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MEASUREMENT OF TWO PARTICLE CORRELATIONS IN MULTIPARTICLE EVENTS IN THE FRAGMENTATION REGION WITH THE SFM SPECTROMETER

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I. General considerations

The study of multiparticle processes will be, besides the search for exotic particles, one of the most interesting fields for ISR physics, since one might hope to find genuine multibody effects. With an average multiplicity of about twelve particles in the final state, exclusive experiments appear to be infeasible because of the too many free kinematical variables.

As a first step single particle spectra have been investigated in inclusive experiments at conventional accelerators and approved ISR experiments are extending these investigations to higher energies.

The next obvious step is to study multiparticle correlations, and we are in particular interested in two-particle correlations. It seems that such correlations can give more detailed information on the dynamics of strong interaction than single particle spectra which are mainly connected with the general properties of the interaction [1) 2) 3) 4)].

Very little is known experimentally on inclusive correlations even at accelerator energies. Some specific theoretical ideas have been developed. They were described already in ISRC 71-30. However it seems that at any rate the experimental results should be approached from a phenomenological point of view, since in certain respects it is not even clear which kinematical variables might be relevant.

The main purpose of this paper is to complement ISRC 71-30 by specifying more precisely the correlations and the kinematical regions we want to investigate, to give more details on the experimental set-up (in particular on the Cerenkov counter) and to provide better estimates for the counting rates.

II. Proposed measurements

The 2-particle inclusive reaction

$$p + p \rightarrow \alpha + \beta + X$$

is described by six independent variables, for example the transverse momenta $p_{\perp\alpha}$, $p_{\perp\beta}$ of particles α and β, the longitudinal scaling variables $x_\alpha = p_{\parallel\alpha}/p_o$ ($p_\parallel$, p_o are the longitudinal and primary momentum in the c.m. system), the missing mass M^2 and the difference $\varphi_{\alpha\beta}$ between the azimuthal angles of particles α and β. Instead of $p_{\perp\alpha}$, $p_{\perp\beta}$ the momentum transfers t_α, t_β are sometimes used. The energies $s_\alpha/M^2 \approx (1 - x_\alpha)^{-1}$, $s_\beta/M^2 \approx (1 - x_\beta)^{-1}$ or the rapidities ξ_α, ξ_β are alternatives to x_α, x_β.

The correlation function for the particles α and β is defined by

$$F(p_{\perp\alpha}, x_\alpha, p_{\perp\beta}, x_\beta, M^2, \varphi_{\alpha\beta}) =$$
$$= P(p_{\perp\alpha}, x_\alpha, p_{\perp\beta}, x_\beta, M^2, \varphi_{\alpha\beta}) - \rho_\alpha(p_{\perp\alpha}, x_\alpha, M^2) \cdot \rho_\beta(p_{\perp\beta}, x_\beta, M^2)$$

where ρ_α and ρ_β are the probabilities for finding the single particles α and β with the respective momenta where P is the probability for the simultaneous emission of α and β. If α and β are produced independently then $F = 0$.

Present theories do not allow to make quantitative predictions on the magnitude of such correlations (see ISRC 71-30) and very little is known experimentally even at accelerator energies. From some general arguments[5)] based on the variance of the average multiplicity it may be concluded that the average correlation should be sizeable, however it is not known how it is distributed over the kinematical range.

As a consequence a large region of phase space should be investigated. The accuracy we are aiming at in the cross section measurement is of the order of a few percent. This can only be achieved by usin the split field magnet (SFM) facility.

We propose to measure the following 2-particle correlations:

1) Two leading nucleons, in particular a proton and a neutron going in opposite directions. The kinematical range would be approx mately $0.1 < p_\perp < 1$ GeV/c, $0.2 < x < 1$ for both nucleons. The

missing mass will cover the range from ~5 to ~40 GeV (see fig. 1 and 2). The full range of azimuthal angles $\varphi_{\alpha\beta}$ will be covered. The study of p - p correlations has been proposed already by another group [6]. Expected counting rates are given in table I.

2) A proton (or a neutron) and a pion (π^+ or π^-) both going in the same direction. For the proton the kinematical range is again $0.1 < p_\perp < 1$ GeV/c, $0.2 < x < 1$, whereas for the pions $0.1 < p_\perp < 1$ GeV/c if $x \leq 0.3$ and $0.1 < p_\perp < 0.5$ GeV/c if $0.3 < x < 0.6$. For $x \gtrsim 0.6$ the coincidence rates will be very small (for details see fig. 3, 4, 5 and table II). The missing mass range will be ~5 to ~40 GeV.

3) Two fast pions ($\pi^+\pi^+$, $\pi^+\pi^-$ or $\pi^-\pi^-$) going in the same or in opposite directions. Since in this case the intensity drops fast both with increasing $p_\perp$ and x for both particles the kinematical range is much more restricted (see table III).

As a first step in the analysis of the data one will look for correlations between the momenta of the two particles in order to check some general predictions of the multiperipheral model. Thus one should expect that correlations disappear if the difference between x_α and x_β (or the respective rapidities) increases. A further question is whether scaling laws exist for $F(p_{\perp\alpha}, x_\alpha, p_{\perp\beta}, x_\beta, M^2, \varphi_{\alpha\beta})$ in a similar way as they have been found for $\rho_\alpha(p_{\perp\alpha}, x_\alpha, M^2)$. It should also be tested whether factorisation holds in correlations.

Of particular interest will be a search for azimuthal correlations, since they can help to reveal the nature of the Pomeranchuk singularity (for a more detailed discussion cf ISRC 71-30). Only one such experiment [7] has been performed at accelerator energies, and it was found that for the reaction $K^+p \to K^o + \pi^- + X$ at 12.7 GeV the azimuthal correlation disappears for missing masses $M^2 > 14$ GeV However the statistical accuray is only about ± 30 %.

4) As a by-product we shall obtain single particle inclusive spectra for $p + p \to n + X$, for $0.2 < x < 1$ and $p_\perp \lesssim 2$ GeV/c. No measurements of the neutron spectrum with a hydrogen target have been performed, not even at accelerator energies. On the other hand the neutron inclusive spectrum is very interesting from a theoretical piont of view (see ISRC 71-30), in particular since there are interesting predictions based on a quark model [4].

