Study of Type I ELM Systematics Using Soft X-ray Analysis on NSTX

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Abstract

NSTX plasmas exhibit a range of ELM behavior during H-mode discharges, including relatively large discrete phenomena classified as 'Type I' ELMs. These ELMs can cause a reduction in the plasma stored energy of up to 15% and can perturb the electron temperature profile by triggering a cold pulse that propagates radially inward on timescales of hundreds of microseconds. However, different operating regimes can exhibit smaller 'Type I' ELMs which have a much smaller effect on the stored energy and electron temperature profile. The soft X-ray system on NSTX has the capability to examine the fast temperature perturbations and measure the propagation of these events via a 'multi-color' technique which uses various X-ray filters to measure the incident X-ray spectrum with different energy cut-off thresholds. This technique is used to study the variety of 'Type I' ELM behavior and relate the differences to NSTX plasma conditions.

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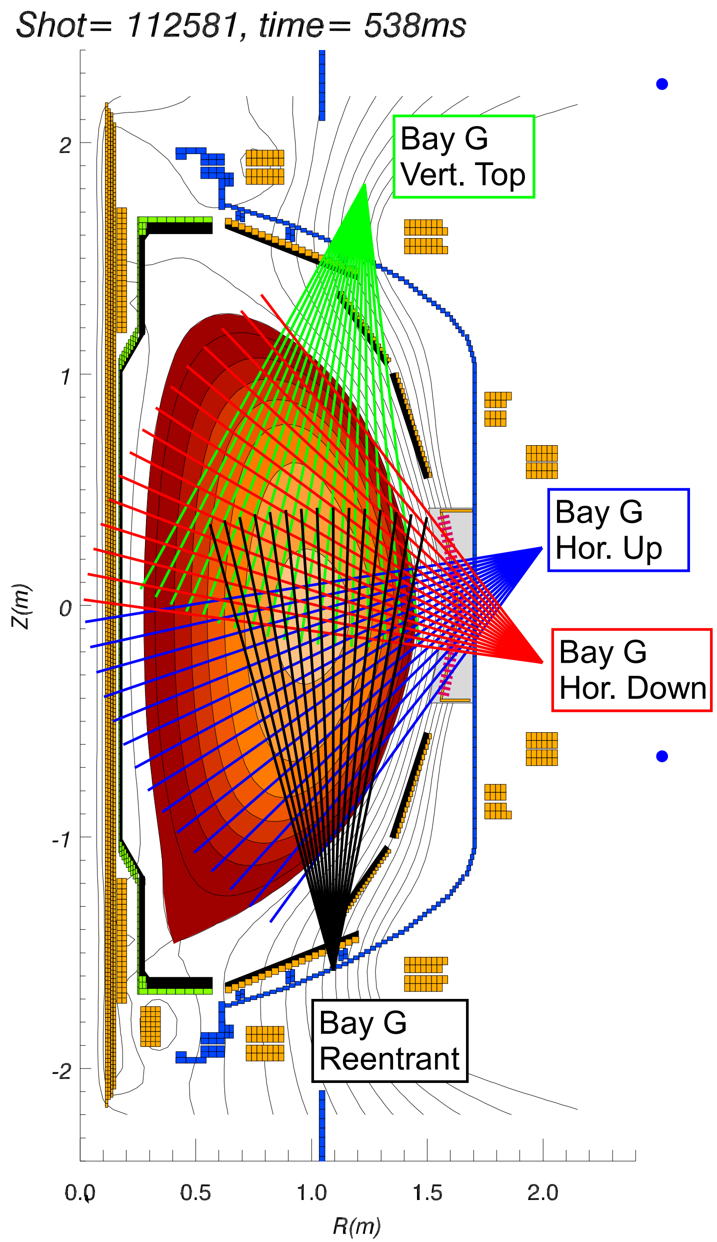
Outline

- SXR system on NSTX
- Identification of distinct ELM regimes in NSTX
- Description/Parameters of ELM Perturbation Study
- Two-color SXR imaging of ELM perturbations
- Differences between Large and Small Type I ELMs
- Characterization of ‘Type I’ ELM perturbation
- Future Work
- Summary

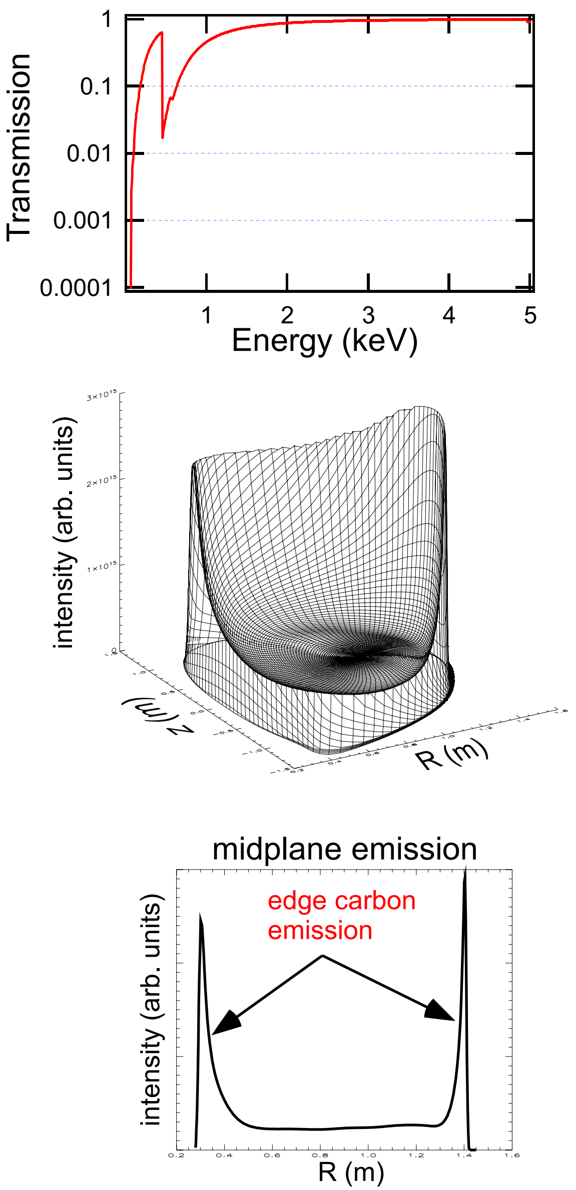
Bay G SXR system provides poloidal spatial coverage



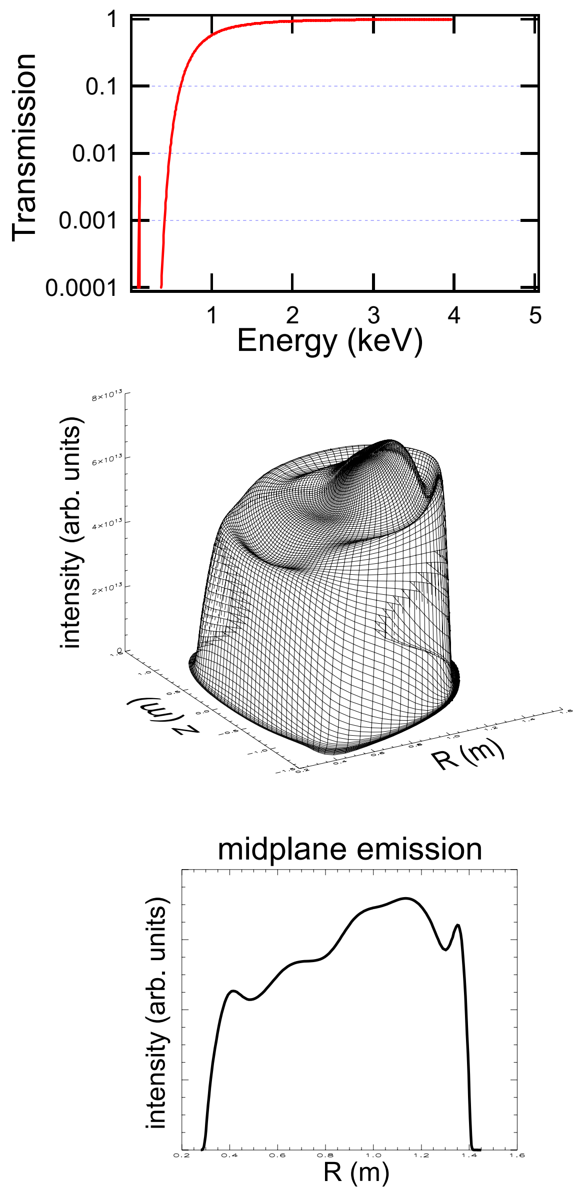
- Imaging and tomographic reconstruction used to analyze plasma activity
  - Oscillatory events (MHD modes, islands)
  - Intermittent events (sawteeth, ELMs, reconnections)
  - Slow phenomena (rotating/locked modes, RWMs)
- Arrays utilize variable filter settings to change plasma region focus
  - 0.4μm Ti filter views primarily edge C emission
  - 10μm Be filter passes X-rays from bulk plasma
  - 100μm Be filter focuses on core plasma emission

