NAL PROPOSAL No. 291

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PROPOSAL TO STUDY MULTIPARTICLE PRODUCTION USING A HIGHLY-ENRICHED NEON EXPOSURE IN THE 30-INCH BUBBLE CHAMBER

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March 1974

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ABSTRACT

We propose to take two short exposures of the bare NAL 30-in. bubble chamber with a highly-enriched neon fill (~95% mole neon, ~5% hydrogen) for a quantitative examination of the space-time structure of hadronic interactions at high energy. From a comparison of data for charged and neutral particle multiplicities, single particle inclusive spectra and multiparticle correlations, as observed in hadron-neon interactions, with analogous data from hydrogen bubble chamber exposures, the nature of multiparticle production in πp and pp collisions can be probed for small space-time intervals. Furthermore, the almost pure ($\gtrsim$ 98%) neon interactions are expected to provide unique information on neutral particle spectra and correlations by using the high probability for gamma-ray conversion and neutron interactions from individual events. We request 30,000 pictures with a 100 GeV/c Cerenkov-tagged secondary beam of protons and π^+'s and 20,000 pictures with 400 (or 300) GeV/c protons.

MULTIPARTICLE PRODUCTION

It has recently been argued by Gottfried,[1] Fishbane and Trefil,[2] and others that hadron-nucleus interactions at high energies may be most informative for understanding the space-time structure of basic nucleon-nucleon interaction mechanisms and for testing proposed models of hadronic secondary particle production. While the accuracy of the present data leaves much to be desired, Gottfried's analysis appears to account for many heretofore puzzling aspects of secondary particle multiplicities, rapidity distributions, and other phenomena observed in cosmic ray and accelerator experiments using nuclear emulsions and other complex targets.

Fishbane and Trefil base their calculations on two classes of multiparticle production models, which may be considered to exemplify the two extremes of current viewpoints about high energy nucleon-nucleon collisions. These classes are:

1. "Coherent-Production Models" (CPM) - a beam-nucleon collision induces a long lived ($\gtrsim 10^{-23}$ sec) intermediate excited state which subsequently decays into multiparticle final states. Models of this type are fragmentation (Nova) and diffractive excitation models. Such coherent processes seem to account[3] for ~20% of the inelastic cross section in pp and π^-p interactions at 200 GeV/c.

2. "Incoherent-Production Models" (IPM) - about 80% of the inelastic cross section is apparently due to final state particles which are produced <u>immediately</u> from primary collisions. Multiperipheral and dual-resonance models take this viewpoint.

In the CPM case an intermediate excited state propagates as a localized entity through a nucleus before decaying. Pions additional to those from scattering on hydrogen arise from intranuclear scattering of the excited fragment. In the IPM case additional pions arise from intranuclear cascading triggered by directly produced hadrons. Detailed calculations find that IPM processes induce many more slow pions than do the CPM (see Fig. 1).

To account for the weak cascading observed in high energy hadron-nucleus collisions, Gottfried[1] has suggested an "energy flux cascade" model in which the energy flux subsequent to a nucleon-nucleon collision does not have time to extend spatially or to materialize into many secondary particles before escaping from the nucleus. The essence of this model is that if this flux strikes a second nucleon within the nucleus it is not readily distinguishable from a single hadron and no large cascading effect occurs.

The following features of Gottfried's model are of primary interest here as a basis for comparing the experimental results of hadron-neon collisions with those from hydrogen target data and for testing this and other theoretical models of multiparticle production:

1. The average multiplicity of produced fast secondaries (i.e., excluding nuclear evaporation products) in a hadron collision with a nucleus of atomic weight A is predicted (with no adjustable parameter) to be

$$\bar{n}_s(h, A) = \bar{n}_c(h, p) \left[1 + (\bar{\nu} - 1)/3 + 0 \left(\frac{1}{\ell n s}\right)\right],$$

when $\bar{n}_c(h, p)$ is the average multiplicity for the same hadron (h) with beam momentum (p) interacting with hydrogen, and $\bar{\nu}$ is the average number of collisions which the hadron makes in traversing nucleus A.

