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The Effectiveness of the Compton Radiography Snout Electron Deflection Yoke and its Application as an Electron Spectrometer

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The Effectiveness of the Compton Radiography Snout Electron Deflection Yoke and its Application as an Electron Spectrometer

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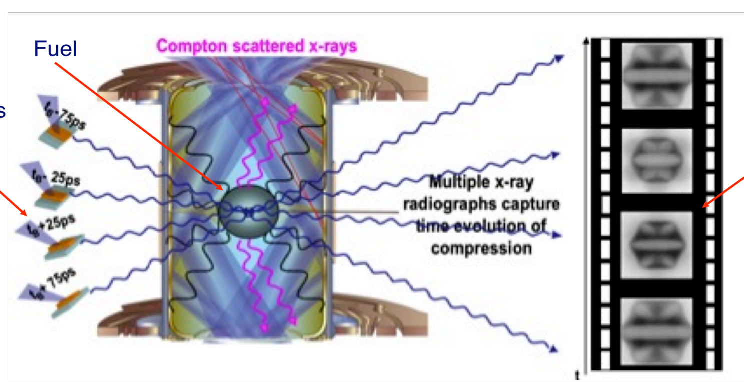
Abstract
The Compton Radiography Snout (CRS) is a prototype of a diagnostic called the High Energy X-Ray Imager (HEXRI) that will be used to record radiographs of imploding fuel cells on NIF. With these radiographs, it is possible to characterize the density and symmetry of the imploding fuel capsule. When the advanced radiography capability is used to generate the high energy x-rays used to backlight the radiographs, hot electrons are also produced. In order to record a clear radiograph, these electrons are deflected away from the imaging plane of the CRS using a permanent magnetic yoke. In an effort to increase the number of parameters that can be used during the scaling of the CRS for NIF, an investigation is underway to add an electron spectrometer capability to the CRS to measure the electron spectrum produced during the ARC backlighting.

Introduction
The Compton Radiography Snout (CRS) is a prototype of a diagnostic called the High Energy X-Ray Imager (HEXRI) that is being tested at the OMEGA laser facility for eventual scaling and use at the National Ignition Facility (NIF). HEXRI will record for radiographs that are spaced temporally, in order to characterize the density and symmetry of the imploding fuel capsule at 4 different times during the fuel implosion.

X-Ray Back Lighters



Resultant images on CCD Camera

Figure 1: The Advanced Radiographic Capability (ARC) will be used to create a series of four radiographs of the fuel implosion spaced in time.

These radiographs will be created using NIF's Advanced Radiographic Capability (ARC) to backlight the target with high energy x-rays. These high energy x-rays are created using the interaction between small gold wire and a short-pulse laser and travel through the target and then into a scintillator which converts the x-rays into light in the visible spectrum. Finally, the radiographs are recorded using a gated CCD camera.

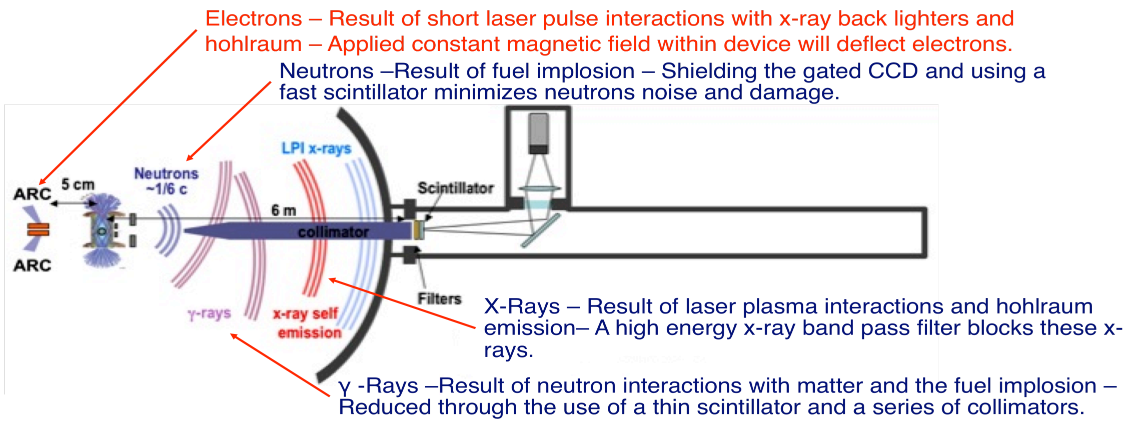


Figure 2: Sources of noise in the High Energy X-Ray Imager.

An issue that arises when recording radiographs of an imploding fuel capsule is that there are many sources of noise that will degrade radiograph quality and contrast. These sources of noise include:

- **Neutrons** – Even before ignition occurs, neutrons will be produced from nuclear reactions taking place during the implosion. These neutrons are minimized as a source radiograph noise by using a gated CCD camera that is placed outside the line of sight of the neutron.
- **X-rays** – X-rays are emitted during hohlraum laser plasma interactions, as well as a from core emission during the implosion. This source of noise is minimized using a series of aluminum and copper filters which act as high pass filter.
- **Neutron Induced γ-Rays** – γ-Rays result from neutron interactions with other matter that is in the target chamber. This source of noise is minimized using tantalum collimators and lead shielding.
- **Electrons** – Incidentally, the process used to create the x-rays used that backlight the radiographs also creates hot electrons. This source of noise is minimized through the implementation of a static magnetic field within the CRS.

