BEAM DIAGNOSTIC DEVELOPMENTS AT NSCL

F. Marti, R. A. Blue, J. Johnson, J. Kuchar, J. A. Nolen, P. Rutt, B. Sherrill and J. Yurkon

NSCL, MSU, East Lansing, MI 48824, USA

ABSTRACT

The NSCL is beginning to commission the first experimental areas for the recently completed K1200 superconducting cyclotron. The final plan calls for our two cyclotrons to be able to deliver beams simultaneously to different experimental vaults. This is accomplished by means of a network of beamlines and switching magnets. Standardized diagnostic chambers are used throughout the beam lines. The availability of moderate cost digital frame grabbers has allowed us to replace wire scanners (or harps), with scintillators and TV cameras that give a two-dimensional current density measurement instead of the more limited x- and y-projections. This technique, in conjuction with slits and pepperpot plates, is used to measure the beam emittance. In addition, we discuss the challenges in developing internal diagnostics for superconducting cyclotrons due to their small size and intricate extraction system, and compare the diagnostics used in the other superconducting cyclotrons already built or under construction.

1. INTRODUCTION

The National Superconducting Cyclotron Laboratory (NSCL) facility will consist of two superconducting cyclotrons, K500 and K1200, delivering beam to several experimental rooms (see fig. 1). Both cyclotrons can operate simultaneously running different experiments. Three ECR's (two

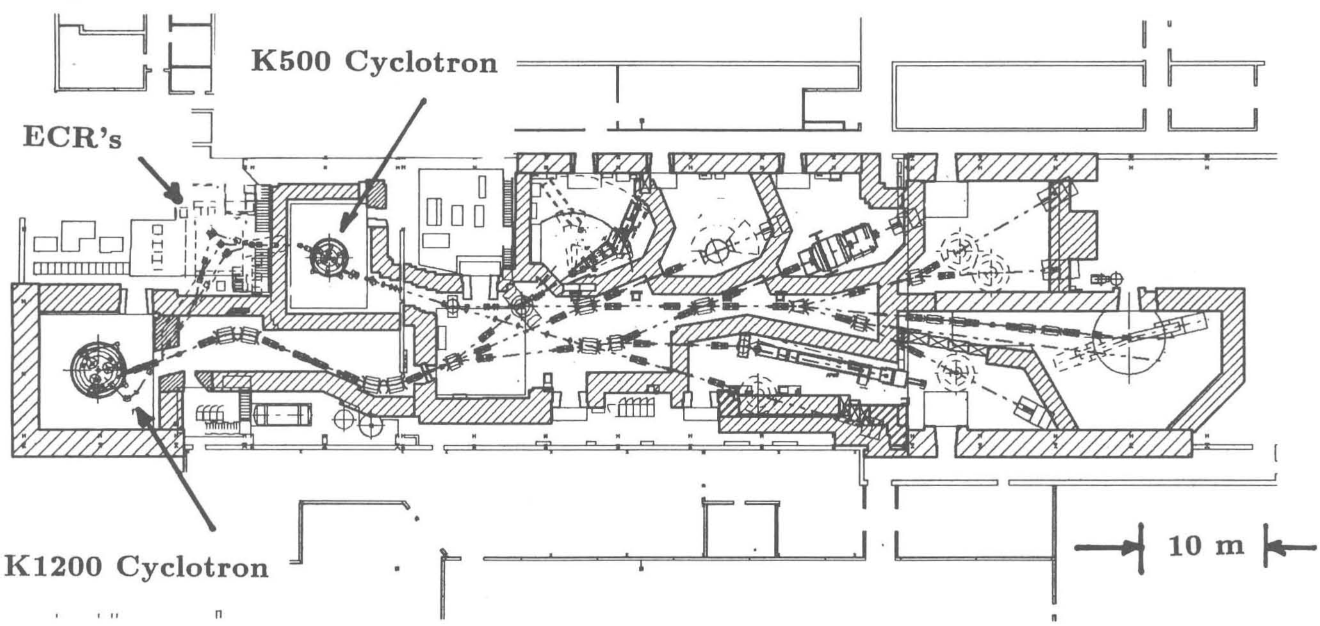

Figure 1: Floor plan of the NSCL experimental area. Both cyclotrons will be delivering beam to different experiments simultaneously. Numerous beam diagnostics stations are required in the final configuration

of them operational, the third under construction) are arranged in a switchyard so that any ECR can deliver beam to the axial injection system of either cyclotron. The intricate beam line arrangement shown in fig. 1 will require an extensive beam diagnostics system.

Since we are just beginning operation of the facility, cost and flexibility were considered in the design at this stage. We planned to try different devices and did not want to change the diagnostic boxes where these devices mount. Besides, space in the beamline is very limited and quickly interchangable devices are useful. This approach guided us to develope a multipurpose beam diagnostic chamber that easily accepts a variety of diagnostic equipment.

Another requirement was the desire of minimizing the radiation produced during beam tuning. We would like to tune with total beam currents of 1 electrical nA or less. The existance of very sensitive phosphors made this goal possible to achieve. The procedure will be to tune the beamline with low intensities obtained by inserting attenuators[1] in the low energy injection line, and when finished remove the attenuators and send the more intense beam to the experiment. Our laboratory has been using scintillators for many years, viewed with TV cameras, for qualitative information. The advent of low cost frame grabbers that digitize normal TV signals allows us to actually obtain accurate quantitative measurements with the scintillators. Several other laboratories are undertaking similar efforts with different beams and goals.[2-4]

2. BEAM DIAGNOSTICS CHAMBER

The basic beam diagnostic chamber that we have adopted is shown in fig. 2. It consists of a 25 cm diameter stainless tube with two large Conflat flanges closing the top and bottom openings. The beam enters and leaves the chamber through two 10 cm pipes on each side of the chamber. A 15 cm viewing port is provided perpendicular to the beam trajectory. The top flange is used in some case to mount a turbo molecular pump. Six half nipples with standard 2.75 inches Conflat flanges are welded on the bottom flange. Four of these flanges are used to mount the actuators that move devices into the beam path, and the other two provide extra electrical feedthroughs or for vacuum gauges.

The basic actuator design consists of three air cylinders, with lengths 1, 2 and 3 (or 4) inches. By expanding and contracting the appropiate cylinders the actuator can change its position by 1 inch increments, allowing up to 6 devices (different scintillators for example) mounted on a single shaft. The hollow shaft allows water cooling and electrical connections that move with the actuator. In the case of a wire scanner for example, only one cylinder (the 4 inch) needs to be moved to scan the whole beam cross section. All actuators are bellows sealed. A smaller version of this standard chamber is used in places where only one actuator is required.

