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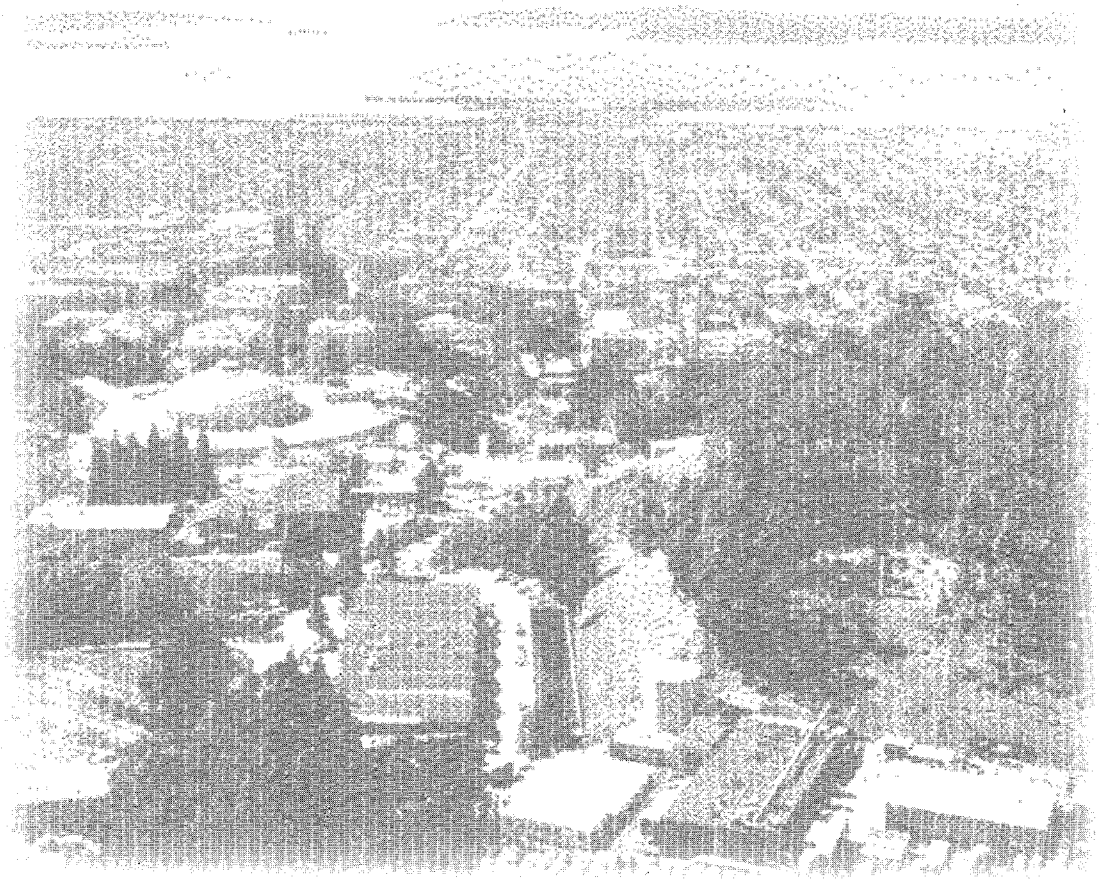

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Phase Width Reduction Project Summary

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Introduction

The purpose of the phase width reduction project, 1993-96, was to reduce the phase width of the 88-Inch Cyclotron beam on target from 5-10 ns to 1-2 ns for certain experiments, such as Gammasphere, which use time-of-flight identification. Since reducing the phase width also reduces beam intensity, tuning should be done to also optimize the transmission. The Multi-turn Collimator slits in the cyclotron center region were used to collimate the early turns radially, thus reducing the phase width from about 5 ns to 1-2 ns FWHM for a Gammasphere beam. The effect of the slits on phase width was verified with a Fast Faraday Cup and with particle and gamma-ray detectors in the external beamline.

Multi-turn Collimator

Because of the correlation of beam position with energy and phase in the early turns, the radial collimation of beam here results in the collimation of phase. A Multi-turn Collimator, designed over 20 years ago by Don Morris, was fortunately still available for use in collimating the beam in the center region. It is shown in Fig. 1. It consists of two slit systems, Col. 1 and Col. 2, each mounted in a shaft coming into the cyclotron just after the deflector at 120 degrees counter-clockwise from the south end of the north-south center line. Each of the two collimators has two tantalum fingers whose gap and position are motor driven and can be remotely controlled from the Control Room console, rack A13. Col. 1 is used at smaller radius and Col. 2 at larger radius. Also each slit can be rotated into or out of the beam from the Control Room with another motor drive. Normally the slits are out of the beam, as can be verified by a limit light. The slit supports were originally water cooled, but due to water leakage into the vault which was difficult to repair, the slits are now air cooled from LN boil-off.

After the slits were first used on some beam development runs, they were removed from the cyclotron and set up on a bench for maintenance and modification during 8/94 - 2/95. Local motor power supplies, pot potentials and controls were set up. The various motions of up/down, position and width were checked out. Backlash was reduced. Slit finger widths were changed from .2 in. for both collimators to .3 in. (Col. 1) and .15 in. (Col. 2), to match turn separation in the radial ranges of Col. 1 and 2, Fig. 1. These values are appropriate for a typical Gammasphere beam, 200 MeV Ar^{9+}. For a beam with much lower turn number there is not enough collimation, while for much higher turn number the beam doesn't clear one blade.

