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

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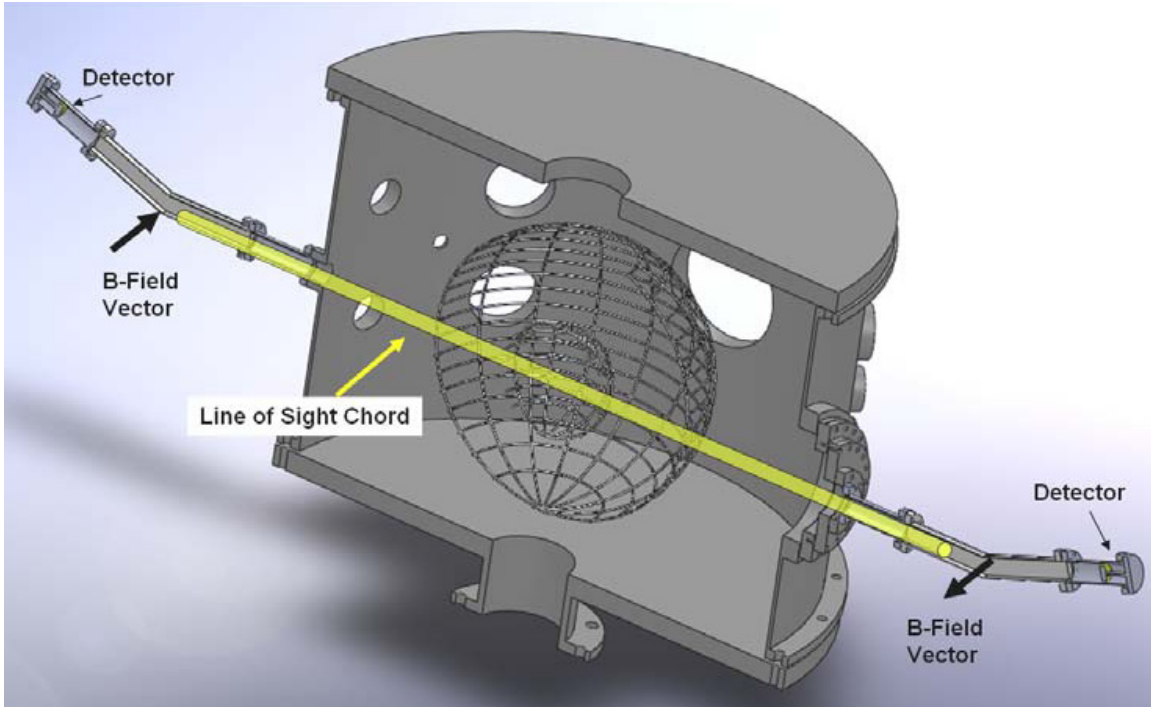
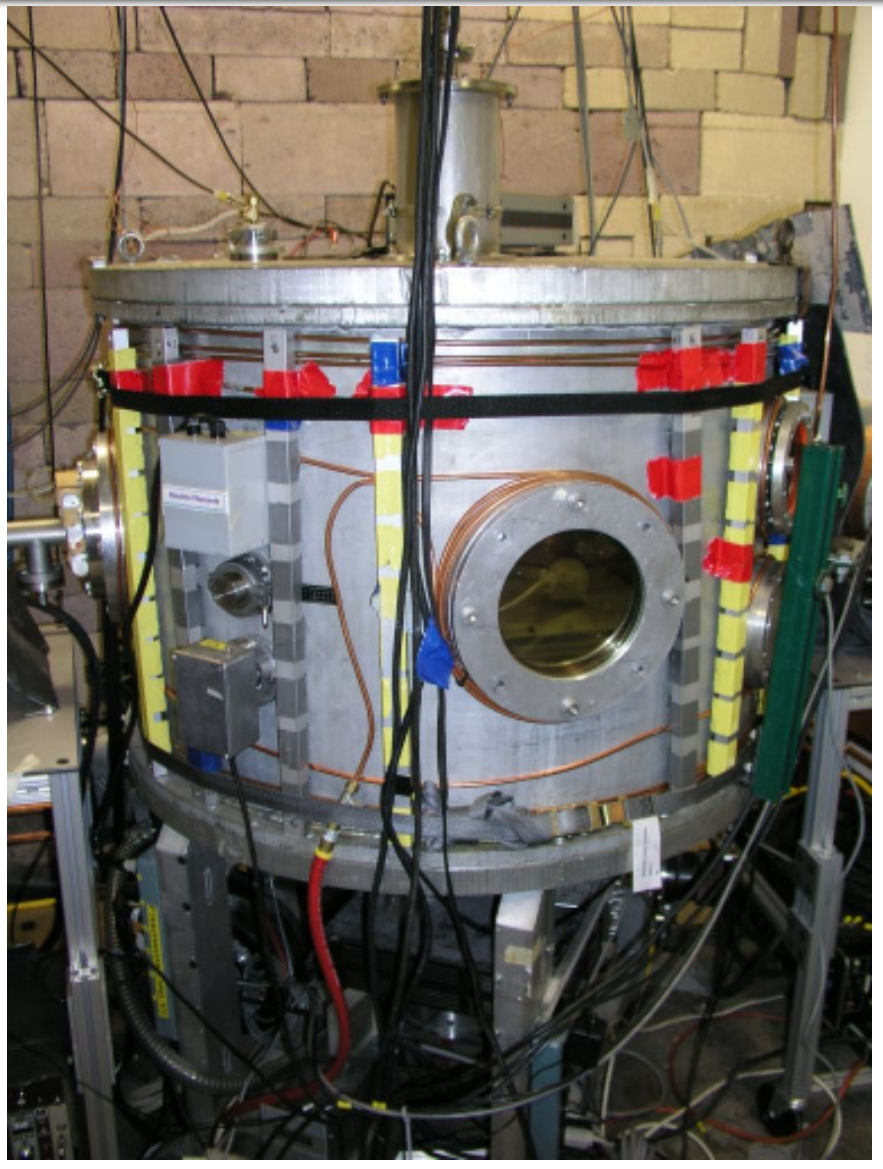
Summary

- Time of Flight (TOF) Diagnostic
  - Design
  - Results
  - Analysis
  - Conclusions
  - Future Plans



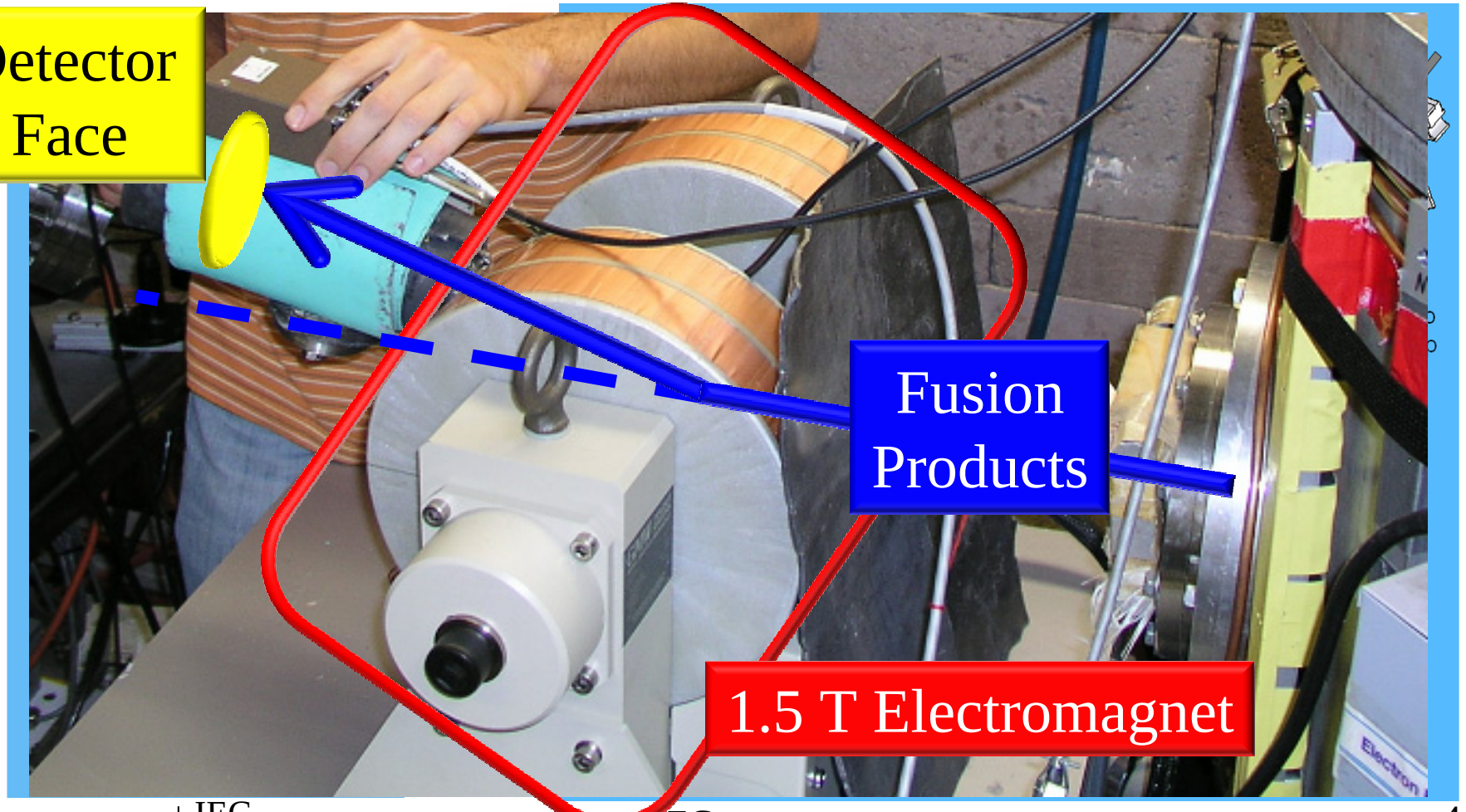
All experiments discussed here conducted on UW IEC chamber known as HOMER

- 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

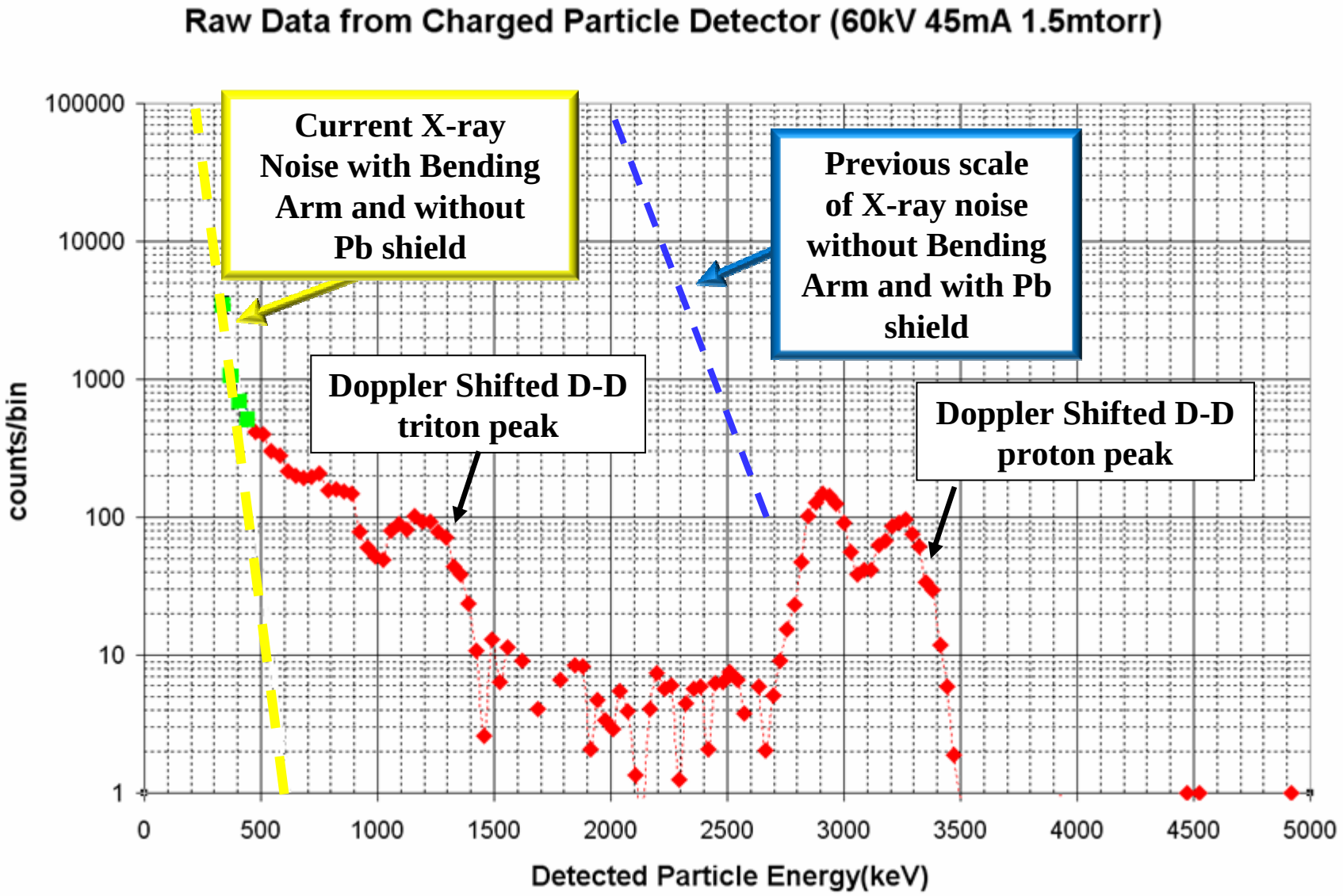


Collimator channel has a 20 degree bend at the elbow taking detector out of line of sight of chamber

