NAL PROPOSAL No. 80-A

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PROPOSAL TO STUDY MULTIPARTICLE-PRODUCTION PROCESSES UTILIZING THE 30-INCH BUBBLE CHAMBER

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ABSTRACT:

We propose to examine production and decay properties of particles produced in $\pi^- p$ collisions at incident momenta of $\approx$70 GeV/c and $\approx$250 GeV/c. Our investigation will be primarily concerned with the characteristics of those particles which are emitted into the backward hemisphere in the $\pi^- p$ center-of-mass frame. We require 80,000 exposures of the 30-inch ANL-NAL liquid hydrogen bubble chamber at each energy. This will provide us with a total of $\approx$20,000 inelastic $\pi^- p$ interactions. Our experiment can be performed utilizing the "bare" chamber in conjunction with the hadron beam proposed for the neutrino area.

I. Physics Justification

We propose to survey the interactions of π^- mesons in liquid hydrogen for two well spaced high-energy points. In particular, we wish to examine the energy region near 70 GeV/c and the energy region near 250 GeV/c. This proposed study will yield new physics information and will in addition be extremely useful for providing direction for second generation experiments. The major reason for requesting two separate high-energy points is the resultant opportunity to examine energy trends of various interesting physical quantities in as unbiased a way as possible; namely, through the use of similar scanning, measuring, and analysis techniques at both π^- beam energies. We believe that $\simeq$0.5 event/μb exposures at each energy will suffice for a preliminary investigation. Assuming a 12-inch fiducial region, and 5-8 beam particles per picture, this will require $\simeq$80,000 exposures of the ANL-NAL 30-inch bubble chamber for each energy point.

The most important reason for conducting general survey experiments at NAL is, of course, the substantial increase in the range of interaction energies which will be accessible there; and the greatest physics discoveries at NAL may, in fact, be forthcoming from as yet unsuspected sources. Consequently, we propose to scan the entire exposure and measure all the events.

Aside from our general goal of keeping alert to the possibilities of observing new phenomena, we intend to examine in a systematic manner the variation of charged-particle multiplicity with beam momentum, correlations between produced particles (e.g., opening angles, momentum transfers, invariant masses, etc.), single-particle momentum distributions, and other similar dynamic properties of multiparticle production processes at high energies.

Before discussing in more detail the specific areas which we want to examine, we wish to stress the fact that there is of necessity considerable uncertainty in <u>any</u> quantitative estimation of the utility of the 30-inch bubble chamber in this new energy regime. While our Monte Carlo simulations have been very useful in providing insight into the kinds of problems which will be tractable, it is clear that the quantitative conclusions necessarily reflect <u>present</u> prejudices concerning the nature of strong-interaction processes at high energies.

We also wish to point out that, although we will undoubtedly obtain quantitative results in several of the areas we want to examine,[1] our experiment is mainly intended to be an exploratory and, consequently, a qualitative investigation of strong-interaction phenomena in a new energy domain.

The following problems are the ones to which we specifically plan to address ourselves:

(1) We will measure topological cross sections for 0-pronged, 2-pronged, 4-pronged, 6-pronged, and 8-pronged charged-particle multiplicities. We also expect to be able to make rough estimates of cross sections for $\geq$10-pronged topologies. From recent measurements of multiplicities obtained in cosmic-ray studies,[2] we estimate that we shall be able to determine cross sections for the 2-,4-,6-, and 8-pronged multiplicities to within a statistical uncertainty of $\approx$2%. Our results will therefore be able to discriminate between various models proposed for the description of high-energy processes.[3] We also expect to measure the average charged-particle multiplicity ($\bar{n}$) to within an accuracy of better than 10%, and thus check that the variation of $\bar{n}$ with beam energy is in fact logarithmic.[4]

(2) We will measure cross sections for inclusive processes such as:

$$\pi^- p \rightarrow \Delta^{++} + \text{anything} \quad (1)$$

$$\pi^- p \rightarrow \Delta^{o} + \text{anything} \quad (2)$$

$$\pi^- p \rightarrow p + \text{anything} \quad (3)$$

$$\pi^- p \rightarrow \pi^- + \text{anything} \quad (4)$$

etc.

