national accelerator laboratory

FN-239
2257

HYPERON BEAM WITH QUADRUPOLE FOCUSING

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A focusing Cerenkov counter[1] can be used in a hyperon beam as a particle survey instrument, to provide a trigger on particle mass, and in a positive hyperon beam, to suppress the proton background. To accommodate the small angular acceptance of the Cerenkov counter, the beam can be modified by adding quadrupole focusing. The beam design provides that particles of a given momentum enter the counter at a well-defined angle. Then the accurate velocity measurement of the Cerenkov counter, combined with its small angular resolution (momentum resolution), define the mass of the particle. The improved momentum-angle correlation in the beam also offers the possibility of better accuracy in the measurement of hyperon momentum. This note is a summary of the design of a quadrupole-focused hyperon beam for NAL.

Figure 1 is a schematic representation of the hyperon beam. The channel is made very narrow to act as a collimator. The magnetic field in the channel is made as high as possible to separate the hyperon beam from the proton beam in the shortest possible distance. The aperture of the channel determines the angle and momentum spread of the beam and also affects the beam intensity.

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Figure 2 gives the angle and momentum distribution of particles at the channel exit for a uniform distribution of particles into the channel. Figure 3 gives the corresponding distributions at the exit of the quadrupole doublet. The momentum is strongly correlated to angle and position in the bending plane (horizontal) at the channel exit as seen in Fig. 4a and Fig. 5.

The beam divergence is, however, too large for a Cerenkov counter to separate Σ and Ξ at 150 GeV/c. The effect of the quadrupoles is to reduce the beam divergence as a function of momentum as shown in Fig. 4b. The effect of the quads on the momentum-angle distribution in the vertical plane is given in Fig. 6.

The addition of quadrupoles increases the beam length and, therefore, increases the loss of hyperons due to decays. (The Σ^- flux at 150 GeV/c is reduced by about a factor of two for a quad doublet that is 3.6 meters long.) For a focusing Cerenkov counter, however, the loss is more than compensated, since a larger fraction of the beam falls within the angular acceptance of the counter. A quadrupole doublet is used as the focusing element, rather than a triplet, to save on beam length. (Also, the dispersion $d\theta/dp$ is larger for a doublet as will be shown.)

The decision to place the quadrupoles downstream of the magnetic channel was based on the desire to segregate the channel and quadrupole designs. The experimental program for the beam does not

rely on the use of the quadrupoles, whereas the magnetic channel is a necessity. It is desirable to add the quadrupoles to the beam only when an explicit experimental need arises, and this can be achieved if the quads are placed downstream of the channel. Furthermore, the channel design must take careful account of the muon background at the experimental setup. For this reason, the magnet coils are kept far apart to disperse the muon beam as much as possible.[2] To introduce quads along the magnetic channel would give them a larger solid angle acceptance, but only at the expense of unduly complicating the muon background problem. Since the use of quadrupoles of small external dimensions is anticipated, the effect on the muon beam is minimized by putting the quads downstream of the channel, which should be a relatively muon-free region.

A summary of quadrupole parameters for two beam configurations is given in Table I. A reduction in quadrupole length can be achieved when a separation is introduced between the quads in the doublet. However, as we've shown, the advantages of putting the quads downstream of the channel are paramount, and, therefore, no separation is introduced between the quadrupoles in this design.

Calculations for the beam design were carried out with the program TRANSPORT and a Monte-Carlo program. The spot size and beam divergence at the target, the variation of path length of rays in

the magnetic channel, the small apertures of magnetic channel and quadrupoles, and the chromatic aberrations of the quadrupoles were included in the calculations. The effects of misalignments of the beam elements and non-uniformities in field gradient were calculated with the Monte-Carlo routine. In this program, the field in the magnetic channel was assumed to be uniform and the trajectory circular with a radius of curvature determined from the particle momentum. The rays were traced separately through each quadrupole by use of a transfer matrix. (The elements of the matrix were calculated separately for each ray and were a function of particle momentum.)

The dispersion of the beam ($d\theta_{HOR}/dp$) at the exit of the doublet is primarily dependent on the arrangement of the quadrupoles. A high dispersion is desirable to achieve good momentum resolution for a given horizontal angle measurement. In this regard it is found that a doublet gives a higher dispersion than a quadrupole triplet when focusing the same momenta. Similarly, a high dispersion can be achieved if the first quad in the doublet is horizontally focusing. The highest dispersion ($d\theta/dp = 0.24$ mrad/GeV/c) is attained if the first quad in the doublet is placed closer to the target as in Setup #2 in Table I; again this quad is horizontally focusing. The dispersion of the configuration chosen for this beam is sufficiently high to be adequate, although it is by no means maximized.

The beam divergence is a strong function of spot size at the target. If the spot size is reduced by a factor of two (to 0.5 mm x 0.5 mm) the beam divergence is reduced by a factor of two for the central momentum and a little less for the off-momentum particles. The calculations in this note assume a spot size of 1 mm x 1 mm with no drift. Figure 7 gives some results for a 2 mm target. Non-uniformities in field gradient of the quadrupoles also cause a broadening of the divergence. The calculations indicate that a field gradient uniformity of 1% is desirable for this beam. A somewhat more critical dependence is seen on the effective length of the quad field. A change in the field length of 0.2% shows a slight broadening in the beam divergence. It is, therefore, desirable that the effective field length be known to this accuracy for this beam.

Axial displacements of the quadrupoles introduce dipole components into the field and cause a translation of the curves in Fig. 4b and Fig. 6b along the θ axis. Position accuracies for the quads of 5 mils are required to eliminate this effect: the translation is 0.002 mrad/mil axial displacement. However, the effect is not serious in that beam pions could be used to calibrate the channel and measure the beam parameters. (A magnetic spectrometer used in the hyperon experiment would be used to measure pion momentum as a function of exit angle for the quad doublet.)

The calculations did not consider the effects of scattering in the channel. Since the momentum of the hyperons is determined by the angle of exit from the quads, the scattered particles will be tagged with the wrong momentum: scattered hyperons will serve to broaden the beam divergence.