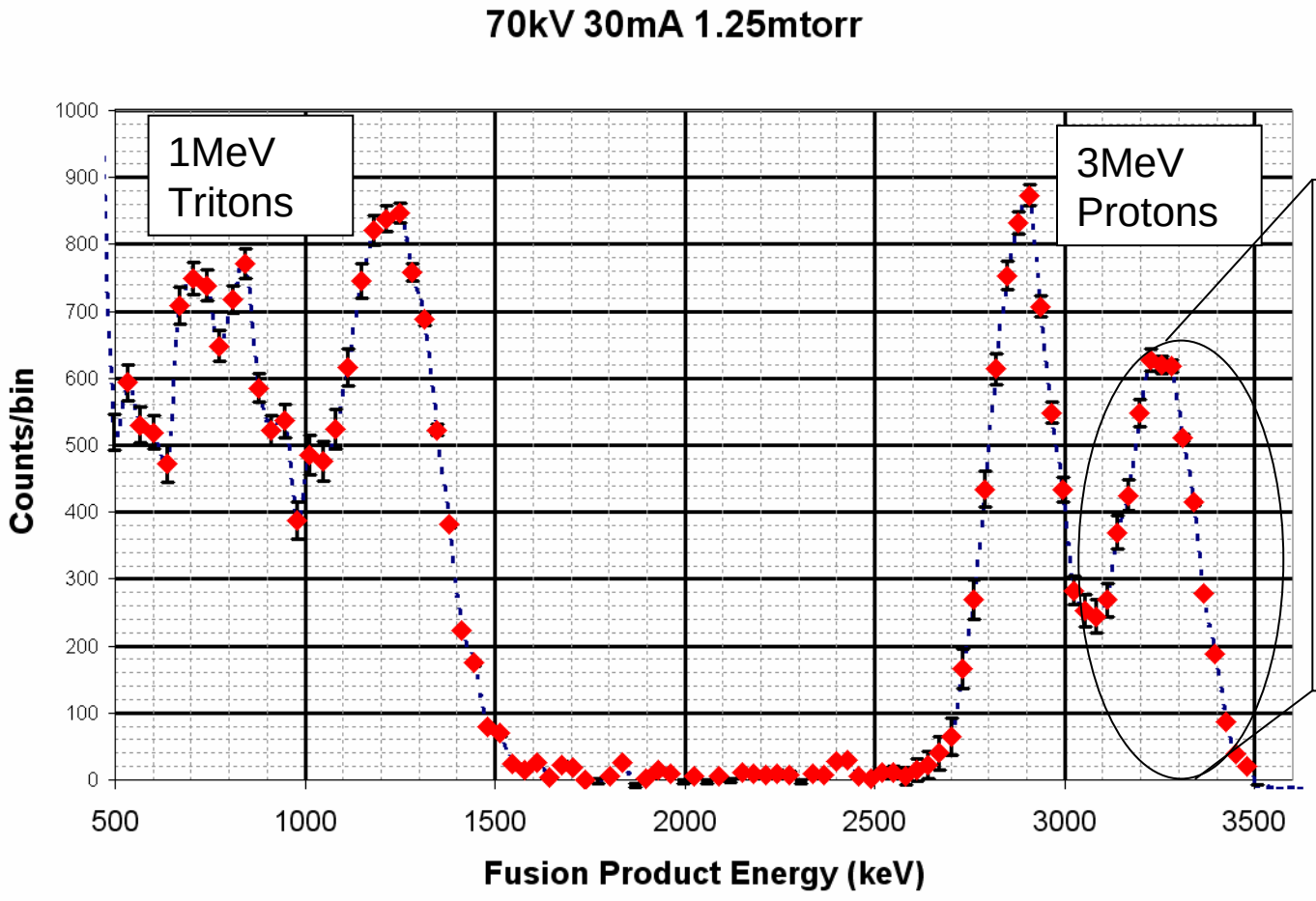
Fusion **I**on **Do**ppler (FIDO) Diagnostic



New setup allows both protons and tritons to be detected



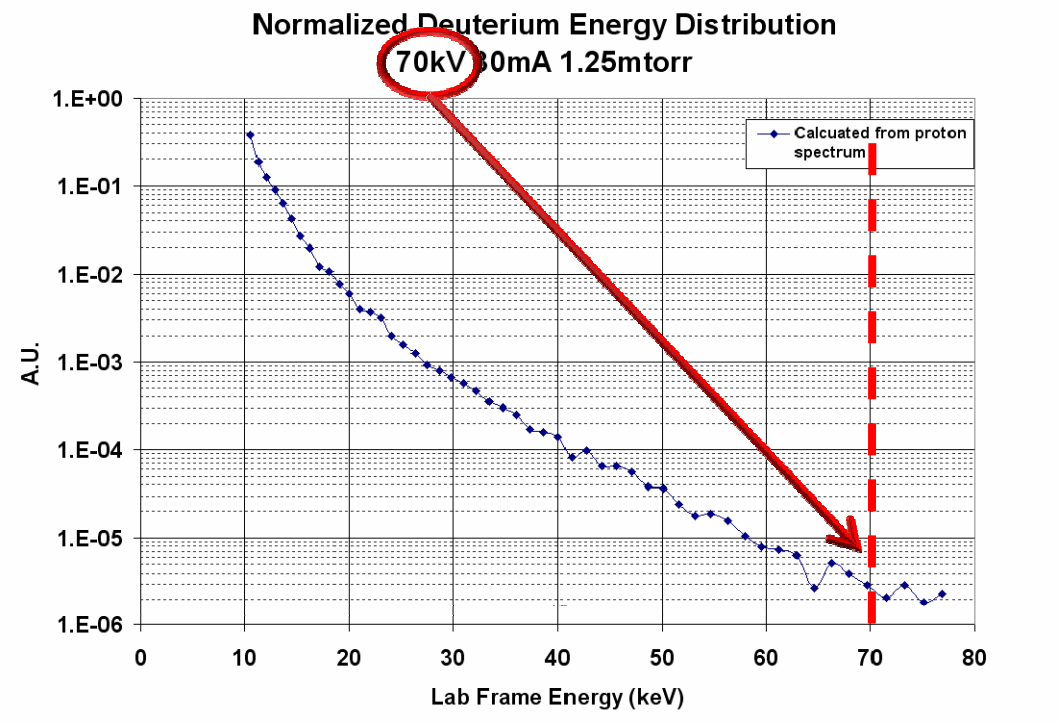
Subtraction of X-ray noise reveals proton & triton peaks of comparable size



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

Calculating the Deuterium Energy Distribution

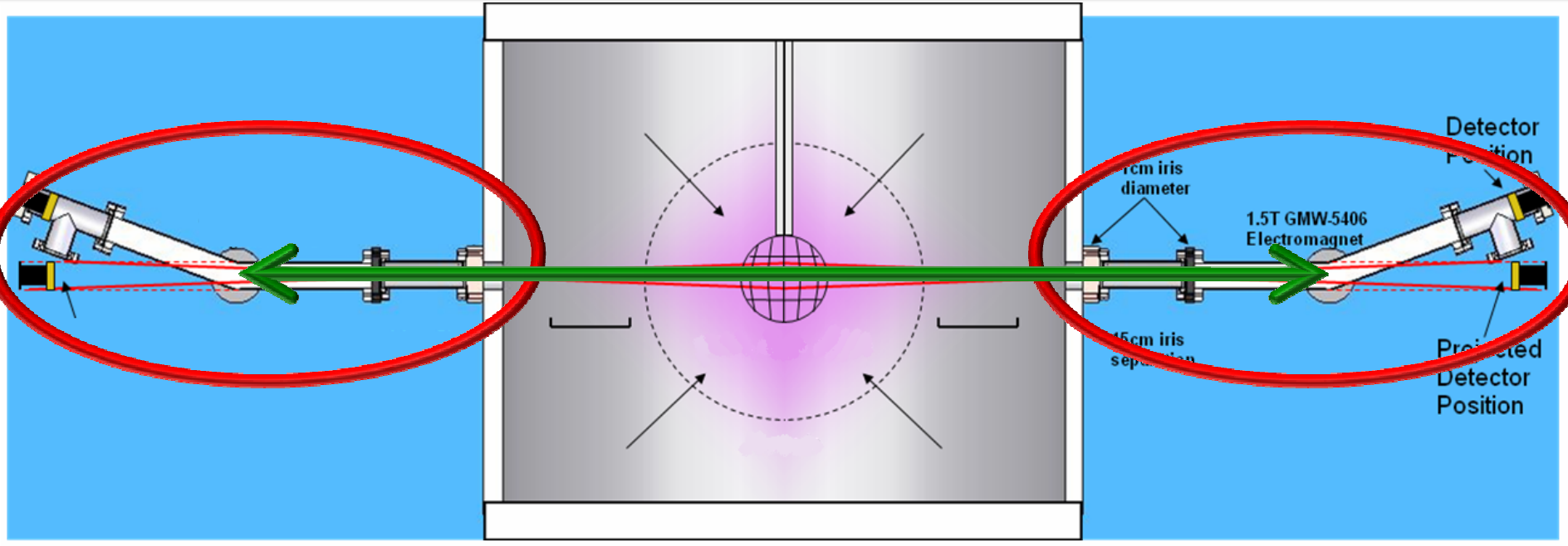
- Scaling the number of counts in each energy bin from the previous data set by $\sigma_{fusion}(E_{bin})$ and normalizing the resulting spectrum yields:



Line averaged spectrum shows:

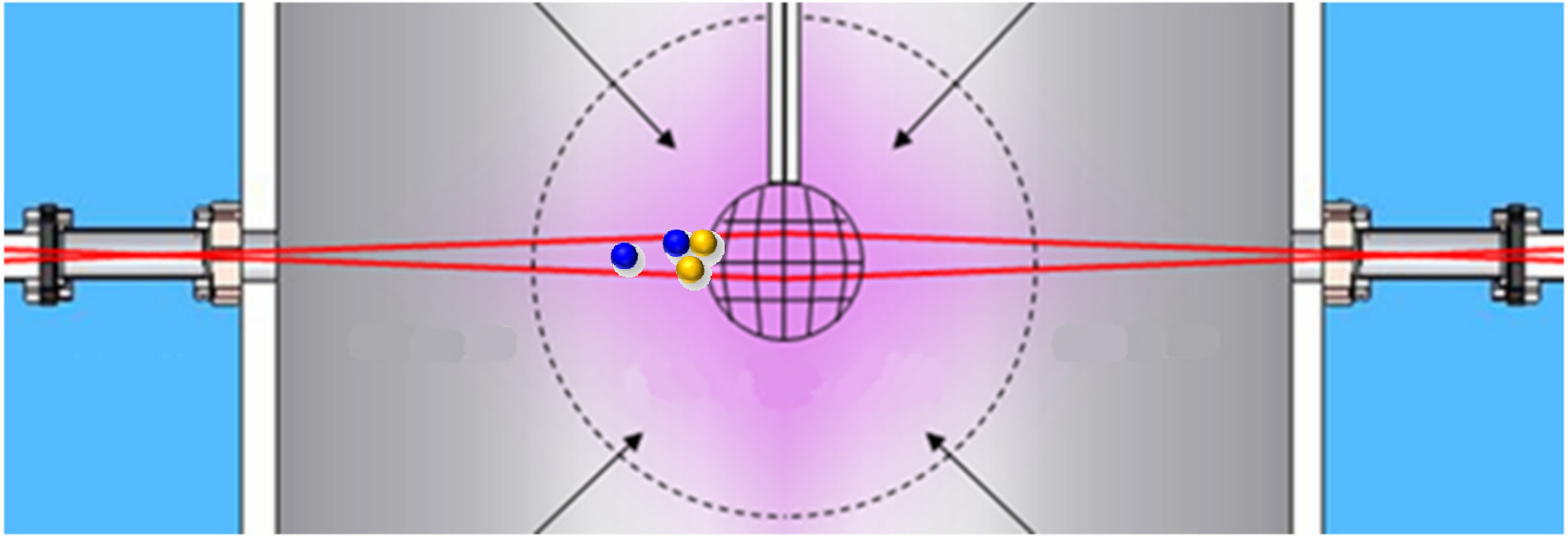
- Few deuterons @ V_{cath}
- Spectrum consistent w/ spectra predicted by G.A. Emmert & J.F. Santarius

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



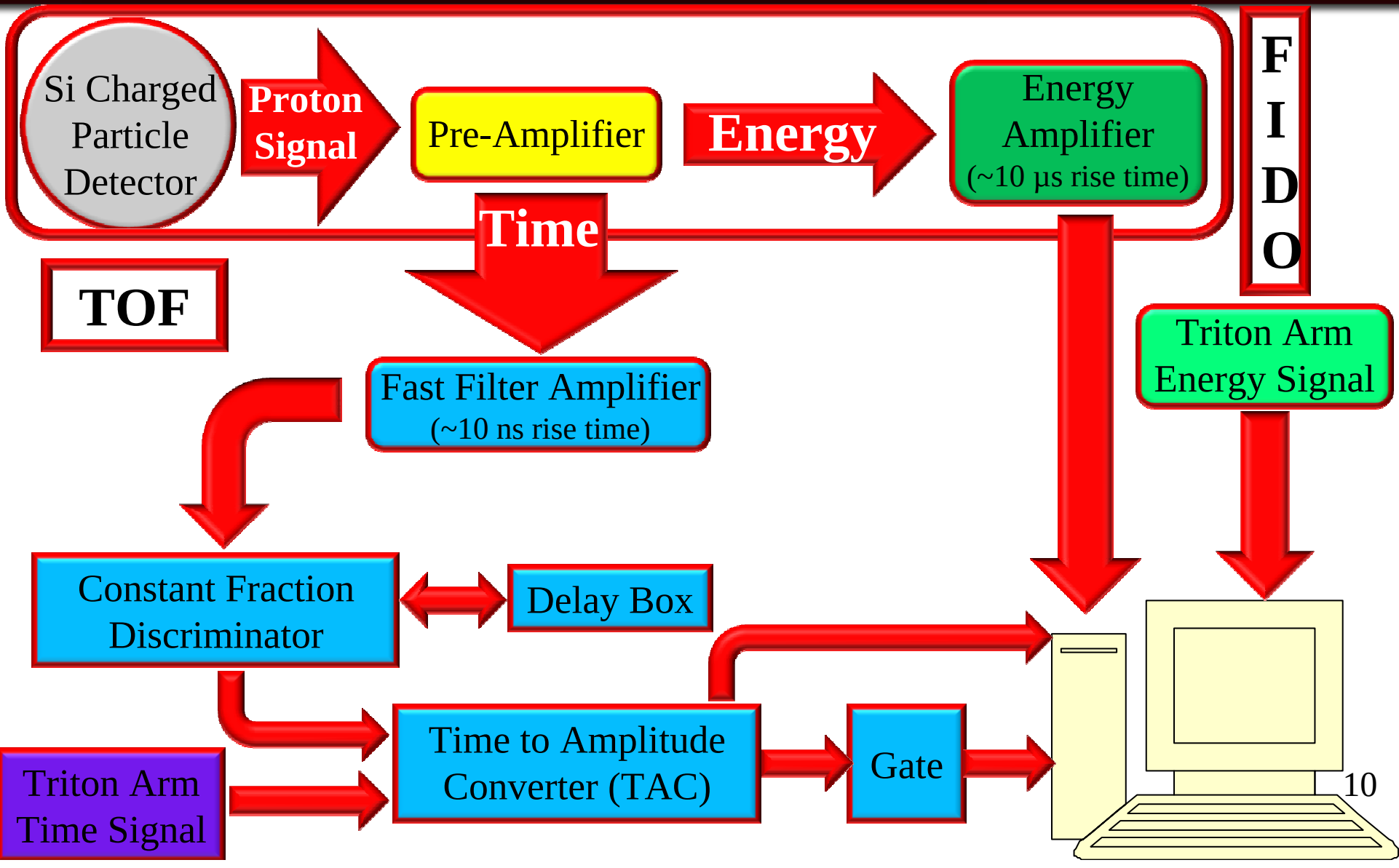
- 2 identical FIDO setups on opposite sides of HOMER
- Direct line of sight created through both arms and center of chamber

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

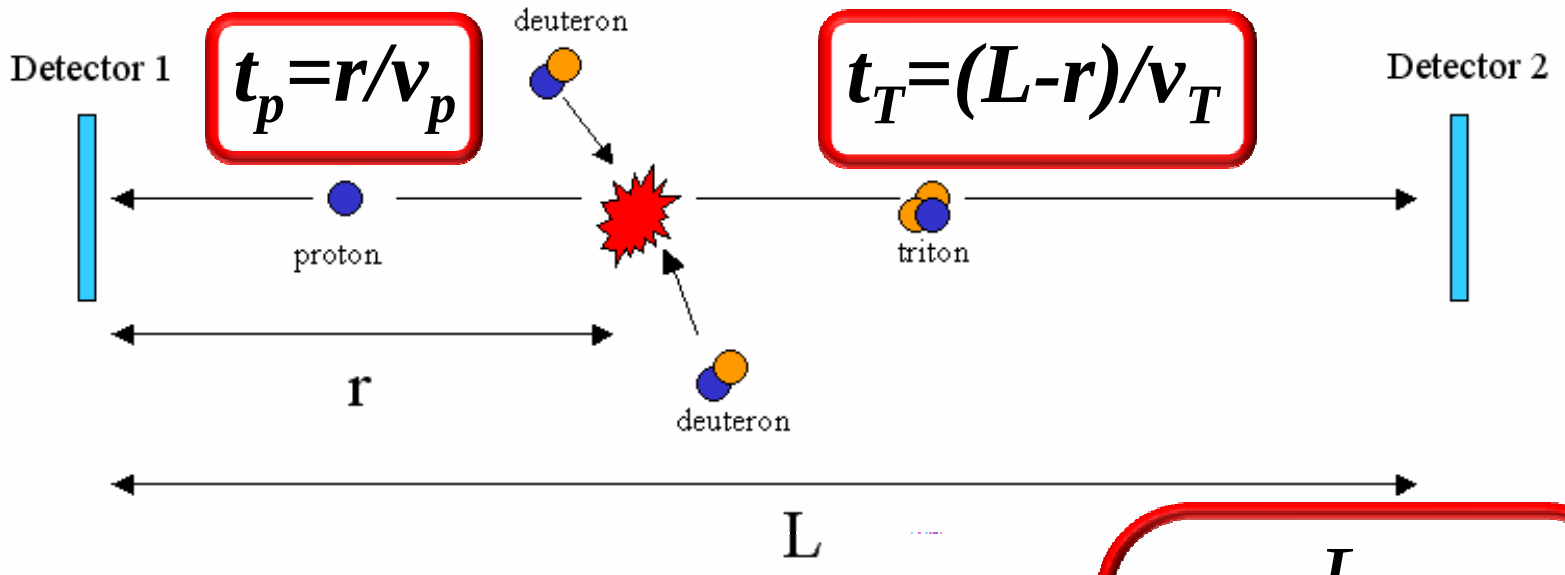


- D-D fusion creates 3.02 MeV proton and 1.01 MeV triton
- Conservation of momentum requires both particles to move in exact opposite direction in center-of-mass frame
- Proton moves approximately 3 times faster than triton, so for this setup, the proton always arrives at the detector first

Timing Electronics



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

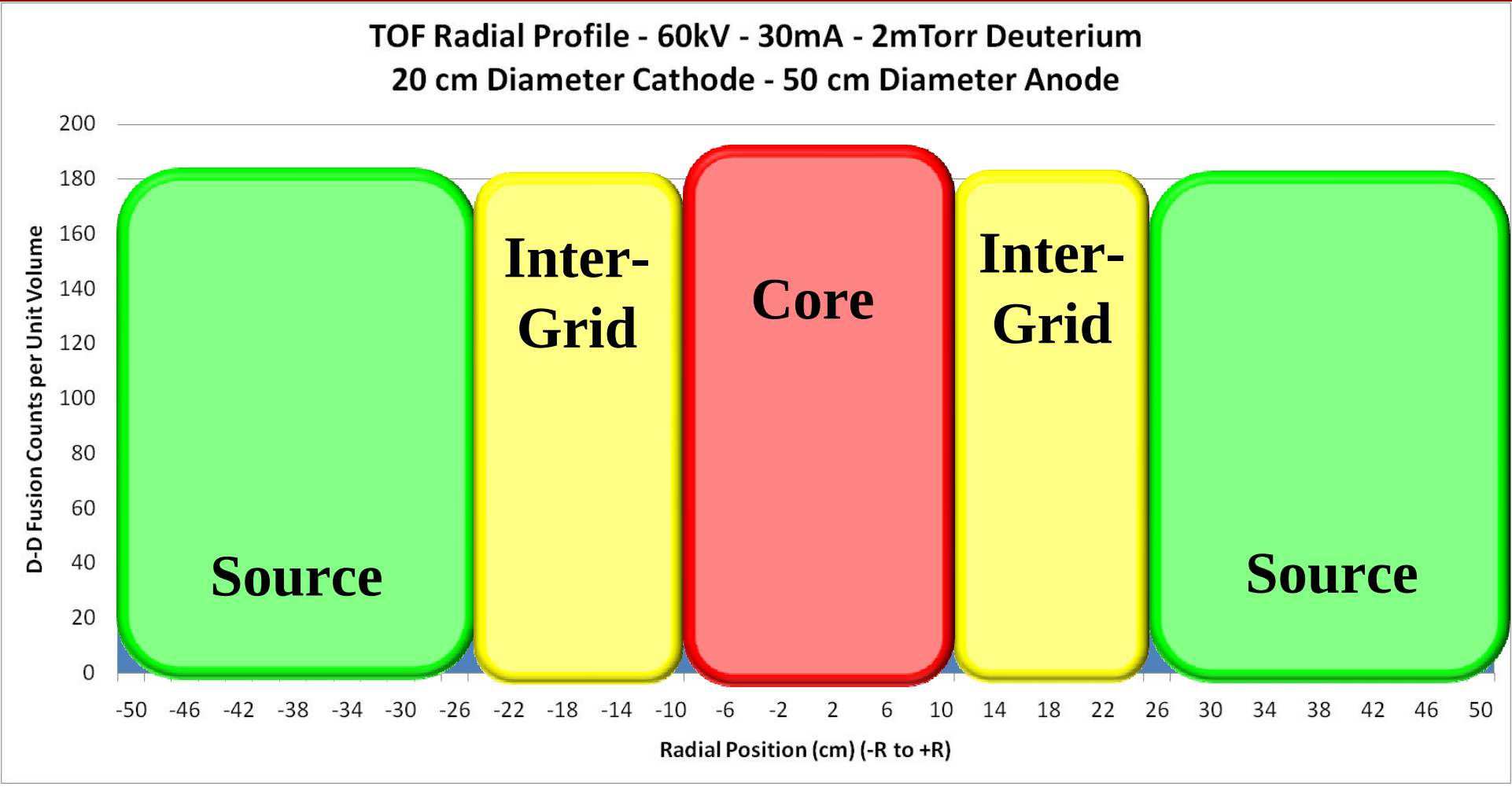


Time to Amplitude Converter (TAC)

