APPENDIX I

MECHANICAL AND OPTICAL SPECIFICATIONS FOR THE 20- AND 8-BeV/c SPECTROMETERS

The mechanical and optical design specifications for the 20- and 8-BeV/c spectrometers are given in Table I.

Magnet arrangements for the spectrometers are shown in Figs. 1 and 2. The 8-BeV/c spectrometer consists of a vertical bend with focusing provided by quadrupoles; second-order correction will probably not be required. The 20-BeV/c spectrometer is more complex, with two vertical bends of opposite sign, a double cross-over between the bends (so the dispersion of the two bends adds), and focusing provided by quadrupoles; a sextupole triplet is necessary for second-order correction. Figures 3 and 4 are sketches of the 8- and 20-BeV/c spectrometers. All the magnetic elements are mounted on carriages that will allow easy changes in angular position.

A. Mechanical Specifications of the 20-BeV/c Spectrometer

1. Magnets and Power Supplies

Based on the optical design, magnets for the 20-BeV/c spectrometer have been designed with the characteristics shown in Table II.

Bending magnets are of standard "door-frame" type with magnetic mirrors and shaped pole ends where appropriate. The quadrupoles are of conventional design with considerable care taken to assure field accuracy. The first bending magnet in the spectrometer is specially designed to allow close approach to zero degrees. The magnet yoke is notched along the center line, and the coil end loops are all on one side of the magnet. The field in this magnet has been kept low, and model tests are under way to insure good field behavior.

Power supplies for the two spectrometers are located in a separate building just outside the south wall of End Station A. Cables are run through utility tunnels to the central pivot pit and then laid along the spectrometer structure to deliver power to individual magnets.

Cooling water is supplied from the research-area low-conductivity system.

TABLE I

		20-BeV/c Spectrometer	8-BeV/c Spectrometer
(1)	Maximum momentum	20 BeV/c	8 BeV/c
(2)	Projected target length (perpendicular to the optical axis)	± 3 cm	± 10 cm
(3)	Beam height	± 0.15 cm	± 0.15 cm
(4)	Acceptance in production angle θ_o	± 4.5 mr	± 8 mr
(5)	Acceptance in azimuthal angle Φ_o	± 8 mr	± 30 mr
(6)	Acceptance in momentum band	± 2%	± 2%
(7)	Solid angle of acceptance ($\Delta\Omega$)	0.13 msr	0.65 msr
(8)	Tilt angle of the p-focal plane	43^o	13.7^o
(9)	Momentum resolution at the tilted focal plane (δ_r)	~± 0.05%	~± 0.05%
(10)	Angular resolution (θ_r)	~± 0.15 mr	~± 0.15 mr
(11)	Momentum dispersion at the p-focal plane D_p	2.826 cm/%	2.955 cm/%
(12)	Angular dispersion at the θ-focal plane D_θ	1.534 cm/mr	4.24 cm/mr
(13)	Angular dispersion at the ϕ-focal plane D_ϕ	0.602 cm/mr	—
(14)	Distance from target to the θ-focal plane	42.5 m	21.50 m
(15)	Distance from target to the ϕ-focal plane	37.41 m	—
(16)	Distance from target to the p-focal plane	43.0 m	22.0 m

TABLE II

SPECIFICATIONS OF THE MAGNET ELEMENTS
OF THE 20-BeV/c SPECTROMETER

Element	Pole-Tip Field (KG)	Field Gradient	Actual Length (inches)	Magnet Aperture (inches)	Required Regulation (%)	Inductance (henries)	Magnet L/R (sec.)	Designed Power Requirement		
								Volts	amps	kW
Q1	---	0.680 kG/cm	80	11.00 dia.	±0.1	0.08	0.67	209	1740	363
Q2	---	0.474 kG/cm	51.25	15.25 dia.	±0.1	0.033	0.83	113	2890	326
Q3	---	0.474 kG/cm	51.25	15.25 dia.	±0.1	0.033	0.83	113	2890	326
Q4	---	0.700 kG/cm	80	11.00 dia.	±0.1	0.08	0.67	209	1740	363
S1	---	0.0128 kG/cm^2	20	9.75 dia.	±0.25	0.027	0.14	70	355	24
S2	---	0.0111 kG/cm^2	20	16.375 dia.	±0.25	0.093	0.34	135	500	70
S3	---	0.0134 kG/cm^2	20	9.75 dia.	±0.25	0.027	0.14	70	355	24
B1	14.850	---	160	5.78(gap) x 24	±0.01	0.15	2.03	190	2570	487
B2	19.480	---	118	14.81(gap) x 12.4	±0.01	0.33	1.74	491	2600	1276
B3	19.480	---	118	14.81(gap) x 12.4	±0.01	0.33	1.74	491	2600	1276
B4	19.740	---	118	7.06(gap) x 12.38	±0.01	0.17	2.27	188	2500	471

The numbers given in the table are pertinent to the condition of operating the spectrometer at 20 BeV/c.

2. Frame, Drives, Alignment and Shielding

Positional tolerances for individual magnets and for the entire system are of prime importance; typical values for these constraints are $\pm$ 0.5 mr in rotation and $\pm$ 0.008 inches in position.

Bending magnets are 40 to 55 tons in weight. The frame to support the magnetic system is about 100 feet long, rising to a height of 20 feet at the detector end. The structure moves on 24-inch diameter wheels about its center pivot point. The wheels are independently driven on the 43-foot and 78-foot rails, and must be controlled synchronously. The detectors are mounted on the shielding carriage, which is independently aligned at the 125-foot and 151-foot rails.

Individual magnets can be adjusted on jacks, backed up by mechanical locking screws.

In order to check magnet position remotely, a position pickup system consisting of magnetic transformers and stretched wires is designed to check each magnet six ways; three in rotation and three in position; that is, x, y, z, pitch, yaw, and roll.

The 20-BeV/c spectrometer concrete shielding weighs about 700 tons. Twenty-four wheels, move the shielding along the 125-foot and 151-foot rails synchronously with the spectrometer frame's movement. Access to the detectors is through the large internal cavity which is also an entrance tunnel. The cavity is 9 feet wide, 6 feet high, and 30 feet long. The spectrometer momentum focal point and detector location is 141 feet from center pivot and 17.5 feet above floor level.

B. Mechanical Specifications of the 8-BeV/c Spectrometer

1. Magnets and Power Supplies

The magnets for the 8-BeV/c spectrometer will have the parameters shown in Table III. (The final quadrupole in the system is overdesigned to allow a possible future modification of the system which will add another quadrupole to obtain a focal plane which is almost square, rather than rectangular. In this modification the highest momentum obtainable will be 5.75 to 6.0 BeV/c.)

A subset of power supplies for the 20-BeV/c spectrometer will be used to operate the 8-BeV/c spectrometer. In the early stage, the two spectrometers can not operate simultaneously because we do not have enough power supplies. It will take less than one hour to change the connections from one spectrometer to the other.

TABLE III

SPECIFICATIONS OF THE MAGNET ELEMENTS
OF THE 8 BeV/c SPECTROMETER

Element	Pole-Tip Field (KG)	Field Gradient (KG/cm)	Actual Length (inches)	Magnet Aperture (inches)	Required Regulation (%)	Inductance (henries)	Magnet L/R (sec.)	Designed Power Requirement	
								Current (amps)	Power (kW)
Q1	---	0.556	40.00	11.00 dia.	± 0.1	0.015	0.320	2880	395
Q2	---	0.557	51.25	15.25 dia.	± 0.1	0.033	0.825	2890	326
Q3	---	0.377	51.25	15.25 dia.	± 0.1	0.033	0.825	2890	326
B1	20.200	---	136.00	13.755(gap) x 22	± 0.01	0.58	3.200	2500	1170
B2	20.200	---	136.00	13.755(gap) x 22	± 0.01	0.58	3.200	2500	1170

The numbers given in the table are pertinent to the condition of operating the spectrometer at 8 BeV/c.

2. Frame, Drive, Alignment and Shielding

Positional tolerances of the magnetic elements are again of prime importance; typical values are the same order of magnitude as those for the 20-BeV/c spectrometer.

The two bending magnets each weigh 90 tons. The supporting structure is 55 feet long, rising to a height of 18 feet at the detector end. Most of the weight of the magnetic system is carried from the structure to the 25 foot and 43 foot rails by a three point suspension carriage. This carriage is attached to the support structure in such a way that radial loading on the central pivot is eliminated.

The spectrometer focal points, 4.25 and 4.75 meters beyond the third quadrupole, are surrounded by 350 tons of concrete shielding. A detector cavity, 6 feet high, 6 feet wide, and 19 feet deep, is provided inside the shielding. A beam extends from the magnet support structure to the far end of the shielding cavity, and the detectors mount on this beam. The shielding, constructed in two vertical halves, rides on two separated carriages that span the 60 foot and 78 foot rails. Access to the detectors is obtained by separating the two shielding halves.

An alignment system for verification of both magnetic element and detector positions is being designed.

C. Optics

Both the 20- and 8-BeV/c spectrometers are arranged to have point-to-point focusing in the vertical plane (the bend plane), and line-to-point focusing in the horizontal plane. The momentum p and the production angle θ are displayed orthogonally at the focal planes, so that kinematic θ, p correlations can be measured.

