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New Capabilities and Results for the National Spherical Torus Experiment

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Princeton Plasma Physics Laboratory
on behalf of the NSTX Research Team

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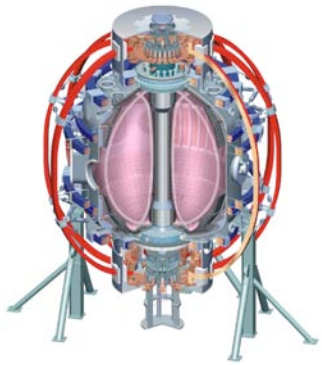

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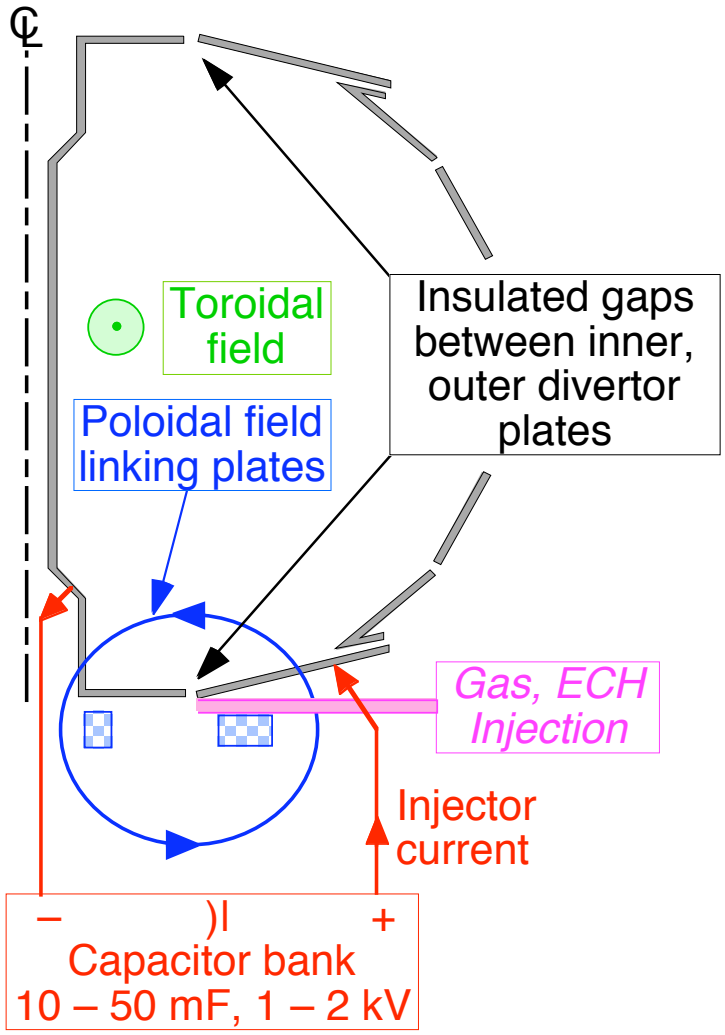
ASCR, Czech Rep
Univ Quebec

NSTX Just Completed 18 Weeks of Experiments Exploiting New Capabilities and Regimes

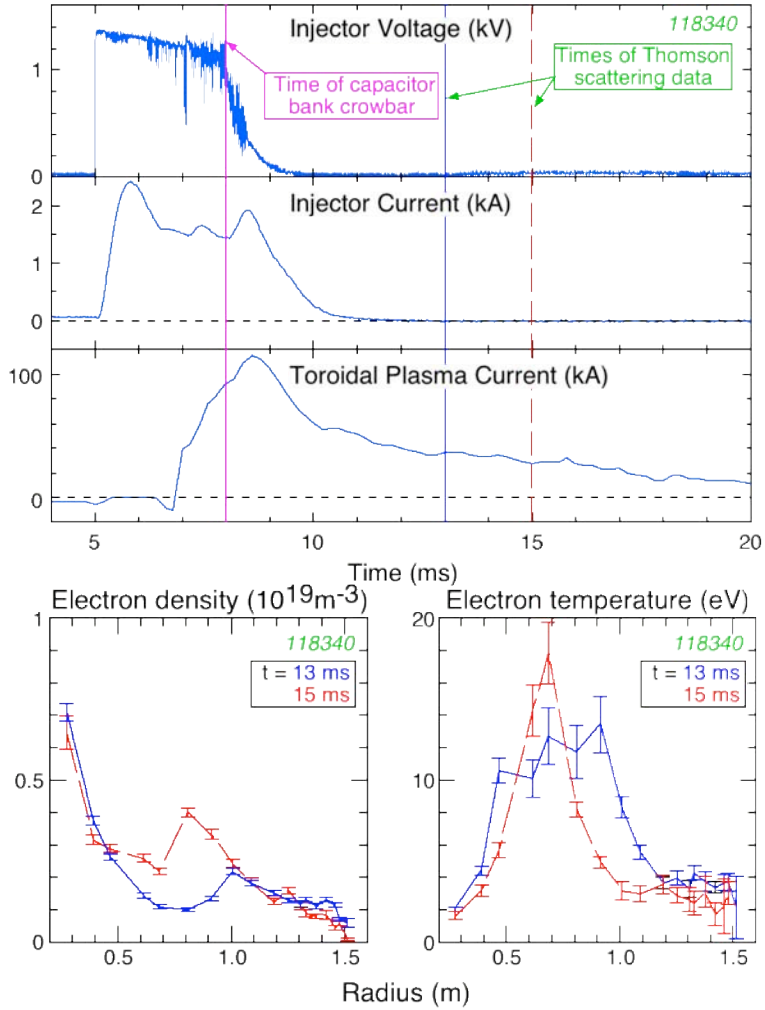
- Good performance of TF coil joints: ~2500 pulses, 75% at 0.45T or higher
  - Operated to 95% of design field (0.6T) at end of run
  - Joint resistances remained below expectations
- Extensive investigation of Coaxial Helicity Injection
  - Higher capacitor bank voltage (1.5kV) and localized gas injection
- New PF1A coils for simultaneous high triangularity and high elongation
- Three pairs of magnetic field perturbation coils
  - Powered by fast Switching Power Amplifiers for Error-Field Correction and Resistive Wall Mode control
- Lithium Pellet Injector, Supersonic Gas Injector
  - LPI used both for plasma perturbation experiments and Li coating
- Movable Glow Discharge electrode
  - More uniform coverage and operation at lower gas pressure

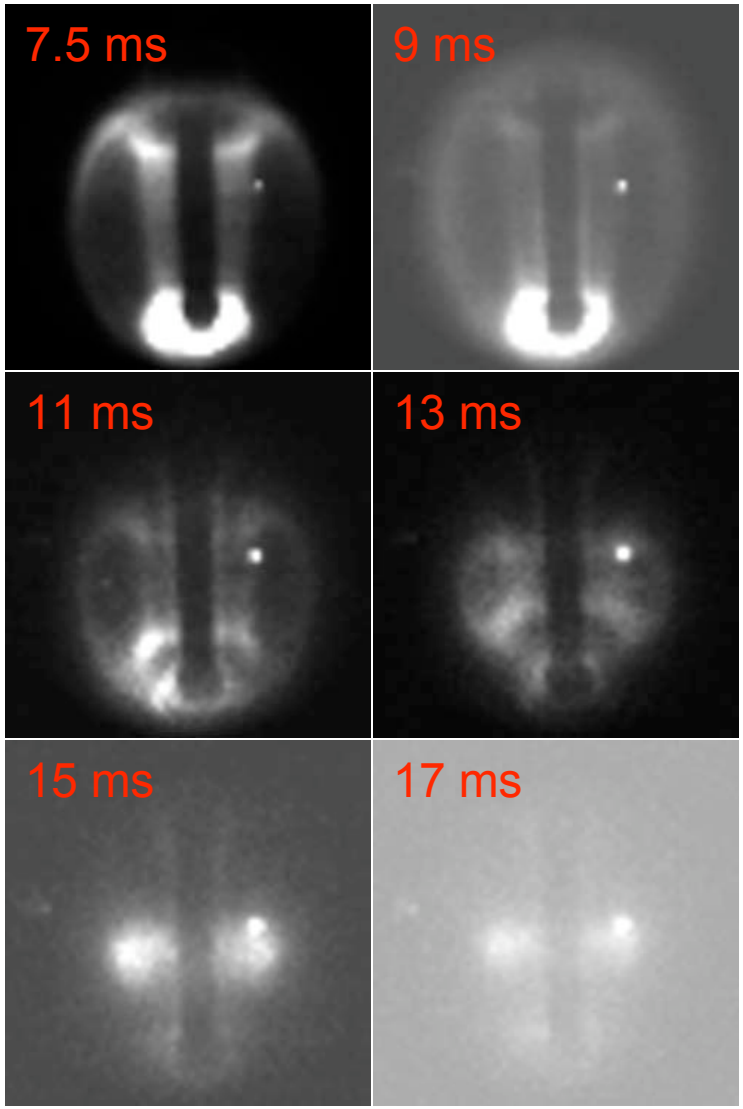
Coaxial Helicity Injection Experiments Benefited from New Capabilities



- Inject gas and microwave power into chamber beneath injector gap
  - Reduced total gas requirement for breakdown
- Capacitor bank with fast crowbar and higher voltage for coil producing initial flux
  - Operated bank at up to 1.5kV
  - Force reconnection to produce closed flux
- Fast cameras to observe plasma on closed flux surfaces

CHI Produced Persistent Current and Closed Flux For ~10ms After the Injector Current Pulse



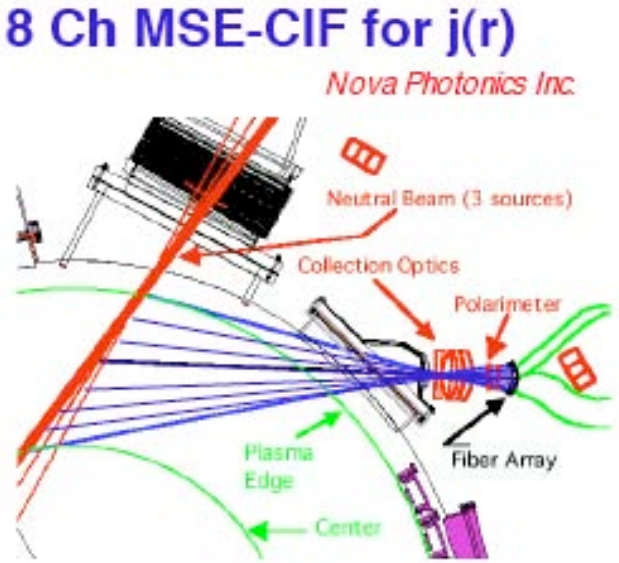


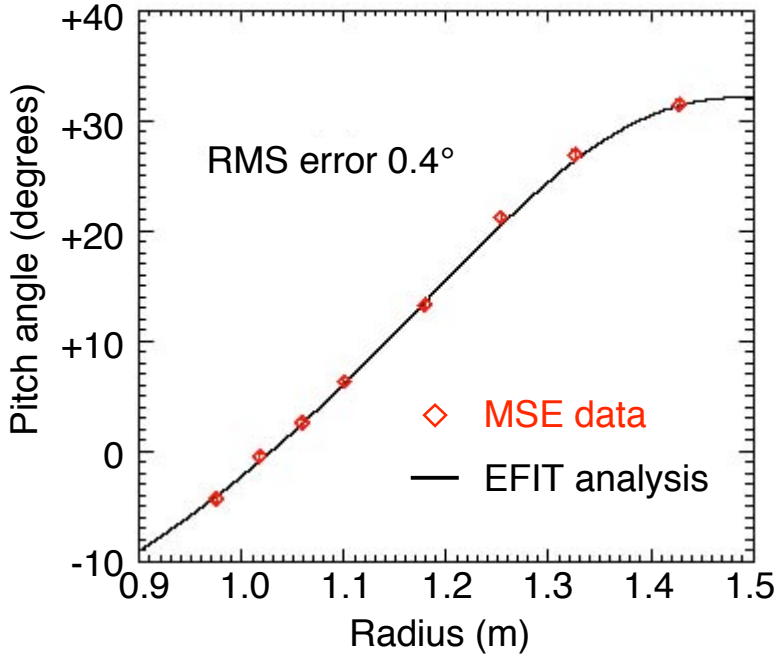
- Need to develop transition to control of toroidal equilibrium