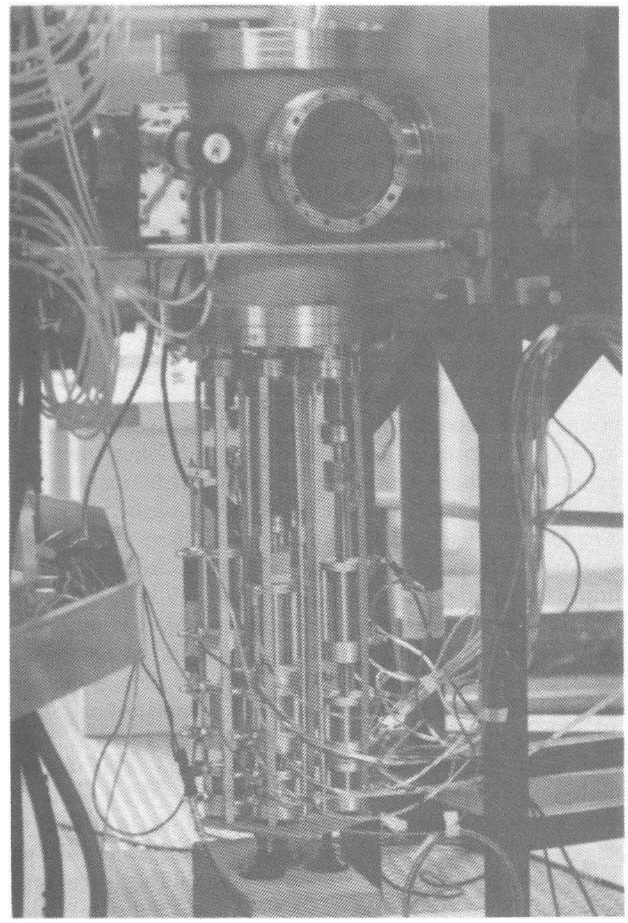

Figure 2: Photograph of the standard beam diagnostic chamber. Equipped with four actuators. Each actuator has 3 air cylinders that move the shaft to 6 different positions. A side port with a large window allows the TV cameras to look at the scintillators.

3. BEAMLINE VIEWERS

1. Phosphors

Phosphor materials are commonly separated into two families.[5] In the first type a wide spectral distribution is possible when the excited electrons jump from the the activator atoms to the conduction band of the crystal and then return to the lower energy level through intermediate steps. These broad-band-emitting phosphors include materials such as sulfides and oxides. Rare earth phosphors belong to the second family, the narrow-band-emitting phosphors. In these, electrons make transitions to the $4f$ orbital of the activator. The spectral emission consists of narrow bands because the electrons are shielded from the fields produced by the outer valence electrons.

The above considerations are important in phosphor selection. One aspect which is still under investigation is the choice of a proper scintillation material and method for depositing it on a metal plate which can be inserted in the beam. For beams from the K500 cyclotron we have almost exclusively used Al_2O_3 plates, which have a very long lifetime but relatively low light output. Chromium doping improves significantly the light output, and experiments elsewhere[6] have proven it to be rugged and radiation resistant. Most of the preliminary work with the K1200 beam diagnostics has been done with a ZnS phosphor, which is widely available and inexpensive. Its light output is much brighter than pure Al_2O_3, and has allowed us to see beams as weak as 10 pA. We have made some initial comparisons of the light output from other types of phosphors such as the rare earth phosphor gadolinium oxysulfide, but ZnS is as bright or brighter. We have also investigated various methods of depositing the phosphors including spraying, electrocathaphoresis,[7,8] and sedimentation. Sedimentation has proven to give the best results. The phosphor powder is put into suspension above the plate to be coated. After several hours the phosphor settles, to form a very uniform deposit on the plate. Varying the amount of material in suspension can be used to control the thickness of the phosphor deposit. We have found that organic and inorganic materials used as binders to hold the phosphor on the plate are damaged very quickly when exposed to the beam and limit the useful lifetime of the plates. Hence, at present, no binders are used. We intend to continue studying new phosphors and different methods of binding. Issues which need to be studied are phosphor lifetime, grain size, decay-time, light-output, and linearity of response.

Experience has shown[5] that phosphors have a linear response for light particles and time average current densities of less than 10 $\mu A/cm^2$. At higher current densities the nonlinearites depend on the details of the pulse structure. Some preliminary linearity studies have been made by Anderson[7] for electrons with the same speed as the H^- ions used in the Neutral Particle Beam Test Stand at ANL, showing that for current densities below 5 $\mu A/cm^2$ ZnS:Ag was very linear, and had a slight quadratic dependance above that current density. However at present no data is available for heavy ions.

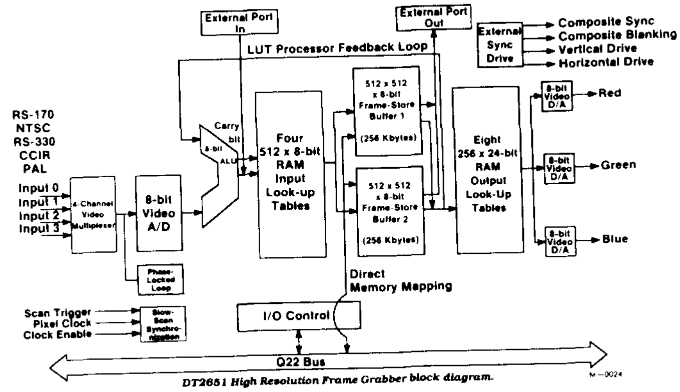

Figure 3: Block diagram of DATA TRANSLATION DT2651 frame grabber. The basic features include: 4 channel multiplexer, 8 bit 10 MHz ADC, two 512x512 frame-store buffers and look-up tables. Pseudo-color representation of gray scales can be done in real time at 30 frames per second. The communication with the coprocessor is done through the two additional ports shown on top of the diagram.

