Research Supported by

H-mode Access and ELMs in NSTX

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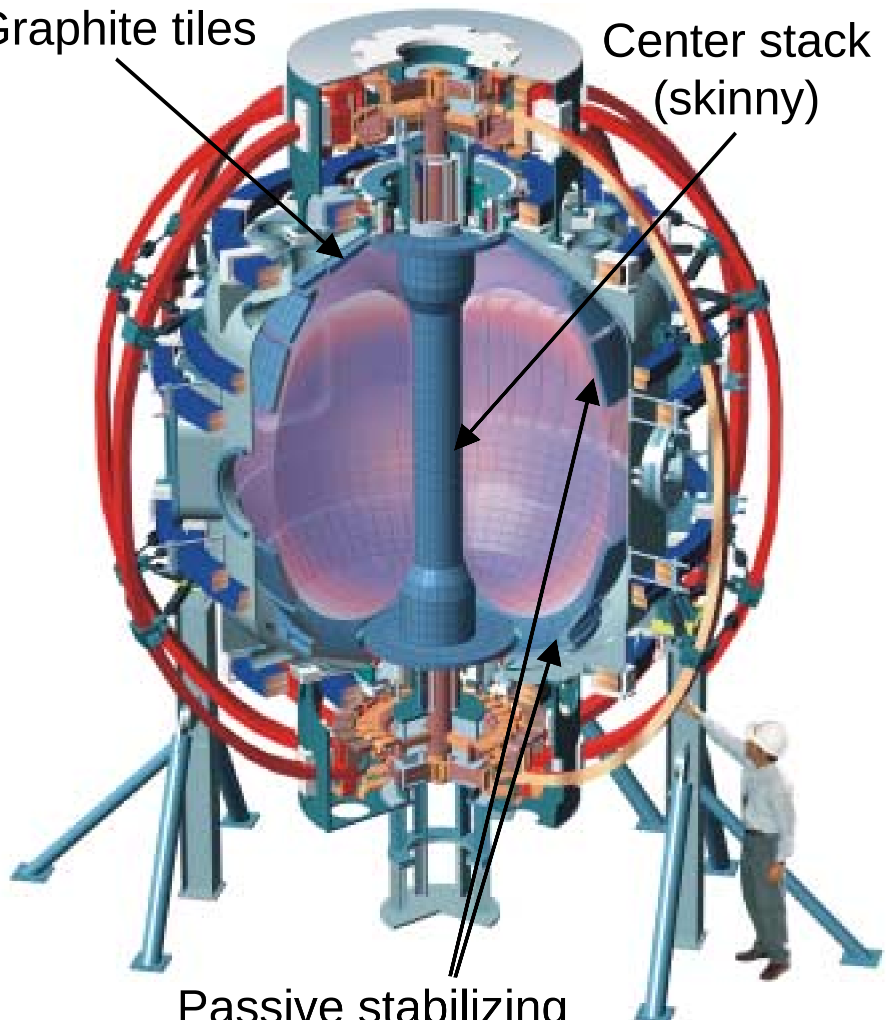
8th Annual ST Workshop

Princeton, NJ, Nov. 18-21, 2002

NSTX H-modes Similar to Conventional Aspect Ratio Tokamaks, with a few Notable Exceptions

- Now have wide H-mode access space
  - Changes in wall conditioning and fueling
- Long pulse, high-β_T with H-mode
- Power threshold relatively high
  - Possible I_p dependence
- Edge fluctuations
- Wide variety of ELM behavior

NSTX Explores Low Aspect Ratio (R/a≥1.27) Physics Regime

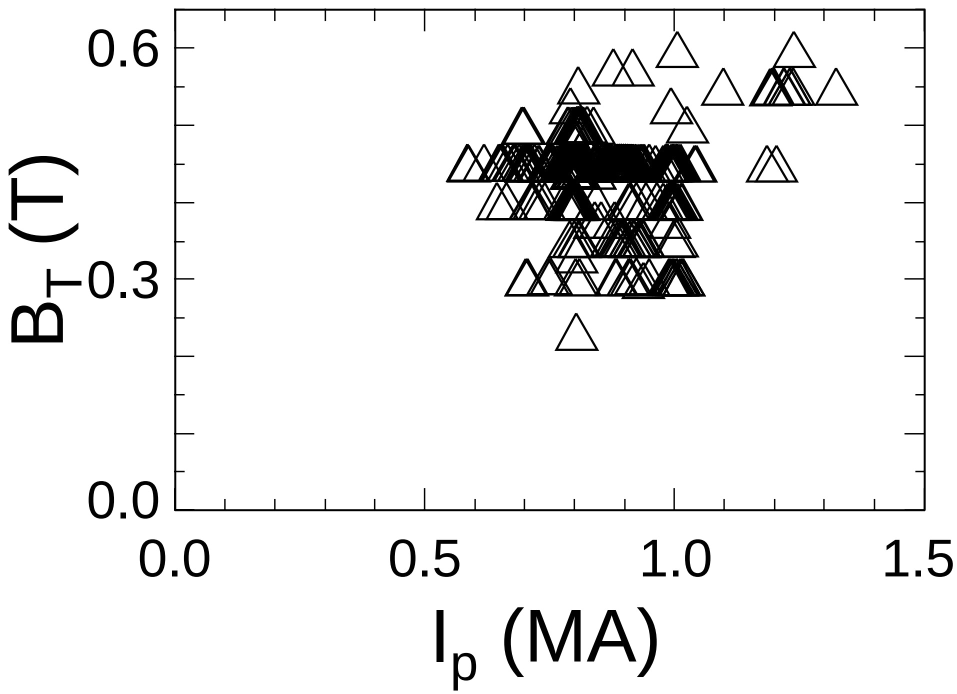


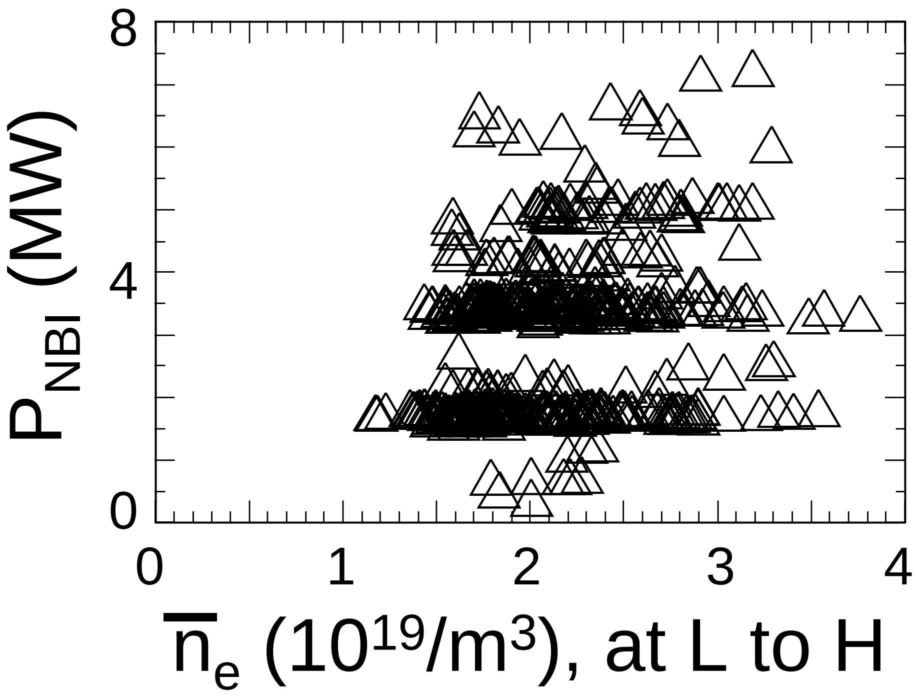
Enabling Capabilities:

- **350° C bake out of graphite tiles**
- **Regular boronization (~3 weeks)**
- **Helium Glow between discharges**
- **Center stack gas injection**
- **Error field reduction**

Parameters	**Achieved**
Major Radius	**0.85m**
Minor Radius	**0.67m**
Plasma Current	**1.5MA**
Toroidal Field	**0.6T**
Heating and Current Drive	
NBI (100keV)	**7 MW**
RF (30MHz)	**6 MW**

The NSTX H-mode Access Space is Wide





- β_T up to 35% and β_p up to 1.4
- H-mode phase duration > 500 ms (with NBI)
- Lower Single Null (LSN) & Double Null (DN) Divertor Configuration.

