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INCLUSIVE REACTIONS

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ABSTRACT

Interests in inclusive reactions are discussed. Three proposed experiments are briefly described, and the kinematic regions accessible to and information available from them are discussed.

I. PHYSICS INTEREST

An inclusive reaction is one in which we look for a special particle(s), say c, with momentum $\vec{p}_c$ in the final state allowing anything else to be produced also.

$$A + B \to C + \text{anything}.$$

For example, one may measure the one-particle distribution function

$$\rho_{1c}(\vec{p}_c, E) \equiv \frac{d^3\sigma}{d\vec{p}_c^{\,3}},$$

at fixed incident energy E, or measure the multiplicity

$$\bar{n}_c(E) \equiv \int \rho_{1c}(\vec{p}_c, E) d\vec{p}_c^{\,3},$$

or the two-particle correlation function

$$\rho_{2c,D}(\vec{p}_c, \vec{p}_D, E) \equiv \frac{d^6\sigma}{d\vec{p}_c^{\,3} d\vec{p}_D^{\,3}}.$$

These measurements are interesting at high energy since

1. A large fraction of the total cross section is due to reactions of high multiplicity at high energy. Study of these distributions is the first step toward understanding the complicated multiparticle states.

2. Various dynamic models have specific predictions on these measurements. For examples,

(1.) Multiperipheral model[1] predicts $\bar{n}(E) \sim \ln E$ and $d\sigma/(E,n)/dn \sim$ Poisson distribution at fixed E.

(2.) Parton model[2] makes the same prediction on $\bar{n}$ as the multiperipheral model. In addition, it predicts that ρ_1 approaches a limit at high energy. Feynman defines

$$x \equiv \frac{p_{\parallel}^*}{\frac{W}{2}}, \quad Q \equiv p_{\perp}^*,$$

where $p_{\parallel}^*$ and $p_{\perp}^*$ are the longitudinal and transverse momenta of the particle in the c.m. system, and W is the total c.m. energy. This model then predicts that

$$\frac{dN}{dx} \sim \frac{1}{x} \text{ for } \frac{1\,\text{GeV}}{\frac{W}{2}} \lesssim |x| << 1, \text{ independent of E,}$$

which implies the production of many pions in the c.m. with small x.

3. Limiting fragmentation[3] predicts ρ_1 of the target (projectile) fragments approaches an energy-independent limit at high energy in the lab (projectile) frame. Yang et al. argue that there is no pionization, i.e., no pions produced with $x \approx 0$.

Recent results from ANL,[4] BNL,[5] CERN,[6] and cosmic-ray data[7] have shown some interesting comparisons to these predictions. It will be very interesting to study these reactions at NAL energy to understand the dynamics of hadron interactions.

There is a great deal of overlap among experiments on inclusive reactions, beam survey, and some inelastic reactions since the equipment they need is quite similar: a hydrogen target, a spectrometer for angular and momentum analysis, and Cerenkov and shower counters, and μ filters for particle identification. Since one looks for smooth functional dependence rather than fine structures in inclusive reactions, the resolutions needed are usually not very high.

II. THREE PROPOSALS

We shall now describe briefly three proposed experiments as representatives to illustrate the facilities needed to study inclusive reactions in different kinematic regions:

A. Proposal 63[8] (Setup 1)

A high-energy survey (up to 500 GeV/c) of the reactions

$$p + p \rightarrow A + \text{anything},$$

where $A = p^{\pm}, \pi^{\pm}, K^{\pm}, \mu^{\pm}, e^{\pm}$, or γ. Since the pp system has forward-backward symmetry in the c. m. system, one needs only to measure the particles in the backward hemisphere, which are slow in the lab. This makes the setup very compact. Figure 1 shows the schematics of the setup; the spectrometer is only 6 ft long, which can fit into the beam transfer enclosures. It is designed to analyze particles with lab momentum up to 2.4 GeV/c, using the Cerenkov counter, time-of-flight, specific ionization losses, and the range and pulse height from the shower counter.

