NSTX

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Characterization of small transport events triggered with n=3 fields below the ELM destabilization threshold in NSTX

J.D. Lore[1,2]

J.M. Canik[2], R. Maingi[2], J.-W. Ahn[2], E.D. Fredrickson[3], A.G. McLean[4], F. Scotti[3], V. Soukhanovskii[4], K. Tritz[5]

and the NSTX Research Team

[1]Oak Ridge Institute for Science and Education
[2]Oak Ridge National Laboratory
[3]Princeton Plasma Physics Laboratory
[4]Lawrence Livermore National Laboratory
[5]Johns Hopkins University

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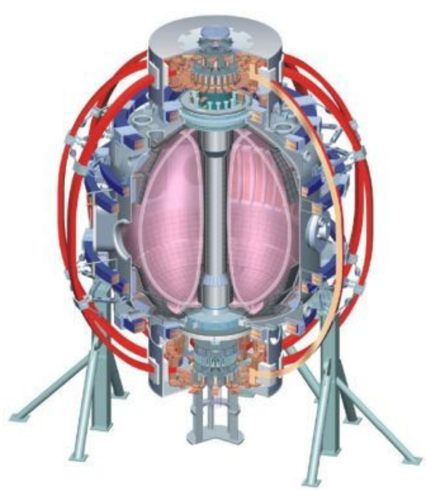

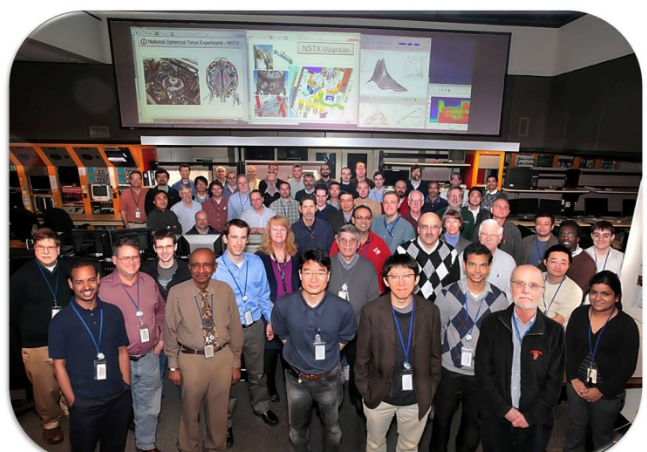

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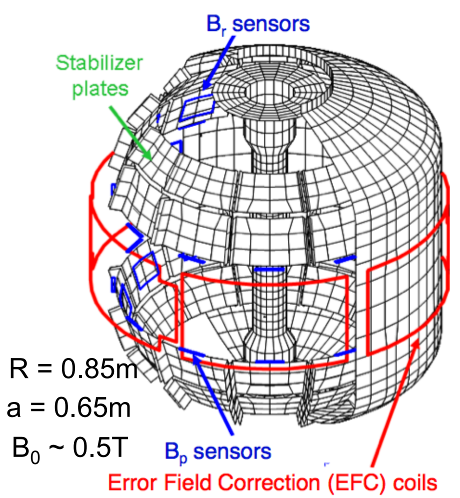
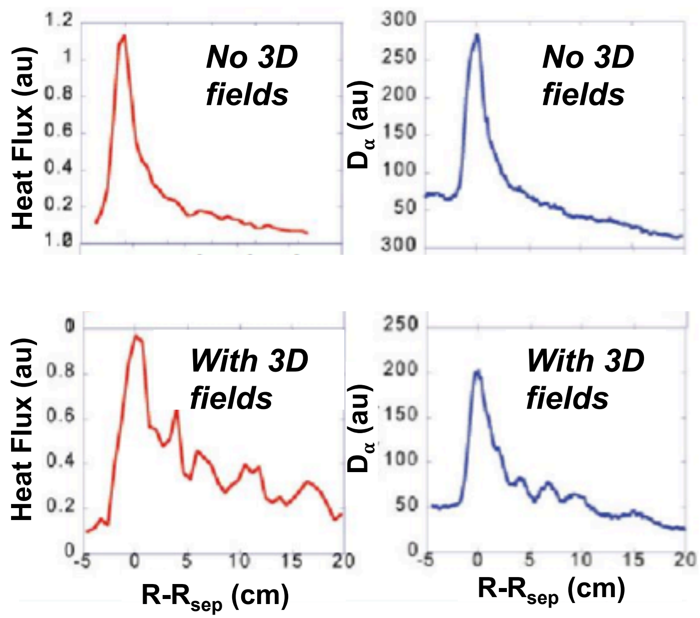
Overview

- A characterization of the transport response to 3D field pulses below the ELM-triggering threshold is presented.
- The pulses produce regular small perturbations measurable by edge diagnostics.
  - Small increases in D_α and edge USXR emission.
  - Spreading of divertor footprints measured by cameras.
  - Small drop in neutron production rate and modulation of GAE mode.
- Responses are consistent with augmented strike point splitting and modified SOL transport.
  - The timescale of the response is proportional to the internal perturbed magnetic field signal.

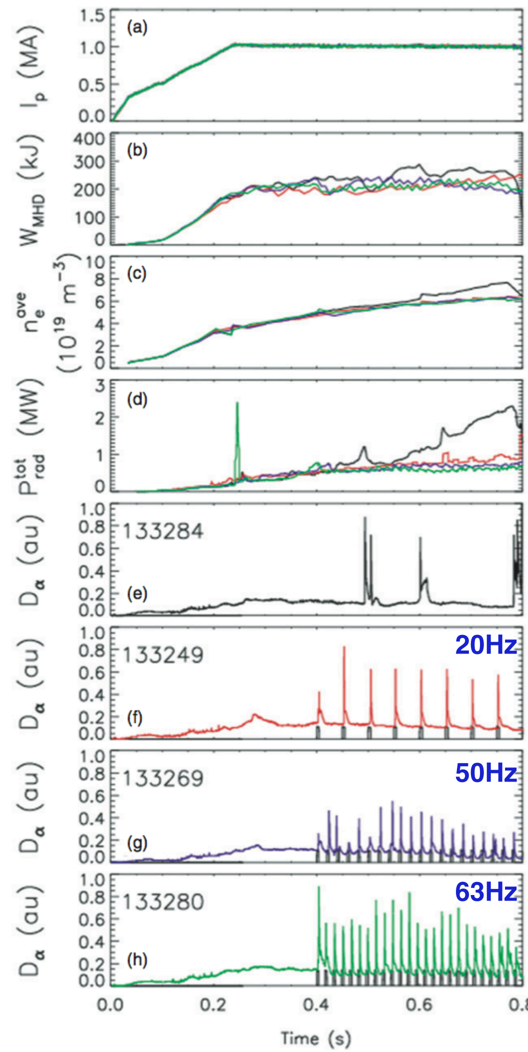
Impurity accumulation in ELM-free H-modes can be controlled with 3D field triggered ELMs

- 3D field pulses are used to control ELM size and frequency in NSTX
- Fields applied with a midplane EFC coil set, external to vacuum vessel (n=1,2,3)
- Applied fields also cause strike point splitting, change recycling properties





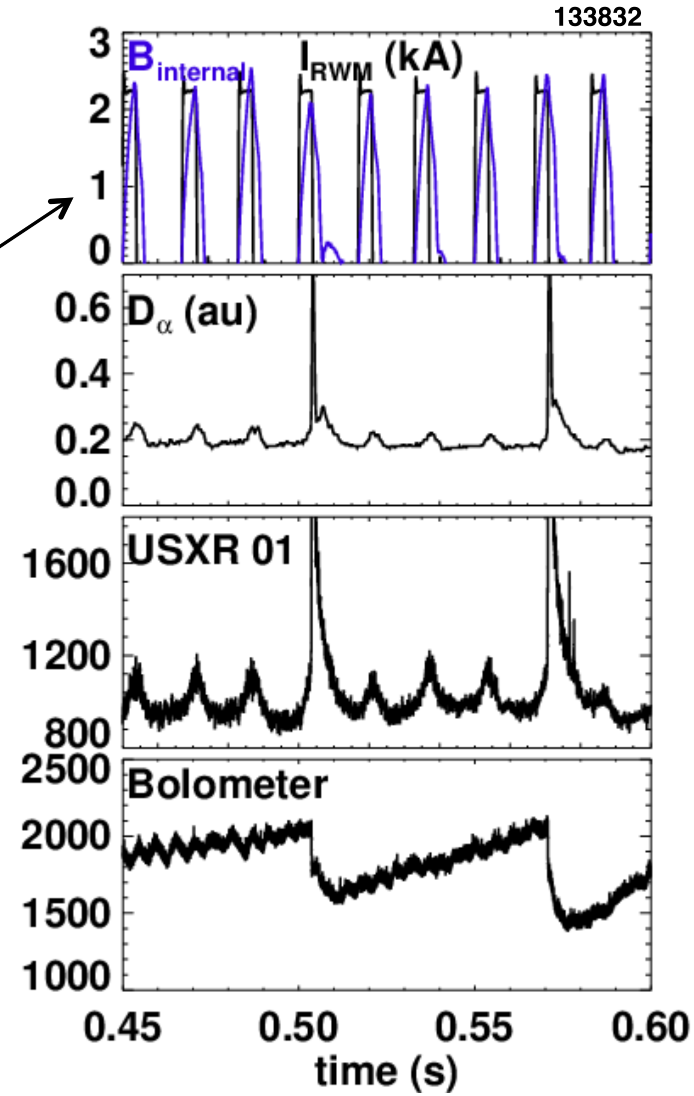
J-W. Ahn, *et al.*, Nucl. Fusion 50, 045010 (2010).



J.M. Canik, *et al.*, Nucl. Fusion **50** 065016 (2010).