III. Experimental set-up

For the proposed experiment the basic set-up of the proportional wire chambers can be used. The essential additions to these chambers are

Cerenkov hodoscopes to identify charged particles,
a total absorption neutron spectrometer,
trigger counters.

a) The use and performance of the Cerenkov counter depends crucially on its optical efficiency, its ability to separate pions, kaons, and protons, and its spatial resolution (see fig. 6a, 6b).

The present layout of the Cerenkov counter optics gives uniform optical efficiency along any horizontal line and also - except near the symmetry plane of the 2 (upper and lower) counters - along any vertical line. This is achieved through use of two cylindrical mirrors for each C counter unit. Light is collected and focussed with uniform efficiency over the entire counter area except close to the horizontal strip where the first mirror from the upper half of the counter touches its counterpart from the lower half. Thus the optical efficiency for C-light from particles coming from the interaction region should be uniform everywhere except in a small strip whose area is about 5 - 10 % of the total area covered, where the optical efficiency will be rising from 0 to optimum.

Calculations concerning the particle separation were based on the following formulae given in CERN/ISRC/69-5 [8]:

Quantum efficiency of PM tube 18 %
Optical efficiency 50 %
9 photoelectrons taken as "yes" signal
1 photoelectron taken as "no" signal

Number of photoelectrons $N_e = 75 \cdot l \cdot (\varepsilon - \delta)$

where l = counter length in cm,
$\varepsilon = n-1$
$\delta = 1-\beta$

and $\varepsilon = K \cdot P$, where P is pressure in kg/cm^2 and K is a constant characteristic for the gas used.

The particle trajectory length within the counter is of the order of 100 cm which imposes the necessity to use a gas with high refractive index such as propane or isobutane. Some results are given below.

gas	pressure	clean separation of π from K and p for momenta p
propane	2.0 kg/cm^2	$3.5<p<7.5$ GeV/c
isobutane	2.0 kg/cm^2	$2.5<p<7.0$ GeV/c

gas	pressure	clean separation of π from p for momenta p
propane	1.5 kg/cm^2	$5.0<p<17.5$ GeV/c
isobutane	1.5 kg/cm^2	$3.5<p<15.0$ GeV/c
isobutane	2.0 kg/cm^2	$2.5<p<13.0$ GeV/c

The spatial resolution of one Cerenkov counter unit depends on the Cerenkov angle and the focusing properties of the optical system. In the vertical coordinate there will be no resolution because the point of interaction is always focussed onto the face of the PM tube. In the horizontal coordinate the light at the focus will extend ~20 cm for a particle producing enough light to satisfy the threshold condition. Always two PM tubes will be hit which gives the opportunity to form a coincidence. Thus 2 charged particles ca clearly be separated within one Cerenkov counter unit alone if their horizontal distance is ≳20 cm. With the additional use of track information from the proportional chambers the separation ability may even be better. Calculations were done to find out how many of the produced charged particles will hit one Cerenkov counter unit and cannot be separated. We used the program FOWL with a constant 7 charged particle final state and a cutoff at $|p|=$ 2 GeV/c crudely representing the influence of the magnetic field. Our preliminary results indicate that in about 10% of the events there will be 2 charged particles traversing one Cerenkov counter unit with a distance ≲20 cm.

b) A <u>neutron total absorption counter</u> N_L will be placed beneath the beam tube on the left side. It will thus be installed just below C_L. There is not enough space available to set up the Cerenkov hodoscope and the neutron counter one behind the other. The reason for installing the neutron counter below (or if necessary above) the beam tube instead of sideways is due to the fact that the azimuthal asymmetries are proportional to cos $\varphi_{\alpha\beta}$ and hence the most precise information is obtained from $\varphi_{\alpha\beta} \approx 0$ and $\approx 180^o$. Now in the SFM the range of accepted $p_\perp$ is larger for particles emitted up or down than for particles produced in the horizontal plane.

A schematic set-up of the neutron counter is shown in fig. 7. It consists of an anticounter A, a converter C (about 6 cm Al), a trigger counter T and a Fe-scintillator sandwich. In order to determine the point of interaction of the neutron two possibilities are considered. First the trigger counter T could be subdivided in a proper way to form a hodoscope. A second way would be to place the anticounter and converter in the split field magnet in front of the proportional chamber No. 21(15) which would then be used to indicate the interaction point.

The following measures will be taken to assure as good an energy resolution as possible. Only neutrons converted in C are counted by requiring a trigger T. As a consequence most of the shower length is contained in the iron. A drawback of this is of course, that the detection efficiency of neutrons is reduced to about 10%. The converter C is smaller than the size of the iron plates thus reducing lateral losses of the shower.

In recent test measurements it was found that for neutron energies around 20 GeV a total Fe thickness of about 70 cm is sufficient to obtain a resolution of about ± 15 % with iron plates 4 cm thick However, for energies below 10 GeV thinner plates (1 to 2 cm) and more scintillation counters sandwiched between the iron are necessary to get a reasonable resolution. Such a counter is under construction.

IV. Event rates

The counting rates were estimated on the basis of the thermodynamical model. The program SPUKJ written by J. Ranft was used to calculate the production spectra for single particles. Results - being very similar to those based on formulae given by Cocconi [9] - are shown for a c.m. energy of 40 GeV in Fig. 3, 4 and 5 for protons, π^+ and π^-. The data are given as function of the variable $x = p_{\parallel}/p_0$ and the transverse momentum $p_\perp$. Similar curves were calculated for 30 and 50 GeV c.m. energies but in terms of these variables the curves were the same with deviations of less than about 30 %. Hence for an estimate the numbers deduced from Fig. 3 to 5 are typical for all energies of interest.

The coincidence counting rates were obtained from the single particle rates by simple multiplication and folding in the instrumental acceptance. This implies that correlation effects are neglected. The results are shown in tables I to III.

All rates are given for the momentum intervals:

- charged particles	$\Delta p_\perp$	=	0.05 GeV/c
	$\Delta p_{\parallel}$	=	0.5 GeV/c
- neutrons	$\Delta p_\perp$	=	0.1 GeV/c
	$\Delta p_{\parallel}$	=	2.0 GeV/c

Except for those cases where $p_\perp$ of both particles is approximately 1 GeV/c or higher the statistical errors which could be obtained during 100 h of running time for one c.m. energy would be better than 5 %. For π momenta above 12 GeV/c the accessible range of $p_\perp$ becomes much smaller, however.

