Non-Solenoidal Tokamak Startup Using High-Field-Side Local Helicity Injection on the Pegasus ST

Grant M. Bodner

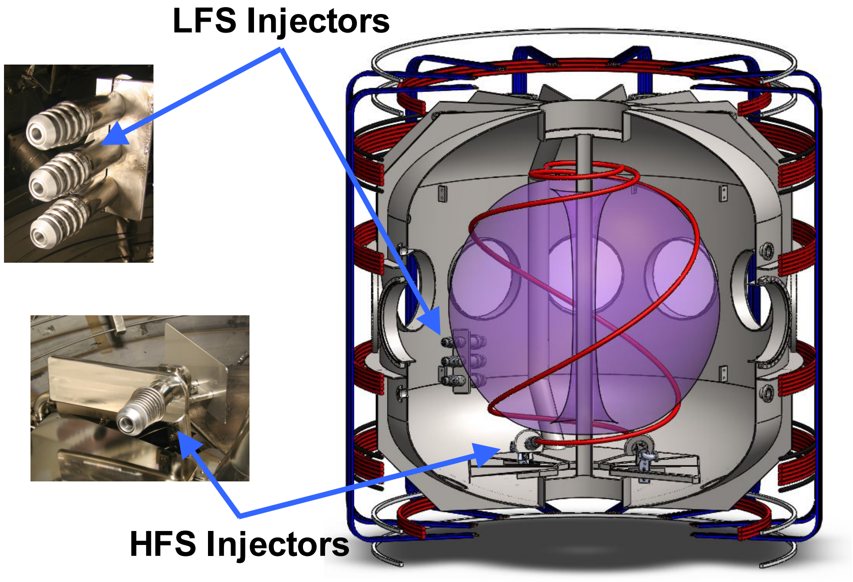
M.W. Bongard, R.J. Fonck, C. Pierren, N.J. Richner, C. Rodriguez Sanchez, J.A. Reusch, A. Rhodes, C. Shaefer, and J.D. Weberski

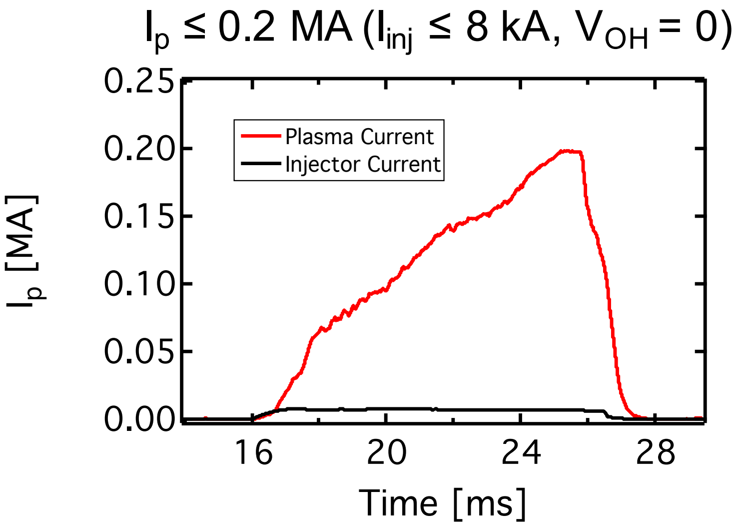
University of Wisconsin-Madison

PEGASUS Toroidal Experiment

APS-DPP
Portland, OR
November 9th, 2018

Local Helicity Injection (LHI) Achieved Using Low-Field-Side and High-Field-Side Injectors





- Edge current extracted from injectors
- Relaxation to tokamak-like state via helicity-conserving instabilities

