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PROPOSAL TO STUDY MULTIPARTICLE PRODUCTION AT THE HIGHEST AVAILABLE MOMENTUM IN ANTIPROTON - PROTON INTERACTIONS USING THE FERMILAB 30-INCH BUBBLE CHAMBER

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ABSTRACT

We propose to study multiparticle production at the highest available momentum of antiprotons in the 30-inch hydrogen bubble chamber. We request 100,000 pictures containing at least one tagged antiproton per picture at about 200 GeV/c or 160 GeV/c depending on whether 500 GeV/c or 400 GeV/c incident protons are available. One of the downstream hybrid systems will be needed with forward neutral particle detection if possible.

The results obtained will be compared with existing data at 100 GeV/c and lower momenta in order to study the s-dependence of various phenomena.

I INTRODUCTION

Antiproton-proton interactions are currently being studied at 100 GeV/c[1] and it is expected that a study will also be made shortly at a momentum in the range 30-60 GeV/c[2]. It is in order that the s-dependence of the various phenomena may be studied that the current request is made. The experiment should also be regarded as a general survey of the properties of $\bar{p}p$ interactions at the "highest possible" beam momentum.

Beam studies (discussed later in this proposal) indicated that with 500 GeV/c (400 GeV/c) incident protons it should be possible to obtain a beam containing about $\gtrsim$ 10% antiprotons at 200 GeV/c (160 GeV/c). By triggering the bubble chamber flash only when antiprotons are detected in the beam it should be possible to obtain about 10,000 interactions in 100,000 picture.

Either the wide gap optical spark chamber system or the proportional wire chamber system should be used downstream of the 30-inch bubble chamber in order to enable accurate measurements on high momentum charged secondaries to be made. Secondary particle identification would be an advantage but should not be regarded as essential to this survey experiment. Likewise gamma detectors should also be regarded as desirable.

II PHYSICS INTEREST

The physics case for studying high momentum $\bar{p}p$ collisions in the bubble chamber is presented in some detail in a proposal for a high statistics experiment at 100 GeV/c also being submitted by our collaboration[3]. In the present proposal it is intended that all events will be measured and all aspects of 200 GeV/c (160 GeV/c) $\bar{p}p$ collisions studied and compared with results at lower momenta and in other hadron-hadron collisions.

In particular the analysis would include the following topics:

1) $\bar{p}p$ topological cross sections: Topolgical cross sections from our 100 GeV/c experiment based on a scan of half the film are given in

Table 1. The corresponding pp cross sections are given for comparison. The values of <n> , D , <n>/D , f_2 and f_2^- for the multiplicity distribution are given in Table 2. The s dependence of <n> , D and <n>/D in $\bar{p}p$ are pp collisions including our data are shown in Figures 1, 2 and 3. The behaviour of the $\bar{p}p$ parameters at higher energies would clearly be of interest.

2) Inclusive single particle distributions including strange particles and resonances.

3) Production of π^0's, provided external gamma detectors are available.

4) Diffractive processes.

5) Exclusive processes.

6) Two particle correlations.

7) Search for "charm" or any other unusual phenomenon.

The study of items 2) through 5) is helped by the symmetry of the $\bar{p}p$ reaction. Thus for example the x and y distributions for $\bar{p}$, π^- or π^+ should be the same as the -x and -y distributions of p, π^+ or π^-. Strange particle decays need only be measured in the C.M.S. backward cone where the detection probability in the bubble chamber is reasonably high and π^0's in the forward cone where with external gamma detectors the conversion probability would also be high. The diffraction of $\bar{p}$'s should be a mirror of the diffraction of protons and likewise the reliability of fits in exclusive channels may be checked by looking at the mirror symmetry of various distributions.

III TECHNICAL DETAILS

The $\bar{p}/\pi^-$ ratio at 3.6mr for 200 GeV/c and 300 GeV/c protons incident on the Beryllium target has been measured by Baker et al [4] and the results are plotted on Fig.4 as a function of p/p_0. It is seen that at a given p/p_0 the ratio increases as the proton momentum p_0 increases. It may be estimated that for 200 GeV/c secondaries the ratio would be about 1% with 400 GeV/c incident protons or about 2% with 500 GeV/c incident protons. Such ratios are probably too low to be considered useful for a bubble chamber experiment.

If instead of using the directly produced $\bar{p}$'s those produced in the decay of $\bar{\Lambda}^o$'s are selected the $\bar{p}/\pi^-$ ratio should be much improved[5]. The unwanted π^- come from K^o_s decay. The ratio $\bar{p}/(K^+ + K^-)$ for direct production might be expected to be proportional to the $\bar{p}/\pi^-$ ratio obtainable from the target "halo" on the assumption that $\bar{\Lambda}^o$ production is similar to $\bar{p}$ production and K^o_s production similar to the mean of K^+ and K^- production. In fact for 300 GeV/c incident protons measurements made at 80, 100, 120 and 150 GeV/c[6] indicate a relationship of the form

$$\left(\frac{\bar{p}}{\pi^-}\right)_{\text{Halo at given } p/p_o} \approx 8 \times \left(\frac{\bar{p}}{K^+ + K^-}\right)_{\text{Direct production at } \frac{1.2p}{p_o}}$$

The factor 1.2 arises from the fact that most of the halo $\bar{p}$ and π^- selected come from $\bar{\Lambda}^o$ and K^o_s with about a 20% higher momentum.

In Fig. 5 the estimate based on the above formula and calculated from the 200 and 300 GeV/c data of Baker et al[4] is plotted. Since there is no discernable p_o dependence we use the curve to predict the ratios which should be observed for 200 GeV/c (160 GeV/c) secondaries using 500 GeV/c (400 GeV/c) proton primaries, namely $\sim$ 12%.

With the Kicker Magnet set to give 10 particles per pulse then if pictures are taken only when at least one antiproton arrives at the chamber the average $\bar{p}$ flux will be $\sim$ 1.5 per picture. This should yield up to 10,000 useful $\bar{p}$ interactions in 100,000 pictures.

The fluxes of antiprotons are expected to be more than adequate based on measurements at 120 GeV/c with 300 GeV/c incident protons. Not more than 10^{11} incident protons per machine cycle would be required even with 5 bubble chamber expansions per cycle.

REFERENCES

1. Fermilab Experiment ## 311: Cambridge, Fermilab, Michigan State University collaboration.
2. Fermilab Experiment ## 344: Purdue.
3. Fermilab Proposal: "Proposal for a High Statistics Study of 100 GeV/c Antiproton-Proton Interactions in the Fermilab 30-inch Bubble Chamber" to be submitted by the Cambridge, Fermilab, Michigan State University collaboration.
4. W.F.Baker et al, NAL-Pub-74/13-EXP(1974).
5. W.W.Neale, Fermilab Report FN-259. Also Fermilab Proposal ## 311.
6. W.W.Neale, Private communication.

FIGURE CAPTIONS

Figure 1. Mean charged particle multiplicity $\langle n\rangle$ plotted as a function of s for $\bar{p}p$ and pp collisions. The curves are drawn for guidance only.

Figure 2. Dispersion $D = \langle n^2\rangle - \langle n\rangle^2$ plotted as a function of s for $\bar{p}p$ and pp collisions. The curves are drawn for quidance only.