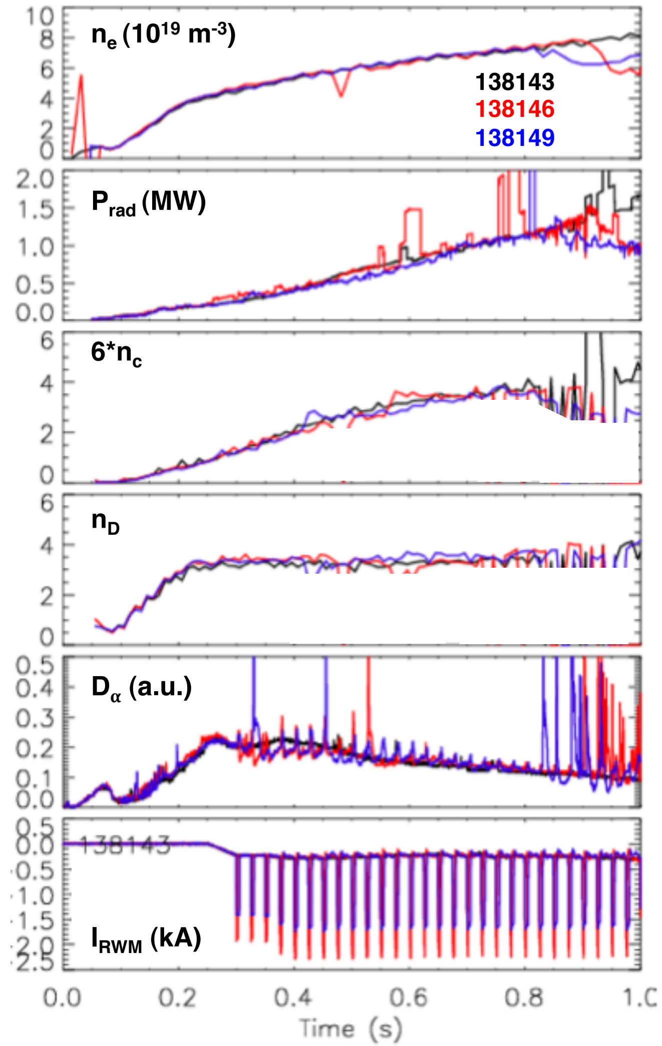
3D field pulses below the ELM triggering threshold still affect transport

- Pulses of insufficient amplitude or duration do not trigger ELMs
  - Example:
    - 4ms, 3.0kA pulses: reliable triggering
    - 3ms, 3.0kA pulses: unreliable
    - 4ms, 2.5kA pulses: unreliable
- Pulses still cause small changes to divertor/edge diagnostic signals
  - Divertor D_α intensity increases, indicating increased particle transport
  - No impact on bolometry
- Response is very different from large ELMs



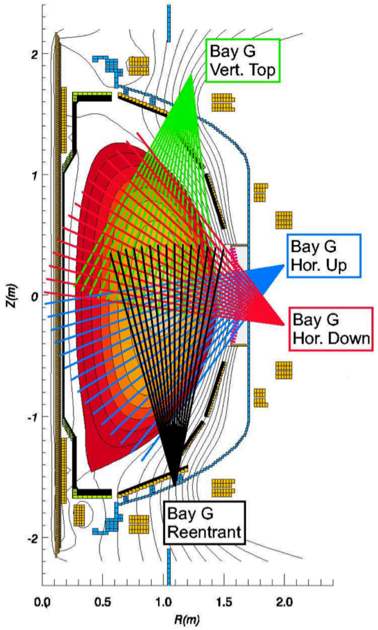
3D pulses below the ELM triggering threshold do not significantly reduce impurity accumulation

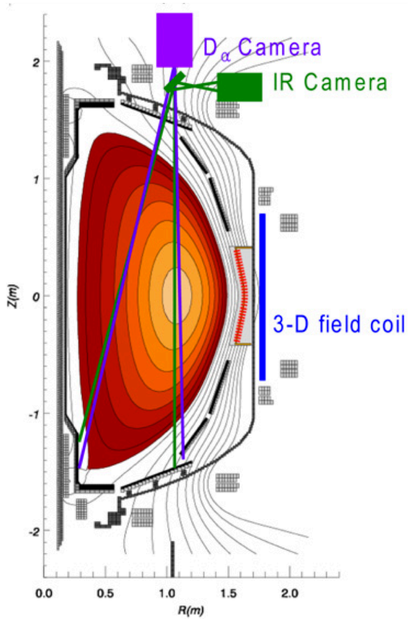
- Modulation in D_α emission can be generated without ELMs
- Impurity accumulation unchanged, secular increase in P_{rad}, n_e, n_c observed
- After a triggered ELM, carbon density, electron density, and P_{rad} drop

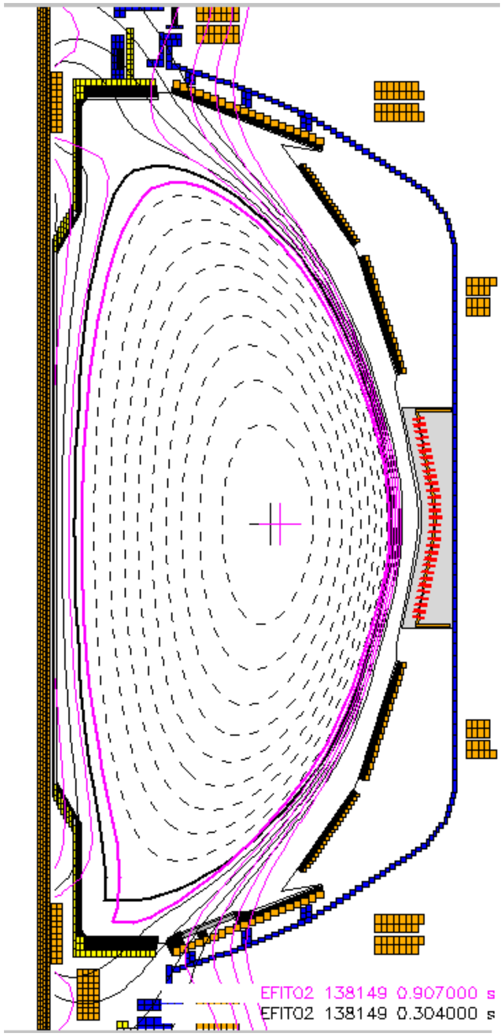


Diagnostics available to measure response to 3D pulses

- Response measured in
  - D_α light (filterscopes, 1D camera)
  - Edge USXR emission
  - Neutron rate
  - Divertor cameras
  - GAE amplitude
- Due to camera alignment and plasma shape, strike point is not in view of 2D IR camera until late in discharge

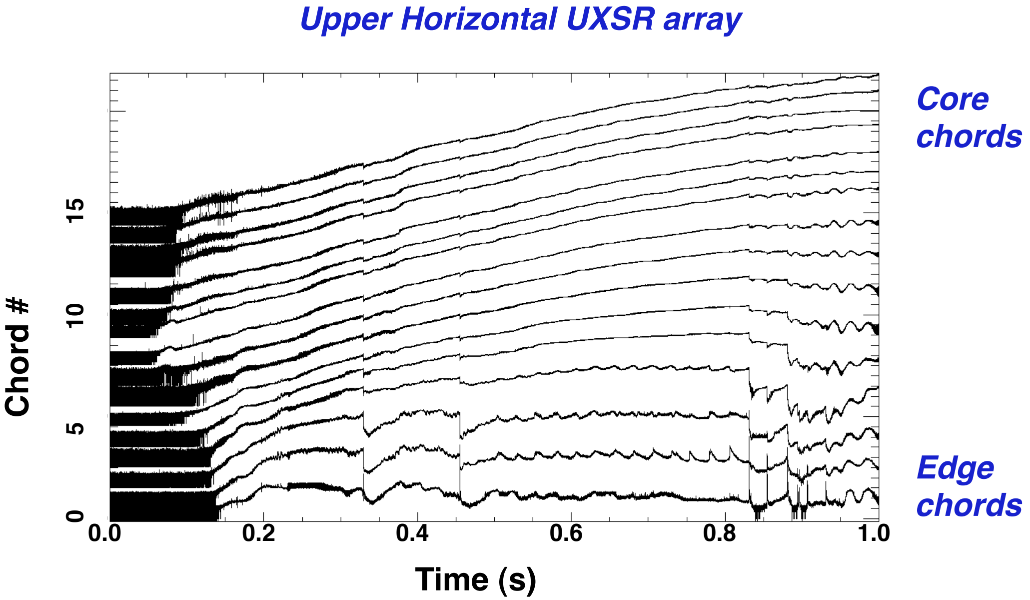


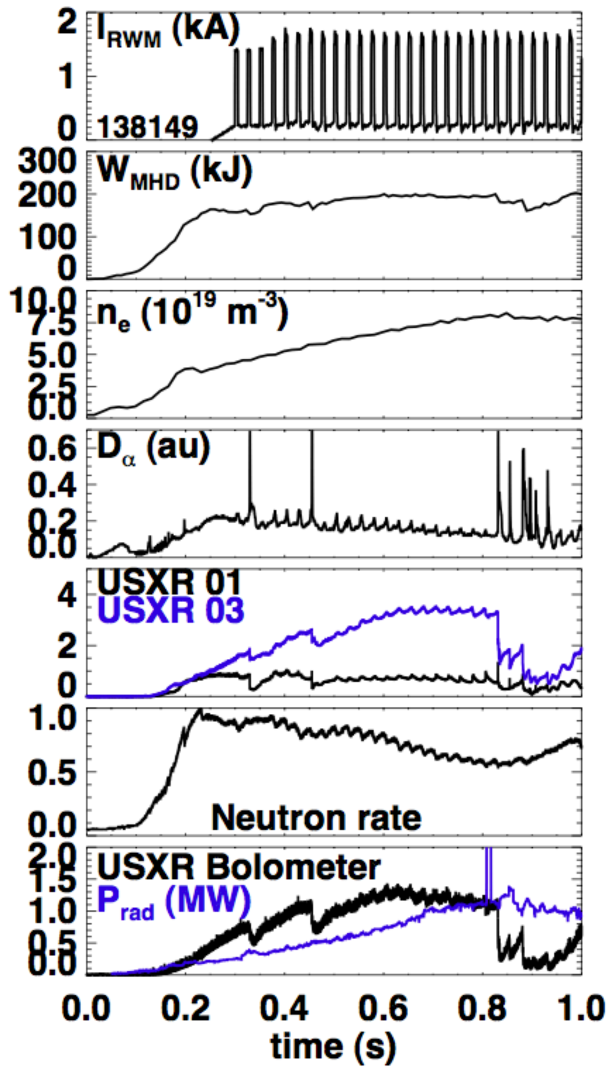




Effect of 3D pulses observed on several divertor/edge diagnostics

- 1.5kA, 6ms pulses applied at 40Hz
- Large ELMs result in changes to global quantities (stored energy, line averaged density, P_{rad} increase)
  - USXR emission affected on all chord views
- Sub-ELM responses localized to edge USXR chords

