U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

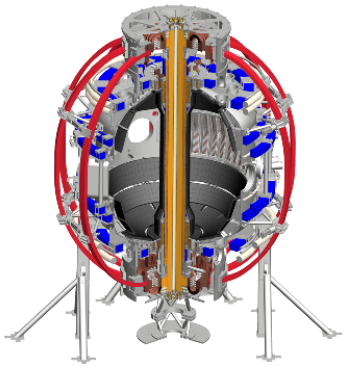
Overview of Initial NSTX-U Plasma Operations

Devon Battaglia

On Behalf of the NSTX-U team

NSTX-U PAC 37
January 26 - 28, 2016

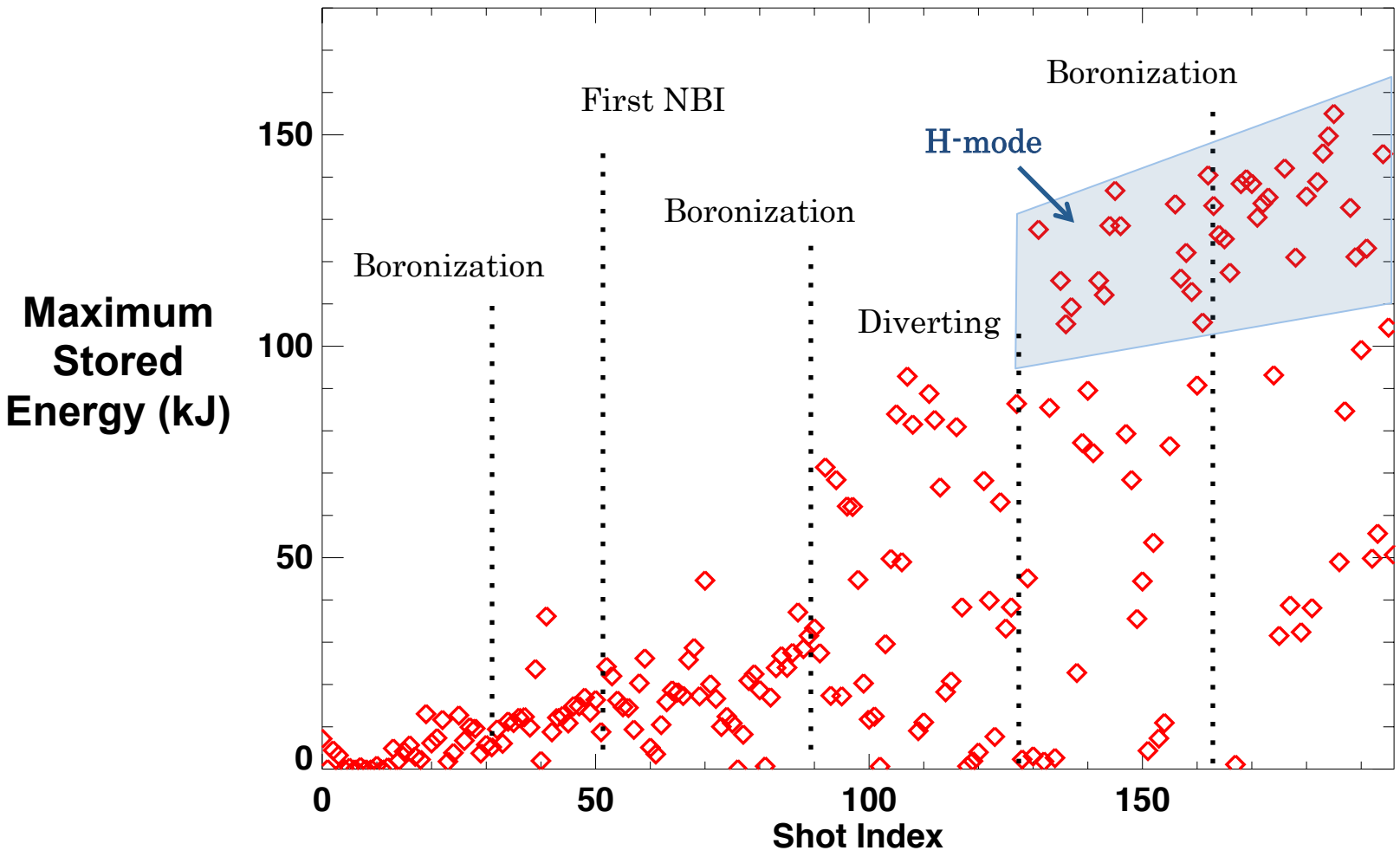
PPPL



Summary of NSTX-U Plasma Operations

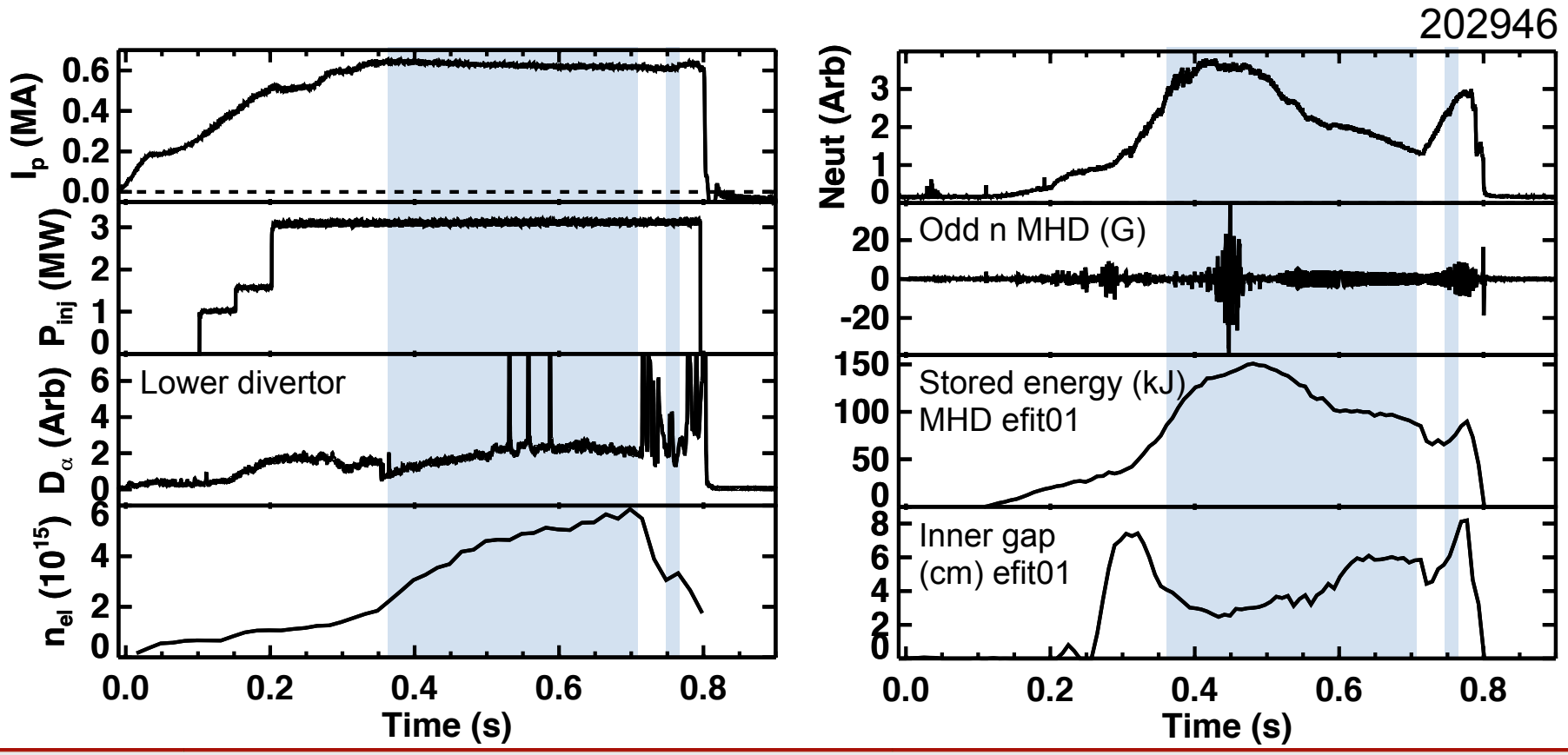
- CD-4 milestone (I_p > 50kA) completed August, 2015
  - I_p ~ 150 kA with GDC and CS bake
- 2.5 days of operation following full vessel bake, before boronization (December, 2015)
  - I_p = 500 kA flattop with inner-wall limited L-mode
  - Progress enabled by I_p, gap and Z feedback control
- 2.5 weeks of operations in January, 2016
  - Neutral beam heating: up to 4MW total from four sources
  - Diverted L-mode and H-mode operations at I_p = 600 kA
    - Good progress toward goal: 1.4 MA, 2s ELMy H-mode by week 8
  - Three boronizations completed