Figure 3. The ratio $\langle n\rangle/D$ plotted as a function of s for $\bar{p}p$ and pp collisions. The curves are drawn for guidance only.

Figure 4. The ratio $\bar{p}/\pi^-$ at production is plotted as a function of the ratio of secondary to primary momentum p/p_o. The results shown are those of Baker et al. at an angle of 3.6mr. for p_o = 200 GeV/c(+) and p_o = 300 GeV/c(⊖). The curves are drawn for guidance only.

Figure 5. The ratio $8 \times \left(\frac{\bar{p}}{K^+ + K^-}\right)$ at $1.2p/p_o$ is plotted as a function of p/p_o. This quantity gives an estimate of the $\bar{p}/\pi^-$ ratio expected for a "halo" beam at various values of p/p_o.

TABLE I

Topological Cross sections for 100 GeV/c $\bar{p}p$ Interactions

Cambridge-Fermilab-MSU

(Experiment ≠≠ 311 - Preliminary Results)

Prong number	Number observed	Corrected Number	Cross-section (mb)	102 GeV/c pp (2)
0	6	6	0.053 ± .022	
2	el. 498	829	7.39 ± .31	7.0 ± .4
	inel.431	443	3.95 ± .36	4.5 ± .4
4	856	869	7.75 ± .24	7.9 ± .3
6	905	906	8.08 ± .24	7.5 ± .3
8	796	790	7.05 ± .23	5.8 ± .2
10	468	461	4.11 ± .18	3.7 ± .2
12	242	235	2.10 ± .13	1.6 ± .1
14	113	109	0.972 ± .090	0.62 ± .07
16	51	49	0.437 ± .061	0.21 ± .04
18	14	13	0.115 ± .031	0.05 ± .02
20	4	4	0.036 ± .018	0.016± .011
Total inelastic		3885	34.65 ± .23	31.9 ± 0.7
Total	4384	4714	42.04 ± .09 (1)	38.9 ± .8

(1) A.S.Carroll et al., Phys.Rev.Lett. 33, 928, 932 (1974)

(2) C.Bromberg et al., Phys.Rev.Lett. 31, 1563 (1973)

TABLE II.

Moments of charged multiplicity distribution from 100 GeV/c $\bar{p}p$ Interactions

Cambridge-Fermilab-MSU

(Experiment ≠ 311- Preliminary Results)

	Value	100 GeV/c pp interactions(1)
$\langle n \rangle$	6.74 ± 0.11	6.32 ± 0.07
D	3.30 ± 0.06	3.13 ± 0.04
$\langle n \rangle / D$	2.04 ± 0.06	2.02 ± 0.03
f_2	4.1 ± 0.4	3.45 ± 0.25
f_2^{-}	-0.65 ± 0.13	0.28 ± 0.07

(1) C.Bromberg et al., Phys.Rev.Lett. 31,1563 (1973)

