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SEARCH FOR MOSSBAUER TYPE NUCLEAR COLLISIONS WITH HIGH ENERGY PROTONS

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ABSTRACT

The collision of a high energy projectile with a massive target (nucleon cluster) can considerably increase the center of mass energy available at NAL. In some cases, such as neutrino interactions, the increased center mass energy might conceivably be 'traded' for higher neutrino energies. Thus determination of the characteristics and the fraction of collisions with nuclei that involve large target masses is of interest. We propose to attempt such a determination using several (A, Z) targets placed directly in front of the 30" hydrogen bubble chamber exposed to a 400 or 500 GeV/c proton beam. We will also search for new particles produced in heavy nuclei near the target and survey the K_S^o spectrum produced in complex nuclei. We require no additional equipment but the bubble chamber and the beam. 60,000 photographs are requested.

Physics Justification

There are two ways of increasing the center of mass energy available for elementary particle collisions aside from larger radius accelerators or the use of super high magnetic fields. The ISR technique has recently been successfully used at CERN and offers a good way to increase the center of mass energy, at the expense of rate, for p p and $\bar{p}$ p collisions. However, for collisions of short lived particles or weakly produced particles like neutrinos this technique is not available. In this case the only way to increase the center of mass energy is to provide heavier targets. The center of mass energy of the collision of a neutrino of energy E_ν with a target of mass M_t is

$$E_{cm} \sim \sqrt{2E_\nu M_t}$$

thus for $E_\nu \sim 300$ GeV and a target mass of 30 M_p (which may sometimes occur for very heavy nuclei) the total center of mass energy would be

$$E_{cm} = 165 \text{ GeV}.$$

To the extent that the collision with several highly correlated nucleons could be considered as a single collision this increased center of mass energy would be useful to study weak interactions at very high energies. Of course to reach the same center of mass energy with a single nucleon target requires a neutrino energy of 9 TeV. Thus the study of these collisions even though complex and messy offers an exciting possibility of entering the truly high energy domain for weak interactions at NAL. We note incidently that if the neutrino cross section were to continue increasing with E_{cm} for these collisions then the heavy target collisions would be amplified compared to hadron collisions where presumably cross sections are approximately independent of E_{cm}. Furthermore the possible existence of these multinuclear collisions must be considered when interpertating experimental data on neutrino-nucleus collisions. Such data will be forthcoming from experiments 1A and 21.

There are several reasons to believe that collisions with large clusters of nucleons in nuclei may not be so infrequent as might be thought at first. We emphasize that it is feasible to experimentally search for these massive target collisions independent of any theoretical arguments.

There is some experimental evidence for collisions on an entire deuteron producing a higher center of mass energy. For example in a recent Wisconsin experiment the reaction [(1)]

$$\bar{p}d \rightarrow \bar{\Lambda}\Lambda n$$

was observed at energies below the threshold for

$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$$

with a cross section observed to be $\sim$ 10% of reactions 2 at 1.8 BeV/c. Similarity the process

$$p + \text{nucleus} \rightarrow \bar{p} + \text{anything}$$

was observed below threshold at PPA energies by Lederman and co-workers.[2]

At very high energies the time between successive collisions with nucleons in the nucleus is decreased by

$$\tau_{coll} = r/\gamma c$$

where r is the internucleon distance.

We may also consider that there is some characteristic time for the production of mesons - perhaps crudely given by the uncertainty principle

$$\tau_{em} \sim \hbar/E^*$$

where E* is the mean energy of the mesons. For ultra large γ's we might expect that the collision time would be shorter than τ_{em} and thus the incident particle can interact with several nucleons before mesons are emitted.[3] In addition, some fraction of the time several nucleons may be within a very small distance of each other thus decreasing τ_{coll} and (for this cluster) allowing $\tau_{em} > \tau_{coll}$. This argument is crude but hopefully not totally misleading. Numerous cosmic ray studies with nuclear emulsions have attempted to determine the number of nucleons involved in nuclear collisions. These studies suffer from the unknown initial energy and the unknown individual energies of the outgoing mesons. Never the less such studies seem to have established that the most likely collisions at high energies are with single nucleons. If multibody collisions with several nucleons were as frequent as 20% it is doubtful that those studies could have established such. Thus cosmic ray data still allow for the possibility of relatively abundant multibody interactions. We further note that some evidence may already exist for the growing importance of multinuclear collisions in nuclei from cosmic ray data. We quote from a recent summary talk by E. Friedlander at the Budapest Cosmic Ray Conference (1969)[4]

> "This correlation suggests strong secondary processes (in nuclei) even in collisions in light nuclei with low nuclear excitation. Their apparent absence at lower energies might imply that some new kind of process involving more nucleons is setting in around $\sim$ 100 GeV"

Thus there are hints of possible new phenomenon in the collisions with nuclei in the energy range accessible to NAL.

These arguments make it plausible that some collisions in nuclei might be truly multibody and that the fractions of such collisions may increase with energy. By multibody we mean that the fast interaction products have an invariant mass that is considerably larger than the center of mass energy of the projectile of energy E_p colliding with a free nucleon. Of course the center of mass energy can be increased by colliding with a single high momentum proton, but, as shown in ref. 2 the probability for these collisions is likely very small for any appreciable increase in the center of mass energy. The total center of mass energy of the projectile and all of the nucleons in the nucleus is a constant for a given E_p. However only a small fraction of this center of mass energy may be 'used' when collisions involve single nucleons, with a larger fraction being 'used' for multibody collisions.

