

Research
Supported by



H-mode Access and ELMs in NSTX

Charles E. Bush

Oak Ridge National Laboratory

M.G. Bell 2), R.E. Bell 2), J. Boedo 3), W.M. Davis 2), E.D. Fredrickson 2), D.A. Gates 2), D.W. Johnson 2),
R. Kaita 2), S.M. Kaye 2), S. Kubota 4), H.W. Kugel 2), B.P. LeBlanc 2), R. Maingi 1), R.J. Maqueda 5),
D. Mastrovito 2), S. Medley 2), J.E. Menard 2), D. Mueller 2), M. Ono 2), F. Paoletti 6), S.J. Paul 2),
Y-K.M. Peng 1), P.G. Roney 2), A.L. Roquemore 2), S.A. Sabbagh 6), C.H. Skinner 2), V.A. Soukhanovskii 2),
D. Stutman 7), D. Swain, 1) E.J. Synakowski 2), G. Taylor 2), J. Wilgen 1), S.J. Zweben 2) *for the NSTX Team*

- 1) Oak Ridge National Laboratory
- 2) Princeton Plasma Physics Laboratory
- 3) University of California, San Diego
- 4) University of California at Los Angeles
- 5) Los Alamos National Laboratory
- 6) Columbia University
- 7) Johns Hopkins University

8th Annual ST Workshop
Princeton, NJ, Nov. 18-21, 2002

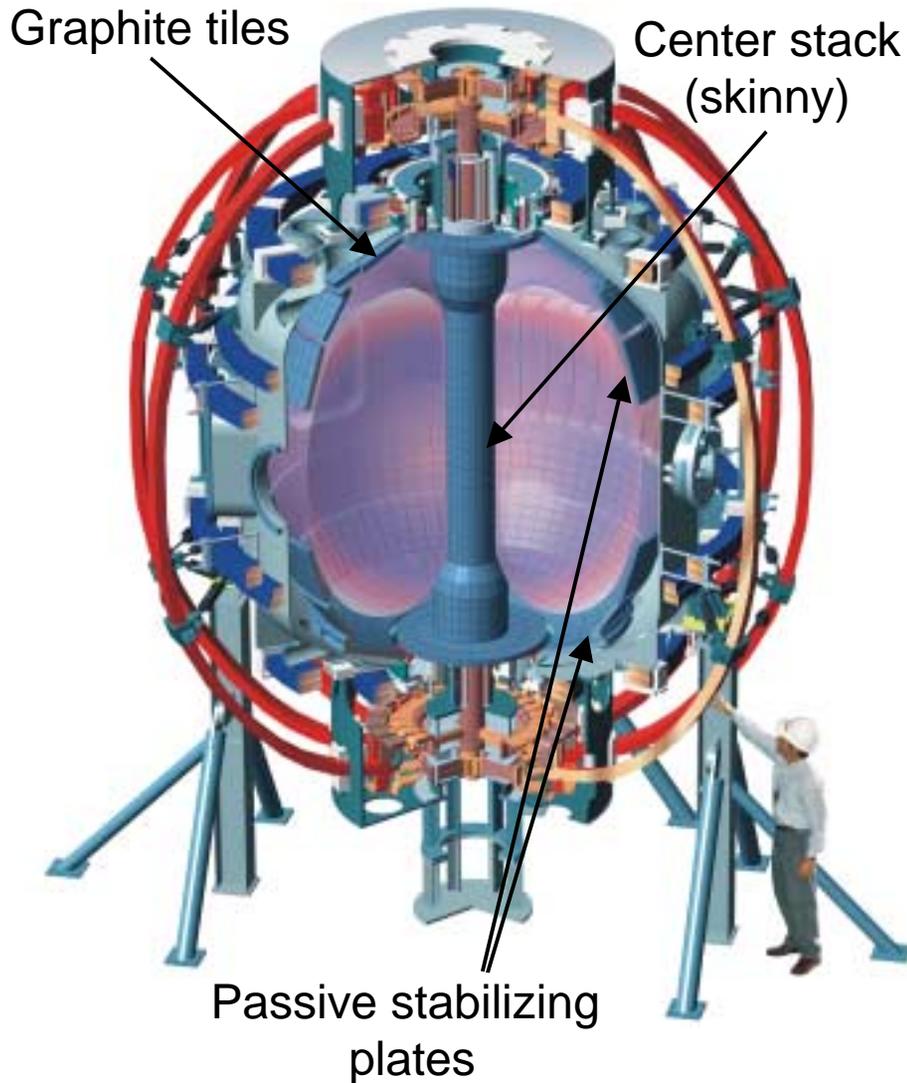


NSTX H-modes Similar to Conventional Aspect Ratio Tokamaks, with a few Notable Exceptions



- 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 ($R/a \geq 1.27$) Physics Regime



Enabling Capabilities:

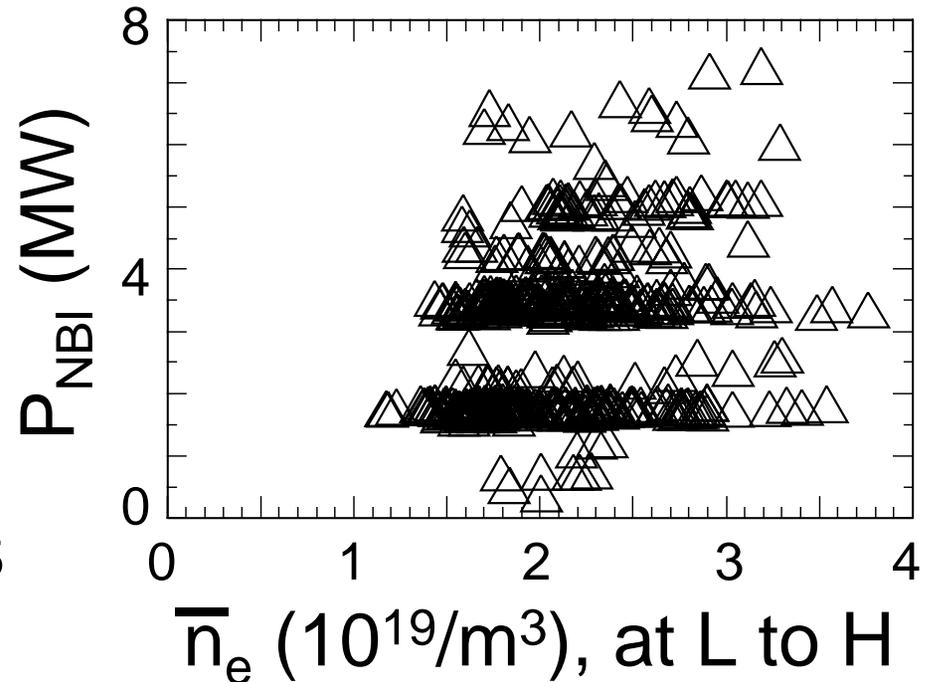
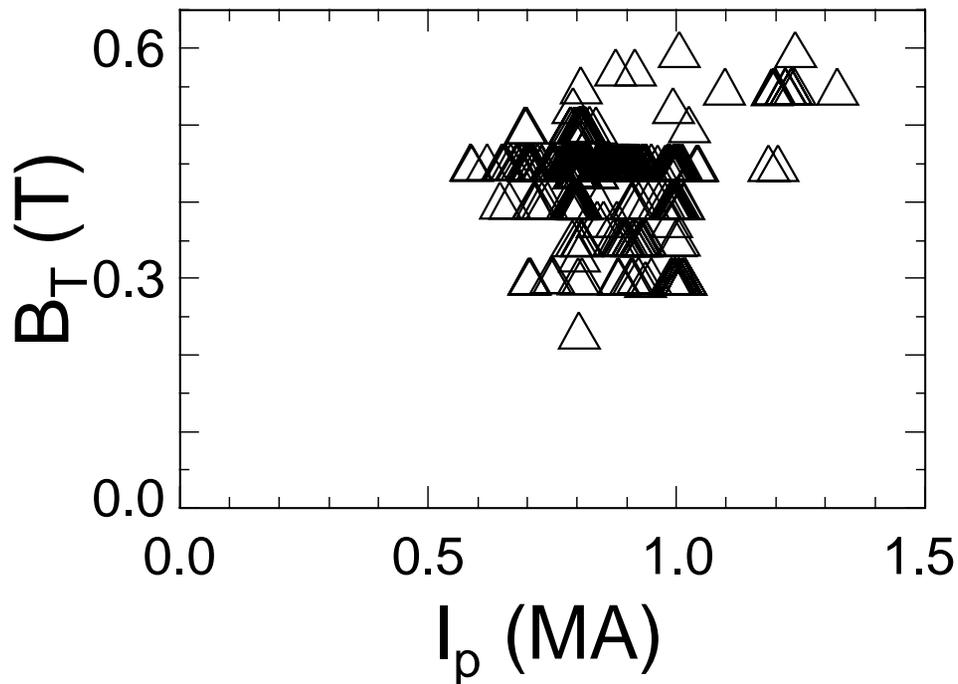
- 350° C bake out of graphite tiles
- Regular boronization (~3 weeks)
- Helium Glow between discharges
- Center stack gas injection
- Error field reduction

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
⇒ Long pulse, high β_T with H-mode
- Power threshold relatively high
 - Possible I_p dependence
- Edge fluctuations
- Wide variety of ELM behavior
- Summary

