NSTX-U

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Towards Identifying the Mechanisms Underlying Field-Aligned Edge Losses of HHFW Power on NSTX

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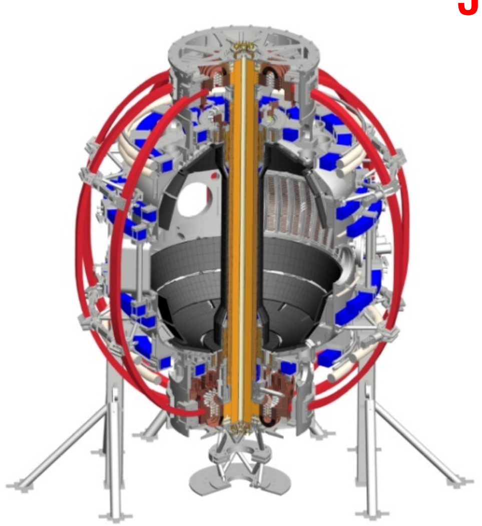

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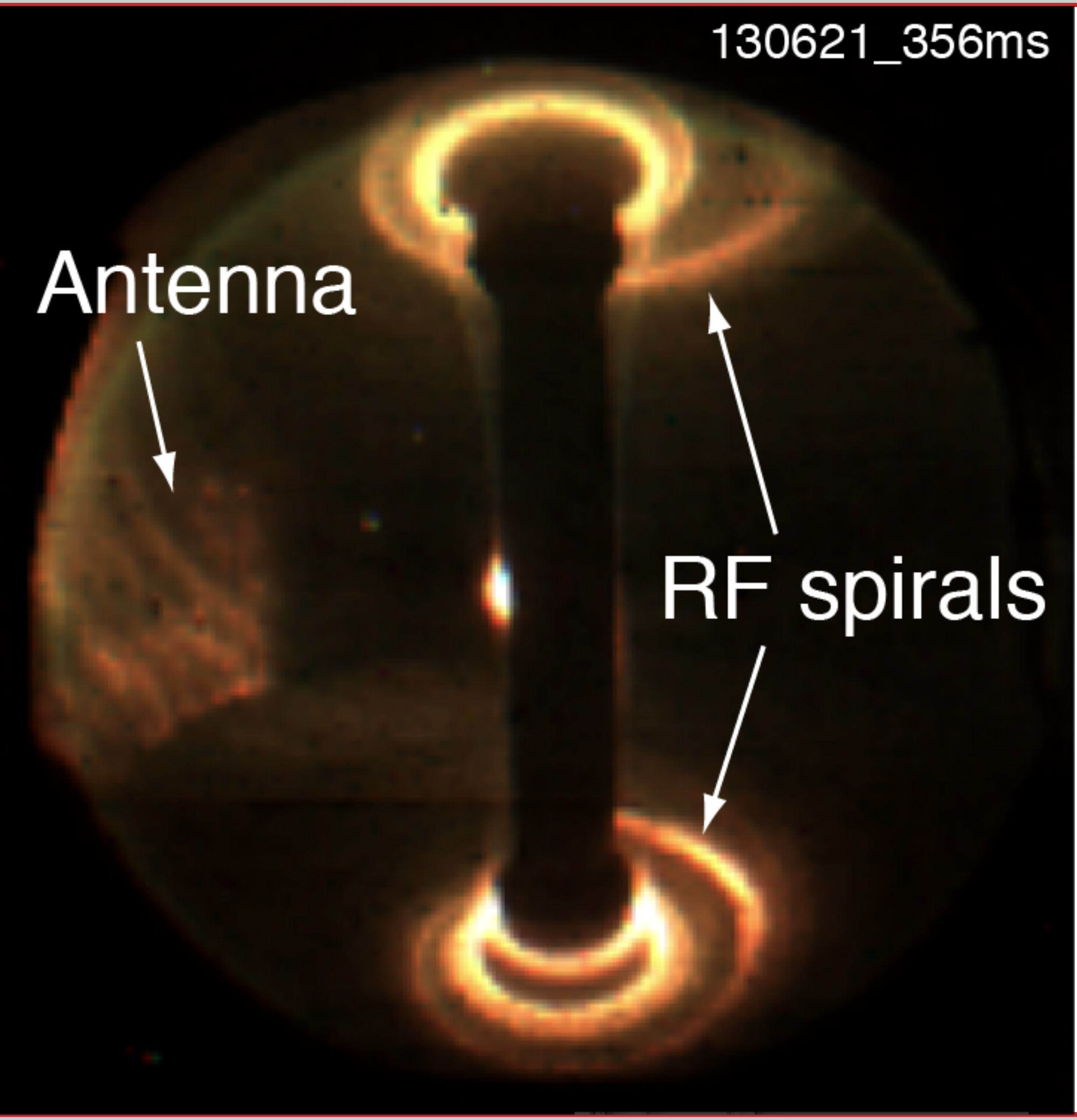
HHFW power lost *directly* to divertor regions along SOL field lines on NSTX



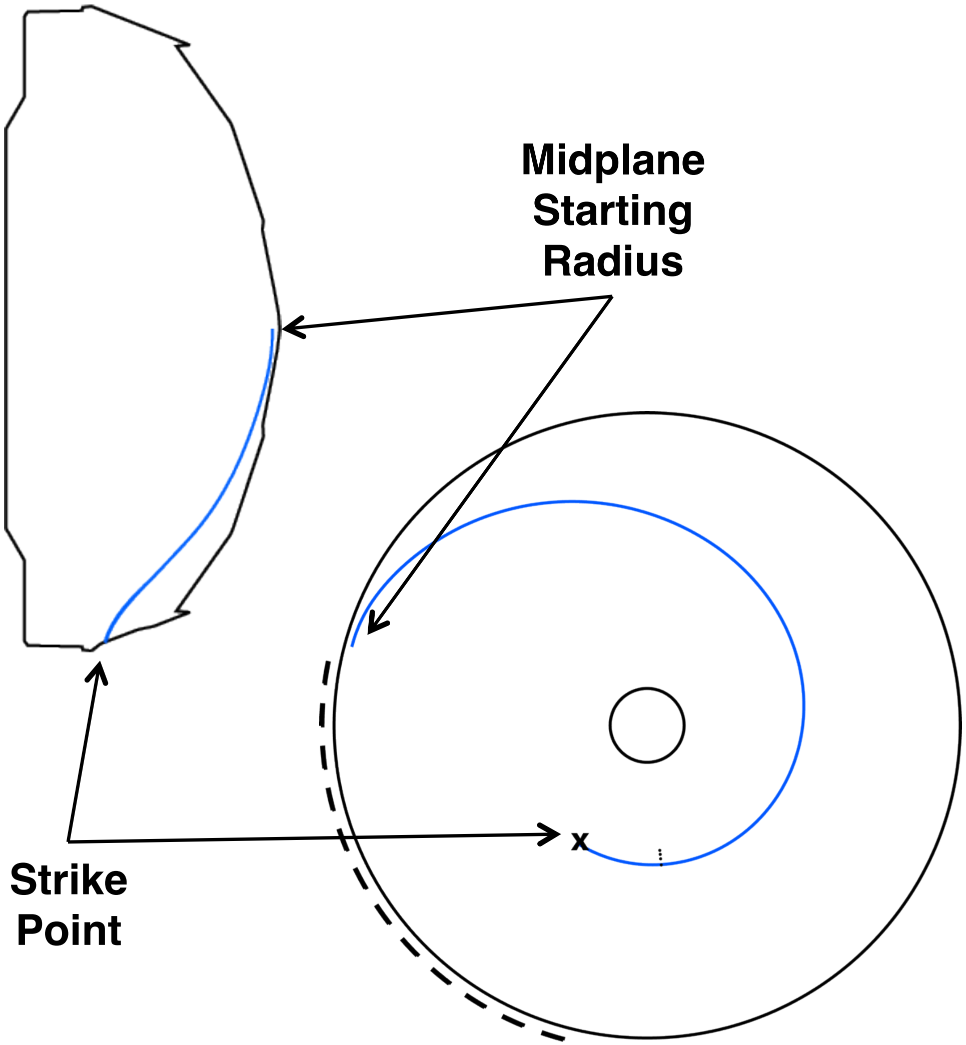
- RF power deposited in bright spirals on upper and lower divertor

- Occurs as waves propagate away from antenna prior to LCFS
  - Large single-pass absorption (high beta)
  - Negligible multi-pass dampening

Outline

- **NSTX exhibits field-aligned loss in SOL**
  - Deposits power in spirals on divertor
  - Losses occur along all SOL field lines around antenna
  - Loss amplitude peaks near antenna and also LCFS
- **Field-aligned losses are significant**
  - Account for large portion of total losses
  - Other loss mechanisms may be significant too
- **Fast-wave propagation in SOL may be responsible**
  - Losses are related to onset density for perpendicular fast-wave propagation
  - Codes show signs of large RF fields in SOL but need proper edge damping.

Field-line mapping models flow of lost HHFW power

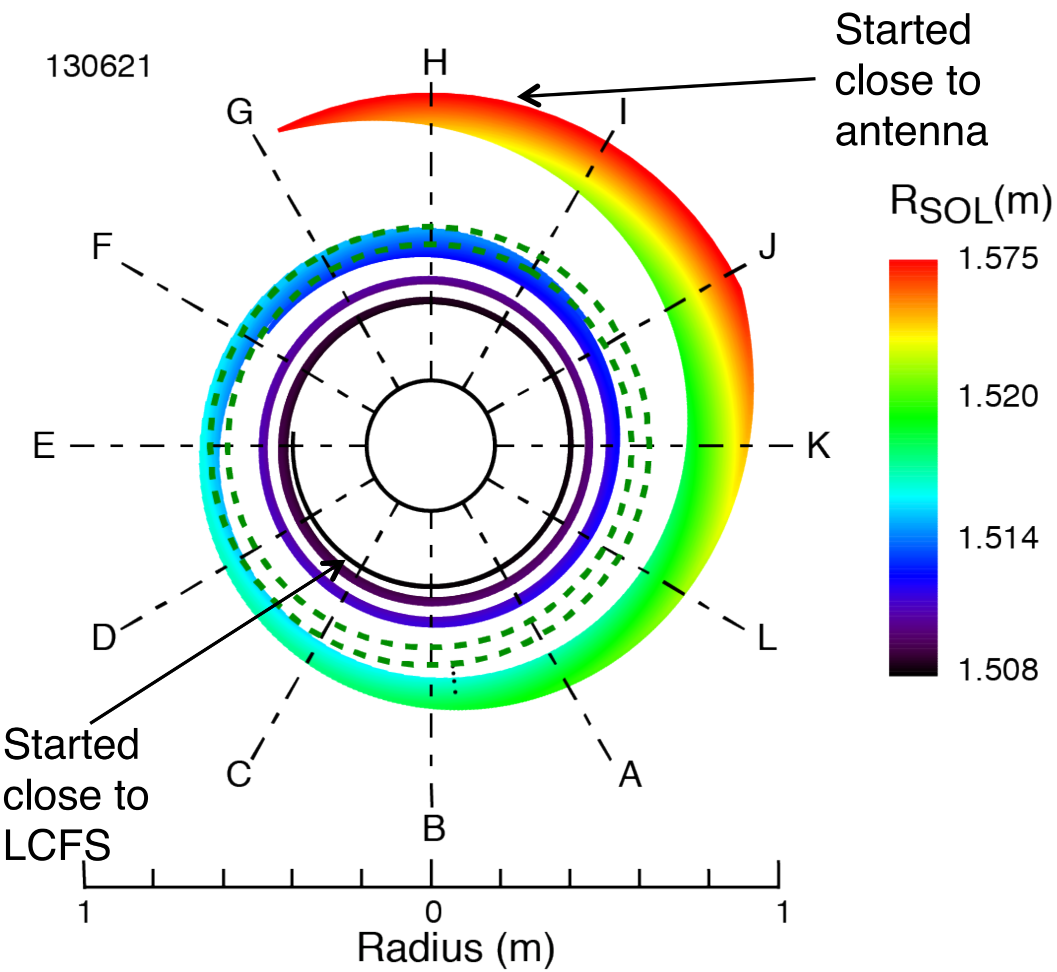


- Start field lines at midplane between antenna and separatrix
- Track field lines until they strike divertor
- Track field lines using SPIRAL code