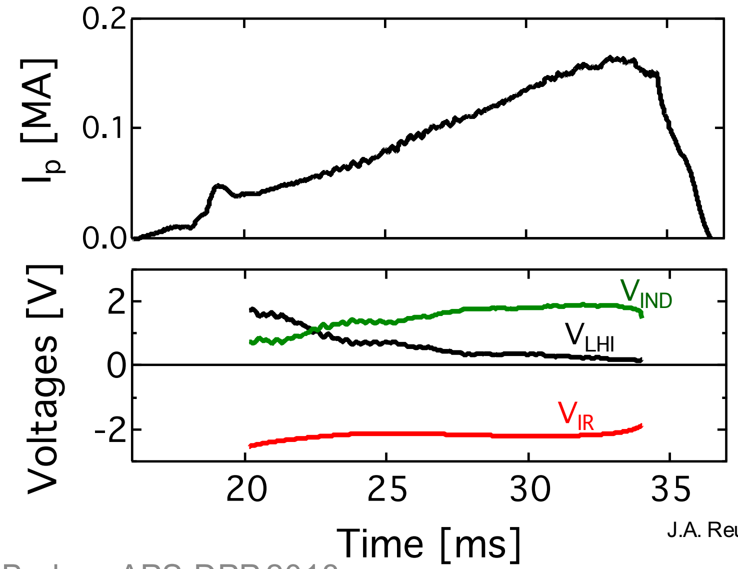
- Current drive quantified by:

$$V_{LHI} \approx \frac{A_{inj} B_{\varphi,inj} V_{inj}}{\Psi_p}$$

Injector Geometries Emphasize Different Current Drives

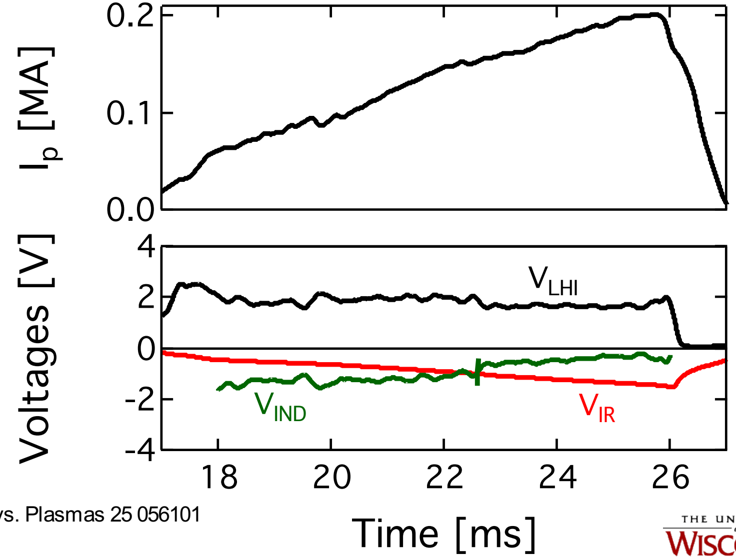
Low-Field-Side Injection:

- Injectors on outboard mid-plane
- High R_{inj} → low V_{LHI}
- Dynamic shape → strong V_{IND}



High-Field-Side Injection:

- Injectors in lower divertor
- Low R_{inj} → strong V_{LHI}
- Static shape → minimal V_{IND}



J.A. Reusch et al 2018 Phys. Plasmas 25 056101

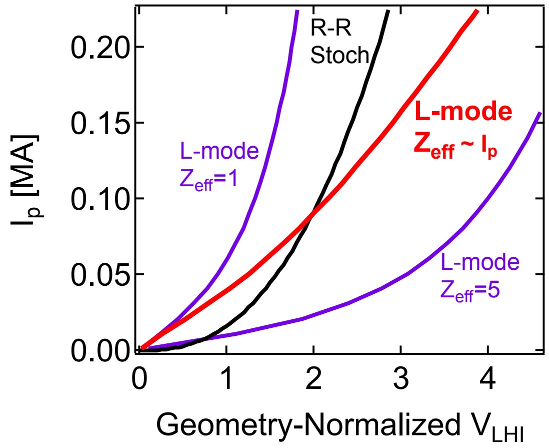
Confinement Properties Set the Current Drive Scaling for HFS Injection