2. The multiplicity and rapidity distributions in the projectile hemisphere are expected to be the same for heavy nuclei targets as for hydrogen.

3. All of the excess produced particles, $(\bar{n}_s - \bar{n}_c)$, appear to be in the target hemisphere.

4. The excess of produced particles is only weakly dependent on the nature of the beam hadron, its bombarding energy and on the nuclear atomic weight or size, being chiefly determined by the average number of collisions, $\bar{\nu}$. For high energy protons on neon (A = 20) we estimate the average number of collisions to be $\bar{\nu}(p, N\ell) \simeq 2.50$, and for π^+ to be $\bar{\nu}(\pi^+, N\ell) \simeq 2.0$. The corresponding multiplicity ratios are then $\bar{n}_s(p, N\ell)/\bar{n}_c(p, p) = 1.50$ and $\bar{n}_s(\pi^+, N\ell)/\bar{n}_{ch}(\pi^+ p) \simeq 1.33$. (It is interesting to note that more dramatic differences can be expected to occur for $\bar{p}$ and K^+ comparisons in the region of 50 GeV/c where their respective inelastic cross sections with nucleons differ widely.)

TECHNICAL ASPECTS OF NEON EXPOSURES

A. Chamber Conditions

In principle, hadronic interactions in a pure neon (A = 20) and xenon (A = 131) bubble chamber would provide ideal conditions for the comparison of multiparticle production with hydrogen data and for quantitative tests of theoretical models. Unfortunately the temperature and pressures normally allowed in the NAL 30-inch chamber are not suited for operation with these pure liquids.

In Table I we list pertinent properties of the more conventional hydrogen and deuterium operating fluids in this chamber, plus the properties of two mixtures of neon and hydrogen which are currently of interest for studying hadronic collisions. Figure 2 also shows the interaction properties[4] of these fluids.

The hydrogen-rich mixture (30% mole neon, 70% hydrogen) in Table I has previously been used in this chamber at Argonne, and is the preferred mixture for the exploratory studies[5] to be carried out at NAL in Experiments 161 and 163. In those experiments there is special interest in scanning for possible new particles produced in neon collisions, as well as scanning for converted gamma rays from the relatively large numbers of hydrogen collisions in the same exposure.

For our purposes, i.e. studying in detail the produced particles under well-defined simple conditions, such a mixture with low neon concentration presents major ambiguity problems for individual events.

Of the 62% neon interactions shown in Table II and Fig. 2, we expect that nuclear fragments and recoils may not be recognizable in many of the neon collisions, and that about one-half of all events may have ambiguous origins, i.e. whether from hydrogen or from "hydrogen-like" collisions with neon.

Based on systematic tests[6] of neon-hydrogen mixtures carried out in the DESY bubble chamber, (in which pure neon was found to be just barely sensitive below 35°K), we have chosen a 95% neon-rich mixture and deuterium-like operation conditions for the experiment being proposed here, with properties as shown in the last column of Table I and also indicated in Fig. 2.

While not a pure target, the hydrogen events are seen to constitute only 2% of the neon interactions in the 95% neon mixture, for which corrections can be safely applied. For events occurring in an upstream 30 cm fiducial region, the average path length for secondary particles will be nearly 50 cm, representing 2 radiation lengths for electromagnetic interactions and nearly 1 interaction length for secondary hadronic collisions. Thus each gamma ray has ~80% probability for conversion, and the likelihood for seeing at least one of the gamma from a π^{o} or η^{o} is nearly 95%. Similarly, there is a uniquely favorable situation for observing energetic neutral hadrons, since ~60% will interact even in this relatively small, but dense, bubble chamber.

From the standpoint of bubble chamber technology and operations, we are prepared to exercise the additional precautions that will be needed for these runs with neon:

1. The cooling hydrogen slurry can reach temperatures in the region of $24^{\circ}K$, where neon freezes. Neon ice was actually formed on the expansion pistons in the first neon experiment with this chamber in 1969.

