Impurity behavior in the steady state ELM-free H-mode on DIII-D

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A new mode of operation with H-mode confinement quality, no ELMs, and steady ion and impurity density has been discovered on DIII-D during experiments with the neutral heating beams injected counter to the direction of plasma current*. We present spectroscopic studies which demonstrate that intrinsic impurity content reaches a stable state with low to modest impurity content. In a discharge which transitions from an ELMing phase to an ELM-free H-mode phase, charge exchange recombination spectroscopy indicates that the carbon content is lower in the ELM free phase. Likewise, the line intensities of high ionization states of nickel are lower. Neutron production is seen to increase, while the radiated power fraction remains low. Analysis of visible bremsstrahlung data will also be presented.

* K. Burrell et al, this conference

Motivation

- A new controlled-density, ELM-free operating mode with H-mode quality confinement was found on DIII-D, “The Quiescent H-mode”
- Initial observations indicated the impurity content was controlled along with the density, i.e. no strong evidence of “impurity accumulation.”
- These discharges have only been observed in beam heated discharges with the injection direction counter to the plasma current direction. Strong pumping is also required.
- Past experience with counter injection has indicated a tendency for significant impurity contamination. Low density discharges also have tendency to have significant impurity content.
- Here we discuss analysis of spectroscopic data of two types of quiescent H-modes, “standard” H-mode level confinement (QH) and “Double Barrier high performance with improved confinement (QDB).

QH (Quiescent H-mode) Exhibits Attractive Properties (see K. Burrell's invited talk)

No pulsed heating of the divertor
- ELM free
- Sawtooth Free

Density Controlled
- Density Maintained at 0.3 to 0.5 n_{GW}
- High T_e, Low n_e good for EC Current Drive

QDB (Quiescent Double Barrier) Discharges Produced QDB = QH:edge + Internal Transport Barrier:ITB

High edge pedestal
- Increases total stored energy compared to L-mode edge NCS.

No ELMs to destroy core transport barrier
- Reduced tearing mode seed islands

$\beta_N H_{89P} = 7$ for $5\tau_E$ ($\beta_N = 2.9, H_{89P} = 2.4$)

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Summary

•QH---Lower Single Null, low-triangularity discharge # 99254, which transitions from a standard ELMing H-mode to a Quiescent H-mode,

›Total density and impurity densities drop at the transition

›Z_{eff} remains about constant at 2.6

›Neutron production increases due to increased T_i.

•QDB---Upper Single Null, high triangularity discharges (103740 and 103818) With internal and edge transport barriers.

›Carbon densities from CER remain constant throughout these discharges, with a core concentration of about 4% (ΔZeff = 1.3)

›Nickel concentration from VUV spectroscopy rises during these discharges.

›ΔZeff exceeds 1.5 from nickel by the end of these discharges.

›Visible Bremsstrahlung indicates total Zeff is high, but constant.

› Nickel content required in TRANSP modeling to match measured neutron production

›Wall Impurity Source may result from a strong interaction with the upper divertor baffle.

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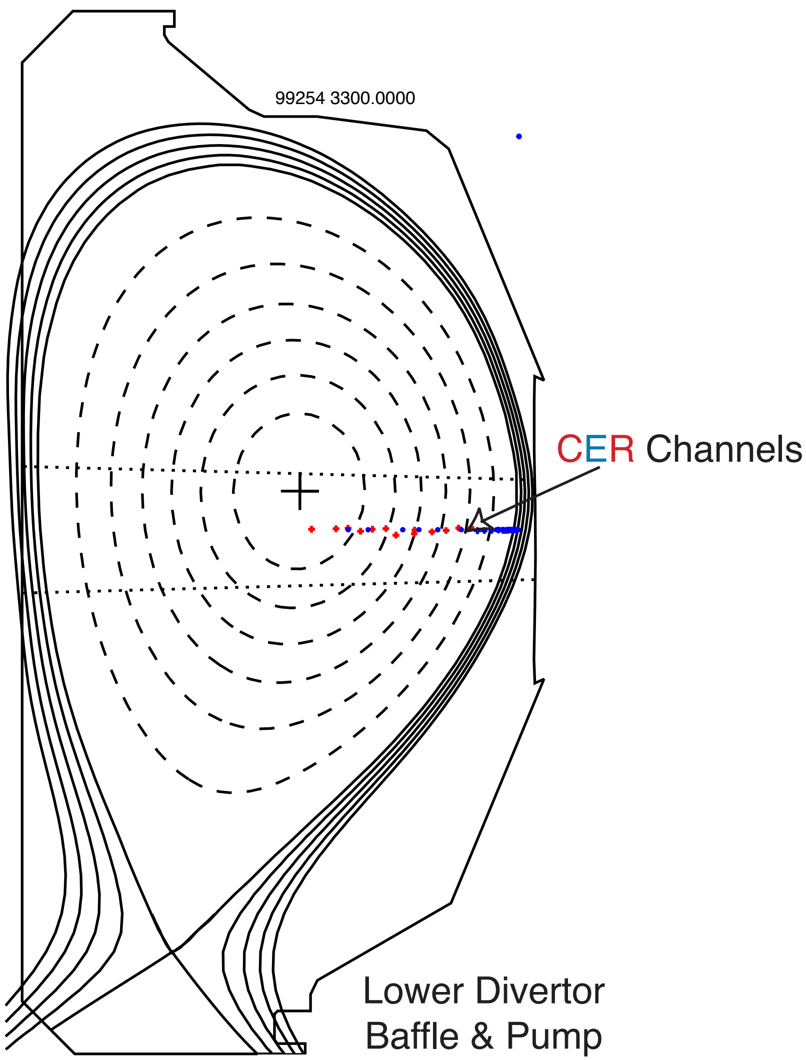
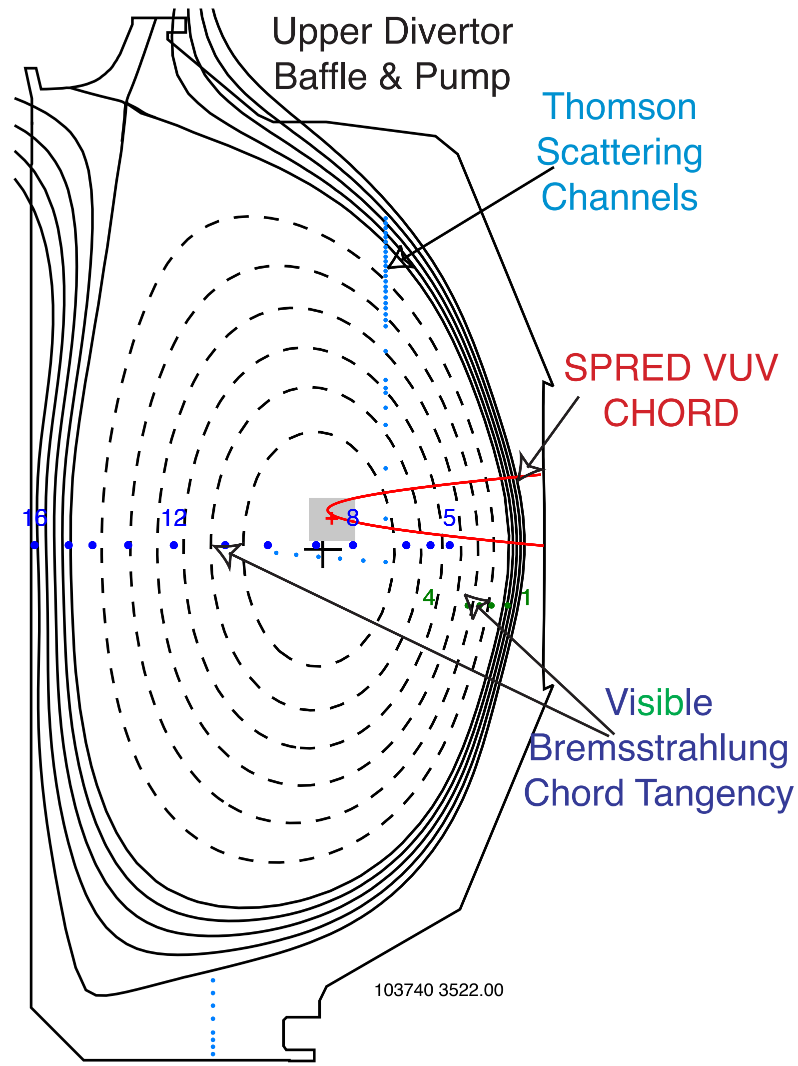
Quiescent Edge H-mode Observed in Counter-Injected, Lower- and Upper-Null, Pumped Discharges

