Comparison of Sawtooth Phenomenology on TFTR and DIII-D

presented by

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This poster reports the results of two experiments on sawtooth stabilization

- The first experiment used "2nd harmonic, H-minority" heating to create a fast-ion tail population to stabilize the sawteeth.
- The objective of the second experiment was to reproduce on DIII-D the NBI sawtooth stabilization seen on TFTR.
- The poster will also discuss the following sawtooth issues:

  Heat pulse propagation -
  Ion, electron and "ballistic" heat pulses.
  Sawtooth precursor structure -
  kink-ballooning and coupled kink-ballooning.

- Where appropriate, results will be compared with similar data from TFTR.

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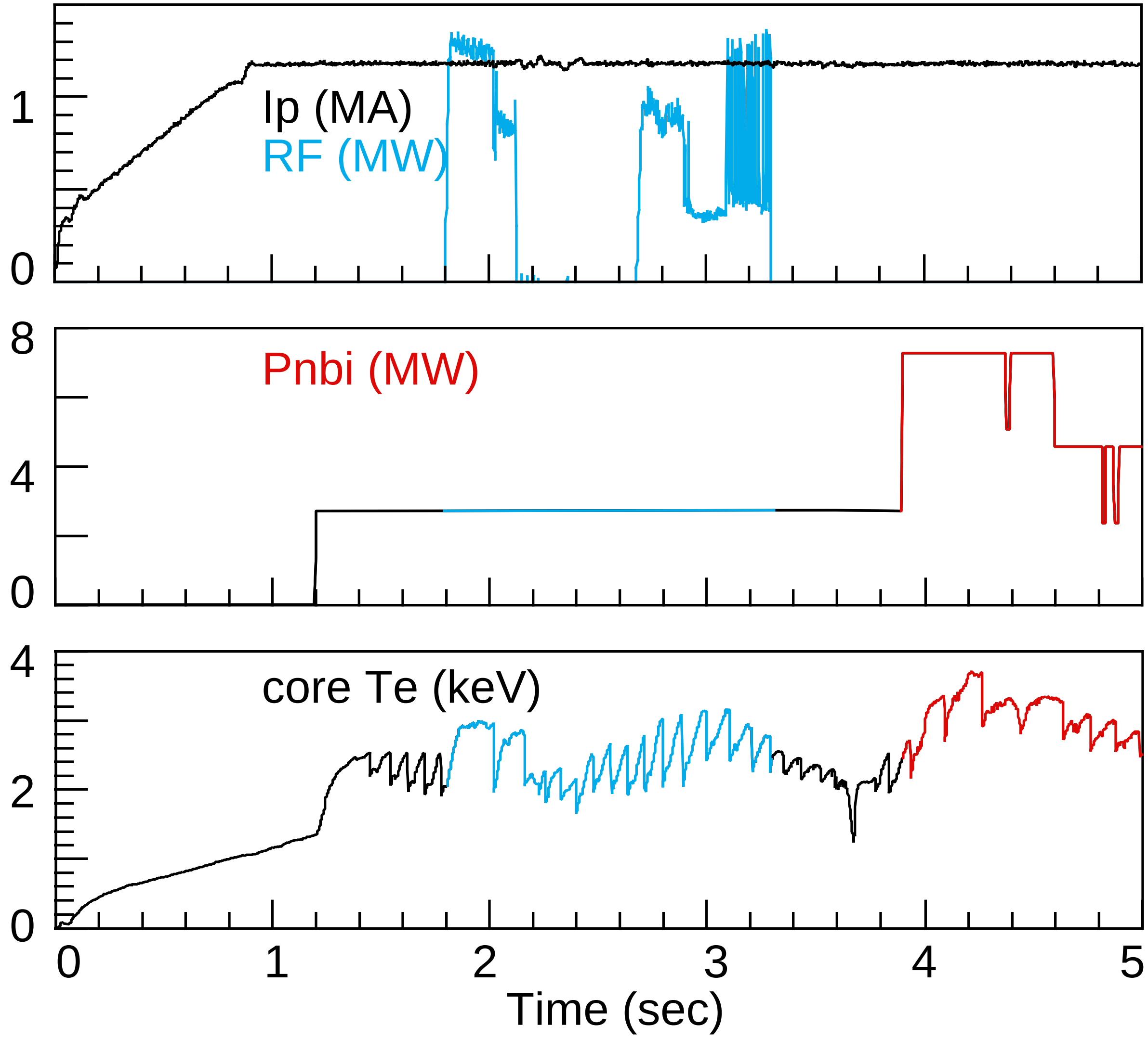
The Experiments were carried out as follows:



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Nominal 2nd harmonic H-minority ICRF heating was used to attempt sawtooth stabilization.

NBI heating was used throughout for diagnostic purposes; a high power interval was added between 3.9-5.0 sec.

The sawtooth period was increased to as much as 250 msec with either NBI or ICRF.

- In both cases q(0) dropped significantly below one prior to the crashes.

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ICRF Sawtooth Stabilization Results

- ICRF power was limited to about 1.2 MW, avoidance of H-mode was difficult (interfered with RF coupling).

  TFTR, with twice the plasma volume, needed about 2.5-3MW.

- Sawtooth periods as long as 250 msec were made.

- Evidence for fast ion tail in observation of TAE or EPM's*.

- Some of the results could also be interpreted as evidence for 4^{th} harmonic heating of D-beam ions.

- Stabilization effectiveness very sensitive to resonance location.

*S. Bernabei, Invited Paper ***

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At sawtooth crash, MSE q(0) rises to unity; in contrast to MSE measurements on TFTR

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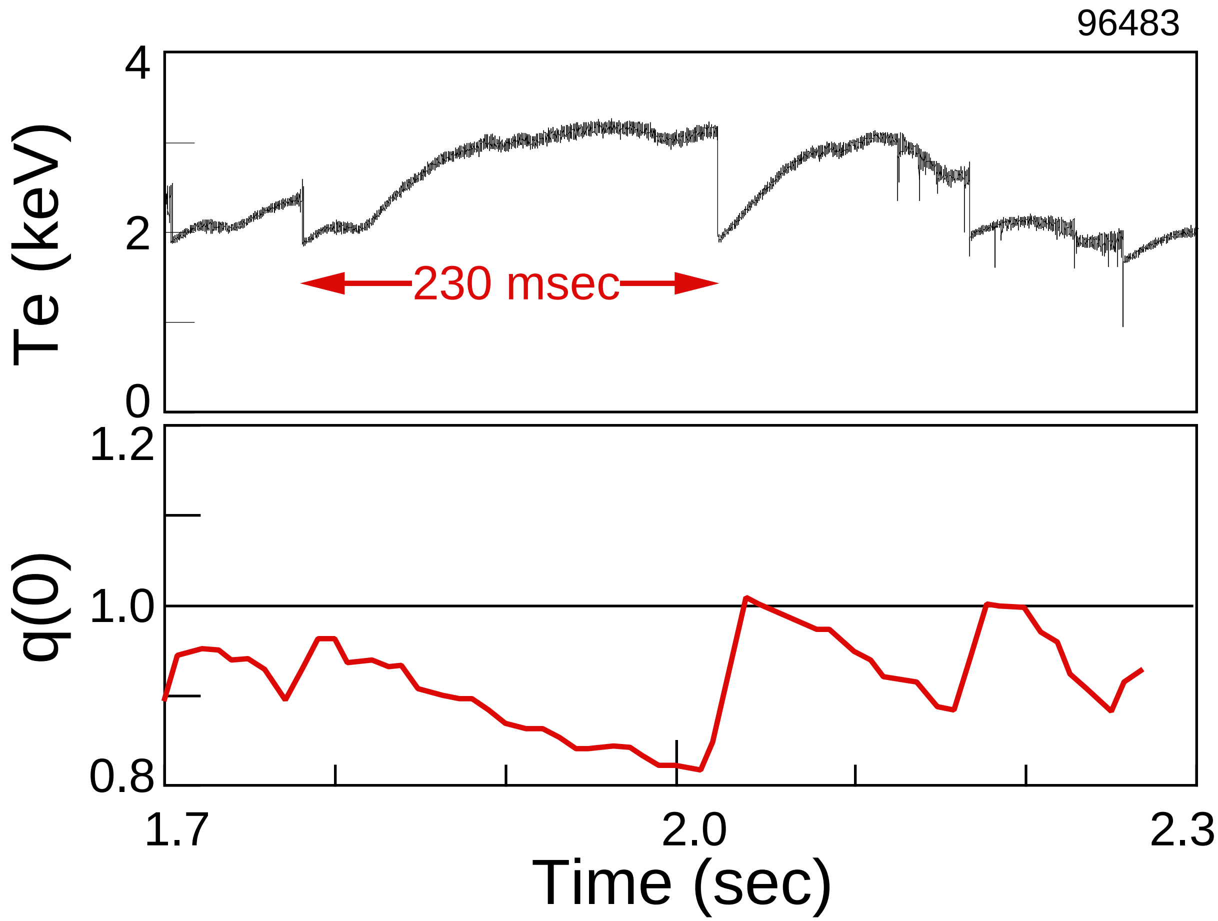

q(0) drops as low as 0.8, but continues dropping throughout the "sawtooth-stable" period.

q(0) drops much lower than usually observed on DIII-D.

