NSTX

U.S. DEPARTMENT OF ENERGY | Office of Science

Boundary Physics Progress and Plans

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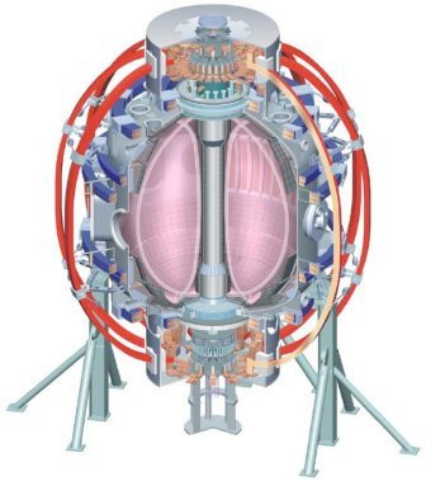
U Maryland
U Rochester
U Washington
U Wisconsin

R. Maingi, OAK RIDGE National Laboratory

For the NSTX Research Team

NSTX PAC meeting
Conference Room LSB-B318, PPPL
Feb. 18-20, 2009



Culham Sci Ctr
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Boundary physics program in NSTX mainly focused on NSTX-U and next step ST design needs

Program also contributes to toroidal confinement and ITER physics

- SOL and divertor physics
  - Particle control: Lithium for pumping and a concomitant fueling program for density control
  - SOL turbulence and transport & SOL width studies
  - Divertor physics, emphasis on heat flux management
- H-mode Physics
  - Pedestal and ELM studies
  - Participation in L-H power threshold studies (transport & turbulence group)

} 1 Lithium Thrust *Skinner*

} 2

} 3

Increasing importance of boundary physics program in NSTX highlighted by upcoming Joint Research Targets (JRT)

- SOL and divertor physics
  - Particle control: Lithium for pumping and a concomitant fueling program for density control
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  - Divertor physics, emphasis on heat flux management
- H-mode Physics
  - Pedestal and ELM studies
  - Participation in L-H power threshold studies (transport & turbulence group)

2009 JRT: hydrogen retention in Li

2010 JRT: heat transport peak heat flux SOL width

2011 JRT: (proposed) pedestal physics

Major facility upgrades (yellow boxes) represent both opportunities to and responsibilities for the boundary physics program

- SOL and divertor physics
  - Particle control: Lithium for pumping and a concomitant fueling program for density control
  - SOL turbulence and transport & SOL width studies
  - Divertor physics, emphasis on heat flux management
- H-mode Physics
  - Pedestal and ELM studies
  - Participation in L-H power threshold studies (transport & turbulence group)

LLD program
Skinner's talk

CS upgrade
Long pulse div.
2nd NBI

CS upgrade
2nd NBI
NCC upgrade

Outline

- **SOL and divertor physics for prediction of plasma-wall interaction footprint using theory-based cross-field transport models**
  - **Divertor heat and particle flux optimization**
    - **Interpretive analytic and 2-D modeling**
  - **Edge transport and turbulence ⇔ SOL width**
    - **World-class SOL turbulence measurements**

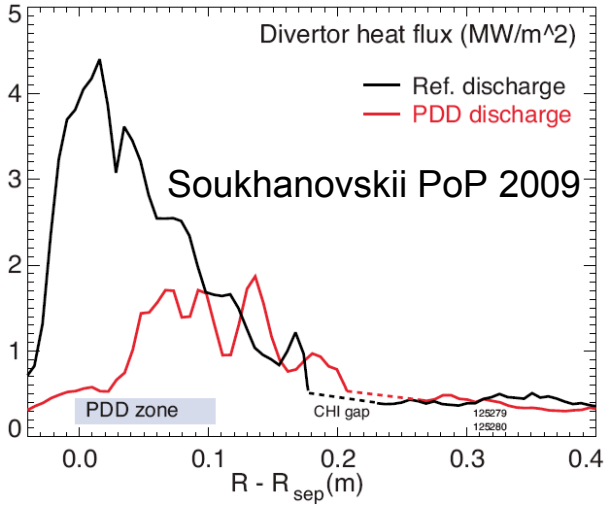
2010 JRT:
heat transport
peak heat flux
SOL width

