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Introduction

Several recent proposals have involved the use of a very high flux separated K (or $\bar{p}$) beam at the AGS in the momentum range ~ 800 MeV/c. It is proposed that such a beam be constructed as a secondary beam from the first target in the slow external proton beam to be used simultaneously with a 0° pion beam and possibly also with a high momentum, ~ 5 BeV/c, separated K beam. Use of the external proton beam offers certain advantages: the target is relatively accessible, the beam can be fairly short; a major disadvantage is that, compared to internal AGS targets, the target in the external beam must be longer, and the images in the separated beam are, therefore, poorer. The purpose of this paper is to examine the possibility of construction of a secondary beam of this type, and to give the detailed design of a specific example.

Target and Production Angle

The separation of particles requires a source which is small in height; the width should also be fairly small so that a good correction can be made for chromatic aberration at the vertical focus at the mass slit since this correction depends on having a clean dispersed image at the first horizontal focus. Using the horizontal and vertical emittances given by Barton and Faure[1] for the external proton beam, it should be possible with the use of the special 3Q36 quadrupoles that are being built for transport of this beam to get a focus at the production target on the order of $\pm$ .010", and the target can be possibly twice this size in cross section which will still be a cross section comparable to internal targets in the AGS. The difficulty in getting a good source arises from the length of the target; since the protons in the external beam can only pass through the target once, the target has to be long enough so that they will have a reasonable chance of interacting in a single traversal. For a secondary beam the apparent horizontal source size is $\ell \sin \theta$ where θ is the production angle and ℓ is the length of the target. To keep the source small, ℓ and θ should be made as small as possible. Various schemes were considered whereby a production angle of 0° could be taken for the 800 MeV/c beam with the higher energy particles for other beams bent back to the center-line; however, it seems difficult to avoid interactions between the three beams using this target particularly if the other beams are to be varied over a wide range of momenta. Therefore, a finite θ appears to be necessary. An advantage of taking a finite production angle for the 800 MeV/c beam is that the yield of Ks will probably be greater at some finite angle than at 0°. For example some measurements at Argonne [2] have shown that for 12.5 BeV/c incident protons on a thick target the yield of 750 MeV/c Ks is greatest at about $\theta = 7.5^{\circ}$, giving about 2 ½ times more flux than at 0°.

The length of the target is dictated by the requirement that it produce maximum secondaries for the 0° pion beam. It can be shown on the basis of a simple theory that the maximum yield of high energy secondaries results from a target of one nuclear interaction length [3]. A target of low Z material would be desirable in order to minimize Coulomb scattering of non-interacting protons, but the density of low Z materials requires that a one interaction length target be fairly long e.g., 29.9 cm in the case of beryllium and this is not acceptable from the point of view of horizontal source size. Therefore, it is proposed that the target be constructed of the highest density material available, for instance iridium, in which case the target length is 6.8 cm. This will give about five times greater rms Coulomb scattering than the beryllium, but since it is not planned to refocus the non-interacting protons in the immediate future, the increase in phase space of non-interacting protons is acceptable. From the point of view of background in the 0^o pion beam, a more important consideration than Coulomb scattering of non-interacting protons is diffraction scattering[4] for which the beryllium target has no advantage over iridium.

Design of the 800 MeV/c Beam

The proposed layout of the 800 MeV/c beam is shown in Figure 1. A ray trace of certain horizontal and vertical rays is shown in Figure 2. Some features of the design are the following:

The central production angle is chosen as 10.5^o: Since the horizontal acceptance is $\pm$ 75 mrad, the limiting rays in the horizontal plane are 6.2^o and 14.8^o. This range includes the maximum of the production spectrum[2]. In order to get a small production angle, and, at the same time, to get as close as possible with the first quadrupoles, a special septum magnet is used with the following dimensions; length 20", height 2", and width 12". A drawing of the front end of the beam is shown in Figure 3. The septum is far enough away from the centerline of the external proton beam so that it will clear the non-interacting protons by the width due to phase space, plus 3 standard deviations Coulomb scattering.

