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CURRENT STATUS OF THE BERKELEY CYCLOTRINO

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Publication Date

1988-06-01



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Presented at the 13th International Radiocarbon Conference,
Dubrovnik, Yugoslavia, June 20-25, 1988

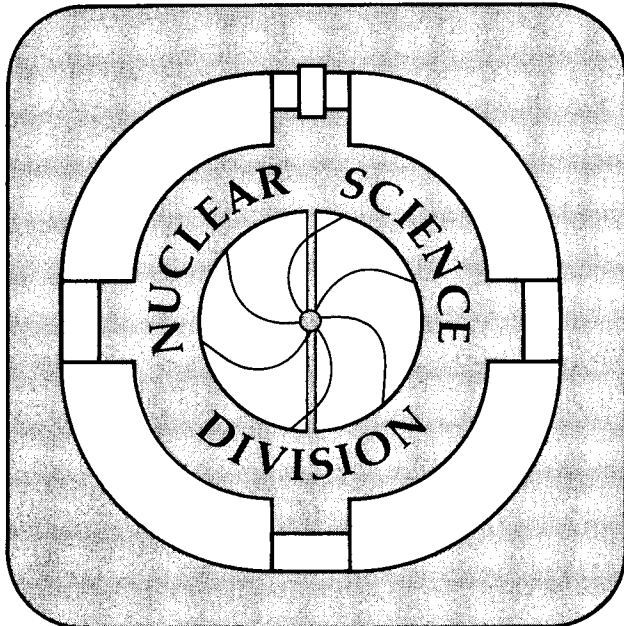
Current Status of the Berkeley Cyclotron

K.J. Bertsche, P.G. Friedman, R.A. Muller,
and J.J. Welch

June 1988

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CURRENT STATUS OF THE BERKELEY CYCLOTRINO

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Abstract

A small, low-energy cyclotron ("cyclotrino") has been designed and built at Berkeley for direct detection dating of ^{14}C with applications to archaeology, geology, and medicine. The system combines the use of a negative ion source to reject ^{14}N with the high resolution of a cyclotron to reject other background ions. We have shown previously that the system has the necessary resolution and background suppression for ^{14}C dating. A new version has been built that allows the microampere currents required for direct detection of modern carbon. Initial tests of the new system will be reported.

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1. Introduction

In response to the heavy demand and relatively high cost of existing accelerator mass spectrometry (AMS) techniques, the small cyclotron ("cyclotrino") project was begun at Berkeley in 1981 (Muller, et al, 1981). The basic idea was to combine the excellent properties of a cyclotron used as a mass spectrometer (Muller, 1976) with the capabilities of negative ion sources to reject unwanted backgrounds such as ^{14}N (Nelson, Korteling and Stott, 1977; Bennett, et al, 1977). A device was envisioned which would be smaller, simpler to operate, and lower in cost than existing devices.

Our initial work has emphasized ^{14}C , partially because of the many users interested in this isotope, and partially because the required mass resolution and beam currents are relatively easy to obtain. Measurements of ^{26}Al , ^{10}Be and ^{32}Si are also possibilities with this system but have not yet been pursued.

2. Design

Design of the cyclotrino has been detailed previously (Welch, et al, in press; Bertsche, et al, 1987) and will be summarized here. The cyclotrino operates with negative ions to avoid interference from ^{14}N . With ^{14}N eliminated, the nearest interfering mass is the molecular ion ^{13}CH , which is heavier than ^{14}C by a part in 1800. This sets the minimum resolution requirements. High resolution is obtained by operating at a high harmonic (9th to 15th) and by using a very flat magnetic field, which causes orbits to be isochronous and hence allows ions to make many turns (100 or so) in the cyclotron. Focusing is purely electrostatic; the flat magnetic field precludes weak focusing. A 12-inch NMR-type laboratory magnet is used, operated at about 10kG. Beam is injected at an energy of less than 5keV and extracted at about 40keV. A custom microchannel plate detector was designed and built to detect the output ions (Friedman, 1986; Friedman, et al, 1988).

The ion beam is injected into the cyclotron using a novel radial injection method, shown schematically in fig. 1 (Morris, 1986). After entering the magnet it is deflected in an electrostatic channel. It curves through a 180° arc, whereupon it strikes an electrostatic mirror at normal incidence. After reflection the beam travels along a circle which is nearly centered on the

cyclotron axis. A final electrostatic deflection channel shifts the beam orbit slightly to center it and to provide clearance between the electrostatic mirror and the beam's first orbit.