To minimize electrons as a source of noise, a stainless magnetic yoke containing two permanent magnets was placed within the CRS. This report presents the results of a CST-Particle Studio and experimental investigation into the effectiveness of this device as an electron deflector. In this report is also presented a means by which electron spectrometer capability could be added to the CRS.

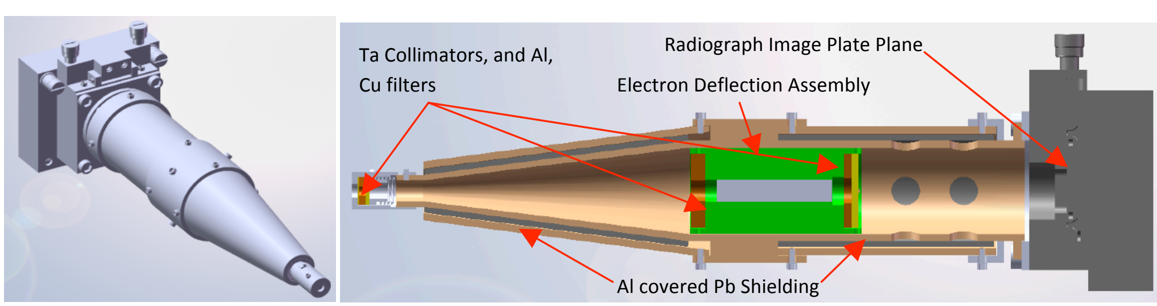


Figure 3: The High Energy X-Ray Imager (HEXRI) prototype, the Compton Radiography Snout (CRS).

Theory

Electron Trajectories within Electron Deflection Assembly

When a relativistic charged particle enters a magnetic field its trajectory changes via the Lorentz force. This theory was applied to develop a magnetic yoke that could be placed within CRS to deflect electrons away from the image plate. The trajectories of electrons traveling through the magnetic yoke can be modeled using the equation for the electron gyroradius shown below in equation (1). This theory models relativistic electrons with a 1-dimensional velocity traveling through a uniform one-dimensional magnetic field as depicted below in Figure 4.

$$R_{gyro} = \frac{mc^2}{qB}(\gamma^2-1)^{\frac{1}{2}} \qquad (1)$$

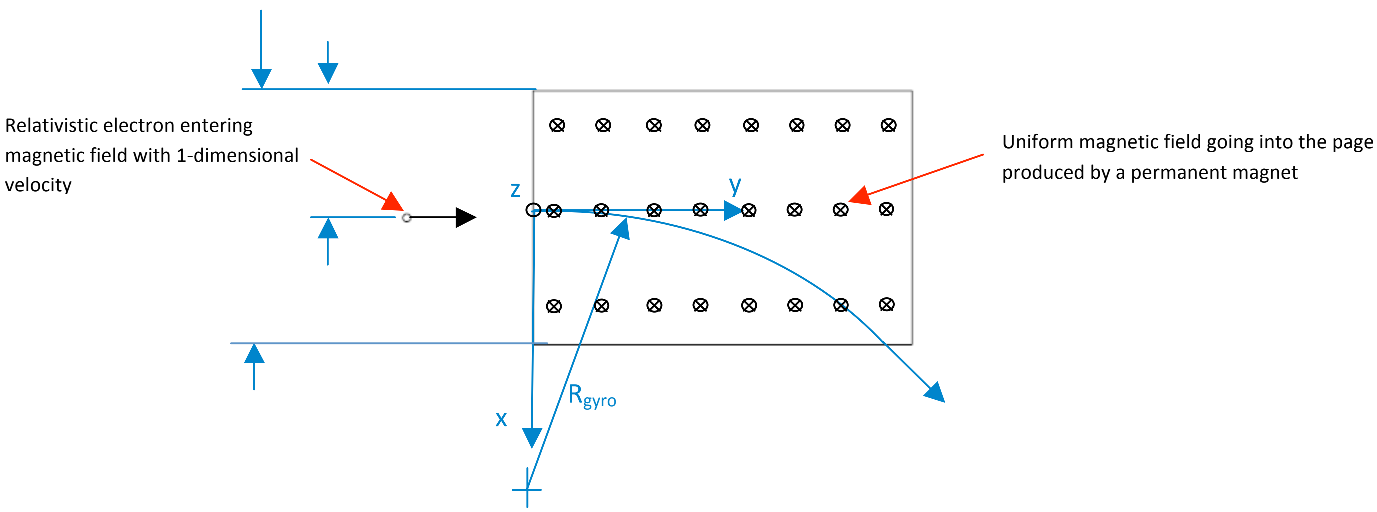


Figure 4: Illustration of electron traveling through uniform magnetic field describing the conditions plotted in Figure 5.

The range of electron energies that are of concern for the CRS, range from 0.5MeV to 10MeV. Figure 5 shows the paths of these electrons as they are deflected by a uniform field of 2kG created using magnets that are 12.7mm wide by 20.8mm long (0.5in x 2 in).

