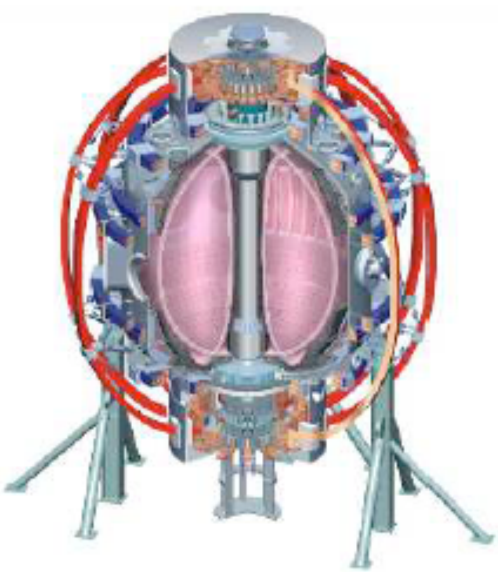
Supported by Office of Science

NSTX Research Results and Plans for FY07-09

College W&M
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

David A. Gates

At the FY 2009 OFES Budget Planning meeting
Gaithersburg, MD
March 13-14, 2007



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
JAERI
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

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

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

Program plan is aligned with the FESAC campaigns for MFE

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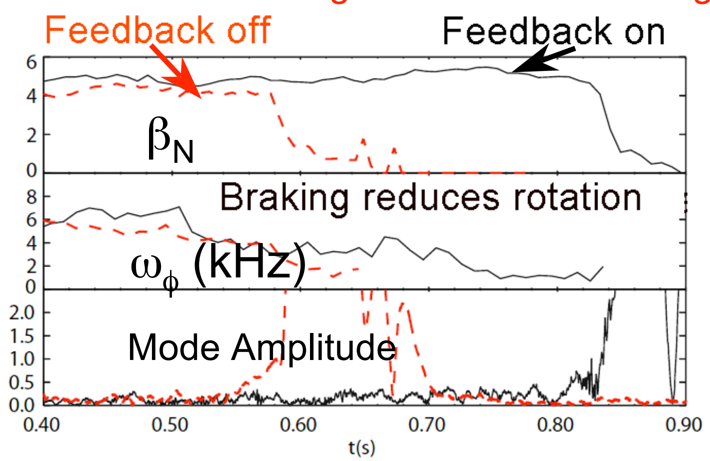
NSTX demonstration of RWM feedback control in low rotation (ITER-like) plasmas

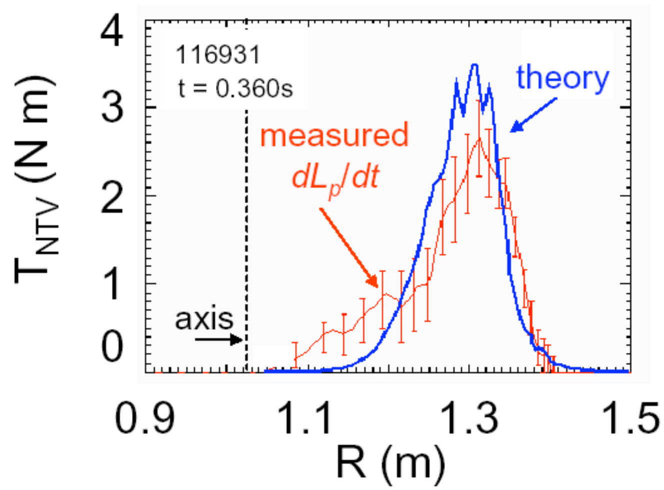
NSTX

Demonstration of RWM feedback with rotation control using non-resonant braking



Sabbagh et al., PRL **97** (2006) 04500

Quantitative prediction of the magnetic braking due to applied n=3 field

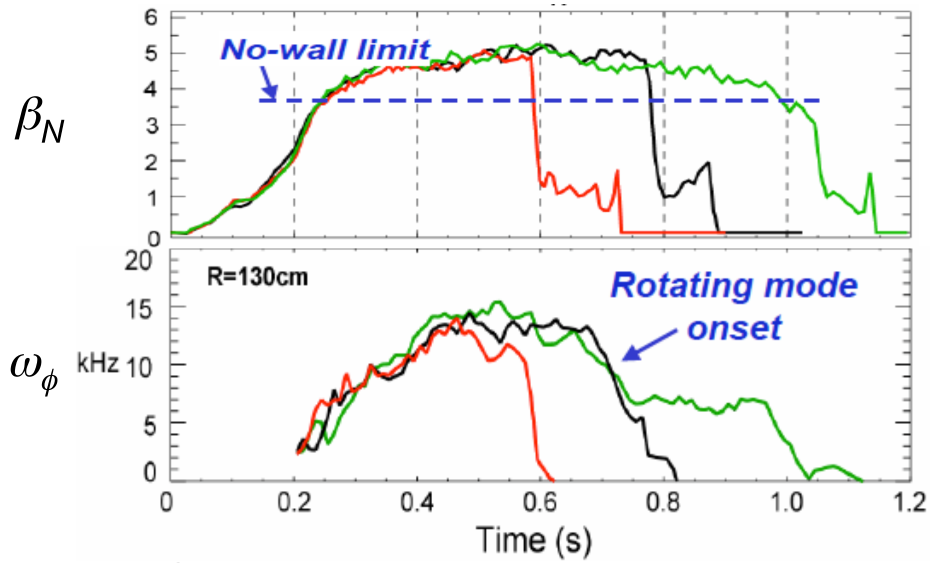


Zhu et al., PRL **96** (2006) 225002 (Ph.D. Thesis, Columbia University)

