Statistics of magnetic moment jumps in collision-less mirror machines

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GOALS

- **Develop a software pipeline for processing data from RMF.**
- **Search for patterns in parameter μ.**

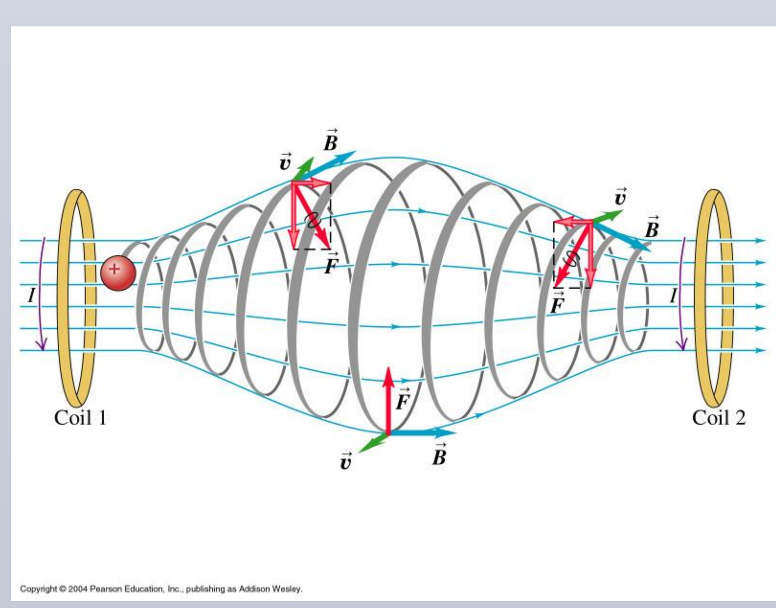
BACKGROUND: μ parameter and the magnetic bottle

- μ is a parameter known as the first adiabatic invariant of a particle. It is defined as the perpendicular kinetic energy of a particle, divided by the magnitude of the magnetic field

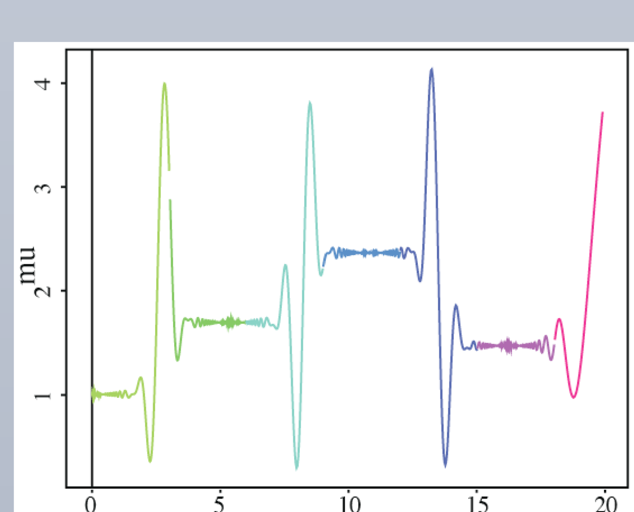
$$\mu = \frac{mv_\perp^2}{2B}$$

- In some magnetic configurations, μ is conserved.

- The magnetic configuration we studied was that of a magnetic bottle. This consisted of two electromagnetic coils with currents in the same direction. This produces a semi-linear magnetic field, with a small bulge in the center, as depicted below.

