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Development of Particle and Impurity Control Techniques for NSTX

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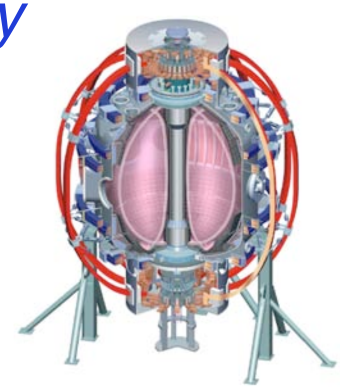

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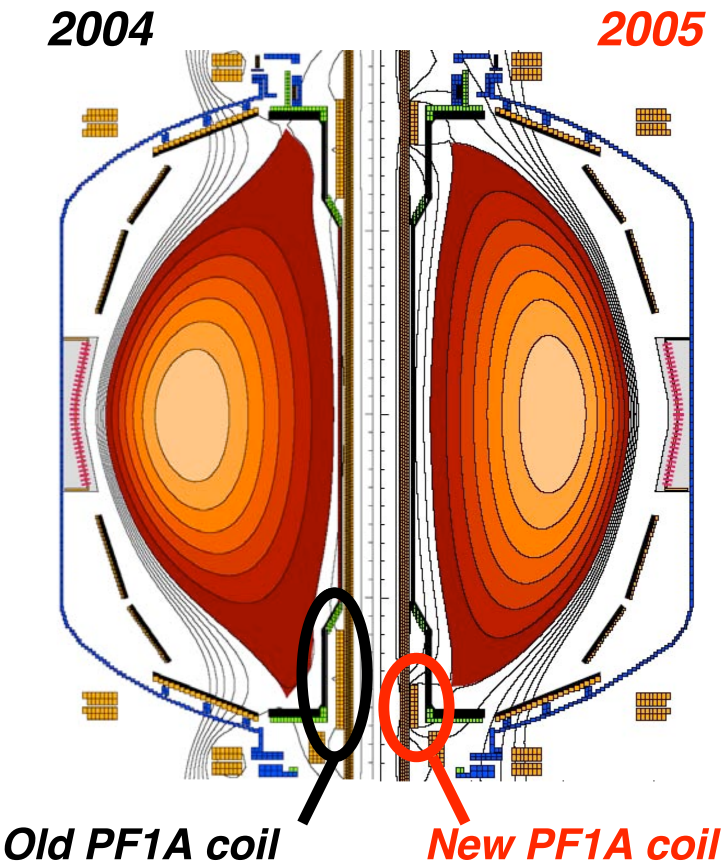
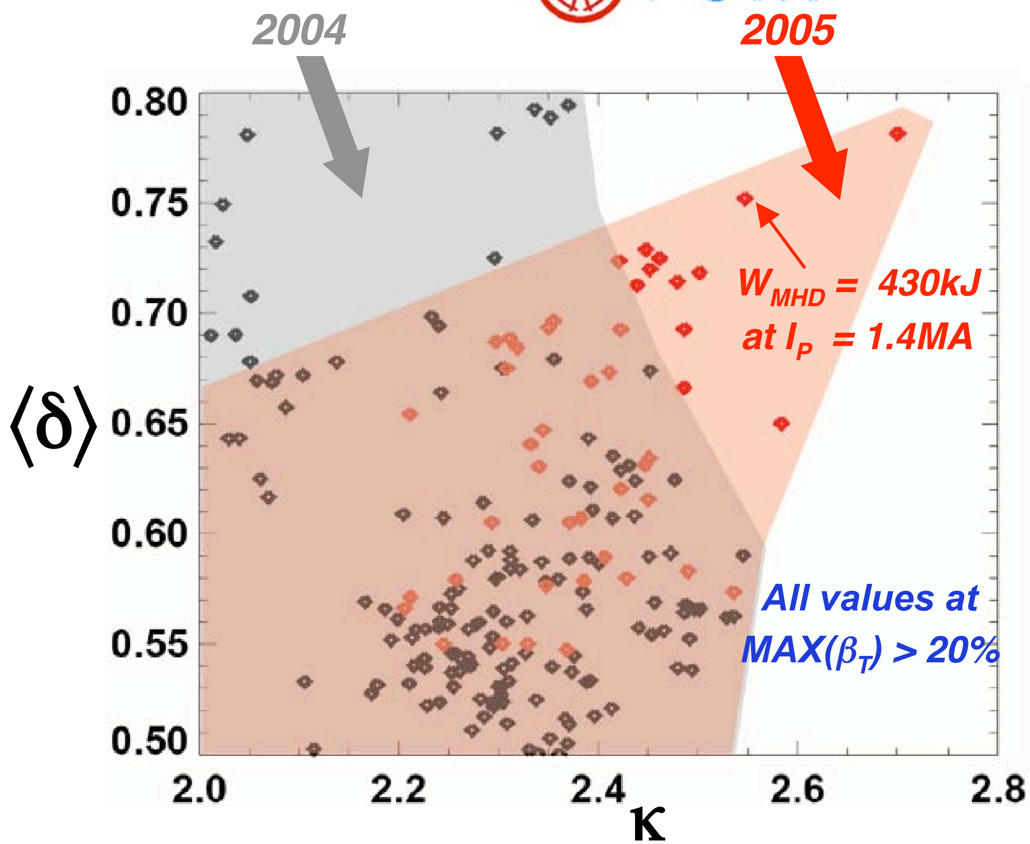
NSTX Uses and Is Developing Many Techniques for Vacuum Conditioning, Density Control and Fueling

- 350°C bakeout of Plasma Facing Components (PFCs) and 150°C bakeout of other vacuum components after vacuum openings
- Boronization using glow discharge in mixture of Helium (90%) and deuterated-Trimethyl Boron ($B(CD_3)_3$, TMB) (~10%, ~10g total)
  - During bakeout (Hot boronization)
  - Routinely at room temperature at intervals of 10 – 20 days of operation
  - At start of a day of operation using a reduced amount of TMB, ~1g
- Helium glow discharge cleaning between shots: 5 – 15 min
  - Recently supplemented fixed anodes on wall with Movable Glow Probe anode for more uniform coverage and operation at lower gas pressure
- Lithium Pellet Injector for coating PFCs with lithium
  - Also used for plasma perturbation experiments
- Gas puffing into divertor private flux region reduces divertor heat flux

High κ, δ with New PF Coils Concentrate Plasma Interaction onto Inboard Divertor





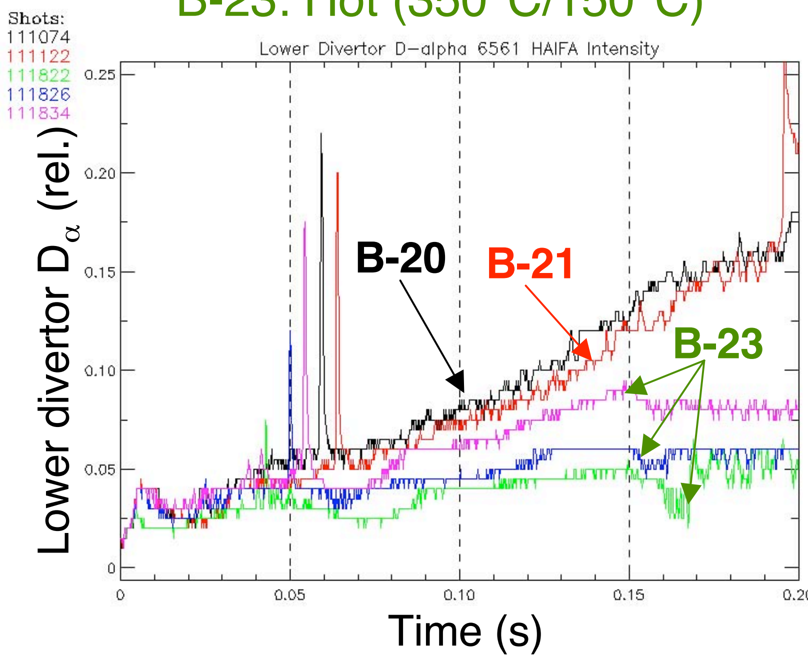
- Highest κ = 2.7 now obtained at highest δ ≈ 0.8
- Small ELM regime in H-mode recovered at high κ > 2.5 with new coils
  - Reduces rate of density rise without deleterious effect on W_{tot}

