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PROPOSAL

FOR A MEASUREMENT AT 4 GeV/c OF THE $\bar{p}p-\pi^+\pi^-$ DIFFERENTIAL CROSS SECTION, AT SMALL VALUES OF t AND u

by

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§ 1) Meaning of the experiment

The reaction we propose to study is related by crossing symmetry to backward πp elastic scattering and its investigation is therefore a test of the models that should account for those reactions as, for instance, baryon exchange mechanism. At high energy backward π^+p scattering has been interpreted by N_α exchange and π^-p scattering by Δ_δ exchange$^{(2,3)}$. Under the assumptions that the trajectories are straight lines and the Regge residues are constant, Barger and Cline $^{(4)}$ have predicted for $\bar{p}p \to\pi^+\pi^-$ at high energy the behaviour shown in Figs 1 and 2: exponential decrease for the forward π^+ (and backward π^-) and exponential decrease followed by a dip and a secondary maximum for backward π^+ (and forward π^-).

Existing data on high energy antiproton annihilation into two charged pions are scanty. Measurements of total cross sections have been performed in bubble chamber experiments at 1.6, 2.7, 3.7, 4.0 GeV/c $^{(5-8)}$. At the first three momenta there are also differential cross section measurements, but the combined number of events is small (36). A counter spark chamber experiment has been run at momenta ranging from 0.72 to 2.64 GeV/c $^{(9)}$, without magnetic analysis and limited to an angular range from 40° to 90° in the center of mass. The same group is reported to be running at 3 GeV/c, with magnetic analysis $^{(10)}$. Finally, an attempt of such a measurement at 8 GeV/c has found 25 candidates for $\bar{p}p \to\pi^+\pi^-$ $^{(11)}$.

We propose to study the reaction at 4 GeV/c. At this momentum direct channel interference should be negligible and a reasonable yield of events should be possible with available beams. The predicted features of the differential cross section that should be checked by our experiment are the difference in slope and magnitude of $d\sigma/du$ at small u between π^+ and π^- and the dip and secondary maximum in the $d\sigma/du$ of π^- at small u.

§ 2) Description of the apparatus

The physical quantities we intend to measure are direction and momentum of the forward pion and direction of the backward one. We are left therefore with one unknown, the momentum of the backward pion, so that the problem is a three constraints one.

The detection apparatus that has been designed to meet the above requirements consists of a suitable set of optical spark chambers and counters, surrounding a liquid hydrogen target, as shown in Fig. 3. The triggering logic is $\check{C}_1 C_1 C_2 C_3 \bar{C}_4 \check{C}_2$.

C_1, C_2, C_3 are conventional scintillation counters to detect the beam particles.

$\check{C}_1$ is a threshold Čerenkov counter and selects the incoming $\bar{p}$ in the unseparated beam: it gives a pulse for e, μ, π, k but not for $\bar{p}$.

$\check{C}_2$ is another threshold Čerenkov counter: it rejects elastic antiproton proton scattering, part of the manybody annihilation processes and the annihilation into two charged kaons. It is a gas counter, filled with Freon 13. To get a yield of about 150 photons per pion, in the investigated β range, 0.9994 to 0.9995 (corresponding to the angular acceptance, see below), a pressure of 3.0 atmospheres at 20 centigrades is required. With such operating conditions the threshold of the counter is at $\beta = 0.9980$, but only at $\beta = 0.9986$ we start getting about 70 photons per pion, so that the real threshold, taking into account the reflecting power of mirrors, the transparency of windows and the photoelectric efficiency, should be between 0.9986 and 0.9990. These values are well above the β values for antiproton proton scattering ($\beta \leq 0.973$) and two kaons annihilations ($\beta \leq 0.993$), but pions from manybody annihilations could trigger the system.

The anticounter C_4 covers most of the forward emisphere, excepted the quite limited forward acceptance cone; it consists of a large array of scintillators and lead sheets, viewed by several photomultipliers, with the main purpose to reduce the background coming from annihilations into many charged pions and into $\pi^+\pi^-$ + $m\pi^o$ (m = 1,2,.....). The full trigger efficiency is discussed in point 5 below.