A beamline transports the beam from the ion source to the cyclotron, shown schematically in fig. 2. An einzel lens captures and slightly focuses the output of the ion source. The beam is further focused to a slit with an electrostatic quadrupole lens. A Wien filter (velocity selector) focuses the mass 14 beam to a second slit, deflecting the mass 12 and 13 ions to a current monitor to provide normalization for ion source output fluctuations. The mass 14 beam (containing ^{14}C and molecular ions such as ^{13}CH) is focused and steered into the cyclotron with a combination of four electrostatic quadrupole lenses.

A beam buncher has been suggested for the small cyclotron, since RF phase acceptance is small (Welch, et al, 1984). The present design allows insertion of a short buncher in the beam line. Alternatively, the quadrupole lenses could be used for beam bunching by coupling an RF signal to the lens electrodes.

The present system is shown in fig. 3. The cyclotron is dwarfed by the injection beamline. By careful design of the lenses and by fixing some degrees of freedom of the system, this injection system could shrink by a factor of two or so. The present size is useful for system development, however, since it allows additional flexibility in the positioning of beam optics.

3. Performance

The design, operation, and performance of an early version of this system has been explained in detail previously (Welch, 1984; Welch, et al, 1987). System performance is illustrated by the mass resolution curve shown in fig. 4, operating at mass 12 on the 11th harmonic. The horizontal axis is calibrated in frequency, which is inversely related to mass. The count rate dropped 10.7 orders of magnitude from the peak to the background with less than 1 part in 1800 frequency (mass) offset. This resolution is adequate for ^{14}C dating.

Unfortunately, ^{14}C at natural levels (one part in 10^{12}) was not detectable in the early version of the cyclotron because its count rate was

below the background of 3 counts per hour. The low count rate was due to the limited performance of a compact ion source located in the central region of the cyclotron. This simple internal ion source eased development and testing of the system, but it could only produce a maximum of about 1nA of C⁻. The system efficiency (fraction of ¹⁴C⁻ reaching the detector) was about 0.5 to 1 percent (Welch, 1984; Welch, et al, 1987). A factor of 100 higher current was needed to see ¹⁴C in modern carbon and another factor of 50 for 30,000 year old samples. Thus, an ion source with about 5000 times higher current (about 5μA) was needed. Hence the current version of the cyclotron with its external ion source.

The performance of the cyclotron is quite promising. The current version of the cyclotron is expected to have a system efficiency (as defined above) of about 10⁻³. It should be possible to improve this by a factor of ten (to about 1%) by optimizing some lens geometries and adding a beam buncher. If this is done, an ion source current of 30μA should result in about two counts per second for modern carbon. For the expected ionization efficiency of 3%, 1000 counts (representing a statistical uncertainty of 3%) could be accumulated in just over 8 minutes from a 70μg sample of modern carbon.

4. Future Plans

The present version of the cyclotron has not yet detected ¹⁴C in modern carbon. It is expected that we will have beam within the next few months.

In addition to archaeological applications, a group of biomedical researchers at Berkeley is quite interested in using the cyclotron for metabolic studies (T.F. Budinger, 1988, pers commun). In this application, a ¹⁴C-tagged compound is introduced into a patient, then fluid samples are taken periodically. The fluid (generally blood) is separated into various fractions by liquid chromatography, and each fraction is tested for ¹⁴C concentration. The cyclotron can contribute to this research by increasing the sensitivity and throughput over the present decay-counting techniques. A gas source will probably be used for this research to enable rapid sample changing and simpler sample preparation.

We thank Dave Clark, Klaus Halbach, John Meneghetti, Don Morris, Dave Plate, and Robbie Smits for helpful discussions, and Peter Bokavich, Armi Meuti, Erv Taylor, Bill Wilke, and John Wool for assistance in obtaining materials and manufacturing the various pieces of this system. We are very grateful for the assistance of the many other employees of the Lawrence Berkeley Laboratory who have worked on this project in its various stages. This work has been supported by the U.S. Department of Energy under contract DE-AC03-76SF00098.

