Proposal to Study Multiparticle $\pi^+ p$ and $p p$ Interactions from 70 GeV and Above Utilizing the 30-inch Bubble Chamber and Associated Equipment at NAL

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ABSTRACT

We propose an investigation of the multiparticle final states produced by high energy $\pi^+\!-p$ and $p-p$ interactions in the region above 70 GeV. This experiment is planned for the 30-inch bubble chamber at NAL since the device will be available at an early date and exploratory experiments can be performed with this proven detector. The experiment is feasible with the unseparated 30-inch hadron beam being designed for Area I. The upper limit on the $\pi^+$ beam energy desired for this experiment is expected to be $\sim 250$ GeV, but will be determined from the composition of the beam and the tagging facilities available.

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I. Introduction

We propose a study of high energy multiparticle $\pi^+$-p and p-p interactions in the 30-inch hydrogen bubble chamber at NAL. A total exposure of 240,000 pictures is requested, with less than five tracks per frame, divided among $\pi^+$ and protons at each of three energies; 70 GeV, 150 GeV and 250 GeV. The upper limit on the $\pi^+$ beam energy, in general, depends on the type and energy of the particle used to produce the $\pi^+$ beam, the kind of tagging facilities available, and the results of a beam survey. With a suitable beam tagging system (which IIT proposed to build), usable $\pi^+$ beams of 250 GeV are possible. This experiment does not necessarily require an associated downstream spectrometer but the scope of the experiment would be broader using a hybrid system.

The justification for early bubble chamber experiments at NAL to explore strong interaction physics has been ably presented in a number of previous Summer Study Reports and NAL proposals. Our discussion will follow a 1970 Summer Study Report which one of us contributed to.¹

The bubble chamber will be a valuable instrument for strong-interaction studies at NAL because it is the only proven detector where all charged secondaries, together with the interaction vertex, are visible. This capability of the bubble chamber makes it very suitable for exploratory studies of unexpected phenomena. In addition, it is possible to detect complex high-multiplicity events which are an essential feature of studies at high energies. These studies are made to learn more about particle production in general and to test specific ideas on high energy limiting behavior as expressed, for example, by Feynman² and by Yang³ and his co-workers. There is also an important need to extend to higher energies the kinds of investigations for which the bubble chamber has proven successful in the < 30 GeV region. The latter includes searches for new particles and the determination of their quantum numbers as well as studies of production mechanisms in general. Results from bubble-chamber experiments will also be valuable for planning and designing more specialized experiments involving either counters, bubble chambers, or hybrid detectors.
II. Physics Justification

There are a number of different types of physics problems for which the bubble chamber is eminantly suitable.

1. Searches for New Phenomena

The good spacial resolution and $4\pi$ solid-angle coverage of the bubble chamber makes it uniquely suitable for searching for unexpected phenomena. A specific possibility might be the discovery of new short-lived particles, with lifetimes of $10^{-13}-10^{-10}$ seconds, for which the bubble chamber would be the only detector capable of revealing a sequence of complex decays.

2. Multiparticle Studies up to the Highest Energies

The bubble chamber makes possible gross studies of all inelastic channels up to the highest energies at NAL. Such studies are very important for developing a theory of strong interactions since unitarity requires that all the inelastic and elastic channels be tied together. The results of these bubble chamber studies should be far more complete and reliable than current cosmic-ray experiments covering the same energy range.

Both Feynman$^1$ and Yang$^2$ and his coworkers have predicted asymptotic behavior as the colliding energy becomes very large. According to the hypothesis of limiting fragmentation (HLF) of Yang, the beam and/or target particles fragment separately. In $pp$ collisions, for example, either one or both colliding protons fragment and produce clusters of particles, $p^+$; i.e.,

$$ p + p \rightarrow p + p^+ $$

or

$$ \rightarrow p^+ + p. $$

The distributions of beam (target) proton fragments asymptotically approach limiting distributions in the beam (target) rest frame. Furthermore, Yang and coworkers assert that there is no "pionization", that is, there will be no particles which do not approach limits in either the beam or target-rest frames.
The parton model of Feynman makes specific predictions about limiting behavior such as Regge power-law behavior for two-body reactions, constant cross sections for diffractive processes, logarithmic energy dependence of mean multiplicity \( n \approx \ln(E) \) or \( n \approx \ln(p_{\text{lab}}) \) and the existence of pionization etc. Many of these results have also been predicted by other models such as the multiperipheral model. In addition, there are many other models which are relevant to the study of high-energy phenomena, i.e., the quark model, the Hagedorn-Ranft (thermodynamic) model, the multi-Regge model, and other multiperipheral models. Detailed discussions of the predictions of these models can be obtained from the references.

