NSTX

Highlights of FY'02 Experiments

M.G. Bell

presented on behalf of

R. Maingi, FY'02 Run Coordinator

and the NSTX Research Team

NSTX PAC-13, Sep 30 – Oct 1, 2002

Los Alamos NATIONAL LABORATORY

NOVA PHOTONICS, INC.

ornl

Sandia National Laboratories

UCLA

UCSD

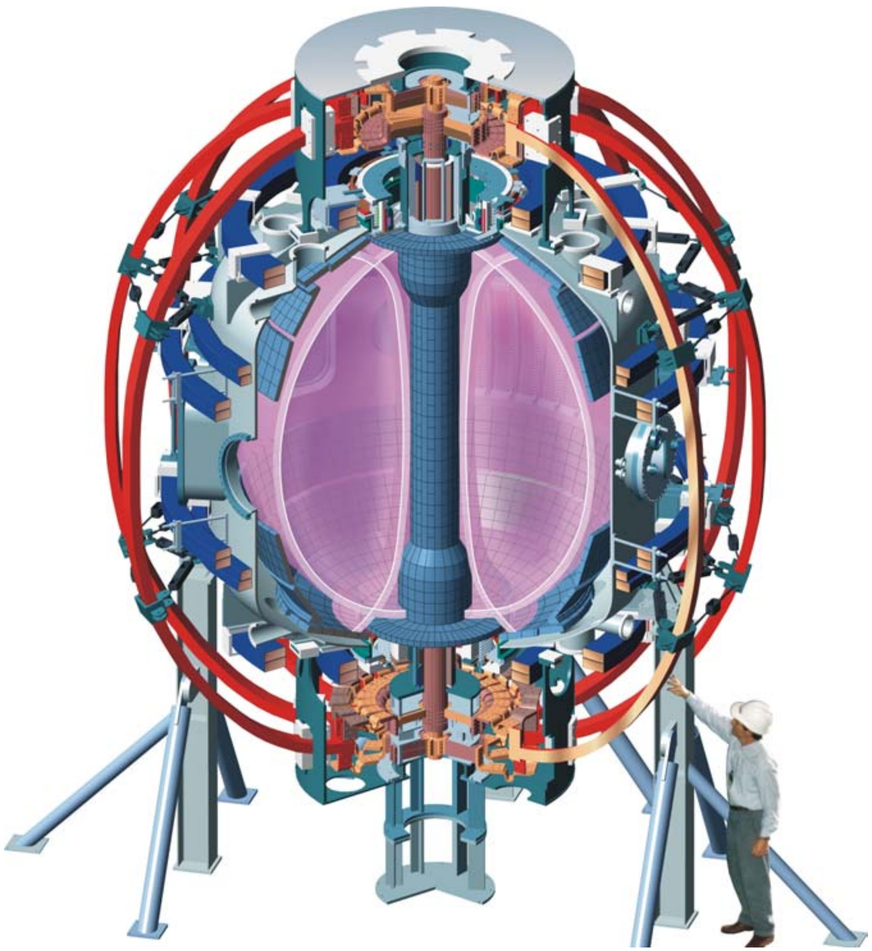
UW

PPPL PRINCETON PLASMA PHYSICS LABORATORY

The Future of Energy on Earth is the Energy of the Stars Fusion Energy

United States Department of Energy

Further Improvements in Capability Benefited Research in FY'02

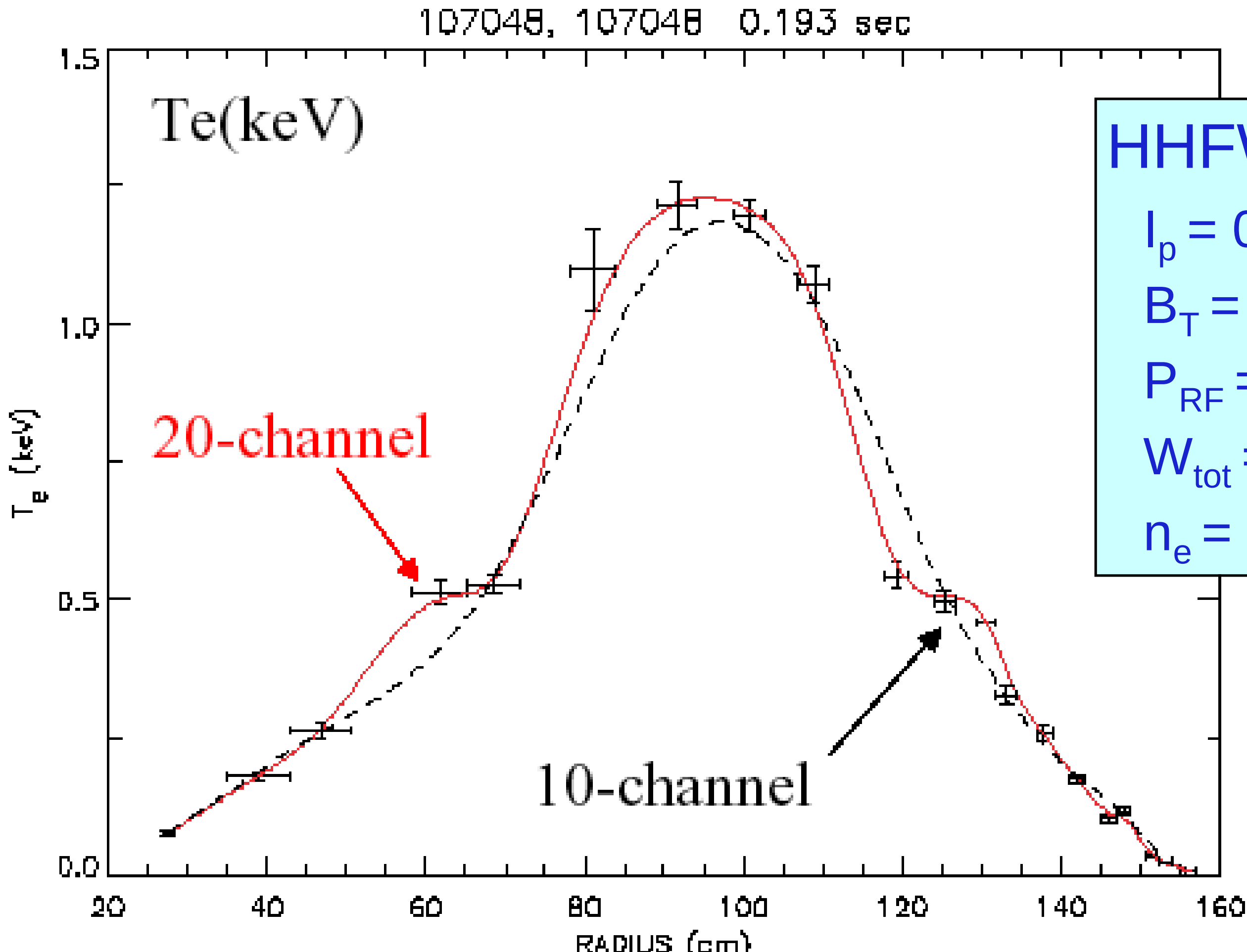


Parameters	Design	Achieved (FY'02)
PFC bakeout	350°C	***350°C***
Gas fueling	LFS	***HFS***
Aspect ratio	1.27	1.27
Elongation	2.2	2.5
Triangularity	0.6	***0.8***
Plasma Current	1MA	1.4MA
Toroidal Field	0.6T	***0.6T***
Heating and Current Drive		
Induction	0.6Vs	0.6Vs
NBI ***(100kV)***	5MW	***7 MW***
HHFW (30MHz)	6MW	6 MW
CHI	0.5MA	0.4MA
Pulse Length	5s	***1s***

New and Upgraded Diagnostics Also Facilitated Detailed Experiments

- 20 channel MPTS at 2 × 30 Hz
- Spatial scanning capability for NPA
- Fast Reciprocating Probe for edge studies
- 2 channel interferometer/polarimeter (FIReTIP)
- Fast and ultra-fast visible cameras for edge fluctuations
- Microwave reflectometers for edge, core fluctuations
- 2-D gas-electron-multiplier x-ray detector
- Prototype divertor bolometer (4 ch)
- Fast Mirnov channels
- Routine “partial kinetic” EFIT analysis
  - measured diamagnetism & pressure profile shape from MPTS
- Between-shots analysis of stability with DCON
  - RWM detection and correlation with rotation slowdown

20-Channel T_e Profiles Reveal New Structure



HHFW heating

- I_p = 0.8MA
- B_T = 0.45T
- P_{RF} = 1.4MW
- W_{tot} = 38kJ
- $n_e = 2.0x10^{19}m^{-3}$

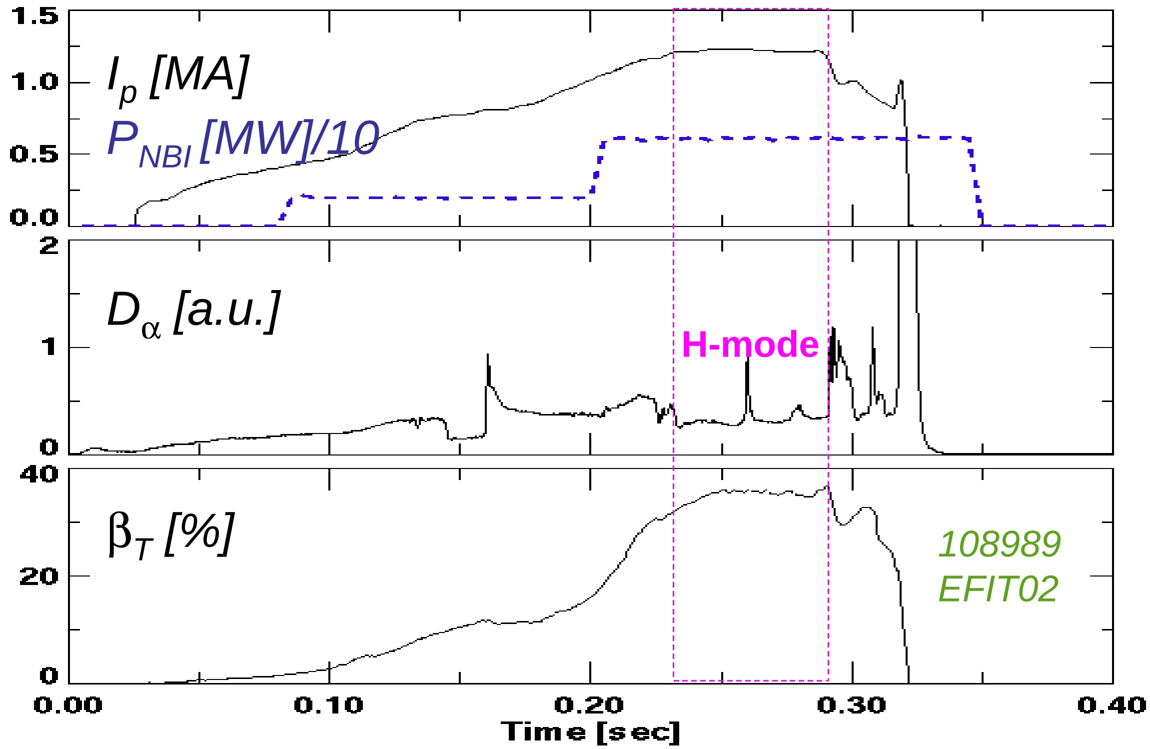
B. LeBlanc

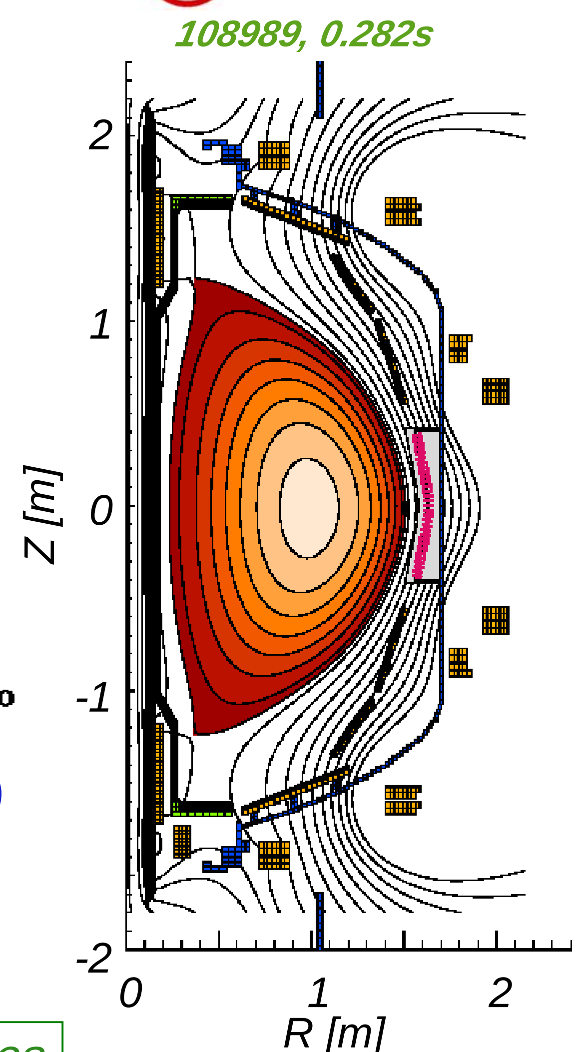
FY'02 Research Organized Into Six Experimental Task (ET) Groups

- **MHD**
  - Jon Menard, Eric Fredrickson
- **HHFW/EBW**
  - Randy Wilson, David Swain *[ORNL]*
- **Transport & Turbulence**
  - Doug Darrow, Dan Stutman *[JHU]*
- **Boundary Physics**
  - Henry Kugel, Charles Bush *[ORNL]*
- **Coaxial Helicity Injection**
  - Roger Raman *[UW]*, Dennis Mueller
- **Integrated Scenario Development**
  - David Gates, Steve Sabbagh *[CU]*