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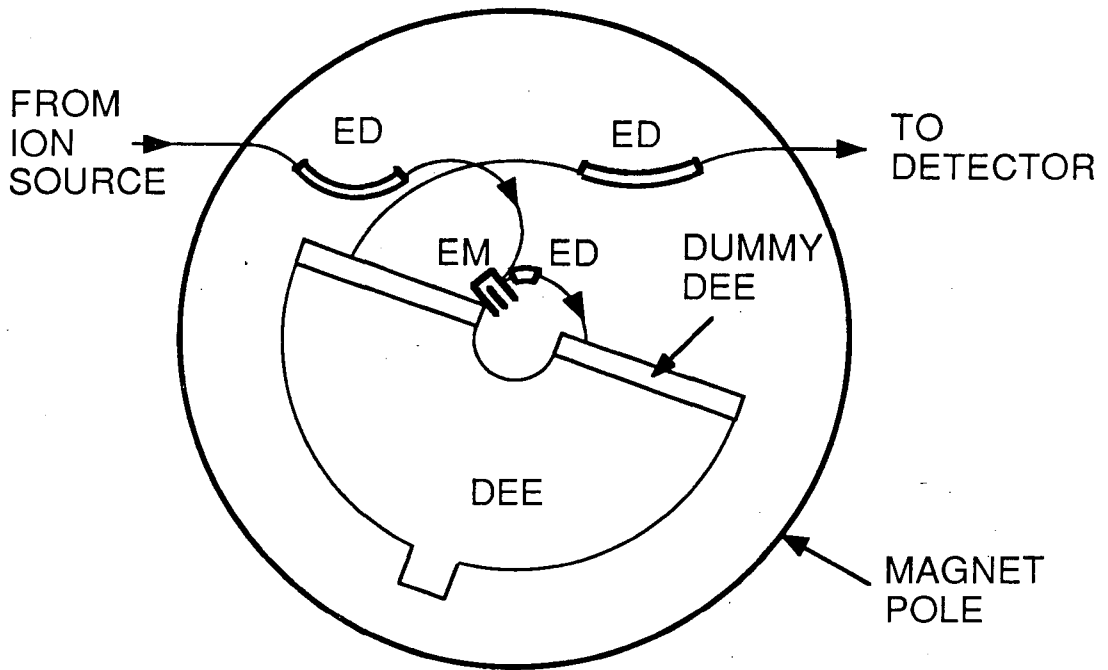
Figure Captions

Fig. 1. Radial injection geometry for the small cyclotron. Arrows show the path of a typical ion as it is injected from the left and is made to orbit the cyclotron axis by passage through electrostatic deflectors and a mirror. After 50 to 100 turns, it exits through another electrostatic deflector and is sent to an ion detector.

Fig. 2. Beam injection scheme for the small cyclotron. The magnet is 30cm in diameter and the beamline is about 1.2m long.

Fig. 3. Overall view of the small cyclotron system. The ion source is in the foreground at the left. The large tank in the center contains the beamline. A current probe is shown being inserted into the dee region.

Fig. 4. Tuning curve of the small cyclotron at mass 12, obtained by accelerating a beam of $^{12}\text{C}^-$ on the 11th harmonic of the cyclotron frequency. This is effectively a plot of mass resolution, as mass is inversely proportional to frequency. From Welch, 1984 and Welch, et al, 1987.



