Development of a Multi-Particle Spectometer

Davis Arthur, Guillaume M. Laurent, and Bree Tatum

Multi-particle imaging techniques are needed to properly unravel the dynamics of atomic and molecular processes at their natural time scale (femtosecond to attosecond). Cold target recoil ion momentum spectroscopy, or COLTRIMS, is an imaging technique that utilizes a uniform electric field and a uniform magnetic field to map the momentum-space distribution of a charged particle (electrons, recoil ions, molecular fragments) to a position on a 2-dimensional particle detector. By recording the position where the particle strikes the detector, as well as the particle's time of flight, the initial momentum of the particle can be reconstructed with unmatched precision and reliability (Ullrich et al., 2003). Over the last two decades, COLTRIMS has risen in prominence due to its application in the field of ultrafast science (Young et al., 2018).

While it is generally assumed that the magnetic field of the COLTRIMS spectrometer is uniform over the full spectrometer region, this assumption is only an approximation. In practice, the magnetic field is usually generated by a pair of Helmholtz coils much larger than the ultra-high vacuum (UHV) chamber enclosing the spectrometer. Induced currents in any conductive materials within the Helmholtz coils (including the frame of the spectrometer) will inevitably deteriorate the uniformity of the magnetic field. Thus far, COLTRIMS experiments have largely ignored such variations, since the induced magnetic fields can be difficult to predict or even measure. In this work, we proposed a novel COLTRIMS design that utilizes a solenoid magnetic field source rather than a Helmholtz coil. A solenoid more closely matches the geometry of current leading COLTRIMS designs, and it can produce a magnetic field with greater uniformity. We anticipate that by enclosing the solenoid within the UHV chamber, we can better shield extraneous magnetic fields from the spectrometer.

The theoretic spatial variation of the magnetic field of a finite solenoid cannot be easily determined using analytical methods. Therefore, in order to better analyze the viability of our design, we approximated the solenoid as a series of finite straight wires. To determine the magnetic field at a given point within our spectrometer, we calculated the magnetic field of each straight wire in the approximation and then applied the principle of superposition. From our approximation, we found that the magnetic field produced by a solenoid with a length to radius ratio of 6:1 will have a spatial variation of less than 5% within the centermost half of the spectrometer, as shown in Figure 1. When only the centermost quarter of the spectrometer is considered, the variation drops to less than 1%.

It is also worth noting that the spatial dependence of the variation near the center of a solenoid is relatively simple. Therefore, it may be possible to account for the non-uniformity in each particle's equation of motion. From our findings, we believe a solenoid is an excellent candidate for the magnetic field source of a COLTRIMS device. We believe that using a solenoid in our spectrometer design will allow us to improve spectrometer resolution by minimizing the effect of extraneous magnetic fields. We have begun preliminary construction of our spectrometer and hope to take our first measurements in the near future.

Statement of Research Advisor

Davis has designed a novel configuration for multi-particle spectrometers used in atomic and molecular experimental physics. To that purpose, he first developed a simulation package to mimic the trajectories of charged particles in the spectrometer. He then used his package to optimize the spectrometer configuration (length, diameter, number of wire loops and shape). Once the design completed, he built and assembled the spectrometer, which will be used in our laboratory over the summer.

–Guillaume M. Laurent, Physics

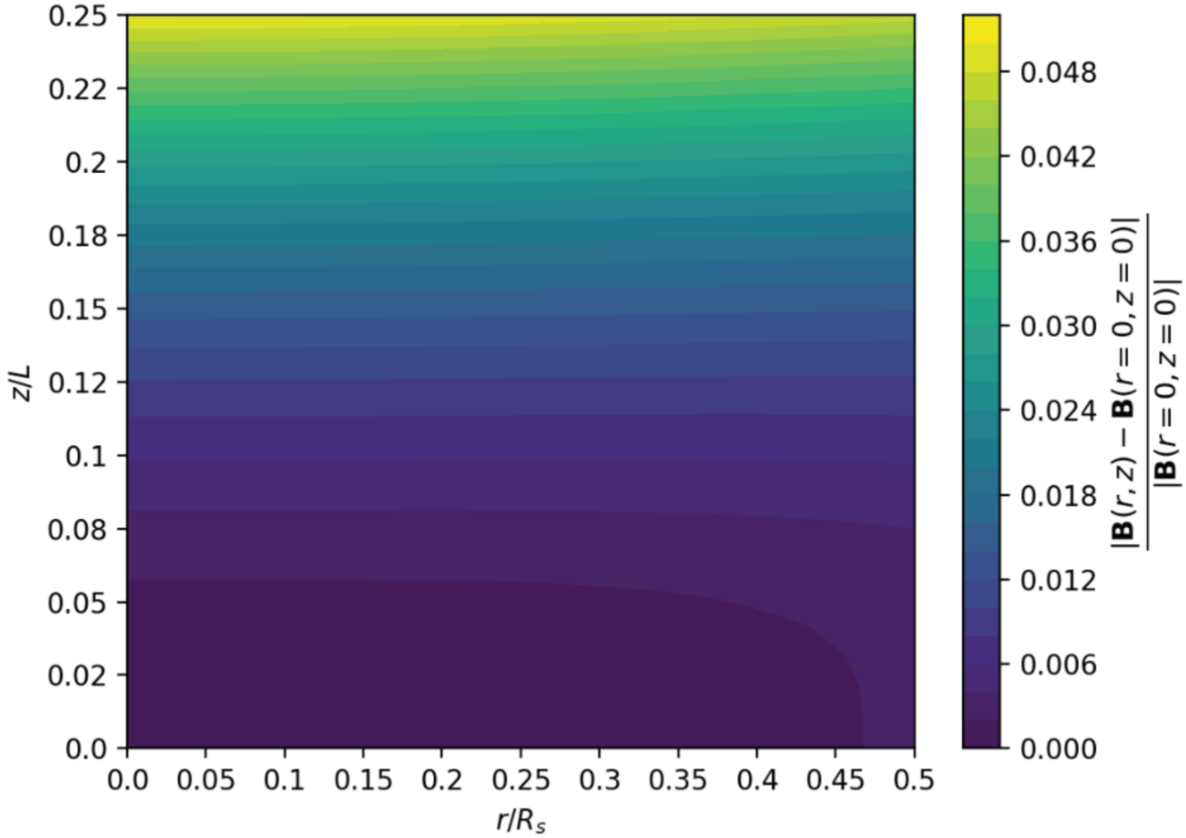

Figure 1: Simulation of the magnetic field uniformity of a finite solenoid with a length (L) to radius (Rs) ratio of 6:1. The coordinate (z=0,r=0) indicates the center of the solenoid. The magnetic field vector at a given radial and axial position is denoted by **B**(r,z).

References

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L. Young, et al. Roadmap of ultrafast x-ray atomic and molecular physics. *Journal of Physics B: Atomic, Molecular, and Optical Physics,* ***51*** (3). 2018.