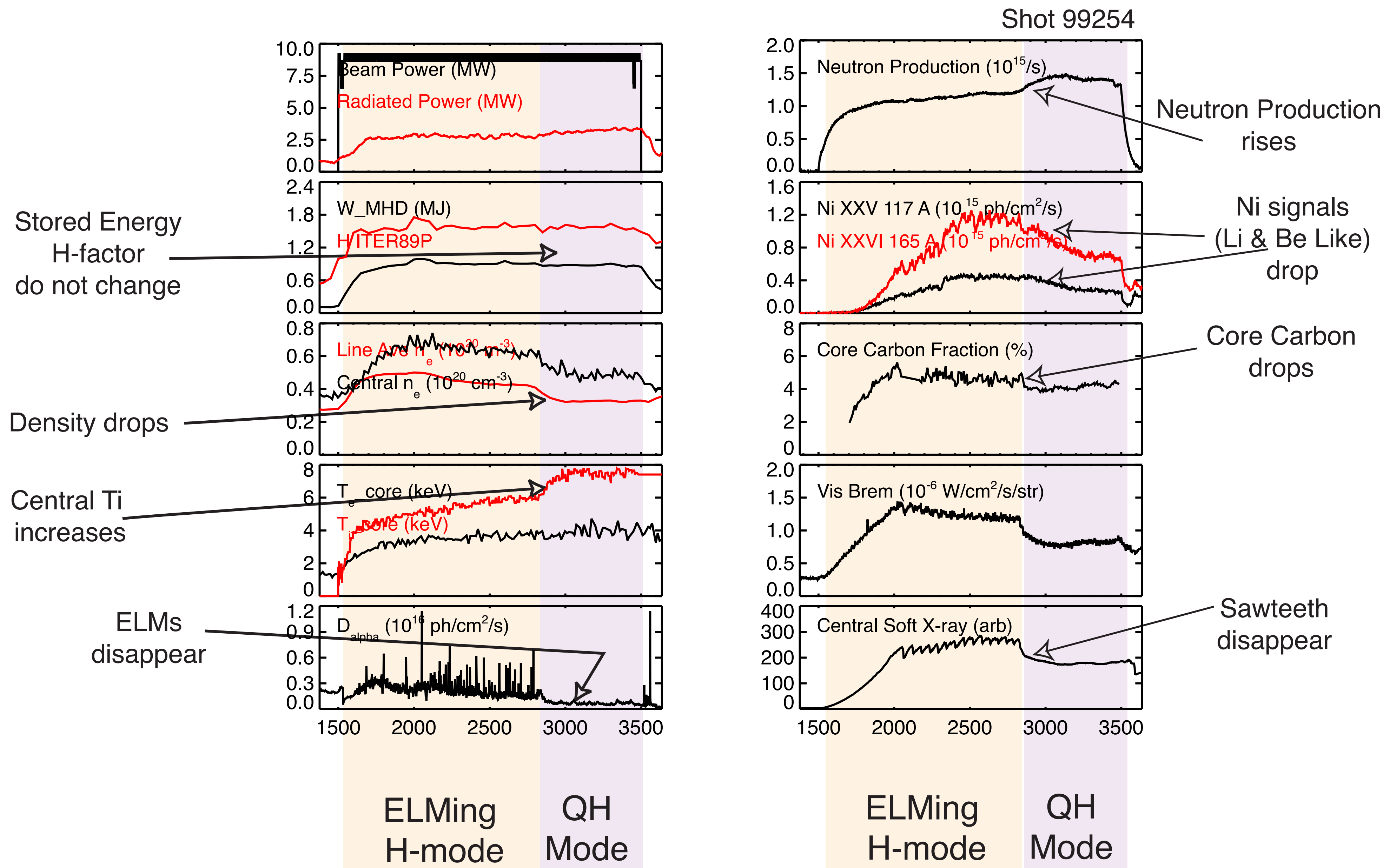


QH-mode Discharge
#99254

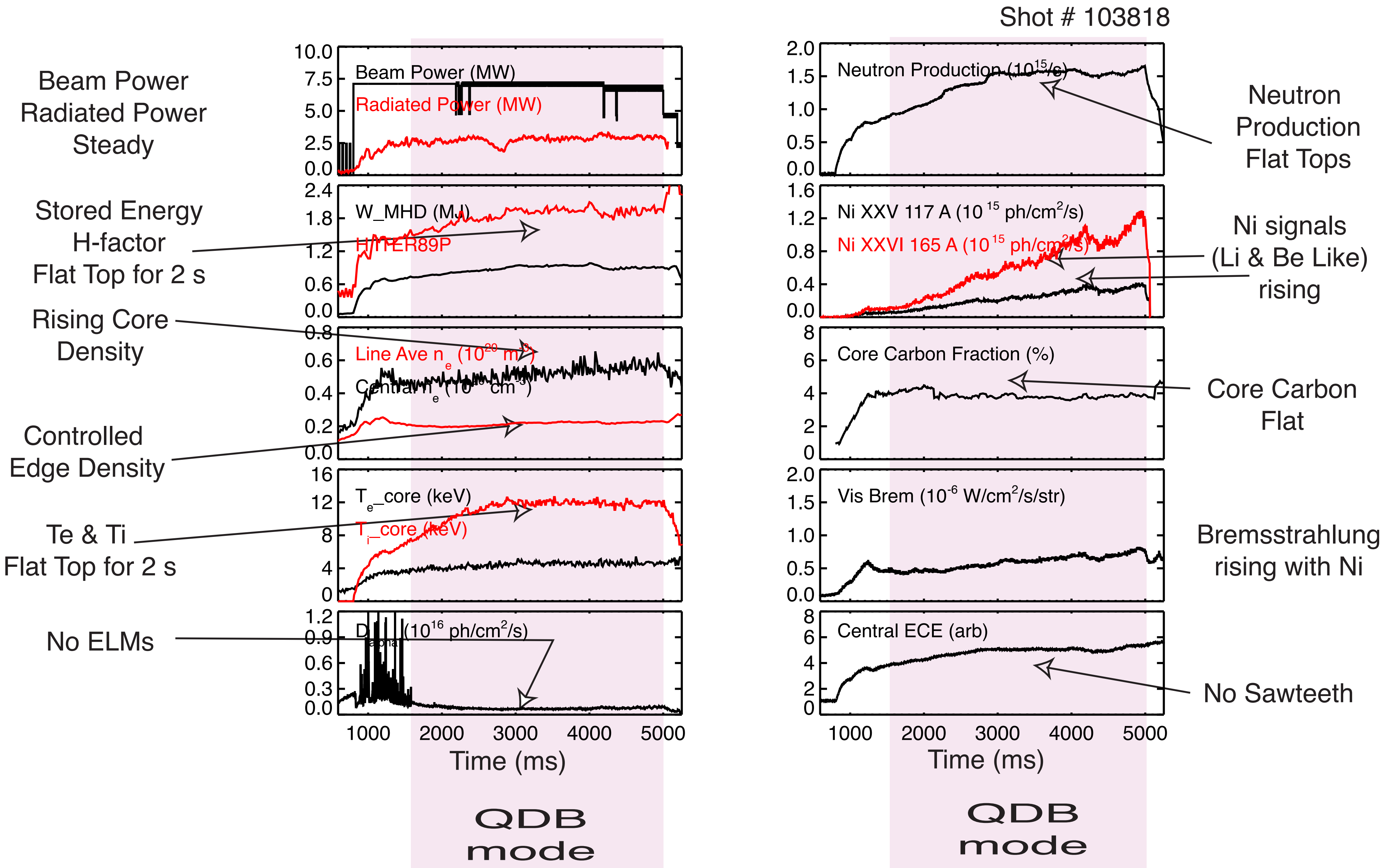


QDB Discharge
#103740

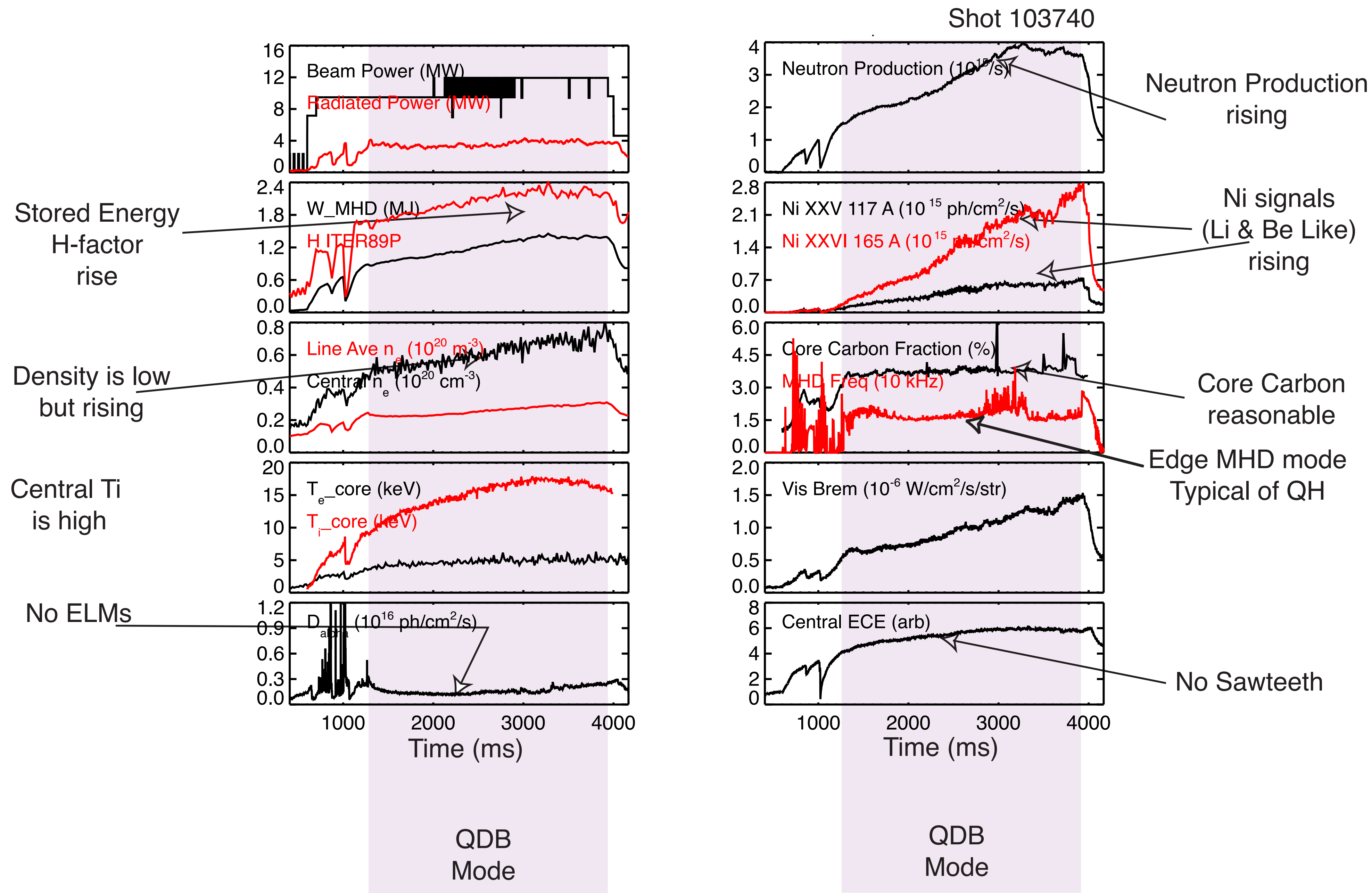
After QH Transition
Density Drops and Impurity Signals Drop



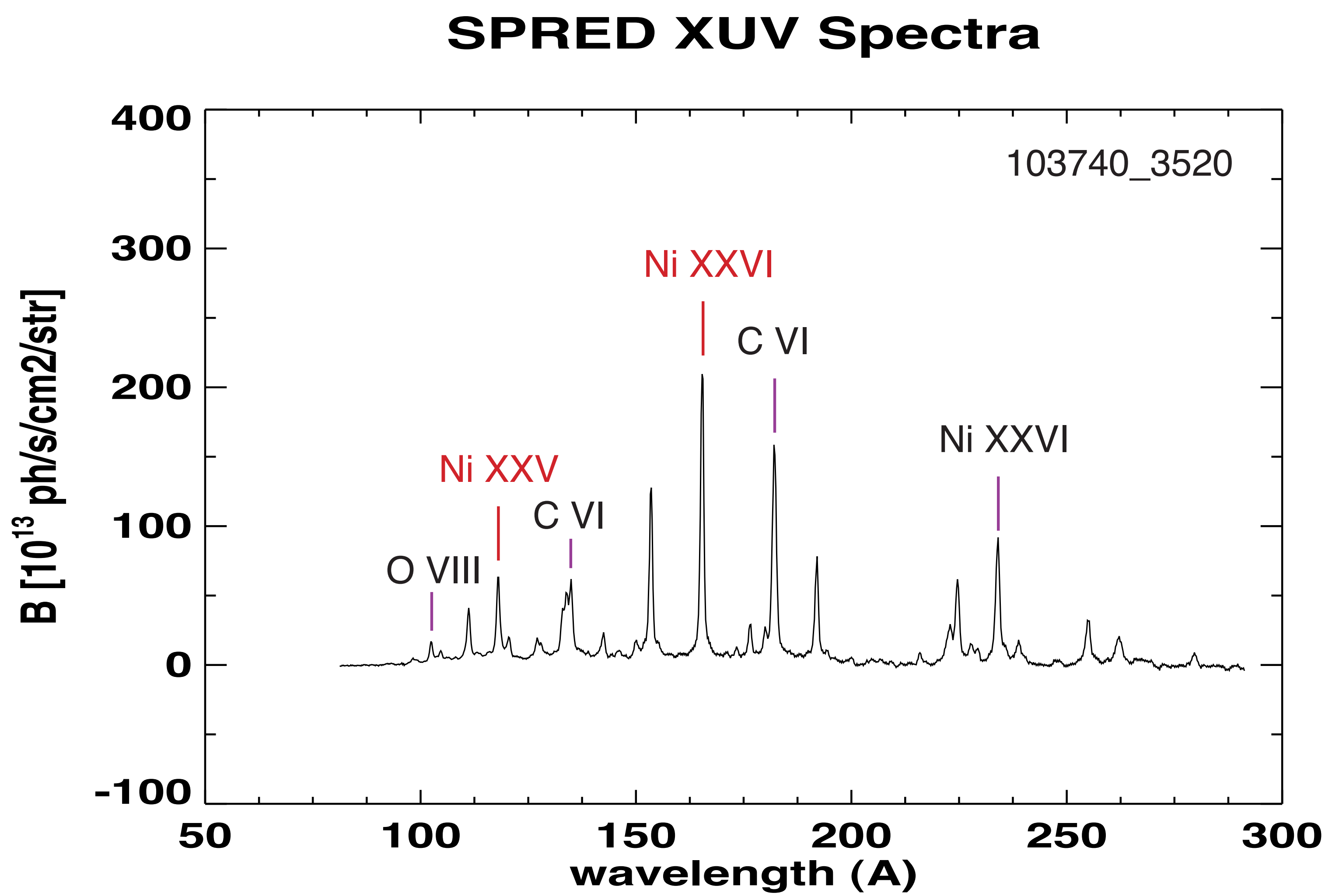
QDB Discharges Exhibit Long Duration at High Performance



QDB Discharge Exhibits Long Duration High Performance



SPRED Spectra Exhibit Bright Nickel and Carbon Lines at the End of a QDB Discharge



Impurity Analysis

Dominant low Z impurity is Carbon (DIII-D has 95% graphite tile wall)
Dominant high Z impurity is Nickel (Inconel vacuum vessel)

C^{+6} density profiles are routinely obtained from CER (charge exchange recombination spectroscopy).

