

High Performance Operation on DIII-D With Reduced Frequency of Wall Conditioning

by
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with

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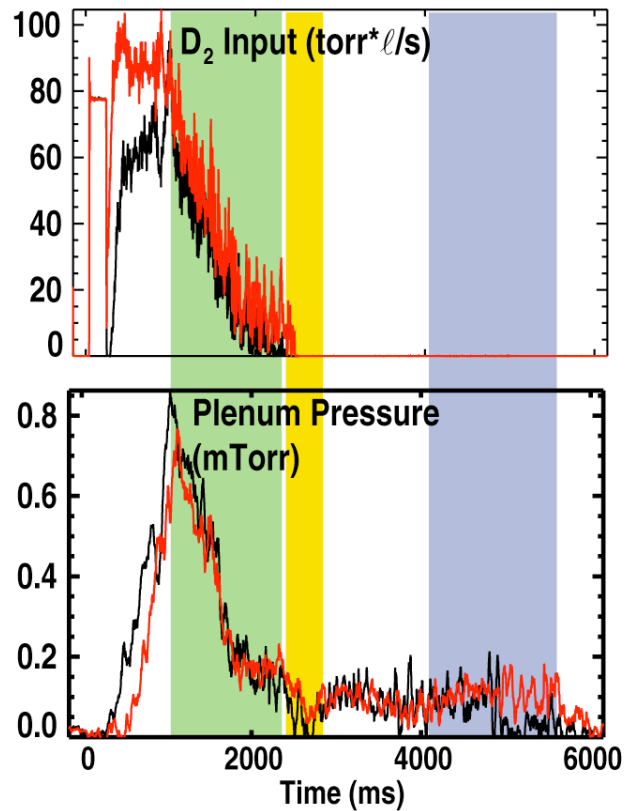
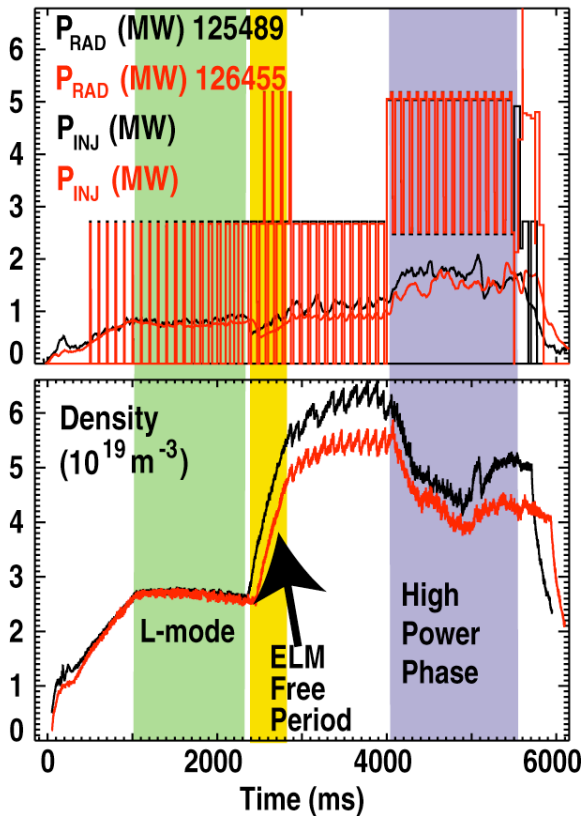


Motivation: Reduce Frequency of Boronizations

- **Long pulse, high duty cycle, superconducting devices not amenable to frequent boronizations**
 - Previous typical plasma-time between BZNs on DIII-D $\sim 10^3$ s
 - On next generation tokamaks (East, K-Star, ITER) this is the order of a fresh BZN after a few discharges
- **Advent of strong divertor pumping on DIII-D led to indications that mean time between boronizations might be extended**
 - BZN/3 weeks was like an apple a day
 - Little or no effects on plasma ops if a BZN was skipped
- **Info on other DIII-D wall conditioning procedures**
 - No high temperature (350°C) bakes between BZNs
 - Except as noted, helium glow discharge cleaning between each shot was continued