High β Achieved with H-mode Operation



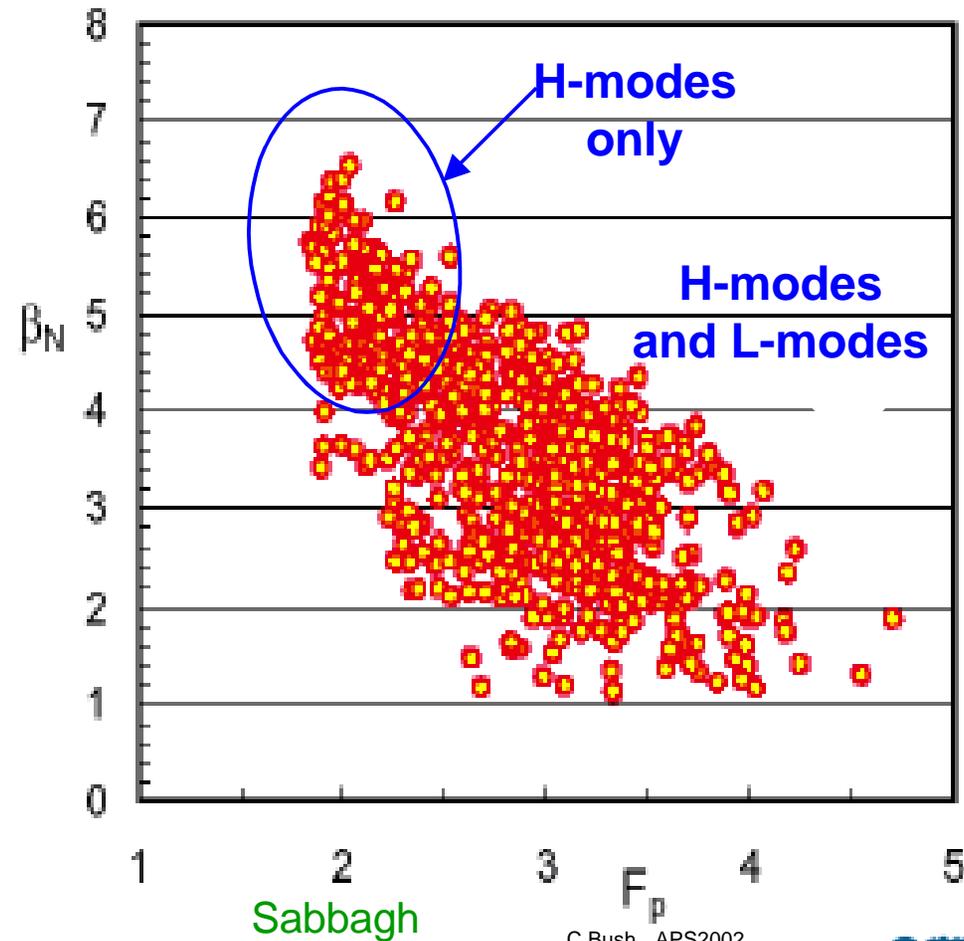
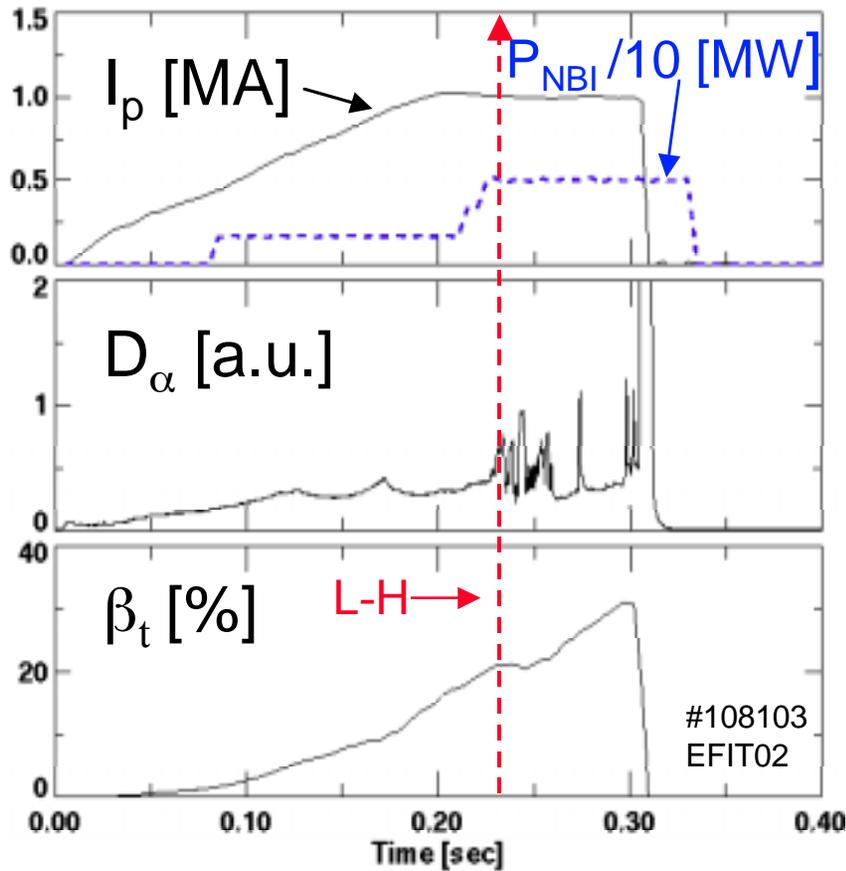
- Plasmas are more stable with broad pressure profiles

$$\beta_T = 31.5\%$$

$$\beta_N^{\max} \sim 6.2$$

$$\beta_T = 2\mu_0 \langle p \rangle / B_0^2$$

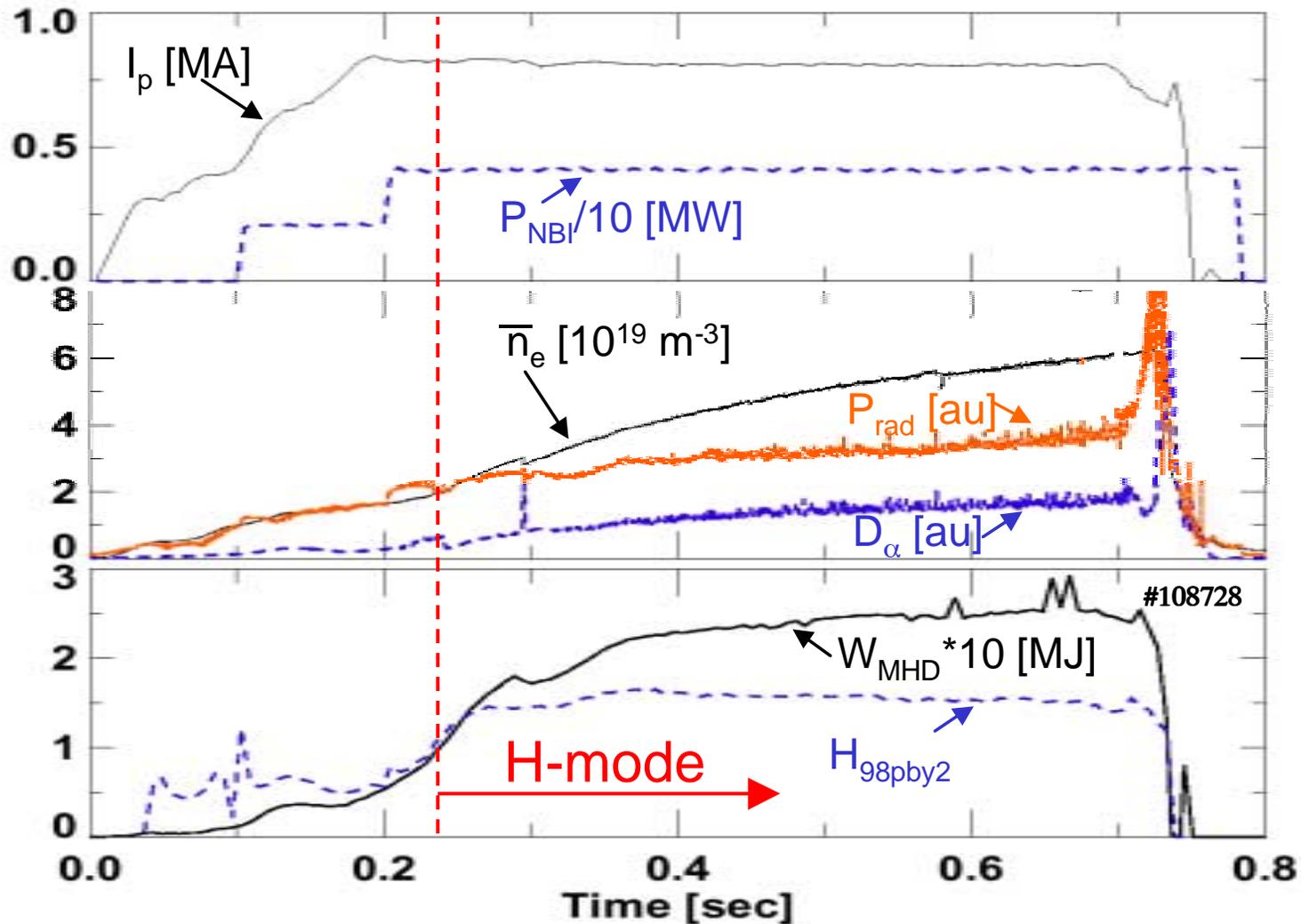
$$F_p \equiv p_e(0) / \langle p_e \rangle$$



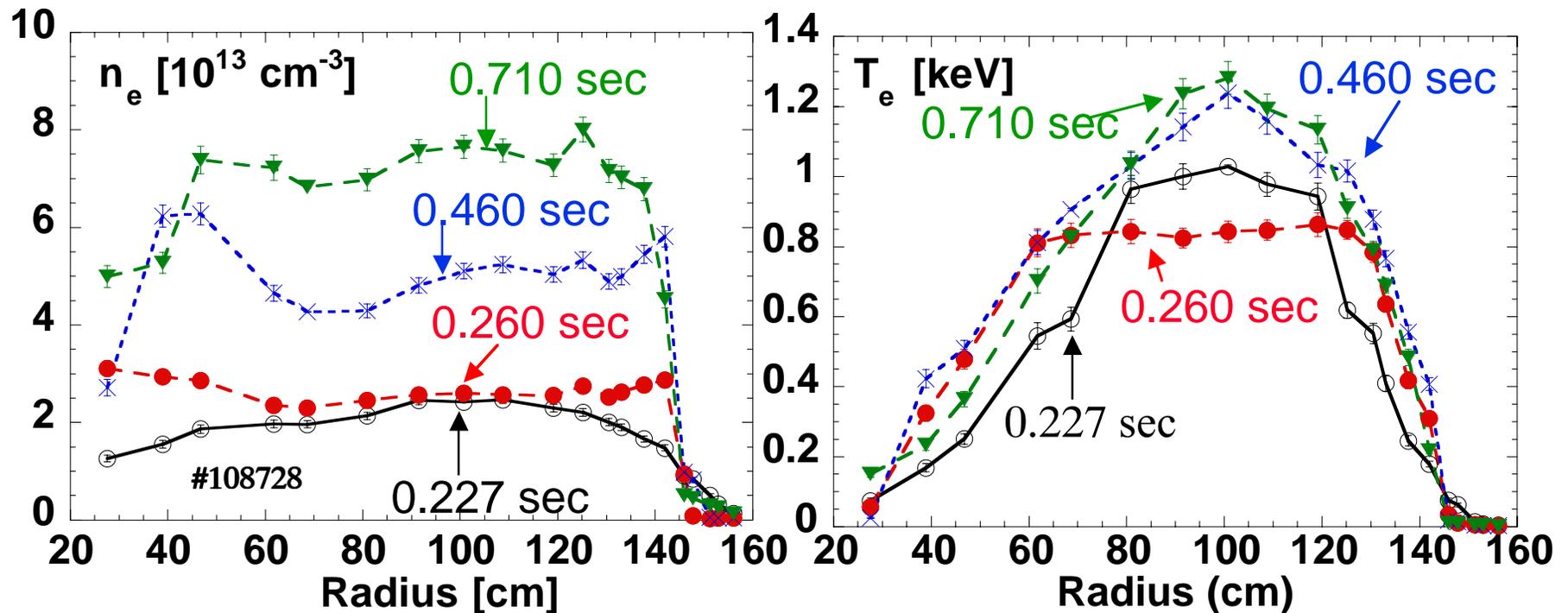
High Performance Sustained During Long-Pulse H-modes



