Experimental investigation of magnetic-field topology via a perturbation method in the PFRC-2 device

U.S. DEPARTMENT OF ENERGY | Office of Science | PPPL PRINCETON PLASMA PHYSICS LABORATORY

Authors: Jack Matteucci, Peter Jandovitz

Advisor: Sam Cohen

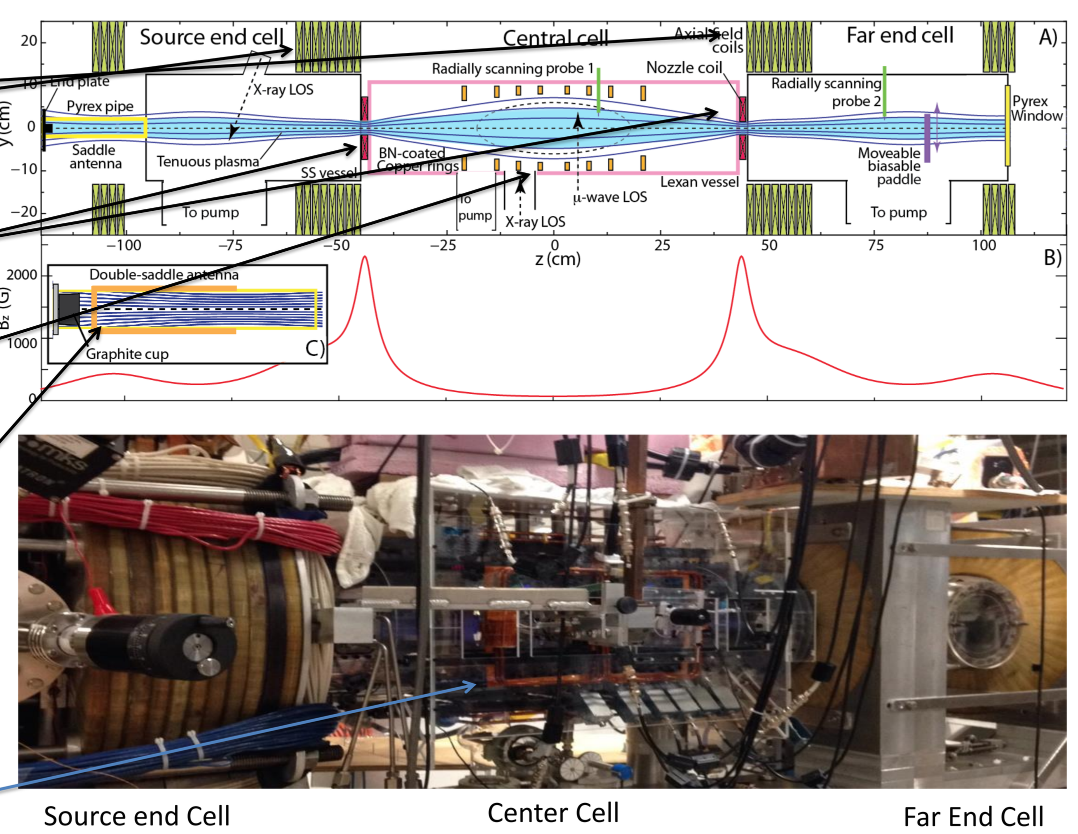
Abstract

The fundamental question about FRC experiments is whether an FRC has actually formed; specifically, does there exist a magnetized, high-beta, plasma configuration with both no toroidal field and a simply connected configuration-space separatrix? We have investigated the latter part of this question, the existence of a separatrix, in the RMF_o-driven PFRC-2 device. The method involved applying an externally generated periodic RF power perturbation to open-field-line seed plasma at one axial end of the device while simultaneously searching for evidence of this perturbation near the presumptive FRC. Measurements of the floating potential were taken at the axial center of the device using a cylindrical Langmuir probe (r = 0.025 cm). When applying no RMF_o, measurements of the floating potential showed evidence of perturbation throughout the entire radial profile of the device, indicating open field lines throughout the device. However, under certain conditions when operating the RMF_o, we found the signal of the perturbation to be weaker within a particular radius, indicating a possible separatrix inside which the magnetic field lines are closed.

The PFRC-II Device

- 2nd generation Princeton FRC experiment driven by odd parity rotating magnetic fields
- Has demonstrated stable plasma discharges for over 100 ms long
- Previous generation demonstrated electron temperatures as high as 400 eV
- Key Components include:

- Main coils (axial field)
- Nozzle coils (mirror configuration)
- SC flux conservers (further field pressure)
- Helicon Antenna (seed plasma)
- RMF antennas (current drive)



View of PFRC II

Why odd-parity RMF current drive?

