V_{eff} Scaling of T_e and n_e Measurements During Local Helicity Injection on the Pegasus Toroidal Experiment

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PEGASUS Toroidal Experiment

Layout Slide (Include for Posters)

12:1 scale Panel size: 8' x 4'

US Legal 8.5 x 14"

US Letter 8.5 x 11"

Populate with section titles, final slide titles

Spacer for Title Strip and Column Headings

Introduction Slide (Summary and Motivation)	Confinement During Non-Inductive LHI	Introduction to V_{LHI} Experiment	Installation of 24-Channel Fiber Mount	Introduction to High TF Operations
Pegasus Overview	Comparisons between Outboard and Inboard LHI	Te and ne at Different V_{LHI}	MHD Comparisons at 50%	
Layout of the Pegasus Thomson Beam Line	LFS LHI Time Evolution	Time Evolution at One V_{LHI} Level	MHD Comparisons at 50%	Full TF Time Evolution
Thomson Spectrometer Overview	HFS LHI Time Evolution	Initial High Bt Results	Density Scaling at 50%	Summary and Conclusions

Thomson Scattering Diagnostic System Deployed to Investigate T_e and n_e During Local Helicity Injection

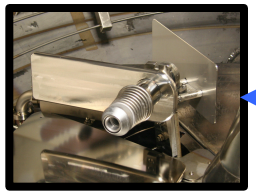
- Collection of T_e and n_e profiles is a critical plasma measurement
  - Equilibrium/Stability
  - Transport and confinement
- Understanding electron confinement during LHI necessary for scalability to MA-class devices.
- New fiber mount deployed to view 24 spatial locations simultaneously
- T_e and n_e profiles collected for multiple injector geometries

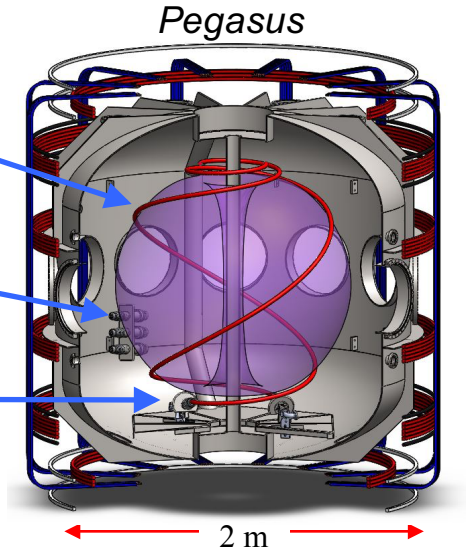
Local Helicity Injection Provides Non-Inductive Startup at Low *A*



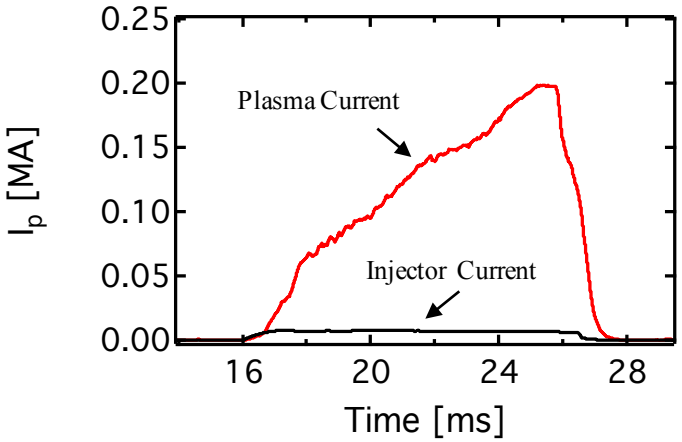
LFS System

HFS System





Non-Solenoidal, High $I_p \leq 0.2$ MA ($I_{inj} \leq 8$ kA)