Various filters isolate X-ray contribution from different regions of plasma

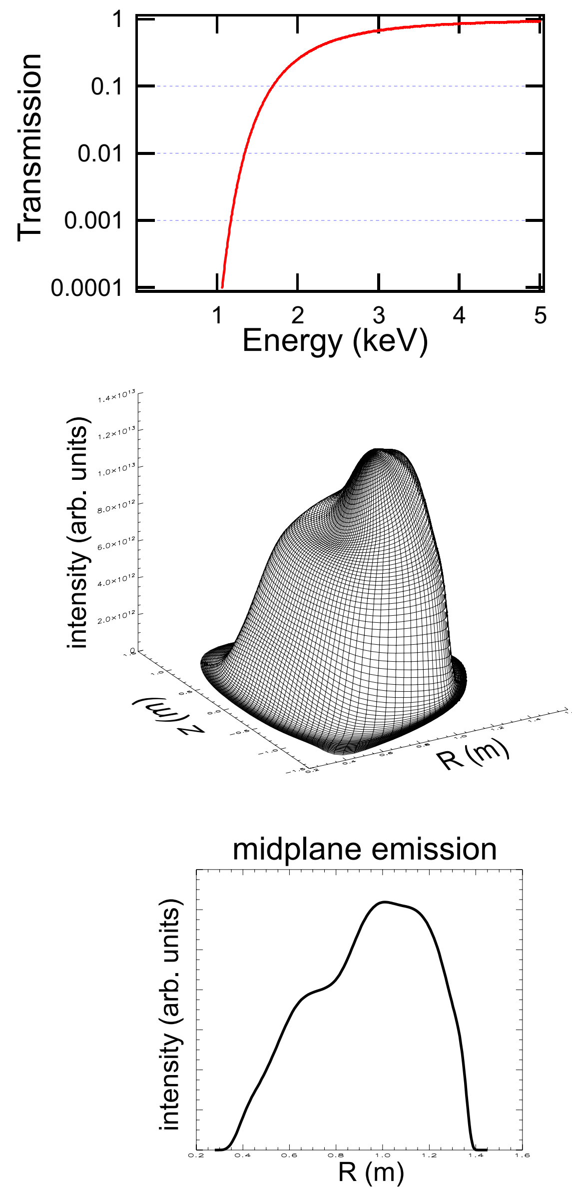
Ti 0.3µm



Be 5µm

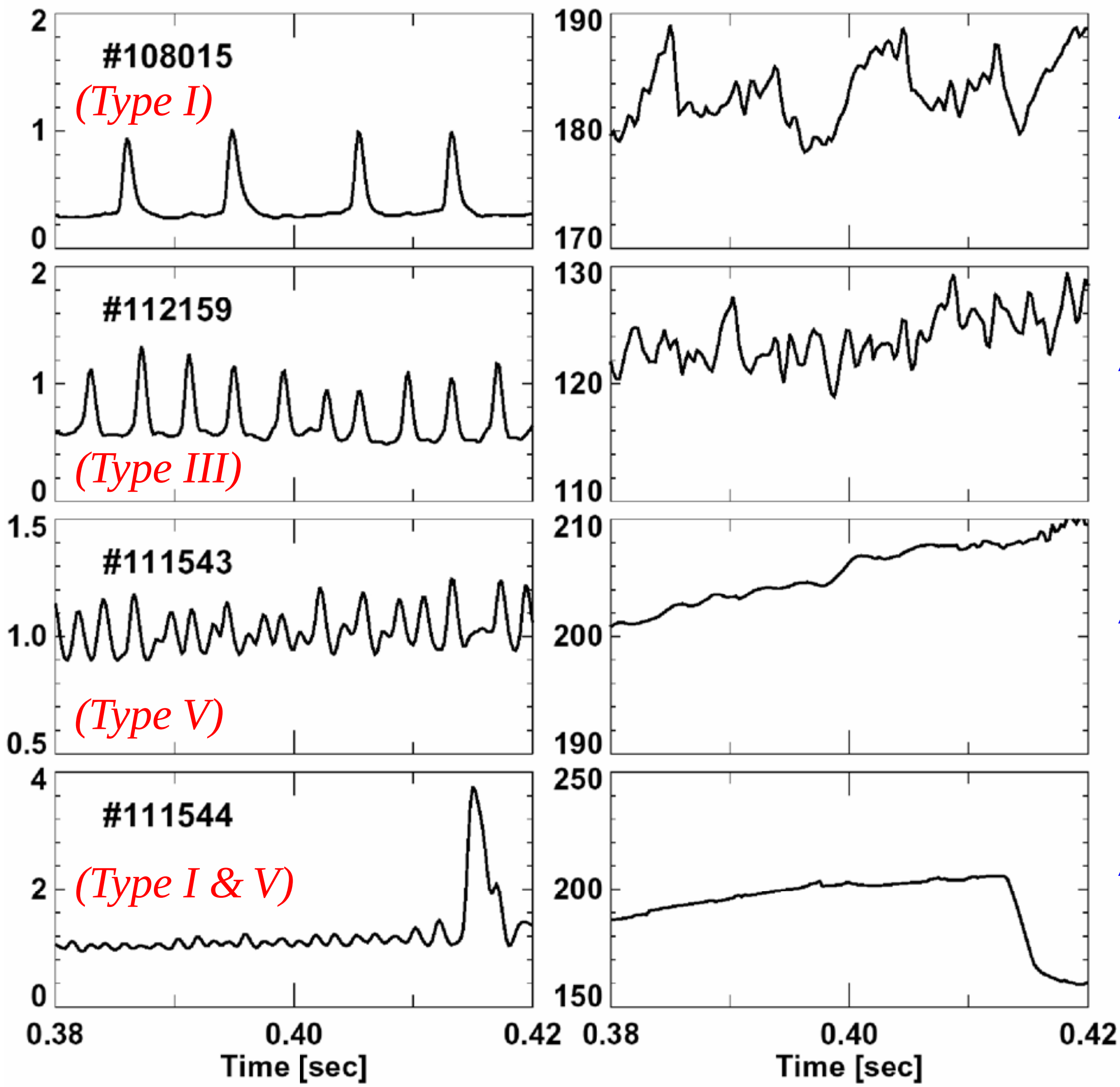


Be 100µm



Many different ELM types observed in NSTX

D_α (arb.units) W_{MHD} (kJ)



$\Delta W_{MHD}/W_{MHD} \sim$ 3-15%

$P_{heat} >> P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \sim$ 1-5%

$P_{heat} \geq P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \leq$ 1%

Wide P_{heat} range

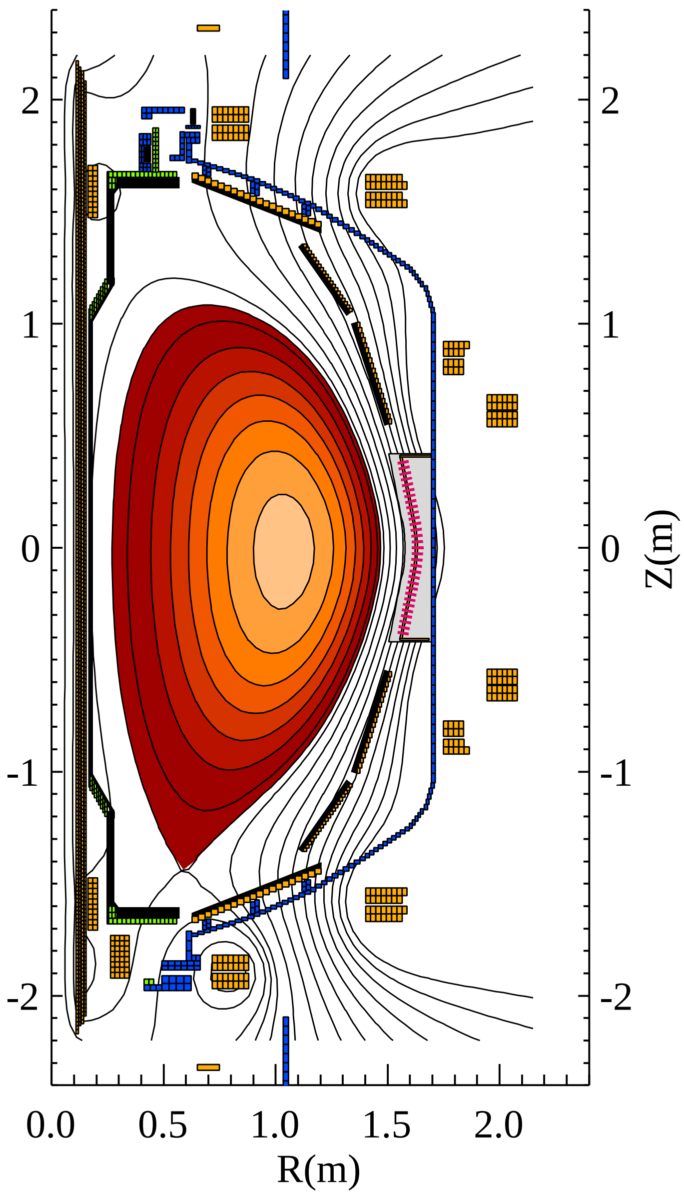
$\Delta W_{MHD}/W_{MHD} \leq$ 30%

High P_{heat} β_N

What Causes Type I ELM Variability?

- Type I ELMs can cause a range of energy loss from ~3-5% to >20%
  - Large energy loss corresponds with global drop of T_e profile
- Global T_e perturbation possibly due to transport effects
  - Only small precursors observed on Mirnovs regardless of ELM size
  - No large MHD modes seen on SXR arrays
  - Time scales of profile perturbation ~100's of μsec
  - No corresponding global perturbation of n_e profile
- If perturbation is driven by transport effects, try to modify electron transport
  - Experiment run on NSTX to scan I_p and measure ELM perturbations

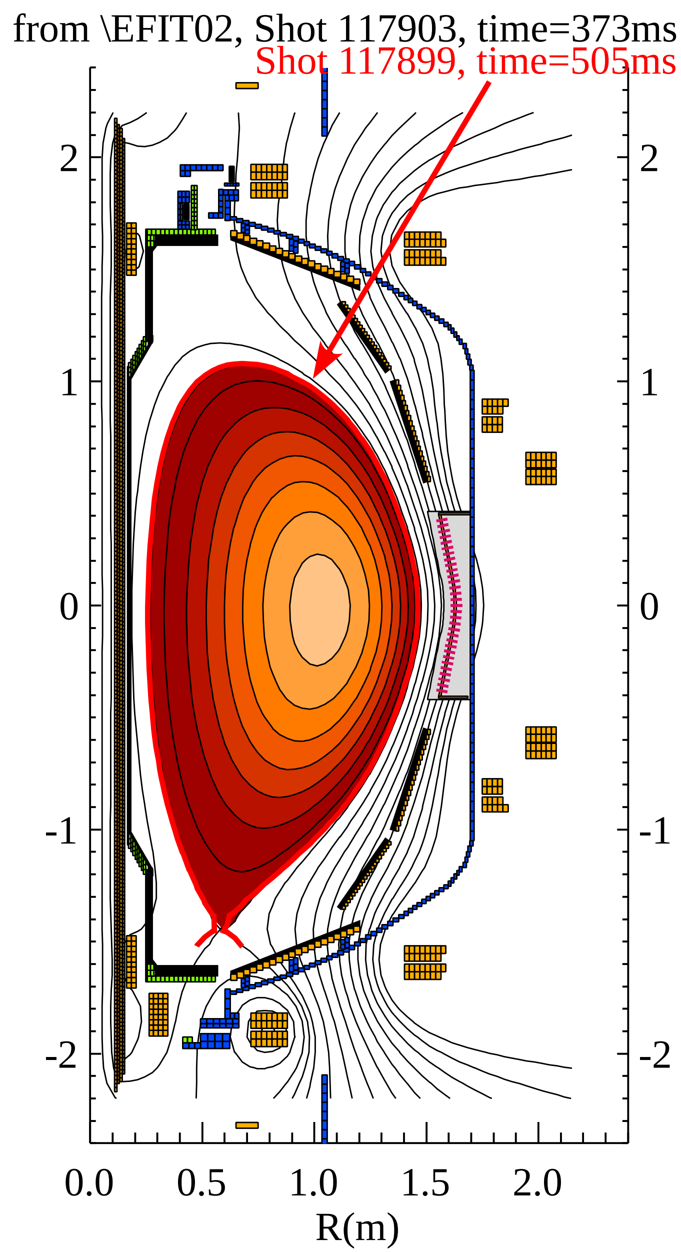
Large/Small Type I ELM perturbation vs. Ip

