Assessment of Impurity Content and Radiated Power in LHI Discharges on the PEGASUS ST

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PEGASUS Toroidal Experiment

Layout Slide (Include for Posters)

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

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8.5 x 14"

Assessment of Impurity Content and Radiated Power in LHI Discharges on the PEGASUS ST

Local Helicity Injection (LHI) is a Promising Non-Solenoidal Startup Technique	Injector Location Emphasizes Different Current Drive	HFS & LFS LHI Successfully Couple to OH CD at B_t=0.15T	In All Cases, Low P_{RAD} Estimated From AXUV Diode
Understanding Impurities Necessary Aspect for LHI Scalability	HFS LHI at B_t= 0.045T, Modest P_{XUV} and Line Emission	Impurity Charge State Balance Shifts Consistent With Higher Temperature After Handoff	Upgrade to AXUV Diodes on Pegasus
Multiple Diagnostics Planned to Measure Impurities	HFS LHI at B_t= 0.15T, Low P_{XUV} Higher Core T_e	Pure OH Driven Plasma: Baselines Impurity Measurements	Assessed VUV & XUV Emission on Ohmic, LHI, and LHI-Ohmic Handoff on PEGASUS
SPRED VUV Spectrometer Provides Impurity Identification, AXUV photodiode used as an estimate of P_{RAD}	LFS LHI at B_t = 0.15T, Comparable to HFS LHI at High B_t	OH Phase of Handoff Plasmas Comparable to OH Only	Reprints

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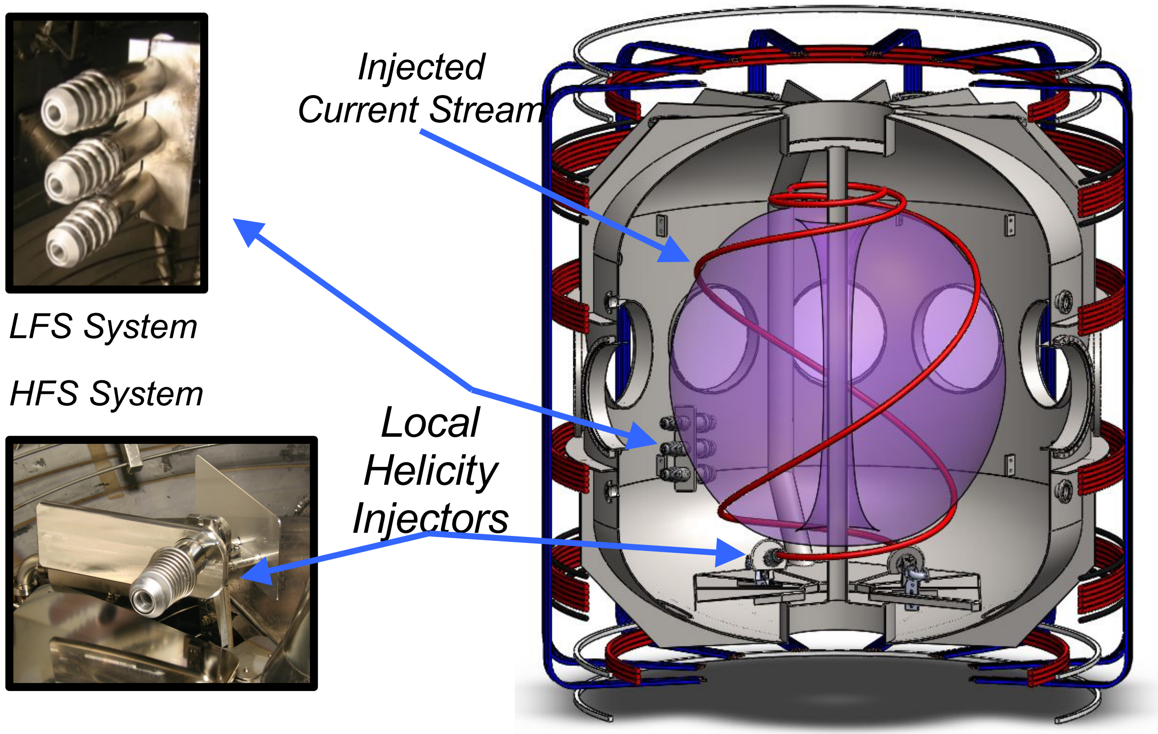
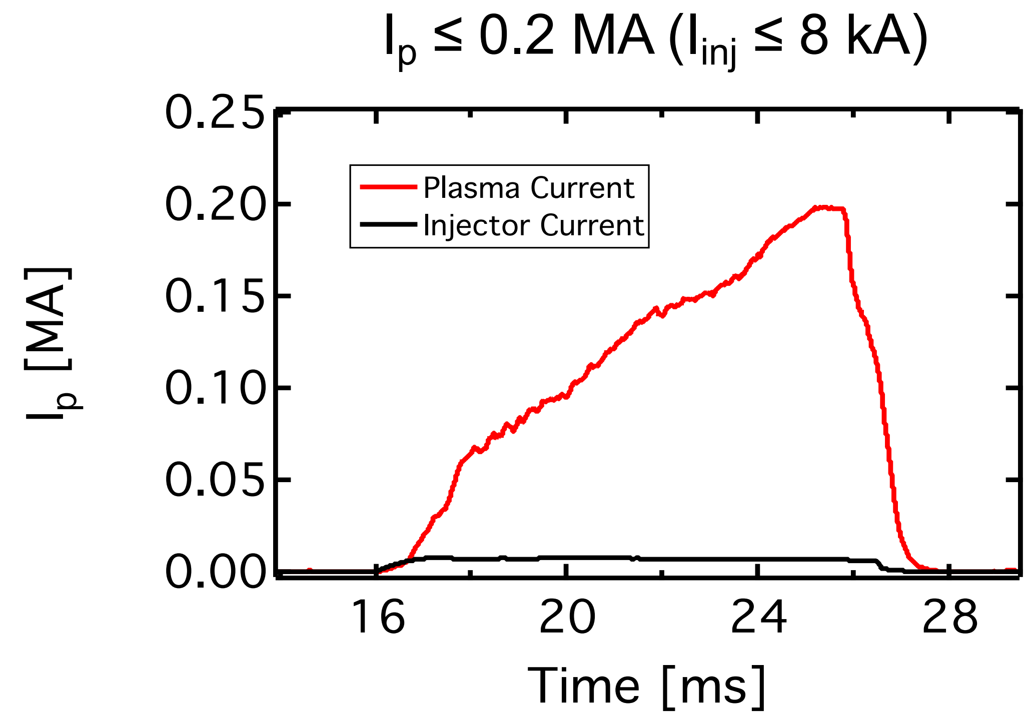
Local Helicity Injection (LHI) is a Promising Non-Solenoidal Startup Technique



