EPPS measurements of particle acceleration due to magnetically driven reconnection

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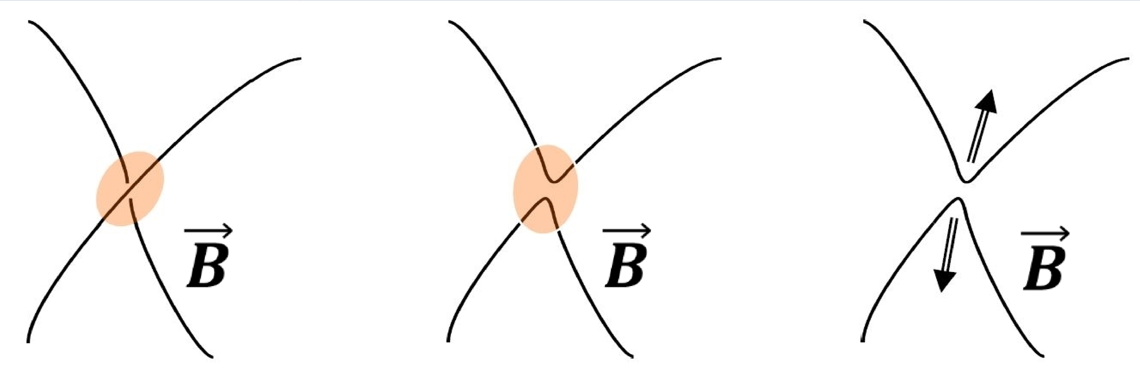
Objectives

The primary objective of this experiment is to determine if particle acceleration due to magnetic reconnection can be experimentally demonstrated through a laser-driven coil setup. Secondarily, we want to determine if the magnetic reconnection particle acceleration mechanism holds angular dependence.

Magnetic Reconnection

Magnetic reconnection is a ubiquitous phenomenon characterized by the rapid breaking and reconnecting of magnetic field lines.



During this topological rearrangement, magnetic energy is converted into plasma flow energy, thermal energy, and nonthermal energy. An unsettled question in reconnection is that of what the nonthermal particle acceleration mechanisms are, and while several theories exist, they are untested in laboratory plasmas due to 1) short Debye lengths for *in situ* measurements of nonthermal charged particles and 2) short mean free paths for remote measurements of nonthermal charged particles.

To bypass this limitation, we have developed a reconnection platform [1] at the Jupiter Laser Facility using laser-powered capacitor coils (Fig. 1a, 1b).

Experimental Setup

In tandem with these laser-driven coils, five electron-positron particle spectrometers (EPPS) are positioned at various angles relative to the driven target to investigate the angular dependence of reconnection particle acceleration. To isolate reconnection-accelerated particles, we compare EPPS data from a reconnection (2-coil) case to a control (1-coil) case.

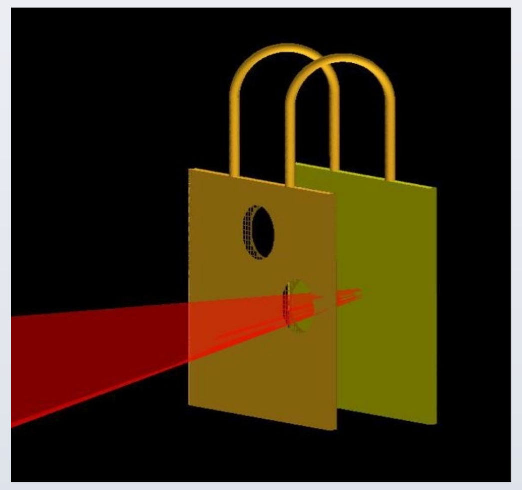


Fig. 1a. View of laser-driven coil system. Using the Titan laser, the rear plate is irradiated, generating an electrical potential difference between the plates. The charge imbalance induces large electrical currents to flow through the coils, which generate ~100 tesla magnetic fields.

