NSTX

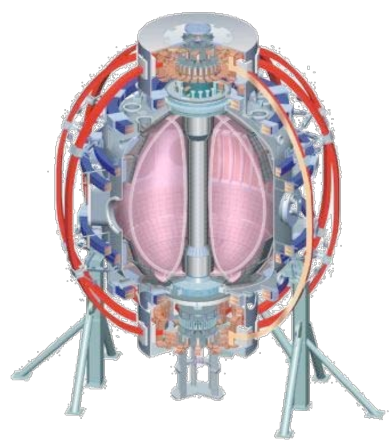
Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Edge Plasma Properties for HHFW Heating on NSTX

J. C. Hosea, PPPL

R. E. Bell, B. P. LeBlanc, C. K. Phillips, G. Taylor, E. J. Valeo, J. R. Wilson (*PPPL*), L. A. Berry, E. F. Jaeger, P. M. Ryan, J. Wilgen (*ORNL*), P. T. Bonoli, J. C. Wright (*PFSC-MIT*), R. W. Harvey (*COMPX*), H. Yuh (*Nova Photon Inc*)

and the NSTX Research Team



50th Annual Meeting of the Division of Plasma Physics
Dallas, Texas, November 17-21, 2008

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

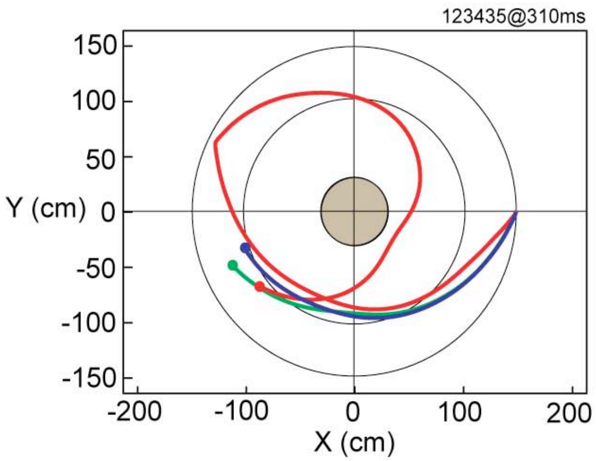
Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

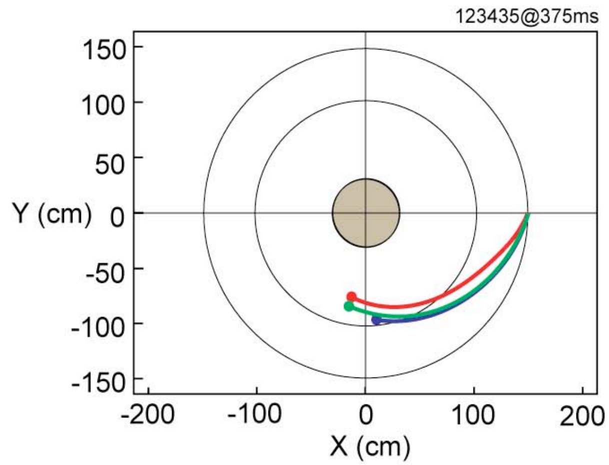
Overview

- ***Motivation:***
  - Efficient RF heating and current drive required in ST devices and ITER
  - Experiments on tokamaks and NSTX found core heating efficiency degraded for low launched parallel wave numbers, $k_{//}$
- ***Approach:***
  - Study dependence of core high harmonic fast wave (HHFW) heating efficiency on antenna phase, magnetic field, and edge density in NSTX
- ***Conclusions:***
  - Results show core heating efficiency improves when fast wave propagation begins away from the launcher and wall
  - PDI production of energetic ions may provide a significant edge RF loss path that also affects the edge rotation
  - Fast camera pictures suggest surface fast waves are depositing considerable RF energy outboard of the outside divertor at smaller $k_{||}$
  - NSTX is an ideal platform for bench-testing advanced modeling for edge loss processes
  - Careful tailoring of edge density profile may be important in ITER

Strong "single pass" absorption for studying competition between core and edge power loss

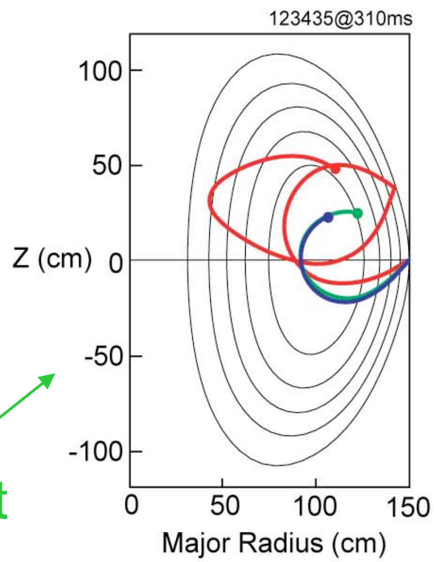
Toroidal views

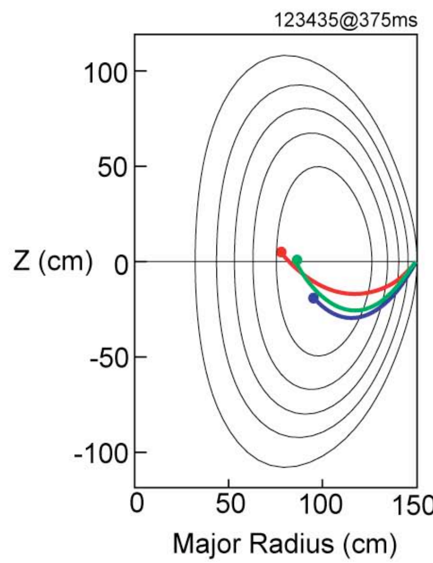




-30°
180°
-90°

Poloidal views





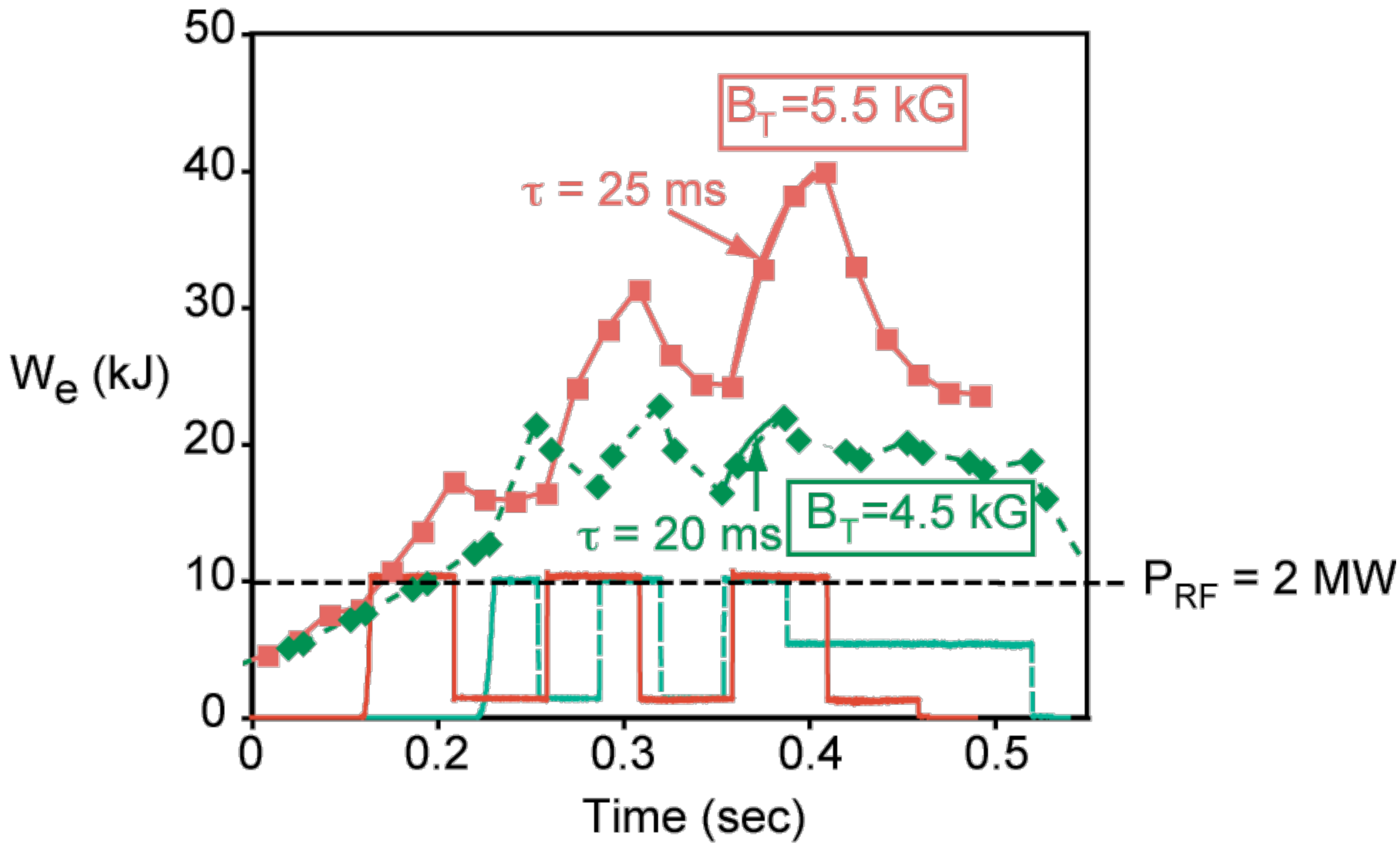
rays stopped when 80% of initial power is damped