Lithium-like (Ni XXVI) and Beryllium-like (Ni XXV) Nickel ions have resonance lines visible with the DIII-D SPRED VUV spectrometer.

MIST modeling of the nickel profiles and emission intensity is used to establish the density profiles of the Ni ions.

- Electron density and temperature profiles are available from Thomson Scattering measurements

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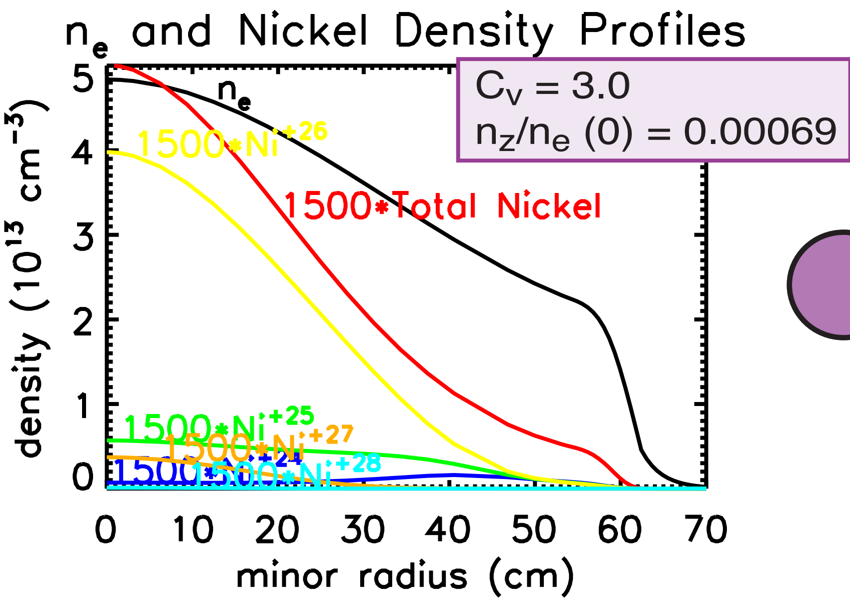
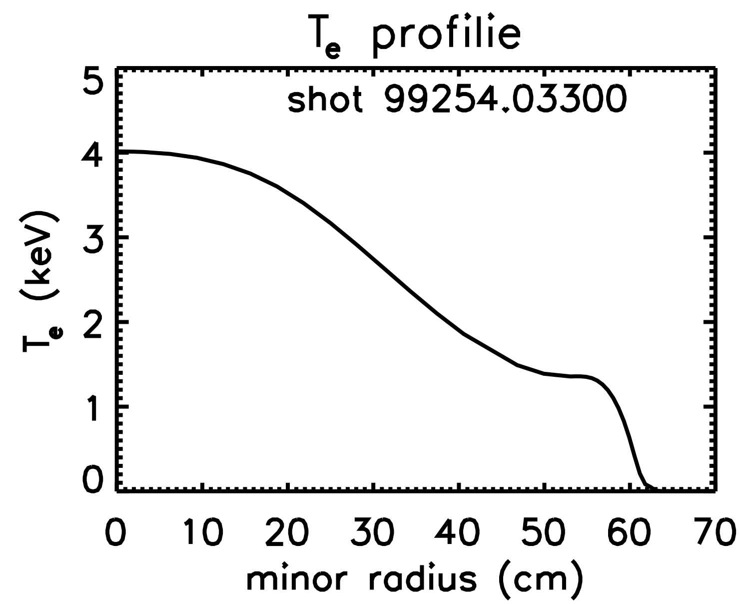
- Beryllium-like emission comes mostly from the outer part of the plasma ($\rho > 0.5$)
- Lithium-like emission comes mostly from the core region of the plasma ($\rho < 0.5$)
- The Nickel central concentration and the profile peaking factor are adjusted manually in the MIST model until reasonable agreement is obtained for the brightness of both measured lines.

- MIST modeling shows that Helium-like Nickel (Ni^{+26}) is the dominant charge state. We have no direct spectroscopic comparison to this charge state.
- Using the C^{+6} profiles from CER, all the nickel ionization state profiles from the MIST modeling, and the n_e and T_e profiles from Thomson Scattering, a comparison to the Visible Bremsstrahlung multichord measurements is made.

Mist Modeling Achieves Good Agreement with Measured Ni Line Intensities

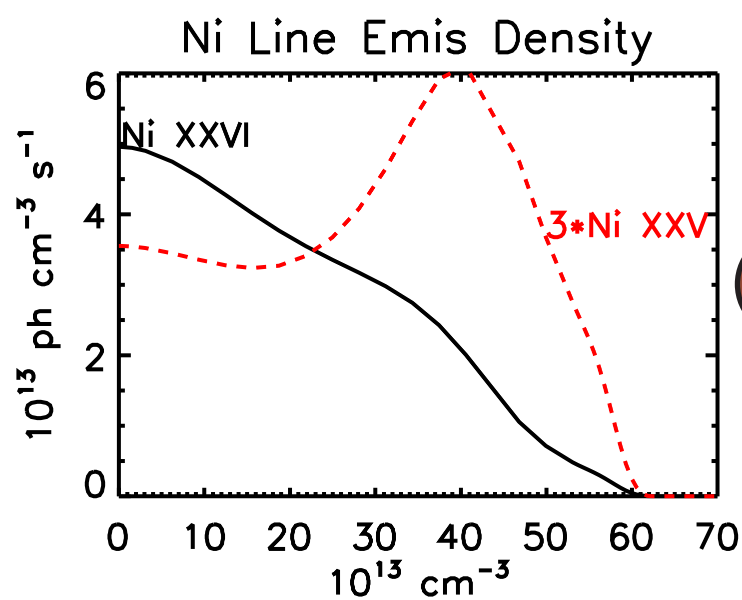




Line Intensity Comparison

Line	MIST	Measured
	$(10^{15} ph/cm^2/s/str)$	
Ni XXV 117 Å	0.287	0.281
Ni XXVI 165 Å	0.694	0.701

