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Illustration of bunch merge simulation in RHIC

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Following are examples of a 4 to 2 to 1 merge of proton bunches in RHIC obtained by running the simulation code rhic2mrg23 [1]. The code is based on the approach advocated in [2]. The turn-by-turn equations used are derived in [3]. Typical RHIC parameters are given in [4, 5].

As the code runs, the user is prompted to enter several numbers.

For these examples, RF harmonic number 1440.0 is entered.

An RF frequency of 112.597 696 626 MHz at this harmonic is entered. This gives a proton energy of 100 GeV.

The merge simulation starts with a uniform distribution of unbunched protons. 2.0 eV-s is entered for the longitudinal emittance of the distribution.

The code will recommend a voltage to capture the unbunched protons into 4 harmonic 1440 buckets. A capture voltage of 142.390 kV is recommended. 144.0 kV is entered.

It is desirable to capture the protons as "adiabatically" as possible. A capture time of 3318 ms is recommended by the code. 3320.0 ms is entered.

A 4 to 2 merge time of 1659 ms is recommended by the code. 1660.0 ms is entered.

A 2 to 1 merge time twice that of the 4 to 2 merge is recommended by the code. 3320.0 ms is entered.

The code requests a "time fraction" FQMRG to be entered. This is a number (from 0.1 to 1.0) that determines the time at which data are recorded during the 4 to 2 merge. The number 0.5 is entered. This encodes the recording of data halfway through the 4 to 2 merge.

Figures 1 through **5** show the results obtained with these entries. The RF voltage program shown in the figures is as advocated in [2].

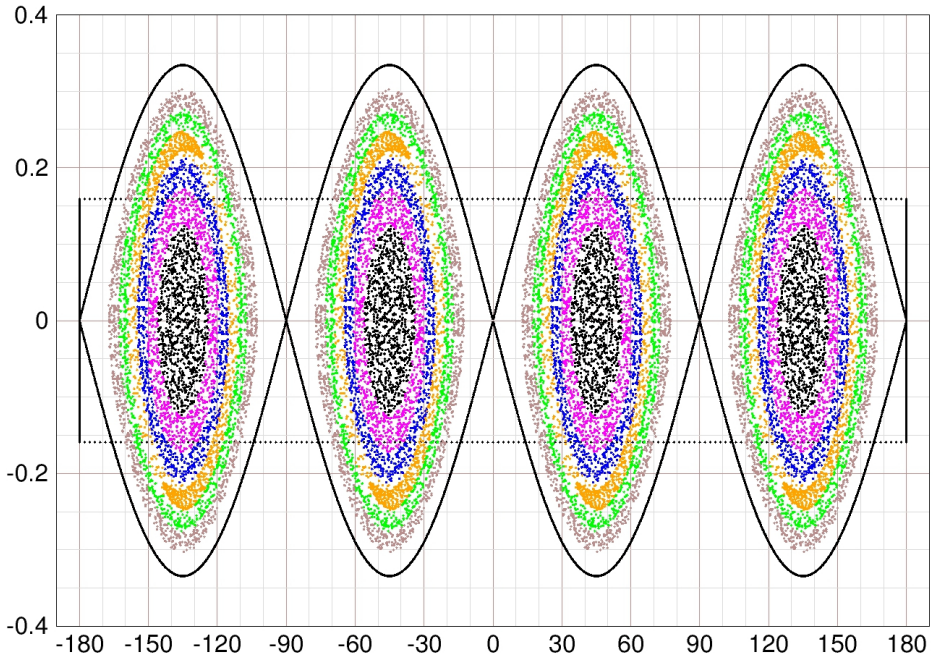
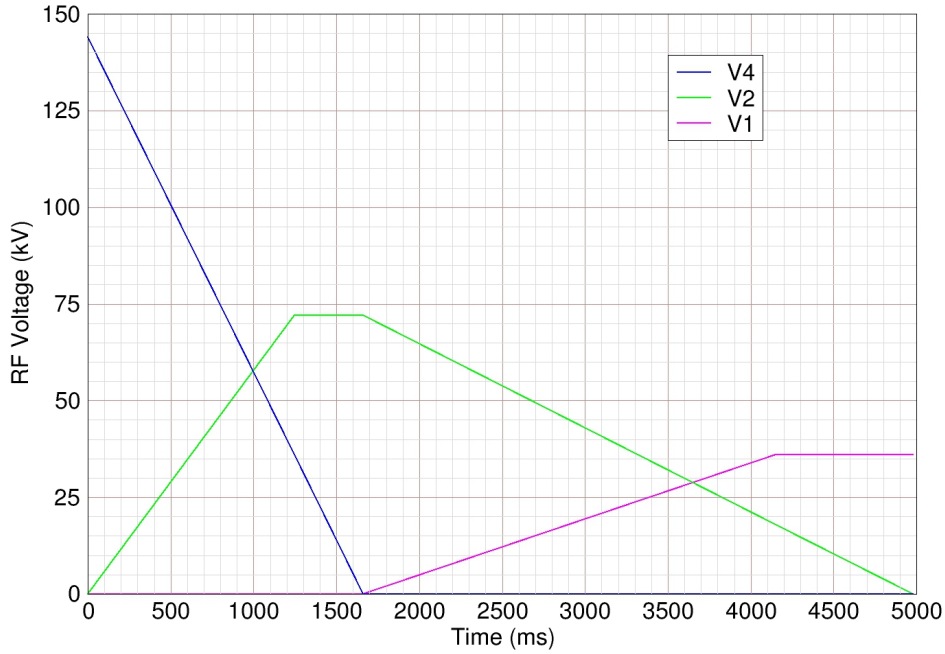


Figure 1: 4 to 2 to 1 merge at time $\underline{t = 0 \text{ ms}}$.



