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PROPOSAL

A STUDY OF ln s PHYSICS IN $\bar{p}$ p INTERACTIONS AT THE SPLIT FIELD MAGNET

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1. INTRODUCTION

The storage of antiprotons in the ISR will open up many areas of physics for investigation. We have outlined the range our interest in this field in a letter of intent[1] and in this proposal we concern ourselves with part of that physics, namely the low p_t, "ln s", physics and with a detailed comparison of $\bar{p}p$ and pp interactions. This physics is of fundamental importance and can be investigated quickly. The other areas, such as hard scattering, lepton production, and annihilation processes, will not be discussed here, but we plan to study these in a second phase.

In the category of ln s physics we include the soft scattering processes which make up most of the $\bar{p}p$ total cross section. Topics to study include $\bar{p}p$ elastic scattering to large momentum transfer, $\bar{p}p$ total cross sections, and a study of minimum bias events to determine topological cross sections, inclusive production, and particle correlations. A comparison of these processes with pp interactions is of basic interest.

Although there is not a great amount of running time involved we consider the physics topics to be of such importance that they should be among the first items studied when antiprotons become available. Because the event rates for many of the processes are large, this first stage program can proceed even if the ISR luminosity has not yet reached the expected value. The second stage will require the maximum possible luminosity.

2. EXPERIMENTAL EQUIPMENT

We plan to use the Split Field Magnet Detector[2], shown in figure 1, in basically its present form. The detector consists of approximately 70,000 wires of proportional chambers covering essentially all 4π steradians of solid angle. The acceptance in rapidity and azimuth is shown in figure 2 for the SFM as it existed before 1977 and as it exists now. Two dipole fields of opposite polarity give momentum measurements over most of the solid angle and an array of time of flight counters and gas threshold Cerenkov counters aid in particle identifcation. It is important to emphasize that this detector has been running in the present configuration since 1977 and is a well understood apparatus.

The only modification necessary for $\bar{p}p$ running is the installation of a new vacuum chamber to accomodate the different ISR orbit for antiprotons. This has been reported on extensively elsewhere[3] and will not be discussed here.

We plan to use the entire array of existing time of flight counters and the Cerenkov counters as shown in figure 1.

The present luminosity monitor can be improved on and, in fact, represents one of the limits to some $\bar{p}p/pp$ comparisons. We are presently looking into the monitors available to see what improvements can be made with a reasonable effort. For example, in order to make a meaningful measurement of the total cross section difference it will be necessary to reach a relative $\bar{p}/p$ precision of at least one percent.

The analysis programs for the SFM already exist and can be used with very few changes. In particular, the basic track finding chain can be used in its present form.

The hardware and software status of the SFM were recently reviewed in detail before the ISRC[4].

3. PHYSICS

We shall describe, in order, elastic scattering at small and large t, inelastic interactions (minimum bias), total cross sections, and some selective triggers.

When estimating rates we shall always assume for $\bar{p}p$ a luminosity of $L = 5 \times 10^{28}\ cm^{-2} sec^{-1}$.

3.1. Elastic Scattering

Experiments on $\bar{p}p$ and pp elastic scattering at relatively small values of $|t|$ yield information on the overall spatial structure of the proton and antiproton. One aim of our proposed experiment is to perform a detailed comparison of $\bar{p}p$ and pp elastic scattering.

3.1.1. $0.05 < |t| < 0.5\ GeV^2$

In this angular region we want to determine the shape of the $\bar{p}p$ and pp distributions, in particular their slope (or slopes), the cross-over point, and the variation with energy.

An early experiment at the ISR[5] has shown that at $\sqrt{s} = 52$ GeV the pp elastic differential cross section is characterised by the presence of two exponential slopes, with a break at $|t| \simeq 0.15\ GeV^2$ (figure 3). For $|t| < 0.15\ GeV^2$ the cross section is described with the exponential form

$$d\sigma/dt = Ae^{bt} \qquad (1)$$

with $b \simeq 12.4\ \mathrm{GeV}^{-2}$; and for $|t| > 0.15\ \mathrm{GeV}^2$ with $b \simeq 10.8\ \mathrm{GeV}^{-2}$.

Recent experiments at Fermilab[6], at lower center of mass energies, suggest instead that the t-distribution is described by the form

$$d\sigma/dt = A \exp(Bt + Ct^2) \qquad (2)$$

(see figures 4 and 5).

We propose to repeat in 1980 an accurate measurement of pp elastic scattering at small t values at one or two energies. In addition to helping us prepare for 1981 running, this will allow a precise check of the t-dependence of the cross section. In 1981 we propose to measure $\bar{p}p$ and pp elastic scattering in this angular region for at least three energies.

For $|t| < 0.5\ \mathrm{GeV}^2$ the elastic cross section is large; thus there are no problems with counting rates. The elastic trigger is simple: we shall require two and only two charged particles going in opposite directions and correlated in the vertical plane. We plan to use only a limited fraction of the available ϕ acceptance in order to limit the effects of the movements of the interaction region in the horizontal plane.

