Exploring Non-Uniformities in Gun-to-Gun Performance on the Six Ion Gun Fusion Experiment (SIGFE)

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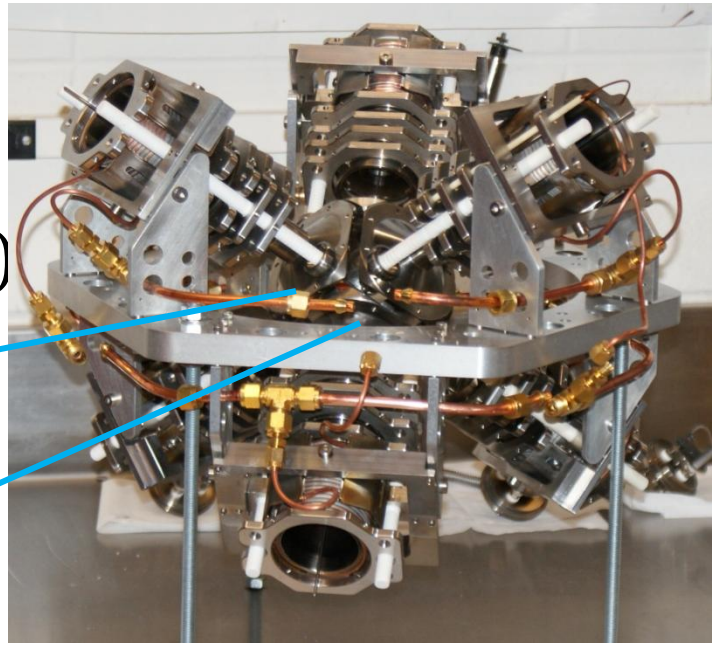
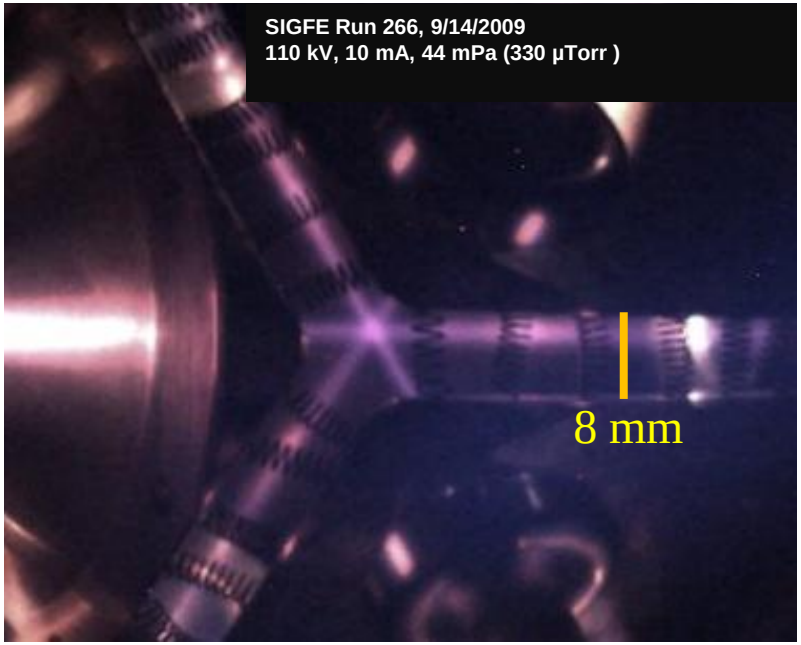
Presentation outline

- Brief summary of experimental design and operation
- Key results from Dr. Brian Egle's previous work on SIGFE
- Description of recent device recalibration
- Discovery of asymmetric gun behavior
- Discussion of reasons for asymmetry

SIGFE converges 6 focused ion beams into center of device

- SIGFE operates at a lower chamber pressure than many gridded IEC devices, as low as 10 mPa (75 µTorr)
- Variable beam focus