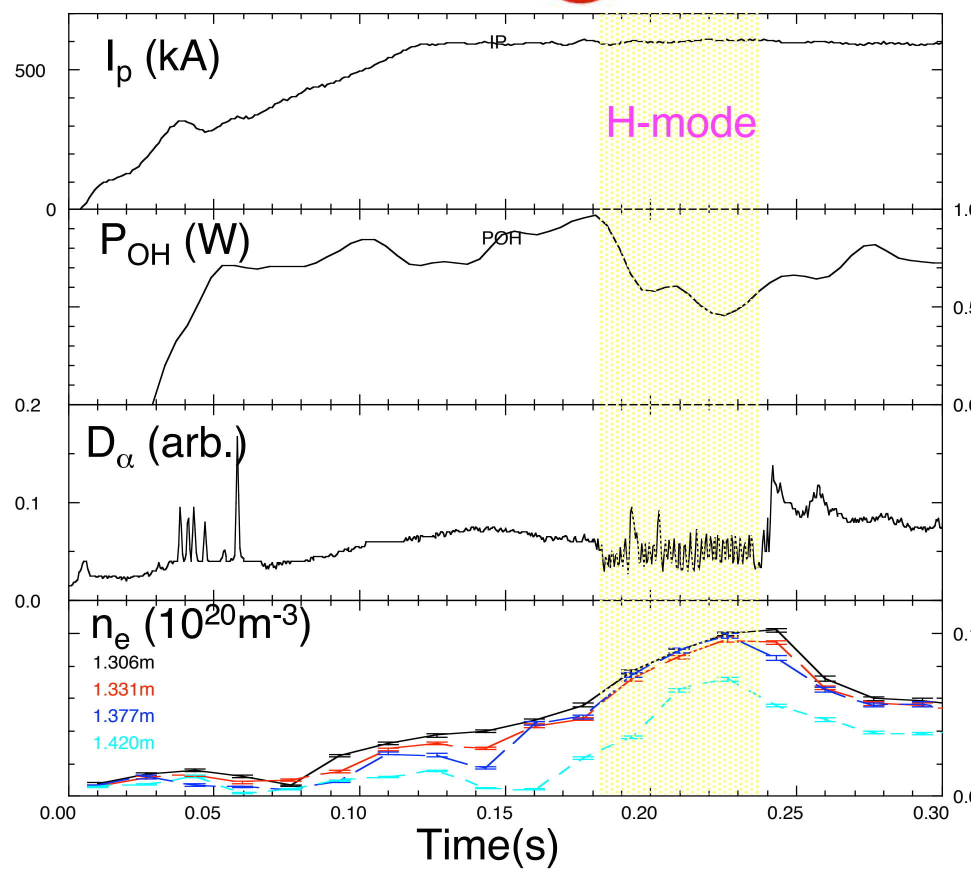
Significant Improvement in Performance Immediately Following Hot Boronization

- ~30 Boronizations (~10g TMB each) have been applied with surfaces at room temperature
  - Reduce oxygen impurities and improve H-mode access
  - Essential to follow TMB with pure He-GDC to remove adsorbed D
- Two Hot Boronizations have been applied with plasma facing surfaces at 350°C and vessel surfaces at 150°C
  - Applied during bakeout after vent and entry to vacuum vessel
  - Performed after water peaks in RGA spectrum had reached slow decay phase (e-folding decay time of several days)
- Compare Hot and Cold Boronizations using fiducial discharges:
  - Lower Single-Null (LSN) divertor discharges, 0.6MA, OH only
  - LSN divertor discharges, 0.8MA, NBI heating

After Hot Boronization, Ohmic Discharges Exhibit Lower D_α and Readily Transition to H-mode

<u>Boronization</u>
B-20: Room Temp.
B-21: Room Temp.
B-23: Hot (350°C/150°C)





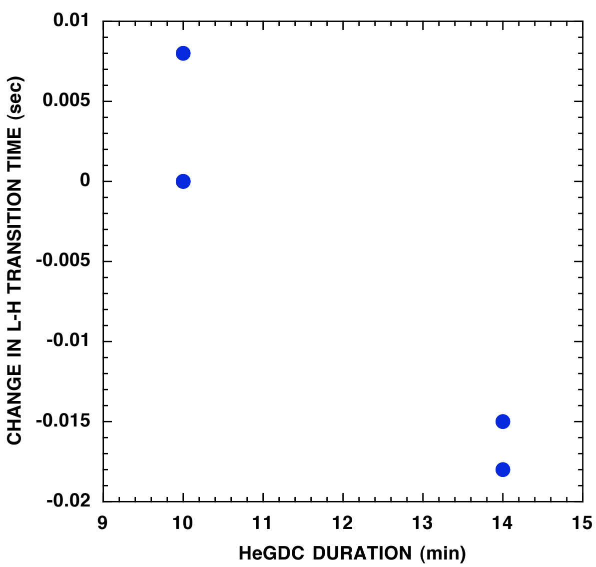
- Lower initial D_α may be due to
  - Less codeposited D_2 in boron film
  - Reduced porosity and trapping sites
- Benefit of hot relative to room temperature TMB declined over ~50 discharges
  - reached similar D_α levels
  - NBI H-modes still readily obtained

Brief Boronization Can Restore Conditions After an Earlier Full Boronization

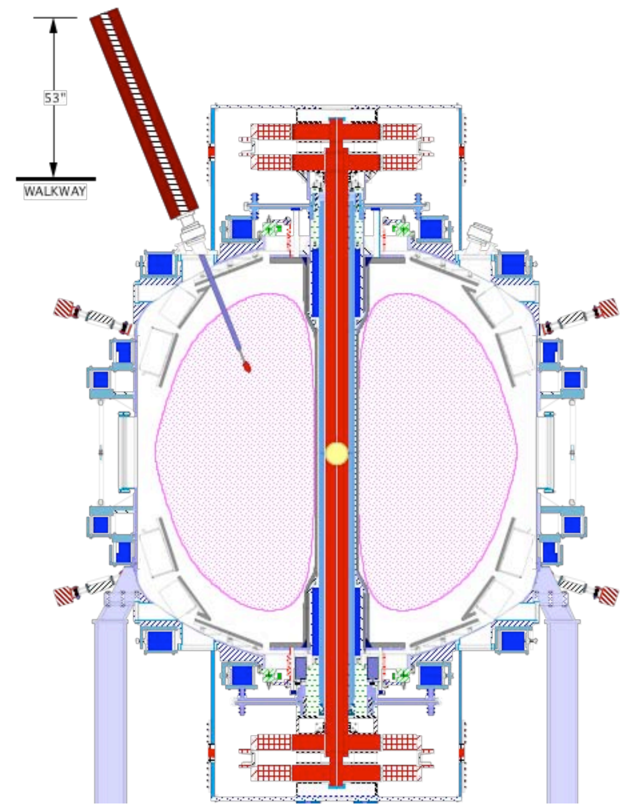
- Performed at start of a day of operation using reduced amount of TMB
  - Takes ~15 minutes to process ~1g TMB
  - Must be followed by comparable or longer period of HeGDC
  - Reduces oxygen contamination and regains H-mode access
- Not a substitute for a full boronization
- Between-shots boronization (0.1g TMB) adversely affected duty cycle due to time required for subsequent pure HeGDC
- Additional brief boronizations and between-shots-boronization do not improve surface conditions, if enough boron is already on the wall

