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ADDENDUM TO P-68

THE STUDY OF p̄p ANNIHILATIONS FROM (p̄p - pp) DIFFERENCES

AT THE HIGHEST ENERGY (150 GeV/c) IN BEBC

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ABSTRACT

The physics aims of our original proposal are revised in the light of recent theoretical and experimental developments. By measuring (p̄p - pp) differences, we seek to investigate p̄p annihilations at the highest available energy, and make comparisons with ēe → hadrons at equivalent DESY, SLAC and CESR energies. The basic parameters of p̄p annihilations will be investigated, such as multiplicity distributions and moments of charged particles, but emphasis will be placed on neutral particle production to which BEBC is especially suited. Measurements of correlations amongst centrally produced particles will test the qq̄ jet structure proposed by Veneziano and co-workers to describe final states in lepton and hadron induced processes.

The (p̄p - pp) difference data will also permit detailed tests of Regge and Mueller-Regge ideas free from complications of pomeron exchange. These data will also complement and provide a basis for comparison with information that could arise from p̄p studies in the ISR energy range.

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1. INTRODUCTION

Developments since this proposal was originally made, suggest that the supporting physics case should be re-stated, as follows:

(a) High energy $\bar{p}p$ annihilations have acquired special interest because of their proposed relationship to $\bar{e}e$ annihilations via the topological approach (and the underlying $q\bar{q}$ jet structure) to lepton and hadron induced processes. We propose to test recent predictions concerning charged and neutral particle multiplicities and correlations, using $(\bar{p}p - pp)$ differences as a measure of $\bar{p}p$ annihilations.

(b) Neutral strange particle channels have been shown to be especially favourable$(*)$ for a study of high energy $\bar{p}p$ annihilations. We propose to study the many aspects of strange particle production detailed below to further the understanding of the dynamics of hadronic annihilations. The neutral strange particle detection capability of BEBC is ideal for such a study.

(c) Apart from their proposed relationship to $\bar{p}p$ annihilations, high energy $(\bar{p}p - pp)$ differences should be studied in their own right for the detailed insight they can provide into the Regge and Mueller Regge formalism free from the complications of the pomeron. We propose to study topological cross sections and moments, particle production cross sections, inclusive single particle distributions, and correlations from $(\bar{p}p - pp)$ with high statistical accuracy.

(d) Recent attempts at a theoretical understanding of $\bar{B}B$ annihilations in terms of quark-duality phenomenology lead directly to the prediction of baryonium states, and candidates have been observed. High energy $\bar{p}p$ interactions should obviously be closely examined for evidence of such states, and we propose to examine particle combinations involving strange particles or slow antiprotons for such evidence. A close comparison with pp interactions in studying such effects is clearly an advantage.

(*) Annihilations are estimated to represent about 8% of events in 150 GeV/c $\bar{p}p$ interactions. However, if one studies strange particle channels the proportion is seen to rise to as high as $\sim$ 20-25% (based on 100 GeV/c results [1]).

(e) It is well-known that antibaryon-baryon annihilations possess a number of basic properties that set them apart from the generality of hadron-hadron interactions. In this connection one might mention the following:

(i) Mean multiplicity $<n>$ higher (typically by 2 - 2.5 units) than for non-annihilations .

(ii) Narrower multiplicity distribution (e.g. $f_2^{--} < 0$, whereas $f_2^{--} > 0$ for pp above 50 GeV/c).

(iii) Higher $<p_T>$ of produced particles.

(iv) Absence of leading hadrons, and broader rapidity distributions.

We maintain that an understanding of annihilation processes is of great importance for high energy hadron dynamics, and recognize that BEBC offers a unique and timely opportunity for their study.

This addendum concentrates on a restatement of the physics case. The technical details, involving, beam, event detection efficiencies, event numbers, etc. remain exactly as in the original proposal (see sect. 3), though measurements since enable us to be confident that the required beam flux and purity can now be obtained.

2. PHYSICS CASE

2.1 Basic properties of high energy $\bar{p}p$ annihilations

Evidence has been emerging that $(\bar{p}p - pp)$ differences afford a useful method of studying high energy $\bar{p}p$ annihilations, and this proposal is based on that proposition. Amongst such evidence[*], we might mention cross section data (fig. 1), the energy dependence of the mean charged multiplicity (fig. 2(a)), and the behaviour of the integrated correlation function f_2^{--} (fig. 3(a)): in general the $(\bar{p}p - pp)$ values could be said to suggest[**] a smooth extrapolation of actual low energy $\bar{p}p$ annihilation measure-

[*] see reference [2] for a recent review.
[**] but see the comments in sect. 2.1.1 regarding the data of fig. 3(a).

ments. This differencing technique will offer the only means for such a study until direct methods become possible involving the elimination of non-annihilation events. Such methods are being used in low energy studies currently in progress at SLAC [3], and may also be applicable [4] to the E.H.S. at CERN, though this device will never have a neutral strange particle detection capability approaching that which is <u>now</u> obtainable with BEBC.

The value of this proposal therefore depends on our being able to obtain $(\bar{p}p - pp)$ difference data from similarly conducted $\bar{p}p$ and pp experiments of comparable statistical accuracy, so as to minimize effects arising from systematic differences of experimental technique. We then propose to study thereby the following basic features of high energy $\bar{p}p$ annihilations.

2.1.1 Charged particle production

The possibility that hadron interactions are reducible in some sense to interactions of constituent quarks is of fundamental importance to hadron physics. Arising from such a possibility are relationships between $\bar{p}p$ annihilations and $e^+e^- \rightarrow$ hadrons, such as[*]

$$\bar{n}_{ppann}(\sqrt{s}) = 3 \, \bar{n}_{ee}(\sqrt{s}/3),$$ (1)

which follow naturally from a scheme visualizing particle production via jets associated with interactions of individual quarks (see fig. 4). More recently, Rossi and Veneziano [5] have used the topological expansion approach to place these ideas on a more sound theoretical framework, and have also suggested more detailed tests of the jet structure of hadronic final states; we shall return to these in sect. 2.2. Meanwhile we note that eq. (1) is not very successful, because it fails to take into account fluctuations in the partition of energy between the jets. On trying to do so, one finds [6] that one should replace $\sqrt{s}/3$ by $\sqrt{s}/\eta$, with $\eta \approx 4.5$. The current experimental situation then appears as in fig. (2(a)), a plot of

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(*) See ref. [5] for a historical review of this relationship.

$\langle n_-\rangle$ versus s. There is a 100 GeV/c estimate for $(\bar{p}p - pp)$ obtained in an exploratory Fermilab experiment (E - 311) by the Cambridge-FNAL-MSU Collaboration [7] but it is clearly of great interest to obtain as reliable and precise a measurement from $(\bar{p}p - pp)$ at as high an energy as possible to see whether $\bar{p}p$ and $\bar{e}e$ are becoming equal asymptotically. Note that the energy of this proposal (s = 283 GeV^2) is equivalent (for $\eta^2 \approx 20$) to e^+e^- annihilations at $\sqrt{s} = 3.8$ GeV, within the SLAC energy range. The statistics available in this proposal will yield a value of $\langle n_-\rangle$ to $\sim$ 1-2%.

A further prediction [5],

$$\bar{n}_{\bar{p}p\,ann}^- (\sqrt{s}) = \frac{3}{2}\,\bar{n}_{pp}^- (\sqrt{s}/\eta),\qquad(2)$$

for which η has the naive value 3/2 but is 1.65 after partition corrections [6], is seen in fig. 2(b) to be not very well satisfied either, and can be closely tested in this experiment.

An alternative scheme [8] exists in which multihadron production is universal, leading to $\bar{n}_{\bar{p}p\,ann}^-(s) = \bar{n}_{pp}(s) = \bar{n}_{\bar{e}e}^-(s)$ instead of eqs (1) and (2) This proposal should contribute to a clear test between these schemes.

Fig. 3(a) shows data for the integrated correlation parameter f_2^{--} which measures the width of the multiplicity distribution relative to a Poisson ($f_2^{--} = 0$). The observed linear relation between f_2^{--} and $\langle n_-\rangle$, currently understood [9] to be due to the formation of a single cluster, is seen to hold as well for $e^+e^- \to$ hadrons, as shown in fig. 3(b). The 100 GeV/c point in fig. 3(a) suggests that f_2^{--} might be departing towards more positive values, indicative of multi-cluster formation; recent dual quark model calculations of Webber [10] indicate that $f_2^{--} \to 1.39$ for $\bar{p}p$ annihilations at high energy and we should obtain a 150 GeV/c estimate to ± 0.2 to test this asymptotic prediction.

Data on inclusive $\pi^{\pm}$ production at 100 GeV/c [11] based on 9000 $\bar{p}p$ events has suggested, e.g., that the rapidity spectrum is broader in $\bar{p}p$ annihilations than in non-annihilations. The dual quark model [10] envisages (fig. 5(a)) $\bar{p}p$ annihilations in terms of the emission of meson

clusters in three strongly-ordered sequences associated with each individual $q\bar{q}$ annihilation, and makes many detailed predictions (see e.g. fig. 5(b)) about the distributions of produced particles (including kaons) e.g., rapidity structure, leading particle effects, correlations, etc. With up to 100 000 events we should be able to investigate such features with great accuracy and test the underlying quark dynamics.

2.1.2 Neutral particle production

In fig. 6(a-c) we show estimates (from ref. [2]) of γ, K_s^o and $\Lambda + \bar{\Lambda}$ production in $\bar{p}p$ annihilations as a function of energy. The 100 GeV/c ($\bar{p}p$ - pp) data points [1] are based on very low statistics (e.g. 230 $\bar{p}p \rightarrow K_s^o$ events) whereas the numbers of such events to be seen in this 150 GeV/c proposal are as set out in table 1[(*)]. It is important to test the dual quark model prediction [10] for $\bar{p}p$ annihilations at high s,

$$\bar{n}(\pi^o) = \bar{n}(\pi^+) = \bar{n}(\pi^-) \tag{3}$$

which the present data of fig. 6(a) has been unable to do. In this context it is worth remembering that the $e^+e^- \rightarrow$ hadron data exhibits the so-called "energy-crisis" [12] of too high a proportion of π^o's (fig. 7(b)) and so whether eq. (3) is satisfied at high energies is doubly interesting. In this proposal we should obtain a value of $\sigma(\pi^o)$ to $\sim 5\%$ on making the usual assumption $n(\pi^o) = \frac{1}{2} n(\gamma)$. The K_s^o data of fig. 6(b) leads to the estimates [2], shown in fig. 6(d), of the number of $K\bar{K}$ pairs per annihilation; also shown in fig. 6(d) are measured values [13] from $e^+e^- \rightarrow K_s^o$ plotted at equivalent[(**)] s-values. A more accurate test (to $\pm$ 0.05 of the ($\bar{p}p$ - pp) value will be possible from this proposal, and help to establish the relationship between $\bar{p}p$ and $\bar{e}e$ annihilations which might emerge at high s.