Run Coordinators: Rajesh Maingi *[ORNL]*, Stan Kaye

Achieved Substantial Progress in β_T

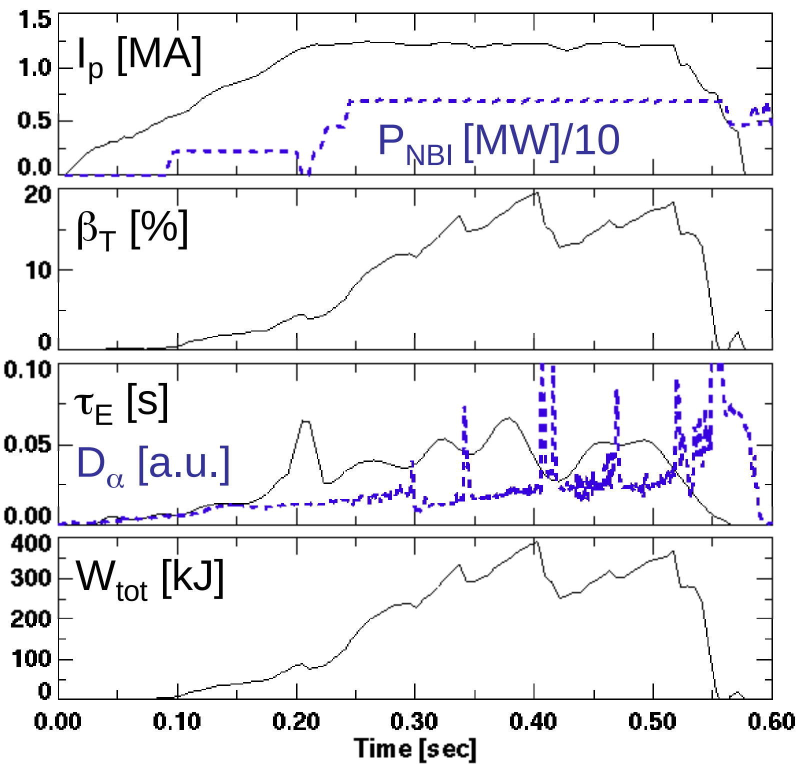


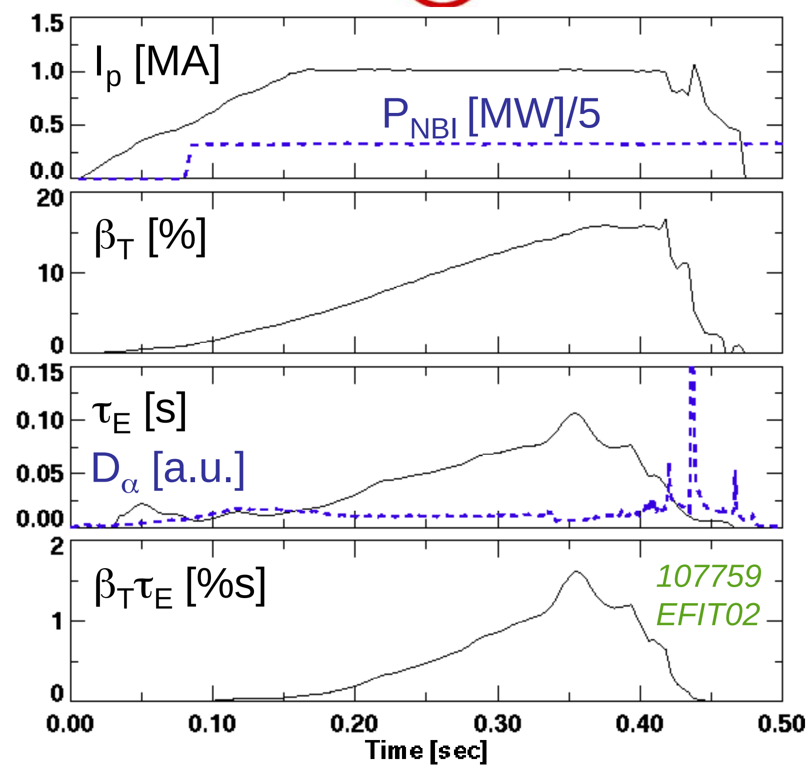


- β_T = 34% (EFIT including ϕ_{dia} and p_e profile)
- $B_T = 0.3T$, $A = 1.4$, $\kappa = 2.0$, $\delta = 0.8$
- $l_i = 0.6$, $q_0 \approx 1.4$
- H-mode broadens pressure profile

D. Gates

Also Produced Highest Stored Energy and $\beta_T \times \tau_E$





- W_{tot} = 390kJ
- B_T = 0.55T, β_T = 20%
- $\beta_T \times \tau_E$ = 1.2%·s
- B_T = 0.4T
- Achieved $\beta_N \times H_{89L}$ > 12 for $8 \times \tau_E$
- Higher B_T decreases β *but lengthens pulse*

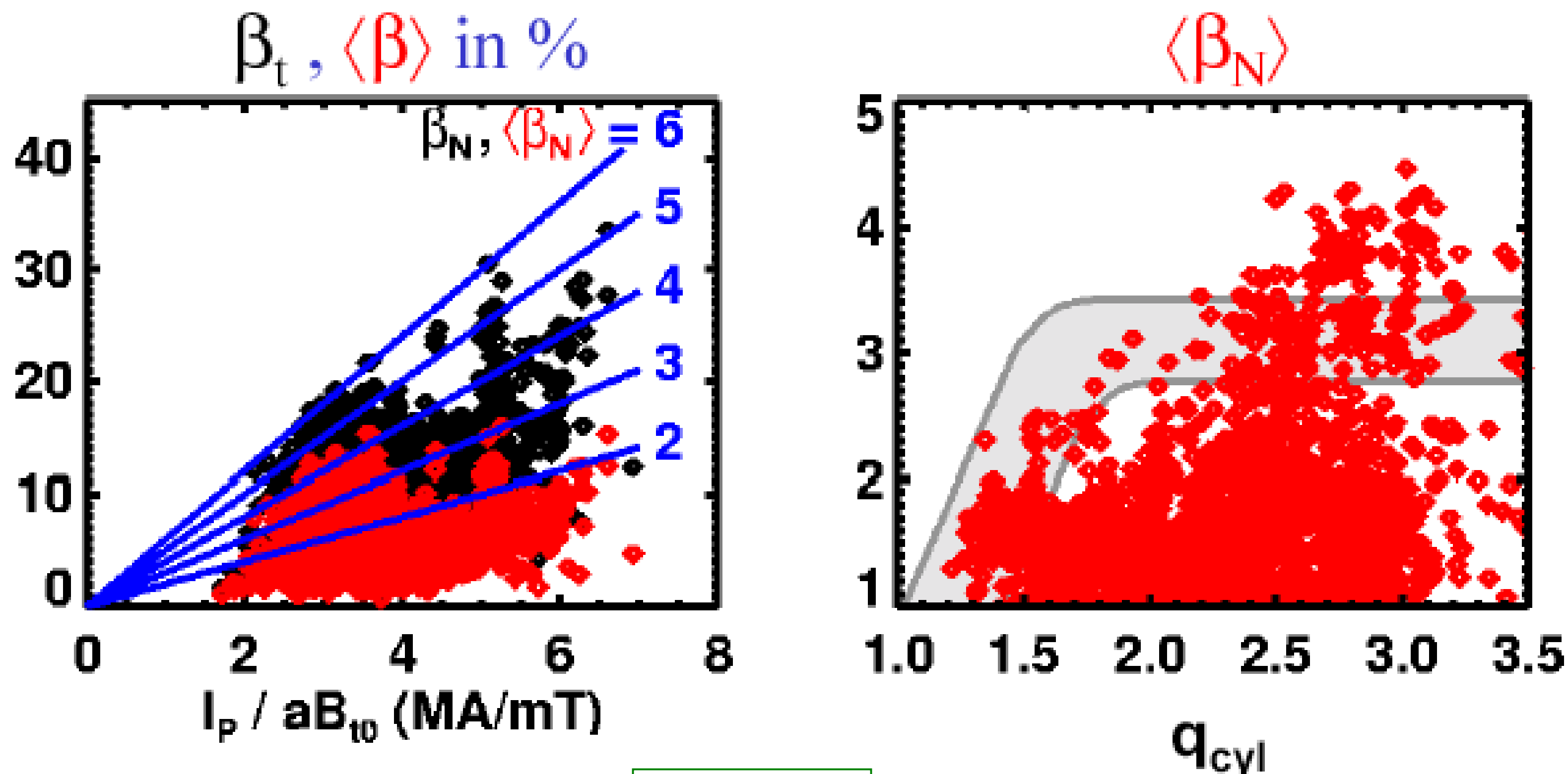
D. Gates , R. Maingi

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

NSTX

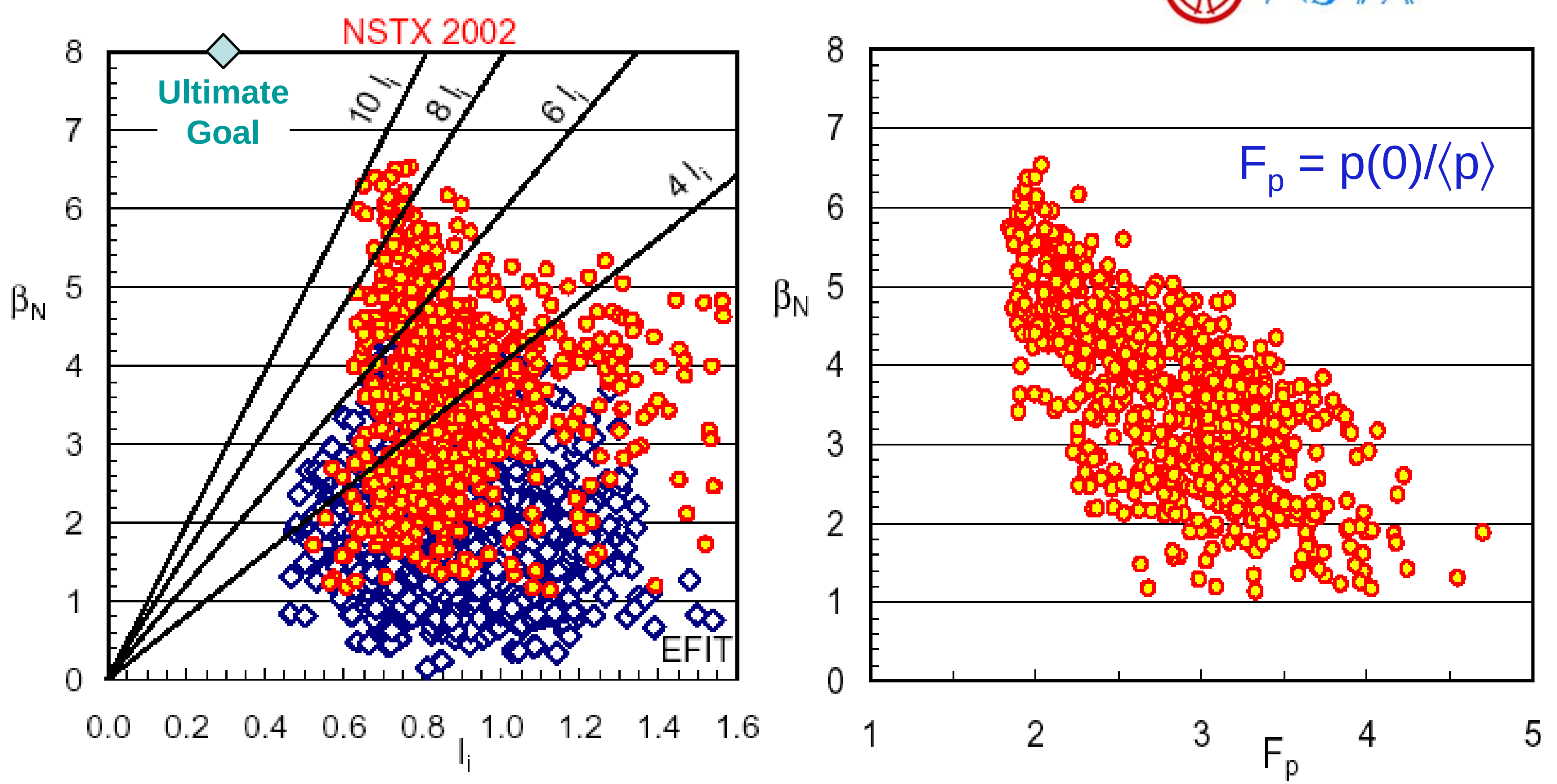
$\beta_t = 2\mu_0\langle p\rangle/B_{T0}^2$ $\langle\beta\rangle = 2\mu_0\langle p\rangle/\langle B^2\rangle$

Range of limits varying A, κ, δ



J. Menard

Achieved Good Progress Towards β_N Goal



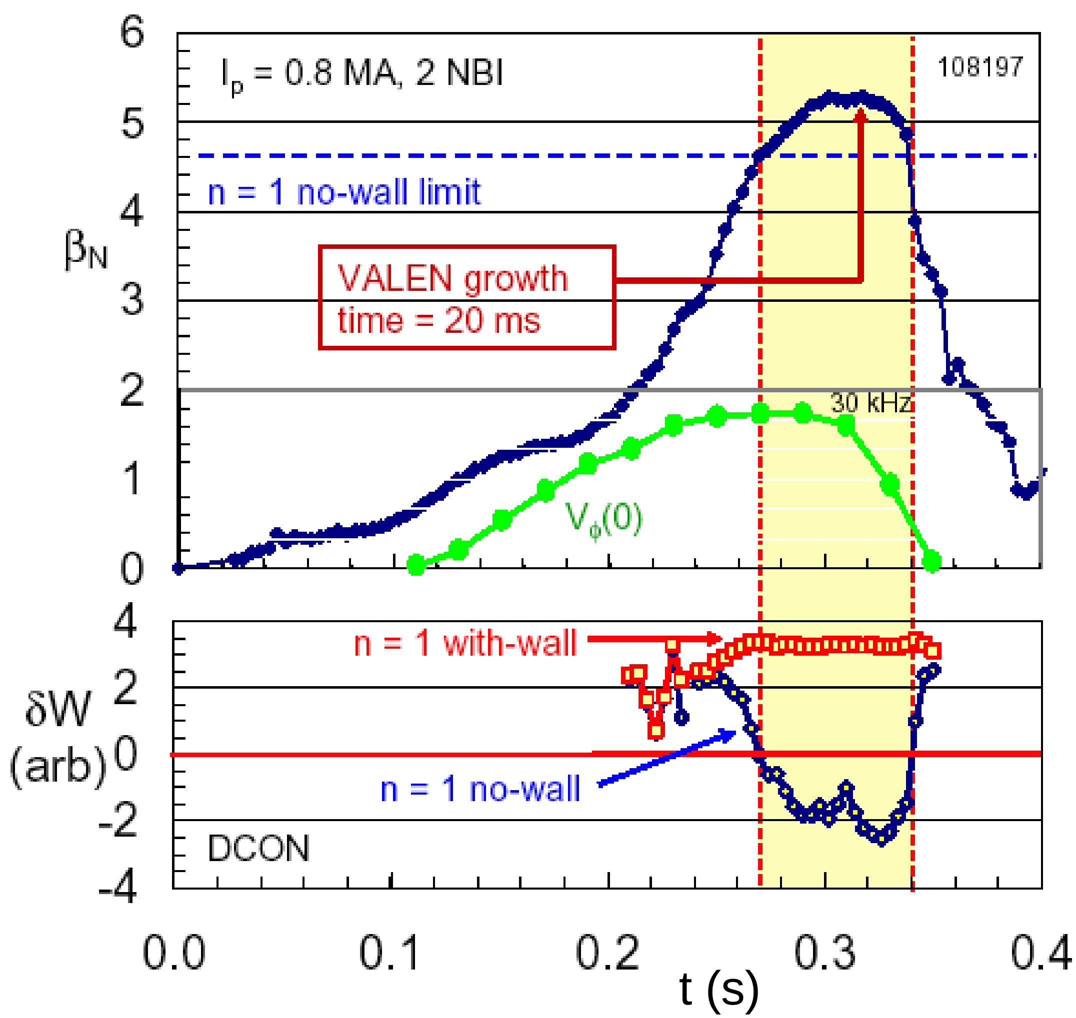
- Exceeded 2001 empirical limit ~ 6 l_i
- Well into wall-stabilized regime
- Pressure peaking factor from EFIT
- Continues well known trend

S. Sabbagh, F. Paoletti

Factors Contributing to Sustained Higher β_N Operation

- Reduction of static error field
  - Realignment of PF5 coils reduced n = 1 component by factor >10 across most of profile
  - Reduced incidence of locked modes at low β
  - May have reduced rotation damping
- Maintaining $q_{min} > 1$ for longer
  - Caveat: conclusion based on EFIT q profiles
  - Previous high-β plasmas collapsed when $q_{min} \leq 1$
  - Maintaining $q_{min} > 2$ at higher B_T decreases rotation damping
- H-mode broadened profiles
  - $F_p = p(0)/\langle p \rangle < 1.9$ (EFIT)
  - Full kinetic (p_e, p_i, p_{fi}) analyses underway to confirm