2. Frame Grabber

Scintillators offer an excellent 2 dimensional display of the beam current distribution. However, until recently, it was difficult to obtain quantitative information from them. They were used mainly to position and focus the beam at the target. Wire scanners and harps gave profile information, although as projections in x and y. If a more detailed measurement was needed then tomographic reconstruction was used.[9] The availability of moderate cost frame grabbers opens new possibilities in this field. Basically these frame grabbers are add-on boards to computers that take the TV signal directly from the camera and digitize the intensity level. This digital signal can then be manipulated arithmetically and then converted back to three analog signals that are sent as the RGB inputs to a color monitor. It is possible with some boards to assign different colors to different intensity levels. In this way subtle differences in gray level become clearly distinguishable. This feature has proven to be very useful in our beam line tuning, giving at the same time position, intensity, and 2-d shape information.

Frame grabber boards are now available for a large variety of computers including, MicroVax, IBM PC and clones, VME Bus, MacIntosh, etc. We selected a frame grabber board for a Q-bus microVax because: a) we already had several microvaxes in the control system for the accelerators, and the database of accelerator parameters was then available to our software; b) we felt that using a PC style computer would require doing a lot more file transfers to the microVaxes where the final analysis would eventually be done and where our main disk storage was located; c) we were more familiar with the microvaxes. These reasons probably would not apply to other installations. Similar boards for PC's are less expensive than the microVax ver-

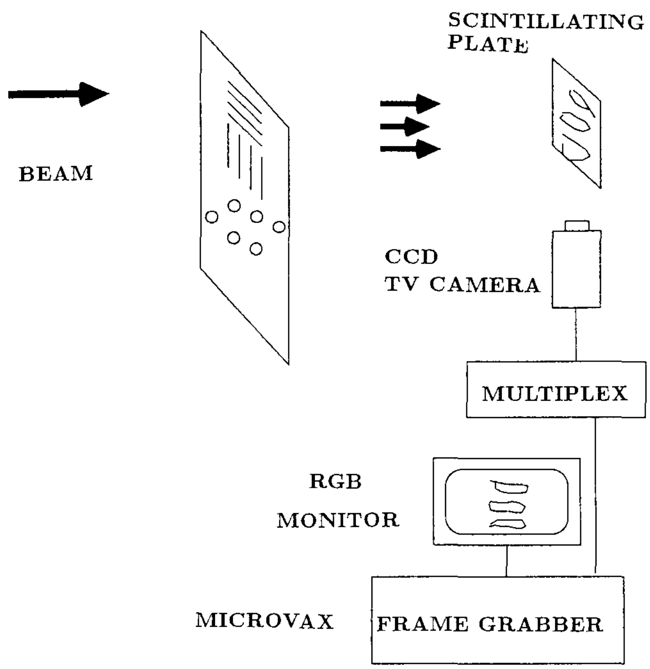

Figure 4: Diagram showing the main components of the beam viewers and emittance measurement system. The beam impinges on the scintillating plate at 45 degrees with the incoming beam. The beam spot is observed through a TV camera at a right angle with the beam path. A perforated plate partially stops the beam for the emittance measurement. The image produced by the TV camera is digitized and transformed to pseudocolors by the frame grabber in the microVax, and displayed on the RGB monitor.

sion.

We bought the high resolution frame grabber DT2651 and the auxiliary frame processor DT2658 with the DT-IRIS software package from DATA TRANSLATION.[10] The block diagram of the DT2651 is shown in fig. 3 and a complete system diagram in fig. 4. There is a four channel multiplexer on the board, but we have an additional multiplexer in front that allows us to have a much larger number of cameras connected to one single board. The DT2651 operates in real time, digitizing, storing, processing and displaying 30 frames per second. Each image is a 512 by 512 pixel matrix (in the 60Hz version only 512 by 480 are usable). The ADC is an 8-bit flash converter operating at approximately 10 MHz. There are two 256Kbyte frame buffers. Either one can be displayed after processing through the look-up tables. It is possible to create overlays that are displayed on top of the incoming picture (this is done by write protecting a bit plane); it is a useful feature that allows to have scales associated with each observing station. The DT2651 provides two asynchronous data ports which communicate at very high speed with the DT2658 coprocessor, without overloading the Q-Bus. The coprocessor is used for frame addition and subtraction, averaging, histogramming, zoom and pan, etc. We must note that these operations are not done in real time, it takes the DT2658 four frame times to complete them.

We use a Cohu 4810 CCD camera,[11] which has an active area of 8.8 by 6.6 mm with a cell size of 11.5 μm (H) by 27.0 μm (V). This camera has a very good sensitivity and it is possible to turn off the automatic gain control and also to set the gamma to 1.

3. Beamline tuning

Our basic use of the phosphor frame grabber combination is to display the beam spot in pseudocolor. This allows for a very fast feedback to the operator of what is happening to the beam in *two dimensions*. After obtaining an image in gray scale, the operator decides what color table to use, we normally use ten different colors. Then from a histogram of the number of pixels vs. pixel intensity the operator selects the minimum (*black*) and maximum (*white*) levels, and the color table translation is applied between these two levels. Every pixel with an intensity higher than *white* will have the same color (i.e. white) and every pixel with intensity lower than *black* will also have the same color (i.e. black). The intensities in between will be divided in ten equally spaced (intensity) levels, each shown as a different color. In this way the shape as well as the current distribution can be observed by the operator. Absolute current readings can be obtained with a Faraday cup behind the scintillator, although once calibrated the total light output could be used as an intensity measure.

The frame grabber can simulate a wire scanner and display the beam profile in x and y projections if so desired. Each of the viewer stations may have an overlay stored with scales, target position or other information that the operator recalls if needed.

4. EMITTANCE MEASUREMENTS

Traditional methods of measuring emittances of particle beams consist of stopping most of the beam, letting a small fraction go through a slit or hole, and measuring the current distribution after a drift distance. In this way the divergence associated with the small beamlet is determined. By looking at different regions of the beam a complete description in the divergence- position phase space can be obtained. An alternative method, the pepperpot approach, is to use a plate with many small holes in a regular pattern that transmits many beamlets simultaneously. This technique is cumbersome to implement because of the difficulties associated with reading a two dimensional distribution of the current density downstream of the pepperpot. The time involved in the pepperpot measurements was so long that it was not widely used. It was much easier to use a plate with slits in the x direction and another with slits in the y direction, and read the current with scanning wires parallel to the slits. This method has the disadvantage that it ignores any possible correlation between the x and y coordinates.

