NSTX

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NSTX FY2010 Research Program Overview

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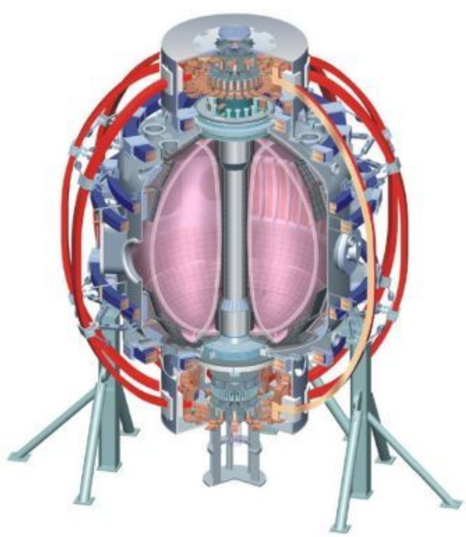
J. Menard, PPPL

For the NSTX Research Team

NSTX FY2010 Research Forum

Plenary Session

Tuesday December 1, 2009



Culham Sci Ctr
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IPP, Garching
ASCR, Czech Rep
U Quebec

Outline

- NSTX Mission
- Organization
- Run Time Allocation
- Prioritization
- FY09 Research Highlights +

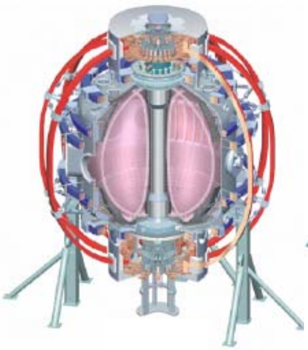
  FY10 Milestones and Priorities
- Forum Action Items

NSTX Mission Elements

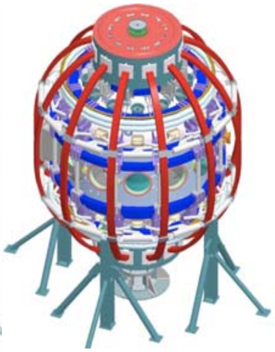
- **Understand unique physics properties of ST**
  - Assess impact of low A, high β, high v_{fast} / v_A on toroidal plasma science
  - Longer term NSTX → NSTX-Upgrade goals:
    - Study high beta plasmas at reduced collisionality
    - Access full non-inductive start-up, ramp-up, and sustainment
    - Prototype solutions for mitigating high heat, particle exhaust

- **Complement tokamak physics, support ITER**
  - Exploit unique ST features to improve tokamak understanding
  - Benefit from tokamak R&D

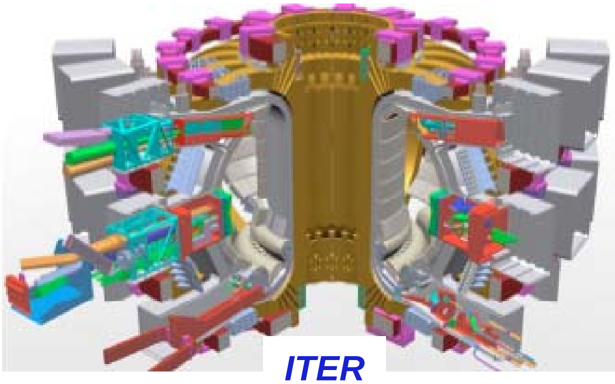
- **Establish attractive ST operating conditions**
  - Understand and utilize ST for addressing key gaps between ITER and FNSF / DEMO
    - ST ReNeW Thrusts 14 (FNS), 13 (PMI), 8 (self-driven high-Q_{DT})
  - Advance ST as fusion energy source



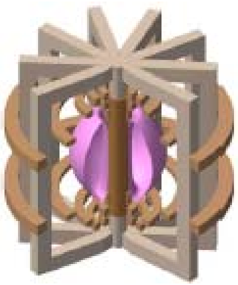
NSTX



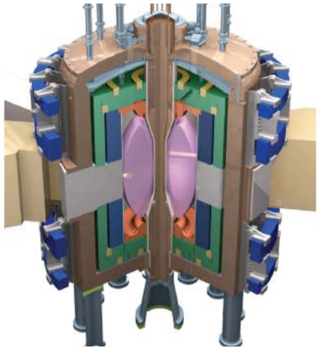
NSTX-U



ITER



PMI toroidal facility (NHTX)



ST-based Fusion Nuclear Science Facility (ST-FNSF)

NSTX research forum organization

- Forum home-page: http://nstx-forum-2010.pppl.gov/
  - Follow “Submit Experimental Proposal Idea” link to submit your ideas
  - Remote connection info is at top of “Agenda” page on forum website

- The NSTX research program is organized by science area into 7 Topical Science Groups (TSGs)

Topical Science Group	Leader	Deputy	Theory and Modeling
Advanced Scenarios and Control	Stefan Gerhardt	Michael Bell	Egemen Kolemen
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	609-243-2823	609-243-3282	609-243-3731
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	609-243-2064	609-243-3176	609-243-2063
Lithium Research	Charles Skinner	Bob Kaita	Daren Stotler
	cskinner@pppl.gov	rkaita@pppl.gov	dstotler@pppl.gov
	609-243-2214	609-243-3275	609-243-2063
Macroscopic Stability	Steve Sabbagh	Jon Menard	Jong-Kyu Park
	sabbagh@pppl.gov	jmenard@pppl.gov	jpark@pppl.gov
	609-243-2645	609-243-2037	609-243-3513
Solenoid-free Start-up and Ramp-up	Roger Raman	Dennis Mueller	Steve Jardin
	rraman@pppl.gov	mueller@pppl.gov	sjardin@pppl.gov
	609-243-2855	609-243-3239	609-243-2635
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	hyuh@pppl.gov	skaye@pppl.gov	thahm@pppl.gov
	609-243-2710	609-243-3162	609-243-2611
Wave-Particle Interactions	Gary Taylor	Mario Podesta	Nikolai Gorelenkov
	gtaylor@pppl.gov	mpodesta@pppl.gov	ngorelen@pppl.gov
	609-243-2573	609-243-3526	609-243-2552

- Final review + scheduling of experimental proposals led by run coordinators:

Coordinator	Deputy
Eric Fredrickson	Steve Sabbagh
eric@pppl.gov	sabbagh@pppl.gov
609-243-2945	609-243-2645

- Operate approx March 1 to ~July/Aug 2010

Run-time guidance for FY2010 run

- FY2010 run-time allocation = 15 run weeks = 75 run days
- 15 days for cross-cutting + calibrations **including 5-10 days for restart w/ LLD + shot/scenario development with LLD** → **60 run days** for TSGs
- Complete 1st priority experiments with 75% of total → 45 run days
  - OFES Joint Facility and NSTX Research Milestone XPs are highest priority, and should be completed within this run-time allocation
- TSGs should develop plans for 1st +2nd priority according to allocation below
  - TSG's are **NOT** guaranteed to receive the full allocation shown
  - Actual allocation will be decided at mid-run assessment

TSG	1st priority XP run days	1st + 2nd priority XPs	Milestones
Advanced Scenarios and Control	**5.5**	**8**	
Boundary Physics	**8**	**10**	Joint, R(10-3)
Lithium Research	**5.5**	**8**	
Macroscopic Stability	**6**	**8**	R(10-1)
Solenoid-free Start-up and Ramp-up	**4.5**	**6**	
Transport and Turbulence	**5.5**	**7**	
Wave-Particle Interactions	**6**	**8**	R(10-2)
ITER high priority	**4**	**5**	
Total	**45**	**60**	

Some programmatic considerations for XP prioritization

(in approximate priority order)

- Viability of proposal given available NSTX capabilities
- OFES Joint Research Milestones
- NSTX Research Milestones
  - Annual milestones + other ST high priority research
  - NSTX-Upgrade design needs – expected high priority:
    - Disruption load diagnosis and characterization
    - Heat flux mitigation strategies – novel magnetic geometries, detachment
    - Particle and impurity control for long-pulse
- ITER high priority research
- ITPA – especially where NSTX is lead/prominent experiment
- Experiments potentially leading to high profile publications:
  - PRL, Science, Nature
- Career development (thesis, post-doctoral research)
- Any good idea generated during the course of the run

