DIII-D High Field Side Lower Hybrid Current Drive Experiment: Overview and Status

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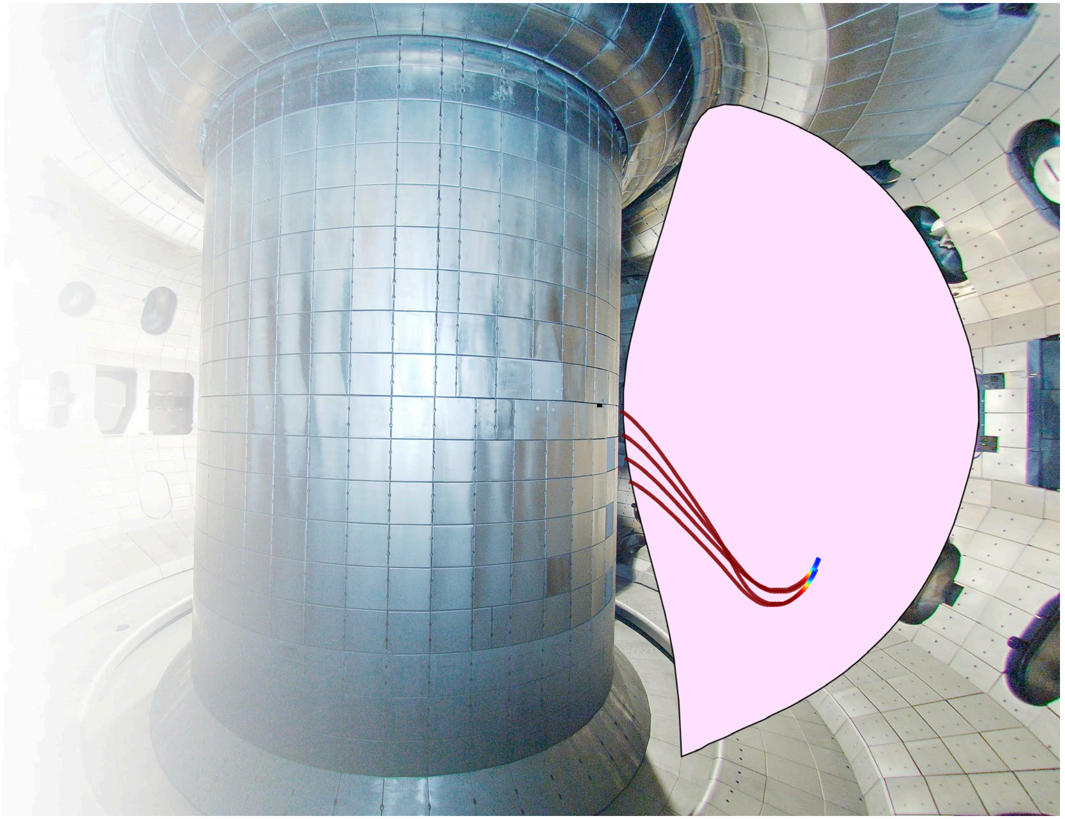