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Weak, rotating precursor visible, final growth of island must be very fast.

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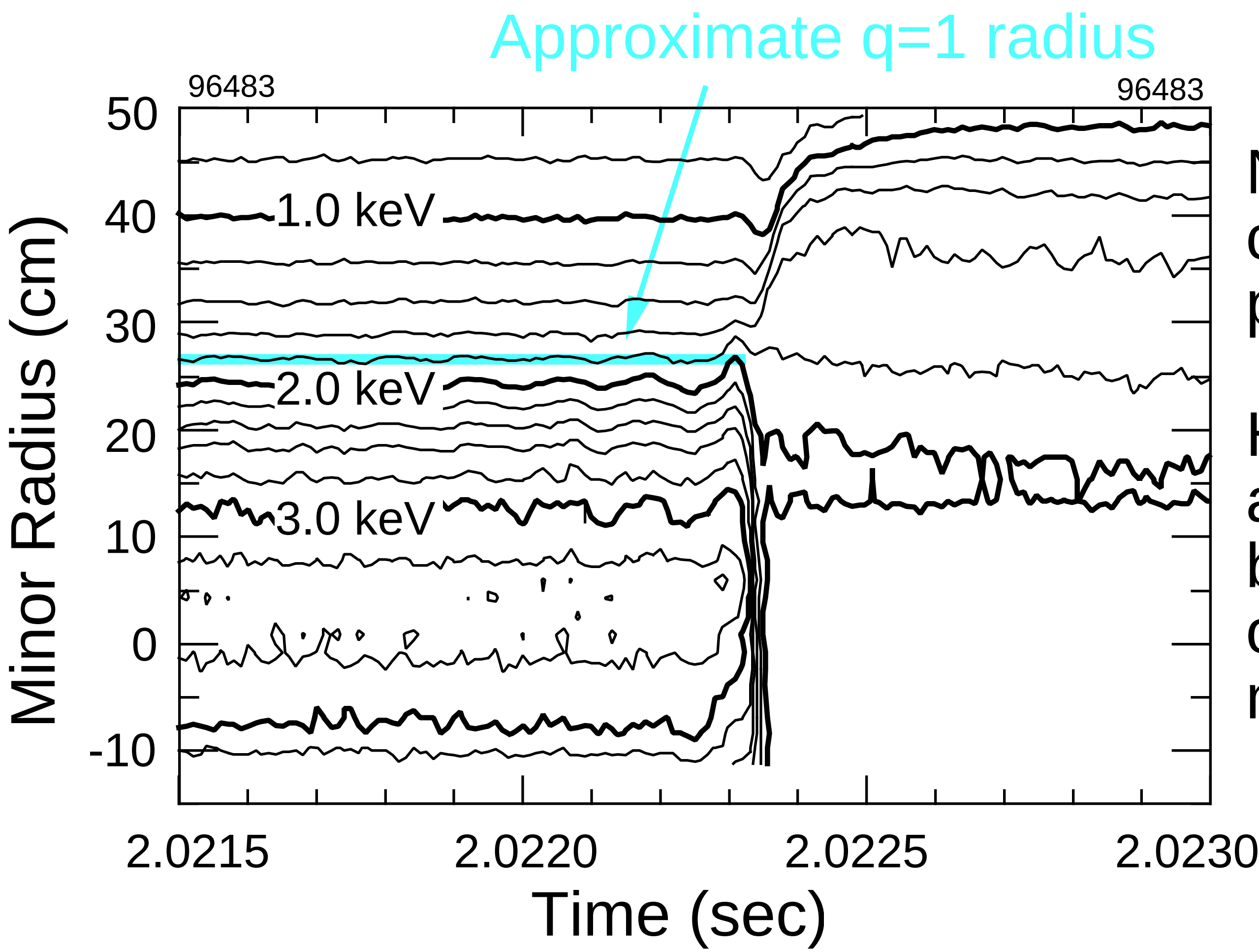

No ballooning character to precursor

Heat pulse still appears strongly ballistic*; possibility of plasma motion must be investigated.

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*Fredrickson, et al, Phys. Rev. Lett. 65 (1990) 2869

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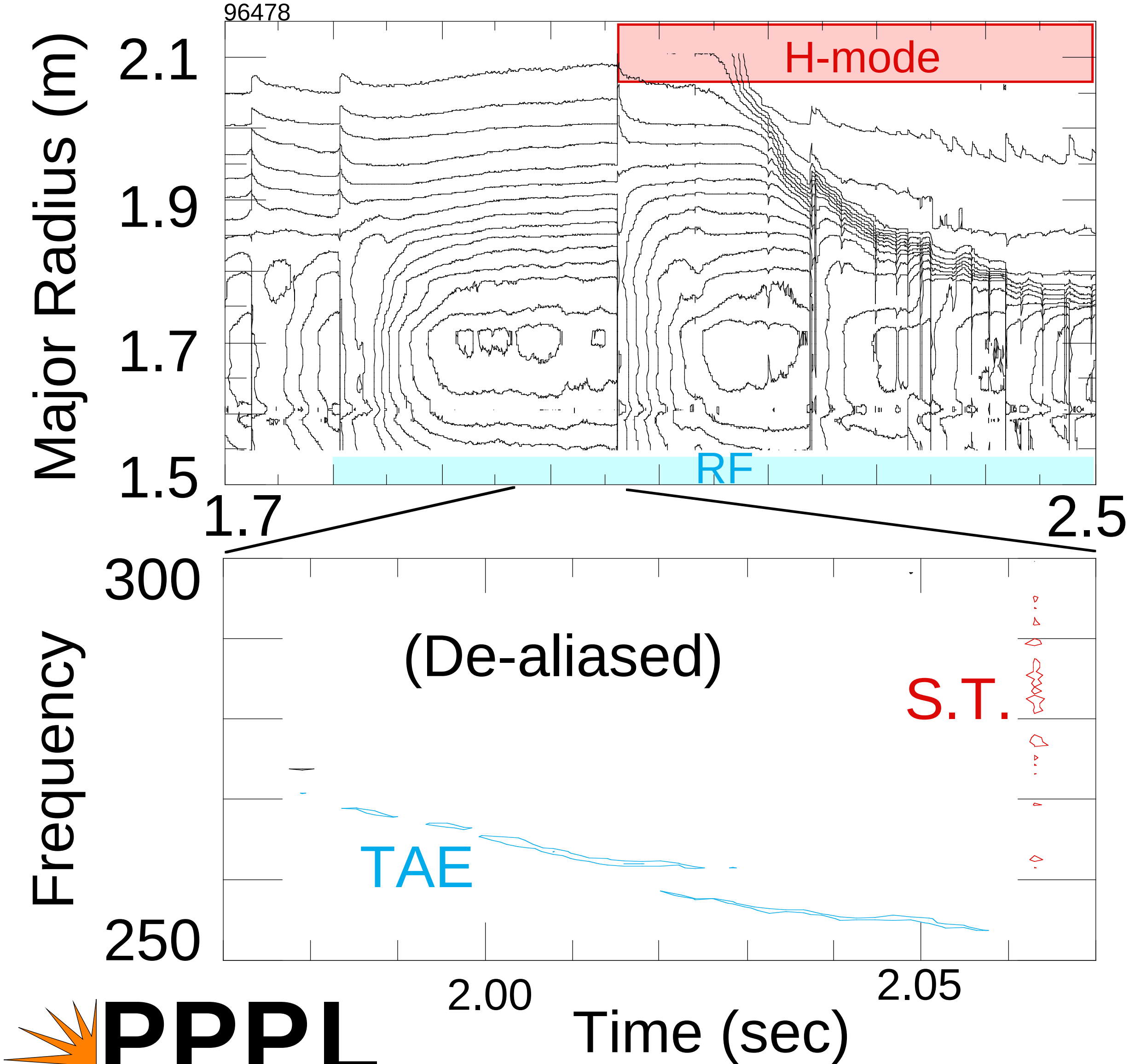
"TAE" modes show up just before sawtooth crash indicating presence of fast ion tail.



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H-modes were often triggered at sawtooth crash.

ELM's affected ICRF coupling, edge density rise cut-off ECE signal.

Identification as "TAE" or "EPM"* not clear at this point; frequency drop could be "chirping" or density rise.

*S. Bernabei, Invited Talk
Fredrickson, Nucl. Fusion 35 (1995) 1457.

