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A Proposal to Study Hadron-nucleus Collisions at NAL Energies Using 30" Chamber Filled with Pure Neon

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Beams	:	(i) Protons at 100 GeV/c (ii) Protons at 400 GeV/c (iii) Negative pions at 100 GeV/c.
Chamber	:	30" Bubble Chamber filled with pure neon and with 32 kG field.
Number of pictures	:	5000 pictures (35 mm cameras - 3 views) for each of the three beams with about 3 tracks/picture

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Summary

We propose to study inelastic interactions of 100 GeV/c protons, 400 GeV/c protons and 100 GeV/c π^- with neon using the 30" chamber filled with pure neon. The exposure required is 5K for each of the beams mentioned above, with about 3 tracks per picture. If for some reason exposure with pure neon is not possible, we would like to have exposure with neon-hydrogen mixture with the highest possible neon content.

The main objectives of this proposal are to obtain in collisions with neon nuclei: (i) hadron-neon absorption cross sections in order to gauge the extent of multistep regeneration effects inside nuclei, (ii) distributions of multiplicity of charged particles and γ-rays, (iii) effective cross section of a system of produced hadrons as a function of multiplicity of the system, (iv) coherent inelastic production cross sections and (v) rapidity distribution of charged particles and γ-rays (and also of K_1^0 and Λ^0) in the target fragmentation region in the hadron-nucleus collisions to obtain information on the mechanism of target fragmentation.

1. Introduction

During the last few years there has been a considerable spurt of interest in the study of hadron-nucleus collisions. Two main reasons may be cited for this. First and foremost is the phenomenal success of multiple scattering formalism of Glauber's theory(1) which has made it possible to correctly incorporate the nuclear effects in the understanding of coherent and incoherent scattering and production of particles in collisions of hadrons and photons with nuclei. As an example of the application of the Glauber theory one may mention some of the recent determinations[2-5] of cross sections of unstable (against strong interactions) hadrons, such as ρ, ω, f, A_1 etc. against nucleon. The second reason is the realisation that it may be possible to test different models of multiparticle production in hadron-nucleon collisions by confronting their predictions of multiparticle production in hadron-nucleus collisions with experimental data[6-9].

Recent studies[4,10-16] on hadron-nucleus collisions have revealed interesting and unexpected features which require further detailed studies for evolving a suitable model for mutliparticle production in hadron-nucleon collisions. One of these recent hadron-nucleus studies[10,11] using a stack of nuclear emulsion exposed to 200 GeV/c proton beam is due to some of the authors of the present proposal. Outstanding features of hadronic multiparticle production in nuclei which have been revealed through these studies may be summarised as follows:

(i) The effective interaction cross section of a system of outgoing hadrons is not appreciably different from that of a single hadron on a nucleon[4].

(ii) The ratio R of multiplicity in p-emulsion collisions ($\langle A \rangle \approx 73$ for emulsion) to that in pp collisions is only 1.7 right from a few tens of GeV to a few TeV[10-14]. The dependence of multiplicity on the mass number A is $\sim A^{0.13}$ in the above energy range[10-12,17]. These observations indicate that there is no appreciable multiplication of hadrons inside the nucleus. This is consistent with observation (i).

(iii) The nuclear log tan θ (which is a measure of the rapidity) distribution of the forward cone particles, after excluding coherent production, is similar to that of the pp collisions[9,13]. This indicates that even the feeble multiplication that does take place in a hadron-nucleus collision occurs in the target fragmentation region and not in the projectile fragmentation region.

(iv) Coherent cross section seems to be small; 25-30 mb (3-4% of inelastic cross section) in p-emulsion collisions at 200 GeV[16]. This feature is puzzling if one tries to understand this in terms of diffractive dissociation[18]. The cross section for incoherent inelastic interaction on a single nucleon at the periphery forms[18] a fairly large fraction (20-25%, in emulsion at 200 GeV to 8 TeV) of the p-nucleus inelastic cross section. This observation is also consistent with observation (i).

In addition to the above salient features there are indications that the inelasticity in p-nucleus collisions is not very different from that of pp collisions. Also many of the quantities show feeble energy dependence, if any, beyond a few tens of GeV, e.g. R, inelasticity, $\langle N_h \rangle$ - the average number of heavy prongs in emulsion (which is a rough measure of secondary collisions inside the nucleus).