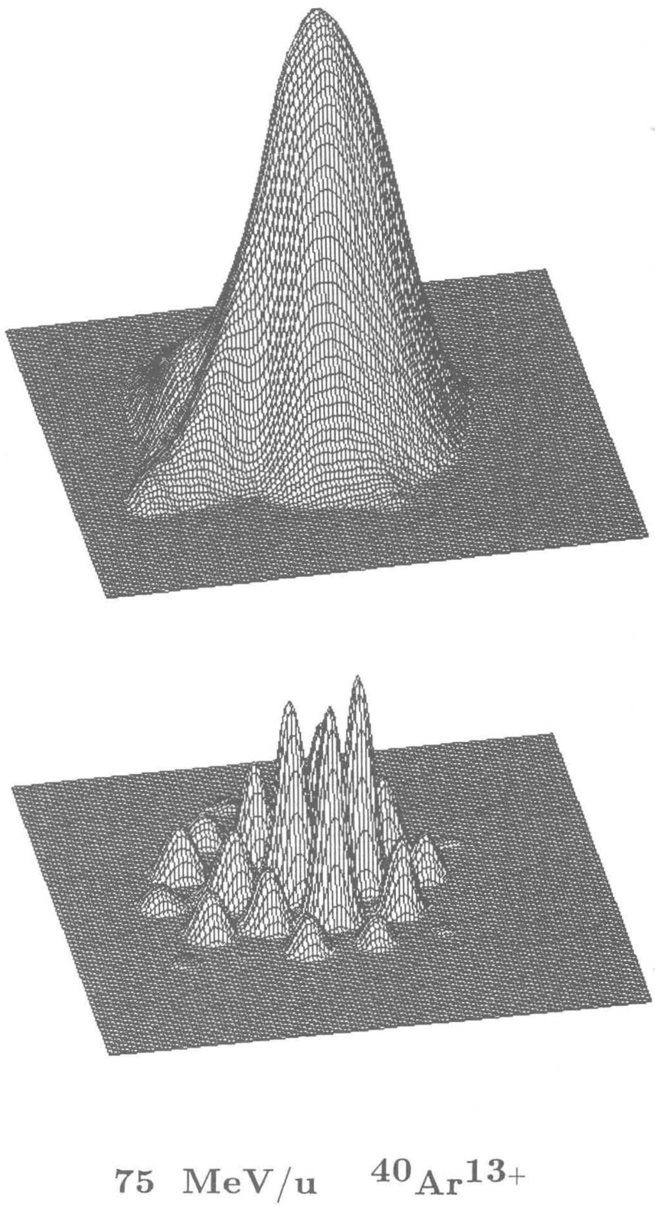

Figure 5: 3-dimensional plot of intensity vs. x-y for the the direct beam (top) and for the beam with the pepperpot plate inserted (bottom). The raw data is being displayed, no smoothing was performed. A total current of 0.5 enA of 75 MeV/u $^{40}Ar^{13+}$ was utilized.

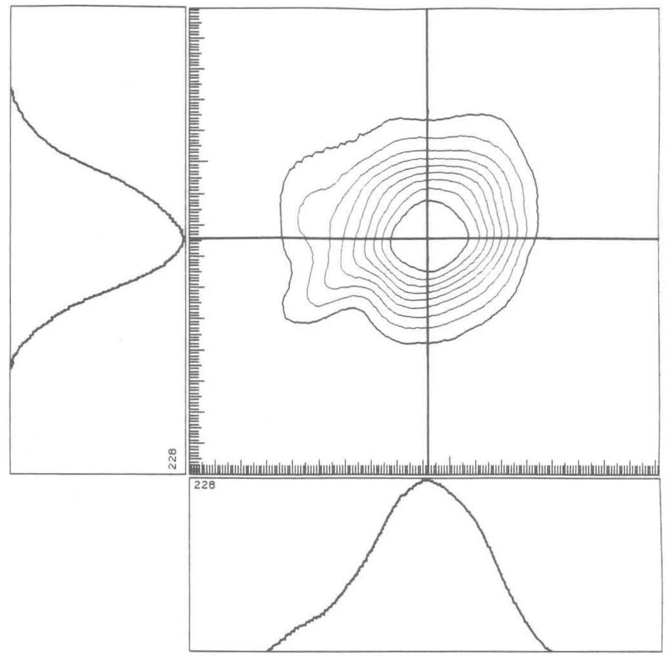

Figure 6: The data shown in fig. 5 (top) but shown as a contour plot. The two lines that cross at the center of the beam define the cross sections shown at the bottom and on the left. They are not projections as would be obtained by a wire scanner, but actual cross sections through the beam. The smallest tick mark is 0.1 mm. The total area plotted coresponds to approximately 18 by 15 mm.

The scintillating plate plus frame grabber technique is a very good solution to the speed problem in the pepperpot method. In just a fraction of a second a complete digitized image is available for processing. Fig. 4 shows the setup used to measure the emittance of the extracted beams of the K1200 cyclotron, the distance between the perforated plate and the scintillating plate is 1 m. Three different patterns of perforated plates can be inserted into the beam. One of them is a pepperpot plate with 0.8 mm diameter holes, separated by 2 mm between rows and columns in a staggered pattern. The other two plates are vertical and horizontal slits, with a slit width of 0.5 mm and a distance of 3 mm between centers. These slits are used to simulate the scanning wire method, but as the slits are fixed, the resolution is poor. A movable slit would give better resolution, but the current system was used to illustrate the method. An automatic system could be implemented to move a single slit in a stepwise mode and record the profile for every step. But it would have no advantage over the scanning wire or harp arrangement, and would not provide the information obtained with the pepperpot system.

We show in fig. 5 a 3-dimensional plot of intensity vs. x-y for the the direct beam (top) and for the beam with the pepperpot plate inserted (bottom). No smoothing of the data was done. The actual raw data is being plotted as is the case in the other figures presented in this paper. A

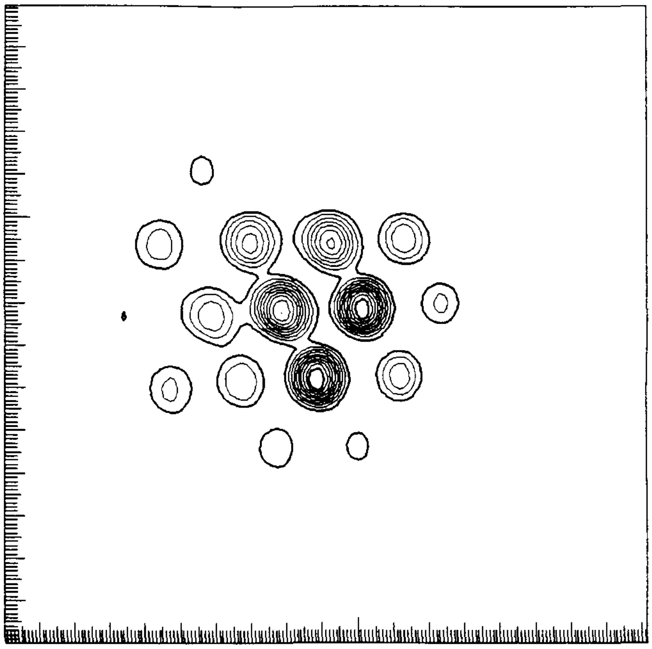

Figure 7: The data shown in fig. 5 (bottom) but shown as a contour plot. The scale is the same as in fig. 6.