The optical design of the front end of this beam is a quadrupole triplet, one of the elements of the triplet being behind the trailing edge of magnet D2. The polarity of the first two quadrupoles must be such that the horizontal acceptance angle is larger than the vertical acceptance angle in order to minimize optical aberrations in the vertical image at the mass slit. Therefore, the polarity of the first quadrupole, Q1, is horizontally focussing, and the horizontal aperture is determined by what gets through Q1. But this arrangement is inefficient because it results in a very wide beam in the vertical plane; rays that get through Q1 and Q2 will be intercepted by the plates of the separator, which has a four-inch gap in this design. Q3 is a vertically defocussing quadrupole; Q1 and Q2 are adjusted so that, together with Q3, they make the vertical rays parallel inside the separator; thus, these rays are converging inside D2, and they are brought in to give a narrower beam in the vertical plane which will clear the separator plates. The result is illustrated by the vertical ray trace of Figure 2. The horizontal and vertical acceptance of the beam are determined by a variable collimator behind Q2. This is sufficiently far downstream from production target so that it is not imaged at the mass slit.

The effect of horizontal target size is minimized by having a large amount of dispersion and a small horizontal magnification. Two magnets, D1 and D2 are used to bend the beam through a total angle of 41.2°, giving a relatively large dispersion. This design also has the feature that the elements downstream of D2 are accessible from outside the external beam tunnel since the beam is bent away from the proton beam and through the shielding wall. Magnets Q4 and Q5 are operated so that Q5 is horizontally focussing; this makes the horizontal image relatively small. The vertical rays are parallel in the separator. The horizontal rays are converging in the separator in order to get off-momentum rays through Q4 and Q5.

The horizontal and vertical rays are focussed at the same point, the mass slit, and accommodation for chromatic aberration of the vertical image is accomplished by a tilted mass slit, shown in Figure 4. Use of a sextupole to correct for chromatic aberration was considered; however, the scheme adopted here has the following advantages: 1) The beam is shorter by about 50" than a beam incorporating a sextupole. 2) The horizontal magnification is smaller at the momentum focus which makes recombination of momentum easier at the second focus. 3) The aperture required downstream of the mass slit is smaller than in a beam with a sextupole, and it is possible to use only 8" diameter quadrupoles in the rest of the beam, while 12" quadrupoles would be needed with the sextupole design. 4) Since both the horizontal and vertical rays are focussed at the same point, the mass slit, there exists the possibility of putting a counter at this point without excessive increase in the phase space of the rest of the beam.

The design of the rest of the beam after the mass slit depends on the experiment being done with it. The layout shown is designed to give reasonably small horizontal and vertical images with the minimum length from the mass slit to the second focus. Magnet D3 an 18D36 provides a second momentum selection after the mass slit in order to clean up the beam. D3 also provides partial momentum recombination. Complete recombination would require another bending magnet and additional beam length; this possibility is not considered here since reasonably good images can be obtained without recombination. The trailing edge of D3 is raked so as to give horizontal focussing; this is necessary because of the off-momentum rays, which would otherwise fall outside the aperture of magnets Q6 and Q7. In the design shown Q6 is horizontally defocussing and Q7 horizontally focussing; this design gives the smallest horizontal image. For an experiment in which stopping Ks are desired, Q6 and Q7 could be reversed in polarity; the horizontal image would then be fairly large but would have a clean dispersion so that a wedge-shaped degrader could be placed in front of the target to equalize momentum and make all particles stop at the same depth in the stopping target. Another alternative: for the largest possible K intensity, some experimenters might want to use the mass slit as a target in order to get the shortest possible beam.

Expected Yield and Purity

The solid angle acceptance, momentum acceptance and length of this beam are 5.2 mstr., $\pm$ 2% and 529 inches respectively. No data presently exists on the yield of 800 MeV/c Ks obtained from 30 BeV protons incident on a thick target. A solid estimate of yield is, therefore, not possible. Some data from ANL[5] indicates a yield of 2.64×10^4 K^+ at 0^o production angle from 10^{11} protons incident on a .85 nuclear interaction length Cu target into an acceptance angle of one mstr. and a momentum acceptance of $\pm$ 1%. Assuming the same yield of 10.5^o from 30 BeV/c protons, this beam would give 2.5×10^5 K^+ at the second focus for 10^{12} protons incident on the target. Possibly half as many K^- would be obtained. This figure for the expected yield takes into account losses due to particles striking the mass slit and other apertures of the beam. These losses are estimated from a Monte Carlo calculation. This calculation also yields the momentum acceptance of the beam, which is shown in Figure 5.