R. Raman, B. Nelson (U. Wash.), R. Maqueda (Nova), B. LeBlanc

Motional Stark Effect Diagnostic Routinely Measures Magnetic Field Line Pitch

- 8 channels span from outer edge past magnetic axis
- Calibrated by NBI into neutral gas with known applied fields
- EFIT provides between-shots analysis for q-profile
  - Can include correction for E_r using CHERS v_ϕ profile
  - Also applying LRDFIT, ESC equilibrium codes

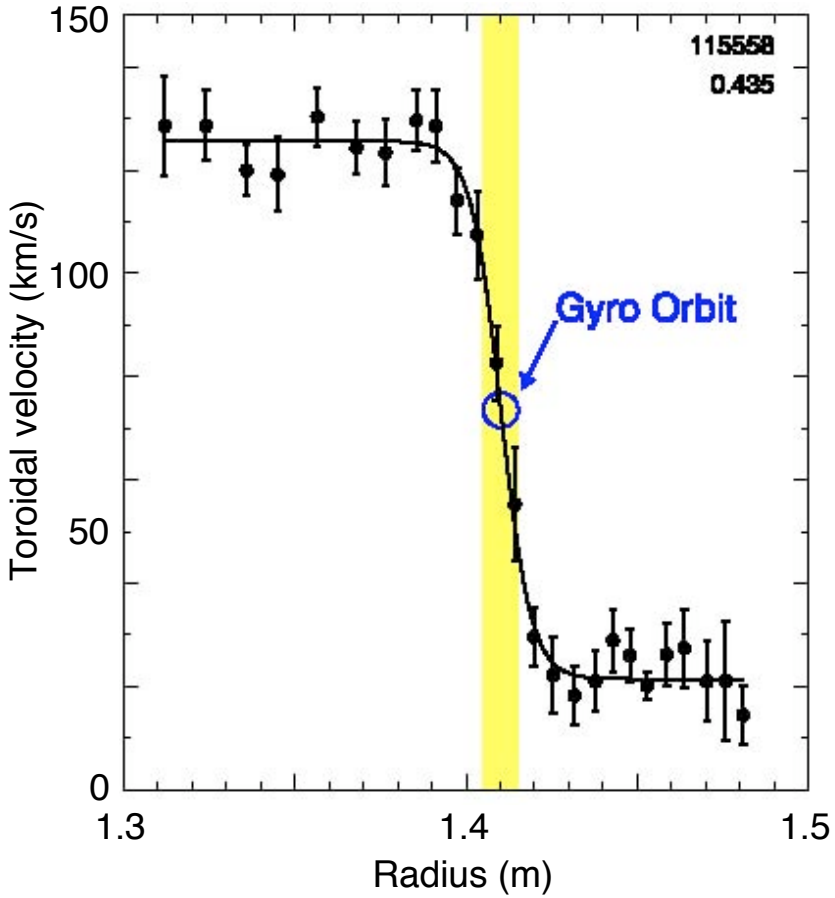


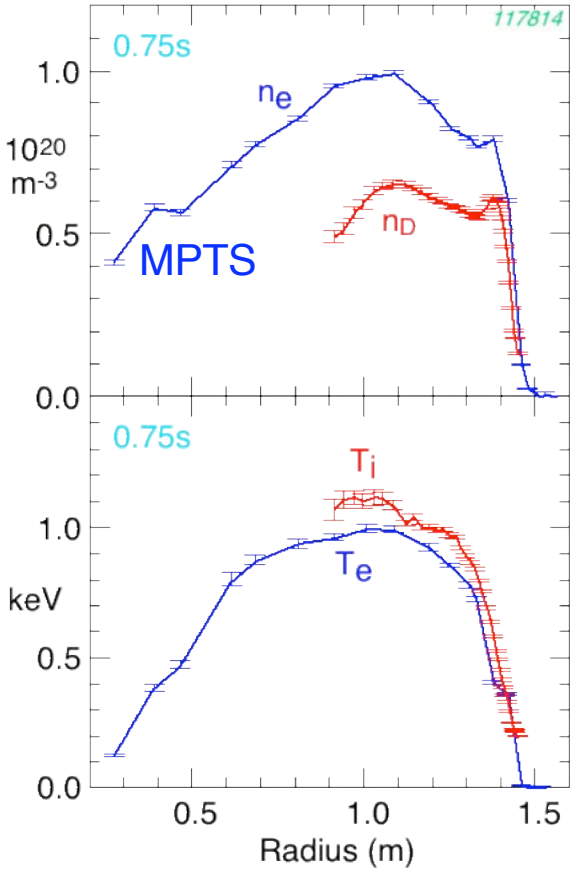


F. Levinton, H. Yu (Nova Photonics), S. Sabbagh (Columbia U.)

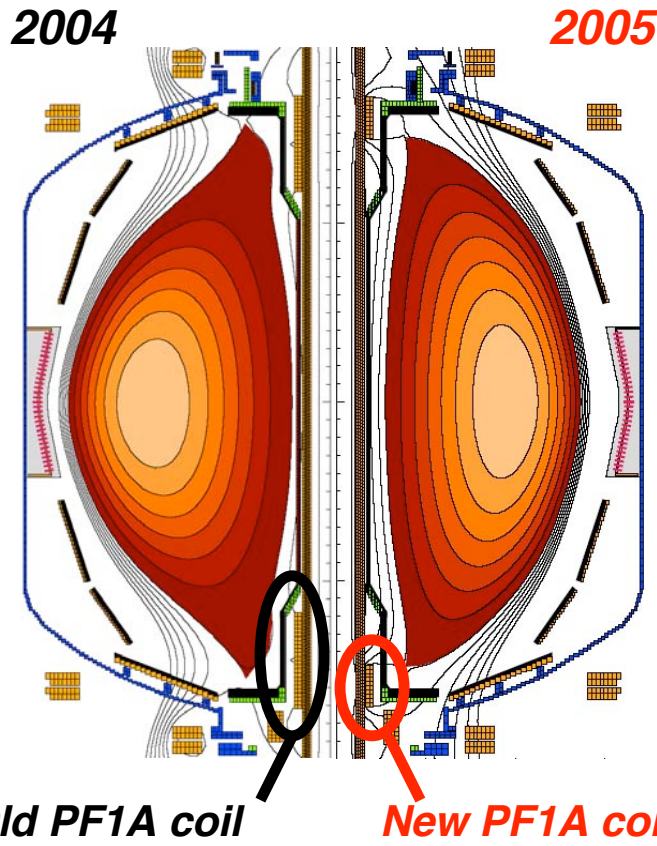
51-Channel Charge-Exchange Recombination Spectroscopy Reveals Extreme Gradients

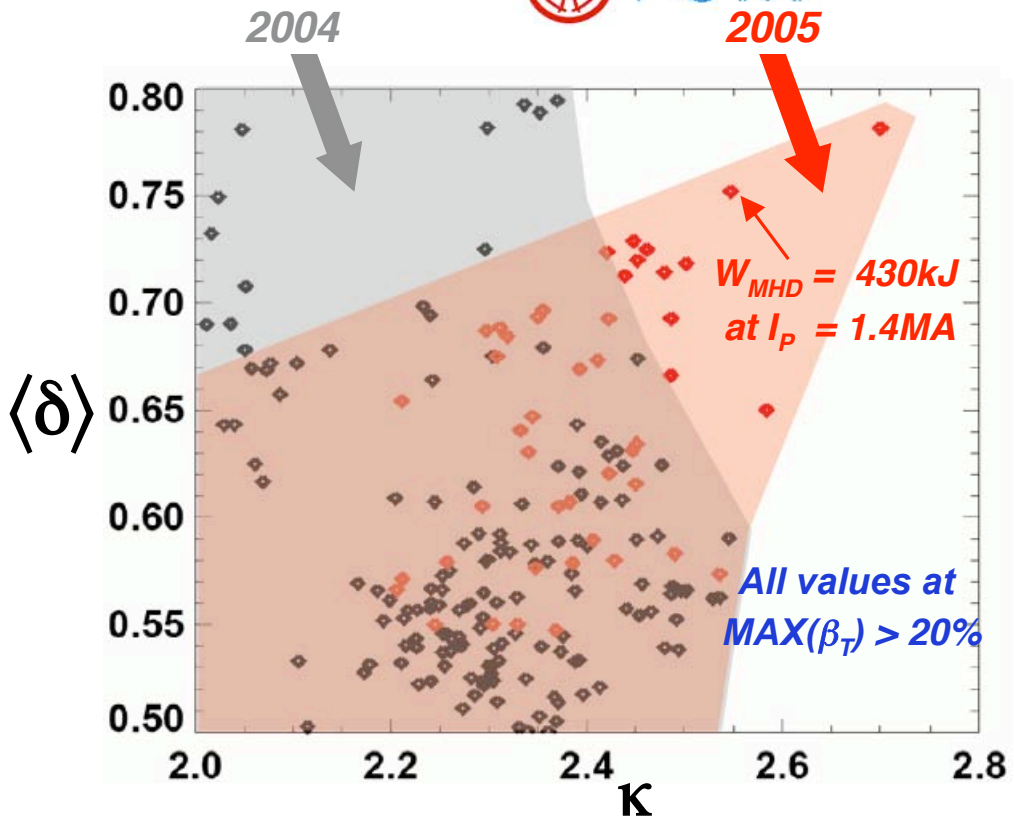
- Diagnostic measures $T_i(R)$, $v_\phi(R)$, $n_C(R)$
  - Infer $n_D(R)$ under assumption that carbon is dominant impurity