Reactions such as (1), (2), and (3), which require ionization information and involve the production of massive particles, can only be measured when these particles are emitted backwards in the collision center of mass,[5] i.e., when the particle momenta are $\lesssim 1.5$ GeV/c in the lab. Reaction (4), however, can be studied quantitatively for π^- momenta $\lesssim 10$ GeV/c. The longitudinal momentum (p_ℓ) spectrum of the π^- in the target-fragmentation region will be particularly interesting in view of our recent studies[6] concerning the observation of limiting behavior and factorization of inclusive reactions at presently achievable energies. Moreover, since reaction (4) can be studied successfully (even at 250 GeV/c) for p_ℓ values which correspond to the so-called "pionization" region,[7] the cross section for this reaction near $p_\ell(\mathrm{cm}) \approx 0$ will provide a measure of the importance of the pionization process in hadronic collisions at high energies. The fact that at NAL energies there will be less kinematic ambiguity in the definition of the regions where processes such as fragmentation or pionization are expected to dominate, will provide clearer tests of the theoretical ideas pertaining to these phenomena.

(3) The strange-particle and antiparticle-production cross sections are rising rapidly with energy for beam momenta in excess of 5 GeV/c. It will be interesting to see whether these cross sections level off at NAL energies. To examine this question we plan to scan the film for all Vee-particle decays. The 30-inch chamber sensitivity is adequate for Vee-particle momenta $\lesssim$5 GeV/c. It should therefore be possible to measure Λ^o,$\bar{\Lambda}^o$, and K_s^o production cross sections in this restricted kinematic region. (On the basis of present trends, we expect to obtain, for example, the cross section for Λ^o production in the region of proton fragmentation to better than ≈10% accuracy at each beam energy.) The special Vee scan will also provide information concerning the possible existence of new neutral particles. Long-lived massive particles have been predicted to exist on theoretical grounds;[8] these new objects could appear as anomalous Vee events in the bubble chamber.

(4) We plan to examine the boson mass spectrum, particularly through the use of the missing-mass technique. Massive bosons having a charge of 0, 1 or 2 can be produced in conjunction with Δ^o, p or Δ^{++}; since the missing mass resolution, especially for massive boson

systems is expected to be reasonable (see Section III of this proposal), this technique should prove to be exceedingly useful for searching for new "giant" resonances, or massive diffractive dissociation products, if these are produced with sufficiently large cross sections.[9] To complement the missing-mass search we plan to also study the invariant-mass combinations for the simpler fast-meson systems, as well as the slower systems which originate from fragmentation of the target. Although the mass resolution for the projectile fragments will not be very good, it nevertheless should suffice for obtaining the general features of these spectra.[10] The invariant masses of the target fragments will be well determined and should prove to be particularly interesting in answering questions pertinent to items such as $N^*(1470)$ production, and the substructure of the more massive fragmentation products of the proton.

We are confident that, with our extensive experience and continuing interest[11] in the high-energy domain of strong interactions,we shall be able to execute the proposed experiment in the shortest time possible. Although preliminary results, based particularly on scanning of the exposure, will be available within several months of the run, we expect that it will require a full

year to complete the entire experiment. These exploratory results will undoubtedly have important bearing on the theoretical questions to which we have aluded, as well as on the direction of the future program for the experimental study of hadronic collisions at NAL.

II. Experimental Equipment

Our proposal requires a π^- beam with a momentum spread of $\frac{\Delta p}{p} \lesssim 0.5\%$ and an angular resolution of $\lesssim 0.5$ mr. From discussions with S. Pruss, we surmize that our requirements are well within the design values of the proposed hadron beam to the 30-inch chamber.[12] Since we are not relying on the availability of a beam tagging system, we consequently require a π^- purity of $\gtrsim 95\%$. (Although if the background is due mainly to μ^- we can accept up to 10% contamination.)

As implied earlier, we believe that these exploratory studies should be conducted using the "bare" chamber so as to get a "quick look" at the new energy regime. More elaborate studies, employing upstream and downstream detection equipment and consequently the outlay of substantial additional expenditure in both physicist-time and money, could benefit greatly from

the information thus acquired. In this regard it might be pointed out that if an initial period of "bare chamber" operation were scheduled for the 30-inch chamber, then the data-taking rate could be substantially increased during this period if the chamber were set up in its "normal" manner (i.e. with the present beam-entry window upstream); in this ANL mode of operation the number of beam tracks/pulse could be doubled without causing confusion due to the overlapping of tracks. (In the planned NAL mode of operation for the 30-inch chamber - which is of benefit only to spectrometer operation of the chamber - a steel bar effectively limits the number of beam particles to the 5-8 employed in this report).

III. Technical Details

We now wish to comment on the technical feasibility of our program with regard to the specific points itemized in section I of this proposal.