Figure 6 is a histogram showing the expected vertical image cross section at the mass slit together with the displaced image of the pions. The separator is assumed to be operating with 500 kV across a four-inch gap. On the basis of optics alone, we could say that a mass slit 0.120" high would exclude 98% of the pions and reject only 10% of the Ks. Actual purity will be lower due to slit scattering, decay in flight, Coulomb scattering from windows, etc. The separation appears to be comparable to the separation obtained in other beams operating at the AGS. One factor that would tend to reduce contamination in this beam is the very sharp bends in magnets D1 and D2. Because of these bends, the separator is looking at a section of the proton beam far removed from the target, and very little junk of the wrong momentum should reach the mass slit.

Extension to Higher Momentum

The K to π separation would deteriorate rapidly above 800 MeV/c, but the magnets could be driven harder to give a separated $\bar{p}$ beam up to about 1.1 BeV/c. The limiting factor would be magnets D1 and D2. The beam could be laid out with smaller bends in magnets D1 and D2 so that higher momentum could more easily be achieved, but this would result in less good images in the mass slit. The design adopted here is primarily intended to give the best possible separation at 800 MeV/c.

Modifications to Use Existing Magnets

The beam design above uses six 8Q12 quadrupoles and a special 1" septum magnet, none of which are available at the present time. It would be possible to build a beam using existing magnets which would give good particle separation, but which could be longer and have less solid angle acceptance. A possible design would use a 15C30 as a septum, a production angle of 12° and use Cosmotron 8Q16 magnets in place of the 8Q12s. This beam would give about 40% of the yield of the present best design. The lower yield results mainly from the fact that the first quadrupole has to be 80", instead of 48" in the best design, from the target resulting is a small solid angle acceptance. With the special septum and one N8Q12 the rest of the beam could be built with 8Q16 magnets with very little loss in yield; however, the 8Q16s would be driven close to their maximum gradient at 800 MeV/c and there would be little leeway for pushing the momentum higher.

Acknowledgements

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JDF/pam

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FIGURE 1 LAYOUT OF 800 Mev/c Beam

