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New Capabilities and Results for the National Spherical Torus Experiment

M.G. Bell

for the

NSTX Research Team

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Poster P5.117

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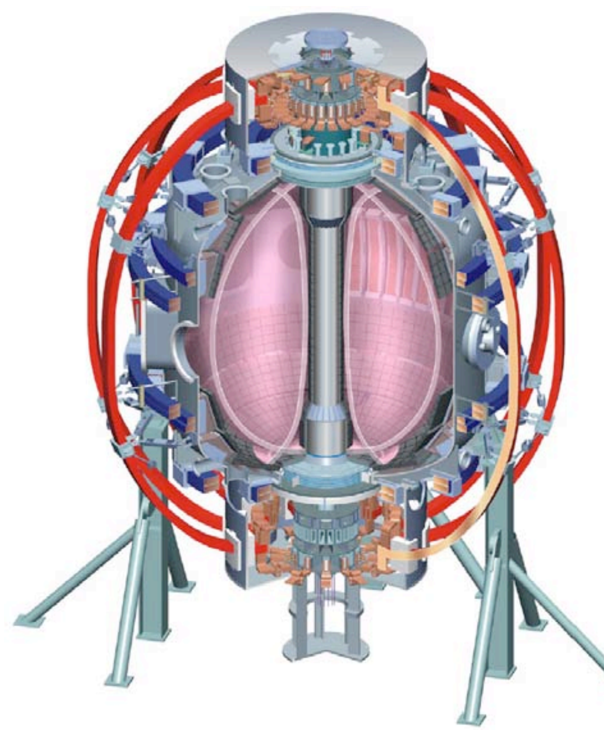

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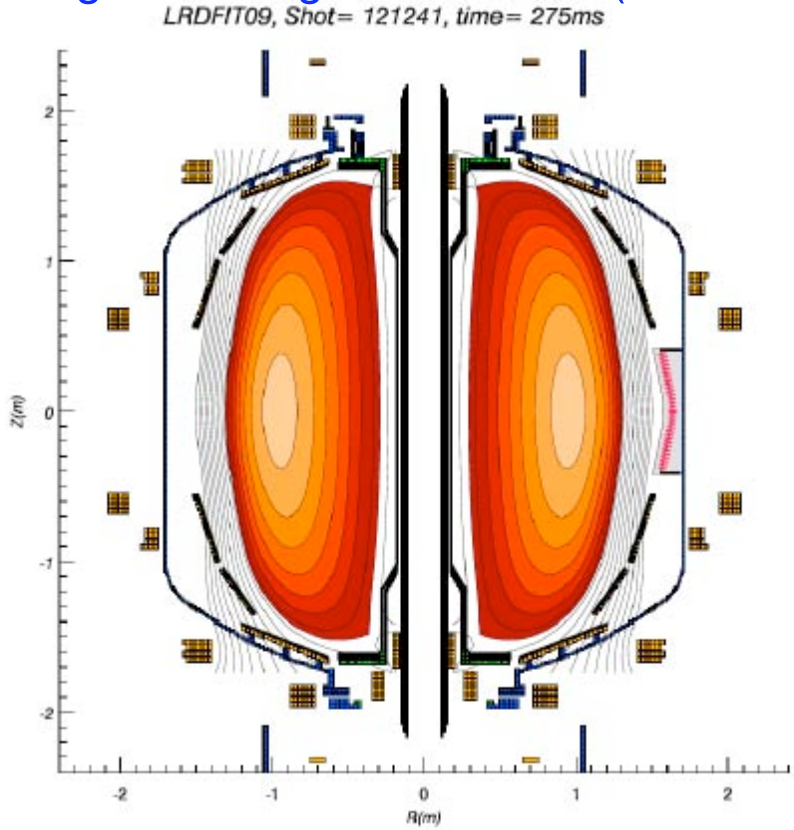
NSTX Just Completed 12 Weeks of Experiments Exploiting New Capabilities and Regimes

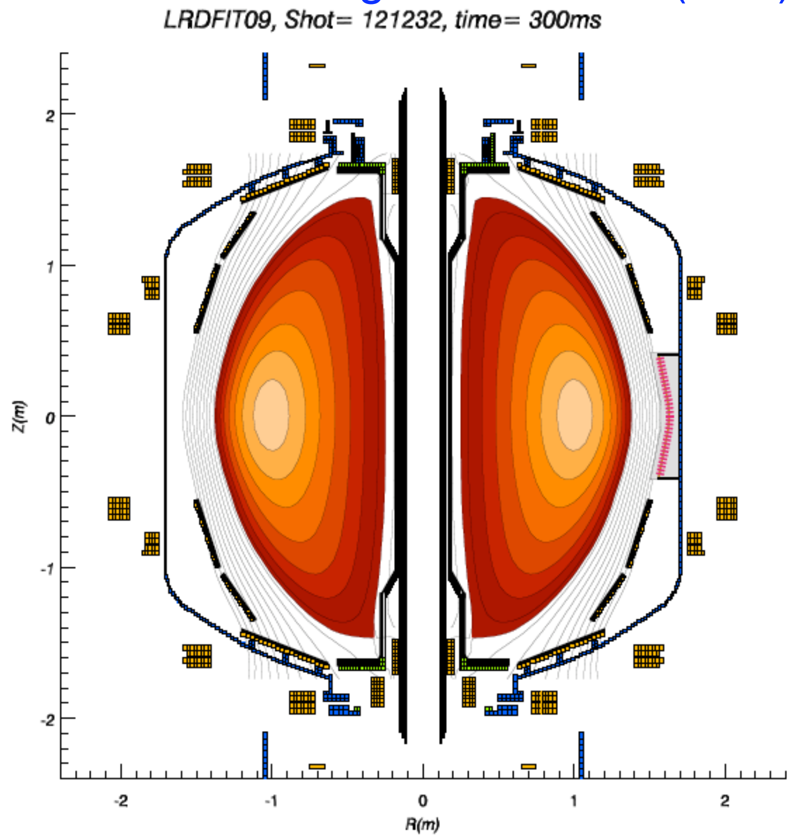
- Good performance of TF coil joints: now ~4200 pulses since 2004 rebuild
  - Operated to 0.55T (designed for 0.6T)
  - 75% at 0.45T or higher
  - Joint resistances remained below expectations
- Optimized shaping with new PF coils for high triangularity and elongation
- Three pairs of magnetic field perturbation coils
  - Powered by fast Switching Power Amplifiers for Error-Field Correction and Resistive Wall Mode control
- Lithium Evaporator, Supersonic Gas Injector *(**see P-5.118**)*
- Extensive investigation of Coaxial Helicity Injection *(**see P-5.113**)*
  - Larger capacitor bank (45mF) and higher voltage (1.85kV)
- New and upgraded diagnostics
  - High-k scattering for electron-scale fluctuations

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

Highest elongation κ=2.95 (transient)



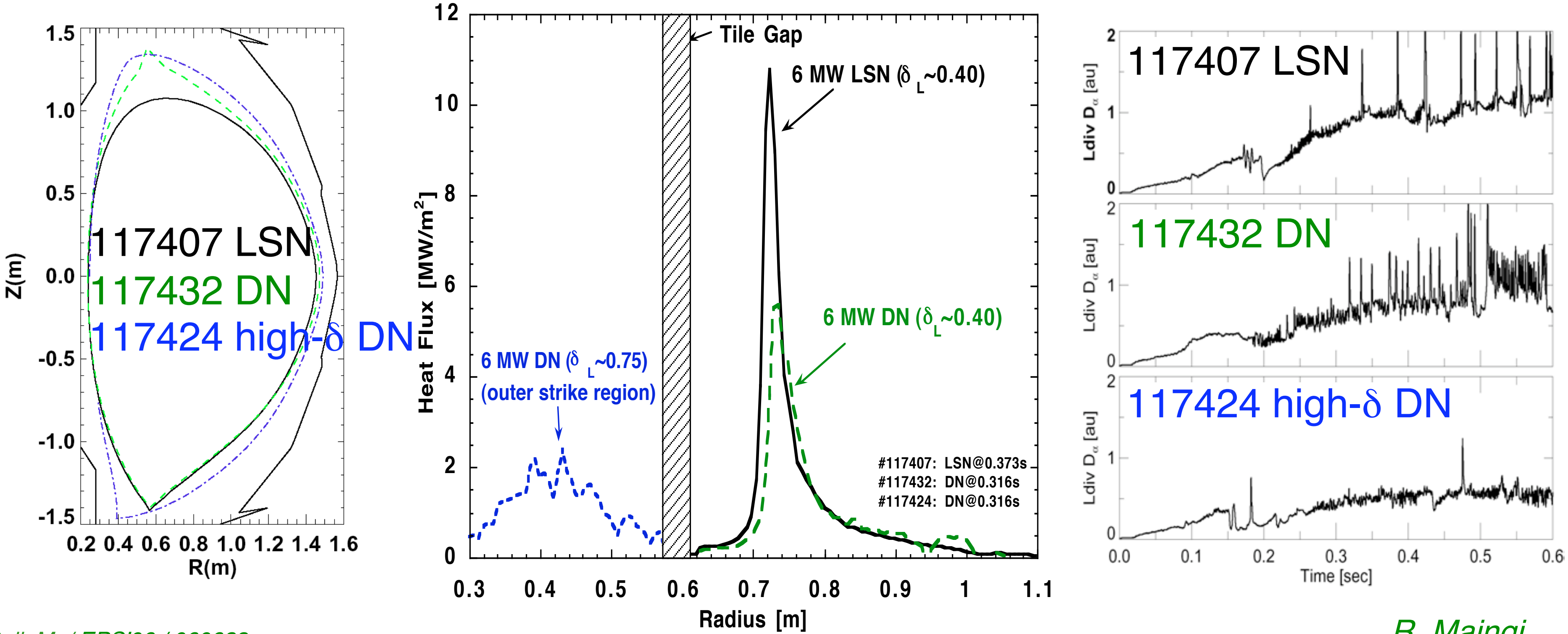
Sustained elongation κ=2.55 (0.1s)



