Spatial and Energy Profiling of D-D Fusion Reactions in an IEC Fusion Device

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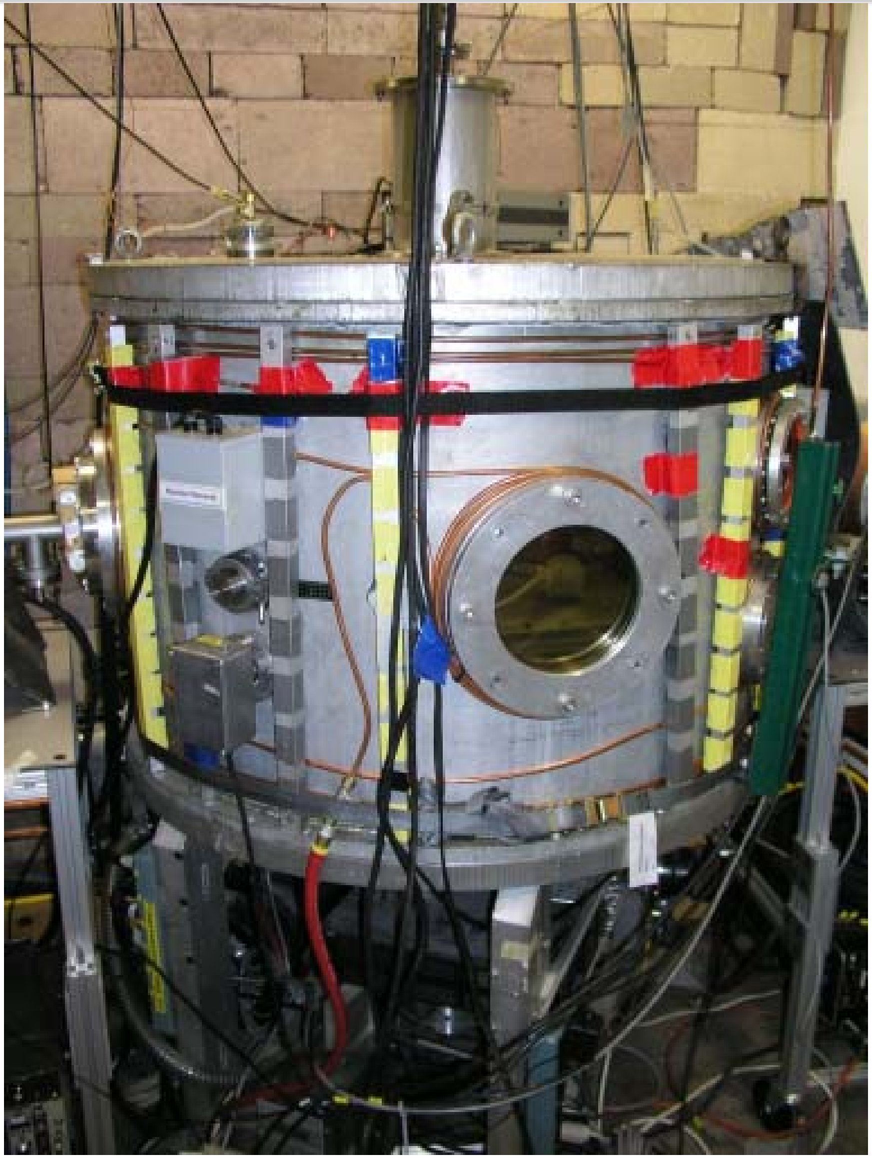
Outline

- Fusion Ion Doppler (FIDO) Diagnostic
  - Energy Profiling Results
- Time of Flight (TOF) Diagnostic
  - Preliminary Spatial Profiling Results

All experiments discussed here conducted on UW IEC chamber known as HOMER

- Cylindrical Aluminum Chamber
  - **Diameter**: 91 cm
  - **Height**: 65 cm
- **Feed Gas**: Deuterium
- **Typical Operating Parameters**
  - **Pressure**: 1.5 - 2.5 mTorr
  - **Voltage**: 40 – 160 kV
  - **Current**: 30 – 60 mA



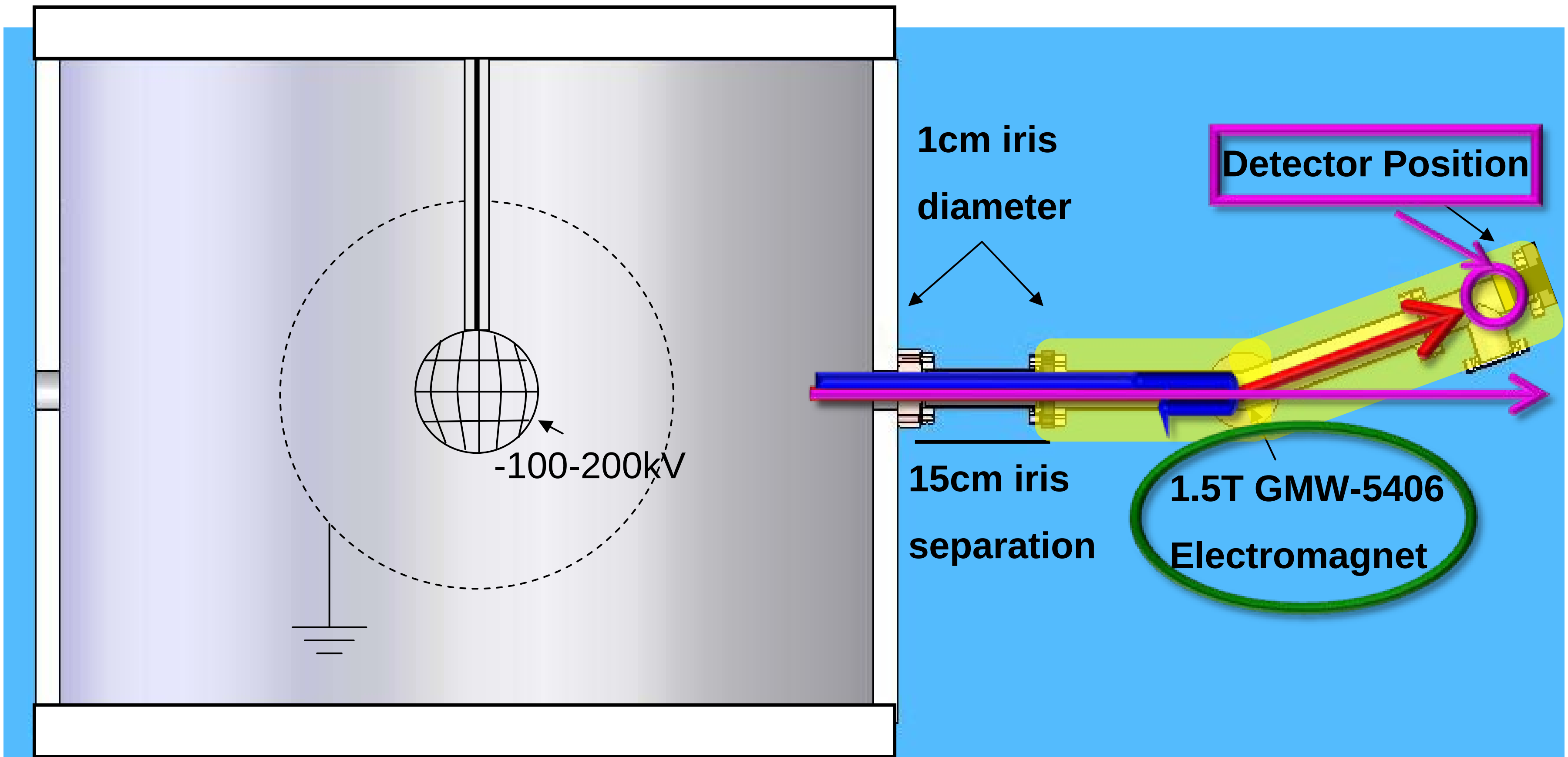
Fusion Ion Doppler (FIDO) Diagnostic developed by D. R. Boris (2008)

- **Goal** – Examine the Doppler Shift imparted to D(d,p)T fusion products by the deuterium reactants to unfold the deuterium energy spectrum within HOMER IEC device.
- **Problem –** X-ray noise overwhelms triton (1.01 MeV) peak and clouds proton (3.02 MeV) peak making Doppler Shift unreliable to read.
- **Solution** – Move charged particle detectors out of line of sight of chamber.
- **Results** – The line averaged energy spectrum of deuterium ions and fast neutrals obtained over a wide range of parameter space within the HOMER IEC device.