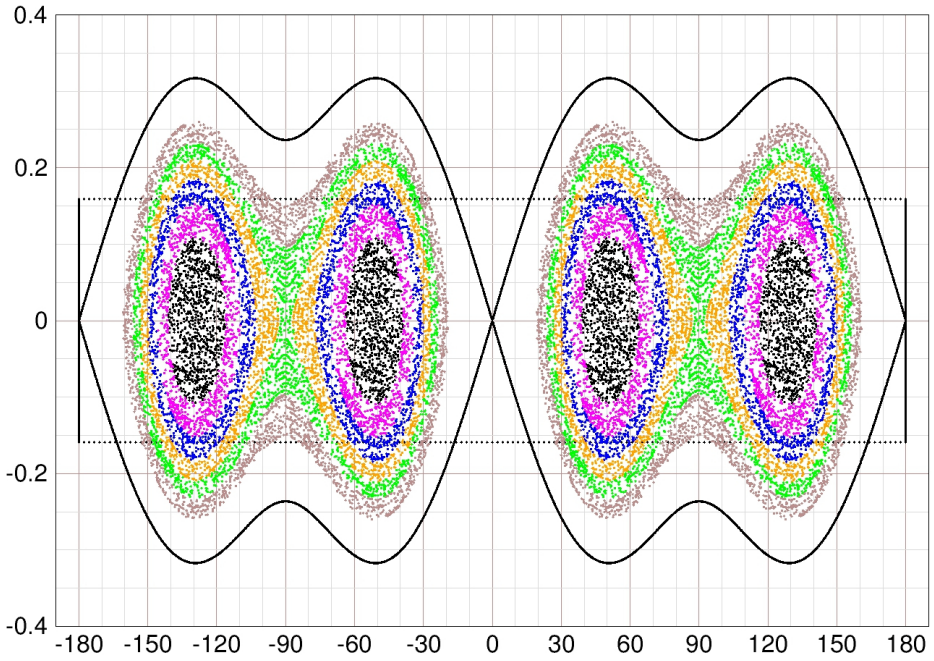
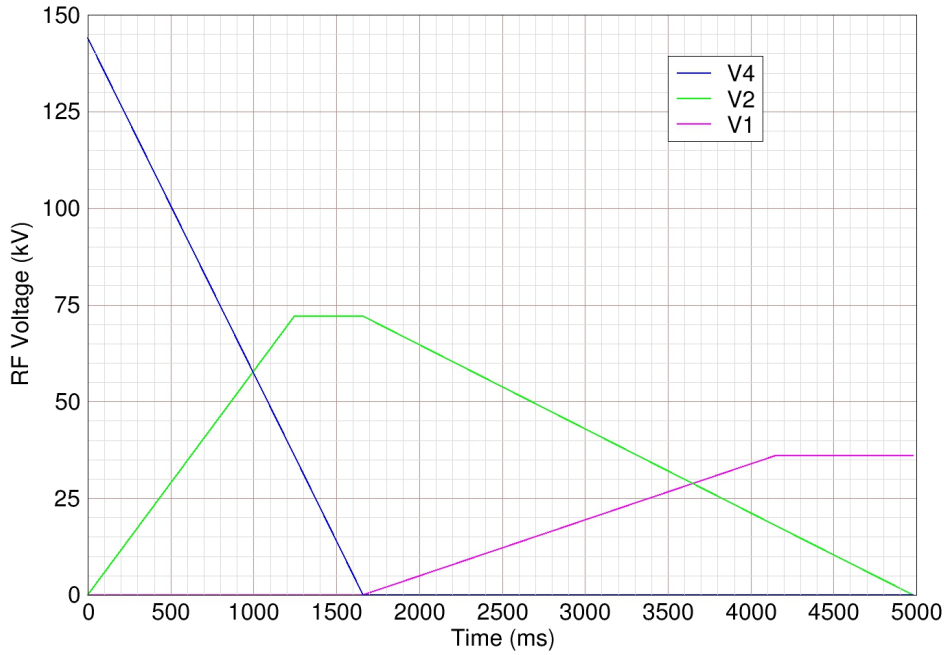


Figure 2: 4 to 2 to 1 merge at time $t = 622.5$ ms.