Some frequently asked questions prior to/during forum…

- Q: Will NSTX have a counter-I_P campaign in FY2010?
  - A: Very unlikely – emphasis will be on milestones + LLD, HHFW, BES, and further, NSTX only has 15 run weeks – 2 less than FY2009
- Q: Will NSTX have a reversed-B_T campaign in FY2010?
  - A: This is possible if there is strong (and broad) scientific justification
- Q: Which TSG should this proposal be submitted to?
  - A: If unclear, decision will generally be made based on TSG expertise needed to get best results, and which TSGs have run-time + available XP leaders
- Q: Is this a Lithium or Boundary or ASC proposal?
  - A: A bit of a gray area… but here is the **Lithium Research TSG** scope:
    - Diagnostic and PMI/divertor proposals focusing on LLD-specific issues and operation
    - XPs to "commission" and "characterize" the LLD, compare to LITER-only from FY09
    - Li dropper research, and Li-related development work – such as evaporation of Li into He, on-purpose evaporation of Li from plates
    - XPs to diagnose, understand, and reduce/eliminate **sources** of impurity accumulation during Li ELM-free H-mode
    - Tests / challenges of Li-related theory and modeling

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  FY10 milestones and priorities
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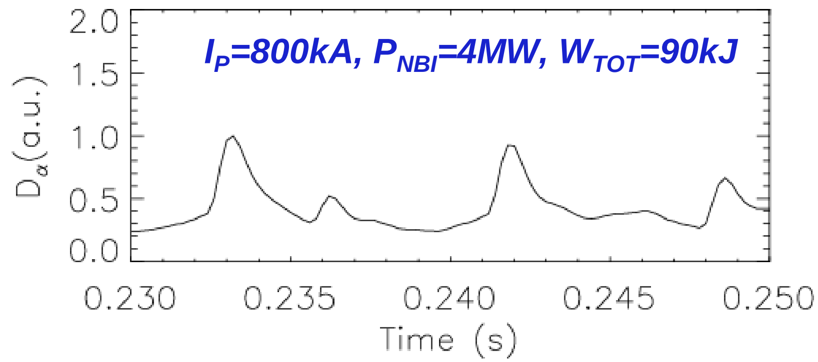
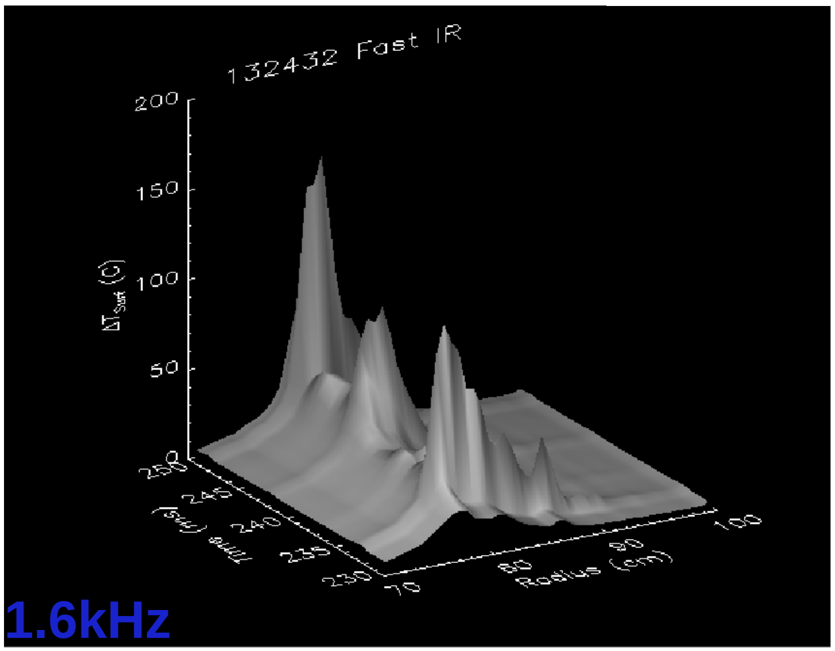
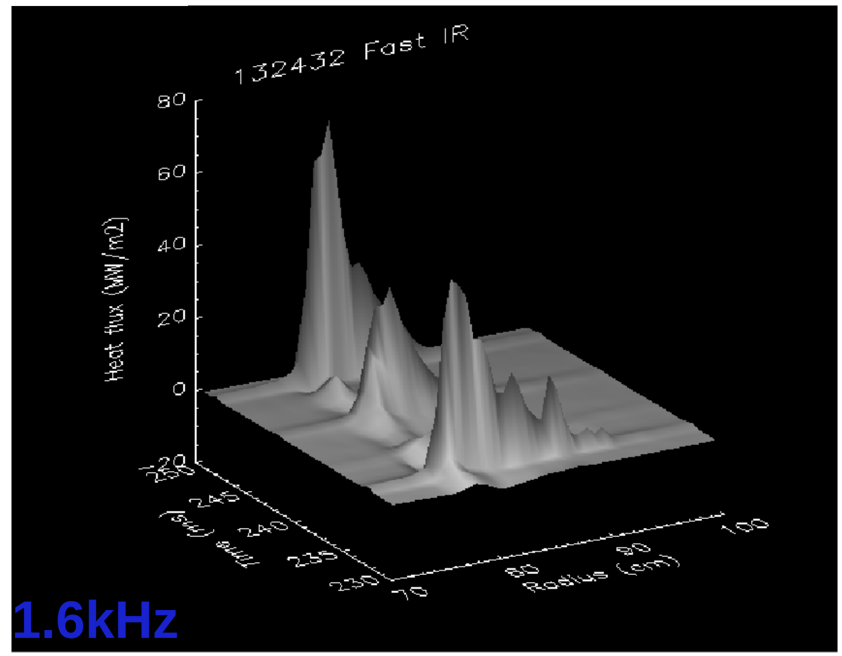
FY09 First fast IR camera data measuring ELM-resolved variation of divertor surface temperature and heat-flux



ΔT_{surf} = 100-150°C

ΔQ = 40-60MW/m^2





Short ELM rise time gives only one frame for a rising ELM even at 1.6kHz

ELMs push strike point out by 2-3cm

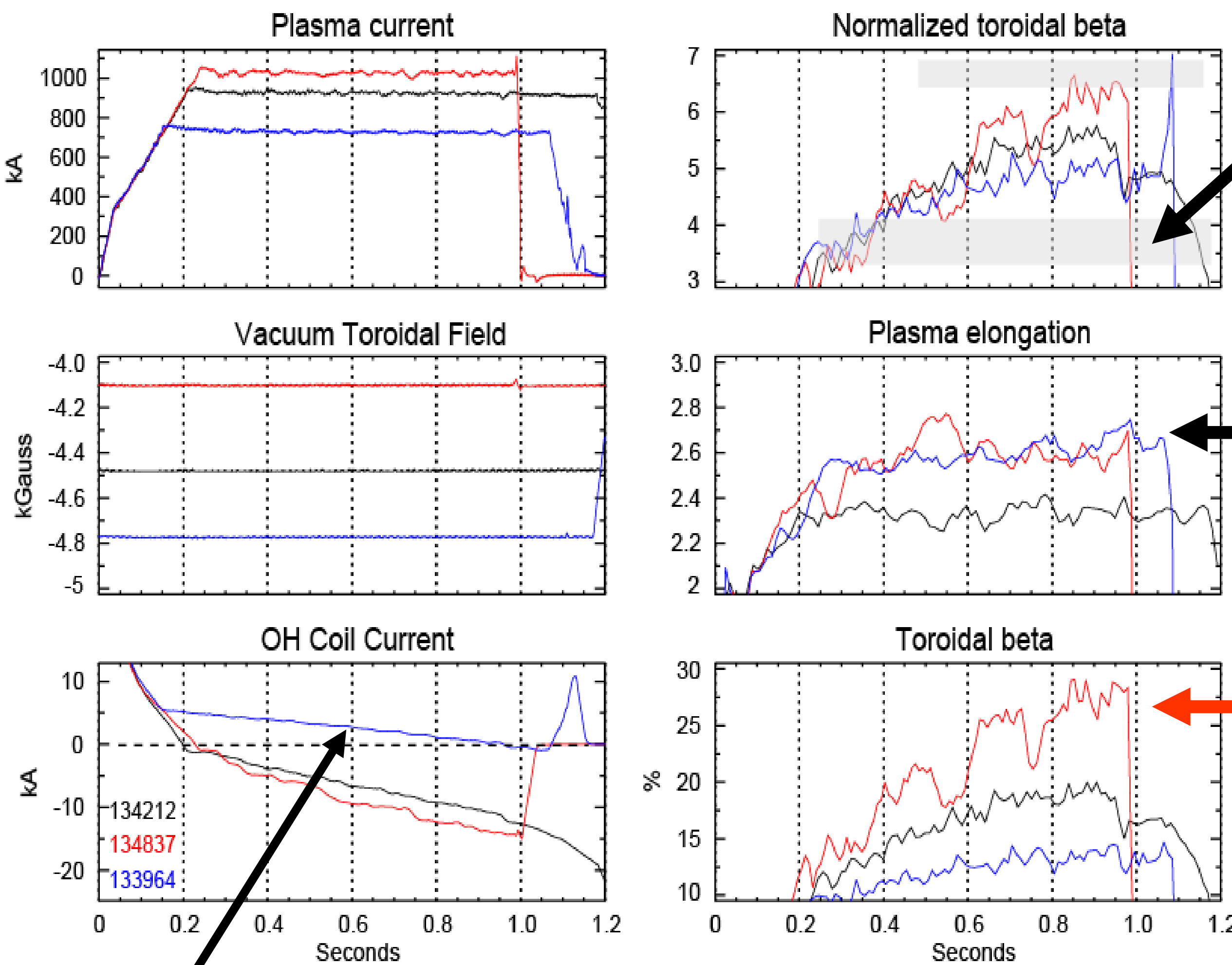
- ***Important for understanding ELM heat loss, projecting ELM interaction with LLD***

Boundary Physics FY2010 OFES Joint Research Milestone

- "Conduct experiments on major fusion facilities to improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER."

