NAL PROPOSAL NO. 194

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PROPOSAL TO SUTDY
PROTON - DEUTERON INTERACTIONS IN THE 30 - INCH BUBBLE CHAMBER

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PROPOSAL TO STUDY PROTON-DEUTERON INTERACTIONS IN THE NAL 30-INCH BUBBLE CHAMBER

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We propose to expose the NAL 30-inch bubble chamber filled with deuterium to protons at 200 GeV and 400 GeV, with 100,000 pictures at each momentum. We will study odd prong multiplicity cross sections, inclusive distributions, two-particle correlations, neutron diffraction dissociation, π^0 multiplicities, neutral strange particle production and coherent pd scattering.

Exposure:

We propose to make two exposures at 200 GeV and 400 GeV with 100,000 pictures at each energy. We intend to run with five beam tracks per picture, i.e. we have ~ 1 interaction (pp or pn) every other picture. About one-fourth of all pn interactions can be picked up without any background (see next chapter). With 7,000 events at each energy, our exposures contain then a number of bias-free pn events similar to the exploratory pp exposures in progress now.

It is difficult to reconstruct, in particular, high multiplicity events in space, due to the difficult track matching of fast forward going tracks which are close to each other in space. Currently, the track matching in the 200 GeV pp exposure is done by operators using specific bubble density patterns of the tracks.[1] This is a slow procedure and does not allow the fast measurement of a large number of multi-prong events. We propose, therefore, to place a plastic plate, about 1/2 cm thick, into the far down stream part of the chamber. The plate causes a gap on the tracks and hence enables one to measure a corresponding point on the track in each view, considerably diminishing the track matching problem. The installation of this small plate does not pose any problem and can be done in a short time.[2] The 30-inch chamber was successfully run with several plates at ANL.

If one selects events with a spectator proton of less than 0.3 cm length, one has negligible background from pp interactions. These "odd prong" events, however, about 60% of the pn interactions are not bias-free since ~ 7% of the

genuine odd prongs are turned into even prongs by secondary interactions with the spectator proton. This 7% distortion, however, can be calculated using existing pp data and can at least be partly corrected for (see next chapter).

We expect 16,000 odd prong events at each energy.

"Engineering" of the Deuteron-Target:

We want to study pn reactions and hence have to consider the following background reactions:

pp reactions,

pn reactions with secondary interaction on the spectator proton, and

pd coherent reactions.

We, therefore, select events in the following two classes:

(1) Even prongs with a slow proton backward in the lab: This proton must be a spectator proton. Experience with d-experiments in the 30-inch chamber tells us that we capture ~ 25% of all pn reactions in this way. Fig. 1 shows the measured spectator proton momentum distribution from a 5.5 GeV K^-d experiment in the 30-inch chamber. About 43% of the Hulthen distribution are measurable and ~ 50% visible which gives us 25% in the backward half of the solid angle.[3]

These events are bias-free and will be used for the measurements of odd multiplicity cross sections σ_n.

(2) "Odd" prong events: These are pn interactions with a spectator proton length less than 0.3 cm which corresponds to 68% of the Hulthen distribution. The background reactions are (we exclude here the one-prongs which will be discussed later):

(i) pp interactions with a slow recoil proton, i.e. a pp four-prong of this kind simulates a pn three-prong. Fig. 2 shows the momentum distribution for the slow recoil proton from four-prongs

in the 200 GeV pp exposure.[4] The fraction of events with $lp < 0.3$ cm (i.e. $p < 0.1$ GeV) is about 1%. For higher prong numbers, this fraction becomes smaller which is to be expected and observed in the 100 GeV pp data.[5] We neglect this part of the background.

(ii) Coherent inelastic pd interactions: The d form factor causes the coherent cross section to fall off sharply as a function of t, $d\sigma/dt \sim e^{-30t}$, hence the coherent processes are diffractive. Diffraction dissociation into low mass N^* up to 30 GeV is found to be energy independent and is expected to stay about constant up to our energy.[6] Hence, we use results at 28.5 GeV[7] in order to estimate the coherent cross section for $pd \to d(p\pi^+\pi^-)$. With $\sigma_{coh} = 200\ \mu b$ and an estimate of $\sigma_3^{pn} \approx 4.5$ mb, we arrive at $\sim 5\%$ background for σ_3^{pn}. For higher multiplicities, i.e. higher mass $(p\pi\pi\ldots)$ systems recoiling against the d, we expect negligible background.