- Characterize effectiveness of RWM feedback and dependence on rotation
  - Use n=3 magnetic braking to study effect of varying plasma rotation (MDC-12)
  - Study dependence on control algorithm, sensor type, system latency
- Understand physics of RWM stabilization and control as a function of rotation
- RWM physics at low aspect ratio (MDC-2)
- Contribute to ITPA and USBPO active control effort MHD Task Force initiative to design joint ELM/RWM control coil for ITER

Addresses T1,T2, and T3

NSTX extends pulse length with error field correction



No error field correction at high β_N
Real-time correction of known error fields
Real-time EF correction + n=1 B_P feedback

Dynamic Error field correction increases pulse length above the no-wall limit and maintains plasma edge rotation

Addresses T1,T2, and T3

- Perform additional experiments to study EF/RWM physics
  - Lock mode threshold experiments
  - Error field control and assessment (MDC-3, Ph. D. thesis)
  - n=3 braking with n=1 error field correction (MDC-3)
- Study aspect ratio dependence of neoclassical tearing mode thresholds and amplitudes (MDC-4)
- Contribute to ITPA disruption database
  - Contribute I_{halo} data to ITPA database
  - Diagnose thermal quench with tangential X-ray camera and multi-color USXR
  - Develop disruption impact projections for CTF based on ITER studies

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NSTX

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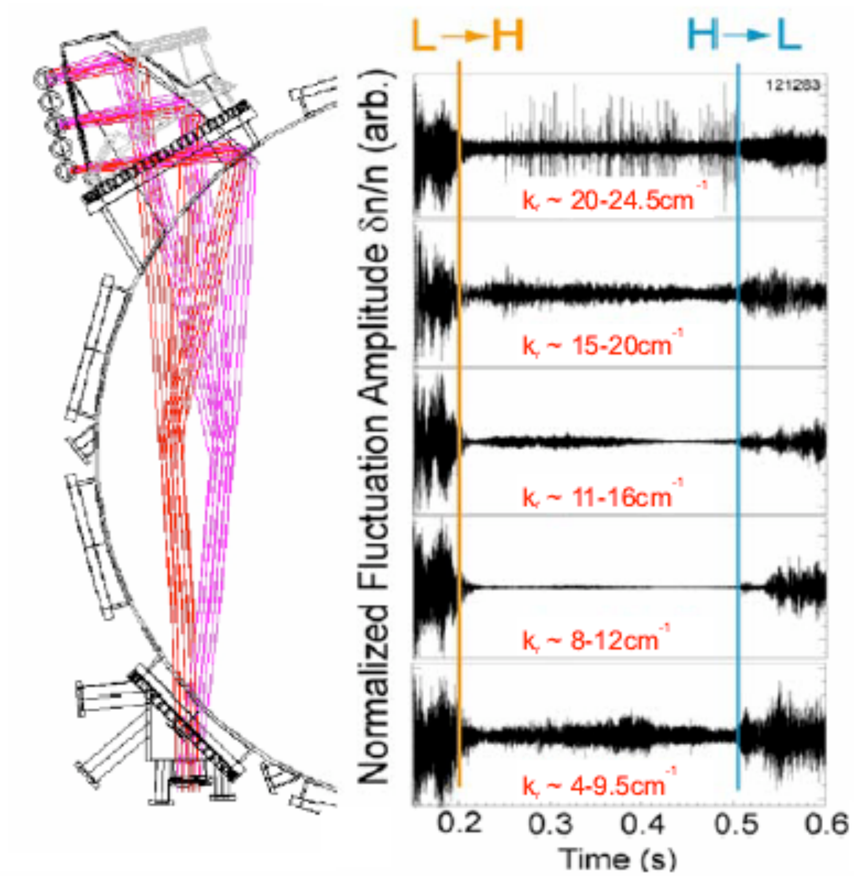
Low aspect ratio permits a unique opportunity for investigating electron turbulence in the $k_\perp \rho_e \sim 1$ regime

NSTX

- Study variation of local high-k turbulence with plasma conditions
  - Reverse shear, H-mode, and L-mode plasmas (Ph. D. thesis)
  - Develop physics understanding of electron confinement for ITER
- Investigation of rational q on ITB formation (TP-8.2)
- Effect of β on nature of electron turbulence
- Ion transport and heating
  - Ion power balance (Ph. D. thesis)
  - NBI driven momentum transport studies (TP-8.2)
- Measure poloidal rotation at low A and compare to theory

