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Proposal No. 0163A
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PROPOSAL FOR A STUDY OF THE INTERACTION OF HIGH ENERGY $\pi^{\pm}$ WITH NEON

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December 1, 1971
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* Spokesman - F. T. S. - AC 919-684-8228

PROPOSAL:

To study high energy π interactions in the 30" bubble chamber filled with a hydrogen-neon mixture.

PURPOSE:

The purpose of the exposure is several fold.

1) To determine the multiplicity distribution in neon and compare this with data obtained in hydrogen.
2) To study the multiplicity of π^0's produced in π^--p interactions.
3) To look at the inclusive momentum distributions of produced pions and compare hydrogen and neon.
4) Quark search.
5) To search for Electromagnetic showers.
6) To look at diffraction dissociation on neon.
7) To look at the properties of stopping tracks -- to see whether exotic stable particles are produced.

METHOD:

We propose to use the 30" MURA-NAL chamber filled with an H_2-Ne mixture ($\rho \sim .2$) to give a radiation length of about 2 meters. We also propose to use the MAMI wide gap chamber system downstream.

MOTIVATION:

The purpose of the experiment is to study the effects of very high energy cascading in a heavy nucleus. This cascading in principle makes it possible to reach states that are not readily available in a single pion-nucleon collision. It was pointed out over three years ago[1] that it was possible to reach much higher mass complexes than can be readily reached in single collisions. Likewise, it is possible to reach states of high strangeness or high angular momentum in multi-particle collisions.

In collisions at 100 BeV and above the cascade should not behave at all like the cascades that one is used to thinking of in electron-photon showers. This is caused by the fact that the Lorentz contraction causes the products of the cascade to remain well inside of the range of their nuclear forces. Thus the energy of the incoming particle will remain well collimated as it progresses through the nucleus. The drawing in Fig. 1 shows a cross section of a neon nucleus. The lines show the characteristic cones for particles of 100, 50, 25, 12.5, 6.25 BeV. If a shower really started at a point as indicated then only 3 nucleons would be involved in the cascade. The products of momenta more than 6 BeV would be in the side cone. All of the produced particles would essentially simultaneously interact with each of the three nucleons successively. It might be that the multiplicity of produced particles would be the same as in a single π-nucleon collision. Who knows?

In a study which we are doing with 10 GeV π^+ we seem to find evidence for a sizable class of interactions in which multiplicities of 2x , the average hydrogen multiplicity, are found. It would be interesting to see if this effect persists at higher energies.

Also at 10 GeV we find that π-nucleus collisions are a very copious source of very low energy (20 - 40 MeV) pions. It will be interesting to see if this effect persists or increases.

The first thing to look at in this experiment would be the multiplicity and momentum distribution of individual particles. This information alone will give interesting insights into the physics of the situation. If we find dramatically higher multiplicities or a few events of dramatically higher multiplicities (40 - 100 pions for example), it would be a strong indication of new sorts of particles being produced or basically new processes going on.

PARTICLE SEARCH:

We would also use the pictures for doing the sort of search carried out in emulsion 15 - 20 years ago. That is a search for stable super-strange particles. The neon in the chamber enhances the stopping power of the chamber by a factor of 3 at least. It is admittedly a long shot, but it would be simple to try.

ELECTROMAGNETIC EFFECTS:

Our experience using 10 BeV π^+ in neon shows that we can separate Neon and hydrogen events on the basis of topology with some precision. There are hydrogenic type collisions in neon which will contaminate the hydrogen sample. These events are apparently similar to hydrogen events in all respects. We thus should be able to do a study of hydrogen interactions in the neon-hydrogen (with this $\sim$ 20 per cent background from neon). What makes this unique is that we will be able to study π^0 and η^0 production much better (better statistics and precision) than any other experiment to be done until an H_2 target is placed in the 15' chamber. The radiation length should be about 2 meters as compared to 9 meters in pure hydrogen.