A comparison with previous experiments indicates that a precise analysis requires approximately 500 000 events at each energy and for each type of collision. This level of statistics will yield the parameters of equation (2) with statistical precisions of $\Delta A/A = \pm 0.5\%$, $\Delta B/B = \pm 0.6\%$, and $\Delta C/C = \pm 5.0\%$.

For proton-proton collisions, data taking is limited only by the acquisition rate of 30 events per second. The required statistics can then be obtained in a few hours.

For $\bar{p}p$ collisions, the total number of elastic events for $|t| >$ 0.05 GeV^2 is given by

$$N(|t|>0.05) \simeq L\ (\Delta\phi/2\pi) \int_{t_{min}}^{t_{max}} d\sigma/dt\ dt$$

$$\simeq L\ (A/b)\ (\Delta\phi/2\pi)\ \exp(bt_{min}) \qquad (3)$$

Assuming $L = 5 \times 10^{28}$ cm^{-2} sec^{-1}, $A = 80$ mb/GeV^{-2}, $b = 12$ GeV^{-2}, and $\Delta\phi/2\pi = 1/6$ one obtains 30 events per second. Thus for $\bar{p}p$ elastic scattering at small t the rates are high and the measurement will be done as quickly as for pp.

It is somewhat more difficult to estimate the precision with which the crossover point will be determined, but it should be better than 0.05 GeV^2. For comparison, data from FNAL[7] is shown in figure 6.

3.1.2. $0.5 < |t| < 5.0$ GeV^2

In this t-range the pp elastic differential cross section is characterised by a minimum at $|t| \simeq 1.5$ GeV^2, a maximum at 2.0 GeV^2, followed by an exponential decrease (see figure 7 and reference [8]). The location of the minimum moves toward smaller values of $|t|$ when the center of mass energy increases.

We plan to measure $\bar{p}p$ elastic scattering in this angular range in order to establish if such a dip-bump structure also exists in $\bar{p}p$ and to see if it has the same energy dependence as in pp. For this last purpose we need to perform the measurements at at least three energies.

The high t elastic trigger is similar to the one used for low t elastic scattering; we shall require two and only two charged particles going in opposite directions. Since the cross section in this region is small, the trigger has to be tighter than in the previous case: we shall require anticoincidences of charged particles outside the forward and backward cones, and remove elastic scattering events for $|t| < 0.5$ GeV^2.

If the $\bar{p}p$ differential elastic cross section is similar to the one for pp, we shall obtain approximately 200 elastic events per day for $|t| > 1.0$ GeV^2 (to be compared with 40000 for pp). A meaningful measurement requires about 100 hours of running time per energy. If the luminosity would be lower than the assumed value of 5×10^{28} cm^{-2} sec^{-1}, it should still be possible to obtain a meaningful measurement by including the large angle elastic trigger when performing inelastic measurements.

3.2. Minimum Bias Trigger

Because of its nearly total coverage of solid angle, the SFM is a unique device with which to study minimum bias events. A minimum bias trigger has existed for a long time on the SFM[9] and since the improvements of 1977 it covers 96 percent of the total pp cross section with a beam-gas background in the trigger of less than 2 percent. It is defined by requiring three or more hits in any one of the three regions of the detector. Even with the reduced luminosity of the $\bar{p}$ running, the trigger rate is several orders of magnitude greater than the data acquisition rate of 30 events per second. In a few hours of running at each energy a sufficiently large sample of data can be taken. However, it is important that this running takes place during very clean conditions. A few short special runs may be necessary.

The analysis time for minimum bias events is about 1 second (CDC

7600) per event, and it is this which limits the number of minimum bias events used for physics.

The analysis of these events would proceed in several stages, requiring progressively larger numbers of events. From a relatively small sample, about 20000 events, we shall extract the following: a) the topological cross sections, b) mean number of charged particles and higher order moments, c) mean transverse momentum, d) single particle inclusive spectra in rapidity and transverse momentum, and e) particle correlations (for example, short and long range rapidity correlations). Figure 8a shows a raw charged multiplicity distribution from the SFM of pp data at $\sqrt{s}$ = 62 GeV. When the data are corrected for the approximately 15 percent of the tracks that are not reconstructed and the low multiplicity diffractive events removed, the distribution of figure 8b results.

To study other topics is may be necessary to analyze a larger number of events. However, a fast selection process can be envisioned so that most events will not be analyzed in full. By writing a reasonably large number of events on tape and using a fast filter to select the subsample of interest, high statistics can be achieved at modest computer cost.

3.3. Measurement of $\Delta\sigma \equiv \sigma_{tot}(\bar{p}p) - \sigma_{tot}(pp)$

From the measurements of elastic scattering at small angles and of inelastic interactions in the minimum bias mode we shall in principle obtain two independent measurements of the difference of the $\bar{p}p$ and pp total cross sections. In particular:

i). From the ratios of the differential elastic cross sections for

$\bar{p}p$ and pp for $|t| < 0.5$ GeV^2, using the optical theorem one has

$$\frac{\sigma^2(\bar{p}p)}{\sigma^2(pp)} = \frac{[d\sigma/dt(\bar{p}p)]_{t=0}}{[d\sigma/dt(pp)]_{t=0}} \frac{[1+\rho(pp)]}{[1+\rho(\bar{p}p)]} \quad (4)$$

where ρ = Re f(0)/Im f(0) and the t = 0 differential cross section may be obtained by fitting the elastic data to equations (1) or (2).

