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

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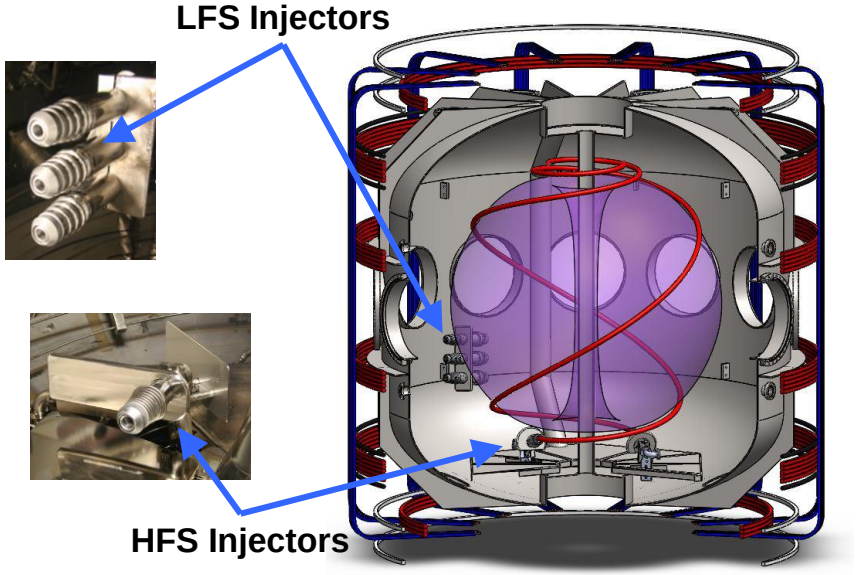
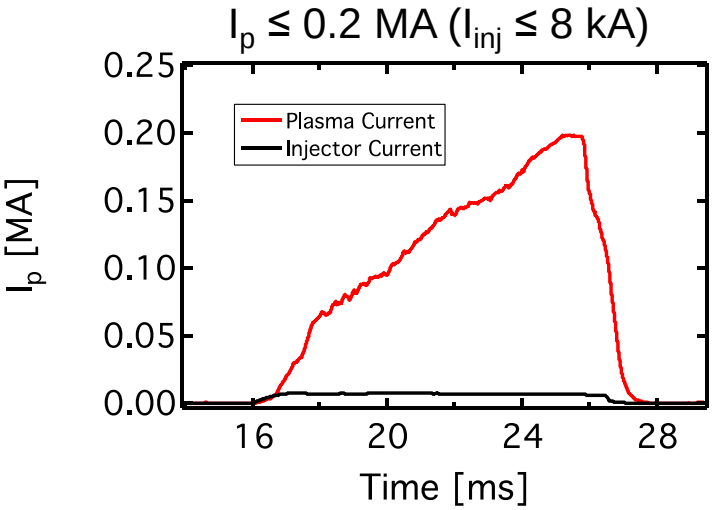
PEGASUS Toroidal Experiment

A New Campaign Studies Local Helicity Injection (LHI) Using High-Field-Side Injectors





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

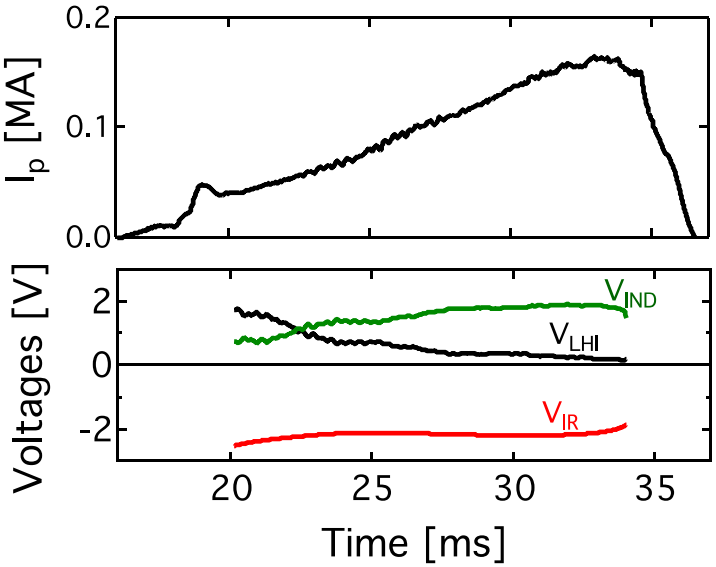
- Current drive quantified by:

$$V_{LHI} \gg \frac{A_{inj} B_{j,inj}}{\Upsilon} V_{inj}$$

Injector Geometries Emphasize Different Current Drives

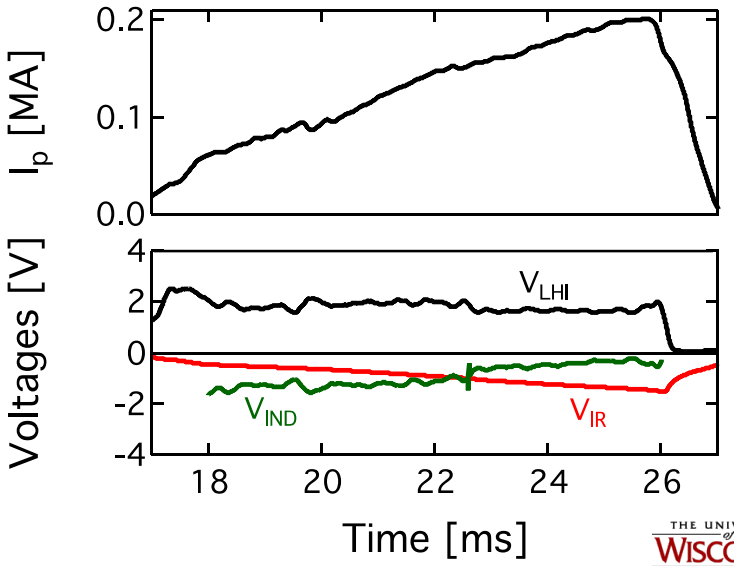
Low-Field-Side Injection:

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



High-Field-Side Injection:

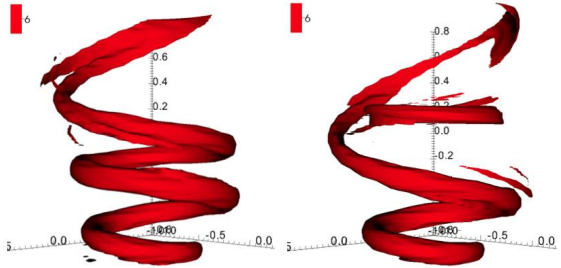
- Injectors in lower divertor
- Low R_{inj} → strong V_{LHI}
- Static shape → minimal V_{IND}



LHI Plasmas Exhibit MHD Activity on Multiple Scales

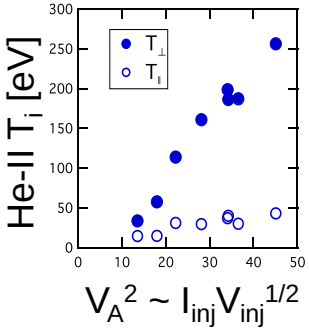
1. Instability of current filaments
   - Long wavelength, low frequency:
     - Line-tied kink
     - Filament merger and reconnection
     - Dominates external magnetics
   - Short wavelength, high frequency:
     - Correlated with anomalous ion heating
     - Reconnection-driven turbulence?
2. Instabilities of the tokamak plasma
   - Tearing, kink modes
   - Relevant to hand-off