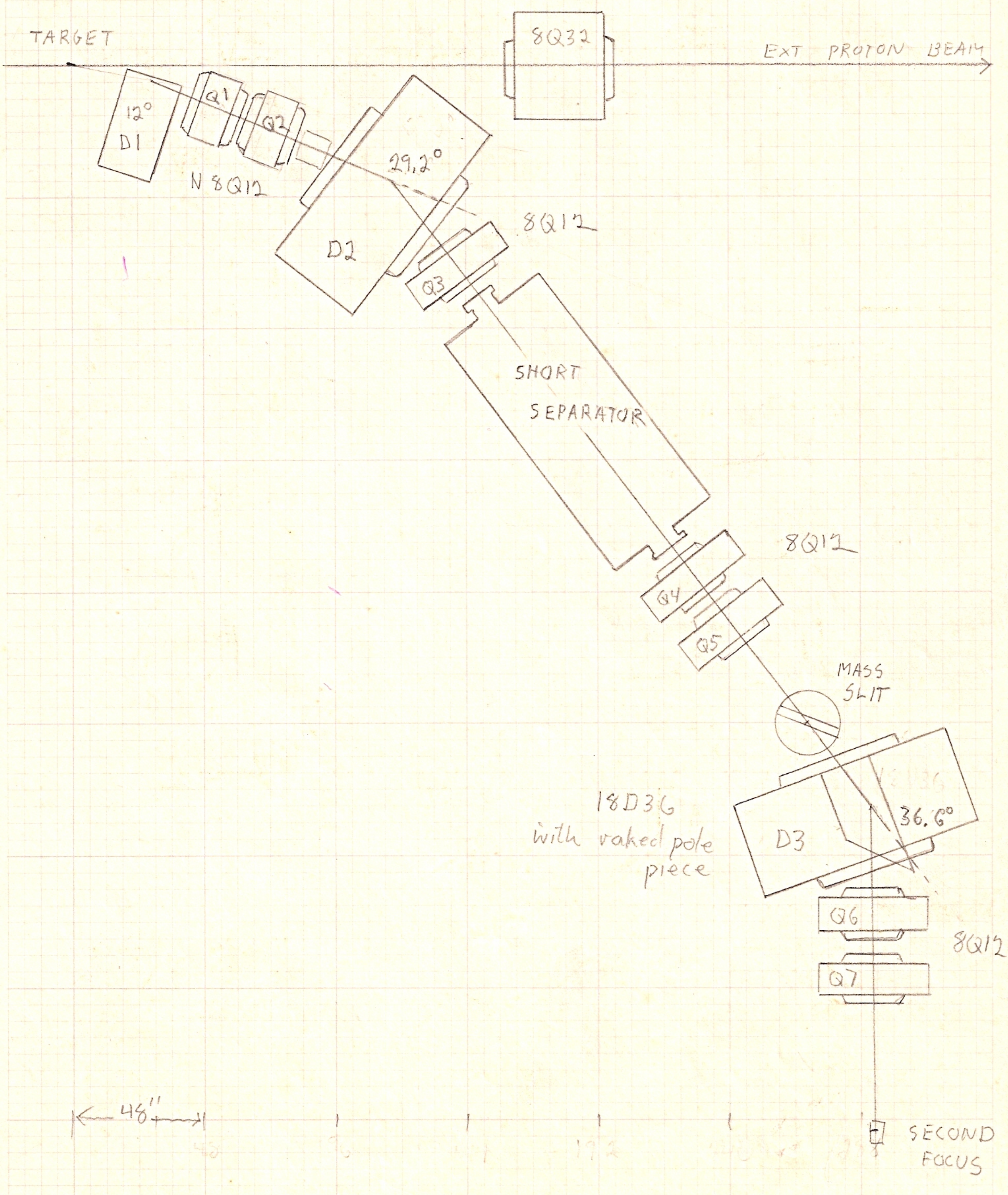