Helium GDC Routinely Applied Between Shots to Control Deuterium Recycling and Impurities

- Previously employed two fixed anodes mounted on outer wall
  - 2 – 4 mTorr (0.25 – 0.5 Pa)
  - ~1.5A per anode
- Applied for 5 – 15 min.
  - Longer promotes earlier H-mode
    - Benefits high-β, pulse length



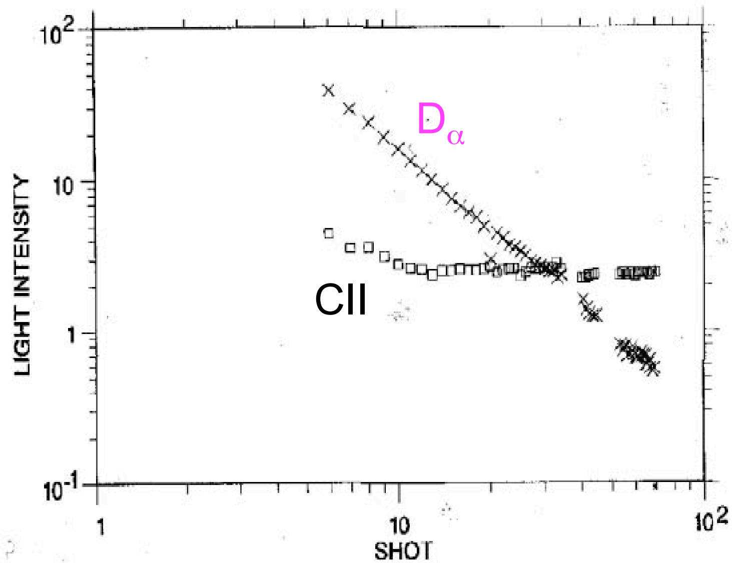
- Recently supplemented fixed anodes with a movable anode
  - Extensive experience not yet accrued
  - ~2 min insertion/withdrawal time



OH Helium Discharges Can Supplement HeGDC for Removing Adsorbed Deuterium From PFCs

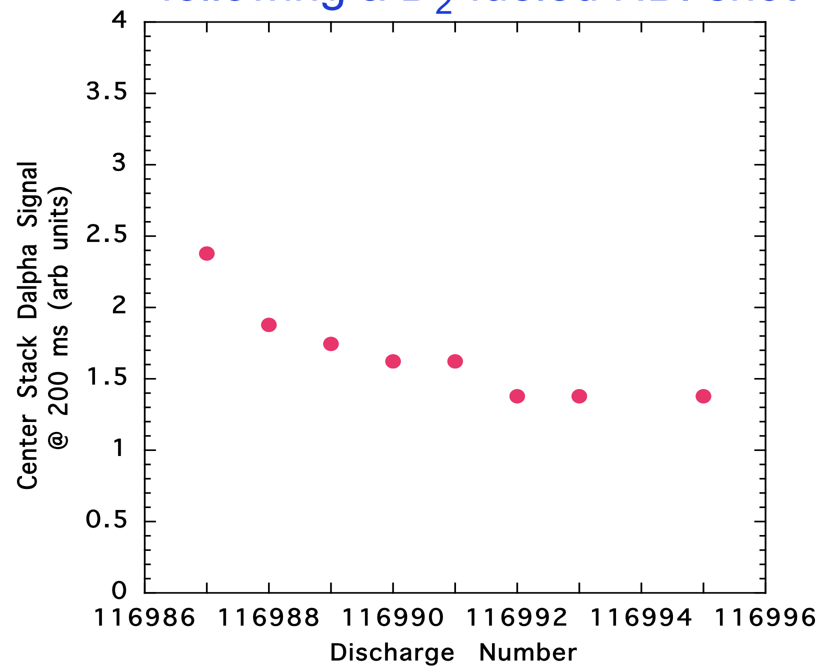
- Ohmically heated helium discharges were effective in removing deuterium from carbon surfaces in TFTR
- In NSTX OH-He discharges limited on center-stack produced rapid drop in D_α emission initially but reduction asymptoted at ~40% after ~6 shots
  - CIII emission from chord viewing inner limiter remained constant

