Overview of NSTX Experiments in 2002

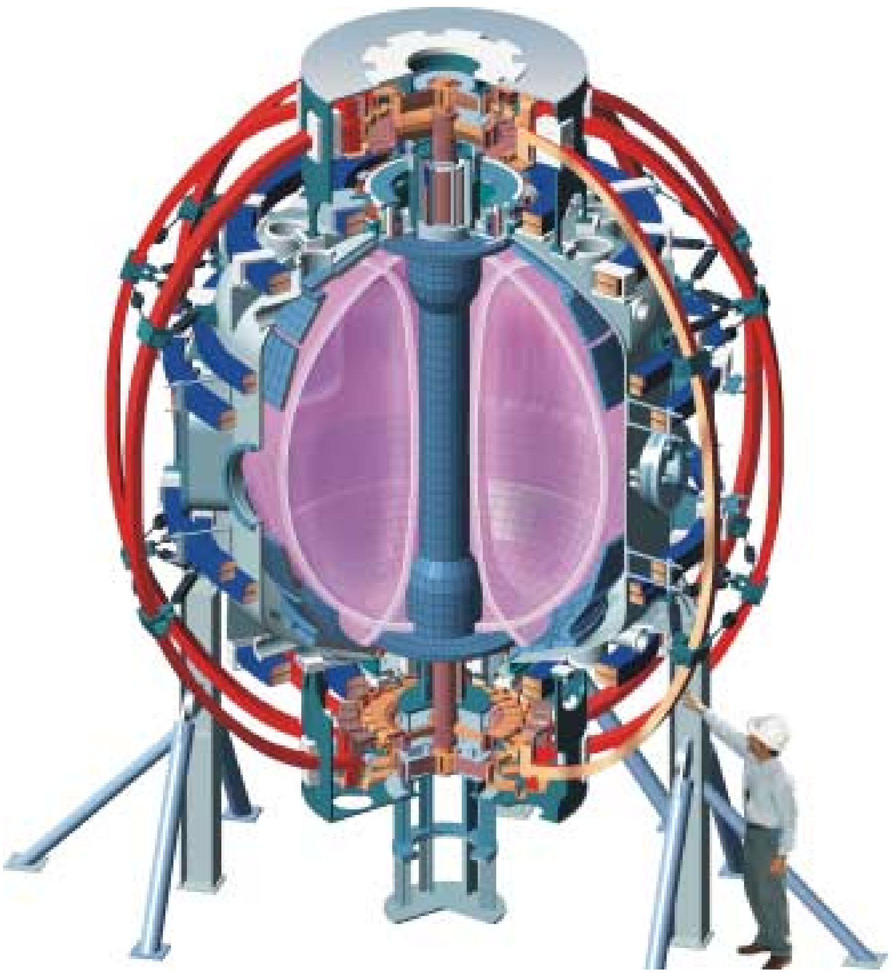
M.G. Bell

for the

NSTX Research Team

ST Workshop, Nov 18 -21, 2002

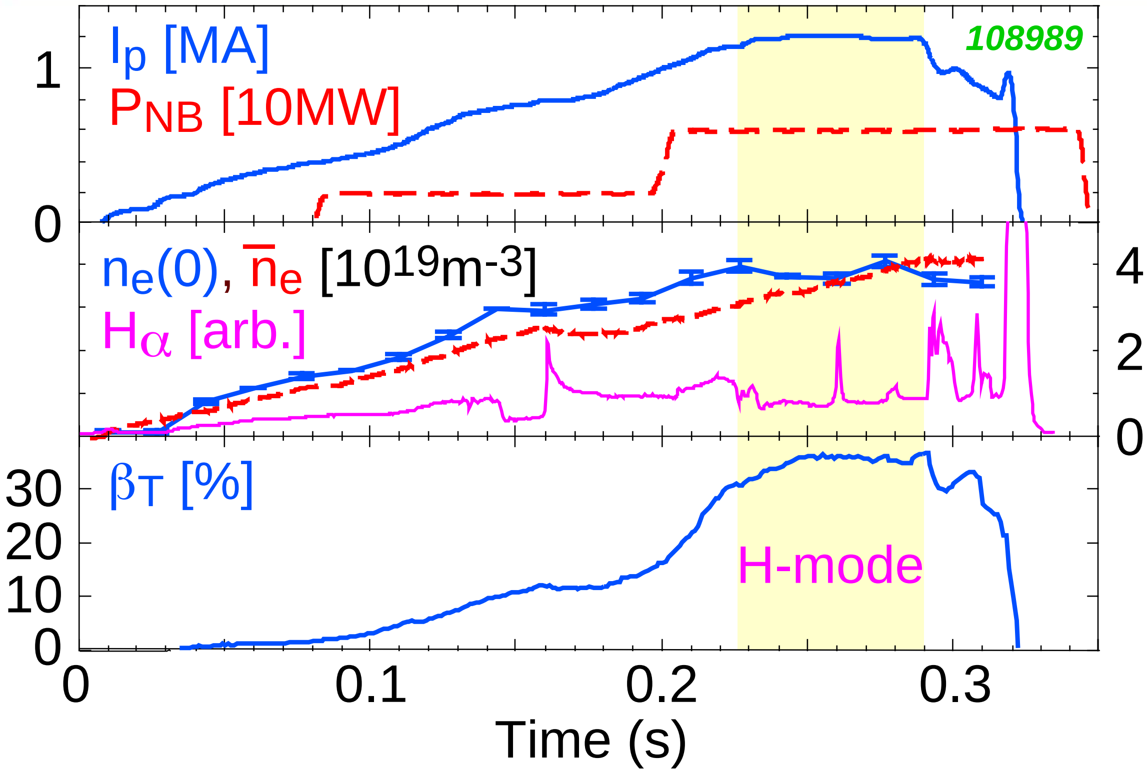
Experimental Capabilities Were Improved for 2002 Campaign

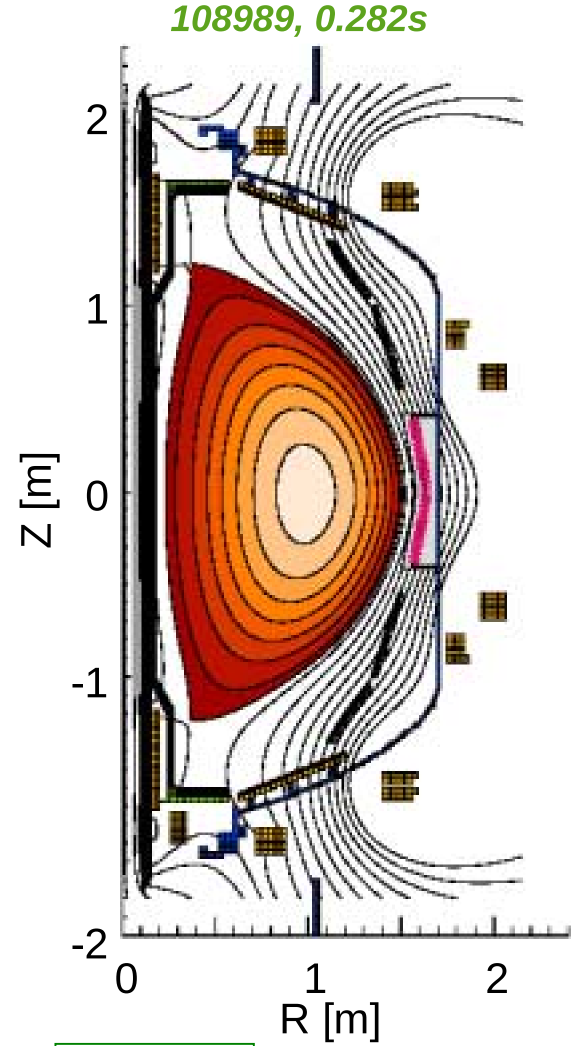


Capabilities
(this year)

PFC bakeout	***350°C***
Gas fueling	***HFS***
Aspect ratio	1.27
Elongation	2.5
Triangularity	***0.8***
Plasma Current	1.5MA
Toroidal Field	***0.6T***
NBI ***(100kV)***	***7 MW***
HHFW (30MHz)	6 MW
- full antenna phase control	
Pulse Length	***1s***
Reduced PF error field	

Achieved Substantial Progress in β_T





- β_T = 35% (EFIT with ϕ_{dia} and p_e profile)
- B_T = 0.3T, A = 1.4, κ = 2.0, δ = 0.8
- l_i = 0.6, $q_0 \approx 1.4$
- H-mode broadens pressure profile

