

## Illustration of bunch merge simulation in AGS

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# Illustration of bunch merge simulation in AGS

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Following are examples of a 4 to 2 to 1 merge of proton bunches in AGS obtained by running the simulation code ags2mrg23 [1]. The code is based on the approach advocated in [2]. The turn-by-turn equations used are derived in [3]. Typical AGS parameters are given in [4, 5].

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

For these examples, RF harmonic number 12.0 is entered.

An RF frequency of 4.453 913 448 73 MHz at this harmonic is entered. This gives proton  $G\gamma = 45.5$ .

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 12 buckets. A capture voltage of 0.0527 kV is recommended. 0.053 kV is entered.

It is desirable to capture the protons as “adiabatically” as possible. Because of the long synchrotron period (372 ms), a capture time of 74,707 ms is recommended by the code. A shorter time, 10,000 ms, is entered to reduce the running time of the code.

A 4 to 2 merge time of 37,353 ms is recommended by the code. 4000.0 ms is entered.

A 2 to 1 merge time twice that of the 4 to 2 merge is recommended by the code. 8000.0 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 **11** show the results obtained with these entries. The lower graph in each figure shows the RF voltage program. The voltage program is as advocated in [2].

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. Note that the effective longitudinal emittance of the “black” particles increases significantly as the merge progresses. This a consequence of doing the merge too quickly. The code recommends a 4 to 2 merge time of some 37 seconds to maintain adiabaticity. **Figures 6** through **11** show the same merge with the particles color-coded according to the RF bucket they initially occupy. Here one sees that the effective longitudinal emittance of the entire bunch remains about the same throughout the merge. Note that Figure 10 is obtained by changing the color of the magenta and blue particles in Figure 9 to black and orange respectively.

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 1.044 indicating a 4.4% growth of the 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 12** through **16** show the results obtained for the case in which the merge times are reduced by a factor of 4. One sees significant perturbation of the distribution of particles with respect to longitudinal oscillation amplitude. Some of the particles reach the border of the RF bucket, giving an effective longitudinal emittance equal to the bucket area. The growth factor calculated by the code in this case is 1.312 indicating 31% growth of the longitudinal emittance.

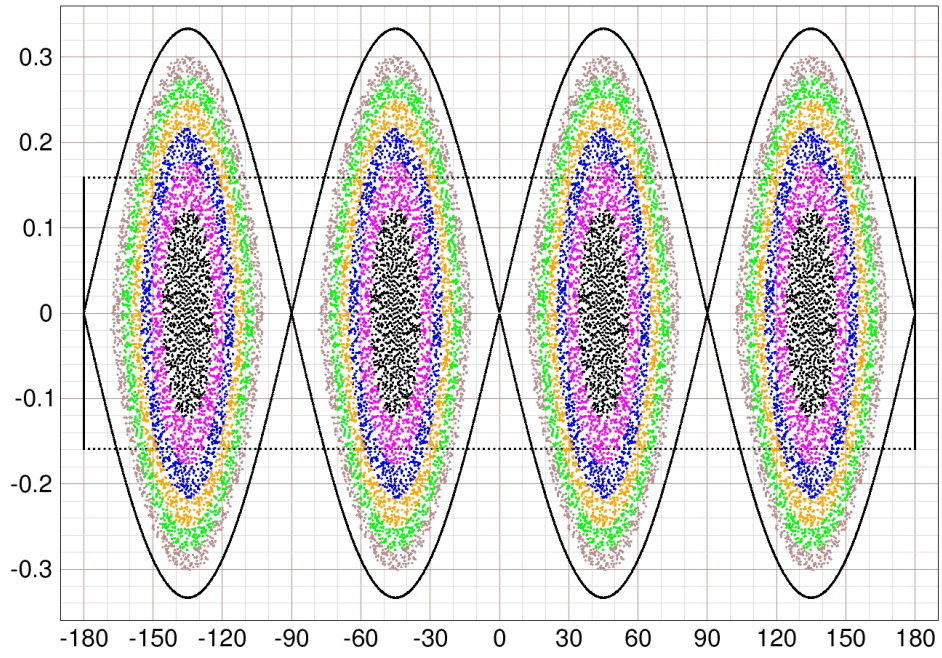
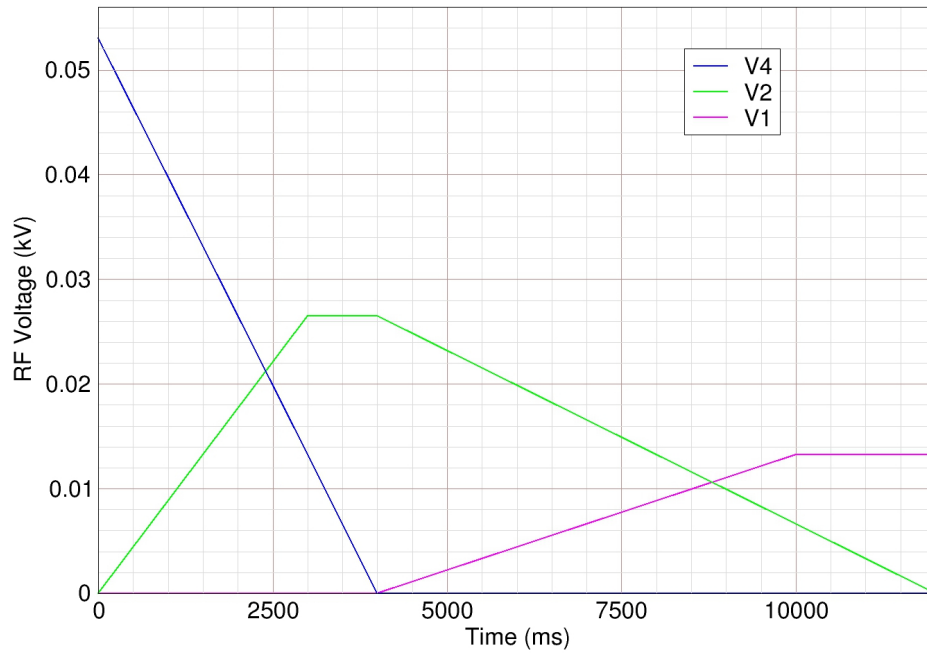


Figure 1: 4 to 2 to 1 merge at time  $t = 0$  ms.



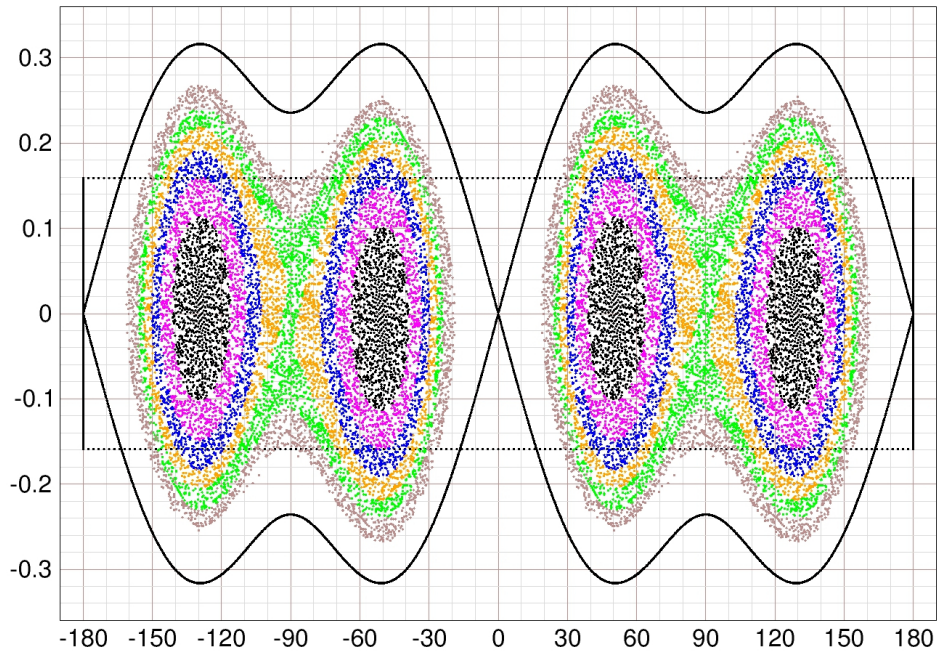
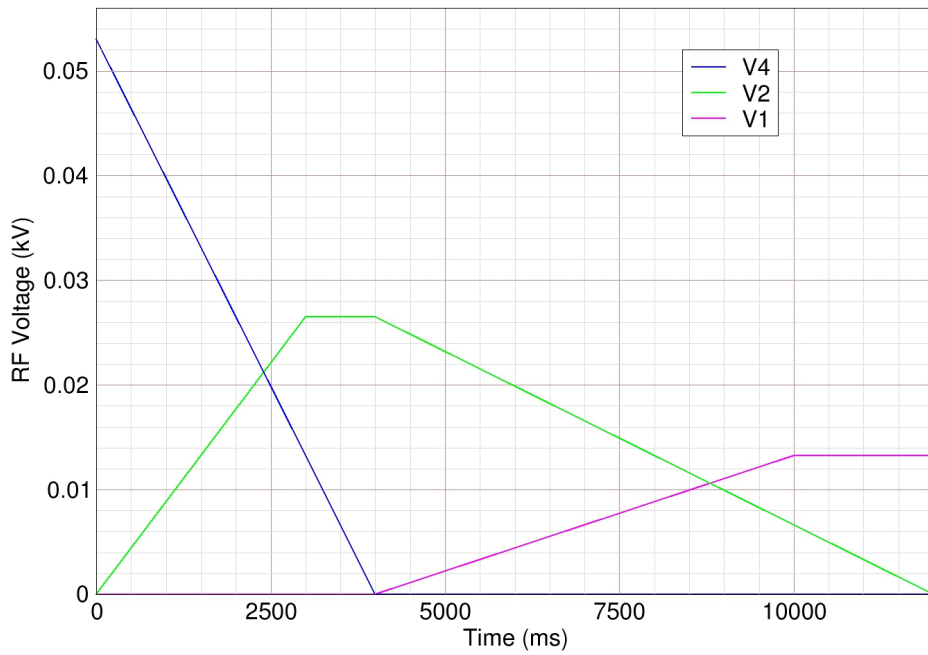


