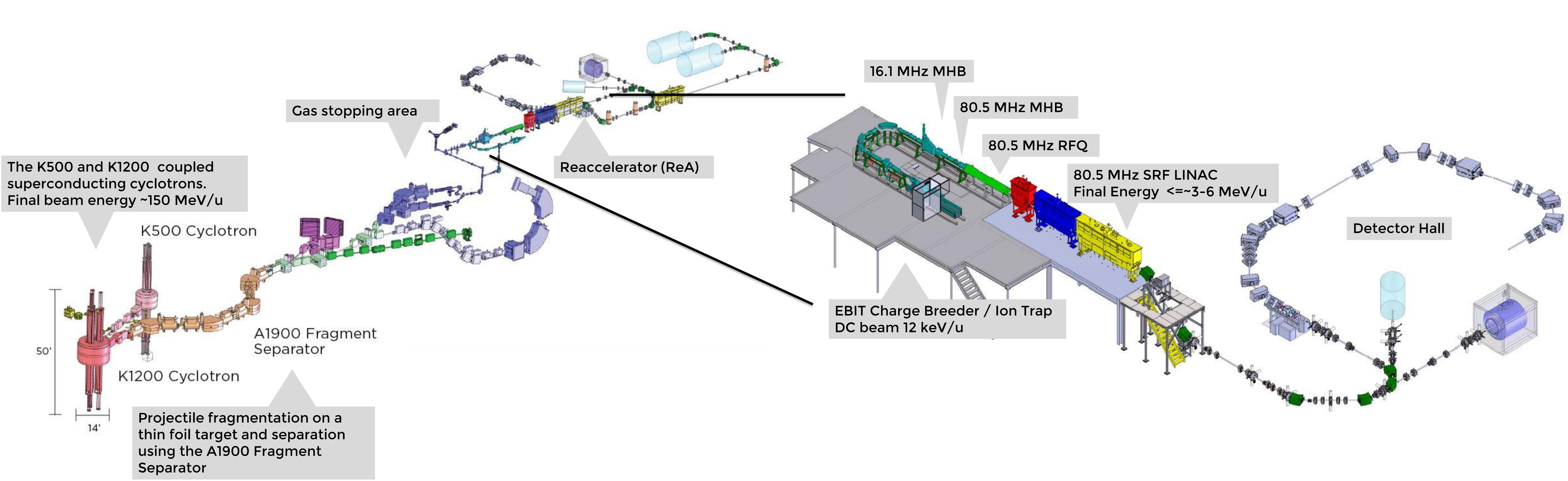
COMMISSIONING RESULTS FOR A SUBHARMONIC BUNCHER AT REA

Alt, D., Brandon, J., Krause, S., Lapierre, A., Morris, D. Nash, S. Usher, N. Villari, A., Williams, S., Zhao, S. – Facility for Rare Isotope Beams, East Lansing, MI, Syphers, M. – Northern Illinois University, DeKalb, IL

Abstract

The reaccelerator facility (ReA) at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) offers a unique capability to study reactions with low-energy beams of rare isotopes. A beam from the coupled cyclotron facility is stopped in a gas stopping system, charge bred in an Electron Beam Ion Trap (EBIT), and then reaccelerated in a compact superconducting LINAC. The original beam repetition rate at the ReA targets was the same as the LINAC RF frequency of 80.5 MHz. In order to add the capability to bunch at a lower frequency (desirable for many types of experiments using time of flight data acquisitions) a 16.1 MHz buncher has been designed, constructed, and commissioned. This paper reports the results of the commissioning of the device, and outlines some future avenues for further improvement of the properties of the bunched beam.