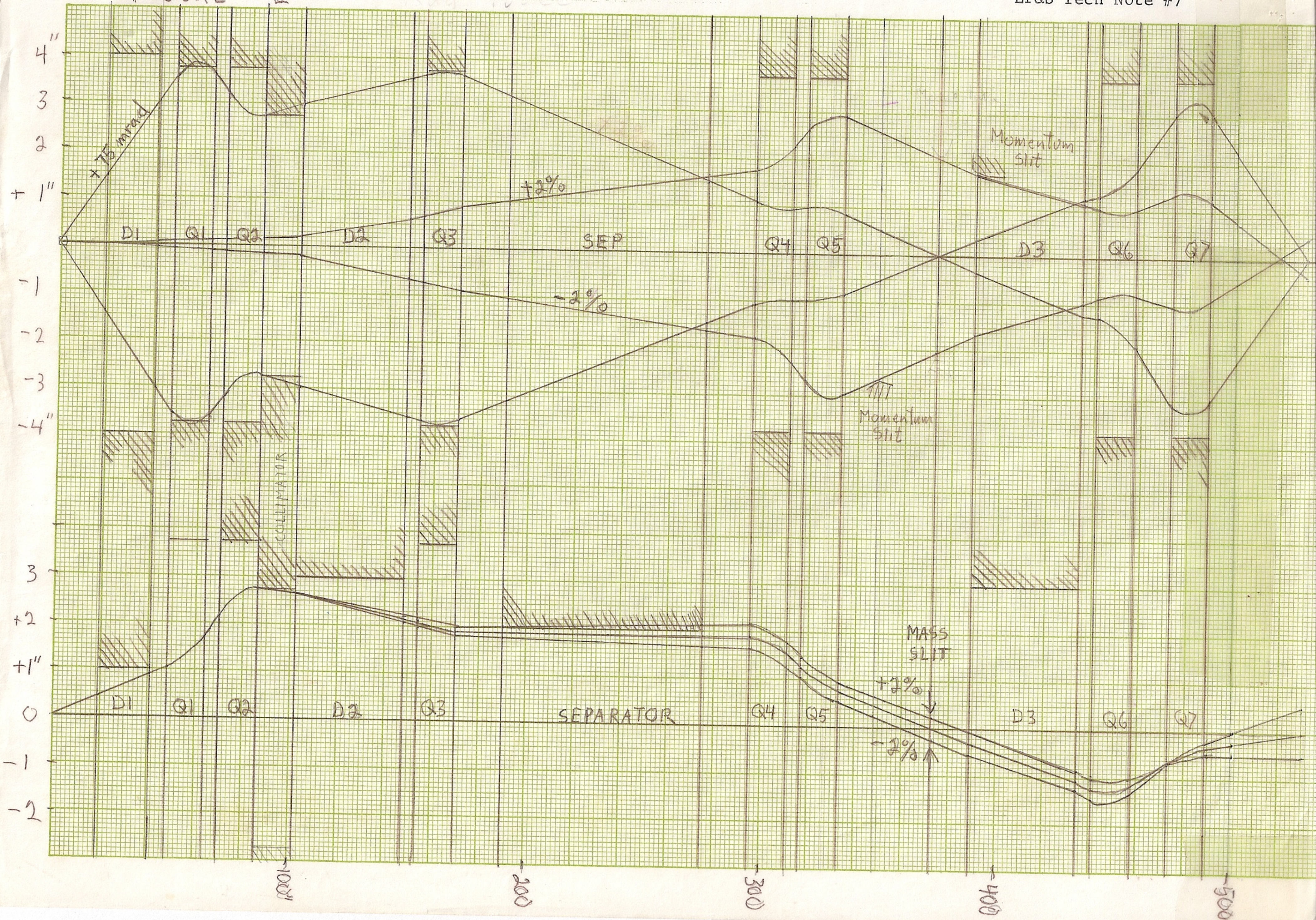