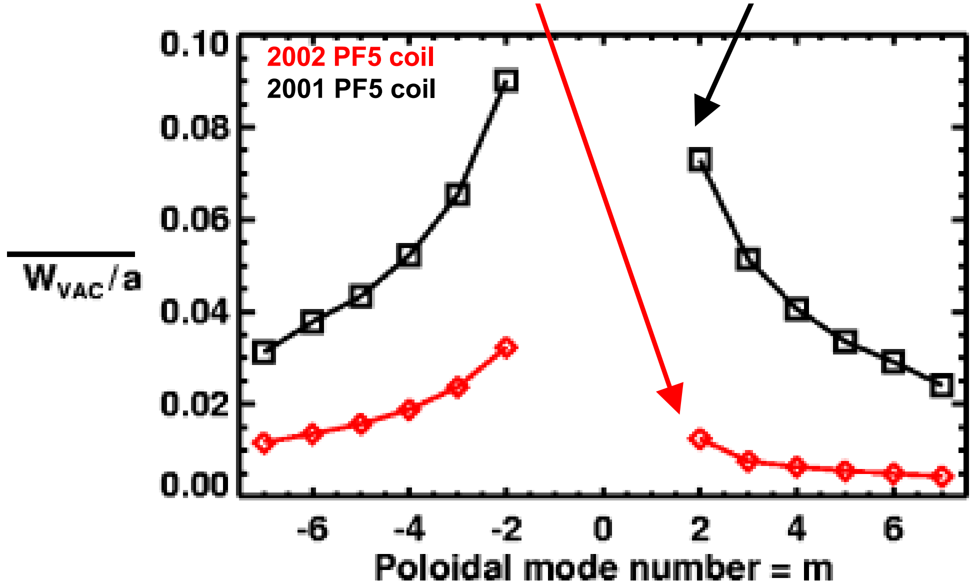
D. Gates

Several Factors Contributed to Sustained Higher β Operation

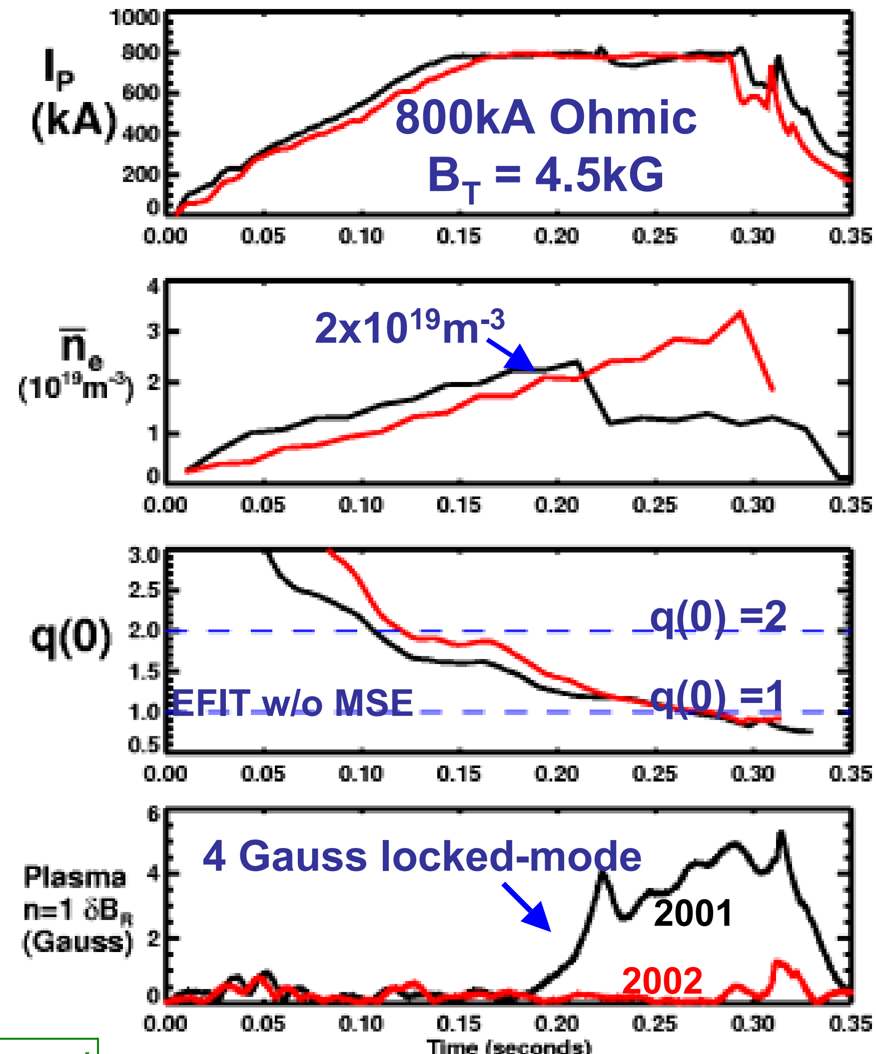
- Reduction of static error field
  - Reduced incidence of locked modes at low β
  - Reduced rotation damping
- Maintaining q_{min} > 1 for longer
  - Previous high-β plasmas collapsed when $q_{min} \leq 1$
  - Higher initial T_e & purity increased conductivity
- H-mode broadened profiles

Reshaping & Realignment of Outer PF Coil Reduced Error Field & Mode Locking

- PF5 (vertical field) coils found to generate large n=1 δB_r
- Coils re-shaped prior to '02 run
- Vacuum island widths now ***reduced to < 1cm*** (from ~5cm)

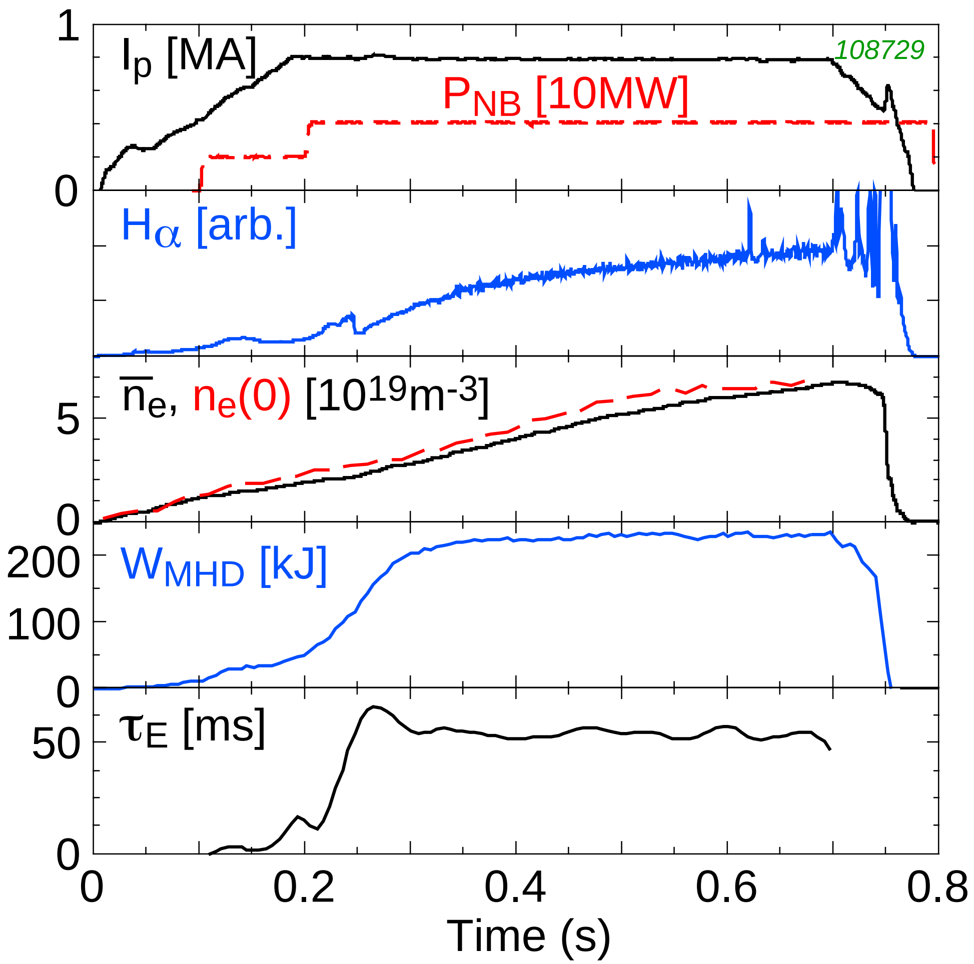


(NSTX operates with m > 0 resonant)



J. Menard

High-Field-Side Gas Injection Improved Both Reproducibility and Longevity of H-mode



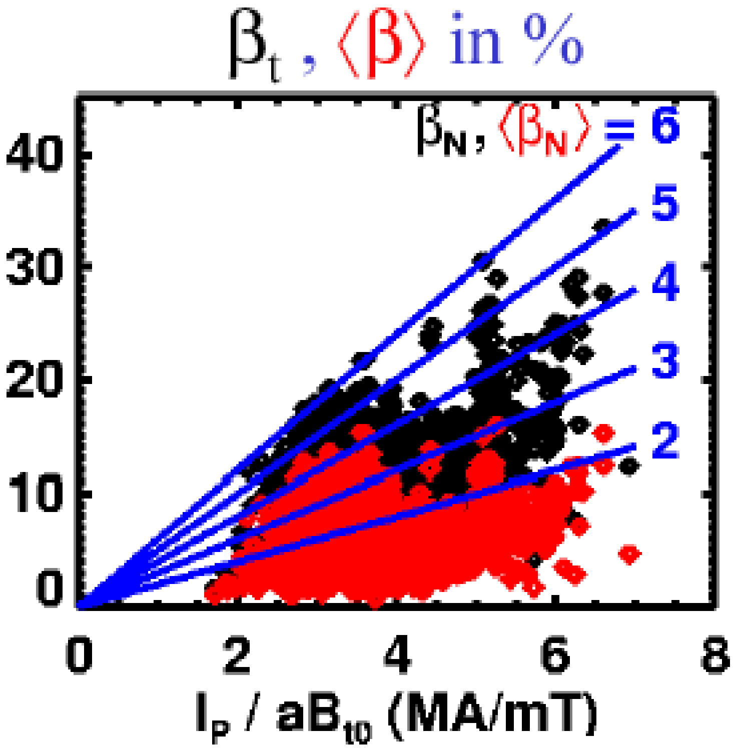
- HFS injector gives large initial flow then continuing lower flow
  - contributes to density rise
- LFS fueling with rate similar to HFS produces
  - Delayed transition
  - Shorter H phase
- Can also get H-mode by loading walls with D_2 gas
- Confinement similar in all cases

