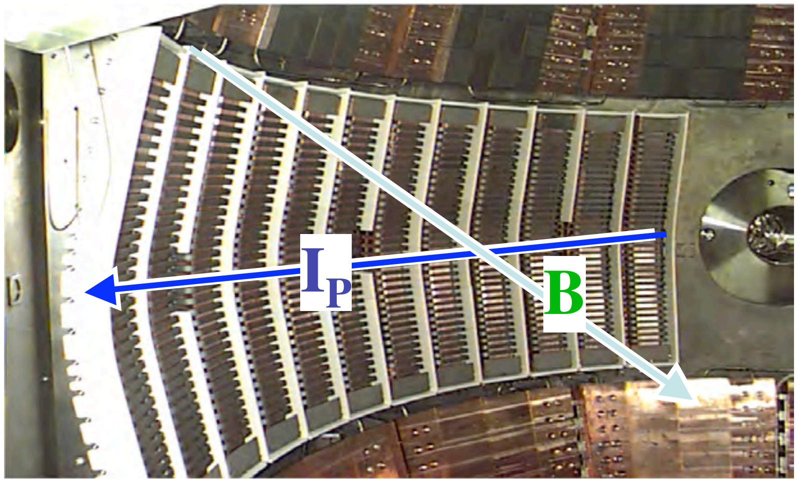
Status of HHFW heating with ELMs in H-mode

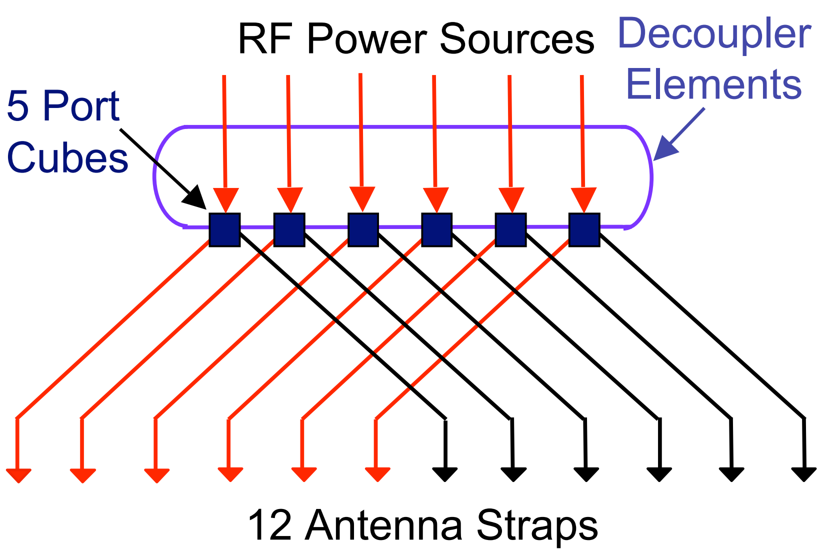
by Joel Hosea

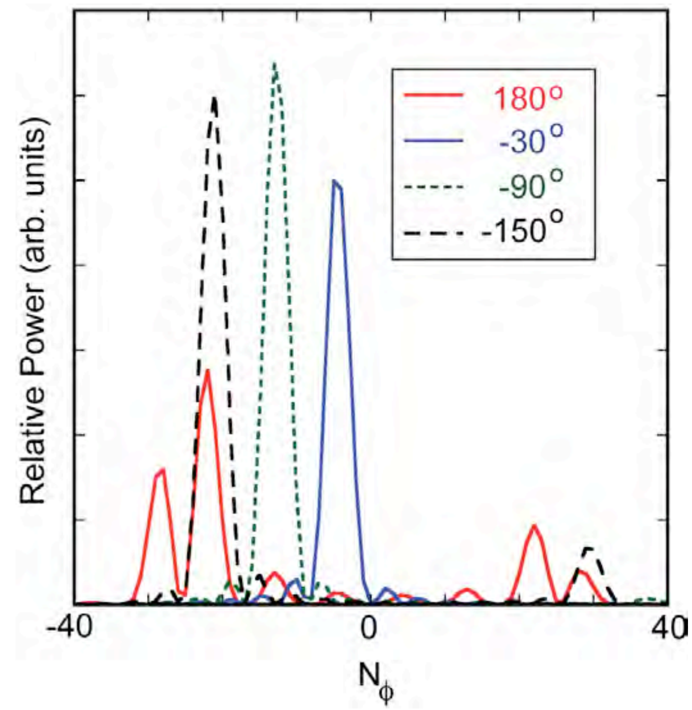
RF WPI-SFG Meeting
April 24, 2009

NSTX HHFW antenna has well defined spectrum, ideal for studying dependence of heating on antenna phase



HHFW antenna extends toroidally 90°





- Phase between adjacent straps easily adjusted between 0° to 180°
- Large B pitch affects wave spectrum in plasma core

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

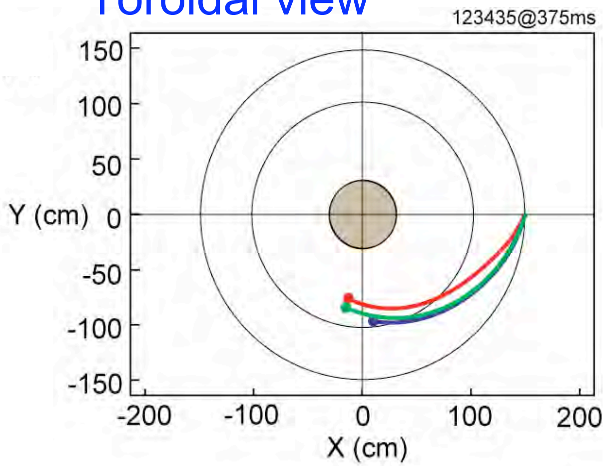
GENRAY:

— -30°

— 180°

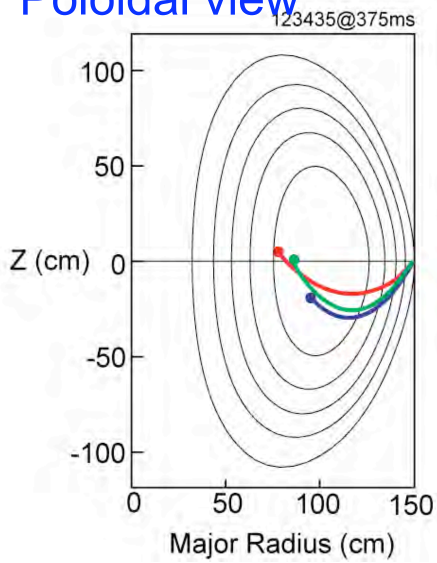
— -90°

Toroidal view

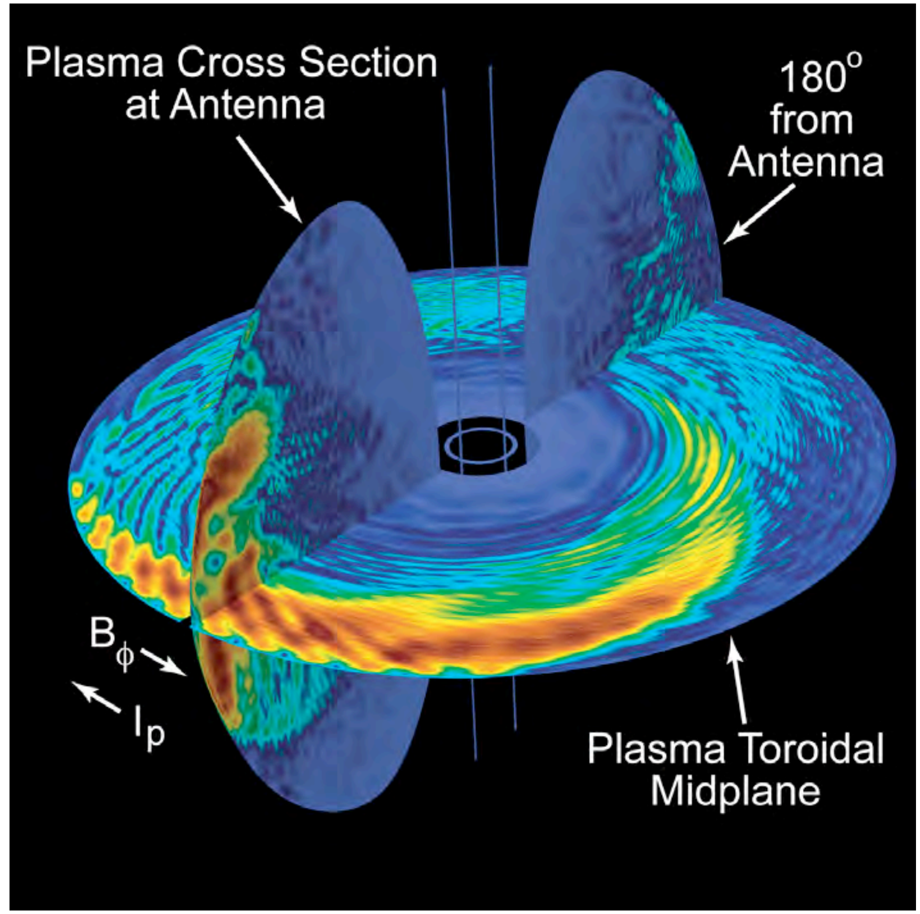


rays stopped when 80% of initial power is damped

Poloidal view



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

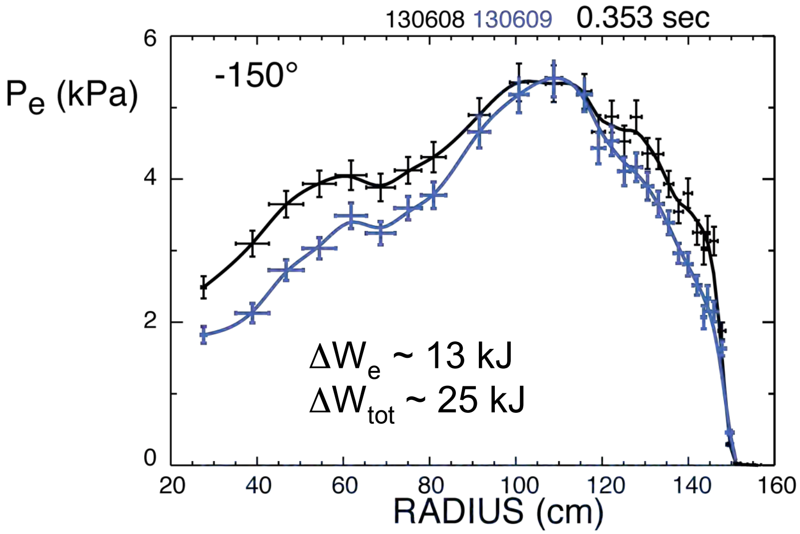


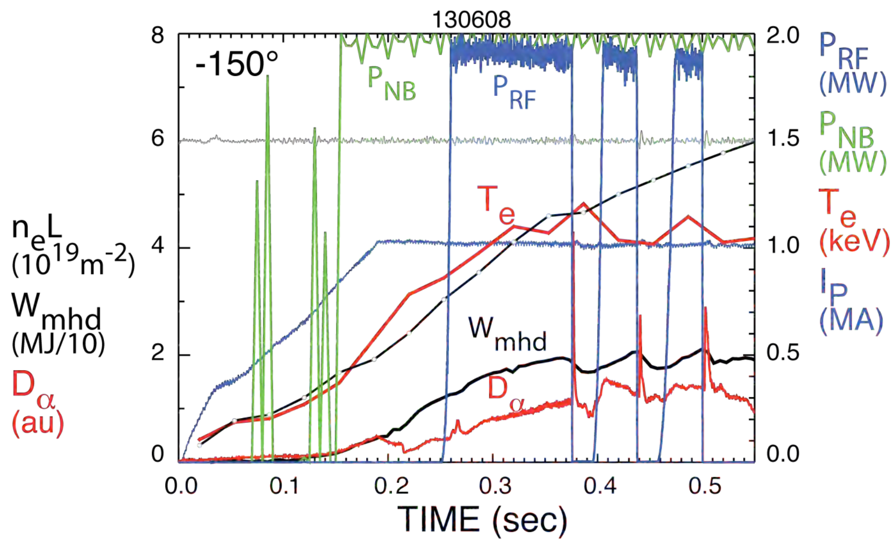
- Edge power loss occurs in the vicinity of the antenna -- there is no multi-pass damping

