NEW RESEARCH OPPORTUNITIES AND PROPOSED EXPERIMENTAL EMPHASES FOR FY 2002

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For the National NSTX Research Team

NSTX Program Advisory Committee Meeting #11
Princeton, NJ
Oct. 4-5, 2001

Outline

- Planning process
  - milestones
  - decision points
  - new facility and diagnostic capabilities
- Topical area research program
  - Transport
  - HHFW heating and current drive
  - MHD studies
  - Boundary Physics
  - Non-inductive startup
- Draft program emphases

NSTX research plan is in early phase of multi-step planning process

- Fundamental ST physics issues addressed by milestones
  - Milestones and decision points drive program priorities
- Formulation of plan has multiple steps
  - NSTX Results Review (9/19 - 9/20)
  - **Top-down planning and PAC input (10/4 - 10/5)**
  - Refined analysis presented at APS meeting (11/’01)
  - NSTX Research Forum (11 or 12/’01)
  - Refinement of research plan and PAC input (12/’01 - 3 /’02)
- 12 run weeks in FY ‘02

NSTX milestones address crucial ST physics issues and drive research plan

- Effectiveness of HHFW CD (FY '02)
- 500 kA CHI discharge, feedback control, add induction and HHFW to CHI (FY '02)
- Transport with high β and rotation ('02)
- MHD stability without wall stabilization ('02)

- Wall heat flux measurement (FY '03)
- Sustainment of ~ 1-s pulses (FY '03)
- Simultaneous high β and τ (FY '03)

Research plan must provide data for near-term decision points

- *EBW System (end FY ‘02)*
- *RWM Active Stabilization (end FY ‘02)*
- *NTM scientific assessment - input to EBW plan (mid FY ‘03)*
- *Advanced PFC and density control (end FY’03)*
- *RWM Active Stabilization System FDR (end FY ‘03)*
- *EBW System FDR (end FY ‘03)*

NSTX Facility Plan (•) and Program Decision Points (♦)

	FY01	FY02	FY03
Experimental Run-Weeks	7; 8	13(12)	13
TF system		• Fix Water Leak	
NBI	• 5 MW; • Modulation		• β Feedback
HHFW	• 6 MW (k = 14/m)	• 6 MW (k = 7/m)	• Real-Time ϕ Control
CHI	• I_{inj} = 50 kA	• Absorber Design; • Installation	
EBW	• Emission/Conversion	• System Design (0.4 MW); ♦ System Decision	♦ FDR
Wall Conditioning Pwr & Part. Cntrl.	• Gas B-zation; • Plasma B-zation	• Li/B Pellet Injector; • Hi-Temp Bake	♦ Long-Pulse Upgrade
Fueling	• Gas Puff, NBI	• Inboard Gas Fueling	
RWM Control	• Mode ID	♦ System Decision	♦ FDR
NTM Control	• Mode ID	• Mode Avoidance	♦ EBW & Profile Requirements
Locked Mode Coil	• Installation; • Mode ID	• PF5 Corrections	
Plasma Control	• Sky-II On-line	• 150 Inputs, GIS Control, n_e Feedback	

NSTX Diagnostics Implementation Plan (FY01-03)

* collaborator diagnostics in red

	FY01	FY02	FY03 (preliminary) (collaborator diagnostics not included)
Experimental Run-Weeks	7 8	13(12)	13
MPTS	• 60 Hz, 10 Ch	• 20 Ch	• 90 Hz, 30 Ch
CHERS	• Tor CHERS 18 Ch	• Tor CHERS 70 Ch	• Pol CHERS
MSE (Nova)		• CIF 2 • 10 Ch	• LIF
FIReTIP (UCD)	• 2 Ch	• 4 Ch	• 7 Ch
Locked Mode	• 6 Compensated loops		
USXR (JHU)	• 3 Pol fans • Mirror Array	• Pol fan at 2nd Tor position • Higher density top arrays	
Hi-Freq Mirnov	• 3 ch	• 7 ch	
Particle Detectors	• Fixed sightline NPA • Faraday loss probe • Neutrons	• 2-D Scanning NPA • Scintillator Loss Probe	
Fluctuations	• Core Reflect. (UCLA) • Edge Reflect. (ORNL) • Gas Puff Imaging (LANL)	• Add. Correl. Reflect. (UCLA) • Fast Scan. Edge Probe (UCSD) • MHz Gas Puff Imaging (PSI, LANL)	
Divertor Physics	• Hα 1D CCD (ORNL) • Div. IR Cam. (ORNL)	• 2nd 1D CCD (ORNL) • Divertor Bolometer	
Cameras	• HHFW Antenna IR • 2nd Fast Vis. (LANL)	• Additional IR Camera • Fast Div. Visible (Hiroshima U)	

Transport and turbulence research guided by near term milestone

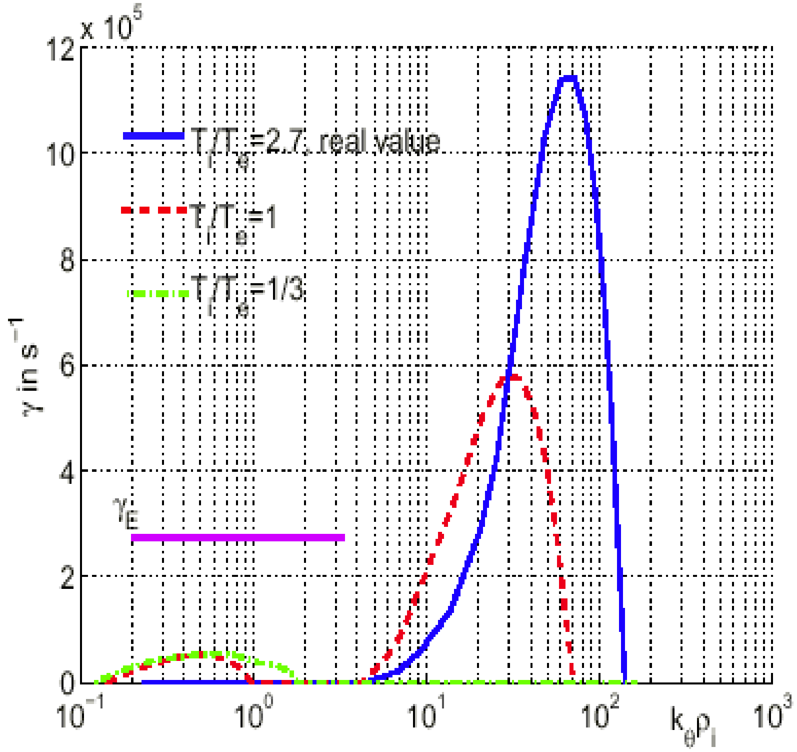
- Transport at high β and high rotation - FY '02
- Simultaneous high β and τ - FY '03
- New capabilities
  - inner wall gas puffing, density feedback
  - high temperature bake-out
  - 20 channel Thomson
  - 70 channel CHERs (March '02)
  - correlation reflectometer (UCLA)
  - edge reciprocating probe (UCSD)
  - faster gas-puff imaging camera ~ 1 MHz (LANL)
- Draft run time allocation - 9 days
- Research topics
  - Resolution of two fluid power balance
  - Thermal transport and confinement studies
  - H-mode and other studies

Resolve two-fluid power balance

- Determine additional sources of power
  - Compressional Alfven Eigenmodes (CAE) effects
    - More beam power and voltage scans, beam blips
  - Centrifugal heating via high rotation
- Refine loss terms
  - e-i coupling with high rotation
    - poloidal density asymmetry?
  - FLR effects on neoclassical transport
- Continue data validation comparisons!

