NSTX

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Overview of FY10 milestone results, early FY11 results and new capabilities

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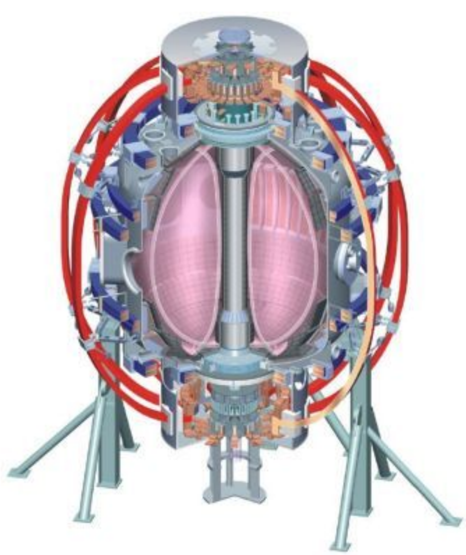
Steve Sabbagh, Deputy Run Coordinator

for the NSTX Research Team

NSTX PAC-29
PPPL B318
January 26-28, 2011



Culham Sci Ctr
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U Quebec

NSTX FY2010 research milestones:

- JRT: Improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma; improve divertor projections for ITER.
- R(10-1): Assess sustainable beta and disruptivity near and above the ideal no-wall limit:
- R(10-2): Characterize HHFW heating, current drive, and current ramp-up in deuterium H-mode plasmas.
- R(10-3): Assess H-mode pedestal characteristics and ELM stability as a function of collisionality and lithium conditioning

- Density and impurity control research (LLD)
- Measurements of internal fluctuations (coherent & Turbulent) (BES/high-k scattering/reflectometers)
- Experiments to support upgrade (Snowflake, LLD, impurity control)

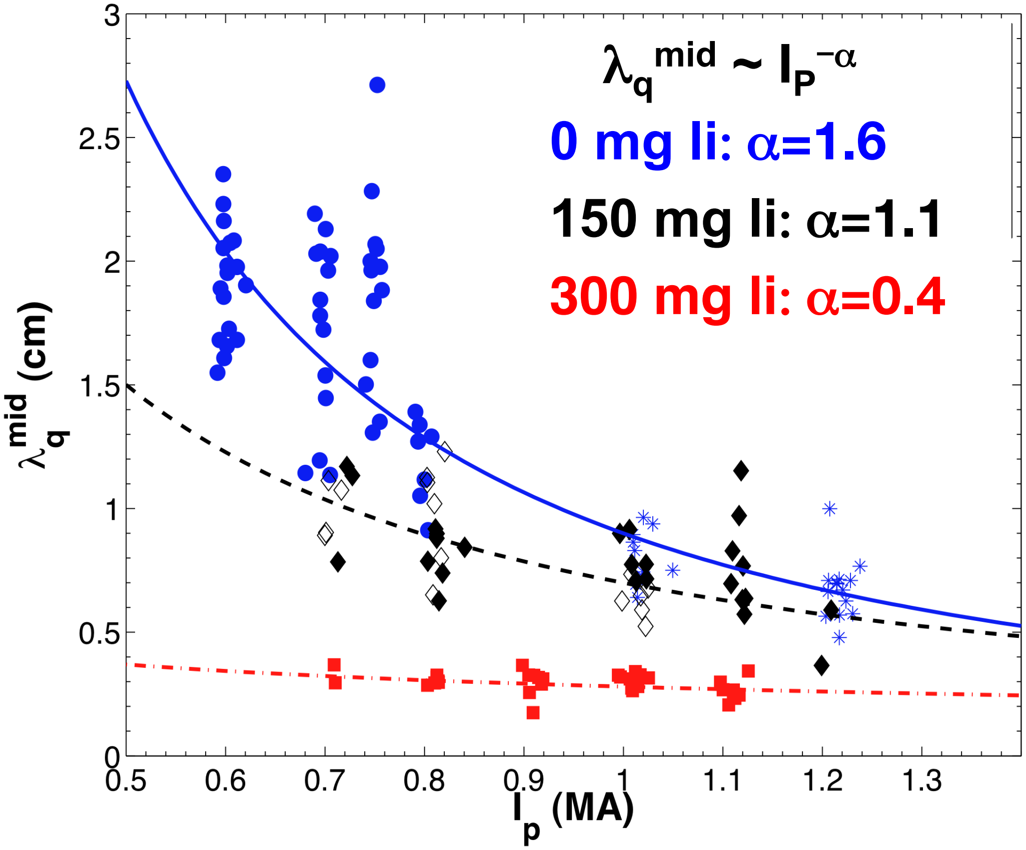
- 43 XPs had run time, 39 completed in 15 weeks of 2010 campaign.
- 10 supporting XMPs were completed using 15 run days.
- 4 weeks of FY11 campaign completed.

FY10/11 run time allocated towards Milestones, experiments relevant to NSTX-U and commissioning of new hardware

TSG	Run Time Guidance (days)	Milestones	Days used FY10	Days used FY11
Advanced Scenarios and Control	8(11%)	R(10-2)	11.3(15%)	2.0
Boundary Physics	10(13%)	JRT, R(10-3)	14.3(19%)	1.5
Lithium Research	8(11%)		11.6(15%)	1.7
Macroscopic Stability	8(11%)	R(10-1)	11.1(15%)	0.6
Solenoid-free Start-up and Ramp-up	6(8%)	R(10-2)	3.4(5%)	2.6
Transport and Turbulence	7(9%)		6.8(9%)	9.5
Wave-Particle Interactions	8(11%)	R(10-2)	3.8(5%)	1.0
Enabling Experiments*	20(27%)		13.0(17%)	2.4
Total	**75**		**75.3**	**21.3**

- CHI delayed for divertor conditioning, run time made up in FY11
- T&T XPs deferred to 2011 to use BES diagnostic
- *7.5 days to condition HHFW antenna, high power HHFW deferred to FY11

