NAL PROPOSAL NO. 190

Correspondent:
Dr. R. Engelmann
Building 362
Argonne National Laboratory
Argonne, Illinois 60439

From January 11, 1973 on:
SUNY at Stony Brook
Stony Brook, L. I., New York
11790

PROPOSAL TO

STUDY MULTIBODY FINAL STATES IN pp COLLISIONS AT 200 GeV/c USING THE NAL 15-FOOT BUBBLE CHAMBER

R. Engelmann, J. Lee-Franzini, C. Moore and M. Pratap

SUNY at Stony Brook

October 27, 1972

October 6, 1972

Proposal to

Study Multibody Final States in pp Collisions at 200 GeV/c Using the NAL 15-Foot Bubble Chamber

R. Engelmann, J. Lee-Franzini, C. Moore and M. Pratap
SUNY at Stony Brook

We propose to expose the NAL 15-foot hydrogen bubble chamber to 200 GeV protons. We intend to take 20,000 pictures. Multiparticle final states will be studied by measuring the momenta of all charged final state particles with the exception of a few very fast tracks where at least the charge and the emission angle of the particle will be determined. Comparison with various models for high energy multiparticle production will be made.

Additionally, K^o and Λ production will be studied as well as π^o production and the correlation between π^o and charged particles.

Exposure

We propose to do a small exposure of 20,000 pictures with 200 GeV incident protons early in the running schedule of the NAL 15-foot bubble chamber. Apart from the physics program given below, we feel that we can be helpful in understanding the 15-foot chamber as an instrument in its early

phase. (One of the authors (R. E.) has gained experience with the ANL 12-foot chamber during its first 2-1/2 years of operation.) The proposed run is very short: the exposure can be completed within one day!

We intend to work with a beam intensity of 3 incident protons per picture which would yield 1 inelastic event per picture in our fiducial volume. Since the beam profile is rather narrow - about 6 inches wide - we feel that it is necessary to limit the number of events per picture to ~ 1-2, in order to be able to analyze the complicated multiparticle events. Additionally, we take a conservative fiducial volume of 10 feet leaving at least 1 foot beam track length in the "nose cone" of the 15-foot chamber and a minimum of 4 feet track length for the secondaries downstream in the chamber. With an inelastic cross section of 32.7 mb[1], we will have ~ 20,000 inelastic reactions in our fiducial volume. Table I gives the event rates for each topology.

Table I

Number of Prongs	Number of Inelastic Events[a]
2	1600[b]
4	3400
6	4240
8	3500
10	2750
12	2100
14	1040
16	540
18	180
20	100
22	30
	Total ~ 20,000

[a] We use $\sigma_{inel} = 32.7$ mb[1].

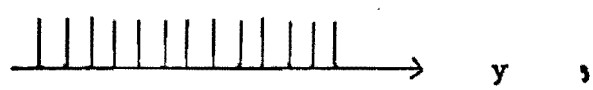
[b] We assume a loss of about 30% for inelastic two-prongs with a short recoil proton.[2]

Physics Justification and Event Analysis

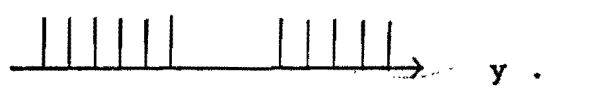
High energy collisions are described in the "multiperipheral and independent emission"[3] picture and in the "fragmentation"[4] picture. Recent measurements of the moments of inelastic multiplicity distributions, $\langle n_c \rangle$ and $\langle n_c(n_c - 1) \rangle$, where n_c is the number of emitted charged particles, do not allow to distinguish between these two classes of models.[5] It is, therefore, necessary to investigate multiparticle processes in greater detail, in particular, to study completely measured individual events rather than integrated quantities like $\langle n_c \rangle$ or single particle inclusive spectra.

