Advancing Non-Solenoidal Startup on the Pegasus ST

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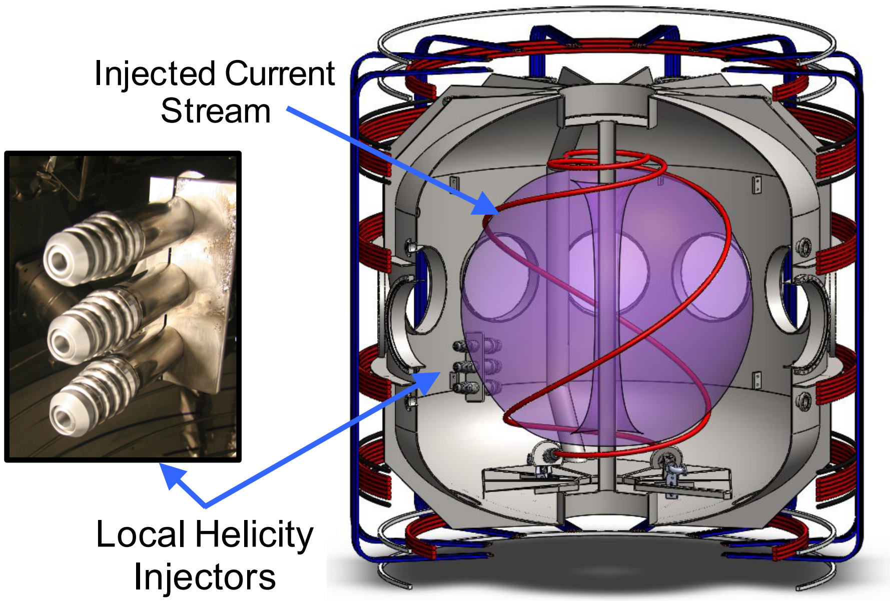
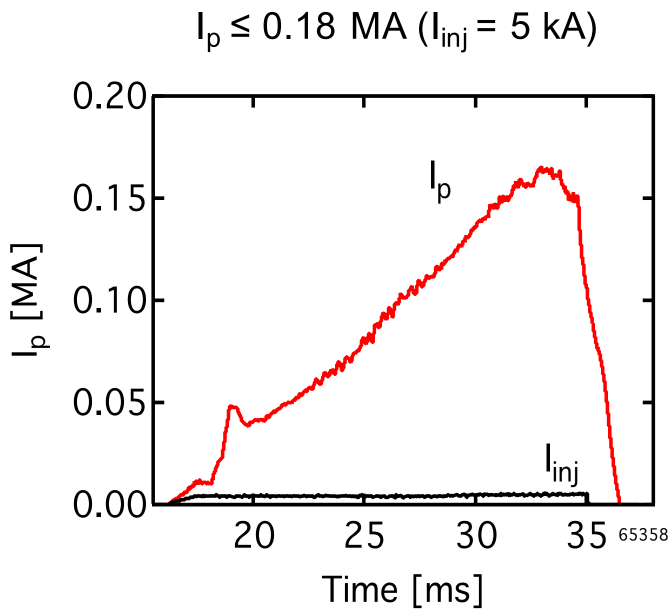
PEGASUS Toroidal Experiment

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





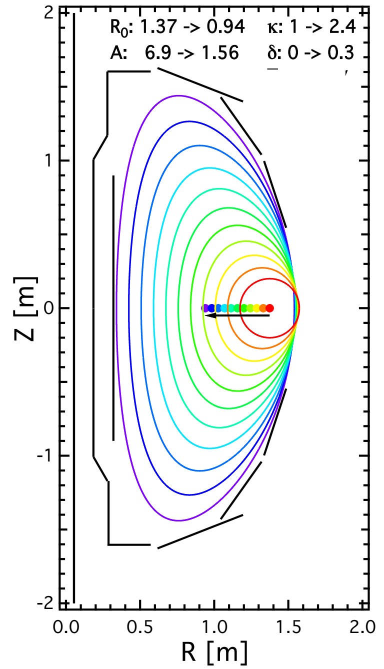
- Compact, modular washer-stack arc sources inject edge current
- Unstable current streams form tokamak-like state via magnetic reconnection, Taylor relaxation
- Physics and engineering tradeoffs strongly coupled to injector location