Tools for Evaluating Need for BZN

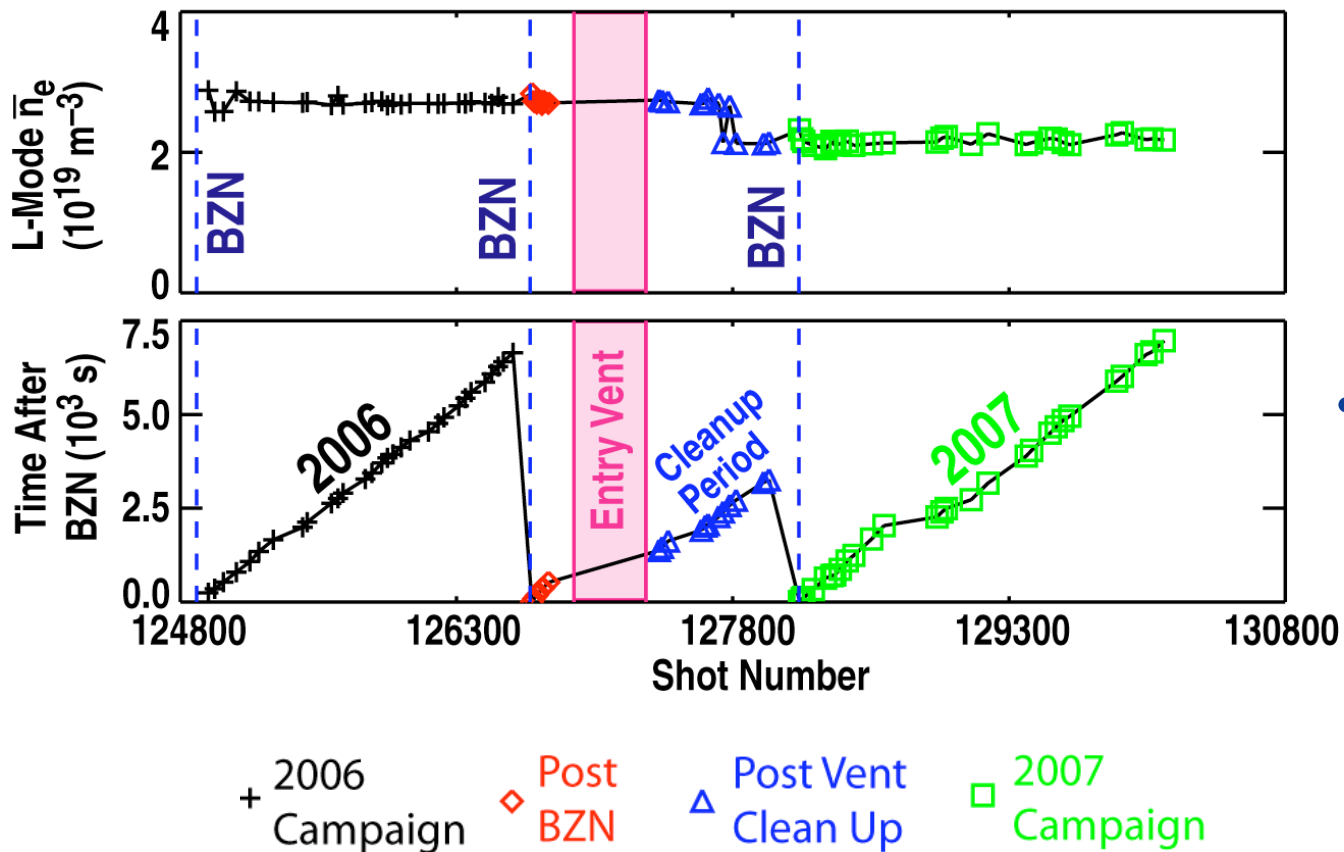
1. Daily reference shots (DRS) monitor long term changes that reflect wall conditions.



