FY2003 Research Plan and Relation to Five Year Goals

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21-22 January 2003

Outline

- 2003 Goals and Capabilities
- Topical area research program organized by ETs and relation to Five Year plan
  - Heating and Current Drive (Taylor, Ryan)
  - Co-Axial Helicity Injection (M. Bell, Raman)
  - MHD (Sabbagh, Gates)
  - Transport and Turbulence (LeBlanc, Darrow)
  - Boundary Physics (Kugel, Kaita)
  - Integrated Scenario Development (Maingi, Menard)
- Research plan logic

Program Planning Steps

- PAC-12 (2/02)
- FWP (3/02)
- NSTX Results and Theory Review (9/02)
- NSTX Research Forum (9/02)
- PAC Input (9-10/02)
- Refinement of run plan (10-11/02)
- Beginning of FY03 run (12/02)

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- Initial Presidential budget guidance – 21 run weeks in FY03

Reduced Budget Forces Hard Choices

- Set of milestones has been modified to reflect reduced run time (21 to 12 run weeks)
- Original set of milestones (before possibility of 21 run weeks) retained
  - Others delayed or reduced
  - Budget, time, facility capability considerations
- XPs delayed, reduced in scope
- Diagnostic upgrades postponed

Reduced Run Time Compromises Scientific and Technical Progress (21→12 weeks)

- Retained milestones
  - High-β and τ_E for $\Delta t \gg \tau_E$
  - Non-inductive current drive to assist in startup and sustainment of ≥ 1 sec pulses
  - Edge heat flux dispersion and effect of PFC at high power
  - CHI coupling to OH
- Delayed/reduced scope – some work will still be done
  - Persistent CHI coupling to other non-inductive CD techniques
  - Interactions among resonant error field response, correction fields and rotation
  - Requirements for EBW heating and current drive

Run time allocations for FY03 (12 run weeks)

	FY 2003 (12 wks)		FY2003 (21 wks)
HHFW heating & CD	8 days	(13%)	15 days
CHI	8 days	(13%)	15 days
Transport	7 days	(12%)	13 days
MHD	7 days	(12%)	13 days
ISD	7 days	(12%)	13 days
Boundary (heat flux)	5 days	(8%)	8 days
Enabling/cross-cutting	8 days	(13%)	10 days
Scientific Contingency	10 days	(17%)	18 days

NSTX Facility Plan (•)

	FY02	FY03	FY04
Experimental Run-Weeks	12	12	?
TF system	• 6 kG		
NBI		• Real-Time β Feedback	
HHFW	• Pre-prog. Phasing	• Antenna Feed-Thru Imp.	• F/B Phase Control
CHI		• New Absorber • Absorber Field Null Control Coils	
EBW		• Optimized Ant. Assembly	
Wall Conditioning Pwr & Part. Cntrl.	• 350 C Bakeout	• Li/Boron Pellet Injector • Density Feedback	
Fueling	• HFS Gas Fueling	• HFS Gas Fueling Improvement	
Resonant Field and RWM Control	• PF5 Realign • Locked Mode Coils	• 2x12 Wall Mode Sensors	• Res. Field Control • 2x24 Wall Mode Sensors
Plasma Equilibrium & Control	•Non-Mag. Pickup Coils • rtEFIT	• 2x6 I-D Mirnovs, Flux Loops for CHI absorber • Density Feedback • rtEFIT Algorithm Dev.	• MIMO (GA)

NSTX Diagnostics Implementation Plan (FY02-04)

* collaborator diagnostics in red

	FY02	FY03	FY04
Experimental Run-Weeks	12	12	?
MPTS	• 20 Ch		
CHERS	•18 Ch (interim)	• 51 Ch Toroidal CHERS	
XCS		• 2D XCS	
MSE (Nova)		• CIF 1-4 Ch	• 10 Ch
FIReTIP (UCD)	• 2 Ch	• 4 Ch	• 7 Ch
USXR (JHU)	• Pol fan at 2nd Tor pos	• Higher resolution	
X-rays		• PICXS	
Particle Detectors	• 2-D Scanning NPA • Faraday loss probe • Neutron, Diamond Detectors	• Scintillator Loss Probe • Neutron Collimators	
Fluctuations	• Correlation Reflectometry (UCLA) • 2D GEM X-ray (Frascati/JHU) • Fast Scan. Edge Probe (UCSD) • MHz Gas Puff Imaging (PSI, LANL)	• Dynamo Probe •1 mm Interferometer	• 2D Fast X-Ray Pinhole Camera • Tangental High-k • MIR
Impurities	•VIPS, VB, Fiberscopes •VUV (JHU)	• Multi-Chord Spectrometer (JHU)	
Divertor and Boundary Physics Cameras	•Langmuir, Tcouples •FRP (UCSD), Coupons (SNL) • Div. 1D CCD (ORNL) • Div. IR Cam. (ORNL) • Fast 2D Div. Visible (Hiroshima U)	• Div. Bol., Edge Flow Spectroscopy • Quartz Dep. Monitors	