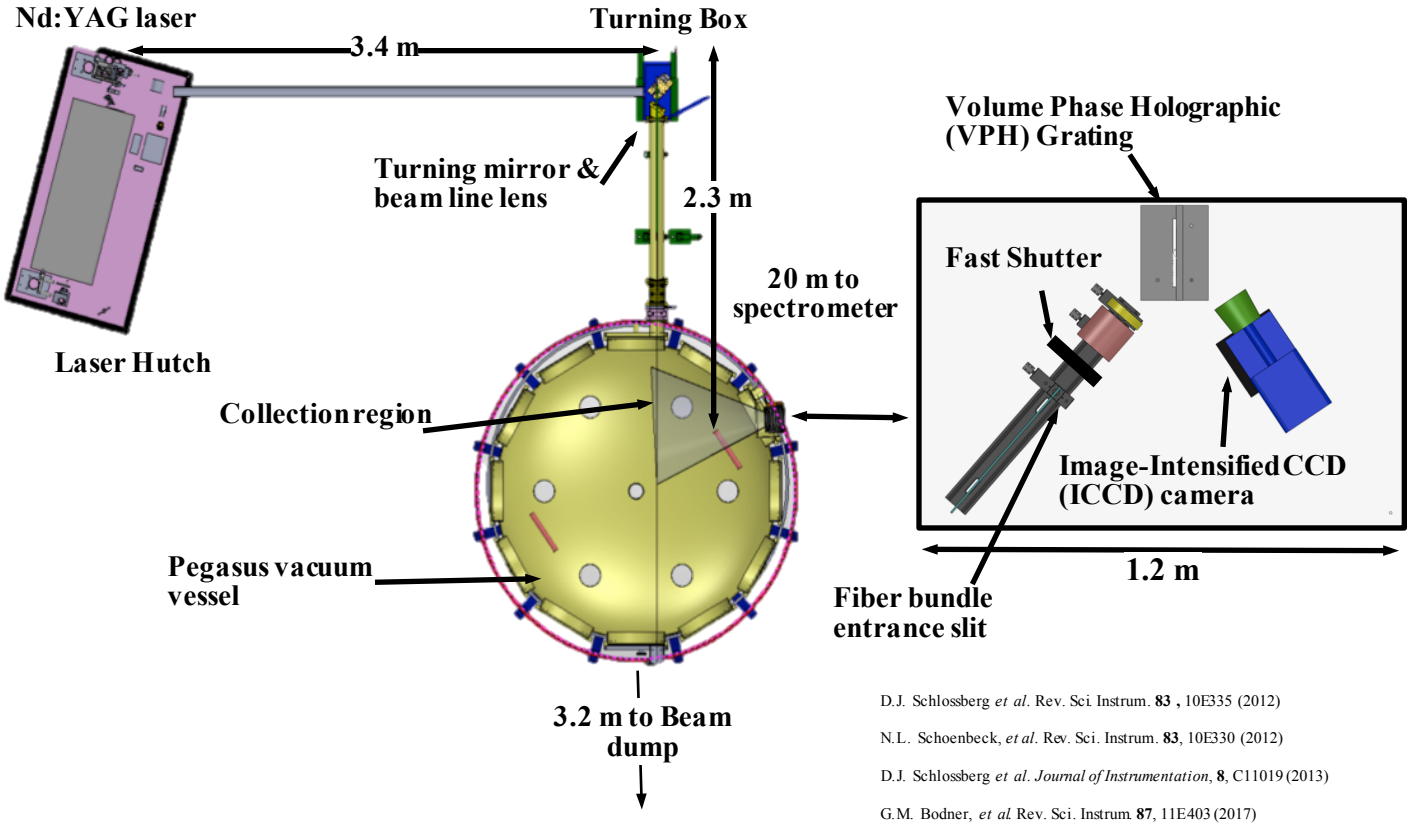


Pegasus Parameters

A	$1.15 - 1.3$
R [m]	$0.2 - 0.45$
I_p [MA]	≤ 0.25
B_T [T]	< 0.15
Δt_{shot} [s]	≤ 0.025

- Edge current extracted from small, modular injectors
- Relax to tokamak-like state via helicity-conserving instabilities
- Used routinely for startup on PEGASUS

Layout of the Pegasus Thomson Scattering Diagnostic



D.J. Schlossberg *et al.* Rev. Sci. Instrum. **83** , 10E335 (2012)

N.L. Schoenbeck, *et al.* Rev. Sci. Instrum. **83**, 10E330 (2012)

D.J. Schlossberg *et al. Journal of Instrumentation*, **8**, C11019 (2013)

G.M. Bodner, *et al.* Rev. Sci. Instrum. **87**, 11E403 (2017)

New Fiber Mount Allows For Simultaneous Observation of 24 Spatial Channels

- Good reproducibility allows laser-off shots for background subtraction
- Background channels repurposed as additional data channels
- Previous configuration required moving fiber mounts to view plasma profile



Previous Configuration*



Current Configuration*



4 Data Channels
4 Background Channels



8 Data Channels

*Figure shows 8 of 24 total fiber channels

I_p Scaling of Non-Inductive LHI Startup Critically Depends on T_e

- Local Helicity Injection (LHI) creates tokamak plasmas with high power edge current injection
- Physics encapsulated in hierarchy of models:

1. Maximum I_p Limits[1]:

Taylor Relaxation

$$I_p \le I_{TL} \sim \left(\frac{I_{TF} I_{inj}}{w} \right)^{1/2}$$

Helicity Conservation

$$I_p \le \frac{A_p}{2\pi R_0 \langle \eta \rangle} \left(\frac{A_{inj} B_{\phi,inj}}{\Psi} V_{inj} + V_{IND} \right)$$

[1] D.J. Battaglia, et al. Nucl. Fusion **51** (2011) 073029. N.W. Eidietis, Ph.D. Thesis, UW-Madison, 2007.

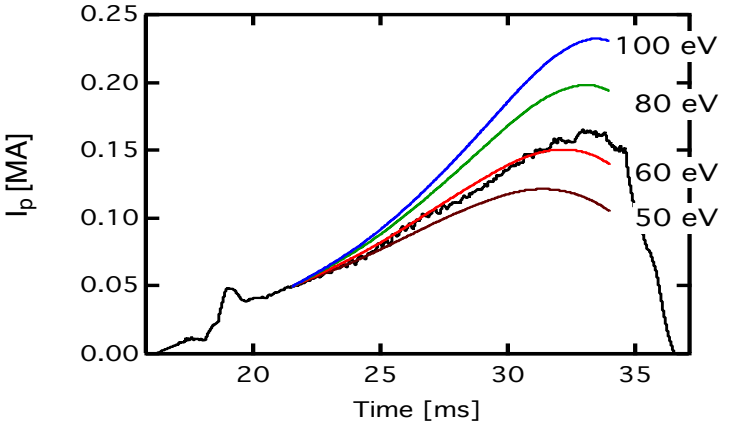
2. 0-D Power Balance Model for $I_p(t)$:

T_e dependent terms

$$I_p [V_{LHI} - V_{IR} + V_{IND}] = 0 \; ; \; I_p \le I_{TL}$$

3. 3D Resistive MHD (NIMROD)

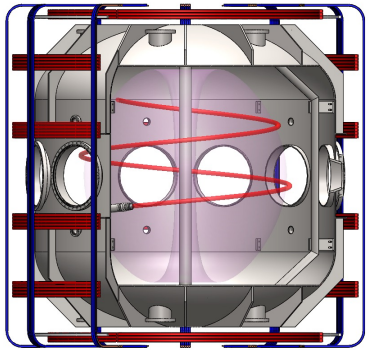
Projections from 0-D Power Balance Model Demonstrating Impact of T_e on LHI Performance



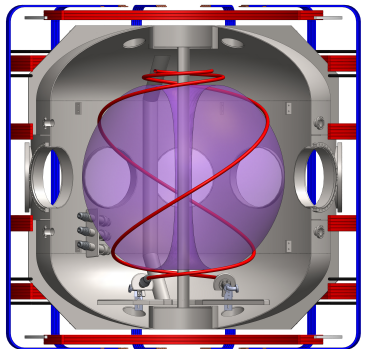
Different Injector Geometries Emphasize Different Current Drive Mechanisms

- Low-Field-Side (LFS) injection:
  - Injectors near outboard midplane
  - Shape evolution → V_{IND} dominates
- High-Field-Side (HFS) injection:
  - Injectors in lower divertor
  - Static shape → V_{LHI} dominates
- Different current drive mechanisms may lead to different electron transport

Low-Field Side Injection (LFS)



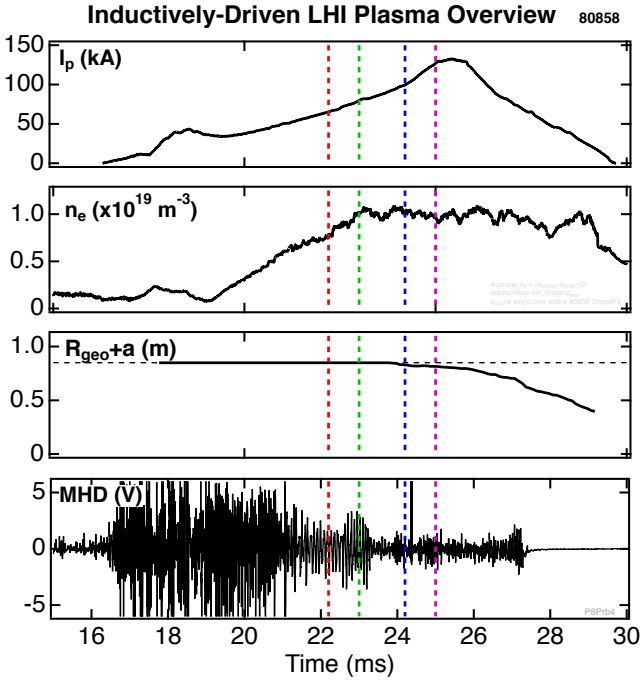
High-Field Side Injection (HFS)



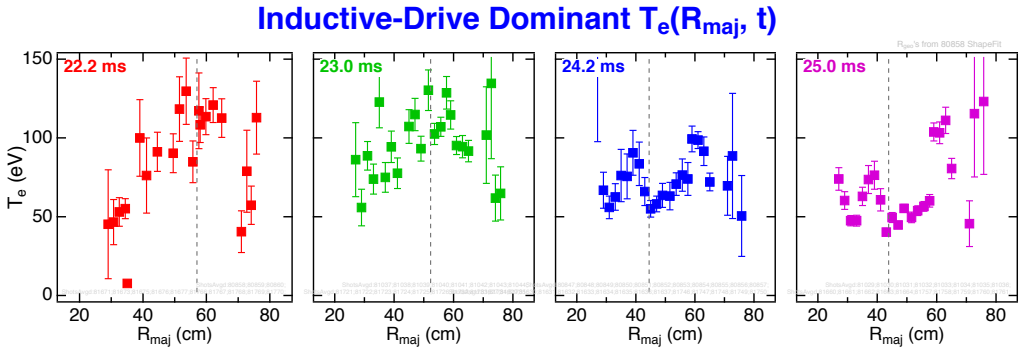
$$I_p[V_{LHI} - V_{IR} + V_{IND}] = 0$$

$$V_{LHI} = \frac{V_{inj}A_{inj}B_{inj}}{\Psi_{TF}} \sim \frac{1}{R_{inj}}$$

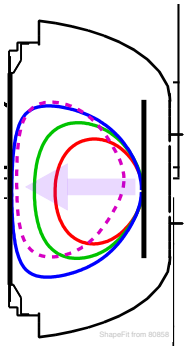
LFS LHI at High B_t Produces Peaked T_e Profiles with Core T_e > 100 eV, When Coupled to Injectors