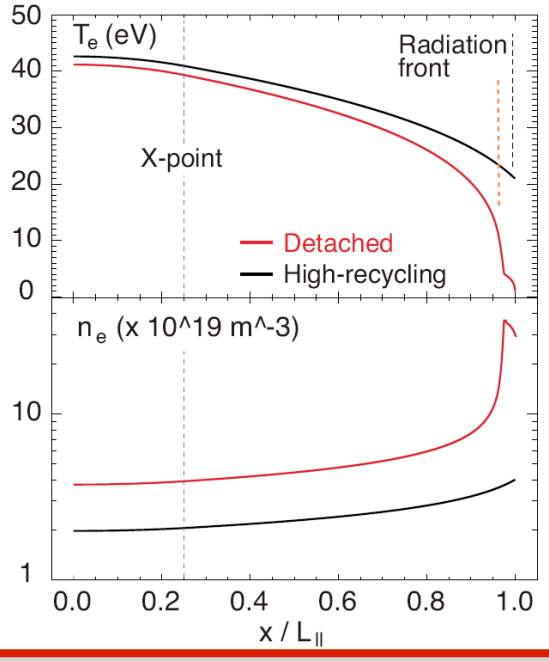
- Pedestal and ELM Physics

Divertor physics and detachment physics program focuses on needs for NSTX-Upgrade and next step ST design

- ST effects: low $\ell_{||}$, small R, low in/out power split make outer leg detachment difficult
  - *Power management through flux expansion and partial detachment (PDD) will be required for heat dissipation in high power ST's*
  - *ST effects above allow broader test of detachment physics in 2-D codes*
- Heat flux management through plasma shaping and detachment with good confinement shows promise in NSTX
  - Considering He, CD_4 puffing

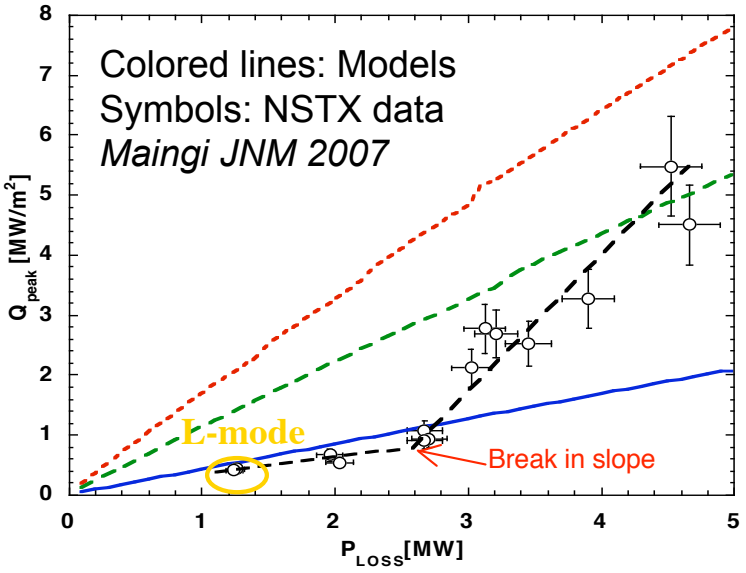
PAC23-09

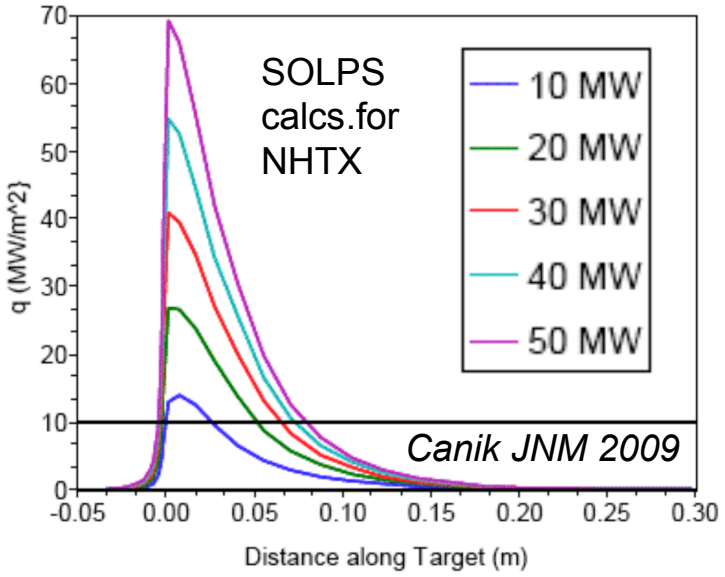




Long pulse center stack upgrade and 2nd NBI will challenge existing carbon PFCs while presenting prospect of very high heat flux studies