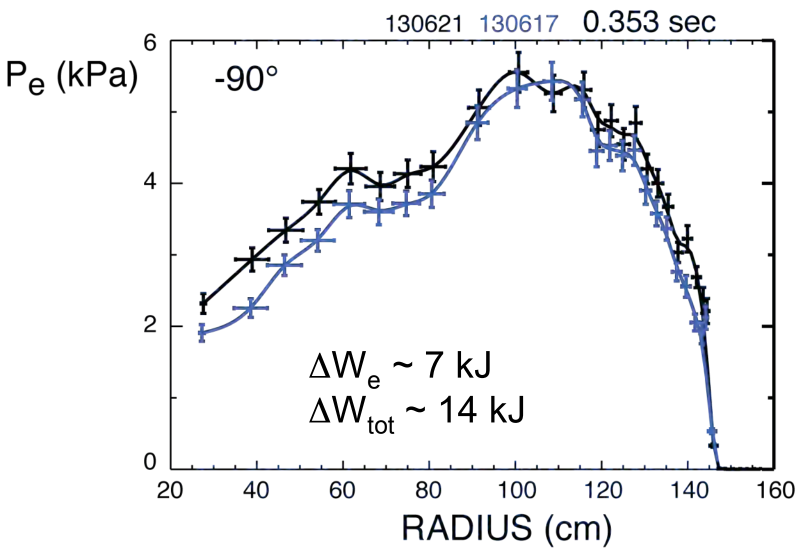
HHFW Operation in H-mode Plasmas

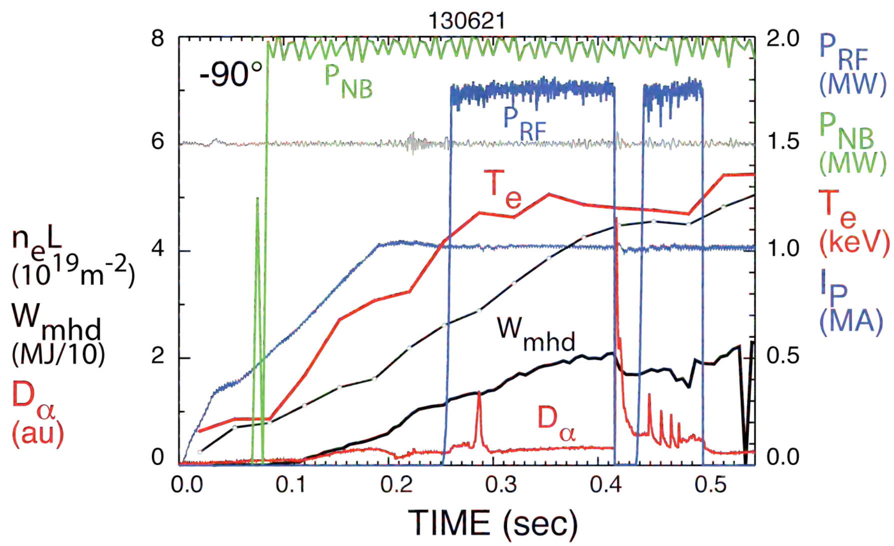
- Initial experiments show heating dependence on $k_{||}$ similar to that for L-mode
  - Degradation of heating at -90° ($k_{||} = -8\ m^{-1}$) relative to that at -150° ($k_{||} = -14\ m^{-1}$)
- Major edge power loss channel observed
  - Losses from SOL in front of antenna to the outer divertor plate linked along the magnetic field lines
- Strong edge pressure gradient appears to lead to large type I ELMs at both antenna phases
  - Arcs occur prior to excursion of D_{alpha} light in most cases
- Arcs are not due to increase in reflection coefficient
  - Can power RF through an ELM in the absence of an arc
  - Time derivative of reflection coefficient can be used to discriminate between ELMs and arcs

Heating H-mode plasmas at -150° and -90° antenna phases





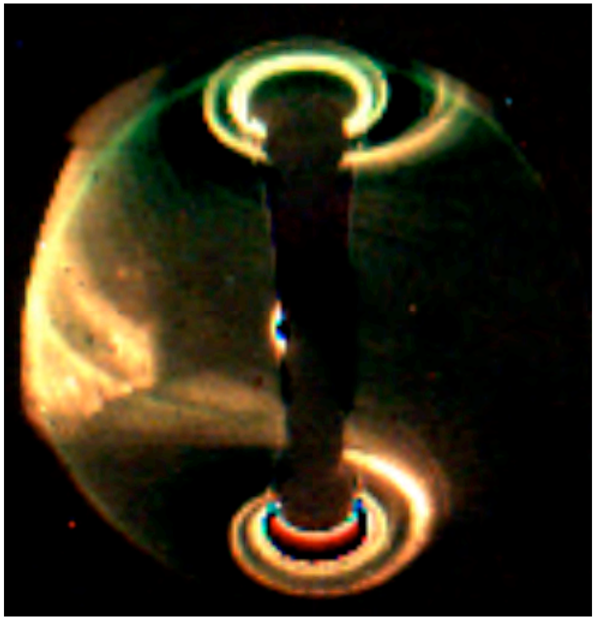




Stronger interaction along field lines at lower phase/longer wavelength

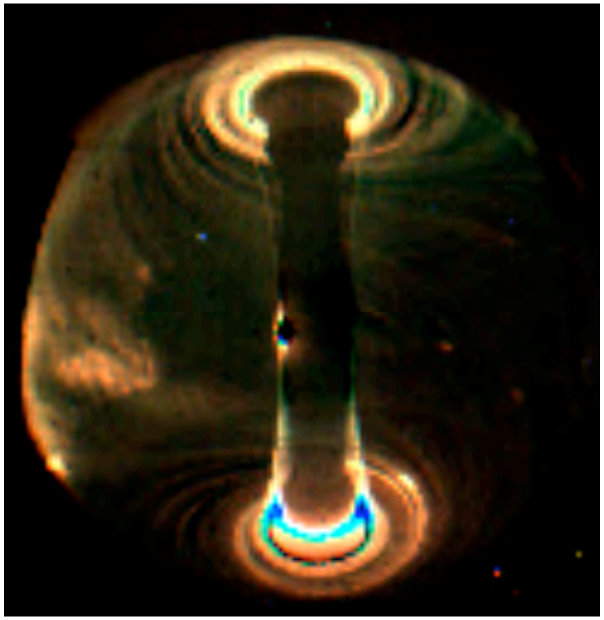
P_{RF} = 1.8 MW, P_{NB} = 2 MW, I_P = 1 MA, B_T = 5.5 kG

130621 -90°



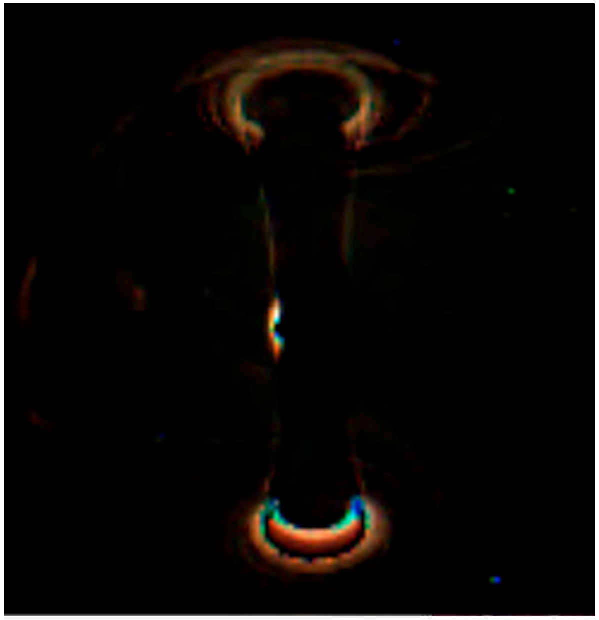
0.33512 sec (-.25012)

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 greater at -90°, consistent with lower core heating
  - Also, suggests RF fields move away from wall at -150° along with the onset density
- Time for "hot" spot to decay away is ~ 20 ms at -90° and ~ 8 ms at -150°

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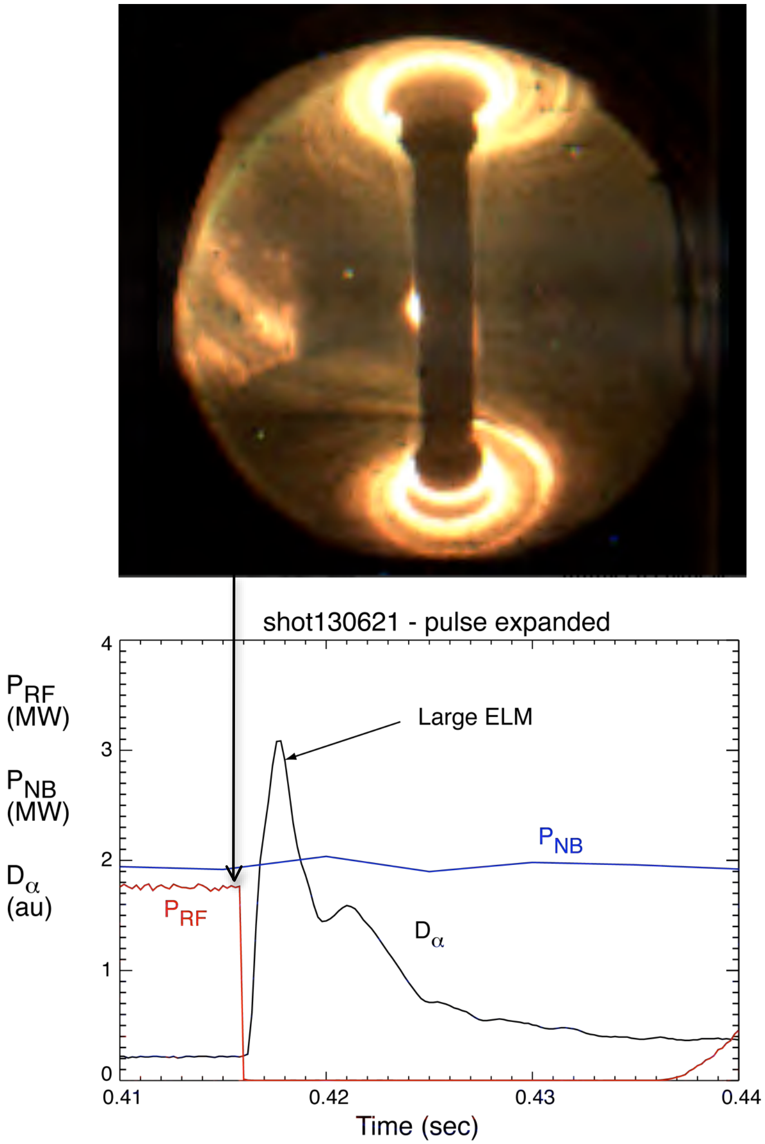
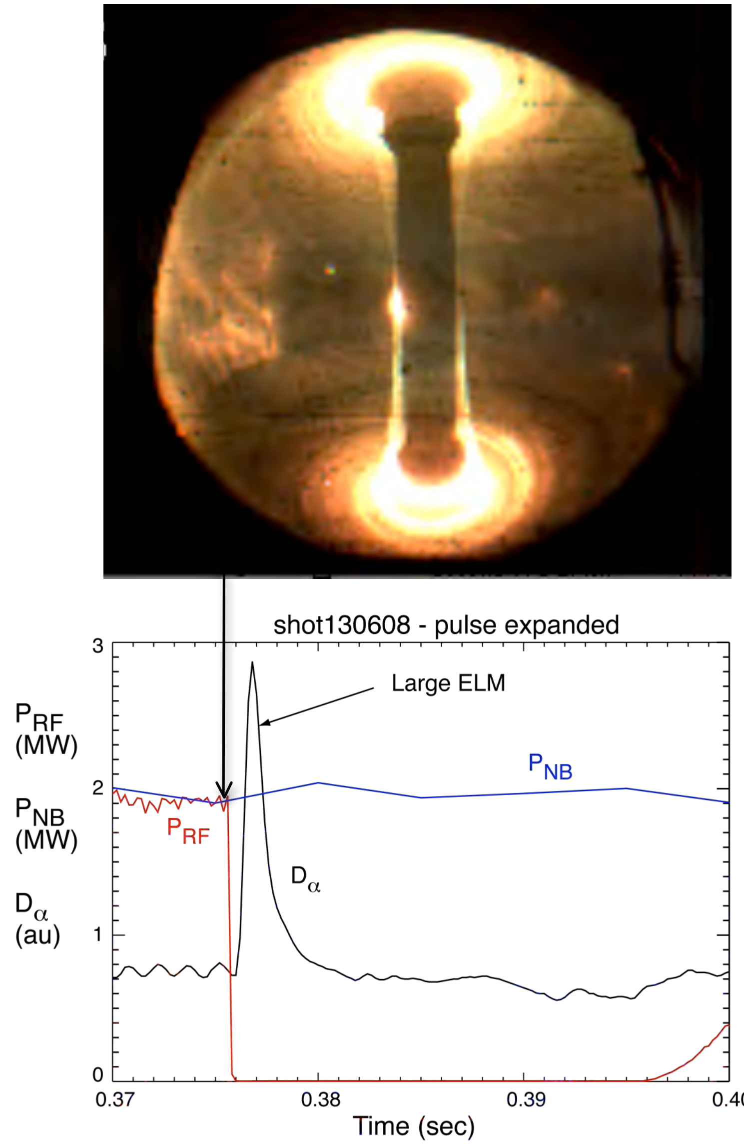
RF arc occurs just prior to the type I ELM divertor D_α signal pulse for both phases

