Beam Defining Slits and Focusing Grids Near the Ion Source

W. I. B. Smith

At ANU we have attempted to improve beam quality by getting a large beam from the ion source and then stopping most of this beam at slits near the ion source, in an attempt to accelerate only that beam which we may expect to extract. This work was done together with Dr. A. H. Morton with the assistance of Mr. R. W. Parkes.

Figure 172 demonstrates very elementary theory. We have a uniform field in front of the ion source for a little over a centimeter and then the beam coasts freely until the next dee crossing where the ions undergo impulsive acceleration. We have limited the extent of the r-f field in this region by making the dee gap smaller. Simple theory shows that if the r-f electric field is always perpendicular to the dee edge, then the centers of rotation are always on the center line between the dees. AB and DE are the lines of the orbit centers of the beam on the first and second half-turns. The figures 0°, 30°, 60°, and 90° on the orbits and on the lines of orbit centers refer to the starting phases of the ions from the ion source, 0° corresponds to zero dee voltage, and 90° to peak dee voltage.

If the whole acceleration occurs in a completely uniform field, this line of centers runs straight from 0° to 90°. If the accelerating field is very concentrated near the ion source, there is a folding of the line of orbit centers from 0° to 90° and then back to 180°. The figure shows an intermediate case, a good bunching of orbit centers for ions that leave the ion source between 30° and 60° of phase.

In our setup (Fig. 173), there is essentially no phase bunching. However, one gets good energy bunching on the first half-turn and the second half-turn. In the plot of the distance of the orbit center from the ion source against the starting phase, one has good bunching of the orbit centers.

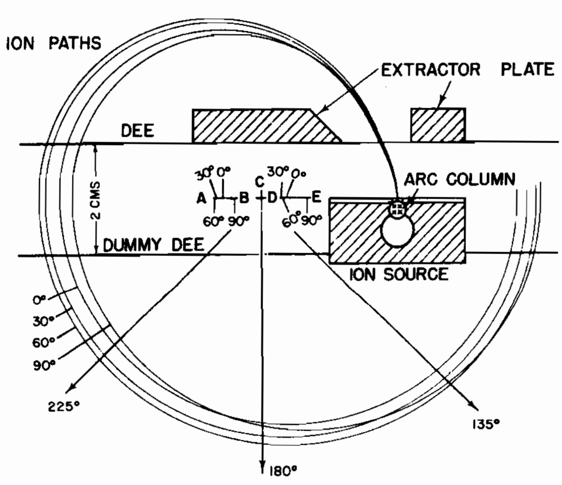

Fig. 172. Calculated orbits near ion source.

Figure 174 is a plot of the calculated beam density in radius taken on the second half-turn; there is very good bunching of the beam. The beam is essentially bunched over about 2 mm of radius.

Figure 175 shows the measured bunching along the three azimuth angles, over a 45° range in the dummy-dee half of the machine. The radius of the beam is about 2 in.; I am sorry, we have changed our centimeters to inches. On the first turn the beam is confined radially to about 0.3 in. on all azimuth angles; this confirms that the dee centers are bunched and that the energy of the beam is also bunched.

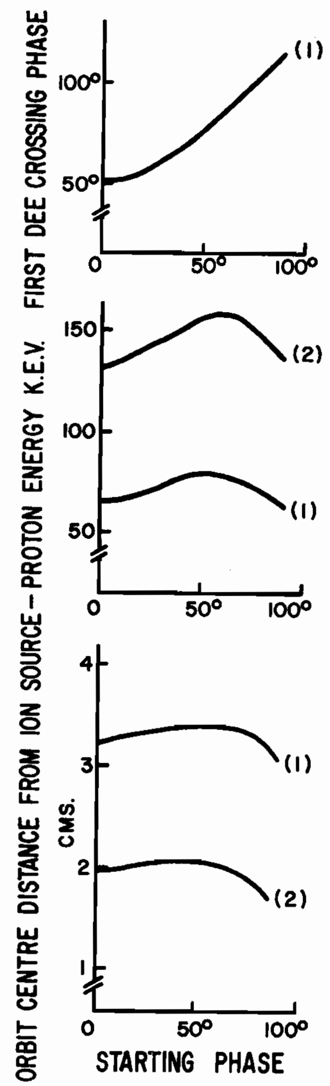

Fig. 173. Phase, energy, and orbit center bunching.