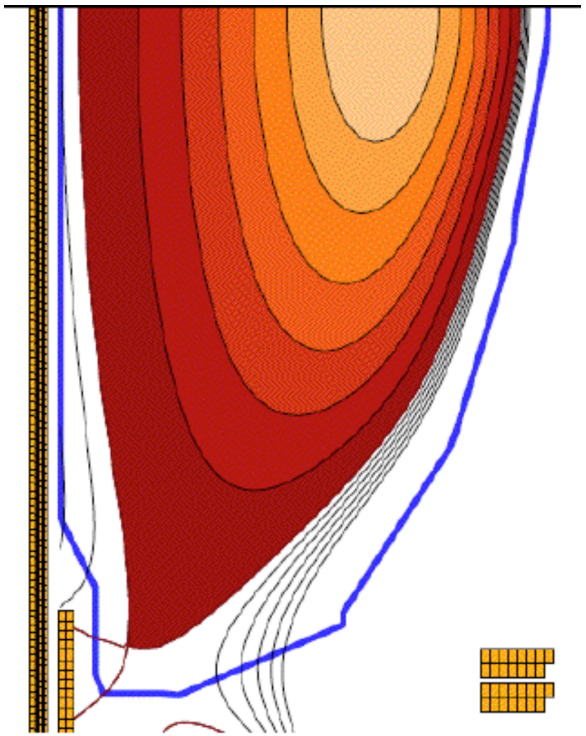
- Maximum pulse length of 2-3 sec for existing graphite ATJ PFCs
  - NSTX data (upper panel): P_{NBI}=6 MW, LSND, I_p=0.8 MA, B_t=0.45 T
  - q_{peak} of 20-30 MW/m^2 may be possible with 2nd NBI, if scaling holds
- q_{peak} might be even higher at I_p=2 MA
  - q_{peak} increases non-linearly with I_p, because λ_q falls quickly
  - q_{peak} also drops when ELM-free (w/Li)
  - Might require double-null geometry, or novel divertors (X-D, super X-D, or snowflake)
- High heat flux allows broader parameter range for experiments and improved predictive capability for next step STs,
  - NHTX low flux expansion (lower panel)



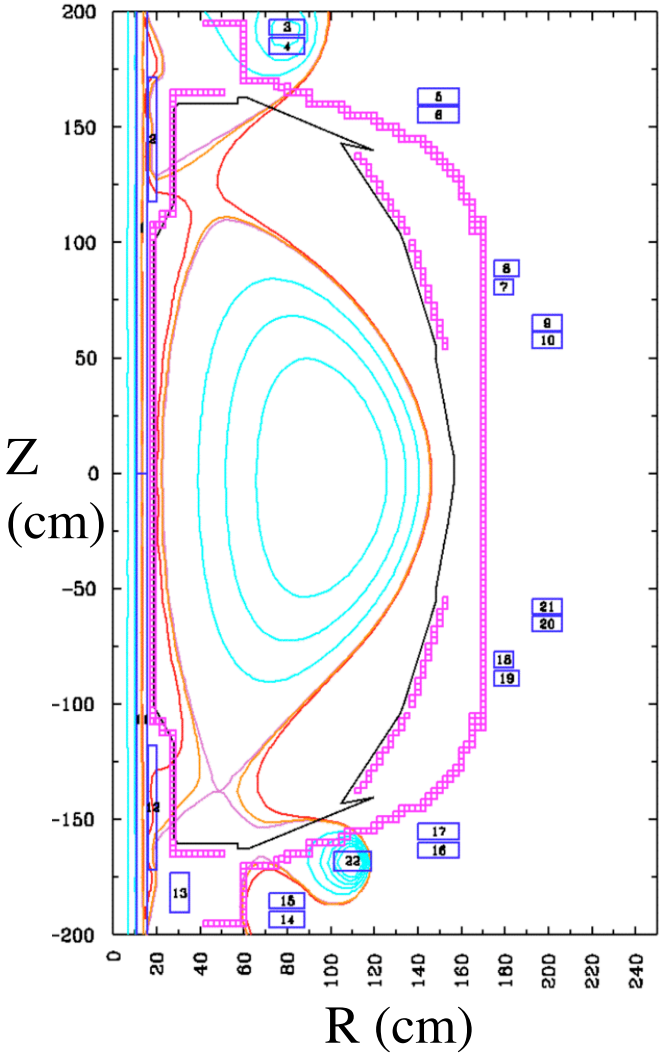


Novel divertors (X, Super-X, snowflakes) being considered for heat flux management with center stack and 2nd NBI upgrades

