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STUDY OF THE A-DEPENDENCE OF INCLUSIVE PROCESSES AND ASSOCIATED MULTIPLICITY

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ABSTRACT

It is proposed to study the A-dependence of inclusive processes using the M-6 focussing spectrometer facility and a π^0 detector. For each "inclusive" event detected, the associated charged particles will also be detected and their angles measured. The purpose of the experiment is to explore general features of the space-time development of production processes over a wide kinematic region and also to answer specific questions raised by models which have been put forward to explain present data on multiparticle production in nuclei. Six hundred hours of beam time are requested.

Introduction

In recent years the production of particles in high energy hadron-nucleus collisions has attracted increasing interest. The reason is simple. The few measurements[1] that have been made gave results which contradicted a priori expectations, coupled with the fact that such measurements probe two important aspects of hadronic interactions; the space-time development of the production process and the nature of hadronic interaction at large distances.

Experimental work in this field is still in the "preliminary survey" stage. Present knowledge is limited to the A-dependence of average multiplicity,[1] pseudo-rapidity distributions,[1] and the production of particles at 0^{o} and 90^{o} in the c.m. system.[2,3] Essentially nothing is known about leading particle effects, about inclusive spectra over a wide kinematic range or about correlations between particles produced in nuclei.

We propose to survey as much of this material as possible over a wide kinematic region using the single arm spectrometer and multiplicity detector of experiment E118A together with a detector for π^{0}'s produced at large P_t. The prime purpose of the experiment is exploratory in nature and is not aimed at answering any one question. The data will, however, answer some specific questions raised by models which have been put forward to explain present data on multiparticle production in nuclei.

Physics Background

In high energy hadron-nucleus collisions, to a good approximation, the nucleus can be considered as a dense collection of nucleons. The nuclear structure, correlations between nucleons, etc. can be ignored in first order. This follows from the fact that the wavelengths of the incident and produced particles are much smaller than nuclear radii, and the characteristic times of hadronic interactions are much shorter than nuclear periods. The density of this collection of nucleons is of a magnitude which has made the nucleus a powerful tool for studying hadronic interactions. For example, the weak A-dependence of the multiplicity and pseudo-rapidity distributions has shown that the asymptotic final multiparticle states in hadron-hadron collisions are formed over distances much greater than nucleon sizes and that there is a hierarchy of production times, the slowest particles being produced first.[1] The observation[3] that the production of particles with large transverse momenta grows with A faster than $A^{1.0}$ suggests that nucleons in the nucleus can behave in a cooperative manner, which would be indicative of the presence of a long range component in the elementary hadron-hadron interaction.

Presently there is no single model which explains in a quantitative or qualitative manner <u>all</u> the features of hadron-nucleus collisions at high energies. The Multiperipheral Model[4] and Gottfried's Energy Flux Cascade Model[5] have been very successful in interpreting the multiplicity data but say little about the production of particles at high P_t. Farrar's quark model[6] and Pumplin and Yen's parton model[7] give plausible explanations of the large P_t behavior but say little about the multiplicity data. Qualitatively the data has also been explained in part by models such as Stodolsky's bremstrahlung analog model[8] and applications of the bag model.[9]

Clearly any model which purports to describe the fundamental hadron-hadron interaction must also account for the gross features of hadron-nucleus collisions. Since the models quoted above make very different assumptions about the elementary interaction, from a theoretical point of view, it is important to understand the essential elements of the models which account for their agreement with data. For the same reason, from an experimental point of view, it is important to study the limitations of these models and, what is even more important, to search for further unexpected differences that may exist between hadron-hadron and hadron-nucleus collisions.

At Fermilab energies, comparison of inclusive spectra from hydrogen and heavy nuclei is virtually unexplored territory. There is only the preliminary beam survey data for the forward production of particles by 300 GeV protons;[2] there is the data on the production of particles near 90° in c.m. system by 200, 300, and 400 Gev protons;[3] and there are two proposals, E406 and E418, to study inclusive spectra at 0° and 15° respectively in the laboratory frame of reference.