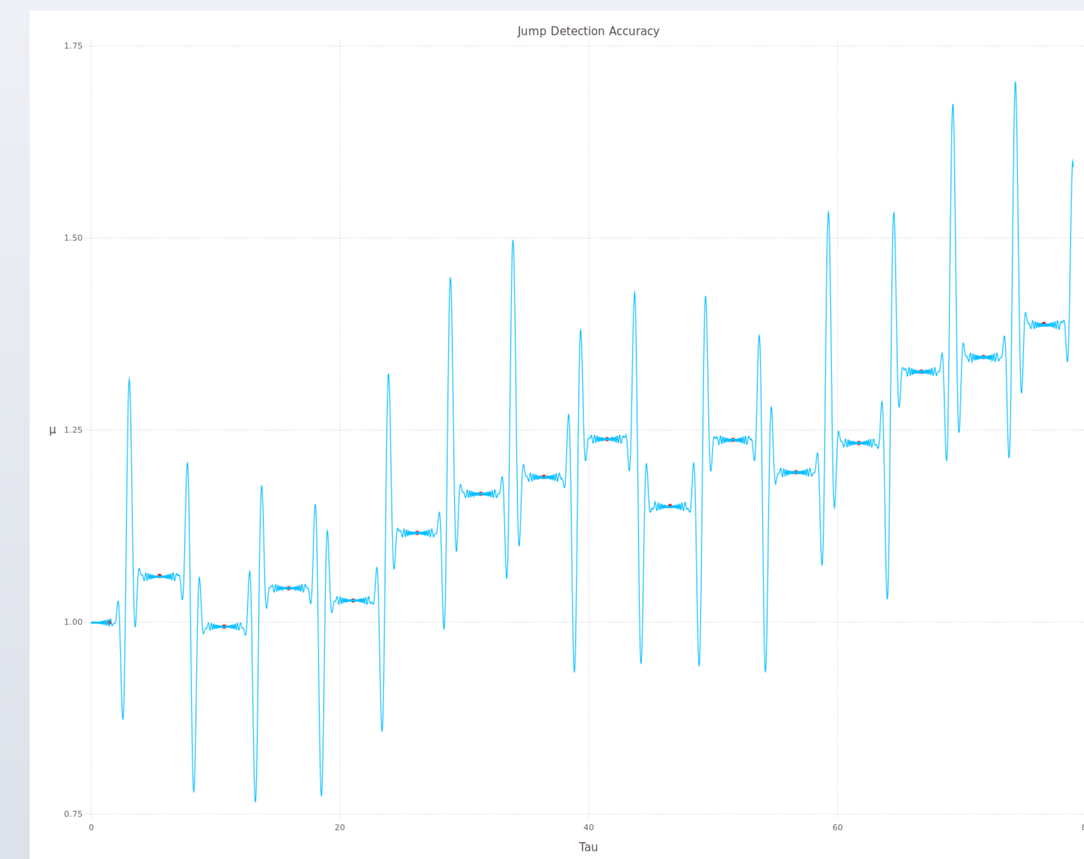


- In this configuration, μ is not conserved, and the value becomes chaotic. However, μ tends to change in the form of discrete jumps, as shown below.



Software Pipeline for data processing

- Needed to design a software package that could handle the large amount of data generated from long particle runs (1.3 GB - 2.3 GB for individual files).
- The program was designed in Julia, a new numerical computing language that retains the speed of low compiled languages.
- We noticed that they only occur when the particle passes through the origin of the machine. We then used this fact to mark the ends of a jump. We then took the midpoint of Tau between these points, and the median of the μ values between the jump ends to get our jump mark.
- This algorithm has the following benefits:
  - The simplicity allows quick and efficient debugging.
  - The algorithm runs in O(n) (linear) time, allowing the program to scale efficiently with processor speed and data size.
  - The algorithm could be easily parallelized in the future for large data runs.

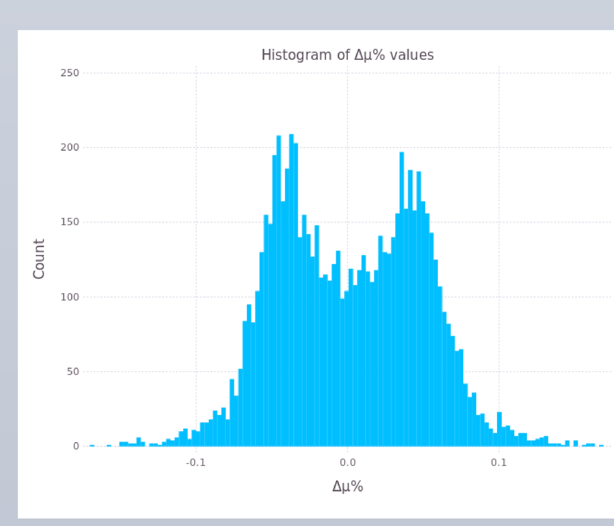


This chart displays the actual μ value (blue) and the predicted μ value (red).