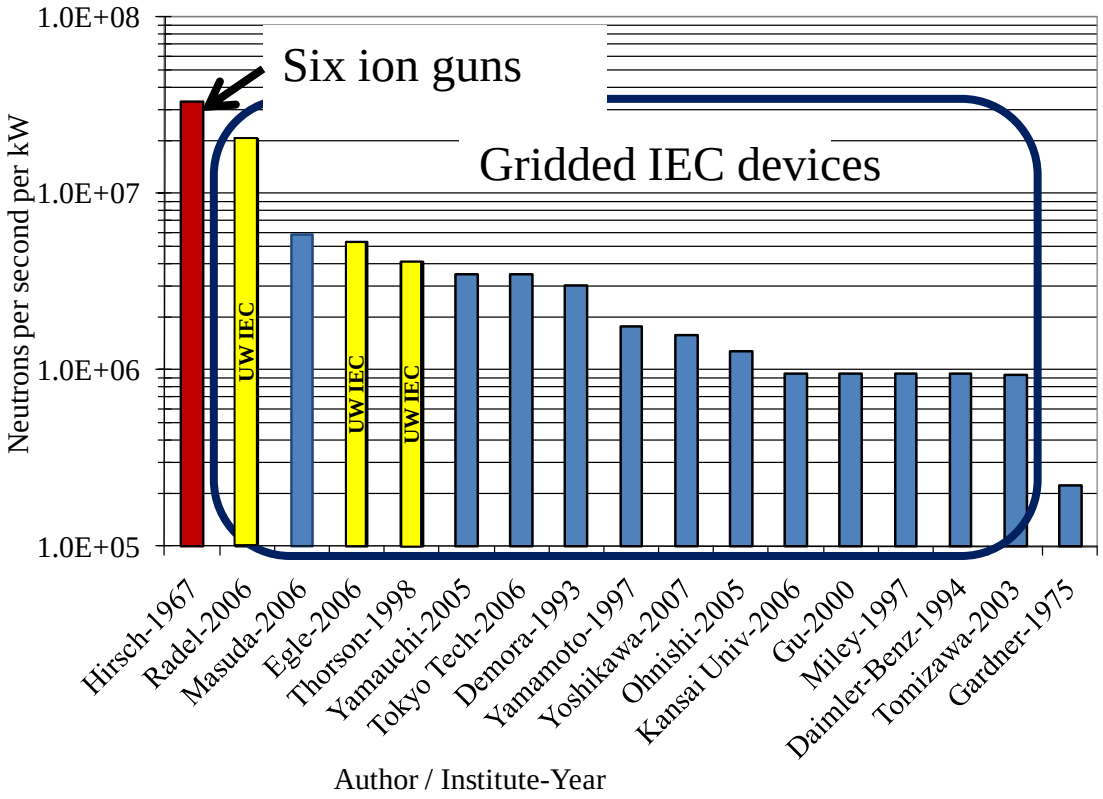


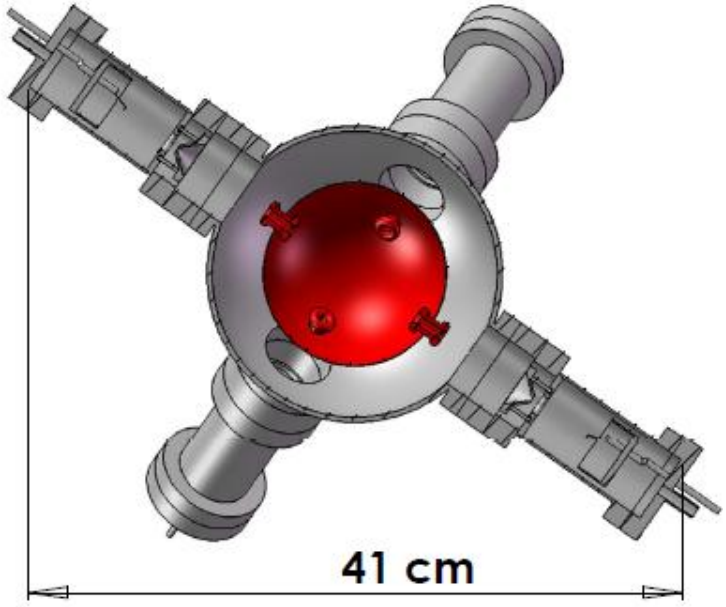


- Possible IEC operational modes
  - Beam-background
  - Beam-embedded
  - Converged core
  - Multiple virtual electrodes (Poissors)

SIGFE replicated and expanded the Hirsch experiment from 1967

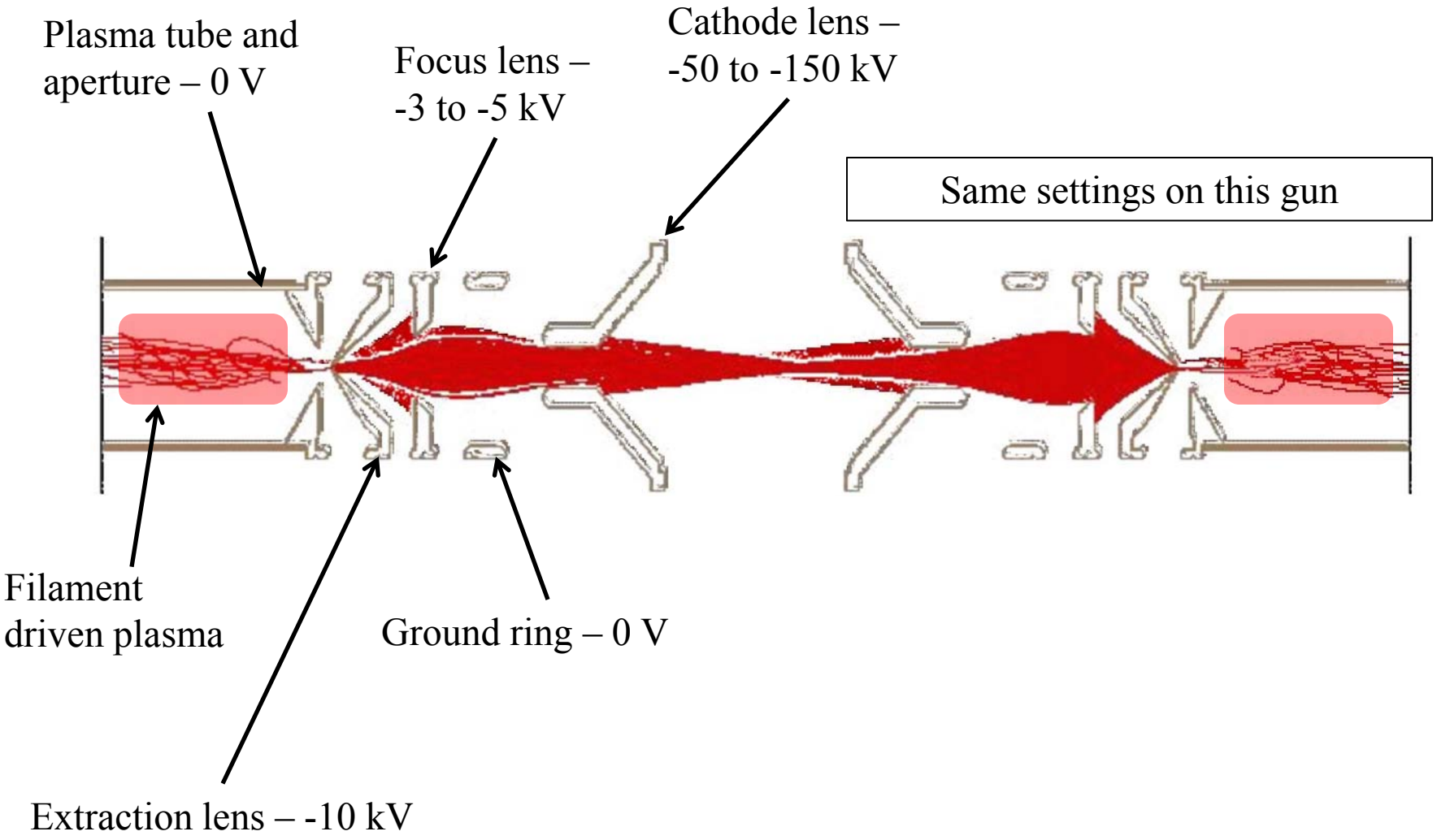
- Original Hirsch device was most efficient IEC for neutron production per kW input power