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Table I

Estimation of counting rates [h^{-1}] for $L = 2\times10^{30}\ cm^{-2}\ sec^{-1}$

n-p coincidences

E_{CM} = 40 GeV

$x_p = 0.2$ $x_n = 0.2$

neutron $p_\perp$ [GeV/c] \ proton $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	160	100	60	10
0.4	220	140	80	20
0.6	180	120	60	10
0.8	120	80	40	10

efficiency of neutron counter $\varepsilon_n = 0.1$

$\Delta p_\parallel$ = 2 GeV/c
$\Delta p_\perp$ = 0.1 GeV/c } for neutrons

Table IIa

Estimation of counting rates [h^{-1}] for L = 2×10^{30} cm^{-2} sec^{-1}

π-n coincidences

E_{CM} = 40 GeV

x_n = 0.2 x_π = 0.2

$\Delta p_\parallel$ = 2 GeV/c, $\Delta p_\perp$ = 0.1 GeV/c } for neutrons

positive pions $p_\perp$ [GeV/c] \ neutron $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	1200	1600	1360	920
0.4	620	830	720	470
0.6	200	250	230	160
0.8	30	40	30	20

negative pions $p_\perp$ [GeV/c] \ neutron $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	1200	1600	1360	960
0.4	1200	1600	1400	960
0.6	530	670	580	400
0.8	90	120	90	70

Table IIb

Estimation of counting rates [h^{-1}] for L = 2×10^{30} cm^{-2} sec^{-1}

π-p - coincidences

E_{CM} = 40 GeV

x_p = 0.2 x_π = 0.2

positive pions $p_\perp$ [GeV/c] \ protons $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	1530	1000	510	110
0.4	780	520	260	60
0.6	250	160	80	20
0.8	40	20	10	3

negative pions $p_\perp$ [GeV/c] \ protons $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	1530	2000	1370	350
0.4	780	1040	700	180
0.6	250	320	220	60
0.8	40	50	30	10

Table IIc

Estimation of counting rates [h^{-1}] for L = 2×10^{30} cm^{-2} sec^{-1}

πp - coincidences

E_{CM} = 40 GeV

x_p = 0.2 x_π = 0.5

positive pion $p_\perp$ [GeV/c] \ proton $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	120	80	40	9
0.4	120	80	40	9
0.6	50	30	15	4
0.8	20	15	7	2

negative pion $p_\perp$ [GeV/c] \ proton $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	120	80	40	9
0.4	150	100	50	12
0.6	60	40	20	5
0.8	25	15	9	2

Table IId

Estimation of counting rates $[h^{-1}]$ for $L = 2\times10^{30}\ cm^{-2}\ sec^{-1}$

π - n coincidences

E_{CM} = 40 GeV

x_n = 0.2 x_π = 0.5

$\Delta p_{\parallel}$ = 2 GeV/c
$\Delta p_{\perp}$ = 0.1 GeV/c } for neutron

positive pion $p_\perp$ [GeV/c] \ neutron $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	95	125	105	70
0.4	100	130	110	75
0.6	40	50	45	30
0.8	15	25	20	15

negative pion $p_\perp$ [GeV/c] \ neutron $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	95	125	105	70
0.4	120	160	135	95
0.6	50	65	55	35
0.8	20	25	25	15

Table IIIa

Estimation of counting rates [h^{-1}] for $L = 2\times10^{30}$ cm^{-2} sec^{-1}

π-π coincidences

E_{CM} = 40 GeV

x_π = 0.2 x_π = 0.2

positive pion $p_\perp$ [GeV/c] \ positive pion $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	11200	5700	1800	270
0.4	5700	2930	920	140
0.6	1800	920	290	40
0.8	270	140	40	6

negative pion $p_\perp$ [GeV/c] \ positive pion $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	11200	5700	1800	270
0.4	11400	5800	1850	280
0.6	4800	2460	780	110
0.8	800	410	130	20

negative pions $p_\perp$ [GeV/c] \ negative pions $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	11200	11400	4800	810
0.4	11400	11700	4900	830
0.6	4800	4900	2070	350
0.8	800	830	350	60

Table IIIb

Estimation of counting rates [h^{-1}] for $L = 2\times10^{30}\ cm^{-2}\ sec^{-1}$

ππ coincidences

$E_{CM} = 40$ GeV

$x_\pi = 0.5$ $x_\pi = 0.5$

positive pions $p_\perp$ [GeV/c] \ positive pions $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	65	70	25	10
0.4	70	70	30	15
0.6	25	30	10	5
0.8	10	15	5	3

negative pions $p_\perp$ [GeV/c] \ positive pions $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	65	70	25	10
0.4	85	90	35	15
0.6	35	35	15	7
0.8	15	15	6	3

negative pions $p_\perp$ [GeV/c] \ negative pions $p_\perp$ [GeV/c]	0.2	0.4	0.6	0.8
0.2	65	85	35	15
0.4	85	115	45	20
0.6	35	45	20	8
0.8	15	20	8	3