- Shot taken as first shot most mornings
 - Also serves as a check on beam duct condition
- Spectroscopy
 - Impurity influx/content
 - Z_{eff} , Radiated Power
- Gas Balance
 - Fueling
 - Exhaust
 - Recycling
 - Density Rise/Loss

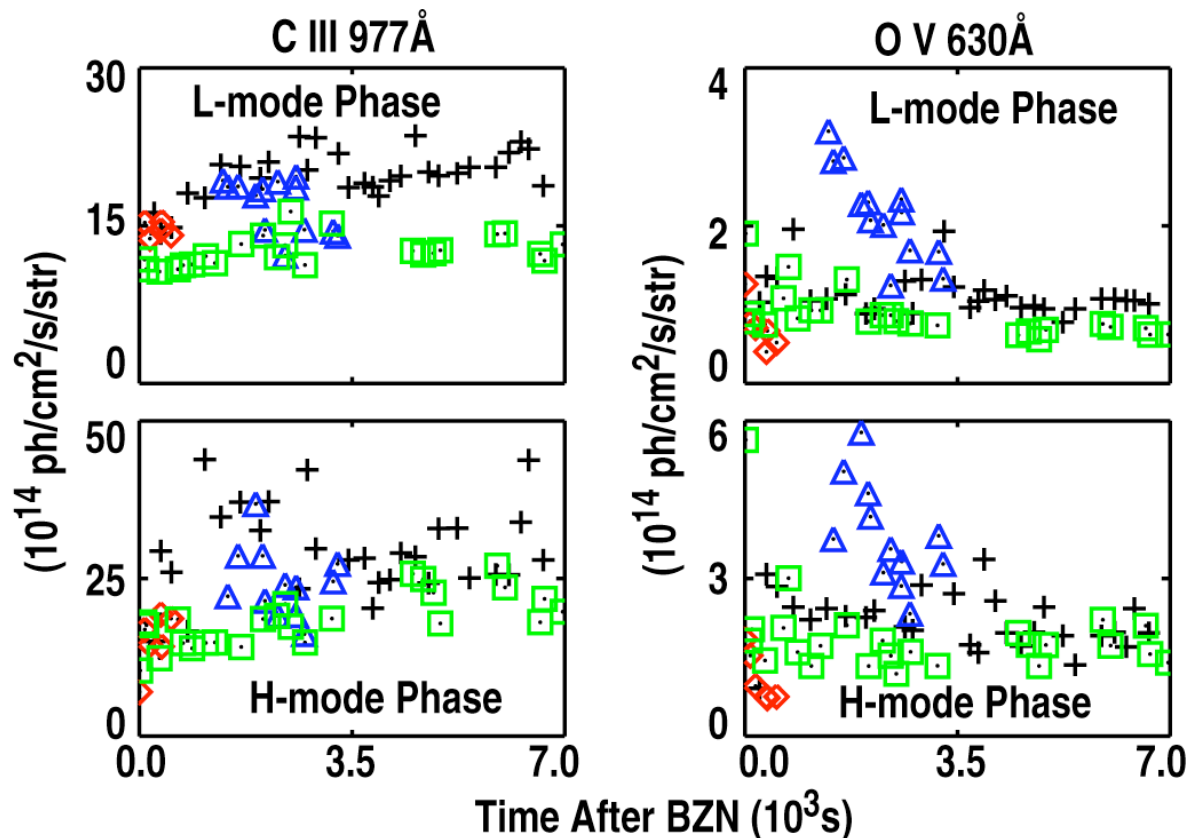
2. High performance discharges were repeated during the 2006 and 2007 campaigns

A Total of 88 Usable Shots Obtained Over 2006 and 2007 Campaigns



- Density during L-mode under feedback control
 - L-mode target density dropped in 2007 to lower net fueling
- ~ 7000 seconds of plasma ops during both campaigns
 - BZN late in 2006 campaign useful for pre/post BZN comparisons