We propose to run the chamber with an H-neon density of about .2 g/cm^2. This gives a radiation length of $\sim$ 2 meters, which means a conversion probability of $\sim$.2 in the chamber. In looking at γ-rays at high energies, it is important not to have too short a radiation length since the first conversion tends to wipe out the downstream part of the chamber. It is also important to minimize the numbers of secondary interactions in the chamber. The proposed radiation length would be useful for looking at events with large numbers of relatively low energy γ-rays which are produced over a large solid angle. The chamber is unfortunately too small really to look very effectively for several very high energy photons.

APPARATUS REQUIRED:

We propose to use the 30" MURA-NAL chamber filled with a Neon-hydrogen mixture to give a density of not more than .2 g/cm^3. We also propose to use the wide-gap spark chamber spectrometer to make measurements on high momentum particles.

We would like to use π^- in the 100 - 200 BeV range with a $\Delta P/P$ of not more than 1 per cent.

We would require 50K pictures with $\sim 4\ \pi^-$ tracks per picture. On the basis of multiplicities expected from hydrogen, we would expect the order of 10 events having 20 π's or more produced. Thus we should have a meaningful number of events to make a Neon-hydrogen comparison so far as particle spectra and multiplicities.

REFERENCES

1. W. D. Walker, Phys. Rev. Letters 24, 1143 (1970).

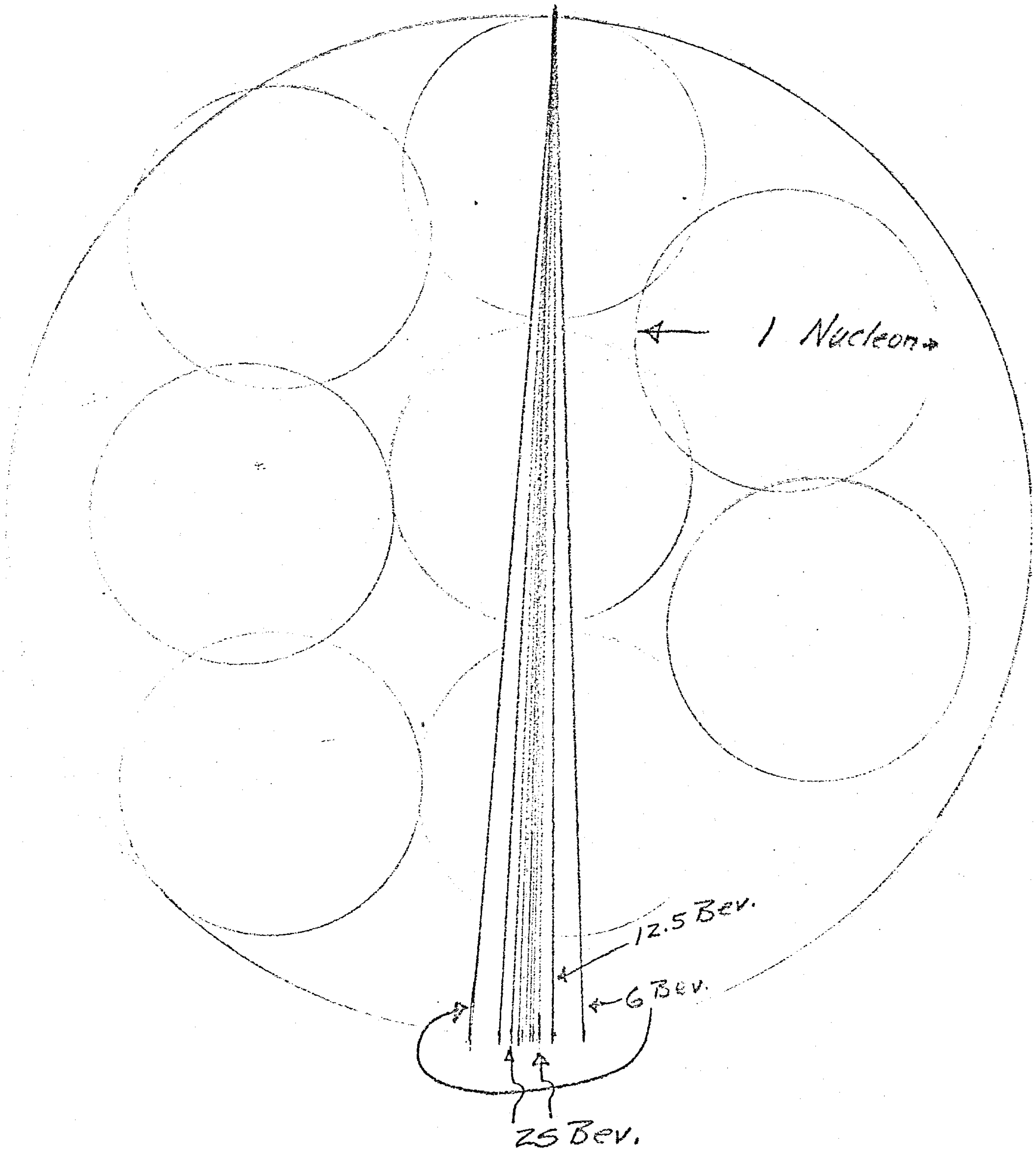

Fig. 1 - Cascade in Neon

NAL PROPOSAL No. 163-8

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PROPOSAL FOR A STUDY OF THE INTERACTION OF HIGH ENERGY π^- WITH NEON

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December 1, 1971

163-9

PROPOSAL FOR A STUDY OF THE INTERACTION OF HIGH ENERGY π^- WITH NEON

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PROPOSAL:

To study high energy π interactions in the 30" bubble chamber filled with a hydrogen-neon mixture.

PURPOSE:

The purpose of the exposure is several fold.

1) To determine the multiplicity distribution in neon and compare this with data obtained in hydrogen.
2) To look for relatively stable particles produced at very high energies.
