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NSTX

XP 944 & 946
Results From the HHFW Experiments

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NSTX Results Review
PPPL September 15, 2009

HHFW Operation in 2009

- New center-grounded, double end-fed current straps were installed in the machine during the last opening.
- Modifications to the external transmission line system were completed in June and HHFW operation started in July.
- 7 full and 2 half days of HHFW operation, most of which were identified as plasma conditioning the new antennas (XP26)

Most operation was devoted to conditioning new HHFW system

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July 6	XP26	He L-mode conditioning	1.5 MW/180º 3.0 MW/-90º
July 7	XP26	D L-mode conditioning	2.6 MW/-90º 2.0 MW/-150º 1.6 MW/+90º
July 8 (1/2 day)	XP944	Ip, phase scans in L-mode	2.0 MW/-90º 1.6 MW/-150º
July 13	XP26	D H-mode conditioning	4.0 MW/-90º
July 14	XP26/XP946	phase, Ip scan in H-mode (0.7, 0.8, 0.9 MA)	2.0 MW/-90º 2.0 MW/-150º 1.2 MW/+90º
July 22	XP26	Vacuum and L-mode condtioning	4.2 MW/-90º
July 23	XP941 (Kaye)	L-H threshold power	3.6 MW/-90º (pulse shaping)
July 24	XP26 (XP946)	H-mode conditioning (0.45 and 0.55 T)	2.6 MW/-90º 3.1 MW/-150º
August 13	XP26	Reverse field operation	1.4 MW/-90º 1.4 MW/+90º

HHFW System Upgrade

- **The Goal**
  - Bring the system voltage limit with plasma (~15 kV) up to the vacuum limit without plasma (~25 kV). This would increase the power limit by a factor of ~2.8.
  - This strap modification is the most direct test of the hypothesis that electric field in the strap/FS region is fundamental breakdown mechanism in plasma operation.
- **System Changes**
  - Moved strap ground from bottom to center of strap. Moves peak voltages ~ 45 cm from previous locations. Increased critical gaps ~20-25%.
  - Peak voltages and electric fields on the strap should be reduced a factor of ~2 for same strap current (antenna power).
  - Peak voltages and electric fields in the antenna box should be reduced a factor of ~1.4 for same strap current (antenna power).
  - Peak voltages in the system should remain the same for same strap current (antenna power).
  - Feeding strap from both ends entails additional $\lambda/2$ loops. Space constraints required using 3-inch line in places.

Transmission Line Modifications

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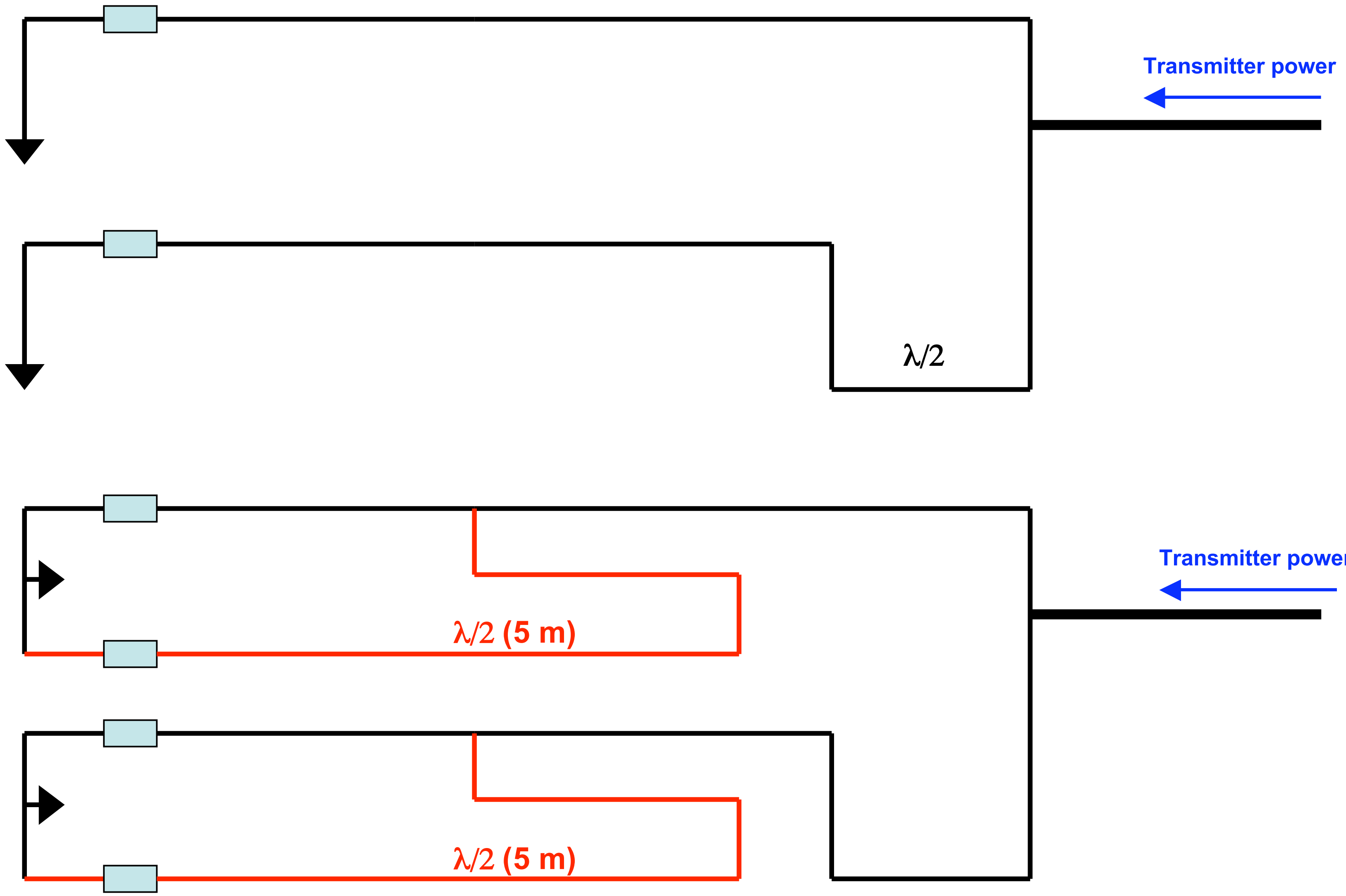
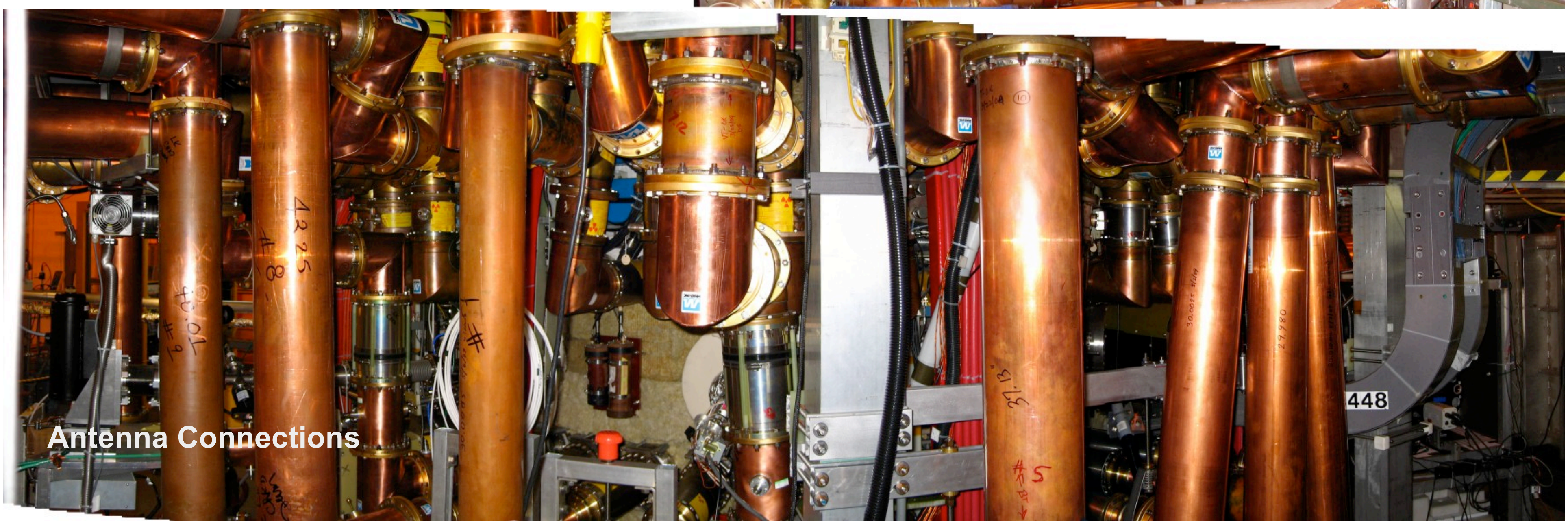