Thermal transport studies guided by calculations; Confinement studies focus on R/a effects

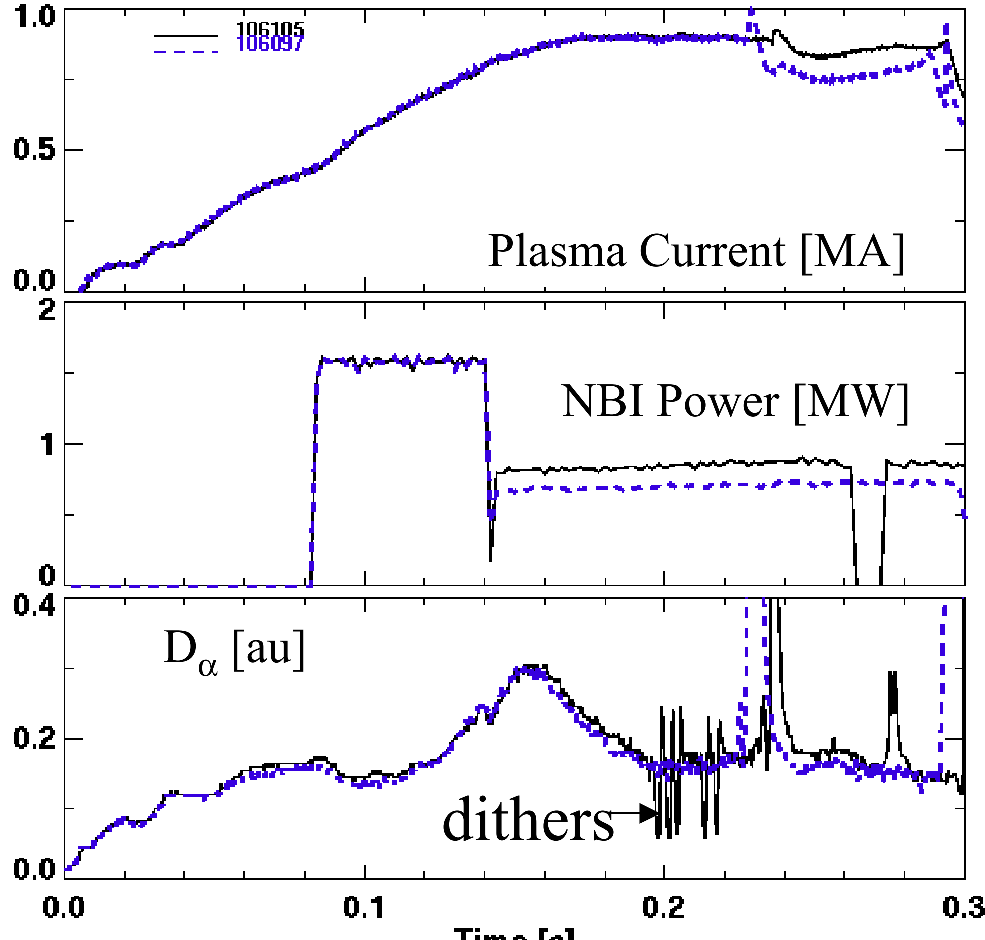
- Use gyrokinetic predictions to design XP's
  - electron transport dominates
  - T_e/T_i stabilization of ETG
  - Effects of high β and rotational shear
  - rotation scans?
- Measure long-λ turbulence (UCLA)
  - short-λ measurement ~ '04?
- Role of R/a in global τ_E
  - inter-machine w/DIII-D
  - within NSTX: 1.3<R/a<2



Bourdelle

H-mode Studies will focus on transport rates, LH physics, and pulse length extension

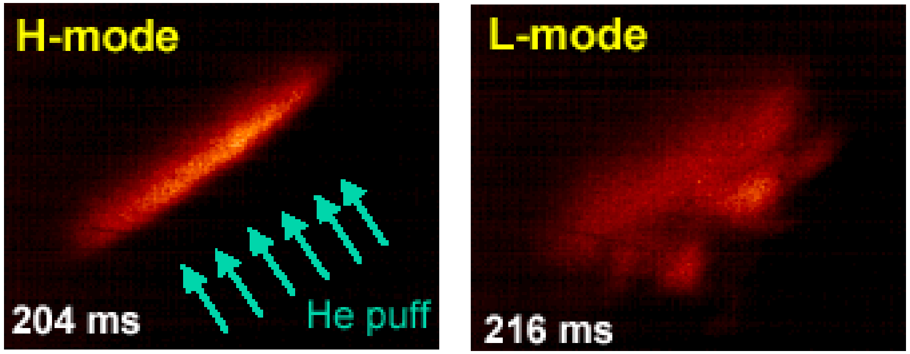
- Power balance and transport
- Measure parametric dependence of $P_{L\text{-}H}$
  - Compare local parameters at L-H transition with models
- Optimize quasi-steady H-modes
  - longer duration
  - lower pressure peaking
  - higher β and τ target

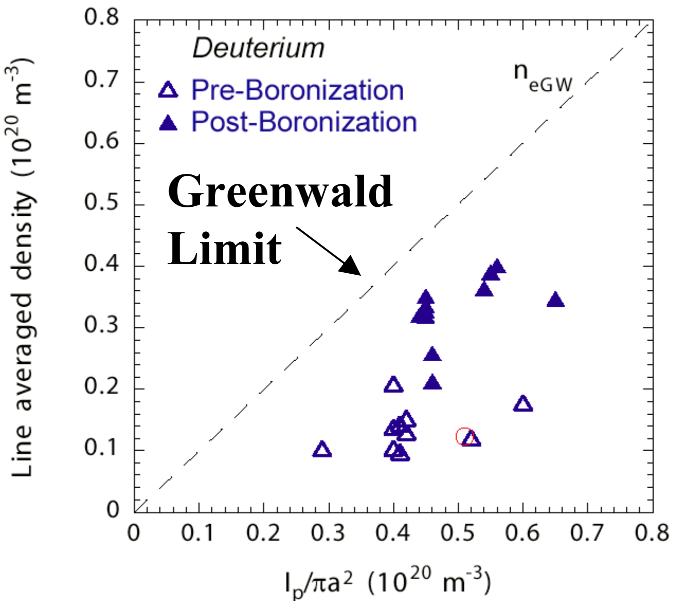


Bush, Maingi

Run time needed for edge turbulence and transport studies, test of operational limits, and impurity transport