2. The fluid temperature must be kept high enough to prevent the fluid components from separating and causing a milky suspension. This problem is more severe for the hydrogen-rich mixture in column three of Table I, to be used for Experiments 161 and 163.

3. Because of the high vapor pressure of neon-rich fluids, the static chamber pressure must also be kept high, but not too close to the pressure relief valve set points.

4. To get sufficient sensitivity, e.g., ~10 bubbles/cm, the expansion has to be deep, but still shallow enough to insure that the fluid remains in compression. The cone-shaped windows in the 30-inch chamber are especially sensitive to possible loss of hydrogen seals if the expanded pressure falls so low as to put the operating fluid under tension. This concern is mechanically more serious for nearly pure neon conditions.

B. Beam Requirements

The exposure requested here is for 30,000 pictures with 100 GeV/c tagged proton and π^+ secondary particles (as has been obtained by NAL Experiments 121A and 2B), and for 20,000 pictures with 400 GeV/c protons (although 300 GeV/c protons would be acceptable if they are more readily available at the time of this exposure). Since σ(p + neon)/σ(pp) $\simeq A^{2/3} \approx 7$, with ~2 tracks per picture the total exposure will yield over 20,000 analyzable interactions in the upstream portion of the bubble chamber.

DETAILED PHYSICS OBJECTIVES

With the essentially pure neon operating conditions described here for the NAL 30-inch bubble chamber, we can expect to carry out tests on the multiparticle production processes discussed above, in addition to exploring new terrain.

a) We intend to measure both the charged and neutral particle multiplicities for neon interactions and to compare them to pp-collision data, particularly from Experiment 2B.

b) We expect to measure the single-particle inclusive rapidity (see Fig. 1) and transverse momentum distributions for secondary p, $\pi^{\pm}$, and neutral particles. Slowing and stopped $K^{\pm}$ are also expected to show up. The target fragments should be relatively slow and recognizable, and the multiple Coulomb scattering contribution to the momentum errors for the slower particles ($\lesssim$ 15 GeV/c) should not exceed a

few percent. In the projectile hemisphere, we expect to be able to measure rapidity (y) to $\Delta y \sim 0.2$. This resolution is clearly good enough to make meaningful comparisons with the hydrogen data.

c) Coherent charged particle production in the projectile hemisphere can be analyzed directly without the ambiguities experienced with the presence of H_2 events in hydrogen-rich neon exposures. For this reason, it would be useful to have both a π^+ and proton beam exposure. This can be done at the same time (as in E121A and E2B using 100 GeV/c tagged positive secondaries).

d) The short radiation length should allow ~2 radiation lengths and ~80% probability for detecting each gamma ray from π^o, η^o, etc. decays. Neutral pion multiplicity distributions and correlations are of particular interest. The second moment correlations f_2^{+o}, f_2^{-o}, f_2^{oo} can be compared directly with the charge particle values for f_2^{+-}, f_2^{--}, f_2^{++} in the same hadron-neon collisions as well as in hydrogen interactions.

e) The short collision length in dense liquid neon will provide unique detection of neutral hadrons. In particular, more than half of the energetic neutrons are expected to interact in the fiducial volume, possibly allowing measurements of leading particle pseudo-rapidity distributions ($\eta = -\ell n \tan\theta/2$).

f) The high probability for observing gamma rays will make possible the study of two-particle rapidity correlations for each of the following pairs: ++, +-, --, ch-ch, γ+, γ-, and $\gamma\gamma$. These data will be interesting both in their own right as well as for comparisons with hydrogen target data.

g) By using the "hydrogen-like" events, we will be able to make comprehensive studies of coherent diffractive dissociation on a known heavy nucleus. The highly peripheral ($e^{-10A^{2/3}t}$) dependence of the nuclear form factor enables the coherent events to be selected by imposing a small t cut, and the absence of visible recoil fragments.

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[2] P. M. Fishbane and J. S. Trefil, Phys. Rev. Letters 31, 734 (1973); Nucl. Phys. B58, 261 (1973); Phys. Rev. D, to be published.

[3] See for example, J. Whitmore, NAL-Pub 73/70-EXP, Experimental Results on Strong Interactions in the NAL Hydrogen Bubble Chamber, submitted to Physics Reports (1973).