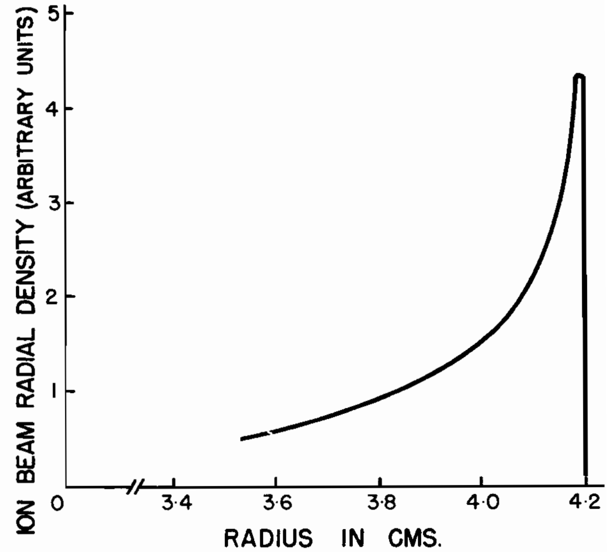

Fig. 174. Calculated radial beam distribution on first turn.

Figure 176 is a photograph of the beam-defining slit system we used in the machine showing the ion source, the dee, and the dummy dee. The slit on the first turn is 1 mm wide and can be moved radially. We have two 0.5-mm slits that we can place on the second and third turns. To measure the positions of the orbits we have a total of four targets placed at 45° azimuth intervals; only one is shown. We can move these targets radially and determine three points on the orbit. The slide shows a piece of copper placed in the dee to determine a point on the orbit inside the dee; it did not last very long.

Notice we have a very standard extraction system, a 0.0075-in. tungsten

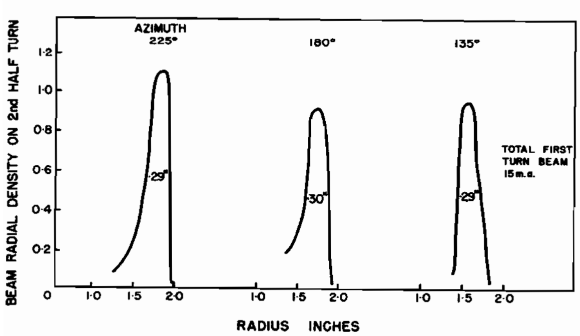

Fig. 175. Measured radial beam distribution on first turn.

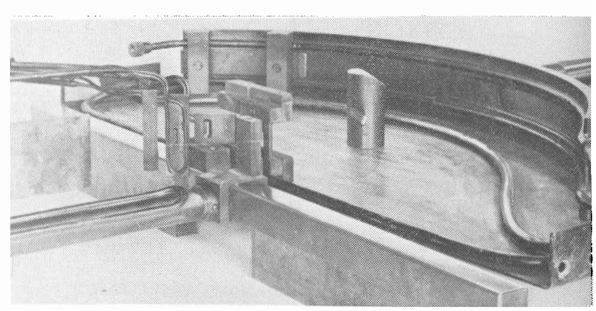

Fig. 176. Beam defining slits on first three turns.

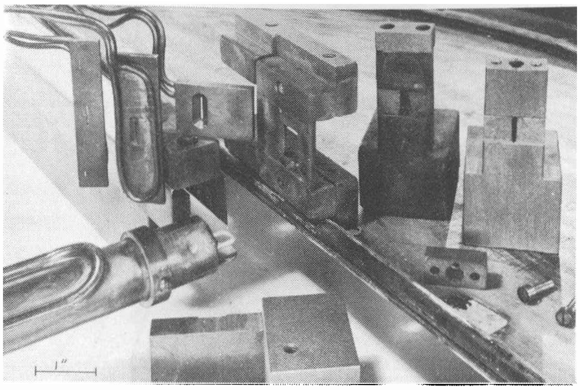

Fig. 177. Ion source hoods and beam defining slits on first three turns.

splitter 1 in. high and a copper deflector plate held at 70 kv; the deflected beam channel is initially 7 mm wide, widening out to 14 millimeters.

