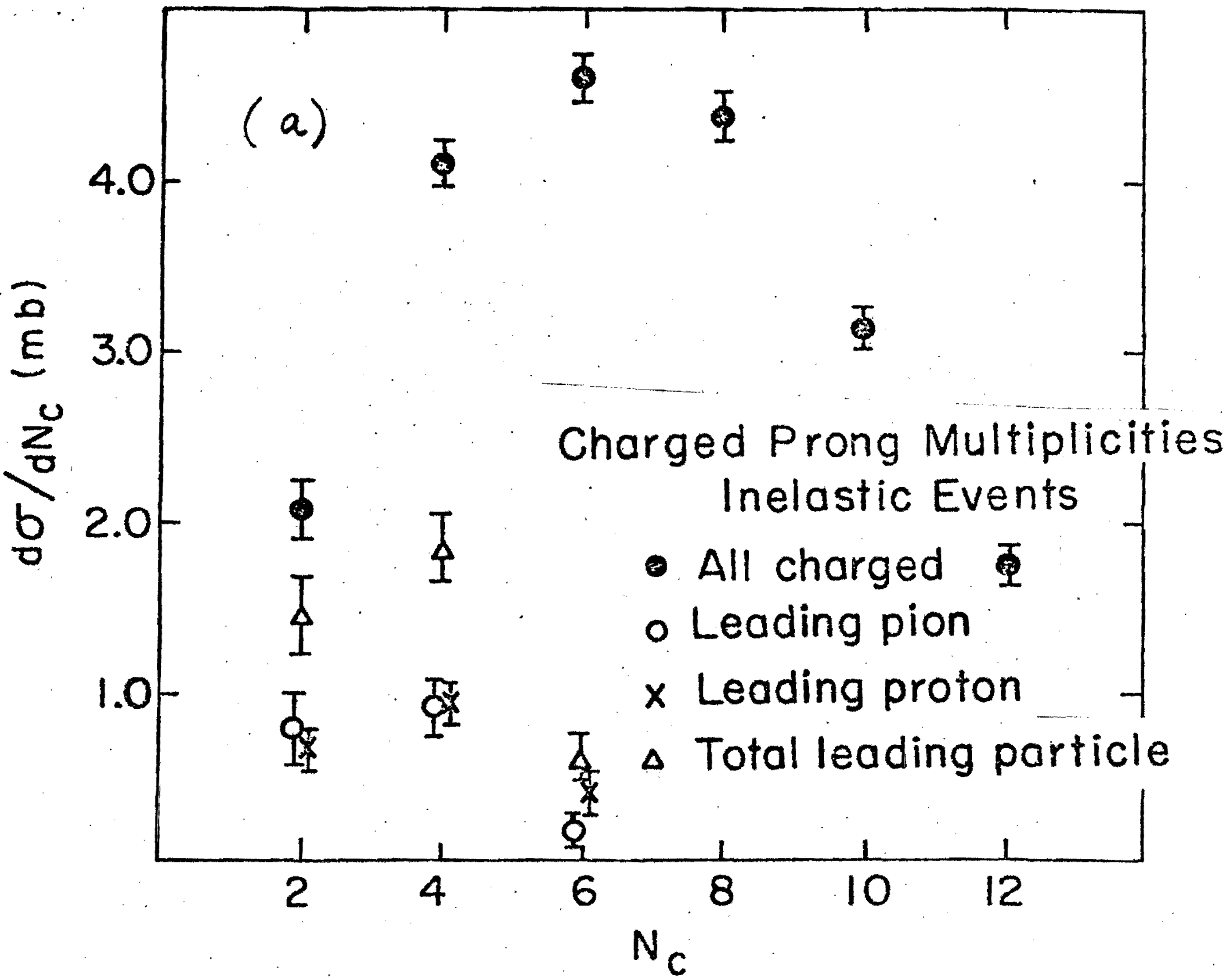
I. Hybrid Proportional Wire Chamber - FNAL 30-inch bubble chamber system with Forward Gamma Detector

