Beam Quality and Operational Experience with the University of Rochester Variable-Energy Cyclotron

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I feel slightly apologetic about being here; the only azimuthal variation in the field of our machine is accidental. We do have a good deal of experience now with our variable-energy machine, however, and I think that you might be interested in some comments on how it has worked out. Actually, I will describe the beam handling system and the beam quality, and perhaps comment on the operating experience.

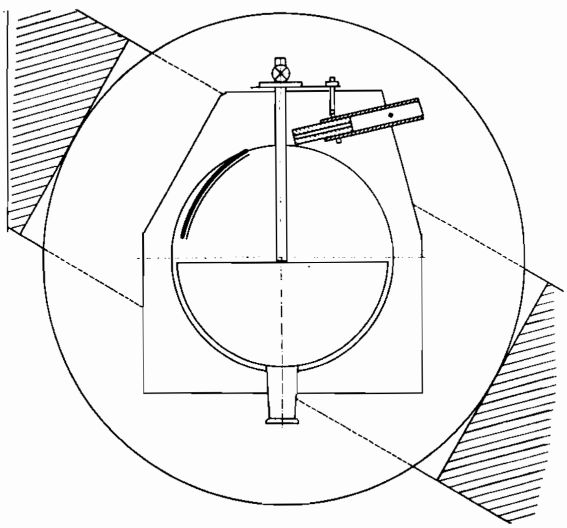

Fig. 212. Beam extraction system of the University of Rochester Variable-Energy Cyclotron.

Figures 212 and 213 illustrate the extraction and beam handling system of the Rochester machine. A conventional electrostatic deflector brings the orbits out about 1.5 in. An iron pipe extending to the edge of the pole tip brings the beam out of the magnetic field of the cyclotron. The beam is then focused through a slit and analyzed before going into the scattering chamber. The iron pipe produces a very large perturbation in the magnetic field. At the deflector radius it produces about a 15% drop in the field over a small

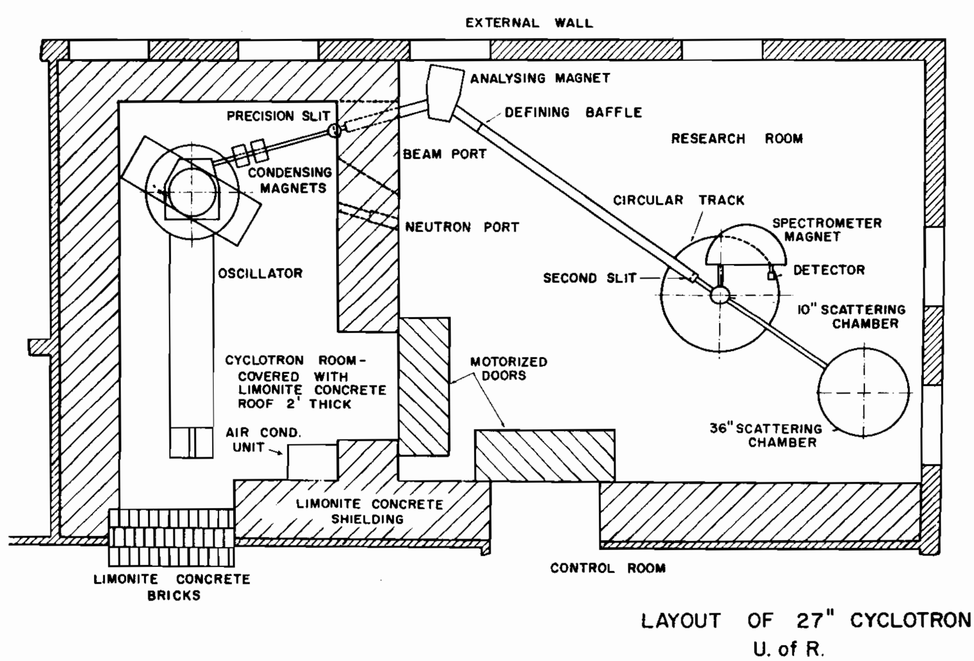

Fig. 213. External beam handling system.

angular region. We empirically compensate for this perturbation by adjusting the position of the pole tips on the machine until the beam orbits are centered, and have found that once the orbits are centered at a given energy there is very little movement of the orbits when the field is changed for other energies. With a single adjustment of the deflector, the iron pipe, and the pole tips we can run from 2 to 7 Mev with protons, and 3 to 4 Mev with deuterons.

Typical operating currents are 10 to 20 ma at the deflector radius. However, the orbits in the machine are apparently rather compact and well defined because we typically extract about 25% of the circulating beam through the deflector. On a catcher plate behind the deflector we find that this beam forms a spot about 5 mm square. Between 1/4 and 1/2 of the deflected beam can usually be extracted through the iron pipe and condensing magnets; a typical beam current on the slit is 1 to 2 microamperes. These are day-to-day operating currents at any energy. If we take anywhere from half an hour to a couple of days to get everything adjusted at a particular energy, we can increase these beam currents 2 to 5 times. The beam spot on the slit is usually 1 to 2 mm wide and about 10 mm high, although this can be focused to a spot about 2 mm square.

One point we have found in connection with the operation of the machine is that as we vary the energy it is impossible to reproduce all the operating conditions precisely. This is not surprising but it is a factor to be considered in any extraction system intended to operate over a range of energies. There is a slight tendency for the axiz of the beam coming out of the machine to move around, and this can lead to quite severe defocusing of the beam coming through the condensers. One has either to have the devlection system or the condensers adjustable so that the focus at the slit can be maintained. Actually, in our machine we have both of these movable; from time to time we have to adjust them slightly.