OH target

RF heated plasma

See C. K. Phillips poster NP6-106 for more details

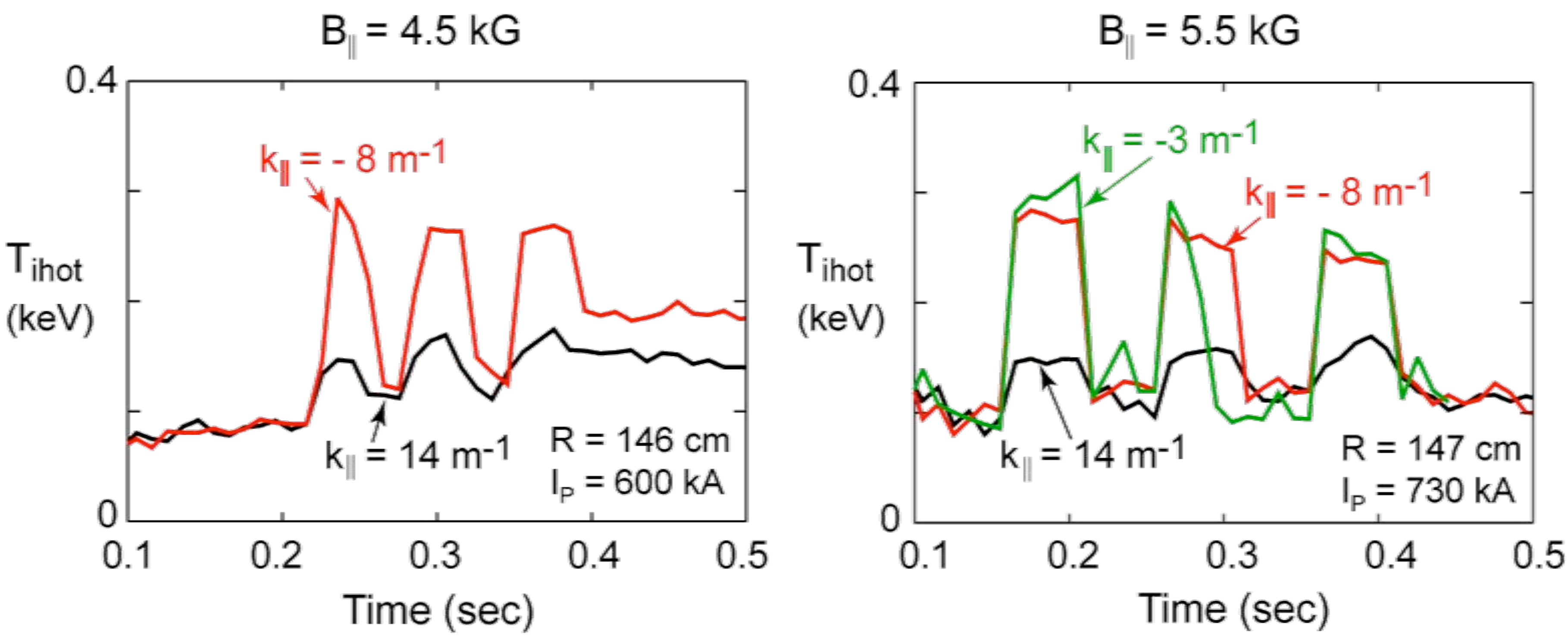
Heating efficiency for $k_{//}$ = 8 m^{-1} increased substantially as B_T increased from 0.45T to 0.55T



- ΔW_e for B_T = 0.55 T is ~ twice value for 0.45 T over same time interval
- RF power deposition to electrons increases from ~ 22% to ~ 40% at higher B_T, total efficiency increases from ~ 44% to ~ 65%

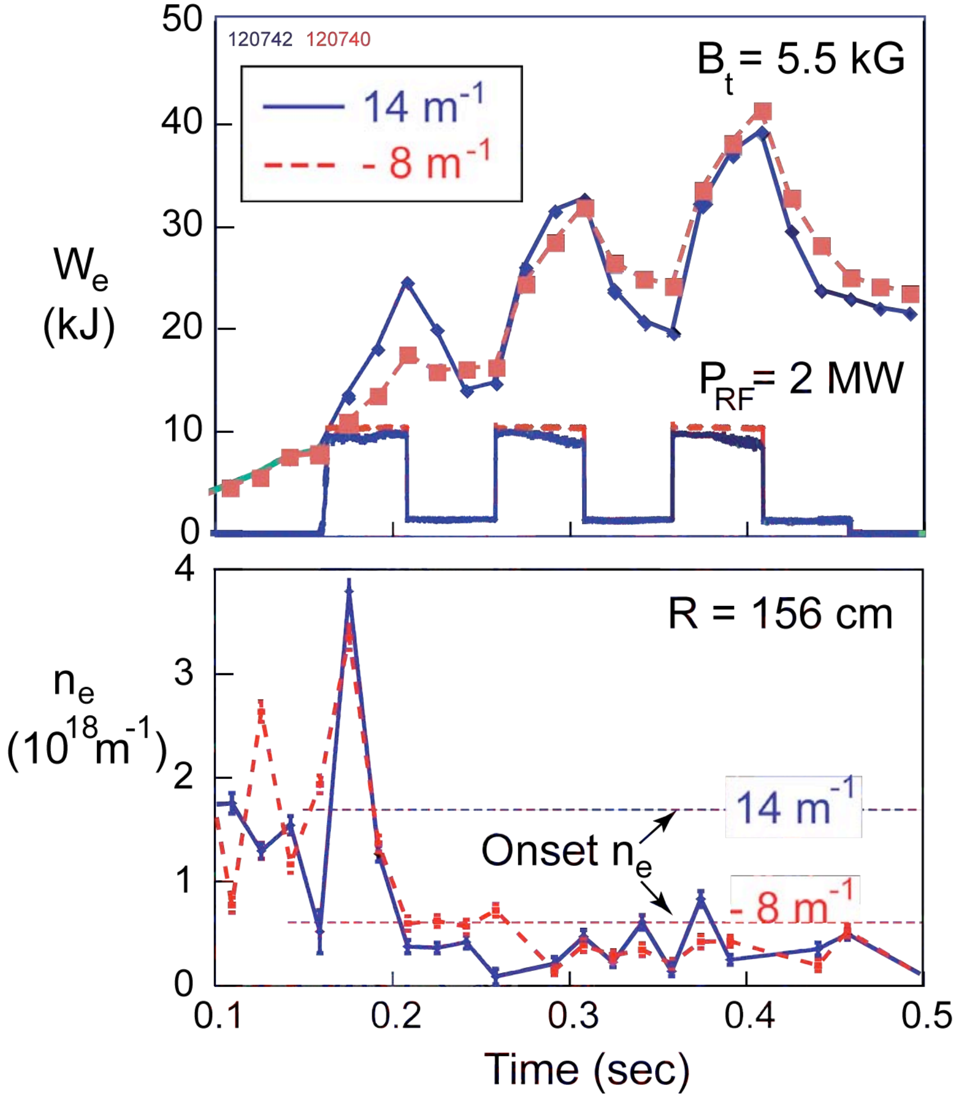
Improved heating at $k_{//}$ = 8 m^{-1} *not due* to reduced edge heating from parametric decay instability (PDI)

Edge ion heating as a measure of PDI losses



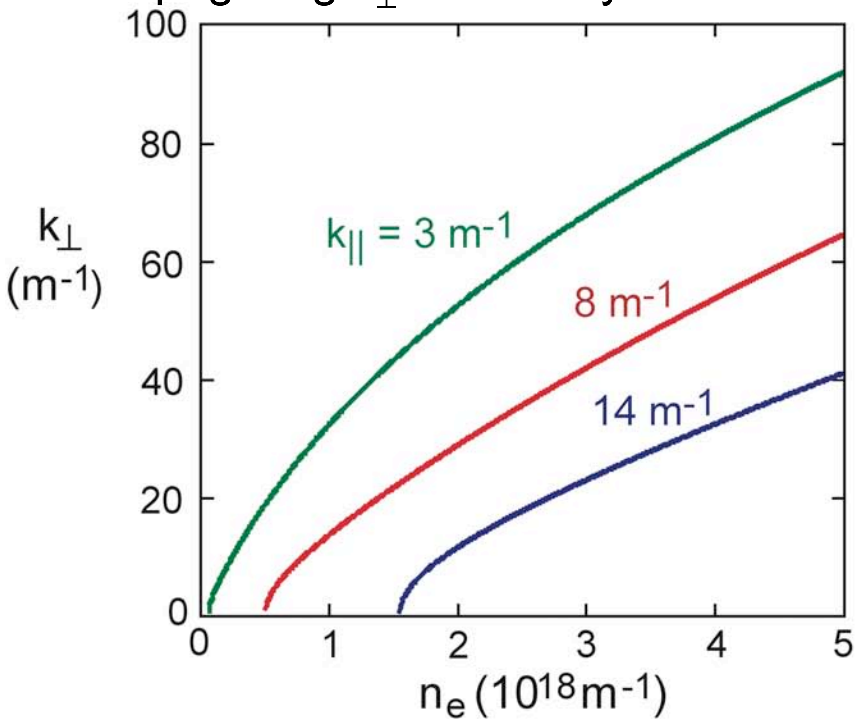
- Edge ion heating comparable at 0.45T and 0.55T with $k_{||}$ = - 8 m^{-1}
- PDI edge heating similar at $k_{||}$ = - 3 m^{-1} and - 8 m^{-1} ⇒ suggests other surface wave losses account for decrease in heating efficiency

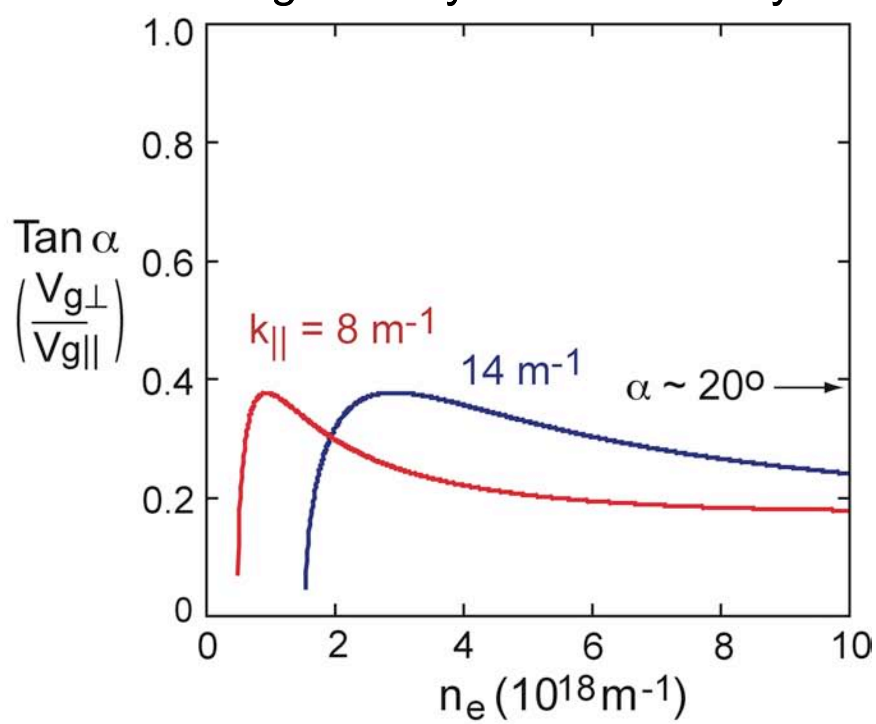
Edge power loss increases when perpendicular propagation onset density is near antenna/wall



- ΔW_e at - 8 m^{-1} about half ΔW_e at 14 m^{-1} for the first pulse
- ΔW_e at - 8 m^{-1} and 14 m^{-1} comparable for the last two RF pulses
- Density in plasma edge is high for first pulse and low for last two pulses
- Edge density affects heating when above onset density close to antenna, consistent with surface wave propagation near antenna/wall contributing to RF losses

