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Determination of Fusion Spatial Profiles in the HOMER IEC Device using the Time of Flight Diagnostic

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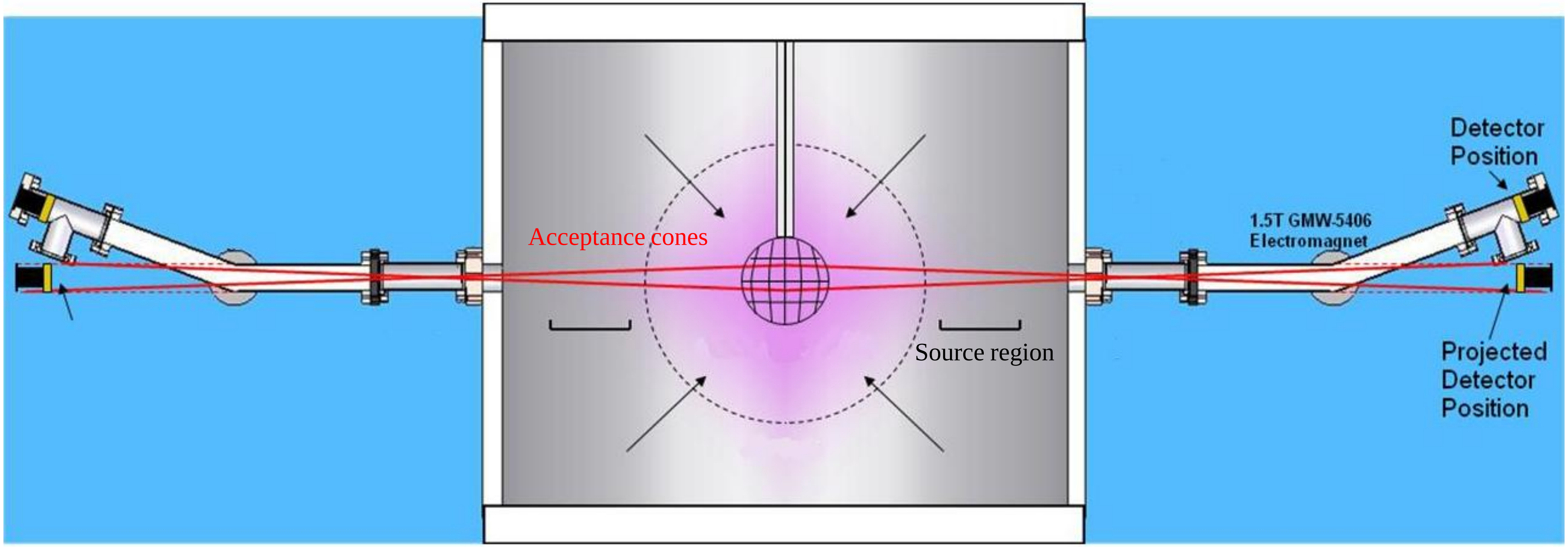
Outline

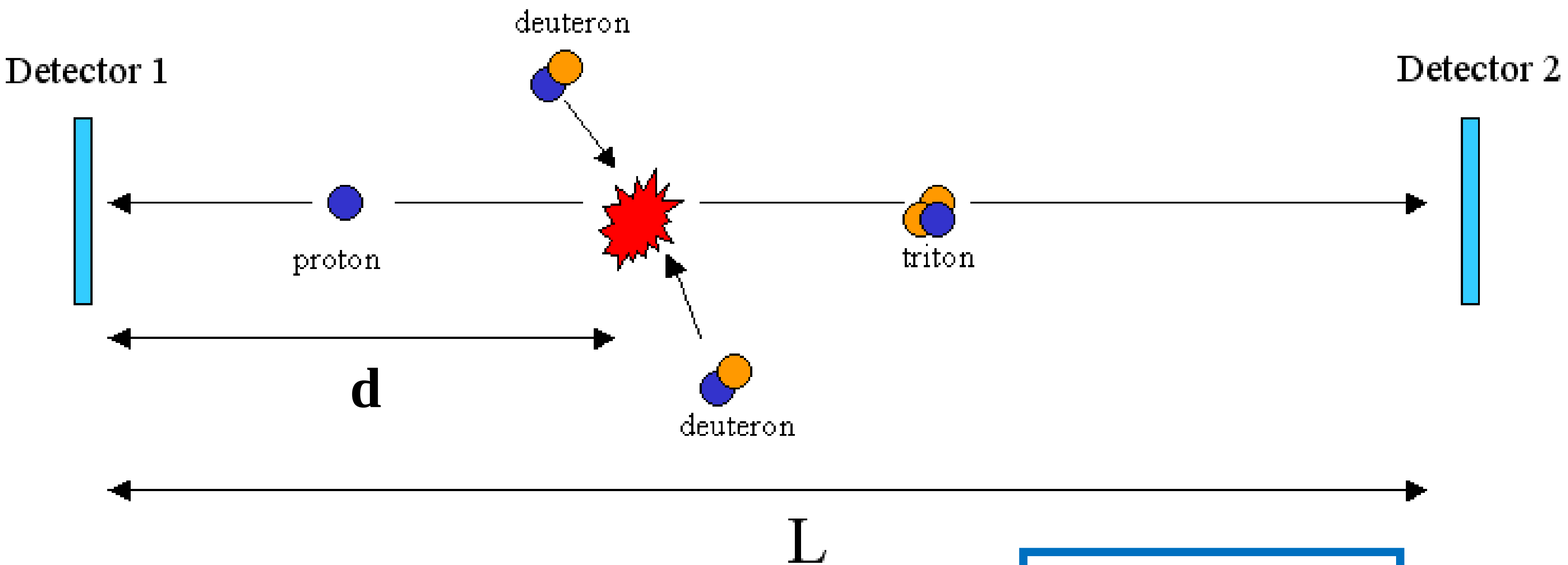
- Overview of the Time of Flight (TOF) diagnostic.
- Update on the applicability of the Fusion Ion DOppler (FIDO) diagnostic.
- Using the TOF diagnostic to determine the velocity distribution function of the deuterium reactants.
- Applying a weighting factor to account for geometrical effects of the diagnostic.
- Putting it all together to determine the underlying fusion profile in HOMER.
- Experimental advances and future work.