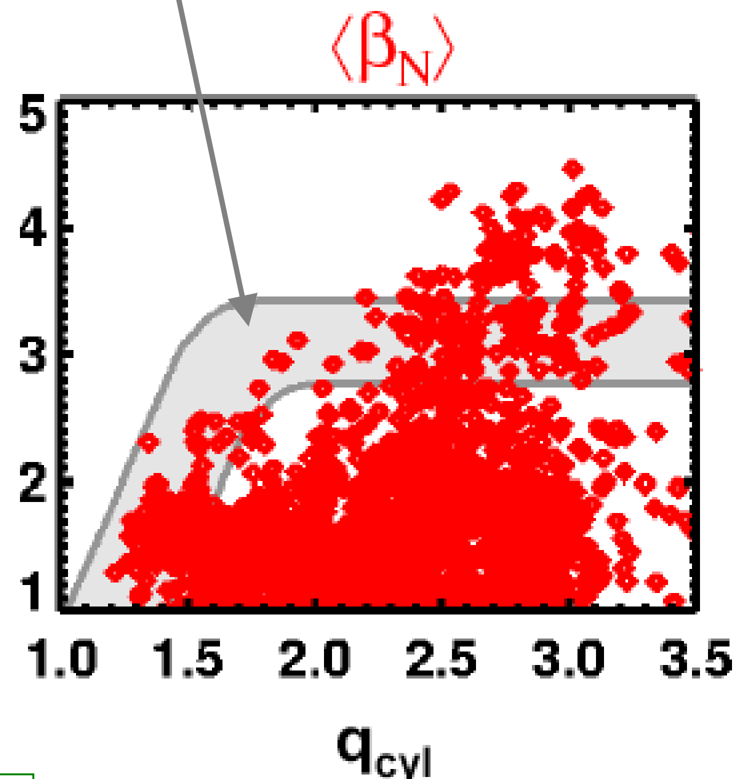
R. Maingi, C. Bush

Exceeded *Optimized* No–Wall β_N Limit Calculated in Theoretical Study

$\beta_t = 2\mu_0\langle p\rangle/B_{T0}^2$ $\langle\beta\rangle = 2\mu_0\langle p\rangle/\langle B^2\rangle$