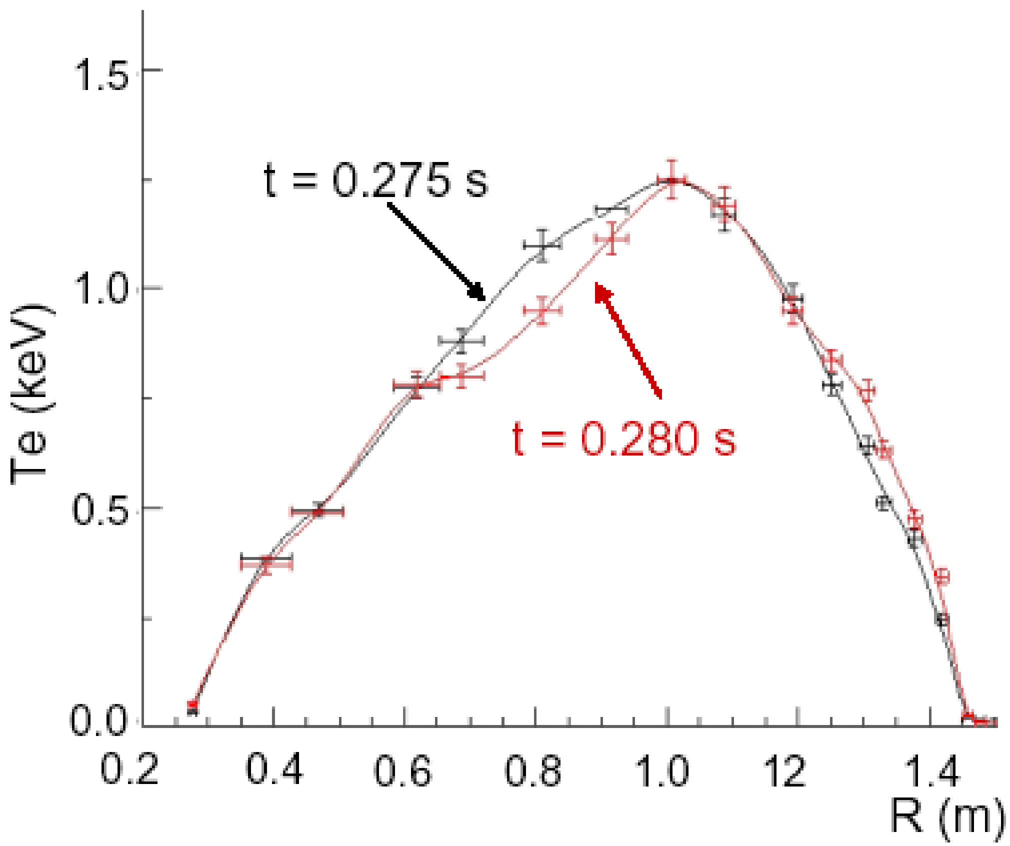
Analysis Shows Wall Stabilization Effective with Sufficient Rotation

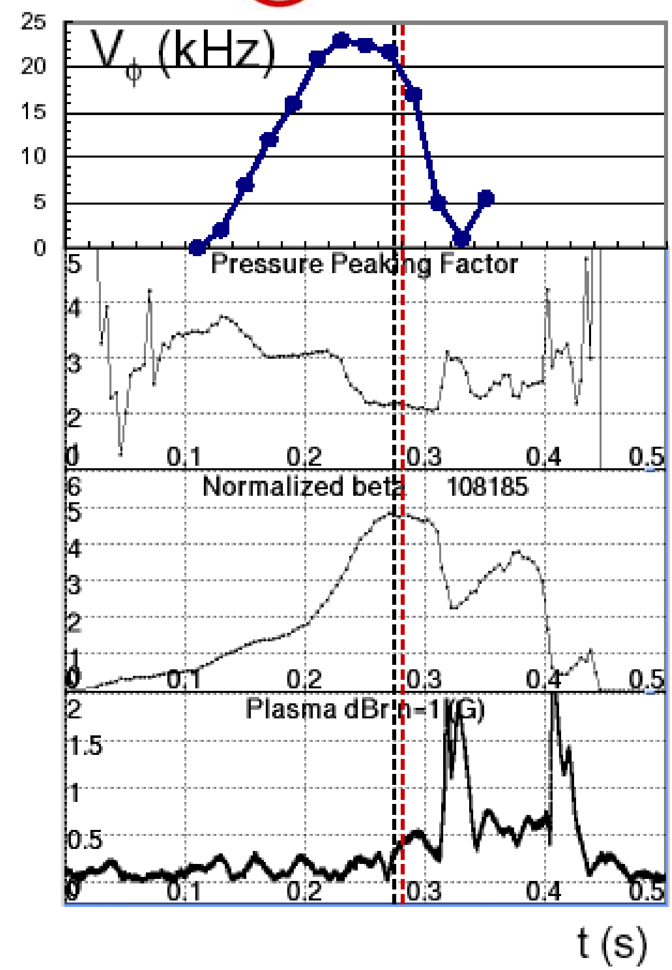


- β collapse after $\sim 3.5\times\tau_{wall}$
  - Exceeded no-wall limit for up to $\sim 20\times\tau_{wall}$ in best case
- VALEN shows effective coupling of mode to wall
  - Coupling becomes less effective at higher β_N
    - Perturbation shifts from outboard side towards divertor region
- Collapse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

S. Sabbagh, J. Bialek

T_e Profiles Reveal Kink-like Displacement During RWM

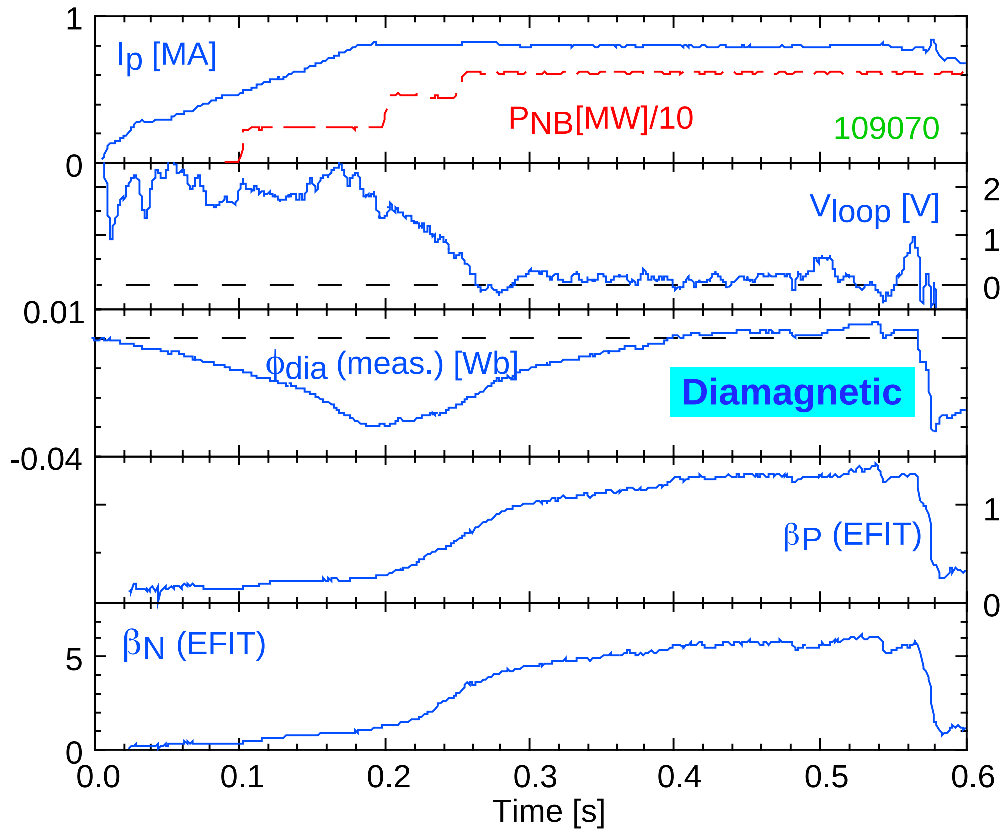




- Syncopated operation of MPTS lasers

S. Sabbagh, B. LeBlanc

Created Diamagnetic Plasma With β_N/l_i = 10



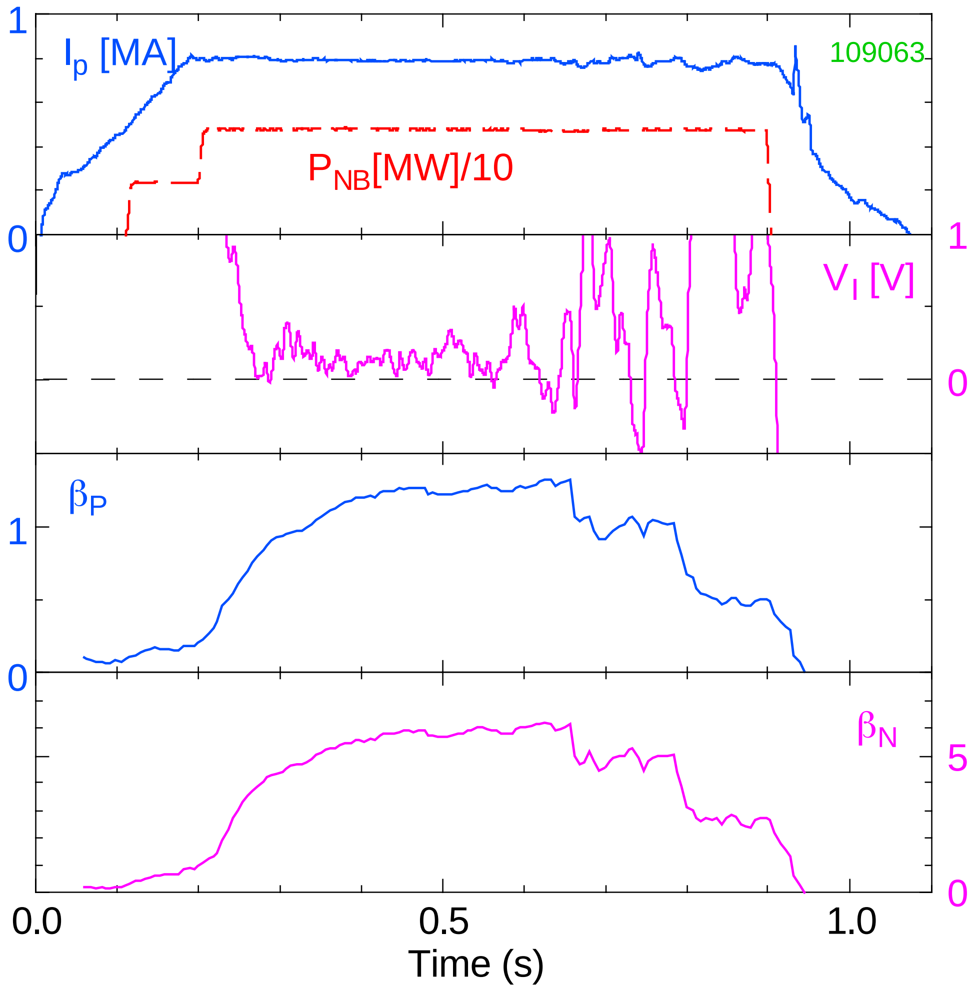
- ϕ_d = +5mWb
- "Partial kinetic" EFIT
  - β_P = 1.4
  - β_N = 6.2
  - l_i = 0.6
- $V_{loop} \approx$ 0.1V
  - for ~0.3s

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

Achieved 0.8MA Pulse with 1s Duration, 0.7s Flattop

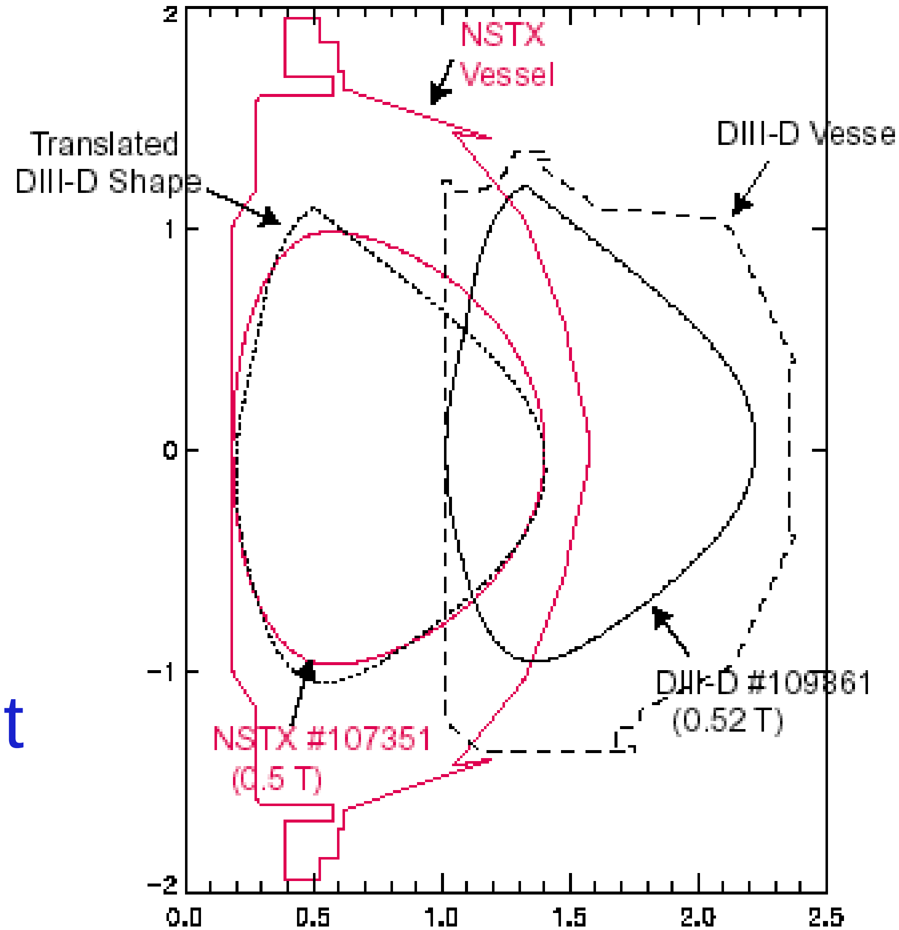


- B_T = 0.5T to 0.95s
- NB-A,B 100kV NB-C 80kV
  - Extra current drive appears beneficial
- W_{tot} collapses by 0.75s in all similar shots
  - largely internal

