NSTX

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FY2009 Run Campaign Highlights

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For the NSTX Research Team

NSTX Program Advisory Committee
(PAC 27)
PPPL
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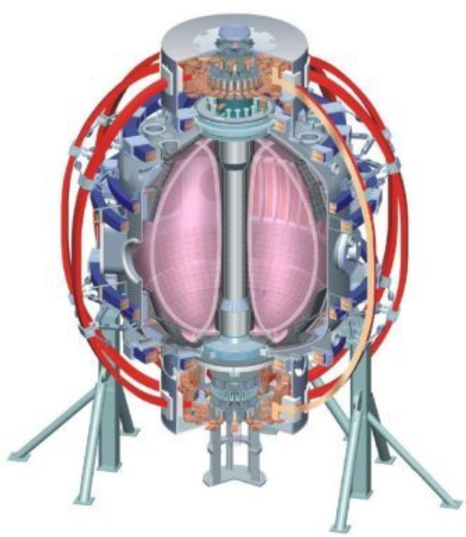

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
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ORNL
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U Washington
U Wisconsin

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

FY09 Run Was Very Efficient (95% Successful Shots) and Utilized New Capabilities

PAC25-4 & 2

Group	Run Time Guidance (%)	Final Assigned Time (%)
MHD	13	18
Wave-Particles	13	14
T&T	11	8
Boundary	13	12
SFPS	11	6
ASC	13	13
Lithium	6	9
Normal TF	80	80
Reversed TF	7	7
Enabling	13	13
Total Run Days	70 days	84.2 days

New Capabilities for 2009:

- **Routine Li usage (≥ 65% of shots)**
- **CHI absorber PF coils**
- **HHFW antenna grounding modified & system commissioned**
- **Beta feedback with NBI modulation**
- **Operated w/ reversed TF for first time**

Total run days: 84.2
Milestone: 31% [Normal TF]
ITPA related: 40% [Normal TF]
ST related: 100%

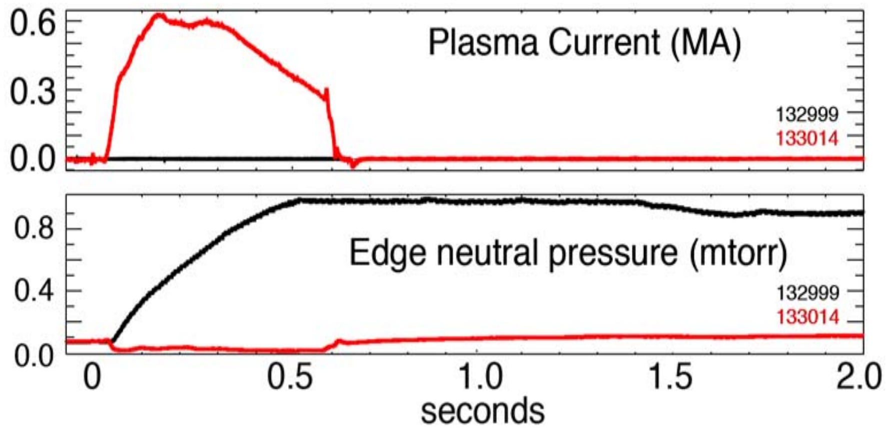
NSTX Completed 4 Research Milestones in FY2009

- DOE Joint Research Target/Milestone: *"Conduct experiments on major fusion facilities to develop understanding of particle control and hydrogenic fuel retention in tokamaks"*
  - *…identify the fundamental processes governing particle balance by systematically investigating a combination of divertor geometries, particle exhaust capabilities, and wall materials.*
  - *…NSTX is pursuing the use of lithium surfaces in the divertor…*
- R(09-1) Understand the physics of RWM stabilization and control as a function of rotation
  - RWM stabilization mechanisms characterized over a wide range of plasma rotation and collisionality conditions
- R(09-2) Study how j(r) is modified by super-Alfvénic ion driven modes
  - Emphasis on the effects of AE modes on the beam CD profile
- R(09-3) Perform high-elongation wall-stabilized plasma operation
  - Assess BS current at high elongation and q, and NBICD at low density - operating near the ideal-wall limit

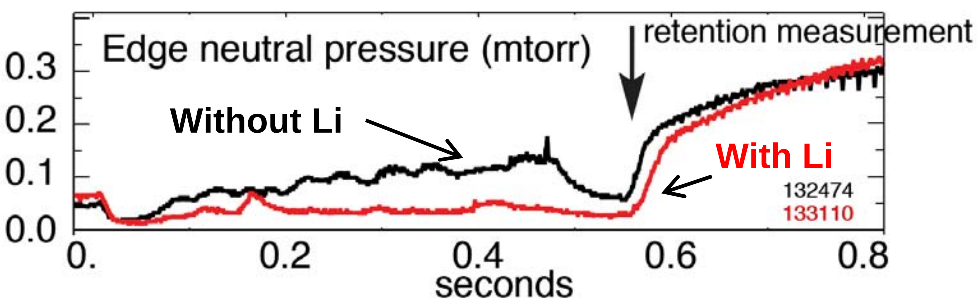
NSTX Contributions to Retention Milestone Important for Understanding Li pumping, ITER T Retention