The position and gap readings were re-calibrated. The Collimator system was then re-installed in the cyclotron. The local control box is stored in cabinet A66, west of the EM shop. The calibration graphs are shown in Fig. 2. Col. 1 operates at radii of 5-11 inches, while Col. 2 operates at larger radii, 9-13 inches. The azimuthal offset of the fingers was removed for simplicity, but this removal was later found to cause interference of Col. 2 with the upper dummy dee water line, so the inner limit of Col. 2 was set to 9 in. rather than 7 in. The inner limit can be restored to 7 in. by returning to the original design, if desired.

Diagnostics

A. Fast Faraday Cup

The primary phase width monitor is the Fast Faraday Cup, Fig. 3. It gives immediate (typically within 1 sec.) information on a scope showing the beam pulse shape, while particle counter techniques may require a minute of counting time. This fast response is very valuable in tuning the many cyclotron and beam line parameters for narrow phase width.

The beam is stopped by the Cup on a tantalum plate, which is part of a tapered 50 ohm line that reduces to match a co-ax cable at the back end. The front tantalum collimator can be insulated for biasing - negative for suppression of secondary electrons, or positive for extracting secondary electrons, giving a signal gain. Bias can remove the tail on the beam pulse. Also a thin foil can be clamped on following the collimator, for biasing. It was found that the higher intensity beams (several μA) burned a hole in the foils tried, aluminum and havar. A wire grid used here also broke and shorted. The collimator and foil/grid should be connected to a power supply or grounded, when used. Since the foil/grid had problems, their mounting was removed and the collimator was moved closer to the cup.

The Cup was built in two versions. Version 1 has a coax cable connection from the cup to a feed-through on a nearby plate of the beam box. The cable flexes in vacuum on every insertion. Version 2 is an improved design that runs the co-ax cable up the support shaft, with no flexing of the cable in vacuum. Version 2 also has water cooling on the ground side of the cup and is fully remote-controlled for insertion on an air cylinder from Control Room console rack A12. Normally Version 1 is stored in the east alley storage and Version 2 is in the beamline at the end of Cave 4, a low noise position near a point of interest, Cave 4, containing Gammasphere or the 8 pi spectrometer.

The signal from the Cup is normally amplified by an HP 8447F preamp/amp combination close to the Cup. The HP 8447F has a gain of about 250, and is linear up to 7 mV input, or 1.7 V output. It has a bandwidth of 100 kHz to 1.3 GHz, down 6 db at 75 kHz and 1.5 GHz. In some cases a ferrite ring around the cable can suppress high frequency oscillations. The signal is sent to the control room by a low loss cable, Andrew Heliax, 7/8 in. dia. Two of these cables have been installed, one from the vault, near the switching magnet, and one from Cave 4 near the Cave 4C beam plug, to rack A11, bottom row, in the control room. The rf synthesizer synchronizing output is also connected here. These signals can be connected to a sampling scope. An AVTECH AVMM-1-C pulser, purchased for the project, can produce a signal simulating beam pulses with widths down to 1 ns and repetition rates up to 25 MHz. This signal can be used to test the amplifier, or can be sent down the cable from the Faraday Cup to the control room. This pulser is kept in a cabinet in Dennis Collins' lab.

The first sampling scope used was a Tektronix CSA 803, with a color touch screen. Presently we use a Tektronix TDS 820, purchased for this project, with simpler operation and a black and white screen. It has a sensitivity of 2-200 mV/div, with maximum usable input of 1.6 V PP, and safe input up to +/- 6 V. Sweep speeds are 20 ps - 2 ms/div. The internal trigger requires 80 mV PP and the external trigger requires 40 mV PP, with maximum of +/- 1.5 V. Since the beam signal is usually less than 50 mV, the external trigger is normally used, obtained from the rf system synthesizer. The response time is a fraction of a second to a few seconds. We can select the number of traces to average to improve the signal to noise ratio in a trade-off with response time. For example with 20 nA on the Cup, the response time is about 5 sec. The scope picture can be recorded with a Canon BJ-30 bubble jet printer. The collimator bias is run on a standard 50 ohm cable to junction box SJ30 in Cave 4 and then to Rack A628, plug 2 in the control room. It can be biased negative to suppress secondary electrons from the Cup, but this can cause production of secondary electrons from the collimator itself. Recently it has been run 100 V positive to collect the Cup secondary electrons quickly, to avoid distortion of the fast signal by the cloud of secondary electrons. This polarity gives some signal amplification also. Instructions for use of the Cup in Cave 4 are given in Appendix 1 and instructions for Cup removal from the beam pipe are given in Appendix 2.

With 100 nA of beam on the Cup, without phase reduction, the amplified signal to the scope would be 12 mV peak, assuming 10% microscopic duty factor. This is about 6 divisions on the scope at maximum sensitivity, and normally visible above the noise at fast (1 sec.) response time. Positive Cup collimator bias will increase this signal. A display is shown in Fig. 4.

The Cup can also be used to measure the pulse width and rise time of beam pulsed with electrostatic plates in the axial injection line. The instructions given in Appendix 1 can be used, except that the scope trigger (+/- 1.5 V max.) comes from the pulser, not the synthesizer. If the pulsing is not synchronized with the rf, the amplitude on the scope will not represent the peak values of the case above, but average values of beam intensity, since the microscopic pulse pattern will shift from one pulser pulse to the next. So the amplitude on the scope will be lower by the duty factor (≈10%) than for the synchronized case. In this non-synchronized case it would be better to use a fast analog (≈100 MHz) scope than to use the sampling scope. One could also use the fast scintillator or gamma detector (below) with an analog scope.