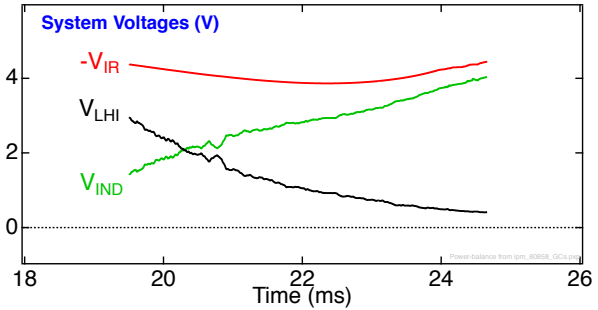


I_{TF} ~ 288 kA

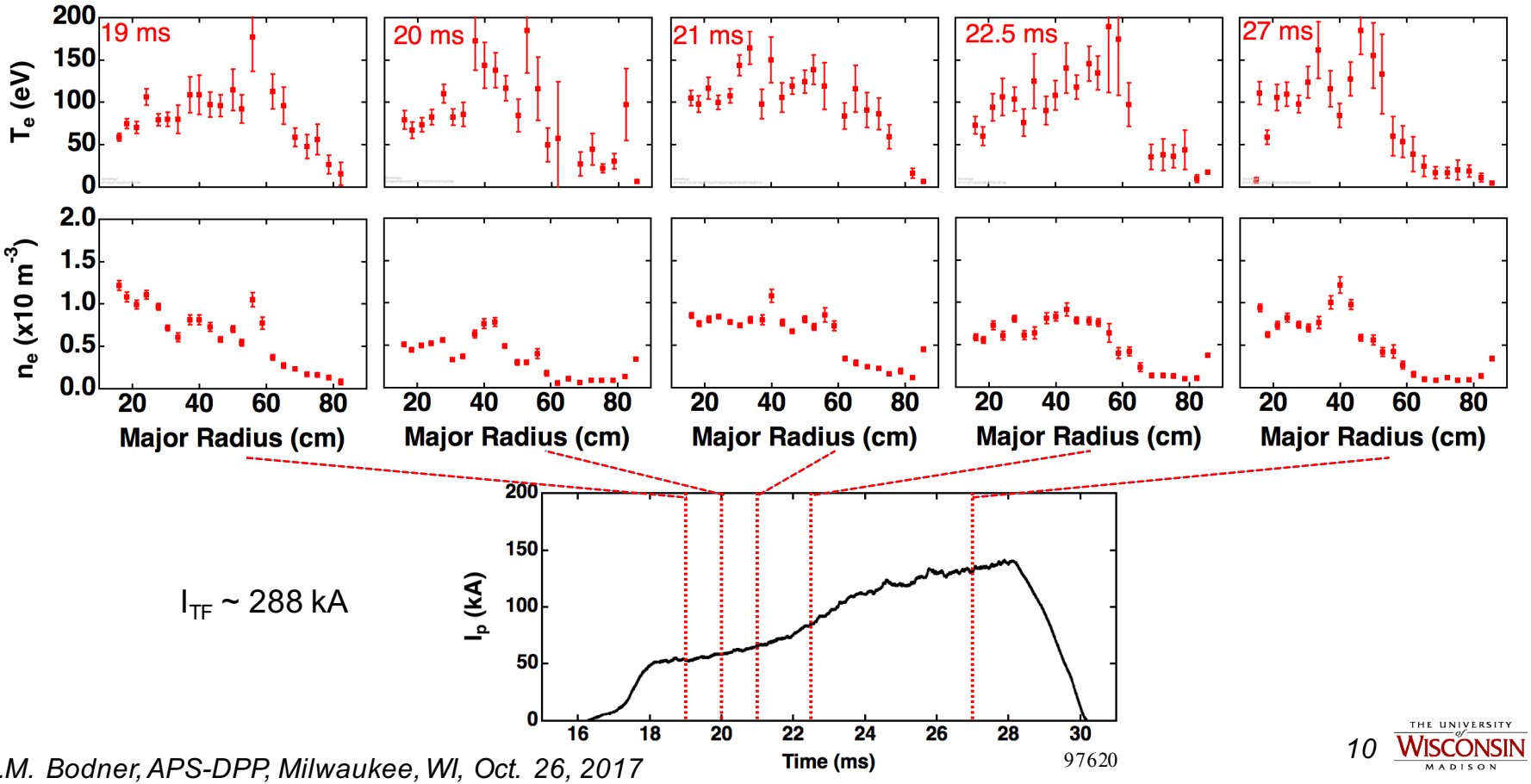


- Peaked T_e profiles near comparable to Ohmic confinement





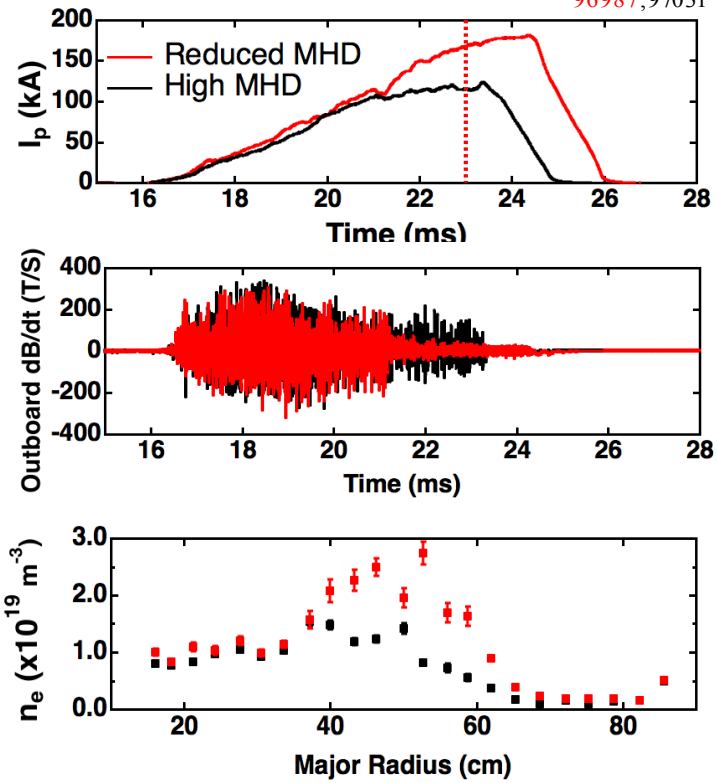
Similarly HFS LHI at High B_t Observes Peaked T_e Profiles