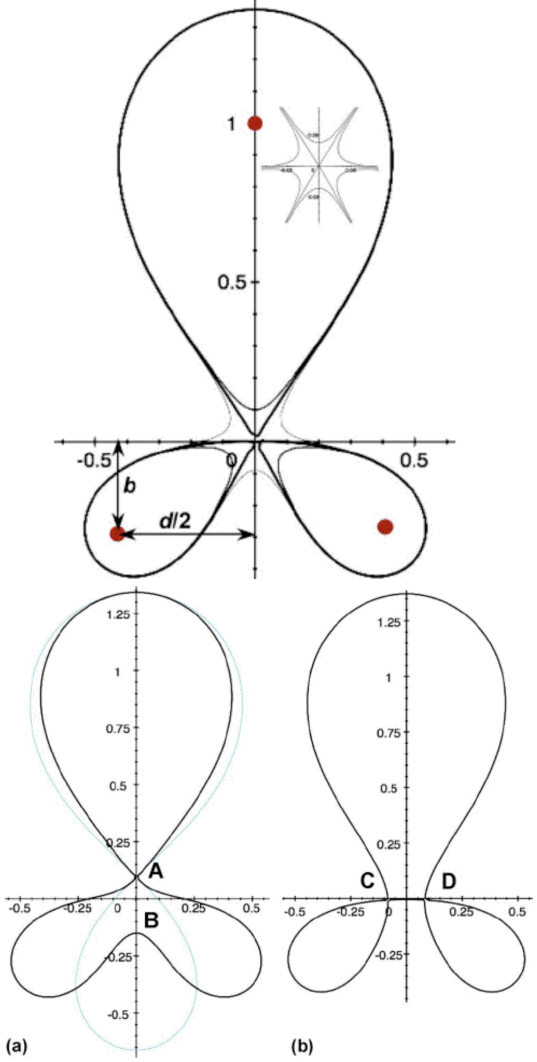
X-divertor



Super X-divertor



Snowflake divertors



Divertor and detachment Physics Plan

2009-2011

- Lower divertor power accountability and transient loading studies
- Improved detachment control for long pulse discharges
- Divertor performance dependence on geometry
- MARFE characterization studies
- Effect of 3-d fields on heat flux spreading

New tools: Fast IR camera (09), divertor bolometer (09), divertor imaging spectrometer (10)

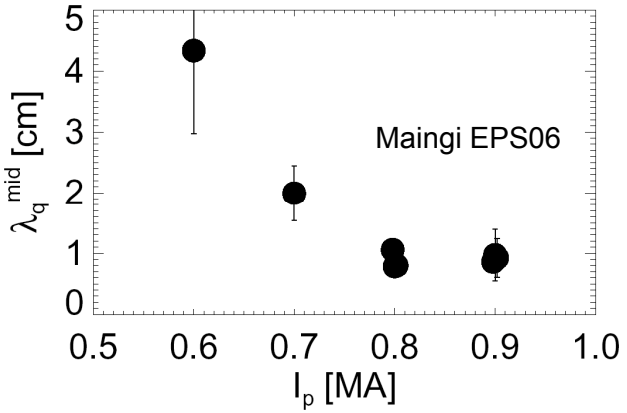
Once CS and NBI upgrades become available

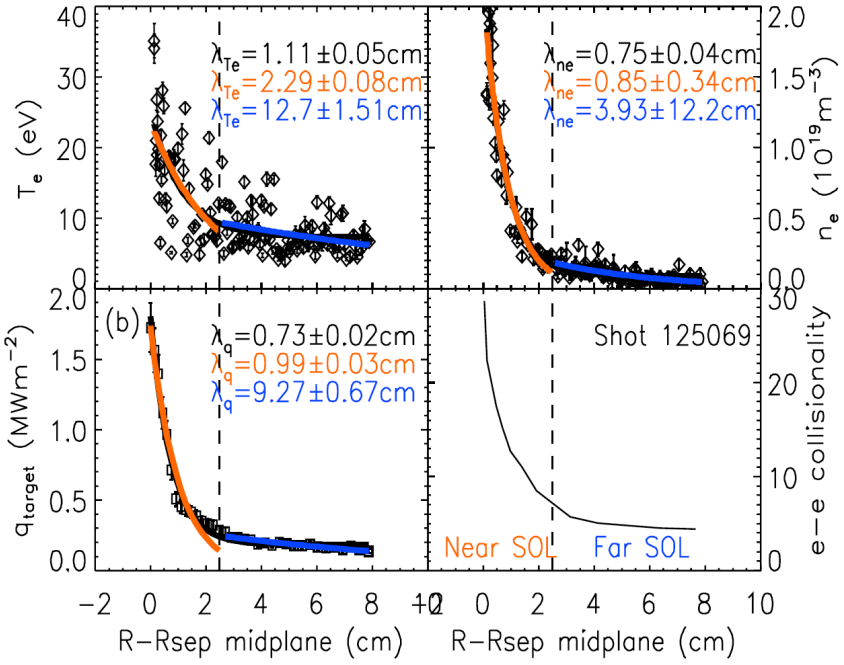
- Long pulse heat management at high I_p, B_t, P_{NBI}
- Private flux region physics studies