Heating and Current Drive (HHFW/EBW)

- Provide heating and current drive to supplement OH and NBI
  - Heating for enhanced bootstrap, reduced flux consumption
  - Direct current drive
  - Improve electron confinement, pressure profile modification

- Five year research goals (HHFW)
  - *Dependence of HHFW coupling on plasma configuration and density*
  - *HHFW compatibility/effects with NBI heating (also ISD)*
  - *CD and wave-particle interactions*
  - Develop solenoid-free startup

- New capabilities in 2003
  - HHFW antenna modified to increase voltage/power limit

Italics – Elements covered, in part, in FY03

HHFW FY2003 Research Plan

- HHFW coupling
  - Develop antenna conditioning techniques
  - Develop startup scenarios to optimize coupling to plasma
  - Establish good coupling for electron heating
    - Vary gaps, antenna phasing, go to high density
- CD/wave-particle interactions
  - Operate at higher power levels and longer pulse ($\leq$ 6 MW)
  - Measure j with MSE
- HHFW coupling with NBI
  - Develop scenarios to optimize RF coupling to NBI
  - Complete study of fast ion acceleration (thesis work)

EBW FY2003 Research Plan

- EBW five year goal is to demonstrate and employ efficient coupling of X/O mode to EBW
  - Electron heating and EBW-assisted non-inductive startup
  - Possible suppression of NTMs
- FY2003 research focused on establishing basis for high power heating and current drive system
  - Demonstrate ≥80% B-X and/or B-X-O conversion
    - Use limiters to reduce L_n and increase conversion efficiency
    - Reflectometry to measure L_n
    - Local gas feed to ensure adequate density