beam current of 0.5 enA of 75 MeV/u $^{40}Ar^{13+}$ was being observed. It is important to use the maximum dynamic range of the ADC in the framegrabber. As the intensity of the image changes significantly when inserting the pepperpot plate, it would be useful to have a remote iris lens on the TV camera. The emittance measuring setup is placed after quadrupoles which allow us to choose the beam size and divergence that works best with the hole size and drift space between the perforated plate and the scintillator. That implies no overlap between the beamlets from adjacents holes. Once the phase space ellipse is calculated at the plate position, it is transported backwards to a point upstream of the quadrupoles using the known transfer matrices. A TRANSPORT calculation can then be started from that point to match the cyclotron extracted beam to the beam transport system.

The data from fig. 5 is presented as contour plots in figs. 6 and 7. We note that the profiles at the bottom and on the left in fig. 6 correspond to cross sections through the beam as shown in the contour plot. They are not the profiles that we would obtain with wire scanners (i.e. total projections on the x and y axis). The smallest tic marks on the scales correspond to 0.1 mm intervals. The resolution in these pictures was approximately 15 pixels/mm. We can probably obtain twice this resolution by changing the optical arrangement and reducing the field of view. The area plotted corresponds to approximately 18 by 15 mm, corresponding to half the size in x and y of the total digitized frame.

Once the digitized image is available in the microVax we identify the individual peaks in the pepperpot configu-

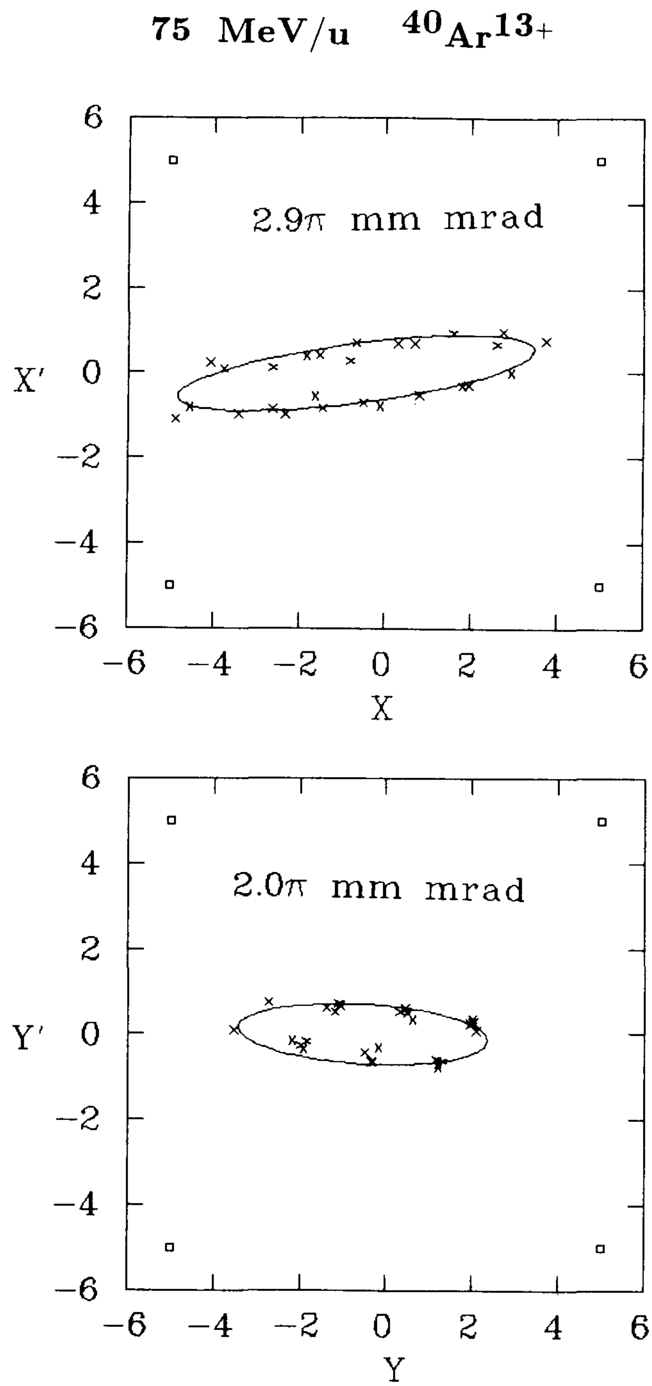

Figure 8: Phase space ellipses determined from the data given in figures 5, 6 and 7.

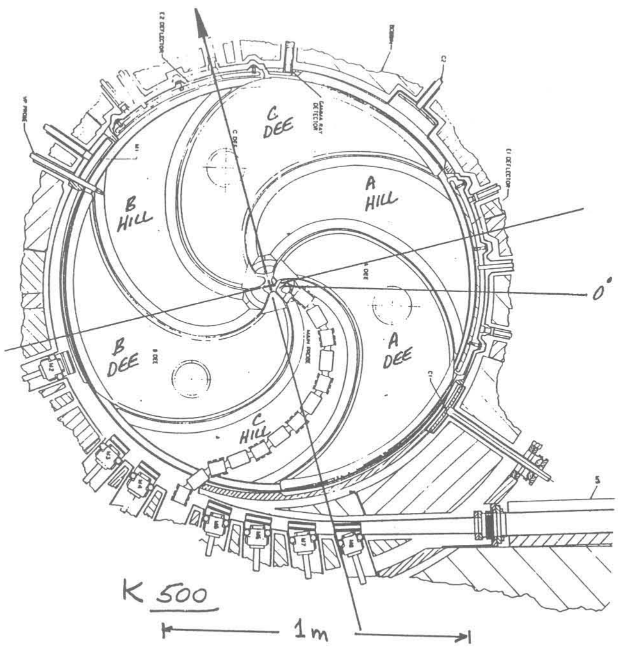

Figure 9: Median plane cross section of the K500 cyclotron, showing the main probe in its innermost position. The median plane penetrations associated with the extraction elements, electrostatic deflectors and focusing bars, limit the space available for beam probes.

ration. From the peak analysis the divergences in x and y are determined and assigned to the known x and y of that hole. Unless one of the holes is different, there is an unknown offset in (x,x') and (y,y'). This offset just gives a displacement of the phase space ellipses that is not significant. Ellipses are now fitted to the points and their area gives a measurement of the emittance. An example of this calculation for the data of figs. 5, 6 and 7 is given in fig. 8. It is interesting to observe in the bottom half of the figure the grouping of points in the (y,y') space. For each y we had several holes illuminated, and each of them contributed a pair of points to the diagram. The fact that they are in compact groups implies little correlation between x and y.