Figure 2: 4 to 2 to 1 merge at time  $t = 1500$  ms.



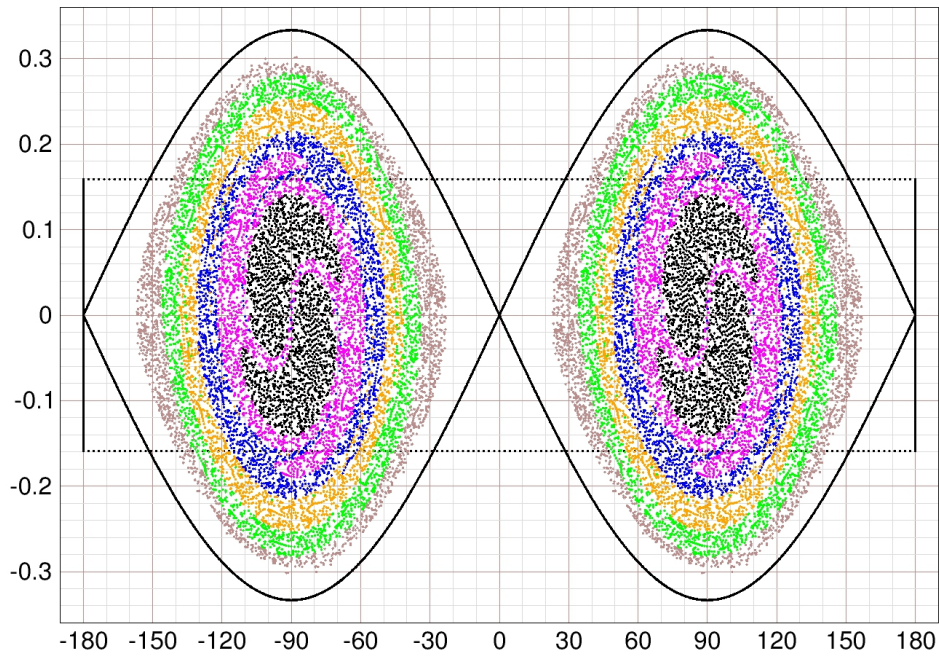
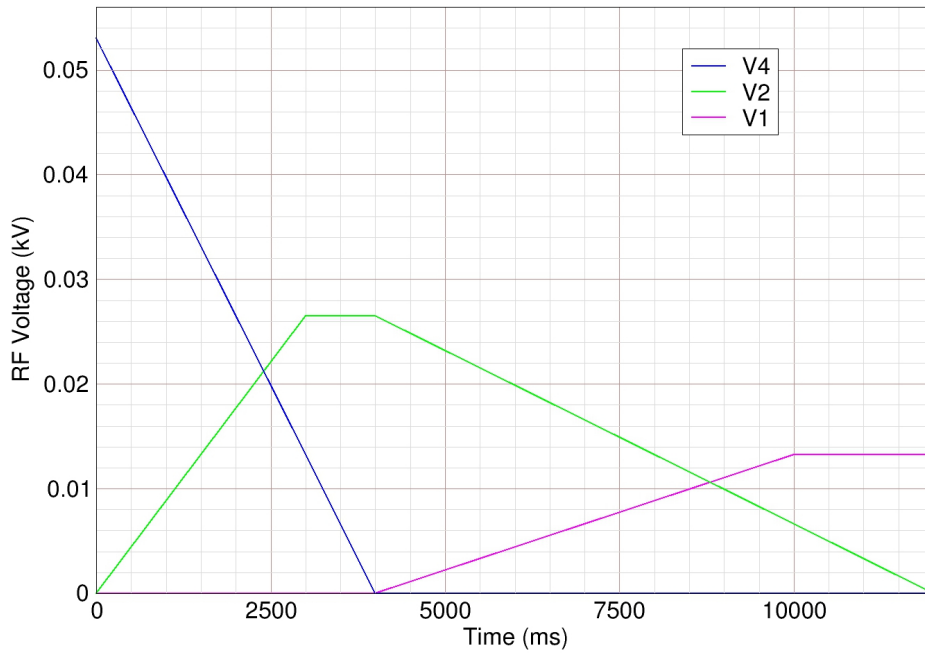


Figure 3: 4 to 2 to 1 merge at time  $t = 4000$  ms.



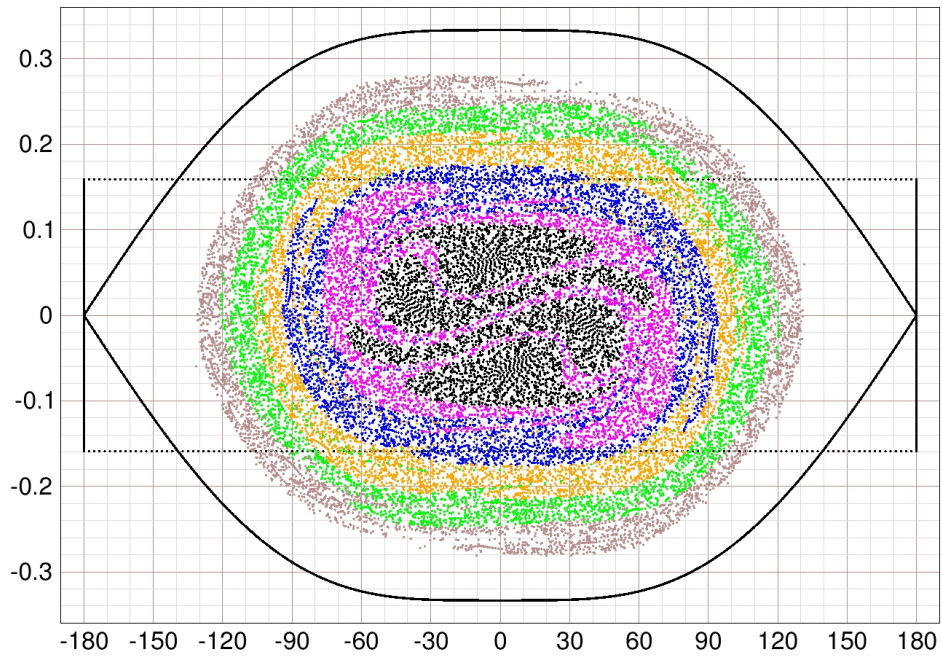
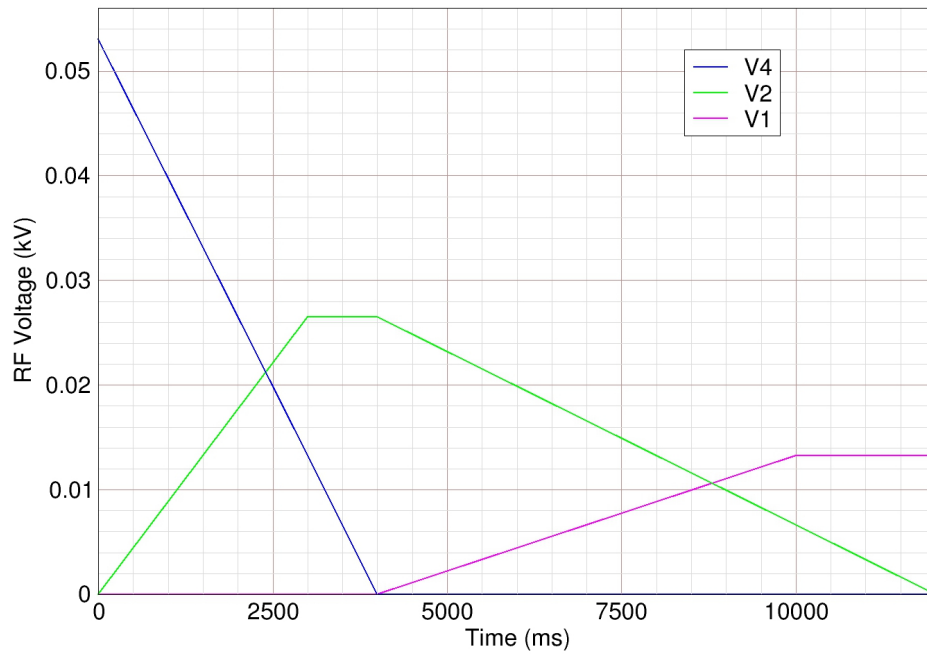