- Gas-puff Imaging: Test BOUT and BAL predictions
  - configuration/shape
  - safety factor, I_p and B_t
- New edge reciprocating probe (n_e, T_e, E_{DC}, $\tilde{\phi}$, $\tilde{n}_e$, $\tilde{T}_e$)
- Density and q-limits after high temp. bake-out
  - link between turbulence and density limits
- More impurity transport experiments





Current drive milestones and decision points require high level of resources in FY '02

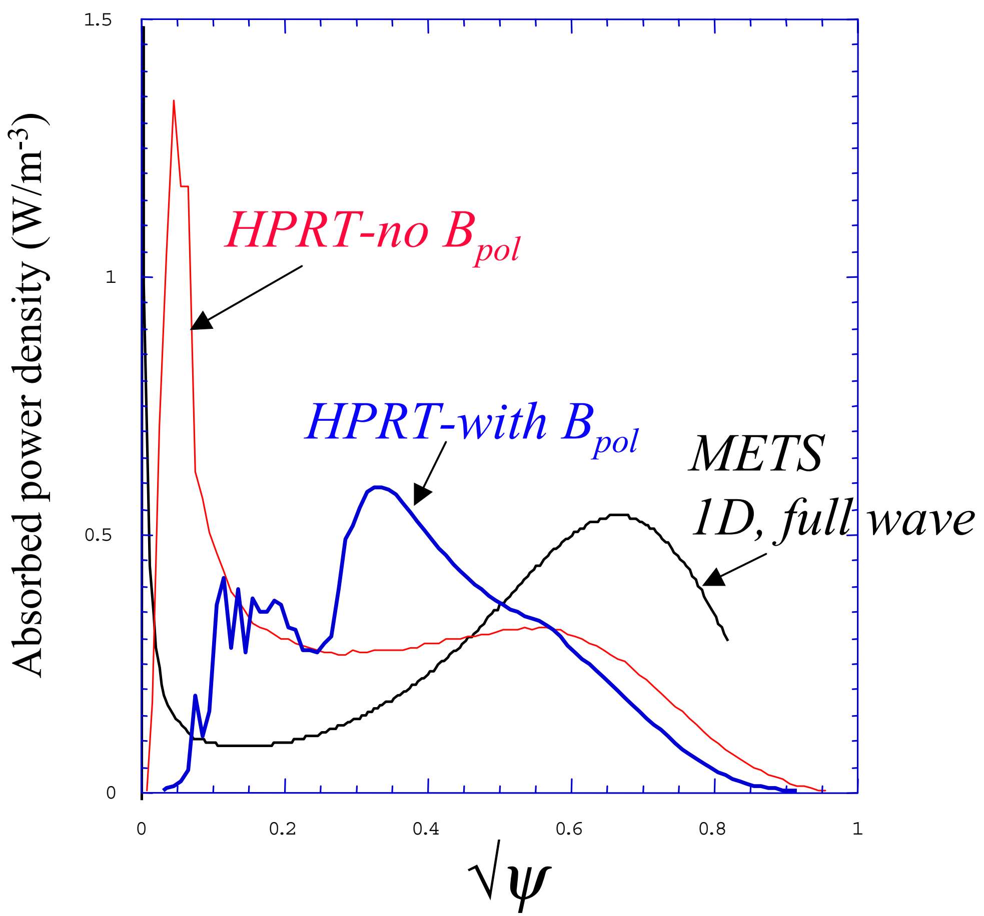
- Effectiveness of HHFW current drive - FY '02
- Startup and sustainment ~ 1s pulse - FY '03
- *EBW System (end FY '02)*
- *EBW System FDR (end FY '03)*
- New capabilities
  - high temperature bake-out
  - improved shape control for RF coupling
  - 6 MW power at 7 m^{-1} and longer pulses
  - edge reciprocating probe
  - scanning NPA
  - 2 channel MSE shake down (March '02)
- Draft run time allocation - 12 days

Current drive will be focus of near term HHFW research

- Optimizing pulse length and power coupling
- Heating studies
  - deposition profile
  - coupling to CHI plasmas
- Current drive studies
  - Long-pulse RF driven H-modes
  - EBW plan
- RF interaction with NBI

Large code benchmarking effort crucial to modeling of HHFW deposition profile

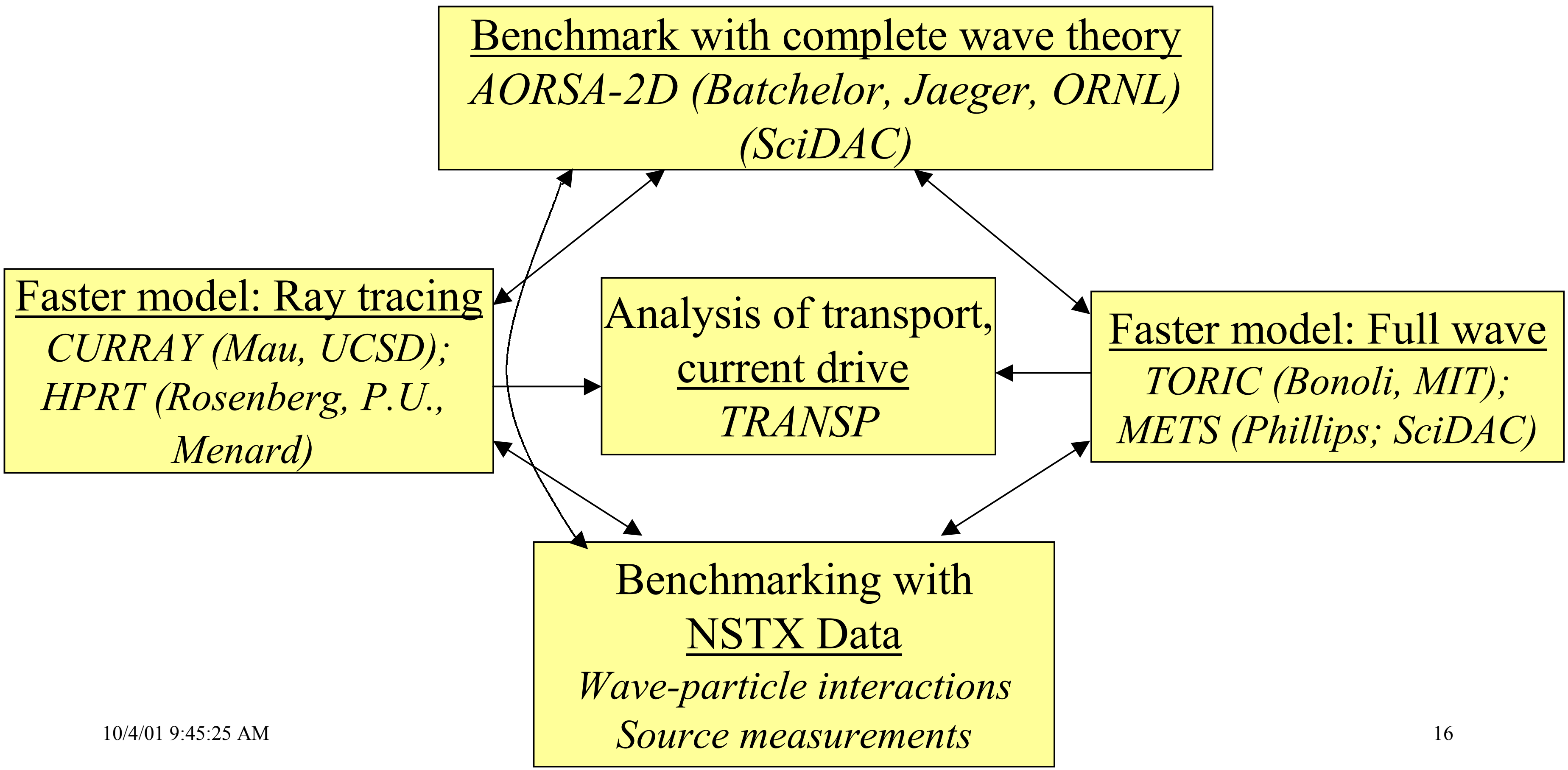
- Ray tracing and full-wave codes show significant heating profile differences
- 2-D effects shift profile in ray-tracing code
- Benchmarking of codes part of SciDAC effort
  - more NSTX data required