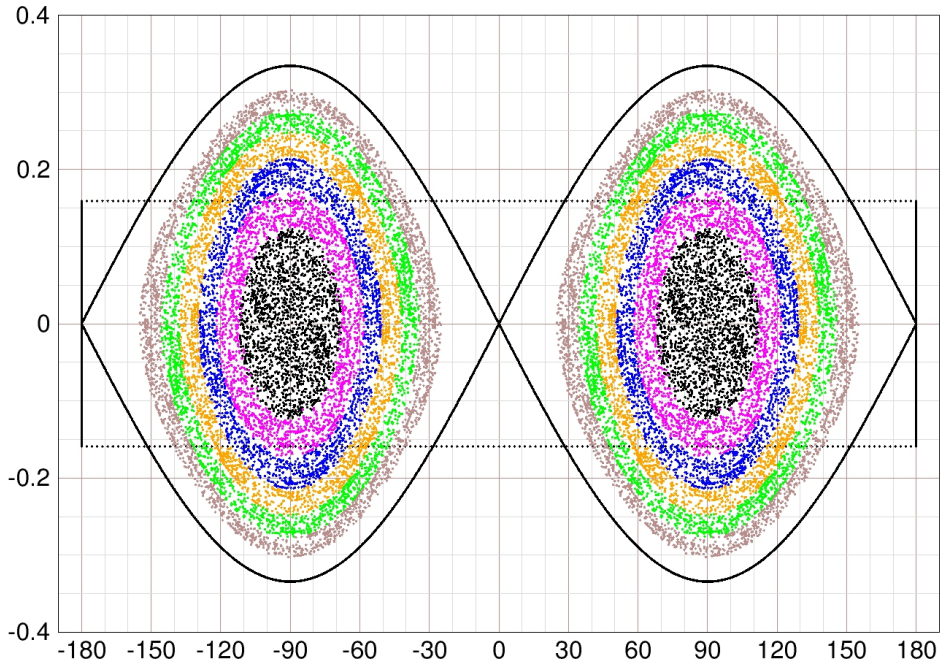
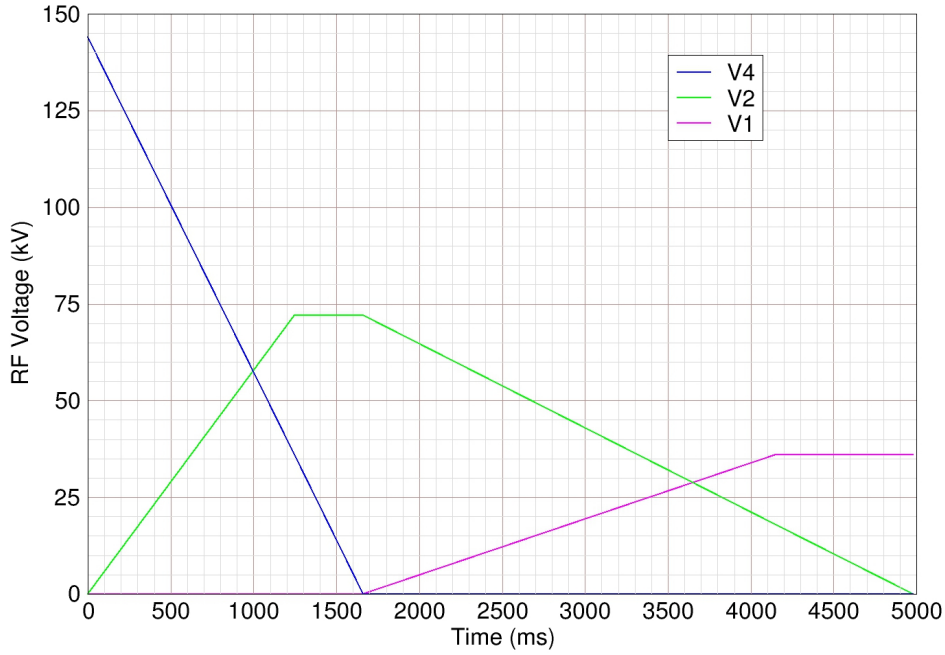


Figure 3: 4 to 2 to 1 merge at time $t = 1660$ ms.



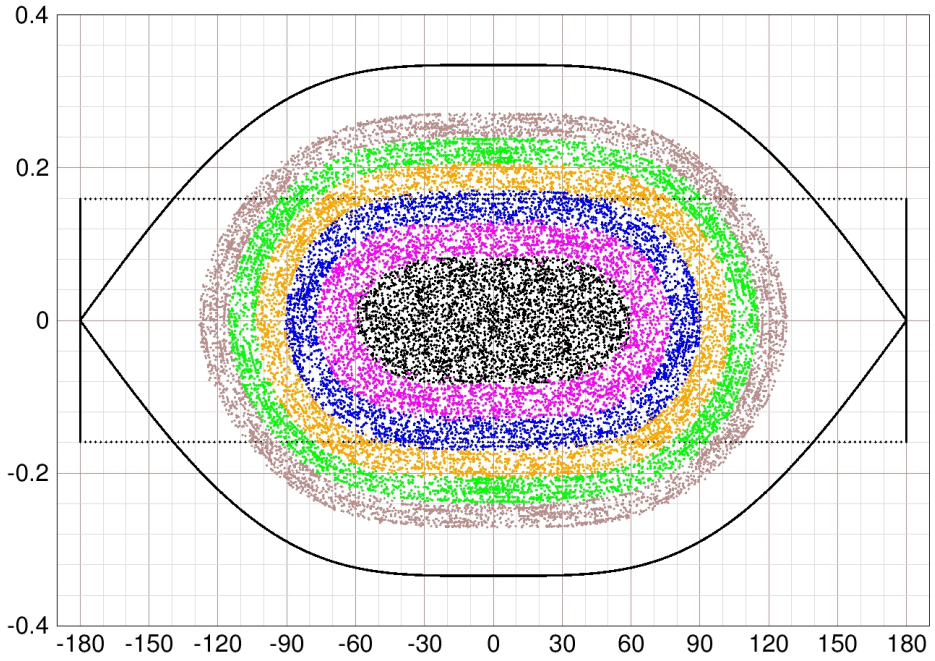
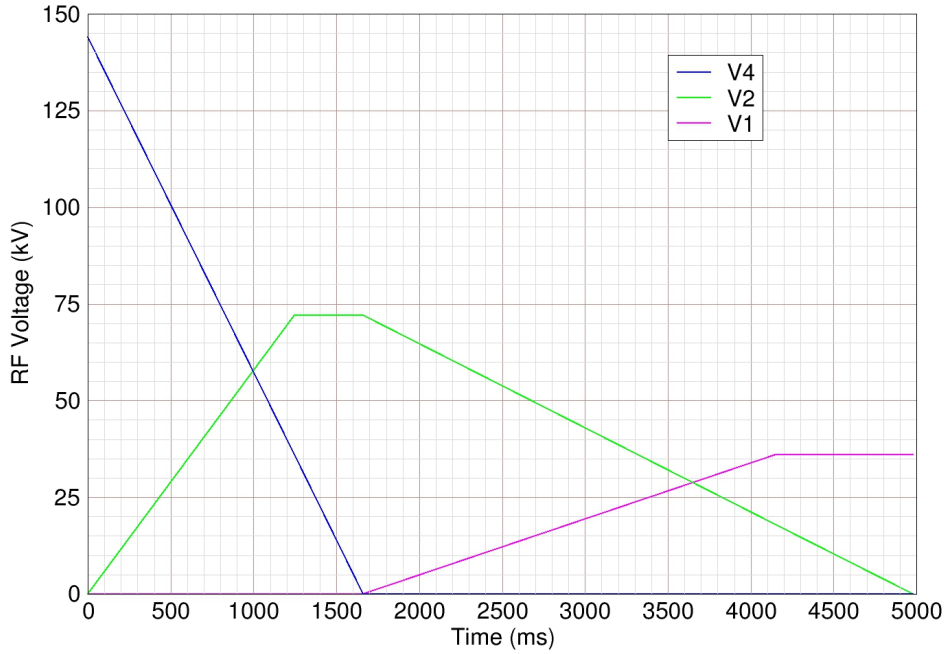