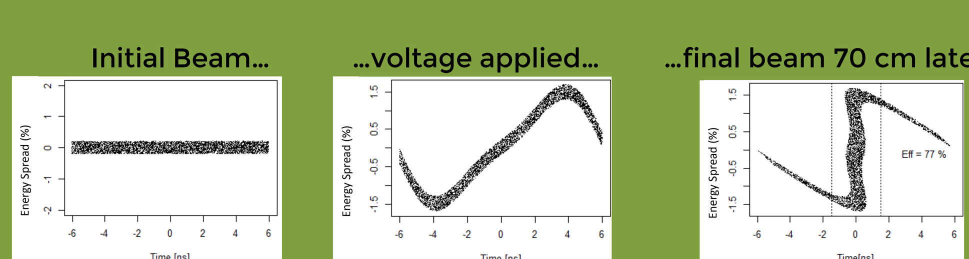
THE COUPLED CYCLOTRON / REACCELERATOR FACILITY AT NSCL



Multiharmonic Bunching

A standard way to longitudinally bunch a continuous beam for acceleration in RF cavities is the Multiharmonic Buncher (MHB). An accelerating/decelerating voltage is applied in the longitudinal direction by a pair of electrodes. Particles arriving early in phase are slowed, while particles arriving late are accelerated, and all particles converge at a time focus at a later point.

Example: Current ReA 80.5 MHz Multiharmonic Buncher:



Ideally, the applied voltage waveform should be a perfect sawtooth wave, where the voltage ramps linearly and returns instantaneously to the starting voltage at the end of the ramp. For high frequencies and voltages, this is impractical, so the desired waveform is approximated using the first few Fourier components. The more components, the longer the linear range of the waveform, and the better the bunching efficiency. (Efficiency is here defined as the fraction of the beam particles arriving at the focal point within a specified time window relative to the reference particle.)

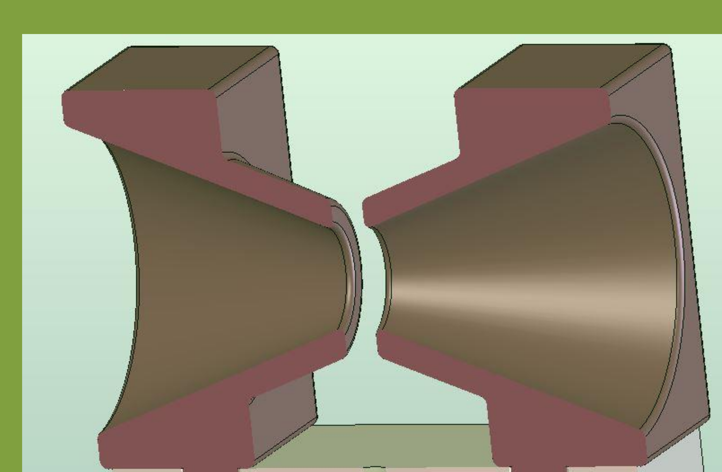
Device Overview

Frequency

Since the goal of the current project is to increase bunch separation at the detectors, the frequency chosen was the 5th subharmonic of the LINAC frequency, or 16.1 MHz, giving a final separation of 62.1 ns between beam bunches.

Number of Modes

The device is designed to use three Fourier components to produce the bunching waveform. Only two components were used for the commissioning study.



CST Studio model of the buncher electrodes.

Voltage and Focal Length

The device is located 2 m upstream of the focal point at the entrance of the RFQ, and 1.73 m upstream of the timing wire used for this measurement.

The on-axis peak voltage needed for the first mode at this location is ~1700 V for the highest rigidity beam specified for ReA, Q/A = 1/5.

Electrodes

The bunching voltage is applied to the beam by a pair of conical, gridless electrodes with an aperture diameter of 20 mm, separated by a gap of 6mm. They are mounted to an alumina block for electrical isolation and mechanical stability.

Resonant Structures

The 16.1 MHz and 32.2 MHz sinusoidal components of the bunching waveform are generated in two λ/4 coaxial structures. The longer structure is also resonated in 3λ/4 mode to produce the 48.3 MHz component.

