NAL PROPOSAL No. 114

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INTERACTION OF 200-500 GeV PROTON WITH EMULSION NUCLEI

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ABSTRACT

We are interested in exposing Ilford G-5 pellicles to proton beam from the lowest to the highest energy value available. The exposures shall be along the plane of the pellicles with a flux density of 10^4 to 10^5 particles/cm^2. We shall study the primary interactions, the multiplicity and the cross-section as a function of primary energy which will vary from 200-500 GeV.

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DEPARTMENT OF PHYSICS AND ASTRONOMY

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December 21, 1971

Professor Edwin L. Goldwasser
National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois

Dear Professor Goldwasser:

Thank you for your letter of December 16, 1971. I am sorry that my previous proposal was brief as the time was very short for submitting that proposal. I am sending an additional information for our proposal No. 114, which will cover most of the details that one needs in an emulsion experiment. We are very anxious to have the beam at whatever high energy it is available.

With best regards.

Yours sincerely,

P.L. Jain

P.L. Jain
Professor of Physics

PLJ/jhs

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STUDY OF 200-500 GEV PROTON AND PION INTERACTION WITH NUCLEAR EMULSION

by

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ABSTRACT

High energy ($\sim 10^{12}$ ev) work has been done with cosmic rays where the identity and the energy of the primary particle is not known and hence it is hard to understand the mechanics (i.e. statistical, fireball, H-quantum and isobar model) through which the secondary particles are produced. Thus we are interested in the studies of hadron interactions with the known energies of the highest man-made proton and pion beams (200-500 GeV) and this study will help us to understand which of the existing models are the correct ones to discuss the Π-Π, Π-N, N-N and N-nucleus interactions at higher energies.

we shall determine the inelasticity, multiplicity, transverse momentum, angular distribution of the secondaries in CMS, etc. at these energies and shall compare these values with those obtained from the other known beams. We are also interested in the coherent product of the particles with (200-500) GeV negative pions on emulsion nuclei and shall also study their production cross section as a function of energy. We shall be interested in the analysis of any unusual events which are produced either by pions or protons with emulsion nuclei at these energies.

STUDY OF 200-500 GeV PROTON AND PION INTERACTIONS WITH NUCLEAR EMULSION

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I. Introduction

(a) Study of Jets

Due to the availability of high energy particles from B.N.L. and CERN accelerators, physicists have tried to understand nucleon-nucleon and meson-nucleon interactions up to energy of 30 GeV. During the last couple of years, preliminary data on these studies have also been available to 60 GeV from Serpukhov.[1,2]

For the last one decade or so, some work has been done with cosmic ray jets[3,4] ($\sim 10^{12}$ ev). However, cosmic ray measurement the multiple production of particles are not very refined. Even in a very carefully performed experiment, one obtains only the total cross sections, integral particle production cross-sections, multiplicity and inelasticity distributions, etc., and seldom an accurate differential angular or differential "t" distribution. The main difficulties are the low flux intensity of such high energy events and also the lack of control on the energy of the primary beam. These difficulties allow several radically different models or theories to co-exist (i.e,, statistical, fire-ball, H-quantum, isobar model, etc.) which show the mechanism of high energy nucleon-nucleon or nucleon-nuclear collision. Thus we see that while the fireball, isobar plus fireball and multi-pheripheral model way account for most of the data, none has been shown to be unique.

One of the difficulties with such high energy experiments is that the energy measurements are not well refind. Up to the present time, the most common method used for determining the energy of the primary particle is Castagnoli's method[5] from the angular distribution of the second particle produced in the interaction. This method assumes that the secondary particles are symmetrically produced in forward-backward direction for each event in the center of mass system, but this assumption is not always satisfied for each event. We have previously modified this formula up to accelerator energies[6], i.e,, 30 GeV. But what happens at 200-500 GeV, we do not know. Without the knowledge of the primary energy, it was not possible to determine the other parameters of high energy interactions accurately. These parameters are the bases for understanding the mechanism of interactions at 10^{12} ev energy.

(b) Coherent Production of Multipion Final States

Recently several theoretical[7-10] papers have considered a special type of inelastic interaction between a high-energy particle and a nucleus acting as a whole: a coherent interaction[10] i.e., an interaction where the nucleus remains in its fundamental state. The consequence of this is that no individual nucleon in the nucleus plays a particular role in the interaction and that the total amplitude is given by the sum of the amplitudes for each nucleon. This means that for the nucleus to act coherently in a reaction, one would expect that the recoil momentum (q) should not much exceed the inverse of the nuclear radius R, i.e., $q = R^{-1}$, nor the Fermi momentum which is typically a few times R^{-1} ($h = c = 1$). The coherent reactions should thus appear as much more forward peaked than the reactions on free nucleons and their differential cross-sections at zero degree should also be larger. The simplest example is elastic scattering on nuclei which has been observed and extensively studied in a very large range of nuclear masses, incident particles, and energies, primarily by spark chamber and counter techniques[11-12]. Inelastic coherent reactions, in the sense that the nucleus remains intact but the incident particle does not, have only been observed by nuclear emulsion[13-17] and bubble chamber[18-19] techniques. We shall indicate in the next section that coherent interactions studied with nuclear emulsions give a better result than with the bubble chamber. It has been found that the cross section for the reaction ($\pi^- + \text{nucleus} \to \pi^+ \pi^- \pi^- + \text{nucleus}$) is much smaller[10] at (6 to 8) GeV/c than at 14 and 16 GeV/c. The coherent production at 45 and 60 GeV/c in nuclear emulsion were also studied by Russian groups. The possibility of further increase of the cross-section was suggested by the Polish group[16,20], who worked with an average energy of negative pion $\simeq$200 GeV. This study at 200 GeV/c is of course not free from a number of serious objections.

