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NSTX Research Results and Plans for FY06-08

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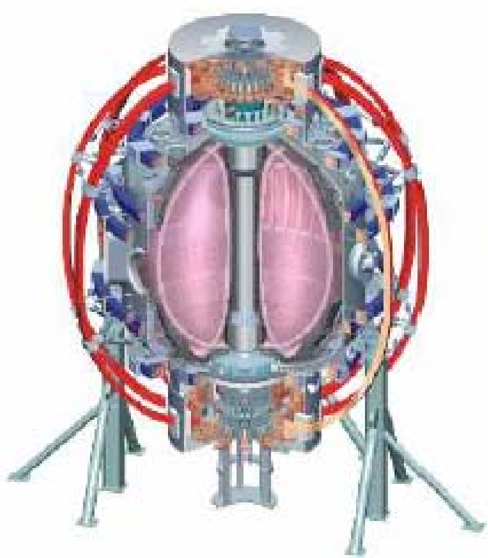
Jonathan Menard

FY 2008 OFES Budget Planning Meeting
Gaithersburg, MD
March 14 – 15, 2006



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NSTX contributes broadly to fundamental toroidal confinement science in support of ITER and future ST's

- Macroscopic Stability
- Transport and Turbulence
- Boundary Physics
- Waves and Energetic Particles
- Solenoid-free Start-up, Ramp-up, and Sustainment

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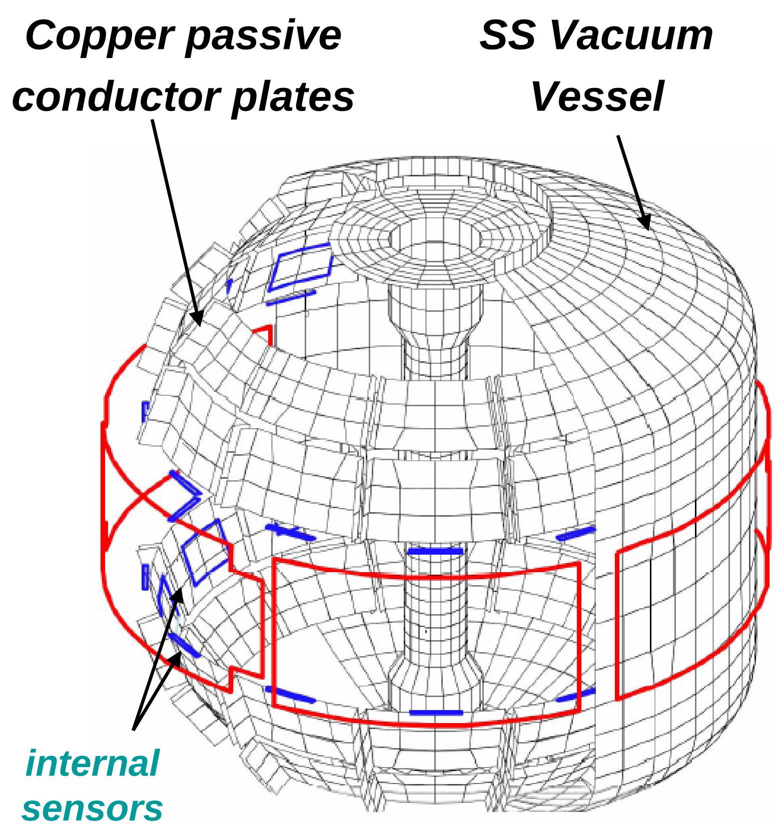
New facility and diagnostic upgrades allow testing of ITER-like active mode control system