B. Particle and Gamma-ray Detectors

A fast scintillator plastic particle detector with photo-tube (-1400 V bias) can be inserted into the beamline by an air cylinder controlled from the control room, to count individual particles in the beam using standard counting electronics. It is presently installed in a box in vacuum on beamline 4C at the downstream end of Cave 4, near the Fast Faraday Cup. The fast cable from Cave 4 to the control room is used for either the Fast Cup or this scintillator signal. A TAC in the Control Room is used to display the time structure on a multi-channel analyzer, with a signal from the rf synthesizer as a stop signal. The circuit is shown in Fig. 5. The intensity must be reduced with attenuators in the axial injection line. The counting takes about a minute, and so is more difficult to use in tuning than the Fast Faraday Cup. But it provides a useful calibration for the Fast Cup. There was good agreement between the scintillator and Fast Faraday Cup measurement of phase width.

Information similar to that from the scintillator above can be obtained from a BaF gamma ray detector and phototube (+1400 v bias) placed in air just outside the beam pipe at a Faraday cup. It also uses standard counting electronics, Fig. 5, and needs a beam attenuator to adjust the intensity.

C. Wire Probe Scanning

A vertical tantalum wire, .030 in. diameter, is placed at the end of the Target Probe which can traverse the cyclotron beam acceleration region from a mounting port between DP3 and the staging line. Current can be read from the wire and plotted on the chart recorder in the control room. The turn pattern of the beam can be seen in this plot, and indicates how far out in radius turns can be seen, and thus how close we are to single turn extraction. For a 200 MeV Ar^{9+} beam, about 200 turns of the predicted 220 turns can be seen, when using the Multi-turn Collimators. The turns generally overlap. Note that a gate valve has to be opened to run this probe in.

Dee Voltage Regulation

Single turn extraction conditions are necessary for the narrowest phase width. Dee voltage needs to be measured to .1% and regulated to about .2% against ripple and drift. Dee voltage ripple is monitored with a Tektronix 2235 scope at A17 using a demodulator built by D. Collins (to right of scope). The rf signal is picked up capacitively in the final rf amplifier box at the "tub sample" point. The line voltage ripple on the scope is normally 2 mV P-P or less, for 60 kV of rf. The most sensitive gain of 2 mV/div., AC, is normally used. The other scope channel is used in parallel with a dc gain of 1 V/div. to monitor dc level. The dc level is about 1 V for 60 kV of rf. To find the rf ripple relative to the rf 0-peak level, we divide the scope ripple value by the scope dc value and divide the result by 1.5 for demodulator effects. The ripple has been reduce from .3-.5% to about .2-.3% with electronic improvements. It is assumed that the % ripple of the dee voltage is the same as that at the final amplifier where it is measured.

This system provides a sensitive monitor of the stability of the rf system, which can be important for special beams such as single turn extraction studies. If the rf ripple is low one can see evidence of single turns on the Beam Stop as the dee voltage is changed a few hundred volts.

Calculations

Orbit calculations were made of the central region of the cyclotron to understand the effect of the defining slits ("Multiturn Collimator") in defining the beam phase. Computer programs used were from NSCL, Michigan State University. The first was RELAX3D (originally from TRIUMF) for the three-dimensional calculation of the electric field potential map of the center region electrodes: the dee and dummy dee inserts and the inflector. The second is Z3CYCLONE for calculating the particle orbits produced by the magnetic field and the electric potential during its sine-wave oscillations.

Orbits, starting with a spread of phases and realistic transverse emittance area, were tracked through the electrostatic inflector and through acceleration in the center region. Tracking was carried to full radius in some cases to be sure that the orbits were suitable for extraction. The valley coil azimuthal locations of magnetic field maxima were recalibrated against the control room azimuthal readouts by measuring the positions of the maxima with a Hall probe with the dee tank open (Ref. 1). The amplitude calibration was also checked. This permitted accurate values of these coil effects to be included in the calculations. The definition of phase in the program was improved to make it independent of centering, with help from NSCL. With these improvements, there was good agreement between centered orbits in the calculation, with valley coils included, and actual cyclotron runs. Examples of calculations are found in a notebook (Ref. 2)

Beam Development Runs

A series of beam development runs were made to develop the methods of reducing the beam phase width. Records were kept in a logbook (Ref. 3). A typical Gammasphere beam was chosen as a standard beam: 200 MeV $^{40}Ar^{9+}$. This beam is near the top of 3rd harmonic operation, like a Gammasphere beam, with an energy of 5 MeV/u.

In a typical Gammasphere simulation run the beam would be tuned well on the beam stop, and then the transmission maximized to FC4C1 near the Fast Faraday Cup at the end of Cave 4, using the New High Transmission Solution for Cave 4C (Ref. 4). Then the Fast Faraday Cup would be used to monitor the phase width while minimizing it with the Multi-turn Collimators and other cyclotron parameters. Collimator 1 was typically set to about 5 inch radius, near the inner limit of its range, and .1 inch gap. Collimator 2 was used on some runs, at about 12 inches radius and .1 inch gap. The phase width could be verified with the particle or gamma-ray detectors. Some of the parameters affecting the phase width are valley coils, rf frequency and dee voltage. Two beam line motor-driven collimators in Cave 3 which sometimes help define the phase width are vertically moving AS3A1Y near a vertical waist and horizontally moving AS3A2X near a horizontal waist.

