Physics Analysis for NSTX Research

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Physics Analysis Plans

NSTX

- Goal is to develop understanding of present results
  - Develop science basis for toroidal physics at low R/a
  - Develop strategies to improve performance

- Status and plans for analysis tasks and tool development required to achieve NSTX research objectives
  - Focus on near-term (FY01-02)

- Physics plans fall into the areas of
  - MHD
  - Turbulence and Transport
  - Energetic Particles
  - HHFW
  - CHI
  - Boundary Physics

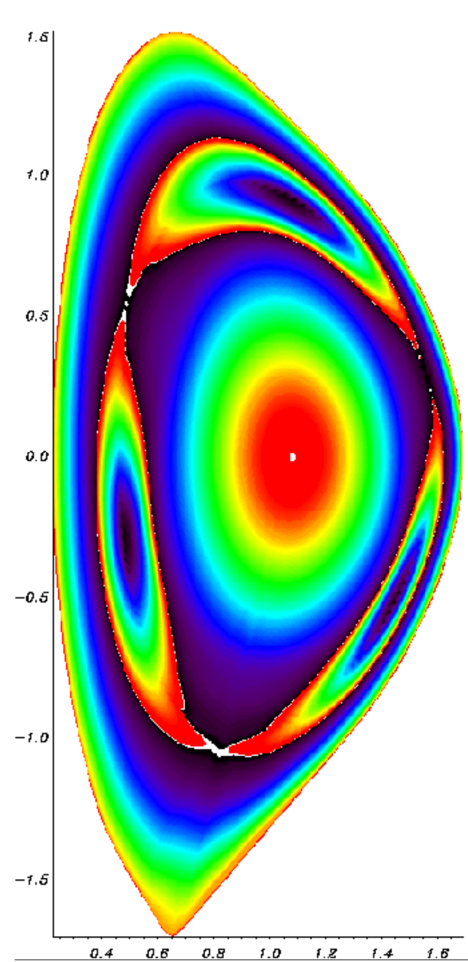
MHD

- NSTX discharges exhibit a range of MHD phenomena
- Study these phenomena within framework of resistive and ideal MHD theory
  - EFIT reconstructions/TRANSP/TSC bases for stability studies (GA, Columbia, PPPL)
    - M3D, PEST III, NIMROD for resistive stability (PPPL, LANL)
    - Links to DCON, PEST, GATO established (LANL, Columbia, PPPL, GA)
  - More complete diagnostic set
    - Toroidal Mirnov coil array
    - Locked mode coils (FY01)
    - Kinetic profiles ($T_e(r,t)$, $n_e(r,t)$, $T_i(r,t)$, $v\varphi(r,t)$,…)

Neoclassical Tearing Mode Analysis

MHD which may be linked to NTMs observed to limit discharge performance (β_{pol}~0.3 to 0.5)