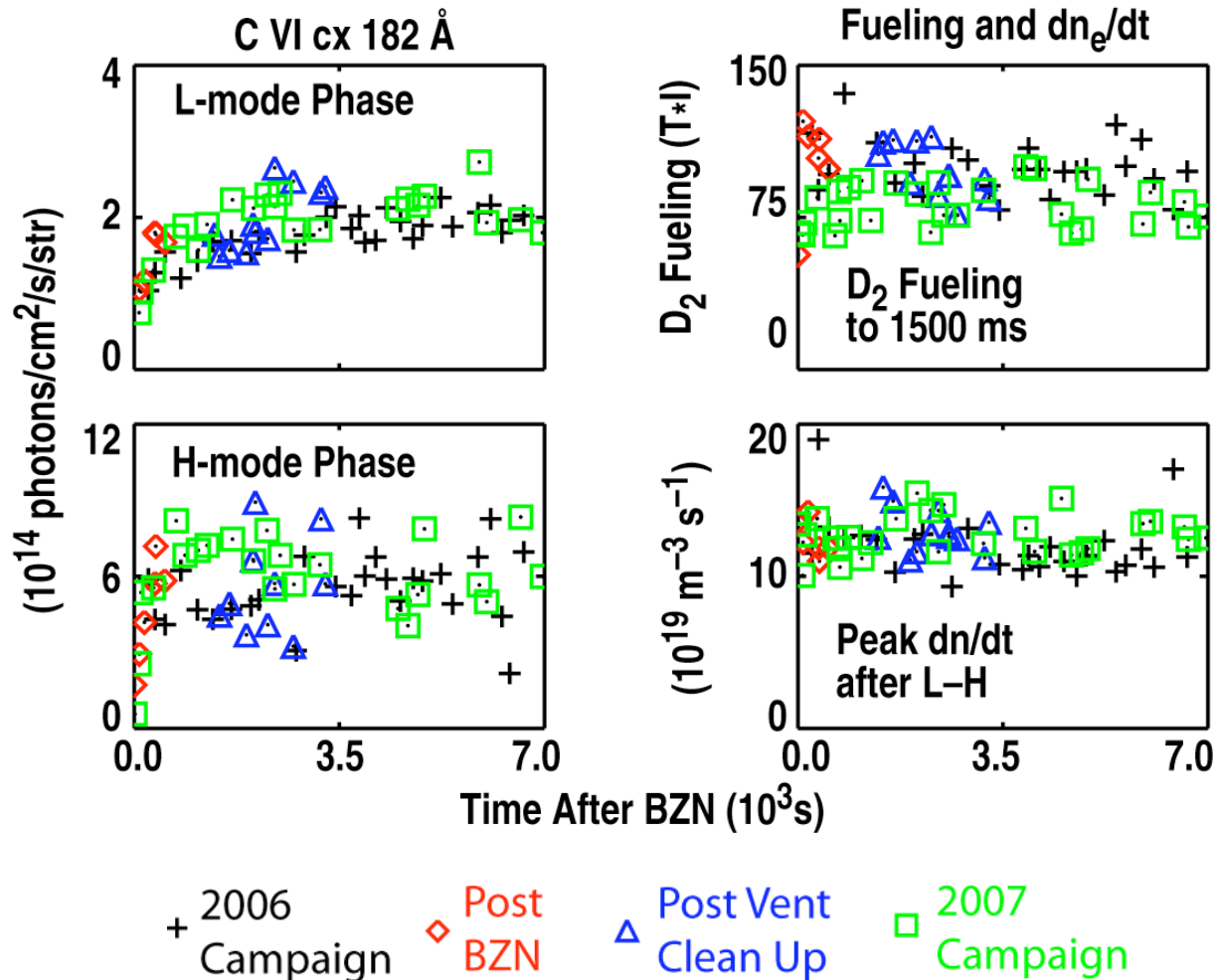
DRS Edge Impurity Emission Shows No Secular Trend Except After Entry Vent



+ 2006 Campaign ◇ Post BZN △ Post Vent Clean Up □ 2007 Campaign

- Edge lines indicate little long term trend in influx at midplane
- Oxygen emission is high immediately after the vent -- returning to normal levels during the plasma clean-up period
- Carbon: weak upward trend early in the period -- saturates after ~3500 s