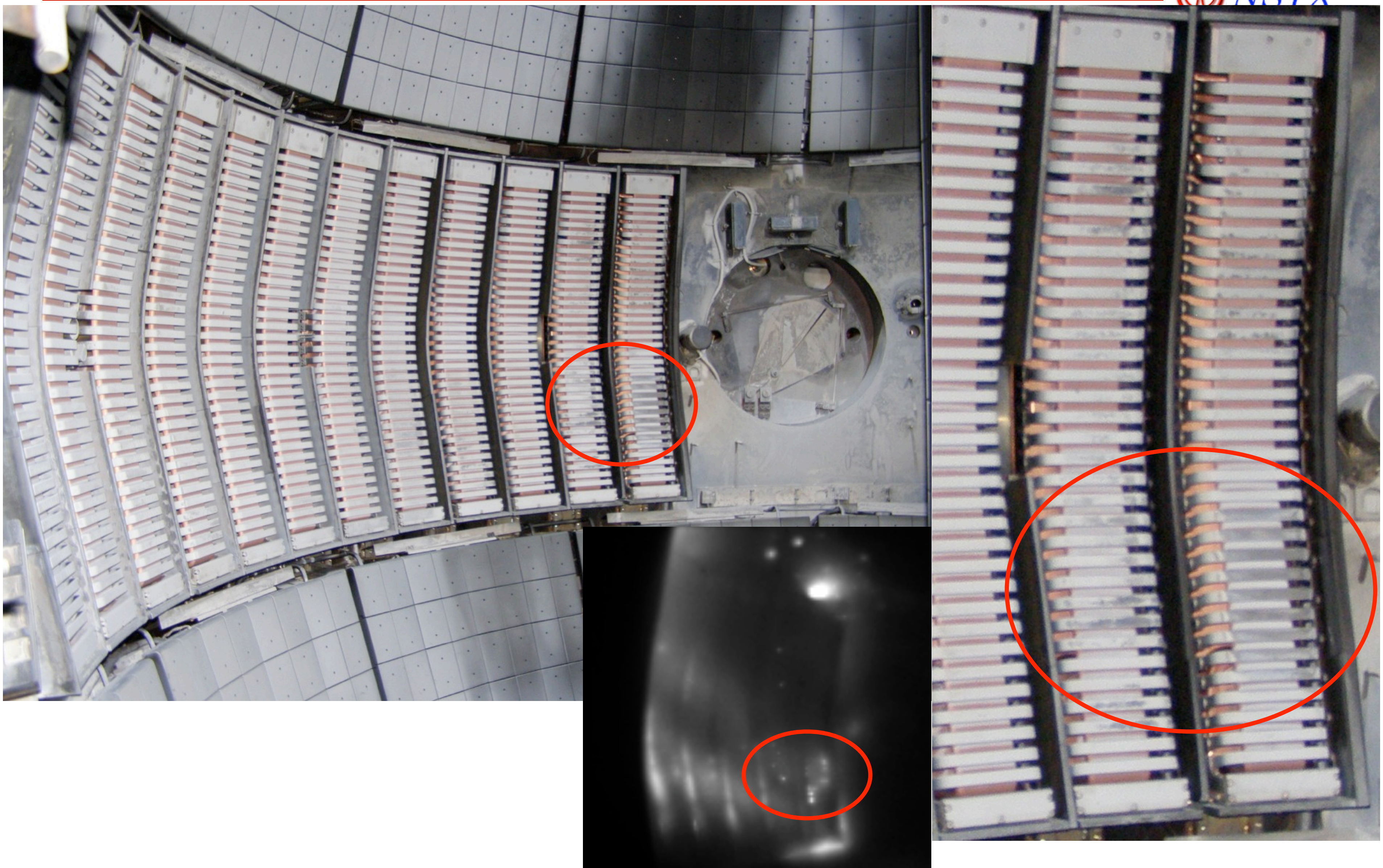
Crowded Conditions For Installing ~60 m Additional Line



Antenna Conditioning (XP26)