Low-β NSTX equilibrium showing a 3/2 tearing mode

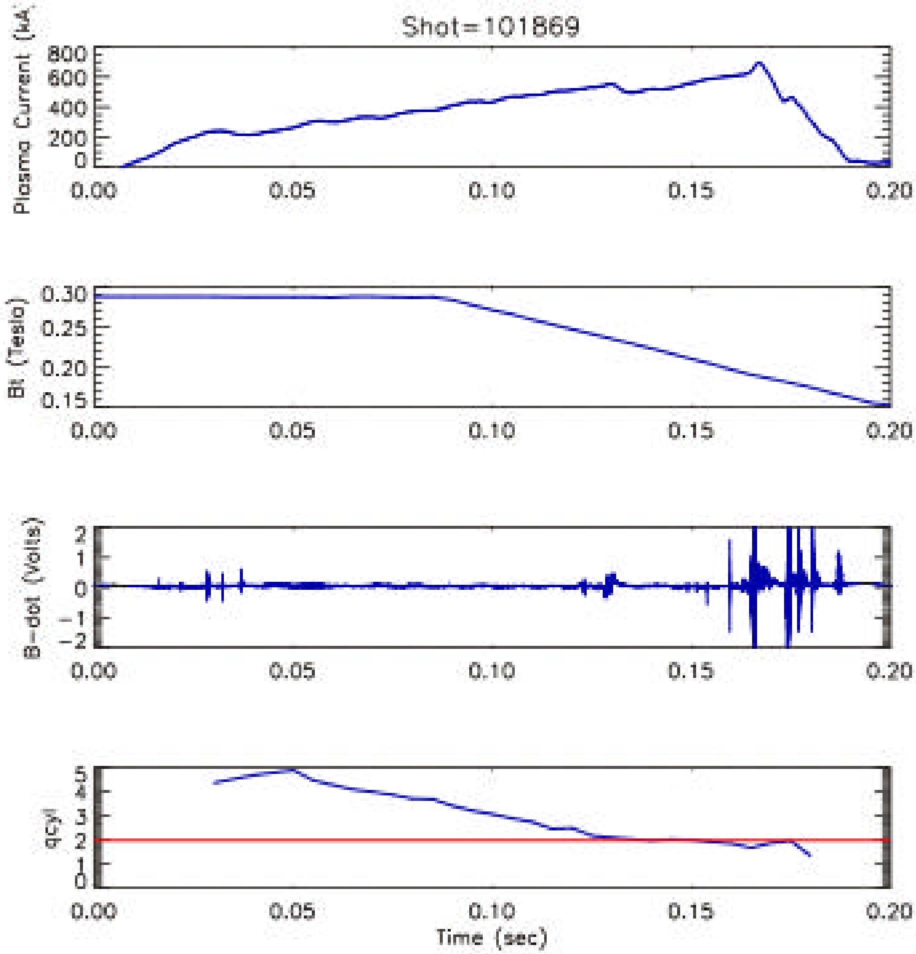


A. Rosenberg (grad student)

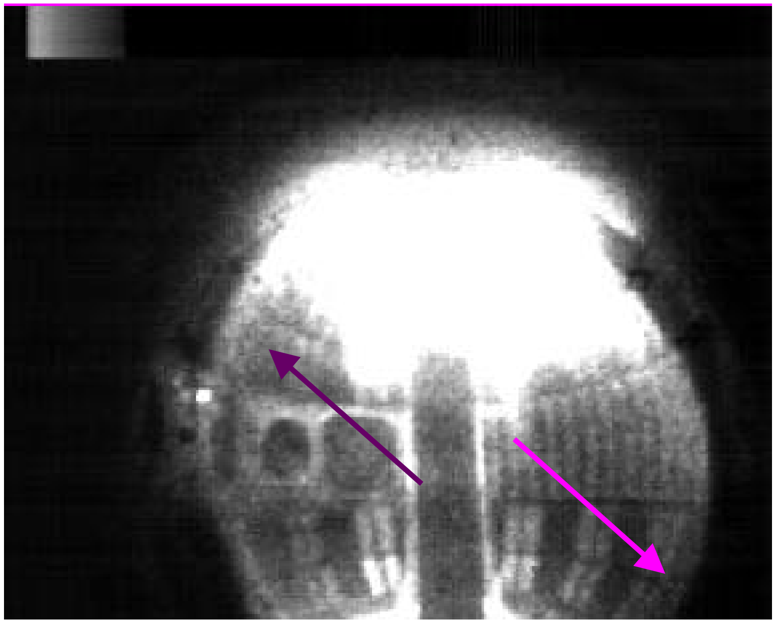
- Use PEST-III to calculate Δ´, and eigen-function
- Use NIMROD subroutines to calculate neoclassical terms
- Combine and plot results in IDL
- Has led to numerous improvements in PEST-III (high-β, low-A resolution issues)

q-Limit Manifest as Kink Induced Discharge Termination

NSTX



t=168 msec



XP approved to study current driven kink modes (FY01)

PEST, GATO, DCON for ideal analysis

MHD (cont'd)

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- Determine passive plate electrical configuration for optimal high-β stability and plasma control (PPPL, Columbia, GA) [FY02]

  ---> MHD code benchmarking

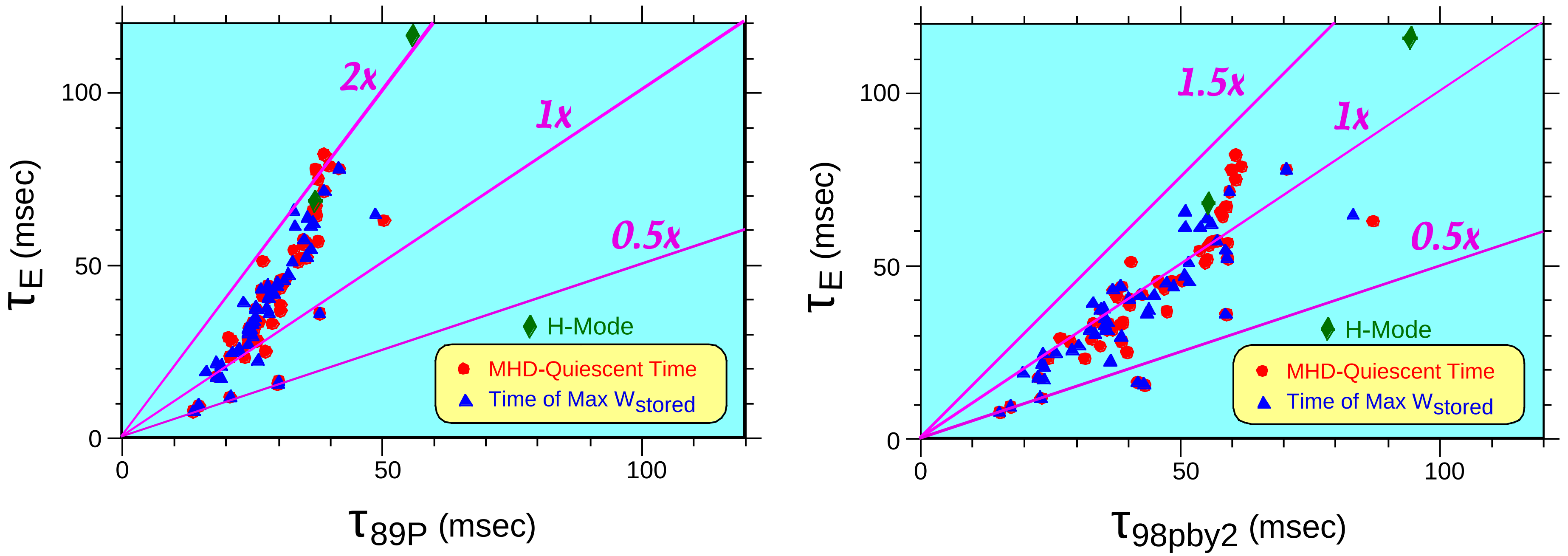
  - Benchmark axisymmetric PEST, GATO, DCON for reference NSTX equilibrium (β_t=25%)
    - Marginal β_t comparable
    - Differences in B_{norm} (coordinate system dependent)
  - B_{norm} input to VALEN for 3D calculation; study of various electrical configurations
  - First step towards assessing need for and designing active mode control system (decision point end of FY03)

Transport and Turbulence

NSTX

- Global τ_E studies are using results from EFIT magnetic reconstructions
  - EFIT run routinely between shots; results available on tree
  - Important to make code (not just results) available to group
- Local transport studies will be performed using TRANSP
  - Local analysis started
  - "Between-and-Among-Shots" TRANSP (BEAST) in preparation (Spring-Summer '01)
- Validating results among EFIT, diamagnetic loop, kinetic profiles (MPTS)
  - Kinetics vs magnetics stored energy comparisons
  - Self-consistency of kinetic profiles