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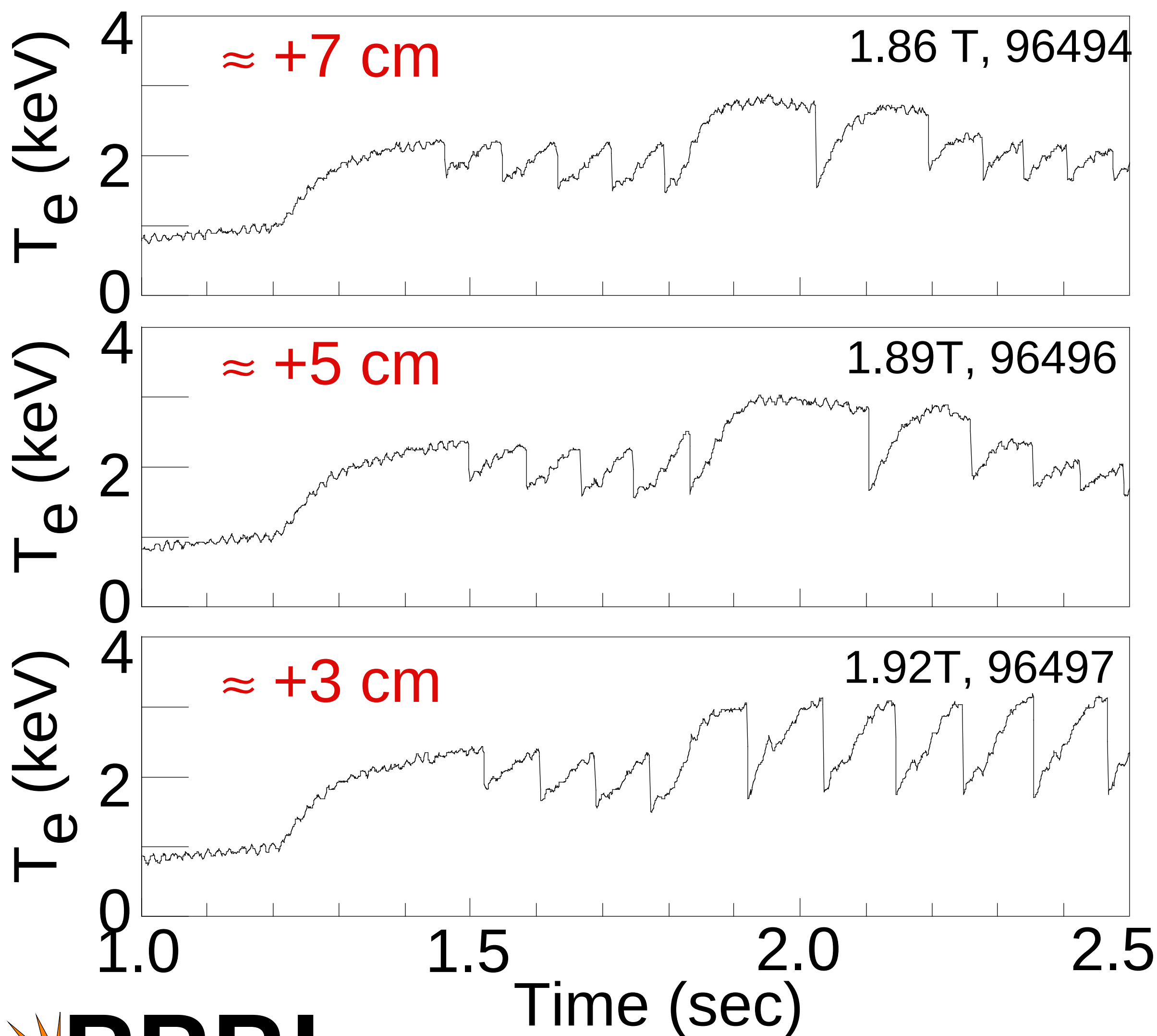
Best stabilization with heating slightly on high field side.



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Sawtooth period was very sensitive to ICRF resonance location.

Beam voltage and power scans were also done to investigate possibility of 4th harmonic D heating of beam ions

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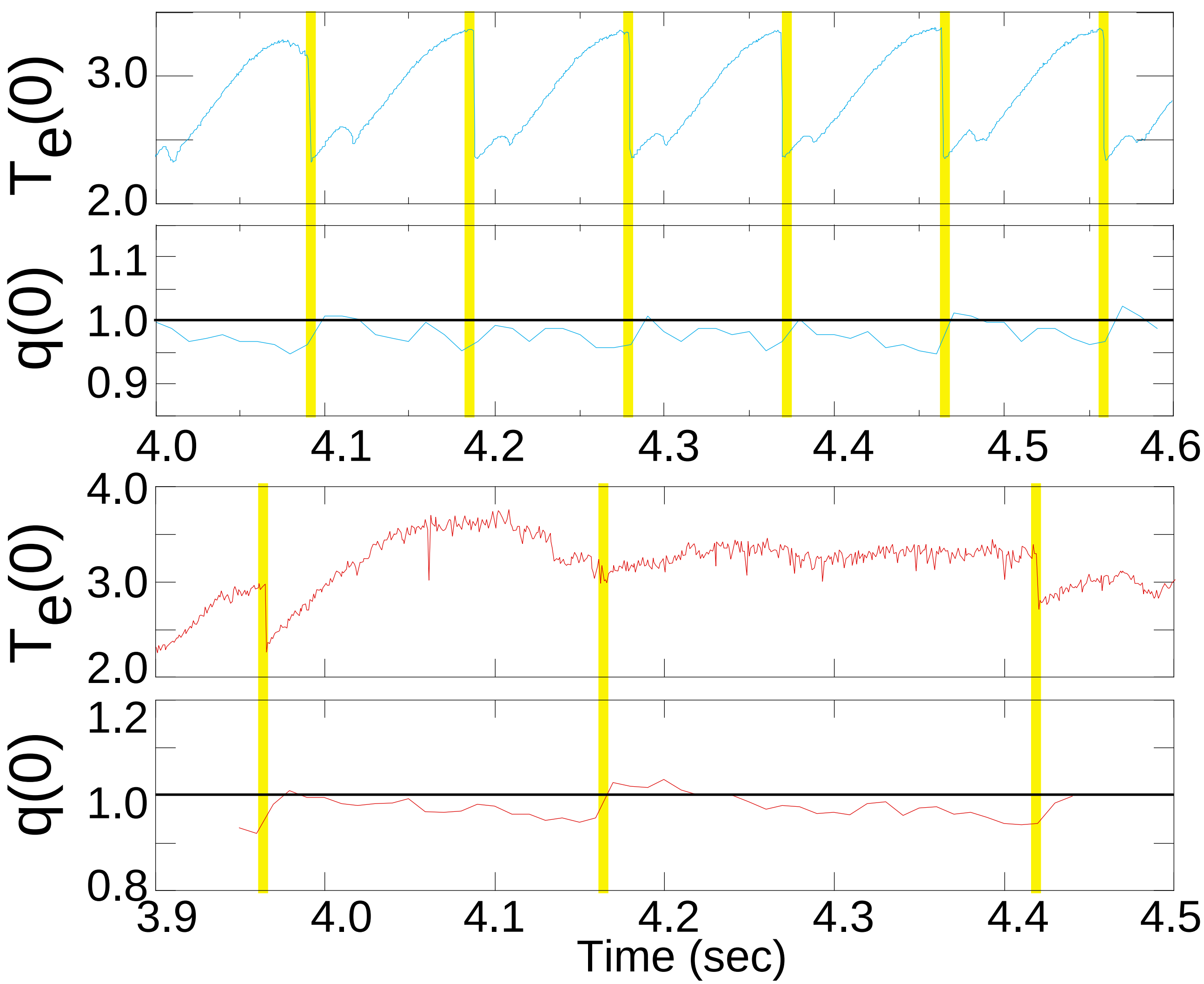
NBI Sawtooth Stabilization Results

- Above NBI power of about 9 MW, avoidance of H-mode was difficult, broader Te, pressure, raised q(0)>1.
- Sawtooth periods as long as 250 msec were made.
- q(0) dropped to near 0.9 before sawtooth, period lengthening could be due to slower current diffusion (beam/bootstrap currents).
- Detailed comparisons with theoretical models will follow more careful analysis of the data.
- Future experiments might reduce elongation, move to limiter to more closely simulate TFTR conditions.

Sawtooth period increases with Beam Power



MSE q(0) jumps to unity at each crash.

q(0) drops to nearly 0.9 in some cases.

Drop is slower at higher power; sawtooth period may reflect slower current diffusion.