We have performed extensive Monte Carlo simulations in order to verify that the resolution in the 30-inch bubble chamber will be sufficient to permit us to examine the items discussed in section I. The details of

some of these calculations are contained in the attached report.[13] We have checked that the a priori errors used in these calculations do, in fact, correspond to what is known about the characteristics of the 30-inch chamber. Using the actual errors which were found to be suitable for slow tracks observed in a 5.5 GeV/c K^-d experiment,[14] we calculated the errors on missing masses recoiling from these slow tracks as a function of the beam-momentum characteristics. These "more realistic" calculations have corraborated the findings in the previously reported study.[13] We summarize our conclusions below:

(1) For particle momenta below 10 GeV/c the 30-inch chamber can provide adequate momentum information ($\Delta p/p \lesssim 5\%$). In Fig. 1 we give a graph from a recent report[15] which indicates the sort of π^- laboratory momenta which correspond to reaction (4) at 200 GeV/c. It is clear that a sizeable region of momentum space near $p_\ell(\mathrm{cm}) \approx 0$ will be able to be surveyed with adequate resolution. Thus it appears that reaction (4) can be studied easily in the region of target fragmentation (where the Coulomb errors limit the accuracy), as well as in the pionization region(where the track length and consequently the measuring error limits the resolution).

(2) The average errors expected for missing masses recoiling from a slow proton or a slow $\Delta(1236)$, as a function of the missing mass, are indicated in Fig. 2. The calculation is for 200 GeV/c (these errors are determined largely by the momentum and angle errors on the slow particles and therefore, to a good approximation, scale linearly with beam momentum). It is clear from the figure that the missing mass information will be precise only for large recoiling masses. However, wide lower mass enhancements could also be observed using this technique.

(3) Figure 3 displays the error expected on the invariant mass of two charged pions as a function of the dipion mass and total momentum (the manner of the dipion decay will clearly affect this error; we choose to display the average error). Here again it is observed that this technique for studying particle correlations will be severely limited by resolution, particularly for high-momentum systems. In some ways, however, the effective mass calculation complements the missing mass calculation in that the effective mass is best determined for small q-values. We might point out (see enclosed report) that the invariant mass of a three-particle system, for example, can be approximately 2

times more precisely than that of a two-particle system having the same invariant mass (again, this is somewhat a function of the angular distribution of the decay).

We have not discussed the less controversial aspects of this proposal since we believe that it is well established that the 30-inch bubble chamber is a proven and valuable device for studying particle interactions below 10 GeV/c. Thus the investigation of inclusive reactions and dissociation near the proton-fragmentation region, as well as searches for slow anamolous Vees, etc.. can be carried out with no special difficulty.

References

1. See, for example, the discussion in R. Burnstein et al, NAL 1970 Summer Study, Report SS-164, p.315, and the bibliography given in Appendix A.
2. L. W. Jones et al, Phys. Rev. Letters 25, 1679 (1970).
3. G. Chew and A. Pignotti, Phys. Rev. 176, 2112 (1968); C. P. Wang, Nuovo Cimento 64, 546 (1969); R. Feynman, High Energy Collisions, Gordon and Breach (1969); C. N. Yang et al, High Energy Collisions, Gordon and Breach (1969); C. E. DeTar, Phys. Rev. D3, 128 (1971), and other references given in these papers.
4. We expect about a 20% change in the average multiplicity between our two energy points, and $\gtrsim$30% change relative to presently available data.
5. The cross sections for such processes are expected to remain large. See, for example, M. Ross in Proceedings of Boulder Conference on High Energy Physics (1969).
6. S. Stone et al, University of Rochester Report UR-875-335 (1971), and the BNL-Rochester-Wisconsin Collaboration results, M. S. Chen et al, University of Rochester Report, UR-875-340 (1971).
7. See, for example, T. T. Chou and C. N. Yang, Phys.

Rev. Letters 25, 1072 (1970).

8. V. Mathur and S. Okubo in Phys. Rev. 181, 2148 (1969), for example, speculate on the existence of particles having a new "charm" quantum number.

9. With regard to this question see the recent papers by Peccei and Pignotti, Phys. Rev. Letters 26, 1076 (1971), and H. Abarbanel et al, Phys. Rev. Letters 26, 937 (1971).

10. The multiperipheral model, for example, predicts low-mass clustering for emitted 2-pion systems. Thus a mass resolution even as poor as a few hundred MeV will suffice to determine whether such effects take place at high energies.

11. We are familiar with the 30-inch chamber (B. Werner's Ph.D. thesis involved an experiment using this chamber) and we have recognized expertise in the area of bubble-chamber film analysis. We have previously analyzed 7 GeV/c $\pi^- d$, 7 GeV/c $\pi^+ p$, and 13 GeV/c $K^+ p$ experiments, and we are presently performing an experiment in collaboration with Johns Hopkins examining the interactions of 24 GeV/c π^+ mesons in deuterium.