New Reduced MHD Regime Observed at low B_t

- MHD transition characterized by rapid increase of I_p and n_e
- Thomson measurements indicate increase in n_e in the Reduced MHD regime
- Understanding the MHD transition may be necessary to access to higher I_p

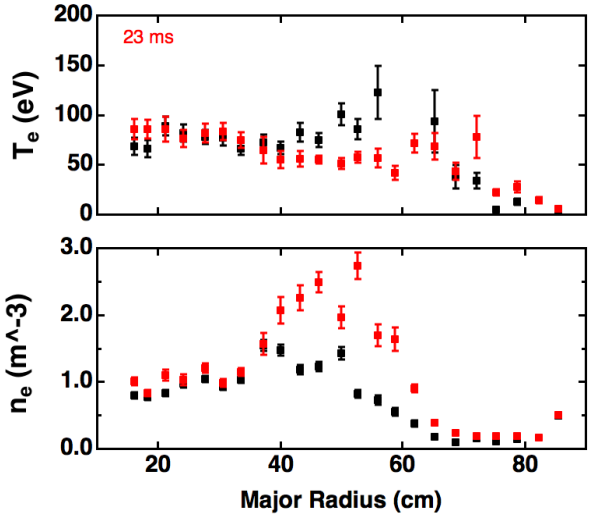
96987;97031

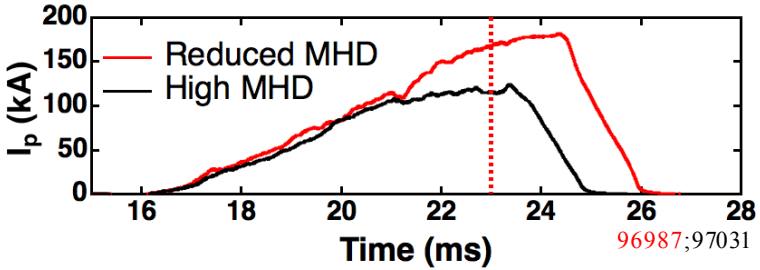


I_{TF} ~ 144 kA

MHD Transition Reduces Core and LFS Edge T_e

- Core T_e largely unaffected by MHD transition
- Increased n_e leads to reduction in T_e
- T_e profiles differ from those at high B_t

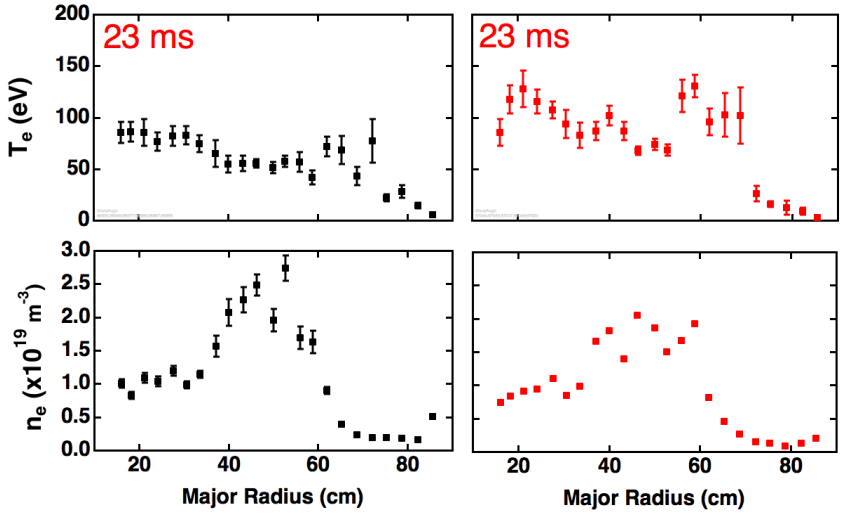


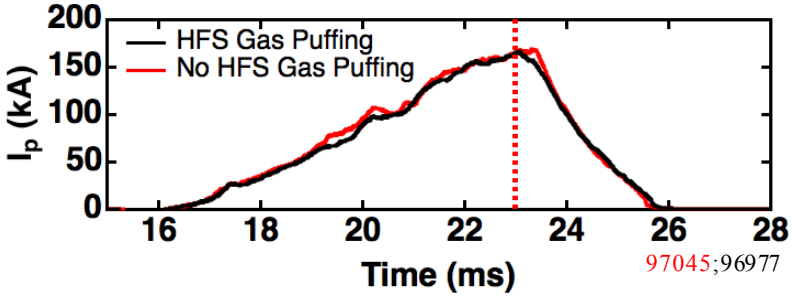


I_{TF} ~ 144 kA

Increased T_e Can Be Observed in the Reduced MHD Regime With Reduced Neutral Fueling

