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Dissertation Proposal

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Title

A charged fusion product diagnostic for a spherical tokamak.

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A Charged Fusion Product Diagnostic (CFPD) for a Spherical Tokamak

1 Introduction

1.1 Background

An increasingly technological society deems scientific research geared towards meeting future energy demands highly significant. A deeper understanding of the physics of a plasma, a hot ionized gas, and nuclear fusion reactions is necessary to make fusion energy production a viable alternative energy source. The sun, for example, has plasma temperatures up to 10^7 Kelvin (K).[1, p. 13] While this massive star can rely on gravitational forces to confine its plasma, scientists have had to take up the challenge of confining plasmas of temperatures greater than the sun in our laboratories, a task greatly inconvenienced by the fact that plasmas are too hot to contain with solid materials. Fortunately, a group of successful plasma confinement devices called tokamaks offer a unique opportunity to study fusion reactions within the context of plasma dynamics. My dissertation topic comprises designing a new instrument (the CFPD), which uses the advantages of a tokamak to study plasma behavior through detecting the products of these fusion reactions.

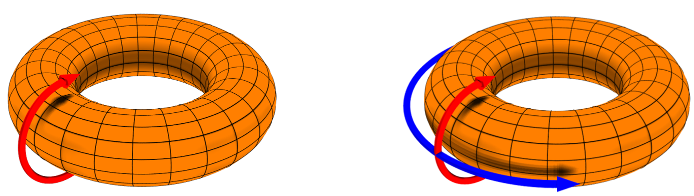


Figure 1: (a) The line indicates the poloidal direction.[10] (b) The line perpendicular to the poloidal direction indicates the toroidal direction.[11]

Tokamaks use magnetic coils and high currents to create toroidal and poloidal magnetic fields to confine a plasma (See Figure 1). To bring the plasma to temperatures high enough to maintain plasma equilibrium and facilitate nuclear fusion reactions (up to 10^8K), the tokamak incorporates several heating methods.[5, p. 476] The CFPD focuses on the deuterium-deuterium reaction. One proton and one neutron composes the nucleus of deuterium, an abundant stable isotope of hydrogen extracted from saltwater. Fusion reactions between deuterons, deuterium that becomes ionized by losing an electron, take place within the plasma. When two deuterons fuse, they can create a proton and a triton, an unstable isotope of hydrogen whose nucleus consists of one proton and two neutrons. Charged products from this nuclear fusion reaction, d(d,p)t, follow trajectories dependent on the magnetic field configuration in the plasma. The CFPD's main interest lies in protons with energies of 3MeV and tritons with energies of 1MeV as they have a gyroradius larger than the radius of the plasma itself; this allows them to leave the plasma very quickly and are therefore not confined. As they leave the plasma, they can hit the vessel/ tokamak wall, equipment inside the vessel wall, or a well-placed detector.

1.2 Research Objective

Charged fusion product studies have focused on evaluating plasma heating method performance through detecting particle loss in specific regions of the plasma.[6] During preliminary attempts to create a fast ion emission profile in the Axially Symmetric Divertor EXperiment, Bosch noted that the original diagnostic design prevented discussion regarding where the protons and tritons were produced in the plasma.[3] Strachan's experiment took advantage of proton motion in the magnetic field to detect the protons as they

TERM	MAJOR GOALS
Summer 2012	Diagnostic design/ assembly/ testing
Fall 2012	Diagnostic design/ assembly/ testing, apply for 2013 fellowship
Spring 2013	Initial testing and Electrical Design Review at MAST
Summer 2013	Diagnostic installation and data collection at MAST
Fall 2013	Data analysis, dissertation, apply for 2014 fellowship
Spring	Data analysis, dissertation
Summer 2014	Data analysis, dissertation, write paper for publication
Fall 2014	Dissertation defense and submit paper for publication

Table 1: Timeline to degree completion.

drifted toward the vessel walls; these measurements have a low time and position resolution.[7] Though Zweben was able to clearly detect signals from alpha particles, they had broad pulse widths resulting in "a lack of intrinsic energy resolution;" again this study has not been done for a spherical tokamak.[8]

My research focus is to find out where and at what rates in the plasma the previously discussed particles are created. A prototype diagnostic will be designed, constructed, assembled, and installed in the Mega Amp Spherical Tokamak (MAST) in the Culham Centre for Fusion Energy (CCFE) in the United Kingdom for data collection. Subsequent data analysis will be used to reconstruct the time-dependent d(d,p)t charged fusion product profile in the plasma (see Table 1). MAST neutron count rates measured by the Fission Chamber and Neutron Camera will act as an ideal validation of the CFPD, as it measures the same profile through a different technique.[4] The CFPD's results can be used to study the neutral beam ion density profile, as well as the effects of Magnetohydrodynamic instabilities on that profile. This work provides the foundation for future research in spherical tokamaks. Observe that while increased plasma densities in the National Spherical Torus Experiment Upgrade will result in smaller signals for its current primary diagnostics measuring the neutral beam ion density profile, increased plasma densities and reaction rates will increase the time resolution of the CFPD.