One of the two pictures mentioned might reveal itself in the structure of individual events in the following way:

If one plots the rapidities (y) of all tracks in a given event along one axis,[6] a multiperipheral process may yield an evenly spread out picture,



Whereas a fragmentation process may show a clustering of rapidities,



Preliminary studies of individual events at 200 GeV[7] don't show such a striking effect as illustrated in Fig. 1 for various topologies. Hence

more quantitative comparisons have to be made between model predictions and multiparticle production data at high energies, requiring high statistics and little bias in the analysis.

Multi-charged particle final states:

The 15-foot chamber is well suited for such an analysis: In order to measure in a bubble chamber the momenta of all tracks of multiparticle events, or at least their angles in space, one has to match the track measurements from different views. At 200 Gev this is a task which cannot be accomplished by standard bubble chamber matching software, since there are many tracks relatively close to each other in space. Currently such track matching is done in an analysis of 30-inch 200 GeV pp film by a careful inspection of secondary interactions, δ rays and bubble density patterns by human operators.[7] This method, although reliable, is slow. In the 15-foot chamber, one will see the exit points of fast forward going tracks in the scotchlite and can hence use this corresponding point for a faster computer matching. From Fig. 1, one deduces for our fiducial volume an average separation of $\sim$ 1 cm for tracks in the forward cone at the downstream end of the chamber. Considering the initial setting error in space, ϵ, obtained in the ANL 12-foot chamber [8], it is reasonable to assume $\epsilon \simeq 500\ \mu$ for the 15-foot chamber in its early phase. With this value and the separation of tracks quoted, a successful automatic computer matching is guaranteed.

Fig. 2 shows the momentum error for various momenta as a function of track length for $\epsilon = 500\ \mu$. Most of the momenta in 200 GeV pp interactions

will be well measurable with the exception of a few very fast tracks where at least the angle and the particle charge will be known. Fig. 3(a) and (b) display lines of constant lab angle and lab momentum on the Peyrou plot for $pp \to \pi$ + anything and $pp \to p$ + 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, $P^*_\parallel$ and the Feynman variable $x = 2P^*_\parallel / \sqrt{s}$, where s is the total CM energy squared. All momenta corresponding to $x \leq 0.2$, well across the symmetry line $x = 0$ in the CM, will be measured to at least 10%. The symmetry in the pp CM system can be used to check the data close to $x \approx 0$.

Various suggestions for representing multiparticle data have been made in the literature: One method is to display front-back asymmetries of multiplicity distributions.[9] One measures the cross section for production of n_R particles in the right hemisphere (forward in the CM) and n_L particles in the left hemisphere (backward in the CM), $\Sigma(n_L, n_R)$, for fixed total charged multiplicity $n_c = n_L + n_R$.

One plots

$$P(n, n_L) = \Sigma(n, n - n_L)/\Sigma(n/2, n/2)$$

which in pp collisions has to be symmetric about $n_L = n/2$ and with the multiplicity cross section $\sigma(n_L)$ is

$$P(n, n_L) = \sigma(n_L)\,\sigma(n - n_L)/[\sigma(n/2)]^2 \quad .$$

In a fragmentation picture, with possible large multiplicity fluctuations in

each hemisphere, one may expect asymmetric events, i. e., events with unequal numbers of particles produced in the left and right hemispheres. In a multiperipheral model, where wide multiplicity fluctuations are unlikely, one may expect a symmetric distribution.

Already this simple test requires at least the measurement of all particle momenta in the backward hemisphere in order to divide each event into its two hemispheres.

Another method is the measurement of the dispersion δ in rapidity for each event.[10] With N particles in an event, the average rapidity is

$$y = \frac{1}{N} \sum_{i=1}^{N} y_i$$

and

$$\delta = \left[\frac{1}{N-1} \sum_{i=1}^{N} (y_i - \bar{y})^2 \right]^{1/2} .$$

Multiperipheral-type models predict a strong dependence of δ on the multiplicity n_c, whereas fragmentation type models predict δ rather independent of n_c.

