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

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### Introduction Slide (Summary and Motivation)

- Pegasus Overview
- Layout of the Pegasus Thomson Beam Line
- Thomson Spectrometer Overview

### Confinement During Non-Inductive LHI

- Comparisons between Outboard and Inboard LHI
- LFS LHI Time Evolution
- HFS LHI Time Evolution

### Introduction to $V_{LHI}$ Experiment

- $Te$ and $ne$ at Different $V_{LHI}$ Level
- Time Evolution at One $V_{LHI}$ Level
- Initial High Bt Results

### Installation of 24-Channel Fiber Mount

- MHD Comparisons at 50%
- MHD Comparisons at 50%
- Density Scaling at 50%

### Introduction to High TF Operations

- Full TF Time Evolution
- Summary and Conclusions

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**12:1 scale  Panel size: 8’ x 4’**

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**Populate with section titles, final slide titles**

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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

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Local Helicity Injection Provides Non-Inductive Startup at Low \( A \)

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

**Pegasus Parameters**

- \( A \): 1.15 – 1.3
- \( R \) [m]: 0.2 – 0.45
- \( I_p \) [MA]: \( \leq 0.25 \)
- \( B_T \) [T]: \( < 0.15 \)
- \( \Delta t_{shot} \) [s]: \( \leq 0.025 \)

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Layout of the Pegasus Thomson Scattering Diagnostic

Nd:YAG laser

Turning mirror & beam line lens

Laser Hutch

Turning Box

Collection region

Pegasus vacuum vessel

3.4 m

2.3 m

20 m to spectrometer

Volume Phase Holographic (VPH) Grating

Fast Shutter

Image-Intensified CCD (ICCD) camera

3.2 m to Beam dump

1.2 m

Fiber bundle entrance slit


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

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

*Figure shows 8 of 24 total fiber channels

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• 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
     
     $I_p \leq I_{TL} \sim \left(\frac{I_{TP} I_{inj}}{W}\right)^{1/2}$

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

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

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

  3. 3D Resistive MHD (NIMROD)

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

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Different Injector Geometries Emphasize Different Current Drive Mechanisms

- Low-Field-Side (LFS) injection:
  - Injectors near outboard midplane
  - Shape evolution $\Rightarrow V_{\text{IND}}$ dominates

- High-Field-Side (HFS) injection:
  - Injectors in lower divertor
  - Static shape $\Rightarrow V_{\text{LHI}}$ dominates

- Different current drive mechanisms may lead to different electron transport

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

\[ V_{\text{LHI}} = \frac{\frac{V_{\text{inj}} A_{\text{inj}} B_{\text{inj}}}{\Psi_{\text{TF}}} \cdot \frac{1}{R_{\text{inj}}}} \]
LFS LHI at High $B_t$ Produces Peaked $T_e$ Profiles with Core $T_e > 100$ eV, When Coupled to Injectors

- Peaked $T_e$ profiles near comparable to Ohmic confinement

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Similarly HFS LHI at High $B_t$ Observes Peaked $T_e$ Profiles

$I_{TF} \sim 288\, \text{kA}$
- 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 $I_p$
- 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 $B_t$

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$I_{TF} \sim 144 \text{ kA}$
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

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$V_{LHI}$ 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 $I_{TF} \sim 86.4$ kA
- $T_e$ and $n_e$ profiles collected at three different levels of $V_{LHI}$

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

Static Geometry: $V_{IND}=0$

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Hollow $T_e$ Profile Features Reinforced at Increased Input Power

- Anomally high $T_e$ observed in plasma edge

$I_p$ (kA) vs Time (ms)

$I_{TF} \sim 86.4$ kA

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

$T_e$ (eV) vs. Major Radius (cm)

$n_e$ ($\times 10^{19}$ m$^{-3}$) vs. Major Radius (cm)

$I_{TF} \sim 86.4$ kA

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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$^{-3}$

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$T_e$ Profile Structure Has a Strong Dependence on $B_t$

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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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