Significant progress over the first few weeks in commissioning NSTX-U

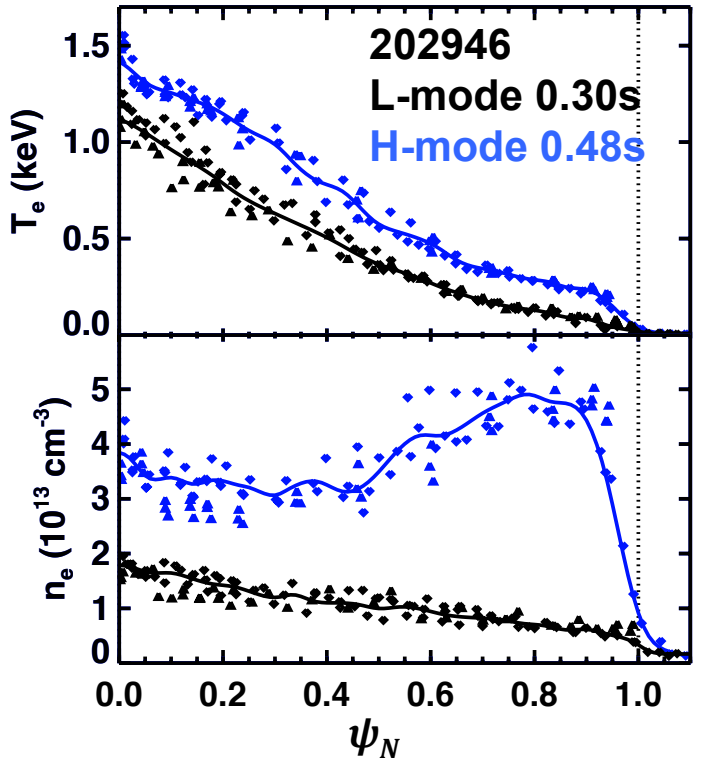


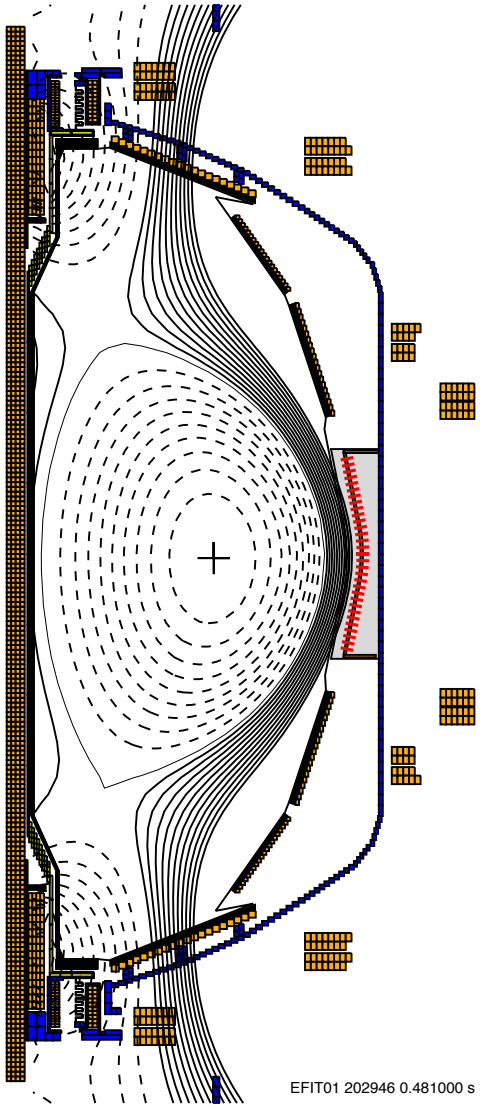
Reliable H-mode access has been achieved on NSTX-U

- H-mode with NBI > 1.5 MW at I_p > 500 kA, B_T = 0.65T
  - H-mode achieved with only 0.9 MW NBI in a few cases
  - B_T exceeds maximum in NSTX