G.J. Kramer et al., 22 IAEA FEC (Geneva, 2008) CD-ROM file IT/P6-3,
G.J. Kramer et al., submitted to Plasma Phys. Cont. F. (2012)

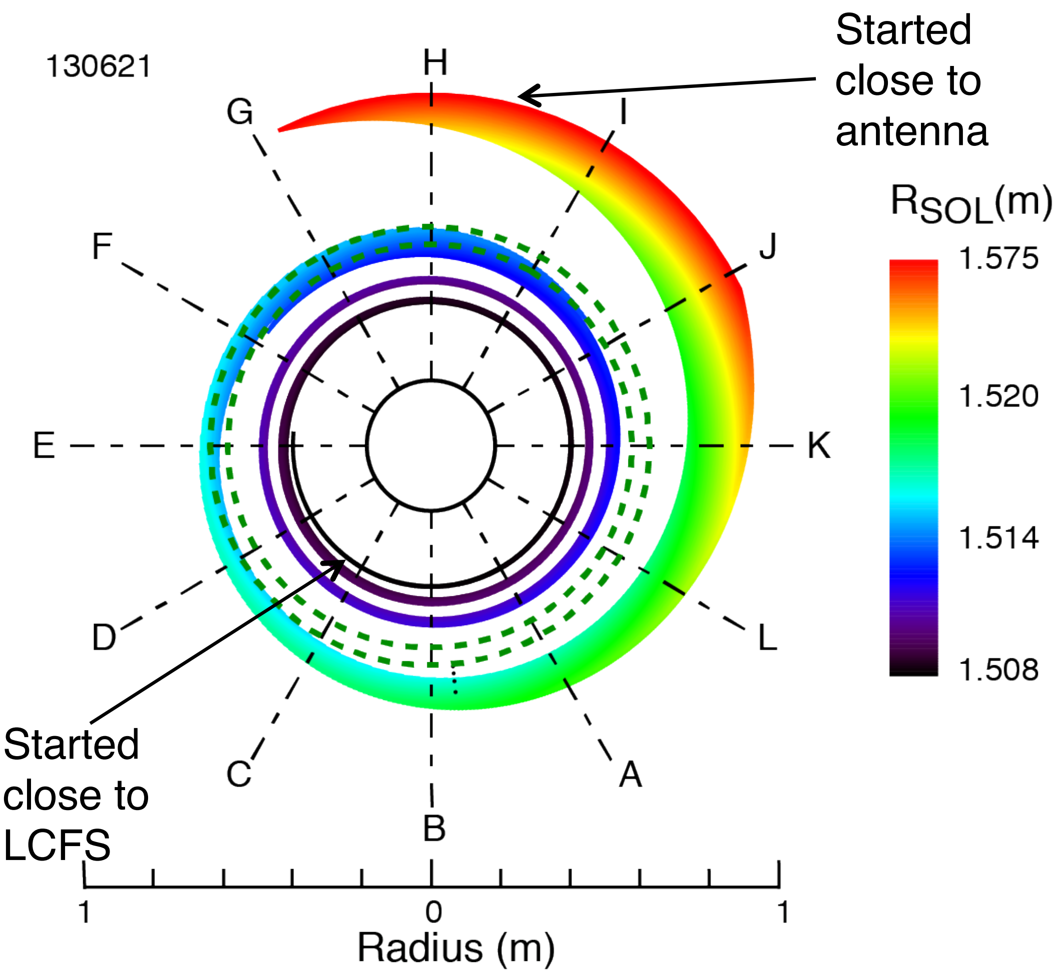
Computed strike points form a spiral that closely matches the observed RF spiral

Strike points on divertor for field lines started at midplane…

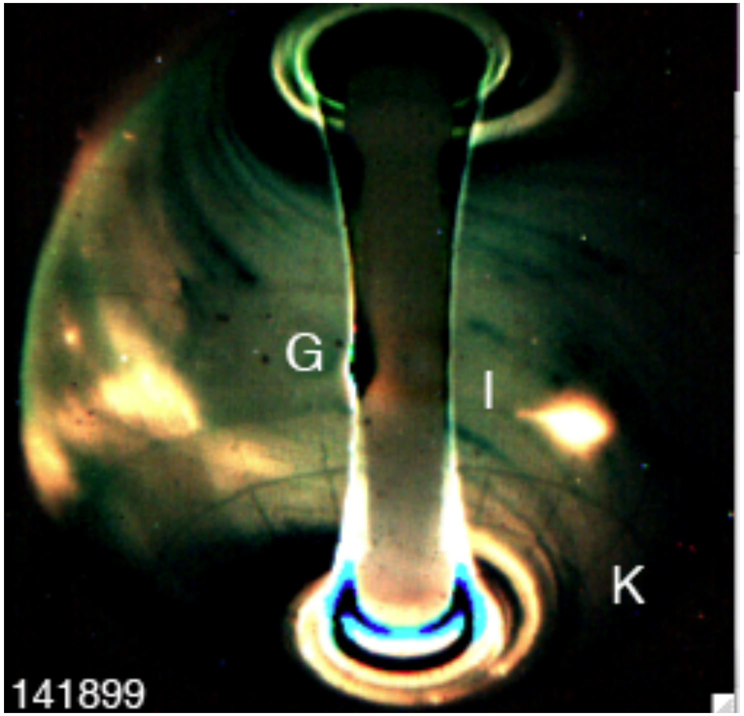


Computed strike points form a spiral that closely matches the observed RF spiral

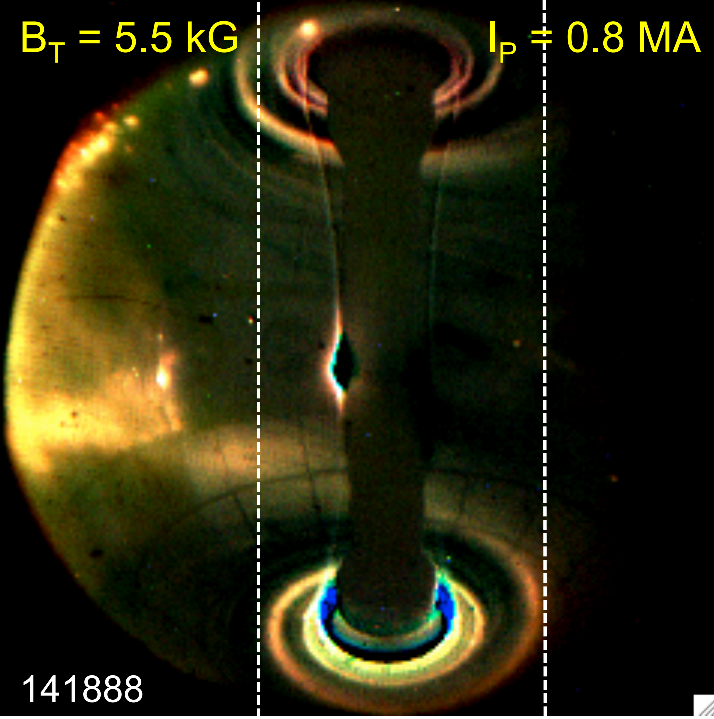
Strike points on divertor for field lines started at midplane…

