NSTX

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Overview of ITER Urgent Needs / Cross-Cutting Research TSG for FY2011 Research Forum

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U Colorado
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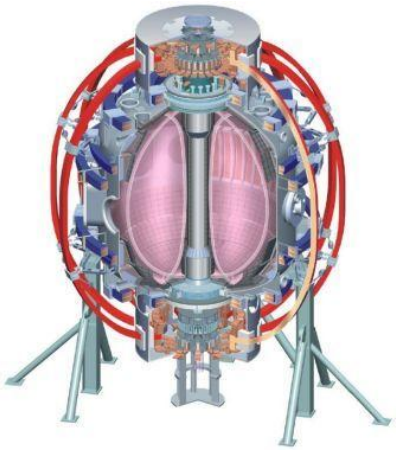
U Rochester
U Washington
U Wisconsin

J.E. Menard

R. Maingi, A.H. Boozer

PPPL B318
March 4, 2011



Culham Sci Ctr
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U Quebec

ITER Urgent Needs + Cross-Cutting (ITER/CC) TSG

- The purpose of the ITER/CC TSG is to coordinate/lead research on issues urgent to ITER design and operation that cross-cut multiple NSTX TSGs.

- The ITER/CC TSG will also coordinate/lead research on cross-cutting issues critical to NSTX, NSTX Upgrade, and ST development.

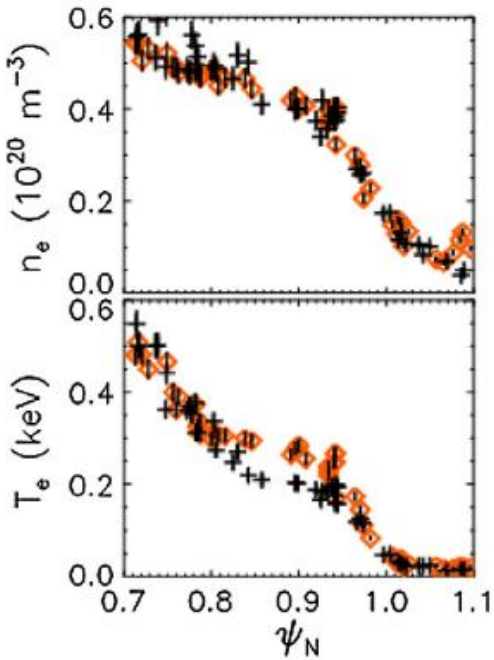
- The primary organizing principle for the ITER/CC TSG for the FY2011-12 run is to utilize and understand various particle transport control methods to optimize integrated plasma performance.

Research Priorities for ITER/CC TSG

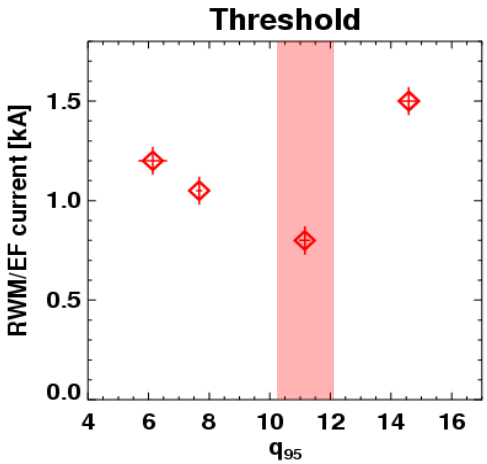
- Investigate H-mode pedestal transport, turbulence, and stability response to 3D fields
  - Especially the influence of 3D fields on ion/impurity particle transport
- Investigate *combinations* of active techniques for reducing core impurity accumulation - especially in ELM-free H-mode
- Organize experiments and analysis in support of cryo-pump design for NSTX Upgrade
- Oversee ELM research to ensure a coherent research program and minimize experimental overlap
- Other cross-cutting research?

NSTX provides a unique environment to better understand the H-mode pedestal response to 3D fields for ELM control

- ELMs stabilized by Li coatings
  - Edge density, pressure gradients reduced
    - Maingi et al, PRL 103, 075001 (2009)
- ELMs <u>triggered</u> by 3D fields, not suppressed
  - Small density change during n=3 3D fields
  - T_e and pedestal pressure increase → ELM
    - Canik et al, PRL 104, 045001 (2010)

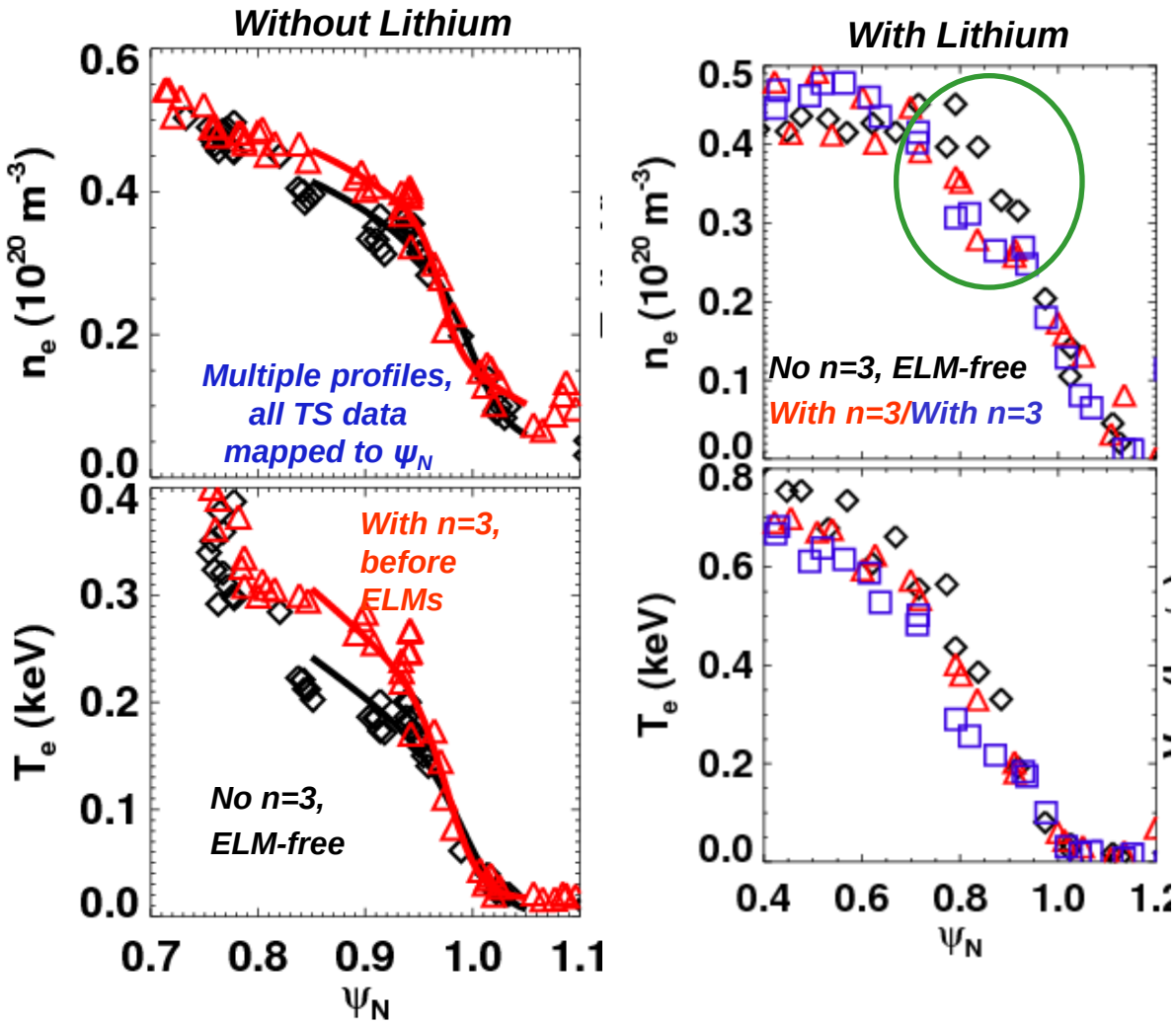


- Optimal q_{95} ~ 11 for ELM triggering
  - Vacuum Chirikov > 1 width ~ 0.3 for all cases
  - What is underlying physics of this dependence?