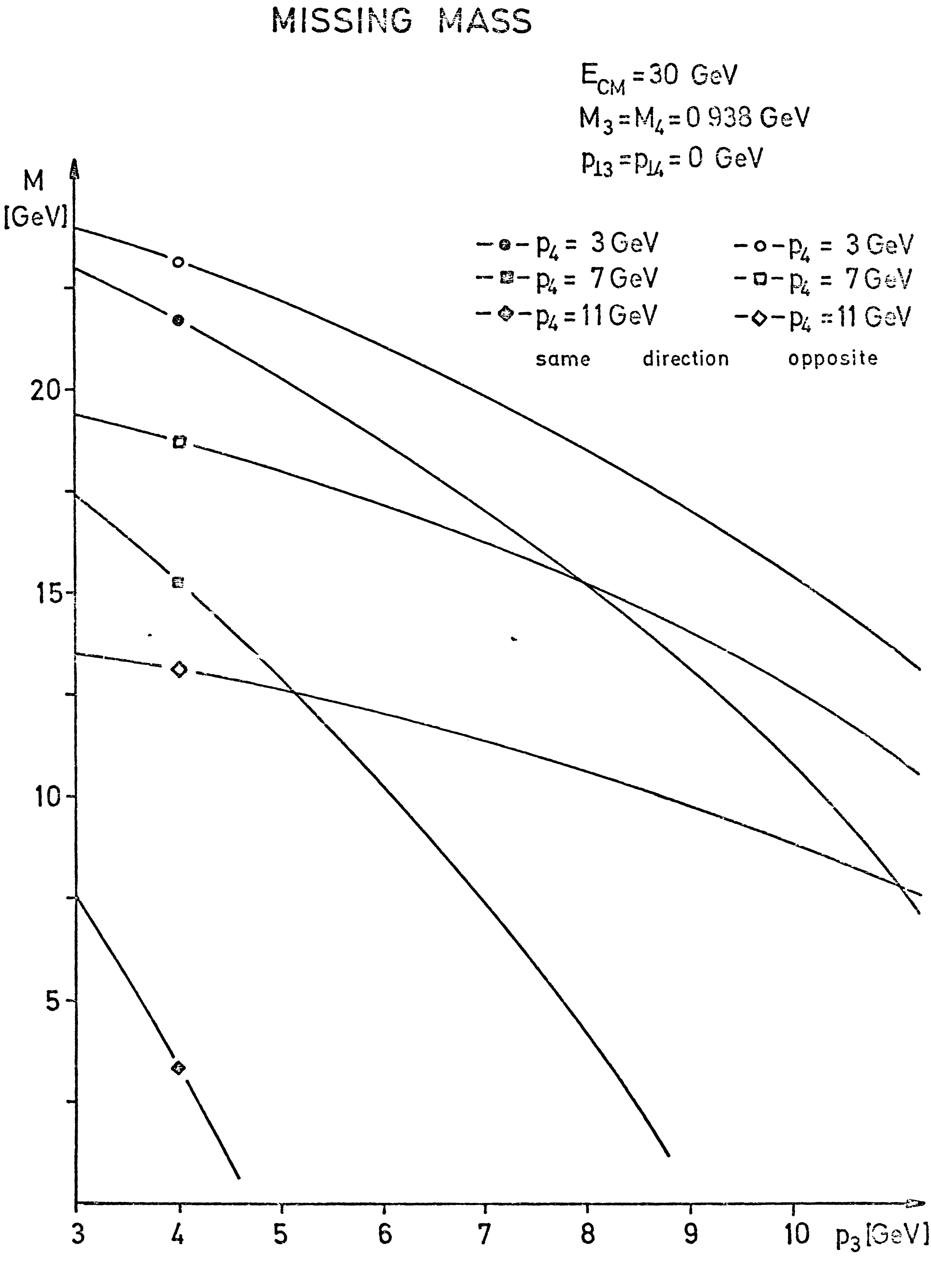

MISSING MASS
E_CM = 30 GeV
M_3 = M_4 = 0 938 GeV
p_⊥3 = p_⊥4 = 0 GeV
M [GeV]
-●- p_4 = 3 GeV
-■- p_4 = 7 GeV
-◆- p_4 = 11 GeV
-○- p_4 = 3 GeV
-□- p_4 = 7 GeV
-◇- p_4 = 11 GeV
same
direction
opposite
20
15
10
5
3
4
5
6
7
8
9
10
p_3 [GeV]