- Milestone elements:
  - Measure the divertor heat flux profiles and plasma characteristics in the tokamak scrape-off layer in multiple devices to investigate the underlying thermal transport processes.
  - Utilize unique characteristics of C-Mod, DIII-D, and NSTX to enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality, beta, parallel heat flux, and divertor geometry).
  - Coordinate experiments using common analysis methods to generate a data set that will be compared with theory and simulation

FY09 ASC milestone Sustained high-elongation and wall-stabilized operation was extended from β_T = 15-20% to 20-30%



- Above n=1 no-wall limit for ~$2\tau_{CR}$

- ***High elongation κ =2.6 sustained***

- β up to factor of 2 higher (β_T = 25-30%)
  - Pressure, density, confinement increase throughout shot

- High β_P → Lowest OH flux consumption so far
  - Projects to ~2-3s pulse

- Non-inductive fraction = 60-65%
- But, models under-predict total I_P by ~20%
  → Non-inductive fraction could be as high as 75%
  - Investigating data uncertainties: n_e, Z_{eff}, MSE, …

Macroscopic Stability FY2010 NSTX Research Milestone

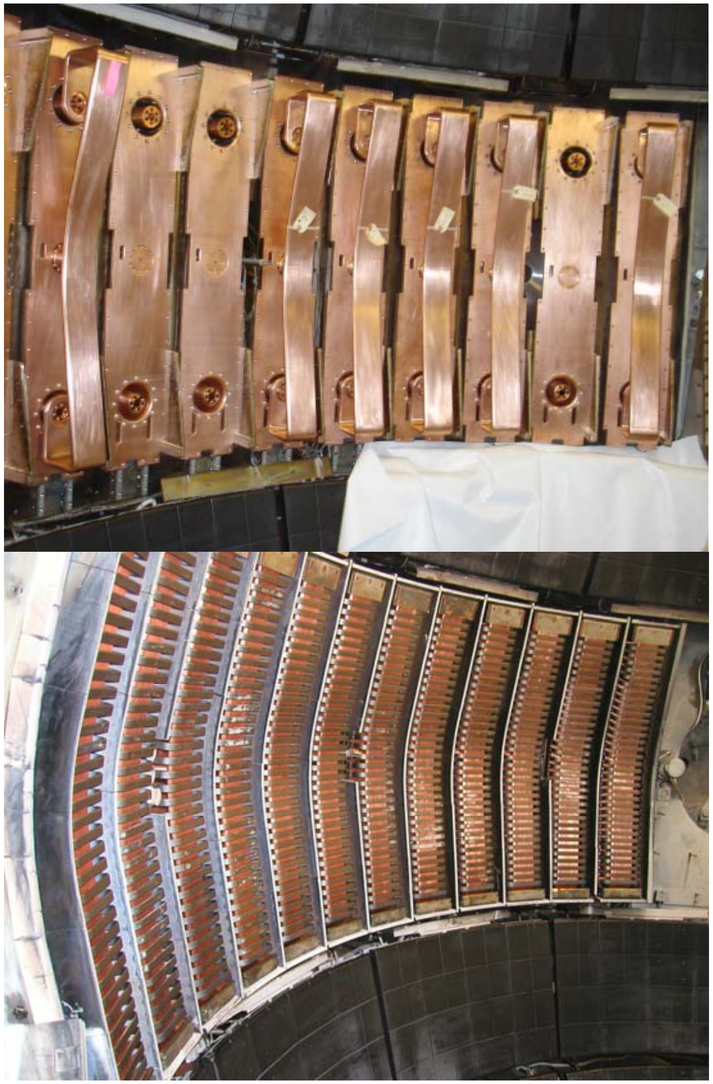
- R(10-1): Assess sustainable beta and disruptivity near and above the ideal no-wall limit:

- Utilize new <u>mode control tools/software</u> to characterize and quantify the achievable beta sustainment and disruption avoidance in the ST:
  - β_N control via active control of applied neutral beam power
  - Improvements in RFA and RWM detection via sensor compensation
  - Improvements to the RWM feedback algorithm via avanced state-space control
  - Real-time feedback on measured RFA (future)

- Characterize degree to which other instabilities (2/1 NTM) impact disruptivity

- Improve predictive capability:
  - Measure mode characteristics with SXR, magnetics, MSE, and calculate ideal beta limits, plasma response to 3D fields, RWM stability and control (DCON, IPEC, MISK, MARS-F/K, and VALEN)

FY09 HHFW group successfully completed antenna upgrade + external loop installation during NSTX operations



- Achieved new record $T_e(0)$ = 6keV, produced RF-heated H-mode for L-H threshold studies.

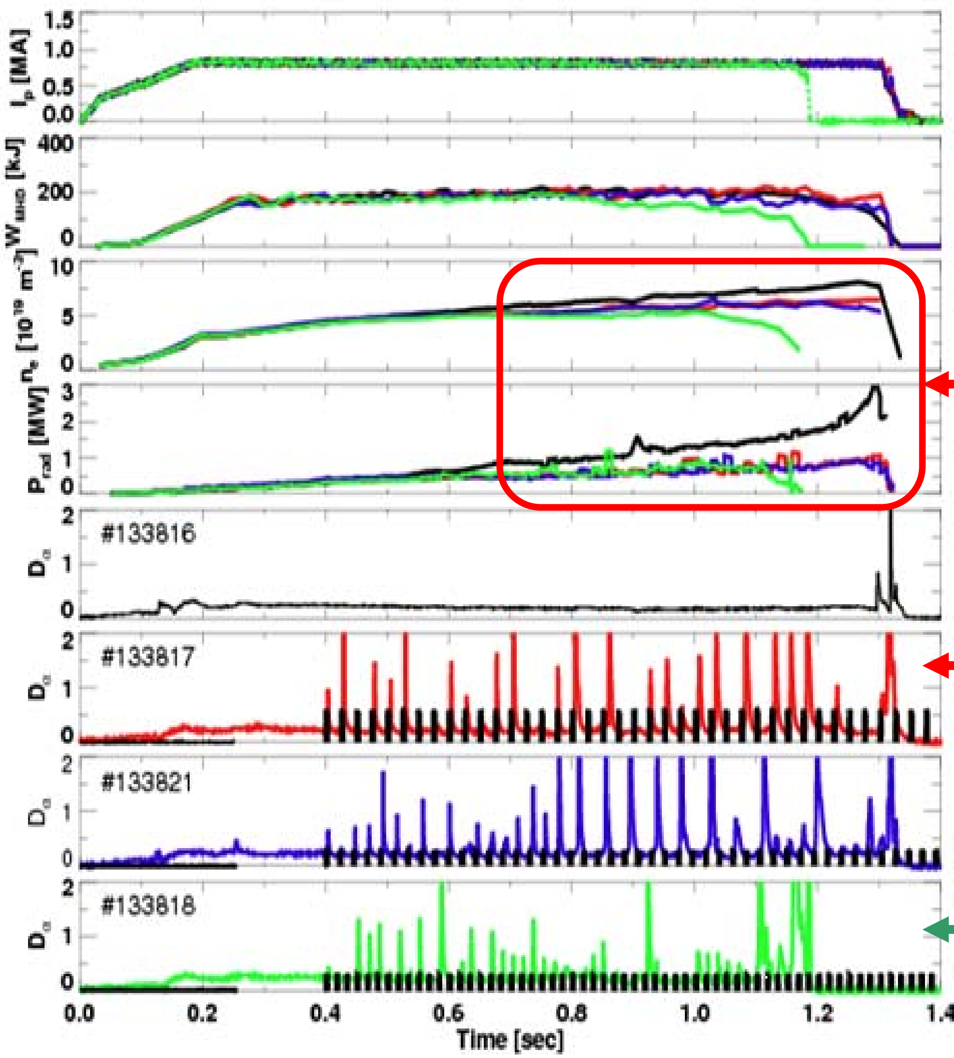
Wave-Particle Interaction FY2010 NSTX Research Milestone

- R(10-2): Characterize HHFW heating, current drive, and current ramp-up in deuterium H-mode plasmas.