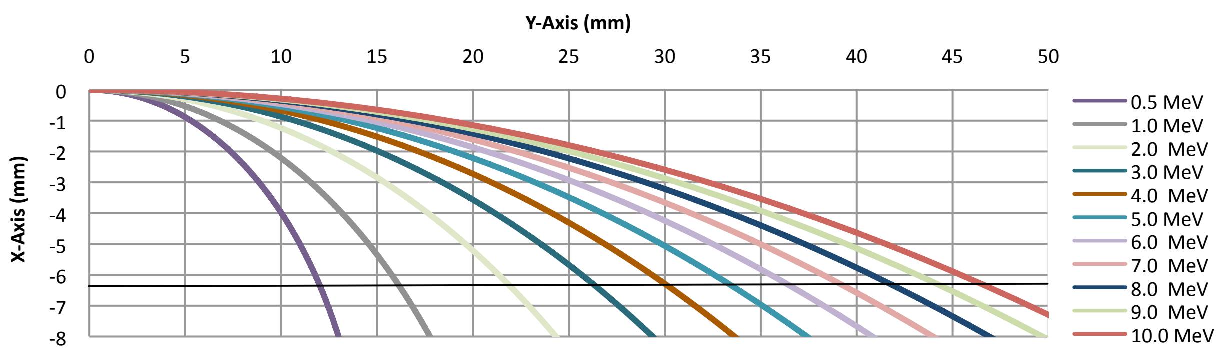


Figure 5: Electron paths as they enter at the center of the magnet and collide with the image plate that will be used to add spectrometer capability to the HEXRI.

Spectrometer Resolution

Ideally, the electrons entering an electron spectrometer would have a 1-dimensional velocity which would result in them having discrete impact locations along the imaging plane. However, the electrons have a range of entrance conditions based on the diameter of the collimators used in the spectrometer and how far the collimator is from target chamber center (TCC).

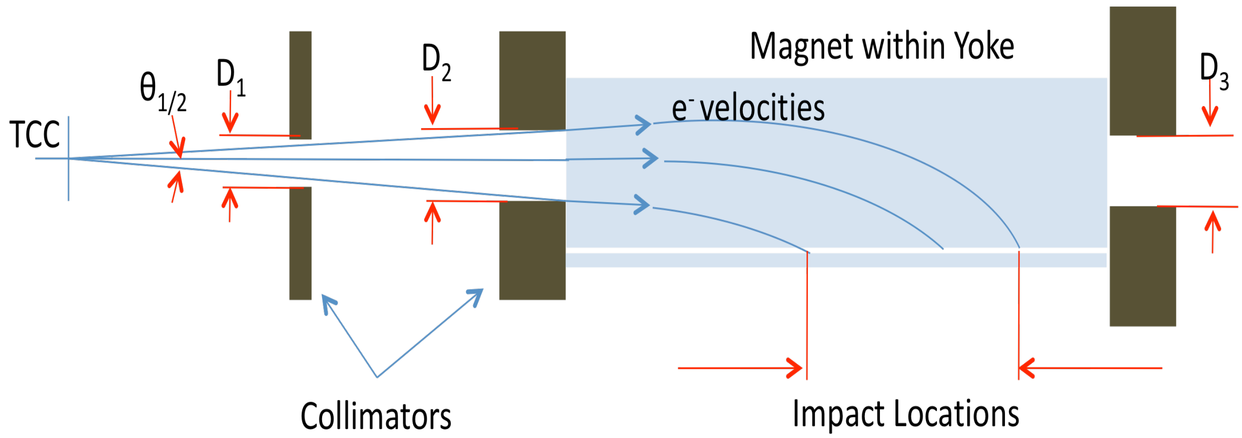


Figure 6: Illustration of the different entrance conditions that are possible based on electrons traveling from target chamber center through the series of collimators within CRS.

Using these parameters, the maximum and minimum electron impact locations at the image plane can be plotted using the maximum and minimum electron trajectories. This gives an effective resolution of this device as an electron spectrometer.

The current set of collimators on the CRS have a minimum diameter of 4.50mm and result in the range of impact locations for 1, 5 and 10 MeV electron impact locations shown in Figure 7-a. With the smallest diameter collimator replaced with one that is 1mm in diameter a much finer resolution is attained that could be used to measure the electron spectrum within CRS (Figure 7-b).

