Advancing Non-Solenoidal Startup on the Pegasus ST

Joshua A. Reusch

J.L. Barr, G.M. Bodner, M.W. Bongard, M.G. Burke, R.J. Fonck, J.L. Pachicano, J.M. Perry, N.J. Richner, C. Rodriguez Sanchez, D.J. Schlossberg

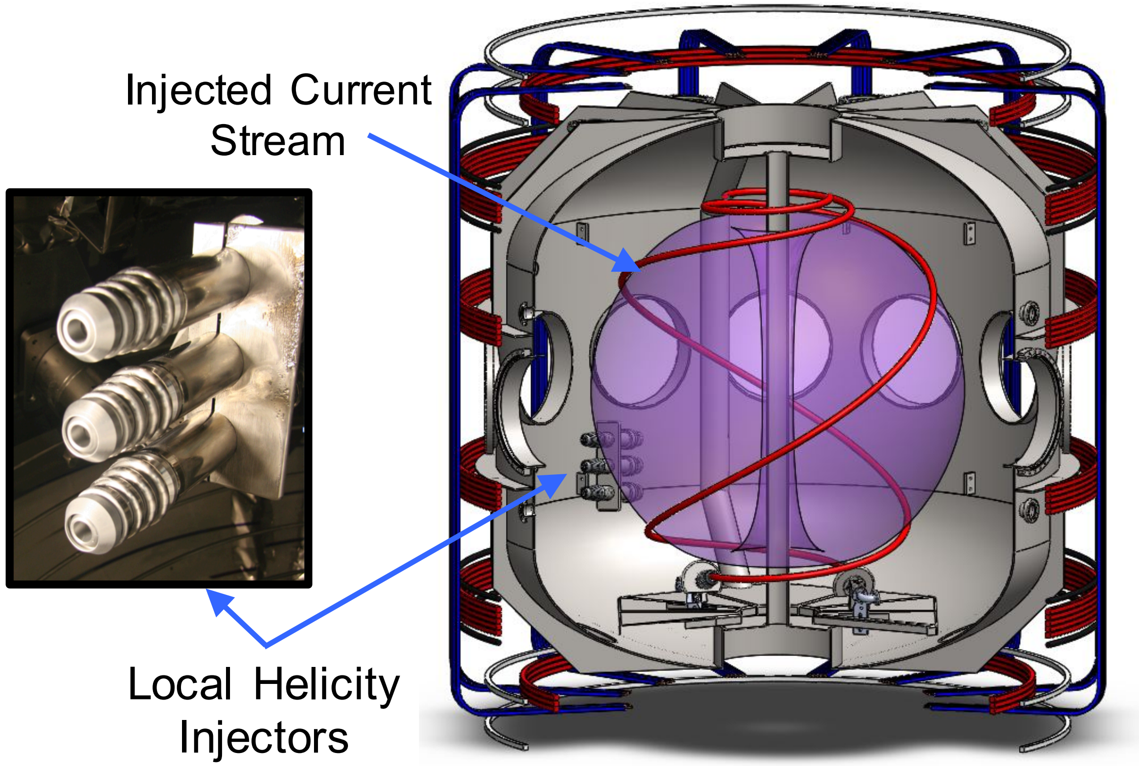
University of Wisconsin-Madison

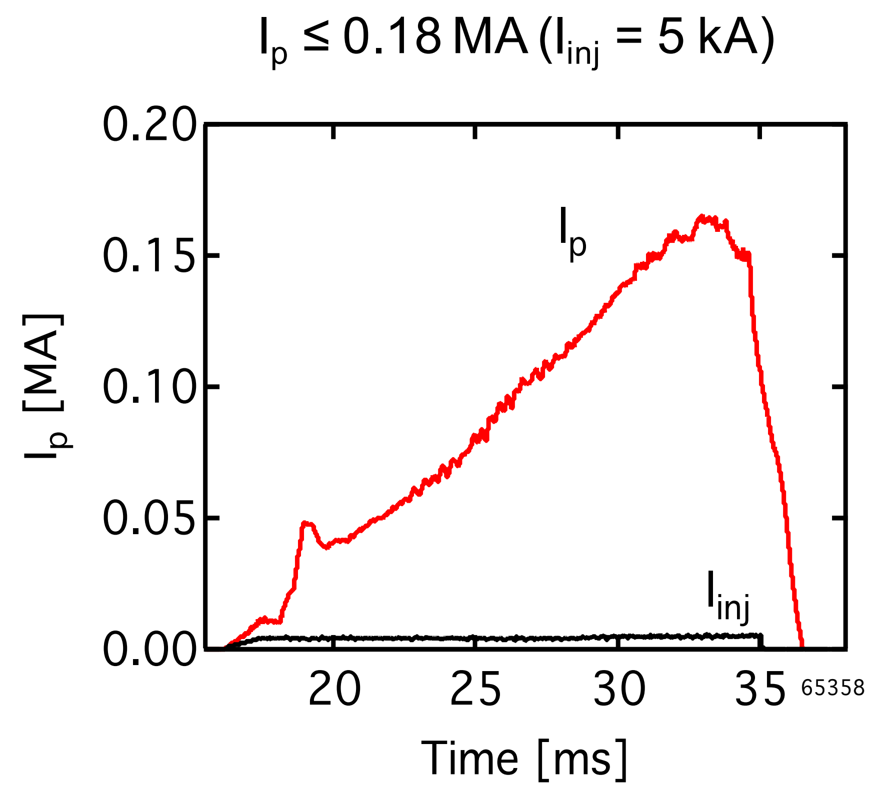
58th Annual Meeting of the APS Division of Plasma Physics

Nov. 1, 2016

PEGASUS Toroidal Experiment