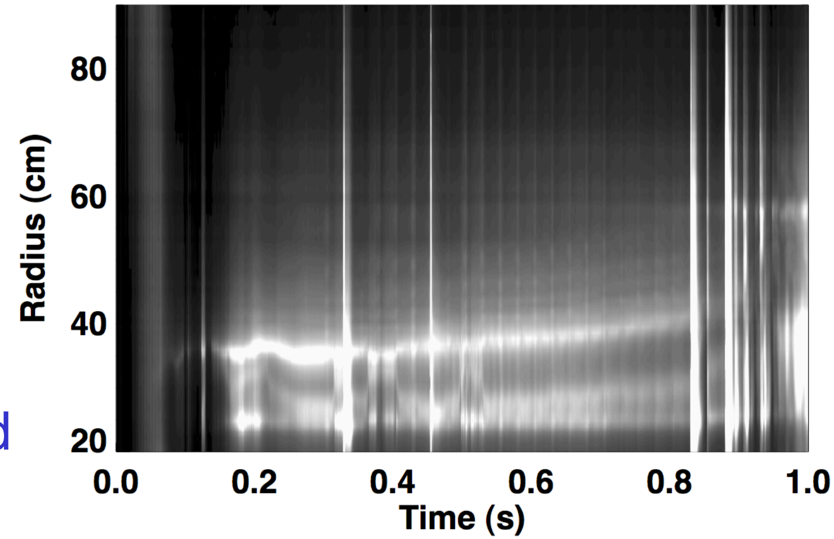




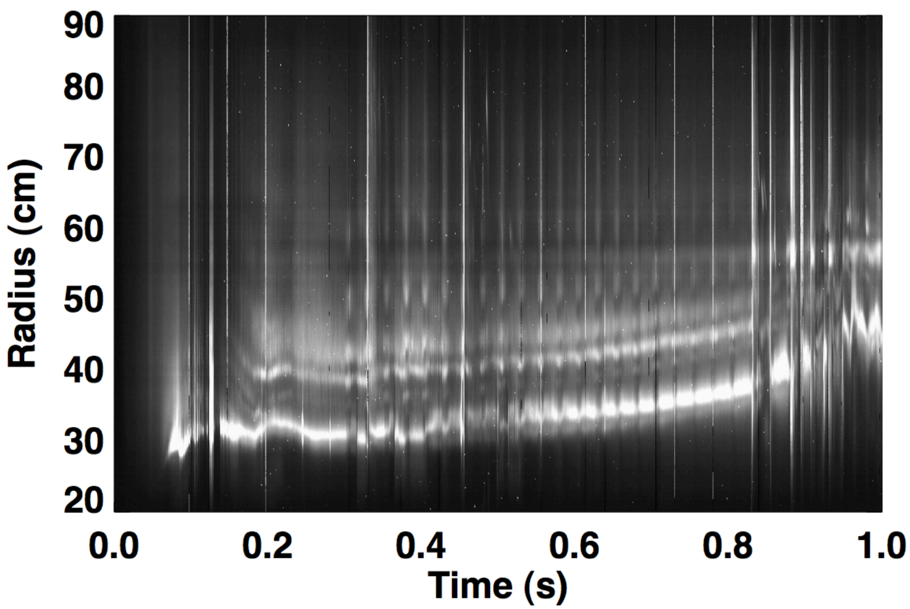
2D divertor cameras show spreading of target fluxes during 3D field pulses

- 3D field pulses result in 'spreading' of divertor flux
  - Results consistent with augmented strike point splitting (SPS) due to 3D field application
  - Intrinsic SPS due to error fields is observed before the pulses are applied

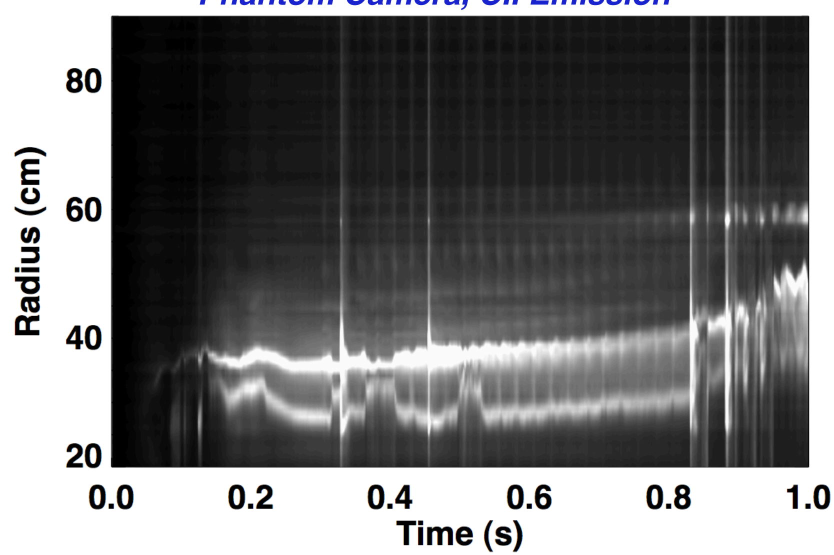
Phantom Camera, D_α Emission 138149



1D D_α camera

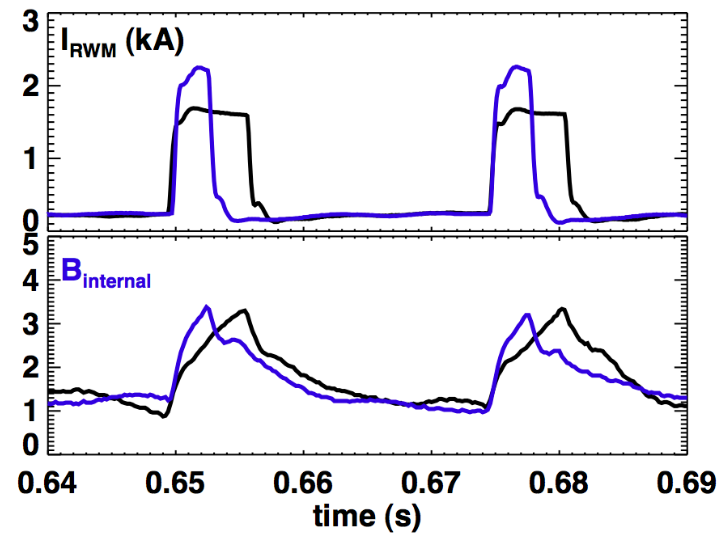


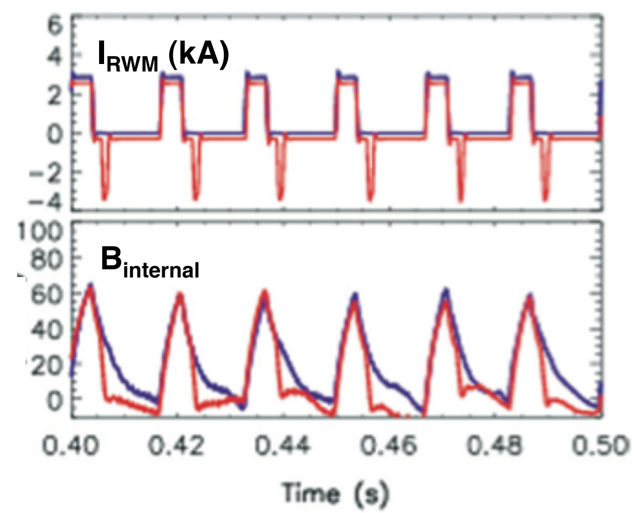
Phantom Camera, CII Emission



Internal field perturbation lags external field due to vacuum vessel eddy currents

- The measured internal field perturbation peaks at the end of the applied current square-wave pulse
  - The internal field decays slowly (~10ms) due to induced vessel eddy currents
- The duration of internal field perturbation can be reduced by applying a negative spike at the end of the current pulse
  - This method is not used for the results presented here