Figure 4: 4 to 2 to 1 merge at time $\underline{t = 4150 \text{ ms}}$.



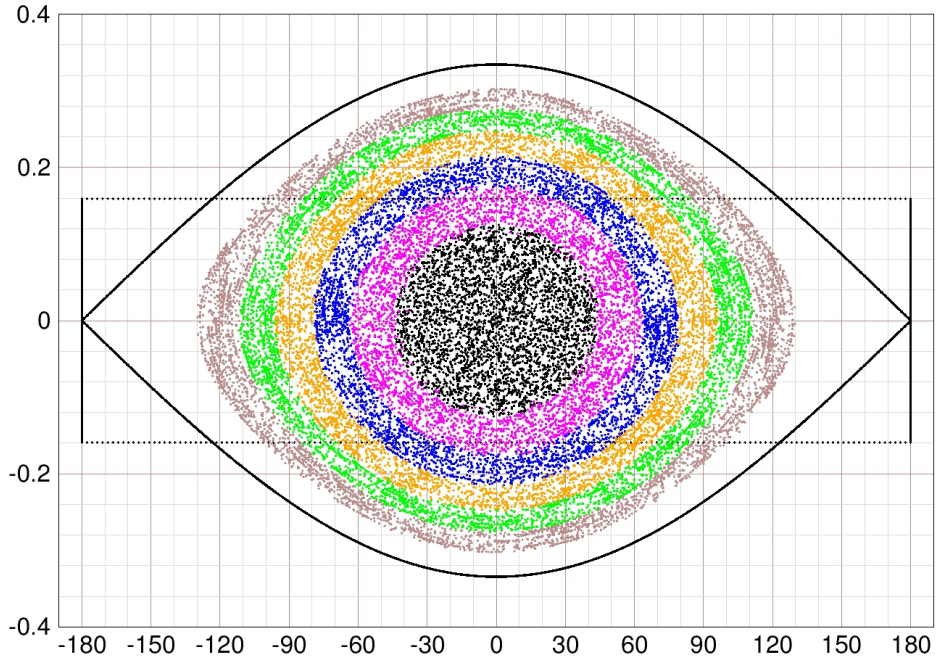
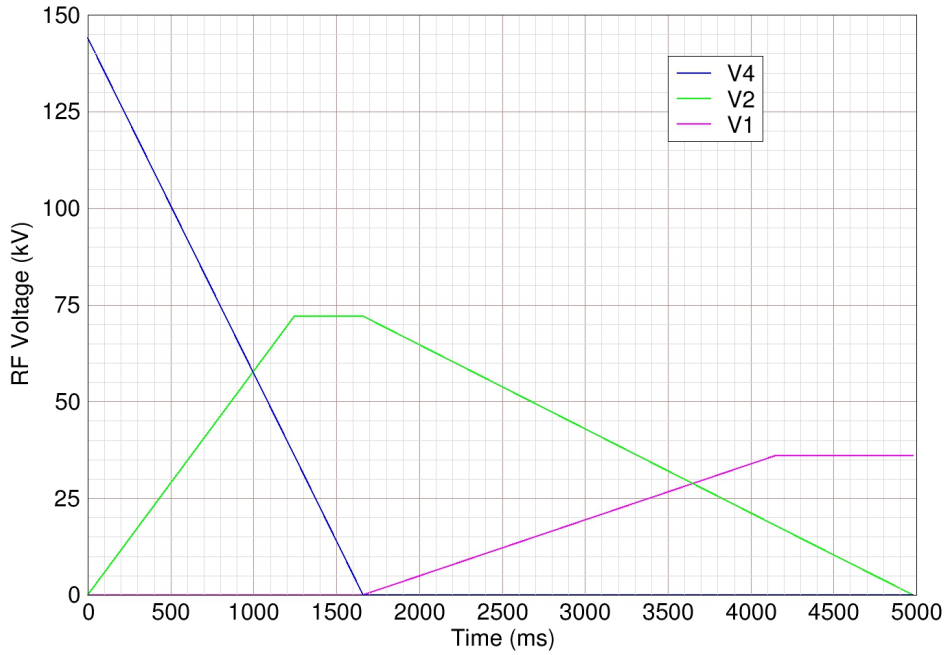


Figure 5: 4 to 2 to 1 merge at time $\underline{t = 4980 \text{ ms}}$.