With the statistics envisaged in section 3.1.1 for elastic scattering, we can measure $\Delta\sigma$ to a statistical accuracy of about 0.2 mb (to be compared to a $\Delta\sigma$ of 1-3 mb). But in order to make effective use of such accuracy one needs a better monitor, as discussed in section 2.

ii). From the ratios of minimum bias events:

$$\frac{\sigma(\bar{p}p)}{\sigma(pp)} = \frac{N(\bar{p}p)}{N(pp)} \frac{L(pp)}{L(\bar{p}p)} \quad (5)$$

where N($\bar{p}p$) and N(pp) are the corrected number of minimum bias events. Here the relative luminosity precision is more important because the measurement of cross section is proportional to L, while in i) it is only proportional to $\sqrt{L}$. Nevertheless the statistical accuracy would be adequate to a precision on 0.2 mb.

These measurements will be otained in the natural course of the experiment but will not be as precise as those of experiments R210 and R211. However, the data could provide a useful corroboration if a suitable luminosity monitor is obtained.

3.4. Selected Triggers

We plan to use a number of selected triggers (probably to run in parallel with the large angle elastic scattering trigger) to select some specific channels which could be relevant to ln s physics problems. Examples of triggers under study are:

i). 20^0 Cerenkov trigger

At present there are no data on K/π or K/p correlations. By triggering on one or more particles going toward the 20^0 Cerenkov counters we could obtain Cerenkov identified tracks to enable us to study rapidity correlations with a K or p in the region of the Cerenkov counter.

ii). π^+, π^- spectra at large angles.

The π^+ and π^- spectra produced at 90^0 in $\bar{p}p$ collisions should be equal because of CP conservation. We may attempt a comparison for pions produced at large angles at the highest ISR energy.

iii). Diffractive Trigger

This trigger would require a total of less than 6 particles with none produced at large angles. A specific example is the reaction $\bar{p}p \rightarrow (\bar{p}\pi^+\pi^-)+(p\pi^+\pi^-)$, but other reactions will also be present. The comparison of the various diffractive processes should give further information on Pomeron exchange mechanisms.

4. SUMMARY OF REQUESTS

We would like to take data at three energies, preferably $\sqrt{s}$ = 20, 52, and 63 GeV. Because it is likely that many users will want a variety of energies in the early periods of $\bar{p}p$ running we are prepared to take data at a number of energies and with special conditions such as the use of the Terwilliger scheme. If more energies are available we will take low t elastic scattering and minimum bias events but will place a lower priority on processing them.

Table 1 shows our minimum needs for computer and beam time. Some of the numbers are necessarily only rough estimates because selection and reconstruction times are not well known. This is particularly true of the special triggers and second stage minimum bias processing. As can be seen from table 1, we request 500 hours of running time of which 75 hours represents pp running, 25 hours of it to come in 1980. The estimated computer needs are 300 CDC 7600 hours, to be shared among the collaborating institutions.

In table 2 we estimate the available computer time in 1980 and 1981 at each of the laboratories. Because of the already large backlog of SFM processing for pp data, we are planning to use the CERN computers only for Monte Carlo generation of track finding parameters, bicycle- on-line checks of the data, fast filtering, and processing a small number of events to validate the programs being run at other laboratories. As the table shows, the available computer time exceeds our minimum requirements.

In summary, we are requesting 500 hours of beam time, 25 hours of it to be pp running in 1980, 50 hours of pp in 1981 and the rest $\bar{p}p$ running early in the $\bar{p}p$ program in 1981. The request for computer time at CERN is minimal.

In a future communication we will better specify our plans for the second stage of $\bar{p}$ running.

<u>Table 1</u>: Summary of Beam and Computer Needs

	events per energy	total data taking time (hrs)	CDC time per event (secs)	total time (CDC hrs)
<u>$\bar{p}p$ (3 energies)</u>				
elastic scattering				
low t	5×10^5	12	0.12	52
high t	1000	300	0.12	3
minimum bias				
full sample	5×10^5	12	?	60
reduced sample (full analysis)	2×10^4	-	1.0	35
selected triggers	?	same as high t elastic	?	50
<u>pp (3 energies)</u>				
elastic scattering and minimum bias	same as above	75	same as above	100
TOTALS		500		300

Table 2: Available Computer Time in CDC Hrs

	1980	1981
Ames	20	120
Bologna	20	80
CERN	20	40
Heidelberg	20	40
TOTALS	80	280

References

[1] D. Drijard et al, CERN/ISRC 78-24.

[2] P. G. Innocenti et al, 'The Upgraded SFM Detector', CERN/ISRC/79-4, p.1.

[3] See for example, P. Bryant, 'Expected ISR Performance with Anti-protons; ISR Division pp Study', CERN/ISRC/79-4, p. 79.