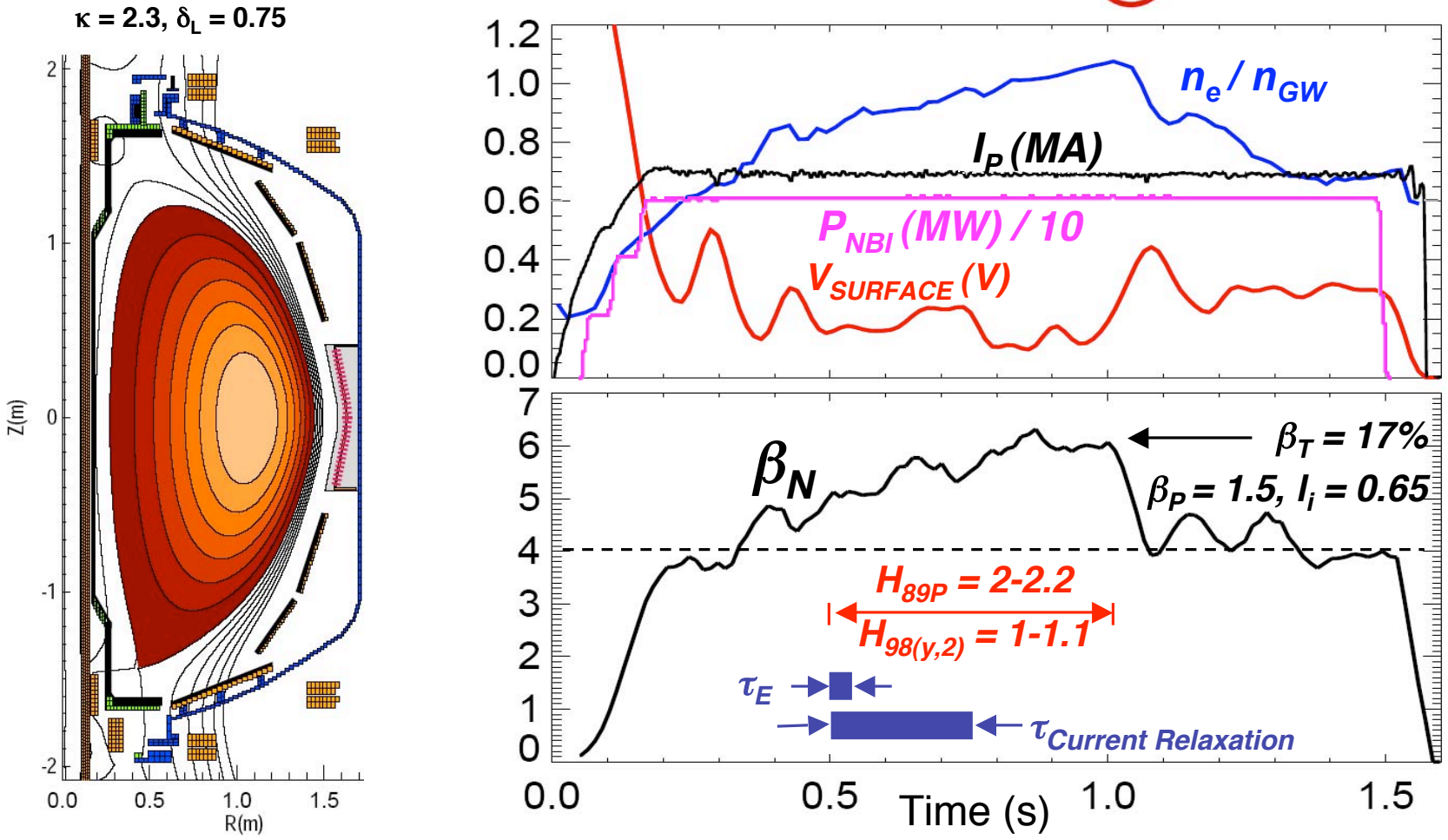
New Inboard Divertor Coils Increase Accessibility of High-Triangularity, High-Elongation Shapes





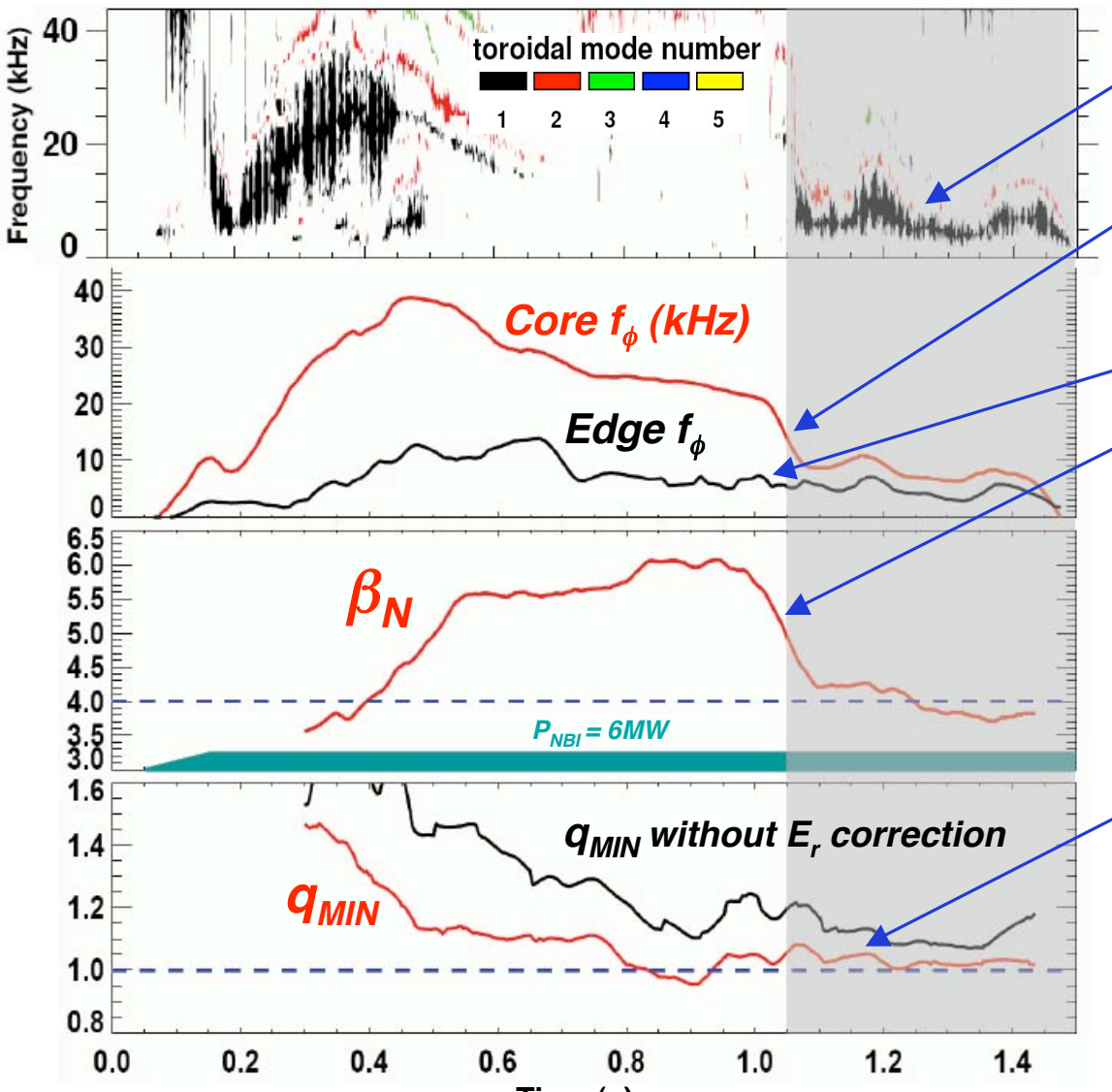
- Highest $\kappa = 2.7$ now obtained at highest $\delta \approx 0.8 \Rightarrow S \equiv q_{95} I_P/aB_T = 35$ MA/m·T
  - Record stored energy = 430kJ at $I_P = 1.4$MA, $\beta_N = 5.3$, $\beta_T = 29\%$, $q^* = 2.3$
- Small ELM regime recovered at high $\kappa > 2.5$ with new coils
  - Previously observed onset of large ELM-like events when $\kappa > 2.2$

Record Pulse-Lengths Achieved at Moderate Current by Operating with Sustained H-mode



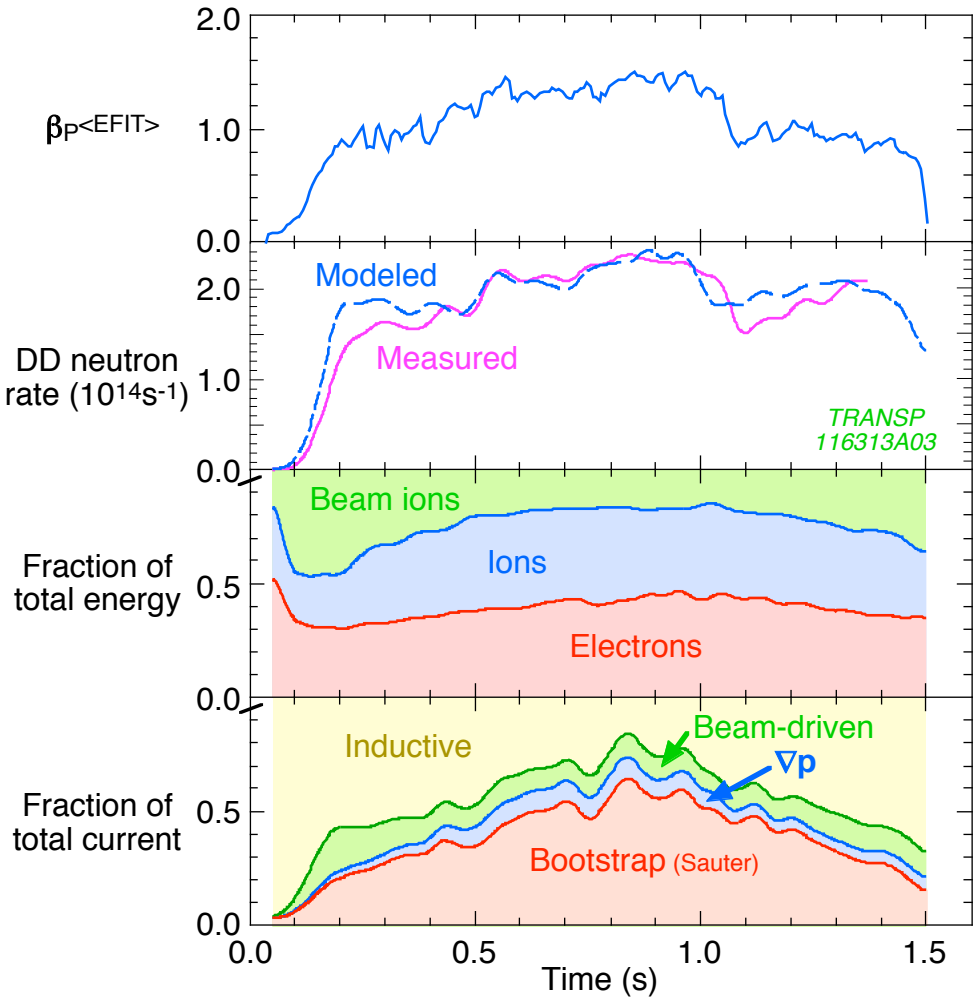
- H-mode with small ELMs ⇒ lower flux consumption, slow density rise
- High β_P increases bootstrap fraction ⇒ lower flux consumption

Low Loop-Voltage Quiescent Phase Ends at Onset of Saturated n=1 Mode When $q_{min} \rightarrow 1$