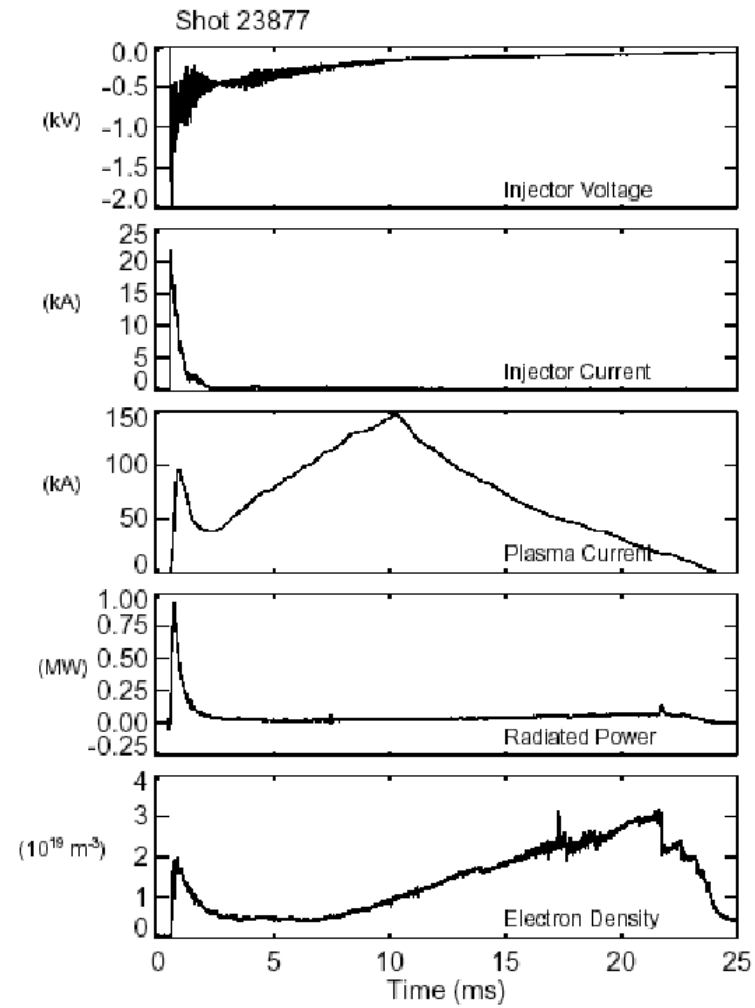
Co-Axial Helicity Injection

- Five year goals
  - *Develop method for non-inductive current initiation*
    - *Couple to other current drive schemes*
    - *Enable solenoid-free startup to high β_{pol}*
  - Possible technique for driving edge current during discharge sustainment phase

- New capabilities in 2003
  - Components/electronics related to noise and arcing redesigned
  - New, long ceramic insulator
  - PF absorber field control coils

CHI 2003 Research Plan

- Employ short pulse startup scenario developed on HIT-II
  - Couple to ohmic
- Develop extended CHI pulse
  - ≥ 400 kA, "hundreds" msec
  - Investigate new absorber performance
  - Utilize absorber field coils
  - Develop control capability
- Demonstrate flux closure
  - Magnetic fluctuations, kinetic profiles
  - Equilibrium reconstruction and modeling (ESC, EFIT, MFIT, TSC)



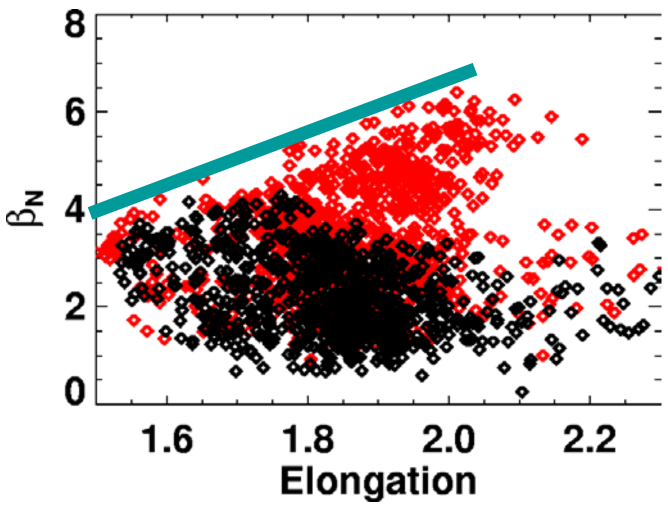
MHD Stability

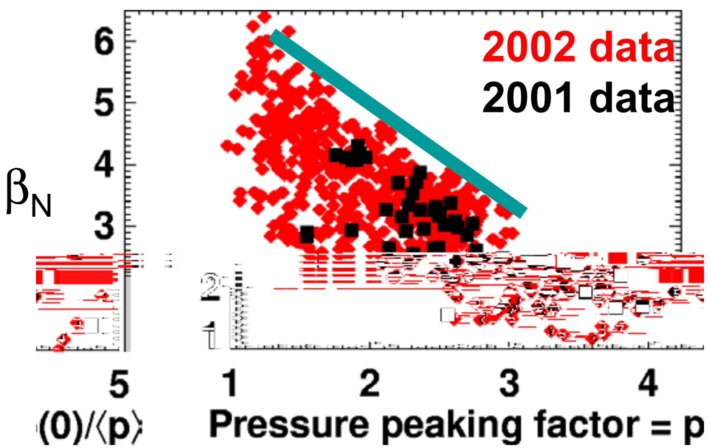
- A major five year goal is to develop the physics basis for sustained operation near the with-wall limit
  - *Influence of shape, rotation and profiles on global stability*
  - *Fast ion MHD*
  - *Error fields and locked modes*
  - *RWM physics*
    - *Passive stabilization*
    - Active control
  - *ELM stability*
  - NTM suppression

- New capabilities in 2003
  - Divertor Mirnov array
  - RWM sensors
  - MSE-CIF (1 to 4 channels)

Influence of shape, rotation and profiles on global stability

- β-limit dependence on δ in DND
  - δ<0.4, ELM trigger physics
- Stability limits at high κ, reduced l_i in LSN
  - κ>2.0 @ 800 kA
- Continue to assess shear flow stabilization in core kinks

