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Overview of Commissioning Operations on the National Spherical Torus Experiment Upgrade (NSTX-U)

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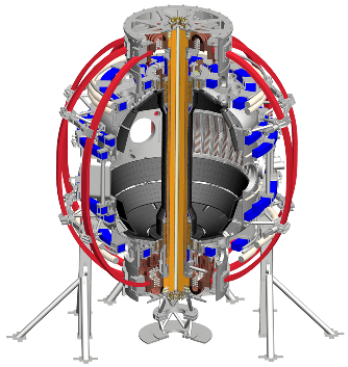
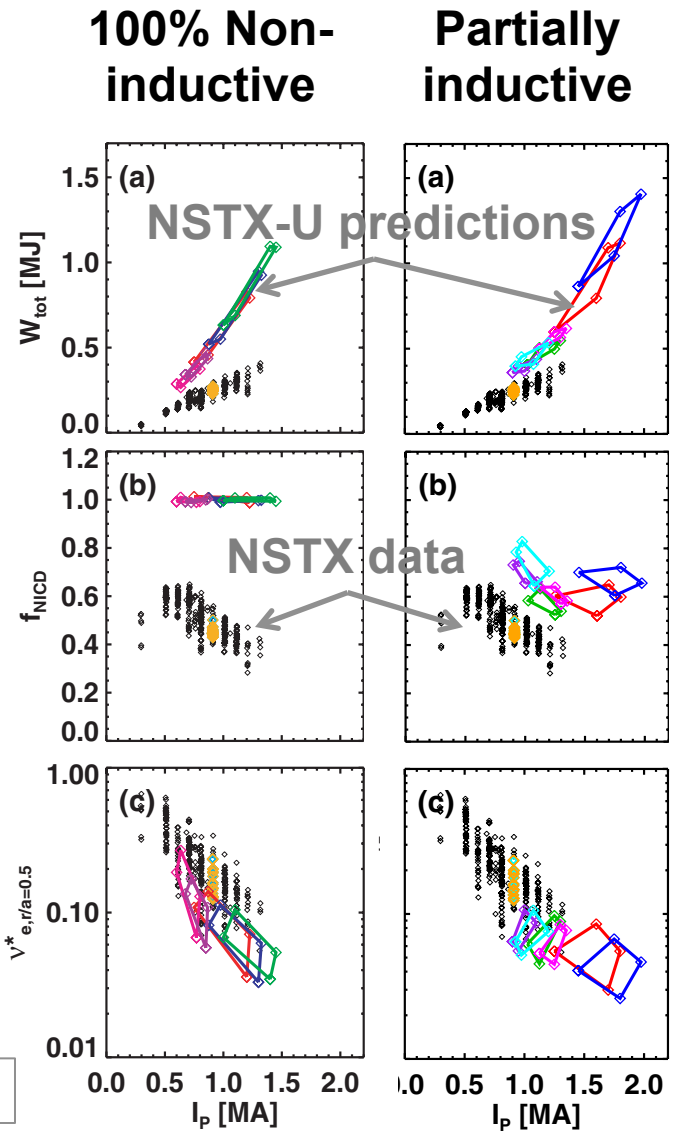


OVERVIEW

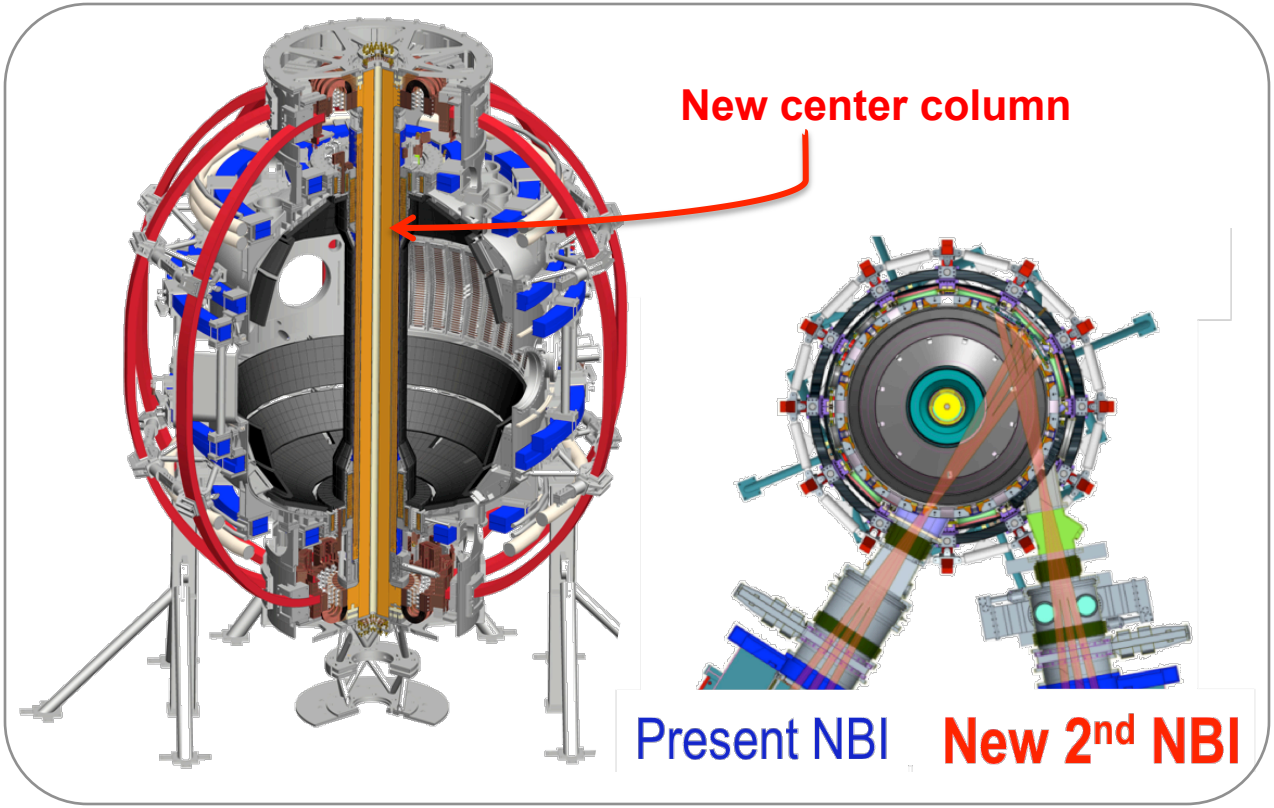
NSTX-U will access new physics regimes in the low-aspect-ratio geometry