B. Proposal 23[9] (Setup 2)

Study of reactions

$$\pi^{\pm}p \rightarrow A + \text{anything},$$

from 50 to 170 GeV/c, where $A = \pi^{\pm}$ or $K^{\pm}$ for $0 < x < 0.4$, $Q < 0.5$ GeV/c. The setup is shown schematically in Fig. 2. Pions of momentum 1.5-80 GeV/c are identified by three threshold Cerenkov counters. Current of the magnet is adjusted such that particles with a selected $p_{\perp}$ are bent parallel to the incident beam line. This simplifies the triggering and eliminates the need to move any part of the spectrometer.

C. Proposal 52[10] (Setup 3)

Study of reactions

$$A + p \rightarrow B + \text{anything},$$

where A, $B = p^{\pm}, K^{\pm}, \pi^{\pm}$ with 40-160 GeV/c incident momentum. The setup is designed for an almost complete kinematic range $-1.0 \leq x \leq +1.0$ and $Q \leq 3.5$ GeV/c. Figure 3 shows the forward arm, which has a variable length up to 200 m long to accomodate the Cerenkov counters needed to identify 160-GeV/c particles. Change of angles is achieved by sliding each element laterally on rails. The backward arm (not shown), which has fixed length, is simpler and much shorter and pivots about the vertical axis from 25° to 155° to detect particles from 0.5 to 1 GeV/c.

III. COMPARISONS

These three setups are optimized for different kinematic regions, which results in great differences in size and complexity. The regions accessible to each setup can best be illustrated with Peyrou plots with contours of lab angle (dashed curves) and momentum (solid curves). Figures 4-9 show the Peyrou plots for $A + p \rightarrow \pi + \ldots$ and $A + p \rightarrow p + \ldots$ at 100, 200, and 500 GeV/c incident momentum. In Figs. 6-9, the scales for $p_\perp^*$ and $|p_\parallel| < 2$ GeV/c are expanded to show the details in regions with small Q and x. The kinematical regions accessible to these 3 setups are shown by dot-dash curves.

Setup 1 does not detect all the particles produced in the backward hemisphere because of the limitation of 2.4 GeV/c lab momentum. (To do a perfect job, its capability would have to be expanded to 20 GeV/c, which destroys the elegance in its design.) It detects most of the particles except protons with $x \gtrsim -0.2$ and pions with $x \simeq 0$ and $Q > 0.2$ GeV/c (loss of K, μ are similar to π). This makes it difficult for the study of pionization but will be perfectly all right for $|x| >> 0$ and for beam survey since most of the particles have $|x| >> 0$.

Setup 2 is designed for the region $0 < x < 0.4$ and $Q < 0.5$ GeV/c for incident momentum 50 to 170 GeV/c. This limits p_{lab} within the range 1.5-80 GeV/c (Fig. 5) which results in a relatively simple design (as compared with setup 3). This region is most interesting for pionization and scaling-law studies.

Setup 3 is largest in scope because it is designed to cover $-1.0 < x < +1.0$ and $0 < Q < 3.5$ GeV/c which is essentially the complete kinematic range. It will give the most complete information on ρ_1; then $\bar{n}$ can be obtained by integrating ρ_1 over the complete phase space and using the total cross section obtained from other experiments.