After passing through the analyzer the beam passes through a slit about 1 mm wide by 5 mm high and provides currents of about 0.1 ma in the small scattering chamber with an energy resolution of 0.2%. This sort of operation is possible over most of the energy range of the machine with only minor adjustments of the deflection system. We simply tune the oscillator (as described in the session on r-f systems), tune the magnet, and set the analyzer to the desired energy. The energy spread of the beam coming out of the machine is about 1.5%. This is measured just by sweeping the beam across a fluorescent screen at the entrance to the scattering chamber.

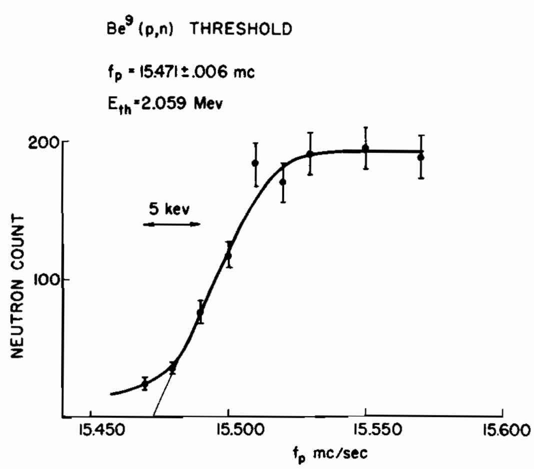

Fig. 214. Measurement of the $Be^9(p,n)B^9$ threshold.

The angular divergence of the beam is small, probably because of the shielding through the fringe field of the cyclotron. The angular divergence of the beam is limited by a baffle just after the analyzer, and we find that essentially all the beam in an energy band 0.2% wide passes through a slit 3/8 in. wide about 10 ft from the scattering chamber. This implies that the angular divergence of that part of the beam having a particular energy is of the order of 1/10 degree.

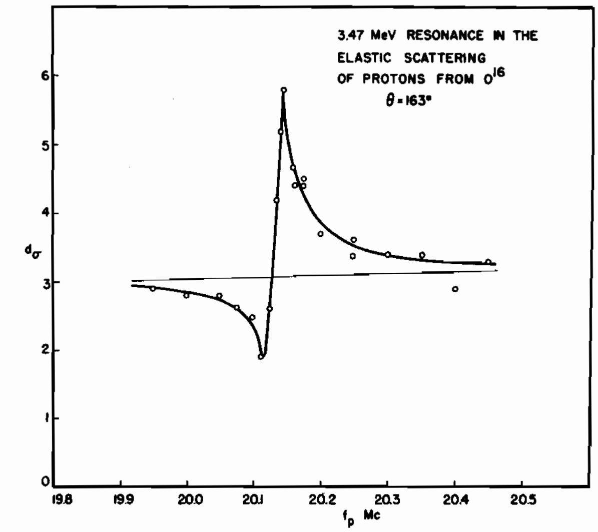

Fig. 215. Differential cross section at 165° for elastic scattering of protons from O^{16}.

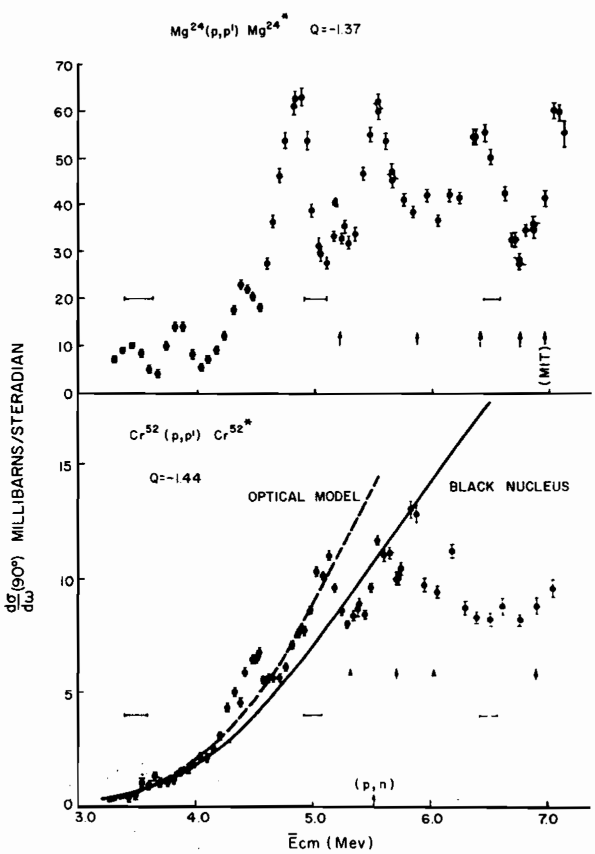

Fig. 216. Differential cross sections at 90° for the inelastic scattering of protons from Mg^{24} and Cr^{52}.

You may be interested in seeing the sort of work that has been possible with this machine. Figure 214 shows a measurement of a (p, n) threshold used for calibration of the analyzer magnet. Actually, in this case the energy range is so small that we went through the threshold just by tuning the analyzer magnet, leaving the cyclotron frequency and magnet current fixed. A similar sort of measurement is shown in Figure 215, which shows a resonance in the elastic scattering of protons from oxygen. Once again, this is over a small energy range but it is large enough that we had to tune the oscillator and cyclotron magnet. Figure 216 shows a measurement extending over an energy range from 3 59 7 Mev*. Typically the time taken to count a point is comparable with the time taken to change the energy of the machine and get the beam at a new energy.

BLOSSER: I was just doodling here a little with respect to how much beam you want. It turns out that if you put 1 ma on a 32nd of an inch spot with 1/4 deg divergence, this is about 6 amp/cm² per steradian, which is actually a very high quality beam in terms of the sort we are talking about.

*I am indebted to Dr. F. D. Seward for permission to use this data.