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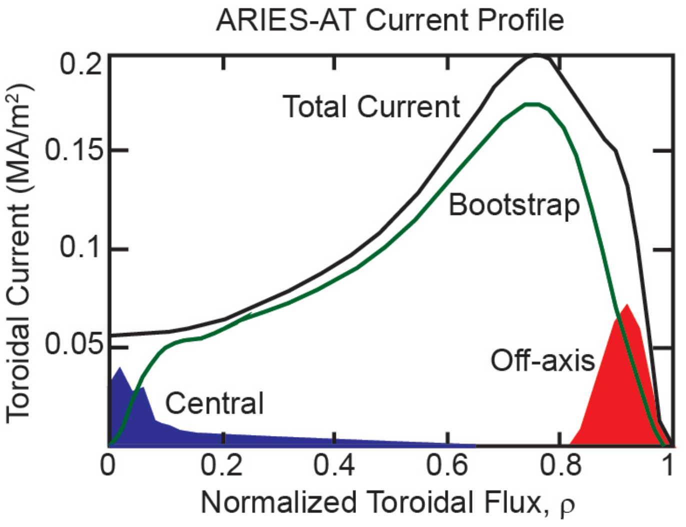
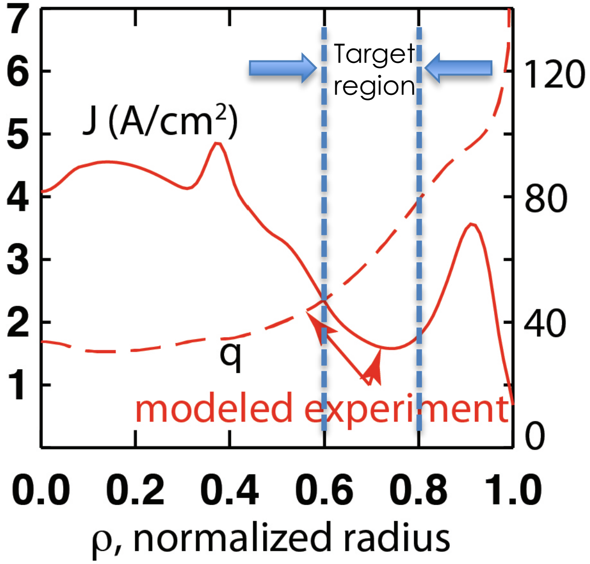
MIT PSFC Plasma Science and Fusion Center

Off-axis Non-Inductive Current Drive is a Key Enabling Technology

- **Steady-state tokamak reactor studies have concluded that high-bootstrap-fraction operation is highly advantageous.**
  - Maximizing bootstrap current to reduce external drive requirements.
  - Remaining current must be driven non-inductively and off-axis.
- **Efficient, robust, steady state current drive is required to make the tokamak a viable concept for fusion electricity.**
  - Power required for current sustainment is a major constraint upon plant efficiency.
- **For DIII-D, broad current profile is required for "high q_{min}" scenario.**
  - Seek external current drive source peaked $0.6<\rho<0.8$.
  - Current density ~40 A/cm^2 is required for current profile control.



Najmabadi et al., Fus. Eng. Design **80**, 2006.



Adapted from C. Holcomb PAC 2017.

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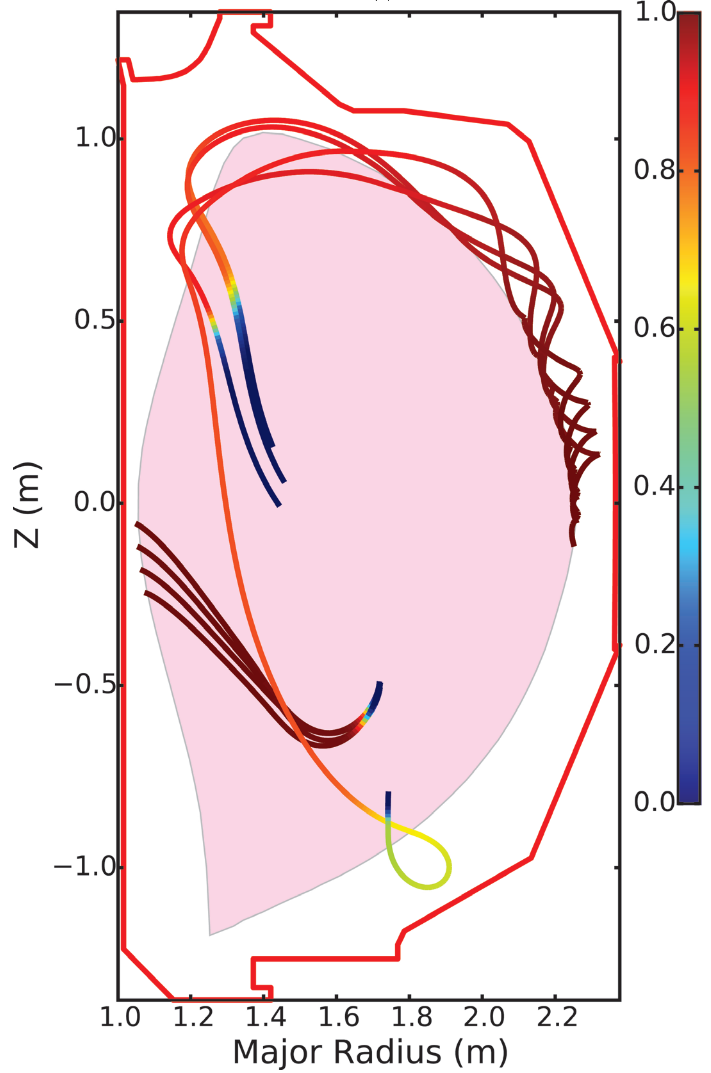
HFS LHCD: Potentially Effective Tool for Off-axis Current Drive