(iii) Secondary interactions in the deuteron:

$$\left.\begin{array}{l}\text{pn + secondary interactions}\\ \text{pp + secondary interactions}\end{array}\right\}$$

always lead to an even prong number, whether the interacting secondary is charged or neutral. Hence, the odd-prongs are pn events, but a certain fraction of the genuine odd prong interactions is turned into even prongs by secondary interactions. We make

the conservative estimate that the secondaries in the average are spread out in a $\pm 30^{\circ}$ cone with respect to the beam. We estimate then for the probability to hit the spectator proton in this cone about 7%. For low n, this distortion of the odd multiplicity cross sections does not depend strongly on the multiplicity, as observed in 16 GeV $\pi^- p$ production of multiple π events (up to 5 charged π's) in nuclei. This is discussed by one member of the Stony Brook group, A. S. Goldhaber.[8] For higher multiplicities, Goldhaber will use existing pp data and estimate the secondary interaction effect on spectra and correlations in deuterium. Additionally, the effect of secondary interactions can be studied empirically by comparing the even pd events with no Hulthen-like proton with the pp data from the hydrogen exposures.

With these calculations and empirical checks, we feel confident to use the odd-prong events for inclusive distributions and two particle correlations.

Finally, we discuss the one and two-prong events: The "one"-prong events with a spectator of less than 0.3 cm length will be mostly missed in the scan. Hence, we do not consider them for the measurement of σ_1.

The two-prongs, one-prong being the backward spectator, will be found due to their bad signature with about half the efficiency of the higher prong events.

At last, we mention that an estimate for <u>coherent processes</u> can be made. This requires a very careful scan for short recoils, in particular, for

the two-prongs.

We use the elastic coherent pd cross section measured at 19 GeV[9] and assume energy independence. The visible t range for the coherent events is $0.017\ \mathrm{GeV}^2 < t < 0.03\ \mathrm{GeV}^2$ which corresponds to a range in d-recoil length of $0.1\ \mathrm{cm} < \mathrm{ld} < 0.3\ \mathrm{cm}$. We estimate to find 450 coherent elastic events pd → pd at each energy. Background events are:

(i) pp → two-prongs with one slow recoil p,

(ii) pn → one-prong and a short spectator track, and

(iii) pd → pd + neutrals.

(i) Most of the pp two-prong events in the momentum range which correspond to our recoil length selection have angles θ with the beam of $\theta > 66^\circ$. The recoil d has $\theta < 45^\circ$. We scan in this region and hence can neglect pp background.

(ii) Assuming about 10 mb for σ_{pn}(el. + inel. one-prong), we estimate a background of 300 such events with $\theta < 45^\circ$. This background can be subtracted by using the data outside this angle range.

(iii) The inelastic coherent contamination is small. We use results from Ref. 7 and estimate to have 40 events pd → $d(p\pi^+\pi^-)$ in the same range of ld as above for both energies. This is about a 10% background in the elastic coherent sample. With $\sigma_3^{pn} \approx 4.5$ mb, we have 160 events pn → 3 prong + $p_{spectator}$ in our region for ℓ_{recoil} and θ. Hence, this inelastic coherent process itself can only be poorly estimated.

Physics Justification:

1. Odd Prong Multiplicity Cross Sections σ_n:

The energy dependence of σ_n for odd n will be studied and compared with the even prong pp topological cross sections. For this at least two energies at NAL are needed. In particular, it will be of interest to see whether σ_7 and σ_9 turn over in the NAL energy range (σ_8 seems to fall off at 300 GeV). Data at 28.5 GeV are currently being analyzed.[11] Our results will be additional data for the study of σ_n as a function of n in testing models for multiparticle production.

2. Single Particle Distributions:

The 30-inch chamber is well suited to measure the momenta of all particles emitted in the backward hemisphere. Fig. 3(a) and (b) display lines of constant lab angle and lab momentum on the Peyrou plot for $pp \rightarrow \pi$ + anything and $pp \rightarrow p$ + anything respectively at 200 GeV. On the vertical axis, the transverse momentum $P_\perp$ is shown. The horizontal axis gives the longitudinal momentum of the secondary in the CM, $P^*_{||}$ and the Feynman variable $x = 2P^*_{||}/\sqrt{s}$, where s is the total CM energy squared. Due to the sharp fall-off of the $P_\perp$ distribution for all types of secondaries, one expects only a small fraction of events to have $P_\perp > 1$ GeV. Fig. 3 then shows that the complete backward hemisphere gets captured if all lab momenta up to 15 GeV/c are measured as is possible in the fiducial volume which we choose.[12]

For 400 GeV incident energy π's and K's are still measurable in the complete backward hemisphere.