3) To look at the inclusive momentum distributions of produced pions and compare hydrogen and neon
4) Quark search.
5) To search for Electromagnetic showers.

METHOD:

We propose to use the 30" MURA-NAL chamber filled with an H_2 - Ne mixture ($\rho \sim .25 - .3$) to give a radiation length of about 1 meter. We also propose to use the MAMI wide gap chamber system downstream.

MOTIVATION:

The purpose of the experiment is to study the effects of very high energy cascading in a heavy nucleus. This cascading makes it possible to reach states that are not readily available in a single pion-nucleon collision. It was pointed out over a year ago[1] that it was possible to reach much higher mass complexes than can be readily reached in single collisions. Likewise, it is possible to reach states of high strangeness or high angular momentum in multi-particle collisions.

In collisions at 100 BeV and above the cascade should not behave at all like the cascades that one is used to thinking of in electron-photon showers. This is caused by the fact that the Lorentz contraction causes the products of the cascade to remain well inside of the range of their nuclear forces. Thus the energy of the incoming particle will remain well collimated as it progresses through the nucleus. The drawing in Fig. 1 shows a cross section of a neon nucleus. The lines show the characteristic cones for particles of 100, 50, 25, 12.5, 6.25 BeV. If a shower really started at a point as indicated then only 3 nucleons would be involved in the cascade. The products of momenta more than 6 BeV would be in the outside cone. All of the produced particles would essentially simultaneously interact with each of the three nucleons successively. It might be that the multiplicity of produced particles would be the same as in a single π-nucleon collision. Who knows?

The first thing to look at in this experiment would be the multiplicity and momentum distribution of individual particles. This information alone will give interesting insights into the physics of the situation. If we find dramatically higher multiplicities or a few events of dramatically higher multiplicities (40 pions for example), it would be a strong indication of new sorts of particles being produced or basically new processes going on.