FIGURE 2



4"
3
2
+ 1"
-1
-2
-3
-4"
+ 75 mrad
D1
Q1
Q2
D2
Q3
SEP
+2%
-2%
Q4
Q5
D3
Q6
Q7
Momentum Slit
Momentum Slit
COLLIMATOR
3
+2
+1"
0
-1
-2
SEPARATOR
MASS SLIT
+2%
-2%
100"
200
300
400
500

FIGURE 3

800 MeV/c BEAM

LAYOUT OF FRONT END

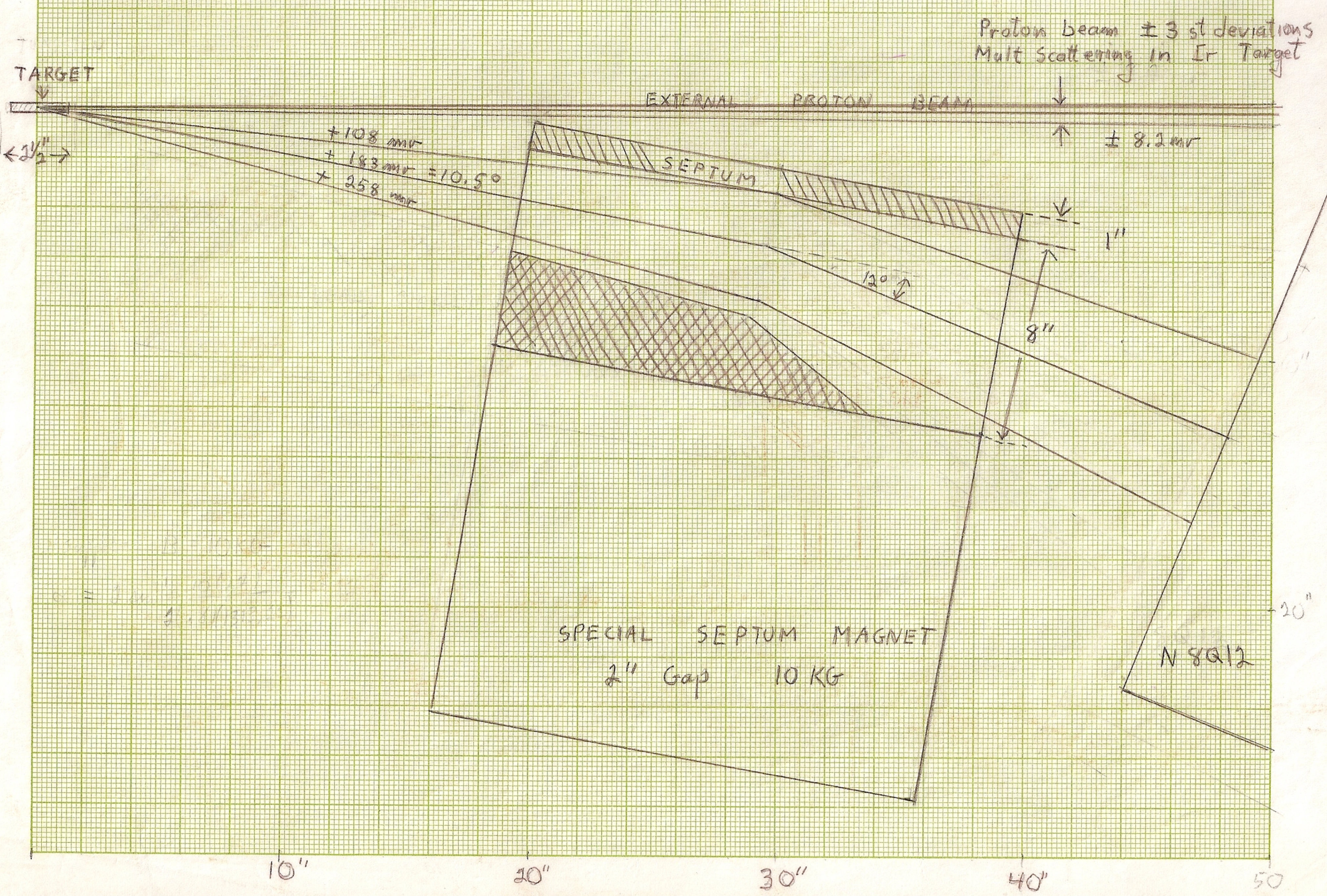


