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XMP-26
High Power Operation of the NSTX HHFW Antenna

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NSTX Results & Theory Review
PPPL, December 2, 2010

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Summary of High Power HHFW Operation for 2010

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- 2010 HHFW operation with the LLD filled by evaporated lithium from the LITER applicators was problematic.
- In 2009 the upgraded antennas conditioned fairly rapidly to the 4 MW level in a lithium environment.
- In 2010, reliable operation above 1.2 MW was unachievable even after aggressive antenna conditioning.
- Lithium expulsion from antenna surfaces was greater than observed last year at similar power levels.
- Dust and granular particles were seen during HHFW operation that were largely absent in years past.
- Antenna conditioning can be set back significantly by one plasma “event”.

Maximum HHFW system voltage with plasma basically unchanged (~15 kV) between 2009 & 2010

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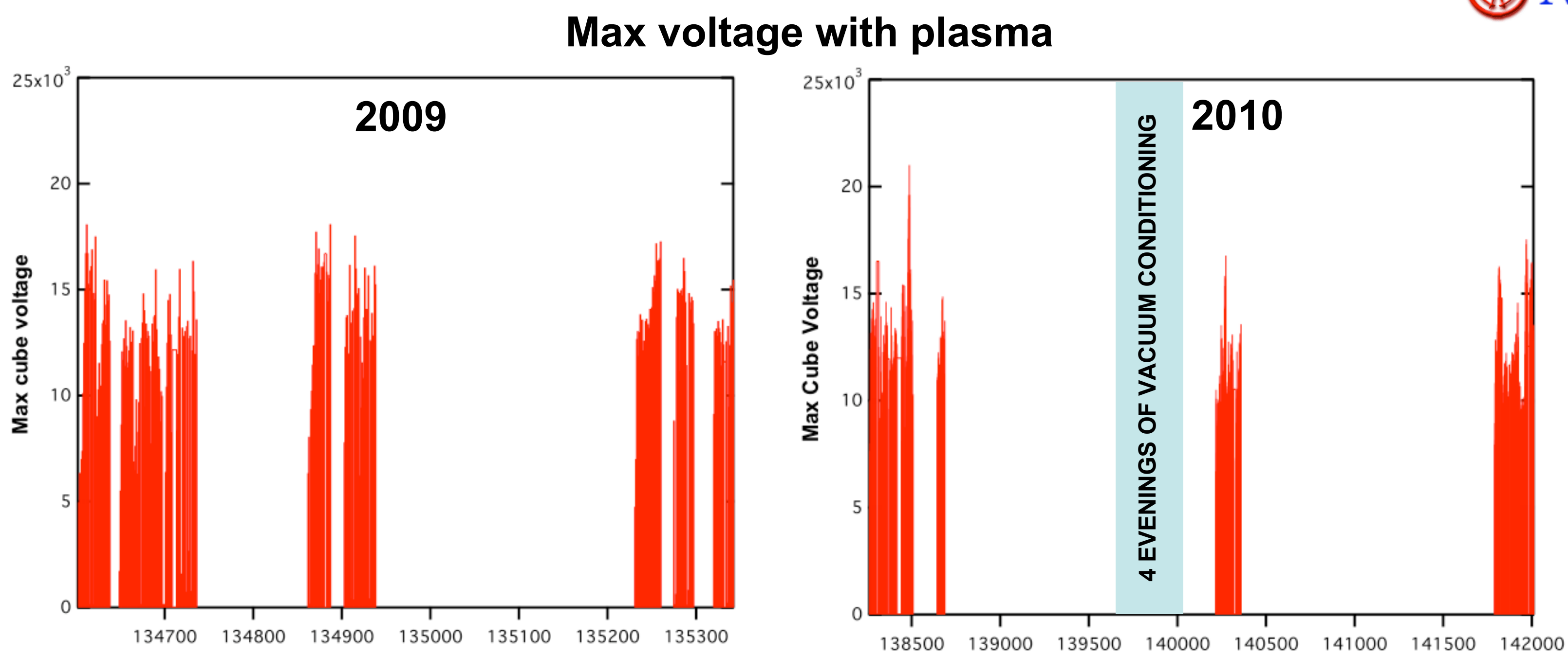
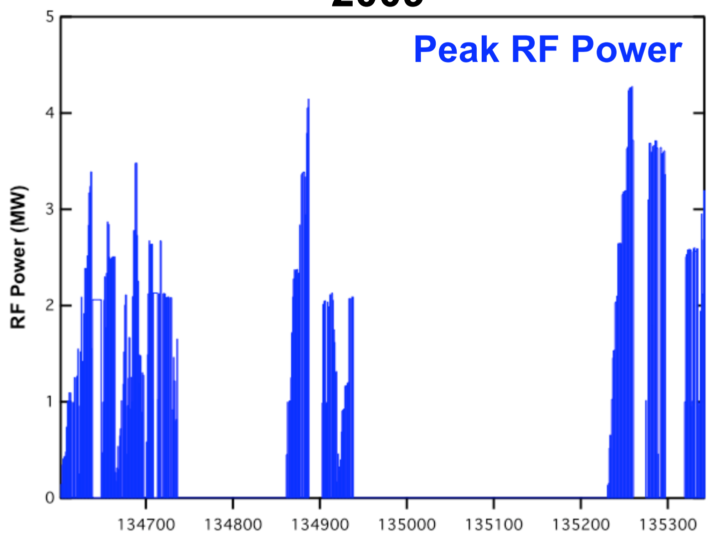


