# Affects of Biasing on Instabilities in a Helicon Plasma

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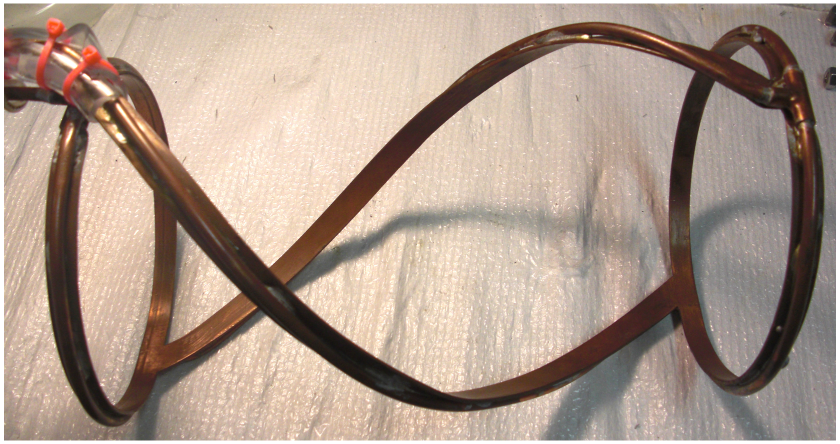
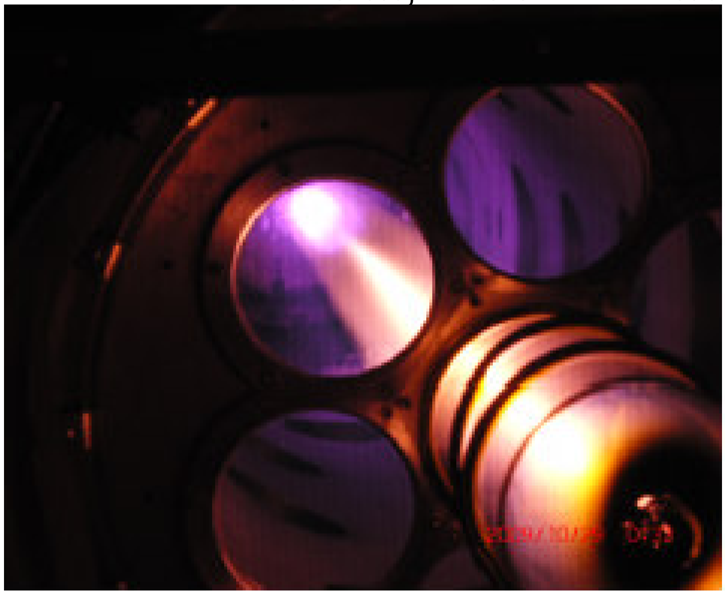
Recent experiments have been done using the Helicon-Cathode Device (HelCat) at the University of New Mexico. Measurements via a Mach probe have revealed that in the center of the plasma, flow is away from the source, but in the edge region, the flow reverses, and is towards the source. It has also been observed that drift-waves exist in system, and these are able to be suppressed using a system of concentric bias rings and a transparent grid . During suppression of the drift-waves, several effects have been observed. One, the reverse parallel flow in the edge of the plasma disappears, and two, as expected, the radial transport decreases. The exact relationship between the radial transport and the parallel flow is unknown, but experiments are ongoing. Evidence will be presented to show that a parallel electric field is not capable of suppressing the drift-waves seen in HelCat, and that the strong reverse flow appears to be an effect of the radial transport. Further understanding is being sought using various computer codes developed at EPFL: a linear stability solver (LSS1), a one-dimensional PIC code/sheath solver, ODISEE2, and a global, 3D Braginski code, GBS1. Basic overview of results will be presented.

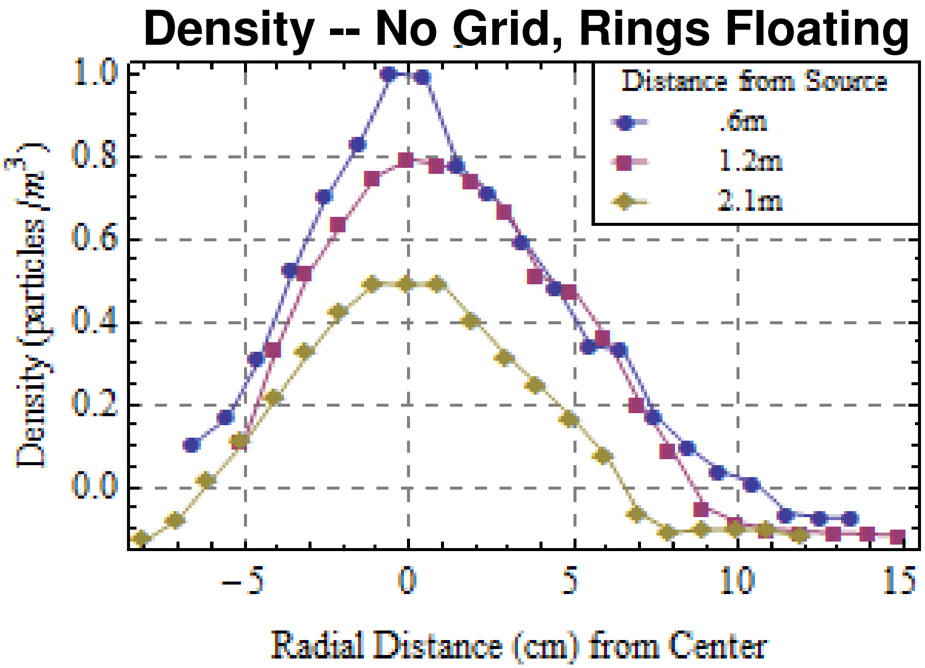
1. P. Ricci and B.N. Rogers (2009). Phys Plasmas 16, 062303.
2. J. Loizu, P. Ricci, and C. Theiler (2011). Phys Rev E 83, 016406.

# Helicons

- RF Source that excites a helicon mode
  - m=1 antennas most common
  - f~10-30 MHz
  - Power~ few kWatts
- High density, n~$10^{19}$-$10^{20}$
- Moderate/high neutral fill ~mTorr
- Blue core region
  - Neutral depletion?
  - In HelCat, 2-3cm in radius







# Helicon-Cathode Device (HelCat)

- **Length: 4 m** — **$B_z$: ≤ 2.2 kG (220 mTesla)**
- **Diameter: 50 cm** — **10 ms (cat.) – steady state (hel.), 1 Hz rep rate**

**RF helicon plasma**

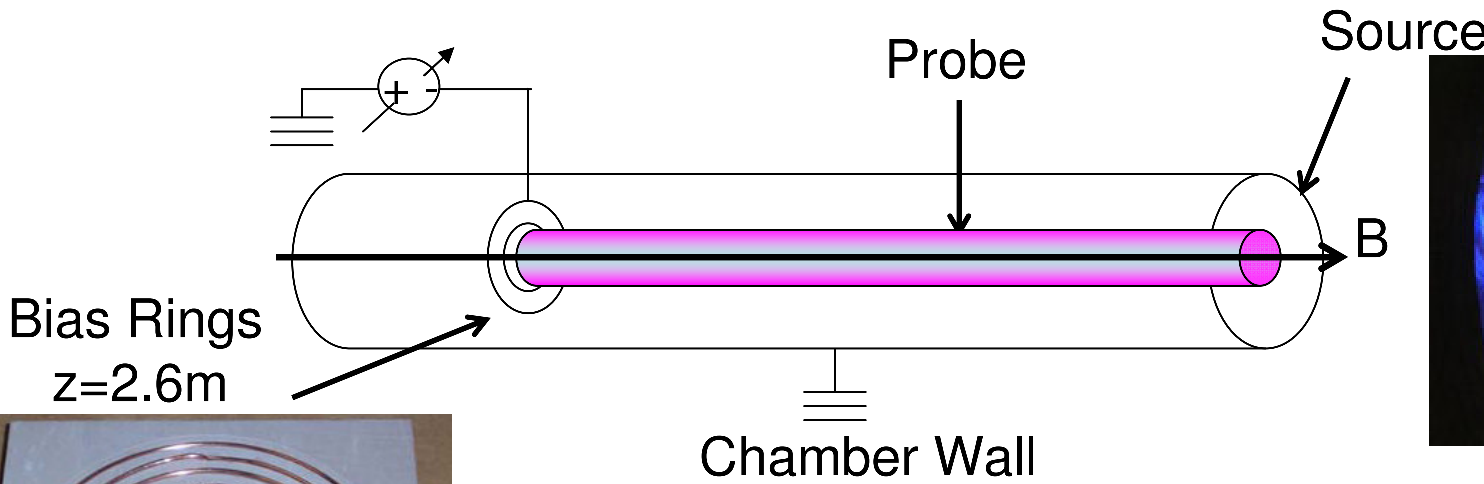
- **n ~ 1-10 × $10^{19}$ $m^{-3}$**
- **Te ~ 3 – 8 eV**
- **Ti ~ 0.1 eV ?**
- **D = 10 – 20 cm**
- **$P_0$ ~ $10^{-3}$ Torr**

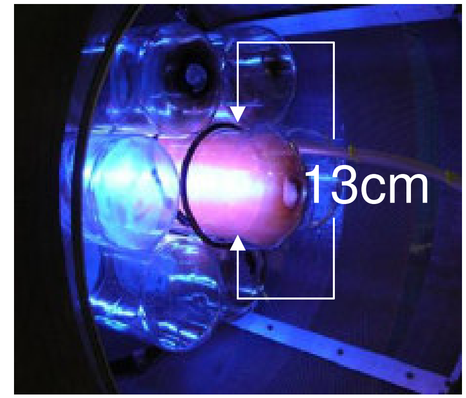
- **$c_s$ ~ $10^3$ – $10^4$ m/s**
- **$\rho_s$ ~ 3 – 40 mm**
- **$L_n/\rho_s$ ~ 2 - 10**
- **$\nu_{in}$ ~ $10^5$ - $10^3$ $s^{-1}$**
- **$\nu_{in}/\omega_{ci}$ ~ $10^{-3}$ - 1**
- **$\lambda_{mfp,in}$ ~ 5 – 50 cm**
- **$\beta < 10^{-2}$**
- **$v_{alfen}$ ~ $10^4$ m/s**

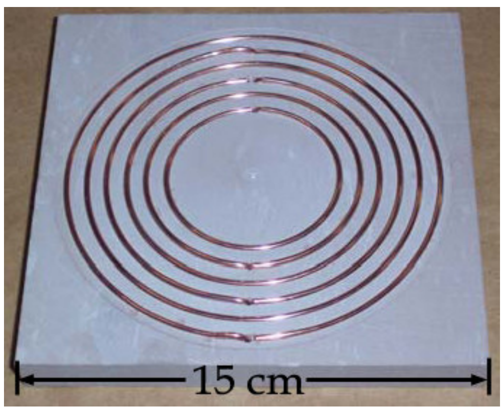
## Diagnostics

- **Electrostatic and Magnetic Probes**
- **Interferometers (40 GHz, 96 GHz)**
- **Fast cameras**
- **Visible Spectroscopy**

# Experimental Setup

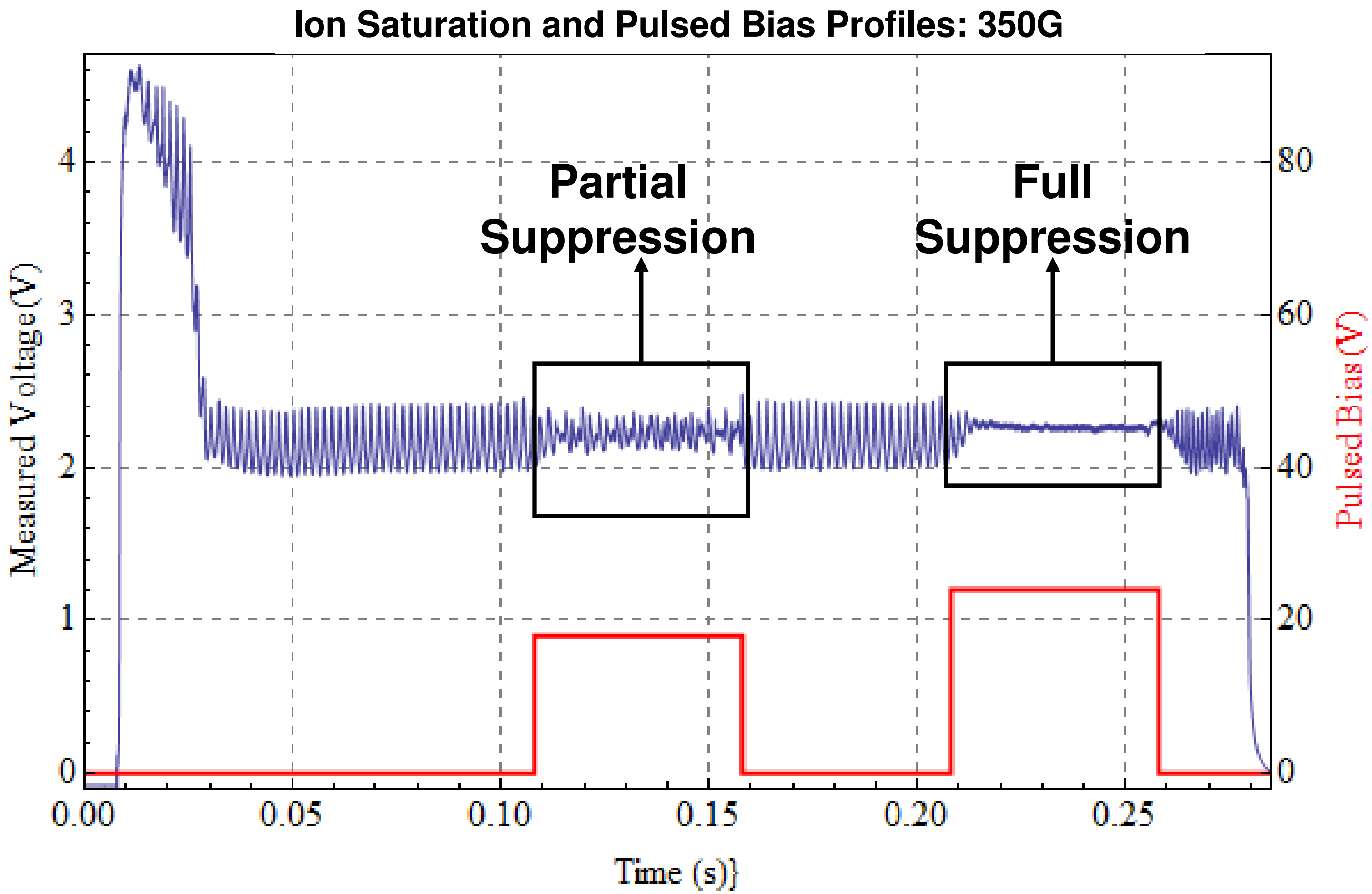


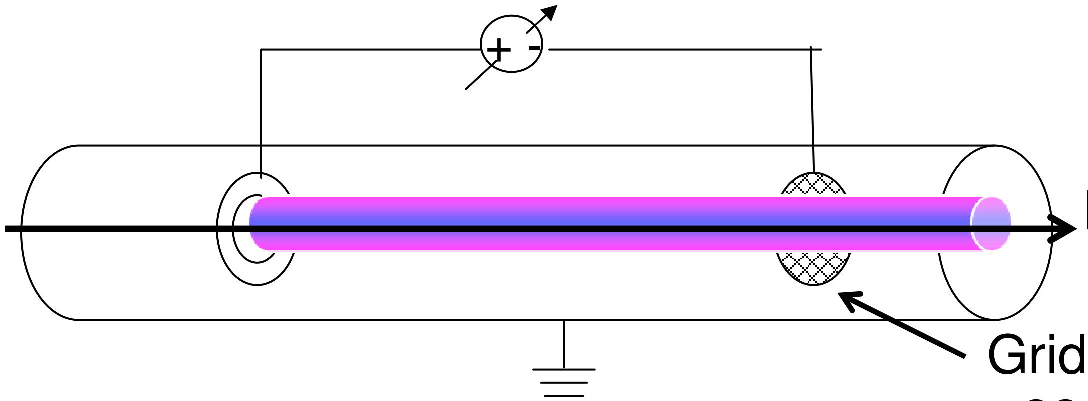



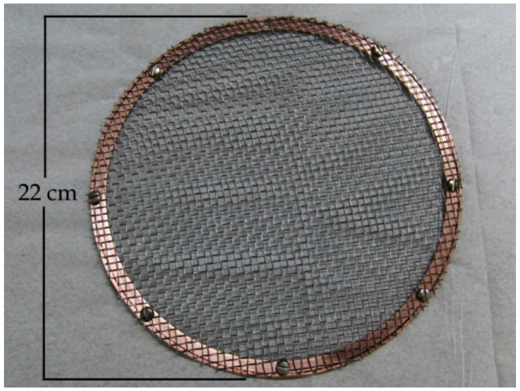

- Use biasing to suppress intrinsic drift-waves
  - Qualitatively, the behavior is the same if rings are biased as one, or separately.
- Parameters that affect the result of biasing are:
  - Magnetic Field Strength
  - Pressure
  - Helicon power