PARTICLE SEARCH

We would also use the pictures for doing the sort of search carried out in emulsion 15 - 20 years ago. That is a search for stable super-strange particles. The neon in the chamber enhances the stopping power of the chamber by a factor of 5 at least. It is admittedly a long shot, but it would be simple to try.

ELECTROMAGNETIC EFFECTS

We propose to run the chamber with an H-neon density of about .3 g/cm^2. This gives a radiation length of 1 meter, which means a conversion probability of ~.4 in the chamber. In looking at γ-rays at high energies, it is important not to have too short a radiation length since the first conversion tends to wipe out the downstream part of the chamber. The proposed radiation length would be useful for looking at events with large numbers of relatively low energy γ-rays which are produced over a large solid angle. The chamber is unfortunately too small really to look very effectively for several very high energy photons.

APPARATUS REQUIRED:

We propose to use the 30" MURA-NAL chamber filled with a Neon-hydrogen mixture to give a density of not more than .3 g/cm^3. We also propose to use the wide-gap spark chamber spectrometer to make measurements on high momentum particles.

We would like to use π^- in the 100 - 200 BeV range with a $\Delta P/P$ of not more than 1 percent.

We would require 50 K pictures with ~5 π^- tracks per picture. On the basis of multiplicities expected from hydrogen, we would expect the order of 10 events having 20 π's or more produced. Thus we should have a meaningful number of events to make a Neon-hydrogen comparison so far as particle spectra and multiplicities.