II. 300 GeV/c $\pi^-$ beam

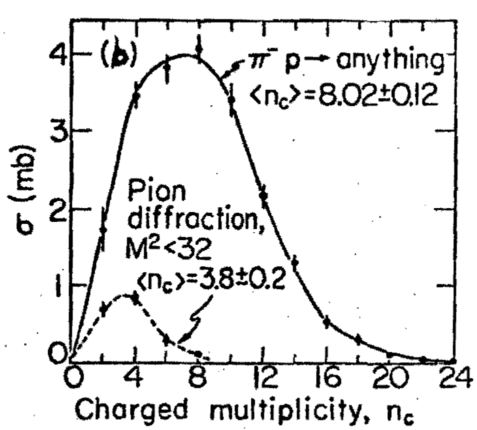
III. On-site computer facility to calculate survey parameters and check data acquisition programs

## Scope of the Experiment

This experiment will be accomplished by use of the Proportional Wire Chamber FNAL 30-inch bubble chamber system with Forward Gamma Detector. A total of 200,000 pictures are requested of 150 GeV/c incident $\pi^-$. The film will be scanned and measured by the groups proposing this experiment. The time required for film acquisition should be about two weeks.



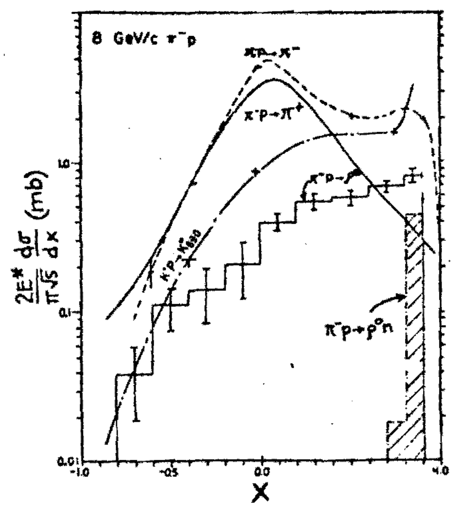
(a)
4.0
3.0
2.0
1.0
dσ/dN_c (mb)
2
4
6
8
10
12
N_c
Charged Prong Multiplicities
Inelastic Events
All charged
Leading pion
Leading proton
Total leading particle

(b)
π⁻ p → anything
⟨n_c⟩=8.02±0.12
Pion
diffraction,
M²<32
⟨n_c⟩=3.8±0.2
σ (mb)
0
1
2
3
4
4
8
12
16
20
24
Charged multiplicity, n_c

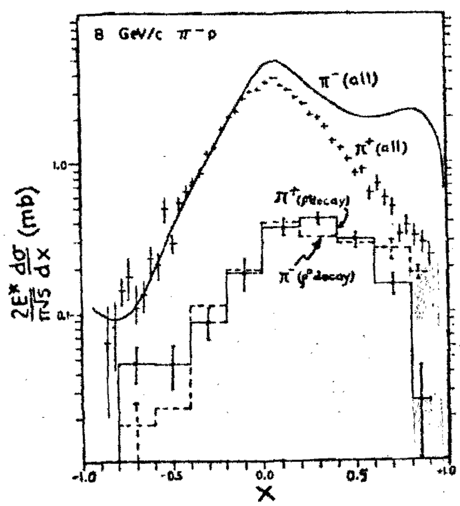

(b)

Figure 1



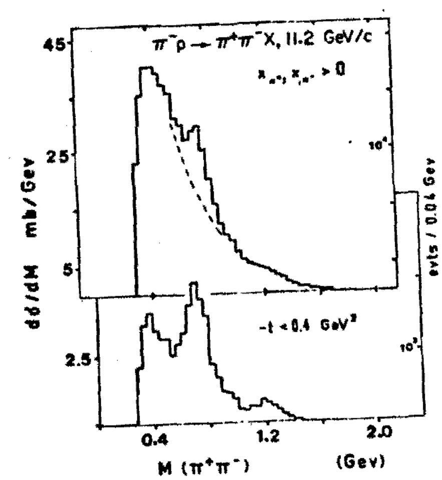
8 GeV/c π⁻p
π⁻p→π⁻
π⁻p→π⁺
π⁻p→ρ⁰
π⁻p→K⁰890
π⁻p→ρ⁰n
2E* dσ / π√s dx (mb)
X


(a)



8 GeV/c π⁻p
π⁻(all)
π⁺(all)
π⁺(ρ⁰decay)
π⁻(ρ⁰decay)
2E* dσ / π√s dx (mb)
X


(b)



π⁻p → π⁺π⁻X, 11.2 GeV/c
-t < 0.4 GeV²
dσ/dM mb/Gev
evts / 0.04 Gev
M (π⁺π⁻) (Gev)