By measuring the π^- inclusive spectrum (or the semi-inclusive distribution for different topologies) we study, say, in the region of large X, target fragmentation, i. e. fragmentation of the n,

$$n \rightarrow \pi^- + \ldots \quad .$$

If there is no I-spin exchange between beam and target clusters, the above process must be equal to $p \rightarrow \pi^+ + \ldots$ for which counter data may be used in order to test whether I = 0 exchange is dominant. It is difficult to distinguish between π^+ and p emission in the full kinematical range in a bubble chamber. In a limited kinematical region though, at large negative X, $-1.0 < X < -0.5$, it is possible to test the I = 0 exchange relations with bubble chamber data:

$$(p \rightarrow \pi^+ + \ldots) = (n \rightarrow \pi^- + \ldots)$$
$$(p \rightarrow \pi^- + \ldots) = (n \rightarrow \pi^+ + \ldots) \quad .$$

The Short Range Correlation picture predicts that the distributions for the process $a + b \rightarrow c + \ldots$ in the central region of the rapidity variable, $Y = \frac{1}{2} \log (E + P_{||} / E - P_{||})$, are independent of the particle types a and b and depend only on c. We will test this hypothesis by comparing our pn data with the hydrogen pp data.

3. Two Particle Correlations:

With the help of the improved track matching technique using

the inserted plate, we will obtain a high statistics sample of events which have the space angles of all charged secondaries measured. Approximating the rapidity Y by

$$Y \approx \log (\tan \frac{\theta}{2}) \quad ,$$

we will measure Y correlations in both hemispheres. Additionally, it will be interesting to compare the correlation of π^- with the slow proton from n fragmentation (near X = -1) with the same correlation from proton fragmentation.

4. Diffraction Dissociation:

Various theoretical estimates for the associated multiplicity as a function of Missing Mass squared in processes

$$pp \rightarrow p + MM^2$$

have been made.[13] Measurements in the 100, 200 and 300 GeV hydrogen exposures are being carried out. In the process

$$pn \rightarrow p + MM^2 \quad ,$$

the n has to be more excited than the diffractive p in the pp events.

It will be of interest to compare our results with the hydrogen data, the associated multiplicity as well as the proton x-distribution, which for pp processes at ISR energies exhibits a pronounced dip at $x \approx 0.9$ and a sharp diffractive peak at $x = 1.0$.

5. Coherent Processes:

We will be able to measure the elastic coherent cross section at

both energies as outlined before, and we will give a rough estimate of the inelastic coherent process

$$pd \rightarrow d(p\pi^{+}\pi^{-} + \ldots)$$

with low mass of the system $(p\pi\pi\ldots)$.

6. π^{o} Multiplicity:

As shown in Ref. 14, one can identify γ rays in both hemispheres, at least at 200 GeV, and hence measure the γ (or π^{o}) multiplicity and compare it with the pp results.

7. Neutral Strange Particle Production:

In 200 GeV pp interactions, it is possible to identify all K^{o}'s and Λ's produced in the backward hemisphere.[15] This still will held for K^{o}'s at 400 GeV whereas Λ's will be identified up to $x = -0.1$. The V^{o} single particle distributions will be compared with the pp data.

Equipment and Manpower:

Our equipment available for the analysis of the film includes four scan tables equipped with image plane digitizers, three Vanguard measuring machines, and one Vanguard measuring machine with a TV zoom lens for difficult events which require large magnification.

The personnel consists of

12 full-time scanners

2 Ph. D. students

4 Ph. D. physicists .

One of the authors (R. E.) has extensive experience with the analysis of 200 GeV pp interactions in the 30-inch chamber. We have a completely running software system. Additionally, we will have access to the 200 GeV pp data and can easily obtain distributions which are needed for corrections or physics comparisons. We are, therefore, confident that we will be able to do a fast and reliable analysis of the film.

We emphasize once more that the installation of the small plastic plate into the chamber is simple and greatly enhances the possibility to do interesting physics. The changeover to deuterium running is an appropriate time to easily install the plate.