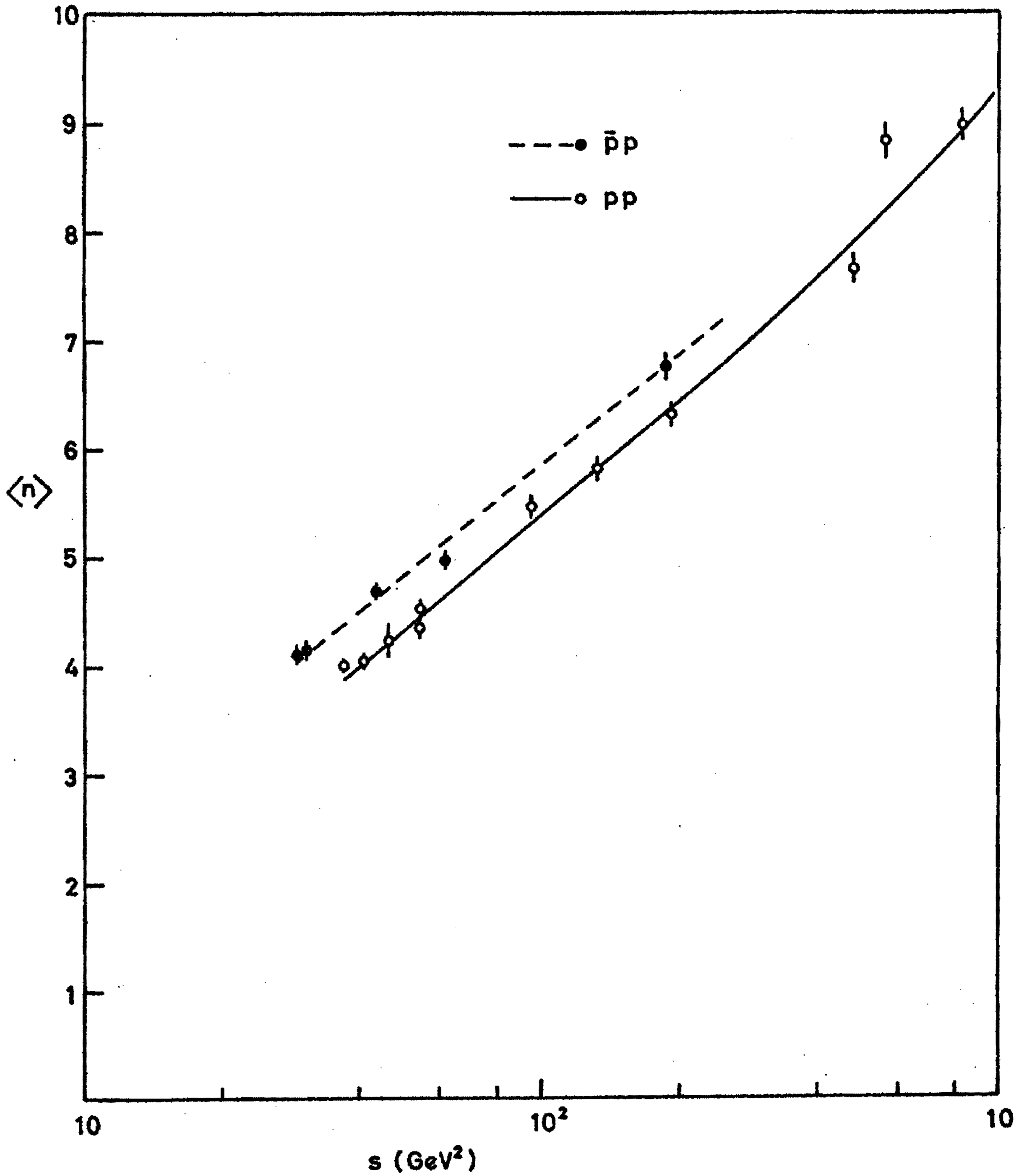


FIGURE 1

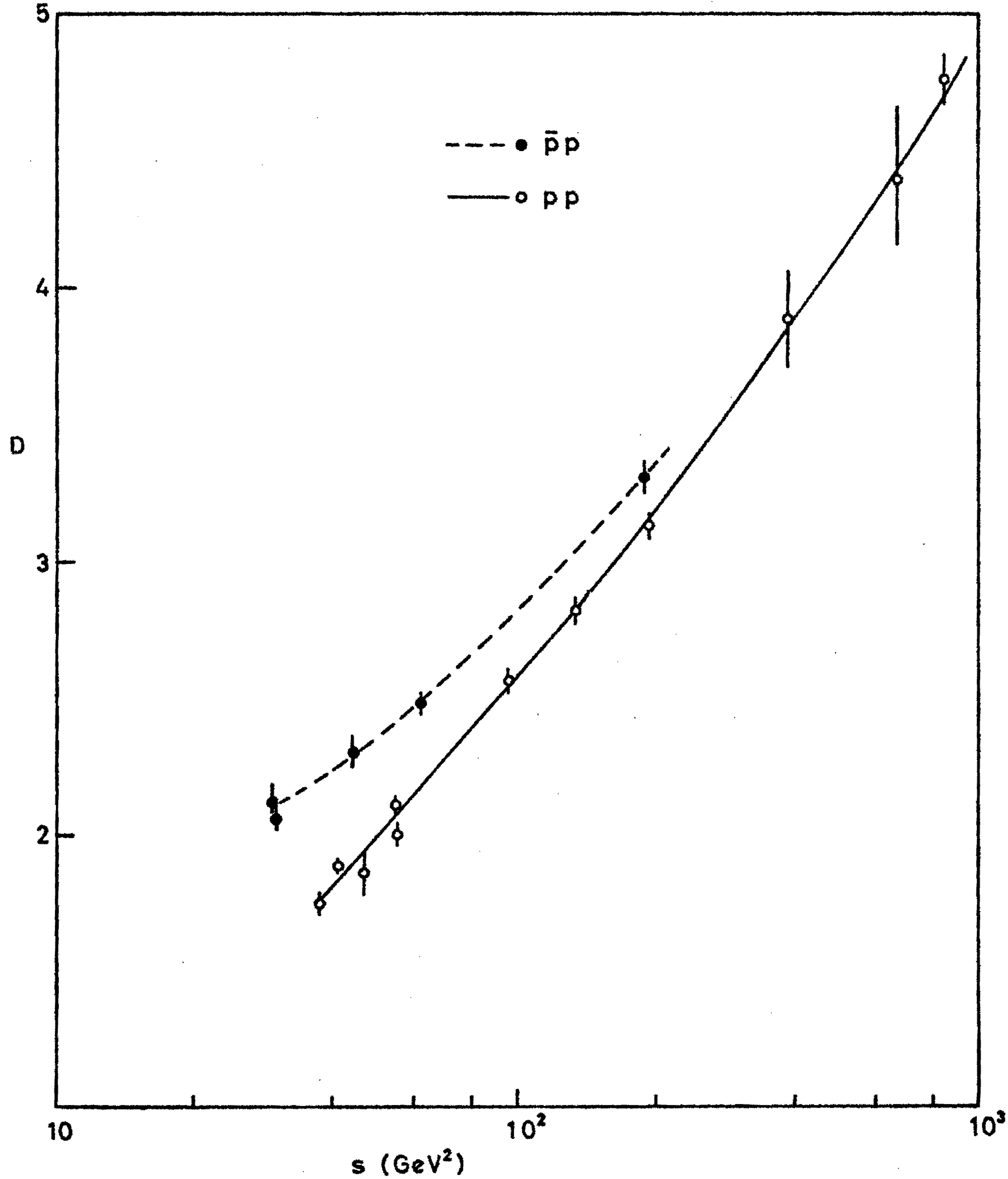
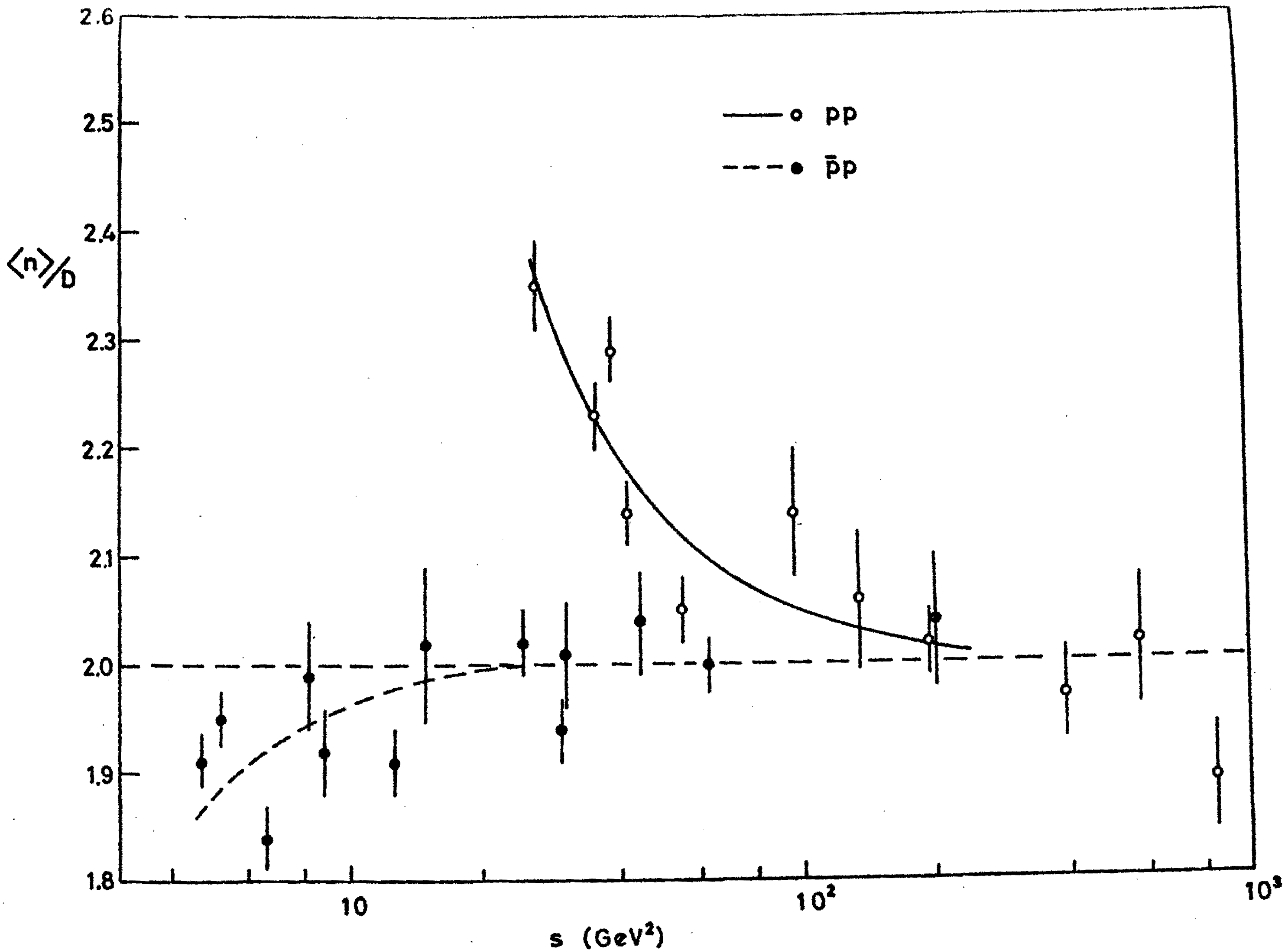