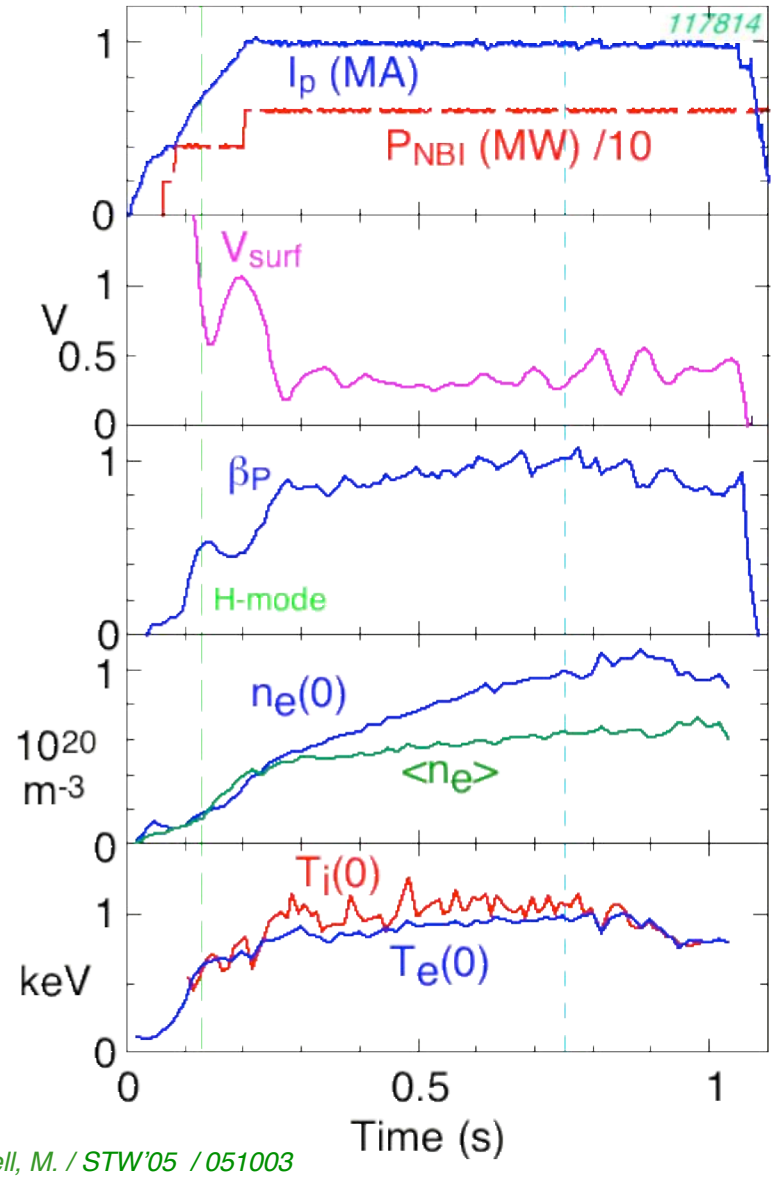
- Saturated n=1 mode persists for 0.5s
- Central rotation drops by factor 3
- Edge f_ϕ maintained
- β_N decreases
  - β_N = 6 above no-wall limit
  - β_N = 4 below no-wall limit?
- q_{min} sustained near 1
  - No sawteeth observed
  - Similar to hybrid mode

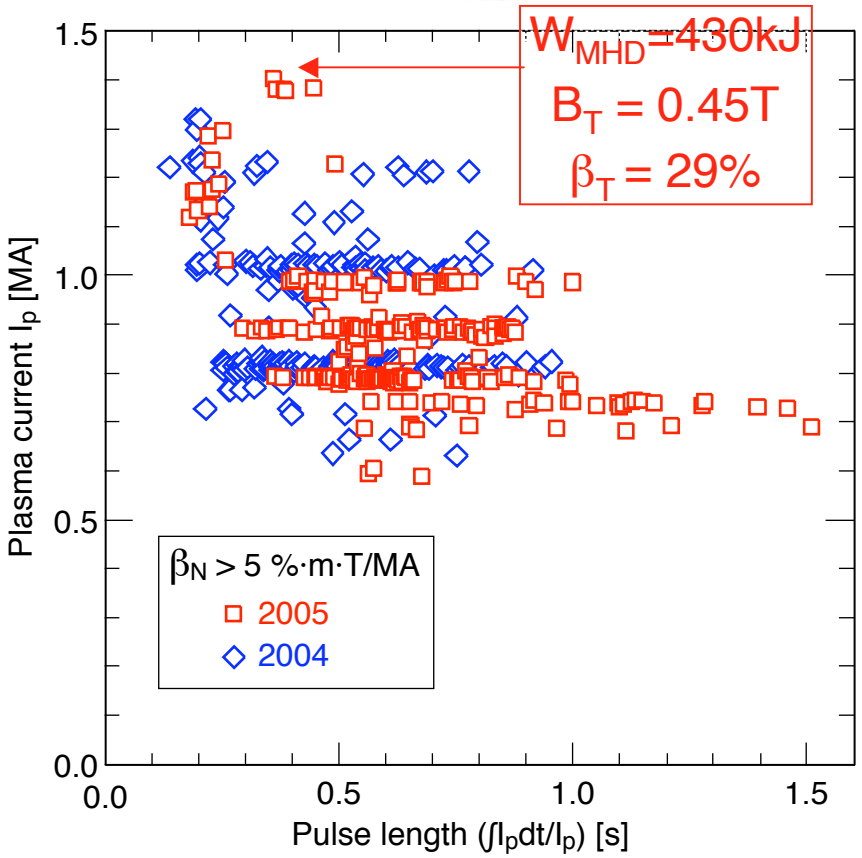
Long Duration Discharges Exceed 70% Non-Inductive Current During High-β Phase



- TRANSP model agrees with measured neutron rate during high-β phase
- TRANSP over-predicts neutron rate early and late when low-f MHD present
  - Fast-ion diffusion and/or loss likely
  - Assessing impact on J_{NBI} profile and q-profile
- 85% of non-inductive current is ∇p-driven
  - Bootstrap + Diamagnetic + Pfirsch-Schlüter

Also Extended Pulse Length at Higher Current

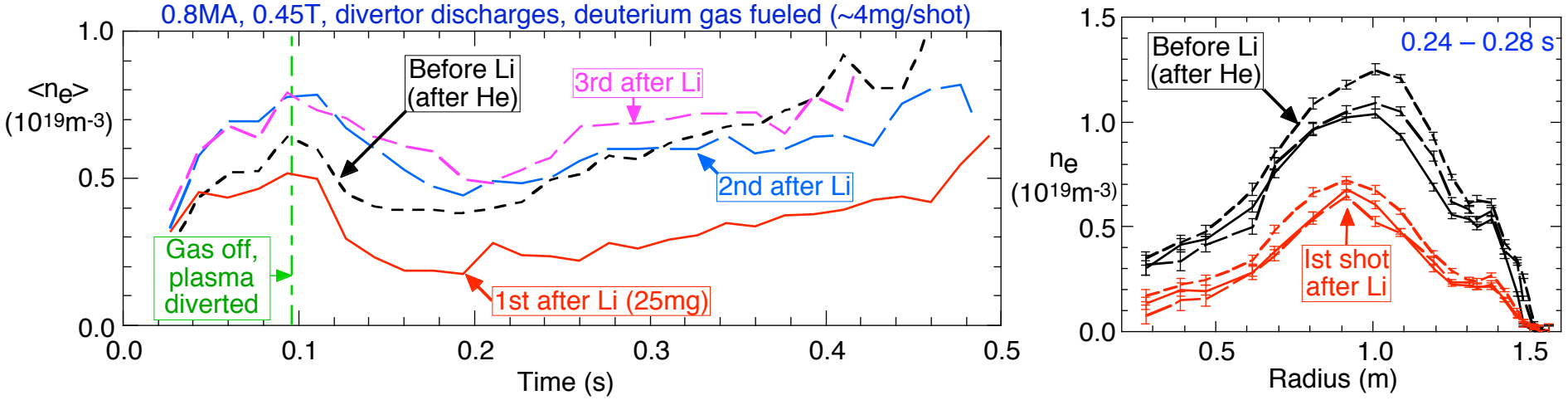




- At high I_p, contribution reduced from
  - bootstrap current ($f_{BS} \propto \varepsilon^{1/2}\beta_P$)
  - NB-driven current (higher density)

Lithium from Injected Pellets Deposited on Plasma-Facing Surfaces Provides Edge Pumping

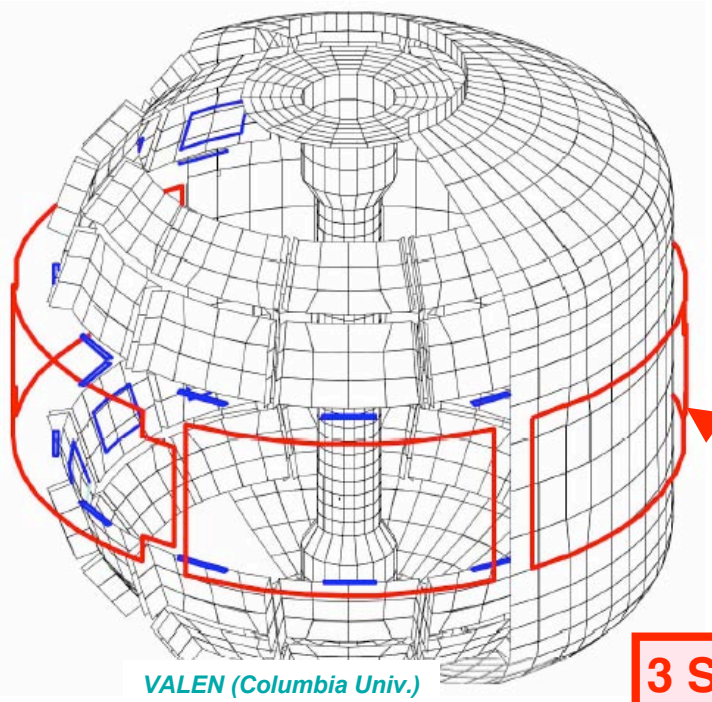
- Fired lithium pellets (1.7 – 5 mg) from multi-barrel pneumatic injector into sequences of ohmically-heated helium discharges
  - Limited on center-stack tiles or lower-single-null divertor
  - After "pre-conditioning" surfaces with OH helium plasma
  - 1 or 2 pellets per discharge, 24 – 30 mg total lithium in each sequence
- Dramatic reduction in density in 1st subsequent NB-heated deuterium gas-fueled discharge (~3.5mg D_2) in both configurations



- Effect disappeared by 3rd similar discharge
  - Expected if most injected gas reacts with deposited lithium