- H-mode duration ~ 500 ms, $W_{\text{MHD}} \sim 250$ kJ, $H_{98\text{pby}2} = 1.5$



n_e and T_e Profiles Evolve Differently During Long H-mode



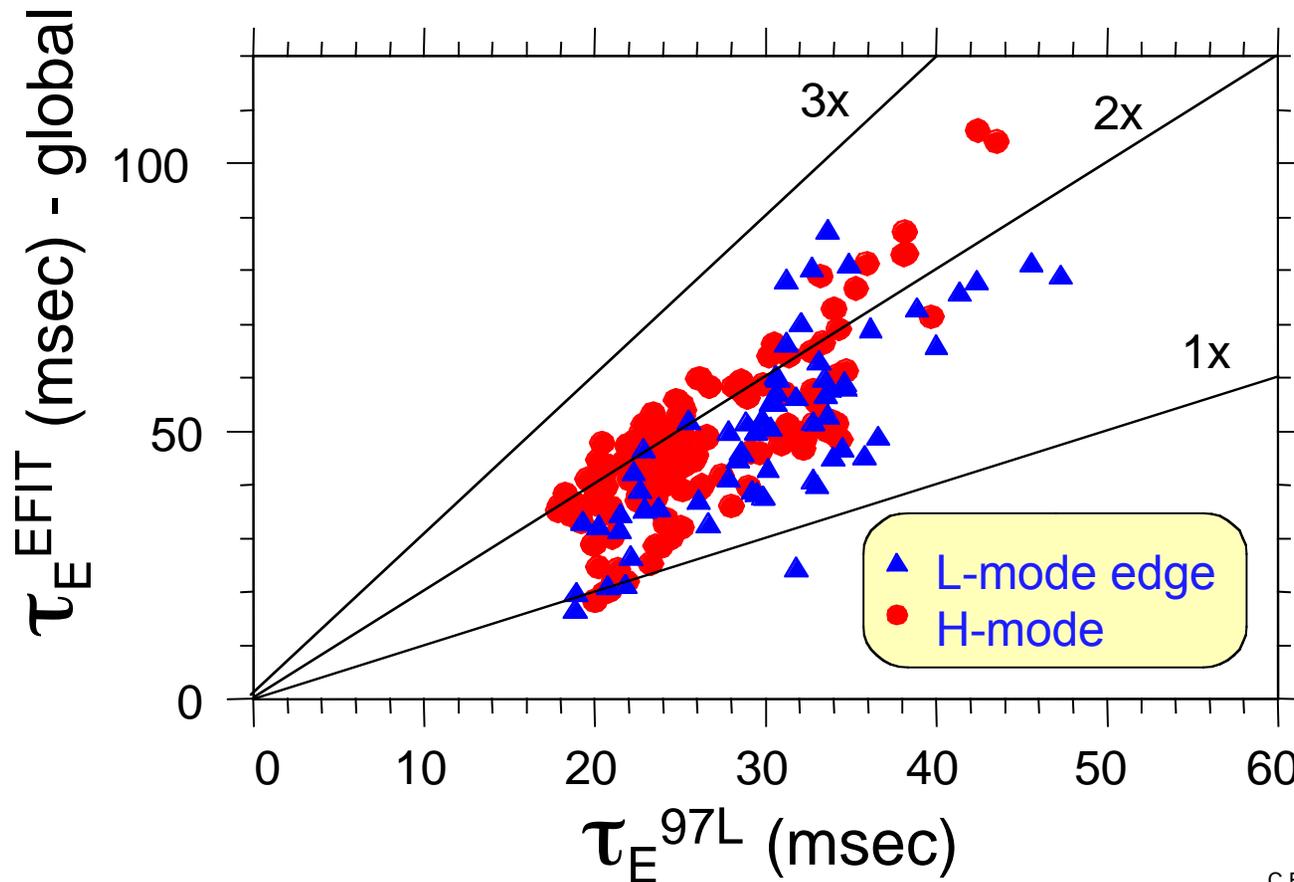
- n_e profile hollow after transition and fills in 300-500 ms
- T_e profile flattens initially and peaks later in time