- Highest κ now obtained at highest $\delta \approx 0.8 \Rightarrow S \equiv q_{95}\, I_P / aB_T = 41$ MA/m·T
- Small (Type V) ELM regime recovered at high $\kappa > 2.5$ with new coils
  - Previously observed onset of large ELM-like events when $\kappa > 2.2$

Increased Triangularity Reduces Peak Heat Flux to Divertor Target

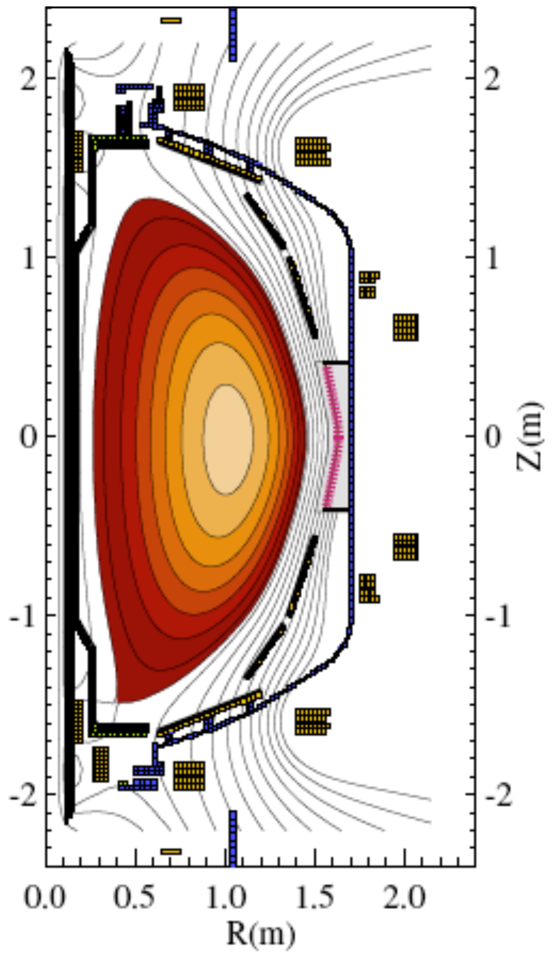
- Compare **single-null** & double-null configurations with triangularity $\delta \approx 0.4$ at X-point and **high triangularity δ = 0.8 double-null** plasmas
  - Measure heat flux with IR thermography of carbon divertor tiles
- Peak heat flux decreases as **1 : 0.5 : 0.2**
- ELM character changes: Type I → Mixed → Type V

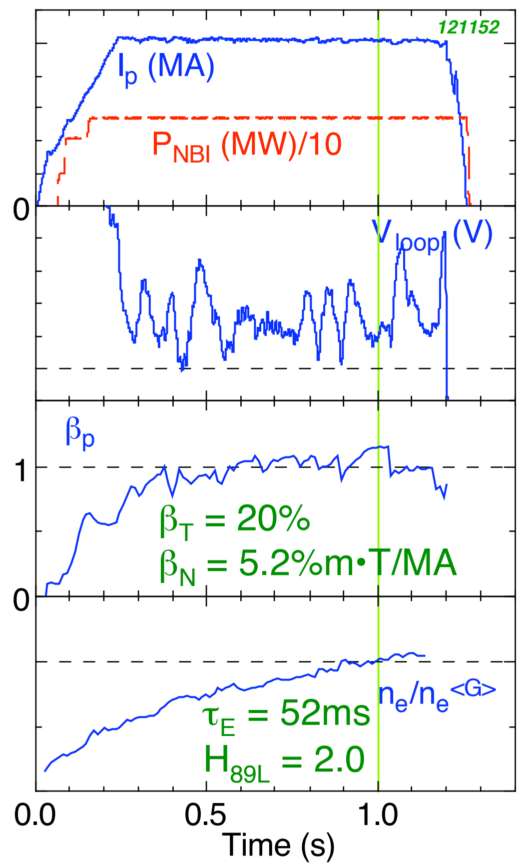


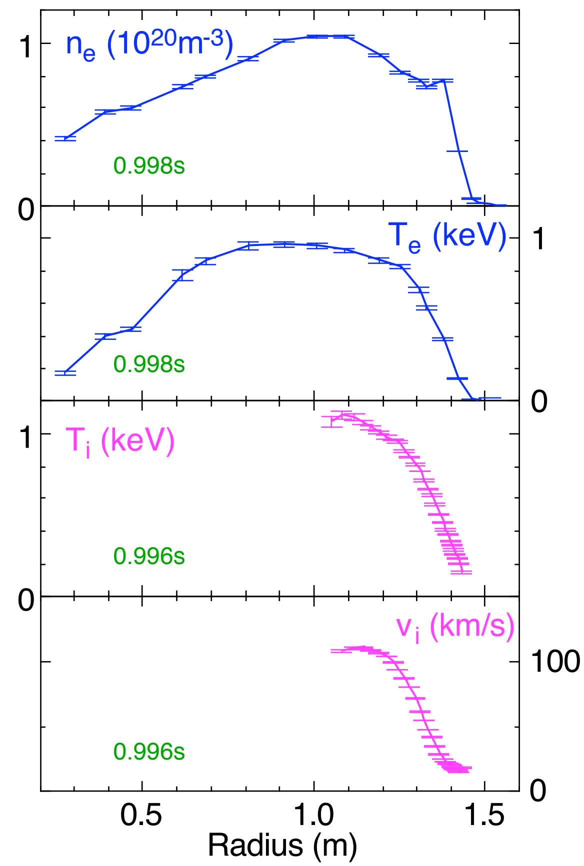
Record Pulse-Lengths Achieved at High Current by Operating with Sustained H-mode

NSTX

A = 1.4, κ = 2.3, δ = 0.75, l_i = 0.49



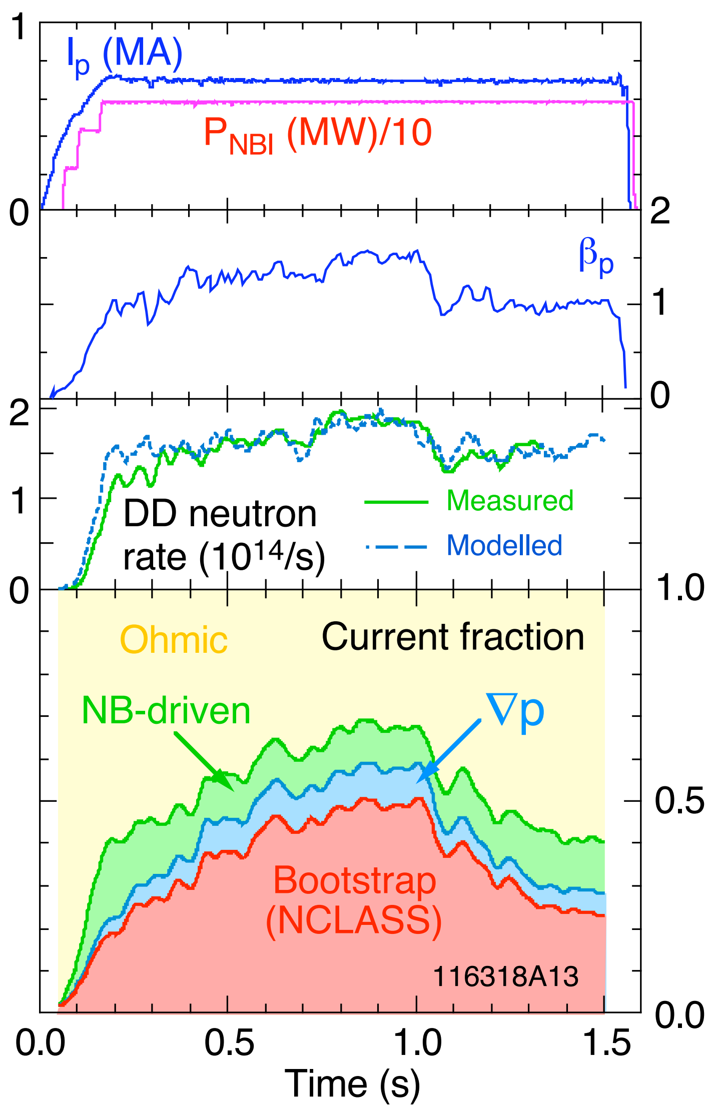




- H-mode with small ELMs ⇒ lower flux consumption, slow density rise
- High β_P increases bootstrap fraction ⇒ lower flux consumption