Fig.1

MISSING MASS

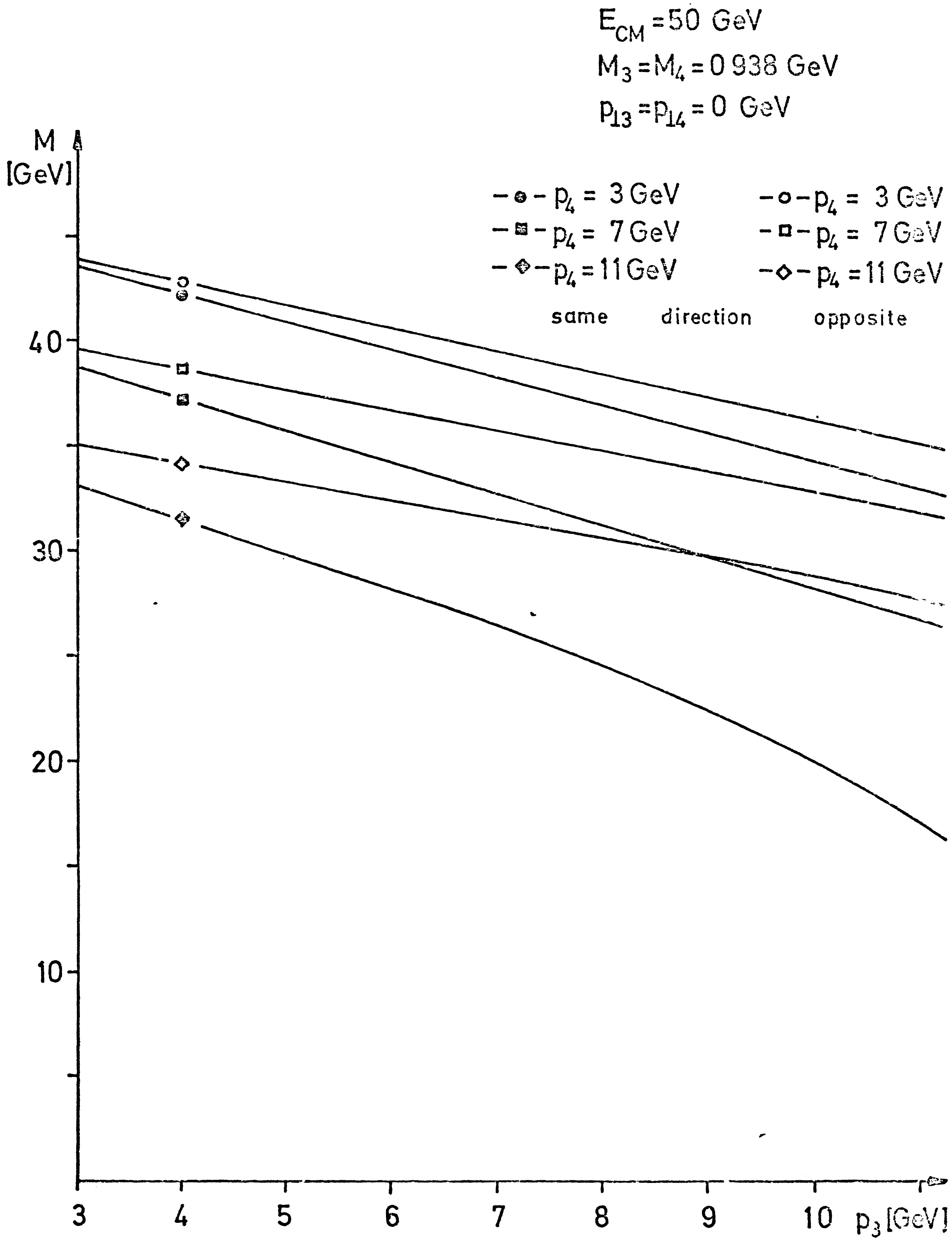
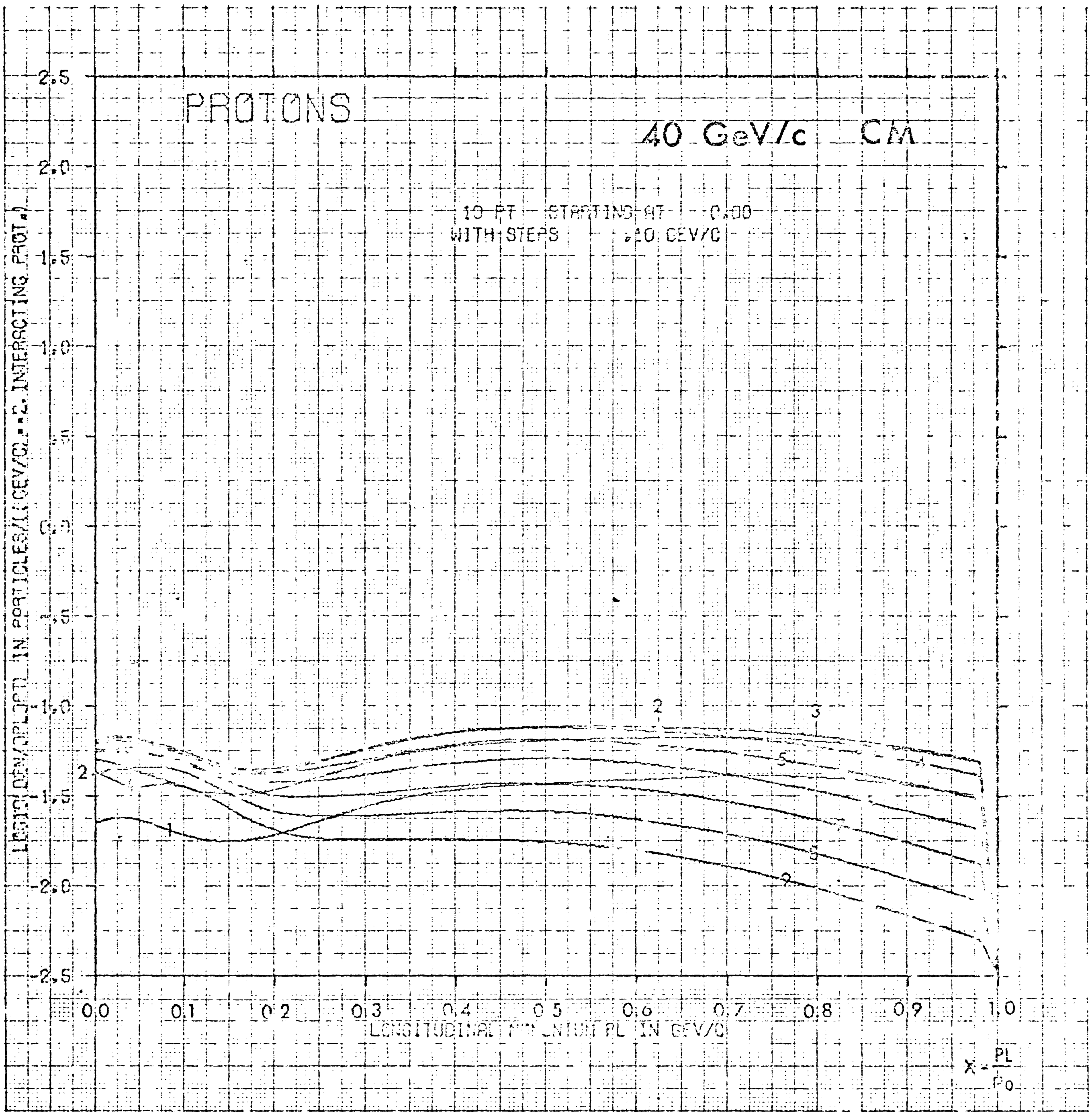


Fig. 2



PROTONS
40 GeV/c CM
WITH STEPS
2,5
2,0
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
-2,0
-2,5
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
$X = \frac{PL}{Po}$