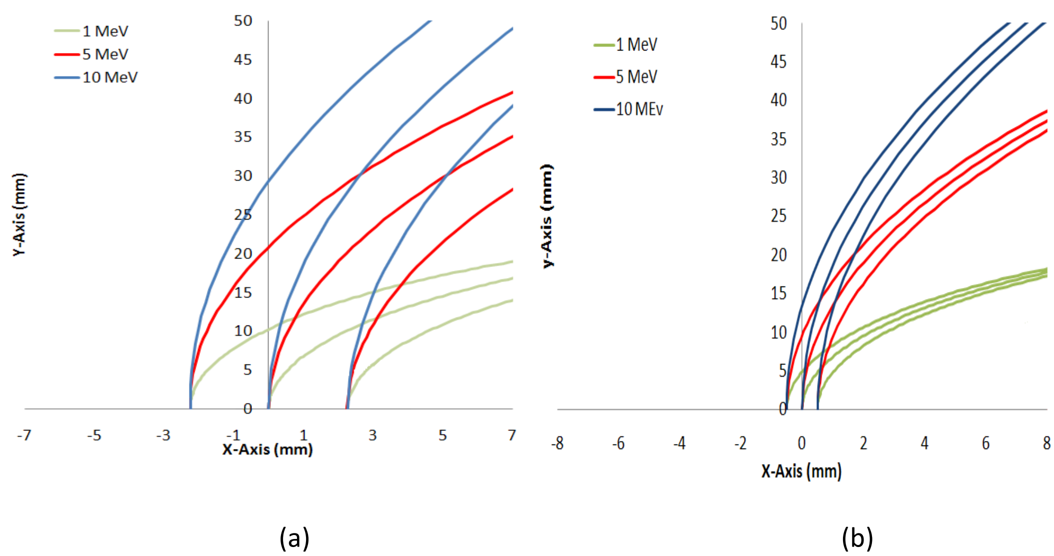


Figure 7: Electron trajectories plotted for the range of entrance conditions associated with a 4.5mm diameter (D1) collimator (a) and a 1mm diameter collimator (D1) (b).

Adding Spectrometer Capability to CRS

The CRS already contains an electron deflecting assembly. This electron deflection assembly can be turned into an electron spectrometer by simply adding a means with which we can load and unload image plate from the plane of the magnets within the electron deflection assembly within CRS. Figure 4 shows a cross section along the equatorial plane of the CRS which illustrates how this could be accomplished.

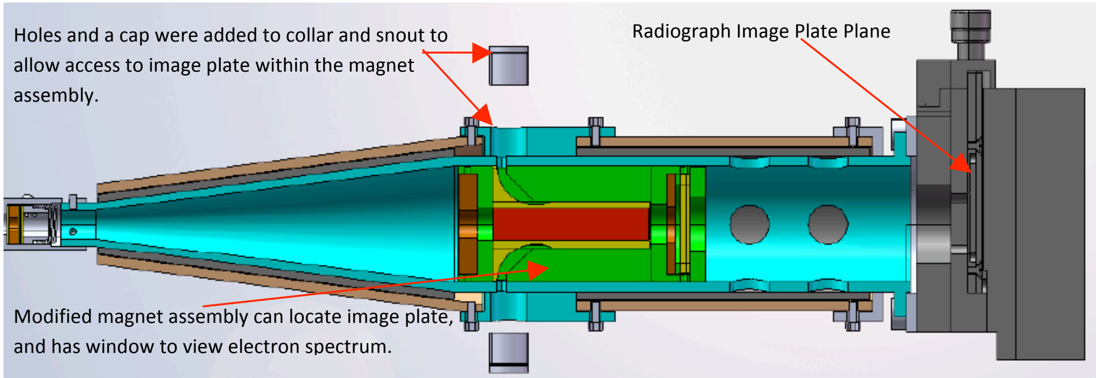


Figure 4: Modifications designed into CRS to allow measurement of electron spectrum.

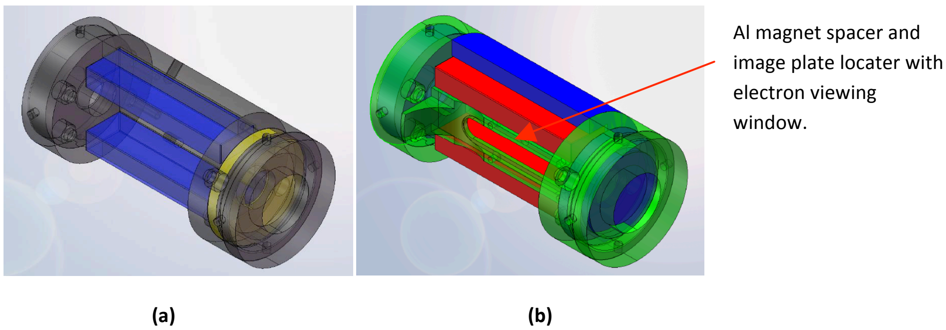


Figure 5: The original magnetic yoke design (a) and the suggested modifications to the magnetic yoke to allow for measurement of electron spectrum (b).

CST-Particle Studio Simulation

CST-Particle Studio was used to model the magnetic fields within the device as well as the electron trajectories through the device in three dimensions. This model takes into account material properties, as well as fringe field effects. However, it does still neglect electron-electron interactions as well as external electric and magnetic fields.