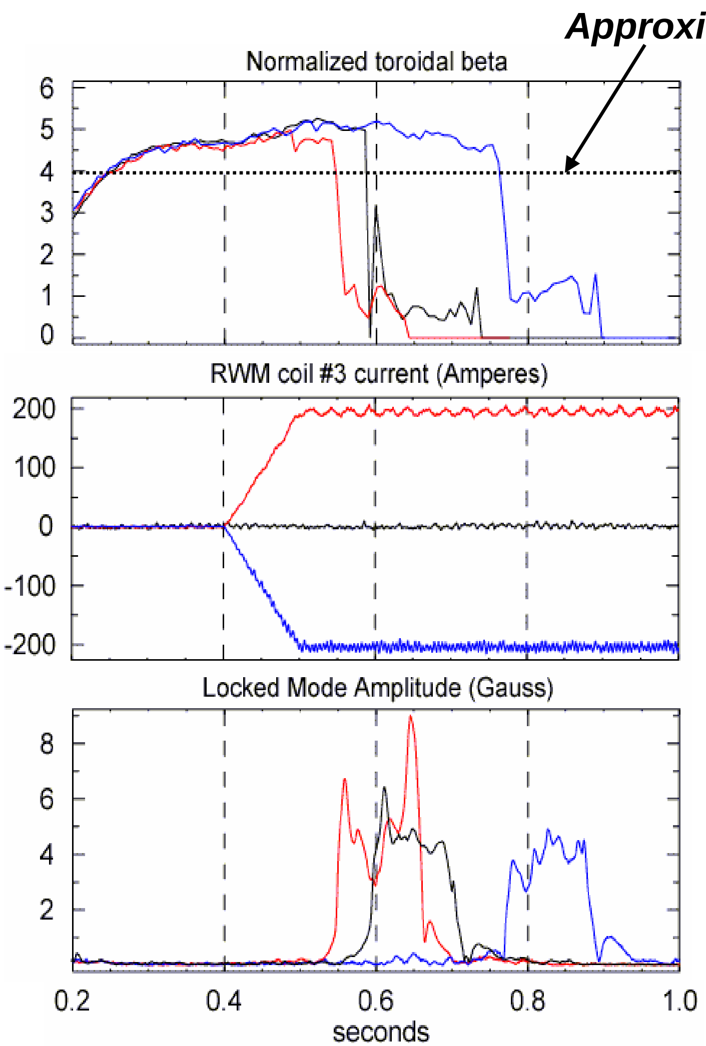


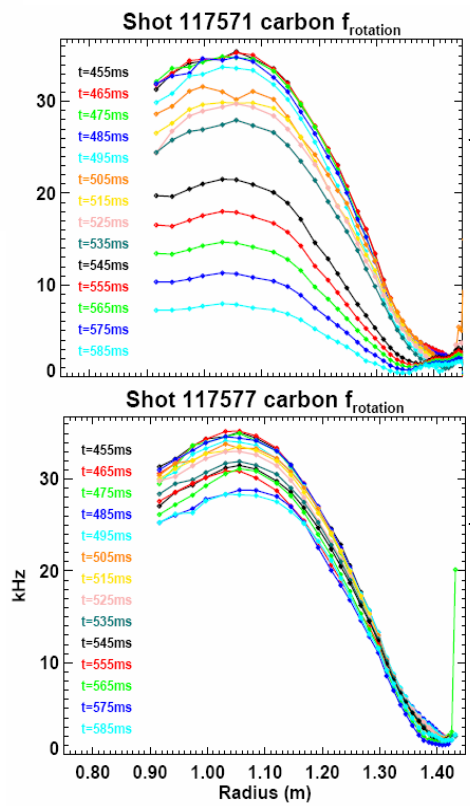
VALEN Model of NSTX

6 ex-vessel midplane control coils

- NSTX mode control system similar to US proposal for ITER
  - Located at vertical midplane
  - Coils behind vessel wall
  - Fields couple to nearby blanket-like passive conducting structure
  - Excellent test-bed for validating ITER RWM control models
- NSTX research:
  - Error field correction
  - Plasma rotation reduction/control
  - Resonant field amplification (RFA)
  - Active RWM control

Error Field Correction aids sustainment of high β_N





- Error field control important to ITER and future STs
- Rotation damped in "non-correcting" direction
  - leads to earlier locking and shot termination
- Rotation damping weaker in "correcting" direction
- Time-varying error field likely due to TF motion from OH/TF coil interaction

Research Plans for MHD

- First tests of dynamic error field control (DEFC) (FY06)
  - Compare to pre-programmed EF control
  - Complete low-density locked-mode experiments (MDC-6)
- Transition from DEFC to RWM control (FY06-07)
  - Use n=3 magnetic braking to slow plasma rotation below RWM Ω_{crit} (MDC-2)
  - Study dependence on control algorithm, sensor type, and system latency
- Contribute to ITPA and USBPO active control effort (FY06-08)
  - MHD Task Force initiative to design joint ELM/RWM control coil for ITER
- Perform additional experiments to study EF/RWM physics (FY07-08)
  - n=1 RWM critical rotation scaling (MDC-2)
  - Study n > 1 modes: error fields, rotation damping, RFA, unstable RWMs
- Contribute to ITPA disruption database to aid ITER and CTF (FY06-08)
  - Contribute additional I_P quench-rate and new I_{halo} data
  - Diagnose thermal quench w/ tangential X-ray camera & multi-color USXR
  - Develop disruption onset and precursor detection and prediction
  - Develop disruption impact projections for CTF based on ITER studies