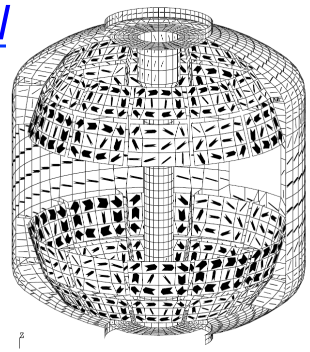
λ_q^{mid} found to vary strongly with I_p, independent of B_t and P_{loss} as part of FY 2010 Joint Research Target



- α depends on level of lithium conditioning, as does leading constant (Gray, IAEA 2010)
  - Data includes slow IR + fast two-color IR cameras
- SOLT modeling reproduces P_{loss} trend, but not I_p dependence (Myra, PoP 2011)
- XGC-0 modeling reproduces ~ $1/I_p$ dependence in tokamaks, from neoclassical physics (Pankin, IAEA 2010)

R10.1: New RWM state space controller sustains high β_N

Full 3-D model

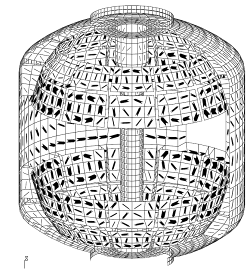


~3000+ states

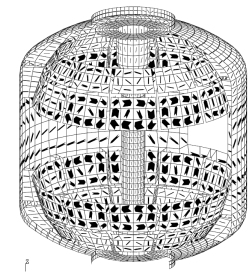
State reduction (< 20 states)

RWM eigenfunction (2 phases, 2 states)

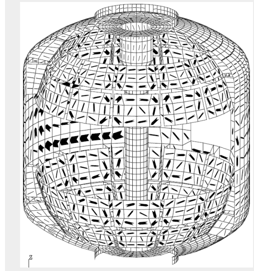
$(\hat{x}_1, \hat{x}_2)$



$\hat{x}_3$



$\hat{x}_4$



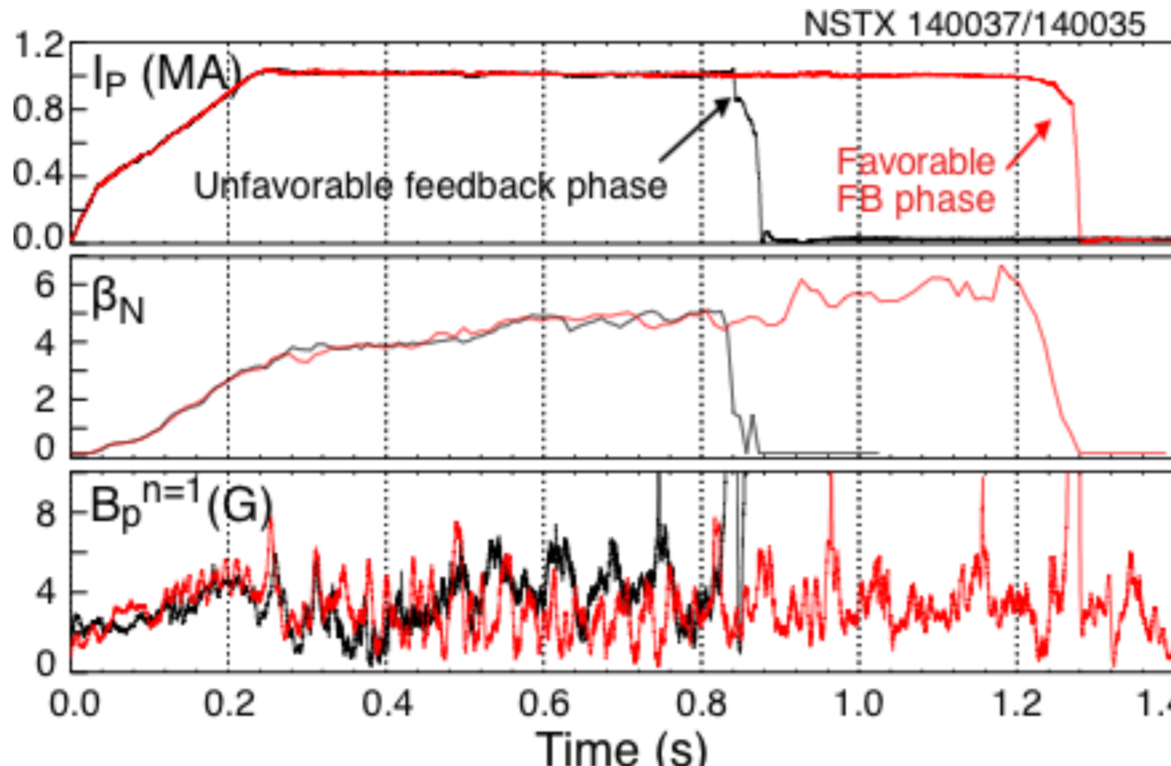
$\hat{x}_N$

truncate

- *device R, L, mutual inductances*
- *instability B field / plasma response*
- *modeled sensor response*

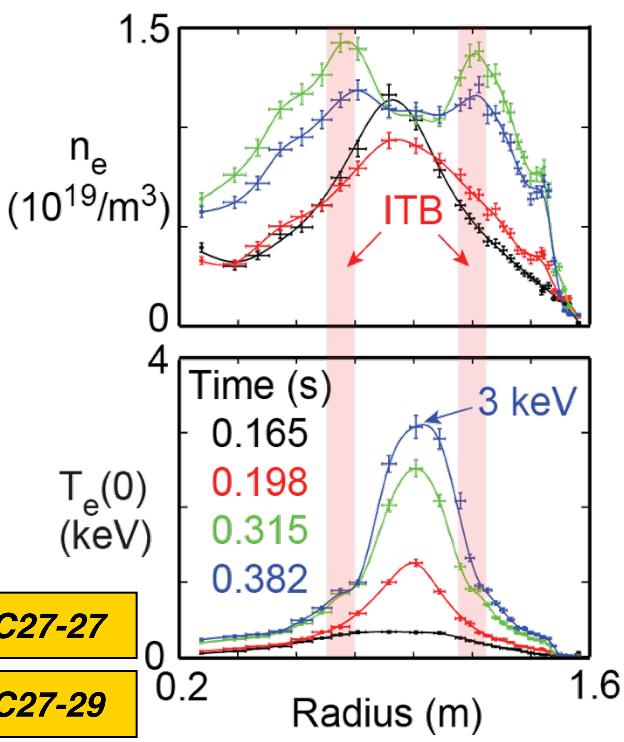
- *Controller can compensate for wall currents*
  - *Including mode-induced current*
  - *Examined for ITER*
- *Successful initial experiments*
  - *Suppressed disruption due to n = 1 applied error field*
  - *Best feedback phase produced long pulse, $\beta_N = 6.4$, $\beta_N/l_i = 13$*