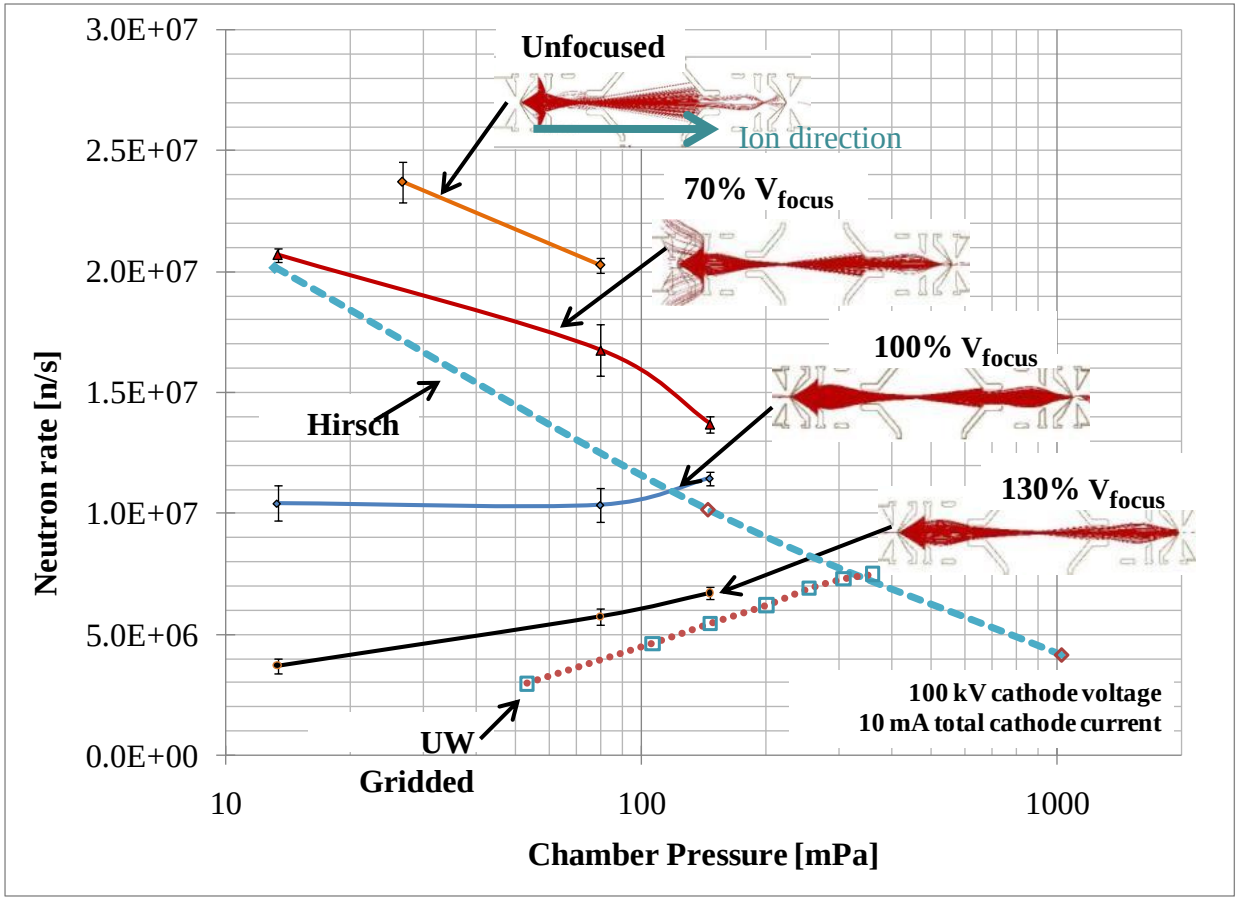
- SIGFE replicated some of the main mechanical and electrical features of Hirsch's experiment

Schematic of two opposing guns



SIGFE's n rate vs. pressure is different than gridded IECs, for certain parameters

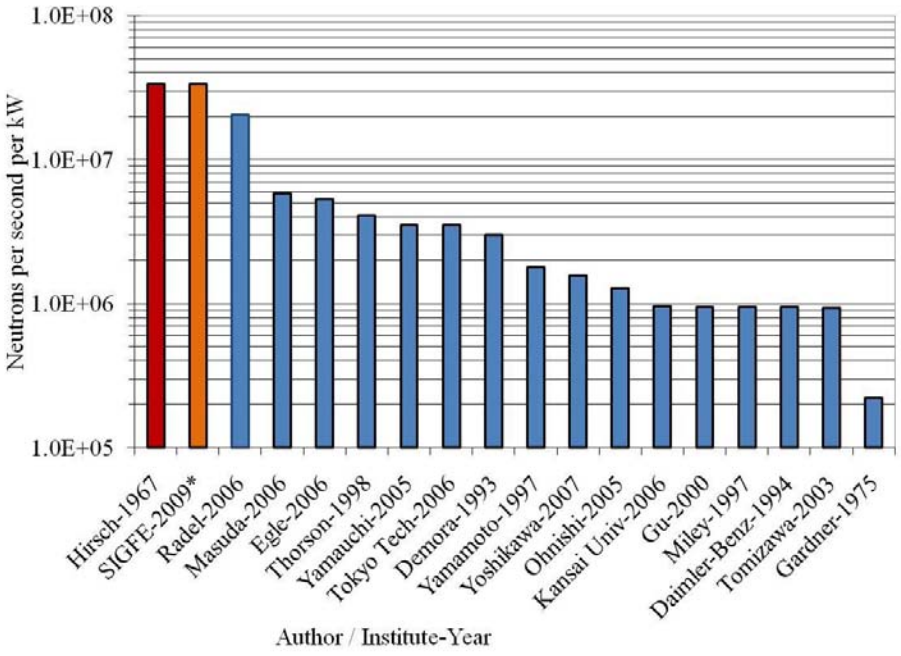
- 100% is ideal focus
- Neutron rates in an ideally focused SIGFE depend little on pressure
- Neutron rates in UW gridded devices and an over focused SIGFE are proportional to pressure