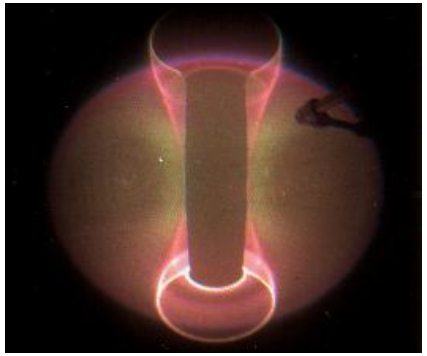


Excellent diagnostic availability has enabled rapid progress

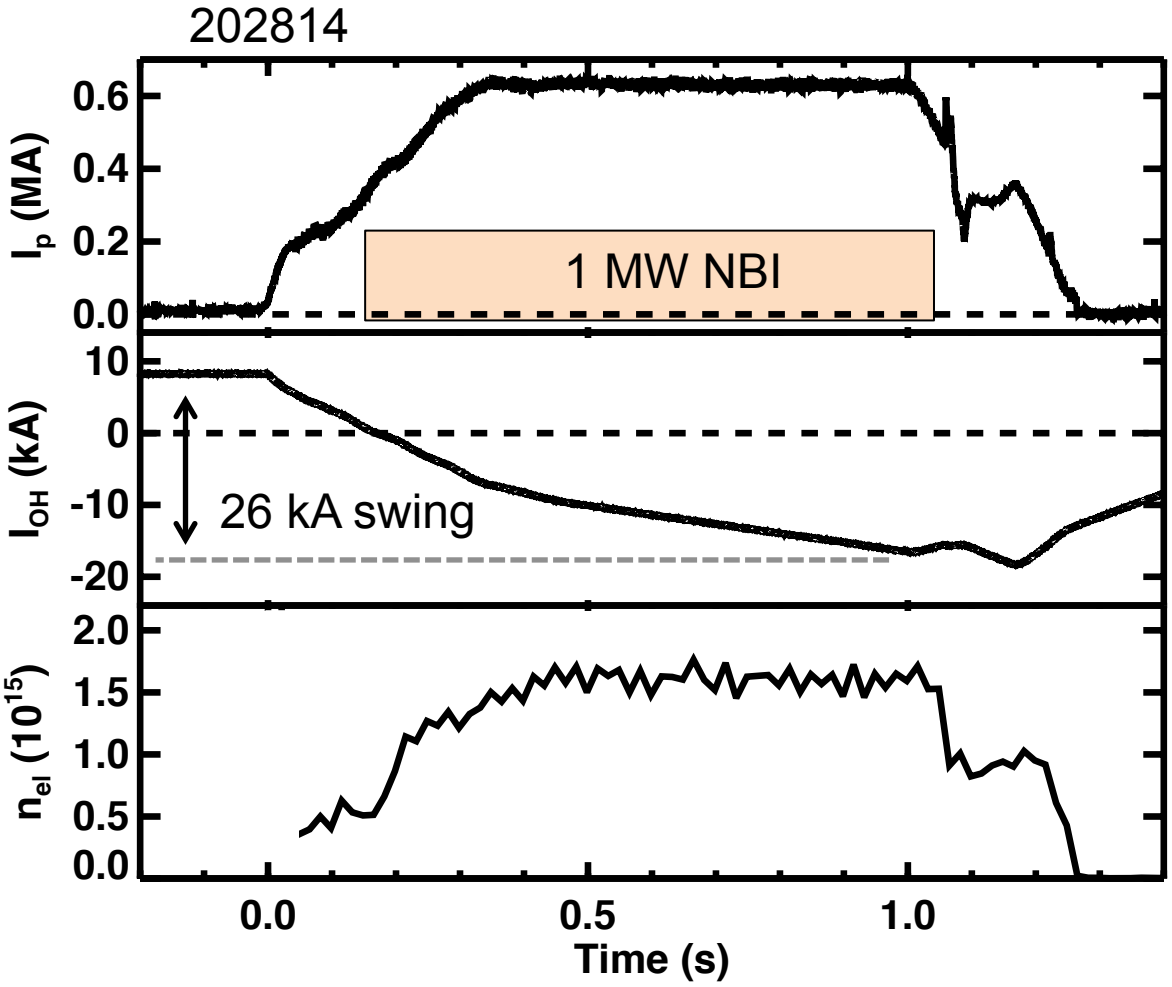


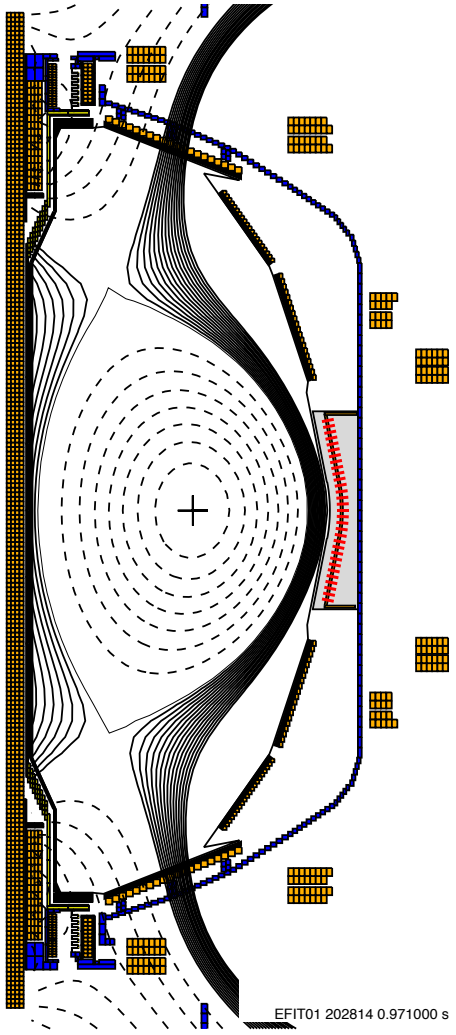


I_p	0.58 MA
B_{T0}	0.61 T
P_{NBI}	3 MW
P_{OH}	0.2 MW
A	1.6
κ	1.53
l_i	0.97
δ_{lower}	0.55
W	151 kJ
β_T	7.86%
β_P	1.22%
β_N	4.66
τ_e	50 ms



Stationary diverted L-mode operations has also been achieved





These discharges have already been used to support research operations

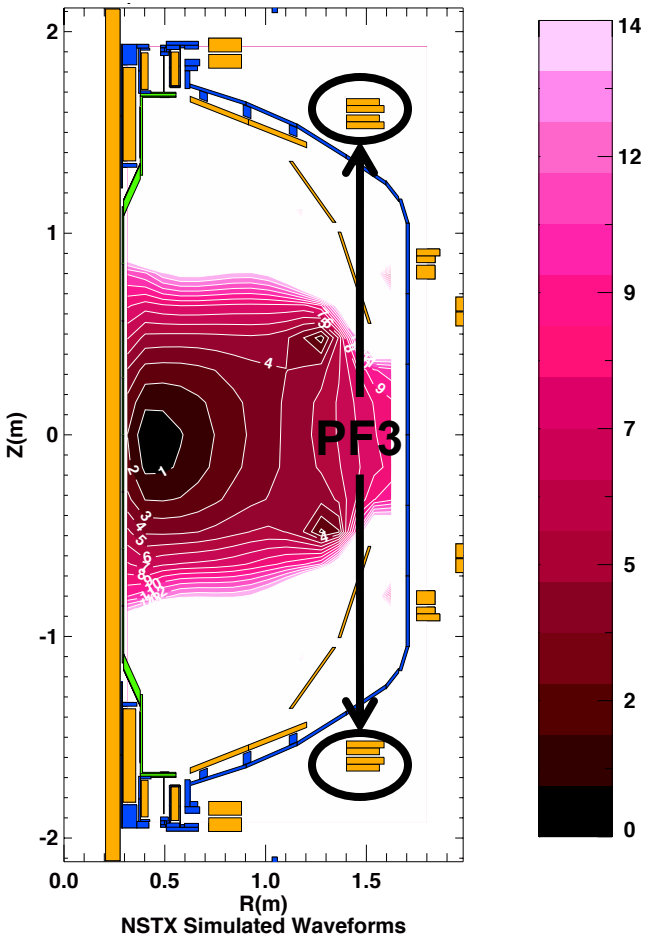
Significant progress has been made on a number of commissioning activities