[4] K. Jaeger, Argonne National Laboratory Report BBC-150, unpublished (1971).

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[6] G. Horlitz, S. Wolff, and G. Harigel, DESY Preprint 73/41 (September 1973).

TABLE I

Properties of Operating Fluids for NAL 30-Inch Bubble Chamber

Property \ Fluid	Hydrogen H_2	Deuterium D_2	Hydrogen-Rich 30% Mole Ne 70% Mole H_2	Neon-Rich 95% Mole Ne 5% Mole H_2
Temperature T - ^oK	26.3	31.5	27.8	31.5
Static Pressure P_s - psia	78	95	95	~110
Expanded Pressure P_{exp} - psia	40	40	60	~30
Density g - gm/cm^3	0.062	0.14	0.25	1.1
Radiation Length X_o - cm	1050	900	120	27
Collision Length λ - cm	442	240	200	68
Fraction Neon Interaction	0	0	0.62	0.98

FIGURE CAPTIONS

Fig. 1 Predicted π^- rapidity distributions for CPM and IPM production processes; scale has been (roughly) set by eyeballing 205 p-H_2 data points to a theoretical p-H_2 cruve assumed for calculations.

Fig. 2 Radiation length, (X_o), and the fraction of Neon interactions (F), as a function of the percentage of Neon.