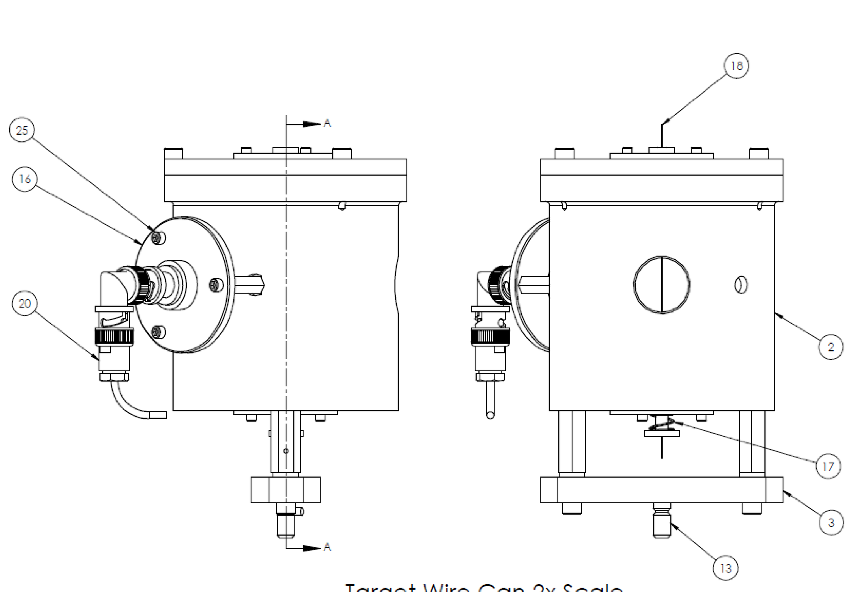
LLRF Controller

The resonant structures are driven by a low level RF controller using closed loop active feedback, which allows for phase and amplitude stability of the three modes.

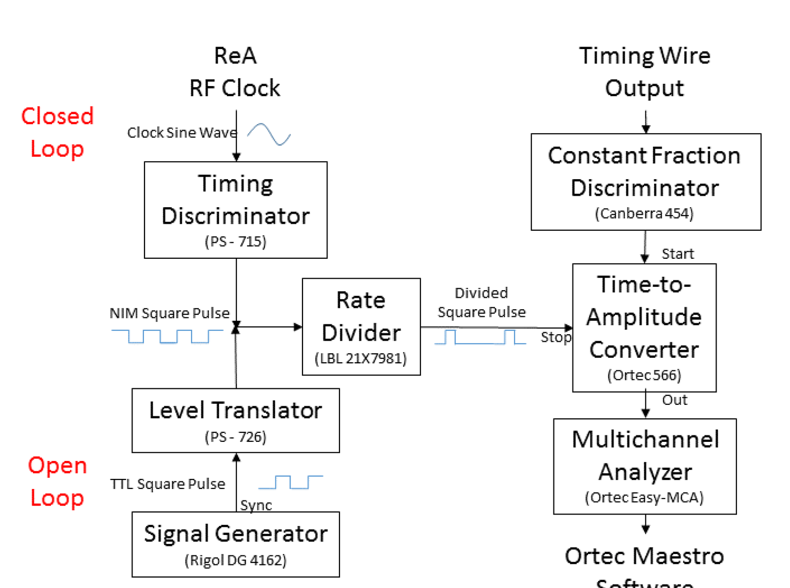
The buncher as installed, with resonators visible

Testing Methodology

The primary device used for evaluating the time structure of the bunched beam was the timing wire detector depicted below. The central wire is held at a high potential difference with the coaxial cylinder, producing a radial electric field. When the beam strikes the wire, secondary electrons are emitted, and detected by a multichannel plate (#16 in the diagram).



Target Wire Can 2x Scale



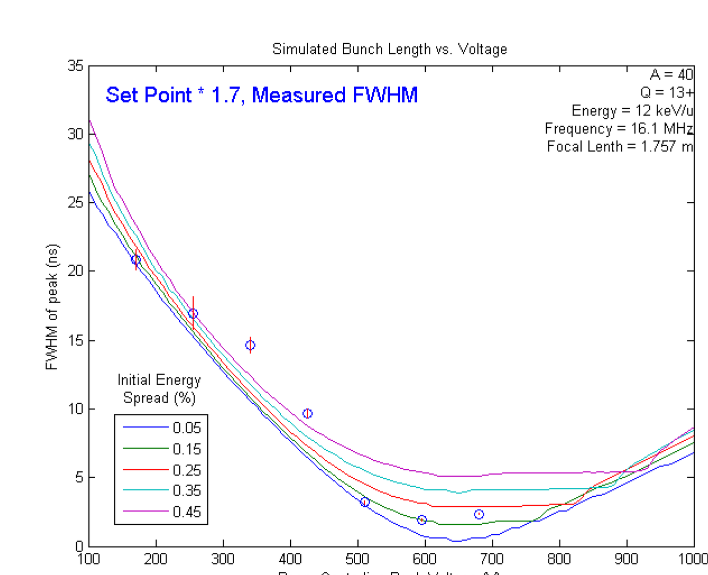
The data acquisition path is shown above. The signal from the timing wire is connected to the "start" input of a time-to-amplitude converter, which is stopped by a clock signal synchronized to the ReA RF clock. This produces an output pulse proportional in input to the time delay.