Solution to Minimizing X-Ray Noise

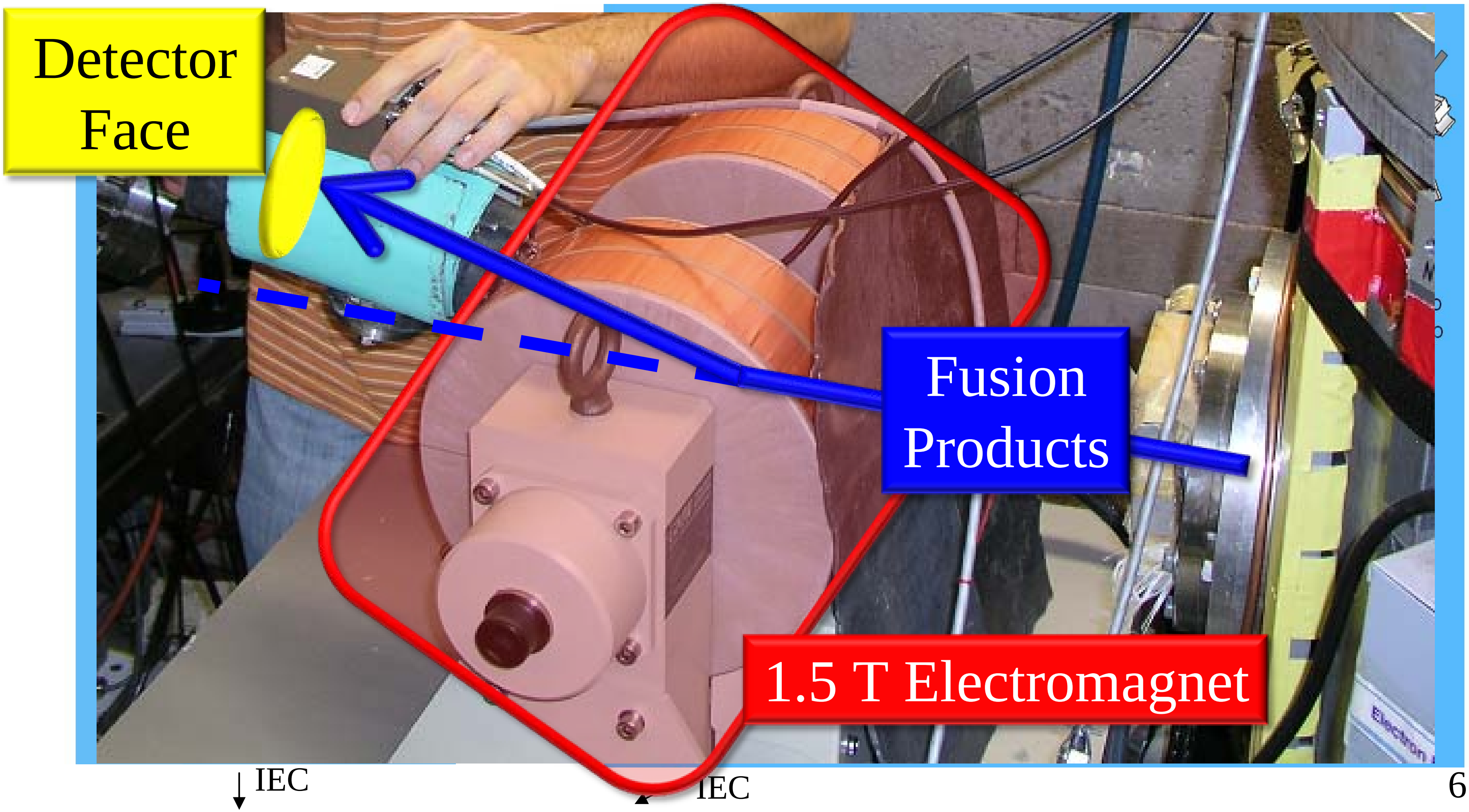
- Detector face moved out of line of sight of chamber
- Magnetic Deflection
  - Fusion products (MeV)
  - Secondary electrons (Hundreds of keV)

- Pb shielding around collimator channel and detector mount

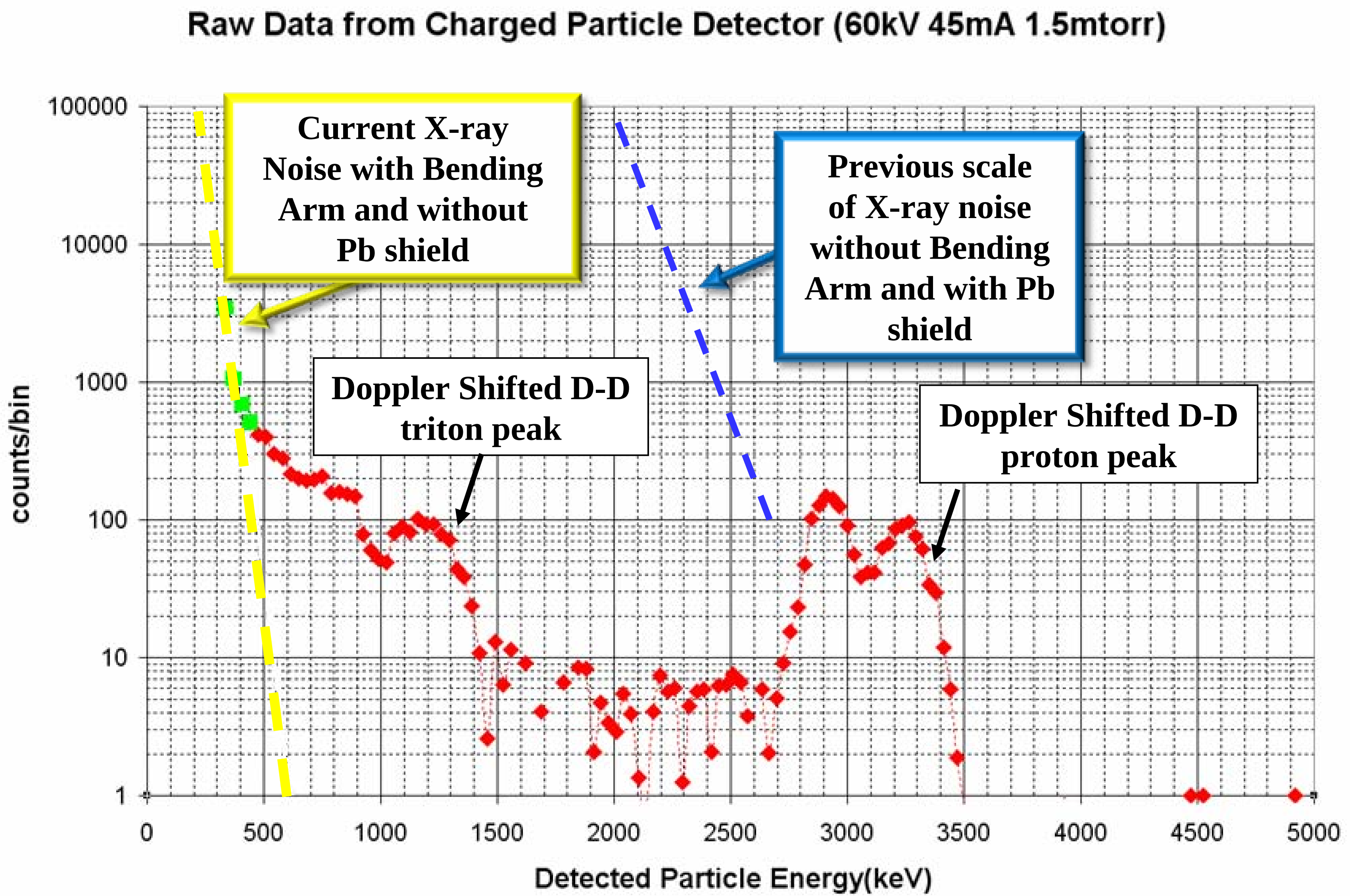


Collimator channel has a ~20 degree bend at the elbow taking detector out of line of sight of chamber

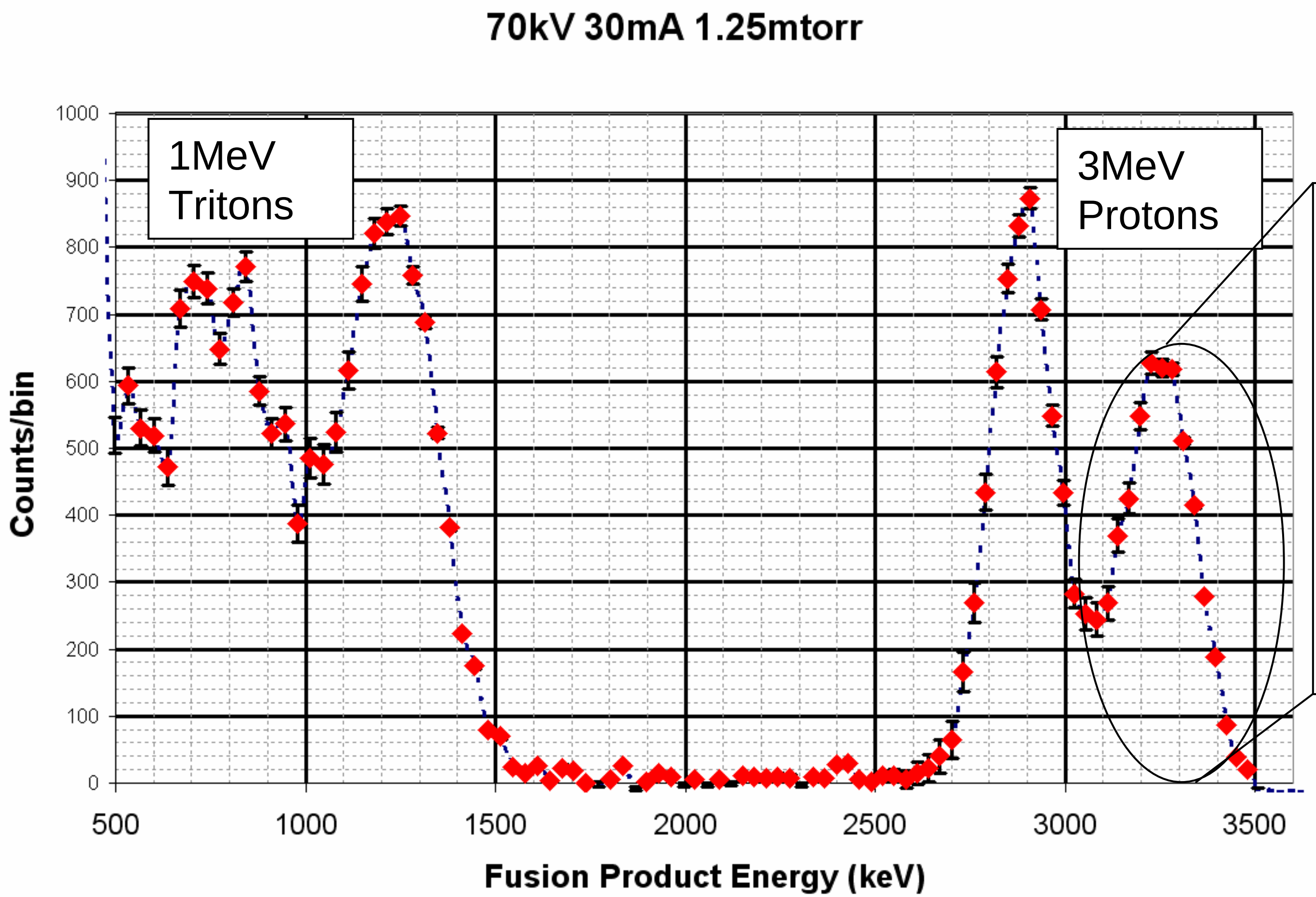
Fusion **I**on **Do**ppler (FIDO) Diagnostic