Rosenberg, Menard, Phillips

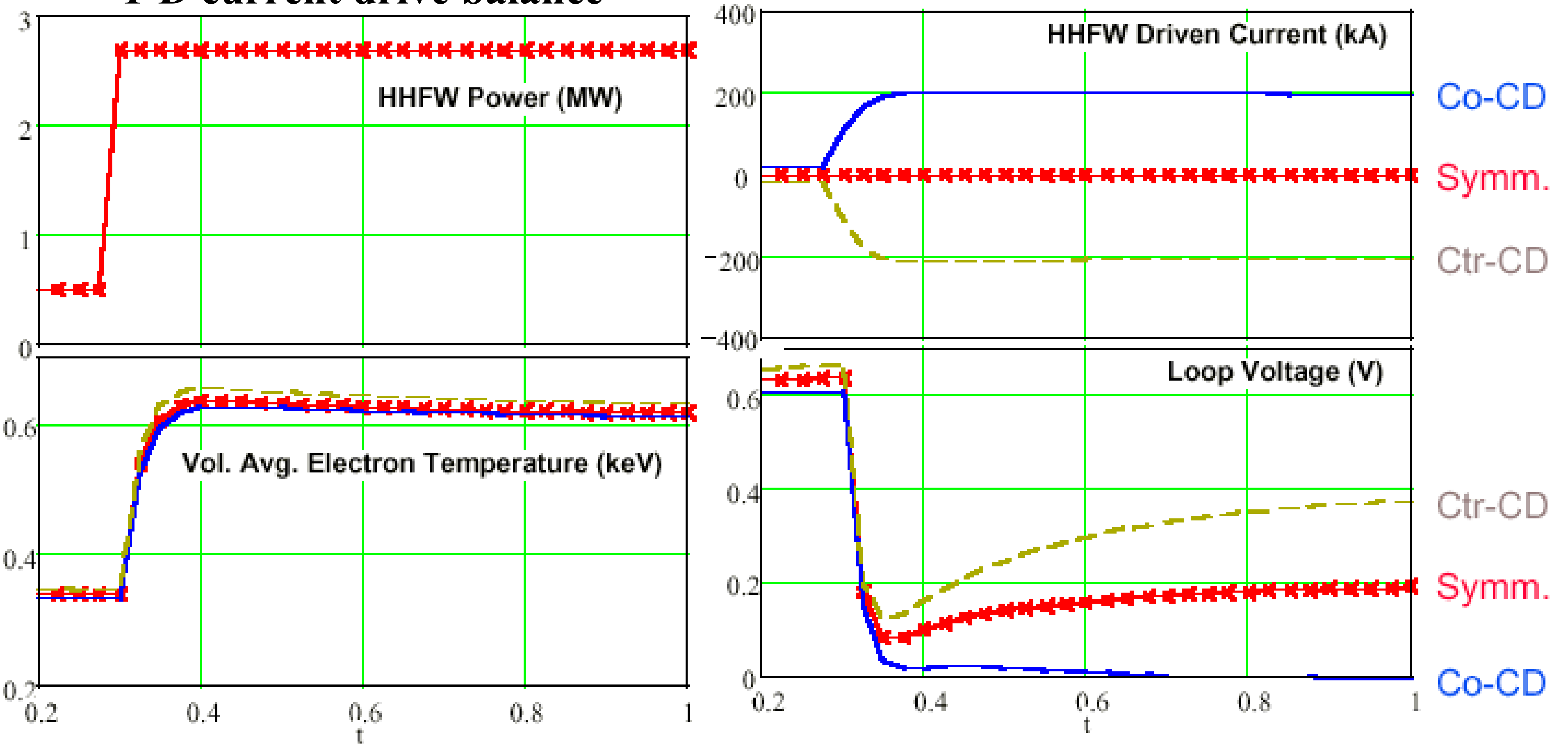
Benchmarking with advanced theory and data key to understanding HHFW

Approach: *benchmark and test* faster models against most sophisticated theory and measurements



Simulation shows loop voltage changes difficult to measure under ‘normal conditions’