Pedestal profiles show varying response to n=3 field application with/without lithium

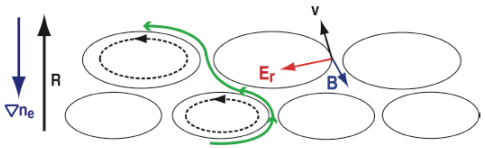
Profiles compiled from several shots:
Black before, colors after n=3 (but before ELMs)



- ***Without lithium***
  - ***No strong change in density (natural rise same as control shot)***
  - ***T_e, pressure gradient increases after n=3 field is applied***
- ***With lithium***
  - ***Flattening in n_e seen from Ψ_N~0.8-0.9***
  - ***Also seen in T_e-> island?***

E×B convective transport and island shielding

Island and stochastic field line E x B convection increases transport, reduces ∇p, stabilize P-B modes



- Island **E** x **B** convective cell transport hypothesis
  - Consistent with Δn during RMP experiments in limiter plasmas
- Assume $T_{e_x\text{-}pt} = 1.033\ T_{e_o\text{-}pt} = 1033$ eV inside islands and $B_T = 1.9$ T, $B_p = 0.6$ T

$$\Delta\phi_{isl} = 3k\left(T_{e_x-pt} - T_{e_o-pt}\right) = 100\ eV$$

$$E_\perp = \Delta\phi_{isl}/\Delta R_{s\to o} \to \Delta\phi_{isl}/\Delta Z_{x\to o}$$

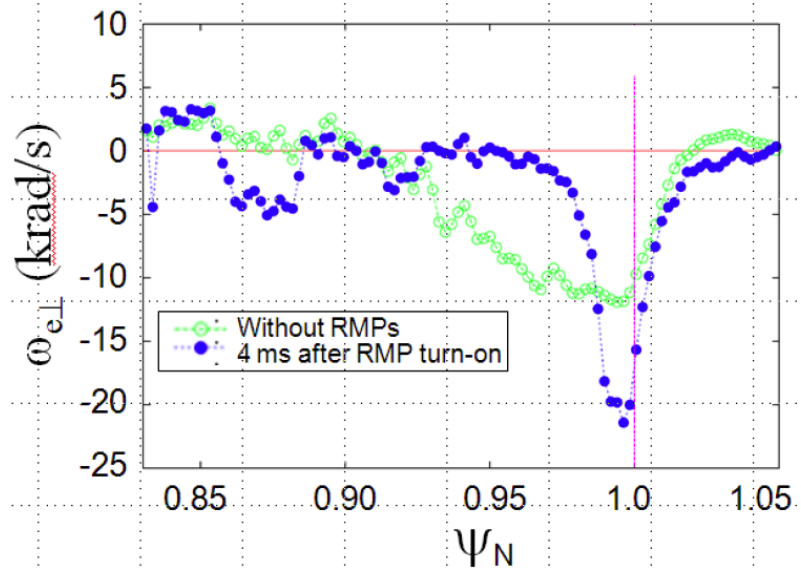
$$E_\perp = 200\ V/cm \to 10\ V/cm$$

$$v_{\perp_gc} = \vec{E}\times\vec{B}/B^2 = 1.05 \to 0.05\times10^6\ cm/s$$

$$D_\perp = \Delta R_{isl} v_{\perp_gc} = 52.5 \to 0.25\ m^2/s$$

- Ambipolar $\mathbf{E}_\perp$ hypothesis (contributes to island convection)
  - stochastic field lines, due to island overlap, intersect divertor
  - electrons leave resulting in an ambipolar $\mathbf{E}_\perp$ and a radial **E** x **B** convection of ions and electrons
  - $\Gamma_p = -D_\perp \nabla n_{ped}$
- Increased radial step size hypothesis (contributes to island and stochastic ambipolar convections)
  - Magnetic islands increase the radial collisional transport step size
  - $D_\perp = \left(w_{island}\right)^2 v_{Te}/2\pi qR + \left(a\rho_i^*\right)^2/\tau_e$

DIII-D NATIONAL FUSION FACILITY | T. E. Evans | 10 ECPM Evans-1/1 1 Sept. 2010



Chang, DIII-D 3D physics seminar, 1/5/11

- **Rotation screening reduction and enhanced transport when $\omega_e^{perp} \to 0$ ($\omega_e^{perp} = \omega_e^* + \omega_{ExB}$)**

- Can we control $\omega_e^{perp} \to 0$ in pedestal using n=3 and n=2 RMP
- Does particle transport increase when $\omega_e^{perp} \to 0$?
- Infer island opening from measured/simulated 3D equilibrium response?

Milestone R(11-4): H-mode pedestal transport, turbulence, and stability response to 3D fields - *Responsible TSGs: ITER/CC, T&T, BP, MS*

- The use of three-dimensional (3D) magnetic fields is proposed to control the H-mode pedestal to suppress ELMs in ITER
  - However, the mechanisms for particle and thermal transport modification by 3D fields are not understood
- Study possible mechanisms for modifying transport:
  - zonal flow damping
  - stochastic-field-induced ExB convective transport
  - island shielding reduction as $\omega_{e-\perp} = \omega_e^* + \omega_{ExB} \rightarrow 0$ (XGC0)
  - banana diffusion or ripple loss
- Measure pedestal turbulence trends vs. applied 3D field
  - BES, high-k scattering, gas-puff imaging
  - Independent control of n=1,2,3 applied 3D fields - 2nd SPA (ARRA)
- Measure pedestal profile response, edge particle transport
  - Improved Thomson scattering, impurity injection, edge SXR