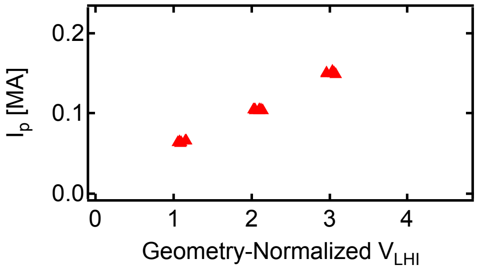
- Ohmic and stochastic confinement scalings predict non-linear I_p-V_{LHI} relationships

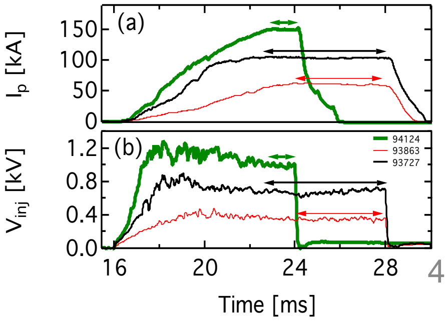
$$V_{LHI} = I_p R_p \rightarrow T_e^{3/2}$$

- Experiment shows I_p proportional to V_{LHI}
  - Suggests fixed $\langle \eta \rangle$

- However, may not be fully representative
  - Experiment conducted at low $B_t \sim 0.045$ T
  - Short I_p flat top
  - n_e was not controlled





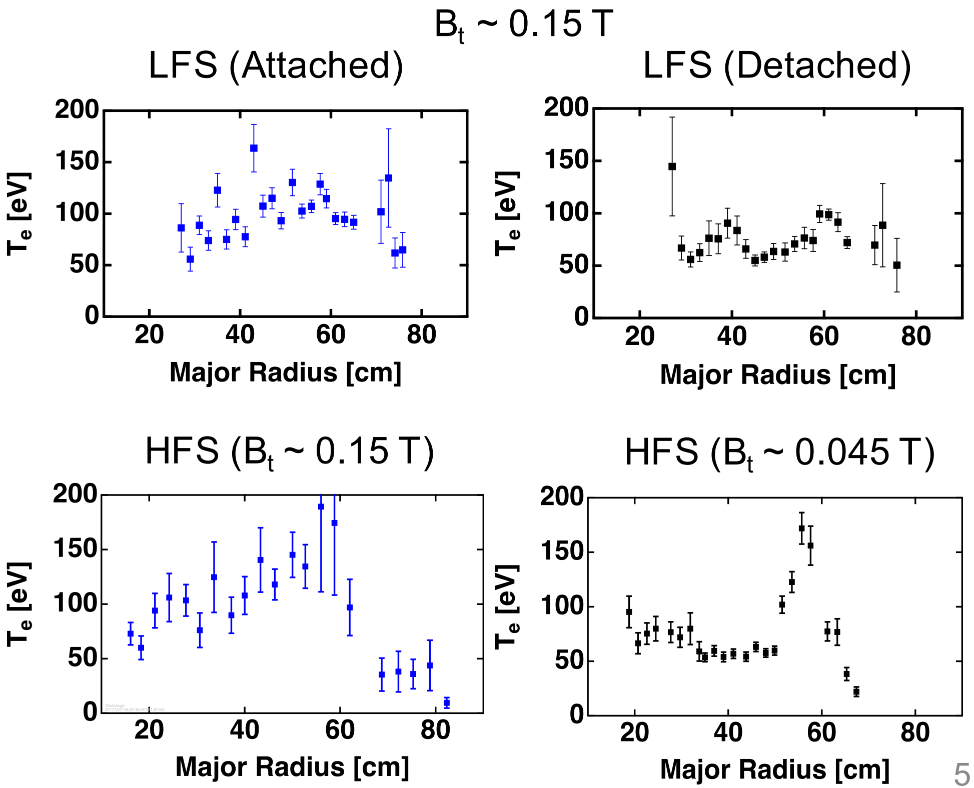


J.M. Perry et al 2018 Nucl. Fusion 58 096002

T_e Profile Structure Suggests Varying Degrees of Current Stream Structure in the Plasma Edge

- In LFS discharges, profile structure depends on attachment of plasma to the injectors
  - Peaked when attached
  - Hollow when detached