Figure 4: 4 to 2 to 1 merge at time  $t = 10000$  ms.





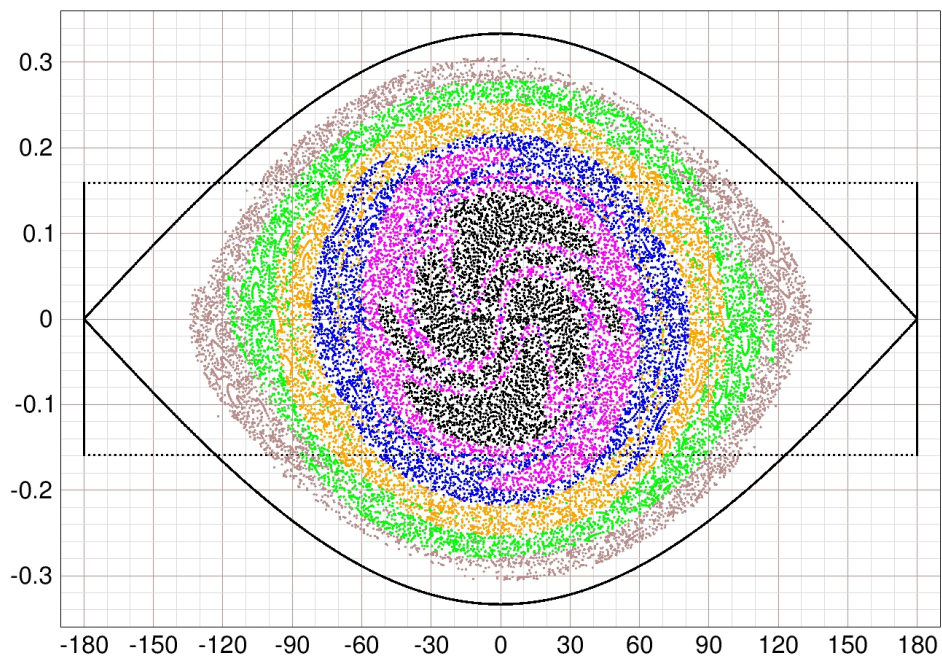
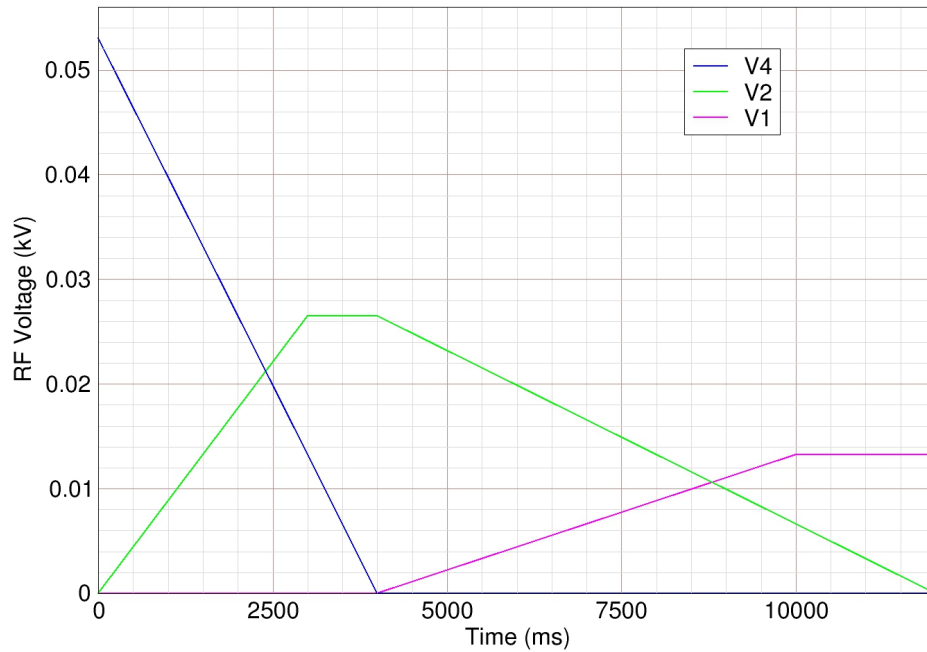


Figure 5: 4 to 2 to 1 merge at time  $t = 12000$  ms.



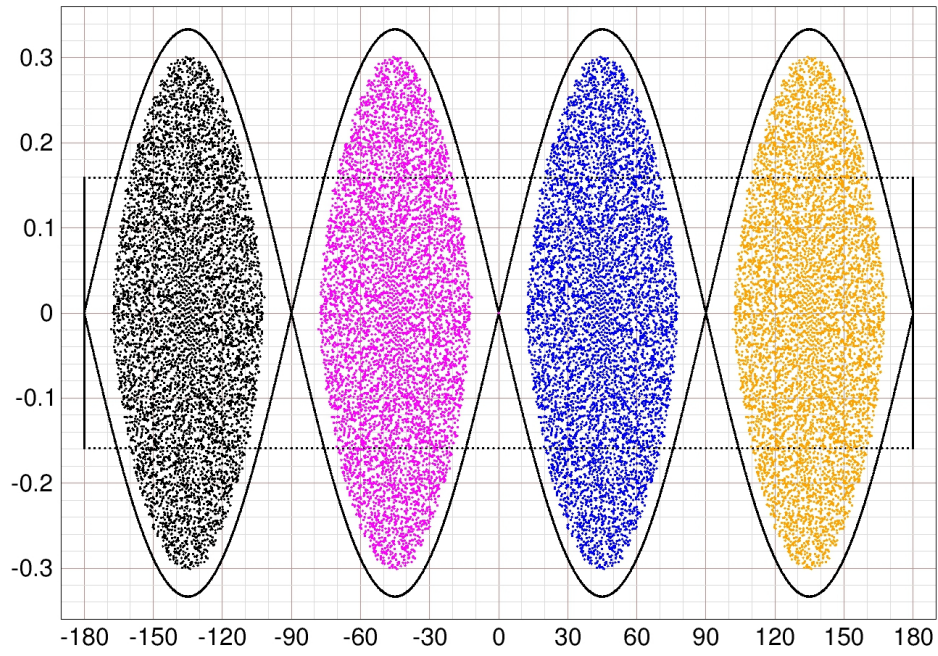
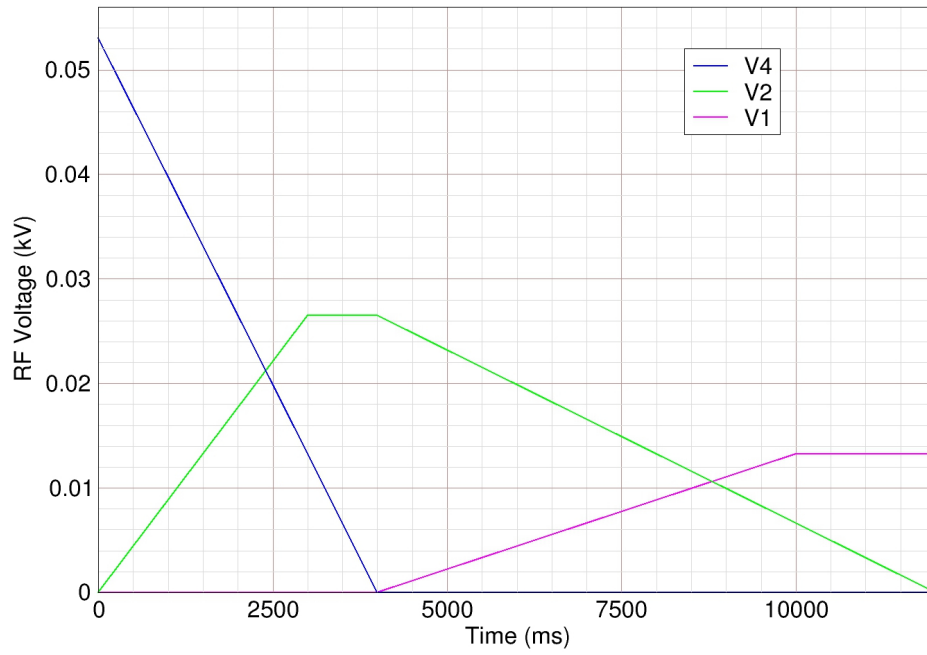


Figure 6: 4 to 2 to 1 merge at time  $t = 0$  ms.