New tools: Long-pulse divertor, divertor Thomson, 2nd NBI, X-point/divertor VUV spectroscopy

Edge T & T studies will focus on connection between measured turbulence characteristics and SOL widths

- Dependence of heat flux width (λ_q^{mid}) not well understood in tokamaks
  - λ_q^{mid} larger in NSTX than high aspect ratio tokamak analytic scalings
  - Strong I_P dependence of NSTX λ_q^{mid}, but magnitude at high I_p overlaps with tokamak database
    - λ_q^{mid} further reduced by ~ 50% in lithium induced ELM-free H-modes
  - Ratio of λ_{Te}/λ_q consistent with electron conduction dominance in near SOL (Ahn, PoP 2008)
- Modeling of effect of turbulent transport on SOL widths commencing
  - Turbulence modeling already connecting to analytic theory of blob propagation
  - New BES system will augment gas-puff imaging for SOL turbulence measurement





Ahn PoP 08

Edge T & T Physics Plan

2009-2010

- Comparison of midplane and div. turbulence characteristics with models, e.g. blob behavior in highly radiative plasmas: SOLT(Lodestar), BOUT(LLNL)
- Scaling of midplane λ_n, λ_T, λ_Γ, λ_q with major parameters
  - Comparison with SOL width models: semi-analytic (ORNL/UCSD), 2-D SOLPS (ORNL) and UEDGE (LLNL), kinetic XGC-0 (CPES)
  - Comparison with turbulence characteristics
- Edge biasing with local electrodes and probes for SOL width control - convective cell generation test

New tools: fast IR camera (09), BES (10), divertor biasing capability (10), LLD(10)

2011-2013

- More detailed comparisons with above codes and new diagnostics; XGC-1 (CPES) turbulence code will also be used for detailed comparisons
- Upgraded biasing capability, if warranted

New tools: new divertor diagnostics

Outline

- SOL and divertor physics

- **Pedestal and ELM physics toward pedestal width prediction and improved understanding of ELM suppression**

  *** **Critical for ITER**: ***limit on ELM $\Delta W/W_{tot} < 0.3\%$***

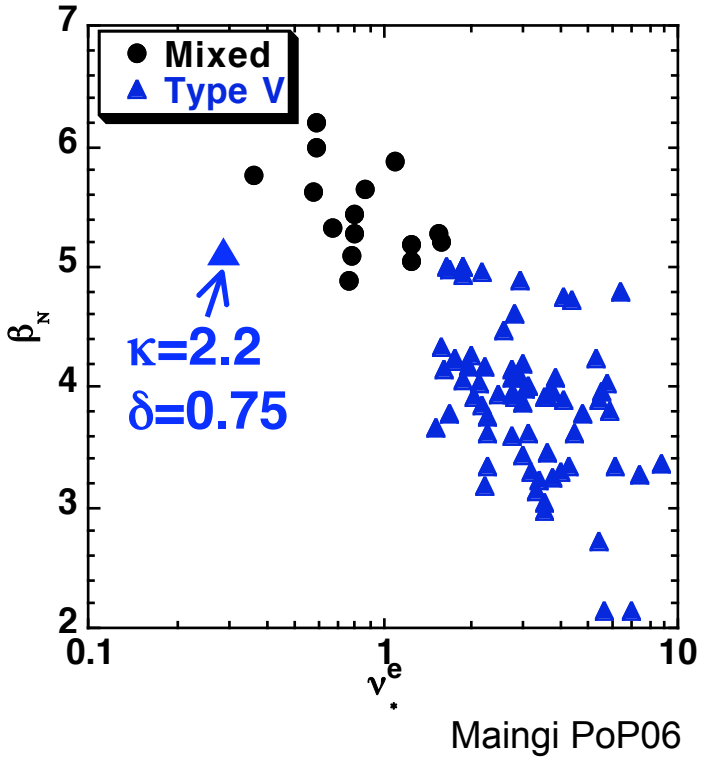
  – **Characterization and theory comparison at low R/a**