J.A. Reusch, APS-DPP 2016

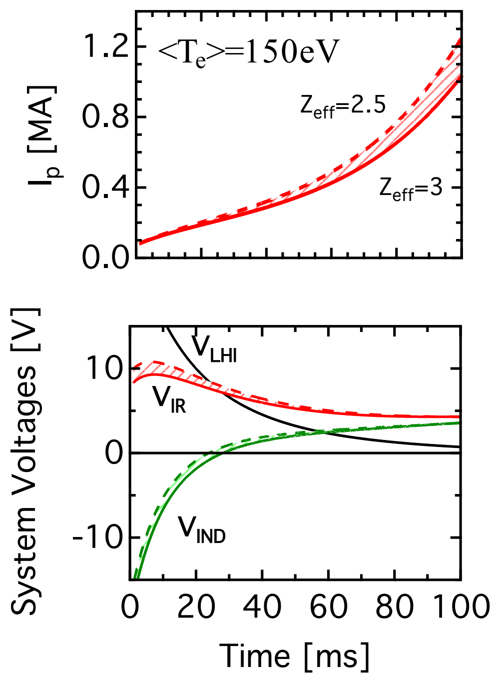
0-D Power Balance Model Used to Explore Projections for NSTX-U Startup

- $I_p(t)$ 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



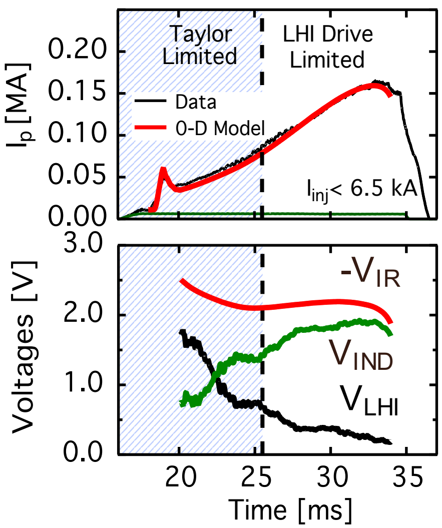
- Helicity dissipation (V_{IR}) dependent on T_e
- Importance of V_{LHI}, V_{IND} depends on injector geometry, plasma growth scenario
  - Final plasma depends strongly on full time evolution
- LFS mid-plane injection: V_{LHI} early, V_{IND} late
- HFS divertor injection mainly V_{LHI}

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

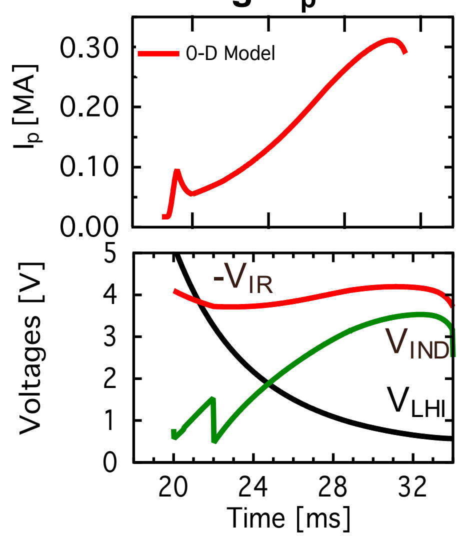
On Pegasus: Utilize Different Injector Geometry to Emphasize Different Drive Mechanisms

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

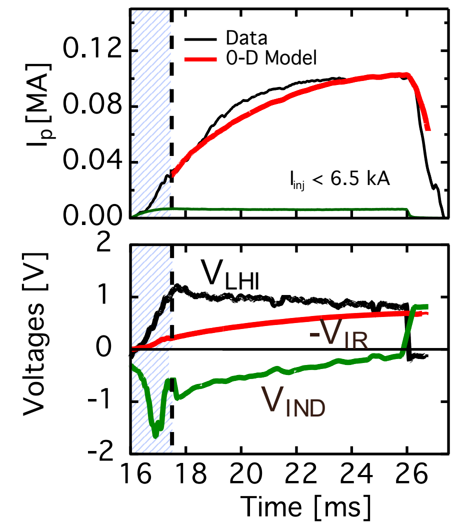
Outboard Mid-plane (LFS)