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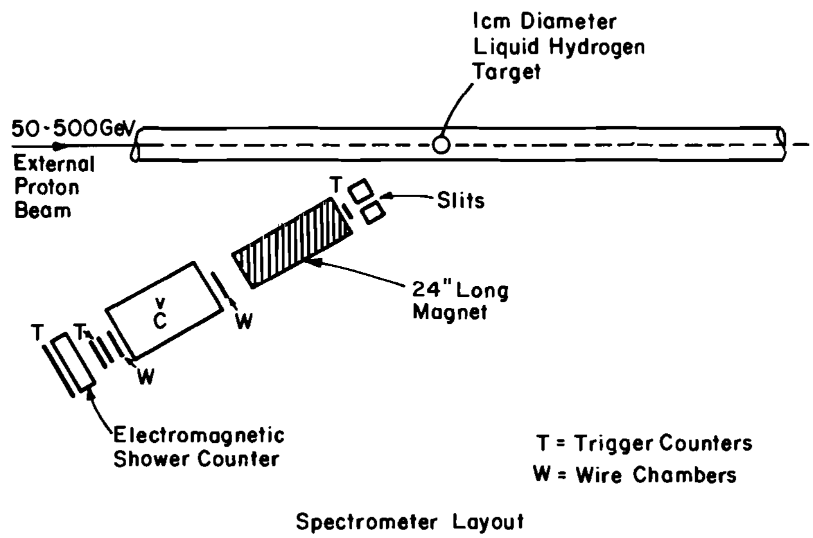

Fig. 1. Schematics of Setup 1. Total length of spectrometer = 6 ft located in proton beam transport tunnel leading to beam dump.

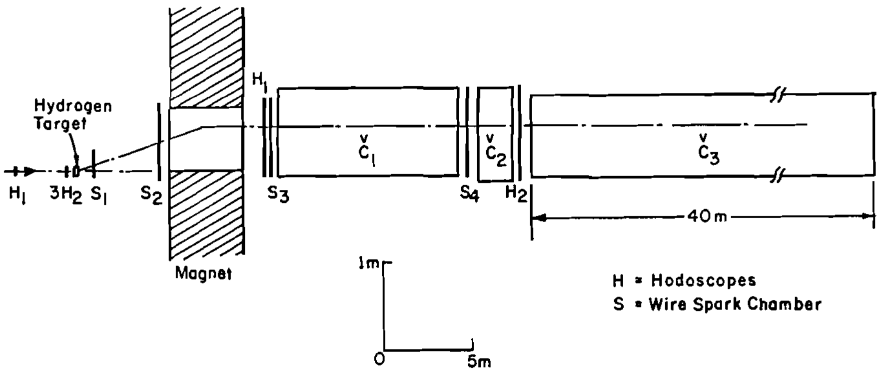

Fig. 2. Schematics of Setup 2. Current of the magnet is adjusted such that particles with a selected $p_\perp$ are bent parallel to an incident beam line.

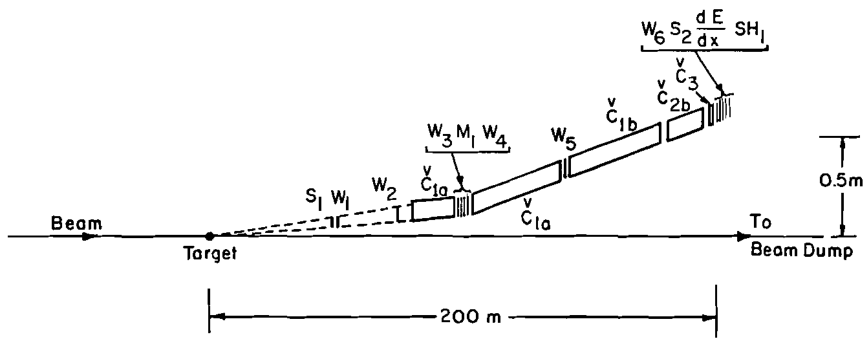

Fig. 3. A sketch of the layout of the "forward" spectrometer configuration of Setup 2 as seen from above. The dimensions shown are for the momentum band 80-160 GeV/c. The scale for any other momentum band is obtained by scaling the longitudinal distances linearly with momentum.