  – **Active control with 3-D fields**

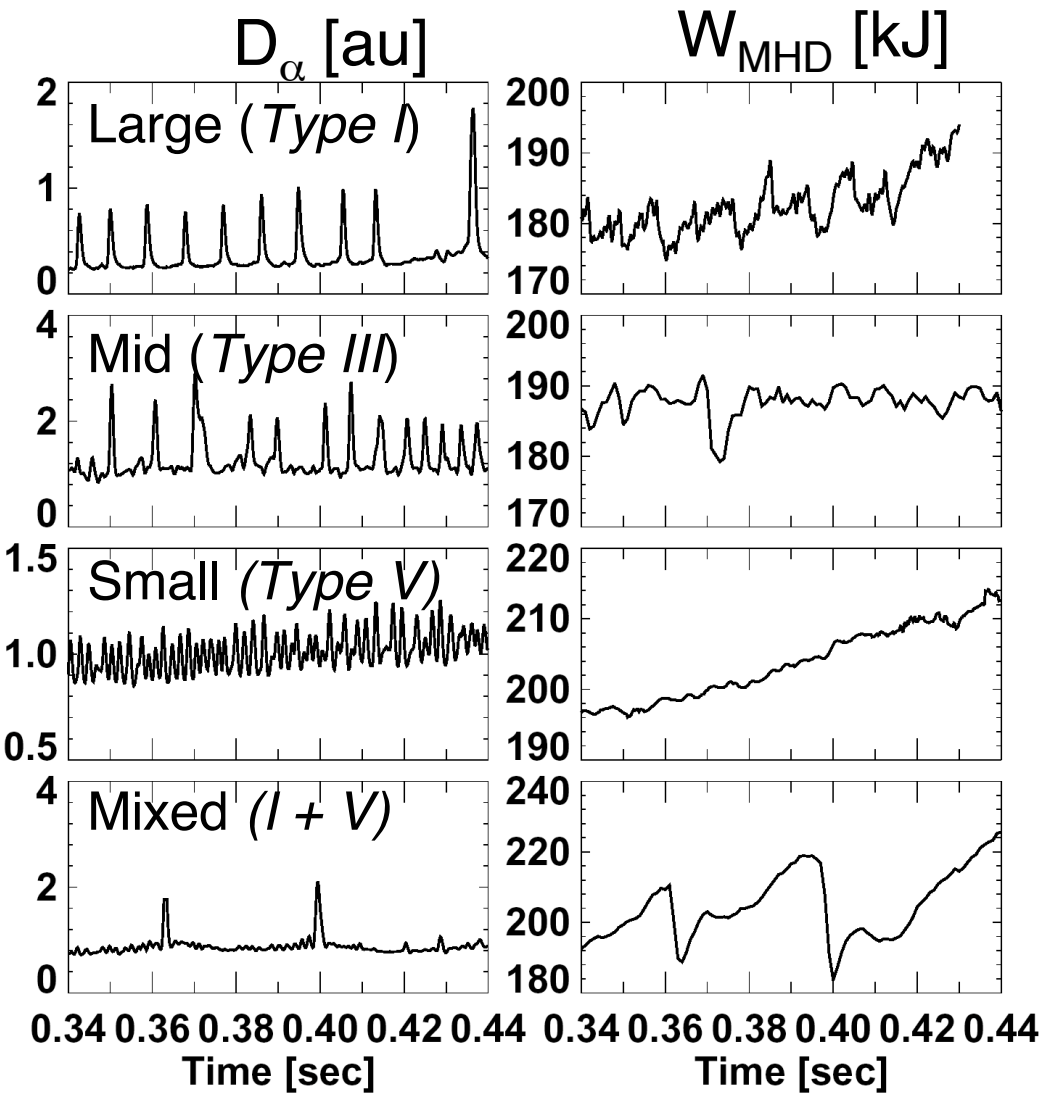
2011 JRT: (proposed) pedestal physics

Variety of ELM regimes observed in NSTX, with ELM size generally decreasing with collisionality

- Many ELM types observed in NSTX, including promising small ELM regime
- Occurrence of large ELMs at low ν^* motivates research