Outline

- Now have wide H-mode access space

$\Rightarrow$ Long pulse, high β_T with H-mode

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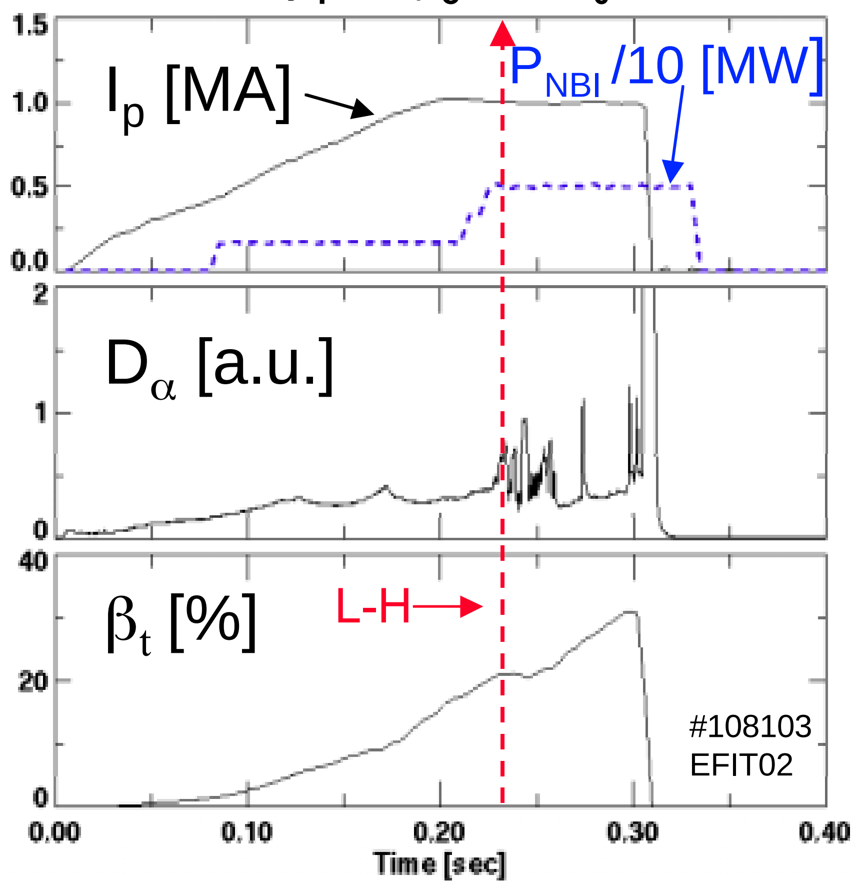
High β Achieved with H-mode Operation

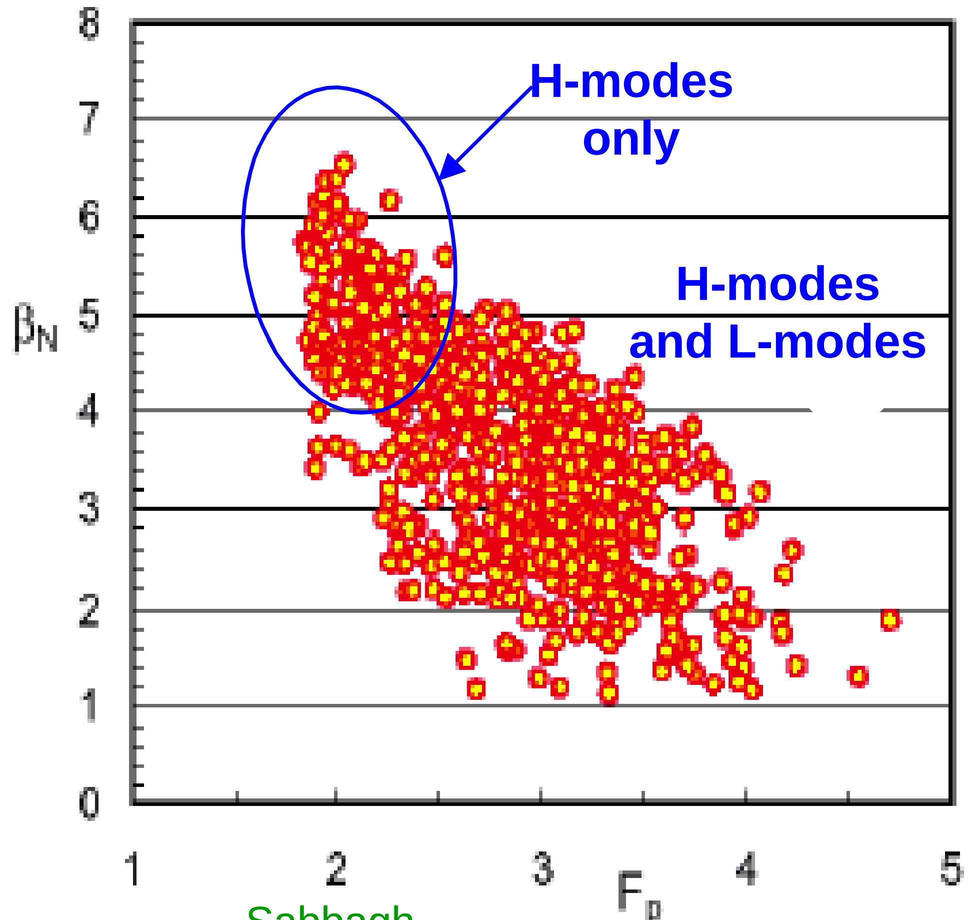
- Plasmas are more stable with broad pressure profiles