(*) We would obtain statistics on Λ^o and K_s^o greater by a factor of $\sim$ 25 from FNAL experiments to data, with the number of γ's greater by a factor of $\sim$ 100.

(**) i.e. for an e^+e^- energy squared of s/20 when the $\bar{p}p$ value is for s

The plot of fig. 6(c) is suggested by Mueller Regge theory [14], a constant excess of $\bar{p}p$ over pp being attributable to annihilations at sufficiently high s. Values to ∿ 1-2% of the quantities plotted should be obtainable at 150 GeV/c to test whether

$$\sigma_{\bar{p}pann} \; (\Lambda + \bar{\Lambda}) \sim s^{-\frac{1}{2}} \; \ln s \qquad (4)$$

as expected.

Other basic parameters to be measured with ($\bar{p}p$ - pp) data are the mean charged multiplicities associated with neutral production, and the mean number of neutrals associated with different charged multiplicities. It has been suggested [15] that at Fermilab energies the behaviour of $<n(V^o)>$ with increasing n_{ch} shows evidence for the onset of a new mechanism associated with high multiplicities. This proposal would yield about 1300 $\bar{p}p$ annihilation events with $n_{ch} \geq 14$ and with associated γ's and allow a detailed investigation of the source of any such effect.

Finally, this experiment will permit a detailed study of single neutral particle inclusive distributions. For example, in fig. 8(a) we compare $d\sigma/dy^*$ for 100 GeV/c $\bar{p}p$ and pp interactions [1] producing Λ or $\bar{\Lambda}$ based on 157 events. The marked excess of $\Lambda + \bar{\Lambda}$ near $y^* = 0$ in $\bar{p}p$ over pp suggests a process $\bar{p}p \to (\bar{Y}Y) + \pi$'s, via the annihilation diagram shown in the inset, particularly as most of the $\Lambda\bar{\Lambda}$ pairs seen were found to have a low effective mass (< 3.5 GeV). Our proposed experiment should permit a detailed examination of this central excess, and furthermore have ∿ 300 $\bar{p}p \to \Lambda\bar{\Lambda}$ pairs (the size of BEBC being vital in detecting these central particles). Thus this experiment could yield answers to further possible detailed questions about the process, such as what is the associated charged multiplicity, whether there are any associated K_s^o, etc. Other inclusive distributions to be studied include rapidity distributions of K_s^o and γ, and p_T-distributions of Λ, $\bar{\Lambda}$, K_s^o and γ to pursue the question of high-p_T effects.

2.2 Two-particle correlations of produced particles in high energy annihilations

Although certain correlation parameters have been mentioned above we single out for emphasis a detailed study of correlations, particularly among hadrons produced in the central region. Such a study will make possible entirely new tests of fundamental aspects of hadronic processes in a previously unexplored area, e.g. of correlations involving strange particles. We would emphasize that BEBC is an instrument ideally suited to tackling now many of these questions, in view of the large number of identified strange particles listed in table 1.

In a detailed study of two-particle correlations we would include topics from among the following aspects of $\bar{p}p$ annihilations for investigation.

2.2.1 Between charged pions

We have mentioned the parameter f_2^{--} in 2.1.1 above. Measurement of the correlation function

$$R(y_1, y_2) = \sigma_{inel} \frac{\frac{d^2\sigma}{dy_1 dy_2}}{\frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}} - 1 \qquad (5)$$

for the production of two π^-'s will permit a test of the recent prediction by Giovannini and Veneziano [16], that for $y_1^* \approx y_2^* \approx 0$,

$$(R^{--} - 1)_{ee} : (R^{--} - 1)_{pp} : (R^{--} - 1)_{\bar{p}pann} = 3 : 1.5 : 1 \qquad (6)$$

which amounts to a sensitive test of the $q\bar{q}$ jet structure of lepton - and hadron - induced processes via Bose-Einstein effects. Existing data (ref. [16]) suggests $R_{pp}^{--} \approx 0.5$, so we have the clear prediction

$$R_{ee}^{--} = 0 \qquad (7)$$

$$R_{\bar{p}pann}^{--} = 0.67. \qquad (8)$$

We believe we can measure $R^{--}_{\bar{p}pann}$ to perhaps $\pm 15\%$ for comparison with a future SLAC, CESR or PETRA value from $\bar{e}e$, provided a correction can be made for K^- and $\bar{p}$ contamination[(*)]. We note that the BE effect is predicted to be small in $\bar{e}e$ and largest in $\bar{p}p$ annihilation. This comes from the fact that two π^-'s in the $\underline{same}$ jet (as with $\bar{e}e$) cannot be neighbours and tend to have different momenta, whereas two π^-'s in different jets (3 jets in $\bar{p}p$) can be essentially dynamically uncorrelated and allow the BE effect to become strong. We note also that the predictions (7) and (8) are in striking disagreement with those of "universal emission" models, e.g. of ref. [8], which imply a universal value for R^{--}[(**)].

An equivalent prediction for $\pi^+\pi^-$ correlations exists, namely

$$R^{+-}_{e^+e^-} : R^{+-}_{\bar{p}p} : R^{+-}_{\bar{p}pann} = 3 : 1.5 : 1 \tag{9}$$

which should hold at all (y^*_+, y^*_-) in the central region. It should be possible to test this result again provided a correction[(*)] can be made for charged kaons and $p^{\pm}$ amongst the $\pi^{\pm}$'s in the central region.

Production of ρ^0's by $\bar{p}p$ annihilations should be very strong (~ 3 mb at 150 GeV/c [17]) and yield ~ 7000 ρ^0 events which can be studied closely as regards associated multiplicity, associated K^0_s production, etc.. Comparison with $\bar{e}e \to \rho^0$ when data becomes available might afford further tests of the jet structure of these processes.

2.2.2 Between neutral and charged pions

From observed γ's we should obtain an estimate of

$$f^{-0}_2 = \tfrac{1}{2} <n_{\pi^-} \, n_{\gamma}> - \tfrac{1}{2} <n_{\pi^-}> <n_{\gamma}> \tag{10}$$

(*) In E311 we corrected for $K^{\pm}$ using K^0_s, which BEBC will yield here with high efficiency. Slow protons can be removed on the basis of ionization, and C-invariance provides a very useful constraint on the final $\pi^{\pm}$ distributions.

(**) In a recent report, G. Goldhaber (LBL Physics Notes, TG-287, Aug. 1977) has shown that SPEAR data from 3 to 7.4 GeV cms energy exhibit a striking phenomenon: the GGLP (Bose Einstein) effect, clearly present below ~ 4.5 GeV, disappears suddenly and is not seen at 6.2, 7.4 GeV, i.e. in the region where jet structures become clear. Although $s = 283$ GeV^2 might not be large enough to test eq (6-8), it is certainly enough to

for $\bar{p}p$ annihilations to $\sim \pm 0.4$, for comparison with the dual quark model [10], which predicts the value $f_2^{-o} = 1.7$ at 150 GeV/c.

There is also a $q\bar{q}$ jet prediction [16] for the central region of the form

$$R_{ee}^{-o} : R_{pp}^{-o} : R_{\bar{p}p\,ann}^{-o} = 3 : 1.5 : 1 \qquad (11)$$

which should be tested.

2.2.3 Between K_s^o's and π's

Using γ's and charged π's we should be able to obtain estimates to $\sim \pm 0.05$ of $f_2^{K_s\pi^o}$ and $f_2^{K_s\pi^\pm}$, a still largely unexplored area. Assuming that, as in 12 GeV/c $\bar{p}p$ interactions [18], 10% of K_s^o come from $K^*(880)$ decays, we expect a signal of ~ 800 events in both $\bar{p}p$ and pp, leading to an estimate of $\bar{p}p \rightarrow K^*$ in high energy annihilations. This could be of great interest to dual models based on production of clusters, particularly in comparison with ρ^o-production.

2.2.4 Between strange particles

As mentioned in sect. 2.1.2, we expect ~ 200 $\Lambda\bar{\Lambda}$ pairs from central region annihilations. There will also be ΛK_s^o and $K_s^o K_s^o$ pairs as given in table 1; information regarding $K\bar{K}$ production in $\bar{p}p$ annihilations should arise from the latter.

In the context of central region $B\bar{B}$ production (as in the inset to fig. 8(a)) it is worth mentioning that with a potential interaction path length of 2 m, about 18% of produced n and $\bar{n}$ will interact in the chamber to give ≥ 3 prongs[*]. If $n\bar{n}$-pair production (as in fig. 8(b)) in $\bar{p}p$ annihilations is ~ 1 mb, about 900 of such pairs will be seen via either n or $\bar{n}$ (in 80 cases both n and $\bar{n}$ of the pair will be seen). This represents a 10% signal[**] on the total of 8 600 events in which either n or $\bar{n}$ interacts (table 1). It will be very interesting to compare $n\bar{n}$ with $\Lambda\bar{\Lambda}$ production in high energy annihilations.

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[*] A correction can be made for K_L^o interactions based on K_s^o decays.

[**] Note that the rapidity of the n or $\bar{n}$ can be estimated from lab angle of production alone via the pseudo-rapidity $\eta = - \ell n \tan \theta/2$

2.3 Study of ($\bar{p}p$ - pp) differences

Apart from their proposed connection with $\bar{p}p$ annihilations, ($\bar{p}p$ - pp) differences are of intrinsic physics interest in their own right because they permit a detailed test of the Regge and Mueller–Regge formalism free from the complications of the pomeron. Clearly most of the inclusive and correlation data discussed in sects 2.1 and 2.2 can be interpreted in this light, the unifying concept being that ($\bar{p}p$ - pp) is dominantly a result of ρ and ω exchanges.

Data has already appeared from E-311 relating to single and double pion production in $\bar{p}p$ at 100 GeV/c. Amongst the phenomena investigated have been

(a) Scaling of ($\bar{p}p$ - pp) $\rightarrow \pi^-$ in the target fragmentation region, as represented by fig. 9 [11], which shows that data at 12 GeV/c and 100 GeV/c scales according to the difference in the $\bar{p}p$ and pp total cross sections.

(b) Comparison of $\pi^{\mp}$ production in the target fragmentation region from ($\bar{p}p$ - pp), ($\pi^- p$ - $\pi^+ p$) and ($K^- p$ - $K^+ p$) differences as a function of s leading to estimates [2] of the appropriate reggeon particle vertices; the π^- production data is shown in fig. 10.