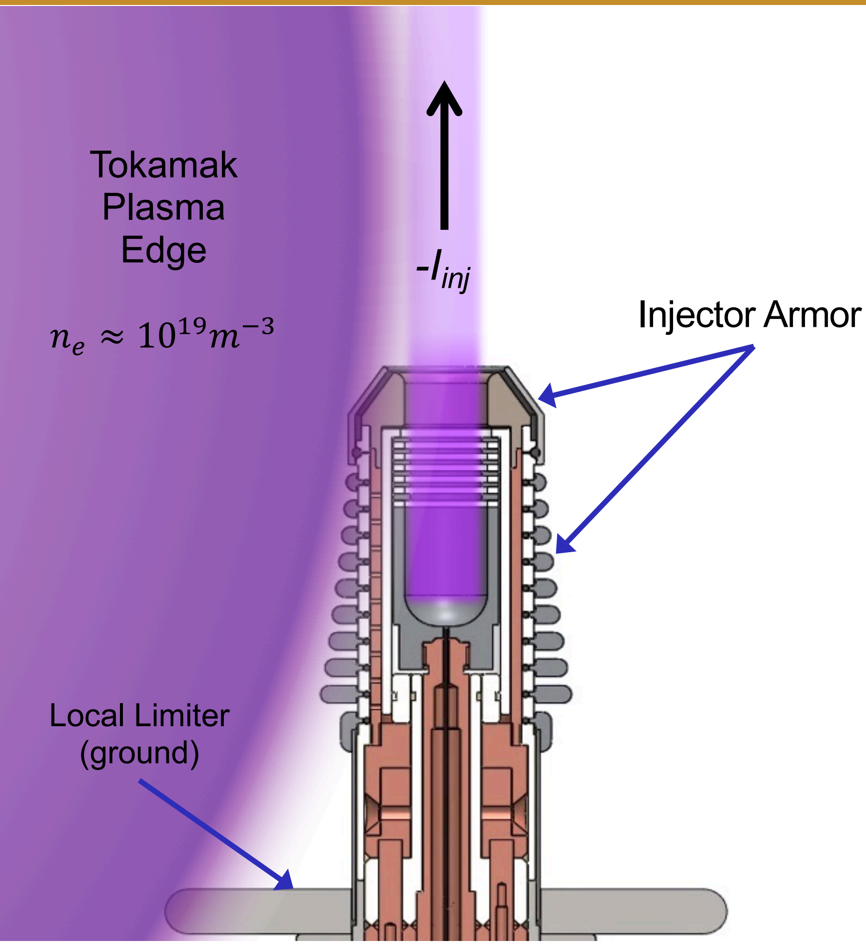


- Edge current extracted from injectors
- Relaxation to tokamak-like state via helicity-conserving instabilities
- Used routinely for startup on PEGASUS

- Current drive quantified by:

$$V_{LHI} \approx \frac{A_{inj} B_{\varphi,inj}}{\Psi} V_{inj}$$

Understanding Impurities Necessary Aspect for LHI Scalability



- LHI is useful if its targets can be transitioned to subsequent CD
  - Acceptably low Z_{eff}
- Impurity roles
  - Helicity dissipation and plasma resistivity

$$I_p \sim \frac{V_{LHI}}{R_{pl}} \sim \frac{V_{LHI}}{<\eta>} \sim \frac{V_{LHI}}{<Z_{eff} T_e^{-3/2}>}$$

  - Radiation losses impact power balance
- Technical considerations
  - High $P_{inj} \sim$ MW adjacent to tokamak edge

Multiple Diagnostics Planned to Measure Impurities

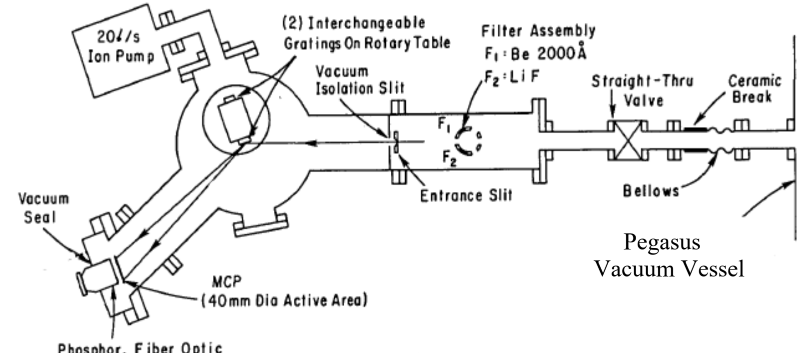
- SPRED VUV Spectrometer to identify impurity species
  - New high-resolution grating for metallic line identification
- AXUV diode measurements to estimate P_{RAD}
  - Photodiode sensitivity drops at lower energies
- Multi-Point Thomson Scattering measure $T_e(R)$ and $n_e(R)$
- Planned CHERS diagnostics for individual species measurements

SPRED VUV Spectrometer Provides Impurity Identification, AXUV photodiode used as an estimate of P_{RAD}

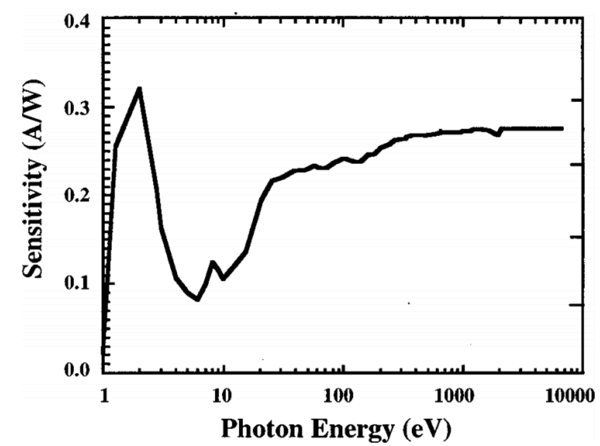
- SPRED VUV Spectrometer
  - Line of Sight along $R_{tan} = 20\ cm$
  - 10 – 110 nm range
  - Spectral resolution ~ 0.2 nm

- AXUV diode proxy for P_{RAD}
  - High quantum efficiency
  - Line of Sight along $R_{tan} = 19.6\ cm$
  - High Sensitivity ~ 0.24 A/W

Spectrometer Layout



R. J. Fonck et al., Applied Optics 21.12, 2115 (1982)



R.L. Boivin et al., Rev. Sci. Instrum. **70**, 260 (1999).