The energy of present accelerators (< 30 GeV) is not high enough to properly investigate highly inelastic channels and thereby test theoretical models. In one familiar case, it is because kinematics prevents the clean separation of beam fragments, target fragments, and pionization. Studies of bubble-chamber data at NAL should show how various quantities including multiplicities and momentum distributions of specific channels vary with energy up to 500 GeV and yield energy dependent parameterizations of the data. This kind of survey should provide data to test the models discussed previously. It should be emphasized that the bubble chamber has no high-energy cutoff for these studies since valuable information will be provided from unfitted data at the highest energies. Moreover, studies in specific channels should be possible with a hybrid detector system to identify neutrals when conventional fits are not satisfactory.

In this proposal, we are requesting an experiment involving two projectile particles, \( \pi^+ \) and protons, for the following additional reasons: (1) To test whether the "fragments" of the target proton are independent of the projectile; (2) To compare "fragments" of the different projectiles \( \pi^+ \) and \( p \); (3) To allow a comparison with \( \pi^- p \) experiments which have been proposed by a number of groups.

A \( \pi^+ p \) and \( p p \) experiment has the advantage that both the projectiles are positively charged and in the final state, and the negative tracks should be created pions uncontaminated by the incident projectile.
3. Conventional Bubble-Chamber Studies

It will be interesting to extend to NAL energies the "bread-and-butter" type of bubble chamber strong interaction physics. This approach will probably be most fruitful in the \( \lesssim 100 \text{ GeV} \) range where unambiguous four-constraint kinematic fits should be most easily obtained.

It will also be important to pursue searches for new particles or resonances at higher masses and determine their quantum numbers where possible. In addition, studies of production mechanisms will be possible and energy-dependent investigations of two-body channels will be valuable for testing Regge behavior. It hardly needs further mentioning that the extended range of energies provided by NAL will provide an exciting list of experiments to perform by the bubble chamber technique which has proven so effective in the past.

4. "Small" Bubble Chamber

The essential feature of the physics problems which have been discussed can be investigated with a "small" bubble chamber at NAL since the unique properties of bubble chambers for hadron physics (i.e.; visibility and precision determination of the vertex, \( 4\pi \) solid-angle detection with high efficiency, accuracy of slow particle measurement and discrimination, excellent detection efficiency for high multiplicity events, availability of working analysis programs and analysis equipment, and ability to observe and analyze unknown phenomena, clearly apply to any existing smaller bubble chamber. To be sure there are limitations inherent in using a "small" bubble chamber but the addition of an associated hybrid system\(^{13}\) as proposed, could compensate for many of these limitations. Nonetheless, we feel that even a bare "small" bubble chamber is an important first step in studying high energy phenomena.
III. Experimental Arrangement

For this experiment we need a short spill (< 1 millisecond) beam of less than five tracks per picture of $\pi^+$ and protons controlled by a kicker magnet. An unseparated beam with $\frac{AP}{P} \sim 0.1\%$ is being designed for Area I. A beam survey and a $\pi^+$ tagging system are required for portions of this experiment. Further details concerning features of the beam will be discussed in this section.

1. General Features of the Area I Hadron Beam

The Area I hadron beam as presently conceived is a flexible design which allows several methods for producing beams. The beginning of the beam accepts a particle produced or by-passed from the Area I target box. The exact spectrum of particles produced depends on the beam momentum and on the particular load in the target box but principally $p$, $\pi^+$, $\pi^-$, and $\mu^+$ will be produced by interactions or decay. These particles enter an aperture in the neutrino shield ("torpedo"), where the $p$, $\pi^+$, $\pi^-$ and $\mu^+$ can be momentum analyzed, and transmitted through the beam or focused and retargetted -- retargetting produces purer beams of hadrons by removing most of the non-interacting $\mu$ contamination. Initially at turn-on, the Area I 30-inch hadron beam may be a simplified version of the design with not all features available.