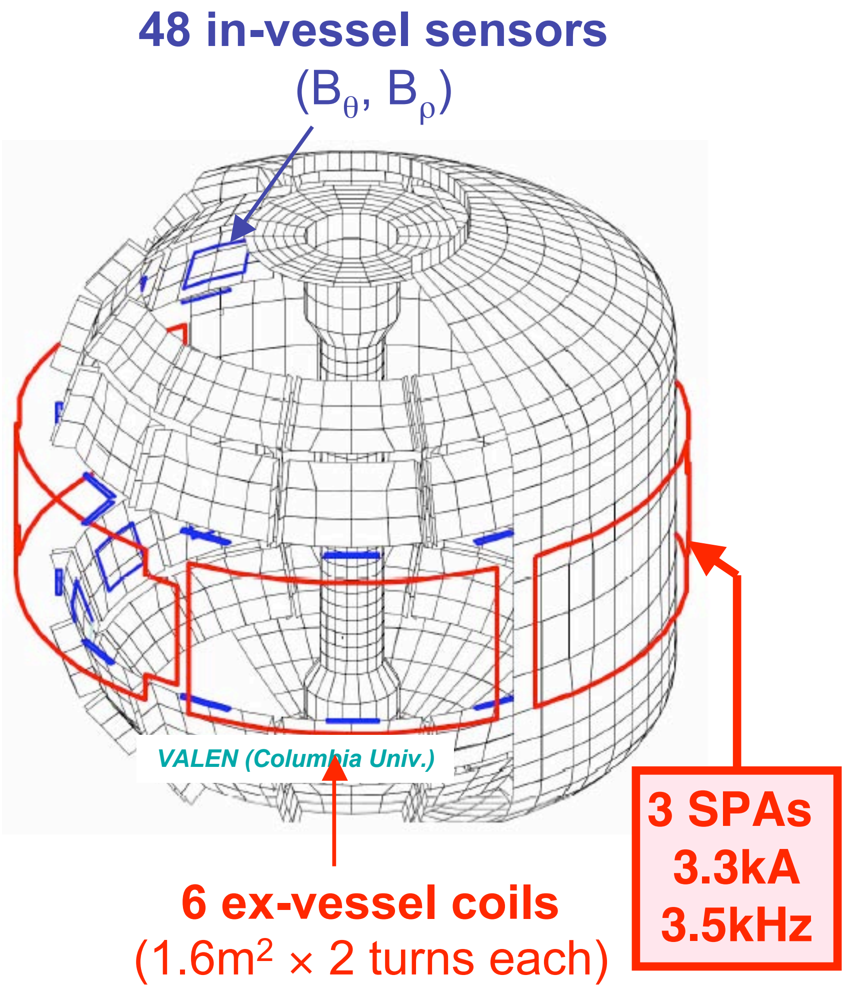
D. Gates, J. Menard

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



- TRANSP model agrees with measured neutron rate during high-β phase
  - Model includes anomalous fast ion diffusion during later phase when low-m MHD activity is present
- 85% of non-inductive current is ∇p-driven
  - Bootstrap + Diamagnetic + Pfirsch-Schlüter

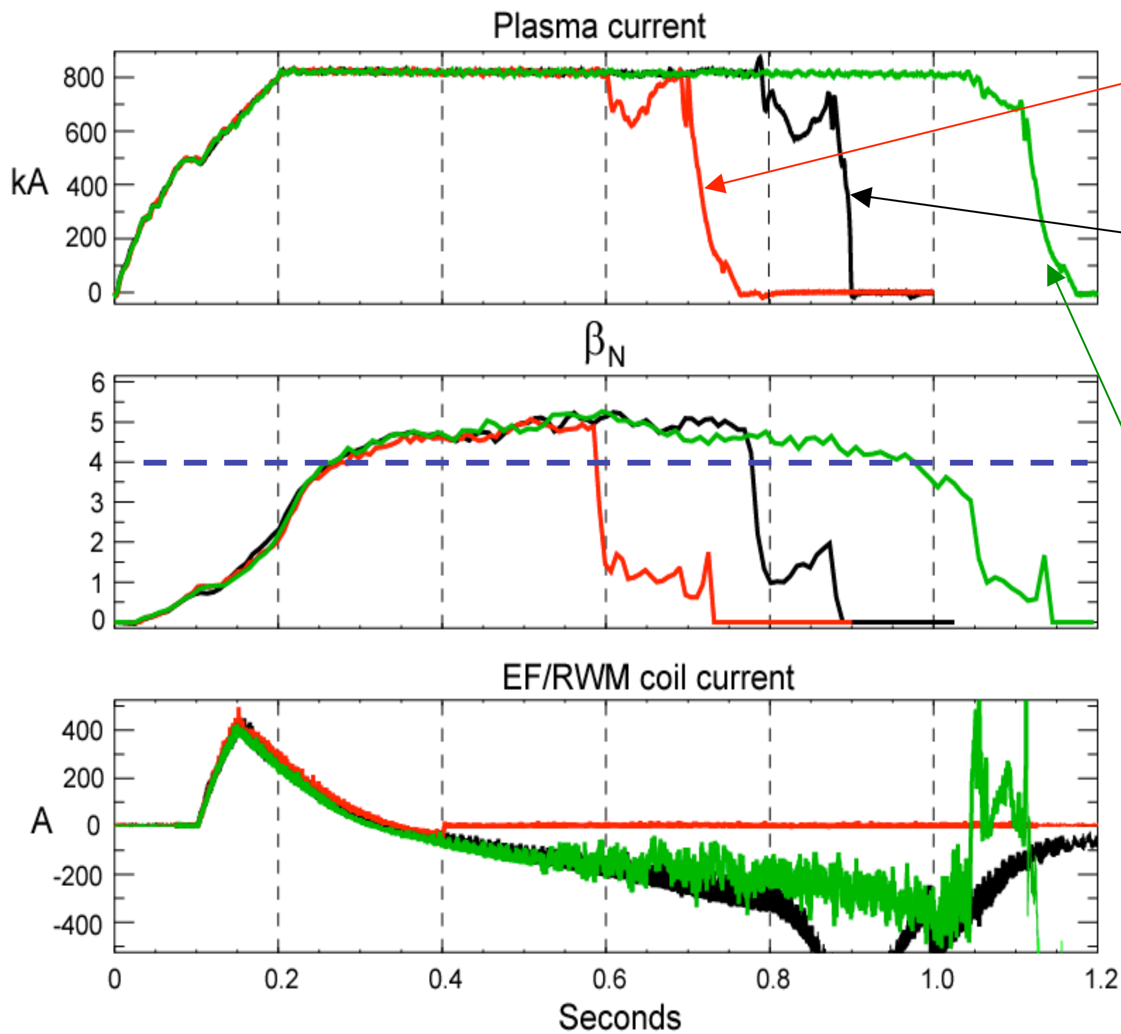
External Radial Field Coils Used to Counteract Error Fields and Improve Plasma Stability



- External midplane control coils closely coupled to vacuum vessel
  - Similar to ITER port plug designs
- Investigated both pre-programmed corrections to error fields and feedback on mode amplitude
  - Signals from magnetic sensors processed in real-time
- Internal sensors detect n = 1 – 3 **Resistive Wall Modes (RWM)**
  - Unstable n = 1 – 3 RWMs already observed in NSTX (Sabbagh *et al.*, NF **46** (2006) 635)

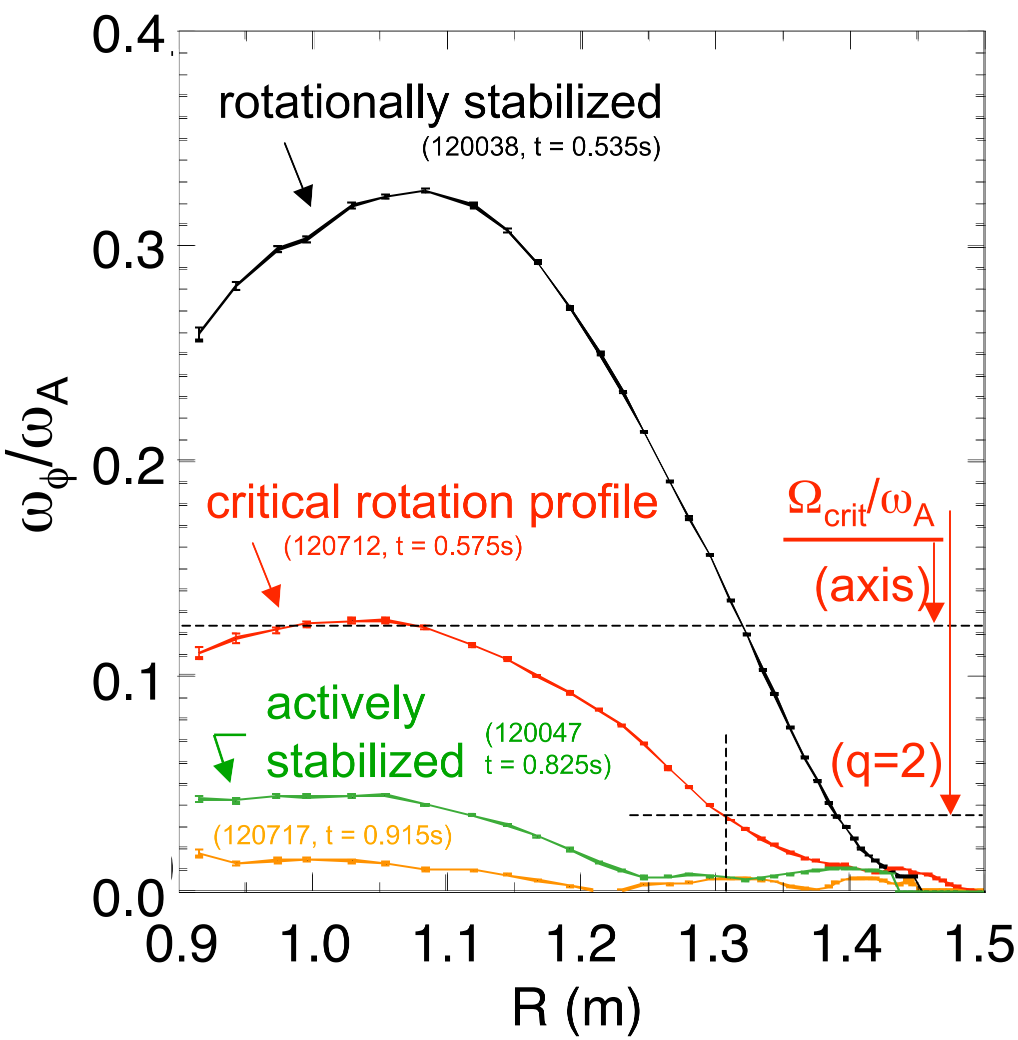
S. Sabbagh, A. Sontag (Columbia), J. Menard, D. Gates