Phase = - 90° just prior to arc before elm

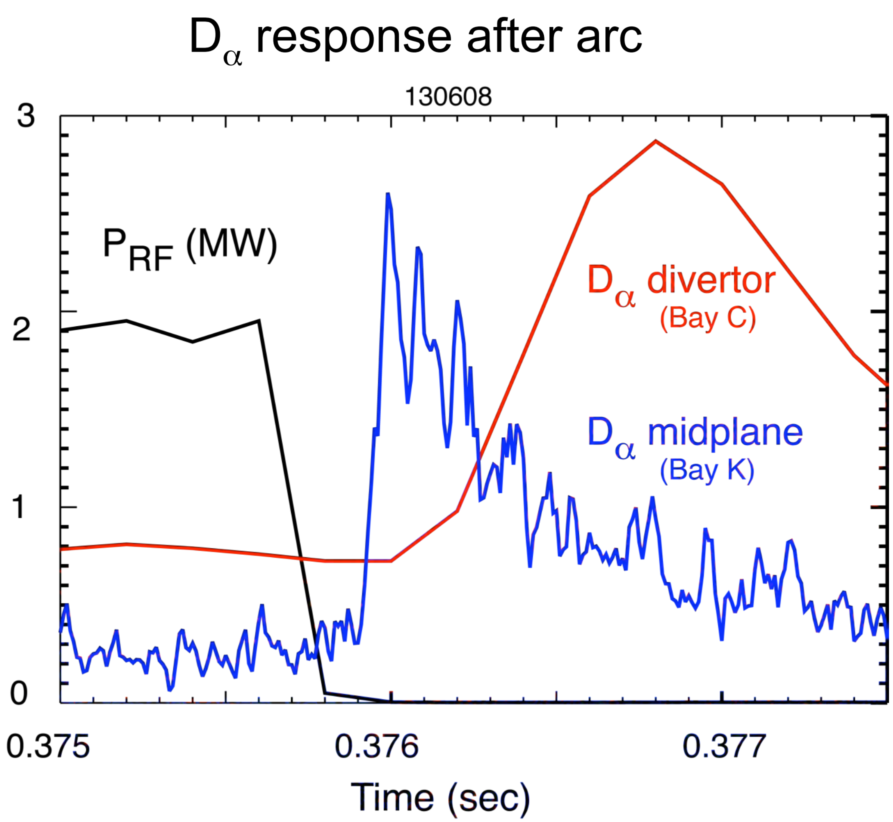


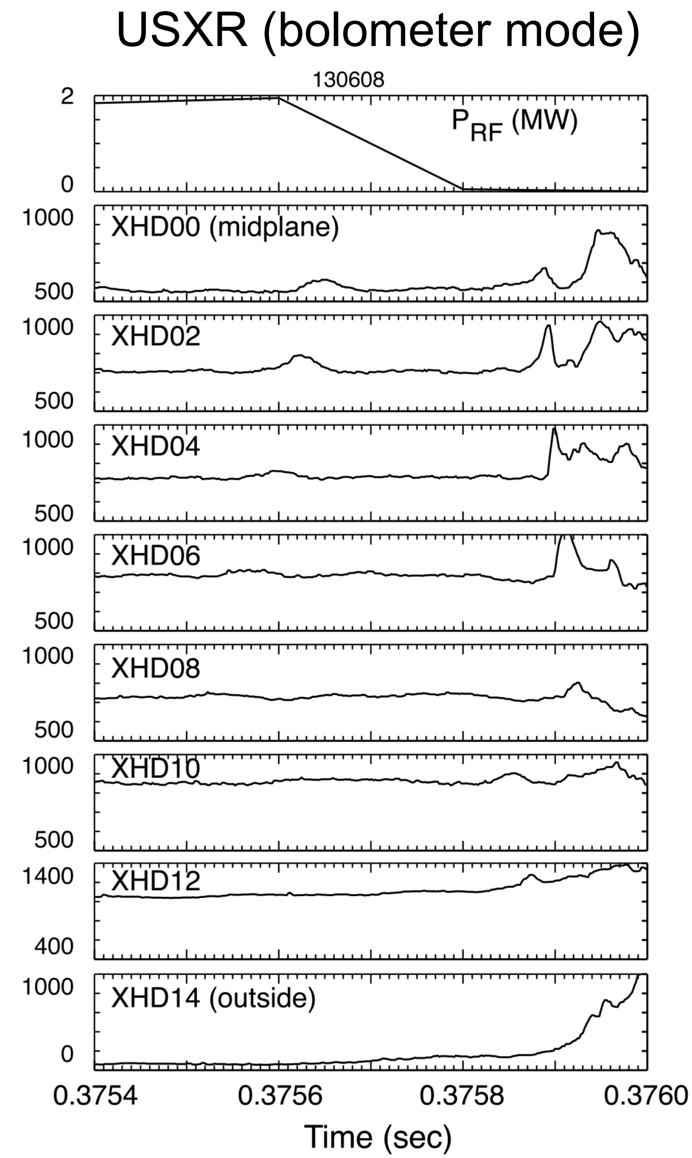
Phase = - 150° just prior to arc before elm



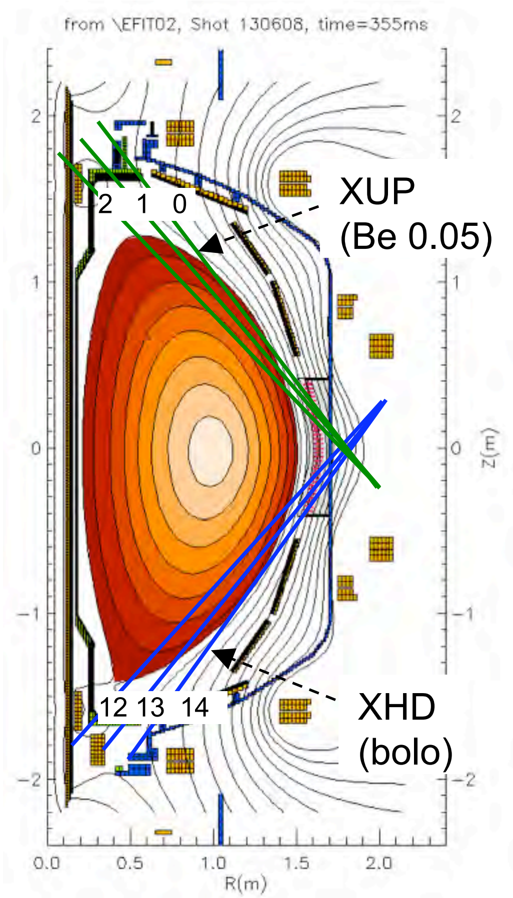
Precursors to the divertor D_{alpha} signal appear to be responsible for the arc

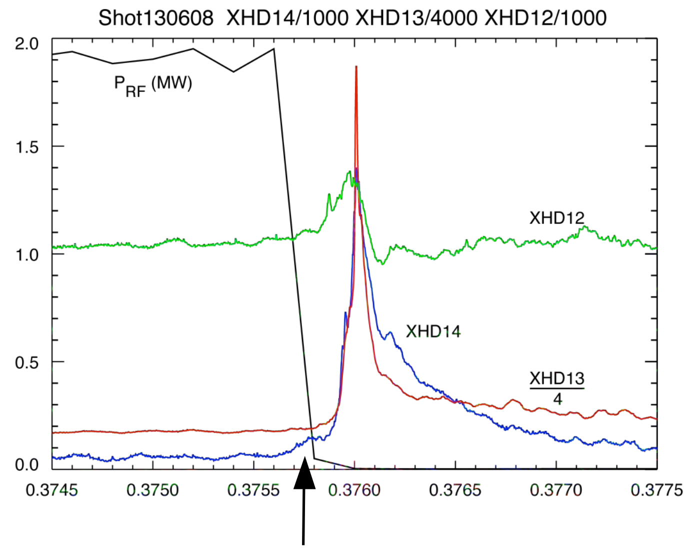
- D_{α} for ELM responds after the arc
- USXR detects activity in range of time for the arc
- Faster digitization is being implemented for tracking the arc time

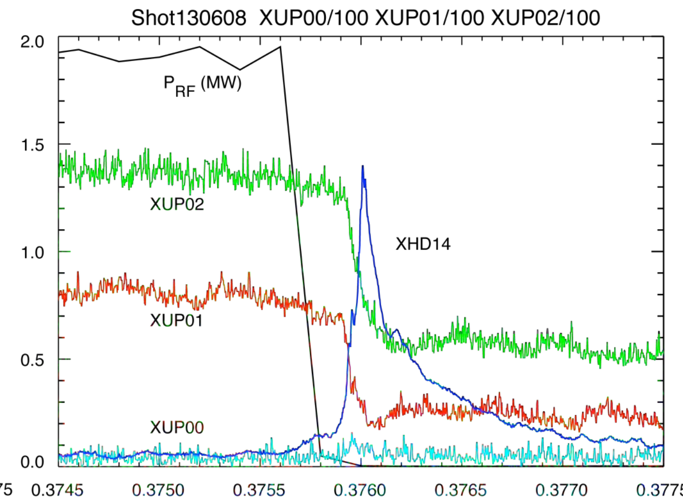


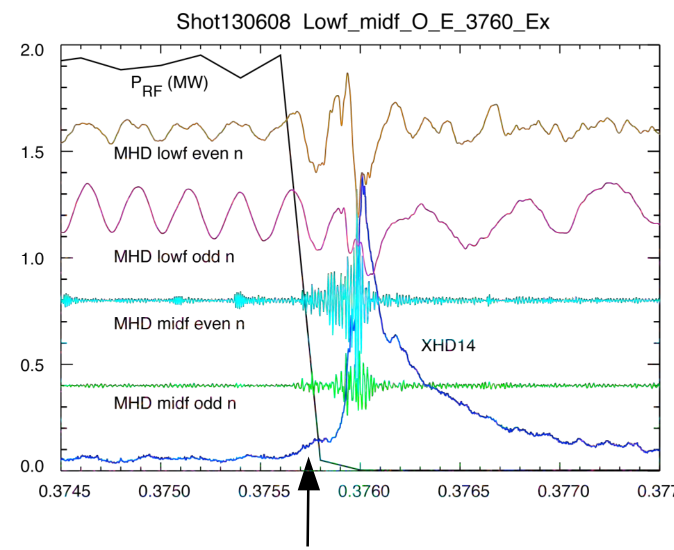


Soft X ray and MHD signals are best indicators of early ELM phase (Shot 130608 -150°)