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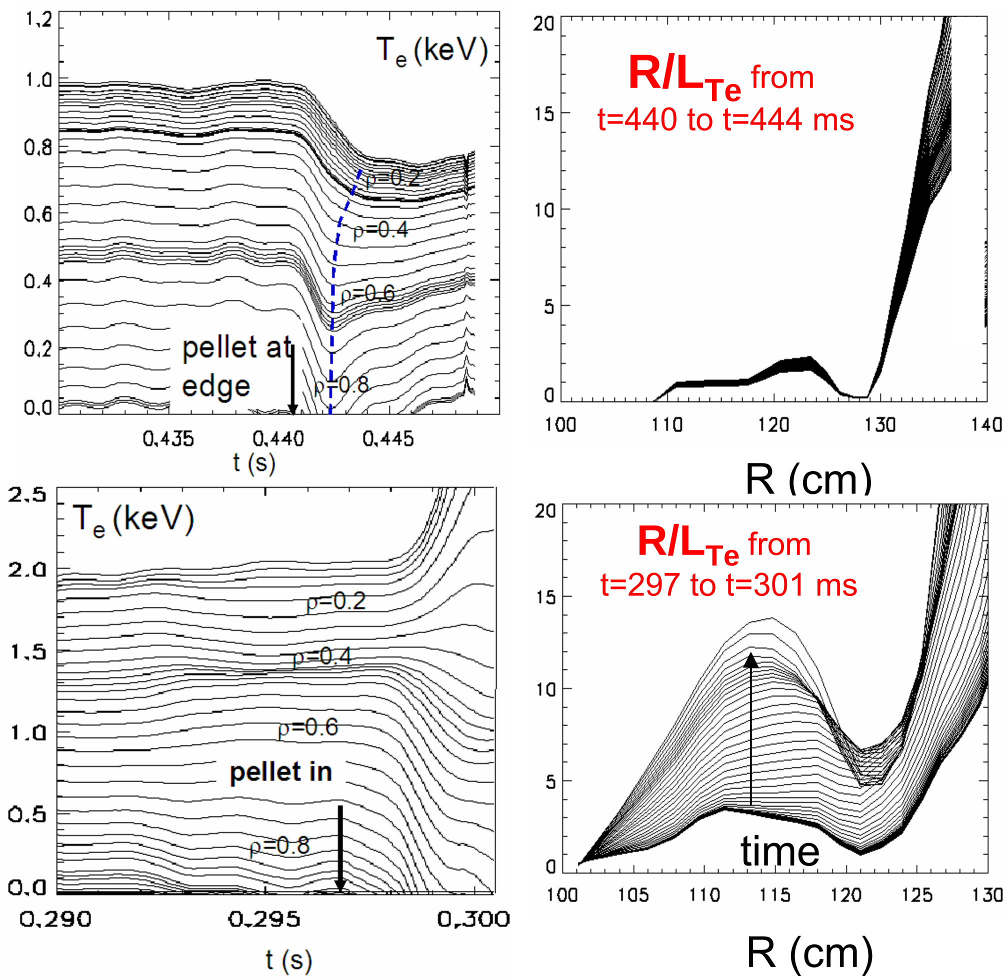
Perturbative transport experiments are elucidating the role of critical temperature gradients in electron thermal transport

NSTX

- q profile reconstructed using 8 channel MSE
- Lithium pellet injection into edge to perturb Te profile
- “Two-color” SXR measures T_e profile evolution with high time resolution



← 6MW monotonic-q H-mode

– Core T_e profile exhibits clear critical gradient behavior – ETG?

← 2MW reversed-q L-mode

– Core SXR T_e actually ***increases*** ⇒ very different transport properties

Research Plans for Turbulence and Transport

- Measure electron-gyro-scale fluctuations w/ high-k scattering system
  - *NSTX provides unique opportunity: suppressed ion turbulence, diagnostic access*
  - Study of reversed-shear discharges with & without eITBs (FY06)
  - Study variation of local high-k turbulence with plasma conditions (FY07) (Ph.D. Thesis)
- Extend perturbative studies of electron transport (FY06)
  - Upgraded 3-color “optical” SXR array + TESPEL (doped pellets) injection
  - Examine roles of collisionality, critical gradient and current
- Effects on transport of reducing recycling by lithium coating (FY06)
- Develop high-performance double-barrier – eITB + H-mode (FY06) (TP-8.1)
- Study scaling of confinement – β, A, B_T dependence (FY06) (CDB-2,6,8)
- Investigation of ion transport and heating (FY06-08)
  - Momentum transport study with NBI heating (TP-6.3)
  - Neoclassical theory as $B_P \rightarrow B_T$ (GTC-Neo), FLR effects
  - Non-classical heating mechanisms, e.g. stochastic ion heating
- Measure poloidal rotation at low A to constrain theory (FY08)
  - Compare to neoclassical theory + full shearing rate for turbulence simulations
  - Poloidal flow shear layer important in internal transport bifurcations?