- Over-arching goal: Establish HHFW as a reliable, high-power H&CD tool for start-up and sustainment, transport studies, scenario optimization…
- Milestone Goals:
  - Sustain 100% non-inductive plasma with BS + RFCD at any I_P
  - Develop bootstrap current over-drive ramp-up of ST plasma for the first time
  - Heat electrons in reduced-n_e NBI sustained H-mode to enhance NBICD
  - Develop HHFW as central current drive profile control tool in D H-mode

- Improve predictive capability:
  - Simulate, understand BS+HHFW I_P ramp-up/sustainment (TSC, TRANSP)
  - Measure HHFW acceleration of NBI fast-ions and compare to theory, and assess impact on advanced scenarios with strong NBI heating (CQL-3D, AORSA, TORIC, GENRAY)

FY09 ELM triggering using n=3 perturbations optimized to control density and radiation, maintain high confinement

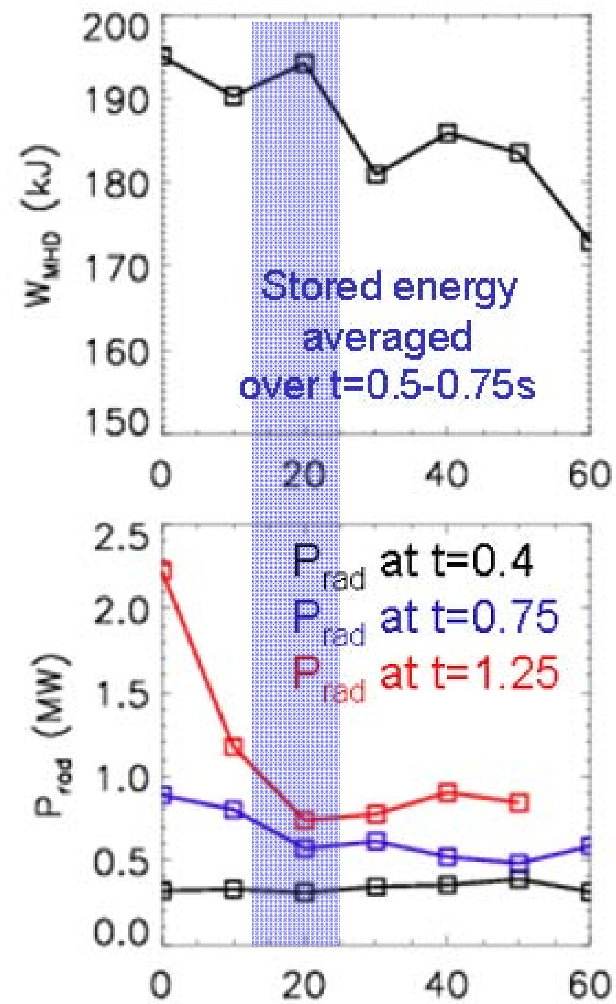


n_e & radiation rise arrested

But ELM size can be large
($\Delta W/W_{TOT}$= 10-15%)

Higher $f_{trigger}$ reduces size
($\Delta W/W_{TOT}$ ~ 5%)

Favorable n=3 amplitude and triggering frequency found



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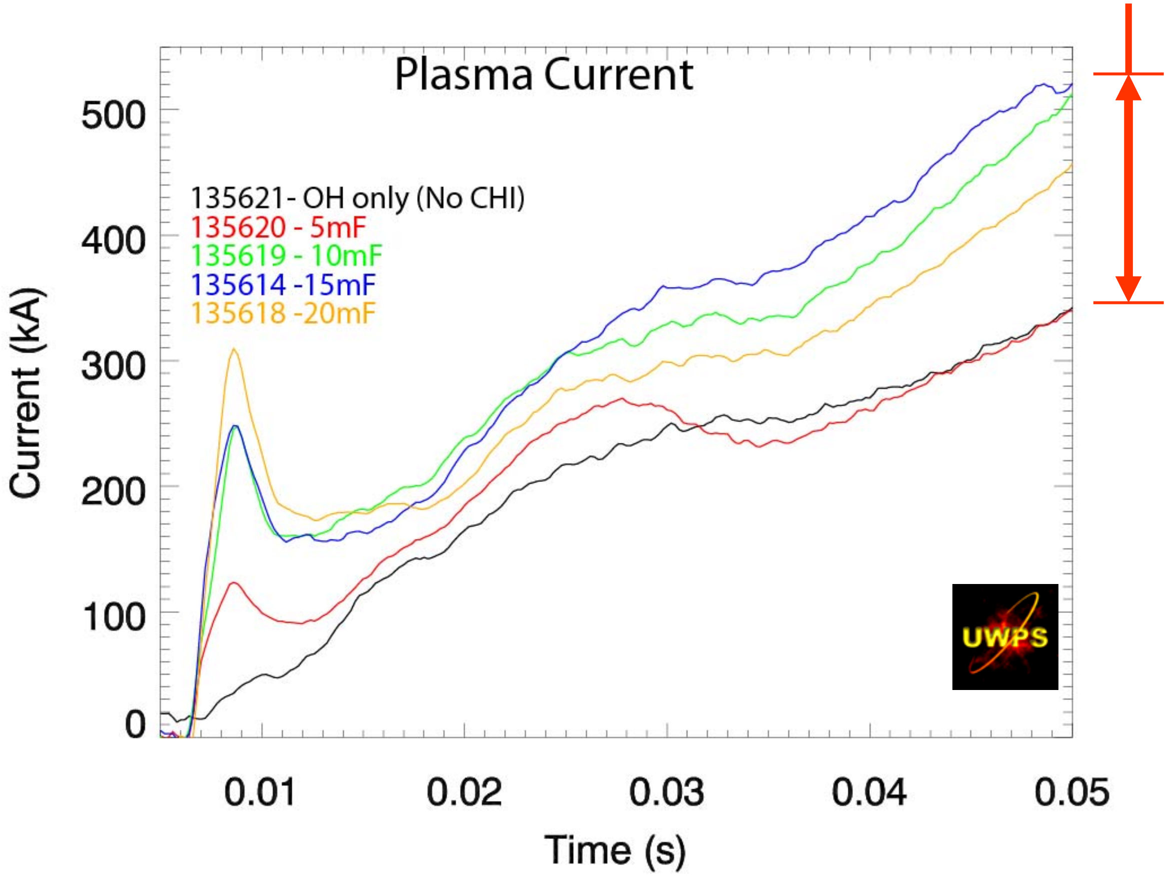
Boundary Physics FY2010 NSTX Research Milestone

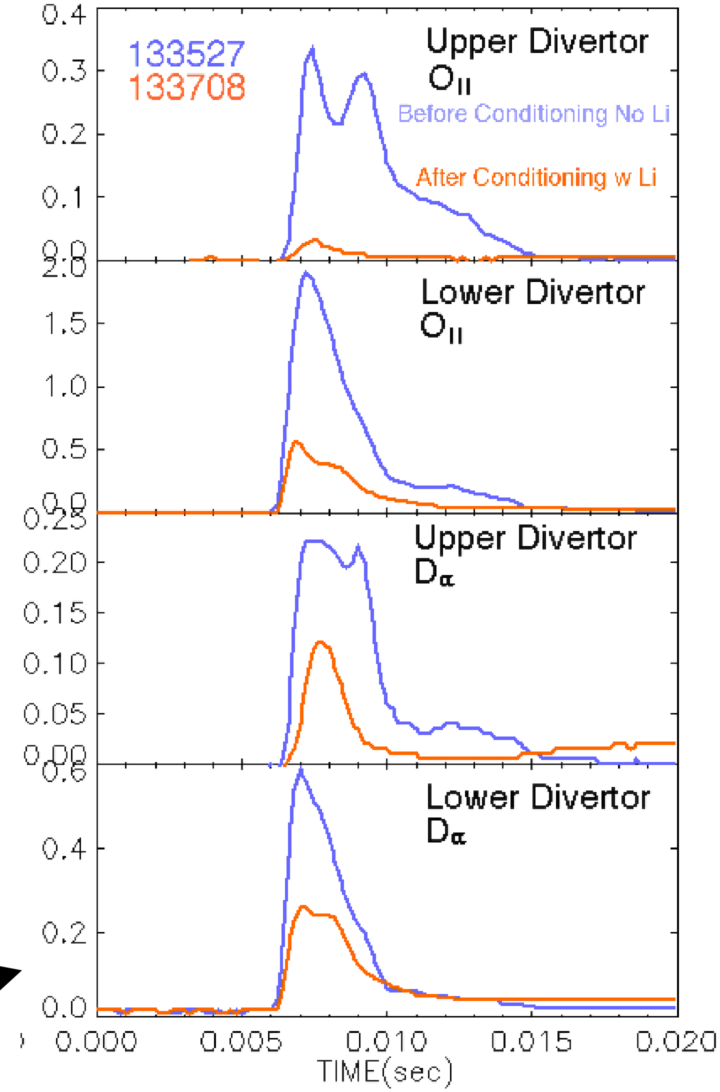
- R(10-3): Assess H-mode pedestal characteristics and ELM stability as a function of collisionality and lithium conditioning