- Even parity RMF (past attempts at FRC current drive) are shown to open up field lines.[1,4]
- Odd parity RMF maintains field line closure – existence of separatrix surface through which no field lines penetrate.[1] This is predicted to greatly improve particle and energy confinement, as well as electron and ion heating at proper conditions.[2,3]

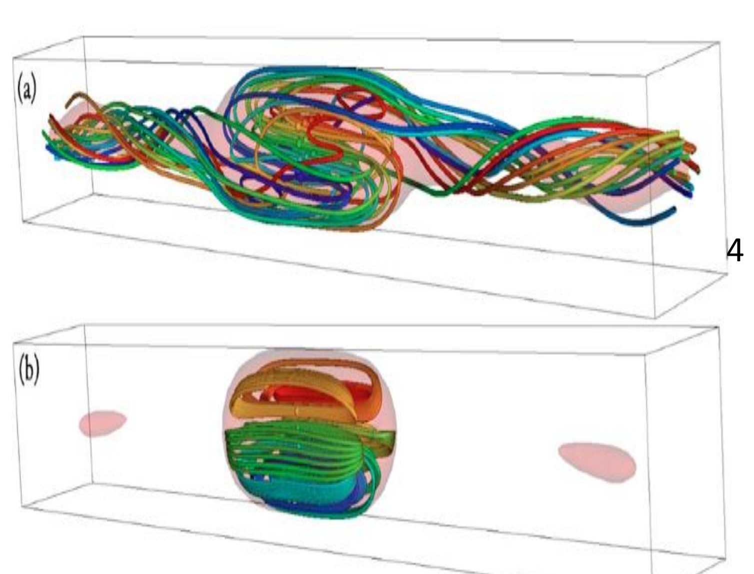
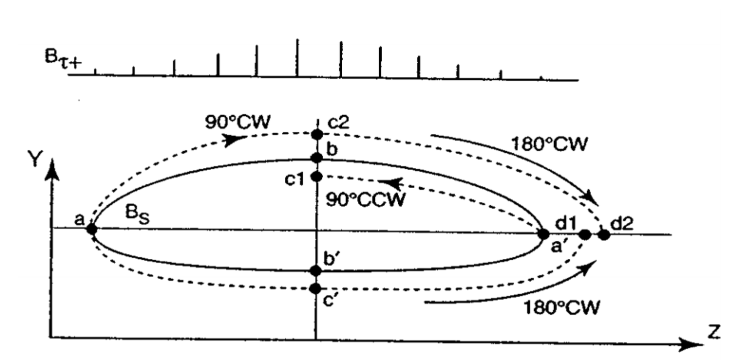
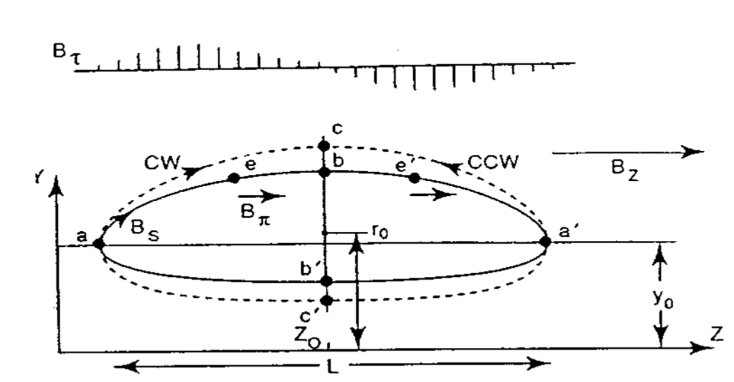


FIG. 10. (Color online) Field lines launched from the midplane 20 μs after the RMF has been ramped off for (a) an even-parity calculation and (b) an odd-parity calculation.