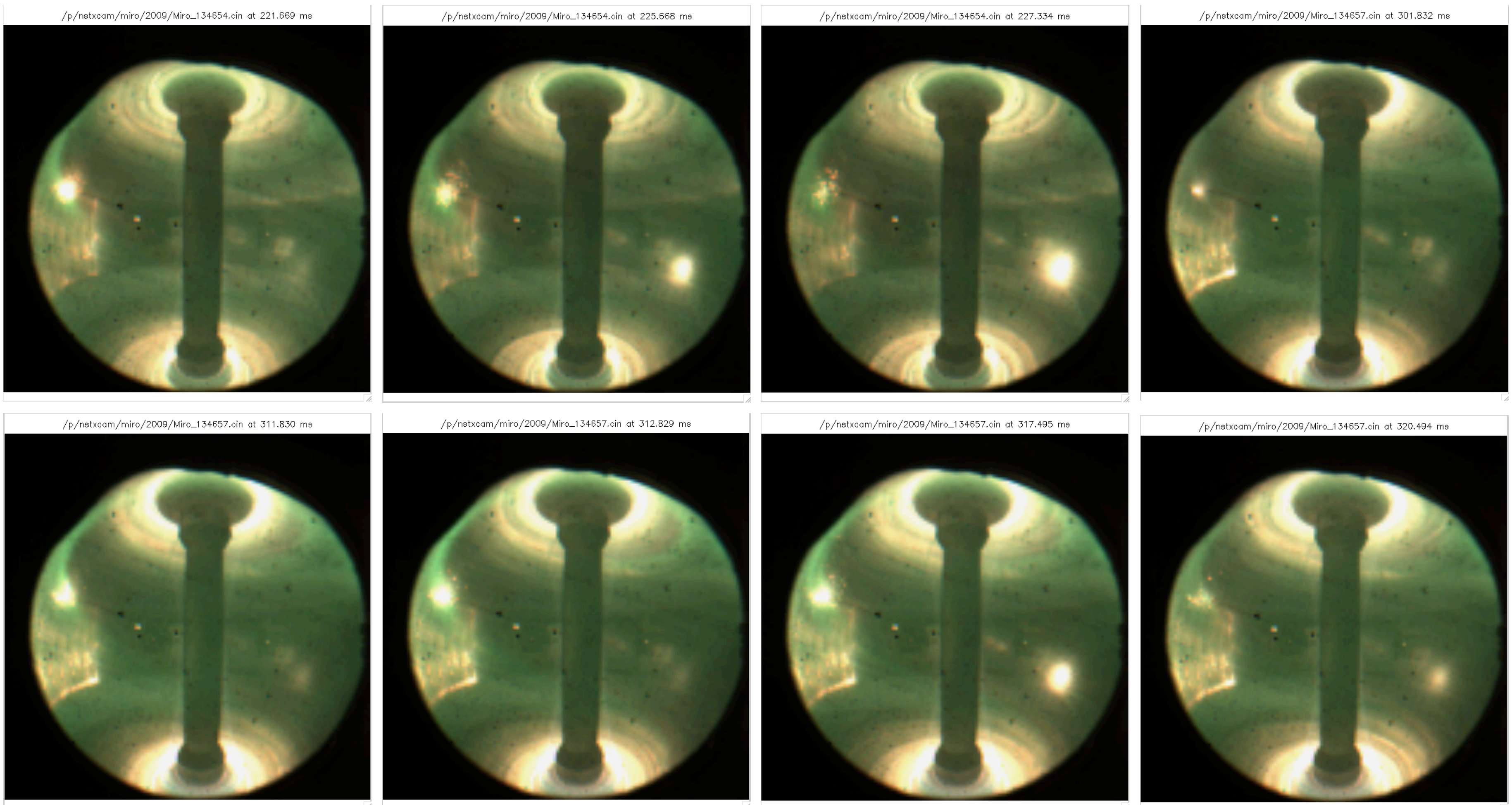
- **Vacuum conditioning**
  - Brand new current straps need high voltage/current conditioning to remove surface irregularities.
  - System voltage limits after extensive Li operation were often below 10 kV, but quickly conditioned up to previous 22-25 kV limits.
  - Fast camera observation (July 22) indicated that breakdowns were occuring in the antenna box.
  - **Conclusion**: introduction of 3-inch line sections did not reduce previous system vacuum voltage limit.
- **Plasma conditioning**
  - Brought brand new straps up to previous power levels (2-3 MW) more quickly than in the past.
  - Evidence that Li coating of antenna frame, FS, and BN limiters is contributing to antenna arcing.

Persistent glow at site of FS surface irregularity



Plasma conditioning of antenna
– ejection of material from antenna surfaces

- Power limited by lithium sputtering outside of antenna enclosures (on BN limiters)
- Not limited by RF voltage on antenna
- Appears to be an RF current induced effect



Plasma Conditioning Example (XP26)