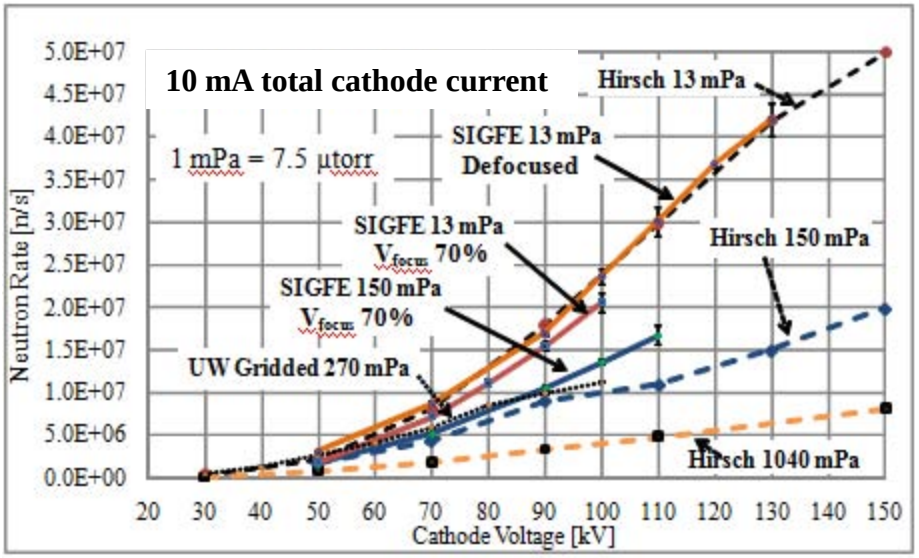


- SIGFE's, as well as Hirsch's experimental neutron rates scale inversely with pressure when under focused

SIGFE matched Hirsch's neutron rates, evidence points to beam-embedded fusion

- SIGFE replicated the Hirsch device D-D fusion rates for the same parameters in the defocused state

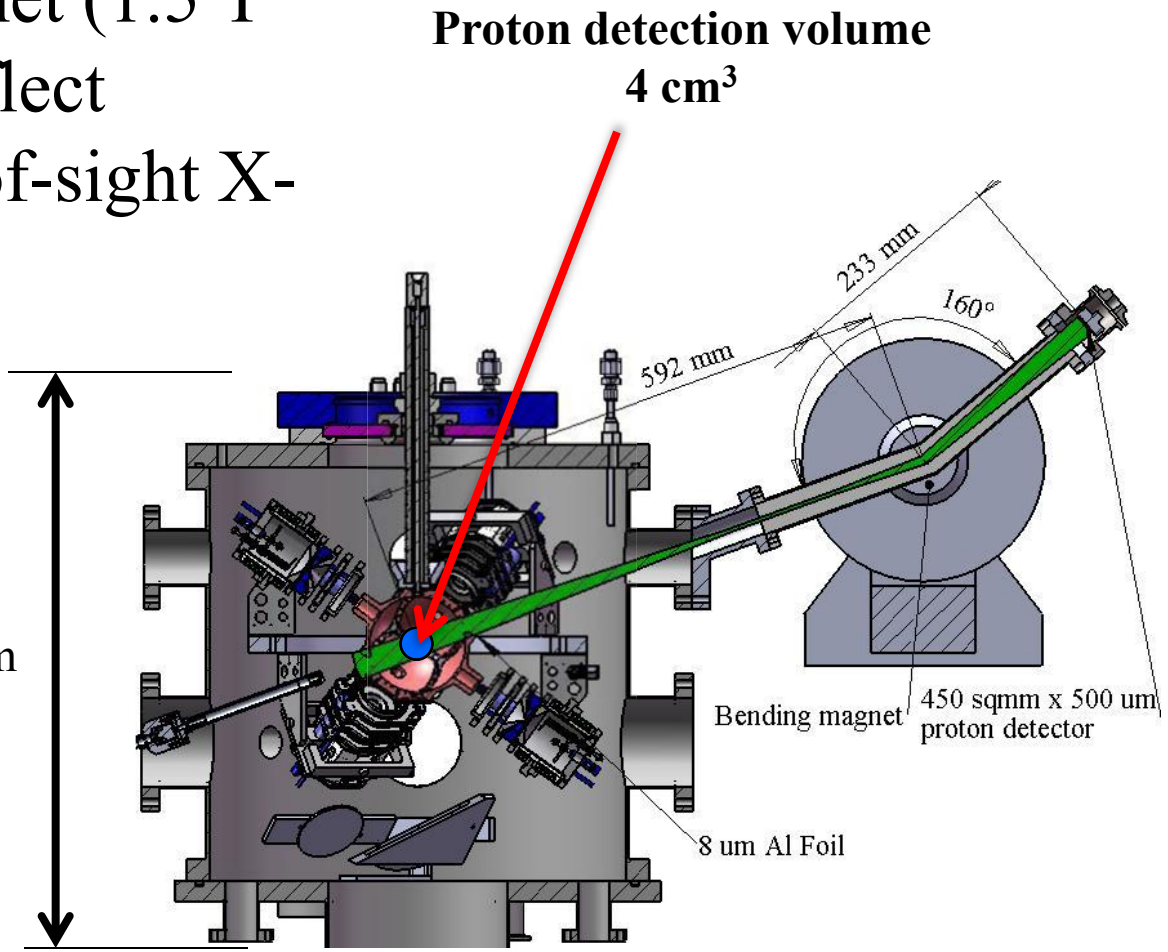




- Results of defocused run suggest beam-embedded, inside cathode, as dominant mode of fusion in SIGFE