- Neutral fueling changed by eliminating HFS gas puffing
- Edge T_e increases, resulting in hollow profile structure
- Extensive n_e scaling experiments planned for the near future

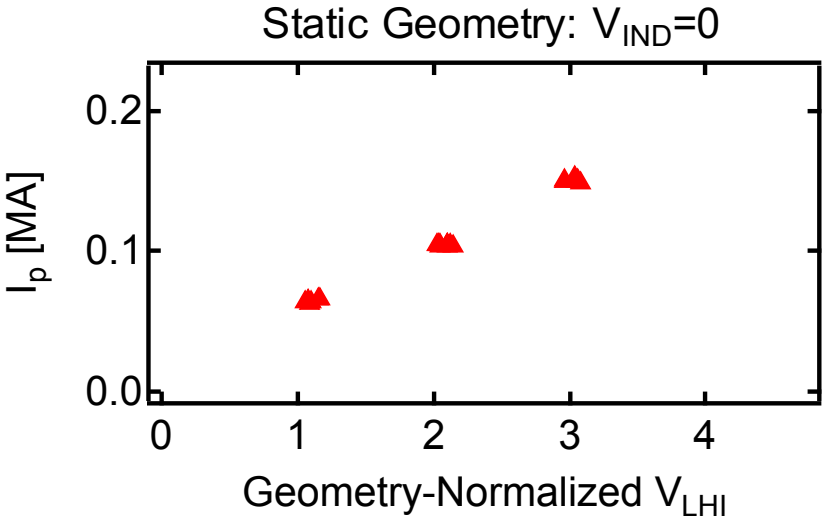




I_{TF} ~ 144 kA

V_{LHI} Scaling Performed to Determine Effect of Input Power on T_e at Reduced B_t

- I_p scales roughly with V_{LHI}
- LHI-only discharges with static geometry and I_{TF} ~ 86.4 kA
- T_e and n_e profiles collected at three different levels of V_{LHI}



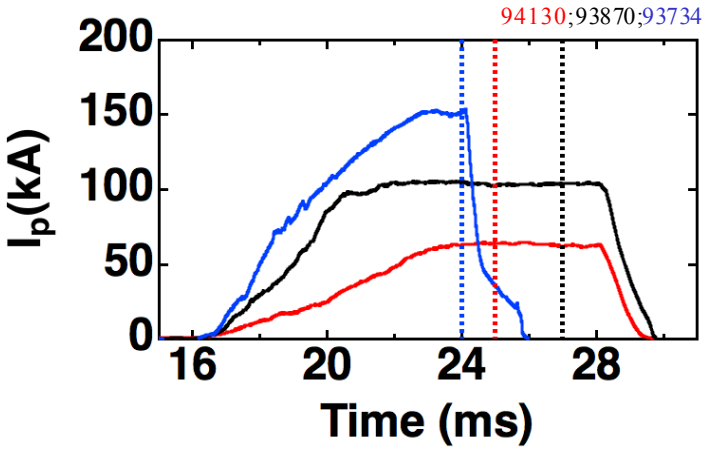
$$V_{LHI} = \frac{V_{inj} A_{inj} B_{inj}}{\Psi_{TF}} \sim \frac{1}{R_{inj}}$$

Constant

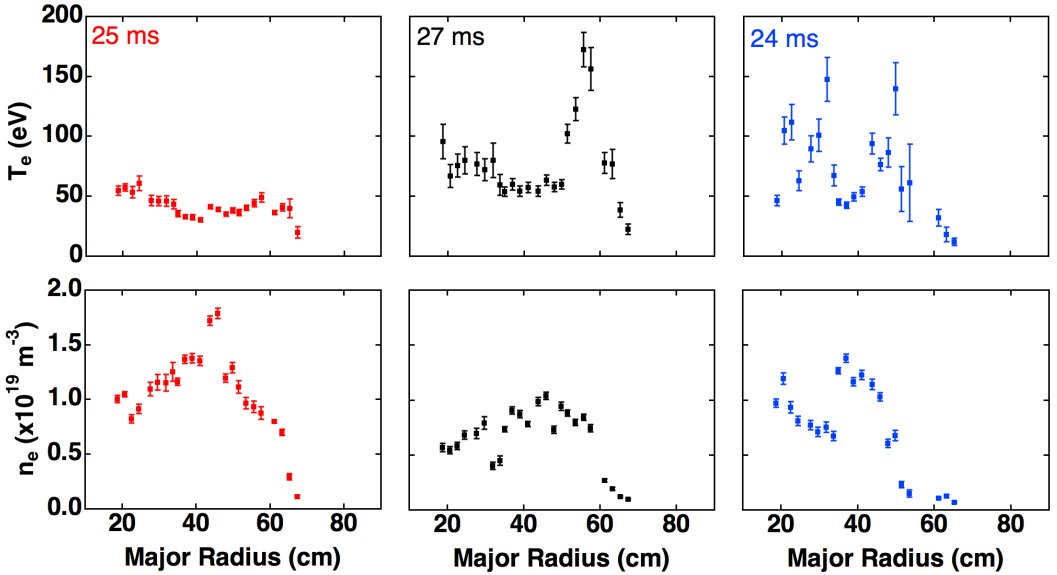
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Hollow T_e Profile Features Reinforced at Increased Input Power