Energy Confinement Enhanced Over Both L- and H-mode Predictions

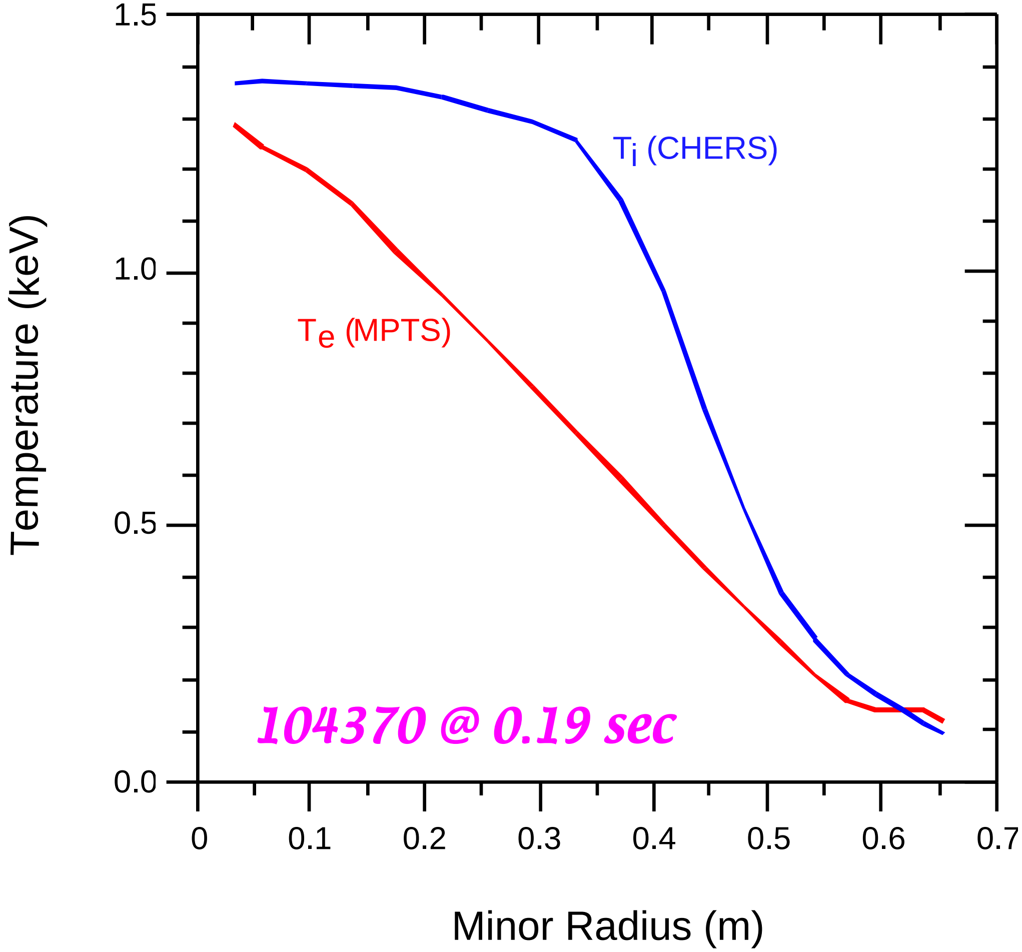


Investigate neoclassical and turbulence-driven confinement levels with NCLASS, GTC, FULL, GS2 (FY01-02)

- Role of flow shear

Local Measurements Available for Power Balance Studies

NSTX



Kinetics/Magnetics discrepancy exists

W_{EFIT}=117 kJ

$W_{Kinetics}$=83 kJ

Local Power Balance Studies Have Started

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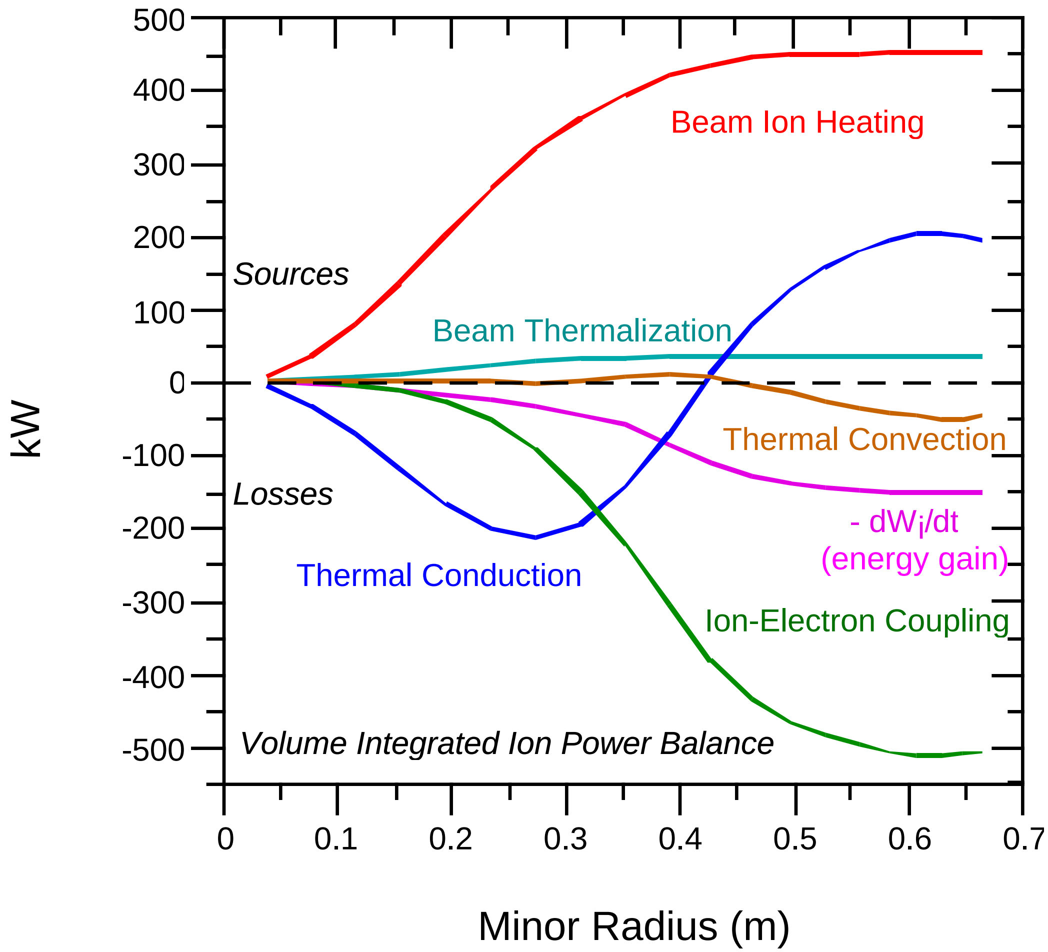

Large T_i-T_e in outer region can lead to negative thermal conduction

Ion-electron coupling would limit T_i to lower values in outer region

Role of MHD?