- Determine the relative roles of reduced pedestal density and collisionality versus the possible direct effects of lithium
- Utilize particle pumping and density control from LITER, LITER+LLD
- Assess L-to-H threshold, pedestal height and barrier width, pedestal stability (affecting ELM type and size), and the down-stream divertor plasma and surface conditions
- Improve predictive capability:
  - Pedestal: Compare experimental profiles to prediction (XGC, GTC-Neo)
  - ELMs: Utilize high-resolution kinetic equilibrium reconstructions + linear and non-linear ELM-stability codes (ELITE, PEST, M3D), compare to experiment

FY09 Extensive conditioning campaign improved divertor conditions for successful coupling of CHI to induction

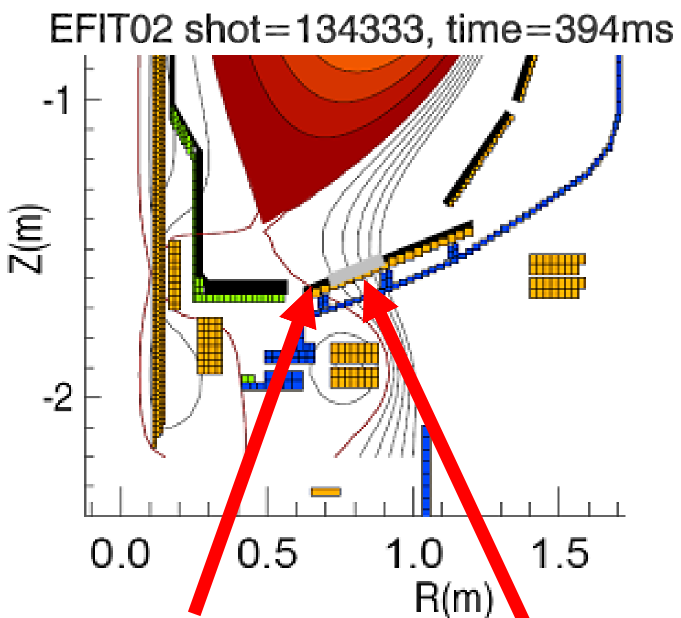
CHI coupled to induction + NBI-heated H-mode
with 180kA sustained current savings





- **Upper divertor conditioned with NBI-heated USN plasmas**
- **Lower divertor conditioned with sustained CHI plasma**
- **Li evaporation used to reduce oxygen, increase D pumping**
- **CHI voltage duration (absorber arcs) reduced**

FY09 Control of lower divertor strike-point implemented to enable and optimize operation with LLD in FY2010

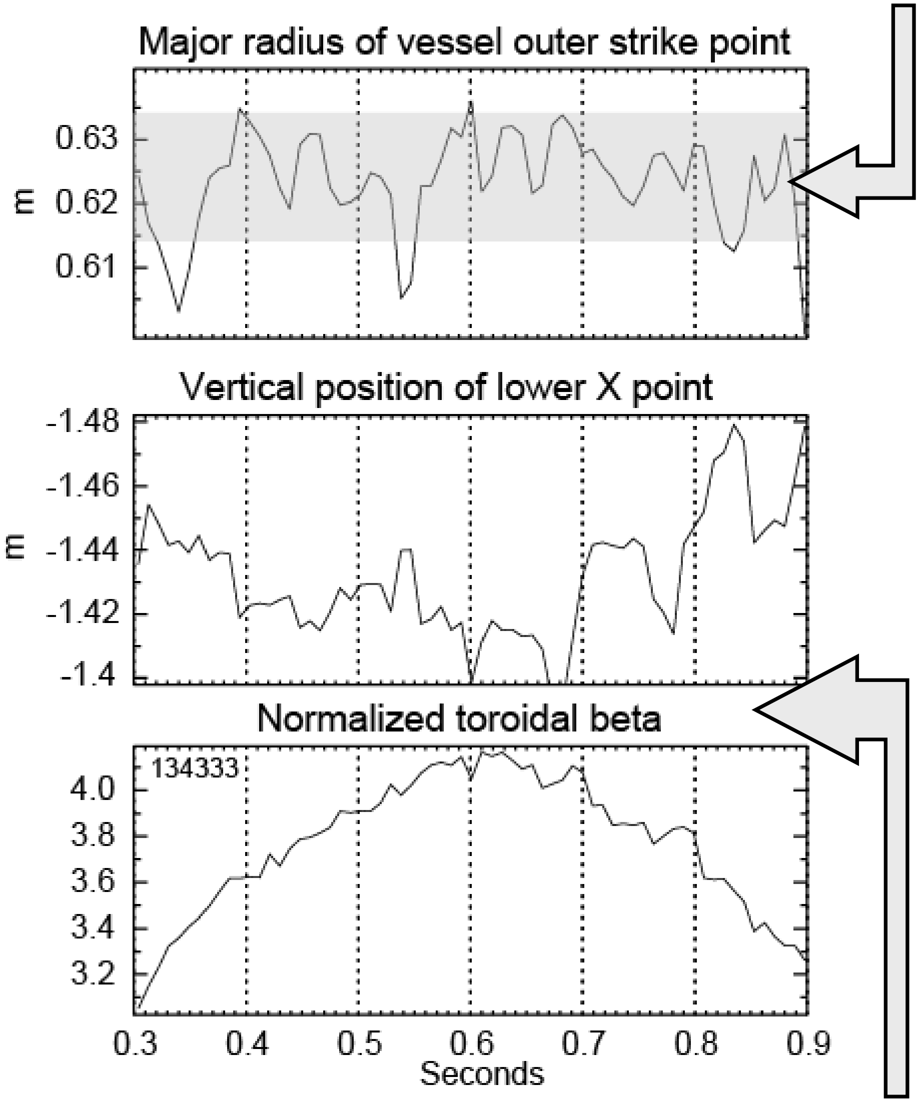


Strike point

LLD plate (FY2010)