- Used pulsed bias system
  - Bias pulses on for approximately 50ms
  - 50ms between pulses allow plasma to “recover”
- Use two biases: 18V and 24 V (~6$T_e$ and 8$T_e$)
  - 18V causes a partial suppression intrinsic instability
  - 24V causes full suppression for low magnetic field

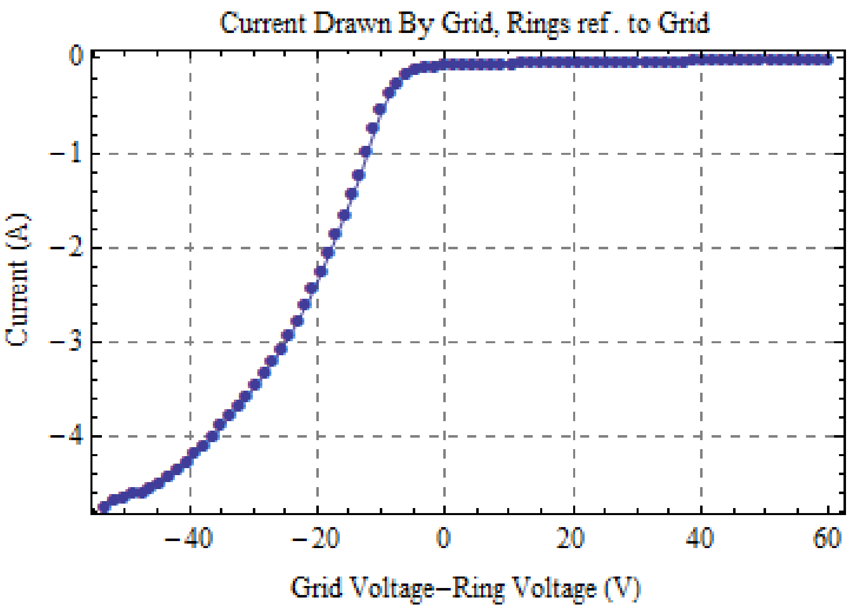


# Alternate Setup: $E_r$ vs $E_{||}$



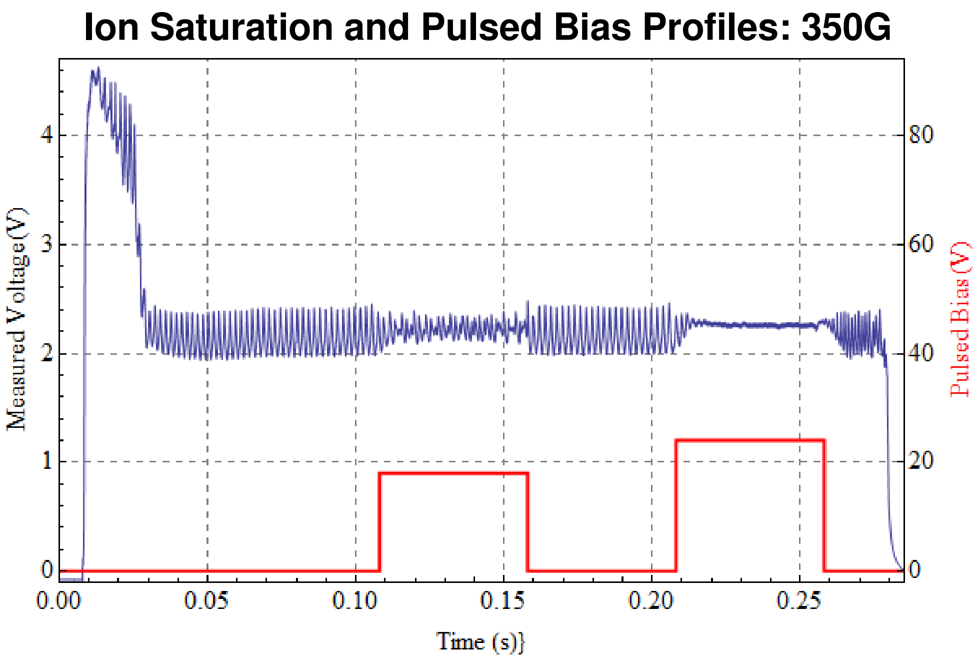



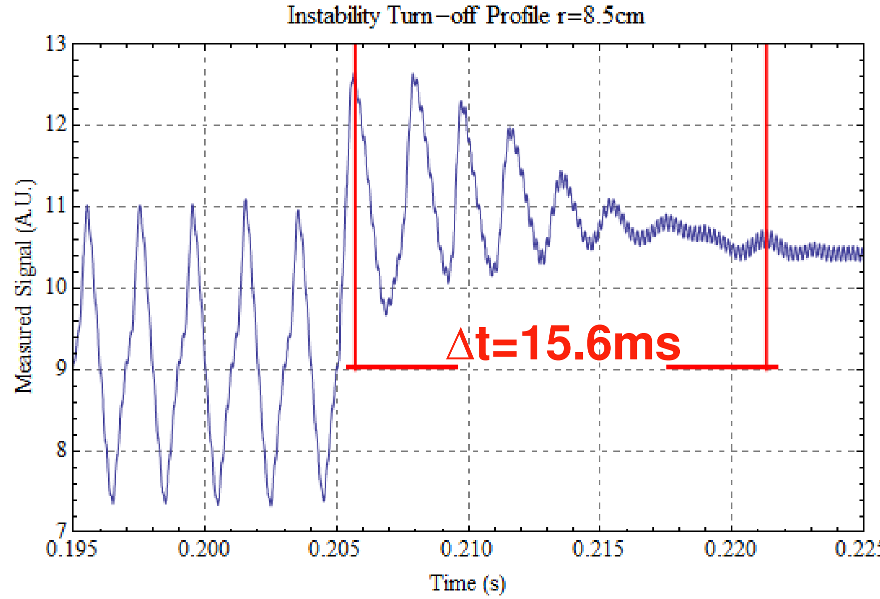

- Setup parallel bias to affect particle
  - Unable to suppress or affect plasma profiles
- Able to achieve similar results using grid when biased w.r.t. wall
  - $E_r$ appears to be essential for suppression

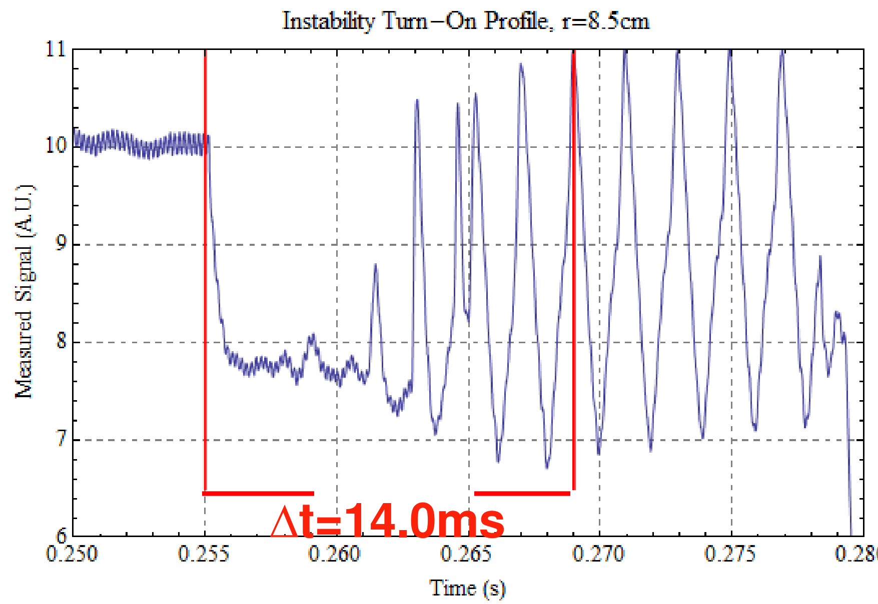


# Fluctuations and the Effect of Bias

- Easier to suppress drift-waves at low magnetic field



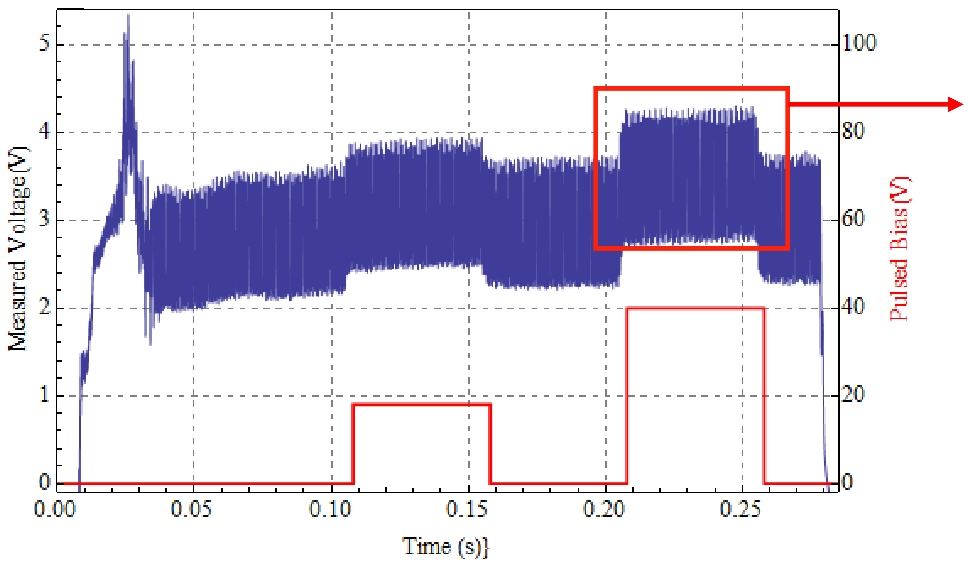



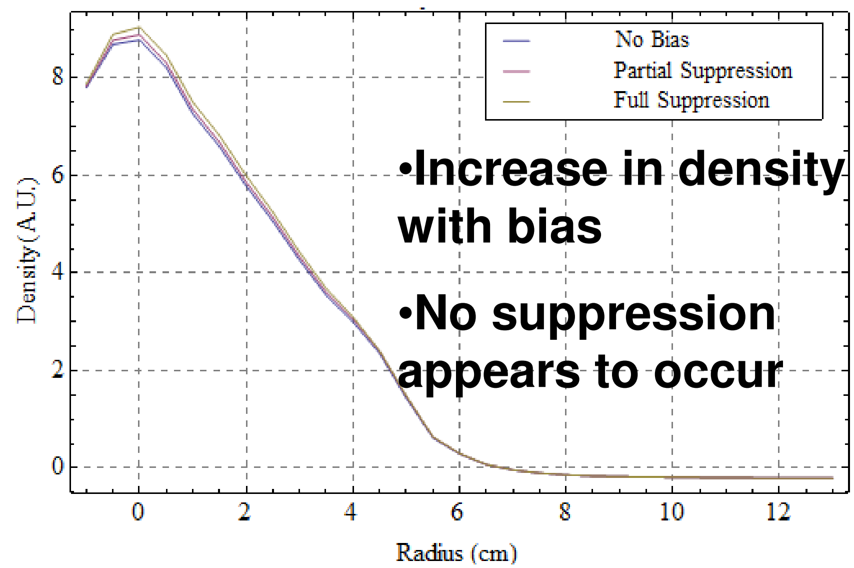

- Able to see instability turn-off and turn-on in time
  - Can try to use to find 1/e folding time
    - Future work
  - Use later to compare with theoretical values

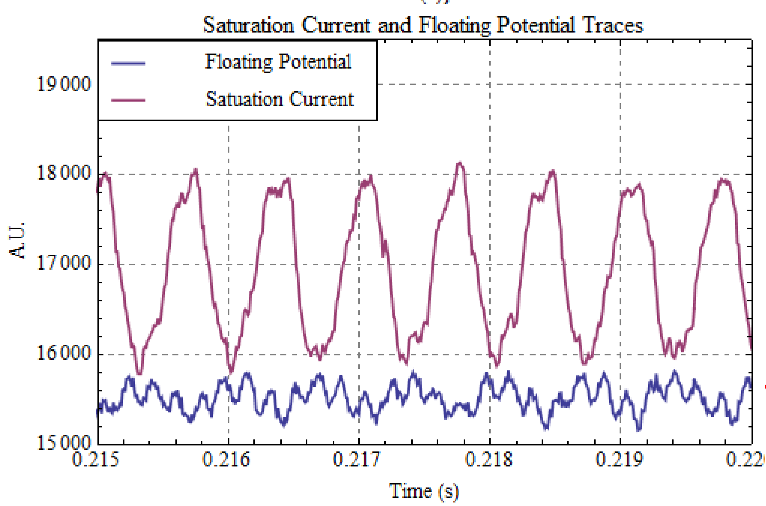
- Medium strength magnetic field, unable to suppression fluctuations
- Visible density increase in ion saturation trace