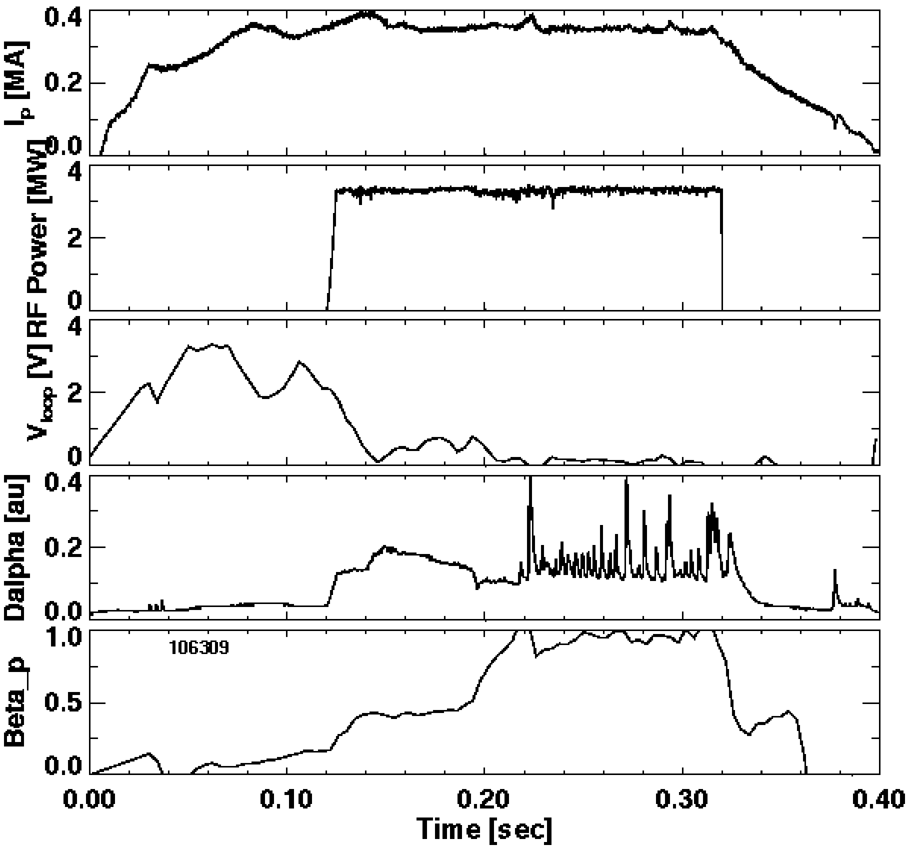
1-D current drive balance



Ryan, Swain, Wilson

HHFW driven H-modes may provide a suitable current drive target

- High β_p, low loop voltage ($\epsilon\beta_p \sim 0.7$)
- ELMy up to 120ms length
- Was limited by TF flattop - TF fix will allow extension
  - Good target for ~ 1s startup and sustainment milestone also



LeBlanc, Wilson

EBW decisions will be made based on data from NSTX and other machines

- Theoretical projections
  - Efficient current drive (0.1 A/W at 3 x 10^{19}, 50% conversion)
  - Localized heating, FWHM ~ 10 cm
  - Emission studies inverse problem of current drive (A. Ram)
  - Next step: realistic time-dependent simulations
- Part 1 - NSTX studies
  - Assess NTM role in limiting beta over broader range of conditions
  - Continue EBW emission studies on NSTX
  - New horn w/local limiter for EBW low power coupling tests (ORNL)
- Part 2 - take advantage of other machine results
  - MAST, Pegasus, and CDX-U EBW research
  - ECCD stabilization of NTM in DIII-D, ASDEX-Upgrade

LeBlanc, Wilson

Experiments required to understand and improve RF and NBI compatibility

- NPA data shows fast ion tail being pulled out by HHFW

- Simple ray-tracing calculations using NSTX profiles predict high fast ion absorption in certain low β discharges

- Effect previously shown to diminish with increasing β (Menard, PAC-7)
  - increase β
  - decrease relative beam ion density (subject of student thesis)

Rosenberg, Menard, Medley

MHD topical area has substantial near term milestones and decision points

- <u>MHD mode identification at high β - FY '02</u>
- <u>Simultaneous high β and τ - FY '03</u>

- *RWM Active stabilization (end FY '02)*
- *RWM Active stabilization system FDR (end FY '03)*
- *EBW System (end FY '02)*
- *NTM scientific assessment - input to EBW plan (mid FY '03)*
- *EBW System FDR (end FY '03)*

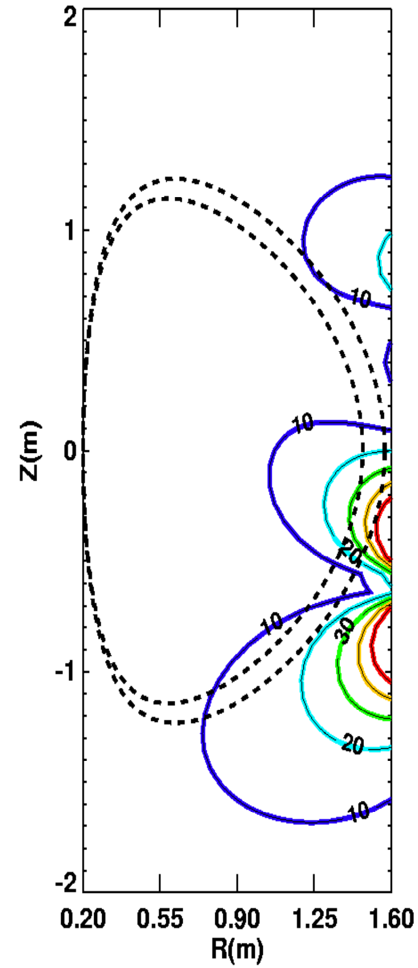
MHD research will focus on identification of β limits and modes in a range of conditions

- New capabilities
  - PF5 error field reduction
  - Inner wall gas-puffing → longer pulse H-modes?
  - Additional SXR for slow and non-rotating modes
  - 70 channel CHERs, 20 channel Thomson
  - Major upgrade to magnetic and fast sensors
  - Between-shot analysis of locked-mode data
- Draft run time allocation - 9 days
- Research topics
  - Scaling of β limit with equilibrium parameters
    - wider range of δ , κ
    - dependence on pressure and current profile shape
  - Locked modes and error fields
  - Resistive wall modes
  - Neoclassical tearing mode avoidance

Error field will be reduced in upcoming run

- Re-align PF5 coil centroid
  - Reduce 30-50G edge error
  - Minimize n=1 component

