NAL PROPOSAL No. 280

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PROPOSAL TO STUDY pd INTERACTIONS AT 205 GeV/c IN THE 30-INCH BUBBLE CHAMBER

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We propose to analyze pn and coherent pd interactions at 205 GeV/c using 100,000 pictures of the 30" bubble chamber.

I. Introduction

Studies of pp interactions in the 30" chamber at NAL energies have yielded a number of very interesting results. The precise studies of charged-particle multiplicities severely constrains any model of high energy interactions. The existence of a low-mass diffractive peak has been established and its nature partially elucidated. The cross section for this process seems to be about 6 mb independent of energy and is roughly equal to that for pp elastic scattering. The single particle inclusive spectra for π^-, K^o, p show scaling behavior between 200 GeV and the ISR at least in the fragmentation region. Neutral pion production has been studied and a positive correlation with charged pion production observed. The strange particle (K^o, Λ/Σ^o) production cross sections were found to be much higher than for proton energies from 20-30 GeV. Correlations amongst the pions in the central region of rapidity suggest a multiperipheral-like production mechanism for most of the inelastic cross section.

We have carried out a number of interesting experiments with a 40 GeV π^- exposure obtained at Serpukhov and independently observed that most of the above features also hold for π^- interactions.[(1)]

We propose to extend these exploratory studies to pn interactions obtained by filling the 30" bubble chamber with deuterium. Such a study cannot be done with the CERN ISR. We will make use of information coming from the downstream optical spark chambers, but do not consider the hybrid system essential for most of the physics objectives of this proposal.

Since tracks from the target vertex are slow in the laboratory, one can study the neutron vertex interactions very well in the bubble chamber. In addition, a detailed comparison of these data with our 205 GeV pp data will facilitate separation of the pp from pn interactions. The outstanding optical quality of the 30" chamber makes it the first choice for an exploratory experiment of this type in which accurate measurements of short proton tracks (spectators) is essential.

II. Physics Objectives

A. Charged Particle Multiplicity Distributions

In the proposed experiment, we will measure the cross section for producing n charged particles in the final state, σ_n, as a function of n. In particular, we will compare σ_n vs. n for pn interactions with our results for pp interactions at the same energy.[2] We do not expect much difference between pp and pn interactions especially for the higher multiplicities. A difference in the lower multiplicities (1-7 prongs) would be a manifestation of differences in the proton and neutron diffractive breakup. There will be a serious scanning problem in looking for the one-prong events $pn \rightarrow p$ or $\pi^+ + (n, \pi^o, \pi^o, \ldots)$, but the beam deflection tagging system used in Exp. 2B will help to locate frames containing such events. Since we will tabulate all observed interactions, we will also obtain data on σ_n for pp interactions. In order to minimize ambiguities in pn interactions due to rescattering off the spectator proton, we will use the σ_n data from Ref. (1) as a constraint on the pp data in this experiment, and thus obtain σ_n for pn interactions. The fraction of pp events we found in Exp. 141 that, after a careful examination, have an odd prong count is only 0.2%, so the experimental pn, pp separation should be relatively clean, apart from the rescattering effects.

B. Diffraction Dissociation in pn Interactions

Studies of diffraction dissociation of the target proton in the inelastic reaction

$$pp \rightarrow (\text{slow } p) + X \quad (1)$$

have been done at 102[3], 205[4], 303[5] and 405[3] GeV/c. The results show a large peak at low missing mass squared M_x^2, which comes mainly from the two- and four-prong events, with a small contribution from the six-prong topology. The deuterium experiment will allow a more detailed study of this diffractive effect:

1. <u>I = 1 Exchange</u>

In this experiment, we will study the isovector exchange contribution to the target neutron dissociation by using the charge exchange inelastic reaction

$$pn \rightarrow (\text{slow } p) + X \quad . \quad (2)$$

We note that it is very difficult to study the corresponding charge exchange process in hydrogen

$$pp \rightarrow (\text{slow } n) + X \quad (3)$$

because of the problem of detecting neutron recoils with reasonable efficiency and low background. If, indeed, the low-mass peak in the proton case comes only from I = 0 exchange as one expects, then it should be absent in the $n \rightarrow p$ events. In reaction (2) we can study the properties of the M^2 distribution such as the associated multiplicity as a function of M^2. In particular, reaction (2) allows a search for pion exchange, a process for which there is to date no clear evidence in pp interactions at NAL energies. The inclusive cross section is expected to be small,[6] but the process should be observable in this experiment.