**Ion Saturation and Pulsed Bias Profiles: 705G**




**Density Profile: 705G**

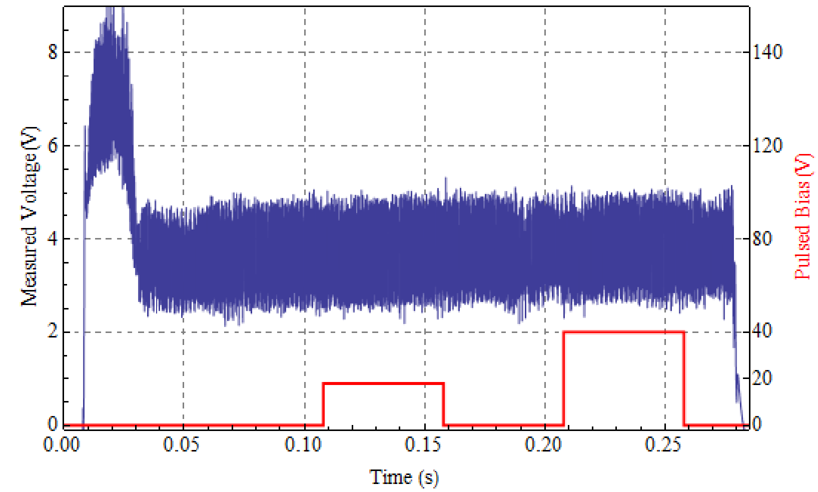


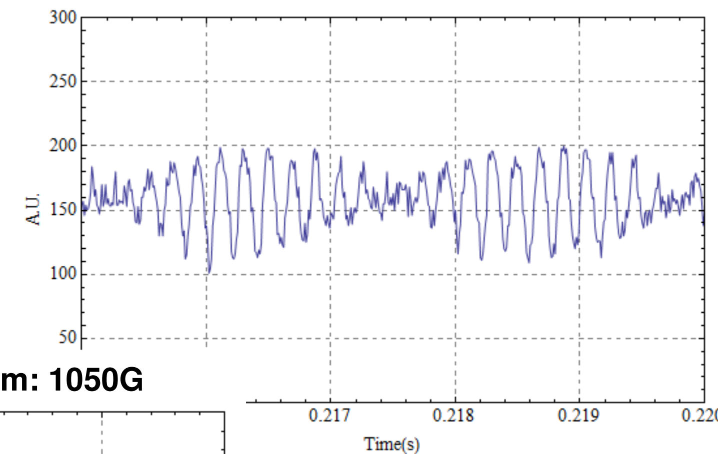

- Potential exhibits a second set of fluctuations
  - Possibly Kelvin-Helmoltz instability
  - Frequency ~5kHz

- At high magnetic field unable to suppress fluctuations
- For inner radii (0-5cm) plasma appears weakly turbulent
- For outer radii (after 5cm) plasma ‘stable’
- f=5kHz instability dominate from 5-8cm
- DW’s reappear around 8cm
  - f=500Hz
  - ‘Secondary’ instability still present

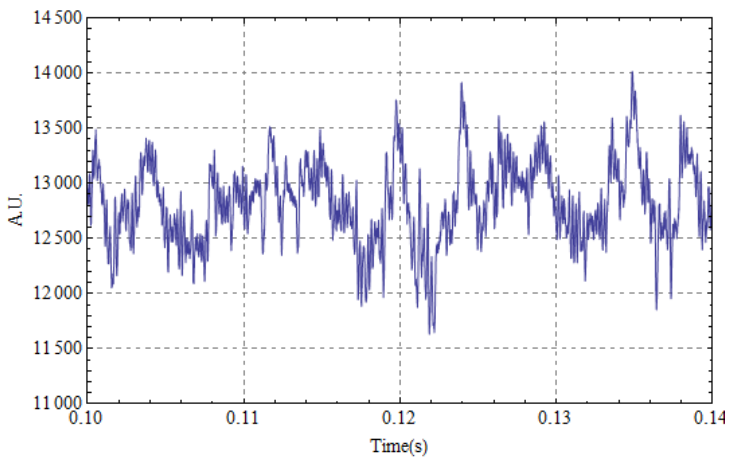
**Ion Saturation and Pulsed Bias Profiles: 1050G**



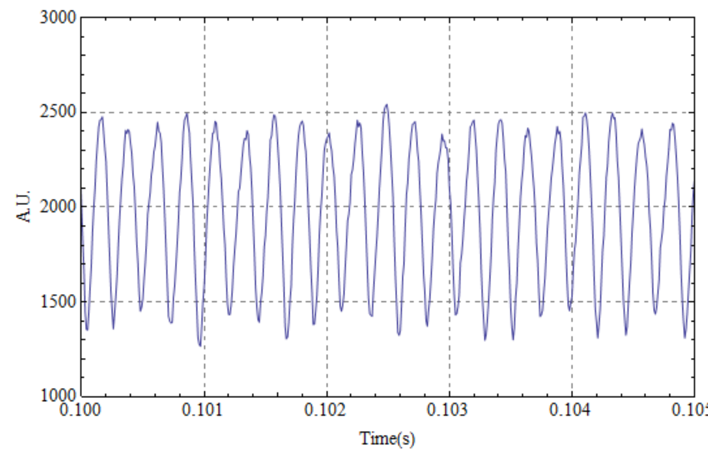

**Ion saturation at r=8cm: 1050G**




**Ion saturation at r=4.5cm: 1050G**

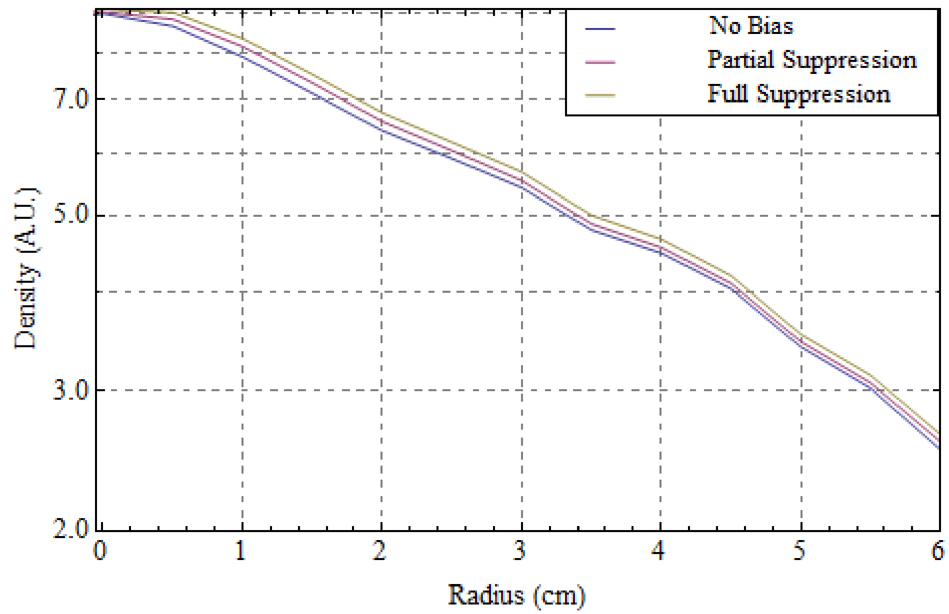



**Ion saturation at r=6cm: 1050G**

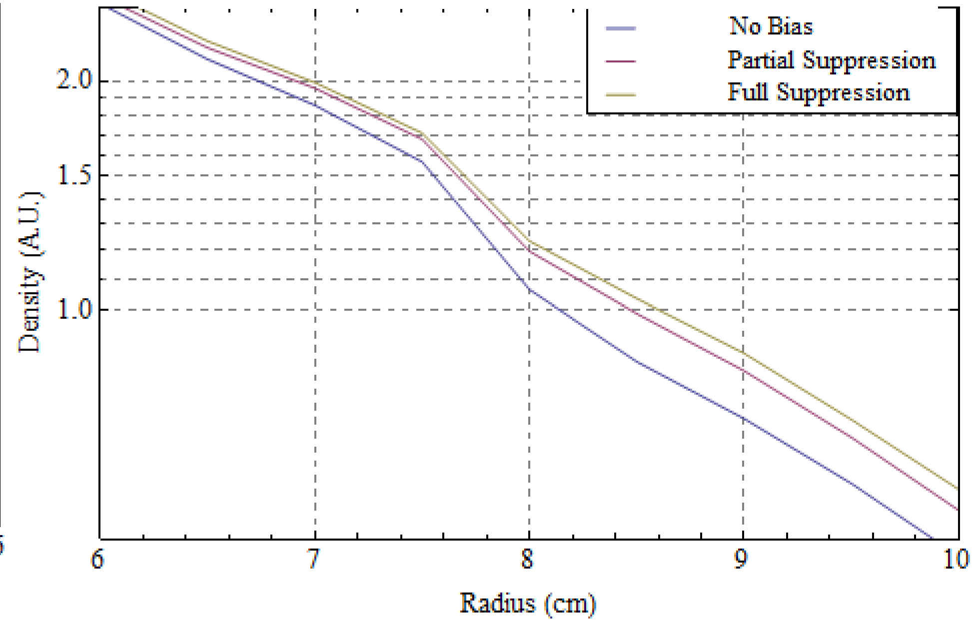


# Density Profiles

**Log Plot of Density Profile: 350G, r=0-6cm**

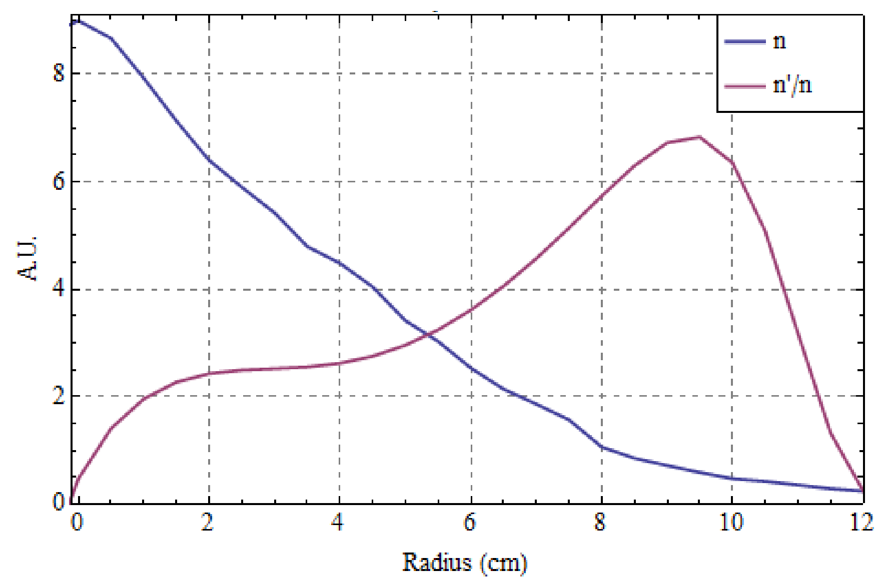


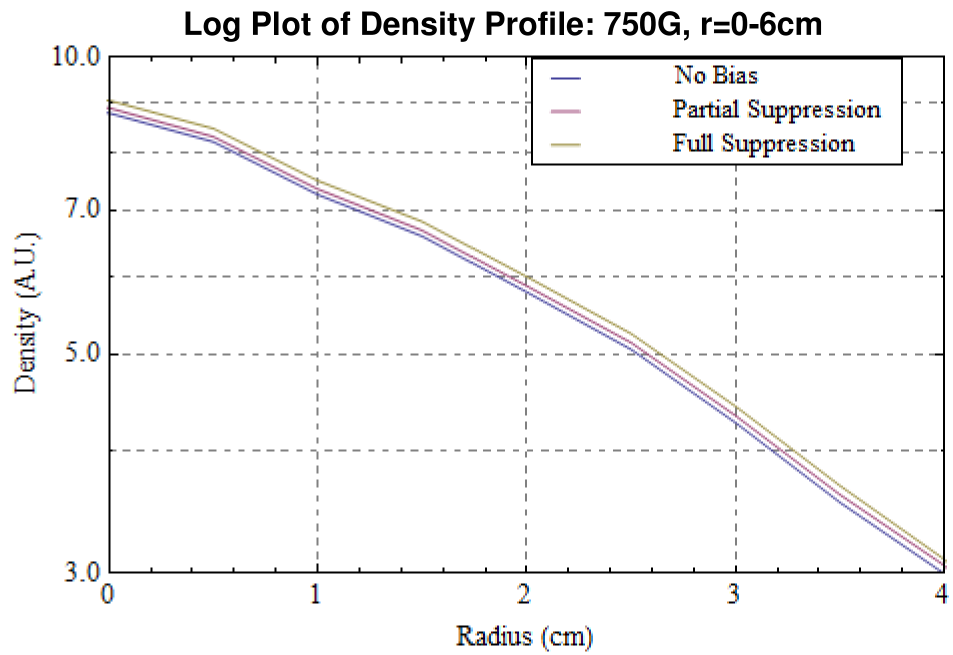

**Log Plot of Density Profile: 350G, r=6-10cm**

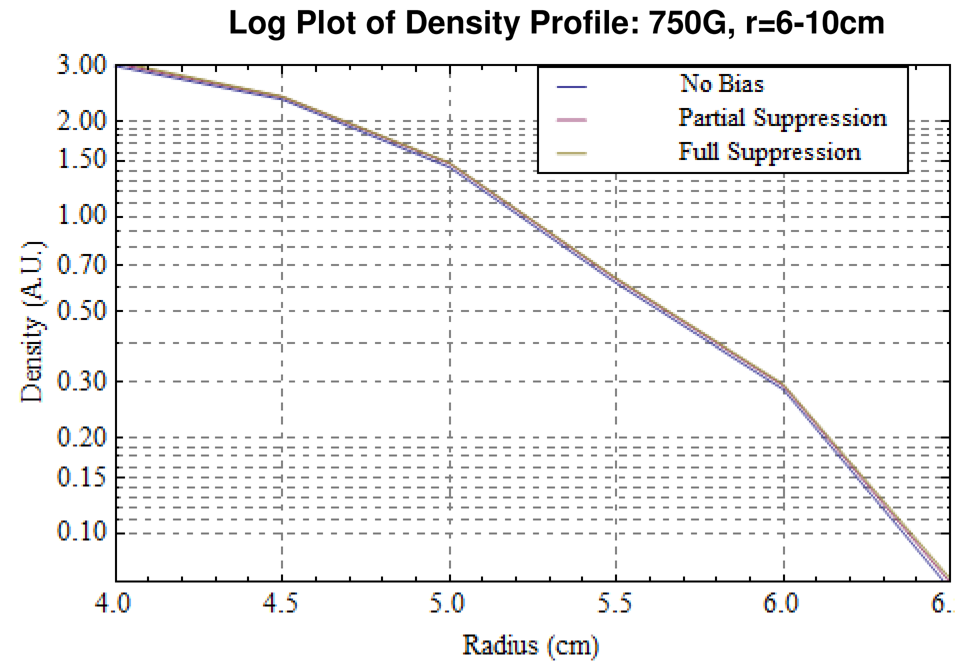



- Density peaks in the center, falls off in Gaussian
- Density increases as instability suppresses
  - Increase appears to be across whole plasma column
  - visible on ion saturation traces
- n'/n peaks at 9cm