12. J. Lach and S. Pruss, NAL Report TM-285, 2254.000 (1971).

13. P. Slattery, Proceedings of International Conference on Bubble Chamber Technology (ANL 1970), p.145, M. Derrick ed.

14. B. Werner, Ph.D. thesis, Northwestern University (unpublished), and private communication from B. Musgrave.

15. C. Y. Chien et al, The NAL 1970 Summer Study, Report SS-182, p.411.

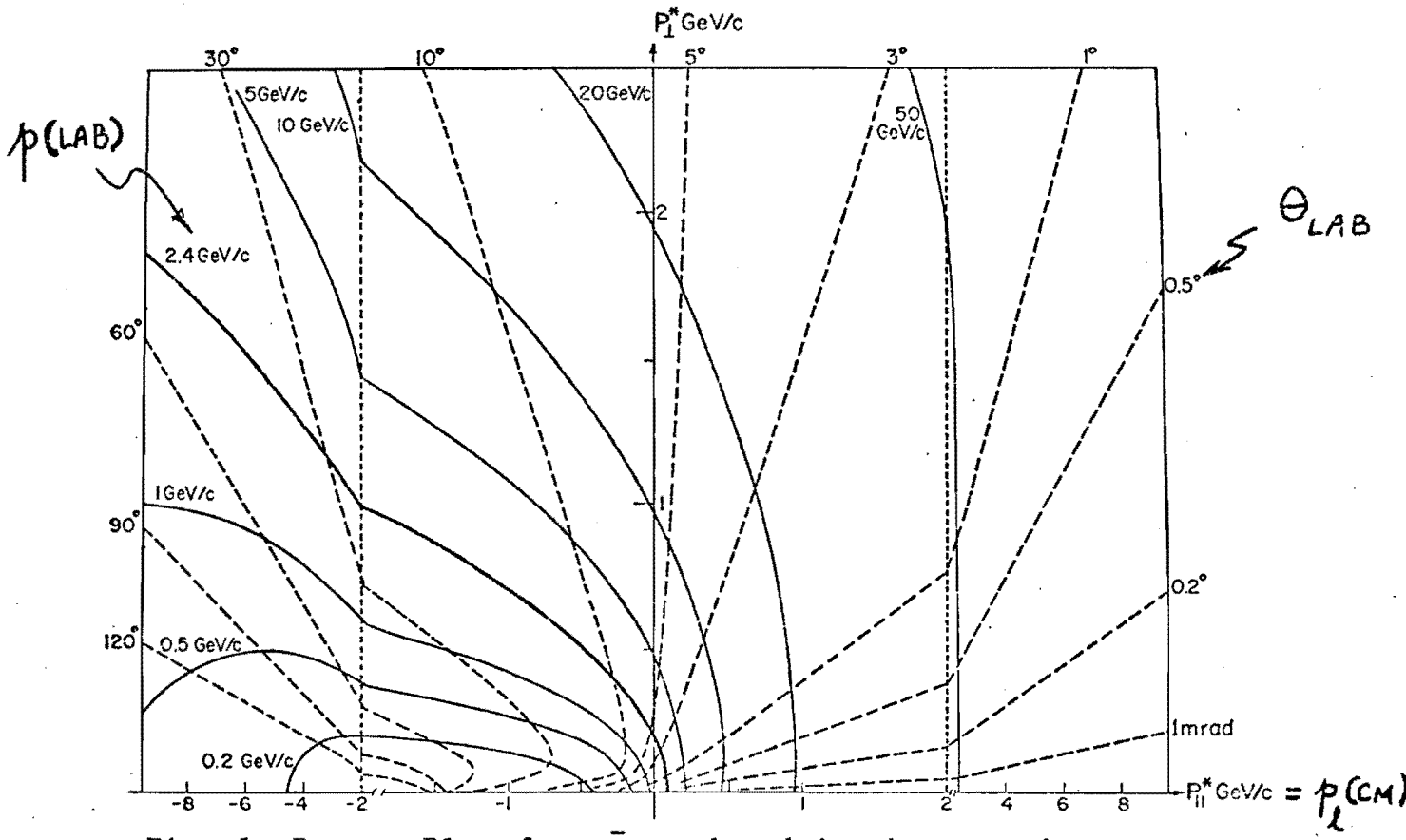


Fig. 1. Peyrou Plot for π^- produced in the reaction $\pi p \rightarrow \pi^- +$ anything at 200 GeV/c incident momentum.