- XMP-101: Inductive startup on NSTX-U
- XMP-106: Magnetics calibration
- XMP-126: Initial I_p and R control
- XMP-105: Initial n=0 control
- XMP-118: Boronization characterization
- XMP-127: Neutral beam checkout
- XMP-132: Automated rampdown development
- XMP-107: Neutron calibration transfer
- XMP-133: Increase elongation in L-mode
- XMP-116: Initial H-mode access in NSTX-U
- XMP-121: Six SPA and RWM coil checkout
- XP-1506: Low-beta locked mode studies

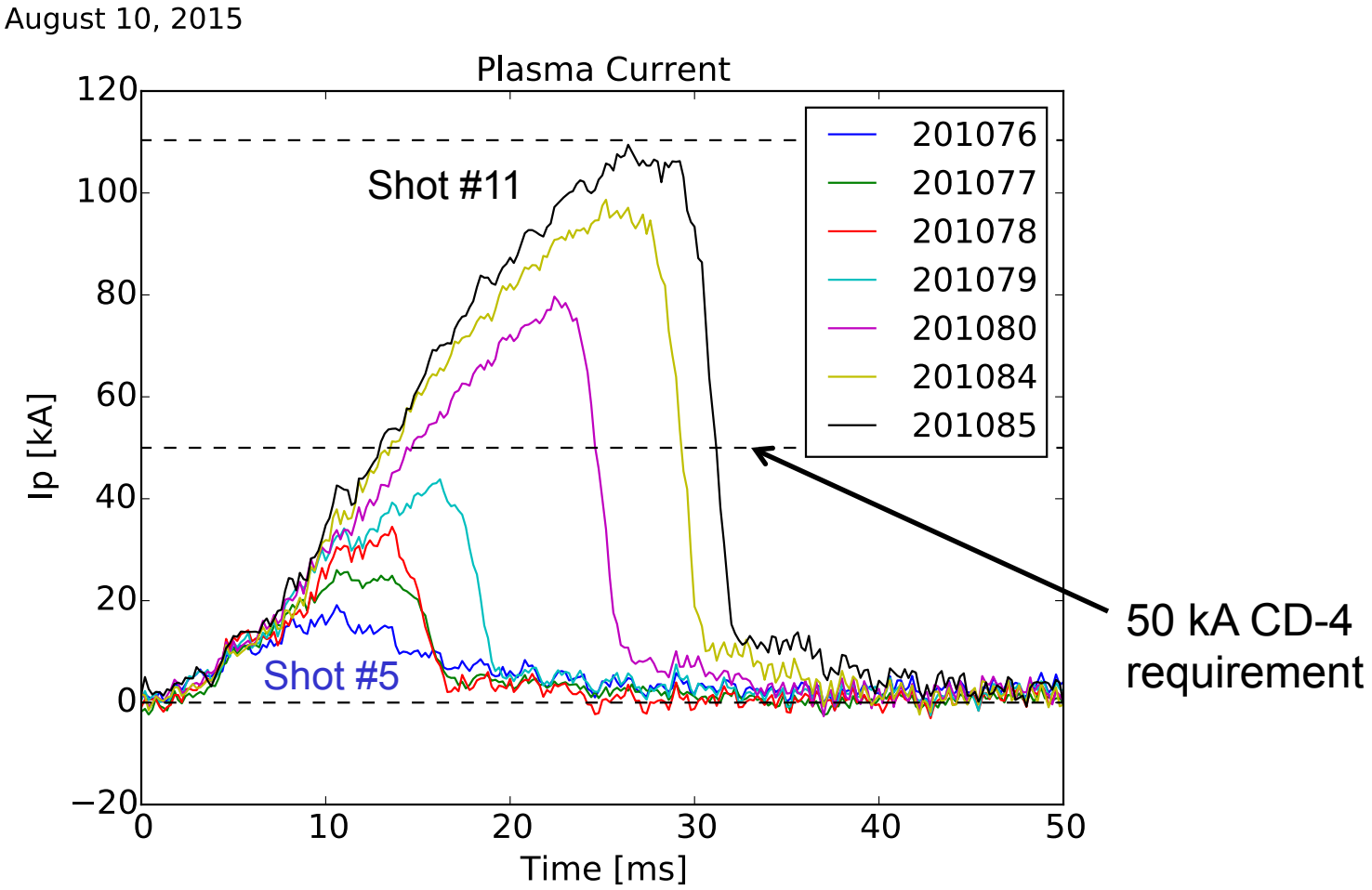
Inductive startup scenario informed by vacuum field modeling

- Solenoid provides confining B_Z
  - Bipolar PF3 coils null this field
  - V_{loop} via ramping OH and PF3 fields
- Null properties sensitive to fields from induced wall currents
  - LRDFIT wall model used to prepare scenarios in advance
  - About 200 kA total wall current at breakdown
- PF3 and PF5 coils provide additional B_p following breakdown
  - Must maintain passive R and Z stability