If an appreciable fraction of high energy collisions in nuclei result in a elevated center of mass energy then the production of very massive objects becomes possible. For example, Perkins and Fowler have noted several events where an electromagnetic cascade seems to be 'rejuvenated' many radiation lengths from the origin. One possible explanation of this effect is the production and decay of a new heavy neutral particle. The neutral particle cannot be a Λ or Ξ^0 since many photons were produced at the point of the new cascade. The incident energies of the events that Perkins and Fowler observed were in the TeV range, and perhaps accessible at NAL energies only by collisions with nuclear clusters. The experiment proposed here could search for the production of such an object as well as short lived charged particles that are indicated by kinks in charged tracks in the bubble chamber. The K_S^o spectrum and rate produced by 400-500 GeV protons on complex nuclei would be measured and will be useful for an early estimate of the neutrino spectrum that comes from K^+ decays.

Finally we note that Walker has suggested the use of successive nuclear collisions of mesons with an increase to the center of mass energy in each collision, to produce very massive mesonic states.[6] We expect that it may be possible to separate this 'chain' of interactions from the 'cluster' interaction by the larger multiplicity of mesons formed in the 'chain' interaction. It has been observed that the meson multiplicity distribution observed for high energy collisions in nuclei consists of a Poisson like distribution and a much broader distribution.[4] Recent experiments with hydrogen targets at Echo Lake confirmed that hydrogen collisions give a Poisson like distribution in multiplicity. The broad distribution mentioned above perhaps represents the effects of 'chain' collisions. Only detailed experimental studies of the multiplicity, invariant mass and net charge of the produced system can answer these questions.

Experimental Technique

We propose to expose thin heavy nuclear targets to 400 or 500 GeV/c protons and to analyze the 'jets' produced in the target in the bubble chamber. The large magnetic field and excellent spatial resolution of the 30" bubble chamber make it an adequate analyzer for the jets coming from such targets. We have had considerable experience with the use of this bubble chamber over the past several years. Specifically we propose to measure a lower limit on the center of mass energy of the collision by measuring the invariant mass of the outgoing charged particles assuming that they are all pions. The invariant mass of the outgoing system is given by

$$M^2 = (\Sigma_j E_j)^2 - (\sum_j \vec{P}_j)^2 \tag{1}$$

To experimentally determine M^2 requires a measurement of all outgoing particle momenta and identification of the mass of these particles. In order to obtain a lower limit on this mass (which we expect to be usually within 30% of the actual mass) we assume first that all outgoing particles are π mesons, the invariant mass is then given by

$$\begin{aligned} M^2 = n_{ch} M_\pi^2 + n_{neut} M_\pi^2 &+ (\sum_{i \neq j} E_i E_j - \sum_{j \neq i} P_i P_j \cos \theta_{ij})_{ch} \\ &+ (\sum_{i \neq j} E_i E_j - \sum_{i \neq j} P_i P_j \cos \theta_{ij})_{neut+ch} \end{aligned} \tag{2}$$

where θ_{ij} is the angle between mesons i and j and ch and neut-ch denotes sums over charged particles only and sums over combinations of neutral particles only and neutral-charged particles, respectively. A lower limit (that is easily measured experimentally) on M is obtained by keeping only charged particles in the sum above-giving

$$M_{ch}^2 = n_{ch} M_\pi^2 + (\sum_{i \neq j} E_i E_j - \sum_{i \neq j} P_i P_j \cos \theta_{ij})_{ch} \tag{3}$$

Finally since in cosmic ray collisions of energies 10^{12} - 10^{15}ev the ratio of π^{o}'s to $\pi^{\pm}$ is approximately 1/3 we expect on average that[3]

$$M \sim 3/2\ M^{ch}$$

The largest contribution M^{ch} comes from wide angle large energy particles since in the forward direction or at very small angles the $\Sigma\ E_iE_j$ - $\Sigma\ P_iP_j\ \cos\ \theta_{ij}$ term makes a contribution of the order of the (pion mass)^2. Thus we expect some high target mass (and high M^{ch} mass) collisions to produce several wide angle high energy particles. This will be one signature for high target mass events. For collisions that involve 4 nucleons the total center of mass energy is doubled (M^2 is increased by 4). In these cases we would expect that M^{ch} would exceed the center of mass energy for collisions with single target nucleons.

A second signature for multinucleon collisions is given by a charge excess of the outgoing fast particles over the Q = 2 obtained for pp collisions in the nucleus.

Specifically then a signature for multiparticle collisions is given by

$$\Sigma Q_i > 2$$

and $\qquad M^{ch} > 28$ GeV (for 400 GeV protons)

We therefore propose to place various (A, Z) targets in front of the thin window of the 30" chamber. Each target will be ∞ 1/10$ of an interaction length. The target would be exposed to ∿ 5 protons each machine pulse so that on average there will be an interaction in the target for every other bubble chamber expansion. For each target we would like 15,000 expansions giving 7,500 interactions. The targets we plan to use would be Be(9), Al(24), Cu(63), Pb(207), where the values of A have been chosen to increase by a factor of ~ 3 from target to target. The point of interaction of the incident proton can be determined from the narrow jet that invariably accompanies collisions at these energies

The resulting pictures would be scanned for events with $Q > 2$ and/or events with some wide angle high energy tracks. All events with these characteristics will be measured and the M^{ch} mass will be determined.

We have available considerable scanning and measuring equipment for the 30" bubble chamber. It is expected that the first results from this experiment would be available within a few months after the completion of the run.

People Working on the Experiment

We expect that one or two postdoctral people will join the experiment before the end of the summer of 1971. One or two graduate students will also work on the experiment.

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