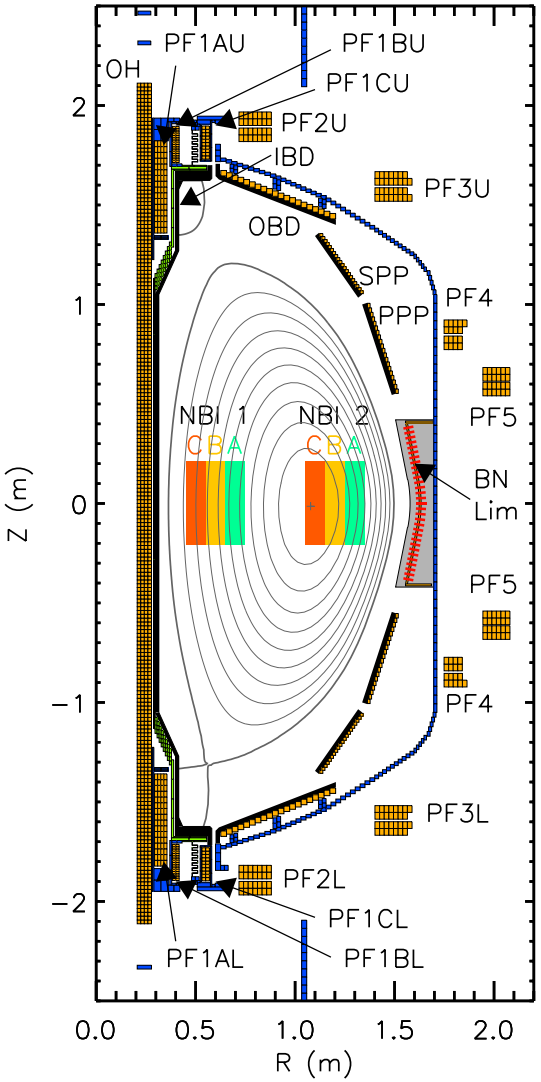
- NSTX-U will access 100% non-inductive operation
  - Sustain I_p > 1 MA for many current redistribution times
- Access lower v* over a large range in β
  - Unique regime to study transport and stability physics
- Informs aspect ratio optimization of next-step devices



S.P. Gerhardt et al., Nucl. Fusion **52** (2012)

Upgrade elements include a new central magnet and a second neutral beam





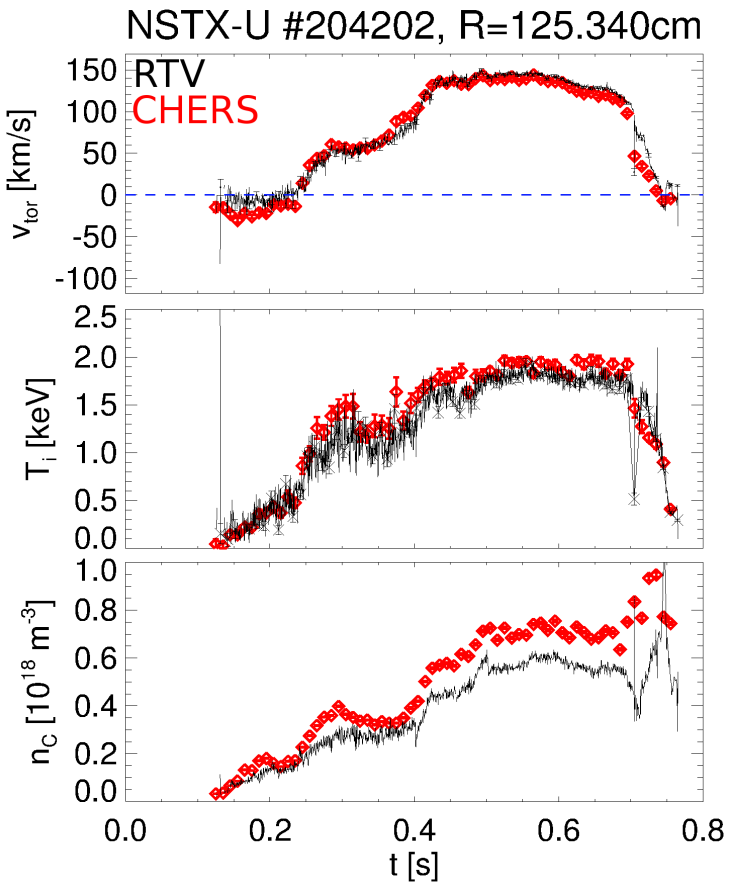
Full-field H-mode operation

	B_T (T)	I_p (MA)	t_{pulse} (s)	P_{heat} (MW)
NSTX	0.55	1.2	1	5
NSTX-U	1.0	2.0	5	10

NSTX-U completed ten productive weeks of operations in 2016

- First operation with new systems
  - Example: Updated plasma control and digital coil protection
- 90% of commissioning activities completed
  - Developed stationary L-mode discharges
  - Matched NSTX H-mode performance for $I_p \leq 1$ MA
  - Many magnetic and kinetic profile diagnostics commissioned
    - Real-time CHERS for rotation control →
- Run ended prematurely due to PF coil failure