J. Menard

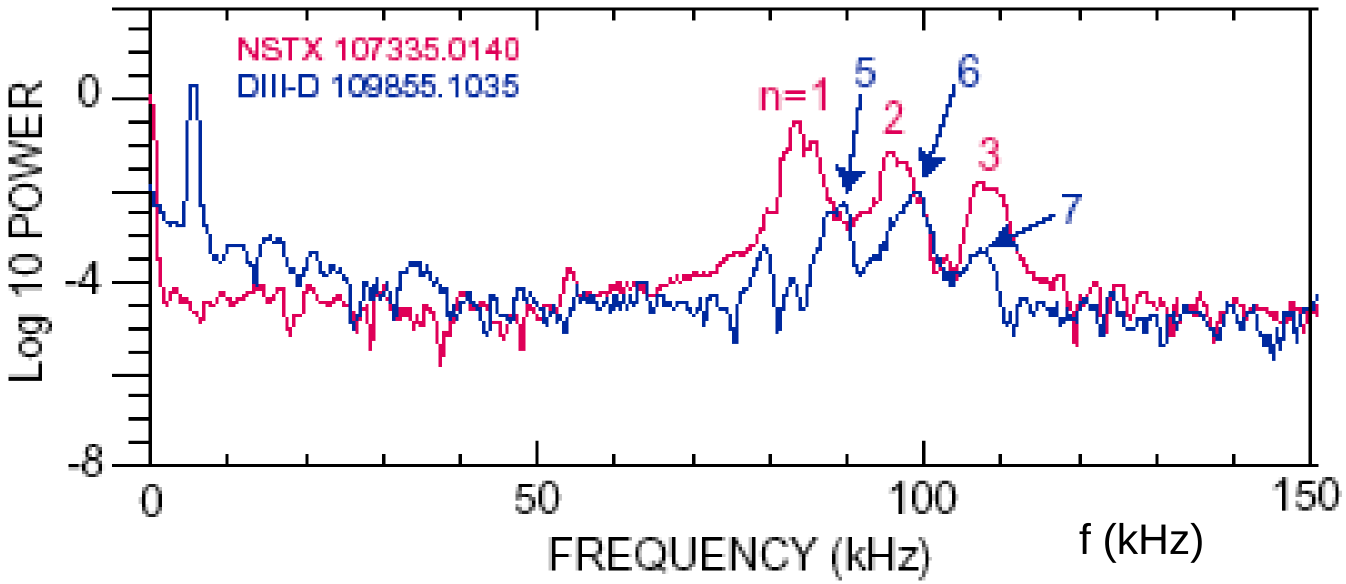
Conducted a Similarity Experiment with DIII-D on Alfvén Modes

- Matched NSTX field and shape in DIII-D
  - B_T = 0.5T - not fully optimized in DIII-D
- Similar NB systems
  - ⇒ match $v_{beam}/v_{Alfvén}$
- Study R-dependence of threshold, dominant mode numbers



W. Heidbrink

Observe "Classic" TAE Features

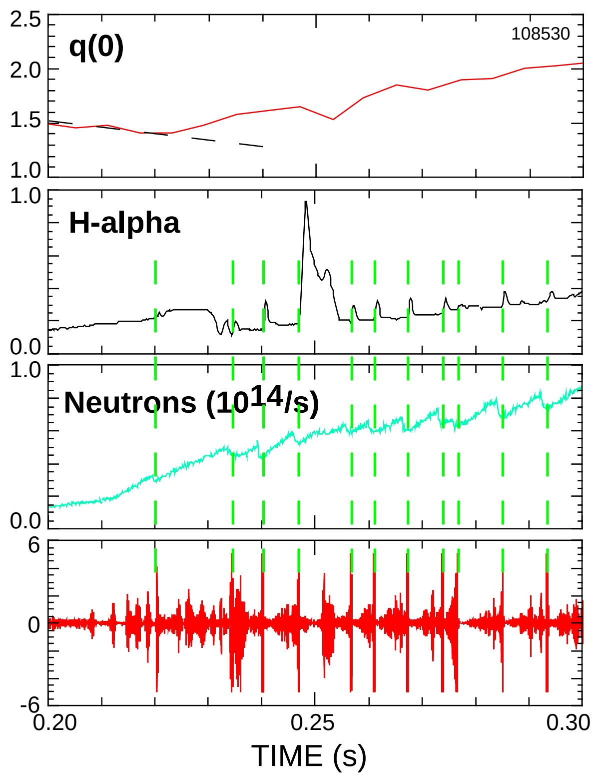


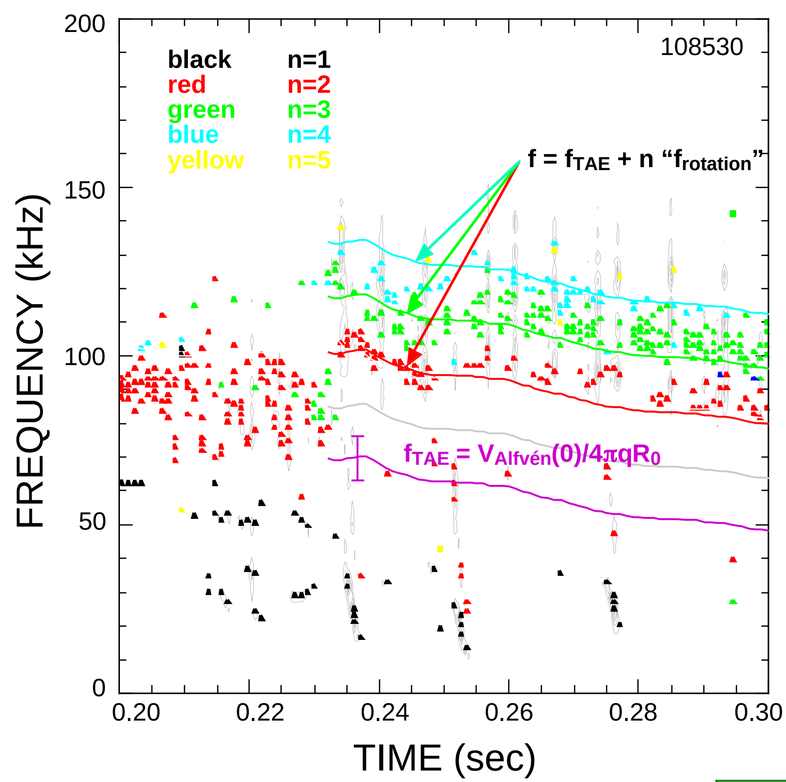
- Toroidal mode number higher in DIII-D than NSTX
  - Expected from theory
- Analyzing threshold dependence on $\beta_{\text{fast-ion}}$
- Observe other high-frequency features in NSTX spectrum

W. Heidbrink

Observed New Bursting Instability in TAE Range

- Accompanied by fast-ion losses and H_α spikes
- Most evident in H-mode plasmas with q(0) > 1
  - First bursts can precede H-mode transition



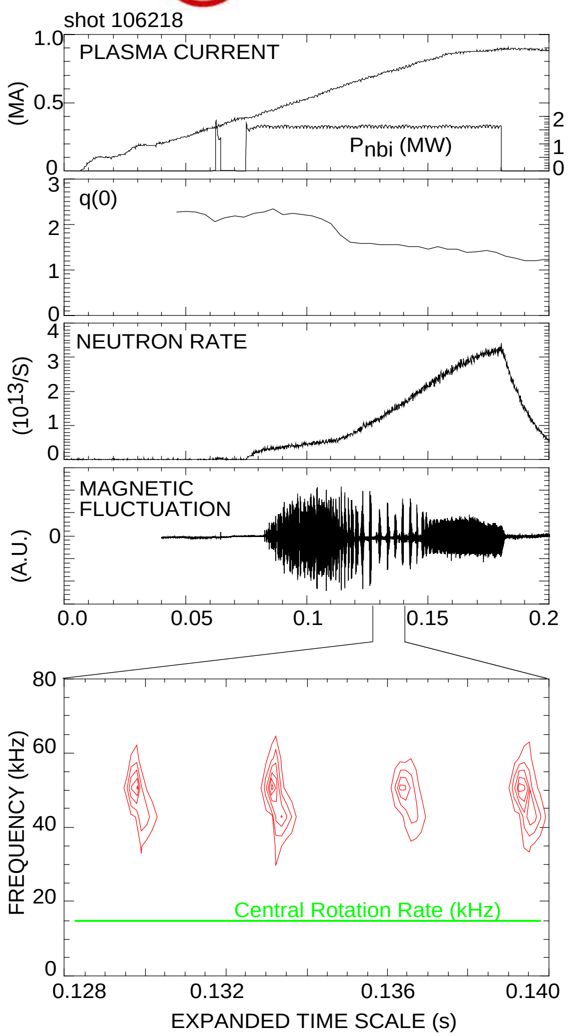


Multiple modes burst at same time

E. Fredrickson

New Fishbone Instability Identified

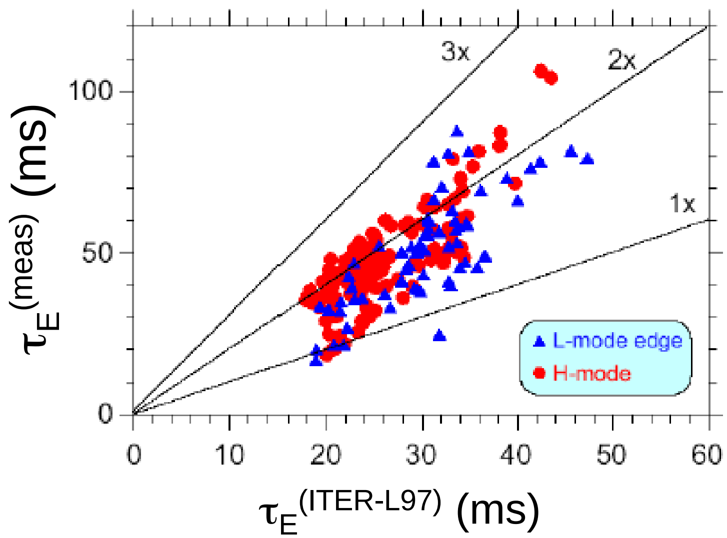
- Theory suggests instability driven by trapped ions with large bounce angle
- Range of mode frequencies suggests resonance with bounce frequency of lower energy beam ions
  - Calculate bounce frequencies for fast ion distribution modeled by TRANSP
  - No effect of bursts on neutron rate

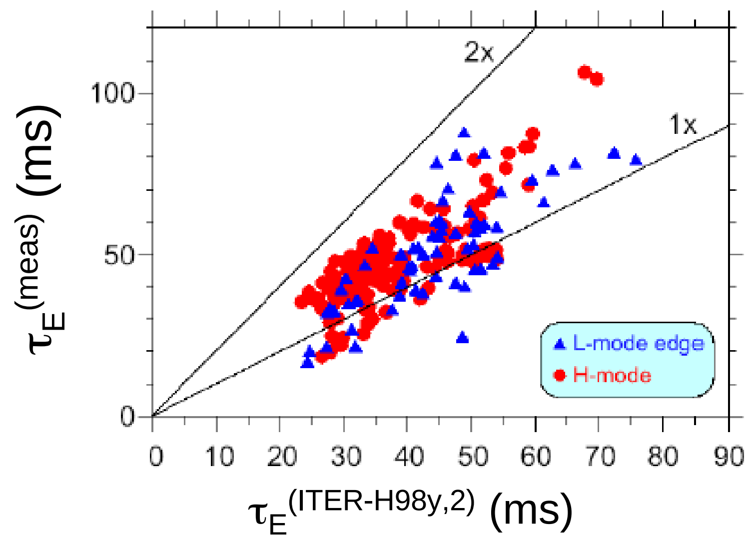


E. Fredrickson

Global Confinement Continues to Exceed Conventional Scalings

- Magnetic data only (EFIT01)
- Include Ohmic and injected NB power
  - No RF heated discharges in this data set
- Data from near maximum in stored energy
  - Exclude highly transient discharges