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Increase in period is roughly Linear with NBI

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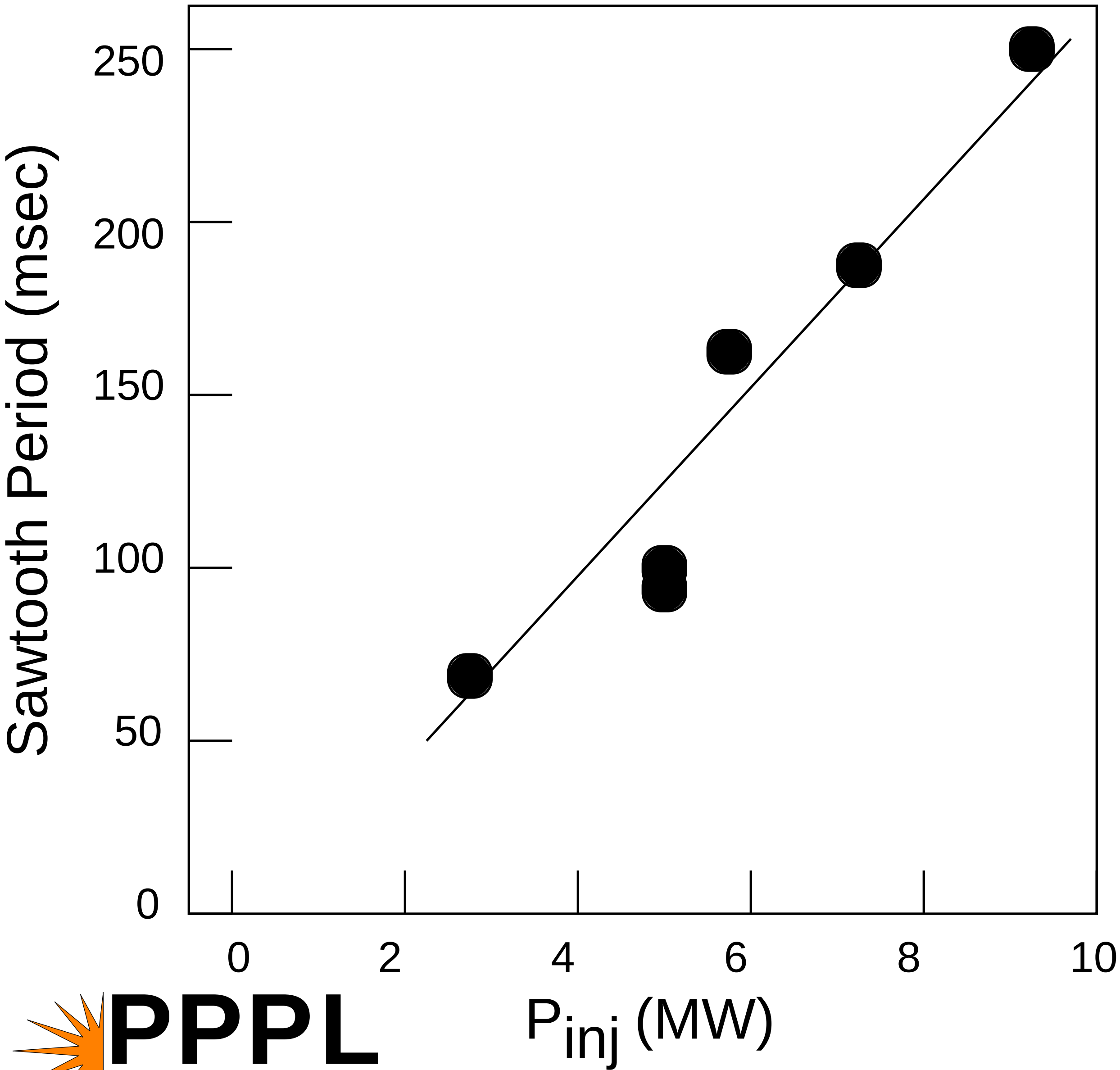

- Eventually, H-mode clouds the issue, broadens current profile, raises q(0)≈1.

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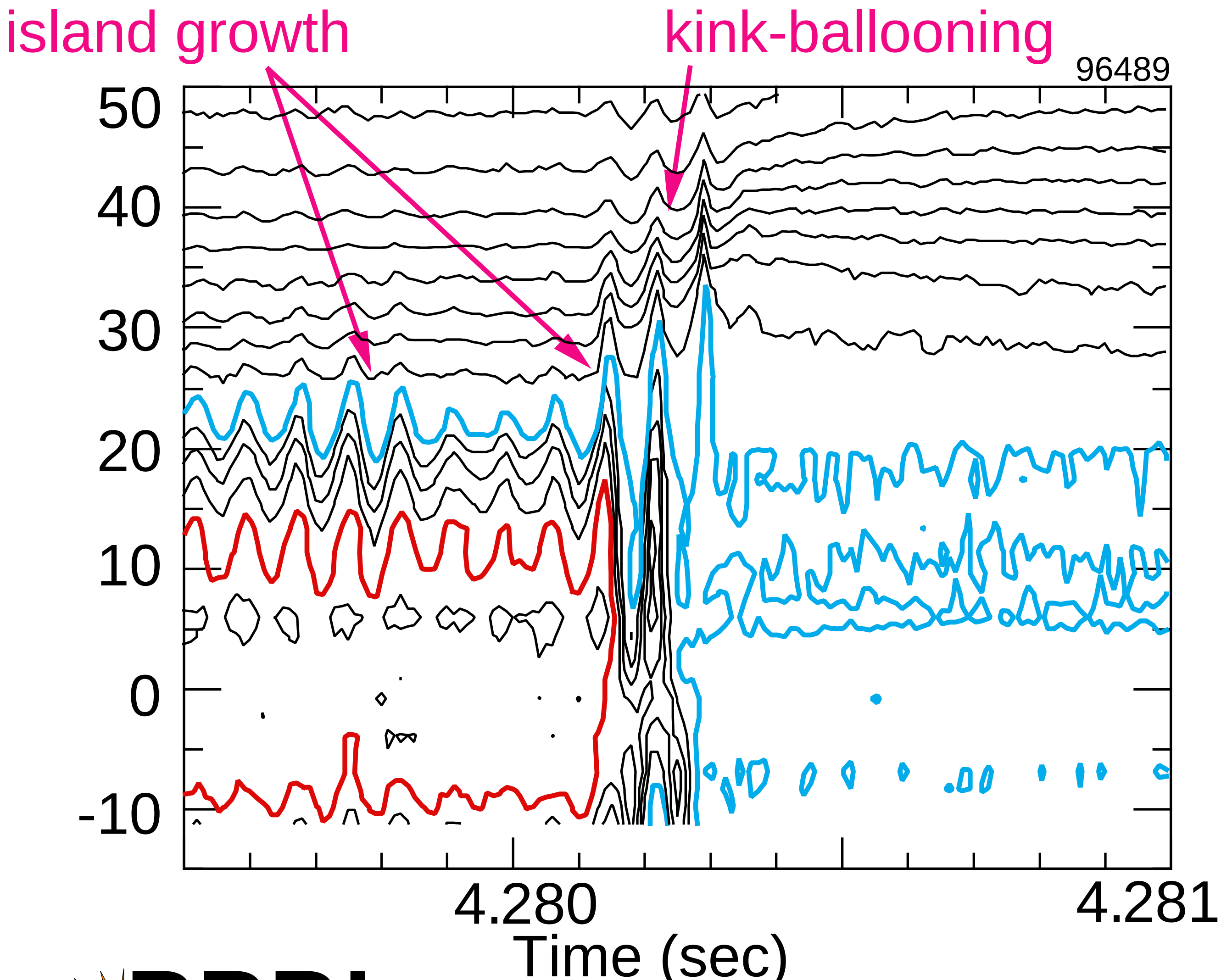
Sawtooth Precursor has "Ballooning-Kink" structure as found on TFTR*



Bandwidth not adequate to see moderate-n ballooning modes.

Main island growth occurs late in precursor phase, as on TFTR.

$\beta_n \approx 1.2$ vs. 0.85 for ICRF.

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*Park, et al., Phys. Fluids B 3 (1991) 507.
Fredrickson, et al., Phys. Rev. Lett. 65 (1990) 2869

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Strong Ballistic Effect in Te Heat Pulse

- Experimental heat pulses compared to χ^{pb} simulation.