[4] O. Ullaland and D. Drijard, 'Status Report of Experiment R416', ISRC open meeting of 19 March, 1980.

[5] M. Holder et all, Phys. Lett. 35B (1971) 355; 36B (1971) 400.

[6] A. Schiz et al, FERMILAB-Pub-79/81-EXP and references therein.

[7] D. S. Ayres et al, Phys. Rev. D15 (1977) 3105.

[8] U. Amaldi and K. R. Schubert, CERN-EP/79-155, and references therein.

[9] D. Drijard et al, Nucl. Phys. B155 (1979) 269.

FIGURE CAPTIONS

Figure 1. Split Field Magnet (SFM) detector in the late 1980 configuration.

Figure 2. Acceptance of SFM detector as function of rapidity y and azimuthal angle ϕ. (a) old detector (pre-1977) and (b) present detector.

Figure 3. t distribution for pp elastic scattering for $|t|<0.4$ GeV^2 at a center of mass energy of 53 GeV[5].

Figure 4. $d\sigma/dt$ for elastic pp scattering at 200 and 175 GeV/c[6].

Figure 5. Local slopes for πp and pp elastic scattering in the low t region[6].

Figure 6. (a) normalized $\bar{p}p$ and pp elastic differential cross sections. (b) location of the cross-over point, t_c, as a function of lab momentum[7].

Figure 7. pp elastic differential cross sections for $|t|<4.0$ GeV^2 at $\sqrt{s}$ = 23.5 to 62.5 GeV[8].

Figure 8. SFM minimum bias trigger for pp collisions at $\sqrt{s}$ = 63 GeV. (a) Observed charge multiplicity distribution; (b) charge multiplicity distribution corrected for acceptance and with diffractive events removed (preliminary analysis)[4].