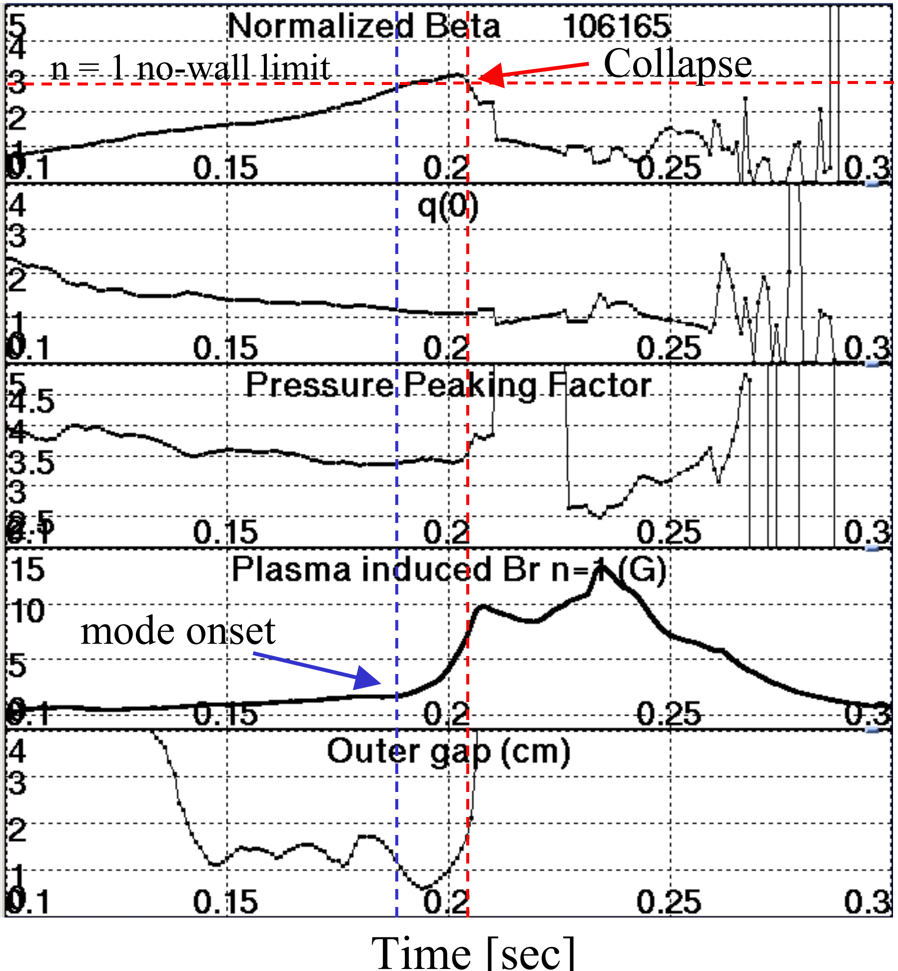
- Measure error-field early in next run
  - Scan density and rotation change island size and compare with pre-fix



Menard, Fredrickson

Resistive wall mode research to focus on confirmation of mode characteristics

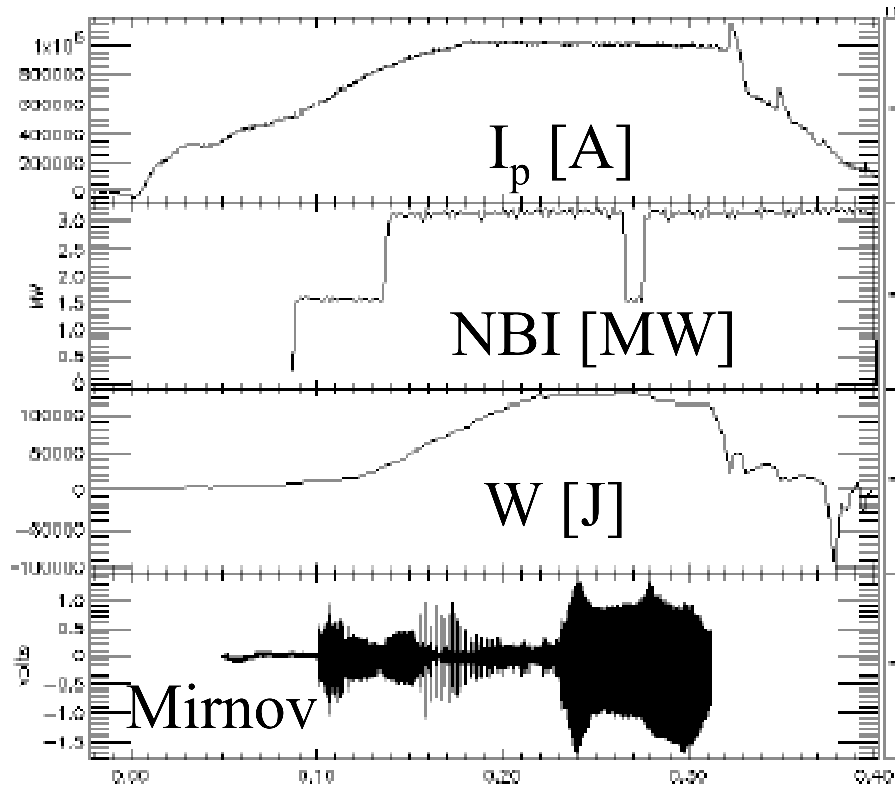
- Measure dependence of outer-wall gap on mode growth time
- Determine characteristics of mode coupling to passive stabilizers in ST geometry
- Conduct our part of DIII-D & NSTX similarity expt. - RWM dependence on R/a



Sabbagh

Near Term Neoclassical Tearing Mode Studies to focus on avoidance techniques

- Data in hand to show limit on $\beta_p \sim 0.4$-0.5 at high I_p
- Will study p(r) and q(ψ) dependence
- Will also study effect of reduced error fields and high temp. bake
  - avoidance possible?
- Need n_e, T_e, T_i, v_ϕ, and q(r) with better spatial and time resolution for model comparison -> FY ‘03



Gates, Fredrickson

Coaxial Helicity Injection overview

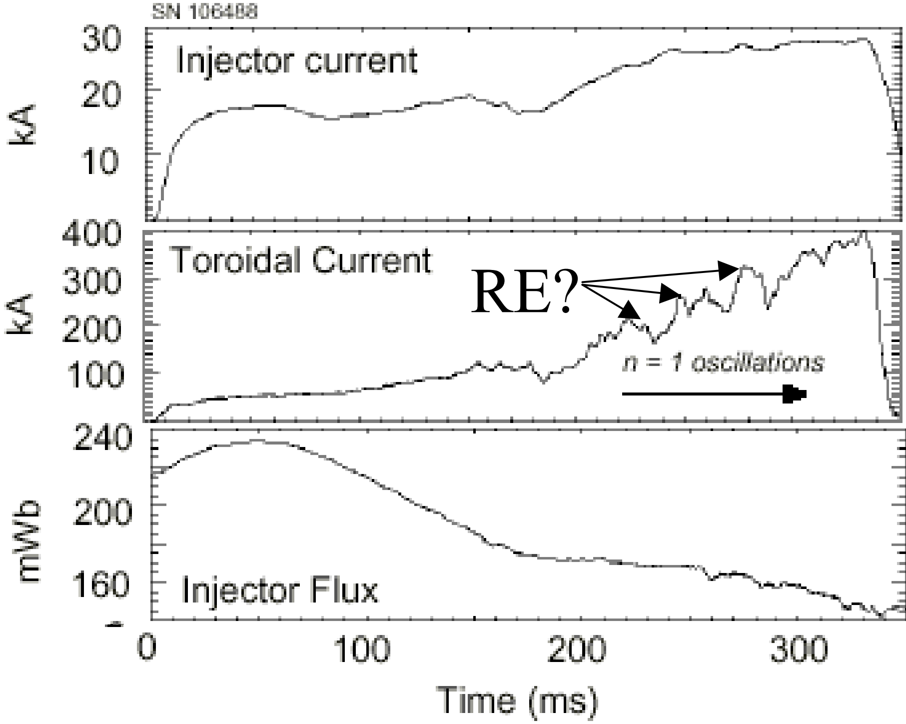
- 500 kA, feedback control, add heating to CHI - FY '02
- Startup and sustainment ~ 1s pulse - FY '03
- New capabilities
  - high temperature bake
  - EM noise pickup reduction
  - new feedback control algorithm
  - insulator upgrade: 8 cm long, high-field side - end FY '02
  - edge reciprocating probe with dynamo tips ~ end FY '02
- Draft run time allocation - 6 days
- Research topics
  - Flux closure studies
  - Feedback control
  - Adding CHI to Ohmic
  - Adding induction, HHFW to CHI