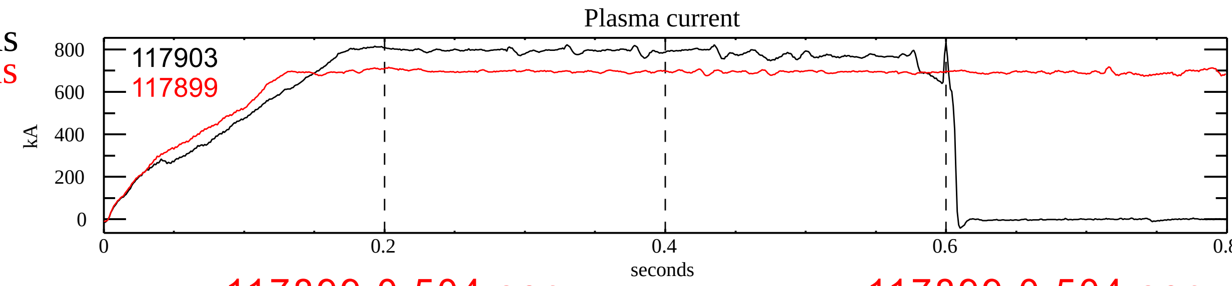


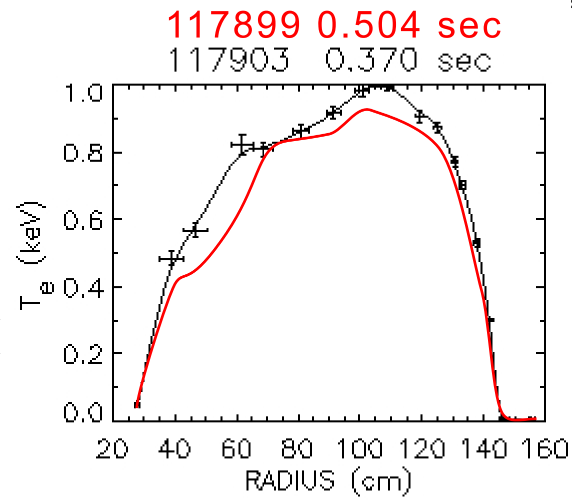
I_p	0.7 - 0.95MA
B_T	0.45T
P_{NB}	5.5MW
W_{MHD}	180 - 200kJ
β_T	10 - 15%

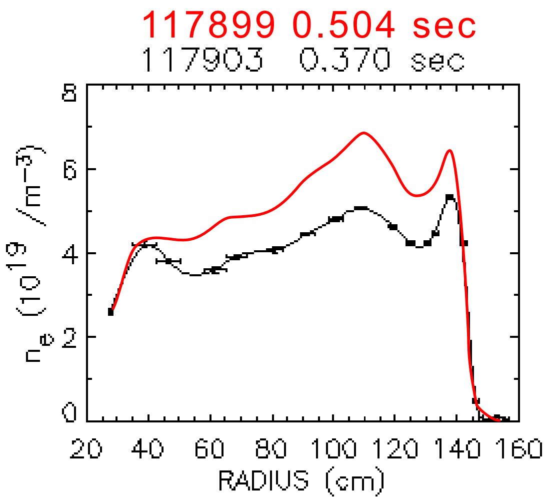
- Qualitative difference seen in ELM perturbation
  - Low I_p (0.7MA) → small perturbation ΔW~3-5%
  - High I_p (>0.8MA) → large perturbation ΔW~10-20%
- SXR arrays show difference in penetration of ELM perturbation

Plasma Boundary Similar between Discharges



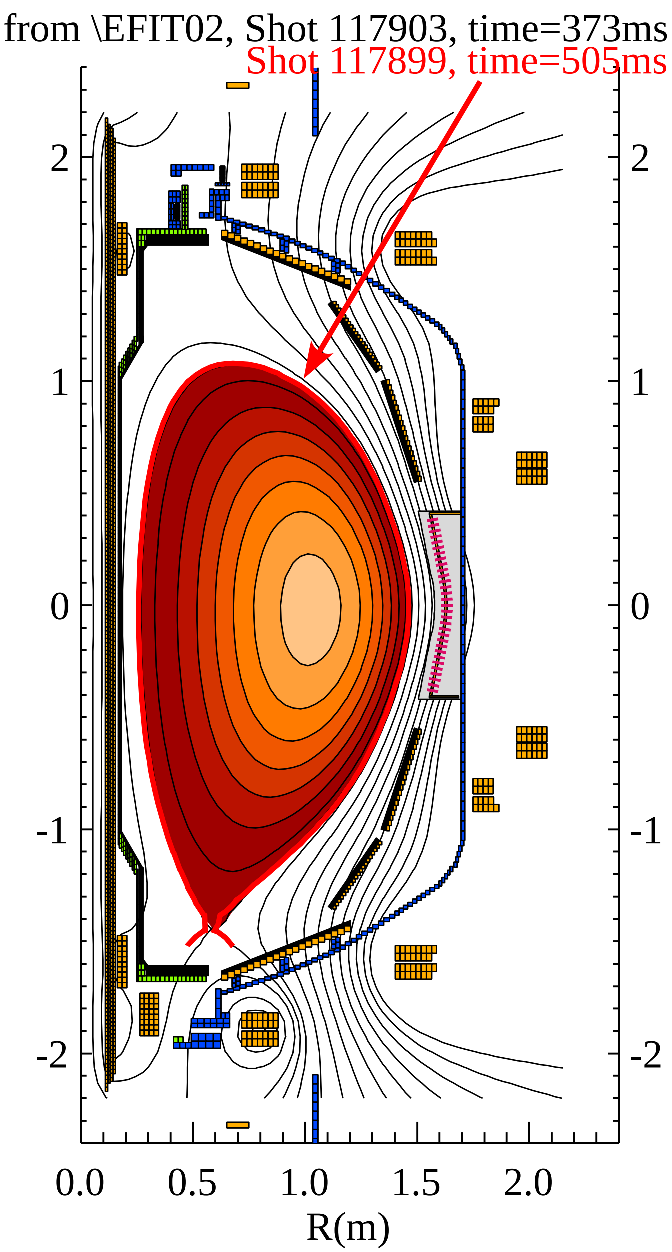


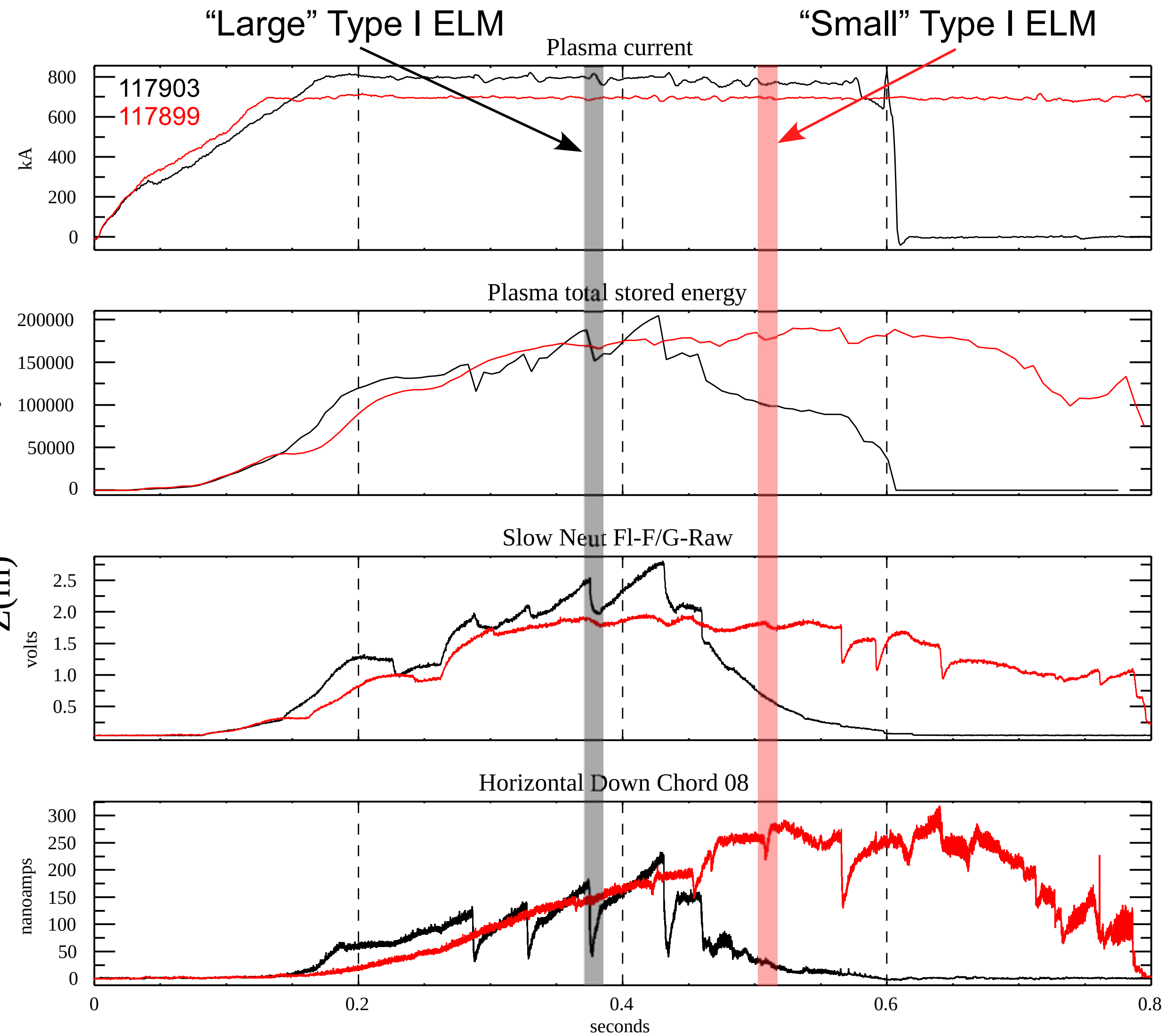




- Higher current discharge corresponds to ~10% higher core T_e, lower $n_e(r)$
- Edge T_e and n_e gradients similar
- No large scale islands or other coherent MHD modes observed