4



FRC field lines w/ addition of RMF_even [1]



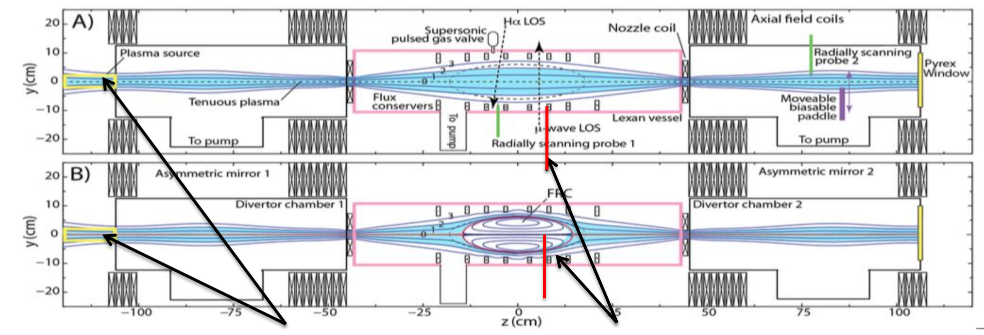
FRC field lines w/ addition of RMF_odd

How we test the magnetic topology:

- We modulate the seed plasma power (on and off) at a characteristic frequency (30 kHz) and search for the strength of this signal in the floating potential of a probe within the center cell as a function of radius.
- During seed plasma operation, we observed the emission of X-rays and extremely negative potentials (< - 1 KeV) on floating surfaces in both end cells.
- These measurements are indicative of a small population ($N_e < 10^8$ cc^{-1}) of hot electrons ($T_e > 300$ eV) that are generated in the source end cell.
- Energetic electrons are highly collisionless, follow magnetic field lines, and lower the floating potential of a Langmuir probes within their path.
- We look for differences in this profile when the RMF is on and off – particularly for a separatrix during the RMF – a radius inside which the strength of the signal drops, indicating the hot electrons follow open field lines around this radius.

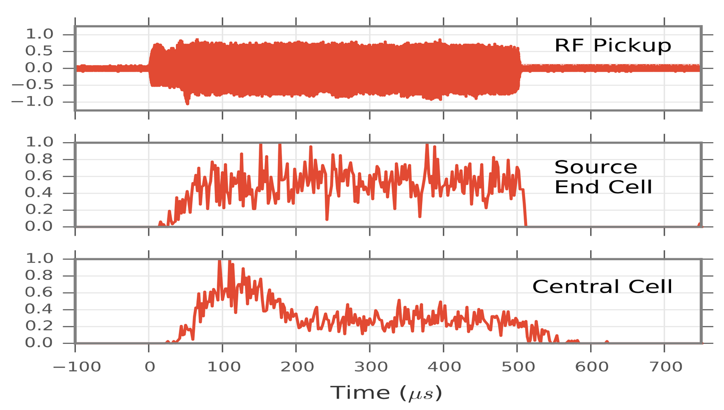
Run with Helicon source

Run with Odd Parity RMF + Helicon source

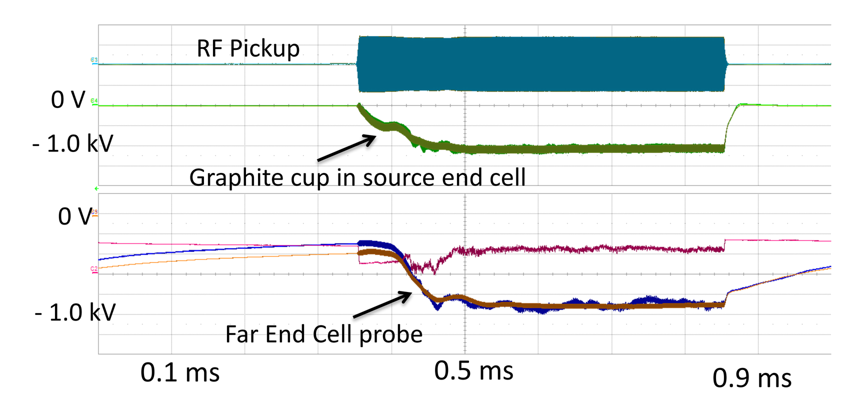


Helicon source | Radial scan w/ probe

Measurement of hot electrons during seed plasma production via floating potential and x-ray generation