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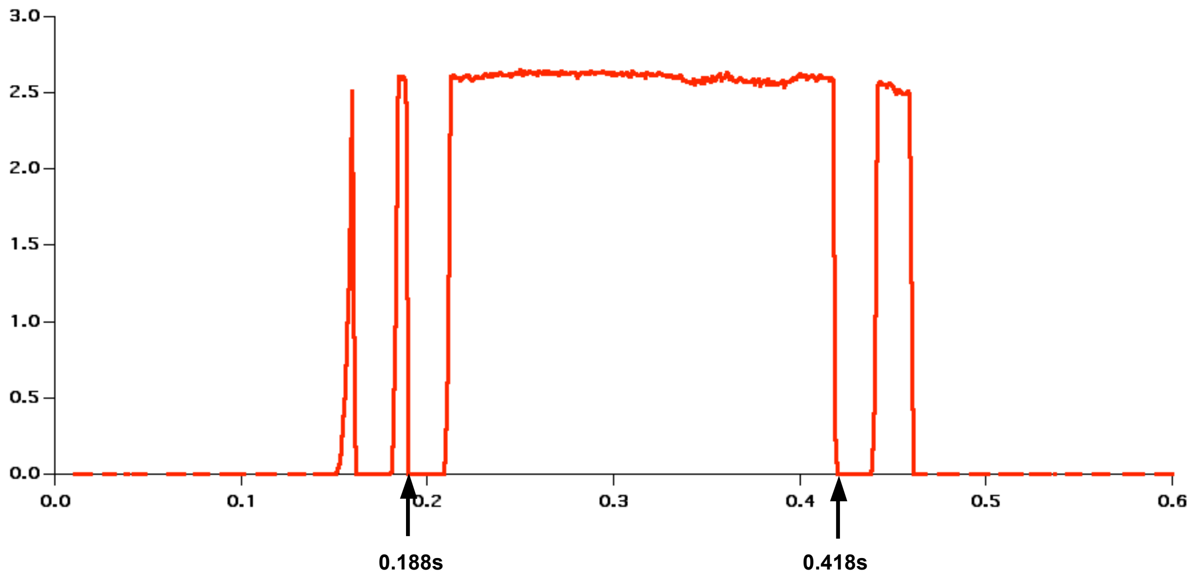
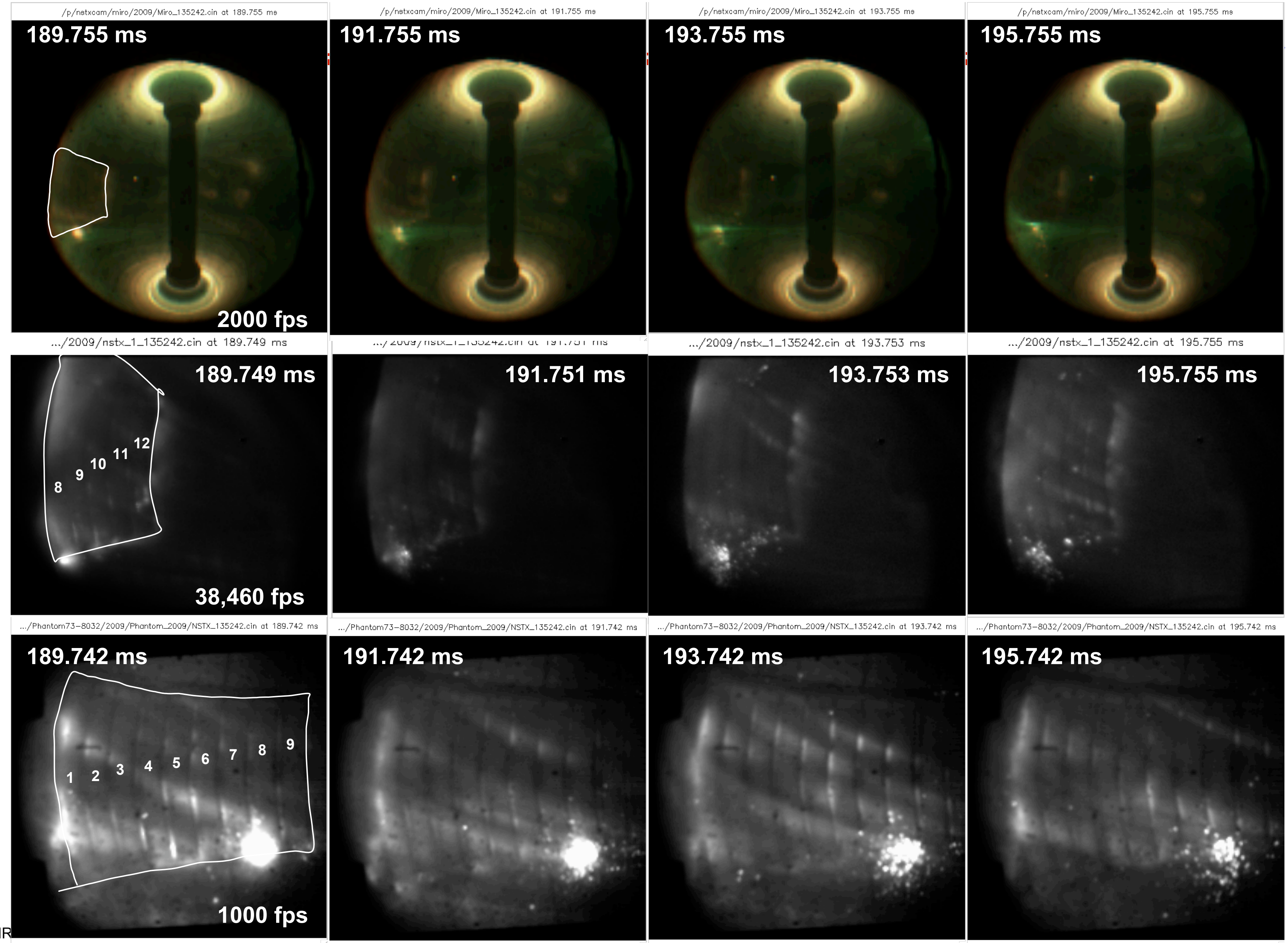
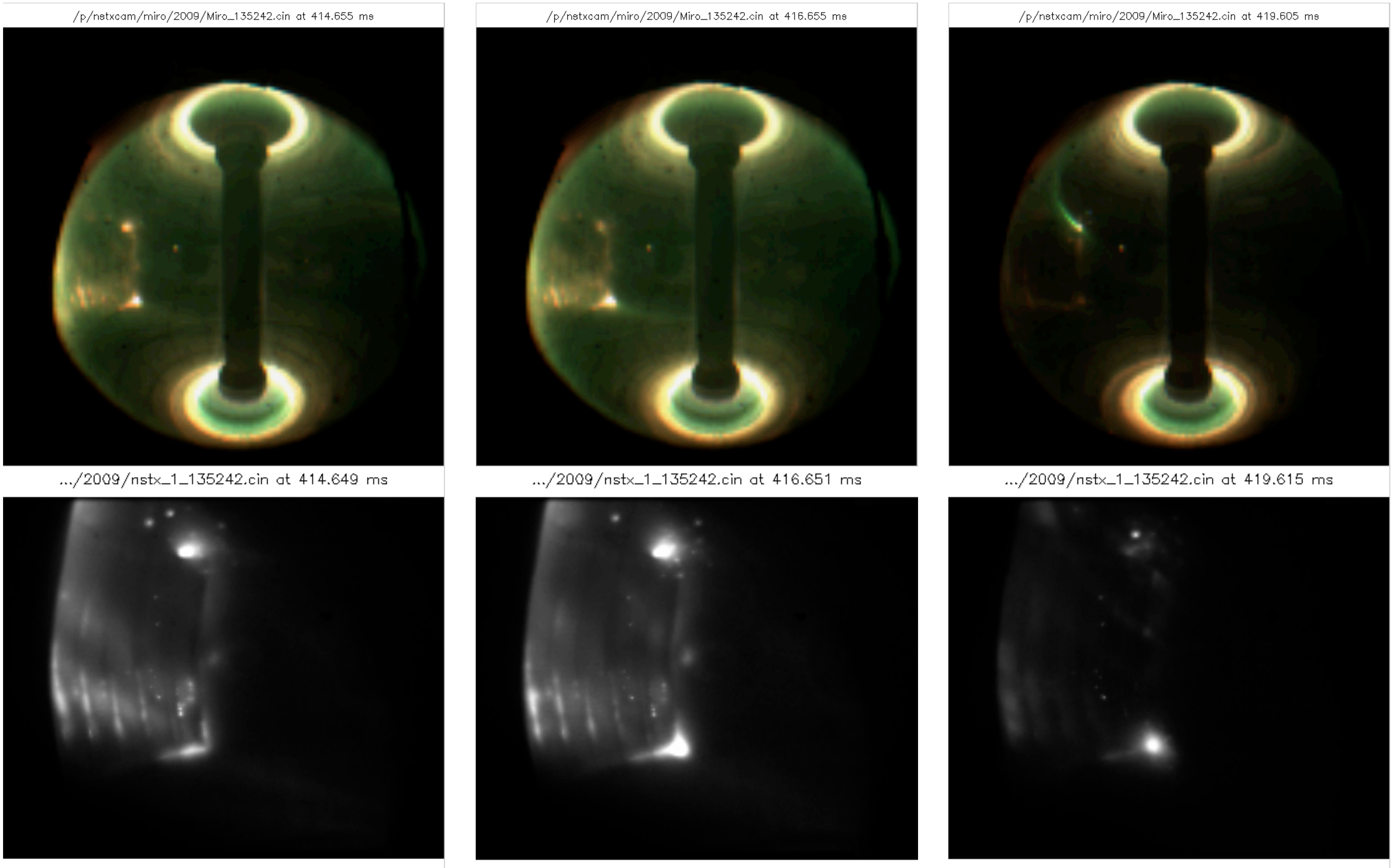
- July 22 - Had three cameras observing antenna during plasma condtioning in He, L-mode plasma.
- Shot 135242 had three transmitter trips during a 200 ms, 2.6 MW pulse at -90º phasing.