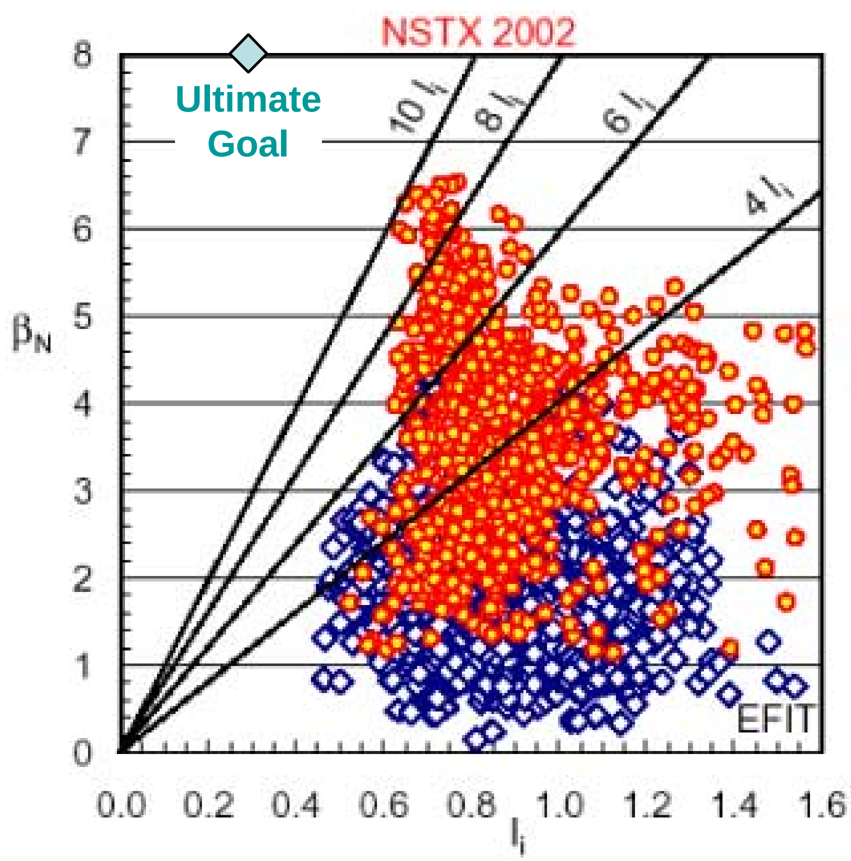
Range of limits varying A, κ, δ

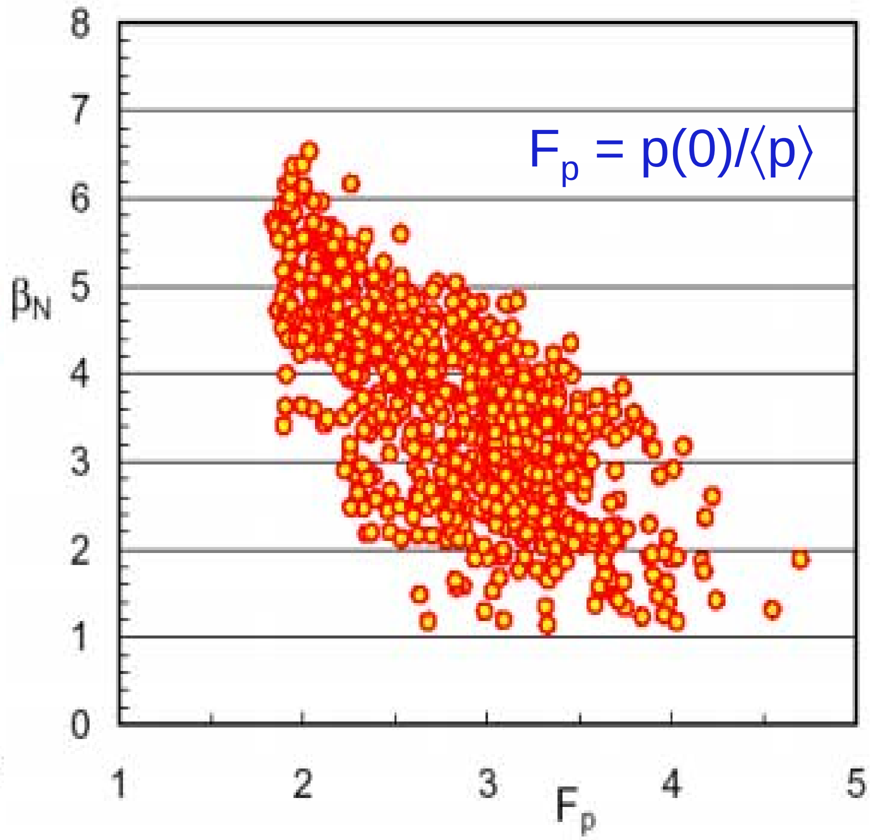




J. Menard

Achieved Good Progress Towards NSTX Goal in Normalized-β β_N



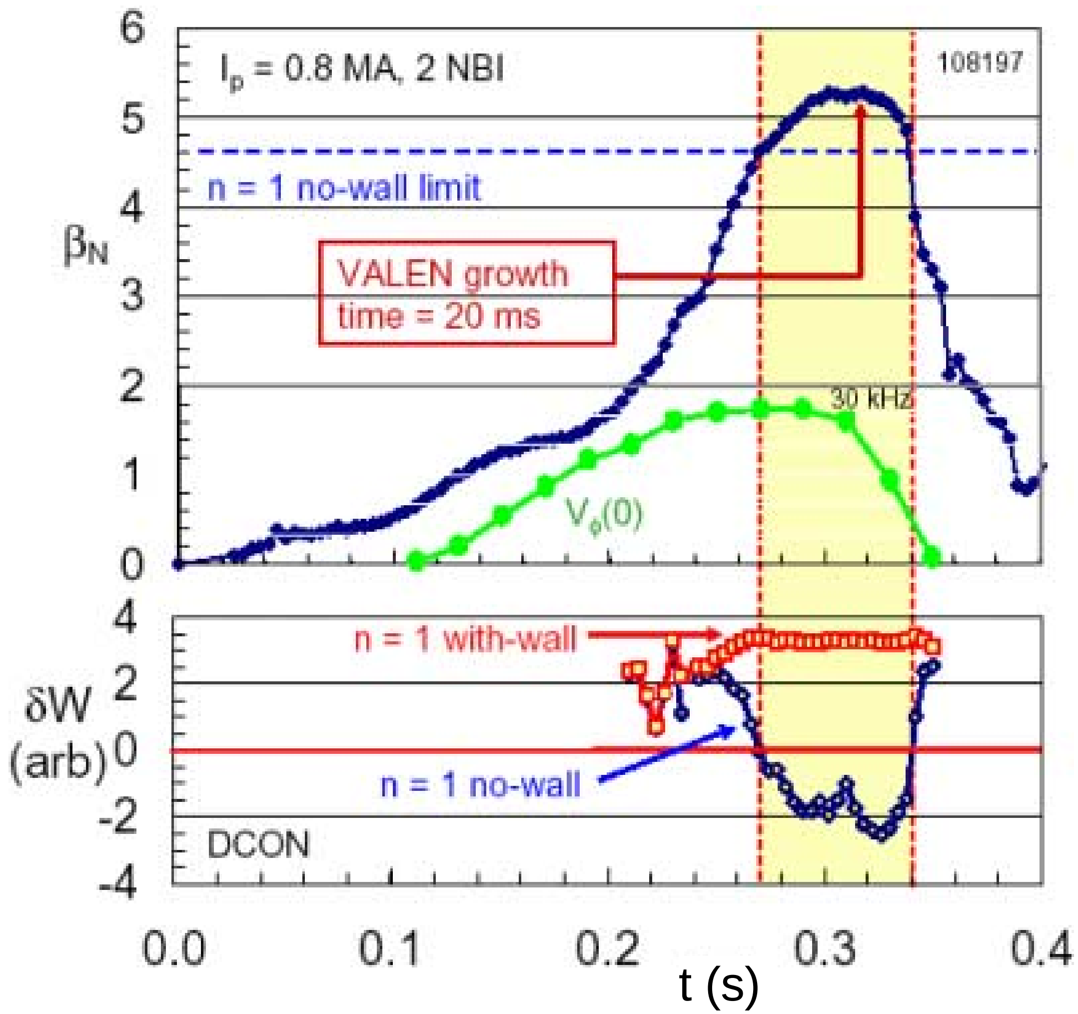


- Exceeded 2001 empirical limit ~ 6 l_i
- Well into wall-stabilized regime

- Pressure peaking factor from EFIT
- Continues well known trend

S. Sabbagh, F. Paoletti

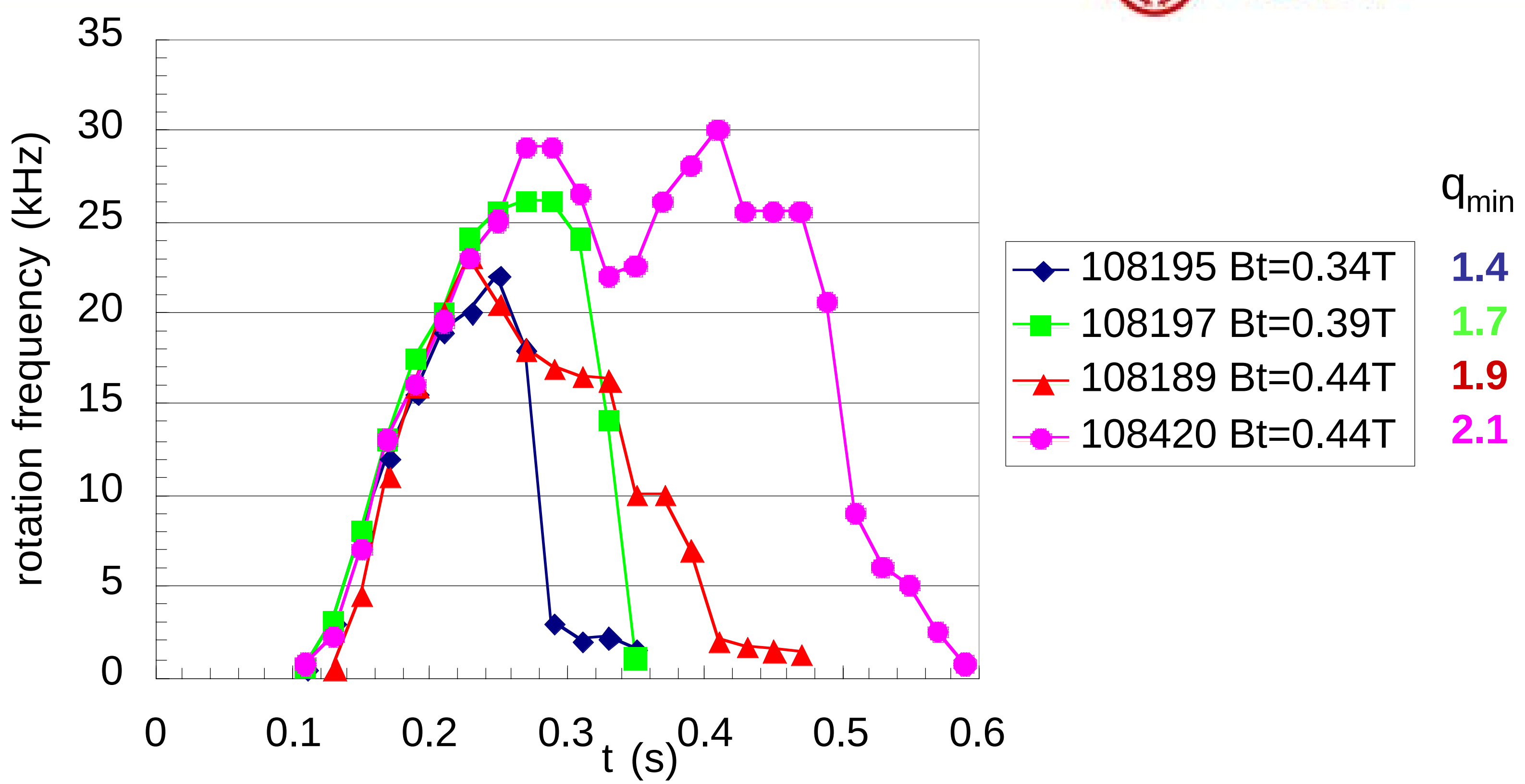
Analysis Shows Wall Stabilization Effective with Sufficient Rotation



- β collapse after ~$3.5\times\tau_{wall}$
  - Exceeded no-wall limit for up to ~$20\times\tau_{wall}$ in best case
- VALEN shows effective coupling of mode to wall
  - Coupling becomes less effective at higher β_N
    - Perturbation shifts from outboard side towards divertor region
- Collapse occurs after rapid decay of rotation
  - CHERS measurement
  - Timescale ~ τ_{wall}

S. Sabbagh, J. Bialek

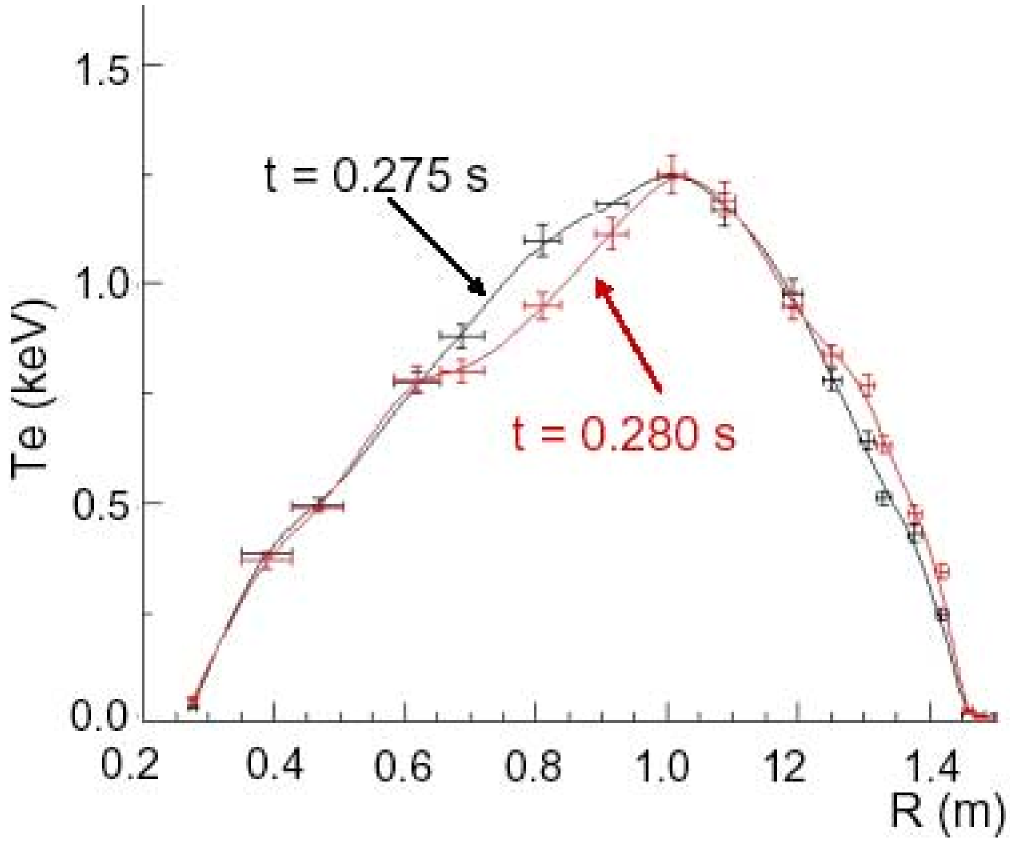
Damping of Toroidal Rotation Decreases with Increasing q_{min}

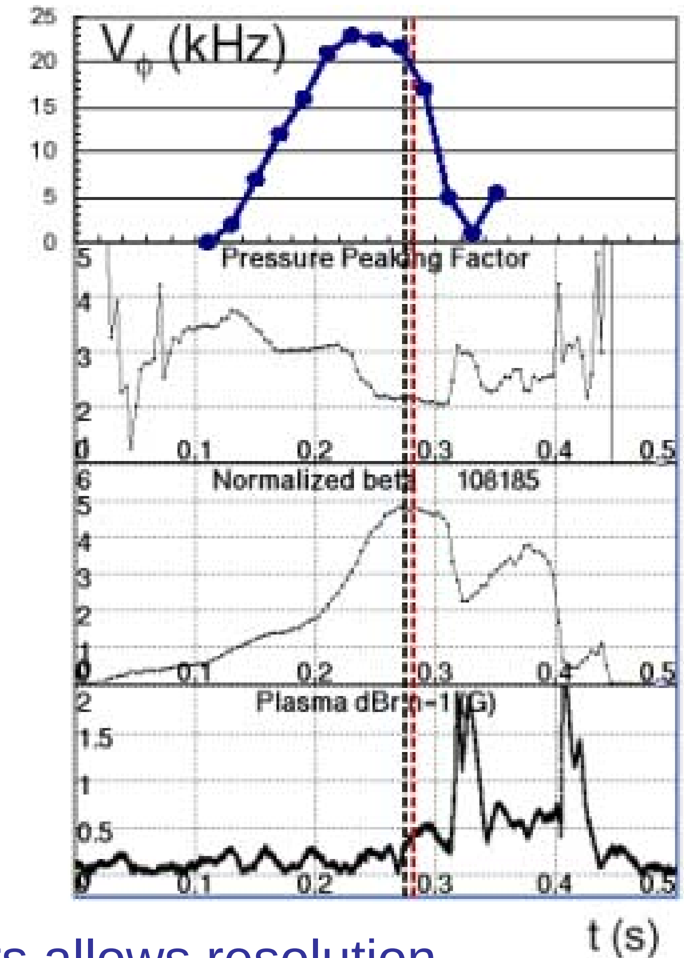


- Rotation decays across profile in case of RWM
- Consistent with theory of global rotation damping