A closeup view of these beam defining slits is shown in Fig. 177. This also shows an old ion source hood which has become eroded and the new ion source hood, not yet used. You will notice the hood is eroded near the bottom of the ion source slit, where most of our beam comes from. The slit is 1 cm high; I agree with the Los Alamos results that a slit 3 to 5 mm high would be ample. The beam defining slits should ac. ılly be in the median plane, but this was only a mockup.

We have four targets. We take the beam on one target just as the beam enters the dee, and then we move in three other targets in turn at 45° azimuth intervals and take the beam off the first target. It requires a movement of 0.1 to 0.2 in. to take the beam away from the first target. Figure 178 shows results with a 1-mm slit on the first turn and a 0.5-mm slit on the third turn of the machine. This gives us three points on the orbit.

Plots of the orbit centers are shown in Figure 179. We moved the 1-mm slit on the first turn so we could take portions of the beam in turn. If you try to get orbit centers for the whole beam you get a mess, but by splitting the beam up into pieces you get this line of orbit centers. A, B, and C refer to measured orbit centers with the 1-mm slit in three differing positions. On the slide, (13), is the line of orbit centers at 13 cm radius, and (21) is the line of orbit centers for the beam at 27 cm radius, showing the precession of the beam by the motion of the orbit centers along

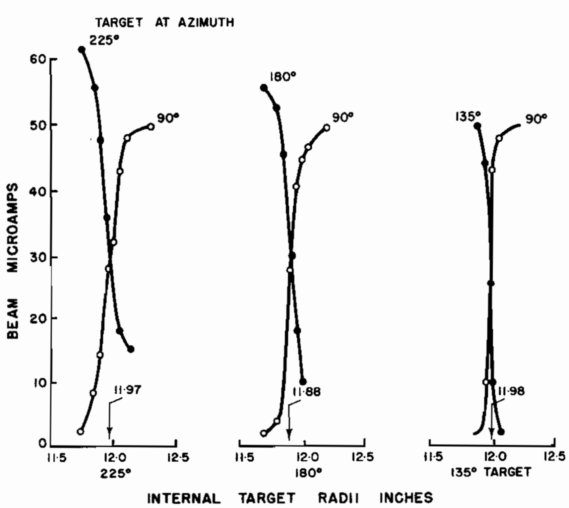

Fig. 178. Determination of three points on proton orbit.

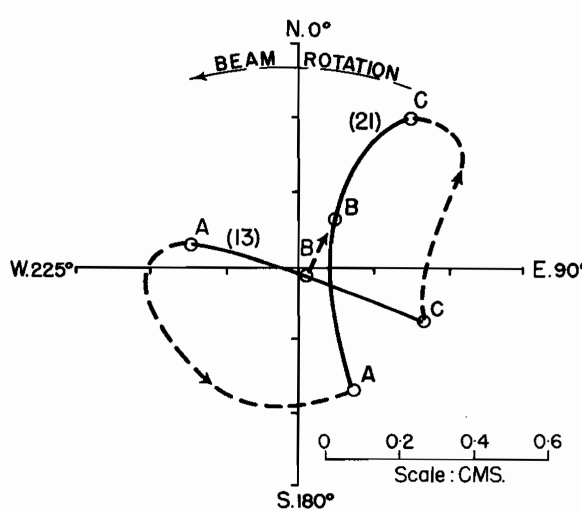

Fig. 179. Measured distribution of orbit centers.