Transmitter 1 (straps 1 & 7) trips off at 188.1 ms



Transmitter 5 (straps 5 & 11) trips off at 418.1 ms



Last week of HHFW Operation was the most productive

July 22: Vacuum/plasma conditioning XMP26, and HHFW in He L-mode plasma XP944

- Conditioning is removing lithium deposited on antenna surfaces
- Achieved P_{RF} > 4 MW, T_e ~ 5.8 keV @ 3.7 MW and @ 2.7 MW
- Transitioning to H-mode at high power

July 23: L-H Transition with HHFW in He and D plasmas XP941 (Kaye et al.)

- Supported L-H transition with programmed P_{RF} pulse up to 3.7 MW
- Achieved transitions L-H and H-L without arcs
- Strong electron heating, T_e up to ~ 5.8 keV in He

July 24: HHFW in NB driven deuterium H-mode plasma XP946

- Relatively high n_eL operation
  - -90° with P_{RF} ~ 2.7 MW without arcs
  - -150° with P_{RF} ~ 2.5 MW without arcs
- Coupling through relatively large repetitive ELMs without trips/arcs

High T_e for P_{RF} = 2.7 MW in He L-Mode XP944 7/22

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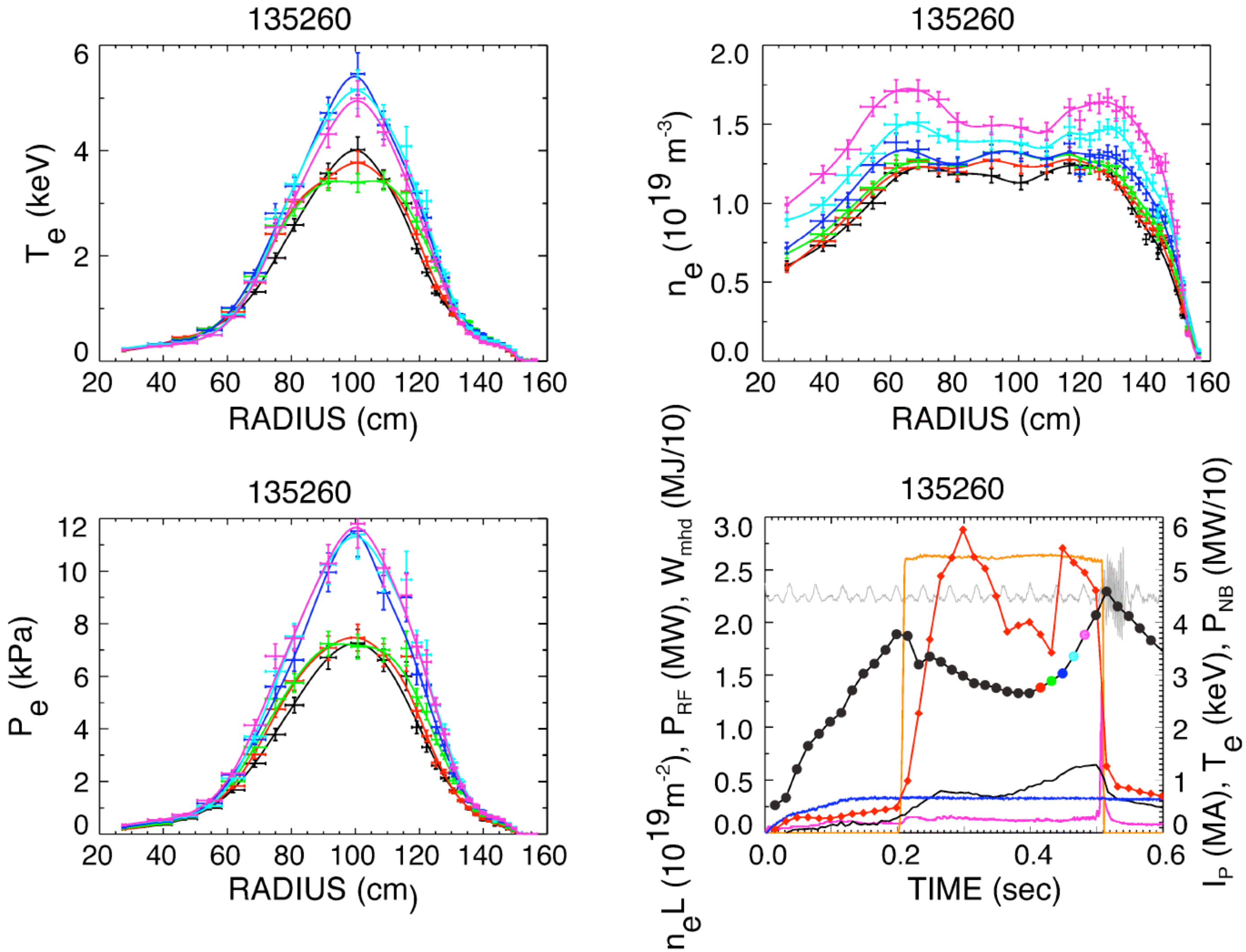
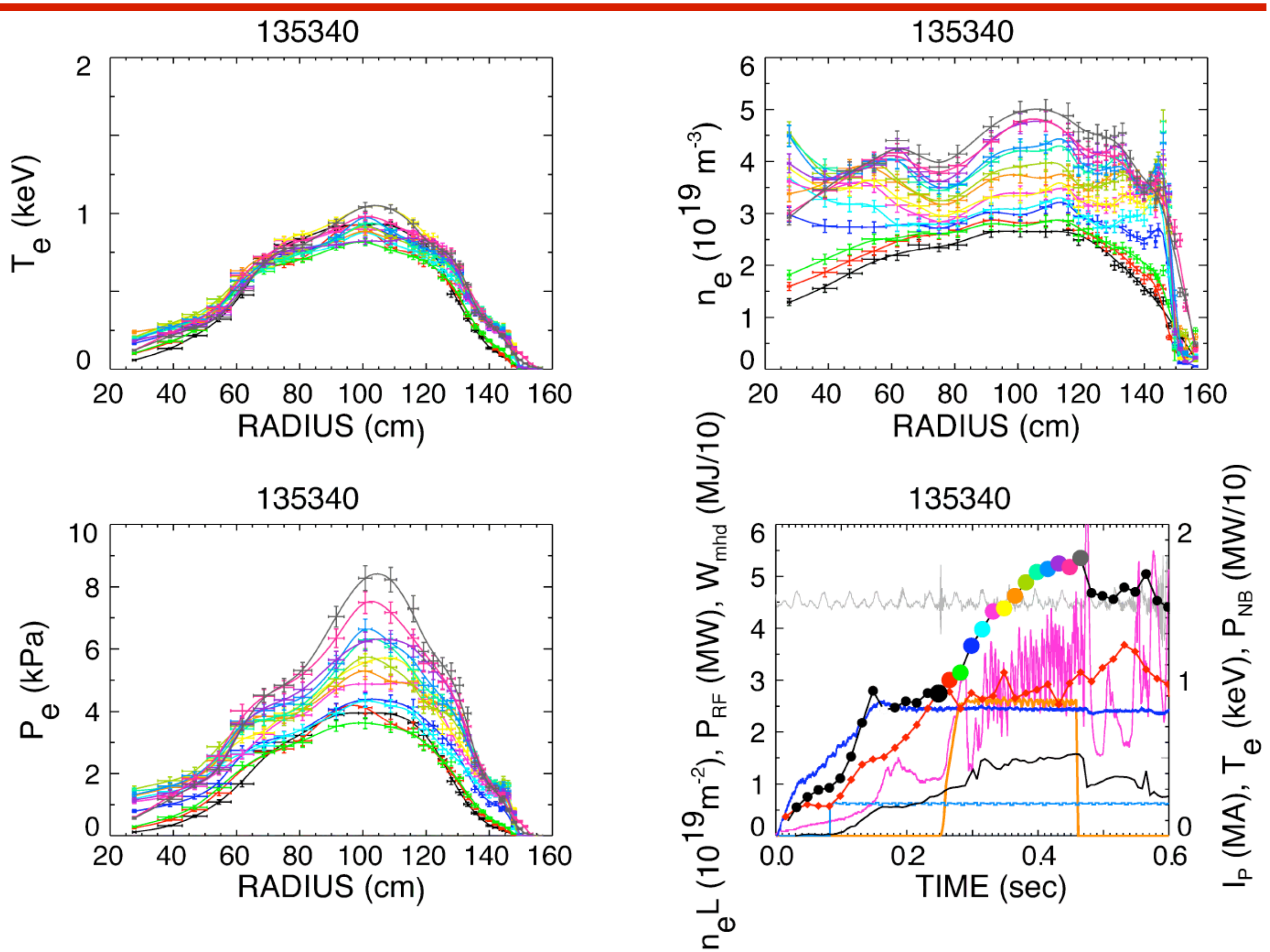