An alternative way to determine the beam σ matrix would be to determine the beam size at the scintillator as a function of the strength of a quadrupole placed upstream in the beamline,[2] but no information on the correlations wuold be obtained.

5. INTERNAL BEAM DIAGNOSTICS

We will outline in this section the internal diagnostics in our two superconducting cyclotrons, the K500 and the K1200, describe the operating experience we have had with them, and briefly outline the diagnostics in operation or planned for the other superconducting machines already built and in construction.

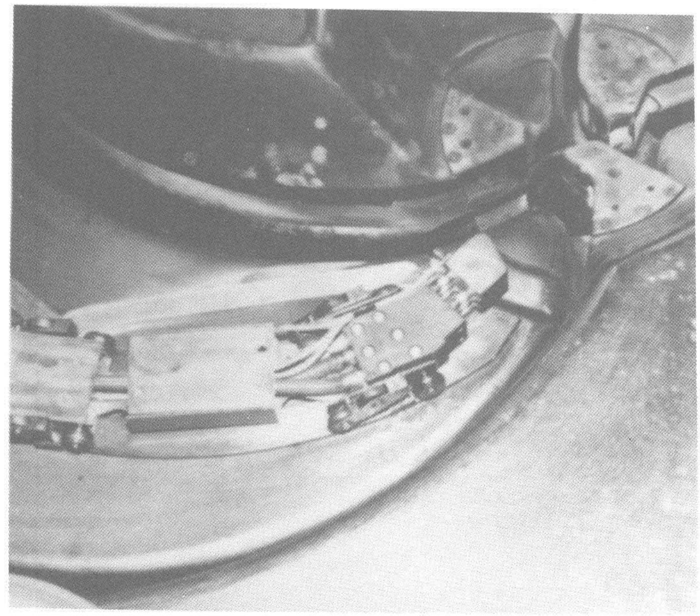

Figure 10: Photograph of the K500 main probe on its track.

1. K500

The K500 superconducting cyclotron has been in operation since 1982. It was originally planned as an injector for the larger K1200, but since then, the development of ECR sources has made this coupling less attractive, given that the same goals can be achieved with simpler schemes.

The beam being injected into the cyclotron is first detected on the anode of the spiral inflector. Turning off the inflector power supply and connecting the anode to a current meter gives a simple way of measuring the current.

The diagnostic devices share with the rest of the subsystems in the cyclotron the challenge of designing hardware for a compact accelerator. The extraction radius is 66 cm. Due to the high magnetic field at extraction, 5 T, the extracted orbit path is very long (almost 360 degrees) and requires numerous elements,[12] see fig. 9. These devices require positioning drives which take a section of the periphery limiting the space available for diagnostic tools like beam probes. The hill spiral angle is 174 degrees/meter. This steep angle prevents a radial probe from reaching the center of the machine. We have built a probe that moves on a spiral track mounted on the hill,[13] see fig. 10. The tracks, probe and positioning system must fit in the vertical gap on the hill (2.7 cm). The probe consists of a series of cars, not unlike a toy train, that carry the water cooling lines and electrical connections to the probe head. The cars move on wheels that follow the track mounted on the lower hill liner. Spring loaded wheels rest on the top liner to prevent the cars from jumping off the track. The head consists of three fingers (0.6 cm high) mounted vertically one on top of the other, see fig. 11. Normally the beam hits the middle finger. In addition a wire placed in front of the three fingers serves as a differential probe. The sum of all the currents

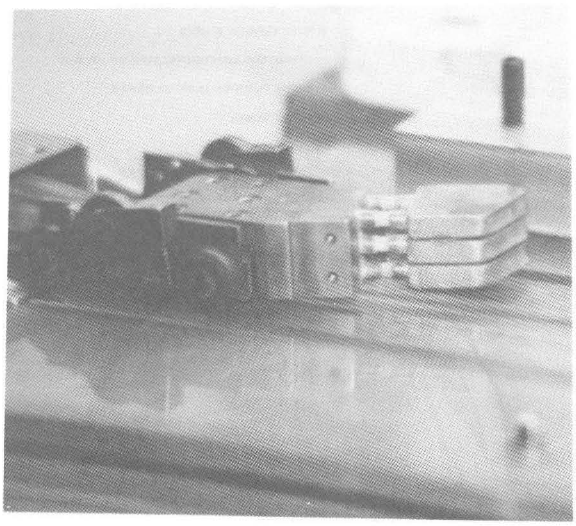

Figure 11: Three finger head of the K500 main probe. The differential probe (wire) has been removed. Spring loaded wheels keep the cars from jumping off the spiral track.

is done in the computer and displayed as total current.

As can be seen in fig. 10, the probe is close to the dees near the center. When the probe is inside a radius of 15 cm, RF pickup prevents us from obtaining a reliable measurement. Besides, RF pickup can freeze the wheels of the cars in that region. Consequently we avoid moving the probe inside 10-15 cm with the RF on. In case of break down the probe can be removed from the machine through a vacuum lock.

There is second probe, the VP probe, of a much simpler design, that moves in a straight line near extraction outside a radius of 50 cm. This probe is a multipurpose probe with interchangable heads. In its basic configuration, it consists of a total and a differential jaw designed to help in the centering of the beam prior to extraction. But it has proven to be sufficient as the only probe during the times that the main probe was under repair. This probe, as well as the main probe, intercepts the beam during the extraction path downstream of the electrostatic deflectors. This same probe drive can be fit with a gamma ray probe[14] designed to determine the RF phase of the internal beam near extraction, and it has also been used to support a target for the radioactive beam studies.[15]

In the extraction region the beam can be measured on some of the focusing elements, that are electrically isolated.