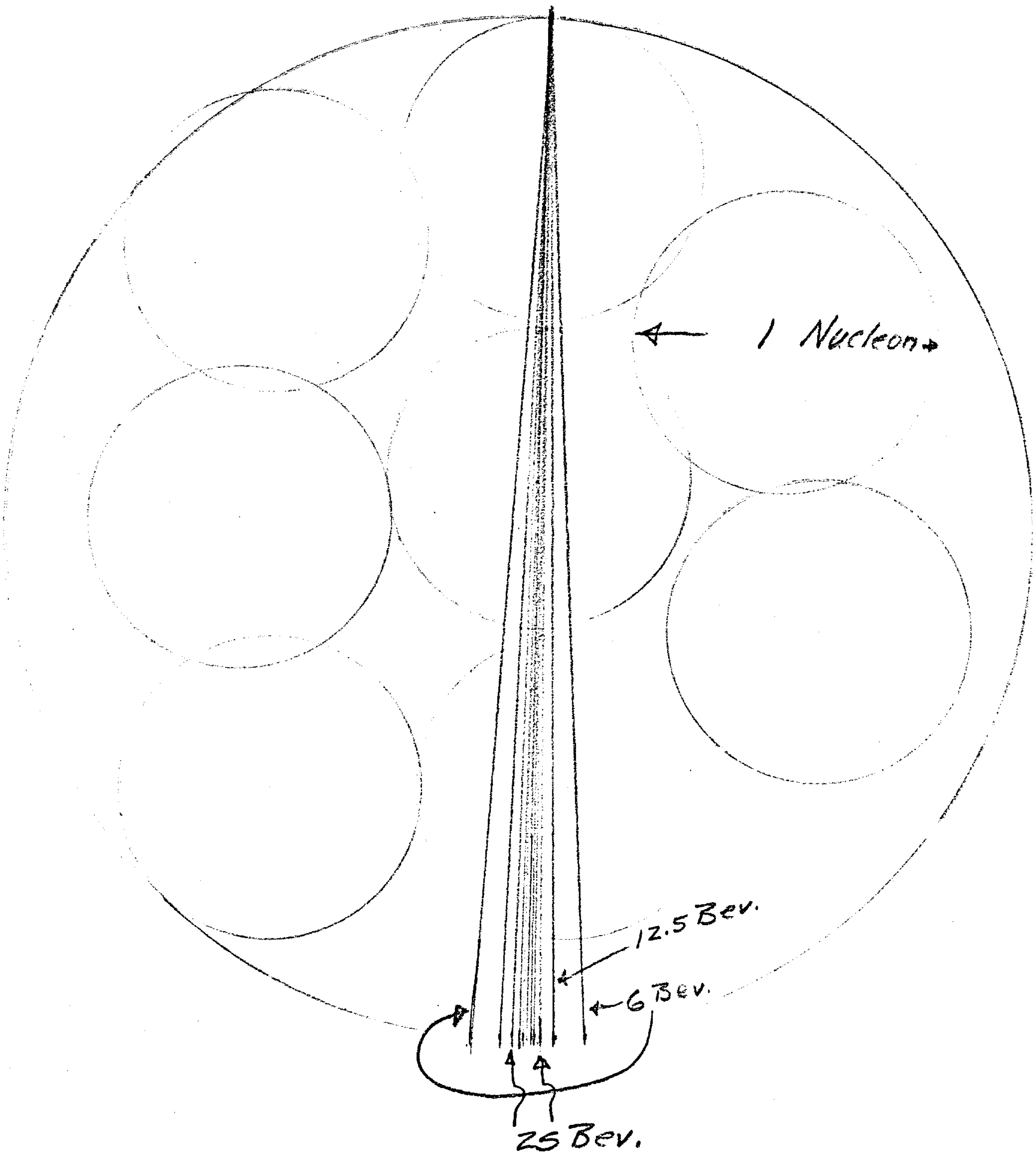

Fig. 1 - Cascade in Neon

163-14

MULTIPARTICLE COLLISIONS AT HIGH ENERGIES*

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The hadronic cascade of high-energy particles in nuclei is discussed. As the incident energy of the bombarding particles is increased, a larger fraction of the products of the first collision strike the second nucleon. In a few successive collisions of relatively small momentum transfers in which the bombarding mass is increased, it is possible to double the energy available in the center-of-mass system. This can conceivably be a very useful analytical tool at high energies.

In the last ten years the subject of multiple scattering of high-energy particles in nuclei has received a considerable amount of theoretical and experimental study.[1,2] The interest has mainly centered on elastic and coherent processes. In this note we want to consider the possibilities of the study of inelastic processes arising from multiple interactions in a complex nucleus. We are not particularly interested in the usual sort of nucleonic cascade which flares out laterally as it proceeds through the nucleus. As the energy of the incident particle is increased the particles associated with the upper vertex, i.e., those particles going forward in the center of mass, tend more strongly toward the forward direction. [The characteristic angle would be the order of $\sim(2m\pi/E_{\rm inc})N$, where N is the multiplicity.]

For 20-BeV pions incident the characteristic angle might be 50 mrad. The spread in the products would in such a case be only a few tenths of a fermi in traversing a medium heavy nucleus. This means that the incident energy would remain very localized laterally as the particles traverse the nucleus. A large class of cascades that develop would be nearly longitudinal in character. Thus the incident particle should drill out a fairly sharp hole in the nucleus so far as the energetic cascade is concerned. The longitudinal dispersion of the fast cascade should also be very small also since essentially all the particles will have nearly the velocity of light.

It is not unreasonable to suppose that the major part of the energy stays concentrated as the linear cascade progresses through the nucleus. If this is indeed the case, then for those collisions the effective mass of the target is several times greater than that of a single nucleon.[3] This means that the energy available in the center of mass can in effect be increased several fold. For certain classes of interactions this would be equivalent to raising the bombarding energy several fold. Practically this could be of considerable importance as it allows the study of high-mass systems (resonances) at lower bombarding energies. The probability of producing a cascade in which the mass is progressively increased from collision to collision is not known. For 25-BeV π-p collisions the probability of a collision which results only in a small momentum transfer (≤ 600 MeV/c) to the target particle is the order of 20-30%. Thus the possibility of producing a constructive cascade with most of the energy staying with the fast particles as the cascade proceeds is certainly finite.