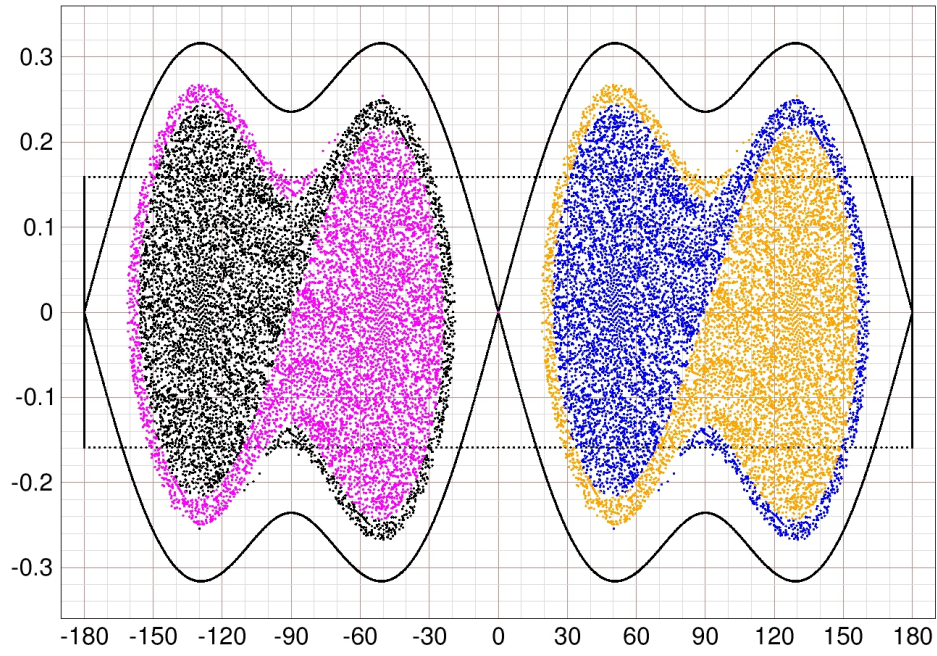
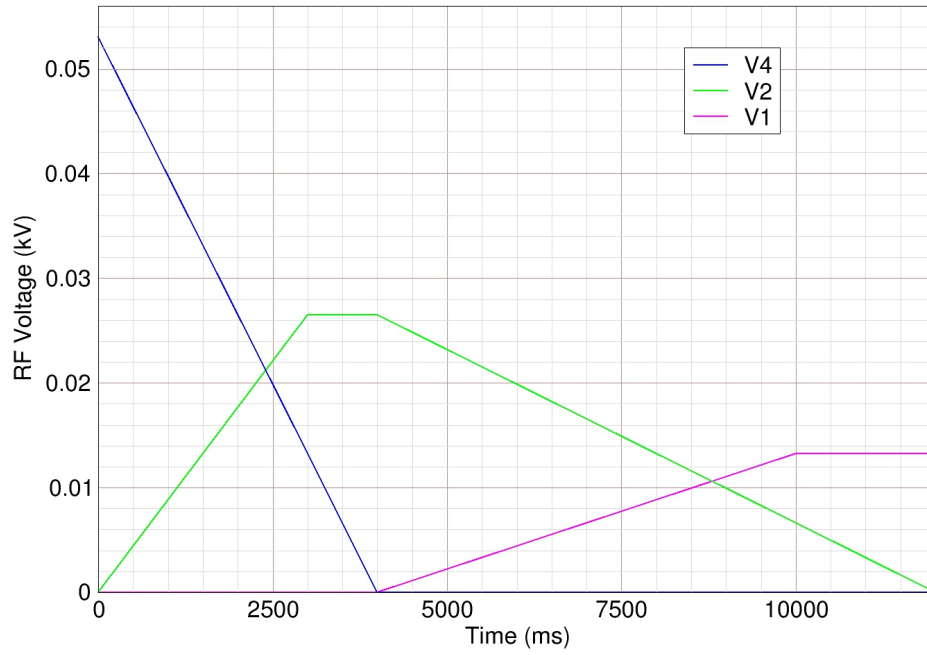


Figure 7: 4 to 2 to 1 merge at time  $t = 1500$  ms.



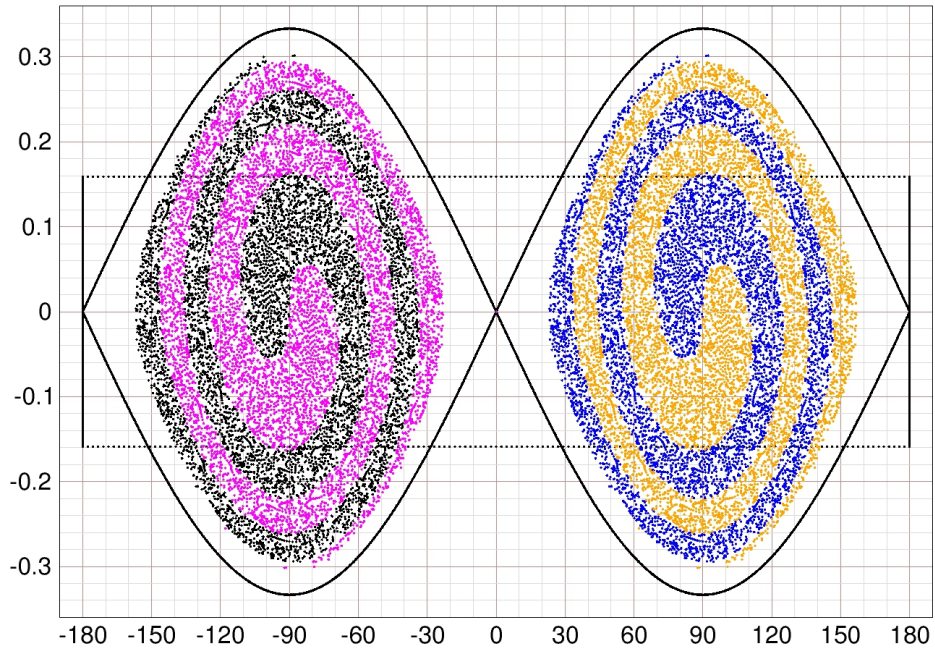
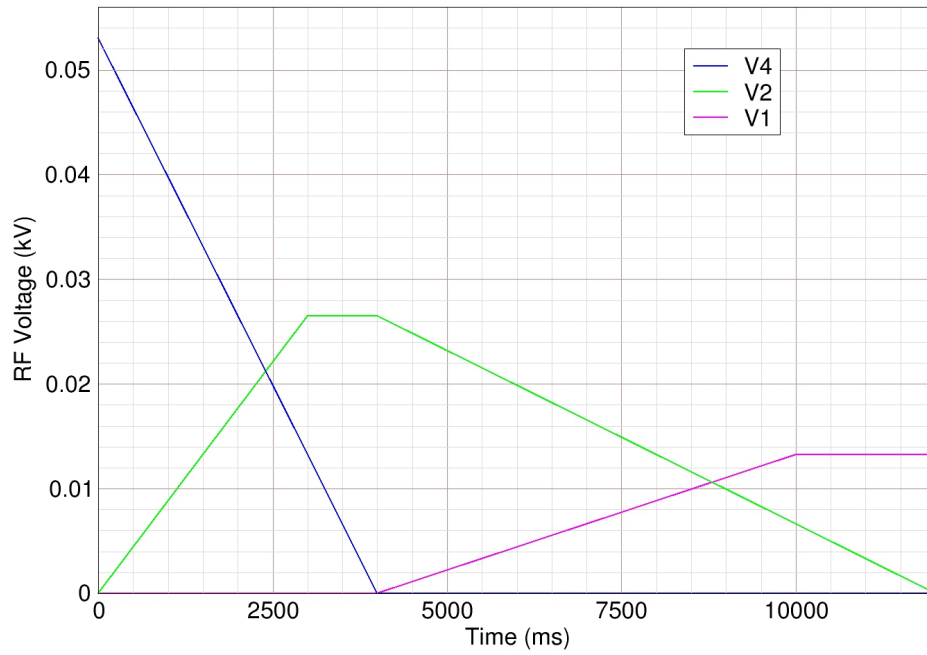


Figure 8: 4 to 2 to 1 merge at time  $t = 4000$  ms.