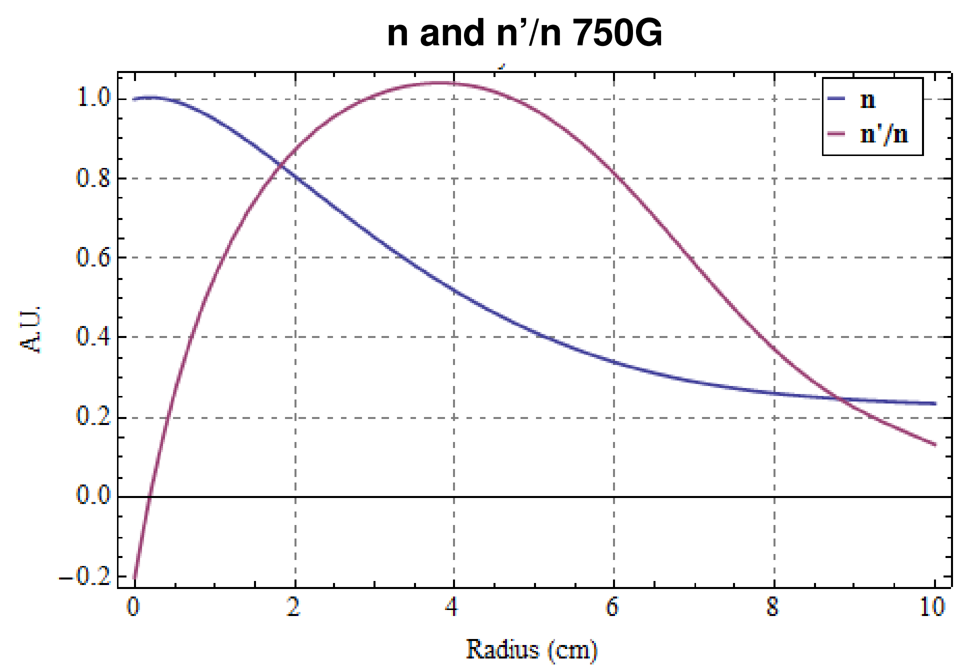
**n and n'/n 350G**



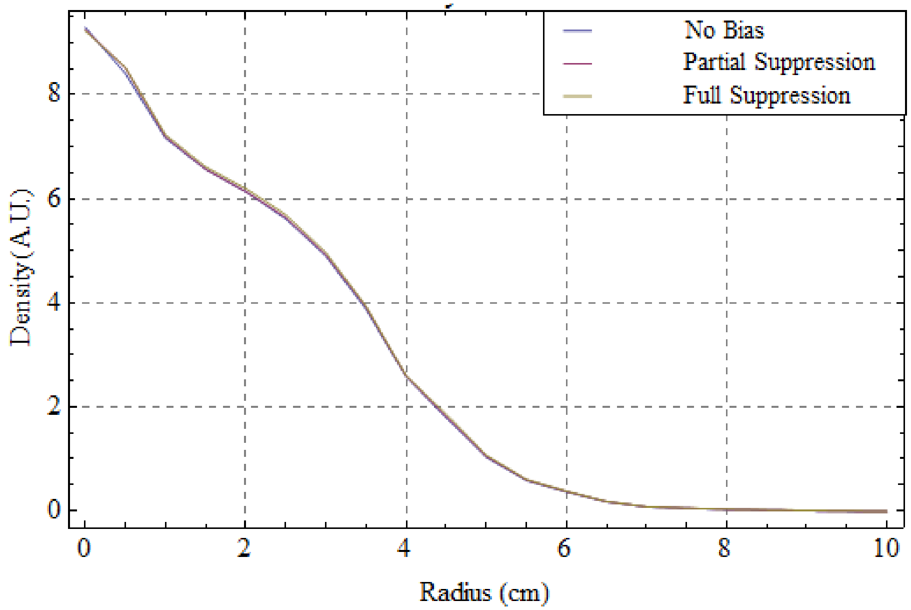


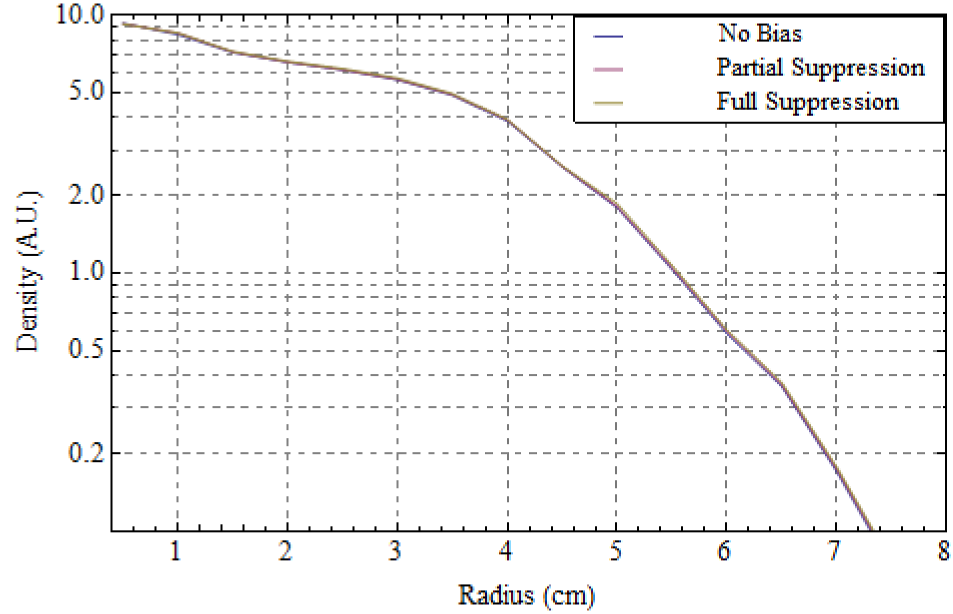

- Higher peak density than at 350G
- Density increases with bias
  - Increase largest in center region (0-4cm)
  - Increase is smaller in outer region
- n'/n peaks further in, around 4cm



Density Profile: 1050G

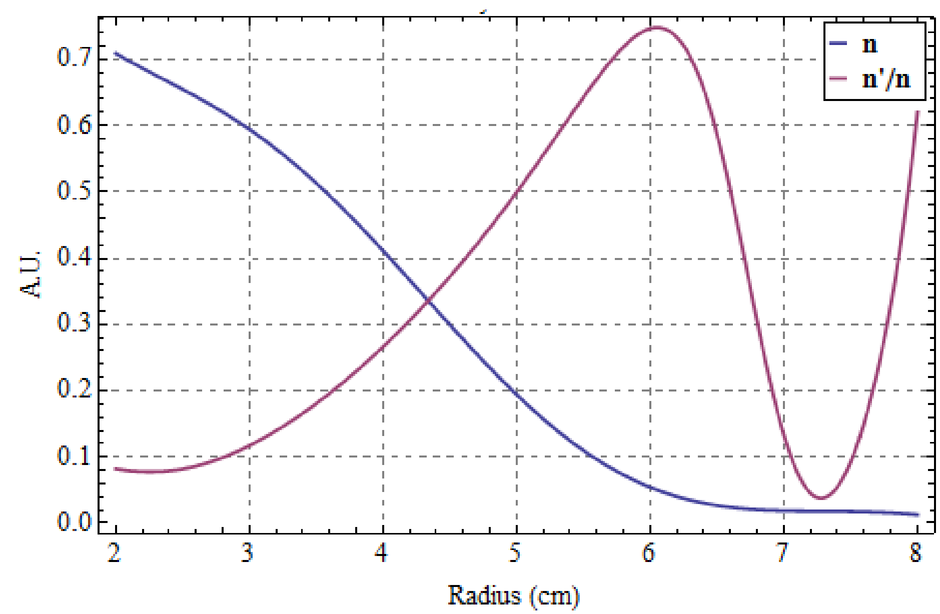



Log Plot of Density Profile: 1050G




- Higher peak density than at 705G or 350G
- No change in density with bias
- n’/n peaks further in, around 6cm

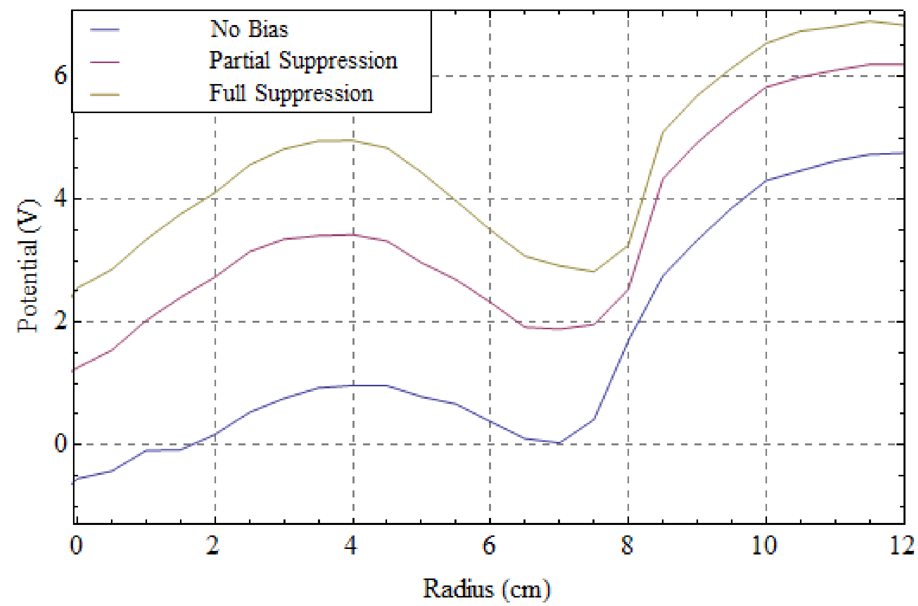
n and n’/n 1050G



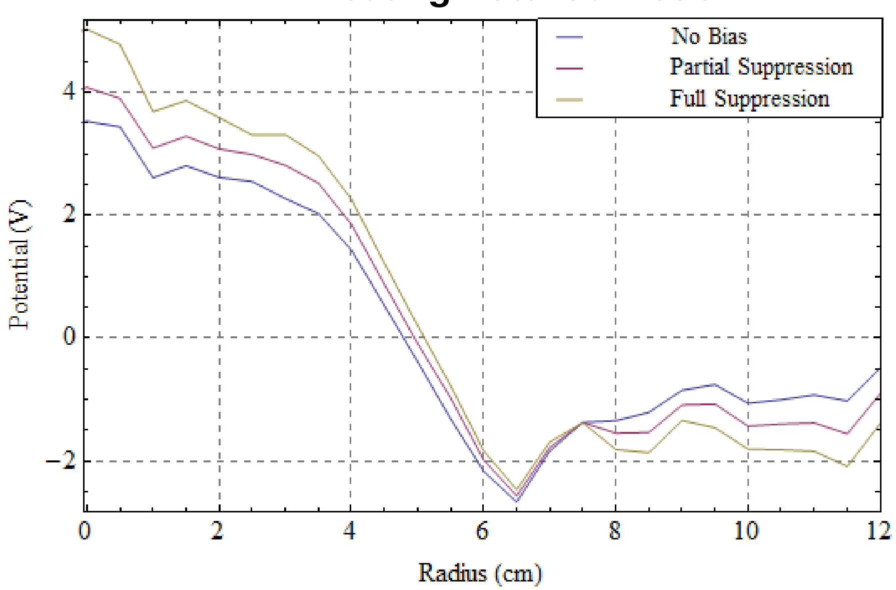
# Potential Profiles

- Overall floating potential increases
  - Basic shapes remains unchanged
- Potential well seen 6-8cm
  - Becomes deeper for increasing magnetic field
  - Moves inward in radius