PAC25-10

Measured high retention ~90% both with and without Li

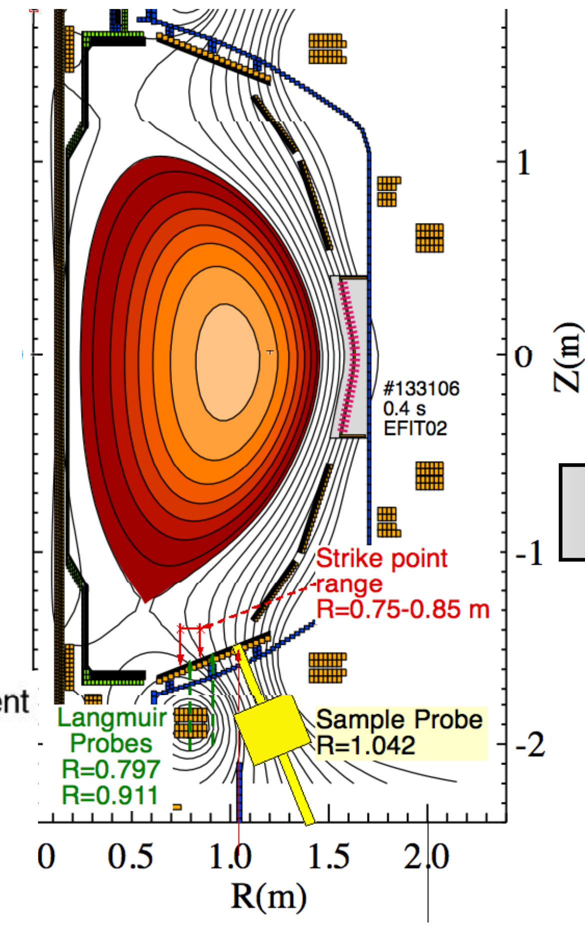


Li increases global retention from 87% to 93% in NBI-heated plasmas

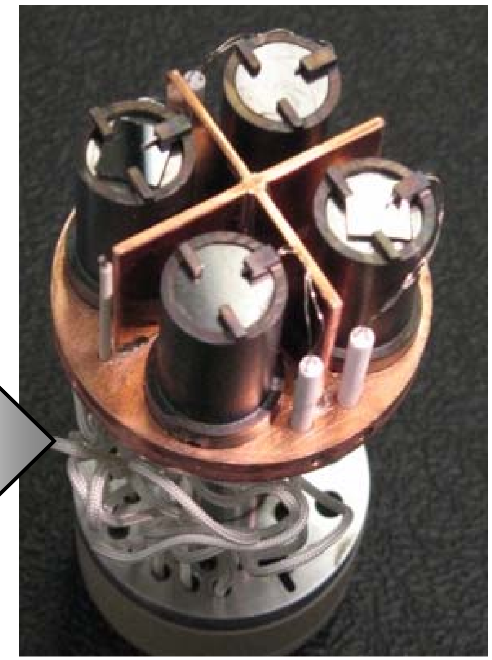


Additional D retained with Li is released promptly after discharge

Discharge magnetic geometry with sample probe location



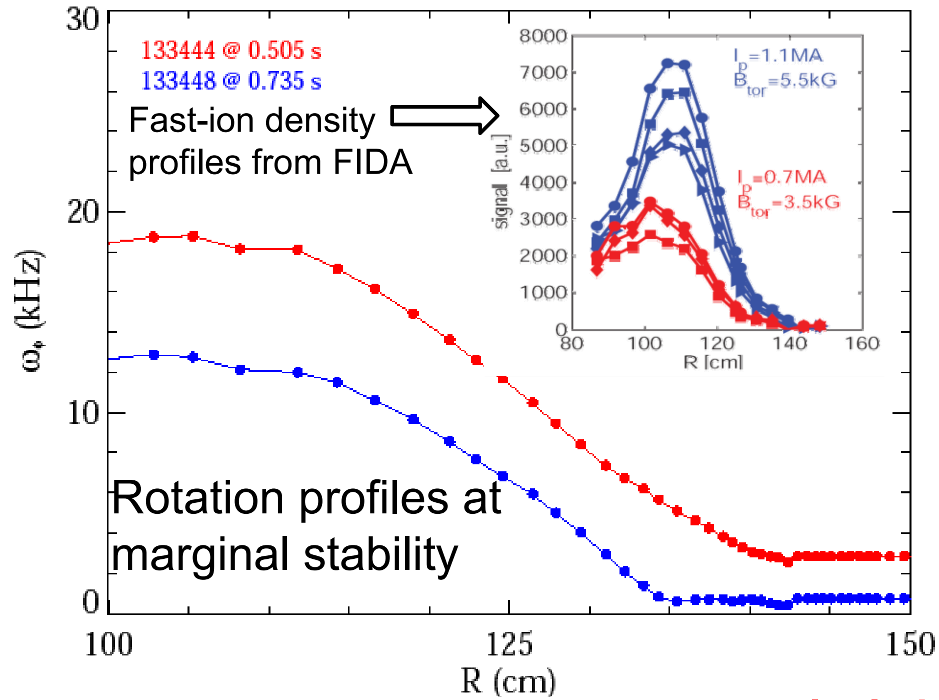
Sample probe with ATJ graphite, Si and Pd samples



PMI probe measurements show molecular state changes with Li concentration

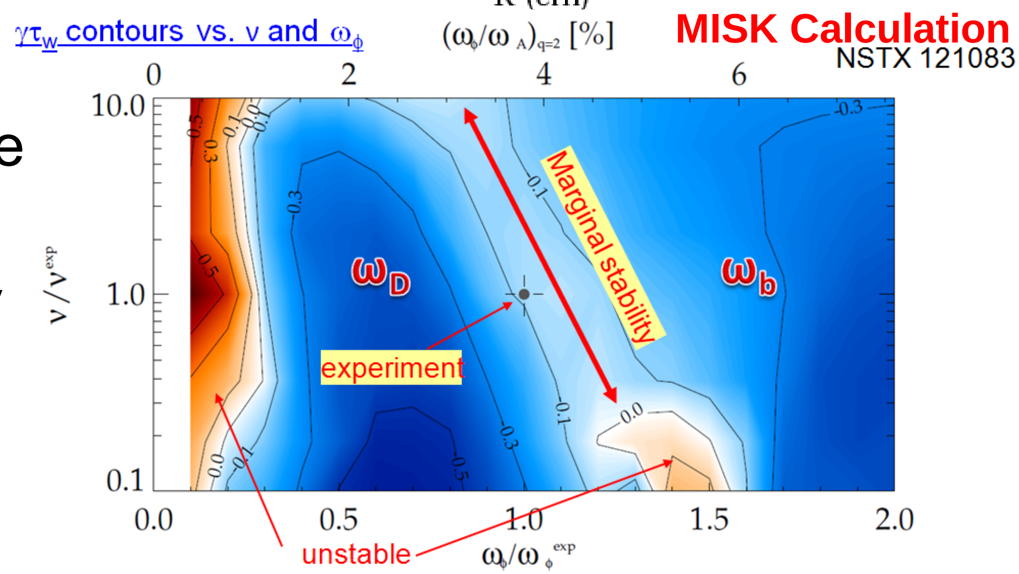
RWM Stability Observed to Depend on Fast-ion Content and Thermal Kinetic Resonances

- NBI power scan at fixed q indicates lower rotation speed is required to stabilize RWM when fast-ion density is higher
  - Consistent with expectation

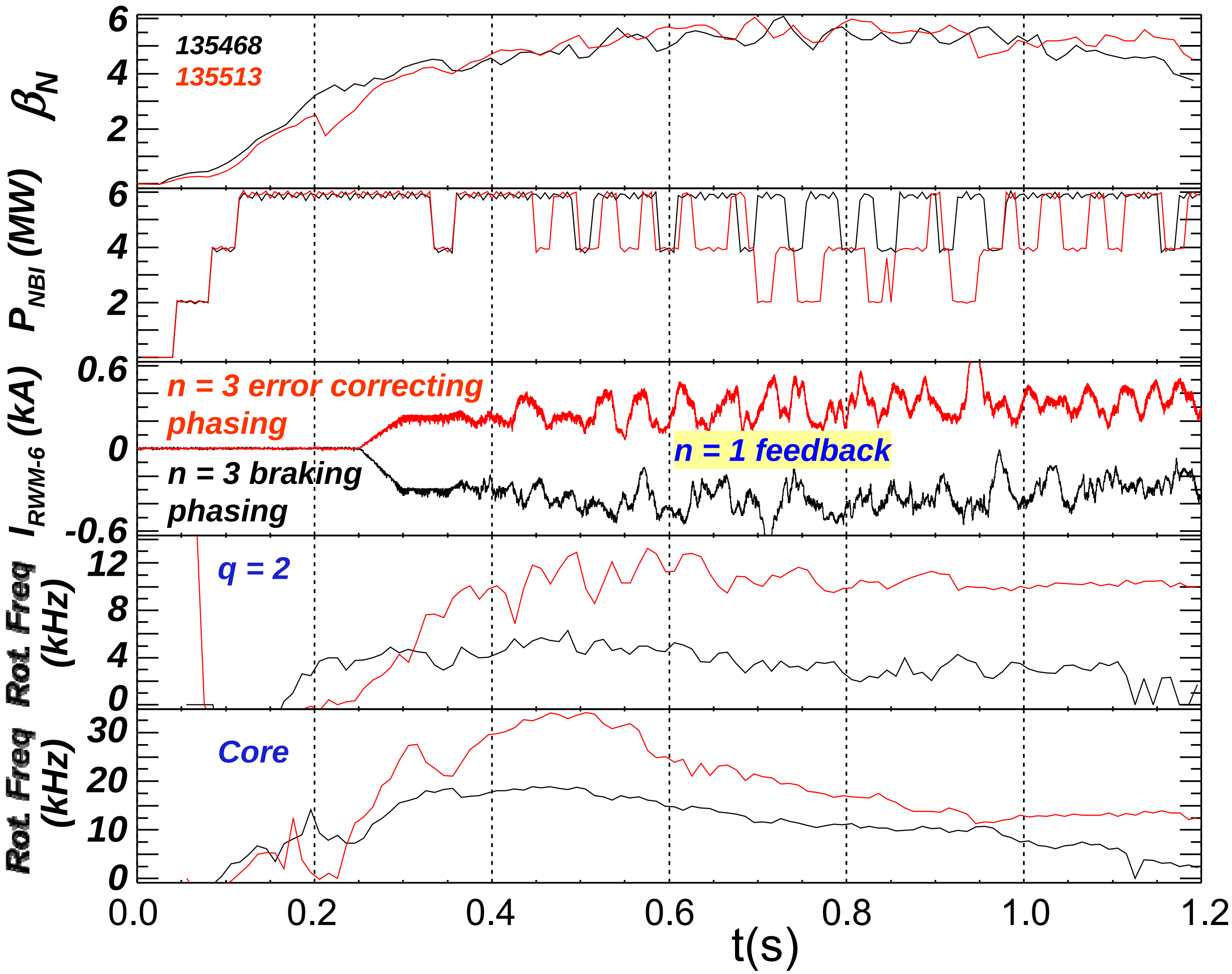


- **Important for higher β_N in ST-FNSF with large fast-ion population?**

- Stabilization from precession drift resonance at low rotation and bounce resonance at high rotation
- Stability dependence on collisionality key for ST fusion burn devices



β_N Successfully Controlled with NBI Feedback at Varied Levels of Plasma Rotation Frequency f_ϕ