1. The 20-BeV/c Spectrometer

The first-order focusing properties of the 20-BeV/c spectrometer are shown in Figs. 5 and 6. The θ-measuring focal plane is perpendicular to the central optical axis of the spectrometer. The p-measuring focal plane is located 50 cm downstream from the θ-focus and is tilted at an angle of 43° with respect to the central ray in order to eliminate some of the chromatic aberrations. The ϕ-measuring focal plane is located 1.395 meters downstream from the exit of the last bending magnet as shown in Fig. 6, and is perpendicular to the central optical axis of the spectrometer. The azimuthal angle, ϕ, is displayed in the vertical direction. The variations of the angular acceptance in θ_o, ϕ_o, and the solid angle as functions of target length and momentum are given in Figs. 7 to 10. In Figs. 7 and 8, the boundary line marked by B1(exit), etc., indicates that the beam is limited by the exit aperture of B1, etc. The equations giving the output coordinates in terms of the input beam variables are as follows (distance in cm, angle in mr, and δ in percent):

At the θ-focal plane,

$$
\begin{aligned}
x = (1.534\,\theta_o &+ 0.0177\,\theta_o\,\delta_o) \\
&-0.0139\,x_o\,\phi_o && (\pm\,0.334\ \text{cm}) \\
&+0.0048\,\theta_o\,\phi_o && (\pm\,0.173\ \text{cm}) \\
&-0.105\,\theta_o\,y_o && (\pm\,0.0708\ \text{cm}) \\
&-0.0878\,x_o\,y_o && (\pm\,0.0395\ \text{cm}) \\
&-0.00254\,x_o\,\delta_o && (\pm\,0.0153\ \text{cm})\ .
\end{aligned}
$$

At the tilted p-focal plane,

$$
\begin{aligned}
y = (2.826\,\delta_o &- 0.0421\,\delta_o^2 - 0.0167\,\theta_o^2) \\
&+0.927\,y_o && (\pm\,0.139\ \text{cm}) \\
&-0.000836\,\phi_o^2 && (-\,0.0535\ \text{cm}) \\
&+0.0407\,y_o\,\phi_o && (\pm\,0.0488\ \text{cm}) \\
&-0.0029\,x_o\,\theta_o && (\pm\,0.0391\ \text{cm}) \\
&+0.0042\,x_o^2 && (\ \ 0.0378\ \text{cm}) \\
&+0.0291\,y_o\,\delta_o && (\pm\,0.00873\ \text{cm}) \\
&+0.0653\,y_o^2 && (\ \ 0.00147\ \text{cm}) \\
&+8.99 \times 10^{-5}\,\phi_o\,\delta_o && (\pm\,0.00144\ \text{cm})\ ,
\end{aligned}
$$

and at the ϕ-focal plane,

$$y = \left[-0.602\,\phi_o + 0.0144\,\phi_o^2 + 0.0253\,\phi_o\,\delta_o - 0.0142\,\delta_o^2 + 0.0358\,\theta_o^2\right]$$

$-0.977\, y_o$	($\pm$ 0.1465 cm)
$+0.0128\, x_o^2$	(0.115 cm)
$+0.0444\, x_o\,\theta_o$	($\pm$ 0.555 cm)
$+0.0417\, y_o^2$	(0.000927 cm)
$+0.0451\, y_o\,\phi_o$	($\pm$ 0.0541 cm)
$+0.0338\, y_o\,\delta_o$	($\pm$ 0.01 cm) .

In the above equations, the numbers in the parentheses are calculated from the following assumed input beam variables:

$x_o = \pm\, 3$ cm	(projected target length)
$\theta_o = \pm\, 4.5$ mr	(production angle)
$y_o = \pm\, 0.15$ cm	(beam height)
$\Phi_o = \pm\, 8$ mr	(azimuthal angle)
$\delta_o = \pm\, 2\%$	(momentum band) .

The second-order terms in the brackets simply curve the lines of constant δ_o, θ_o and ϕ_o in the focal planes, and thus the true δ_o, θ_o and ϕ_o can be obtained by solving a set of quadratic equations.

The overall resolutions in δ, θ and ϕ are calculated as

$$\delta_r = \pm\, 0.059\%$$

$$\theta_r = \pm\, 0.251 \text{ mr}$$

$$\phi_r = \pm\, 0.972 \text{ mr}$$

and the dispersions are

$$D_\delta = 2.826 \text{ cm}/\%$$

$$D_\theta = 1.534 \text{ cm/mr}$$

$$D_\phi = 0.602 \text{ cm/mr} .$$

To be compatible with the momentum and angular resolution, the p-counters are built to have a bin-width of 0.3 cm; and for θ-counters, 0.79 cm. The size of the focal plane is 14.2 cm by 10.2 cm.

When the spectrometer operates at angles other than 90°, the finite length of the target will introduce a "depth-of-field" effect which will change some of the transformation coefficients and also cause some degradation of resolution for targets about 10 cm in length.

More details on the 20-BeV/c spectrometer can be found in SLAC Report TN-65-40.

2. The 8-BeV/c Spectrometer

The first-order focusing properties of the 8-BeV/c spectrometer are shown in Figs. 11 and 12. The p-measuring counter has been tilted to an angle of 13.7° with respect to the optical axis in order to eliminate the main second-order aberration $(y|\Phi_o\delta_o)$. The variations of angular acceptances in θ_o, ϕ_o, and the solid angle as functions of target length and momentum are given in Figs. 13 to 16. The transformation equations which give the output coordinates at the focal planes in terms of the input beam variables are as follows:

$$
\begin{aligned}
x = (4.24\ \theta_o &- 0.0108\ \theta_o\delta_o) \\
&+0.0405\ x_o\delta_o && (\pm\ 0.81 \text{ cm}) \\
&-0.000688\ \theta_o\Phi_o && (\pm\ 0.165 \text{ cm}) \\
&+0.000177\ x_o\Phi_o && (\pm\ 0.0531 \text{ cm}) \\
&-0.000947\ x_o y_o && (\pm\ 0.00142 \text{ cm}) \\
&-0.00053\ \theta_o y_o && (\pm\ 0.000635 \text{ cm})
\end{aligned}
$$

and

$$y = (-2.955\ \delta_o + 0.00417\ \delta_o^2 + 0.000312\ \theta_o^2)$$

$-0.947\ y_o$	($\pm$ 0.14 cm)
$+0.00126\ \Phi_o\ \delta_o$	($\pm$ 0.076 cm)
$-0.00368\ y_o\ \Phi_o$	($\pm$ 0.017 cm)
$-0.000154\ x_o\ \theta_o$	($\pm$ 0.012 cm)
$+0.0000197\ x_o^2$	(0.0020 cm)
$+0.0033\ y_o\ \delta_o$	($\pm$ 0.0017 cm)
$+1.08 \times 10^{-6}\ \Phi_o^2$	(0.00097 cm)
$-0.00253\ y_o^2$	(- 0.00006 cm) .

The numbers in parentheses determine the resolutions of the spectrometer and were evaluated with the following input beam phase volume:

$$x_o = \pm\ 10\ \text{cm}$$

$$\theta_o = \pm\ 8\ \text{mr}$$

$$y_o = \pm\ 0.15\ \text{cm}$$

$$\Phi_o = \pm\ 30\ \text{mr}$$

$$\delta_o = \pm\ 2\%\ .$$

The overall resolutions are

$$\theta_r = \pm\ 0.195\ \text{mr}$$

$$\delta_r = \pm\ 0.054\ \%$$

and the dispersions are

$$D_\theta = 4.24\ \text{cm/mr}$$

$$D_\delta = 2.955\ \text{cm/\%}$$

The counters will have plastic scintillators 0.3 cm wide in the p-hodoscope, and 1.65 cm wide in the θ-hodoscope. Focal plane sizes are 67.5 cm $\times$ 12.0 cm. With a 20 cm long target, the "depth-of-field" effect of the target will degrade δ_r by 50% and improve θ_r by a factor of 2.66 as the spectrometer moves from 90^o to 15^o.

More details on the 8-BeV/c spectrometer can be found in SLAC Report TN-65-29.

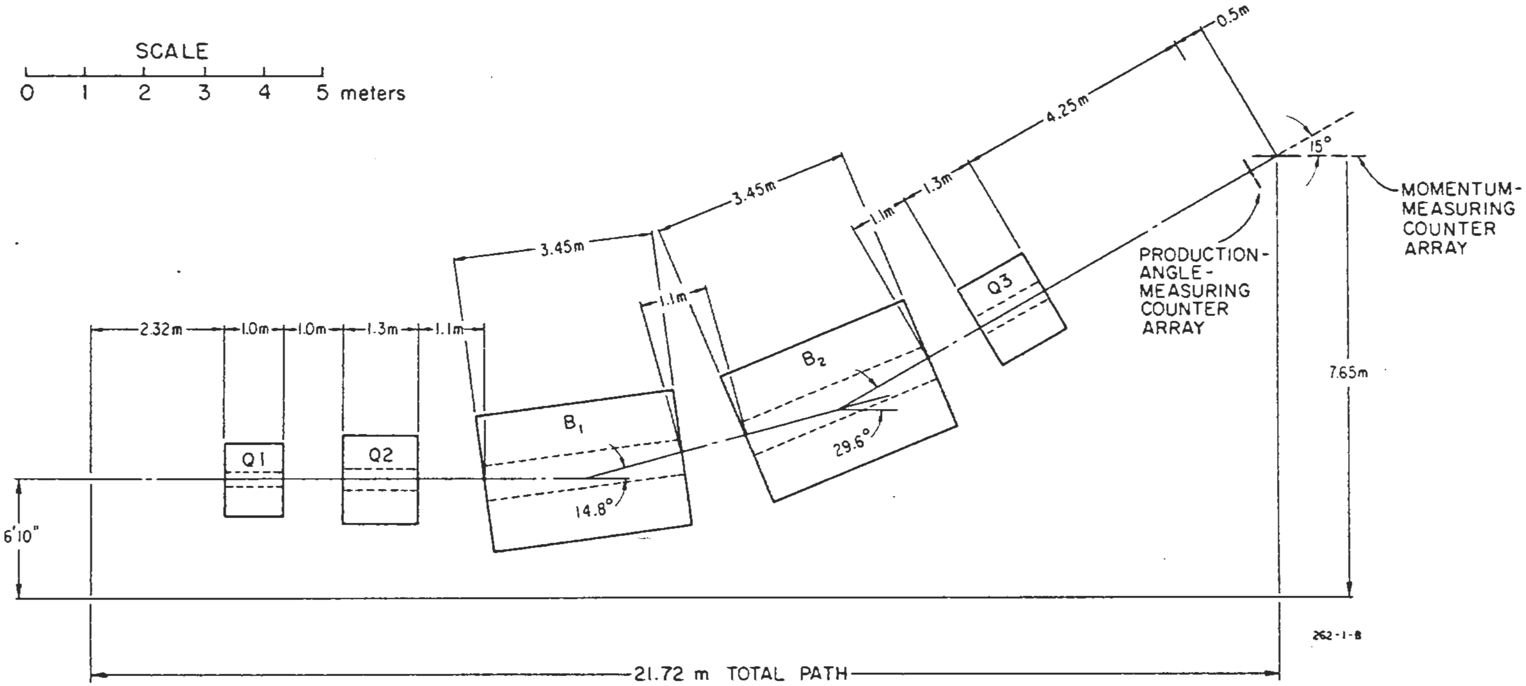


FIG.1 -- MAGNET ARRANGEMENT, 8-BeV/c SPECTROMETER.