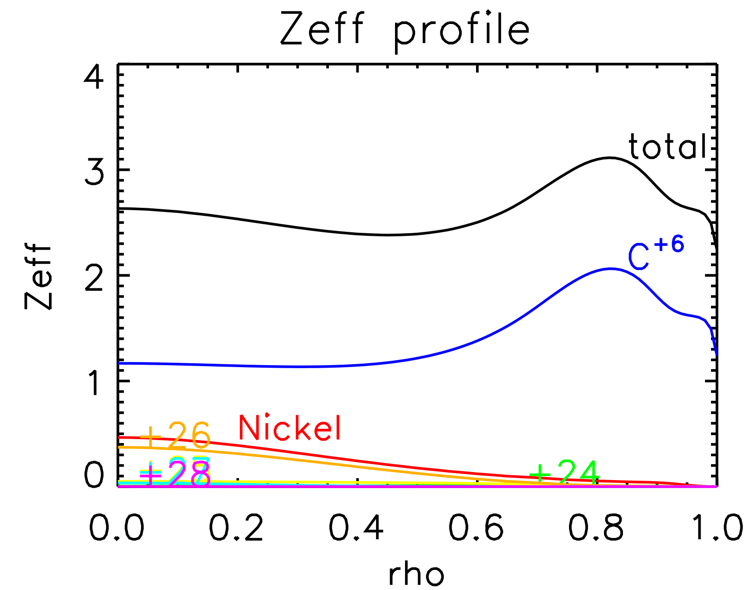
P_{RAD}(NICKEL) = 65 kW

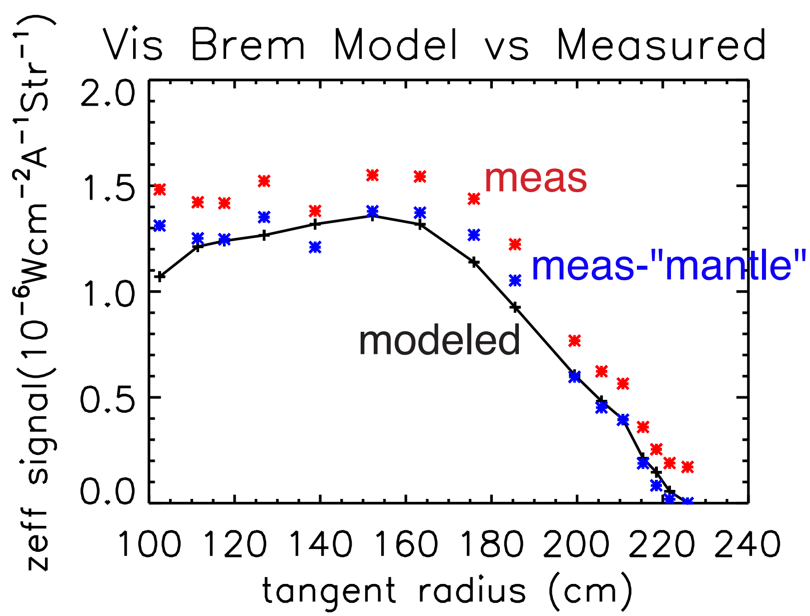


Z_{eff} Does not Change after a Transition from ELMing H mode to QH mode

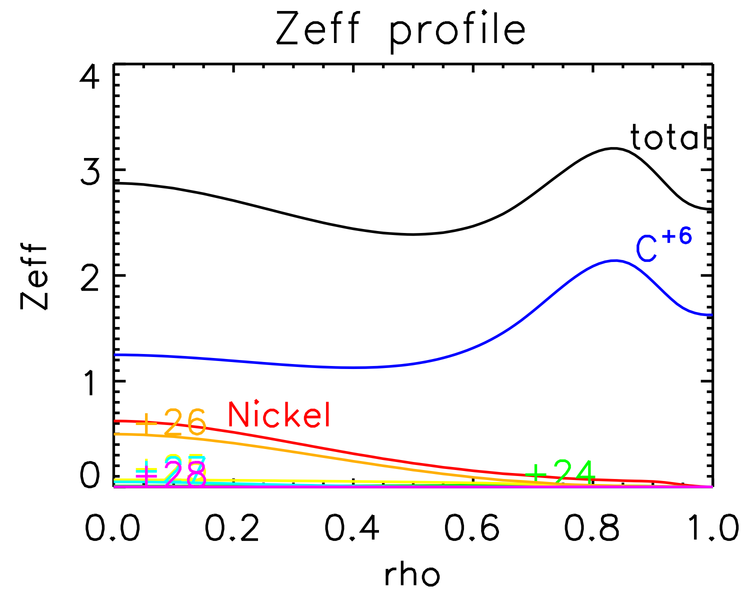
QH Discharge # 99254

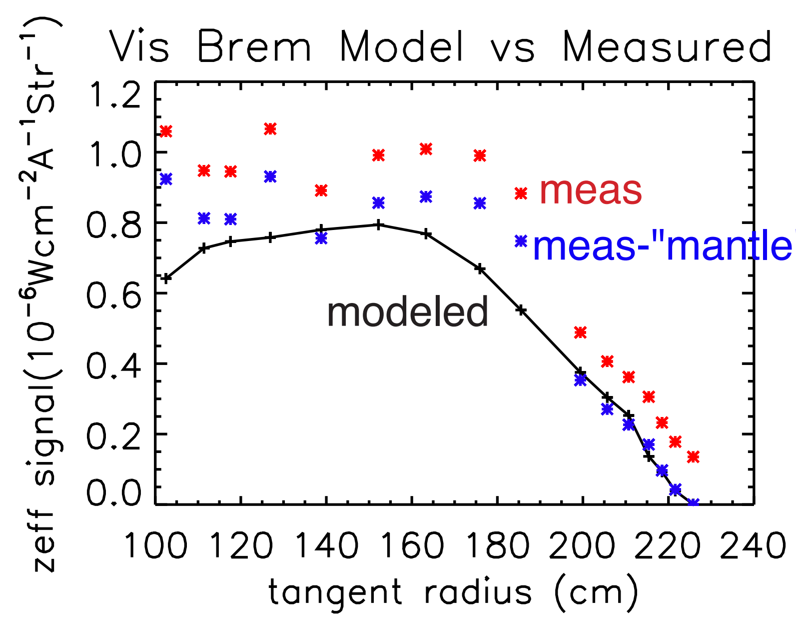
2600 ms: ELMing H-Mode



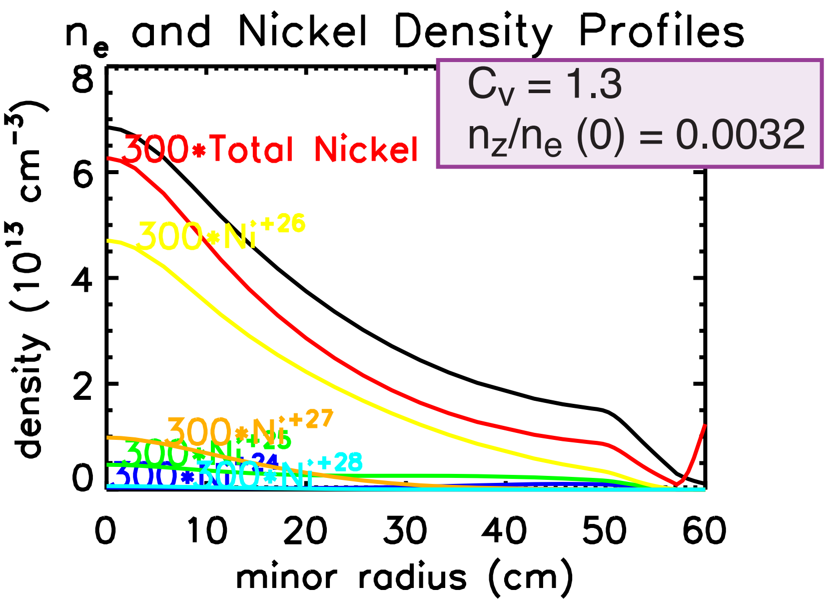


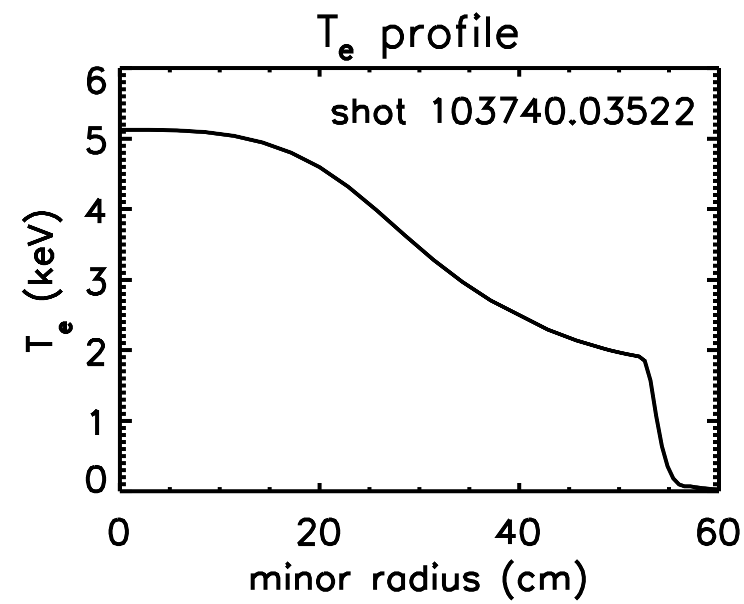
3300 ms: QH-Mode





Mist Modeling Achieves Good Agreement with Measured Ni Line Intensities