TFTR: Limiter Degassing by OH Helium discharges

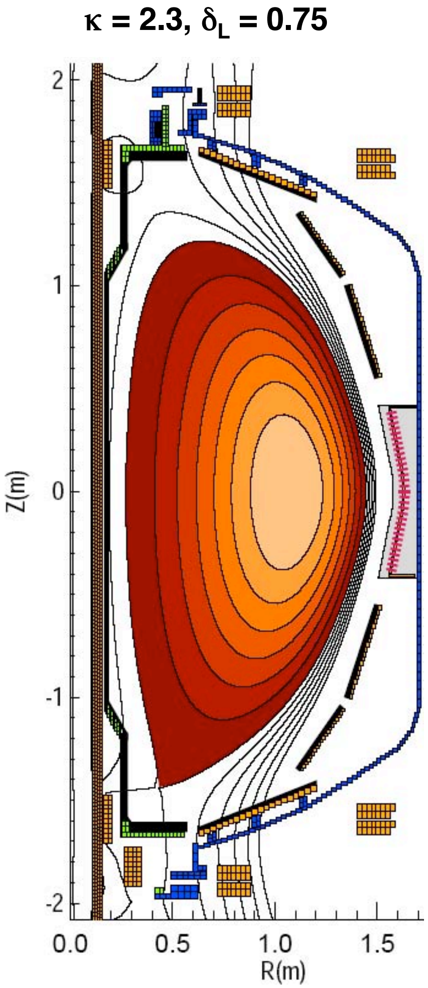


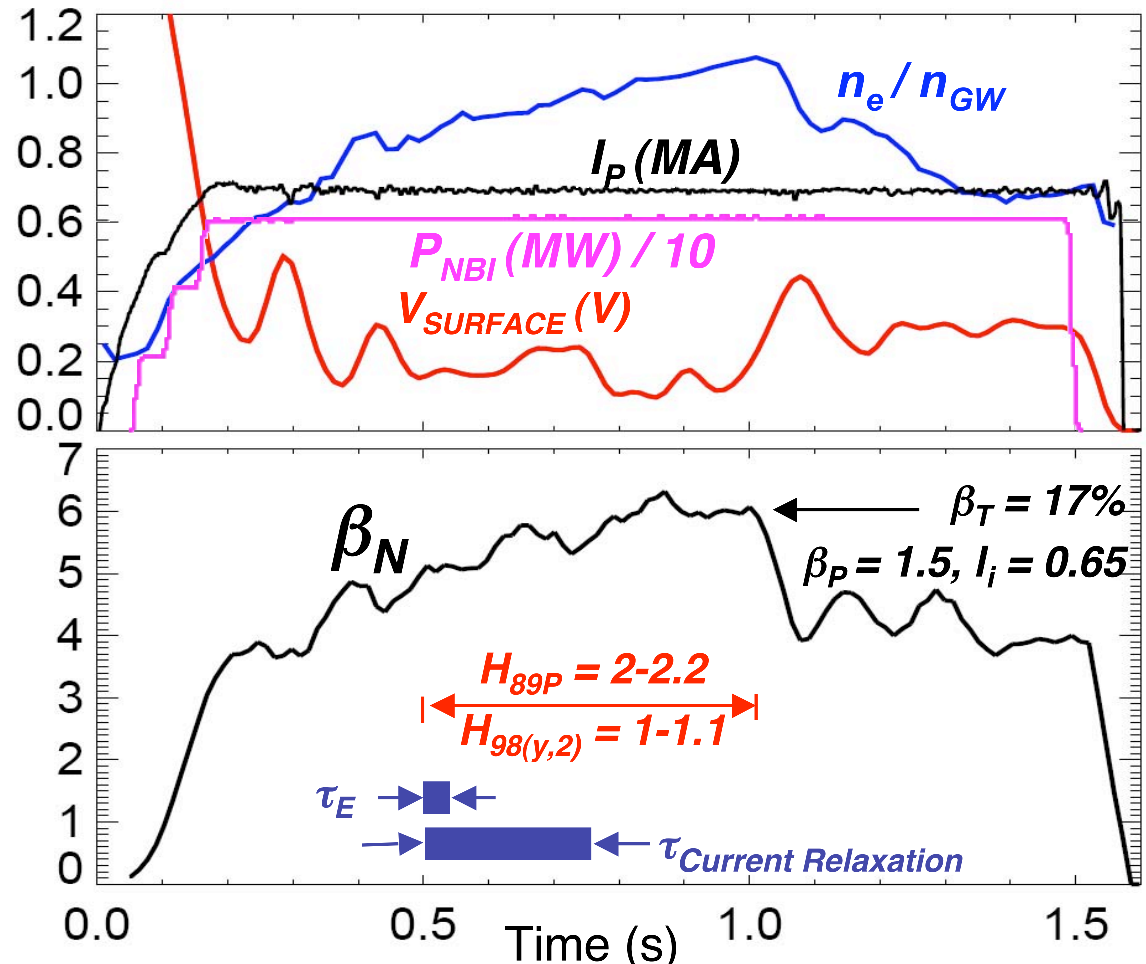
J.D.Strachan *et al.*, J.Nucl. Mater., **196-198** (1992) 28

NSTX: Sequence of OH-He discharges following a D_2-fueled NBI shot



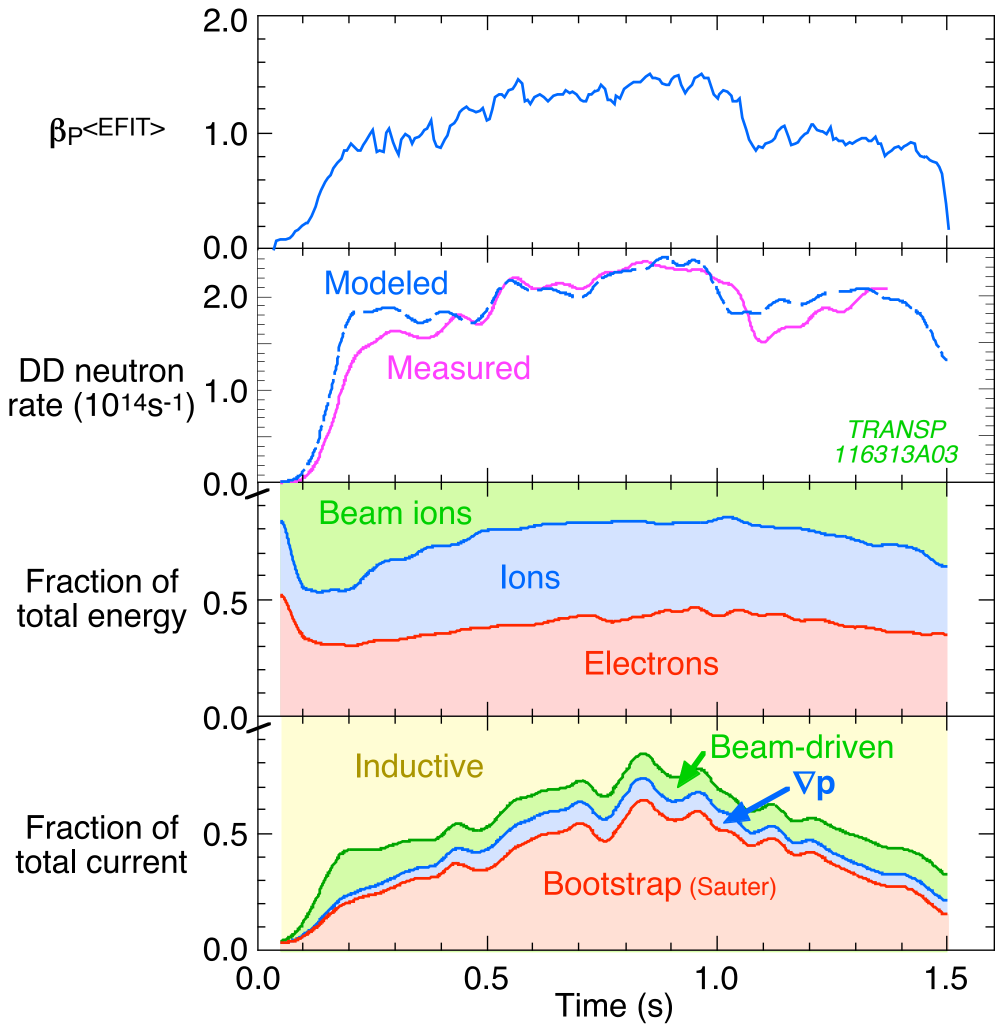
Recent Record Pulse-Lengths Highlight Need for Additional Density Control





- H-mode with small ELMs ⇒ slows density rise
- Density rises until onset of saturated n=1 mode as q(0) → 1
- Probably coincidentally, density reaches Greenwald limit at this time