These pulses are collected by a multichannel analyzer and histogrammed using the Ortec Maestro software to produce a time spectrum of the bunched beam.

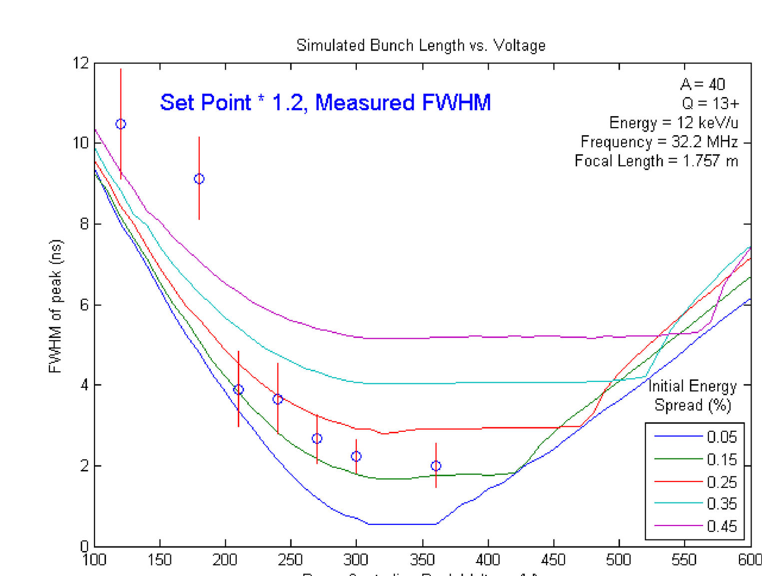
Single Mode Results

For the first set of measurements, each mode was activated by itself with the other modes held to zero amplitude. The voltage applied to the beam was slowly increased, and the average FWHM of the beam distribution in time measured at each voltage.

This curve of pulse width vs. control voltage was superimposed on the results for a simulated beam, allowing for direct calibration of the control system voltage to the on-axis voltage seen by the particles. In addition, this procedure allows for empirical measurement of the initial energy spread of the beam, since that determines the minimum width achievable by the beam pulses.