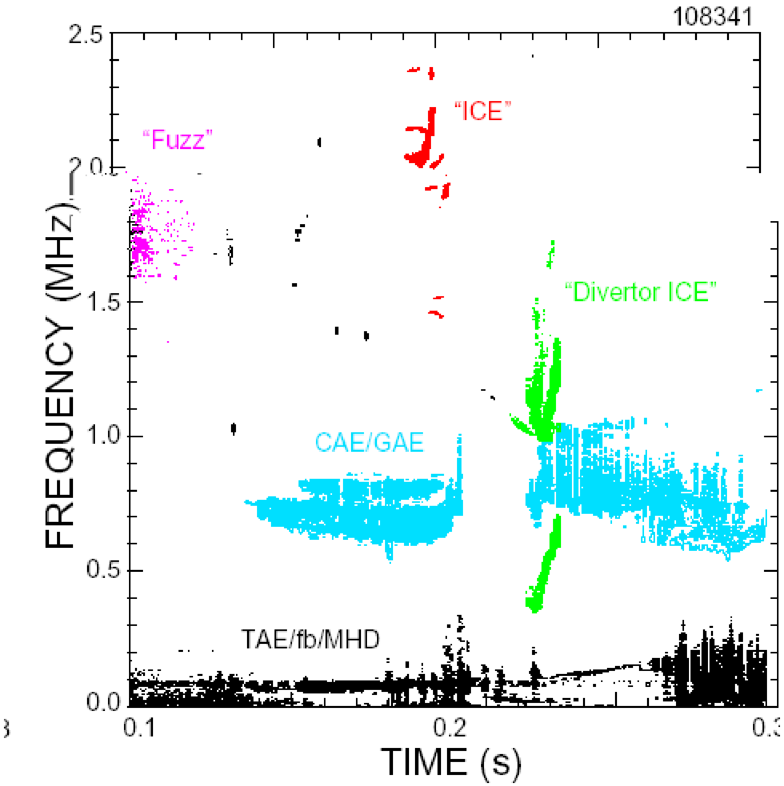




Fast Ion MHD

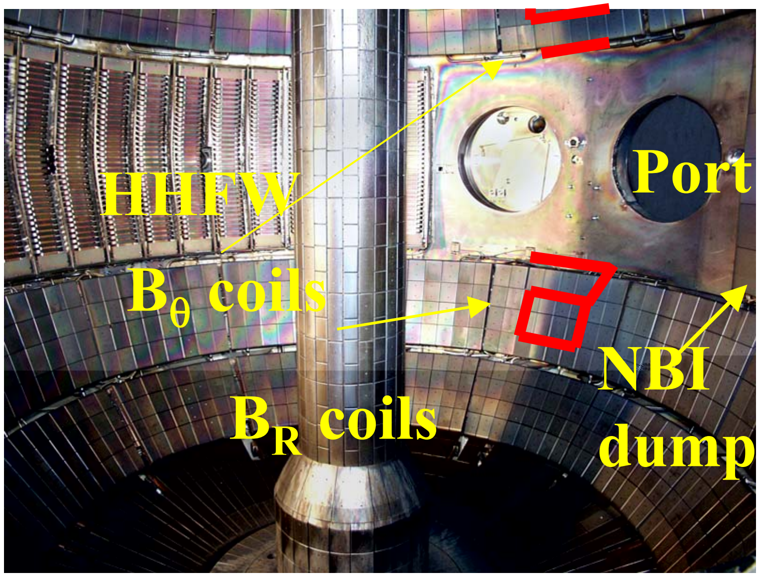
- CAE studies
  - Measure high frequency MHD
  - Determine existence, amplitude and extent of CAEs using core reflectometry
    - Implications for stochastic heating

Modes up to 15 MHz inferred



Error Fields and Locked Modes

- Commission internal RWM/EF sensors
- *Assess sources of residual error fields*
  - PF coils, coil leads, eddy currents
- Determine parametric dependence of locked modes
  - Density, rotation, proximity to no wall limit