Comparison of real-time CHERS system to off-line CHERs

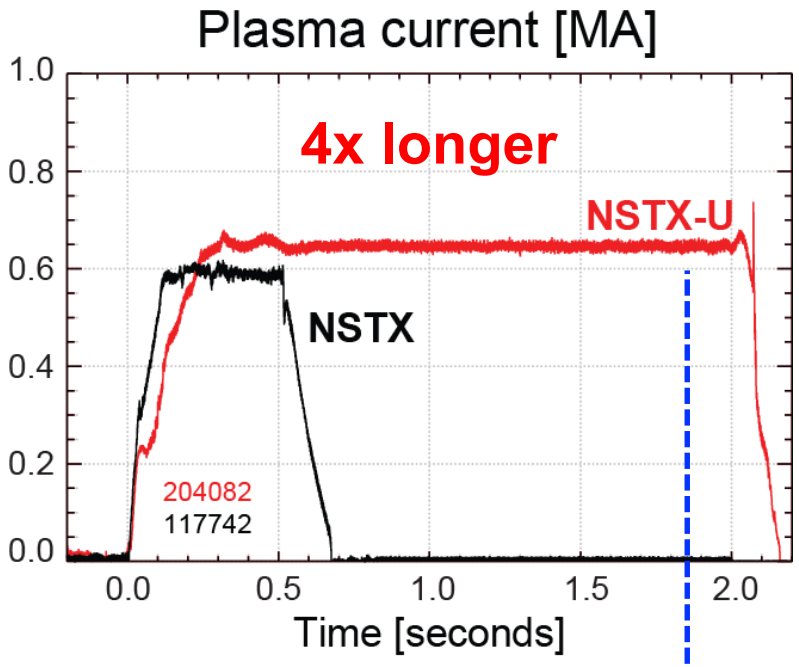


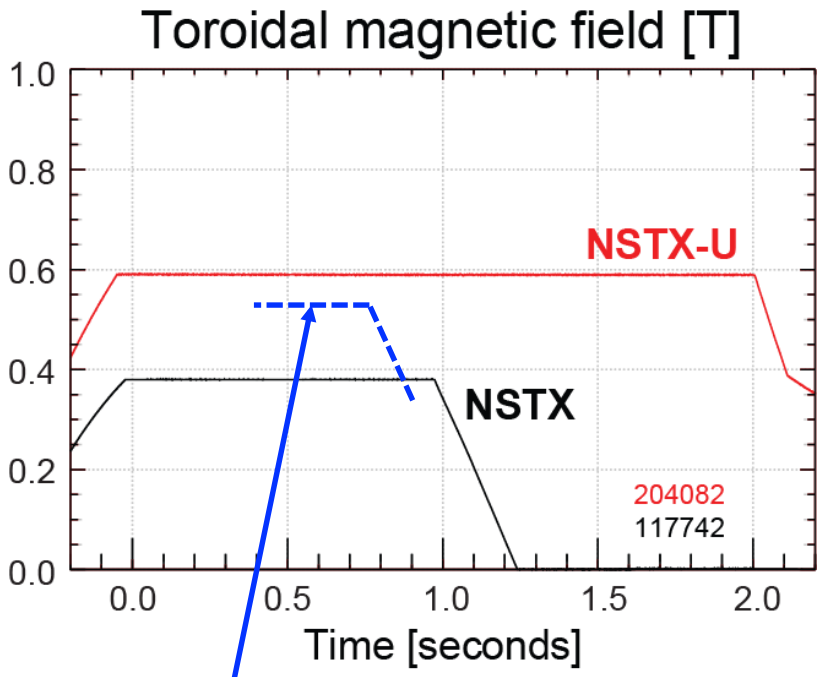
M. Podesta and R. Bell, PPCF **58** (2016)

LONG-PULSE L-MODE

L-mode discharges exceeded pulse length and B_T strength on NSTX

- Enabled by 3 × more ohmic solenoid flux





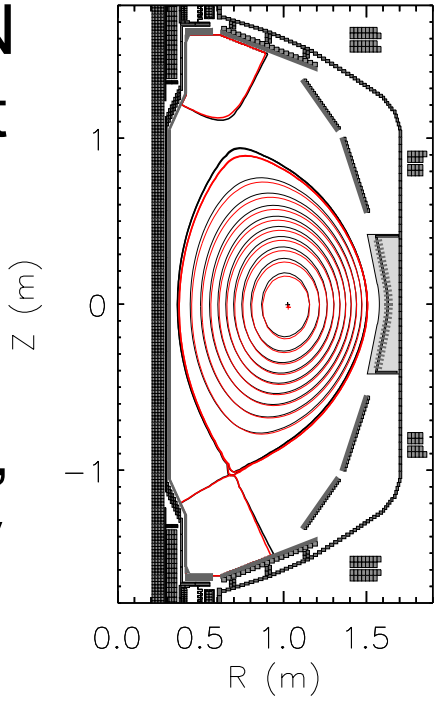
NSTX-U L-mode duration exceeds longest NSTX H-mode

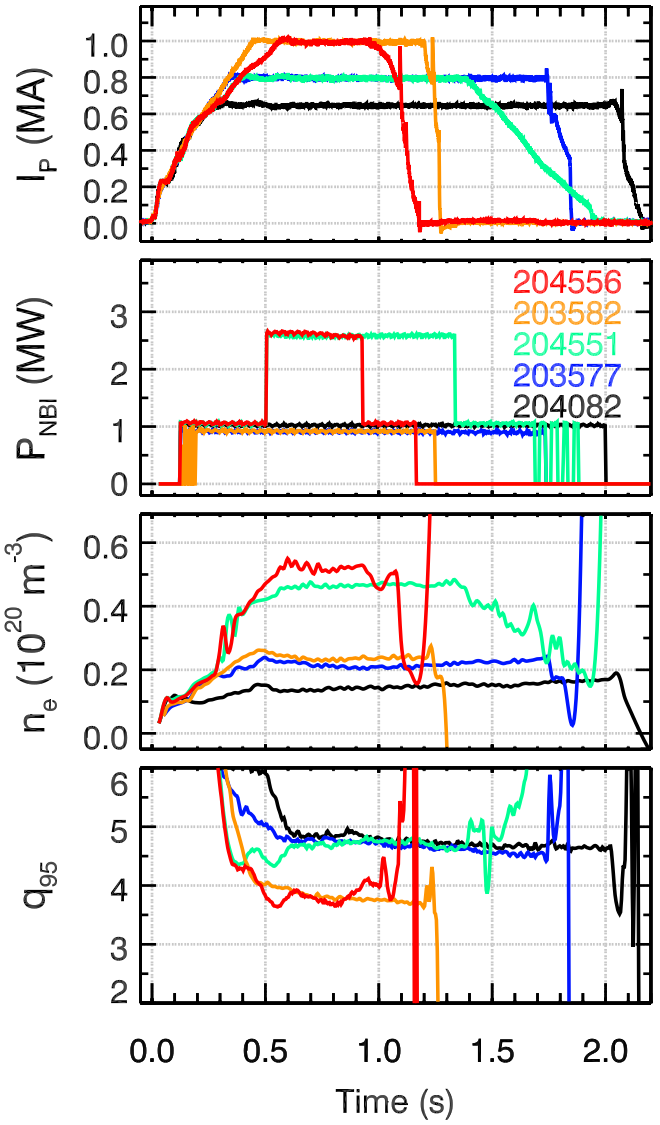
NSTX-U B_T > highest NSTX B_T

J. Menard, NF, *accepted* (2017)

Stationary L-mode discharges with regular sawteeth achieved over a range of I_p and P_{NBI}

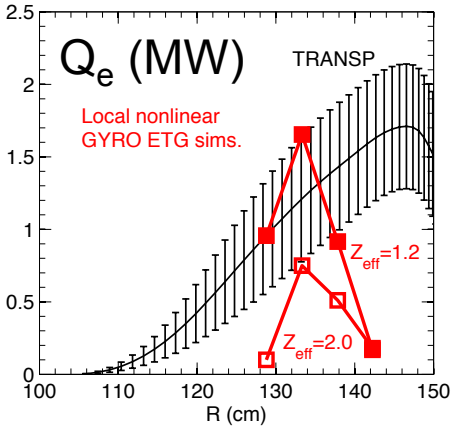
- Stationary L-mode discharges demonstrated up to I_p = 1MA
  - q_{95} > 3.5 with B_T = 0.63 T
  - Pulse length limited by OH flux
- P_{NBI} = 2.5 MW LSN L-mode possible at higher density
- Divertor PF coils operate near limits, restricting flexibility in triangularity