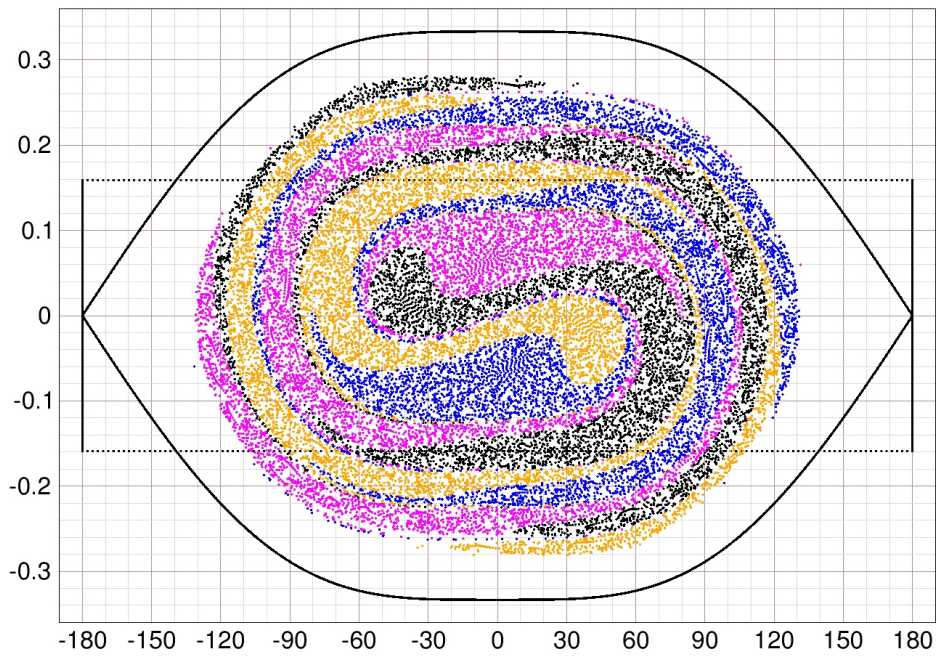
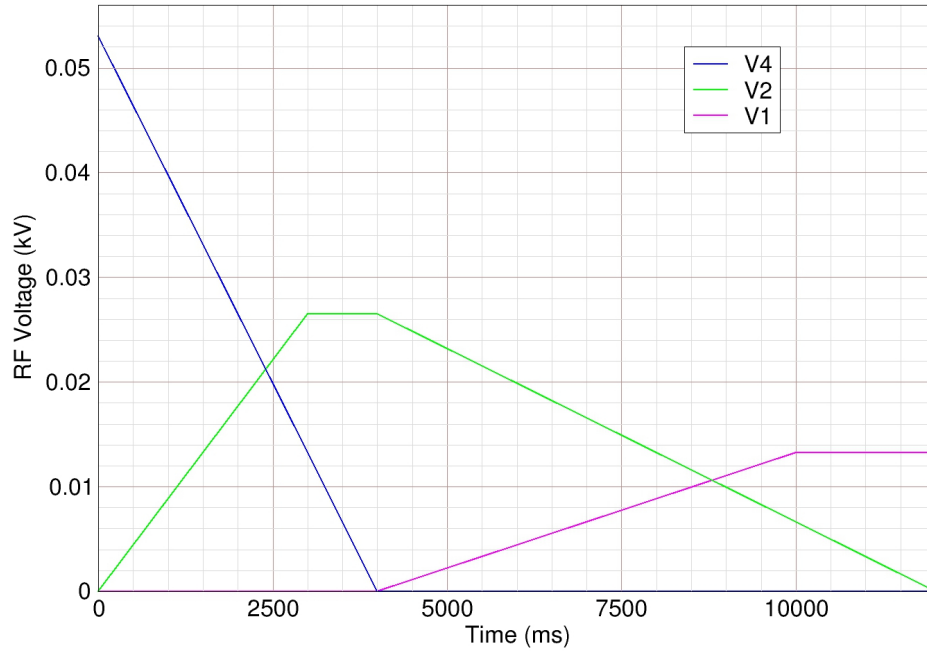


Figure 9: 4 to 2 to 1 merge at time  $t = 10000$  ms.



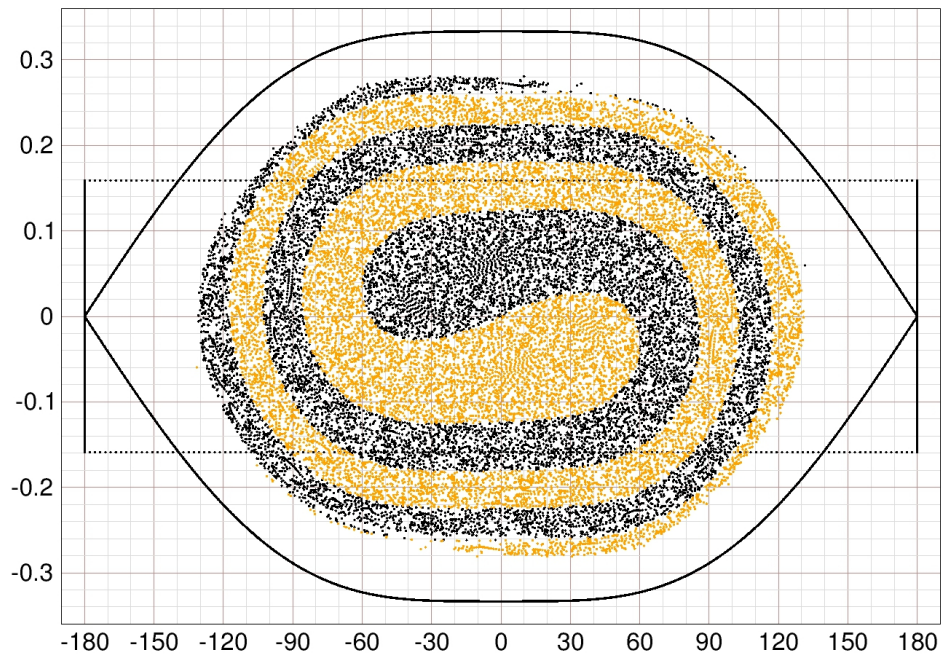
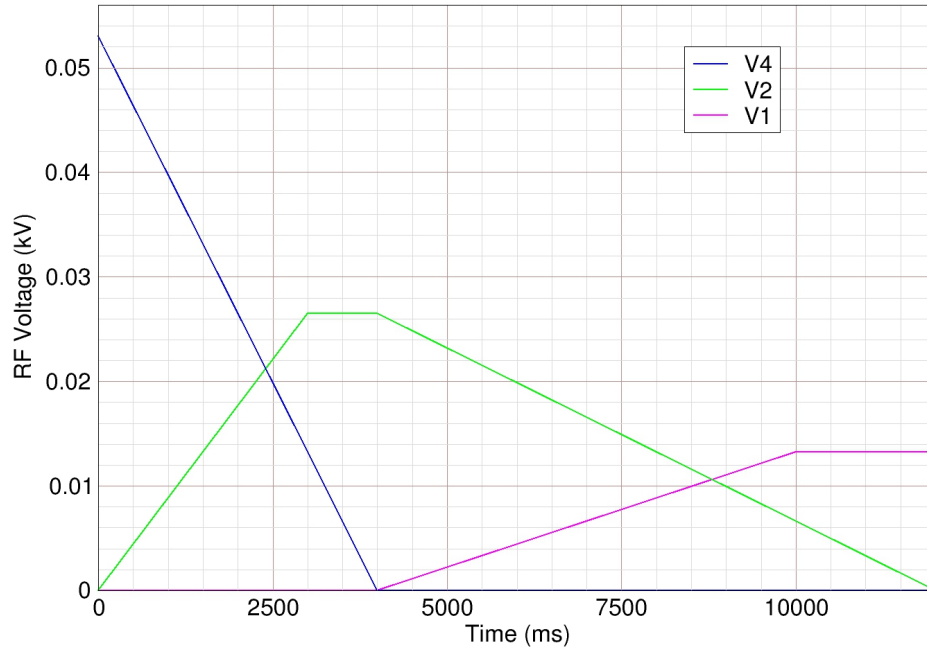


Figure 10: 4 to 2 to 1 merge at time  $t = 10000$  ms.