$$\Delta t = t_T - t_p$$

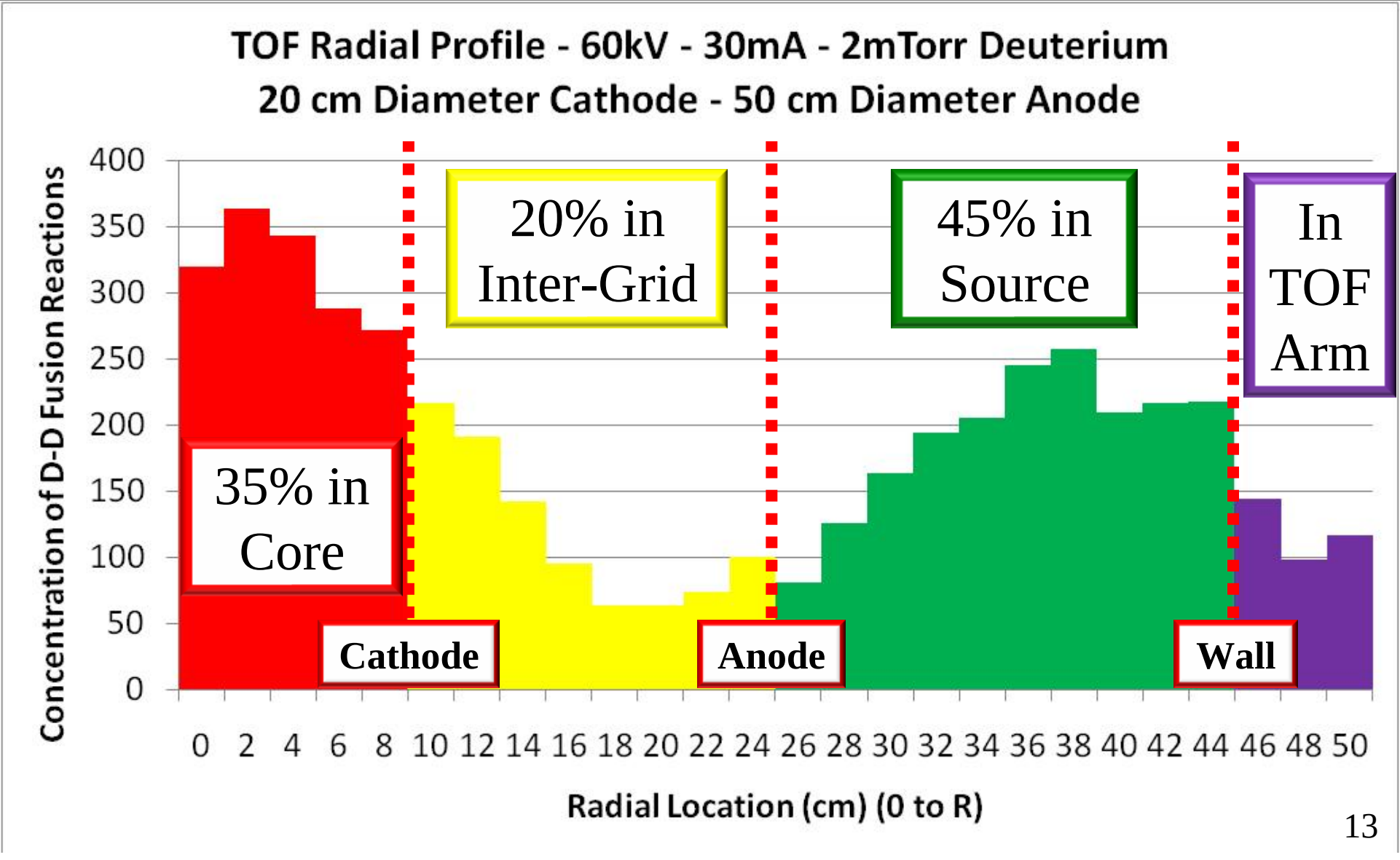
$$r = \frac{\frac{L}{v_T} - \Delta t}{\frac{1}{v_P} + \frac{1}{v_T}}$$

Spatial profile of fusion reactions per unit volume along radial line through IEC

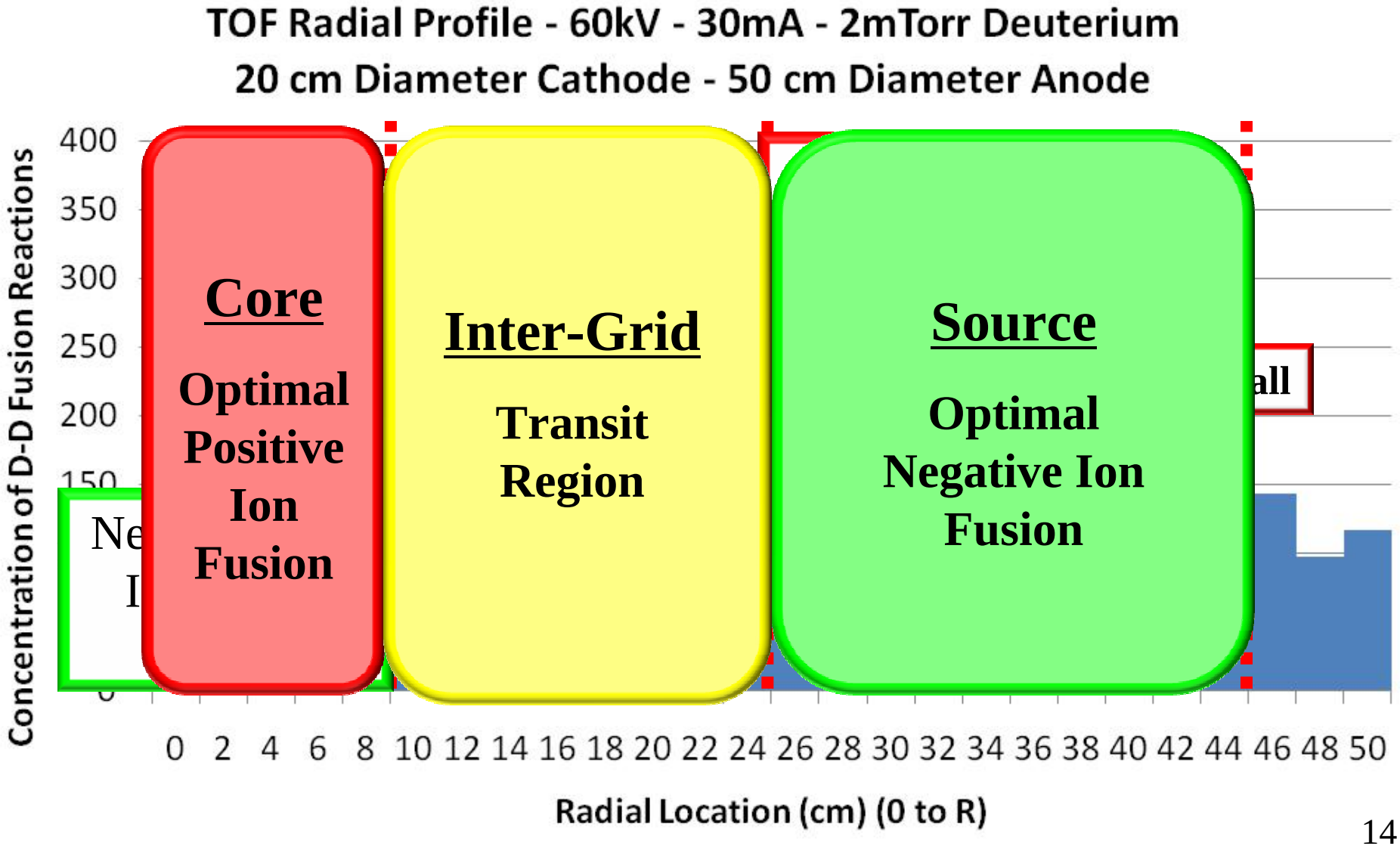


- Plot extends from one side of the chamber (-*R*) to the opposing side (+*R*)

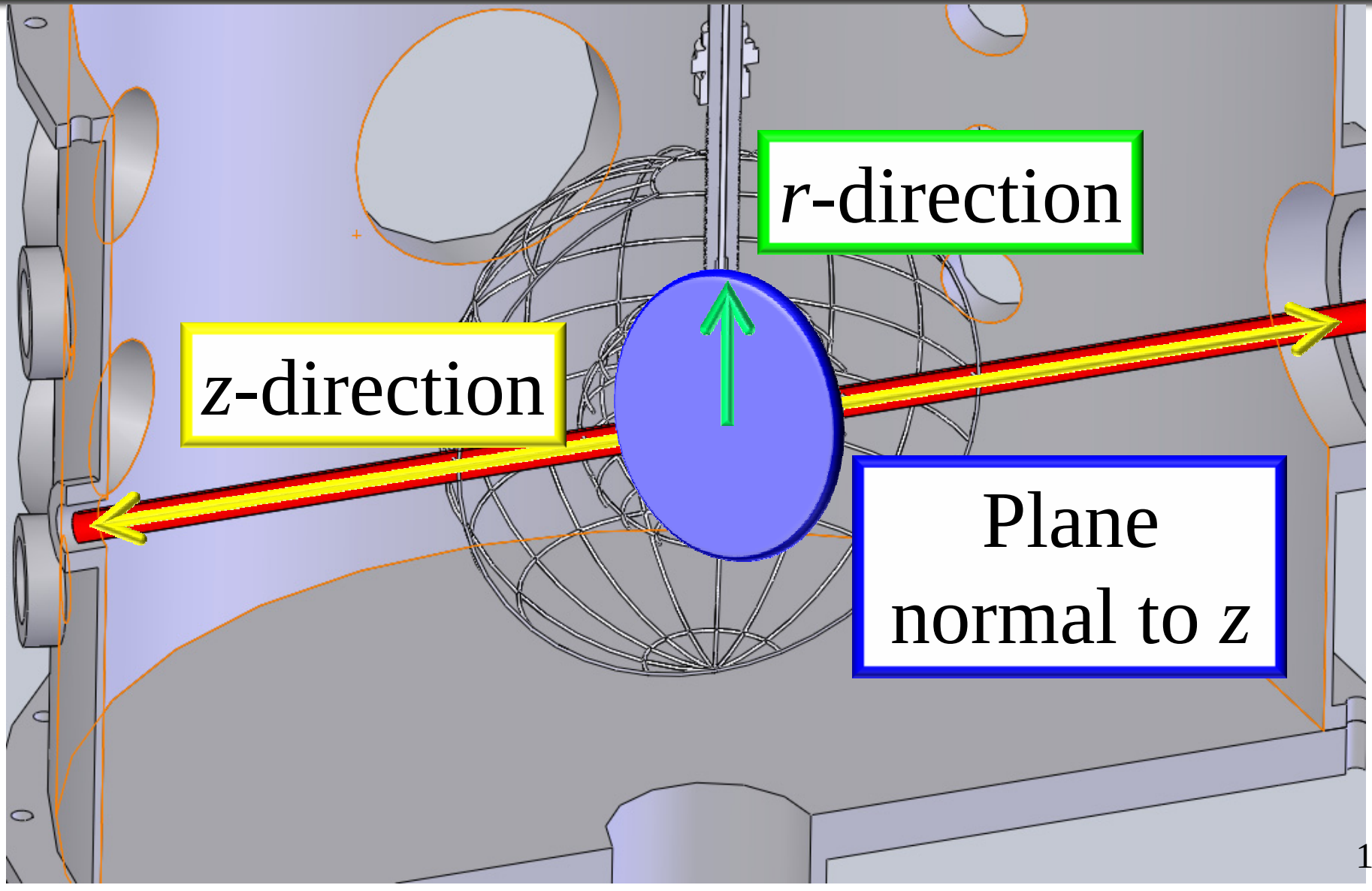
Majority of total fusion occurring along a given radial line is outside of cathode, but highest fusion concentrations (reactions/unit volume) are in the Core