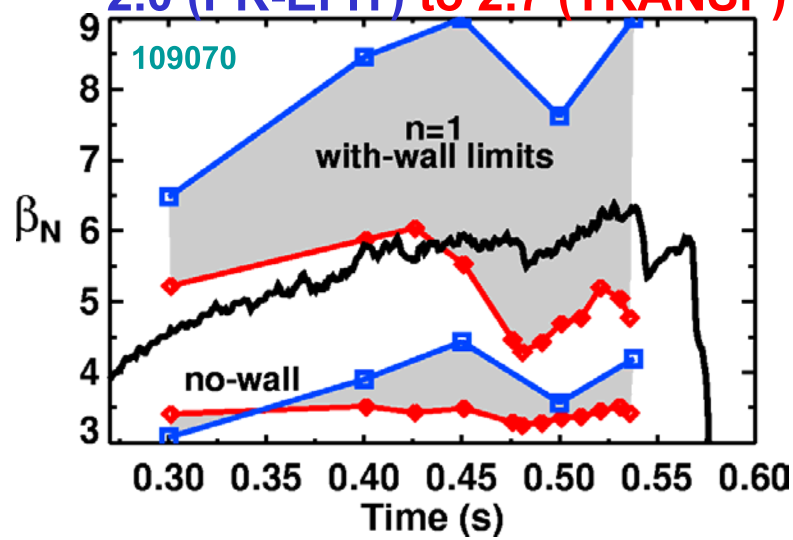
RWM/Kink Physics

- RWM stabilization
  - Determine critical rotation frequency
  - Similarity experiments with DIII-D
    - Rotation physics
    - Mode structure & wall stabilization
  - Rotation damping physics (thesis work)

- Design active coil set (DCON+VALEN)
  - External vs internal
  - Slow and fast response (EF correction/fast feedback for RWM control)

Nearly monotonic $q(\psi)$ with $q(0) < 2$

Vary pressure peaking $p(0) / \langle p \rangle$ = 2.0 (PK-EFIT) to 2.7 (TRANSP)



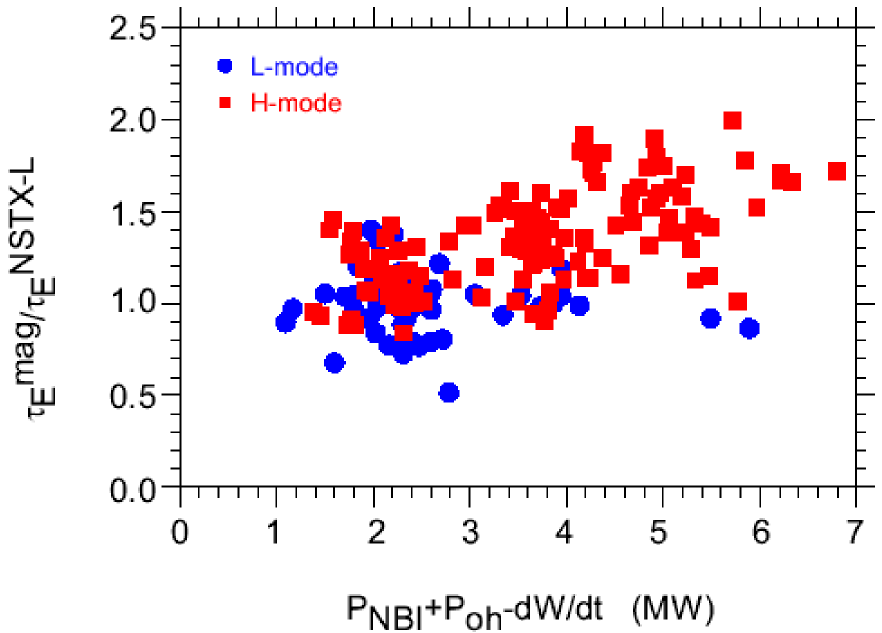
Transport and Turbulence

- Five year goals
  - *Establish key τ_E and transport scalings*
    - *Electron vs ion transport*
    - *Dependence on ρ^*, β_T, ω_{ExB}*
  - *Assess fast ion confinement*
  - *Determine influence of E_r (ω_{ExB}) and β_T on edge turbulence, transport, L-H transitions*
  - Assess roles of low and high-k turbulence in heating and transport
  - Use knowledge gained to control plasma transport and produce p(r), j(r) for high-β_T, non-inductive current drive

Determine Key τ_E and Transport Scalings

- Systematic H-mode scalings in quasi-steady discharges
- NSTX/MAST similarity
- NSTX/DIII-D similarity
- Dimensionless scalings within NSTX
  - OH R/a
  - Initial ρ^*, β_T