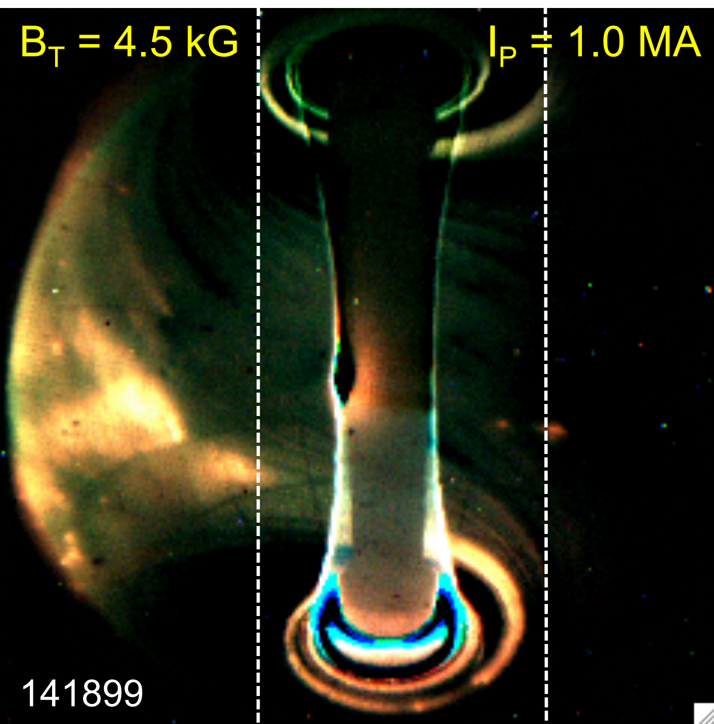


… create spiral pattern close to camera images



R.J. Perkins et al., Phys. Rev. Lett. 109 (2012) 045001



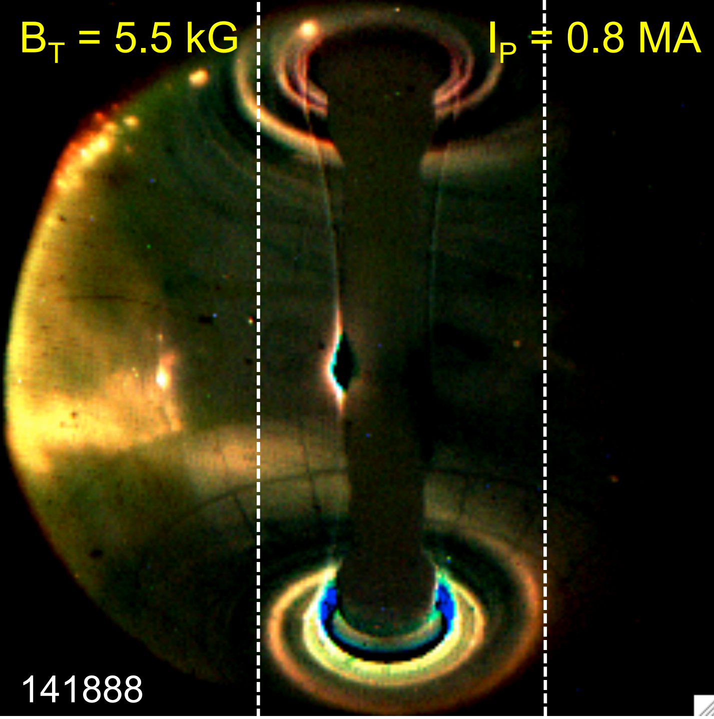


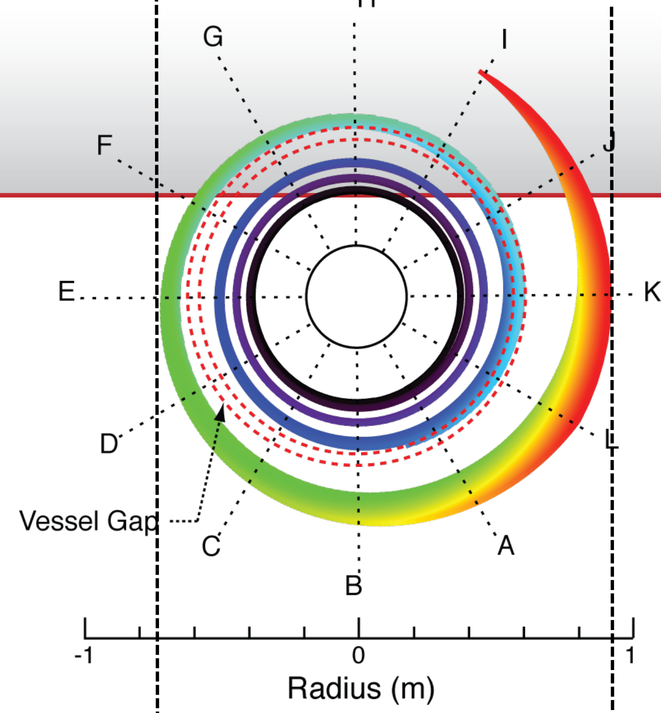
Spiral location moves when magnetic field pitch changes

- Radius shifts by ~ 15 cm inward with increased pitch
  - Low pitch: I_P/B_T = 0.8 MA / 5.5 kG (31°)
  - High pitch: I_P/B_T = 1 MA / 4.5 kG (42°)

- Can sweep RF spiral across diagnostics
  - Langmuir probes
  - Instrumented divertor tiles

141888 time = 0.312s - bkg 0.247s
141899 time = 0.319s - bkg 0.247s


B_T = 5.5 kG
I_P = 0.8 MA
141888


G
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Vessel Gap
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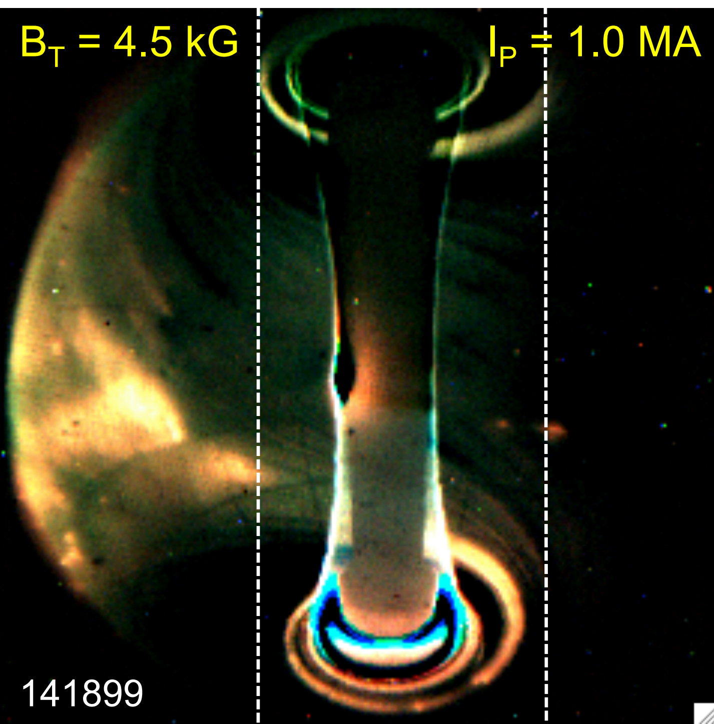
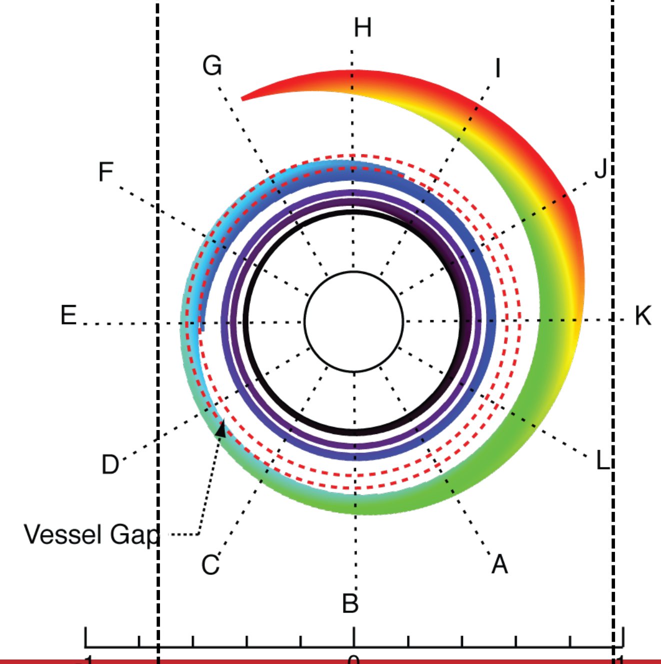
-1
0
1
Radius (m)


B_T = 4.5 kG
I_P = 1.0 MA
141899


H
G
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F
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D
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Vessel Gap
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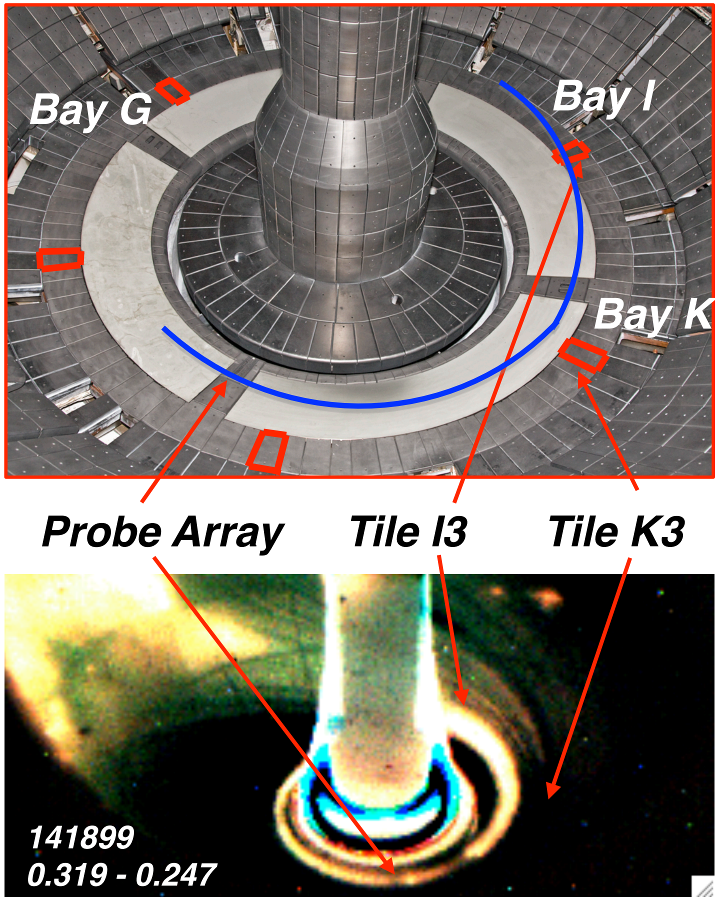
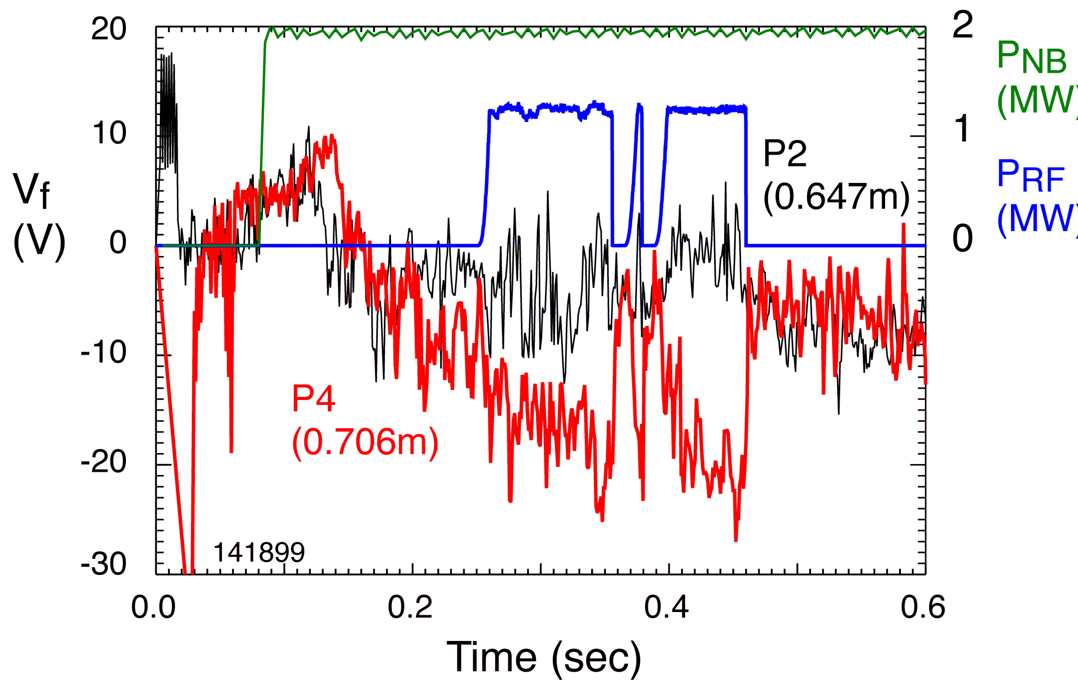
Radius (m)