The TOF system consists of charged particle detectors on opposing magnetic bending arms



- The d(d, p)t reaction emits particles in opposite directions, which can be captured coincidentally by the two detectors.
- The time between particle captures (Δt) is recorded along with the energy of each particle (E_p and E_t).

The energy and timing information specifies the fusion event location in 1-D



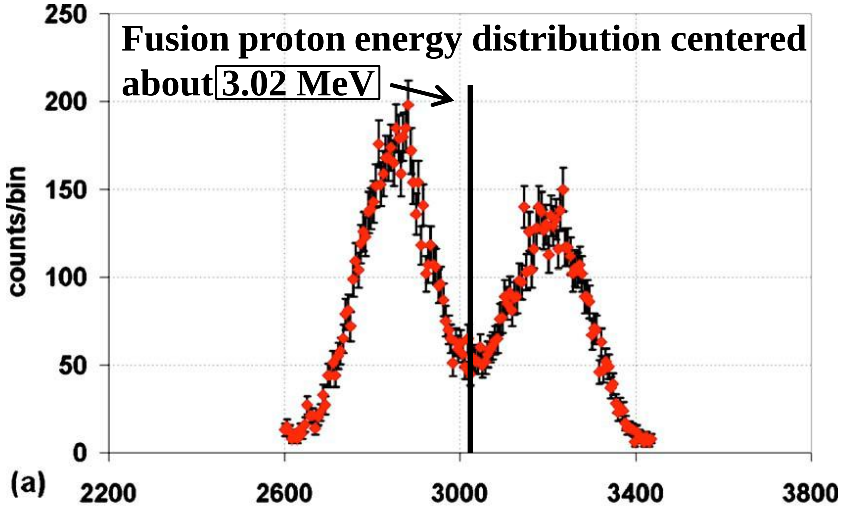
$$\Delta t = t_T - t_P = \frac{L - \mathbf{d}}{v_T} - \frac{\mathbf{d}}{v_P}$$

$$\mathbf{d} = \frac{\dfrac{L}{v_T} - \Delta t}{\dfrac{1}{v_P} + \dfrac{1}{v_T}}$$

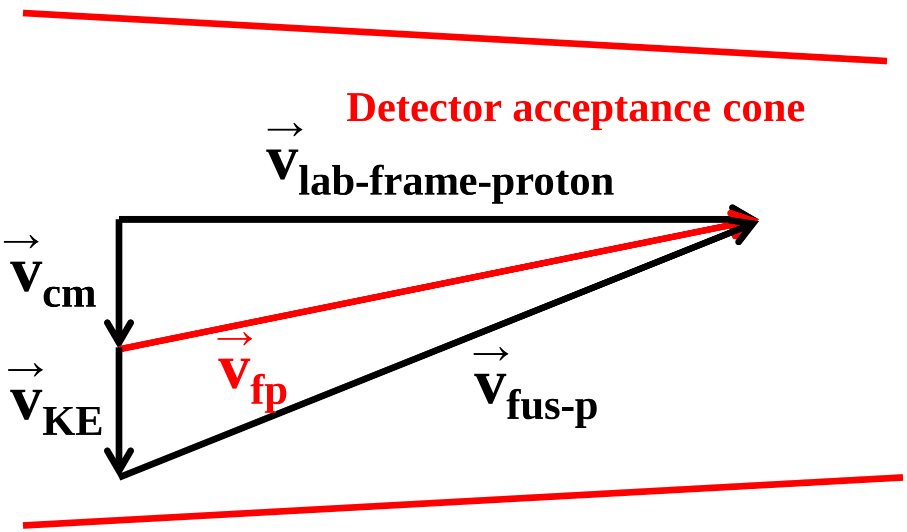
The goal is to describe the total fusion spatial profile across the entire 3-D volume

- Several pieces of information must be known to a high degree of accuracy.
  1. 1-D spatial distribution of fusion events.
     - TOF diagnostic.
  2. Deuterium velocity distribution function.
     - It was thought previously that the FIDO diagnostic provided this, however this is not quite accurate.
  3. Geometrical weighting factor that accounts for the probability for a fusion event to be coincidentally captured from a given point in the volume.
     - Computational mock-up of the device geometry.

The FIDO diagnostic cannot define the velocity distribution function (VDF)



Velocity Distribution Function



- Previous model (2008) assumed that only particles from fusion events with center of mass velocities directed parallel or anti-parallel to the detector axis were captured.

$$v_p = \sqrt{v_{fp}^2 + v_{cm}^2 + 2 v_{fp} v_{cm} \cos(\theta_p)}$$

$$v_t = \sqrt{v_{ft}^2 + v_{cm}^2 + 2 v_{ft} v_{cm} \cos(\theta_t)}$$

Boris, *et al.* Measuring D(d,p)T fusion reactant energy spectra with Doppler shifted fusion products J. Appl. Phys. **107, 123305 (2010)**

The TOF system can generate the VDF because it observes both fusion products

- Assuming all deuteron trajectories are radial
  - We can define a range of possible angles θ between v_{cm} and v_{fusion}.

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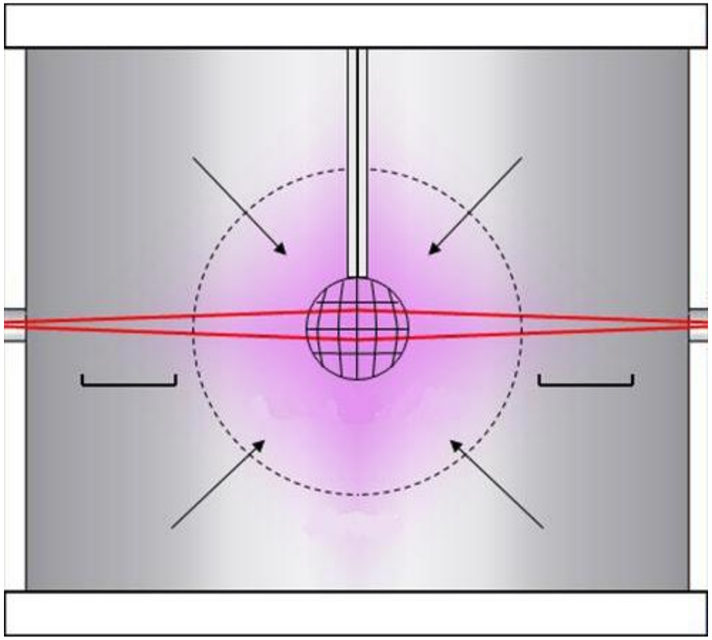

- Within the error of the measurements we can then solve for the approximate center of mass velocity of the fusion reaction at its given location → VDF.