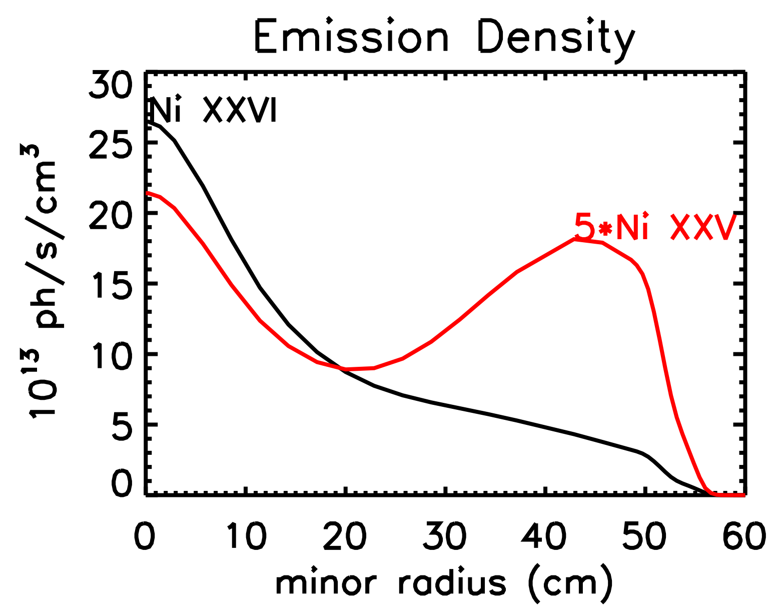




Line Intensity Comparison

Line	MIST	Measured
	(10^{15}ph/cm^2/s/str)	
Ni XXV 117 Å	0.548	0.564
Ni XXVI 165 Å	2.03	2.03

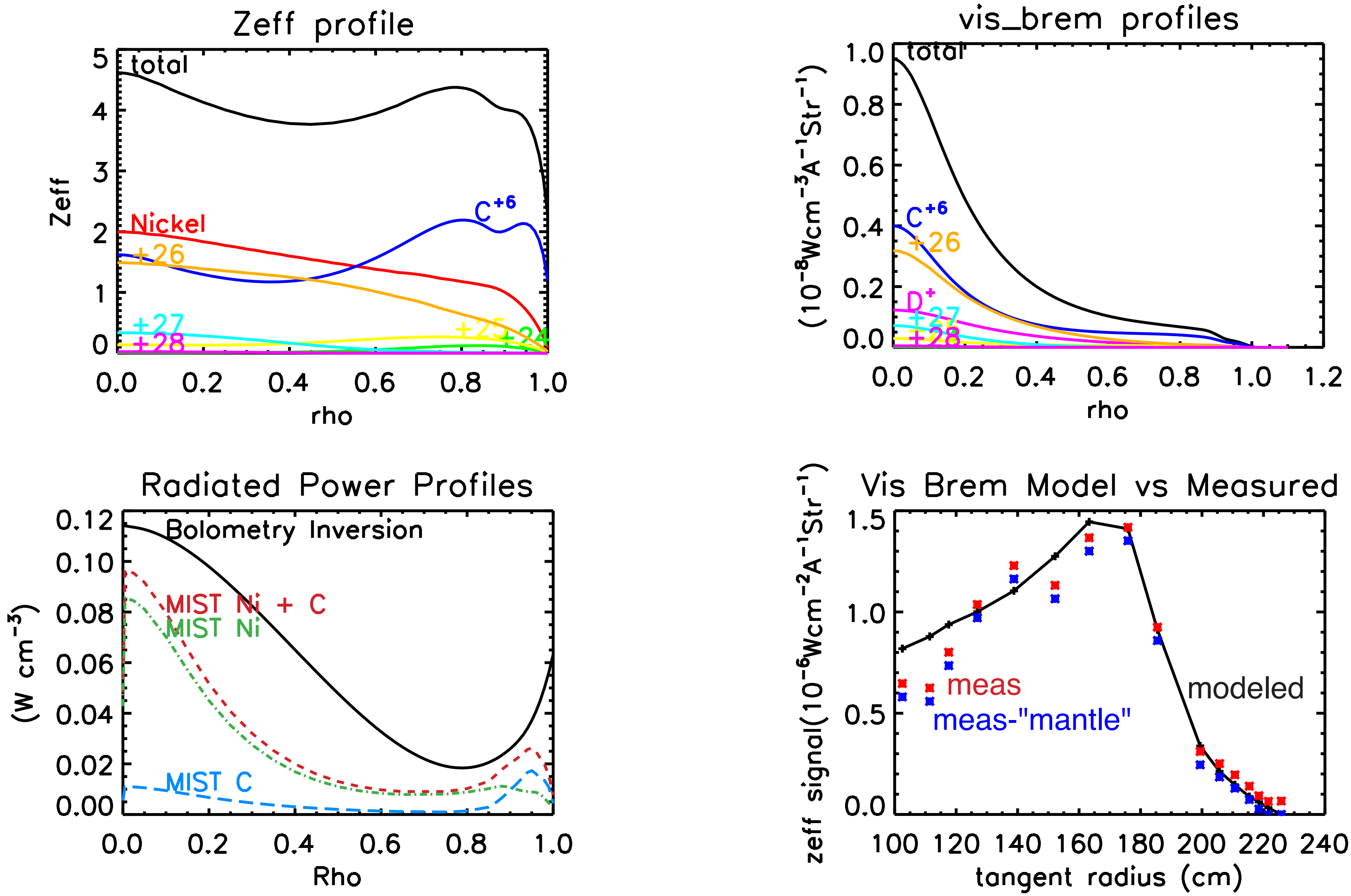
Prad(Nickel) = 270 kW



Z_{eff} and Visible Bremsstralung from Carbon (CER) and Nickel (MIST)

Modeled and Measured Vis_Brem are in Good Agreement

QDB Discharge # 103740 at 3522 ms



QDB Shot 103818, Late in Shot, C + Ni Account for all of Vis_Brem.
Early in time, Vis_Brem indicates more High Z than Spred Ni Lines Show.