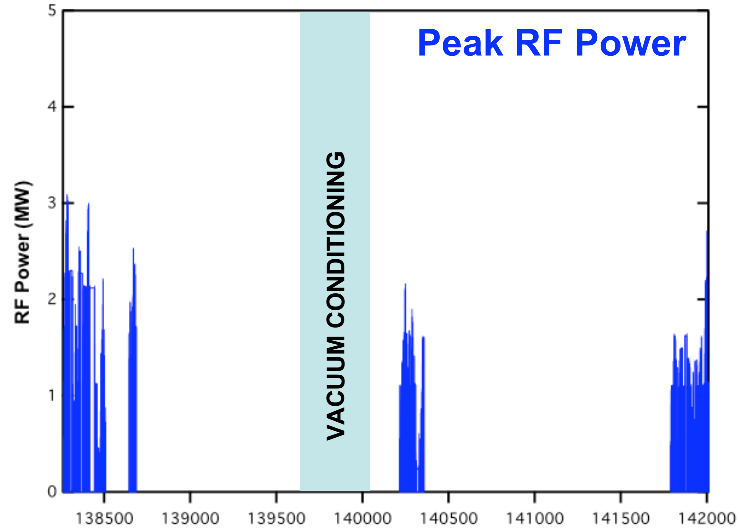
- **Vacuum conditioning needed to achieve these voltages.**
  - Aug 11 - Xmtrs 1&2 up to 18-19 kV (180º), 14-15 kV (-90º)
  - Aug 13 - Xmtrs 3&4 up to 19-20 kV (180º), 14 kV (-90º)
  - Aug 16 - Xmtrs 5&6 up to 22-23 kV (180º), 1&2 up to 20 kV (180º)
  - Aug 18 - Xmtrs 3&4 up to 20 kV (180º)
- **Steady glow often seen near antenna grounds during vacuum conditioning.**
- **Arcs generally appear in high voltage regions (strap top & bottom).**
- **All vacuum arcs occur in the antenna box itself.**