Here a measurement of all tracks in each multiparticle event is desirable, but at least the emission angles are needed if the rapidity is to be approximated by log (tan θ /2). Measurements of rapidity correlations[11] in two particle inclusive distributions help to distinguish between the two classes of models. The correlation function

$$C_2(y_1, y_2) = \frac{1}{\sigma_{inel.}} \frac{d\sigma}{dy_1 dy_2} - \frac{1}{\sigma^2_{inel.}} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2} ,$$

has in an independent emission model an exponential decrease in $|y_1 - y_2|$ when both particles are in the central plateau region, i. e.,

$$C_2 \sim e^{-|y_1 - y_2|/\xi} .$$

From Regge phenomenology one expects $\xi \approx 1\text{-}2$ [11], fragmentation models don't predict a finite correlation length ξ.

If only track angles are measured, the analysis is done with $\log(\tan\theta/2)$ instead of y.

Missing mass analysis:

Detailed model predictions have been made [17] for the average multiplicity as a function of the missing mass squared (MM^2) in the reaction

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

The region of MM^2 considered is in the fragmentation region and is, for 200 Gev incident momentum, $MM^2 \lesssim 100$ Gev^2 which corresponds to $-1. \leqslant x \lesssim -.75$. Most of these protons have labmomemta less than 1 Gev/c. Using ionization information and π^+ trapping in the chamber by the 30 KGauss magnetic field as well as the average RMS deviation from a helix fit to the particle track we will be able to distinguish between the low momentum protons and π^+.

We will study the average multiplicity as a function of MM^2 with about 5000 events.

Neutral strange particles:

Apart from the analysis of the charged secondaries, the production of neutral secondaries can be well studied in the 15-foot chamber.

Fig. 4 shows lab momentum curves for the processes

$$pp \rightarrow \Lambda + \text{anything}$$

and

$$pp \rightarrow K^{o} + \text{anything at 200 GeV},$$

superimposed on the Peyrou plot.

Most events have transverse momenta $P_{\perp}^{*} < 1$ GeV/c.[12] By measuring all $K^{o}(\Lambda^{o})$ with lab momenta less than 10(15) GeV/c, one captures the complete backward hemisphere. With an average potential length of ~ 2 m (leaving ~ 1/2 m for the V^{o} decay tracks), almost all V^{o}'s in the backward hemisphere are captured inside the chamber. We will actually be able to detect V^{o}'s well across the CM symmetry line which is necessary in order to exclude a bias close to x = 0.

Production of π^0:

It is of interest to correlate the multiplicities of differently charged final state pions with each other.

The 15-foot chamber allows, due to its large size, the detection of π^o with reasonable statistical accuracy. The detection efficiency for γ conversions in hydrogen is 15% for our fiducial volume. Preliminary results in the NAL 30-inch chamber[13] show that the average π^o multiplicity, $\langle\pi^o\rangle$, derived from the γ multiplicity, rises with the charged multiplicity, n_c, in 200 GeV pp interactions. At lower energies, 12 GeV[14] and 19 GeV[15], $\langle\pi^o\rangle$ is independent of n_c. The dynamical significance of such a correlation is investigated for various models in Ref. 16.

Table II lists the number of γ, K^o, Λ estimated from results given in Refs. (12) and (13) for our fiducial volume in the backward hemisphere.

Table II

Neutral	Number of Neutrals in the Backward Hemisphere[a]
γ	3200
K^o	720
Λ	340

[a]Note that a large fraction in the forward hemisphere will be detected too

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 lense for difficult events which require large magnification.

The personnel consists of

12 full-time scanners

2 Ph. D. students

4 Ph. D. physicists .

We emphasize that for a reliable track match, the scotchlite panelling in a small region at the downstream end of the 15-foot chamber must be of high quality, i. e., very well joined such that the endpoints of fast forward going tracks are clearly visible.

We would welcome a collaborative effort with the NAL 15-foot bubble chamber group or work at a different momentum parallel to them in the earliest stage of the 15-foot bubble chamber running.

References and Footnotes

1. G. Charlton et al., Phys. Rev. Letters 29, 515 (1972).

2. We estimate the loss from an analysis of pp elastic scattering in the ANL 12-foot chamber. J. H. Campbell et al., "Preliminary Results on 12 GeV/c Proton Interactions in the Argonne 12-Foot Hydrogen Bubble Chamber," ANL/HEP 7124, June 1971.