2. Proton Beams

Proton beams of 100% purity and machine energy can be obtained in Area I by diffraction scattering or diverting protons and directing the particles into the "torpedo". This method can be used to produce early proton beams of 200 GeV and above, since those are the usual machine energies (the machine can also be run at 100 GeV). By retargetting these protons on a target in the hadron beam, one can produce variable energy proton beams in the forward direction of $\geq 95\%$ purity for $p \geq 0.6 P_{beam}$ that is, proton beams of momenta from $\nu$ 60 - 300 GeV/c. For the case where 200 - 400 GeV/c protons are incident on a wide band neutrino load in the Area I target box, and for a secondary beam produced by retargetting positive particles in the region 100 - 300 GeV/c, then one
obtains protons in the forward direction of $\geq 95\%$ purity for $p > 0.6$ $p_{\text{beam}}$ and in this way proton beams from $\sim 60 - 180$ GeV/c can be obtained. In a similar way, the discussion could be extended to cases of other target box loads.

3a. $\pi^+$ Beams - from Proton Interactions

In order to produce $\pi^+$ beams from proton collisions one wants to target the highest energy protons obtainable. This yields $\pi^+$ beams of $\geq 40\%$ purity for $p_{\pi^+} < 0.4 p_{\text{beam}}$. In this way, one can produce $\pi^+$ beams of up to $\sim 300$ GeV/c. The purity as a function of momentum is shown in Fig. 1 and Fig. 2. Such a beam is practical for experiments from $30 - 250$ GeV/c if there was a tagging system available to flag out the appreciable proton contamination at the higher energies, and a beam survey to determine the muon contamination. In our proposed experiment, the 70 GeV $\pi^+$ exposure (if produced by 500 GeV protons) probably does not require a tagged beam since the $\pi^+$ are estimated to be $\sim 85\%$ pure at that momentum and the proton contamination can be corrected for. However, a beam survey is required to establish the purity.

3b. $\pi^+$ Beams - from $\pi^-$ Interactions

We have investigated the possibility of producing a high energy $\pi^+$ beam from $\pi^-$ interactions on a secondary target at the beginning of the Area I hadron beam. Our results are that "... we expect that the reaction $\pi^- + \text{Be} \rightarrow \pi^+$ ... will be a suitable source of high momentum $\pi^+$ mesons with small proton contamination and with a yield which is less than an order of magnitude down from that of the reaction $\pi^- + \text{Be} \rightarrow \pi^- + \ldots"$. We are of the opinion that this method can produce purer beams than the procedure outlined in 3a. However, we expect that such a beam would not be available soon after turn-on, since there are no firm plans to initially install a secondary (hadron) target in the 30-inch beam.

4. Determination of Beam Characteristics

For our experiment it is necessary to determine the purity of the positively charged Area I Hadron beam. However, this is a general problem
shared by all users of the beam and therefore, the installation of a general facility in the beam line, like a Differential Cerenkov Counter would be justified. The initial 30-inch beam is not collimated well enough to accept a CERN DISC counter. But several threshold Cerenkov counters, \(^{18} \sim 50\) meters long, in coincidence and anti-coincidence would be adequate for a detailed beam survey of up to \(\sim 250\) GeV. We understand that this is planned.\(^{19}\) If one of these threshold Cerenkov counters were left permanently in the beam line it would be relatively simple to make a system for tagging \(\pi^+\) mesons (IIT proposes to do this).

5. Exposure Parameters, Experiment Preparation, and Data Reduction

The experiment proposed involves a total of 240,000 pictures to be divided approximately equally between \(\pi^+\) and protons at three different energies; 70 GeV, 150 GeV, and 250 GeV with less than five tracks per picture. For accurate control of the number of beam tracks, a kicker magnet should be installed in the beam line. We would like the proton exposures (100,000 pictures, total, at 70 GeV, 150 GeV and 250 GeV) as soon after turn-on as possible. We think this is possible even with the simplest 30-inch beam line. Also the 70 GeV \(\pi^+\) exposure (40,000 pictures) may be feasible soon after turn-on, since the \(\pi^+\) beam may be \(\sim 85\%\) pure and the proton contamination could be corrected for by using a subtraction procedure with data from the 70 GeV proton exposure. The remainder of the experiment - the 150 GeV and 250 GeV \(\pi^+\) runs (100,000 pictures, total) requires an operating beam tagging system and perhaps a more complicated beam line (a hadron target) and could possibly be delayed.