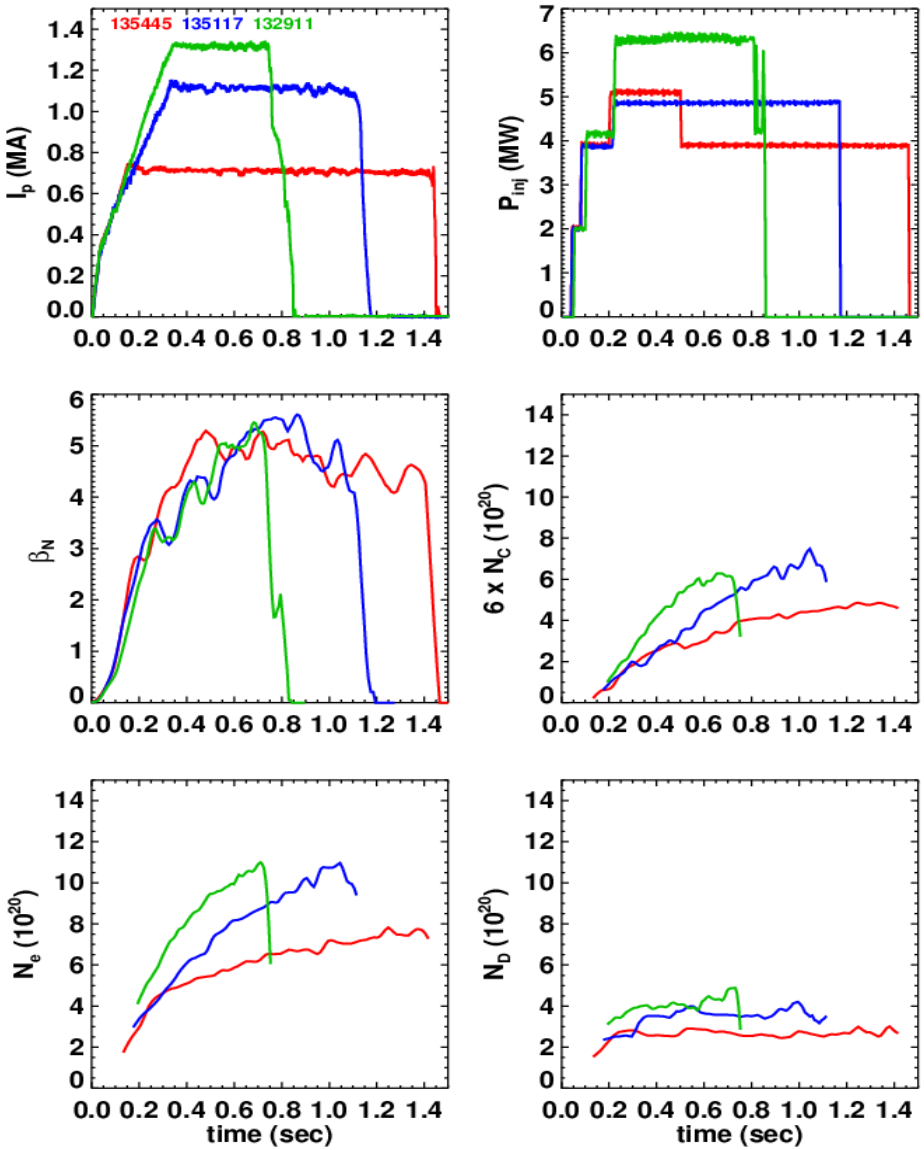
Possible strategy for R(11-4)

from Nov 2010 brainstorming meeting + PAC-29

1. Develop/utilize 2-4 scenarios where 3D δB induced transport modification is likely, compatible w/ broad diagnostic coverage
   - Reproduce shots with varied ELM triggering threshold vs q_{95}
   - Reproduce shots with varied n_e, T_e profiles with/without Li and 3D fields
   - Develop L-mode target, also lower-collisionality H-mode
   - Develop targets w/ slow time-varying q_{95}, J_{edge} to look for "resonances"
2. Perform perturbative transport experiments using scenarios
   - Vary amplitude, phase, n-number (n=2 and 3) of 3D δB
   - ME-SXR + impurity puffs with varied species to extract impurity D, v
   - SGI for Δn_e, heat pulse propagation using ME-SXR, MPTS, reflectometry
   - BES, high-k, GPI, FIReTIP to look for changes in edge turbulence
   - SXR imaging to detect edge islands
   - HDLP array to measure changes in SOL hot electron fraction
   - SOLPS (b2/EIRENE) to model edge transport vs. q, Li, 3D δB

NSTX can maintain constant deuterium inventory with Li evaporation for range of operating scenarios

- Range of optimization targets:
  - Long Pulse
  - Sustained high-β_T
  - Maximized W_{MHD}
- Strong LITER evaporation and few or no ELMs.
- Carbon is accumulated, but Deuterium inventory is constant.



Greenwald fractions evolve similarly for range of I_P

- Definitions:
  - Electron Greenwald fraction

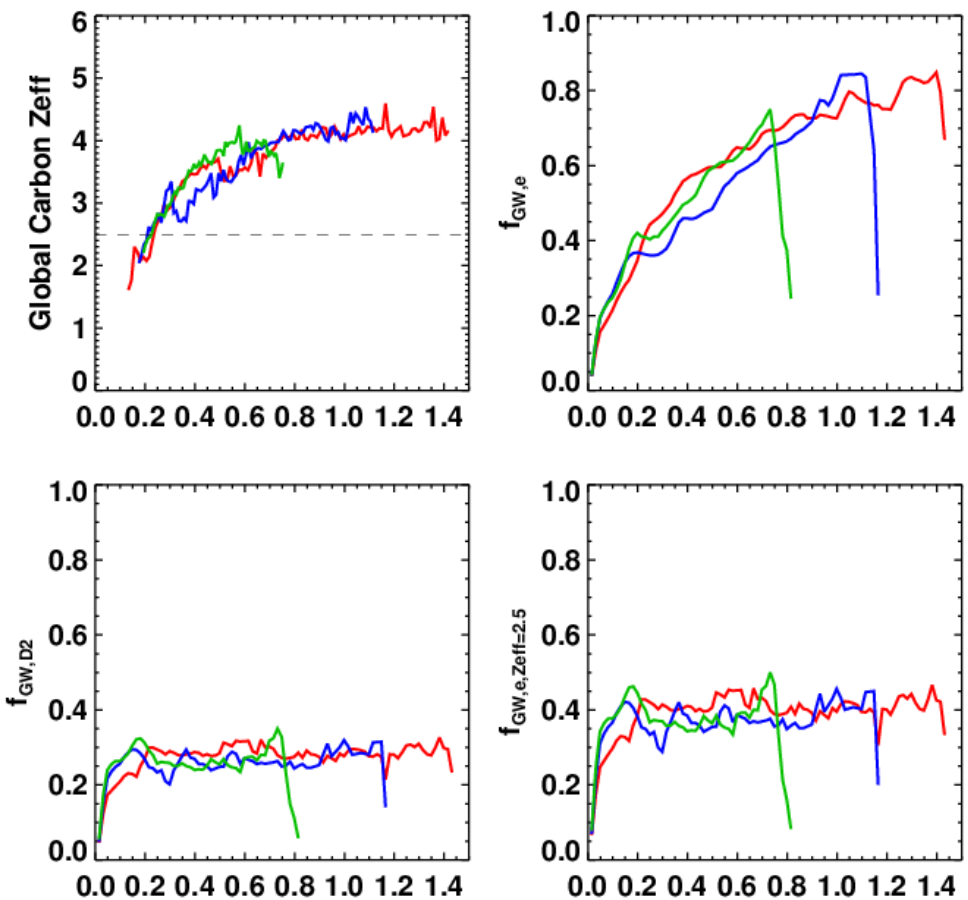
$$f_{GW,e} \propto \frac{\bar{n}_e}{I_p} a^2$$

  - Inventories: N_C, N_D, N_E
  - Deuterium Greenwald Fraction (i.e. Z_{eff}=1)

$$f_{GW,D2} \propto f_{GW,e} \frac{N_D}{N_E}$$

  - Equivalent Greenwald Fraction for a given requested Z_{eff}.

$$N_{E,Zeff} = \frac{5N_D}{6 - Z_{eff}} \qquad f_{GW,Zeff} \propto f_{GW,e} \frac{N_{E,Zeff}}{N_E}$$



Can carbon inventory be reduced/controlled while maintaining constant (low) D inventory?