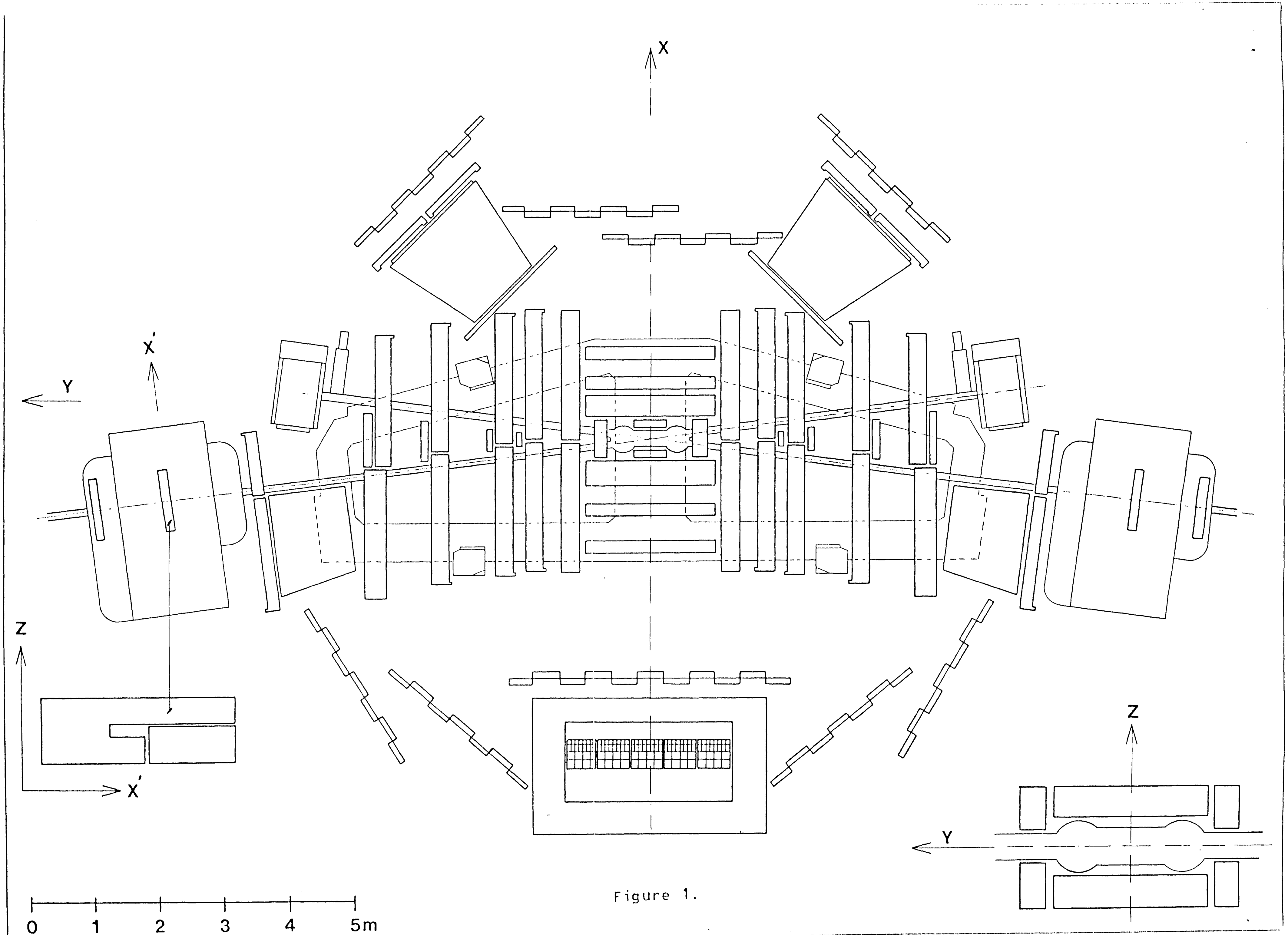
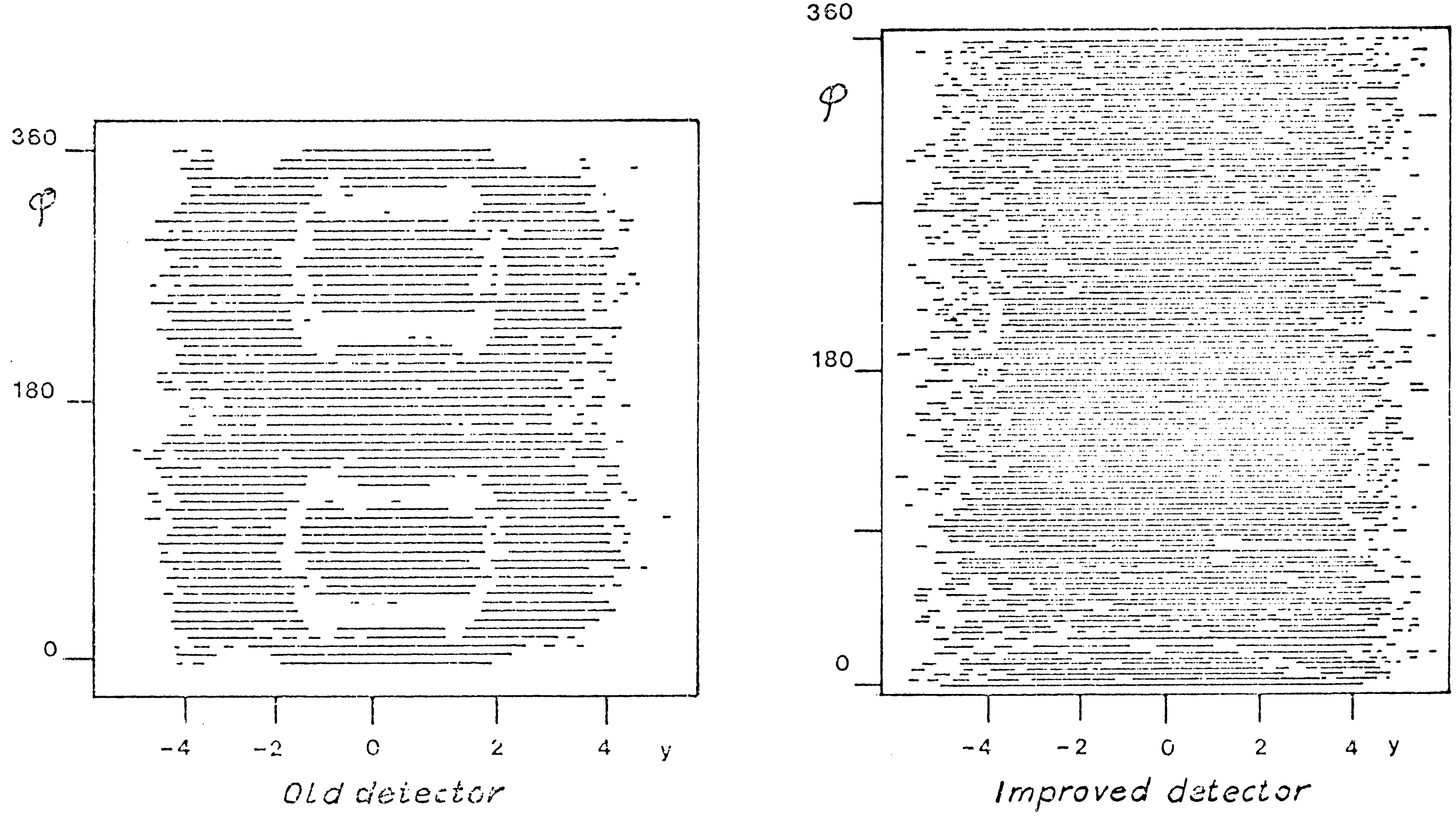


Figure 1.


360
φ
180
0
-4
-2
0
2
4
y
Old detector
360
φ
180
0
-4
-2
0
2
4
y
Improved detector

(a) (b)

Figure 2.

