Diagnosing the High Energy Deuterium Spectra in IEC Devices Using Doppler Shifted Fusion Products

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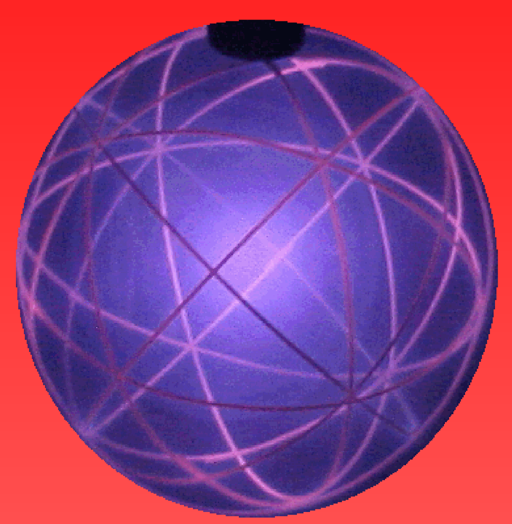

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Abstract:

The UW-Inertial Electrostatic Confinement (IEC) device is comprised of concentric spherical metallic grids within a cylindrical vacuum vessel. The central grid, which can be held at high negative potentials (180kV with current power supply), is the device cathode, while the outer grid, held at ground potential, is the device anode. This configuration accelerates ions, created near the anode, toward the center of the device. A weakly ionized cold plasma, created by a filament assisted DC discharge outside the anode, is the ion source for the device. The fill gas for this device is typically deuterium at 1-4 mTorr, thus leading to D-D fusion rates on the order of 10^8 fusions/s. The high energy protons and tritons resultant from D-D fusion reactions have been observed using charged particle detectors. The diagnostic employing these detectors, FIDO (Fusion Ion Doppler shift), is capable of discerning the Doppler shift on D-D fusion products imparted by the center of mass energy of the deuterium reactants. From the fusion product spectra compiled by a multi-channel analyzer the energy spectra of the deuterium reactants can be calculated. Using this diagnostic the effect, on the deuterium spectra, of varying the parameters of fill gas pressure, cathode voltage, cathode current and grid geometry have been examined.

Doppler Shifted Fusion Products

- In IEC experiments with high background pressure (>0.1mtorr) the detected protons and tritons from D-D fusion carry with them a Doppler shift resulting from the center of mass energy of the beam background fusion reaction that birthed them.
- Thus the manner in which the center of mass velocity of the deuterium reactants is added to the velocity of the fusion products follows the law of cosines.

$$v_t = \sqrt{v_f^2 + v_{cm}^2 \pm 2 v_{cm} v_f \cos\Theta}$$

- The velocity imparted to the fusion product from the Q value of the fusion reaction is denoted v_f, that imparted to the fusion product from center of mass velocity of reacting particles is denoted, v_{cm}, the total velocity of the fusion product is denoted v_t, and the angle between v_{cm} and v_f is denoted **Θ**. **(See Figure 1)**

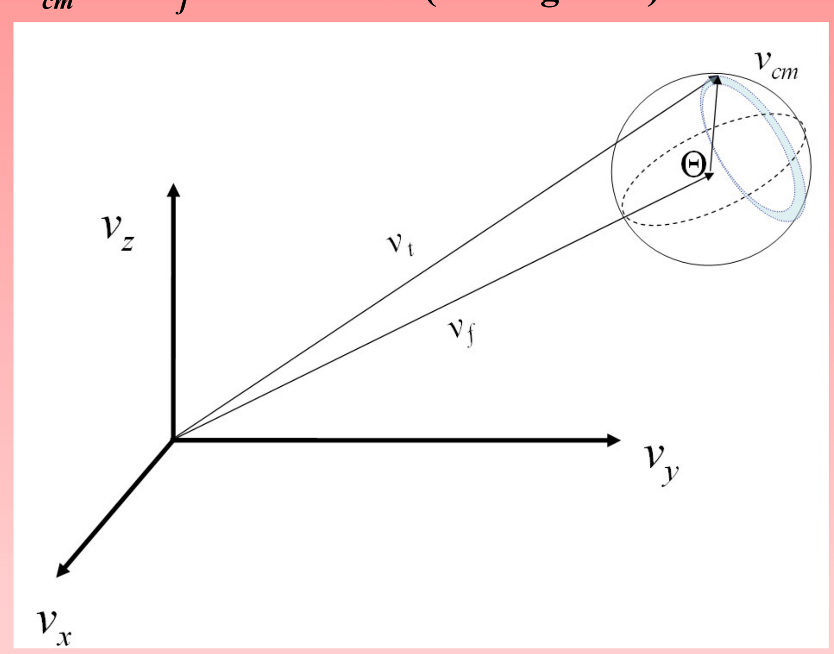


Figure 1: This illustrates the sphere in velocity space traced out by the v_t velocity vector. It also shows how each specific angle of Θ creates a differential ring on the velocity sphere.