DRS Core Impurity Emission Shows Similar Trends to the Edge Emission

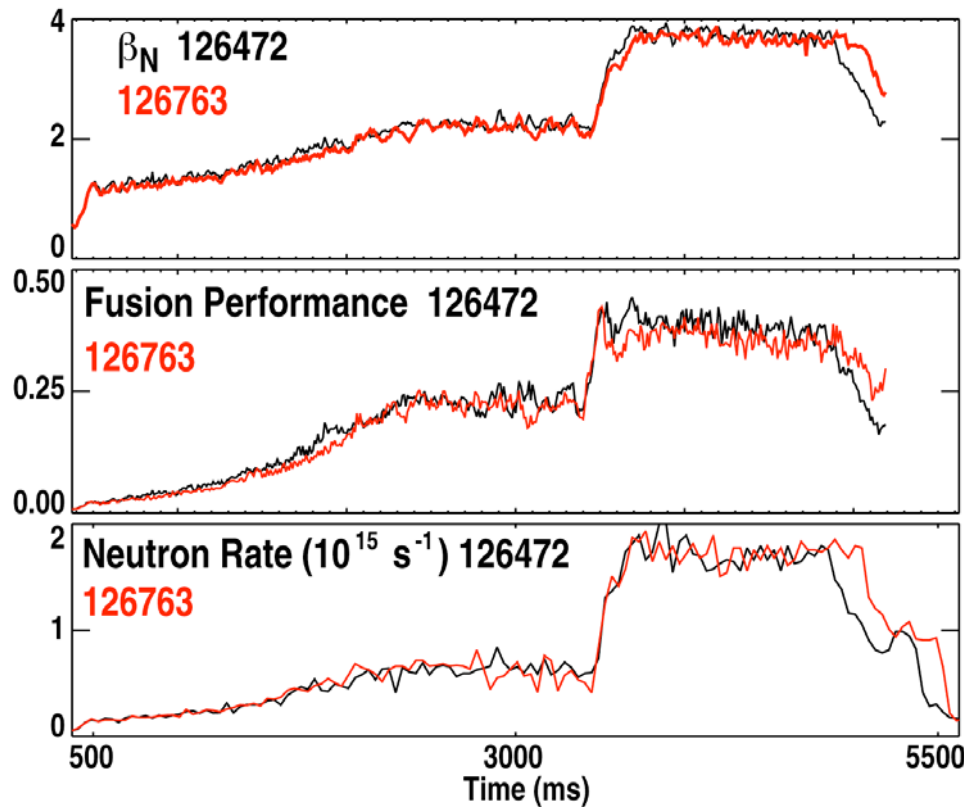


- No secular trend is seen in C VI charge exchange emission after an initial transient
- Gas fueling and rate of density rise after the L-H transition show no secular trend
- Visible Bremsstrahlung and O VIII CX show no long term trend. Nickel core emission rises for ~ 3500 s then saturates at negligible levels

Advanced tokamak (AT) and Hybrid Discharges Show No Degradation in Performance Over 7000 s with No BZN

- High performance Hybrid and AT discharges were occasionally repeated throughout campaign
- Seven strongly-pumped hybrid discharges were sequentially repeated without helium glow discharge cleaning between each discharge
- No degradation in performance (H_{89} , $G = \beta_N H_{89} / q_{95}^2$, neutron production).