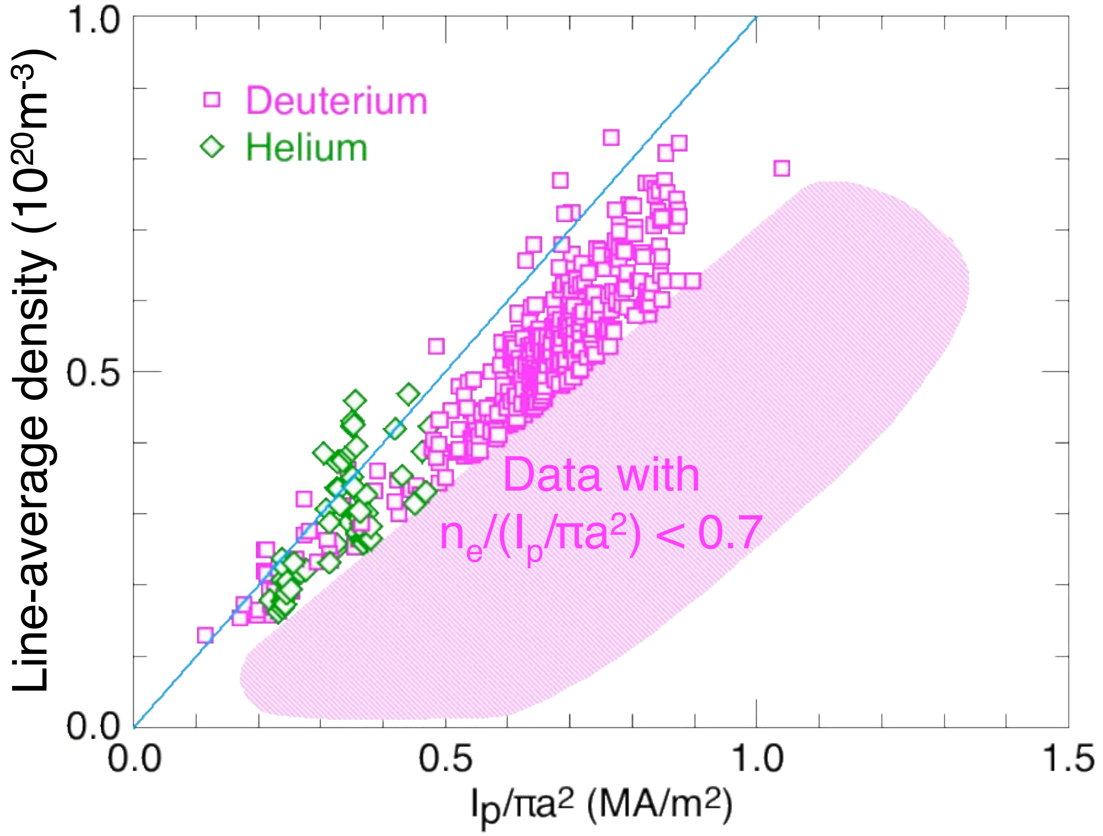
Long Duration Discharges Exceed 70% Non-Inductive Current During High-β Phase



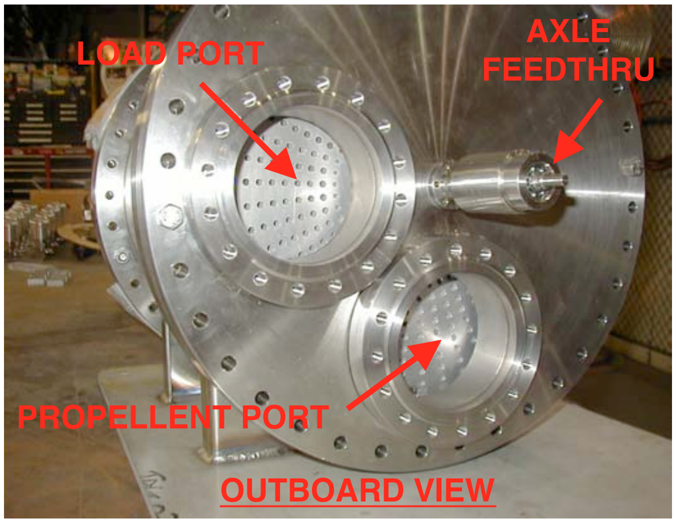
- TRANSP model agrees with measured neutron rate during high-β phase
- TRANSP over-predicts neutron rate early and late when low-f MHD present
  - Fast-ion diffusion and/or loss likely
  - Assessing impact on J_{NBI} profile and q-profile
- 85% of non-inductive current is ∇p-driven
  - Bootstrap + Diamagnetic + Pfirsch-Schlüter

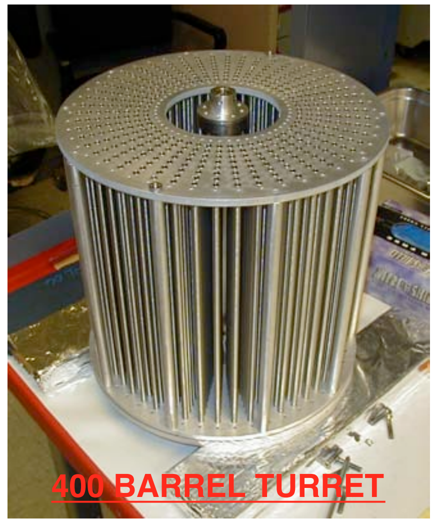
Greenwald Limit Does Provide a Practical Limit on Density in NTSX Gas-Fueled Plasmas

- Data for ~2800 shots in 2004–5 with deuterium and helium gas fueling
  - NB fueling is also significant in longer pulse discharges



NSTX Lithium Pellet Injector Used to Coat Plasma Contact Surfaces with Lithium





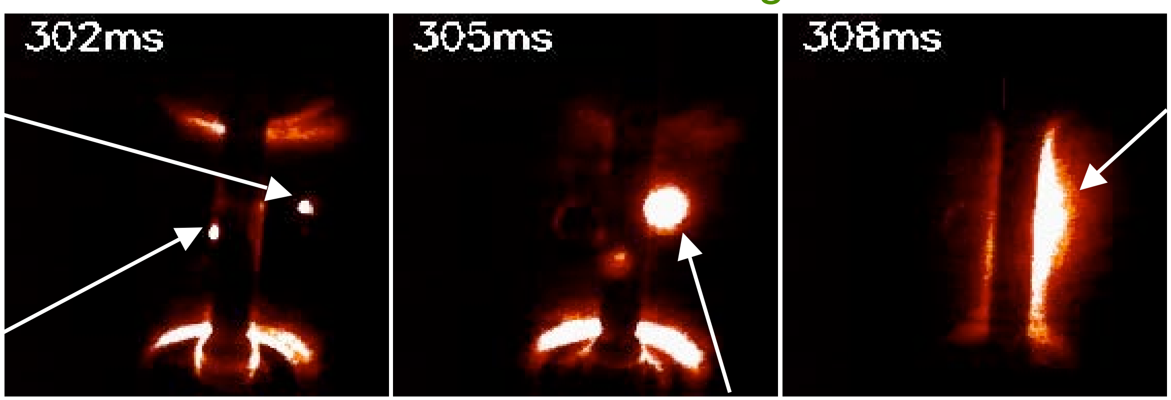
- Sabot-style injector for
  - solid pellets (<1 – 5 mg) &
  - powder (micro-pellets)
- 10 – 200 m/s radial injection
- 1 – 8 pellets per discharge
- 400 pellet capacity