(c) Central region production of charged pions in ($\bar{p}p$ - pp), which is shown to have the required s-dependence (fig. 11), and leads to estimates [2] of the appropriate reggeon – particle couplings (of relevance to dual theories) when compared with ($\pi^- p$ - $\pi^+ p$) data.

(d) An understanding of double fragmentation in terms of a product of single fragmentation distributions; factorization shown to hold (see fig. 12) in pomeron and reggeon exchange independently [19].

These can be thought of as preliminary results from an exploratory experiment.

The present proposal will have ten times the statistics for pion production, and also permit for the first time similar analyses of strange particle production given the large number of K_s, Λ and $\bar{\Lambda}$ events available.

To take just one example: comparing central region (i.e. $d\sigma/dy$ at $y^* = 0$) production differences of $\Lambda + \bar{\Lambda}$ in $K^{\mp}p$ and $p^{\mp}p$ collisions, one can show [2] that:

$$\Delta(\frac{d\sigma}{dy}(K^{\mp}p \rightarrow \Lambda + \Lambda^-))/\Delta\sigma_t(K^{\mp}p) = \frac{3}{2} g_{\Lambda\omega\omega} + \frac{1}{2}g_{\Lambda\rho\rho} \qquad (12)$$

$$\Delta(\frac{d\sigma}{dy}(p^{\mp}p \rightarrow \Lambda + \bar{\Lambda}))/\Delta\sigma_t(p^{\mp}p) = \frac{9}{5}g_{\Lambda\omega\omega} + \frac{1}{5}g_{\Lambda\rho\rho} \qquad (13)$$

where $\Delta\sigma_t(K^{\mp}p) \equiv \sigma_t(K^-p) - \sigma_t(K^+p)$, etc. The 70 GeV/c K^-p and K^+p experiments in BEBC should lead to a value for (12) with an accuracy comparable to that ($\sim 5\%$) we should obtain for (13), leading to values of the Regge couplings $g_{\Lambda\omega\omega}$, $g_{\Lambda\rho\rho}$ to $\sim 10\%$, for comparison with theoretical expectations.

2.4 Search for baryonium states

The search for baryonium states, i.e. $B = 0$ resonances having a large coupling to $\bar{B}B$ relative to the ordinary mesons, is of great current interest because of its implication for quark-duality ideas, particularly as applied to $\bar{B}B$ annihilations. We refer the reader to a recent review by Montanet [20] of the experimental position as it affects $\bar{B}B$ interactions, and to Rossi and Veneziano [5] for a discussion of the theoretical implications.

Such a search should obviously be carried out using $\bar{p}p$ interactions of the highest energy, because of the possible existence of new high mass states having production thresholds at large beam momenta. The detection of such states, produced with very small cross sections, depends crucially on the observation of narrow peaks on a large background. The good mass resolution(*) of BEBC, even for complex topologies, is of great value in such investigations, as has already been demonstrated in a 12 GeV/c

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(*)   We expect that the higher average momentum of secondaries in this experiment will worsen the mass resolution compared with 12 GeV/c, but in the central region of production (where the average momentum is $\sim 3\frac{1}{2}$ times that at 12 GeV/c) should yield a fine enough $\delta m \sim 20-30 \, \text{MeV/c}^2$.

$\bar{p}p$ experiment, which claims [21] to have observed a narrow enhancement with
M = 2600 MeV (the "I-meson") with S = ± 1 in the $(K^o_s \pi^\pm \pi^+ \pi^-)$ final state
in the six-prong plus V^o topology. This proposal will have about 25% of
the V^o events from $\bar{p}p$ in the six-prong + V^o category, implying
0.25 x 8300 = 2075 6pr + K^o_s events, to be compared with ∿ 1000 such events
in the 12 GeV/c experiment. Whether we will be able to observe the proposed
I-meson will of course depend on the s-dependence of the production cross
section (σBR ≈ 20 µb at 12 GeV/c). However, this experiment will have access
to a far greater mass range, and is in essence exploratory.

As to supposed baryonium states decaying to $\bar{p}p$, in this experiment
we might hope to see such states when they are produced (inclusively)
nearly at rest in the laboratory (as suggested by fig. 13), by means of
a search for slow $\bar{p}$'s using ionization. An existing candidate would be the
state of mass 2950 MeV decaying into $\bar{p}p\pi^-$, recently observed [22] in a
study of 16 GeV/c π^-p interactions amongst exclusive states such as
$\pi^- p \to (\bar{p}p\pi^-)X^+$, $X^+ = p$, $n\pi^+$, $p\pi^o$ etc., a σBR ∿ 1 µb was estimated for the
2950. Our proposal would probably require σBR $\gtrsim$ 10 µb for any effect to
be observable in such a search.

One could also look for exotic baryons near the $pp\bar{p}$ threshold,
e.g. $\bar{p}p \to \bar{p}_f(pp\bar{p})_{B_5}$ by fig. 14, again looking for a slow $\bar{p}$. The need for
5-quark baryons is comparable, theoretically, to that for 4-quark mesons
(baryonium) [23].

If we observe any effects, it will clearly be of value to check
whether they appear amongst pp events as well, for some indication of the
production mechanism.

2.5 More general investigation of $\bar{p}p$ and pp interactions at very high energy

It goes without saying that though this proposal aims principally
to investigate ($\bar{p}p$ - pp) differences for information on high energy $\bar{p}p$
annihilations, data will naturally arise with high statistics on $\bar{p}p$ and
pp interactions separately. This will make possible investigations at
higher energy than before in the $\bar{p}p$ case, and with vastly greater statistics
for neutral particle production (see footnote page 6) for both $\bar{p}p$ and pp
collisions. The observations at the beginning of sect. 2.2, regarding
a first study of correlations at high energy, will therefore also apply

One of the aims of this experiment is therefore to conduct a detailed investigation of correlations in the central region for high energy $\bar{p}p$ and pp interactions. The accuracy of determination of the various correlation parameters will of course be much better than for $(\bar{p}p - pp)$ e.g. for $\bar{p}p$ interactions a quantity like $f_2^{K^o_s \pi^{\pm}}$, based on 8300 K^o_s and 740 000 charged tracks, should be obtainable to $\sim$ 8%, a considerable improvement on the accuracy ($\sim$ 35%) [24] of existing FNAL experiments.

3. SUMMARY

We request a 100 K picture exposure of "bare" BEBC filled with hydrogen to a 150 GeV/c $\bar{p}$ beam, and a similar exposure to 150 GeV/c protons. The $\bar{p}$ beam will be derived from 300-400 GeV/c protons and is expected to be $\gtrsim$ 90% pure. We will require upstream tagging of $\bar{p}$'s, and the Cerenkov counters to be used for the $\sim$ 110 GeV/c K^- beam of experiment WA 28 will be appropriate for this experiment. We would greatly appreciate an early instalment of 20-30 K pictures to check our analysis procedures on BEBC film. The joint measuring capabilities of Cambridge and MSU are expected to be fully adequate to the task of handling the numbers of events involved.

Our principal physics objectives are to use the method of $(\bar{p}p - pp)$ differencing to investigate $\bar{p}p$ annihilations at the highest energies and make comparison with $\bar{e}e \to$ hadrons at SLAC, DESY and CESR energies. Particular stress will be placed on the study of neutral particle production, and on the study of correlations in the central region, with a view to investigating the relationship of lepton-and hadron-induced processes.

The theoretical importance of these topics – the properties of $\bar{p}p$ annihilations and $(\bar{p}p - pp)$ differences at high energies, and studies of correlations amongst produced particles at high energies – has been stressed in a recent review [25].

Technical developments [26] may lead to cooled $\bar{p}$ beams and within a few years to the possibility of $\bar{p}p$ interactions being studied at ISR energies at CERN. The recent workshop on Future ISR Physics has reported [27] that "... Inclusive and correlation measurements can be made (on the ISR) in such a way that a detailed comparison between pp and $\bar{p}p$ is possible with the same apparatus. This could reveal annihilation effects particularly in the central region". We would claim that BEBC can <u>now</u> do much of this physics with good accuracy at energies up to 150 GeV/c. As well as producing valuable information for current physics, the data from this proposal could, therefore, complement and provide a basis for comparison with information from future ISR experiments.

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Table 1

Expected number of events detected in 100K $\bar{p}p$ and 100K pp pictures at 150 GeV/c

	$\bar{p}p$		pp	
	σ(mb)	No. of events	σ(mb)	No. of events
Λ^o	2.4	3200 ⎫	3.2	3300 ⎫
$\bar{\Lambda}^o$	2.4	1800 ⎬ 5000	0.2	230 ⎬ 3530
K^o_s	6.0	8300 ⎭	5.0	7000 ⎭
γ	220	50000	200	45000
$\Lambda\bar{\Lambda}$	0.5	275	0.15	80
ΛK^o_s	0.4	350	0.8	420
$\bar{\Lambda}K^o_s$	0.4	70		
$\gamma\gamma$	1000	20000	900	18000
$\pi^o \to \gamma\gamma$	110	2200	100	2000
$K^o_s K^o_s$	0.6	450	0.5	400
n or $\bar{n}$ interactions ⩾ 3pr	20	8600	20	8600
V^o's		63300		55530
Interactions		100000		100000

FIGURE CAPTIONS

Fig. 1   Differences in total cross sections for $\bar{p}p$ and pp interactions
as a function of the incident beam momentum. Total $\bar{p}p$ annihilation
cross sections are also shown.

Fig. 2   (a) S-dependence of mean multiplicity for negative particles from $\bar{p}p$
annihilations, from ($\bar{p}p$ - pp) data, and from pp collisions.
for comparison we show data from $e^+e^- \to$ hadrons, based
on eq. (1) for $\eta^2 = 20$.

(b) Same $\bar{p}p$ annihilation and ($\bar{p}p$-pp) data as (a), but with data
from pp collisions, plotted according to eq. (2) with
$\eta^2 = 2.7$, shown for comparison.

Fig. 3   (a) Plot of $f_2^{--} = \langle n_-(n_--1)\rangle - \langle n_-\rangle^2$ versus $\langle n_-\rangle$ for data as in
fig. 2(a). The result of a straight line fit to the data
is shown.

(b) Variation of f_2^{--} with $\langle n_-\rangle$ for various annihilation and non-
annihilation data, as indicated.

Fig. 4   Schematic diagrams representing jets in (a) $\bar{e}e \to$ hadrons,
(b) $\bar{p}p$ annihilation.

Fig. 5   (a) Three sequences of cluster-emitting quarks representing
$\bar{p}p$ annihilation.