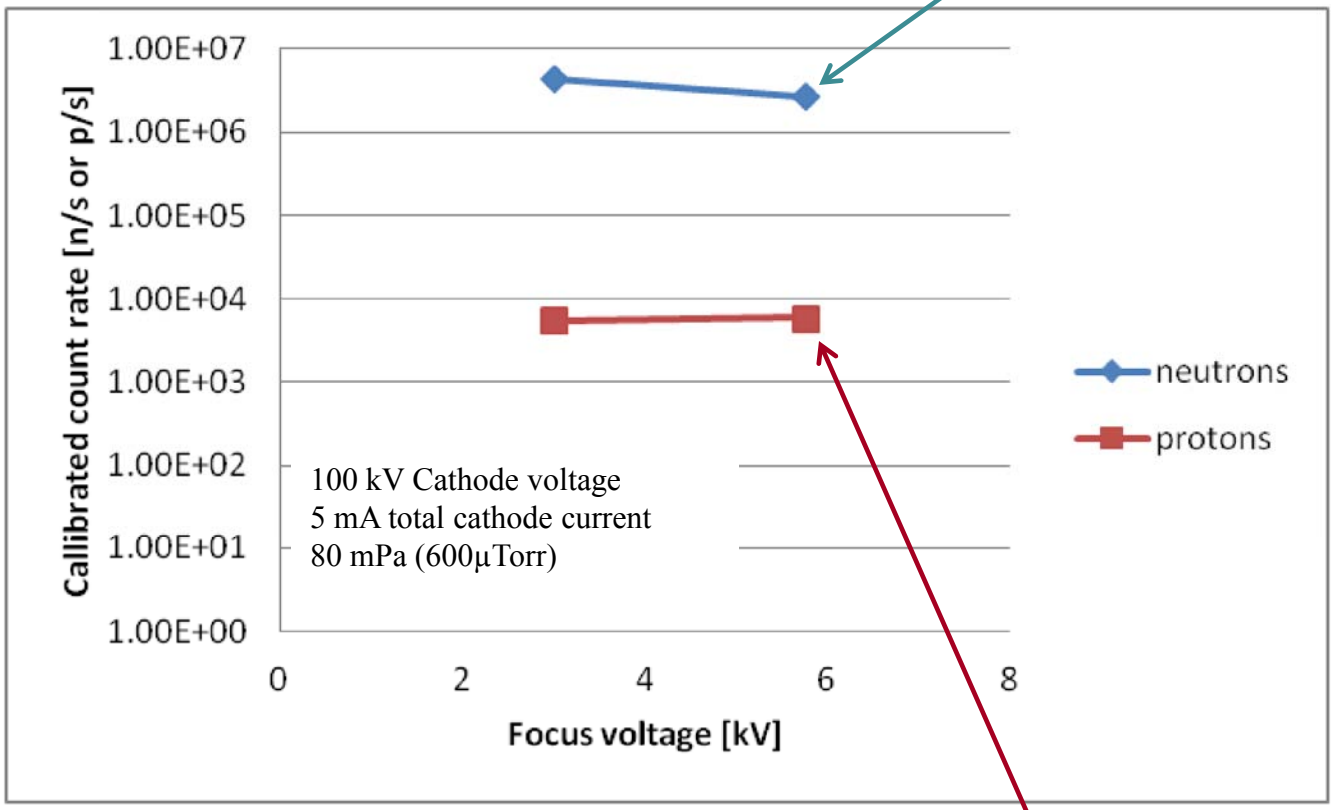
SIGFE used bending magnet to reduce X-ray noise while looking at cathode center

- A strong electromagnet (1.5 T max) was used to deflect particles out of line-of-sight X-rays to reduce noise
- Detector was looking as a small volume along the center of the cathode where the 6 beams intersected

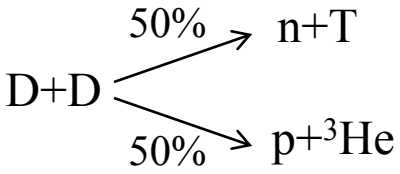


Proton rates from proton detector were compared to measured neutron rates

Neutrons from whole device



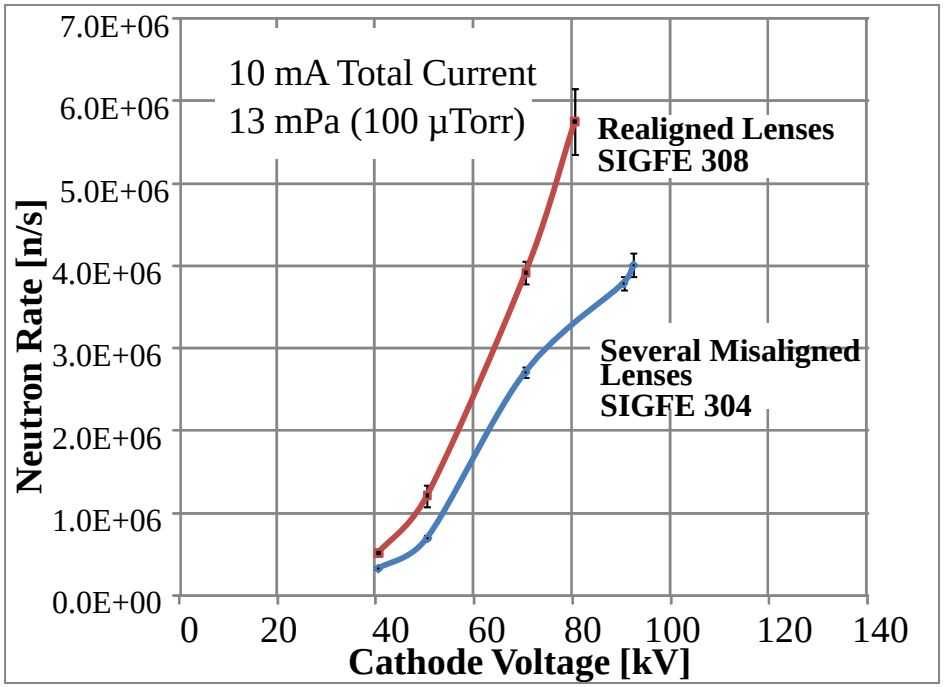
Protons from beam intersection

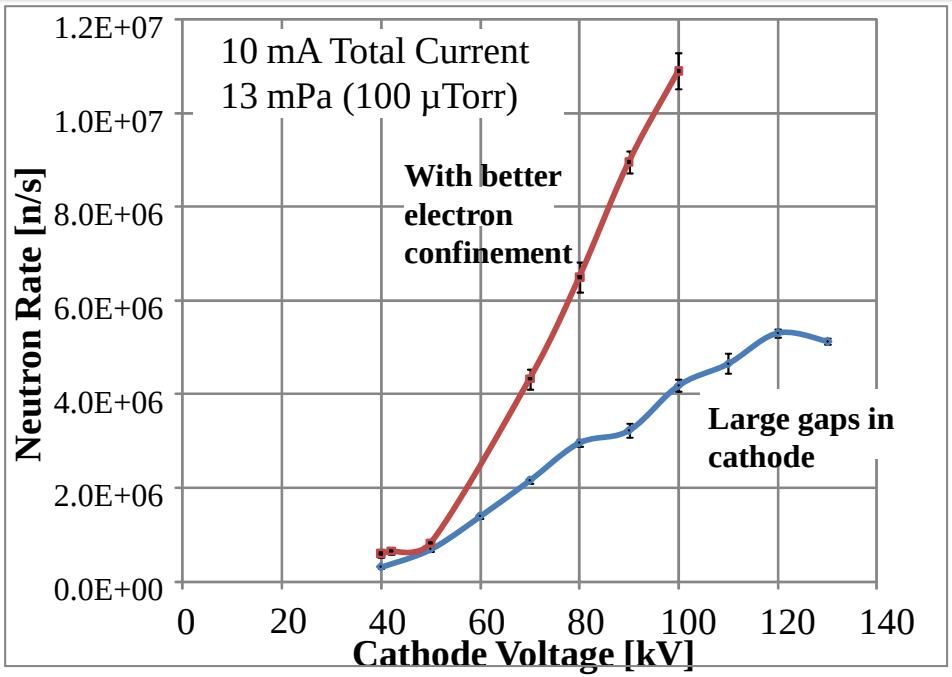


- The equal branching ratio of D-D fusion says one should have an equal number of protons and neutrons found in the system
- When adjusted for detector view-factor, almost 1000 times more neutrons detected in whole device than protons from the center
- **Most fusions must be occurring elsewhere**