External Radial Field Coils Used to Counteract Effects of Intrinsic Error Fields

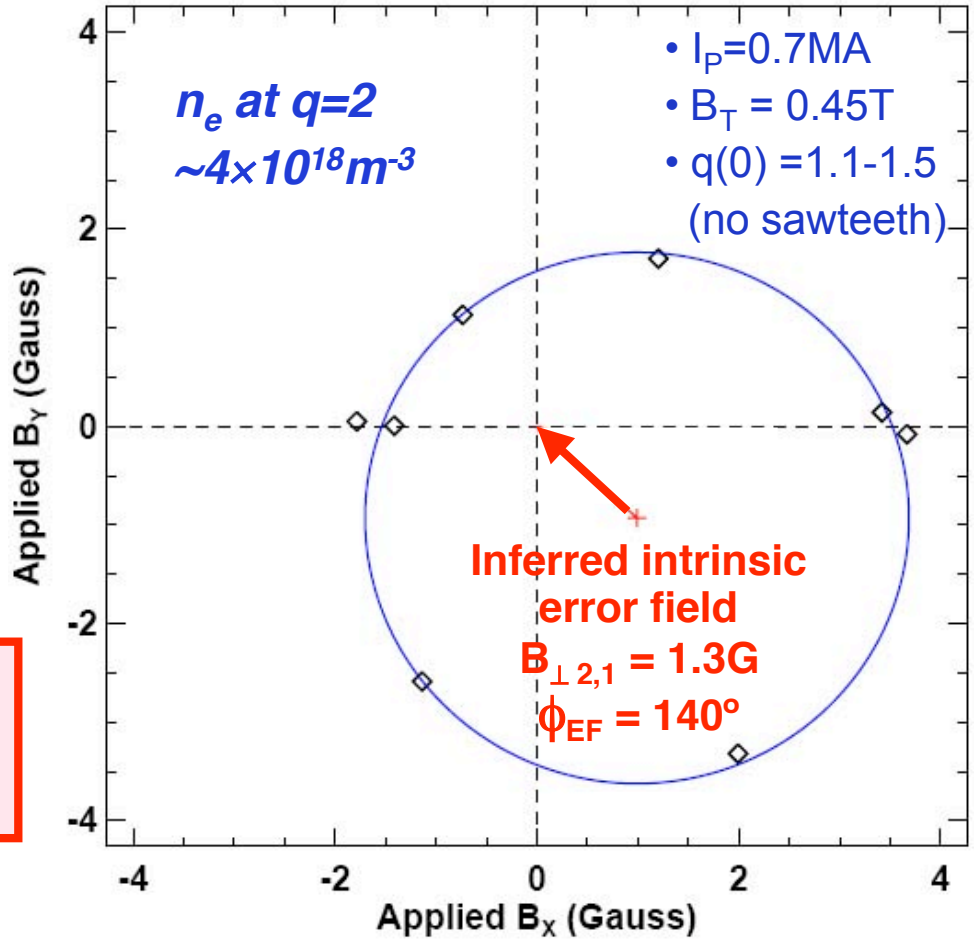
- Investigated threshold for occurrence of locked-modes in low-density, low-β discharges as magnitude and direction of radial field varied



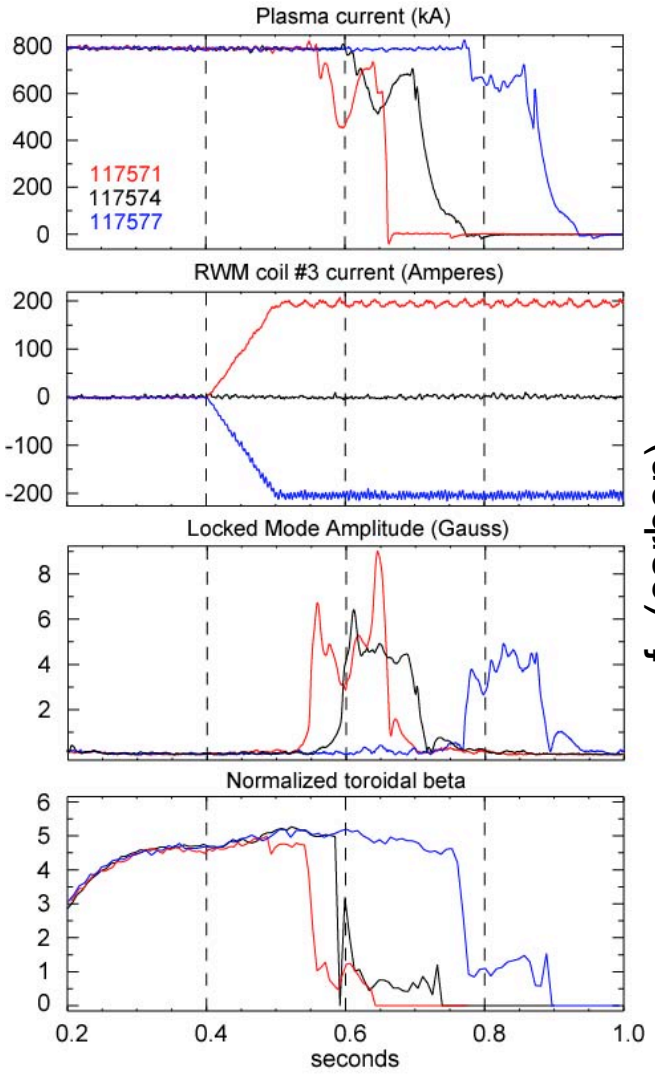
VALEN (Columbia Univ.)

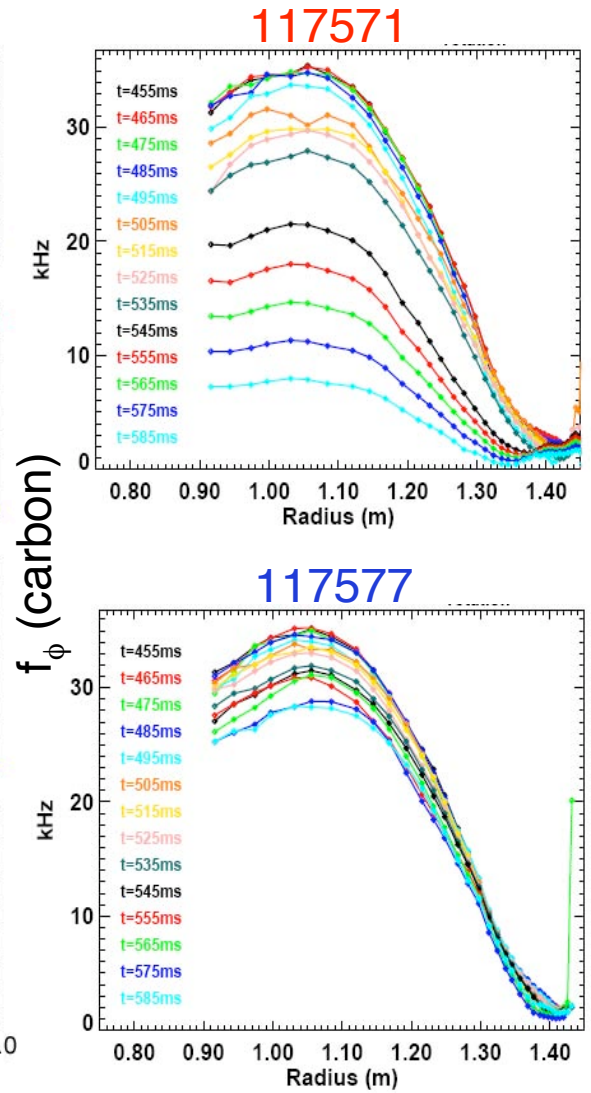
6 ex-vessel coils
(1.6m² × 2 turns each)
48 in-vessel sensors
(B_θ, B_ρ)

3 SPAs
3.3kA
3.5kHz



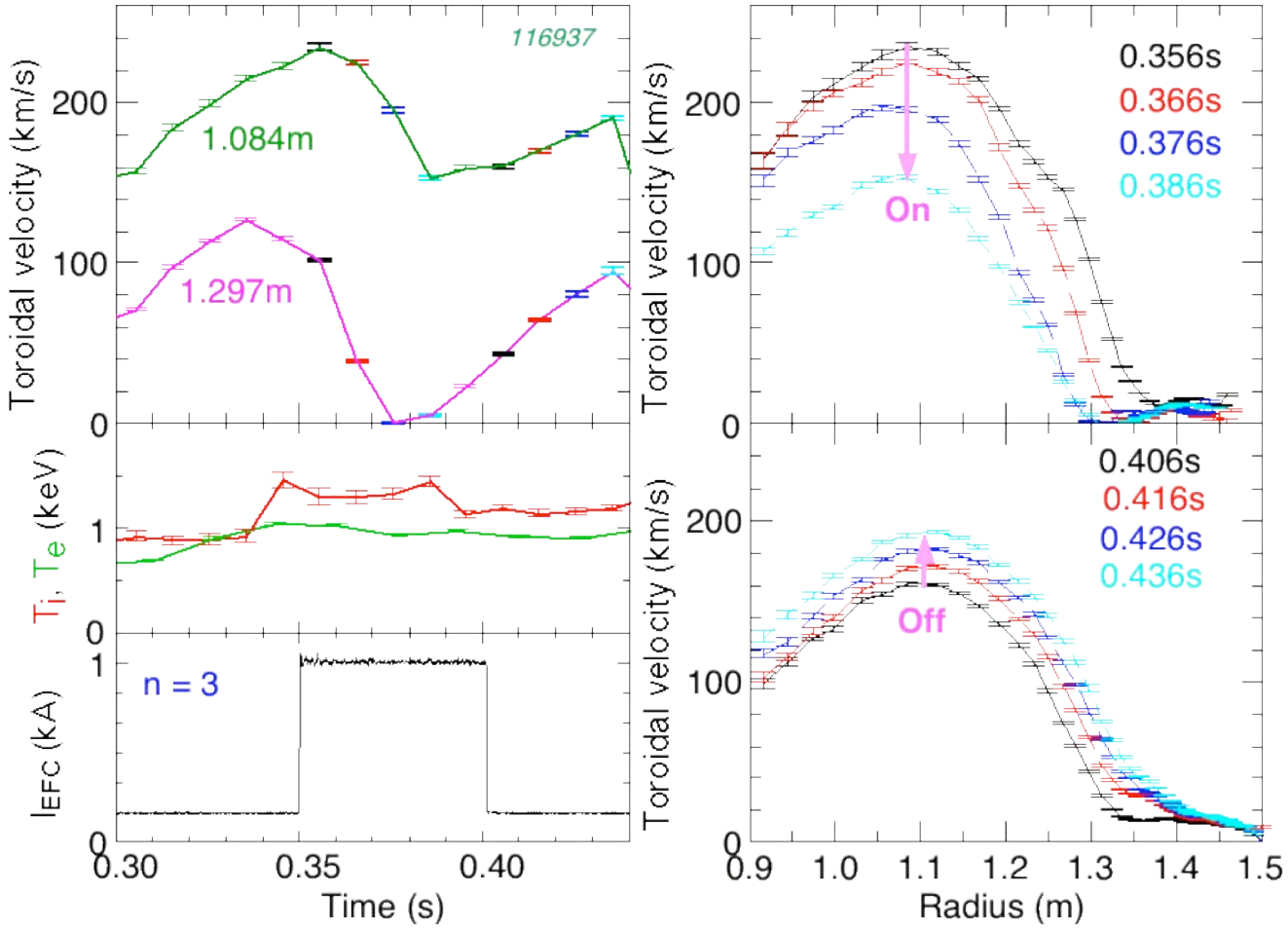
Applying n=1 Correction Field with External Coils Extended Pulse Length at High β_N