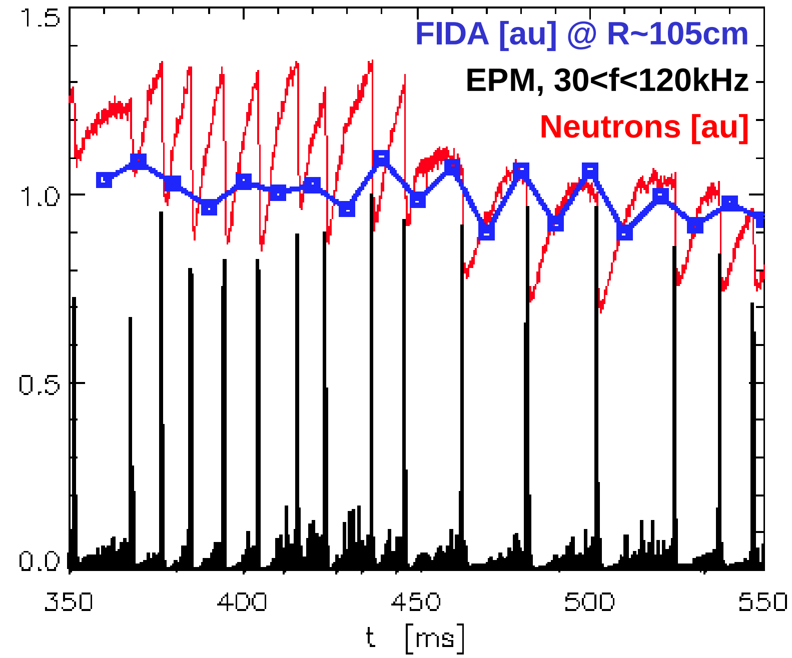


- Steady β_N established over long pulse
  - Independent of f_ϕ over a large range
- Prelude to f_ϕ control
  - Reduced f_ϕ by n = 3 braking does not defeat beta control
  - Increased P_{NBI} needed at lower f_ϕ

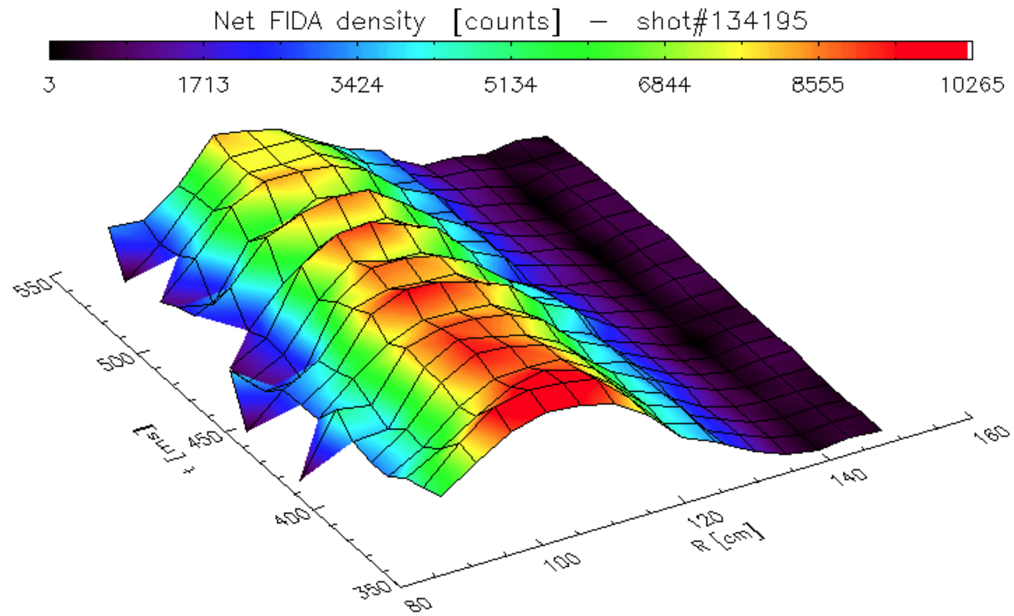
PAC25-17-(1)

Energetic-Particle Modes (EPMs) Show Avalanching Behavior; Effects on Plasma Current Under Investigation

- Chirping EPMs cause fast ion losses
  - Drops up to 30% observed in neutrons, perpendicular FIDA (Fast ion D-alpha), sFLIP (scintillator Fast Loss Ion Probe)
- Loss arises & vanishes within ~300μs (sFLIP)
- Change of magnetic pitch angle during bursts, measured with MSE, is of the order of background fluctuations

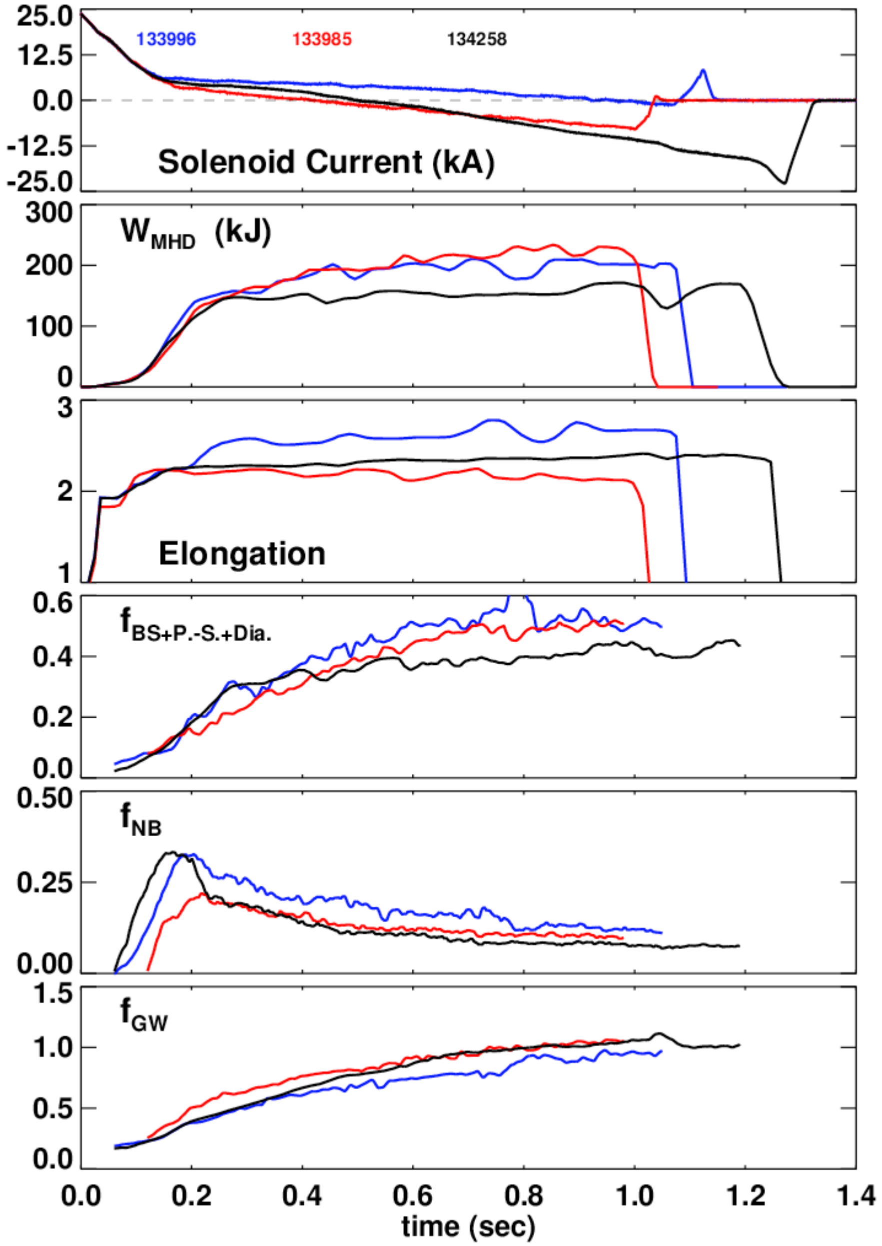


- Tangential FIDA (2011) will measure co-going fast ion redistribution – more relevant for current drive
- More extensive modeling is planned to understand effect of fast ion redistribution on beam-driven current profile



R09-3

Achieved Reliable Scenario with High-κ, High-β_P 60-65% Non-Inductive Fraction, then Extended to High-β_T