Impurity control research plan will focus on combining techniques

- Envisioned techniques
  - Magnetic balance control for early carbon reduction
    - Will look for I-mode as part of ITPA JEX and FY11 JRT
  - Divertor gas puff and/or snowflake for source reduction
  - ELM triggering (3-D fields, vertical jogs) for impurity flushing
  - Core radiation control with central HHFW
  - Explore the accessibility of reduced Li evap. scenarios with high performance + intrinsic small ELMs for particle control

- NSTX device modifications:
  - Improved tile-to-tile alignment
  - Mo covers on RWM B_z zensors; removed some CHI gap B_z sensors
  - Mo tile upgrade

Beginning-of-run issues, longer-term activities

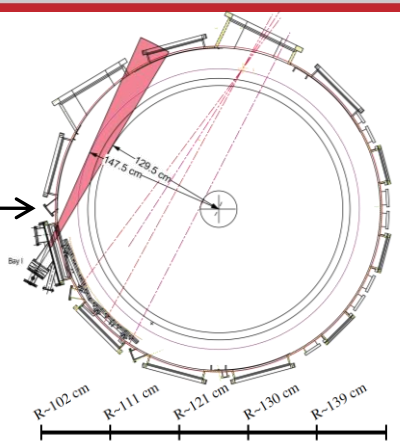
- Need to address several cross-cutting beginning-of-run issues:
  - Incremental/controlled Li introduction to access high performance research-grade plasmas - with ELMs (use D glow for passivation?)
    - XMP or XP? Led by LR, ASC, or BP, or ITER/CC?
  - Initial assessment of Mo tile performance – impurity response, Mo influx, plasma performance
    - Led by BP, ASC, or ITER/CC?

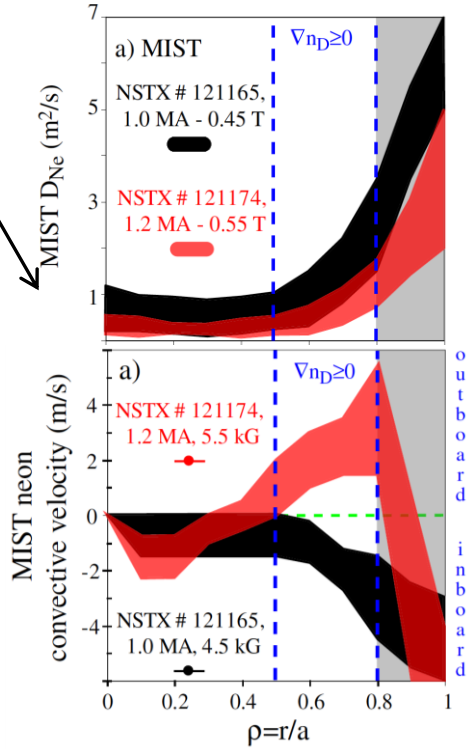
- Organize experiments and analysis in support of cryo-pump design for NSTX Upgrade
- Oversee ELM research to ensure a coherent research program and minimize experimental overlap
- Other?

BACKUP

Particle Transport can be measured via X-ray Emission from Plasma Impurities with new high-resolution SXR array

- 5 photodiode arrays with different filters
- 20 spatial channels with ~1 cm resolution of plasma edge, time resolution >10 kHz
  - Older array can not assess edge transport
  - Preliminary data obtained in 2010
  - Synergy with pulsed Thomson (8 add'l edge channels) plus supersonic gas injector



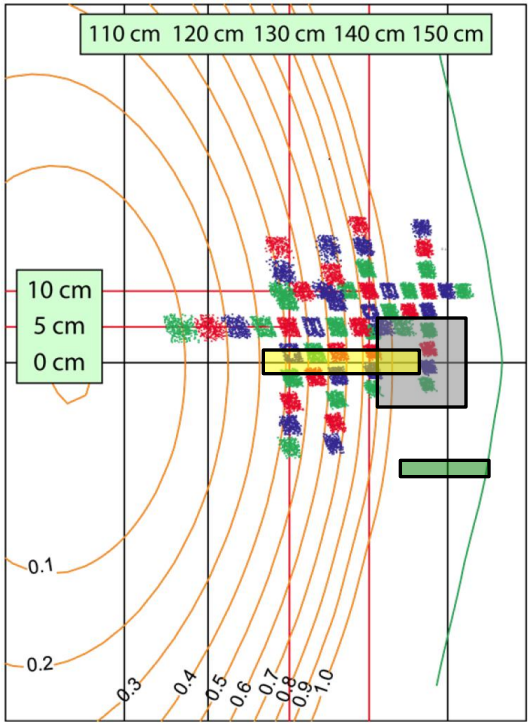


- Transport studies
  - Carbon build up in ELM-free discharges: separation of diffusion and convection
  - Transport variation in pedestal region: how does the particle transport change with lithium and/or with applied 3D fields?

Clayton

Models for increased transport with 3D fields and measurement capabilities being assessed

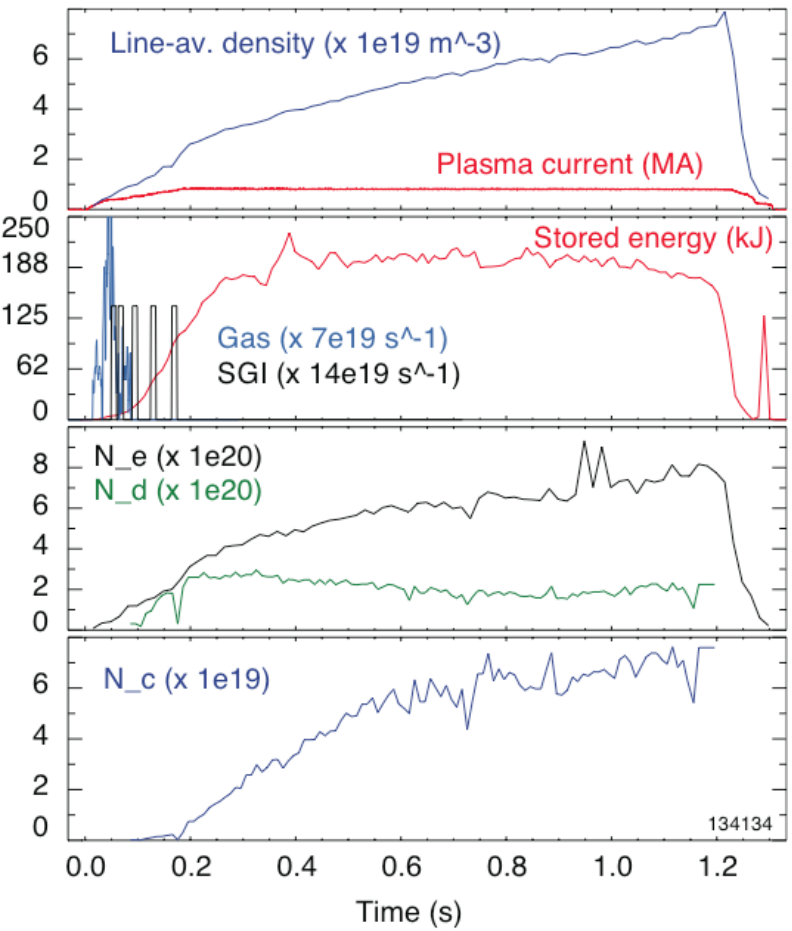
- Turbulence change with applied 3D fields
  - Radial/poloidal coverage with BES; compare and contrast with results on DIII-D
  - Midplane separatrix and SOL with GPI; no obvious differences so far)
  - Midplane edge with new high resolution SXR
  - *Tunable radius* with high-k scattering
  - Midplane separatrix and SOL with reciprocating probe
  - *Lower divertor* with dense Langmuir probe array (requires particular geometry)