Addresses T4 and T5

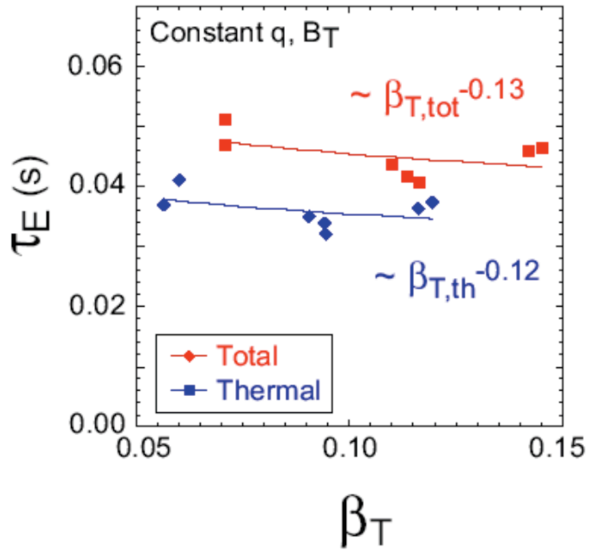
Microwave scattering system measures reduced fluctuations during H-mode



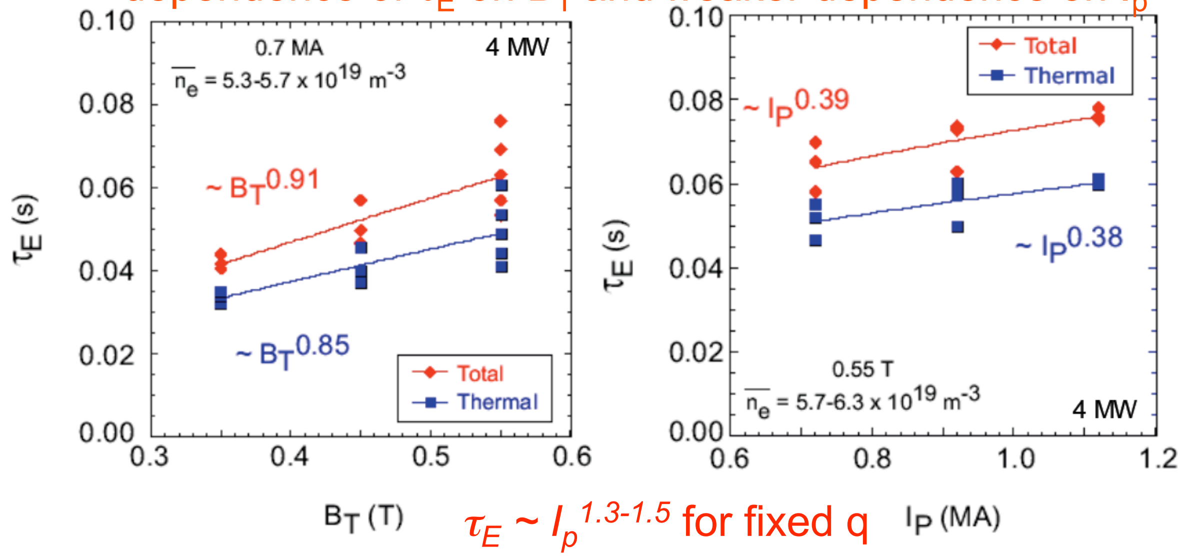
- Measurement from axis to edge
- Good radial resolution

NSTX is addressing key transport scaling questions

β-scan at fixed q, B_T shows weak degradation of τ_E with β on NSTX



NSTX τ_E exhibits strong scaling at fixed q with strong dependence of τ_E on B_T and weaker dependence on I_p



- Confinement scaling experiments
  - Contribute low aspect ratio data to ITPA database (CDB-6)
  - β scaling of confinement (important ITER issue) (CDB-2)
- Z-scaling of impurity transport (Ph. D. thesis)
- Develop momentum confinement scaling relation