The single arm spectrometer in the M6 beam line is ideally suited to study the kinematic regions not covered by the above experiments, and there is good reason to believe that some interesting facts may be hidden in these regions. Both at large and small angles unexplained phenomena of different character have been observed. On the one hand, for particle production at 90° in the c.m. as P_t is increased from 0 to 4 GeV/c the A-dependence of the inclusive cross-section increases from about $A^{2/3}$ to about $A^{4/3}$.[3] On the other hand, in the forward direction, per collision, there is a decrease in particle production; the A-dependence goes approximately as $A^{1/2}$ for x-values above 0.3.[2]

The Proposed Experiment

We propose to explore the region between these two extreme behaviors by using the single arm spectrometer facility and an array of lead glass π^0 detectors to compare the inclusive spectra from a number of nuclei ranging from hydrogen through lead over a large kinematic range. Furthermore, to provide additional information which could significantly help in understanding the physics of these phenomena, we intend to measure for each spectrometer event and for each π^0 event at a $P_t > 1$ GeV/c the associated charged particle multiplicity and pseudo-rapidity distribuiton using the multiplicity detector of experiment #118A.

Our preliminary plan is to collect data for incident π^+, K^+, and P^+ at an energy of 175 GeV on H_2, Be, Al, Cu, Sn, and Pb. The inclusive distributions of π^+, K^+, and P^+ produced from these targets will be measured with the spectrometer at momenta between Pmax and 20 GeV/c and angles between 0 and 19 mr in the laboratory. The spectrometer data will explore the A-dependence of the inclusive distribution for values of x ranging from about .95 to about 0.1 and from $P_t \simeq 0$ to $P_t \simeq 1.25$GeV/c. The π^0 detector will be maintained in a fixed position during the entire experiment and will cover an angular range between 70 and 210 mr, and its front end will be segmented such as to define the P_t of the π^0 to about 10%. This detector will measure the A-dependence of the inclusive π^0 distribution for a range of P_t from 1.0 to about 4.0 GeV/c. The multiplicity detector[10] consists of 9 proportional wire chambers, a segmented Cerenkov detector, and a scintillation counter hodoscope. For each event, it will measure the charged particle multiplicity for laboratory angles between 0 and about 150° and the angular distribution for laboratory angles greater than 40 mr. This will enable the A-dependence of the average charged particle multiplicity to be measured as a function of x and P_t of the particles detected in the spectrometer or lead glass counter.

This exploratory investigation, in addition to exposing new phenomena, should answer some of the questions raised by the present data and theoretical models. To give a few examples, the experiment will provide significant information about the following questions:

i) It will check if the inclusive distribution of the leading particle is only weakly, if at all, dependent on A as predicted by all current models[1] which have been put forward to explain the multiplicity data. Specifically, if we represent the inclusive cross section for $a + b \rightarrow c$ + Anything by the expression

$$\frac{1}{\sigma_{ab}} \frac{d^3\sigma}{dp^3/E} = f_{ab}^{c}(x, P_t)$$

what is the ratio of $f_{aA}^{c}(x, P_t)$ (Nuclear Target) / $f_{ap}^{c}(x, P_t)$ (Proton Target) as a function of A and how does the A-dependence vary in different regions of x and P_t?