Local Helicity Injection (LHI) is a Promising Non-Solenoidal Startup Technique



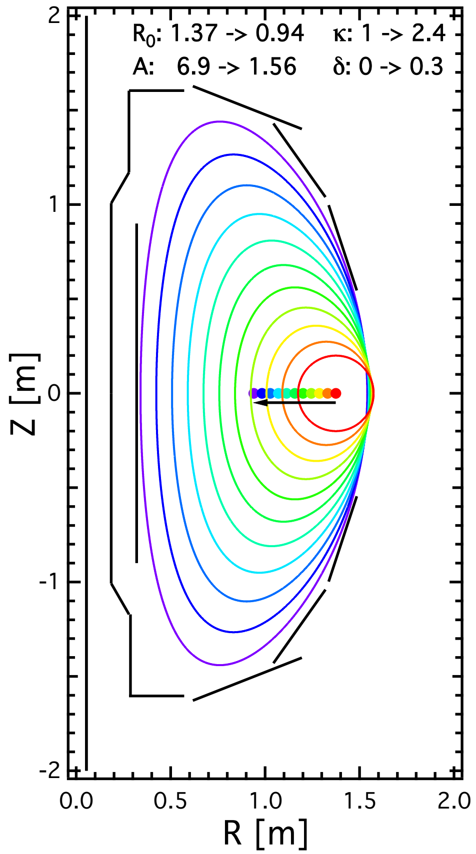


- Compact, modular washer-stack arc sources inject edge current
- Unstable current streams form tokamak-like state via magnetic reconnection, Taylor relaxation
- Physics and engineering tradeoffs strongly coupled to injector location

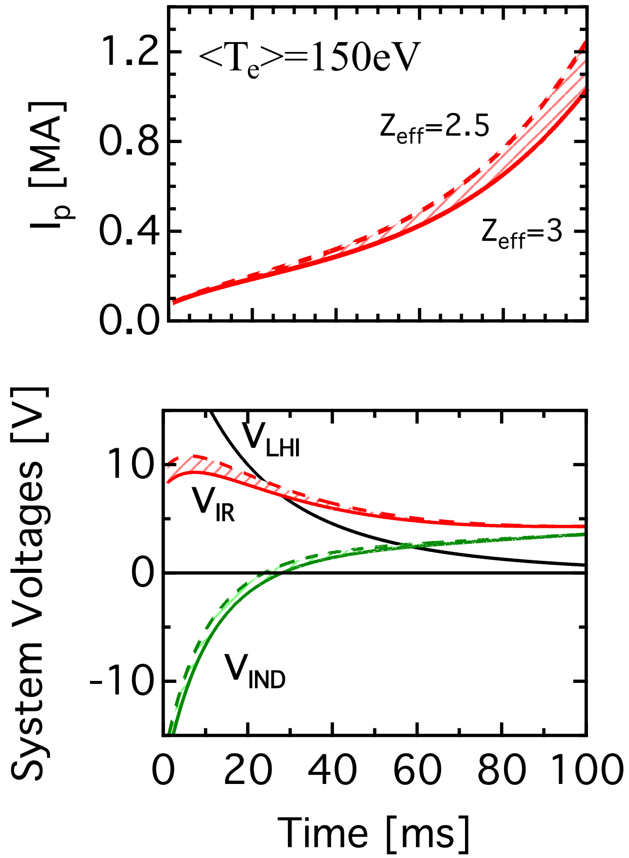
0-D Power Balance Model Used to Explore Projections for NSTX-U Startup