State space feedback with 12 states



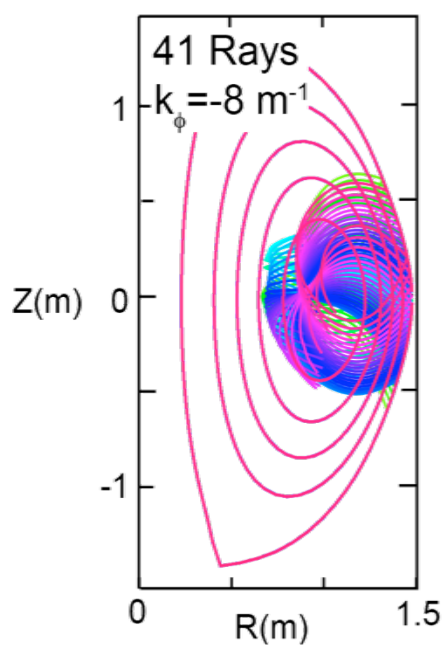
R(10-2): Characterize HHFW heating, current drive, and current ramp-up in deuterium H-mode plasmas.

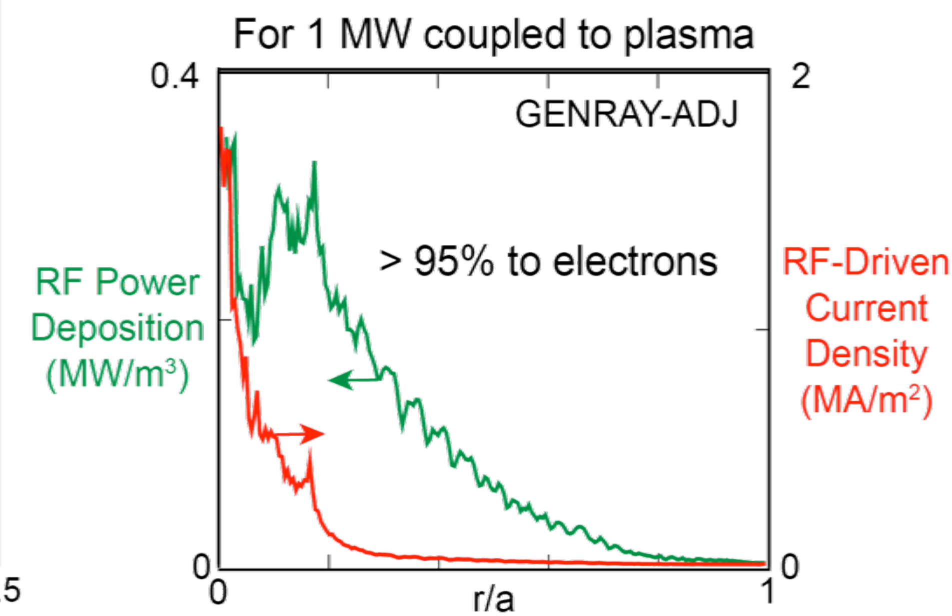
- Low I_p HHFW experiments in 2005 could not maintain P_{RF} during H-mode
- Produced sustained RF-only H-mode in FY10:
  - ➢ Better plasma-antenna gap control than in 2005, due to reduced PCS latency
  - ➢ Modeling predicts I_{RFCD} ~ 85 kA, $I_{Bootstrap}$ ~ 100 kA → f_{NI} ~ 60 %
  - ➢ **High f_{NI} enabled by positive feedback between ITB, high $T_e(0)$ and RF CD**
  - ➢ f_{NI} ~ 100% requires P_{RF} ~ 3 MW – P_{RF} limited to 1.4MW in FY10 – revisit in FY11