Conclusions

The introduction of quadrupole focusing into the hyperon beam can be done very simply and does not offer any severe restrictions on beam design. The high field gradients can be attained with superconducting quads if not with conventional magnets. A particular quadrupole design that would be adequate was discussed in FN-235. Although designed for pulsed operation, these quads would be used in a DC mode to achieve a 10 kG/cm field gradient. They could also be modified to meet the requirements of field gradient uniformity and mechanical tolerance.

Acknowledgments

The author is grateful to Joe Lach and Jim MacLachlan for discussions of the beam and the high field gradient quadrupoles. For discussions of the applicability of superconducting quadrupoles, we are grateful to Ron Fast and Bruce Strauss. Much of the Monte-Carlo routine was written by Joe Lach. A subroutine written by Dave Carey

was used to trace rays through the quadrupoles. The author is grateful to Arthur Roberts for initiating interest in the quad beam design and for many valuable discussions.

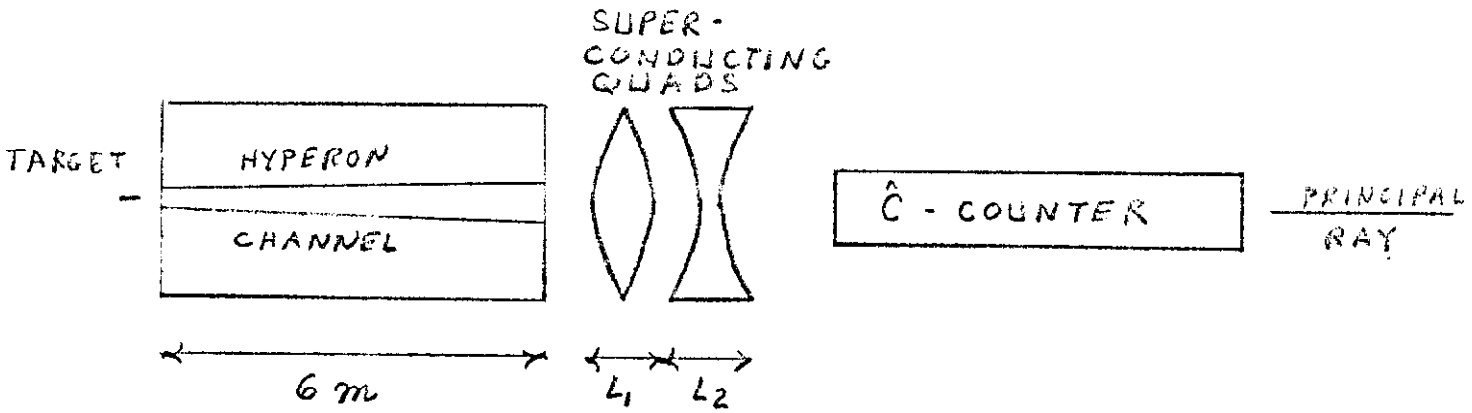
References

[1]See, e.g. Arthur Roberts, NAL Report FN-234.

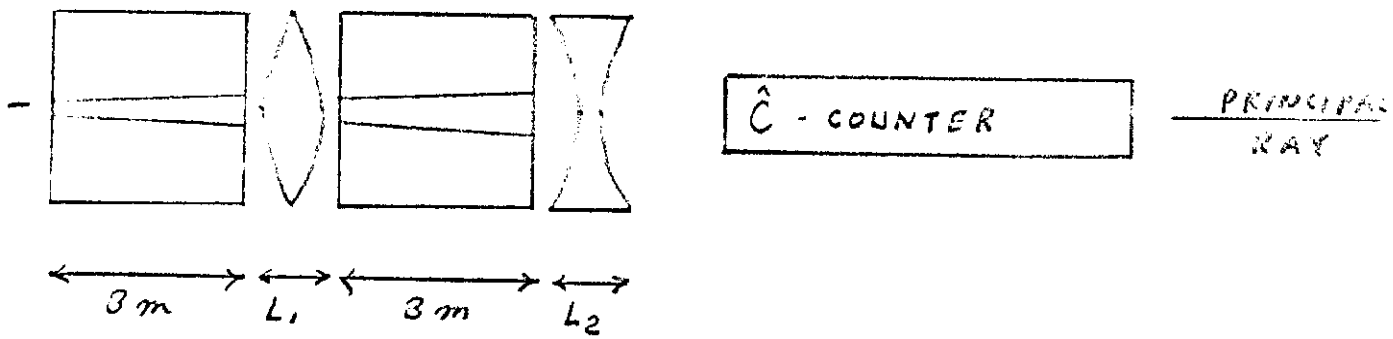
[2]The magnet design was done by R. March.