FIGURE 2



2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
⟨n⟩/D
pp
p̄p
10
10²
10³
s (GeV²)

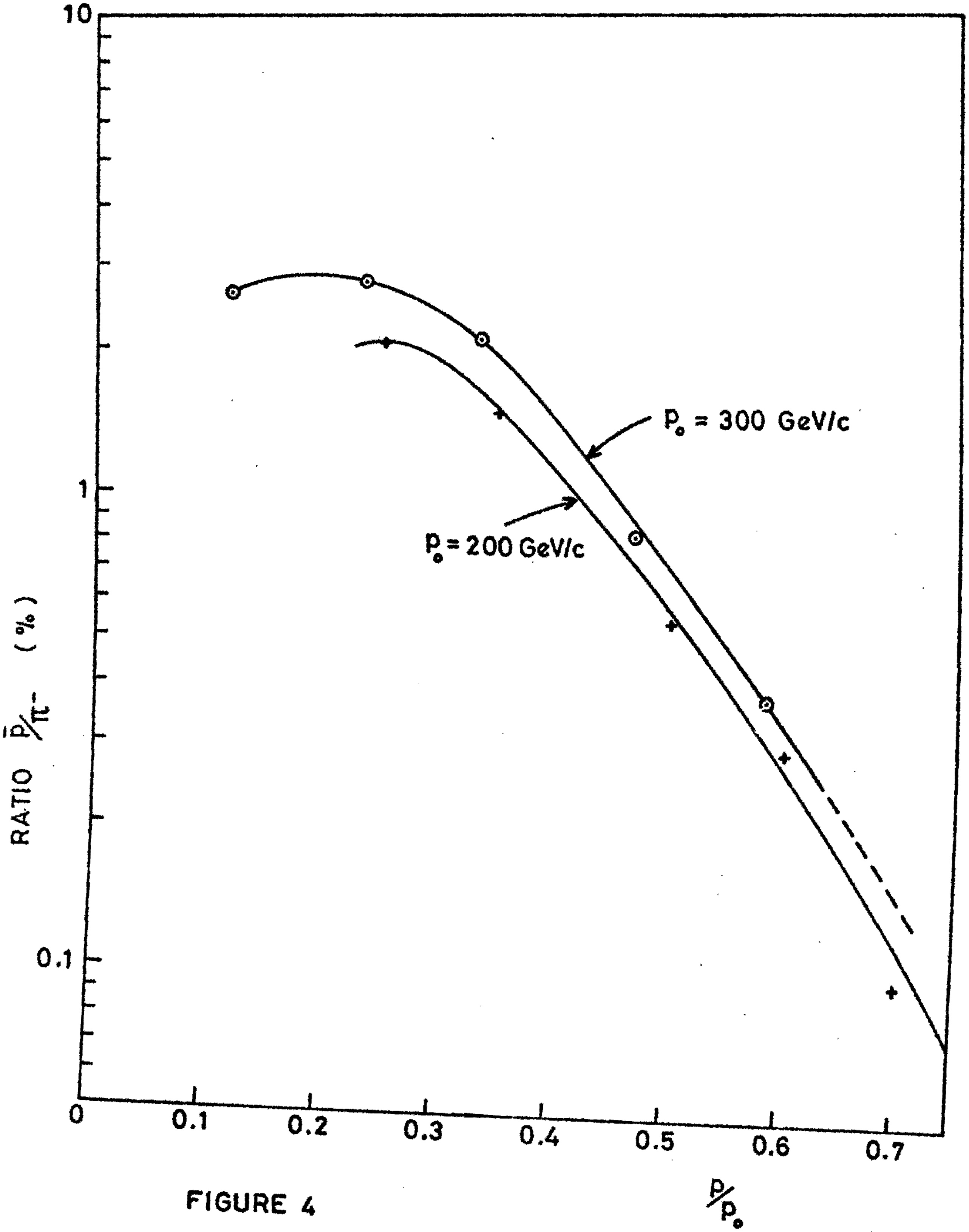


FIGURE 4

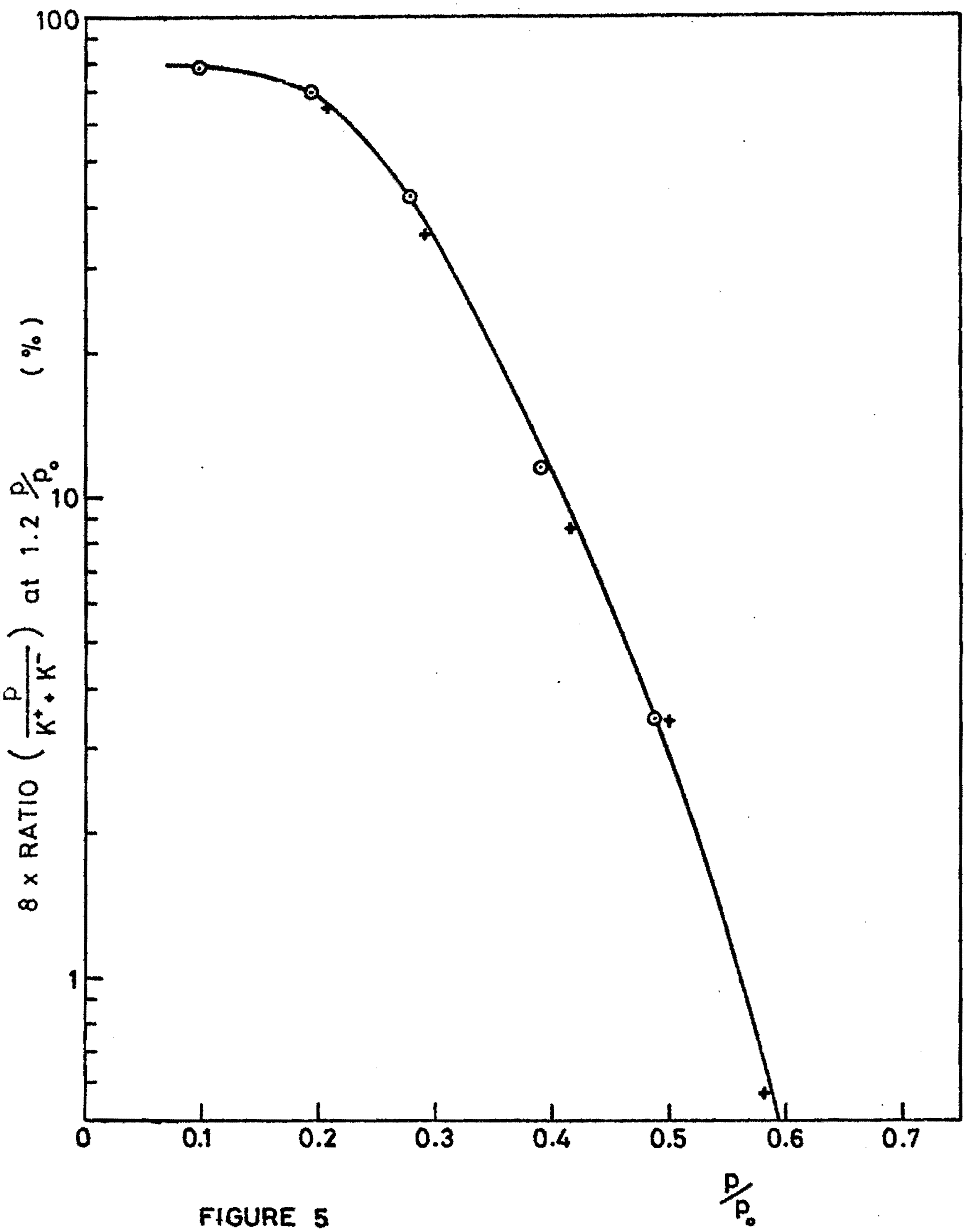

100
10
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
8 x RATIO $\left(\frac{\bar{p}}{K^+ + K^-}\right)$ at 1.2 p/p_o (%)
p/p_o