- With field in "non-correcting" directions, rotation is damped
  - Earlier island locking and/or RWM formation
- In "correcting" direction, near-edge rotation collapse is avoided
  - Extends pulse length at high-β

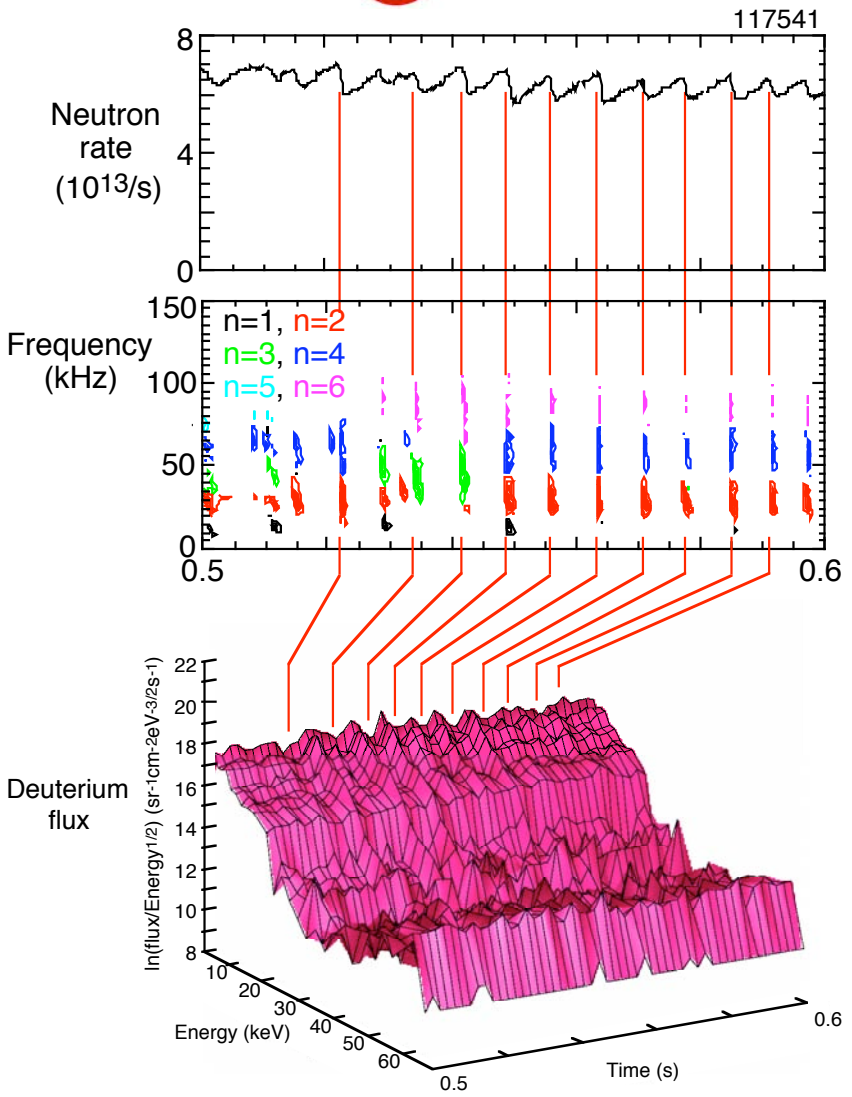
Applied n = 3 Stationary Field Used to Control Plasma Rotation Reversibly



- Rotation stops completely in vicinity of resonant q = 3 surface
  - Neoclassical toroidal viscosity affects inner region
- Rotation can recover if RWM is not destabilized

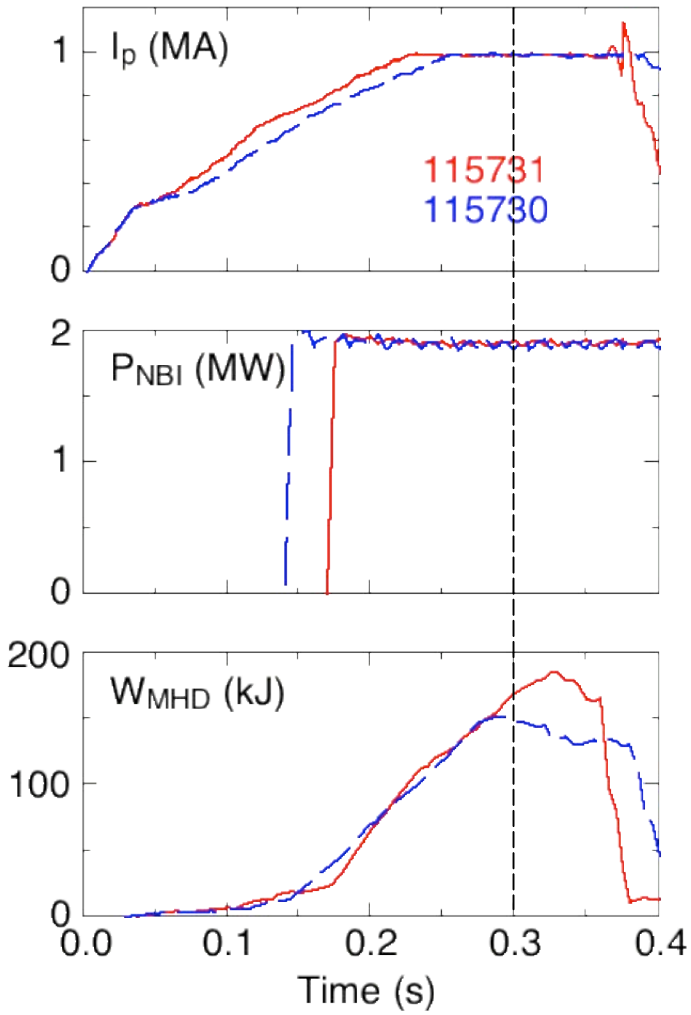
Repetitive Bursts of MHD Activity Affect Fast Ion Population During NBI Heating

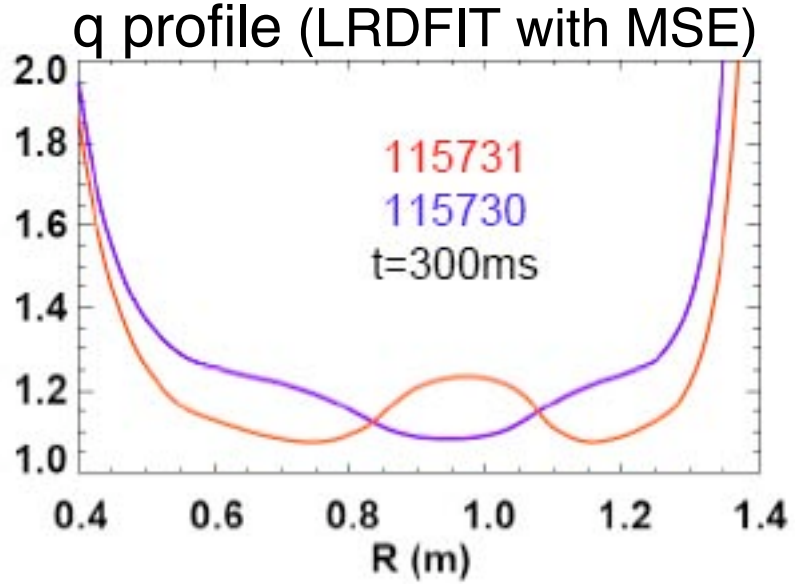
- Bursts of MHD activity detected by Mirnov coils are kinetic instabilities driven by population of fast ions
  - Instabilities chirp in frequency
  - Toroidal mode numbers n = 2 – 6
- Bursts are coincident with rapid drops in DD neutron rate
  - Mainly beam-target reactions
- NPA measures energy and pitch angle resolved effect on fast ions
  - Depleted over wide energy range
  - No D_α spikes to suggest changes in edge neutral density



E. Fredrickson, S. Medley

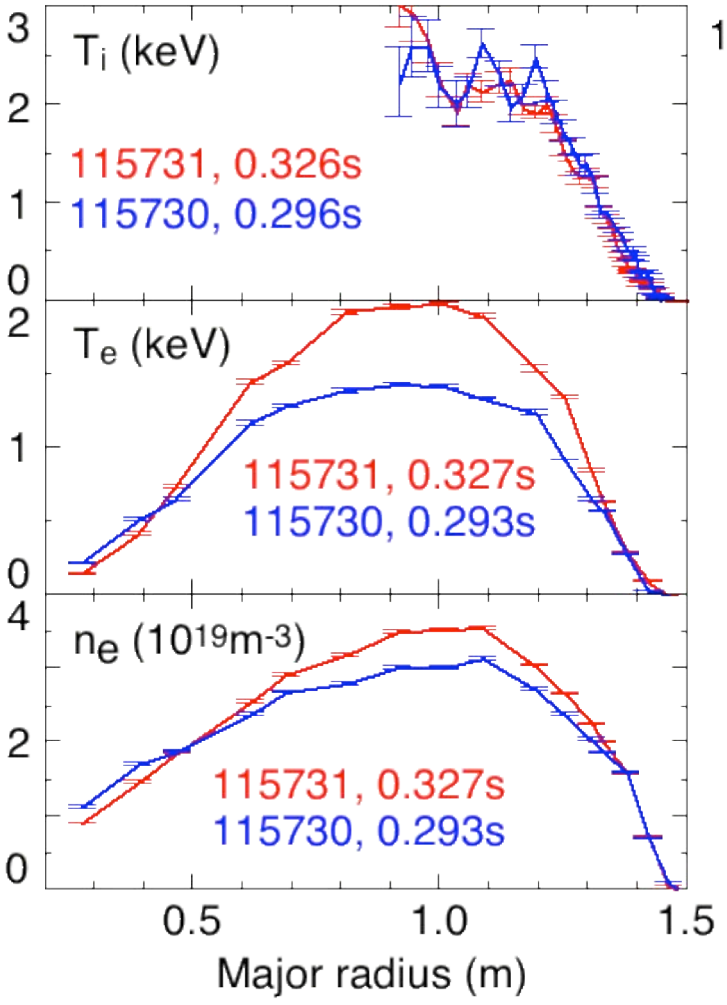
Robust Reversed-Shear Startup by Varying Ramp-Rate, NB Timing and Gas Injection