- When viewing the charged particle fusion products in an IEC device with FIDO the parallel and anti-parallel components of v_t can be isolated by constricting the acceptance cone to the charged particle detectors used in the diagnostic. **(See Figures 2 & 3)**

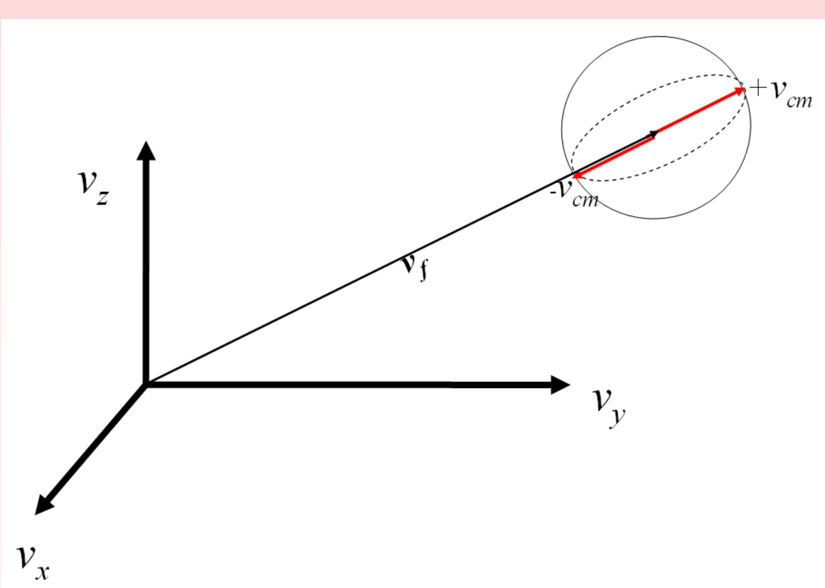


Figure 2: The parallel and anti-parallel components of the total velocity vector of a fusion product

Experiment Schematic

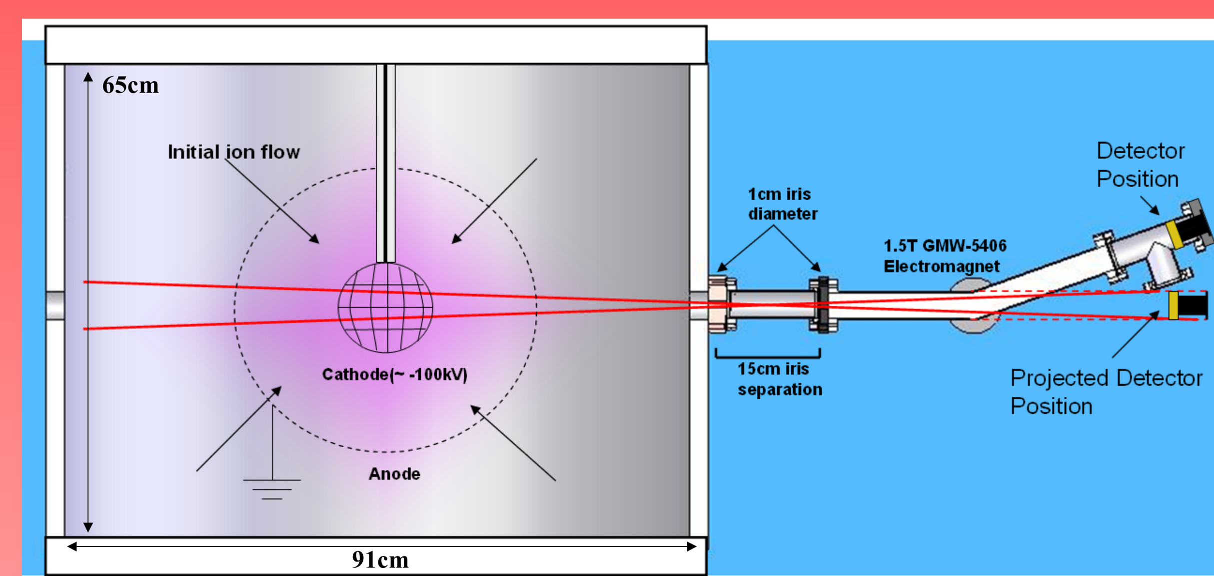


Figure 3: A schematic of the FIDO diagnostic is shown to illustrate the how the diagnostic geometry enhances of the detection of fusion products with only parallel and anti-parallel velocity components.