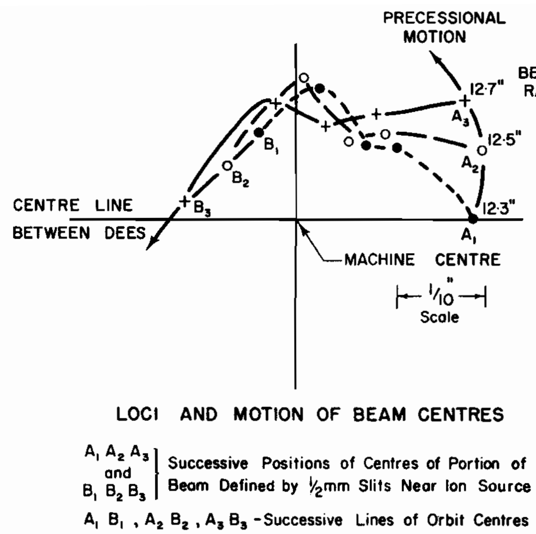

Fig. 180. Measured distribution of orbit centers.

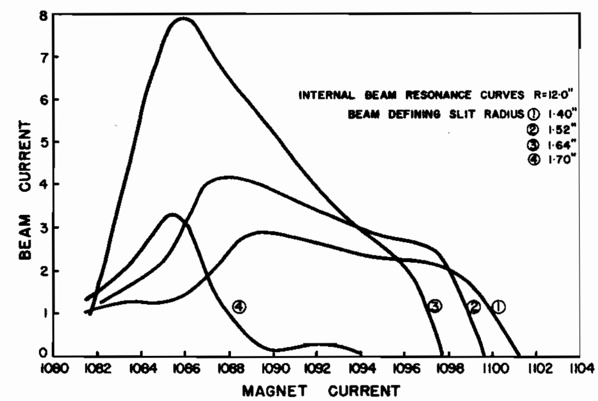

Fig. 181. Measured resonance curves.

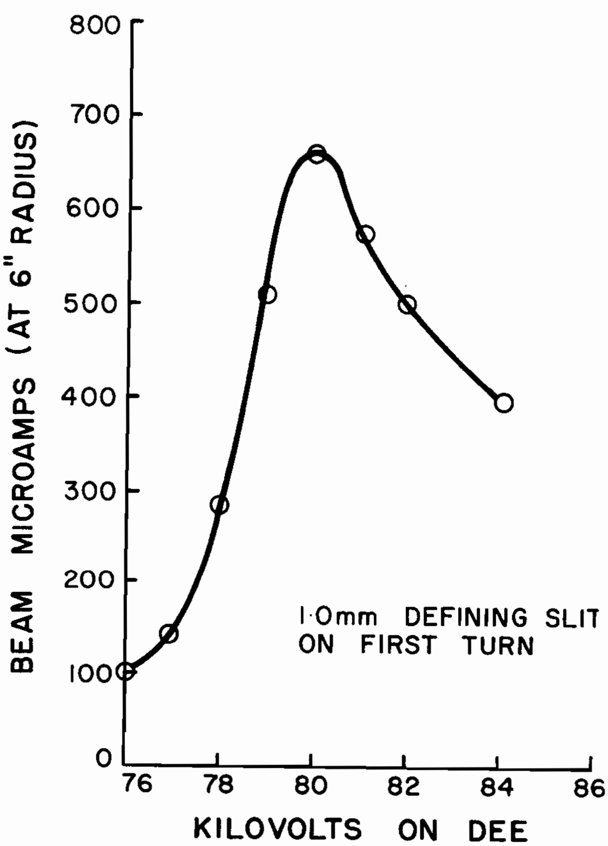

Fig. 182. Internal beam as function of dee voltage.

the dotted lines. As the beam moves out with the clit in position B the orbit center remains essentially on the center o of the machine.

Figure 180 gives some further measurements of orbit centers close to the extraction radius of 12.7 inches. The black dots are one line, each dot is for one position of the central defining slits; the beam is precessing fairly rapidly in this region.

We have taken resonance plots, that is, plotted the beam current vs the magnet current for four different positions of the defining slits near the ion source, Figure 181. The position and shape of these resonance curves differs with the positions of the slits, indicating that we are picking out different phase ranges. It shows here some indication of a double hump, which indicates a folding of the line of orbit centers; in some positions of the slit you are really getting two lots of phase angles coming through the slit.