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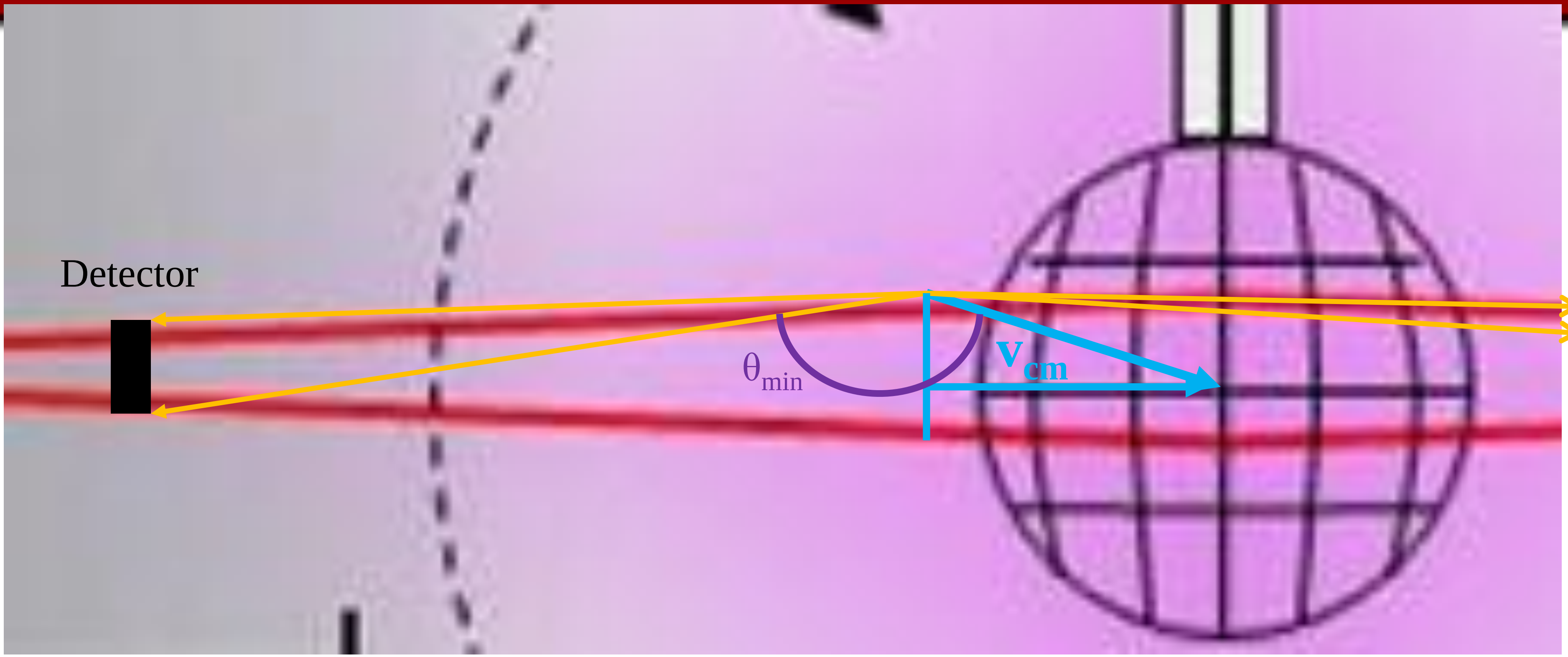
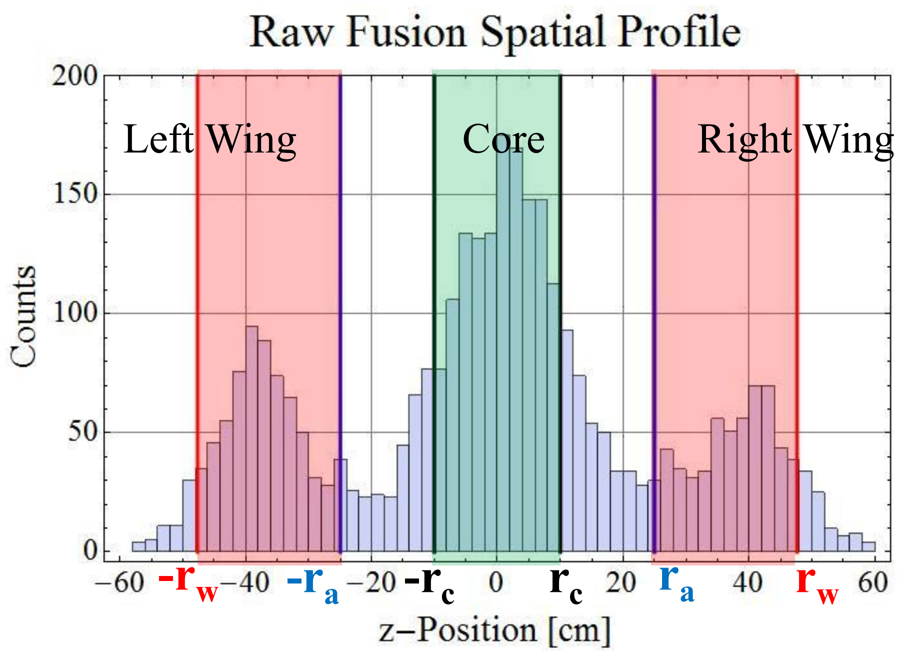


The raw VDF has nearly uniform structure across the device, even in the "wings"