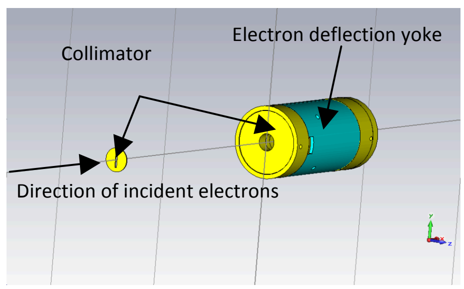
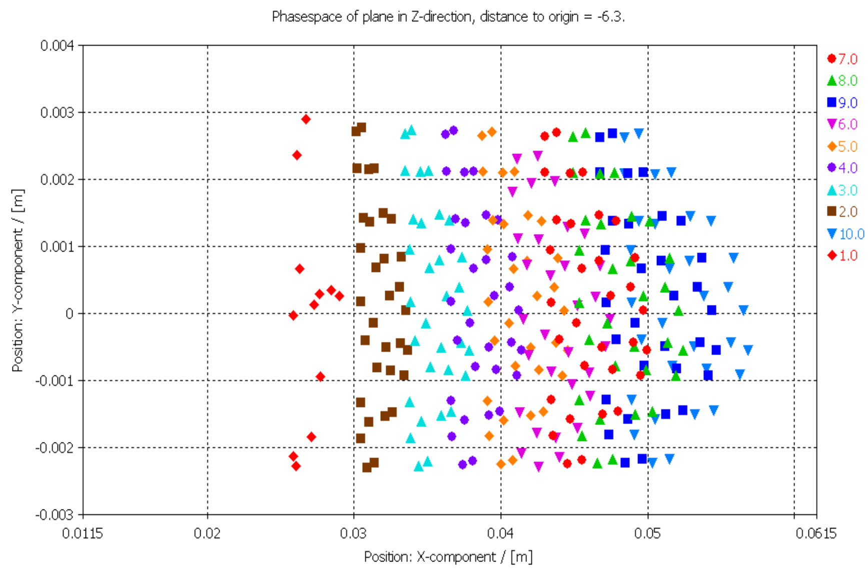


Figure 8: Illustration of the system modeled in particle studio. Only pertinent parts of the device were modeled to decrease simulation run time.

The results of this simulation are the electron impact locations at the image plate plane for this device's function as an electron spectrometer and plots of the magnetic fields for two longitudinal cross sections for both variations of the magnetic yoke. The electron impact locations are presented below, and the magnetic field plots of the device are presented in the appendix as they are rather large images. Figure 9 illustrates the effectiveness of the CRS as an electron spectrometer with its current smallest collimator of 4.5mm. Figure 10 illustrates the improvement in electron spectrometer resolution if a 1-mm diameter collimator is used.



Figures 9: Electron Spectrum seen with modified CRS and the current 4.5mm diameter collimator. Each colored shape corresponds to a different electron energy in MeV listed at the top right corner.

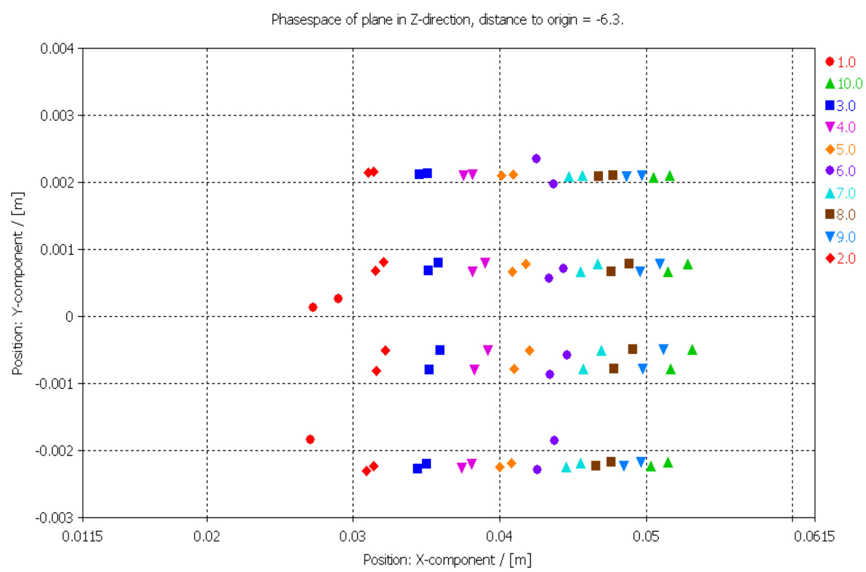


Figure 10: Electron spectrum observed with modified CRS and a 1mm diameter front collimator. Each colored shape corresponds to a different electron energy in MeV listed at the top right corner.

Experiment

The three main goals of this experiment are to:

1. Measure the magnetic fields within the CRS magnetic yoke and verify the particle studio model.
2. Test the effectiveness of the current magnetic yoke as a device for removing electron noise from the CRS image plate plane.
3. Test a prototype modified electron deflection assembly as an electron spectrometer within the CRS and compare with particle studio results.

Testing the effectiveness of this device as an electron deflector will be accomplished by recording images at the image plate using the CRS, both with and without the magnet yoke in place. By comparing these images, the reduction in electron noise due to the magnetic yoke will be determined.

Testing of this device as an electron spectrometer will be accomplished by placing the modified yoke within the CRS and measuring the electron spectrum using both a 4.5mm diameter collimator and a 0.5mm diameter collimator. The electron spectrum will also be measured using a calibrated electron spectrometer, so the results of both devices can be compared.