3. For reviews of multiperipheral models, see G. F. Chew in Multiperipheral Dynamics, Coral Gables Conference, 1971 (Gordon and Breach, New York); W. R. Frazer et al., Rev. Mod. Phys. 44, 284 (1972); S. Gasiorowicz, DESY Report T-71/6 (July 1971).
   For independent emission models, see e.g., A. Krzywick, Nuovo Cimento 32, 1967 (1964); D. Sivers and G. Thomas, ANL/HEP 7218, Phys. Rev. (in press).

4. J. Benecke, T. T. Chou, C. N. Yang, and E. Yen, Phys. Rev. 188, 2159 (1969)

5. E. L. Berger, "An Interpretation of the Multiplicity Distribution at 200 GeV/c," ANL/HEP 7229, Phys. Rev. Letter (in press).
   The new results at 100 and 300 GeV/c essentially don't change Berger's conclusions. J. W. Chapman et al., "A Measurement of the Charged Particle Multiplicity in pp Collisions at 102 GeV/c," Contribution No. 746 to the XVI International Conference on High Energy Physics, Chicago (September 1972); F. T. Dao et al., "pp Interactions at 303 GeV/c: Multiplicity and Total Cross Section," submitted to ibid.

6. Rapidity $y = \frac{1}{2} \log \left[\frac{E + p_L}{E - p_L} \right]$ where E and p_L are energy and longitudinal momentum.

7. G. Charlton et al., "Angular Distributions and Rapidity Correlations for 200 GeV pp Interactions," submitted to the XVI International Conference on High Energy Physics, Chicago (September 1972).

8. K. Jaeger, "Parameters and Characteristics of the 12-foot Chamber," ANL/HEP 7210, March 1972.

9. S. Nussinov, C. Quigg and J. M. Wang, "Asymmetries of Multiplicity Cross Sections," Stony Brook Preprint, June 1972.

10. E. L. Berger, A. Krzywicki and G. Fox, "A New Experimental Method for Discriminating Between High Energy Models for Multiparticle Production," ANL/HEP 7230, July 1972.

11. R. C. Arnold, "Lectures on Inclusive Reactions," ANL/HEP 7139, November 1971.

12. G. Charlton et al., "Neutral Strange Particle Production at 205 GeV pp Interactions," contribution to the XVI International Conference on High Energy Physics, Chicago, September 1972.

13. G. Charlton et al., "The Reaction $pp \rightarrow \gamma$ + Anything at 205 GeV and Its Implications for π^0 Production, ibid.

14. G. Charlton et al., "The Reaction $pp \rightarrow \gamma$ + Anything at 12.3 GeV," ibid.

15. H. Bøggild et al., Nucl. Phys. B27, 285 (1971).

16. E. L. Berger, D. Horn, G. H. Thomas, "Correlations Between Neutral and Charged Pions in Multiparticle Production," ANL/HEP 7240, September 1972.

17. S. Ellis, Nal, private communication;

Figure Captions

Fig. 1 $\eta = \log [\tan \theta /2]$ distributions of individual tracks for a sample of events of various multiplicities. The rapidity $y \approx \eta$.

Fig. 2 Momentum error $\Delta p/p$ versus track length for a setting error $\epsilon = 500\ \mu$. Contributions from measuring error and Coulomb scattering are given.

Fig. 3 (a) Curves of constant lab angle and lab momentum on a Peyrou-plot ($P_\perp^*$ vs. $P_\parallel$ or $x = 2P_\parallel^* / \sqrt{s}$) for 200 GeV interactions $pp \to \pi$ + anything.

(b) Ditto for $pp \to p$ + anything.

Fig. 4 All V^o's in the reactions $pp \to \Lambda$ + anything and $pp \to K^o$ + anything have lab momenta less than 10 GeV/c and 15 GeV/c respectively. The corresponding decay lengths are given.