Addresses T4 and T5

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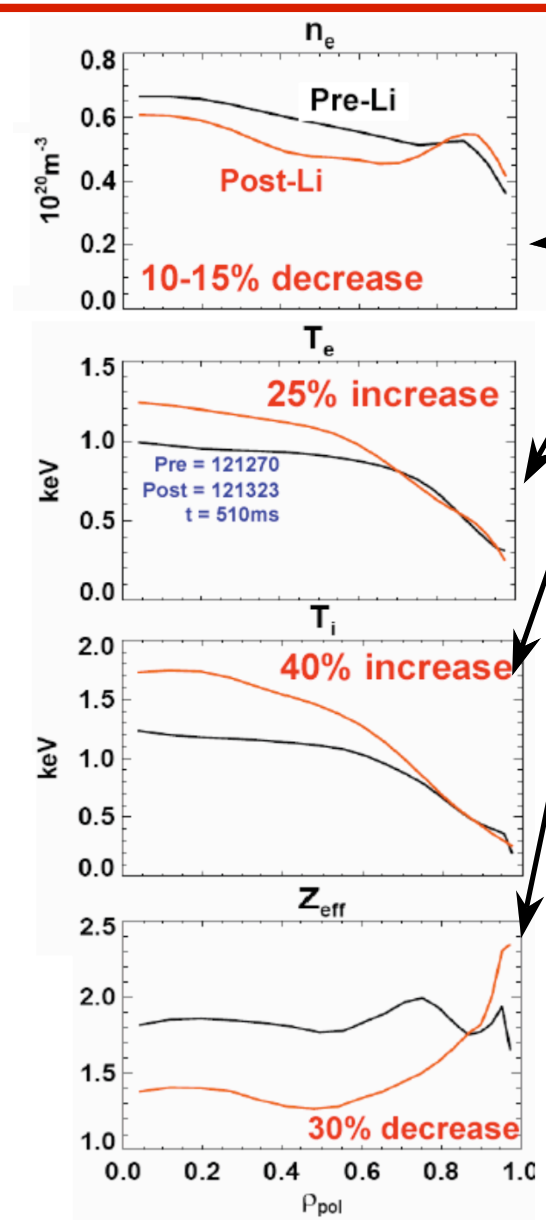
Lithium Evaporator (LITER) Produced Particle Pumping and Improved Energy Confinement in H-mode Plasmas

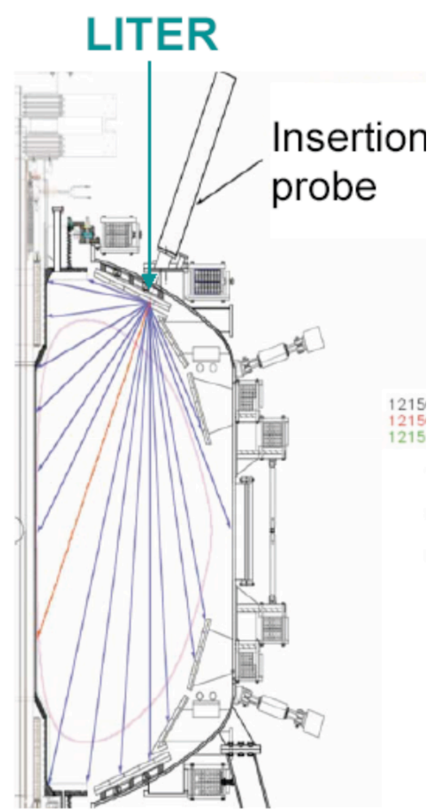
NSTX

- Study impact of lithium evaporation from modified LITER device on plasma performance in H-mode plasmas
- Will study performance of Sandia designed Liquid Lithium divertor module
  - Incorporate CDX-U/LTX experience onto NSTX

Addresses T13 and T15



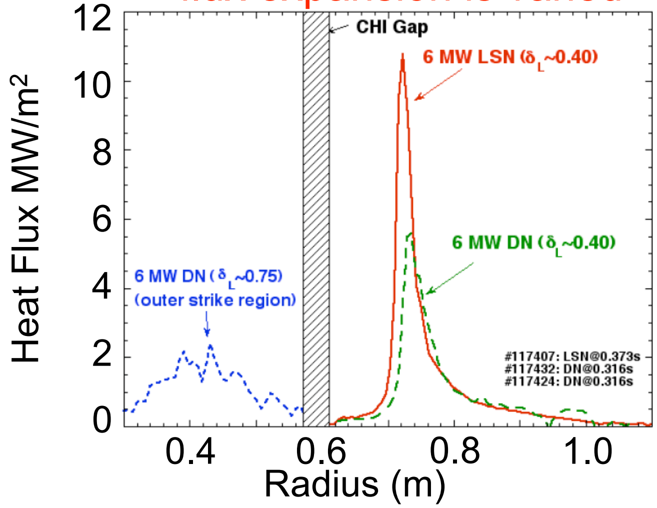
LITER decreased density And Z_{eff} while increasing T_e and T_i



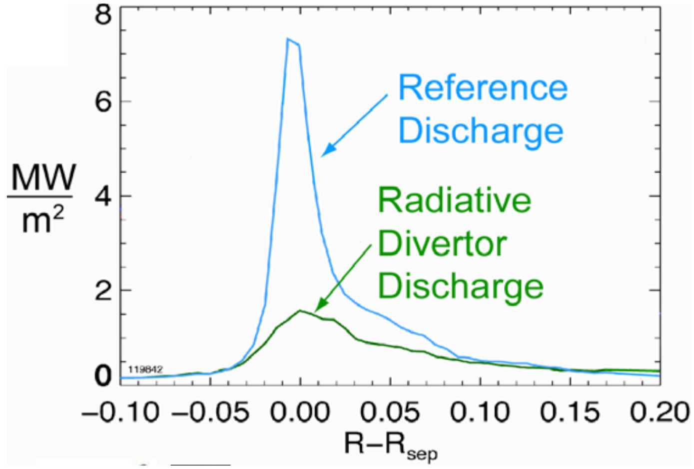
Flexible NSTX open divertor allows study of flux expansion with differing plasma geometries