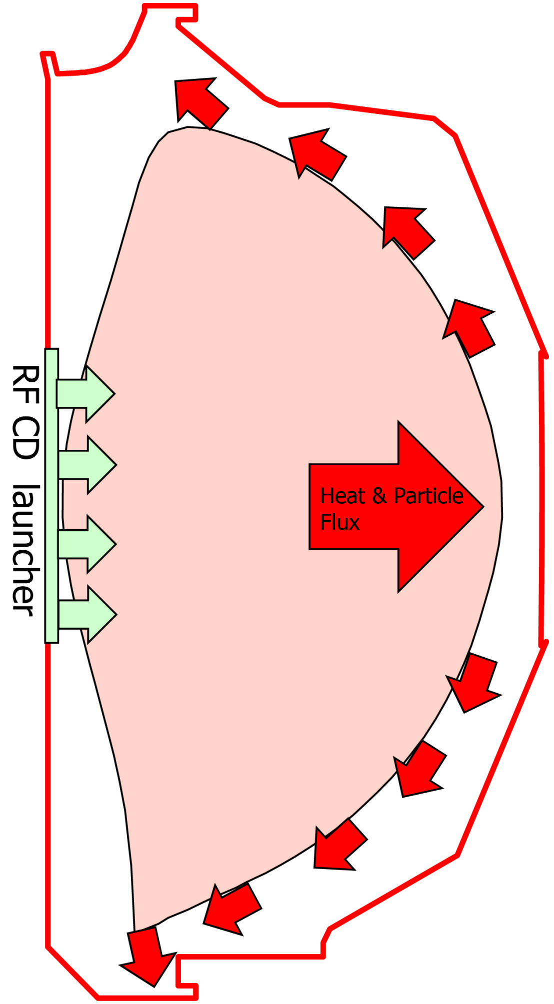
- **HFS launch increases local B and improves wave accessibility:**
  - Wave accessibility: $n_{||acc} \sim \sqrt{n_e}/B$
- **Wave penetration is competition between absorption and wave accessibility.**
  - Wave absorption: $n_{||abs} \sim \sqrt{30/Te}$
- **Current drive efficiency scales strongly with launched $n_{||}$.**
  - Current drive efficiency $\propto 1/n_{||}^2$
- **On HFS, higher local B improves accessibility for low $n_{||}$ which improves wave penetration and current drive efficiency.**