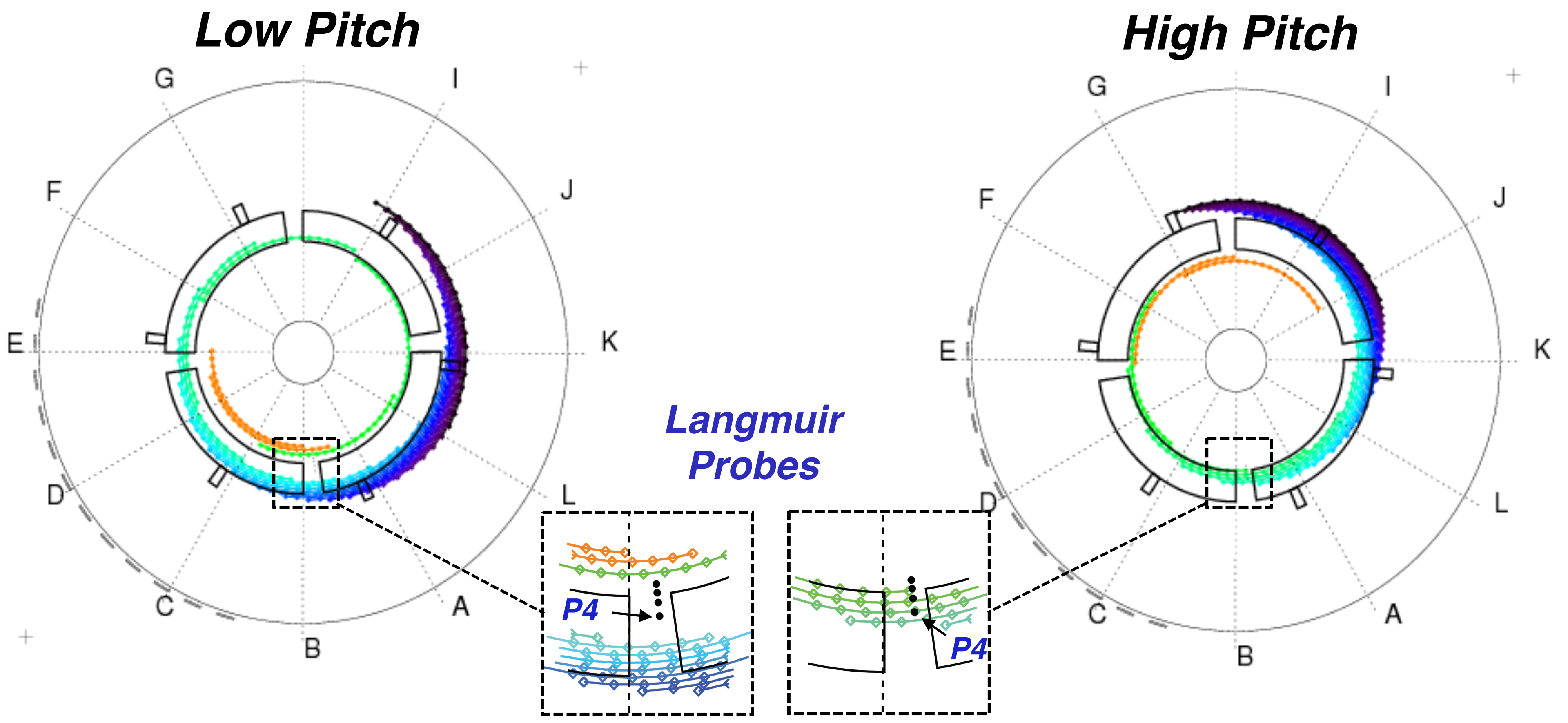
High field pitch puts spiral over Langmuir probe* 4 but not on other probes a few cm in





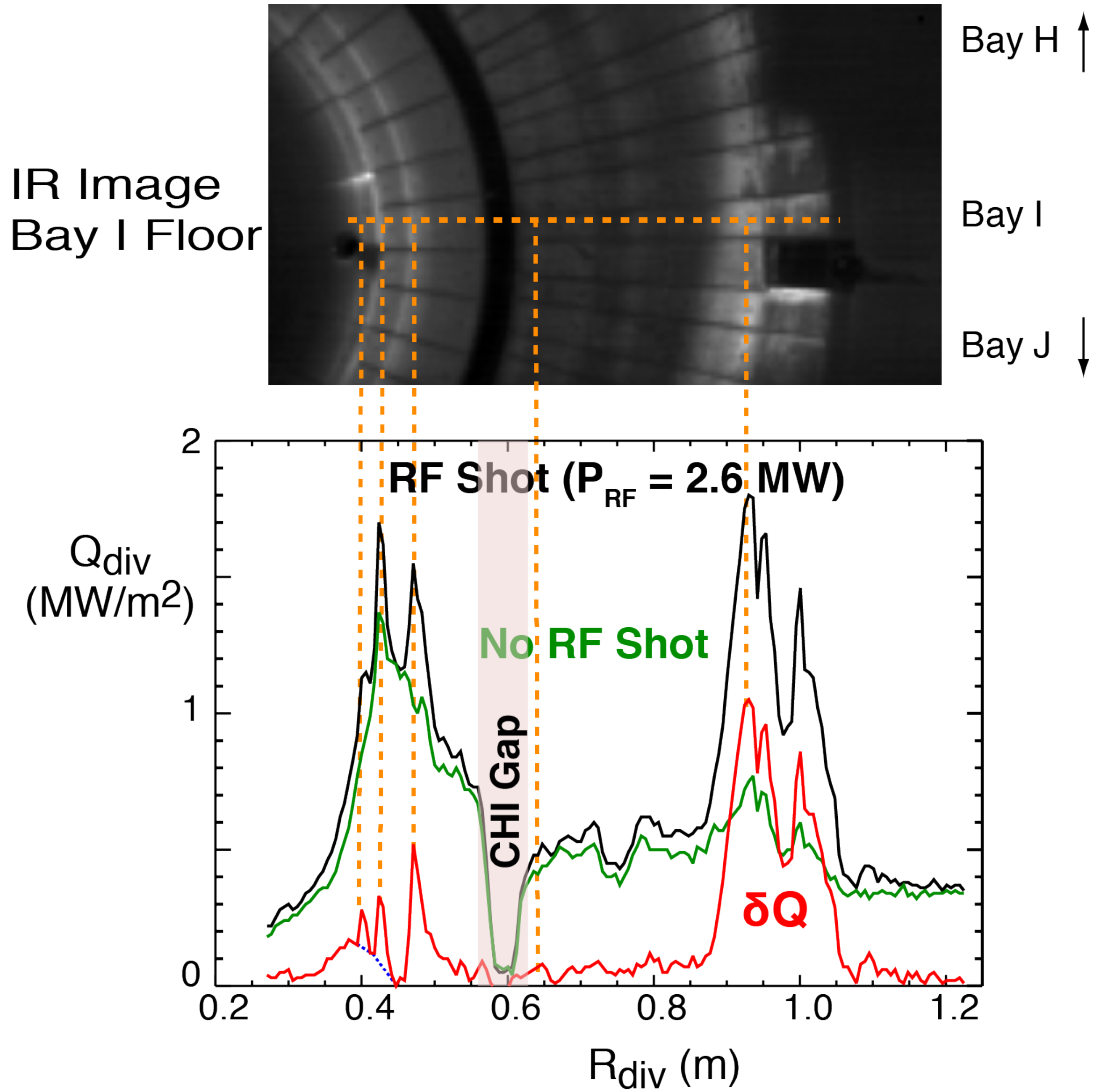
- Langmuir probe P4 floating potential responds strongly to RF
- Langmuir probe P2, 6 cm inboard, has a much weaker response
- RF-induced effects are localized

Modeling indicates that edge RF power propagates along field lines



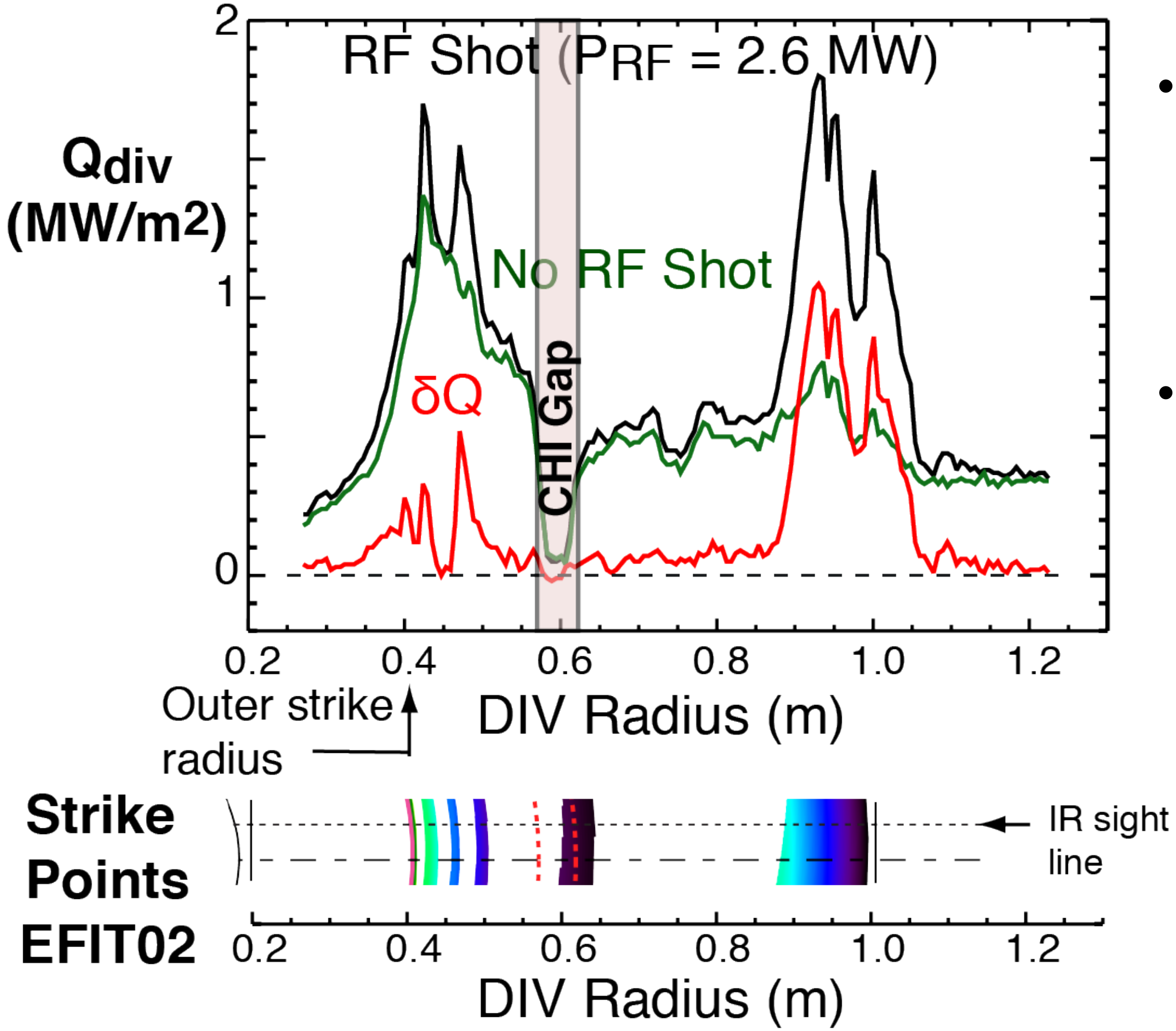
- Computed strike point spirals match tile and probe measurements
- High field pitch places spiral at probe 4 location
  - Probe connected to SOL 4 cm away from antenna