Cathode voltage: -60 kV, Cathode current: 30 mA, 2 mTorr (0.267 Pa) D_2



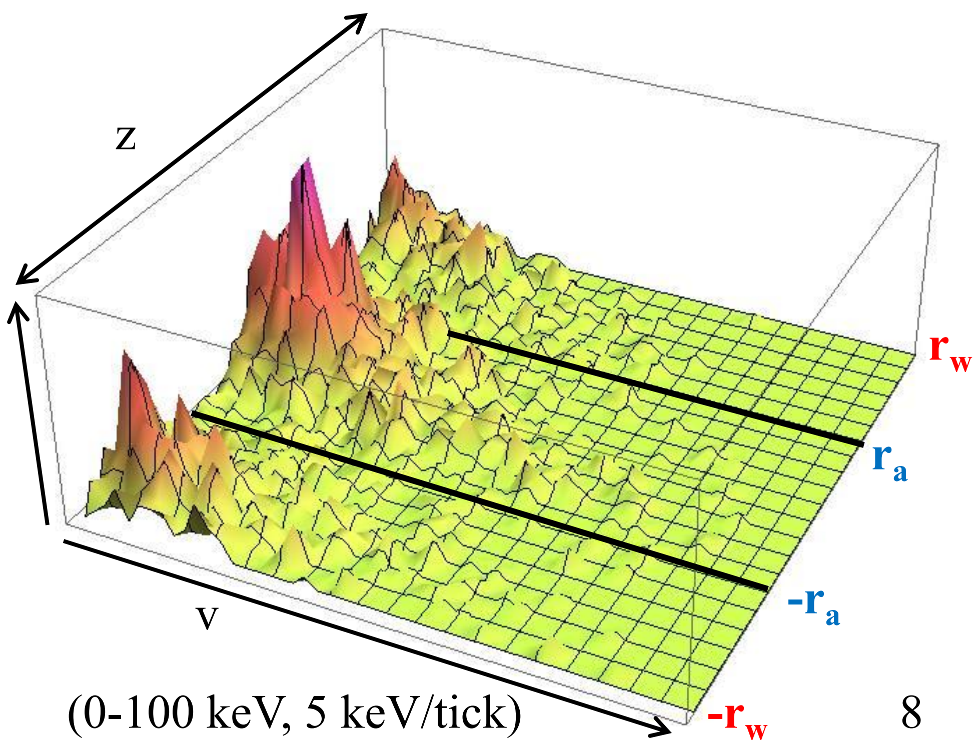
Cathode (r_c = 10cm)

Anode (r_a = 25cm)

Chamber wall (r_w = 47.5 cm)

3500 counts taken over 45 hours of run time by David Donovan

Some fusion events are observed inside the collimator channels of the TOF system



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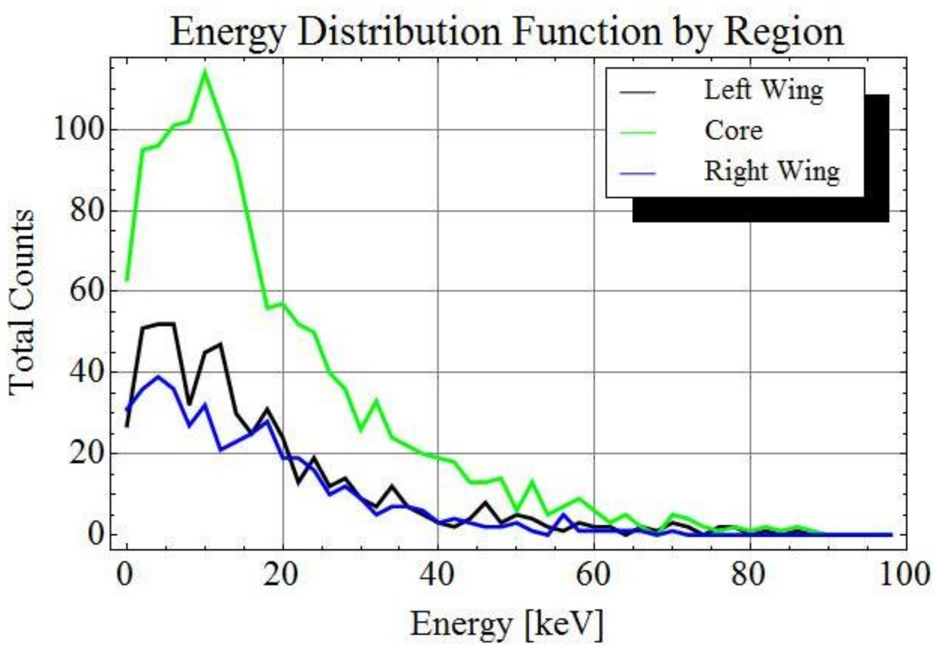
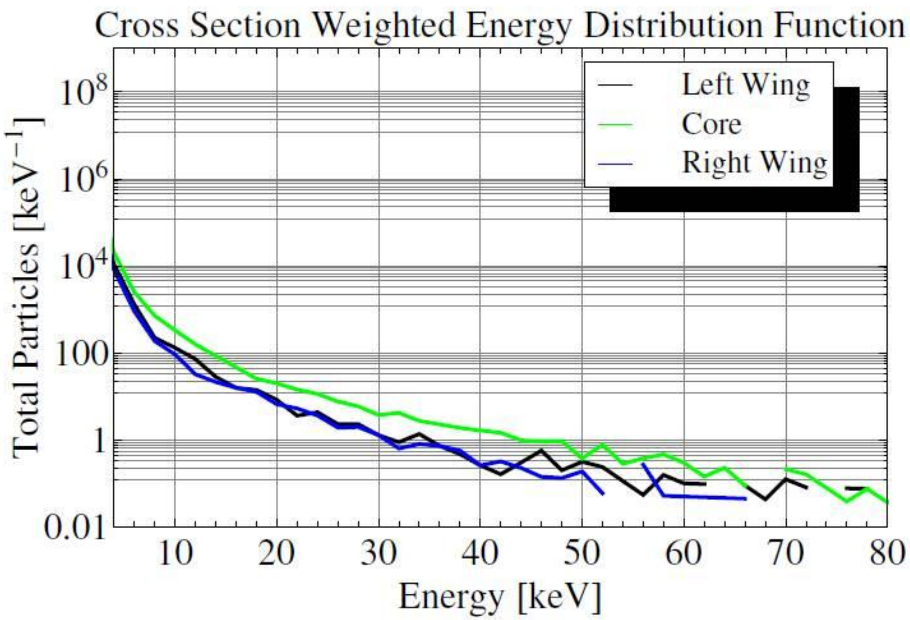
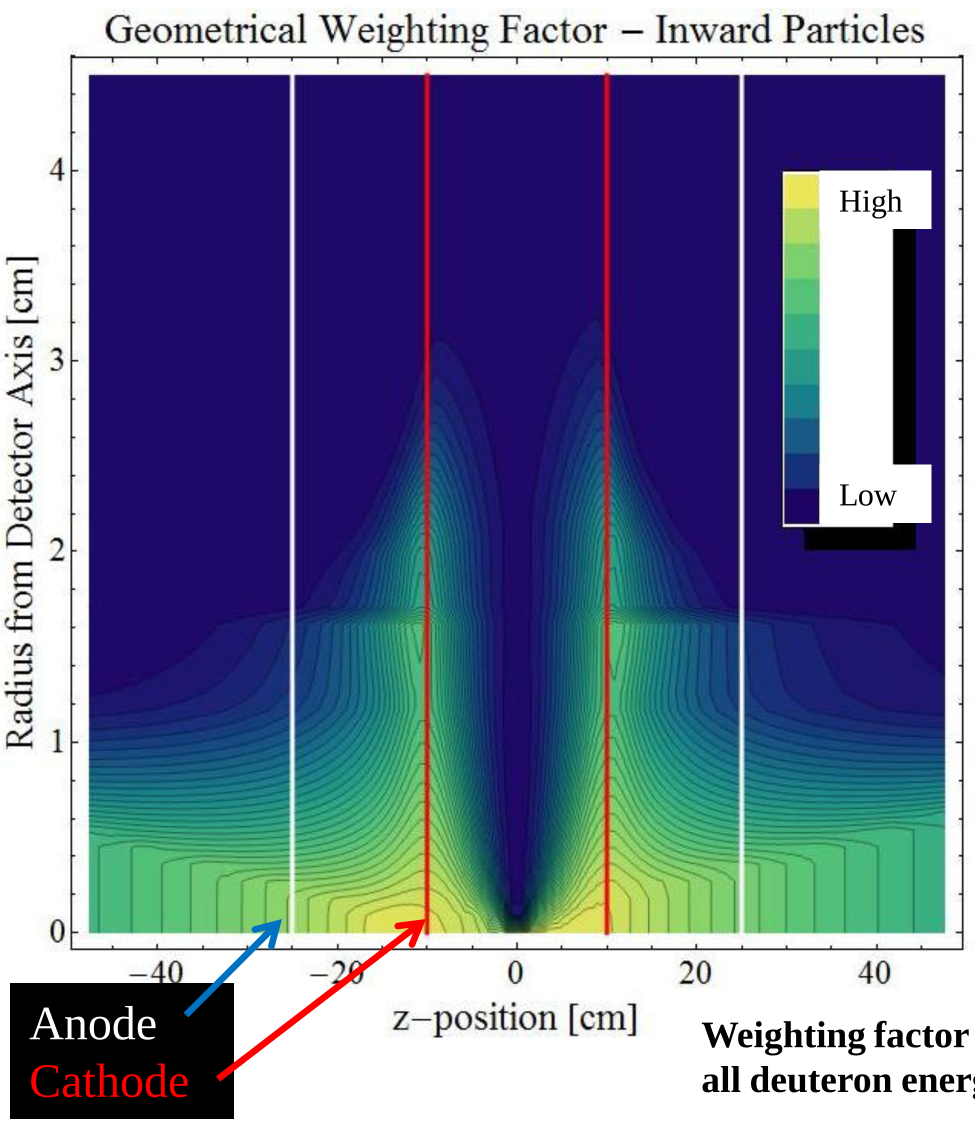