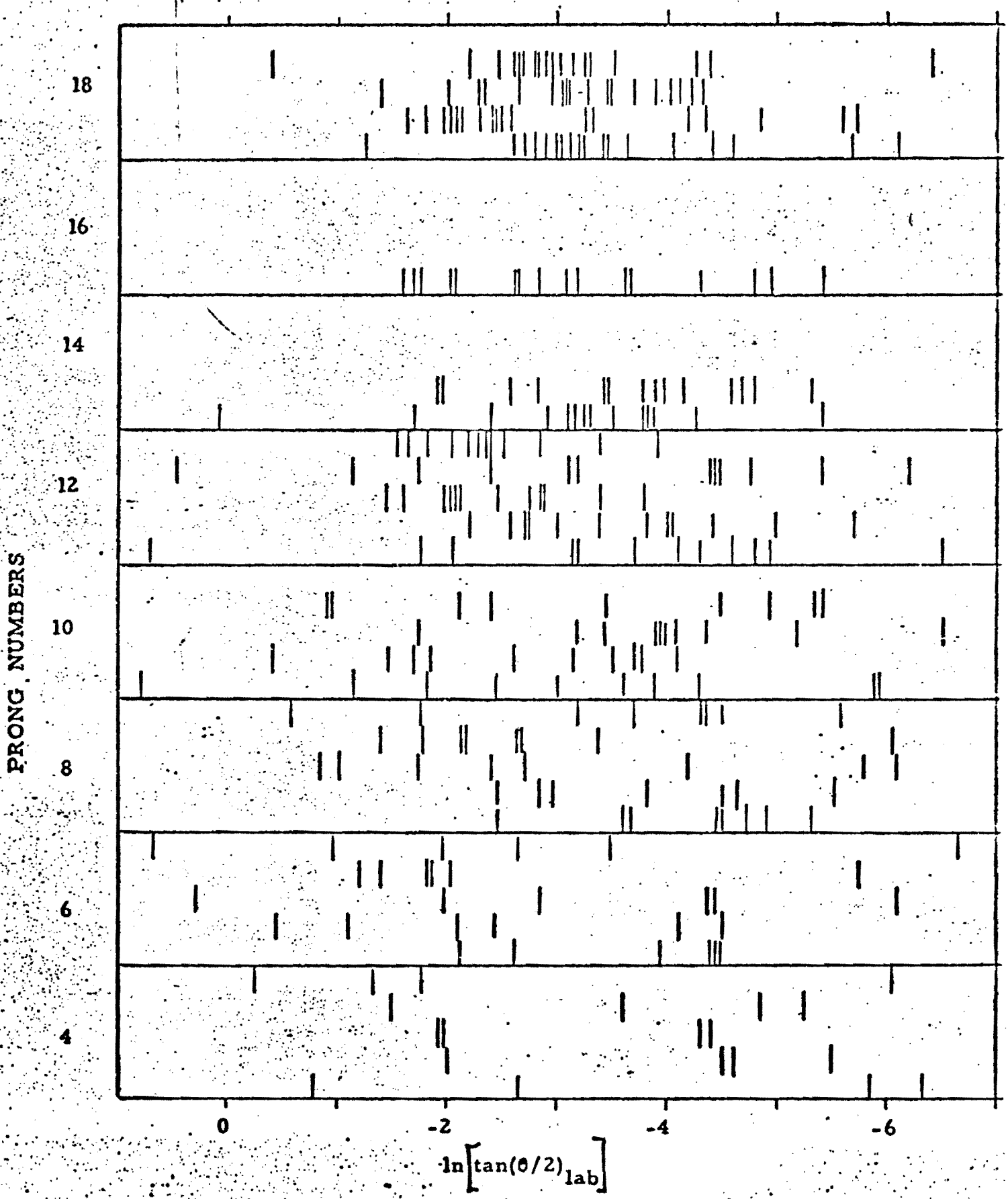