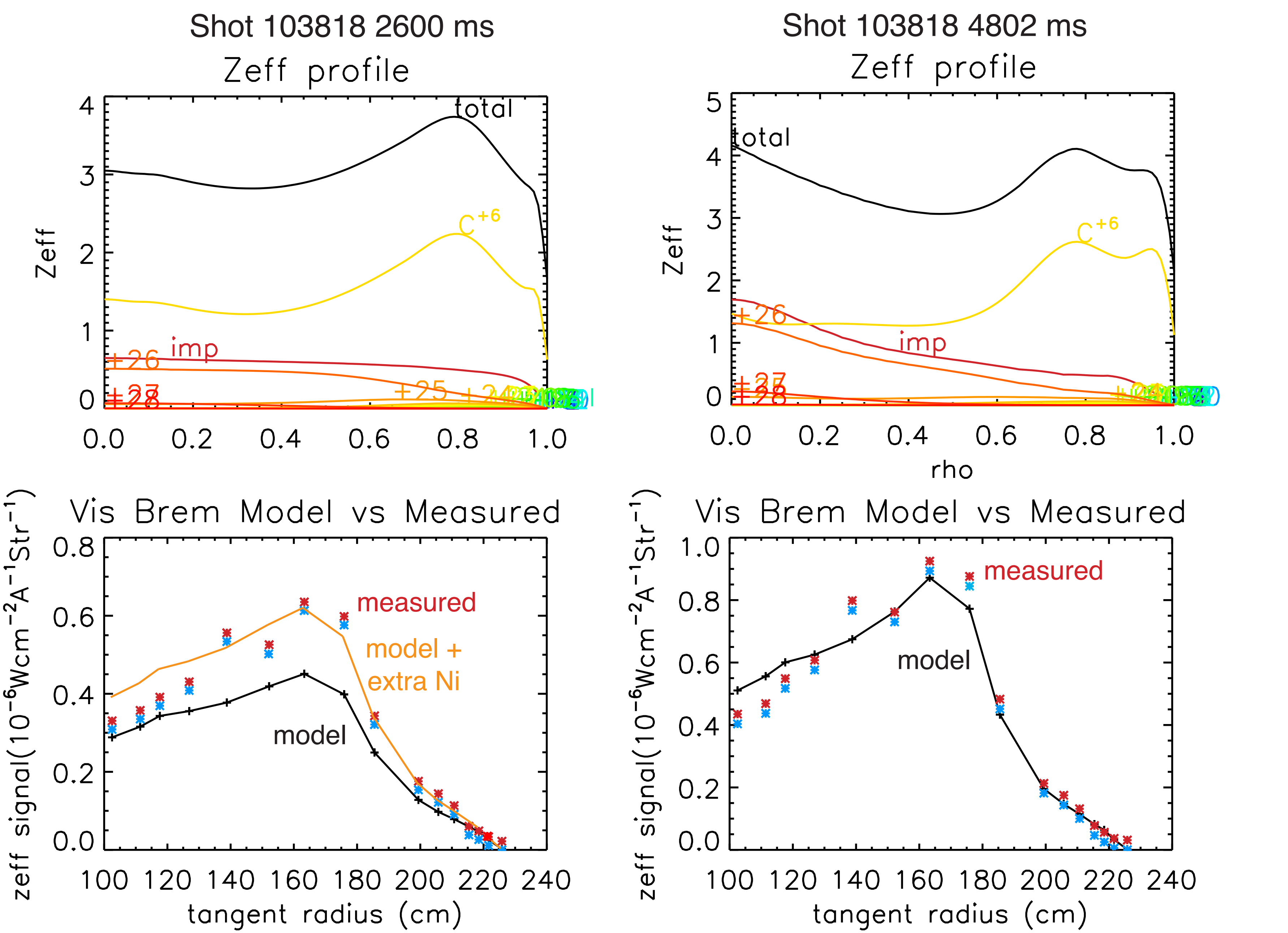


Table Summarizing the Central Zeff Resulting from This Analysis

Mode	Shot	Time	ΔZ_{eff}^{*}	ΔZ_{eff}^{*}	$\Delta Z_{eff}^{\S}$	Z_{eff}
		(ms)	Carbon	Nickel	other	Total
ELMing H	99254	2600	1.2	0.5	0	2.6
QH	99254	3300	1.2	0.5	0	2.7
QDB	103818	2600	1.4	0.6	1.1	4.1
QDB	103818	4802	1.4	1.7	0	4.1
QDB	103740	2005	1.5	0.7	0.6	3.8
QDB	103740	3522	1.6	2.1	0	4.7
ELMing-HP	104276	6000	0.7	0.05	0.6	2.3

* Using Carbon from CER, and Nickel from Mist modeling

§ Add extra impurity to improve the match to visible bremsstrahlung

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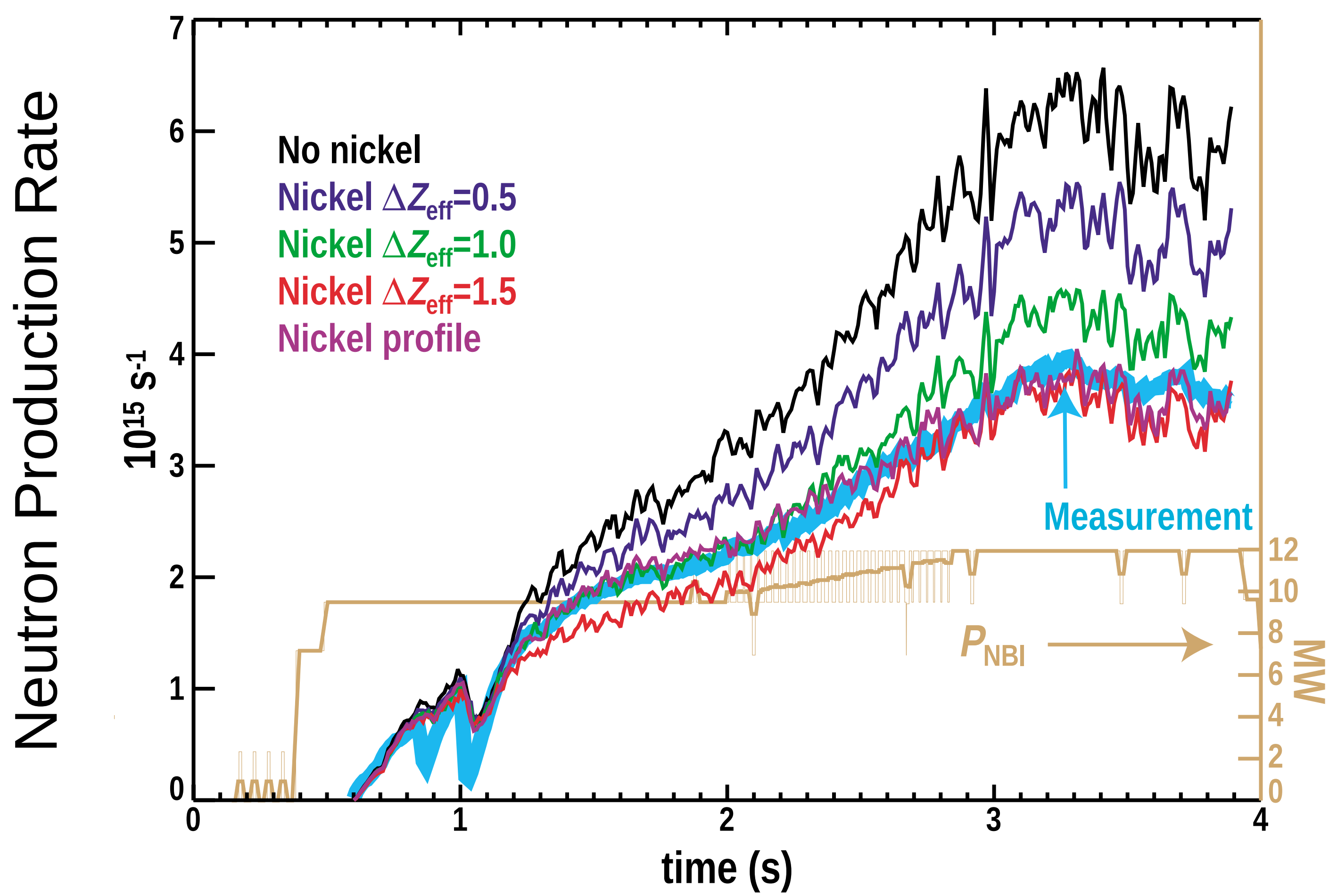
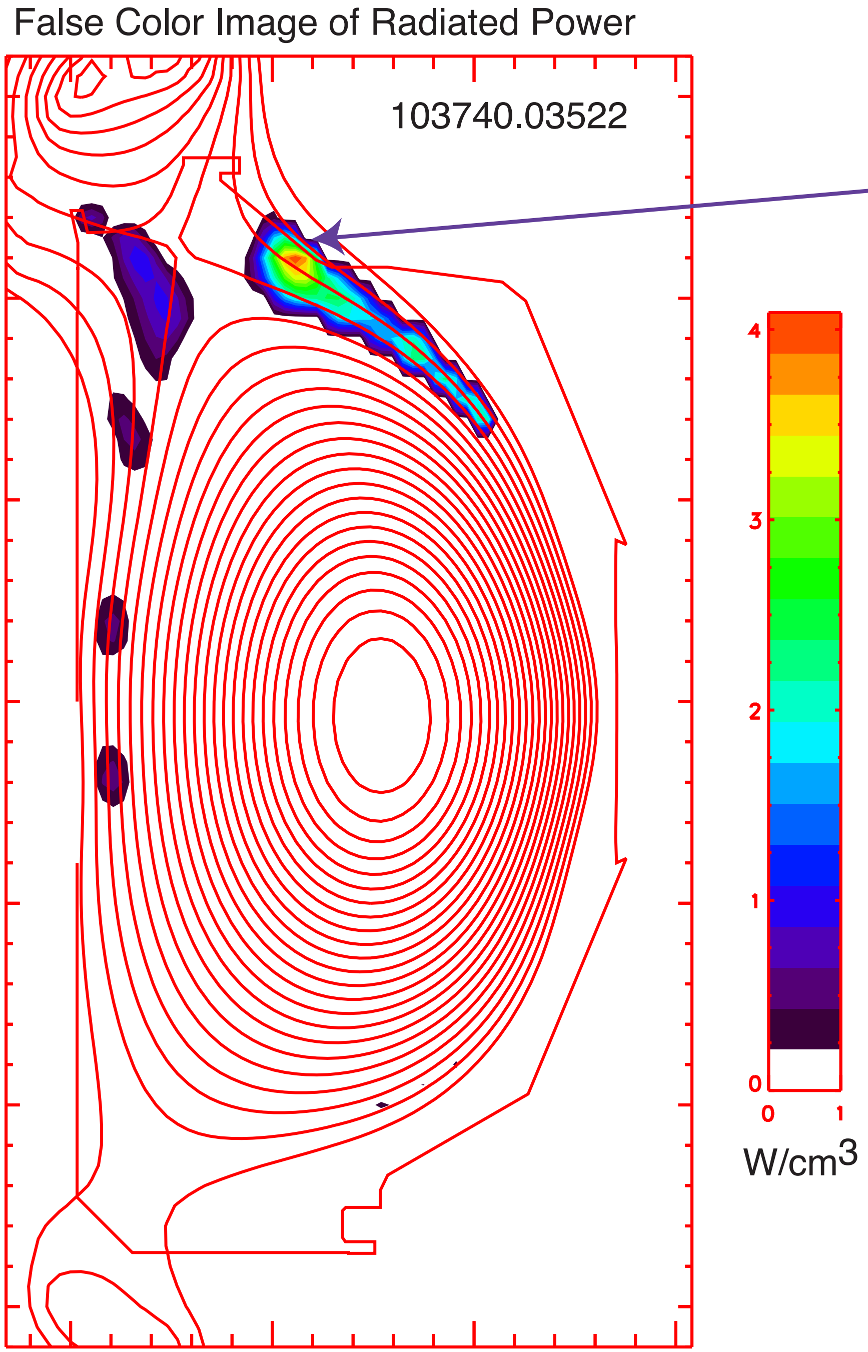
TRANSP Modeling of QDB Discharge Shows Agreement with Measured Neutron Production When Nickel Is Included

