40→200MHz Rebucketing in the SPS

S. Hancock
CERN AB-RF

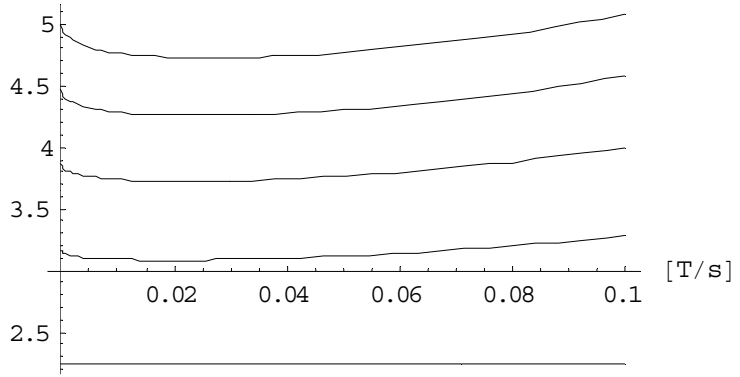
Overview

Rather than consider another new machine (cf., PS2 proposed for the LHC upgrade), we have tried to overcome the space charge bottleneck at SPS injection by adding a "modest" 40MHz rf system to the existing infrastructure. This would allow much longer bunches to be transferred from the PS. Then, near transition when the bunches are short enough, the standard 200MHz system would take over for the bulk of the acceleration.

Conceptually, this is fine, but the baton must be passed between buckets of very different aspect ratio (h=924→4620), which means that mismatching the bunch is unavoidable.

Bucket Aspect Ratio

I begin with the $^{6}He^{2+}$ case and start by examining the ratio between the aspect ratios of the two rf buckets as a function of ramp rate.

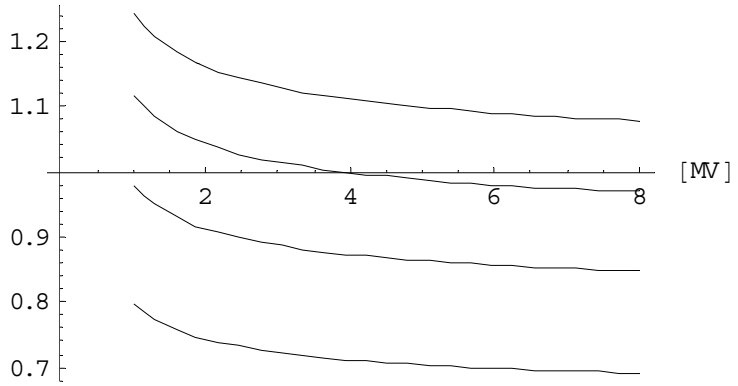


Here, the 40MHz voltage is fixed at 1MV (which is the limit of what might be considered as "modest" and which explains the moderate upper limit in ramp rate for the early part of the cycle) and the different curves are for 200MHz voltages of 1, 2,… 5MV (from bottom to top).

These curves are independent of γ. (Note the flat line at $\sqrt{5}$ when the two rf voltages are equal.)

Bucket Length Filling Fraction

Despite the previous plot, even a small ramp rate is important because it shrinks the 200MHz bucket length and buying this back with voltage is costly in terms of mismatch. So I take 0.02T/s and look for the lowest 200MHz voltage compatible with the bunch length provided by a 1MV 40MHz bucket.

