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PROTON INTERACTIONS IN HEAVY NUCLEI AT 200 GEV*

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ABSTRACT

Nuclear track emulsions were exposed to 200 GeV protons at the National Accelerator Laboratory. One of the emulsion plates was loaded with granules of Tungsten. Interactions in the emulsion and with the Tungsten granules were located and angular measurements were made on the shower particles. The average number of charged evaporation particles produced on Tungsten was found to be 29.4 ± 4.3, which is much larger than expected. Moreover, the average multiplicity of shower particles is 16.8 ± 3.8, about twice as large as that for p-p interactions. The corresponding values for the emulsion are 7.2 ± 0.5 and 13.9 ± 0.6 for the multiplicity of evaporation and shower particles, respectively. The angular distribution of shower particles produced on Tungsten was compared to that for p-p interactions. These data are in qualitative agreement with recent calculations by Fishbane and Trefil.

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INTRODUCTION

Recently there has been renewed interest in the nature of internuclear cascading resulting from collisions of hadrons with heavy nuclei. This is in part due to the belief that the study of the inclusive distributions in such reactions may allow one to distinguish between various classes of models for particle production on individual nucleons. In order to make such distinctions with nucleon targets, one must study the correlations among the produced particles.

Fishbane, Newmeyer, and Trefil[1] have discussed the possibility of inferring the character of the p-p interaction by measuring the multiplicity and the production angular distribution produced by protons on nuclei both as a function of the incident momentum and of the atomic number of the nucleus. In this paper we would like to present some initial data obtained during a recent exposure of nuclear emulsions (one of which was loaded with granules of tungsten) to 200 GeV protons at the National Accelerator Laboratory and compare these data with the theoretical predictions made by these authors.

Fishbane and Trefil[2] have divided the current models for multiparticle production into two classes: (1) coherent production models (CPM) in which an intermediate excitation propagates through the nucleus before it decays, and (2) incoherent models (IPM) in which the secondaries are produced directly. In the latter case, the secondaries can interact with other nucleons in the nucleus producing an intranuclear cascade. In either case, the nuclear part of the interaction is considered to be incoherent and therefore a summation is performed over all final nuclear states.

Both calculations are based on an extension of the Glauber theory. In the case of the IPM, the model chosen for the p-p interaction was of the multiperipheral type.

The CPM calculation was based on a nova model. Further information about the details of these calculations has been published[2-3] by these authors.

The qualitative results of the calculations for both models can be summarized as follows:

i) The rapidity distribution in the projectile region is approximately the same as for p-p collisions.
ii) In the target region, the rapidity distribution exceeds that for p-p collisions.
iii) The multiplicity is predicted to be larger than for proton targets.

The models differ in their prediction of the magnitude of the average charged shower particle multiplicity $\langle n_s \rangle$ (although they do not differ much for certain energies) and in the dependence of the multiplicity on the total center of mass energy (s) and on the atomic number (A) of the target. The IPM calculation predicts[4]

$$\langle n_s \rangle = E + F \ln s$$

where E and F are independent of A for values of A greater than 10. The CPM calculation predicts[4]

$$\langle n_s \rangle = \tfrac{1}{2}(C\,A^{\frac{1}{3}} + 1)\ \langle n \rangle_H$$

where $\langle n \rangle_H$ is the multiplicity on a hydrogen target and C has a value close to ½.

EXPERIMENTAL PROCEDURE

One of the nuclear track plates (Ilford G-5) was prepared with a dispersion of tungsten powder in the emulsion. The use of small granules made it possible to observe nearly all of the tracks produced in a given collision. For example, the collision shown in Fig. 1 took place near the middle of an irregular piece of tungsten, yet all but the shortest recoil track can readily be seen.