β_T = 31.5%
β_N^{max} ~ 6.2

$F_p \equiv p_e(0)/\langle p_e \rangle$

$\beta_T = 2\mu_o\langle p\rangle/B_0^2$



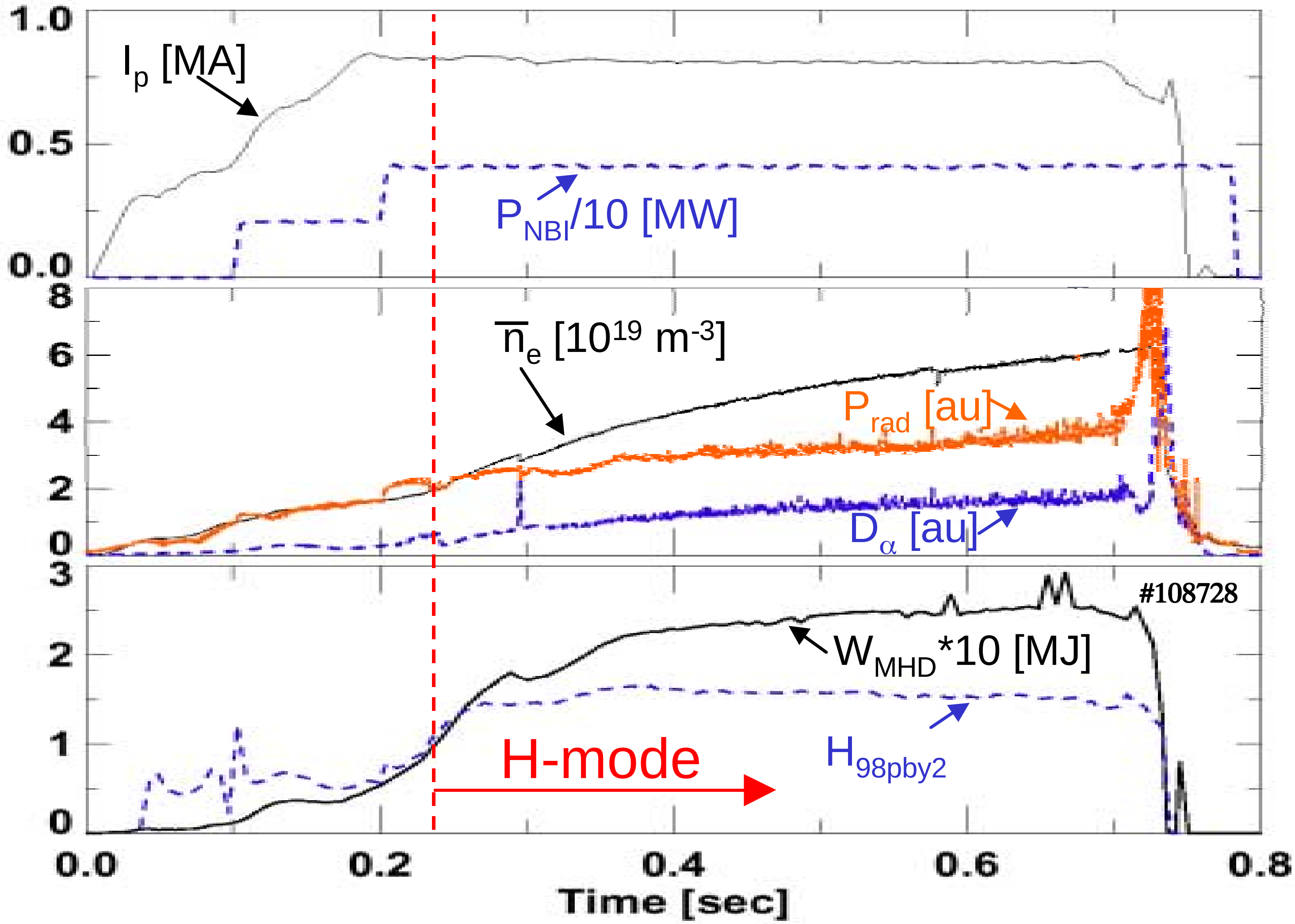


Sabbagh

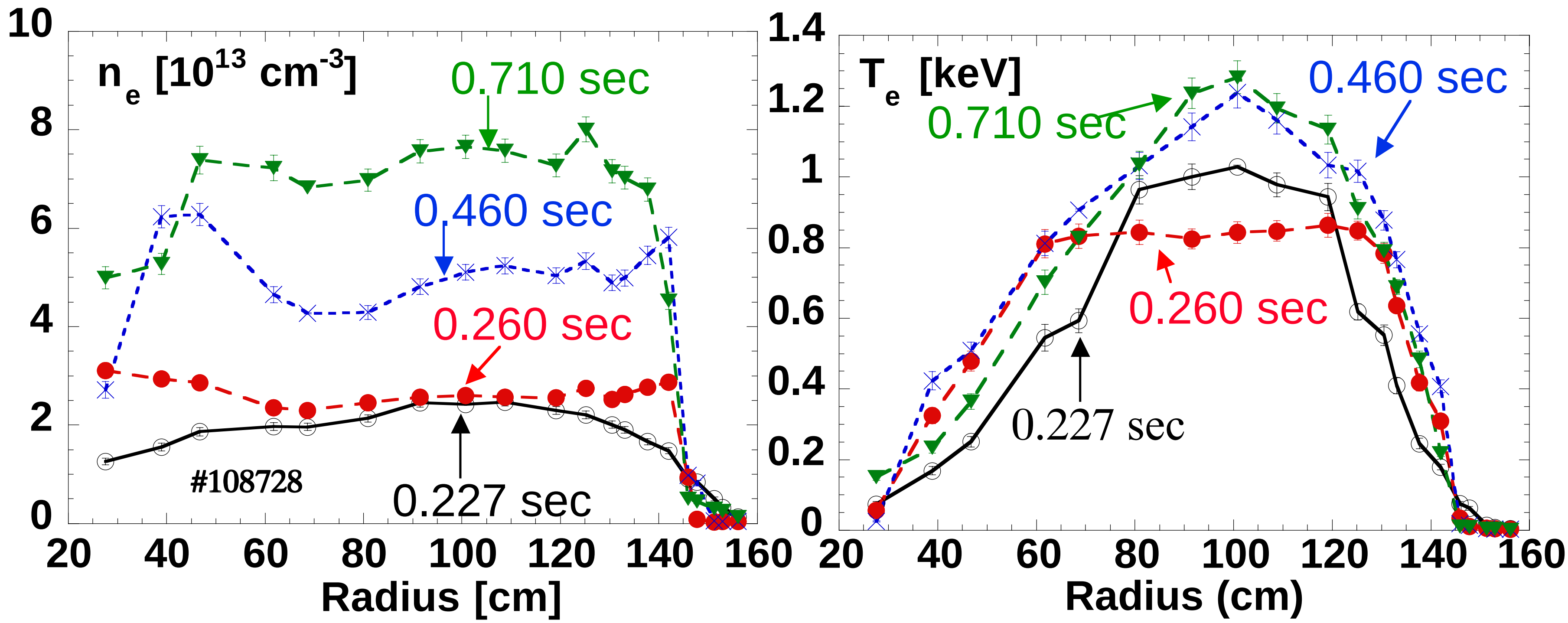
C.Bush, APS2002

High Performance Sustained During Long-Pulse H-modes

- H-mode duration ~ 500 ms, W_{MHD} ~ 250 kJ, H_{98pby2} = 1.5



n_e and T_e Profiles Evolve Differently During Long H-mode

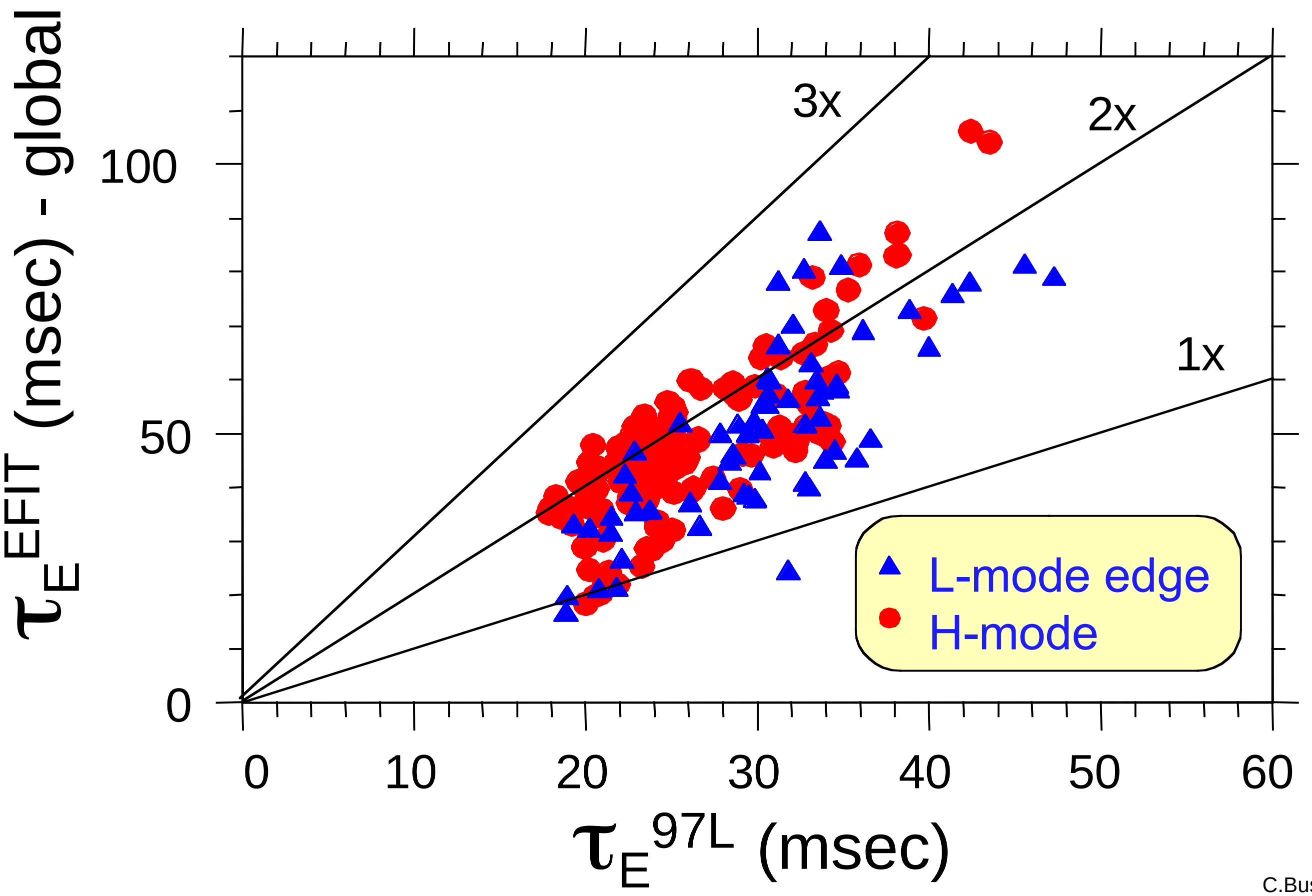


- n_e profile hollow after transition and fills in 300-500 ms
- T_e profile flattens initially and peaks later in time

LeBlanc

Confinement Enhanced Over Values Given by Conventional Aspect Ratio Scalings

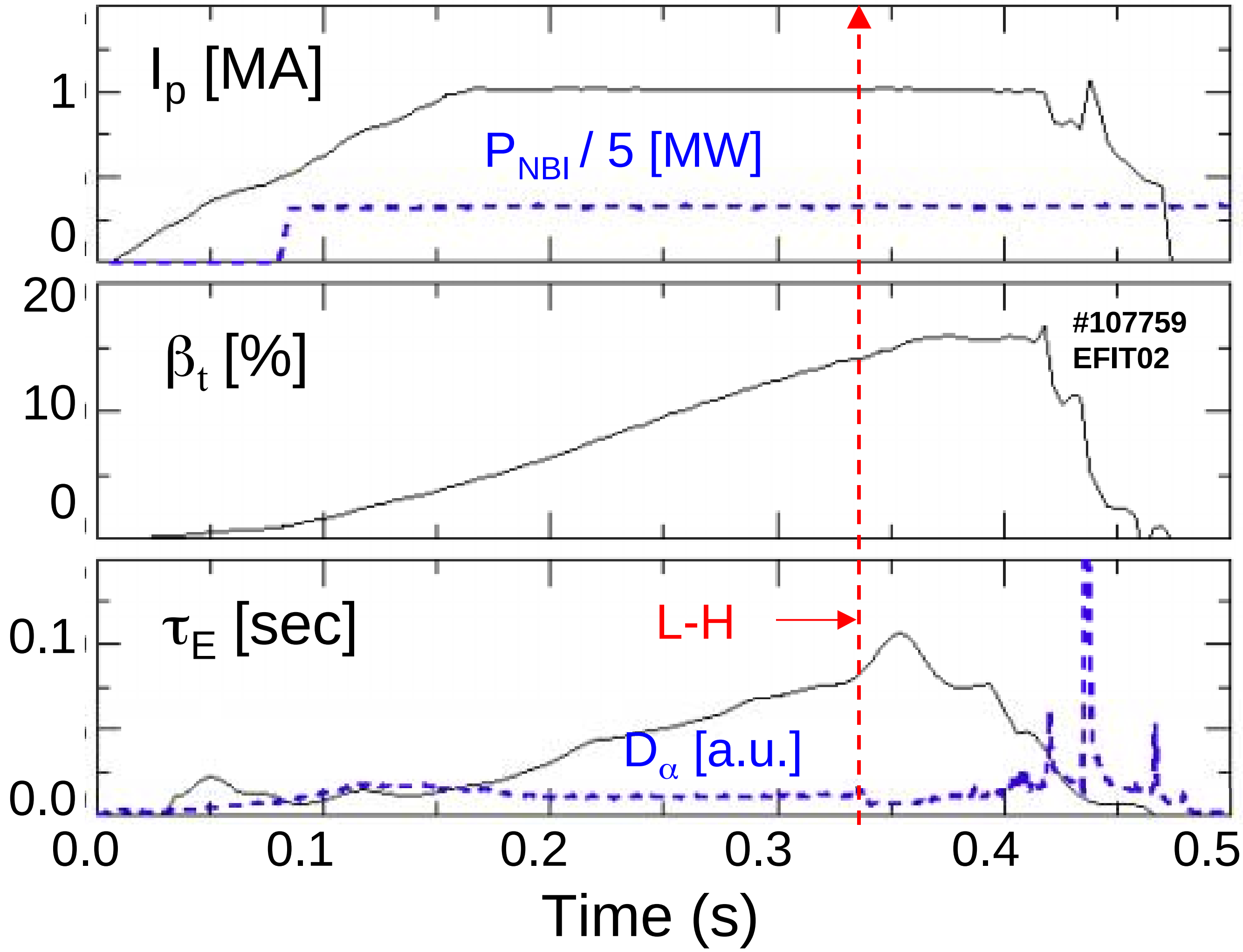
- $1 \leq \tau_E^{NSTX} / \tau_E^{97L} \leq 2.5$
- Values are quasi steady state