During a 3 day run in 2/96 with 114 MeV 22Ne to Gammasphere, the phase was monitored with the Fast Cup. The phase width was 1.2 - 1.4 ns and the drift was about 1 ns, probably due to cyclotron main or trim coil drift.

The Multiturn Collimator was tested with the highest energy beam, 130 alphas, in 11/96. It was found that Collimators 1 and 2 completely blocked the beam at all settings because of the reduced turn spacing in the cyclotron, smaller by a factor of 2.5 than the Gammasphere beams. To use the Collimator with this beam, narrower slits would have to be used.

Some low energy hydrogen and deuterium beams of about 1 MeV/u were run in 1997-98 by the Wozniak group for studies of neutron production. For these low turn number, wide turn spacing beams Collimator 1 was used with closed gap, acting as a single finger, at its larger radius region. Collimator 2 could then be used, also with closed gap.

A variation in optics which could be tried is to use a wide beam rather than a waist at the switching magnet to reduce the energy spread of the beam, and thus the phase width, with a following slit, since phase and energy are correlated. For more energy resolution the High Resolution Solution for Cave 4C (Ref. 4) with defining slits at AS3A1 and AS41 could be used.

Recommendation for Future Improvements

The present Multi-turn Collimator 1, which goes to smaller radius than No. 2, has a minimum radius of 4.6 inches (See Fig. 2). For Gammasphere and BGS beams at 5 MeV/u the first turn has a radius of about 3 inches. The phase selection would be cleaner if this collimator could be used on the first turn. So we would move the inner limit of the collimator position and gap in about 2 inches with extensions on their support structure. The slit fingers would need to be widened because of the greater turn separation here. Multi-turn Collimator 2 could be unchanged, for larger radius collimation.

Acknowledgments

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References

1. Note: 88" Cyclotron Valley Coil Measurements by D. J. Clark, 7/29/94 in DJC MAC Folder "Valley Coil Meas. 7/94"
2. Notebook "Cyclotron Central Region Calculations - 1994", Clark/Xie.
3. Log Book: Phase Width Studies 1994 - .
4. Note: The Beam Optics System for Gammasphere by D. J. Clark, 1/9/95, distributed to control room, etc.

Appendix 1 - Run set-up instructions with new Fast Faraday Cup (FFC) and sampling scope. Return equipment after run.

1. Roll out cart with Tektronix TDS 820 sampling scope from Dennis Collins Lab room 138B, to control room near console. Cart also has Canon BJ-30 printer on top of scope and small bias supply HP6212C on lower shelf.
2. Plug in AC power cords of scope, printer power module, and bias supply, and turn on their power switches.
3. Test scope and operator's scope knowledge by connecting 50 ohm cable (green) from the RF synthesizer plug at A30, bottom, to Channel 1 of the scope. The trigger choice should be set to Chan. 1. This will display a square wave trigger signal of about 1.5 volts whenever the synthesizer is on (almost all the time). To get scope trace the vertical, horizontal and trigger level have to be set properly. If no trace appears, try "Autoset" button .
4. After a trace appears on the scope the printer can be tested by loading paper at back, pushing "on line" button, "form feed" if necessary and "Hardcopy" on scope. A reproduction of the screen should appear.
5. Connect the cables for operation with beam.
   a) Connect 50 ohm cable from the synthesizer to the scope trigger
   b) Connect 50 ohm cable from the Cave 4 FFC plug at A11, bottom, to Chan. 1 of the scope.
   c) Connect bias supply to FFC front collimator bias at A6, Cave 4 section. Set to +110 V. Current should be 0 on meter.
6. In Cave 4 at FFC, turn on power to HP 8447F amplifier with front push button.
7. Tune Gammasphere/8π beam optics for maximum transmission to FC4C1 and small round beam spot at phosphor PH4C1. Note transmission from beam stop to FC4C1.
8. Set beam level at FC4C1 to 100 nA or less, insert FFC with push button on A12 and remove FC4C1 to look for beam trace on scope. (FFC amplifier has AC input and so FFC won't read on a standard meter unless connections are changed in Cave 4. There is a 1 k-ohm bleeder at the FFC to discharge dc current).
9. Several useful features of the scope are as follows. Cursors can be selected with the "Cursor" button. On the "Measurement" menu the "Select Measurement"-"Positive Width" buttons can be used to show full-width half max. of trace on the screen, a useful feature so the cursors don't have to be set on each measurement. On the "Acquire" menu "Mode Average" can be used with handwheel to average over a number of traces for a clear trace. More traces give a slower but clearer response.

Appendix 2 - Complete removal of Fast Faraday Cups from beamline box, and replacement.

Old Cup:

Removing old Fast Faraday Cup from beamline box: (8/96)

This cup is manually plunged and retracted when in use.

1. Disconnect signal and bias cables from Cup.
2. Plunge Cup manually into beamline.
3. Rotate Cup & shaft 90 deg.
4. Remove box bolts and lift Cup and faceplate assembly slowly out of box.
5. Check for residual radioactivity and store in bag.

Installing old Fast Faraday Cup: Reverse above procedure.

New Cup:

Removing new Fast Faraday Cup from beamline box: (8/96)

This cup is air actuated for plunging and retracting.

1. Blow down water if it was used.
2. Disconnect water at Cup connection.
3. Disconnect signal and bias cables from Cup.
4. Plunge Cup into beamline from control room.
5. Disconnect air and air cylinder electrical plug.
6. Loosen clamp on shaft to permit shaft rotation.
7. Rotate Cup & shaft 90 deg. while adjusting position of brass spacer on air cylinder shaft for clearance.
8. Remove box bolts and lift Cup and face plate assembly slowly out of box.
9. Check for residual radioactivity and store in bag.
10. Reverse procedure to re-install Cup.