- $I_p(t)$ from 0-D power balance model: $$I_p\left[V_{LHI} + V_{IR} + V_{IND}\right] = 0$$

Shape evolution for LFS LHI on NSTX-U



NSTX-U: Projected

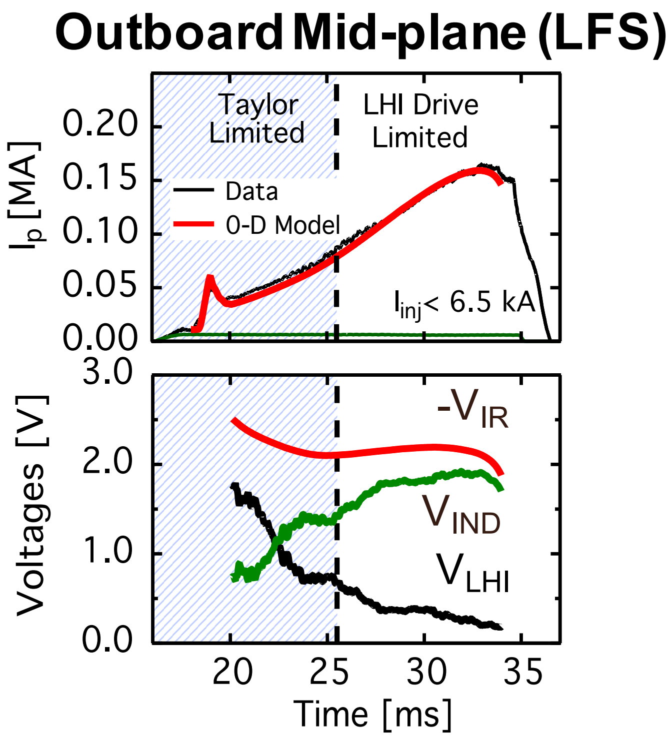


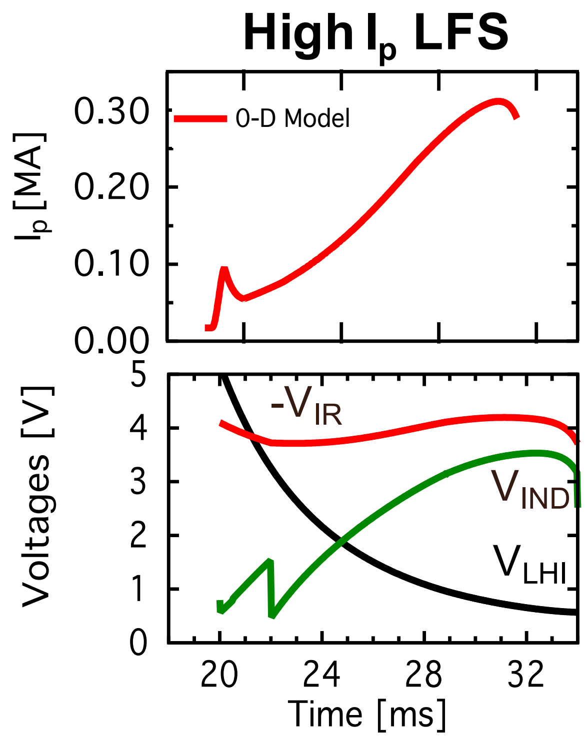
- Helicity dissipation (V_{IR}) dependent on T_e
- Importance of V_{LHI}, V_{IND} depends on injector geometry, plasma growth scenario
  - Final plasma depends strongly on full time evolution
- LFS mid-plane injection: V_{LHI} early, V_{IND} late
- HFS divertor injection mainly V_{LHI}