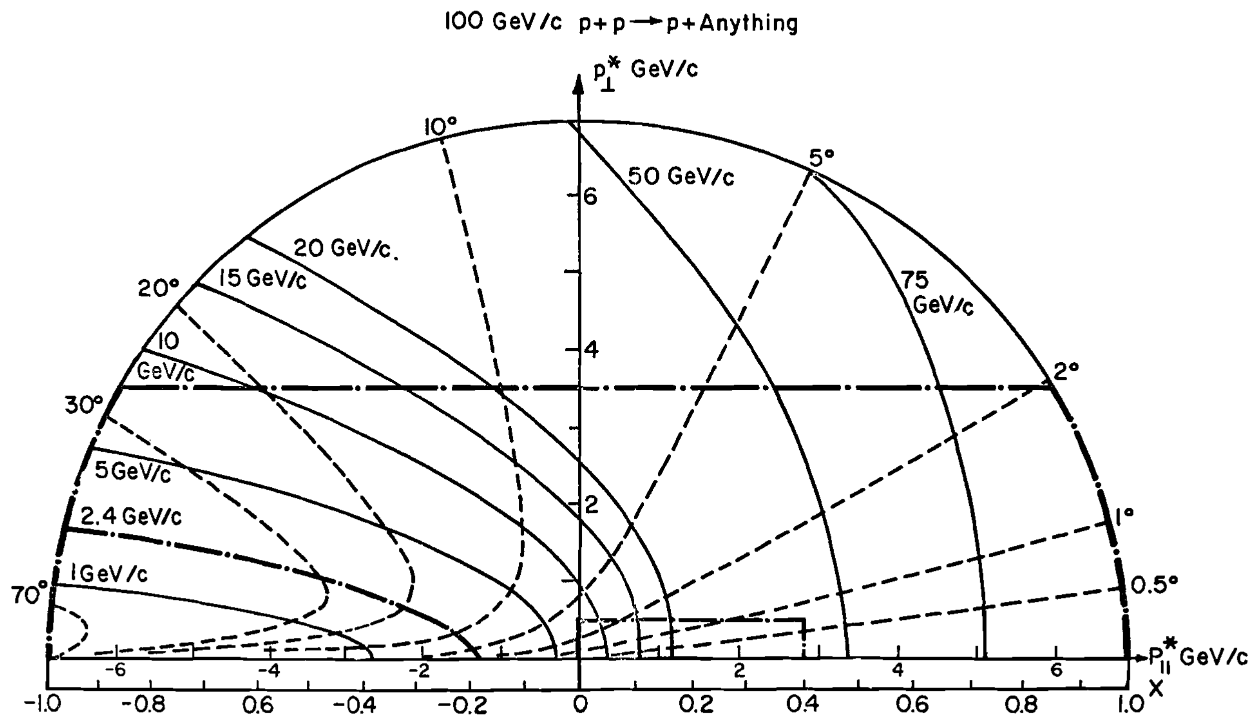

Fig. 4. Peyrou plot for the p in reaction A + p → p + . . . at 100 GeV/c (A = p, K, π.) Contours of lab angle (dashed curves) and momentum (solid curves) and regions accessible to Setups 1, 2, and 3 (bold lines) are also shown.