R. Bell, S. Sabbagh

T_e Profiles Reveal Kink-like Displacement During RWM

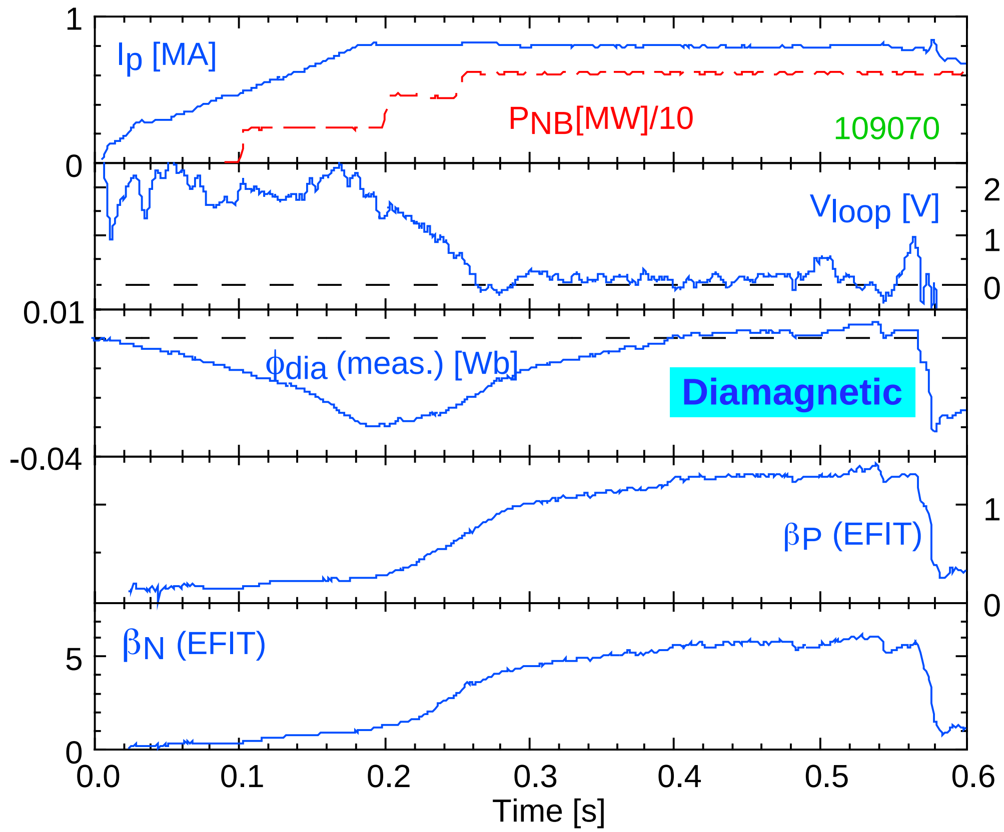




- 20 spatial points available for 2002 run
- Syncopated operation of 2 × 30Hz lasers allows resolution of transient phenomena to ~1ms

S. Sabbagh, B. LeBlanc

Created Diamagnetic Plasma With β_N/l_i = 10



- ϕ_d = +5mWb
- "Partial kinetic" EFIT
  - β_P = 1.4
  - β_N = 6.2
  - l_i = 0.6
- $V_{loop} \approx$ 0.1V
  - for ~0.3s

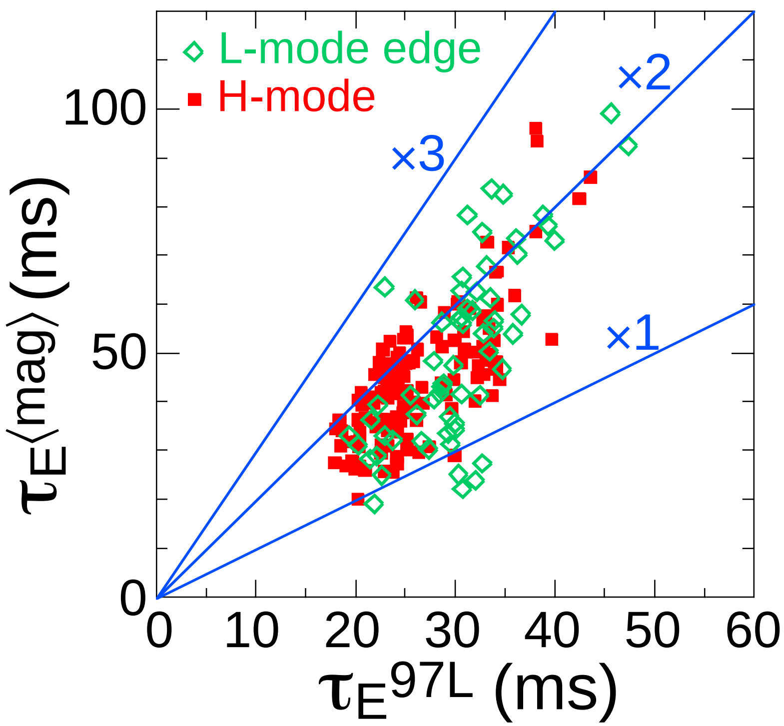
TRANSP calculation using neoclassical resistivity

- $I_{non\text{-}ind}/I_p$ = 0.6
- $I_{bootstrap}/I_p$ = 0.42 (at 0.5s)

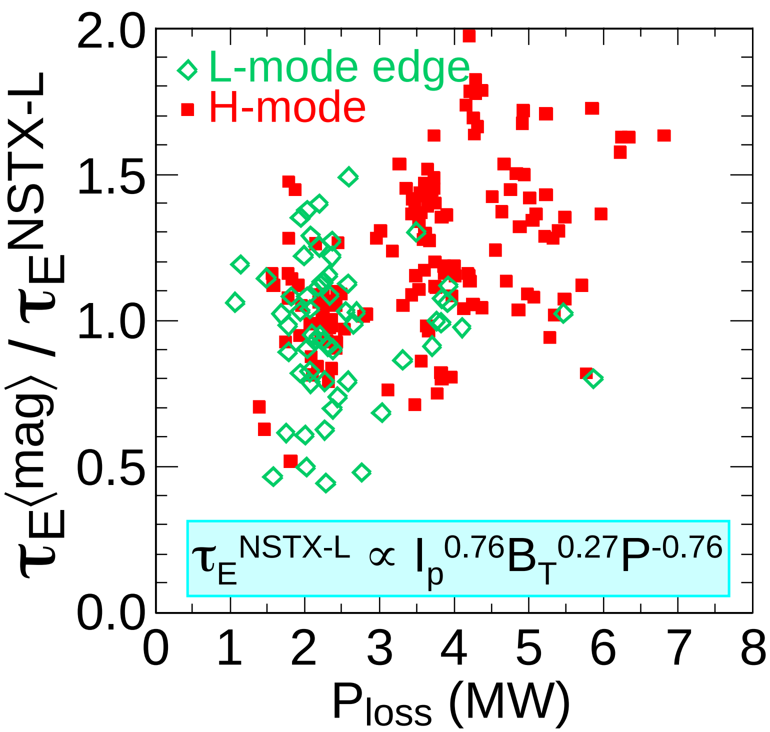
J. Menard, S. Sabbagh

Global Confinement with NBI Exceeds Standard Tokamak Scalings

Both L and H -mode plasmas can exceed ITER-97L scaling



Weaker power degradation in H-mode (~$P^{-0.5}$) than L-mode

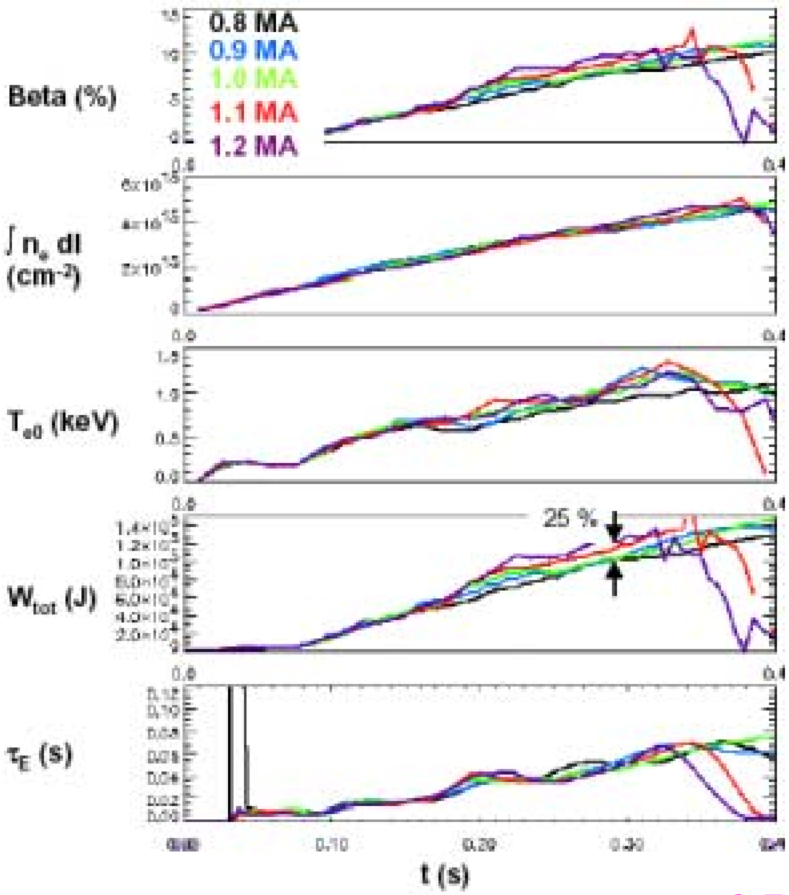


- Confinement times from EFIT near peak W_{tot}
  - include NB *injected* and Ohmic power