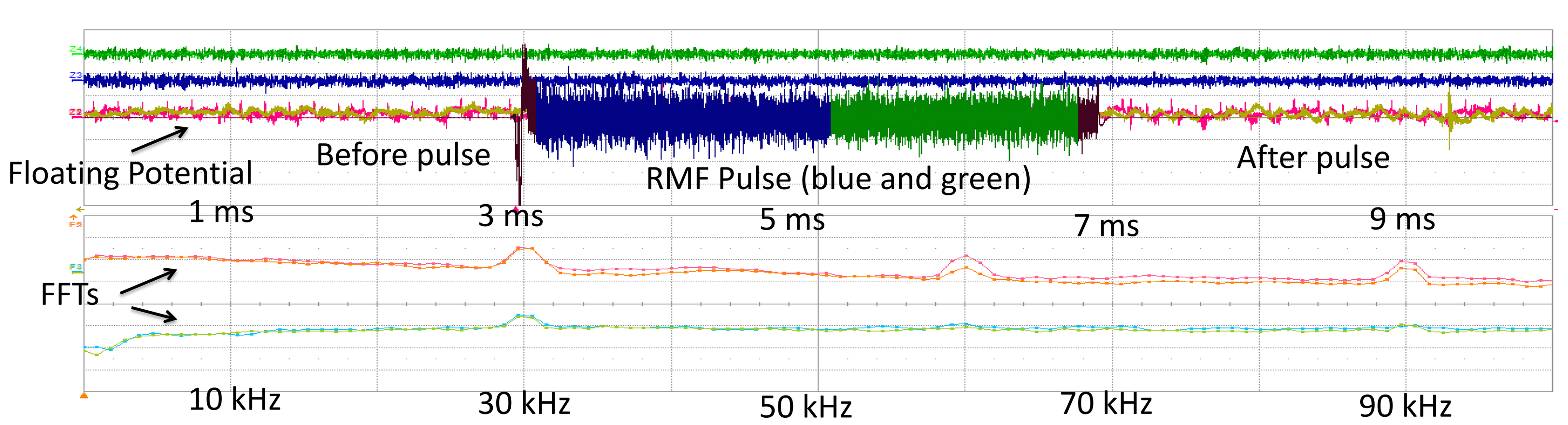
X ray count measurement during 1 kHz square modulation to helicon power



Floating potential measurements during 1 kHz square modulation to helicon power

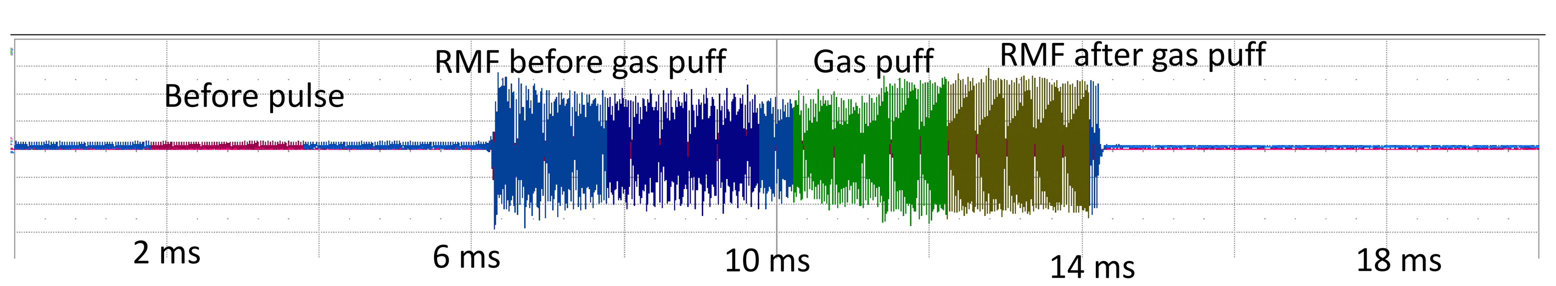
Data Acquisition

- Looked at floating potential oscillations at 30 kHz as a function of radius.
- Probe connected to DSO via 1.7 MHz LPF and 24 kHz HPF.
- Observed floating potential before, during, and after RMF_o pulse.
- Investigated different magnetic field strengths, RMF powers, and chamber pressures.



Above: Probe trace of floating potential during RMF pulse. FFTs of before, during 1st and 2nd halves, and after RMF_o pulse shown below pulse.

Below: Probe trace of floaing potential during RMF pulse with gas puffing at t = 11 ms.