Hypothesis: The VDF in the wings is not peaked at a higher energy than the core suggesting that the wings are not due to higher energy negative ions.

We still need to account for the acceptance cone geometry's effect on recording counts



- Fusion products emitted from certain regions cannot be captured by both detectors
  - Example: fusion events at the center of the device with center of mass velocities perpendicular to the detector axis cannot be observed by the TOF

Weighting factor shown is summed over all deuteron energies from 0-100 keV

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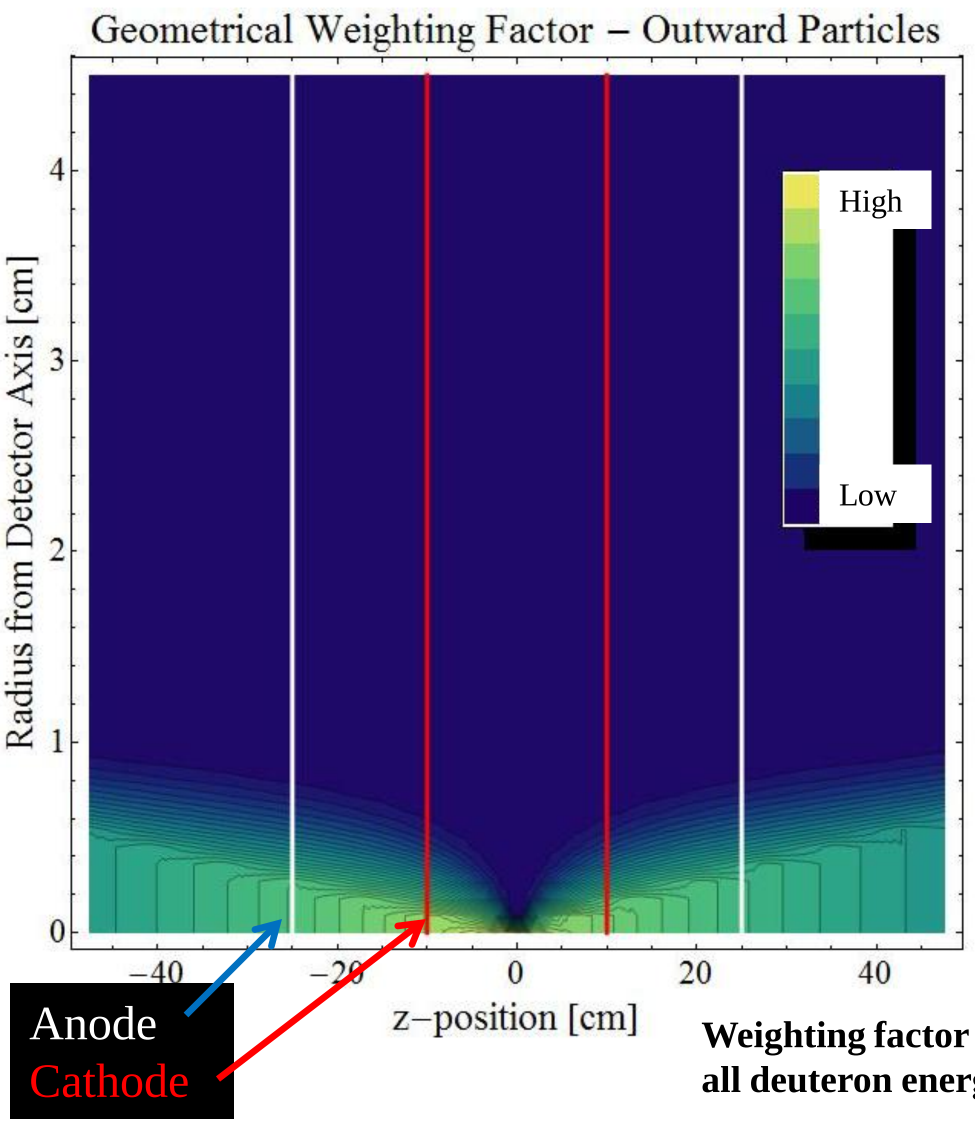