Maximum HHFW power with plasma much lower in 2010 than in 2009

2009



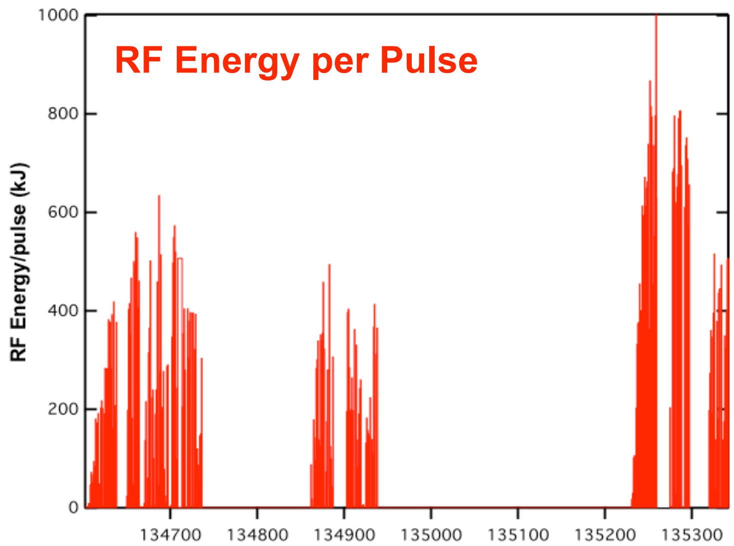
2010



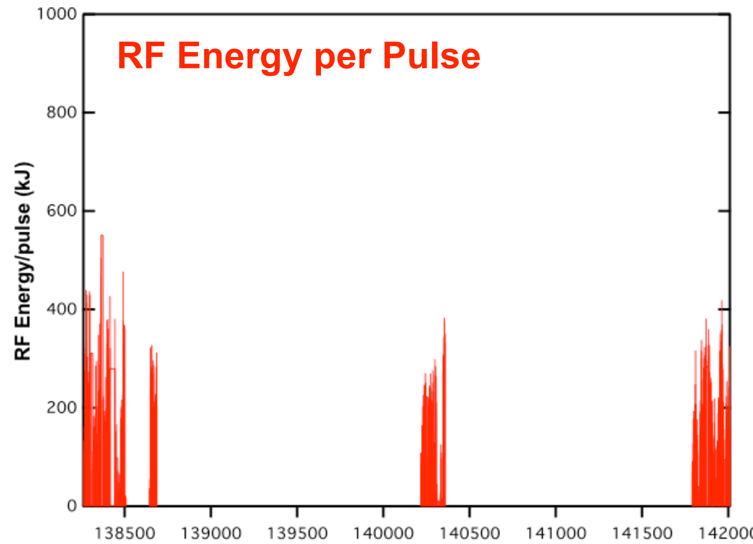
- **In 2009 the RF power gradually increased (>4 MW) as the antennas were cleaned/conditioned, both during each day's operation and throughout the campaign.**
- **In 2010, the RF power quickly hit a limit between 1-2 MW and never improved.**
- **Extensive vacuum conditioning did not increase power level limit.**

HHFW energy per pulse much lower in 2010 than in 2009 and did not improve during campaign

2009



2010



- **In 2009 the RF energy per pulse increased as power increased and number of trips decreased. The pulse length was increased for XPs at the end of the year.**

- **In 2010, the RF energy per pulse never improved, due to power limit and continual arcs and trips.**

Location of lithium ablation spots generally do not depend on array phasing, but on lithium accumulation

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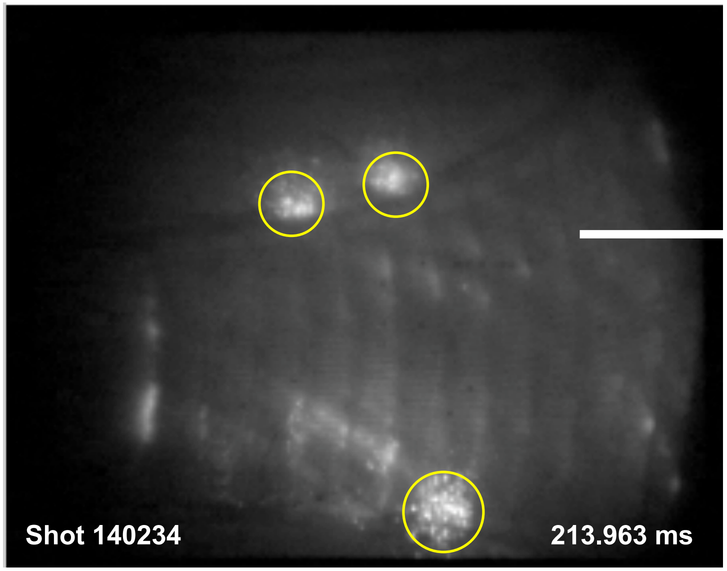
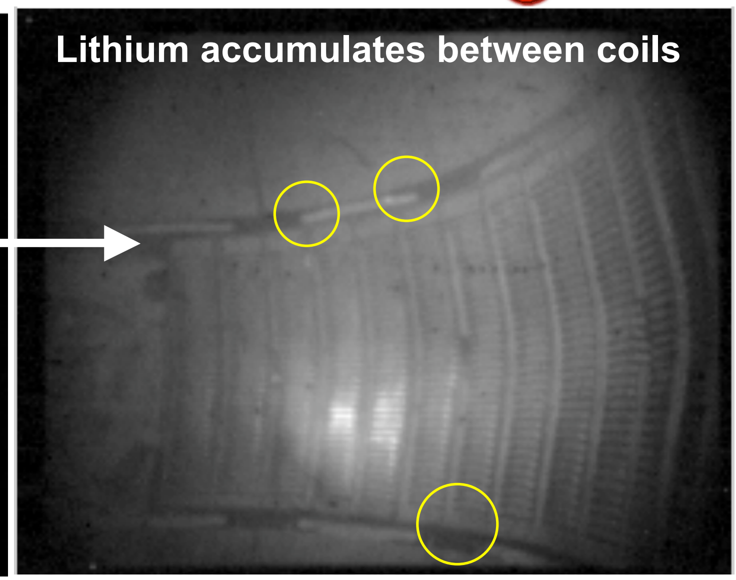
23 August 2010
I_p = 0.6 MA
B_T = 0.55 T
He discharge