Divertor IR camera measures strong RF-induced heating



- RF spiral appears in IR image
- Heat profile taken along horizontal line
- RF-induced divertor heating (δQ) in red
  - Shot 135333 with RF (ELMy H-mode)
  - Shot 135334 no RF
  - Difference gives RF heat
- Several RF-induced heat peaks clearly resolved

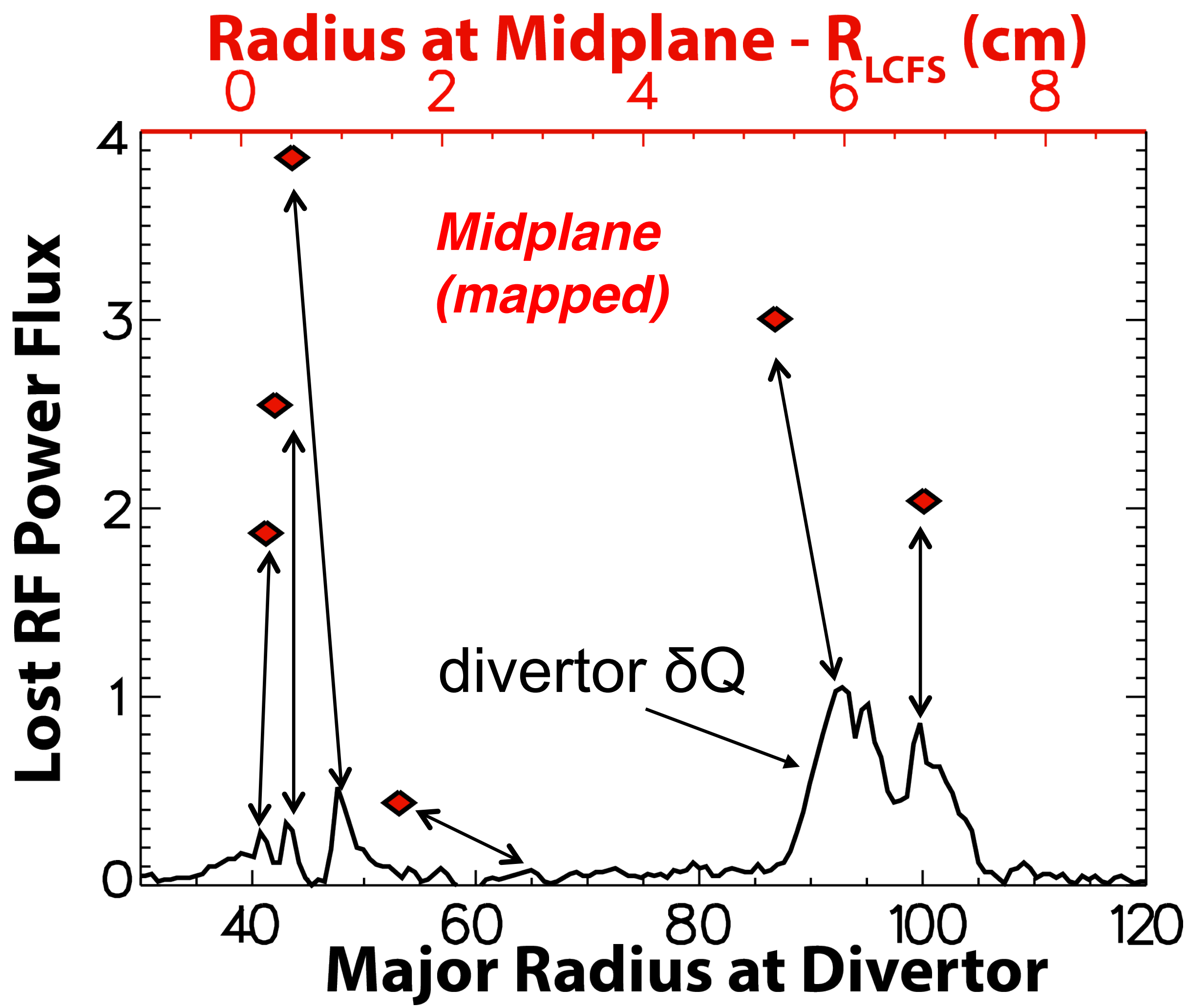
IR camera data agree with calculated strike points



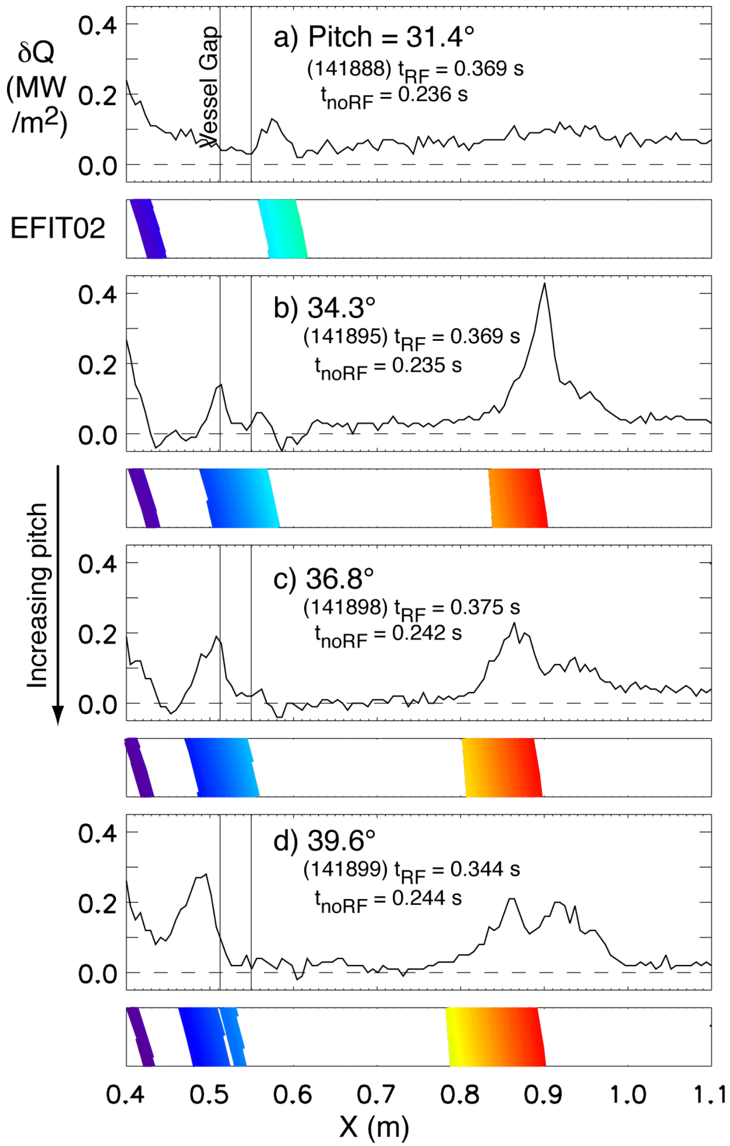
- RF deposits heat at Bay I regions at several radii
- Measured radii of RF heat peaks coincide with strike points computed by SPIRAL

Lost-HHFW-power profile at midplane is large near LCFS as well as antenna

- Midplane profile shows two-peak structure:
    - Peaking of power coupled close to antenna and LCFS
    - Relatively low coupling in between
- Loss mechanism cannot be localized to antenna

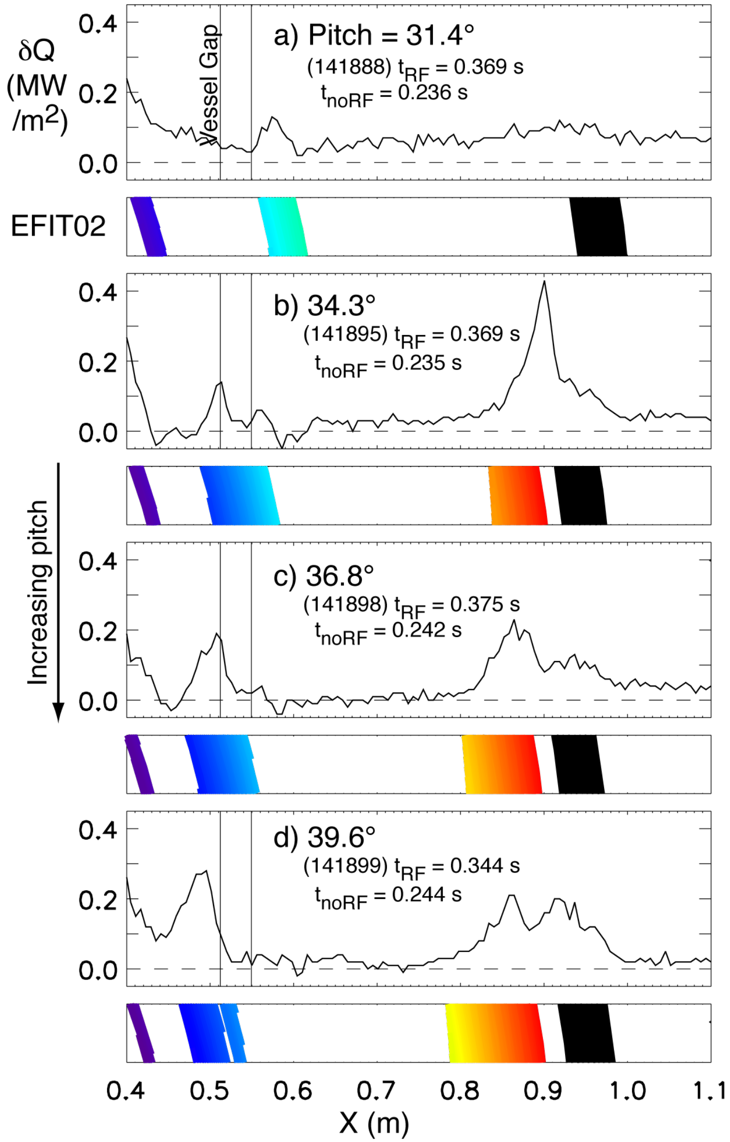


SPIRAL strike points generally agree with Qdiv for pitch scan

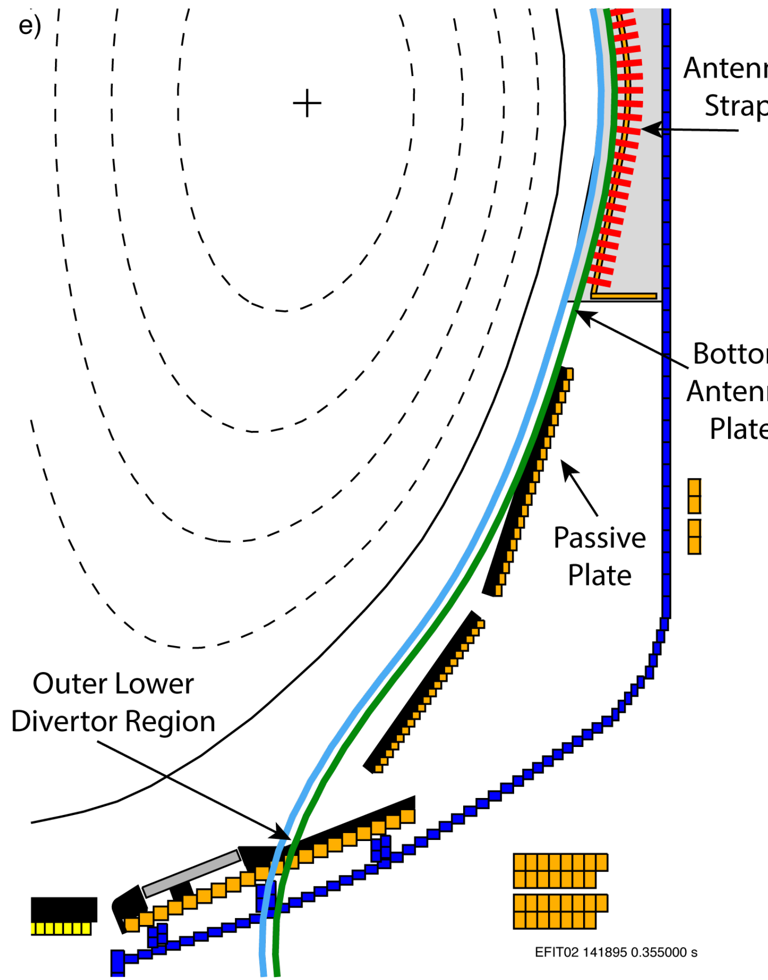


- SPIRAL strike points agree with heat peak
- Second heat peak moves inward with increasing pitch
  - Also grows in amplitude
  - Strike points track this motion
- A portion of heat falls outside range of strike points from midplane