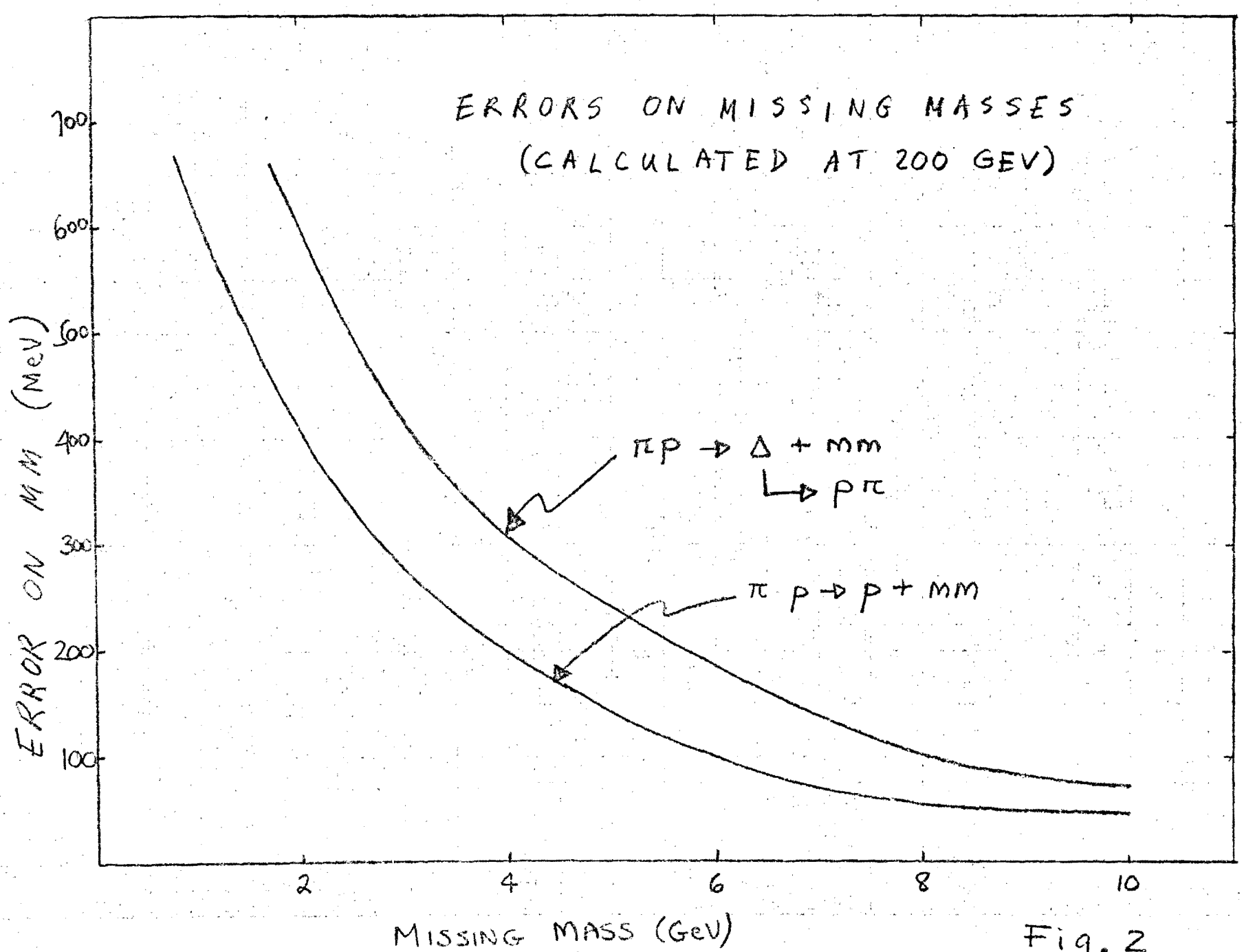
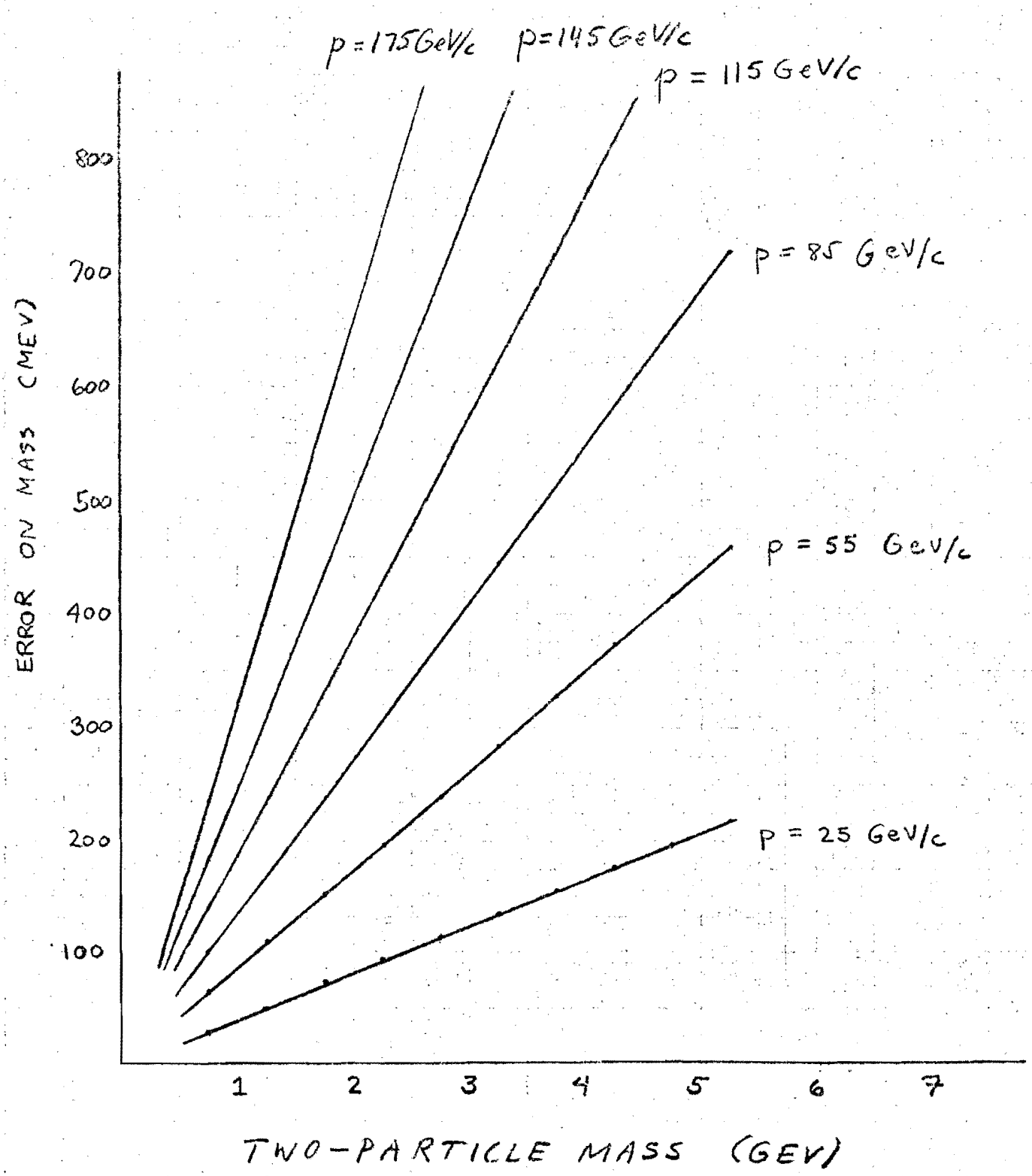