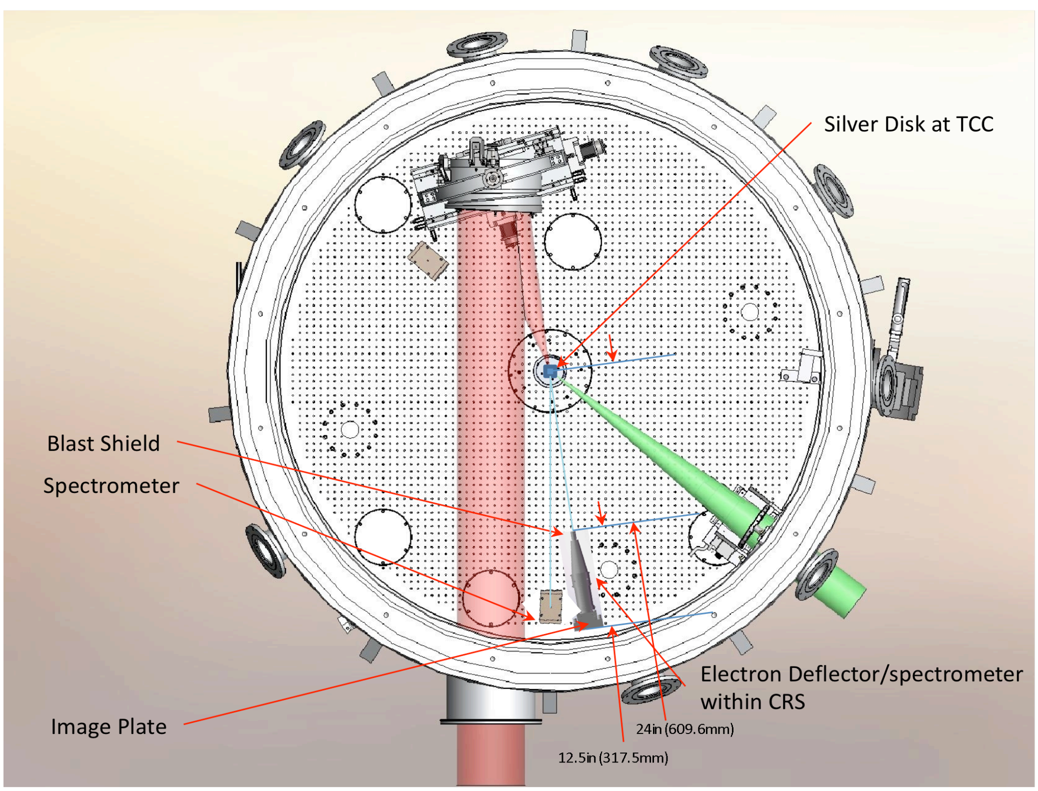


Figure 11: Shown here is the proposed experiment location within the Titan chamber. They are placed here because opposite the short pulse there will be a high concentration of electrons.

Results/Conclusions:

As of September 18th 2009, CST Particle Studio simulations of this device were completed and small set of experimental tests were completed in the Titan target chamber of the Jupiter Laser Facility during a ride along experiment. Due to the low intensity of the shots performed during the experiment, not enough relativistic electrons were produced during each shot to sufficiently test the electron spectrometer capability over its operating range (0.5MeV to 10MeV). Continued testing of the performance of the electron spectrometer capability of the CRS for higher laser intensities is planned for October 2009. After these tests, a more thorough analysis of the effectiveness of this electron spectrometer capability will be performed.

Appendix

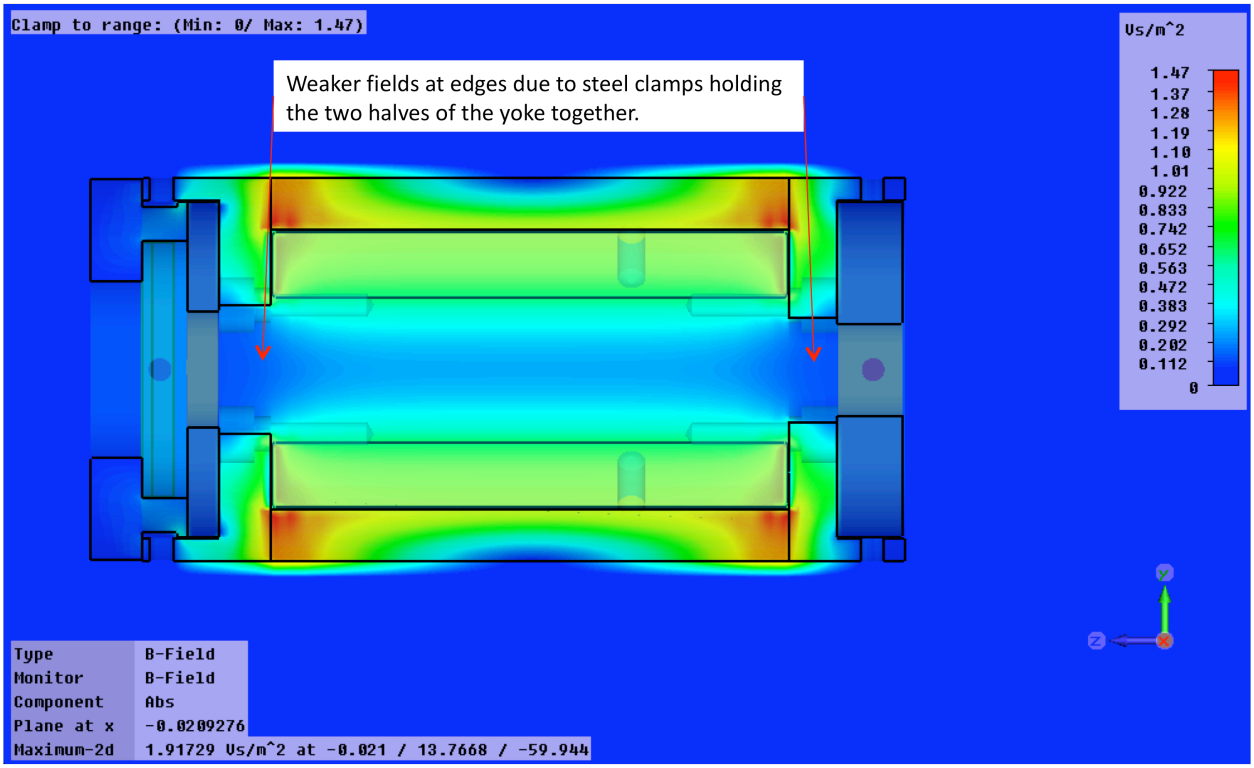


Figure 1: Current design magnetic yoke absolute magnetic field strength in Tesla (Vs/m^2) for a cross section through the center of the magnet.