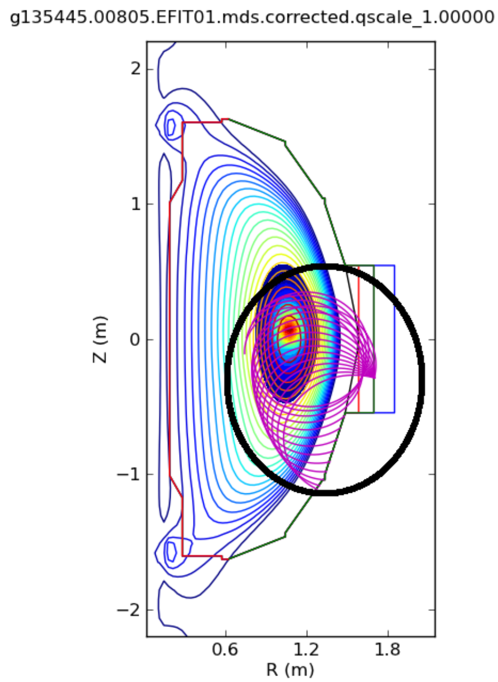
2 Experimental Design

2.1 Simulations

Previous studies have made use of codes to calculate proton trajectories or orbits backwards in time from the detector into the plasma to the point of its origin.[3][9] We use a modified version of the Lorentz orbit code, which I updated to compile with the free gnu compiler collection available for most operating systems, for calculating proton orbits and the emissivity, proton emission profile, in the plasma. Software has been developed to visualize particle orbits within the plasma as they hit an array of detectors near the tokamak vessel wall (see Figure 2). Different orientations are simulated so that the actual physical orientation of the detectors, with respect to the tokamak vessel, plasma boundaries, and magnetic fields, can be chosen to sample the central hottest region of the plasma.

2.2 Mechanical Design

A non-magnetic stainless steel module will house four silicon surface barrier detectors. This steel module will attach to an already existing probe arm on MAST, which will move the diagnostic into the tokamak vessel for data collection. An outer ceramic cover will shield sensitive equipment from the plasma and accompanying electric and magnetic fields inside the vessel. Thin foils will cover the surface of the detector's active area to filter out signals from soft x-rays and light emitted by the plasma. A dielectric plastic will insulate the detectors from the steel housing unit to avoid electrical noise drowning the small detector signals.



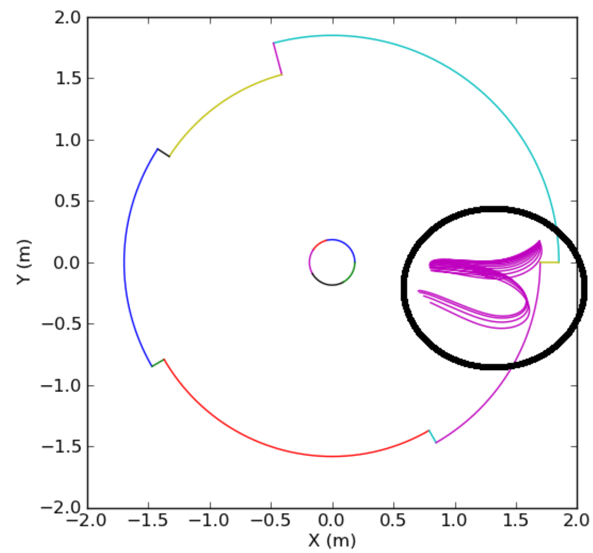


Figure 2: (a) Poloidal view of proton orbits/ trajectories associated with a detector array. (b) Mid-plane toroidal view of particle orbit in plasma.

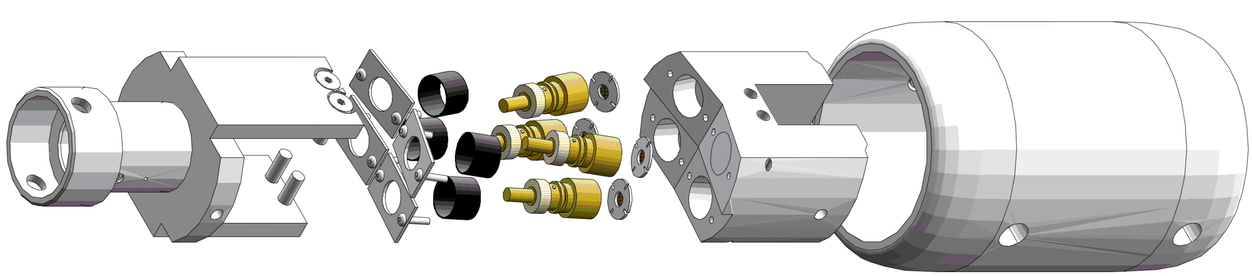


Figure 3: Diagnostic design CAD drawing.