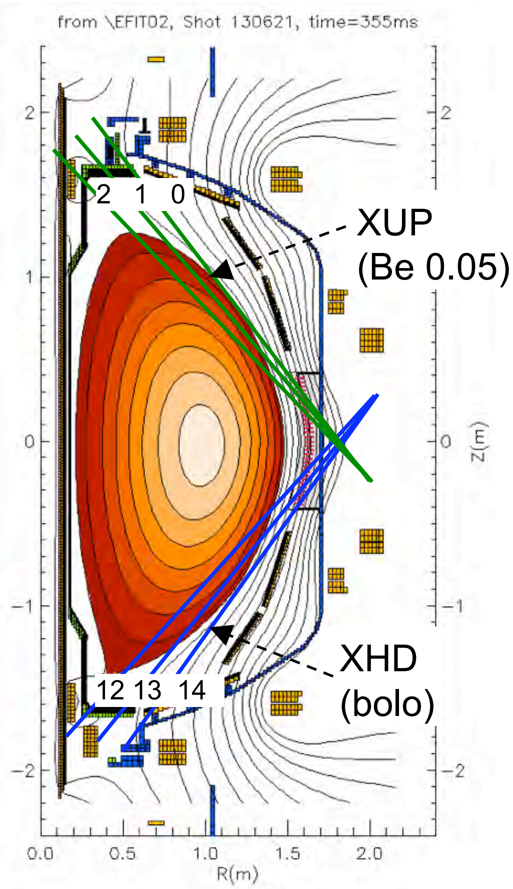


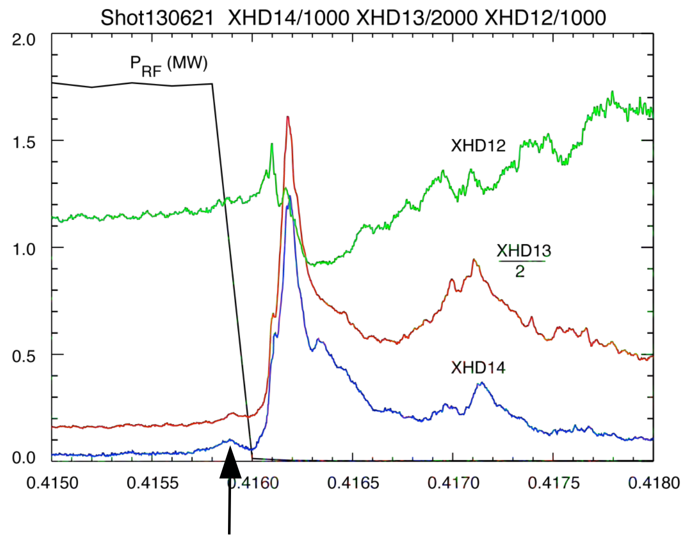


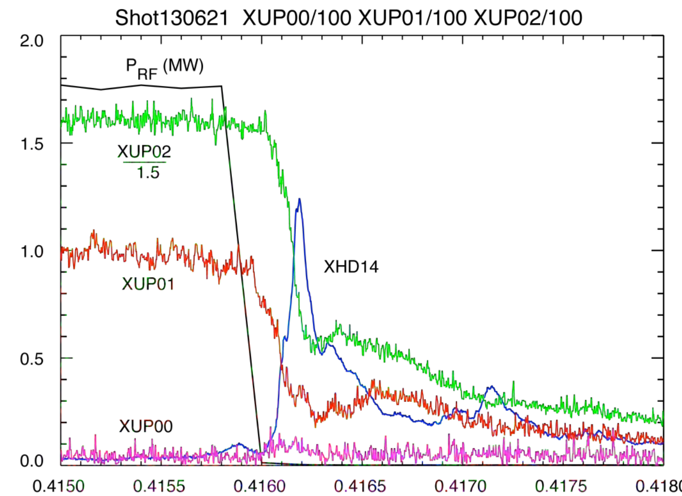


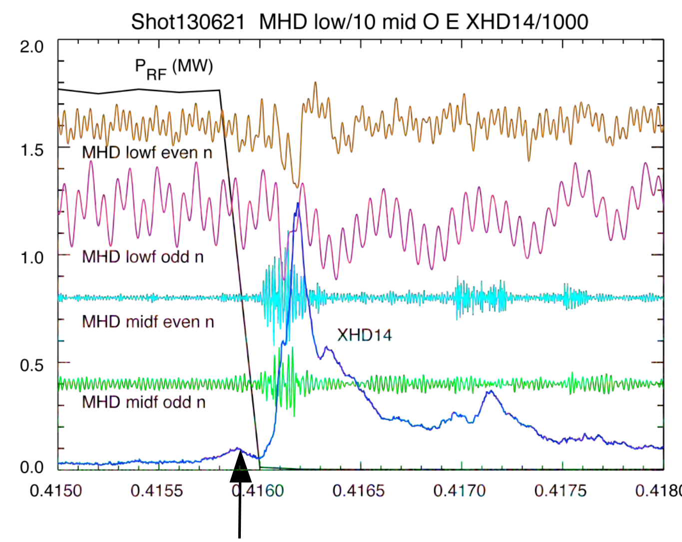
- Clear activity at arrows during the arc time for XHD14 at edge and on midf and lowf MHD
- Slight indication on XUP01 near edge during arc time

Soft X ray and MHD signals are best indicators of early ELM phase (Shot 130621 -90°)

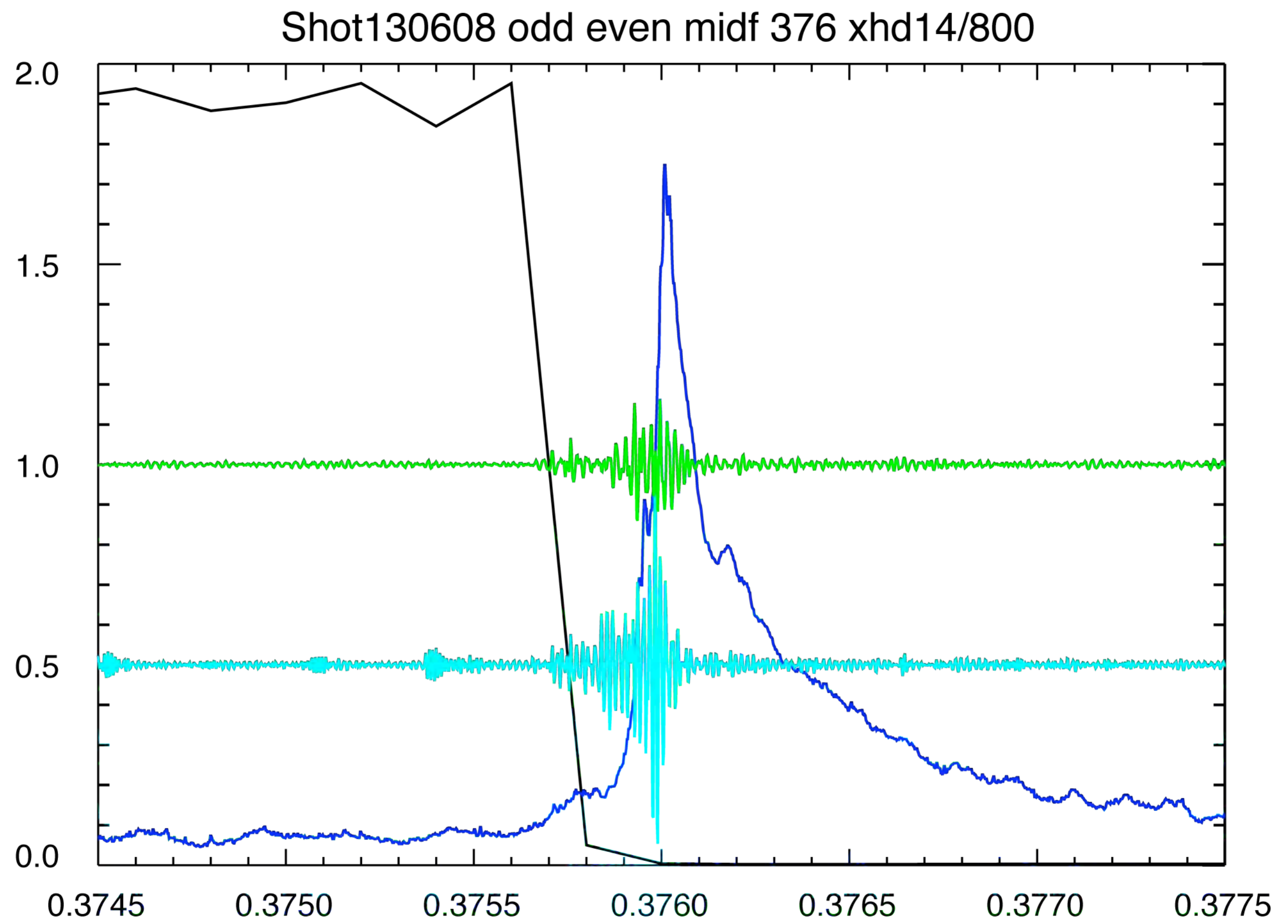






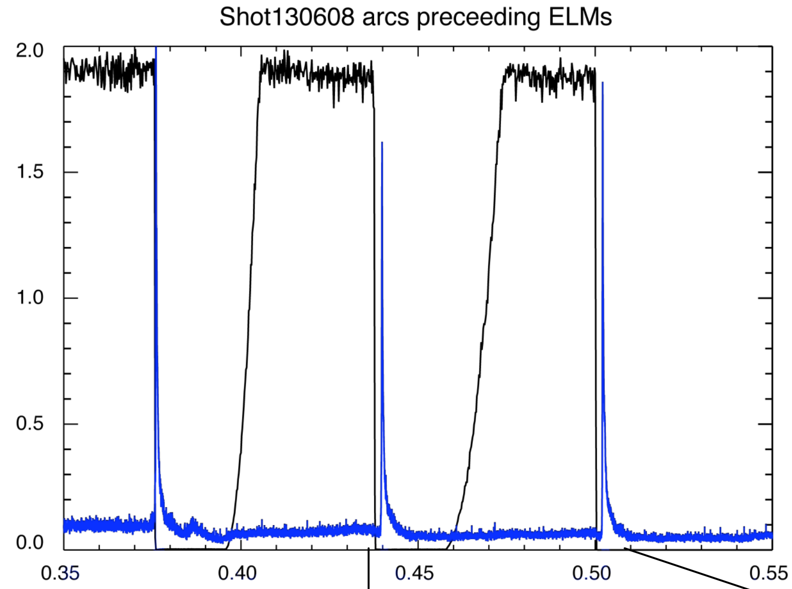


- Clear activity at arrows during the arc time for XHD14 at edge and on midf and lowf MHD
- Indication on XUP01 in edge during arc time