LeBlanc

Confinement Enhanced Over Values Given by Conventional Aspect Ratio Scalings



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

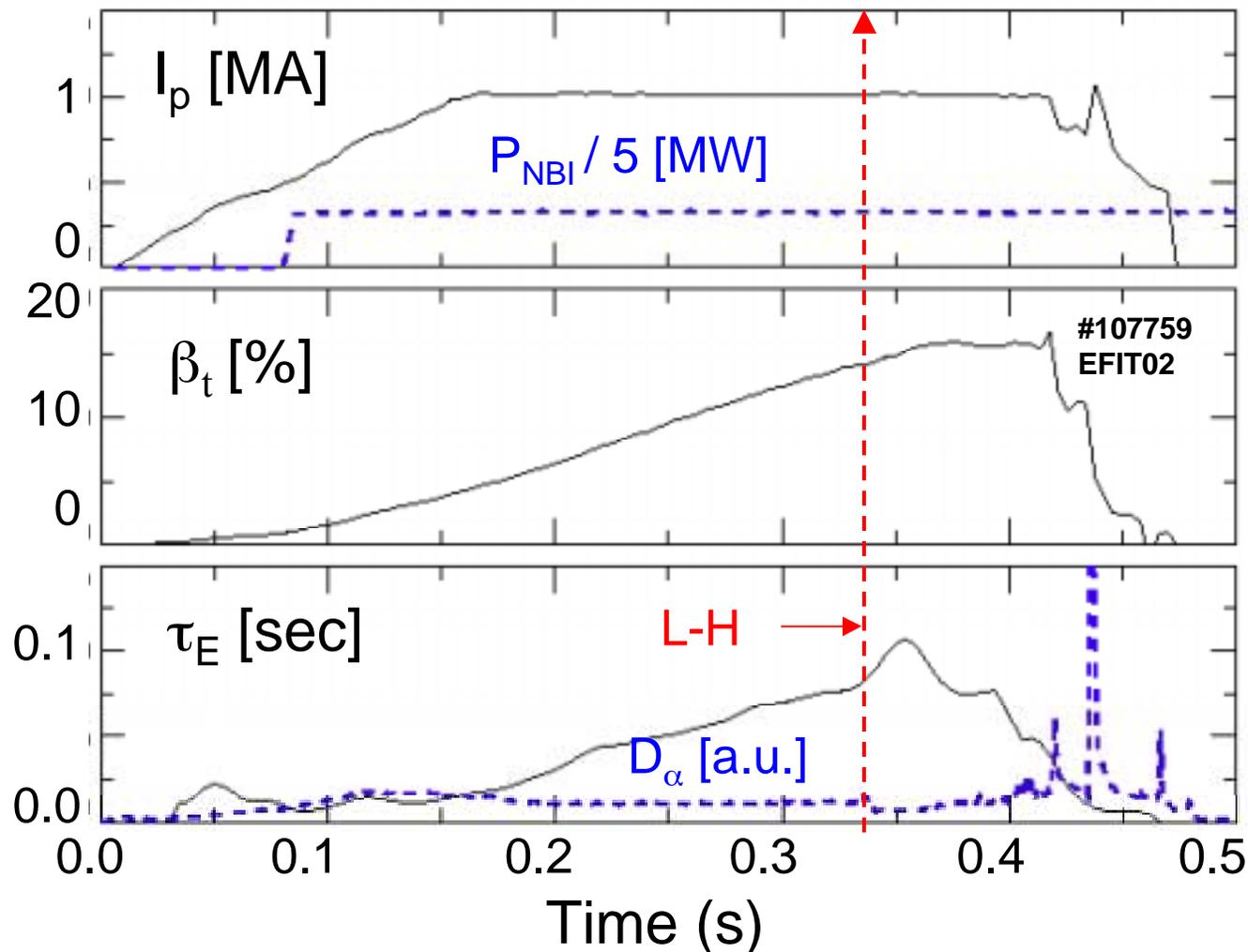


S. Kaye

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

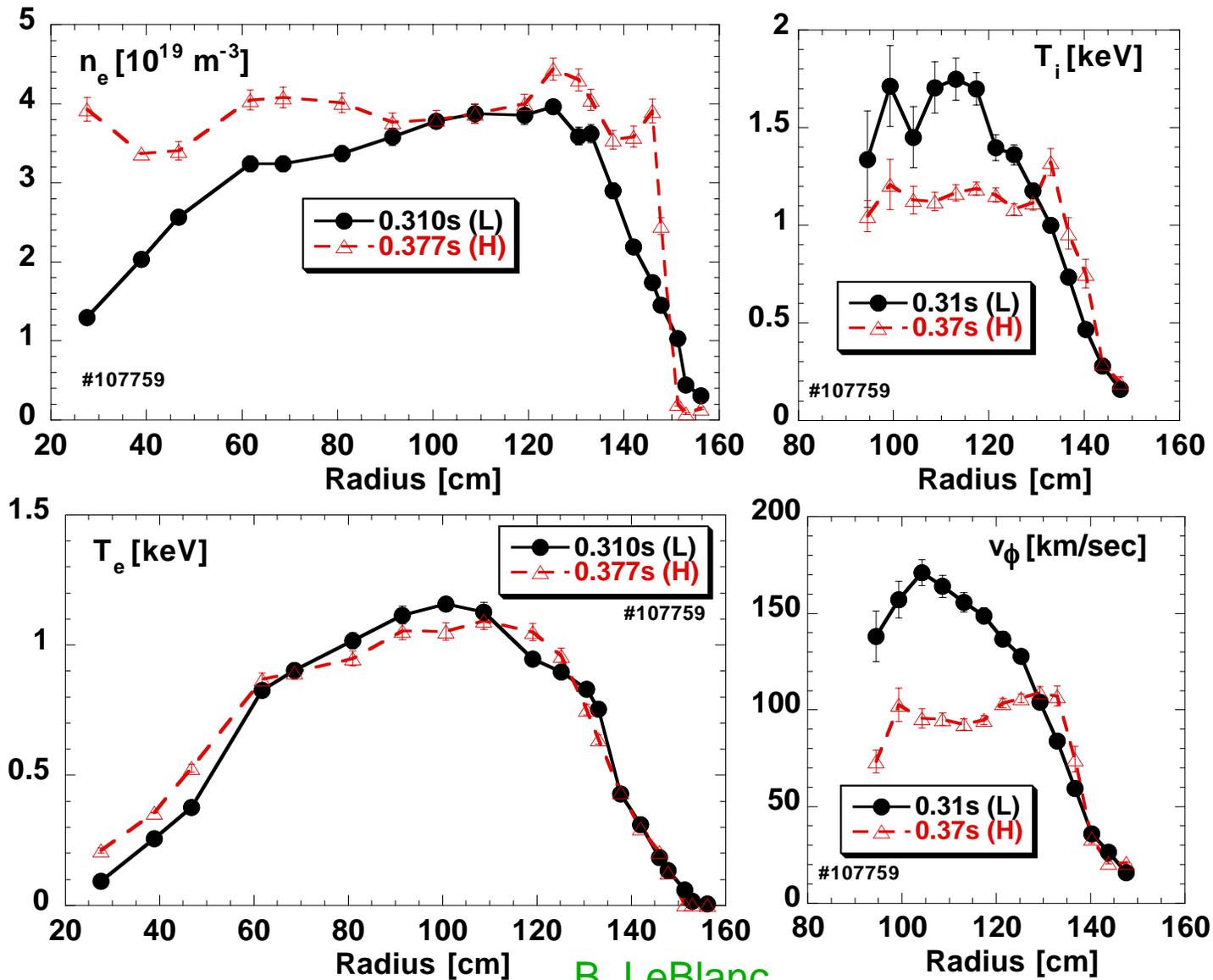


- Gain in going from high performance L-mode to H-mode is modest



Sabbagh

Profile Comparisons: L-mode/H-mode



B. LeBlanc

C. Bush, APS2002

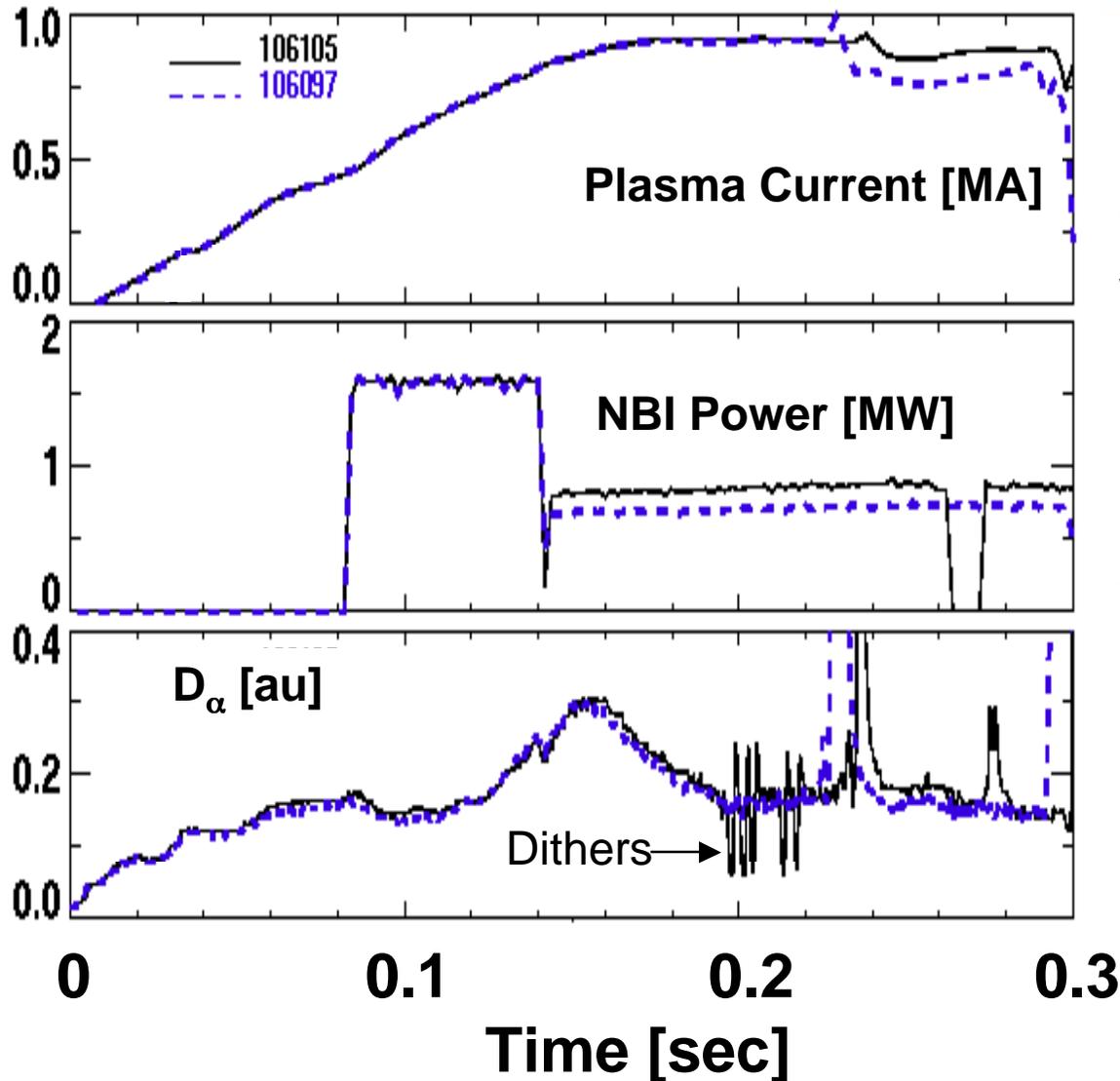
R. Bell
oml

Outline



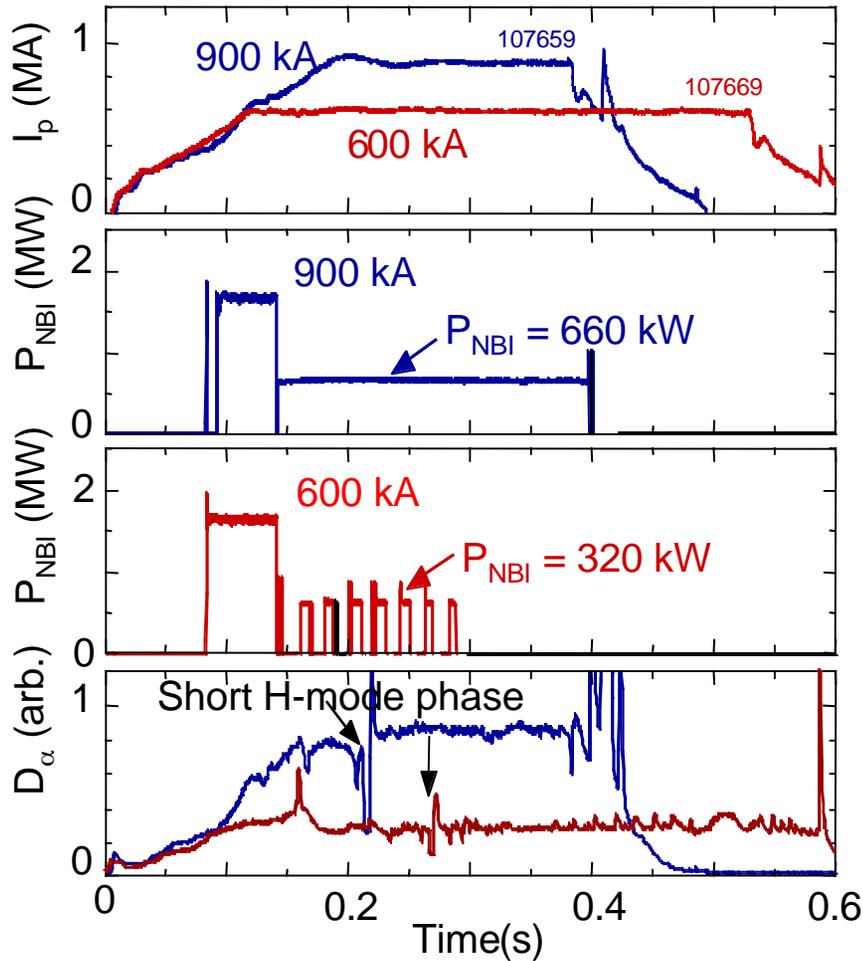
- Now have wide H-mode access space
- Long pulse, high β_T with H-mode
- ⇒ Power threshold relatively high
 - Possible I_p dependence
- Edge fluctuations
- Wide variety of ELM behavior
- Summary