Degradation of heating efficiency at lower $k_{//}$ likely due to HHFW propagation too close to antenna/wall



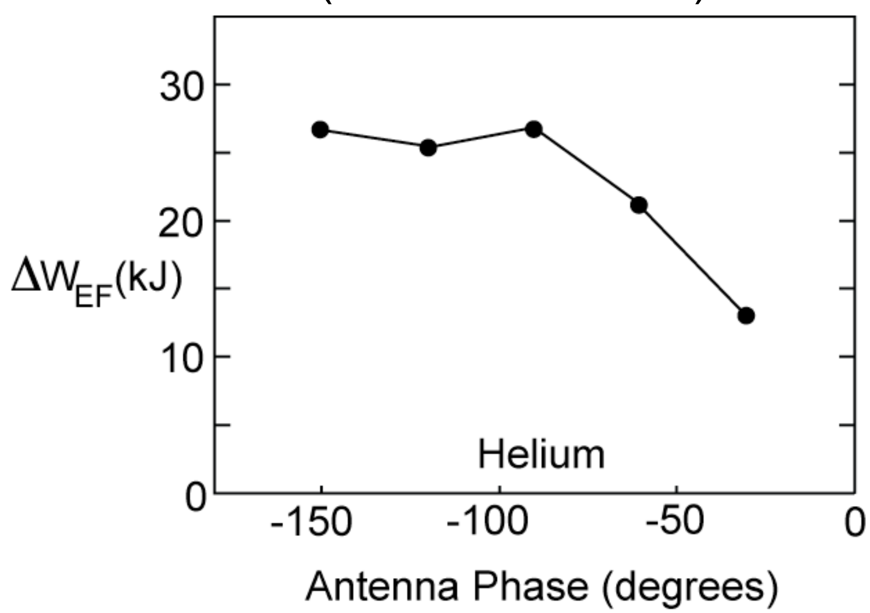


Onset density is $\propto B^* k_{||}^2/\omega$

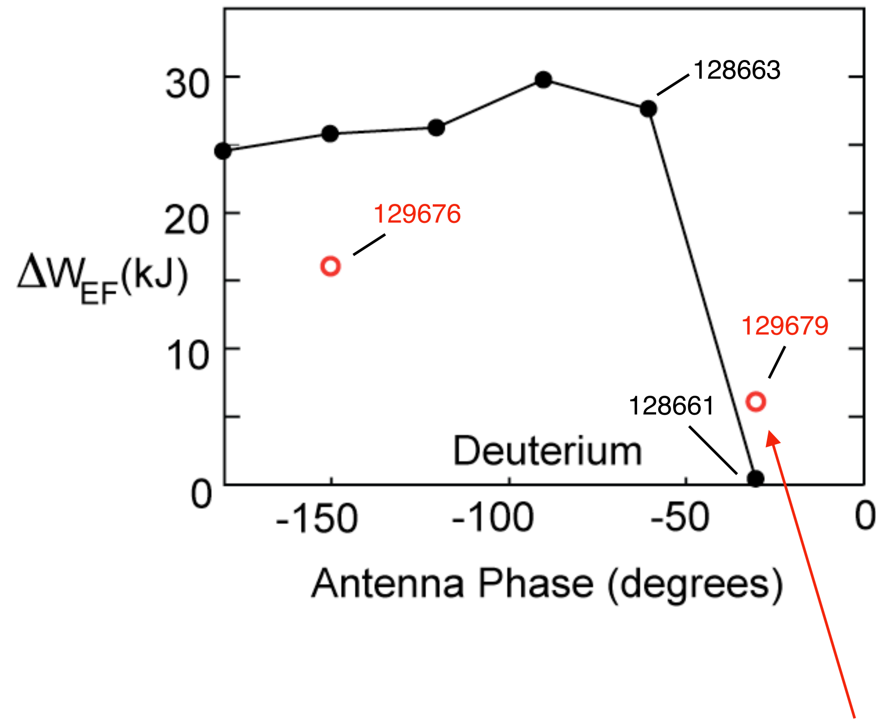
- Propagation is very close to wall at $k_{||}$ = 8 m^{-1}, on wall at $k_{||}$ = 3 m^{-1}
- Losses in surface should be higher for lower $k_{||}$
- Propagation angle relative to B much less than for lower harmonic case
- Increasing B should move onset farther from antenna, increasing heating

RF-induced increase in stored energy falls off at longer wavelength in Helium and Deuterium plasmas

P_{rf} ~ 1.8 MW in He-4 plasmas
(~ 80 ms duration)

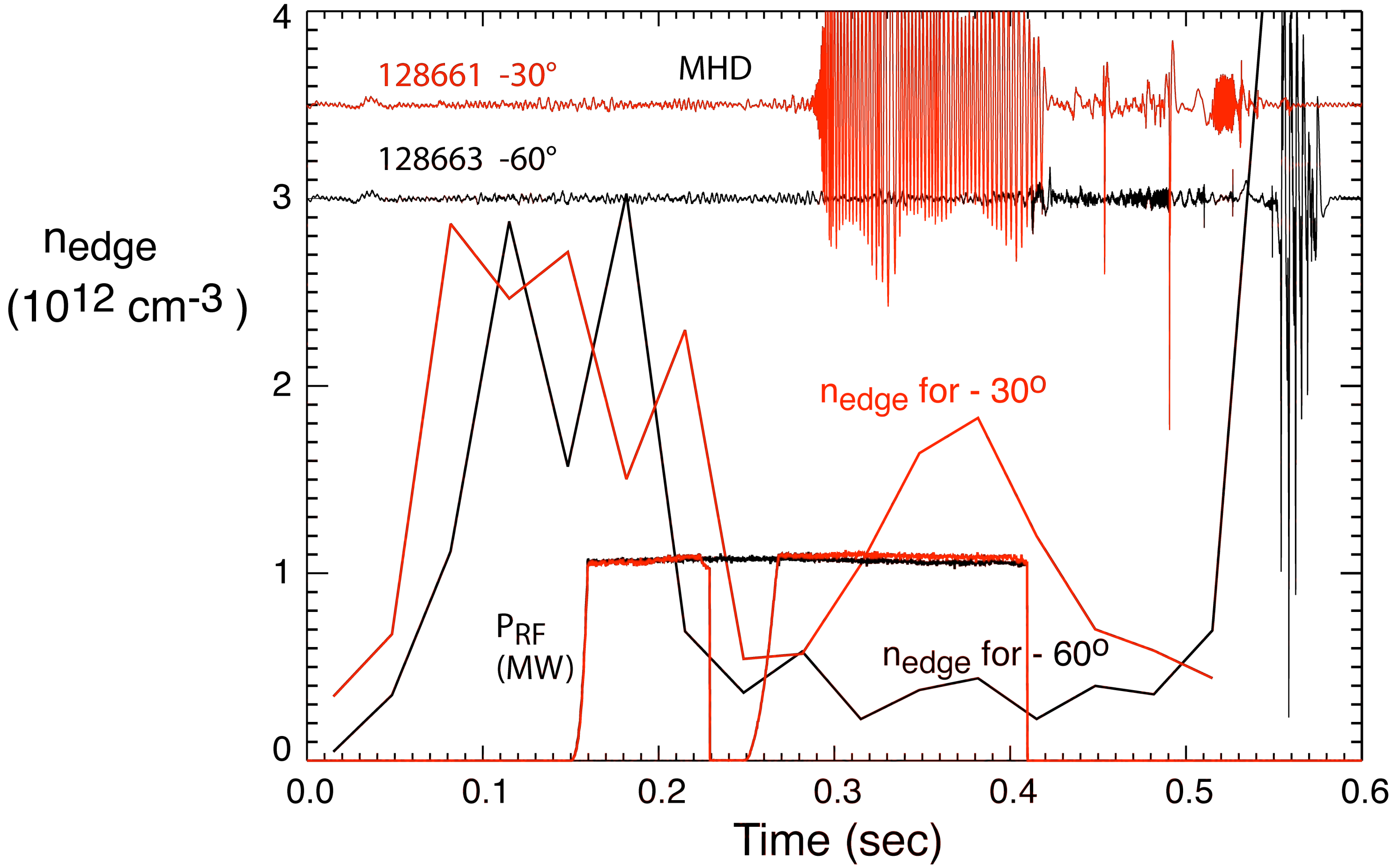


P_{rf} ~ 1.1 MW in D plasmas
(~230 ms duration)



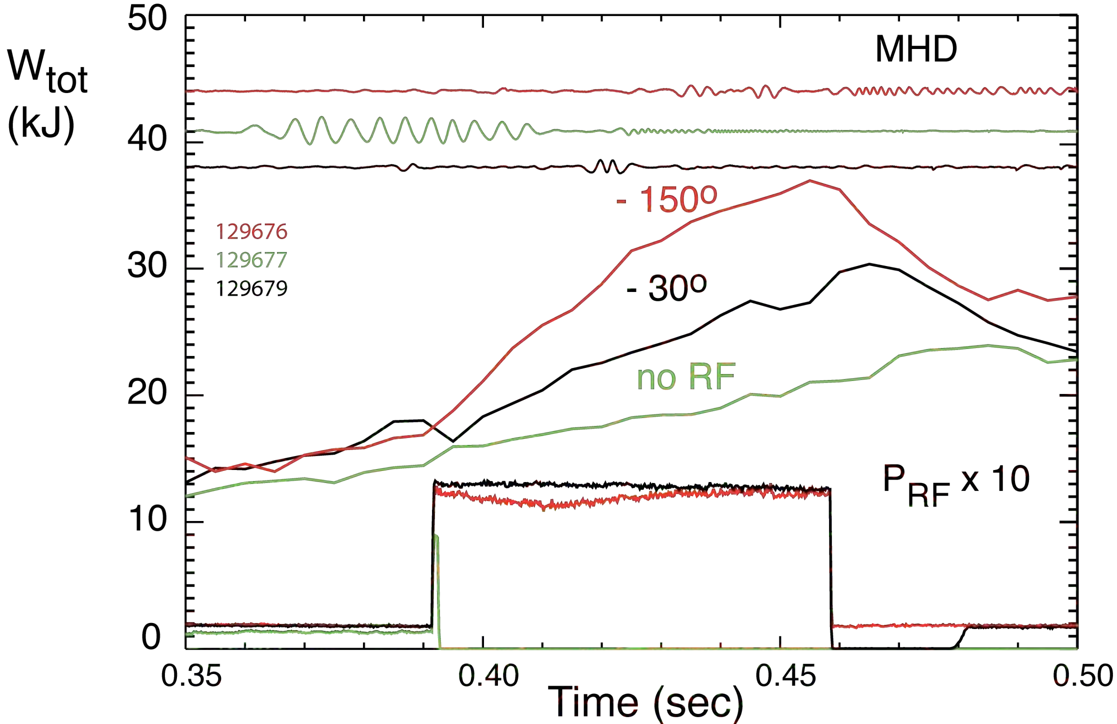
Noticeable increase in ΔW_{EF} with -30° phasing in D plasmas with Li edge conditioning, even with shorter rf duration (67 ms)