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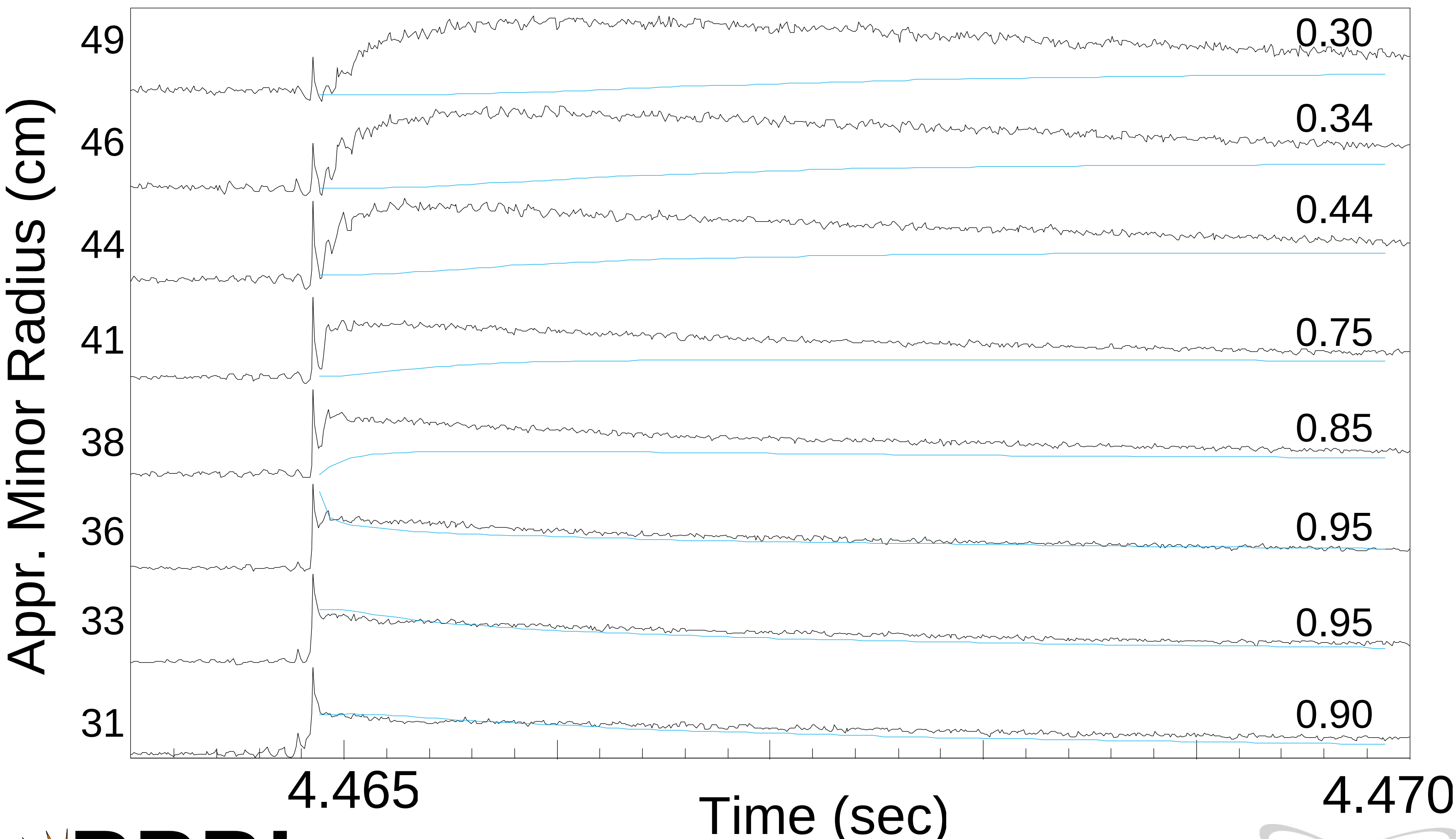

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Soft x-ray cameras show ballistic heat pulse is not from plasma movement

- Soft x-ray chords integrate emmission from outside tangency radius, should continue to rise after ECE stops.

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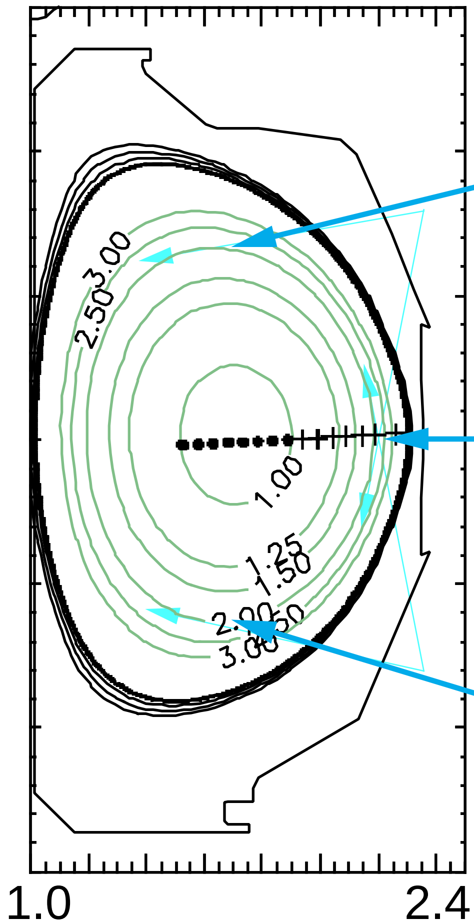

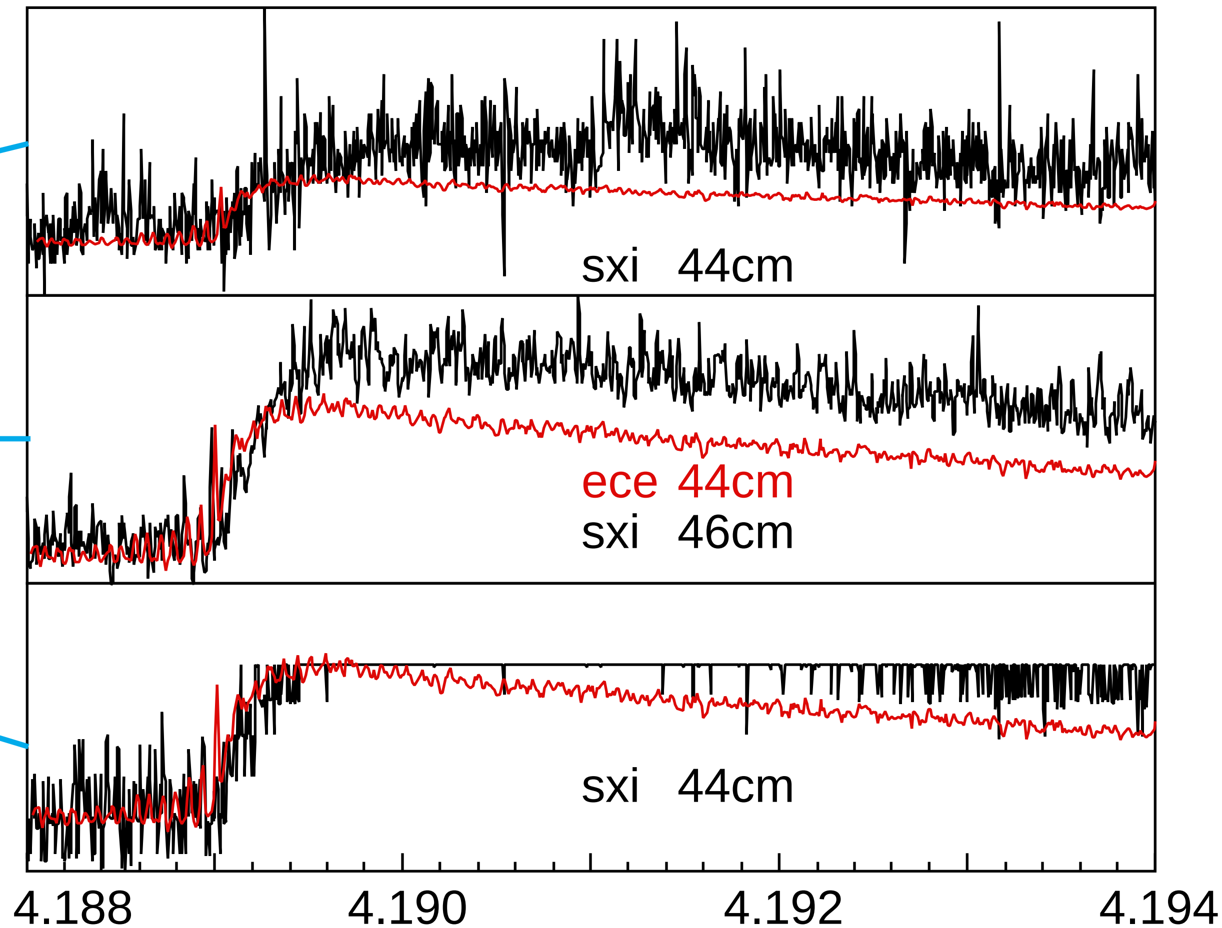

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Weaker ballistic effect seen at lower β, smaller q=1 radius