Local Measurements Available for Power Balance Studies

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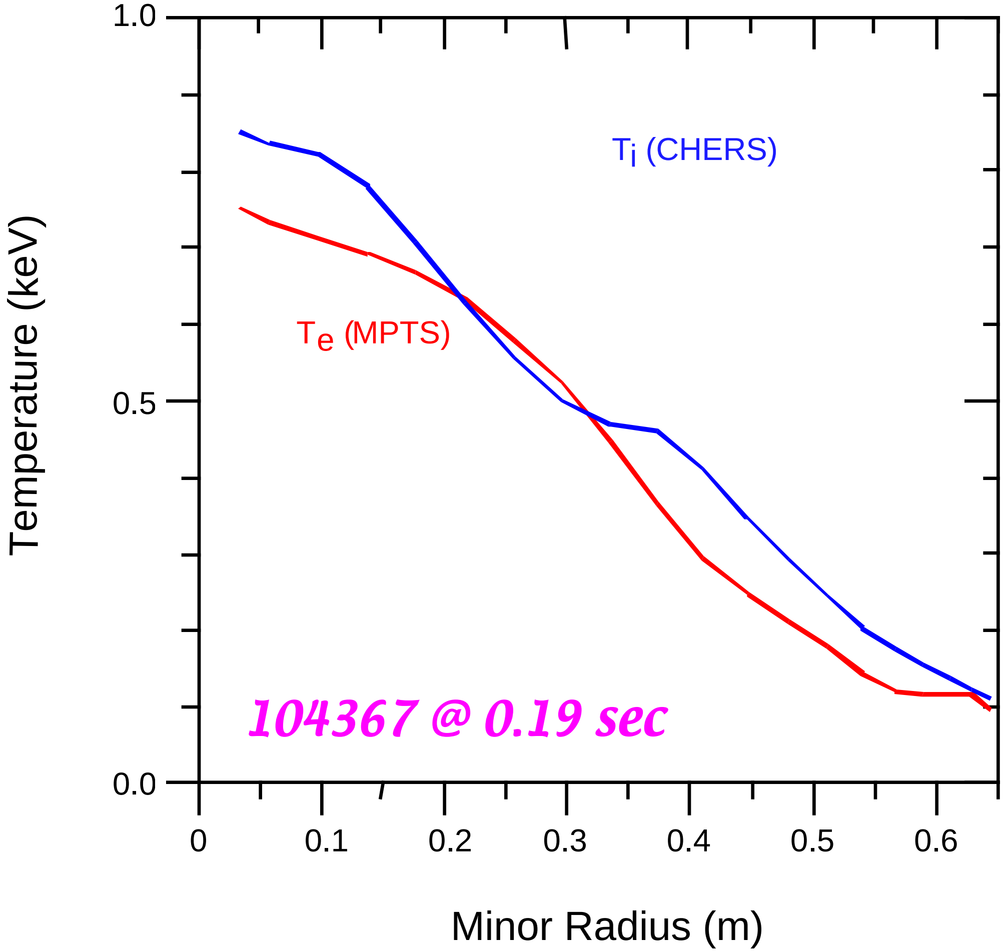

Kinetics/Magnetics discrepancy exists

W_{EFIT}=56.5 kJ
$W_{Kinetics}$=40 kJ

Ion-electron coupling issue a non-factor when T_i~T_e

Local Power Balance Studies Have Started

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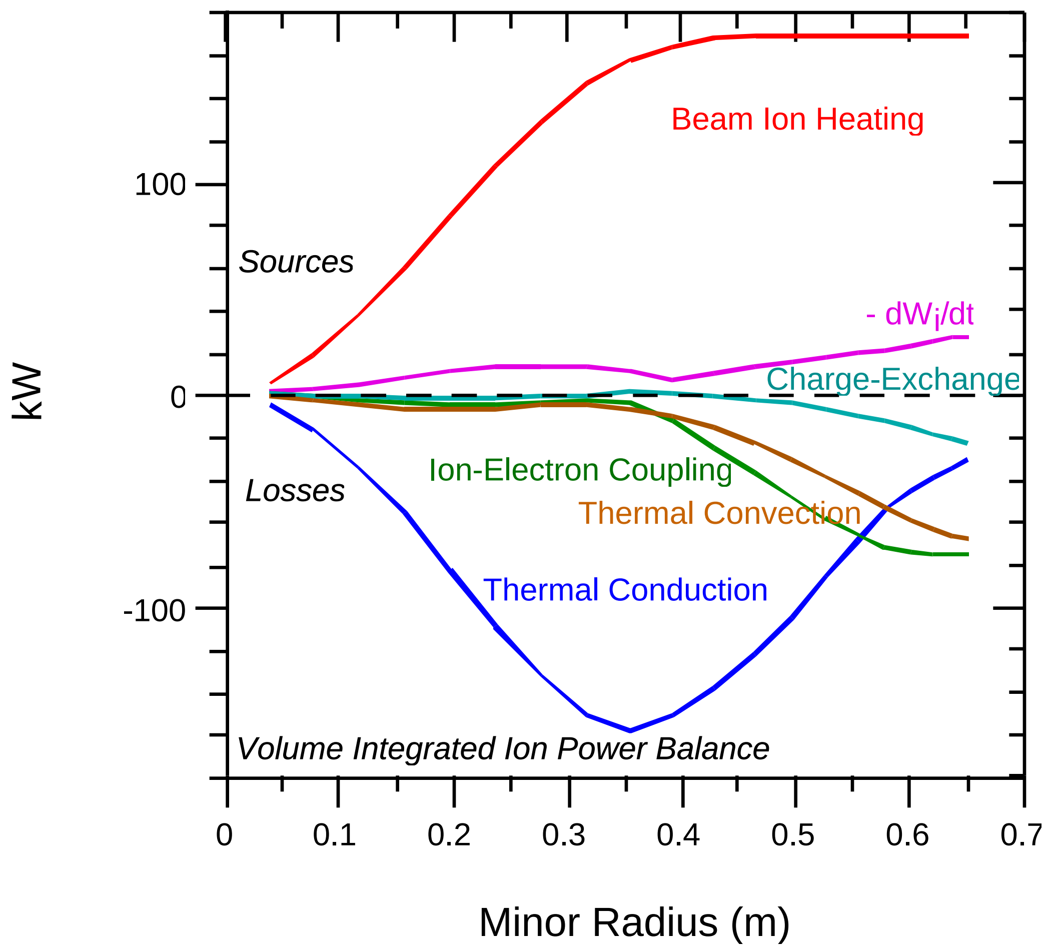