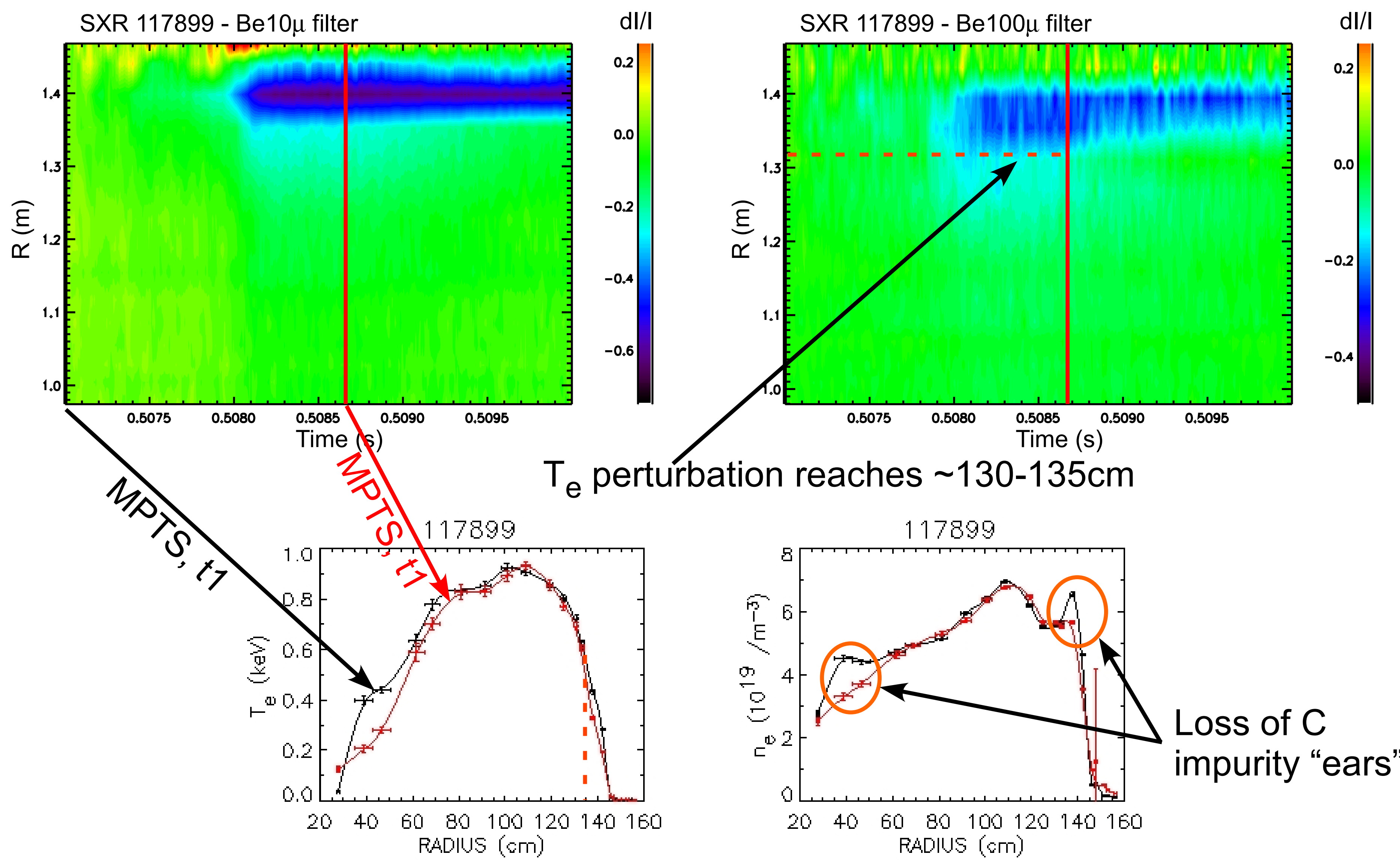
ELMs Show Difference in T_e Related Signals





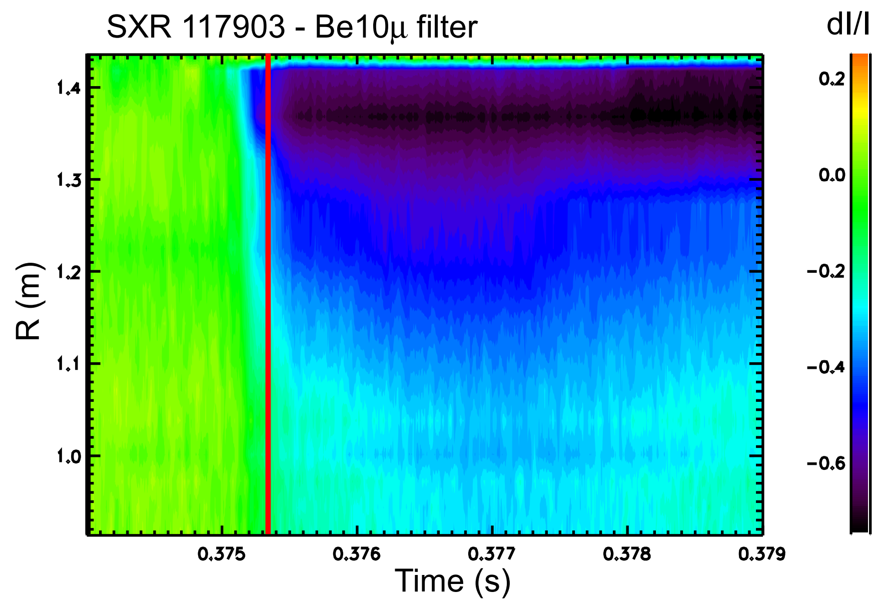
- I_p change appears related to different ELM character

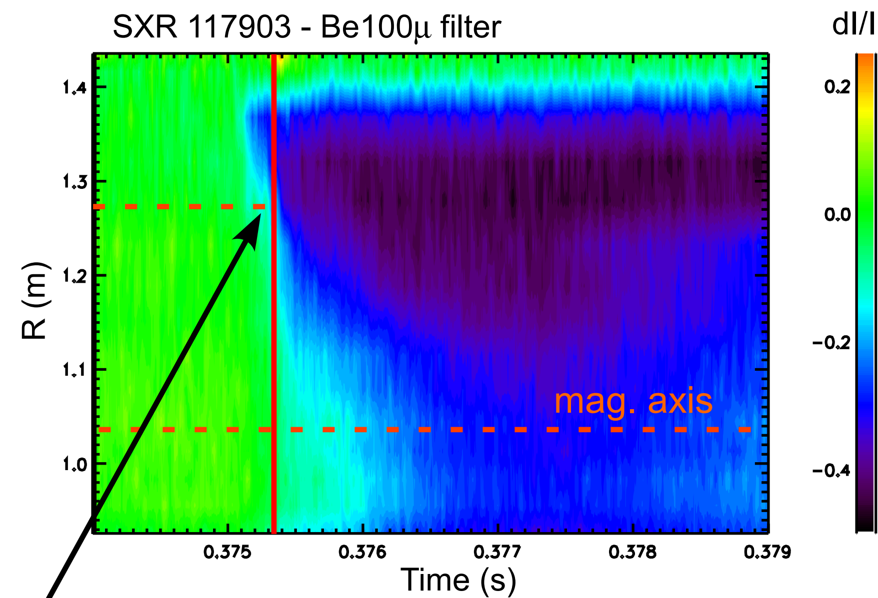
Small Type I ELM Shows Limited Penetration



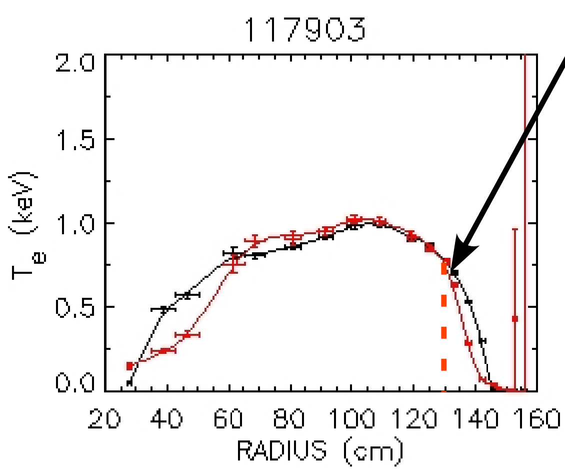
- Core electron density and temperature remains relatively unchanged

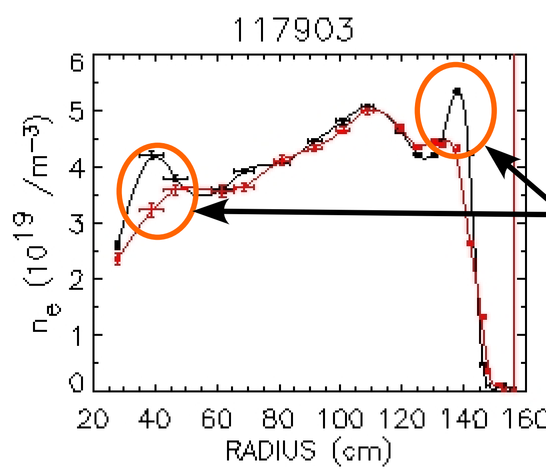
Large Type I ELM Perturbation Extends to Core





Perturbation at MPTS t2 ~130-135cm



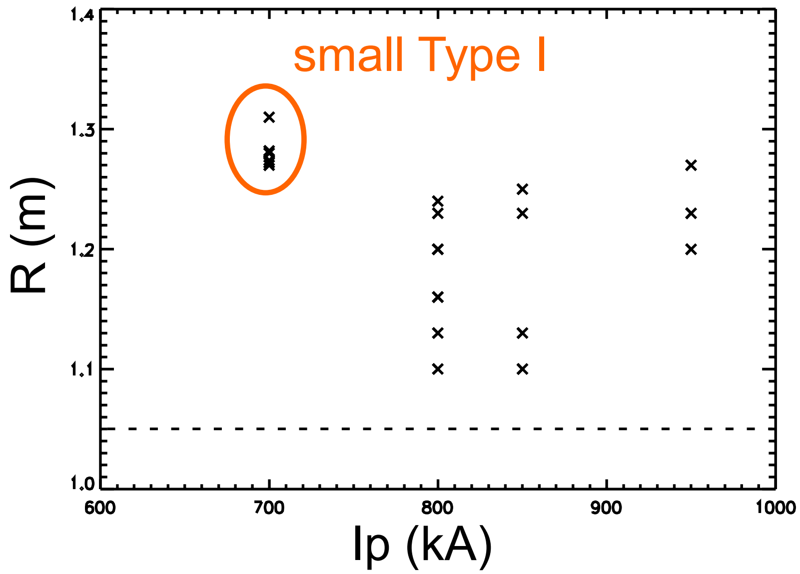


Like "small Type I" loss of ears but no central n_e perturbation

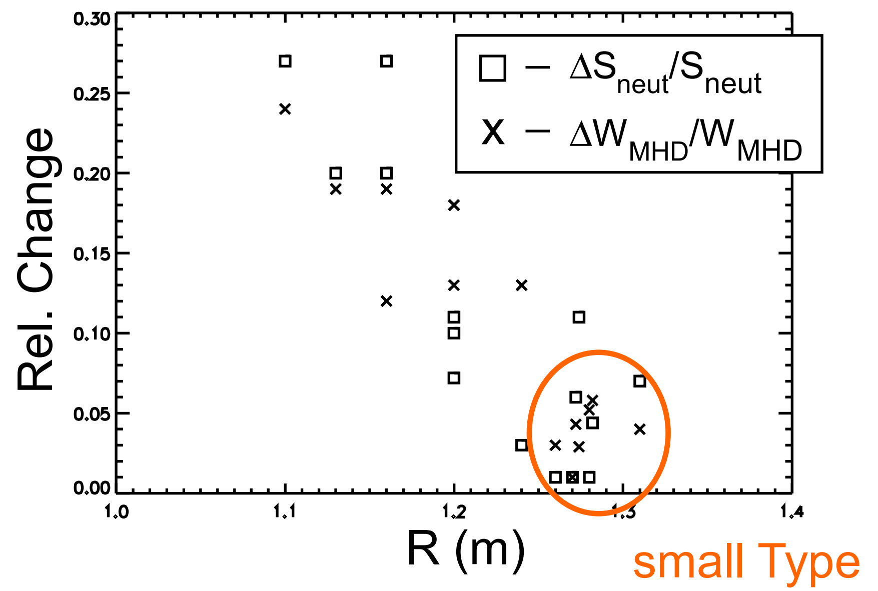
- T_e perturbation reaches core after ~2ms

