New Capabilities and Results for the *National Spherical Torus Experiment* *

M.G. Bell, Princeton Plasma Physics Laboratory
on behalf of the NSTX Research Team

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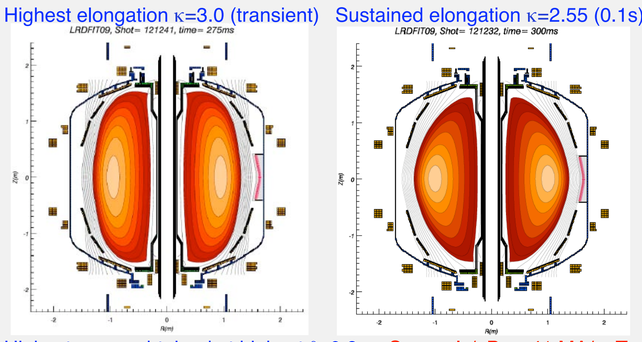
Supported by

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

- Good performance of TF coil: 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=3.0 (transient) Sustained elongation κ=2.55 (0.1s)

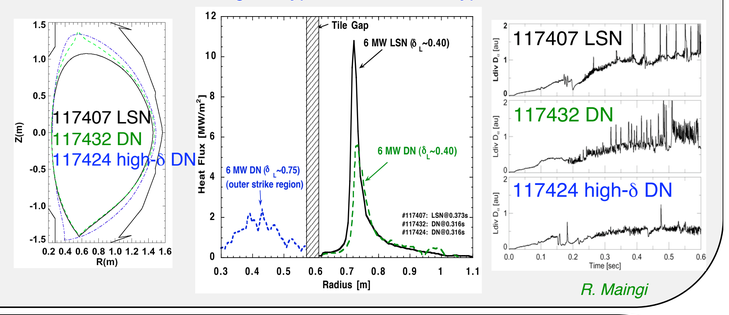


- Highest κ now obtained at highest $\delta \approx 0.8 \Rightarrow S \equiv q_{95} I_P/aB_T = 41$ MA/m·T
- Small (Type V) ELM regime recovered at high $\kappa > 2.5$ with new coils
  - Previously observed onset of large ELM-like events when $\kappa > 2.2$

D. Gates , J. Menard

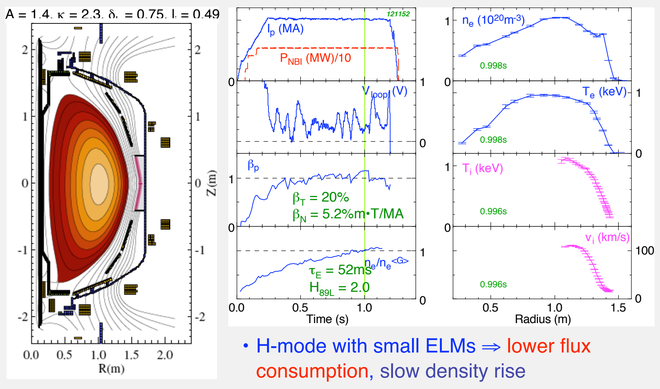
Increased Triangularity Actually Reduces Peak Heat Flux to Divertor Target

- 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



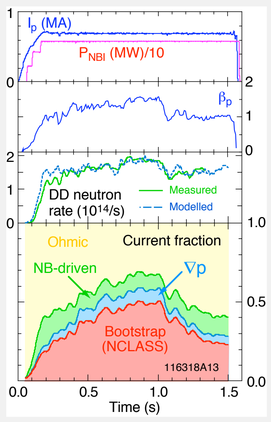
R. Maingi

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



- H-mode with small ELMs ⇒ lower flux consumption, slow density rise

Long Duration Discharges Reach ~70% Non-Inductive Current



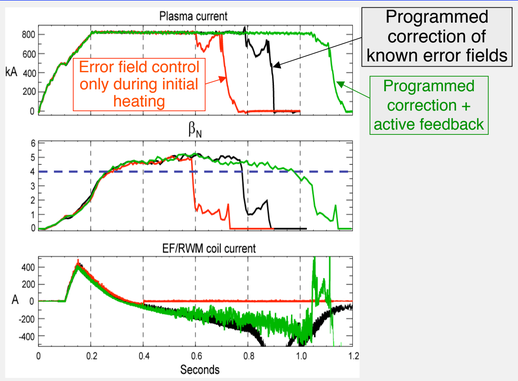
- TRANSP model agrees with measured neutron rate during high-β phase
  - Model includes anomalous fast ion diffusion during later phase when low-m MHD activity is present
- 85% of non-inductive current is ∇p-driven
  - Bootstrap + Diamagnetic + Pfirsch-Schlüter