The target is a 40 cm long, 4 cm in diameter, mylar cylindrical container, filled with liquid hydrogen and enclosed into a thin wall jacket. This jacket has a mylar window downstream the target and its backward shape has been designed to minimize the paths across the walls of the backward scattered pions.

The momentum analysis of the forward pion is performed by magnet M (1x1x0.5 m^3 gap, 15 K gauss), while its direction is measured by means of spark chambers 1, 2, 3, 4 suitably spaced to allow precise measurements. The magnet gap limits the angular acceptance of the system: at 4 GeV/c, with a center of the target-center of the magnet distance of 2 m, the forward cone with half opening of 6° is totally covered: from 6° to 13°, with respect to the antiproton direction, the efficiency drops from 100% to 0%; as a matter of fact, due to the finite size of the target, each event has to be weighted by an appropriate factor, depending on the interactions coordinates. For the backward pion the corresponding angles are from 180° to 130° to 90°. In Table I a summary of some relevant kinematical quantities is given. It can be seen that 13° corresponde to u = - 0.86 (GeV/c^{22}), well beyond the secondary maximum.

The direction of the backward pion is detected by means of two sets of spark chambers, covering most of the backward emisphere, again suitably spaced to m reach good precision measurements. The interactions point coordinates are computed from the intersectionsof the pion directions and the beam direction, as given by spark chambers B1 and B2.

All forward spark chambers have thin aluminum foil plates and a gap of 0.6 cm, as well as the beam chambers and the first set of backward chambers (the ones near the target). For the second set of backward chambers, which are going to be quite large, we are planning to use thin aluminum plates, 0.05 to 0.10 cm, with the same gap size.

The precision of the measurements is related to the distances amongst the chambers, the magnetic deflection angle and the geometrical reconstruction accuracy. Our apparatus should yield less than $\pm\ 5\cdot10^{-3}$ rad for directions and less than 3% for $\Delta p/p$.

§ 3) Counting rates.

The available data on $(\bar{p}p \rightarrow \pi^+\pi^-)$ are shown in Fig. 4. At 4 GeV/c a value of about 3.5 μb is expected, on the basis of extrapolation and of a direct measurement (with large error). The relationship between cross section and counting rate, $\sigma = R/nt$, being n the number of protons per cm^3, $4{,}28\cdot10^{22}$, and t the target length, 40 cm, gives $R = 6\cdot10^{-6}$ events/particle. At an expected average of $3\cdot10^4$ PS pulses per day and $4\cdot10^3$ antiproton per pulse we get 720 events per day. Since the integrated geometrical efficiency of the apparatus is close to 50%, the daily yield is ∿360 events. A total number of 3500 events has been computed as necessary to reproduce the detailed shape of the predicted cross section with a reasonable confidence level. On this purely statistical basis we require 20 useful days or ∿7200 events.

The total time that we expect to spend on the experimental area can then be estimated as three-four months. One month is required to assemble all the equipment and to test the optics and the photography. At least another month is needed to time all counters, test the electronic logic, the Čerenkov counters and the chambers in the real beam (we are planning preliminary runs in the appropriate test beams). About one useful month of running time is eventually required, comprehensive of the empty target run.

§ 4) Beam requirements.

The PS beam d28, to be built after the 1968 summer shutdown, will meet the above requirements. It should yield $\sim 4 \cdot 10^5$ particles per pulse, 1% being antiprotons, in the 4 GeV/c region, with the internal beam circulating at 23 GeV. No special requirements are imposed on $\Delta p/p$ and divergence and focussing. Values of 1% and a 2x2 cm^2 focused area with $\sim 20 \cdot 10^{-3}$ rad divergence would suit our purposes.

With the quoted external intensity and a beam spill of 200 m/sec, the average particle separation is 500 nsec. Even in presence of some bunching reliable electronic operators are predictable, using a 100 Mc system.

§ 5) Background.

Background events that can simulate $\bar{p}p \rightarrow \pi^+\pi^-$ come from annihilation into several charged pions and into $\pi^+\pi^- + m\pi^0$ (m = 1, 2,.......).