- 111 mg injected using 0.4 – 5 mg pellets, 100-150 m/s, 1-2 pellets/shot

Plasma TV in Li I light

Lithium pellet traversing plasma

Center stack gas injector



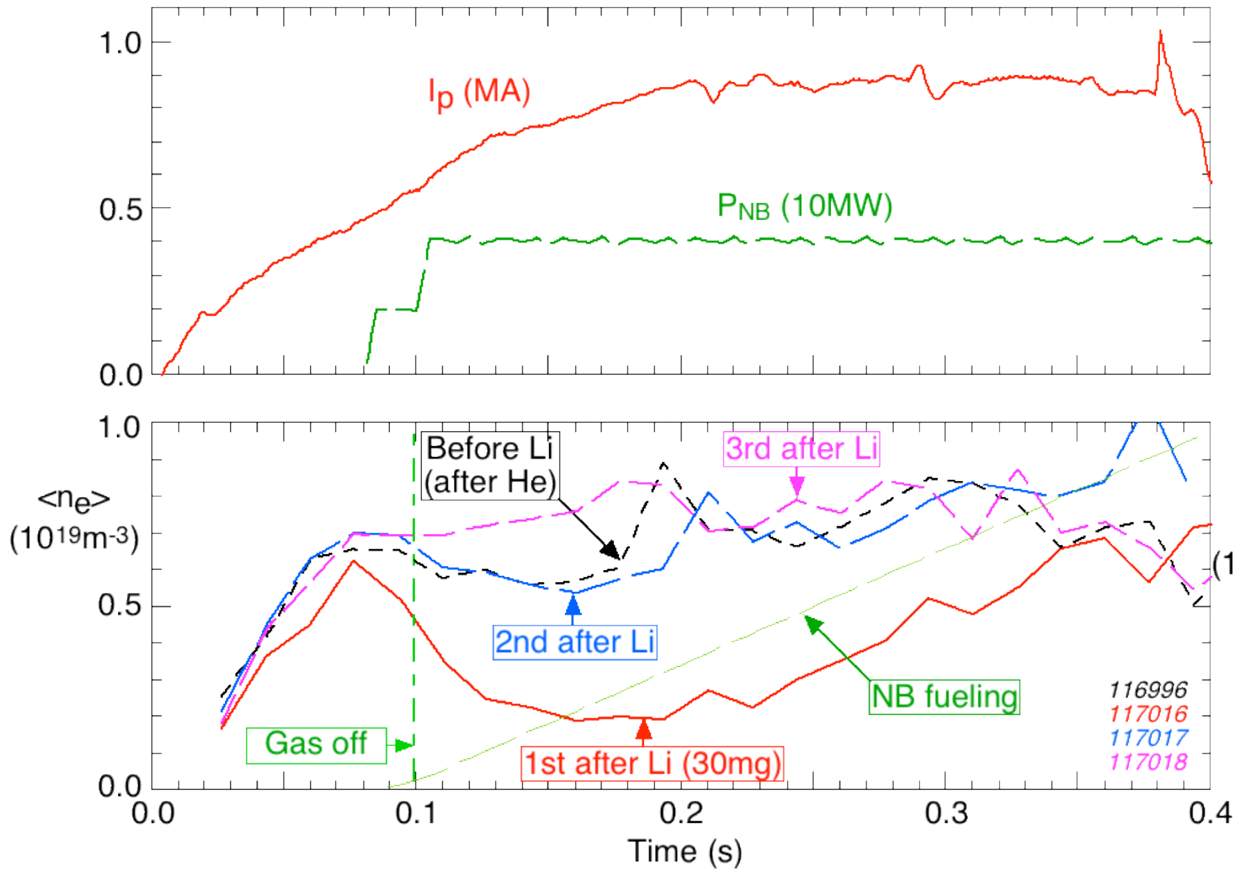
Lithium vapor spreading along center-stack after impact

Pellet plasmoid approaching center-stack

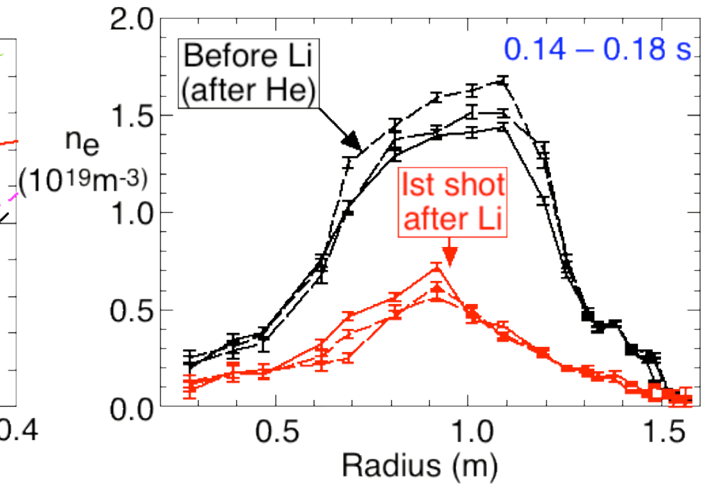
First Experiment on Lithium Wall Pumping: Discharges Limited on Center Stack

- Attempt to replicate TFTR experience with lithium deposition on C
  - TFTR: Plasma volume ~35m^3; inner limiter wetted area ~10m^2
  - NSTX: Plasma volume ~12m^3; inner limiter wetted area <2m^2
- "Pre-condition" surface with sequence of OH helium discharges
  - TFTR prescription: need to reduce deuterium recycling first
- Run three deuterium discharges in same configuration with NBI heating: reference shots
- Fire lithium pellets (1.7 – 5 mg) into sequence of similar OH helium discharges
  - 1 or 2 pellets per discharge
  - 30mg total lithium in sequence
- Run series of deuterium discharges with NBI
  - Compare with reference shots to assess effect on density and profile
- Process was then repeated with 24mg lithium deposited

Lithium Produced an Immediate, Dramatic Reduction in Density but Benefit Short-Lived



Center-stack limiter discharges, 0.45T; D_2 gas fueling, ~3.5mg per shot

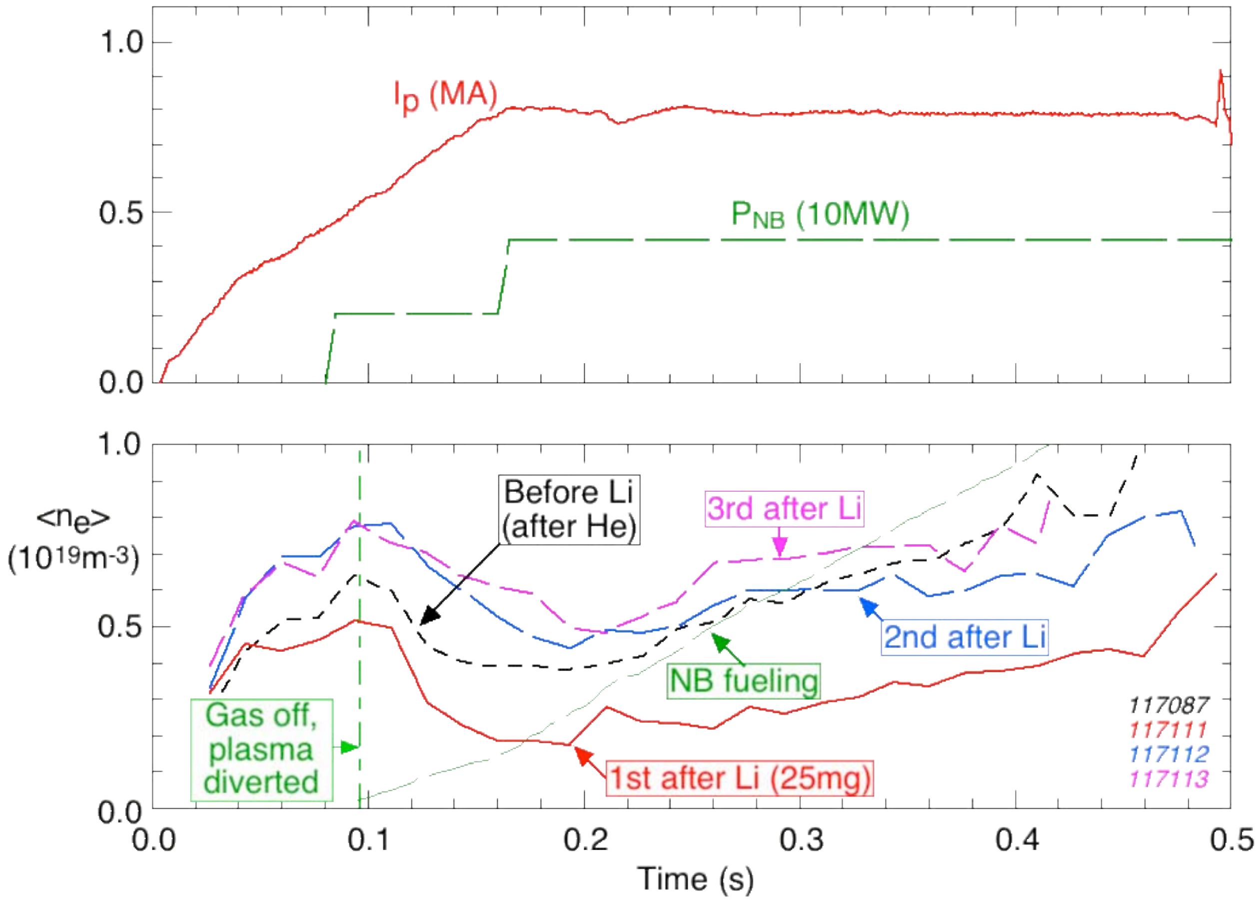


- Density after end of gas puff reduced by factor >2 after lithium coating
  - Rate of density rise matched NB fueling after initial rapid pumpout
  - Density profile quite peaked in *both* pre- and post- lithium cases
- Effect had dissipated on second similar shot