ELM Perturbation Shows I_p Threshold Effect between 0.7 - 0.8MA

Perturbation penetration

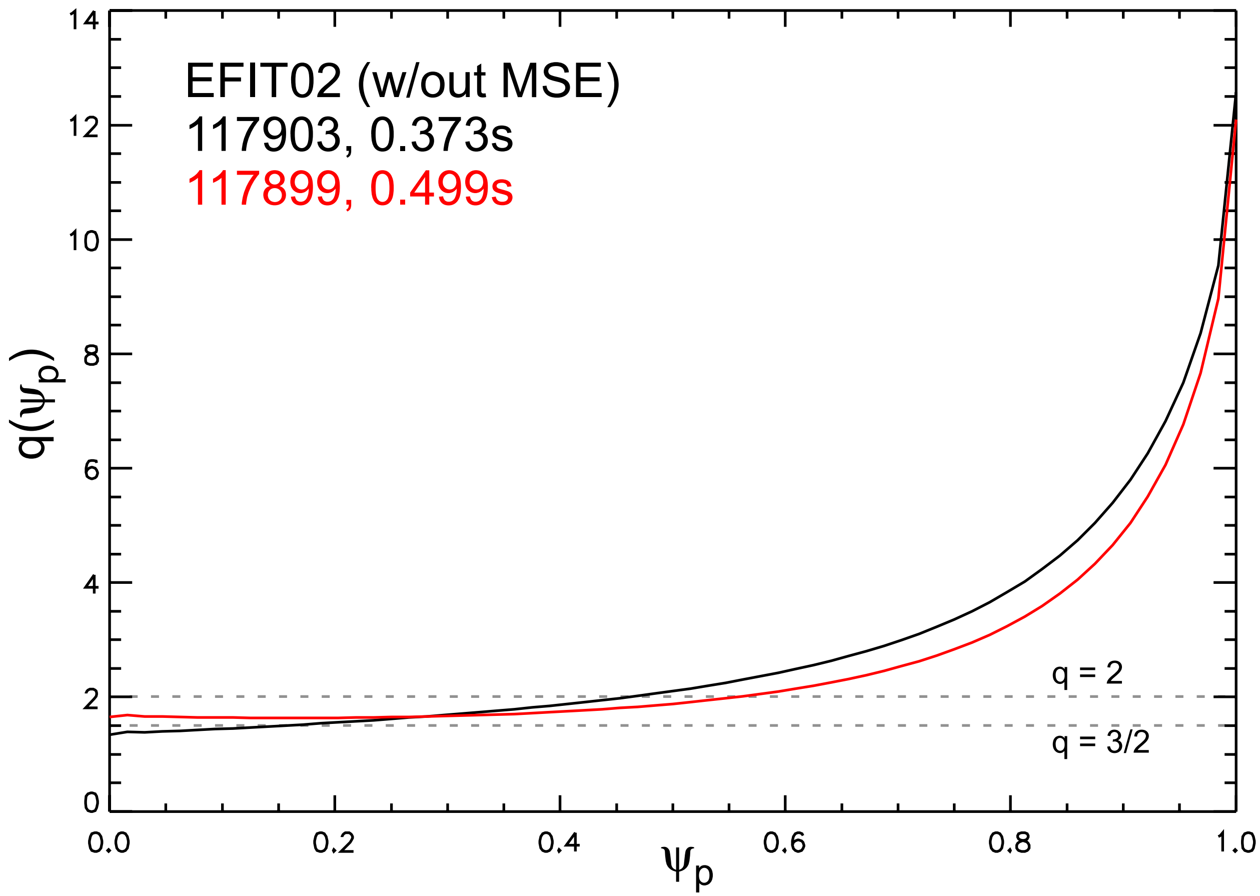


Correlation with W_{MHD}, S_{neut}



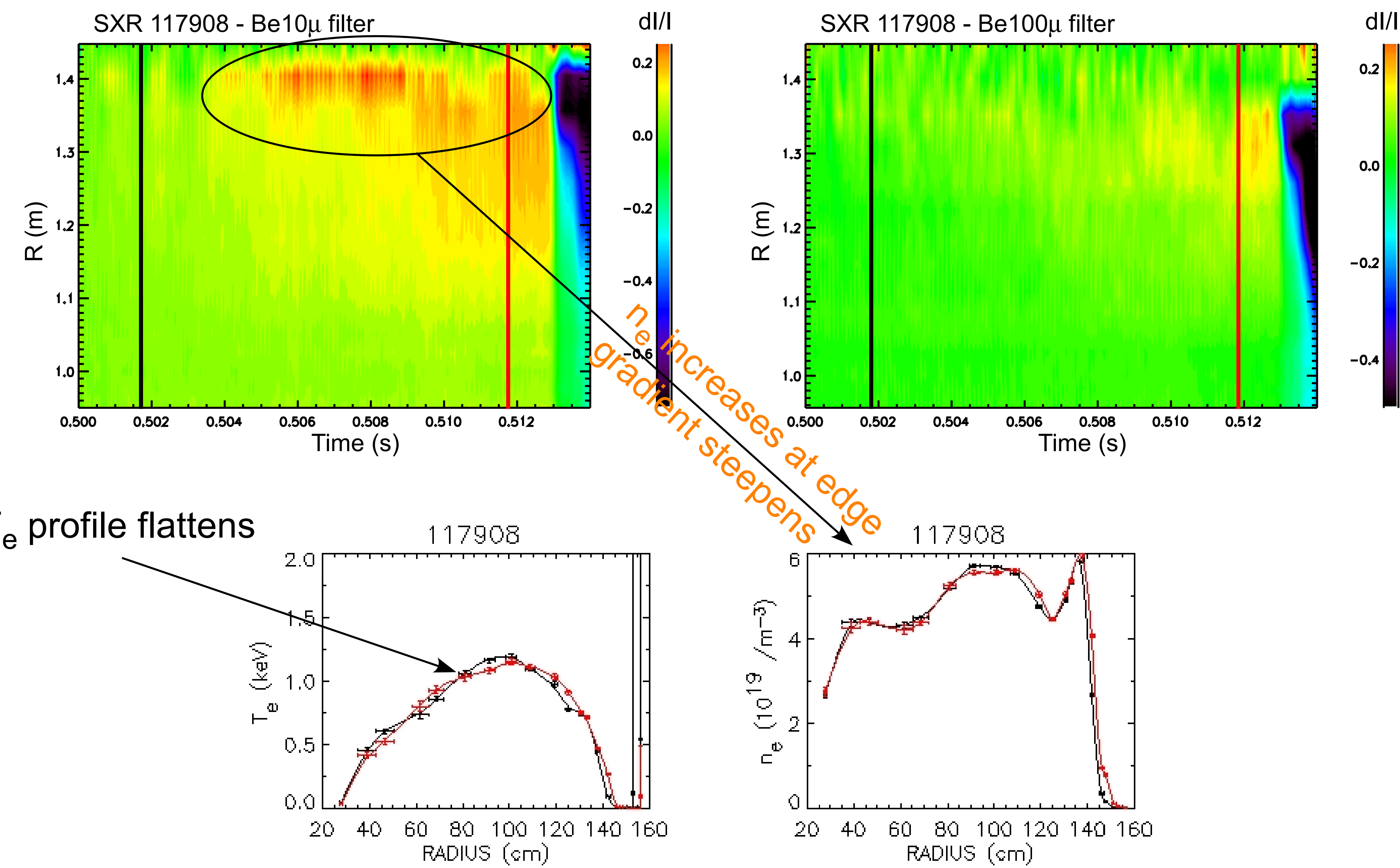
- Below I_p threshold, ELM penetration limited to ~125-135cm
- Above I_p threshold, ELM penetration can extend to plasma core
- W_{MHD} and S_{neut} reductions correlate well to penetration distance (lin. corr. -0.9, -0.85 respectively), consistent with T_e perturbation

q profile shows some differences between "small"/"large" ELM events



- If perturbation is transport related, could depend on $q(\psi_p)$ or I_p density gradients
- MSE, higher resolution T_e, n_e profiles needed for accurate stability calculations