SETUP #1 ⚬

TABLE I



SETUP #2 ⚬



FOR POINT TO PARALLEL FOCUSING AT 150 GeV/c

SETUP	FIELD GRADIENT	L_1	L_2
	KG/cm	m	m
#1	10	2.0	1.6
#1	20	1.2	1.1
#2	10	2.0	0.9
#2	20	1.1	0.5

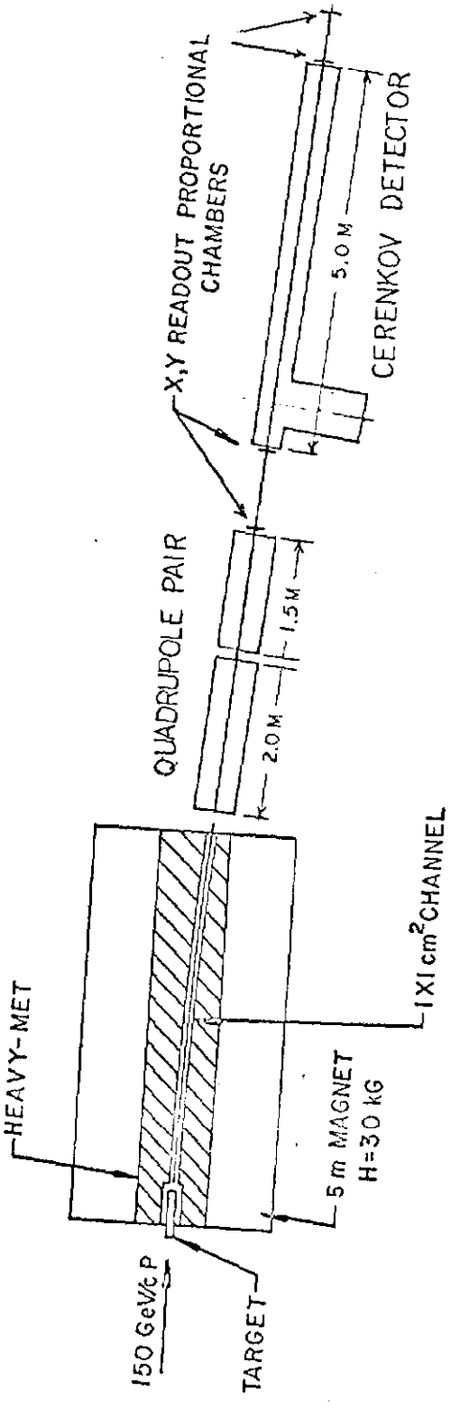

X,Y READOUT PROPORTIONAL CHAMBERS
5.0 M
CERENKOV DETECTOR
QUADRUPOLE PAIR
1.5 M
2.0 M
1 X 1 cm² CHANNEL
HEAVY-MET
5 m MAGNET
H=30 kG
150 GeV/c P
TARGET

Fig. 1

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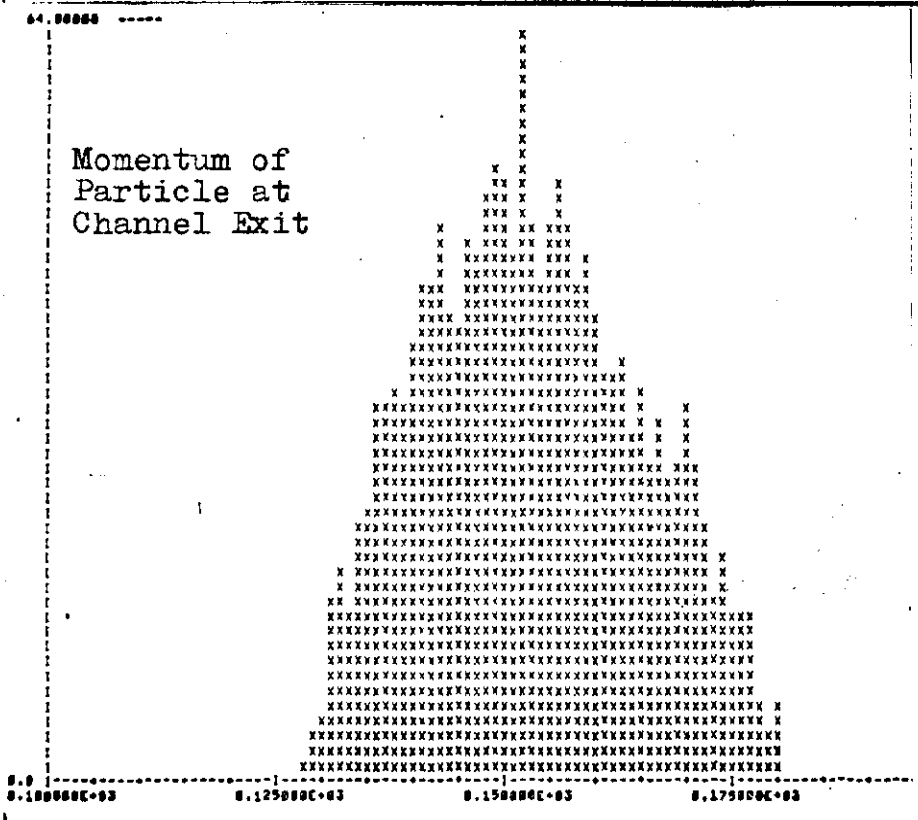
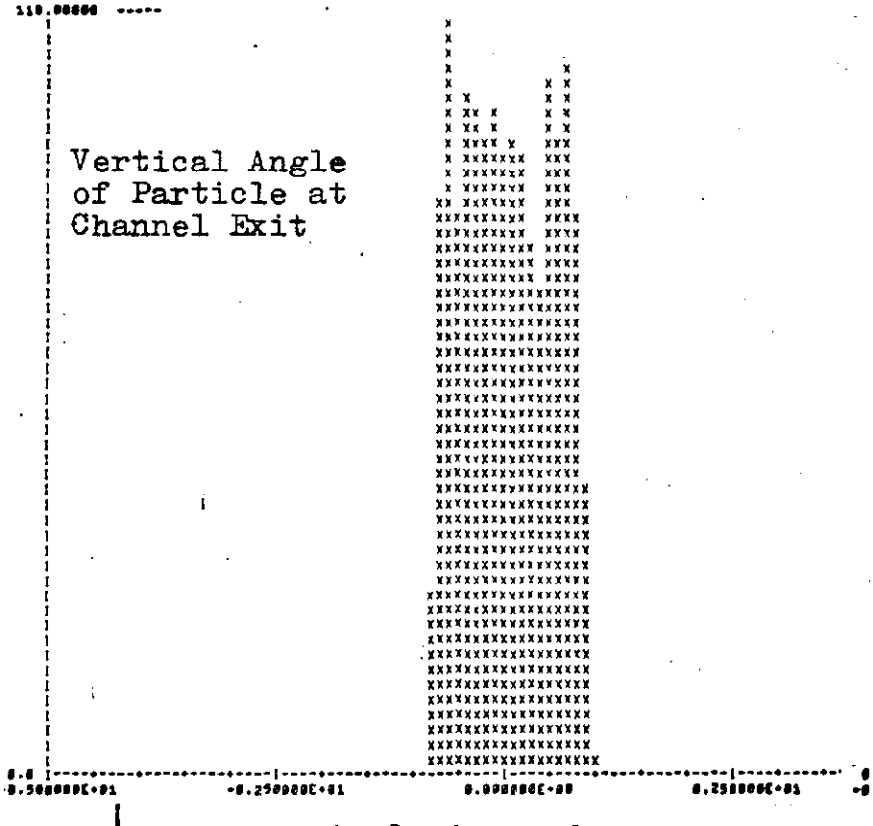
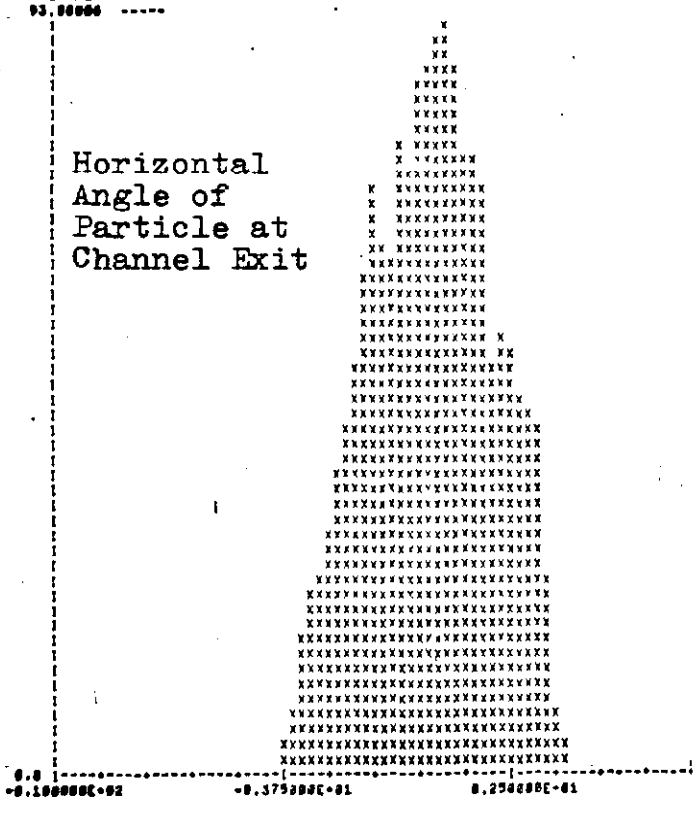