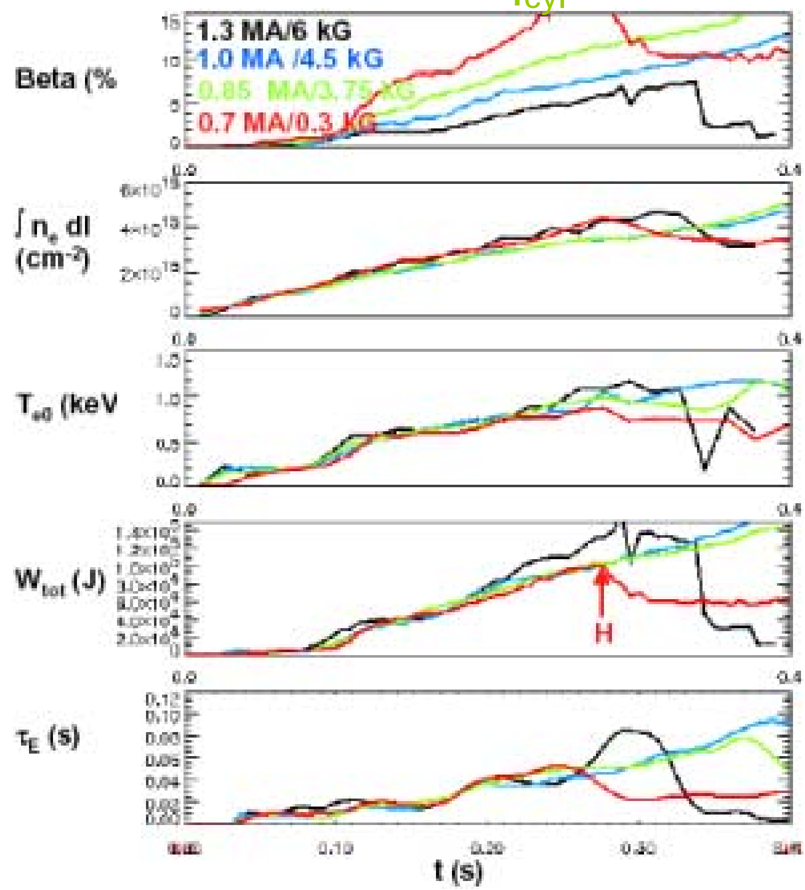
S. Kaye

Weak Dependence on I_p Observed in Transient Plasmas With Rising W_{tot}

Fixed B_T = 0.45T



Fixed q_{cyl}

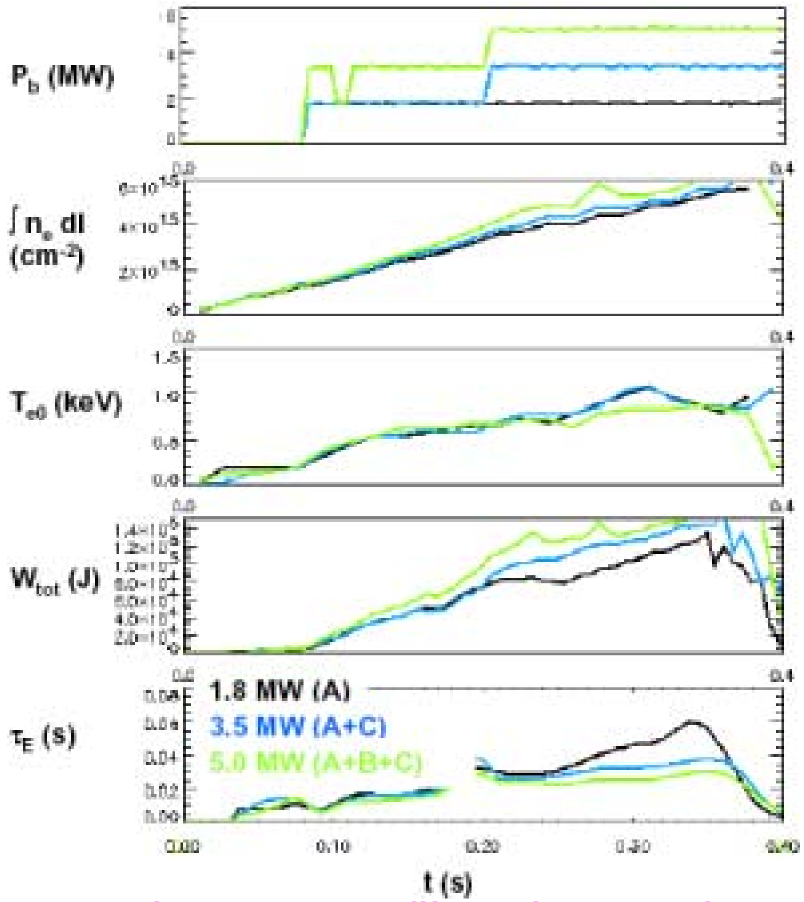


$\Rightarrow \tau_E \propto I_p^{<0.5}$ - w/o orbit loss correction

D. Stutman

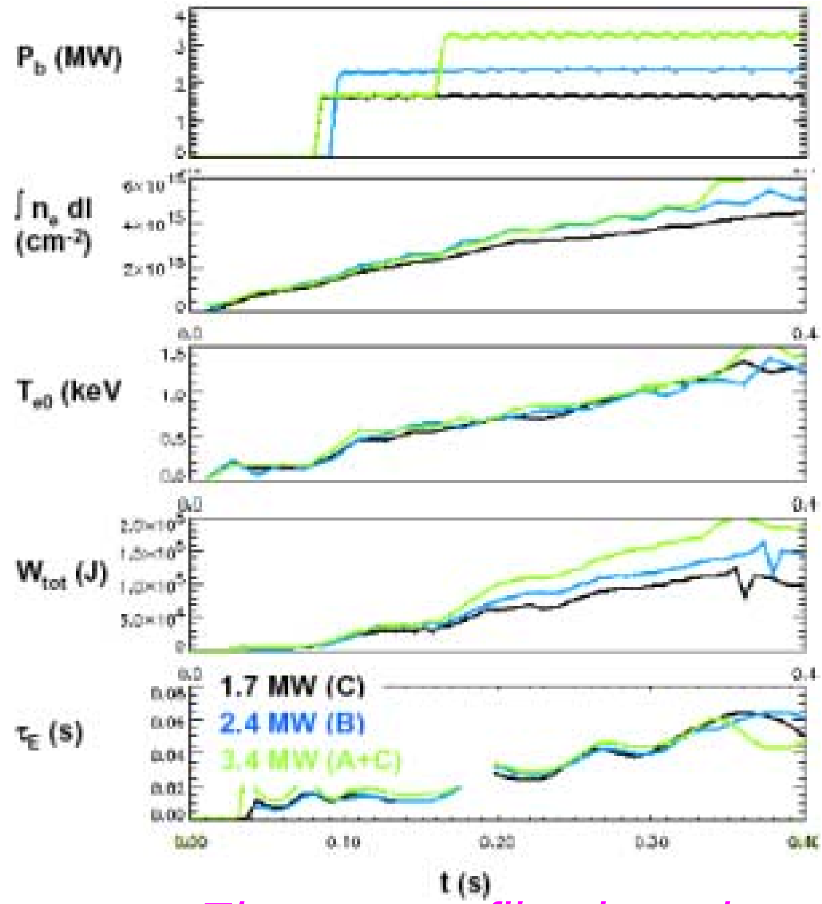
P_{NB} Scans Reveal Complex B_T Dependence

B_T = 0.45T: rapid τ_E degradation



Electron profiles do not change

B_T = 0.6T: small τ_E degradation

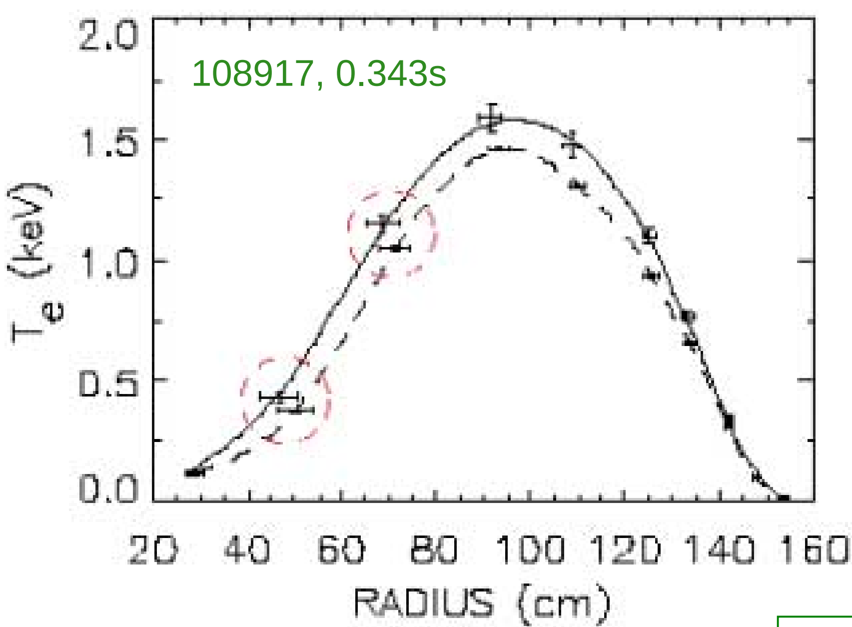


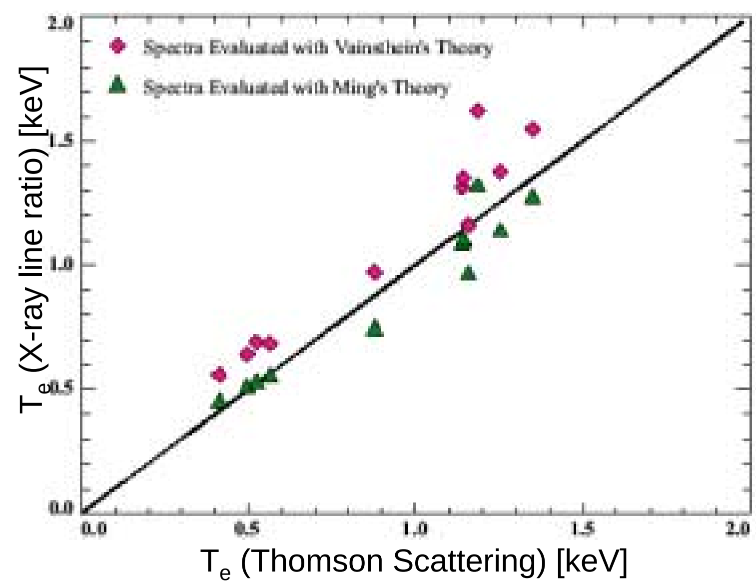
Electron profiles broaden

D. Stutman

Recalibrated Profile Data Available for Kinetic Analysis

- Spectral recalibration of Thomson scattering ⇒ higher T_e
  - –Now agrees with reanalyzed x-ray line ratio data
- Spatial recalibration resulted in slightly broader profile
  - –Line-integral density from MPTS agrees with interferometer
- In-situ calibration of CHERS instrumental width ⇒ slightly lower T_i