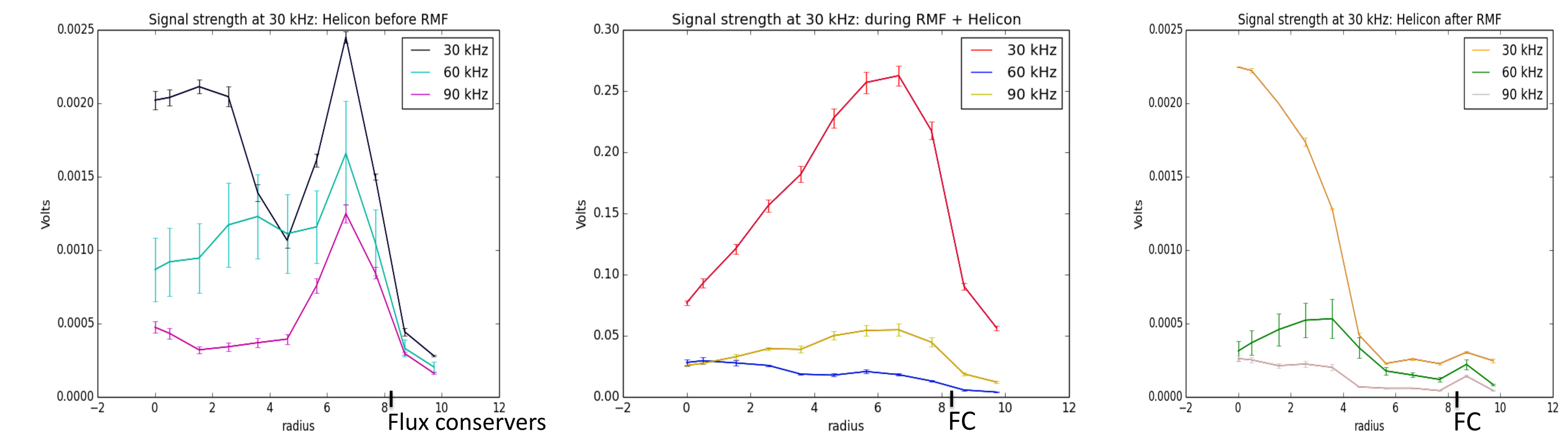


Searching for a Separatrix

Plotted below is the signal strength at 30 kHz and its first two harmonics , 60 kHz and 90 kHz, as a function of radius for various run conditions. The crucial comparison is between **Helicon only** (before the RMF) and **RMF + Helicon** (during the RMF).

A separatrix as formed by RMF_o would be characterized by a full profile during Helicon only and a hollow signal profile during the RMF.

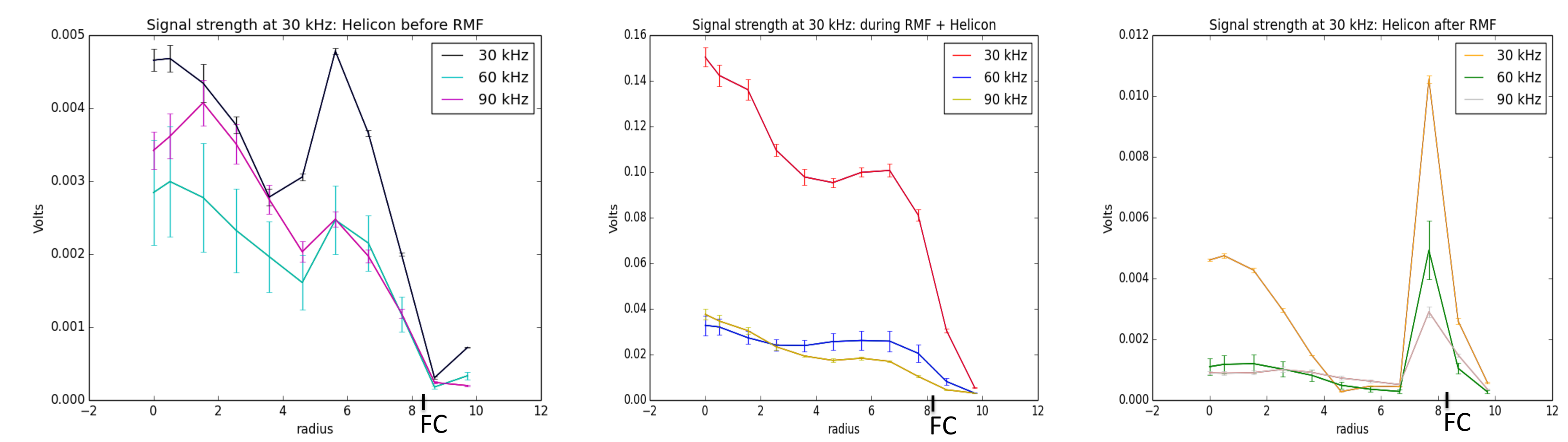
Possible Separatrix: Low axial field, Low Neutral Pressure, No Gas puffing



Helicon Only (before RMF) | **RMF + Helicon** | **Helicon Only** (after RMF)

Conditions above: 61 A in Main coils, 300 A in Nozzle coils Center Cell pressure = 0.35 mT, RMF Power = 12 kW, 4 ms pulses, helicon modulation at 30 kHz at 100 W