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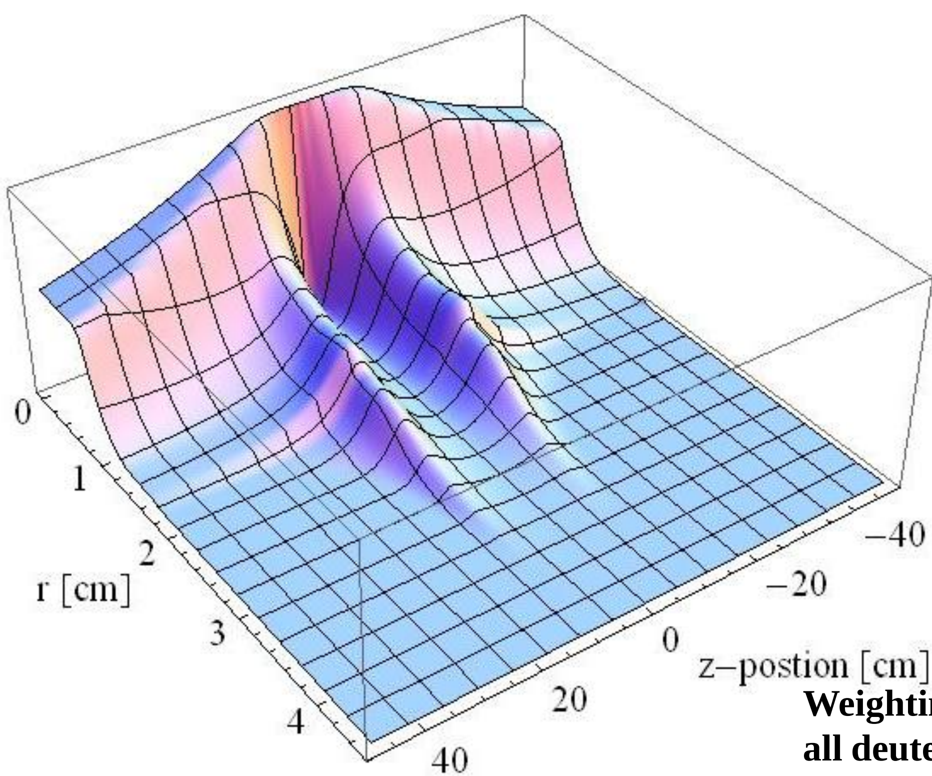