Flux closure assessment requires EFIT upgrades and more data

- EFIT upgrades underway
  - private-flux region current
  - SOL current
- Need Thomson data close to core
- Flux closure may be stimulated with new capabilities
  - most likely at high I_{tor}
  - highest I_{tor} requires good wall conditions to avoid absorber arcs (sets limit on injector flux ramp-down rate)
    - high temp. bake will help
    - increasing TF should help increase I_{tor}

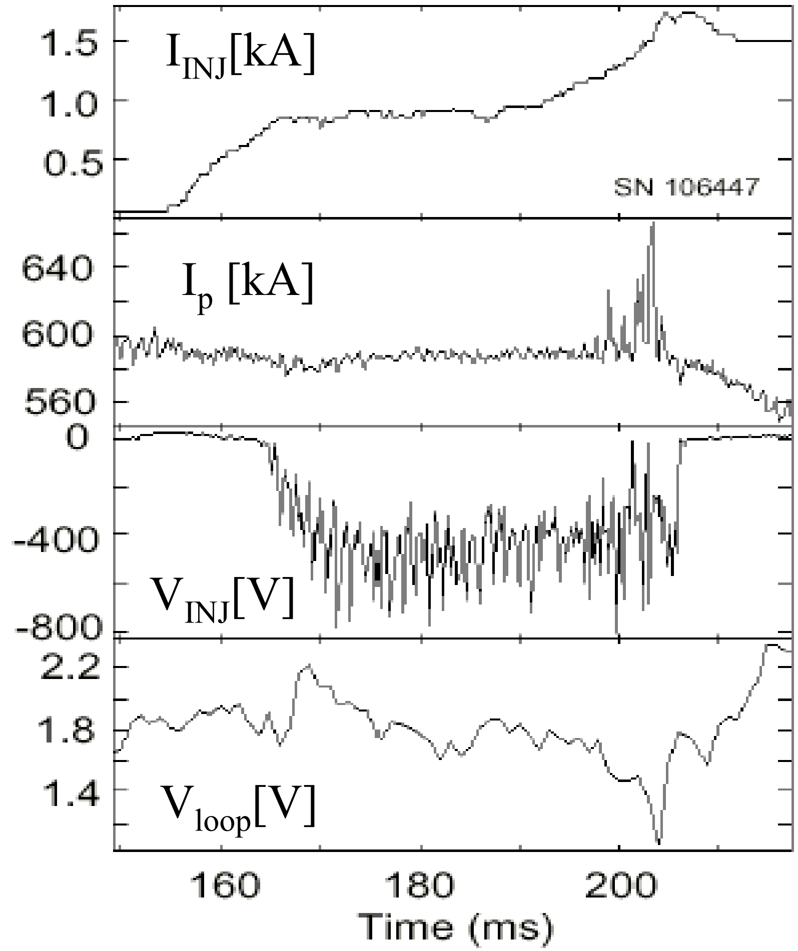
Begin testing feedback control of CHI discharges

- Start feedback control tests via CHI voltage and PF coil control
  - I_p control
  - R,Z position control
- Vary TF to control n=1 amplitude (and reconnection events - RE)
  - n=1 may be needed for flux closure RE's
  - smaller n=1 -> smaller RE?



Adding CHI to ohmic discharges will use hardware upgrades

- Initial expts. saw I_p drop
  - Reduced this I_p drop by improving absorber field null and increasing upper δ
- Improved grounding for noise reduction in progress
  - EFIT analysis limited by noise
- Improved control of lower dome gas injection
- Need improved ohmic plasma target shape?



Mueller

Adding ohmic to CHI discharges requires absorber modification

- Need high current plasmas for target
  - arc-free discharges at high I_{tor} are irreproducible
- Adding V_{loop} > 2 V appears to trigger absorber arc
  - absorber null affected by OH fringing field
  - new insulator available in '03
    - extended to 8cm length from 1.5cm
    - located on HFS, similar to HIT-II
- Initial HHFW coupling studies can be done without insulator change