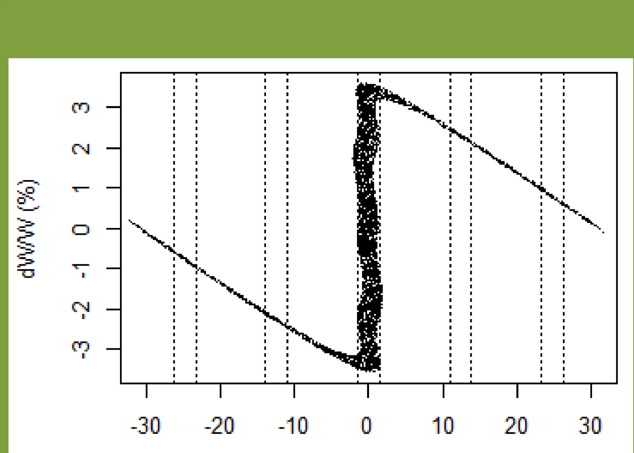
16.1 MHz Mode



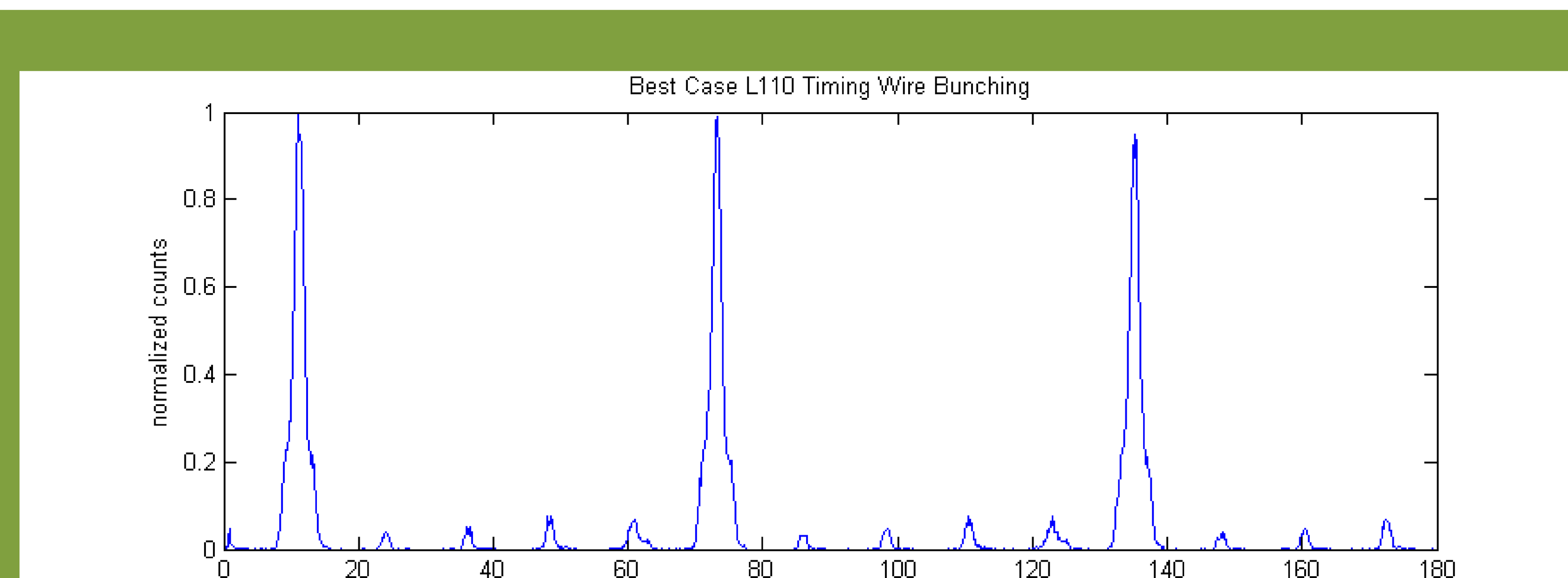
32.2 MHz Mode

Combined Results

Once each mode was tested individually and a basic calibration of control system vs. on-axis voltage made, the beam was then sent through the RFQ and the LINAC to a timing wire after the third cryomodule. This allowed for observation of the satellite bunches, which are produced when the unbunched beam enters the RFQ acceptance for undesired "buckets."



The source of satellite bunches. When the beam is bunched at a period less than the RF period, some beam will enter the acceptance windows of unwanted RF cycles.



As can be seen here, the majority of the beam at the detector has been successfully bunched at the 62.1 ns fundamental period of the buncher. Roughly 13% of the beam at the detector remains in satellite bunches, and simulation predicts that this number could be reduced further with improved tuning.

Total transmission from the ion source to after the LINAC:
No bunching: 30%
16.1 MHz bunching: 50%
80.5 MHz bunching: 75-80%

Future Plans

The 16.1 MHz buncher has been successfully installed and beam bunching with a period of 62.1 ns demonstrated. Desirable future goals include increasing overall transmission and decreasing the proportion of the beam located in the satellite bunches. To that end, future plans include:

- Physical modifications to the resonator to improve the stability of the 3rd mode.
- Firmware upgrades to the LLRF module in support of the same.
- Improved calibration to bunch more of the beam into the main bunch.
- Long term: exploration of various methods to eliminate the satellite bunches entirely.

It is hoped that this capability will be made available to NSCL users in the next PAC review cycle.

MICHIGAN STATE UNIVERSITY

Supported by Michigan State University, National Science Foundation: NSF Award Number PHY-1102511.