Installing new Fast Faraday Cup: Reverse above procedure.

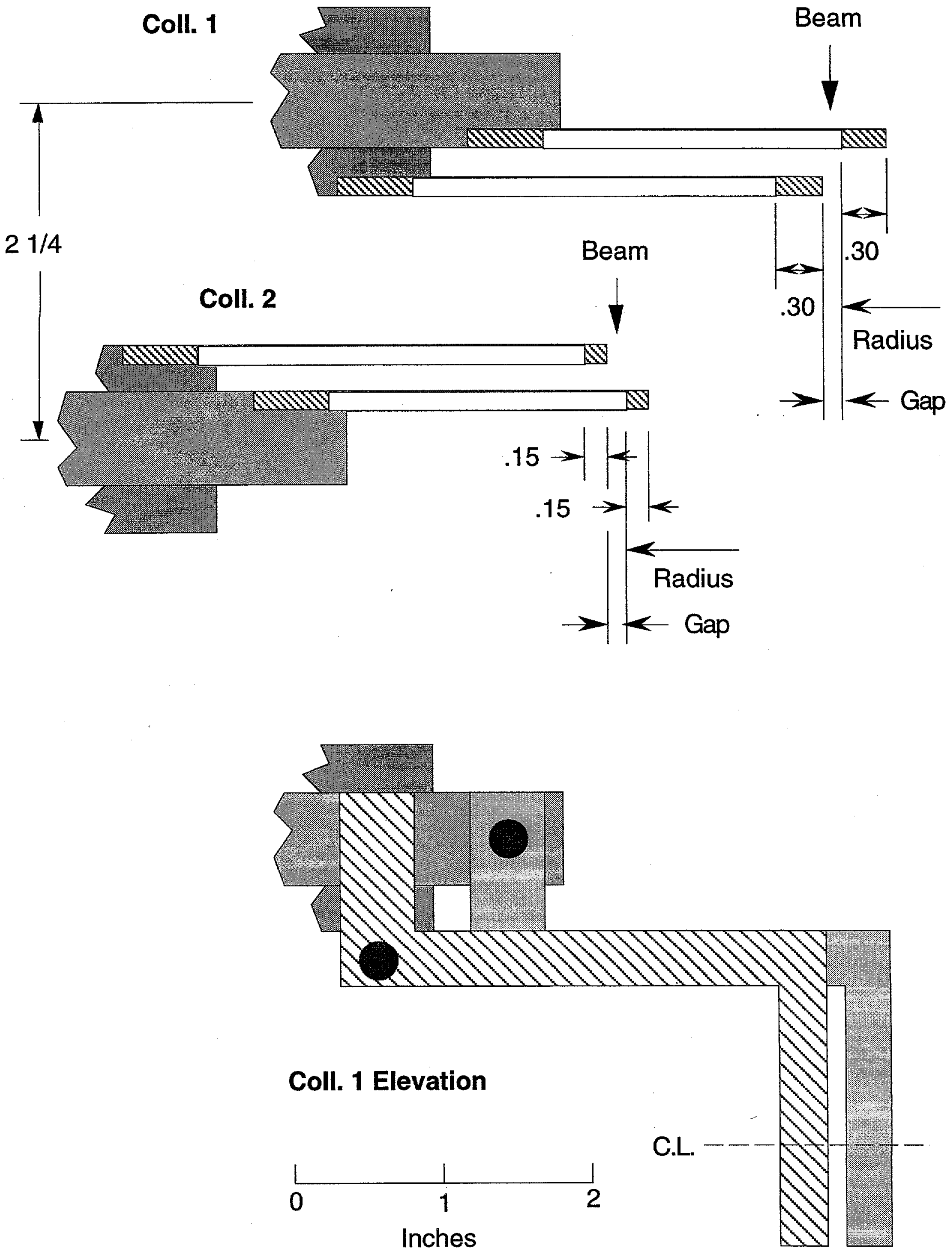

Fig. 1. Multi-turn Collimator layout

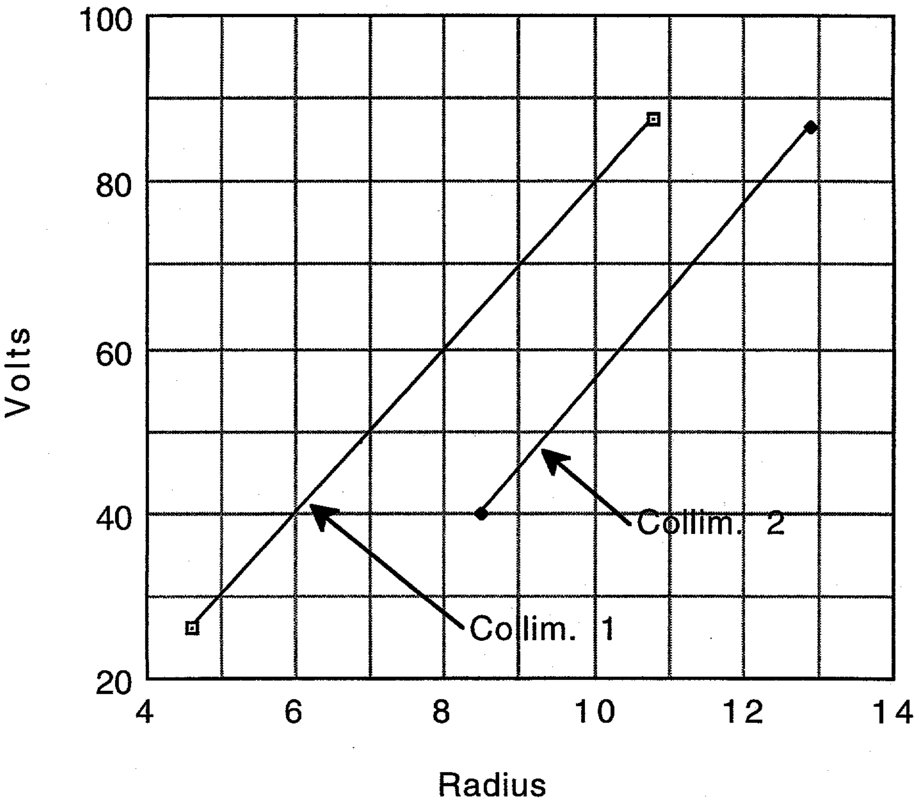

Fig. 2. Multi-turn Collimator calibration

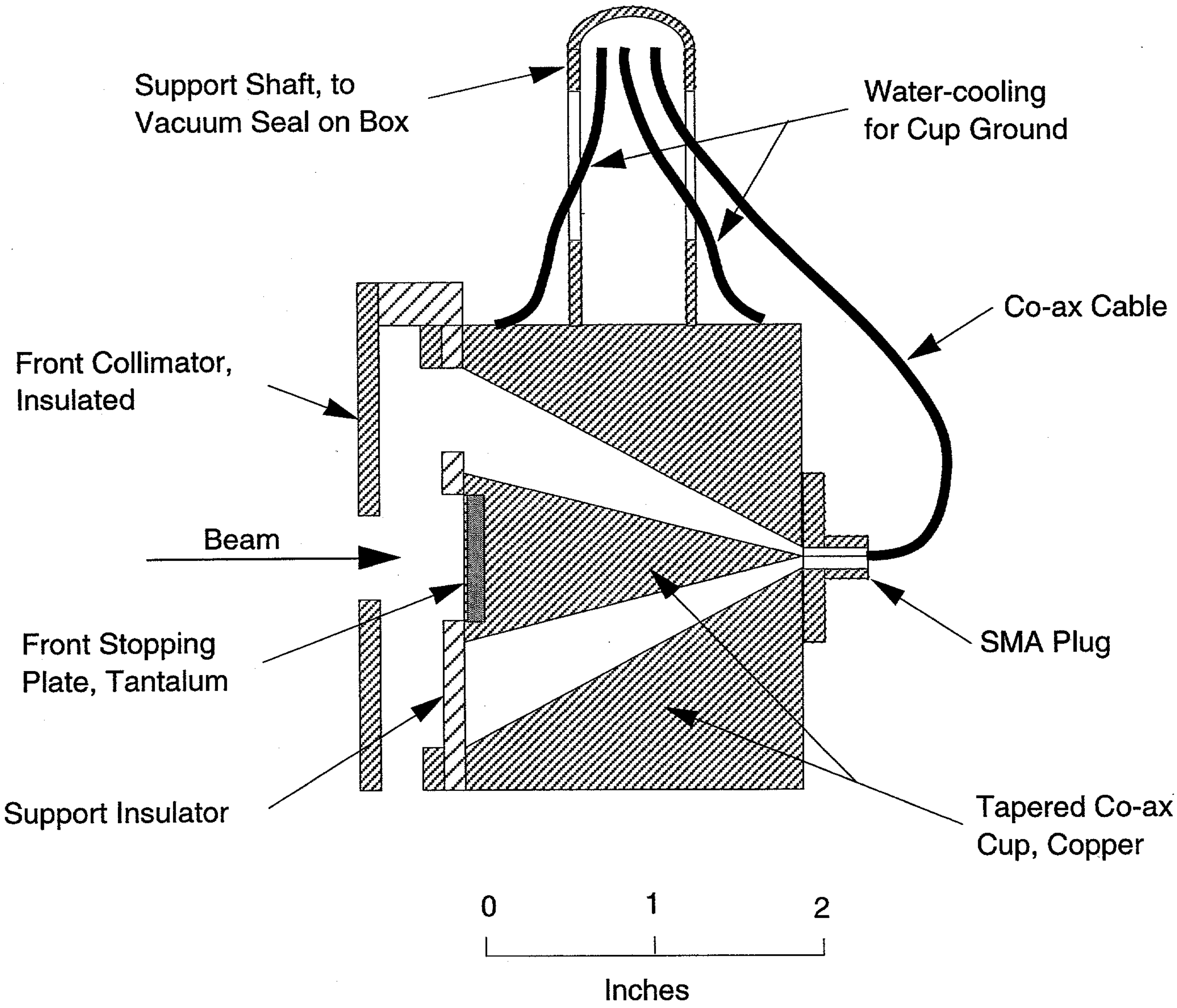