The multicolored layers seen in **Figures 1** through **5** show the distribution of particles with respect to longitudinal oscillation amplitude during the merge. The amplitudes are encoded by assigning colors to the particles based on their amplitudes in the initial RF buckets. The code calculates and displays the area occupied by the merged bunch. The ratio of that area to the area occupied by the initial distribution of unbunched beam is called the "growth factor," which in this case is found to be 1.002 indicating essentially no growth of longitudinal emittance.

Upon completion of the merge, the code asks the user if another merge is desired. If so, the user must enter "y." The user is then prompted to enter new merge times. All other parameters of the merge keep the values originally entered. Before proceeding with this new merge, the data files written during the first merge must be renamed if the user wishes to keep them. **Figures 6** through **10** show the results obtained for the case in which the merge times are reduced by a factor of 10. One sees some perturbation of the distribution of particles with respect to longitudinal oscillation amplitude. In particular, the effective longitudinal emittance of the "black" particles increases as the merge progresses. Nevertheless, the growth factor of the entire bunch is still close to 1. The code calculates a factor of 1.015 indicating a longitudinal emittance growth of just 1.5%.

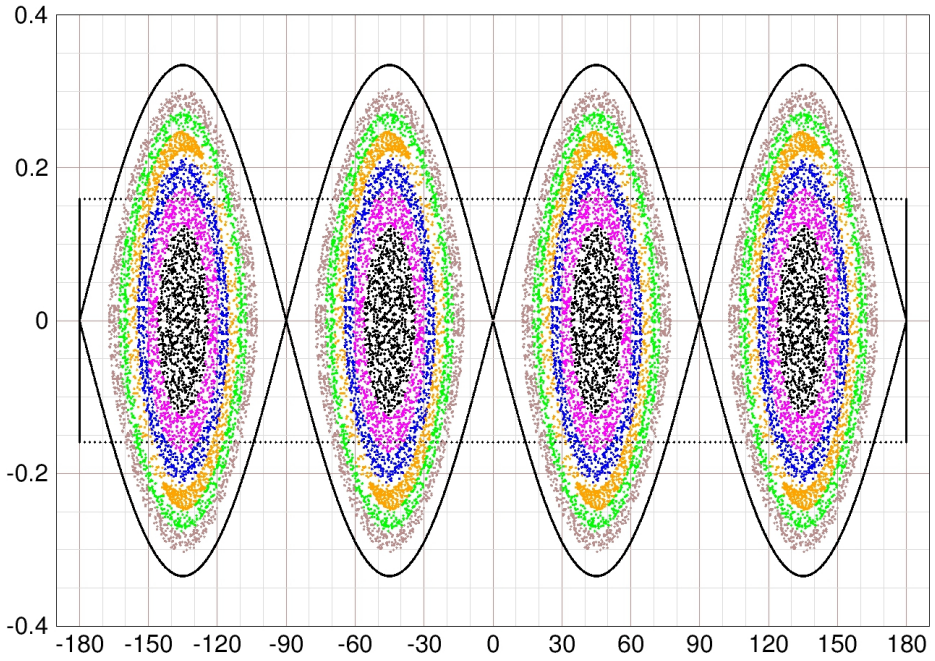
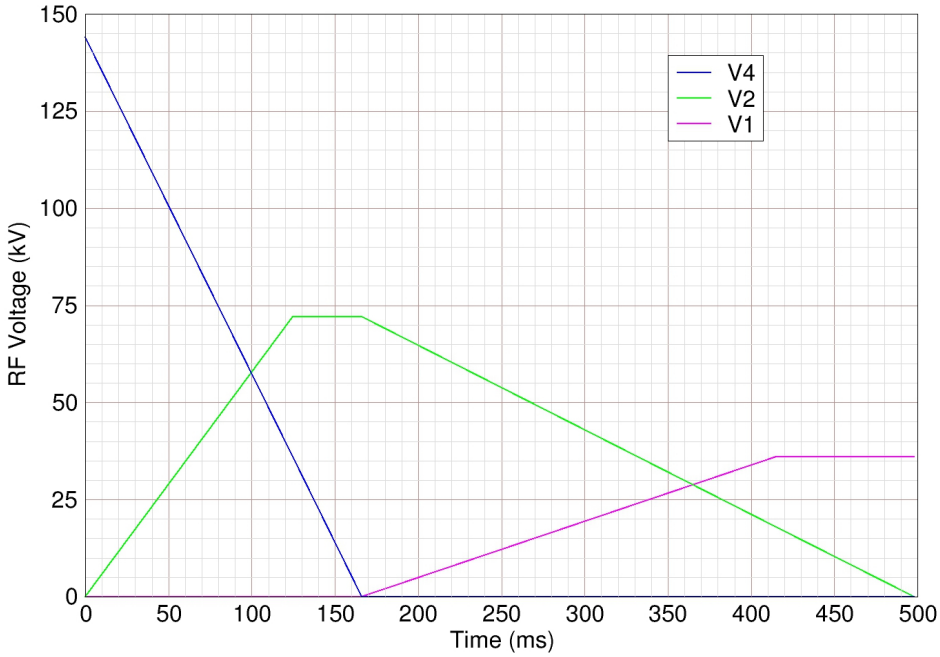


Figure 6: 4 to 2 to 1 merge at time $\underline{t = 0 \text{ ms}}$.