- Look for pumpout in L-mode plasmas
- Increase divertor turbulence with divertor biasing
- Probe edge stability with new SPA (more spectral control)
- Use Snowflake and 3D fields to probe edge stability

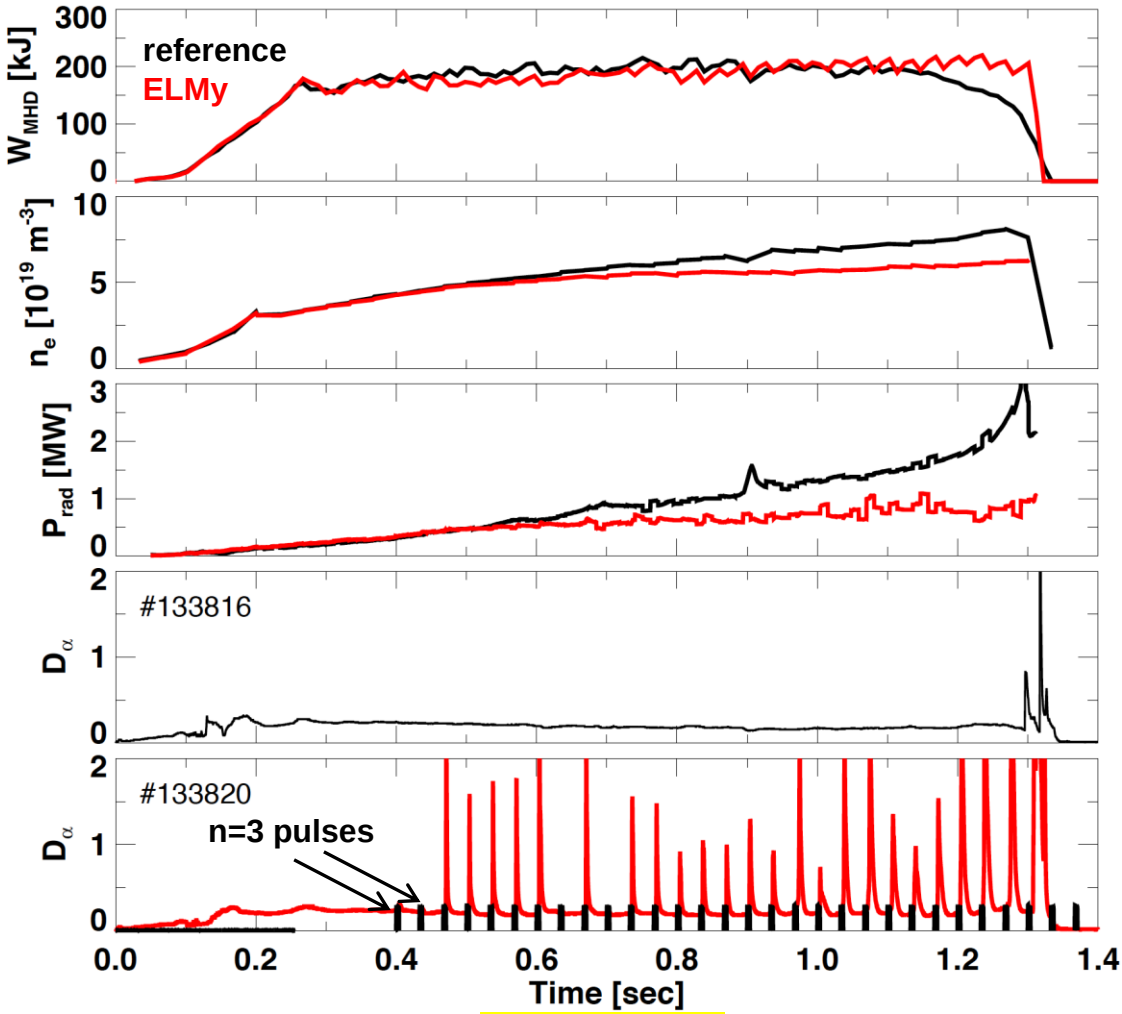
Control of core deuteron typically achievable with Li coatings, but core impurity control more difficult