NSTX

Peak heat flux can vary x4 as flux expansion is varied



Radiative divertor regime outer strike point heat flux reduced by 4-5



- Study variation and control of heat flux in the SOL
- Radiative edge studies
- ITPA joint experiments in support of ITER
  - Pedestal structure and ELM stability in DND plasmas (PEP-6)
  - Pedestal scaling with Aspect ratio (PEP-9)
  - Cross-machine comparison of ELM regimes (PEP-16)
  - Edge turbulence characterization (DSOL-15)
  - Cross-machine comparison of deposition (DSOL-17)
- Supersonic gas injection fuelling studies

Addresses T10 and T13

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

NSTX

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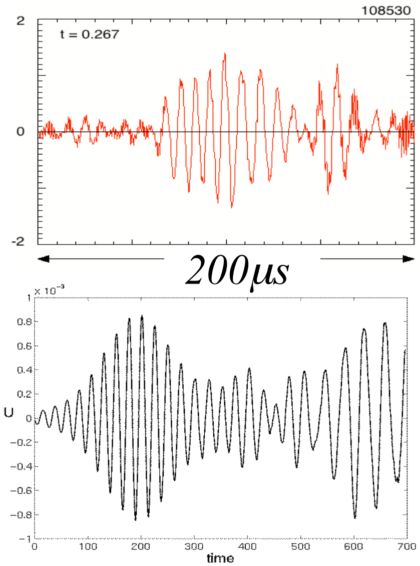
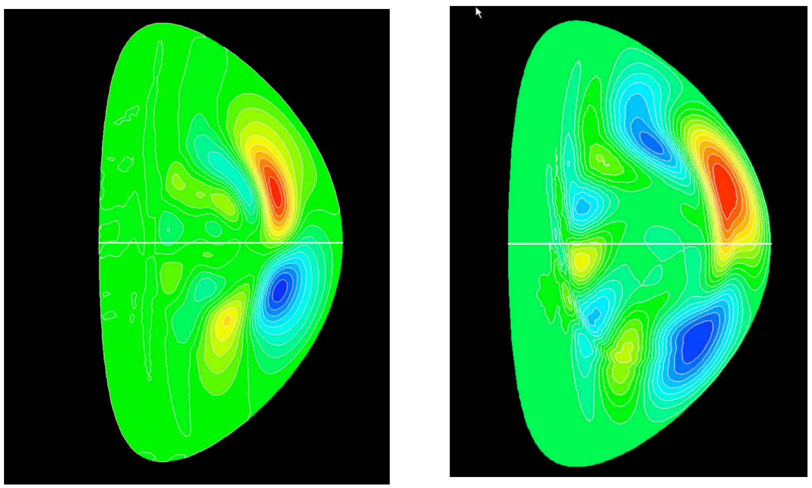
NSTX Accesses ITER-Relevant Fast-Ion Phase-Space Regime

M3D TAE simulations give mode growth ~ 50 - 100 μs in reasonable agreement observations



Bursting/chirping behavior results from:

- Non-linear modification of fast-ion distribution
- Change in mode structure
- Predicted to be present on ITER



t=0.0 t=336

- Measure, identify, and characterize super-Alfvénic ions modes (MDC-10)
  - Measure mode structure and complete equilibrium with reflectometry, higher resolution Mirnov array, and MSE
  - Determine losses as a function of β_{fast} and $v_{fast}/v_{Alfvén}$ (MDC-11)
  - Characterize effects using fast lost ion probe, NPA, SSNPA (Ph. D. Thesis)
  - Compare results to theory ⇒ develop quantitative predictive capability for ITER
- Investigate physics of Alfvén cascades

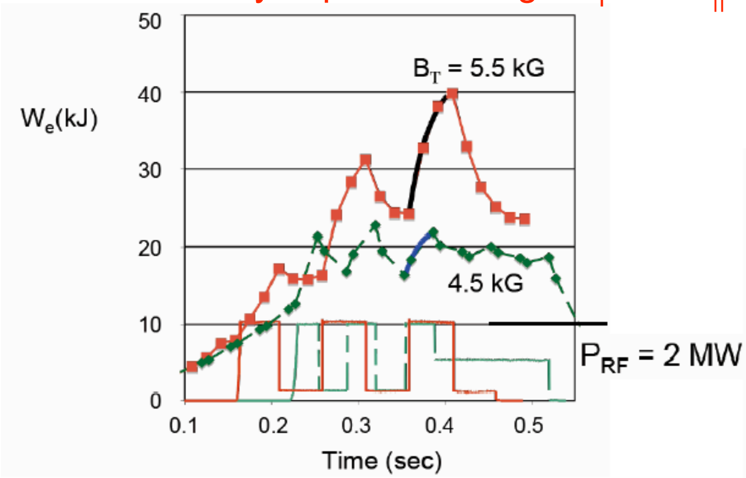
Addresses T11 and T12

- Investigate impact of fast ion MHD on q-profile (SSO-2.2)
  - Investigate MHD effects in plasmas with elevated central q (hybrid mode)