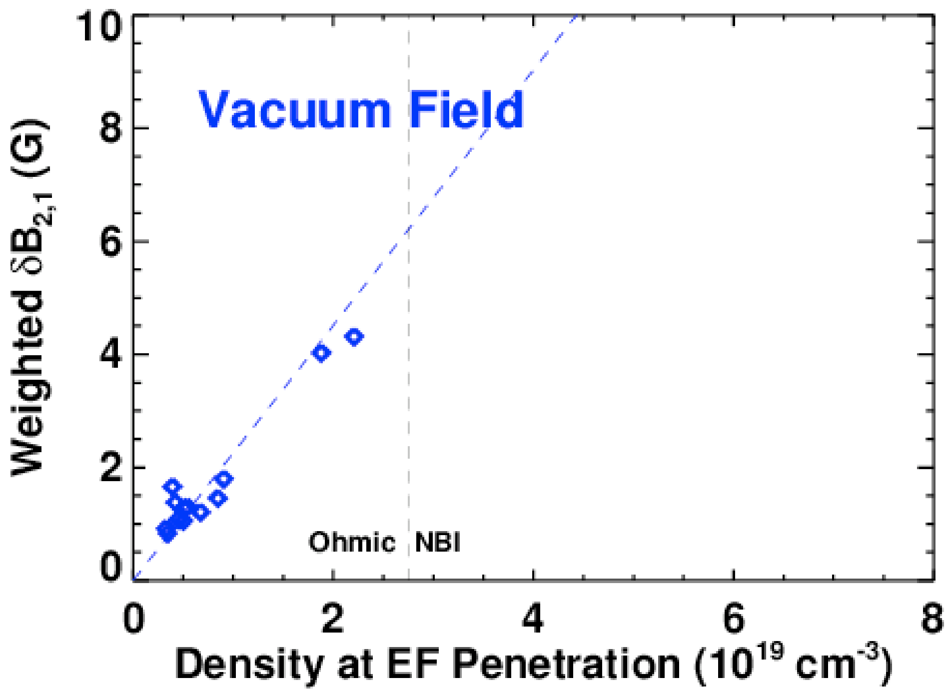


- Key features for these scenarios
  - High elongation to increase bootstrap fraction.
  - Reduced density for larger NBCD.
  - Improved confinement with lithium conditioning.
  - Improved stability with RWM feedback & dynamic error field control.

- Scenario then extended to higher normalized current $I_N=I_P/aB_T$
  - High elongation assists in avoiding edge-q limits at high normalized current
  - Long pulse obtained with flat-top averaged β_T > 23 %
    - Sustained periods with β_T~30%

High-β Error-field Penetration Threshold Correlates Linearly with Density if Plasma Response Effects are Included (IPEC)

- Compare the resonant 2/1 amplitude to the line average density, at the time of mode penetration
- Wide variety of data in the scan:
  - Ohmic L-mode plasma at low density



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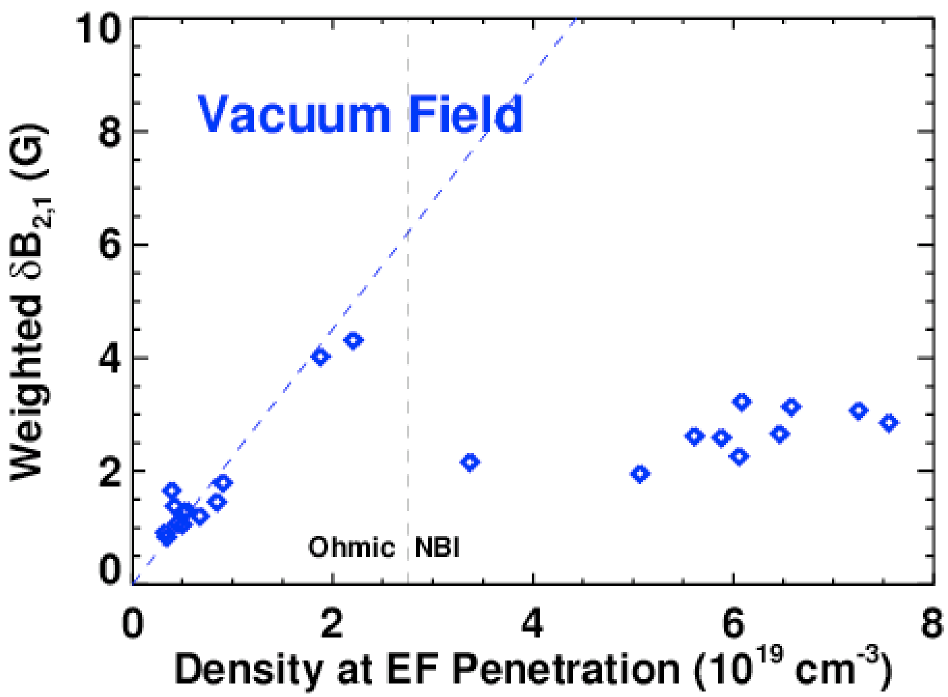
  - Vacuum field: Linear scaling with density fails; error-field penetration at high-β appears to occur at anomalously low density



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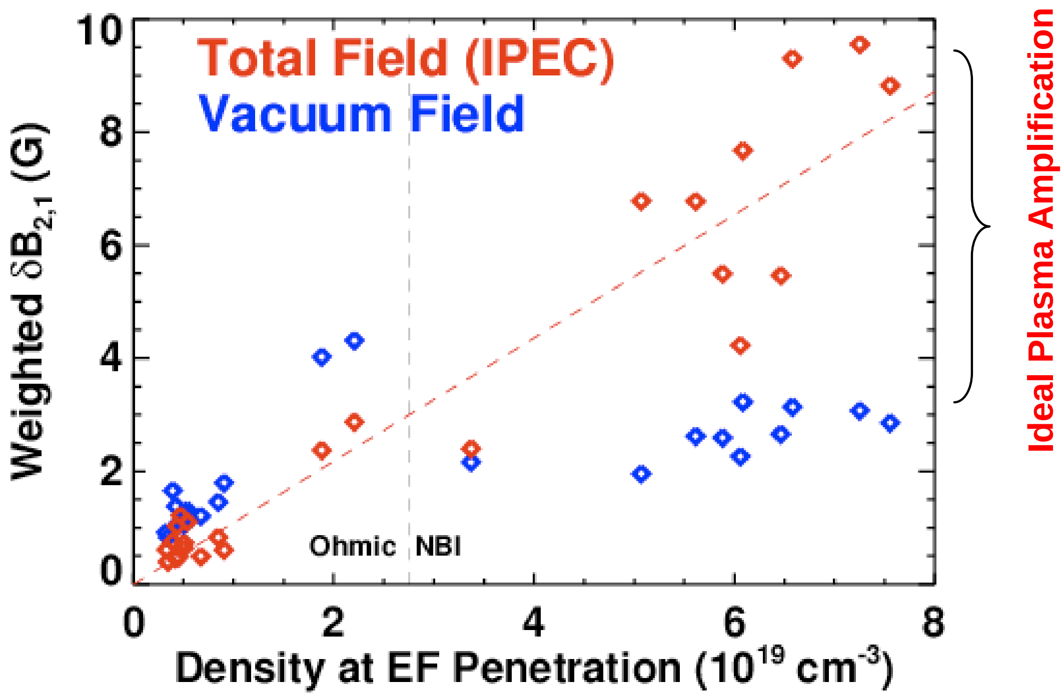
- Wide variety of data in the scan:
  - Ohmic L-mode plasma at low density
  - NBI-heated H-mode at high density
- IPEC results demonstrate importance of plasma response:
  - Vacuum field: Linear scaling with density fails; error-field penetration at high-β appears to occur at anomalously low density
  - IPEC: Error field penetration threshold scales more linearly with density