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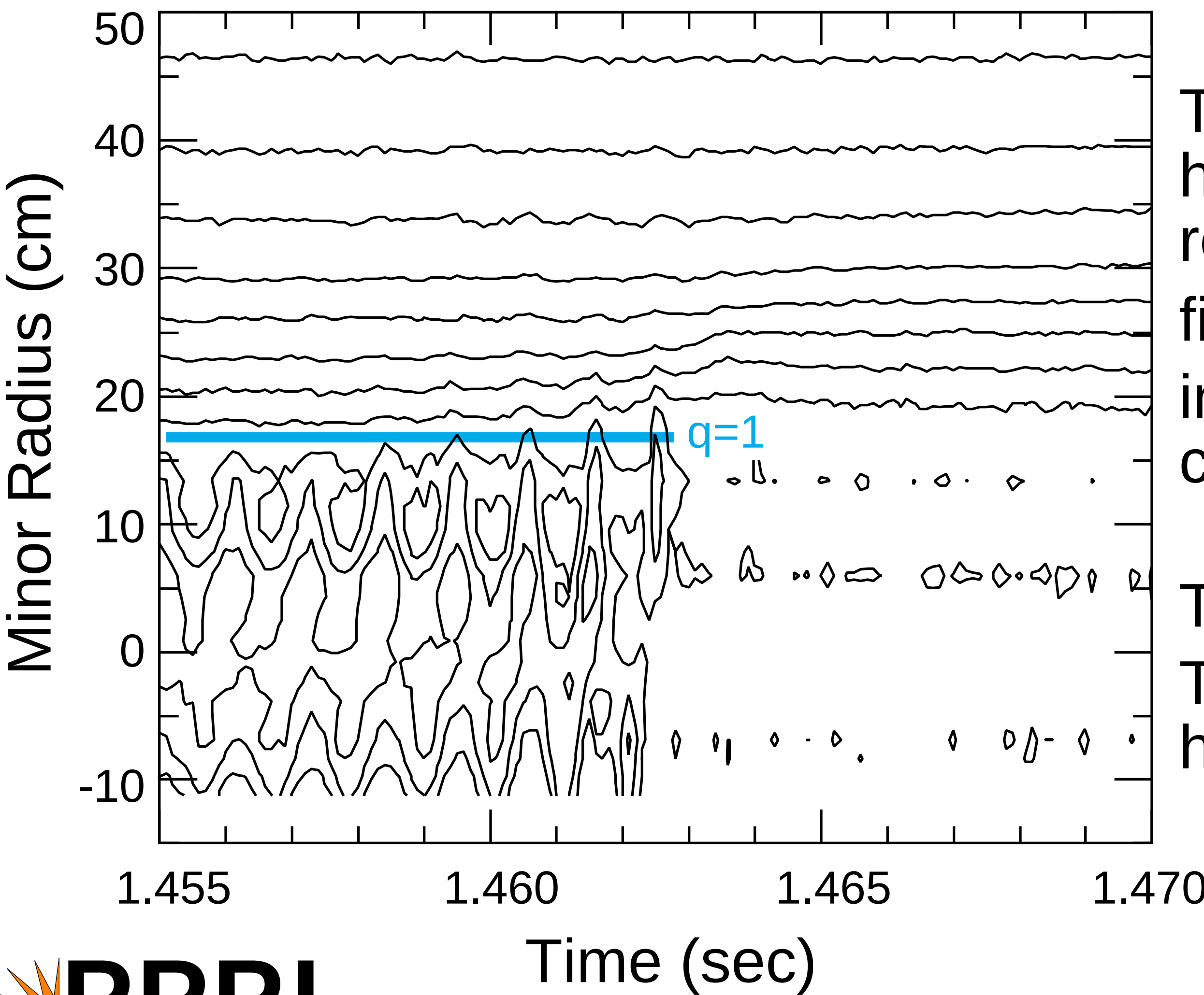

The ballistic effect has been assumed to result from stochastic fields caused by β-induced mode coupling.

The scaling with β in TFTR is not clear, however.

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1-fluid transport code used for simulations

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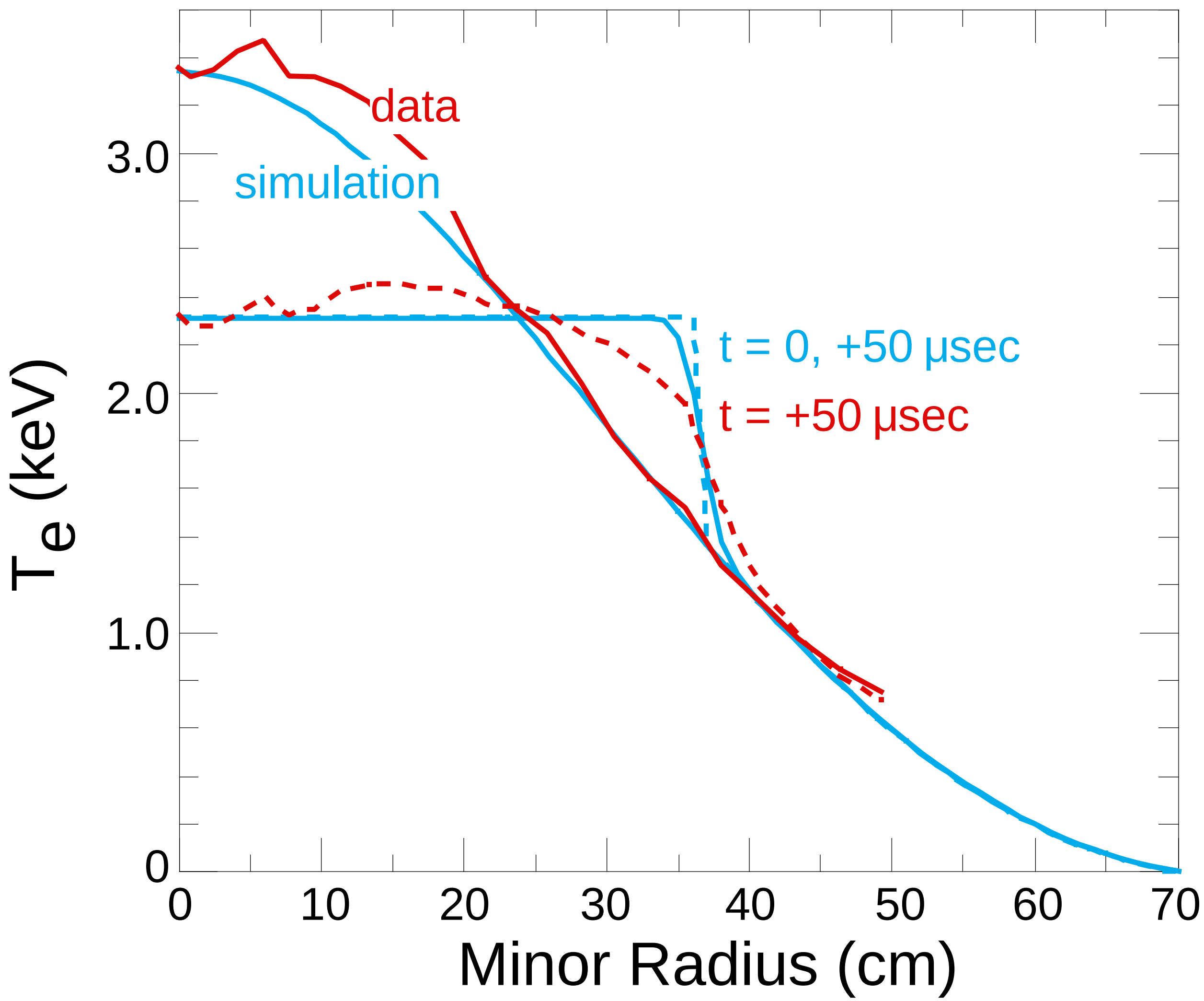

Simulation fits Te profile and models sawtooth crash reasonably well.

The mechanism for the ballistic effect rounds the reconnected profile very quickly.

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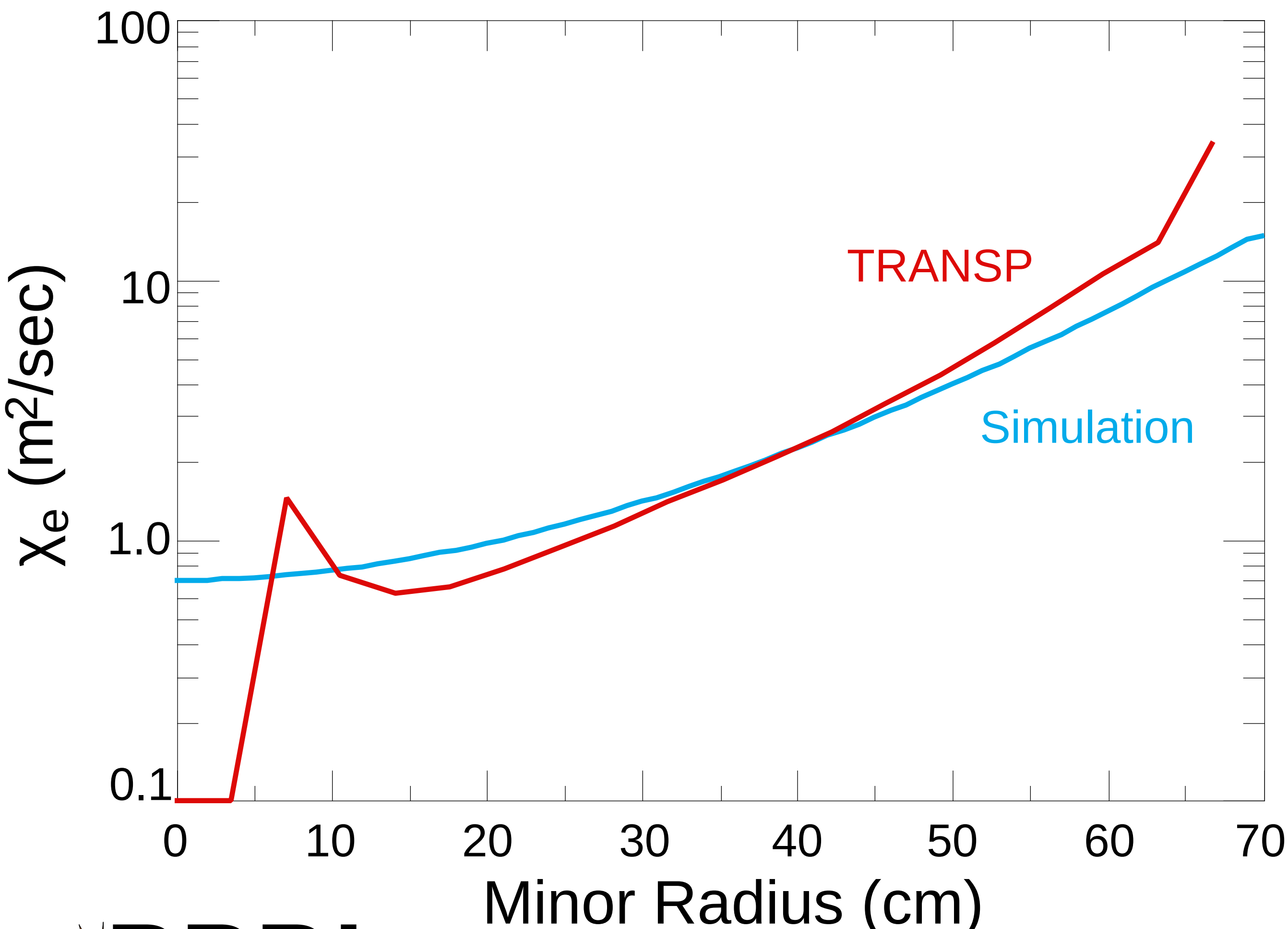
Simulation uses analytic expressions for χ, heating and density profiles