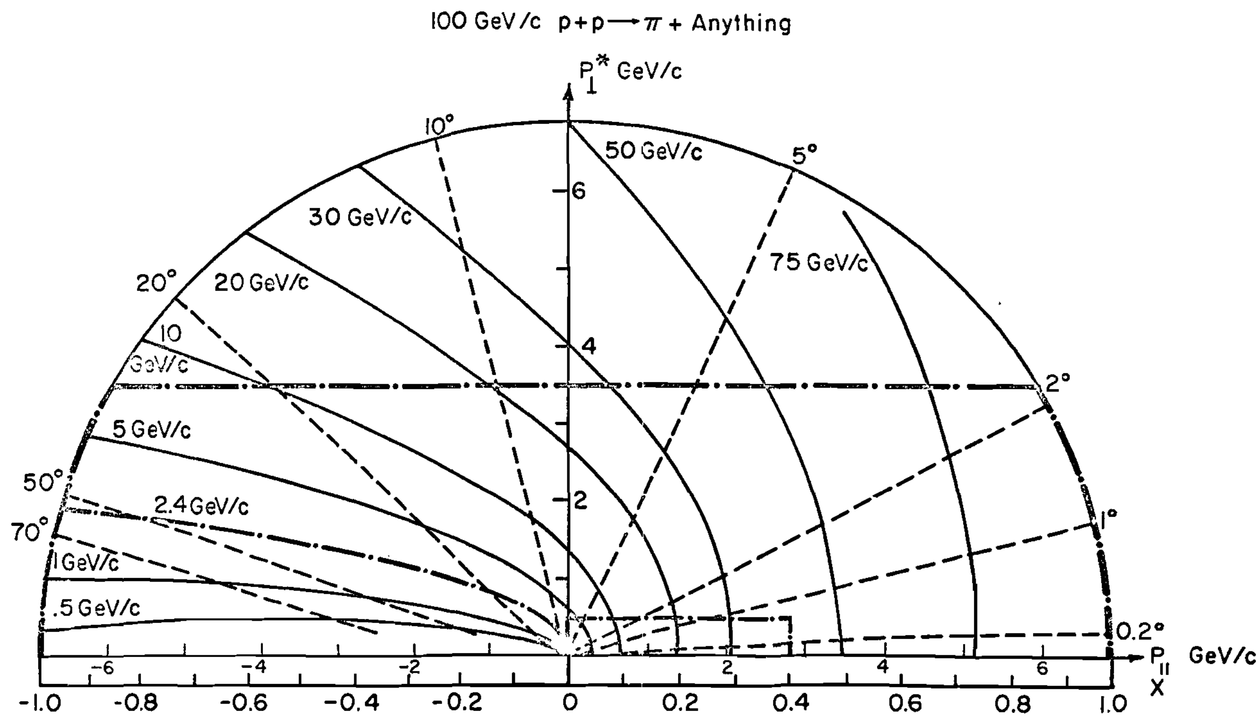

Fig. 5. Same as for Fig. 4 for A + p → π + . . . at 100 GeV/c.