Lens alignment and electron confinement are important to performance

- The system measures total, not beam current
- 10 mA could be any combination of ion and electron currents

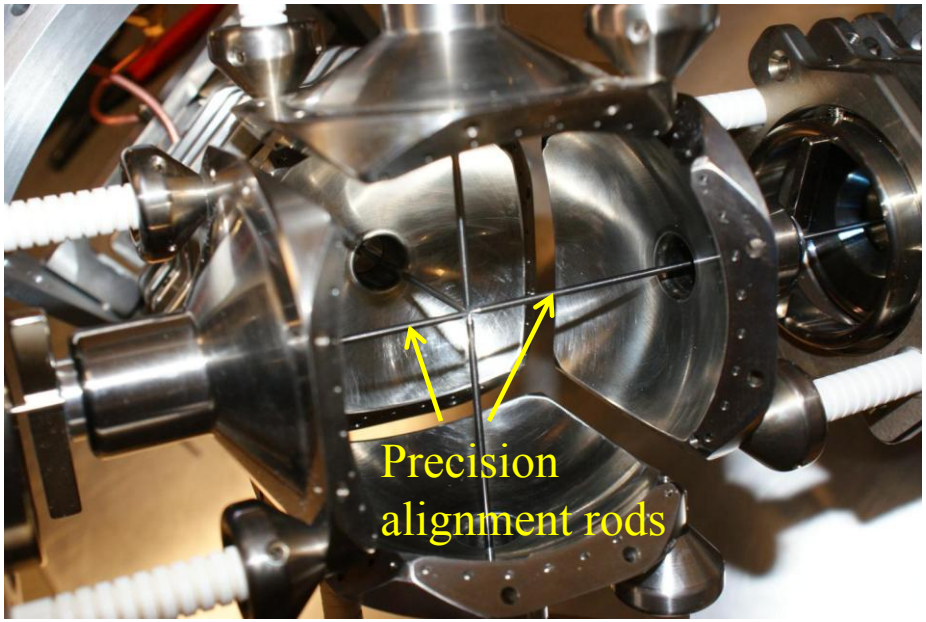


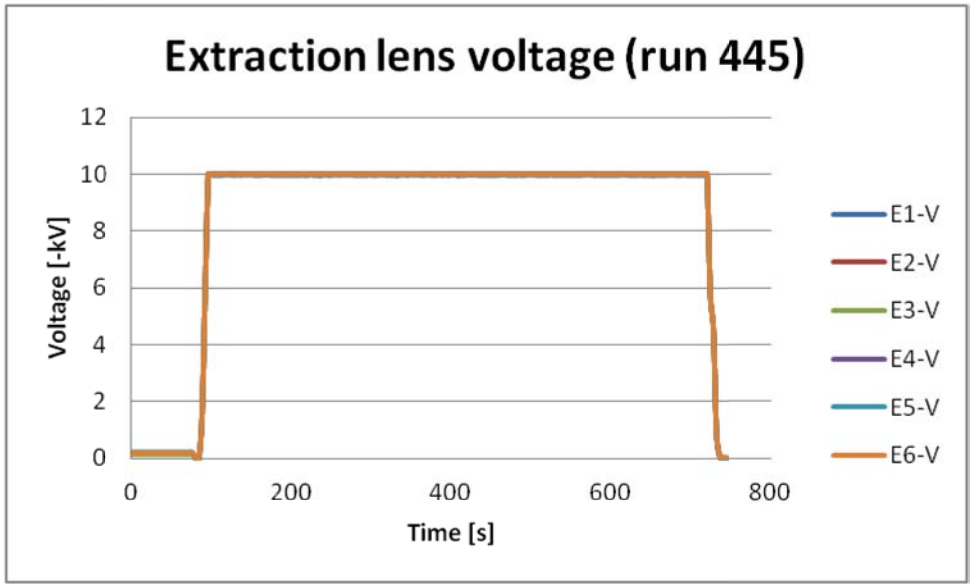


- 2-3 times improvement in performance observed with good lens alignment and better electron confinement in the cathode

Mechanical and electrical system is very symmetrical gun-to-gun

- Lenses were machined to <0.05 mm
- Lens spacing <0.1 mm different gun-to-gun
- Guns aligned to <0.2 mm