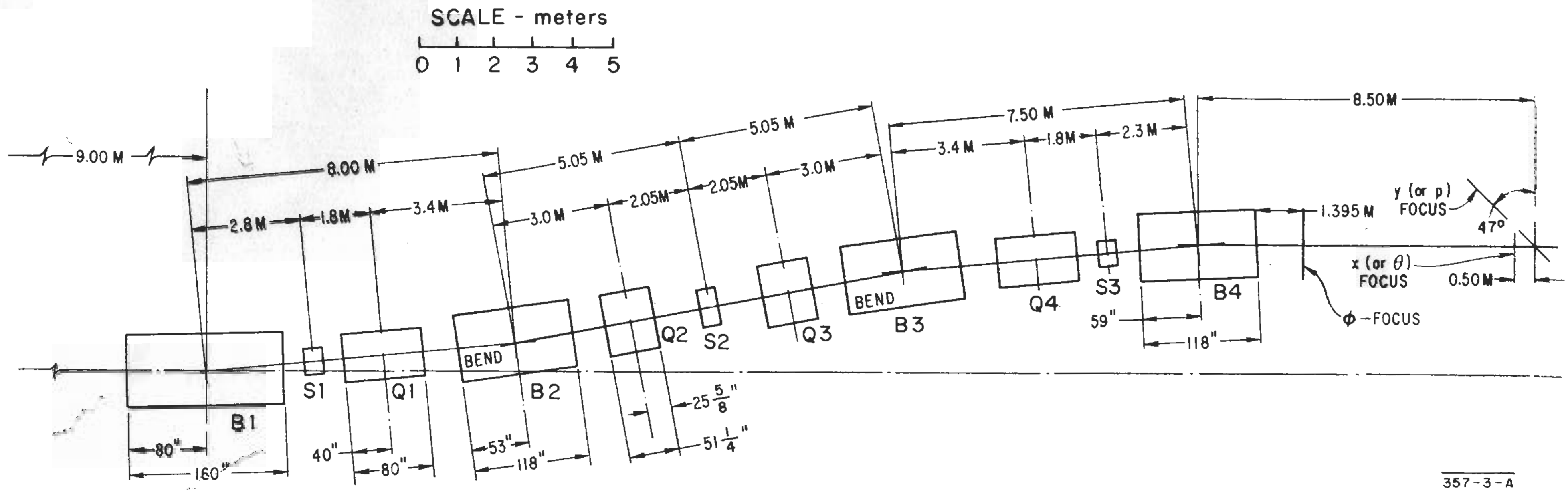
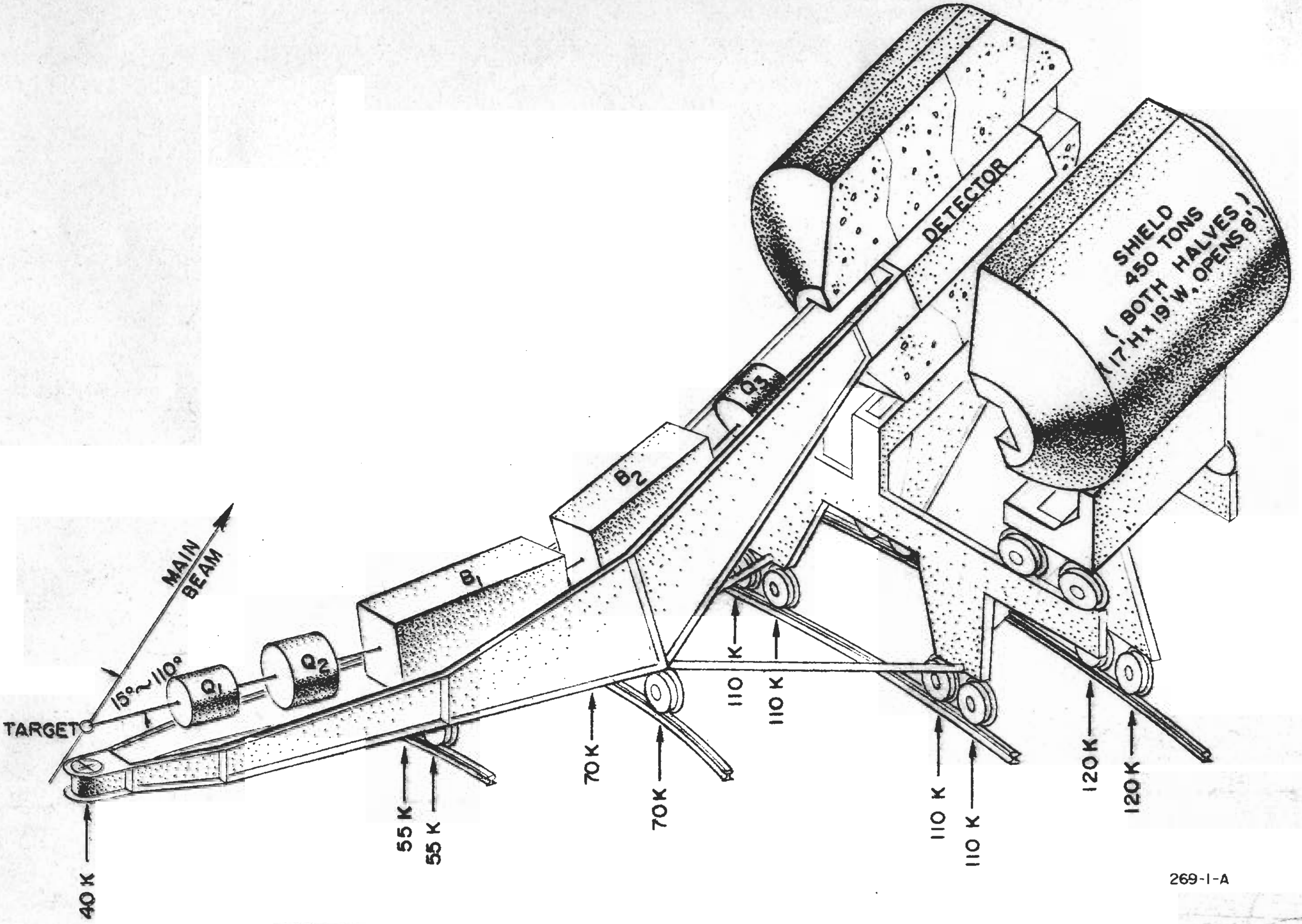