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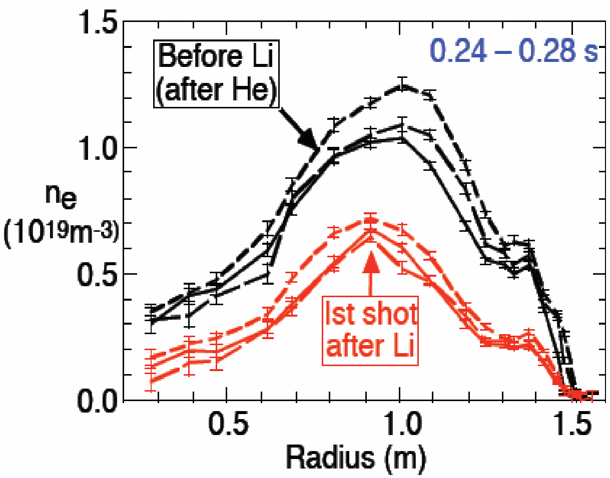
Research Results and Plans for Boundary Physics (I)

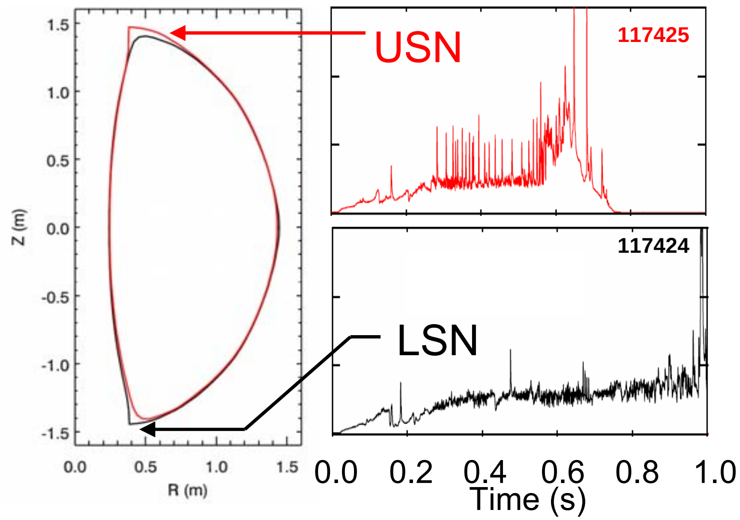


- 2005: Achieved factor of 2 density decrease using Li pellet deposition on lower divertor
  - Required injecting Li pellets for many discharges
  - Lithium passivated after only few discharges (consistent w/ amount deposited)
  - ⇒ ***2006 - Li evaporator*** *to deposit more Li with improved deposition control*

PLANS:

- Recycling & density control with Lithium for long pulse scenarios (FY06)
  - Develop efficient fueling sources: Supersonic Gas Injection
  - Control low-density locked modes with EF correction
- Characterize material migration vs. shape & pulse length (FY06-07) (DSOL-18)
  - Migration studies relevant to PFC integrity and tritium retention in ITER
- Divertor heat load mitigation/detachment at high performance, low ν^* (FY06-07)
  - Document outer divertor baseline and partially detached discharges
  - Develop detachment scenarios for high performance plasmas
  - Evaluate detachment by impurity injection and impact of ELMs

Research Plans for Boundary Physics (II)



- 2005: Small change to plasma boundary ⇒ large change in ELM stability & pulse-length
  - Precise control of X-point balance made possible by using rt-EFIT (GA)
- ELM control important for ITER and CTF
  - ITER/ITPA studying role of magnetic balance

PLANS:

- Small ELM regime – cross-machine comparison (FY06-07) (PEP-16)
  - Obtain complete dataset for small ELM regimes (FY07)
  - Measure ELM radial penetration depth (FY06-07) (PEP-10)
- Use aspect ratio variation to understand pedestal physics (FY06) (PEP-9)
- Further develop “enhanced pedestal” H-modes (2 × higher T_{ped}) (FY06-07)
  - First evidence of current hole in ST – playing role in improved confinement?
  - Use in concert with lithium to further reduce ν^*
- Characterize H-mode pedestal with poloidal CHERs (FY08)
  - Poloidal rotation measurement for complete E_r (outboard coverage initially)
  - Study role of orbit squeezing effects, E_r shearing rates in pedestal transport