New setup allows both protons and tritons to be detected



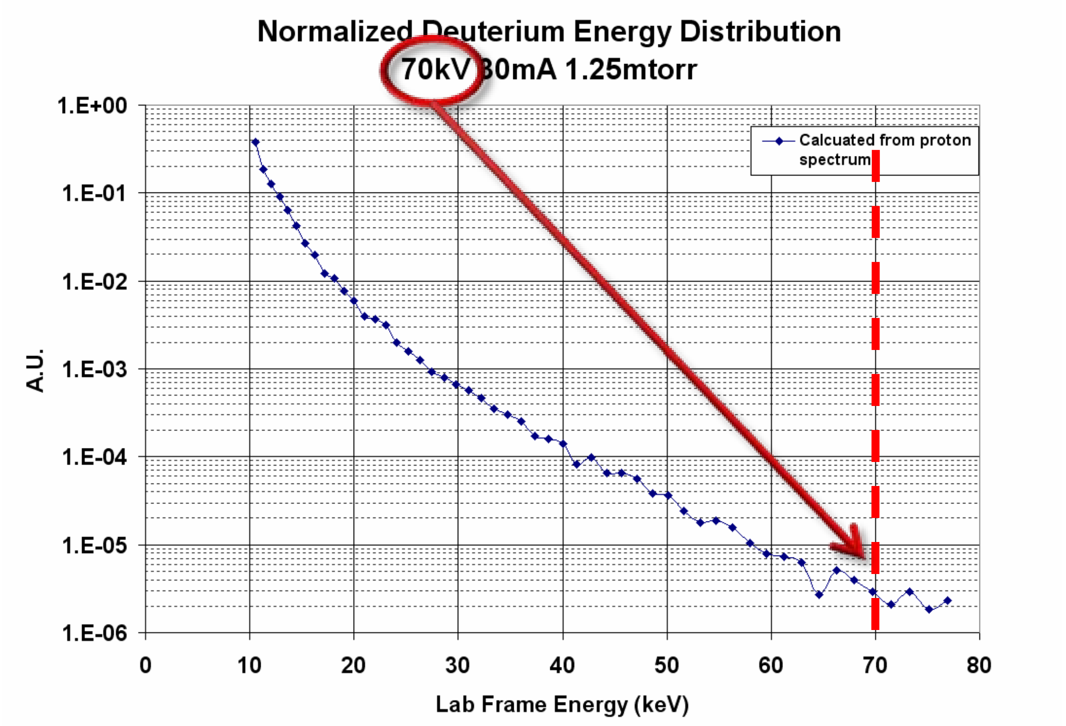
Subtraction of X-ray noise reveals proton & triton peaks of comparable size



Examining either side of the double peaked spectra can yield center of mass energy of the deuterium reactants

Calculating the Deuterium Energy Distribution

- Scaling the number of counts in each energy bin from the previous data set by $\sigma_{fusion}(E_{bin})$ and normalizing the resulting spectrum yields:

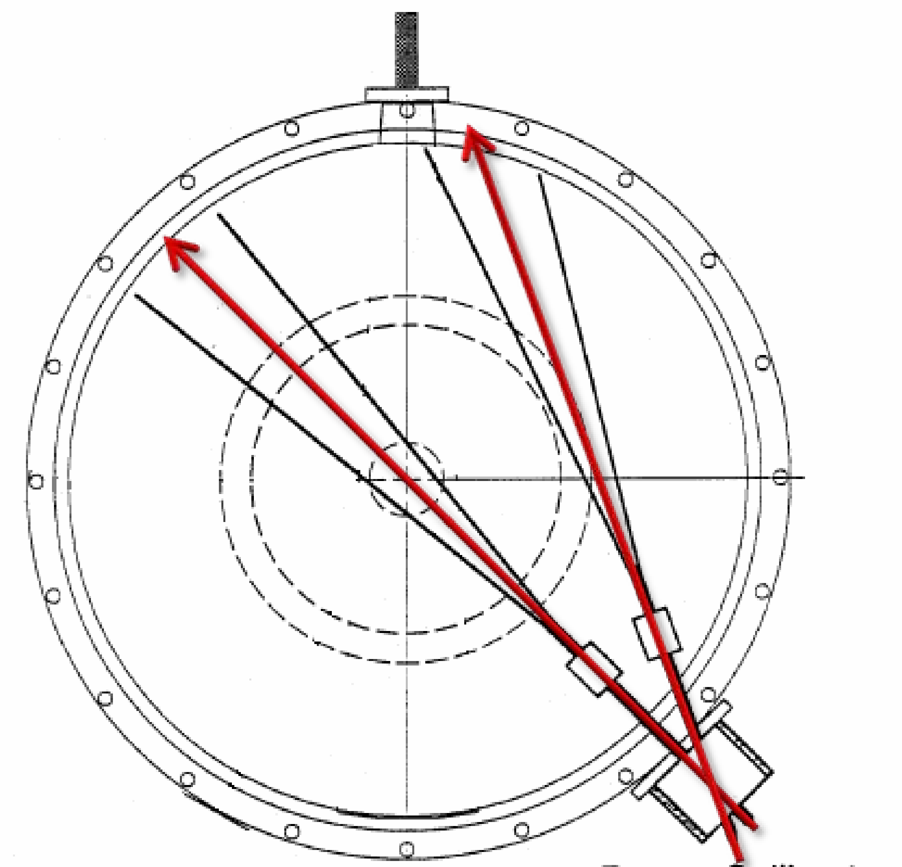


Line averaged spectrum shows:

- Few deuterons @ V_{cath}
- Spectrum consistent w/ spectra predicted by G.A. Emmert & J.F. Santarius

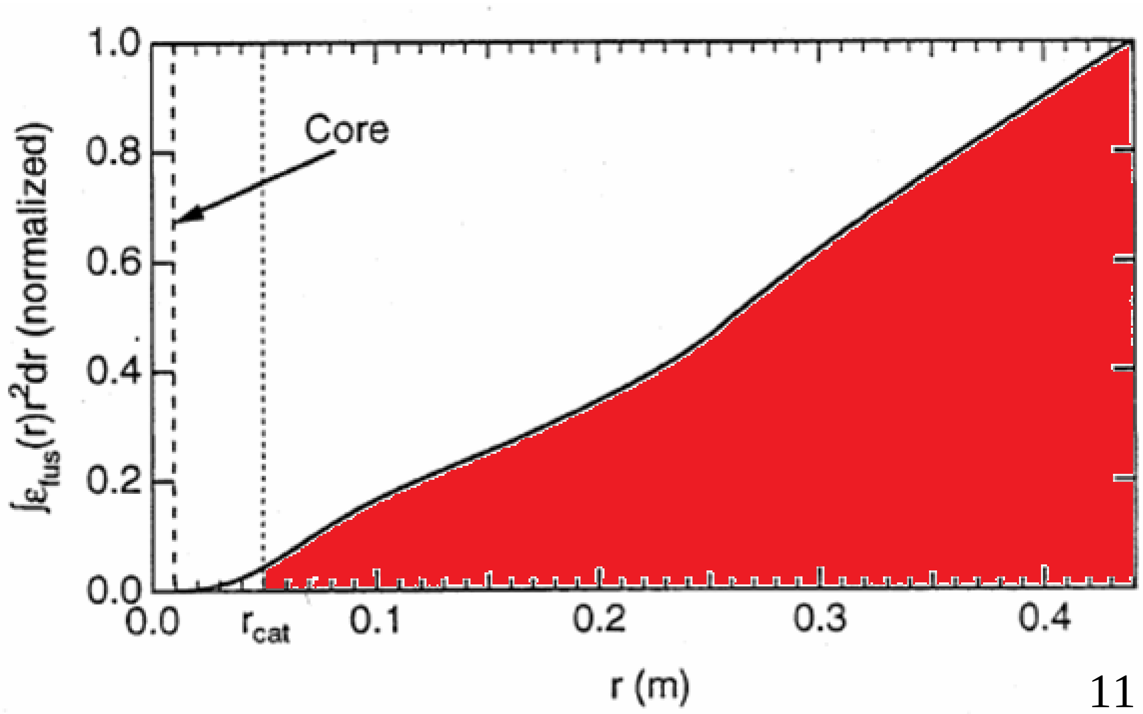
Previous Work on Spatial Profiling Using Collimated Proton Detector