Channel Parameters

Width-Entrance	0.3 cm.
Width-Exit	1.0 cm.
Height	1.0 cm.
Radius	166.7 m.
Field	30.0 kgauss
Principal Ray	150.0 Gev/c
Target Size	1.mm x 1.mm

FIG. 2





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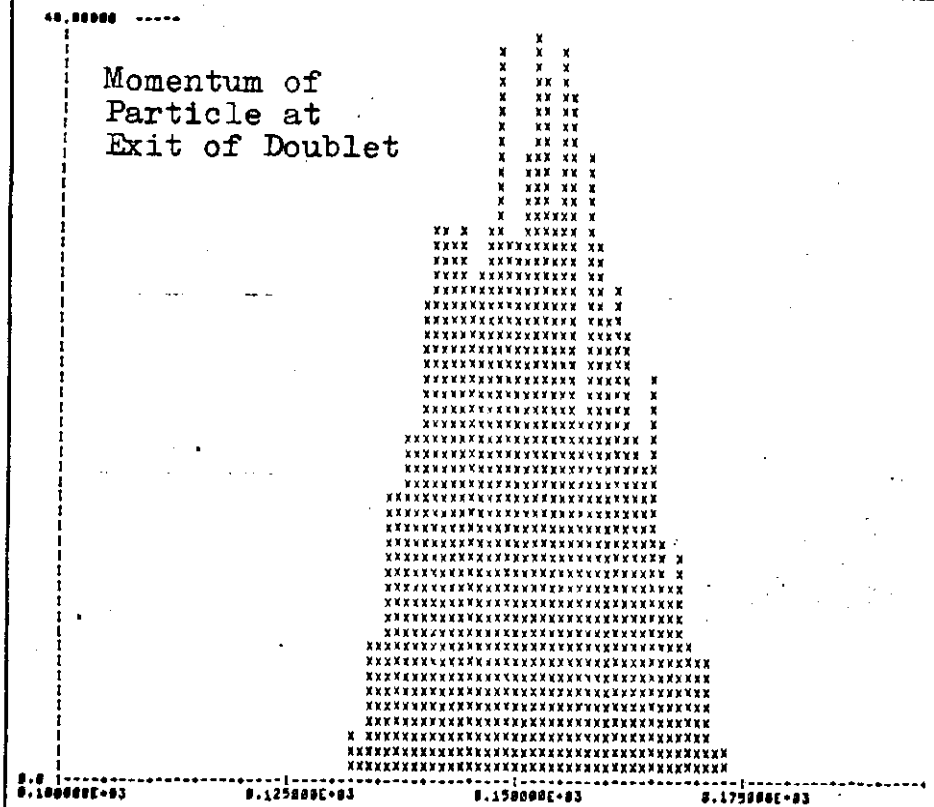
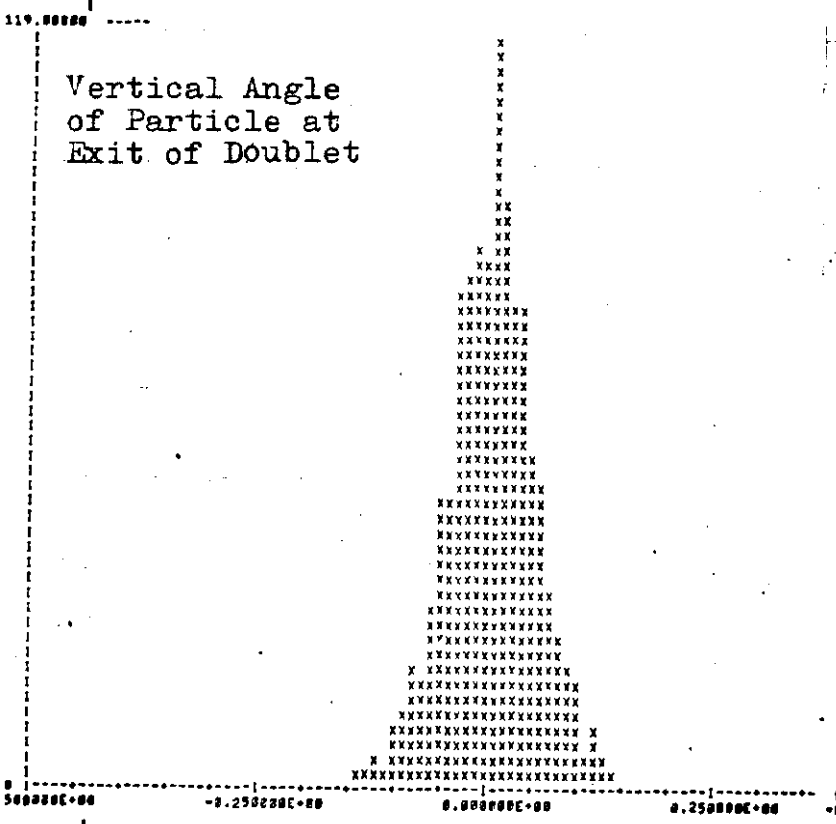
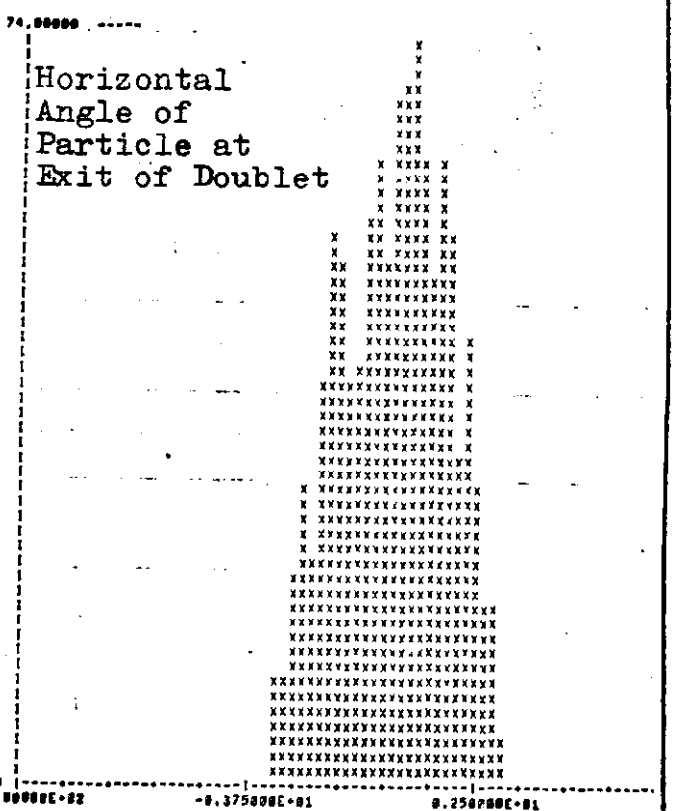