PAC27-27

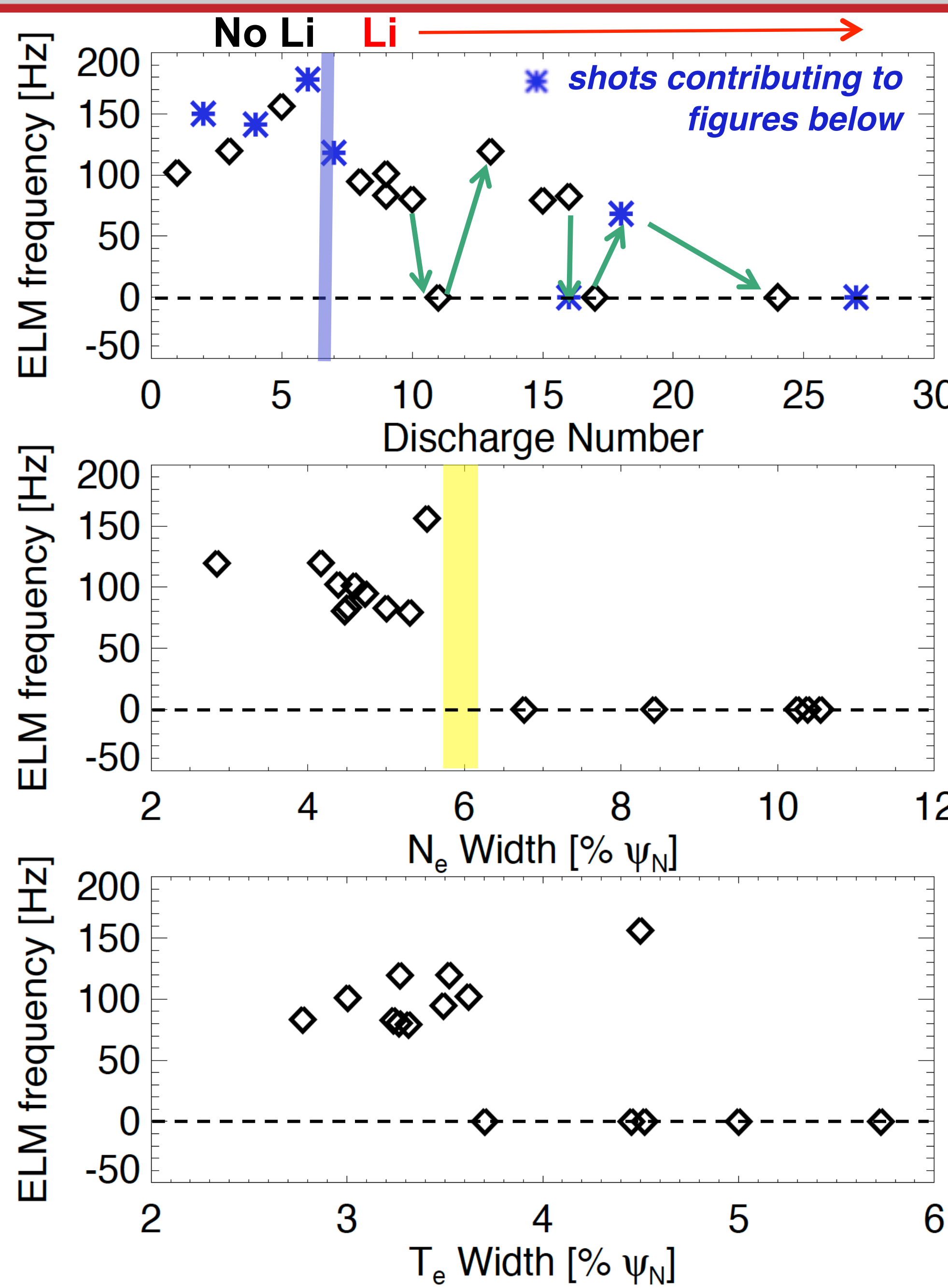
PAC27-29





R10-3: Assess pedestal characteristics as a function of collisionality and lithium conditioning

- To first order, effect of LLD on pedestal and ELMs inseparable from global effect of lithium on graphite
  - Low deposition amounts between discharges retain ELMs, higher deposition amounts mostly ELM-free
- Analysis of lithium coating scan shows that density gradient relaxation/profile broadening critical for ELM suppression (Maingi, IAEA 2010)
- Substantial progress on pedestal height/width vs. I_p (Diallo, APS 2010)