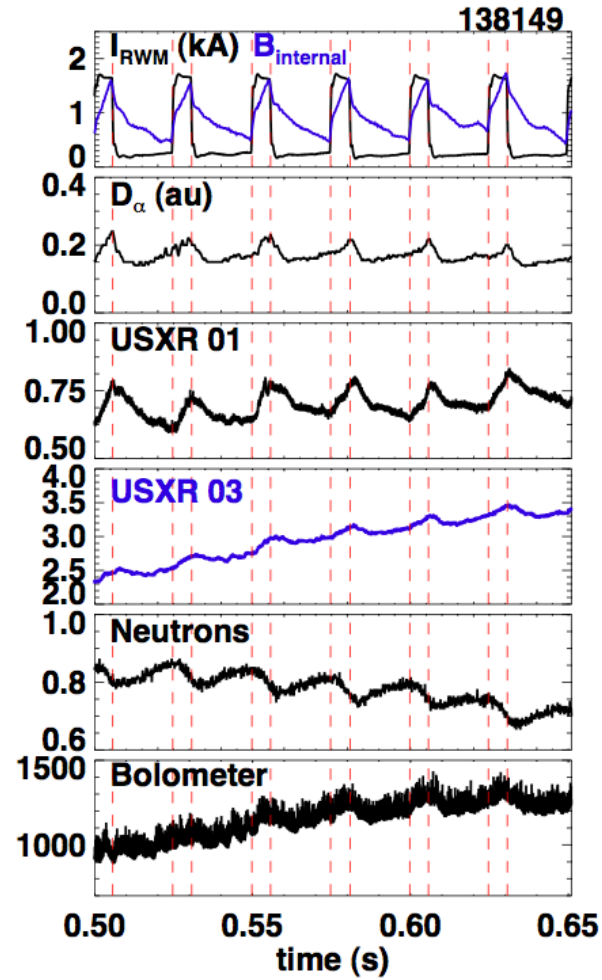




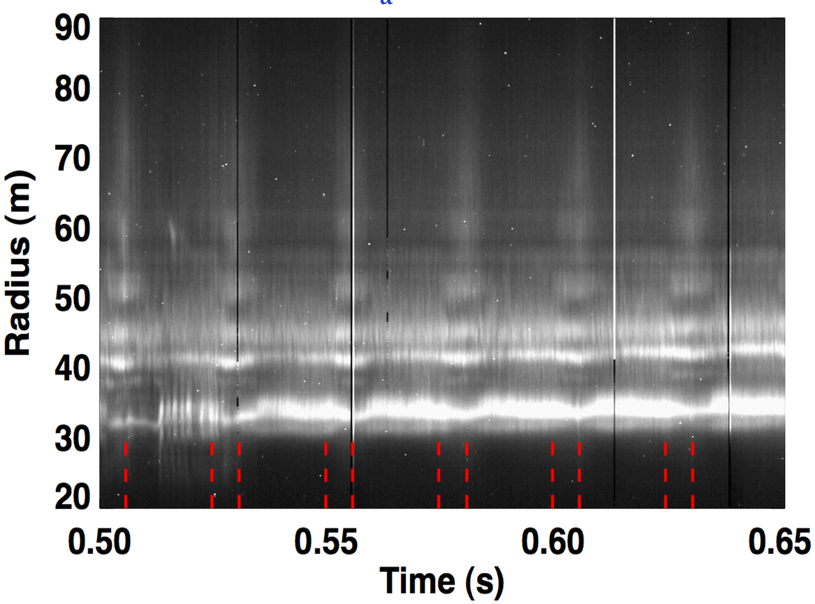
J.M. Canik, *et al.*, Nucl. Fusion **50** 065016 (2010).

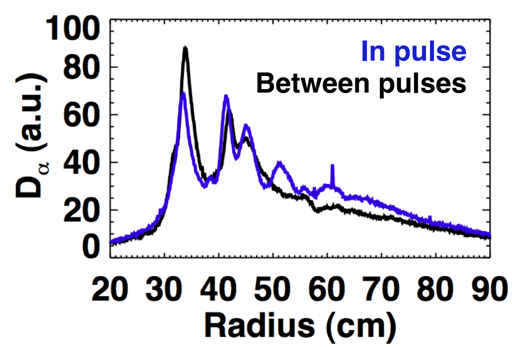
Responses follow internal magnetic field oscillation

- The internal perturbed field response is delayed by the vacuum vessel
- Responses follow the time evolution of the internal field
- Divertor D_α increases, addition peaks observed consistent with augmented SPS



1D D_α camera

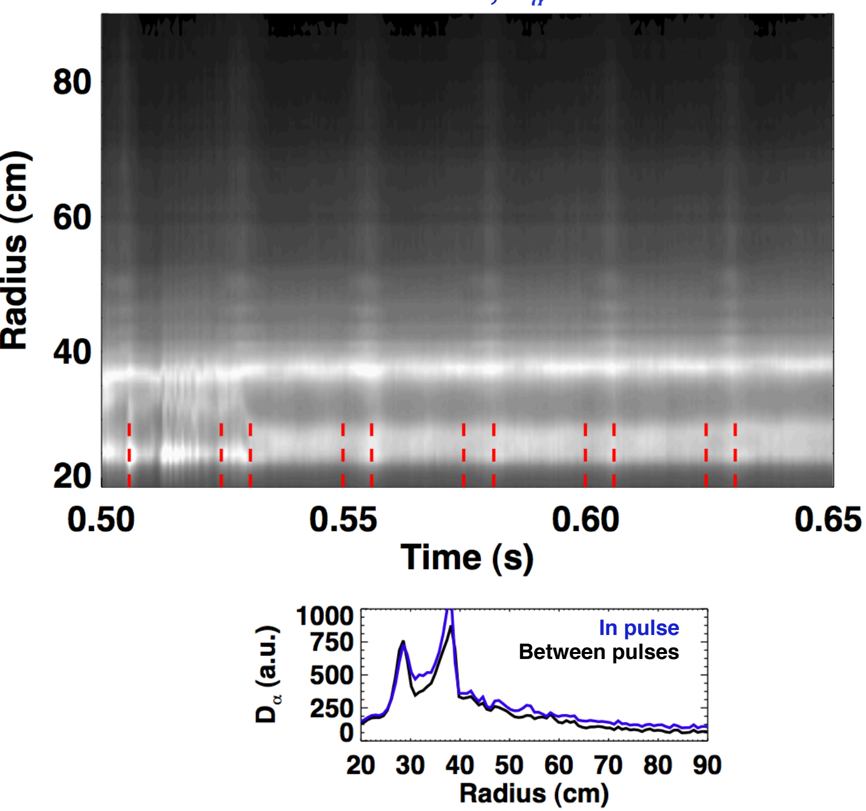




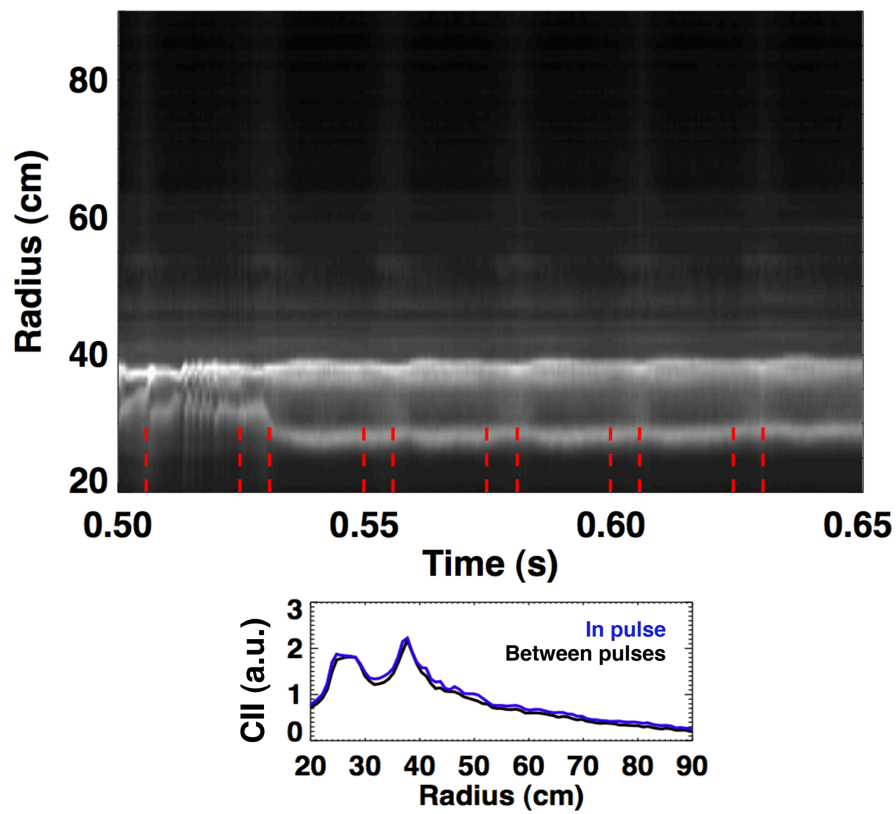
Spreading and augmented splitting of divertor footprints measureable in D_α and CII emission

- Phantom cameras show spreading of footprint patterns during pulse
  - Augmented splitting measurable but not as clear as 1D ccd camera
- Fast IR camera view does not include strike point in this configuration