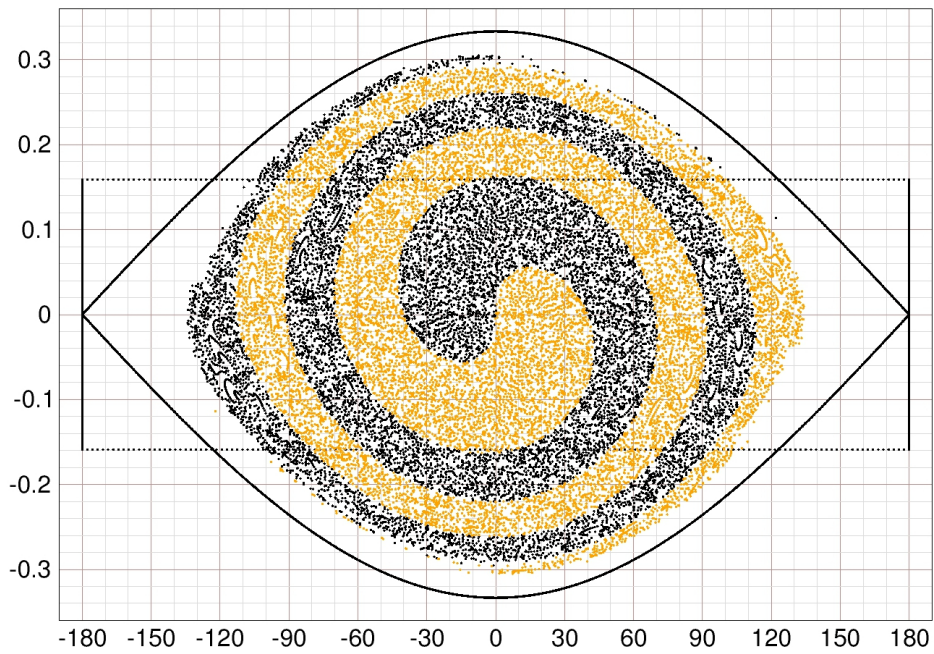
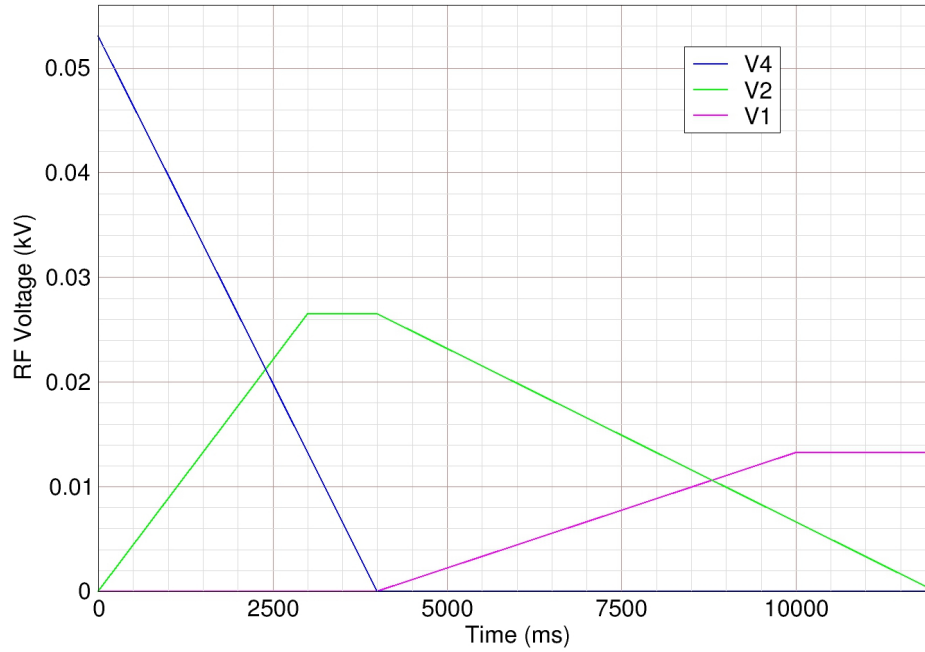


Figure 11: 4 to 2 to 1 merge at time  $t = 12000$  ms.



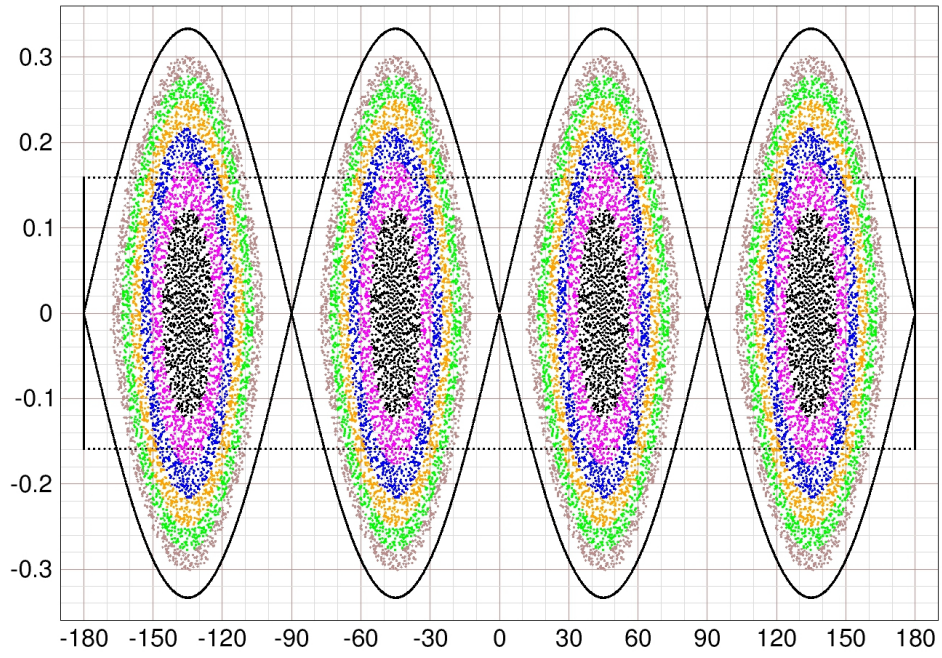
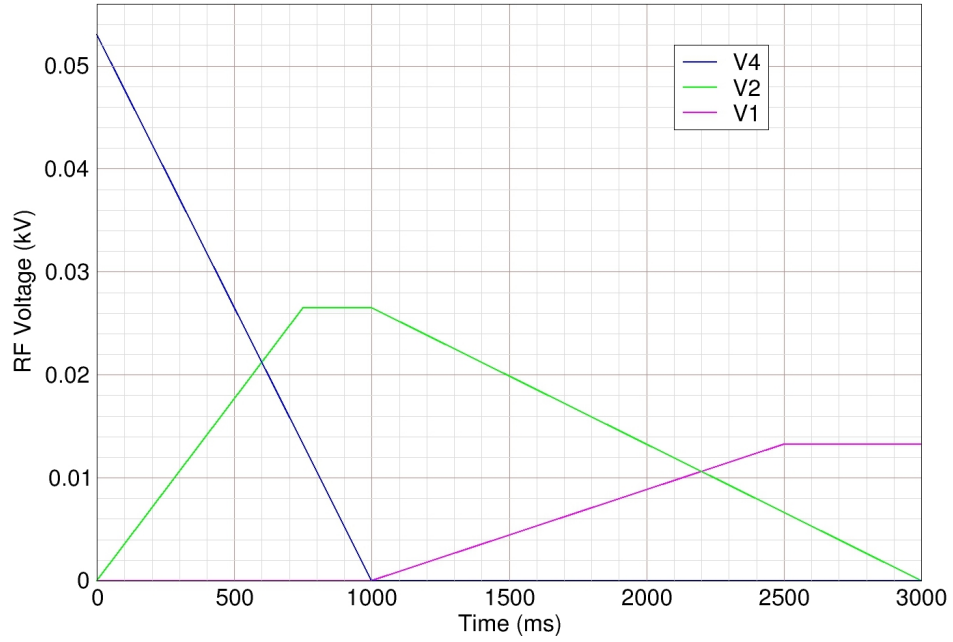


Figure 12: 4 to 2 to 1 merge at time  $t = 0$  ms.