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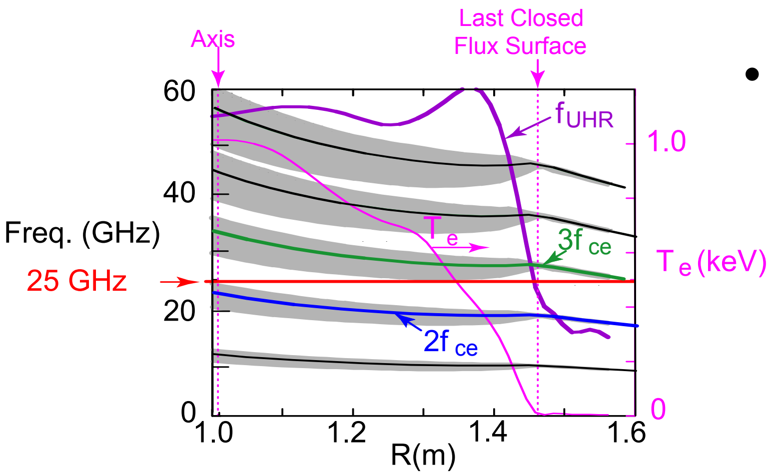
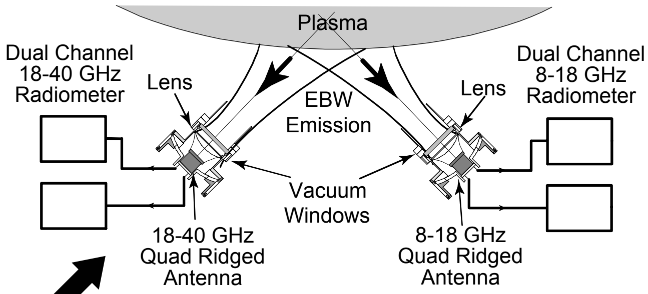
Research Results and Plans for EBW



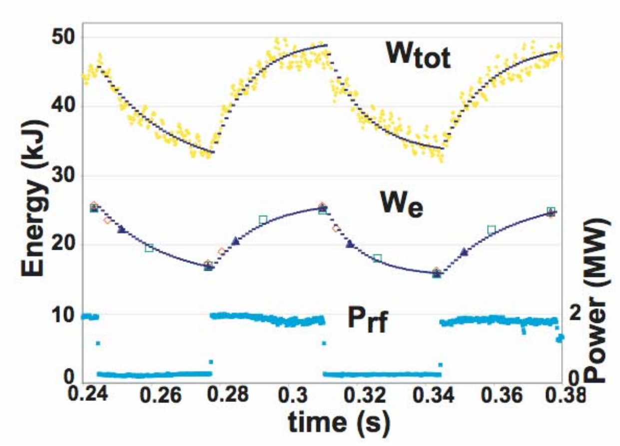
- 2005: Emission measurements consistent with $3f_{ce}$ emission from large r/a
  - Evidence for collisional damping at f_{UHR}, possibility for $2f_{ce}$ overlap



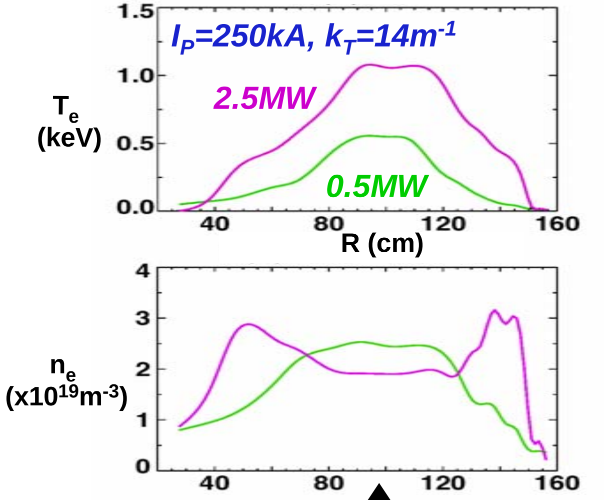
PLANS:

- Test EBW coupling models for both L & H-mode plasmas (FY06) (Ph.D. Thesis)
  - Utilize remotely-steered B-X-O antennas covering 8-40 GHz
- MAST collaboration: 28GHz startup/ramp-up (FY06-07), B-X-O (FY07-08)
- Enhance modeling capabilities through collaboration (FY06-08)
  - Radial transport, Ohkawa anti-pinch effect on BS - CQL3D/GENRAY [Comp-X]
    - Also EBE from non-thermal electrons – same model used for ECE on ITER
  - Include EBW mode conversion in GENRAY, optimize EBWCD scenarios [MIT]