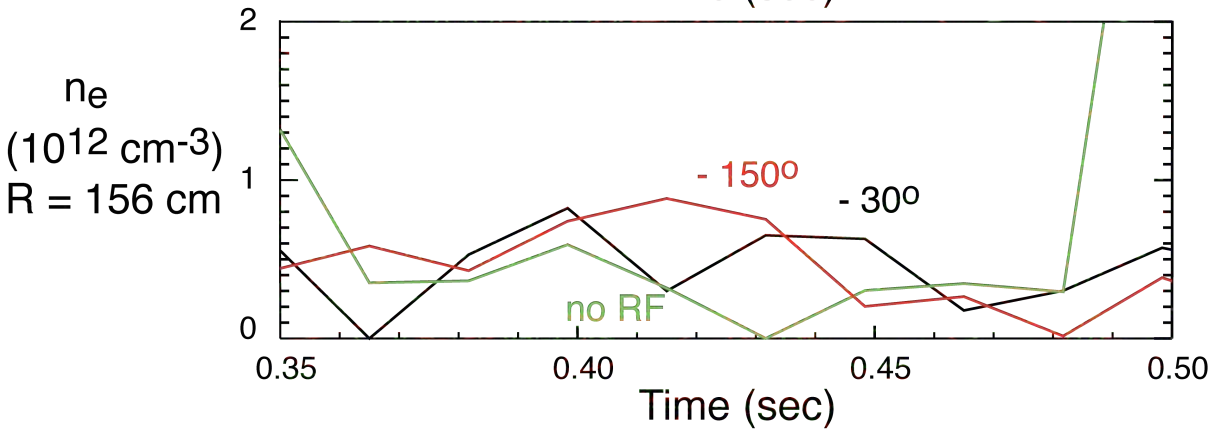
Edge density from Thomson scattering well above wave onset density for -30° D_2 case due to instability



- This result is consistent with our earlier conclusion that relatively high edge density increases edge power deposition

Lithium conditioning reduced edge density allowing first observation of heating in D_2 at 30° phasing



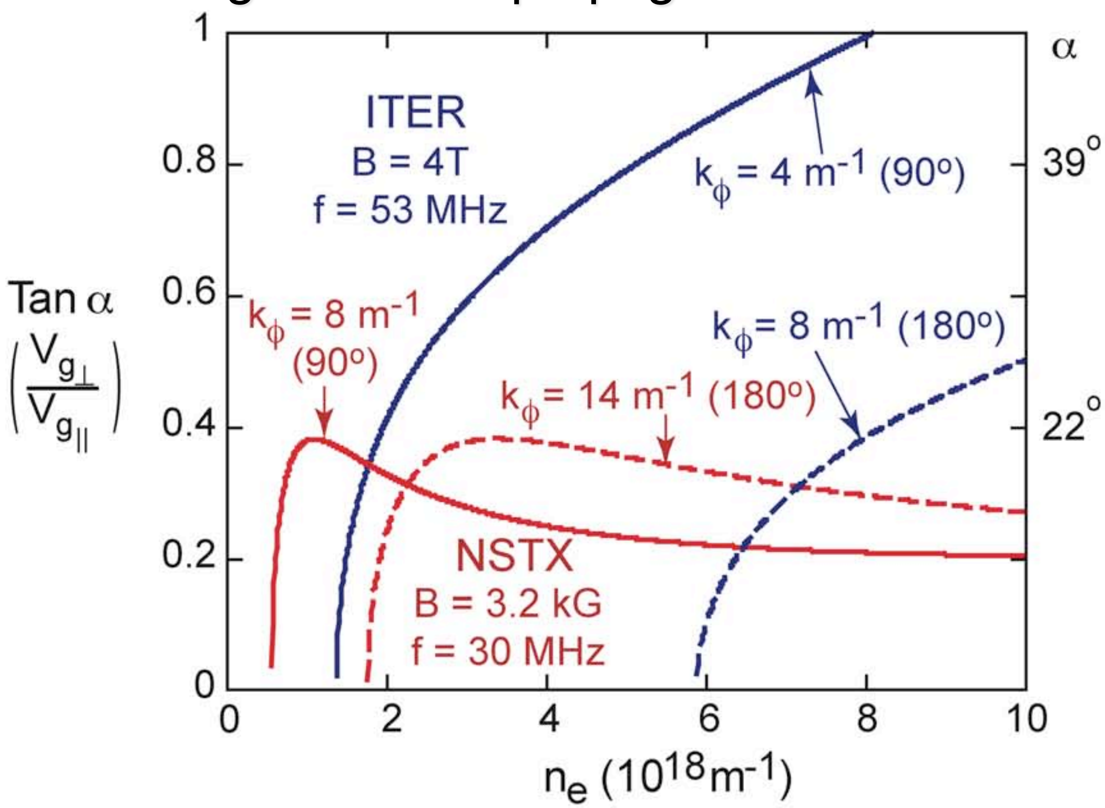


- Heating at -30° is ~ 40% of value at -150°

(shot 129679)

NSTX results indicate surface wave damping could be important for ITER ICRF heating

Angle of wave propagation relative to B



- $k_\phi \sim 4\ m^{-1}$ at 53 MHz for CD phasing in ITER
- Propagation onset density is relatively low: $\sim 1.4 \times 10^{18}\ m^{-3}$
- For scrape off density above onset density, surface wave damping should be significant

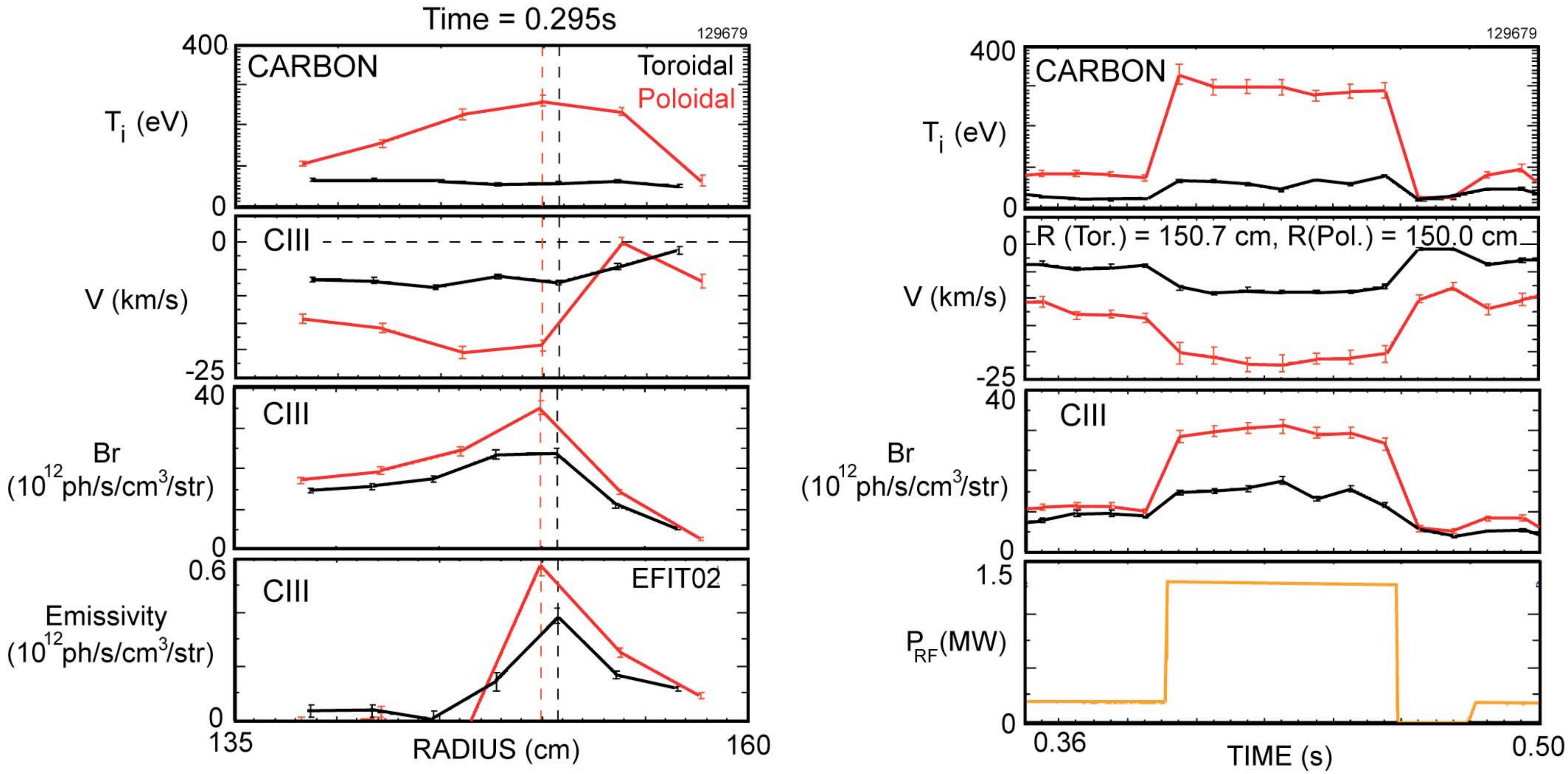
- Surface wave damping on TFTR could have caused the serious antenna heating observed with $k_\phi \Rightarrow \sim 0\ m^{-1}$ (0° between antenna straps)
- Divertor entry erosion on ASDEX and C-Mod could be caused by surface wave damping

Edge loss mechanisms need to be identified experimentally and included in advanced RF codes

- Searching for edge RF power loss processes on NSTX:
  - Collision effects
  - Sheath effects
  - PDI effects
  - Antenna reactive field losses
  - Propagating FW losses
  - Non-toroidally symmetric, localized losses
  - Etc.
- Diagnostic tools on NSTX include:
  - edge reflectometer
  - edge CHERS
  - probes for PDI effects
  - cameras for visible and IR light
  - etc.