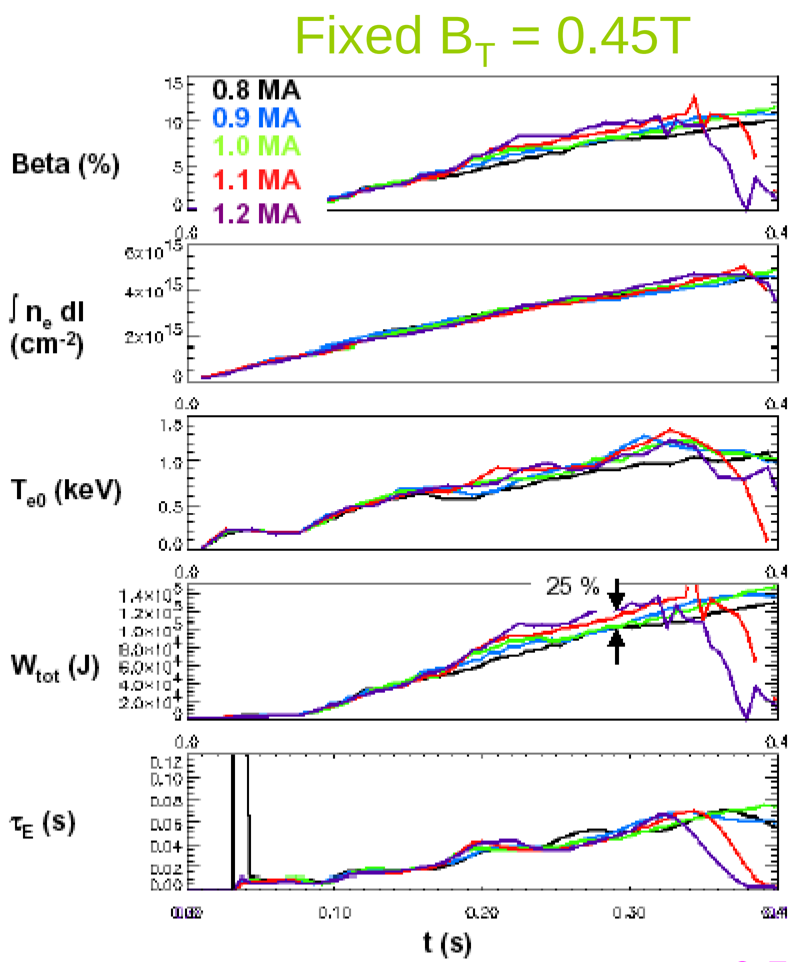


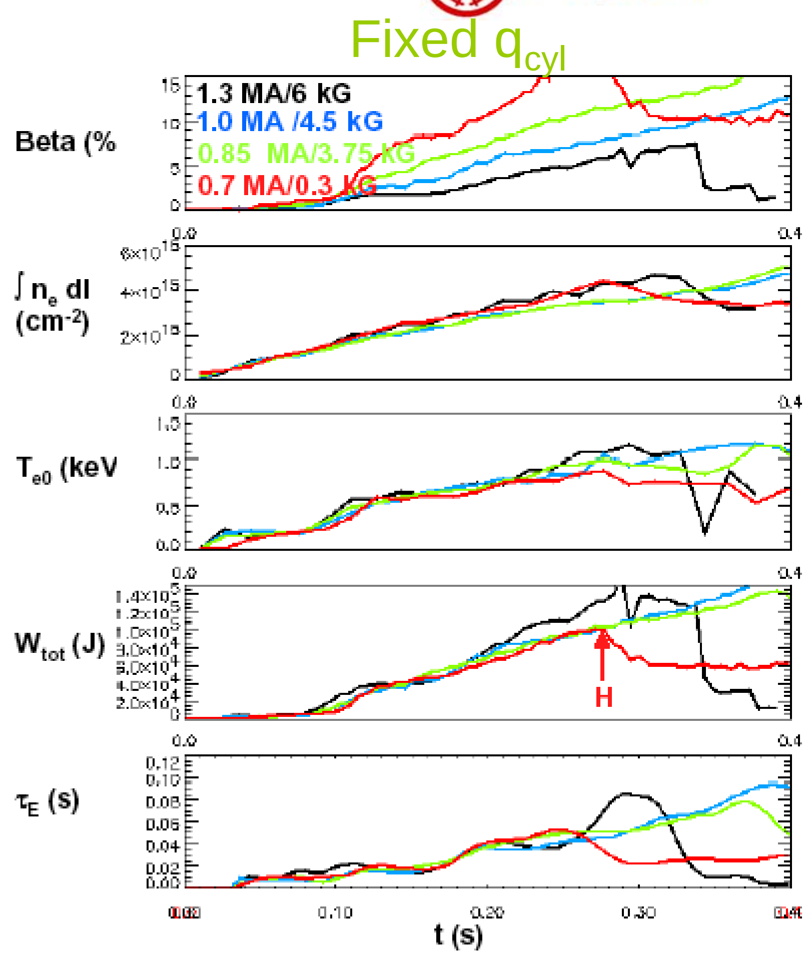


Single parameter scans reveal intriguing trends

S. Kaye

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





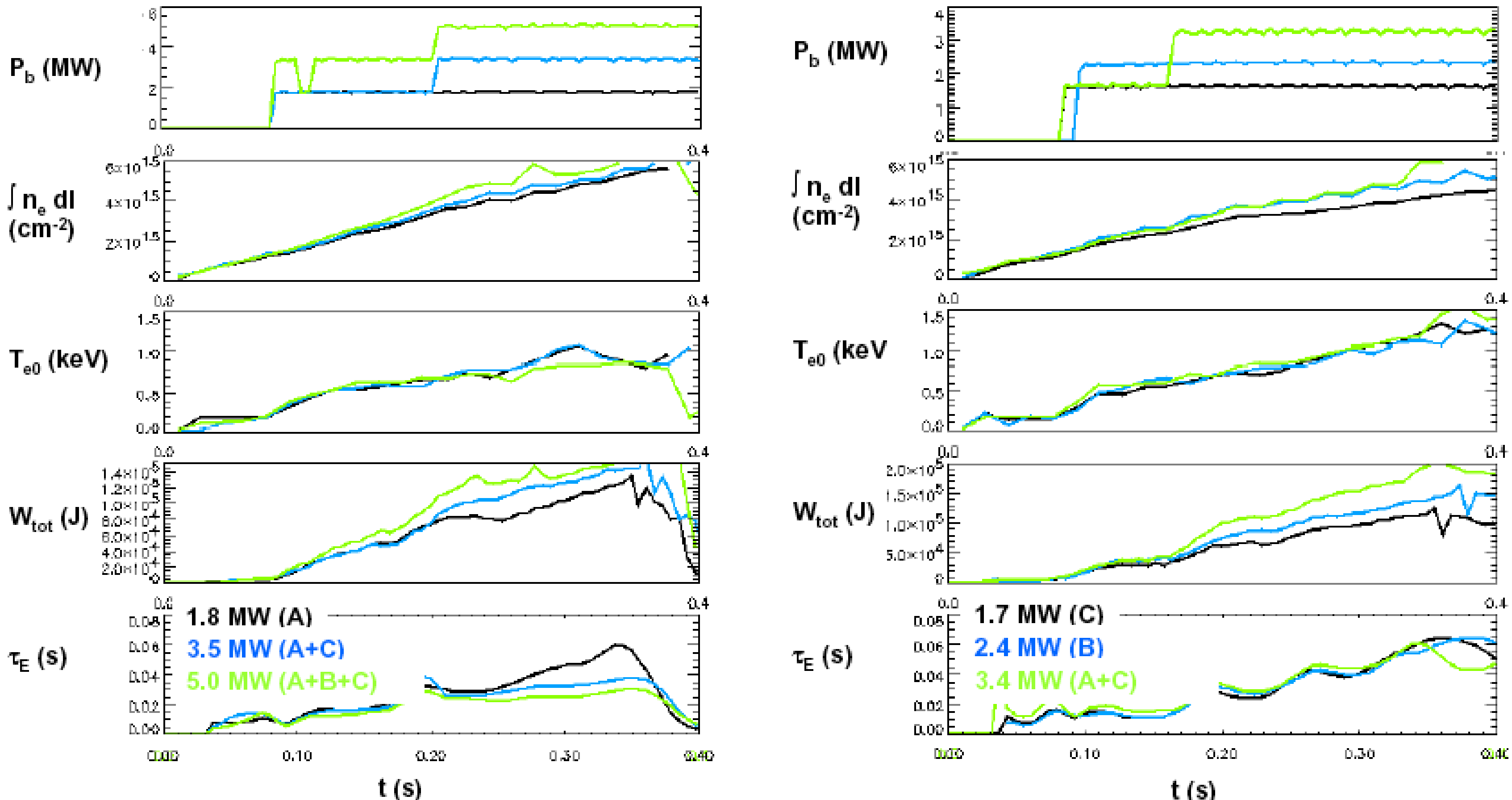
$\Rightarrow \tau_E \propto I_p^{<0.5}$ - w/o orbit loss correction

D. Stutman

P_{NB} Scans Reveal Complex Dependence on B_T

B_T = 0.45T: rapid τ_E degradation

B_T = 0.6T: small τ_E degradation



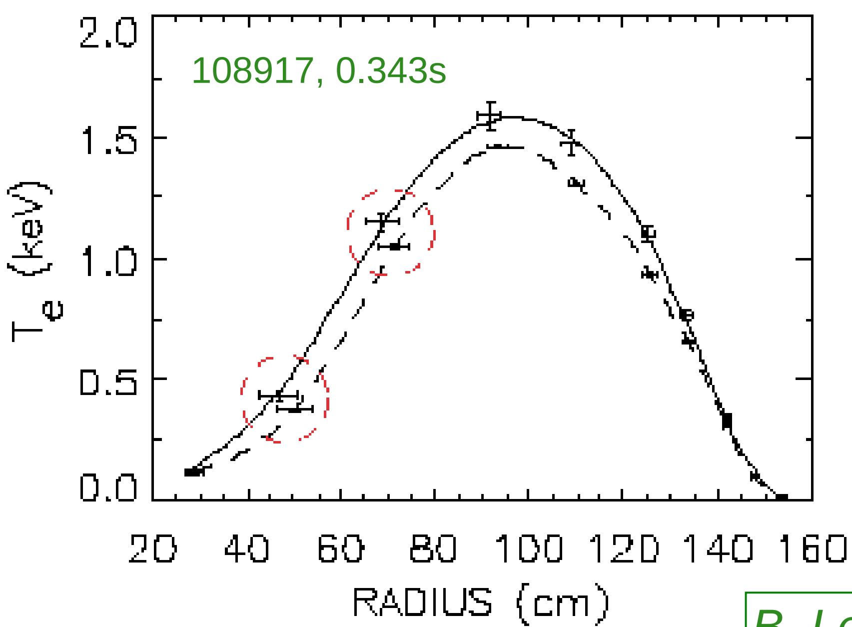
Electron profiles do not change

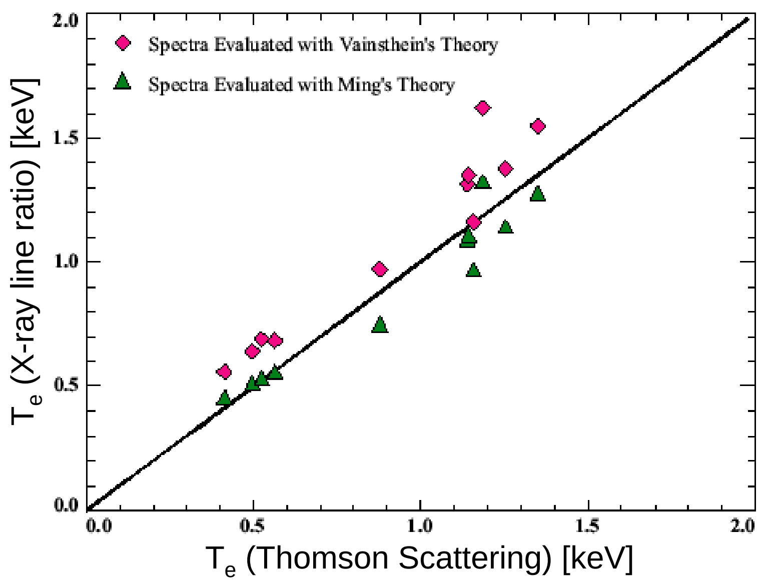
Electron profiles broaden

D. Stutman

Upgraded, Recalibrated Thomson Scattering Data Available for Kinetic Analysis

- Spectral recalibration resulted in higher T_e
  - –Most significant at lower 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





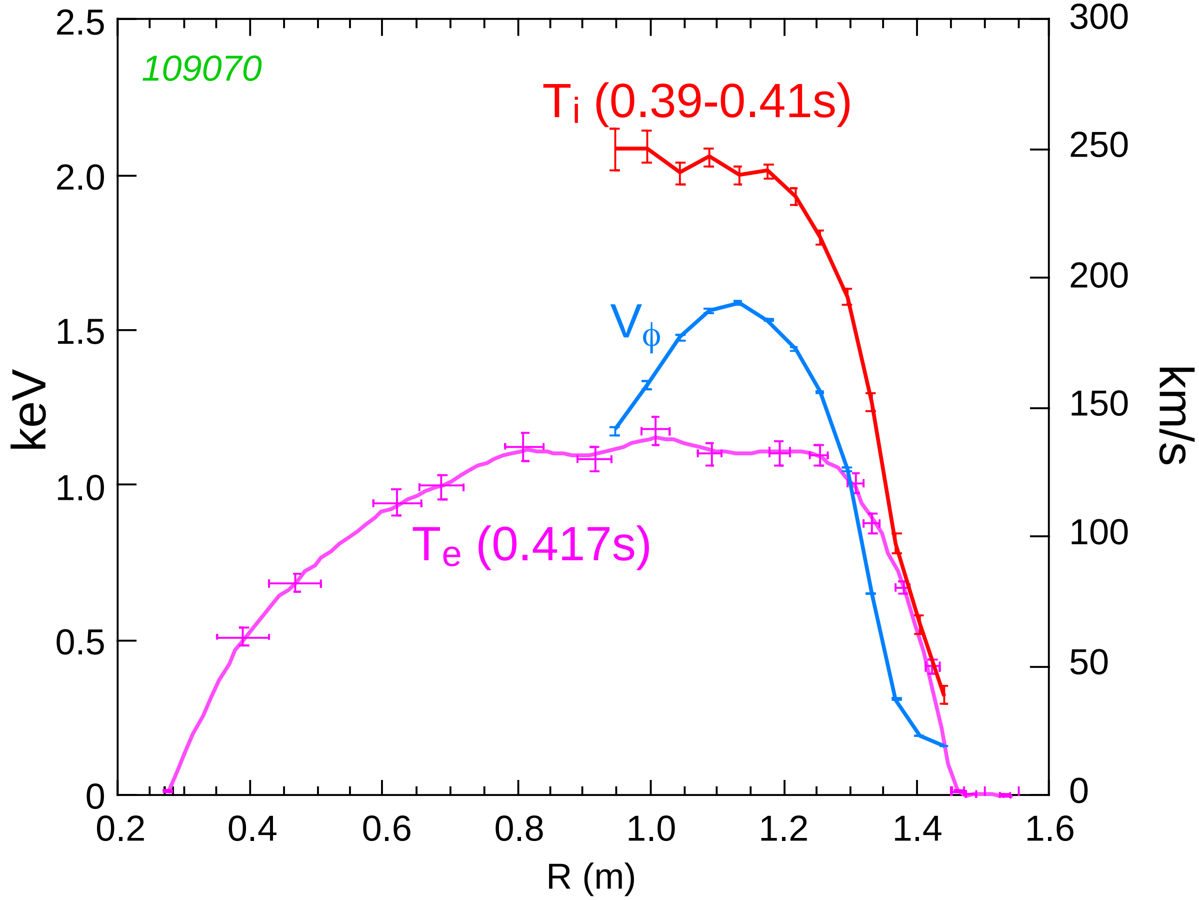
B. LeBlanc, R. Bell, D. Johnson, M. Bitter

Progress in CHERS T_i Calibration and Analysis

- *In situ* calibration of spectrometer instrumental function using neon glow in vacuum vessel
- Spatial recalibration of main and background viewing arrays when vacuum vessel opened
- Gained understanding of spatial and temporal variation of background light
  - Role of specular reflections from NB armor
  - Reduced T_i in region $r/a \approx 0.6$
- Final analysis now proceeding
  - Prioritized by needs for IAEA, APS meetings
- Additional manpower on installation of upgrade CHERS system from new postdoc.

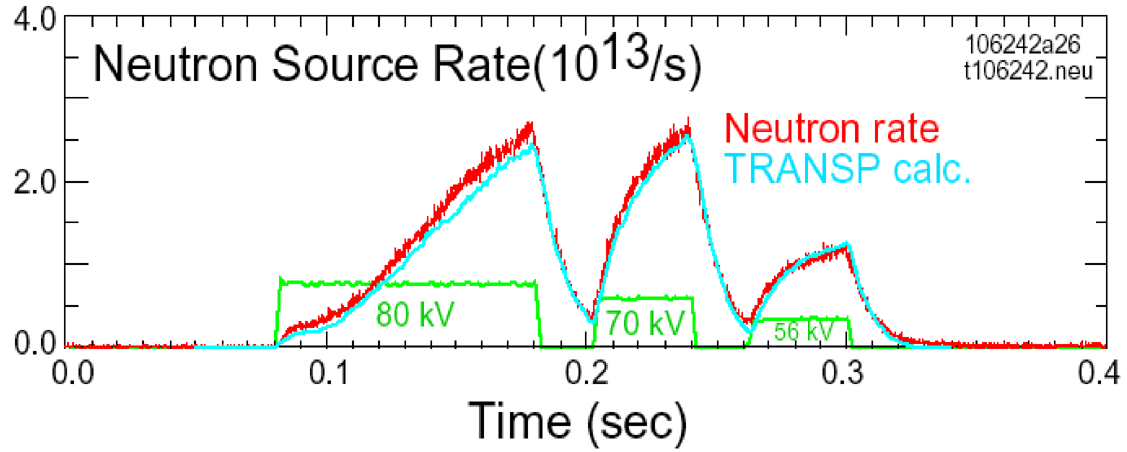
R. Bell, T. Biewer

Example of T_i, v_{phi} Profiles from Recalibrated, Reanalyzed CHERS Data



Recalibration of T_i, T_e Will Permit Reanalysis of Local Power Balance

- With new T_e data, neutron decay rate after NB blips is very well modeled by TRANSP



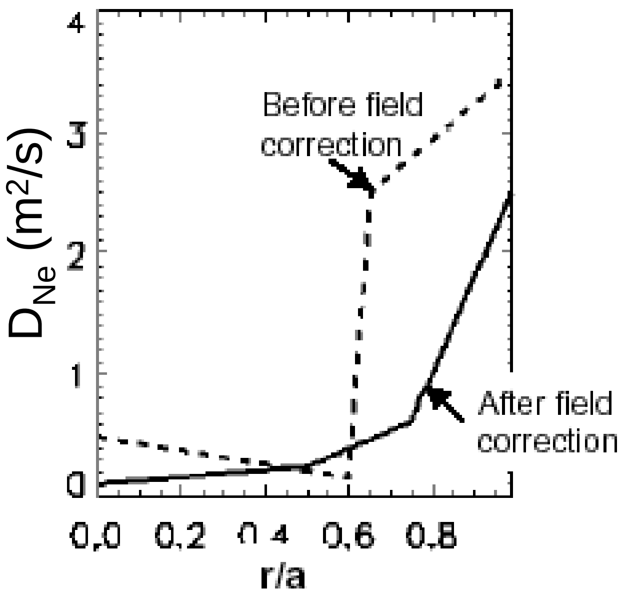
- $T_e \uparrow$, $T_i \downarrow$ $\Rightarrow$ reduced $P_{ie} \propto n_e^2(T_i - T_e)/T_e^{3/2}$
- Beginning reanalysis with new T_i data