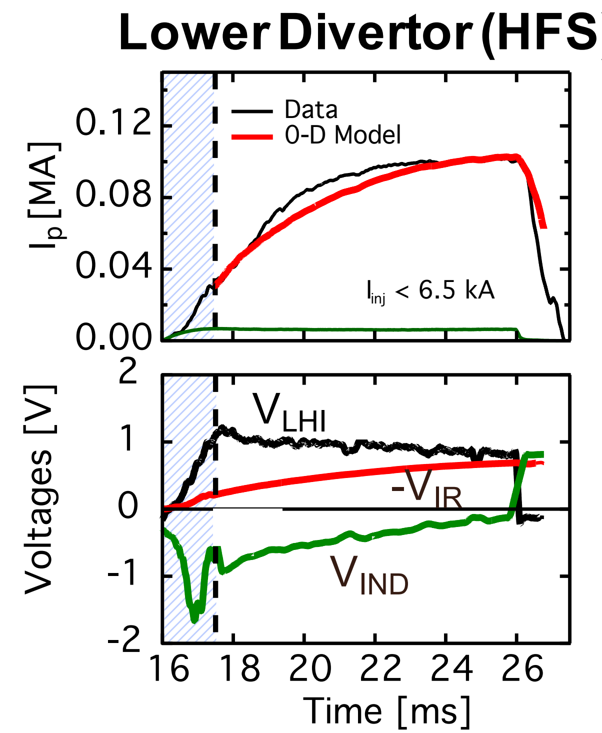
- ***Need to explore plasma evolution with different dominant drive terms***

On Pegasus: Utilize Different Injector Geometry to Emphasize Different Drive Mechanisms

- $I_p(t)$ from 0-D power balance model: $I_p\left[V_{LHI} + V_{IR} + V_{IND}\right] = 0$







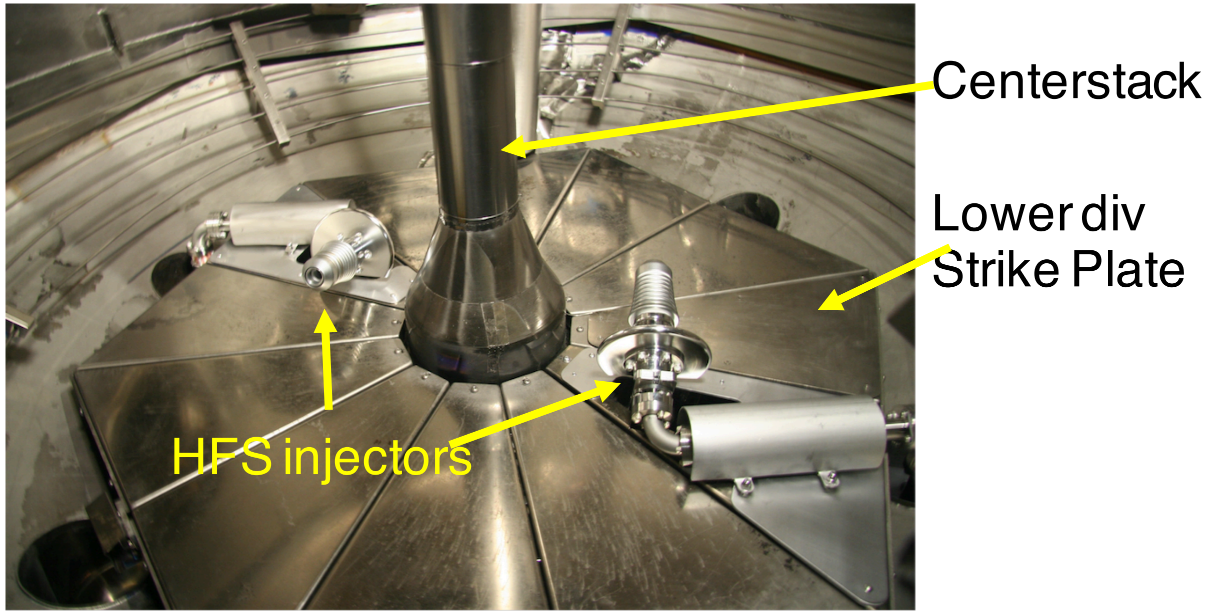
V_{IND} dominant → ***V_{LHI} dominant***

- Vary relative drive ratios to inform predictive model
- Future: Test scaling to high I_p in both LFS and HFS injection

New Helicity Injectors in the Divertor Region of Pegasus are Installed and Operating