FIG. 2--MAGNETIC COMPONENTS OF 20 BeV/c SPECTROMETER



269-I-A

FIG. 3-- SUPPORT SYSTEM FOR THE 8 BeV/c SPECTROMETER

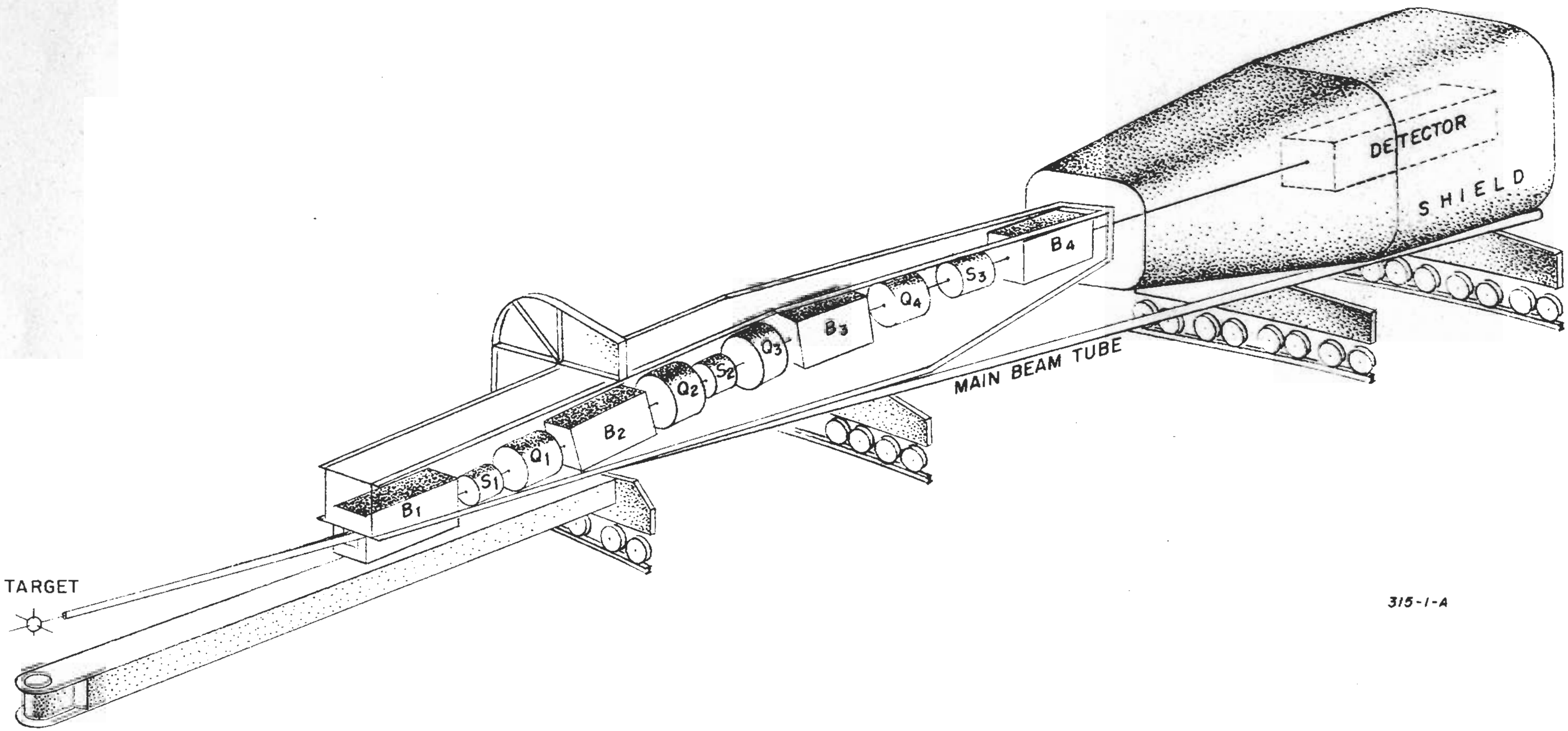
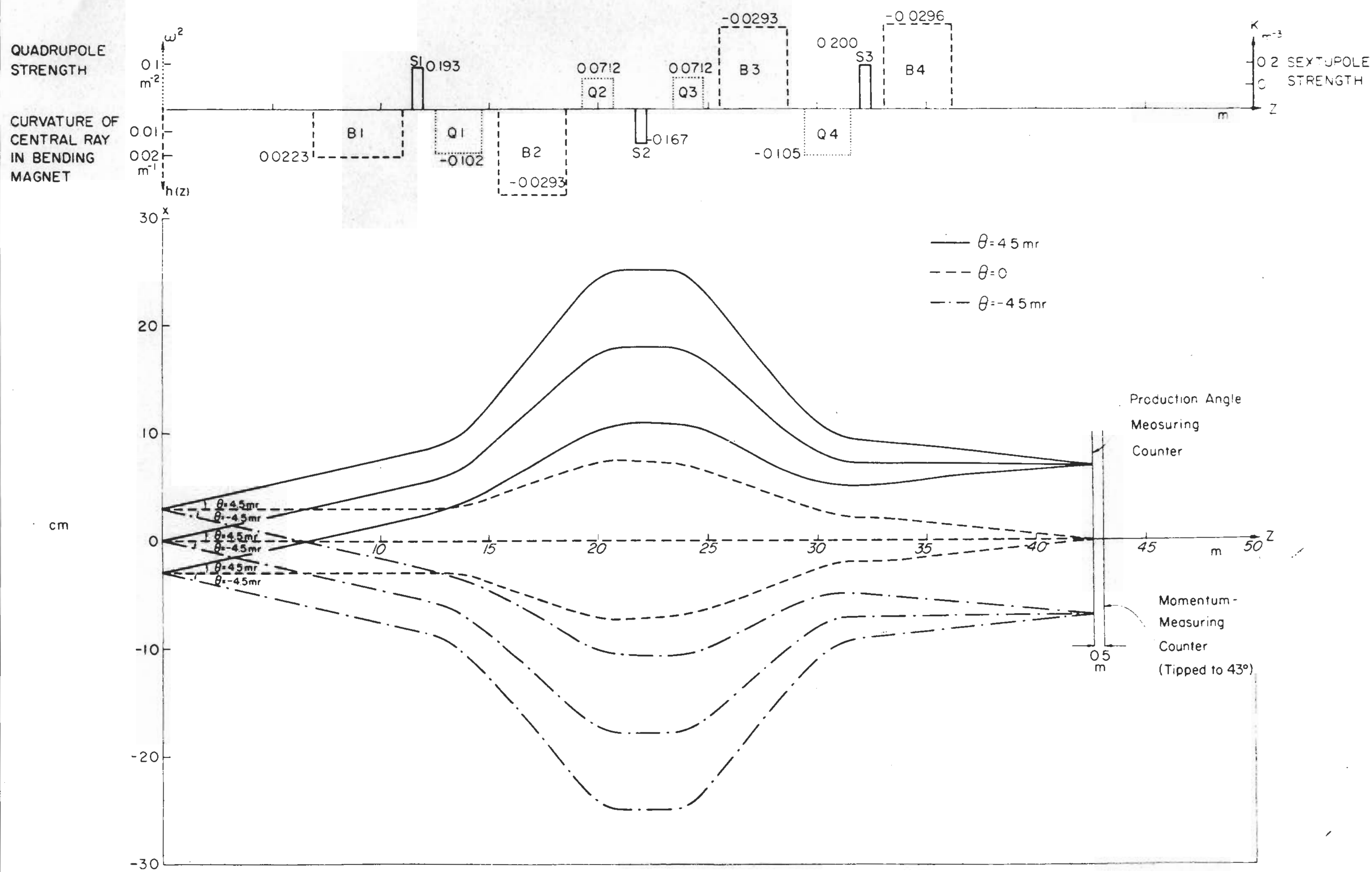
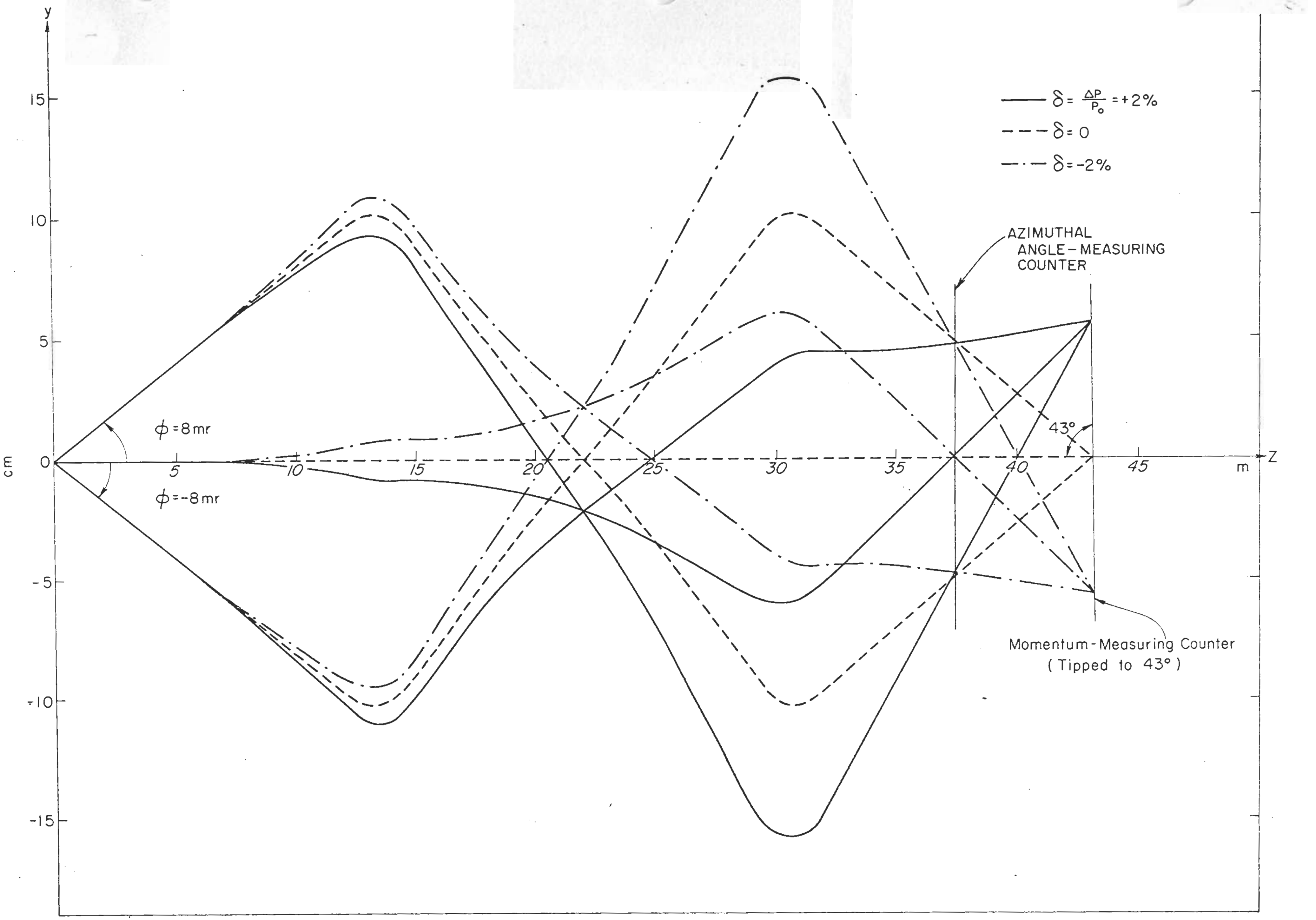