E. Fredrickson, S. Kaye

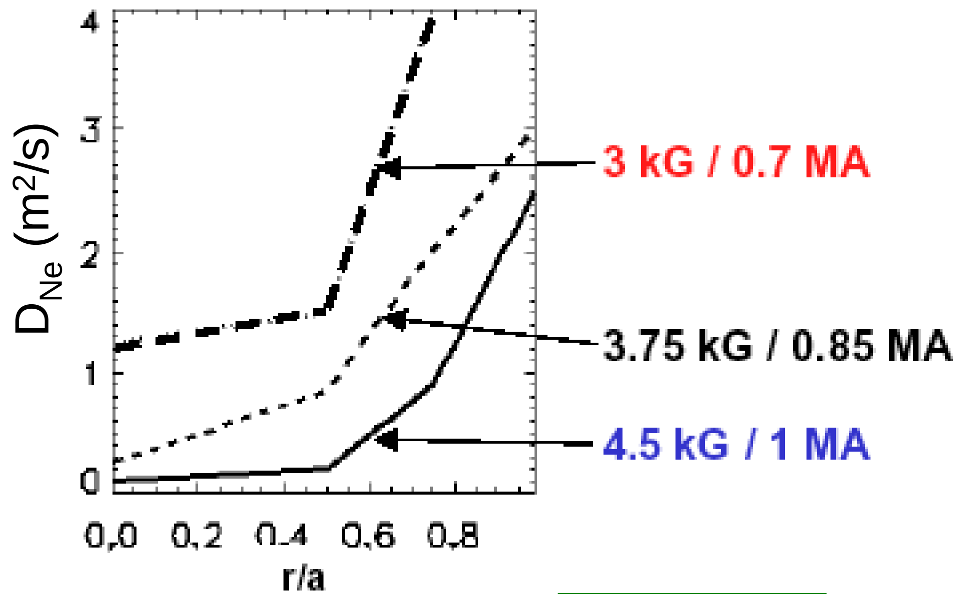
Evolution of X-ray Profiles After Neon Injection Yields Trends in Particle Transport

- 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

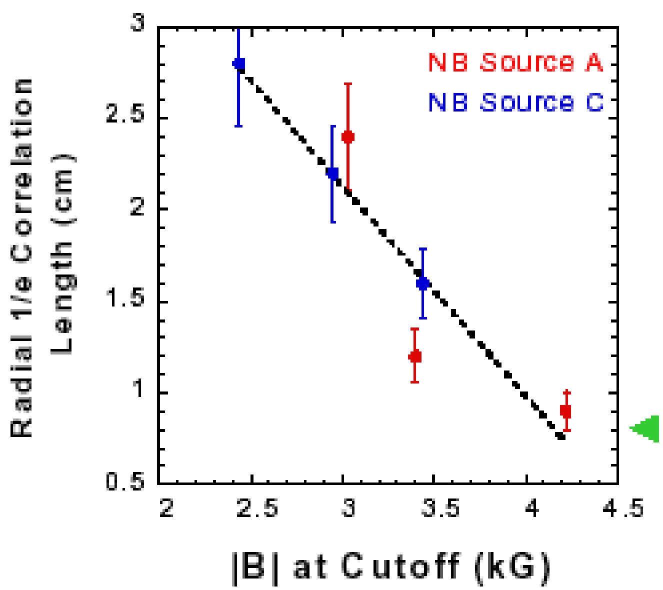


D. Stutman

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

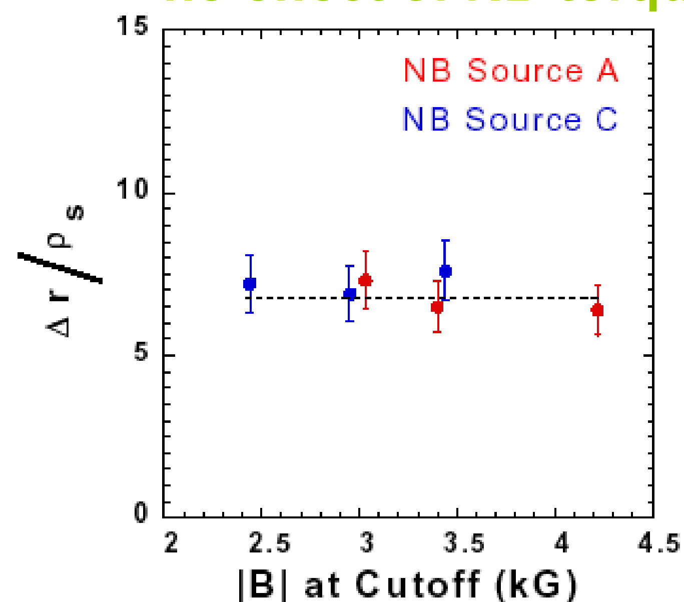
Data for I_p, B_T scan at const. q_{cyl}



Approx. resol'n

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

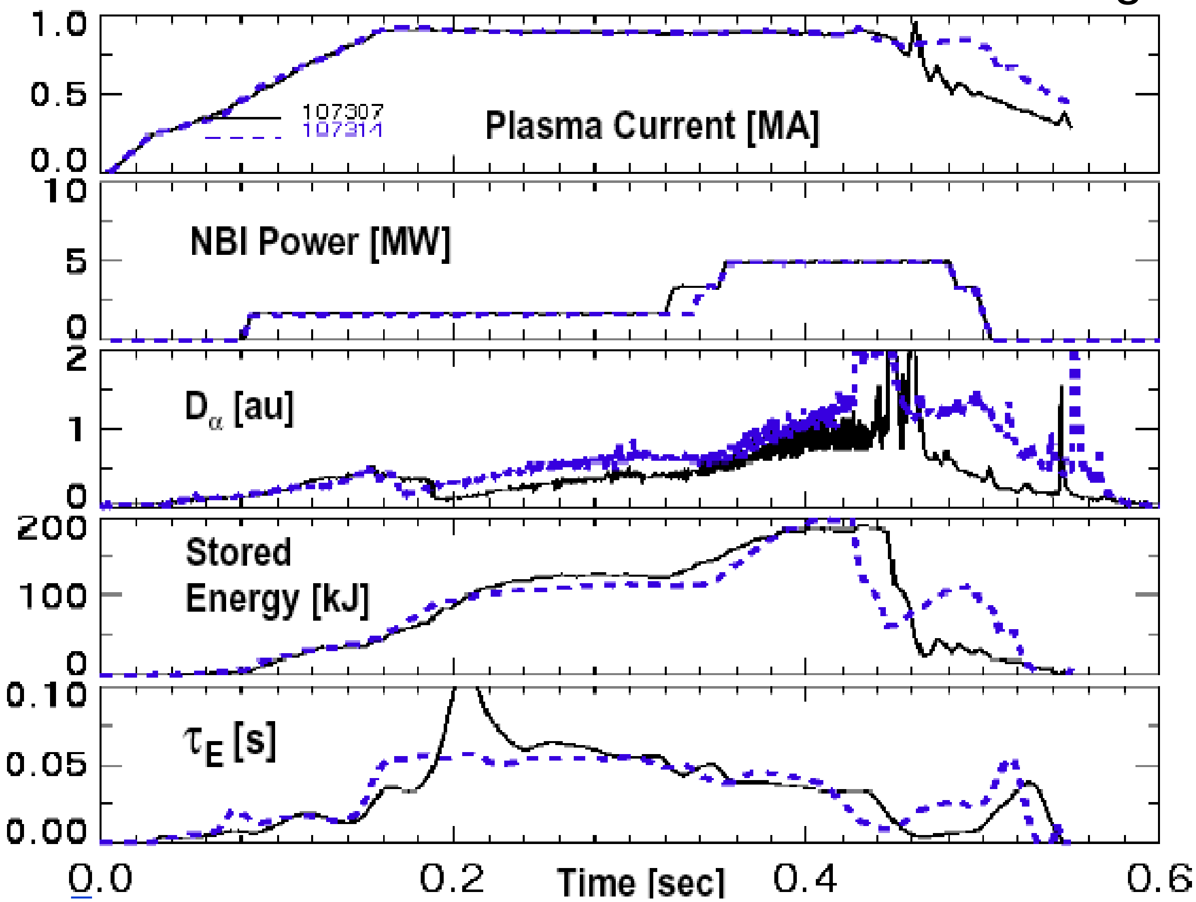
- no effect of NB torque



M. Gilmore

Improved Reproducibility of H-mode with HFS Gas Fueling but Comparable Performance

- - HFS fueled — Wall fueled after loading

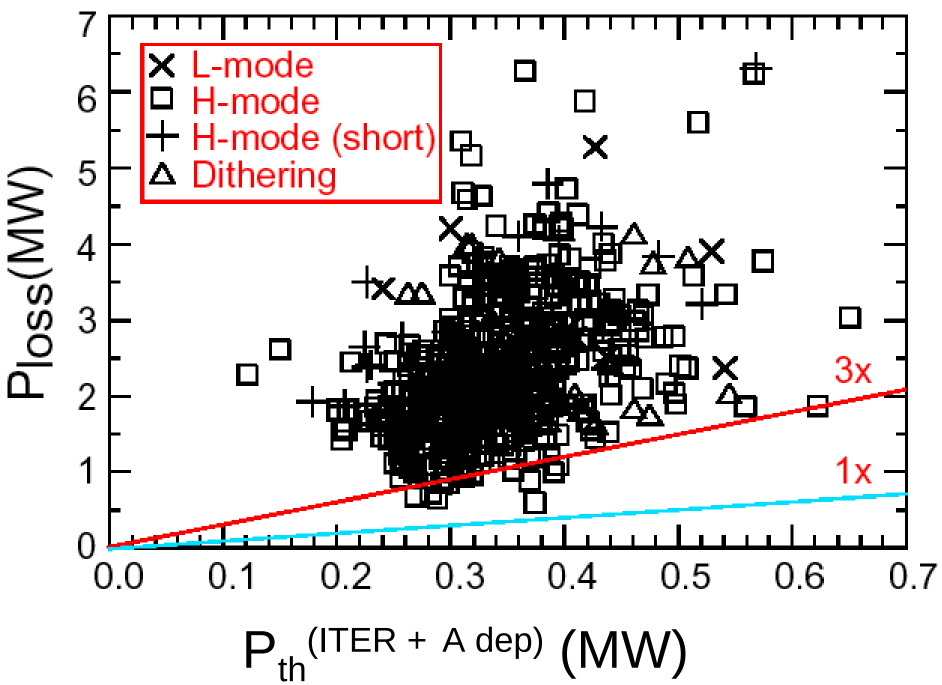


- HFS injector gives
  - –large initial flow
  - –continuing lower flow through pulse
- LFS fueling with rate similar to HFS produces
  - –Delayed transition
  - –Shorter H phase

R. Maingi, C. Bush

Threshold Power Approaching Revised ITER Scaling Including Aspect-Ratio

- Comparison with reanalysis of ITER database including $A^{-0.46}$ dependence (Snipes, *to be published*)
- NSTX data includes >500 shots since 350°C bakeout



H-modes obtained for:

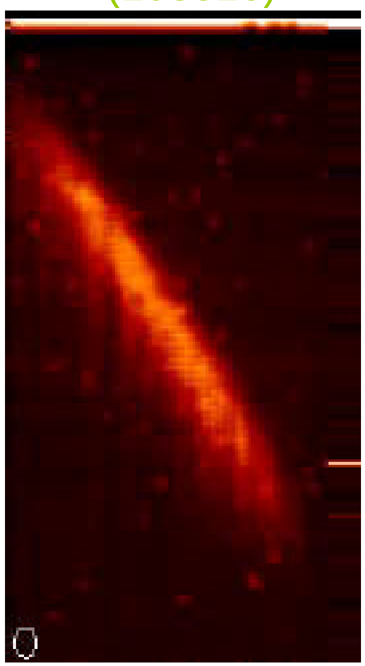
- Lower-single-null (LSN) & double-null (DN) divertor
- NBI and/or RF heating
- P_{NBI}: 0.3 - 7 MW
- I_p: 0.7-1.3 MA
- B_T: 0.3 - 0.6 T
- n_e: 1.5 - 4.8 × $10^{19}m^{-3}$ (transition)
- Duration: >0.5s

C. Bush

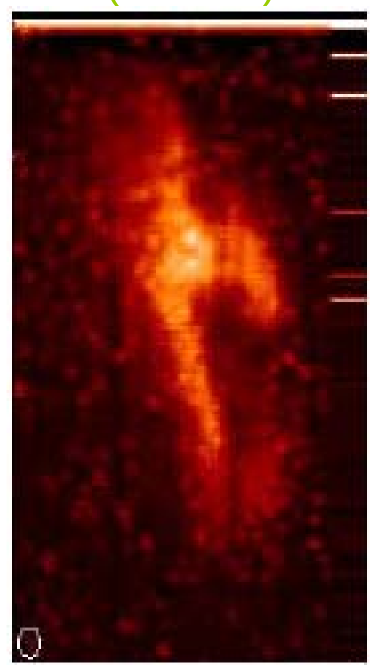
Upgraded Gas Puff Imaging Diagnostic Yielded Wealth of Data on Edge Turbulence

- Used PSI-4 camera *(Princeton Scientific Instruments)*
  - 28 frames, 160 × 80 pixels, 100000 frames/s, 10μs exposure
- Filters for observing He, D_2, Ar puffs from line source

H-mode
(108316)



L-mode
(108609)

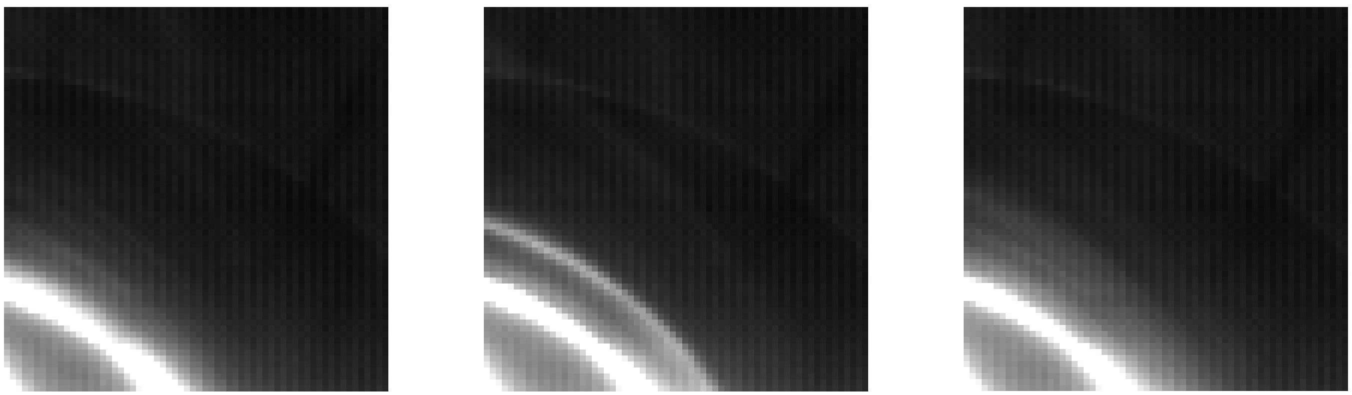


R. Maqueda, S. Zweben

Fast Camera Images Show 3-D Structures in Divertor D_α Emission

- Used very fast camera (40,500 fps)
- Vertical view of lower divertor
- Observes bright structures elongated along field lines