- The 1 cm diameter irises prevent fusion products with large perpendicular velocity components from being detected.
- The 20° angle arm allows D-D protons and tritons to bend into the detector via the 1.5 T magnetic field present at the elbow
- In general for this setup, the perpendicular energy component allowed to enter the detector will scale as,

$$E_\perp = E_\parallel \left(\frac{d_{iris}}{R_{iris}} \right)^2$$

where d_{iris} and R_{iris} represent the diameter of the irises and separation between the irises respectively.

- The elbow also eliminates the detection of X-rays in the charged particle detector which are copiously produced in IEC devices from e⁻ induced bremsstrahlung radiation emanating from the wall of the device. **(See Figure 4)**

X-ray Noise Suppression in the FIDO Diagnostic

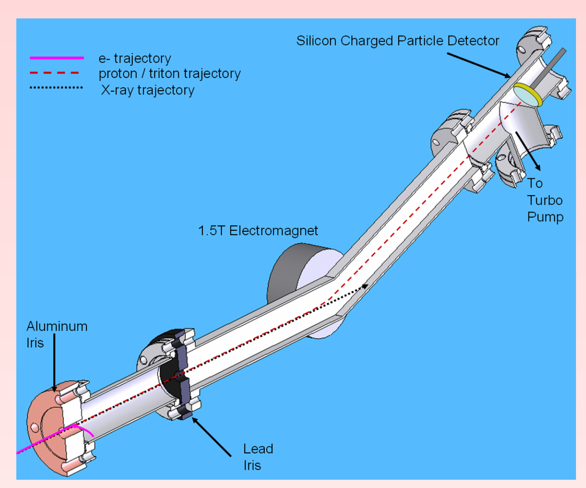


Figure 4: This schematic illustrates the trajectories taken by e-'s, fusion products, and X-rays in the FIDO arm

- The 20° bend in FIDO is sufficient to bend the fusion products containing the v_{cm} information into the charged particle detector while keeping the detector out of the line of sight of secondary electrons and X-rays they produce.

Experimental Results

- The fusion product energy spectra obtained by FIDO show a dramatic reduction in X-ray noise. This allows both tritons and protons from D-D fusion to be observed.
- The double peaked structure to the spectra is owed to the constricted view factor which allows only the parallel and anti-parallel shifted fusion products to enter the detector. **(See Figure 5)**

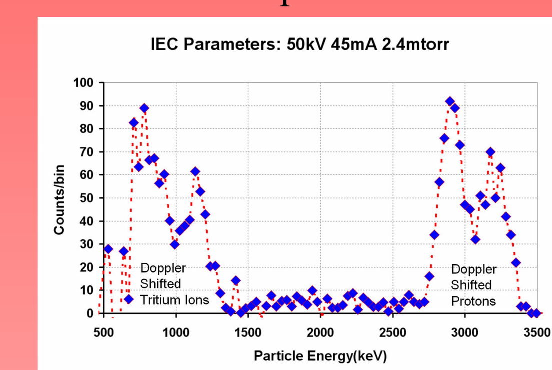
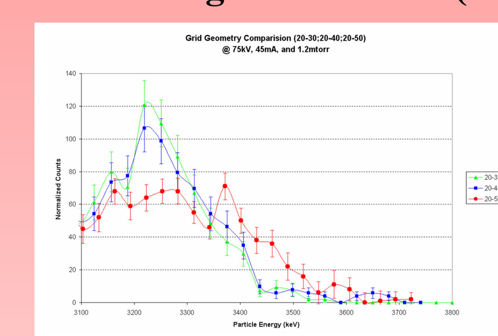


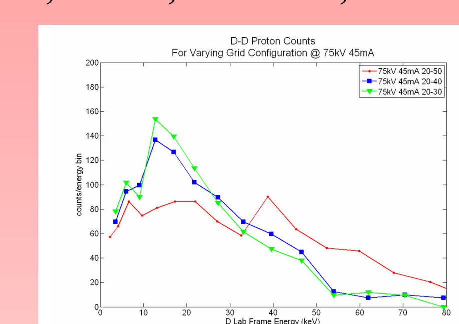
Figure 5: Above is a fusion product energy spectrum that shows both Doppler shifted tritons and protons from D-D fusion. Prior to the FIDO diagnostic this resolution was impossible, due to X-ray noise.