FIG. 4 -- PICTORIAL VIEW OF 20 GeV/c SPECTROMETER

Opp 1



FOCUSING PROPERTIES OF THE 20-BeV/c SPECTROMETER IN THE HORIZONTAL PLANE



ING PROPERTIES OF THE 20-BeV/c SPECTROMETER IN THE VERTICAL PLANE

299-6-D

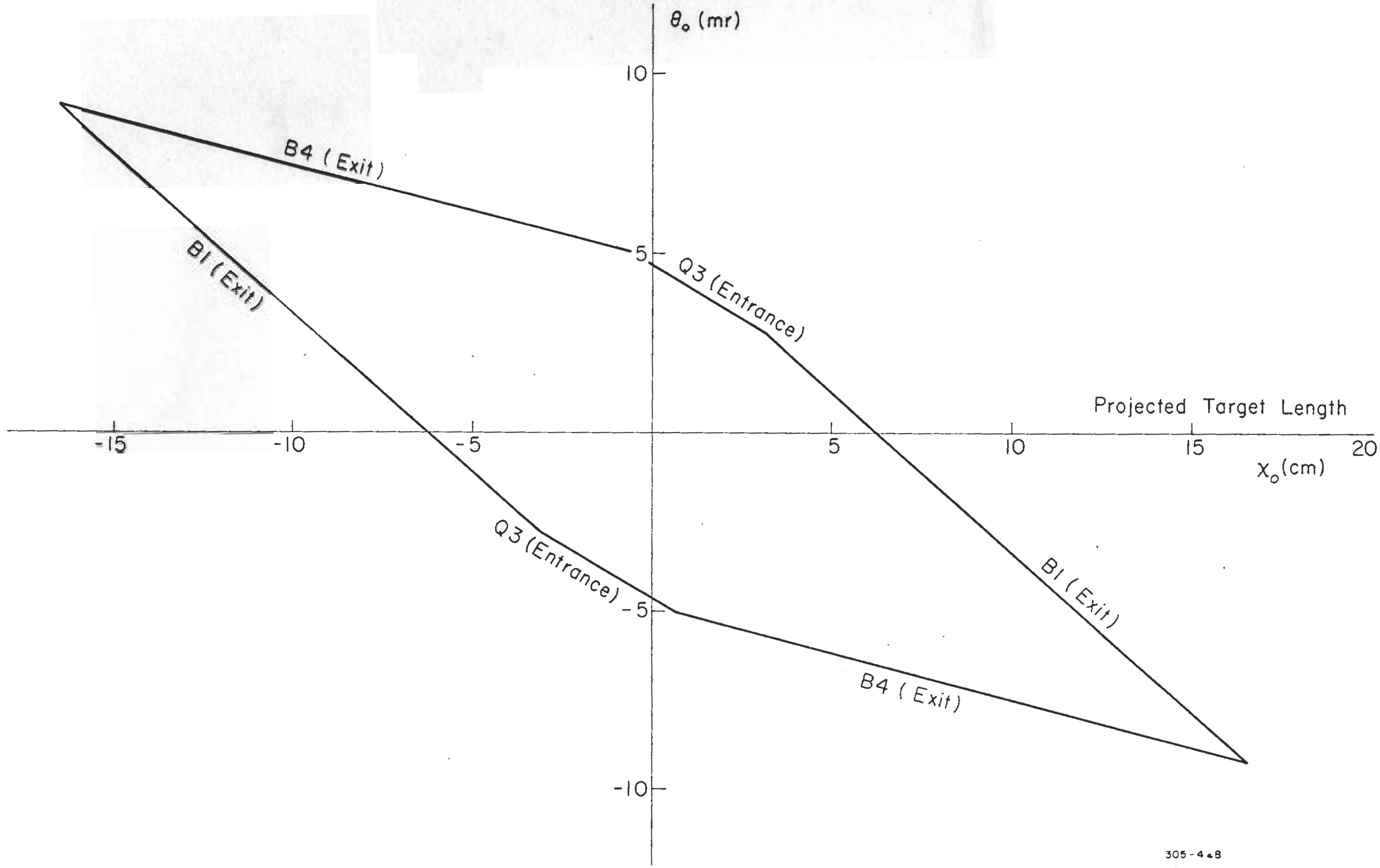


FIG. 7 -- θ_o ACCEPTANCE OF THE 20-BeV/c SPECTROMETER

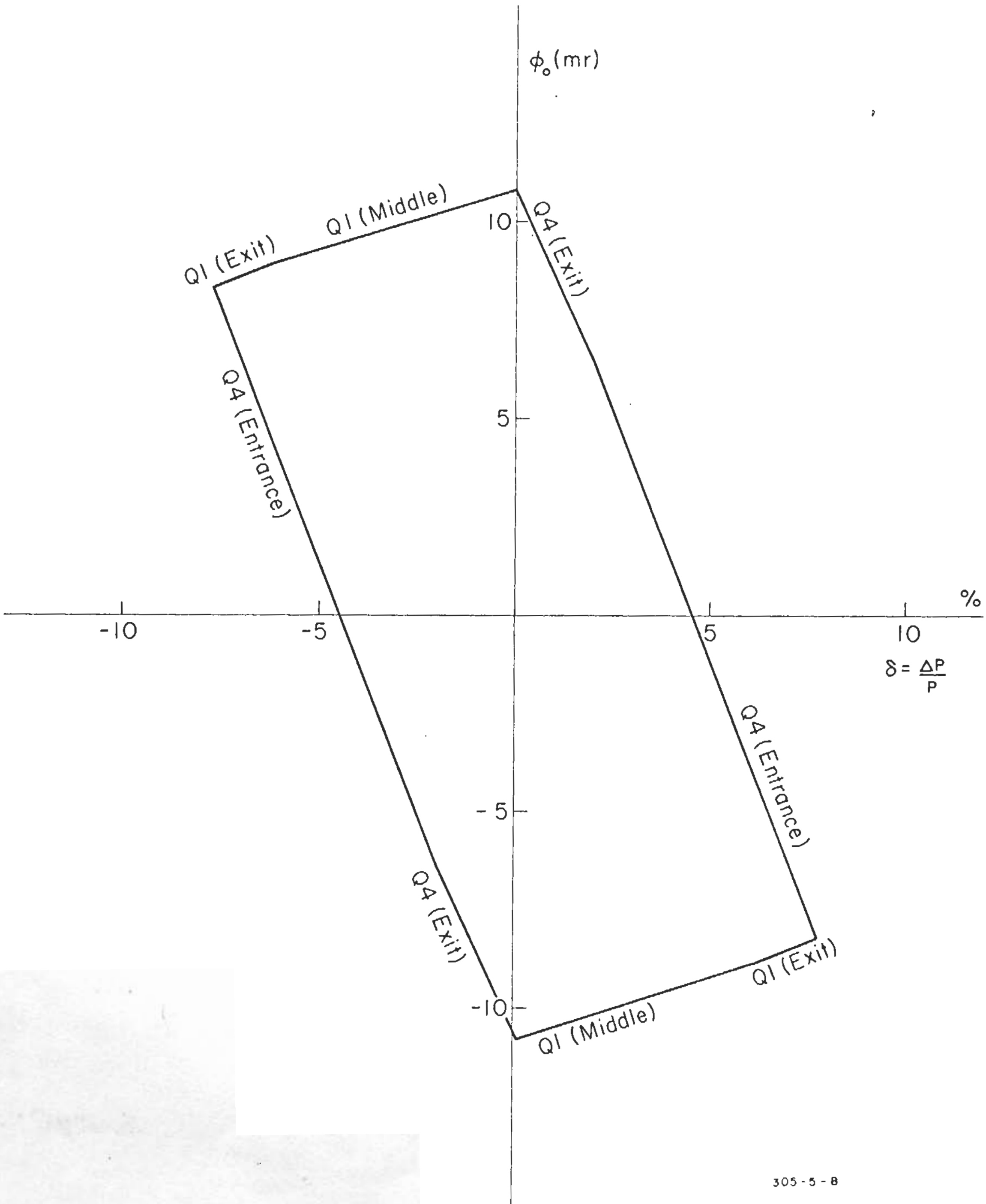


Fig. 8 - ϕ_o ACCEPTANCE OF THE 20-BeV/c SPECTROMETER