After preparation, the plates were exposed to the 200 GeV proton beam at the National Accelerator Laboratory until an intensity of about 100,000 tracks per square centimeter had been obtained. The emulsion plates were scanned by following proton tracks. The tungsten plates were area scanned. Each event was examined to insure that it had an incoming track pointing in the direction of the beam. For tungsten events, the emitted tracks were required to project back to an origin within a tungsten granule. Spacial measurements were made on each track in order to determine the production angle of each particle. These emitted tracks were grouped according to the usual criterion:

i) Tracks with an ionization less than 1.4 times that of a minimum ionizing track were classified as shower particles, n_s.

ii) Tracks with an ionization greater than this were classified as evaporation, or heavy tracks, N_h.

During the scanning of the plate loaded with tungsten powder, 25 possible events were located. Eight of these satisfied the criteria for an event taking place on tungsten. Since several possible events with a small number of tracks were found in the scanning, we do not believe that our results are biased against low multiplicity events. A partial second scan of the plate reinforces this belief.

EXPERIMENTAL RESULTS

Based on a sample of eight events, we find the average multiplicity of shower tracks $\langle n_s \rangle$ to be 16.8 ± 3.8 for

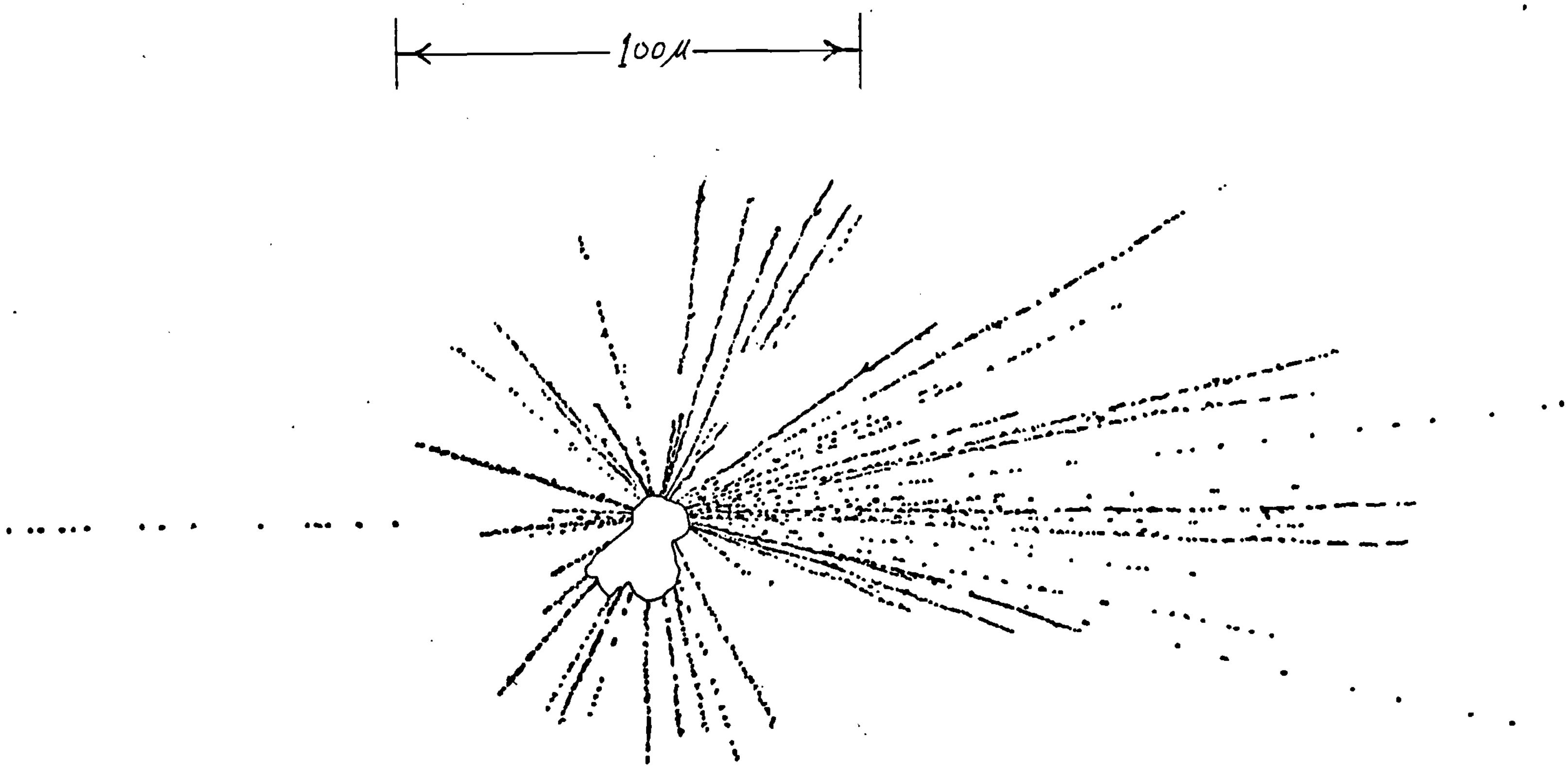

Fig. 1. Collision of 200 GeV proton with a tungsten nucleus. A total of 66 tracks radiate from a common center within the tungsten powder target located in the nuclear emulsion. 18 of the tracks were classified as shower particles.

collisions of 200 GeV protons with Tungsten nuclei. The corresponding value for 181 events taking place in the emulsion is 13.9 ± 0.6. The quoted errors correspond to one standard deviation. In comparison, the average multiplicity for p-p collisions at 205 GeV has been measured[5] in a hydrogen bubble chamber to be 7.65 ± 0.17.

