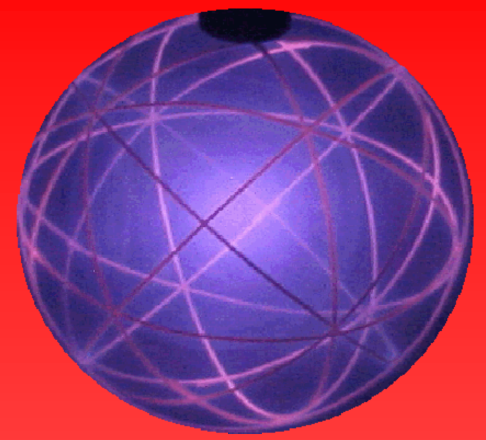

Spatial and Energy Profiling of D-D Fusion Reactions in an Inertial Electrostatic Confinement Fusion Device

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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 using deuterium fuel.

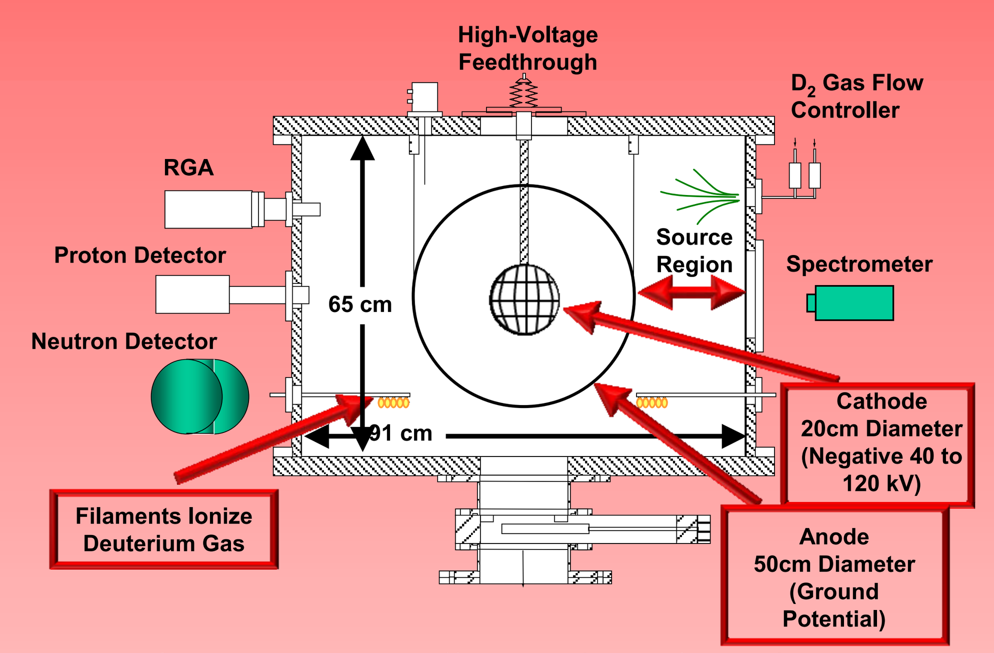

Figure 1: UW-Madison IEC Device HOMER

➢HOMER utilizes concentric, highly transparent spherical grids as the electrodes.

➢Majority of ion source species created are D_3^+, with lesser fractions of D_1^+ and D_2^+ also created.

➢Typical Operating Parameters
- Cathode Voltage: -40 to -120 kV
- Anode Voltage: Ground
- Ion Current: 30 – 75 mA
- Feed Gas: Deuterium
- Pressure: 1.5 – 2.5 mTorr

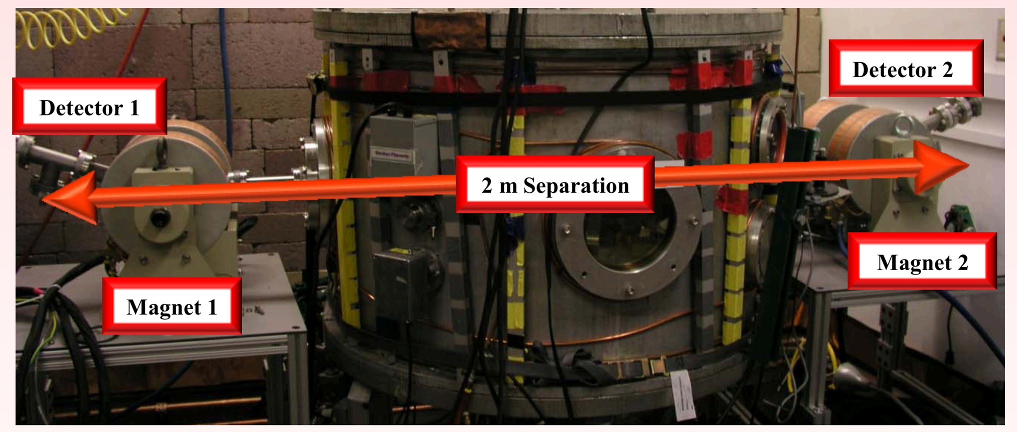

Figure 2: Photo of HOMER with both FIDO arms making up the TOF setup.