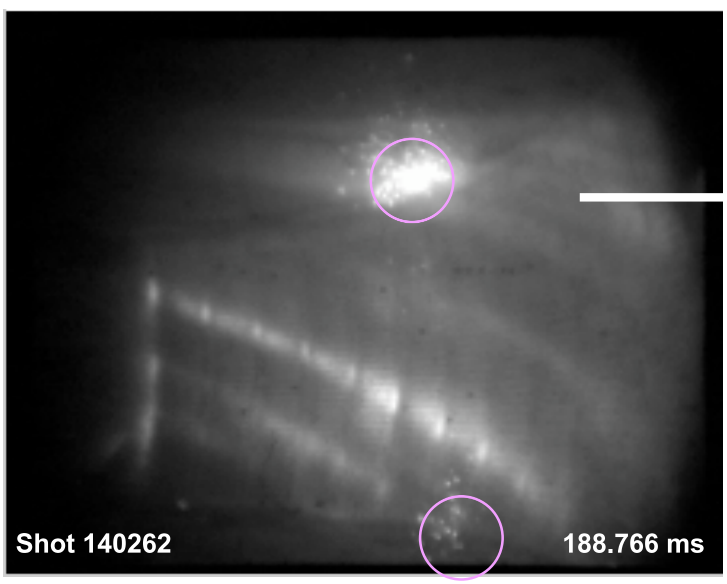
P_{RF} = 1.5 MW
$\Delta\phi$ = -90º

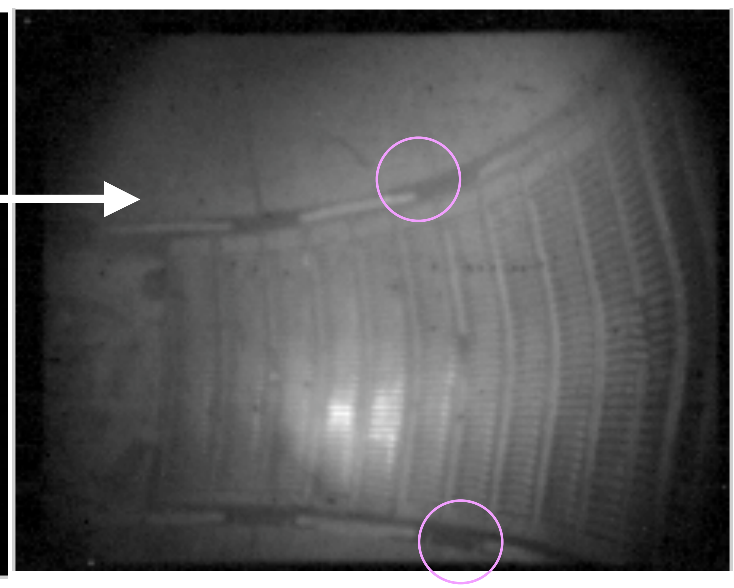




24 August 2010
I_p = 0.6 MA
B_T = 0.55 T
He discharge

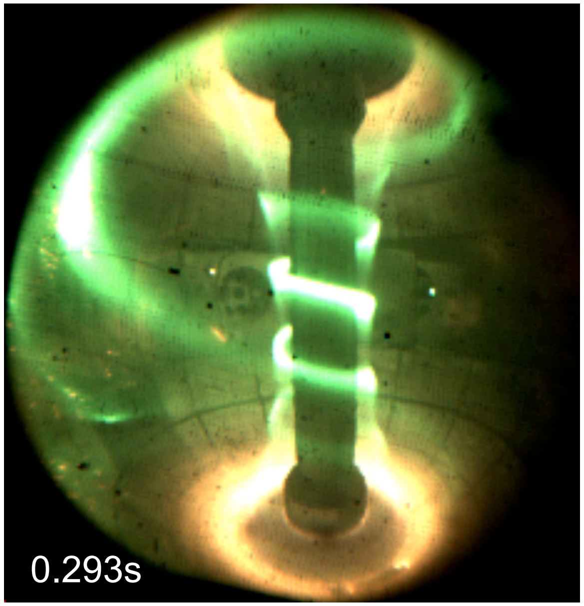
P_{RF} = 1.3 MW
$\Delta\phi$ = 180º