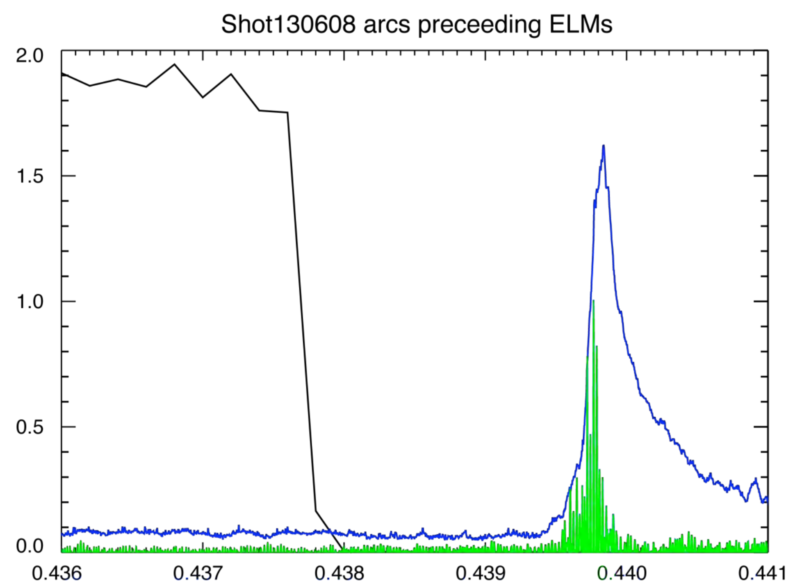
Shot130608 odd even midf 376 xhd14/800
2.0
1.5
1.0
0.5
0.0
0.3745
0.3750
0.3755
0.3760
0.3765
0.3770
0.3775

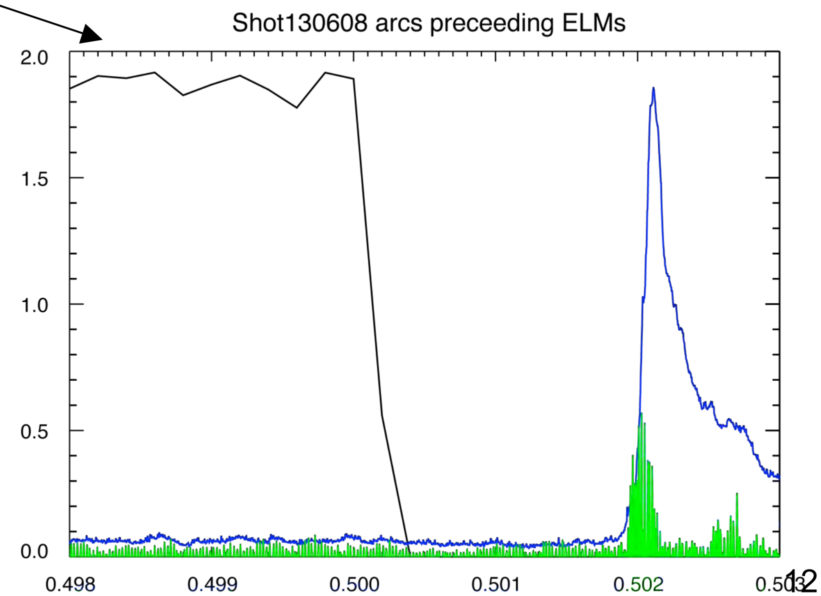
Type 1 ELMs can occur after removal of RF power (arc or cutoff)



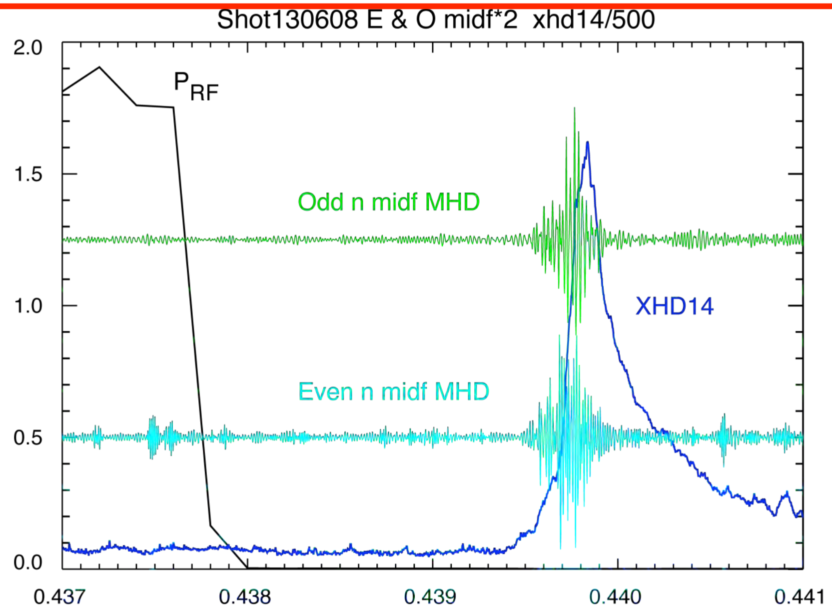
- Delay of ELM after removal of P_{RF} suggests RF supports higher edge pressure without ELM

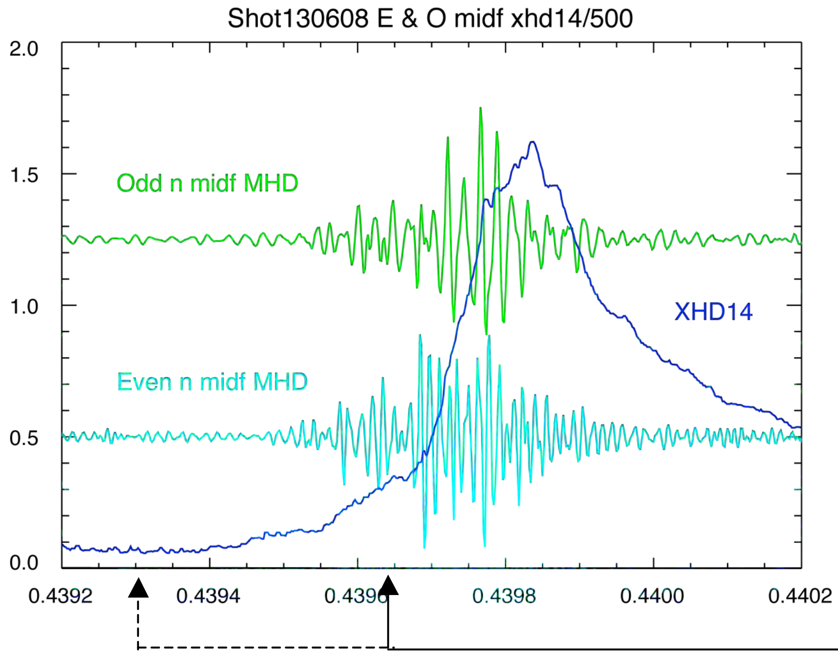
- Mechanism of possible RF ELM stabilization needs further study (Zakharov)



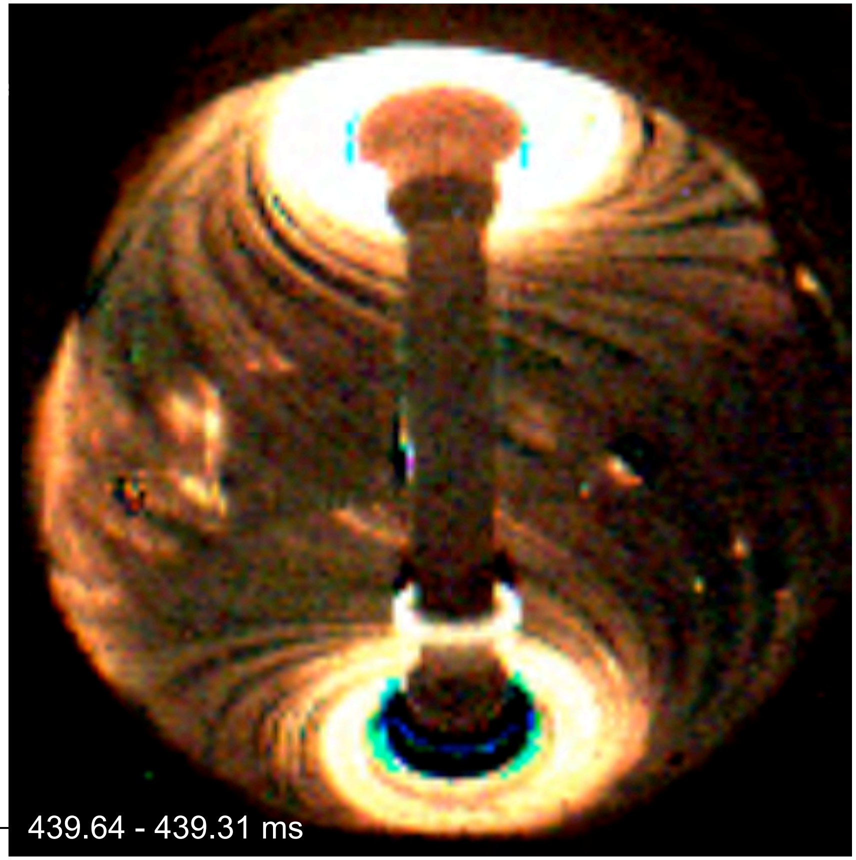


MHD after arc (mid frequency) is relatively quiescent during delay to ELM

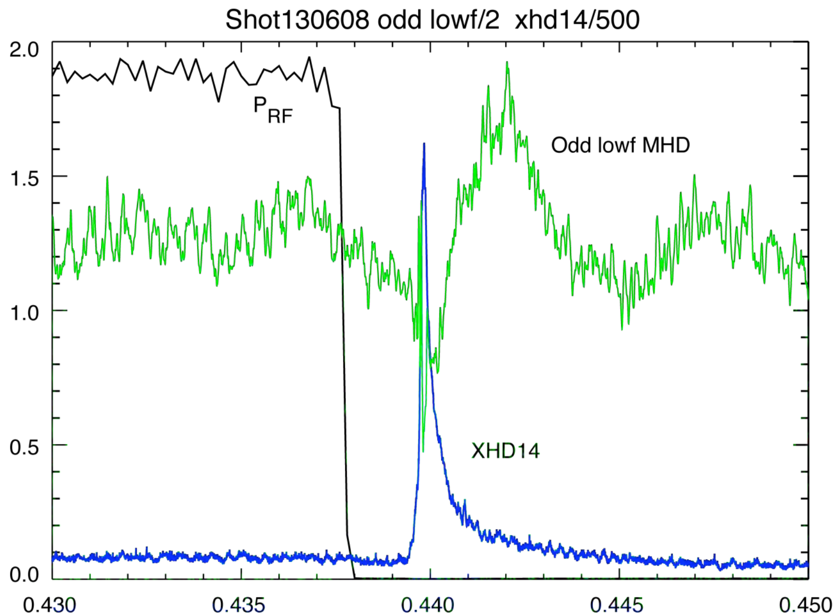




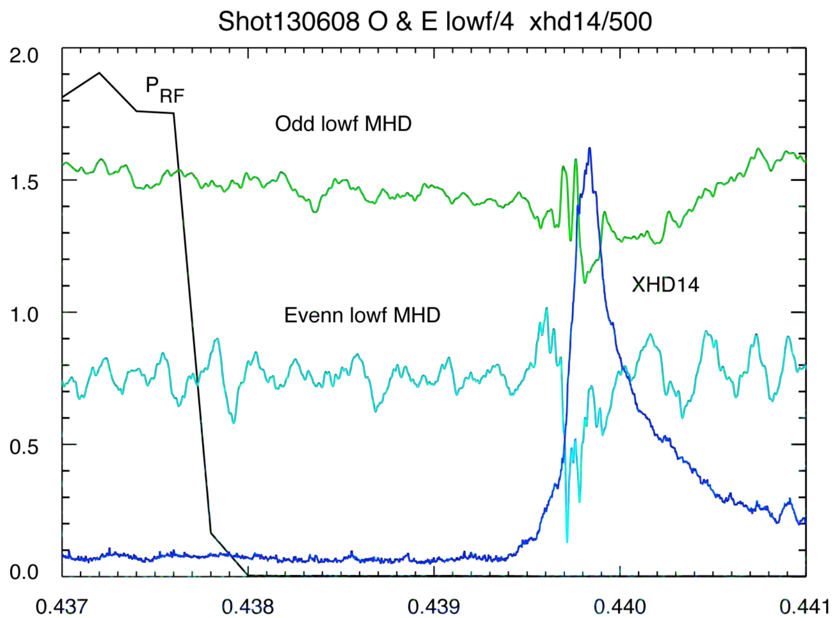
- midf MHD peaks during the ELM buildup
- Some MHD activity near arc - blobs?
- ELM helical structure viewed early in ELM buildup