- *Example with SGI fueling*



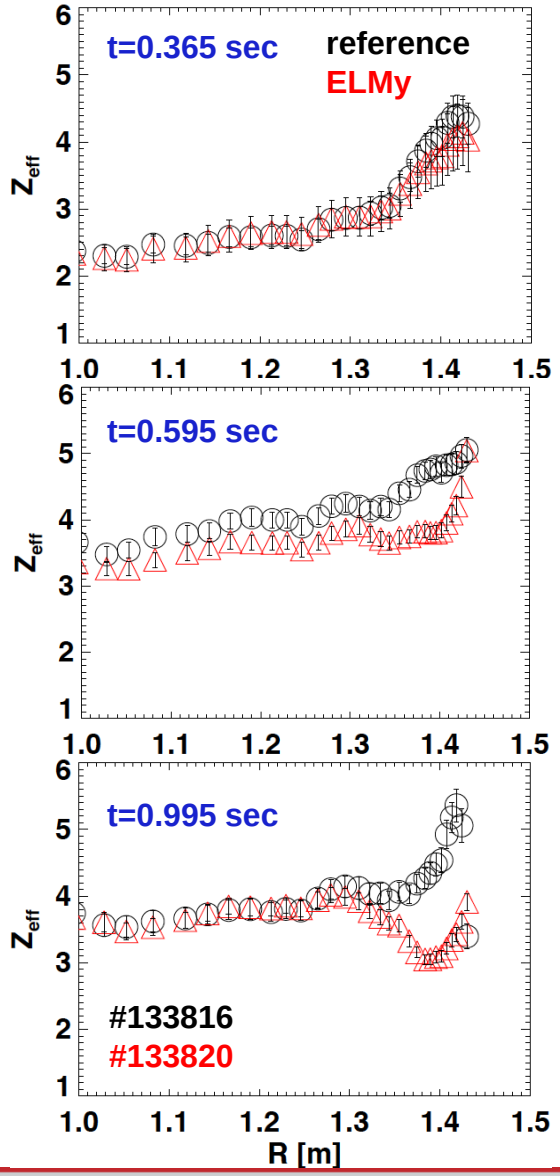
Soukhanovskii, IAEA 2010

- *ELM triggering with n=3 pulses*

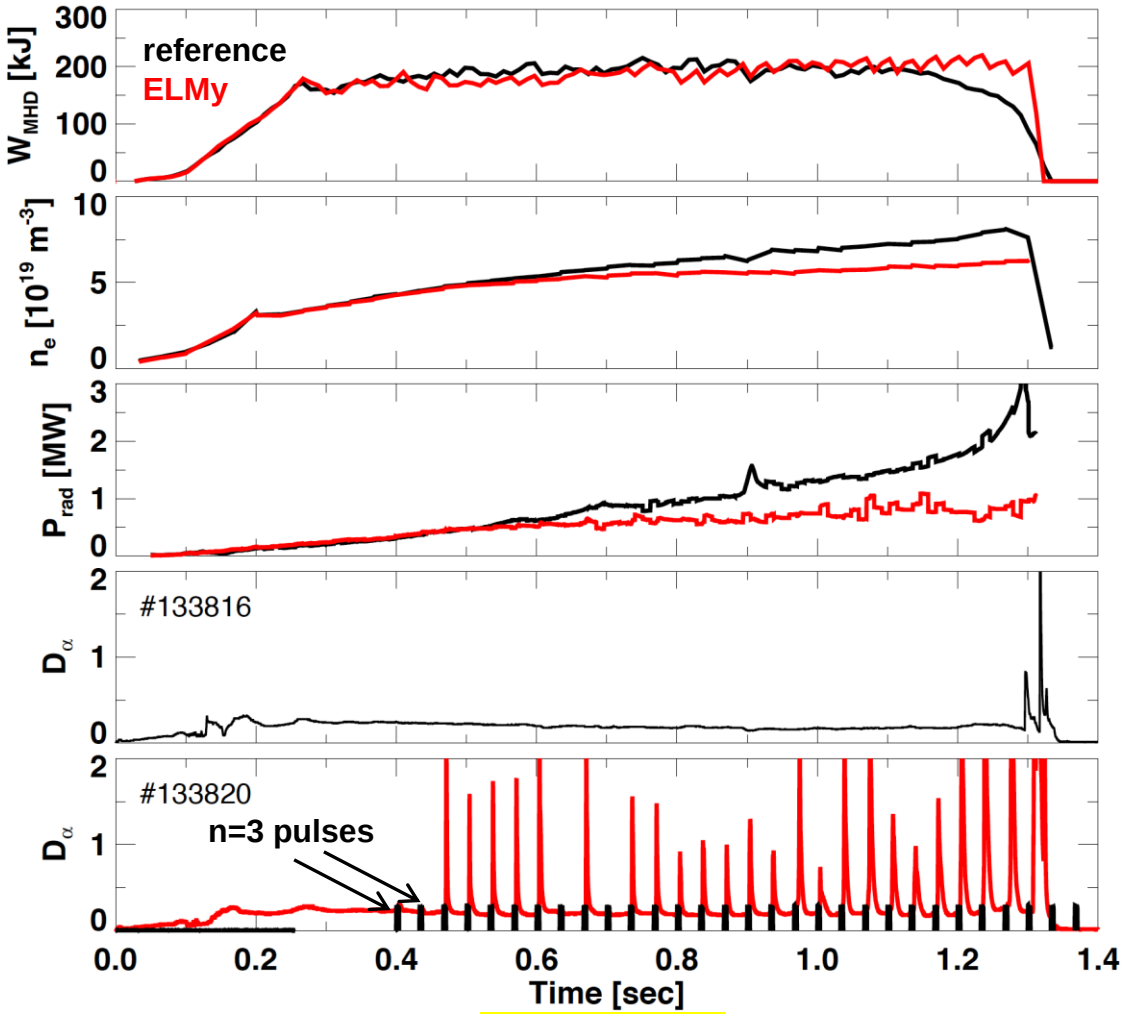


Canik, PRL 2010

ELMs triggered with 3-D fields successful at reducing P_{rad} and edge Z_{eff}, but not core Z_{eff}

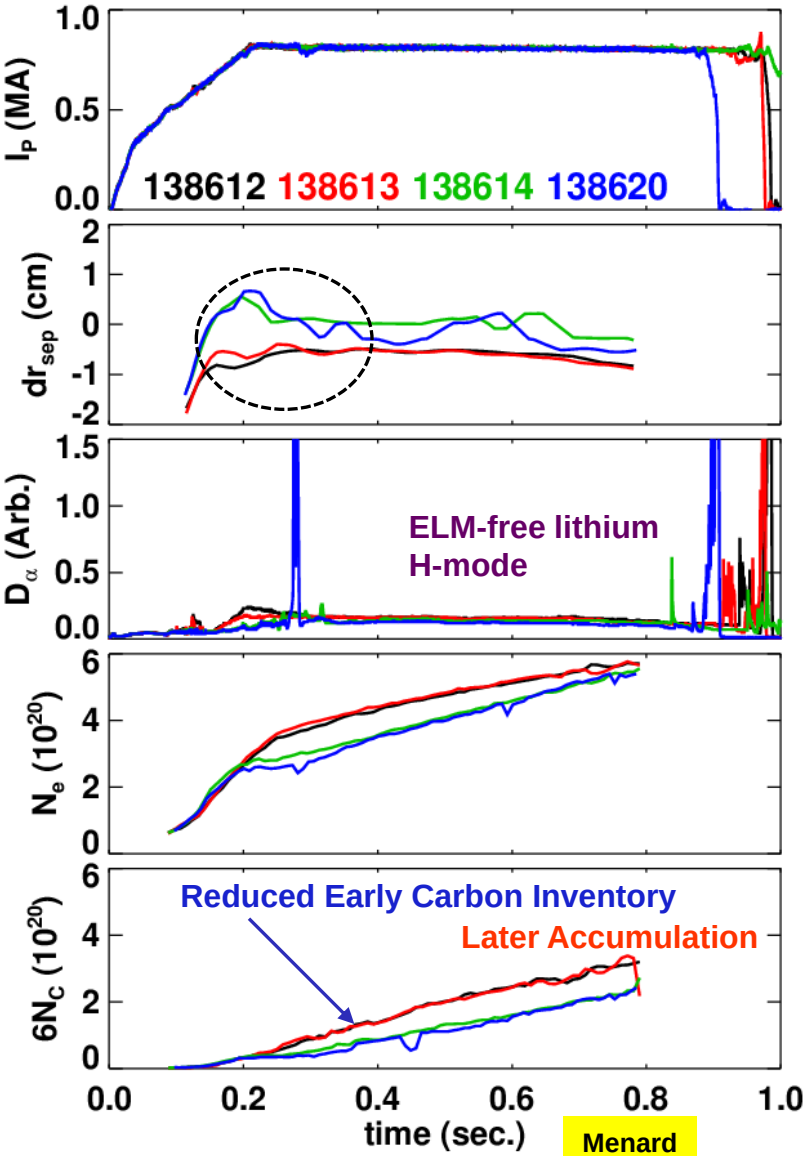


- *ELM triggering with n=3 pulses*



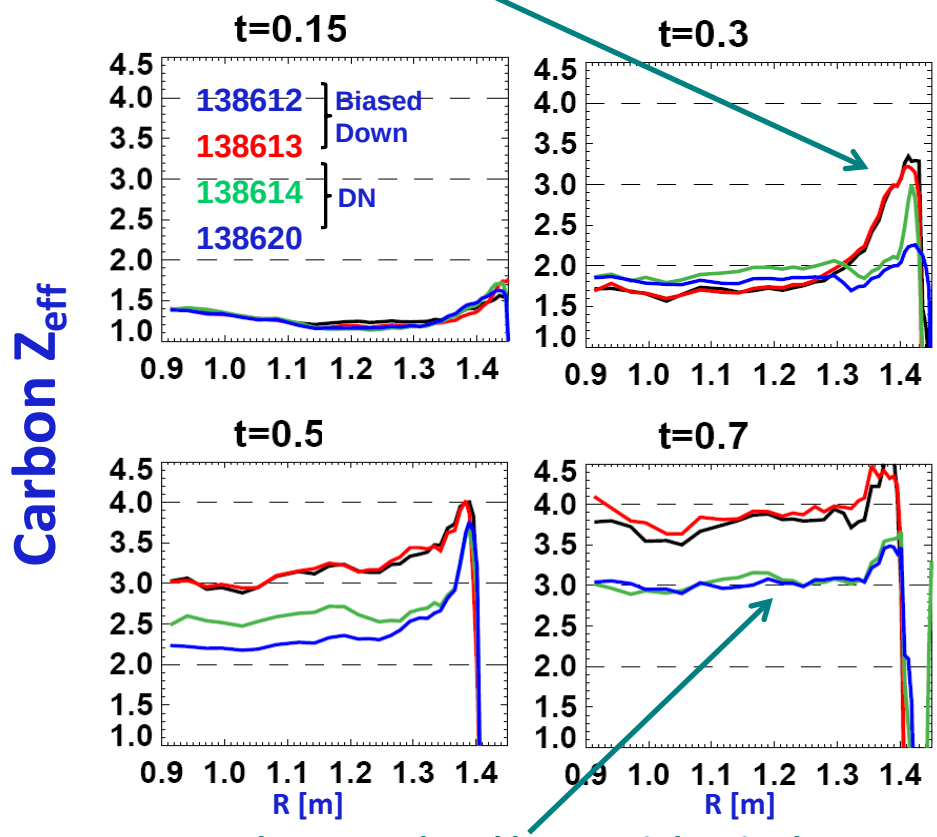
Canik, PRL 2010

Biasing upward (unfavorable ∇B) reduces early carbon, but impurities still increase in time