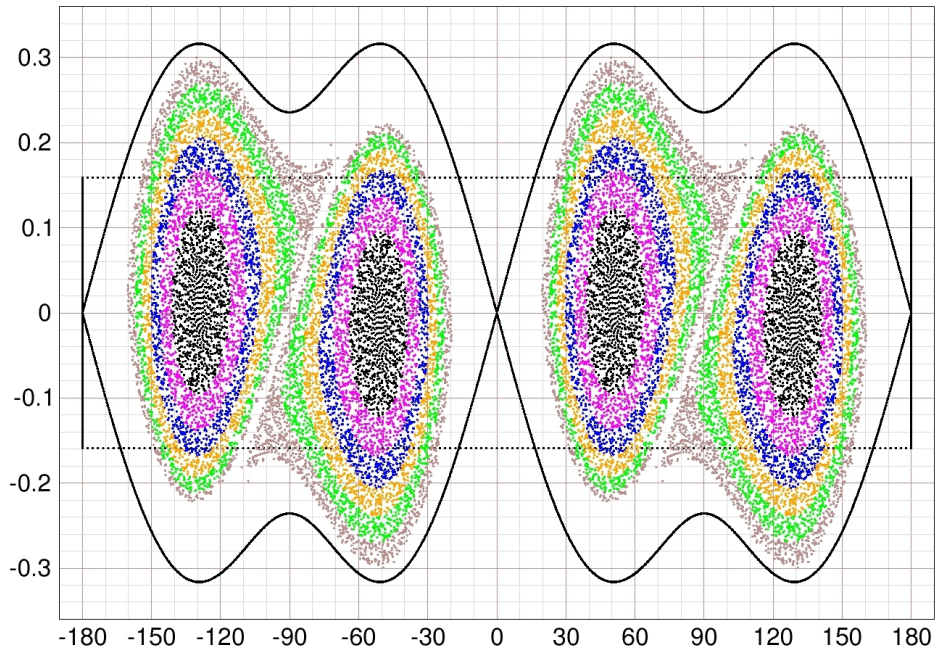
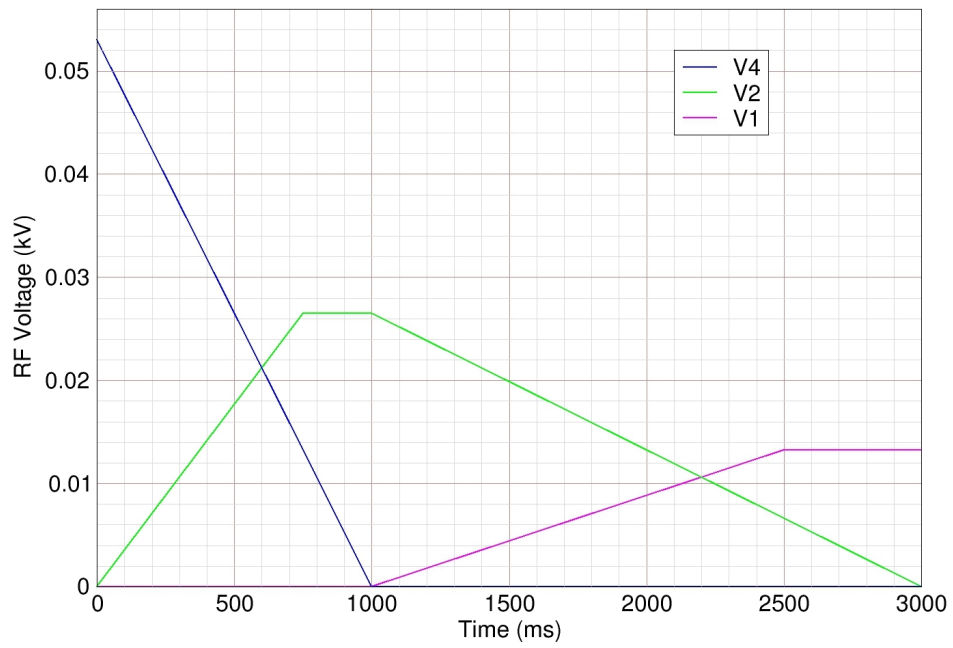


Figure 13: 4 to 2 to 1 merge at time  $t = 375$  ms.



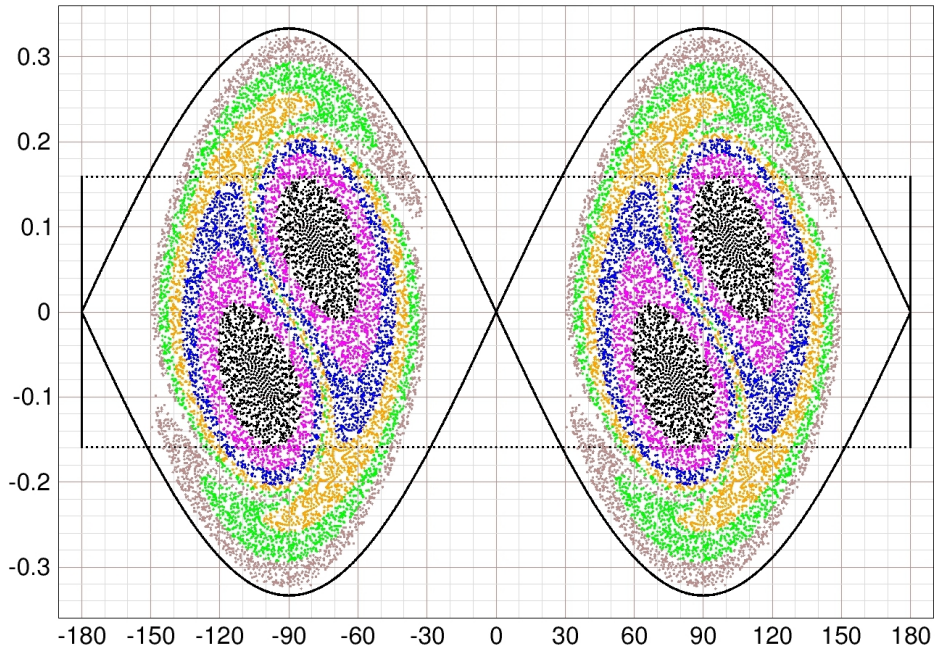
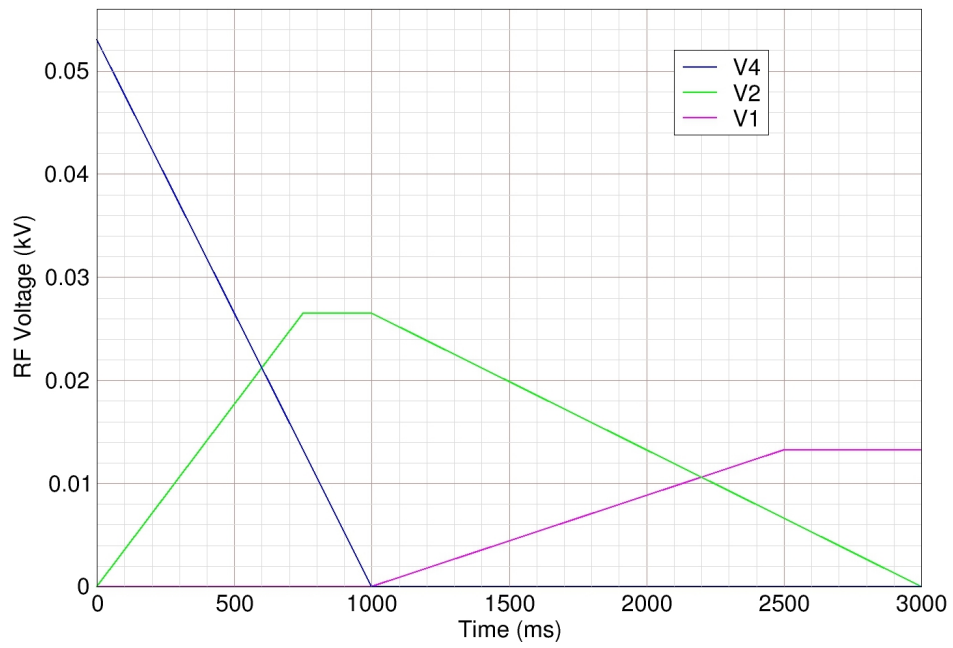


Figure 14: 4 to 2 to 1 merge at time  $t = 1000$  ms.