One can further study the A dependence of the multiplicity by attempting to separate the emulsion events occurring in silver and bromine from those in the carbon, nitrogen, oxygen group. By assuming cross-sections proportional to $A^{\frac{2}{3}}$, one calculates that 10 of the events should have occurred in hydrogen, 45 events in the CNO group, and 126 events in Ag-Br. Secondly, we have assumed that hydrogen events all have $N_h = 0$ and that all events of $N_h > 8$ occurred in silver or bromine.

One can eliminate the 10 hydrogen events from the sample of $N_h = 0$ events by using the known p-p multiplicity of 7.65 ± 0.17. Since 64 events have $N_h > 8$, 62 events must be selected from the events of $N_h \leq 8$ to include in the Ag-Br sample. The remaining unselected events are attributed to the CNO group. While this selection process can proceed under a variety of different assumptions, the Ag-Br group multiplicity can be determined within rather narrow limits. The limits on the CNO group multiplicity are less stringent since all CNO events are subject to the selection process (as opposed to only half of the Ag-Br events).

The input data for this analysis are as follows:

i) for all 181 events in emulsion,

$$\langle n_s \rangle = 13.9 \pm 0.6$$

ii) for 171 non-hydrogen events,

$$\langle n_s \rangle = 14.3 \pm 0.6$$

iii) for 64 events with $N_h > 8$

$$\langle n_s \rangle = 18.4 \pm 1.1$$

iv) for 107 non-hydrogen events with $N_h \leq 8$

$$\langle n_s \rangle = 11.8 \pm 0.5$$

Quoted errors are one standard deviation.

The "best estimate" of the Ag-Br and CNO multiplicities was obtained by plotting the N_h distribution for $N_h > 8$ and smoothly extrapolating it through the $N_h \leq 8$ region such that exactly 62 events were contained in the extrapolation region. This gave the number of events of each N_h value to be included in the Ag-Br sample. Events for each N_h value were then assigned a multiplicity equal to the average for all events of that N_h. (Thus, the assumption was that for a particular $N_h \leq 8$ the average multiplicities are equal for Ag-Br and CNO events.) The values obtained are:

$$\langle n_s \rangle = 15.4 \pm 1.0 \qquad \text{for Ag-Br}$$

$$\langle n_s \rangle = 11.2 \pm 1.5 \qquad \text{for CNO}$$

The errors quoted are a subjective estimate based on the sample standard deviations given earlier and a feeling for possible systematic errors based on the analysis to follow.