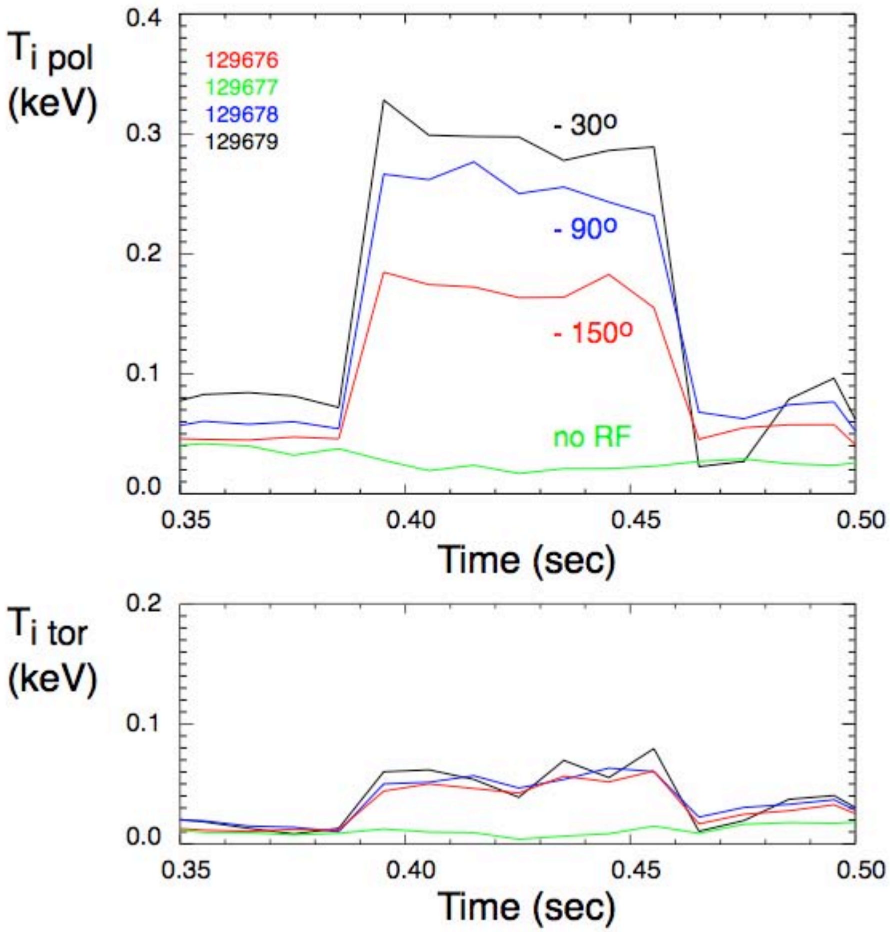
Revisiting possible parametric decay effects in plasma edge

Poloidal heating in edge may eject energetic edge ions



- Edge ions are heated to hundreds of eV: CIII, CVI, LiII, and Helium
- Emission location for CIII and CVI is ~ 150 cm, just inside separatrix
- Edge ion heating may result in loss of energetic ions to SOL and the divertor

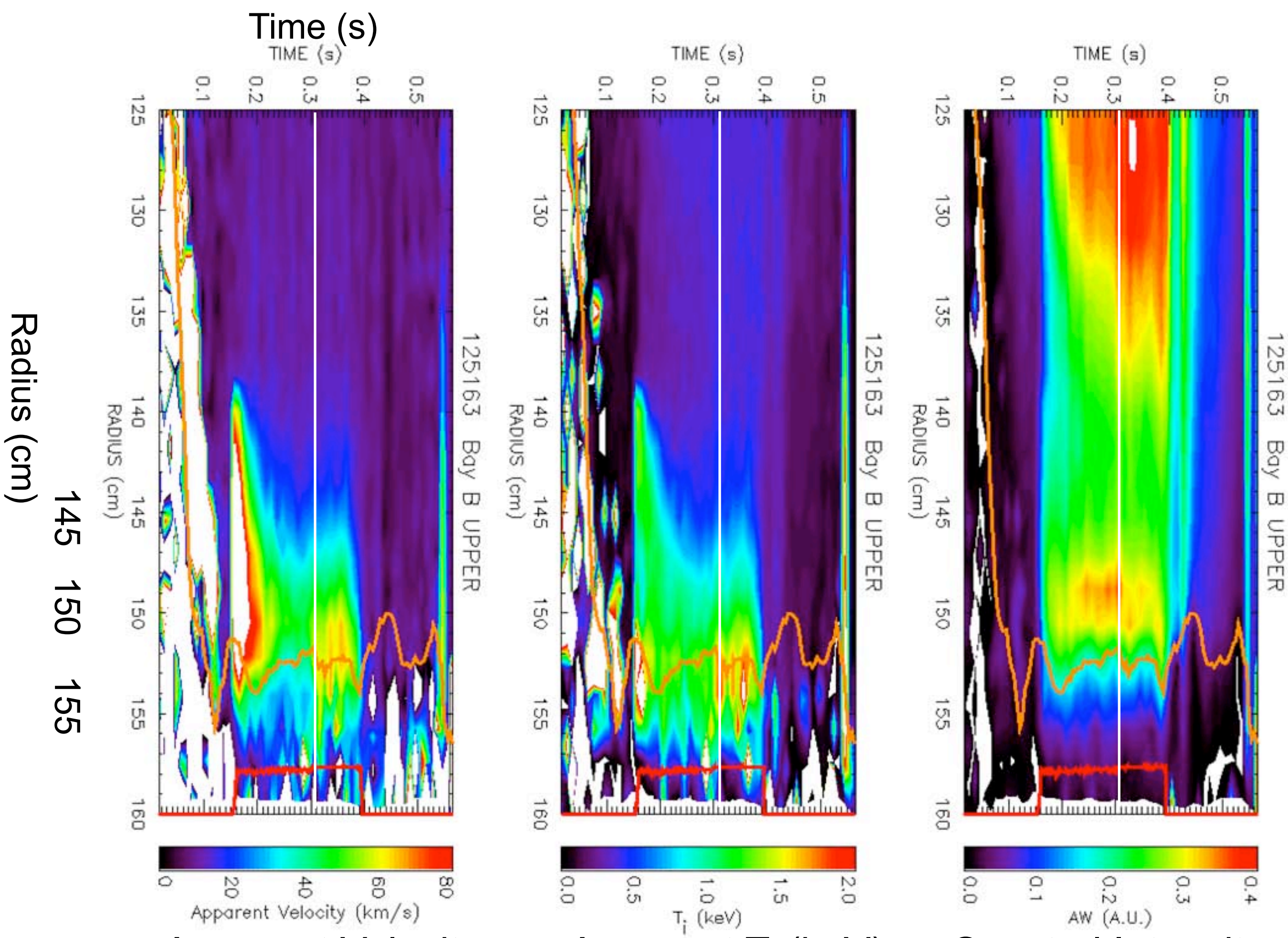
Edge ion energy depends on antenna phase



- Energetic ion losses should be greater at lower antenna phase
- Does location of energetic ions change with phase?

PCHERS shows apparent CVI edge heating and poloidal velocity depend on antenna phase