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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 bremsstrahlung radiation produced when electrons impact 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.

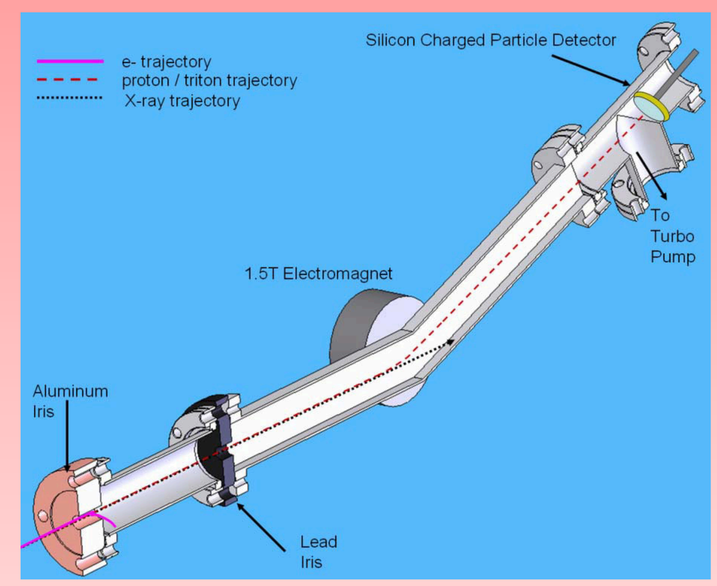


Figure 3: FIDO Arm with 20 degree and 1.5T magnet at elbow.

➢**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. [1]

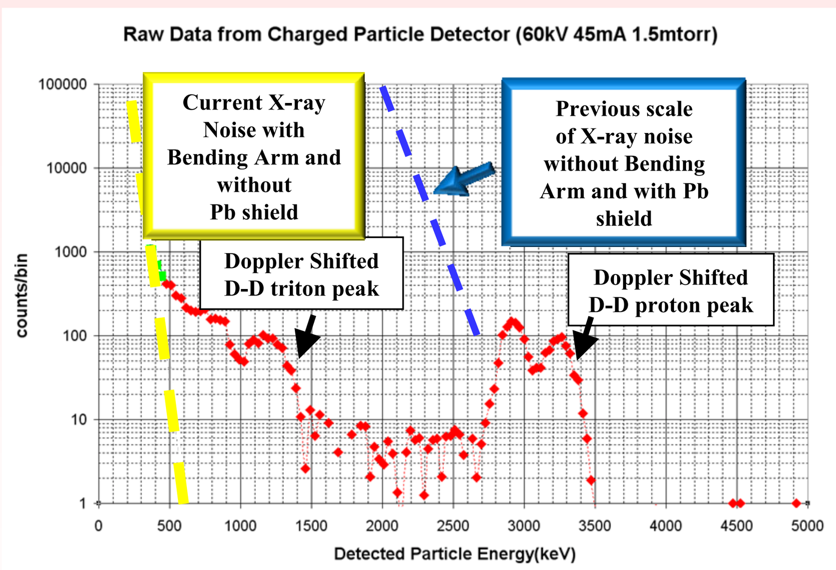


Figure 4: Raw energy spectrum collected from FIDO diagnostic demonstrating scale of noise reduction. [1]

[1] D.R. Boris, G.L. Kulcinski, J.F. Santarius, D.C. Donovan, and G.R. Piefer, "Measuring D(d,p)T Fusion Reactant Energy Spectra with Doppler Shifted Fusion Products," *Journal of Applied Physics* 107, 123305 (2010).

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 times at which charged particles reach the detectors.