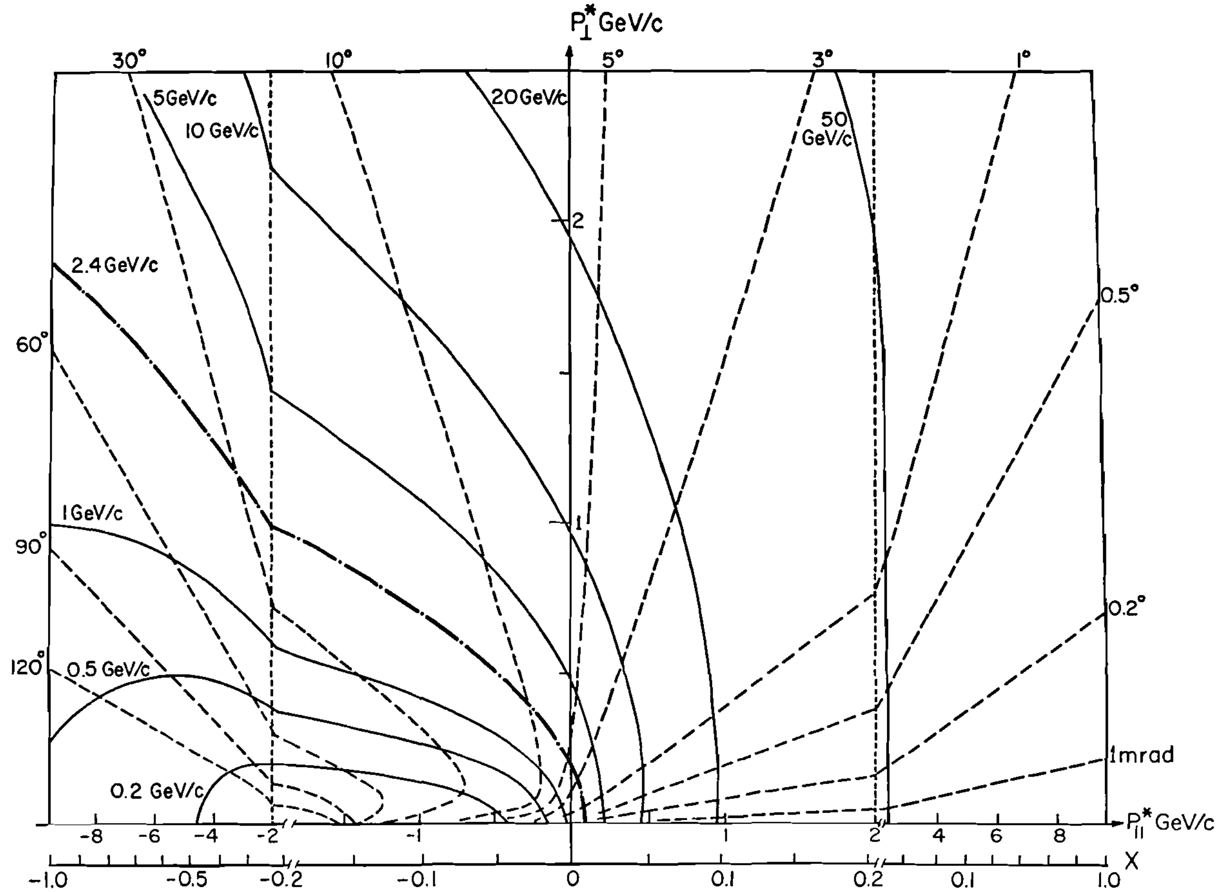

Fig. 6. Same as for Fig. 4 for A + p → π + . . . at 200 GeV/c (scales have been expanded).