II Method of Approach

In the first phase we are planning to expose four stacks; two in the 200 GeV/c proton beam, and two in the 200 GeV/c negative pion beam. The stacks are composed of G-5 pellicles of dimensions 10 cm x 20 cm x 600 micron. For each beam, we shall use high and low fluxes, which are as follows.

(i) Large Flux $\sim 5 \times 10^5$ particles/cm^2,

(ii) Low Flux $\sim 5 \times 10^4$ particles/cm^2.

Each beam shall enter the stack from 10 cm width side in such a way that the beam is parallel to the plane of the emulsion (along its 20 cm length). After the development of the stack a part of the stack with large flux will be area scanned where we shall find events with large multiplicities and the predominant interaction is with a nucleus. The part of the stack with pion and proton beams with low fluxes shall be scanned along the track. This study will help us, not only in finding the interaction cross-section of the beam particle with emulsion nuclei, but also in finding the white stars (with no black prong). White stars we shall use in Π-N and N-N interactions studies for finding the answers to a number of questions mentioned in this proposal.

III. Description of Proposed Research

We have mentioned above that the measurements with cosmic ray are not so refined. But whatever may be the difficulties, we may summarize first what we have learned from cosmic ray experiments regarding multi-particle production, which is as follows[1-4]:

(a) The inelastic cross-sections for high energy collisions in proton-complex nucleus collisions ≃ constant or vary by not more than 20% in the energy range 30 GeV - 1000 GeV.

(b) The multiplicity of the secondary particles increases slowly with energy (as $E^{\frac{1}{4}}$ roughly) in the range 10 - 10^4 GeV.

(c) Inelasticity is independent of energy and is considerably less than unity (~ m_{Π}/m_p).

(d) Transverse momentum P_T is constant ≃ 400 MeV/c.

(e) At all energies, pions are the most numerous secondaries, accounting for about 80% of the total. The energy division among the secondaries is not uniform, the bulk of the energy being usually carried by only one or two particles. If a single secondary particle - presumably the original primary nucleon - is mainly responsible for the propagation of the nuclear cascade, it carries on an average about 50% of the original primary energy. The remaining 50% of the energy is radiated as pion and heavier particles. The majority of these heavy particles must be baryons, as the energy content of the K particles is known to be much smaller than that of the pions.

(f) At 10^{12} ev energy range, peripheral collisions are very probable and it has been proposed that the dominant mechanism in this case is virtual pion exchange between the meson clouds and cores of the nucleons. Symmetrical showers correspond in this picture to Π - Π collisions, asymmetrical ones to Π -N and N - Π collisions. The core - core (N - N) collisions are evidently much rarer.

(g) The angular distributions of the secondaries is anisotropic in the CMS. Preference for emission in the forward and in the backward directions in the CMS increases with energy. The maximum in the angular distribution of the shower particles (in the symmetric events) has been interpreted as isotropic emission from unstable isobars (fireballs). What would be interesting to study is that such isobars are found as a result of resonances in the Π-Π and Π-N system.

We pointed out earlier that the studies with cosmic ray events at 10^{12} ev energy are not as refined as those with the events produced with the accelerator particles at 30 GeV. Nucleon-nucleon and meson-nucleon interactions have been extended recently to 60 GeV and the general characteristics have been observed in Π^- interaction in nuclear emulsion. It has been found[1,2] that the average number of prongs in Π^- proton collision is 6.4 ± 0.16.

The majority of secondary particles are emitted into the forward hemisphere in the Π-proton CM system especially in low-multiplicity events. We are interested in the detailed studies of proton and Π^- meson interaction with emulsion nuclei at 200 - 500 GeV. We would like to know their interaction cross section values and would like to study the nuclear cascades developed by the high energy incoming particle in the emulsion nuclei. We are hoping that by working with the known energies of the highest man made proton and pion beams (200 - 500 GeV) we can not only find the correct formula for determining the still higher energies of the primary particle (cosmic-ray jets), but also of learning which of the existing models or theories are the correct ones to discuss the Π^- Π, Π-N, N-N and N-nucleus interactions at these energies. We shall test Yang's hypothesis on limiting fragmentations of the target and of the projectile at such energies. We would, of course, be interested and shall be looking for any unusual phenomena produced by high energy primary beams in nuclear emulsion.

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