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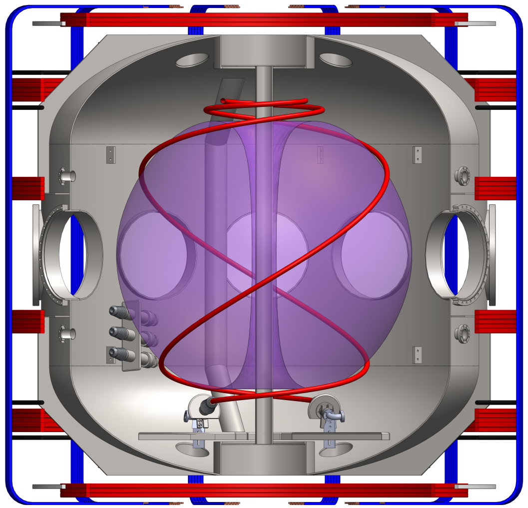
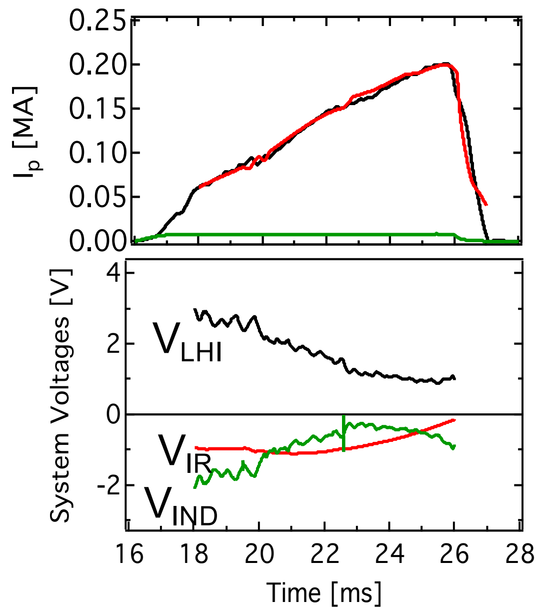
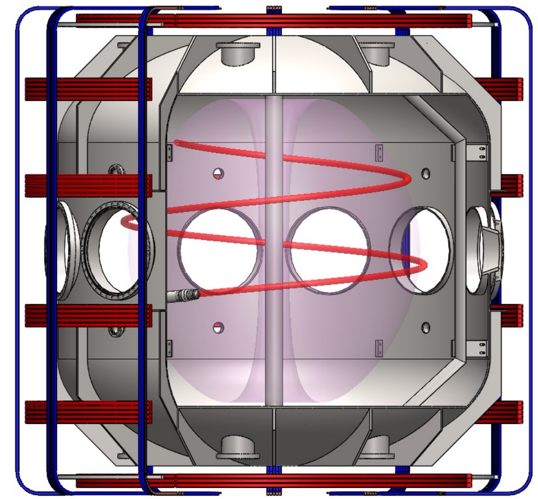
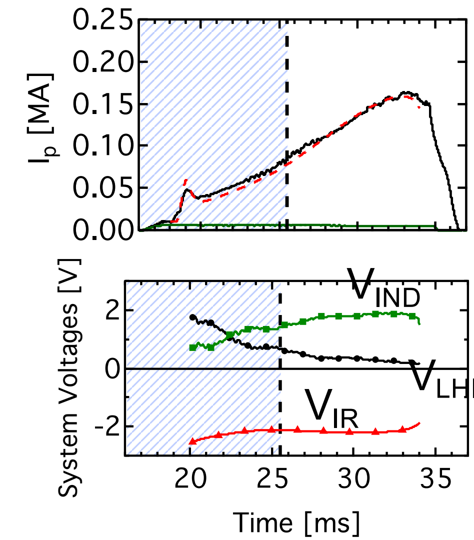
Injector Location Emphasizes Different Current Drive









High-Field-Side (HFS) Injection:

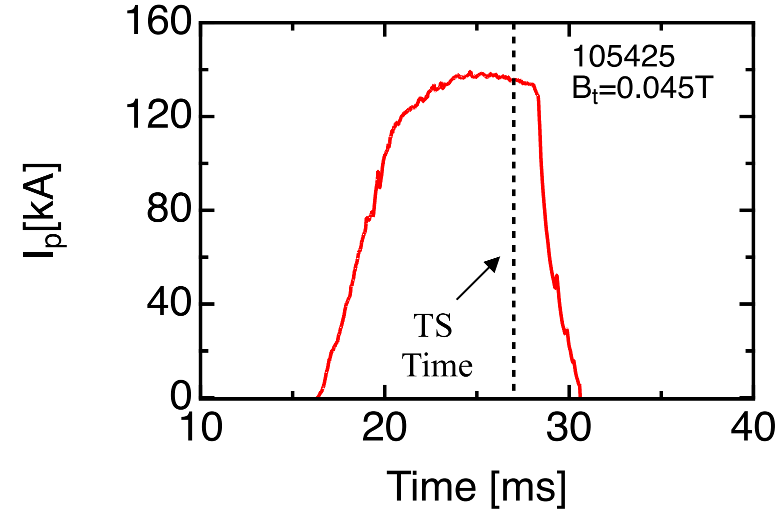
- Injectors in lower divertor
- HFS injection dominated by helicity drive
- P_{inj} ~ 4 MW

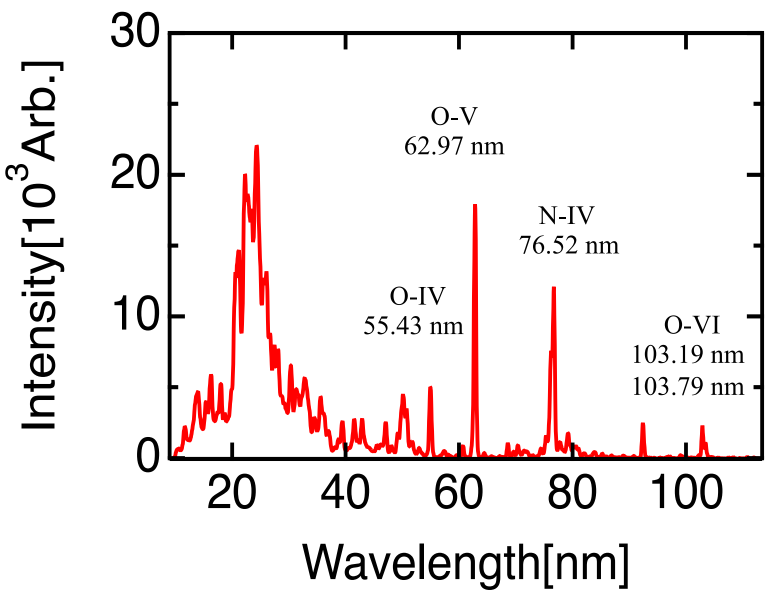
Low-Field-Side (LFS) Injection:

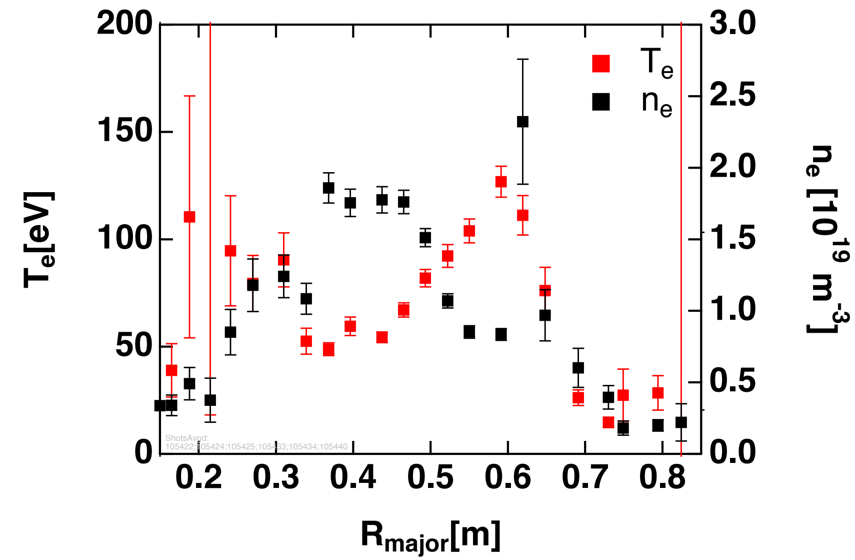
- Injectors on outboard mid-plane
- LFS injection maximizes inductive drive
- P_{inj} ~ 2 MW

HFS LHI at B_t= 0.045T, Modest P_{XUV} and Line Emission

- I_p flattop ~140kA, reduced-MHD regime
- Hollow T_e profile
- Max. P_{XUV} ~25kW/m^3
- VUV emission dominated by O and N
  - Absence of Ti XI line due to lower T_e