- Anomalously high T_e observed in plasma edge

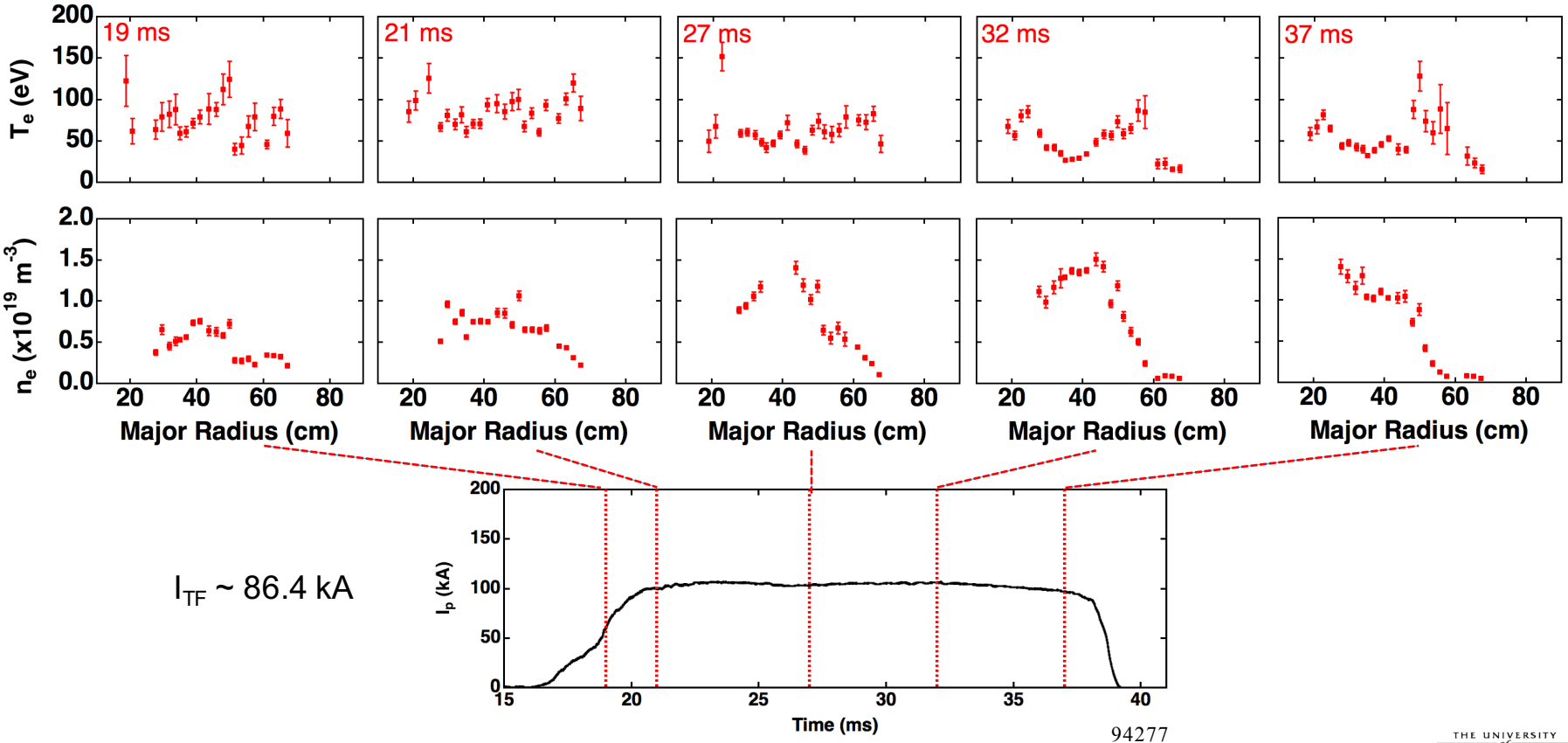


I_{TF} ~ 86.4 kA



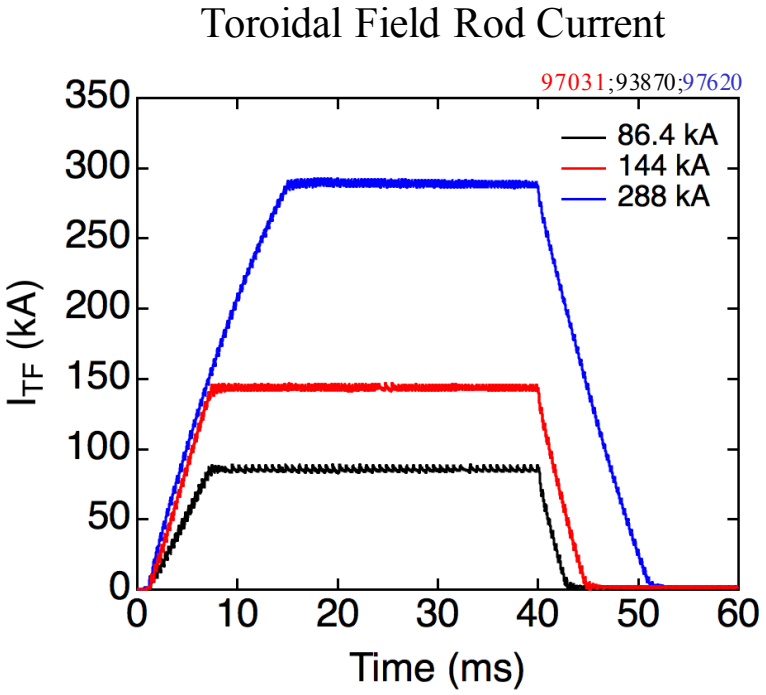
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Time Evolution at Constant V_{LHI} Shows T_e Profiles Transition from Flat to Hollow with Peaked n_e Profiles