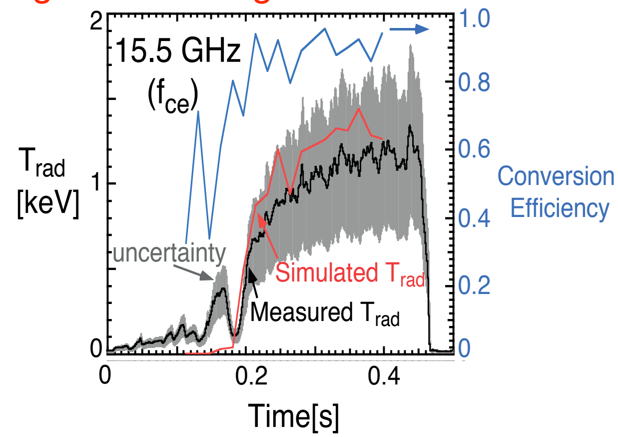
E. Fredrickson, Phys. Plasmas **13**, 056109 (2006)

Research Plans for HHFW and EBW research

HHFW efficiency improved at high B_T and $k_{||}$



B-X-O mode coupling in L-mode at f_{ce} - good theory agreement - high conversion efficiency



- Investigate efficient HHFW efficiency at higher TF
  - Optimize heating efficiency versus plasma parameters (gap scan, upper vs. lower SND) - measure coupling with new RF probes
  - Document current drive at higher TF with MSE
- Investigate 13m^{-1} current drive phasing
  - Input to decision on antenna upgrade
- Investigate intrinsic rotation of HHFW heated discharges (TP-6.1)
- Understand physics of EBW emission in H-mode plasmas (Ph. D. Thesis)
- Improve EBW modeling capabilities through collaborations
- Collaborate with MAST on 28GHz system

Addresses T11

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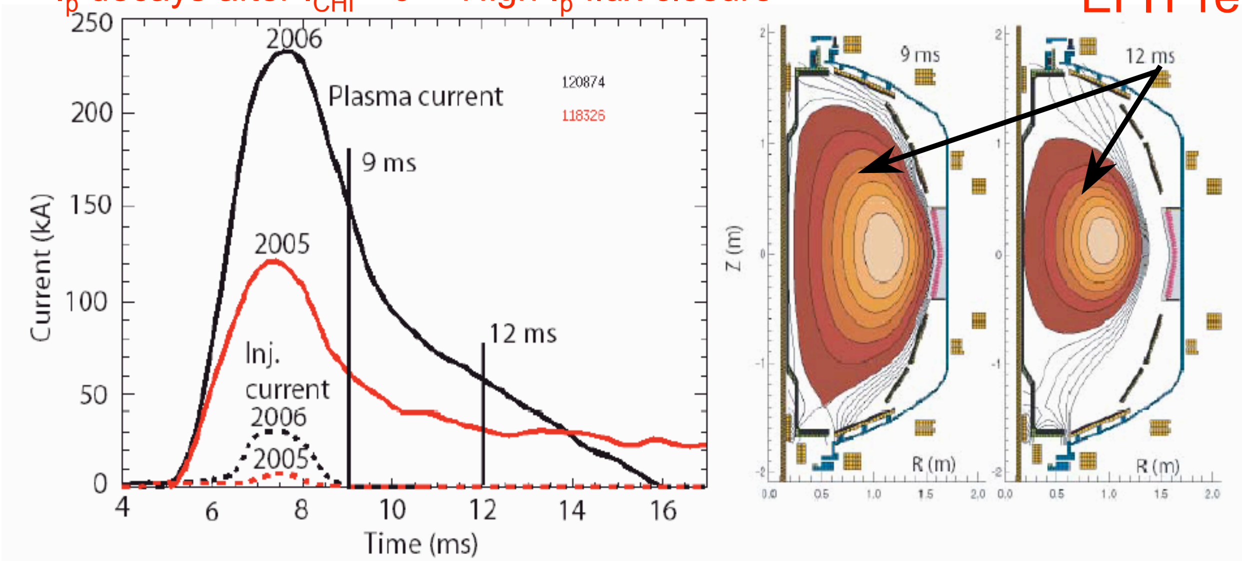
160 kA of Closed Flux Current Produced in NSTX by Transient CHI

NSTX

3x as much current as previous result

I_p decays after $I_{CHI} \rightarrow 0 \Rightarrow$ High I_p flux closure

EFIT reconstructions



- Maximize CHI current
  - Incorporate higher voltage capability to raise CHI I_p
- Couple CHI to Ohmic ramp-up
- Reduce flux consumption during ramp-up phase
  - Mimics small iron core transformer
- Use ECH pre-ionization for improved PF only startup scenarios
- Use ECH to heat CHI startup plasmas
- Investigate Pegasus-like plasma gun option