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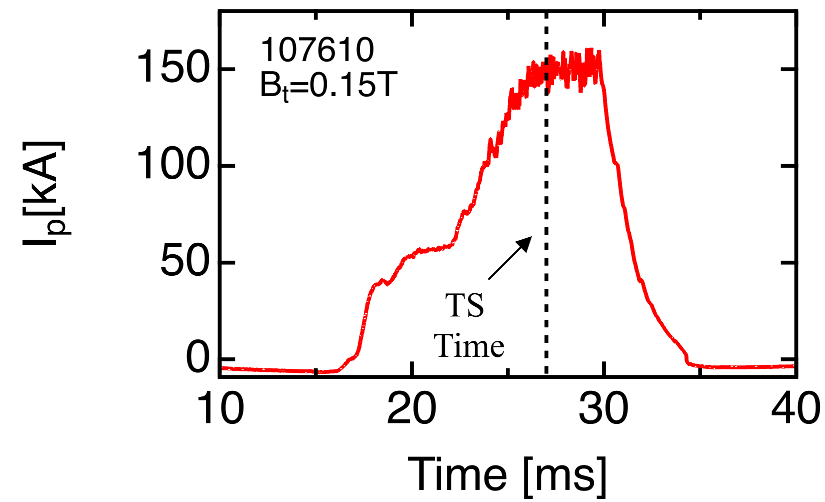
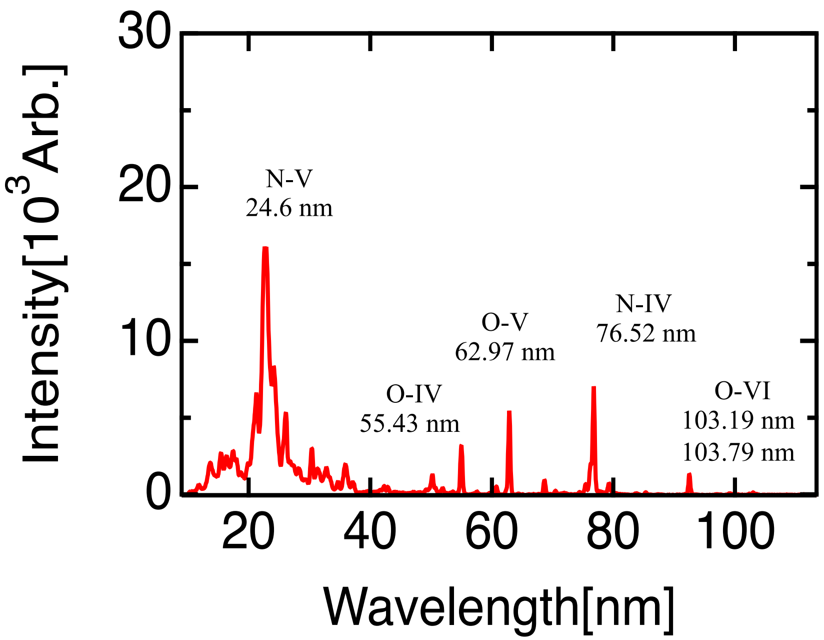
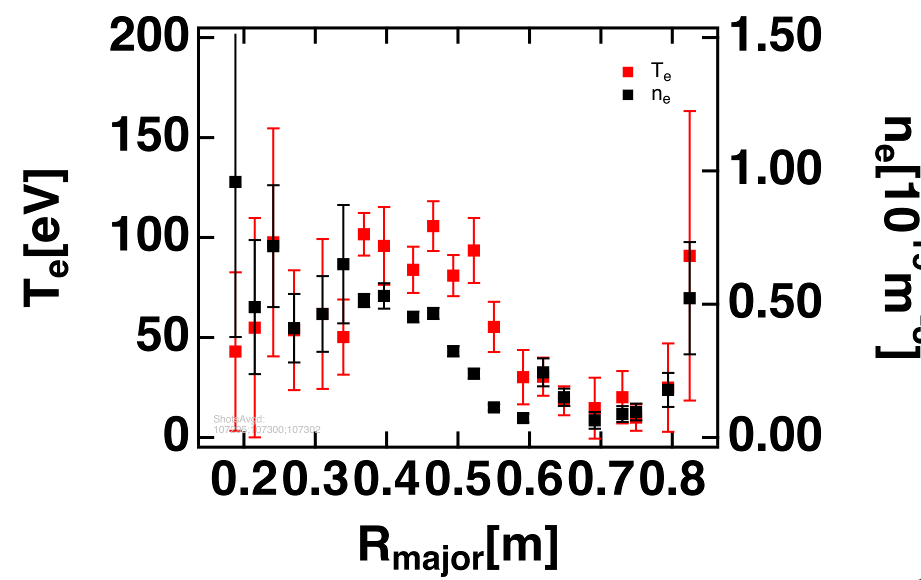
HFS LHI at B_t= 0.15T, Low P_{XUV} Higher Core T_e

- I_p flattop ~150kA, high-MHD regime
- Peaked T_e and n_e profiles
- P_{XUV} ~2kW/m^3
- VUV emission dominated by O and N