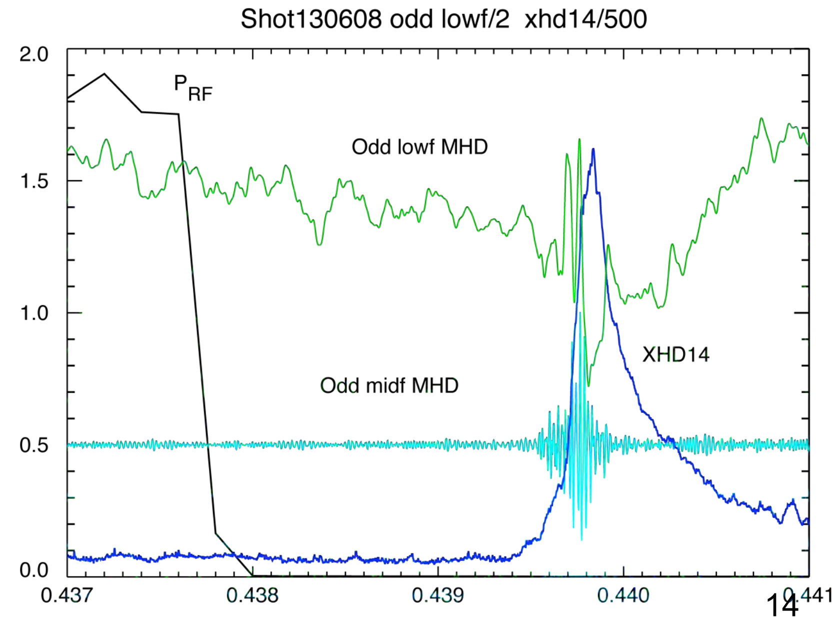


Low frequency MHD response during ELM

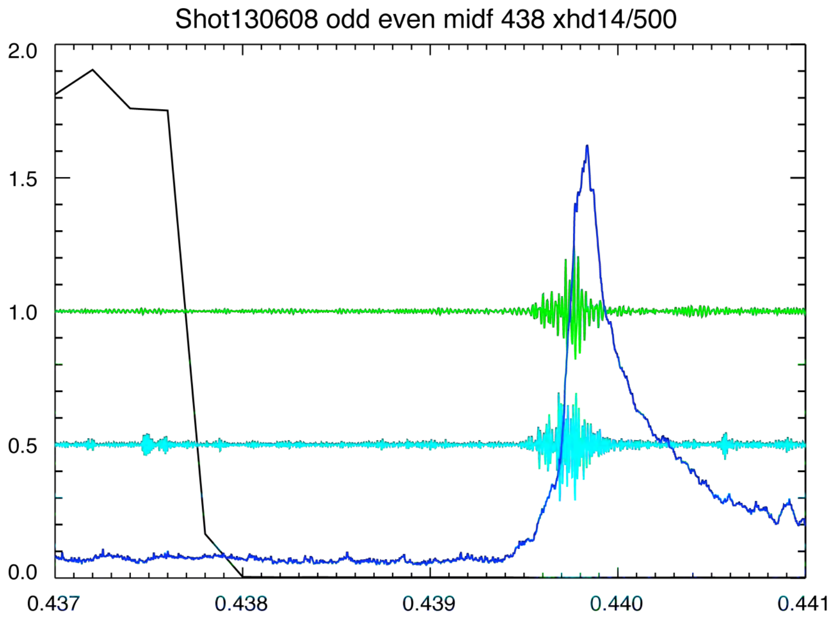


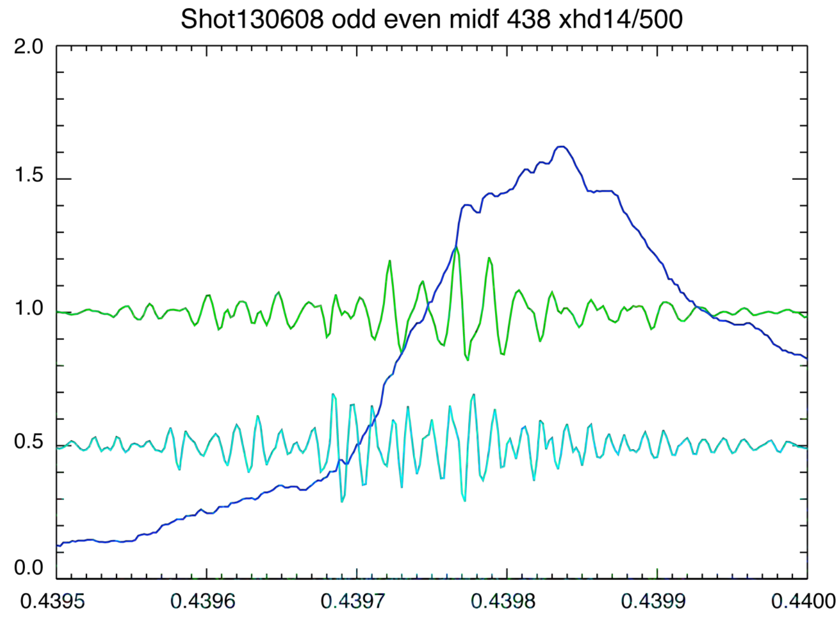
- Relatively fast response during ELM rise
- n odd and even response different - n odd appears to have slow response after ELM associated with equilibrium control
- Lowf response is slower than the midf response as expected



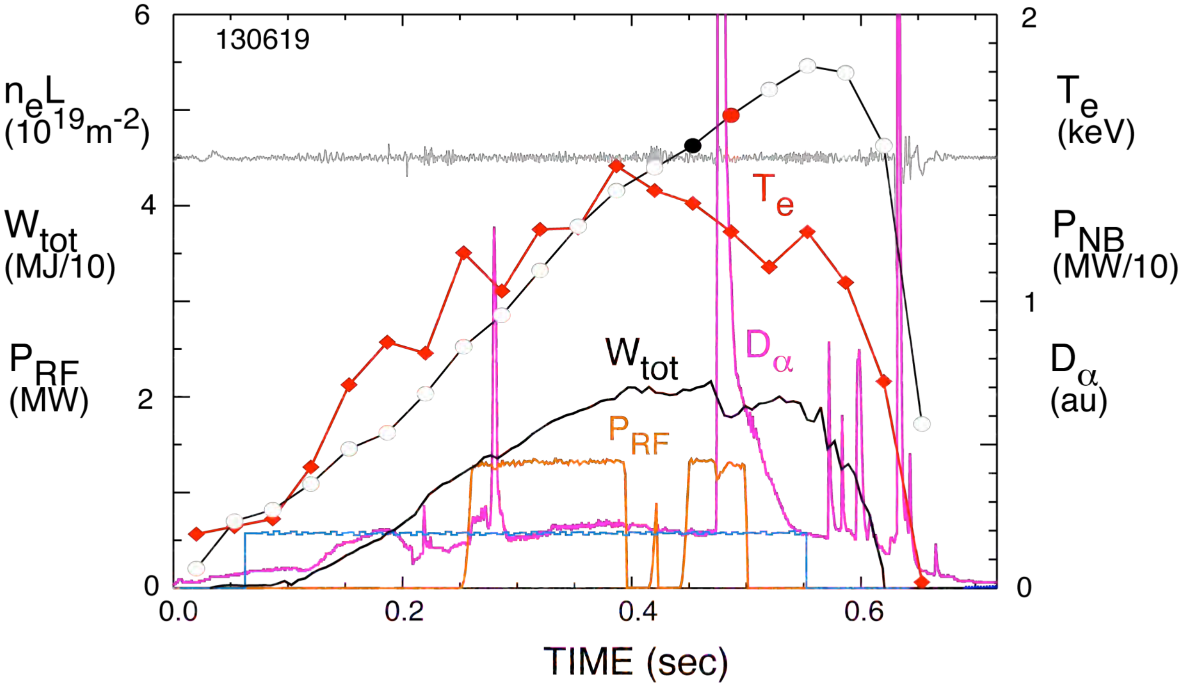


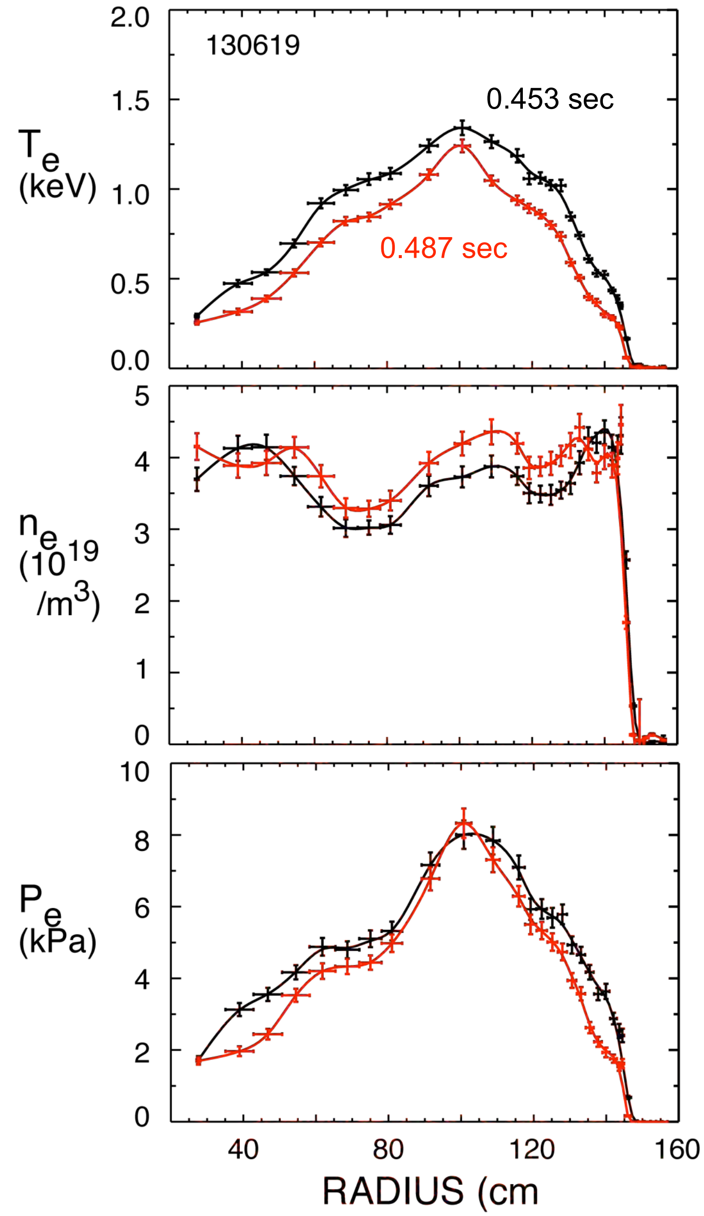
Even midf MHD has higher frequency than odd midf MHD