Quadrupole Parameters

Gradient	10.0 kg/cm
Aperture	2.0 cm.
Length 1st	2.028 m.
2nd	1.590 m.

FIG. 3





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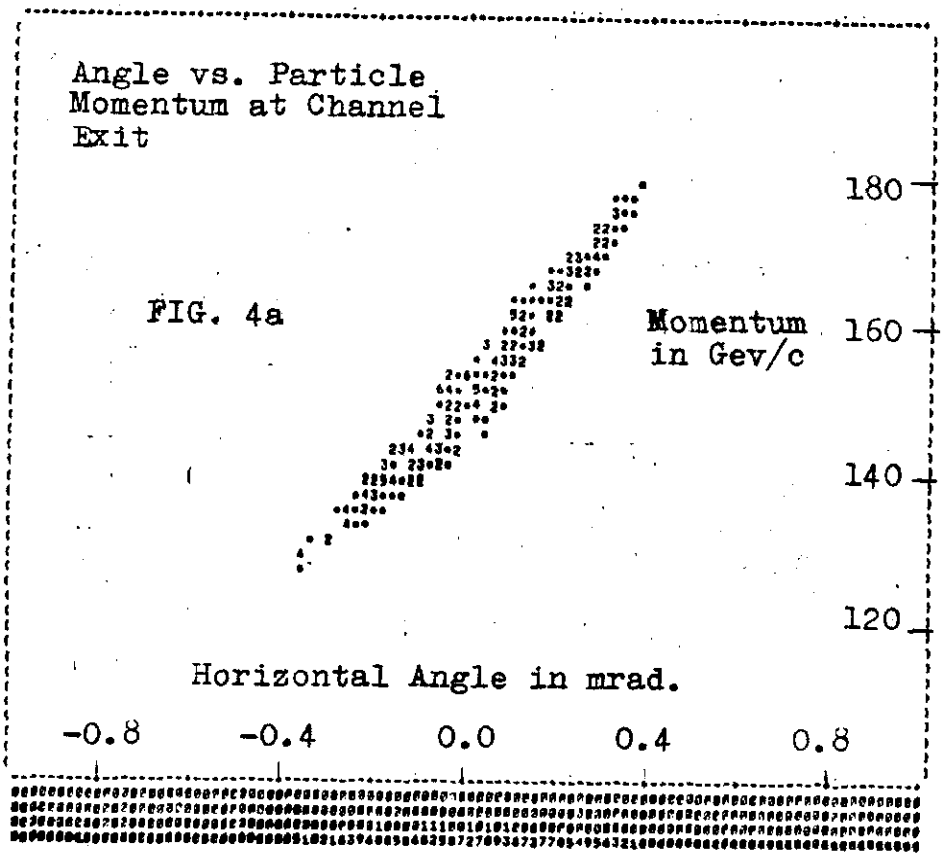