Future simulations will improve fit to χ, explore non-linear and explicitly ballistic transport models.

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Ion Temperature measurements at 2 msec intervals see heat pulse

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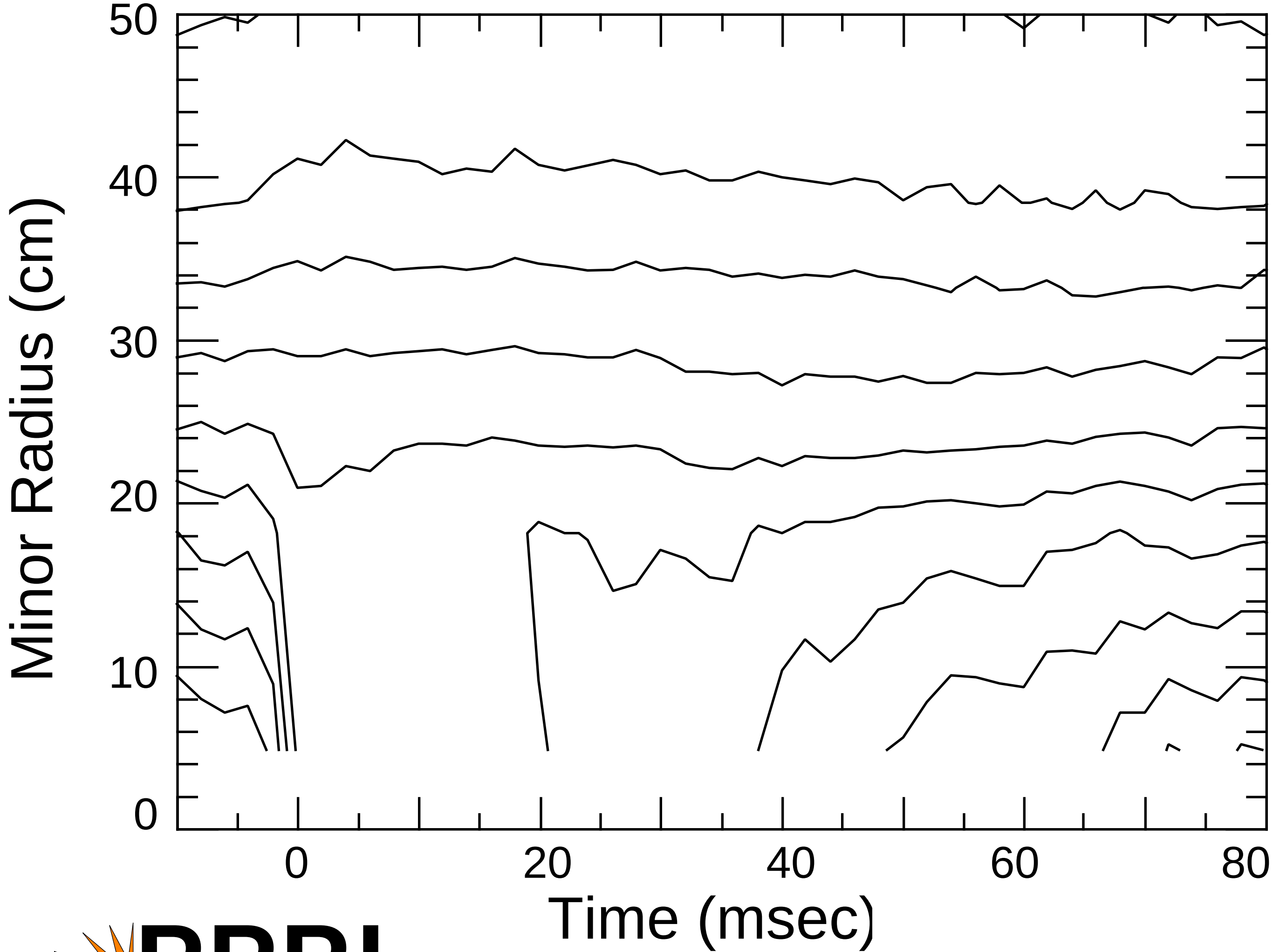

Heat pulses aren't exactly ballistic;

more analysis is necessary to understand them.

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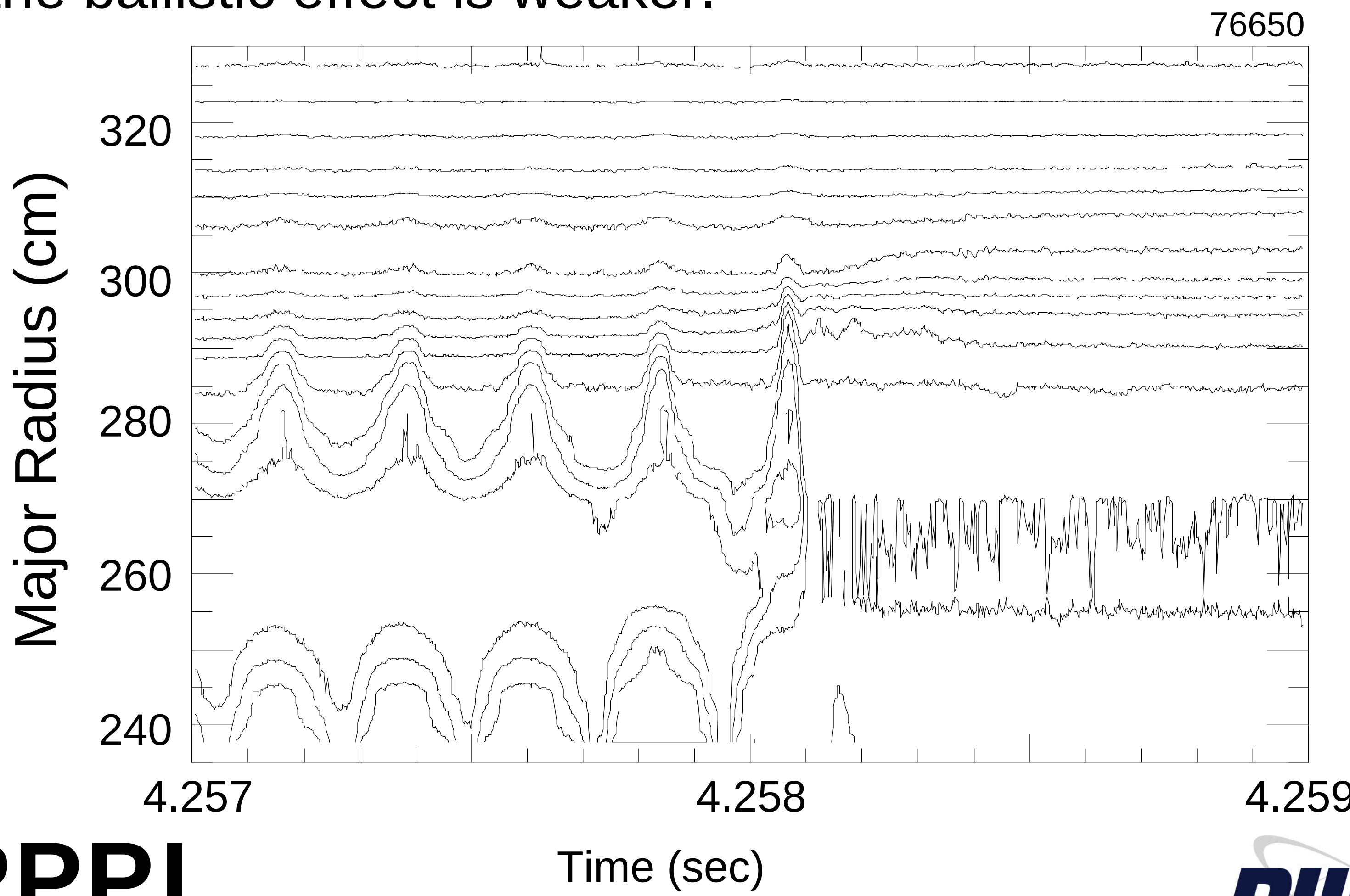
Comparison with TFTR Sawteeth

- Many features of the sawteeth and subsequent heat pulse propagation appear similar between TFTR and DIII-D.
- The most important difference is in the behavior of q during the sawtooth crash.
- The sawtooth precursor on DIII-D shows much of the same behavior as was seen on TFTR: the outward n=1 ballooning, sometimes rapid final growth of the island.
- The higher bandwidth ECE diagnostics on TFTR have also seen moderate n ballooning modes in sawtooth-like events.
- The "ballistic" component of the heat pulse seems relatively much stronger on DIII-D; the origin of this effect is still unknown.