(c)

Figure 2

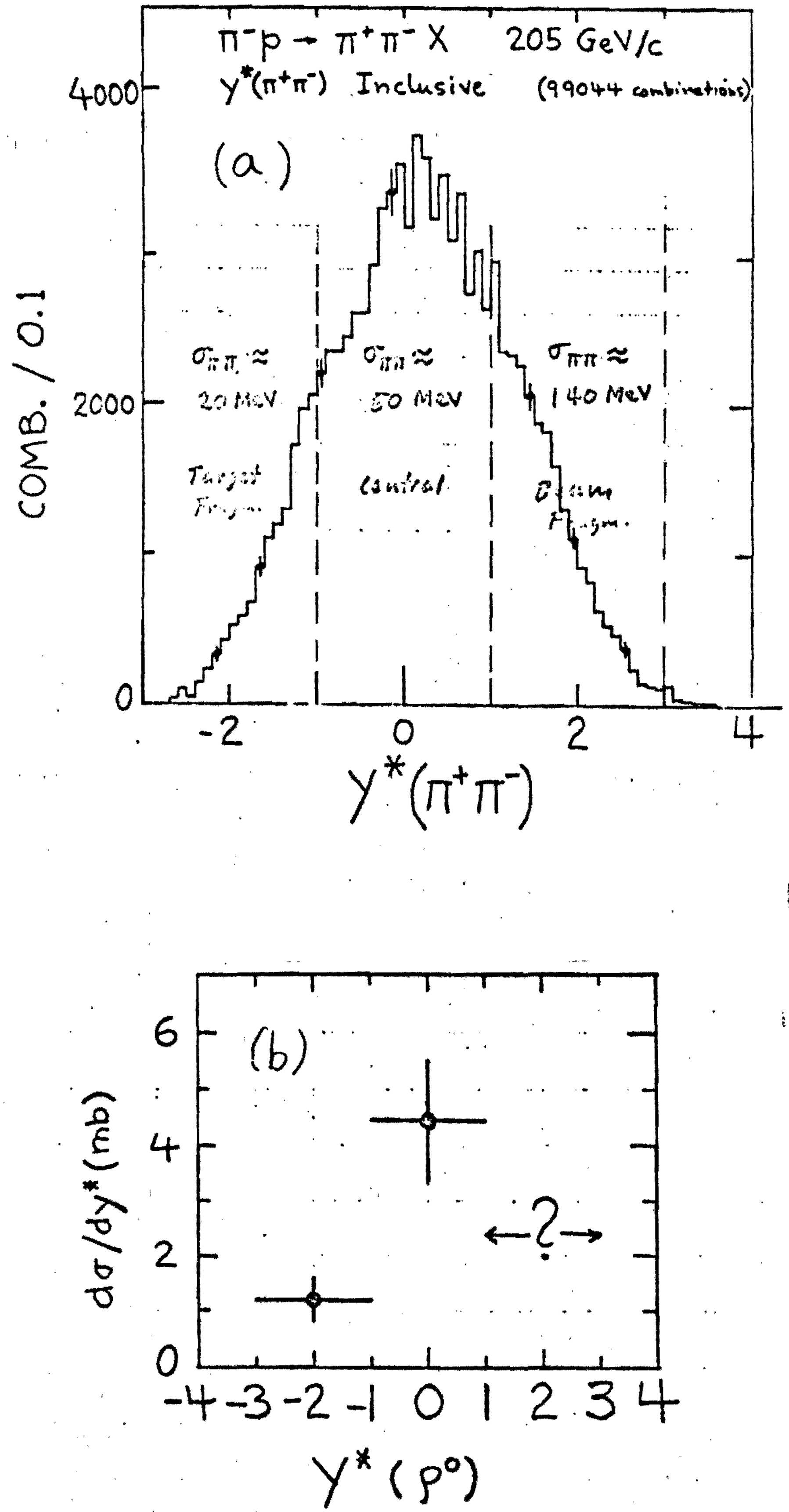

π⁻p → π⁺π⁻ X 205 GeV/c
y*(π⁺π⁻) Inclusive (99044 combinations)
(a)
σππ ≈ 20 MeV
σππ ≈ 50 MeV
σππ ≈ 140 MeV
Central
COMB. / 0.1
y*(π⁺π⁻)
(b)
dσ/dy* (mb)
←?→
y* (ρ°)

Figure 3