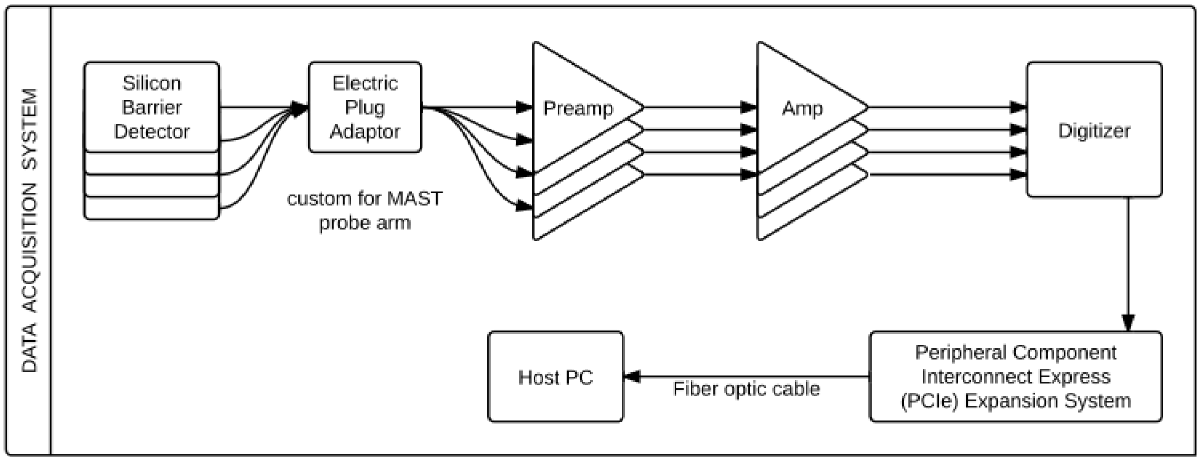


Figure 4: Data acquisition schematic.

All pieces, aside from the ceramic shield, will be manufactured by the FIU Physics Department machine shop. I have designed and created machine drawings for all pieces to be manufactured, with the exception of a few pieces MAST requires us to replicate. The mechanical design, see Figure 3, also takes into account thermal expansion for different materials; all materials have to be approved for use in Ultra High Vacuum (UHV), up to 10^{-10} Torr. This design concept has been approved in a MAST Design Review.

2.3 Electronics and Data Acquisition (DAQ) Design

UHV coaxial cables will connect the detectors to the probe arm. The non-terminated ends of the in-vacuum cables will be connected by MAST technicians to a custom-made electric male connector for the probe arm. Preamplifiers will connect to the beginning of the probe arm, on the air-side of the vessel and 10 feet from the detectors. The preamplifiers will connect to timing filter amplifiers, which will then connect to four input channels on a 60MHz digitizer. The digitizer is installed on a PCI express expansion box connected to a rack mount computer through a fiber optic cable. Data from the digitizer is transferred to the computer and stored as Hierarchical Data Format (HDF) files (see Figure 4). Using LabVIEW software installed on the computer, I will control the data collection parameters, such as the digitizer rate and collection time, through custom written and configurable programs for data acquisition. An HDF file size of 23MB per channel for 0.5s of digitized data, at a rate of 60 MHz, will be used to estimate data storage for MAST experiments. Our DAQ has been created to collect data for particle rates up to a few MHz.[2]

3 Data Collection and Data Analysis

Data collection in MAST, located at the CCFE, will take place in May or June of 2013. I am currently in communication with MAST colleagues regarding preparations for our diagnostic's data collection. I will ship all major components of the CFPD to CCFE and install them in MAST. Test runs of the diagnostic in Spring 2013 will provide an opportunity to assess noise levels and any induced electromagnetic interference normal machine operations might create. Several weeks of data collection are expected.

Using equilibrium condition magnetic field configurations for MAST, our simulation software will be used to determine the trajectories along which emitted charged particles, particularly protons, are detected. The actual data, voltage values recorded in HDF files, will be calibrated to reveal pulses created by protons and possibly tritons. Calibration will take into account plasma current data, plasma instabilities, plasma temperature, and signals from operating machinery. Data for these will be available from the CCFE. Pulses will be binned to find traces of protons and tritons. The binned data can then be integrated, along time intervals, to be counted and compared to MAST global yield rates (see Figure 5).[4] Analysis will yield the proton and triton rates detected for comparison with simulated results. Simple models for the emission profile will be fitted to this first set of data.