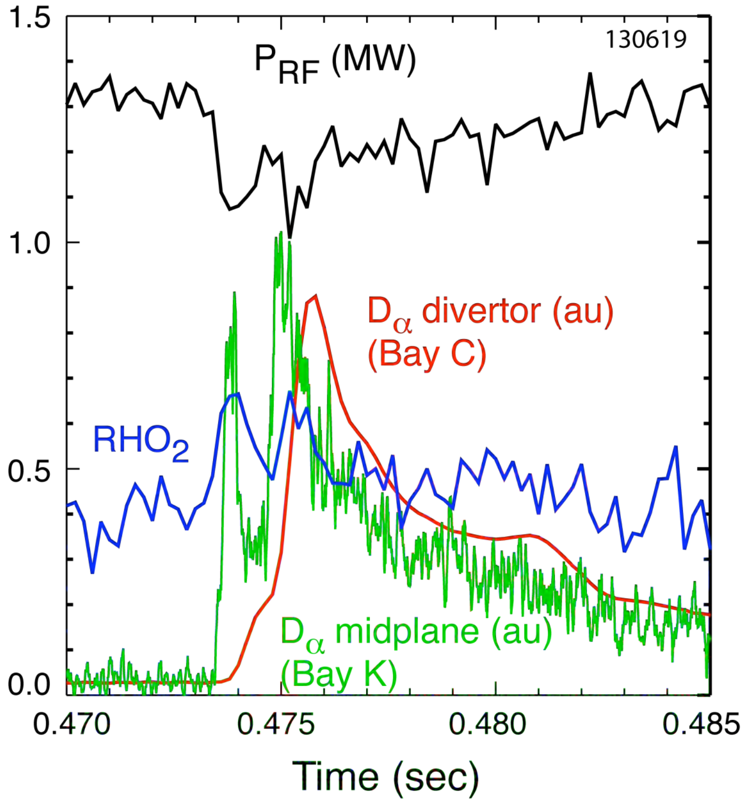
Large type I ELMs can occur without RF arcs

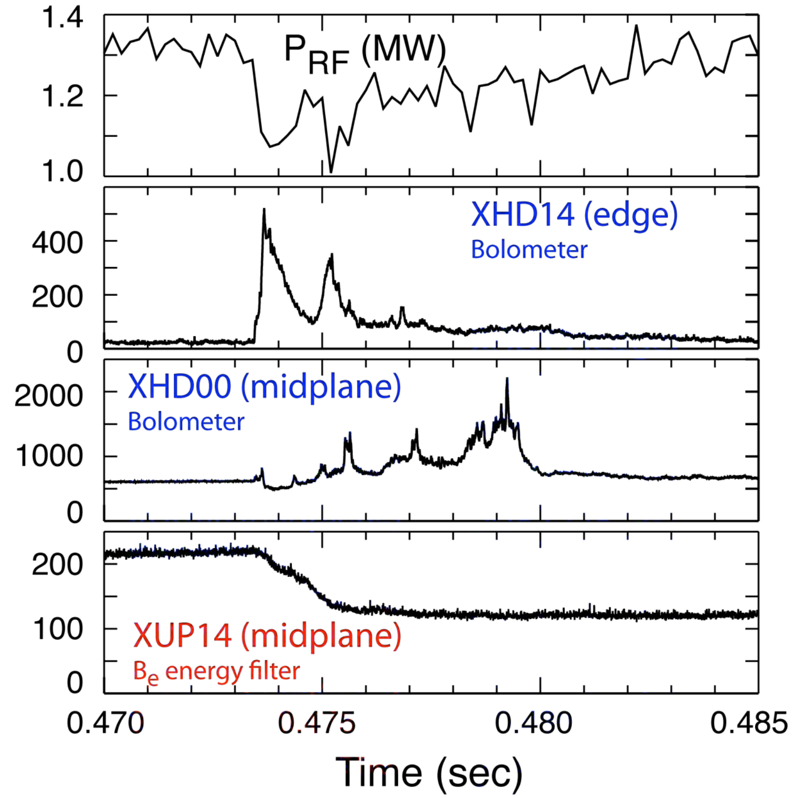




- RF does not arc off preceding the large ELMs at somewhat lower power
- Also, arc can occur without ELM
- ELM effect on stored energy is large
  - ➢ reduction of electron energy is evident almost to plasma axis

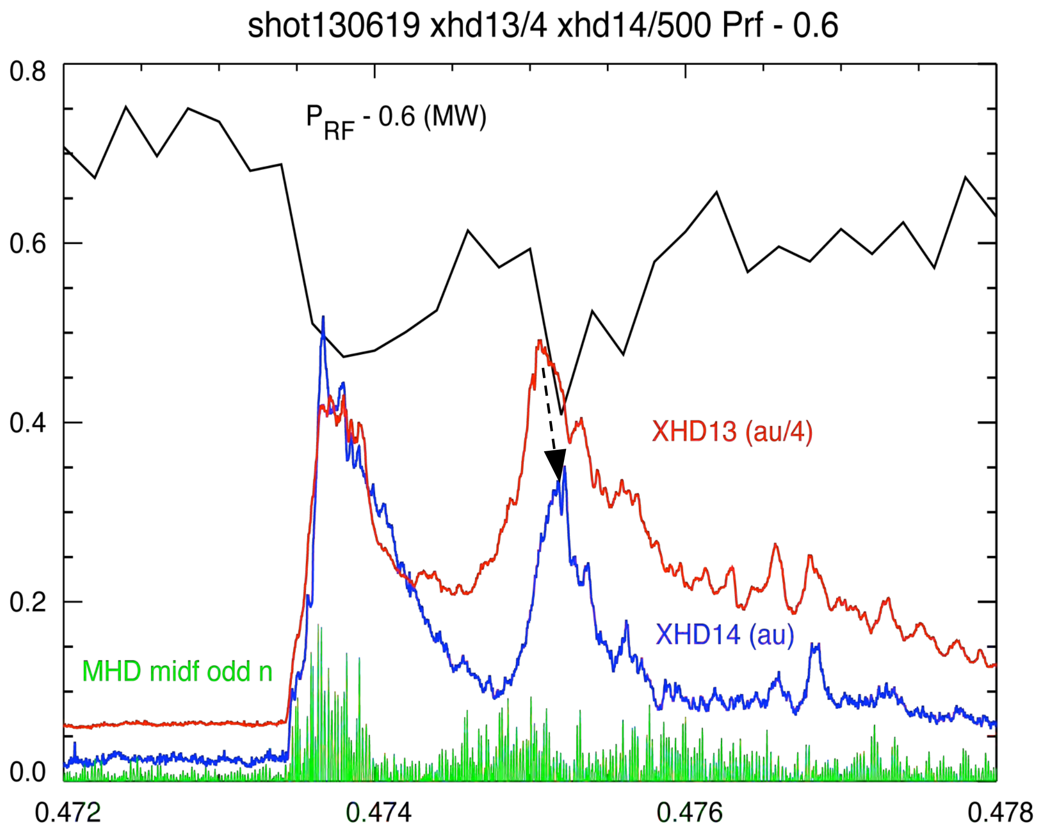
RF response to a type I ELM without an arc

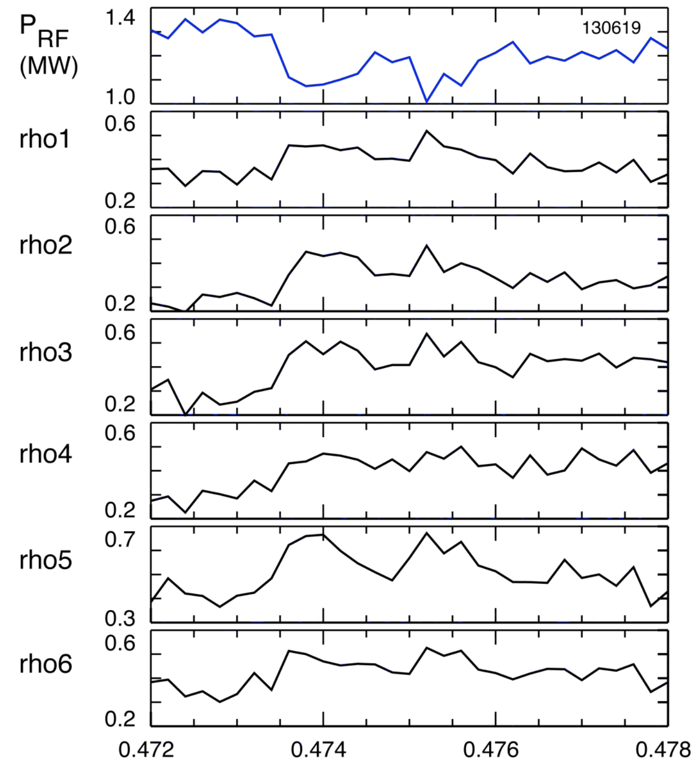




- Reflection coefficient of sources respond to edge density produced by ELM
- Double peak structure for ELM seen in D_α at midplane and on edge USXR
  - precursor activity is small
- Core electron energy drop due to ELM occurs over ~ 2 msec
- RF heating through ELMs is possible in general with arc/ELM discrimination based on the relatively slow rate of rise of the ELM RF reflection coefficient

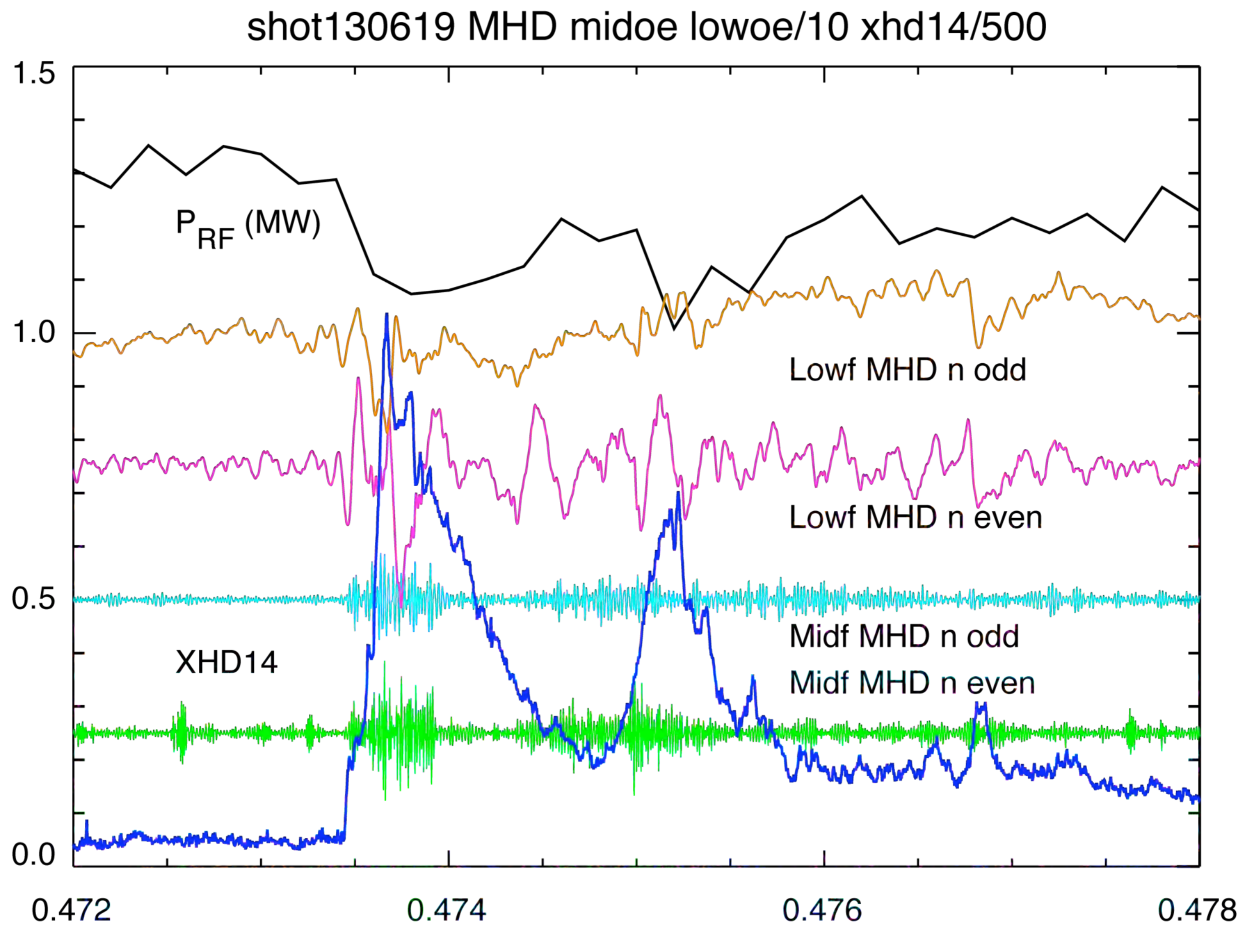
Effect of large type I ELM on RF power coupled