Correction of Intrinsic Error Fields Extends High-β_N NSTX Discharges



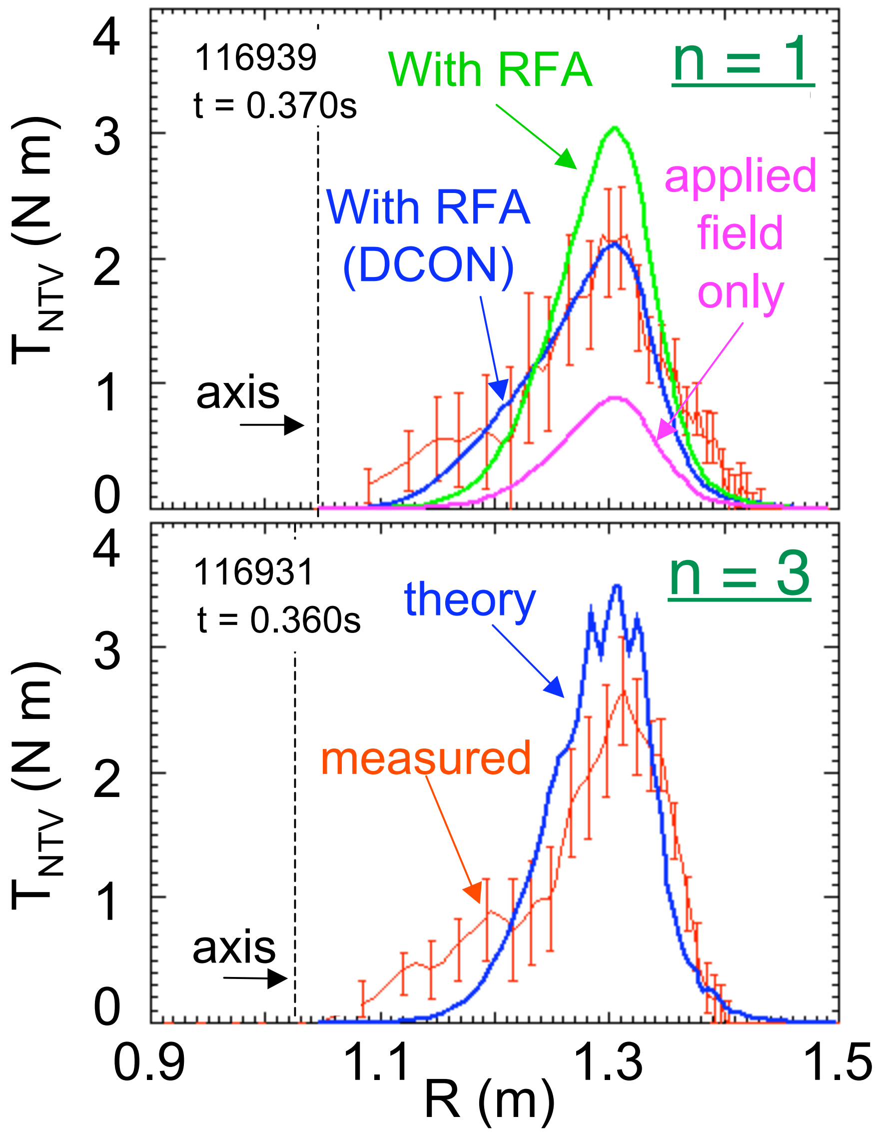
- Error field control only during initial heating phase
- Predictive correction of known error fields
  - OH × TF interaction
- Predictive correction + active feedback

Non-resonant n = 3 Static Magnetic Braking Used to Suppress Intrinsic Rotation for RWM Studies



- Intrinsic rotation in NSTX typically fast and sufficient for passive stabilization of RWM
  - Reached ω_ϕ/ω_A = 0.48 on axis
- Entire rotation profile important for RWM passive stabilization
  - not just single radial location
- With braking, rotation reduced well below RWM critical rotation profile
  - The ω_A/Ω_{crit} = 0.2 at q = 2
  - The ω_A/Ω_{crit} = 0.3 on axis
  - Below rotation predicted for ITER Advanced Scenario 4

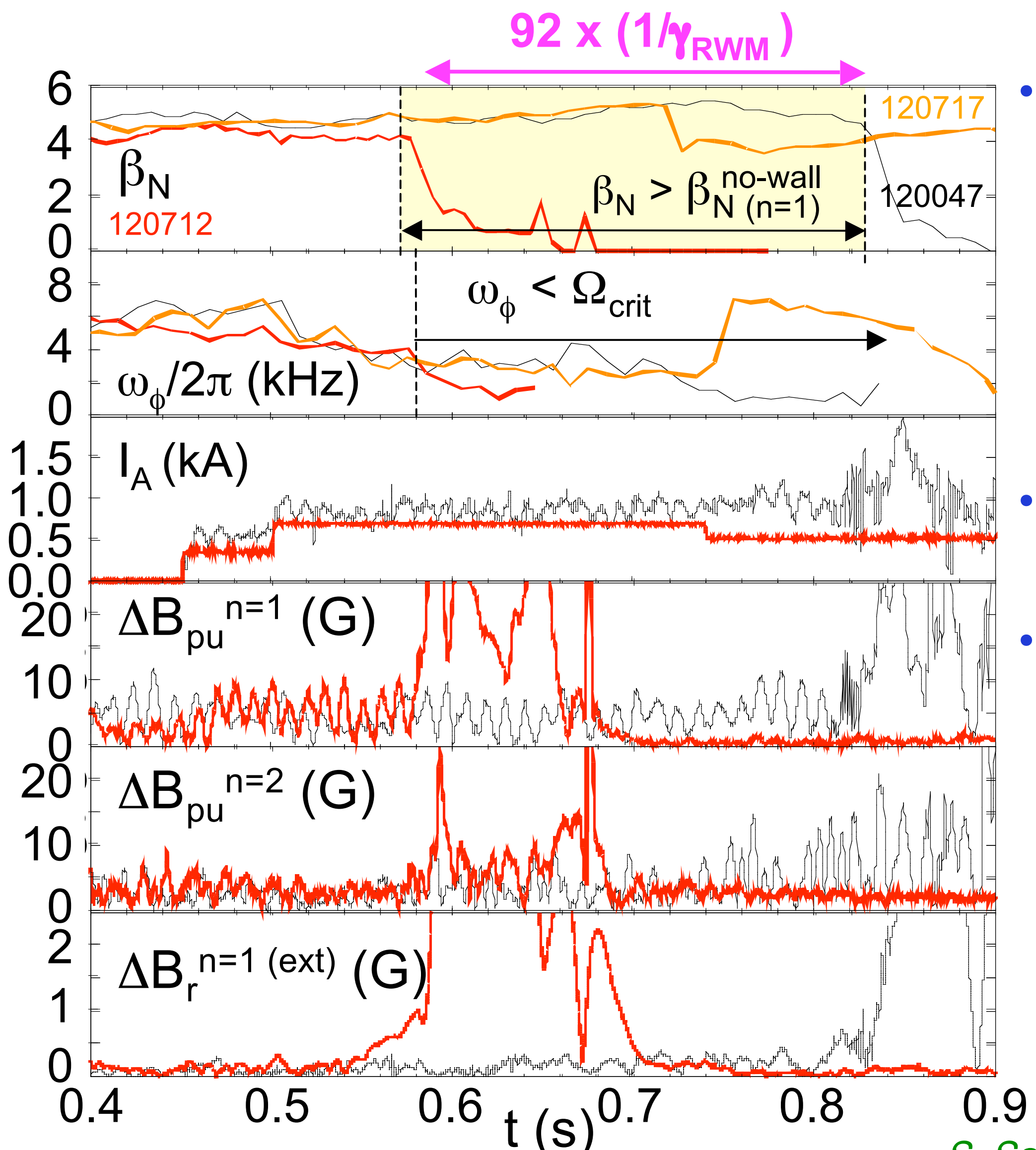
Observed Rotation Damping by Magnetic Braking Explained by Neoclassical Toroidal Viscosity



- Model based on details of applied damping fields
  - Spectrum of n's and m's required, not just primary mode
- Pressure-driven resonant field amplification (RFA) included in calculations
  - Increases non-axisymmetric field at high beta
  - Based on mode spectrum of applied field, or DCON computed mode spectrum
- Trapped particle effects are important at low aspect ratio (W. Zhu *et al.*, PRL **96**, 225002 (2006))

W. Zhu, S. Sabbagh (Columbia), R. Bell

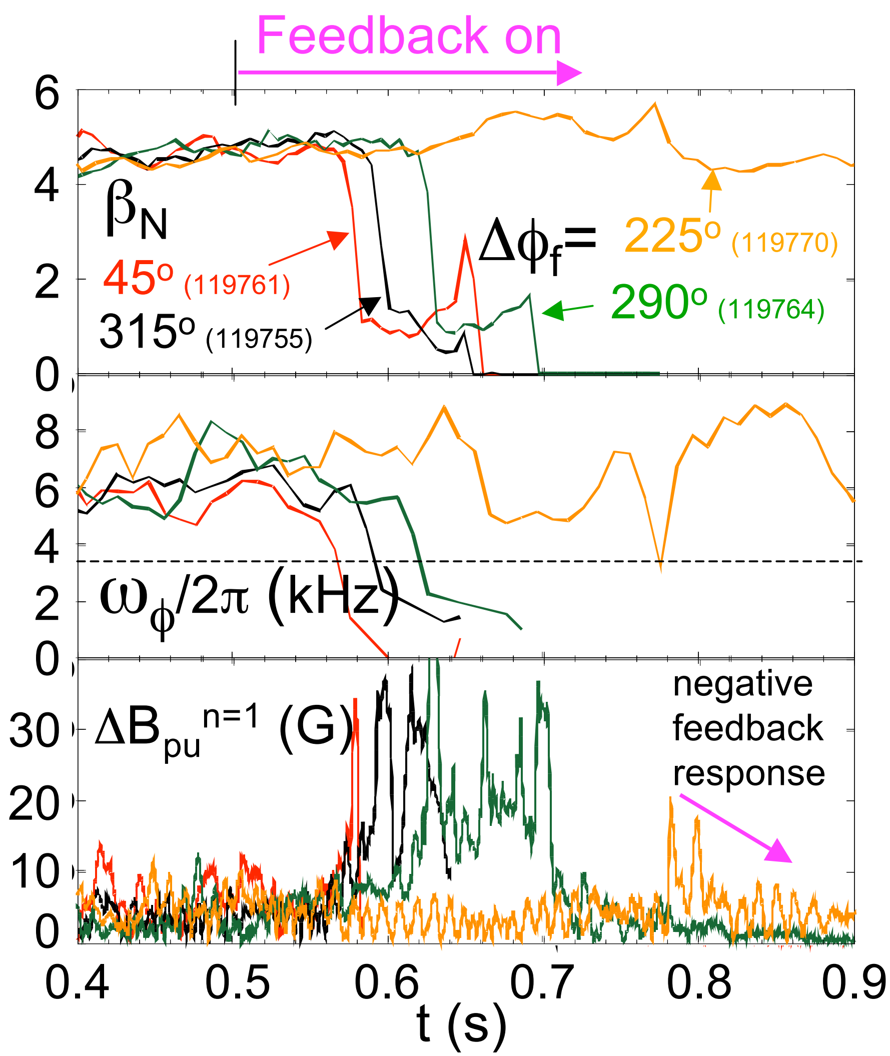
RWM Stabilized by Feedback for ~ 90/γ_{RWM} at ITER-Relevant Rotation Rate