ED = ELECTROSTATIC DEFLECTOR
 EM = ELECTROSTATIC MIRROR

XBL 874-1818

Fig. 1

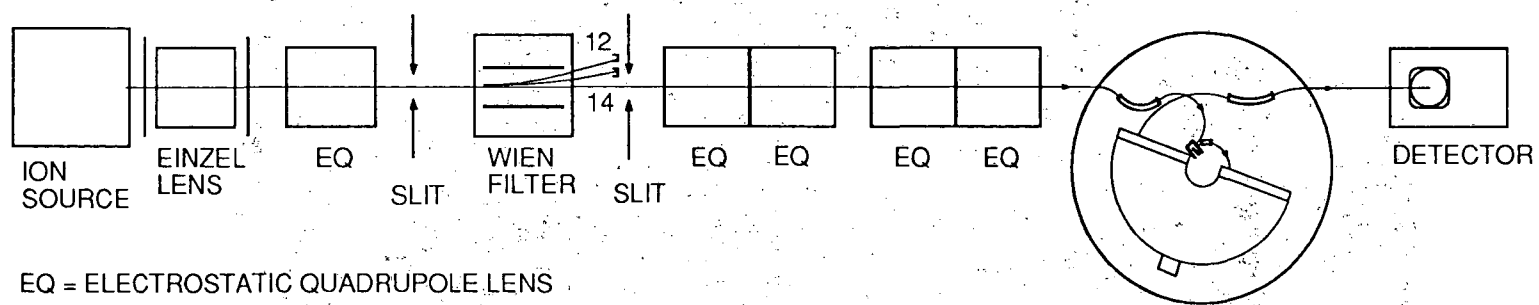


Fig. 2

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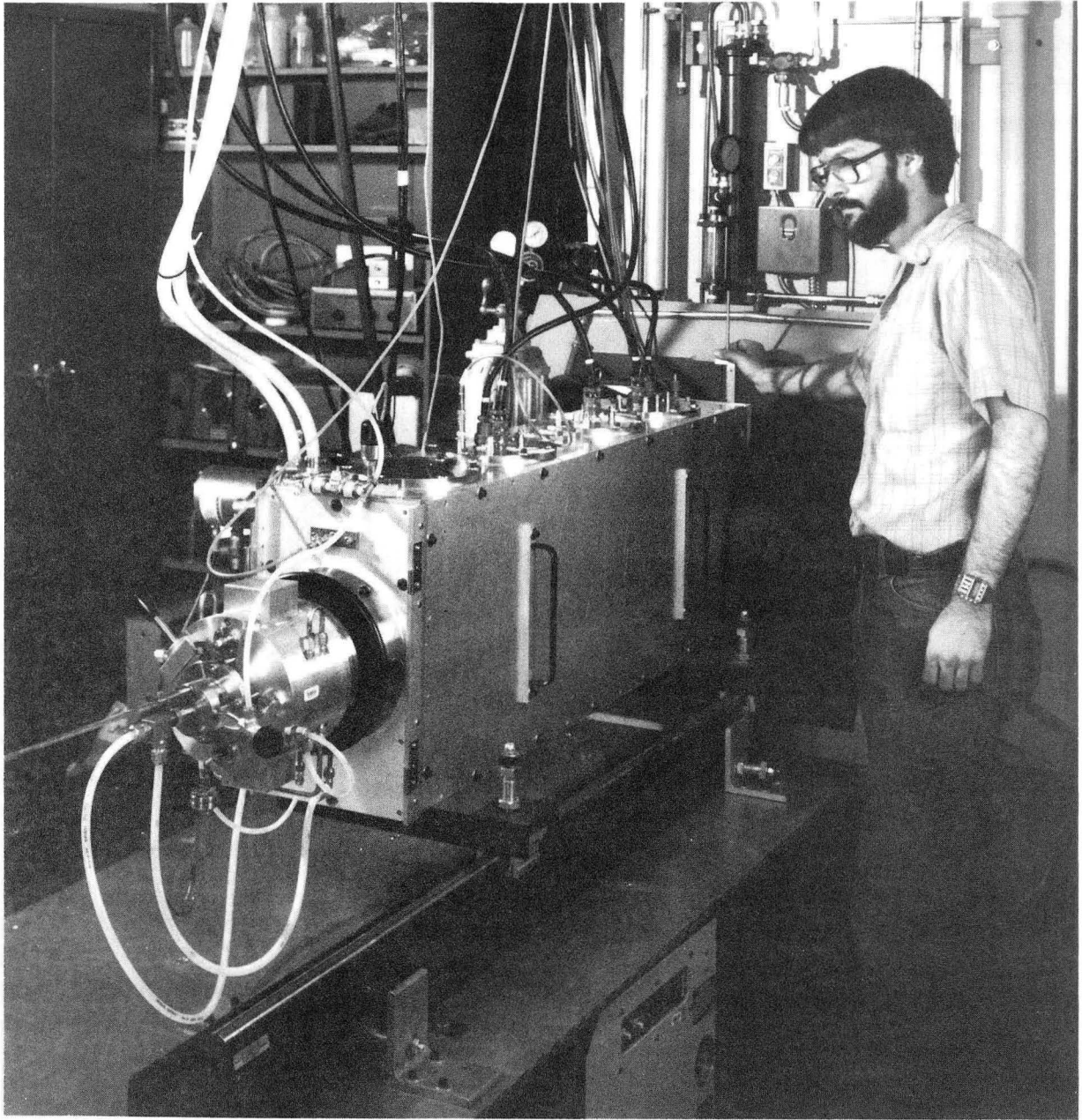