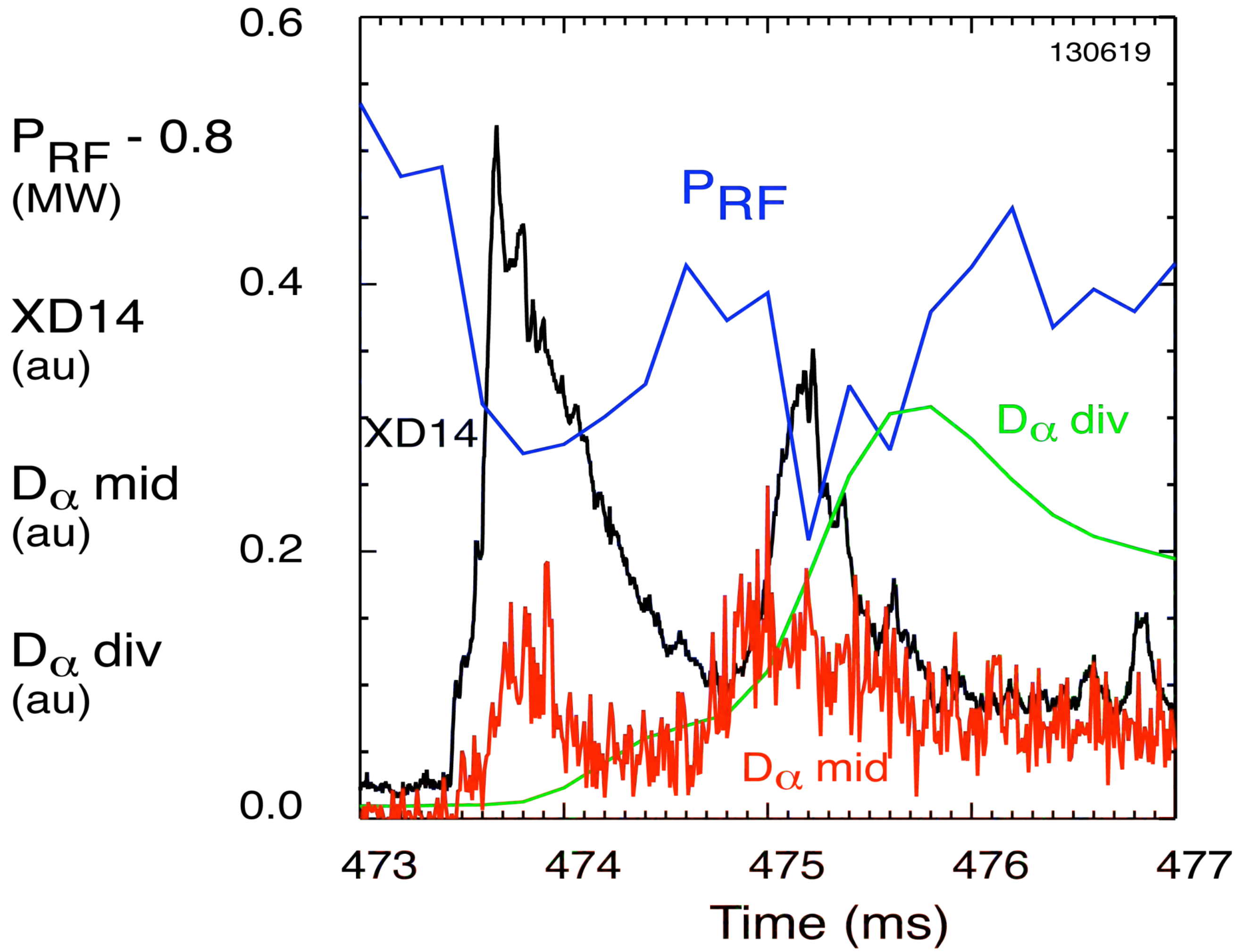




- Can power through a large ELM at P_{RF} ~ 1.3 MW with trip reflection coefficients for sources set to 0.7
- Two peaks for XHD14 and 13 edge bolometer signals show two large ELMs and “density” propagating toward antenna (plasma edge) in time
- Source rho values increase slowly for ELM relative to their response time for a high voltage arc - Can discriminate between arc and ELM rise times to leave RF power on during ELM

MHD with RF on during ELM



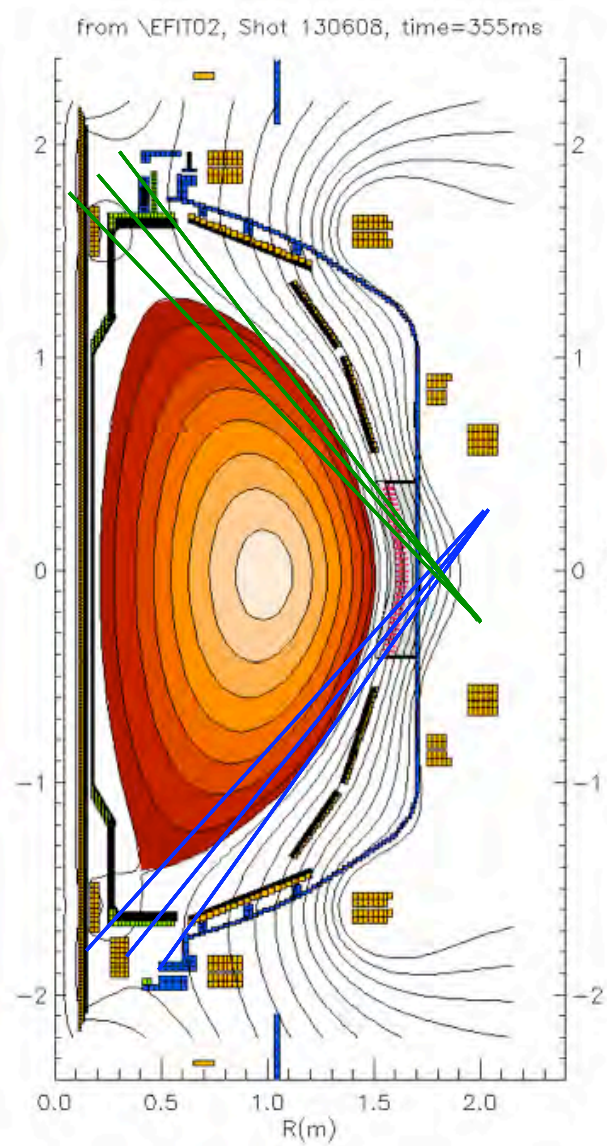


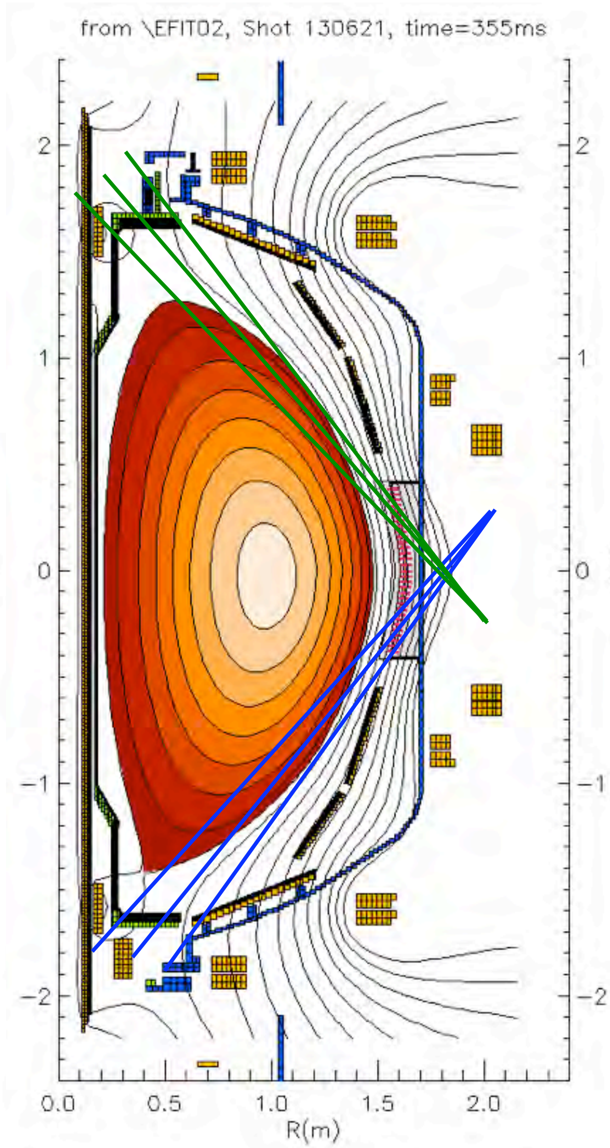
0.6
0.4
0.2
0.0
P_{RF} - 0.8
(MW)
XD14
(au)
D_α mid
(au)
D_α div
(au)
130619
P_{RF}
XD14
D_α div
D_α mid
473
474
475
476
477
Time (ms)

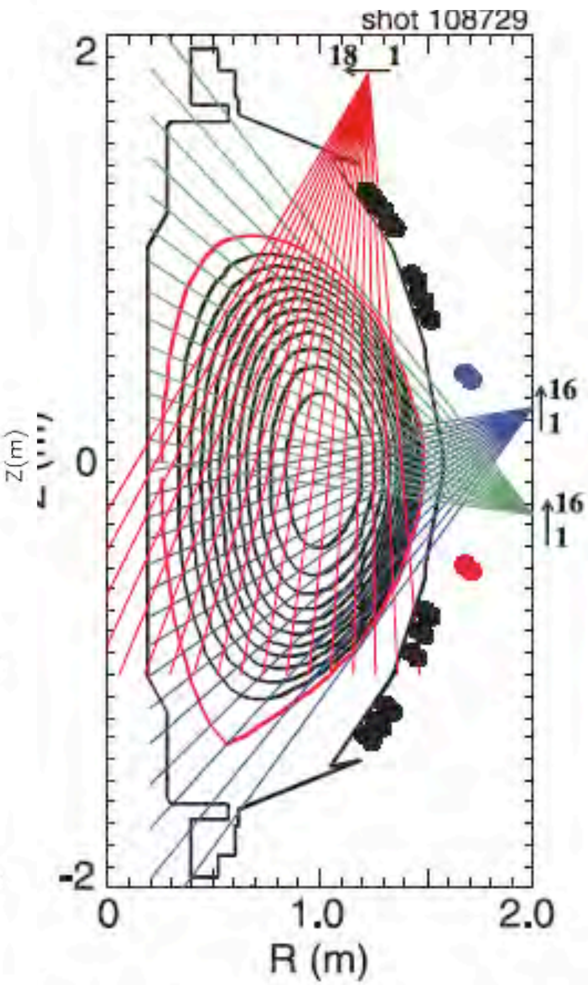
Signatures for ELM

- Dalpha divertor
- Dalpha midplane
  - Coincident with Dalpha/lithium light seen on camera view of center stack during the peak of the ELM
- Lithium
- carbonIII
- Mhd midf odd-even n
- Mhd lowf odd-even n
- Usxr bolometer XHD
- Usxr energy XHUP (0.05 Be filter)
- HHFW antenna reflected power

➢ Usxr bolometer XHD in edge is best indicator of density near antenna


from \EFIT02, Shot 130608, time=355ms
R(m)
Z(m)


from \EFIT02, Shot 130621, time=355ms
R(m)
Z(m)


shot 108729
R (m)