- Rotation ω_ϕ reduced below critical rate by non-resonant *n* = 3 braking starting at 0.45s
  - Rotation falls to less than ½ $\omega_\phi/\Omega_{crit}$ predicted for ITER (Liu *et al.*, NF **45** (2005) 1131)
- Feedback on n = 1 mode added to static n = 3 braking currents
- Discharge exceeds $\beta_N^{no\text{-}wall}$ for both n = 1 & 2 modes
  - Time evolution of growth rate computed by DCON
  - n = 2 amplitude increases slightly but remains stable during feedback on n = 1 mode

S. Sabbagh, A. Sontag (Columbia), J. Menard, R. Bell

Positive/Negative Feedback Created by Varying Relative Phase of n = 1 Current Components

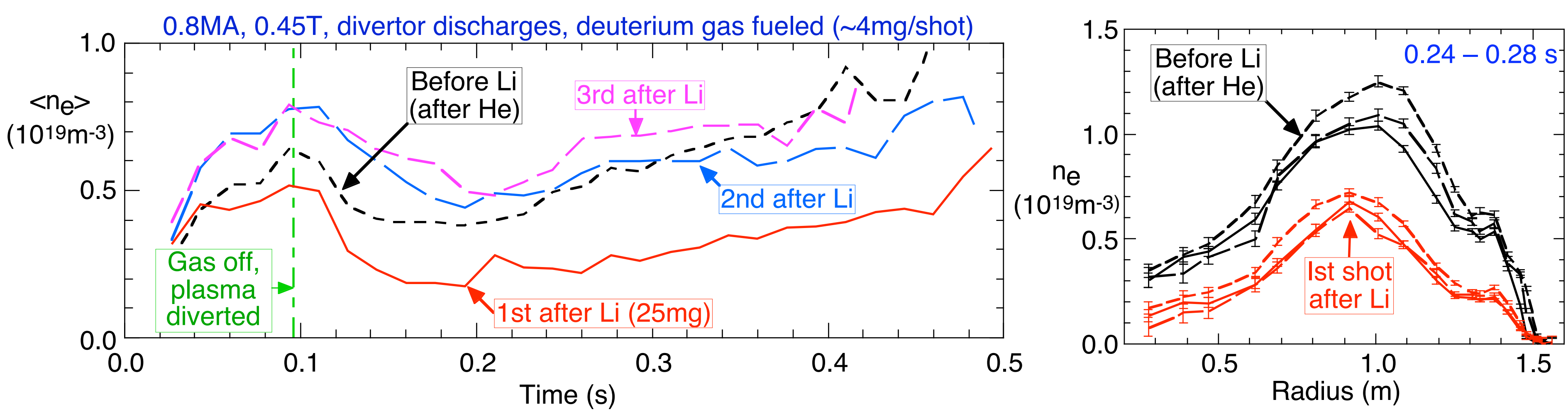


- RWM active feedback on n = 1
- Varied phase delay $\Delta\phi_f$ of control current relative to phase of detected n = 1 mode
- Pulse length increases when phase delay $\Delta\phi_f$ = 225° creates negative feedback on mode amplitude
  - Damped system response to internal plasma mode seen at t = 0.78s
- Gain scan also performed
  - Sufficiently high gain created feedback loop instability

S. Sabbagh, A. Sontag (Columbia), J. Menard, R. Bell

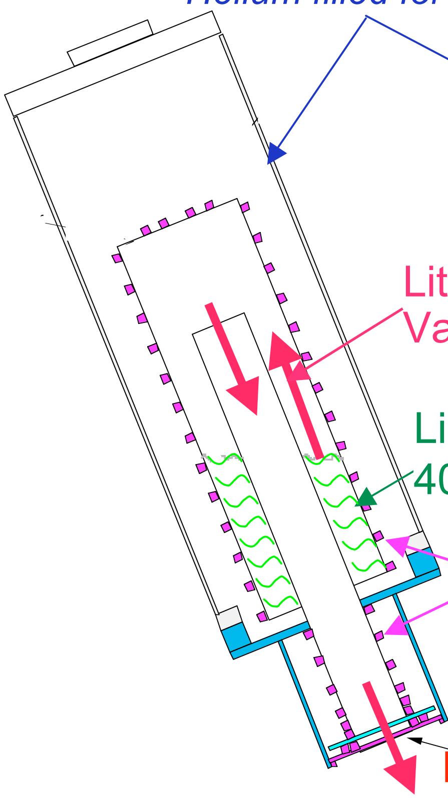
Lithium from Injected Pellets Deposited on Plasma-Facing Surfaces Provides Edge Pumping

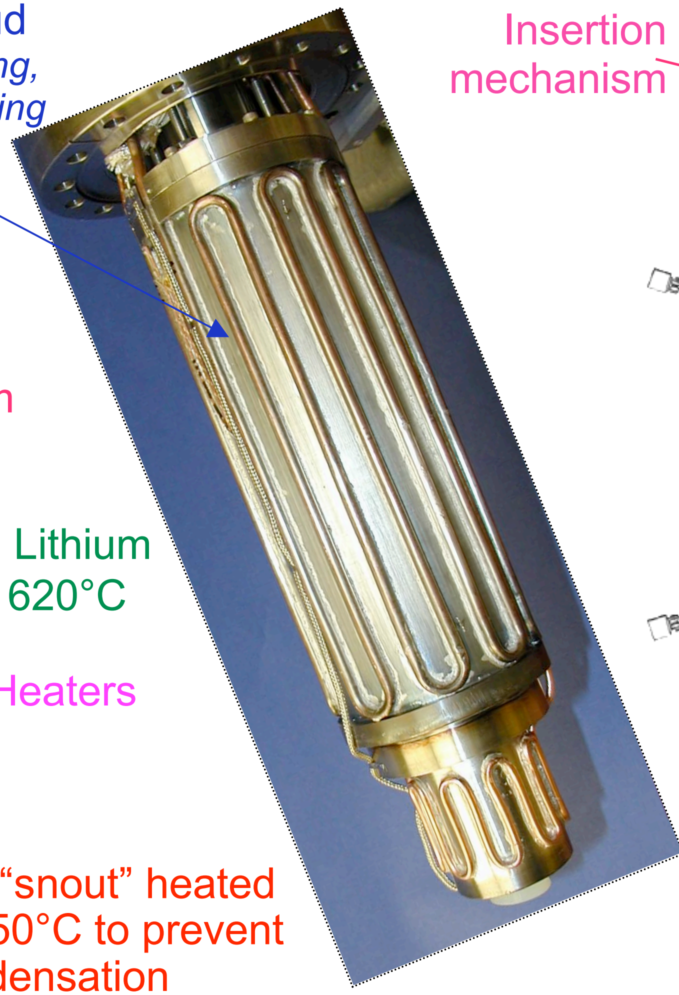
- Fired lithium pellets (1.7 – 5 mg) from multi-barrel pneumatic injector into sequences of ohmically-heated helium discharges
  - Limited on center-stack tiles or lower-single-null divertor
  - After “pre-conditioning” surfaces with OH helium plasma
  - 1 or 2 pellets per discharge, 24 – 30 mg total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

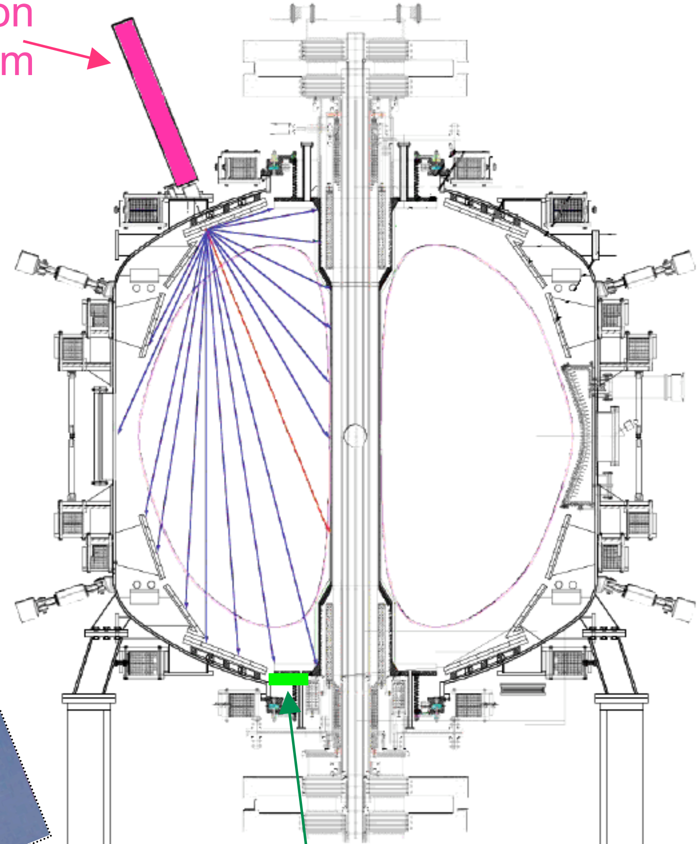


- Effect disappeared by 3rd similar discharge
  - Expected if most injected gas reacts with deposited lithium