Phantom Camera, D_α Emission

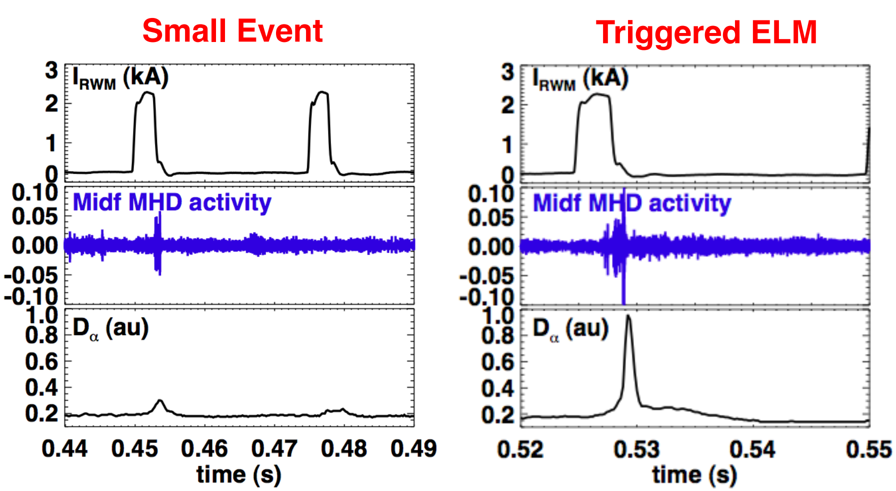


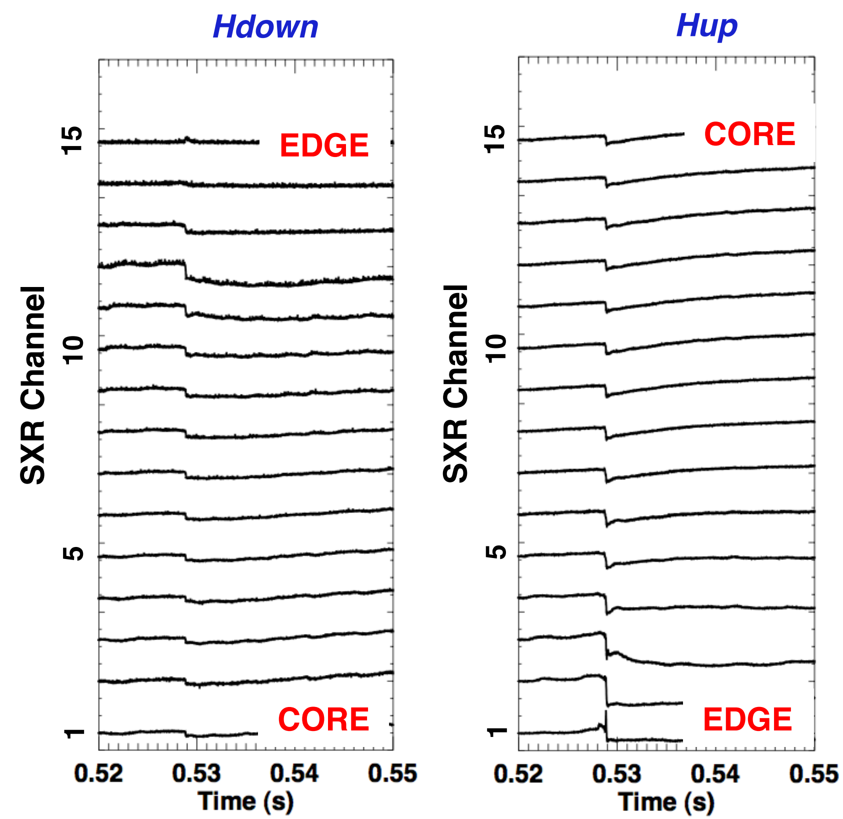
Phantom Camera, CII Emission



Small response is very from that of a regular triggered ELM

- Inversion layer indicated by edge SXR channels during regular ELM
  - No clear inversion layer for small transport event, effects localized to far edge channels
  - High resolution USXR system planned for NSTX Upgrade
- No consistent MHD activity during small transport events
  - However some pulses trigger MHD activity with no ELM

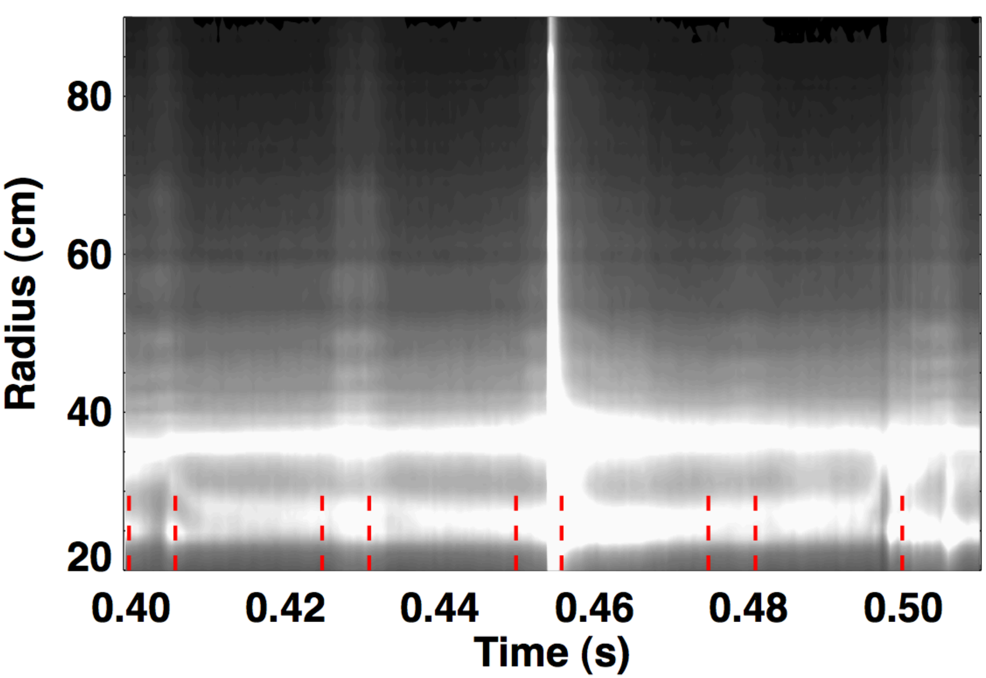


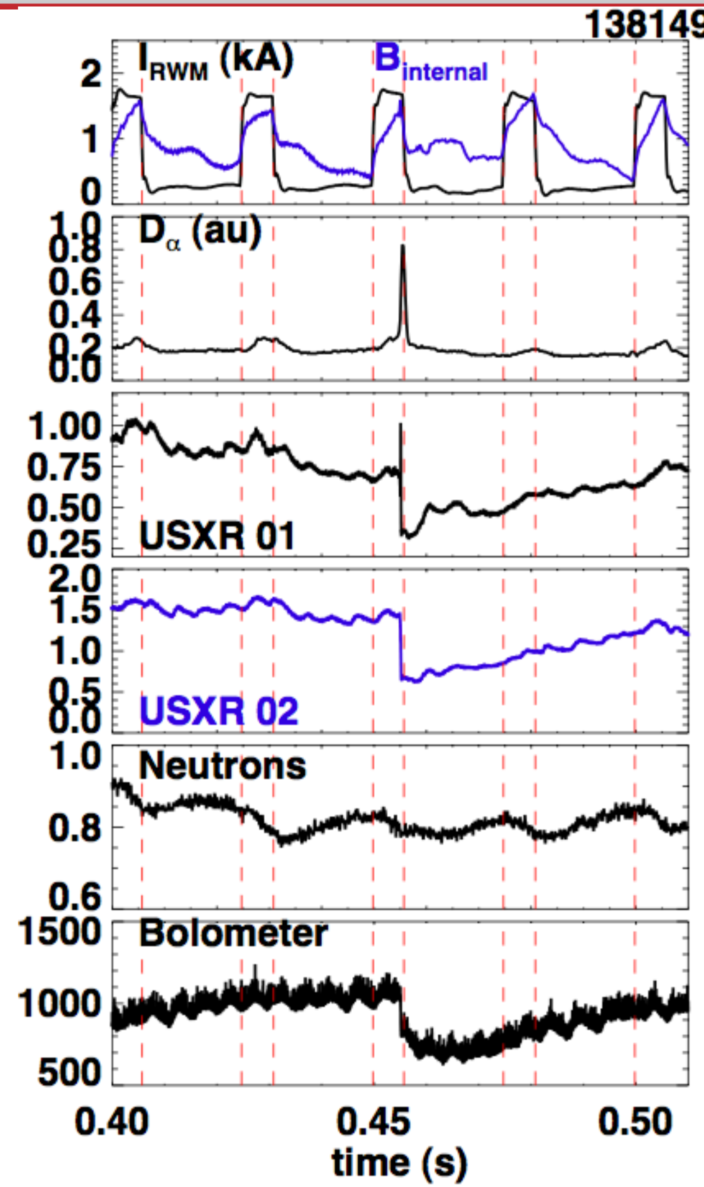


Large ELM response appears superimposed over 3D pulse response

- Increase in D_α, affects on USXR and neutron rate occur before ELM triggered
- Recovery timescale much longer for large ELM

Phantom Camera, D_α Emission

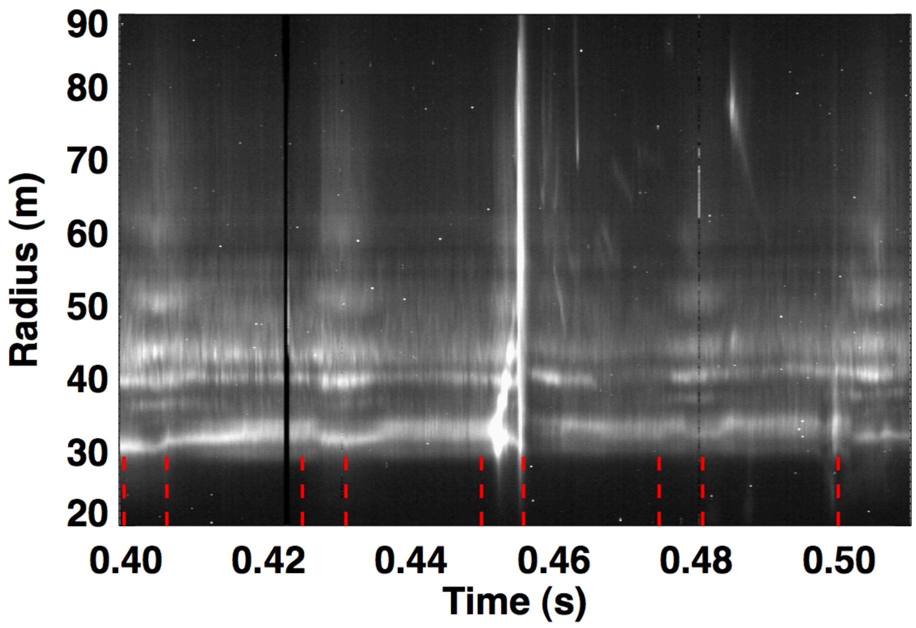




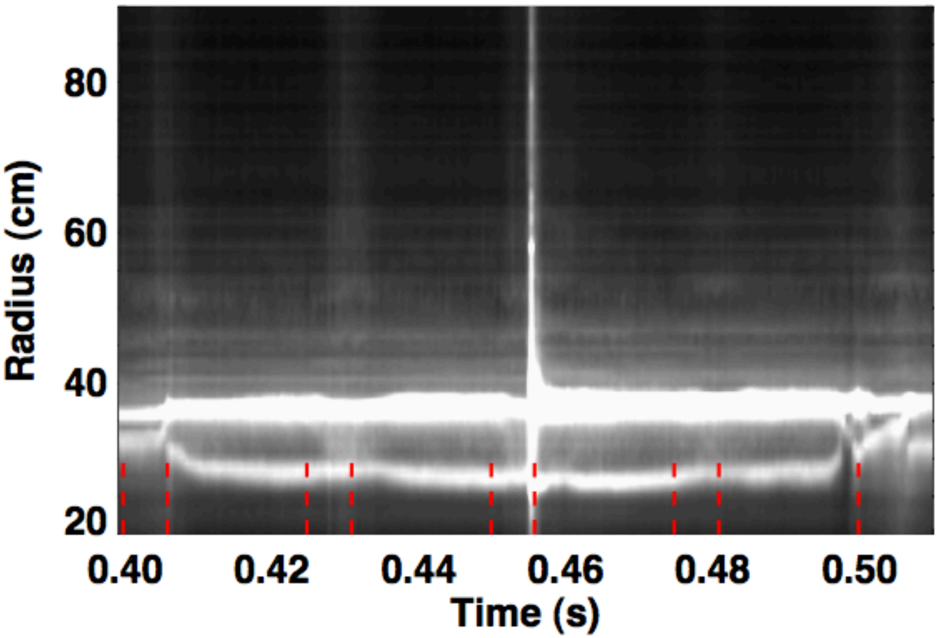
Large ELM response appears superimposed over 3D pulse response