S. Kaye

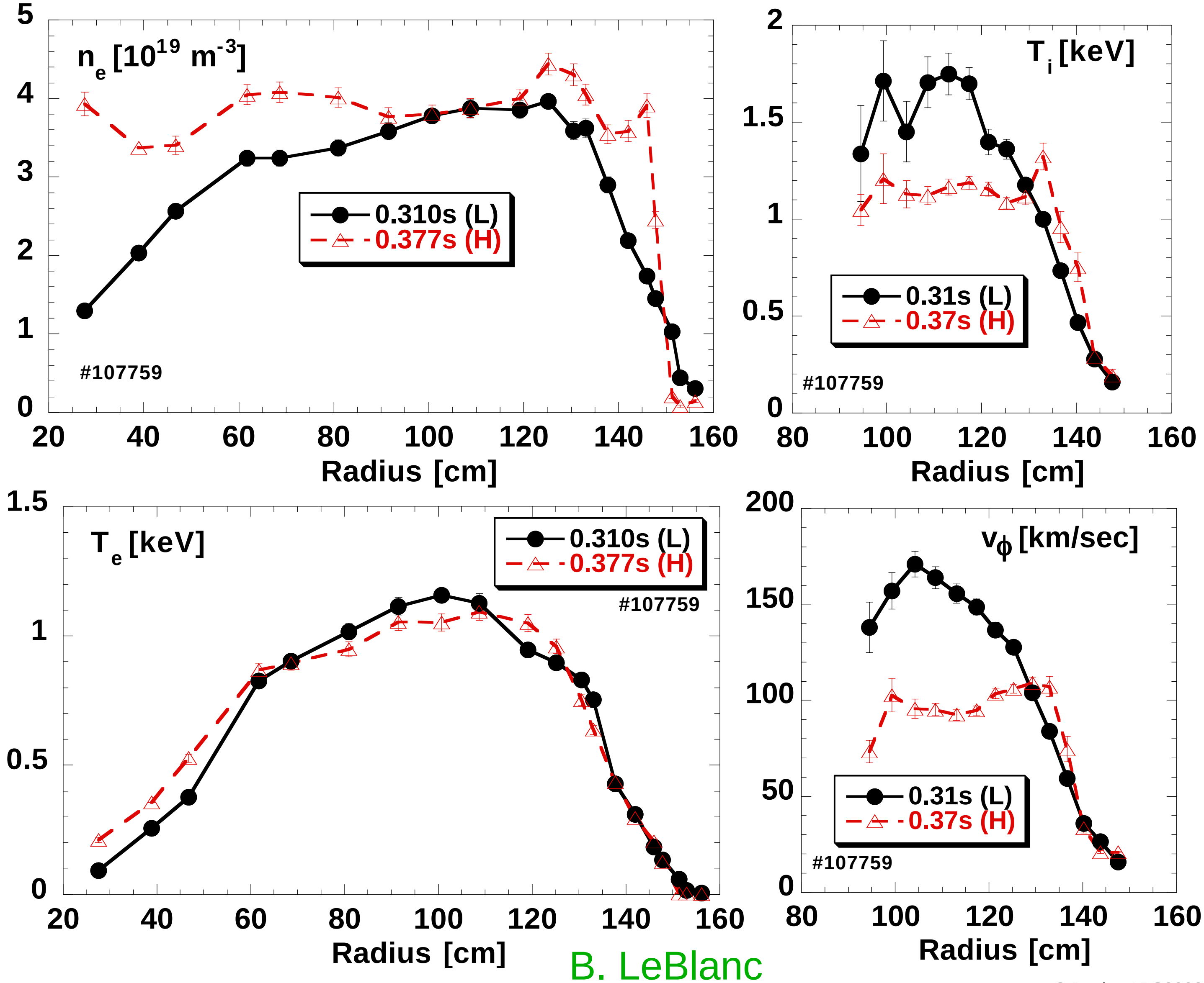
Confinement Gain in Steady-state After the H-mode Transition is Often Modest

- Gain in going from high performance L-mode to H-mode is modest



Sabbagh

Profile Comparisons: L-mode/H-mode



B. LeBlanc

R. Bell

Outline

- Now have wide H-mode access space
- Long pulse, high β_T with H-mode

$\Longrightarrow$ Power threshold relatively high

  – Possible I_p dependence

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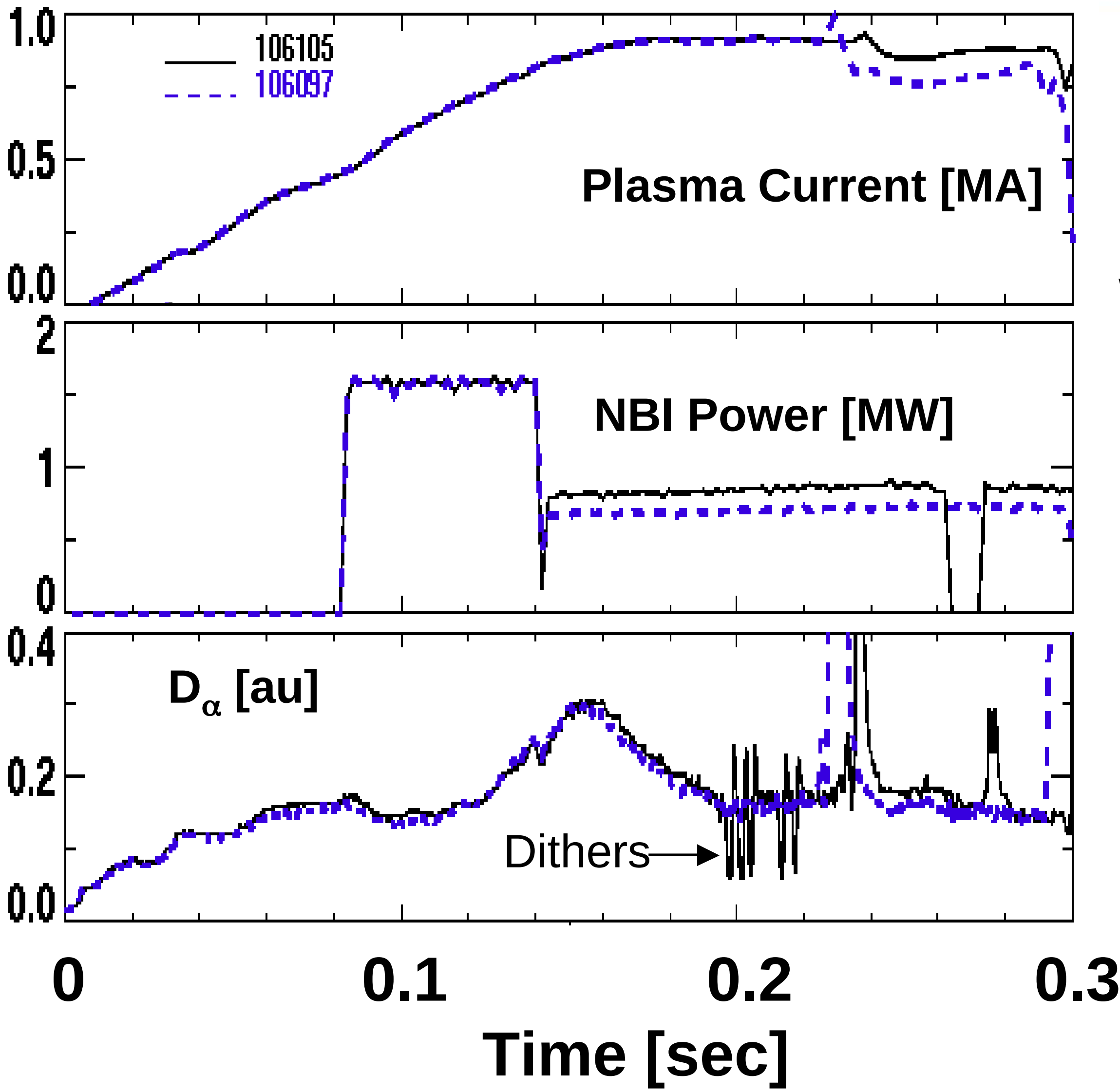
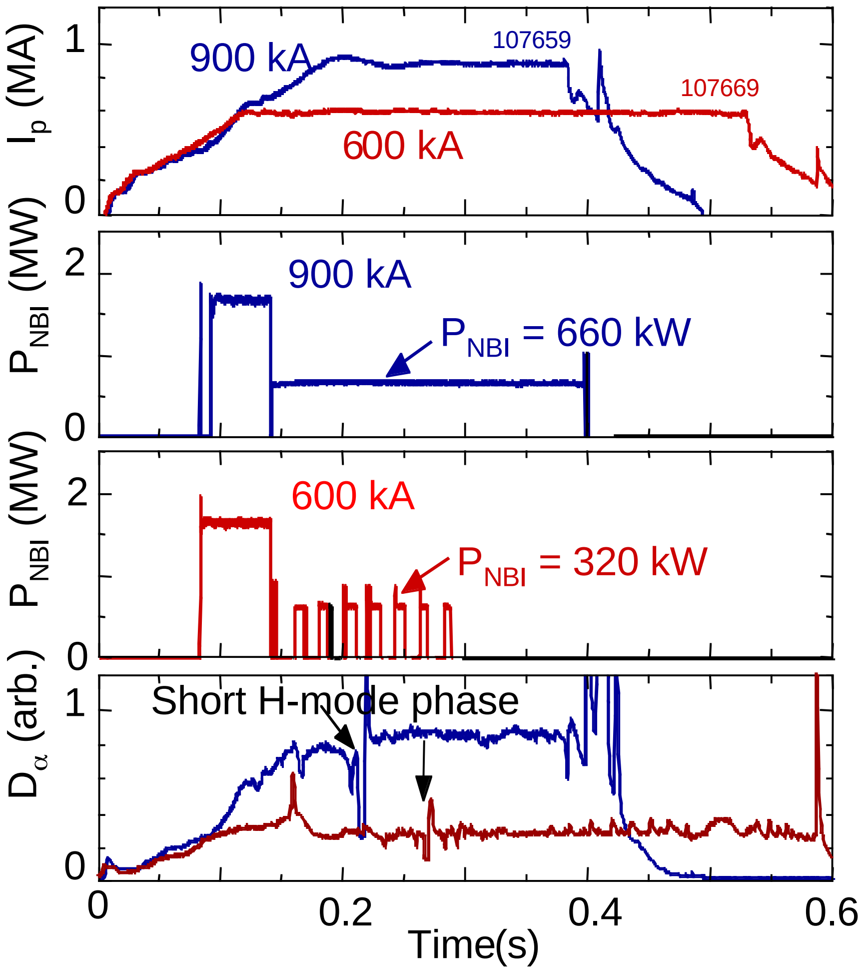
L-H Power Threshold Found by Reducing NBI Power Until Very Short H-phase or Dithers Occur