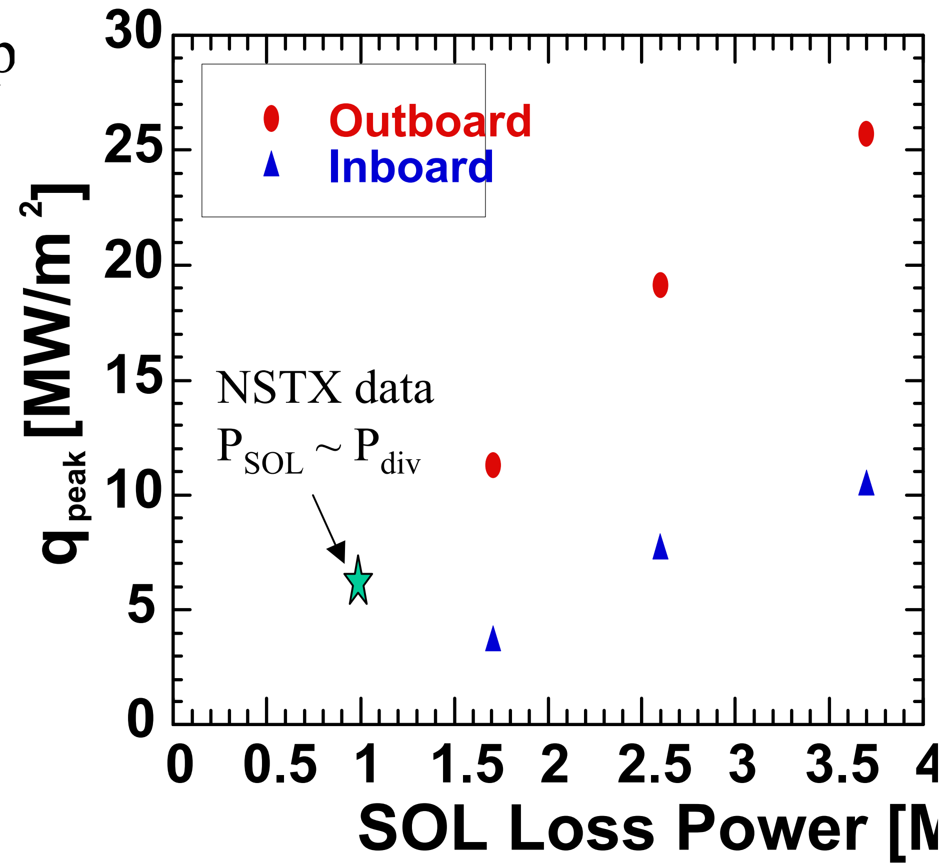
Boundary Physics overview

- Heat flux scaling - FY '03
- *Advanced PFC and density control - end FY'03*

- New capabilities
  - edge reciprocating probe, 2nd IR camera, divertor bolometry
  - 70 channel CHERs, 20 channel Thomson
  - high temperature bake, plasma boronization
  - inner wall gas fueling, density feedback
- Draft run time allocation - 6 days
- Research topics
  - Heat flux scaling
  - SOL transport and core fueling studies
  - Wall Conditioning Studies

Heat Flux Scaling experiments will focus on density and source dependence, and power accountability

- Conduct experiments to help find ‘missing power’
  - 2nd IR camera
  - new divertor bolometer
- Determine heat flux in H-mode discharges and lower density L-modes
- Measure effect of NBI vs RF heating on heat flux

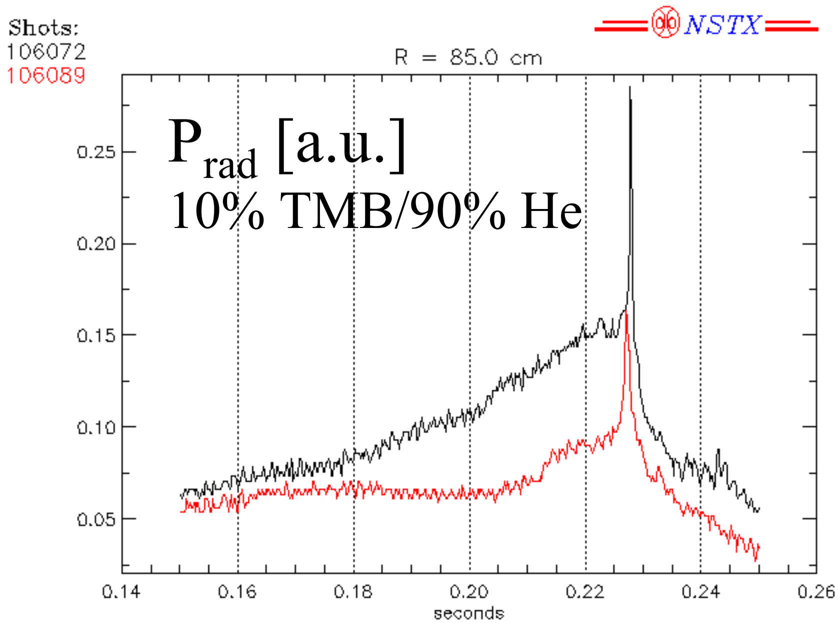


Edge/SOL transport and core fueling studies will contribute to long-pulse PFC/density control decision point

- Divertor fluctuations with new camera
  - complements main chamber camera
- SOL transport with new edge reciprocating probe
  - role of fast, convective transport
  - main chamber recycling vs. divertor recycling
- Fueling efficiency of new inner wall gas injection system will be compared with low-field fueling and NBI
  - IW fueling improved H-mode performance on MAST
- Data-constrained edge plasma and neutrals modeling will be used to assess poloidal distribution of core fueling

Impact of high temperature bakeout and TMB fueling on wall conditions will be measured

- High-temperature bakeout should allow rapid vent recovery
  - fiducial discharges
- Fueling with pure Tri-methyl borane (TMB) will be tested
  - replenish boron coating in 'real time'
  - improve performance?



NSTX Physics Analysis Plans and Tools (FY01-03)

	FY01	FY02	FY03

Core Transport

Characterize Global Confinement

EFIT/TRANSP →

Resolve Power Balance Issues/Assess Local Transport Properties

TRANSP/TSC →

Determine Physics Basis for Transport

Linear GS2/FULL →

Non-linear GS2, NCLASS upgrade →

Neo theory w/ FLR →

Gyro-kinetic treatment →

Develop anomalous htg models →

Predictive Transport Modeling (Physics Studies/Scenario Development)

TRANSP, NTCC, TSC, BALDUR →

MHD

Study Ideal Stability Properties

PEST-I, II/DCON →

Study Resistive/Neoclassical MHD

PEST-III, M3D, NIMROD(?) →

Implement full 3D equil/stability →

Characterize RWM Response/Asses Req. for Active Mode Control

VALEN (3D) →

Fast Particles

Implement Full Orbit Codes

EIGOL, Glasser code → LOCUST (w/atomic physics) →

Rapid Determination of Fast Ion Loss Boundaries

Egedal code →

Treat Non-Adiabatic Behavior of Fast Ions

Yavorskij (theory) →

Fast Particle Driven Instabilities

CAEs linear → CAEs Non-linear, TAEs, EPMs →

NSTX Physics Analysis Plans and Tools (FY01-03)

	FY01	FY02	FY03

RF/CHI

Determine HHFW Heating/Current Drive Profiles

Ray tracing (CURRAY, HPRT) →

Integrate into TRANSP →

Full wave (TORIC, AORSA)

Study Effect of HHFW on Electron and Fast Ion Distributions

Develop self-consistent model →

EBW Current Drive

Ram (theory) →

Determine Flux Closure During CHI Startup

MFIT/ TSC → EFIT, Develop theory/model for underlying physics →

Boundary and Divertor

Determine Particle Transport Properties Inside Plasma

DEGAS →

Characterize Particle and Power Flux in SOL

UEDGE/DEGAS →

Understand Edge Fluctuation Properties

BAL (linear), BOUT (non-linear) →

Draft run time allocations for FY '02

	FY 2001(actual)		FY 2002 (draft)	
HHFW heating & CD	16 days	(24%)	12 days	(20%)
Transport	11 days	(17%)	9 days	(15%)
MHD	14 days	(21%)	9 days	(15%)
CHI	5 days	(8%)	6 days	(10%)
Boundary (heat flux)	1 day	(2%)	6 days	(10%)
Enabling/cross-cutting	18.5 days	(28%)	6 days	(10%)
Scientific Contingency	{13 days	(20%)}	12 days	(20%)

NSTX has an exciting set of experiments to execute this year!

- Plan driven by milestones and decision points
- Significant new facility and diagnostic capability
- Anticipate large number of quality experimental proposals
- But... hard pressed for run time