- In HFS discharges, profile structure depends upon the level of B_t
  - Peaked at max B_t
  - Hollow at reduced B_t

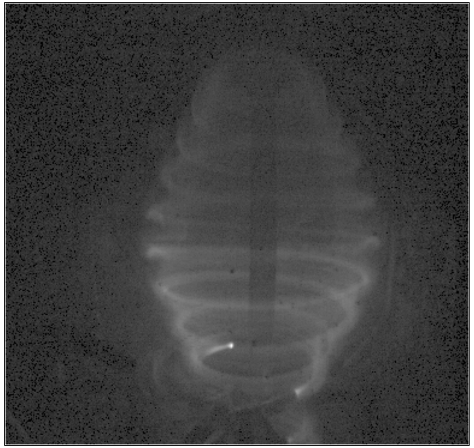


THE UNIVERSITY of WISCONSIN MADISON

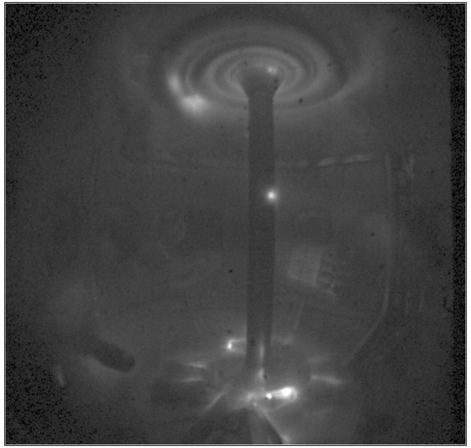
Operation at Max B_t is Critical to Scale LHI to Larger Facilities

- HFS injection more difficult at max B_t
- Increased B_t causes injector streams to pass closer to the other injector
- Cathode spots are more likely to occur early in the discharge at max B_t