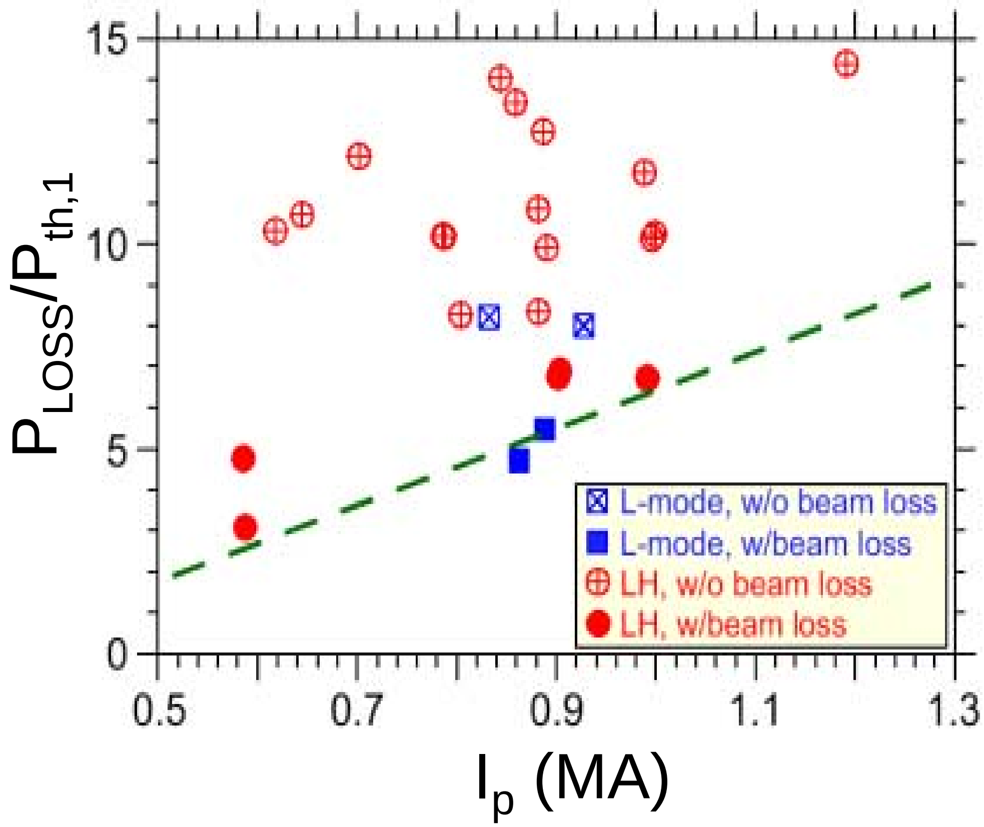
- NBI power reduced with beam voltage; even lower power using beam modulation
- Dithers observed with $P_{NBI} \geq P_{th}$
- ELM-free discharges when $P_{NBI} >> P_{th}$

C.Bush, APS2002

Power Threshold Experiments Show Possible I_p Dependence



- 600 kA: P_{LOSS} = 0.63 MW (P_{FLOSS} = 0.10 MW)
- 900 kA: P_{LOSS} = 1.40 MW (P_{FLOSS} = 0.11 MW)



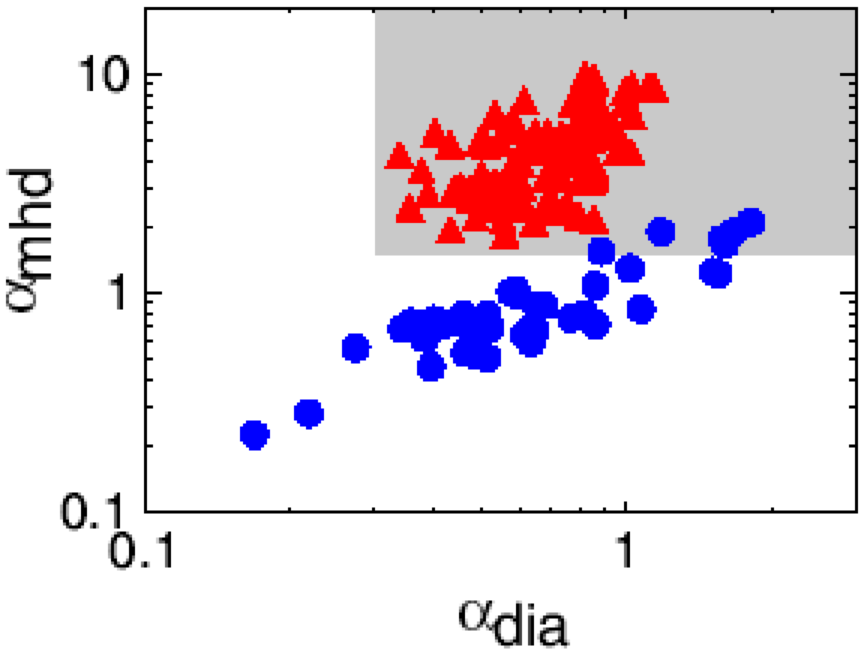
- $P_{LOSS} = P_{OH} + P_{NBI} - dW_{plasma}/dt - P_{FLOSS}$
- $P_{th,1} \sim n_e^{0.61} B_T^{0.78} a^{0.89} R^{0.94}$ (Snipes et al., IAEA 2002)

Comparisons with L/H Transition Theories

NSTX

Drift-Ballooning
Rogers and Drake,
PRL, 1998

● L-mode ▲ H-mode



$\alpha_{mhd} = -Rq^2 d\beta/dr$

$\alpha_{dia} = (\rho_s \Omega_e / \nu_{ei})^{1/2} / (L_n R)^{1/4} q$

- Qualitative agreement with theory
  - -L and H-mode groups distinct
    - -Decreased L_n, increased β in H-mode

Kaye

- Similar results for Peeling and Drift-Alfven mode theories

ornl

Outline

- Wide H-mode access space
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- Power threshold
  - Possible Ip dependence

$\Rightarrow$ Edge fluctuations

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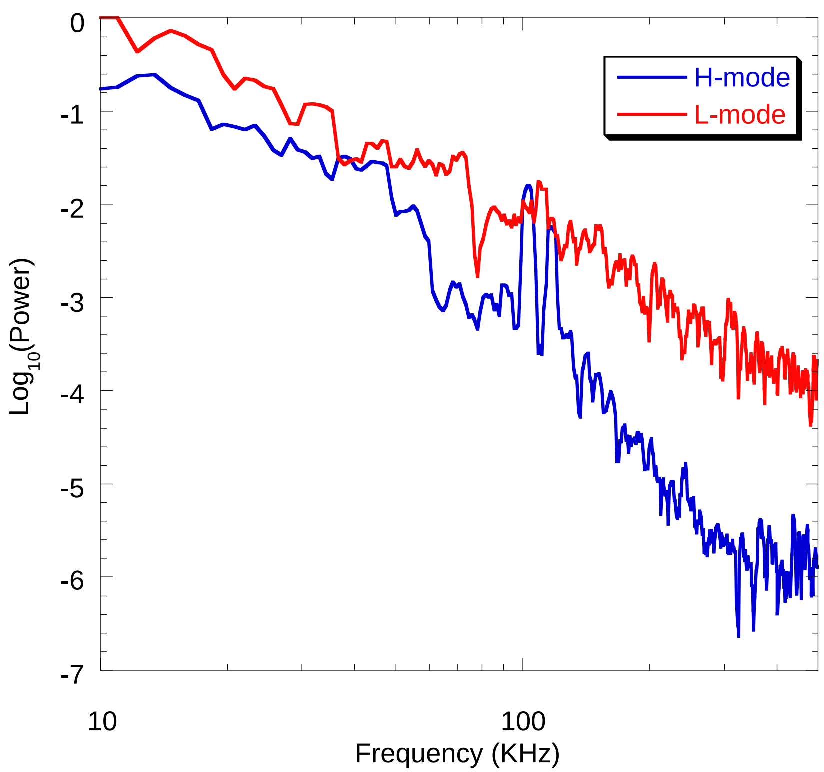
Scrape-off Layer Turbulence is Reduced During H-mode