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

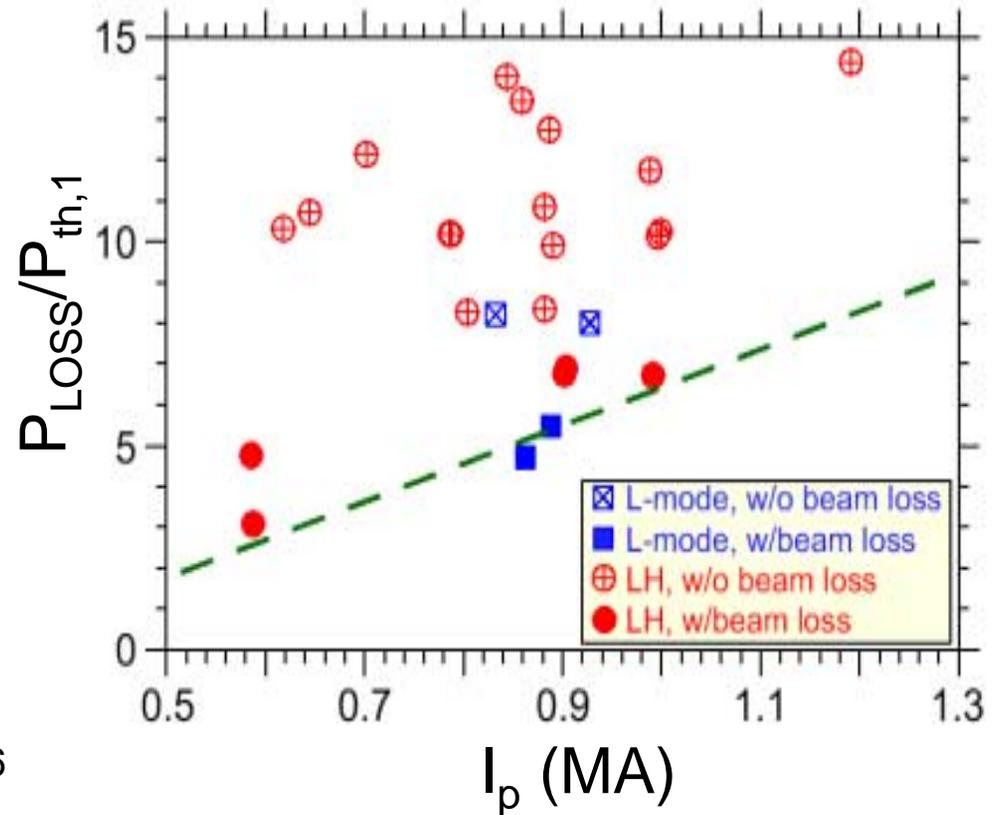


- NBI power reduced with beam voltage; even lower power using beam modulation
- Dithers observed with $P_{\text{NBI}} \geq P_{\text{th}}$
- ELM-free discharges when $P_{\text{NBI}} \gg P_{\text{th}}$

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)



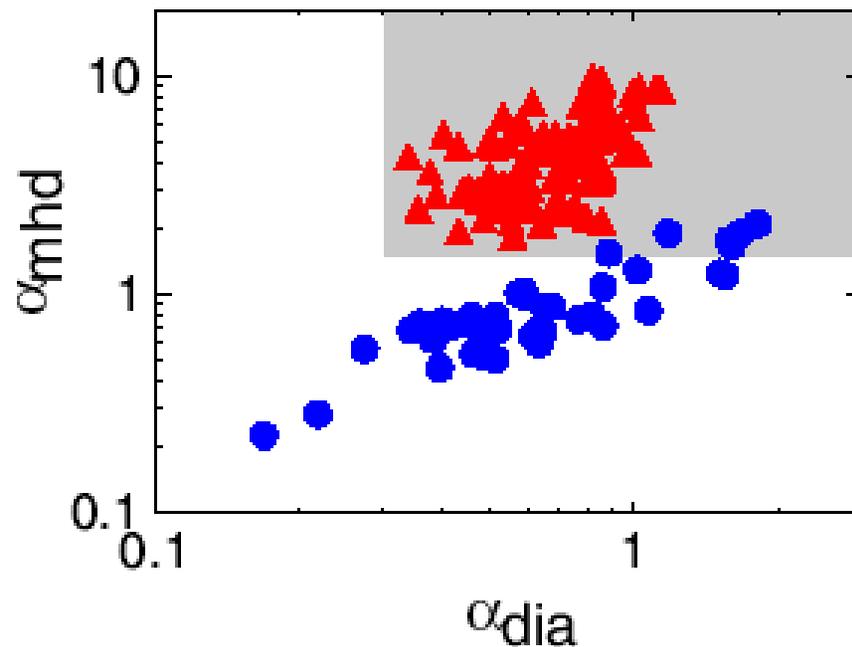
- $P_{LOSS} = P_{OH} + P_{NBI} - dW_{plasma}/dt - P_{FLOSS}$
- $P_{th,1} \sim n_e^{0.61} B_T^{0.78} a^{0.89} R^{0.94}$ (Snipes et al., IAEA 2002)

Comparisons with L/H Transition Theories



Drift-Ballooning
Rogers and Drake,
PRL, 1998

● L-mode ▲ H-mode



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

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

- 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

Outline



- Wide H-mode access space
 - Long pulse high β_T with H-mode
 - Power threshold
 - Possible I_p dependence
- ⇒ Edge fluctuations
- Wide variety of ELM behavior
 - Summary

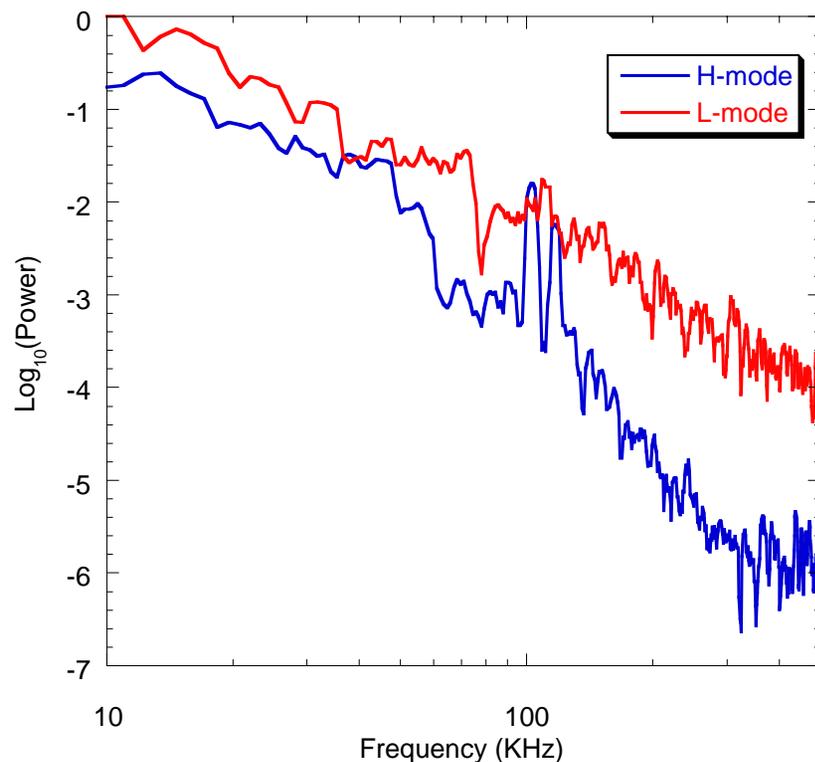
Scrape-off Layer Turbulence is Reduced During H-mode



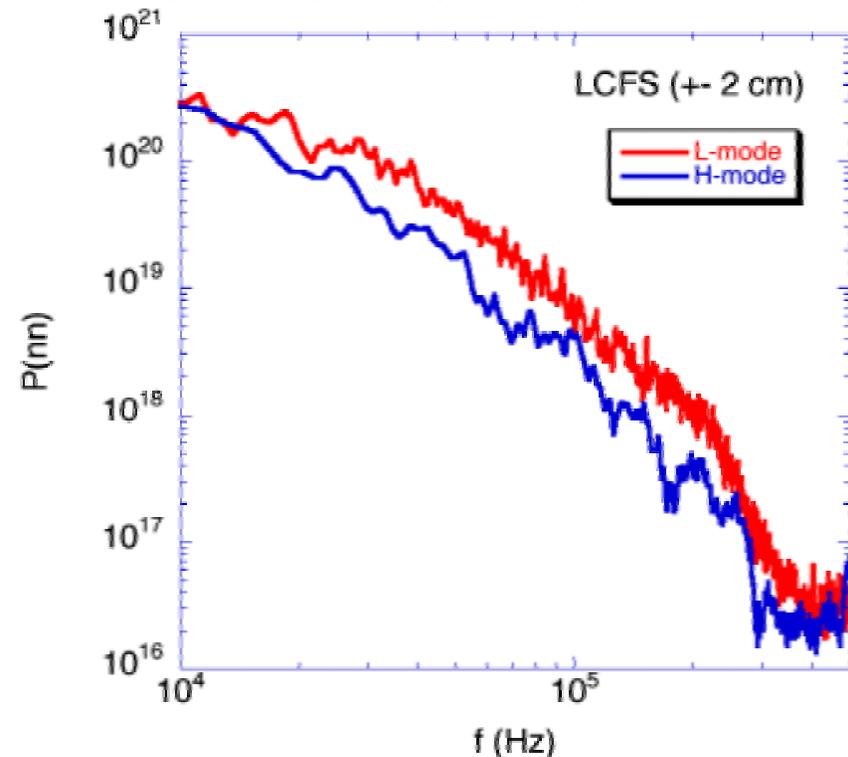
In SOL where $T_e \leq 20$ eV, $n_e < 3 \times 10^{12}$ cm $^{-3}$:

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

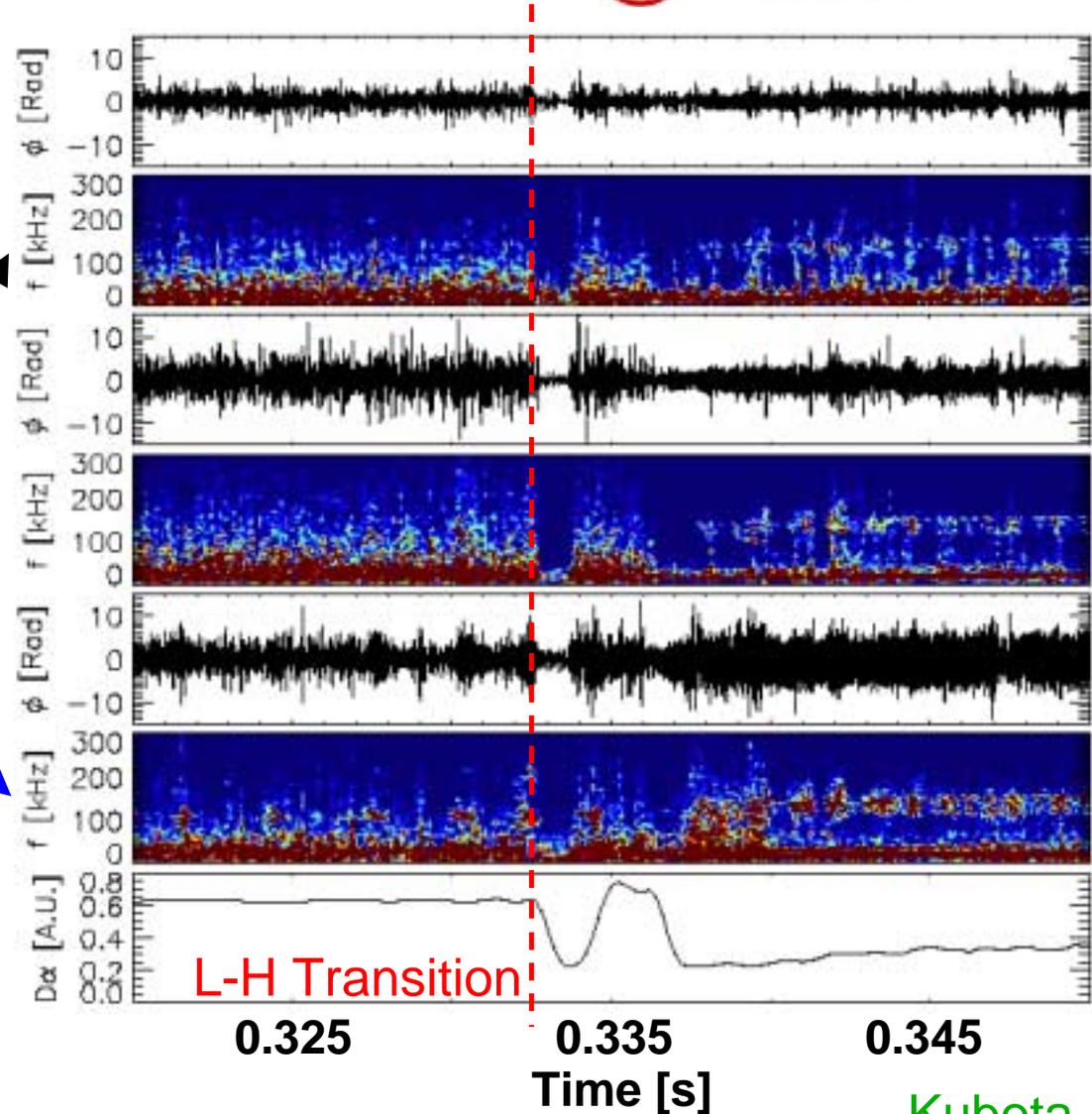
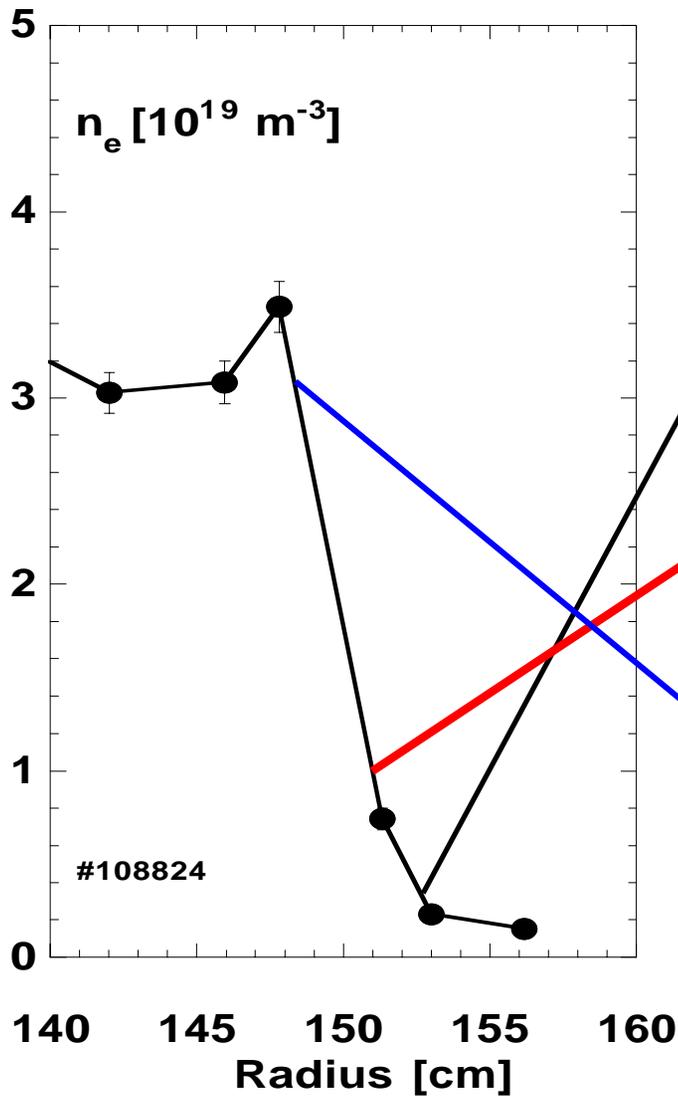
HHFW reflectometer (Wilgen, Swain, ORNL)



Edge Langmuir probe (Boedo, UCSD)



Fluctuation Amplitude Reduced in Steep Density Gradient Region



Outline

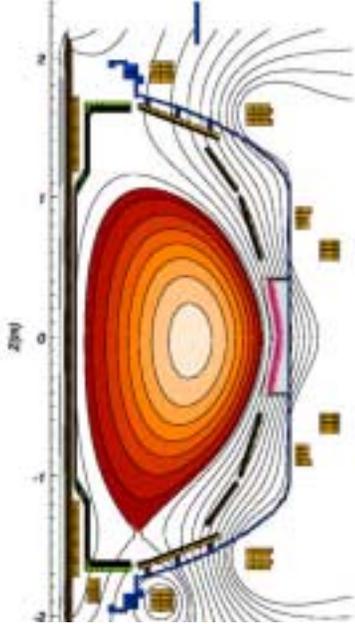


- Now have wide H-mode access space
 - Long pulse, high β_T with H-mode
 - Power threshold relatively high
 - Possible I_p dependence
 - Edge fluctuations
- ⇒ Wide variety of ELM behavior
- Summary

ELM Behavior Depends on Operating Conditions

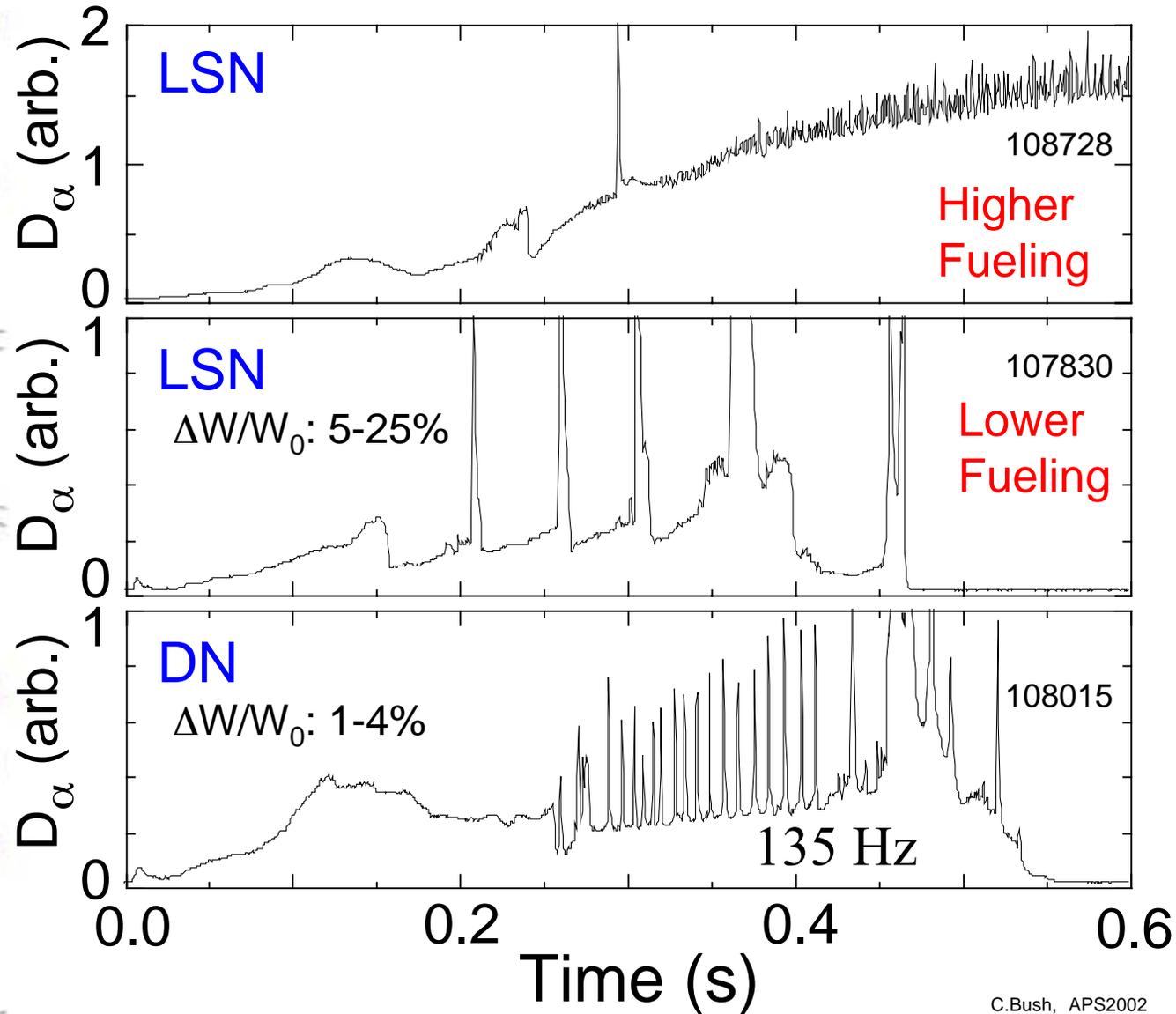
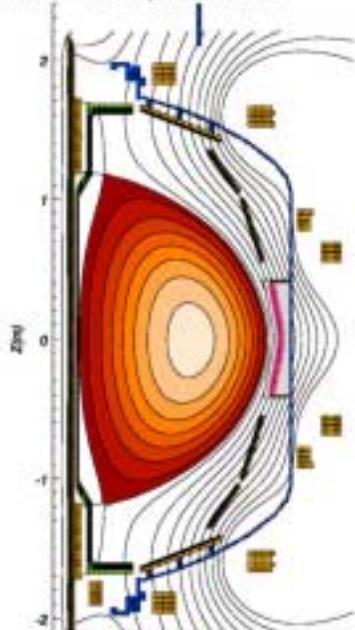