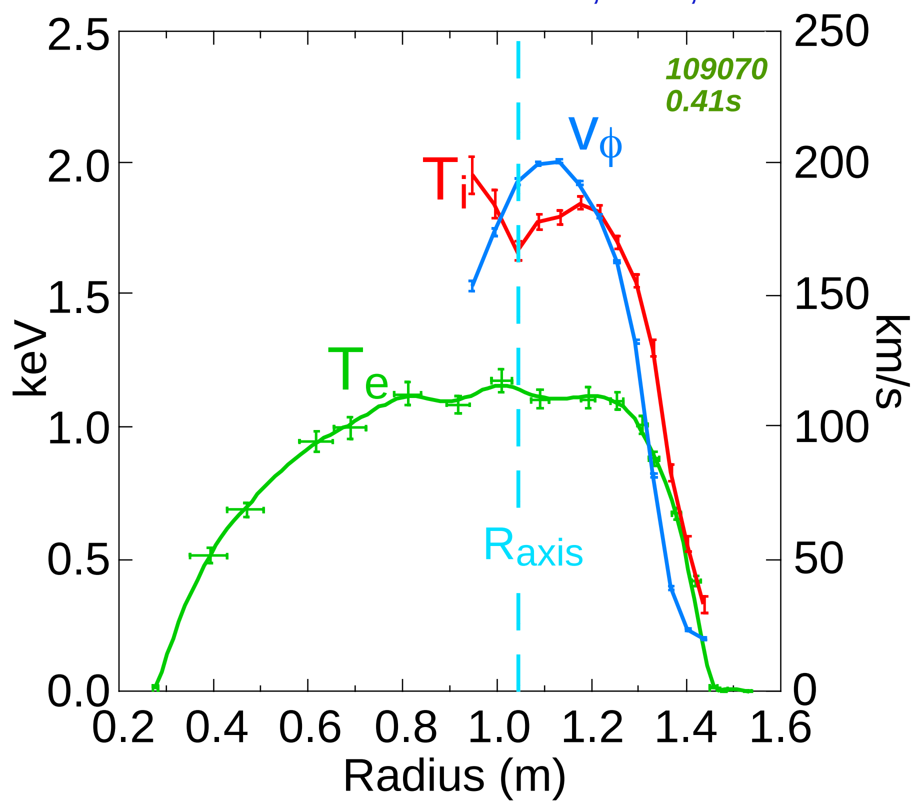




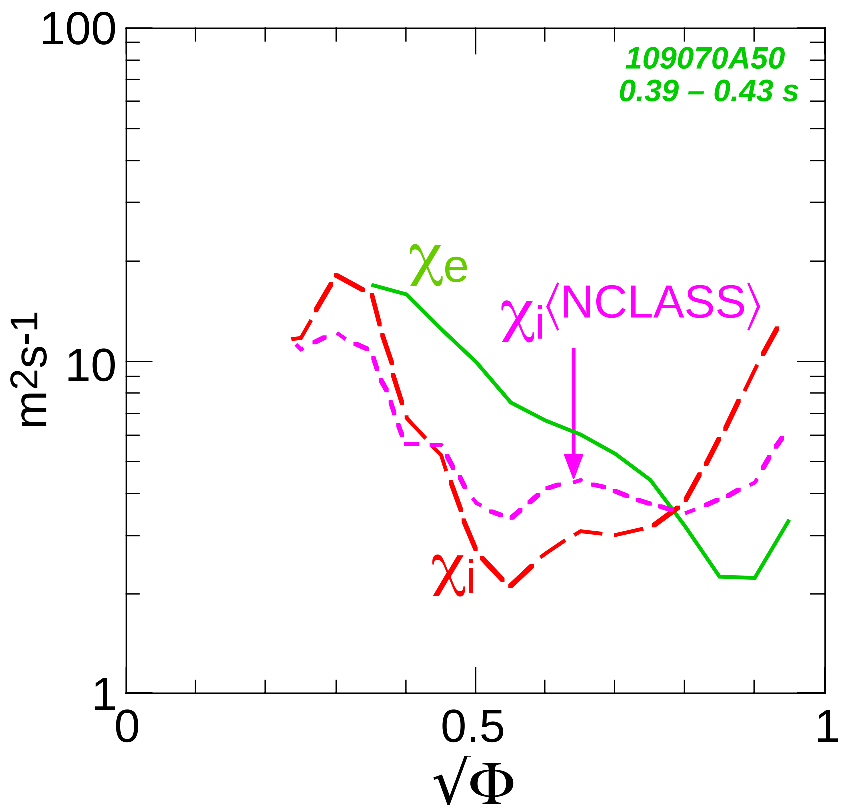
B. LeBlanc, R. Bell, D. Johnson, M. Bitter

Analysis of Power Balance Confirms Low Ion Transport & Shows Unusual Features

$T_i > T_e$ throughout core
although classical $P_{b,i}/P_{b,e} \approx 0.7$



$\chi_i \sim \chi_I^{\langle NCLASS \rangle} < \chi_e$
Diffusivities decrease with r/a



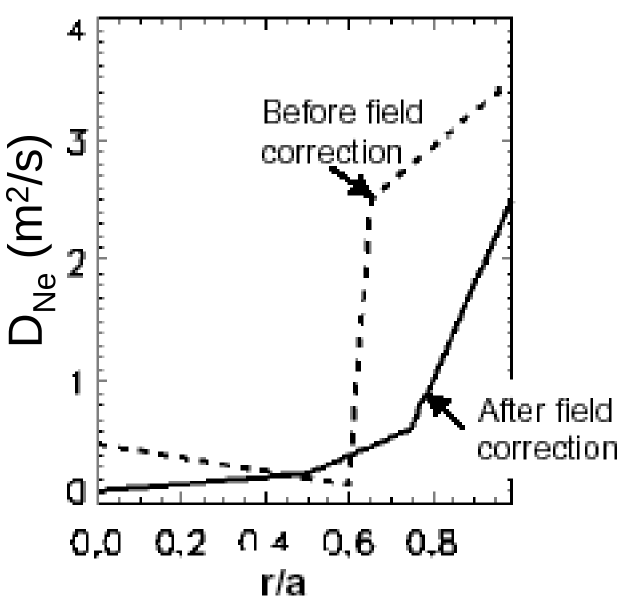
- In some discharges T_i locally exceeds $\chi_I = 0$ prediction

S. Kaye, D. Gates

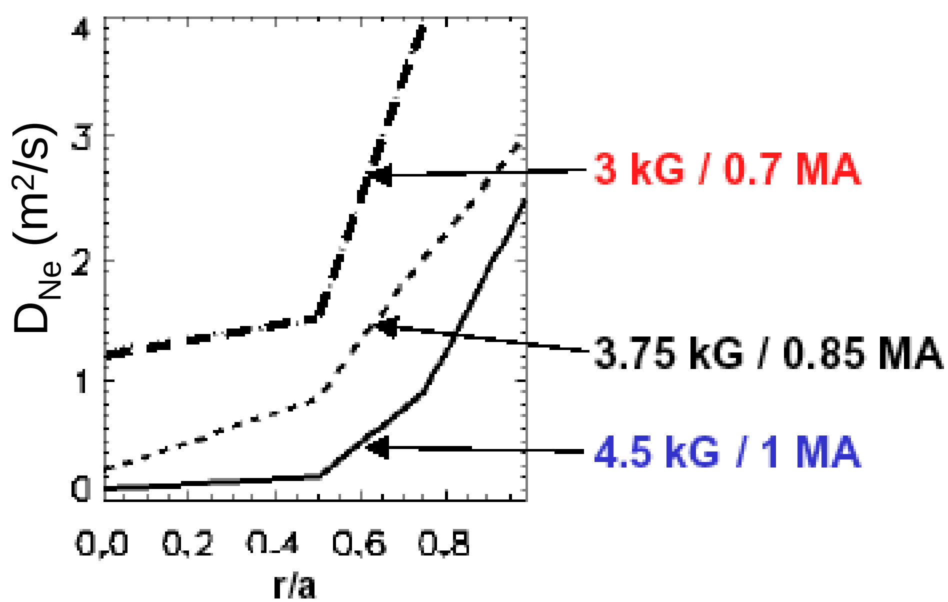
Evolution of X-ray Profiles After Neon Injection Yields Trends in Particle Transport

- Filtered USXR arrays distinguish partially and fully stripped Ne
- Time-dependent analysis with MIST code allows fit for D_{Ne}
  - Solution may not be unique but trends are evident

Reduced edge diffusivity since error field reduced



I_p, B_T scan at const. q_{cyl} shows clear trend in particle diffusivity

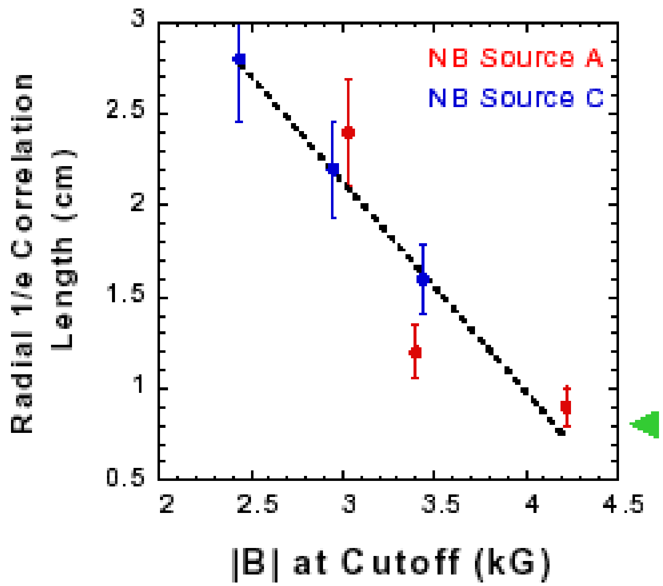


D. Stutman

Correlation Reflectometer Reveals Complementary Change in Fluctuations

- Two-channel swept-frequency reflectometer measures correlation decay length of density fluctuations
- Measures few cm inside the LCFS: 0.90 < r/a < 0.98