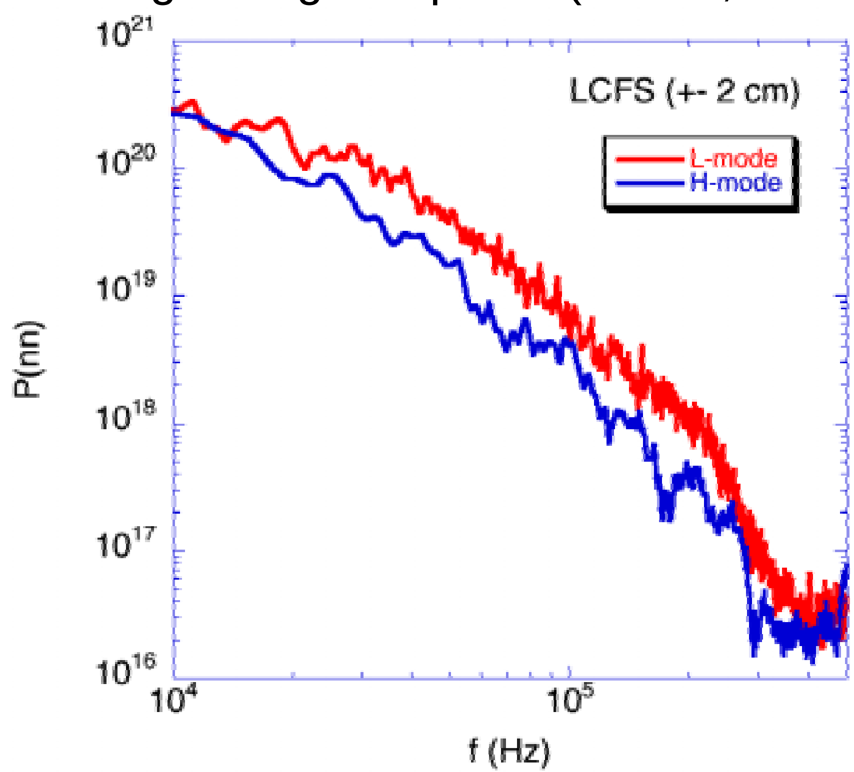
In SOL where $T_e \leq 20$ eV, $n_e < 3 \times 10^{12}$ cm^{-3}:

- Density fluctuations reduced during H-mode
- Frequency spectrum broader in L-mode

HHFW reflectometer (Wilgen, Swain, ORNL)

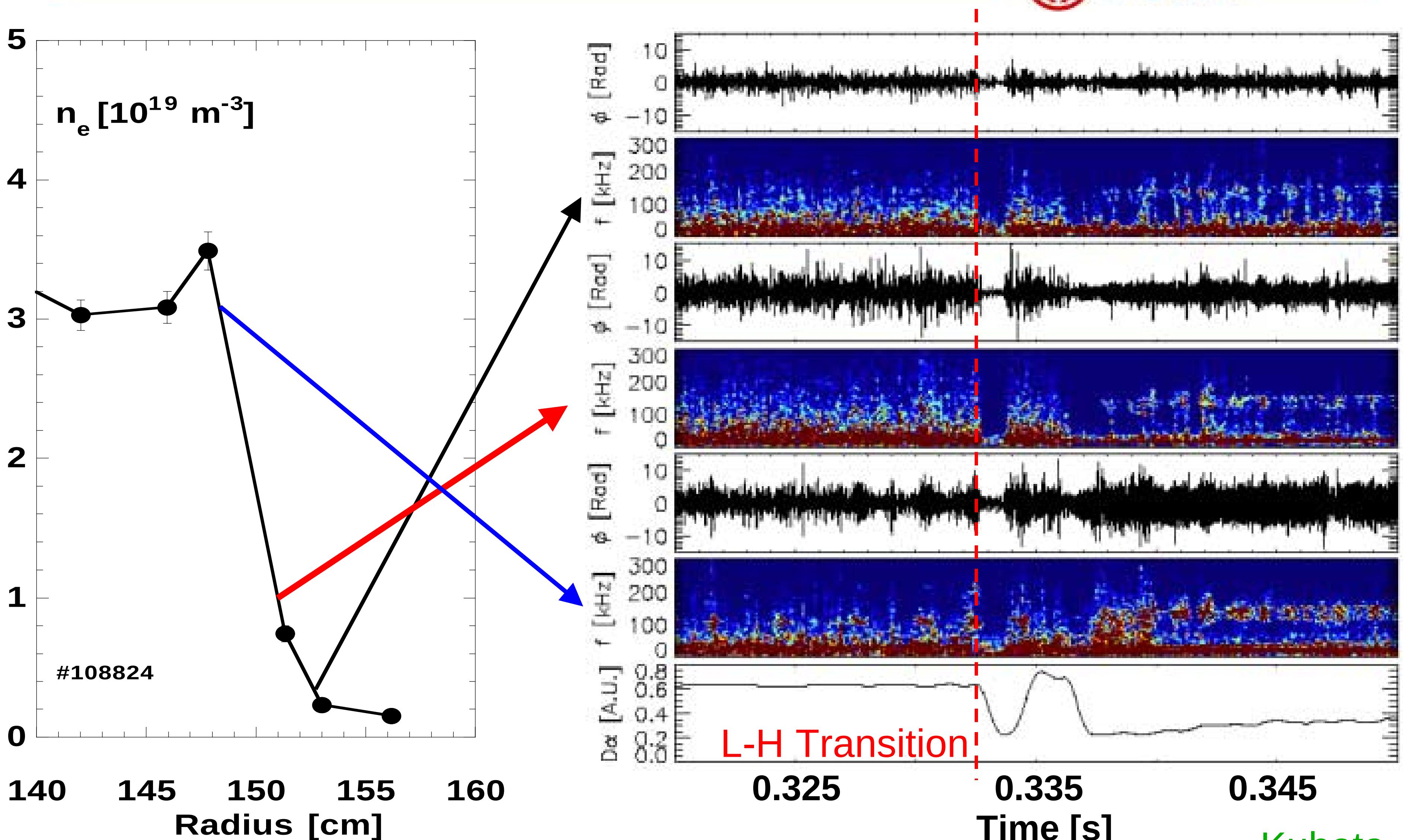


Edge Langmuir probe (Boedo, UCSD)



C.Bush, APS2002

Fluctuation Amplitude Reduced in Steep Density Gradient Region



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Kubota

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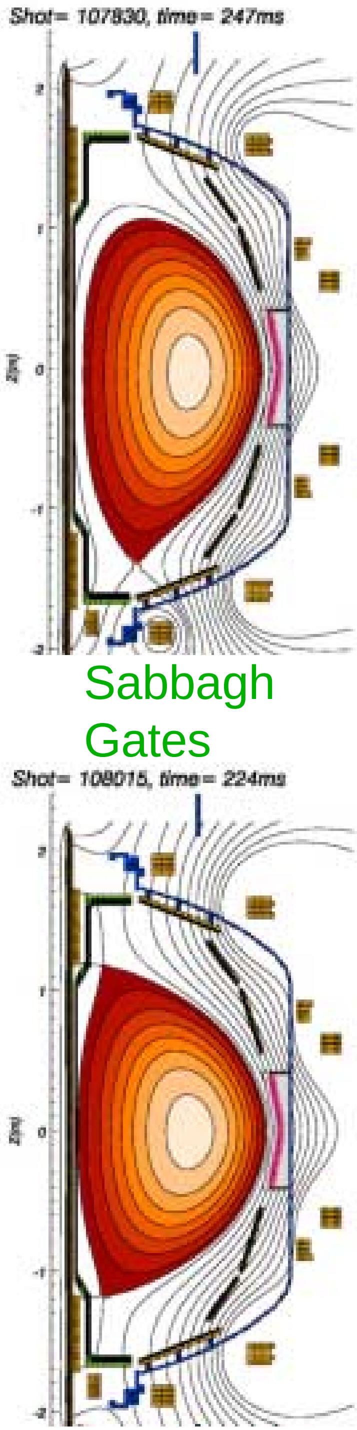
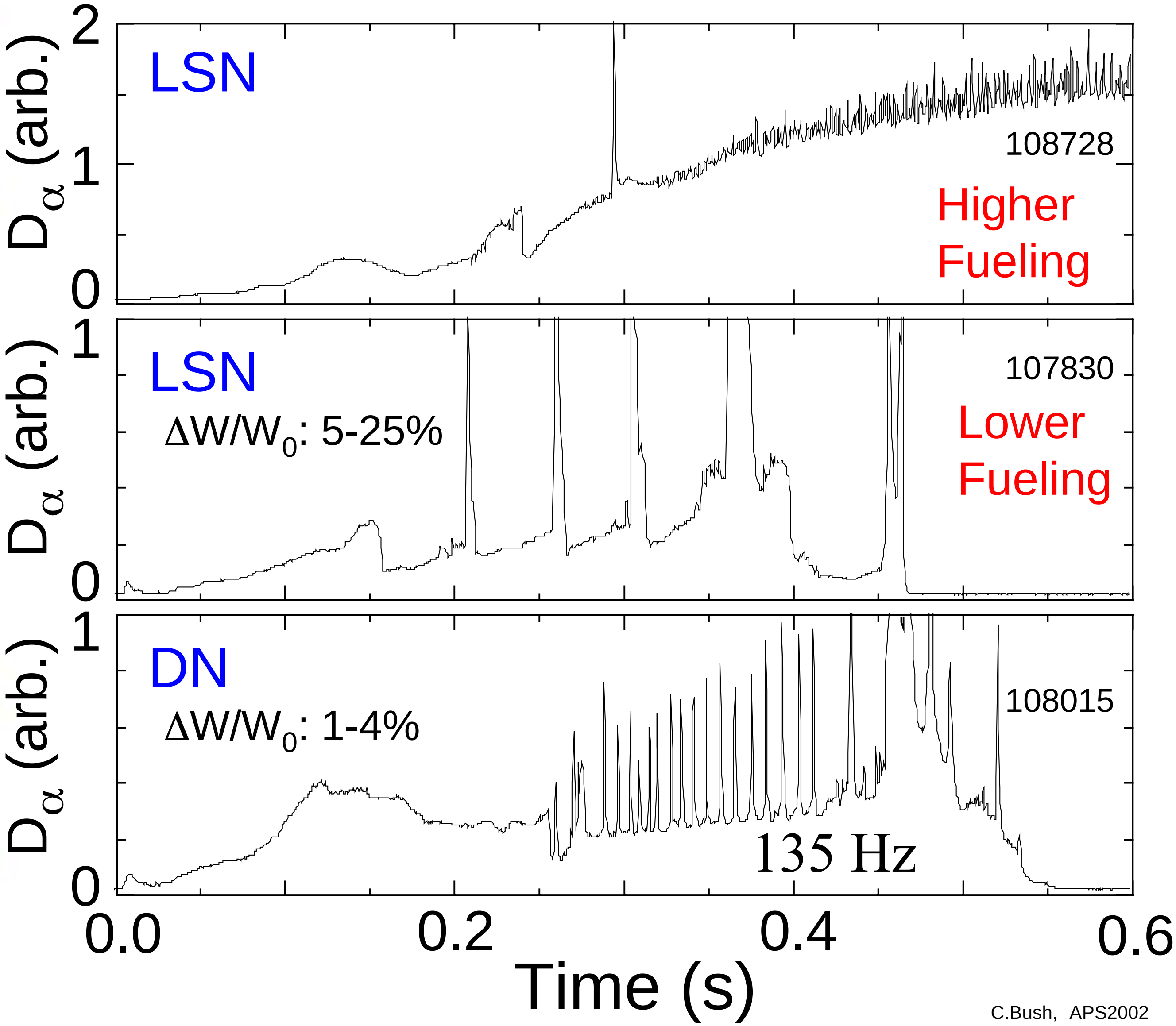
ELM Behavior Depends on Operating Conditions