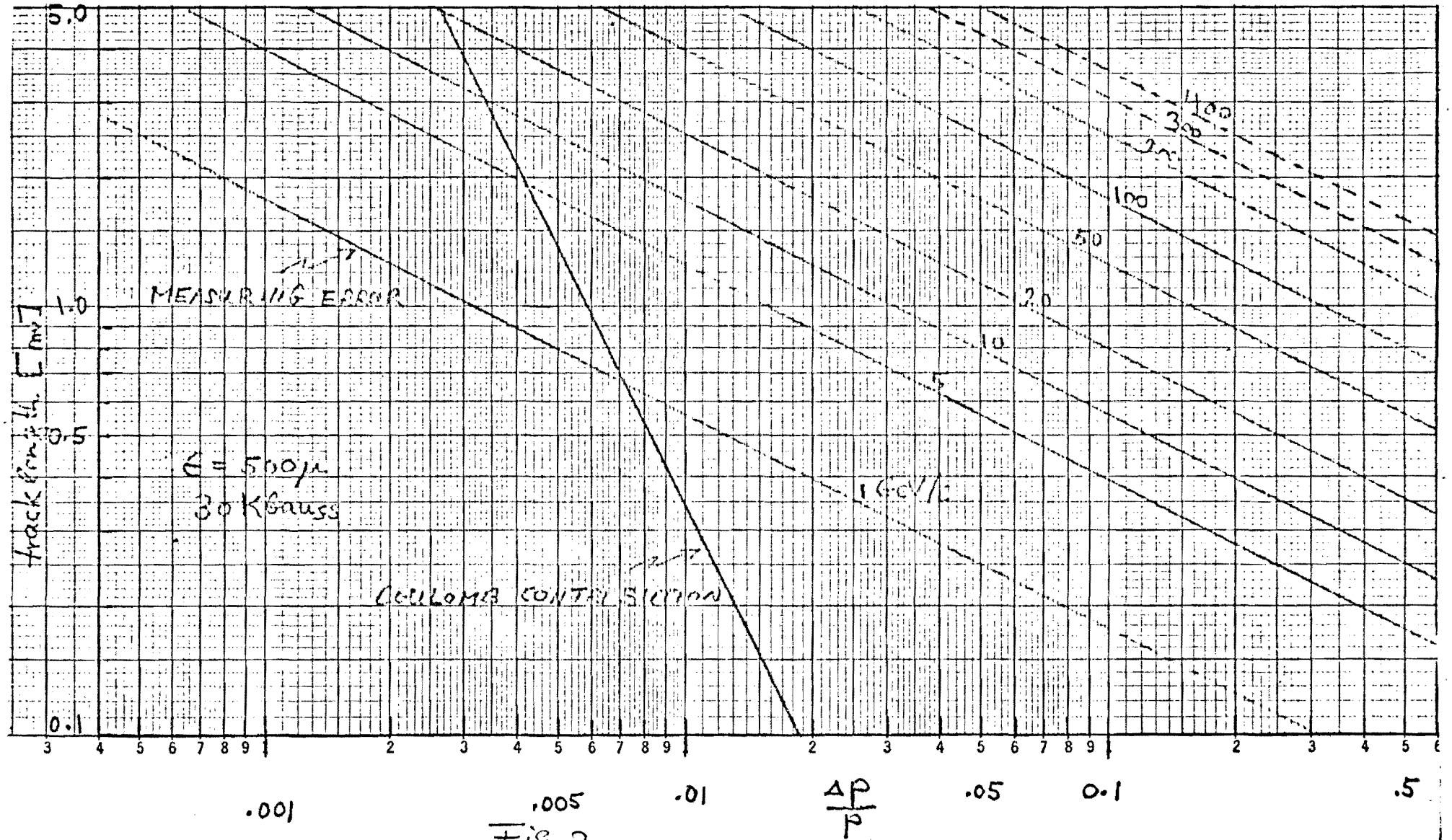