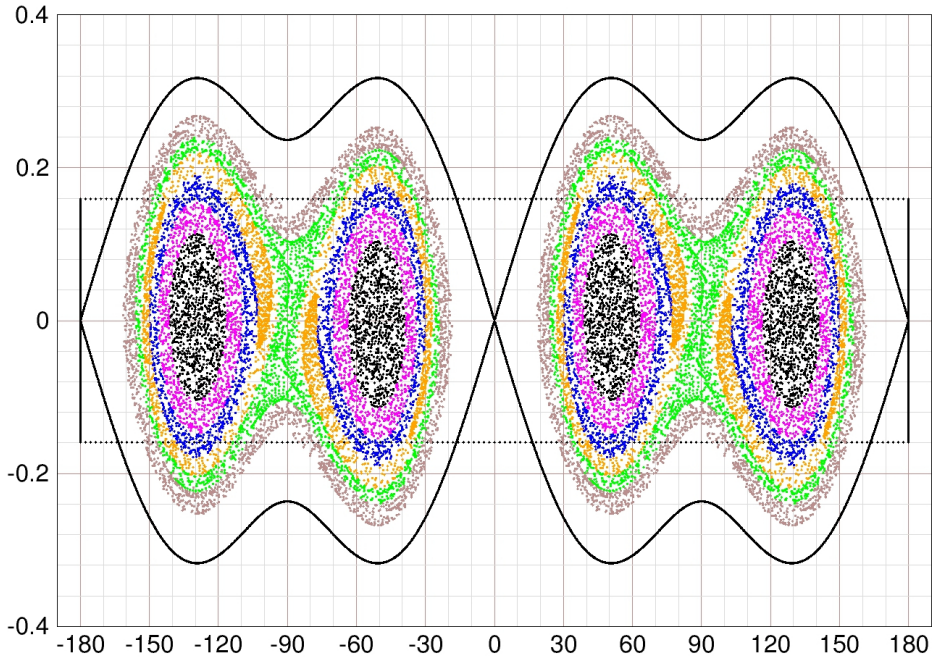
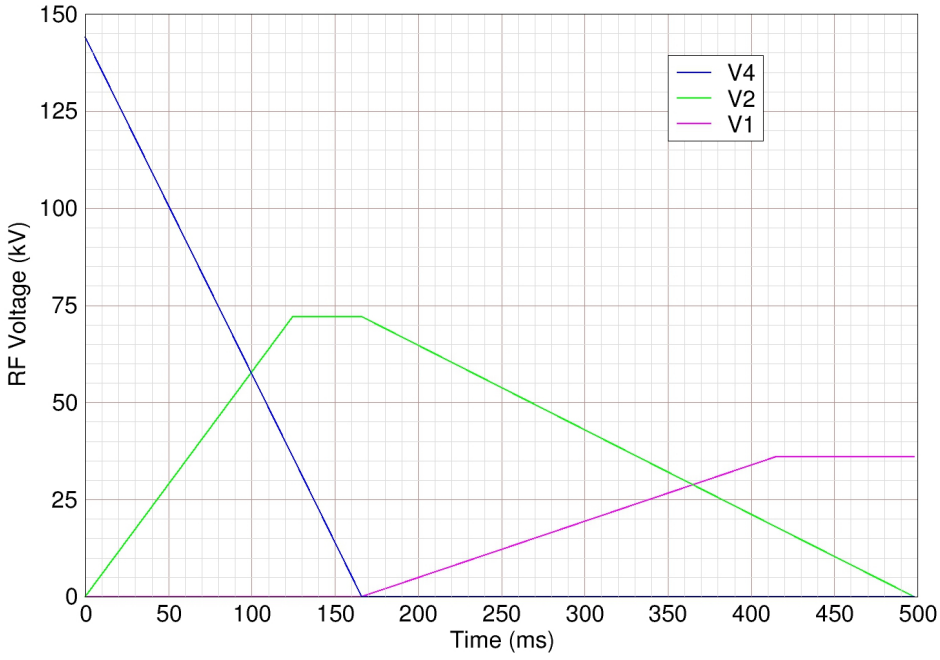


Figure 7: 4 to 2 to 1 merge at time $\underline{t = 62.25 \text{ ms}}$.