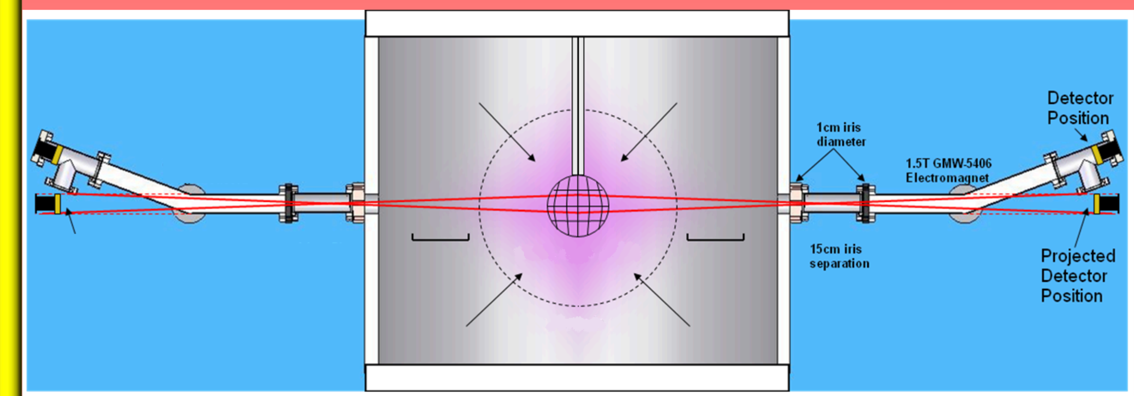


Figure 5: Schematic of TOF diagnostic on HOMER utilizing two identical FIDO setups to create a line of sight through the core of the device.

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.

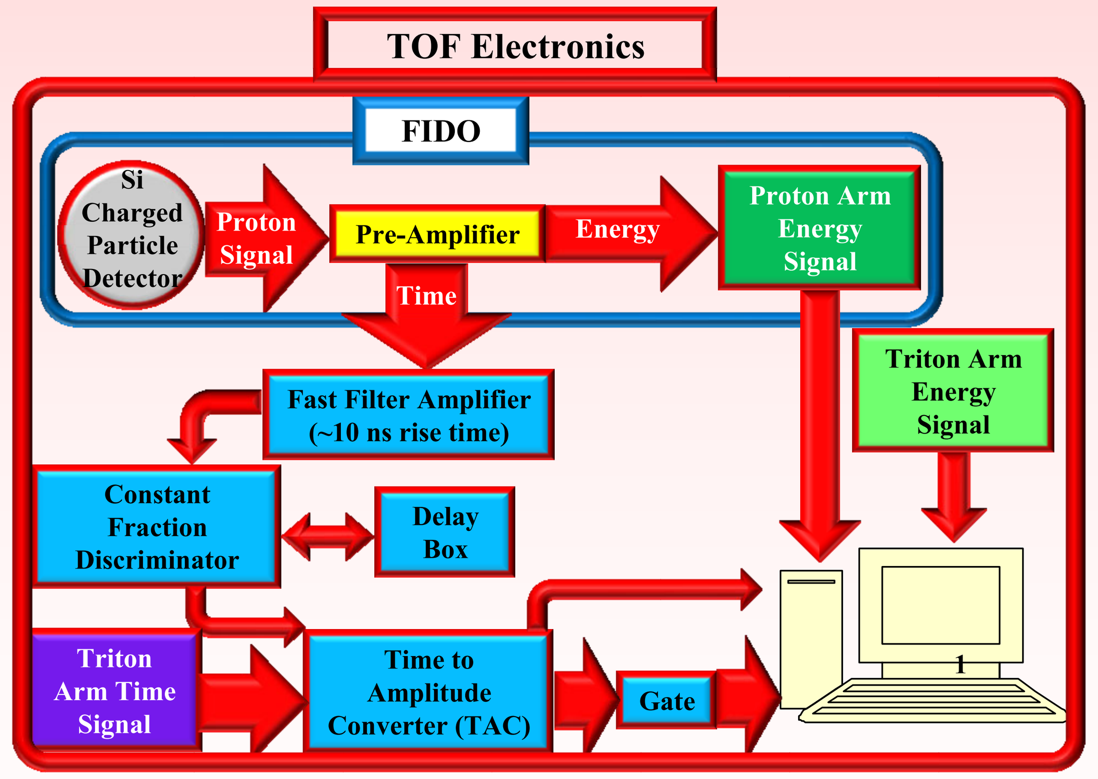
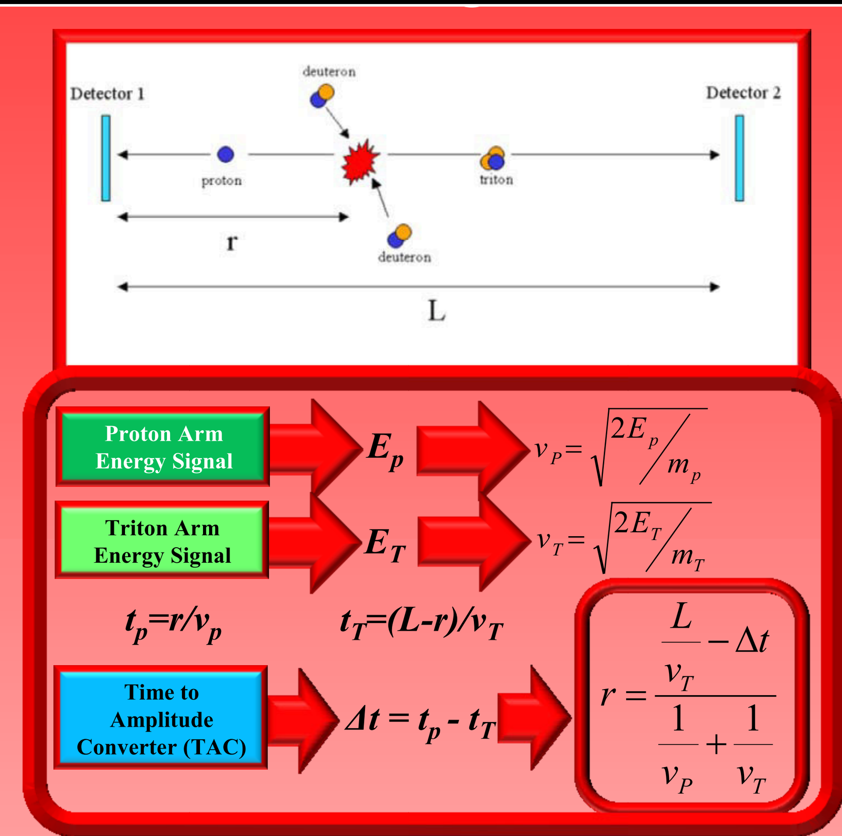