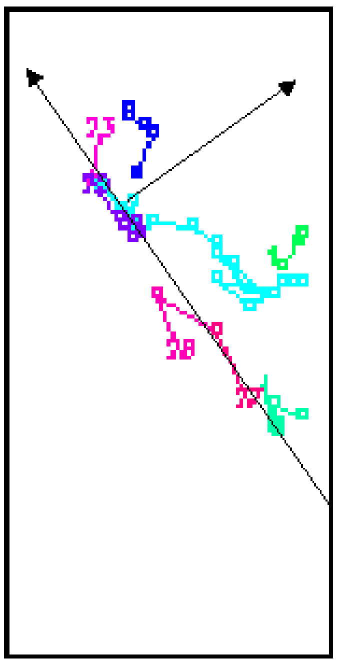
Images through a grassy ELM in an H-mode discharge



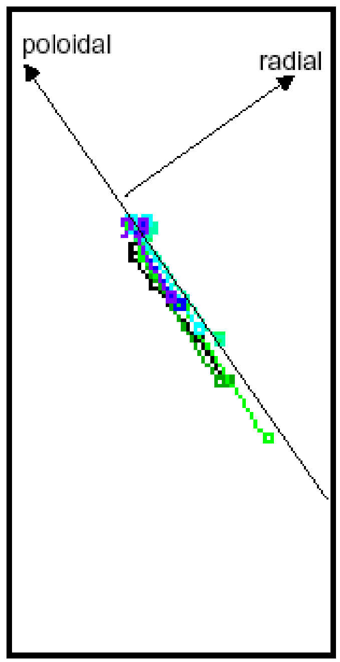
H. Nishino, U. Hiroshima

Propagation of GPI "Blobs" Varies with Confinement Mode

- Developed algorithms to track blobs automatically
  - In H-mode, blobs propagate mainly poloidally
  - In L-mode (including OH), there is outward radial motion

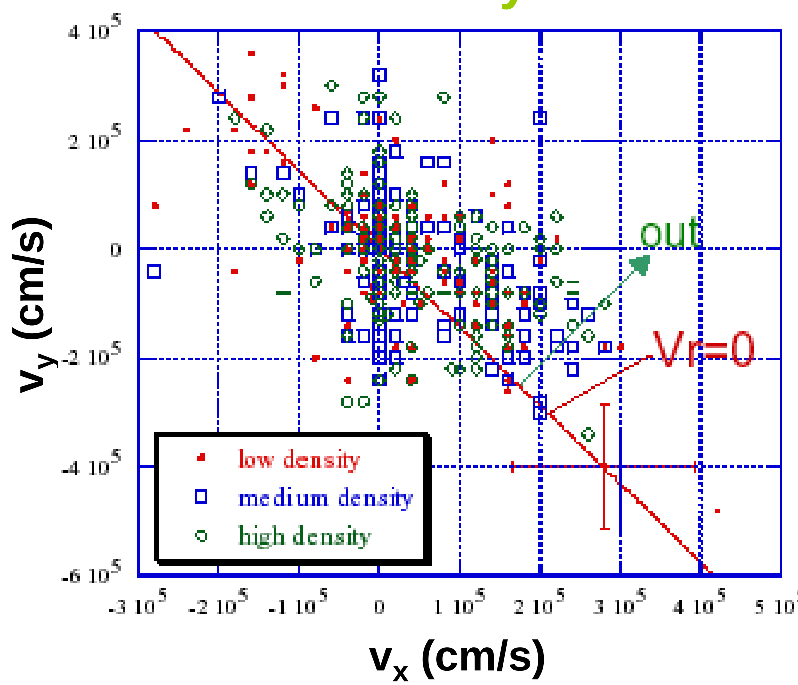


shot 108164 - ohmic



shot 108316 - H-mode

OH density Scan

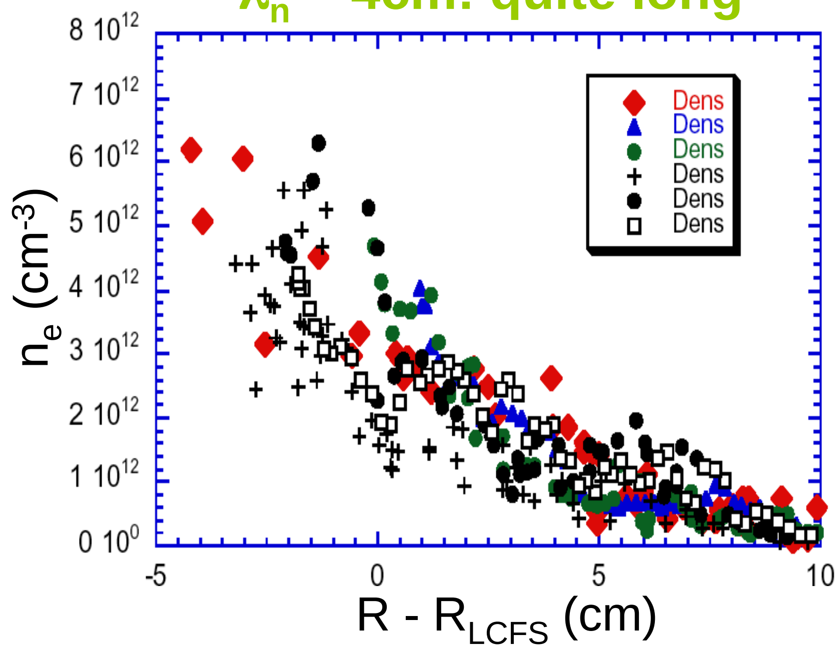


A. Keesee (WV U.), R. Maqueda, S. Zweben

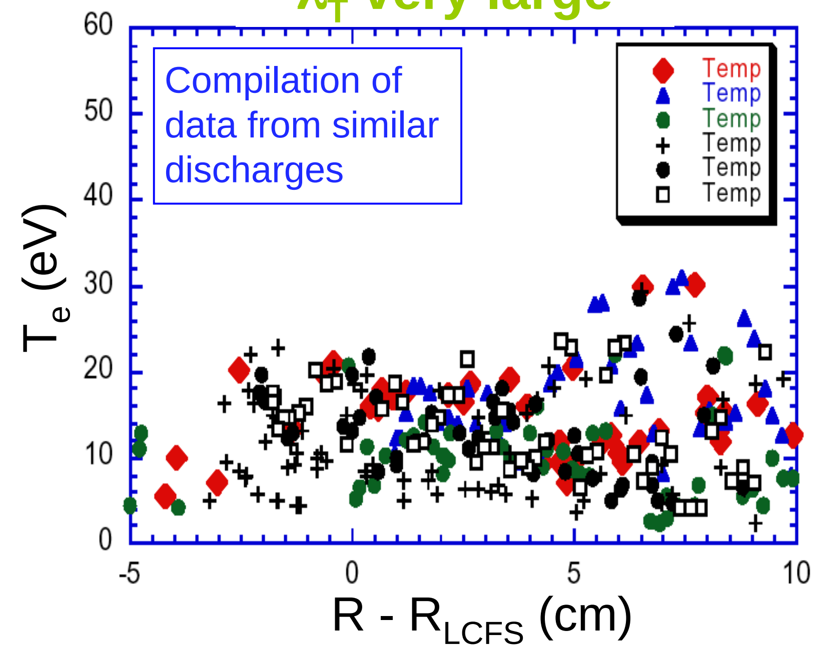
Broad Scrape-off Measured with Fast Reciprocating Probe

- 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



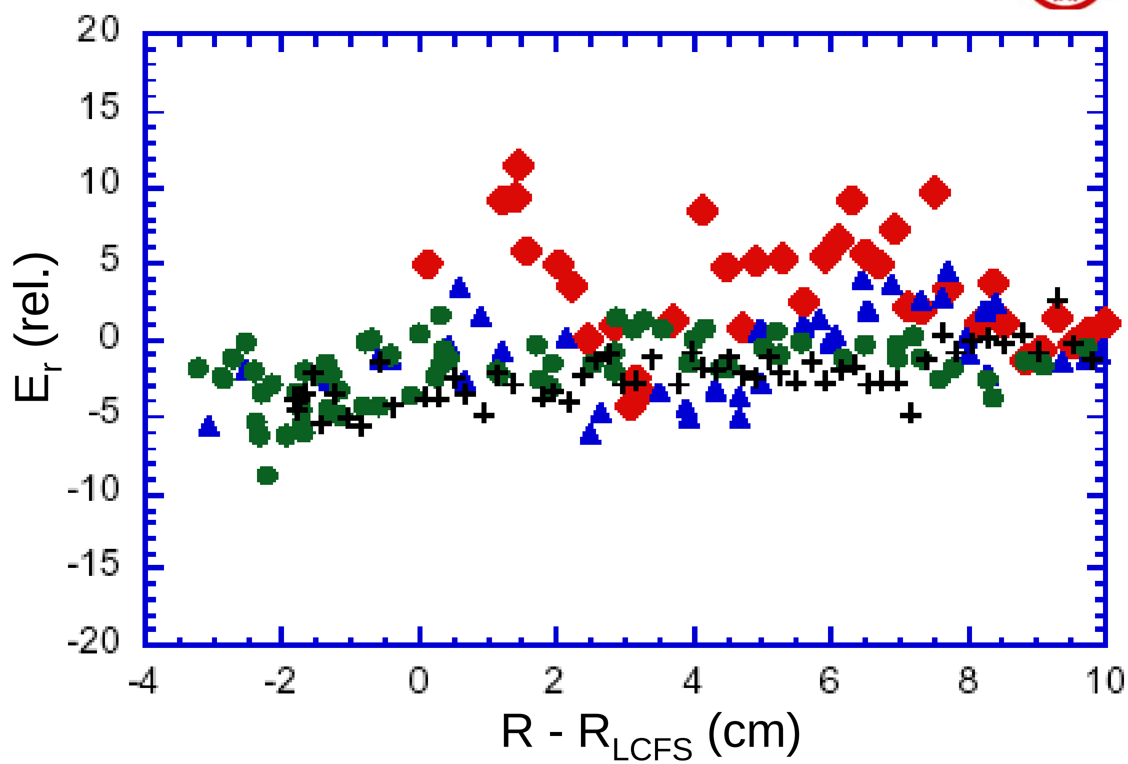
T_e at LCFS ~20eV
λ_T very large



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

J. Boedo

Probe Did Not Detect E_r Shear Layer Associated With H-mode Edge Barrier

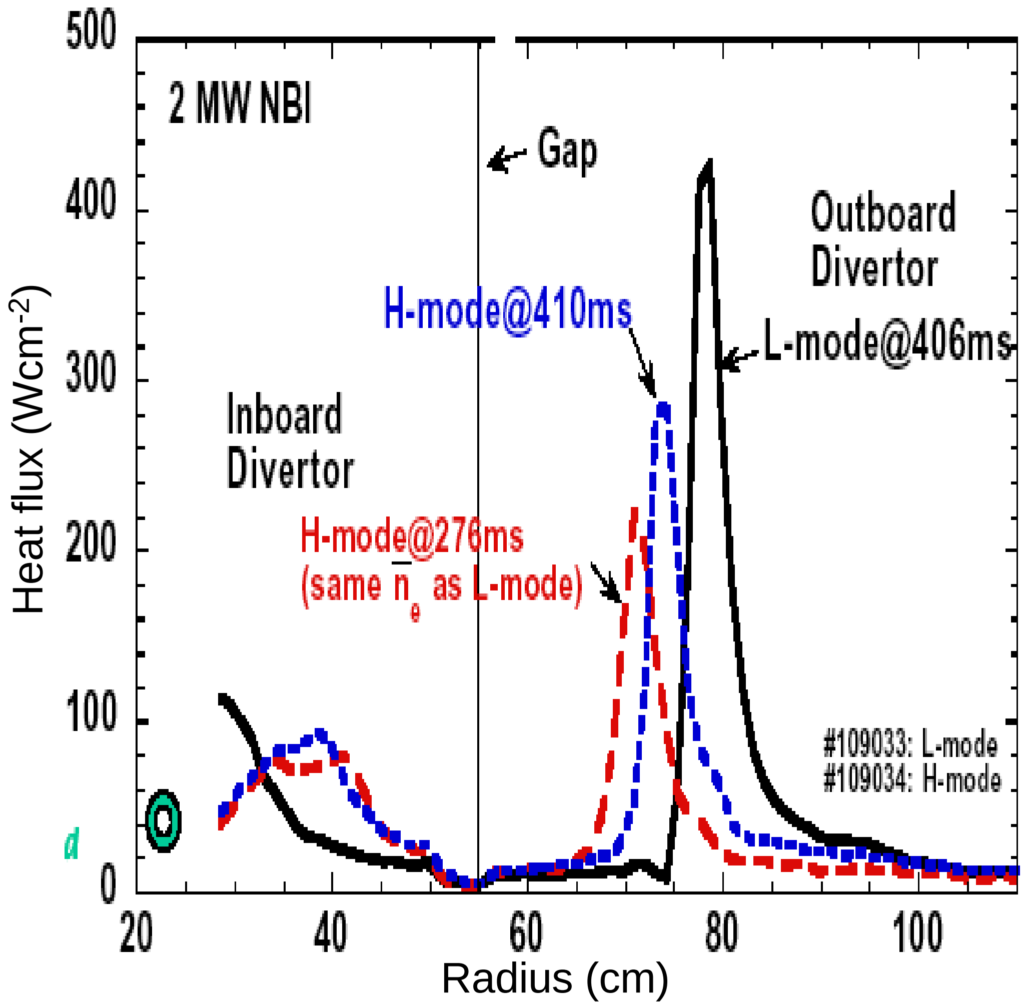


- Shear layer may be further inside LCFS *or*
- May be an error in LCFS position from EFIT *or*
- Transport barrier physics may be different

J. Boedo

Peak Heat Flux to Divertor Tiles Higher in L-mode than H-mode

NSTX



- IR measurement of tile surface temperature
  - Calibrated during 350°C bakeout
  - Tile surface reached 300°C in 0.2s
- 1-D model for heat diffusion
- Heat flux much higher at outboard strike point
- H-mode fluxes acceptable for 2 - 3 s at this power
  - Possible issue for 5s full NB + RF power