FIGURE 5

Revised

NAL PROPOSAL NO. 392

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ABSTRACT

We propose to study multiparticle production at the highest available momentum of antiprotons in the 30" hydrogen bubble chamber. We expect to obtain 15,000 interactions of tagged antiprotons in 100,000 pictures, at 160 or 200 GeV/c, depending on whether 400 or 500 GeV/c protons are available. Either the proportional wire chamber system, or the wide gap optical spark chamber system will be required downstream.

The results of this experiment will be used for comparison with data at 100 GeV/c and below, with a view to establishing the s-dependence of various phenomena, and particularly the annihilation process.

I. Introduction

This document updates our FNAL proposal P392 to study multiparticle production in $\bar{p}p$ interactions at the highest available $\bar{p}$ momentum using the FNAL 30" bubble chamber. We feel that it is appropriate to submit this re-appraisal of our proposal at this time in view of recent improvements to the $\bar{p}$ beam and new results available from our experiment E311 on $\bar{p}p$ interactions at 100 GeV/c.

Our present view regarding the N3 beam is that with 400 GeV/c (500 GeV/c) incident protons it is possible to obtain a beam containing $\sim$ 20% $\bar{p}$'s at 160 GeV/c (200 GeV/c). If we trigger the bubble chamber flash so that pictures are only taken when $\bar{p}$'s are detected in the beam we expect to obtain some 15k useful interactions on 100,000 pictures selected from some 200,000 bubble chamber expansions. Such an exposure is similar to that obtained in experiment E311. Full beam details are given in section III.

Recently available results from our experiment E311 [1-5] show that significant effects from annihilations are seen at 100 GeV/c. Furthermore, considerable theoretical interest now centres on questions of central production and "clustering" in multiparticle production in high energy hadron interactions. It is clear that in $\bar{p}p$ annihilations at high energy, where leading particle effects are suppressed, we have a unique system for investigating these effects. These physics questions are discussed in detail in section II.

Finally we remark that the 30" hybrid HBC is by far the best available detector for the proposed physics program and that significant new physics results would be obtained within a few months of our requested film being obtained.

II. Physics Case

We intend to scan and measure all $\bar{p}p$ events and by comparing the resulting distributions with the corresponding pp distributions at the same beam momentum* to obtain information on the annihilation component of our data. Such data will be of interest in its own right as a first survey of $\bar{p}p$ interactions at the "highest possible" beam momentum and will moreover provide valuable insight into the s dependence of various phenomena seen in our E311 data. In particular we shall study the following topics:

(a) Topological cross-sections

(i) In fig 1(a) we show the average charged multiplicity ($\langle n \rangle$) as a function of s for both $\bar{p}p$ and pp interactions. Values for $\bar{p}p$ are consistently higher than pp values and there is no real indication that they are converging at higher momentum. Since such convergence is expected at high enough energies additional $\bar{p}p$ data would be of interest.

(ii) In fig 1(b) we show the ratio $\langle n \rangle/D$ as a function of s, where $D = [\langle n^2 \rangle - \langle n \rangle^2]^{\frac{1}{2}}$ is the dispersion of the multiplicity distribution. The ideas of KNO scaling suggest that this ratio should tend to a constant asymptotic value. Such an approach to a constant value (2.0) does seem to be observed for pp interactions. However, while the low energy data for $\bar{p}p$ are also consistent with this value (early scaling in $\bar{p}p$), there is a suggestion in our E311 point at 100 GeV/c that the ratio $\langle n \rangle/D$ for $\bar{p}p$ is rising above 2.0. An additional point near 200 GeV/c would be of great help in deciding this question which has important implications for models.

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* pp data from the 30" HBC are available at 100, 200, 300 and 400 GeV/c. Should our data be taken at a beam momentum of 160 GeV/c we do not anticipate any problems using simple scaling ideas to interpolate the pp data to this energy.

(iii) In fig 3 we show the correlation integral f_2^{--} for negative tracks as a function of $<n_->$, for both $\bar{p}p$ annihilations (estimated from ($\bar{p}p$ - pp) distributions above 7 GeV/c) and pp interactions. It has been well known for some time that the negative values of f_2^{--} for $\bar{p}p$ annihilations can be understood in terms of a single cluster formation model. Indeed, such a model predicts a form:

$$f_2^{--} = b <n_-> + C \qquad ....(1)$$

with b in the range -0.7 to - 0.6 depending on assumptions made about the way the cluster decays. The positive value of f_2^{--} for high energy pp interactions can similarly be understood as the result of multiple cluster production. Our E311 point at 100 GeV/c seems to indicate a deviation away from the form (1) suggestive of the onset of multiple cluster formation in annihilations at sufficiently high s. It would be of great interest to clarify this trend.

(b) Single particle inclusive distributions

In fig 3 we show preliminary data from E311 on the lab rapidity distributions of π^+ and π^- for $\bar{p}p$ interactions, compared with pp data. The difference between these distributions, also shown, may be considered to represent the "annihilation" component, and it will be of interest to examine how these distributions change with energy. Similarly, fig 4 shows c.m.s. rapidity distributions from E311 for γ , K_s^o and $\Lambda^o/\bar{\Lambda}^o$ production. In all cases the cross-sections for production of neutrals in $\bar{p}p$ interactions are greater than in pp (and incidentally tend to be associated with higher charged multiplicities), and in the case of γ and $\Lambda^o/\bar{\Lambda}^o$ production the differences are seen to be strongly concentrated near $y^* = 0$. In this context it is worth observing that we only need to use data from backward hemisphere only in $\bar{p}p$ interactions, since distributions in forward and backward hemispheres may be related by C-invariance.

(c) Two particle correlations and clusters

This subject is of interest, particularly with a view to observing effects due to annihilations, which again one hopes to identify through comparisons with pp data. As we have indicated earlier, the behaviour of f_2^{--} for the annihilations indicates that multiple cluster formation may be becoming important above 100 GeV/c, and we would hope to investigate this process, and its energy dependence, through some form of cluster analysis, particularly for the high multiplicity events, which are rich in annihilations.