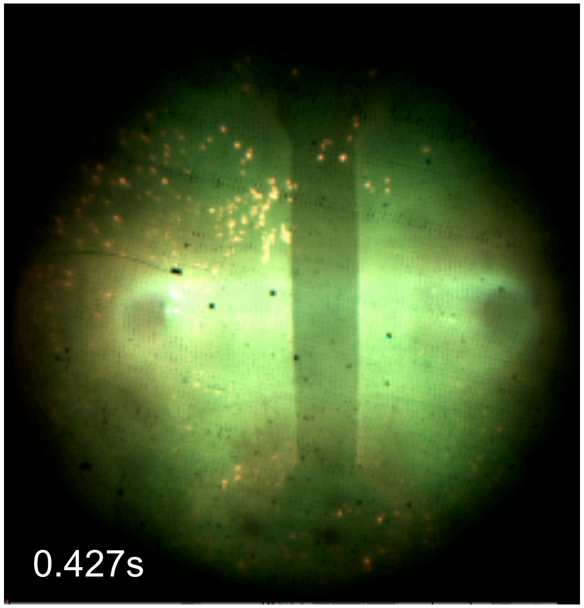


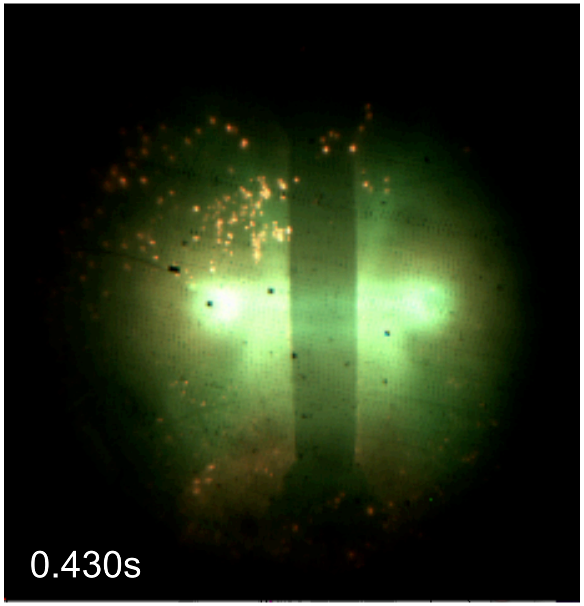


Lithium deposition affects HHFW antenna with coatings and dust projectiles

Shot 141988 B_T = 4.5 kG, I_P = 0.9 MA, Helium, P_{RF} = 1.9 MW







Lithium from top of antenna moving along field line.