ERRORS ON MISSING MASSES
(CALCULATED AT 200 GEV)
ERROR ON MM (MeV)
700
600
500
400
300
200
100
2
4
6
8
10
MISSING MASS (GeV)
$\pi p \to \Delta + mm$
$\hookrightarrow p\pi$
$\pi p \to p + mm$

Fig. 2

Fig. 3

ERROR ON MASS OF TWO-PARTICLE SYSTEM OF MOMENTUM P.



Appendix to Proposal

The Monte Carlo simulation referred to in the proposal is described in pages 10-15 of UR-875-324; the pertinent figures are 8-19. These figures are described in detail in the text. Although Figure 19 is for a beam momentum of 100 GeV/c, the quantity ΔM is approximately proportional to the beam momentum.

NAL PROPOSAL No. 80

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GENERAL SURVEY OF π^- INTERATIONS IN A HYDROGEN BUBBLE CHAMBER

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July, 1970

July 6, 1970

Dr. F. T. Cole
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Dear Dr. Cole:

This letter is with regard to the recent call for preliminary proposals for the first round of experiments at NAL. We wish to inform you at this time of our serious intent to pursue an investigation of $\pi^- p$ interactions at NAL energies utilizing the bubble chamber technique. The experimental details of our proposal will be treated in a later and more formal communication once the following items become more clarified: (1) The final design characteristics of the large bubble chamber facility, and (2) which (if any) of the presently available medium-sized bubble chambers will be provided for preliminary survey experiments at NAL. In this note we will only briefly describe the nature of our intended strong interaction surveys, some of the motivation for these studies and, finally, we will make some comments on the technical feasibility of executing the experiments in question.