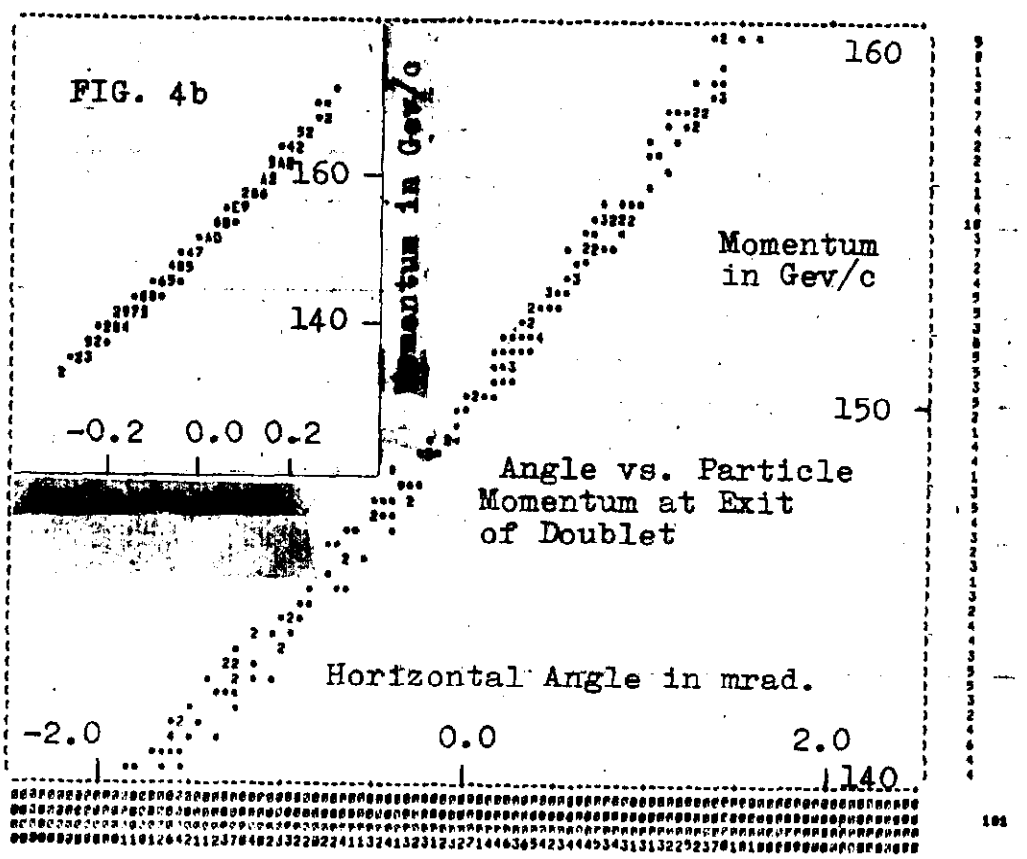

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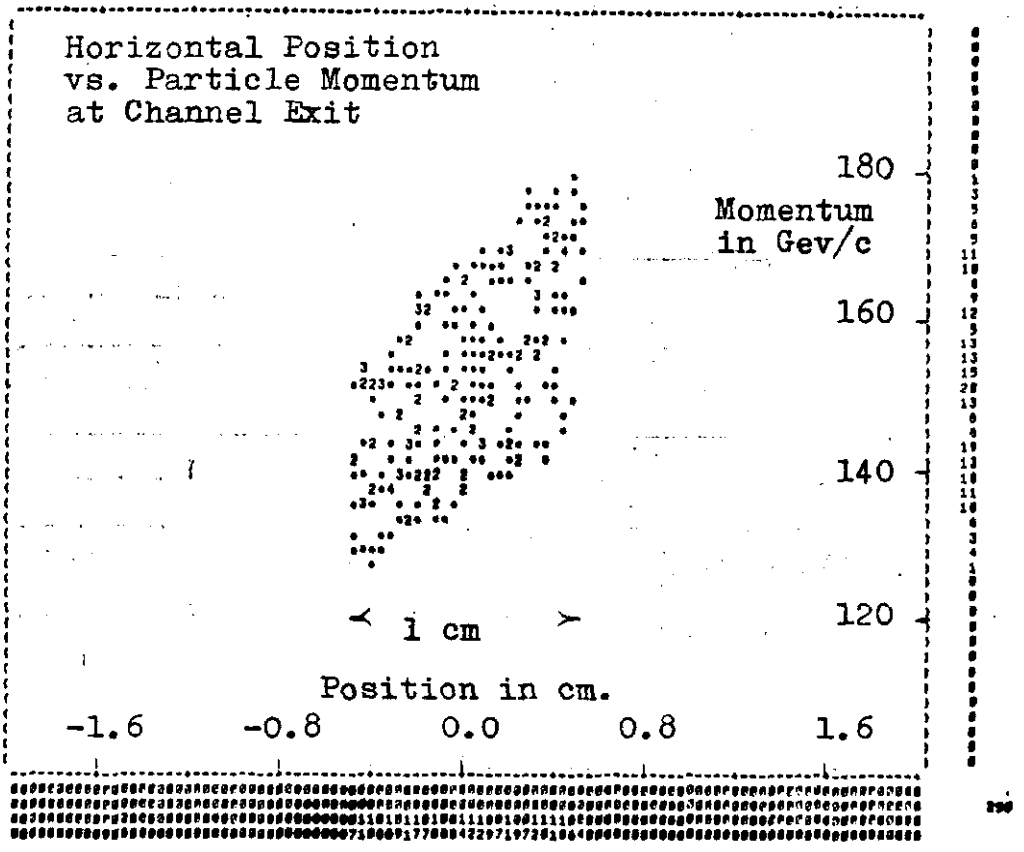