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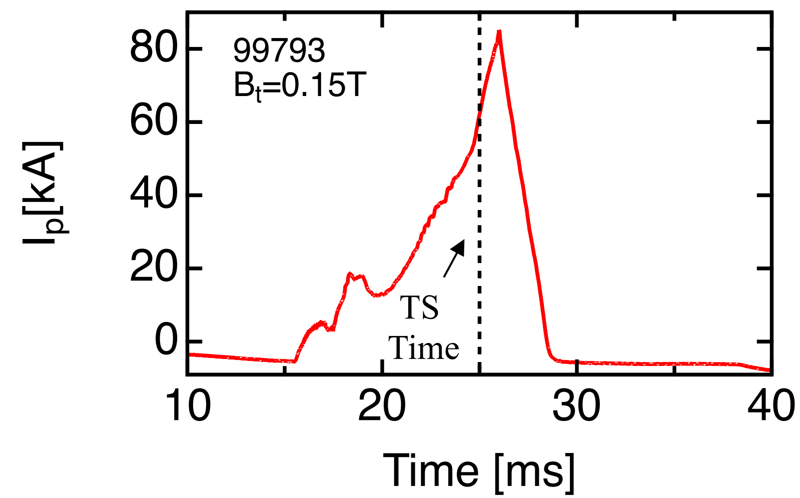
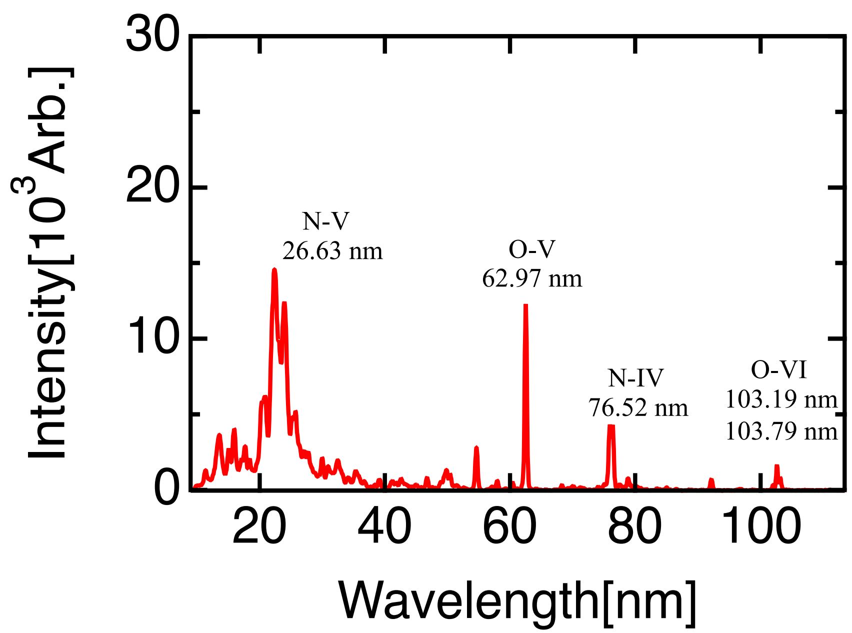
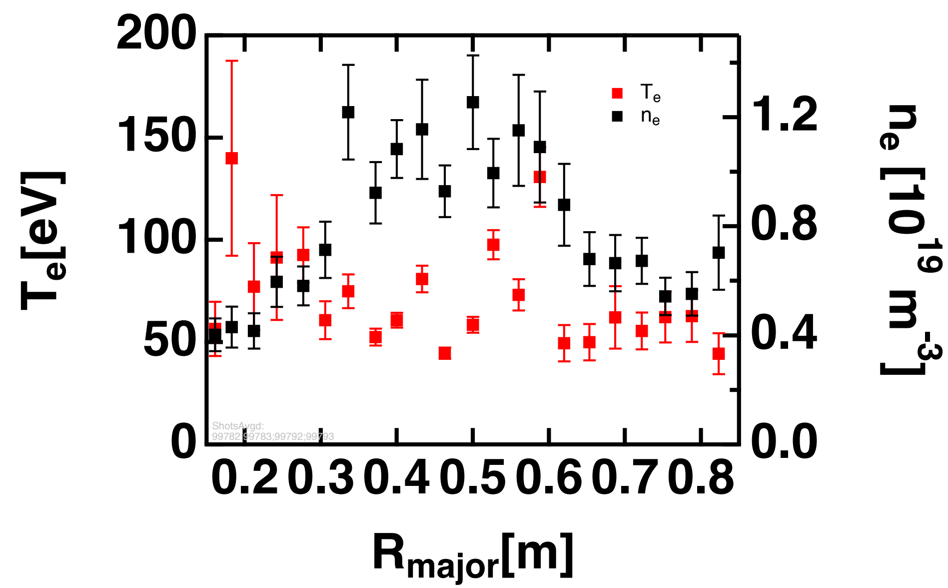
- Peak I_p ~ 90kA
- Lower T_e and peak n_e
- P_{XUV} ~0.5kW/m^3
- Similar SPRED Spectrum







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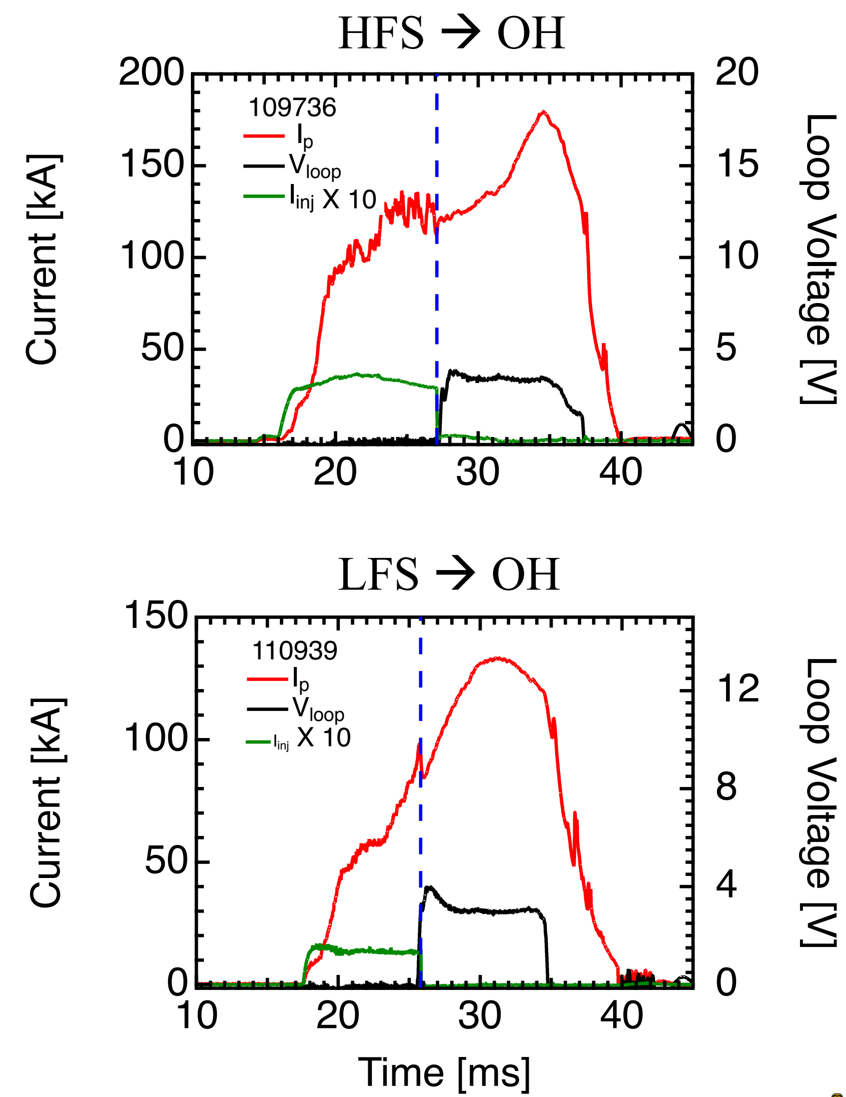
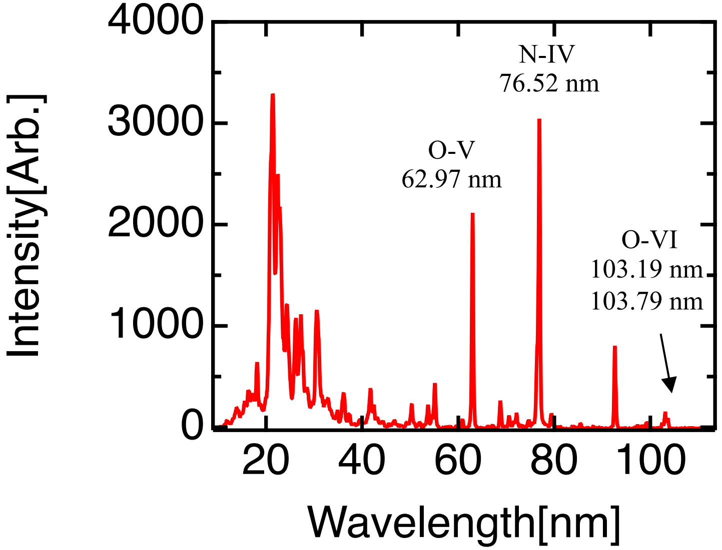
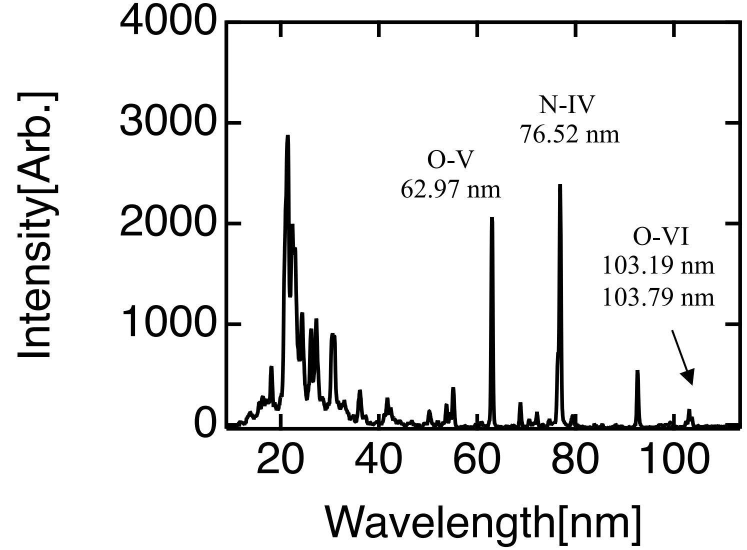
HFS & LFS LHI Successfully Couple to OH CD at B_t=0.15T