If it is assumed that the CNO average multiplicity cannot exceed (except by force of statistics) that for Ag-Br one calculates the maximum CNO multiplicity and the minimum Ag-Br multiplicity by forcing them to be equal. The value so obtained is $\langle n_s \rangle = 14.3 \pm 0.6$ which is quoted above for 171 non-hydrogen events. Similarly the (not too realistic) lower limit for the CNO multiplicity is the p-p multiplicity, 7.65 ± .17. This assumption leads to an upper limit for the Ag-Br multiplicity of 16.7 ± ∿.5. Operating under either of these limiting assumptions, one must select Ag-Br events with $N_h \leq 8$ in such a way that the resulting N_h and n_s distributions for the CNO and Ag-Br groups are skewed unreasonably.

Fig. 2 is a compilation of the above results in which the average multiplicity of charged particles is plotted against $A^{\frac{1}{3}}$. Data for pure hydrogen, CNO and Ag-Br groups in emulsion, all non-hydrogen events in emulsion and tungsten events are included. Theoretical curves for IPM and CPM calculations are shown[2,3]. These predictions are expected to be good to within ∿10%. In spite of large experimental uncertainties several important conclusions are evident. First, the data seem incompatible with A independence. Only by stretching the statistics to their limits can one claim A independence. Secondly, the multiplicities are systematically higher than CPM predictions. However, the slope (within broad limits) is compatible with CPM. Furthermore, it is possible to extrapolate a linear $A^{\frac{1}{3}}$ dependence to include the pure p-p data.

The large value of the average evaporation prong number for tungsten events, $\langle N_h \rangle = 29.4 \pm 4.3$, can be interpreted as a further indication that the intranuclear cascade process is A dependent. By comparison, all emulsion events have $\langle N_h \rangle = 7.2 \pm 0.5$ while for non-hydrogen emulsion events $\langle N_h \rangle = 7.6 \pm 0.5$. Subjecting the emulsion N_h distribution to the same selection process indicated earlier for shower particle multiplicities, one calculates the maximum possible evaporation prong multiplicity for the Ag-Br group to be $\langle N_h \rangle = 10.1 \pm .6$. The ratio of $\langle N_h \rangle$ in tungsten to that for Ag-Br, $R = 2.9 \pm 0.5$, seems too large to be explained by the ratio of nuclear charges $Zw/Z_{Ag-Br} = 1.8$. In emulsion the shower particle multiplicity is linearly related to N_h[6], so that large values of either N_h or n_s are indicative of cascading. By similar reasoning it would seem that since tungsten nuclei are fragmented to a much larger degree than silver or bromine nuclei there must be more secondary cas-