Ion power balance is "well-behaved"

Most of power flow is through electron channel

Transport and Turbulence (cont'd)

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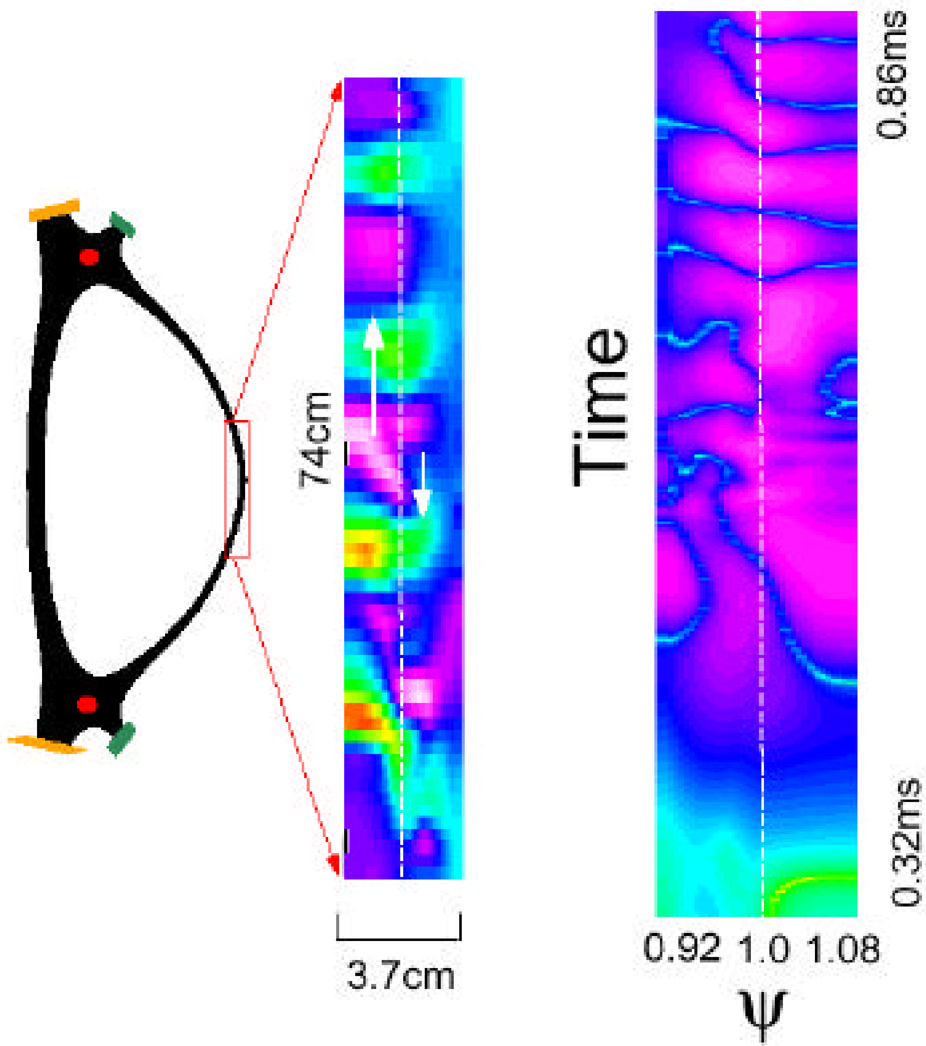
- Use observations of edge turbulence to characterize edge stability (LANL, PPPL)
  - Important for H-mode studies, wave coupling, SOL characteristics, CHI current penetration
  - Diagnostic tools
    - Dedicated gas puff/fast camera for edge turbulence studies
    - Edge reciprocating probe (UCSD)
    - Edge reflectometer (UCLA)
  - Expected turbulence patterns
    - Edge turbulence codes (BOUT - Xu, LLNL, BAL - Myra, Lodestar)
  - Couple testing of turbulence predictions directly to experimental results
    - Configuration scans
    - TF/q scan

Fluctuating density shows sheared poloidal flow and radial streamer structures across the separatrix



10-20 cm poloidal scalelengths consistent with observations

(Xu, LLNL)

Energetic Particles

NSTX

- Fast ion orbit losses being studied numerically (D. Darrow, PPPL; R. Akers, Culham Labs; A. Glasser, LANL)
  - Significant fast ion loss possible
  - Single particle orbit calculations gives most exact picture
    - TRANSP Monte-Carlo guiding center code with FLR corrections being upgraded (FY01)
  - J. Egedal (MIT) - determination of phase space loss cone boundaries may speed up loss estimates (FY01)

- High-frequency modes observed
  - In TAE ($v_{NBI} > v_{Alfven}$) frequency range and higher (≤1.5 MHz)
  - NOVA-K, non-linear codes for understanding modes
  - Fast Mirnovs, ion loss detectors important for assessing impact of modes