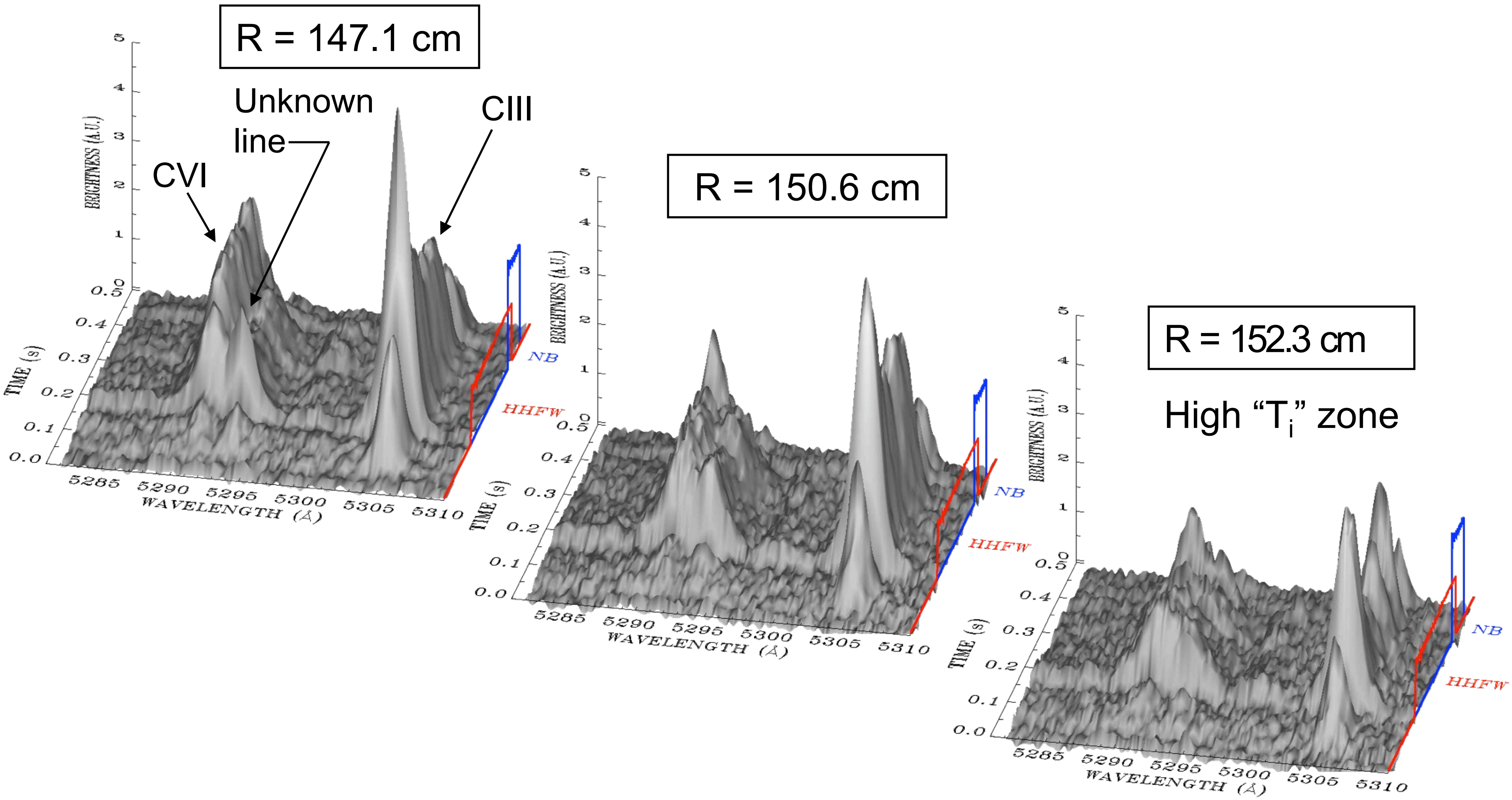
-90° | -30°　　-90° | -30°　　-90° | -30°



Apparent Velocity　　Apparent T_i (keV)　　Spectral Intensity

See R. E. Bell poster NP6-119 for details of PCHERS

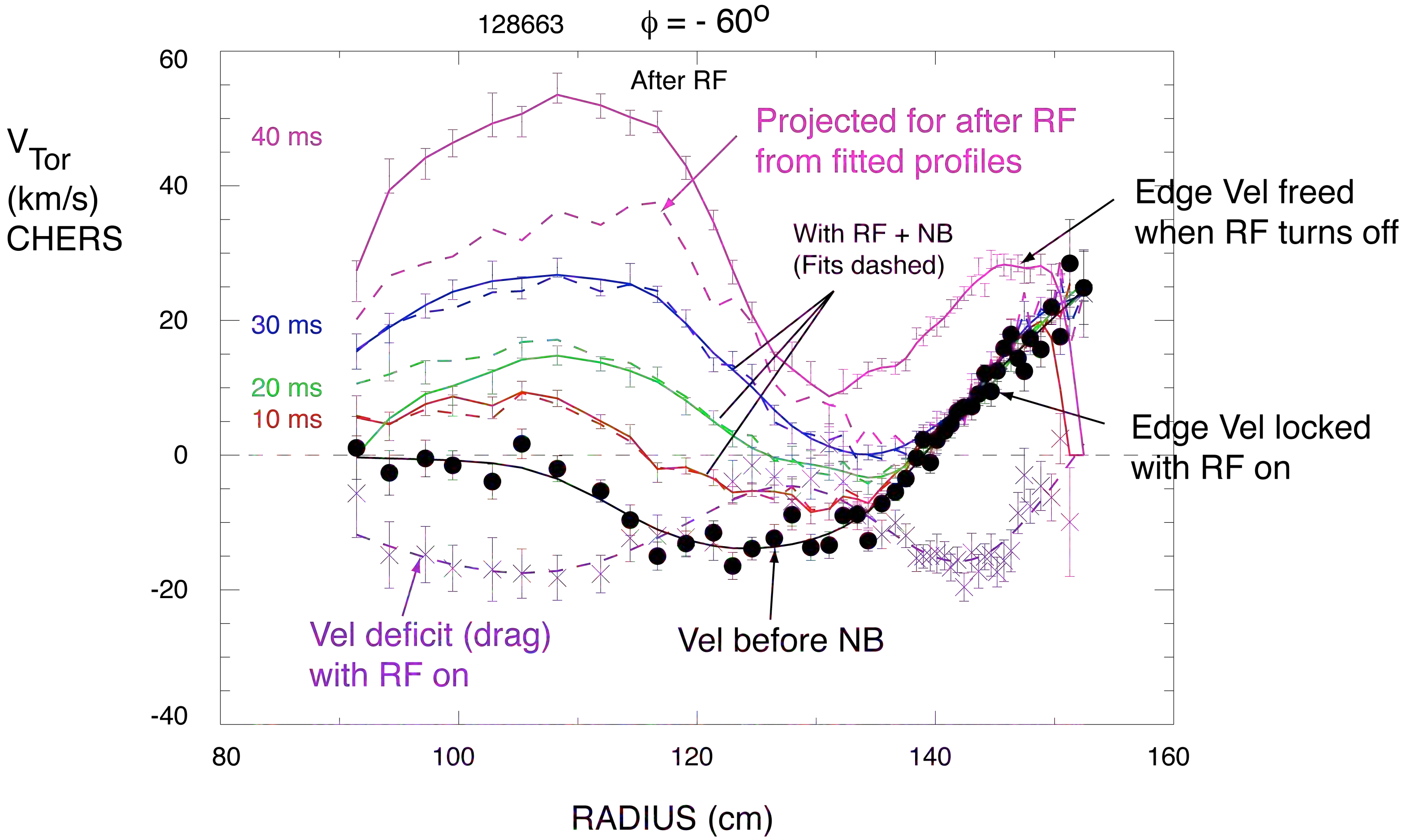
PCHERS spectra show unknown line is close to CVI line in plasma edge



- Higher “temperature” at -30° is caused by multiple line spectra
- Identification of unknown line is being pursued

Edge toroidal velocity appears to be locked when the RF is on with the NB pulse

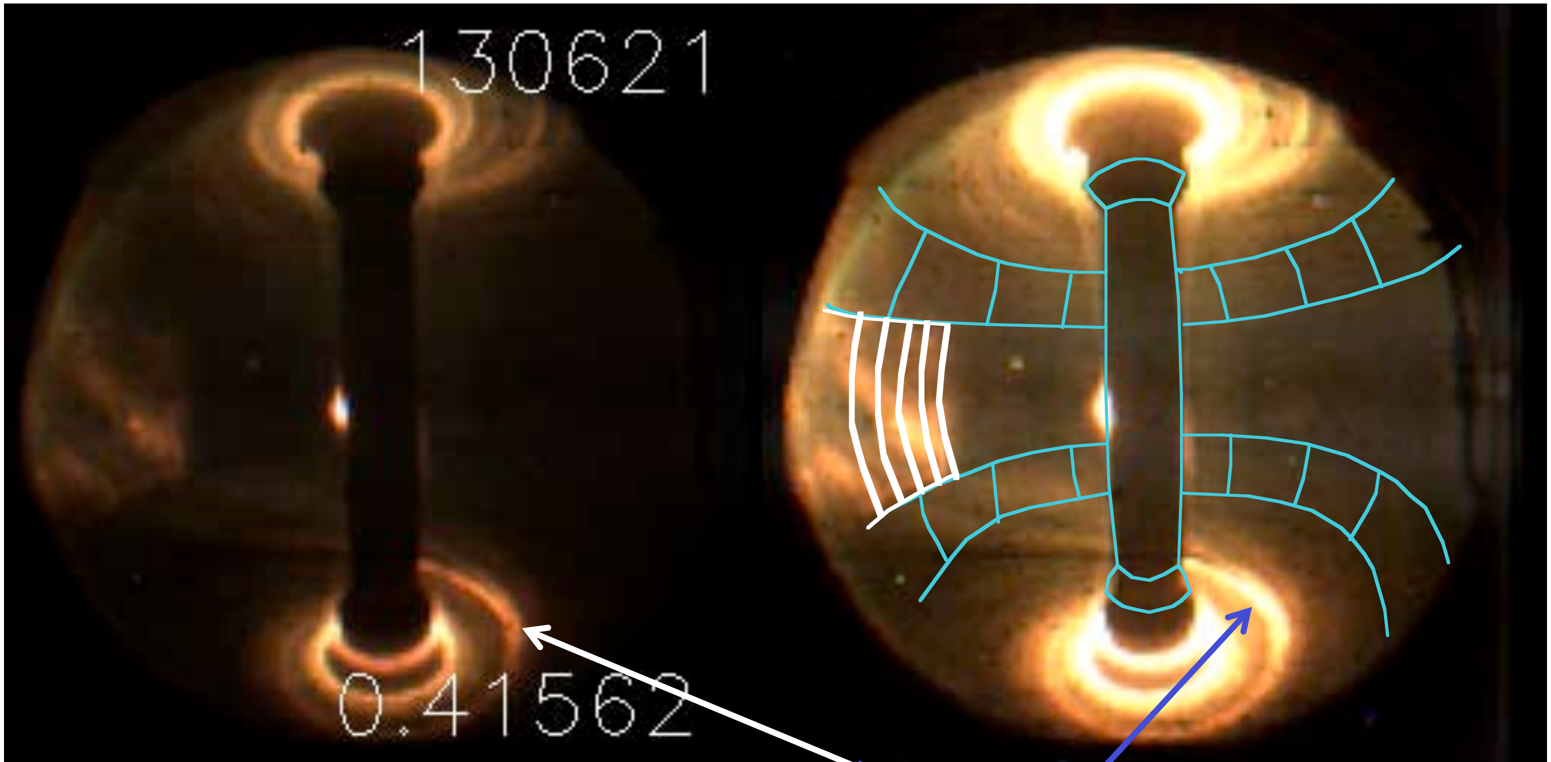
40 ms beam pulse – RF turned of at 30 ms during beam pulse



- The mechanism causing this effect is not understood but it may point to edge ion loss
- The RF apparently provides a drag on rotation inside the plasma as well

Fast waves propagating in the SOL appear to be heating the tiles outside the outer divertor

Fast camera view for phase = - 90° just prior to arc before ELM



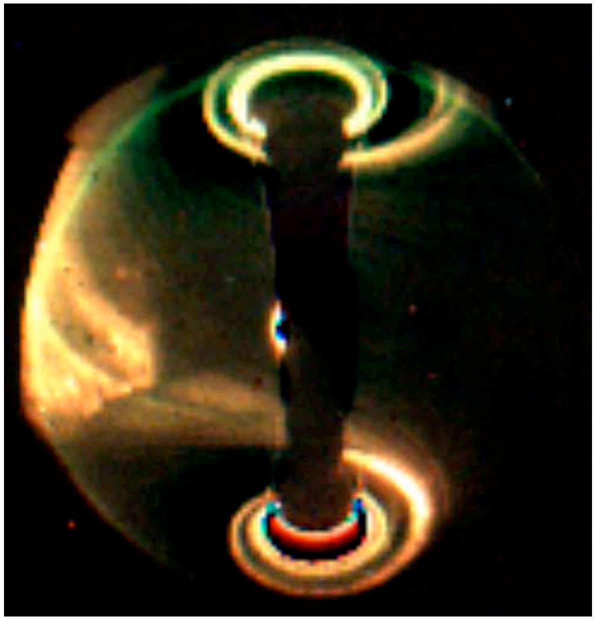
P_{RF} ~ 1.8 MW
P_{NB} = 2 MW
I_P = 1 MA
B_T = 5.5 kG

- RF interaction is localized toroidally
- Appears to be linked with antenna along field lines
- Intensity is dependent on antenna phase dies away after RF is removed
    - decay time depends on phase

Strong interaction along field lines at lower phase/longer wavelength

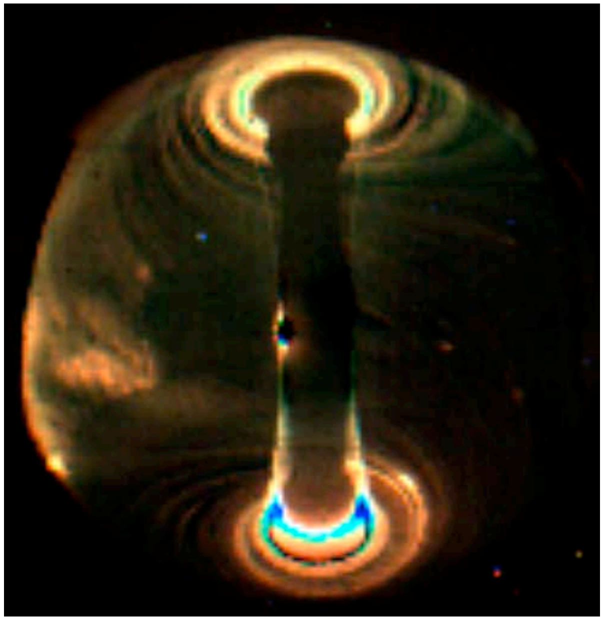
P_{RF} = 1.8 MW, P_{NB} = 2 MW, I_P = 1 MA, B_T = 5.5 kG