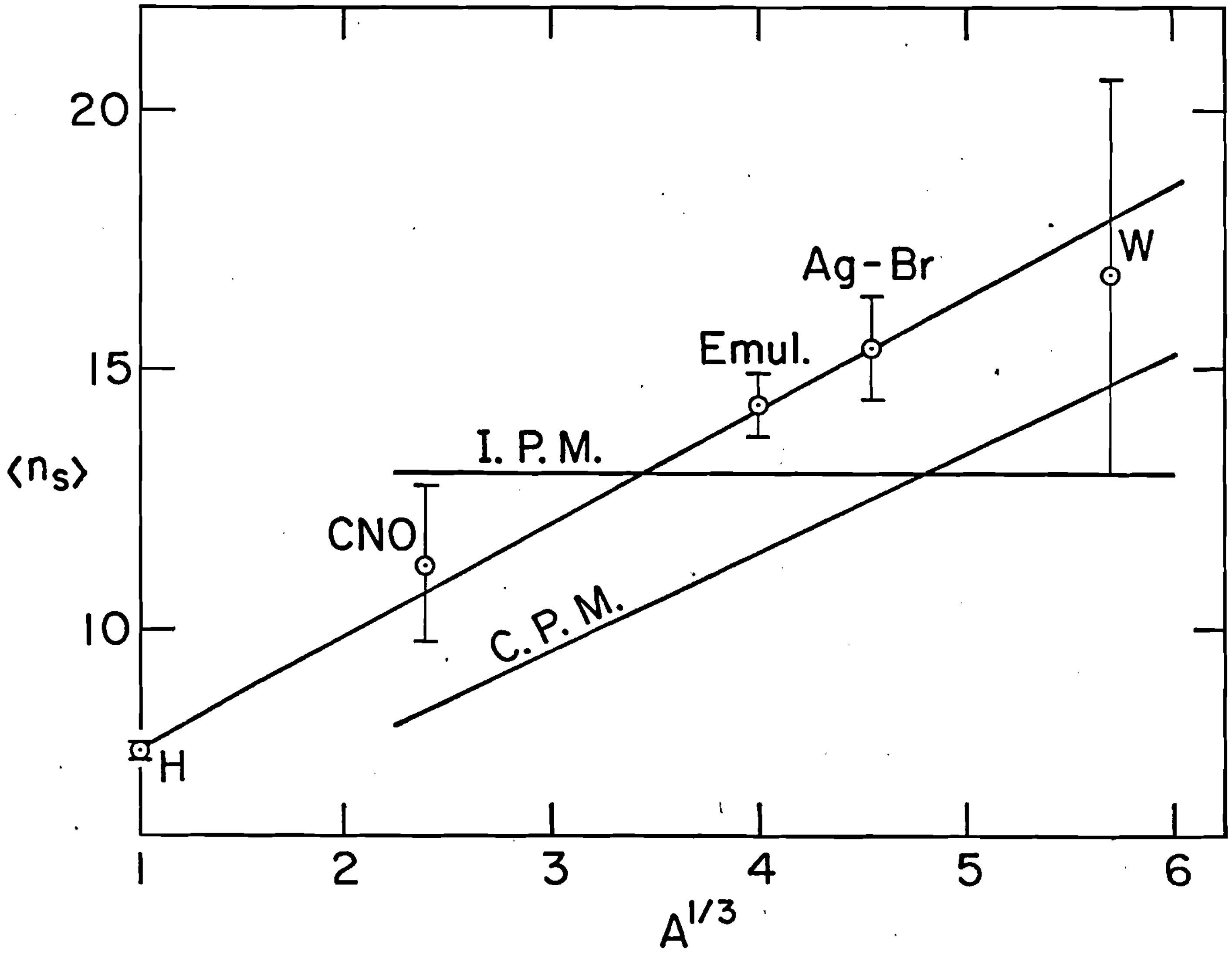

Fig. 2. Average charged particle multiplicity plotted against $A^{1/3}$ for 200 GeV proton interactions in hydrogen, emulsion, and tungsten. Furthermore the emulsion data have been separated into silver-bromine group and carbon-nitrogen-oxygen group events.

cading interactions involved.

Analysis of the angular distribution is best made in terms of the rapidity. This requires a knowledge of the $\beta(\equiv v/c)$ of the emitted tracks, which we did not determine. However, our ionization criterion for the classification of a track as a shower track requires that β be close to one. If we set $\beta = 1$, the rapidity is given by

$$r = -\ln \tan(\theta/2),$$

where θ is the production angle of the track in the laboratory frame of reference.

The histogram in Fig. 3 shows the angular distribution for those events which occurred on tungsten. The comparison data for pure p-p interactions[6] are shown by the points. These have been normalized so that the relative number of tracks corresponds to the relative multiplicities. The solid curve is the prediction of the IPM calculation by Fishbane and Trefil.[2] It has been normalized to their predicted value of 13 for the multiplicity.

We see that the theoretical curve is in qualitative agreement with the experimental data. It is in quantitative agreement for large values of rapidity. Namely, the p-p data and the p-nucleus data agree for small angle tracks. However, in the region of very small rapidity, there exists a considerable excess in the experimental data.