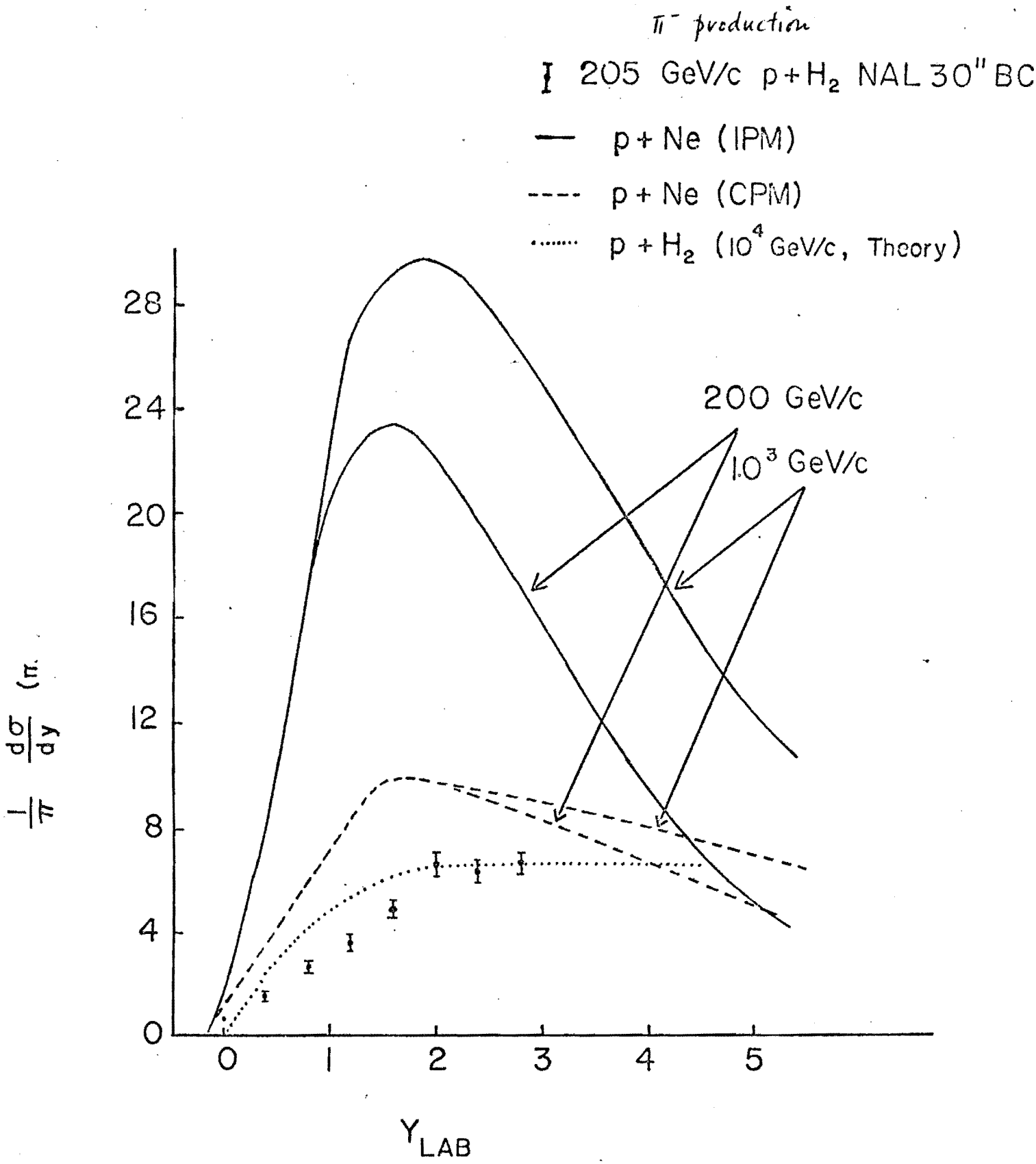
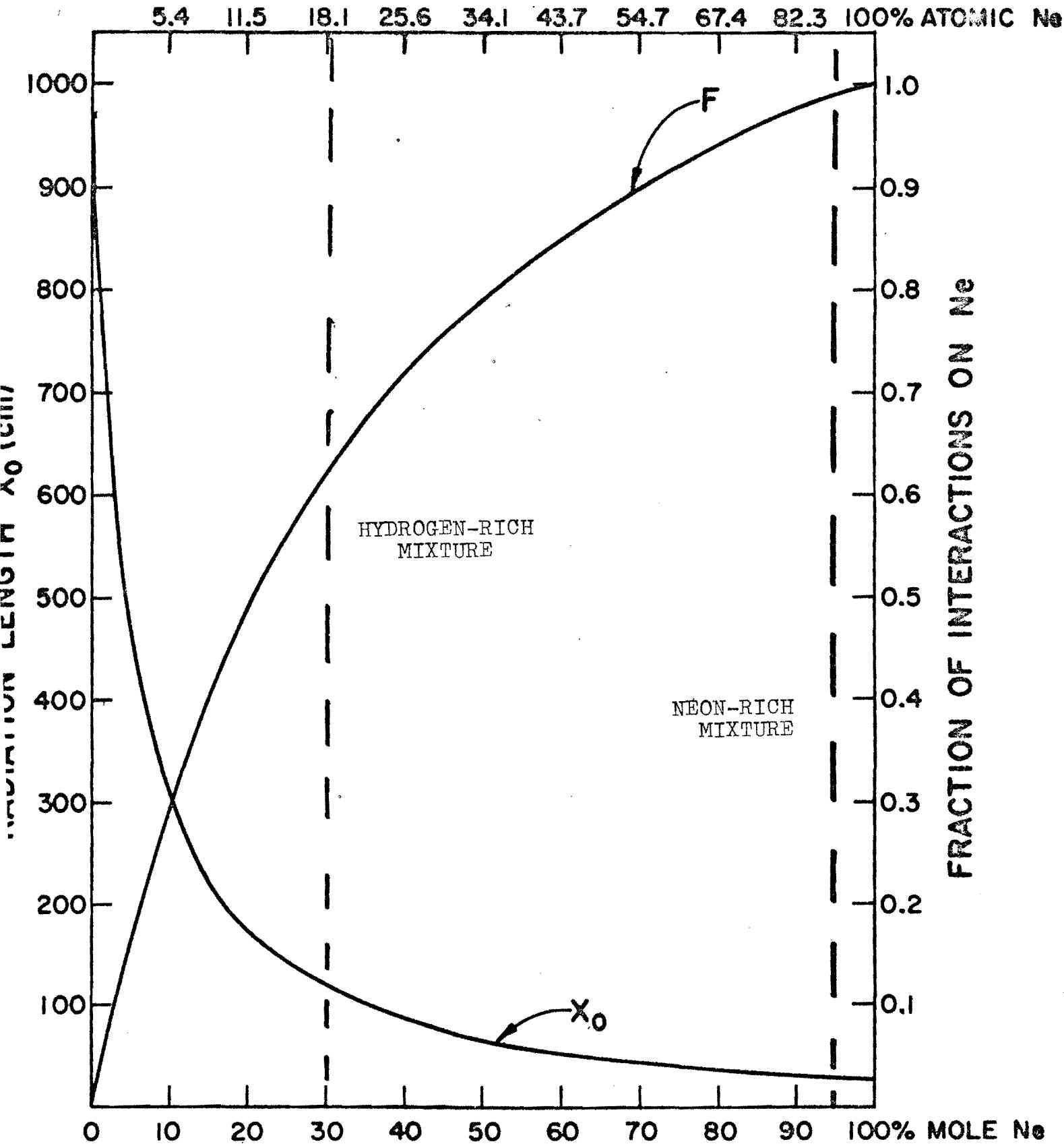