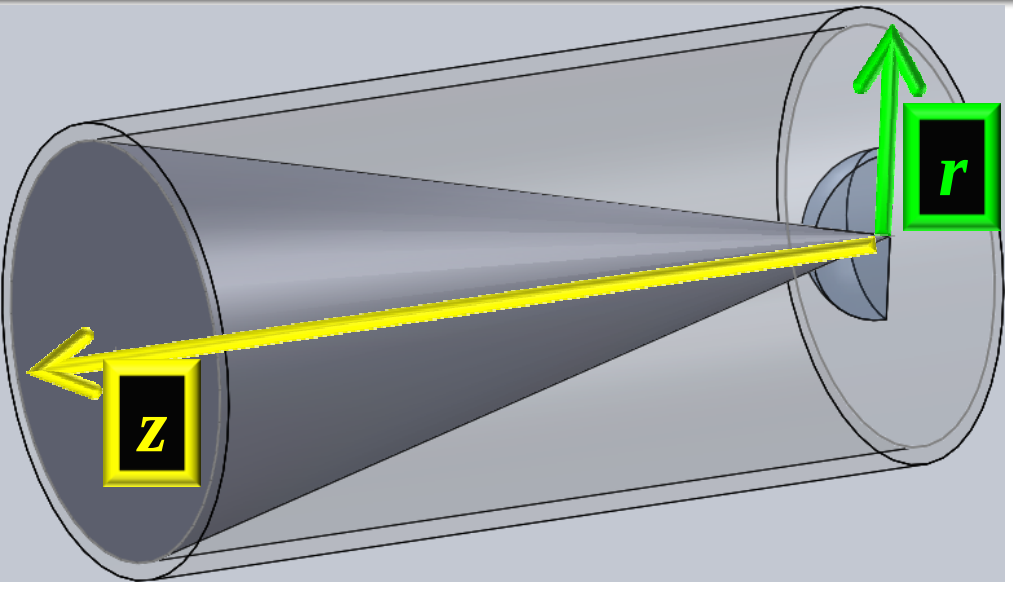
TOF Radial Profile shows a “valley” in the Inter-Grid region where fusion concentrations drops significantly

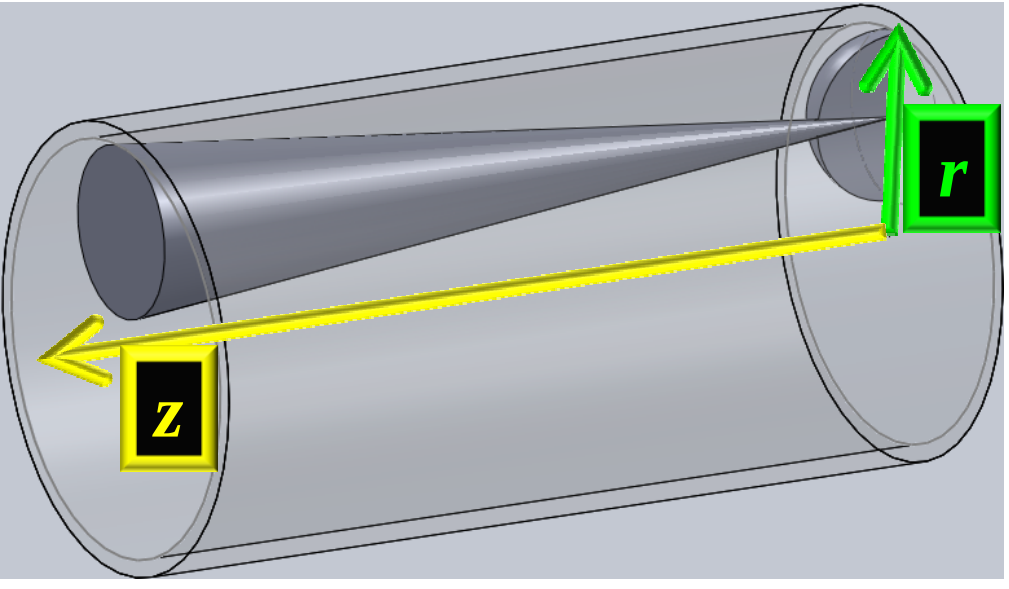


Line of sight between detectors through chamber can be divided into slices for every value of *z*



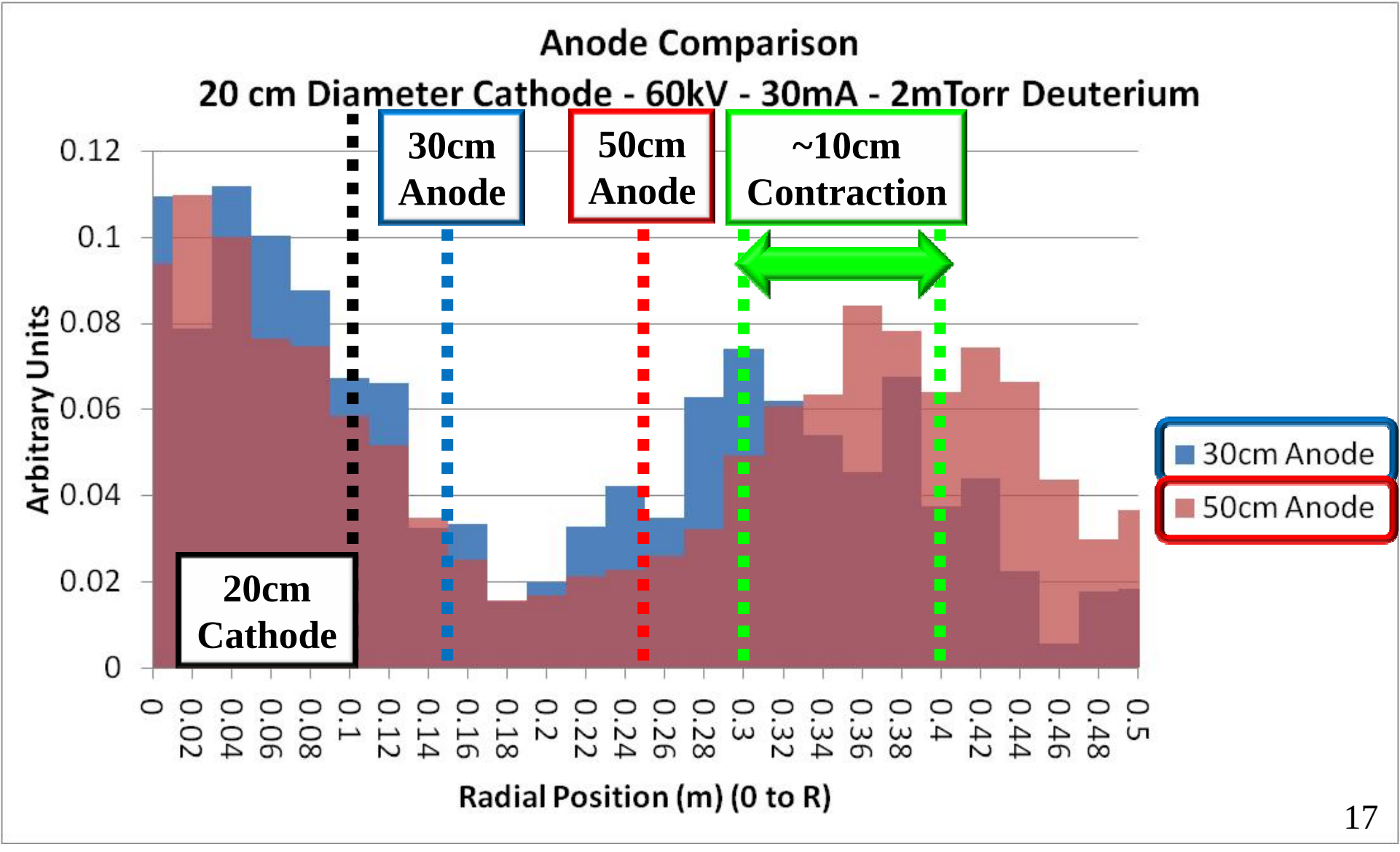
Weighting factor a function of both *z* and *r*



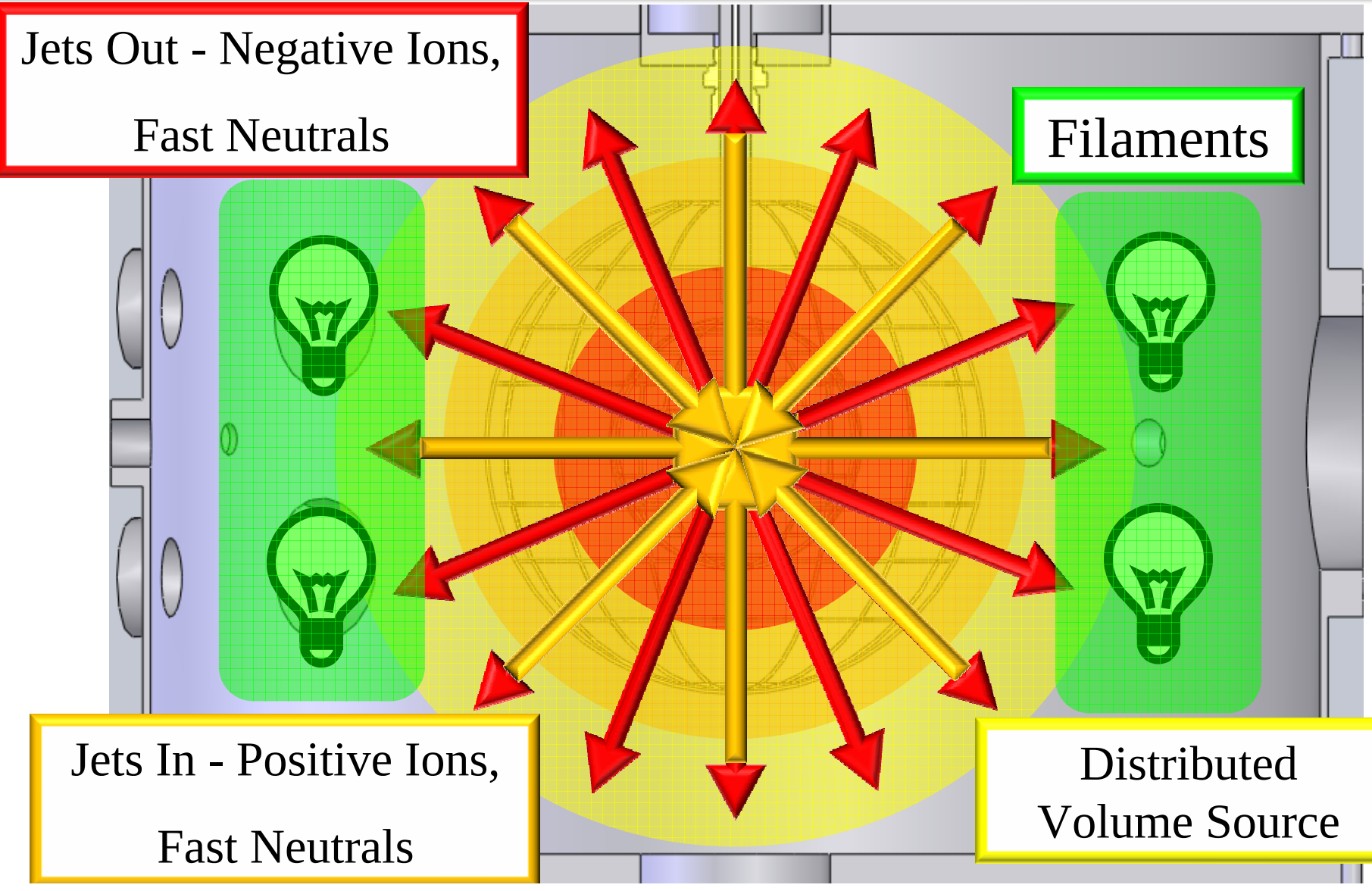


- Fusion products are emitted isotropically in center-of-mass frame
- Preliminary weighting factor ignores influence of initial center-of-mass velocity
- Detectors on each side of *z*-axis
- Probability of capturing a coincident event is dependent upon the fusion product that is least likely to be captured (typically the one travelling farthest)
- As *r* increases, the probability of capture decreases as the solid angle cone shrinks
- Probability is zero when *r* is greater than the radius of the cylinder of view
- The cumulative weighting factor for each value of *z* is found by integrating over all values of *r* within the given *z*-plane
- Weight factor ranges between 1 at the center of the chamber to ~2 at the wall