(d) Exclusive processes

The most interesting channels will probably be elastic scattering, and $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$. In elastic scattering we will be able to examine the energy dependence of the cross-section and of the slope in t, the four momentum transfer. We should expect to obtain $\sim$ 200 fits to the reaction $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$, which will enable us to make comparisons with $pp \rightarrow pp\pi^+\pi^-$ at this energy, and also with lower energy data in $\bar{p}p$ interactions. Fitting of exclusive channels requires the downstream hybrid system.

(e) Diffractive processes

We shall be able to study diffraction of both the p and the $\bar{p}$. Again, C-invariance will be a useful check on the data. Comparison with data on diffraction in pp and πp interactions between 100 and 400 GeV/c, and with $\bar{p}p$ data at 100 GeV/c, will enable us to make tests on factorization.

III. Beam details

The $\bar{p}$ beam will be produced as in E311 using the target "halo" technique [6]. The $\bar{p}/\pi^-$ ratio from direct interactions of protons on a Beryllium target [7] lead us to estimate that for 200 GeV/c secondaries the ratio would be about 1% (2%) with 400 (500) GeV/c incident protons. Such ratios are too small to be useful in a bubble chamber experiment. If instead we use negative particles from the decays of neutrals the $\bar{p}/\pi^-$ ratio may be greatly improved, the $\bar{p}$ coming from $\bar{\Lambda}^o$ decays, and the π^- mostly from K^o_s decays.

Our most recent calculations [8] indicate that by reducing the size of the beam dump we can improve the $\bar{p}/\pi^-$ ratio over that used in E311, and that with 160 (200) GeV/c secondaries from 400 (500) GeV/c incident protons a $\bar{p}/\pi^-$ ratio of $\sim$ 25% will be obtained. By using a deflection trigger on a tagged $\bar{p}$ entering the chamber, or by triggering on 2 or more $\bar{p}$'s entering the chamber, and allowing for the difference between $\bar{p}p$ and π^-p total cross-sections, we should obtain about 15,000 useful $\bar{p}p$ (and $\sim$ 15,000 π^-p) interactions in 100,000 pictures, and about 200,000 expansions.

The fluxes of antiprotons are expected to be more than adequate, based on measurements at 120 GeV/c with 300 GeV/c incident protons. Not more than 10" incident protons per machine cycle would be required, even with 5 bubble chamber expansions per cycle.

IV. Summary

We propose to take 100,000 pictures of a Cerenkov-tagged $\bar{p}/\pi^-$ beam in the 30" hydrogen bubble chamber at the highest available momentum, namely 160 or 200 GeV/c, depending on whether 400 or 500 GeV/c protons are available. Although we would prefer to run with 500 GeV/c protons, we feel that the physics interest in this proposed experiment is such that we should not delay our run solely to wait for 500 GeV/c protons, and accordingly ask for scheduling at the earliest convenient time when primary protons of 400 GeV (as above) are available.

We expect to obtain about 15,000 $\bar{p}p$ interactions, and our primary physics objective will be to investigate the annihilation process, by comparison with results on pp interactions, and to investigate the s-dependence of such phenomena.

References

[1] R.E. Ansorge et al. "Charged particle multiplicities in 100 GeV/c $\bar{p}p$ interactions". Phys. Lett. B (to be published).

[2] R.E. Ansorge et al. "Multiplicity distributions and elastic scattering in 100 GeV/c $\bar{p}p$ interactions". Paper to Washington APS meeting, May 1975.

[3] Cambridge - FNAL - MSU collaboration "Analysis of antiproton reactions at 100 GeV/c". Paper to Palermo Conference, June 1975.

[4] J.G.Rushbrooke et al. "On the difference between $\bar{p}p$ and pp topological cross-sections upto 100 GeV/c". Phys. Lett. B (to be published).

[5] D.R.Ward et al. "Annihilation effects in neutral particle production in 100 GeV/c $\bar{p}p$ interactions". Cambridge pre-print HEP75/18.

[6] W.W.Neale. Fermilab report FN - 269 (1974)

[7] W.F.Baker et al. Phys. Lett. B51 (1974) 303.

[8] W.W.Neale. Private communication.

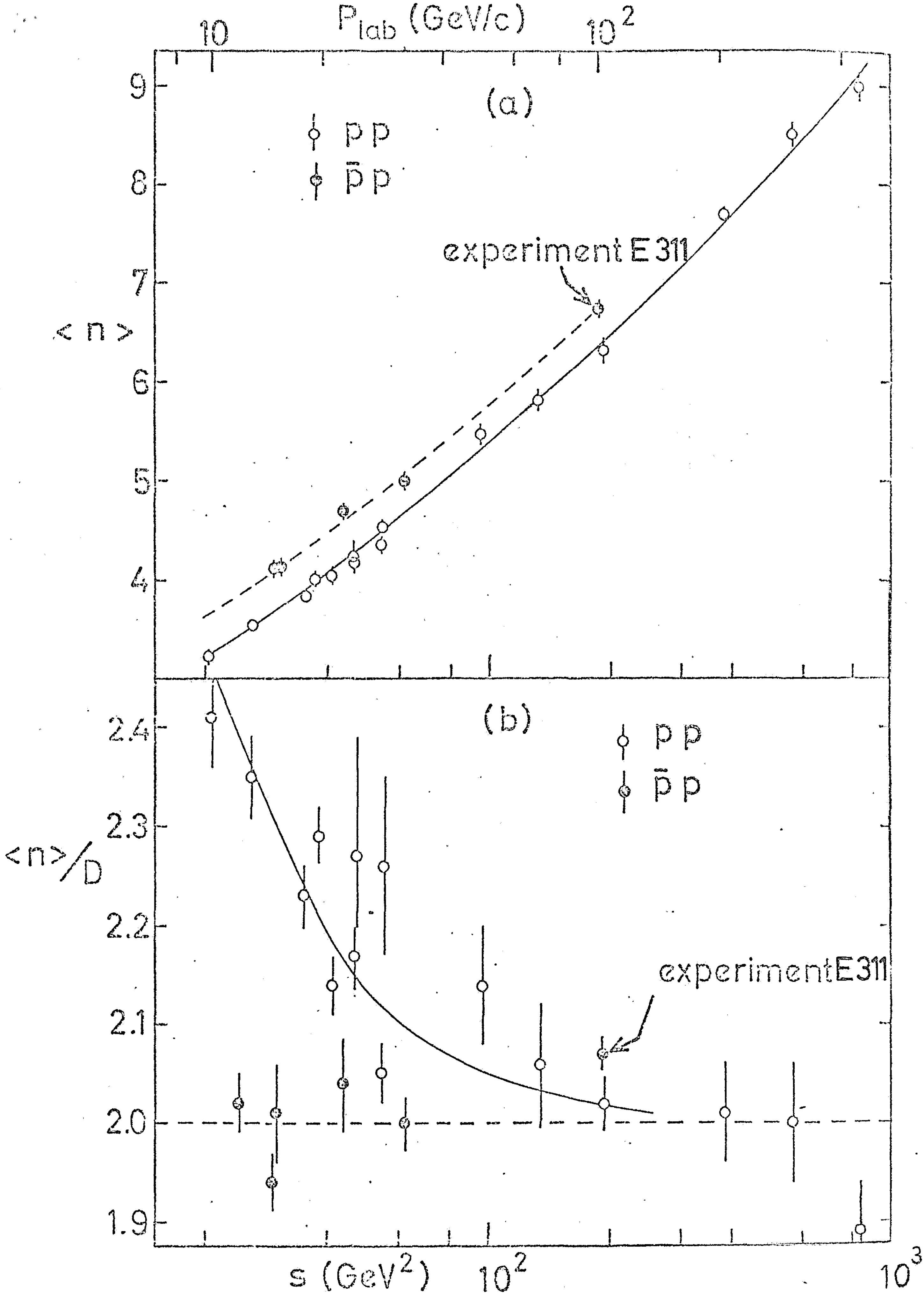
Figures

1. (a) Mean charged multiplicity $\langle n \rangle$ as a function of s for $\bar{p}p$ and pp interactions (b) $\langle n \rangle/D$ as a function of s for $\bar{p}p$ and pp interactions

2. The variation of f_2^{--} with $\langle n \rangle$ for pp interactions and $\bar{p}p$ annihilations (or ($\bar{p}p$ -pp) differences).