High-Frequency Modes

- Observed on Mirnov coils
- Mode frequency depends on plasma parameters

- Modes depend on fast ion distribution

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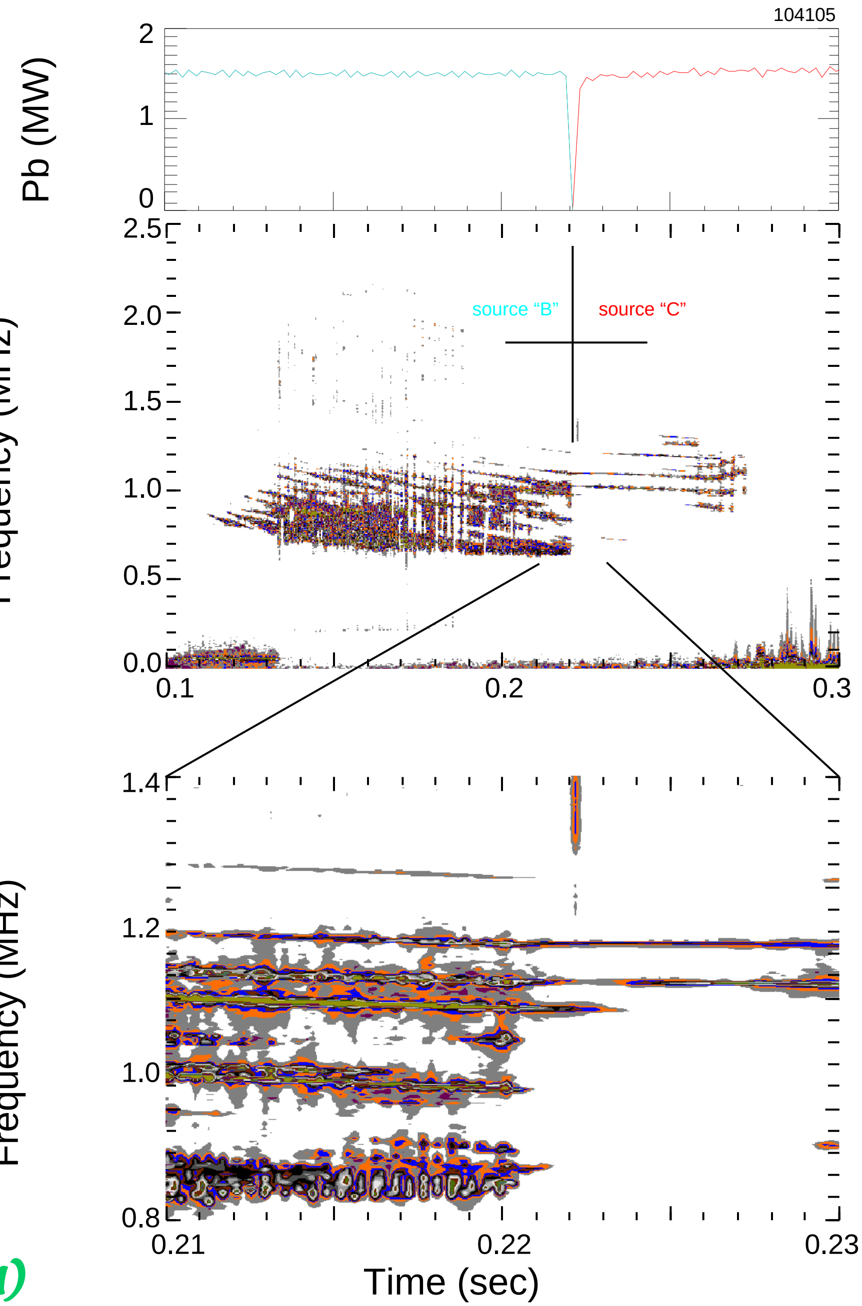
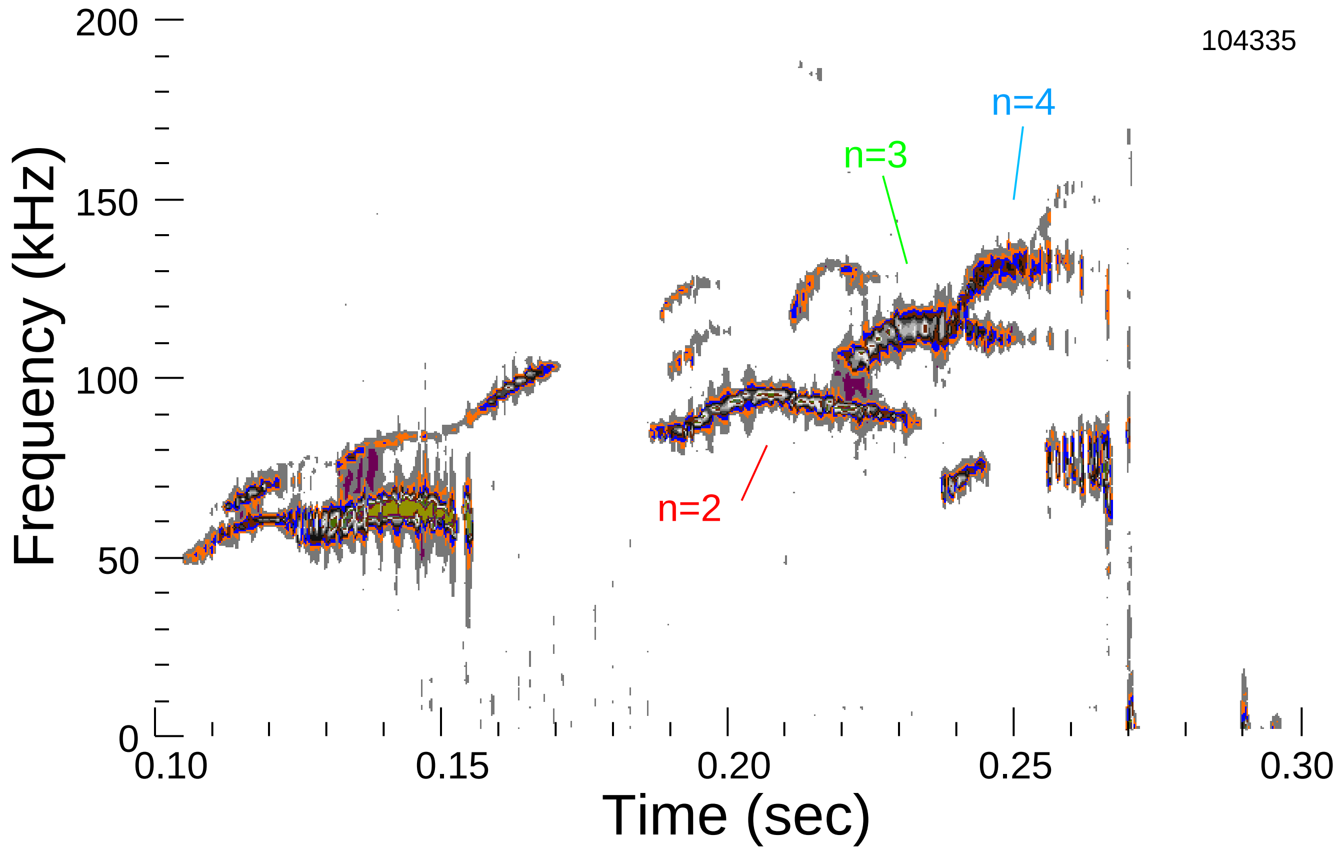
- Considering compressional Alfven waves as source
  - Free energy derived from fast ion phase space anisotropy