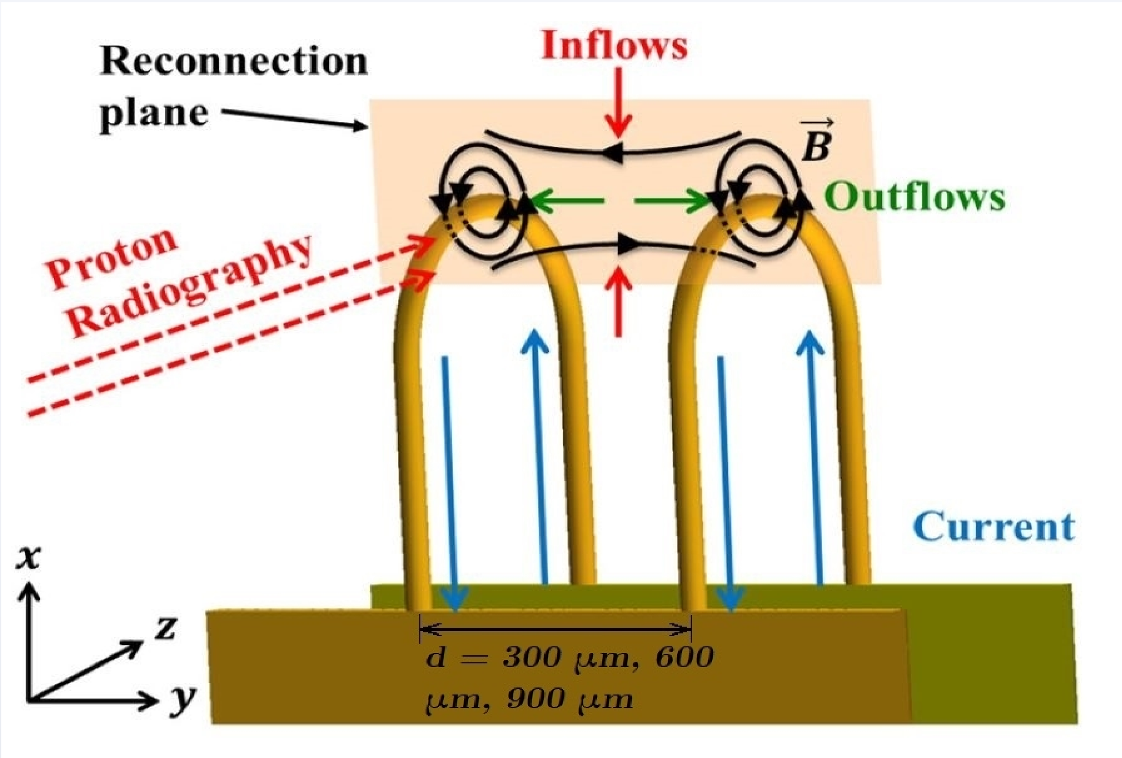


Fig. 1b. Using a laser, the back plate is irradiated with a ~250 joule infrared nanosecond square pulse, generating a potential difference between the plates and kA currents through the coils. From these moving charges, ~100 tesla magnetic fields are generated and diagnosed using proton radiography.

Results

A general Python code for performing cross-correlation analysis on arbitrary functions $F_i(x)$, $F_j(x)$, $i \neq j$ was written. In this, a number $N_{ij} \in [0,1]$ is computed which determines how similar a pair of spectra are, where a higher N implies a higher similarity. Other pairwise numbers were computed, such as energy difference ΔE_{ij} and coil combination $C_{ij} \in \{(1,1), (1,2), (2,2)\}$.

Using scatterplots, we attempted to find what variables determined spectrum similarity. Notably, we found energy difference dependence to be spectrometer-dependent (Fig. 3).

Additionally, we computed the variance and kurtosis among all 1-coil and all 2-coil shots to see if a statistically significant difference between them existed, which would suggest the presence of inherently turbulent or chaotic processes that uniquely pertain to 1 or 2 coils. However, variances and kurtoses were found to be similar, suggesting otherwise.