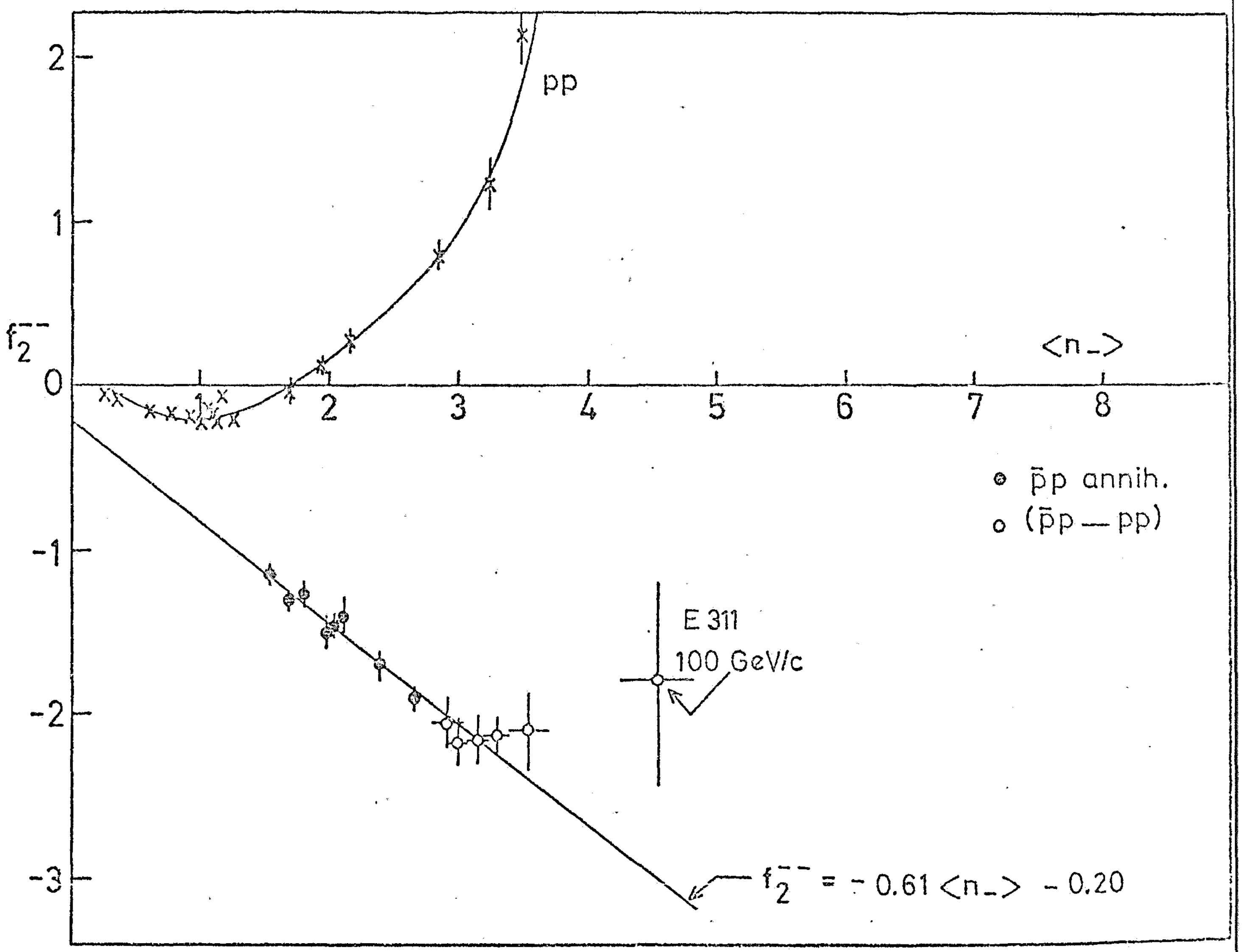
3. Distribution in lab.rapidity for $\bar{p}p \rightarrow \pi^{\pm}$, $pp \rightarrow \pi^{\pm}$ and for the difference ($\bar{p}p$ - pp) (preliminary data).

4. C.m.s. rapidity distributions for $\bar{p}p \rightarrow \gamma$, K_s^o and $\Lambda^o/\bar{\Lambda}^o$, compared with pp data at 100 GeV/c (preliminary data).



P_{lab} (GeV/c)
10
10^2
(a)
p p
$\bar{p}$ p
experiment E 311
< n >
9
8
7
6
5
4
(b)
p p
$\bar{p}$ p
experiment E311
<n>/D
2.4
2.3
2.2
2.1
2.0
1.9
s (GeV^2)
10^2
10^3

FIG.1



2
1
0
-1
-2
-3
f_2^{--}
pp
$\langle n_- \rangle$
1
2
3
4
5
6
7
8
$\bar{p}p$ annih.
($\bar{p}p$ — pp)
E 311
100 GeV/c
$f_2^{--} = - 0.61 \langle n_- \rangle - 0.20$