High I_p LFS



Lower Divertor (HFS)



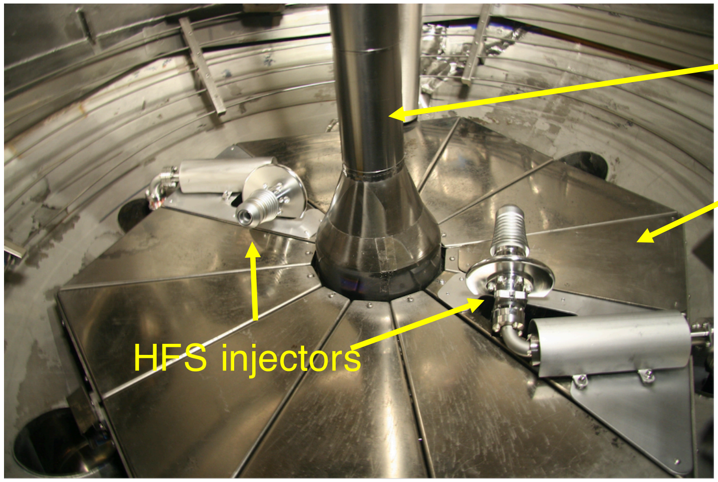
V_{IND} dominant → ***V_{LHI} dominant***

- 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

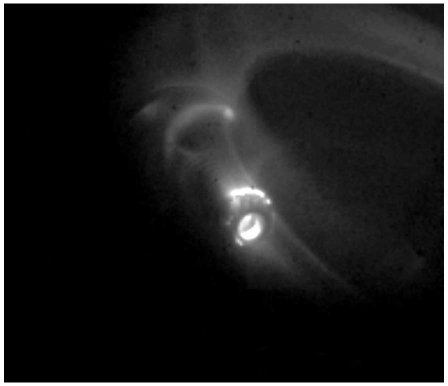
- HFS → 3-4x increased helicity input
  - Access to higher I_p startup
- Static geometry → low V_{IND}
- Injector operation at longer pulse, high-B_{TF}
- Initial HFS injector campaign in progress

Divertor Injectors after Installation



In the Process of Mitigating PMI in the Divertor Injector Geometry

PMI on injector surfaces

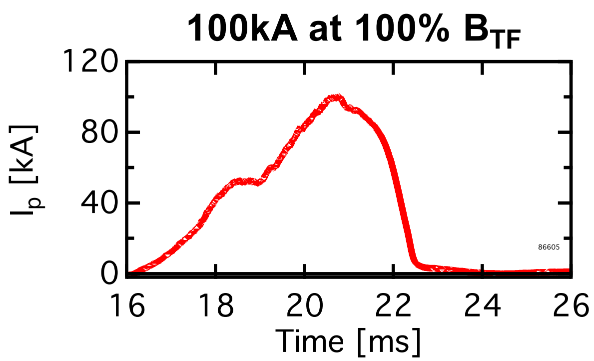


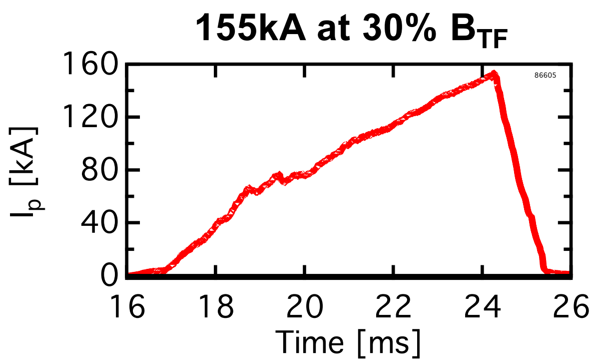
PMI on lower divertor plate

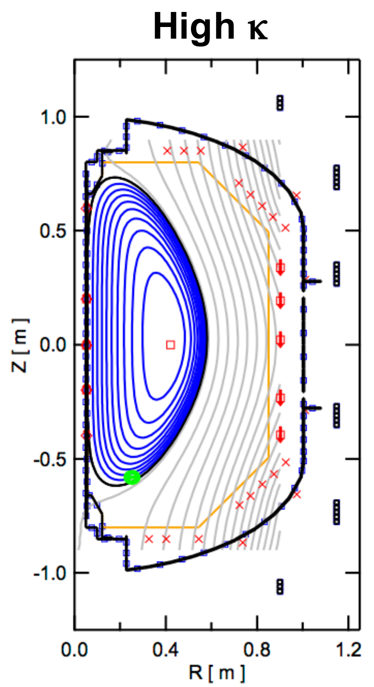
- PMI: Cathode spots, arc-back, divertor plate interaction
- Consequence: Impurity injection, reduced drive, loss of reproducibility
- PMI mitigated: Operation at low B_{TF}, improved alignment and local limiters
- PMI is much reduced, but still optimizing