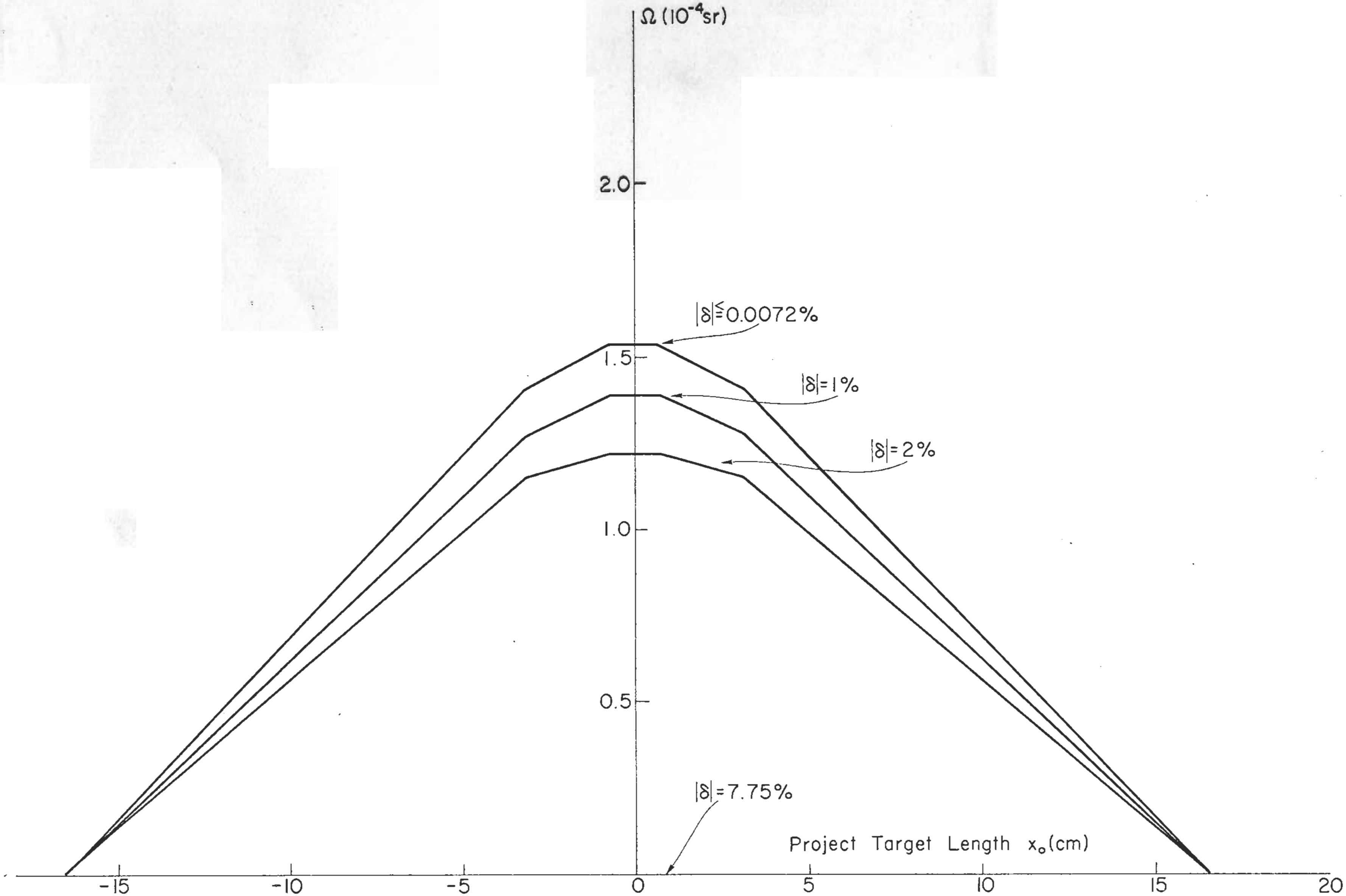


Fig.9--SOLID ANGLE OF ACCEPTANCE OF THE 20-BeV/c SPECTROMETER

305-6-B

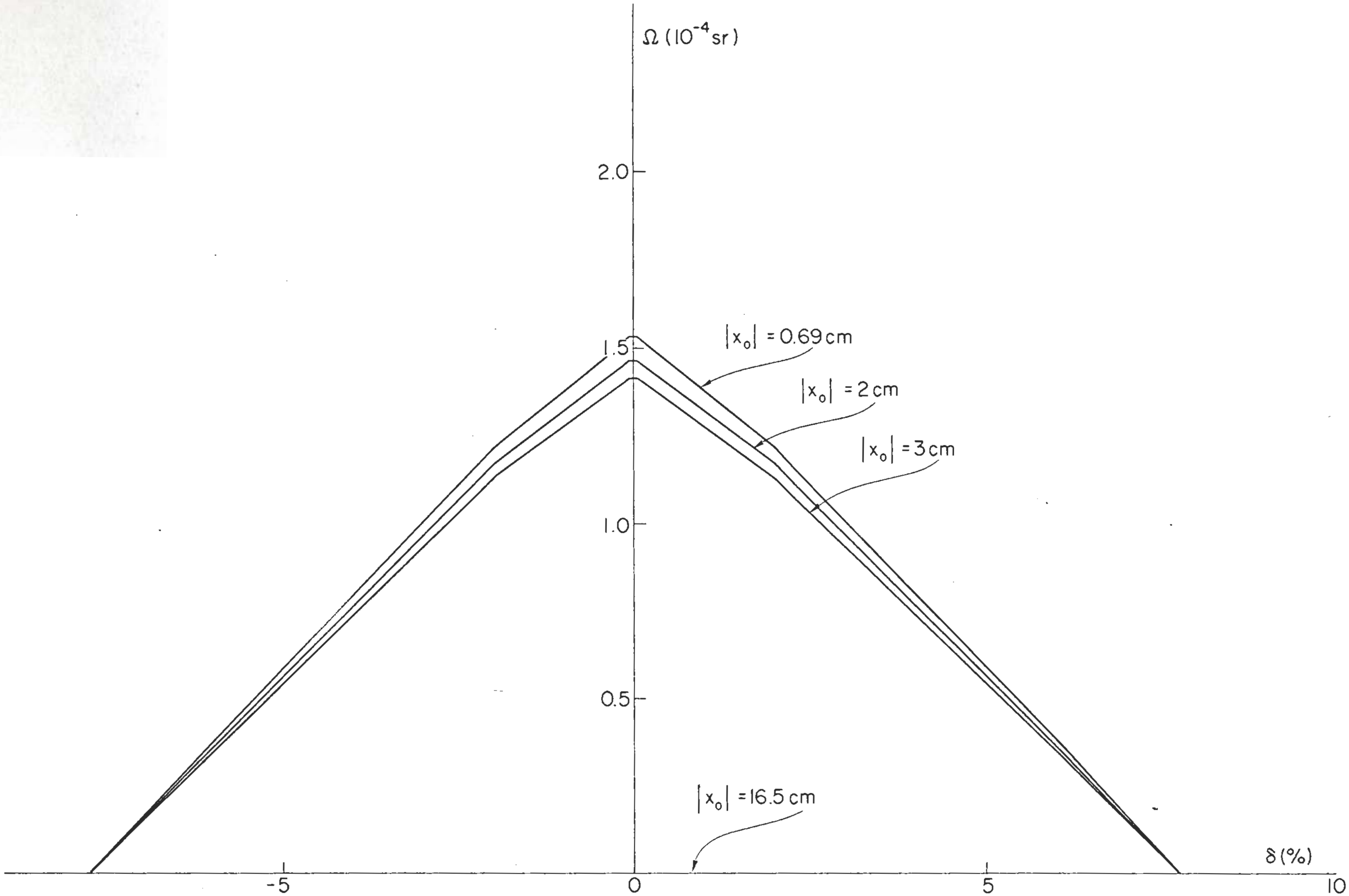


Fig.10-SOLID ANGLE OF ACCEPTANCE OF THE 20-BeV/c SPECTROMETER

305-7-B

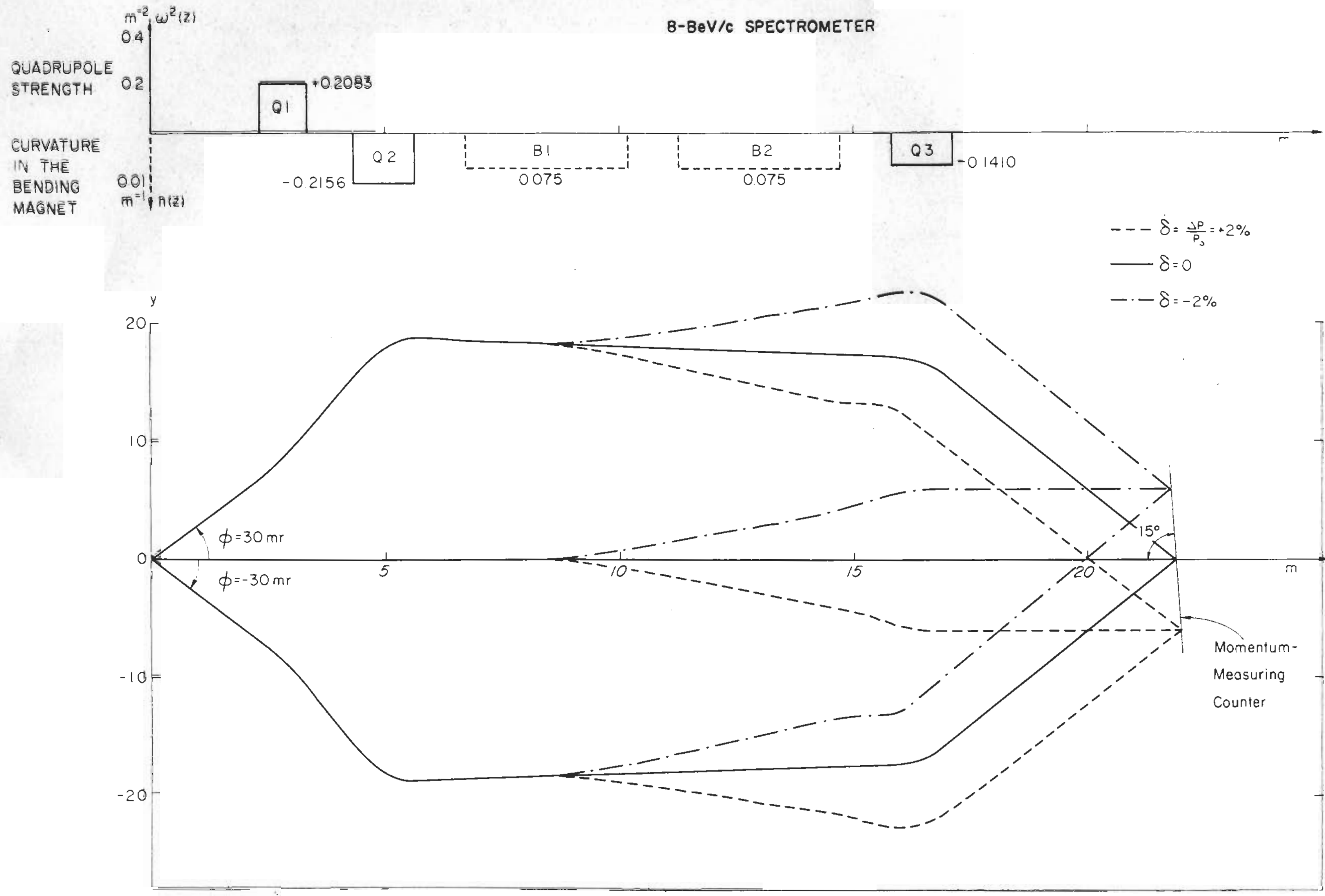


FIG. 11--First-order focusing properties of the 8 BeV/c spectrometer in the vertical plane.