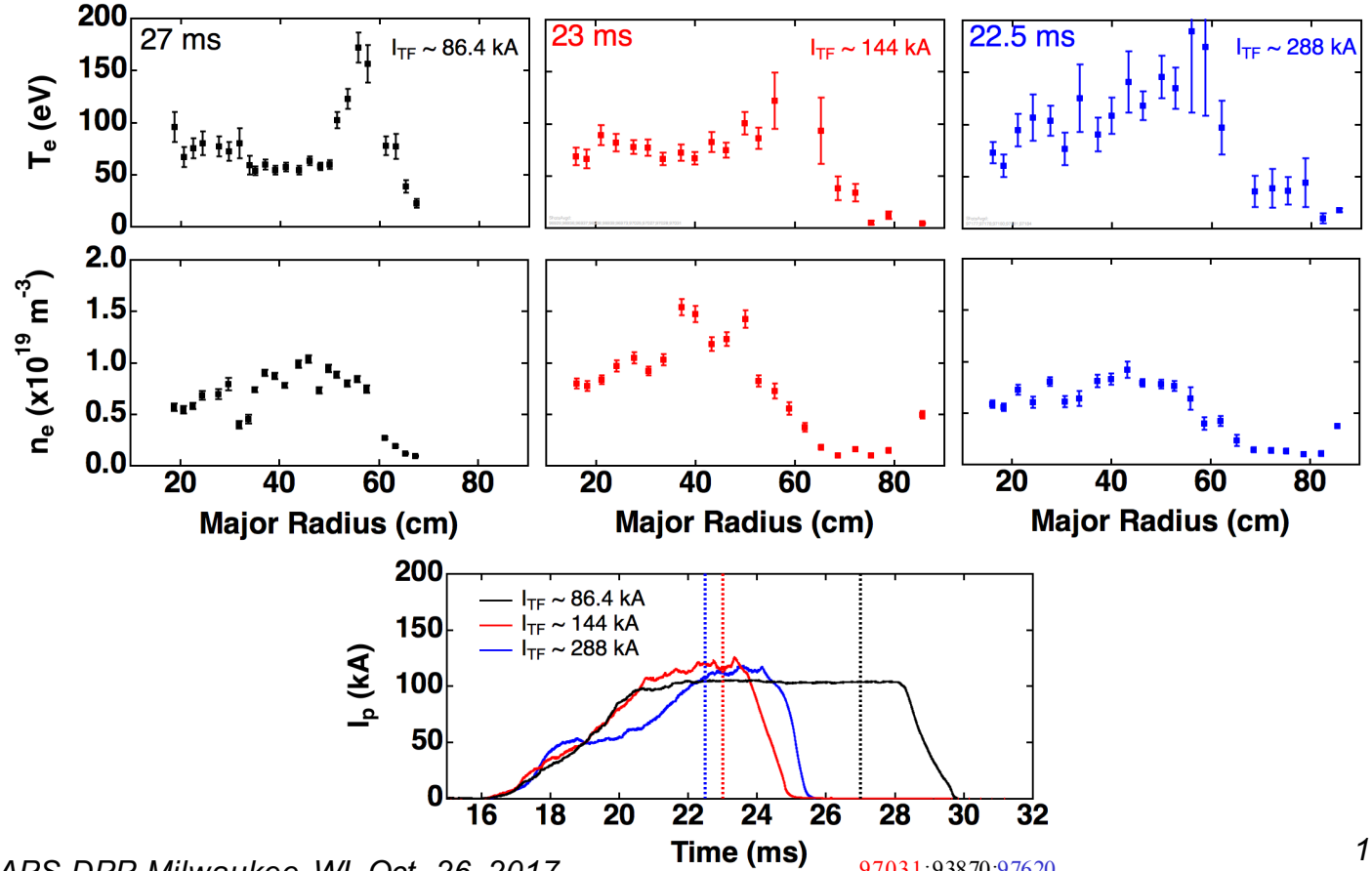


Poor T_e Confinement with Increased V_{LHI} and Reduced MHD Indicate B_t May Have Strongest Impact on T_e

- B_t scaling performed by changing toroidal field rod current, I_{TF}
  - Thomson measurements taken at three different TF rod currents
  - Peaked T_e observed at $I_{TF} \sim 288$ kA
- Discharges at each TF level had comparable I_p and n_e
  - $I_p \sim 100$ kA, $n_e \sim 1 \times 10^{19}$ m^{-3}



T_e Profile Structure Has a Strong Dependence on B_t



97031;93870;97620

Summary and Conclusions

- Thomson measurements at low B_t indicate hollow T_e profiles with anomalously high edge T_e.
- At high B_t, T_e profiles are peaked, near comparable to Ohmic-driven plasmas
- Extensive High B_t operations planned for the future to further investigate confinement during HFS LHI

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