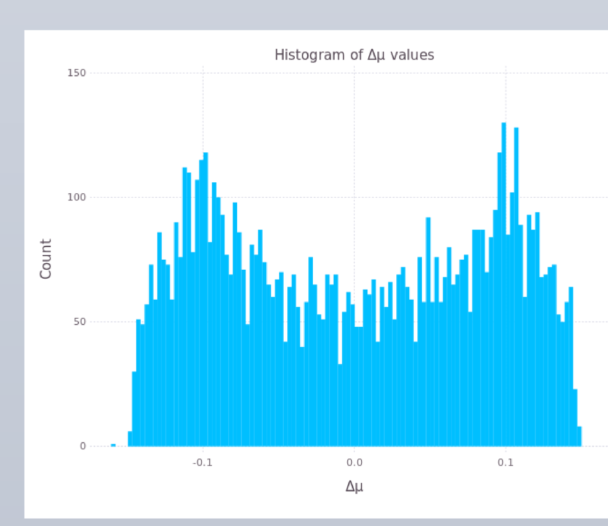
Statistics used

- For this study, we found a particular partial simulation that had a long containment period to achieve sufficient counts to apply statistical methods.
- To study the behavior of μ, we used the following statistical methods: autocorrelation, symbolic logic, and Poincare plots.
- We also were able to find a suitable definition for the phase of the particle, which is the following in spherical coordinates:
  - $\Phi = \mathrm{atan}(V\varphi/Vr)$