D. Gates, J. Menard

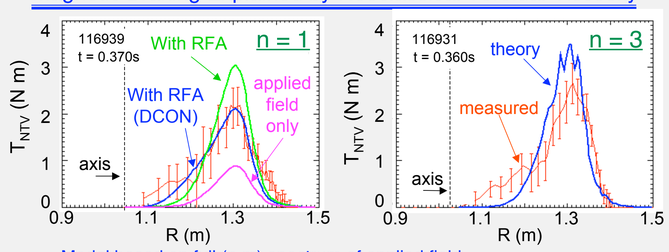
External Radial Field Coils Used to Counteract Error Fields and Improve Plasma Stability

- External midplane control coils closely coupled to vacuum vessel – similar to ITER port plug designs
- Internal sensors detect n = 1 – 3 **Resistive Wall Modes (RWM):** signals processed in real-time
- Investigated both pre-programmed corrections to error fields and feedback on mode amplitude

Correction of Error Fields Extends High-β_N Discharges



Magnetic Braking Explained by Neoclassical Toroidal Viscosity

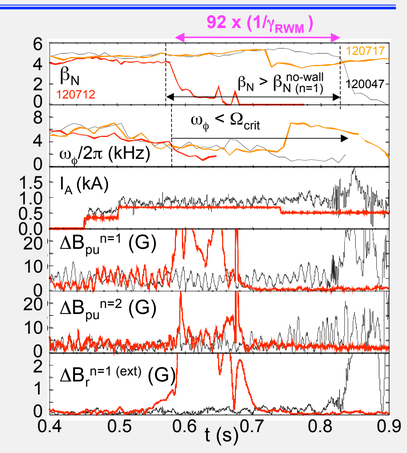


- Model based on full (n,m) spectrum of applied field
- Pressure-driven resonant field amplification (RFA) included
  - Increases non-axisymmetric field at high beta
  - Use mode spectrum of applied field, or computed by DCON code
- Trapped particle effects important at low aspect ratio

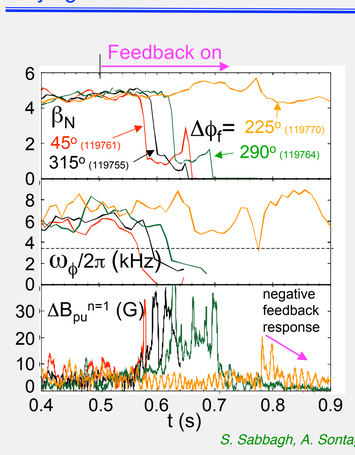
[W. Zhu *et al.*, PRL **96**, 225002 (2006)]

RWM Feedback Stabilized for ~ 90/γ_{RWM} with ITER-Relevant Rotation

- 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 remains stable during feedback on n = 1 mode



Varying Phase of n = 1 Currents Creates Positive/Negative Feedback



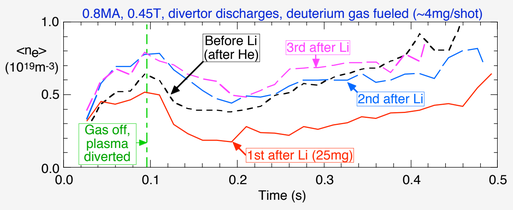
- RWM active feedback on n = 1
- Varied phase delay $\Delta\phi_f$ of control current relative to phase of detected n = 1 mode
- Pulse length increases when phase delay $\Delta\phi_f = 225°$ creates negative feedback on mode
  - Damped system response to internal plasma mode seen at t = 0.78s
- Too high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

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

Experiments with Lithium Coating of Plasma Facing Surfaces

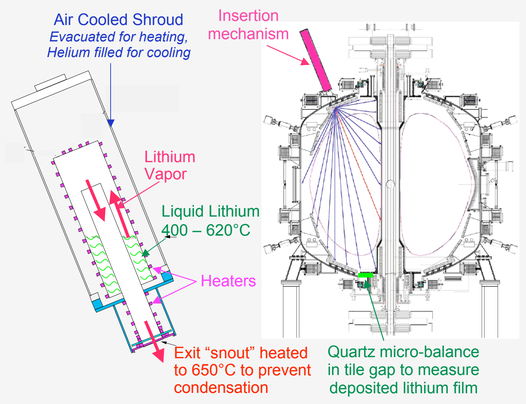
Lithium from Pellets Provides Edge Pumping

- Fired lithium pellets (1.7 – 5 mg) from multi-barrel pneumatic injector into sequences of ohmically-heated helium discharges
  - Limited on center-column or lower-single-null divertor
  - "Pre-conditioned" 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



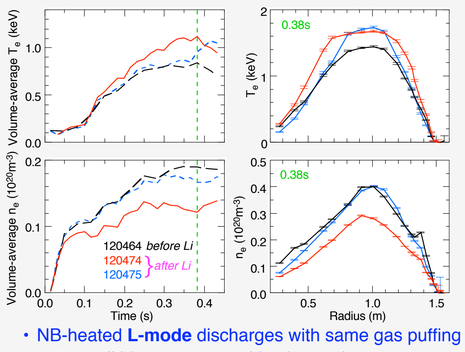
- Effect disappeared by 3rd similar discharge
  - Expected if most injected gas reacts with deposited lithium