- ***LLD plate installation now complete***

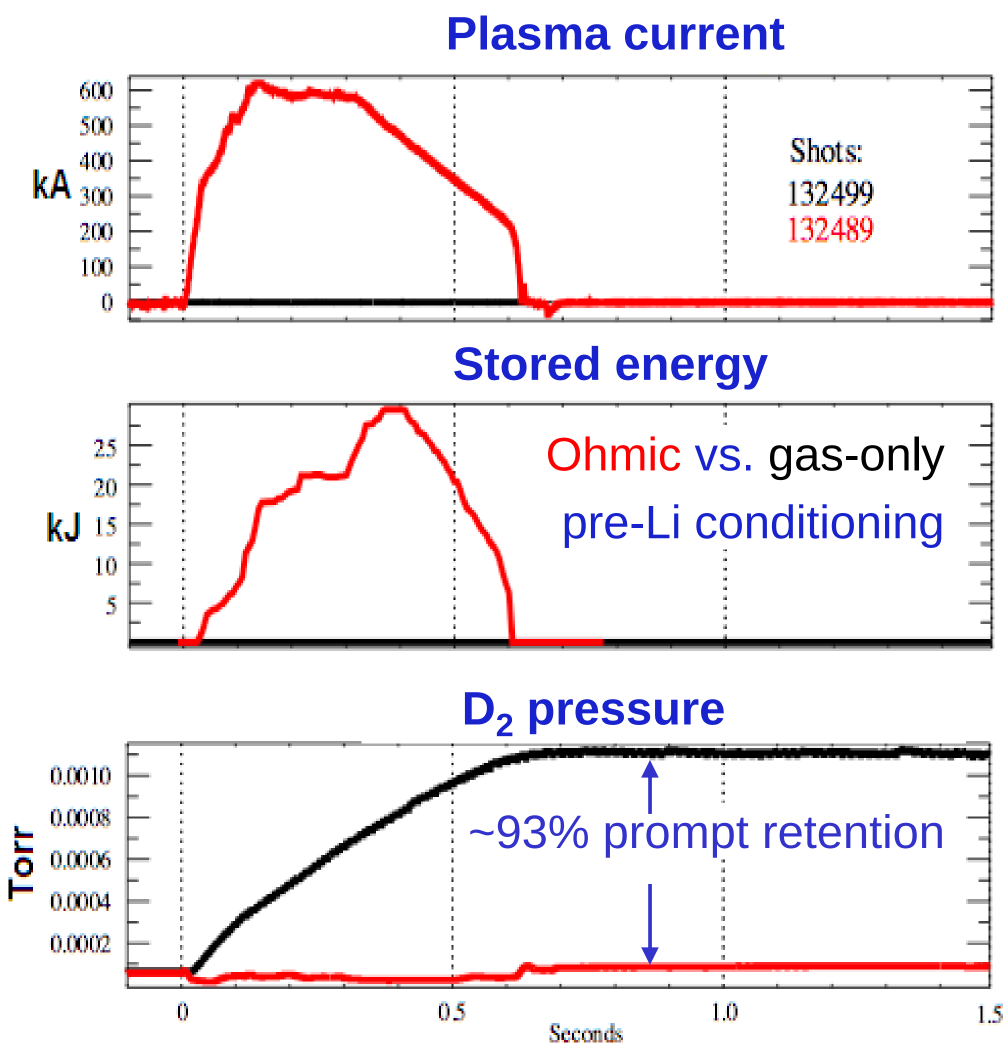
R_{strike} well controlled to ~1cm variation…



…during 8cm variation in $Z_{x\text{-point}}$ and 30% variation in β_N

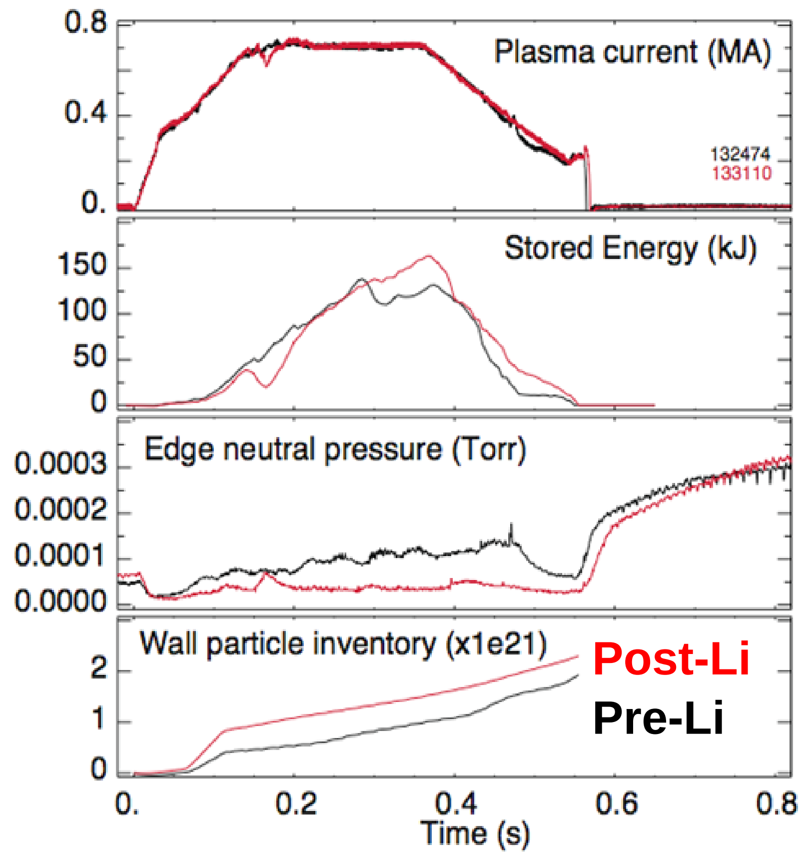
NSTX contributed to hydrogenic retention milestone important for NSTX Li pumping, ITER T retention

- Gas balance measurements show high (~90%) prompt D retention



- Impact of Li on retention is largest for NBI heated plasmas

End of discharge retention	Before Li	With Li
Ohmic	92%	94%
NB heated	87%	93%



Operational and new tool/diagnostic utilization goals for those TSGs without FY2010 milestones (1)

This list is <u>only a subset</u> of TSG goals, but these items should be addressed before/during the forum:

- Solenoid-Free Start-Up and Ramp-up
  - Demonstrate 300kA of OH flux savings with CHI (increase from 200kA)
  - Couple HHFW into CHI → OH target during I_P ramp-up, heat plasma to > 1keV
  - With WPI: Demonstrate 100% HHFW+BS non-inductive sustainment at any I_P
  - With WPI: Ramp-up current from ~200kA to higher I_P with HHFW+BS

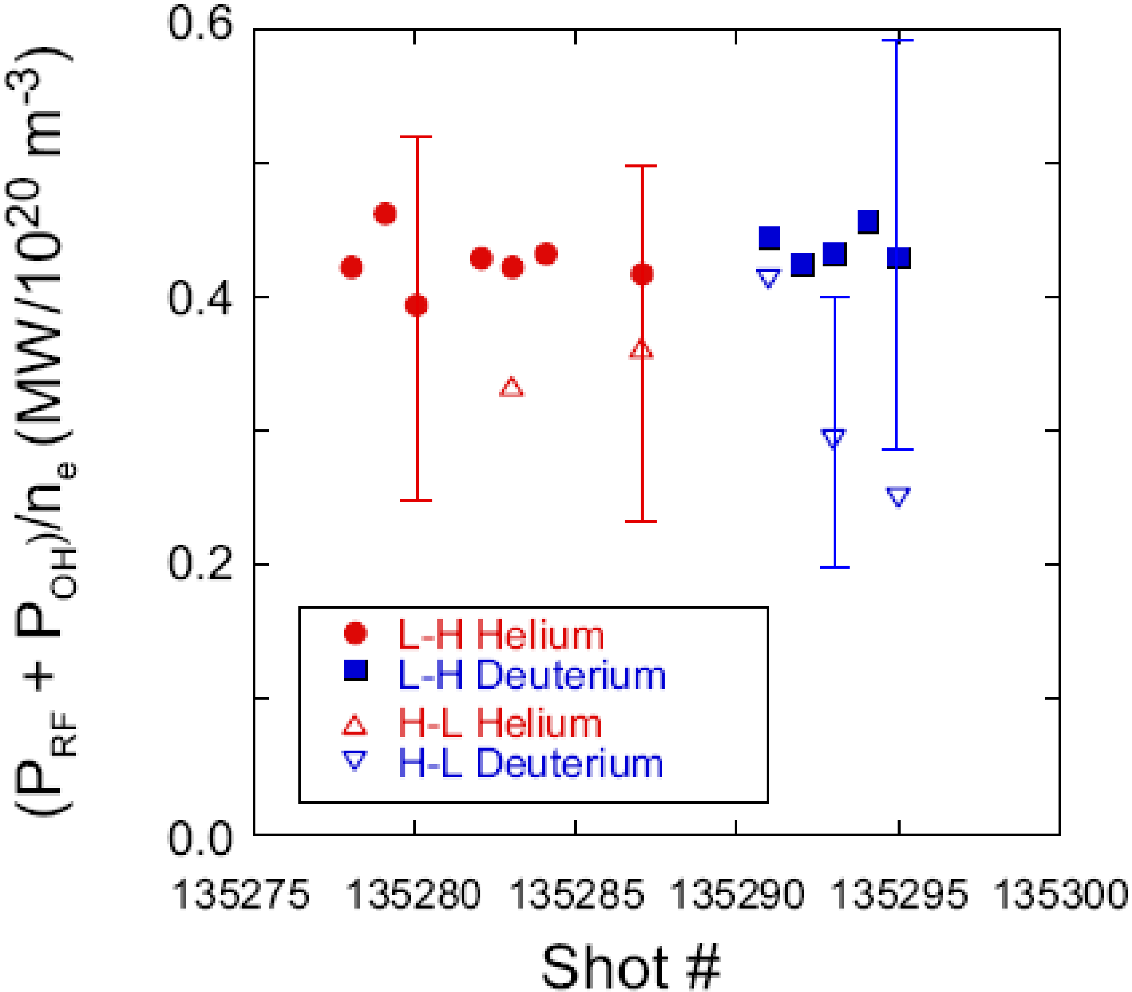
- Advanced Scenario and Control
  - Develop/assess HHFW as control tool in advanced scenarios:
    - Reliably increase central T_e of moderate-high power NBI H-mode with HHFW
    - Assess impurity accumulation vs. HHFW power during Li ELM-free H-modes
    - Heat NBI H-mode during ramp-up to modify J profile evolution
    - Attempt on-axis HHFW CD during NBI H-mode to modify core q-shear