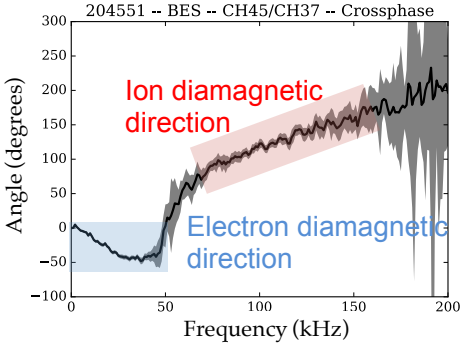


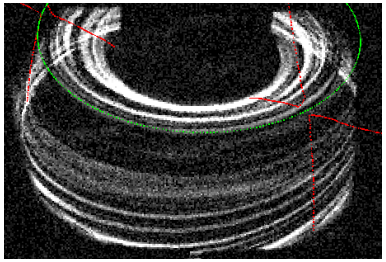


Stationary L-mode discharges supported initial transport experiments

- ST extends range of β, R/a and ρ_* for turbulence theory and simulation
  - Initial local, non-linear GYRO calculations: ETG may account for Q_e at mid-radius
  - Bi-modal ion-scale turbulence measured by BES
  - W. Guttenfelder, *submitted*
- ST geometry supports complete imaging of divertor with fast cameras
  - Divertor localized filaments propagate toward X-point on both divertor legs, uncorrelated with upstream blobs
  - F. Scotti, *in preparation*



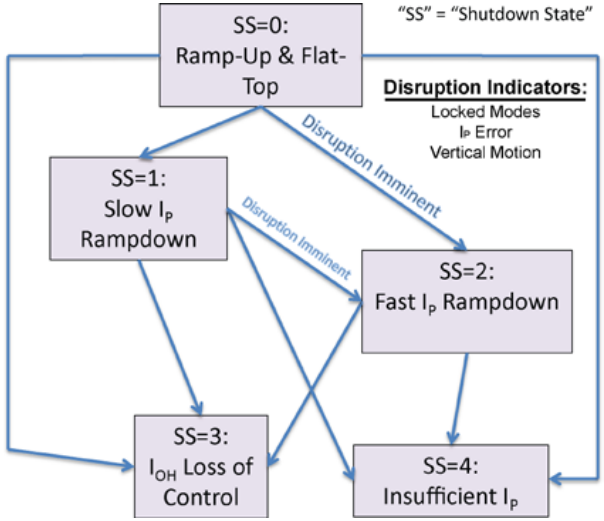




RT CONTROL & EFC

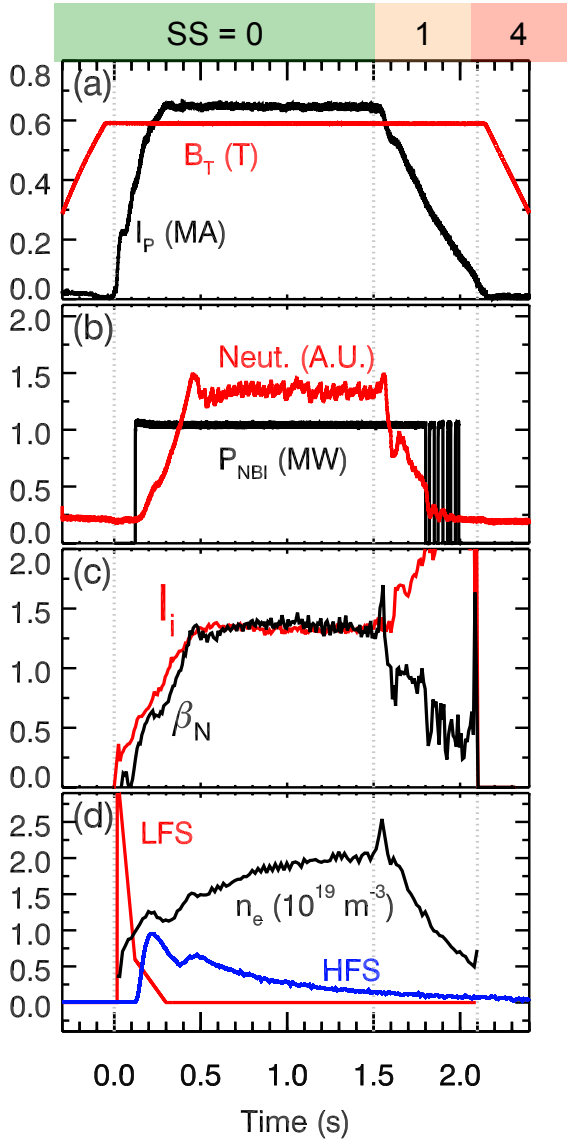
NSTX-U plasma control system (PCS) organized using "state machine" logic

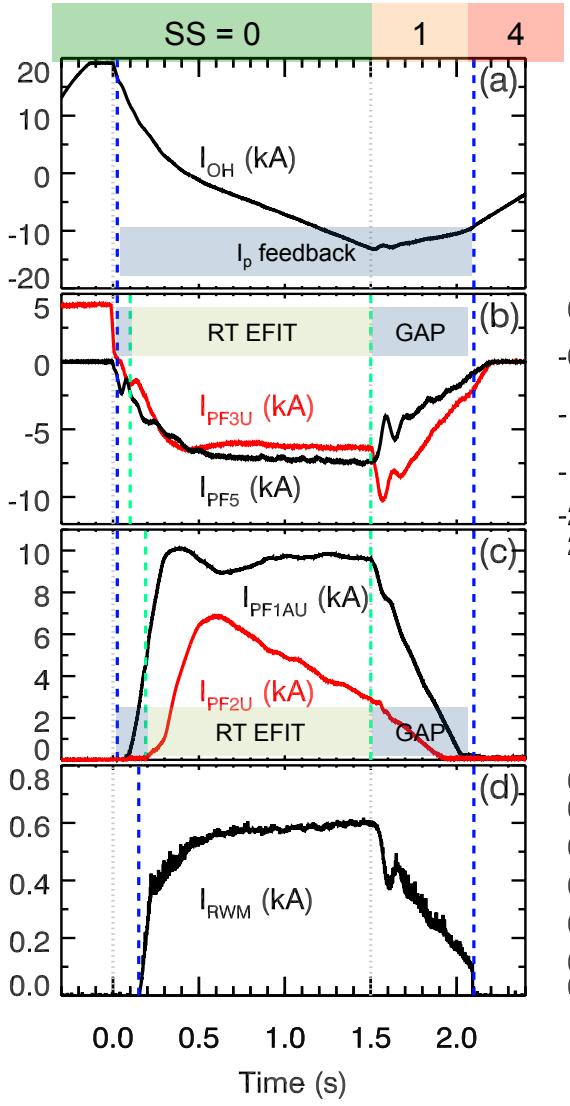
- PCS detects loss of control (LOS), initiates controlled ramp down
  - LOS mechanisms employed on NSTX-U:
    - Loss of vertical stability
    - OH solenoid approaching current limit
    - OH solenoid approaching I^2t limit
    - Large I_p error
    - B_T pulse length limit
  - Control algorithms change with each state
  - M.D. Boyer, *in preparation*