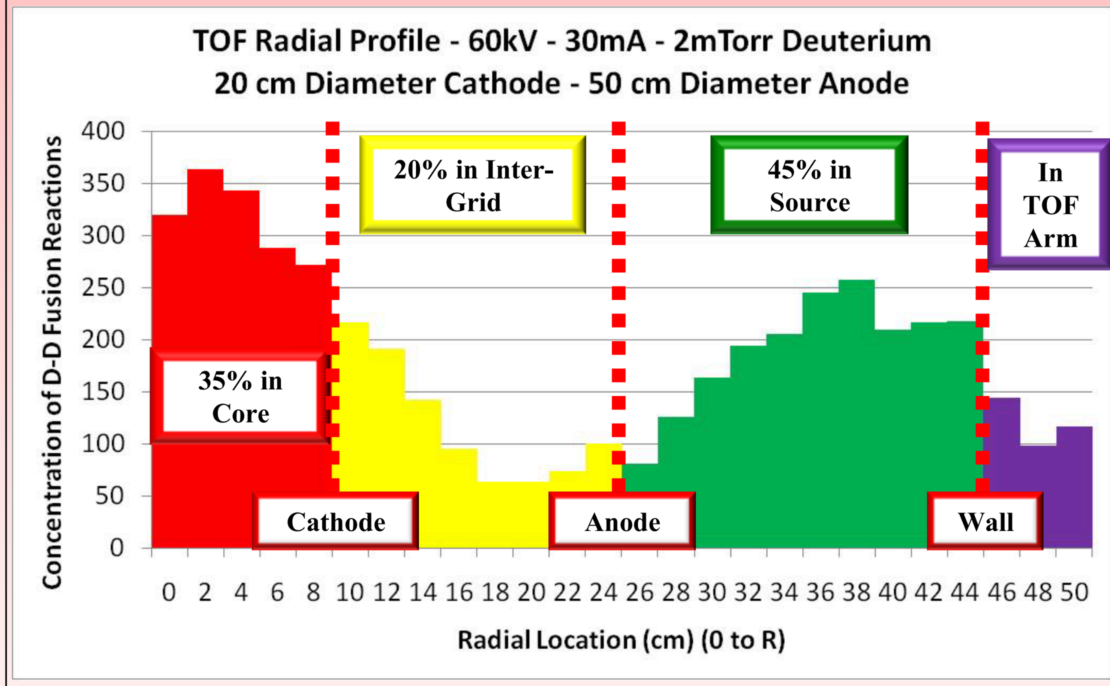
Figure 6: Flow-chart of electronics used in collecting energy and timing signals from each FIDO setup to gather TOF data.



Initial Results

➢Chamber can be divided into 3 regions
- ➢**Core** – Inside Cathode
- ➢**Inter-Grid** – Between Cathode and Anode
- ➢**Source** – Outside Anode (location of tungsten filament electron sources to ionize gas)

➢Spatial resolution is roughly 2 cm.