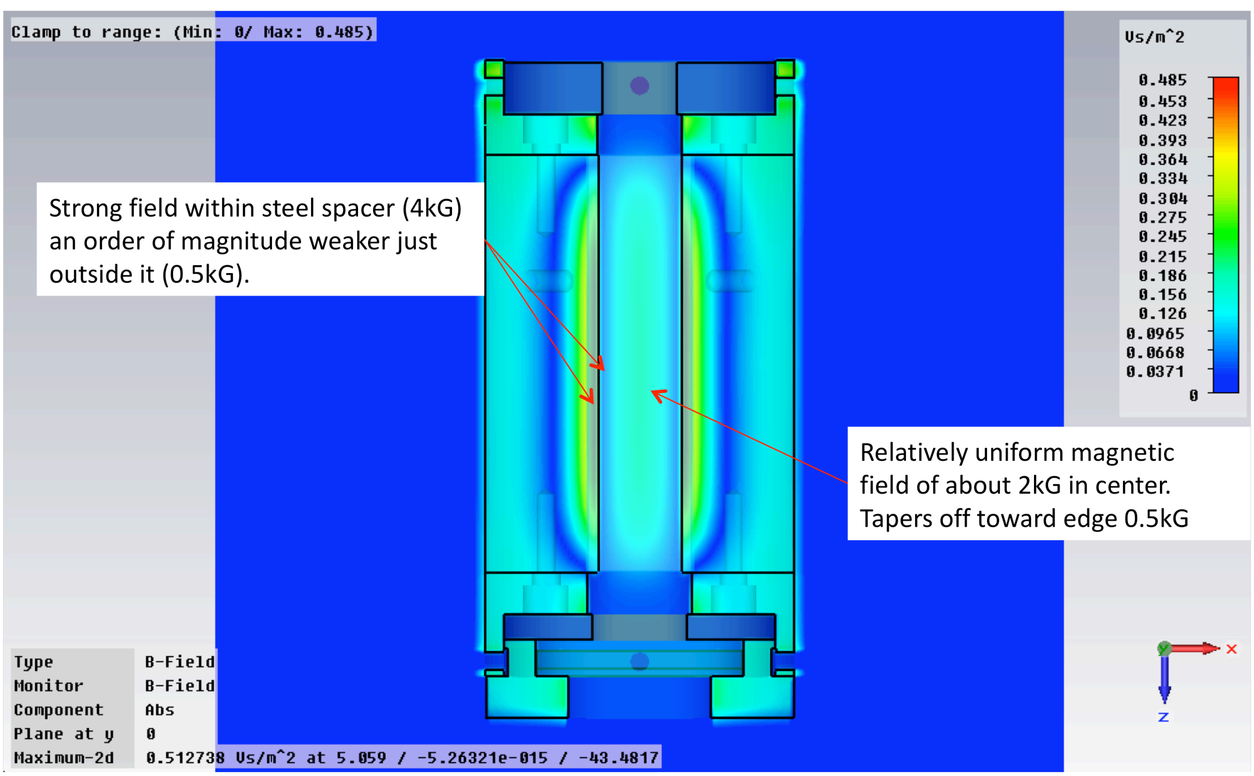
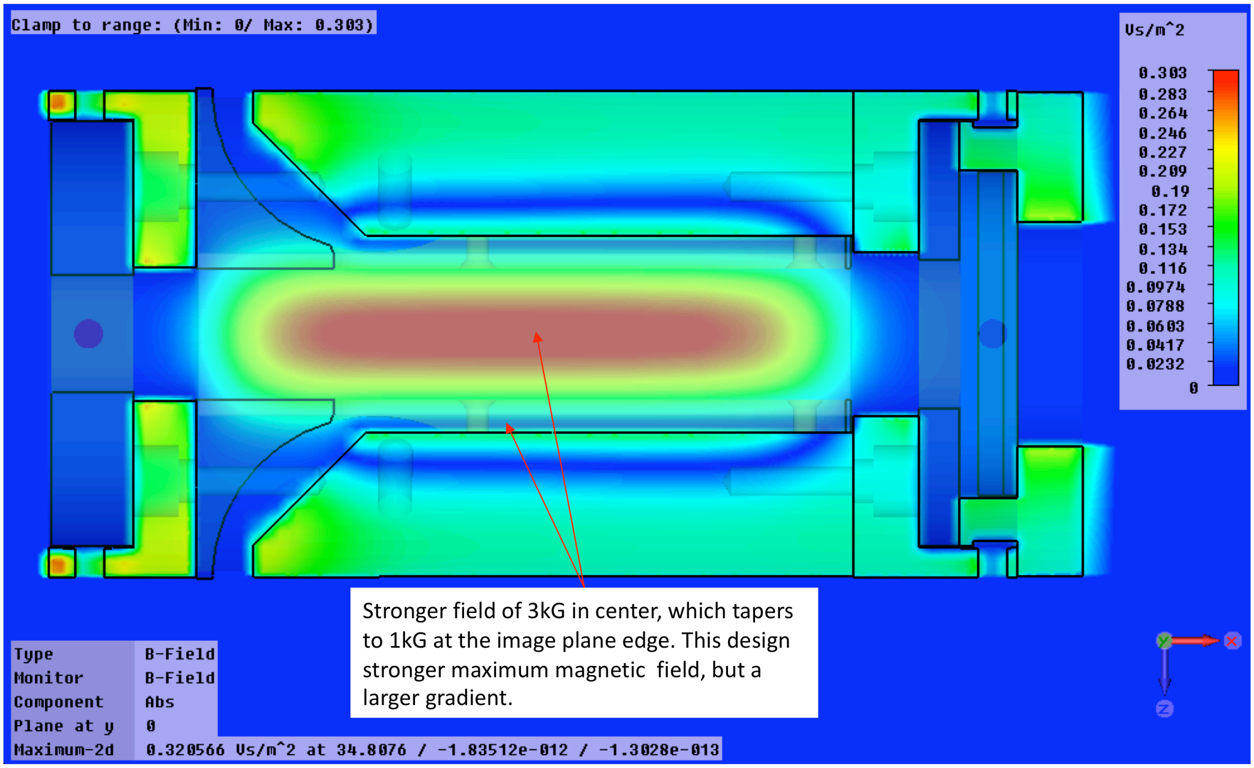