(b) Differences of inclusive cross sections for charged pion
production from $\bar{p}p$ and pp at 100 GeV/c compared with
annihilation model fit of ref. [10].

Fig. 6   (a) Estimates of the cross section as a function of laboratory
momentum for $\pi^c(= \pi^+ + \pi^-)$ production from ($\bar{p}p$-pp), together
with $\bar{p}p$ annihilation values. Also shown are values of the
cross sections for π^0 production from ($\bar{p}p$-pp) and from $\bar{p}p$
annihilations. The straight lines are drawn to guide the
eye (ref. [2]).

FIGURE CAPTIONS (Cont'd)

(b) As for (a) but for K^o_s production.

(c) Cross sections for $\bar{p}p \to \Lambda + \bar{\Lambda}$ and $pp \to \Lambda + \bar{\Lambda}$ scaled so as to isolate any difference between them which could be due to annihilation. The full straight line is a rough fit by eye to the pp data; the dashed line is chosen parallel to it so as to go through the $\bar{p}p$ data (from ref. [14]).

(d) Estimates of the number of $K\bar{K}$ pairs produced per annihilation as a function of laboratory momentum. Shown for comparison are measured values from $e^+e^- \to K^o_s$ plotted at equivalent s-values according to eq. (1) for $\eta^2 = 20$.

Fig. 7   (a) Mean charged multiplicity versus s for $\bar{p}p$ annihilation (open triangles) and for $\bar{e}e$ (closed symbols).

(b) Total energy in charged particles divided by total hadron energy versus s, obtained assuming all charged particles are pions.

Fig. 8   (a) Plot of $d\sigma/dy^*$ vs y^* for $\bar{p}p \to \Lambda + \bar{\Lambda}$ at 100 GeV/c [1]. The inset shows a diagram which could contribute to the observed excess of $\Lambda + \bar{\Lambda}$ in the central region ($|y^*| \lesssim 1$) in $\bar{p}p$ interactions.

(b) Possible diagram for production of $n\bar{n}$-pair in $\bar{p}p$ annihilations.

Fig. 9   (a) Laboratory rapidity spectra for π^- production and the $(\bar{p}p-pp) \to \pi^-$ differences at 100 GeV/c. Also shown (solid curve) are the differences at 12 GeV/c scaled by $\Delta\sigma_t(100 \text{ GeV/c})/\Delta\sigma_t(12 \text{ GeV/c})$.

(b) The ratio $R(y) = \{d\sigma/dy (\bar{p}p \to \pi^-) - d\sigma/dy (pp \to \pi^-)\}/d\sigma/dy (pp \to \pi^-)$ as a function of the laboratory rapidity (ref. [11]).

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FIGURE CAPTIONS (Cont'd)

Fig. 10   Differences in the invariant cross sections for π^- production
in the target fragmentation region, integrated over all p_T^2 and
$-0.4 \leqslant p_L < 0.2$ GeV/c, plotted against $s^{-\frac{1}{2}}$ for $(\pi^-p - \pi^+p)$,
$(\bar{p}p - pp)$ and $(K^-p - K^+p)$. The curves are to guide the eye.
The values shown were obtained from the data of fig. 33 of
ref. [23] by taking the measured values for π^+p, K^-p, $\bar{p}p$ and
subtracting from them values obtained by drawing smooth curves
through π^-p, K^+p, pp data respectively (ref. [2]).

Fig. 11   Values of the invariant cross section at $y_{cm} = 0$ for the
differences $(\bar{p}p - pp) \rightarrow \pi^c$ and $(\pi^-p - \pi^+p) \rightarrow \pi^c$, where
$\pi^c = \pi^+ + \pi^-$, as a function of s. Some values from $\bar{p}p$
annihilations at low energies are also shown. The dashed lines
are fits by eye taking the energy dependence $s^{-0.55}$ used in
fits to $\Delta\sigma_t$ by Barger. The values shown were obtained by taking
the measured values for $\bar{p}p$ and π^+p and subtracting from them
values obtained by drawing smooth curves through pp and π^-p
data respectively (ref. [2]).

Fig. 12   Tests of factorization in double – and single – pion production
at 100 GeV/c: (a) pomeron exchange from pp data, (b) reggeon
exchange from $(\bar{p}p - pp)$ data. Open and closed circles should
agree for $y_f \gtrsim 1.0$ (ref. [19]).

Fig. 13   Possible diagram for production of a heavy meson such as the
X(2950) [22] decaying into $\bar{p}p\pi^-$, with the $\bar{p}$ slow in the laboratory.

Fig. 14(a) Candidate diagram for production of a hypothetical heavy baryon
decaying preferentially into $pp\bar{p}$. There are a fast and a slow
$\bar{p}$ as well as two slow protons in the final state.

(b) Candidate diagram for the process observed in ref. [22].

FIG.1

FIG 2(a)

FIG. 2(b)

$\langle n_- \rangle$

$\bullet$ $\bar{p}p$ annih.

$\circ$ $(\bar{p}p - pp)$
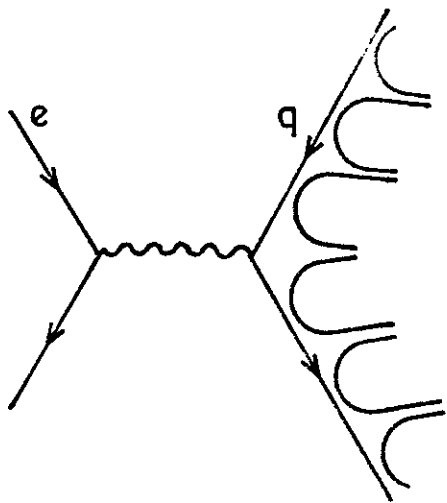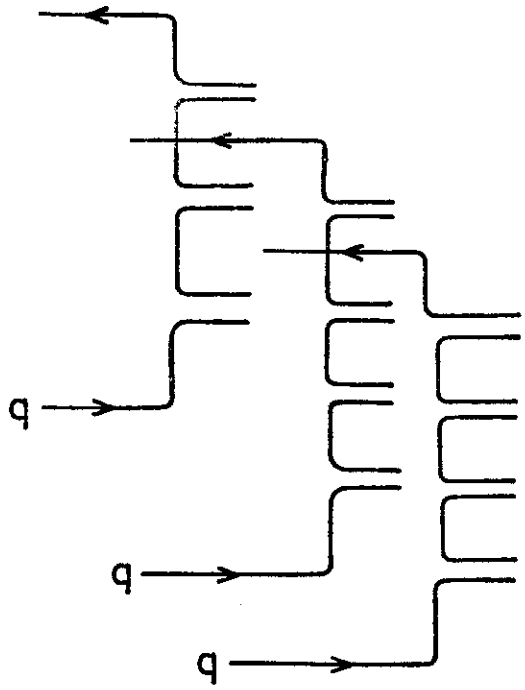
pp

100 GeV/c

$f_2^{--} = -0.61 \langle n_- \rangle - 0.20$

FIG.3(a)

FIG. 3 (b)

(a)   (b)

FIG. 4

(a)

$(\bar{p}p \rightarrow \pi^{\pm}X) - (pp \rightarrow \pi^{\pm}X)$ 100 GeV/c

$\frac{d\sigma}{dy}$ (mb)

200 GeV

ANNIHILATION MODEL: 100 GeV

C.M. RAPIDITY   y

(b)

FIG.5

(a)

$(\bar{p}p-pp) \longrightarrow \pi^c$

$\bar{p}p$ annih. $\longrightarrow \pi^c$

$(\bar{p}p-pp) \longrightarrow \pi^o$

$\bar{p}p$ annih. $\longrightarrow \pi^o$

σ (mb)

P_{lab} (GeV/c)

(b)

$(\bar{p}p-pp) \rightarrow K_S^o$

$\bar{p}p$ annih. $\longrightarrow K_S^o$

σ (mb)

P_{lab} (GeV/c)

FIG. 6

FIG. 6(c)

- • $2 \, \Delta\sigma(K_s^0)/\Delta\sigma_t(p^{\mp}p)$
- ○ $2 \, \sigma_A(K_s^0)/\sigma_A$
- × from $\bar{e}e \longrightarrow K_s^0$ evaluated at $s/20$

p_{lab} (GeV/c)

FIG. 6 (d)

(a)

6.0

⟨N_{CH}⟩

4.0

△ p̄p annihilation
● SLAC-LBL [4]
▼ Frascati $\gamma\gamma$
◖ Frascati $\mu\pi$
■ CEA

2.0

0.0

(b)

0.8

$E_{charged}/E_{total}$

0.6

0.4

◖ e⁺e⁻, SLAC-LBL [1]
▼ e⁺e⁻, Frascati $\gamma\gamma$
△ p̄p annihilation
($= ⟨N_{\pi\pm}⟩/⟨N_{\pi} \text{total}⟩$)