Current Filament Reconnection



* *J. O'Bryan, Physics of Plasmas, **19**, 080701 (2012)*

Anomalous Ion Heating



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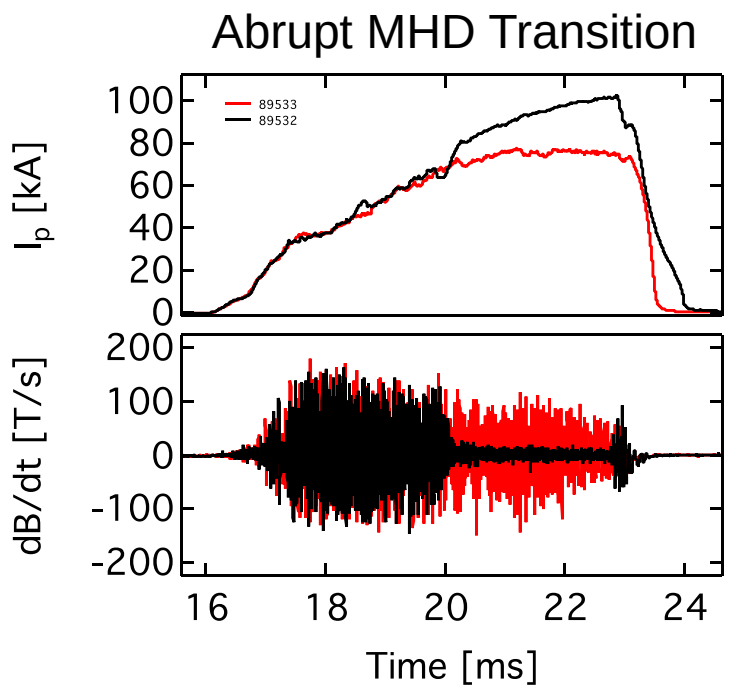
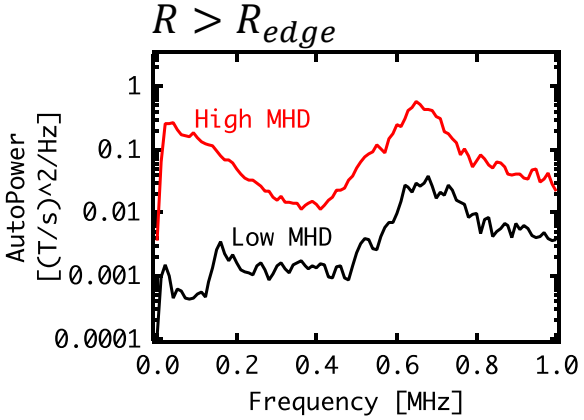
Abrupt Transition in MHD Behavior During HFS Injection

- Large-amplitude, low freq. in early phase
  - Large scale n=1 at 20-80 kHz
  - Line-tied kink of current streams
- Abrupt reduction in low frequency activity under some conditions:
  - I_p growth continues
  - Interpreted as kink stabilization
- Several hypotheses for stabilization mechanism under consideration

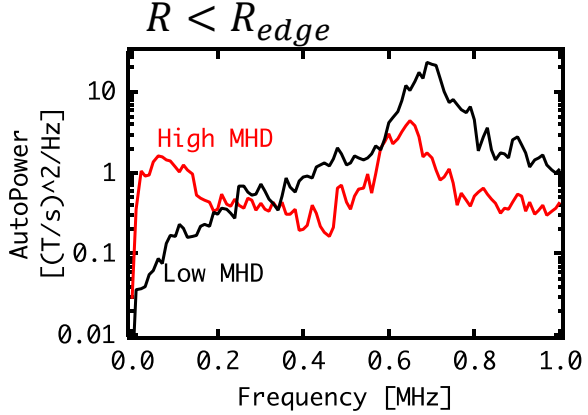


Shift to High Frequency Inside Plasma Edge Suggests Short Wavelength Current Drive Mechanism

- External Measurement ($R > R_{edge}$)
  - Reduction at all frequencies
  - Suppression of large n=1 mode
  - Remaining $\tilde{b}/B$ similar to L-mode