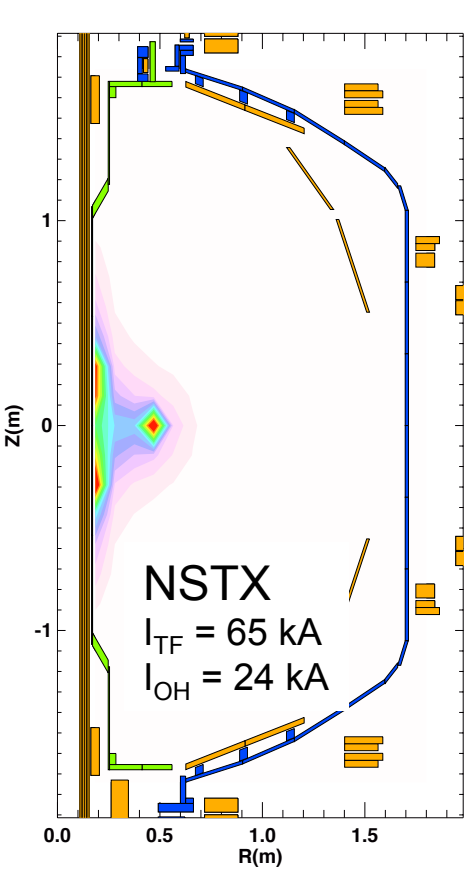
Simulated B_p fields at breakdown

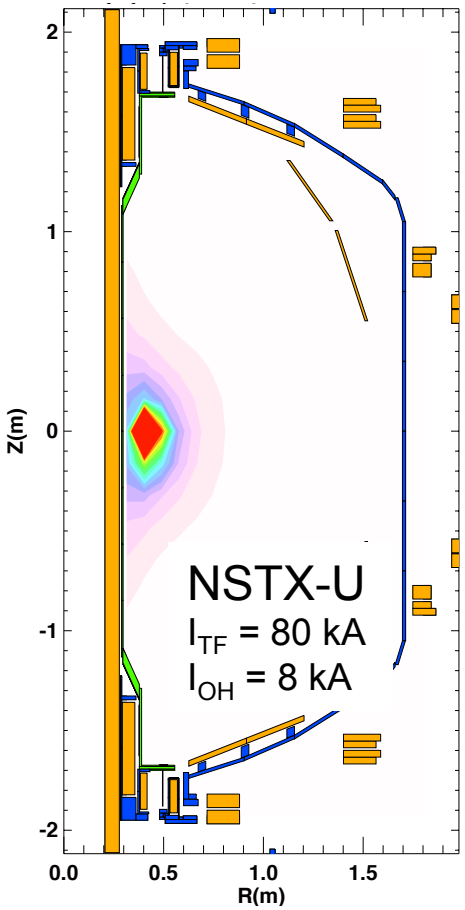


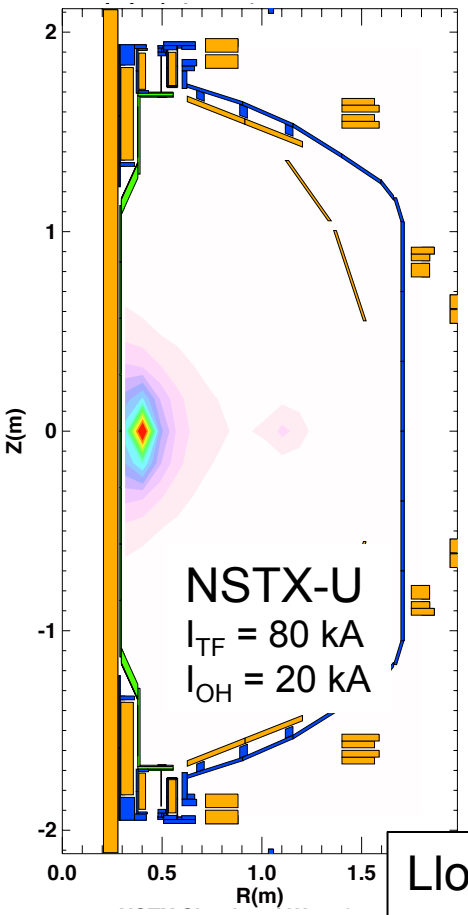
Startup scenario identified via calculations enabled rapid progress in achieving CD-4



Loop voltage required for breakdown in good agreement with calculations







Model: V_{loop} = 2.0 V V_{loop} = 2.4 V V_{loop} = 3.3V

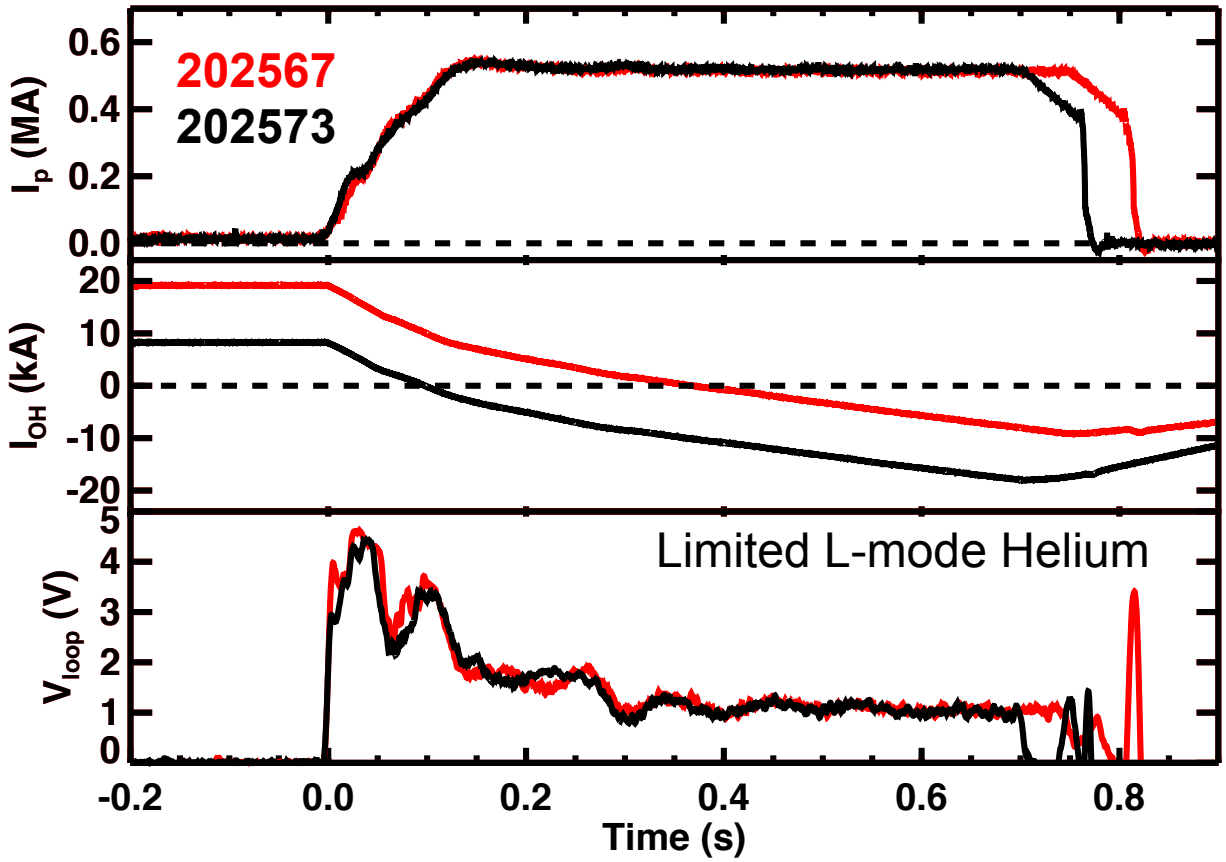
Experiment: **V_{loop} = 2.5 V** **V_{loop} = 3.7 V**

Lloyd parameter:

$$\frac{V_{loop} I_{TF}}{R^2 \langle B_\perp \rangle}$$

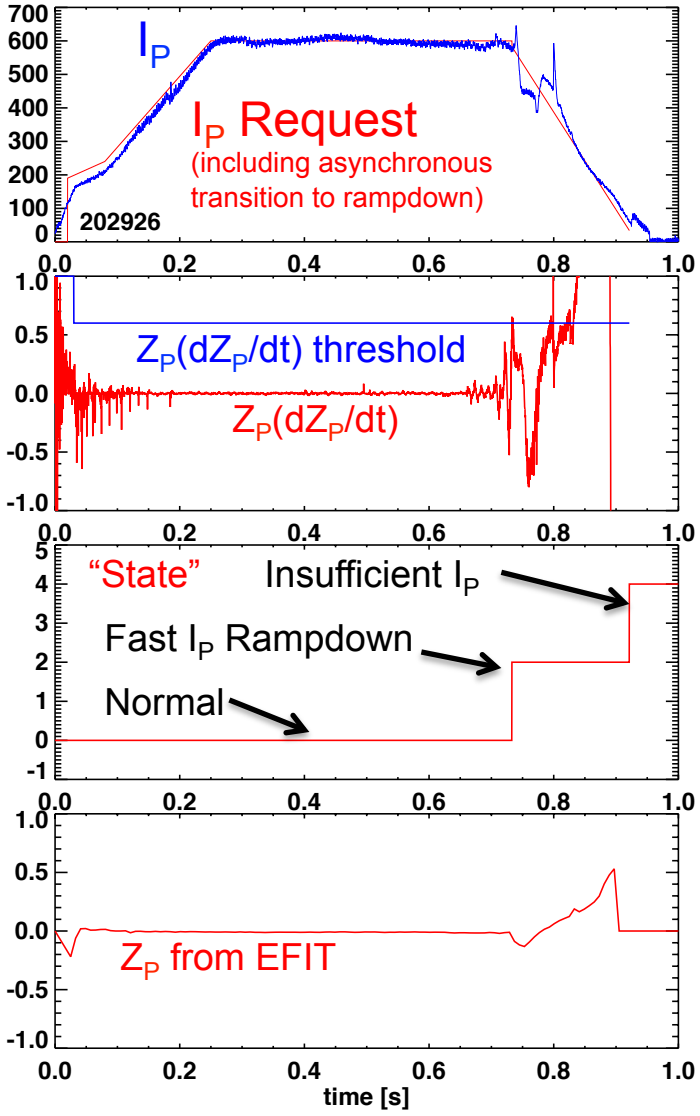
Routine startup at two OH precharge levels has been demonstrated