Fig. 3. Fast Faraday Cup, version 2

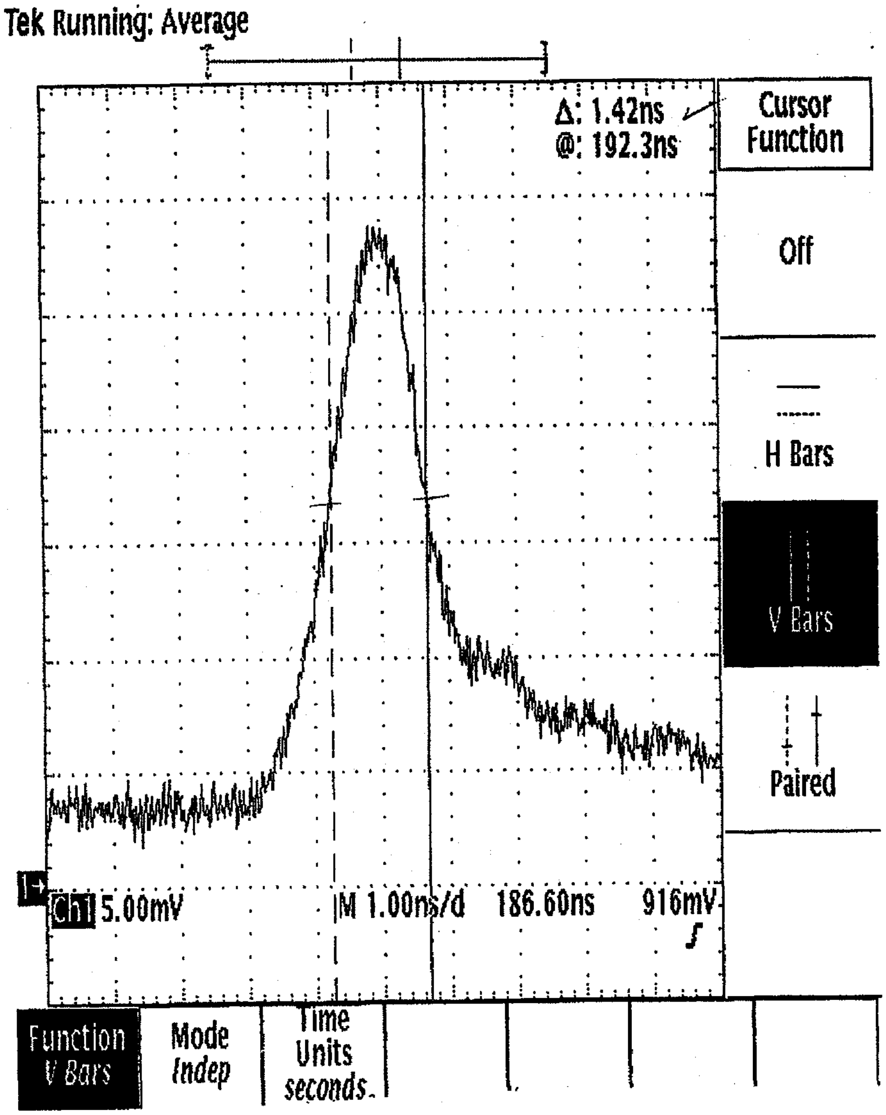

Fig. 4. Display of beam pulse shape from Version 1 Fast Faraday Cup in Cave 4 at end of 4C line. The signal goes through an HP 8447F fast amplifier to a Tektronix TDS 820 sampling oscilloscope in the control room. The horizontal scale is shown as 1 ns/div, and vertical scale 5 mV/div. The Multi-turn Collimator was used to reduce the phase width from 2.4 ns to 1.4 ns FWHM, reducing the intensity by a factor of 10. Gammasphere run beam is Ne-22, 6+, at 114 MeV, 2/21/96, 1220.