0.2

0.0

2.0   3.0   4.0   5.0

$\sqrt{s}$ (GeV)
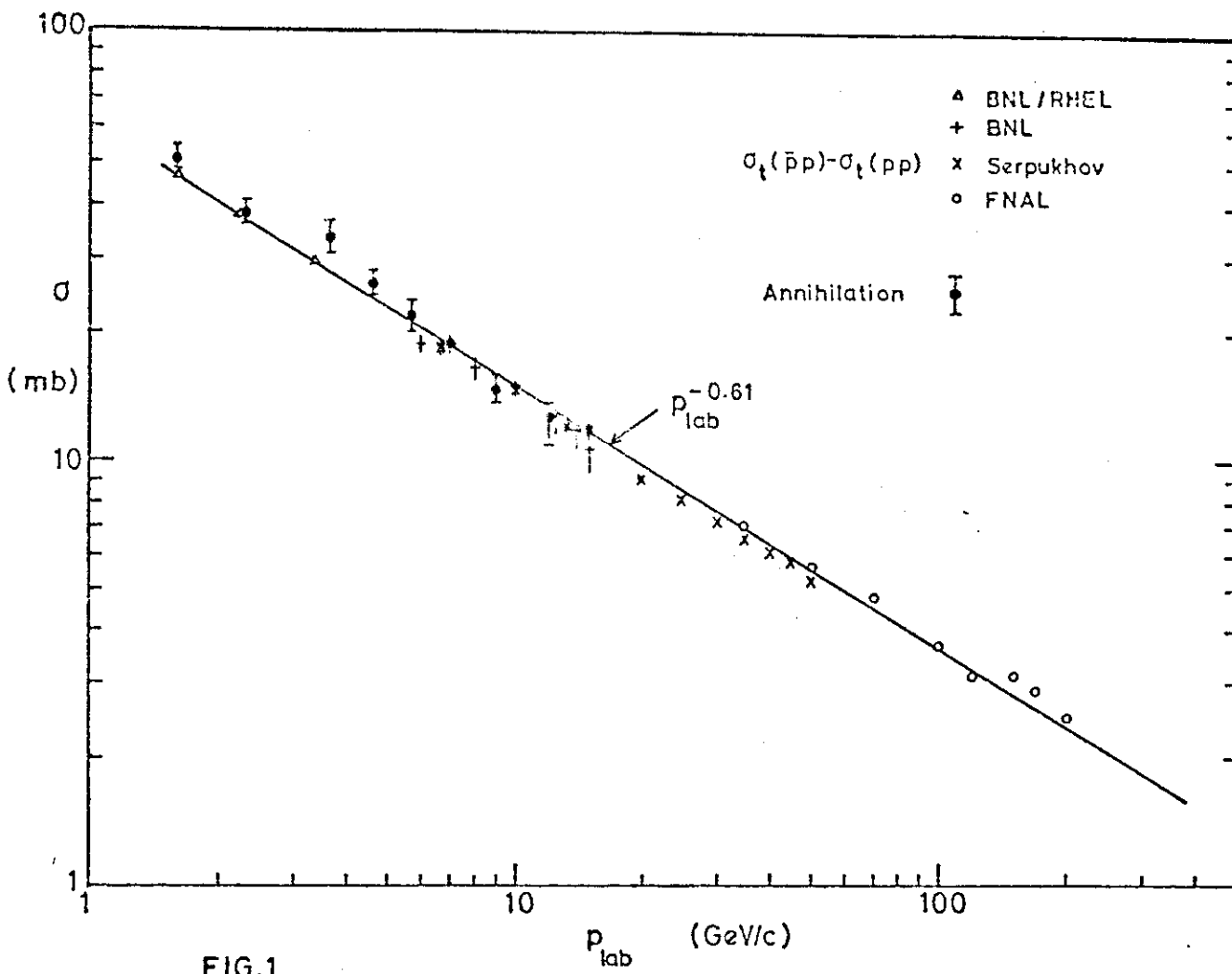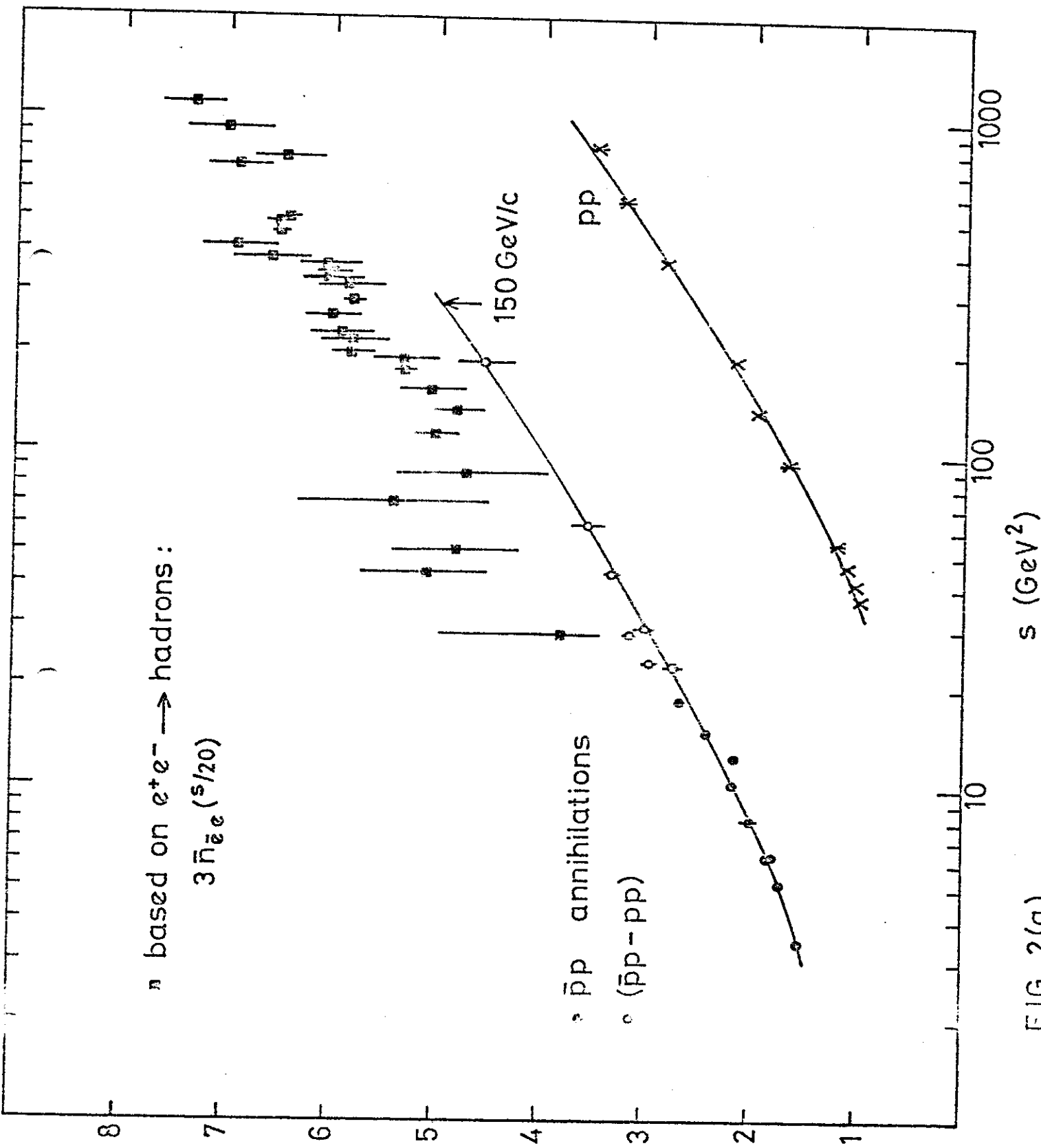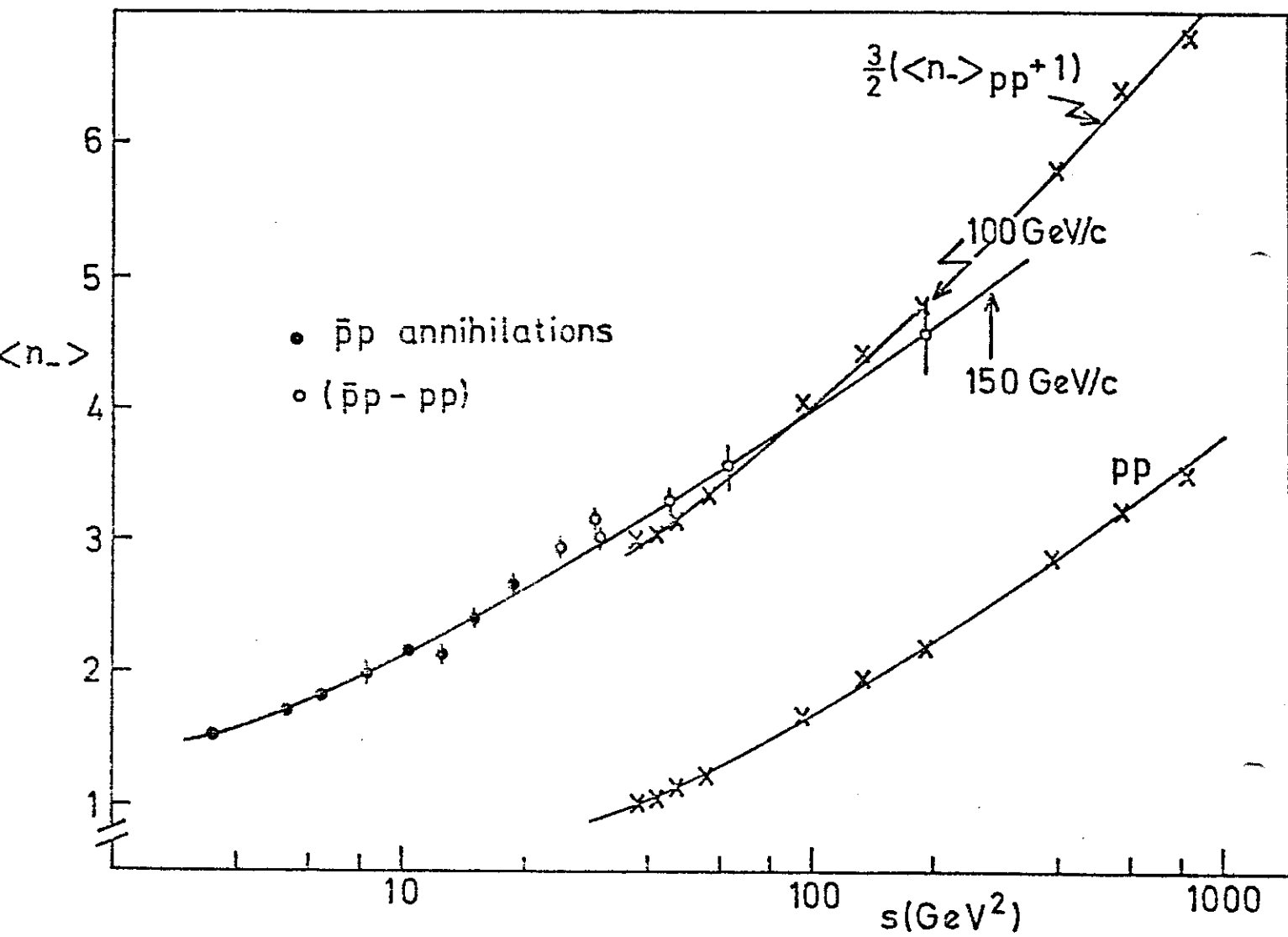