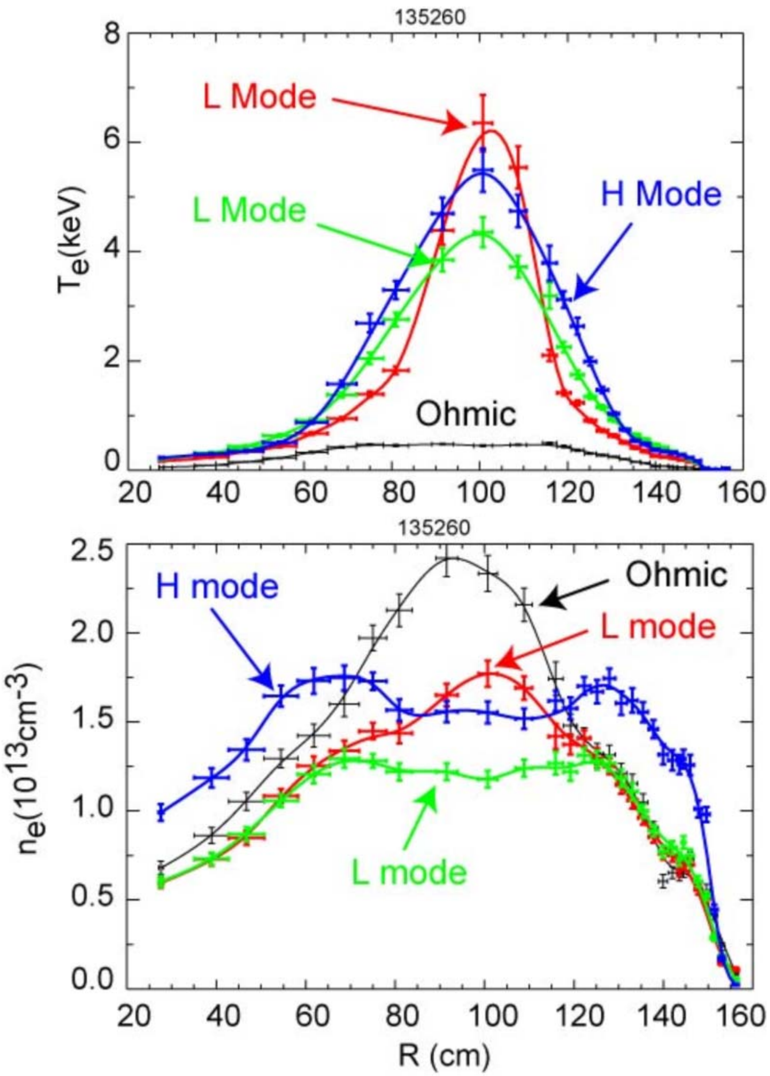


IPEC

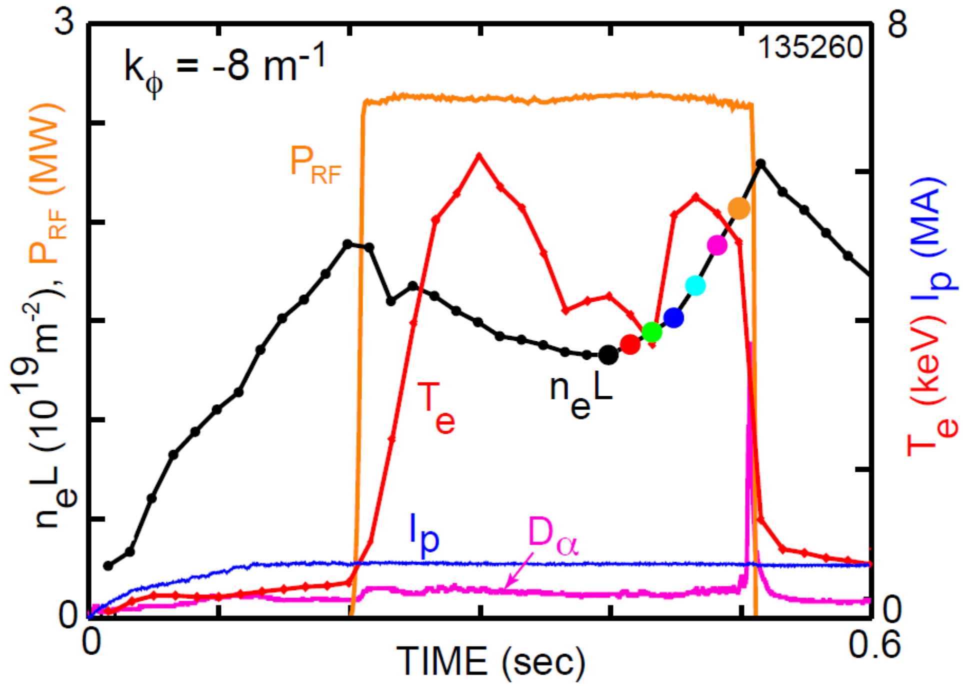
Ideal Perturbed Equilibrium Code

Improved Coupling Efficiency and Achieved Record T_e = 6.2keV Using Upgraded HHFW Antenna

PAC25-7

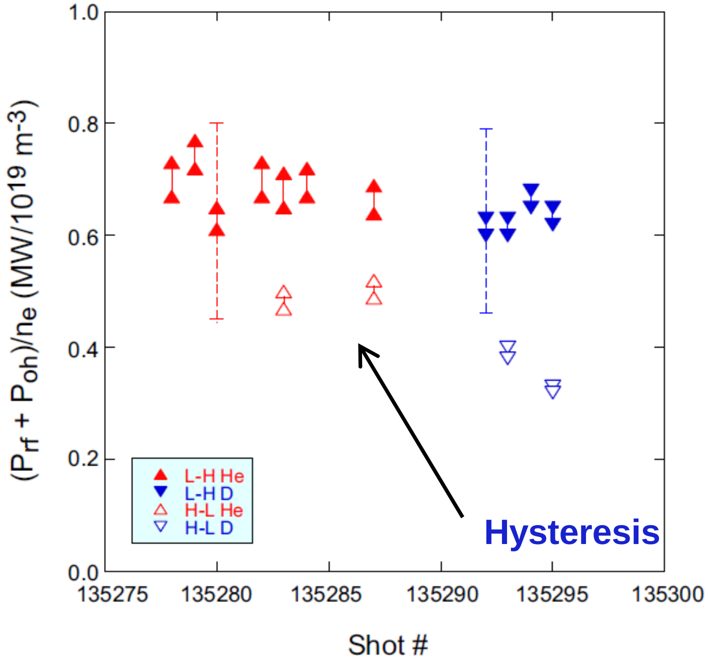


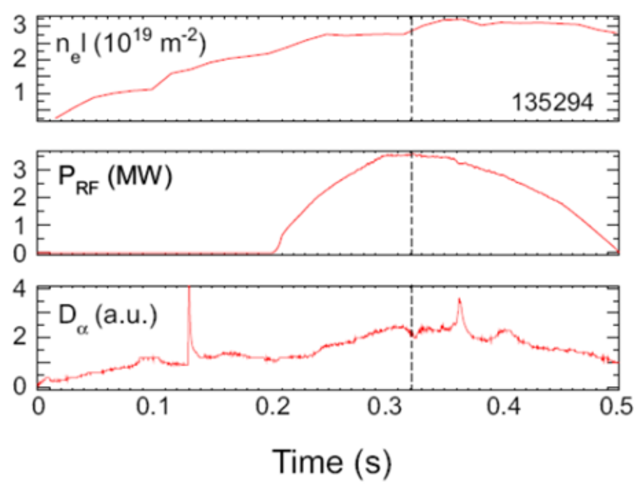
Maintained coupling through L-H transition in presence of ELMs



- Moved antenna grounding point to center of strap to reduce voltage per current
  - System quickly commissioned to previous power levels (2-3 MW)
  - Additional conditioning, combined with improved ELM discrimination should allow P_{RF} > 5MW

Normalized L-H Threshold Power P_{LH}/n_e Similar for He and D Plasmas Heated by HHFW