Shot= 107830, time= 247ms



Sabbagh Gates

Shot= 108015, time= 224ms

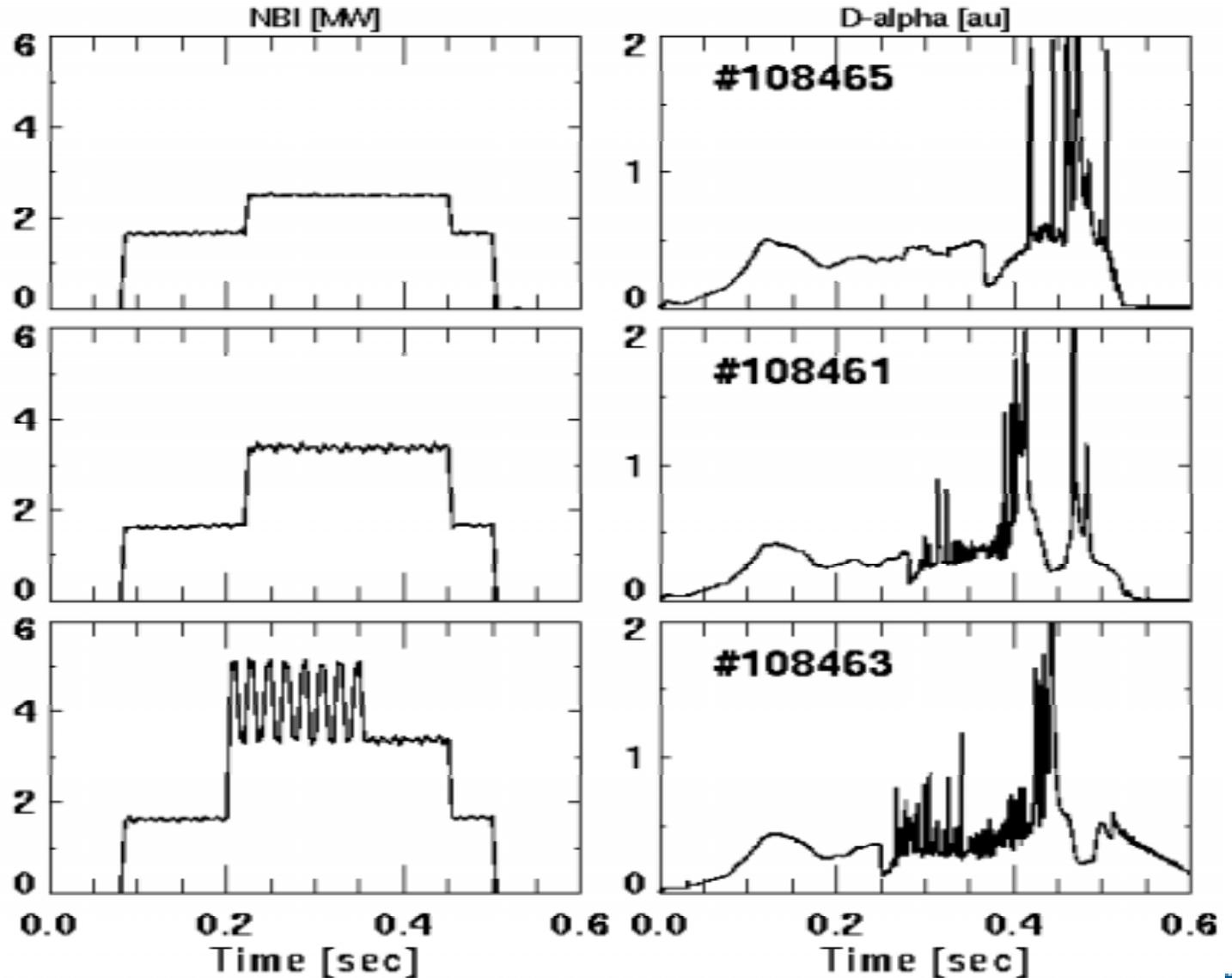


Dependence of L-H Transition and ELM Behavior on Heating Power

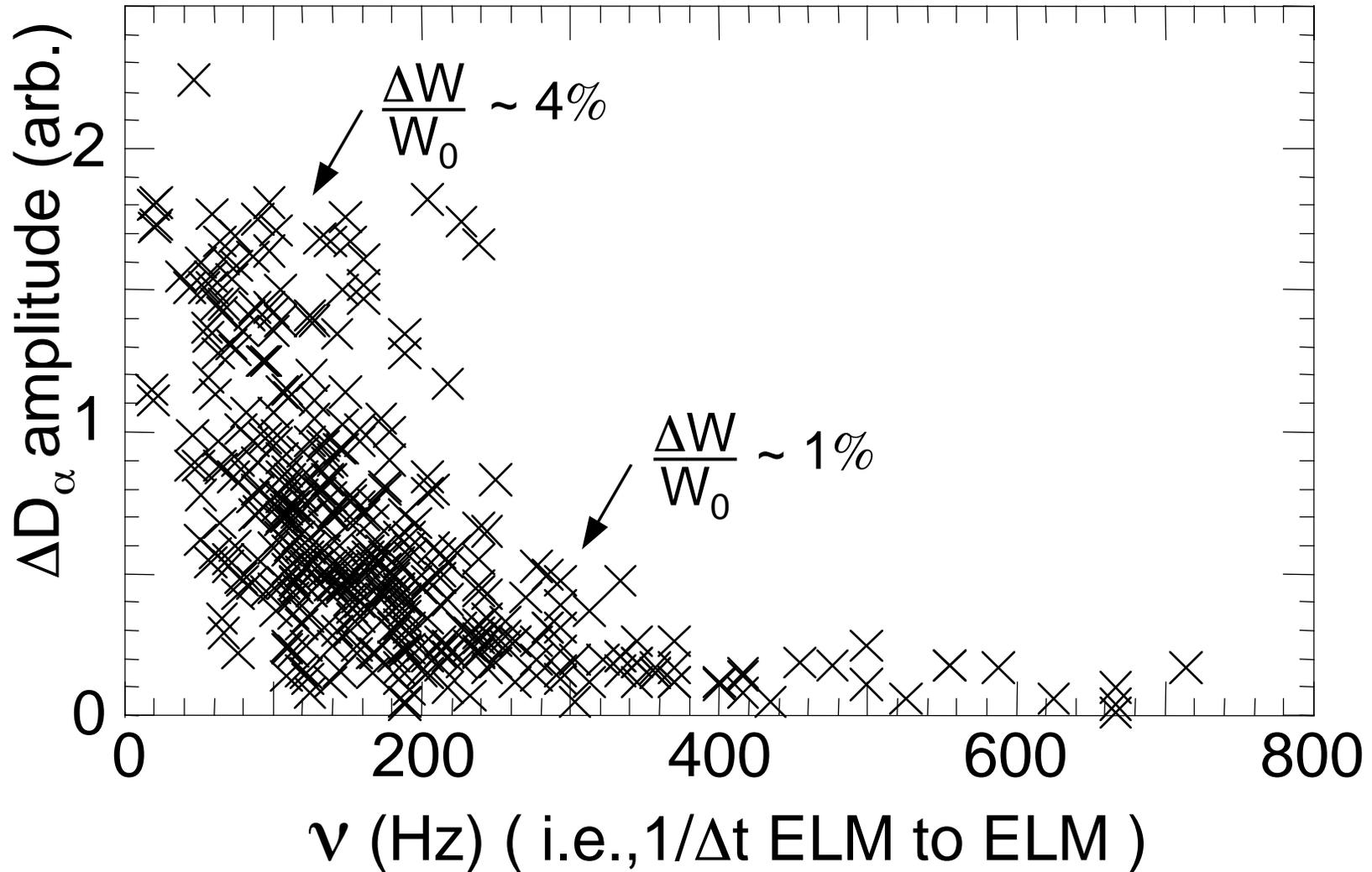


L-H transition
earlier in time
as P_{NBI} is
increased

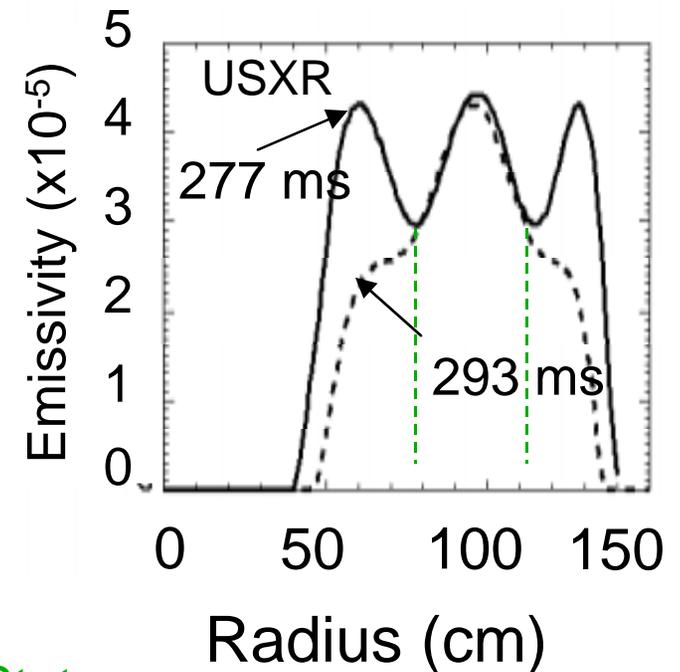
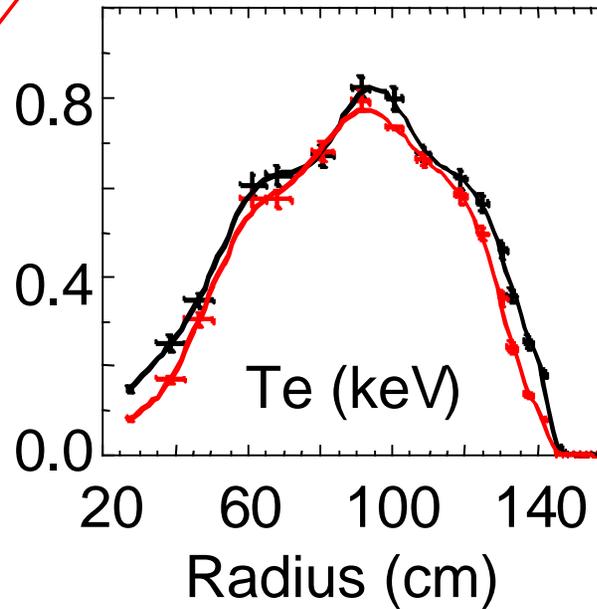
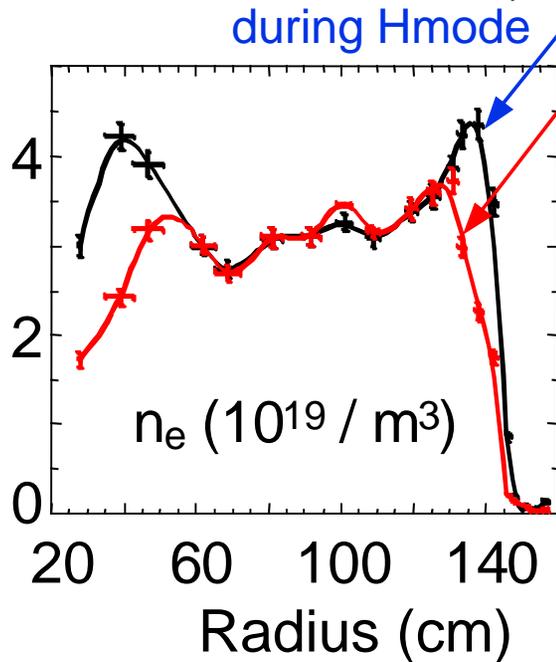