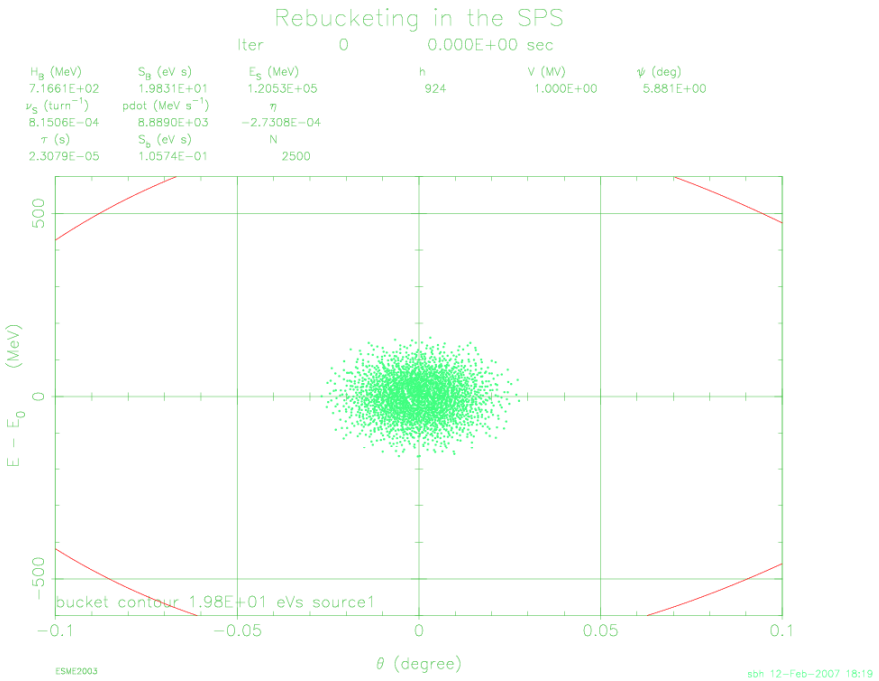


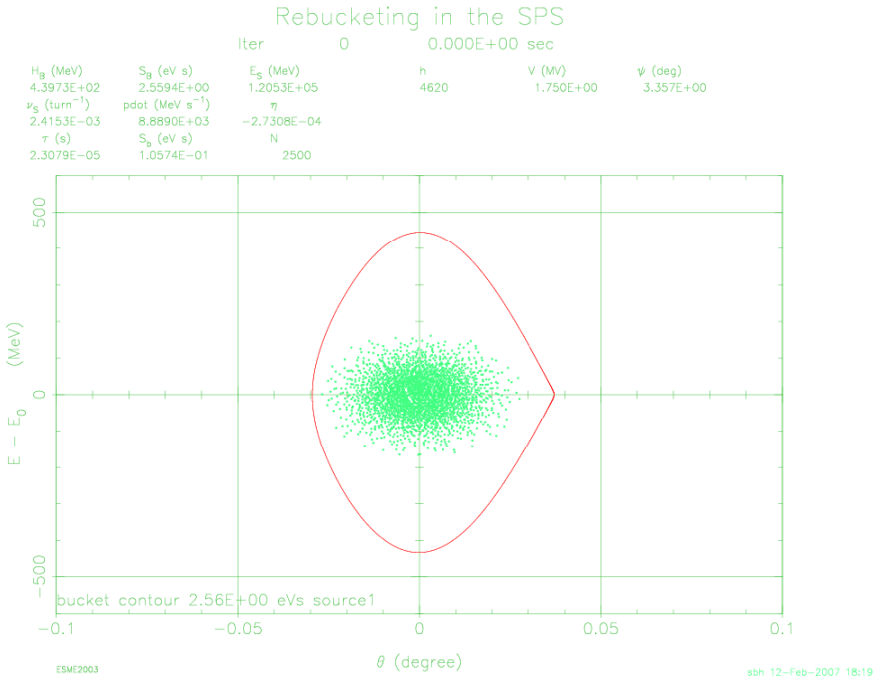
Here, the ratio of 40MHz bunch length to 200MHz bucket length is plotted versus 200MHz voltage for γ=19, 20,… 22 (from top to bottom), i.e., close to transition (γ_{tr}=23).

Increasing proximity to transition gives more margin without matching issues.