2. K1200

In the K1200 the internal diagnostics have evolved in a different direction from the K500. We have not installed an spiral probe that covers the whole range of radii. The larger radius (1m at extraction) with the same spiral as the K500 would require almost 180 degrees turn for the probe between center and extraction. We thought that the K500 design would not work. Studies continue on how to manufacture such a probe. Instead, a multiple probe approach has been taken. A fixed radius probe at 18 cm pops into the median plane and stops the beam. The next measurement can be done beginning at a radius of 50 cm with the A2 probe.[16] This probe moves on a straight line, from r=50 cm outwards. It consists of a three finger head and a differential wire. This probe runs within 7 cm of the dee. In the point of closest approach the RF pickup is of the order of 1enA, but lower when the probe moves away. This probe intercepts the beam again in the extraction path downstream of both electrostatic deflectors, giving a measure of extraction efficiency on a single probe trace. Our electrostatic deflector is separated in three different sections, with two hinges. The position and shape of the deflector is calculated prior to running the beam, but small adjustments are made during tuning. A new probe not used in the K500 is the target probe located at the end of the first electrostatic deflector. This probe has proven to be very valuable while extracting the beam.

Several ideas are being considered at the present time to improve the internal beam diagnostics in the K1200 cyclotron. We would like to build a probe to study the first few turns in the machine, and designs similar to the centering probe for AGOR[17] have been considered. Techniques related to our beamline diagnostics would be interesting extensions inside the cyclotron.

3. Other superconducting cyclotrons

We will briefly review in this section the diagnostics in use at the Chalk River cyclotron, and the planned diagnostics for the Milan and the AGOR (Orsay-Groningen) machines.

The Chalk River cyclotron[18,19] has two radial probes that move on straight lines slightly offset from the machine center, from a radius of 13.5 cm outwards (see fig. 12). The probe heads have five 1 mm wide fingers spaced vertically to cover a total height of 12 mm, and an integral plate for total current measurements. Early versions of these probes had difficulties associated with RF interference and overheating that have been overcome in upgraded versions. The extraction orbit is monitored by a stub probe 20 degrees downstream of the electrostatic deflector. It consists of two plates that give left-right information on the beam position. It is either fully inserted or retracted, moved by an air cylinder. Fixed horizontal and vertical scrapers have recently been installed. But without doubt the most ingenious and distinctive device is the extraction probe. This probe moves along the extraction orbit. A system of springs centers (see fig. 13)the probe head in the small aperture inside the extraction channel. The head will consist of four quadrants (it is operating with two at the present) to obtain vertical and horizontal information on the beam position. A flexible drive (2.5 m long) inserts the probe from outside the cyclotron.

The diagnostics for the Milan cyclotron are described in detail in another paper at this conference.[20] The main probe is a multi-head probe that moves on a spiral track very much like the main probe in the K500 at MSU. Its ab-

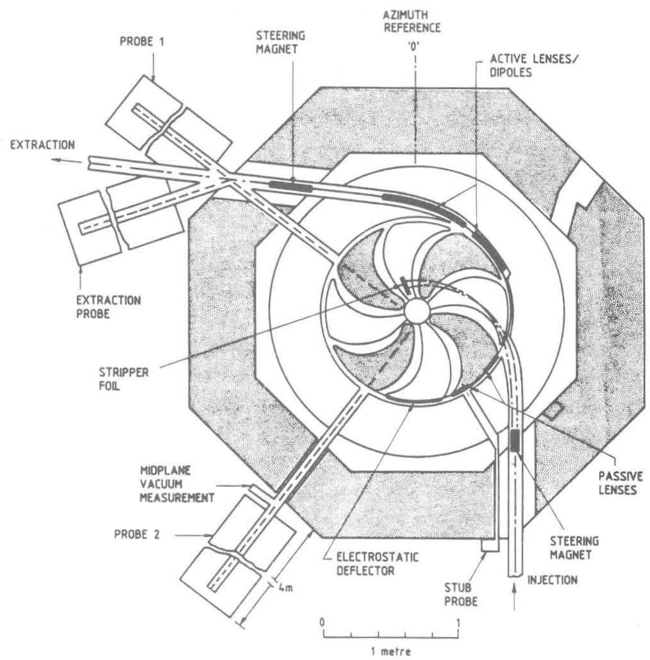

Figure 12: Median plane cross section of the Chalk River superconducting cylotron.

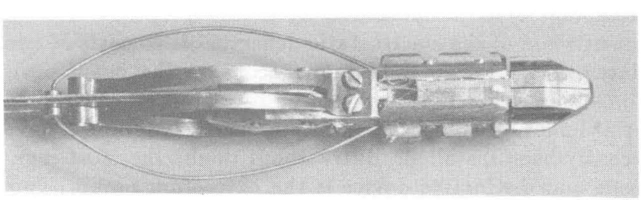

Figure 13: Extraction probe for the Chalk River cyclotron. Note the springs that position the probe within the narrow channel in the extraction path.

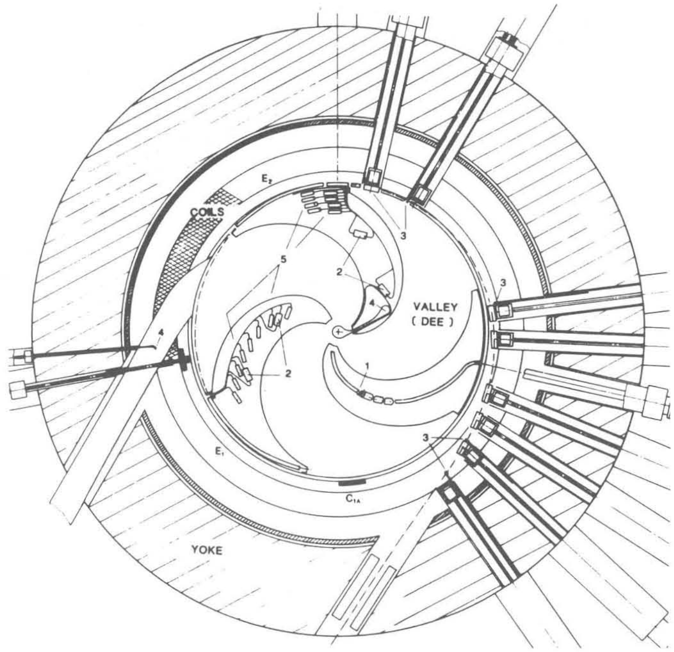

Figure 14: Median plane section of the Milan cyclotron with its beam diagnostics.

solute position is determined by marks on the tracks that are detected by photosensors. This probe will have a four-finger head with a differential plate behind the fingers. A tomography head with three wires is also planned. Two pairs of fixed probes are mounted on the hills not occupied by the main probe and will be used in conjuction with it to determine beam centering. These probes are flipped in and out of the beam by sending a pulse of current that produces a torque which rotates the probes. Four differential probes mounted in front of the magnetic channels will help to position the channels with respect to the extracted beam. A large effort has been put into the design of phase probes.[21] Sixteen low input impedance pick-up probes are placed on two hills covering a radius from 0.33 to 0.88 m, just beyond extraction. These probes are being tested with an electron beam on a bench.