Wave propagation in DIII-D AT discharge with $n_{||}$=2.8



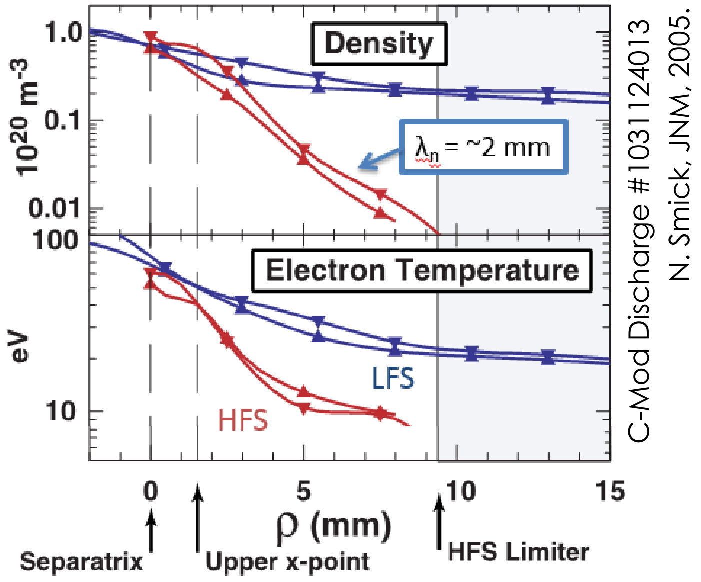
HFS SOL is ideal for RF Couplers

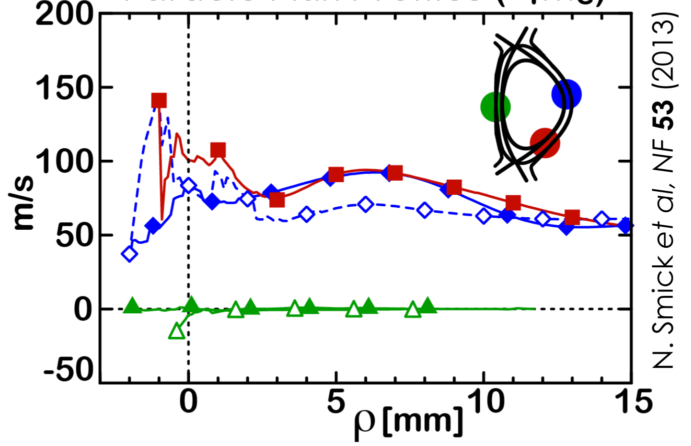
- **HFS location avoids majority of heat and particle exhaust.**
  - Tokamak heat and particles transport to low field side scrape off layer (SOL)



HFS SOL is ideal for RF Couplers

- **HFS location avoids majority of heat and particle exhaust.**
  - Tokamak heat and particles transport to low field side scrape off layer (SOL)
- **HFS SOL density profile is significantly steeper than LFS SOL density profile.**
  - Place coupler closer to plasma.
  - Reduce wave evanescent layer
- **Lower density measured in HFS Double Null (DN) plasmas:**
  - Potential to optimize coupling through magnetic balance.
  - Density control at launcher by adjusting inner gap
- **Expect coupling to remain stable.**
  - Expect reduced scattering from turbulent density perturbations.
  - ELMs are attenuated in single null and do not reach HFS in double null.