- Goal: scalable scenario for arbitrary OH precharge
  - Some experiments desire flexible precharge to optimize constraints from coil heating and coil current limits



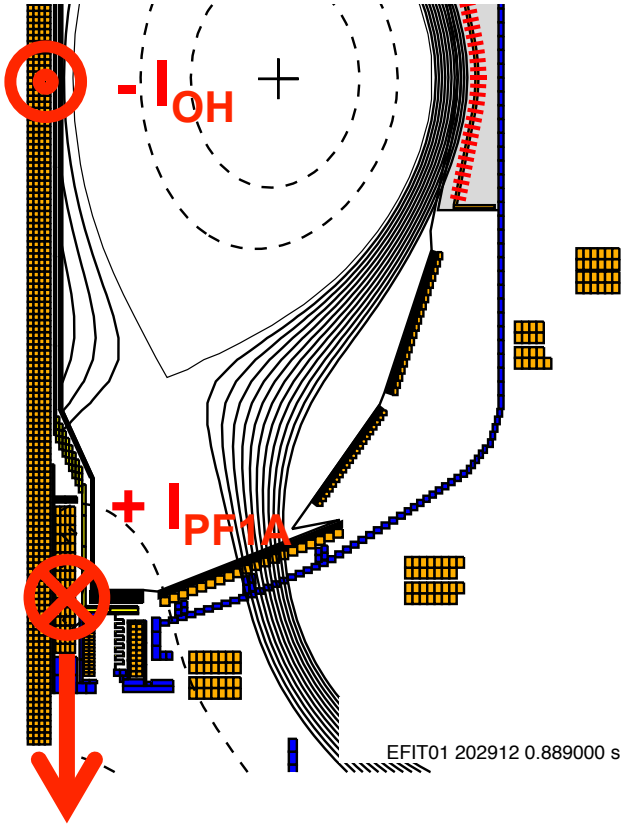
New capability: automated rampdown used in routine operations

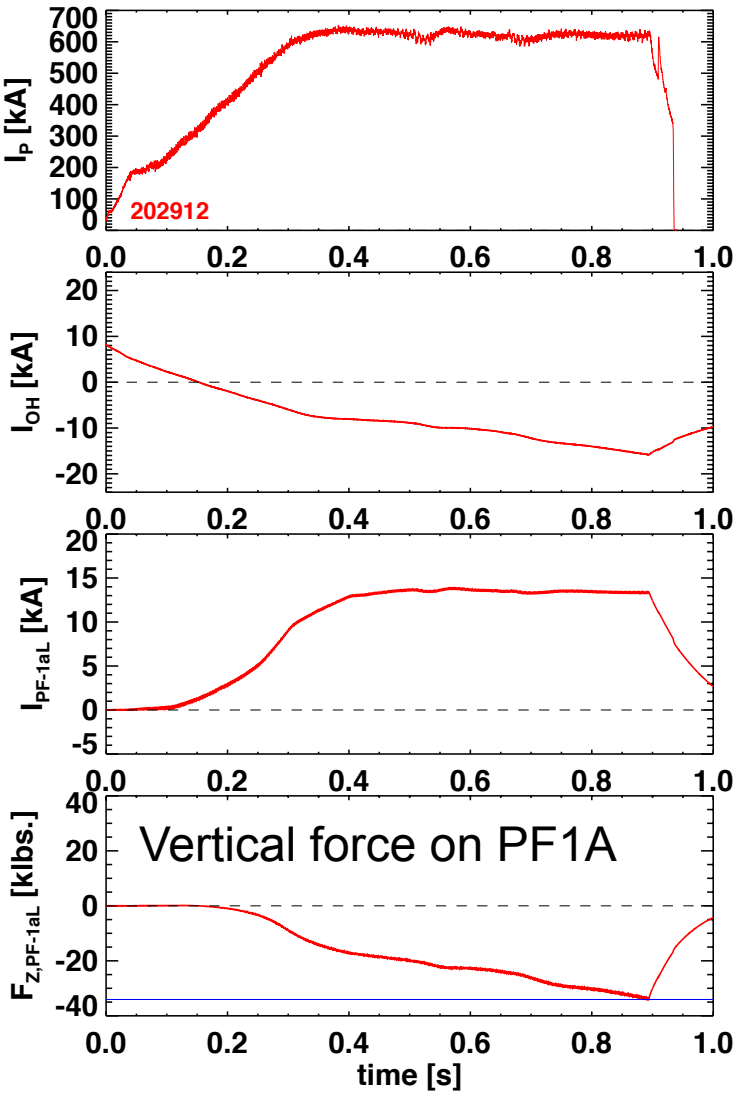
- Plasma control system detects loss of control
  - OH solenoid near maximum current
  - Vertical oscillations exceed threshold
  - Abs(I_p - $I_{p\ request}$) too large
- Feedback control switches to new "states" that attempt to gently end the discharge
- See S. Gerhardt's talk



Digital coil protection system successful in preventing unacceptable coil operation