The first rejection is accomplished directly by the triggering system, via counters $\check{C}_2$ and C_4. A preliminary phase space Monte Carlo m calculation has been made for the two final states $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^0\pi^0$. With the two hypotheses that counter C_4 either has 100% γ-ray detection efficiency or it has no lead and using published cross sections (12), we get the results summarized in the following table.

	$\pi^+\pi^-\pi^0$	$\pi^+\pi^-\pi^0\pi^0$	
triggering probabilities	$0.5 \cdot 10^{-2}$	$0.2 \cdot 10^{-3}$	lead
	$1.7 \cdot 10^{-2}$	$4.8 \cdot 10^{-3}$	no lead
noise to signal ratio	1.4	0.1	lead
	4.8	2.4	no lead

The scarse relevance of the effect from $2\pi^o$ with respect to one π^o is due to lower average β, which helps the rejection of events by $\check{C}_2$ as well as to higher probability to get a count from C_4. Higher π^o multiplicity effects can be roughly estimated by estrapolation from $\pi^+\pi^-$ (phase space), $\pi^+\pi^-\pi^o$, $\pi^+\pi^-\pi^o\pi^o$ noise to signal ratioes as $3.8 \cdot 10^{-2}$ and 3.8 with and without lead.

Similar calculations, performed on $\pi^+\pi^+\pi^-\pi^-$ and $\pi^+\pi^+\pi^-\pi^-\pi^o$ final states, yield noise to signal ratioes of 10^{-2} and $2 \cdot 10^{-2}$, without lead in counter C_4.

The total fraction of background events, summing up all results, is about 1.6/seen $\pi^+\pi^-$, that is, taking into account that the efficiency of counter C_4 will not be 100%, we expect one useful picture every third one.

The final rejection is done on the pictures. Besides the events that will be discarded, because of wrong number of tracks or obviously wrong angular correlations, the separation is going to be based on fitting procedures. Assuming the quoted measurement errors and on the basis of the above Monte Carlo calculations, we expect that less than 3% of the events in the angular distribution will eventually belong to the background.

6) CERN support.

The CERN support that we require for this experiment is as follows:

(1) Čerenkov counter $\check{C}_1$: it should be one of the conventional CERN counters that are widely used with unseparated beam.

(2) Magnet M: it is a C shaped magnet, with 1x1x0.5 m^3 gap and 15 K gauss field.

(3) Dewar and filling pipes for the hydrogen target.

7) Components of the group and home facilities.

The number of physicist that are interested in doing the experiment is ten. Part of us have been working for several years in spark chamber and counter experiments and all of us have experience of bubble chamber work and analysis. We enjoy the technical support of Ing. I.Scotoni and of Padova Electrotechnical and Mechanical Workshop and have ample scanning and measuring facilities.