References

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8. A. S. Goldhaber, "Hadron Structure in High Energy Nuclear Reactions," SUNY Preprint (1972).

9. Belletini et al., Phys. Letters 14, 164 (1965).

10. G. Charlton et al., "Two and Four Prong pp Interactions at 205 GeV,"

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11. R. S. Panvini, Private Communication.

12. The fiducial volume is the same as used by G. Charlton et al., "Study of π^- Production in 200 GeV pp Interactions with Four and Six Charged Particles in the Final State," submitted to the XVI Intl. Conf. on High Energy Physics (1972).

13. S. Ellis, NAL, G. Thomas, ANL, Private Communication.

14. G. Charlton et al., "The Reaction $pp \rightarrow \gamma$ + Anything at 205 GeV and Its Implications for π^0 Production," submitted for publication in Phys. Rev. Letters.

15. G. Charlton et al., "Neutral Strange Particle Production in 205 GeV pp Interactions," submitted for publication in Phys. Rev. Letters.

Figure Captions

Fig. 1 A typical proton spectator momentum distribution measured in the 30-inch bubble chamber. ($K^- d \rightarrow K^- \pi^+ \pi^- n (p_s)$ at 5.5 GeV/c)

Fig. 2 Momentum distribution of the slow recoil proton from 200 GeV pp four-prong events. The maximum spectator momentum accepted in our pn "odd" prongs is marked at 0.1 GeV/c.

Fig. 3(a, b) Lines of constant lab angle and lab momentum for (a) $pp \rightarrow \pi$ + anything and (b) $pp \rightarrow p$ + anything at 200 GeV.