The features (i), (ii) and (iii) mentioned above were sought to be explained in terms of hadronic excitation models in contrast to multiperipheral models[9-11,17,19]. However, the low observed coherent cross section, (iv) above, tends to indicate that single diffractive excitation of the projectile or target hadron cannot account for any appreciable fraction of the inelastic hadron-nucleon cross section. Thus, hadronic excitation appears to be predominantly double rather than single[20].

As mentioned earlier, for a theoretical understanding of the hadron-nucleus collisions vis-a-vis hadron-nucleon collisions at corresponding energies, the formalism of Glauber multiple scattering theory has been used. Questions regarding the importance of multistep regenerative process[21] and the role of off-diagonal terms in the closure of matrix elements for evaluating incoherent cross sections[22] on nuclei have been raised and discussed. These questions may be answered by studying experimental data on hadron-nucleus collisions. Quantities to be critically examined are the absorption cross section of hadrons on nuclei and the ratio of cross sections of coherent and incoherent particle production in nuclei. Apart from the interest in nuclear and particle physics, an accurate determination of absorption cross section in neon at NAL energies is of some importance in cosmic ray physics in order to test the suggestion made recently that appreciable deuteron flux could exist in primary cosmic rays in the energy region 200-600 GeV[23].

In studying details concerning the effect of the target nucleus in hadronic interactions, it is necessary to have a homogeneous target like neon instead of freon or nuclear emulsion. We propose to study interactions of protons at 100 and 400 GeV/c and π^- at 100 GeV/c in the 30" bubble chamber filled with pure neon.

2. Objectives of the experiment

(a) Absorption cross section. To obtain the absorption cross section of protons at 100 and 400 GeV/c and π^- at 100 GeV/c. These will be compared with expectations based on the Glauber model calculations using as inputs the corresponding known hadron-proton scattering amplitudes at the same energies. These absorption cross sections can be determined to a precision of 1% with the requested exposures. Since a decrease of 5% at 100 GeV/c and over 20% at 400 GeV/c is expected for p-neon cross section, as a result of multistep regeneration effects[(21)], our measurements would be of significance in estimating the extent of the regeneration effects and to cosmic ray physics[(23)].

(b) Multiplicity distribution. A detailed study of charged particle multiplicity distribution in neon as a function of N_h will yield information on the cascading process.

(c) Effective cross section of a system of hadrons. As mentioned earlier Bemporad et al.[(4)] have made the important observation that the effective interaction cross sections of systems of 3 and 5 hadrons produced inside a nucleus are not appreciably different from that of a single hadron. It would be interesting to see whether this is true for any system with arbitrarily high multiplicity. By comparing the charged particle multiplicity (excluding slow recoils) distribution in neon for $N_h < 1$ with the corresponding multiplicity distribution in hydrogen, we can evaluate the effective interaction cross section of a system of produced hadrons as a function of multiplicity of the system. Using Glauber theory, one can relate the cross section for a given multiplicity in p-neon collision $\sigma_A(n_{ch})$ to cross section $\sigma_H(n_{ch})$ for the same multiplicity in pp collision

$$\sigma_A(n_{ch}) = \sigma_H(n_{ch})\ N(A, \sigma_1, \sigma_2)$$

$$N(A,\sigma_1,\sigma_2) = \frac{1}{\sigma_2 - \sigma_1} \int \left[\exp(-\sigma_1\ T(b)) - \exp(-\sigma_2\ T(b))\right] d^2b$$

where σ_1 is pp inelastic cross section, σ_2 is the effective cross section of the system and T(b) is the number of nucleons per unit area in the path of the incident proton at impact parameter b.

Thus, one can evaluate the effective interaction cross section of the system of produced hadrons as a function of the multiplicity of the system.

(d) Coherent cross section. One of the difficulties in determining inelastic coherent cross section in emulsion is that there is considerable bias against one prong coherent events because of the difficulty of detecting γ-rays. Since we would be able to detect γ-rays with high efficiency (68%) we should be able to determine the total coherent cross section, which can be obtained from excess of odd multiplicities over even multiplicities. In addition, for events with three or more prongs one can adopt the criterion that $\Sigma \sin \theta_i$ should be less than 0.3 or 0.4; $\Sigma \sin \theta_i$ is a measure of the longitudinal momentum transfer to the nucleus. We would also be able to obtain multiplicity distribution of charged particles and of π^0s in coherent events.