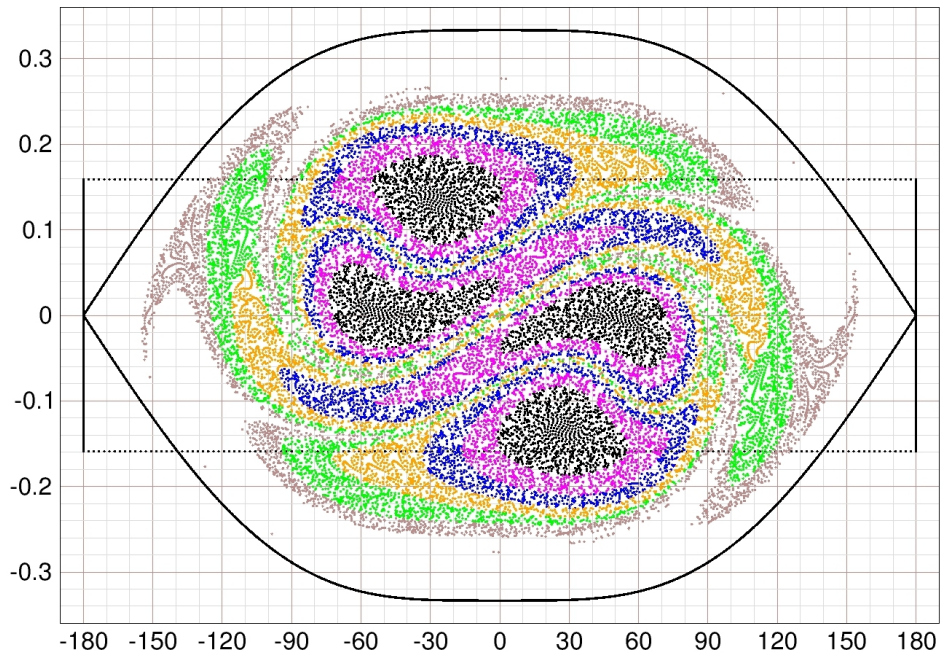
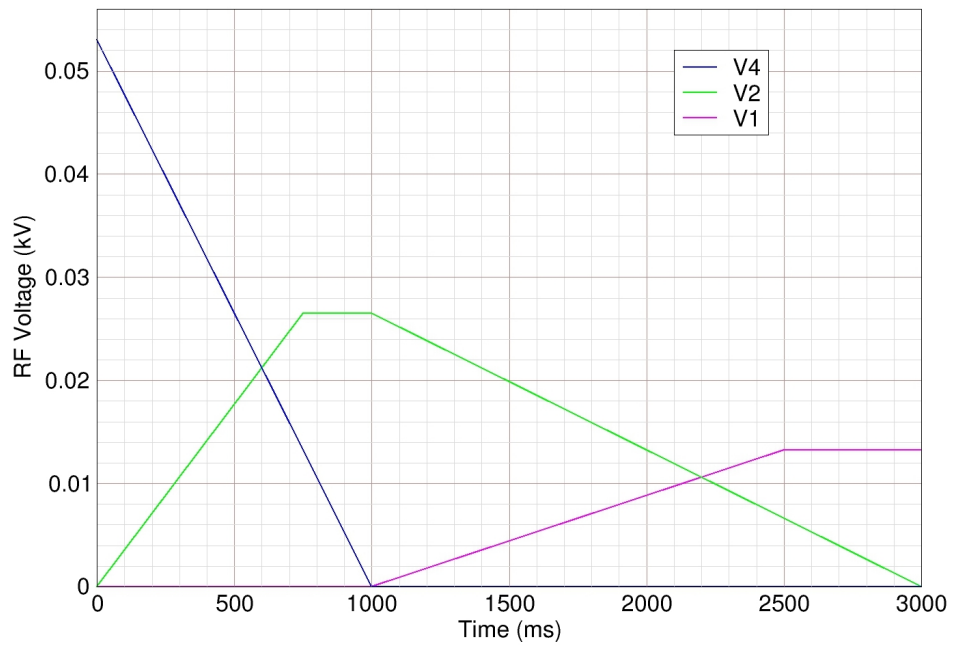


Figure 15: 4 to 2 to 1 merge at time  $t = 2500$  ms.



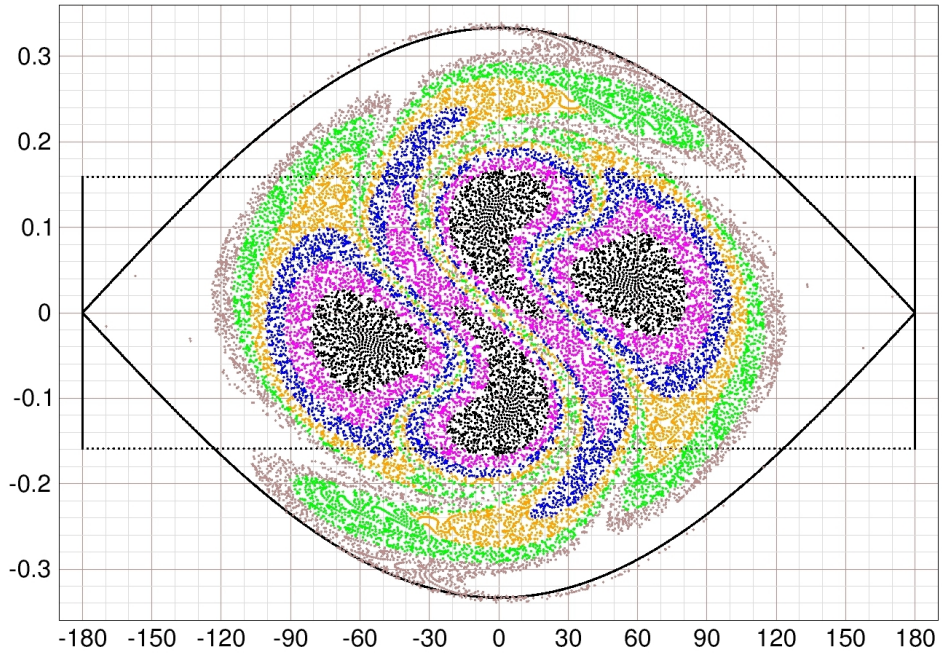
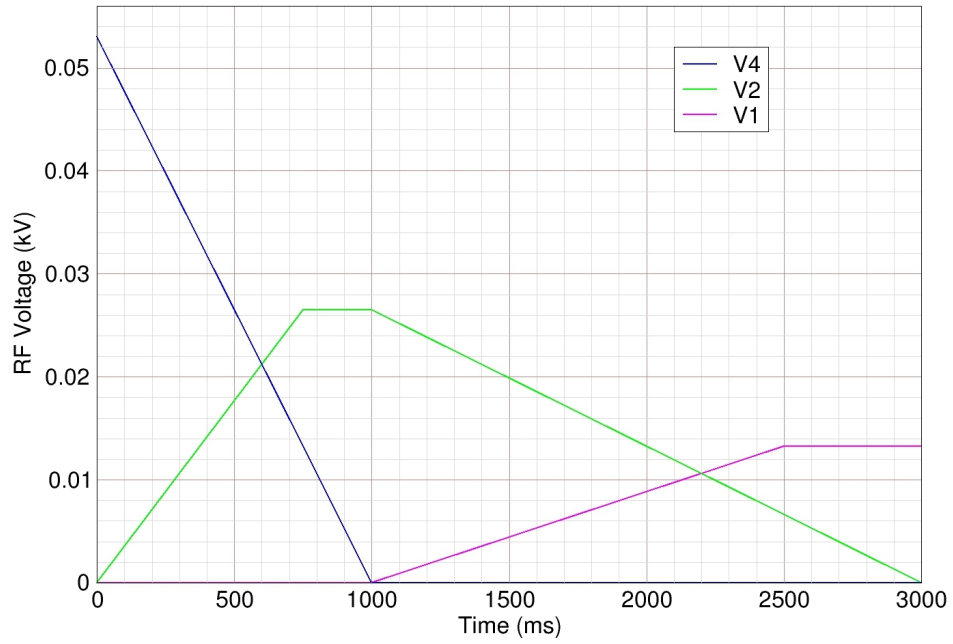


Figure 16: 4 to 2 to 1 merge at time  $t = 3000$  ms.



## References

- [1] C.J. Gardner, Fortran program ags2mrg23. 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.