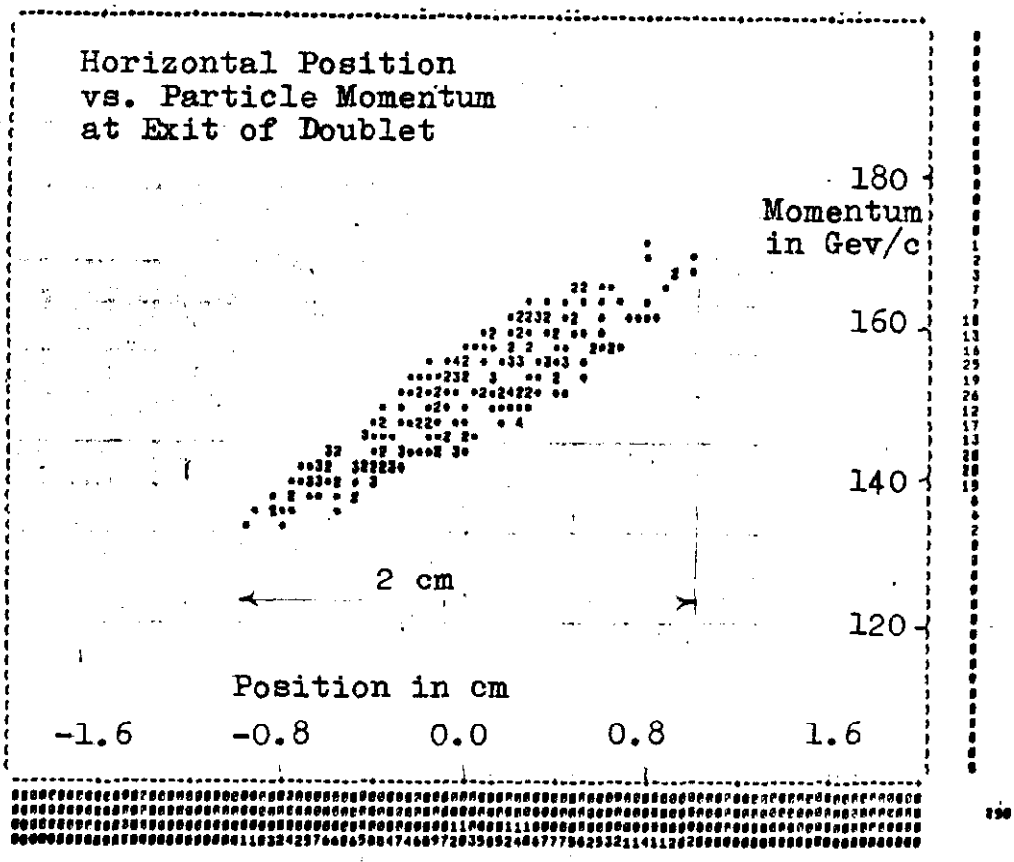

FIG. 5

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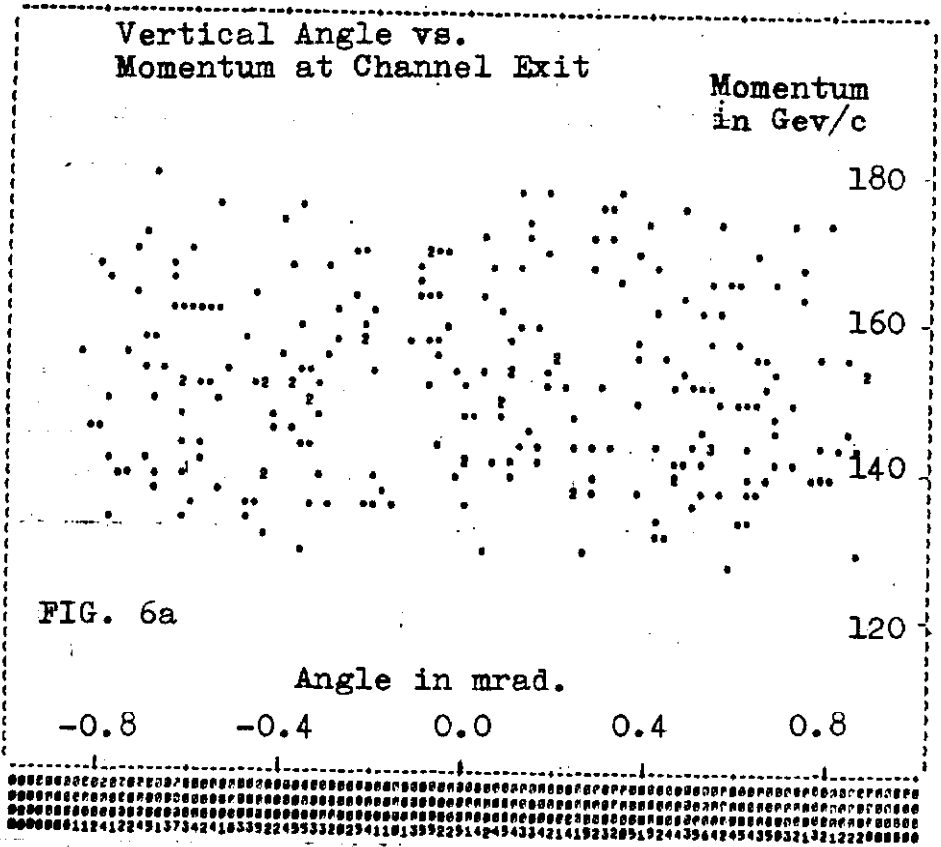