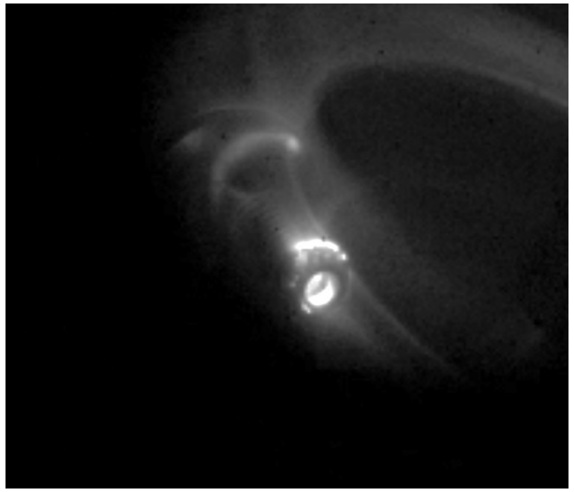
- HFS → 3-4x increased helicity input
  - Access to higher I_p startup
- Static geometry → low V_{IND}
- Injector operation at longer pulse, high-B_{TF}

Divertor Injectors after Installation



In the Process of Optimizing PMI Mitigation Measures in the HFS Injector Geometry

PMI on injector surfaces



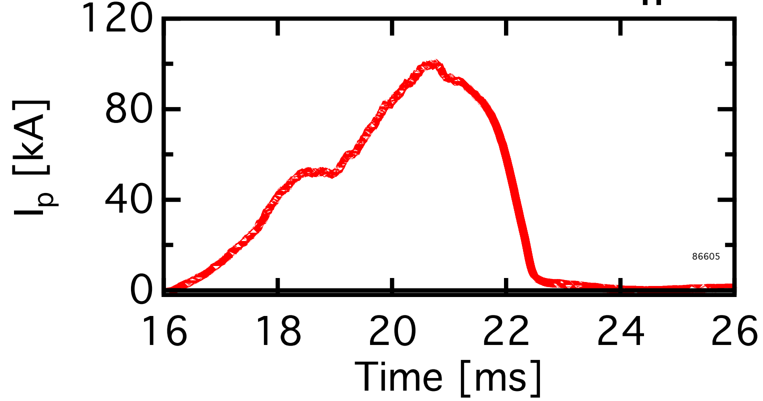
PMI on lower divertor plate

- PMI: Cathode spots, arc-back, divertor plate interaction
- Consequence: Impurity injection, reduced drive, loss of reproducibility
- PMI mitigated: Operation at low B_{TF}, improved alignment and local limiters
- PMI is much reduced, but still optimizing

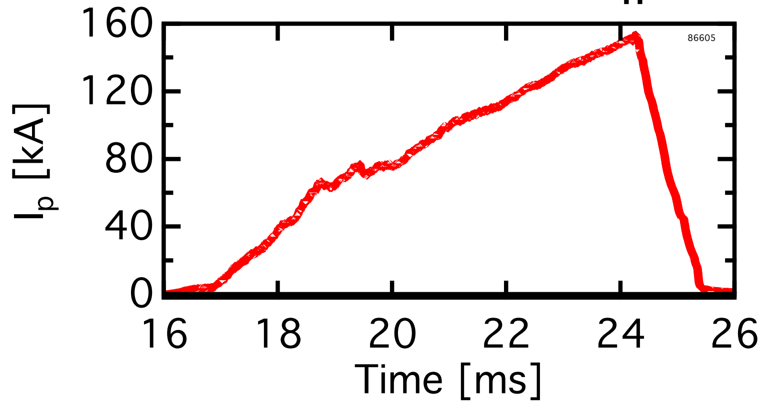
Initial Results from HFS Injector Campaign are Promising

- Larger area injectors (2 cm^2 → 4 cm^2) function well at full field (0.25 T)
- Demonstrated relaxation, current growth at full field
  - First milestone achieved
- I_p > 100 kA to date
- Producing attractive handoff targets
  - $\langle T_e \rangle \sim 100$ eV, $\overline{n_e} \sim 10^{19}$ m^{-3}
- Plasmas are highly elongated
  - $\kappa > 2.6$