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
  - $\kappa > 2.6$

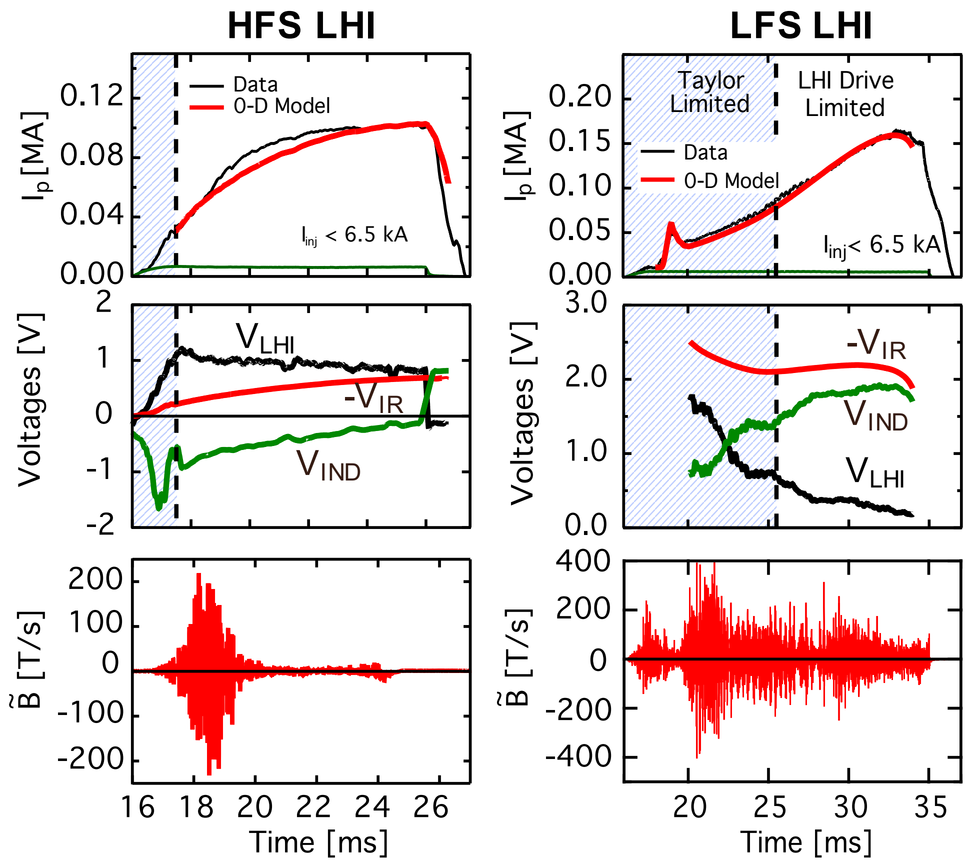






Fully V_{LHI} Driven Discharges at Low B_{TF} Achieved

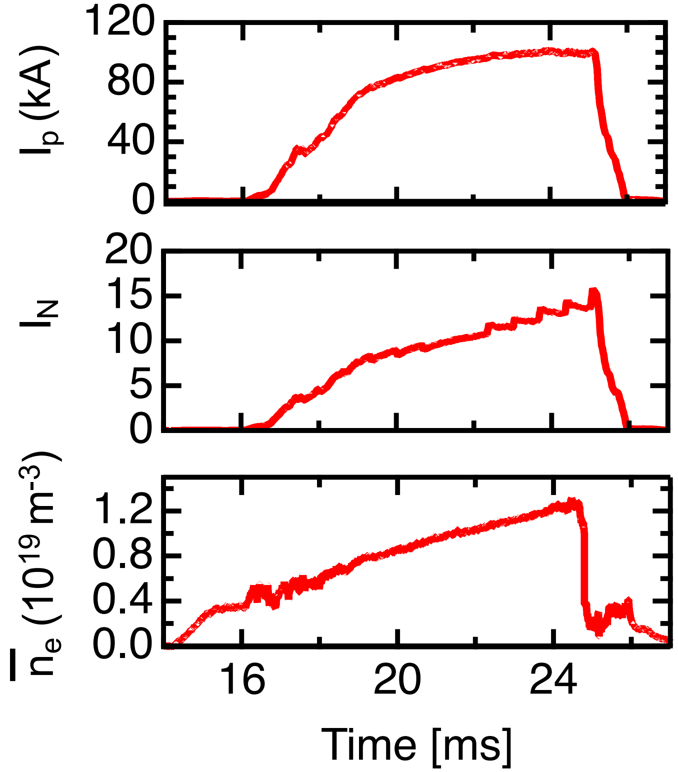
- Full growth and sustainment dominantly driven by LHI
- MHD markedly different from LFS LHI
  - Initial phase: current drive from large scale reconnection of helical streams
  - MHD abruptly drops by an order of magnitude



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