- Previous work done by Thorson (1996) on radially profiling of a spherically gridded IEC device using a collimated proton detector
- Straight 10 cm collimator channel attached to moveable bellows assembly to obtain different lines of sight through the chamber

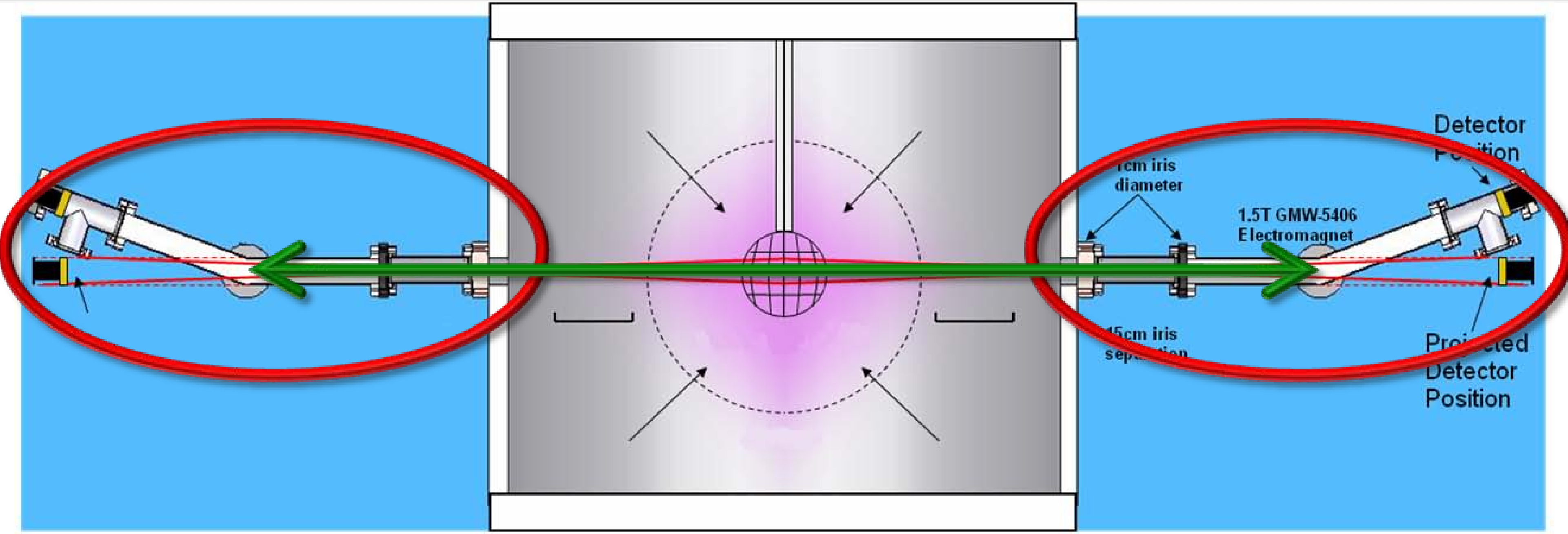


Previous Work Using Collimated Proton Detector

- Experiments conducted at 35 kV, 20 mA, 1.9 mTorr of Deuterium Pressure
- Cathode diameter: 10 cm
- **Most fusion reactions (>90%) believed to occur outside of cathode region**

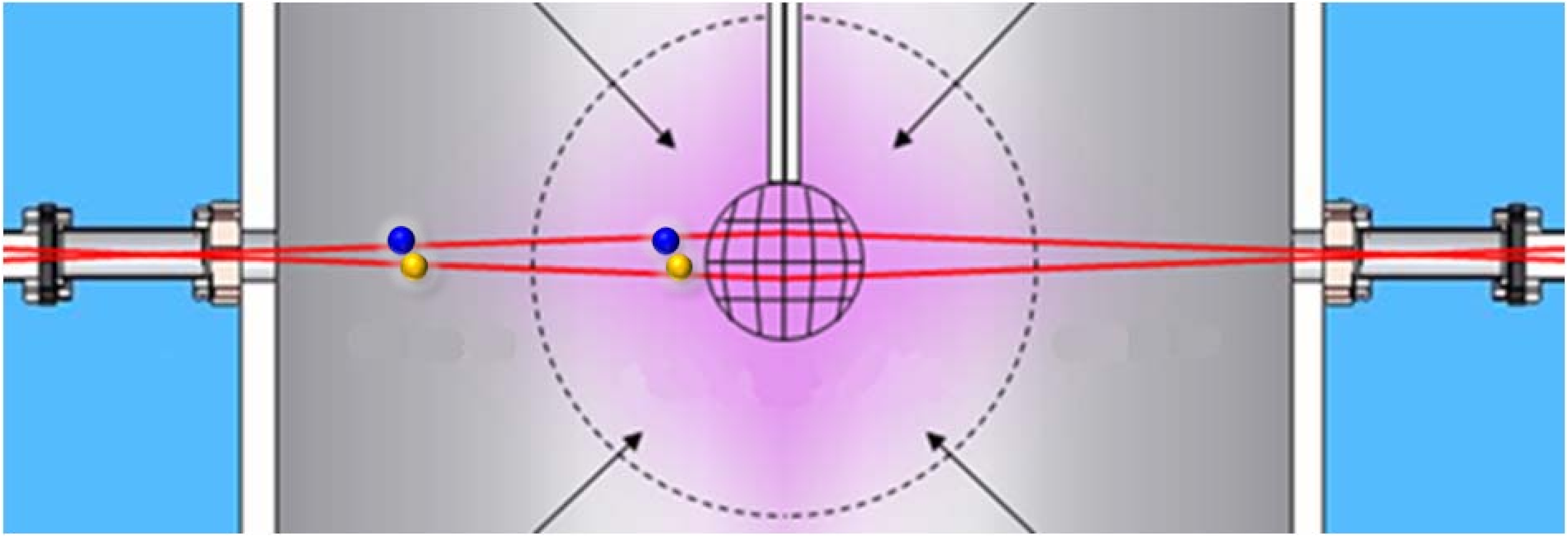


Time Of Flight (TOF) Diagnostic is an Advancement on the FIDO concept



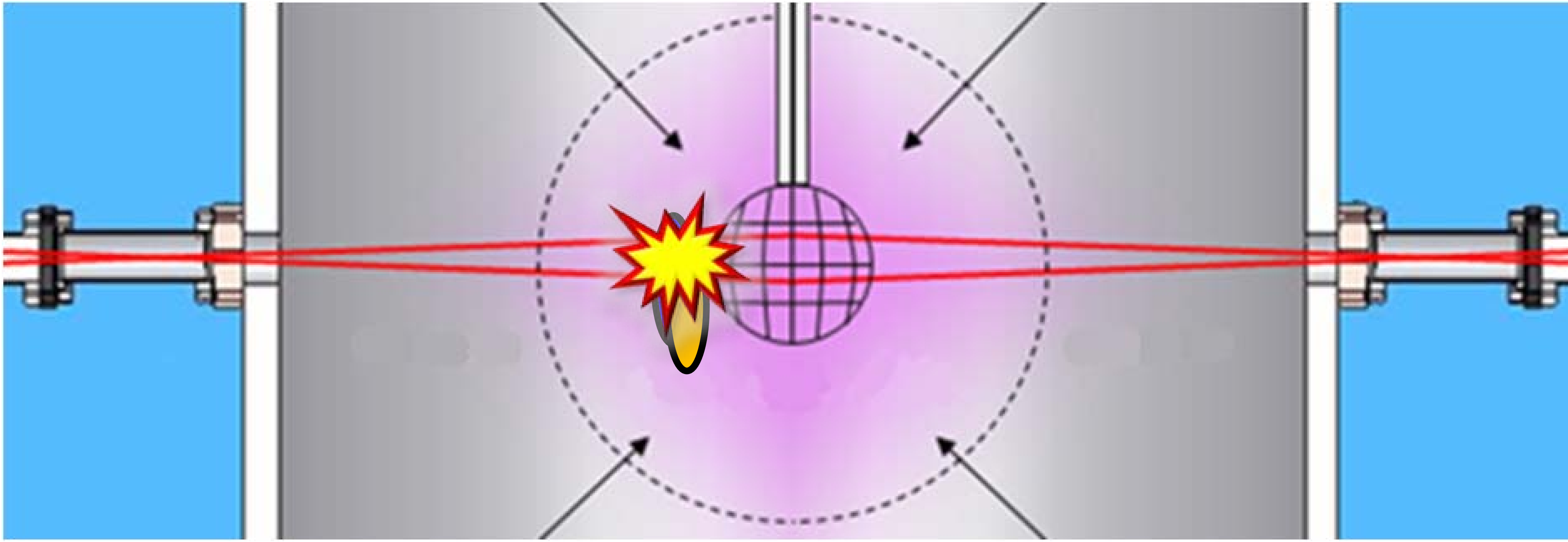
- TOF concept proposed by G. R. Piefer and D. R. Boris (2007) and implemented by D. R. Boris and D. C. Donovan (2008)
- 2 identical FIDO setups on opposite sides of HOMER
- Direct line of sight created through both arms and center of chamber