Reducing anode diameter from 50cm to 30cm caused peak of counts in Source region to contract inward by nearly equal distance as change in radius of anodes

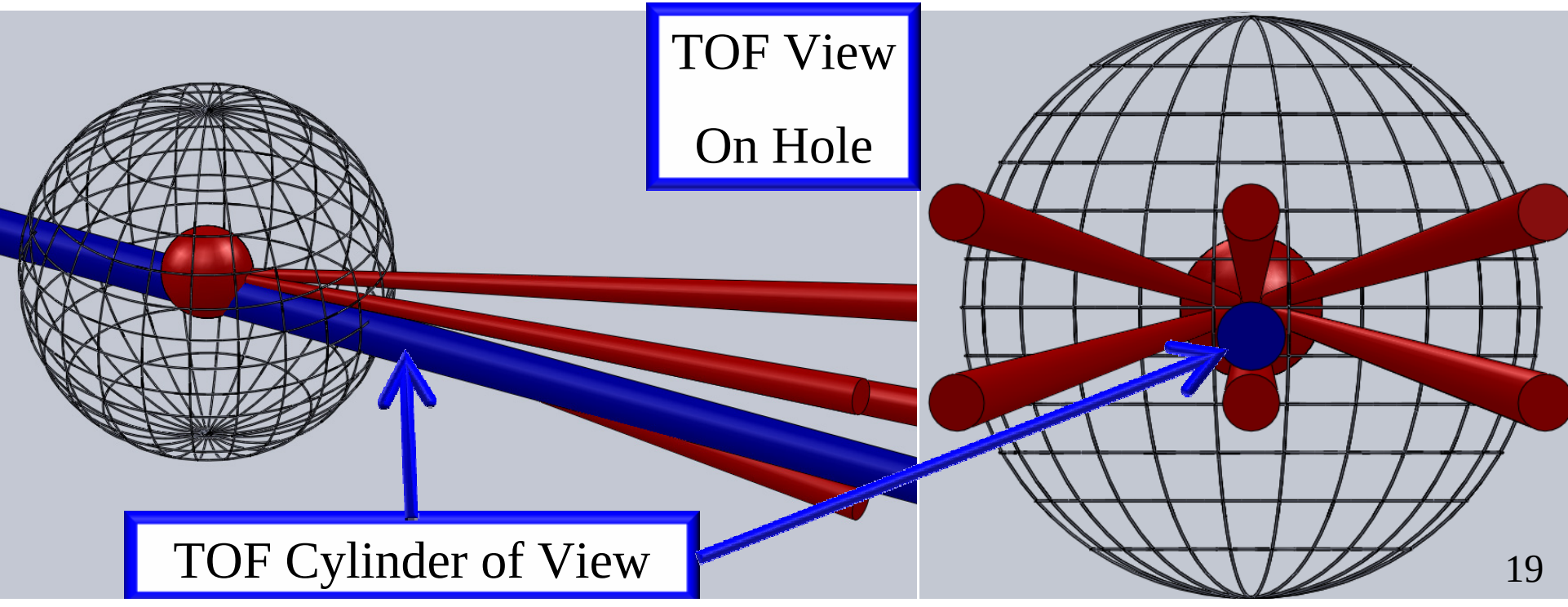


Volume scaling of radial profile not simply dependent on r^2 due to non-uniformities around sphere caused by jets and filaments



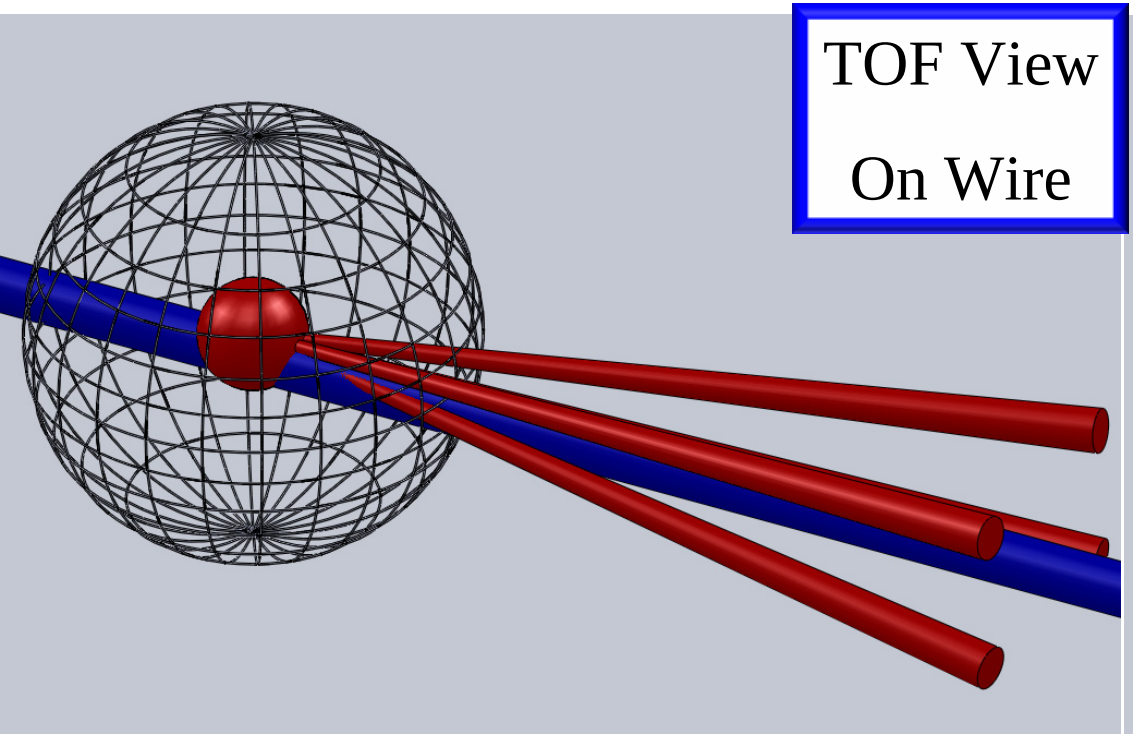
Wire at old cathode equator caused jets emitted from holes in cathode to be directed above and below equator

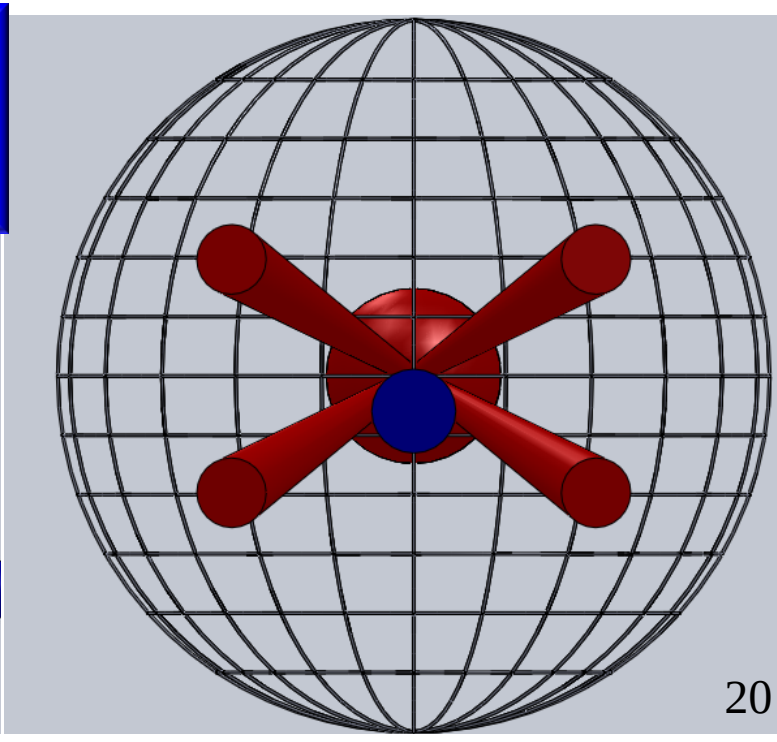
- TOF cylinder of view is determined by the size of the detector, which has a radius of 1.2 cm
- TOF view was centered 1 cm below the equator of this cathode
- TOF profiles collected looking on a cathode hole and on a wire



When old cathode was rotated to give TOF view on a wire instead of a hole, proton counts differed by less than 10%

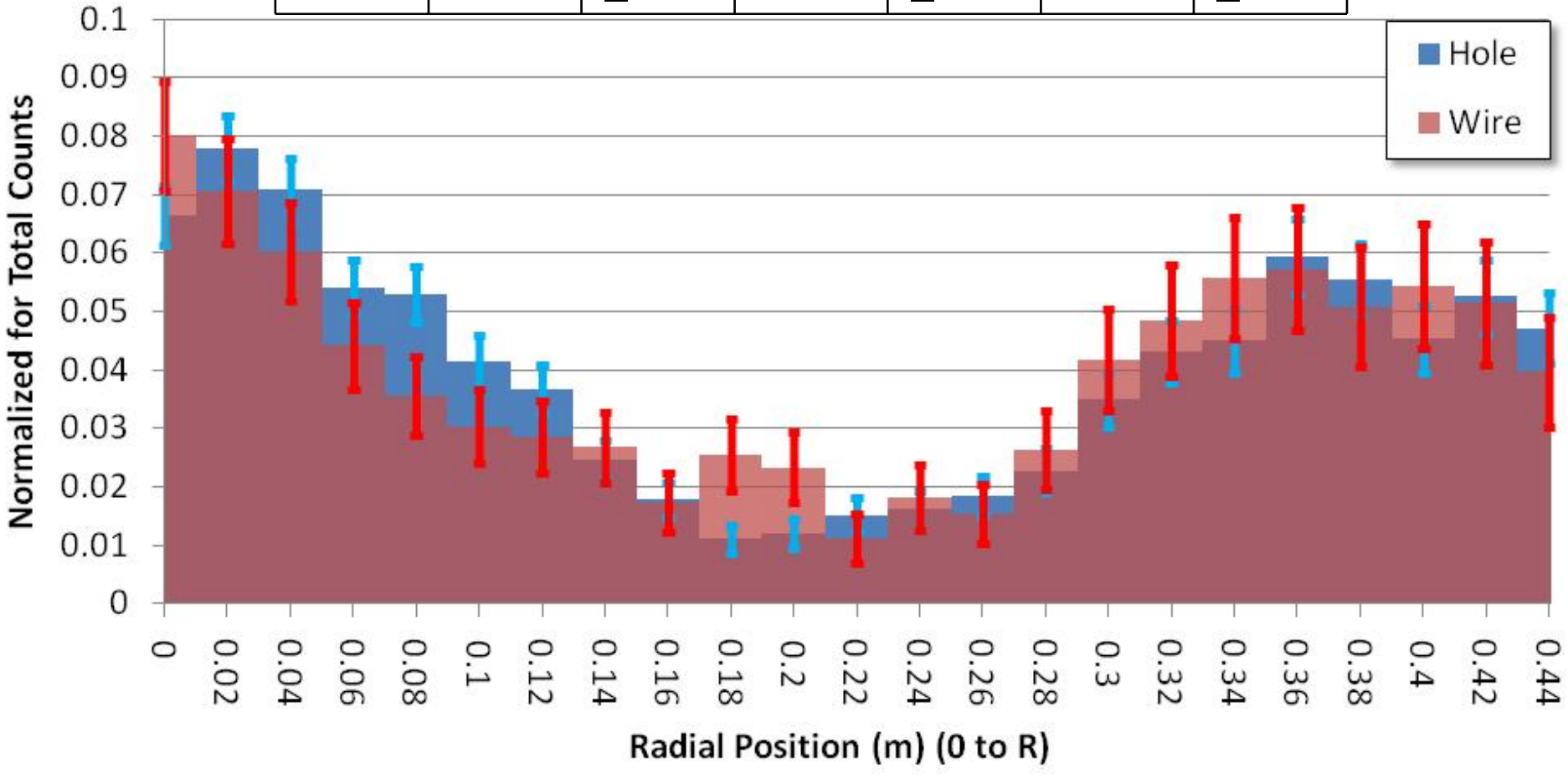
- TOF chord of view did not appear to be directly on a jet in either position due to equator wire
  - Equator wire does not allow jets to be emitted along a radial line parallel to TOF view factor