- The lab frame energy of the deuterium reactants can be obtained from the fusion product spectra as shown below by extracting the lab frame energy and scaling the proton counts by the fusion cross sections

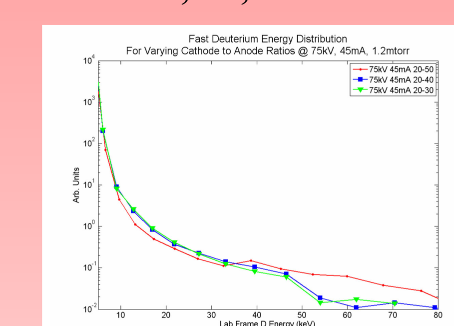
Grid Configuration Scan (75kV, 30mA, 1.5mtorr, 20cm cathode w/ 30, 40, & 50 cm anode)



Up-shifted half of proton spectra with error bars

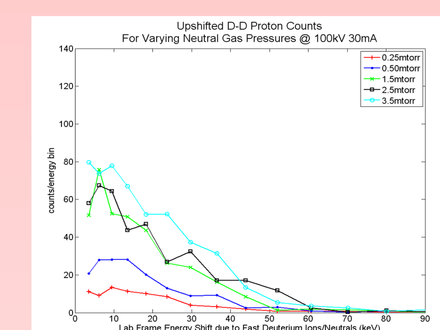


Lab Frame Energy Shift

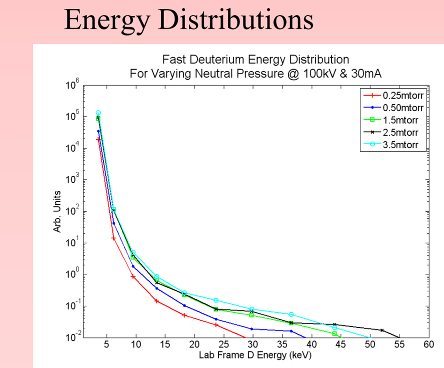


Calculated Deuterium Reactant Energy Distributions

Pressure Scan (100kV, 30mA, 20-40 grid config.)

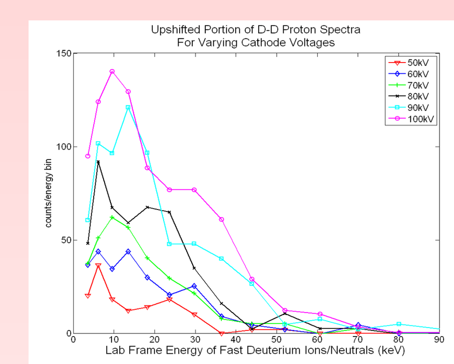


Lab Frame Energy Shift

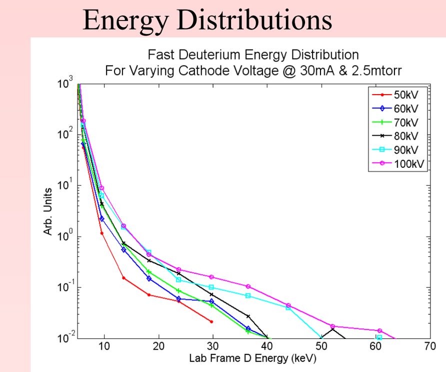


Calculated Deuterium Reactant Energy Distributions

Voltage Scan (2mtorr, 45mA, 20-40 grid config.)

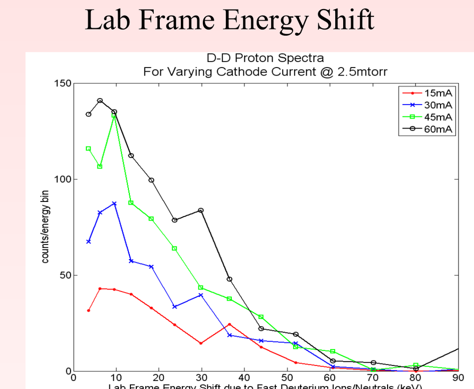


Lab Frame Energy Shift

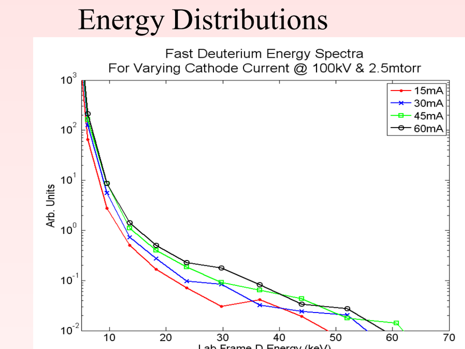


Calculated Deuterium Reactant Energy Distributions

Current Scan (100kV, 2.5mtorr, 20-40 grid config.)



Lab Frame Energy Shift



Calculated Deuterium Reactant Energy Distributions

Conclusion

By examining the energy spectra of Doppler shifted fusion products from the IEC device, and isolating the parallel and anti-parallel components of the spectra, it has been shown that the vast majority of fast particles in IEC devices have energies well below the cathode voltage. This is consistent with current IEC theory that suggests that at high pressures IEC discharges will be dominated charge exchange reactions that produce large numbers of fast neutrals at lower energies. The data also shows that the spectra of these fast neutrals and ions can be altered by varying the grid spacing.

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