AT Performance Insensitive to Time Since Boronization

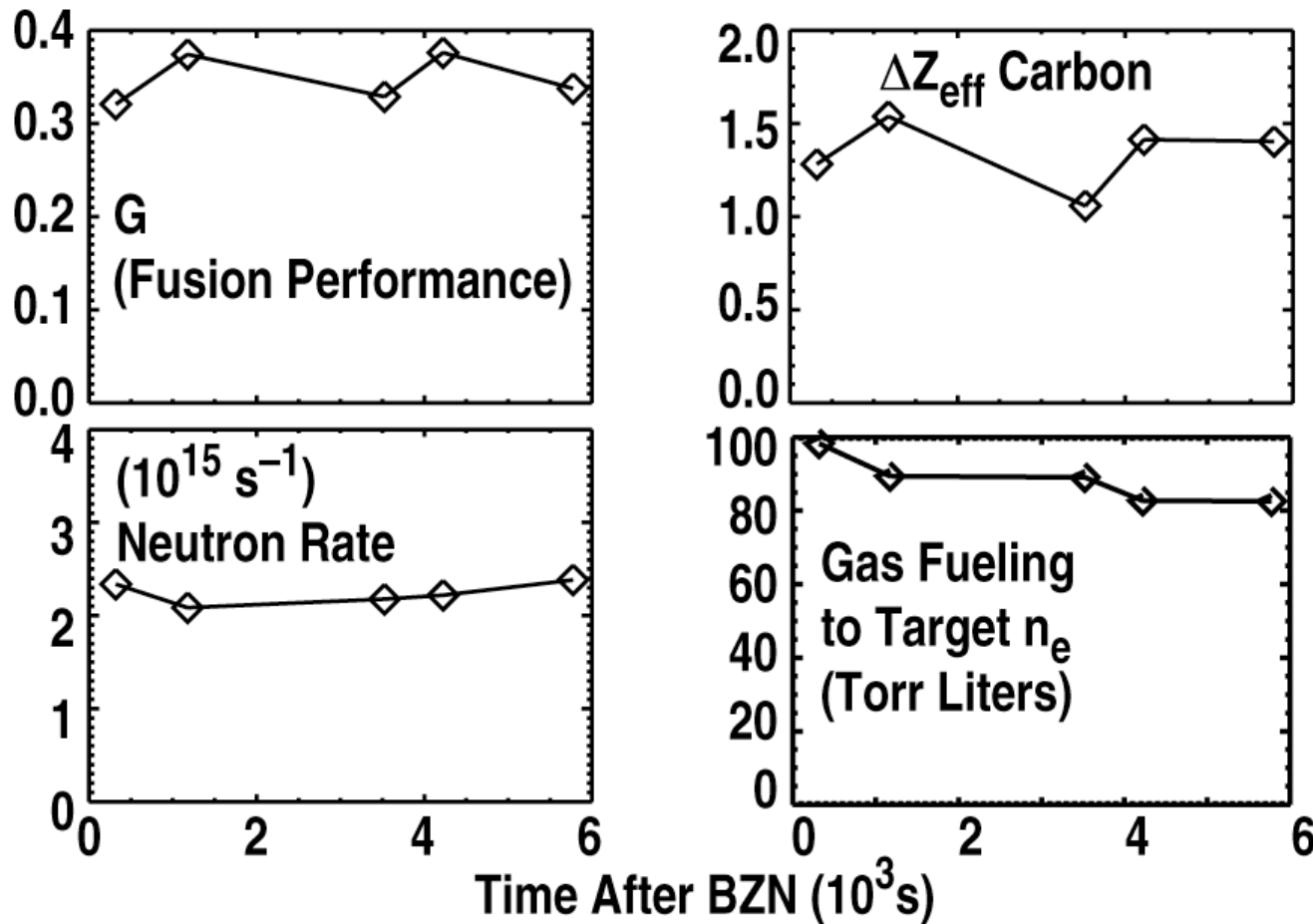


- Shot 126472 taken after 5800 plasma seconds of operation
- **Shot 126763** taken after 320 plasma seconds of operation
- Performance very repeatable

β_N
 $G (\beta_N H_{89}/q_{95}^2)$
 H_{89}
 Neutron Rate (10^{15} s^{-1})
 ΔZ_{EFF} Carbon