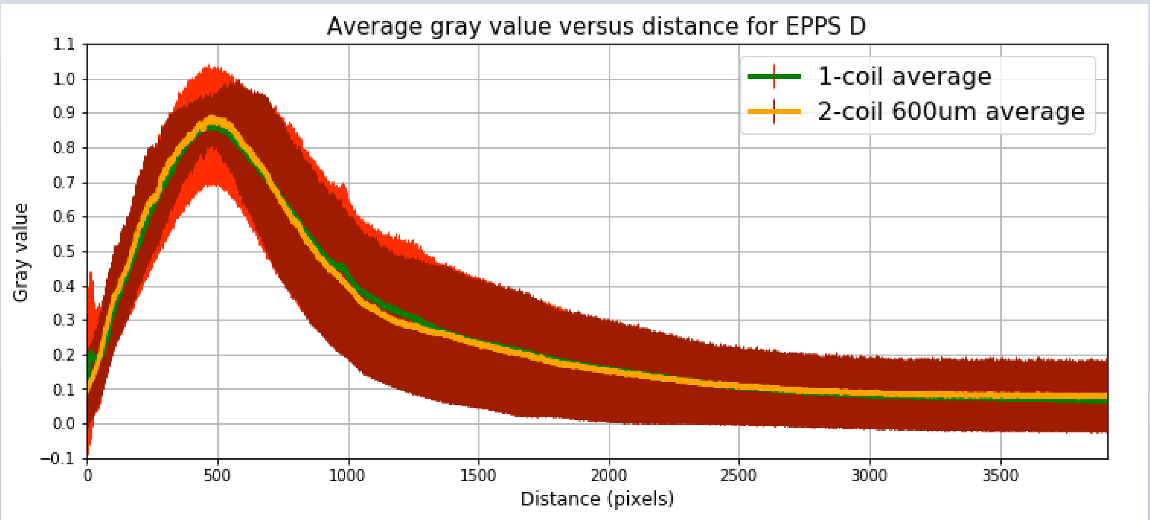


Fig. 2. Average of 1-coil and 2-coil 600μm separation.

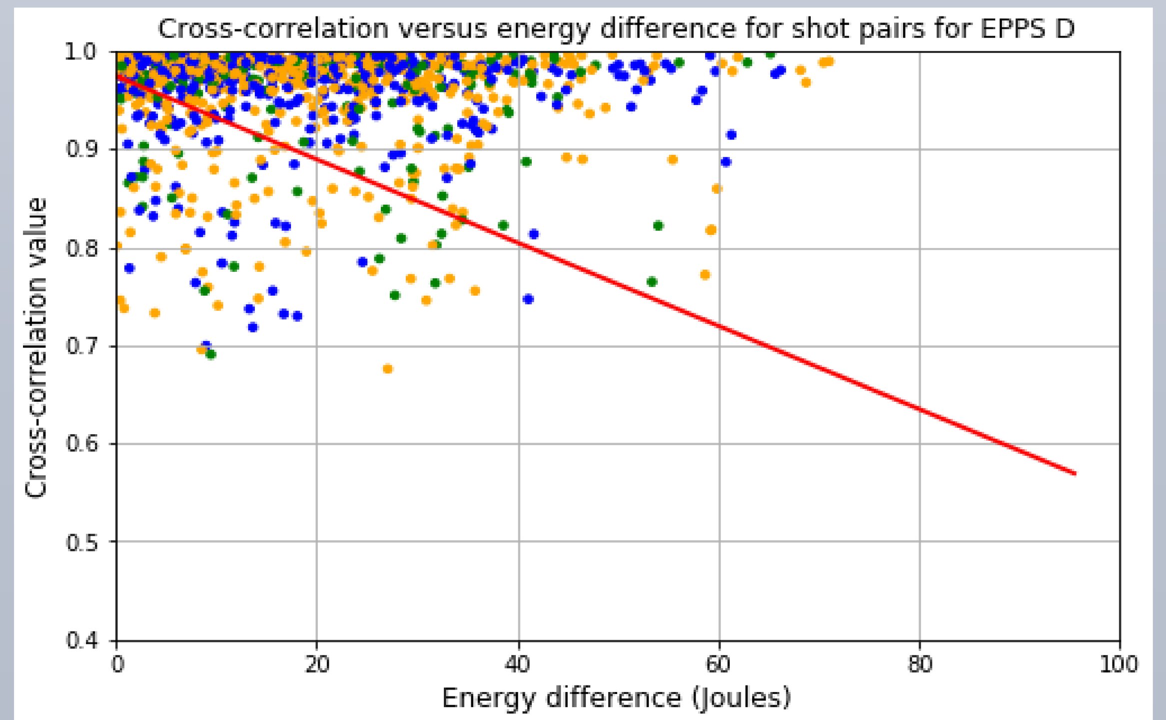


Fig. 3. For EPPS B, C, and D, an inverse relation was found; for EPPS E, no relation was found, and for EPPS A, a direct relationship was found.

Discussion

Parameter conversions from gray value and pixels to particles per energy and energy are not available yet, meaning that comparisons to particle-in-cell (PIC) simulations cannot be made. Consistency with PIC simulation data would constitute evidence for the detection of particles accelerated by magnetically-driven reconnection.

Conclusions/Future Work

Due to the inconsistency of the Titan EPPS data, it is difficult to conclude whether nonthermal charged particles accelerated by magnetically driven reconnection were detected. However, a largely analogous experiment is planned for September 2020 at the OMEGA EP Laser System located at the University of Rochester, which is expected to produce consistent data. Given the generalized nature of the developed code, it should be straightforward to apply it to the new data.

References

[1] Phys. Plasmas 26, 062113 (2019)

Acknowledgements

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