The AGOR cyclotron has a smaller spiral angle from the center to extraction than MSU or Milan, allowing for the use of the much simpler straight radial probes.[17] Three centering probes, one in each hill, flip in and out of beam. A clever string attachment positions them in the beam path. A set of beam phase probes, similar to the probes in use at GANIL, are being planned.

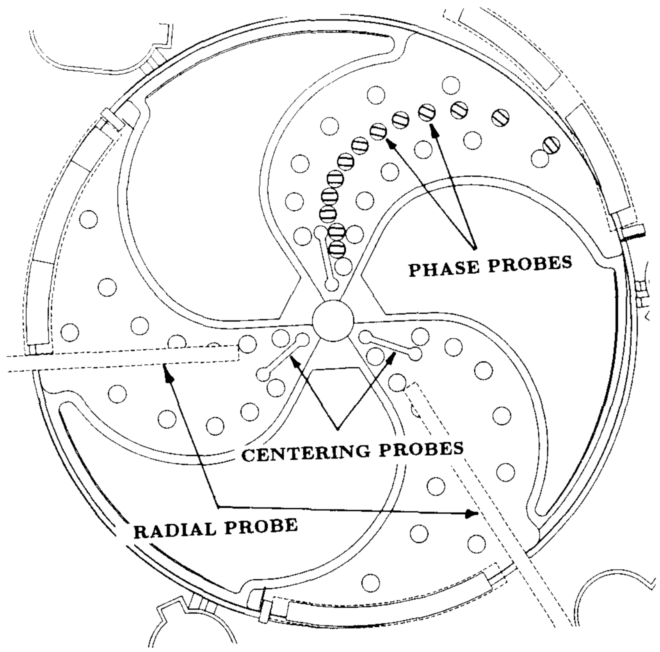

Figure 15: Median plane section of the AGOR cyclotron with its beam diagnostics.

Acknowledgements

We would like to thank Graydon K. Anderson from Los Alamos for his visit to our Laboratory and the many informative discussions we had with him. Work supported by NSF Grant PHY-8611210.

REFERENCES

1) Burton, R.F., D.J. Clark and C.M. Lyneis, *Beam attenuator for the LBL 88 inch cyclotron,* Nucl. Instr. Meth. A270,198 (1988).

2) Ross, M.C. et al., *Automated emittance measurements in the SLC,* in Proceedings of the 1987 IEEE Particle Accelerator Conference, 1987, pp. 725-728.

3) Hassan, A.A., C.L. Fink and M.G. Rosing, *A beam characterization of H^- particles;* and Yule, T.J. et al., *Beam characterization with video imaging systems at the ANL 50-MeV H^- beamline,* presented at the 1989 IEEE Particle Accelerator Conference, Chicago, Ill, March 1989.

4) Russell D.P. and K.T. McDonald, *A beam-profile monitor for the BNL Accelerator Test Facility (ATF),* presented at the 1989 Particle Accelerator Conference, Chicago, Ill, March 1989.

5) Martin, A., Advances in Electronics and Electron Physics, 67,183(1986)

6) Yencho, S. and D.R. Walz, *A high-resolution phosphor screen beam profile monitor,* in Proceedings of the 1985 IEEE Particle Accelerator Conference, 1985, pp. 2009-2011.

7) Anderson, G., LASL, personal comunication.

8) Gutierrez, C.P.,J.R. Mosley and T.C. Wallace, *Electrophoretic Deposition: a versatile coating method,* J. Electrochem. Soc., **109**,923 (1962); and Grosso, P.F., R.E. Rutherford Jr. and D.E. Sargent, *Electrophoretic deposition of luminescent materials,* J. Electrochem. Soc., **117**,1456 (1970)

9) Minerbo, G., *MENT: A maximum entropy algorithm for reconstructing a source from projection data,* Computer Graphics and Image Processing, 10,48 (1979).

10) Data Translation, Inc. 100 Locke Drive,Marlboro,MA 01752-1192,USA and Data Translation GmbH, Stuttgarter Strasse 66, 7120 Bietigheim-Bissingen, West Germany.

11) COHU Inc.,5755 Kearny Villa Road, P.O. Box 85623, San Diego, Ca.

12) Fabrici, E., D. Johnson and F.G. Resmini, *The extraction system for the K500 cyclotron at M.S.U.,* Nucl. Instr. Meth. 184,301 (1981).

13) Fowler, M. and G. Stork, private communication.

14) Milton, B.F. et al., *A gamma ray probe for internal beam phase measurements,* in Proceedings of the 11th Int. Conf. on Cyclotrons, Tokyo, 1986, pp 468-469.

15) Mallory, M. L., *Acceleration of radioactive ion beams in cyclotrons,* in Proceedings of the 11th Int. Conf. on Cyclotrons, Tokyo, 1986, pp 558-565.

16) Ottarson, J., private communication.

17) Laune, B., private communication.

18) Hepburn, J.D., J.D. Walsh and E.H. Williams, *Beam probes for the Chalk River superconducting cyclotron,* in Proceedings of the 1985 IEEE Particle Accelerator Conference, 1985, pp. 1880-1882.

19) Schmeing, H. et al., *Current status of the superconducting cyclotron at Chalk River,* in these proceedings.

20) Acerbi, E., G. Raia, G.C. Rivoltella, L. Rossi, *The beam diagnostics of the Milan cyclotron,* in these Proceedings.

21) Acerbi, E., A. Bosotti, M. Di Giacomo and G. Varisco, *Conceptual design and test of the phase probes for the Milan K800 cyclotron,* in these Proceedings.