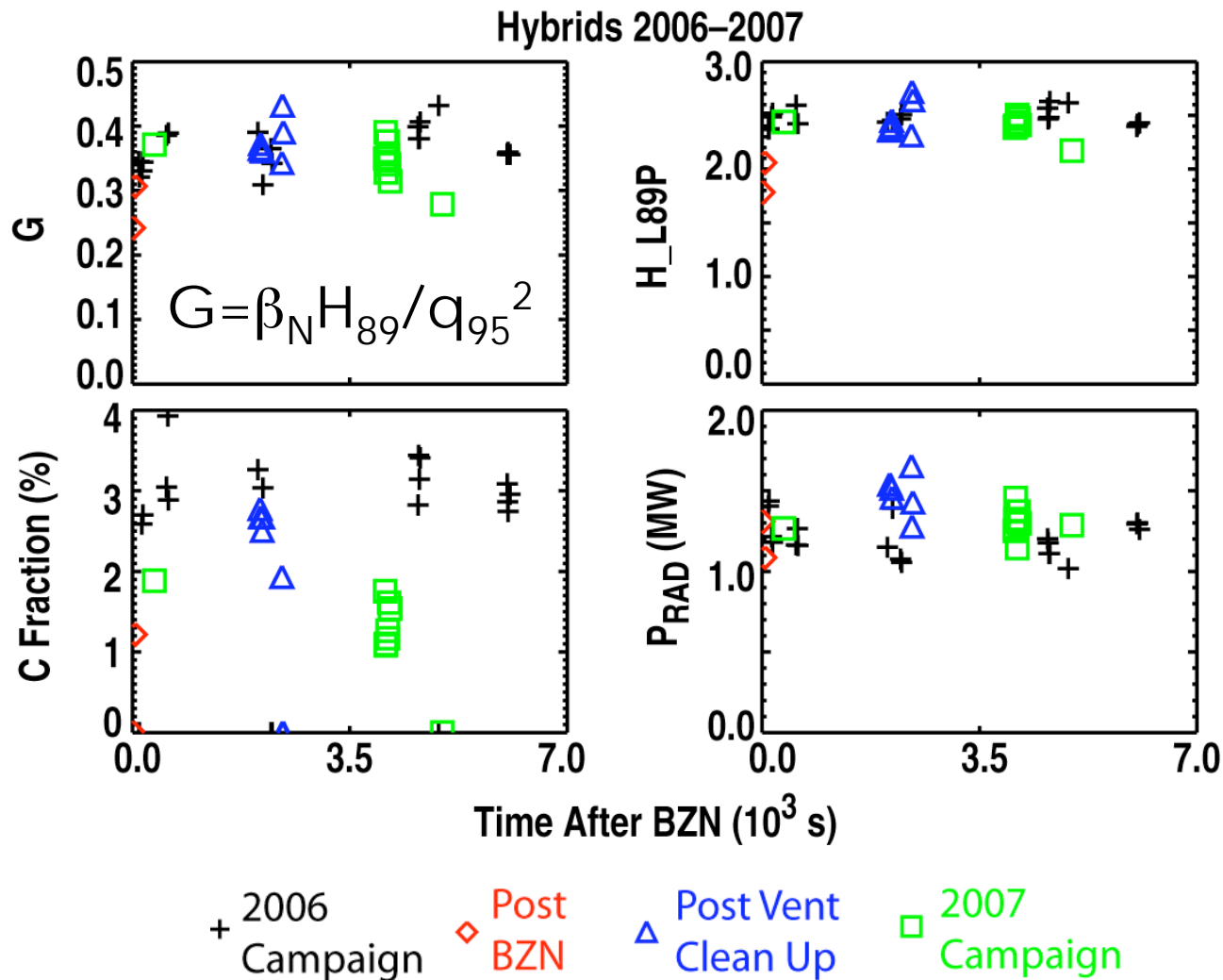
	126472 Before BZN	126763 After BZN
β_N	3.79	3.72
$G (\beta_N H_{89}/q_{95}^2)$	0.38	0.36
H_{89}	2.7	2.6
Neutron Rate (10^{15} s^{-1})	1.7	1.7
ΔZ_{EFF} Carbon	1.4	1.2