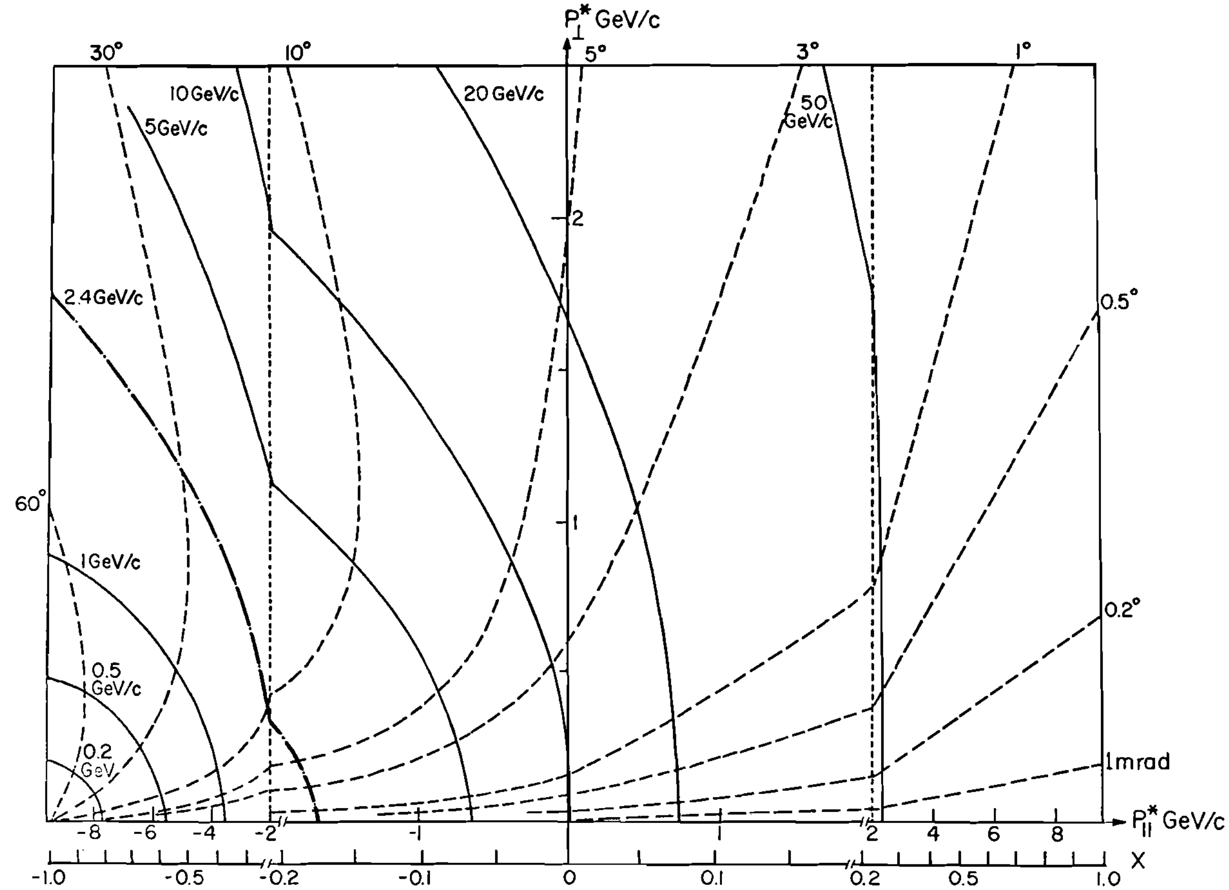

Fig. 7. Same as for Fig. 5 for A + p → p + . . . at 200 GeV/c.

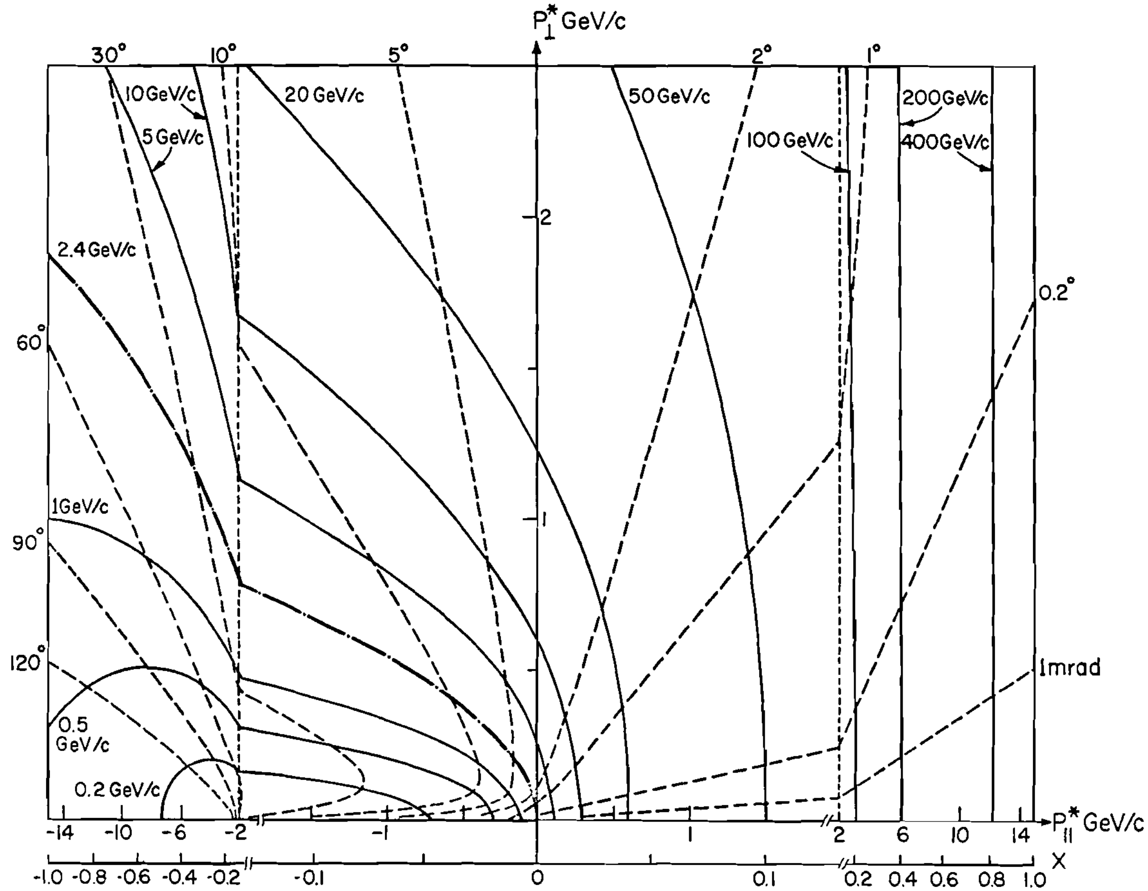

Fig. 8. Same as for Fig. 6 for A + p → π + . . . at 500 GeV/c.