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References

1) This proposal follows a letter of intention, sent on February 20, 1968.
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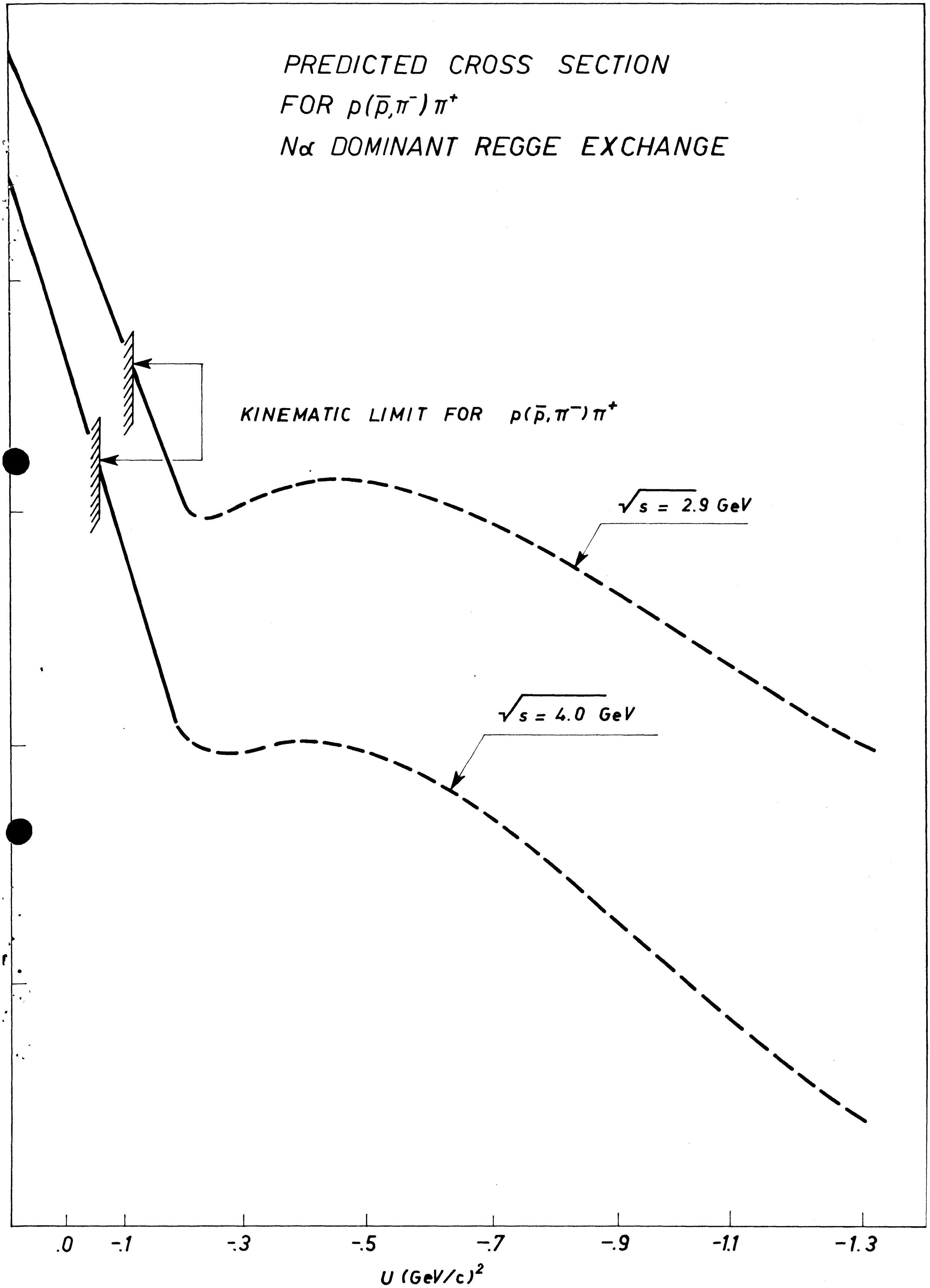
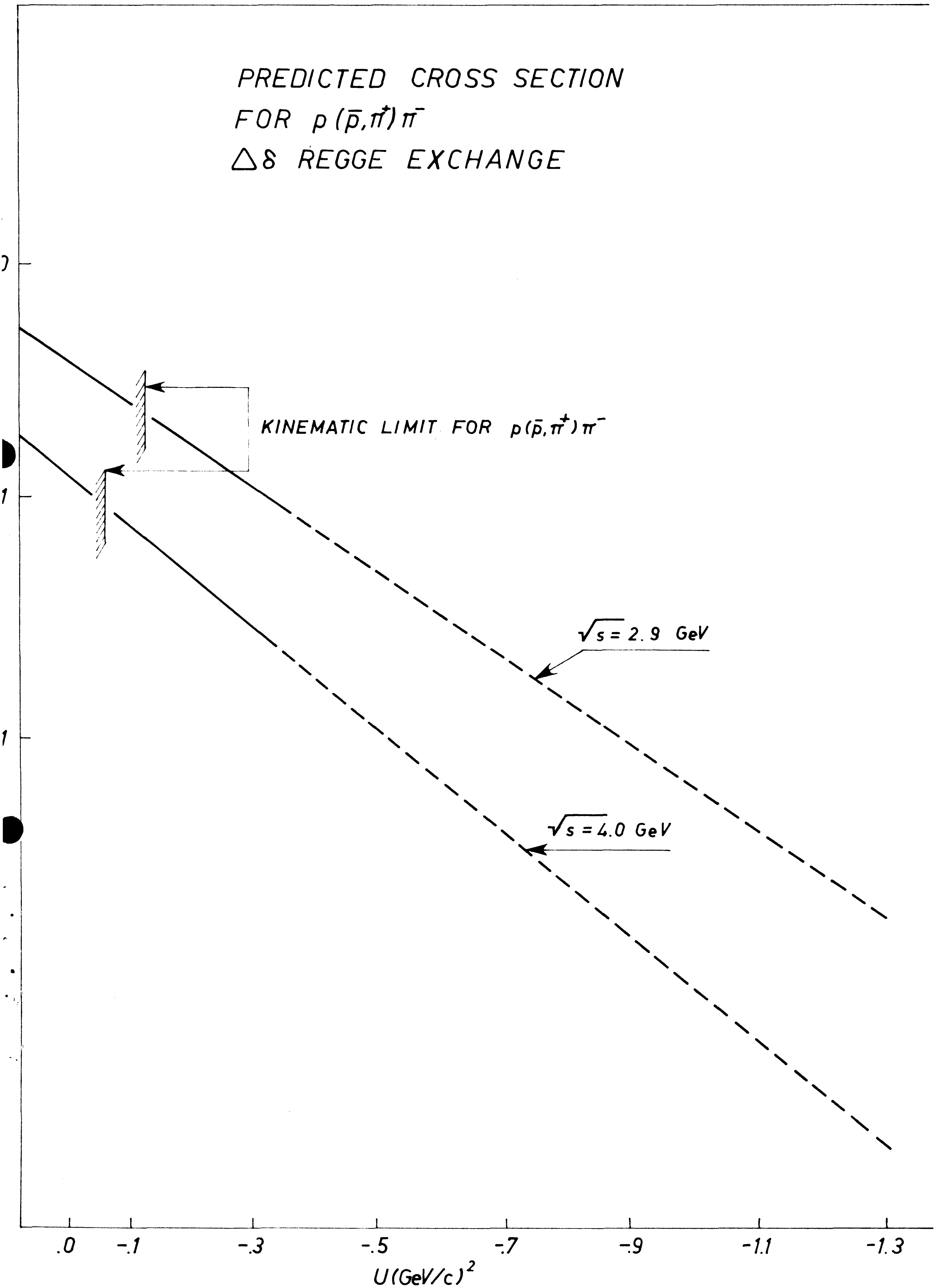
Table I