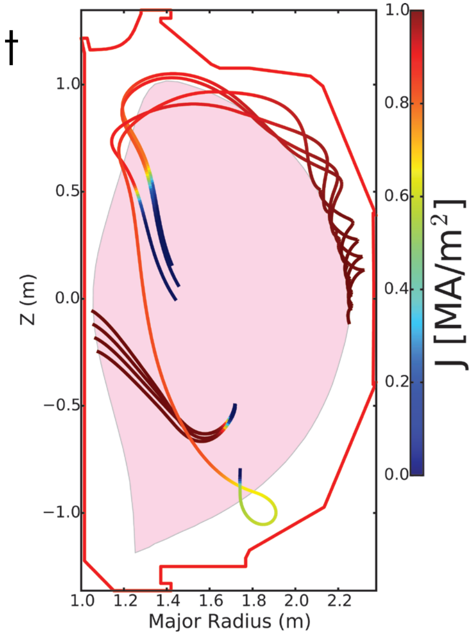


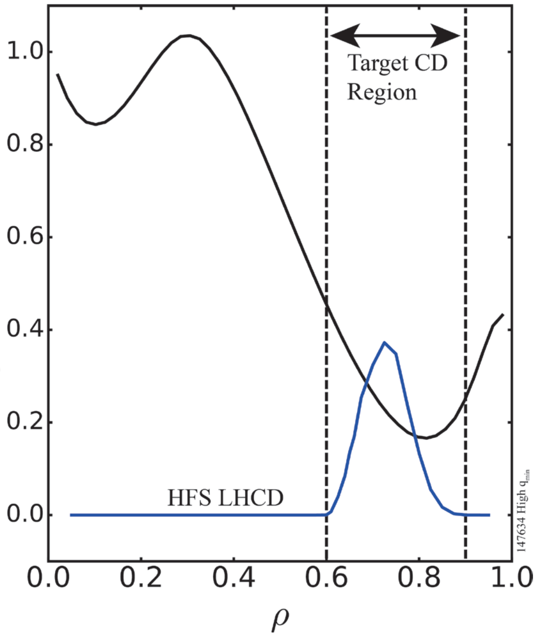


Average Γ_r/n_e from 85 C-Mod Discharges from 1070511, 1070627 & 1090721

Commissioning Thrust: High Field Side Lower Hybrid Current Drive has Potential for Efficient Drive Off Axis Current

- **Long range goal:** Demonstrate efficient off-axis current drive compatible with high performance plasmas and scalable to reactors.
- **DIII-D need:** Current profile actuator consistent with high bootstrap fraction
  - Seek current drive source ~0.4 MA/m^2 and peaked 0.6<ρ<0.8.
- **Priority for FY24-25 studies:**
  - Commission coupler to up to 1 MW, 1 s.
  - Characterization of high field side density profile for coupling studies.
  - Develop broad current profile, high performance target discharges with $+B_T$ and $+I_P$.
- **Risk and deliverables:**
  - Risk is as one would expect associated with a new RF system.
  - Provide q profile control for $B_T \geq +1.6$ T, $n_e < 9\times10^{19} m^{-3}$ in $+I_p$ discharges.
  - Validate HFS wave propagation and SOL benefits for RF actuators.





High Field Side Lower Hybrid Current Drive has Potential to Efficiently Drive Off Axis Current

- **Impact on Fusion Energy mission:**
  - Efficient, robust, steady state current drive is required to make the tokamak a viable steady state concept for fusion electricity.
- **Outline method:** HFS LHCD coupled into AT discharges
- **Why now?:** Unique experiment with potential for q profile control for AT/scenario development discharges.
- **Distinctiveness of DIII-D contribution:** HFS LHCD is virgin physics area where clear leadership can be established.
- **Chances of success:** as good as one would expect associated with a new RF system.
- **Approx run days and years to result:** In FY24, commissioning in piggyback till 500 kW for 100 ms is obtained and 4 days to reach 300 kW and 1 MW, 1 s. In FY25, develop broad current profile for high performance and AT discharges.
- **Physics area(s) involved:** Steady State Scenarios, Burning Plasma
- **Preparation required:** Complete commission klystrons, complete coupler and in-vessel modifications.

HFS LHCD Physics Mission

- **Demonstrate efficient off-axis current drive compatible with high temperature plasmas and scalable to reactors.**
  - Provide q profile control without fueling or significant torque for $B_T \geq +1.6$ T, $n_e < 9\times10^{19} m^{-3}$ with $+I_p$.
  - High current drive efficiency (worst case 80 kA/MW, typical ~150 kA/MW, best case ~250 kA/MW) with deposition peaked off axis for $0.6 < \rho < 0.8$.
- **Validate HFS wave propagation and SOL benefits for RF actuators.**
  - Varying $n_{||}$ results in distinct current profiles – test wave propagation and absorption models.
  - Accurate SOL density profiles enable testing coupling simulation capability.
  - Demonstrate that common challenges for LHCD (coupling, impurities, and thermal load) are largely mitigated by locating the LHCD coupler on HFS.
- **Unique experiment with substantial payoff.**