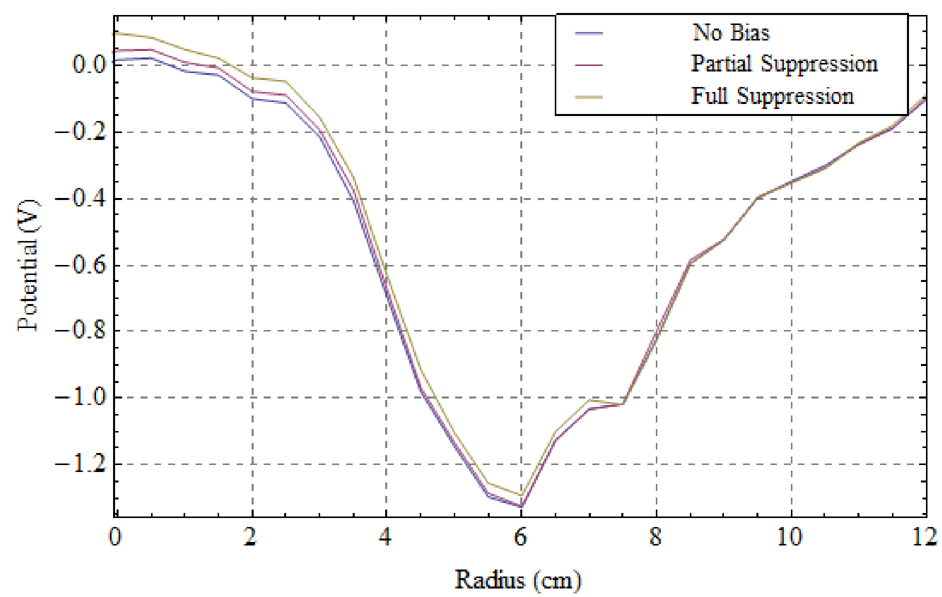
**Floating Potential 350G**




**Floating Potential 705G**

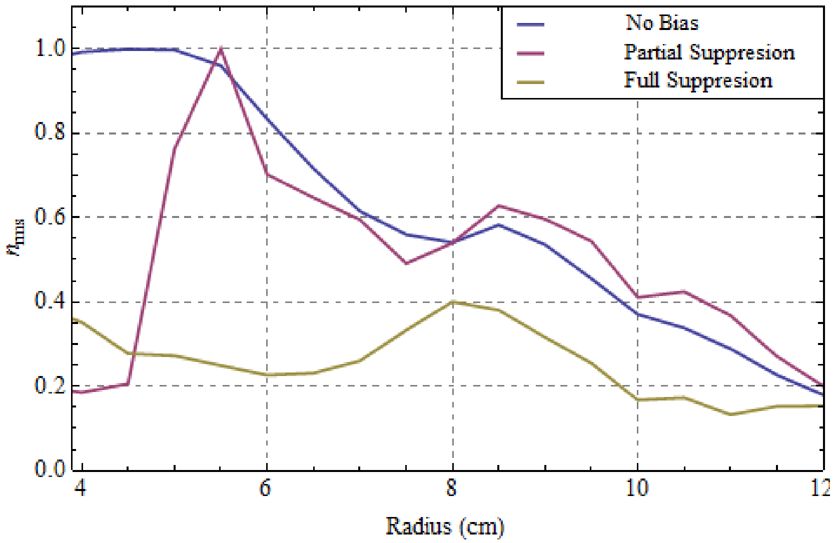



**Floating Potential 1050G**

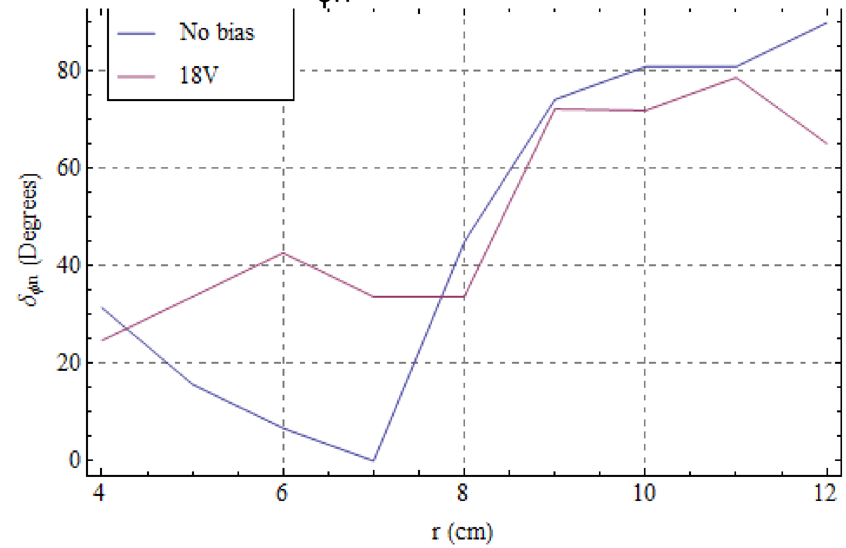


# Radial Transport

**$n_{rms}$ Profile: 350G**

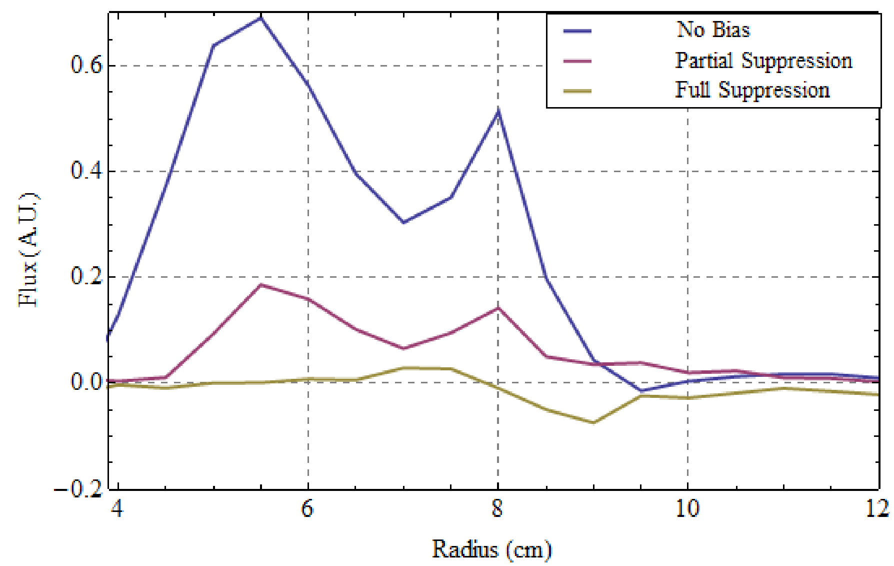



**$\delta_{\phi n}$ Profile: 350G**



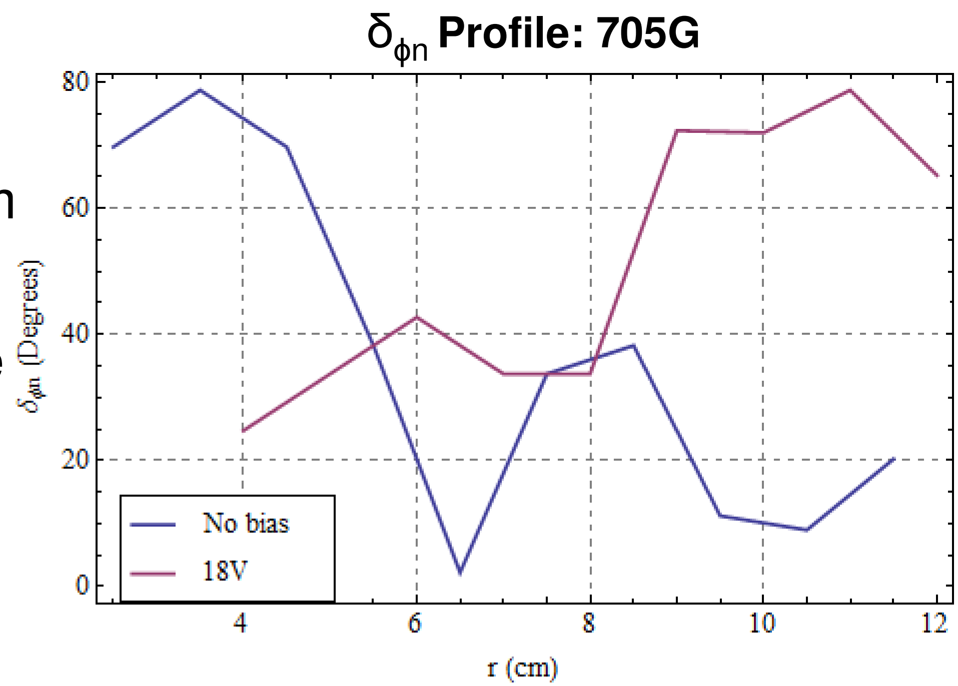

- $n_{rms}$ peaks nears 5cm
  - First peak occurs in flux
- $\delta_{\phi n}$ peaks around 8cm
  - Second peak occurs in flux
- With bias, flux decreases
  - $n_{rms}$ decreases
  - $\delta_{\phi n}$ increases at inner radii

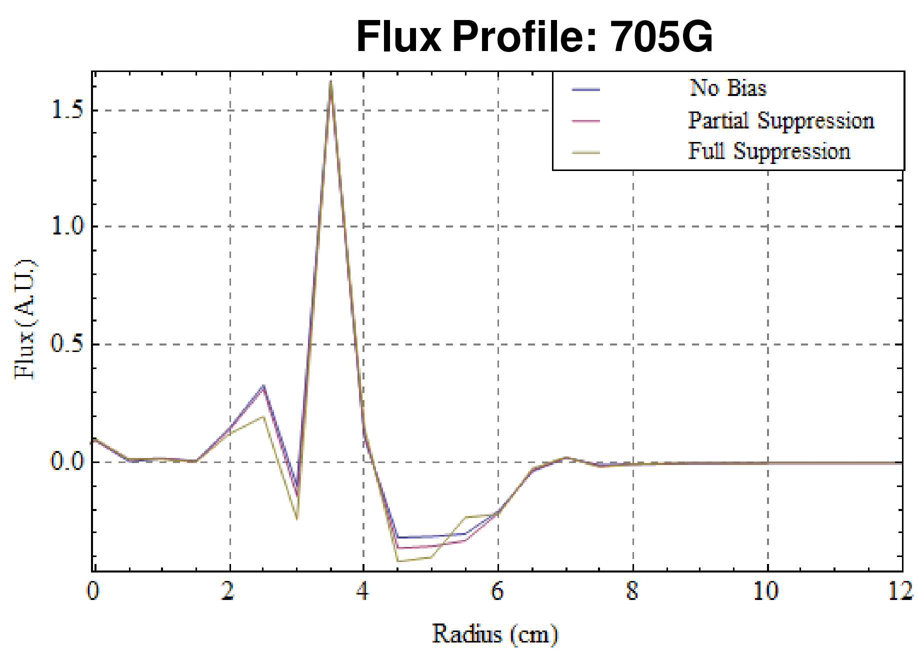
**Flux Profile: 350G**

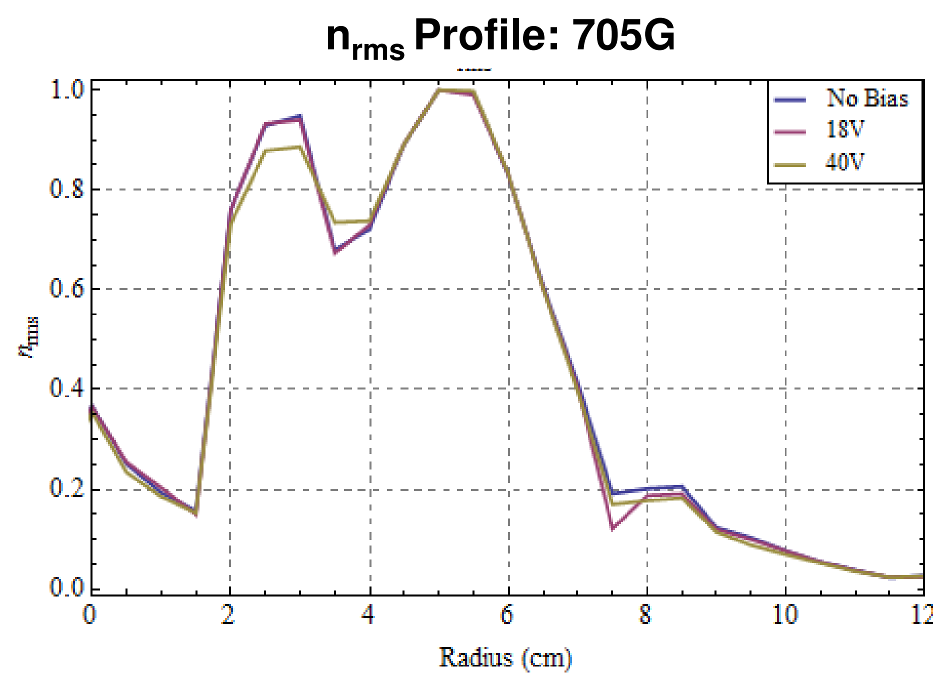



Flux appears to be dependent on both fluctuation amplitude and $\delta_{\phi n}$

- $n_{rms}$ peaks nears 3cm and 5cm
  - Large peak occurs in flux at 3cm
  - Second peak occurs in flux at 5cm
- $\delta_{\phi n}$ peaked near center radii
  - With bias, see a reversal in profile
- With bias, flux is unchanged
  - $n_{rms}$ also essentially the same
  - $\delta_{\phi n}$ decreases at inner radii and increases at edge



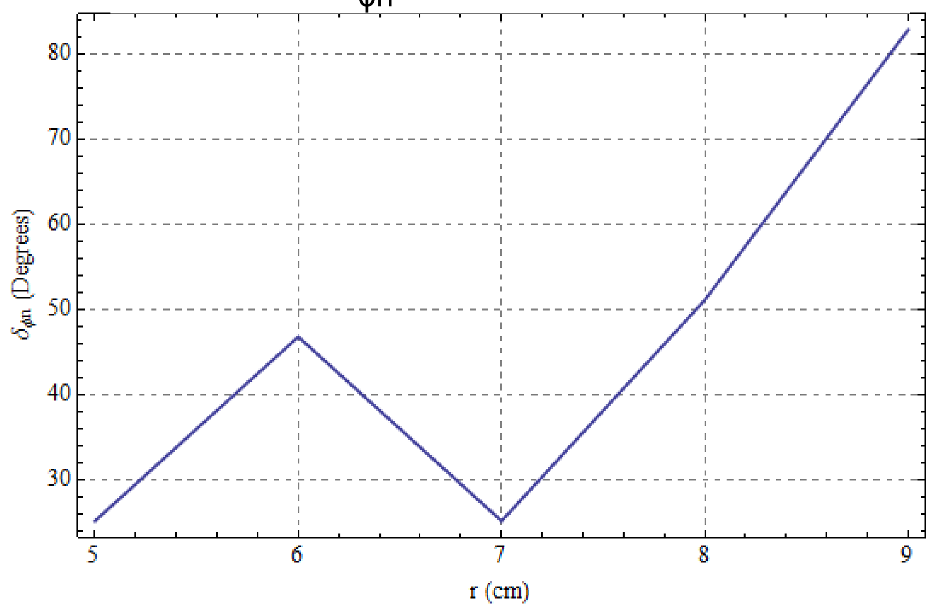



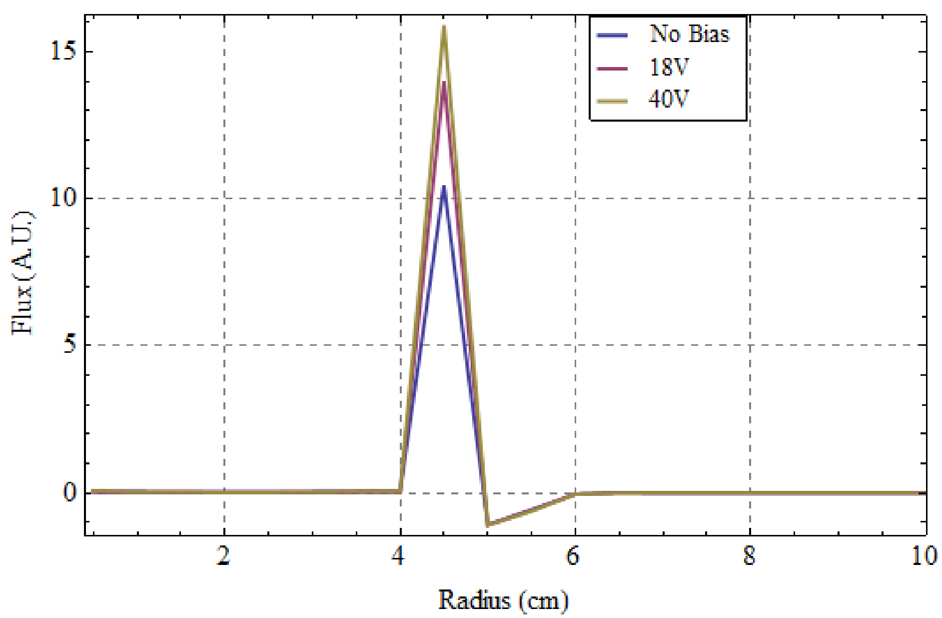

Flux at high magnetic field dependent on fluctuation amplitude

- $n_{rms}$ peaks nears 3cm and 5cm
  - Large peak occurs in flux at 3cm
  - Second peak occurs in flux at 5cm
- $\delta_{\phi n}$ peaked near center radii
  - With bias, see a reversal in profile
- With bias, flux is unchanged
  - $n_{rms}$ also essentially the same
  - $\delta_{\phi n}$ decreases at inner radii and increases at edge