- Lithium Research
  - Oversee and organize development of XMPs and XPs for LLD commissioning
  - Organize XPs to diagnose, understand, and reduce/eliminate ***<u>sources</u>*** of impurity accumulation during Li ELM-free H-mode (expected during LLD operation)

FY09 P_{LH} similar for He and D plasmas (high priority ITER issue)

(several other threshold scaling trends were also measured in FY09)

- HHFW allowed "fine-scale" exploration of P_{LH} for D vs He
- Observed signs of hysteresis

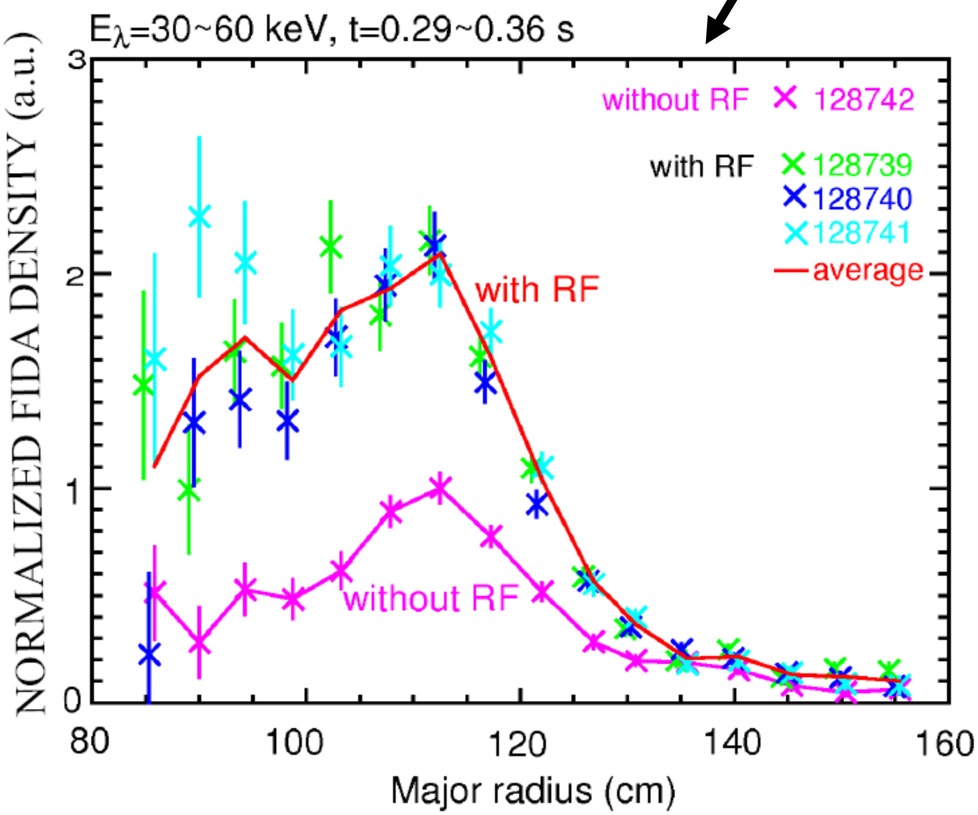


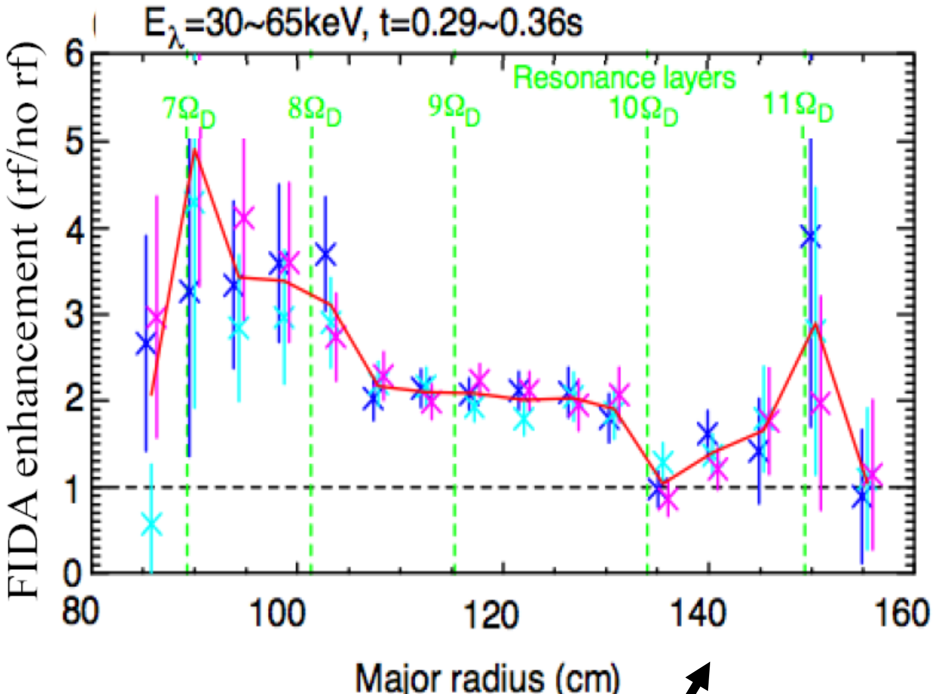
Other scaling trends:

- Plasma current
  - P_{LH} / n_e increased ~2× 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

FY08-09 FIDA diagnostic measured broad HHFW-fast-ion absorption profile due to presence of multiple resonances

- Fast-ion density profile broadens over most of minor radius
  - Central region (R=80-120 cm) shows more pronounced effects





- Multiple resonances lead to broad HHFW absorption

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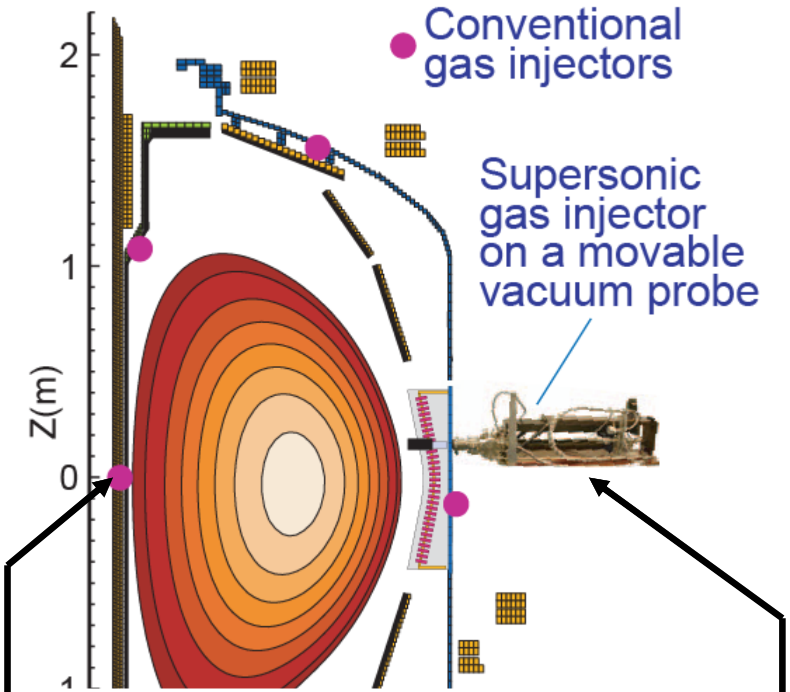
Operational and new tool/diagnostic utilization goals for those TSGs without FY2010 milestones (2)

This list is only a subset of TSG goals, but these items should be addressed before/during the forum:

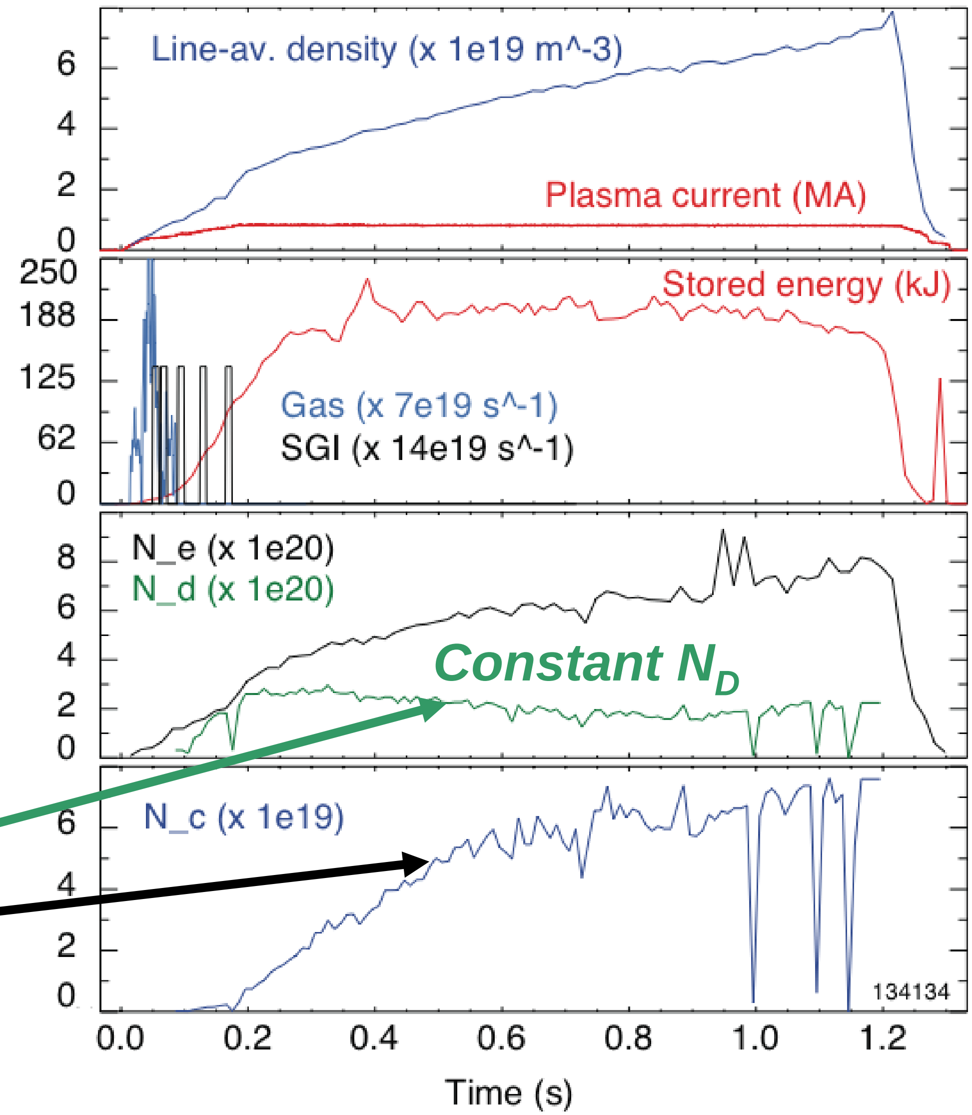
- Transport and Turbulence
  - Utilize LLD + HHFW to explore impact of reduced ν^* on ion & electron transport
  - Extend high-k measurements of GAE, k-scaling of ETG turbulence
  - Obtain a physics result from BES this year (if diagnostic is ready) – examples:
    - Perform initial correlations of ion thermal or momentum transport with $\delta n/n$
    - Measure low-k and high-k at same r/a, assess e-transport correlation with k
  - Measure X-ray emission to study fast electron transport from μ-tearing, GAE, …

- Energetic Particles:
  - Extend FIDA measurements of fast-ion acceleration by HHFW to HHFW+NBI scenarios developed in the ASC group
  - Use linear BES array to measure radial profile of AE eigenfunction in H-mode

FY09 Supersonic gas injection (SGI) enabled control of D^+ content in LITER ELM-free discharges, but C^{6+} dominates N_e



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…**

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Some *examples* of XP ideas supporting ITER high priority research

From ITER Physics Work Programme 2009-2011

Sections 2.1 - ITER Short term activities (2008-2010) and 2.2 - ITER Medium term activities (2011 and beyond)

- 2.1.1 Transport and Confinement during transient phases
  - Assess NSTX confinement, H-mode threshold, etc. during ramp-up/down
- 2.1.2 Access to high confinement regimes in ITER during steady/state and ramp-up/down H, D and DT phases
  - Complete/extend NSTX L-H, H-L threshold experiments from FY2009
- 2.1.3 Characterization of proposed schemes for active ELM control, compatibility with scenario requirements.
  - Contribute NSTX understanding of RMP ELM pacing results

- 2.2.1 Pedestal width, pedestal energy and uncontrolled ELM energy loss in ITER
  - Utilize OFES 3 facility joint research milestone on pedestal structure in FY2011
- 2.2.2 Development of alternative regimes providing high fusion performance in ITER without or with small ELMs compatible with overall scenario requirements
  - Extrapolate NSTX Type V ELMs to low ν^*?
- 2.2.3 Development of alternative methods for ELM control/suppression in ITER and integration with scenario requirements.
  - Extend NSTX vertical jogs and RMP fields for ELM pacing to smaller ELM size
  - Develop NSTX Li ELM-free H-mode with reduced/halted impurity accumulation
- 2.2.6 Momentum transport in ITER reference scenarios and expected plasma rotation in ITER.
  - Use NSTX HHFW to reduce input torque, use NB pulse+CHERS and/or X-ray crystal for Ti and rotation

NSTX is presently participating in 25 ITPA joint experiments

- **Advanced scenarios and control**
  - IOS-5.1 Ability to obtain and predict off-axis NBCD
  - IOS-5.2 Maintaining ICRH Coupliing in expected ITER Regime
- **Boundary Physics and Lithium Research**
  - PEP-6 Pedestal structure and ELM stability in double null
  - PEP-16 C-MOD/NSTX/MAST small ELM regime comparison
  - PEP-19 Edge transport under the influence of resonant magnetic perturbations
  - PEP-25 Inter-machine comparison of ELM control using mid-plane RMP coils
  - DSOL-15 Inter-machine comparison of blob characteristics
  - DSOL-21 Introduction of pre-characterized dust for dust transport studies in divertor and SOL
- **Macroscopic Stability**
  - 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-13 Vertical stability physics/performance limits in highly elongated plasmas
  - MDC-14 Rotation effects on neoclassical tearing modes
  - MDC-15 Disruption database development
  - MDC-17 Physics-based disruption avoidance
- **Transport and Turbulence**
  - TC-1 Confinement scaling in ELMy H-modes: beta degradation
  - TC-2 Power ratio - hysteresis and access to H-mode with H~1
  - TC-3 Scaling of the Low-Density Limit of the H-mode Threshold
  - TC-4 H-mode transition and confinement dependence on ionic species
  - TC-9 Scaling of intrinsic plasma rotation with no external momentum input
  - TC-10 Experimental identification of ITG, TEM and ETG turbulence and comparison with codes
  - TC-12 H-mode transport and confinement at low aspect ratio
  - TC-15 Dependence of momentum and particle pinch on collisionality
- **Waves-Particle Interactions**
  - EP-1 Measurement of damping rate of intermediate toroidal mode number Alfvén Eigenmodes
  - EP-2 Fast ion losses and redistribution from localized Alfvén Eigenmodes

What will NSTX contribute to ITPA in 2010?

- The 8th IEA/ITPA Joint Experiment Workshop (W71) will be held 15-16, December, 2009 in Daejeon, Korea.
  - Purpose of this meeting is to finalize the list of Joint Experiments proposed for 2010 – Stan Kaye will represent NSTX

- TSG leaders: Please review the last Joint Experiment list circulated by Stan, and provide him with the following:
  - For each of the experiments to which NSTX committed, have we completed our experimental work? Analysis work? Etc.
  - In which Joint Expts will NSTX participate next year?, what level?
  - Are there any new Joint Expts that were developed at the recent ITPA meetings relevant to your science area?, will NSTX participate?
  - Are there any Joint Expts that are not on the list that you feel should be (and with which other devices)?

Forum action items for TSG leaders and proposers

- ✓ Actively solicit input from the entire team – experimentalists, modelers, and theorists – to develop an extensive but goal-relevant list of ideas and proposals

- Organize, listen, question proposal presentation and plans

- Develop a prioritized XP idea lists based on run-time guidance for use in planning FY2010 run

- Identify FY2010 ITPA joint expts NSTX should participate in
  - Send information to Stan Kaye by December 7, 2009