π⁻ production
205 GeV/c p+H₂ NAL 30" BC
p + Ne (IPM)
p + Ne (CPM)
p + H₂ (10⁴ GeV/c, Theory)
200 GeV/c
10³ GeV/c
28
24
20
16
12
8
4
0
0
1
2
3
4
5
Y_LAB

Figure ~~2~~ 1

Fig. 2


5.4
11.5
18.1
25.6
34.1
43.7
54.7
67.4
82.3
100% ATOMIC Ne
1000
900
800
700
600
500
400
300
200
100
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
FRACTION OF INTERACTIONS ON Ne
F
HYDROGEN-RICH MIXTURE
NEON-RICH MIXTURE
X_0
0
10
20
30
40
50
60
70
80
90
100% MOLE Ne

FERMILAB Proposal No. 291

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ADDENDUM TO FERMILAB PROPOSAL #291

PROPOSAL TO STUDY MULTIPARTICLE PRODUCTION USING AN ENRICHED NEON EXPOSURE IN THE 15-FOOT BUBBLE CHAMBER

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October 1974

We are submitting an addendum to Fermilab Proposal No. 291 ("Study of Multiparticle Production Using a Highly Enriched Neon Exposure in The 30-Inch Bubble Chamber") to request that this film be taken using the 15-foot bubble chamber filled with a neon-enriched mixture of neon and hydrogen.

In March 1974 we proposed to measure charged and neutral particle multiplicities, single particle inclusive spectra and multiparticle correlations in hadron-neon interactions and to compare them with analogous data from hydrogen bubble chamber experiments.[1] To achieve our physics goals we requested exposure of the 30-inch chamber using a fill which is highly enriched with neon ($\simeq$95% Mole neon). At that time we noted that additional precautions would be needed for 30-inch running using high neon concentrations. Recent experience with operation of this bubble chamber filled with deuterium has further indicated that enriched neon mixtures present operational problems and that elimination of all potential hazards would require engineering tests. On the other hand, we have learned that operation of the 15-foot bubble chamber with neon-enriched neon and hydrogen mixtures ($\gtrsim$50% Mole neon) is being planned for the near future for neutrino experiments.[2] As is discussed below, we believe that all physics goals for Proposal No. 291 can be obtained with <u>short</u> exposures in the 15-foot bubble chamber. Moreover, the larger chamber will enable substantially better determinations to be made of some quantities, particularly those which relate to the study of neutral particles. Therefore, we are

changing Proposal No. 291 from a 30-inch chamber proposal to one using the 15-foot bubble chamber.

The following runs are now requested for this experiment:

Chamber:	Fermilab 15-foot bubble chamber.
Fill:	Neon-enriched neon and hydrogen mixture ($\geq$50% Mole neon).
Exposures:	15,000 pictures using 400 GeV/c protons.
	15,000 pictures using 100 GeV/c protons.
Beam:	2 protons per picture.