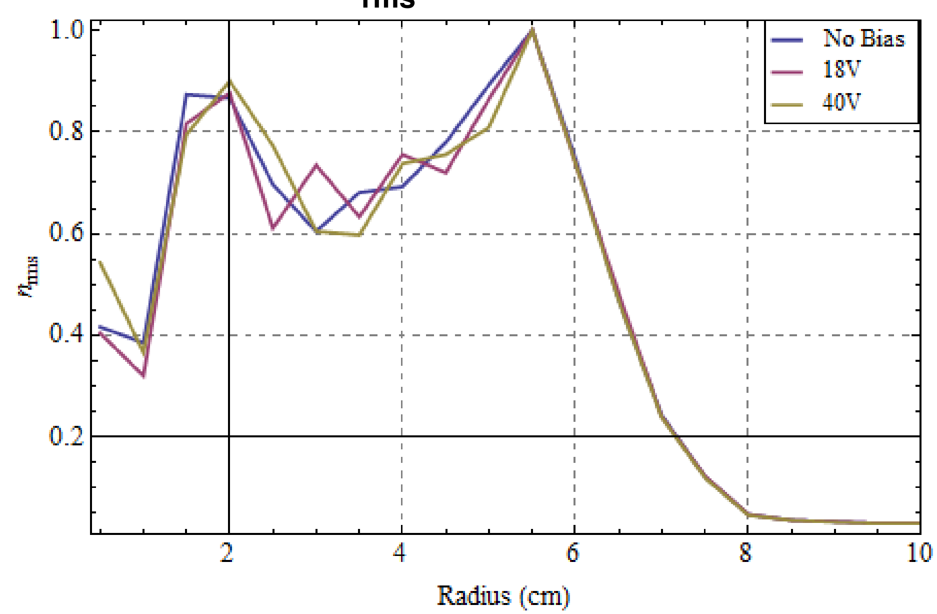
**$\delta_{\phi n}$ Profile: 1050G**




**Flux Profile:1050G**

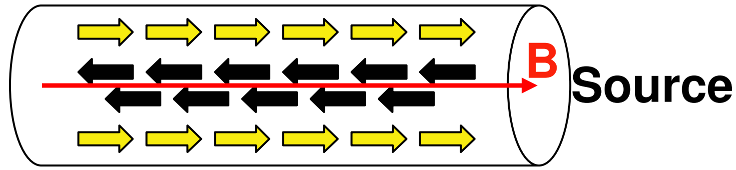



**$n_{rms}$ Profile:1050G**

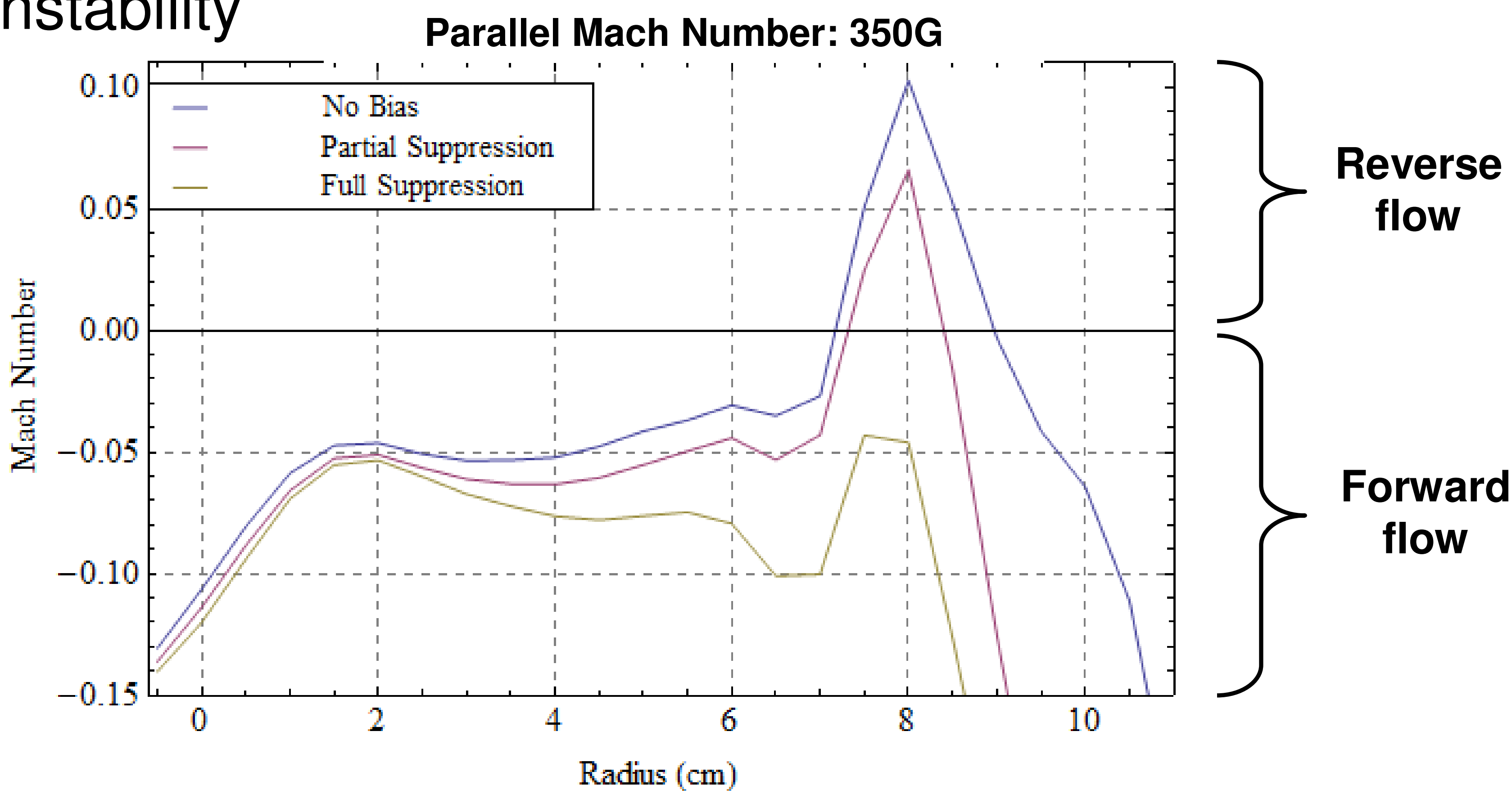


# Flows: $v_{||}$

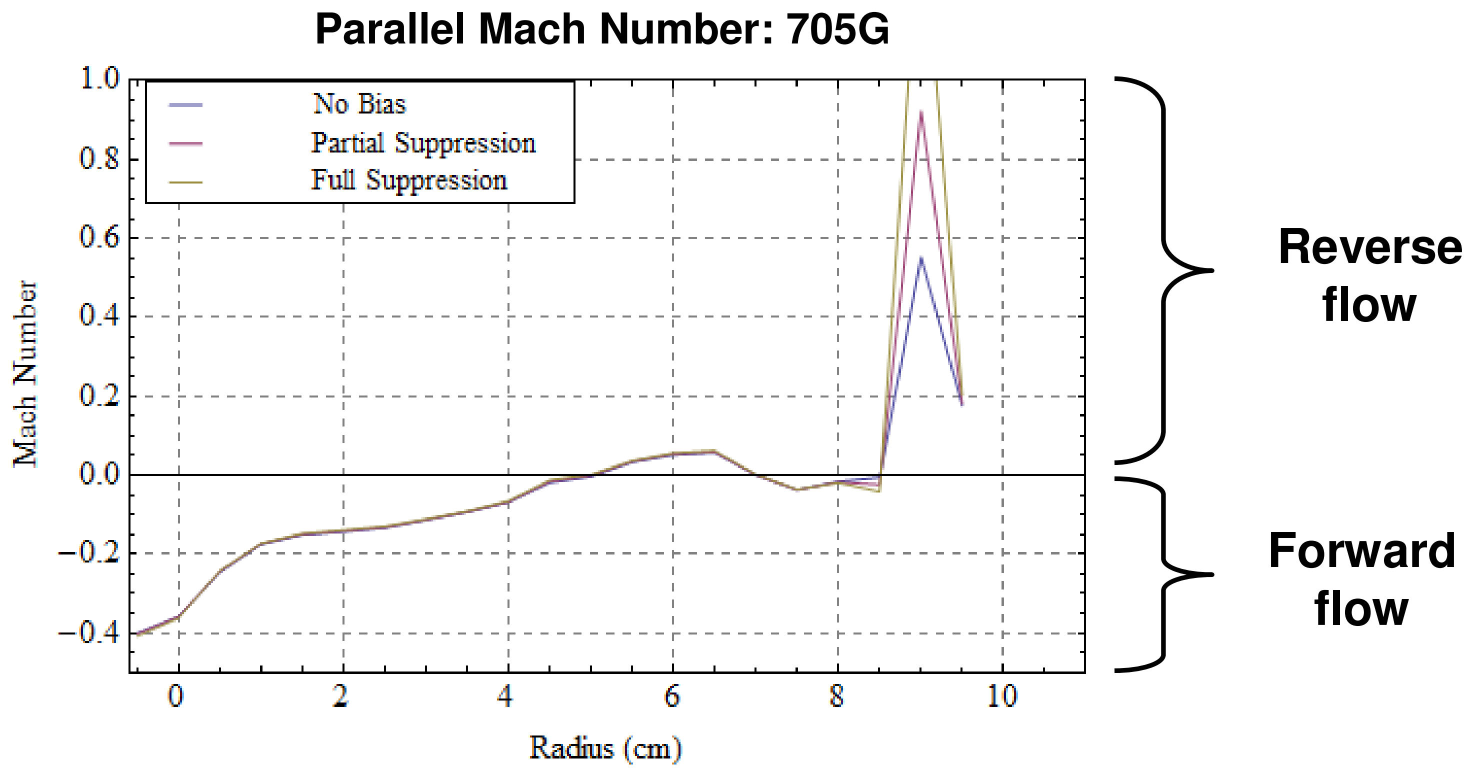
- Without bias, parallel flow exhibits return flow in plasma edge
  - Occurs near peak of n'/n




- Reduces with bias and reverses direction with suppression of instability



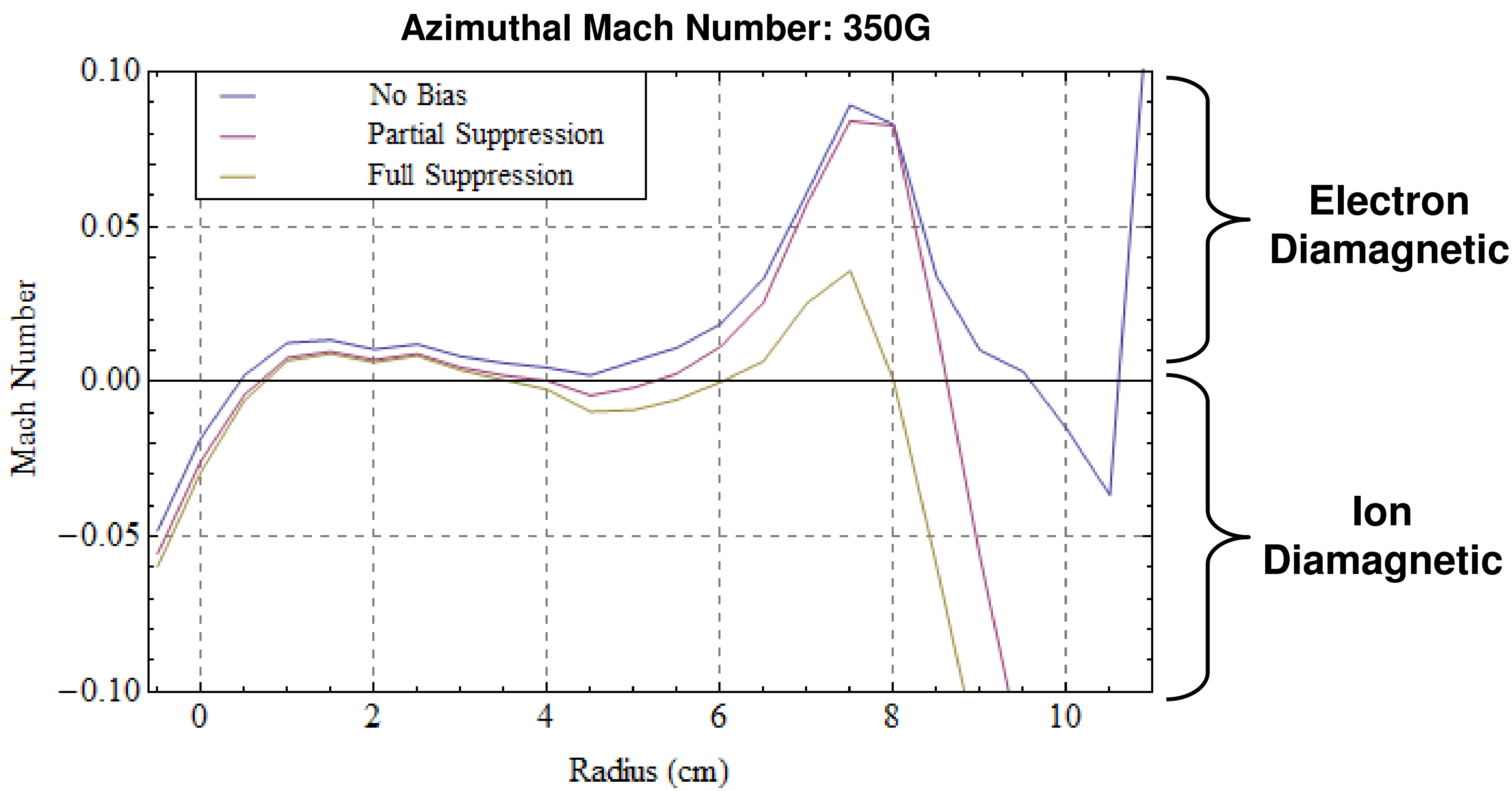
- Return flow exists for higher magnetic field
  - Moved inwards
  - Cross-over radius ~5cm at 705G
- No change with bias



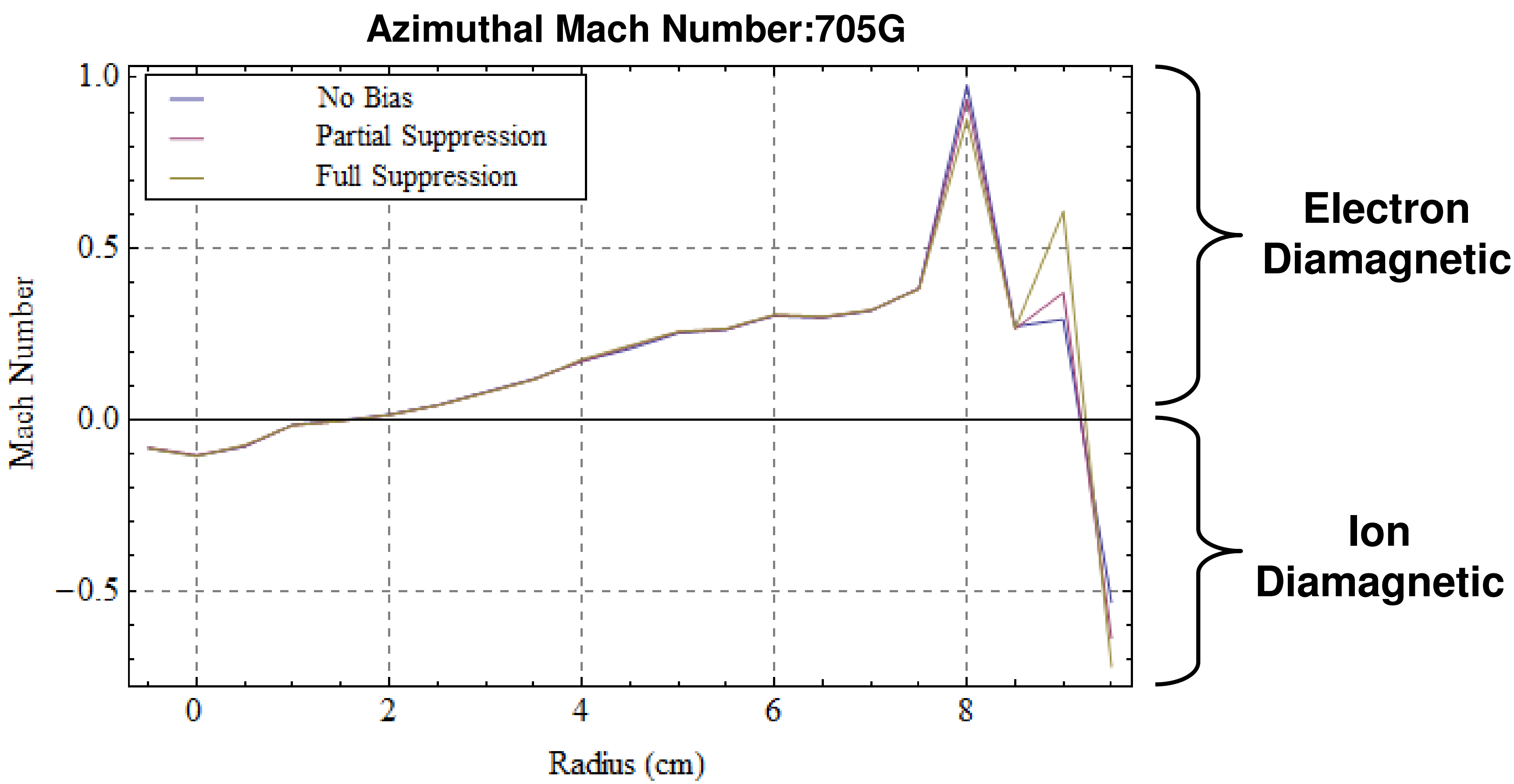

- Appears to be relationship between return flow and instability

# Flows: $v_\perp$

- Azimuthal Flow primarily in the electron diamagnetic direction
- Strong shear in outer region of plasma
  - Reduces with biasing towards ion diamagnetic direction



- Azimuthal flow is now strictly in the electron diamagnetic direction
- Strong shear in outer region of plasma
- As may be expect, no change is seen in the azimuthal flow



# What's Happening? A guess

- Believe parallel reverse flow is an *effect* of the radial transport
  - Reverse flow creates large shear in $v_{||}$
  - Does not appear to cause or affect instability
  - Unable to affect with parallel biasing
- Extra charge particles in outer region due to radial transport
- To satisfy parallel boundary conditions, reverse flow is generated
  - As radial transport is reduced, less charged particles carried to outer region
  - Reverse flow no longer required