D-D fusion events can be detected using coincidence counting methods



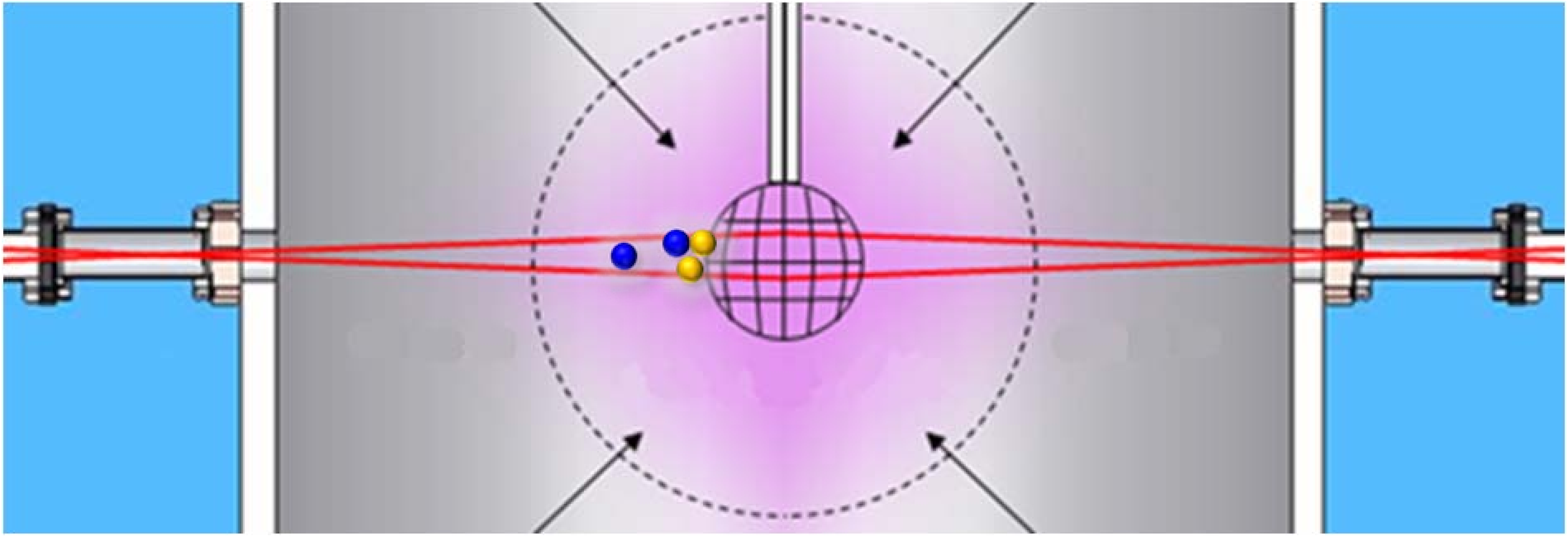
- Fast ions are accelerated radially towards the center of the electrodes
- Fast particles most likely to collide with background neutrals

D-D fusion events can be detected using coincidence counting methods



- If the fast particle has sufficient energy, it fuses with the background neutral

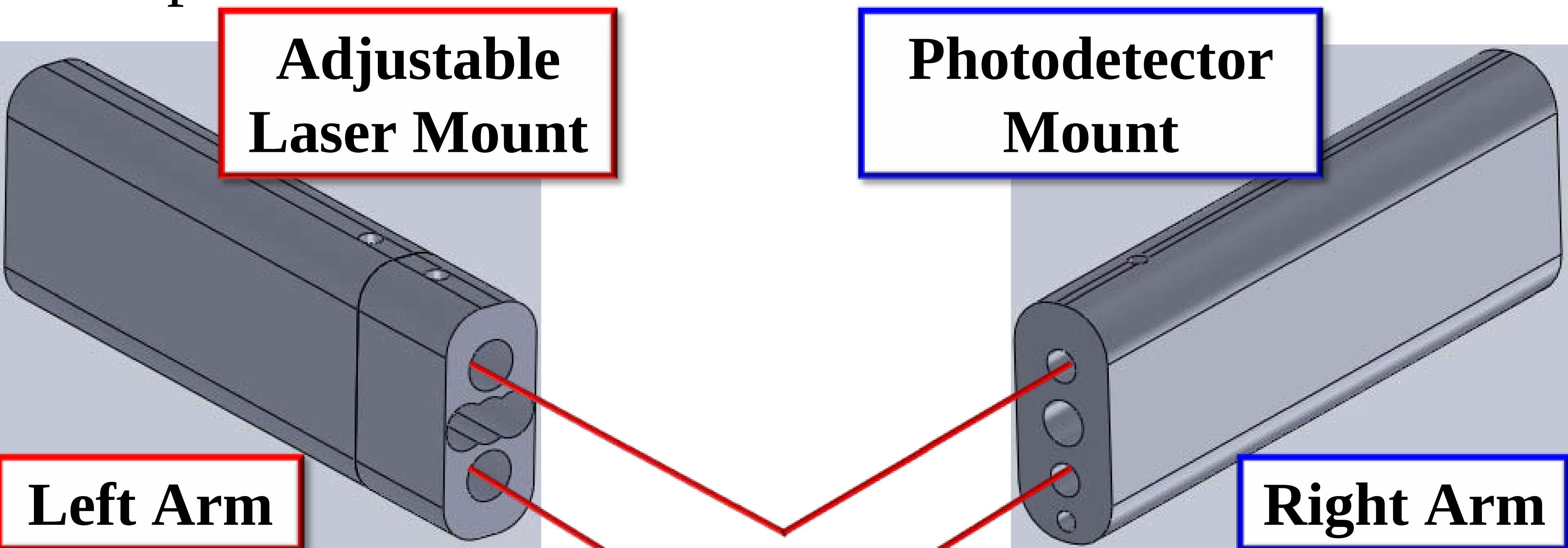
D-D fusion events can be detected using coincidence counting methods



- D-D fusion creates 3.02 MeV proton and 1.01 MeV triton
- Conservation of momentum requires both particles to move in exact opposite direction in center-of-mass frame
- Proton moves approximately 3 times faster than triton, so for this setup, the proton always arrives at the detector first

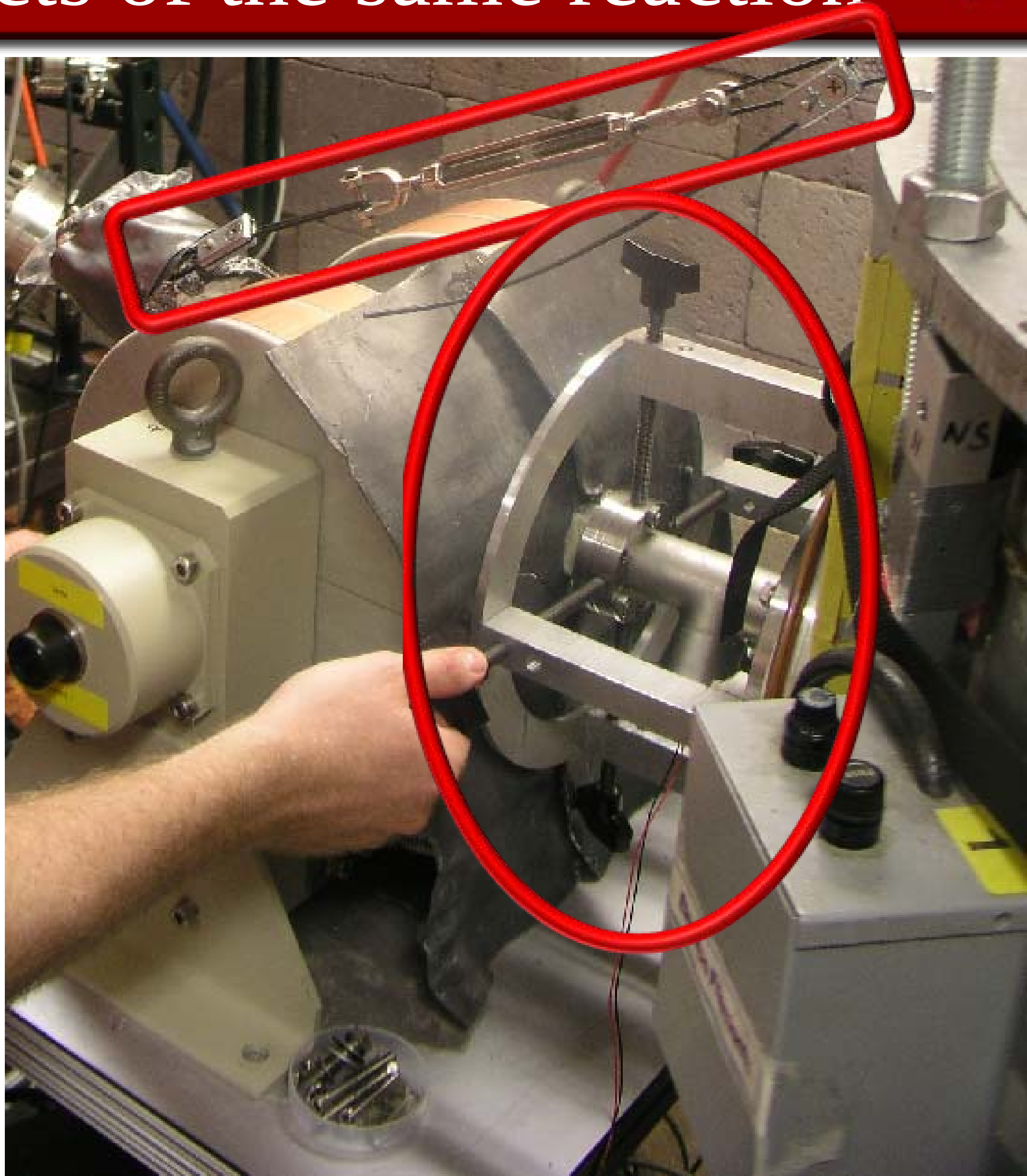
Proper alignment is critical for capturing both fusion products of the same reaction