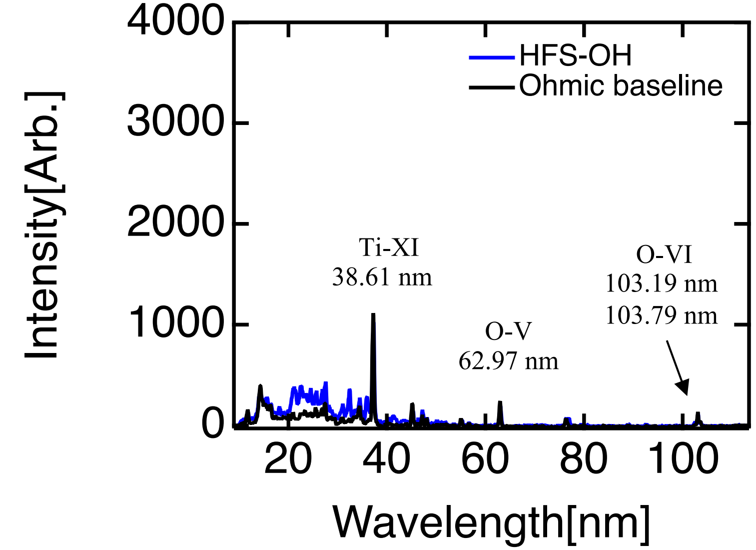
- Smooth transition with min. loss of I_p
- Robust to variations in handoff timing
- LHI startups provides OH flux savings
- Handoff insensitive to LHI $\dot{I}_p$
- OH phase can be compared to OH only

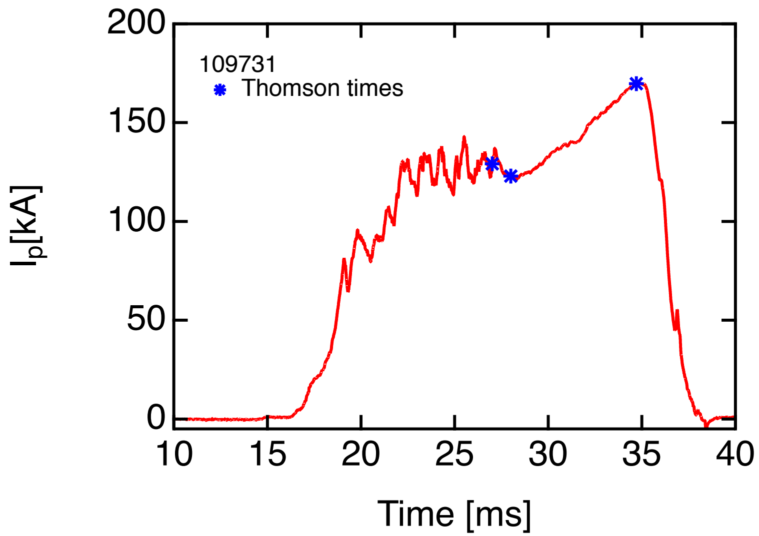


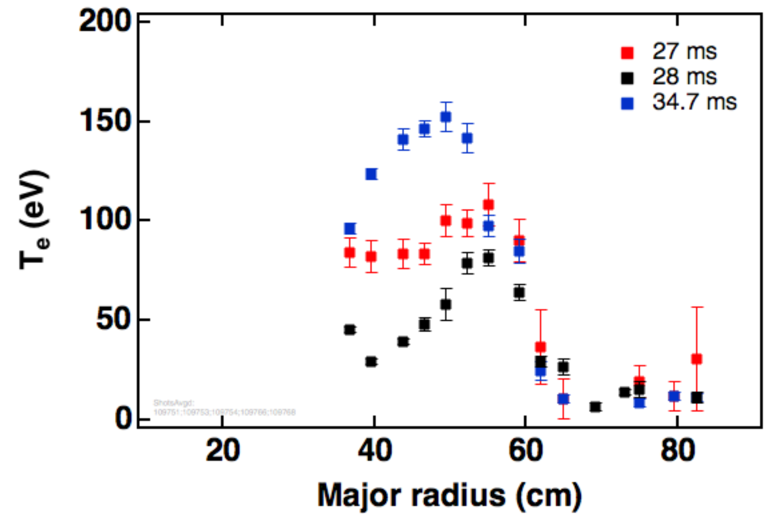
Impurity Charge State Balance Shifts Consistent With Higher Temperature After Handoff