➢High concentration of fusion events seen in Core and Source regions.

➢Unexpected drop in concentration seen in Inter-Grid.

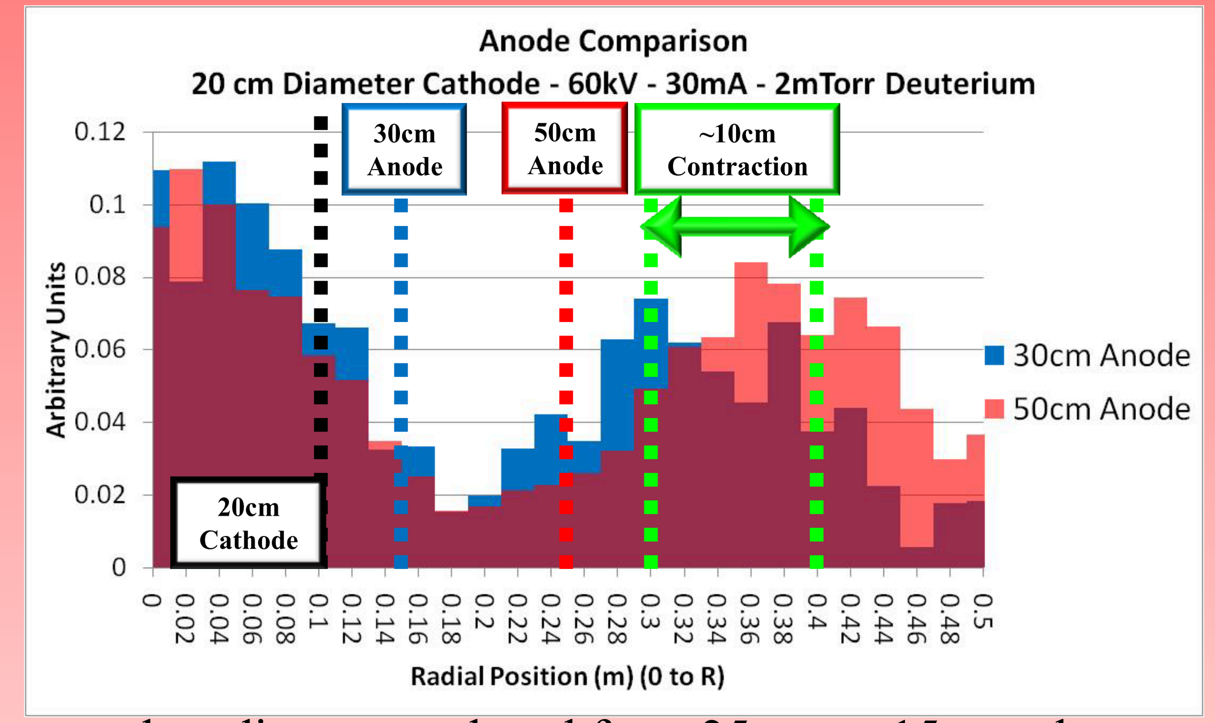
➢TOF uses FIDO diagnostic to determine fusion reactant energy, but is currently unable to determine reactant species (positive ion, high energy neutral, negative ion).

➢TOF is also unable to detect embedded fusion reactions because they do not allow both products to be captured, so above profiles show only beam-background and beam-beam fusion.

➢**Positive ions** reach maximum energy at the cathode moving towards the center, so they are believed to be primarily responsible for **Core fusion**.

➢**Negative ions** reach maximum energy at the anode moving away from the center, which makes them the most likely source of **fusion in the Source**.

➢**Inter-Grid** region appears to be primarily a **transit region** for negative and positive ions, but is not an ideal location for fusion for either.



➢When anode radius was reduced from 25 cm to 15 cm, the center of the peak in concentration in the Source region contracted radially by ~6-10 cm.

➢Since negative ions reach max energy at the anode, the question still remains why the peak in source region counts is ~15 cm beyond the anode in both cases.

Conclusions

➢**The TOF diagnostic offers far greater spatial and energy resolution than any other diagnostic system previously implemented on an IEC device.**

➢**Initial results indicate a high concentration of fusion inside the cathode and outside the anode, with an unexpected lower concentration between electrodes.**

➢**High fusion rates outside of anode indicate greater importance of negative ions than previously expected.**

➢**Fusion concentrations unexpectedly continue to increase with radius beyond the anode, despite negative ions reaching max energy at anode.**

➢**Future goals include increasing rate of data collection in order to obtain more complete fusion reactant energy profiles in each radial bin.**