Fig. 3

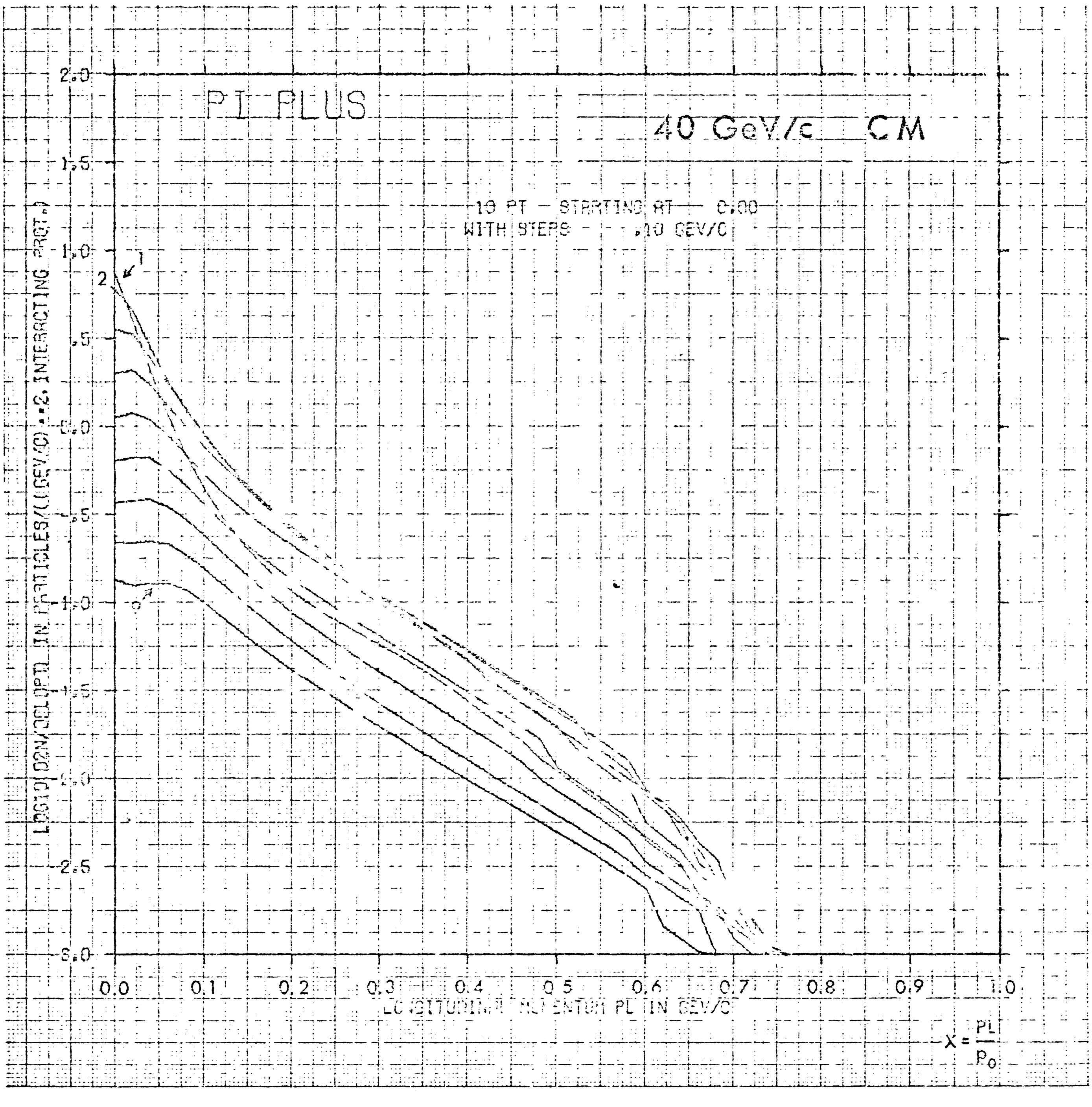
