Spatial and Energy Profiling of D-D Fusion Reactions in an Inertial Electrostatic Confinement Fusion Device

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Inertial Electrostatic Confinement (IEC) Fusion

➢IEC Fusion utilizes negatively charged electrodes to electrostatically accelerate positively charged ions to fusion relevant energies.
➢All experiments discussed herein were conducted on the UW-Madison IEC Device known as HOMER.

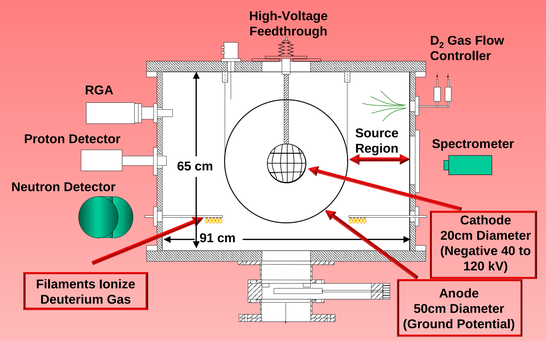

Figure 1: UW-Madison IEC Device HOMER

➢HOMER utilizes concentric, highly transparent spherical grids as the electrodes.
➢Majority of ion species created are D_3^+, with lesser fractions of D_1^+ and D_2^+ also created.
➢Typical Operating Parameters
- •Cathode Voltage: 40 – 120 kV
- •Anode Voltage: Ground
- •Ion Current: 30 – 75 mA
- •Feed Gas: Deuterium
- •Operating Pressure: 1.5 – 2.5 mtorr

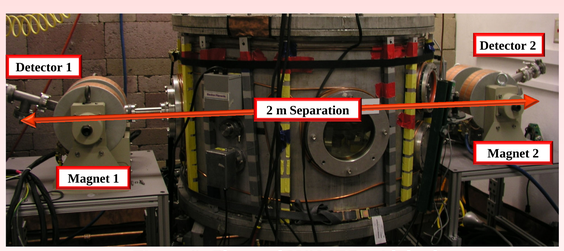

Figure 2: Photo of HOMER with both FIDO arms making up the TOF setup.

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Fusion Ion Doppler (FIDO) Diagnostic

➢**Purpose** - Measure the Doppler shift of the products of D-D fusion reactions in order to back out the center-of-mass energy of the fusion reactants.
  ➢In high background pressure (>0.1mtorr), Doppler shift results from center of mass energy of beam-background fusion reactants.
➢**Challenge** – Reduce X-ray noise sufficiently to accurately discern Doppler shifted peaks of products.
  ➢High levels of X-ray noise from electron induced bremsstrahlung radiation from the wall of the device overwhelm the triton signal (1.01MeV) and distort the proton signal (3.02MeV).
➢**Solution** – Move the charged particle detectors out of the line-of-sight of the IEC chamber.

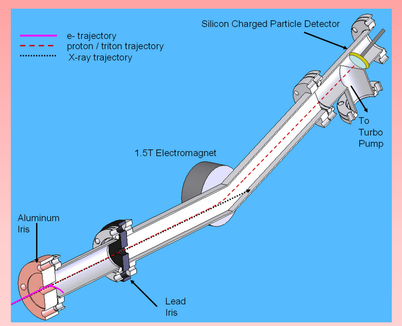


Figure 3: FIDO Arm with 20 degree and 1.5T magnet at elbow.

➢**Method –** Detector placed at end of arm with 20 degree bend at the elbow. Fusion products are bent around the elbow and into the detector using a 1.5T electromagnet.
➢**Result** – Energy spectra of fusion reactants measured with resolution on the order of 5keV.

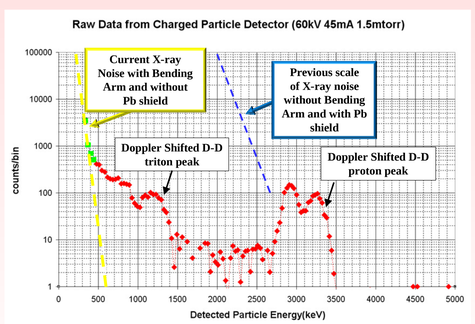


Figure 4: Raw energy spectrum collected from FIDO diagnostic demonstrating scale of noise reduction.