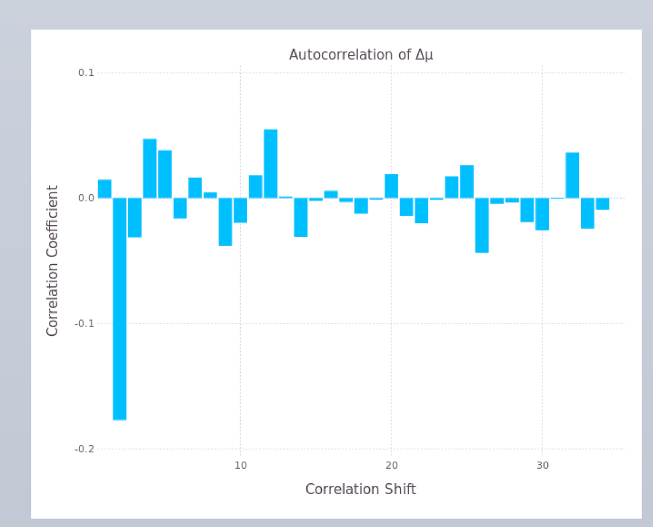
Histogram of Δμ%



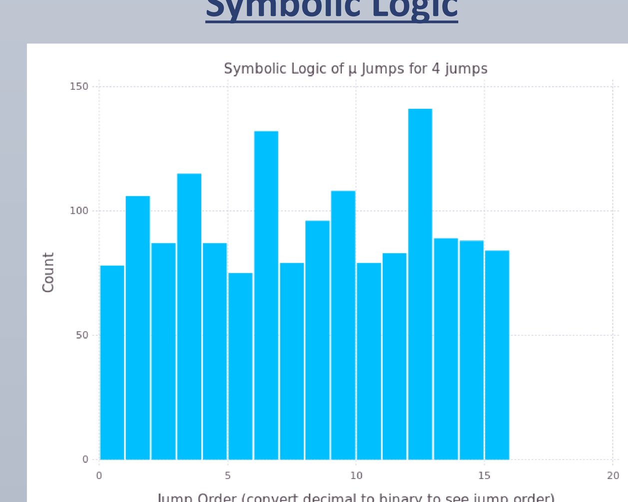
Histogram of Δμ



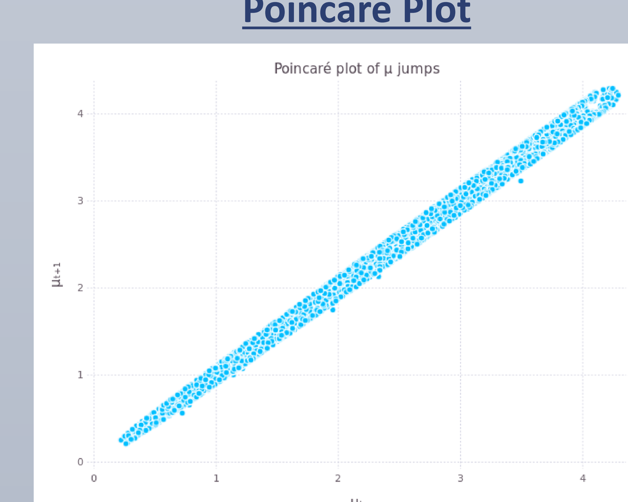
Autocorrelation of Δμ



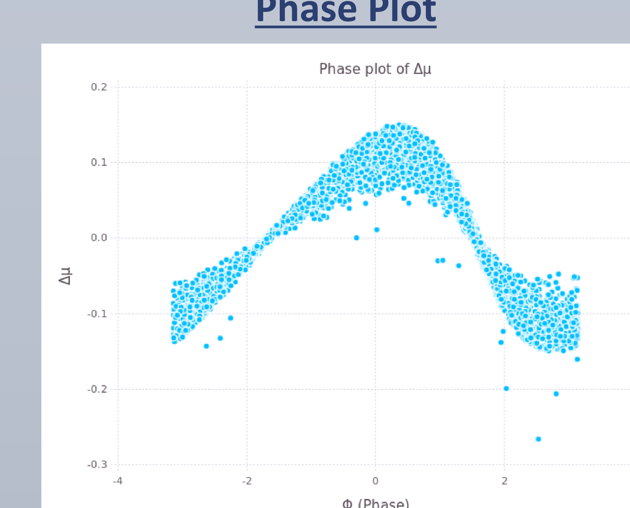
Symbolic Logic



Poincaré Plot



Phase Plot



SIMULATION METHOD

- Individual simulated by RMF 2.0, written by Alan Glasser of Los Alamos National Laboratory.
- Code was parallelized by Alex Glasser.
- Simulations were run on PPPL and Princeton University computers.

Future Work

- Find physical explanations for some of the patterns observed.
- Parallelize data processing pipeline.

CONCLUSIONS

- **The histograms of the change in μ display the arcsin probability distribution, implying that μ operates according to a noisy sine curve.**
- **Autocorrelation displays an inverse correlation in a shift of 2 and a positive correlation with jumps of 8.**
- **Symbolic Logic showed that it was much more likely for positive and negative jumps to occur together in groups of two.**
- **Poincaré plots showed minor signs of abnormal behavior during high μ values.**
- **Phase plot shows that Δμ has a sinusoidal pattern to it. It also contains a small, but noticeable number of outliers.**

REFERENCES

Magnetic Bottle image from http://www2.hawaii.edu/~plam/ph272_summer/L7/27_Lecture_Lam.pdf

Papers:

[1] A. Garren *et al.*, "P/383 USA Individual Particle Motion and the Effect of Scattering in an Axially Symmetric Magnetic Field."

[2] L.R.Henrich, "Henrich - Departure of particles 413-eoa."

[3] T. W. Speiser, "Particle Trajectories in Model Current Sheets 1. Analytical Solutions," *J. Geophys. Rw.*, vol. 70, no. 1, 1965.

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