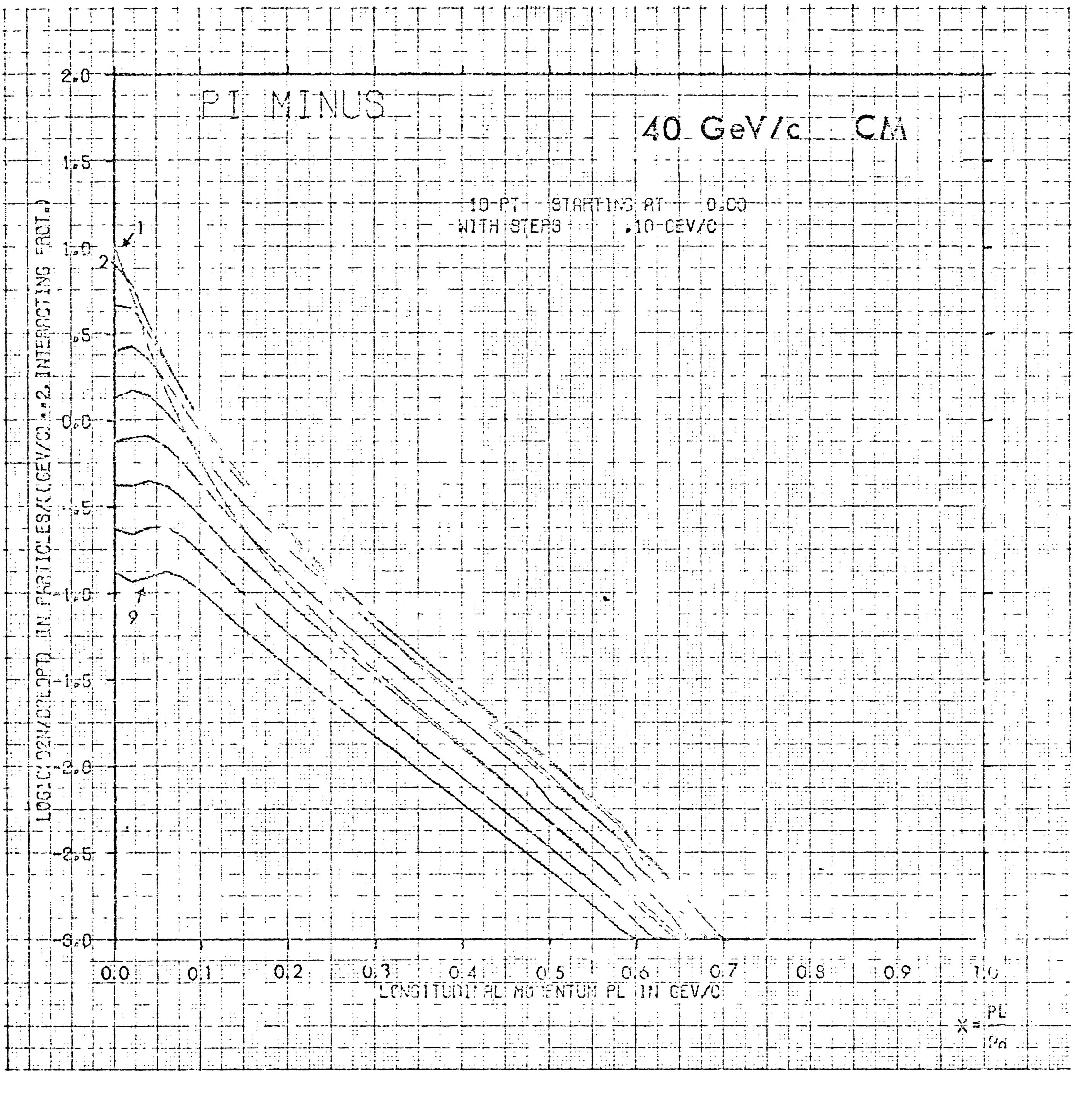
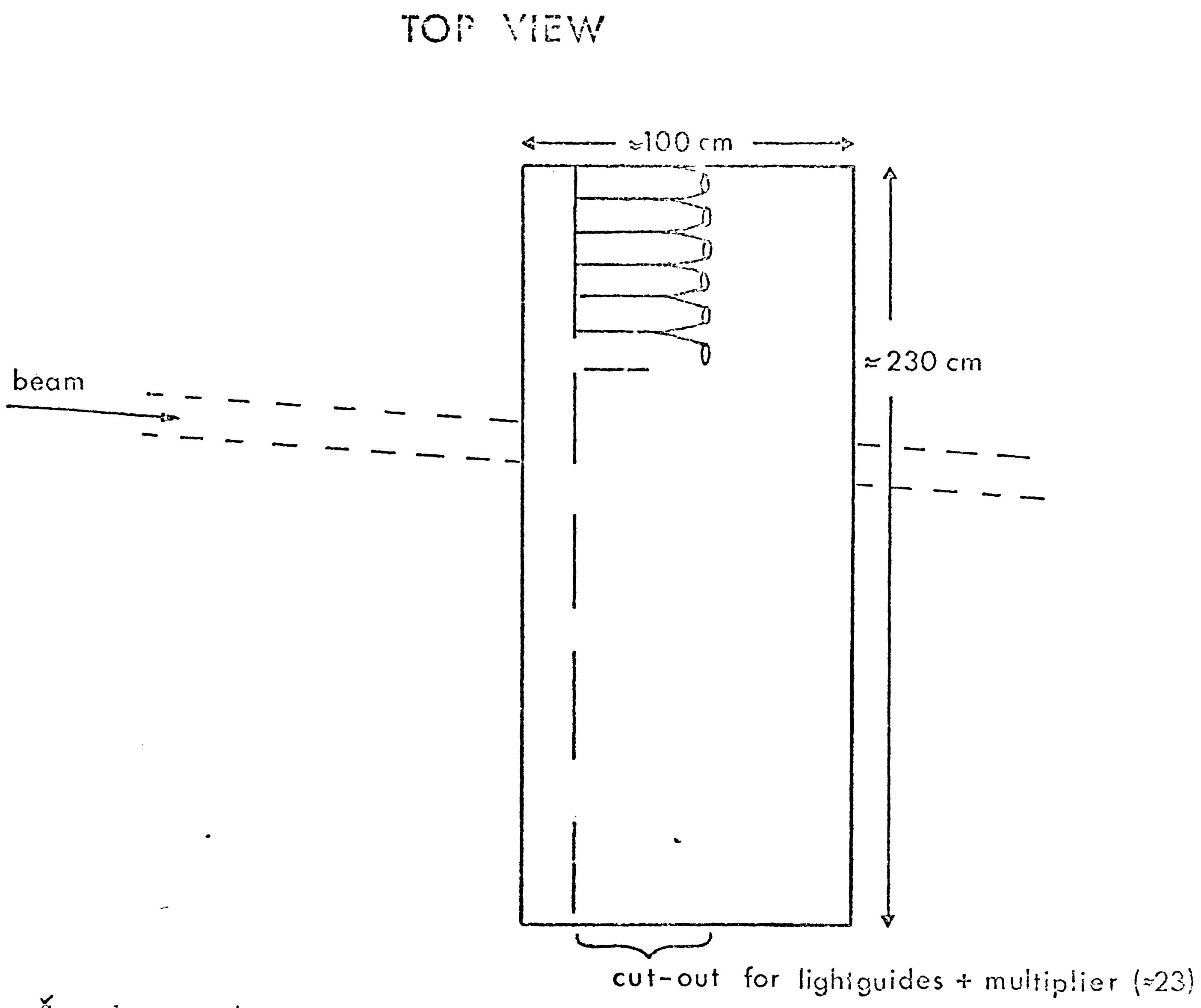