The practical importance of the multistep process is as follows. We know that at high energies the reactions tend to be more and more peripheral. If we imagine a process in which a large mass is excited at the fast vertex then a minimum momentum transfer of $\Delta\sim m^{*2}/2P_{\rm in}$ is required. Such a process is damped by a factor of $\sim e^{(-A\Delta^2)}$. If on the other hand we reach this final state via intermediate lower mass states with three steps each with momentum transfer $\Delta/3$, then the cross section is damped by a factor of $e^{-A\Delta^2/3}$. This is the usual argument for multiple collisions. A more quantitative estimate of the probability of exciting very high masses depends on unknown factors. Numerical work convinces the author that it is rather easy to reach up to masses at or above the kinematic limit in a single collision in a two- or three-step process.[4] In the multi-BeV region the usual experience is that one does not explore well the mass region close to the upper end of the phase space.

One can also think of the cascade by considering the rest frame of the incident particle. Consider for example a 100-BeV nucleon incident on a Cu nucleus. The nucleus appears to be about $\frac{1}{4}$ of a nucleon Compton wavelength thick. The Lorentz contraction would in effect be decreased as the nucleon lost energy in successive collisions. The incident particle would feel three or four impulses approximately equally spaced as it traversed the nucleus.

A few years ago the production of $\bar{p}$'s was observed at the Princeton-Pennsylvania Accelerator[5] well below the threshold energy for the production in nucleon-nucleon collisions. At that time the results were interpreted in terms of the Fermi motion of the target particles in the nucleus. The characteristic momenta seemed rather high and we would presume that what was really being observed was a cascade process. It is worth pointing out that the production was not observed in a light nucleus (Be) but was in Cu. Thus it was possibly a three-step process.

A study of multiple collisions could be quite interesting in other ways. For example we know relatively little about the interactions of fast ρ or ω^0 mesons. These objects are produced abundantly but of course live for a very short time. It is probable that these particles can be converted into heavier objects with the same quantum numbers in diffractive collisions. Thus for example we might find evidence for the ρ':

$$\pi+p\to\rho+p,\quad \rho+p\to\rho'+p, \tag{A}$$

$$\pi+p\to\omega^0+n,\quad \omega^0+p\to\varphi^0+p. \tag{B}$$

Thus (A) would be produced by π collisions in which there is a π exchange followed by a diffractive collision. Reaction (B) could be produced by ρ or B exchange followed by a diffractive collision.[6]

Carbon would be an ideal nucleus to use to observe such double-collision processes. The momentum imparted to the nucleus would be relatively small, but the processes, although not coherent, would not be terribly disruptive of the nucleus. The important thing is that, particularly in the case of Reaction (A), both the collisions ($\pi\to\rho$, $\rho\to\rho'$) can occur at large nucleon impact parameters and are consequently rather probable collisions. We know that diffractive processes occur with rather large cross sections even in the 20-30 BeV region. Thus we would expect the cross section to be modestly large and be associated with small momentum-transfer collisions. This sort of study offers almost the only way to study collisions between unstable particles and nucleons. It is also conceivable that it could be an important tool in resonance hunting and in discovering couplings between unstable particles.

Lower vertex particles.— We have not discussed as yet the production of low-energy particles that come from the target nucleons in the nucleus. These nucleons can serve as a coherent source of radiation. The coherence comes by virtue of the fact that the target particles are located along the path of the incident particle with a definite time relation for excitation. It is conceivable that particles of a given energy would be emitted in Cherenkov cones with $\sin\theta \sim \beta_p/n$ where β_p is the velocity of the emitted particle and n is the effective index of refraction of the particle in the nucleus. Whether or not these particles would get out of the target nucleus obviously depends on the absorption in the nucleus and the phase at production.