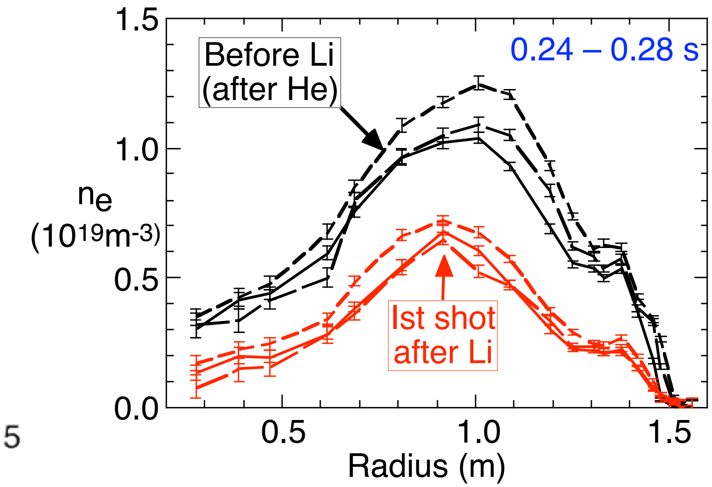
Second Experiment: Lower Single-Null Divertor Discharges

- Similar methodology as for limiter case
  - No precedent from TFTR, but LTX suggested benefits
- "Pre-condition" divertor surface with sequence of OH helium discharges
  - Contact area on divertor much smaller: $<1 m^2$
- Run three reference deuterium discharges in same configuration with NBI heating
- Fire lithium pellets (1.7 – 5 mg) into sequence of similar OH helium discharges
  - 25 mg total lithium in sequence
- Run series of deuterium discharges with NBI
  - Compare with reference shots

In Divertor Discharges, Effect Again Dramatic but Short-Lived



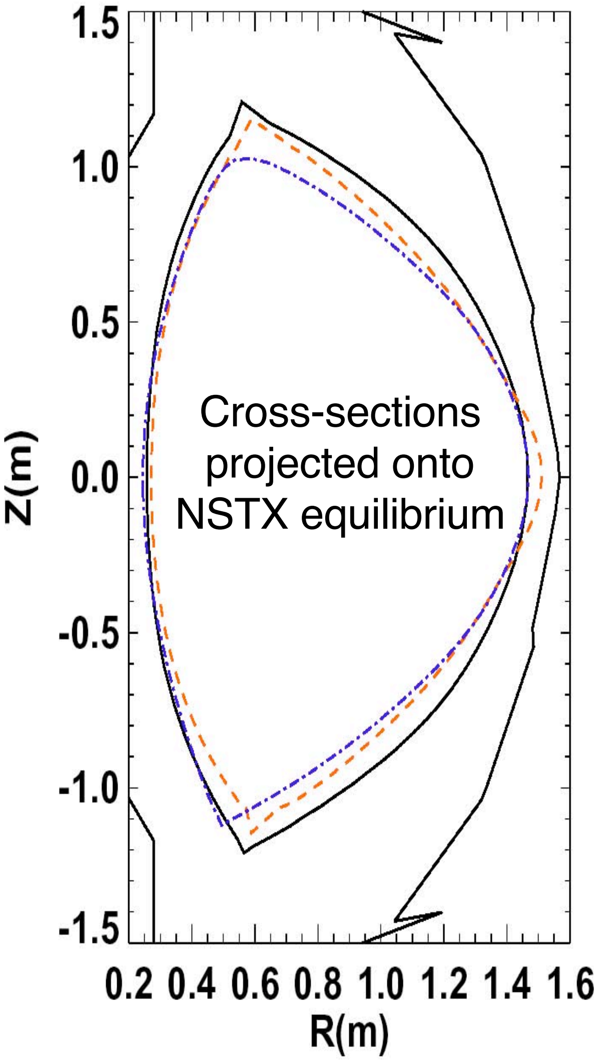
Lower single-null divertor discharges, 0.45T; D_2 gas fueled, ~3.5mg per shot