Example of a hard shutdown in response to a force limit

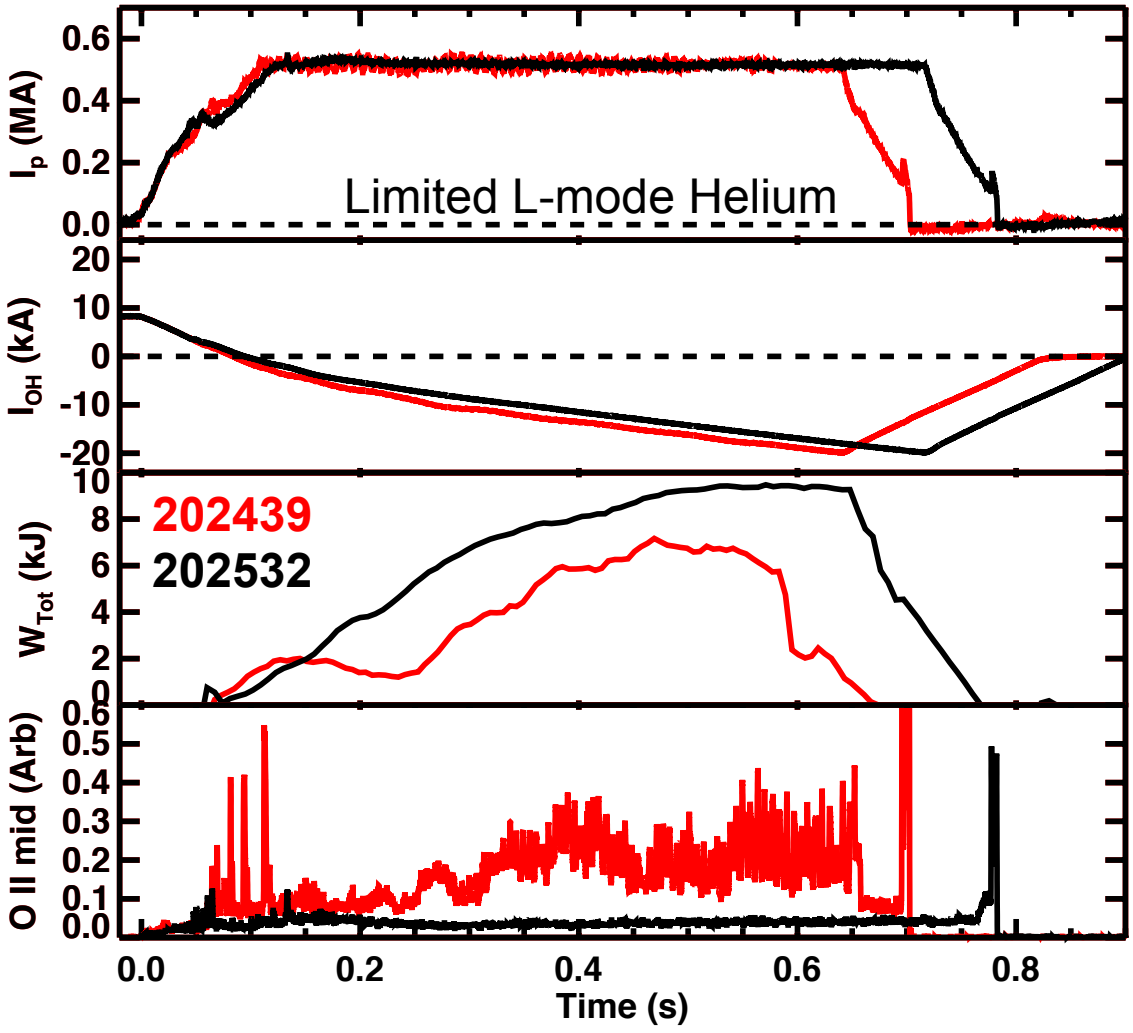




More details in Facility Status talk (M. Ono)

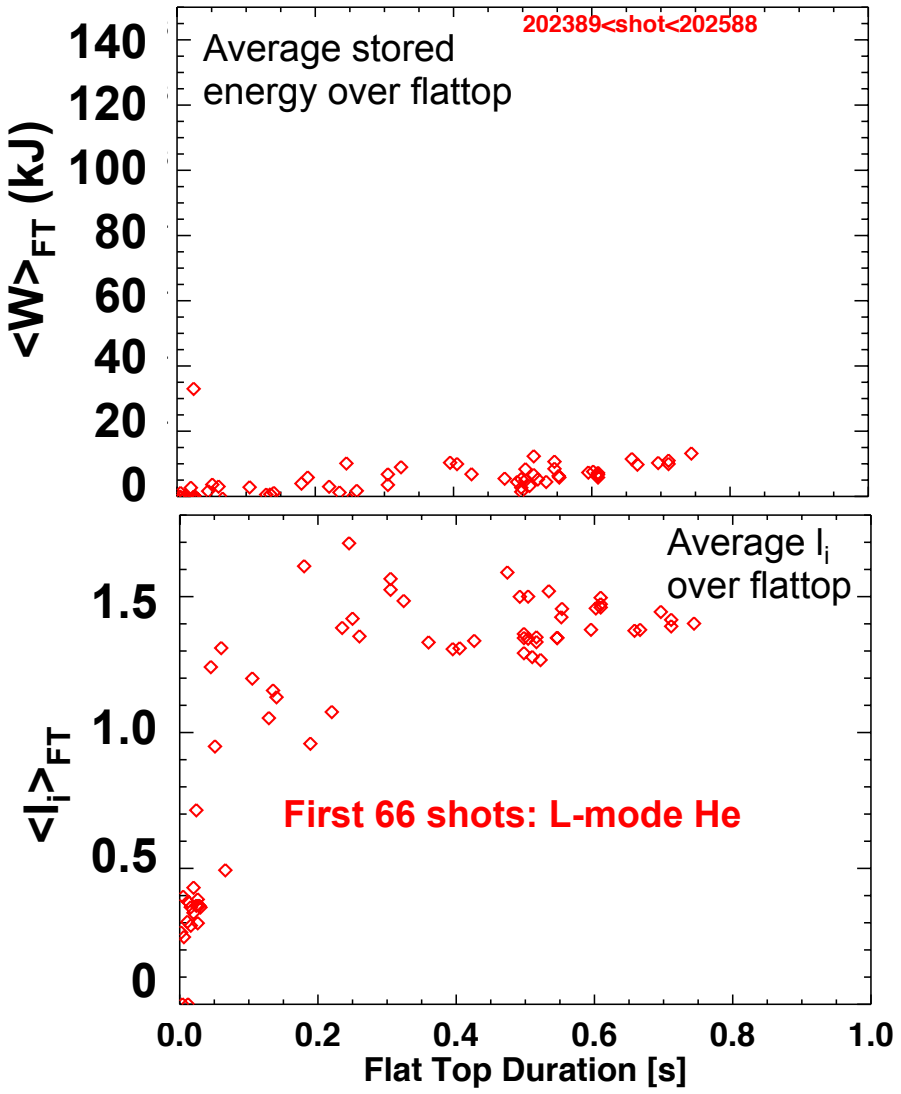
First boronization had positive impact on discharge performance

- Flux consumption and oxygen content reduced
- Measurements of boron deposition and impurity migration have been completed (see M. Jaworski's talk)