Rebucketing

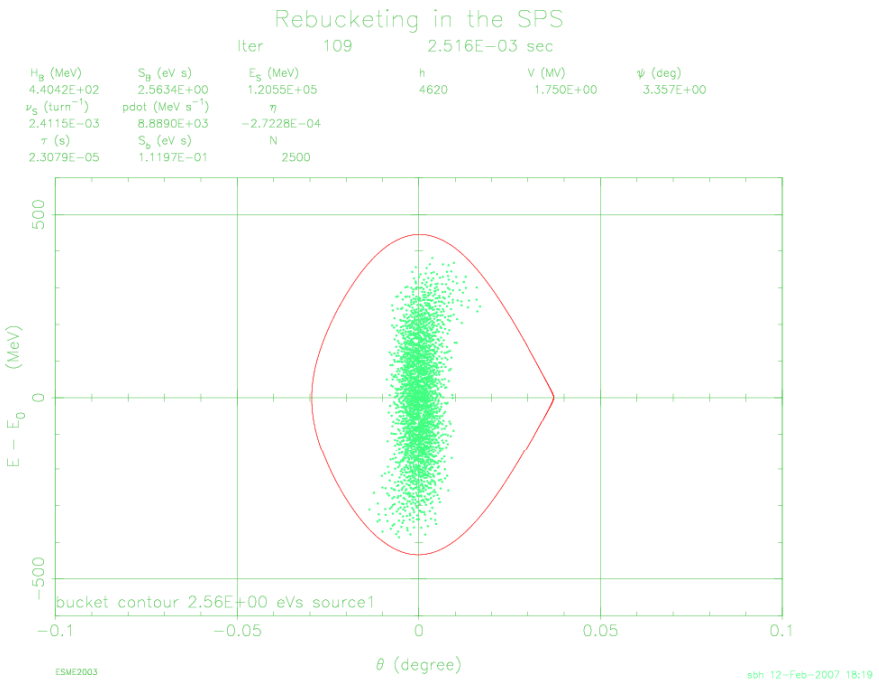
I choose to rebucket at γ=21.5 from 1MV at 40MHz to 1.75MV at 200MHz.

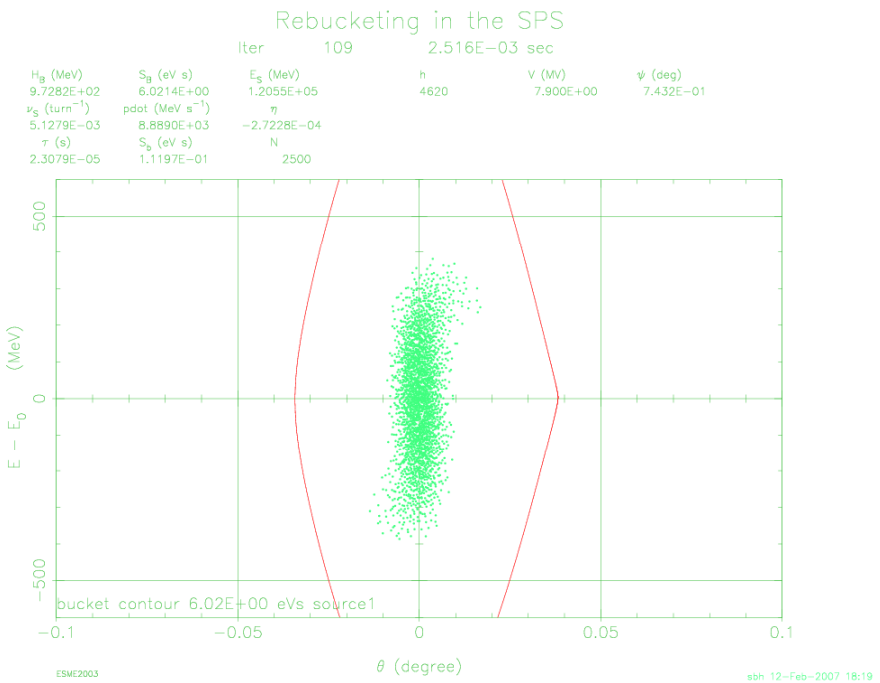




Non-adiabatic Rematching

One quarter of a synchrotron period later, the bunch can be rematched.