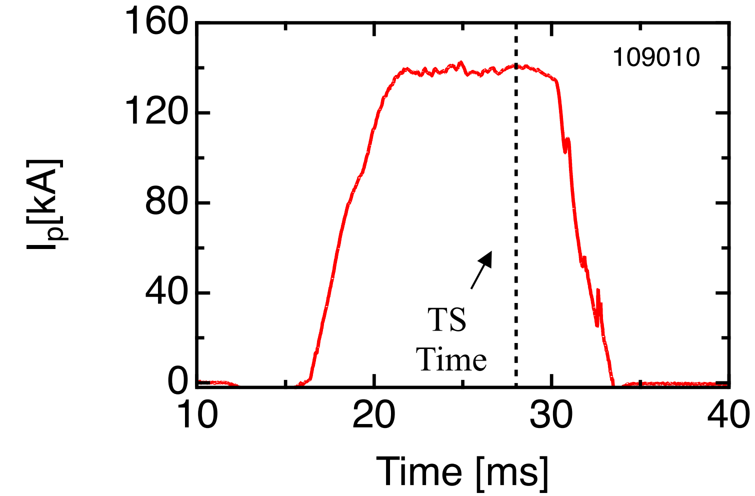


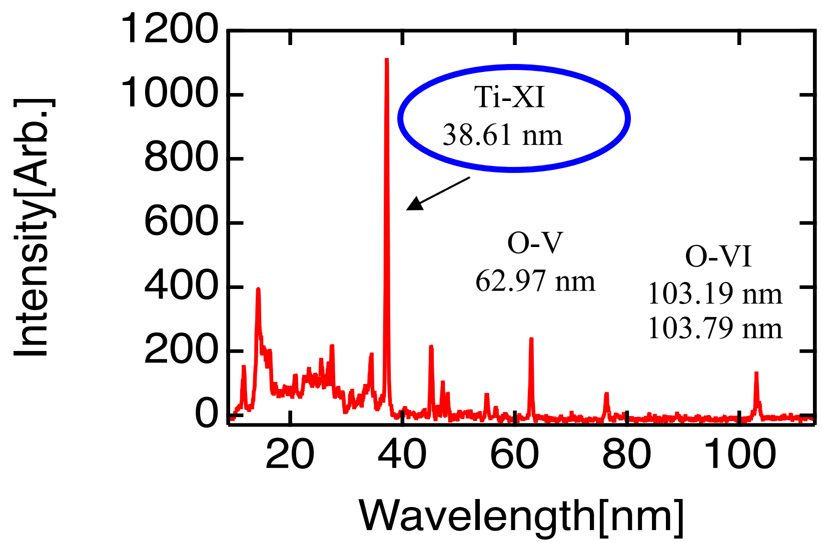


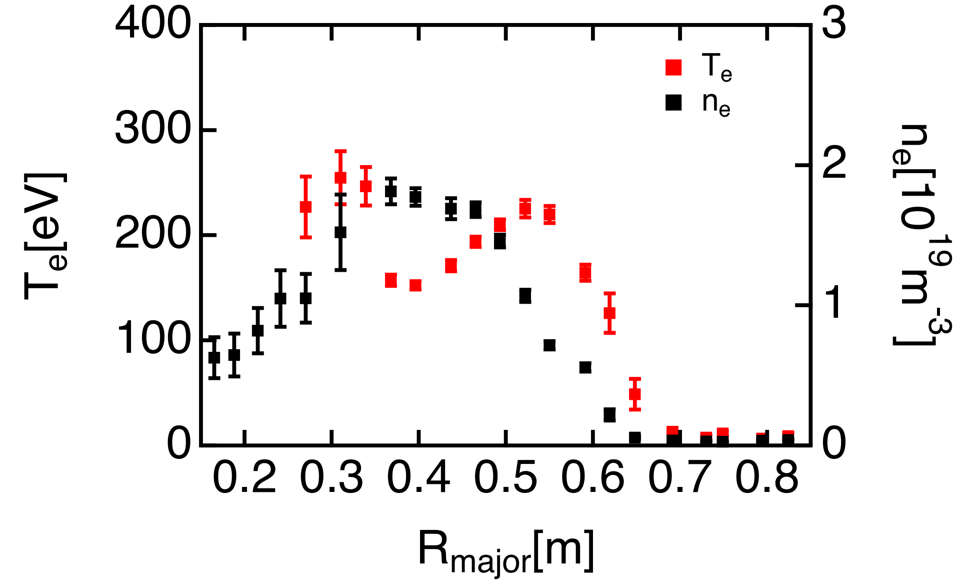


Pure OH Driven Plasma: Baselines Impurity Measurements

- I_p flattop ~ 140kA, H-mode
- Hollow T_e ~ 200eV
  - Not in transport eq. (τ_e long relative to flattop)[1]
- P_{XUV} emission ~0.5kW/m^3
- Bright Ti-XI line observed



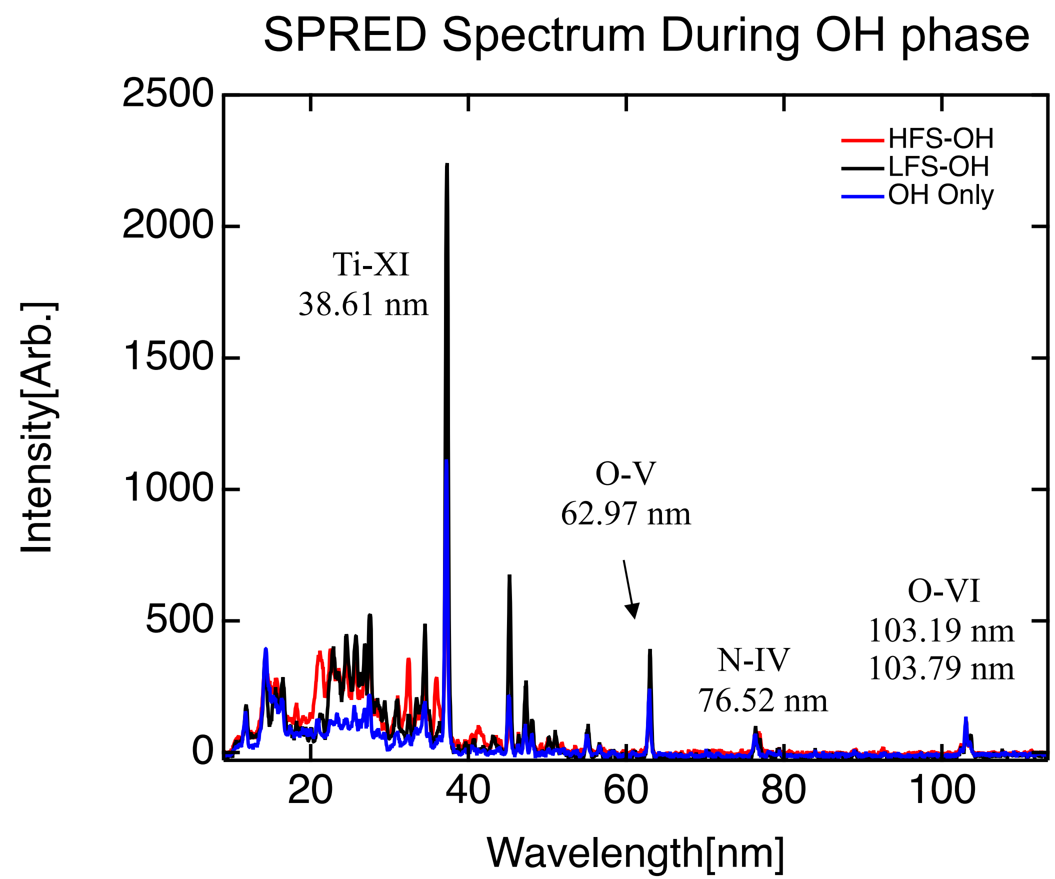




OH Phase of Handoff Plasmas Comparable to OH Only

- SPRED Spectra
  - Bright Ti-XI line observed
  - Relative low intensity low-z, N and O lines

- Low P_{xuv} at end of OH phase in all cases
  - OH baseline ~1kW/m^2
  - LFS-LHI initiated OH ~ 1kW/m^2
  - HFS-LHI initiated OH ~ 2.5kW/m^2