ii) The experiment will provide information on the extent to which the identity of the incident or the produced particle determines the A-dependence of the process. Does the A-dependence of the ratio

$$f_{aA}^{c}(x, P_t) \Big/ f_{ap}^{c}(x, P_t)$$

depend on the identities of a and c, the incident and produced particles, and if so, in what regions of x and P_t? This data should give information on the time evolution of various specific final states. Present data suggests that the A-dependence of the process is dependent on the incident particle.[1] In the forward direction the present limited data on the A-dependence of produced particles also suggests a dependence on the nature of the outgoing particle.[2,11] Because of the array of Cerenkov counters, differential and threshold, in the M6 beam line and in the focussing spectrometer, the spectrometer facility provides particle identification up to the highest momentum available. Since the incident beam contains P^+, π^+, and K^+, each of which can be identified on an event by event basis and the spectrometer can be set to detect simultaneously P^+, π^+, and K^+, various inclusive processes can be simultaneously measured and their A-dependence compared.

iii) The experiment will provide information on whether the exponent in the A^n behavior observed for the production of particles at large P_t depends on the identity of the incident particles, as well as the produced particles. It will also be possible to observe the A-dependence of the charged particle multiplicity which is correlated with the high P_t π^0 events.

iv) Using the spectrometer events the experiment will be able to determine where the A-dependent part of the rapidity distribution sets in, which is of major interest in a number of theoretical models.[1] By comparing these results with other data we can determine whether or not the onset moves to higher values of rapidity with increasing energy as is suggested by emulsion data from cosmic rays and accelerators.[12] Should this observation be confirmed, it would completely undermine all present interpretations of multiparticle production in nuclei.

Apparatus and Run Plan

The M6 focussing spectrometer facility and the multiplicity detector have been extensively described in proposals #96 and #118A. Though there have been some minor technical changes from these descriptions they have in no way altered the design philosophy nor the essential specifications of the apparatus.

The π^0 detector will cover a solid angle of 20 mster, consisting of 4 lead-glass blocks, each 6" x 6" x 15". On the upstream face of this array will be placed 3 radiation lengths of lead followed by a slatted scintillation hodoscope. By discriminating in the fast logic against minimum ionizing tracks in these slats, we can eliminate most of the triggers caused by charged pions. Since a γ ray will have produced a substantial shower in the three radiation lengths the location of the shower can be defined by the scintillation hodoscope. The energy deposited both in the scintillation hodoscope and the lead glass will be proportional to the energy of the incident photon and can be used to determine both the energy of the π^0 and the P_t of the π^0.

The run plan is to collect data from six different nuclei, H_2, Be, Al, Cu, Sn, and Pb at an incident energy of 175 GeV. A course x sweep will be made with the spectrometer at two values of P_t. Measurements will be made at x = .96, 0.8, 0.6, 0.4, 0.2, 0.1 for P_t = .25 and .50 GeV/c. Measurements will also be made as a function of P_t at a value of x = 0.6 extending the P_t range up to 1.25 GeV/c. Roughly half time will be spent taking data from shortened targets, half the length of the standard targets which are specified below. These measurements will allow the elimination of the effects due to the cascading of secondaries in the target through extrapolation to zero target length.

Our estimated counting rates are based on the following:

1) The M6 beam can provide about 2×10^6 protons, 6×10^5 π^+, and 7.5×10^4 K^+ per pulse, and the pulse repetition rate is 5 pulses/minute.

2) The spectrometer tune used will provide a solid angle of 6 μsteradians and a momentum acceptance of 6%.

3) A 20" liquid hydrogen target will be used to provide information on the primary (A=1) distributions. The standard solid targets will be constructed to have the same collision length as the hydrogen target unless their lengths exceed 1/2 of a radiation length, in which case they will be made 1/2 a radiation length long. Table I provides a summary of the lengths of the standard targets.

4) The π^0 detector will have a solid angle of 20 millisteradians.

5) The cross-sections used in the rate estimates for hydrogen are given in Appendix A. The rates for the nuclei were estimated from scaling the hydrogen cross-sections with the ratio of the collision lengths. The π^0 yields are based on the A^n dependence for large P_t yields where n is taken from Cronin et al.[3]

Table II gives counting rates per hour for incident175 GeV π^+, K^+, and P^+ for a range of x values at $P_t = .25$ GeV. The counting rates for the same values of x at $P_t = .50$ are smaller by a factor of about 2.5.