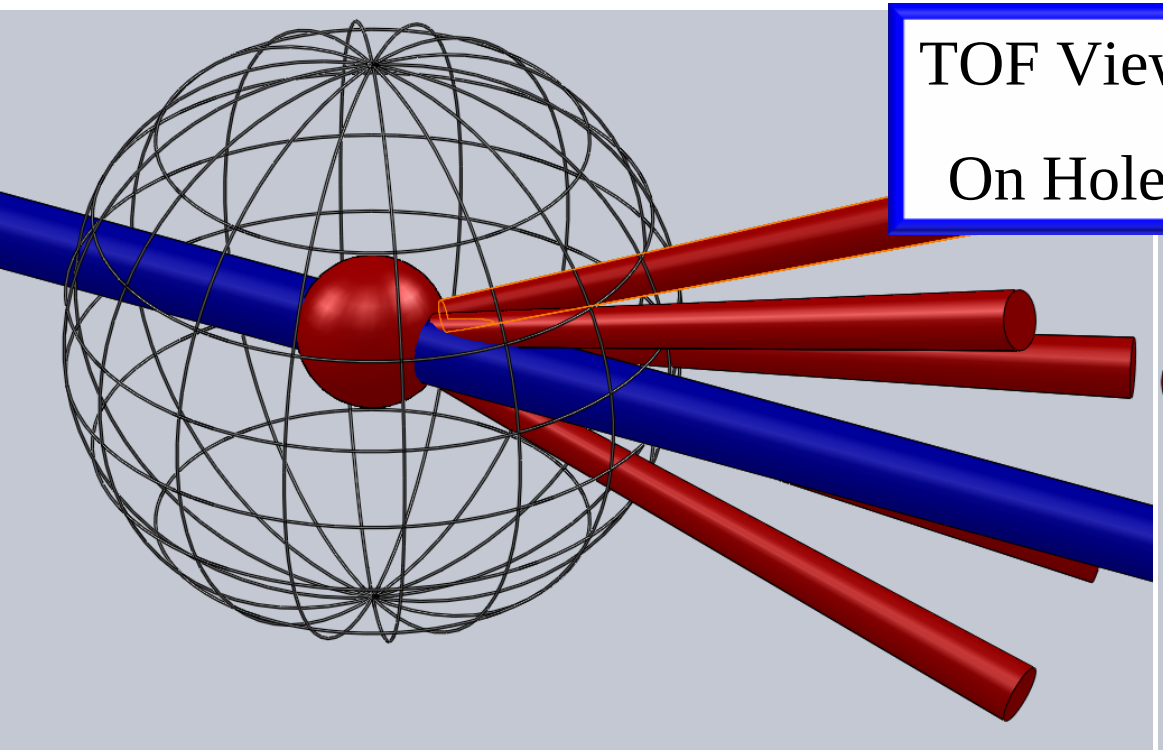
TOF Radial Profiles between On-Hole and On-Wire views of Old Cathode do not differ greatly

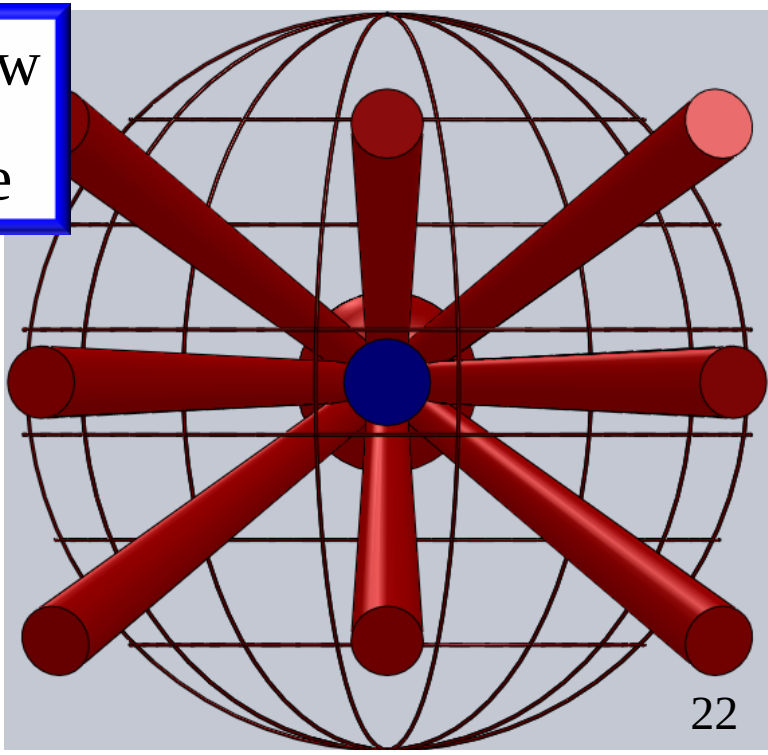
	Core		Inter-Grid		Source	
Hole	37%	±1.7%	18%	±1.2%	45%	±1.8%
Wire	33%	±2.7%	19%	±2.0%	48%	±3.3%



New cathode was constructed with no equator to allow jets to be emitted from the mid-line

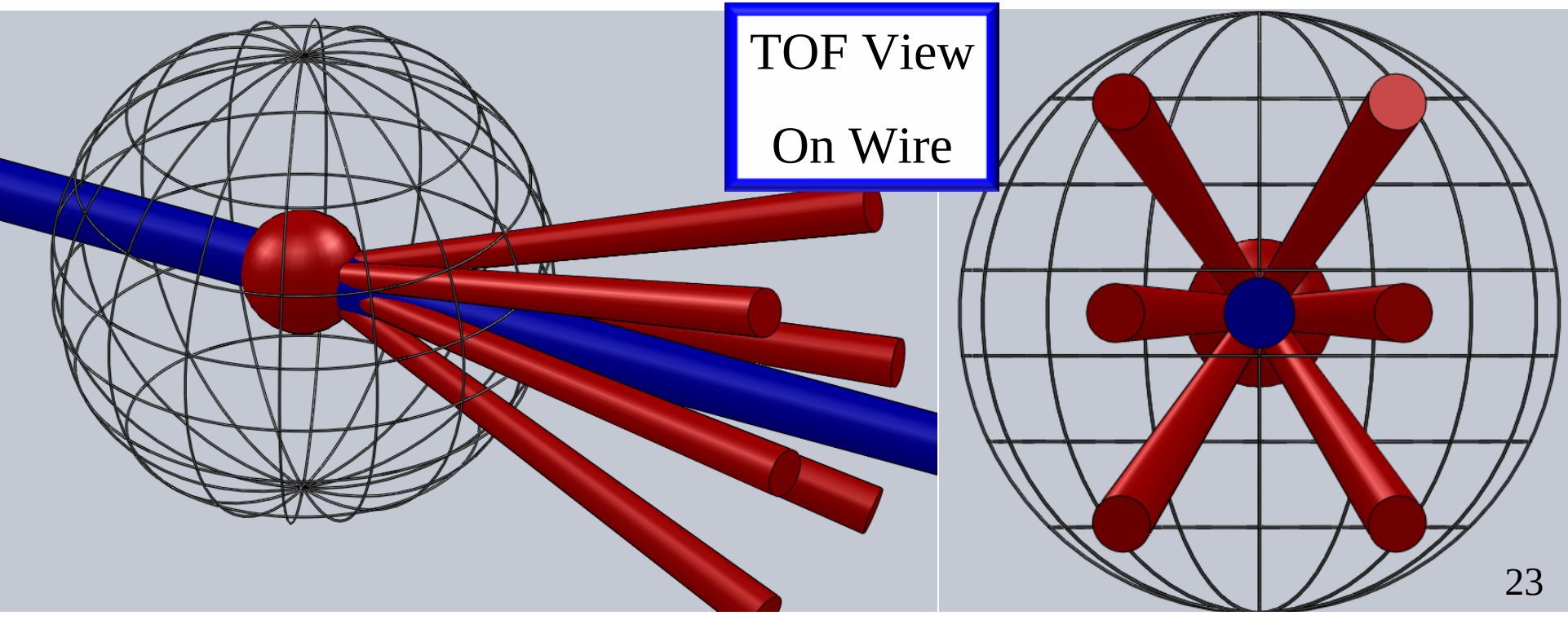
- TOF view no longer 1cm below mid-line, now passes directly through the core
- View should now also be looking directly down a jet





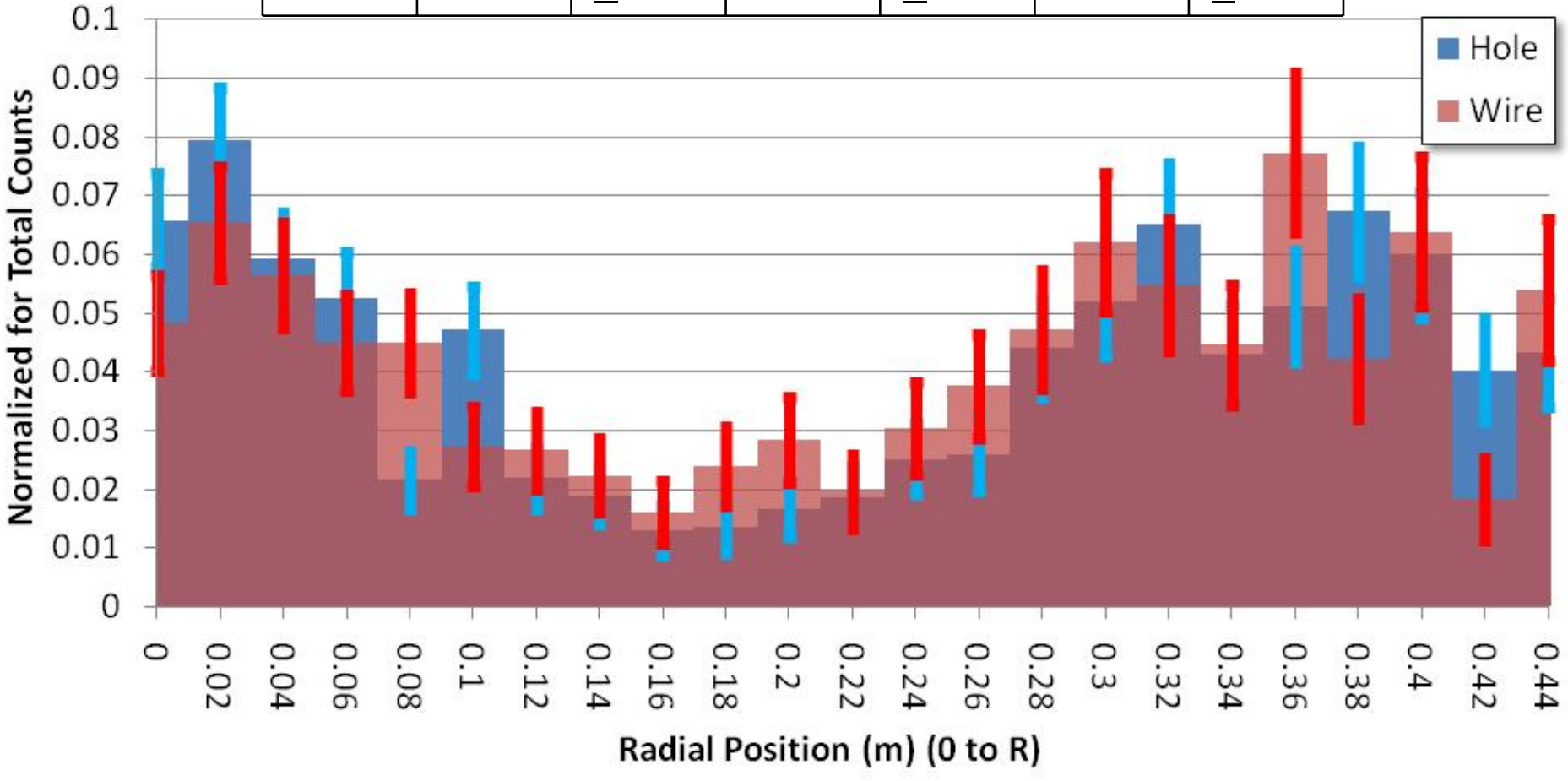
Cathode rotated once again to go from On-Hole to On-Wire view