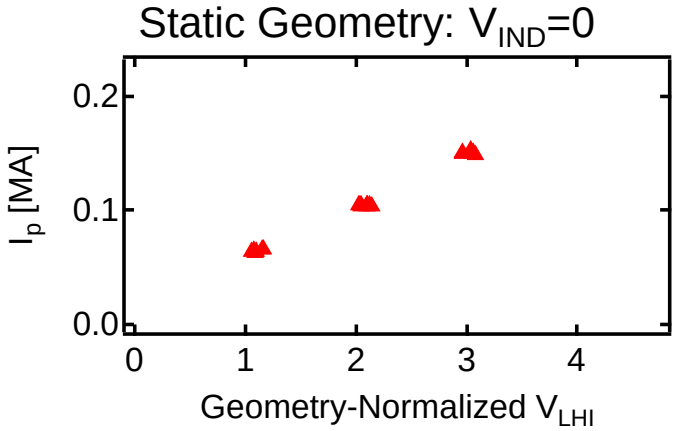


- Internal Measurement ($R < R_{edge}$)
  - High-f activity increases after transition
  - Turbulence, reconnection on smaller scale?
  - Continued I_p growth suggests short wavelength activity drives current

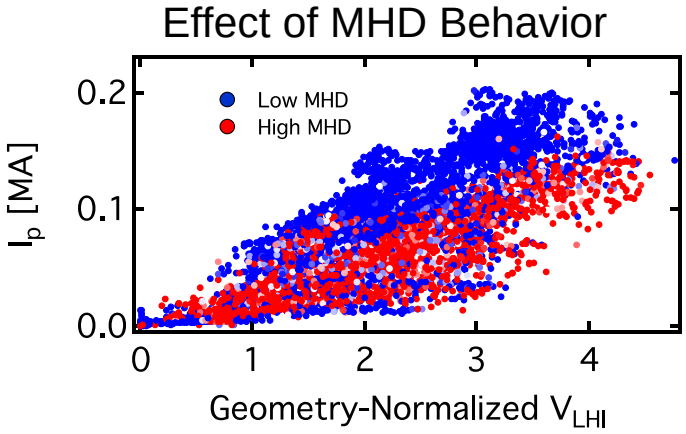


I_p Increases Linearly with V_{LHI} when V_{IND}~0

- Static plasma geometry → V_{IND}~0
  - Linear I_p scaling suggests fixed $\langle\eta\rangle$
  - Z_{eff}, n_e, plasma geometry effects not yet accounted for

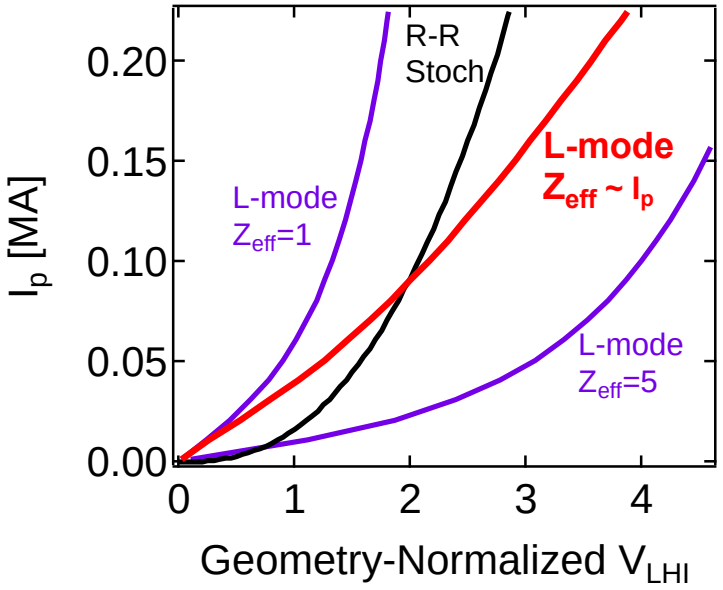


- Greater current drive efficacy following MHD transition
  - Low MHD: up to 50% more I_p
  - Relationship to confinement?