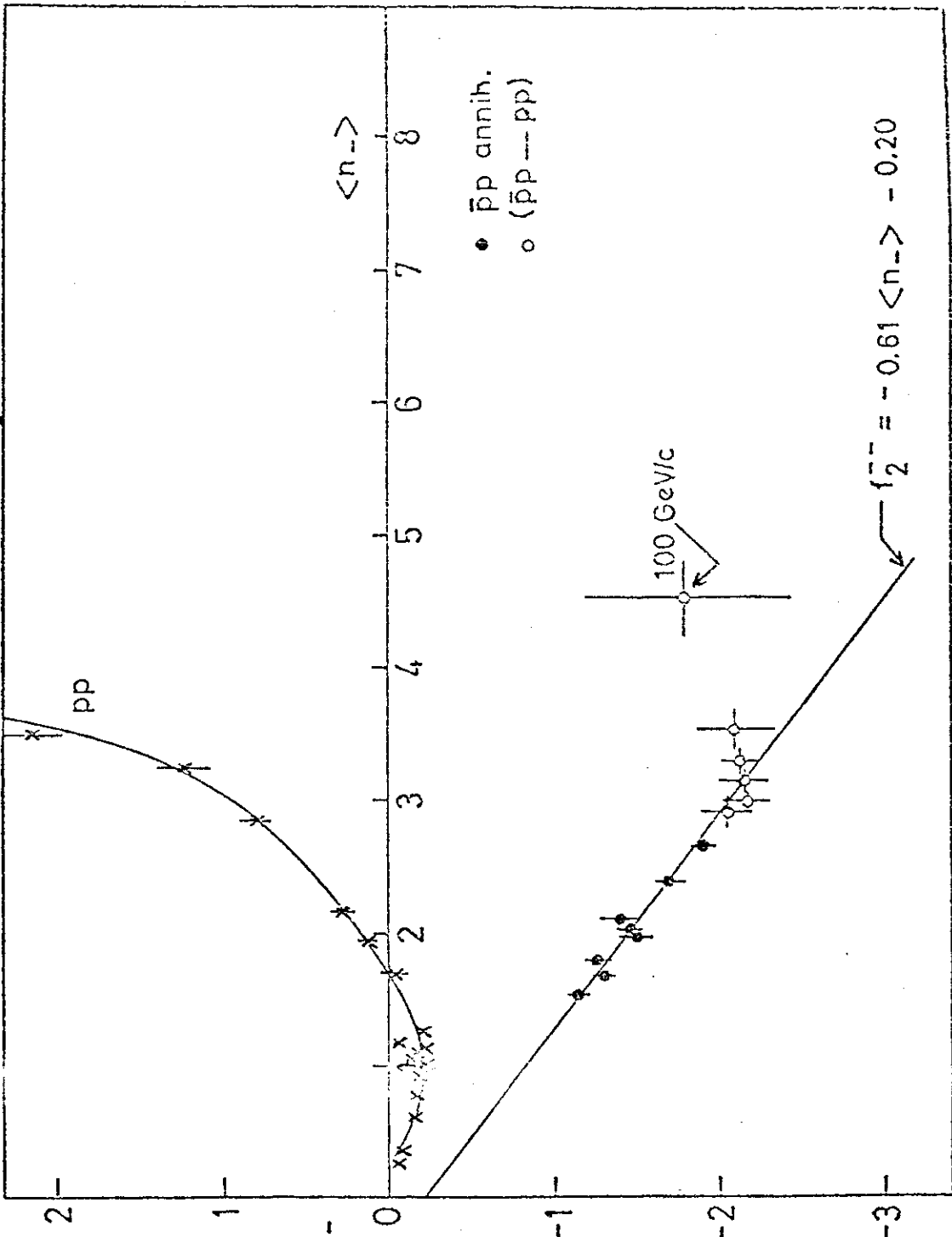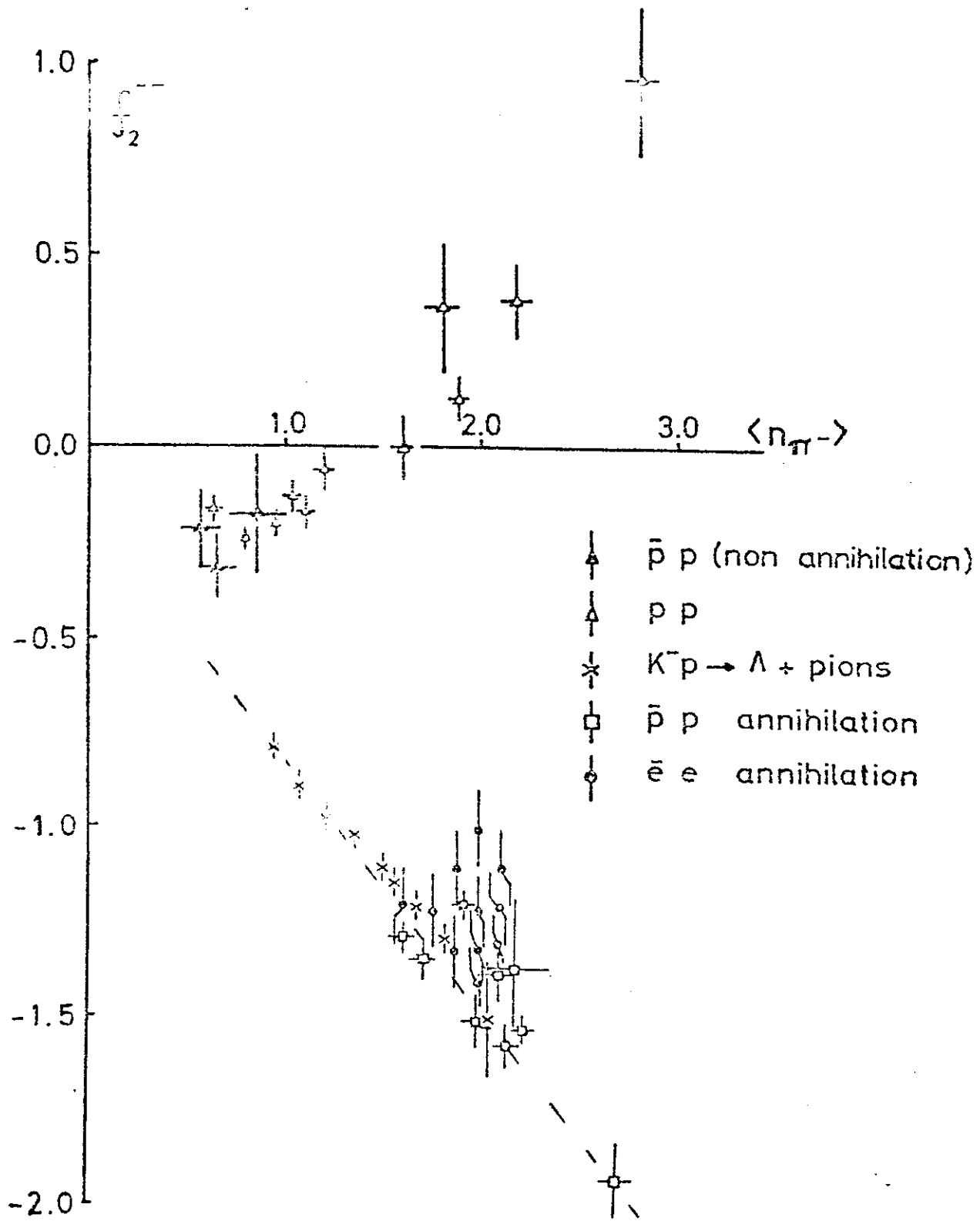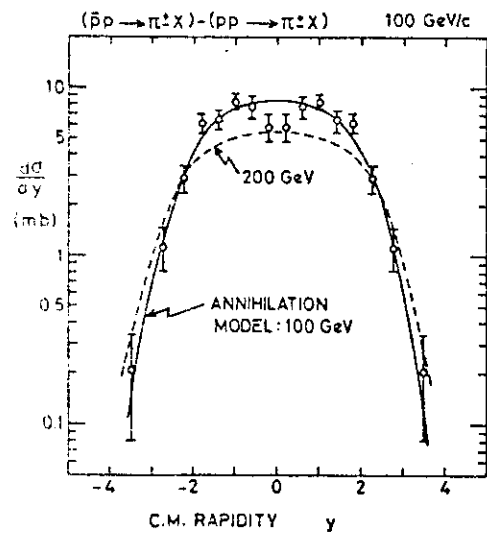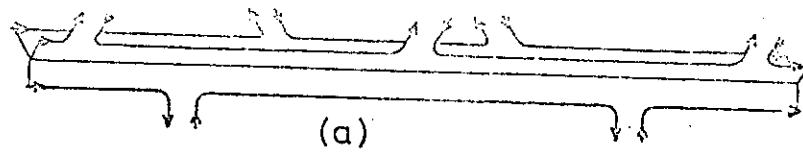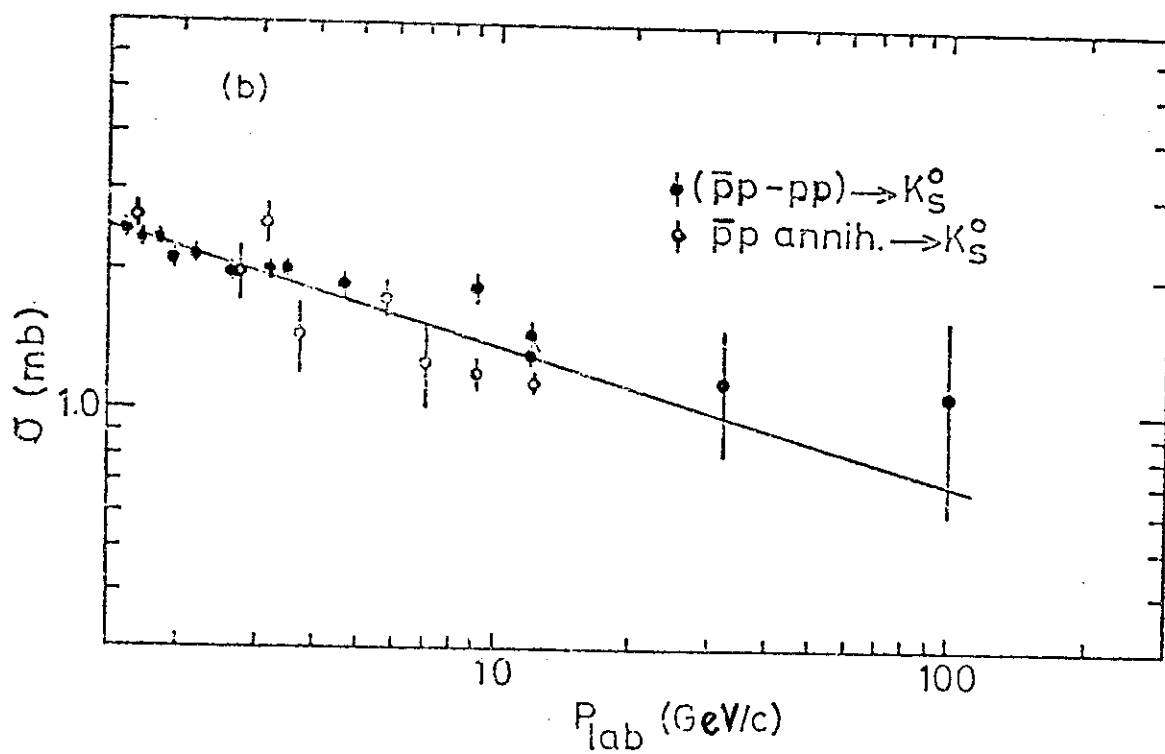