We regard beam interactions to be analyzable if they occur within the upstream half of the 15-foot bubble chamber and if they are at least two feet downstream of beam entrance. With an average of two protons per picture one expects 22,500 acceptable beam interactions in 15K pictures. However, as many as 40% of these may be "spoiled" by high multiplicity interactions occuring in upstream regions of the target liquid or in the chamber walls at beam entrance. Thus, we expect to obtain about 13,500 analyzable interactions at each requested momentum using the 15-foot chamber, of which about 10,700 will be p+neon collisions. The total number of analyzable proton-neon interactions is nearly identical to that which we projected for 50K pictures taken in the 30-inch chamber using a 95% Mole neon fluid.

To define an analyzable fiducial volume in the 15-foot bubble chamber for gammas and vees, it is reasonable to require that their vertices be located at least one foot from chamber

walls. This restriction allows an average 7.5 foot potential path for final state particles, to be compared with about one foot of potential path in the 30-inch chamber. This large difference implies that a 15-foot emperiment has several distinct advantages over a 30-inch chamber exposure:

1) The probability for conversion of gammas is significantly enhanced. In Table I we show properties of low and high concentration neon fills in the 30-inch chamber and of a 50% Mole neon mixture in the 15-foot bubble chamber. The higher conversion probability (0.91 for the 15-foot versus $\leq$0.59 for the 30-inch) is <u>crucial</u> for detection of the high multiplicity portion of π° inclusive spectra. For illustration, Table I shows the probabilities for detecting all gammas in a $3\pi^\circ$ event. Very interesting measurements requiring high conversion efficiency are determinations of second moment correlations f_2^{00}, f_2^{+0}, and f_2^{-0} in hydrogen - like interactions on this film. Also very interesting are determination of the associated average multiplicity and the associated moment $(f_2^{00})n_-$ in these events. Measurement of these parameters is expected "to yield important new information on the isospin structure of multiple production".[3]

2) Study of inclusive K°, Λ°, $\bar{\Lambda}^\circ$ and neutron production will benefit from the increased detection efficiency.

3) The leading particle is more readily identified. This will facilitate studies to be done in peripheral proton-neon collisions, such as search for the asymmetry with respect to the leading particle predicted by R.M.Weiner for production of target fragments.[4]

In addition, this experiment will provide information which will be valuable toward planning future experiments in the 15-foot chamber using a TST surrounded by a neon-hydrogen fill.

The significance of experiments of the kind proposed here, which probe p+nucleon excited states during times comparable to the formation time of the final multiparticle state, has already been demonstrated by emulsion studies at Fermilab energies.[5] That a bubble chamber filled with a neon-enriched Ne-H_2 mixture is an adequate detector for these investigations, has recently been demonstrated with film containing 28 GeV/c p+neon interactions in the BNL 80-inch bubble chamber.[6] Accurate determination of multiplicities and rapidity distributions covering a wide range of beam momenta and target nuclei will be required to settle the physics issues. Our proposed investigations at 400 and 100 GeV/c, together with the work at 28 GeV/c, will provide detailed information for bombardments on A=20 nuclei. Taken together with emulsion studies on heavier nuclei ($A \simeq 70$), sufficient range in both incident momentum and target atomic number will be achieved to highly constrain all models for excited hadronic states at short space-time intervals.

TABLE I

PROPERTIES OF NEON AND HYDROGEN MIXTURES IN THE FERMILAB 30-INCH AND 15-FOOT BUBBLE CHAMBERS

Chamber	30-Inch		15-Foot
Fluid / Property	30% Mole Ne 70% Mole H_2	95% Mole Ne 5% Mole H_2	50% Mole Ne 50% Mole H_2
Collision Length	200 cm	68 cm	154.5 cm
Analyzable Beam Interaction Region	≃20 cm	≃20 cm	≃215 cm
Fraction Neon Interaction	0.62	0.98	0.79
Radiation Length	120 cm	27 cm	73.5 cm
Probability For Gamma Conversion in Analyzable Volume	0.18	0.59	0.91
Conversion Probability For $3\pi^{\circ}$'s	~0	0.04	0.69

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