- Distance between detectors: 2 meters
- Active Detection Area: 450 mm^2
- Laser alignment used to ensure maximum exposure of detector face to chamber

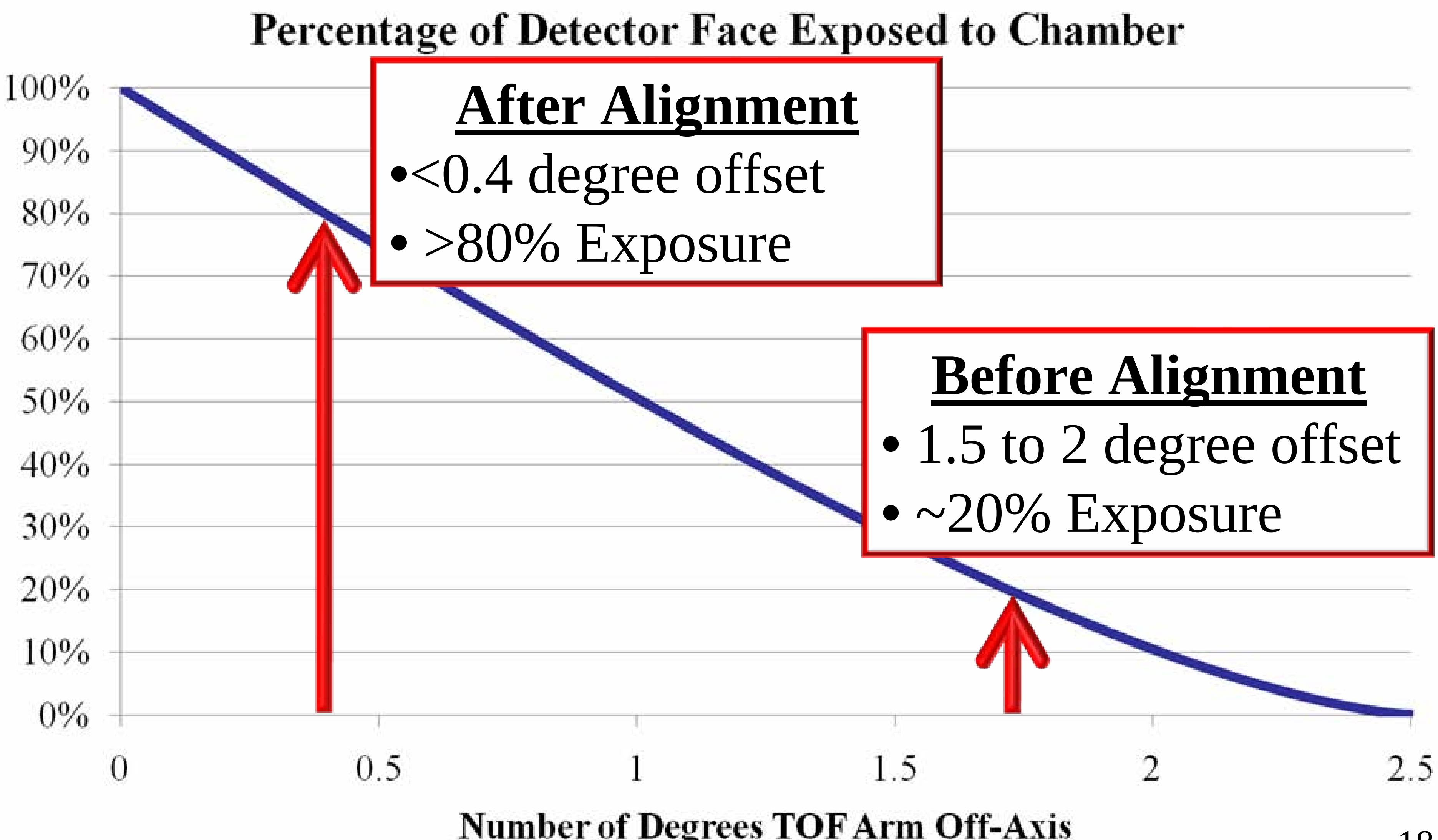


Proper alignment is critical for capturing both fusion products of the same reaction

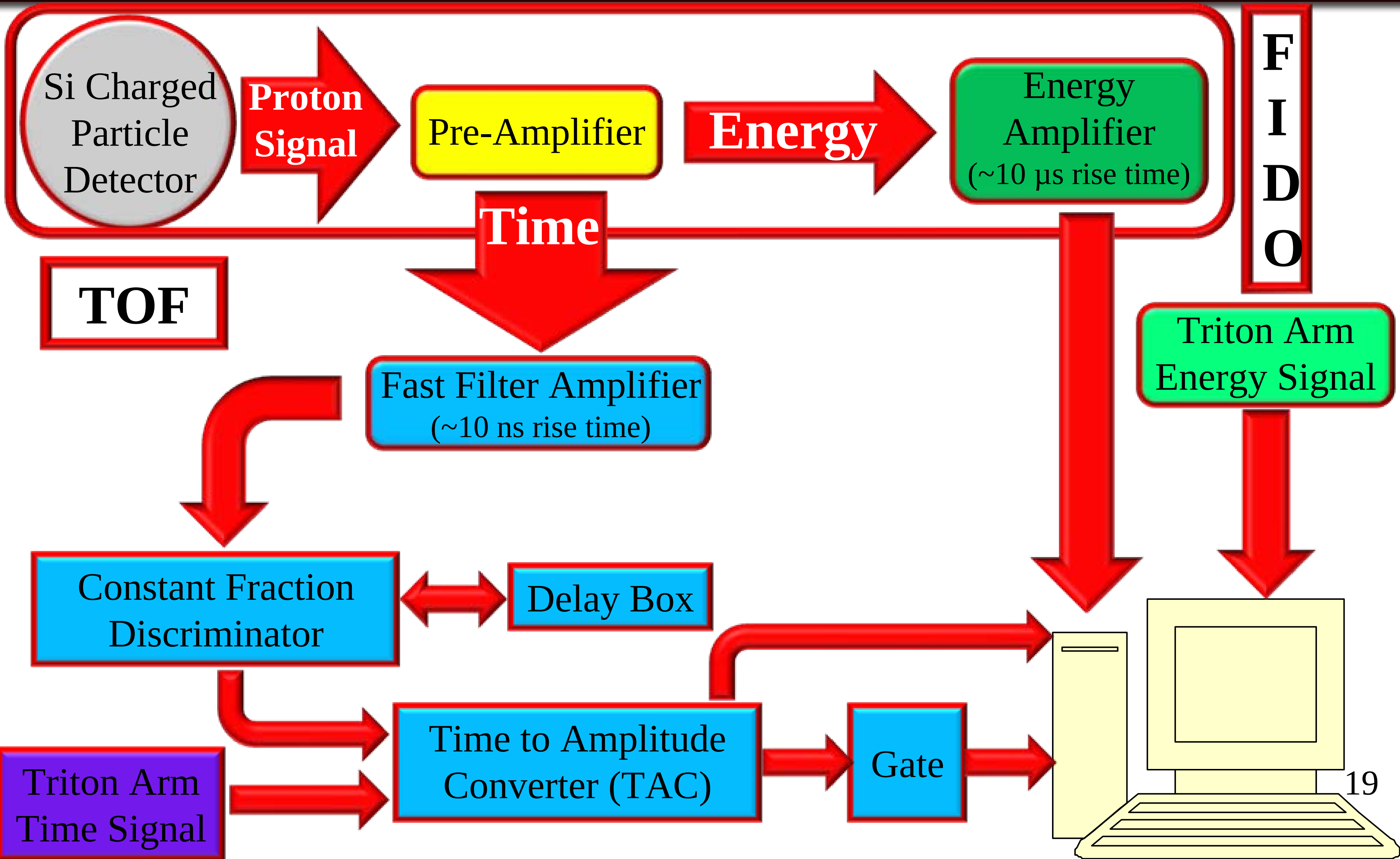
- Turnbuckle and steel cable used to support weight of arm and lead shielding
- Threaded rods used to properly position arm in 2D plane and align with arm on opposing side