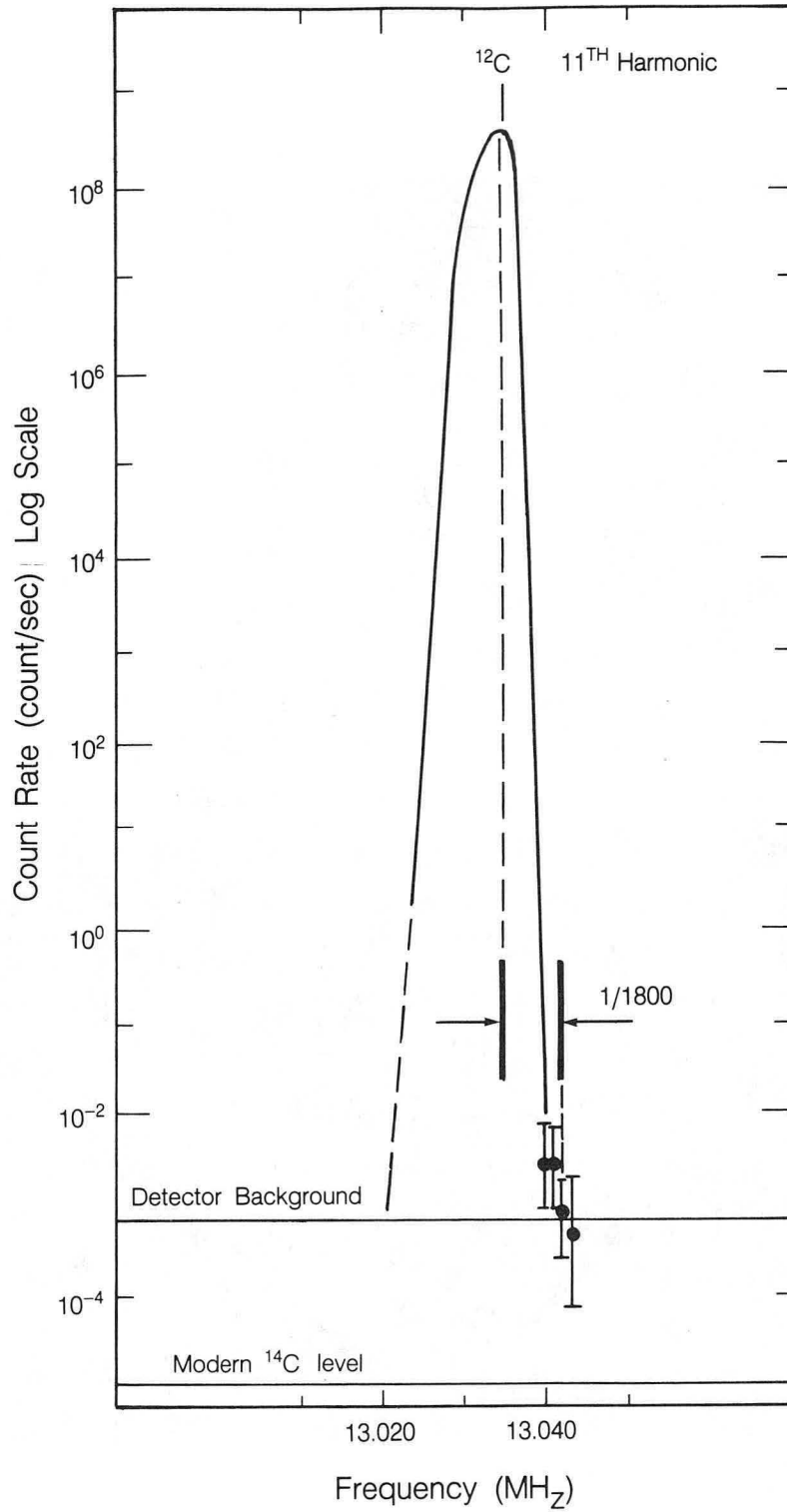


Fig. 3

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XBL 8410-8777

Fig. 4

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