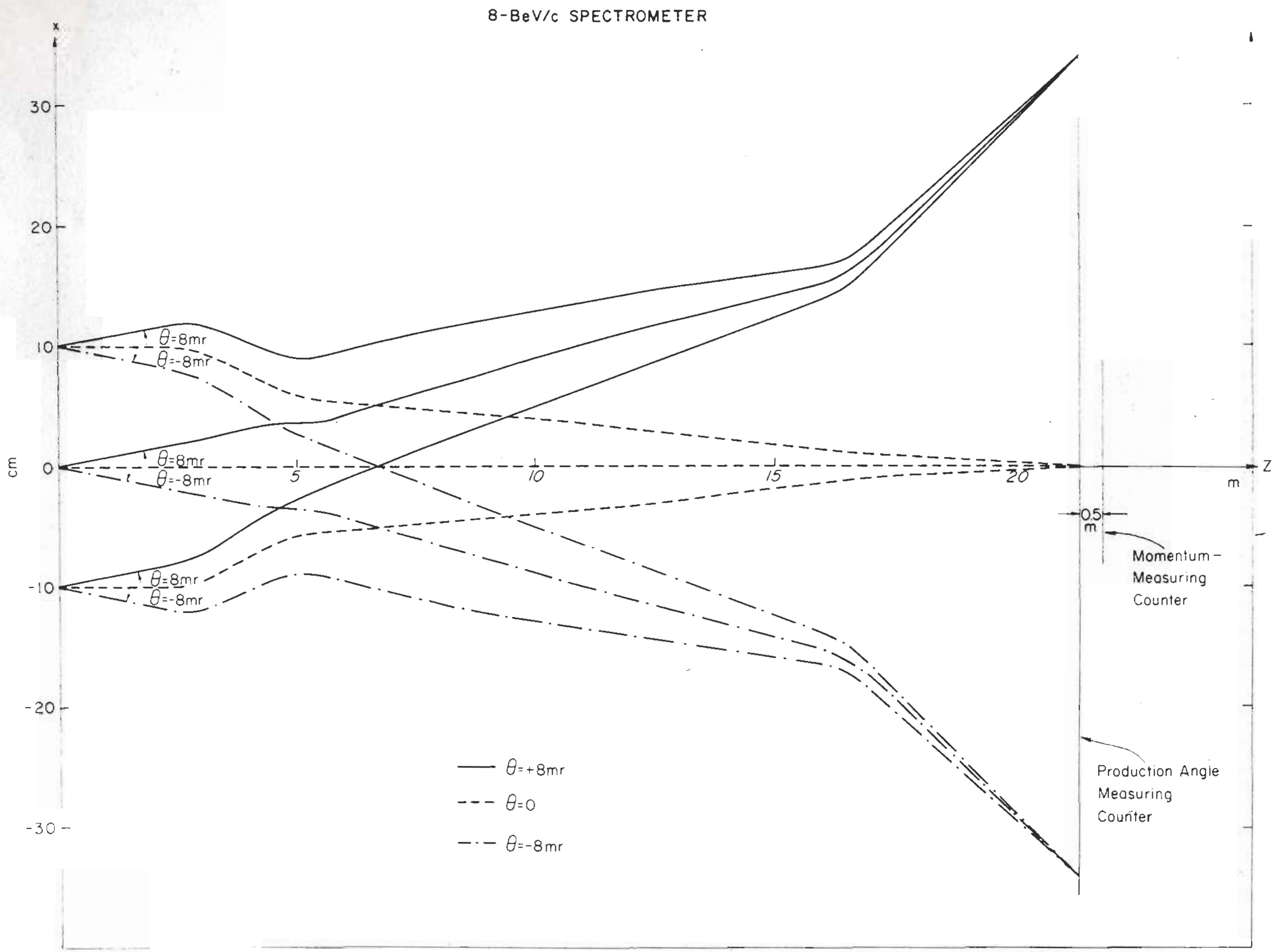


FIG. 12--First-order focusing properties of the 8 BeV/c spectrometer in the horizontal plane.

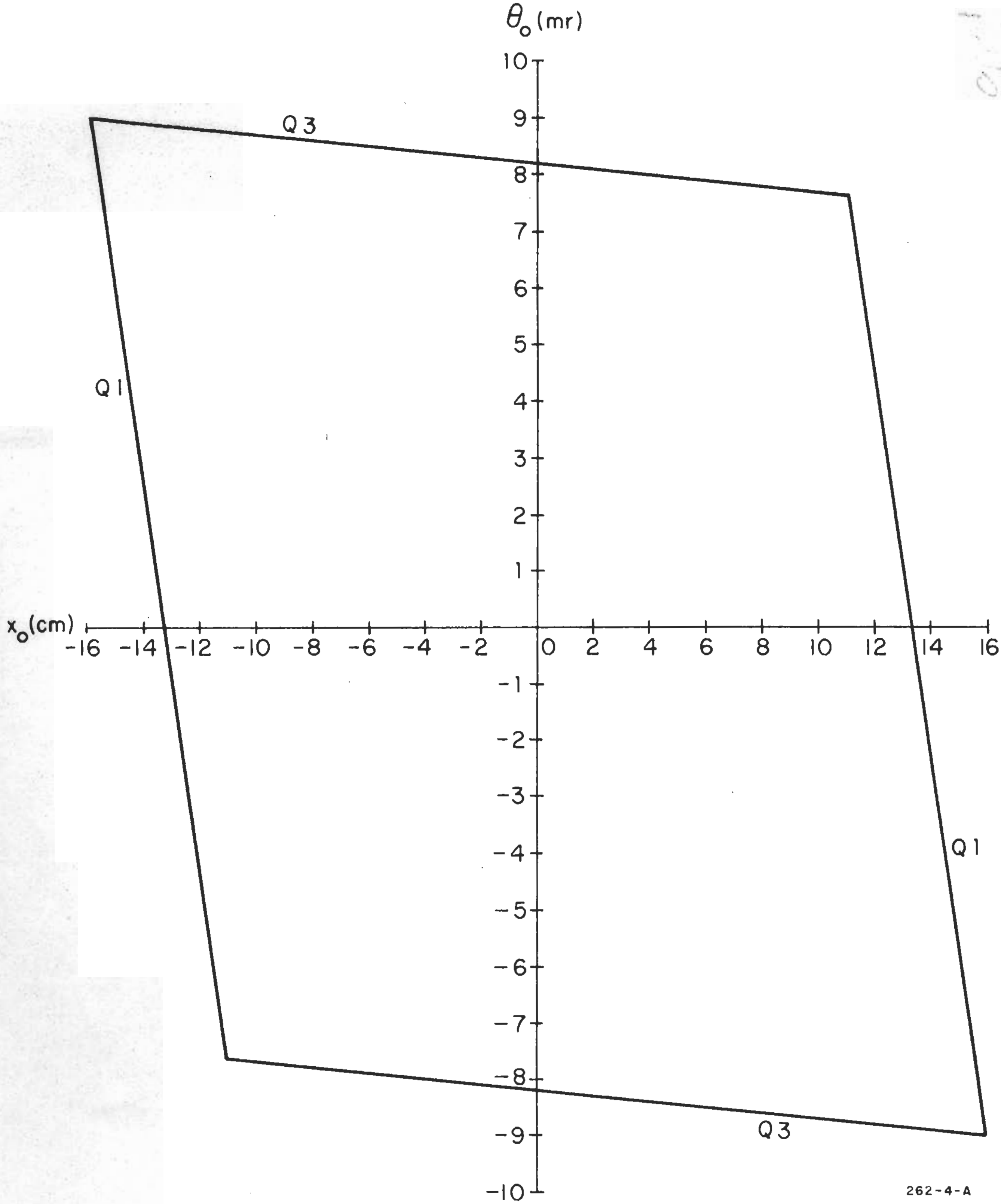


FIG.13-- θ_o - ACCEPTANCE OF THE 8-BeV/c SPECTROMETER.