2. Single and Triple Pion Production in Single Diffraction

For the I = 0 exchange, we can study diffraction dissociation of the target neutron into two charged particles in the reaction

$$pn \rightarrow (\text{slow } p, \pi^-) + X \quad . \tag{4}$$

The corresponding processes in hydrogen

$$pp \rightarrow (\text{slow } p, \pi^0) + X \quad , \quad pp \rightarrow (\text{slow } n, \pi^+) + X \tag{5}$$

have not been studied due to the low detection efficiency for neutral particles in the 30" chamber. In reaction (4) we will look for diffractive production of the $N^*(1470)$ and other similar states and look at the properties of the system X. The particular case where X is a proton gives the exclusive reaction

$$pn \rightarrow pp\pi^- \quad . \tag{6}$$

This reaction can be isolated using kinematic fitting, missing mass techniques, and ionization density information. In our 205 GeV/c pp experiment, we have shown that such methods can be used effectively to study elastic scattering[7] and the reaction[8]

$$pp \rightarrow pp\pi^+\pi^- \quad . \tag{7}$$

We expect reaction (6) to have a substantial cross section as it will be dominated by diffraction. There is evidence from our pp experiment[9] that the shape and position of the low-mass peak depends on the number of pions produced with the one pion state peaking at a lower mass than the two-pion state, etc. This experiment will allow a check on this interesting phenomenon by isolating the 1 and 3π final states $p\pi^-$, $p\pi^-\pi^+\pi^-$ from pn interactions, and comparing them to the 2π state $p\pi^+\pi^-$ already studied in the reaction $pp \rightarrow pp\pi^+\pi^-$.

3. Double Diffraction

Reaction (4) provides a good place in which to look for double diffraction when one expects X to be a simple low-mass system such as $p\pi^+\pi^-$. Double diffraction has not so far been observed although its existence and cross section can be inferred from factorization.

C. Double Charge Exchange

We will also look for double charge exchange in the reaction

$$pn \rightarrow \Delta^{++} + X^- \quad , \qquad (8)$$

where the Δ^{++} is produced in the backward direction in the center-of-mass system. This is a reaction which requires charge two exchange for which there is no clear evidence at lower energies. However, with the opening of new energy regions at NAL, it is desirable to look for such exotic processes.

D. Inclusive $\pi^{\pm}$ Production

To study inclusive $\pi^{\pm}$ production, we will measure all tracks with lab momentum less than 15 GeV/c on a sample of events. At 205 GeV/c, this selection corresponds to measuring all tracks produced in the backward hemisphere in the CM system. Using our pp data for comparison, we will test the following relations between neutron and proton fragmentation:

$$(p \rightarrow \pi^{+} + \text{anything}) = (n \rightarrow \pi^{-} + \text{anything}) \qquad (9)$$

$$(p \rightarrow \pi^{-} + \text{anything}) = (n \rightarrow \pi^{+} + \text{anything}) \qquad (10)$$

If there is no exchange of isotopic spin between the beam and target clusters, these relations must hold. Because of the difficulty of distinguishing π^{+} from p for $p_{lab} > 1.4$ GeV/c, using bubble chamber data alone, this test of these relations will be limited to the kinematic region $-1 < x < -0.6$. The data from this experiment for $pn \rightarrow \pi^{-}$ + anything may be compared with our data for $pp \rightarrow \pi^{-}$ + anything in which we have found evidence for scaling in the fragmentation region and suggestions of a plateau in the central region of rapidity.[10]

E. Coherent Events

In addition to the neutron target interactions, there will also be interactions which leave the deuteron intact. Coherent events of the reaction

$$pd \rightarrow X + d \qquad (11)$$

may be easily measured for $|t| > 0.16\ (\text{GeV/c})^2$. For lower t values, one must apply the separation techniques that we have used in experiments at

ZGS energies.[11] This coherent process requires I = 0 exchange and is an obvious reaction to study in order to gain information on the nature of diffraction dissociation. We will compare the deuteron data with the corresponding distributions in reaction (1) in our pp experiment and in the present pn study.

Among these diffractive events will be a sample of the exclusive reaction

$$pd \rightarrow p\pi^+\pi^-d \quad . \tag{12}$$

We will look for the presence of a diffractively-produced low-mass enhancement in the fast $p\pi^+\pi^-$ system and compare its properties to the $p\pi^+\pi^-$ enhancement that dominates reaction (7) at 205 GeV/c.[8]

Finally, we will measure the cross section for pd elastic scattering for $|t| \geq 0.16\ (\text{GeV}/c)^2$ and compare our results with results obtained at lower energies. The hybrid system beam tag will be useful in locating these events.

F. π^o and Strange Particle Production

We will measure all V^o, which includes all the converted γ-rays in the film, and compare the results for the π^o multiplicity with our pp results.[12] We have shown[1, 12] that for multiplicities up to about 12 in both pp and π^-p interactions, the average number of π^o's per inelastic collision increases with the number of π^- produced.