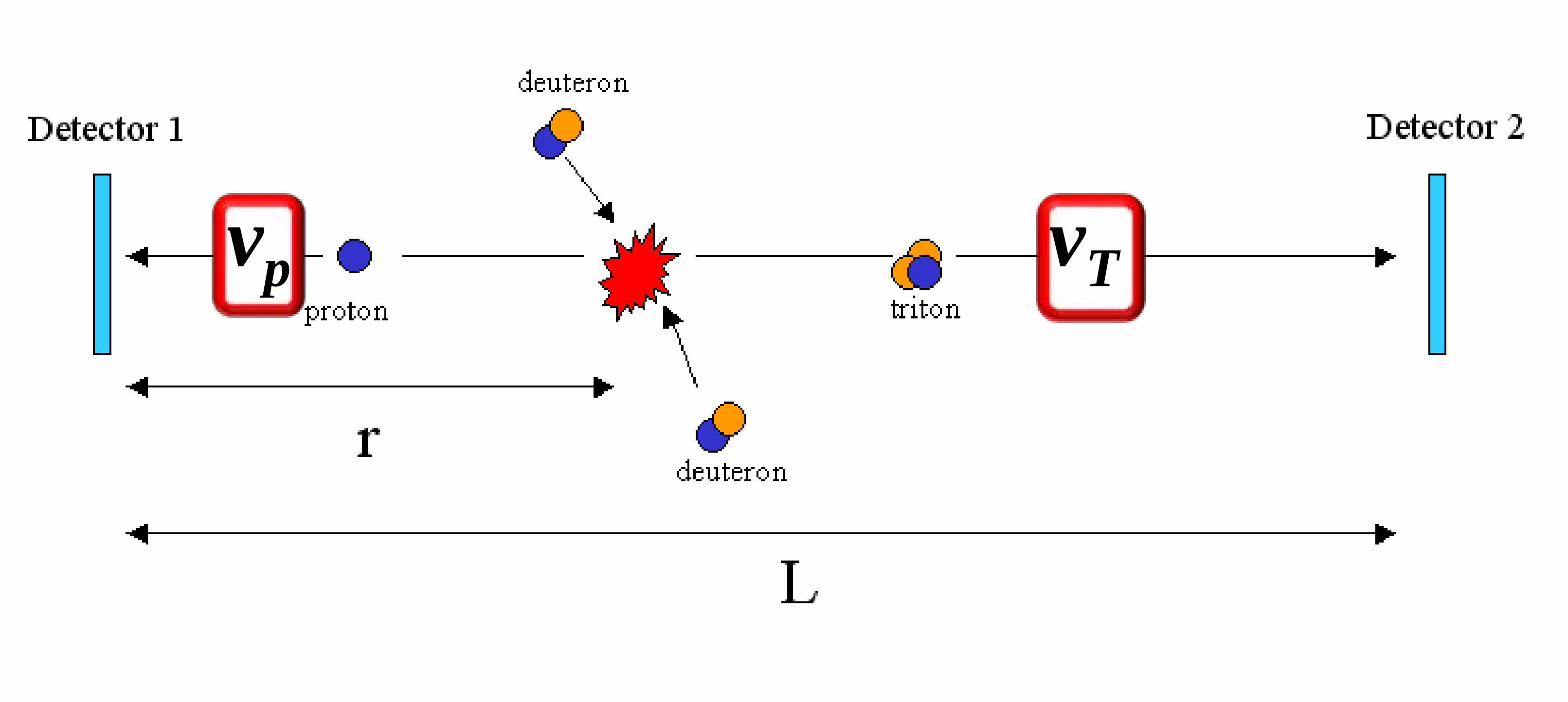
Offset Angle Greatly Affects Detection Capacity



Timing Electronics



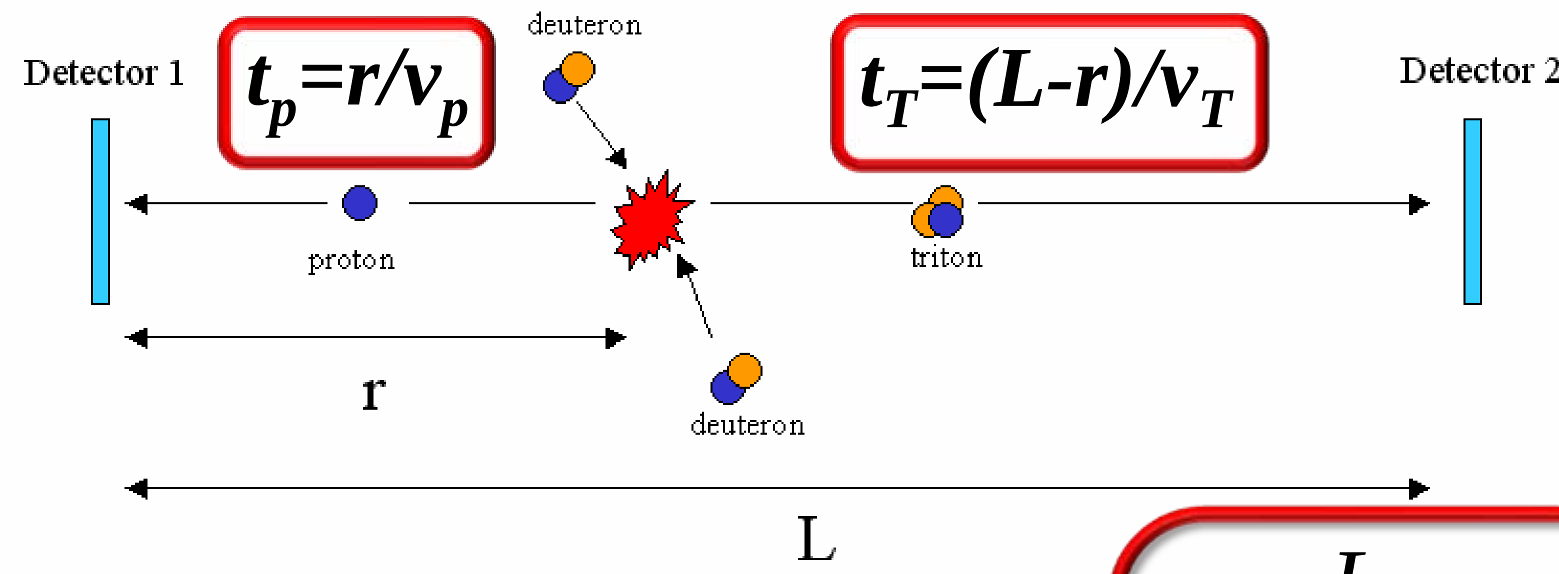
Energy signal from detectors give velocity of fusion products



Proton Arm Energy Signal → E_p → $v_P = \sqrt{2E_p / m_p}$

Triton Arm Energy Signal → E_T → $v_T = \sqrt{2E_T / m_T}$

TAC gives difference in arrival times, equal to difference in TOF of fusion products



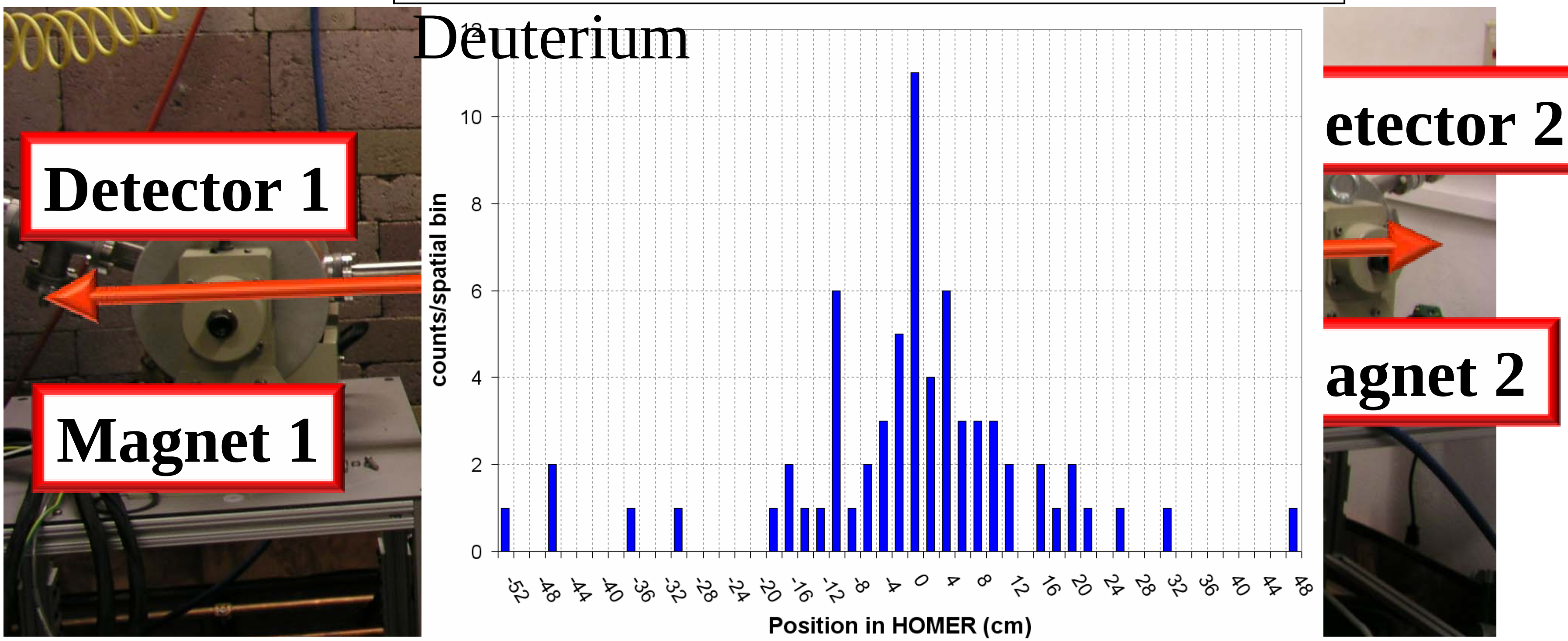
Time to Amplitude Converter (TAC)