- T_e ~ 5.8 keV early and ~ 5.5 keV late in RF pulse
- Transition to H-mode at end of RF pulse

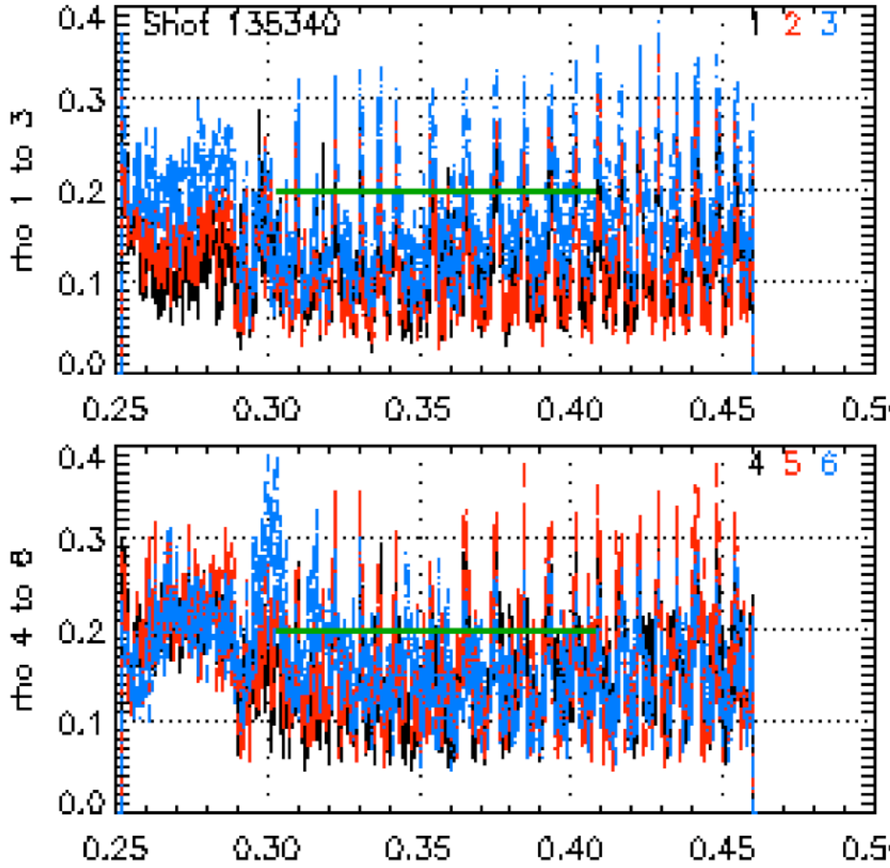
H-mode transition sustained for -150° antenna phasing with NB at P_{RF} ~ 2.7 MW XP946 7/24



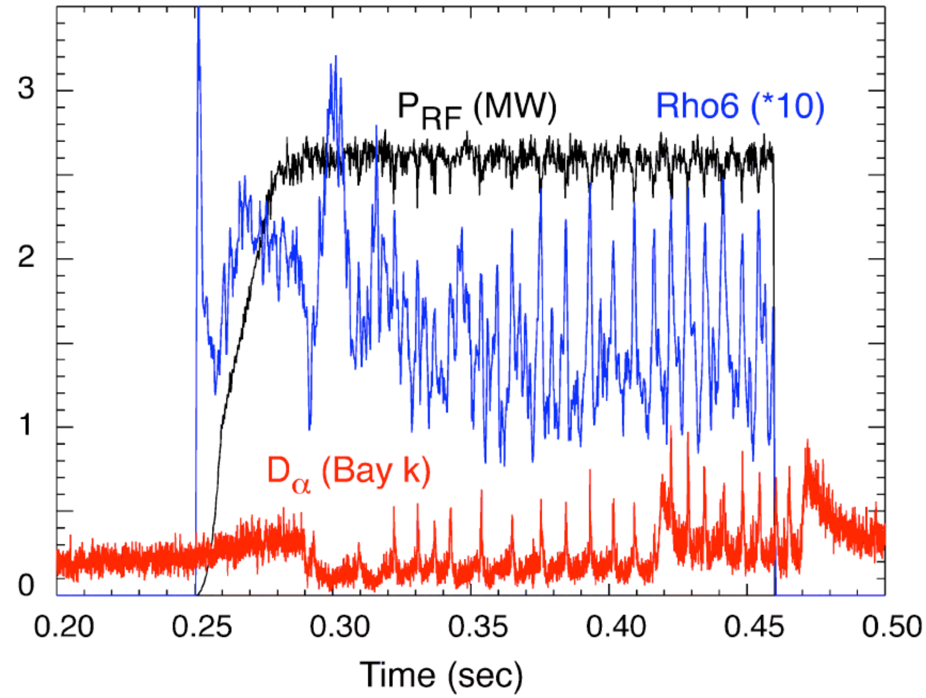
- **Transition to H-mode occurs after RF turn on and without RF arc**
- **Coupling through ELMs maintained**
- **T_e profile broadened with near doubling of n_eL (relatively high density case)**

RF source response to ELMs 7/24

Source voltage reflection coefficients



ELM Behavior



- **Coupling through ELMs possible if trip value of rho can be set to a high value (0.7 in this case)**