The points of Figure 182 were taken with a millimeter slit on the first turn; this is really another way of measuring the radial variation of the beam. As the dee voltage increases one gets a very rapid rise at the dee voltage where the beam starts coming through the defining slit, and then as the beam moves out past the defining slit the beam drops

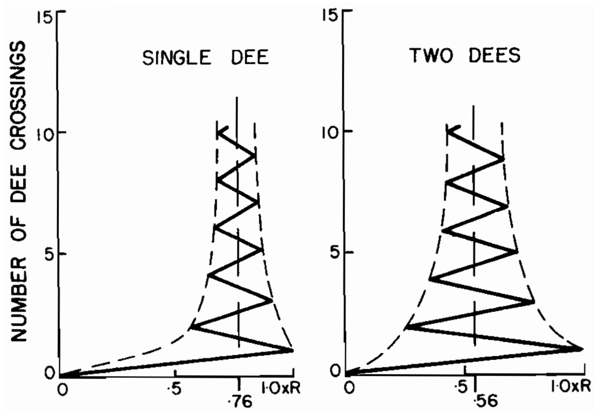

Fig. 183. Movement of orbit centers during initial motion.

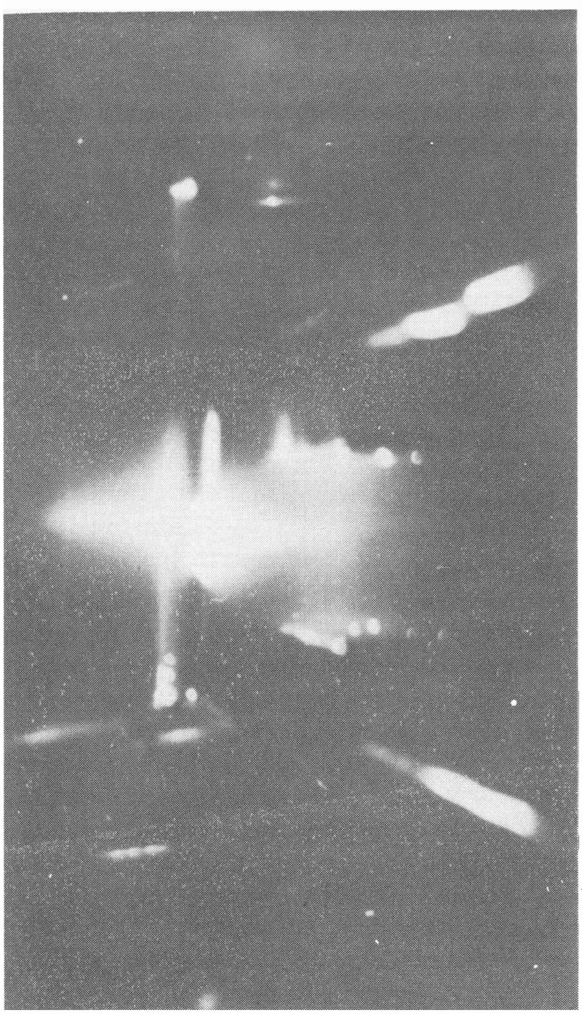

Fig. 184. Initial vertical focusing of ion source beam.

rather slowly. The accelerator tends to be unstable in the region where, as the voltage on the dee rises, the beam current falls and load is taken off the oscillator, and the dee voltage tends to rise further. Unstable operation may occur in this region.

This slide indicates the necessity of having stabilized dee voltage. We stabilized the dee voltage for small power drains on the oscillator by means of a feedback system which involved grid modulation of the oscillator. That is, we took the dee voltage, amplified it, and fed it back through the grid resistance of the oscillator. This takes the ripple out of the dee voltage and stabilizes it to about 0.5% for small power drains. We can get up to 700 μa through a 1-mm slit. With two slits, 1-mm slit on the first turn and a 0.5-mm slit on the third turn, we can accelerate 60 μa. With the third (0.5-mm) slit added at the second turn, we can accelerate about 15 μa to full energy.

Figure 183 shows a calculation of the displacement of the orbit centers during the initial acceleration. The orbit center oscillates as the beam crosses the dee and finally settles down to the position shown, about an inch from the ion source in the case of the single-dee machine; the displacement of the final orbit center from the ion source is somewhat more for a two-dee machine. In our case we have an ion source shifted 1 in. from the center of the machine.