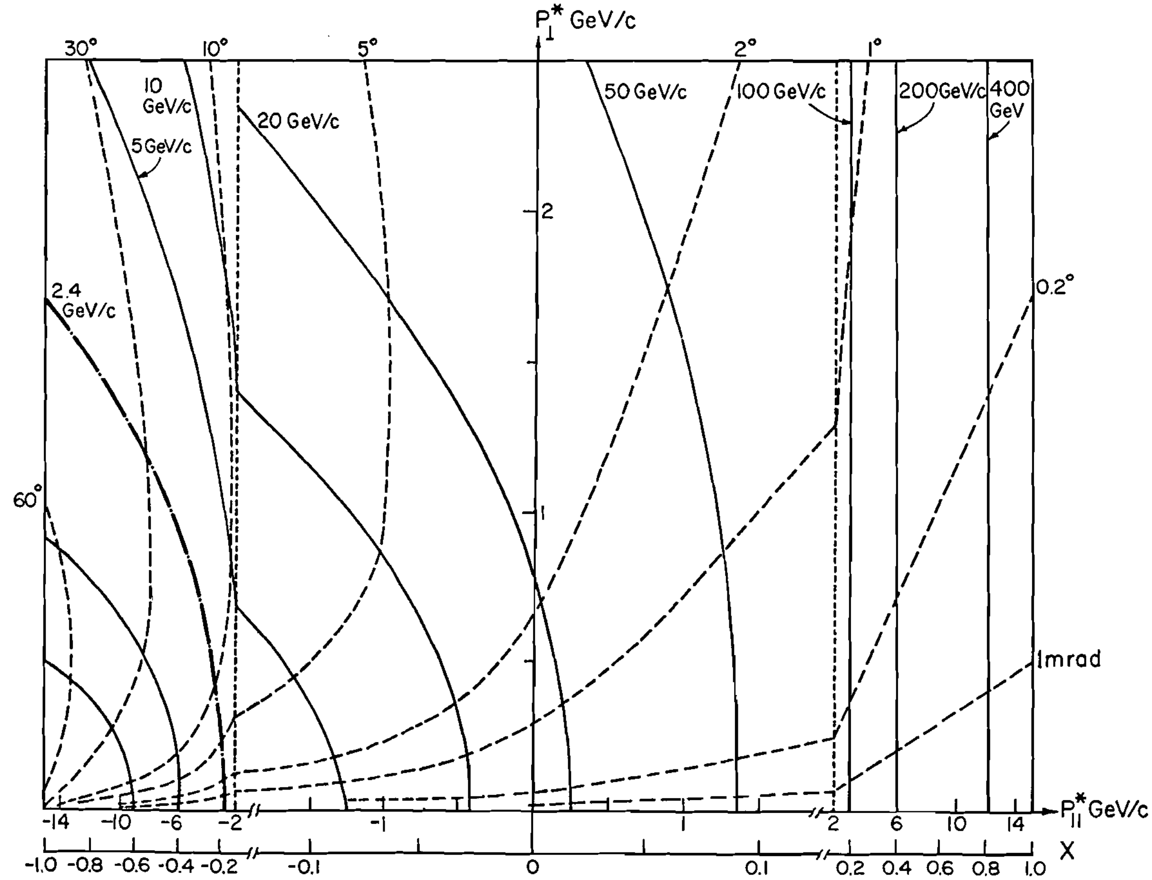

Fig. 9. Same as for Fig. 7 for A + p → p + . . . at 500 GeV/c.