Continuous ramp in P_{RF} allowed fine resolution

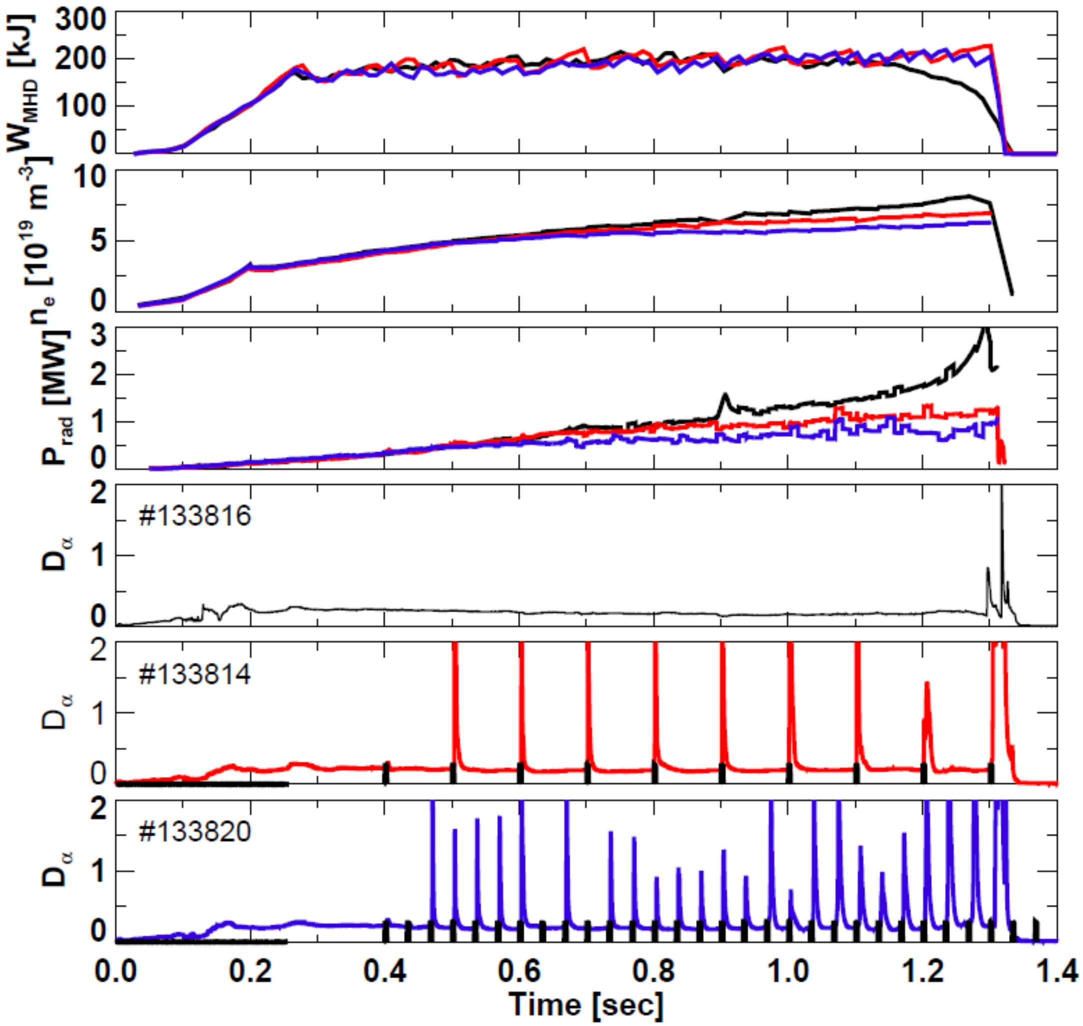
L-H threshold power vs. species is ITER high priority task

Other scalings observed in NSTX:

- Plasma current
  - P_{LH} / n_e increased ~2 x for I_P = 0.7MA → 1MA
- Lithium coatings
  - P_{LH} / n_e decreased ~35% with Li evaporation
- 3D field strength
  - P_{LH} / n_e increased ~65% with 3-4 higher n=3 field
- τ_E weakly dependent on B_T

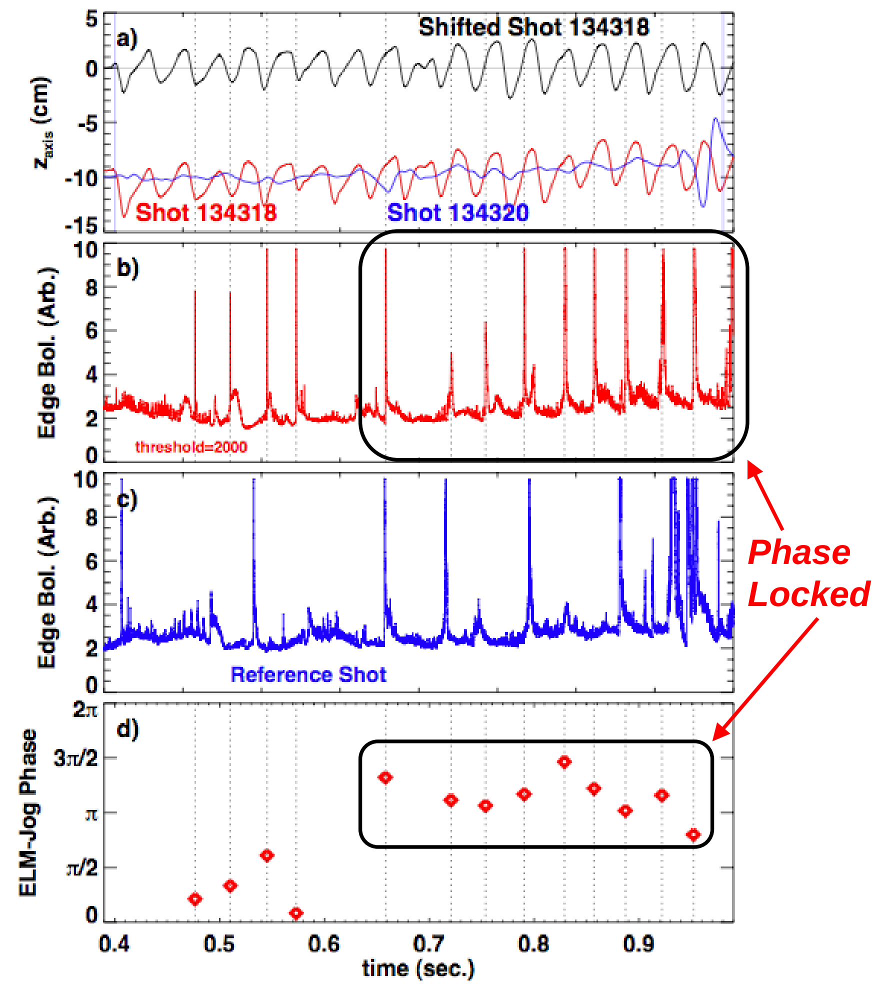
ELM Pacing Developed With Pulsed Non-Resonant Fields and Vertical Jogs

Rapid, Reliable Triggering with Pulsed 3-D Fields



- Reduction in radiated power
- Rapid ELMs lead to smaller per-ELM energy loss [see BP and/or ASC talks for more information]