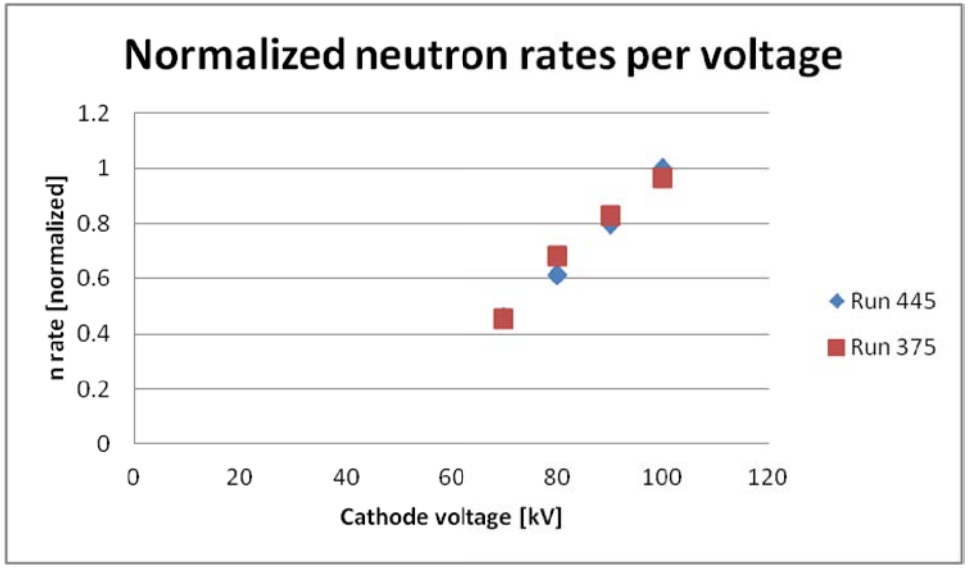


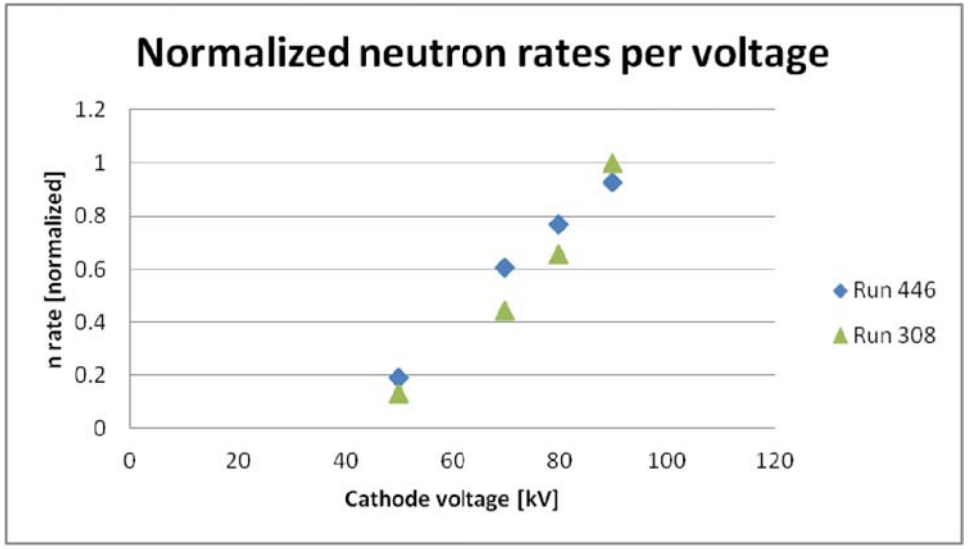


- Focus and extraction lens voltages held within 40 V between guns (normal applied voltage is -4 and -10 kV, respectively)

Recent experiments verify SIGFE is performing the same as in 2009

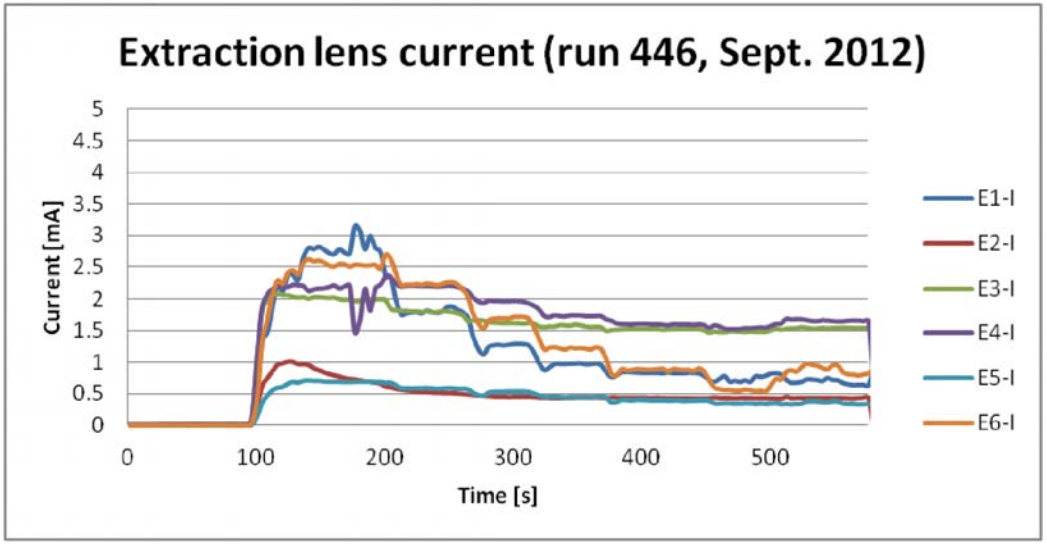
- Before moving forward, experiments were conducted to verify SIGFE was operating the same as when earlier data was taken
- Top graph parameters: 300 μTorr, 10 mA meter cathode current
- Bottom graph parameters: 100 μTorr, 10 mA meter