This is a very bad photograph of the ion source in action (Fig. 184). The camera is not properly in focus, but it indicates the rather strong fosucing action near the ion source of the machine. There is no puller here, but you get the same thing with the puller in action. It is also noticeable that most of the beam coming from the lower part of the ion source rises. This focus is maintained on the second half-turn.

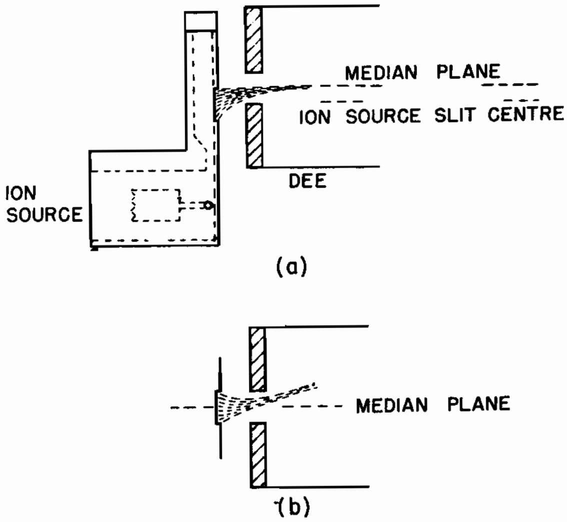

Fig. 185. Initial vertical movement of ion beam.

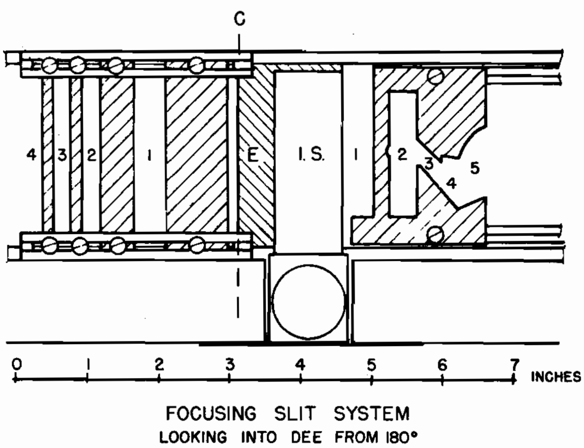

Fig. 186. Focusing grids on dee and dummy dee.

We found it essential to lower the ion source well below the median plane to bring the beam central. This is the same effect, I think, as was spoken of yesterday. People said they had to raise the ion source above the median plane. In our case we have this rather narrow aperture for the beam to go through (Fig. 185). When the ion source is on the median plane, the beam crosses over the median plane into a defocusing region that causes the beam to rise further. But if the ion source is below the plane in our case, the beam enters the defocusing region where it is pulled into the median plane. If instead of having a 1-cm ion source slit, the height were reduced to 3 mm, as at Los Alamos, I should think this effect would be very much less.

Figure 186 shows an attempt to introduce electrical focusing by means of slits on the dee. These electric focusing slits are concerned with axial focusing and bear no relation to the beam defining slits previously described, which define the beam radially. The slide is a view looking into the dee from the dummy-dee side showing the ion source. On the left are carbon slits placed on the dummy dee, and on the right is a carbon plate placed on the dee. In this plate slots through which the first, second, third, fourth, and fifth turns of the beam pass. On the left side the first, second, third, and fourth turns go through between the carbon bars. We could not separate the turns on the right side of the ion source, although I am sure they were separated before the slits were put in. These slits introduce a certain amount of defocusing in the horizontal plane but they cause very good focusing in the vertical plane. You see the beam is quite strongly focused on the third, fourth and fifth turns in the vertical plane. This system of bars is very similar to the system used in the linear accelerator, where grids for the downstream side of the accelerating gap eliminate the defocusing forces.

The falloff of beam with radius is shown in Figure 187; (b) is the falloff without the focusing slits and (a) is with focusing slits. You will see there is a very considerable improvement with the focusing slits. These are actually measured plots, but I think they rather exaggerate the effect; normally the dropoff of beam without focusing slits was not quite as bad as that. The falloff of beam with radius does not repeat very closely with repeated measurements, but must be rather critically dependent on the state or position of the ion source.