$$\Delta t = t_T - t_p$$

$$r = \frac{\frac{L}{v_T} - \Delta t}{\frac{1}{v_P} + \frac{1}{v_T}}$$

Initial Results from Time Of Flight (TOF) Diagnostic

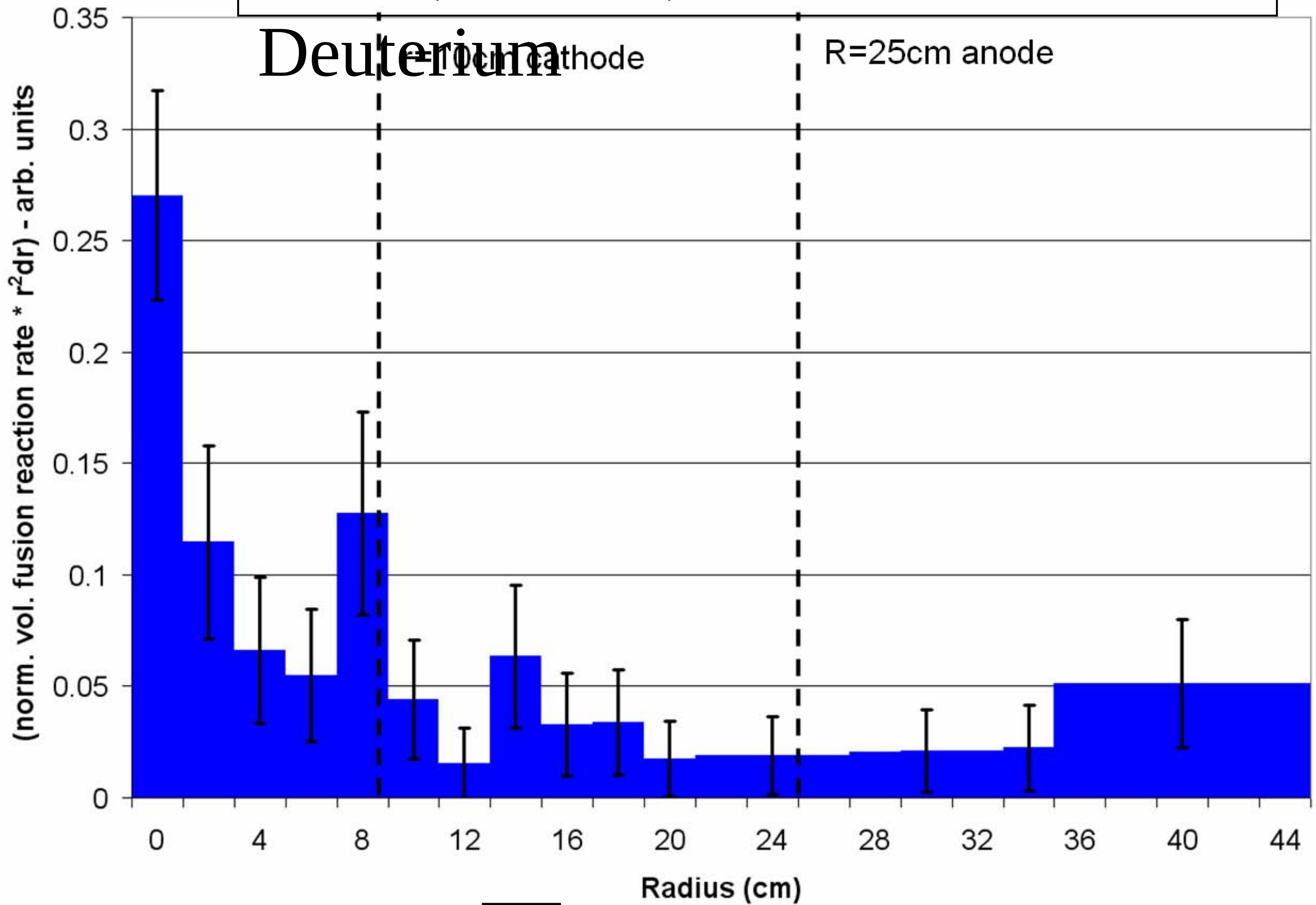
50 kV, 30 mA, 2 mTorr Deuterium



- Spatial resolution is roughly 2 cm
- Initial results have been achieved that indicate a high concentration of reactions inside the cathode

Initial results indicate at least 50% of fusion occurring within the cathode radius

50 kV, 30 mA, 2 mTorr Deuterium



$$\sum bins = 1$$

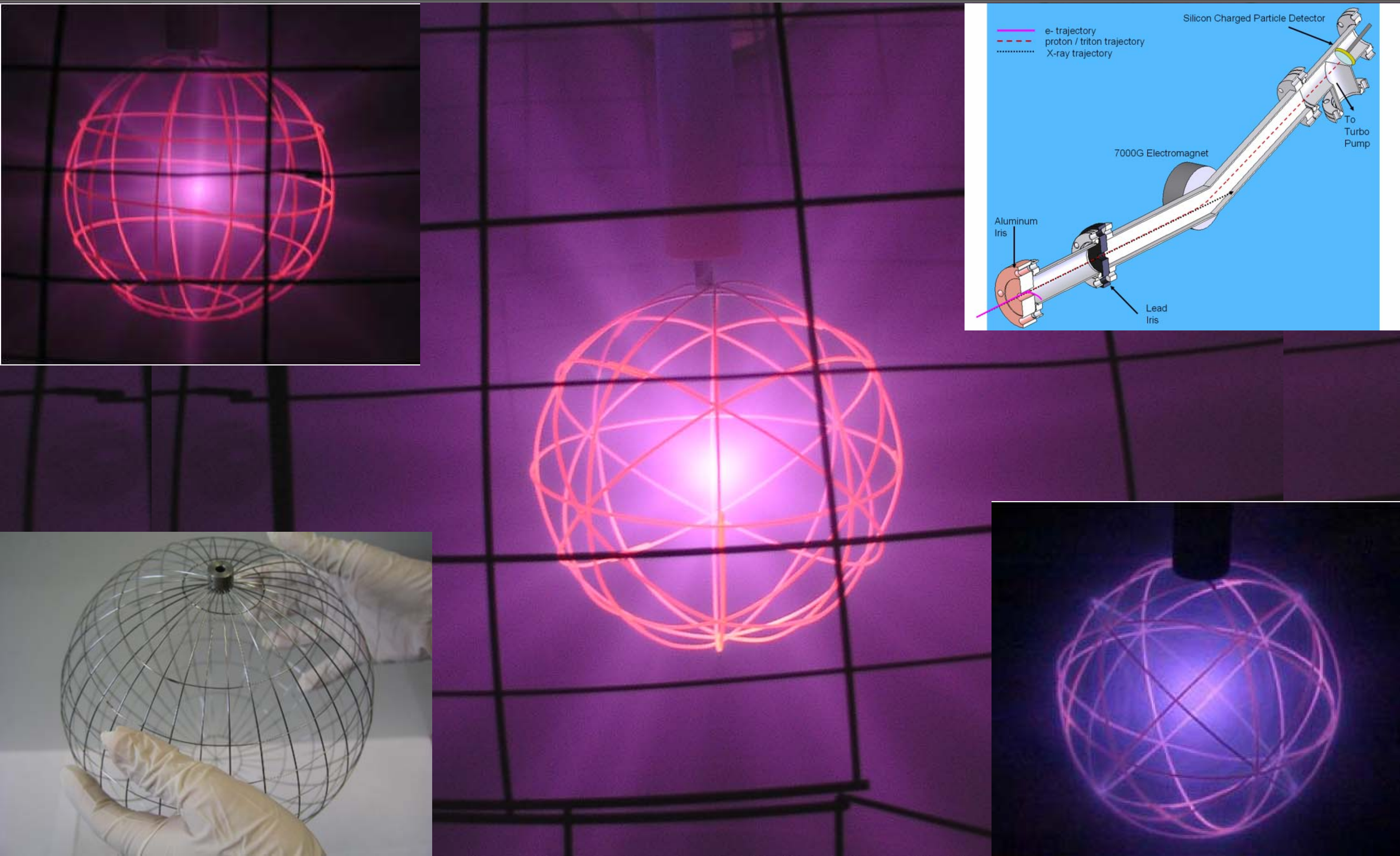
Conclusions for TOF

- Constructed and currently implementing a fusion product time of flight diagnostic capable of measuring the radial spatial profile of fusion reactions within the UW IEC device.
  - The TOF diagnostic has demonstrated the ability to generate spatial profiles of fusion reactions occurring within an IEC device
  - Original Thorson results indicated less than 10% of D-D fusion events occurring within cathode radius
  - Initial TOF results indicate that at least 50% of the D-D fusion reactions within the IEC occur within the cathode radius

Future Plans for TOF

- Implement electronics and software to capture simultaneous energy and timing signals for reactions to obtain 3D plot of:
  - Location of fusion event along radial line
  - Energy of fusion reactants at each location
  - Number of counts
- Use TOF diagnostic to study the change in energy and spatial profiles due to variations in:
  - Voltage
  - Current
  - Pressure
  - Grid Configurations

Questions?


e- trajectory
proton / triton trajectory
X-ray trajectory
Silicon Charged Particle Detector
To
Turbo
Pump
7000G Electromagnet
Aluminum
Iris
Lead
Iris