Advanced Tokamak Benchmark Shots Show Constant Performance Across 2006 Campaign



- These AT discharges extrapolate well to the ITER Q=5 steady state scenario

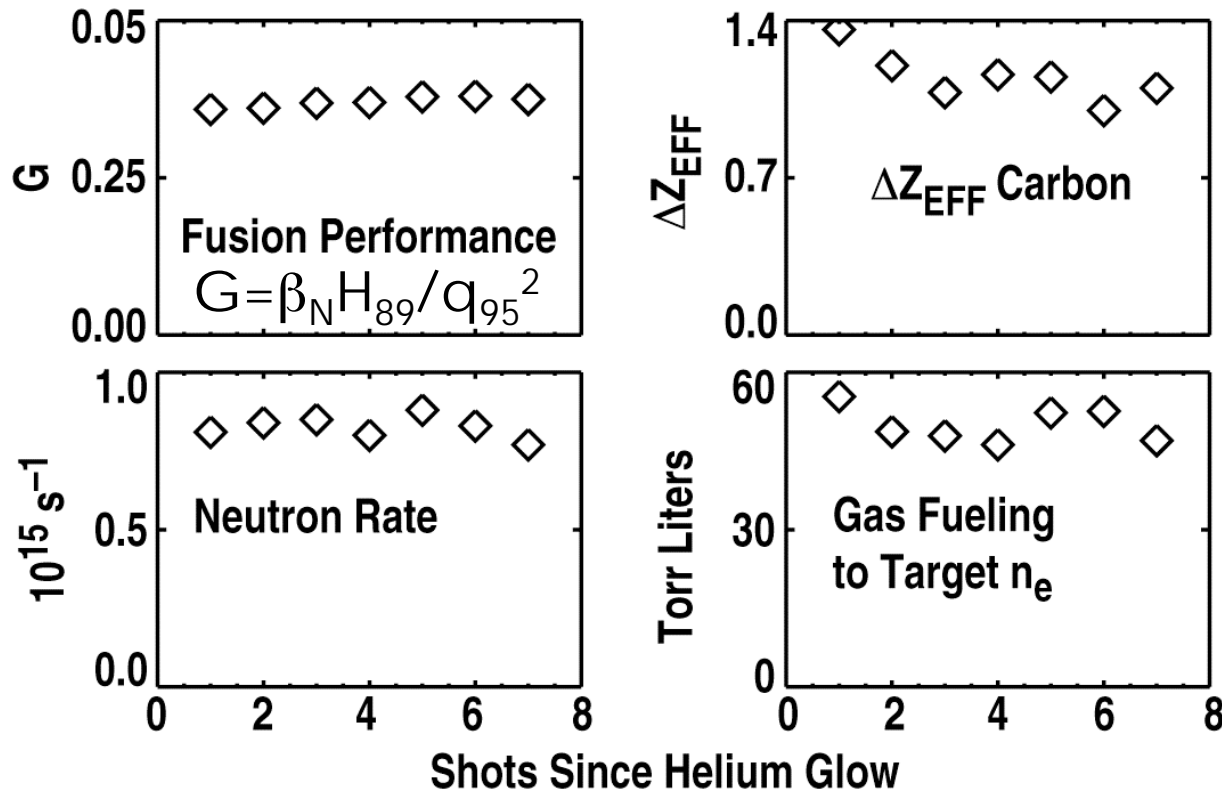
Hybrid Discharges 2006-2007 Have Consistent Performance and Impurity Characteristics



- Hybrid discharges will significantly expand ITER inductive performance

Pumped Hybrid Performance Constant Over Several Discharges With No Between Shot Helium Glow

$$\Delta t_{\text{BZN}} \sim 5800 \text{ s}$$



- Typical of hybrid shots throughout 2006-2007
- Strong pumping is key to maintaining good graphite wall conditions ([R. Maingi, et al., Fusion 36, \(1996\) 245](#))

Discussion: High Performance More Robust With Graphite Walls Compared to High Z Metal Walls

- Tokamaks with metal walls require routine BZN for high performance
 - C-MOD with molybdenum walls (Lipshultz, PSI 2006)
 - AUG with mostly tungsten walls (Neu and Kallenbach, PSI 2006, Hefei)
 - Both cases routine BZNs are required to reduce high Z contamination and associated high radiated power in attempts to produce high performance discharges
- DIII-D used mostly beam heating, C-Mod mostly RF heating

Conclusions

- In DIII-D with an all graphite wall and strong divertor pumping, we have demonstrated the ability to reproduce ITER relevant high-performance discharges over 7000 plasma-seconds of operation with no intervening boronizations or bakes
- Over a short period (~50 plasma-seconds) the ability to maintain hybrid operation without between shot helium glow discharge cleaning has been demonstrated.