Menard

Size of H-mode C impurity "ear" near t=0.3s influences late Z_{eff}

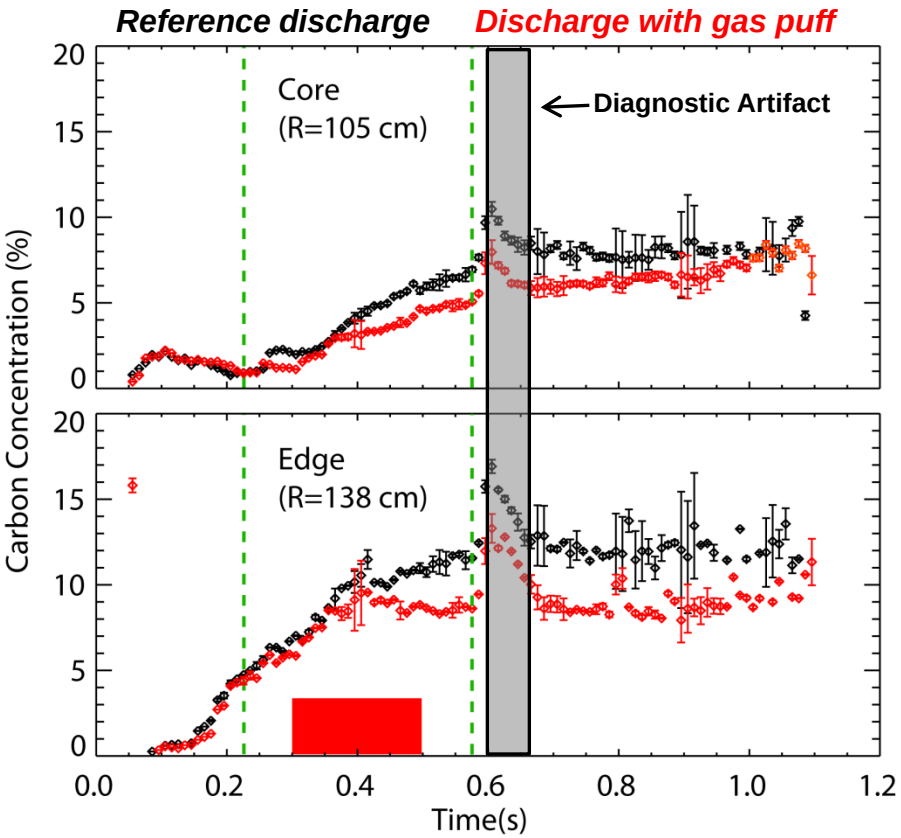


Carbon Z_{eff} reduced by ~1 unit late in shot

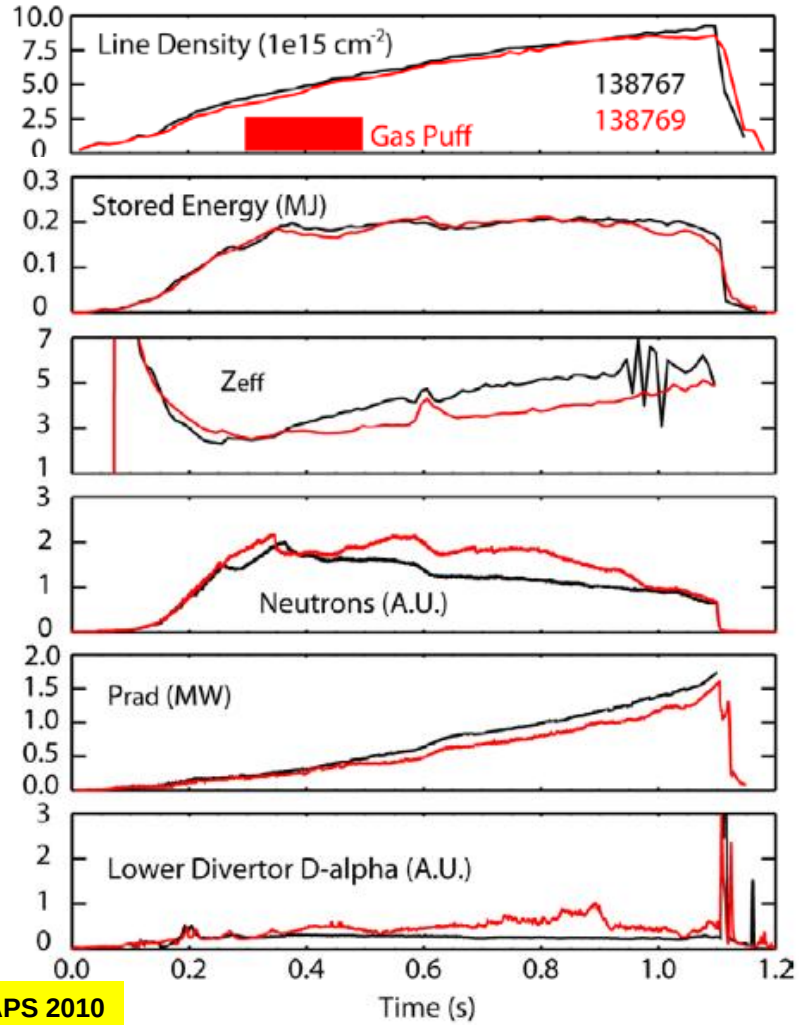
- *Motivates USN H-mode and I-mode search experiments*

Divertor D_2 puffing reduces core carbon density and Z_{eff} ramp rate

- Drop attributed to reduced sputtering
- Central f_C and Z_{eff} still rising
  - *Need to develop ways to reduce central impurities*