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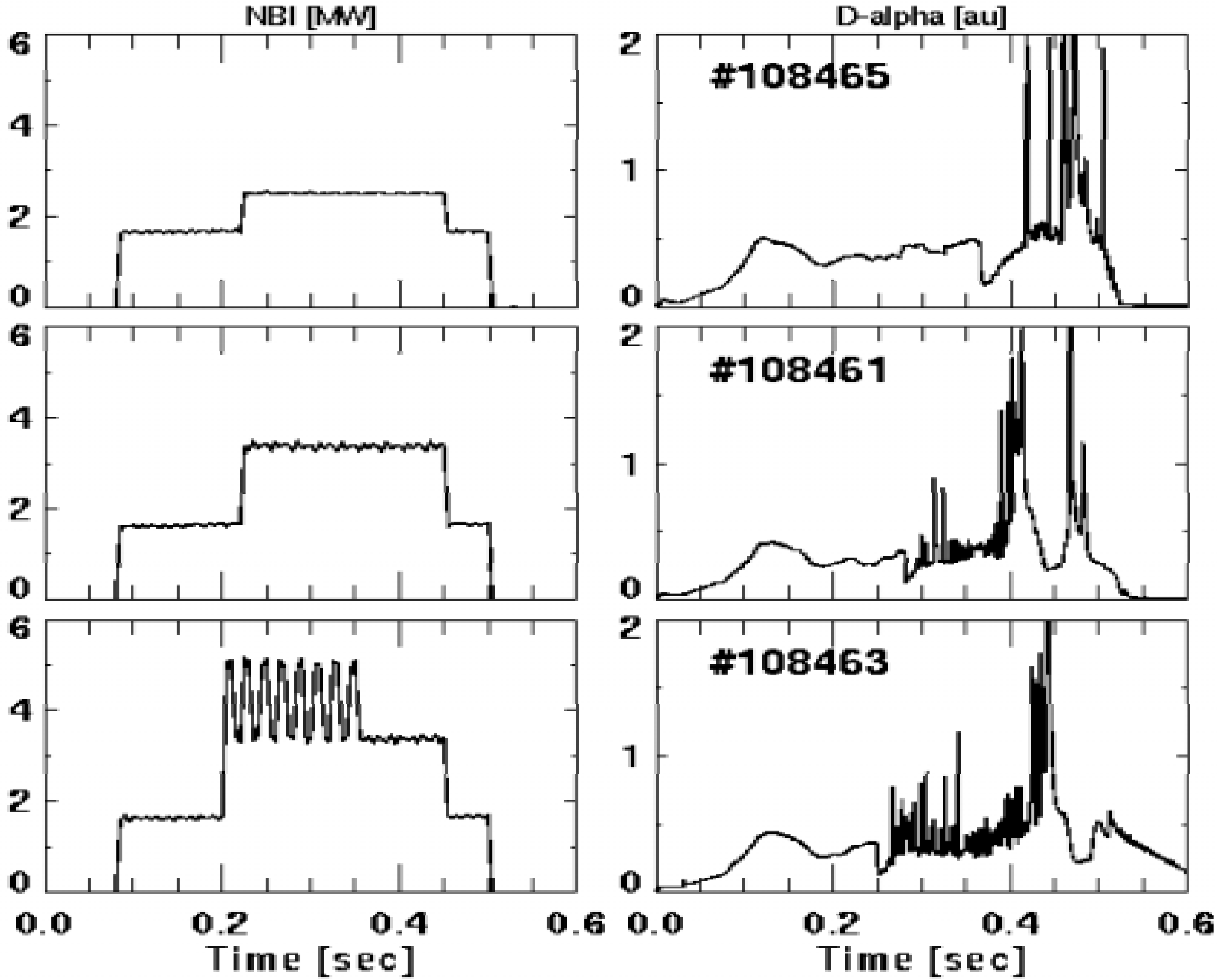
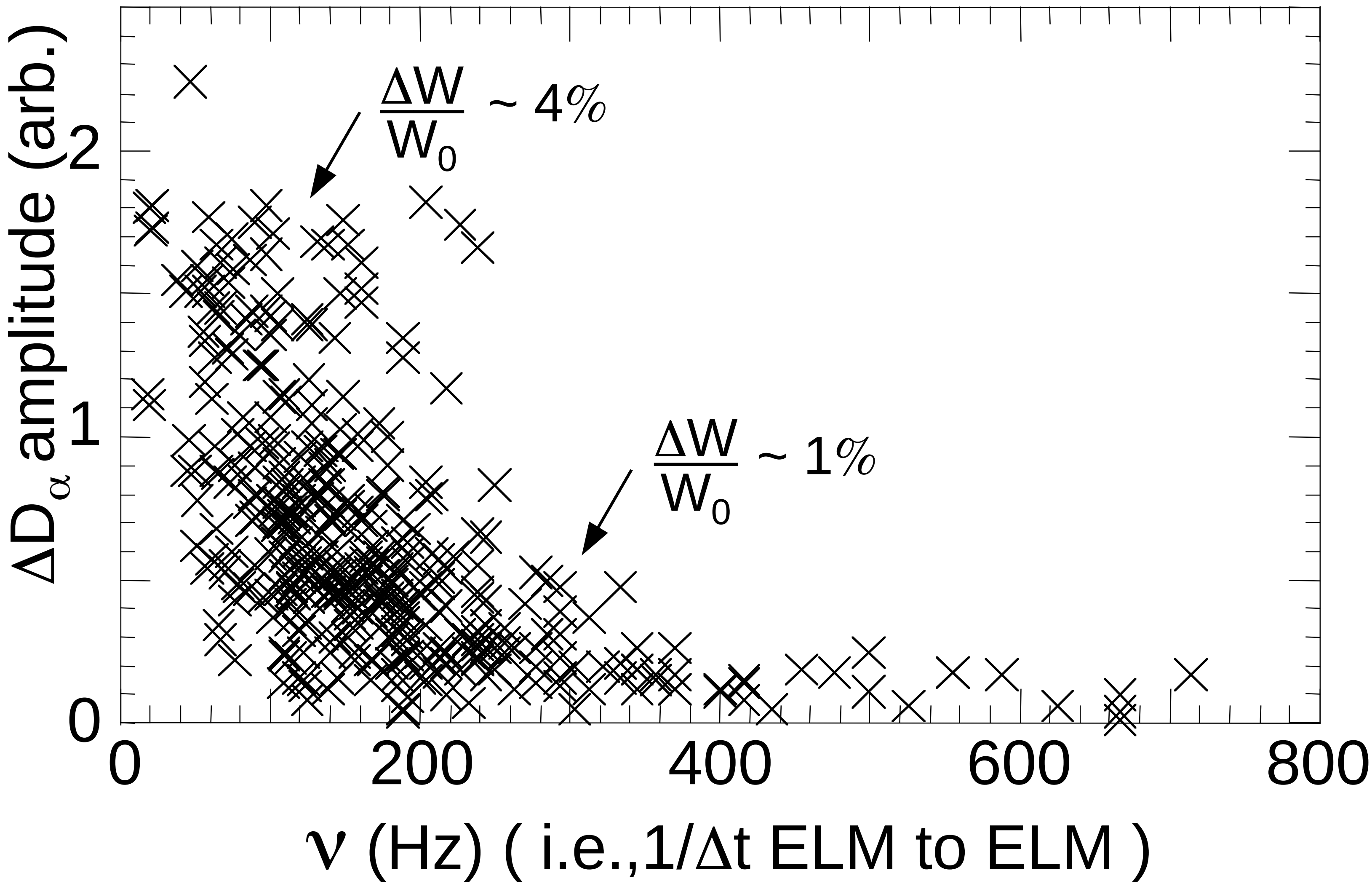
Dependence of L-H Transition and ELM Behavior on Heating Power

- L-H transition earlier in time as P_{NBI} is increased
- ELM frequency increase as P_{NBI} increases