FIG. 2

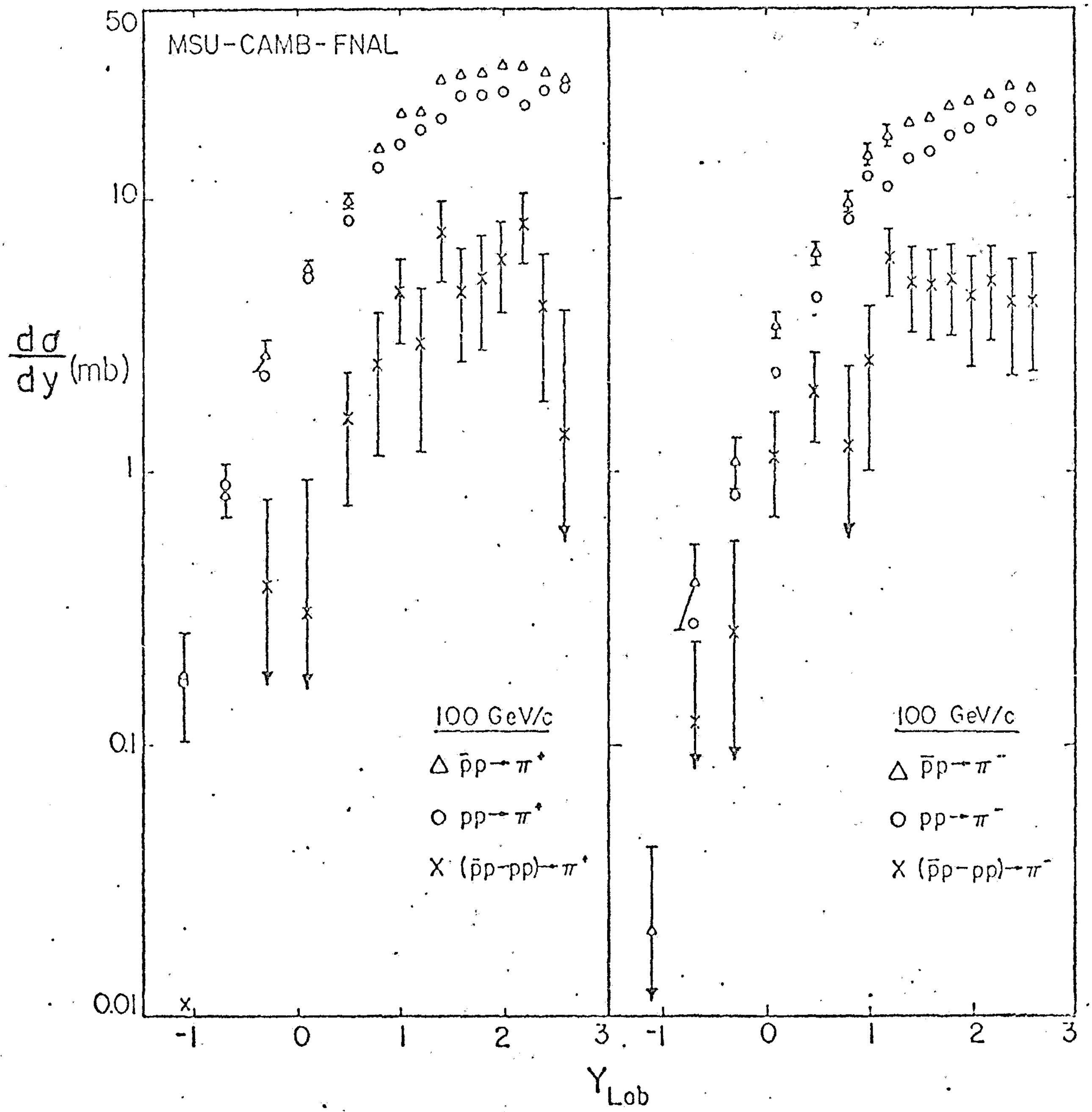
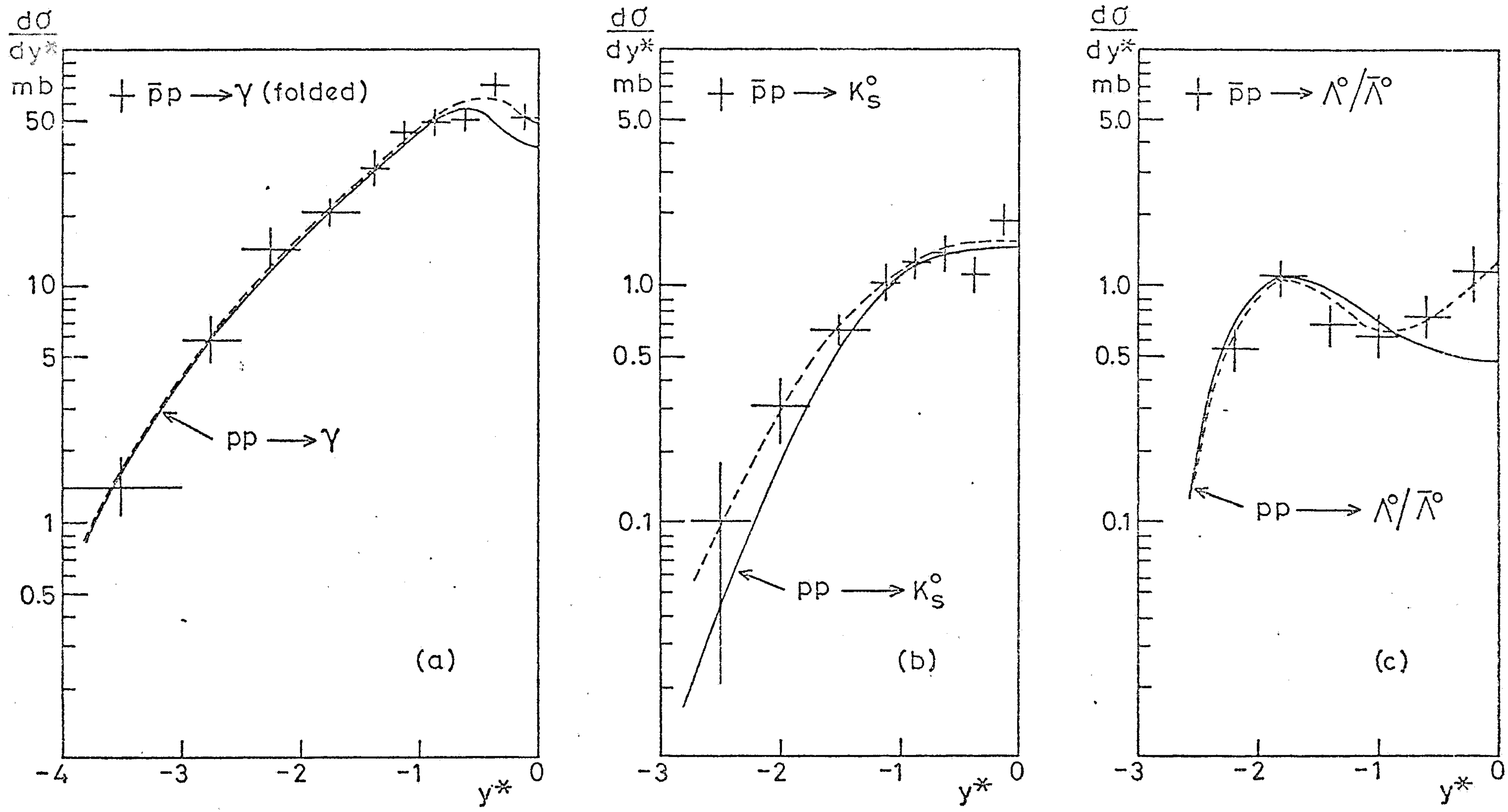

MSU-CAMB-FNAL
50
10
1
0.1
0.01
dσ/dy (mb)
100 GeV/c
Δ p̄p → π⁺
○ pp → π⁺
X (p̄p−pp) → π⁺
100 GeV/c
Δ p̄p → π⁻
○ pp → π⁻
X (p̄p−pp) → π⁻
-1 0 1 2 3
-1 0 1 2 3
Y Lab

FIG. 3



dσ/dy* mb
p̄p → γ (folded)
pp → γ
(a)
y*
p̄p → K^0_s
pp → K^0_s
(b)
p̄p → $\Lambda^0/\bar{\Lambda}^0$
pp → $\Lambda^0/\bar{\Lambda}^0$
(c)

FIG.4