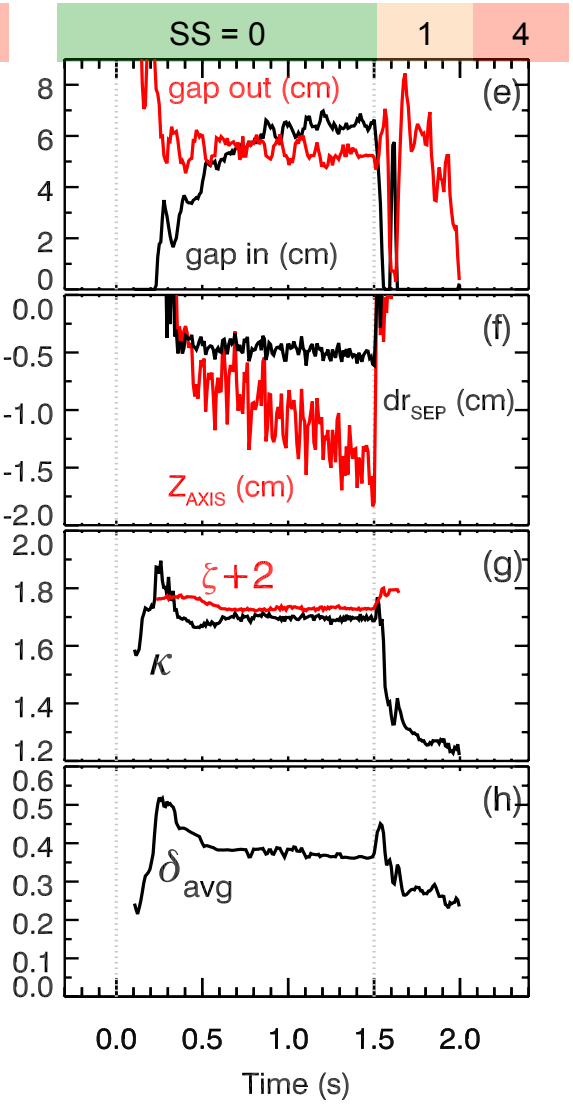


- Disruption Characterization and Forecasting (DECAF) framework in development
  - Classify event chains and test warning thresholds
    - Example: Reduced kinetic RWM model developed for real-time warning of RWM instability onset
  - J. Berkery, *PoP* **24** 056103 (2017) and EPS P1.138

Routine controlled shutdown demonstrated in L-mode discharges





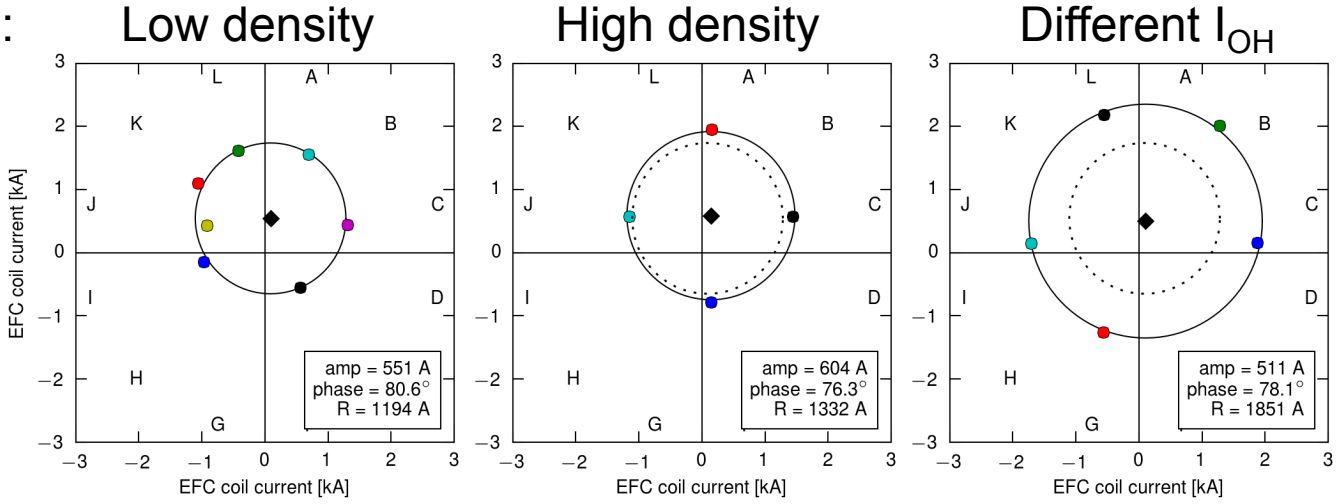


Error fields were identified and corrected via experiments and modeling

- Locking threshold and EF phase and amplitude are independent of density and I_{OH} in L-mode flattop
  - EFC applied n=1 field using 6 windowpane coils

- Metrology and modeling implicate static tilt of inboard TF legs as the primary error field source
  - Alignment of inner TF legs will be improved for the next campaign

L-mode flattop:



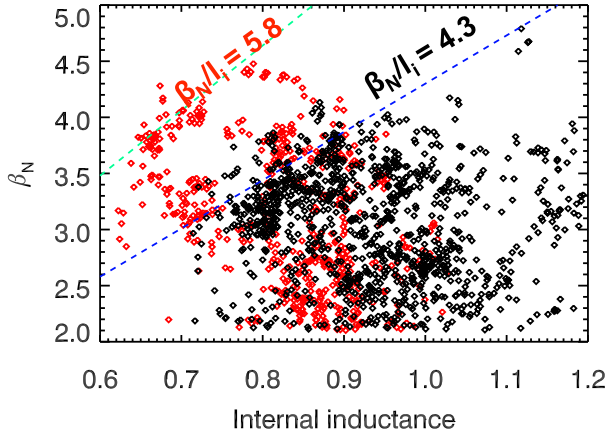
C. Myers, *in preparation*

H-MODE SCENARIO

Progress in EFC, real-time control and NBI heating improved H-mode performance

Maximum β_N/l_i increased with improved EFC

EFC v1 **EFC v2**



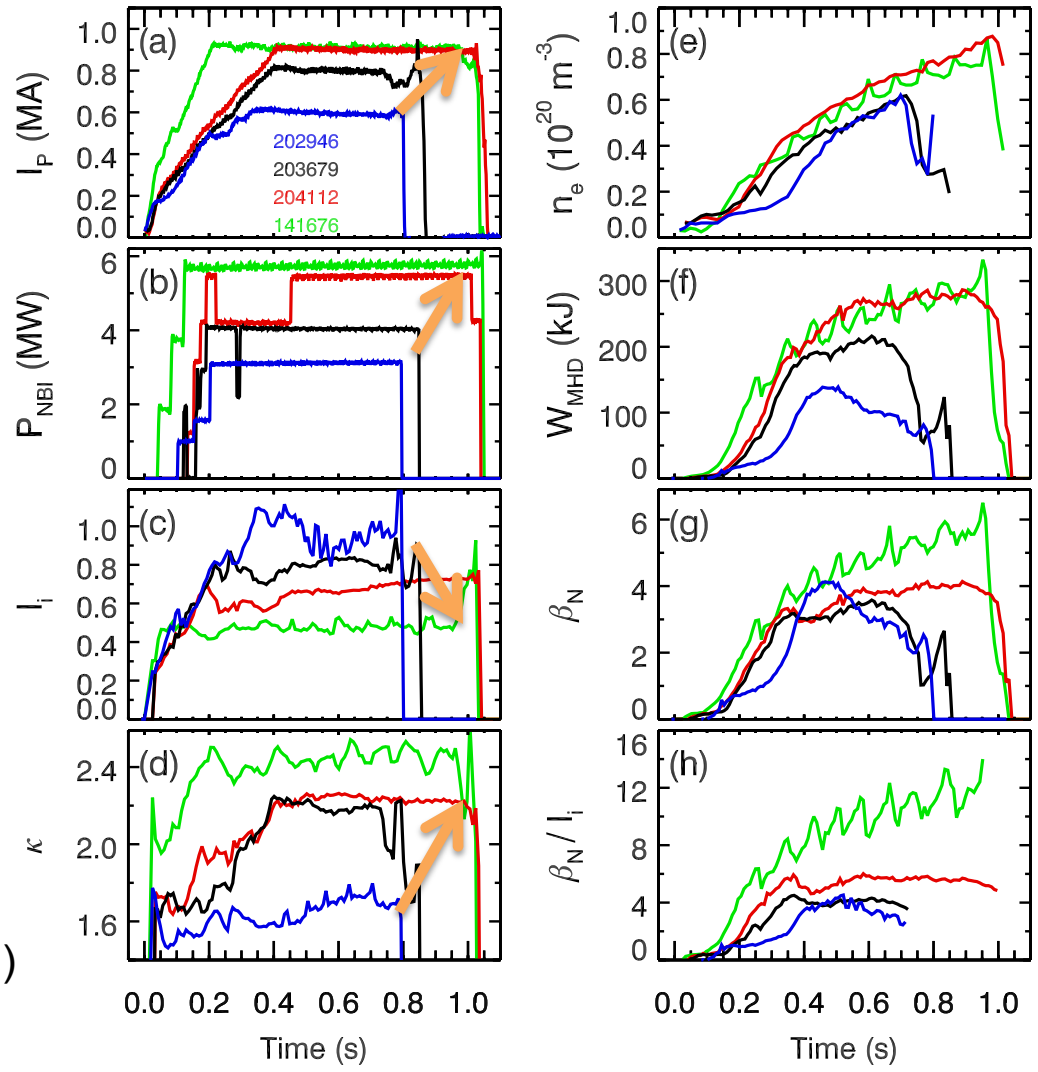
NSTX B_T = 0.44 T

NSTX-U B_T = 0.62 T

Week 3 No EFC

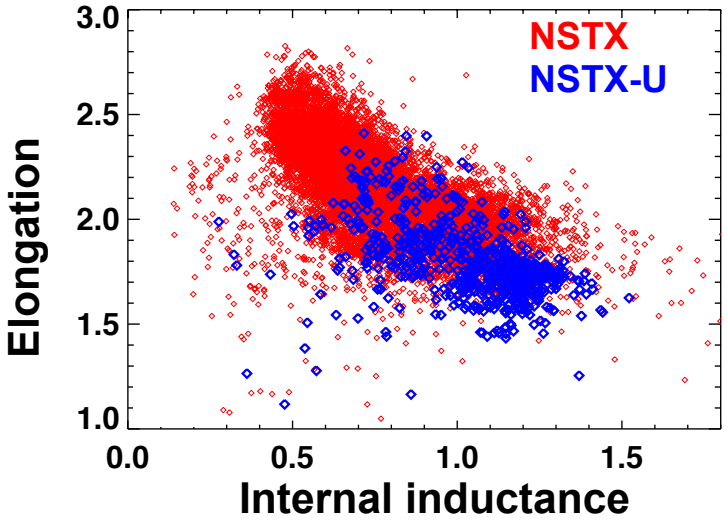
Week 5 Unoptimized EFC phase (v1)

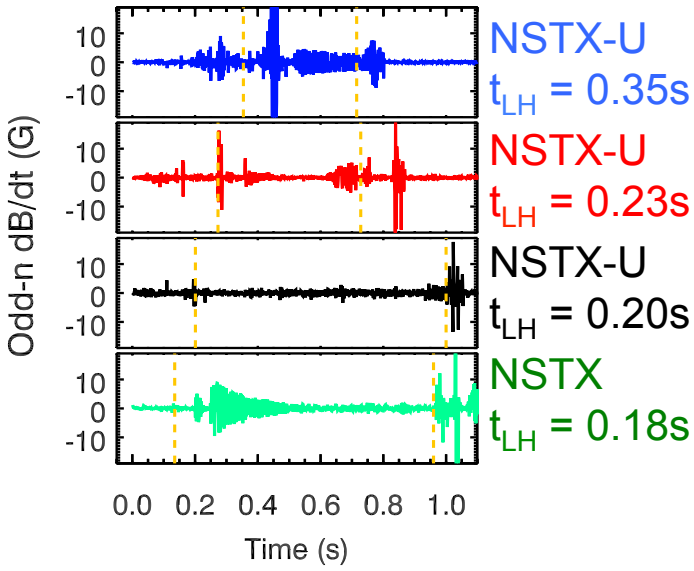
Week 7 Optimized EFC phase (v2)