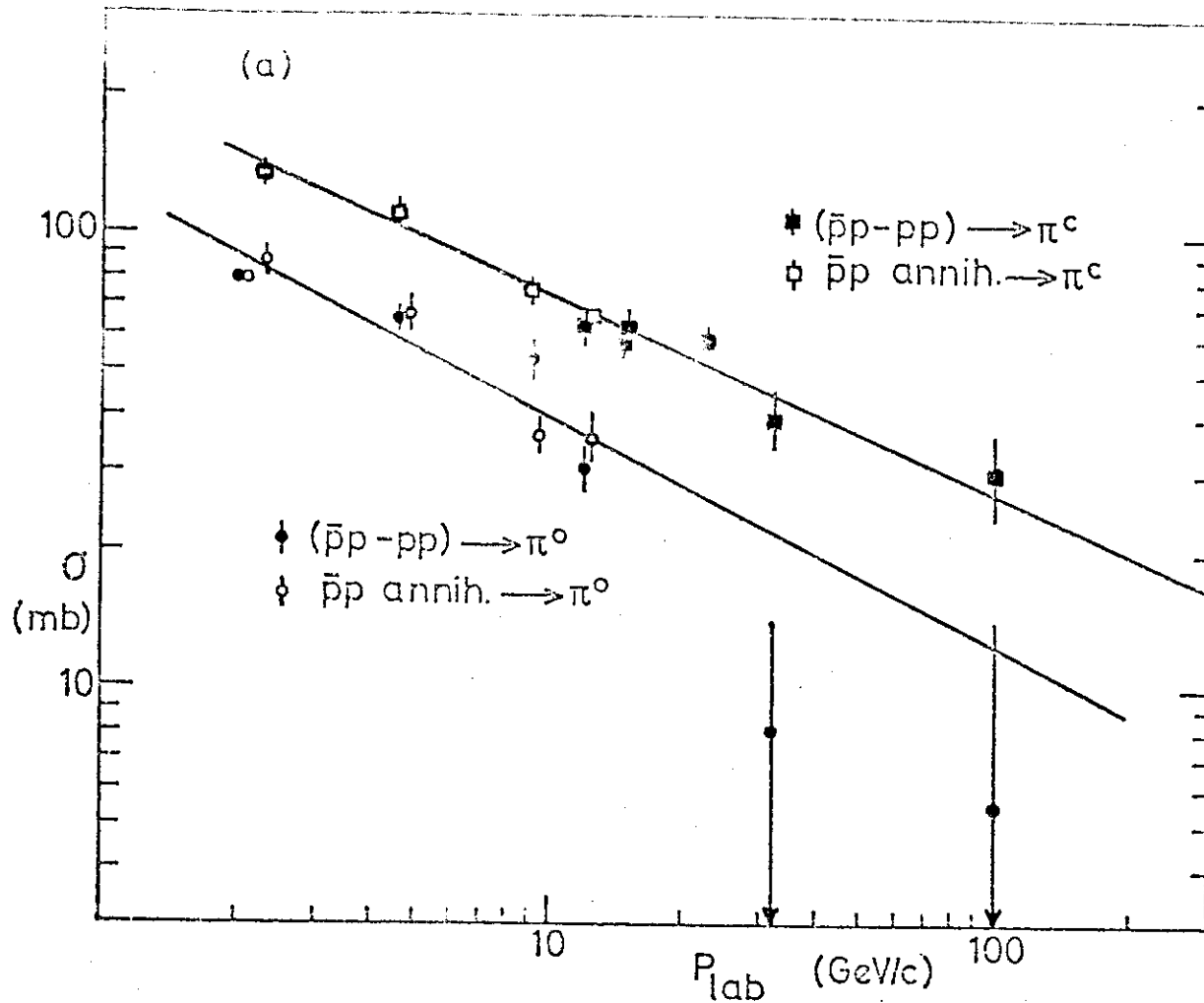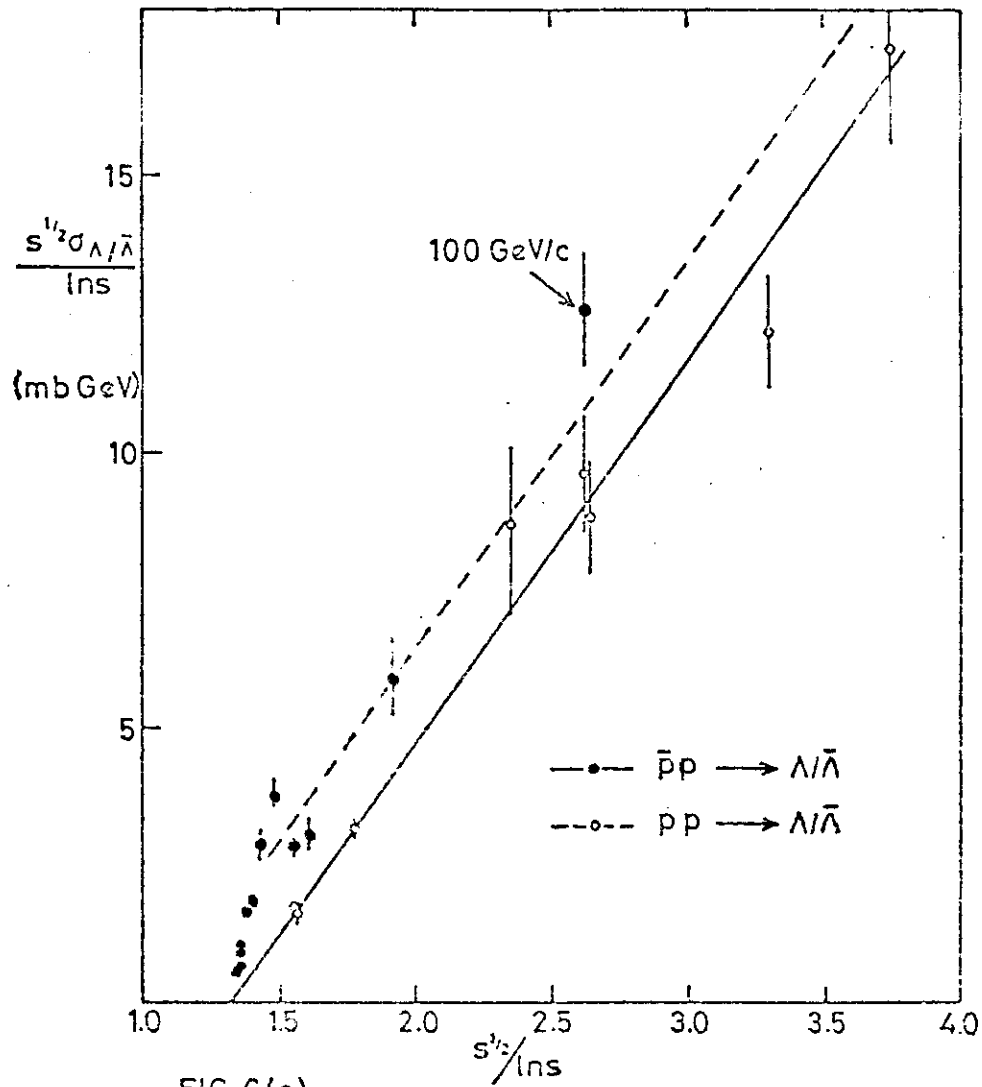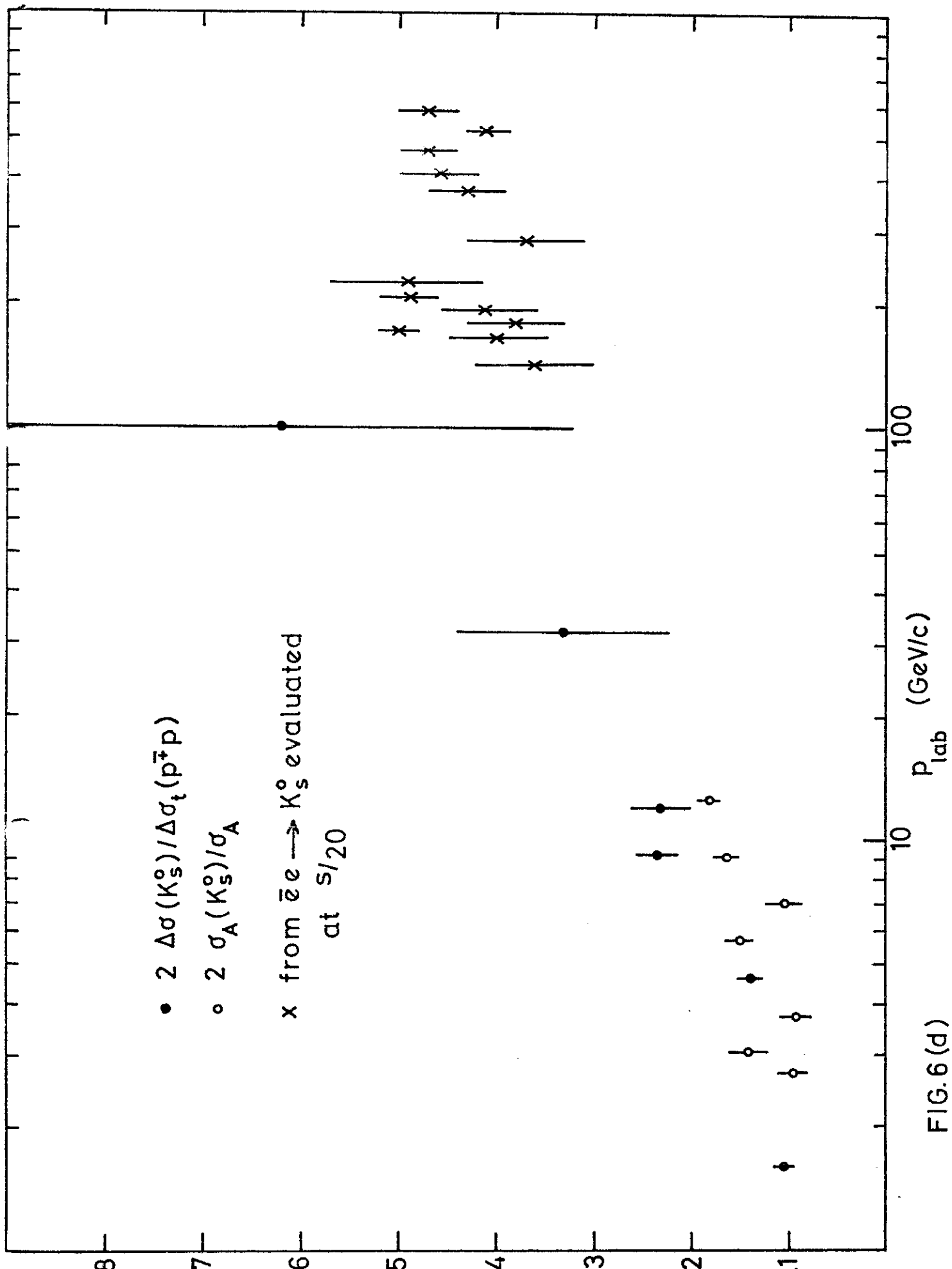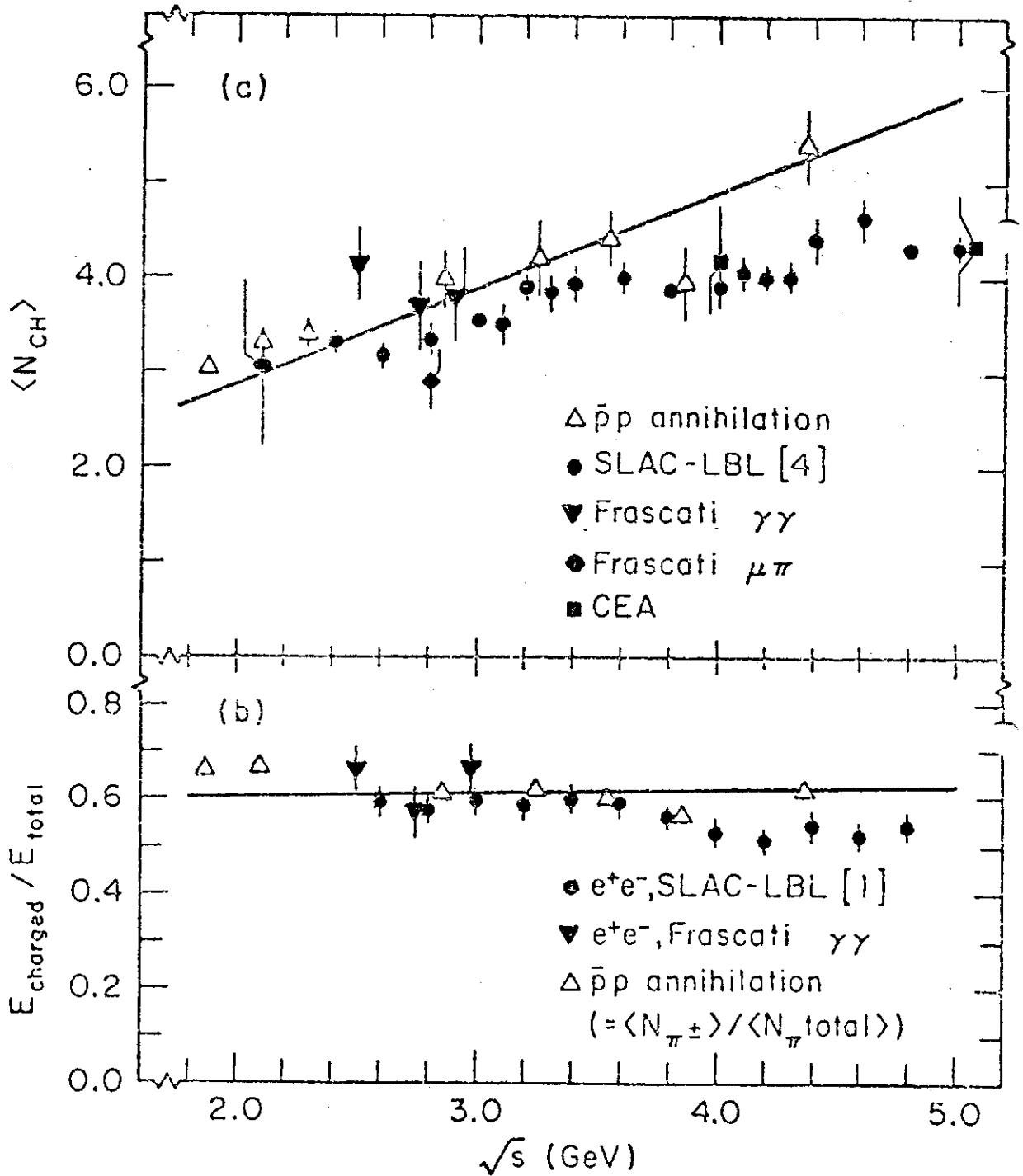
FIG. 7