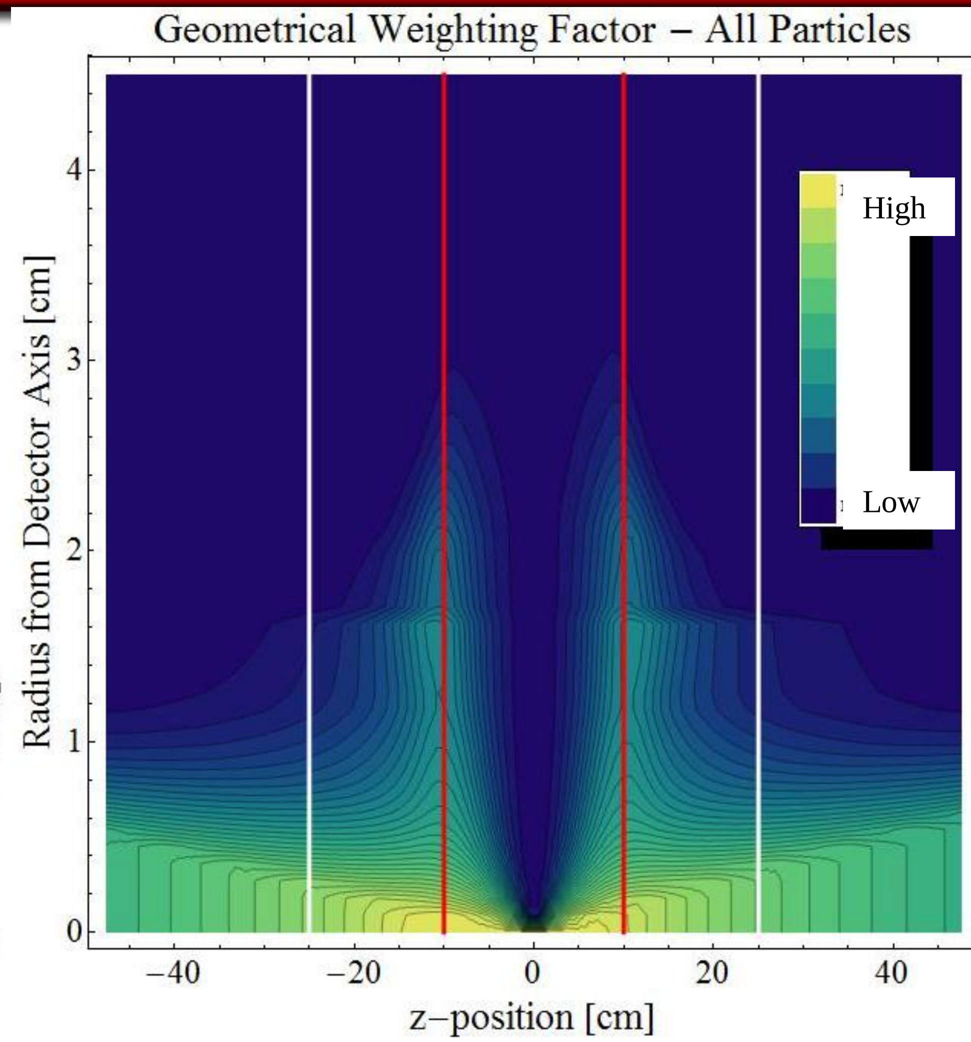

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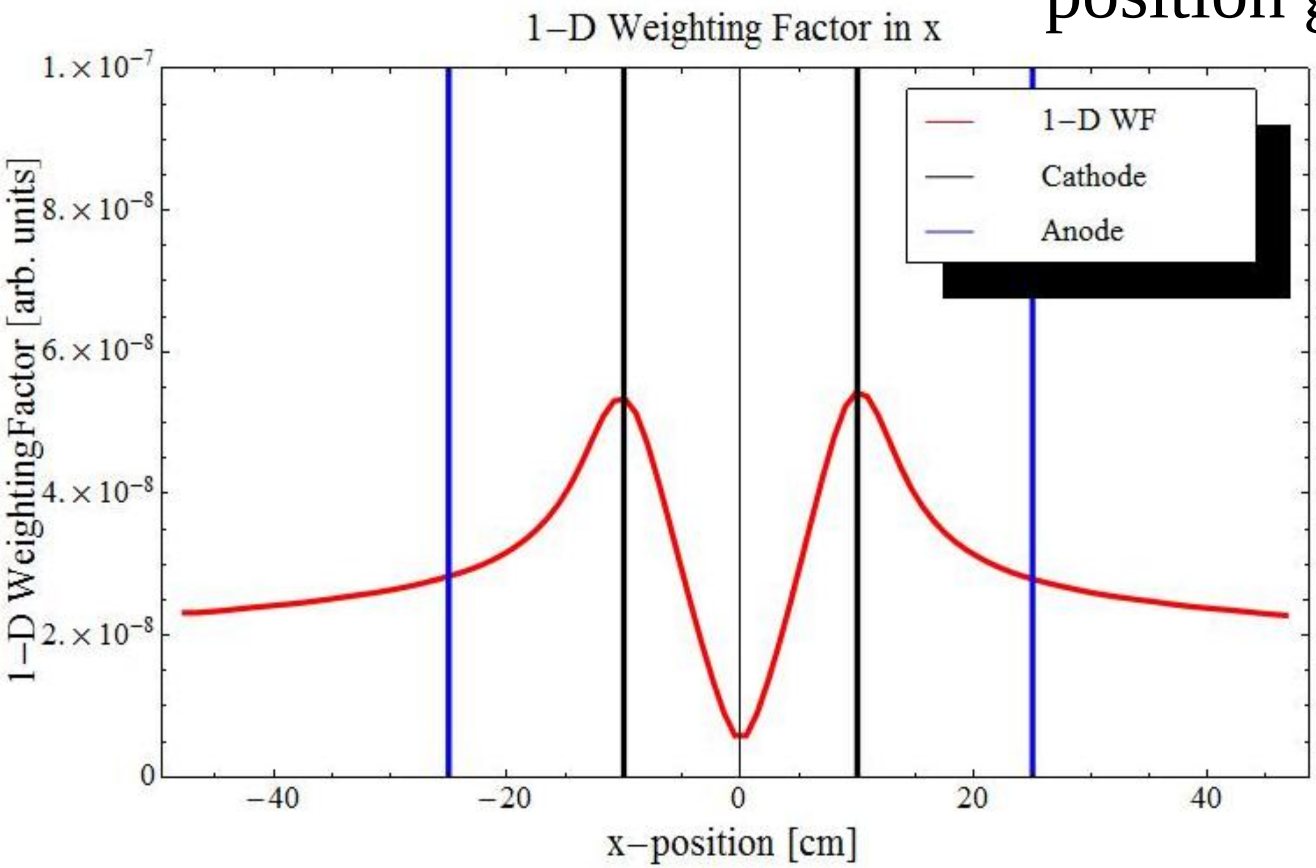
Applying the Weighting Factor (WF) to the VDF gives the underlying 1-D fusion profile