130621 -90°



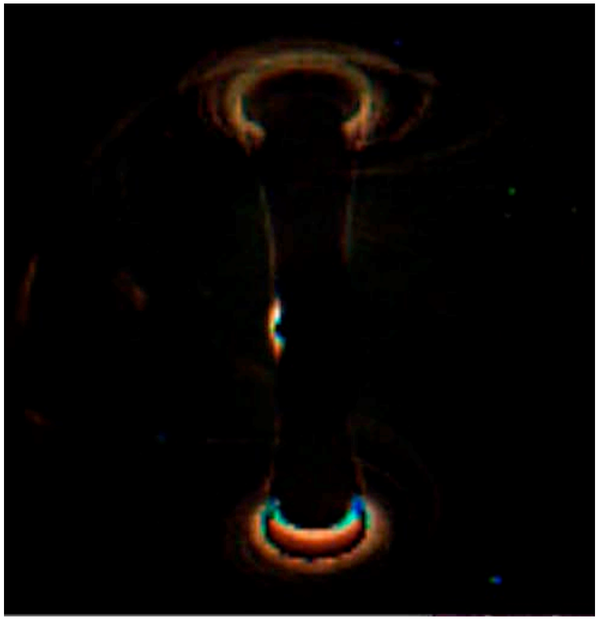
0.33512 sec (-.25012)

130608 -150°



0.33500 sec (-.25002)

130609 No RF

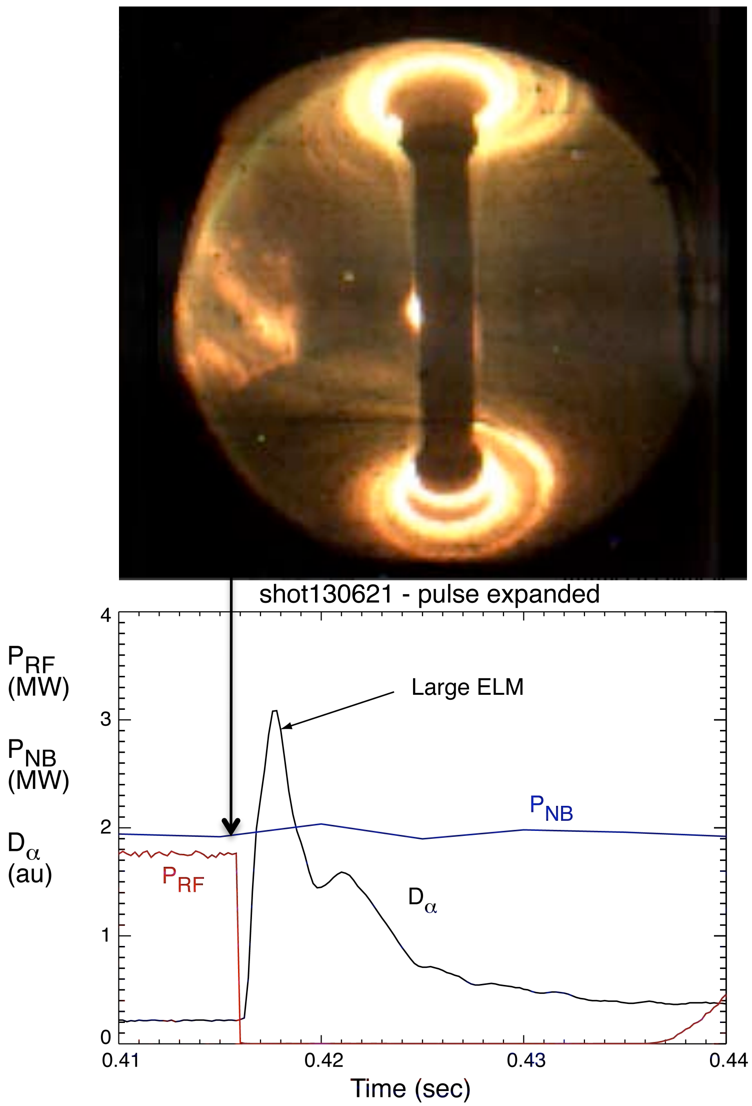


0.34997 sec (-.24999)

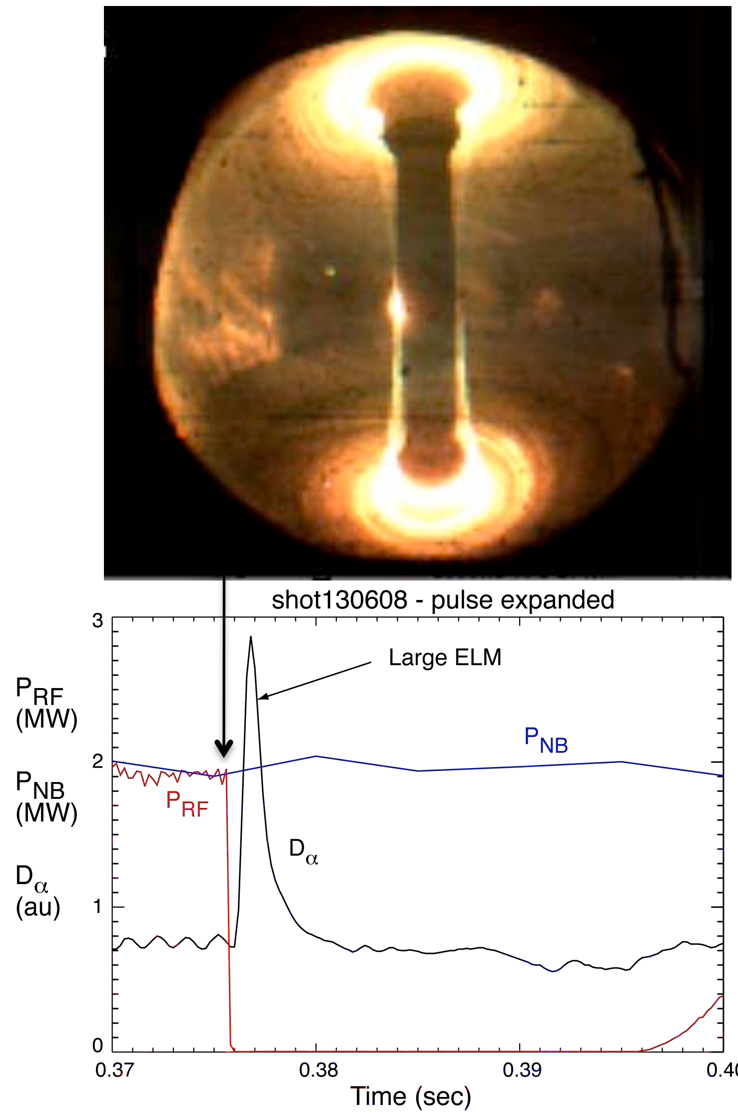
- "Hot region is much more pronounced at -90° than at -150°
  - Edge power loss is probably greater at -90°
  - Also, suggests fields move away from wall at -150° along with the onset density

Time delay of "hot" spots after arc just prior to ELM shows tiles heated more at lower antenna phase

Phase = - 90° just prior to arc before ELM

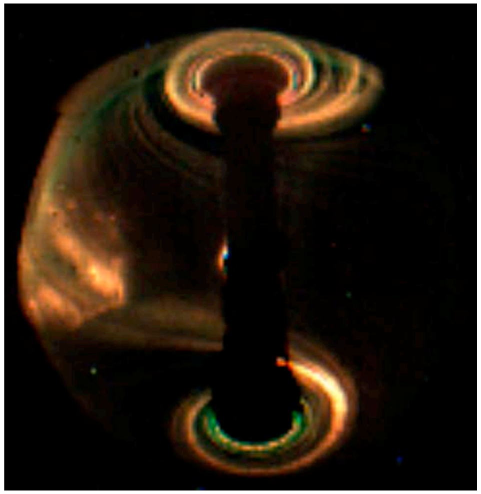


Phase = - 150° just prior to arc before ELM

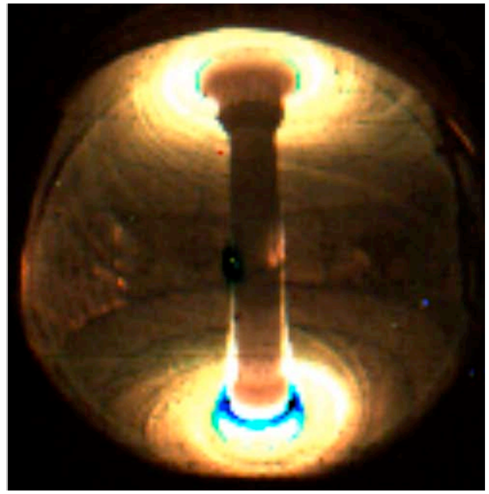


Time delay of "hot" ring for phase = -90° is ~ 20 ms

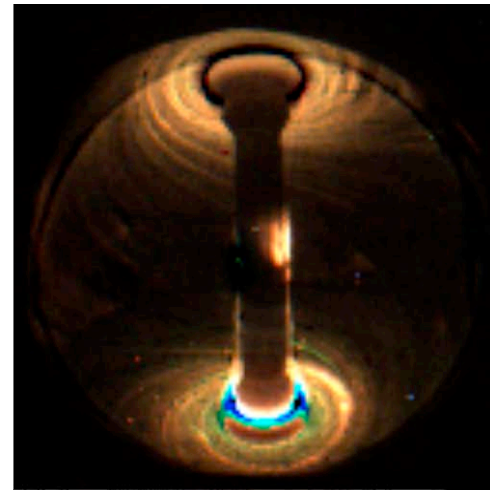
Shot 130621 P_{RF} = 1.8 MW, P_{NB} = 2 MW, I_P = 1 MA, B_T = 5.5kG