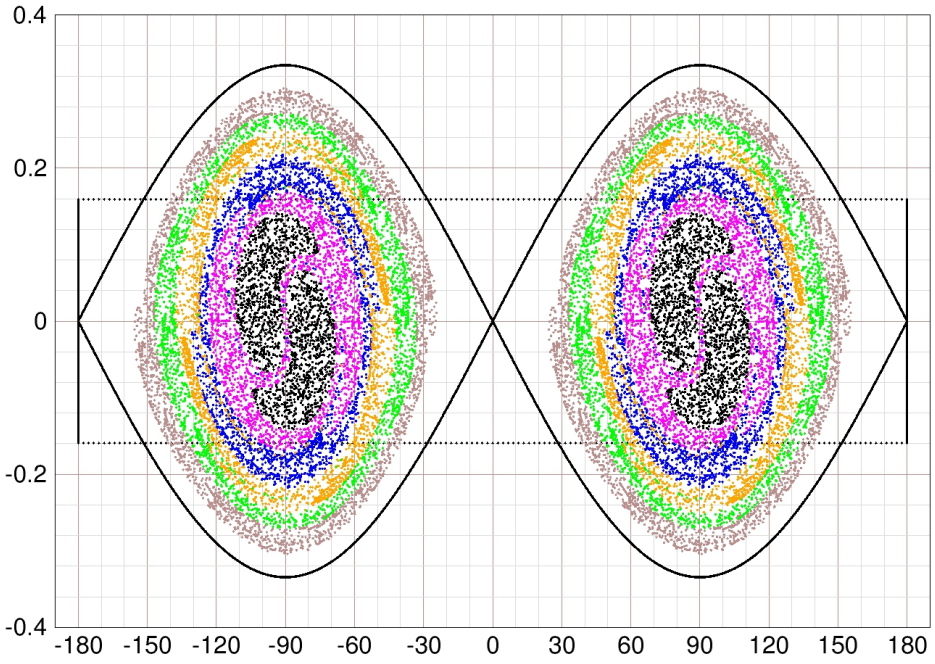
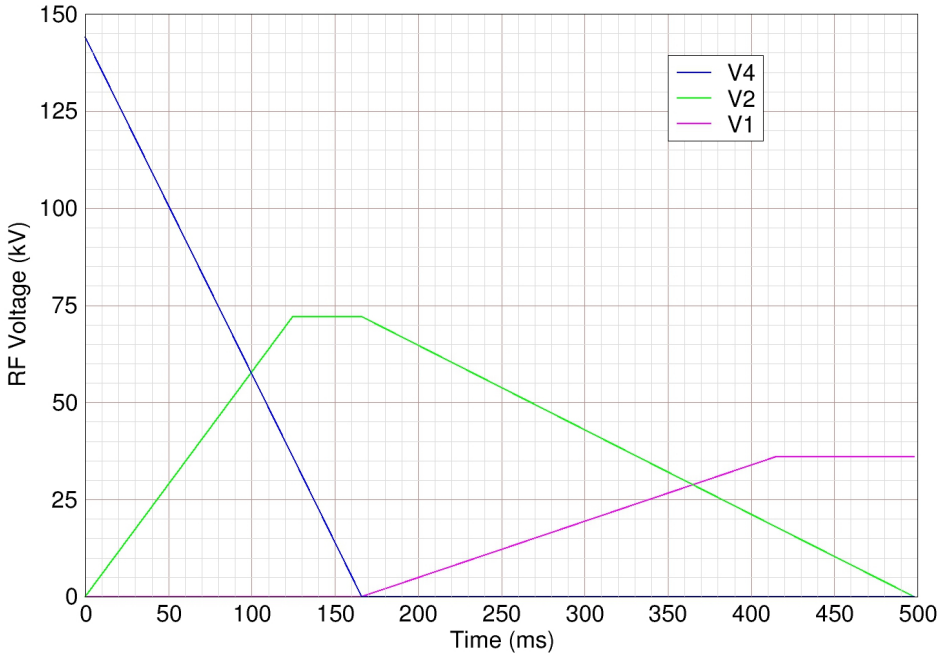


Figure 8: 4 to 2 to 1 merge at time $\underline{t = 166 \text{ ms}}$.



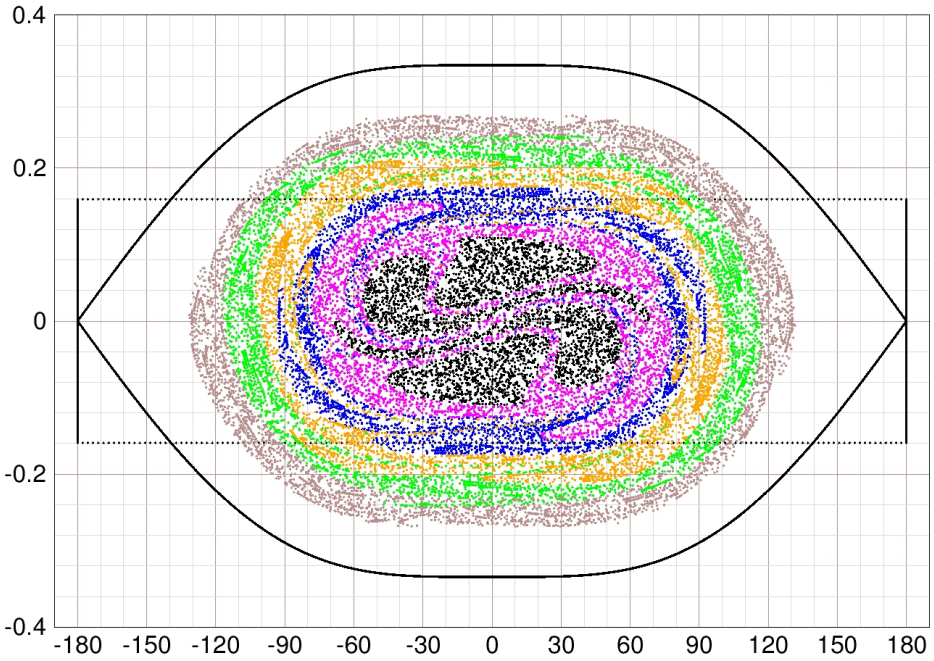
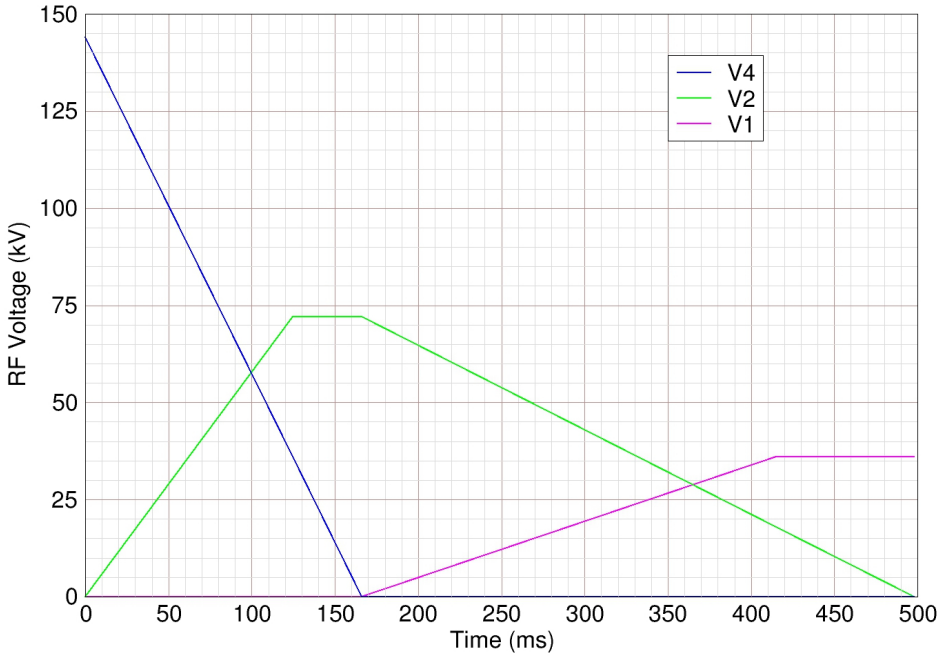


Figure 9: 4 to 2 to 1 merge at time $\underline{t = 415 \text{ ms}}$.