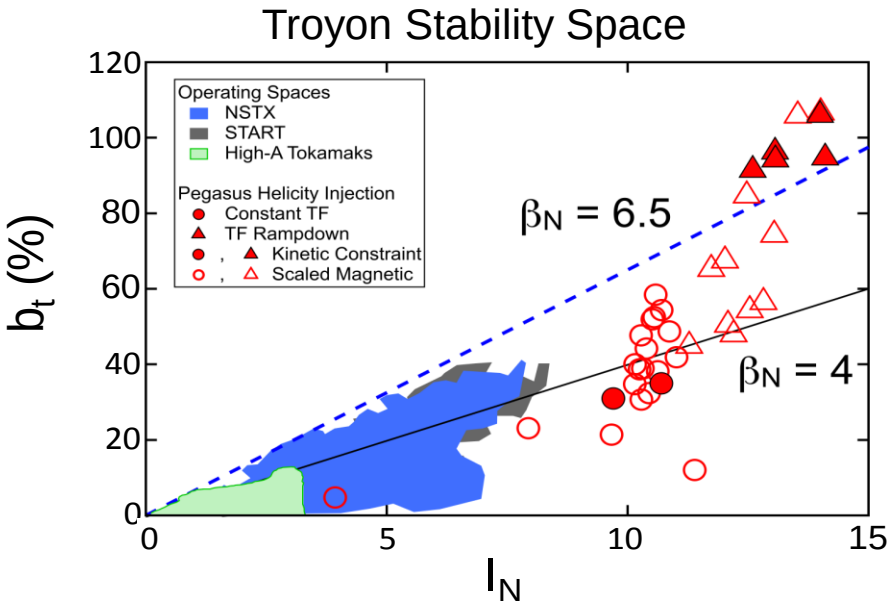
Confinement Properties Set Current Drive Scaling for LHI

- HI balanced by resistive dissipation
  - $\langle \eta \rangle$ influenced by confinement
- Crude estimates of confinement inform operation space
  - Strongly dependent on Z_{eff}
- Resistive dissipation complicated by:
  - Dual confinement zones?
  - Neoclassical trapping, non-thermal electrons
  - Hyper-resistivity?



High-Field-Side LHI at A~1 Provides Access to $\beta_T \sim 1$

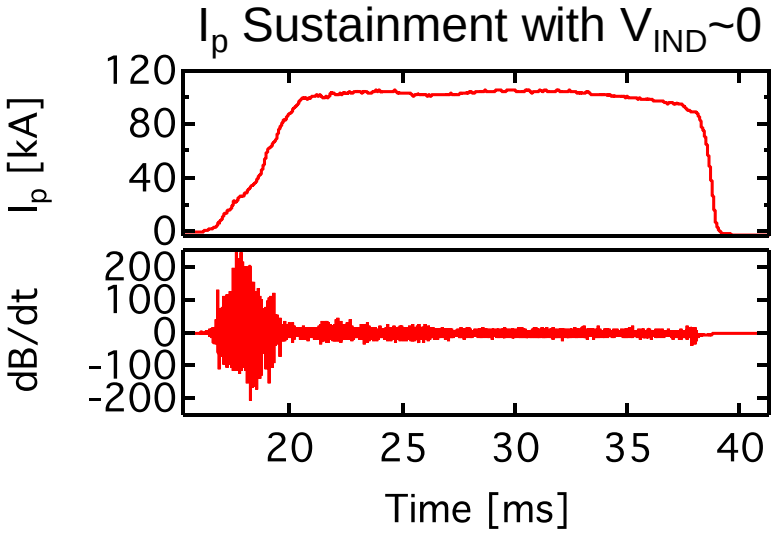
- A~1:
  - Naturally high κ
  - High I_N stability limit
- HFS LHI: unique operation space
  - High I_p possible at low I_{TF}
  - $I_N = 5A\frac{I_p}{I_{TF}} > 10$ accessible
  - Naturally low ℓ_i
  - Strong auxiliary ion heating
- See invited talk Thursday AM
  - *TI3.00004, J.A. Reusch*



1. *D.J. Schlossberg, PRL.* ***119*** *035001 (2017)*

High-Field-Side LHI Builds the Physics Basis for High-I_p Non-inductive Startup and Sustainment

- High-field-side LHI: increased V_{LHI}, reduced V_{IND}
- Novel MHD behavior suggests short wavelength current drive mechanism
- Attainable I_p scales with V_{LHI}; confinement under investigation
- $\beta_T \approx 100\%$ using unique properties of HFS LHI at A~1



See Pegasus posters: Thursday PM