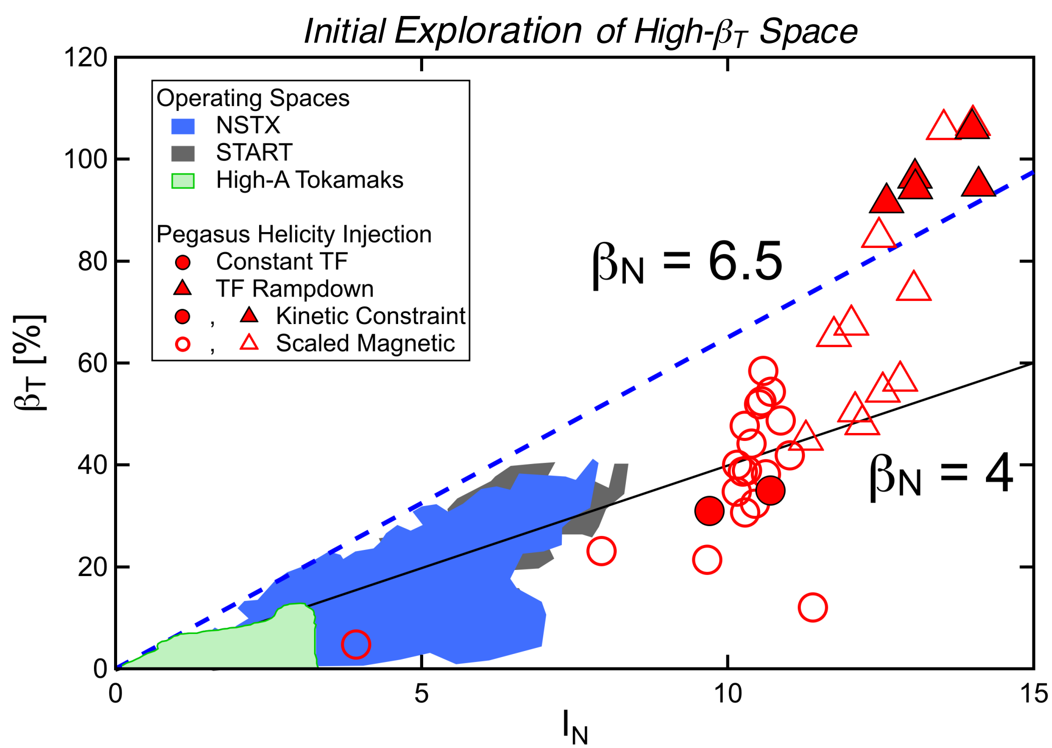
- Low $I_{TF} \sim 0.6\ I_p$
- $I_N = 5A\frac{I_P}{I_{TF}} > 10$
  - Constant or ramped-down B_{TF}
- HFS injector geometry → naturally high elongation
- Ready access to High β_T
  - Aided by anomalous ion heating ($T_i > T_e$)

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



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 Ip scenarios to test scaling
  - Design CHI system for comparison studies (with PPPL, U. Wash)