Profiles change slightly before ELM



- Small precursor usually observed on Mirnovs, edge modes can also exist

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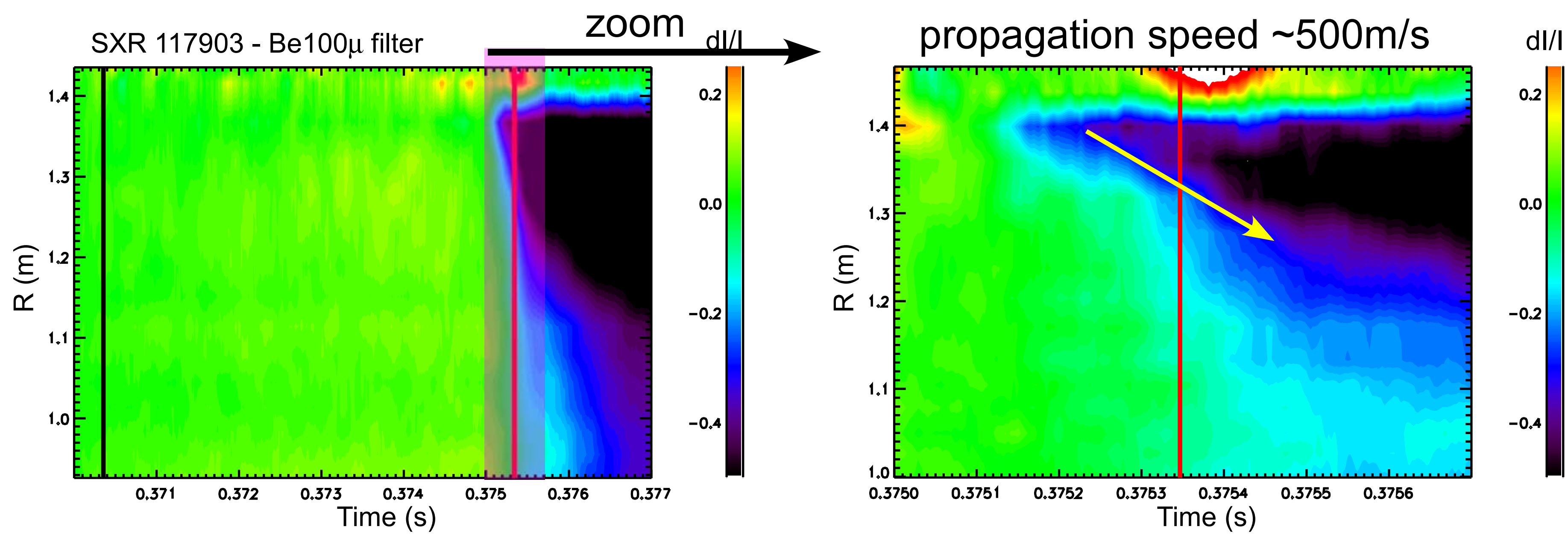
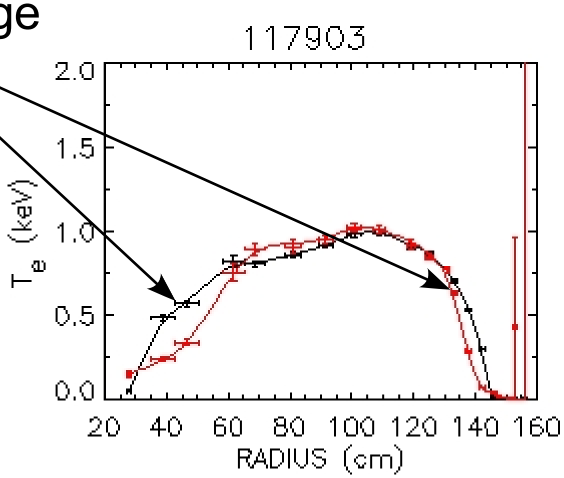
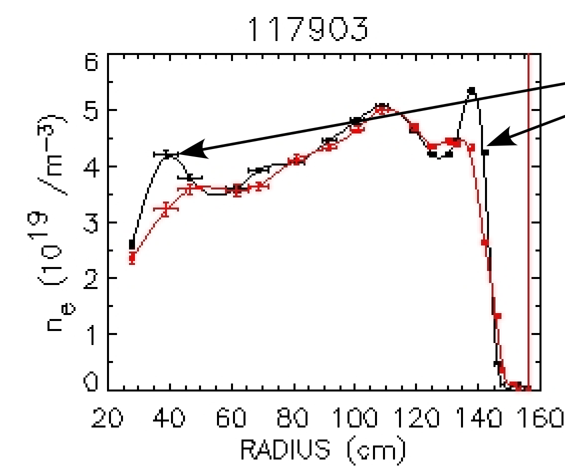
T_e perturbation starts at edge and propagates inward



T_e crash at edge

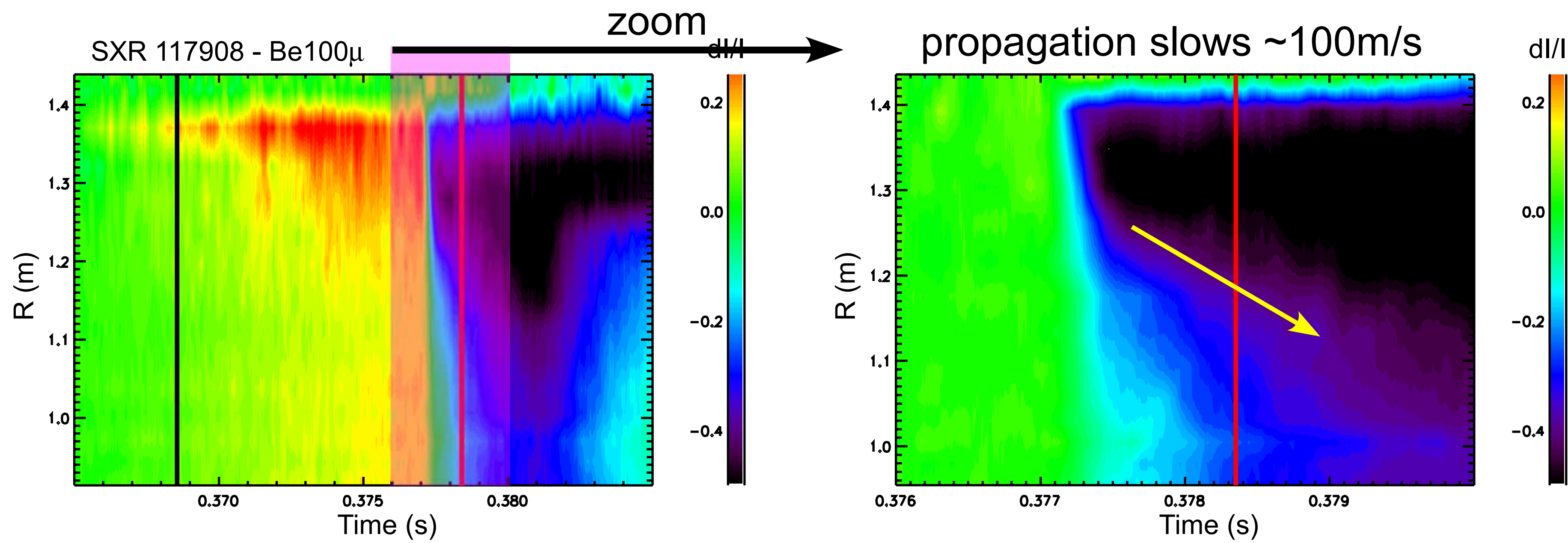


"ears" on density profile collapse

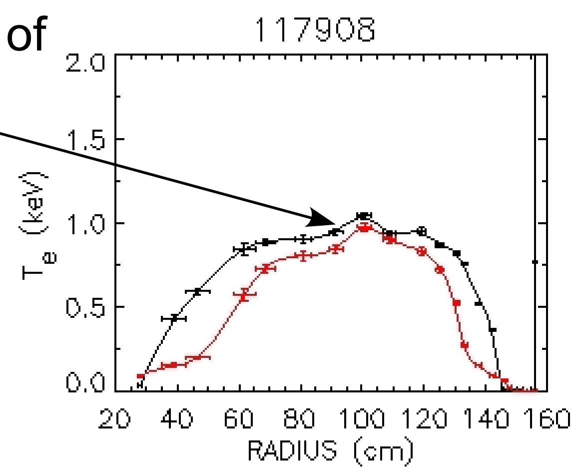


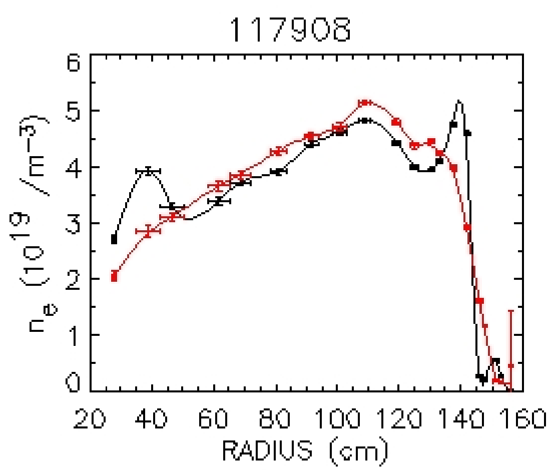
- No large MHD observed on SXR, no significant impact on global n_e profile