- ELM timescale much shorter than pulse response
- ‘Normal’ pulse response affected after ELM until base trends recover

1D D_α camera

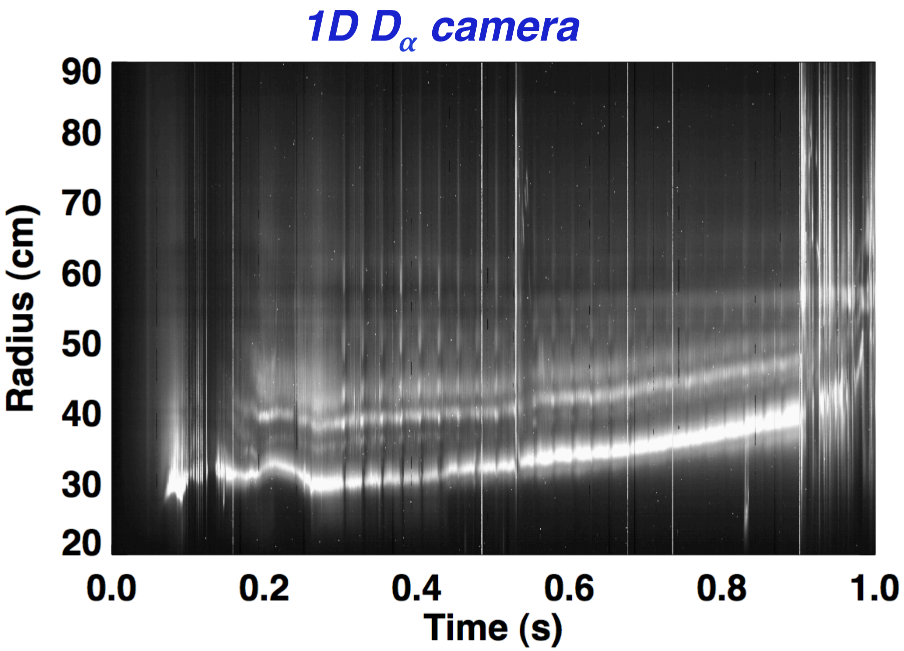


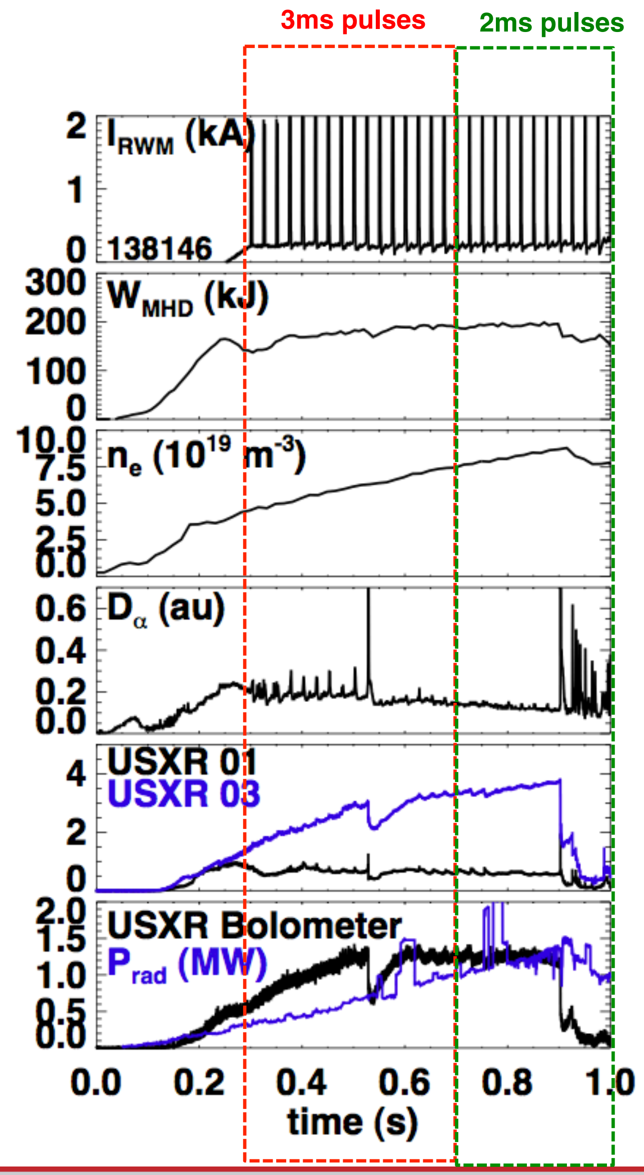
Phantom Camera, CII Emission



Results are similar for other pulse lengths and magnitudes

- Shot 138146 has two different 40Hz waveforms applied
  - 2kA, 3ms pulses
  - 2kA, 2ms pulses
- After triggered ELM D_α response is smaller in magnitude

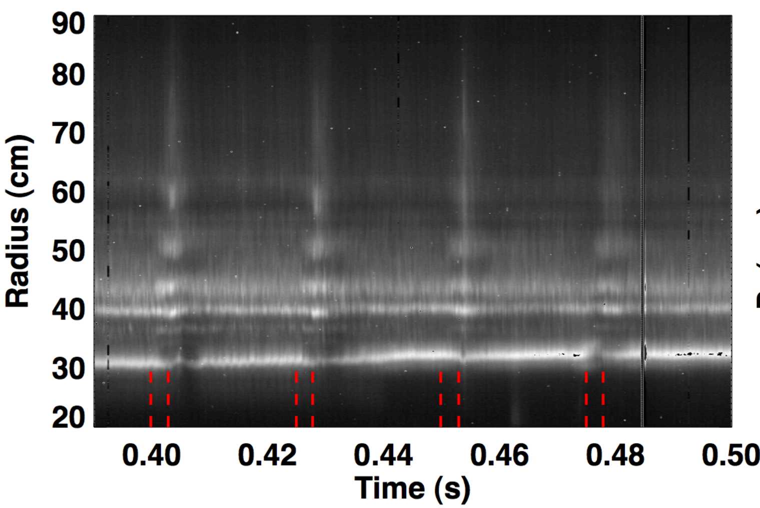


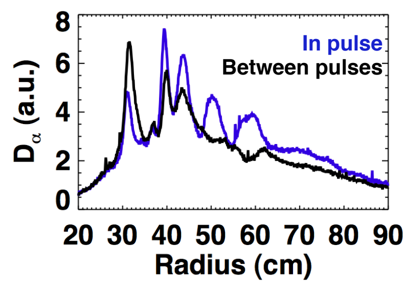


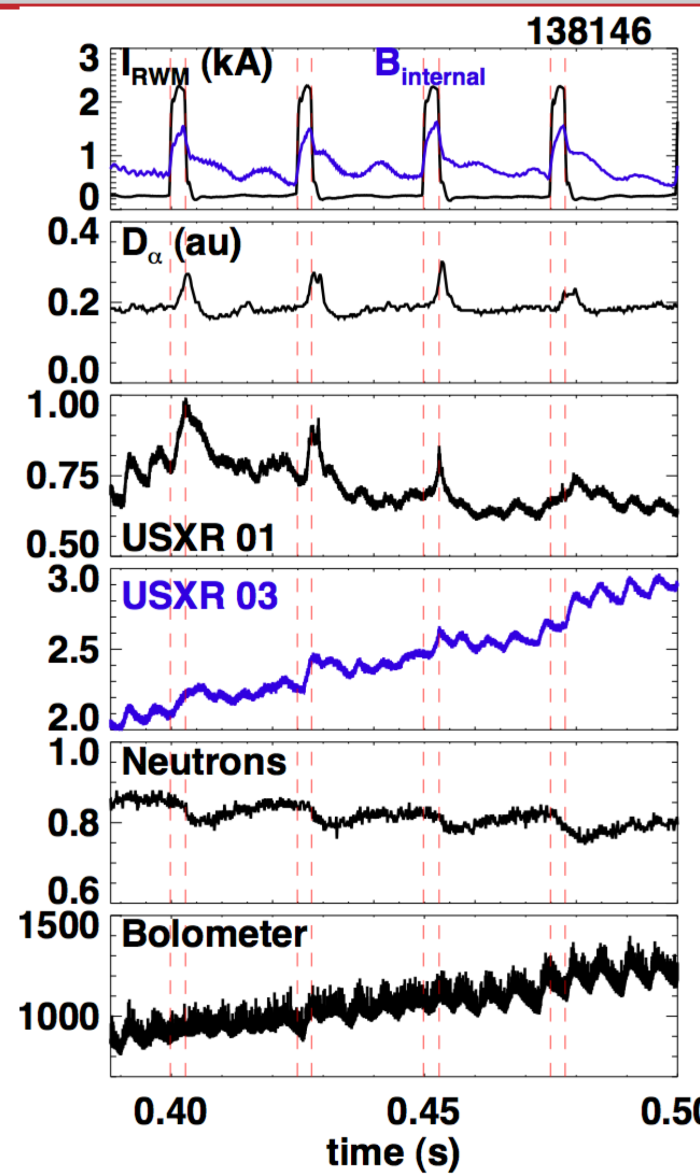
Characterization of small transport events for 3ms, 2kA pulses