This Year, Lithium Evaporator Used to Coat Center-Column and Lower Divertor



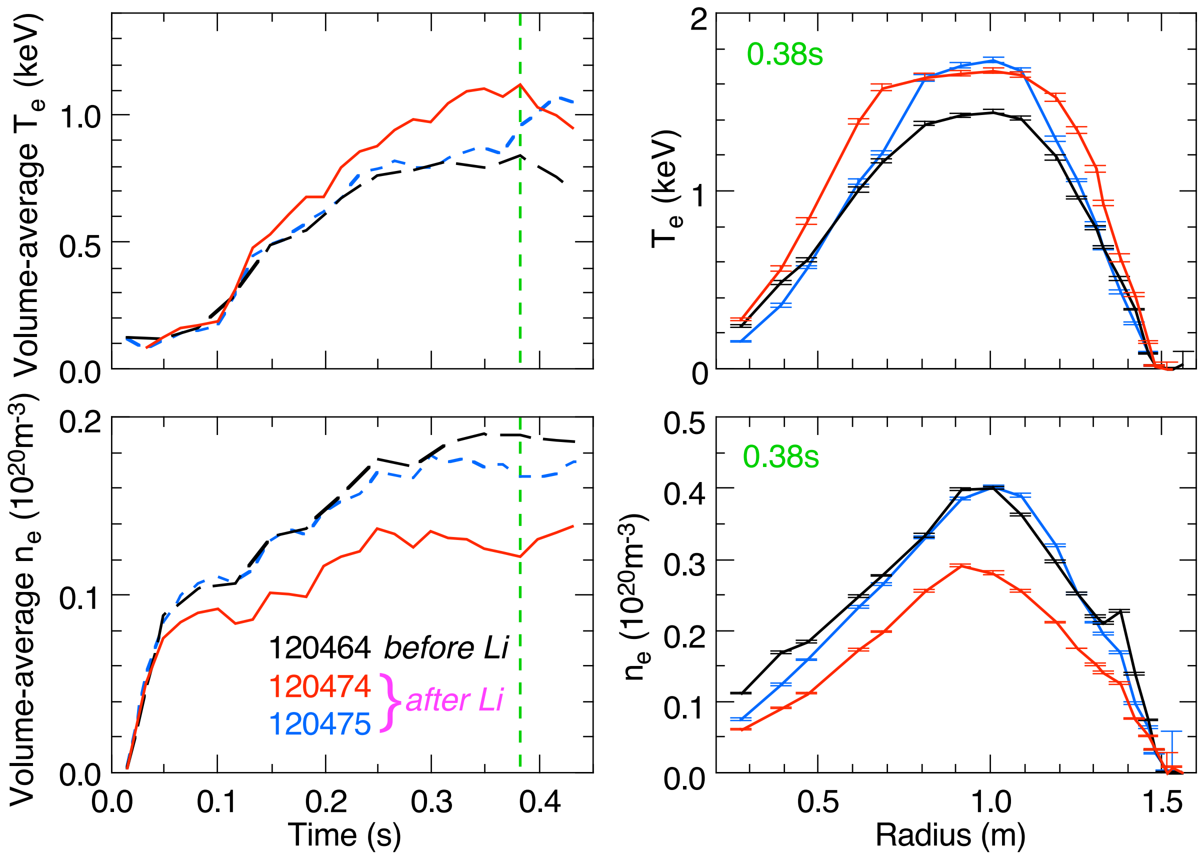




- Evaporation rates up to 8mg/min
- Deposited 14 – 640 mg over periods 60 – 370 min

H. Kugel, D. Mansfield, R. Kaita, R. Majeski, J. Timberlake, C. Skinner

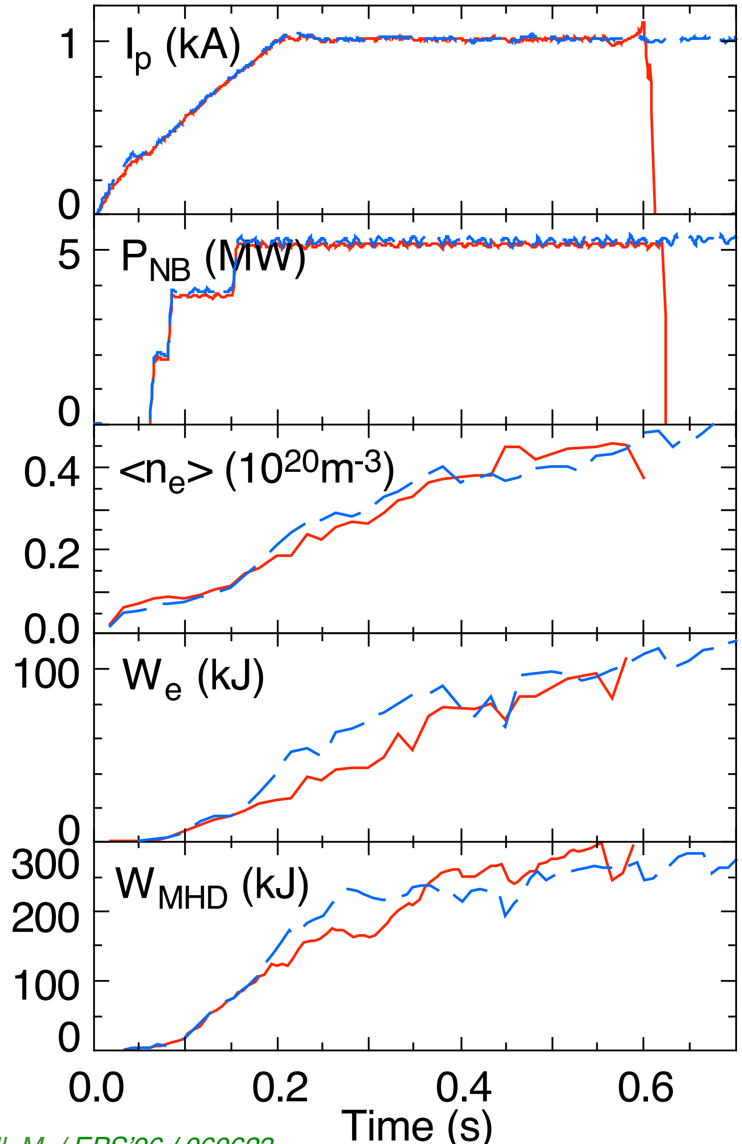
Evaporated Lithium Coating Provides Similar Transient Reduction in Recycling



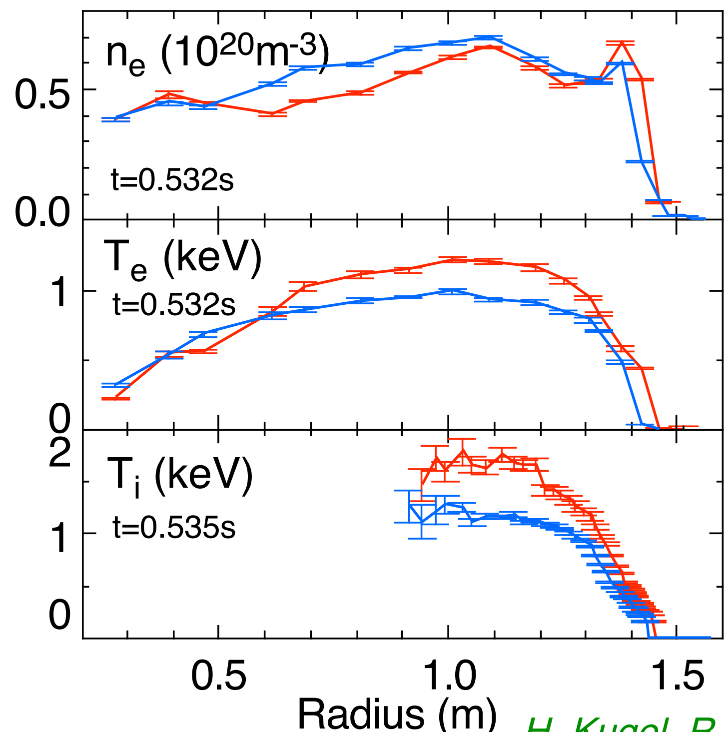
- NB-heated **L-mode** discharges with same gas puffing
- Intervening shots were ohmic helium plasmas
  - Used to prepare the PFCs for lithium
  - May account for up to 60% of observed density reduction
- ~400mg lithium evaporated in about 1 hr

- Reduction in density disappeared on second discharge, *but*
- There was a significant reduction in oxygen impurity radiation
  - *this persisted over several days of operation*

Lithium Coating Affects Core of H-mode Discharges with Small Change in Pedestal



- Both shots *without* helium conditioning
  - Similar gas puff on both shots
- H-mode transition delayed 20ms and dithered for ~50ms on post-Li shot
- ELM spikes slower, atypical post-Li