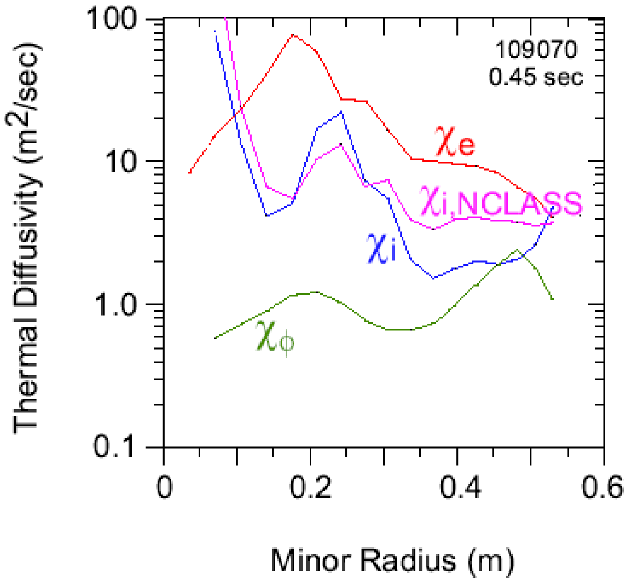
$$\tau_E^{NSTX-L} \sim I_p^{0.76} B_T^{0.27} P_L^{-0.76}$$