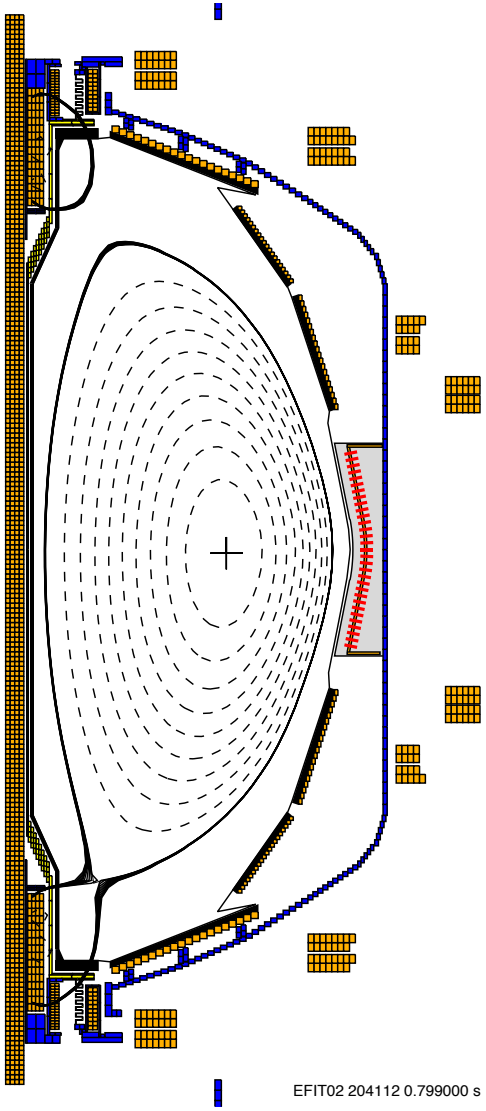
H-mode scenario targets early L-H transition to enable low-l_i, high-κ operation

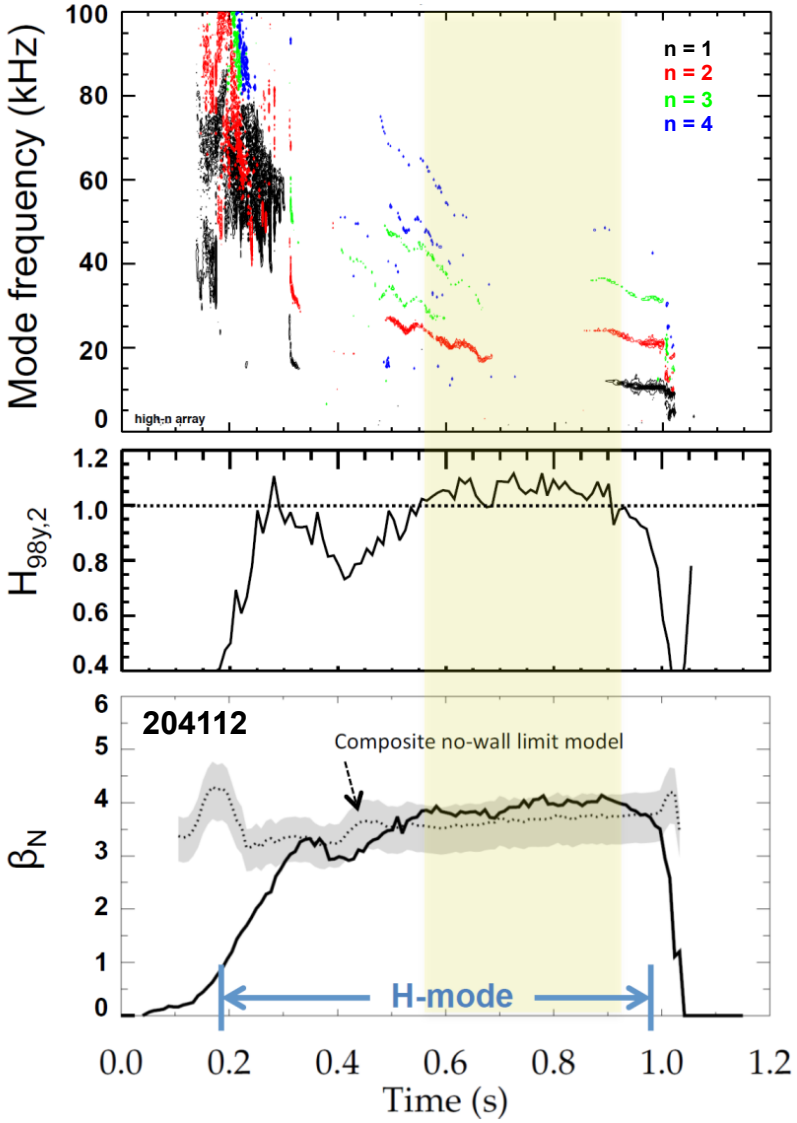
- Improved Z control enabled stable operation at κ similar to NSTX despite higher A
  - New multi-sensor Z detection and noise rejection
- L-H transition early in ramp-up slows current penetration
  - Maintains low l_i, enabling vertical stability at high κ
  - Maintains higher q_{min}, enabling MHD-free operation





Recovered 1 MA H-mode with weak/no core MHD with $H_{98y,2}$ and $\beta_N/\beta_{no\text{-}wall} \geq 1$