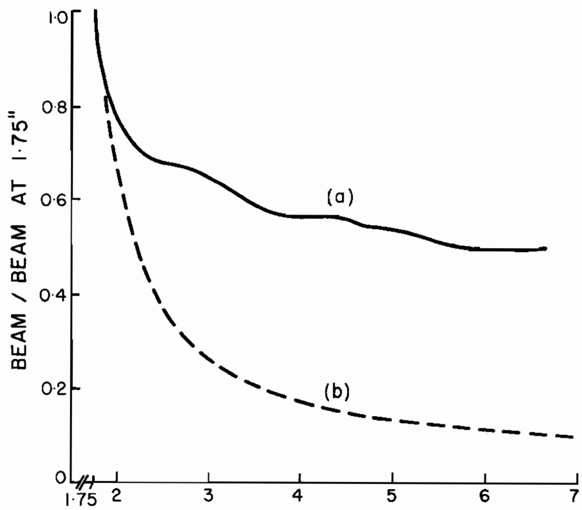

Fig. 187. Beam loss with radius, (a) with and (b) without focusing grids.

Figure 188 is a setup of the cyclotron for an experiment. With the 1-mm defining slit at the center of the machine near the ion source, we could extract 250 μa out of a 350 μa circulating beam; that is, 70% of our circulating beam was extracted. This was with a rather high ripple on the dee. We could not stabilize the dee under these conditions. There was about a 3 or 4% 300-cycle ripple on the dee. So if the dee had been stabilized, the extraction might have been better.

With the three defining slits in position near the center (one 1-mm and two 0.5 mm), the circulating beam was reduced to 10 μa, and we could extract apparently all of it, at least 95 percent. I think our actual measured figure was about 105 percent. [Laughter]

This beam had an energy spread a bit less than 1 percent. This was more beam than we needed for the experiment. We introduced an internal target on the final orbit, and of the 10 μa circulating we took half on this target and allowed the other 5 μa to pass through the extraction system. The external beam then had less than 0.5% energy spread. We kept the magnetic field so that the external and internal beams were equal; this required stabilization of the magnetic field to better than 1 or 2 parts in 10,000. Then our energy was constant from day to day and week to week to within less than 0.5 percent.