July 24 Comparisons for B_ϕ = 4.5 and 5.5 kG at I_P = 800 kA

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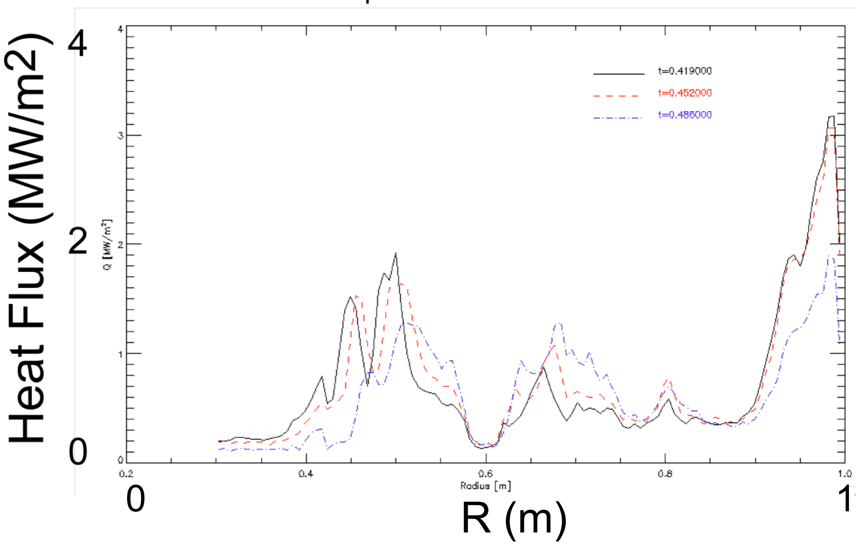
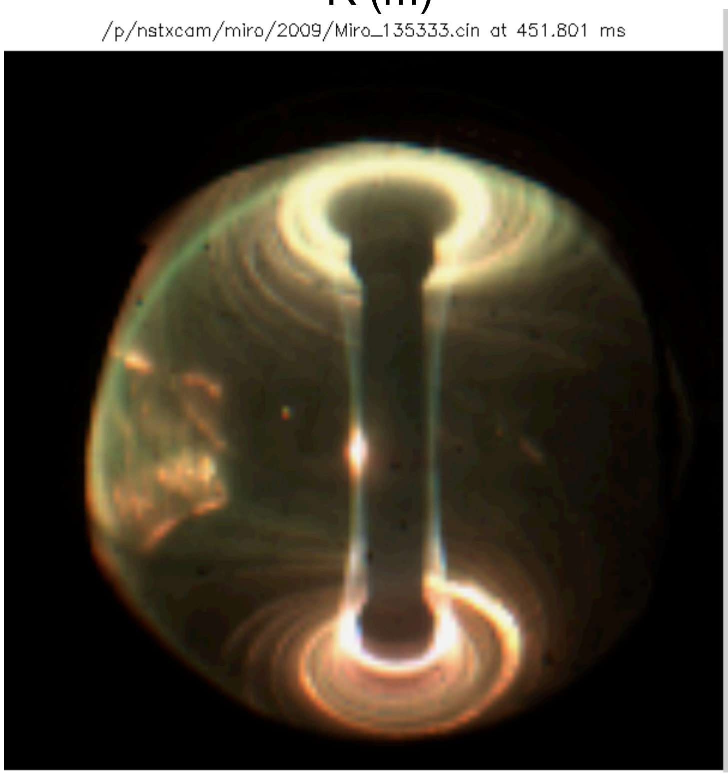
- Relative high density H-modes produced at B_ϕ = 4.5 and 5.5 kG at both -90° and -150° antenna phases
  - n_eL up to ~ 5.5 x 10^{19} m^{-3}
- RF couples through ELMs, both at onset of ELMs and for repetitive ELMs
- Decreasing the pitch of B (B_ϕ from 4.5kG to 5.5 kG) clearly moves the "hot" region (viewed with the visible camera) toroidally away from the Bay I infra red camera view
- The IR response also shows that the heat flux at Bay I (in the radial range of view of the IR camera) due to the RF is much greater at the higher pitch
- These results indicate additional IR camera views are needed to document the edge RF power loss
  - IR views of the vessel bottom out to R ~ 1.2 m at Bays J and K would be ideal for determining the edge RF heat flux. A fast IR camera view of Bay J bottom would also provide considerable insight regarding the possible coupling of the RF power to the ELMs

RF edge heating at Bay I vs B pitch for antenna phase of - 90°

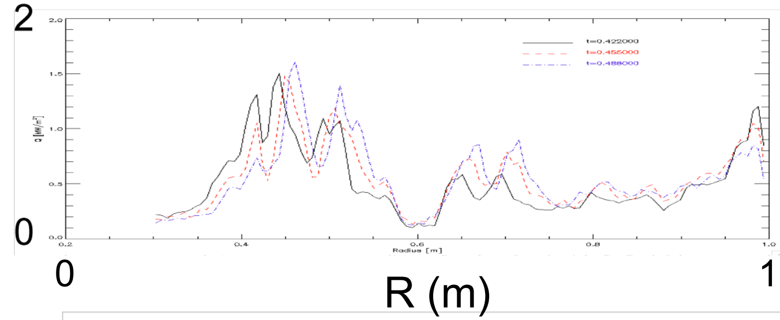
(All panels on same scale)