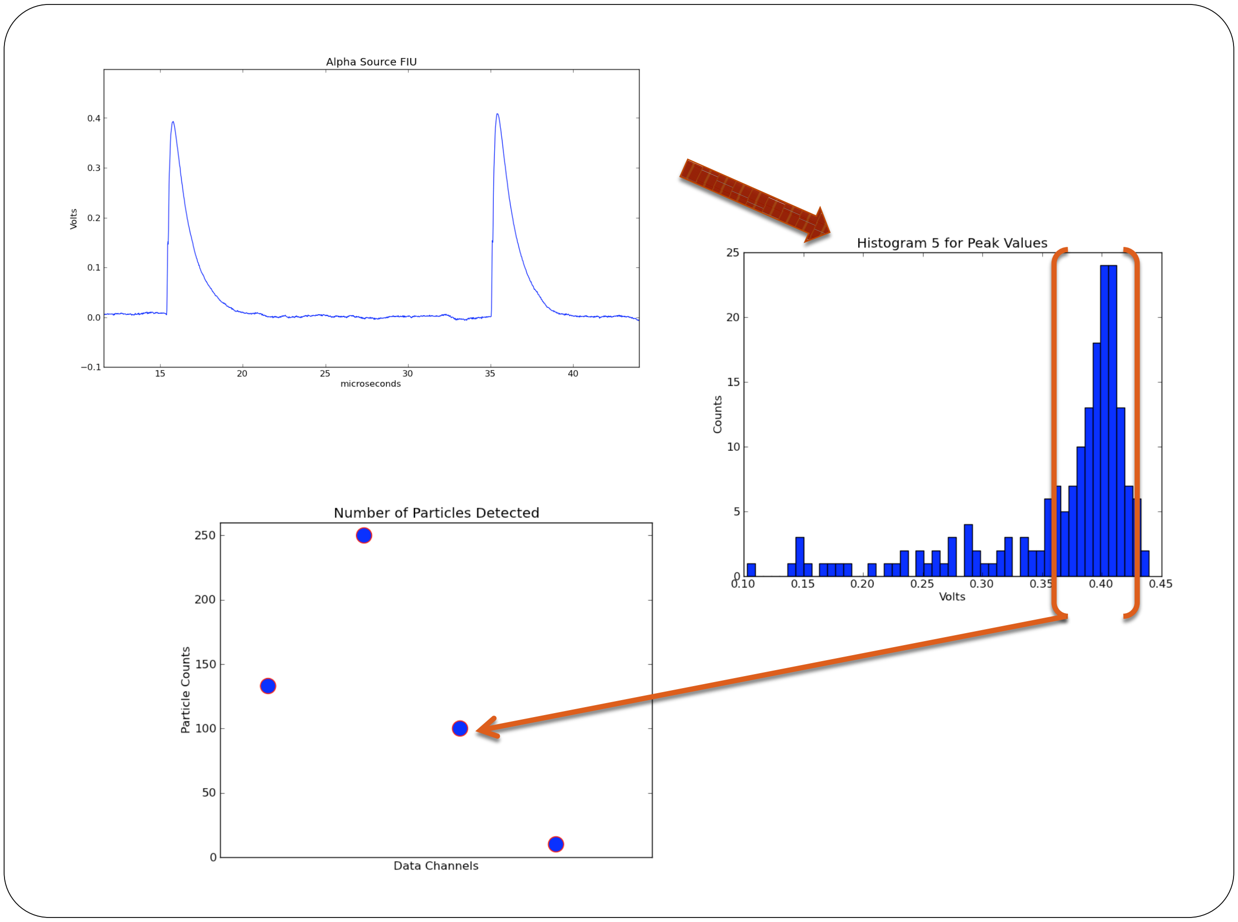


Figure 5: Pulses from raw data, once analyzed, will be binned and integrated to reveal particle count rates for comparison to MAST global yield rates.

References

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[9] S. J., Zweben, et al., Nucl. Fusion **35**, 893 (1995)

[10] An image depicting the poloidal (red, called theta) direction and the toroidal (blue, called phi) directions. Notably absent is the radial coordinate which starts from the center of the tube and points out. 13 September 2006. Made in POV-Ray by Dave Burke. PNG File.

[11] An image depicting the poloidal (red, called theta) direction and the toroidal (blue, called phi) directions. Notably absent is the radial coordinate which starts from the center of the tube and points out. 13 September 2006. Made in POV-Ray by Dave Burke. PNG File.