Table III gives the yield of π^0 events as a function of P_t that will be obtained during the entire experiment.

Based upon the above considerations we estimate that about 500 hours of running time will be required to carry out this series of measurements. In addition about 100 hours of testing prior to data taking will be required.

APPENDIX A

Differential Cross-Section Estimates

There are two generic types of reaction that can be studied, namely those in which the incident and detected hadrons are identical and those in which they are different species. As the representative of the former case, we take the reaction $pp \to pX$ at 450 GeV/c from the ISR.[13] This gives the familiar leading particle rise and peak at $x \to 1$. A parameterization of this data[14] has been obtained as a function of x and P_t. The parameters are listed in Table IV. The latter case is represented by the fit of Carey et al.[15] for the production reactions $pp \to h^-X$. The normalizations for this fit were taken from $pp \to \pi^-X$ inclusive data[16] at $s = 558\ GeV^2$. The one final class of events includes the detection of a forward proton in $\pi^+p \to pX$ for example. We have used a simple fit[17]

$$E \frac{d\sigma}{d^3p}\, \pi^+p \to pX \sim Ae^{-bx^2 - CP_t^2}$$

for the continuum proton spectrum.

We take these reactions to give the prototype invariant cross-sections. We define the invariant distribution function

$$f_{ap \to bX} = \frac{E_b}{\sigma^{TOT}_{ap}} \frac{d\sigma}{d^3p_b}$$

and make the following assumptions for the purpose of estimating counting rates:

a. $f_{hp \to hX} = f_{pp \to pX}$ leading particle fit

b. $f_{h^+p \to q^-X} = f_{pp \to q^-X}$ Carey et al. fit

c. $f_{h^-p \to q^+X} = f_{pp \to q^-X}$ Carey et al. fit for $q^+ \neq p$

d. $f_{h^\pm p \to pX} = f_{\pi^+p \to pX}$ Reference 17.

This involves merely scaling the inclusive cross-sections by the total cross-sections. Jacob[18] presents data indicating that such assumptions as $f_{\pi^+p \to \pi^-X} = f_{\pi^-p \to \pi^+X}$ and $f_{\pi^+p \to \pi^+X} = f_{\pi^-p \to \pi^-X}$ are valid at high energies. The forms a. - d. account for 26 out of the possible 36 incident-detected particle combinations. The other reactions are estimated using

e. $f_{h^\pm p \to q^\pm X} = R f_{h^\pm p \to q^\mp X} = R f_{pp \to q^-X}$

where R is the appropriate +/- ratio as calculated using the Hagedorn-Ranft statistical model ratios.[19] These ratios are close to those experimentally observed at the ISR.[16]

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Table I: Primary Targets

Nucleus	A	Target g/cm^2	Thickness in Rad. Lengths	Thickness in π interaction lengths
H_2	1	3.55	.057	.045
Be	9	4.58	.069	.045
Al	27	6.07	.25	.045
Cu	64	6.50	.50	.039
Sn	119	4.45	.50	.023
Pb	207	3.2	.50	.014