The V^o measurement will include the neutral strange particle production and allow us to compare the results for inclusive K^o, $\overline{K}^o$, Λ and $\overline{\Lambda}$ production with our pp results.[13] In Exp. 141 we have shown that at 205 GeV/c, it is possible to identify all K^o's and Λ's produced in the backward hemisphere in the CM system. In addition, the K^o's produced from $p_L^* = 0$ to $p_L^* = 0.4$ can also be used. Since Λ's have some of the characteristics of a leading particle, one expects some differences between pp and pn collisions, whereas most of the K^o's are associated with the central region and so should be the same for pp and pn interactions.

III. Event Rates

We have estimated the number of events that will be obtained assuming a fiducial length of 45 cm, 6 beam tracks per picture and 100, 000 pictures. The numbers are given in Table I. We note that Exp. 141 has a total of 8800 events so the proposed experiment will have comparable statistics in the pn interactions with a visible spectator. In addition, there will be about half as many coherent inelastic pd interactions.

Table I

Cross Sections and Event Rates

	σ (mb)	Number of Events in Fiducial Volume
Total pd Cross Section	70	70,000
pd Elastic Scattering	7	7,000
pd Coherent Inelastic	6	6,000
pn Interactions Total	28.5	28,500
With Visible Spectator		11,400
pp Interactions	28.5	28,500
pd Elastic, $\|t\| > 0.16$	0.4	400
pd Coherent Inelastic, $\|t\| > 0.16$	0.3	300

IV. Time-Scale

We think this is a topical experiment and that it represents an important step in the 30" chamber program. For practical reasons, deuterium exposures of Mirabelle or the NAL 15' chamber will be some time away and so the 30" chamber can make a unique contribution. Apart from this, as discussed above, the well understood geometry and high optical quality of the 30" chamber that have facilitated the analysis of the hydrogen exposures will be even more important for the deuterium experiments. As we have discussed above, this deuterium exposure will provide answers to several questions which were raised but unanswered in the hydrogen experiments.

Both the Argonne and the Dubna groups are experienced in this kind of physics and will devote a sufficient effort to the experiment to see that the physics results are obtained expeditiously. Some additional effort will be required to optimize communication between the collaborating groups, but by dividing the film equally between the two laboratories, each group will have a good sample of data to use in analyzing the physics results. Papers resulting from this work will be published jointly by the two institutions. We expect to have the first results within six months of the film being available, and the experiment should be complete within about two years.

V. Appendix

Isolating pn, pp and pd Interactions

The main emphasis of this proposal is the study of pn interactions, and we shall now describe how we will isolate these reactions using a deuteron target. Two types of events will be initially classified as pn interactions: (1) events with an odd number of prongs (and therefore the spectator proton is unseen). Using fitted spectator momentum distributions for seen and unseen spectators for highly constrained events in lower energy deuterium experiments, we estimate that the odd prong events in this experiment will constitute about 60% of the pn interactions. (2) Events with an even number of prongs in which one of the prongs is a stopping proton with $p_{lab} < 300$ MeV/c emitted in the backward direction in the laboratory. These events will constitute about 20% of all pn interactions, or half of the events with a seen spectator, since the spectator has an isotropic angular distribution in the laboratory. In some cases, of course, one cannot separate spectator protons from pn interactions from low momentum recoil protons from pp interaction and low momentum deuterons from pd coherent interactions. The separation of these three categories must be done by using the angles of the short baryon track relative to the beam track.

Three types of background processes must be considered for the pn interactions of type (1): (1) secondary interactions near the primary vertex in which a true odd (even) prong event looks like an even (odd) prong event, (2) pp interactions with unseen recoil protons, and (3) inelastic coherent pd interactions with unseen recoil deuterons. All these background processes introduce about a 10% contamination in the pn interactions of type (1). Using our 205 GeV/c pp data as a constraint on the pp data in the proposed experiment will enable us to minimize this background.

We will select as pp interactions those events with an even number of prongs and with no stopping proton with $p_{lab} < 300$ MeV/c. From our pp data, we calculate that this selection will yield 85% of the pp interactions, corresponding to 90% of the inelastic pp interactions. The remaining events, those that are not classified as either pn or pp interactions and are not coherent pd interactions, will be ambiguous between pn and pp interactions. Again, our pp results from Exp. 141 will be very useful in analyzing these ambiguities.

Coherent pd interactions can be selected uniquely by identifying the recoil deuteron; deuterons can be reliably distinguished from protons for $|t| > 0.16\ (GeV/c)^2$ by using range energy relations and ionization density information. This will enable us to study the reactions $pd \rightarrow pd$ and $pd \rightarrow d + X$ in this t-region, although the number of coherent events is reduced substantially due to this $|t|$ cut.

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