Research Results and Plans for HHFW



k_T (m^{-1})	% Power absorbed
14	80
+7	70
-7	55
+3	< 20



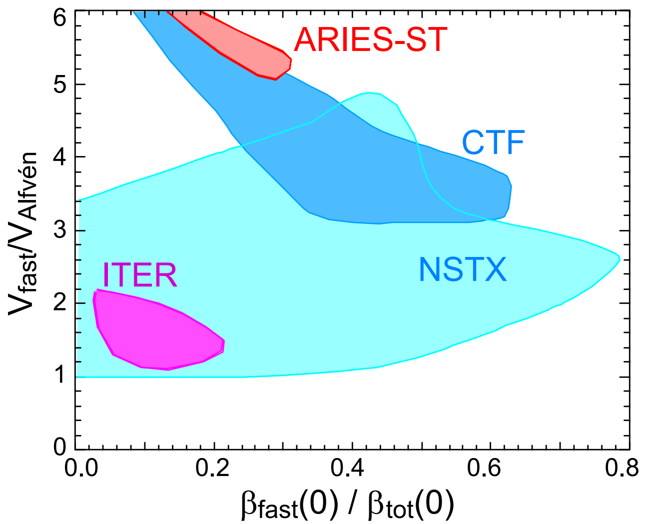
- 2005: Measured reduced absorption in CD phasing
  - Parametric decay into surface waves may explain dependence on k_T
  - ICRF coupling at high power density important issue for ITER
- Produced 1keV H-mode plasmas w/ 65-80% bootstrap fraction at I_P = 250kA

PLANS:

- Perform RF edge field study to investigate causes of parasitic absorption (FY-06)
  - Surface wave excitation damping + parametric decay instability ion heating
  - New RF probes to measure waves in plasma periphery
  - UCLA reflectometer upgrade to measure higher edge densities for RF studies
- Will attempt full non-inductive current ramp-up and heating of CHI target (FY06-07)
  - Will exploit new antenna voltage feedback to reduce RF power trips in H-mode
- Consider antenna modification $\Rightarrow$ directed spectra at 14m^{-1} for improved CD (FY-08)
  - High power operation capable of heating T_e ~ 50eV plasma with 28m^{-1}

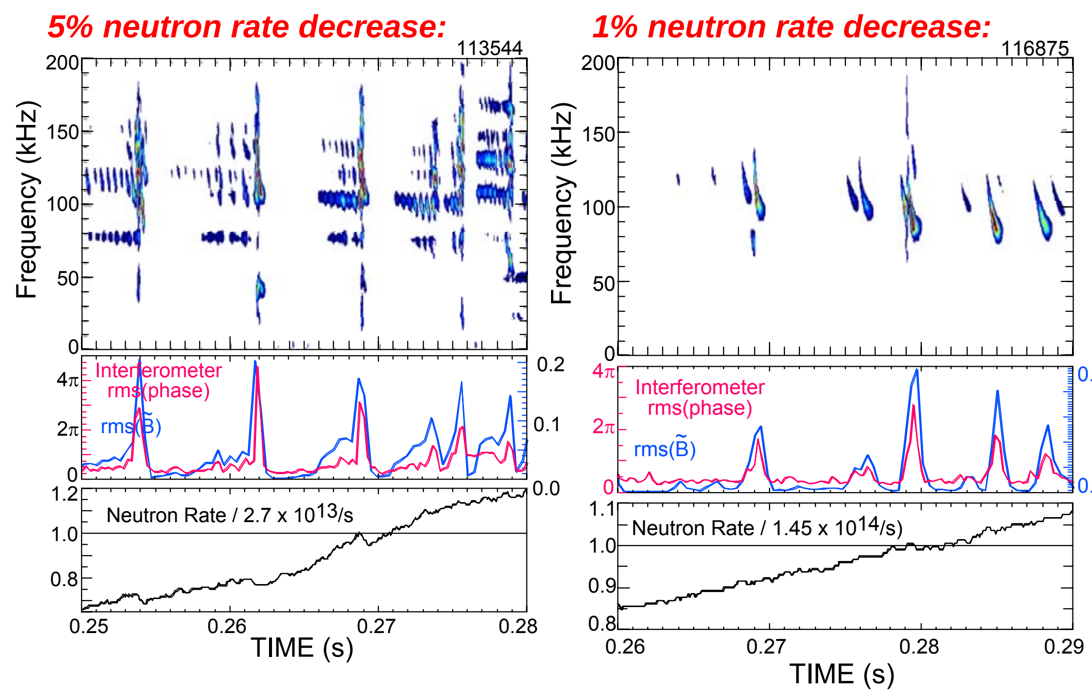
NSTX accesses ITER-relevant fast-ion phase-space island overlap regime with full diagnostic coverage

- ITER will operate in new, small ρ^* regime for fast ion transport
  - $k_\perp \rho \approx 1$ means "short" wavelength Alfvén modes
  - Fast ion transport expected from interaction of many modes
  - NSTX can study multi-mode regime while measuring MSE q profile