Fig 1



5.0
1.0
0.5
0.1
track length [mv]
MEASURING ERROR
ε = 500μ
30 KGauss
COULOMB CONTRIBUTION
400
300
200
100
50
20
10
5
1 GeV/c
.001
.005
.01
.05
0.1
.5
Δp/p

Fig. 2.

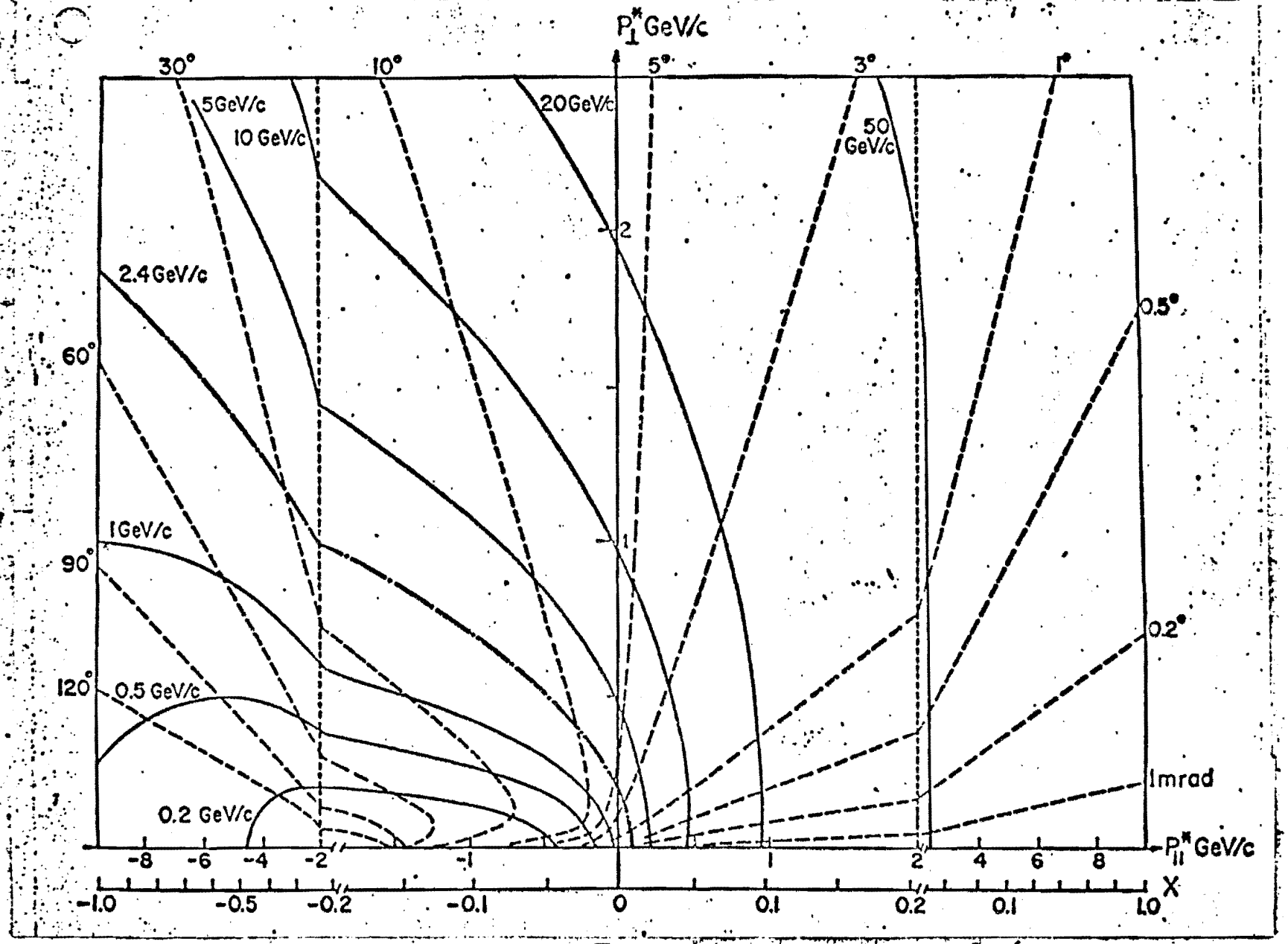


Fig 3a) $p\,p \to \pi$ + Anything at 200 GeV

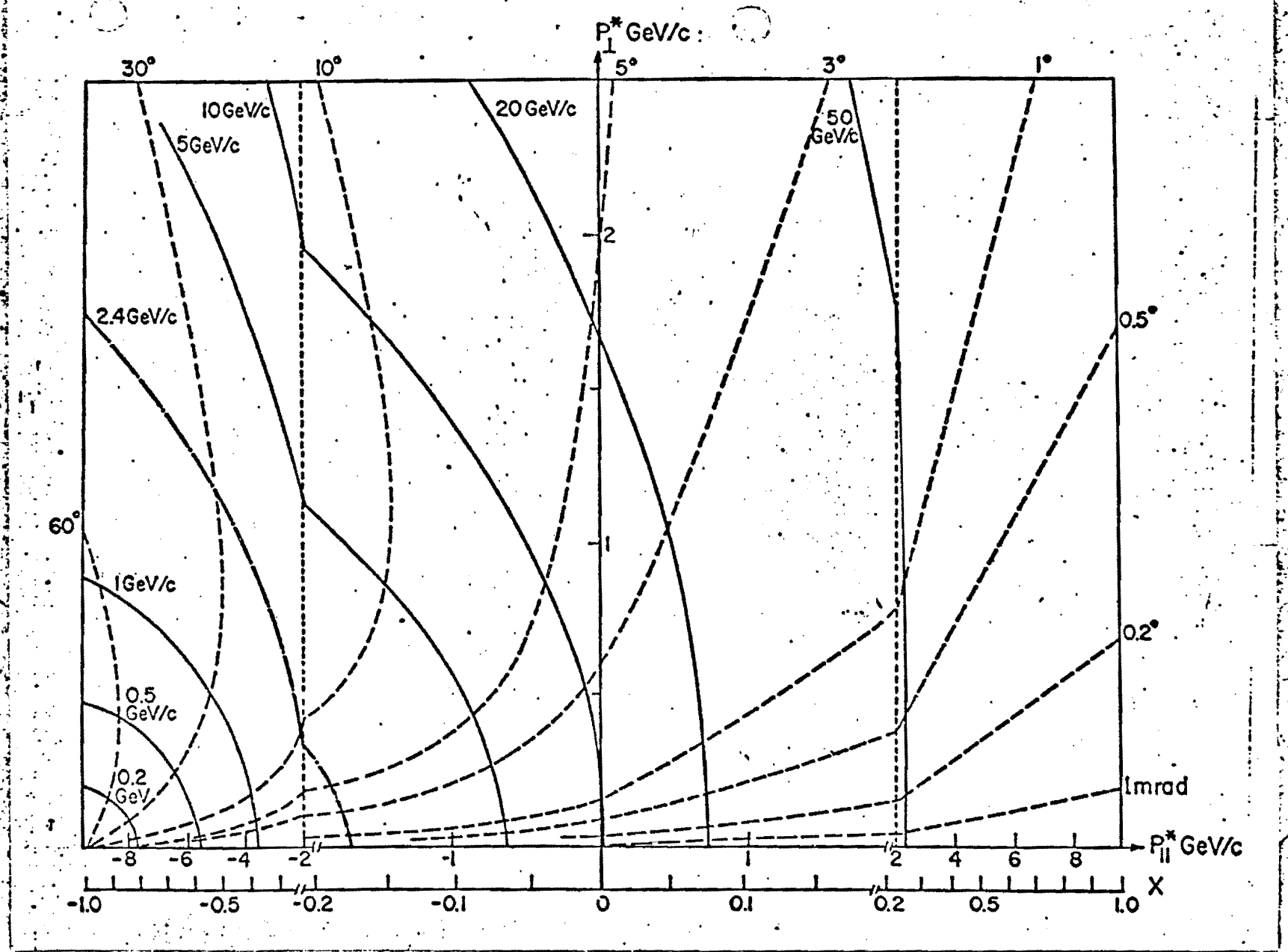


Fig 36) $pp \to p + \text{Anything}$ at 200 GeV