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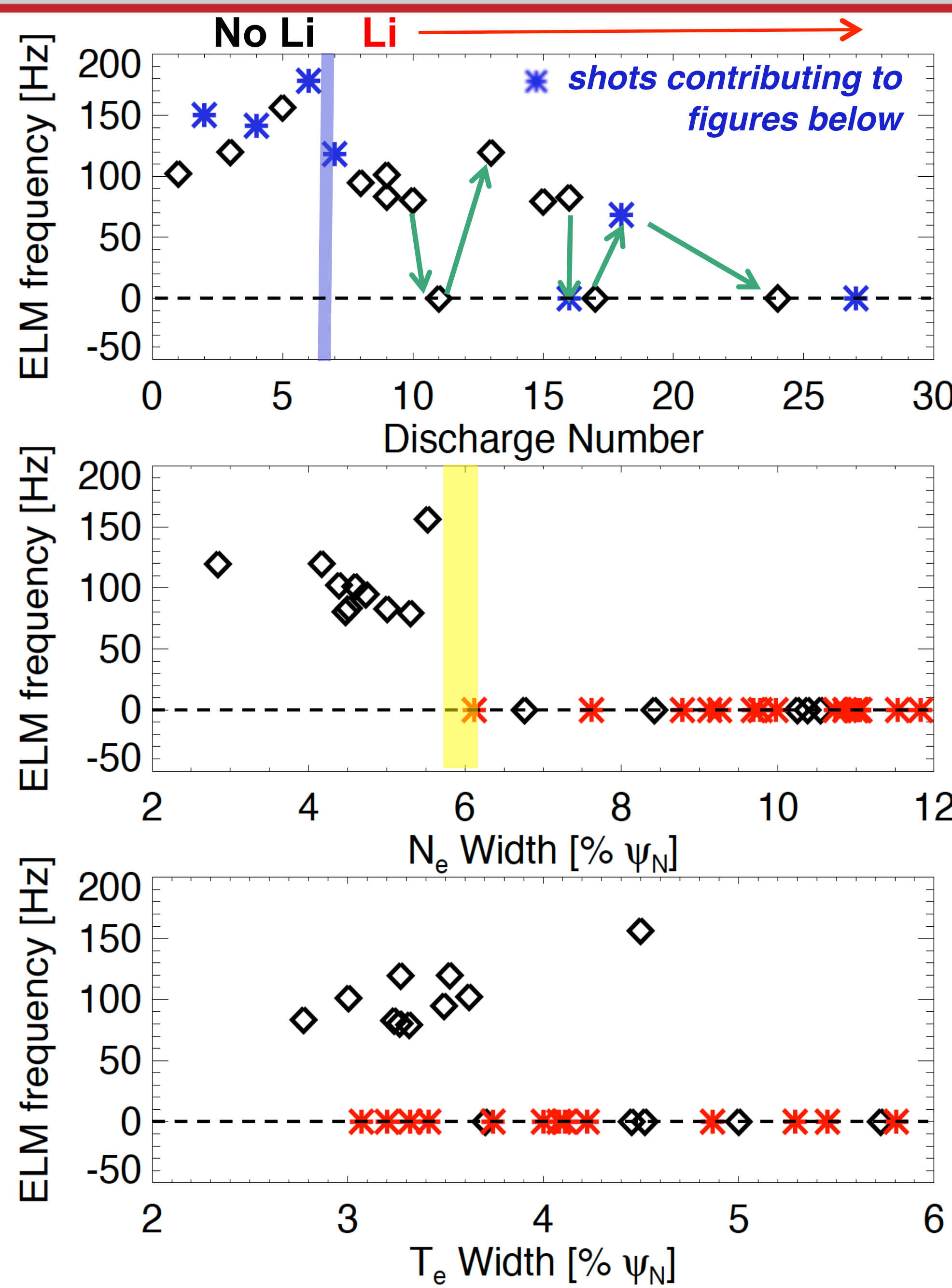
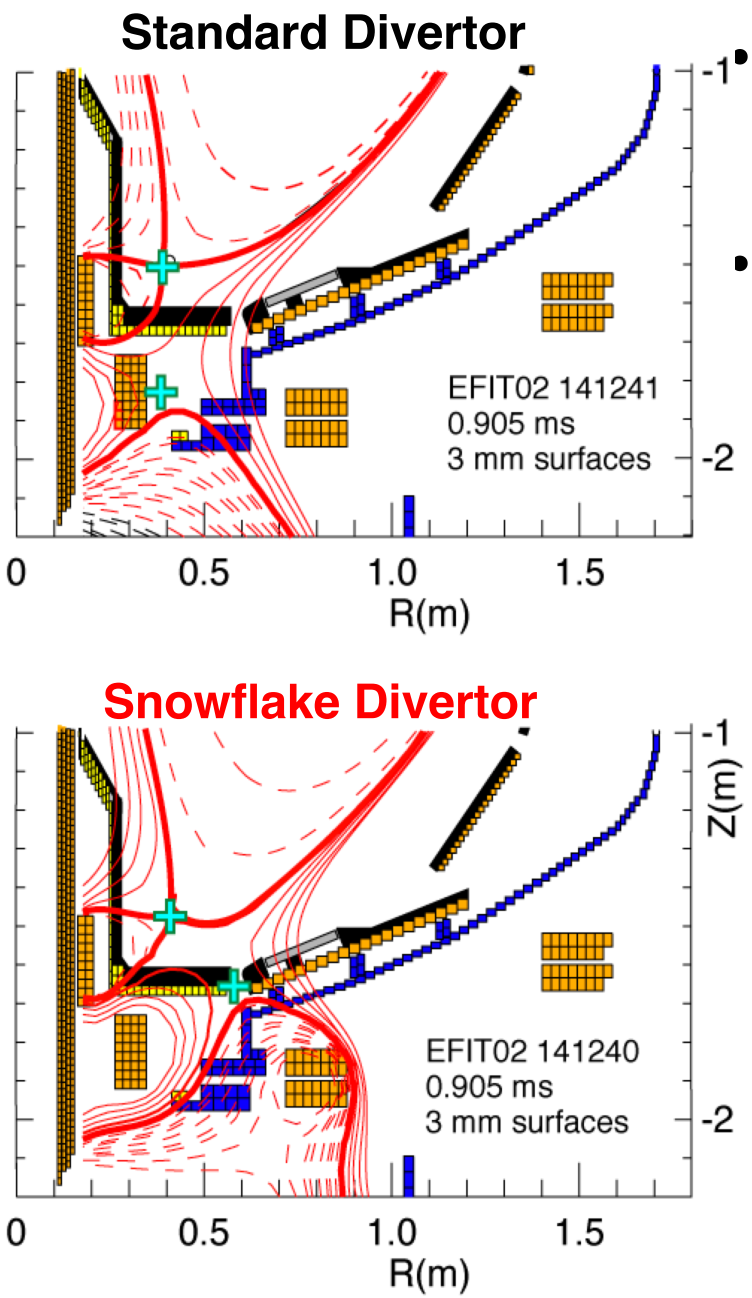
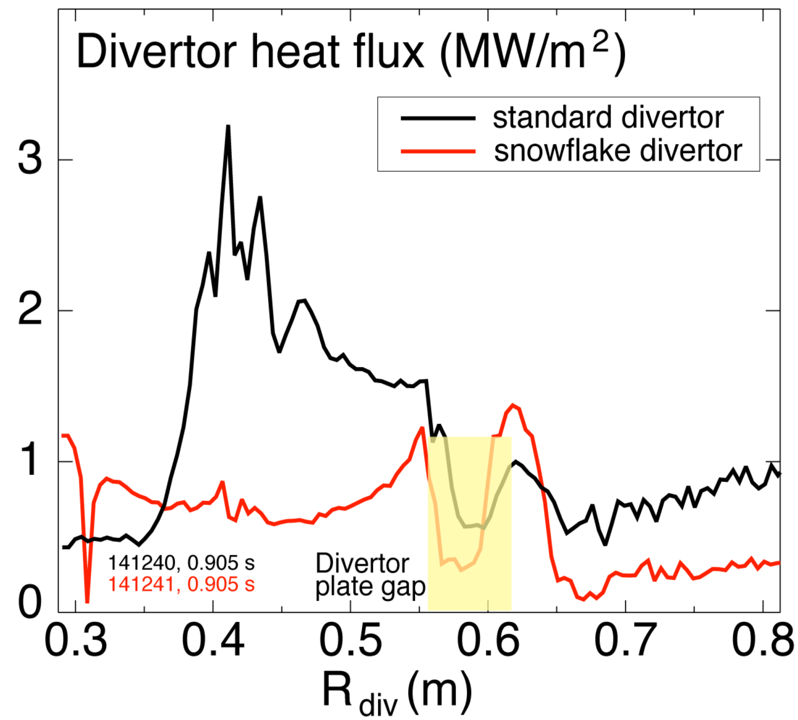