Outer heat appears to come from field lines linking the edge of bottom antenna plate



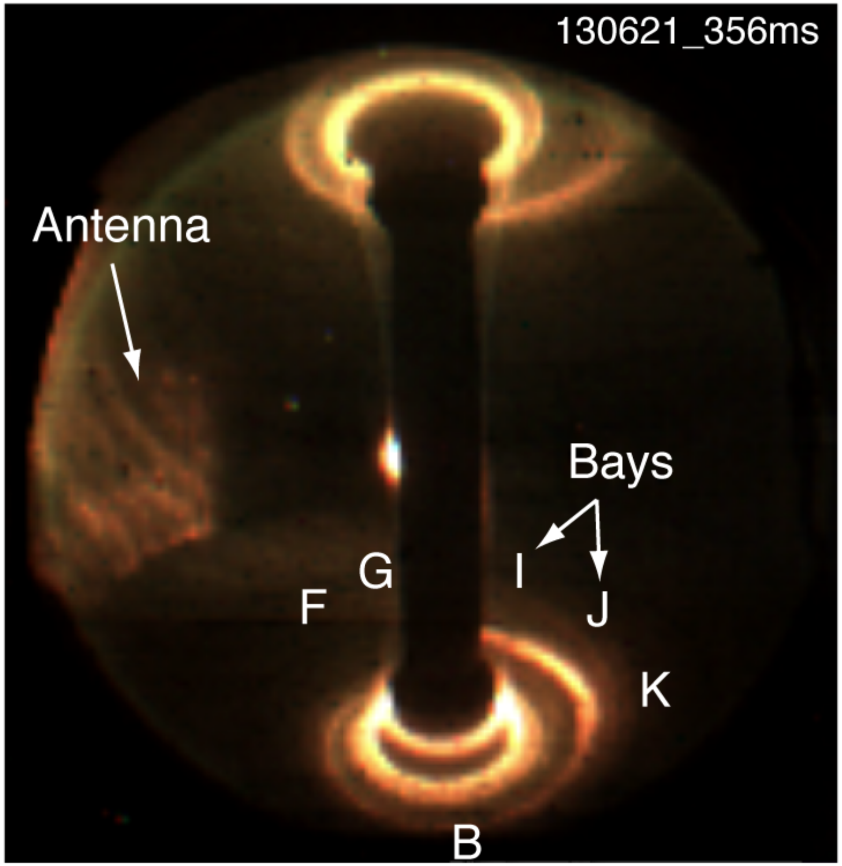
Black strike points connect to edge of antenna bottom plate.



Estimating losses in the spirals is important

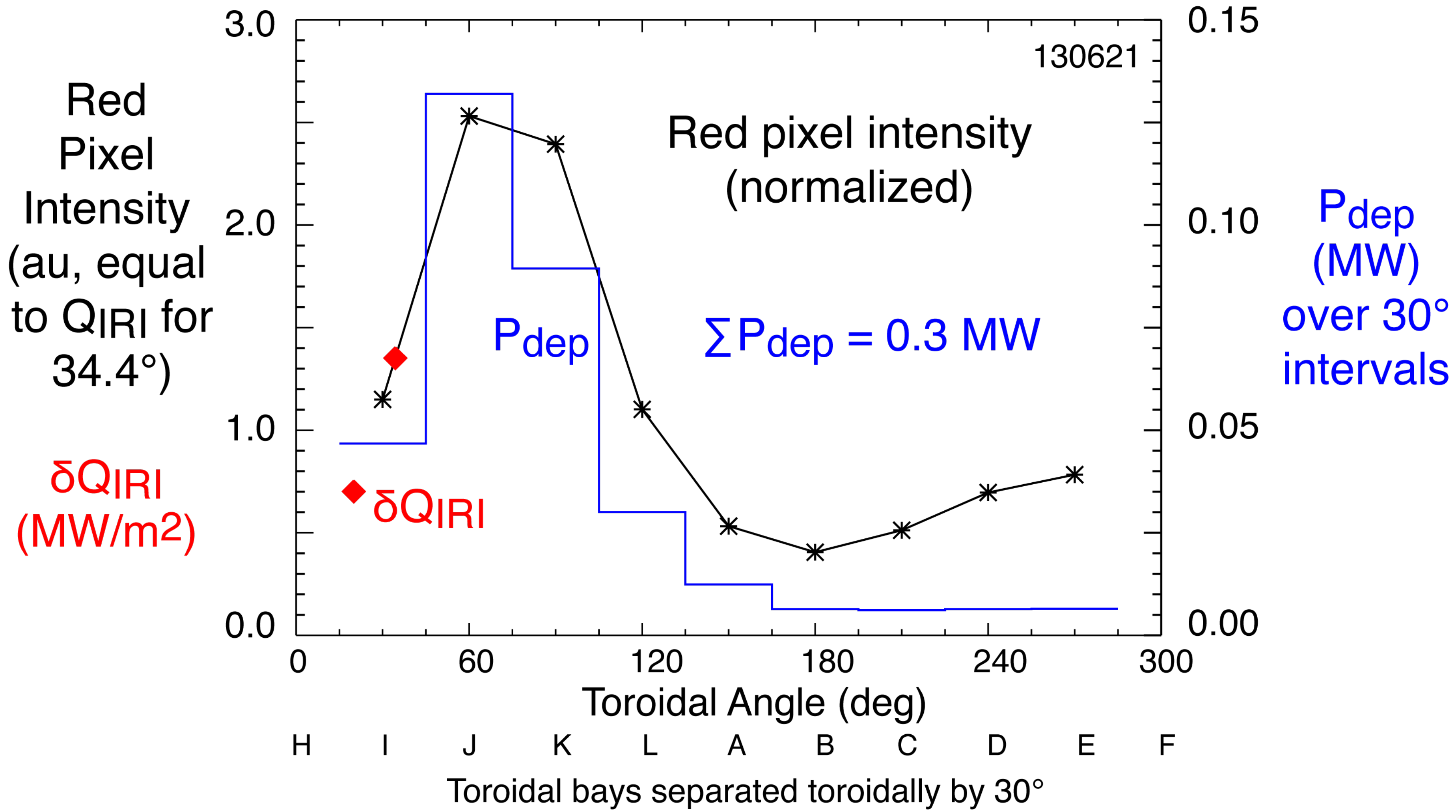
- Determines the overall magnitude of field-aligned losses to divertor
- Decides whether other loss mechanisms are significant
- Losses in spiral cannot yet be determined
  - IR camera coverage is limited
  - Power deposited has strong toroidal variation along spiral
  - NSTX-U will have improved IR coverage

Use red-pixel intensity as a rough proxy for toroidal variation of heat flux



- Red light emission available from wide-angle midplane camera
- Red light emission is subject to spectroscopic issues and is not a perfect representation of heat flux
- However, red emission decays after RF pulse on time scale consistent with heat diffusion

Rough estimate of power deposited in lower spiral



Estimated losses in spirals are significant but other losses may be playing a role

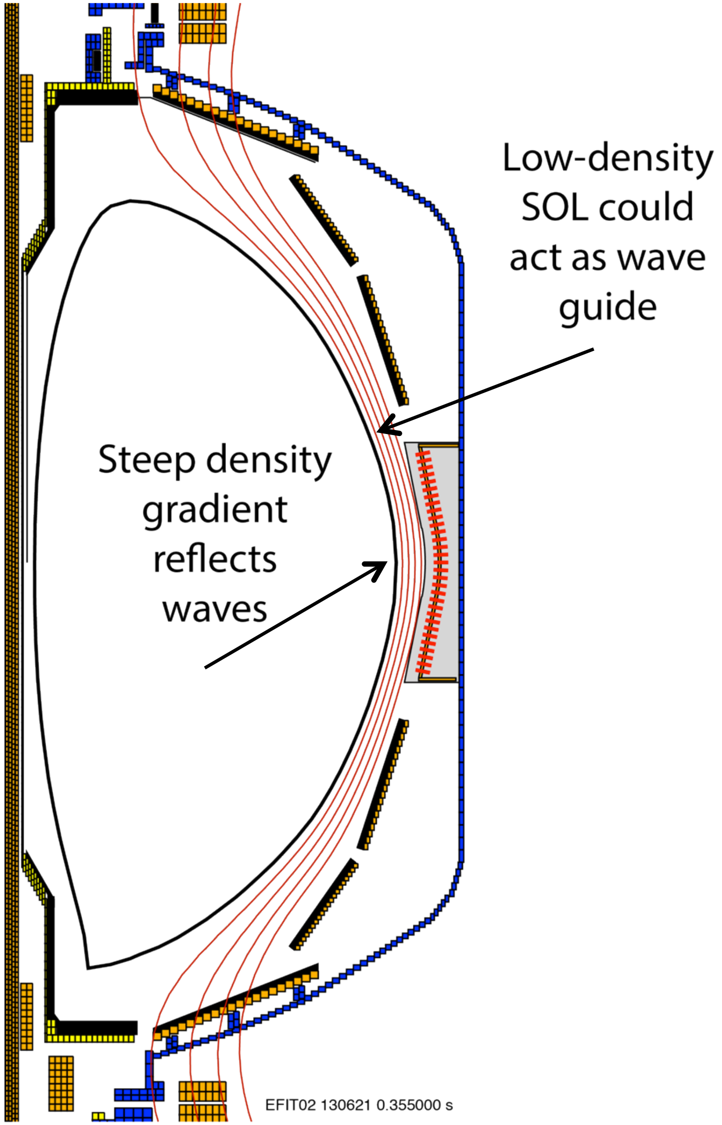
- Spiral losses estimated around 0.6 MW
  - Assuming top/bottom symmetry
- Total losses estimated around 1.1 MW
  - Amount of power missing from the core plasma
- Other losses are probably contributing
  - Parametric decay instability heats edge impurity ions
  - Sheath losses to antenna components and magnetically connected structures

The critical question: what is the mechanism behind these field-aligned losses to divertor?