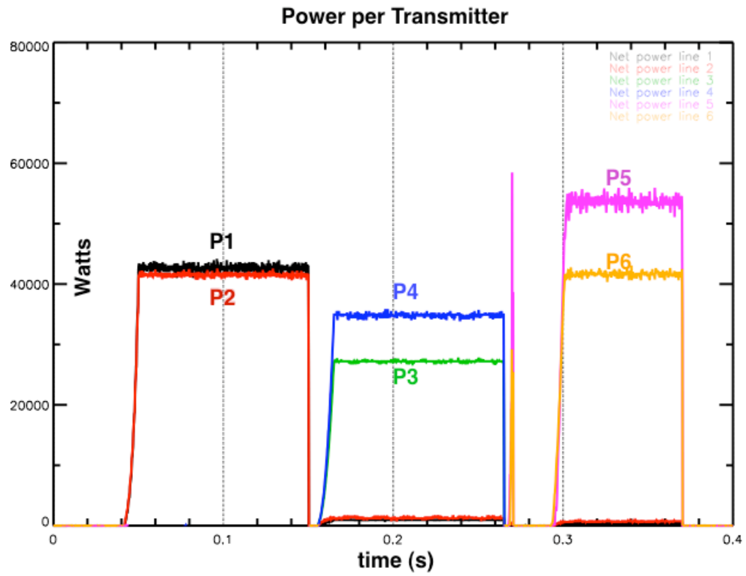
Lithium projectiles at end of shot, moving outward toward antenna

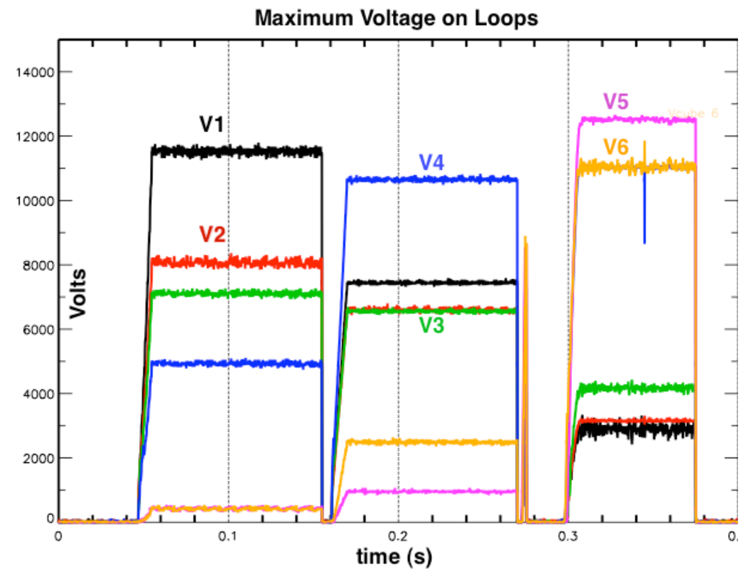
What is the primary cause of increased arcing in 2010?
- **Increased lithium oxide dust?**
- **Increased lithium deposition on the antenna?**
- **Changes in antenna surface properties?**