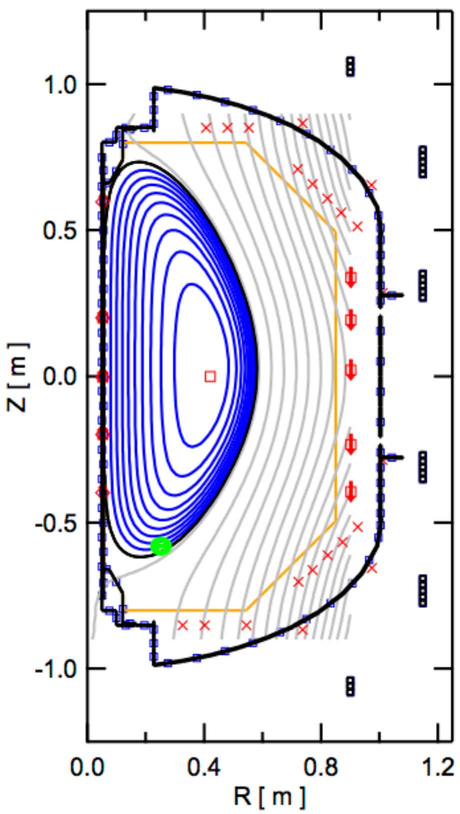
100kA at 100% B_{TF}



155kA at 30% B_{TF}

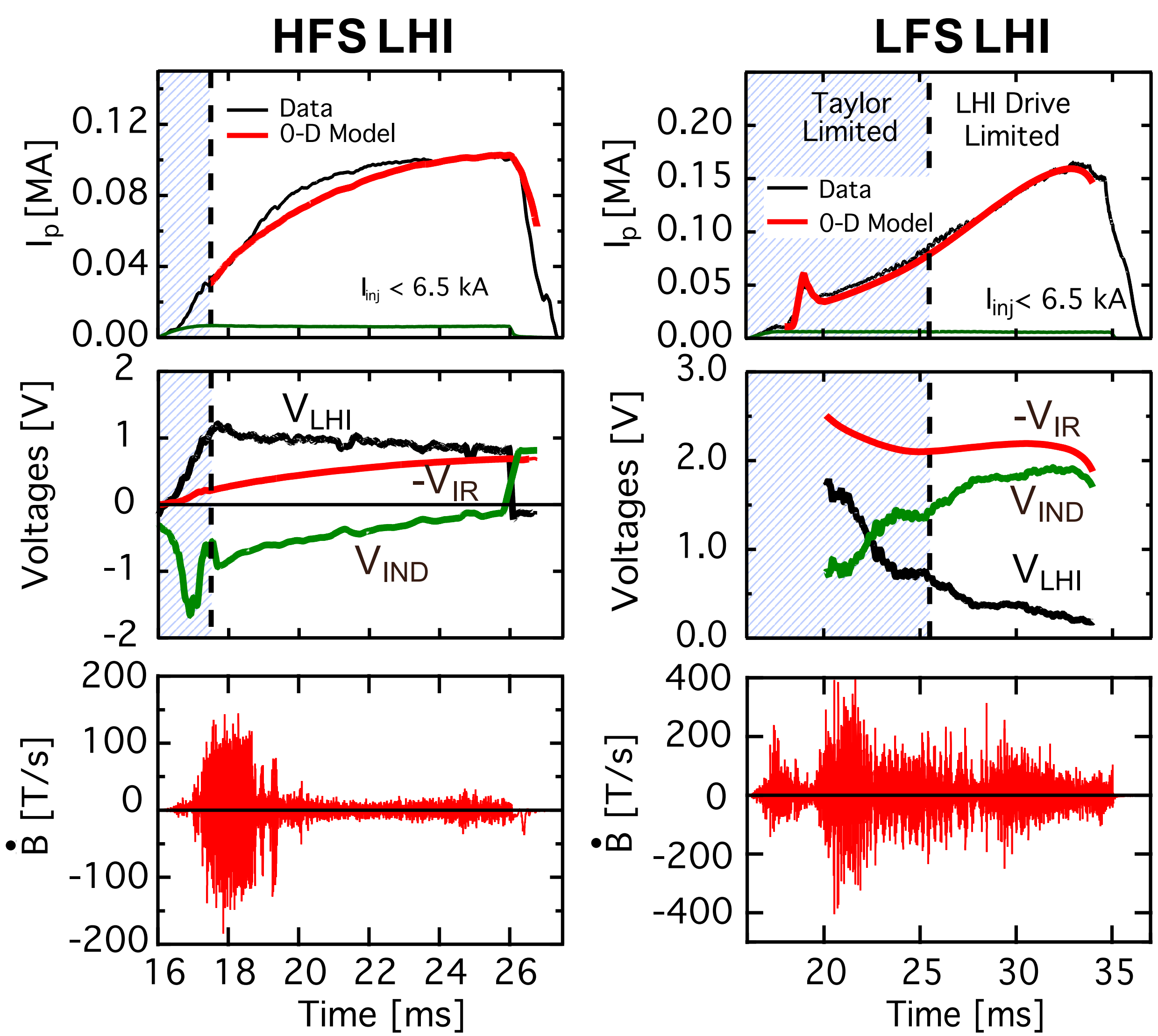


High κ



Fully V_{LHI} Driven Discharges at Low B_{TF} Exhibit Unexpected MHD Phenomenology