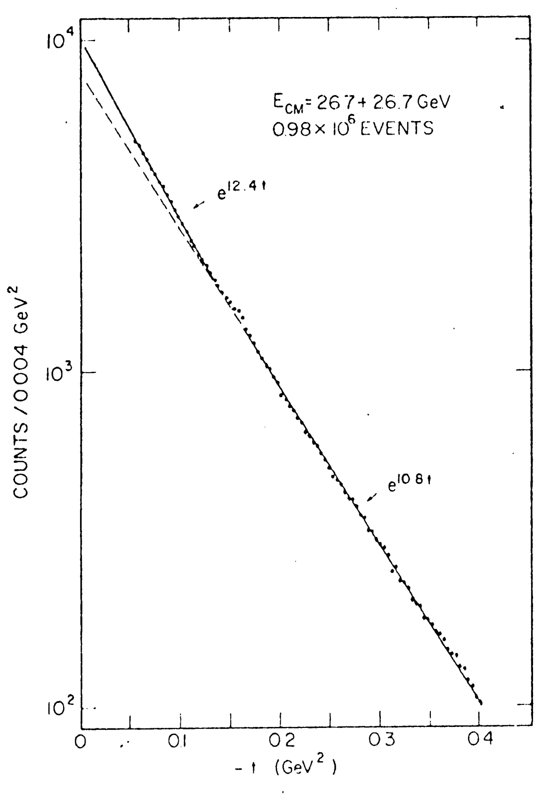


Figure 3.

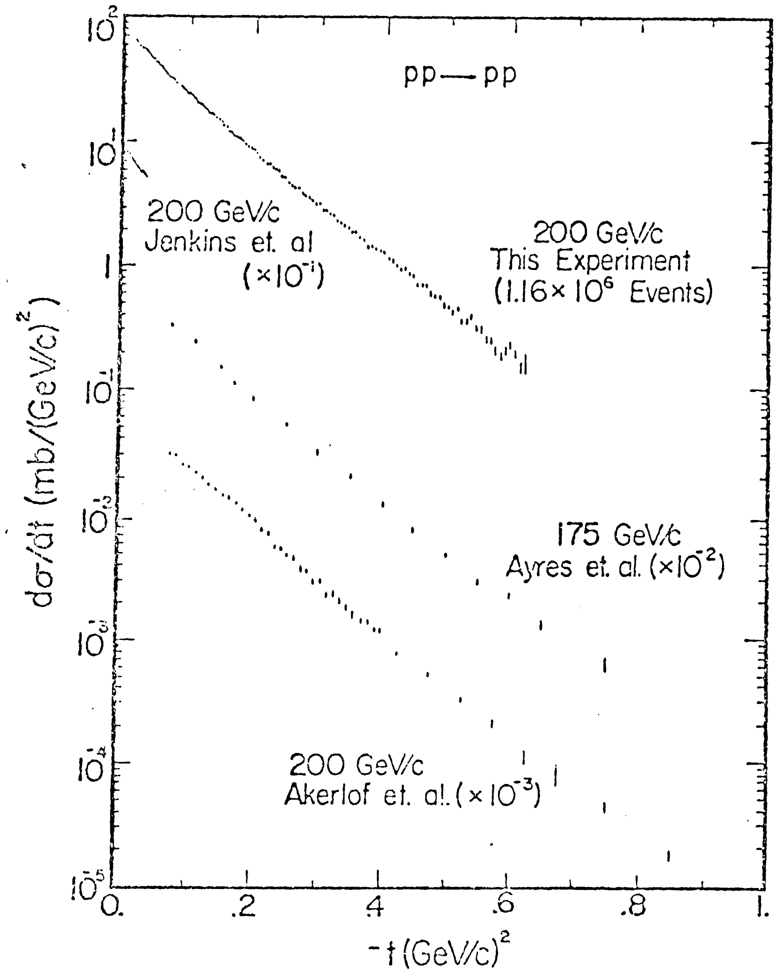


Figure 4.

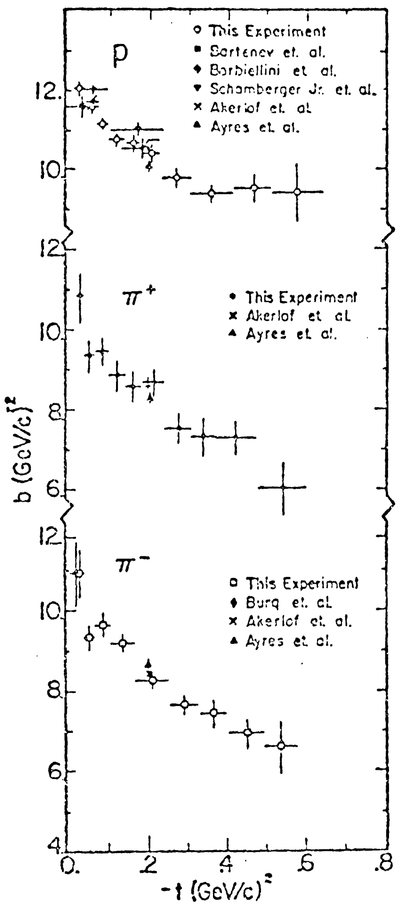


Figure 5.