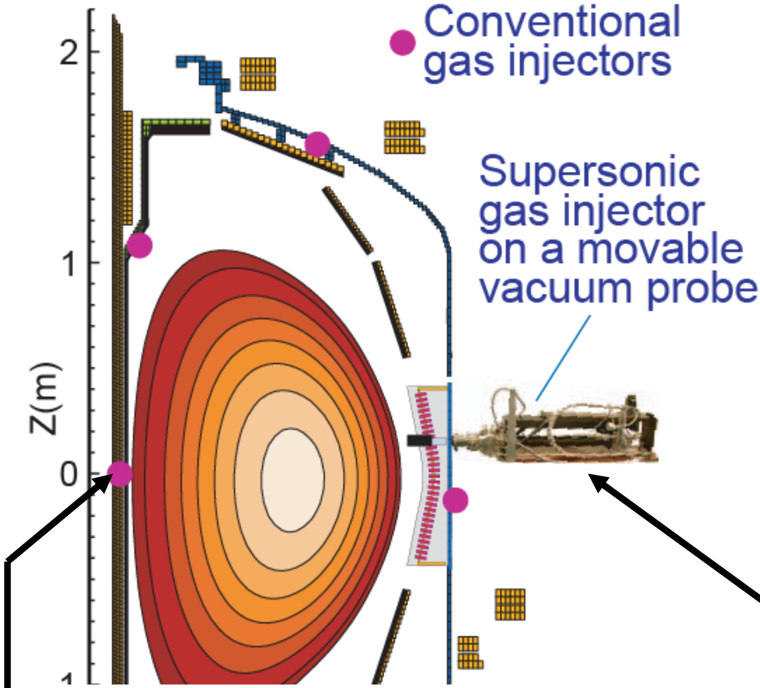
ELM Pacing Via Vertical Jogs



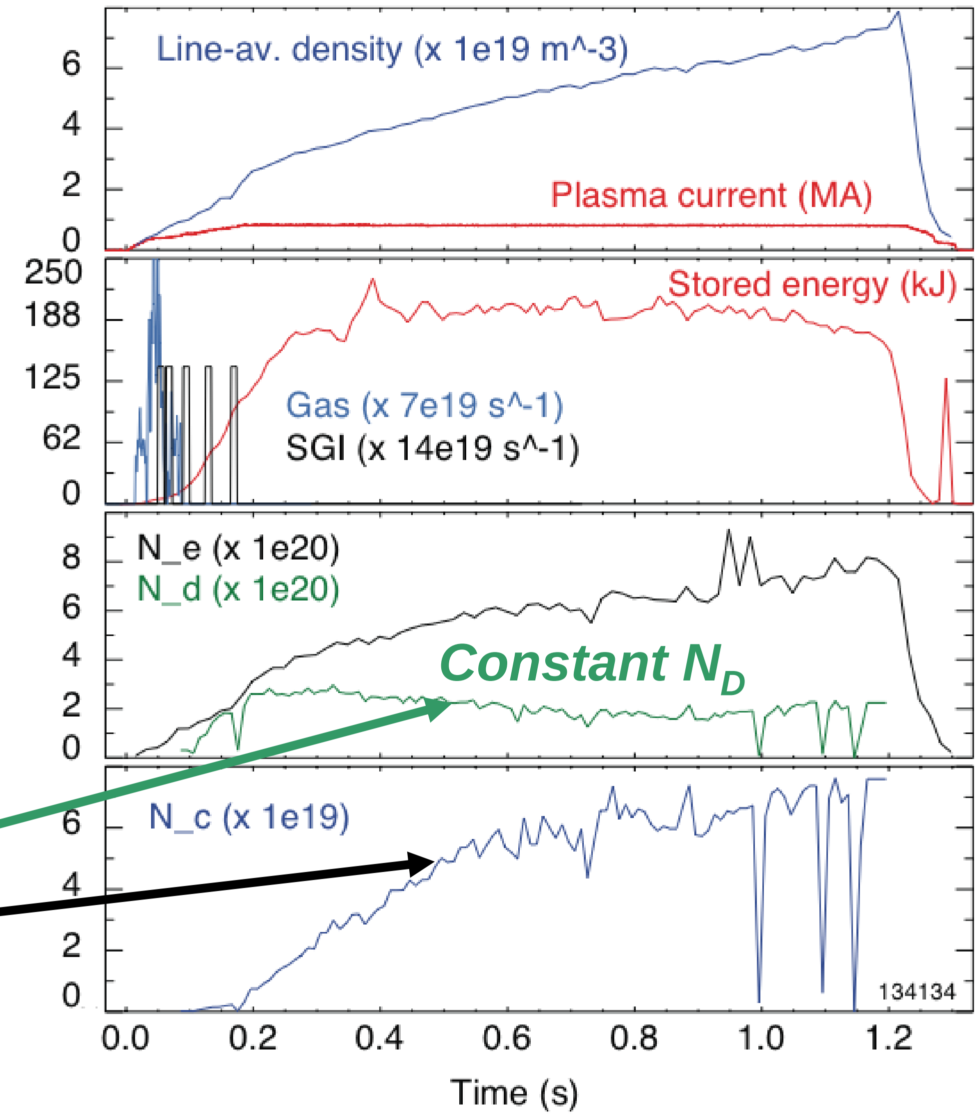
- Vertical jogging successful despite thick continuous vacuum vessel.
- ELMs become phase locked to upward motion *[PAC25-7]*

Supersonic Gas Injection (SGI) Enables Control of D^+ Content in LITER ELM-free Discharges, but C^{6+} Dominates N_e

PAC25-7

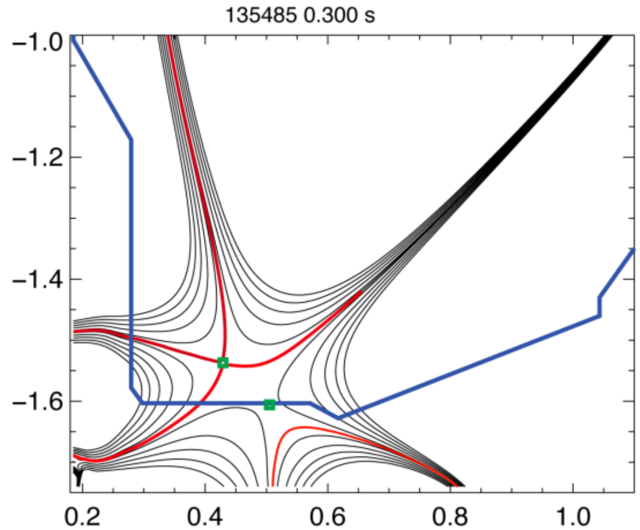


LITER at 9 mg/min, ELM-free

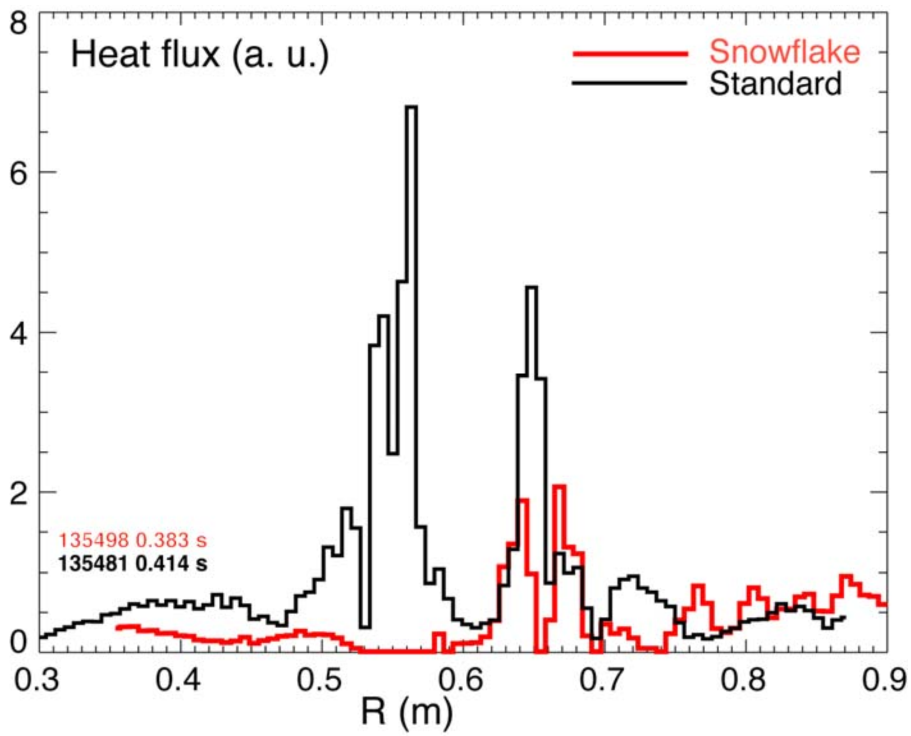


- Replaced high-field-side (HFS) injection with SGI-only fueling
  - HFS used for H-mode access
  - HFS long tube → slow response
- SGI only → D ion density control
- ***N_e* is rising due to carbon**
  - **C confinement too good…**

Strike Point Control Development for LLD was Used to Enable "Snow-flake" Divertor Research