Similar central n_e

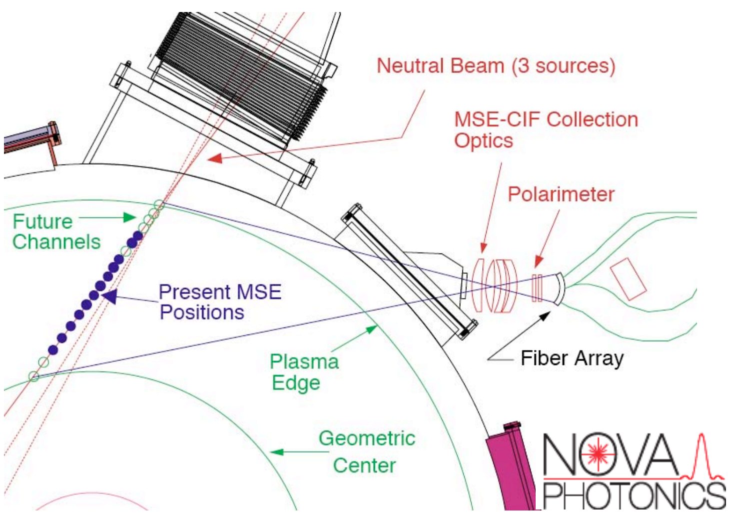
Higher central T_e

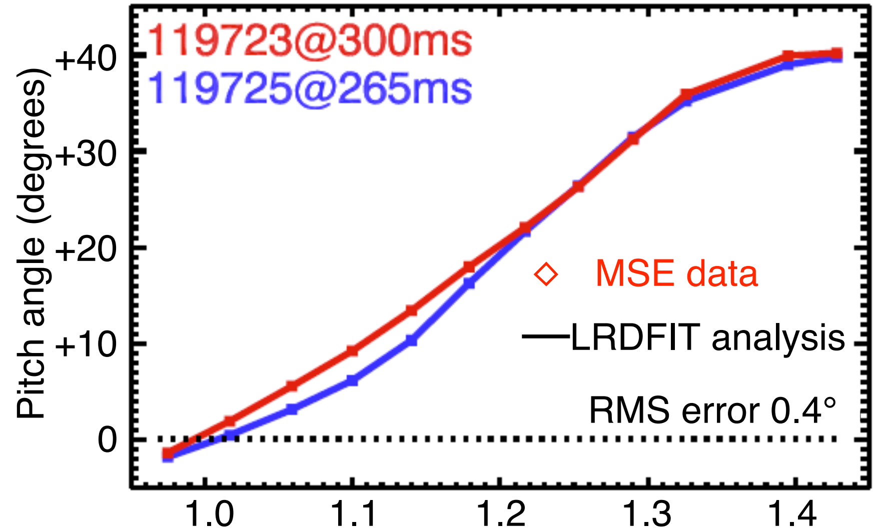
Much higher central T_i

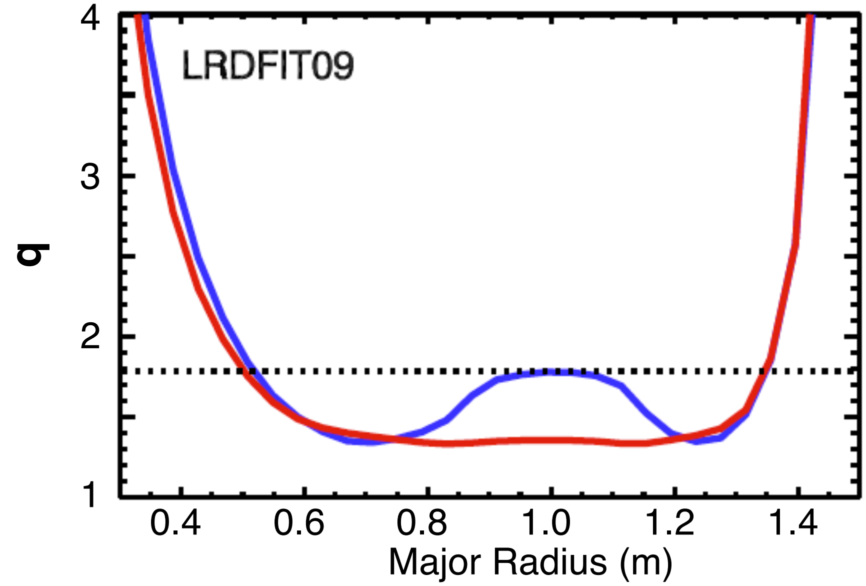
H. Kugel, R. Maingi, B. LeBlanc

Motional Stark Effect Diagnostic Routinely Measures Magnetic Field Line Pitch at 12 Points

- Measures from outer edge past magnetic axis
- Calibrated by NBI into neutral gas with known applied fields
- Analyze with EFIT, LRDFIT, ESC
  - Can include correction for E_r using CHERS v_ϕ profile