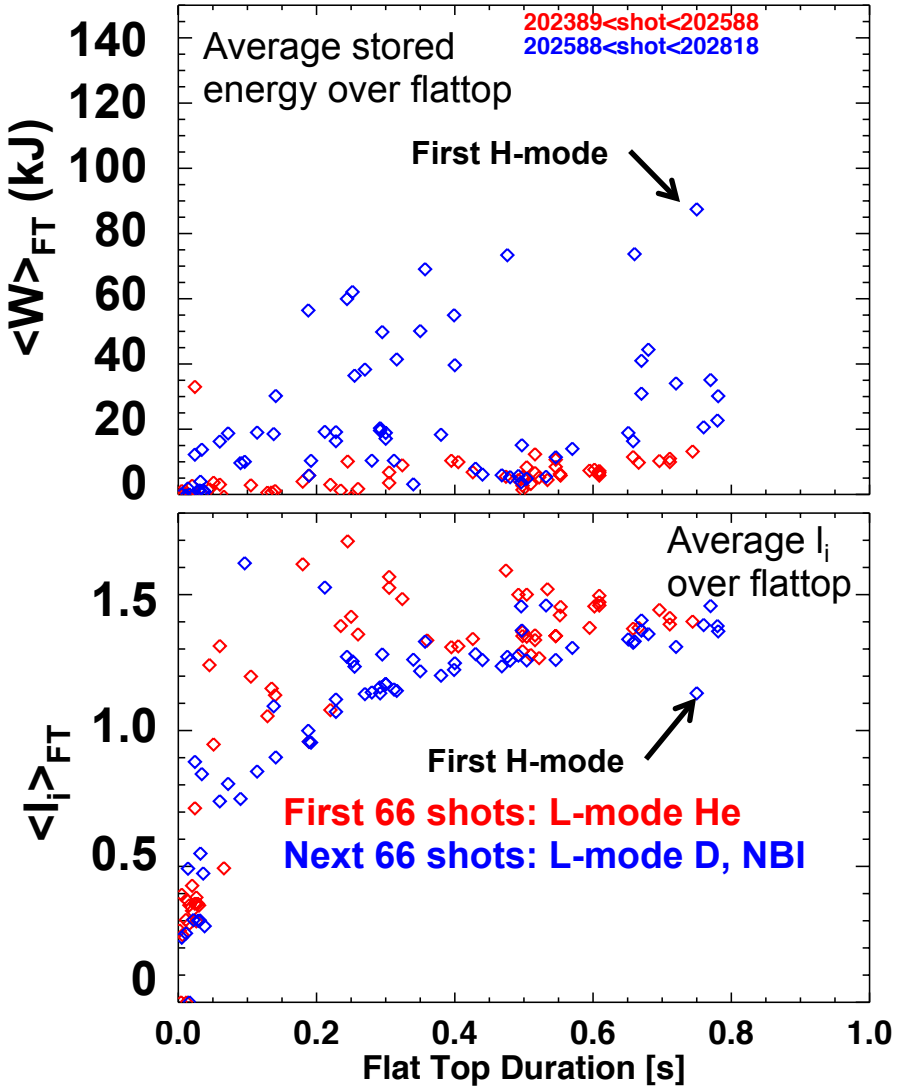
Operations will restart with continued goal of developing fiducial ELMy H-mode discharge

- H-mode operations open path to lower l_i
  - Permits larger κ and I_p range
  - Target l_i ~ 0.5 via an earlier L-H transition, larger NBI power and improved wall conditions
- Target fiducial for FY2016 is an ELMy H-mode discharge at I_p = 1.4 MA



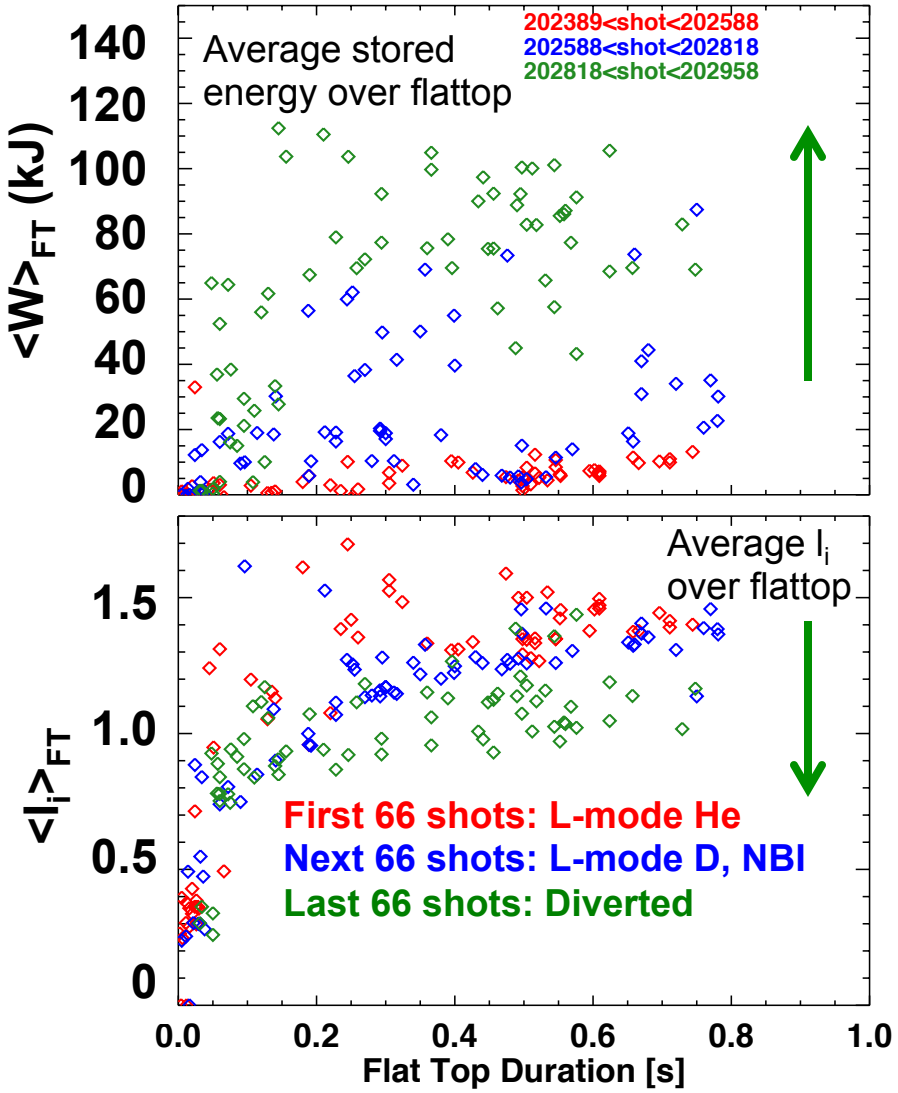
Operations will restart with continued goal of developing fiducial ELMy H-mode discharge

- H-mode operations open path to lower l_i
  - Permits larger κ and I_p range
  - Target l_i ~ 0.5 via an earlier L-H transition, larger NBI power and improved wall conditions
- Target fiducial for FY2016 is an ELMy H-mode discharge at I_p = 1.4 MA



Operations will restart with continued goal of developing fiducial ELMy H-mode discharge

- H-mode operations open path to lower l_i
  - Permits larger κ and I_p range
  - Target l_i ~ 0.5 via an earlier L-H transition, larger NBI power and improved wall conditions
- Target fiducial for FY2016 is an ELMy H-mode discharge at I_p = 1.4 MA



Ongoing commissioning activities will prepare NSTX-U for research program

- Near-term activities include …
  - Optimization of vertical control (see S. Gerhardt's talk)
  - ISOFLUX shape control
    - rtEFIT has been successfully running and is ready to support operations
  - Error field identification and correction
    - Low-beta error field measurements have been completed
  - Diagnostic commissioning and calibration
    - MPTS, CHERS, MSE, NPAs, FIDA
  - NBI power modulation for β control from PCS
    - PCS control of beam termination has been used
  - MHD spectroscopy and RWM control
    - Real-time mode detection in PCS is nearly complete

- Covered in detail in Jon Menard's talk

Plasma operations on NSTX-U is off to a great start!

- First days of NSTX-U have produced H-mode and stationary diverted L-mode discharges
- Control and diagnostic capabilities established quickly
- Research program starting in parallel with commissioning activities