Minimal core MHD

$H_{98y,2} \geq 1$

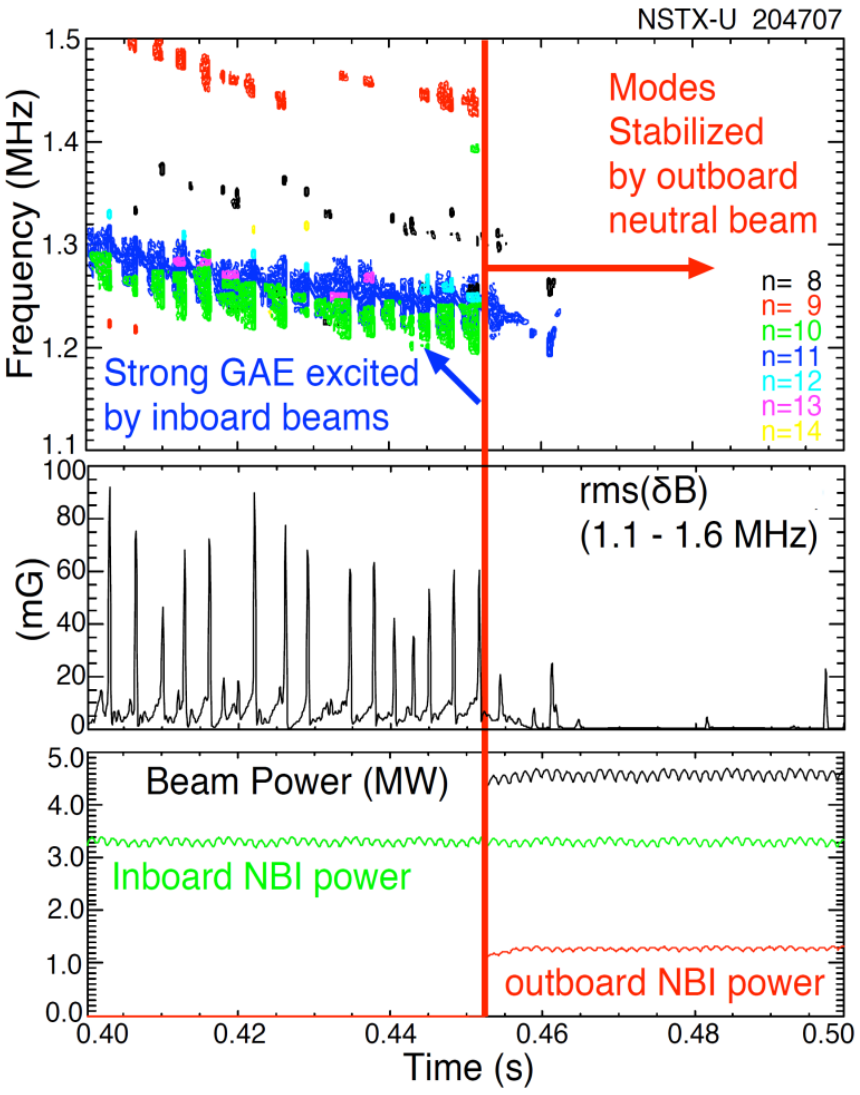
$\beta_N/\beta_{no\text{-}wall} \geq 1$

ADDITIONAL HIGHLIGHTS

More tangential neutral beam increases flexibility in probing NBI physics

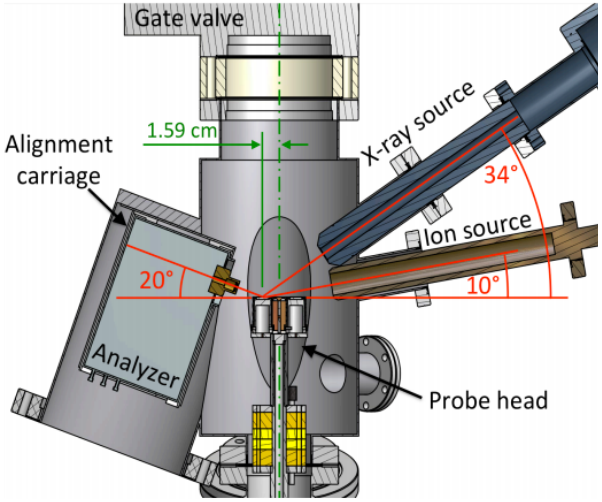
- Off-axis tangential injection increases flexibility in active control of rotation and current profiles
- Tangential injection observed to suppress Global Alfven Eigenmodes (GAE)
  - Consistent with HYM code prediction of mode suppression via reduction of gradients in fast ion distribution

E. Fredrickson et al., PRL, *accepted*



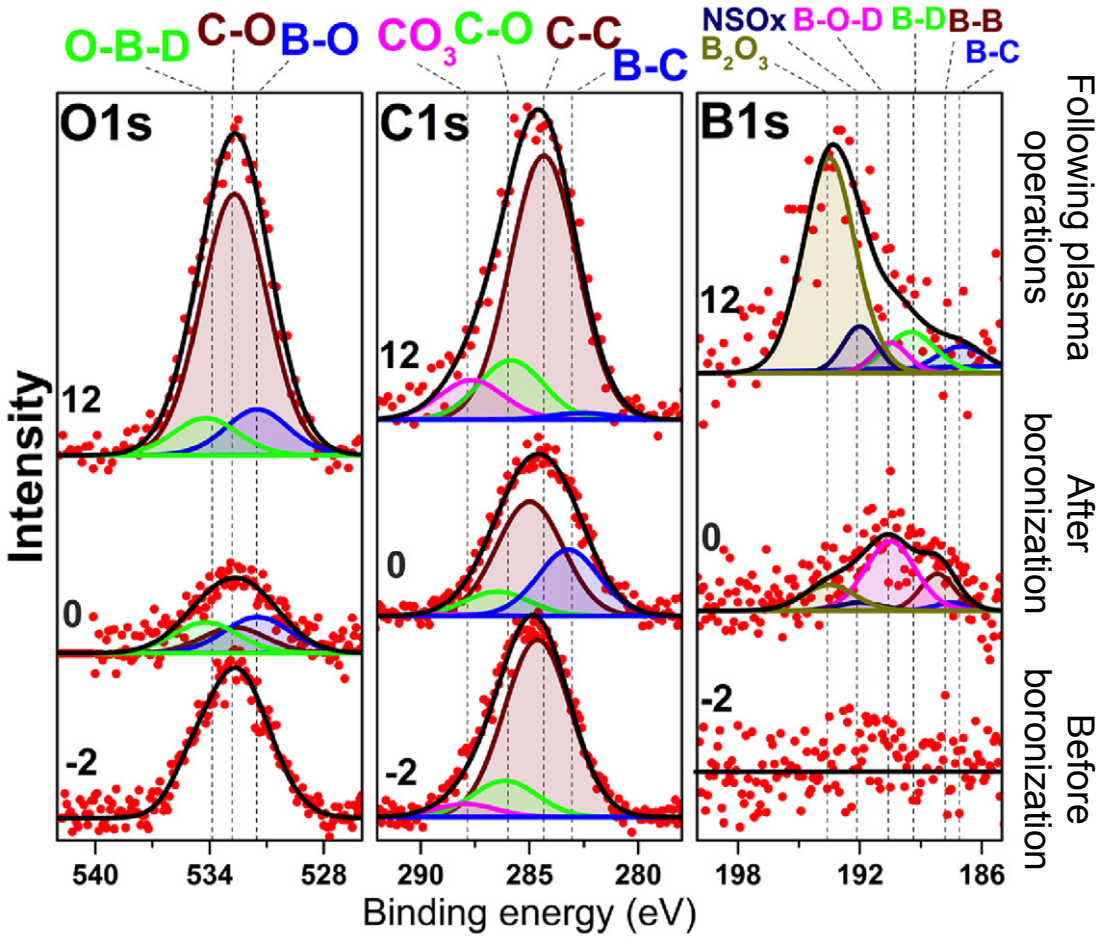
Novel surface analysis tools quantify day-to-day evolution of first wall chemistry

Materials Analysis Particle Probe (MAPP) performs surface analysis of exposed samples in chamber attached to NSTX-U



F. Bedoya et al., Nuclear Materials and Energy, *accepted* (2017)

X-ray Photoelectron Spectroscopy (XPS)



NSTX-U had a productive year, now poised to address key scientific issues by leveraging the low-A regime

- Exceeded NSTX pulse length and B_T in L-mode discharges
  - Initial error field correction, transport and fast-ion physics studies enabled by stationary discharges
  - New fast-ion physics with 2nd NBI, such as GAE stabilization
- Matched best NSTX H-mode performance at $I_p \leq 1.0$ MA
  - Steady progress supported by excellent diagnostic availability and advances in plasma control, NBI and EFC
- Many new systems commissioned and are ready to support the scientific program
  - New diagnostics enable future science and real-time control