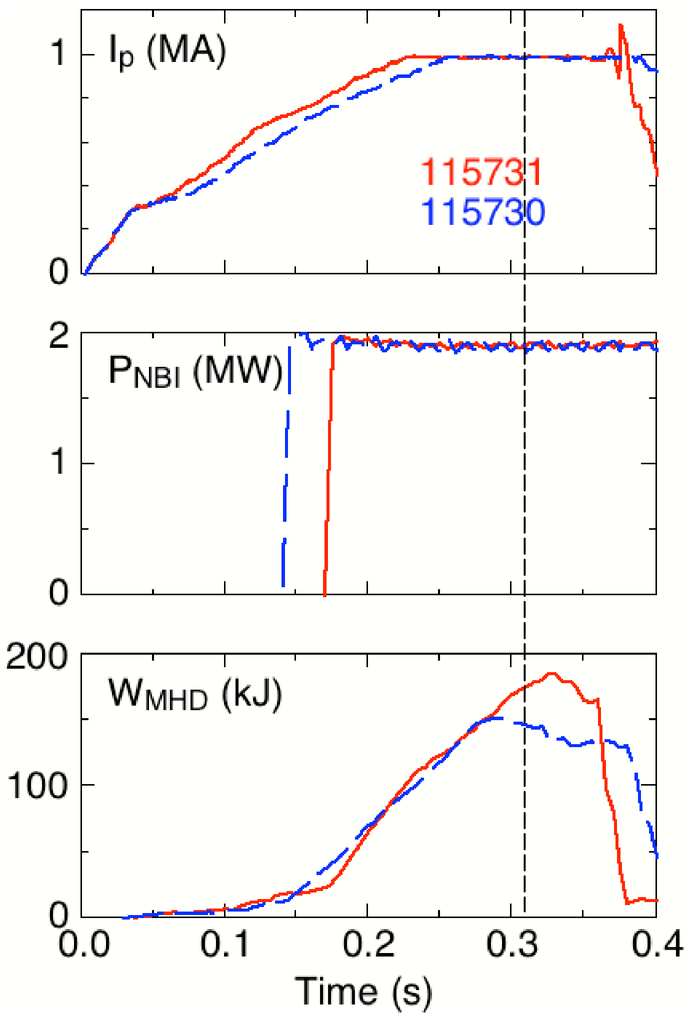


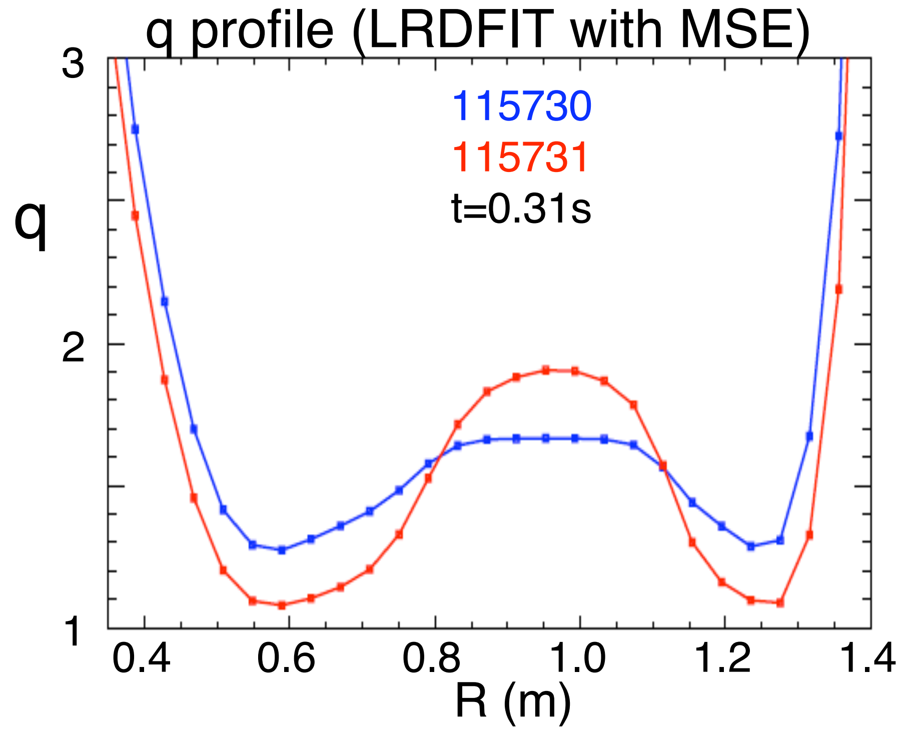




F. Levinton, H. Yu (Nova), S. Sabbagh (Columbia), J. Menard

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

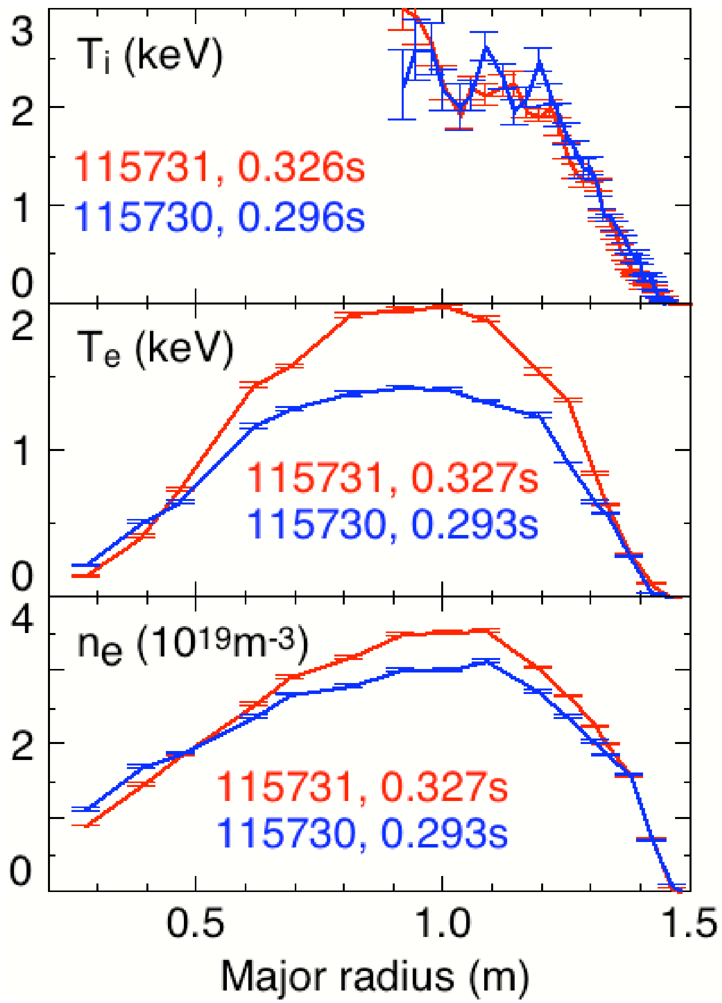




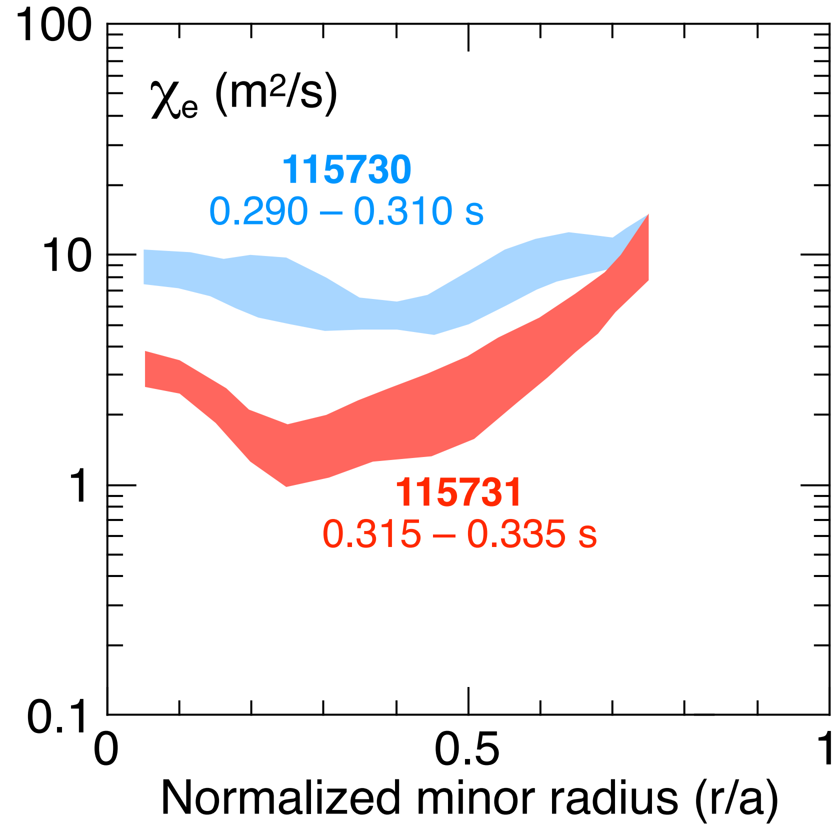
- q-profile very dependent on early MHD activity
  - Events lead to monotonic profile
- Also combined RS with H-mode edge but not yet optimized

F. Levinton, H. Yuh (Nova), J. Menard

Reversed-Shear Appears to Produce an Electron Transport Barrier



TRANSP with classical NB thermalization

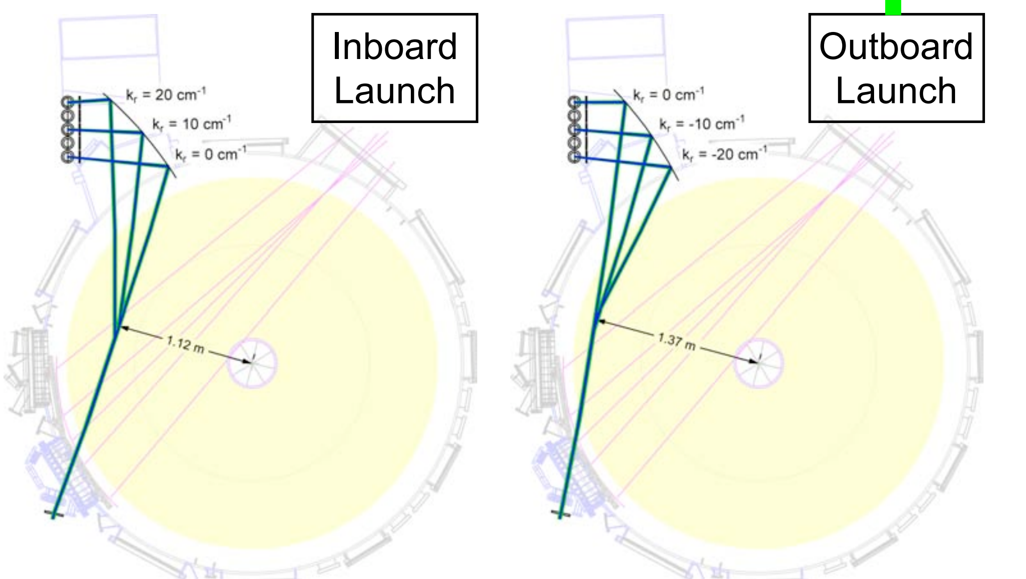


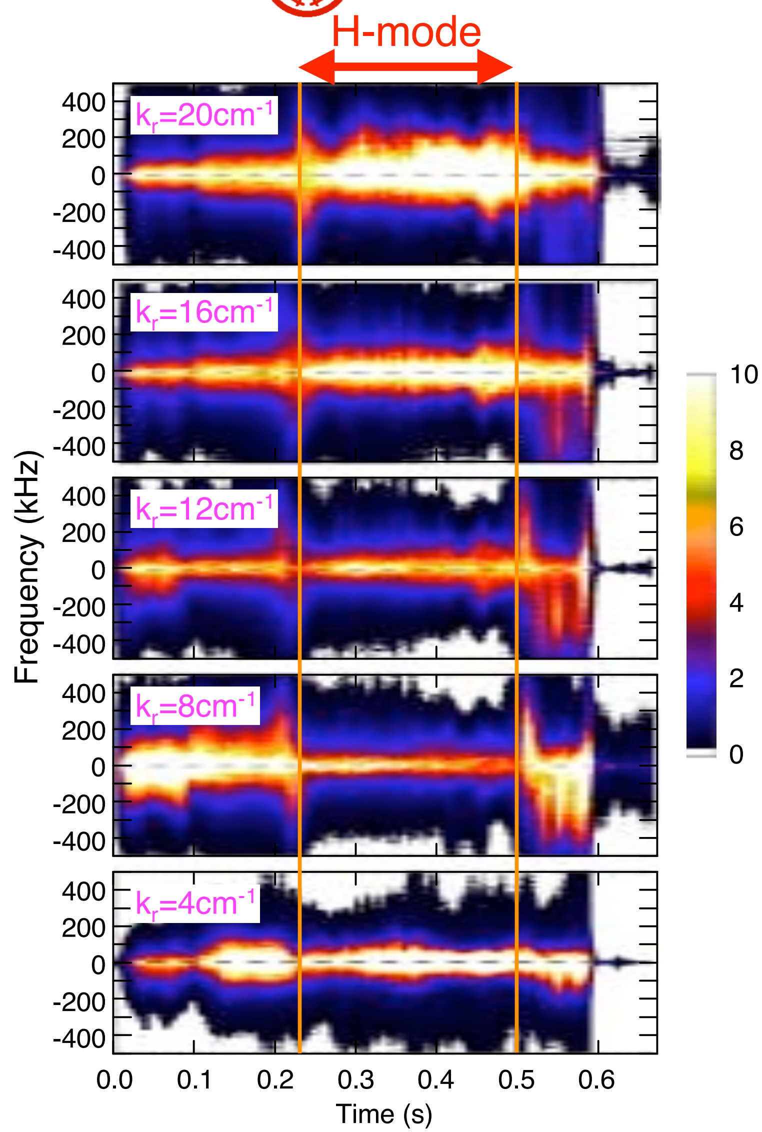
- χ_e reduced by 2–5 in confinement zone

F. Levinton (Nova), R. Bell, B. LeBlanc, S. Kaye

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

- λ = 1mm probe beam launched tangentially near midplane
- Inboard (near magnetic axis) / outboard (near edge) launch configurations
  - k_r = 2 – 22 cm^{-1}
- Five channels with low-noise super-heterodyne receivers





E. Mazzucato, H. Park, D. Smith, C. Domier (UCD)

Status and Plans

- NSTX made significant progress in 2005-6
  - Extension of operating regime and pulse lengh at high κ and δ
  - Error Field Correction and RWM Control coils for improving performance
  - Particle control with lithium coating in both limiter and divertor plasmas
  - Exploration of reversed-shear regime
- Now entering an outage planned to last until December 2006
  - Install “poloidal CHERS” diagnostic for v_θ profile
  - Upgrade lithium coating system to cover entire divertor and wall
  - In situ calibration of high-k fluctuation diagnostic
- Currently expect to operate for ~12 run weeks in 2007
- NSTX 2006 Research Forum for planning experiments in 2007 will take place towards the end of this year
  - Participation by our collaborators is encouraged!