IIT is prepared to take responsibility for making a beam tagging system for \(\pi^+\) mesons operational. IIT envisages that its \(\pi^+\) beam tagging system would be a "stand alone system" which could be displayed on the 30-inch bubble chamber data box or read by the beam logging system computer and written on tapes or printed out. If plans for the downstream spectrometer system are implemented, then our tagging data could be recorded along with the data from the spectrometer system. The \(\pi^+\) beam tagging system of our conception involves one threshold Cerenkov counter (from NAL) and one Charpaca wire plane (12 inch wide with 150 wires) directly
in front of the bubble chamber to give an accurate one dimensional coordinate for the Cerenkov signal. IIT proposes to build the wire plane and make the overall system work.

From the proposed 240,000 photographs we estimate that there will be \( \sim 25,000 \) multiparticle events (\( \geq 6 \) prongs) in a 40 cm chamber fiducial volume. We estimate that this data could be completely reduced (scanned and measured) within two years. Undoubtedly useful preliminary results would be available much sooner. We expect that this experiment would constitute the Ph.D. thesis of Mr. Ronald Petri and involve other students.

6. **Timing of Exposures**

From our viewpoint the experiment could be run in parts at different times with the sequence and timing of the exposures not being critical. We emphasize our request for some early film to provide maximal time for analysis.
FOOTNOTES


13. The proposed hybrid bubble chamber facility for NAL involves additional downstream detectors to aid in the momentum determination of energetic secondaries. Current designs involve a combination of tagging counters and optical wide gap spark chambers on either side of a large aperture spectrometer magnet with possibly more wire planes and magnets further downstream. Charpac counters and Cerenkov counters would be placed upstream for additional beam definition and tagging. For an example of a hybrid system, see NAL Proposal No. 2A.

14. This places requirements on the internal time structure of the beam.


17. R. A. Burnstein (private communication to S. Pruss).


19. NAL Workshop of March 11, 1971
Figure 1

\[ \frac{\pi^+}{P} \text{ AT END OF 1000 m BEAM} \]

200 GeV INCIDENT

HR \( p - Be \)
\[ \frac{\Pi^+}{P} \text{ at end of 1000 m beam} \]

500 GeV incident

HR. p-Be

J. Lack
A Study of Multiparticle p-p and π-p Interactions above 50 GeV by Utilizing a Small Bubble Chamber at NAL

Illinois Institute of Technology High Energy Physics Group

June 15, 1970
Dr. F. T. Cole  
Secretary, Program Advisory Committee  
National Accelerator laboratory  
P.O. Box 500  
Batavia, Illinois  60510

Dear Dr. Cole:

The I.I.T. high energy physics group wishes to express interest in bubble chamber physics experiments at NAL.

First we wish to express interest in the neutrino physics program using the NAL 14-foot chamber when constructed. Since these experiments are several years off in the future, our plans are not as yet formulated.

Second, we wish to express interest and support for an effort of somewhat greater urgency. Namely, the desirability of having a small bubble chamber (~30-inch) available at NAL at the earliest possible date for multiparticle p-p and π-p studies at high energies.

Further details of our interests will be provided in the future.

Yours truly,

Ray A. Burnstein  
Associate Professor of Physics

RAB/els

RECEIVED  
JUN 15 1970  
NAL DIRECTORS OFFICE
TITLE AND ABSTRACT:

Expression of Interest in "A Study of Multiparticle p-p and π-p Interactions above 50 GeV by Utilizing a Small Bubble Chamber at NAL."

EXPERIMENTAL GROUP and CORRESPONDENT:

Illinois Institute of Technology High Energy Physics Group and R. A. Burnstein

Date: June 15, 1970
STATEMENT:

This expression of interest is submitted to appraise the NAL program committee that the I.I.T. high energy physics group wishes to participate in a bubble chamber experiment at NAL. We feel that a useful study of high energy p-p and π-p multiparticle interactions could be carried out with an existing small bubble chamber set up at NAL. We are prepared to collaborate with other interested groups and contribute to the planning and execution of the experiment.

Further detailed considerations relevant to the proposed experiment will be submitted in the future.