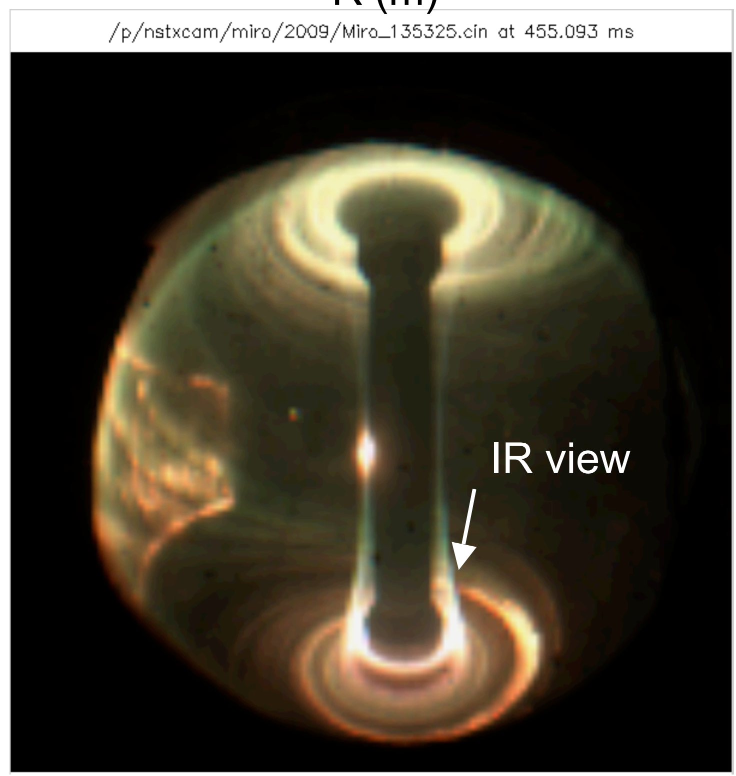
135333 B_ϕ = 4.5 kG, I_P = 800 kA





135325 B_ϕ = 5.5 kG, I_P = 800 kA

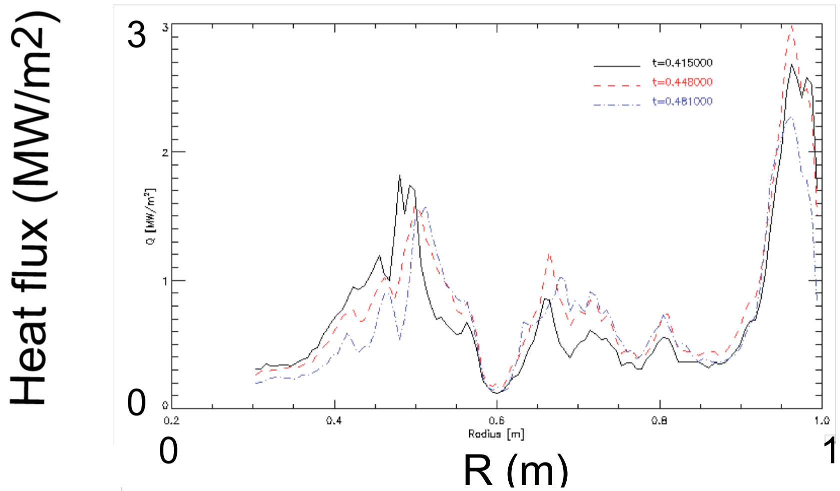


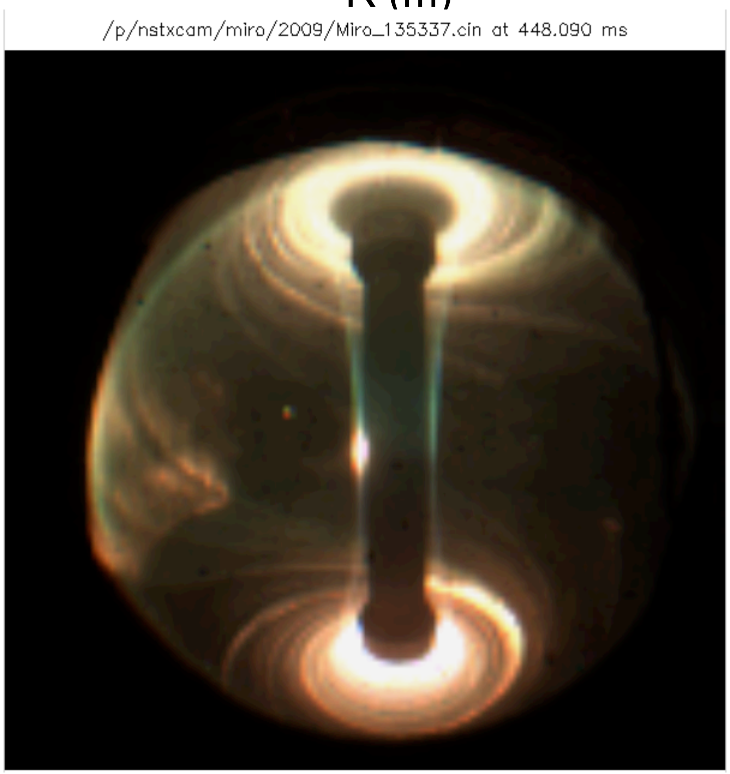


RF edge heating at Bay I vs B pitch for antenna phase of - 150°

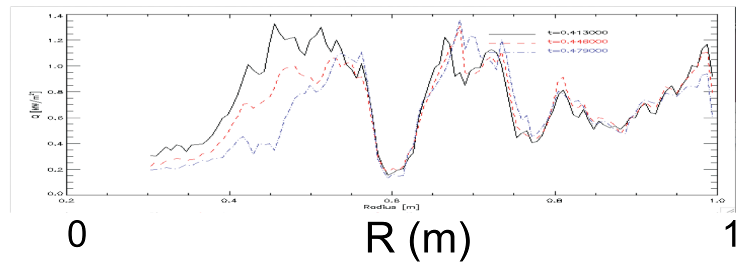
(All panels on same scale)

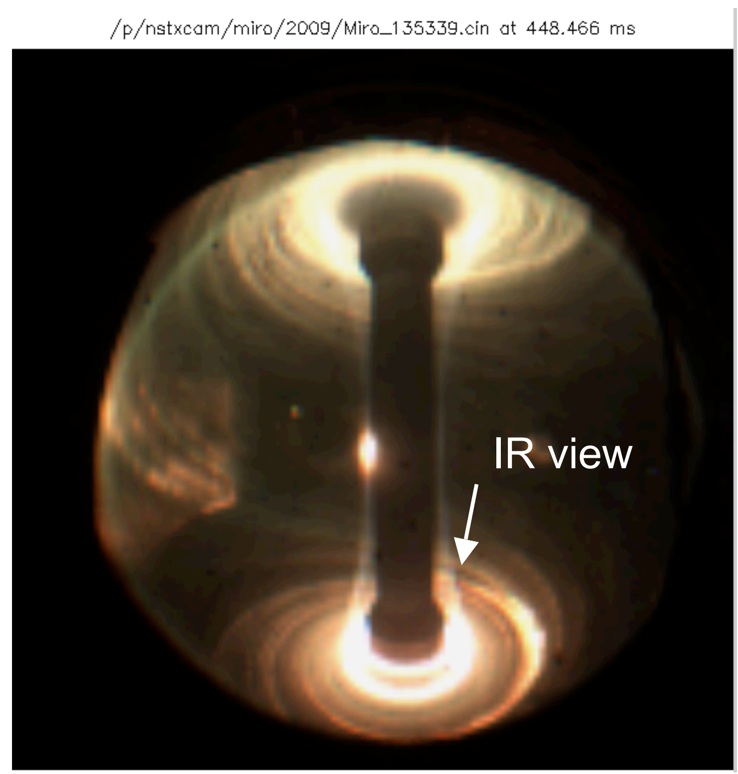
135337 B_{ϕ} = 4.5 kG, I_P = 800 kA





135339 B_{ϕ} = 5.5 kG, I_P = 800 kA





Summary

- Changes in HHFW antenna configuration did not substantially increase the system voltage limit for plasma operation.
  - Currents flowing on antenna frame/FS may determine arcing threshold.
  - Operation was improving during limited run time. Vacuum and plasma conditioning increased power levels, removed Li coatings from antenna structure.
- HHFW performance was significantly improved over last year's operation.
  - In He L-mode plasma (XP944), coupled >4 MW, reached T_e ~ 5.8 keV at 3.7 MW and at 2.7 MW, and achieved H-mode transitions.
  - Supported L-H, H-L mode transition studies (XP941) with programmed RF pulses up to 3.7 MW.
  - Maintained HHFW coupling through L-H mode transition and in presence of relatively large repetitive ELMS (XP946) in relatively high density, NBI-driven plasmas.
- It is expected that extensive antenna conditioning during the next campaign will permit us to reach P_{RF}>5 MW and, combined with improved ELM/arc discrimination, to improve power coupling to the core of H-mode plasmas.