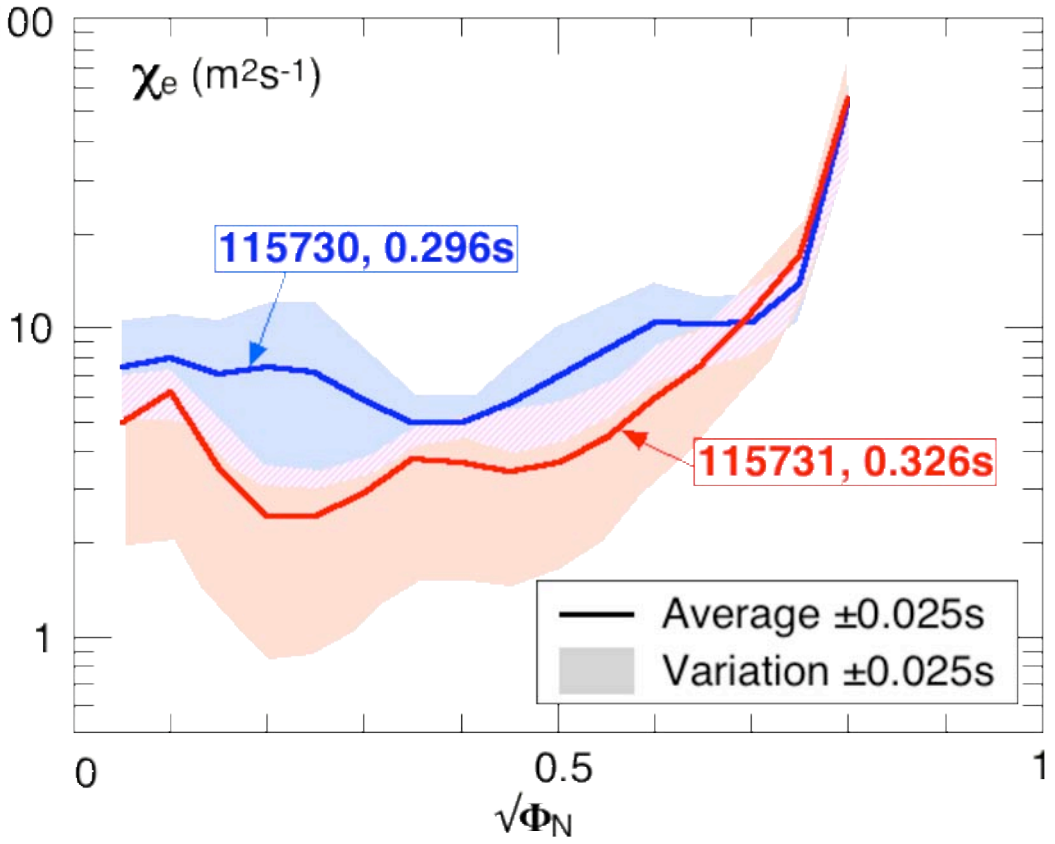


- q-profile very dependent on early MHD acitivity
  - Events lead to monotonic profile
- Also combined RS with H-mode edge but not yet optimized

Reversed-Shear Appears to Produce an Electron Transport Barrier



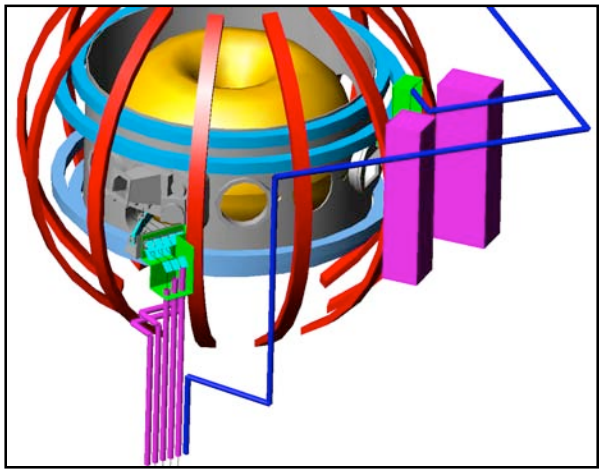
TRANSP with classical NB thermalization

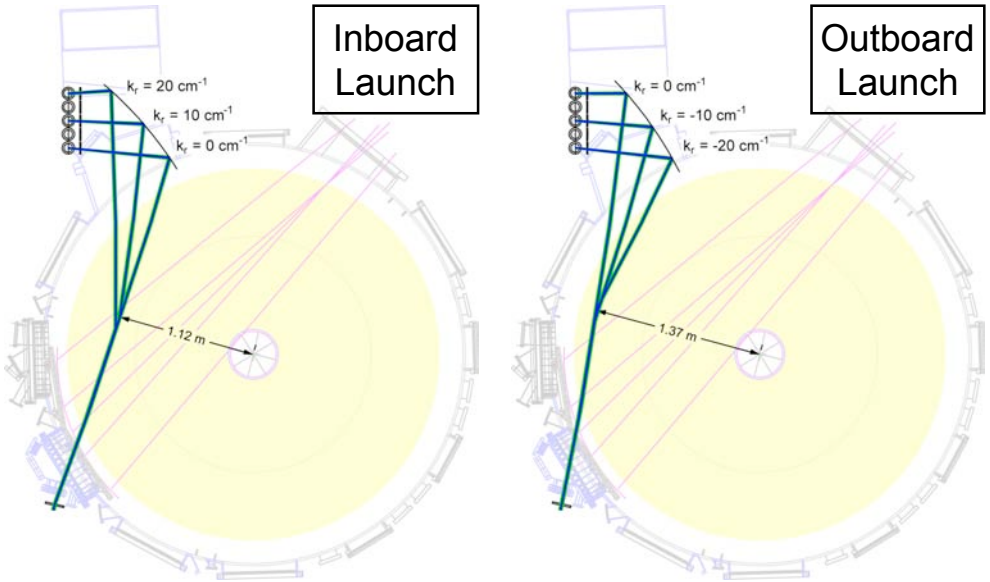


- χ_e reduced by ~2 in confinement zone
- HHFW heating also raised central T_e in RS

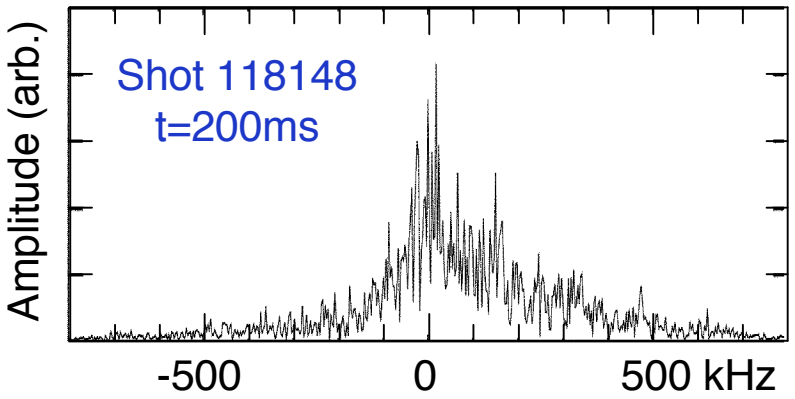
Newly Installed High-k Scattering Diagnostic Will Probe Turbulence Related to Electron Transport

- λ = 1mm probe beam launched tangentially near midplane
- Inboard / outboard launch configurations
  - k_r = 0 – +20 cm^{-1} (in), -20 cm^{-1} (out)
- Superheterodyne receivers (UC Davis)
  - Five channels with NF of ~3000°K
- First scattered signals at end of 2005 run



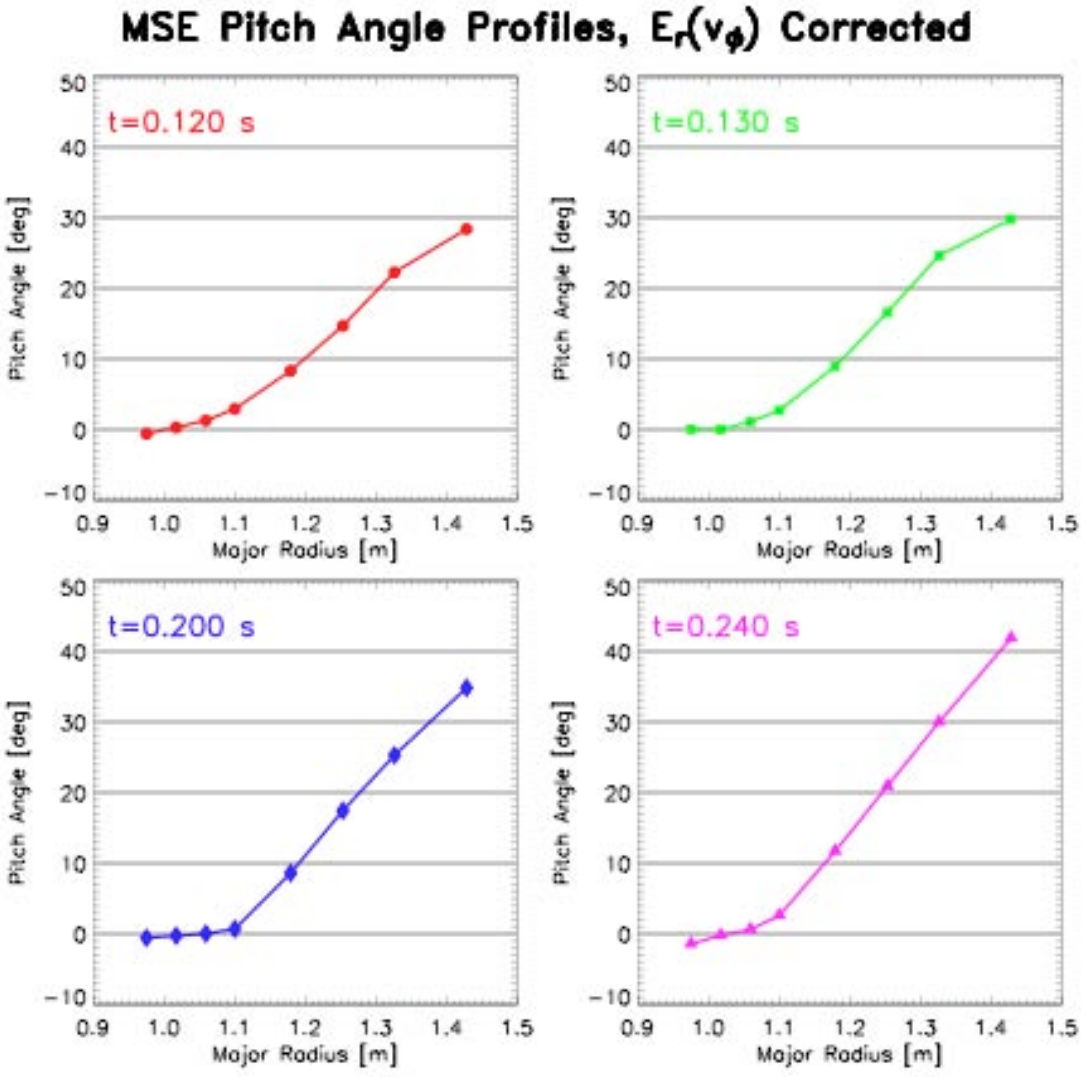


Fourier transform of scattered signal
Outboard launch, k_r = -15cm^{-1}



MSE Shows Evidence for Formation of "Current Hole" in NSTX

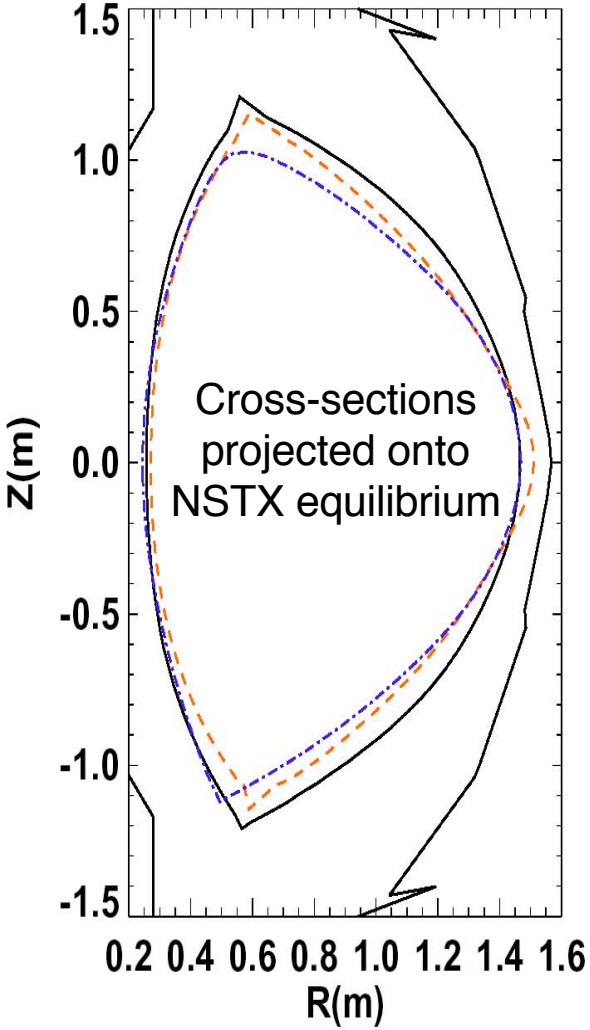
- At 0.12 s current profile is hollow but central current density is finite
- Small region of almost zero current density forms at 0.13 s
- Expands to about 15 cm diameter by 0.20s
- Central current density becomes positive again by 0.24 s