Addresses T6

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- Transport and Turbulence
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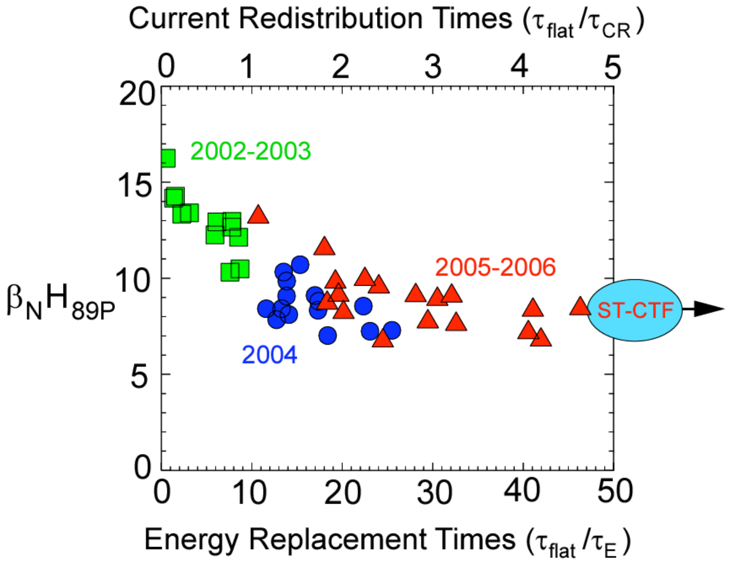
- Waves and Energetic Particles
- Solenoid Free Start-up, Ramp-up
- Integration

High Performance Can Be Sustained For Several Current Redistribution Times at High Non-Inductive Current Fraction

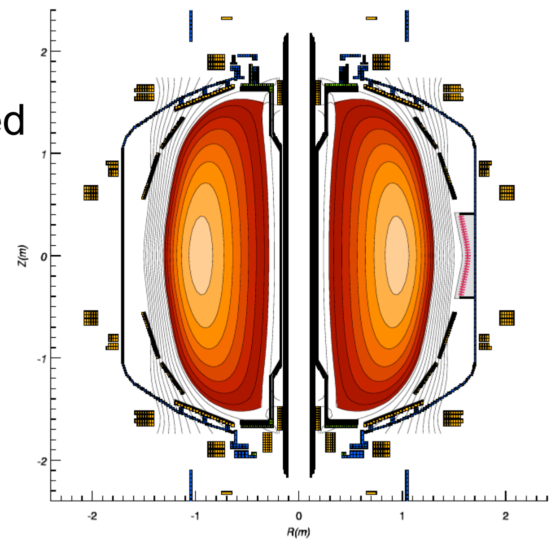
NSTX

High β_N x H89P now sustained 2 x longer with up to 65% non-inductive current fraction



World record shaping achieved $\kappa = 3$, $\delta = 0.8$, $S \sim 41$

Plasma shaping responsible for improved performance



- Investigate high non-inductive fraction plasmas at κ = 2.8 with upgraded control computer
  - Improve MHD stability by improving coupling to stabilizing plates
  - Incorporate lithium coating capability (pending demonstration of LITER upgrade)
- Development of Enhanced pedestal H-mode
- Investigate ELM suppression with resonant magnetic perturbations (support for USBPO/ITER task)

Addresses T3, T13 and T15

Baseline FY07-09 research and “Joule” milestones

NSTX

	FY07	FY08	FY09
Exp. Run-Weeks:	10	12	12
1) Transport & Turbulence:	Study variation of local high-k turbulence with plasma conditions	Measure poloidal rotation at low A and compare with theory	
2) Macroscopic Stability:	Characterize effectiveness of closed-loop RWM control & dependence on rotation using ITER-like control coils		Understand physics of RWM stabilization and control as a function of rotation
3) Wave-Particle Interaction:	Measure, identify & characterize modes driven by super-Alfvénic ions		Study how j(r) is modified by super-Alfvénic ion driven modes
4) Start-up, Ramp-up, Sustainment:		Couple inductive ramp-up to CHI plasma	
5) Boundary Physics:		Study variation and control of heat flux in SOL	
6) Physics Integration:			Perform high-elongation wall-stabilized plasma operation
“Joule” Milestones:	Super-Alfvénic ion driven mode physics	Rotation & momentum transport physics	TBD

20 weeks of run-time in FY08 and FY09 would accelerate start-up, HHFW, liquid Li, and MHD modification of J(r) research

NSTX

	FY07	FY08	FY09
Exp. Run-Weeks:	10	20	20
1) Transport & Turbulence:	Study variation of local high-k turbulence with plasma conditions	Measure poloidal rotation at low A and compare with theory	
2) Macroscopic Stability:	Characterize effectiveness of closed-loop RWM control & dependence on rotation using ITER-like control coils		Understand physics of RWM stabilization and control as a function of rotation
3) Wave-Particle Interaction:	Measure, identify & characterize modes driven by super-Alfvénic ions		Characterize edge plasma-HHFW interactions to optimize core heating efficiency and current drive
4) Start-up, Ramp-up, Sustainment:		Couple inductive ramp-up to CHI plasma	
5) Boundary Physics:		Study variation and control of heat flux in SOL	Characterize performance of a liquid lithium divertor
6) Physics Integration:		Perform high-elongation wall-stabilized plasma operation	Integrate MHD modification of j(r) into optimized operation
"Joule" Milestones:	Super-Alfvénic ion driven mode physics	Rotation & momentum transport physics	TBD