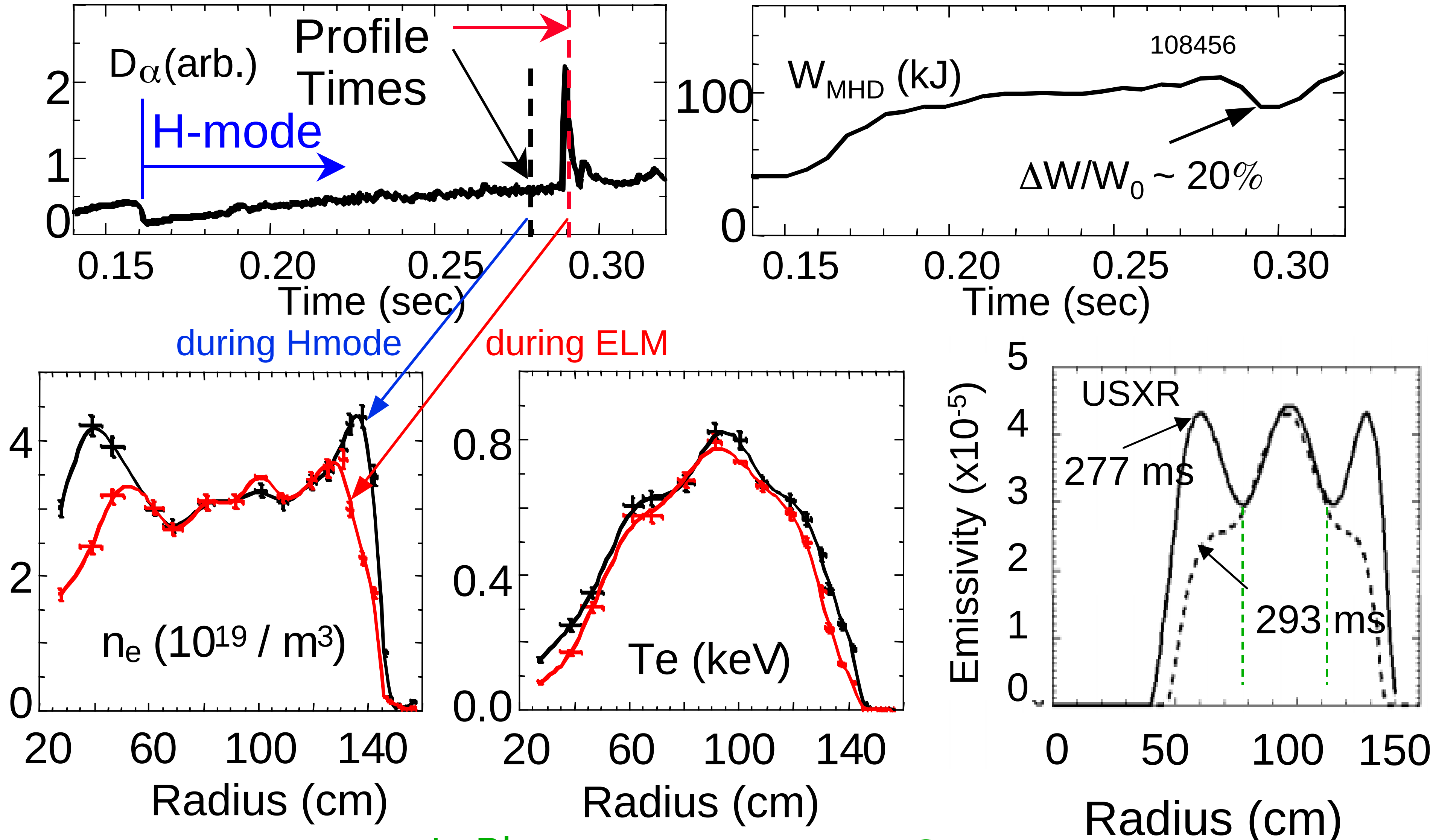


ELM Amplitude Usually Decreases with Increasing Frequency in NSTX: Type I ELMs?



Large ELMs penetrate deep into the plasma

NSTX



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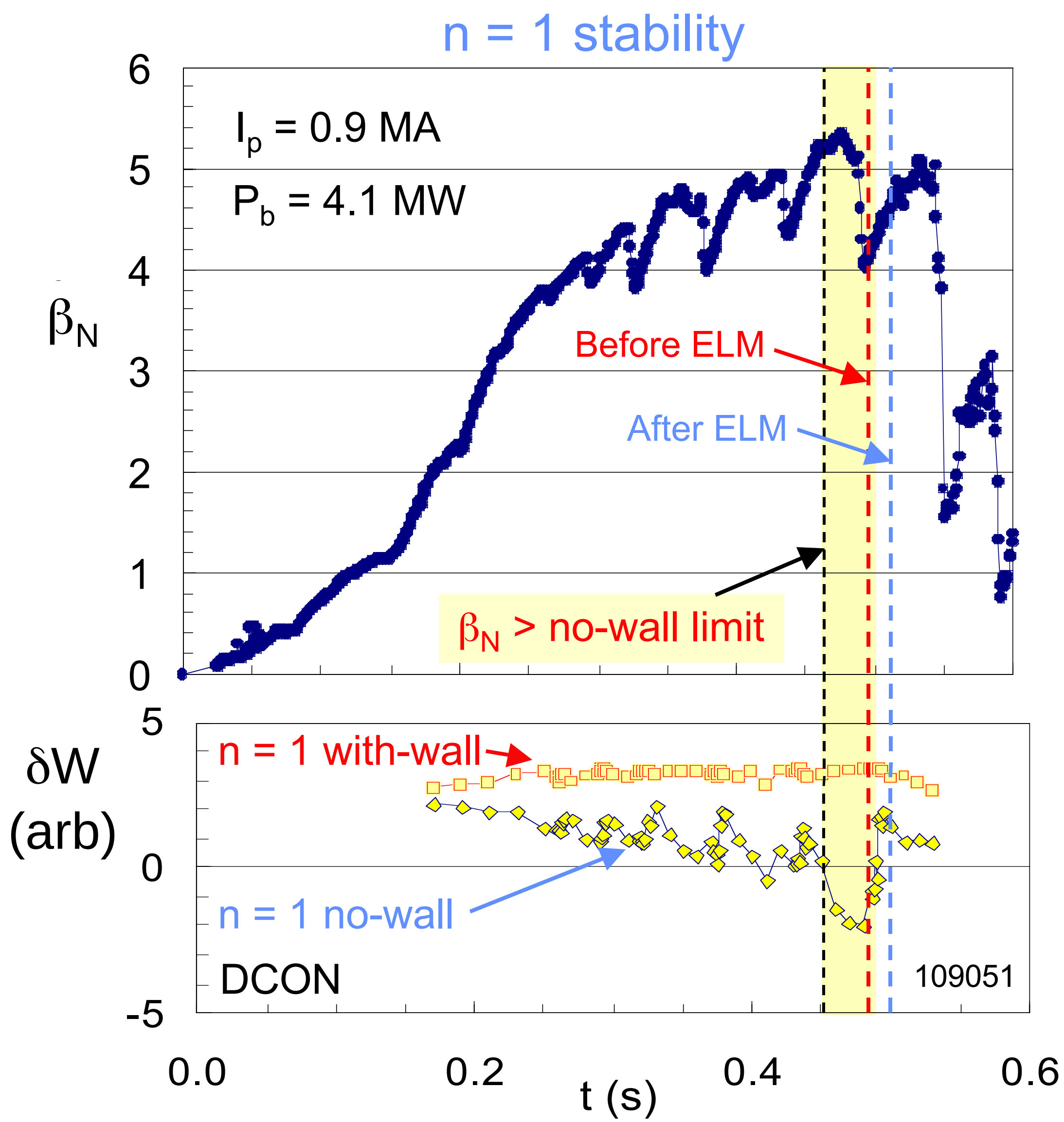
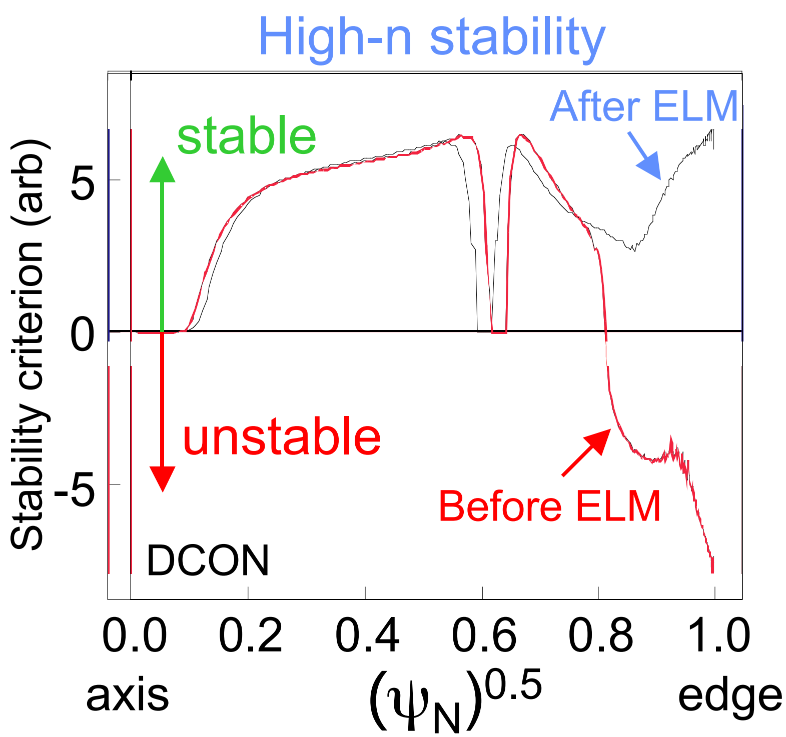
Ideal High-*n* Ballooning Unstable before giant ELM





- Computed as high-n stable after ELM
- n = 1 stabilized by wall
  - No-wall β_N limit exceeded before last ELM

S.A. Sabbagh, A.H. Glasser

NSTX H-modes Similar to Conventional Aspect Ratio Tokamaks, with Some Notable Exceptions

- H-modes allow reproducible high performance on NSTX
- Confinement is enhanced relative to conventional aspect ratio tokamak scalings
- H-mode power threshold higher than ITER scalings
  - Experimental data shows an I_p dependence
- Fluctuation levels lower in H-mode than in L-mode
- ELM characteristics depend on shape and fueling

END