**Evidence is inconclusive at this time.**

**Exact mechanism of reverse flow-radial transport unknown**

# Modeling: Summary

- Currently using two codes in an attempt to better understand physics in HelCat
- Linear Stability Solver (LSS)
  - Use to understand instabilities observed in HelCat
  - Separate which instabilities are dominate
  - Use to compare to measured growth rates
- ODISEE
  - Used to look at sheath affects, particularly at boundary conditions
  - Use to better understand boundary conditions
- Global Braginskii Solver (GBS)
  - Future work: Three dimensional code to solve complete system of equation for HelCat
  - Compare simulation to HelCat data
  - More carefully look at physics causing flows and instabilities

# Linear Stability Solver[1]

- Better understand intrinsic fluctuations in HelCat plasma
  - Drift waves vs. resistive interchange mode
- Find most unstable modes and $k_{||}$
  - Electrostatic Braginskii equations
  - Finite-difference scheme
- Input: Equilibrium profiles
  - Density
  - Potential
  - Temperature
- Output
  - Growth rate of instability

1. P. Ricci and B.N. Rogers (2009). Phys Plasmas 16, 062303.

- Measured m=1 mode in HelCat Plasma
  - LSS gives m=1 dominating for normalized $k_{||}$=.108
  - This corresponds to $\lambda_{||}$=5.82m
  - Experimental value $\lambda_{||}$~5.5m
- Growth rate indifferent to temperature
  - Changes in peak or gradient have little to no affect on instability
- Growth rate sensitive to:
  - Peak density
    - Larger growth rates for lower densities
  - Density Gradient
    - Removing suppresses instability
  - Potential Gradient
    - Removing slightly increases growth rate
  - Resisitivity
    - Removing suppresses instability

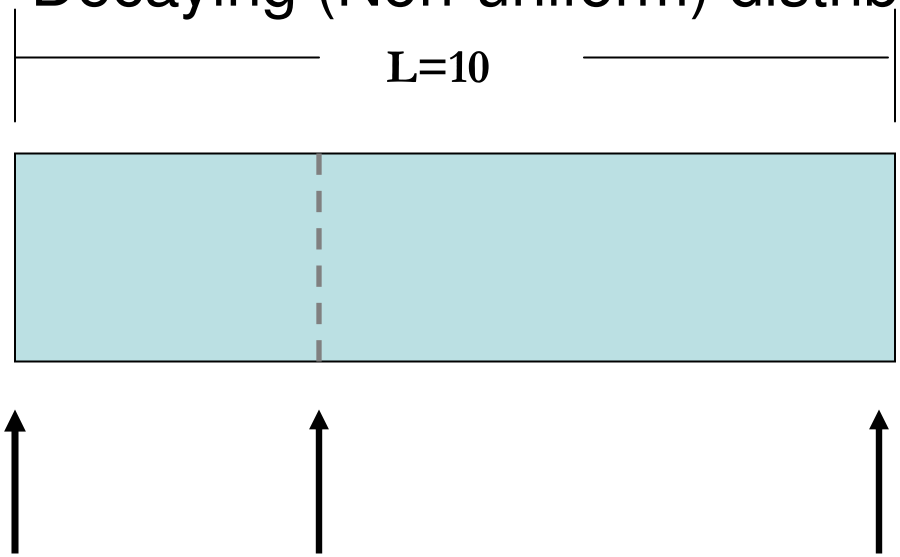
Normalized Growth Rates from LSS Code

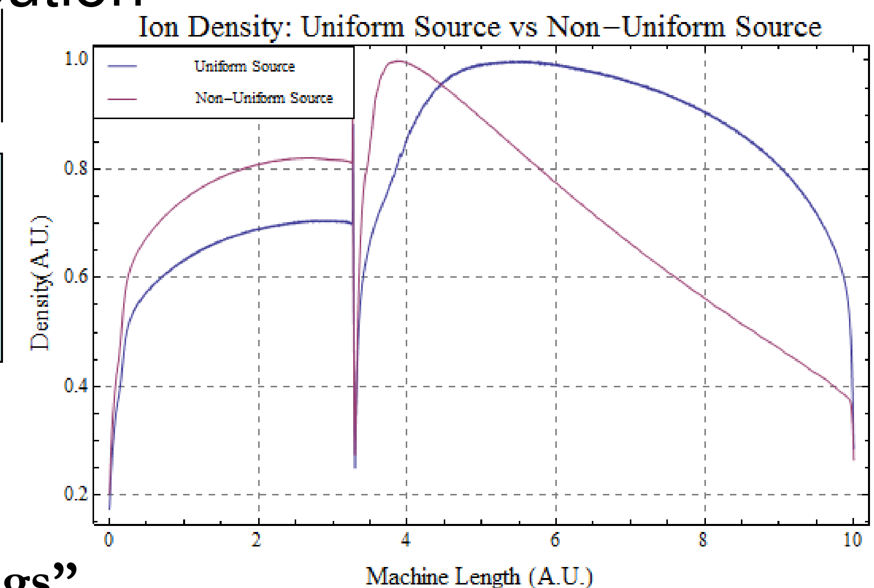
B=350G and n=1*$10^{13}$ $cm^{-3}$

| **Normalized $k_{\|\|}$** | **m=1** | **m=2** | **m=3** |
|---|---|---|---|
| **0** | 2.8991e-14 | 7.3589e-14 | 8.7283e-14 |
| **.1** | 2.9939 | 2.5520 | 1.0272 |
| **.108** | 3.1182 | 2.9391 | 1.1947 |
| **.109** | 3.1402 | 2.9863 | 1.2163 |
| **.11** | 3.1619 | 3.3026 | 1.238 |
| **Maxes at:** | **$k_{\|\|}$=.5** | **$k_{\|\|}$=.7** | **$k_{\|\|}$=1.3** |

# ODISEE[1]

- One-Dimensional Sheath Edge Explorer
- Look at effects of biasing electrodes
- Look at boundary conditions and their affects
- Two possible particle distributions
  - Uniform distribution
  - Decaying (Non-uniform) distribution



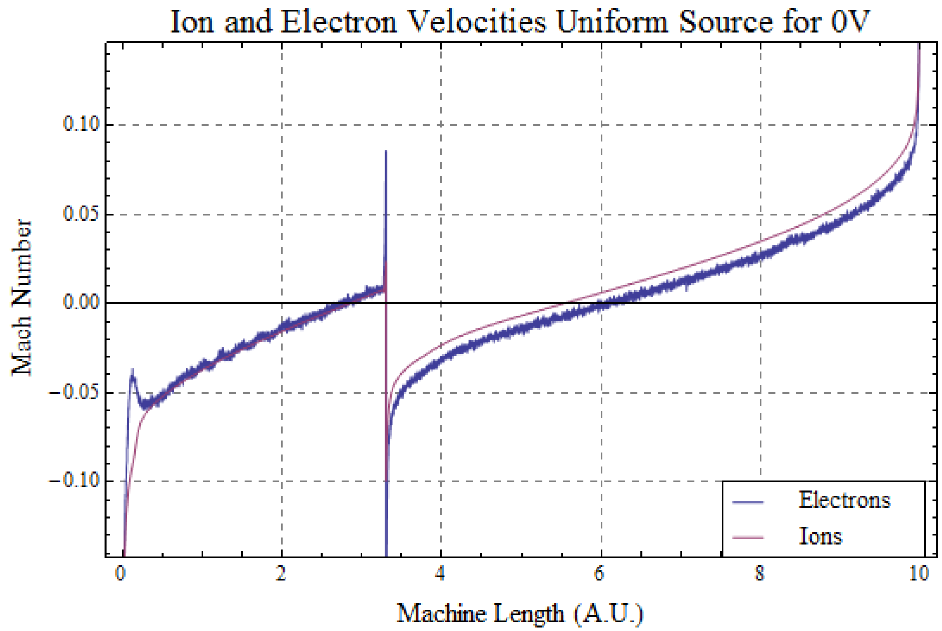

**"Source"**
- Floating

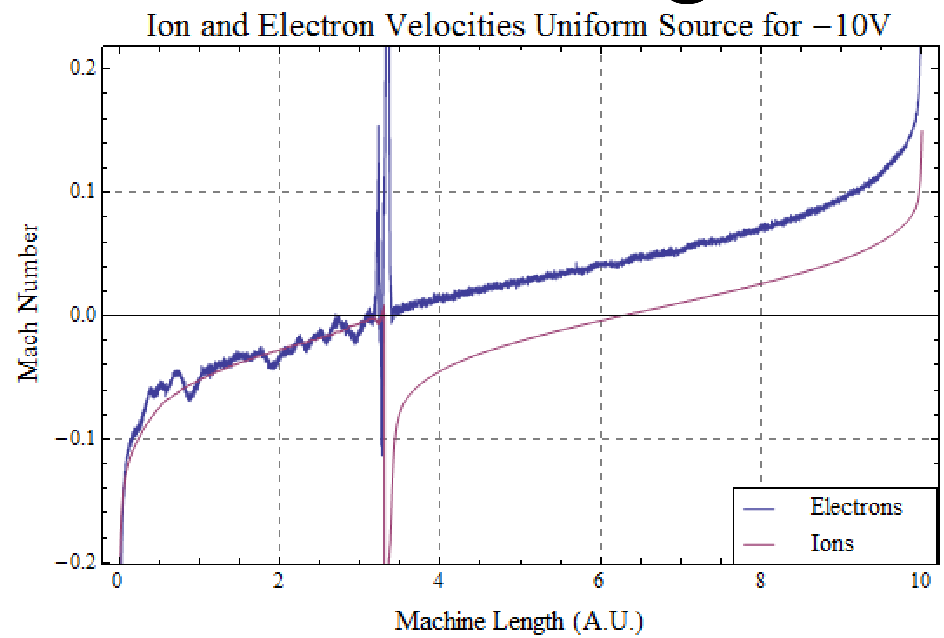
**"Grid"**
- Position
- Biased w.r.t. ground
- Transparency level

**"Rings"**
- Ground

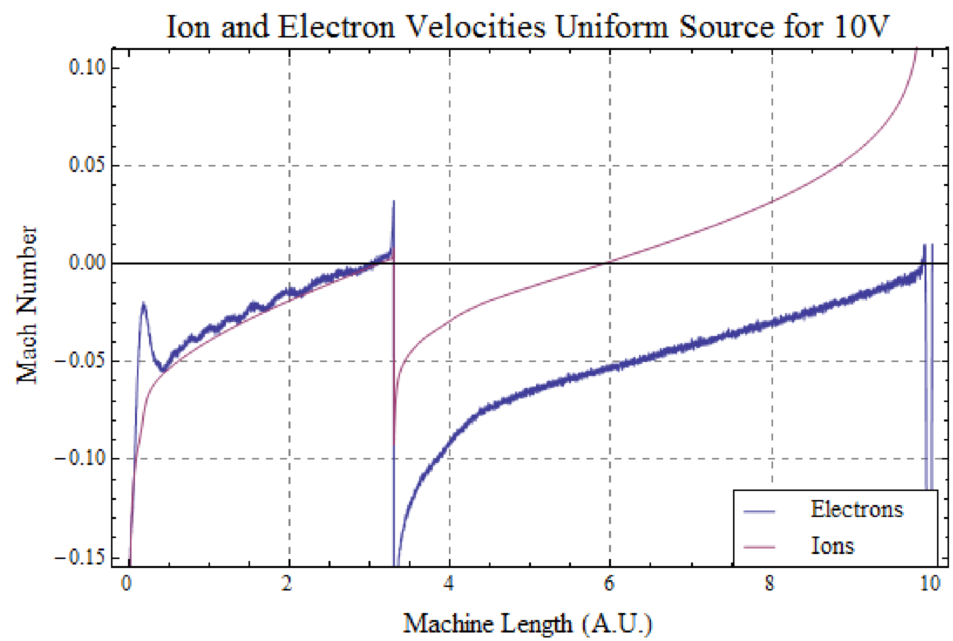
1. J. Loizu, P. Ricci, and C. Theiler (2011). Phys Rev E 83, 016406.