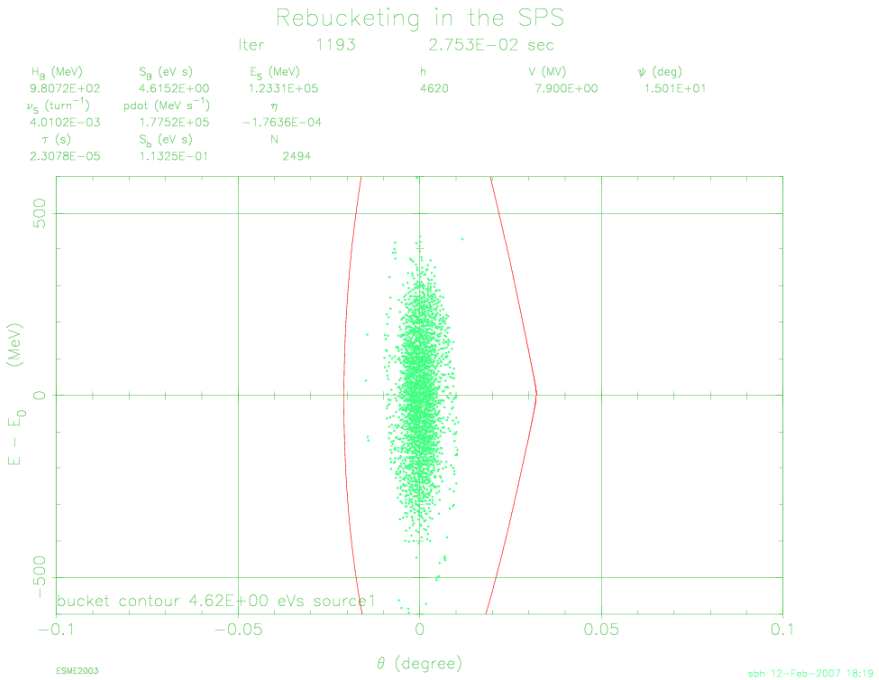


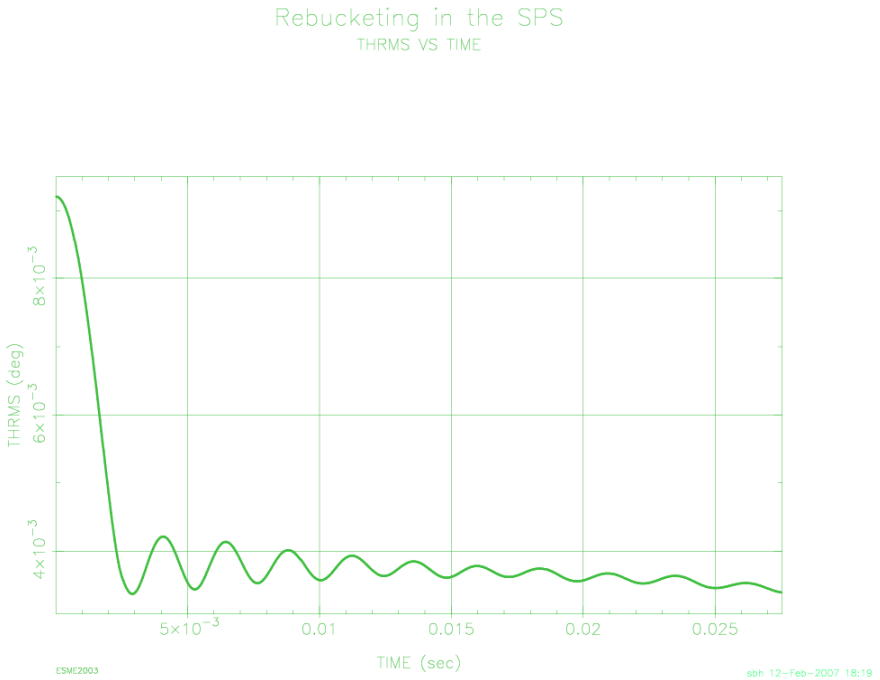


The required step in 200MHz voltage is to 7.9MV, which is almost at the limit of the existing system. Thereafter, the ramp rate can be increased and acceleration can proceed as normal.

Final Product

A small fraction of the bunch population remains at large amplitude.





$^{18}Ne^{10+}$ Case

Despite a larger emittance (2.2 instead of 1.0eVs), the situation is easier in the neon case due to its advantageous charge-to-mass ratio. Although rebucketing must still be performed at the same miniscule ramp rate of 0.02T/s, proximity to transition can be decreased to γ=20 and still have 1MV at 40MHz passing the baton to 1.75MV at 200MHz. 7.8MV at 200MHz is needed to rematch.

Concluding Remarks

1MV is very much the minimum 40MHz voltage required. It also costs cycle time because of the need to slow the (already moderate) ramp rate down to permit rebucketing. However, since the 40MHz system sees almost all the frequency swing during acceleration, more voltage would be expensive.

As an alternative to asking for more 40MHz voltage, one could consider rebucketing at dB/dt=0 as this reduces slightly the problem of matching.

If a total of 150ms are taken to ramp up to 0.1T/s at the start of acceleration, down to 0.02T/s for rebucketing and back up again to a maximum of 0.7T/s, then the time to reach transition is 2.8s for helium and 1.6s for neon.

Performing rf gymnastics close to transition is bound to be a delicate matter.

The usual caveats apply concerning space charge and beam stability.