FIGURE 4 MASS AND MOMENTUM SLIT

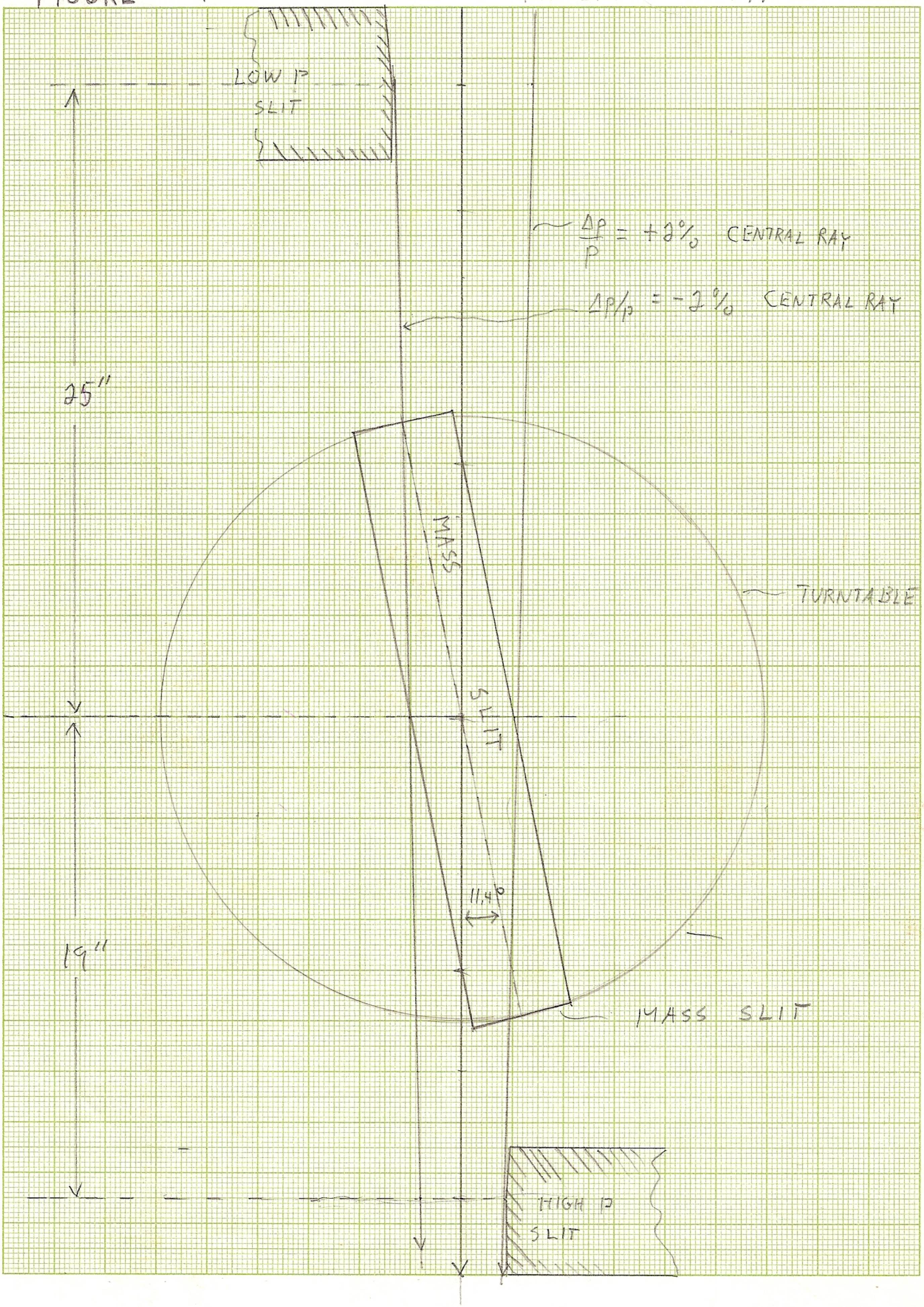


FIGURE 5 MOMENTUM SPECTRUM OF TRANSMITTED PARTICLES

2000 Initial rays $\Delta x' = \pm$ 75 mrad

$\Delta y' = \pm$ 22 mrad

$\Delta p/p = \pm$ 2.5%

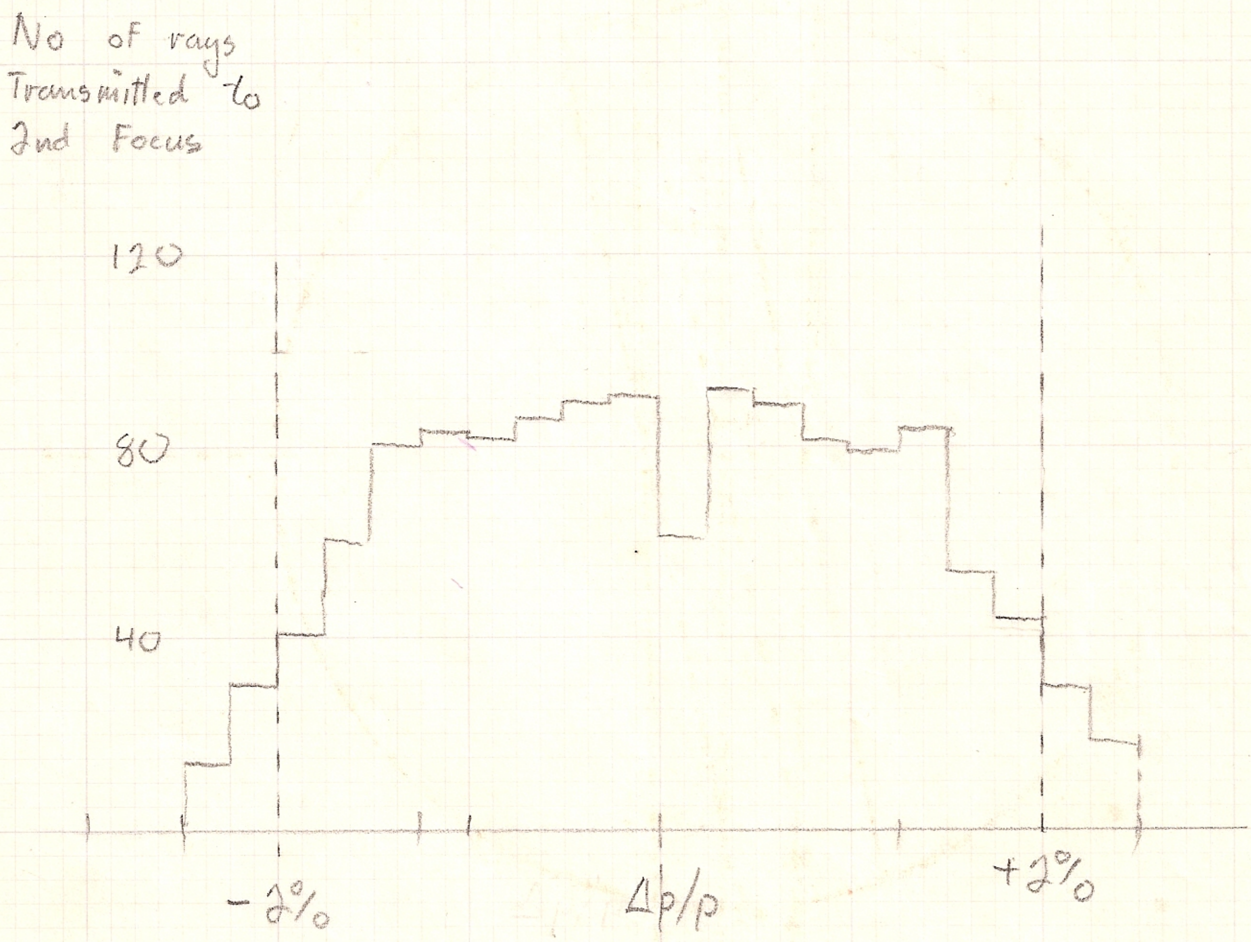