pp̄ - pp CROSS-OVER

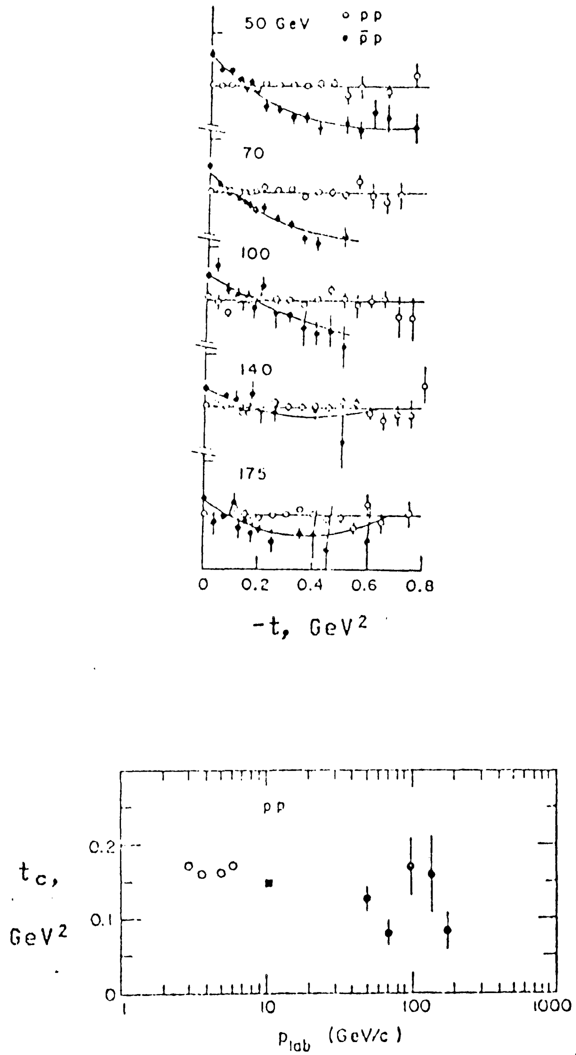


Figure 6.