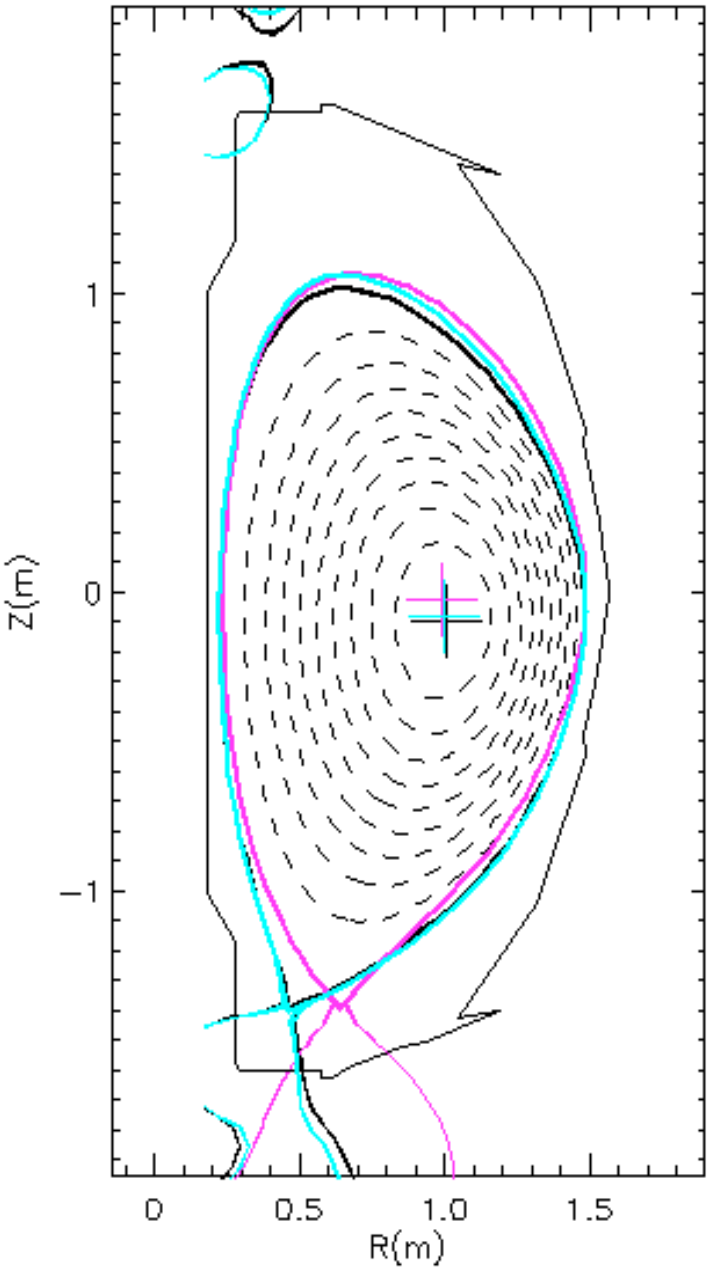
"Snowflake" divertor configurations obtained in NSTX have significantly reduced peak heat flux



- High-δ divertor configuration is transformed into "Snowflake" divertor.
- Significant reduction of peak heat flux observed in "snowflake" divertor.
  - Potential divertor solution for NSTX-U.



Observation that L-H transition power scales with toroidal field at X-point unifies triangularity and field scaling



- ST geometry enhances B_{tX} variation with R_X
- Three comparable discharges:
  - Matched I_p, n_e, Z_X, wall-conditioning

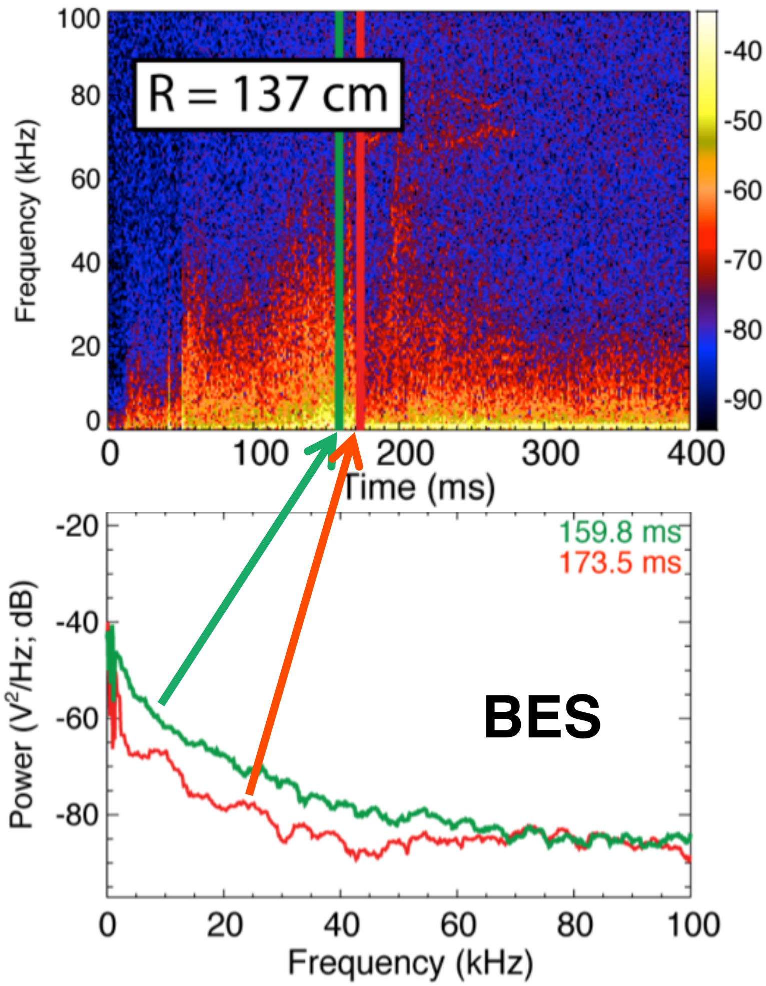
B_{t0} (T)	B_{tX} (T)	P_{Loss} (MW)	R_X (m)
0.55	0.86	1.1	0.47
0.55	0.63	0.7	0.64
0.40	0.63	0.6	0.47