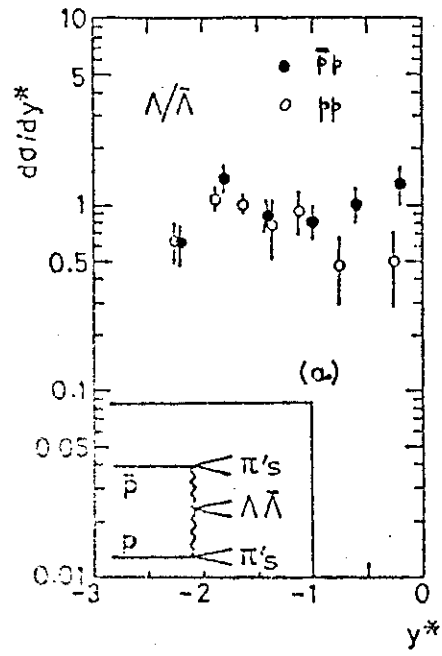
FIG. 8(a)
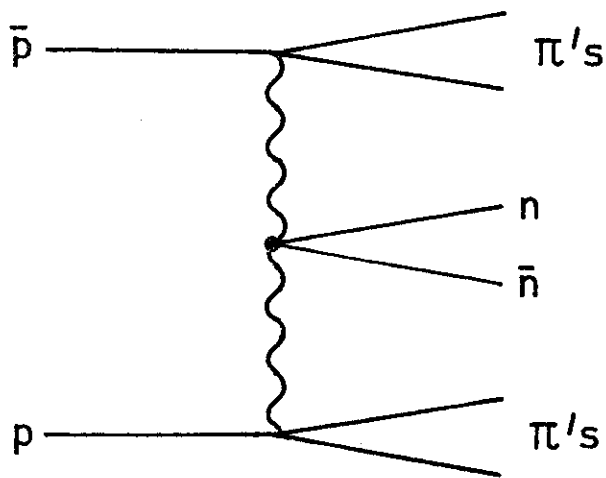
FIG. 8(b)
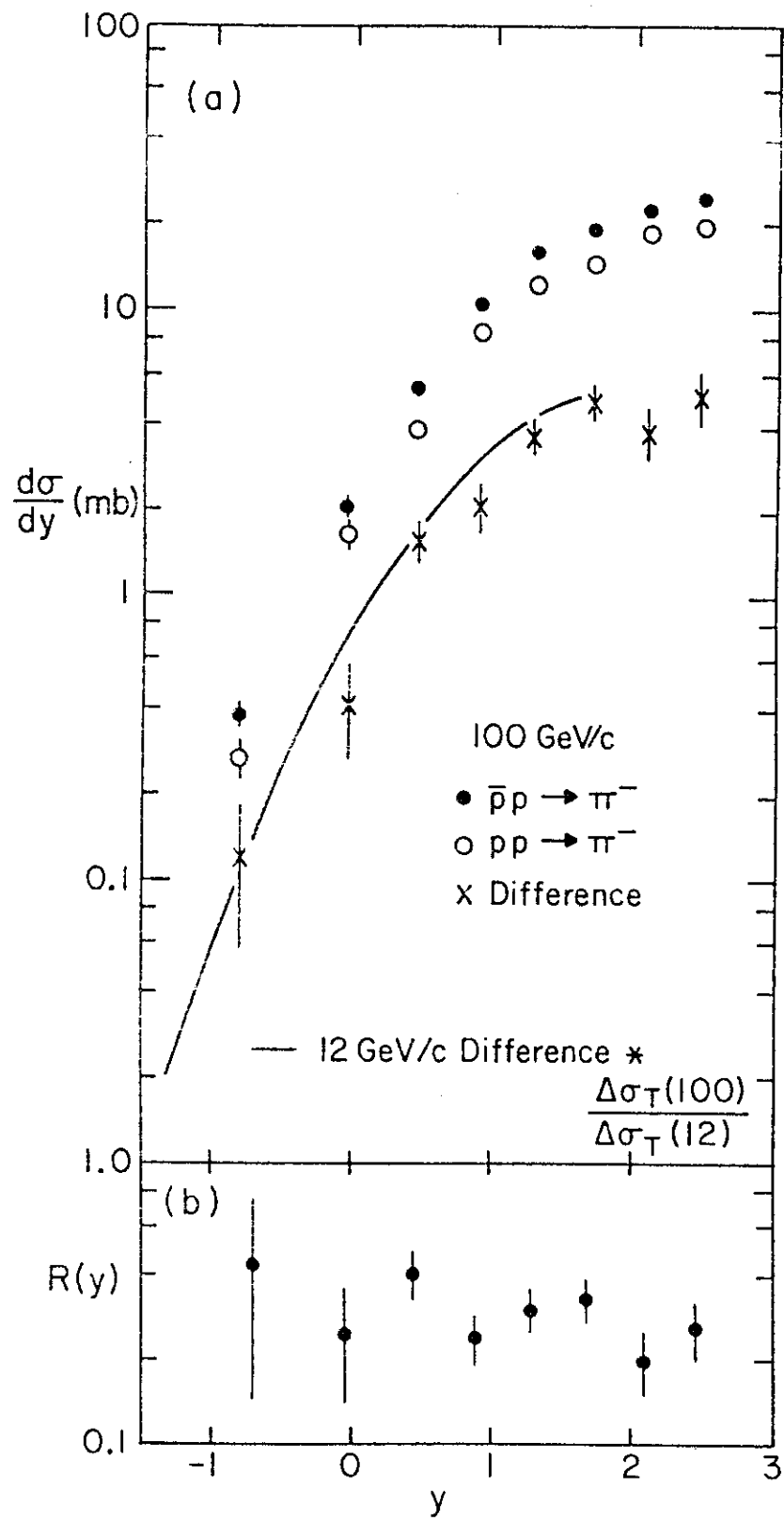
FIG.9

FIG.10

FIG. 11

FIG. 12

Fig. 13

(a)

(b)

Fig. 14