- High $\beta_{fast}(0) / \beta_{tot}(0)$ in NSTX provides drive for multiple modes in larger ρ^* regime

- **NSTX observes that multi-mode TAE bursts induce larger fast-ion losses than single-mode bursts:**



Research Plans for Energetic Particle Physics

- Determine scaling of mode structure and stability + fast ion losses (FY06)
  - Determine TAE avalanche threshold vs. q profile, v_{fast} / v_{Alfven}, etc. (MDC-9)

- Validate/test bootstrap/beam-driven current models (TRANSP) (FY-06)
  - Impact of fast-ion MHD on NBICD important issue for ITER and CTF (SSO-2.2)
  - Develop discharges free of fast-ion MHD activity
  - Compare to J(r) evolution in plasmas with and w/o energetic particle MHD

- Comprehensive diagnosis of mode structure and fast-ion diffusion (MDC-9)
  - MSE measurement of current profile (FY-06)
  - Fast ion loss measurements (FY-06)
    - Fast lost ion probe, solid state NPA, scanning NPA
    - Compare to ORBIT simulations of fast ion losses
  - Measurement of internal mode amplitude/structure (FY-07)
    - FIReTIP, reflectometer, B-field polarization from Mirnovs
  - Improved radial profile measurement of fast-ion redistribution (FY-08)
    - Fast Ion Dalpha (FIDA) diagnostic

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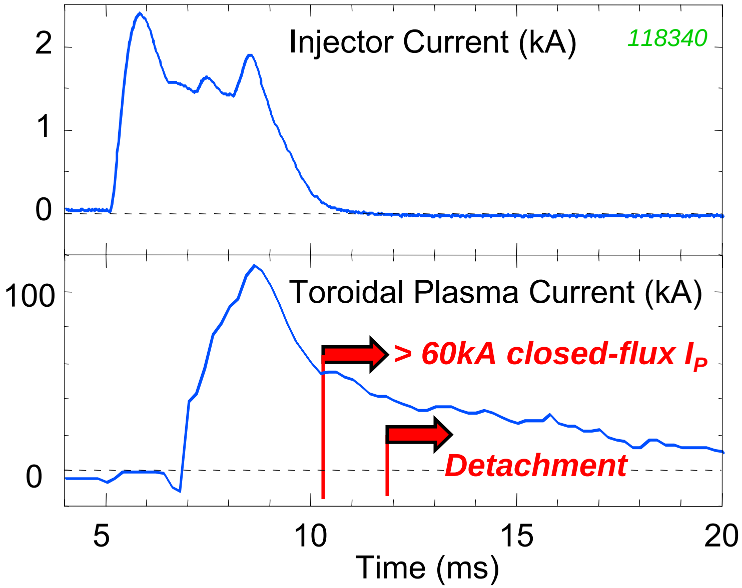
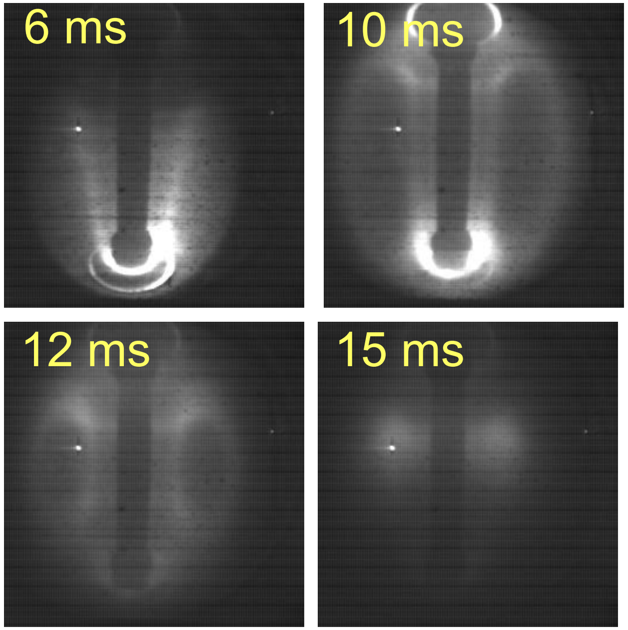
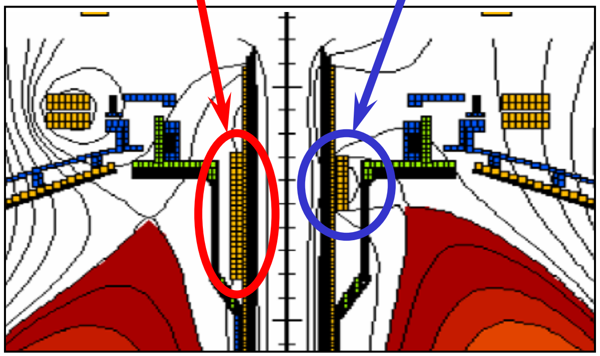
Results & plans for solenoid-free start-up and ramp-up