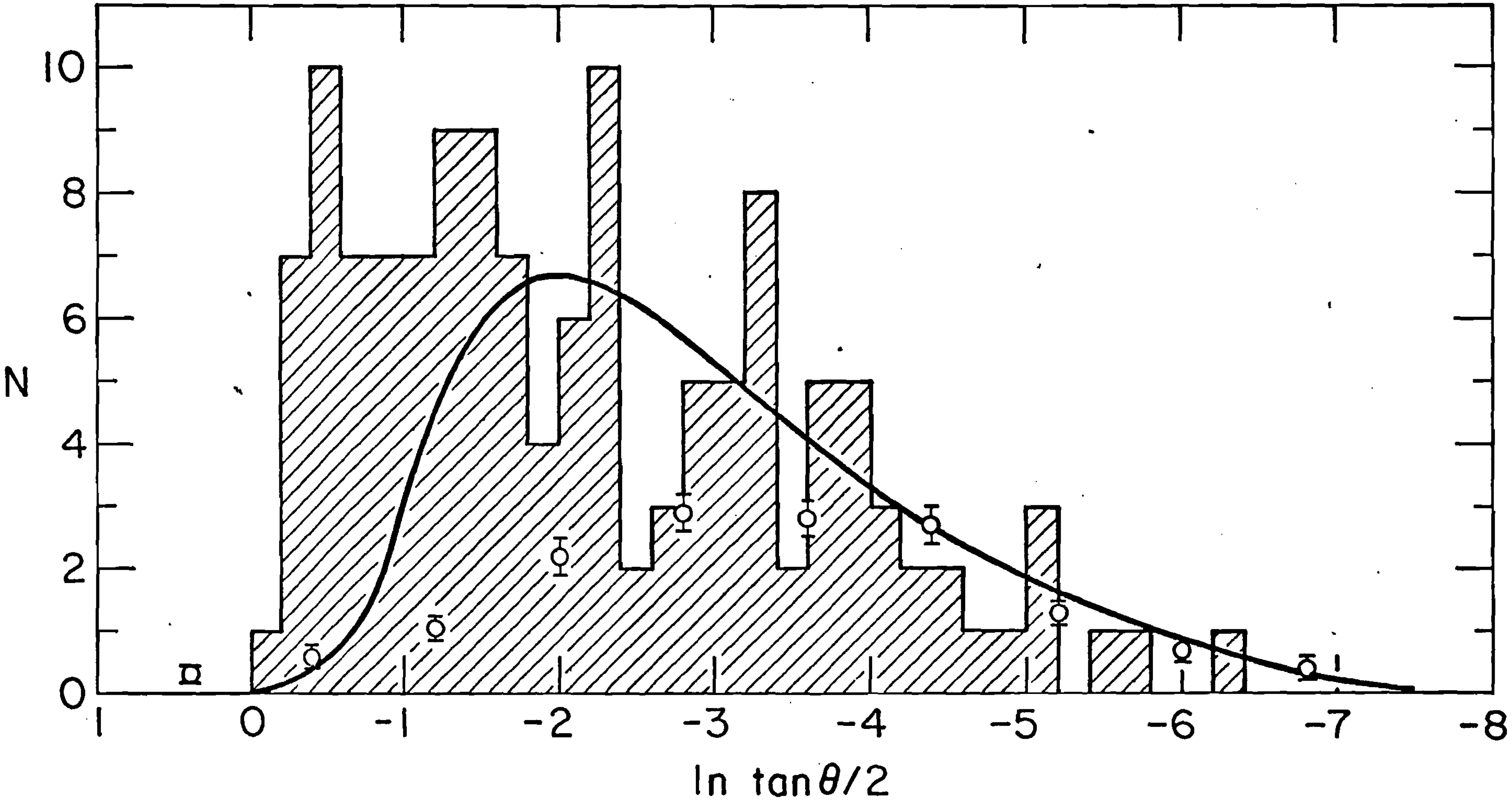

Fig. 3. Angular distribution of emitted particles produced by 200 GeV protons. The histogram is for collisions with tungsten nuclei; while the points are for p-p interactions.[7] The solid curve is a theoretical prediction by Fishbane and Trefil.[2]

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