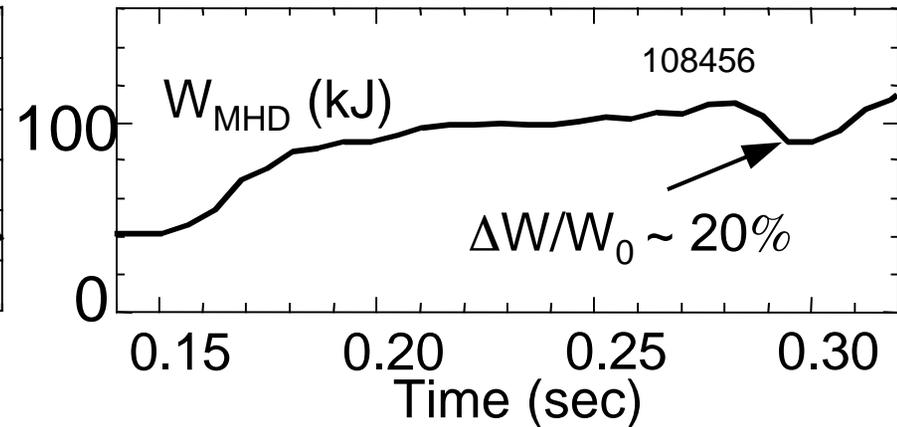
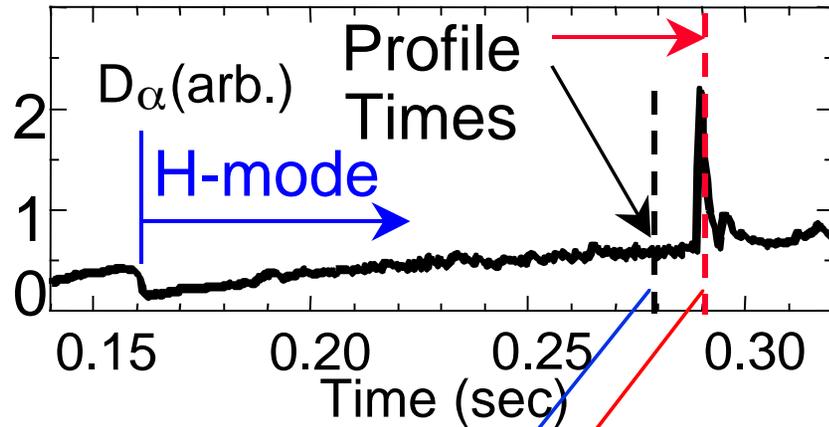
ELM frequency
increase as
 P_{NBI} increases



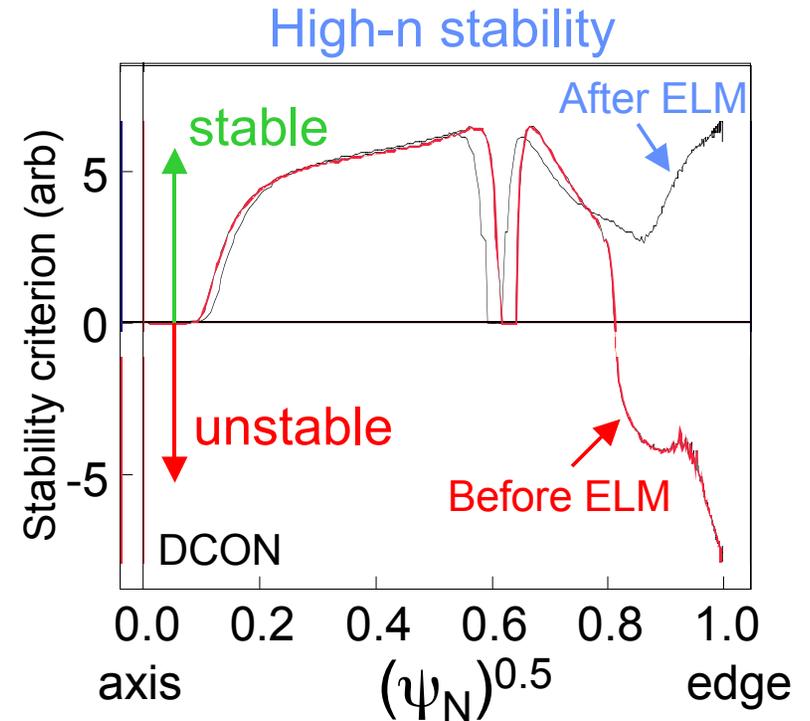
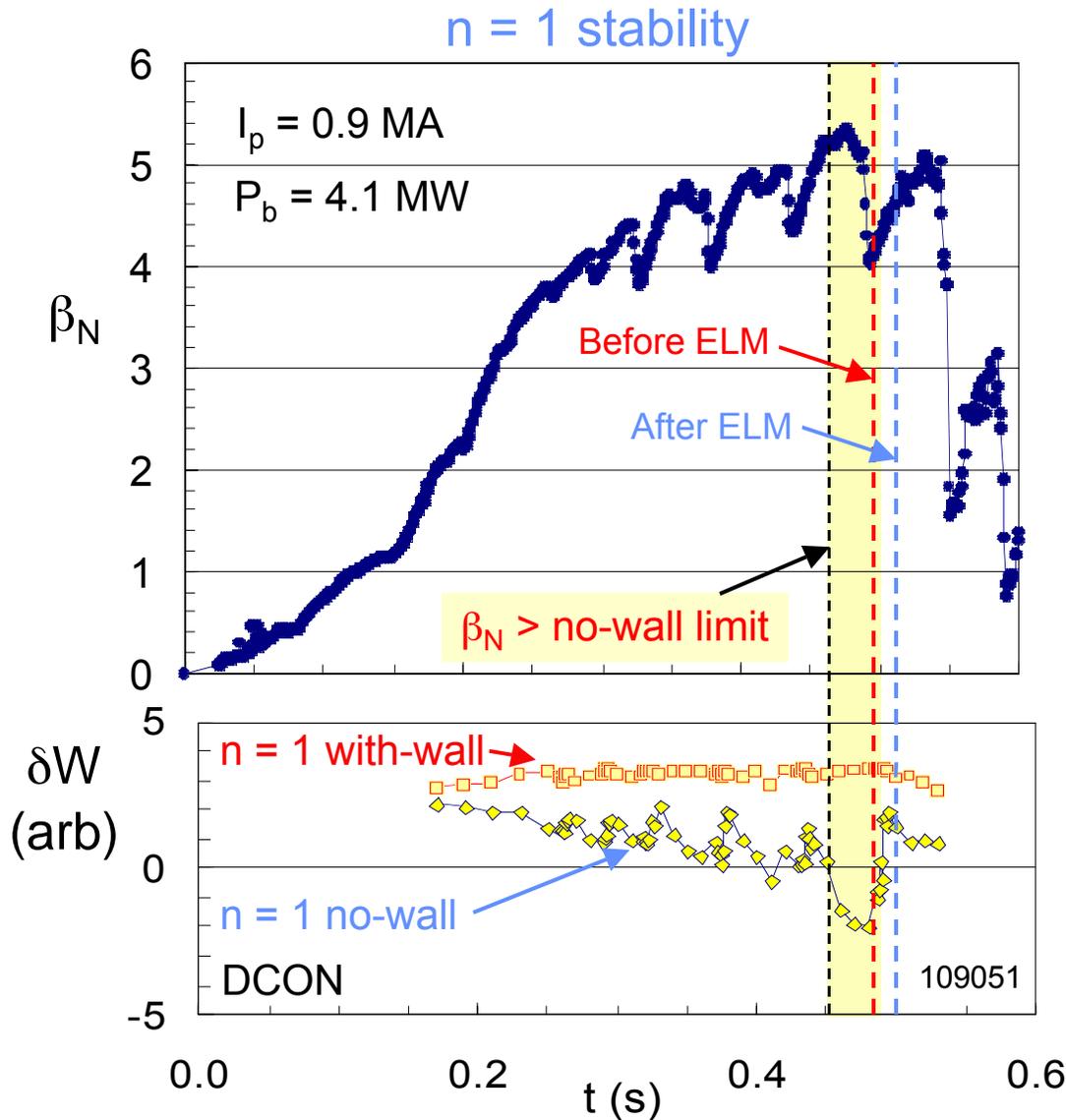
ELM Amplitude Usually Decreases with Increasing Frequency in NSTX: Type I ELMs?



Large ELMs penetrate deep into the plasma



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