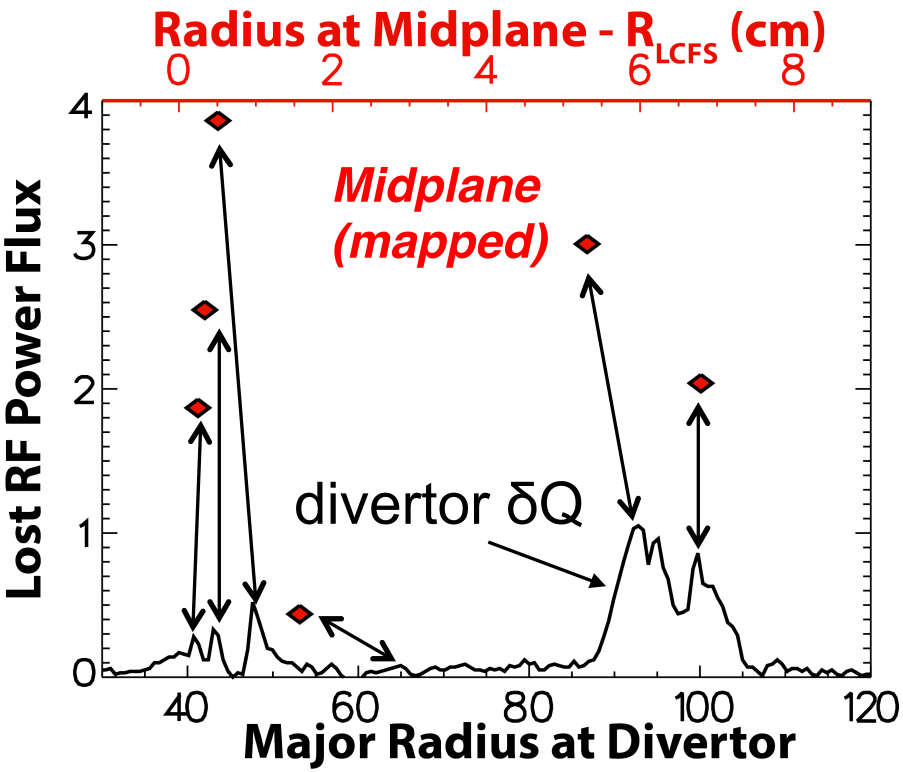
- Fast-wave propagation in SOL is leading candidate
  - Dissipation could occur via RF sheaths formed on divertor tiles
  - Dissipation could also occur via nonlinear saturation of RF currents

- Core heating efficiency related onset density of perpendicular fast-wave propagation (righthand cutoff)
  - If cutoff is too far from antenna, coupling is poor
  - Moving cutoff too close to antenna leads to poor heating efficiency on NSTX
  - Possibly due to significant wave propagation and dissipation in SOL

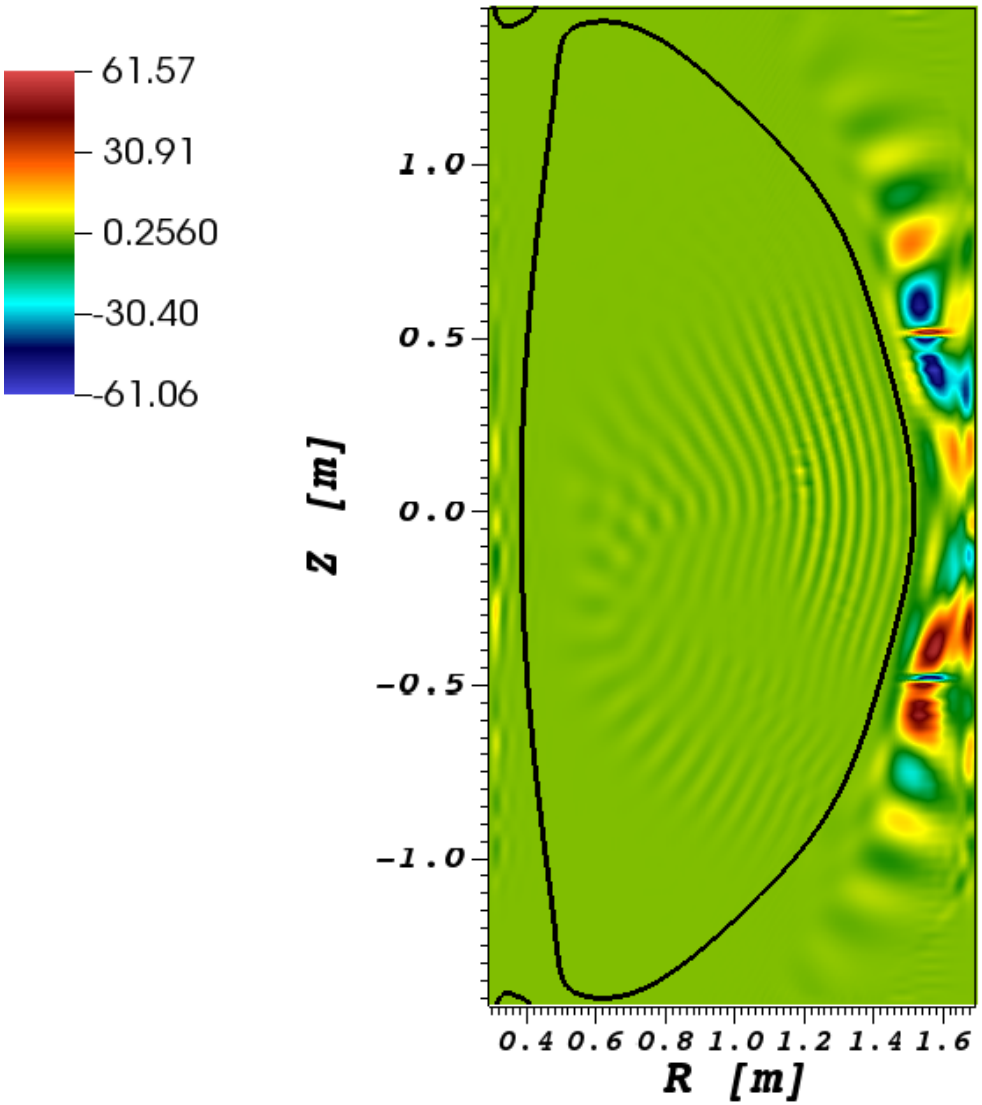
Fast-wave propagation in SOL might explain loss profile



- Wave reflection off pedestal gradient is likely
- Loss profile at midplane could be standing-wave patterns in SOL

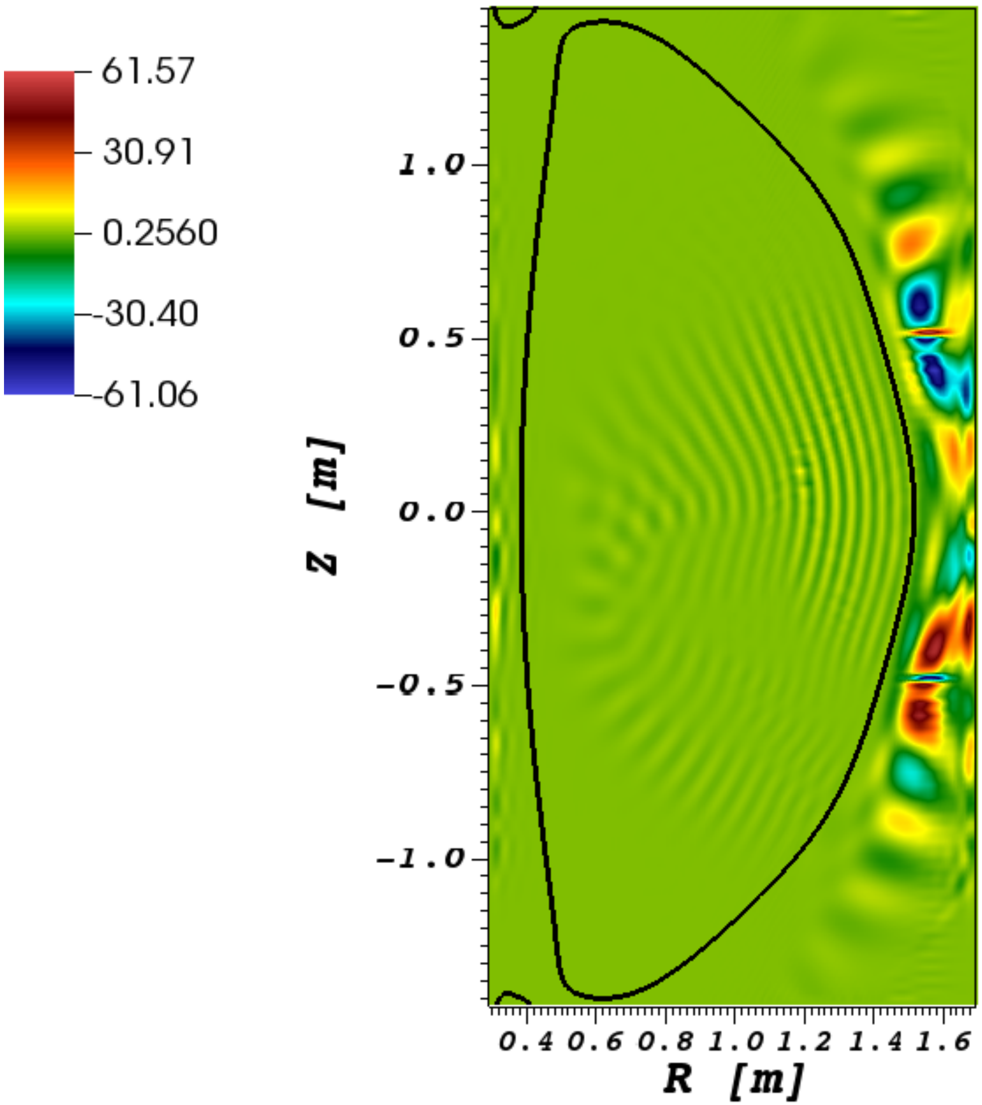


AORSA with SOL shows significant RF fields outside of LCFS



- Possible indication of FW propagation in SOL
  - N. Bertelli, this conference
  - NSTX-U equilibrium, Bt = 1 T
- Edge field amplitudes vary with k
  - P. M. Ryan, this conference
  - D.L. Green et al., Phys. Rev. Lett. 107 (2011) 145001
  - Onset density also a strong function of k

Adding relevant loss mechanisms in SOL is vital for RF codes



- Without edge damping physics:
  - Absorption weak in relatively cold SOL plasma
  - Field-amplitudes grow until Poynting flux to core balances antenna input
  - No real indication of field-aligned power flux in SOL to divertor
- Edge damping competes with Poynting flux to core!