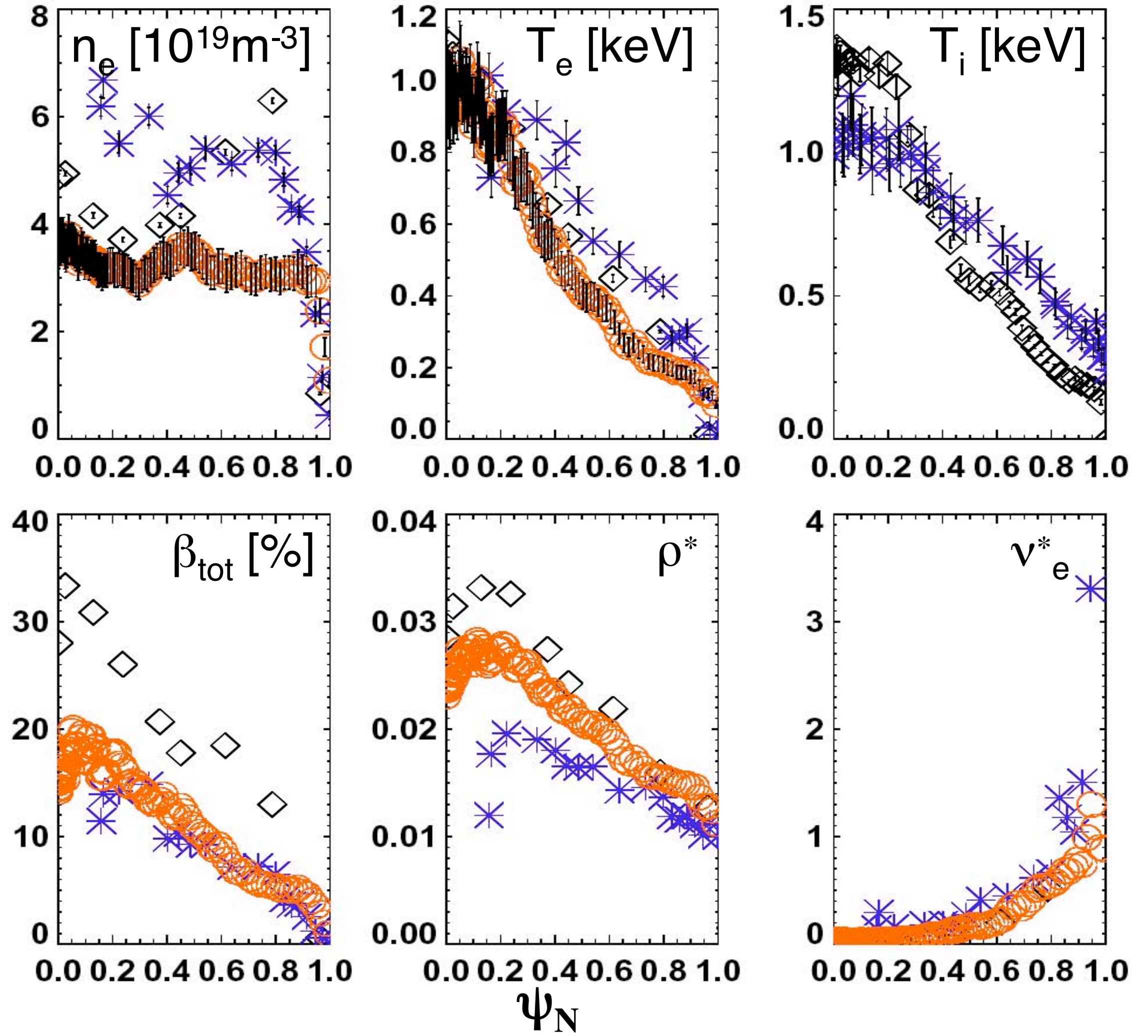


- Density after end of gas puff reduced by factor >2 after lithium coating
  - Rate of density rise below NB fueling rate after initial rapid pumpout
  - Density profile peaked in *both* pre- and post- lithium cases
- Slight effect apparent on second similar shot but absent on third

Capability to Control Edge Density Will Enhance H-mode Pedestal Experiment with MAST, DIII-D

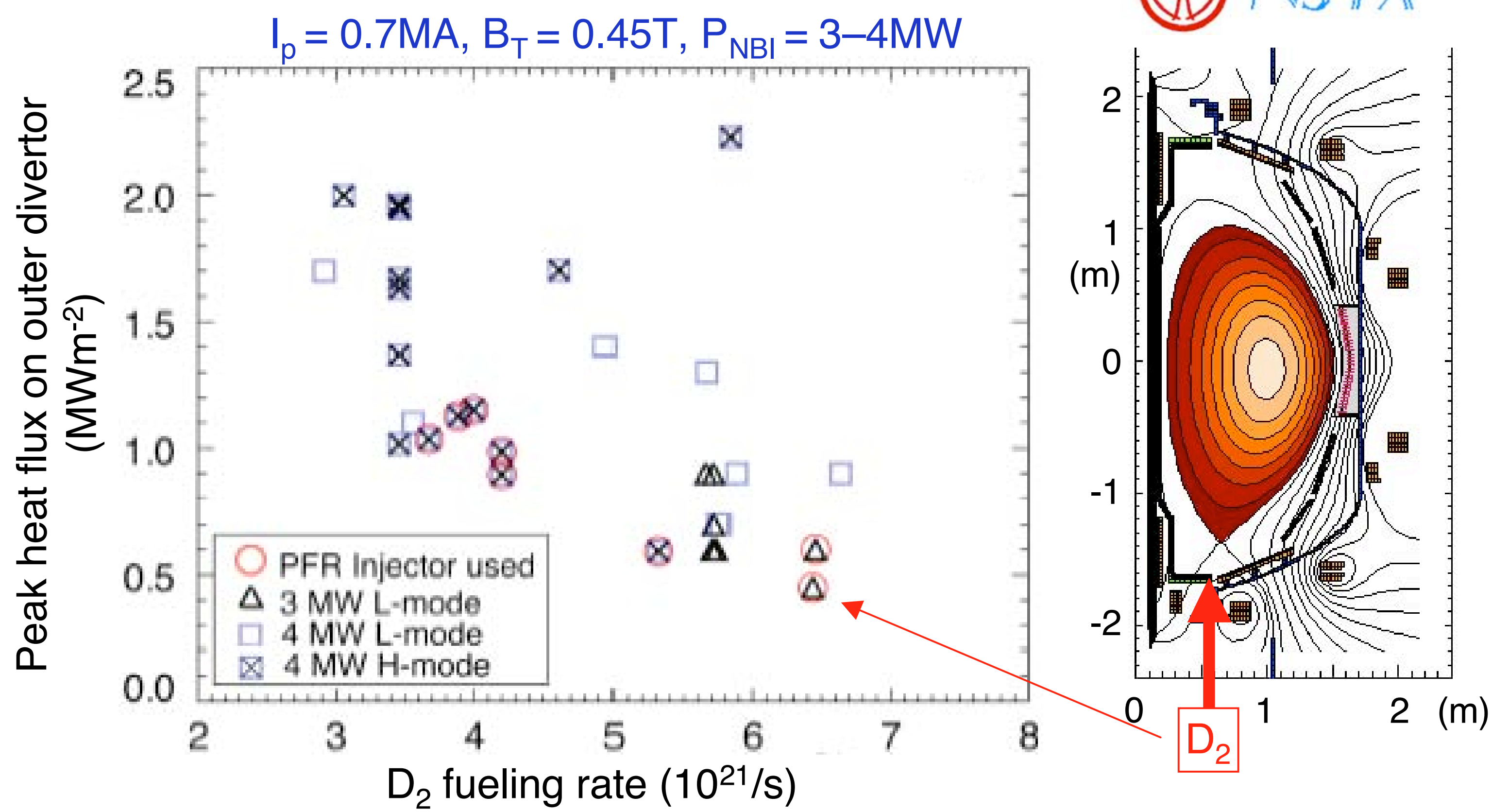
NSTX (117723@427ms) **DIII-D** (121516@1175ms) **MAST** (12899@270ms)





R. Maingi (ORNL), A. Kirk (MAST), T. Osborne (DIII-D)

Puffing Deuterium into Private Flux Region Reduces Outer Divertor Heat Flux by Factor 2–4



- No change in inner divertor heat flux - inner leg already detached
- Evidence for volume recombination from increase in D_γ/D_α ratio
  - Divertor radiation increases but not spatially resolved
- Outer divertor detachment *not* achieved by midplane injection of D_2 or Ne
  - Ne did reduce divertor heat flux by factor 4 by plasma and SOL radiation

Conditioning Plays Important Roles in Achieving NSTX Goals

- Control of impurities crucial for reliably achieving H-mode
  - Broad profiles of H-mode benefit quest for higher β *but*
  - ELM behavior is important to controlling impurities and density
- Boronization has provided a reliable method of reducing impurities and gaining access to the H-mode
  - Boronization on hot surfaces provides some initial benefits but not sustained relative to room-temperature application
- Helium discharge cleaning to control deuterium recycling can be supplemented by OH helium discharges between NBI shots
  - Achieved significant extension of pulse-length at moderate current
  - Continued density rise in H-mode plasmas may limit further progress
- Demonstrated recycling control with lithium coating in both limiter *and divertor* plasmas
- Enabling contributions to physics of H-mode, ELMs, pedestal, confinement

Status and Plans

- Building lithium evaporator for coating areas of divertor and wall
  - Draw on experience in LTX (former CDX-U) and with LPI in NSTX
  - Evaporator will be insertable between shots or run-days
  - Deposit lithium on most of the divertor area
- Preparing for installation during current outage which will last until December
  - Plan to be ready for lithium evaporator experiments in 2006 run
- NSTX 2005 Results Review and Research Forum for planning experiments in 2006 will take place December 12 – 16
  - Participation by our collaborators is encouraged
  - Length of 2006 experimental run is not yet known