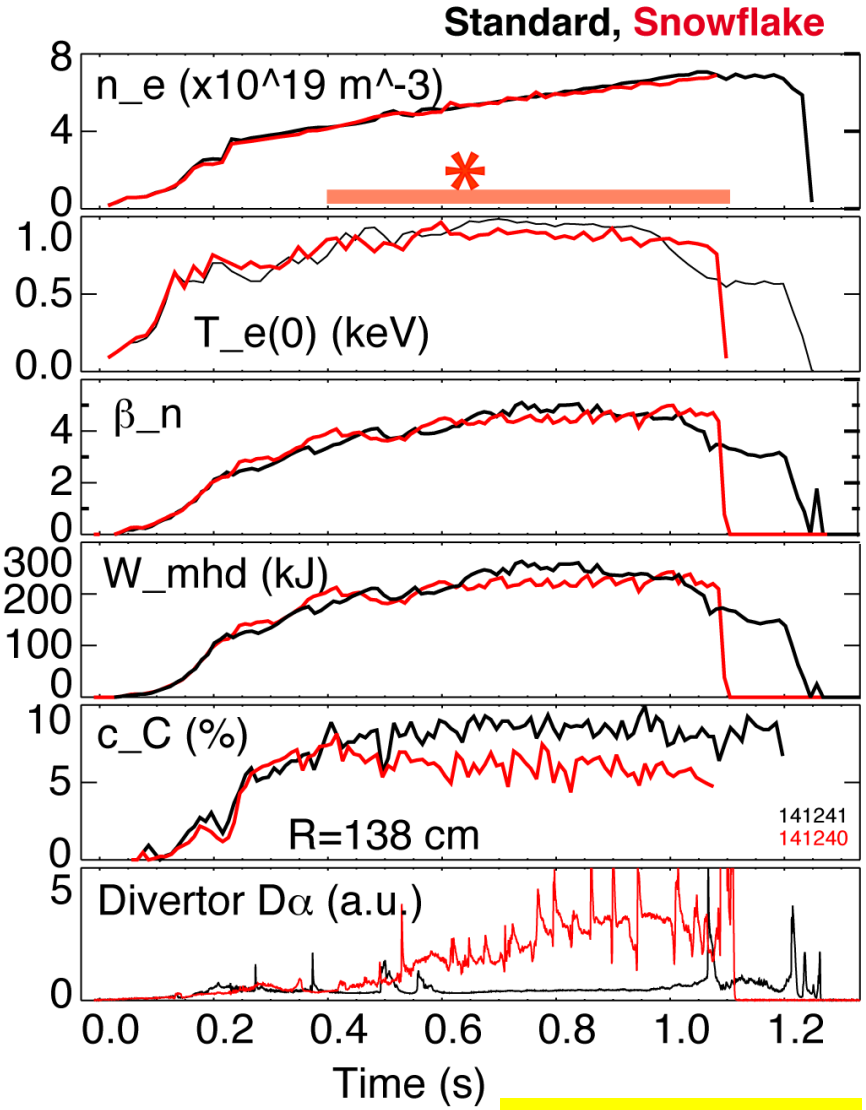


Deuterium Gas Puff From CHI Gap



Scotti, APS 2010

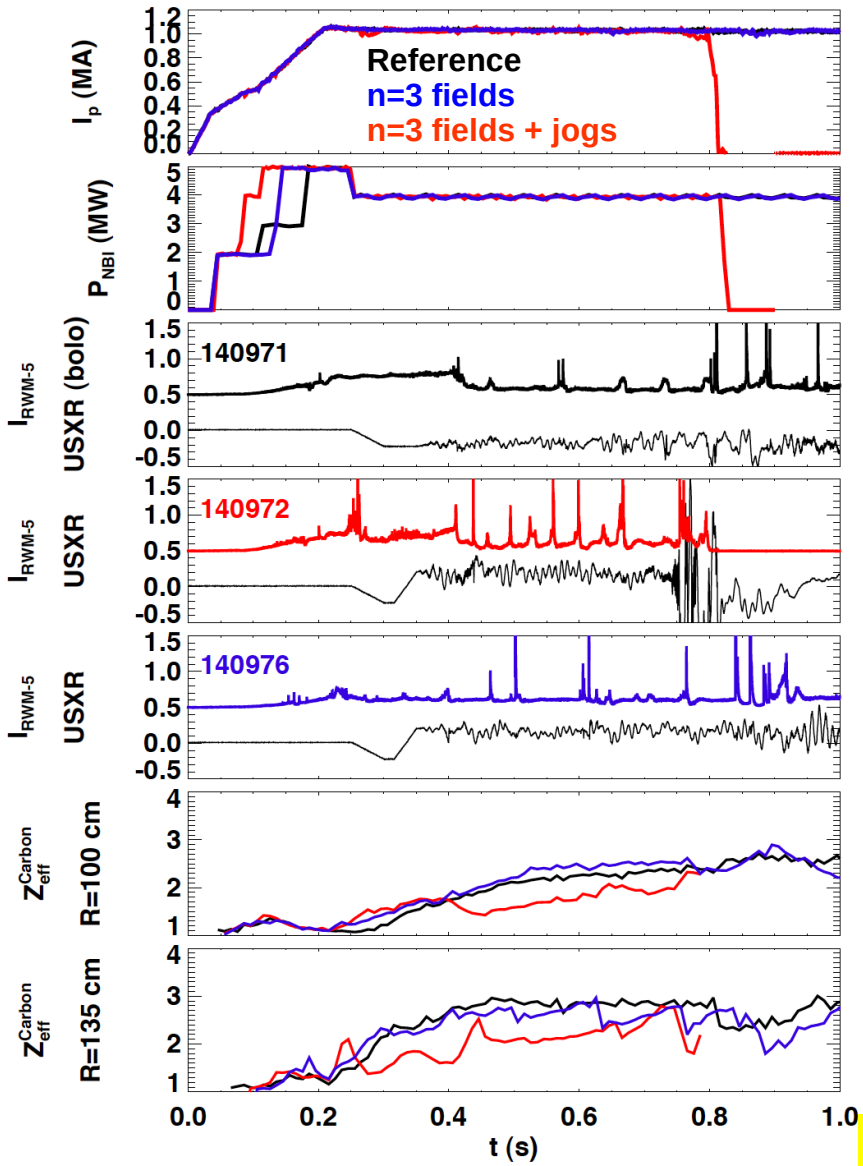
Snowflake configuration also reduces edge carbon



Soukhanovskii, APS 2010

- Snowflake shape facilitates partial detachment
  - Reduces carbon sputtering
- Configuration also brought back ELMs
  - Difficult to separate effect of ELMs vs effect of shape change
- Central carbon still increases, but more slowly
  - *Points again for need for central impurity density control*
- Combined divertor puff and snowflake discharges initiated

Combination of n=3 triggered ELMs and vertical jogs show promise for carbon impurity control



Canik

- ELM frequency higher with combined ELM pace-making techniques *(n=3 DC)*
  - Reference has a few ELMs
  - Z_{eff} from carbon appears to be flattening during ELMy phases
  - May need to combine with other techniques, e.g. divertor gas puff, snowflake, δ_r^{sep} control
- Limited run time in 2010, more in 2011-2012
  - Do jogs reduce minimum n=3 field to trigger ELMs?
  - Jogs + pulsed n=3 fields

Preliminary erosion modeling for inboard Mo tiles shows low sputtering and plasma contamination

- *Goal: Determine if Mo sputtering and plasma contamination is acceptable*
- *So far [D + 1% C,1% Li] sputtering of bare Mo surface*
- First results encouraging:
  Mo sputtering low (<0.01), little core plasma contamination; two caveats:
  - 1: Mo self-sputtering ok but little margin for one sheath condition
  - 2: if substantial carbon impinges on Mo divertor, from e.g., inner wall C sputtering; re-sputtering of this carbon would tend to reach core plasma (~10% of sputtered flux), thus negating some of the benefit of the Mo
- More thorough analysis in progress
  - WBC analysis of inner Mo divertor, with C, Li on Mo w/ material mixing/evolution models…
  - High D pumping / low recycling solution
- Possible issue: melting as observed in C-Mod (*no such melting observed on LLD, even with direct strike point plasma flux*)
- Possible issue: rf acceleration and sputtering (*no such effect observed on LLD with HHFW last year, but had limited rf power*)

Brooks

PAC27-17