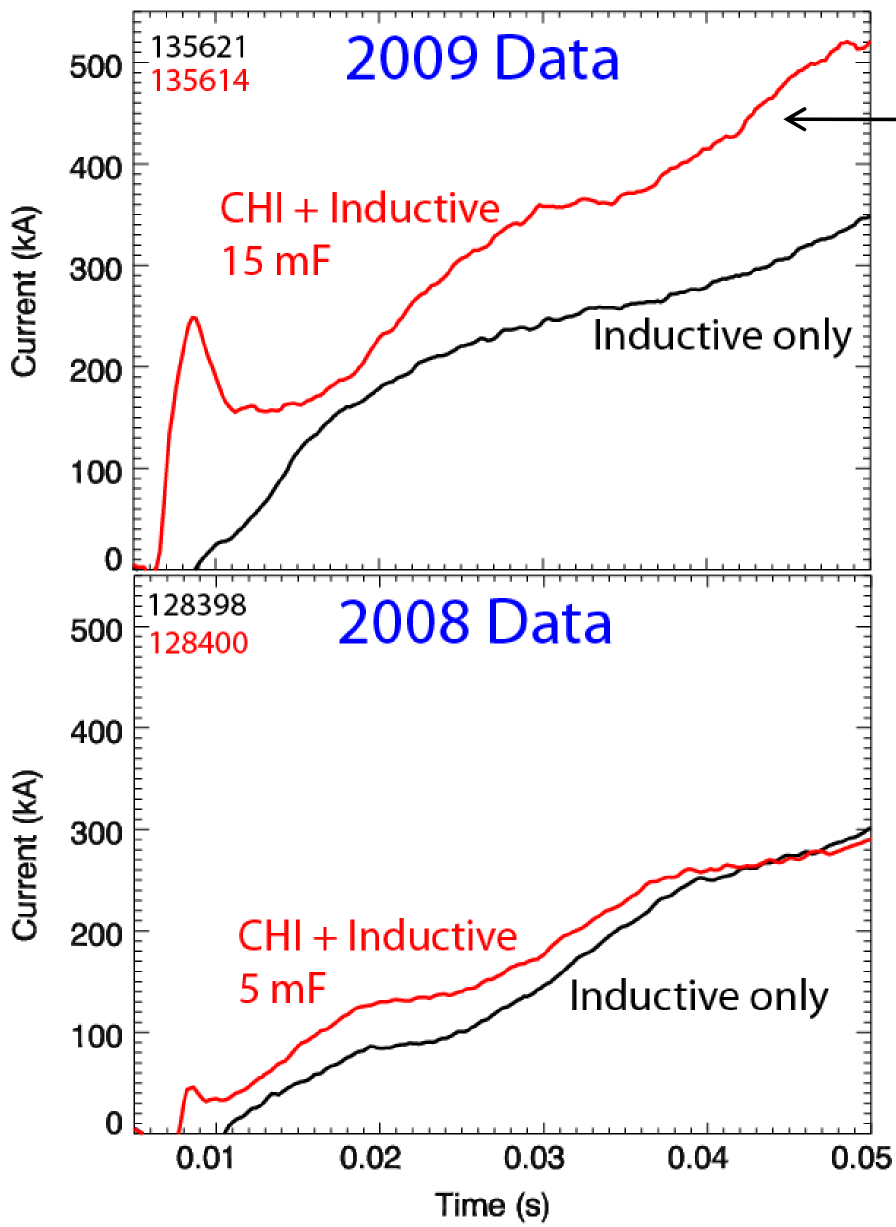


- **Maintained "snowflake"-like configuration for 100s ms**
- **Obtained with lithium**
- **Maintained H-mode confinement with core carbon reduction by 50 %**



- **OSP partial detachment, reduction in divertor peak heat flux**

300kA of CHI Discharge Generated and Coupled to Induction at an Efficiency of 10A/Joule



Discharges with 3-capacitors (20kJ) reaches 525kA

- **-200kA higher than induction-only discharge**
- **-Applied loop voltage is same for all cases**

Methods used to reduce Low-Z impurities:

Long-pulse (400ms) CHI conditioning

Deuterium GDC to reduce oxygen

Buffer field in Absorber to reduce oxygen

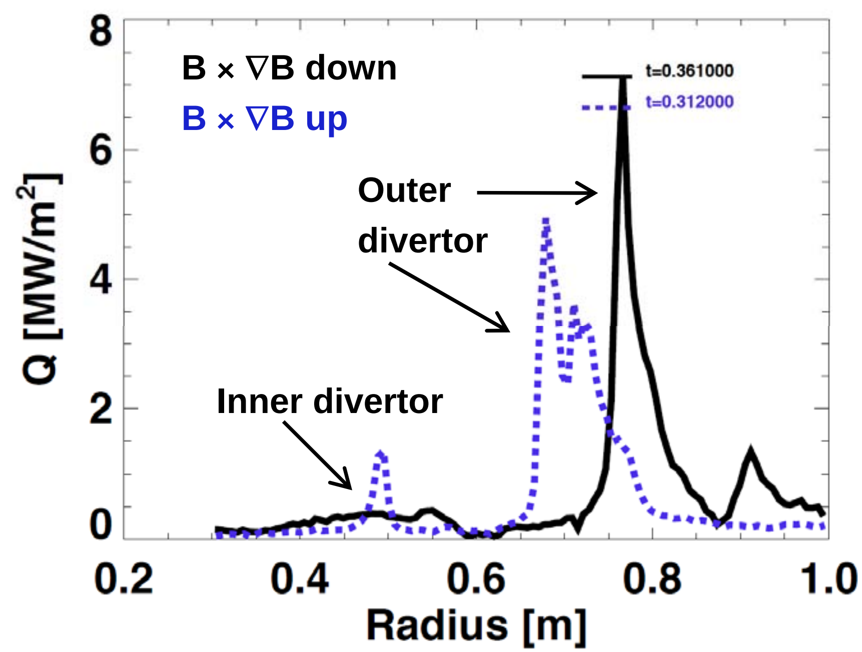
Lithium evaporation

Higher cap bank energy leads to arc – will improve in FY10

Operation with Reversed B_T Leads to Important Changes in Divertor Operation

Divertor detachment

- Inner divertor reattaches and heat flux profile has standard exponential character with **B** × ∇B up



L – H Power threshold

$(P_{RF}+P_{OH})/n_e$ (MW/10^{19} m^{-3})

	USN	LSN
No Li	0.84	1.01
Li	0.51	0.96

$(P_{RF}+P_{OH}-dW/dt)/n_e$ (MW/10^{19} m^{-3})

	USN	LSN
No Li	0.55	0.79
Li	0.41	0.75

FY09 Research Met All Program Milestones, Contributed to several ITER/ITPA Topics & Developed New Capabilities

- Increased gas retention with Li is consistent with the formation of Li-C-O chemical bonds beyond a threshold in Li deposition
  - Multi-machine gas retention data needed for operation with tritium in ITER
- Successful Beta-N feedback used as rotation was varied
  - Stable plasma operation near stability limits should increase shot efficiency
- RWM stability increases with increased fast ion content
  - Important for ITER and ST-FNSF that are expected to have high fast ion content
- 3D coils used for reliable ELM triggering
  - ELM control is an important ITER need
- Achieved reliable scenario with high κ, high β_p with up to 70% non-inductive fraction
  - Non-inductive sustainment important for next-step STs
- Demonstrated 200kA inductive flux savings with CHI (4× increase from 2008)
  - Needed for ST-CTF and reducing cost of tokamak-based power plant
- HHFW antenna modified, and supported ITER-relevant L-H studies (in D_2 vs He)
  - Achieved record 6.2keV Te; L-H power threshold studies important for ITER and ST-CTF
- Operated with Reversed TF for first time
  - Extends understanding of L-H threshold and divertor operation
- More than 50 journal publications
  - Published 6 PRLs, 11 in NF, 9 in PoP, 11 in J. Nucl. Mat. and 4 in PPCF

Backup Slides

NSTX participated in International Tokamak Physics Activity (ITPA) benefiting both ST and tokamak/ITER research

Actively involved in 21 joint experiments – contribute/participate in 33 total

MHD, Disruption Control

- MDC-2 Joint experiments on resistive wall mode physics
- MDC-4 Neoclassical tearing mode physics – aspect ratio comparison
- MDC-12 Non-resonant magnetic braking
- MDC-14 Rotation effects on neoclassical tearing modes
- MDC-15 Disruption database development
- MDC-17 Physics-based disruption avoidance

Transport and Confinement

- TC-1 (was CDB-2) Confinement scaling in ELMy H-modes: beta degradation
- TC-2 (was CDB-10) Power ratio – Hysteresis and access to H-mode with H~1
- TC-4 (was CDB-12) H-mode transition and confinement dependence on ionic species
- TC-6 Effect of Rotation on Plasma Performance
- TC-10 (was TP-7) Experimental ID of ITG, TEM and ETG turbulence + comparison w/ codes
- TC-15 Dependence of momentum and particle pinch on collisionality

Energetic Particles

- EP-2 Fast ion losses and redistribution from localized *AE

Pedestal and Edge Physics, Divertor, Scrape-off Layer

- PEP-6 Pedestal structure and ELM stability in DN
- PEP-19 Edge transport under the influence of resonant magnetic perturbations
- PEP-25 Inter-machine comparison of ELM control by magnetic field perturbations from midplane RMP coils
- DSOL-17 Cross machine comparisons of pulse-by-pulse deposition
- DSOL-21 Introduction of pre-characterized dust for dust transport studies in divertor and SOL

Integrated Operation Scenarios

- IOS-4.1 Access conditions for hybrid with ITER-relevant restrictions
- IOS-5.1 Ability to obtain and predict off-axis NBCD
- IOS-5.2 Maintaining ICRH coupling in expected ITER Regime