ANL 30": $K^- d \rightarrow K^- \pi^+ \pi^- n (p_s)$

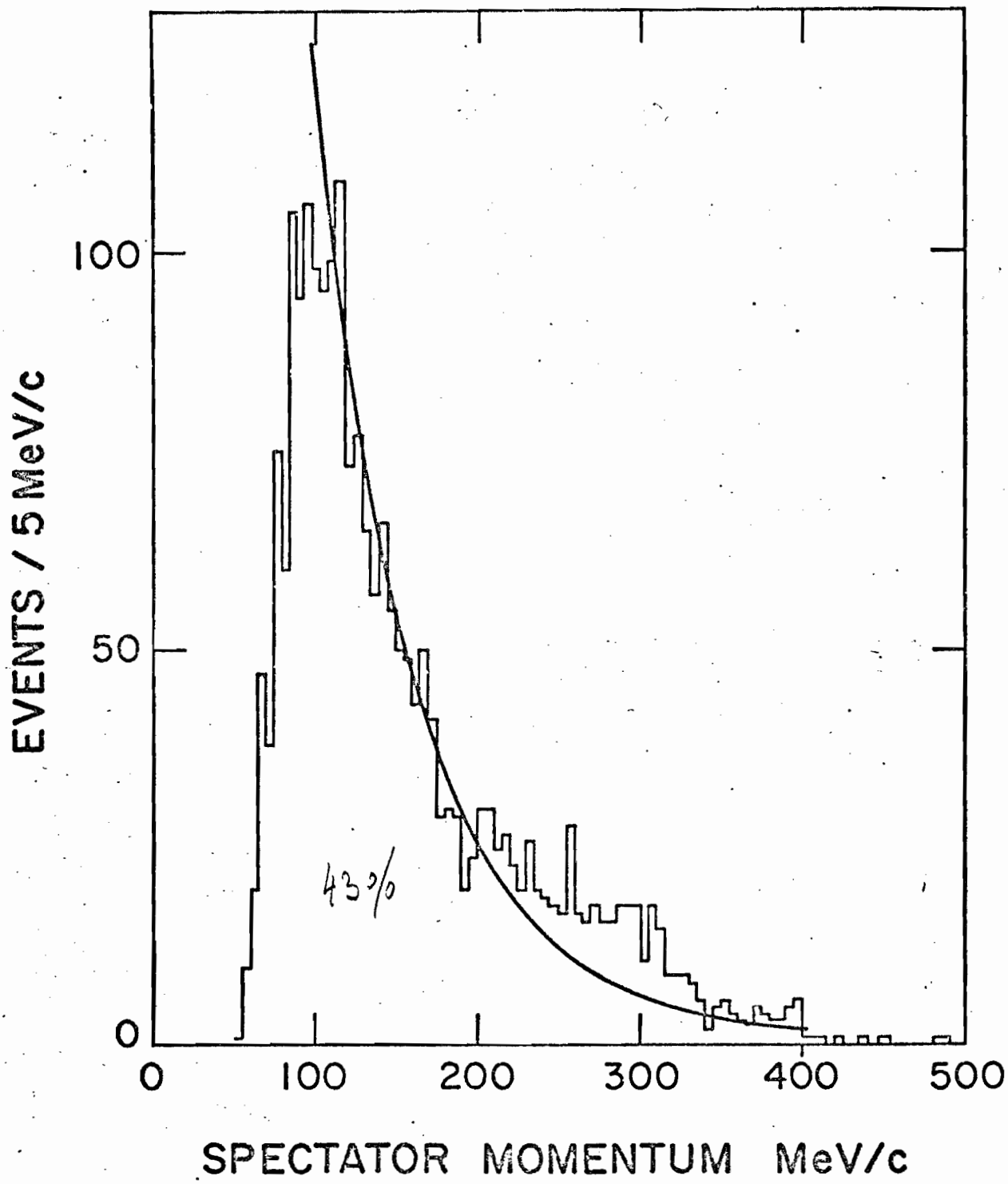
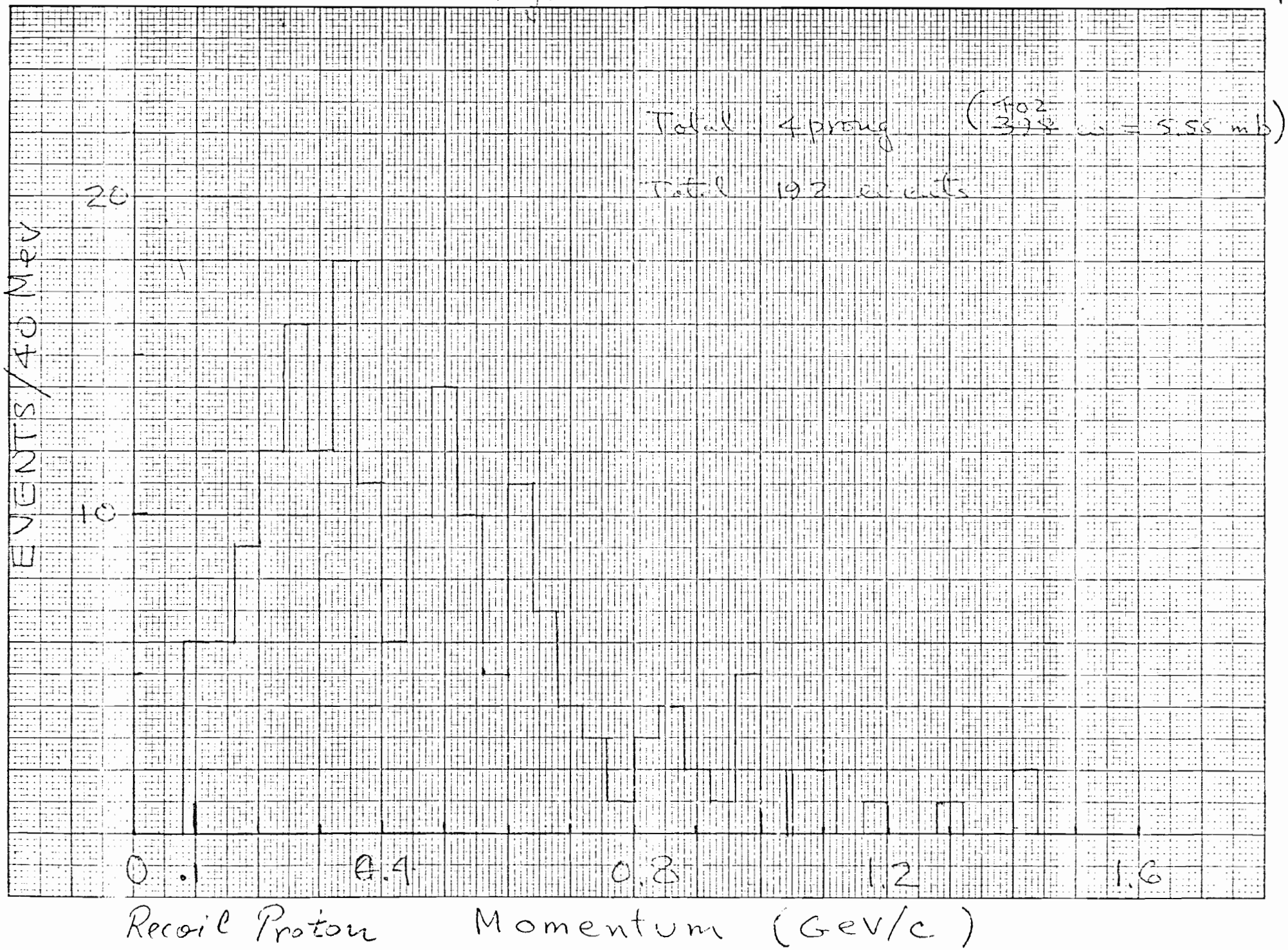