ITPA 2007 Joint Experiments are important opportunities to support and benefit from ITER burning plasma research

NSTX

ID No	Proposal Title	Participating Experiments	07 Priority
CDB-2	Confinement scaling in ELMy H-modes: β degradation	AUG, DIII-D, JET, JT-60U, Tore-Supra(L), MAST, NSTX	1
CDB-6	Improving the condition of Global ELMy H-mode and Pedestal databases: Low A	MAST, NSTX, DIII-D	1
TP-8.2	Investigation of rational q effects on ITB formation and expansion	JET, DIII-D, T-10, TEXTOR,NSTX	1
PEP-6	Pedestal Structure and ELM stability in DN	AUG, MAST, NSTX, JET	1
PEP-16	C-MOD/NSTX/MAST small ELM regime comparison	NSTX, MAST, C-Mod	1
MDC-2	Joint experiments on resistive wall mode physics	DIII-D, JET, NSTX, JT-60U, MAST, AUG, TEXTOR	1
MDC-5	Comparison of sawtooth control methods for neoclassical tearing mode suppression	AUG , DIII-D, JET, NSTX, TCV, HL2A, Cmod, FTU, JT-60U	1
MDC-10	Measurement of damping rate of intermediate toroidal mode number Alfvén Eigenmodes	JET, C-Mod, MAST, NSTX	1
MDC-12	Non-resonant Magnetic Braking	JET, DIII-D, C-Mod, NSTX, TEXTOR, MAST	1
SSO-2.2	MHD in hybrid scenarios and effects on q-profile	AUG, JET, DIII-D, JT-60U, NSTX, C-mod	1
TP-6.1	Scaling of spontaneous rotation with no external momentum input	CMOD, DIII-D, JET, JT-60U, TCV, MAST, NSTX, AUG, TEXTOR, Tore-Supra	2
TP-6.3	NBI-driven momentum transport study	DIII-D, JT-60U, NSTX, MAST, AUG, JET	2
DSOL-15	Inter-machine comparison of blob characteristics	C-Mod, PISCES, TEXTOR, VTF, NSTX, TJ-II,JET, TCV, HT-7, Tore-Supra, AUG, JT-60U, MAST, FTU	2
MDC-3	Joint experiments on neoclassical tearing modes (including error field effects)	C-mod, JET, AUG, DIII-D, NSTX	2
MDC-4	Neoclassical tearing mode physics - aspect ratio comparison	AUG, MAST, NSTX, DIII-D	2
MDC-11	Fast ion losses and Redistribution from Localized AE's	JET, DIII-D, JT-60U, NSTX, MAST, AUG	2
CDB-8	ρ^* scaling along an ITER relevant path at both high and low beta	JET, DIII-D, C-mod, AUG, NSTX	TBD
CDB-9	Density profiles at low collisionality	JET, DIII-D, C-mod, AUG, JT-60U, TCV, Tore-Supra, MAST, NSTX	TBD
TP-8.1	NSTX/MAST ITB Similarity Experiments	MAST, NSTX	complete
TP-9	H-mode aspect ratio comparison	NSTX, DIII-D, MAST	TBD
PEP-9	NSTX-MAST-DIII-D pedestal similarity	DIII-D, MAST, NSTX	TBD
DSOL-17	Cross-machine comparisons of pulse-by-pulse deposition	NSTX, AUG, JET, TEXTOR	piggyback
DSOL-19	Impurity generation mechanism and transport during ELMs for comparable ELMs across devices	AUG, JET, DIII-D, C-mod, JT-60U, MAST,NSTX	TBD
DIAG-2	First mirror Qualification	T-10, TEXTOR, LHD, JET, DIII-D, TCV, AUG, LHD, HL-2A, Aditya, NSTX, HT-7, Tore-Supra	piggyback

NSTX will continue to make fundamental contributions to toroidal science in support of future STs and ITER

NSTX

- Demonstrated RWM feedback control at ITER-relevant rotation and observed quantitative agreement between predicted NTV torque and measured plasma torque
  - With DIII-D and C-MOD will achieve predictive understanding of plasma momentum transport and critical rotation frequency for RWM stability
- Measured high-k scattered spectrum and have measured weak degradation of confinement with β - important for ITER
  - Will make quantitative comparisons to predicted mode fluctuation spectra
- Demonstrated the utility of lithium coating using evaporator technology
  - Incorporating lithium into integrated scenarios leading to liquid Li divertor
- Demonstrated improved HHFW heating at higher TF
  - Will couple HHFW to ECH-heated CHI plasmas
- Tripled closed flux CHI current to 160kA
  - Will use ECH to heat CHI plasmas
- Achieved world record elongation in a controlled plasma
  - Will continue to pursue 100% non-inductive current sustainment in an ST