- Summing the weighting factor over r at each z-position gives the 1-D WF



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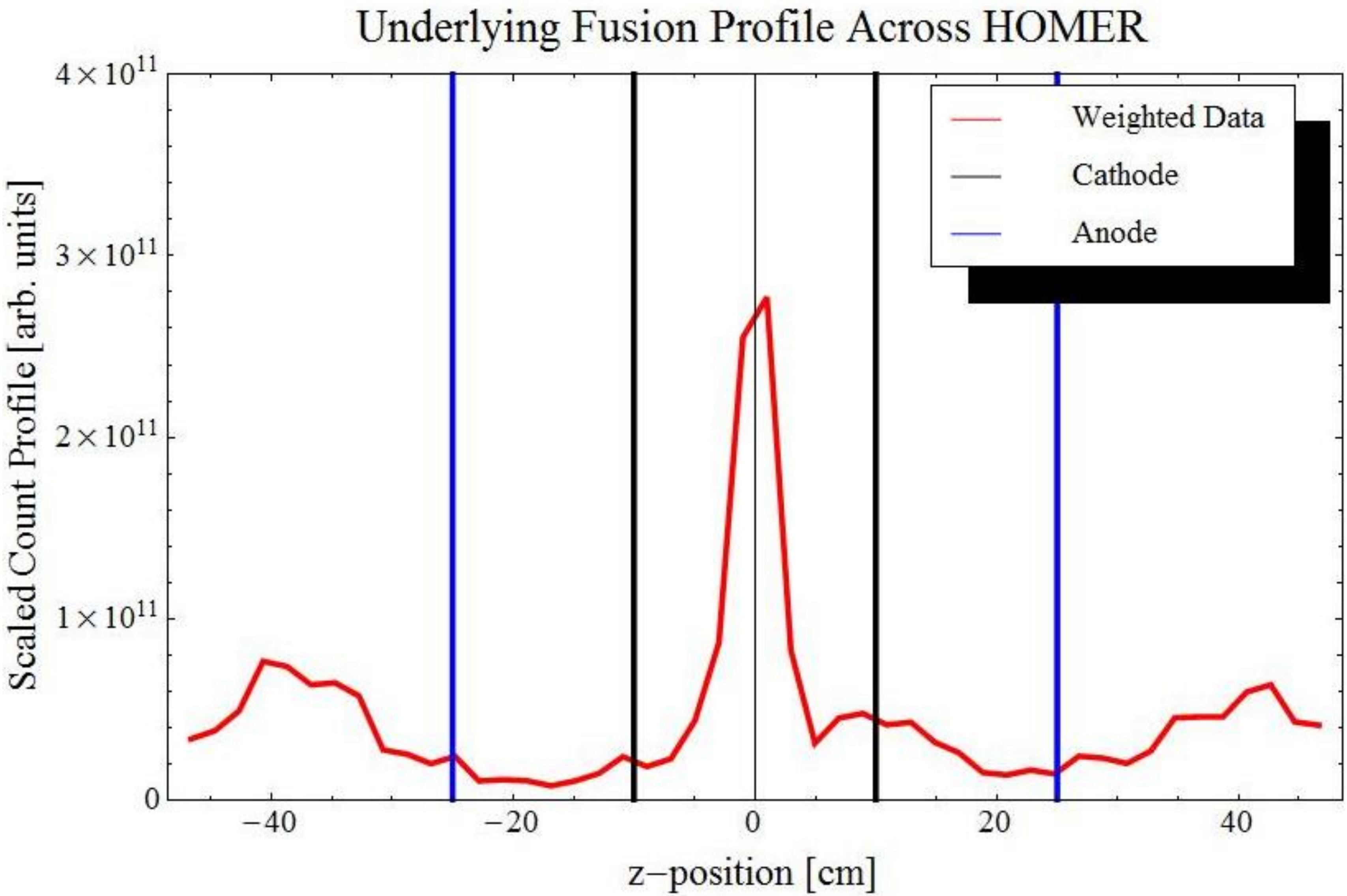
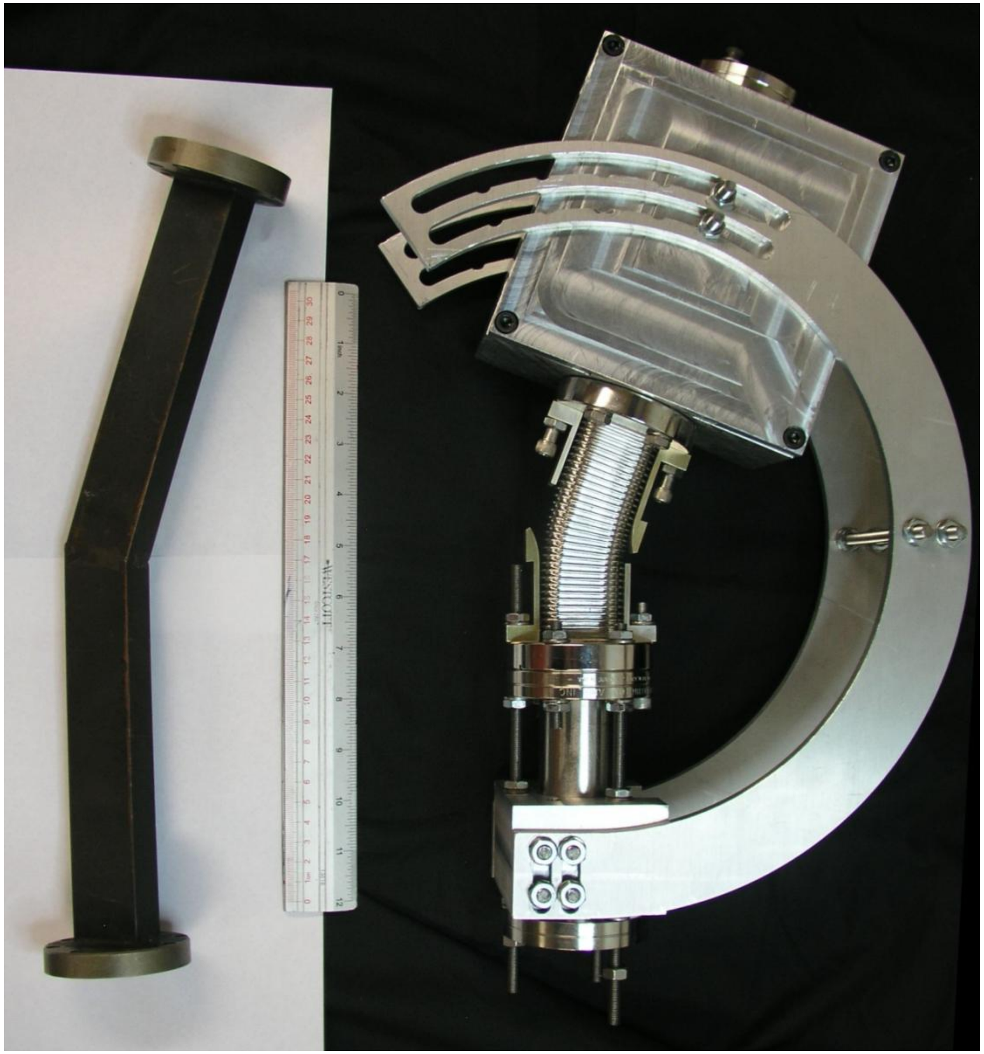


Adjustable bending arms reduce x-ray noise and allow for d-He^3 and negative ion studies

- Large x-ray trap allows incoming x-rays to spread out some upon exiting the collimator channel
- Adjusting to larger angles further reduces x-ray scatter into the detectors
- Additional angles provide for study of higher energy d-He^3 protons and negative ions



Conclusions

- The FIDO diagnostic cannot provide the velocity distribution function (VDF) as required
- The TOF diagnostic can determine the spatial fusion profile in HOMER and the VDF
- Applying a geometrical weighting factor to the VDF reveals the underlying fusion profile
- Adjustable TOF arms reduce noise and allow for additional fusion reaction studies

Some future upgrades for HOMER

- Cooled Si-detectors using thermocouples.
  - Reduce leakage current and maintain energy resolution.
- In situ energy calibration of the Si-detectors
  - Am-241 source to ensure that the detector is calibrated.
- Mobile emissive probe to measure the voltage profile between the anode and the walls.
  - Potential leakage may support fusion outside the core.
- Study of various cathode/anode diameter combinations and effects on the wings.

Q&A

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