- Pulses have increased amplitude, shorter duration than previous case
  - Responses are correspondingly faster
- Responses peak near time of $B_{internal}$ maximum
- Clear augmentation of strike point splitting measured on D_α camera

1D D_α camera



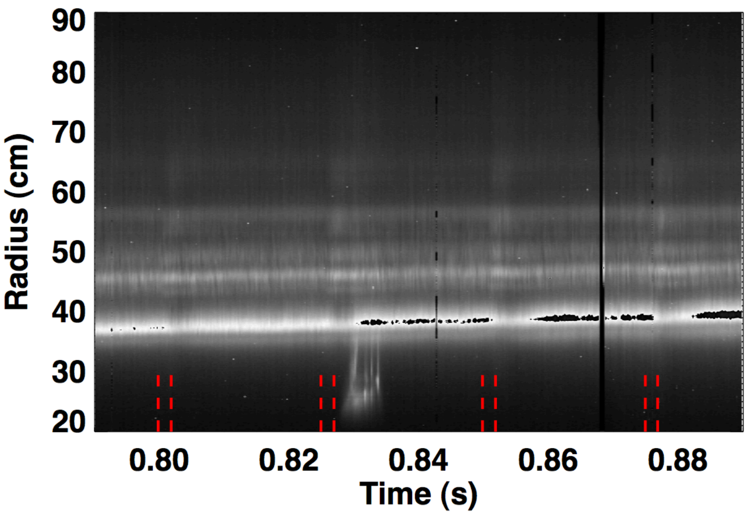


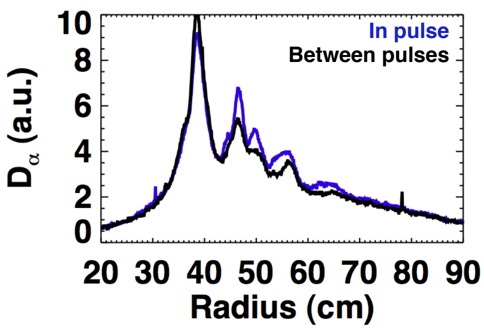


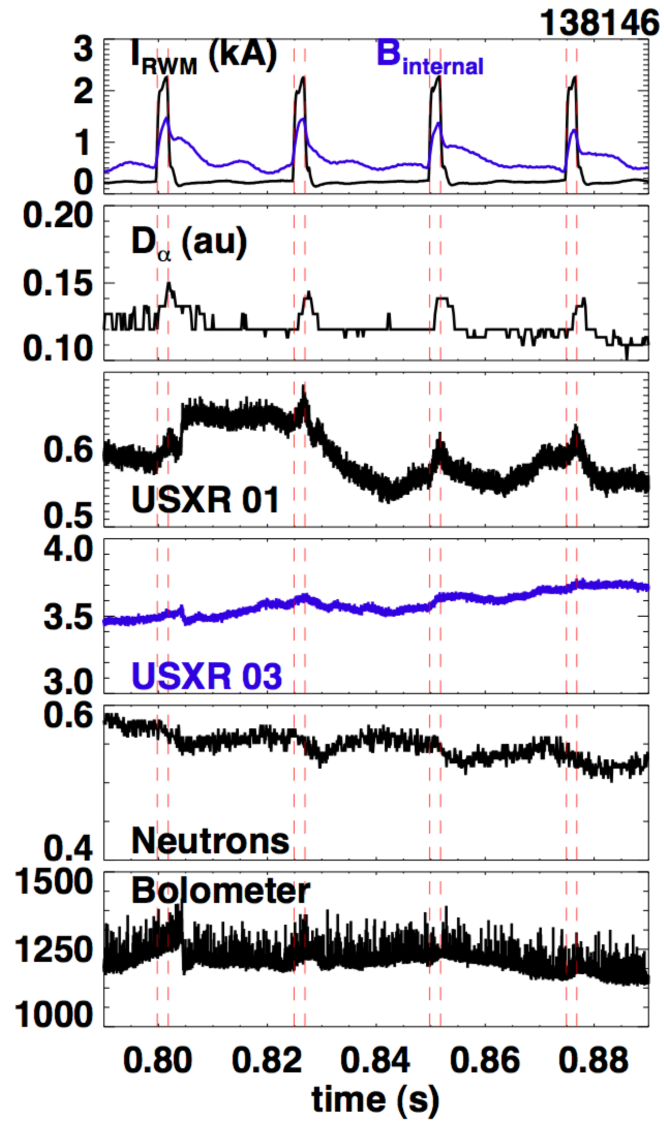
Characterization of small transport events for 2ms, 2kA pulses

- Shortest pulse duration used, 2ms
  - Responses are small but measurable
- Augmented strike point splitting again measured

1D D_α camera

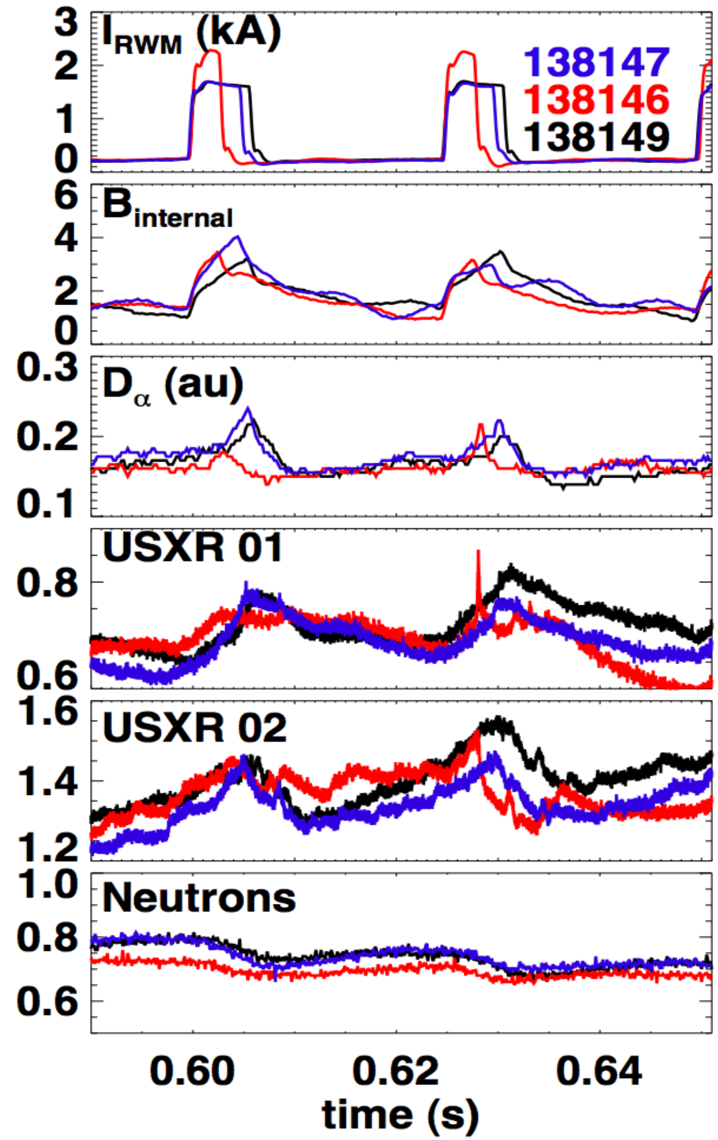






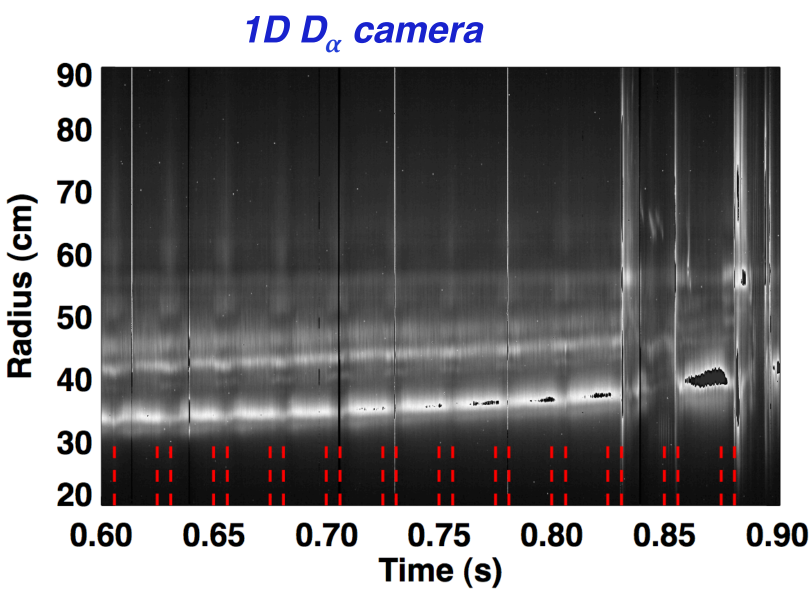
Timescale of responses are strongly correlated with the internal perturbed field