NEED TO INSPECT THE ANTENNA FOR CLUES

Develop More Efficient Antenna Cleaning/Conditioning Techniques

➡ Between-shot, sequential transmitter vacuum conditioning

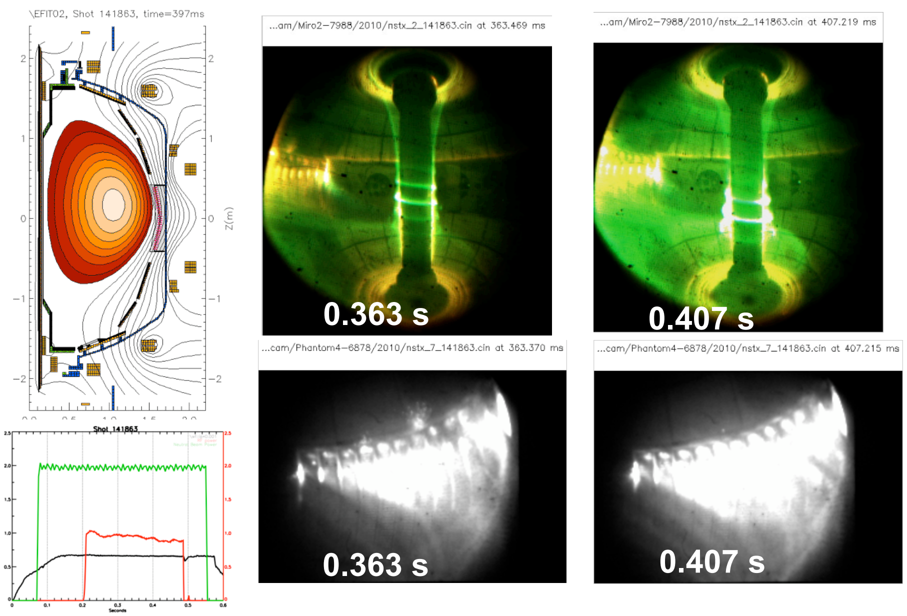




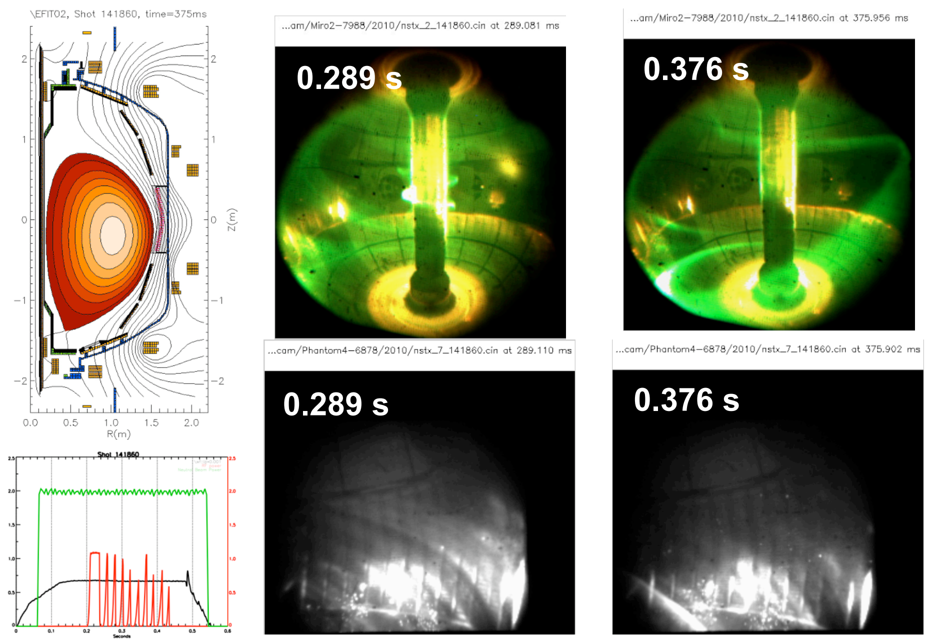
- **Transmitters were sequentially pulsed in pairs for vacuum conditioning between shots.**
- **3 x 0.1s/30 s for 300 s**
- **Advantages:**
  - Increases overall effective duty cycle.
  - Easier to match and to adjust power levels for each loop than for all six simultaneously.
  - Arcing on one loop wouldn't trip all six transmitters. The other pairs get full conditioning pulse during their turns.
- **Disadvantages:**
  - Although de-couplers isolate nearest transmitters from one another, voltages still appear on unpowered loops due to uncompensated mutual inductances (next-to-nearest neighbors).
  - Need to switch the matching between vacuum and plasma loading each shot.

Develop More Efficient Antenna Cleaning/Conditioning Techniques
➡ Plasma Scrubbing of Antenna

Cleaning Top of Antenna



Cleaning Bottom of Antenna



- Moved NBI-heated plasma ± 20 cm vertically from shot to shot to "plasma scour" top and bottom of antenna.
- Profuse lithium expulsion throughout, enhanced while RF is on.
- Observed no great improvement in power capability after limited testing (4 shots).

Future HHFW Operation Plans
Need to protect antennas from Li contamination

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- Improve shielding/cleaning antenna arrays
  - Improve between-shot conditioning techniques
  - Evaluate effectiveness of plasma scrubbing
  - Modify BN limiters?
  - Shield above array?

- More directed method of filling LLD needed to keep antenna surfaces clean
  - Improved collimation on LITER closest to antenna?
  - More effective LLD filling technique?