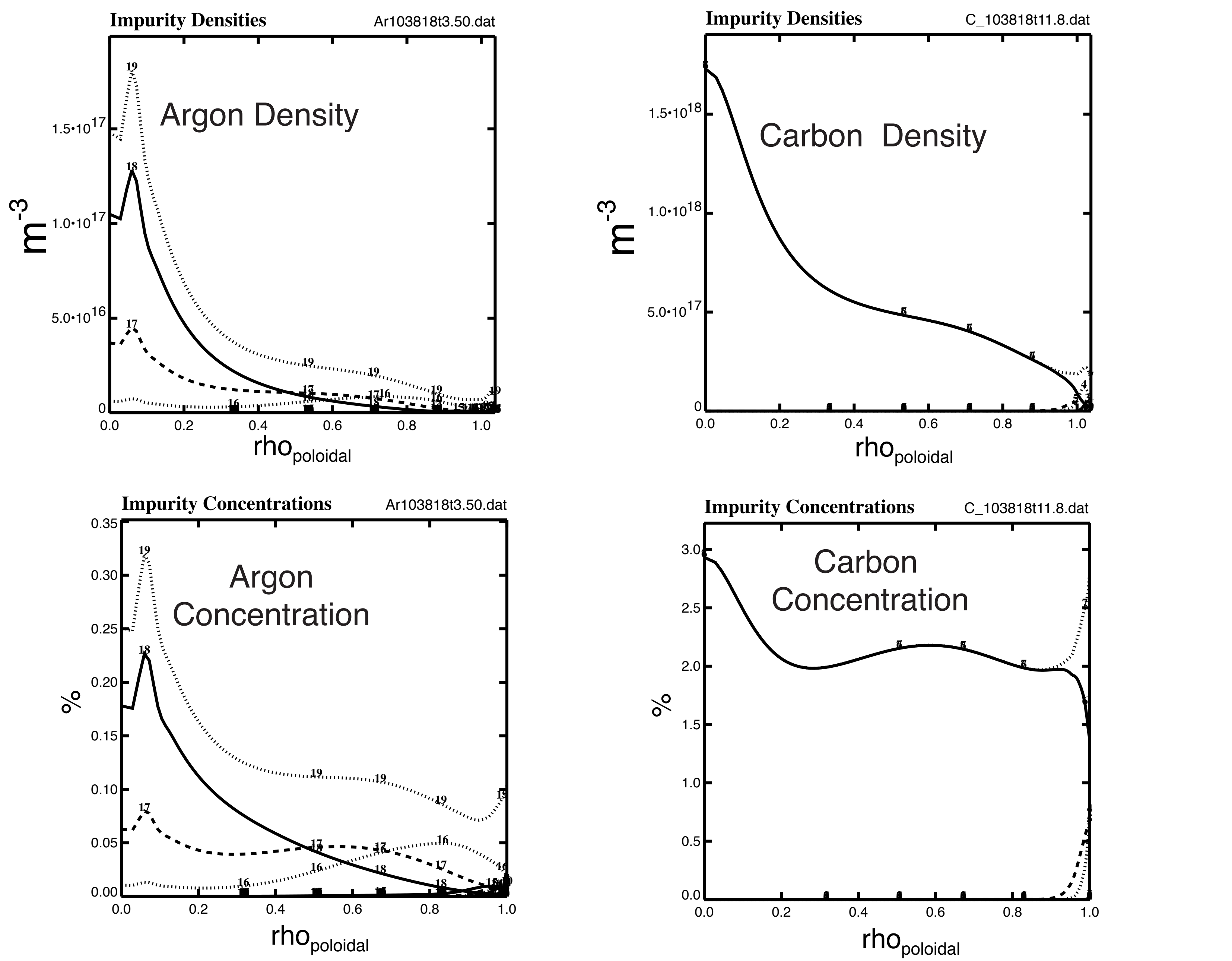


Bolometer Inversion Indicates Possible Source of Wall Impurity Influx



The 3 cm SOL Flux Surface Intersects the Upper Divertor Baffle Well Below the X-point

Strahl Neoclassical Model Predicts Higher Z Impurities Will be More Strongly Peaked in Shot 103818 at 3300 ms



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