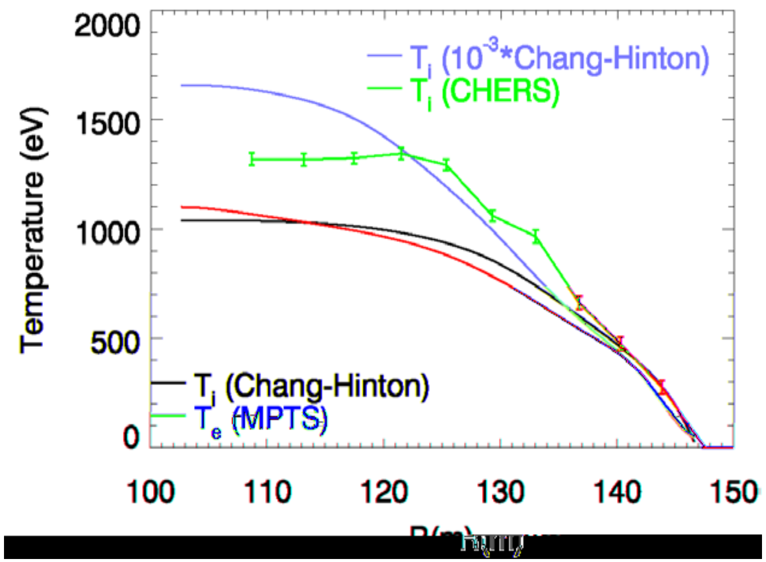


χ-scalings will also be developed from the results of these XPs

Local Transport

- Establish χ_e, χ_i baselines



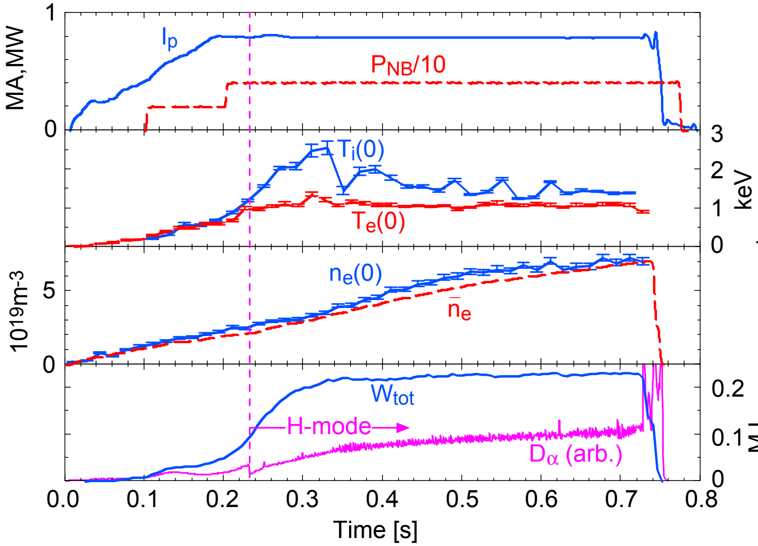


- Momentum transport, role of rotation
  - RF vs NBI

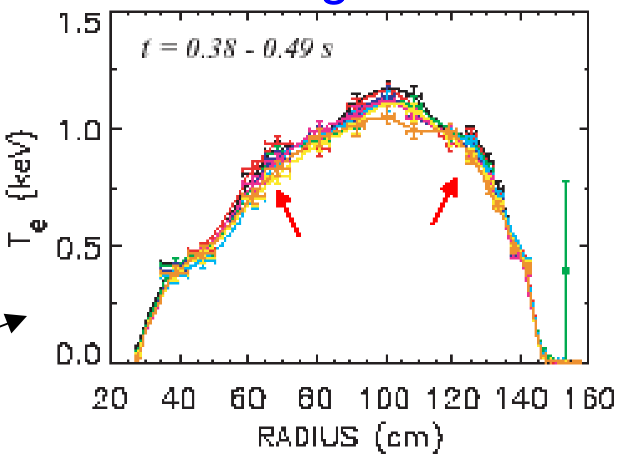
Local Transport - cont'd

- Explore regimes of improved electron confinement
  - Generate e⁻ ITBs at low n_e

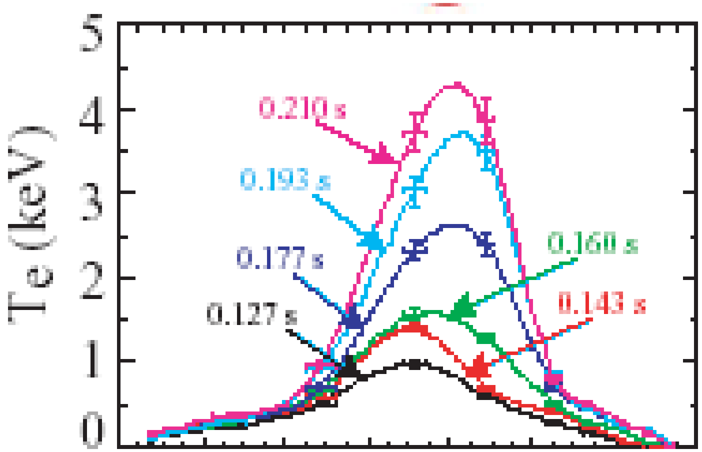
Electrons impervious to transport events



Critical gradient?

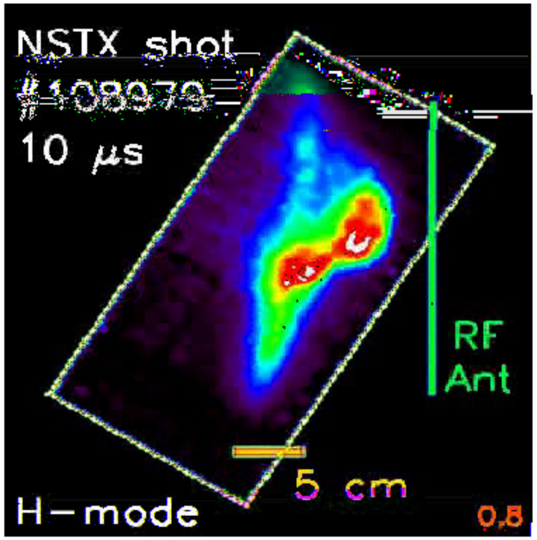


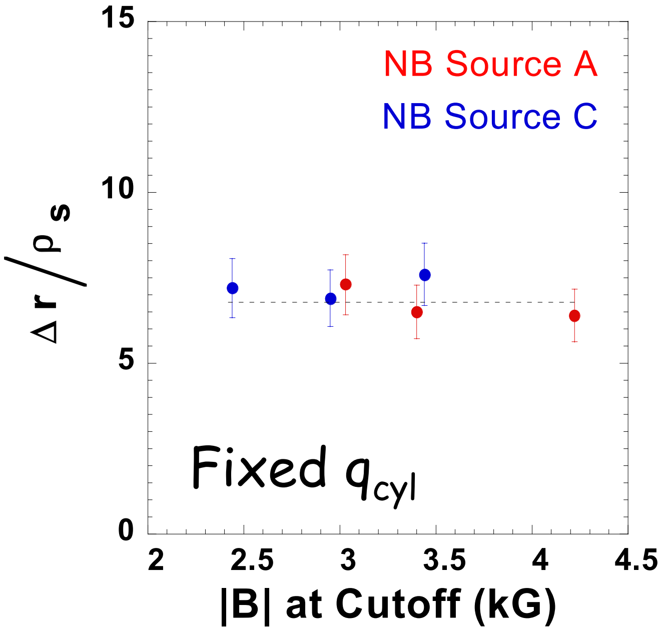
ITB w/ HHFW



Edge Turbulence

- Gas puff imaging/fast probe
  - L-H transitions
- Correlation reflectometry
  - Can connect to local transport results
- FIRETIP/Reflectometer for ITGs in L-mode core