Figure 2: Current design magnetic yoke absolute magnetic field strength in Tesla (Vs/m^2) for a cross section through the equatorial plane of the magnetic yoke.



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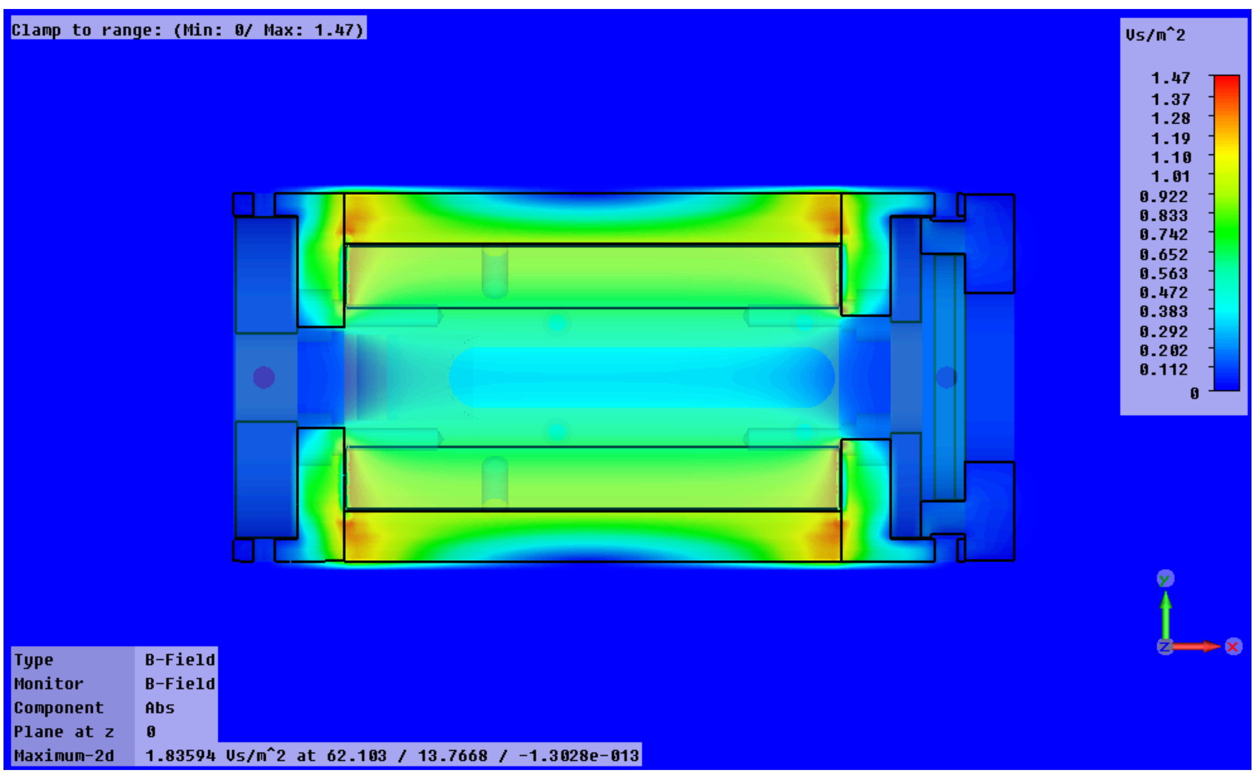

Figure 4: Current design magnetic yoke absolute magnetic field strength in Tesla (Vs/m^2) for a cross section through the equatorial plane of the magnetic yoke.