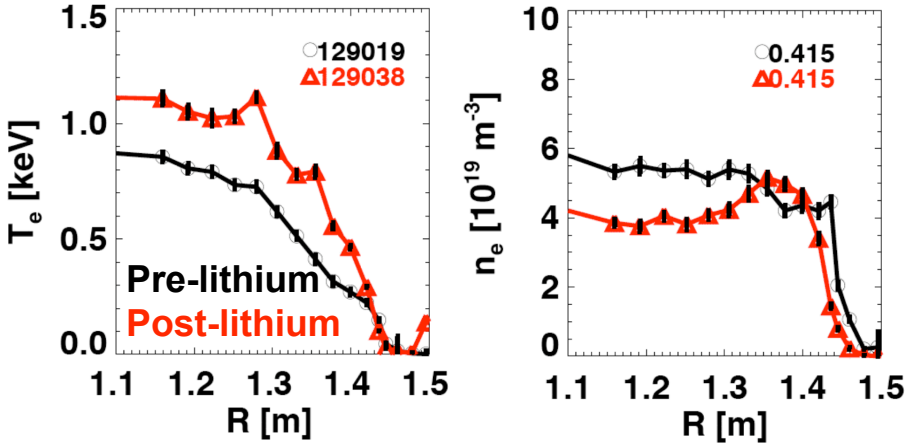
Maingi PoP06

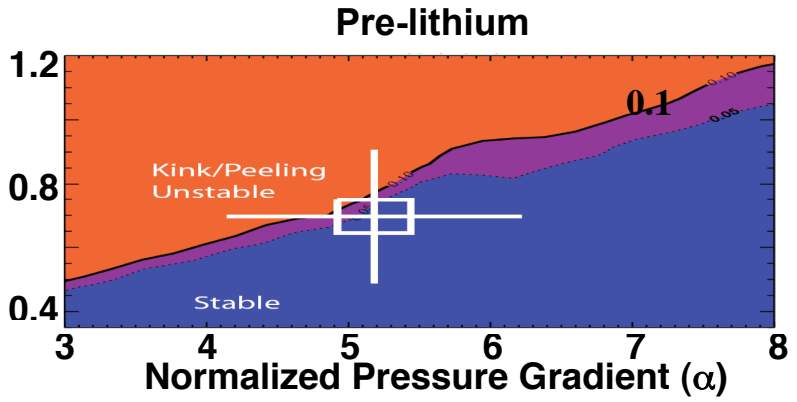


Studies of R/a pedestal dependencies aim to determine the range of applicability of edge stability models

- ELITE calculations suggest existence of high P_{ped} at low R/a and constant pedestal width
  - ➢ Requires low ν^* -> high T_{ped}
- Pedestal dependence on R/a investigated in NSTX, DIII-D, and MAST through ITPA
  - – No clear evidence of larger pressure gradients at low R/a
- *Lithium conditioning eliminated ELMs*
  - – Density profile shift -> pressure profile broadening -> ELM stabilization (PEST)
  - – Mystery: diamagnetic stabilization predicted to stabilize peeling modes in pre-Lithium discharge also (ELITE)