Table II: Estimated Counting Rate per Hour for Incident π^+, K^+ and P^+

		H_2	Be	Al	Cu	Sn	Pb
	π^+	$.265\times10^5$	$.265\times10^5$	$.265\times10^5$	$.178\times10^5$	$.113\times10^5$	$.726\times10^4$
X=.96	K^+	$.286\times10^4$	$.286\times10^4$	$.286\times10^4$	$.191\times10^4$	$.121\times10^4$	$.783\times10^3$
	P^+	$.130\times10^6$	$.130\times10^6$	$.130\times10^6$	$.87\times10^5$	$.37\times10^5$	$.356\times10^5$
	π^+	$.153\times10^5$	$.153\times10^5$	$.153\times10^5$	$.102\times10^5$	$.651\times10^4$	$.419\times10^4$
X=.80	K^+	$.166\times10^4$	$.166\times10^4$	$.166\times10^4$	$.111\times10^4$	$.707\times10^3$	$.455\times10^3$
	P^+	$.704\times10^5$	$.704\times10^5$	$.704\times10^5$	$.471\times10^5$	$.299\times10^5$	$.192\times10^5$
	π^+	$.114\times10^5$	$.114\times10^5$	$.114\times10^5$	$.76\times10^4$	$.486\times10^4$	$.312\times10^4$
X=.60	K^+	$.131\times10^4$	$.131\times10^4$	$.131\times10^4$	$.87\times10^3$	$.55\times10^3$	$.359\times10^3$
	P^+	$.555\times10^5$	$.555\times10^5$	$.555\times10^5$	$.371\times10^5$	$.236\times10^5$	$.152\times10^5$
	π^+	$.565\times10^4$	$.565\times10^4$	$.565\times10^4$	$.378\times10^4$	$.240\times10^4$	$.155\times10^4$
X=.40	K^+	$.752\times10^3$	$.752\times10^3$	$.752\times10^3$	$.503\times10^3$	$.320\times10^3$	$.206\times10^3$
	P^+	$.318\times10^5$	$.318\times10^5$	$.318\times10^5$	$.213\times10^5$	$.135\times10^5$	$.871\times10^4$
	π^+	$.152\times10^4$	$.152\times10^4$	$.152\times10^4$	$.101\times10^4$	$.647\times10^3$	$.416\times10^3$
X=.20	K^+	$.276\times10^3$	$.276\times10^3$	$.276\times10^3$	$.184\times10^3$	$.117\times10^3$	$.756\times10^2$
	P^+	$.119\times10^5$	$.119\times10^5$	$.119\times10^5$	$.797\times10^4$	$.507\times10^4$	$.326\times10^4$
	π^+	$.453\times10^3$	$.453\times10^3$	$.453\times10^3$	$.30\times10^3$	$.192\times10^3$	$.124\times10^3$
X=.10	K^+	$.953\times10^2$	$.953\times10^2$	$.953\times10^2$	$.639\times10^2$	$.406\times10^2$	$.261\times10^2$
	P^+	$.438\times10^4$	$.438\times10^4$	$.438\times10^4$	$.293\times10^4$	$.186\times10^4$	$.120\times10^4$

The above rates are for the standard length targets and for

$P_t = .25$

Table III: π^0 Events for Experiment

P_t GeV/c	Targets H_2	Be	Al	Cu	Sn	Pb
0.5-1.5	14.7 M	18.3 M	20.4 M	19.4 M	18.0 M	15.3 M
1.5-2.5	185K	320K	422K	455K	464K	428K
2.5-3.5	4.4 K	8.7 K	12.1 K	13.6 K	14.3 K	13.6 K
3.5-4.5	160	345	507	597	648	631
4.5-5.5	5	11	16	19	20	20

Table IV: Parameterizations

a. pp → pX at 450 GeV/c from Reference 13

$$E \frac{d\sigma}{d^3p} = \frac{(C_0 + c_1 x + c_2 x^2 + c_3 x^3)}{(b_1 - x)^{b_2}} \exp - (a_1 p_t + a_2 p_t^2)$$

where	a_1 = 1.529/GeV	c_0 = 12.854 mb/GeV^2
	a_2 = 2.645/GeV	c_1 = 10.829 "
	b_1 = 1.044	c_2 = -63.08 "
	b_2 = 1.58	c_3 = 39.85 "

b. $\pi^+ p \to pX$ at 22 GeV/c from Reference 16

$$E \frac{d\sigma}{d^3p} = C e^{-(a x + b p_t^2)}$$

where $a = 1.75$

$b = 6.0/\text{GeV}^2$

$c = 5.7$ mb/GeV^2