Boundary Physics

- Five year goals
  - *Enabling technology*
    - *Evaluate power handling needs and solutions*
    - *Assess fueling and particle pumping needs*
    - *Develop and evaluate wall conditioning techniques*
  - *Science*
    - *Characterize edge power and particle transport regimes*
    - *Understand effects of ST features on boundary physics*
- New capabilities in 2003
  - Li/B pellet injector
  - Supersonic gas injector
  - Improved boronization schemes
  - Fast reciprocating probe, divertor bolometer, fast divertor camera, fast divertor IR camera

Power and Particle Control

- Understand heat flux scaling and power accountability
  - Parametric scaling (I_p, n_e, P_{heat})
  - H vs non-H, SN/DN configurations
  - Detailed edge characterization of edge for SOL transport studies
  - NSTX/MAST comparative studies
- Test methods for reducing heat flux
  - X-point sweeping
  - Detached divertor

Fueling and Wall Conditioning

- Helium discharge cleaning
- Lithium/Boron pellet injection
- Improved boronization techniques

Density control a key issue for long pulse discharges

Integrated Scenario Development

- Five year goals
  - Produce high performance plasmas using various control techniques
    - *Simultaneous high-β_t, τ_E for long duration*
    - *Quasi-steady 1 sec pulses*
    - *NBI/HHFW compatibility*

- New capabilities in 2003
  - rtEFIT shape control
  - Density feedback
  - Improved wall conditioning
  - NBI control for β-feedback

Research Plan Logic – Temporal Progression of Research Activities

	Early Run	Mid-Run	Late Run
H&CD	HHFW system shakedown Electron heating	HHFWCD EBW mode conversion HHFW/fast ion interaction	HHFWCD w/j(r) measurements
CHI	CHI transient startup - couple to OH	High CHI currents CHI plasma control development	Demonstrate flux closure
MHD	EF/RWM sensor calibration Locked mode/EF studies Stability on shape	RWM rotation effects, passive stab. Fast ion and CAE studies Similarity experiments	Stability studies with j(r) meas.
T&T	Global conf. dependences & momentum transport Local transport	Fast ion htg. & confinement Similarity experiments	Dimensionless scalings Edge fluctuations
Bdy	He conditioning Density control	Heat flux scaling and edge char. X-point sweep	Li/B pellets Detached divertor
ISD	rtEFIT development HHFW/NBI compatibility	High-$\beta_T\tau_E$ Long-pulse H-modes	Quasi-steady 1 sec discharges

NSTX Has Developed a Run Plan to Address a Broad Spectrum of Scientific Issues

- Most experimental proposals will take advantage of significant new facility and diagnostic capability to dig deeper into underlying physics
- Experiments support the Five Year research plan
- Addressing these critical elements will allow us to achieve some of our Research Milestones
- 12 instead of 21 run weeks compromises our ability to achieve all of them

Additional Run Time Will Help Advance the Scientific Output and Achieve the Full Set of Research Milestones

NSTX

- Additional experiments
  - More dedicated EBW mode conversion
  - HHFW H-modes and ITBs
  - L-H transition studies
  - Combined electron ITB/H-mode
  - Detailed ELM studies
  - Completion of fast ion similarity studies
  - Fishbones, TAEs
  - NTMs
  - Additional edge turbulence and fast transport
  - CHI coupling to other non-inductive CD

Additional run time for scheduled XPs

Additional Budget Will Allow Accelerated Development of Diagnostic/Facility Capability

- Reduced scope/deferred development tasks
  - Poloidal CHERS
  - High- and Low-k fluctuations (prototypes)
  - Divertor bolometer
  - Fast IR camera
  - RF probe
  - CHI dynamo probe
  - CHI absorber field null power supplies
  - EF/RWM active control