FIG. 6a

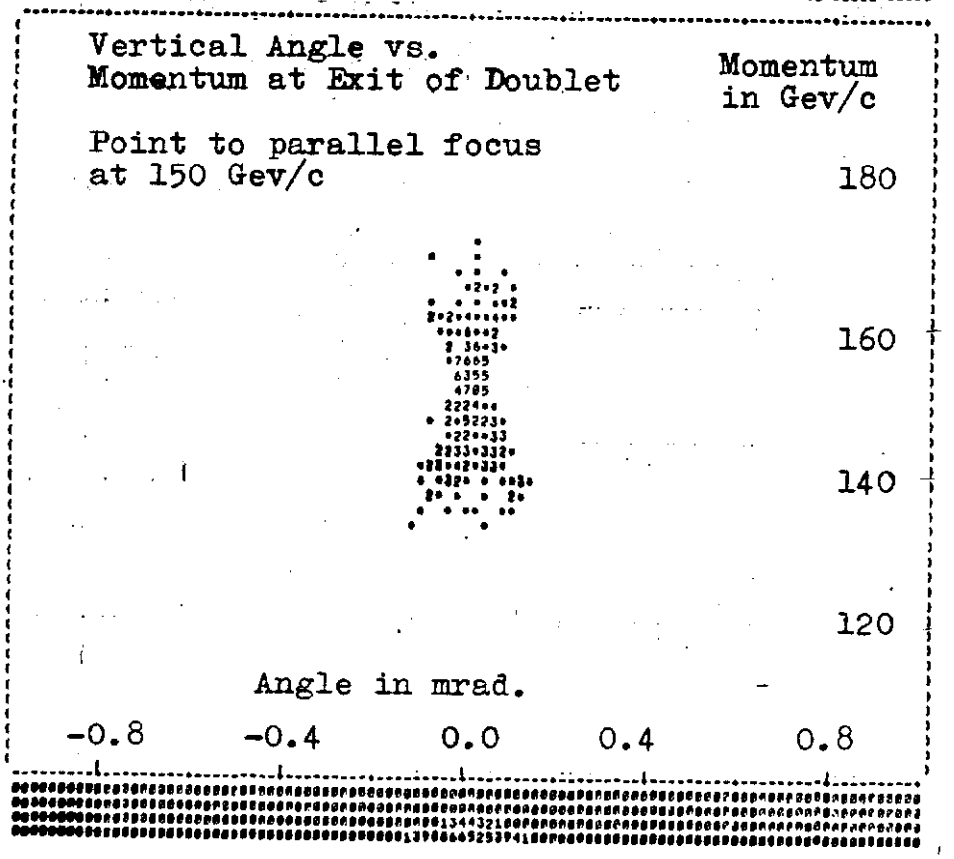

FIG.6

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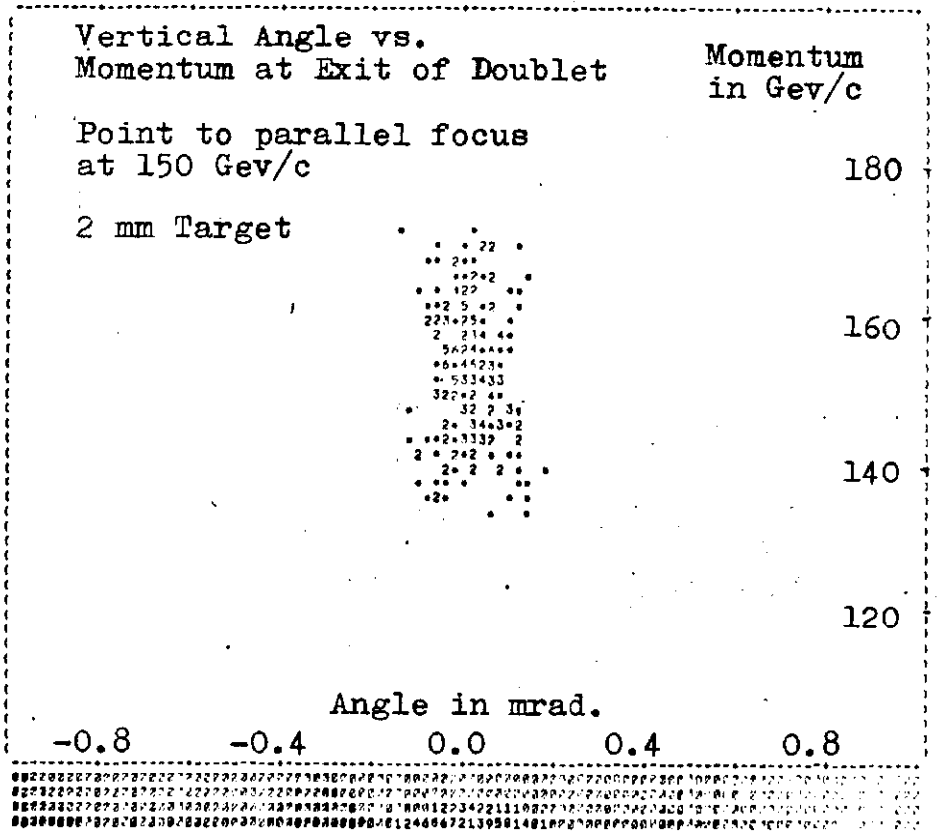

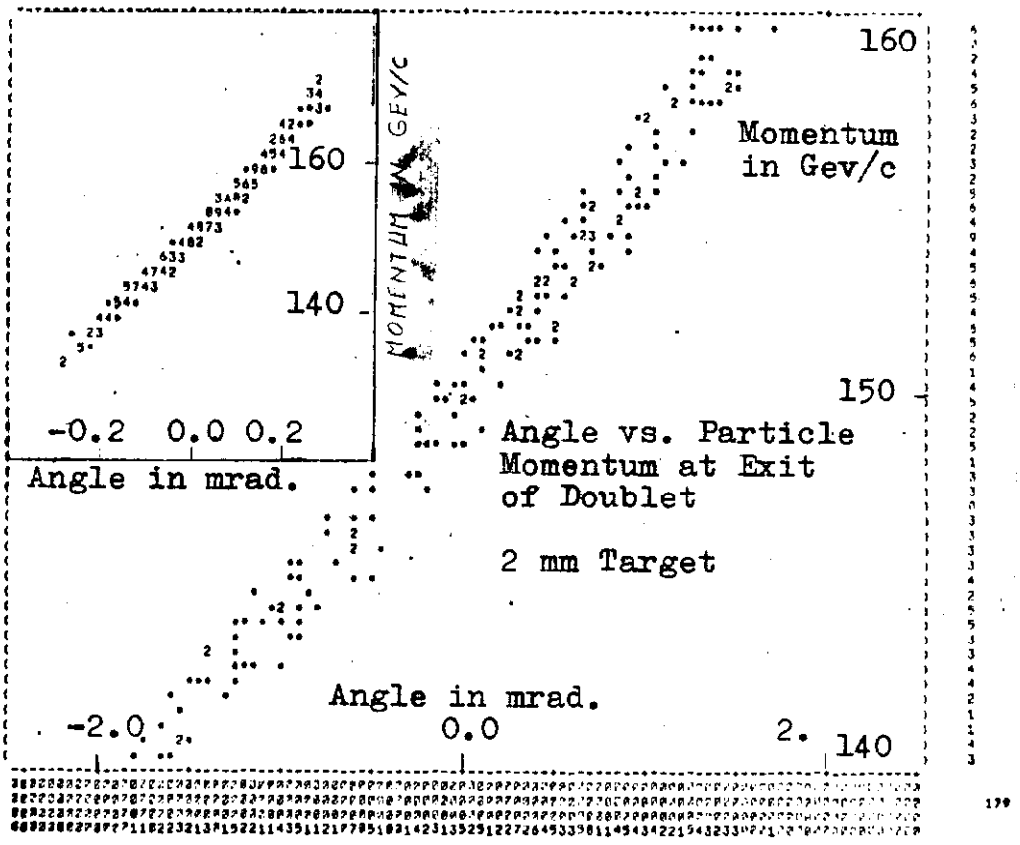

FIG.7