PI PLUS
40 GeV/c CM
10 PT STARTING AT 0.00
WITH STEPS .10 GEV/C
2.0
1.5
1.0
.5
0.0
-.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
$X = \frac{PL}{P_0}$

Fig. 4



PI MINUS
40 GeV/c CM
10 PT STARTING AT 0.00
WITH STEPS .10 GEV/C
LONGITUDINAL MOMENTUM PL IN GEV/C
1
2
9
2.0
1.5
1.0
.5
0.0
-.5
-1.0
-1.5
-2.0
-2.5
-3.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
x = PL / P0

Fig. 5



Čerenkov counter

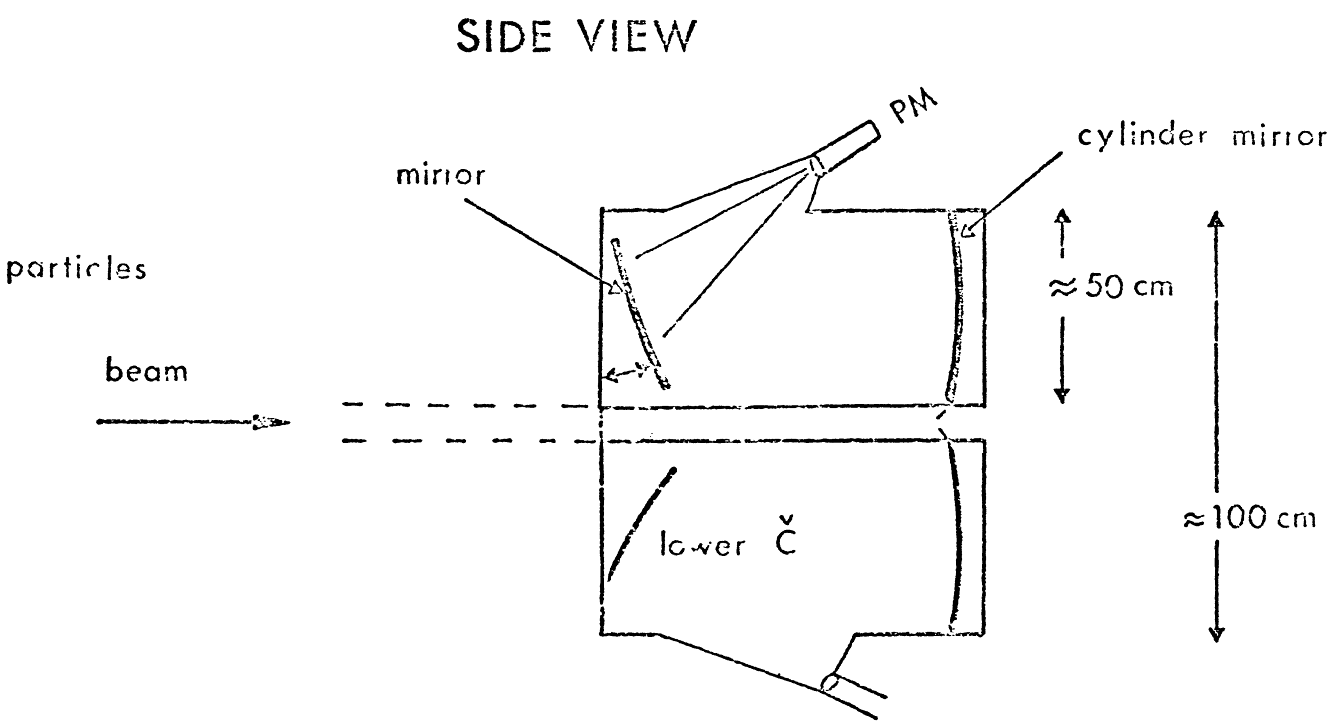


Fig. 6a

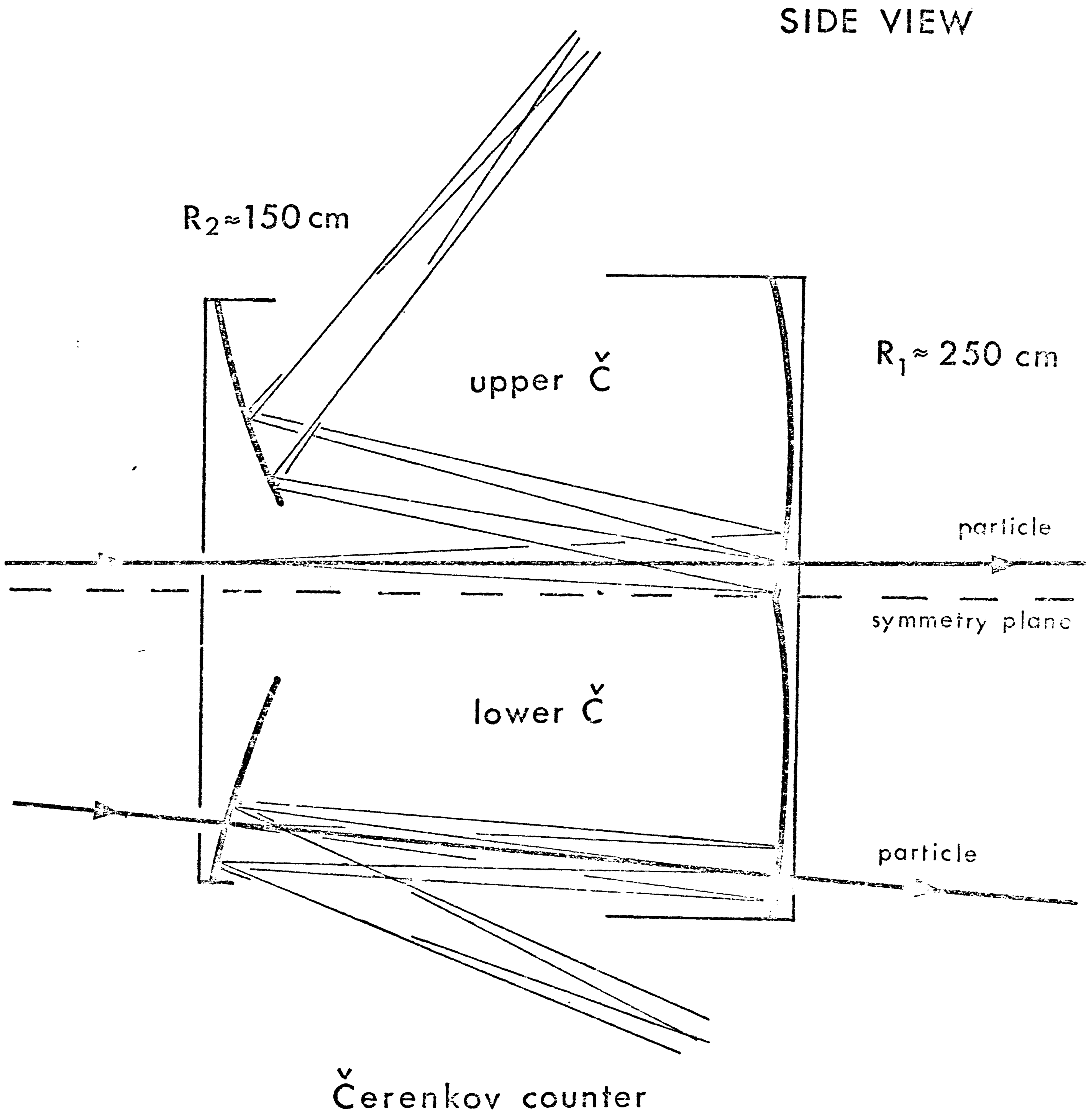
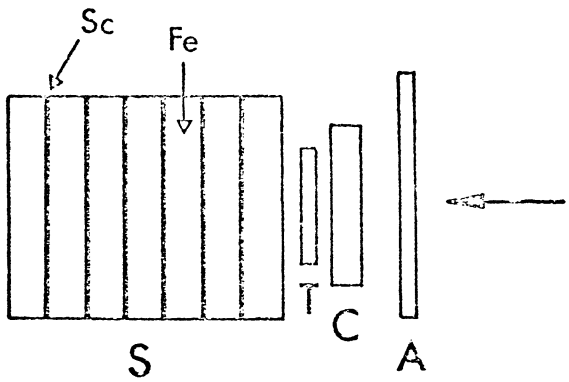

SIDE VIEW
$R_2 \approx 150$ cm
upper Č
$R_1 \approx 250$ cm
particle
symmetry plane
lower Č
particle
Čerenkov counter

Fig. 6 b



Neutron total absorption spectrometer

Fig. 7