T_e Perturbation reaches core of plasma ~1-2ms



T_e perturbation front approaches core of plasma

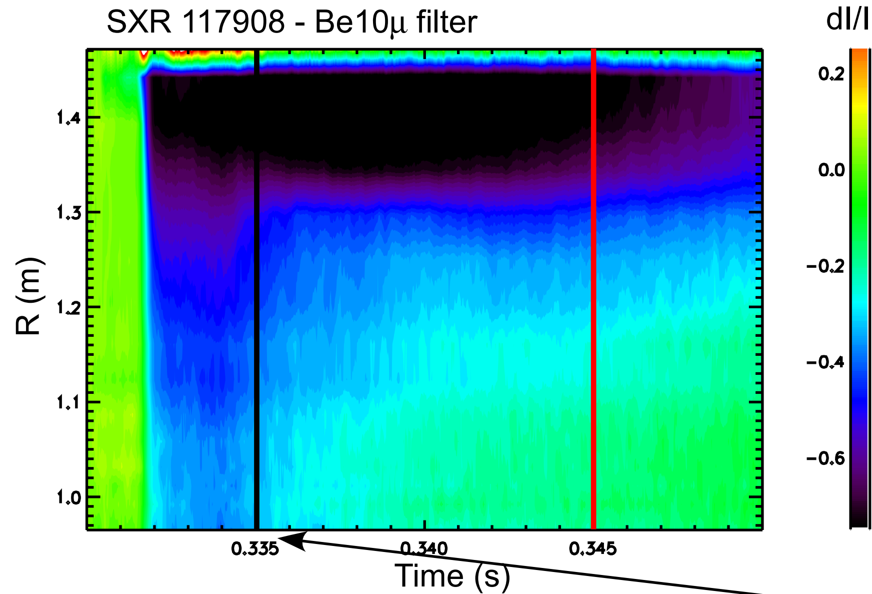


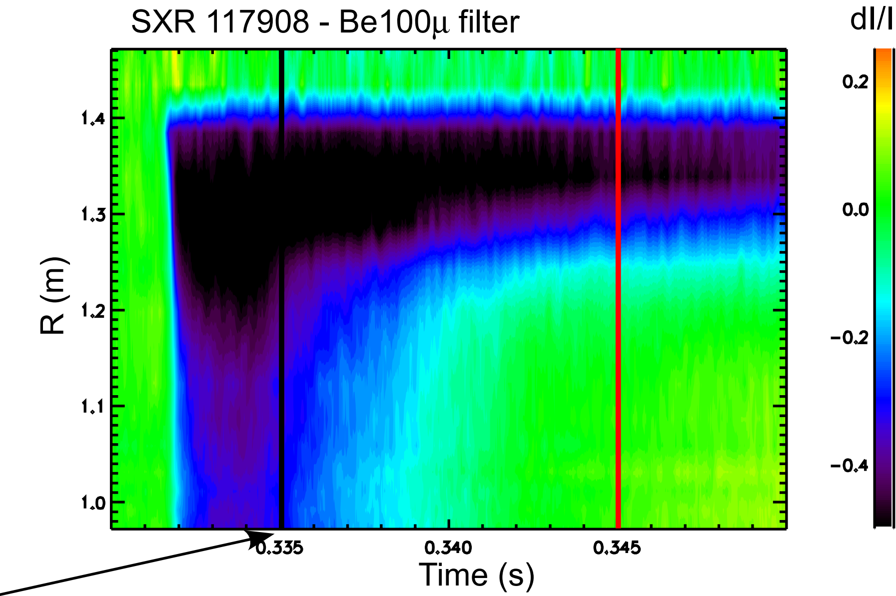


Even during large T_e crash, n_e global profile stable

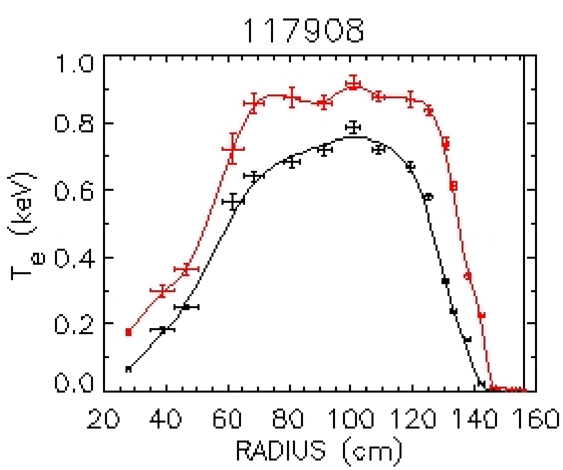
- After perturbation reaches core, T_e evolves over several ms

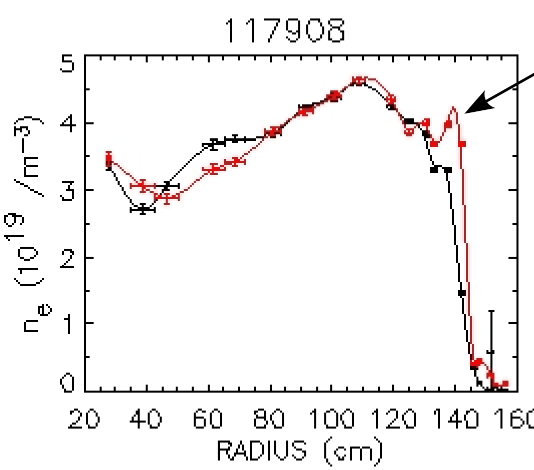
T_e increases globally during recovery phase





Start of profile recovery

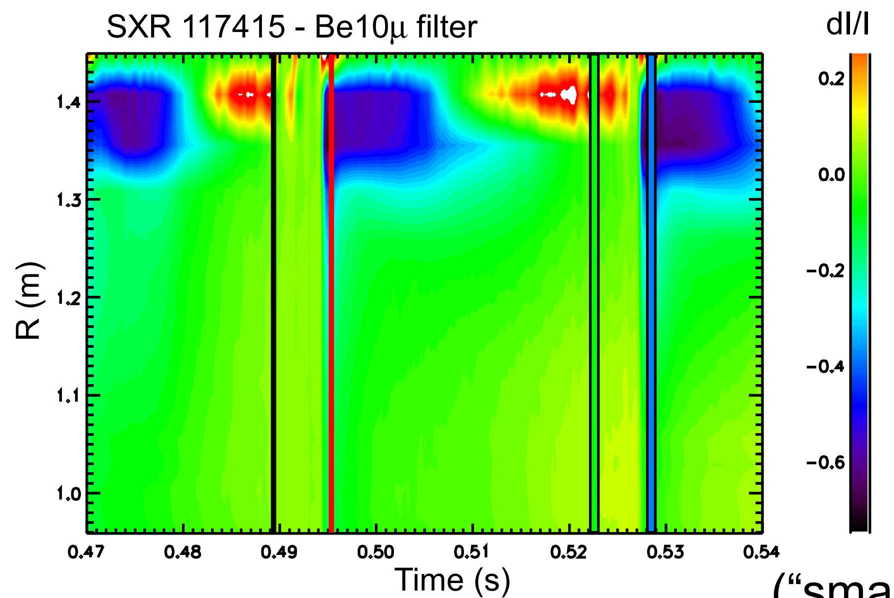


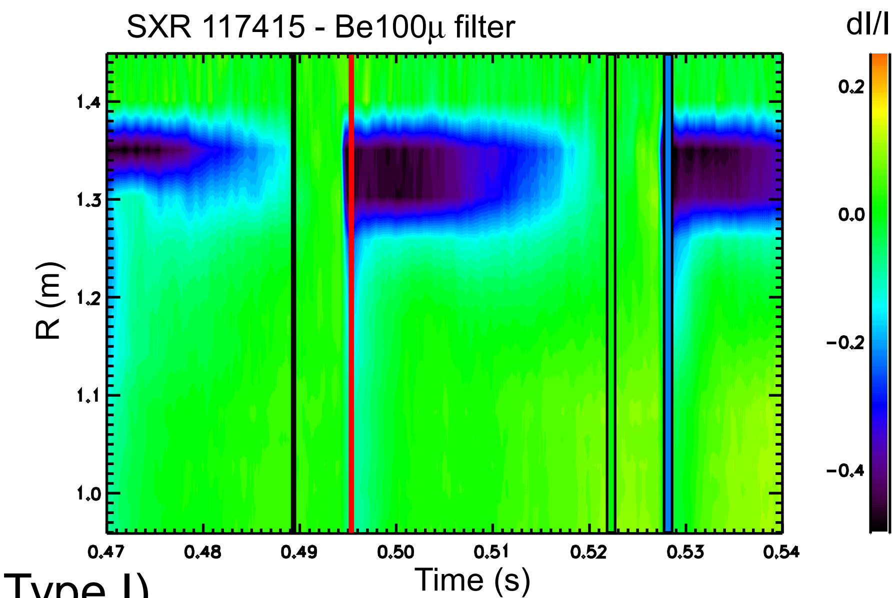


Impurity ears begin to reform

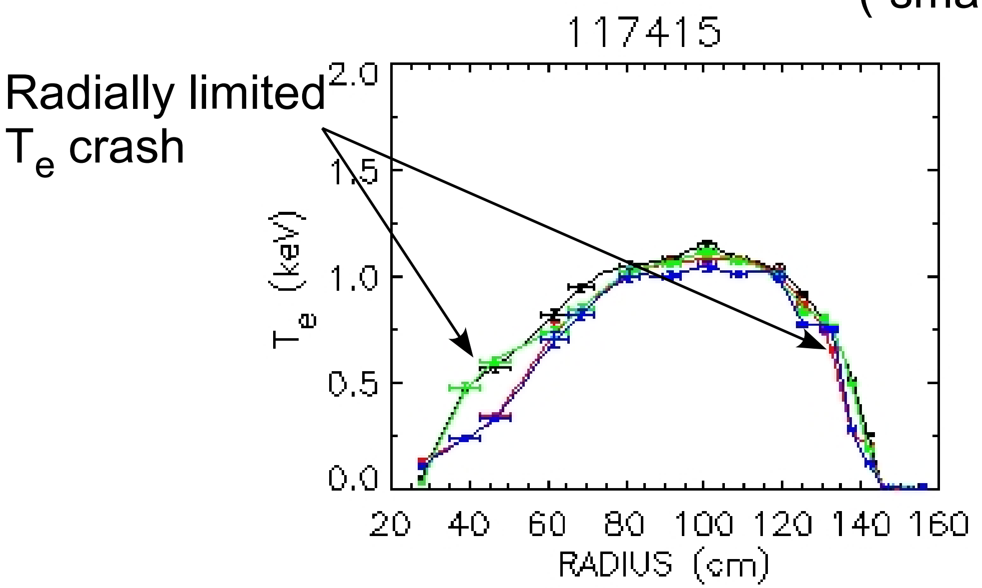
- Profiles approach pre-ELM values during recovery

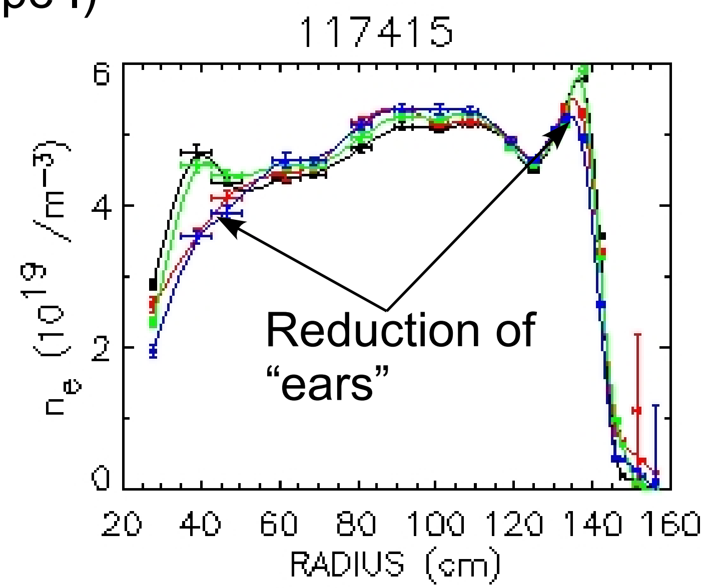
ELM perturbations show repeatable characteristics





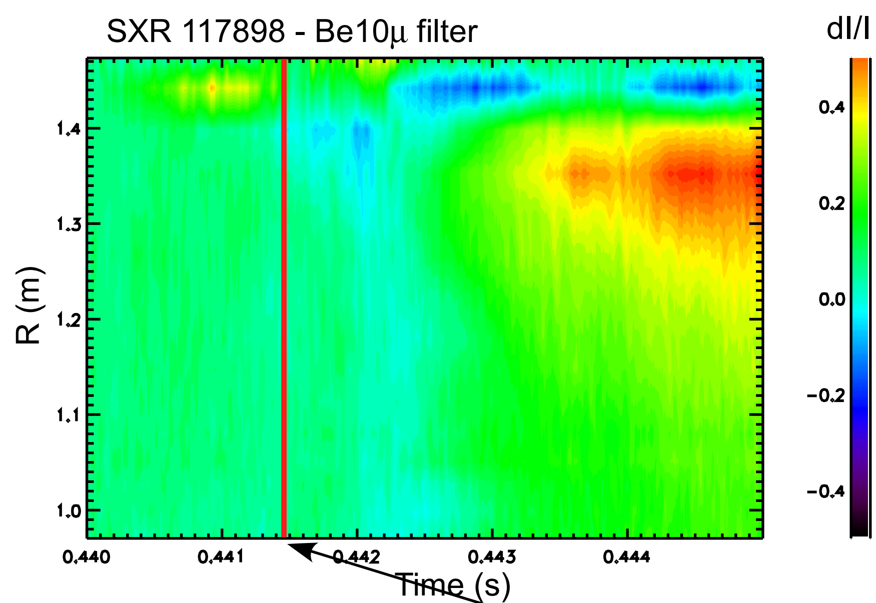
("small" Type I)