Proposal:

We wish to make a general survey of π^- interactions in liquid hydrogen for two well spaced high energy points. In particular, we wish to examine the energy region near 60 GeV/c and the energy region near 150 GeV/c, as soon after NAL turn on as possible. We wish to add, however, that the precise running points will depend on which bubble chamber will be available for this study (simulation tests are presently underway to establish the feasibility of carrying out our experiment in different chambers).

The proposed survey will yield new physics information and will in addition be extremely useful for providing direction for second generation experiments. The major reason for requesting two separate high energy points is the resultant opportunity to examine energy trends of various interesting physical quantities in as unbiased a way as possible; namely, through the use of similar scanning, measuring, and analysis techniques at both π^- beam energies. We believe that a 5 event/μb exposure at each energy will suffice for a preliminary investigation. Utilizing a reasonable fiducial region of the BNL 80-inch bubble chamber, this means $\sim$250,000 pictures per energy point.

Because the physical quantities which we wish to examine will require an exceptionally precise knowledge of the momentum and angle of the incident beam, we envision a need for an accurate mapping of the magnetic field outside of the bubble chamber. We also foresee an unquestionable need for setting up an external counter array in order to ascertain the beam characteristics to sufficient accuracy. The nature of the scheme for measuring the beam-tracks will, again, largely depend on the bubble chamber which will be used in this run, as well as on the exact location of the chamber. (If an

additional chamber aside from the presently envisioned 15 foot chamber is made available to NAL, these survey studies can be carried out either in Area II or in Area I.) Any design proposal must await a final decision regarding the above questions. However, we wish to emphasize that it is our considered opinion based on recent studies[1] that a chamber such as the BNL 80-inch operating in Area II would be particularly appropriate for our intended investigations. Such a chamber, especially with an enlarged magnetic field (30 KG or more), would be useful for survey studies even up to the higher beam energies at NAL, and it could also become a powerful research tool at NAL for the more detailed hadron studies expected to proceed once the envisioned separated beam[2] becomes operational in Area I.*

Motivation:

The most important reason for conducting general survey experiments at NAL is, of course, the substantial increase in the range of interaction energies which will be accessible there; the greatest physics discoveries at NAL may, in fact, be forthcoming from as yet unsuspected sources. The bubble chamber is particularly well suited for general surveys in that it can provide an essentially unbiased early look at the nature of hadronic interactions in this new energy regime.

We intend to scan the entire exposure and measure a large fraction of the events which are found. It is not clear at this time which topologies will be able to be measured in a successful

*It may prove to be very economical, as well as profitable from the point of view of physics output, to place the BNL 80-inch chamber downstream from the NAL 15-foot chamber. In this manner the same separated beam could be made available to both chambers.

manner, and we are investigating this question through simulation studies. We plan, however, to address ourselves to the following class of problems:

(1) Measurement of particle multiplicities at high energies and of production cross sections for various multibody final states. These data will be particularly interesting in view of recently proposed models for high-energy processes,[3] and the reported observations of systematic behavior for multiparticle production cross sections.[4]

(2) The measurement of the invariant masses of multipion systems observed in high-energy collisions will serve to test the ideas underlying the multiperipheral model. The observation of low-mass clusters, their average multiplicity, and the expected severe damping in momentum transfers between such clusters will be particularly interesting.[5]

(3) Measurement of "inclusive" processes such as:

$$\pi^- p \to \Delta^{++} + \ldots$$
$$\pi^- p \to \Lambda^0 + \ldots$$
$$\pi^- p \to \Delta^0 + \ldots$$
$$\text{etc...}$$

Cross sections for these reactions are expected to remain large at high energies and are expected to be of great value in establishing the properties of the strong interactions.[6]

(4) Measurement of the dynamic properties of particle production at high energies - systematic studies of angular correlations and momentum transfers etc.

(5) Study of diffraction phenomena such as A_1, $\pi(1640)$, $N(1470)$, etc. Search for double diffraction processes.

(6) Examination of the boson mass spectrum, particularly through the use of the missing mass technique. Massive bosons having a charge (Q) of Q = 0, 1 or 2 can be produced in conjunction with Δ^o, p or Δ^{++}; since the missing mass resolution, especially for massive bosons, is expected to be rather good[1], this technique should prove to be exceedingly useful for searching for new resonances.