• **Pedestal defined by 3 Thomson channels**
--> *More Thomson channels needed!*

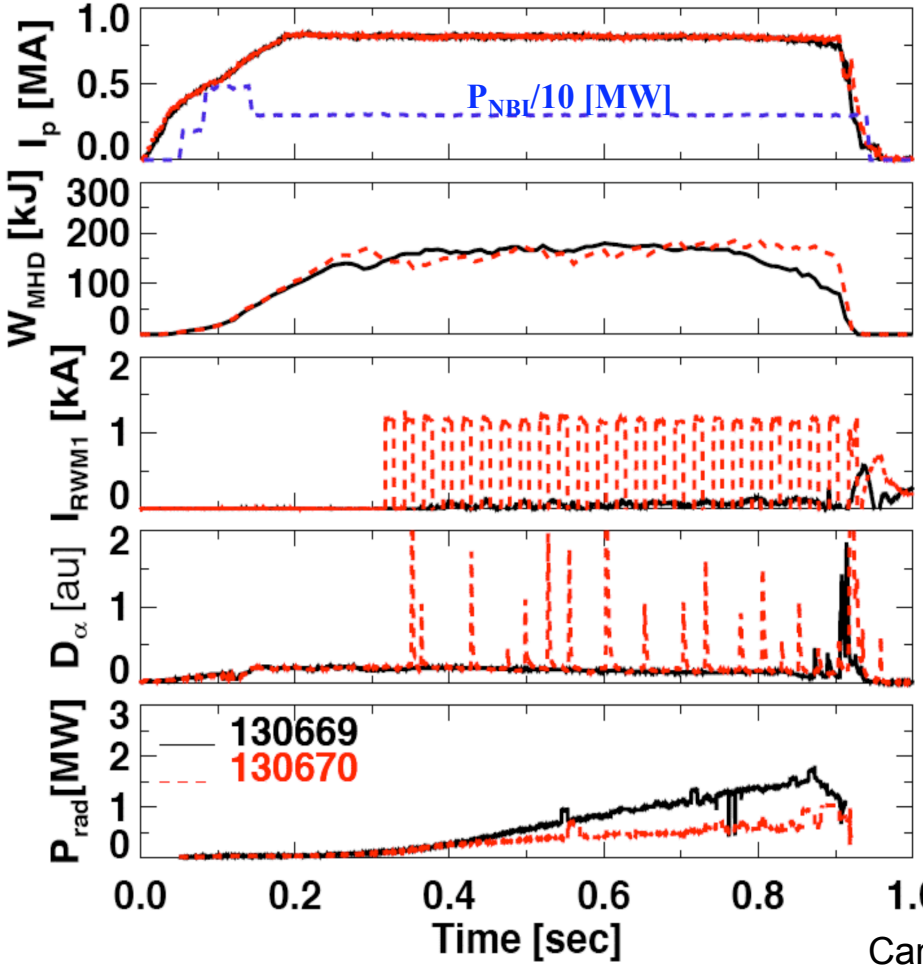




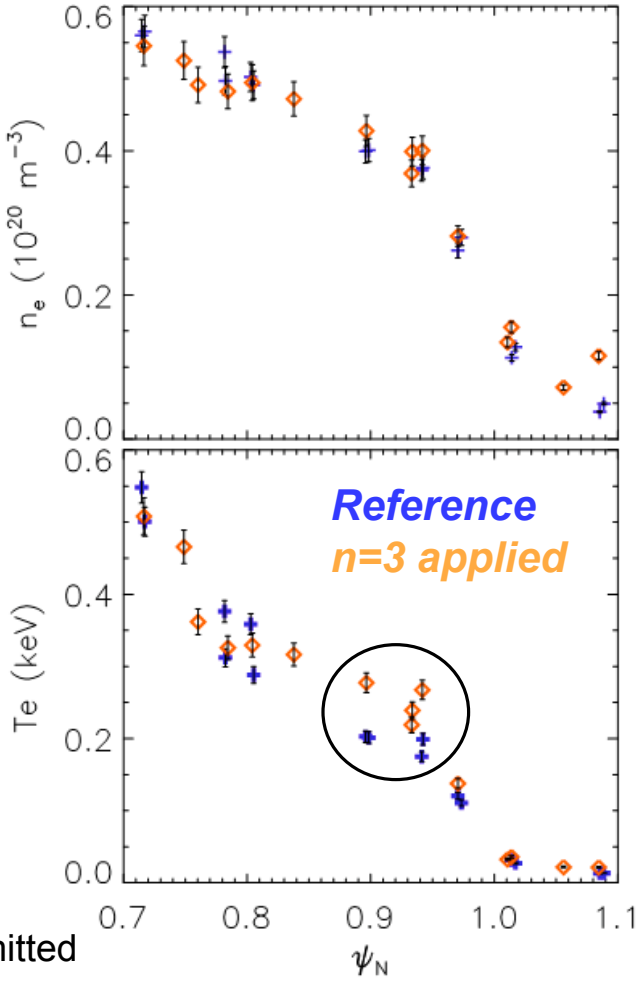
Maingi, PRL submitted

3-D fields used to alter ELM behavior - provides a possible scenario for impurity and radiation control of ELM-free Lithium discharges

Type I ELMs triggered for impurity control (post-lithium, n=3)



Edge T_e and dT_e/dr increased --> n=3 more unstable (PEST)



Canik, PRL submitted

ELM and Pedestal Physics plan

2009-2010

- Assess edge stability of different ELM types, including impact of aspect ratio on pedestal gradients and widths
- Identify dependence of ELMs on δ, κ, SN vs. DN
- Assess effect of lithium on ELM regimes
- Assess effects of 3d fields on edge stability
- Compare pedestal parameters with XGC-0

New tools: LLD (10), edge SXR for fast T_e reconstruction (10)

2011-13

- n=1 feedback with arbitrary n=2,3 for ELM stability (2nd SPA)
- High m,n RMP impact on ELMs and heat flux (internal coils)

New tools: extra edge Thomson channels, NCC upgrade for higher m/n, new divertor diagnostics

NSTX boundary physics program effectively utilizes facility and diagnostic enhancements in 2009-2011

- Particle control and fueling program
  - Uses LLD and associated new diagnostics
- SOL and divertor physics for prediction of plasma-wall interaction footprint using theory-based cross-field transport models
  - Uses new diagnostics (e.g. BES, div. bolometry, fast IR camera, Ly-α)
  - *Additional edge Thomson channels (incremental) very important*
- Pedestal and ELM physics toward pedestal width prediction and improved understanding of ELM suppression
  - Uses new diagnostics
  - *Additional edge Thomson channels (incremental) critical*