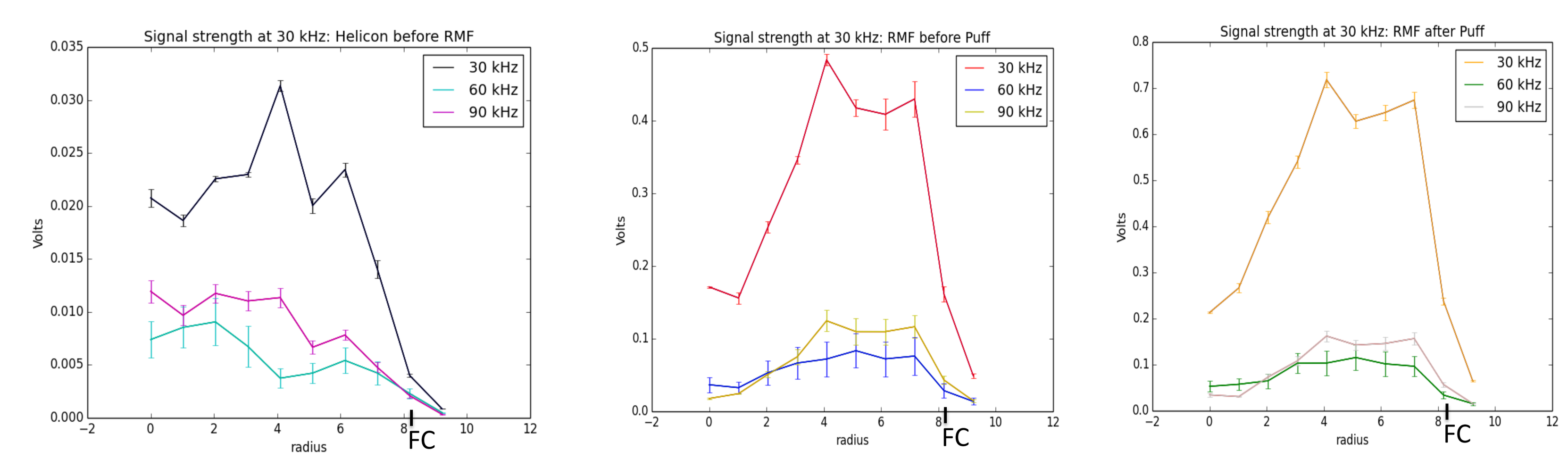
No Separatrix: Low axial field, High Neutral Pressure, No Gas puffing



Helicon Only (before RMF) | **RMF + Helicon** | **Helicon Only** (after RMF)

Conditions above: 61 A in Main coils, 300 A in Nozzle coils Center Cell pressure = 0.70 mT, RMF Power = 12 kW, 4 ms pulses, helicon modulation at 30 kHz at 100 W

Possible Separatrix: High axial field, Low Neutral Pressure, **With Gas puffing**



Helicon Only (before RMF) | **RMF + Helicon (Before Puff)** | **RMF + Hel (After Puff)**

Conditions above: 113 A in Main coils, 300 A in Nozzle coils Center Cell pressure = 0.38 mT, RMF Power = 12 kW, 8 ms pulses, helicon modulation at 30 kHz at 150 W

Conclusions and Future Plans:

- Used creation of hot electrons to investigate magnetic topology of PFRC II both during helicon only and RMF_o + helicon operation.
- Found possible evidence off a separatrix during low neutral pressure operation as indicated by a decrease in perturbation signal within a certain radius during RMF_o operation opposite of the behavior of helicon operation only.
- During high pressure operation, found helicon only and RMF+ helicon operation to have roughly similar radial profiles, indicating no separatrix.
- Conditions corresponding to evidence of separatrix as correspond to conditions of highest x-ray counts (during RMF runs).
- Future plans include investigating separatrix by use on additional off-center probe, as well as further exploring separatrix and electron temperature dependence on conditions

References

1. S.A. Cohen and R.D. Milroy, *Phys. Plasmas* **7,** 2539 (2000).
2. Samuel A. Cohen and Alan H. Glasser, Phys. Rev. Lett. **85**:24 (11 December 2000)
3. D.R. Welch, S.A. Cohen, T.C.Genoni, and A.H. Glasser, Phys. Rev. Lett. **105** (2 July 2010)
4. A. L. Hoffman, H. Y. Guo, K. E. Miller, and R. D. Milroy, Phys. Plasmas 13, 012507 (2006).