(E. Fredrickson, N. Gorelenkov, E. Belova)

Possible TAE or EPM's have also been seen at lower frequencies

- *Frequency range is lower than typical for HF modes.*
- *Qualitative behavior is also different*
- *n-range is as expected*



(E. Fredrickson, N. Gorelenkov)

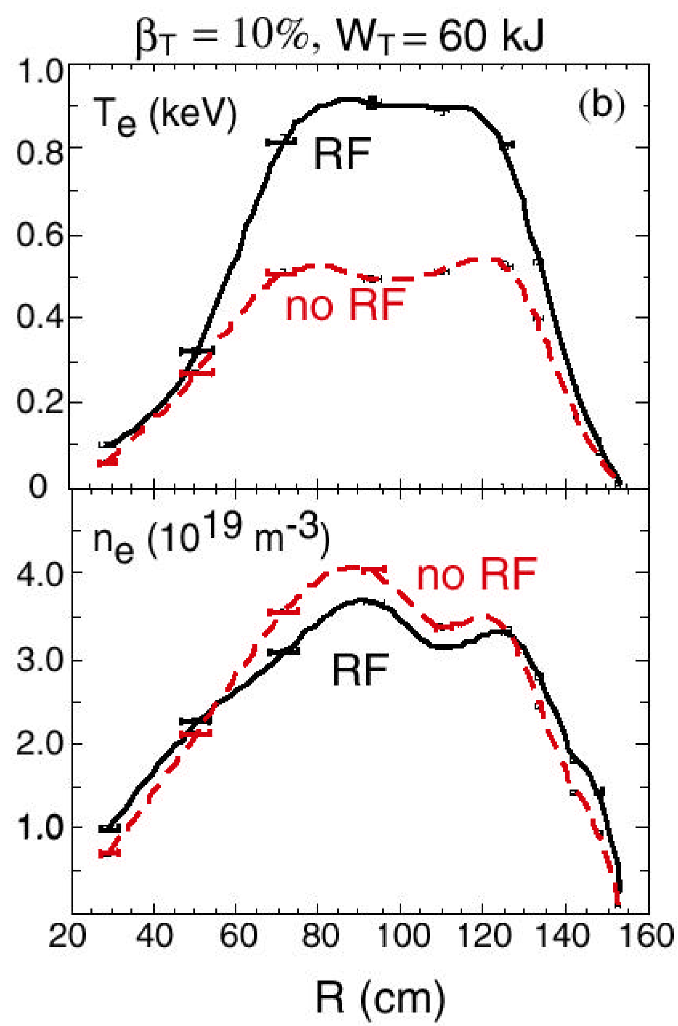
High Harmonic Fast Wave Heating

NSTX

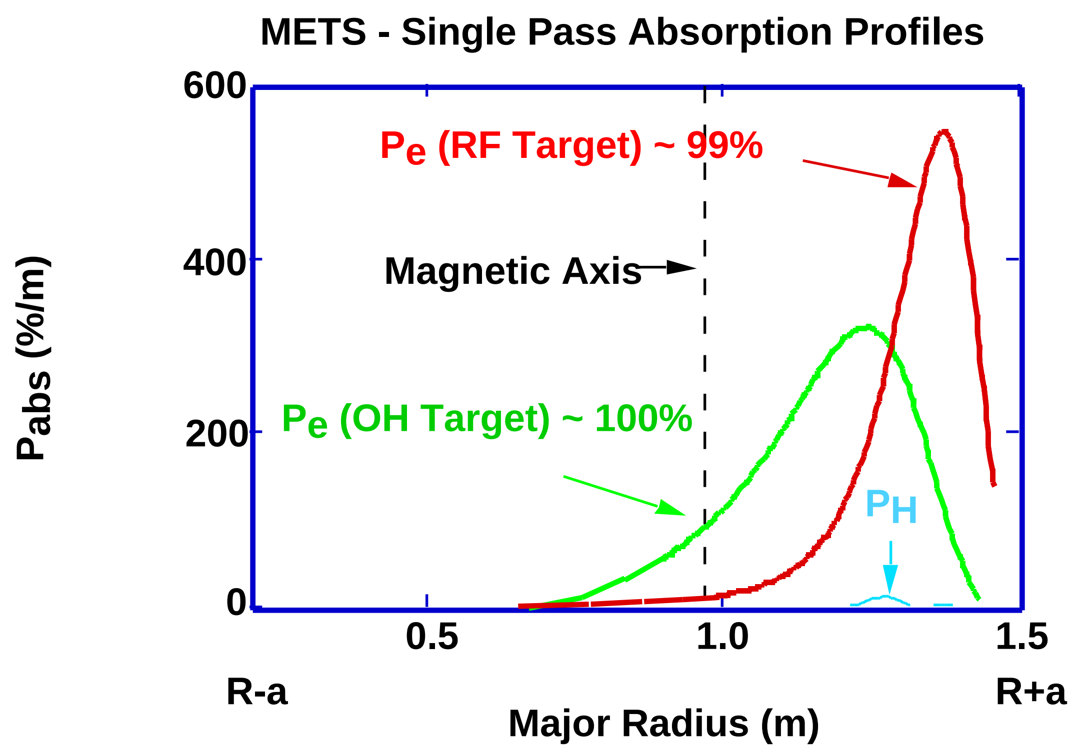
- Develop HHFW heating and current drive package for integration into TRANSP/TSC/EFIT
  - Heating profiles for confinement studies
  - Driven current profiles for equilibrium solutions and current drive accounting
  - CURRAY (Mau, UCSD), HPRT (Menard, PPPL) [Ray Tracing]; TORIC (Bonoli, MIT), AORSA (Batchelor, ORNL) [Full Wave]; METS (Phillips, PPPL) [1D]
  - Benchmark with measurements (FY01)