θ_{LAB}	q	p_f	β_f	p_b	β_b
0°	-0.097	4.513	0.99952	0.513	0.96492
2°	-0.118	4.502	0.99951	0.524	0.96634
4°	-0.176	4.471	0.99951	0.556	0.96992
6°	-0.277	4.417	0.99950	0.611	0.97492
8°	-0.404	4.349	0.99948	0.680	0.97962
10°	-0.568	4.261	0.99946	0.770	0.98396
12°	-0.755	4.162	0.99943	0.871	0.98740
14°	-0.964	4.050	0.99940	0.983	0.99008
16°	-1.196	3.927	0.99936	1.108	0.99216

Table captions:

θ_{LAB}	is the angle that the forward pion makes in the lab. system with respect to the antiproton direction;
q	is the momentum transfer, in $(\mathrm{GeV/c})^2$: it corresponds to t for the forward pion and to u for the backward pion;
p_f, β_f	are momentum and velocity of the forward pion in the lab. system;
p_b, β_b	are the same quantities for the backward pion.


PREDICTED CROSS SECTION
FOR $p(\bar{p},\pi^-)\pi^+$
Nα DOMINANT REGGE EXCHANGE
KINEMATIC LIMIT FOR $p(\bar{p},\pi^-)\pi^+$
$\sqrt{s}$ = 2.9 GeV
$\sqrt{s}$ = 4.0 GeV
.0
-.1
-.3
-.5
-.7
-.9
-1.1
-1.3
U $(GeV/c)^2$


PREDICTED CROSS SECTION
FOR $p(\bar{p},\pi^+)\pi^-$
$\Delta\delta$ REGGE EXCHANGE
KINEMATIC LIMIT FOR $p(\bar{p},\pi^+)\pi^-$
$\sqrt{s} = 2.9$ GeV
$\sqrt{s} = 4.0$ GeV
0
1
1
.0
-.1
-.3
-.5
-.7
-.9
-1.1
-1.3
U $(GeV/c)^2$