Fig. 1

K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 2



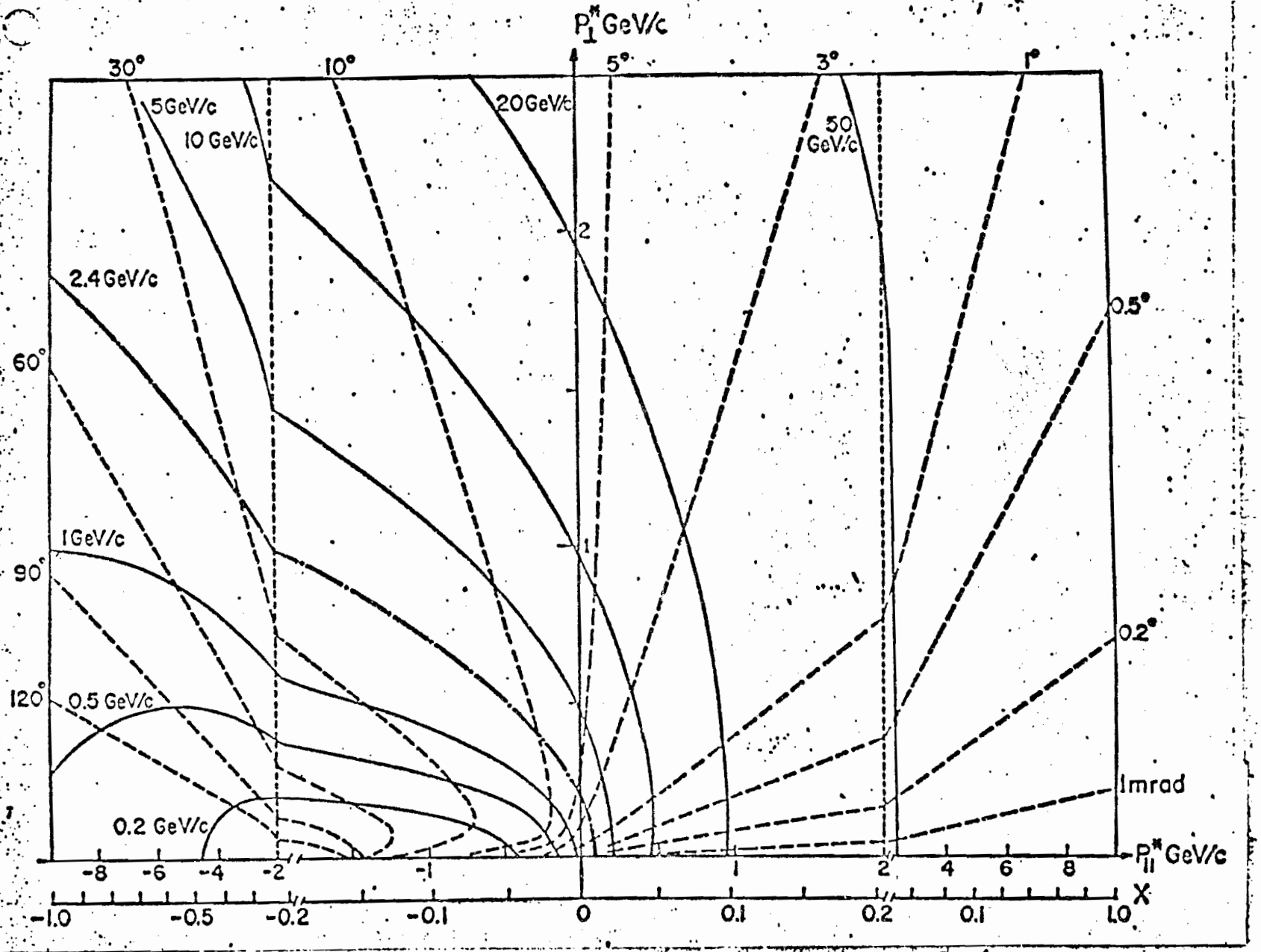