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



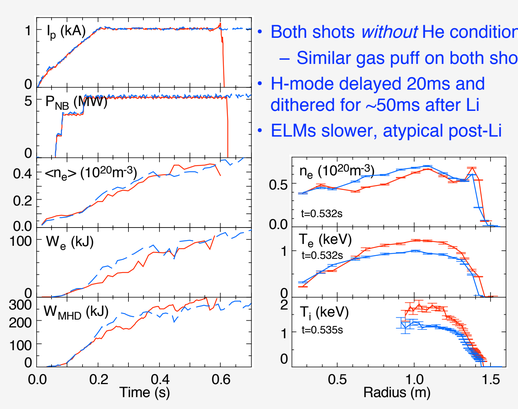
- Evaporation rates up to 8mg/min
- Deposited 14 – 640 mg over periods 60 – 370 min

Evaporated Lithium Coating Provides Similar Transient Reduction in Recycling



- NB-heated **L-mode** discharges with same gas puffing
- ~400mg lithium evaporated in about 1 hr
- No reduction in density on second discharge, *but*
- Substantial reduction in oxygen impurity radiation
  - *this persisted over several days of operation*

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

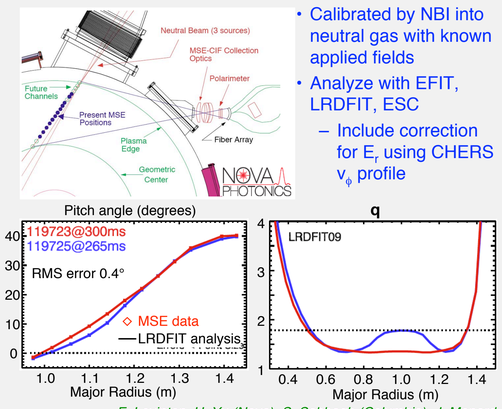


- Both shots *without* He conditioning
  - Similar gas puff on both shots
- H-mode delayed 20ms and dithered for ~50ms after Li
- ELMs slower, atypical post-Li

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

Effects of Changing the Magnetic Shear on Transport

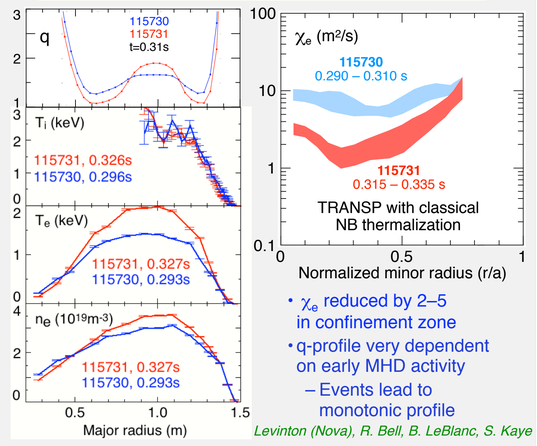
Motional Stark Effect Diagnostic Routinely Measures Magnetic Field Line Pitch Profile



- Calibrated by NBI into neutral gas with known applied fields
- Analyze with EFIT, LRDFIT, ESC
  - Include correction for E_r using CHERS v_ϕ profile

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

Electron Transport Barrier Appears When Shear Deeply Reversed

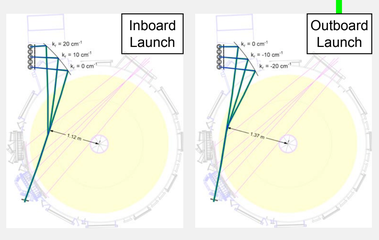


- χ_e reduced by 2–5 in confinement zone
- q-profile very dependent on early MHD activity
  - Events lead to monotonic profile

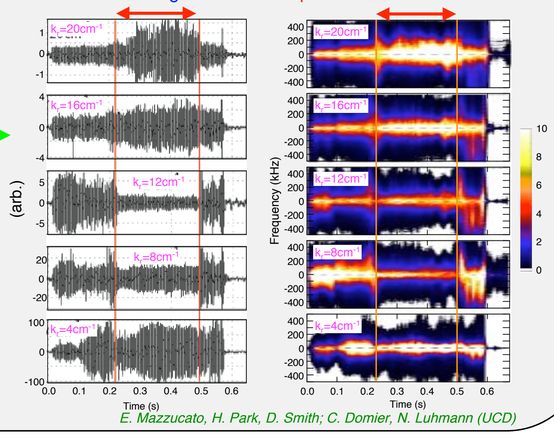
Levinton (Nova), R. Bell, B. LeBlanc, S. Kaye

New High-k Scattering Diagnostic Probes Turbulence Related to Electron Transport

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



Scattered power and frequency spectra for outside launch in discharge with H-mode phase 0.22 – 0.50 s



E. Mazzucato, H. Park, D. Smith; C. Domier, N. Luhmann (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
- 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!