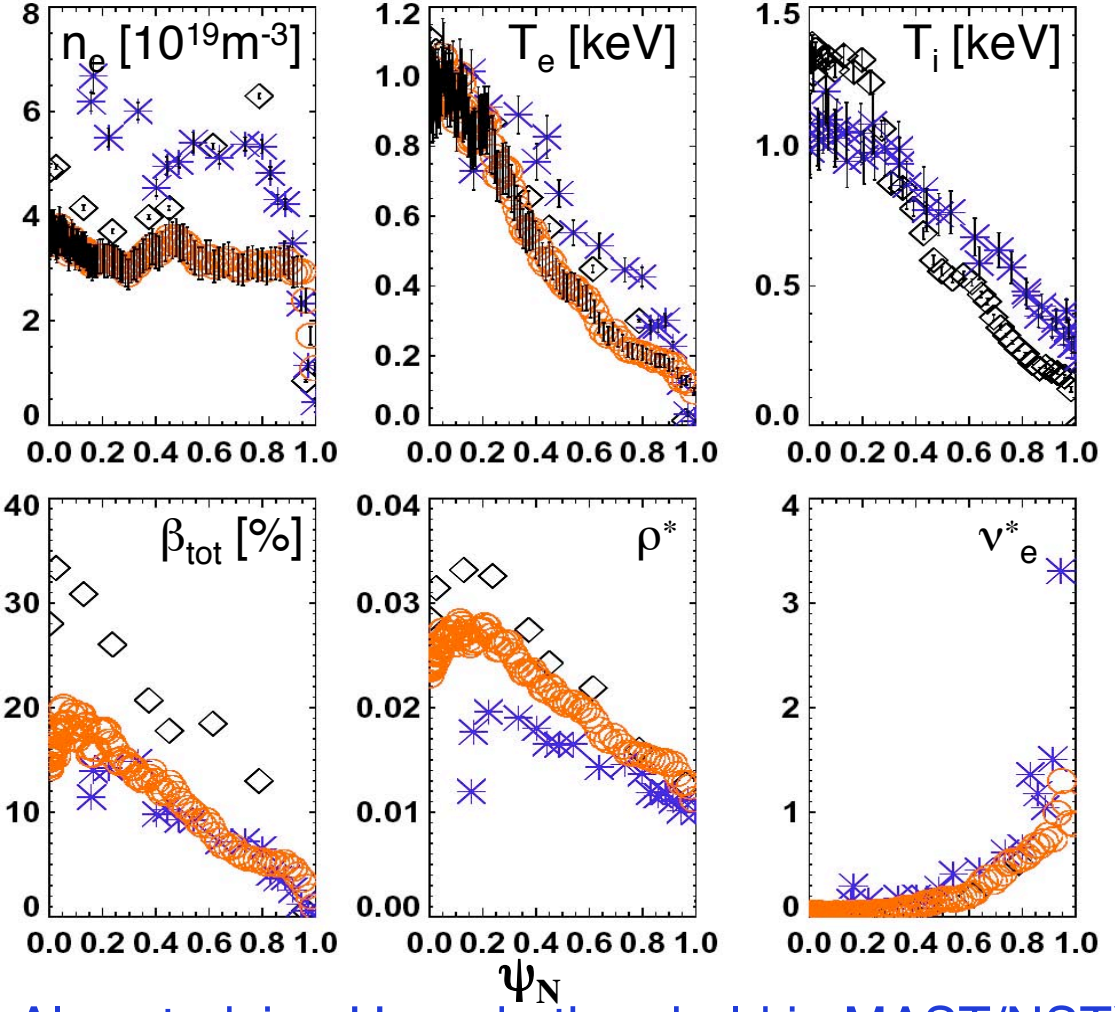


F. Levinton, H. Yu (Nova)

Investigating Aspect-Ratio Dependence of H-mode Pedestal in Experiment with MAST, DIII-D

NSTX (117723@427ms) **DIII-D** (121516@1175ms) **MAST** (12899@270ms)

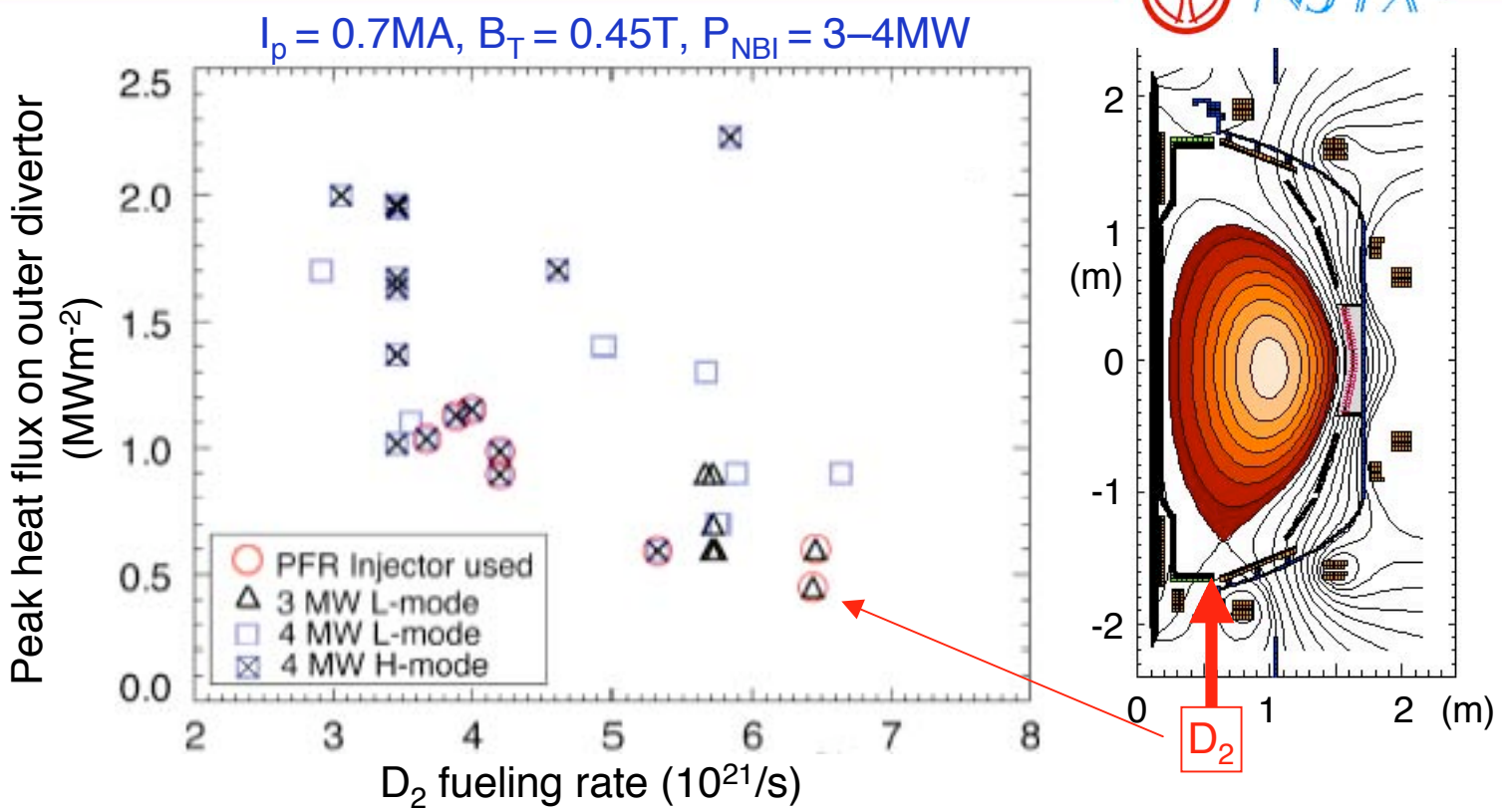




- Also studying H-mode threshold in MAST/NSTX

R. Maingi (ORNL), A. Field (MAST), H. Meyer (MAST), T. Osborne (DIII-D)

Puffing Deuterium into Private Flux Region Reduces Outer Divertor Heat Flux by Factor 2–4



- No change in inner divertor heat flux - inner leg already detached
- Evidence for volume recombination from increase in D_γ/D_α ratio
  - Divertor radiation increases but not spatially resolved
- Outer divertor detachment *not* achieved by midplane injection of D_2 or Ne
  - Ne did reduce divertor heat flux by factor 4 by plasma and SOL radiation

NSTX Made Significant Progress in 2005

- Clear demonstration of persistent current initiated by CHI
- Extension of operating regime at high κ and δ
- First experience with full set of Error Field Correction and RWM Control coils
  - Cancellation of intrinsic error fields
  - Control of rotation and effect on mode growth
- Significant extension of pulse-length at moderate current
- Exploration of reversed-shear regime
  - Beneficial effect on electron confinement
- Demonstration of particle control with lithium coating in both limiter and divertor plasmas
- Contributions to physics of H-mode, ELMs, pedestal, confinement
  - Collaborative experiments and participation in ITPA

Status and Plans

- Now entering an outage planned to last until December 2005
  - Install in-vessel components for “poloidal CHERS” diagnostic
    - Opposing vertical views across NB path to measure v_{pol} and $T_{i\perp}$
  - Install lithium evaporator for coating areas of divertor and wall
    - Build on experience in LTX (former CDX-U) and with LPI in NSTX
  - Examine all TF coil joints and refurbish if necessary
- NSTX 2005 Results Review and Research Forum for planning experiments in 2006 will take place December 12 – 16
  - Participation by our collaborators is encouraged
  - Length of 2006 experimental run is not yet known
    - Awaiting outcome of budget negotiations in US Congress