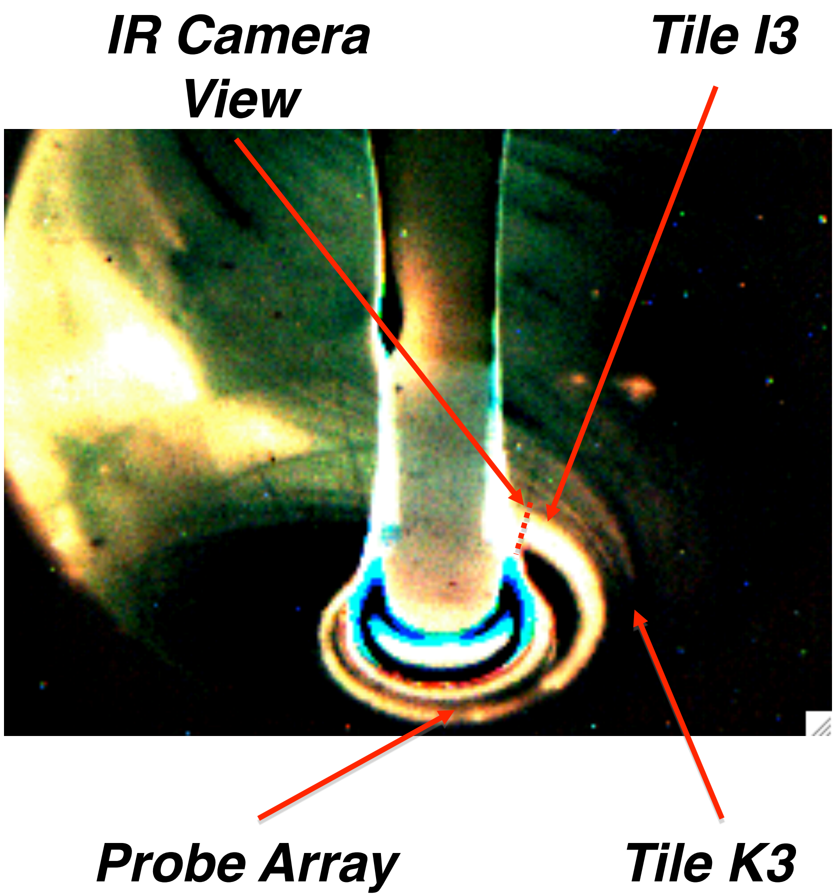
Future work

- Preparations for NSTX-U
  - RF probes needed to confirm presence of RF fields in divertor region
  - Improved IR coverage
  - Field-line mapping predicts optimal location for probes
- Results provide a benchmark for RF codes
  - Codes must reproduce field-aligned loss to divertor
  - May use various edge damping
  - Important for predicting impact on ITER
- Develop cylindrical cold-plasma model
  - Search for densities and magnetic fields combinations that give significant wave-propagation in SOL

Summary

- NSTX exhibits field-aligned losses to the divertor
  - Losses occur across width of SOL
  - Losses peak close to antenna and also the LCFS
  - Field lines connected to antenna bottom plate are involved
- Field-aligned losses are significant but may not account for total RF losses
- Fast-wave propagation in SOL may be responsible
  - Measurements on NSTX-U will confirm or deny presence of RF fields in divertor region
  - Edge damping models must be added to RF codes

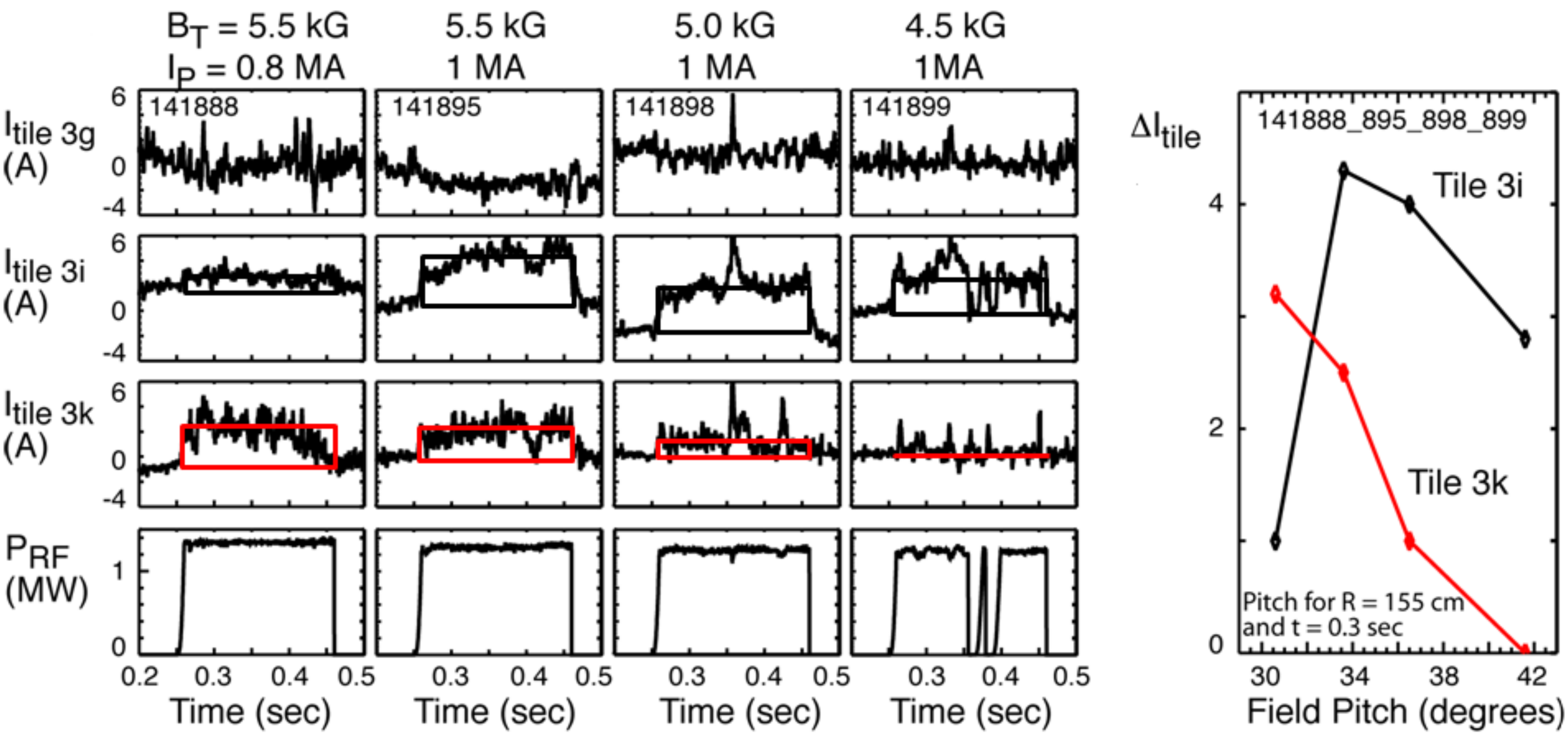
Various diagnostics detect RF-effects in divertor regions



- Spiral moves with changing pitch
- Langmuir probes respond strongly to RF when under spiral
- Current to divertor tiles increase when under spiral
- IR cameras show strong divertor heating under spiral

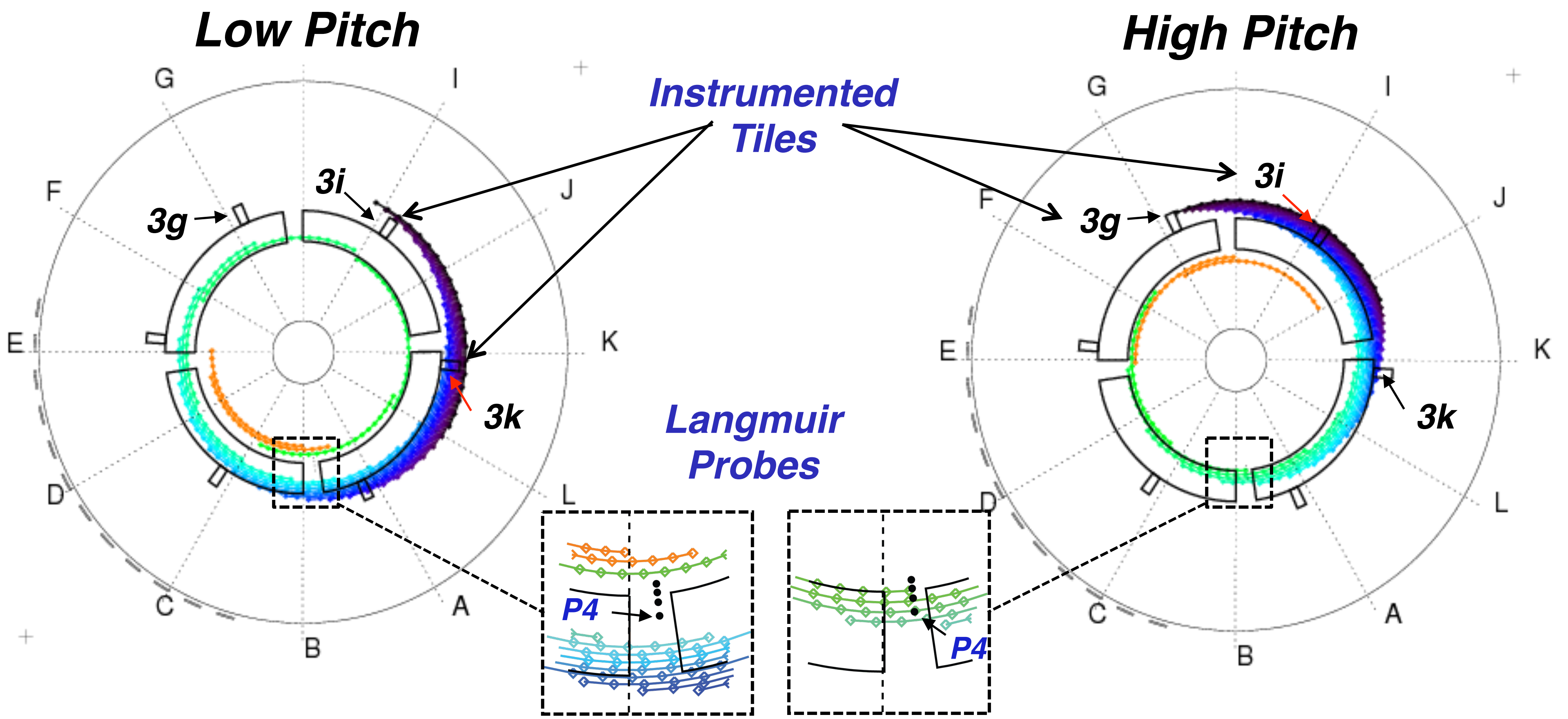
Current-sensor tiles track movement of RF spiral

(k_ϕ =-8 m^{-1}/ϕ_{Ant} =-90°, D_2, P_{NB} = 2 MW)



- Bay K tile current decreases as RF spiral moves inward…
- … while Bay I tile current rises

Modeling indicates that edge RF power propagates along field lines



- Computed strike point spirals match tile and probe measurements
- Spiral goes over tile 3i and off of tile 3k with increasing pitch