- XGC-0 calculation predicts E_r well is deeper with larger R_X
  - Smaller B_{tX} → larger gyro-orbit → enhanced ion loss at X-point

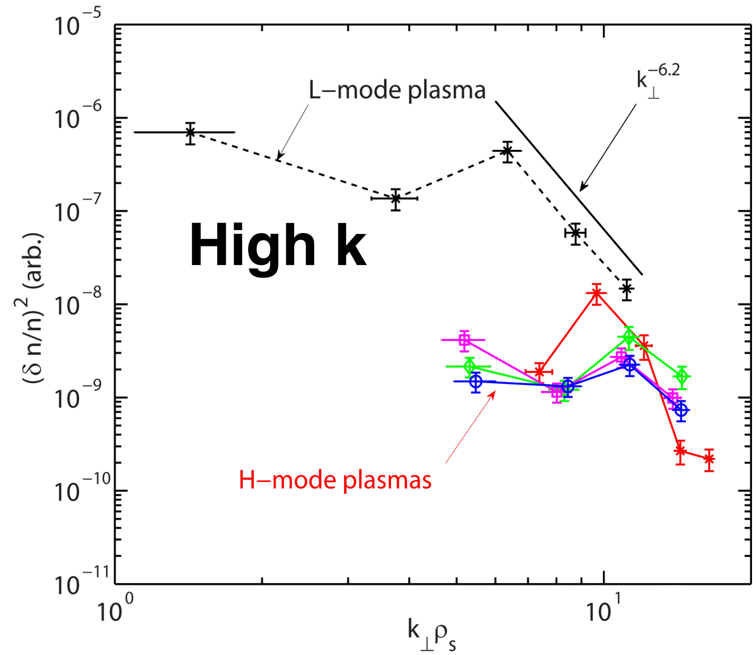
Turbulence level lower in H-mode at low-k (BES), and for $k_\perp\rho_s$ < 10 (High-k scattering)

Drop in fluctuation power is ≈ 10db at lower frequencies.

Reduction in fluctuations not just at plasma edge, extend into plasma.



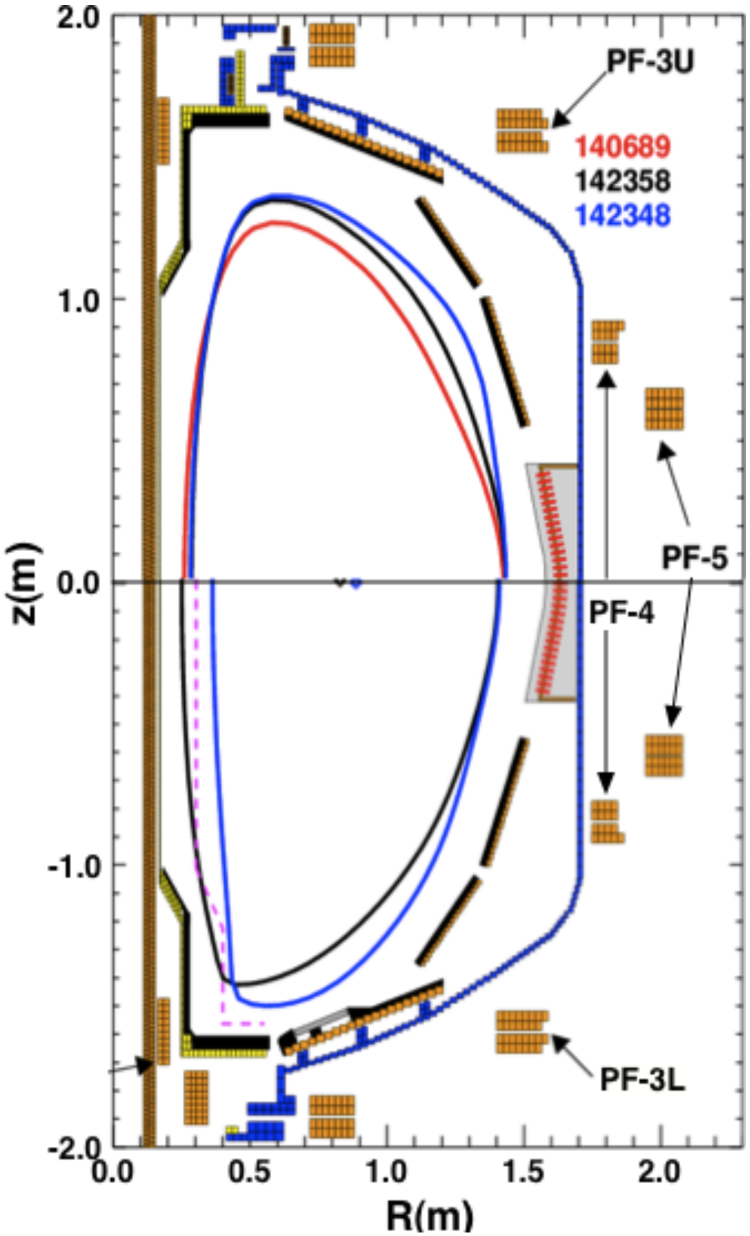
k spectra of normalized density fluctuations in beam-heated L and H-mode plasmas



Spectral power for $k_\perp\rho_s$ >10 similar for L and H-mode.

Large differences, more than 2 orders of magnitude, in spectral power found at $k_\perp\rho_s$ <10 between L and H-mode.