(e) Target Fragmentation. The momenta of the slow particles in the laboratory system can be measured upto a few GeV/c. The slow particles arise essentially from target fragmentation. Since the hypothesis of limiting fragmentation has been fairly well established in the target fragmentation region, it is of interest to see how the rapidity distribution of the target fragments depends on the mass number of the nucleus, e.g. whether there is a rapidity dependent factor or a constant factor independent of the rapidity of the secondary particle. Since the number of heavily ionising prongs N_h is a rough measure of the impact parameter and the effective number of target nucleons, this study will also be carried out as a function of N_h.

It may be mentioned that detailed information on particle spectra in the target fragmentation region is difficult to obtain in counter experiments and the bubble chamber technique is eminently suited for this purpose.

(f) γ-rays. Since radiation length in neon is 24 cm, a large fraction (68%) of γ-rays produced in the reactions will convert within the chamber volume. Multiplicity distribution of γ-rays can be used to deduce π^0 multiplicity distribution as a function of charged multiplicity and for different values of the associated heavy prongs (N_h). Study of angular distribution of γ-rays at large angles would throw additional light on the mechanism of target fragmentation. Detection of γ-rays would also be useful for studying coherent processes as pointed out in (d) above.

3. Details of the experiment

3.1. Exposure

The collision mean free path of protons in neon is 73.5 cm corresponding to $\sigma_{abs}(p\text{-Ne}) \sim 378$ mb. There would be on the average 0.64 events per track in the chamber. In order to be able to make measurements on charged secondaries as well as γ-rays, it is essential that the number of beam tracks per picture are not more than 3. This would yield about 1.5 useful events per picture. To meet the objectives of the experiment it would be sufficient to have

5K pictures at each of the proposed momenta and beam particles. We would like to have as high a magnetic field as possible. The exposure requirements are summarised in Table 1.

TABLE 1

	Beam	Momentum GeV/c	Magnetic field kG	No. of pictures	Beam particles per picture
1)	Protons	100	32	5K	2-3
2)	Protons	400	32	5K	2-3
3)	Negative pions	100	32	5K	2-3

We would like to have 3 view 35 mm camera system for the photographs.

3.2. Time schedule

The group at present has 3 image-plane digitising measuring machines and 5 scanning machines. Another measuring machine will be added shortly. The computational needs are met by the Institute's CDC 3600 computer (64K).

It may be noted that amongst the objectives of the experiment, except for rapidity distributions of the charged particles and the γ-rays, the remainder can be obtained after only scanning which can be completed within 3 months of receiving the film. Thus, some of the important results on σ_{abs}, σ_{coh}, $\langle n_{ch} \rangle$, the distribution of n_{ch} and $\langle n_{\gamma} \rangle$ as a function of n_{ch} will become available within a few months of the arrival of the film.

4. Note about the Bombay Bubble Chamber Group

4.1. There are 6 to 8 post doctoral physicists carrying out active bubble chamber work since 1969. The experiments undertaken so far by the group are:

(i) 'ρ^0-nucleon and f-nucleon total cross sections at 3.5 GeV/c', B.S. Chaudhary et al., Nucl. Phys. B67, (1973) 333.

This experiment was based on 80K pictures of MURA 30" bubble chamber filled with a neon-hydrogen mixture and exposed to 3.5 GeV/c π^+ beam at the Argonne National Laboratory in July, 1969.

(ii) Study of rare bosons like D, E, δ, X^0 and F_1 in $\bar{p}p$ annihilations at 0.78 GeV/c using 1.5 million pictures taken at CERN with the 81 cm hydrogen bubble chamber. This is a collaboration between Bombay, Madrid and Paris (College de France). The Bombay Group is also collaborating with Japanese Groups in Tokyo on the study of $\bar{p}p \rightarrow \bar{n}n$ in the same film.

(iii) Study of neutral pion production in $\bar{p}p$ annihilations at 2 GeV/c employing 200K pictures taken at RHEL using the 1.5 m chamber filled with neon-hydrogen mixture with a built-in hydrogen track sensitive target. This exposure of 200K pictures was taken for us in October 1972.

As mentioned earlier some of the members of the Group have also been recently involved in the study[10,11] of multiparticle production in hadron-nucleus collisions using a stack of nuclear emulsions exposed to 200 GeV/c proton beam at the NAL.

It may also be pointed out that a majority of the members of the Group have been active in the field of experimental high energy physics at accelerator and/or cosmic-ray energies for nearly a decade and a half. We have had a long tradition of work, both experimental and theoretical, on the problem of particle production at high energies and the study of hadron-nucleus collisions. There have recently been important contributions from some of the members of the Group in the area of hadron-nucleus collisions. The requested exposure would go a long way to sustain this high level of activity in this area.

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