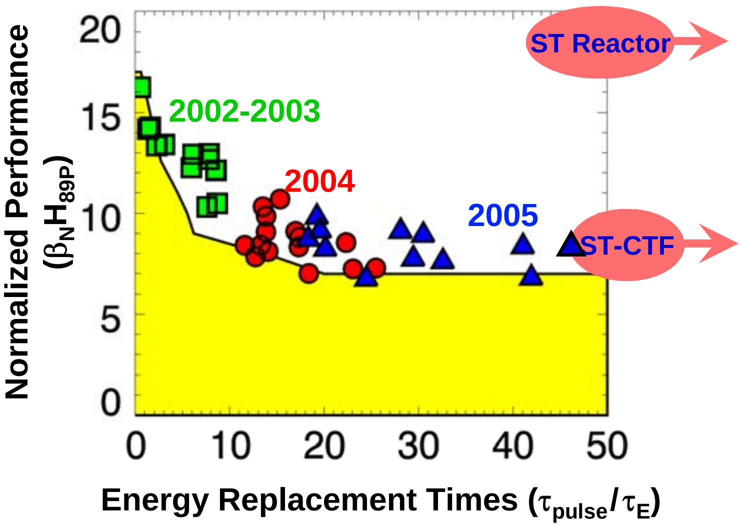
- 2005: Plasma current amplified many times relative to injector current: $60\times \rightarrow \infty$
  - Achieved > 60kA of closed flux current
  - Camera clearly indicates detachment
- CHI plasma start-up research plans: (FY06)
  - Increase V_{CHI} to 2 kV for higher I_P
  - Investigate B_T scaling (higher B_T favorable?)
  - Diagnose with fast camera, soft x-ray array, Thomson scattering, spectroscopy, bolometer
  - Study reconnection physics (dynamo probe)
- Develop hand-off to induction/HHFW (FY06-07)
  - Couple transient CHI to OH ramp-up
  - Study HHFW power coupling
  - Heat CHI plasma with HHFW $\rightarrow$ BS overdrive
- Minimize OH flux consumption during I_P ramp to mimic small iron core in CTF (FY06-07)
  - Improve breakdown null, propagate early H-mode to all scenarios, earlier heating
- PF-only start-up development plans: (FY07-08)
  - Assess higher power pre-ionization sources
    - High $k_{||}$ HHFW, EBW, Plasma Gun (PEGASUS), and CT-Injection

Results & plans for current sustainment research



2005: New coils improved ELM stability at high κ

$\Rightarrow$ **Record pulse length at f_{BS}=50% and CTF $\beta_N H_{89P}$**



PLANS:

- Investigate long-pulse operation with density control from Lithium (FY06)
  - Investigate effect of low density on error fields/locked modes, H-mode access, ELMs
- Improved HHFW-sustained plasmas with improved voltage feedback (FY06)
- Complete studies of MHD effects on q-profile/hybrid scenarios (FY06-07) (SSO-2.1,2.2)
- Investigate current drive physics in CTF conditions (FY07-08)
  - Lower density plasmas with higher NBICD fraction and high total non-inductive fraction
  - Demonstrate high f_{BS} at high κ = 2.8 with rtEFIT control (control computer upgrade)

NSTX will continue to contribute to fundamental toroidal confinement science in support of ITER and future ST's

- Achieved record NSTX pulse-length discharges in a favorable ELM regime obtained with strong shaping and enhanced shape control
  - Improving understanding of role of plasma geometry on stability (edge & core)
- Demonstrated particle control with Lithium coating
  - Only major US facility investigating Li for pumping and power handling
- Dramatically improved physics understanding of error fields, resistive wall modes, plasma rotation damping, and disruptions
  - With DIII-D, will validate RWM control methods for ITER
- Correlated improved electron confinement with measured reversed q-shear
  - Understanding electron transport highly relevant to burning plasmas
- Correlated significant fast particle loss with multi-mode "sea-of-TAE" bursts
  - Mode-induced fast ion loss important to burning plasmas
- Improved understanding of EBW and HHFW coupling efficiency
  - Developing current drive tools essential for ST, useful for AT
- Demonstrated 60kA closed-flux plasma formation in NSTX using CHI
  - Plasma start-up and ramp-up research crucial to ST concept

- Developing knowledge for extrapolating ST to CTF and reactor