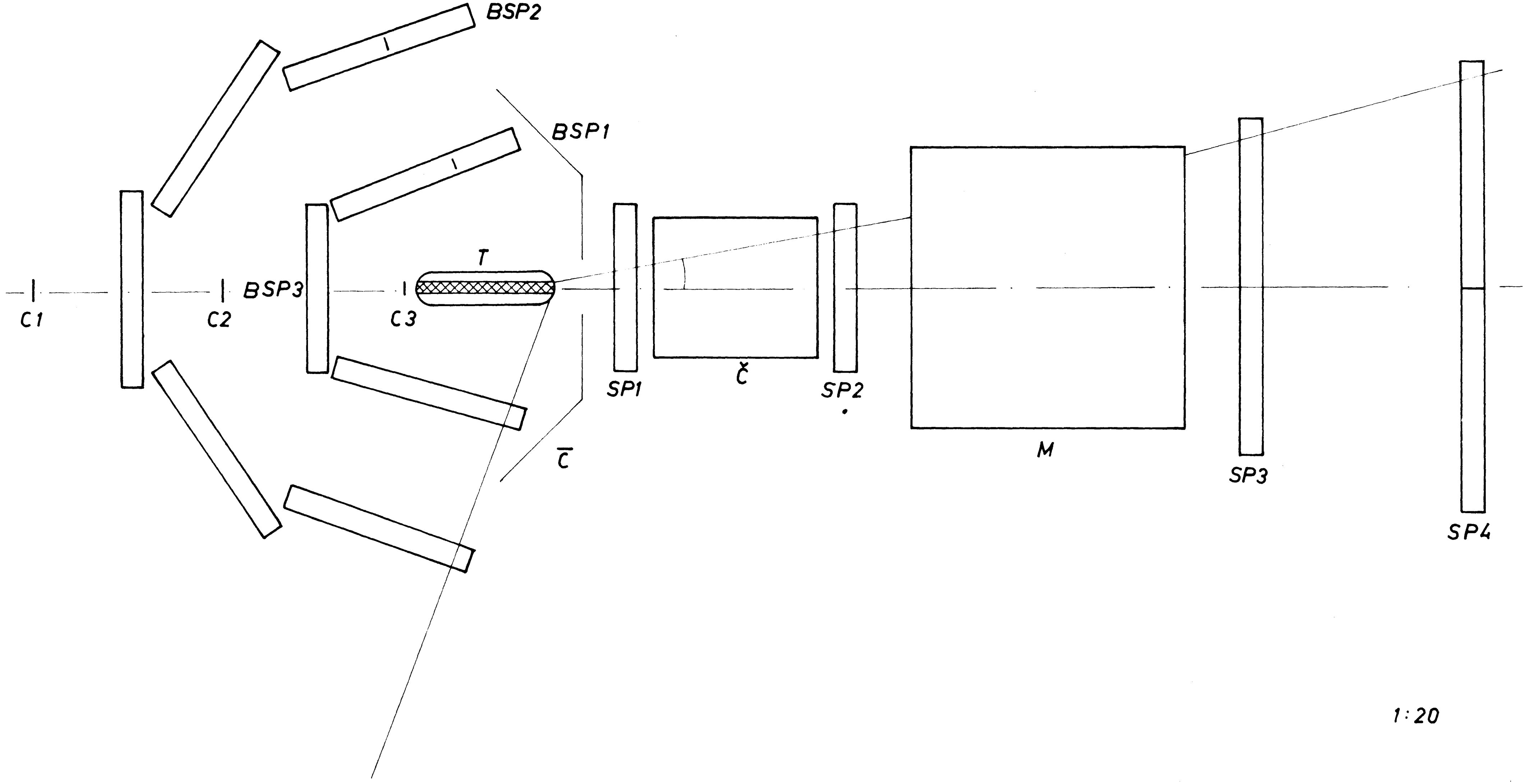


FIG. 3

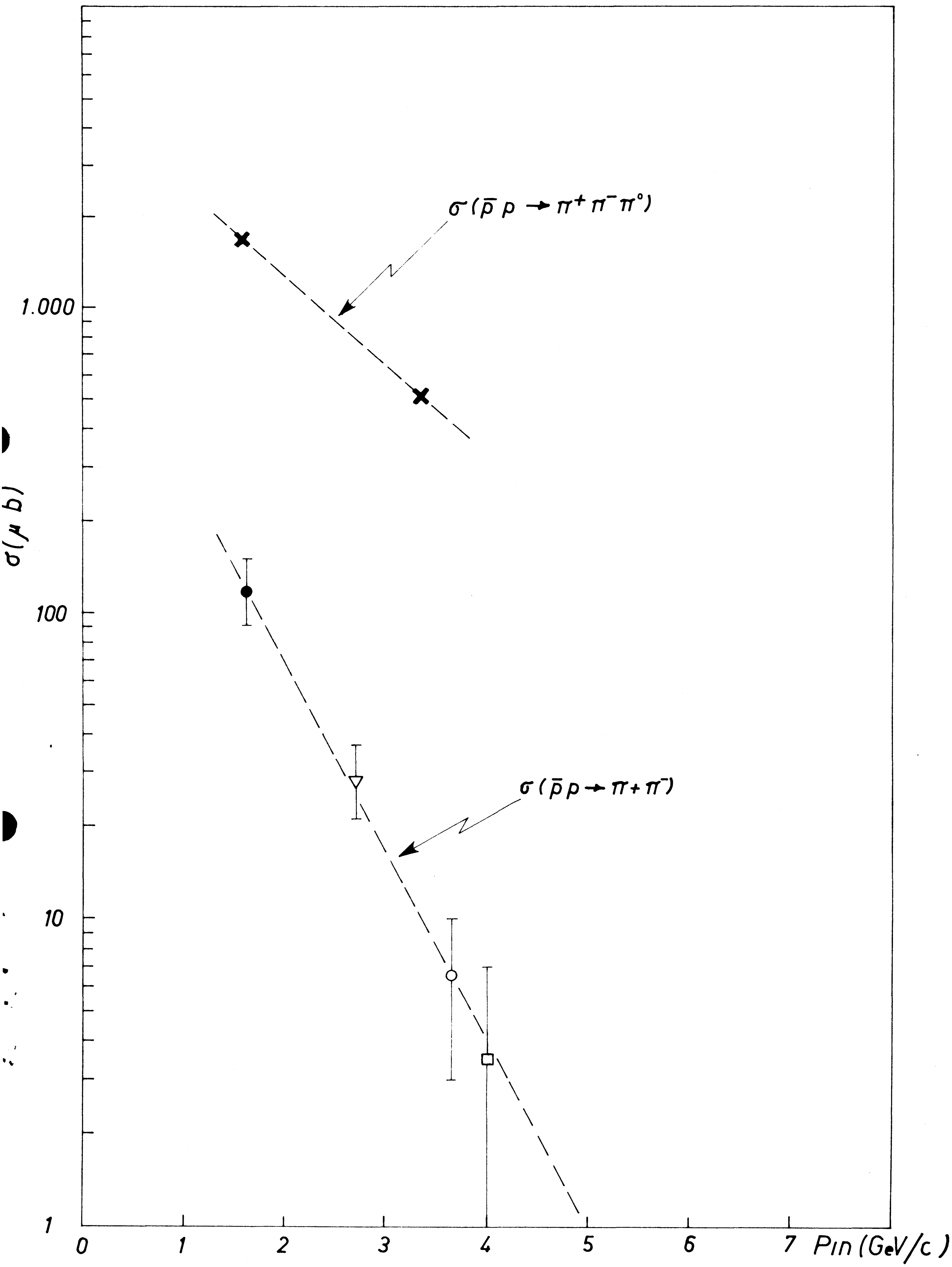


FIG. 4