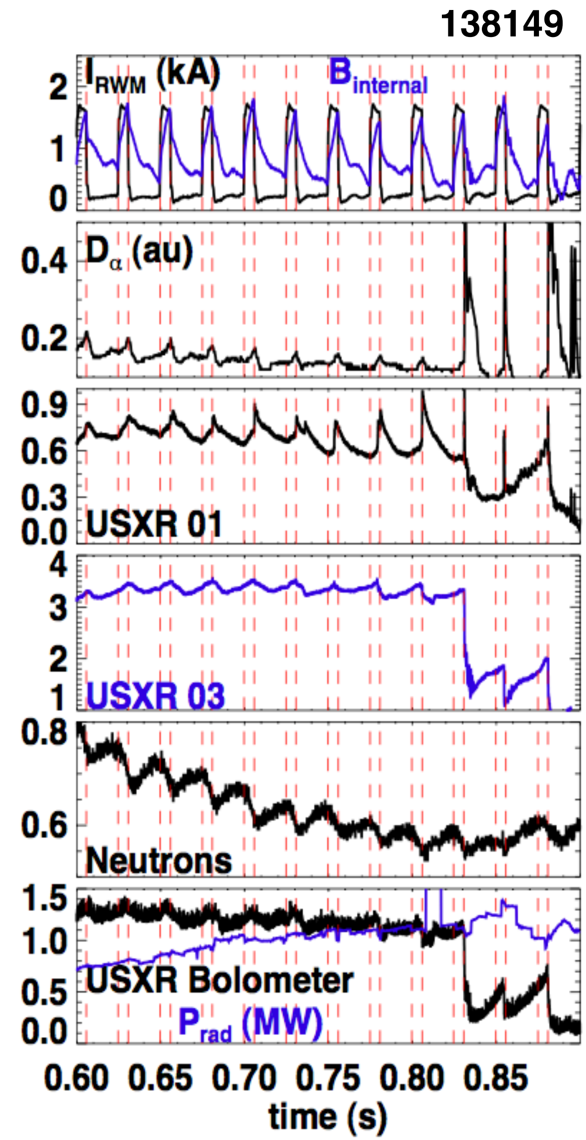
- A shorter 3D pulse results in a shorter response.
- Timescale of strike point splitting/divertor pattern spreading also consistent



Some pulse trains shown indications of fast timescale events

- Some edge USXR channels show fast timescale events increasing in magnitude before a triggered ELM
  - Even in these cases the effect is localized to three or four edge USXR channels
- Divertor footprint appears unchanged, effects very different from large ELMs

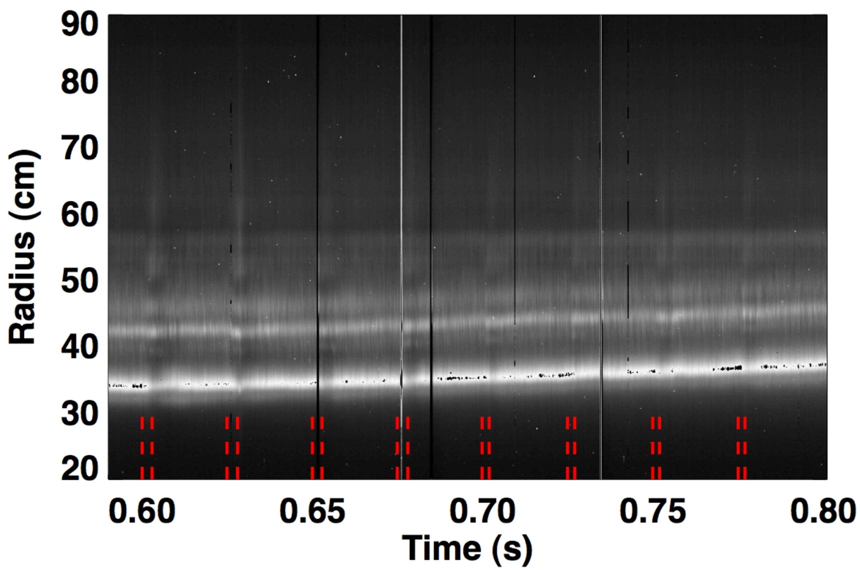


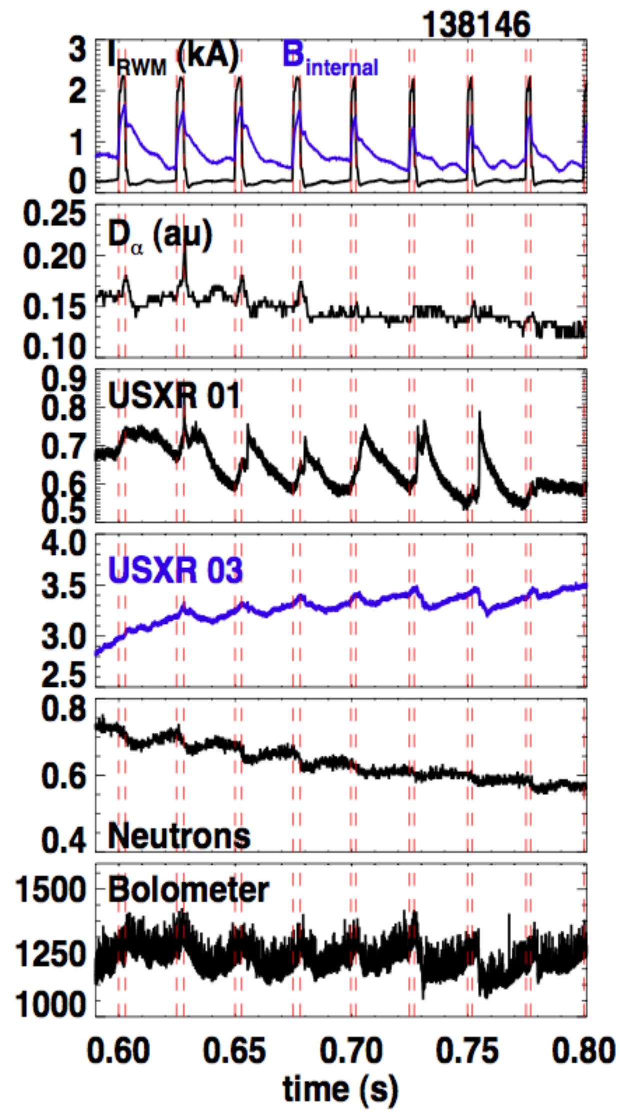


Some pulse trains appear similar to small ELMs, but no obvious divertor signature, P_{rad} effect.

- For some short pulses a fast timescale event occurs shortly after the $B_{internal}$ peak
  - Unclear what causes this different behavior
- Time traces appear similar to small ELM, but no consistent divertor pattern is observed
  - Still no reduction in impurity, P_{rad} evolution in this case.

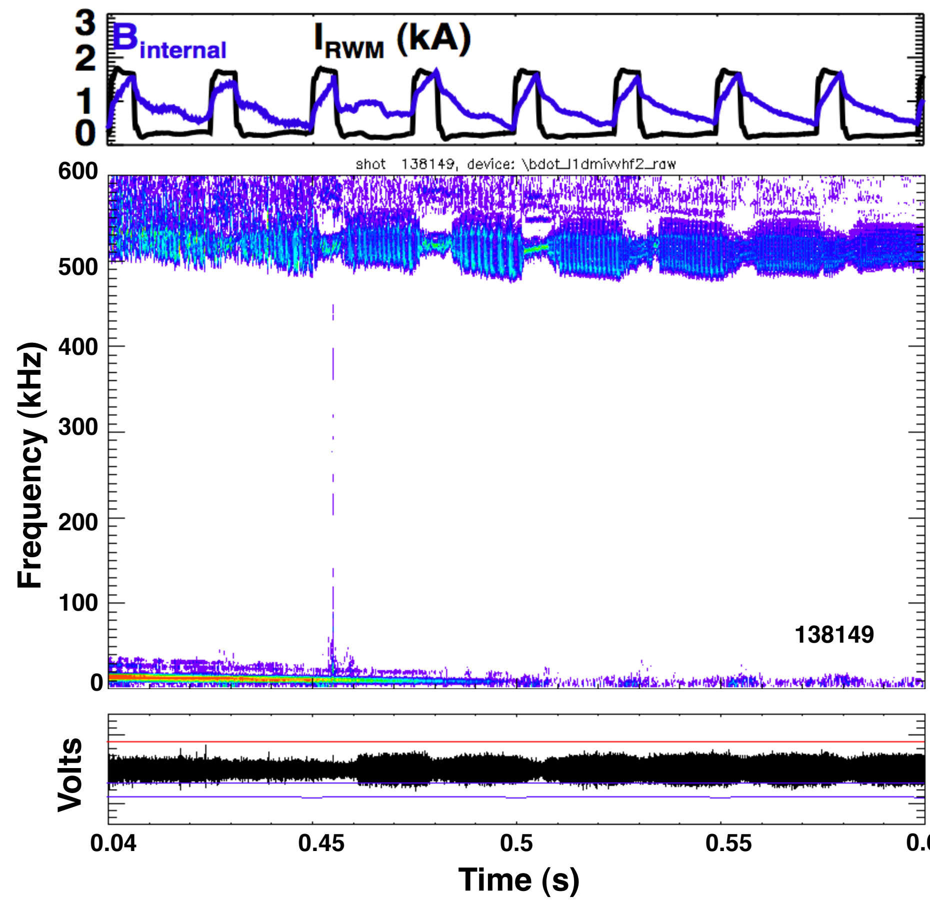
1D D_α camera





High frequency mode is modulated by 3D pulses

- If mode affects fast ion distribution this could explain the drop in neutron rate during pulses
- Change in neutron rate could also be caused by changes to the density profile, difficult to reconstruct Thomson profiles during pulses



Conclusions

- 3D field application below the ELM-triggering threshold results in regular small perturbations measurable by edge diagnostics
  - Small increases in divertor D_α and edge USXR signals
  - Spreading of the divertor footprints measured by fast cameras
  - Decrease in neutron rate and modulation of GAE mode
- The responses are consistent with increases in the SOL transport and strike point splitting
  - Timescale of events are proportional to the timescale of internal magnetic field perturbation
- Some fast timescale events are observed, however the signature is different from ordinary ELMs
- These responses appear to be insufficient to reduce the impurity accumulation and density rise in ELM-free H-modes