Time of Flight (TOF) Diagnostic

Experimental Setup

➢The TOF system is made up of two identical FIDO diagnostics placed on opposite sides of the IEC chamber creating a direct line of sight through both arms and the core of the IEC device.
➢The TOF setup also includes a system of high speed timing electronics in order to accurately capture the exact times at which charged particles reach the detectors.

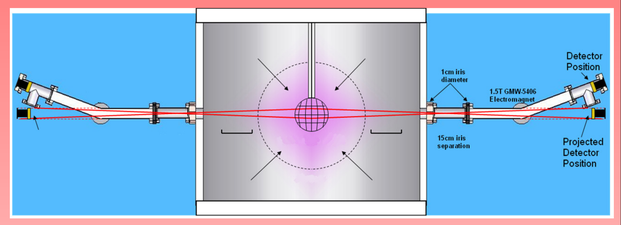


Figure 5: Schematic of TOF diagnostic on HOMER utilizing two identical FIDO setups to create a line of sight through the core of the device.

Method of Operation

➢D-D fusion reaction creates a 1.01 MeV triton and a 3.02 MeV proton.
➢Conservation of momentum requires both products to travel away from each other in the exact opposite directions in the center-of-mass frame.
➢The TOF setup is used to capture both products of the D-D fusion reactions, which occur within a line of sight of both detectors.
➢Energy spectra collected by the FIDO setup are required to account for the slight change in the fusion product velocity due to the Doppler shift.

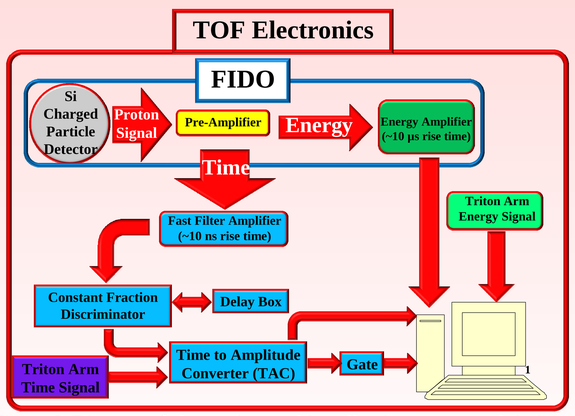
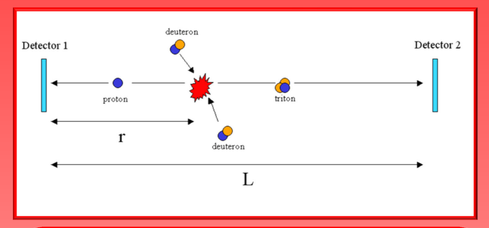


Figure 6: Diagram of electronics used in collecting energy and timing signals from each FIDO setup to gather TOF data.



Initial Results

➢Only timing electronics used to determine spatial location.
➢Average Doppler shift of 200 keV applied to the results.
➢Spatial resolution of roughly 2 cm.

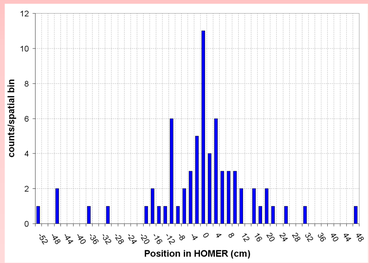


Figure 7: Fusion reactions occurring along radial chord through IEC device. (50kV, 30mA, 2mTorr)

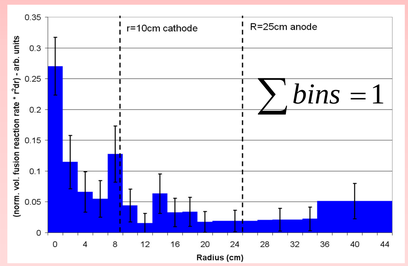


Figure 8: Normalized profile of reactions per unit volume weighted by the spherical shell volume of each radial bin.

Conclusions

➢**Initial results indicate a high concentration (>50%) of all fusion reactions occurring in the IEC device are taking place within the cathode radius.**
➢**Previous IEC experiments and theory indicated that at most 20% of total fusion reactions occurred within the cathode region.**
➢**The TOF diagnostic offers far greater spatial and energy resolution than any other diagnostic system previously implemented on an IEC device.**
➢**Additional upgrades to the diagnostic are planned, which will dramatically increase the rate at which data is collected as well as further increase the spatial resolution to the order of 1 mm accuracy.**