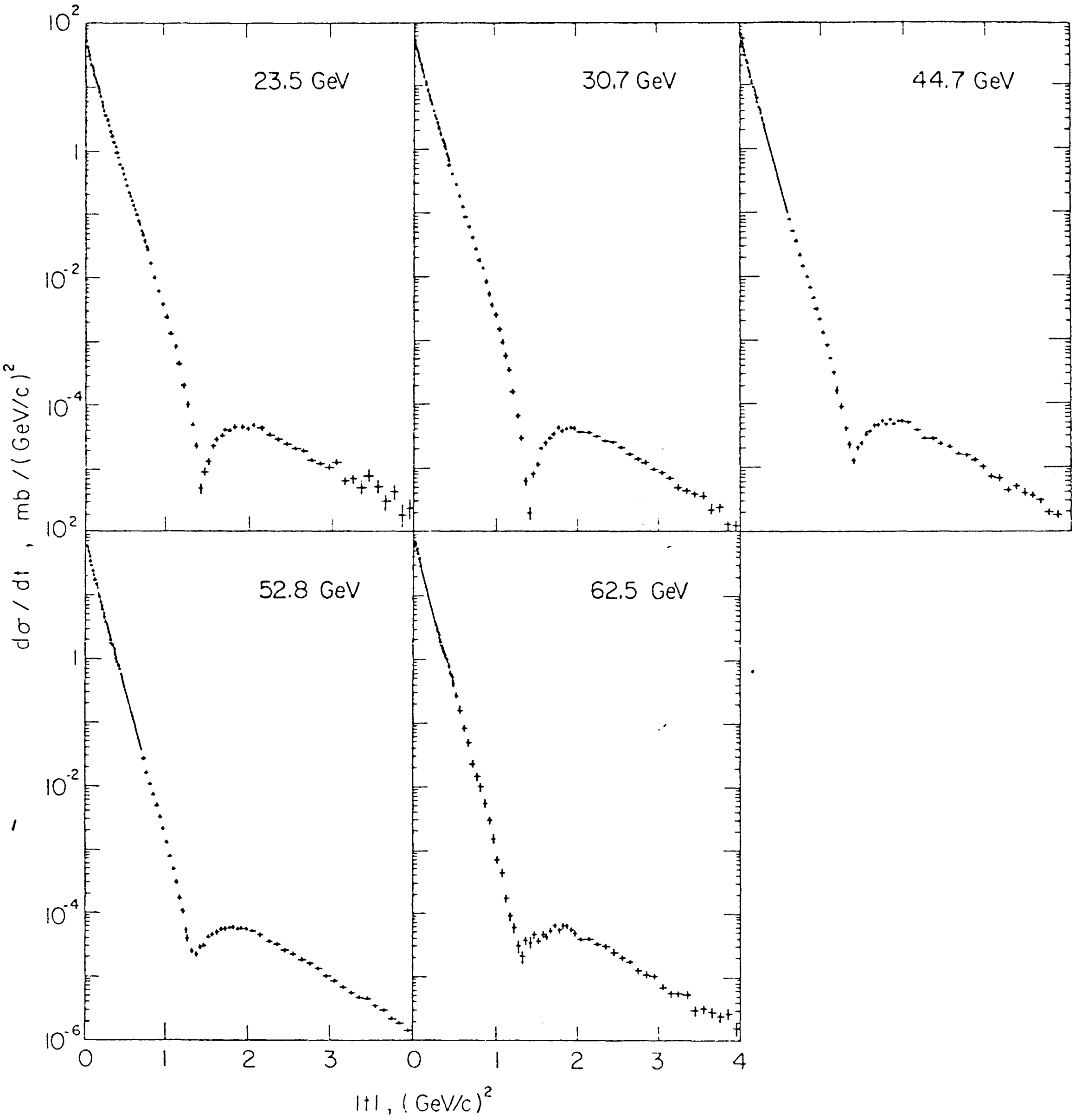
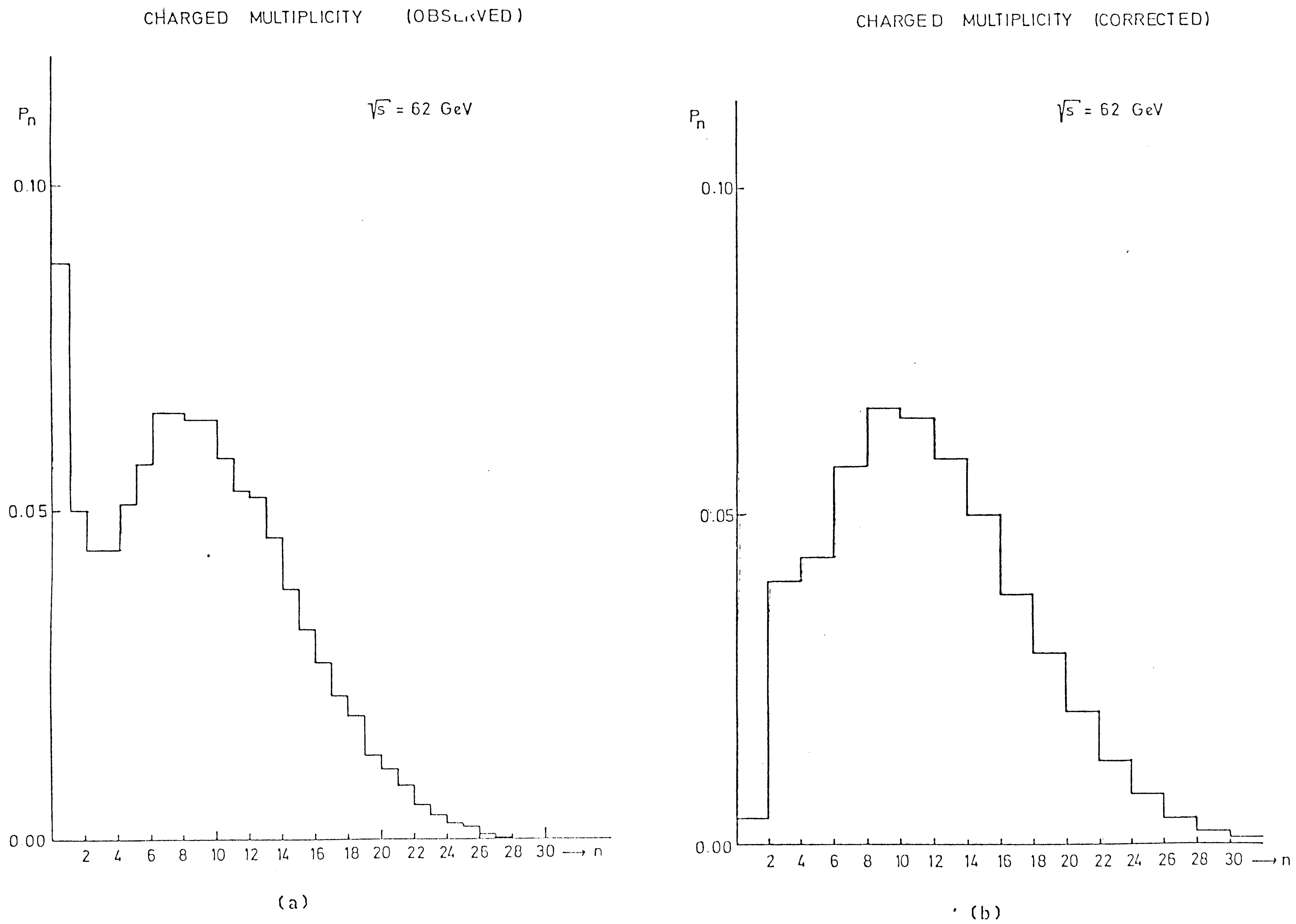

23.5 GeV
30.7 GeV
44.7 GeV
52.8 GeV
62.5 GeV
$d\sigma/dt$, mb / (GeV/c)^2
$|t|$, (GeV/c)^2
10^2
1
10^{-2}
10^{-4}
10^{-6}
0
1
2
3
4

Figure 7.



CHARGED MULTIPLICITY (OBSERVED)
P_n
$\sqrt{s}$ = 62 GeV
0.10
0.05
0.00
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 → n
(a)
CHARGED MULTIPLICITY (CORRECTED)
P_n
$\sqrt{s}$ = 62 GeV
0.10
0.05
0.00
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 → n
(b)

Figure 8.