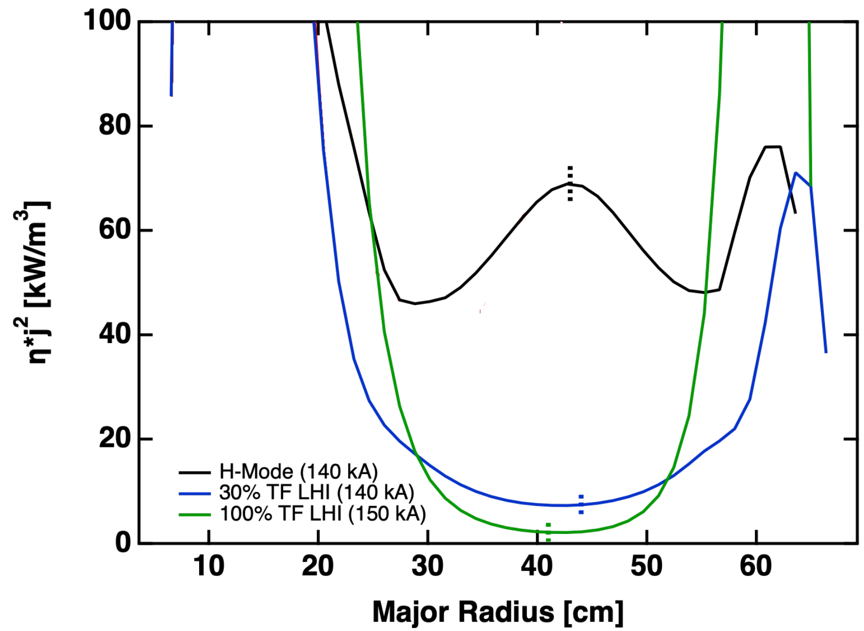


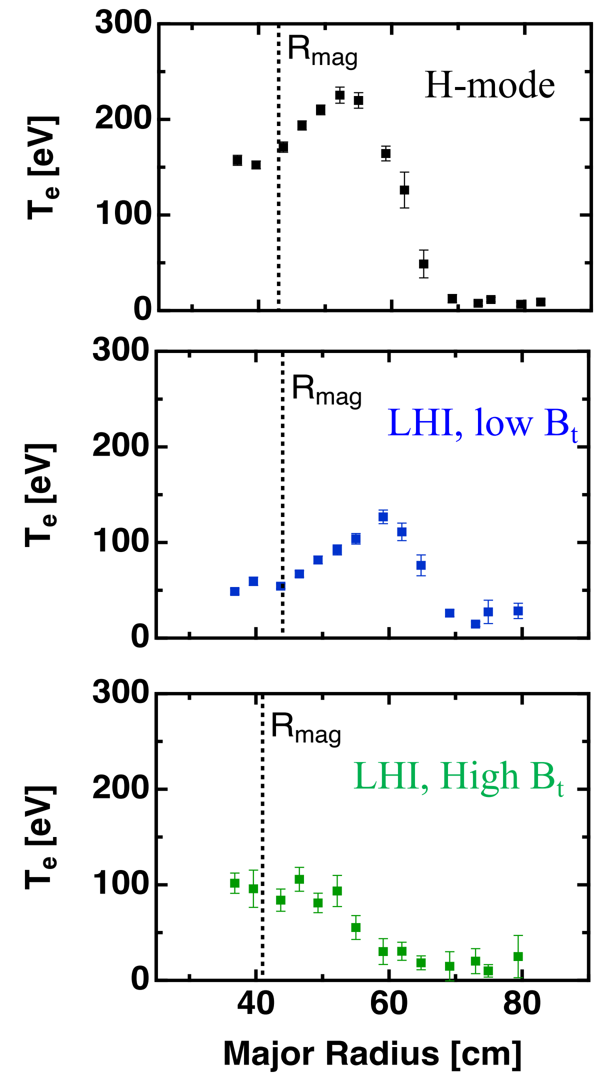
In All Cases, Low P_{RAD} Estimated From AXUV Diode

- Min. P_{RAD} estimated from AXUV diode ($P_{XUV} \leq P_{RAD}$)
  - Ohmic, LHI ($B_t \sim 0.15$ T) core $\eta^* j^2 \geq P_{XUV}$
  - LHI ($B_t \sim 0.045$ T) core $\eta^* j^2 \leq P_{XUV}$
    - Could explain hollow T_e profiles

	$\eta^* j^2_{(0)}$ [kW/m³]	P_{XUV} [kW/m³]
H-mode	70	0.5
LHI, low B_t	7.4	25
LHI High B_t	2	2

Low ℓ_i of LHI → low $\eta^* j^2$ in core





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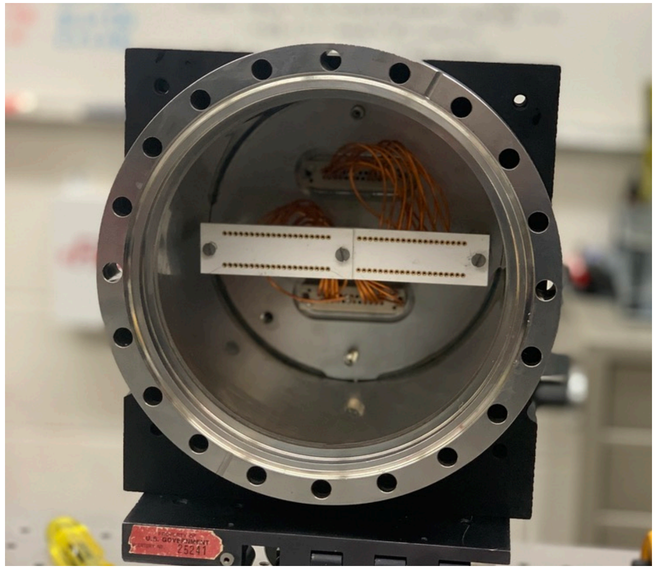
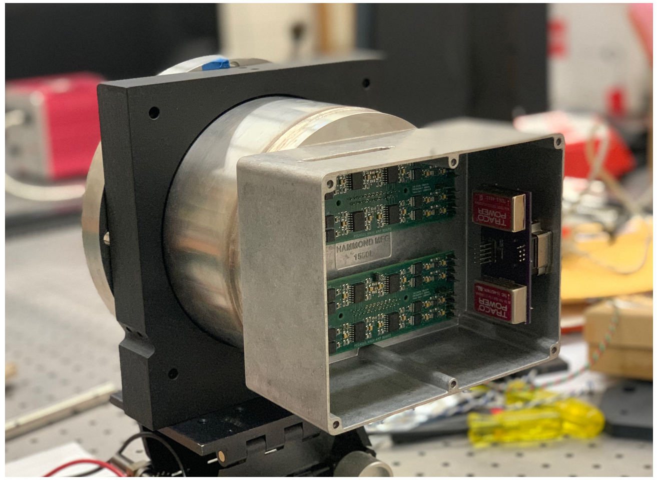
Upgrade to AXUV Diodes on Pegasus

- IRD AXUV-16ELG
  - Two arrays
  - Looking at midplane
  - Tangency radii from 5 to 90 cm



- Amplifier board in airside
  - Three stage board: TIA, AA filter, Diff Driver
  - Gain 100kV/A
  - Board plugs directly into vacuum feedthrough



Assessed VUV & XUV Emission on Ohmic, LHI, and LHI-Ohmic Handoff on PEGASUS

- VUV emission and XUV power is low in PEGASUS
- Radiative losses during LHI don't hinder coupling to OH drive
- Radiated power and observed impurity charge states are similar after handoff to Ohmic baseline discharge
- Low ℓ_i of LHI plasmas produce low $\eta * j^2$ heating in core
  - May explain hollow T_e profiles in low B_t plasmas
- New AXUV diode array to provide profile information

Reprints

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http://pegasus.ep.wisc.edu/Technical_Reports