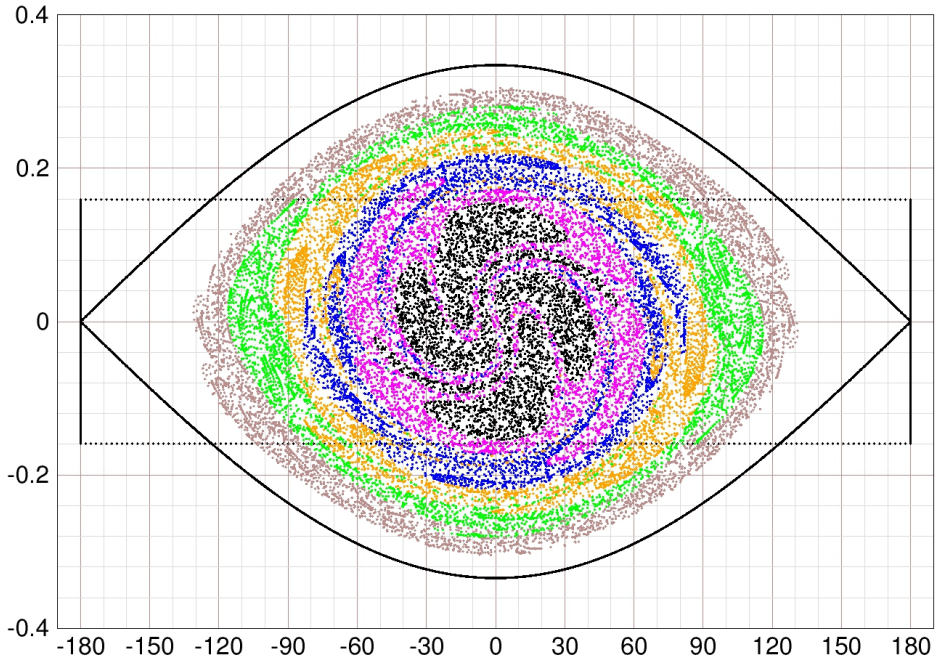
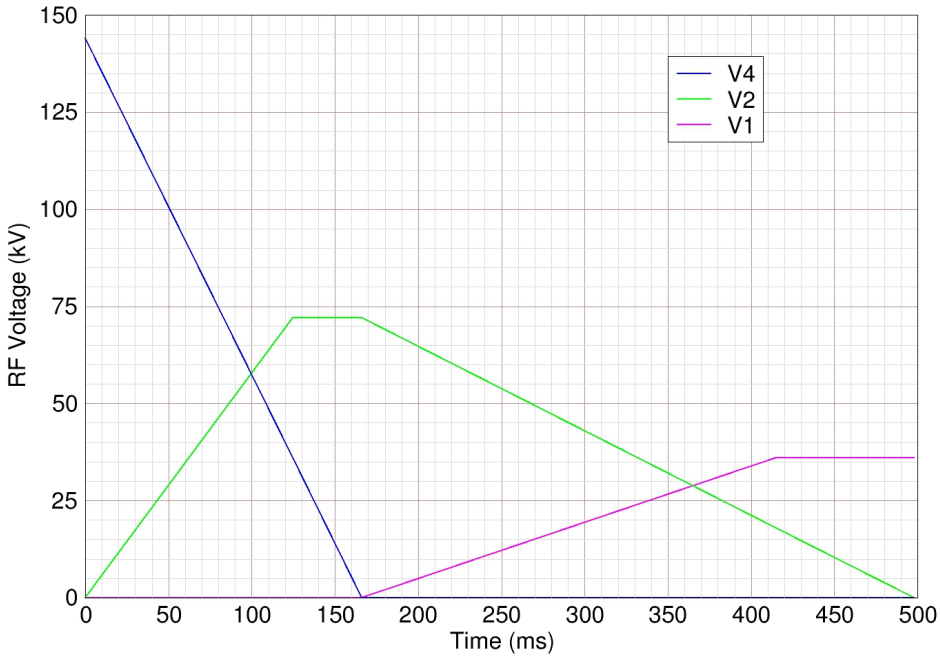


Figure 10: 4 to 2 to 1 merge at time $\underline{t = 498 \text{ ms}}$.



References

[1] C.J. Gardner, Fortran program rhic2mrg23. The source code and executable program are available on MCR computers.

[2] C.J. Gardner, "Notes on the 2 to 1 bunch merge with application to polarized proton bunches in AGS," C-A/AP/Note 689, 27 February 2023.

[3] C.J. Gardner, "Simulations of merging helion bunches on the AGS injection porch," C-A/AP/Note 527, August 2014.

[4] C.J. Gardner, "Polarized proton parameters for the 2015 PP-on-Au setup in RHIC," C-A/AP/Note 549, August 2015.

[5] C.J.Gardner, "FY2016 Parameters for gold ions in Booster, AGS, and RHIC," C-A/AP/Note 574, October 2016.