- Effect of energetic and thermal ions on RF absorption
  - Results from HPRT indicate
    - Ion damping non-negligible above $T_D(0) = 1$ keV
    - Damping on hot ions relatively small (≤5-10%)
  - Subject of PhD dissertation (A. Rosenberg)

Broad response to HHFW heating



Modeling indicates off-axis heating
(local transport issues to explore)



Similar results with CURRAY, TORIC

(J.R. Wilson, C.K. Phillips, T.K. Mau, P. Bonoli)

Co-axial Helicity Injection

Determine CHI equilbrium - open or closed flux surfaces

- Up to 260 kA of current driven non-inductively by CHI

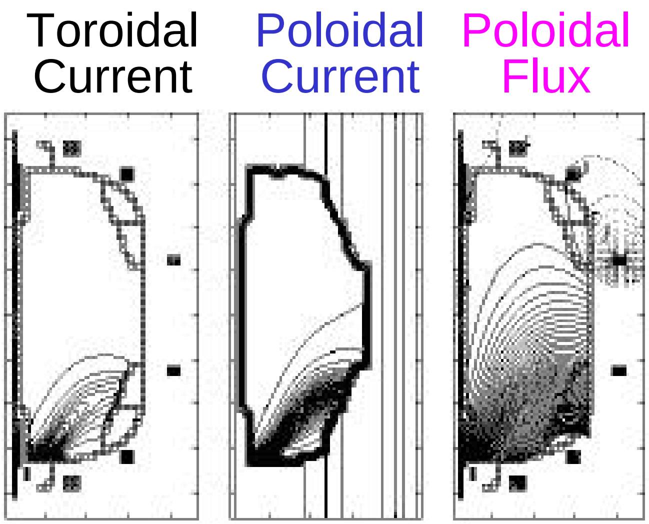
- Used EFIT, MFIT, TSC to determine configuration

- MFIT, TSC indicate flux surfaces remain open; modifications EFIT code underway (Lao, GA) to handle “open” equilibria (allow current in private flux region)

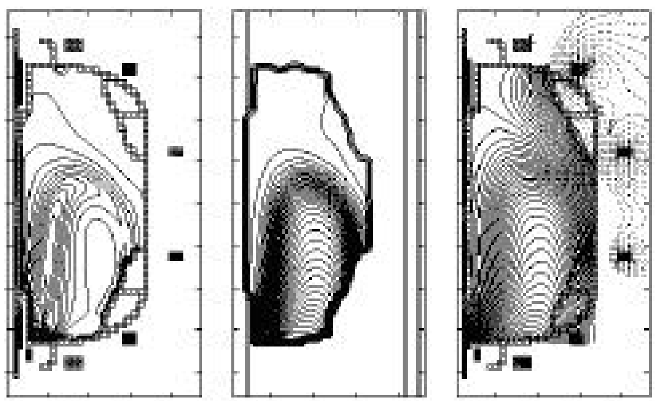
- MFIT (Schaffer, GA) - filament code using magnetics measurements as constraints for equilibrium fit

- TSC (Jardin, PPPL) - dynamic plasma evolution using actual coil currents, measured fluxes to solve for 2D equilibrium

TSC Results

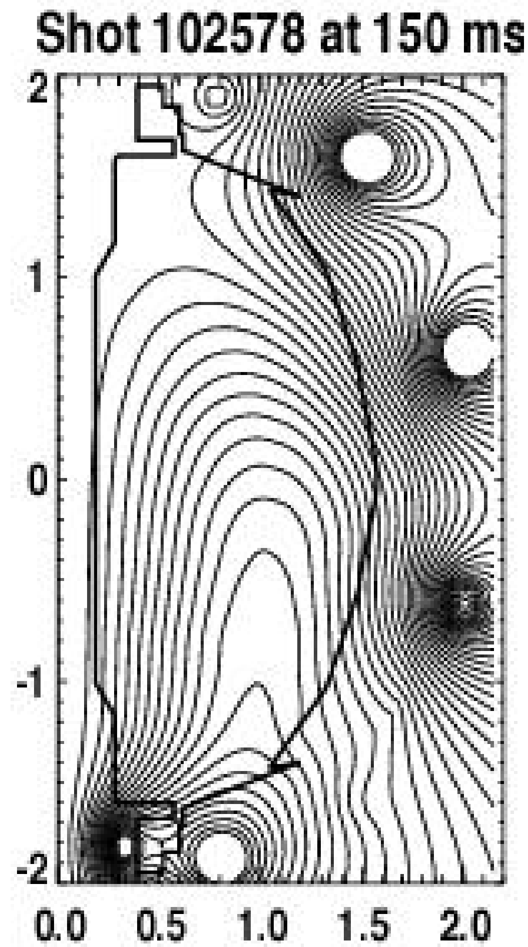


t = 15 ms, I_P = 37 kA
I_{INJ} = 20 kA



t = 150 ms, I_P = 202 kA
I_{INJ} = 20 kA

MFIT Results



Boundary Physics

NSTX

- Model neutral density distribution using DEGAS2
  - Fast camera for D_α emissivity (LANL/PPPL)
  - 1-D CCD camera (ORNL)
- Benchmark models of heat and particle flux in a range of NSTX configurations (IWL, DND, SND)
  - UEDGE/DEGAS2 (LLNL, PPPL)
  - Fast reciprocating probe (UCSD)
  - Divertor bolometer (TBD)
- Determine importance of “Resistive X-modes”
  - Resistive ballooning in the vicinity of an X-point
  - Subject of LODESTAR-LLNL collaboration (Myra, Xu)
  - Cross-cutting with Transport

Summary

NSTX

- Results to date provide broad basis for physics analysis in wide range of areas
  - More comprehensive analyses will be forthcoming as additional diagnostics are commissioned and as data are validated
  - Have identified diagnostics and analysis tools that give large leverage in addressing these issues

- An important general area of work is to develop scenarios for achieving our goals of high β and bootstrap fraction
  - Use recent NBI confinement, stability results as a basis for scenario development
  - Include HHFW deposition and physics-based transport models