- Proton counts dropped by roughly 50-55%
- Jets appear to contain higher concentrations of fusion events and correspond closely to holes in cathode

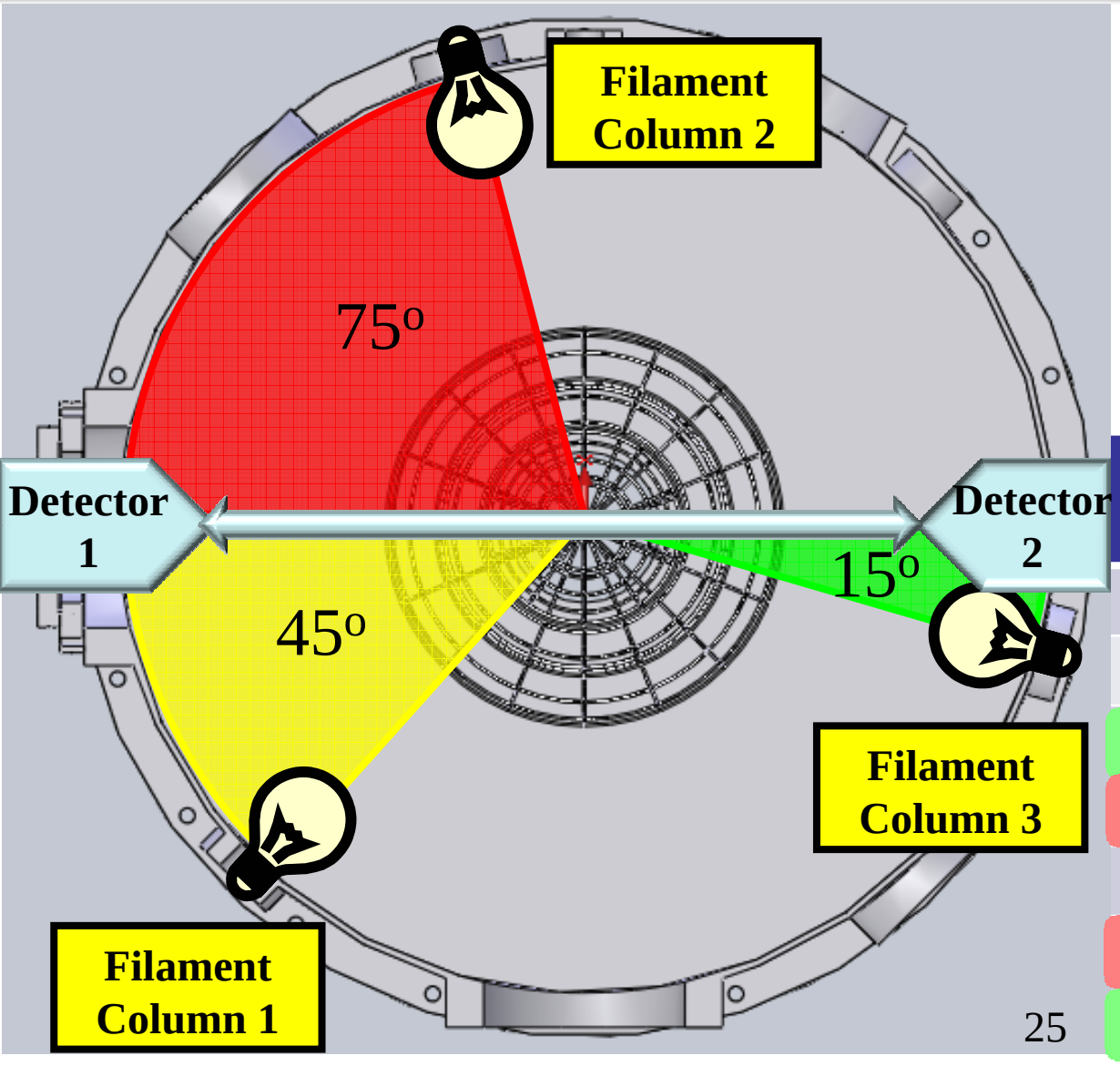


While total proton counts differed, no significant difference seen in radial distribution of fusion reactions between On-Hole and On-Wire case of new cathode

	Core		Inter-Grid		Source	
Hole	31%	±2.5%	17%	±1.8%	53%	±3.2%
Wire	29%	±2.8%	18%	±2.2%	53%	±3.8%



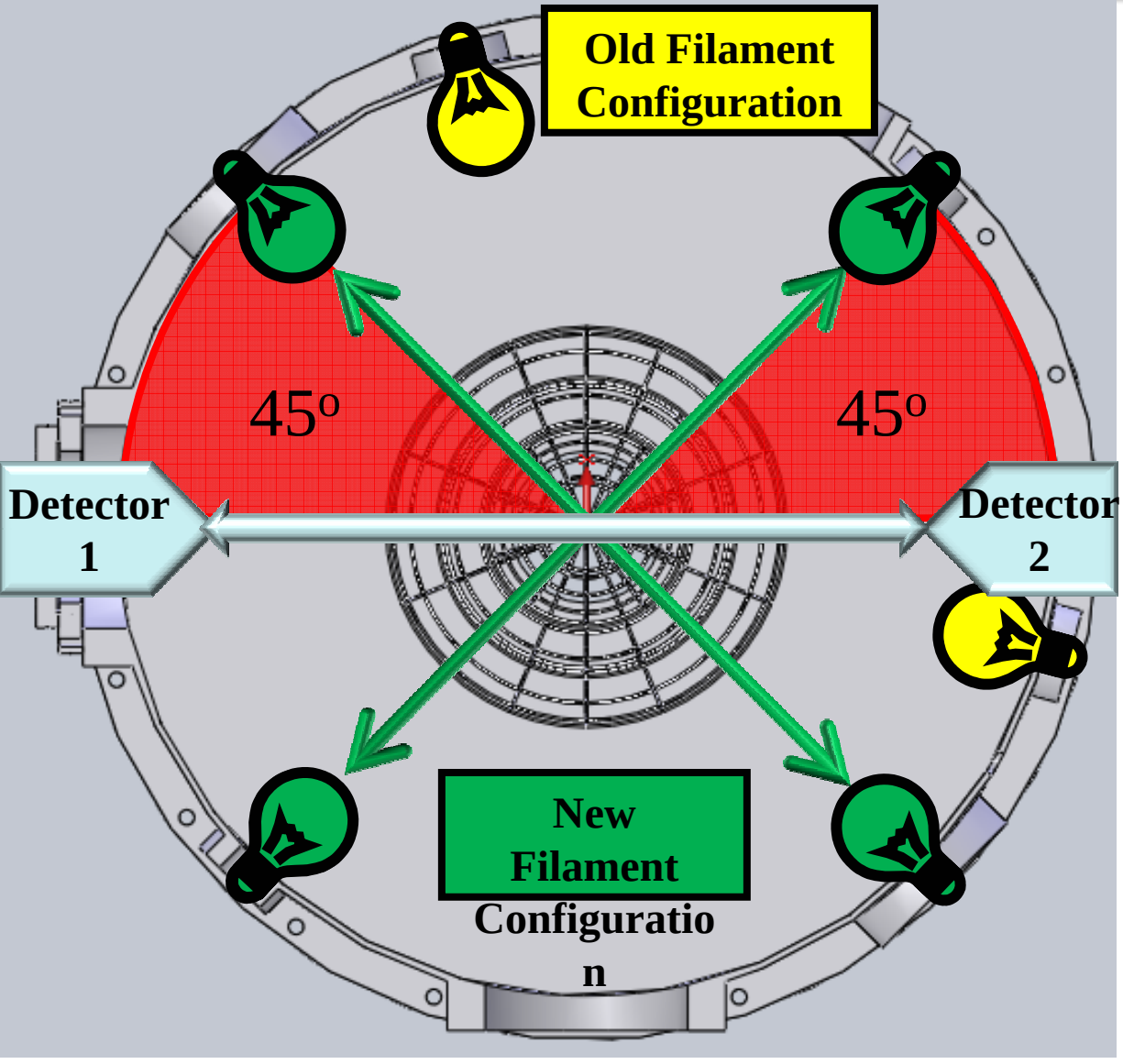
Rate of collection of fusion protons depends heavily on location of filaments



- FIDO counts collected on Detector 1
- Normalized to case when all filaments are on
- All data at same power level
- External neutron detector indicates nearly equal total neutron production rates for system for each configuration

Filament Columns On	Total Counts at Detector 1	Total Protons at Detector 1
1, 2, 3	1.00	1.00
2, 3	0.95	1.00
1	0.91	1.00

Filaments reorganized to gain symmetry about the TOF line of sight



- Old filament configuration removed, consisted of 3 rows
- Filaments moved to positions 45° on either side of both TOF arms, total of 4 rows in use now

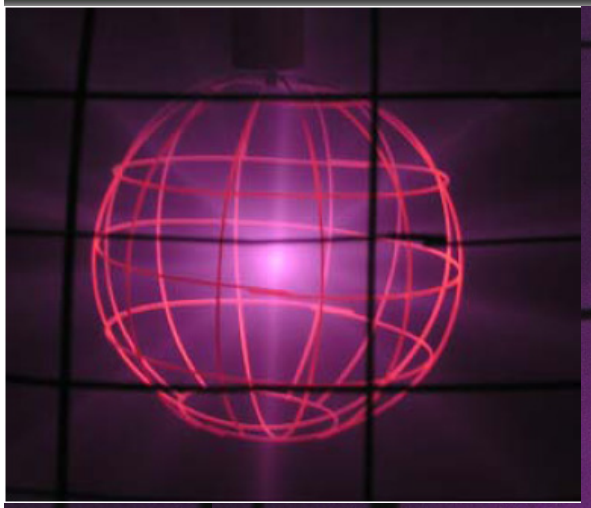
Conclusions for TOF

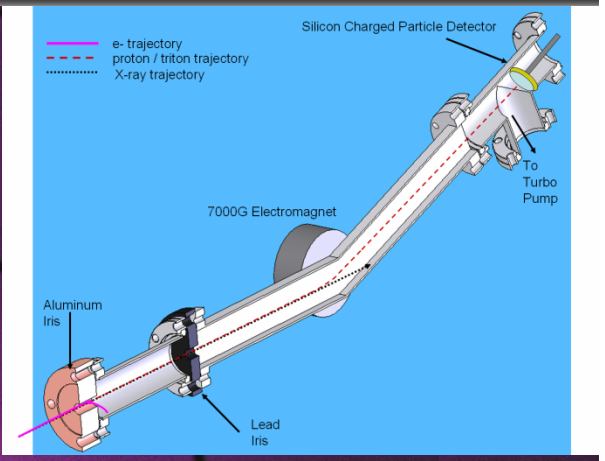
- Constructed and currently implementing a fusion product time of flight diagnostic capable of measuring the radial spatial profile of fusion reactions within the UW IEC device.
  - The TOF diagnostic has demonstrated the ability to generate combined spatial and energy profiles of fusion reactions occurring within an IEC device
  - High concentrations of fusion reactions found in Core and Source Region, with significantly lower concentrations in Inter-Grid Region
  - Non-uniformities measured around the chamber due to jets and ion source location, which make scaling of radial profiles more complex than previously assumed

Future Plans for TOF

- Use TOF Diagnostic to create 3D profiles with:
  x) Location of fusion event along radial line
  y) Energy of fusion reactants at each location
  z) Number of counts
- Use TOF diagnostic to study the change in reactant energy and spatial profiles due to variations in:
  - Voltage
  - Current
  - Pressure
  - Grid Configurations
- Increase statistics to gain better data for FIDO analysis in each radial bin

Questions?




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