PCS upgrades & PF4 coil commissioned to support NSTX-U operations, provide shape control flexibility



- PF-4 coil used in both senses, relative to PF-5.
  - In same sense, gives more vertical field, needed for high current.
  - In opposite sense can increase squareness.
- Coil used in pre-programmed mode, and in shape control loop.
  - With PF-4/PF-5 ratios far larger than required for NSTX-Upgrade

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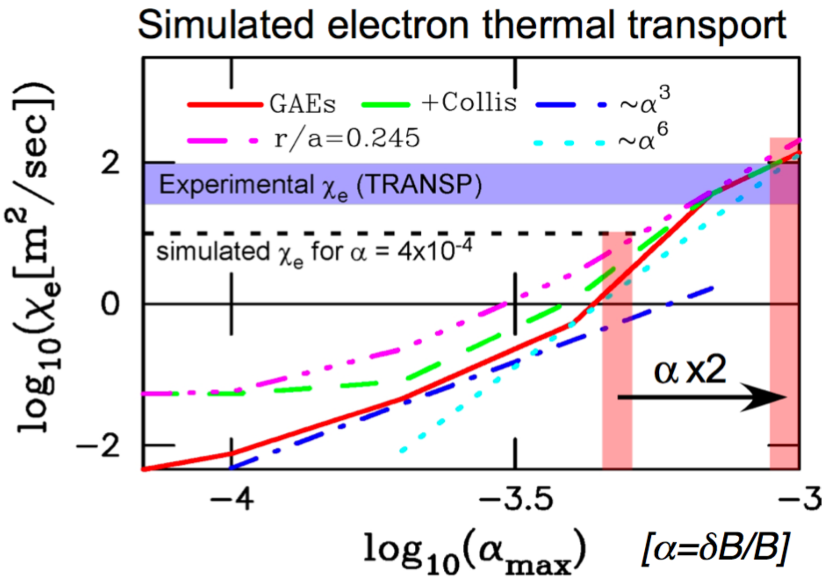
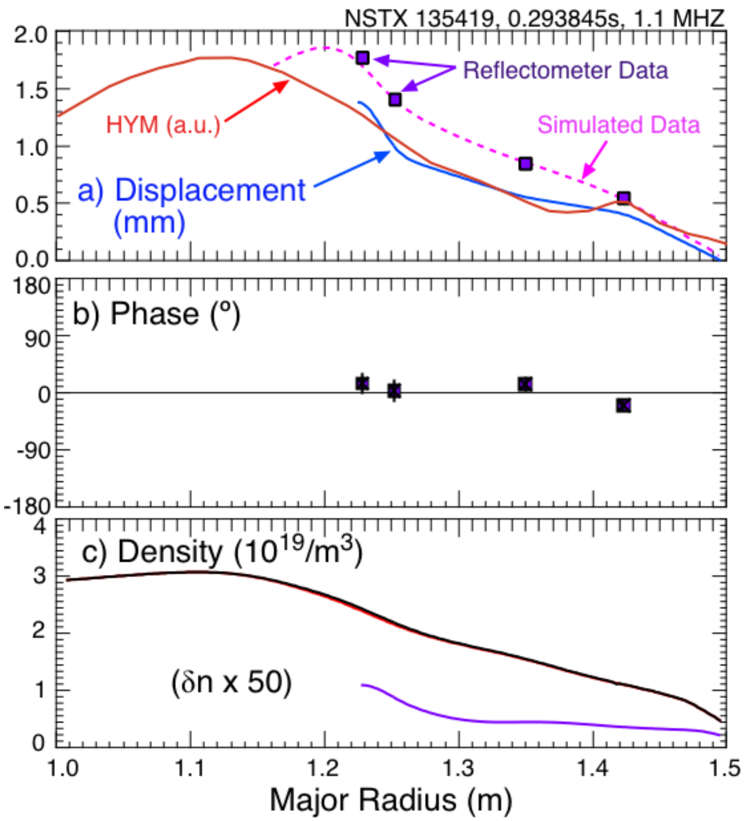
- Higher aspect ratio (NSTX-U) discharges demonstrated simultaneous high β_n ($\geq$ 5) and high κ ($\geq$ 2.6)
- Compare new, higher aspect-ratio boundary, consistent with NSTX-U centerstack, with current high performance plasma shape.

Numerical simulations of Alfvénic modes clarify physics of stability and affect on transport

- HYM code simulations find good agreement with toroidal mode number and measured radial mode structure for GAE.
  - Results validate Doppler-shifted cyclotron resonance drive for modes





- Anomalous electron thermal transport at high power consistent with estimates based on experimental GAE amplitude/spectra
  - improved modeling expected with better GAE mode structure measurements using BES and 16 ch. reflectometer array
- GAE avalanches redistribute fast ions, in some cases triggering TAE avalanches responsible for fast ion losses.

FY10 & FY11 run achieved many important results beyond those related to milestones

- Progress made on impurity reduction with divertor gas puffing, snowflake divertor, and upward bias during current ramp (BP)
- Enhanced Pedestal H-mode (EPH) with H98 up to 1.7 routinely produced, control still an issue (ASC)
- Combined X-point height & strike point control with improved PCS algorithm to enable LLD experiments (ASC)
- Combined B_r and B_θ RWM sensors reduces n = 1 field amplitude and improves stability (MS).
- Lithiated PFC leads to broadened T_e profile, corresponding to reduction in turbulence at $k_\perp \rho_s$ <10, and pedestal-top χ_e (T&T)
- CHI assisted start-up reached 1MA with 65% of non-CHI-assisted ramp-up flux consumption (SFSU)

Summary: FY10 research focused on milestones, upgrade-enabling experiments and optimized use of capabilities

- Demonstrated reliable, high performance operation with LLD.
- λ_q^{mid} found to vary ~ $I_P^{-\alpha}$, independent of B_t, and P_{loss} as part of FY 2010 Joint Research Target; α depends on lithium conditioning.
- More stable operation at high β; new RWM state space controller sustains high β_N plasma
- Analysis of lithium coating scan shows that density gradient relaxation/ profile broadening critical for ELM suppression (R10-3).
- "Snowflake" divertor configurations obtained in NSTX have significantly reduced peak divertor heat flux
- Experiments and analysis have elucidated the scaling of the H-mode power threshold, including a dependence on field magnitude.
- PCS upgrades & PF4 coil were commissioned to support NSTX experiments, provide shape control flexibility
- High power HHFW experiments deferred to FY11 due to conditioning problems, but good results obtained in low current plasmas.