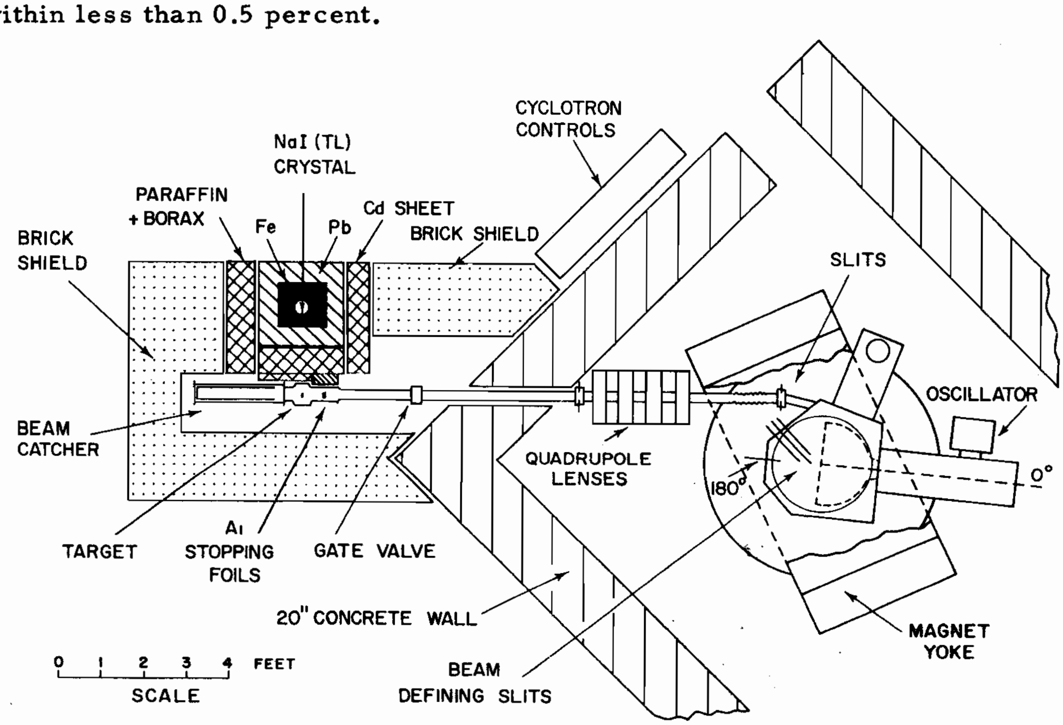

Fig. 188. Experimental arrangement for proton-capture gamma ray studies.

traction radius agreed to within better than 1% with the energy calculated by stopping it in aluminium foils outside the machine. This was additional proof that the beam was rorating about the center of the machine.

SCHMIDT: You had a curve on which you showed the beam as a function of the radius for the slit system and without the slit system.

SMITH: This was a different effect, the use of focusing grids on the dee which are quite distinct from the beam-defining slits. The focusing slits placed on the dee did not stop the beam down essentially, but they eliminated the electric defocusing action of the dees on the early turns, just the same as with grids in the linear accelerator, but in the cyclotron these grids introduced a certain amount of radial defocusing. I am not sure yet whether we can successfully combine the defining grids with the focusing grids on the dee.

BLOSSER: At what angle were your defining slits with respect to the line of dees.

SMITH: The defining slits intercept the beam in the dummy dee area 45^{o} in azimuth after the dee crossing, that is along the azimuth 225^{o} in Figure 172.

BLOSSER: What percentage of your current do you get through these slits?

SMITH: It depends on width; if we had a 0.5-mm slit here we could get 300 a at the final orbit. With no slits we could get 3 milliamperes. So we are getting very roughly 10% of the beam through a 0.5-mm slit on the first turn.

BLOSSER: Do you have any data on whether the percentage of beam you get through the slits varies with the azimuthal angle?

SMITH: We don't have that, but we have a plot (Fig. 175) of the radial beam density along these three azimuths. This is a plot of beam vs radius; it is essentially the same along all three. The orbits of interest seem to be parallel as far as we can tell. This is true only if one has a high field pulling on the ion source and a parallel field. That is, we attempt to make sure the electric field is always perpendicular to the dee. In that case, according to our very crude calculations, these orbits are parallel if this is the high field; for a low field you get this crossing over of orbits effect.

BLOSSER: Do you expect the ions that come out at a particular phase to cross at about 180^{o} or to cross along the line of the dees?

SMITH: No, we don't expect this at all with the geometry that we have, not for the ions of interest that have a bunched orbit center. The ions of highest energy come along parallel, but the ones inside here do crisscross. Slits eliminate then; we are not interested in them. We assume that ions emitted at a particular phase all travel the same orbit, that there is no initial sideways spreading of the beam.

HUDSON: What was the energy spread in your 3-ma beam compared with 0.5 or 1% in the external beam?

SMITH: In the 3-ma beam, orbit centers were distributed over roughly the order of 2 cm, which would be about a 7% spread of energy.

CHAIRMAN LIVINGSTON: Do you have a corresponding figure for the 300-μa defined beam?

SMITH: It was distributed over roughly 2 to 3 millimeters. The spread of orbit centers was reduced to this amount and the energy spread accordingly. If you have a line of orbit centers which is perpendicular to the extraction channel, it means that at the extraction channel you have a big spread of energies. If the line is at right angles to the extraction channel, you have a big spread of angle; so it is impossible to extract efficiently for this big spread of orbit centers.

LIND: About how big was your target spot, that is, what do you focus the 300 μa to at your target?

SMITH: We didn't focus this down. We were diverted to doing nuclear physics experiments. We were also pressured to move the machines; so we had to stop measuring short. The radiation levels were very high, too. We could only work safely with small beams, that is, of the order of 4, 5, or 10 μa through the focusing system. The beam was focused to 8 by 8 mm at 18 ft from the machine by means of a quadrupole lens immediately the beam left the cyclotron.