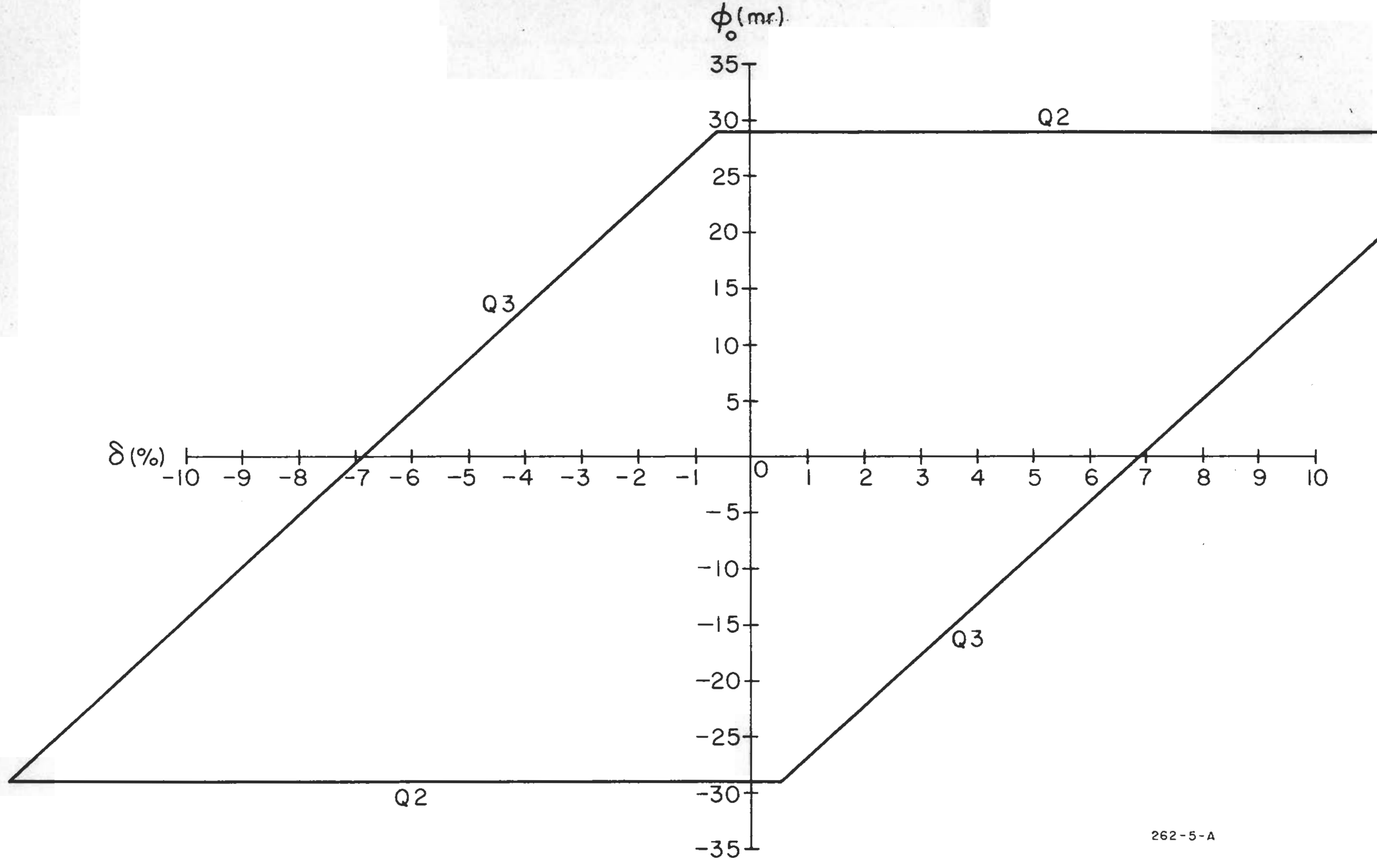


FIG. 14 – ϕ_o-ACCEPTANCE OF THE 8 – BeV/c SPECTROMETER.

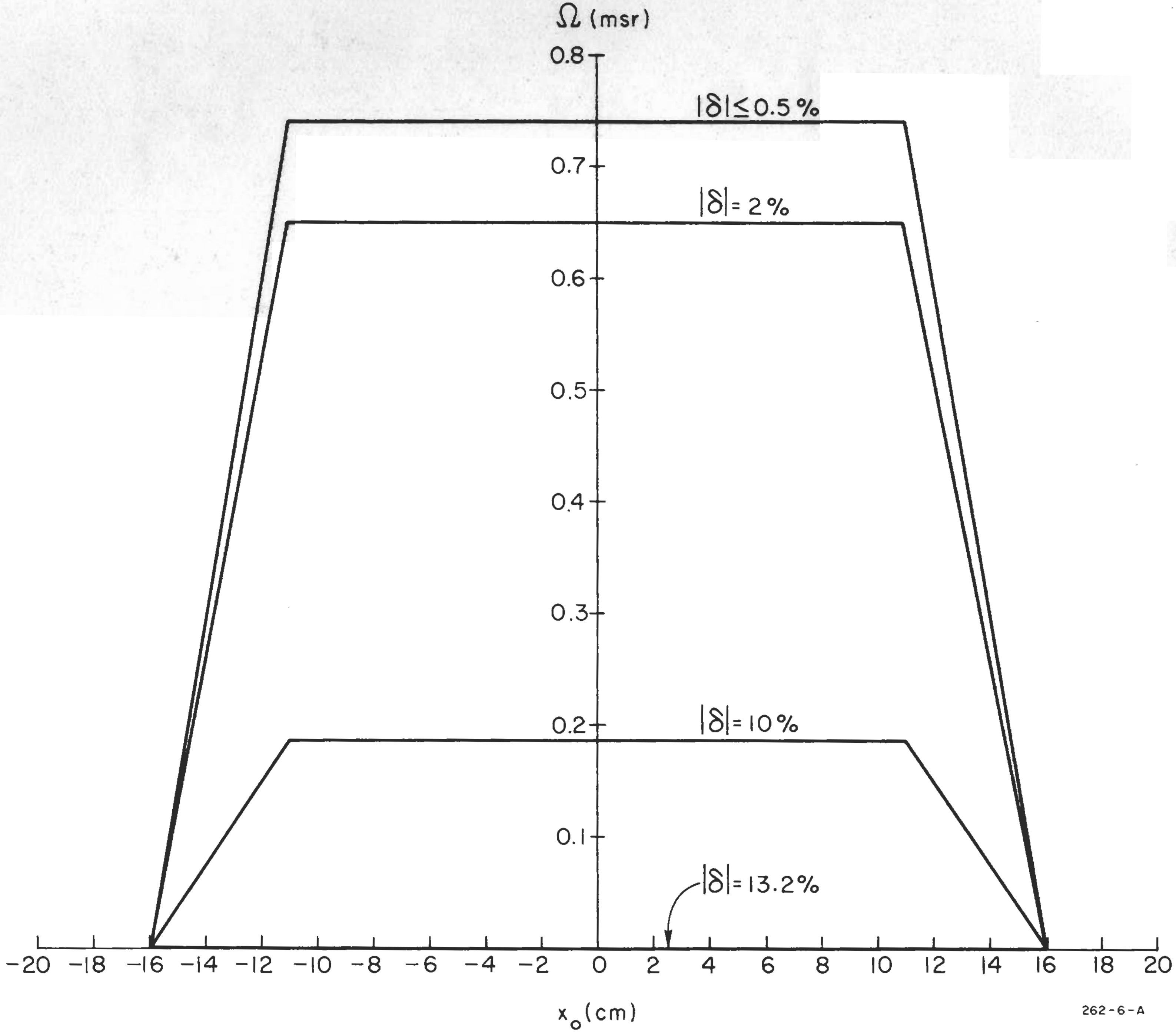


FIG. 15-- SOLID ANGLE OF ACCEPTANCE OF THE 8-BeV/c SPECTROMETER.

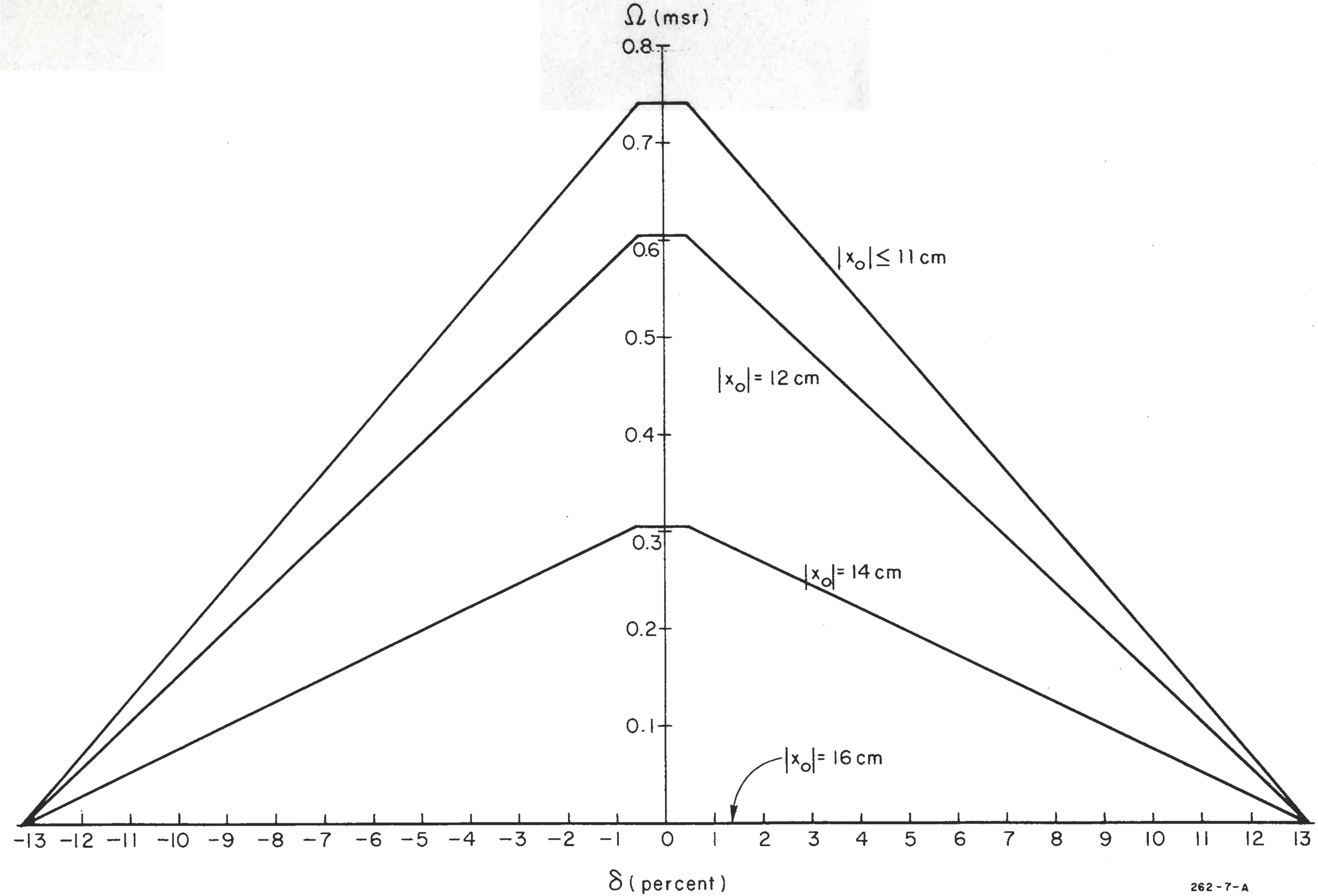


FIG. 16-- SOLID ANGLE OF ACCEPTANCE OF THE 8-BeV/c SPECTROMETER.