We believe that it is important to experimentally investigate these multiple-collision phenomena. Such collisions may turn out to be a very important tool for particle studies. It seems to the author that, in particular, the ability to excite quite large mass values in successive collisions of small momentum transfers could be most useful. The study of heavy objects at lower bombarding energies could be a very important feature since high mass resolution and particle discrimination are much easier at low than at high energies. We certainly agree with the point made by Dorfan et al. that quark searches, etc., have been carried to much higher mass values than one would calculate assuming simple nucleon-nucleon or pion-nucleon scattering. The effect of multiparticle collisions should persist and be important at very high energies. The author has benefitted from conversations with Professor A. R. Erwin and Professor M. Ebel.

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[1]R. J. Glauber, in *Lectures in Theoretical Physics*, edited by W. Brittin and L. Dunham (Interscience, New York, 1959); R. J. Glauber, in *Proceedings of the Second International Conference on High-Energy Physics and Nuclear Structure, Rehovoth, Israel, 1967*, edited by G. Alexander (North-Holland, Amsterdam, 1967).

[2]There are a number of papers on inelastic multiple scattering processes: L. Bertocchi and L. Caneschi, Nuovo Cimento 52A, 295 (1967); J. Formanek and J. S. Trefil, Nucl. Phys. B3, 155 (1967); K. Kölbig and B. Margolis, Nucl. Phys. B6, 85 (1968); B. Margolis, Phys. Letters 26B, 524 (1968); J. S. Trefil, Phys. Rev. 180, 1366, 1379 (1969); G. v. Bochmann and B. Margolis, Nucl. Phys. B14, 609 (1969).

[3]The idea of having the collisions pile up in the nucleus was first mentioned by M. F. Kaplon and D. M. Ritson, Phys. Rev. 88, 386 (1952).

[4]We can estimate the energy available in successive collisions. After one collision the target recoils longitudinally with momentum $\Delta_\parallel$ and the fast particle has mass m^*. In the second collision the available energy in the c.m. system is given by $W_1^2 = W^2 + 2P\Delta_\parallel$ where W = c.m. energy in the first collision. One can see that in a few relatively light collisions it is possible to double the energy available in the c.m. systems of successive collisions. In the production of quarks or any high-mass object, this sort of mechanism might be very important. In production by cosmic radiation with a rapidly falling energy spectrum, a process which in effect lowers the threshold for a given product may be enormously important in producing such products. If for example quarks were produced in such reactions then they would be very asymmetrically produced when viewed from the nucleon-nucleon c.m. frame. Thus they would be found almost always in the cores of air showers. The sort of effect would seem to make some of R. K. Adair and H. Kasha's [Phys. Rev. Letters 23, 1355 (1969)] arguments about rates of quark production less sound.

[5]D. E. Dorfan, J. Eades, L. M. Lederman, W. Lee, C. C. Ting, P. Piroué, S. Smith, J. L. Brown, J. A. Kadyk, and G. H. Trilling, Phys. Rev. Letters 14, 995 (1965).

[6]M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960). Reaction (B) seems to offer interesting possibilities in this respect. We know the π-p cross section for φ production is quite small. If the idea of particle mixing is valid we might expect to find φ production to be much higher in a complex nucleus as a result of $1^- \to 1^-$ transitions produced diffractively. The φ production differential cross section might then be expected to show a slope characteristic of a two-collision process rather than a single-collision process. This is not necessarily so, however, as pointed by Bochmann and Margolis (see Ref. 2) because of the possibility of a coherent diffractive scattering in the $\omega\to\varphi$ process which can have a profound effect on the t distribution which will be energy dependent. I am grateful to Professor Margolis for pointing this

out. We know virtually nothing about the ρ' but again might expect a $1^- \to 1^-$ transition. The ρ would also be expected to diffract up to the g meson. We have discussed the 1^- family of particles because of familiarity. These might better be done with photons incident rather than pions. The sort of diffractive cascading described might occur in any sort of mixed particle states $(f-f')$.