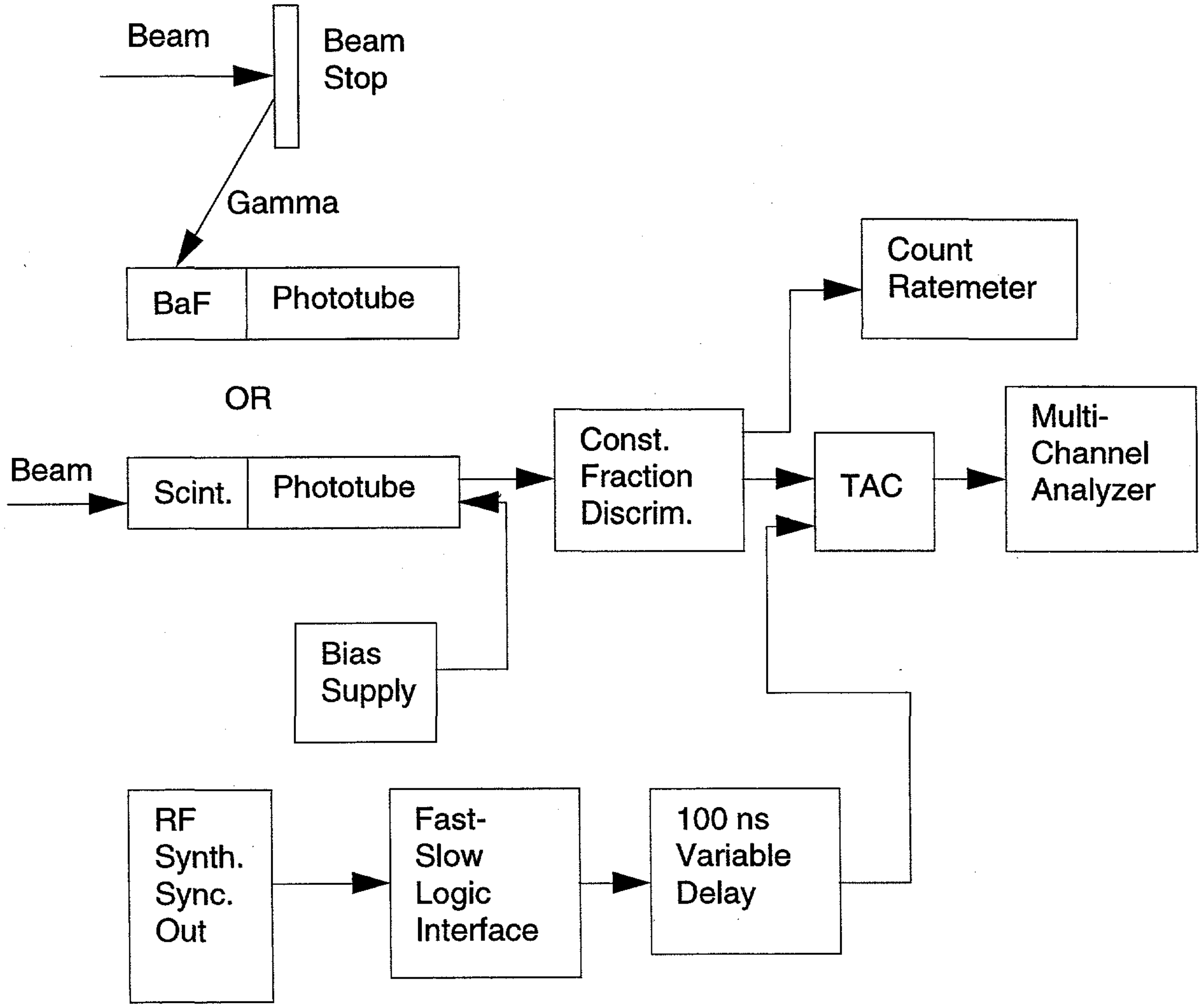

Fig. 5. Electronics schematic for beam pulse shape measurement with BaF detector or in-beam scintillator.

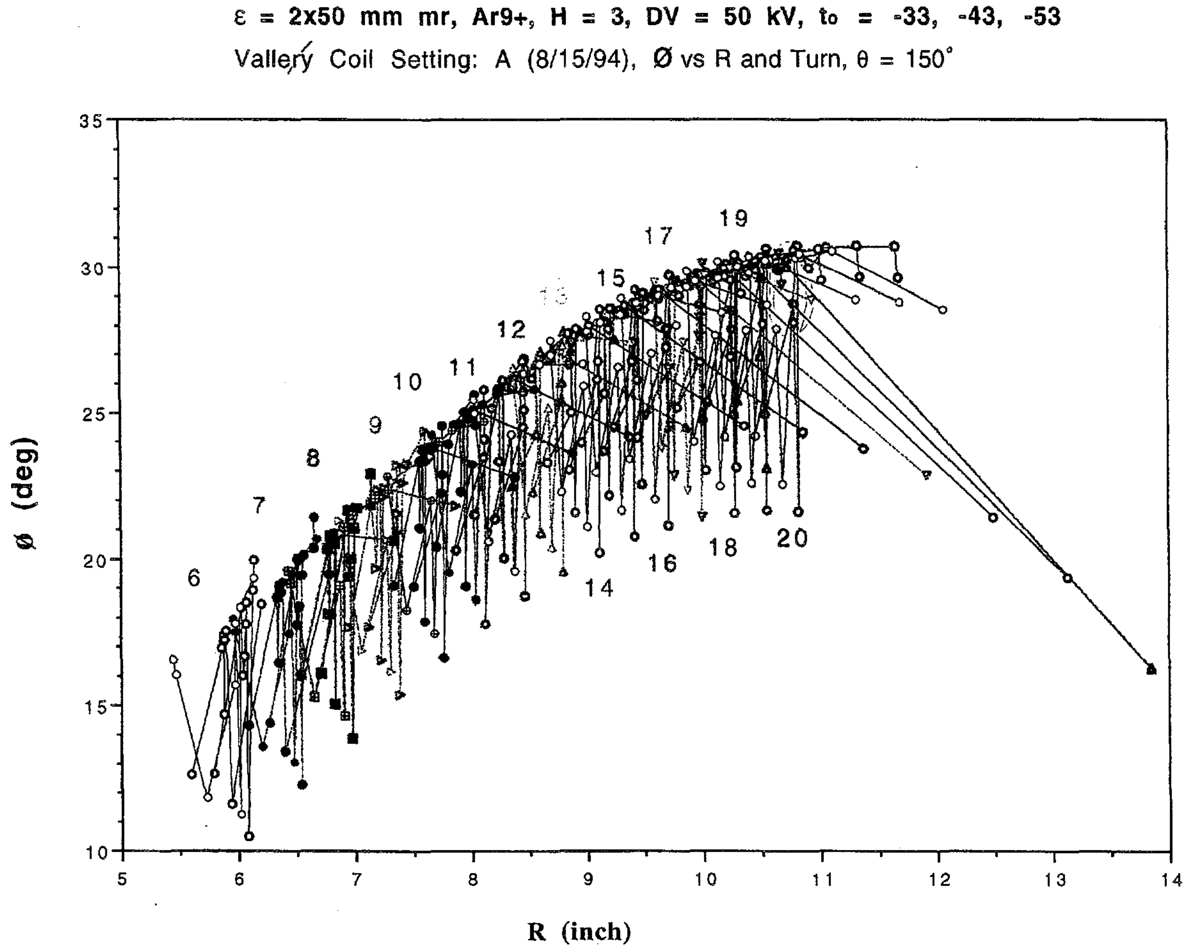

Fig. 6. Calculation of position of orbit, Phi vs. R, as it crosses the Multi-turn Collimator azimuth, for a selection of phase space and starting phase, using the tracking program Z3CYCLONE.