(7) The A_2 production cross section in the reaction $\pi^- p \rightarrow A_2^- p$ appears to exhibit an anomalously weak energy dependence when compared to other two-body processes. This anomaly may be due to the increasing contribution to A_2 production from higher moments of the Pomeranchuk trajectory relative to the ρ- exchange mechanism which dominates at low energies. If this is in fact the case, then the A_2^- cross section would be expected to level off and stop falling with increasing beam energy. Even if the A_2 cross section continues to drop at the present rate we expect to observe $\sim$120 $A_2^- \rightarrow \pi^- \rho^o$ events in our preliminary exposures.

(8) The strange particle and antiparticle cross sections are rising rapidly with energy for momenta in excess of 5 GeV/c. It will be interesting to see at what point these cross sections level off.

(9) We plan to make a careful search for anomalous Vee particles and other new phenomena. Predictions, based on theoretical arguments, have been made concerning the existence of possible long-lived massive particles;[7] these new objects could appear as anomalous Vee events in the bubble chamber.

(10) Feasibility studies are presently underway to determine whether it is possible to obtain a useful measurement of the electromagnetic form factor of the π-meson from large momentum transfer π-e collisions. We estimate that in our preliminary exposures we will obtain $\sim$150 events with $q^2 > 0.1\ M_\rho^2$. A one radiation length Tantallum plate introduced in the downstream part of the bubble chamber may be useful for detecting the electron.

Technical Comments:

The technical problems involved with the measurement of many of the items discussed in the previous section are rather formidable, and studies are presently underway to ascertain the feasibility of these measurements. Our preliminary conclusions, based on previous calculations and on our extensive experience with high-energy scattering experiments, leads us to believe that the major fraction of these experimental goals can be realized.* We also feel that with the availability of two PEPR systems (one at Johns Hopkins and one at Yale), our present scanning/measuring staff, and our large joint pool of physicists, we can process the two proposed exposures in a rapid and efficient manner.*

We expect essentially all the measurements to be done on the two PEPR systems. The time scale for the data extraction will be determined, to the largest degree, by the scanning (and possibly predigitization) of the events on film. This process should take approximately six months; following this period we should have

*These conclusions are based on the assumption that a chamber such as the BNL 80-inch will become available at NAL. We wish to stress, however, that early physics results will be forthcoming only if a careful mapping of the present lens and front-glass distortions of the 80-inch chamber is made prior to the taking of the exposures. We expect

available some of our preliminary results.

We might point out at this time that the measurement of such items as, for example, the average charge-particle multiplicity may also require the use of PEPR. This is because we expect the visual confusion in high-multiplicity events to be such as to make a track count by a human scanner unreliable. We therefore foresee that, in this particular instance, the human scanner would just be used for locating the interactions while PEPR would be used as a total ionization counter by laterally scanning across the tracks comprising the forward cone of the jet (<1° in the forward direction). The number of PEPR hits, obtained in this fashion, would be analyzed in a statistical manner, and merged with PEPR's current track recognition capability in the extraction of the event multiplicity.*

*We do not mean to imply that in terms of pattern recognition PEPR is presently superior to the human eye. Nor do we wish to minimize the difficulties expected in carrying out the suggested measurements. However, it is our belief that PEPR, possibly with human assistance, can be used effectively in the sort of situation described above to obtain valuable data which a human scanner alone could not provide in an unbiased manner.

We hope that the above note will serve as an indication of our enthusiasm and of our serious commitment to continue pursuing particle physics investigations utilizing the bubble chamber technique whenever that technique appears to be best suited for particular particle physics experiments.

Sincerely yours,

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References

(1) N. Gelfand, A. Pevsner, and P. Slattery, 1969 NAL Summer Study, Vol II, p281; and P. Slattery, paper presented at International Conference on Bubble Chamber Technology, ANL, June 10-12, 1970.

(2) J. Lach, 1965 Berkeley Summer Study Vol. I, p190; D. Berley and H. Foelsche, 1969 NAL Summer Study Vol. I, p147.

(3) See, for example, C. N. Yang et al., in High Energy Collisions, Gordon and Breach (1969); and C. P. Wang, Nuovo Cimento 64, 546 (1969).

(4) T. Hofmokl and A. Wróblewski, Physics Letters 31B, 391 (1970); and A. Wróblewski, Physics Letters 32B, 145 (1970).

(5) See, for example, G. Chew and D. Snider, Physics Letters 31B, 75 (1970); and G. Chew and A. Pignotti, Phys. Rev. Letters 20 1078 (1968).

(6) See M. Ross in Proceedings of Boulder Conference on High Energy Physics (1969); and R. Feynman in High Energy Collisions, Gordon and Breach (1969).

(7) V. Mathur and S. Okubo in Phys. Rev. 181, 2148 (1969), for example, speculate on the existence of particles having a new "charm" quantum number.