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FIGURE 6

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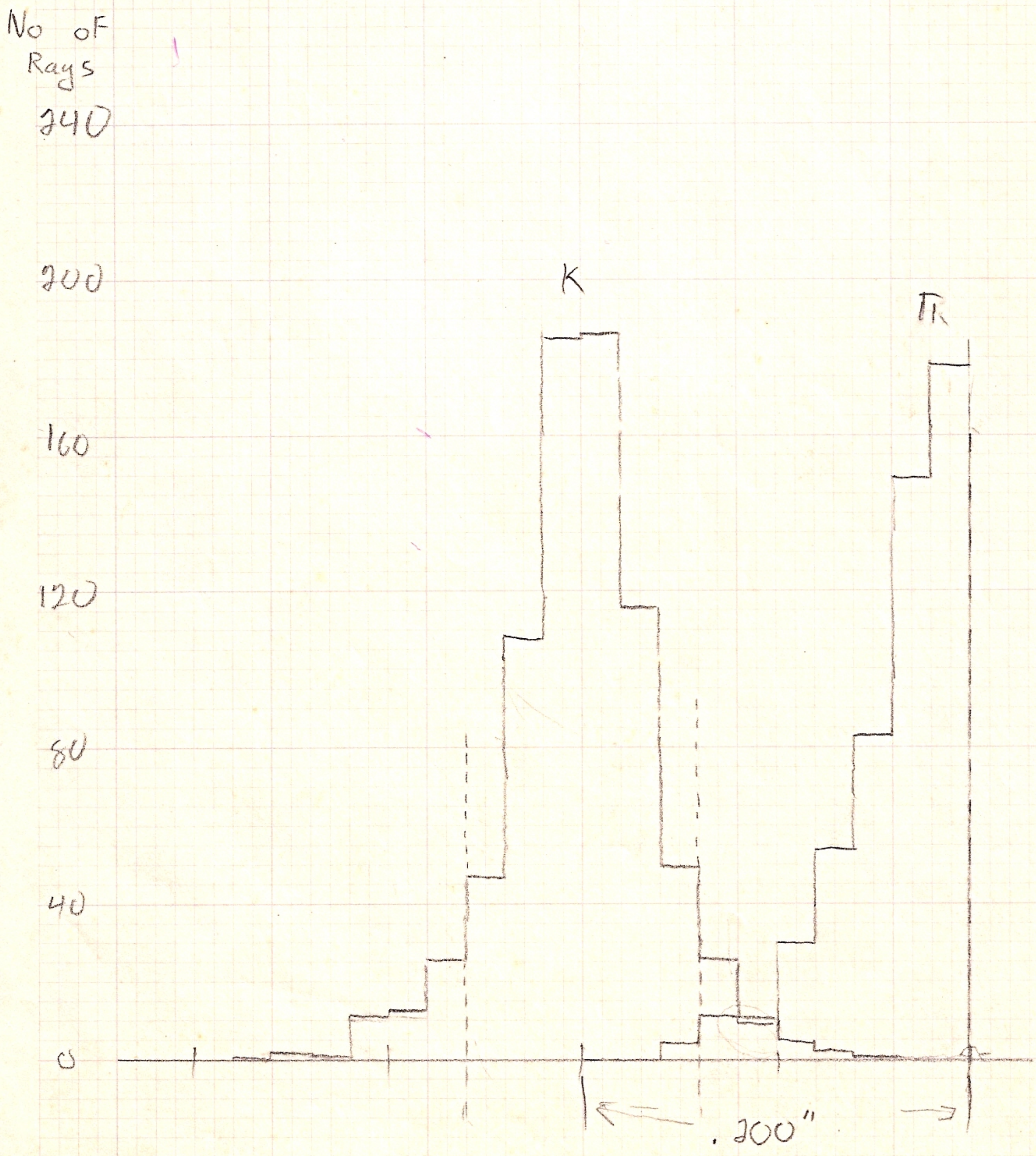
HISTOGRAM OF Y POSITION AT MASS SLIT

EQUAL POPULATIONS OF π AND K



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