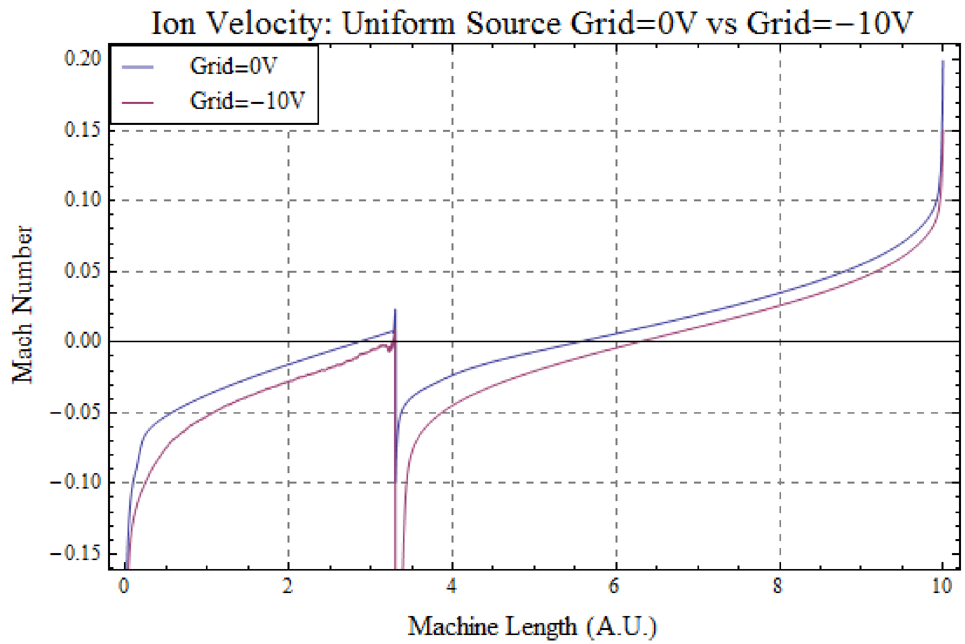
# Uniform Source and Biasing



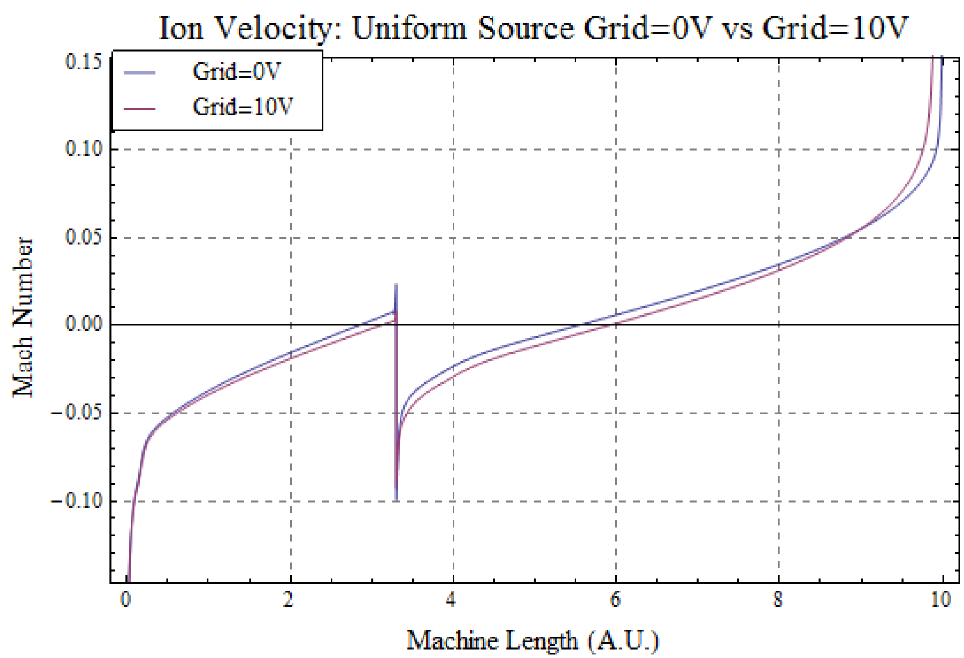



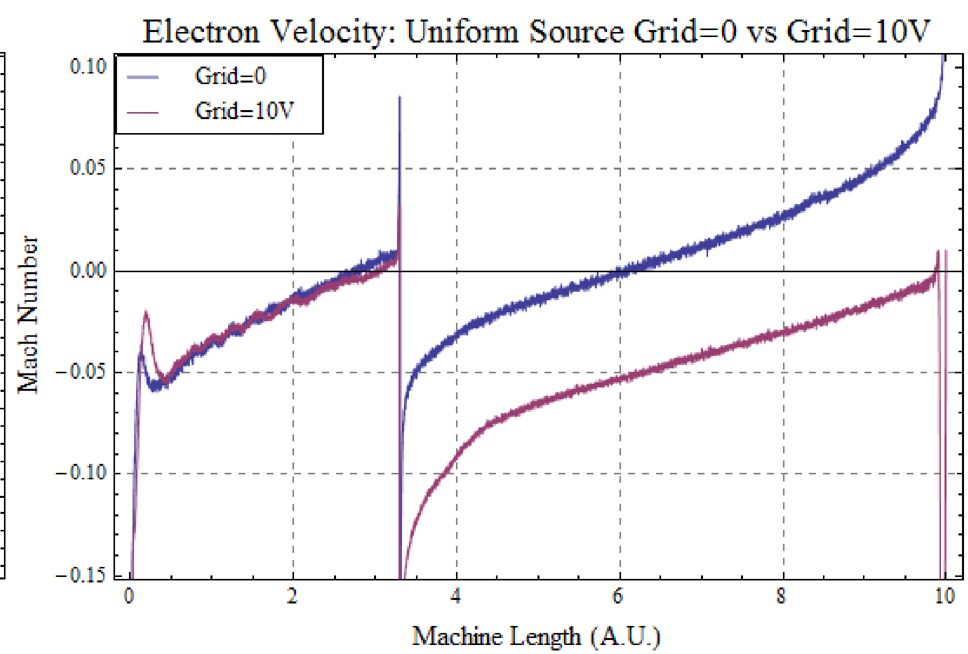

- Bias causes velocity separation between species
  - Positive bias de-accelerates electrons
  - Negative bias accelerates electrons
- Little affect on ions



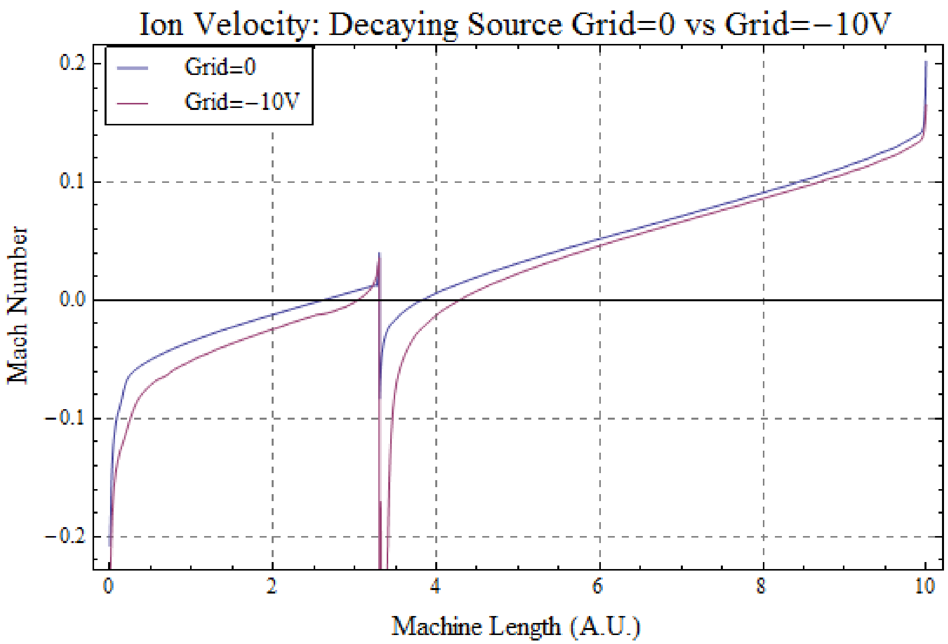



- Biasing appears to have little to have little to no affect on ion velocity
- Biasing has strong affects on electron velocity
  - Positive bias causes pure back flow

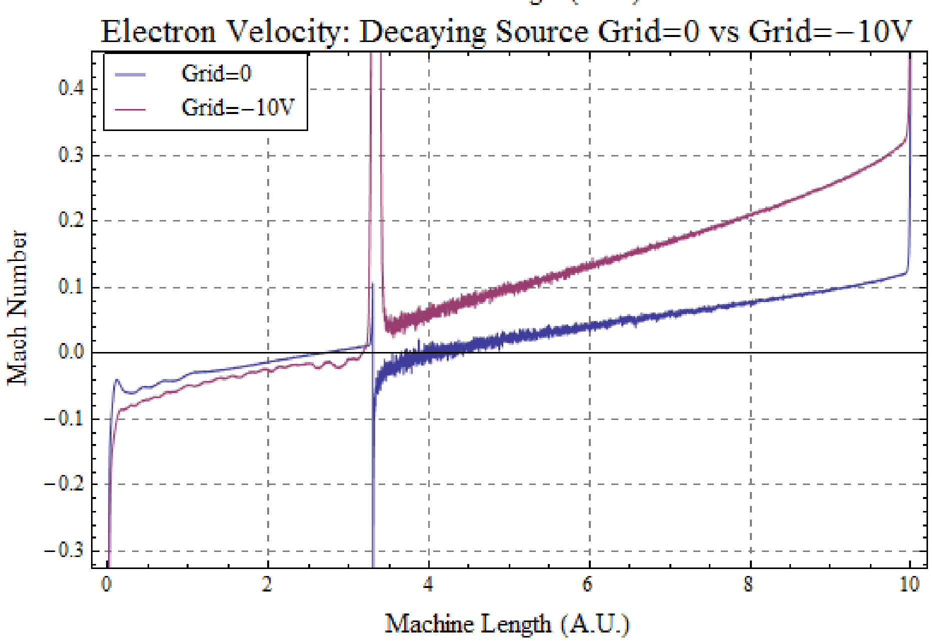


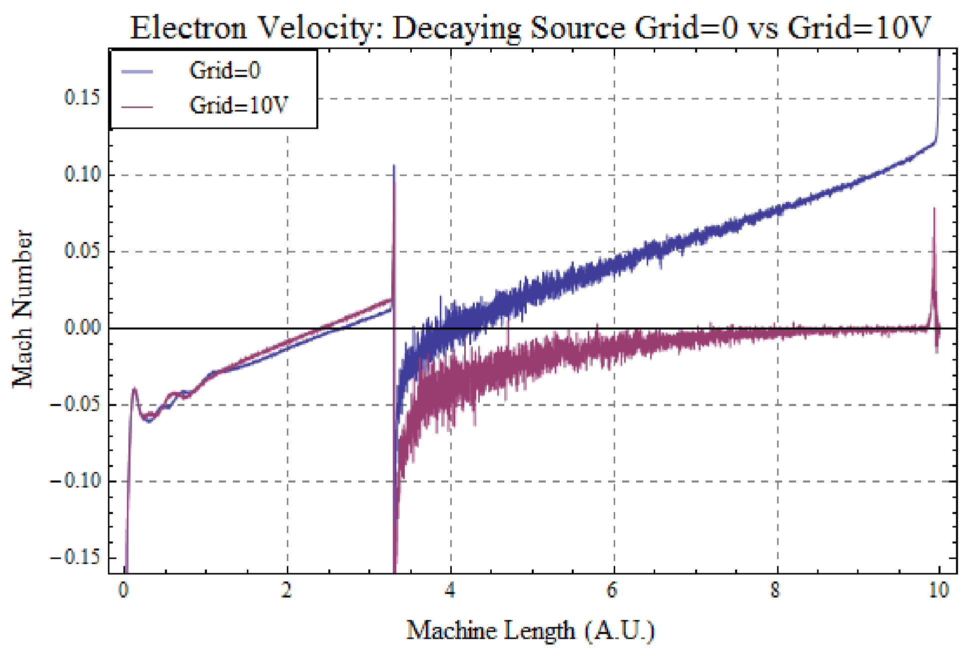



# Decaying Source and Biasing

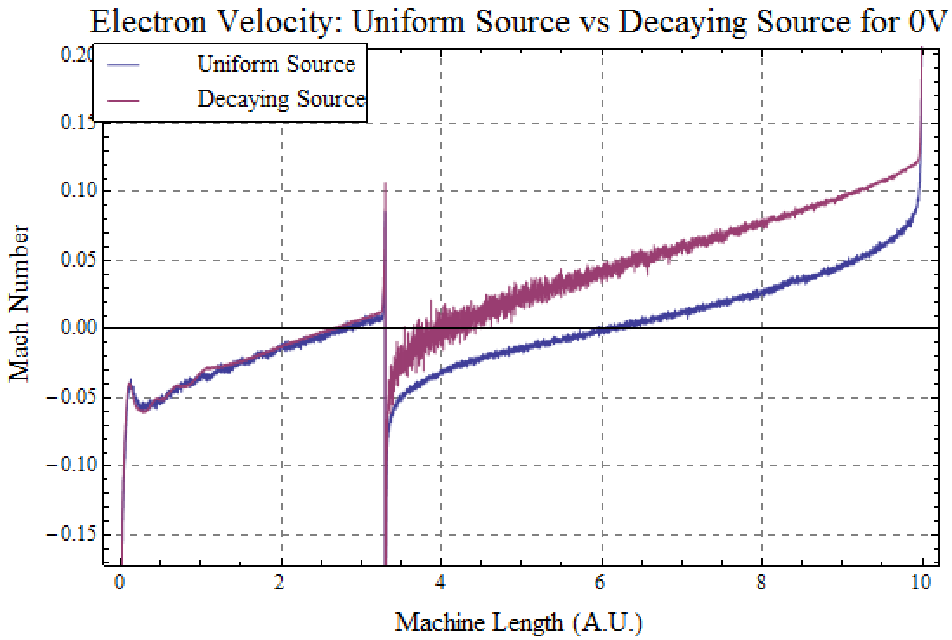



- As with uniform case, bias has little affect on ion velocity
- Strong affect again seen in electron velocity
- Positive bias able to create small backflow
  - Zero flow at L≥7

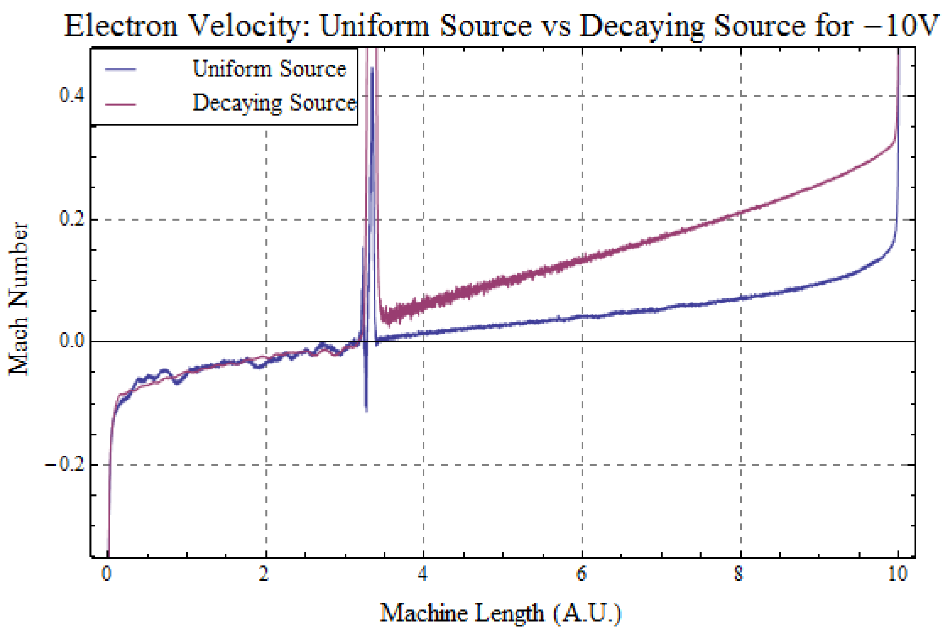


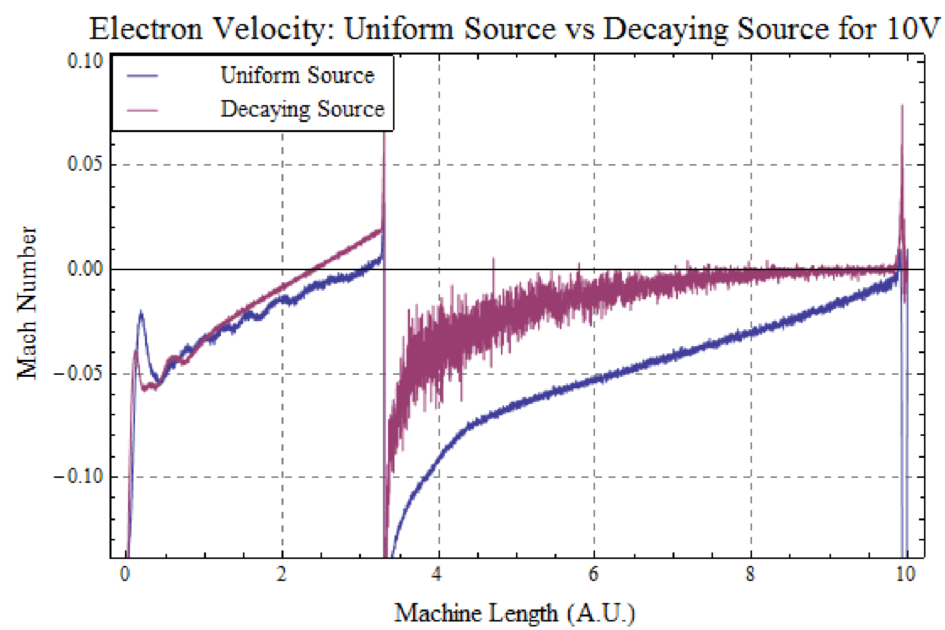



# Uniform Source vs. Decaying Source




- Decaying sources exhibit mostly forward flow
  - Back flow is small and essentially zero
- Particles exhibit larger forward flow values for a decaying source



# Summary

- Biasing is used to suppress intrinsic fluctuations in the plasma
  - Two instabilities present at higher magnetic fields
  - Suppression changes plasma potential and density at low magnetic field
    - More difficult at higher magnetic fields, possibly due to second instability
- Biasing reduces particle flux
  - See changes in both the cross-phase and amplitude
  - Amplitude of fluctuations seems to dictate particle transport
- Reverse parallel flow is exhibited in HelCat
  - Flow is associated with potential wells and n'/n
  - Suppression of fluctuations suppresses reverse
- Working with experiments and models to better understand physics occurring in Helcat