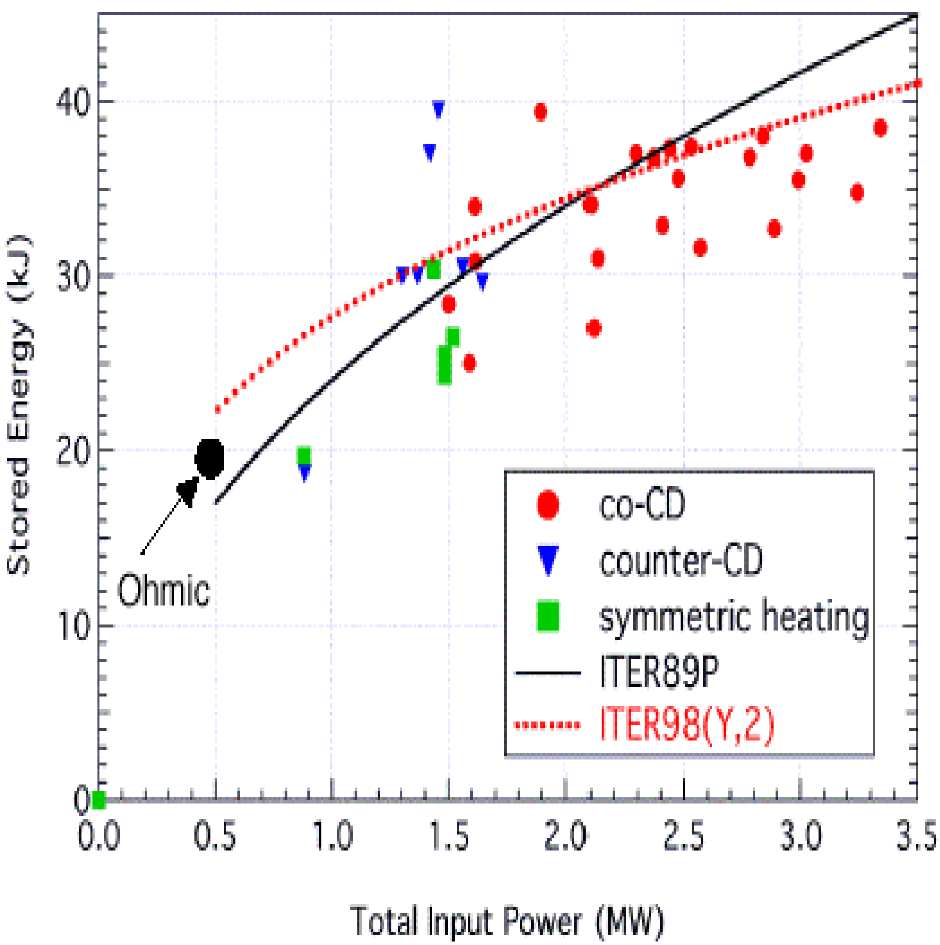
R. Maingi, S. Paul

Technical Aspects of HHFW Performance

- Full phase feedback system worked very well
  - Phases set to arbitrary waveforms between shots
- Power limited to < 3MW throughout run
- During opening, arcing found in all feedthroughs
  - Repairing and modifying center conductors to reduce electrical stress

R. Wilson, D. Swain

HHFW Needs Effective Heating to Produce Current Drive



- Compare measured plasma energy increase with ITER scaling for

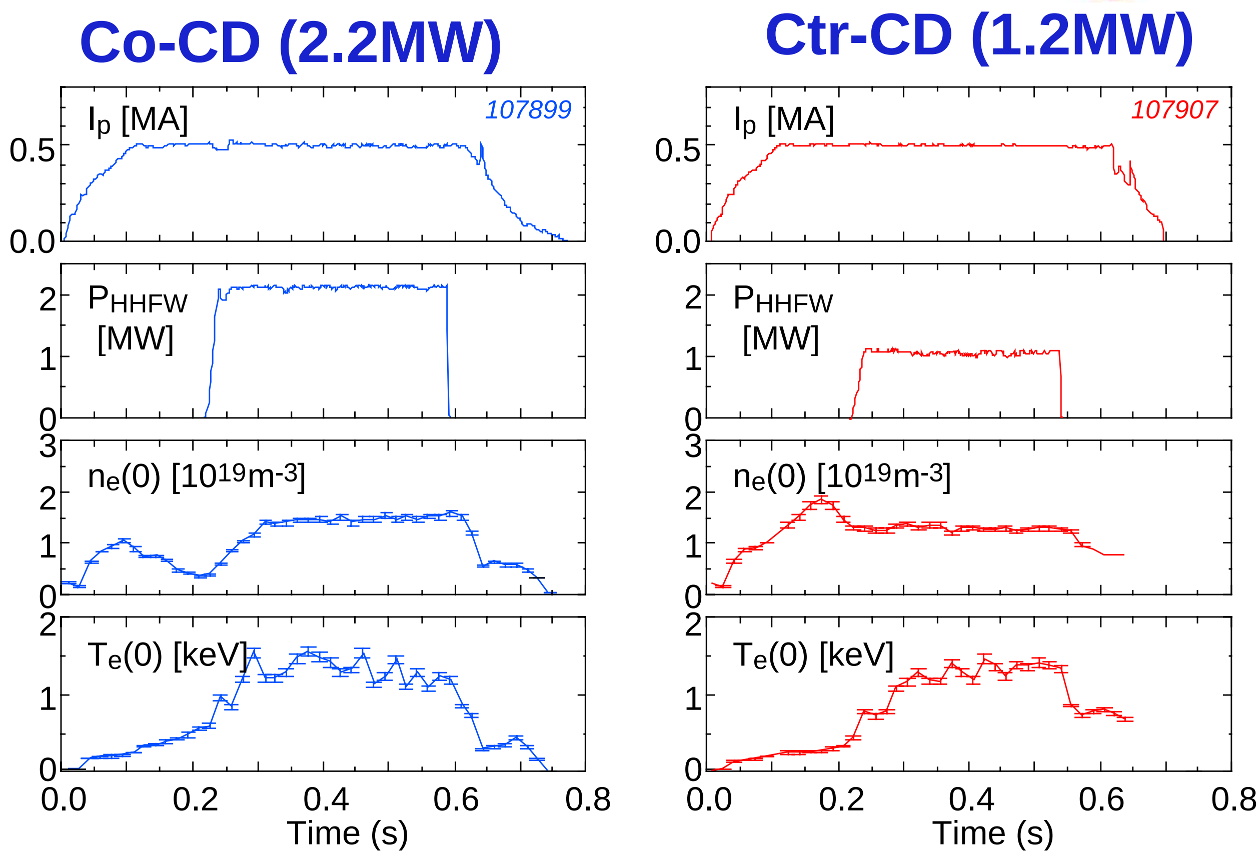
  I_p=0.5MA, B_T=0.45T, H=1

  – Heating quite variable
  – Not yet as effective as NBI which exceeds ITER scaling
- CD antenna phasings produce $\mathbf{k}_{||} \approx \pm 7\text{m}^{-1}$

  ⇒ $T_e(0)$ ~1.2keV for optimum wave coupling

P. Ryan

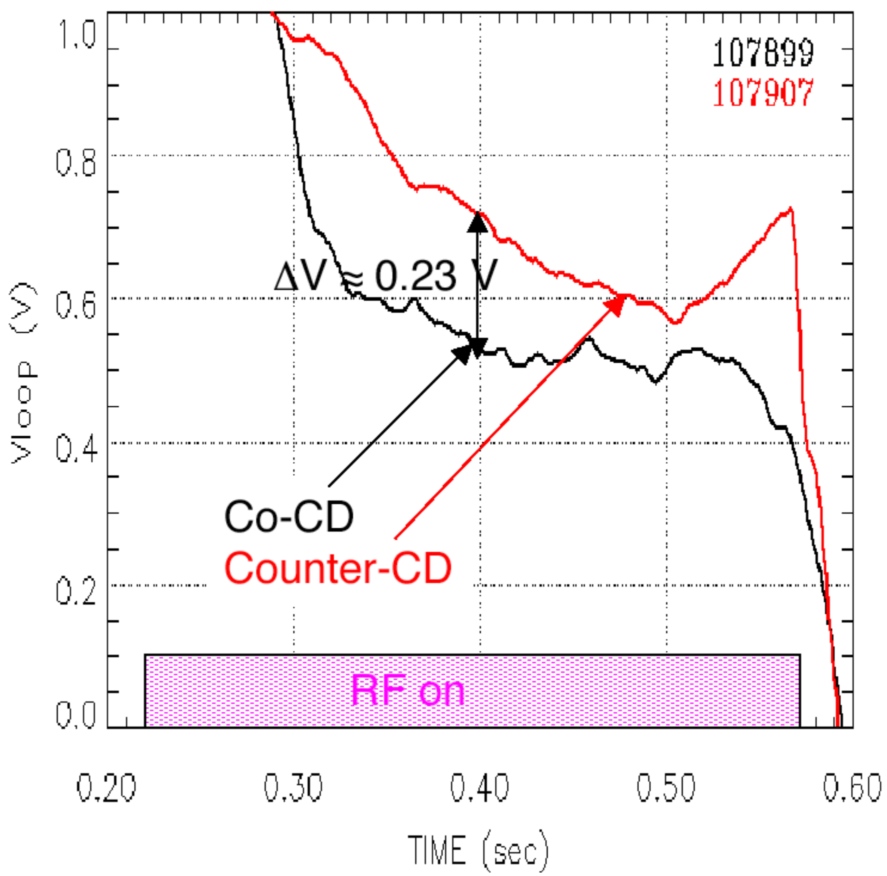
Current Drive Experiment Matched Plasma Conditions with Co/Counter RF Phasings



- Different RF powers required to reach similar central T_e and n_e

P. Ryan

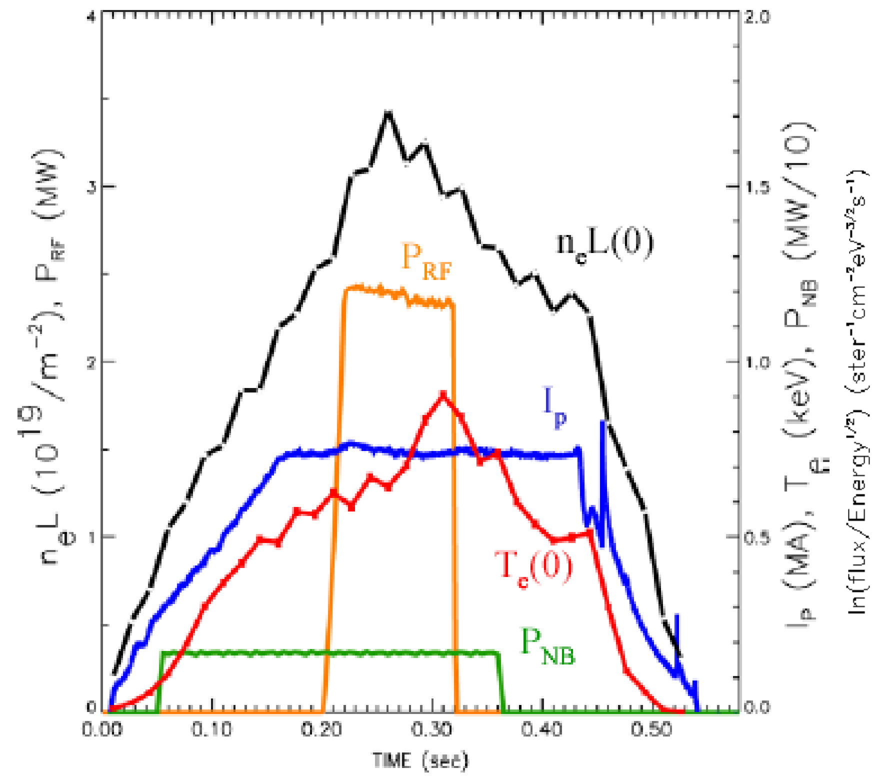
Evidence for Current Drive in Change in Loop Voltage to Maintain Same I_p

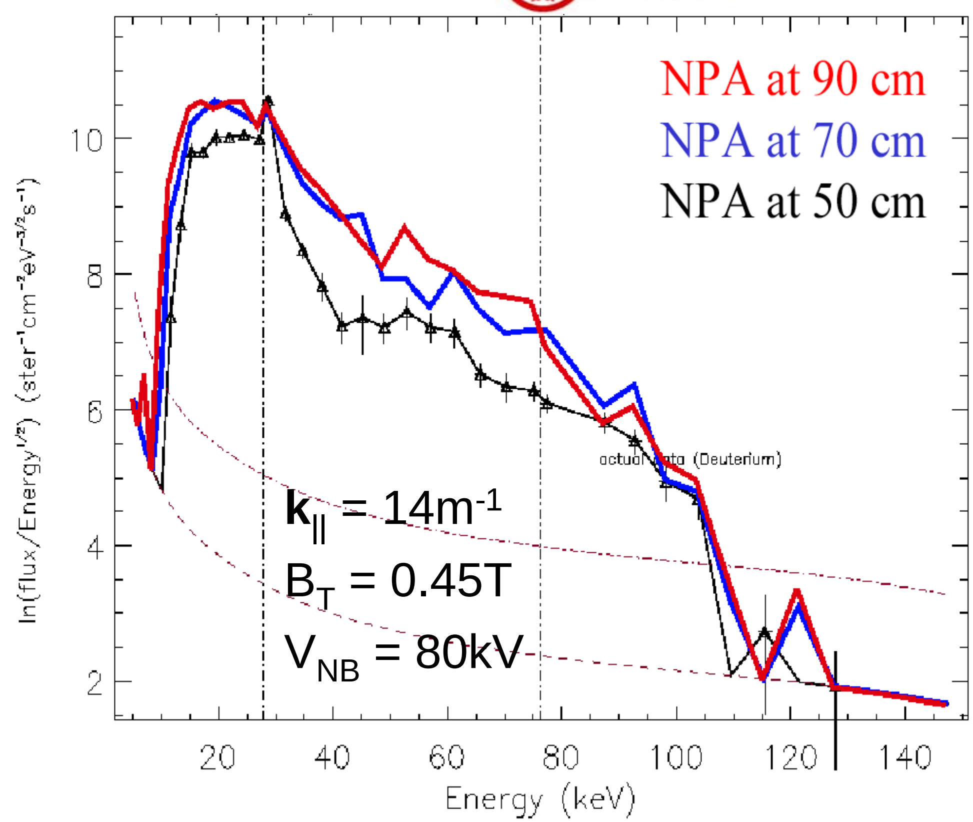


- Current drive indicated *but*
- Difficult to interpret because steady-state not reached
- Magnitude uncertain
- Modeling results
  – 150 kA from zero-D
  – 230 kA from CURRAY
  – 90 kA from TRANSP

P. Ryan, D. Swain, T.K. Mau, S. Kaye

Detailed Study of Fast Ion Interaction with HHFW using Scanning NPA





- Performed scans in B_T, I_p, V_{NB}, $k_{||}$
- Analyzing data with HPRT and upgraded METS codes
  - Assess implications for combined HHFW/NB heating scenarios

A. Rosenberg, S. Medley

CHI Experiments Encountered Technical Problems

1. Conduct experiments at higher TF
   - increase toroidal current
   - study effect on n=1 mode amplitude and frequency
   - ***flashovers in external circuit terminated runs***
   - ***propagated voltage transients into ancillary equipment***
2. Measure edge driven current
   - add CHI to a LSN inductive discharge
   - ***noise pick-up in magnetics disrupted operation***
3. Implement feedback control of CHI plasma
   - sustain plasma shape during high current phase
   - ***postponed until FY03***

CHI Hardware Modification Now Underway

- Redesigned snubber circuits to suppress voltage excursions in external circuit
  - Based on HIT-II and DIII-D experience
- 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
- Working on plasma control system to be able to implement CHI control

We made excellent progress!

- New facility and diagnostic capabilities added
  - Routine H-mode operation
  - Detailed profile measurements
  - Beginning fluctuation studies
- Broadened operating space and increased pulse length
- Significantly increased β and studied associated MHD
  - β_T, β_N, β_P, $\beta_T\tau_E$, $\beta_N H$, W_{tot} reached new levels
  - Detailed studies of RWM and fast-particle modes
- Explored transport in several regimes
  - Global confinement continues to show interesting trends
  - Profile data under analysis now for fall meetings
- First indications of current drive by HHFW

We look forward to a very productive run in FY'03