Fig 3a) $pp \to \pi +$ Anything at 200 GeV

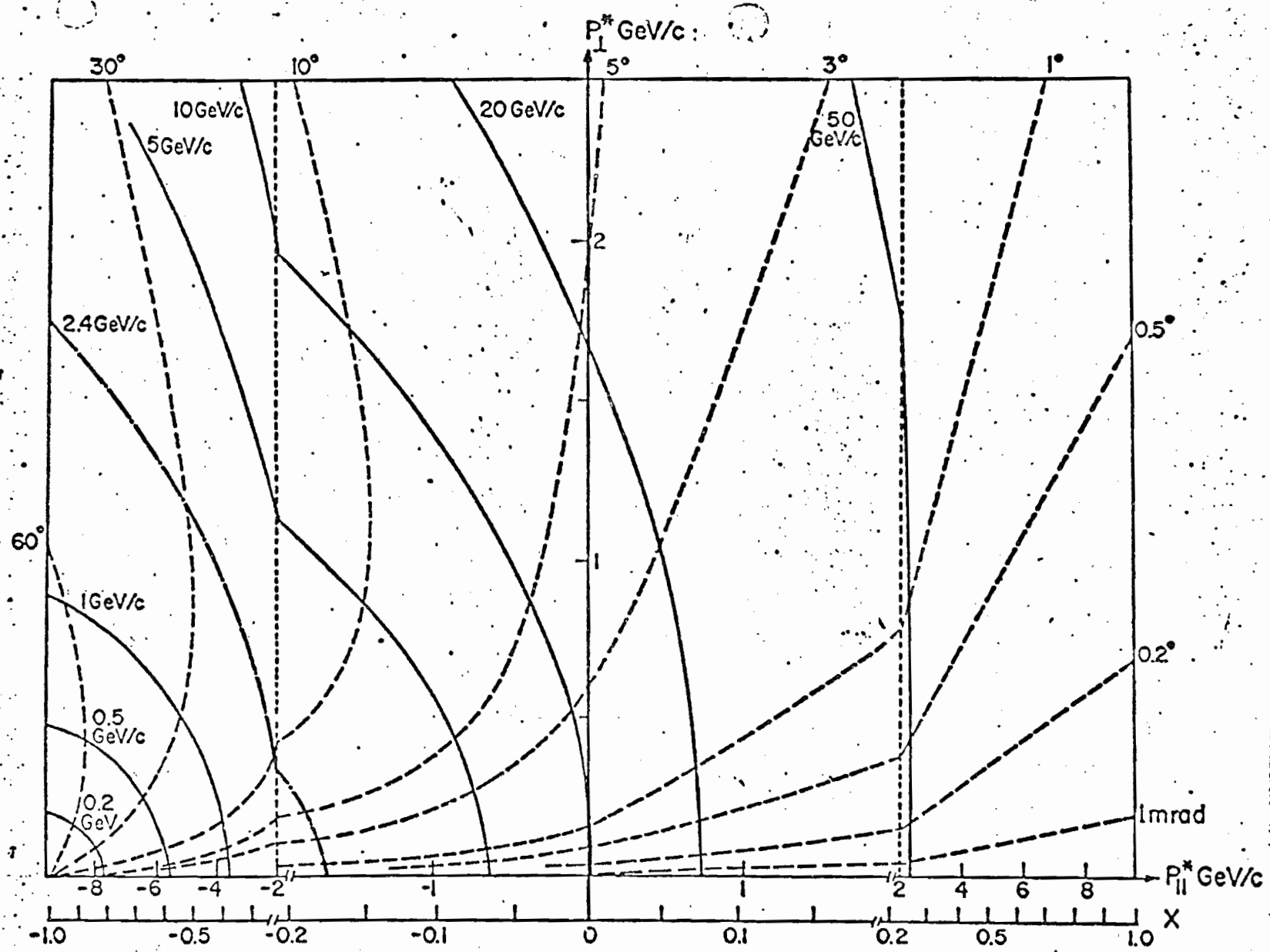


Fig 3b) $p\,p \to p + \text{Anything}$ at 200 GeV