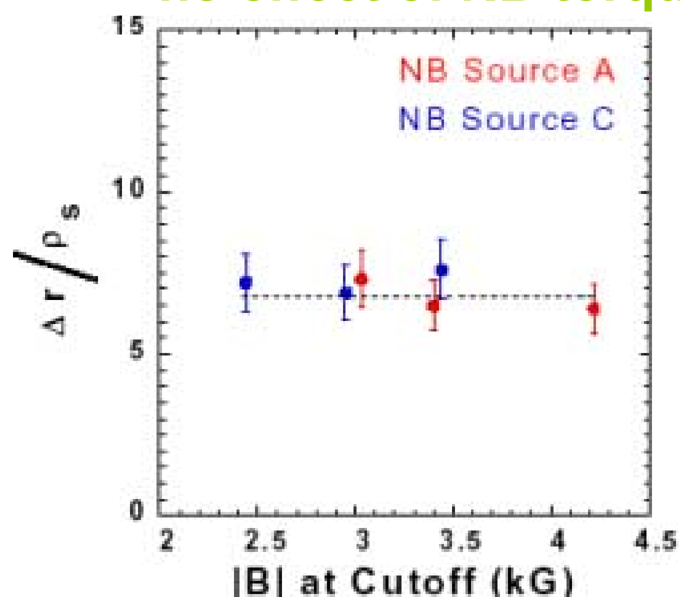
Data for I_p, B_T scan at const. q_{cyl}



Approx. resol'n

Correlation length scales with gyroradius $\rho_s \propto B^{-1}$

- no effect of NB torque

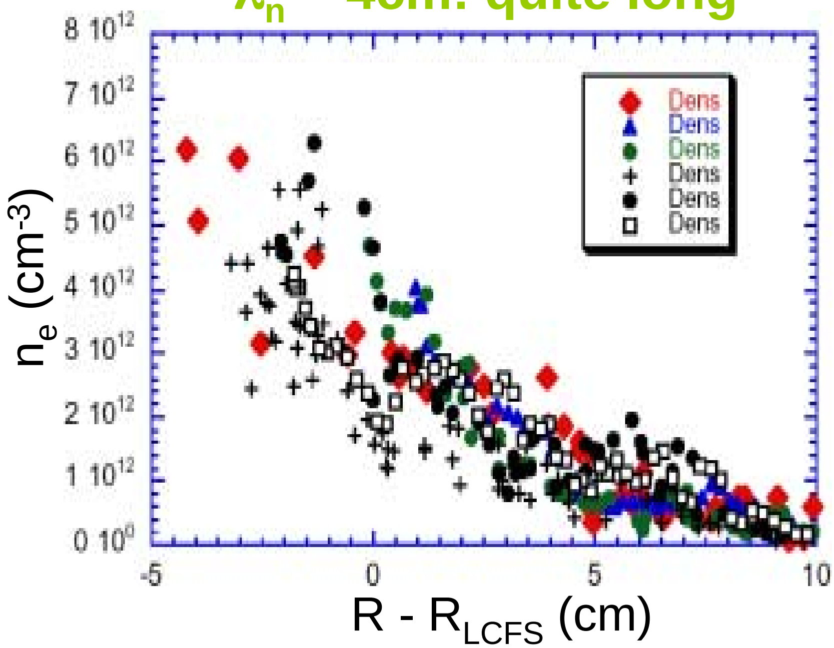


M. Gilmore

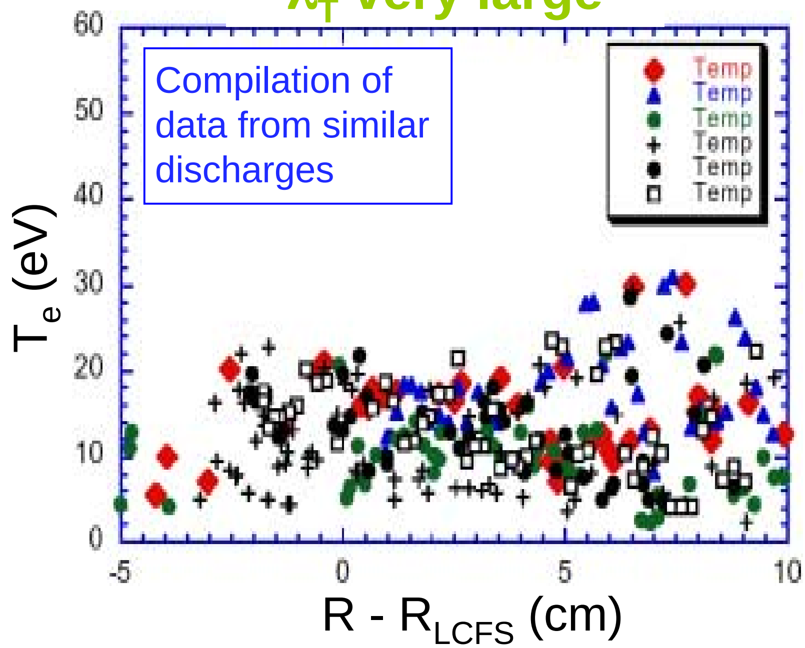
Broad Scrape-off Measured with Fast Reciprocating Probe

- Probe plunges in 100ms up to 4cm inside LCFS (EFIT)
- Measure T_e, n_e, V_f profiles and fluctuations to 1MHz

n_e at LCFS: 3 - 4 10^{12}cm^{-3}
λ_n ~ 4cm: quite long



T_e at LCFS ~20eV
λ_T very large



- Scrape-off appears to steepen in H-mode phases

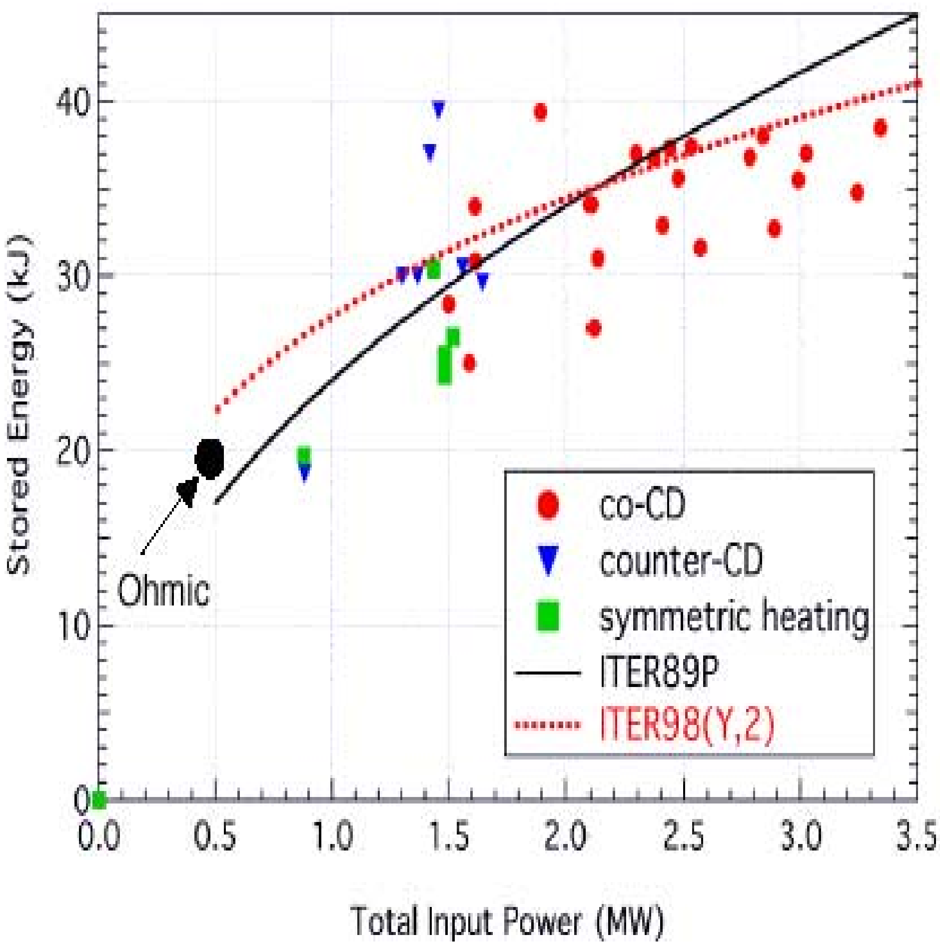
J. Boedo

Technical Aspects of HHFW Performance

- Full phase feedback system worked very well
  - Phases set to arbitrary waveforms between shots
  - Needed to launch directed waves for current drive
- Power limited to < 3MW throughout run
  - During recent opening, found evidence of arcing in all feedthroughs
  - Modified center conductors to reduce electrical stress

R. Wilson, D. Swain

HHFW Heating Not Yet as Effective as NBI



- Compare measured plasma energy increase with ITER scaling for plasma conditions

  I_p=0.5MA, B_T=0.45T, H=1
- Current-Drive antenna phasings ⇒ $\mathbf{k}_{||} \approx \pm 7\text{m}^{-1}$;
  - optimum CD $T_e(0)$ ~ 1.2keV
- Heating phasing ⇒ $\mathbf{k}_{||} \approx 14\text{m}^{-1}$
- Heating quite variable
- Power limited by antenna standoff

P. Ryan

CHI Hardware Modified to Address Technical Problems in 2002 Run

- Improved absorber with long ceramic insulator
  - Similar to successful HIT-II design
- Absorber field control PF coils being installed
  - Design and construction of fast chopper power supplies at University of Washington
- Redesigned snubber circuits to suppress voltage excursions in external circuit
- Improving noise immunity of magnetic diagnostics
- Working on plasma control system to be able to implement CHI control

Achieved Good Progress in 2002

- New facility and diagnostic capabilities added
  - Routine H-mode operation
  - Upgraded profile measurements
- Broadened operating space and increased pulse length
- Significantly increased β and studied associated MHD
  - Detailed studies of β-limiting MHD and fast-particle modes
- Global confinement continues to show interesting trends
  - Ion confinement is good but power balance presents some puzzles
- Beginning studies of edge and scrape-off
- Developing HHFW capabilities for current drive
- Addressing some technical issues for studies of CHI