Current streams in an unrelaxed discharge

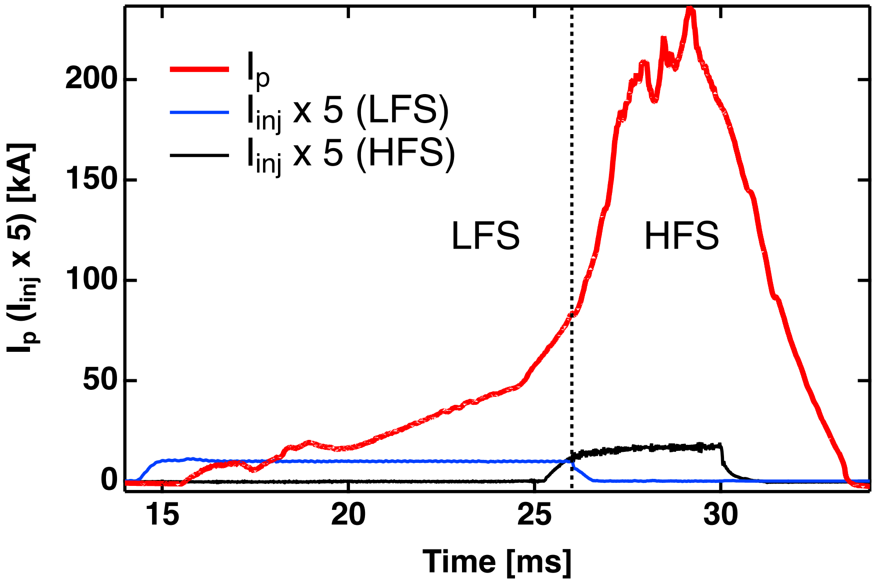


Cathode spots on the outside of the injector



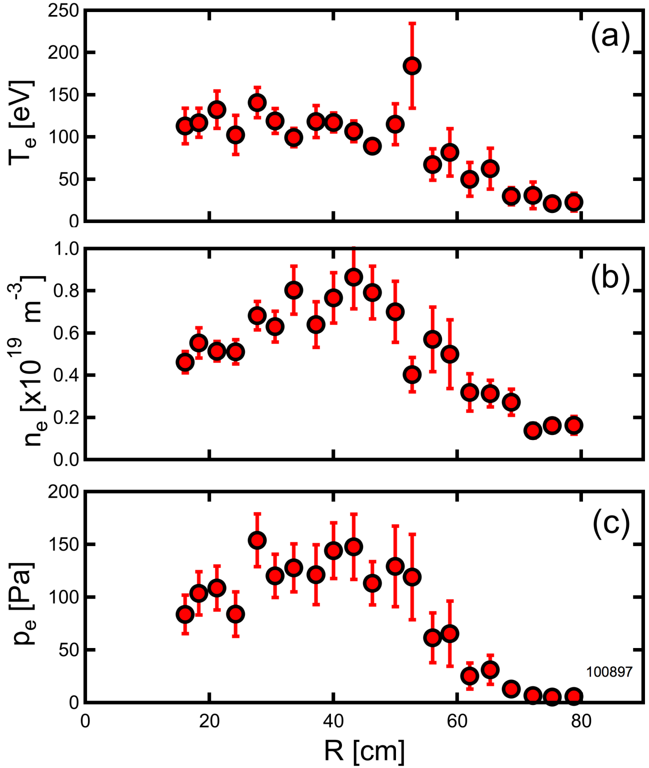
LFS to HFS Injection Handoff Enables Routine Max B_t Operation

- Additive nature of helicity means HI systems can be combined
- Startup with LFS injection at max B_t
  - Eases relaxation requirements
  - Favorable geometry for divertor injectors
- Handoff to HFS injection when presented with full size plasma
  - Mitigates PMI issues
- Proof of principle of the handoff technique



Peaked T_e, n_e, and p_e Profiles During Helicity Driven Phase

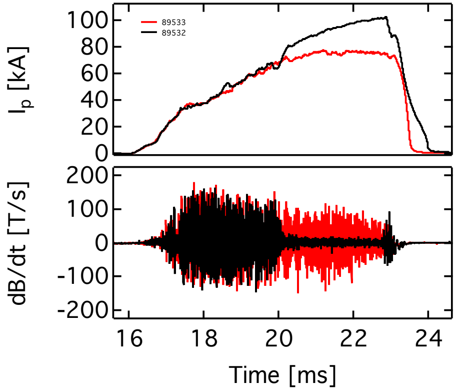
- Core T_e increases during the HFS drive phase to > 100 eV
- Trade-off between n_e, T_e, and I_p; can operate at higher n_e but requires more input power
- Similar results have been observed with HFS injection-only discharges at max B_t



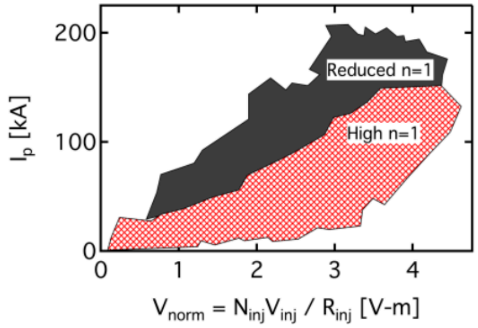
Abrupt Transition in MHD Behavior During HFS Injection

- Large-amplitude, low freq. in early phase
  - Large scale n=1 at 20-80 kHz
  - Line-tied kink of current streams
- Reduction in low frequency activity later in the discharge
  - Low MHD: up to 50% more I_p
  - Interpreted as kink stabilization
- Mechanisms behind this transition are unclear; under investigation

Abrupt MHD Transition



Operating Space for ~8,500 HFS LHI Discharges



J.M. Perry et al 2018 Nucl. Fusion 58 096002

LFS to HFS Handoff Has Allowed For Continued Study of HFS Injection

- HFS injection has been used to create discharges driven purely by helicity injection
- LFS to HFS startup successfully implemented to routinely create high I_p discharges at max B_t
- Peaked T_e, n_e, and p_e profiles observed in purely helicity driven plasmas
- T_e profile suggests varying degrees of current stream thermalization in the plasma edge
- Operating regime with reduced n=1 activity; increased current drive efficiency discovered