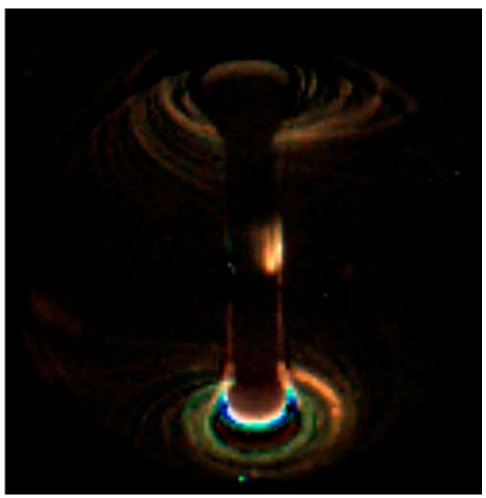
0.41562 sec



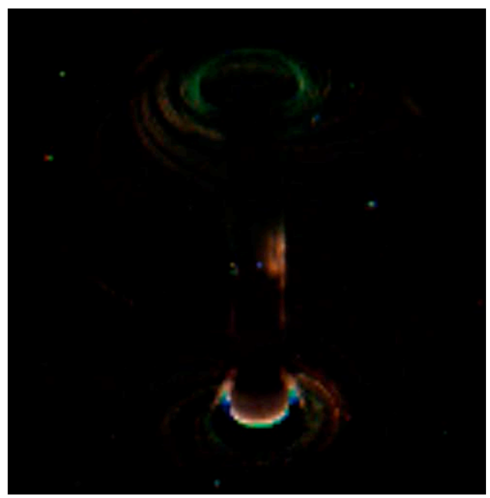
0.42062 sec



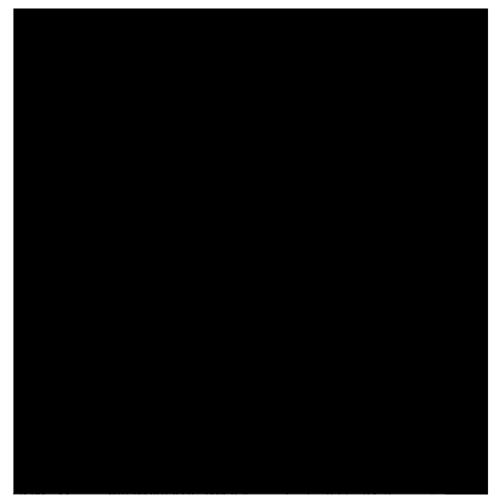
0.42562 sec



0.43062 sec



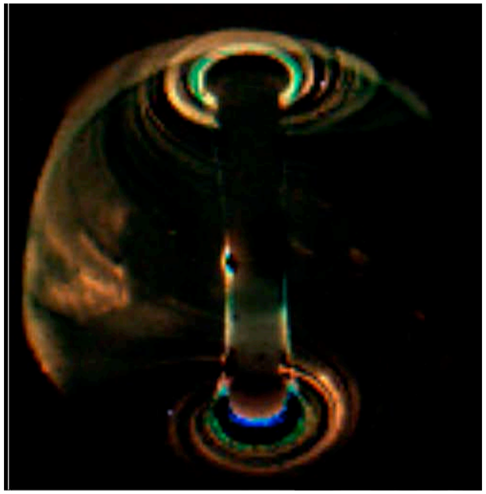
0.43562 sec



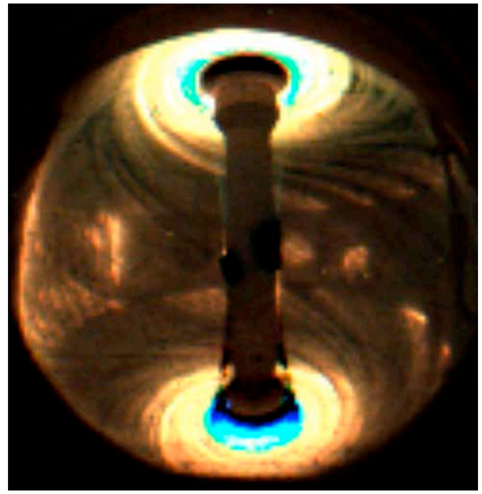
0.43762 sec

Time delay of "hot" ring for phase = -150° is ~ 8 ms

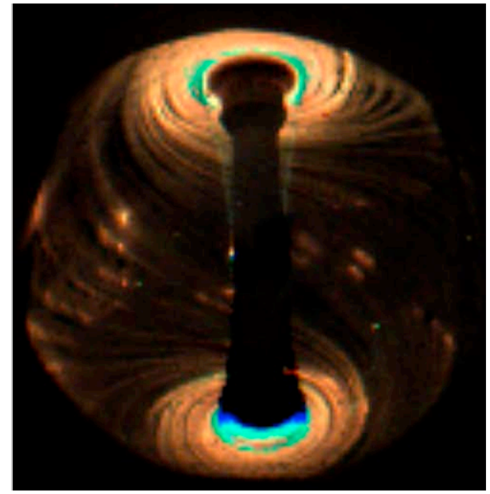
Shot 130608 P_{RF} = 1.8 MW, P_{NB} = 2 MW, I_P = 1 MA, B_T = 5.5kG



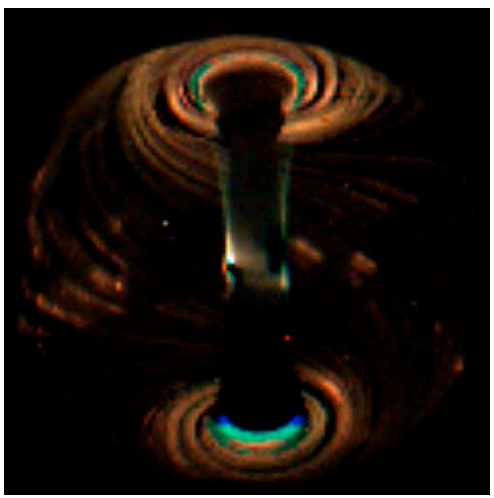
0.37532 sec



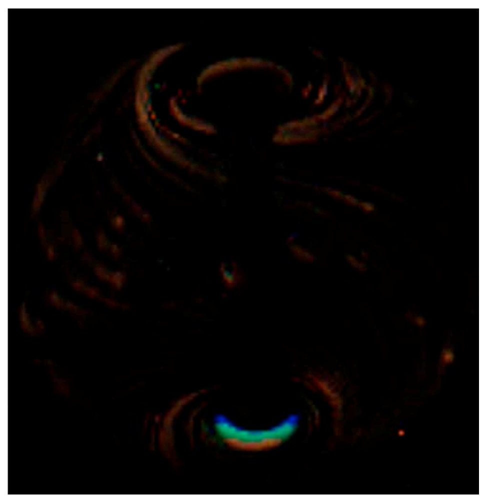
0.37732 sec



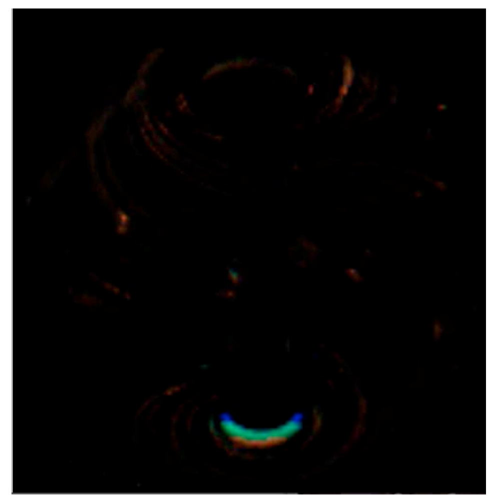
0.37932 sec



0.38132 sec



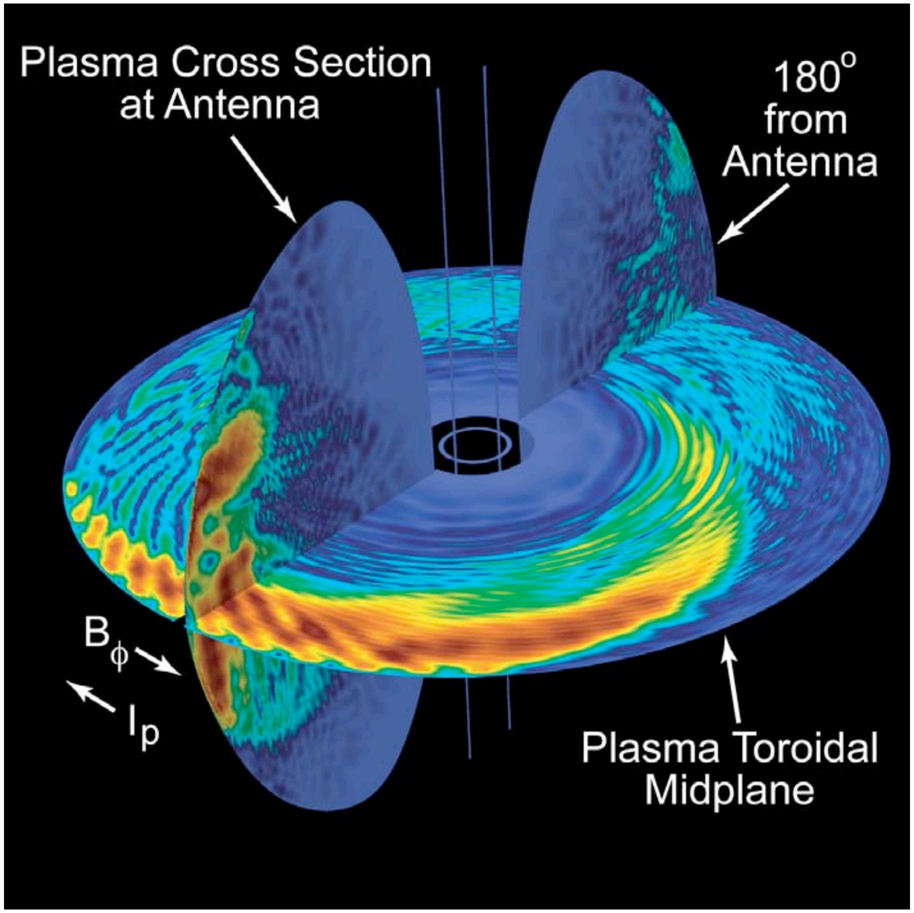
0.38332 sec



0.38366 sec (- 0.38466 sec)

3D codes using full toroidal spectrum are being extended to include surface damping and CD effects

AORSA $|E_{RF}|$ field amplitude for -90^o antenna phase case with 101 n_ϕ



- Waves propagate around plasma axis in + B_ϕ direction
  - similar to GENRAY rays
- Wave fields very low near inner wall
- RF SciDAC project will include edge loss mechanisms in codes
- NSTX is good platform for benchmarking advanced RF codes

See C. K. Phillips poster NP6-106

Conclusions

- Degradation of heating efficiency occurs when the onset density for FW propagation is exceeded too close to the antenna / wall
  - Dramatic increase in core heating efficiency observed at higher B_ϕ & lower edge n_e for -90^o CD phasing (k_ϕ = - 8 m^{-1})
  - RF losses in the plasma edge are a function of k_ϕ & edge density
  - ⇨ *Effect could be important for ITER since wave number is relatively low for some heating/CD scenarios*
- Edge power losses processes are under study on NSTX

– Results show core heating efficiency improves when fast wave propagation begins away from the launcher and wall

– PDI production of energetic ions may provide a significant edge RF loss path that also affects the edge rotation

– Fast camera pictures suggest surface fast waves are depositing considerable RF energy outboard of the outside divertor at smaller $k_{||}$

– NSTX is an ideal platform for bench-testing advanced modeling for edge loss processes

– Careful tailoring of edge density profile may be important in ITER