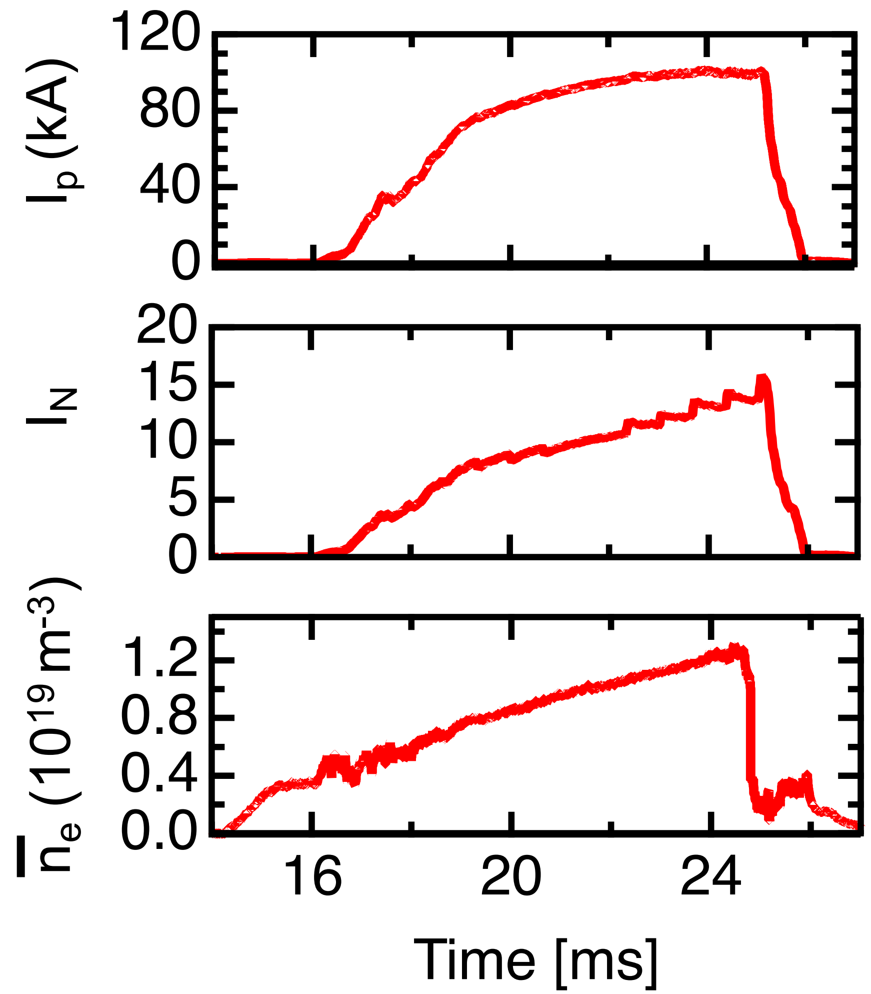
- 0-D model indicates full growth and sustainment by LHI drive
- MHD markedly different from LFS LHI
  - Initial phase: current drive from large scale reconnection of helical streams
  - MHD abruptly drops by an order of magnitude



Interim Operation at Low B_{TF} Allowed Observation of Sustained High I_N, High κ Discharge

- Low $I_{TF} < 0.6\, I_p$
- $I_N = 5A \frac{I_P}{I_{TF}} > 10$
  - Constant or ramped-down B_{TF}
- HFS injector geometry → naturally high elongation
- Ready access to High β_T
  - Aided by anomalous ion heating ($T_i > T_e$)

Access to $I_N > 14$, $\bar{n}_e > 10^{19}\ m^{-3}$ with HFS Injection, B_{TF} Ramp-down