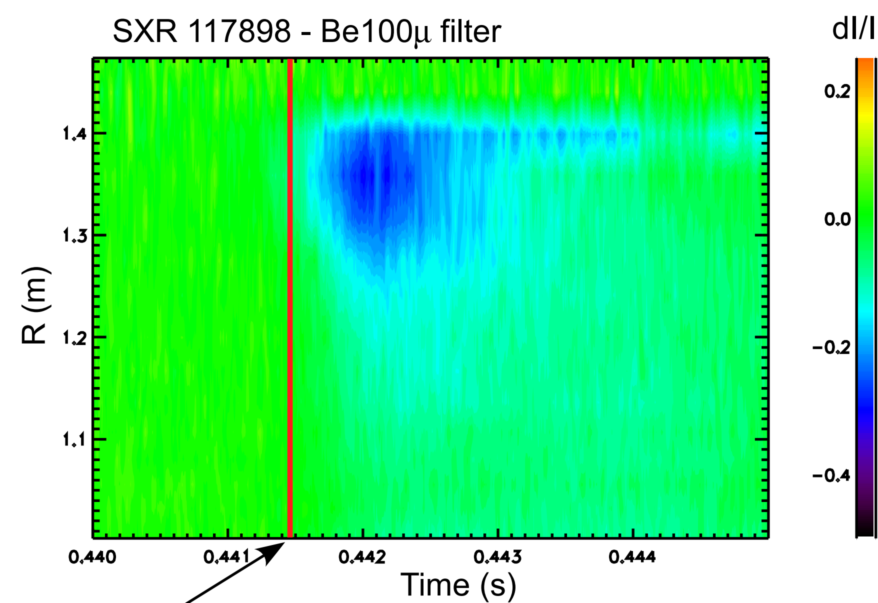




- Subsequent ELMs show similar perturbative effects on T_e, n_e profiles

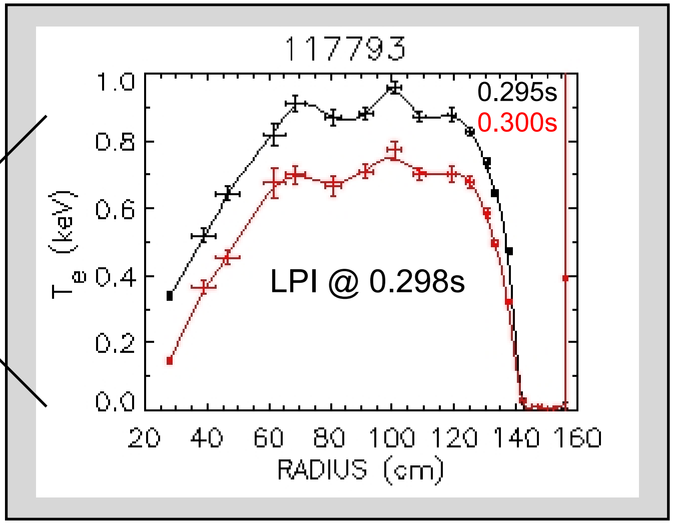
Li Pellet Injection used to create edge perturbation





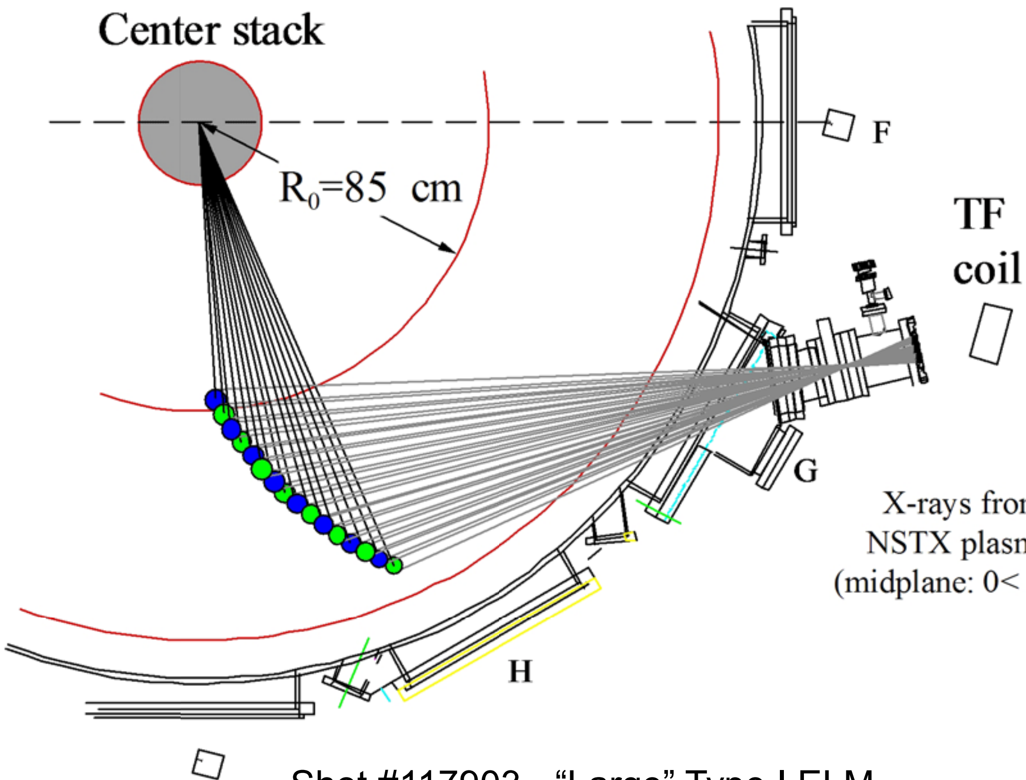
Li pellet injection

- Injection into 0.7MA “small” Type I discharge causes edge temperature perturbation
- Previous injection into H-mode plasmas have caused global T_e perturbation
- More injections needed to verify behavior



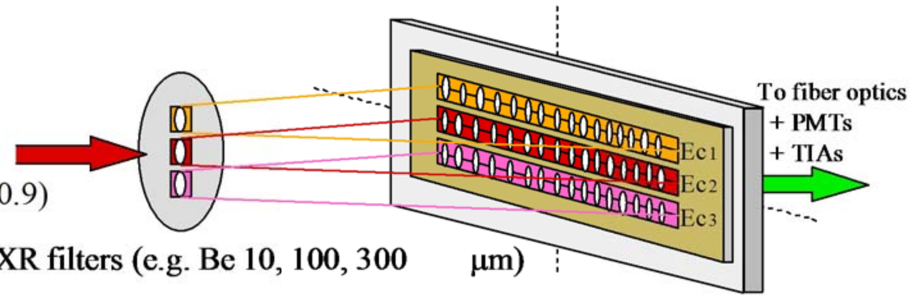
See: Stutman RP1.00027

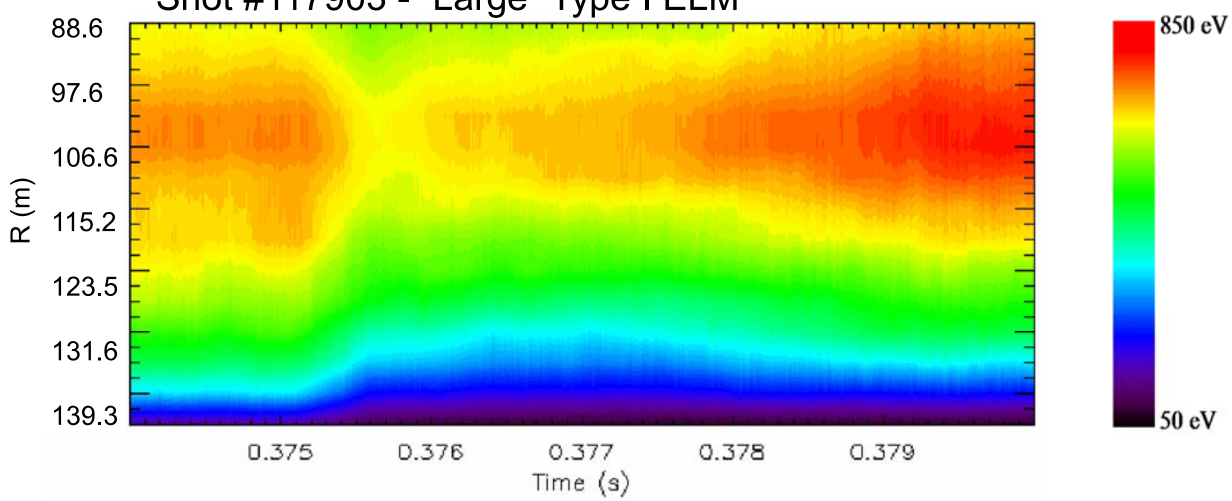
TOSXR array provides multicolor tangential view



Tangential Optical Soft X-ray (TOSXR) array converts X-rays to visible light

Array views same plasma volume through 3 different Be filter thicknesses





preliminary analysis provides time-resolved temperature profiles

time resolution ~0.2ms

See: Delgado RP1.00009

Future Work

- Experimental study will be continued at high TF to isolate I_p and q dependence
  - Help corroborate existence of threshold
  - Provide information to determine whether perturbation is transport related
- TOSXR system upgraded to higher time resolution for multicolor profiles
  - Multicolor measurements from same plasma volume will aid modeling
  - Direct inversion will improve measurement of radial propagation
- Further comparisons with pellet will help differentiate edge effect from subsequent perturbation
  - Measure radial propagation with controlled edge perturbation
  - Compare pellet cold pulse with ELM perturbation

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Summary

- SXR system can be used to follow evolution of ELM perturbations
  - Type I ELMs can cause large T_e crash without corresponding n_e drop
  - Potential I_p threshold for “large”/“small” Type I ELM regime
- Global T_e perturbation possibly due to transport effects
  - Only small precursors observed on Mirnovs regardless of ELM size
  - No large MHD modes seen on SXR arrays
  - Time scales of profile perturbation ~100's of μsec
  - No corresponding global perturbation of n_e profile
- Future investigations to help distinguish between q and I_p effects
  - Higher B_T will allow comparison between q and I_p scan
  - Upgraded MPTS, MSE, and TOSXR diagnostics will improve analysis capability

Reprints