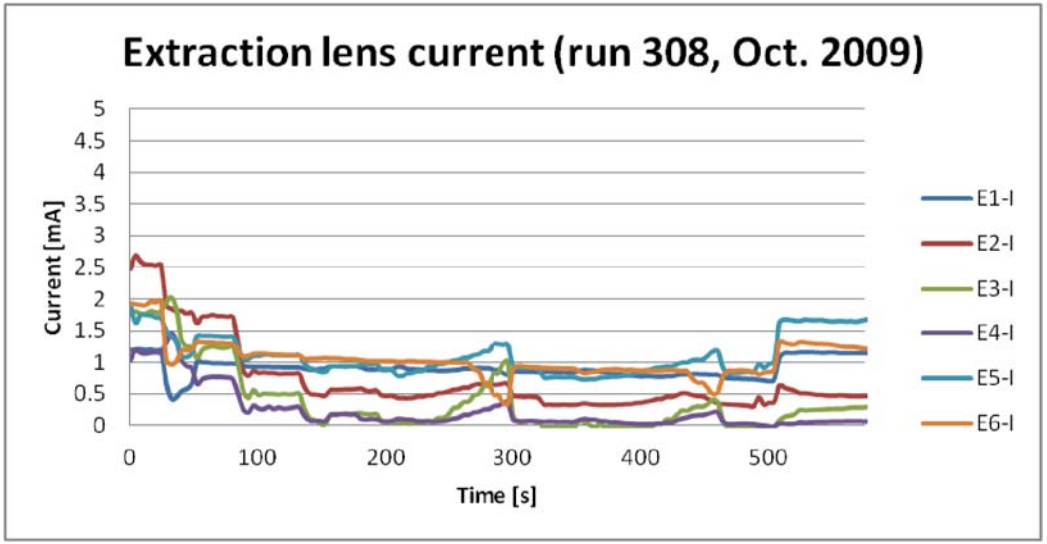




Lens current data suggests differences in plasma and beam from gun-to-gun

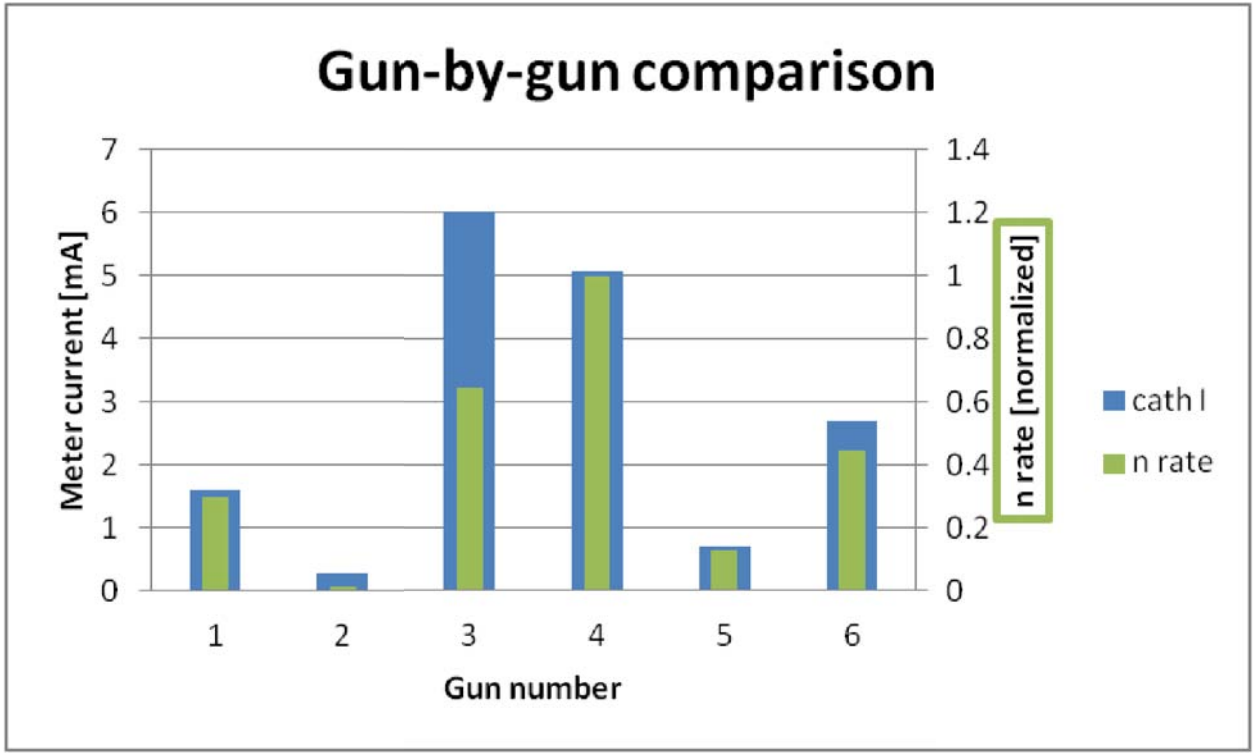
- Total current on focus and extraction lenses is significantly different despite having an aligned system and consistent voltages on lenses
- This suggests significant differences in ion source plasma
- These differences lead to variation in beam focus





Single gun operation also suggests different plasma parameters gun-to-gun

- Filaments were turned on one-by-one
- Cathode current and neutron rates varied from gun-to-gun for same electrode voltages and chamber pressure parameters

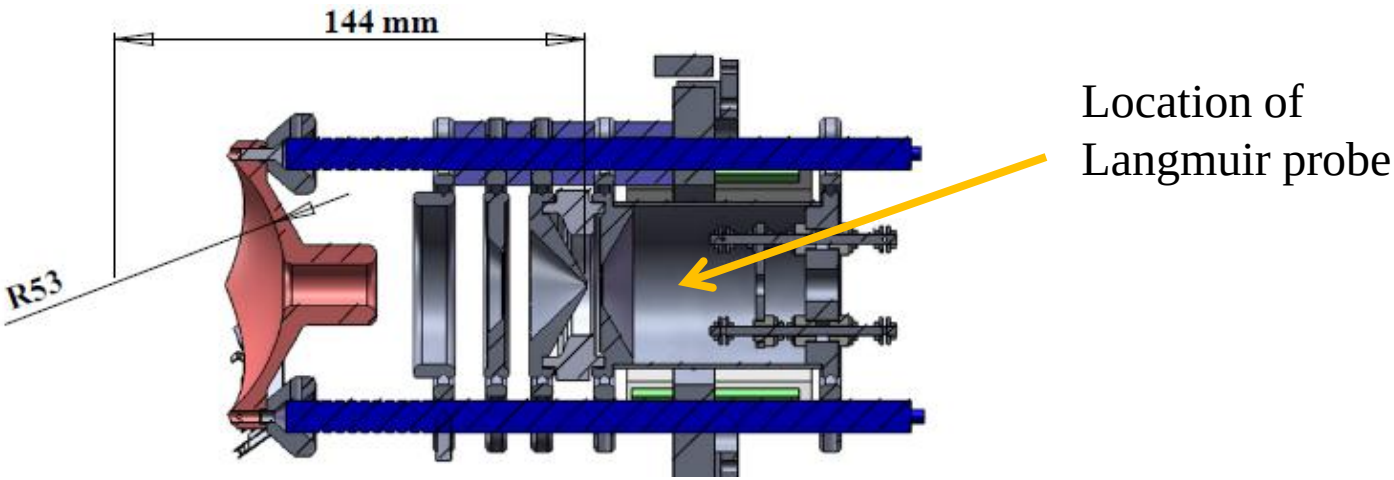


Different filament resistances and source magnetic fields likely account for variation

- Filament resistances during operation vary from gun-to-gun by as much as factor of 2.5
- Filament resistance changes over operation time – amount not yet quantified
- Confining magnetic field differences would also contribute but are hard to measure accurately in current state
  - Permanent magnets set up dipole magnetic field to confine electrons in plasma source region

Adding Langmuir probes will help determine sources of non-uniformities

- Better beam diagnostics and knowing plasma parameters will help determine cause for differences between guns
- Langmuir probe in the plasma source region would be the simplest diagnostic to use in current system



Summary

- SIGFE replicated Hirsch's neutron rates and efficiency
- Fusion rates in SIGFE are most likely due to beam-embedded fusion inside the cathode lenses
- Despite mechanical and electrical symmetry of the system, there is evidence of asymmetries in beams
- Differences in source plasmas between guns is probably the reason for asymmetries

Thank you for your attention – Questions?