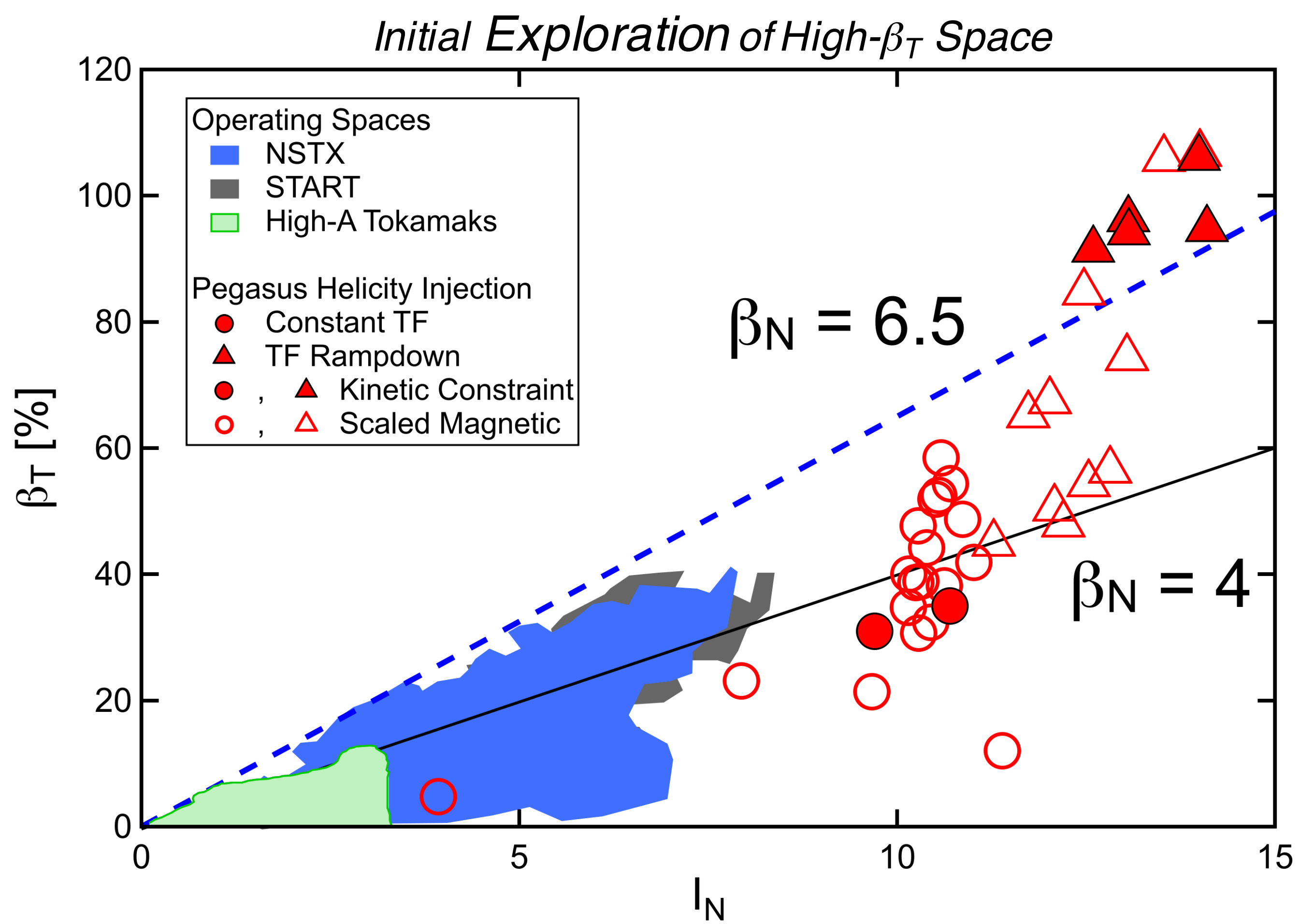


LHI Provides Access to High-β_T at A ~ 1 with Non-Solenoidal Sustainment and Anomalous Ion Heating

- Equilibrium reconstructions indicate high β_T (~<P>/B_{T0}^2)

- High β_T plasmas often terminated by disruption
  - n = 1, low-m precursors

- Expands I_N, β_T space for stability studies at extreme toroidicity



J.A. Reusch, APS-DPP 2016

HFS Injection Enables Exploring Varied Drive Mechanisms. Coincidentally: Unique Access to High I_N, β_T Space

- HFS injector operation and relaxation to a tokamak demonstrated at full TF (B_{TF_inj}~0.25T)
- Completely V_{LHI} driven startup and sustainment realized
- Sharp drop in MHD during I_p ramp suggests change in current drive mechanism
- HFS injection at low B_{TF} enables sustained non-inductive operation at high κ, high I_N, and high β_T
- Present campaign:
  - Optimize HFS injector implementation to mitigate PMI at high B_{TF}
  - Develop high I_p scenarios to test scaling
  - Design CHI system for comparison studies (with PPPL, U. Wash)