Finite pressure modifies the (1/1) tearing mode, causing a bulge beyond q=1 radius

- Island growth in this case is more linear; the ballistic effect is weaker.

TFTR



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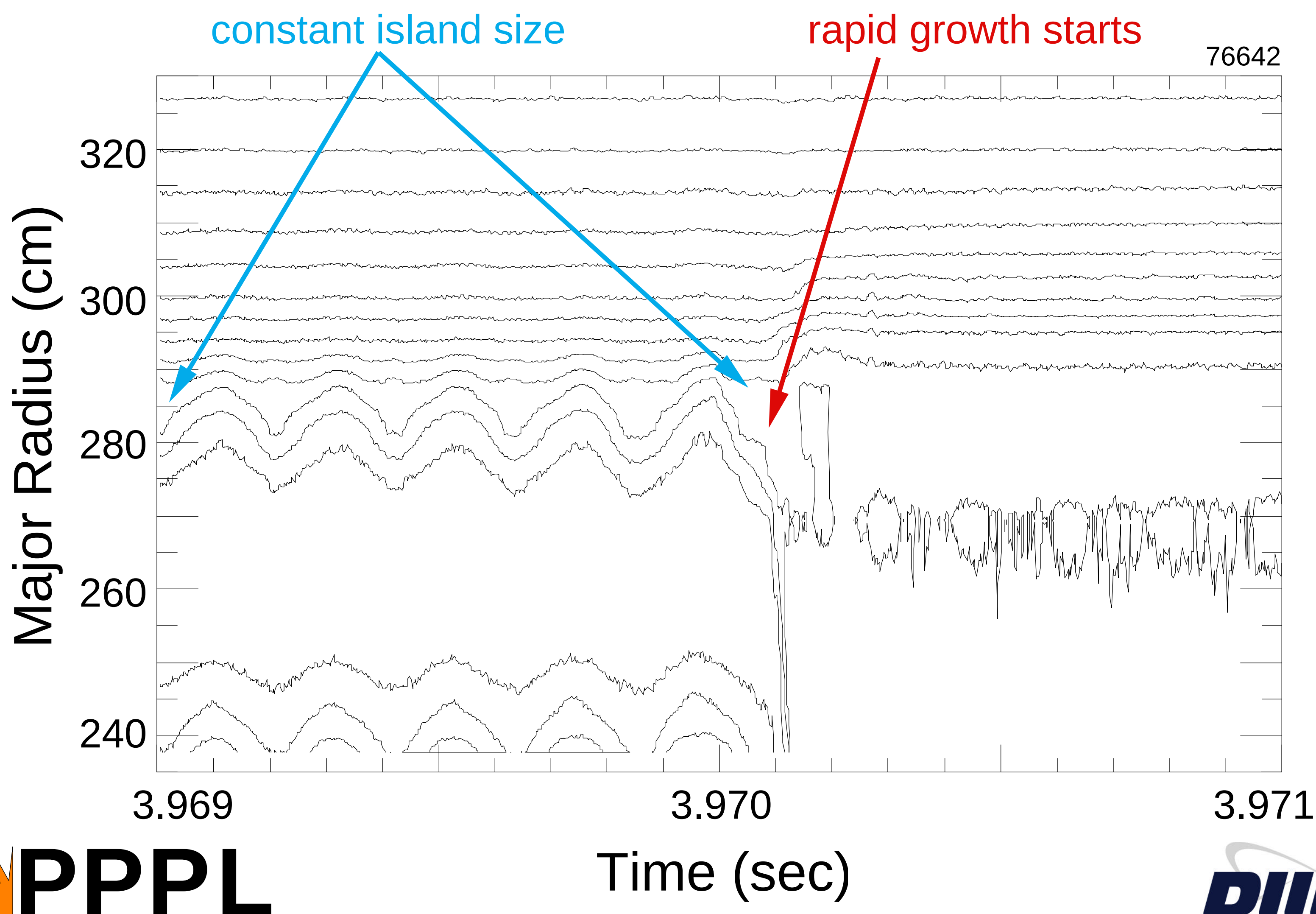
Ballistic effect generally weaker on TFTR

- Sawtooth precursor island growth often non-linear

TFTR



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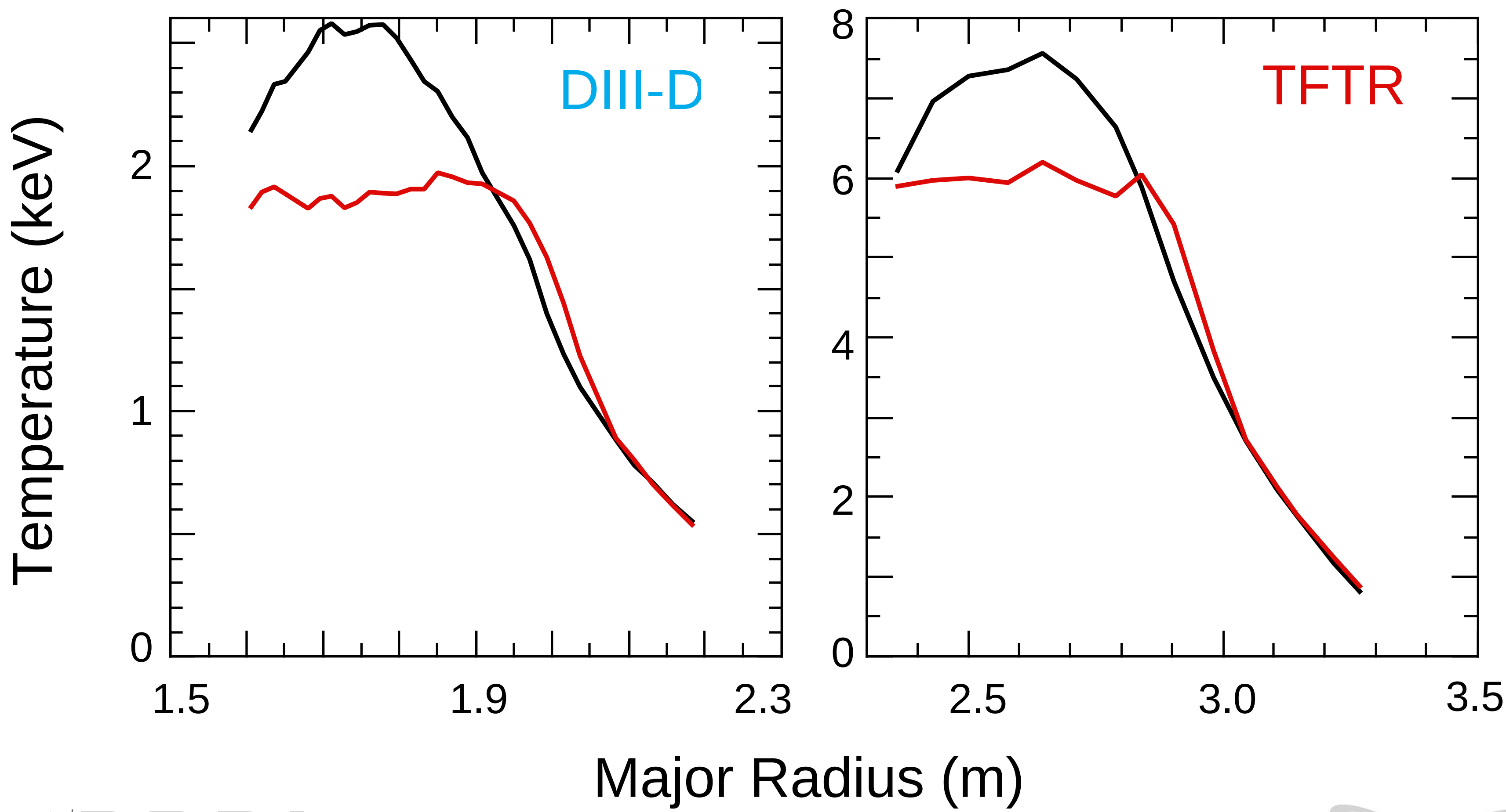
Ballistic effect at low power on DIII-D is comparable to high power on TFTR



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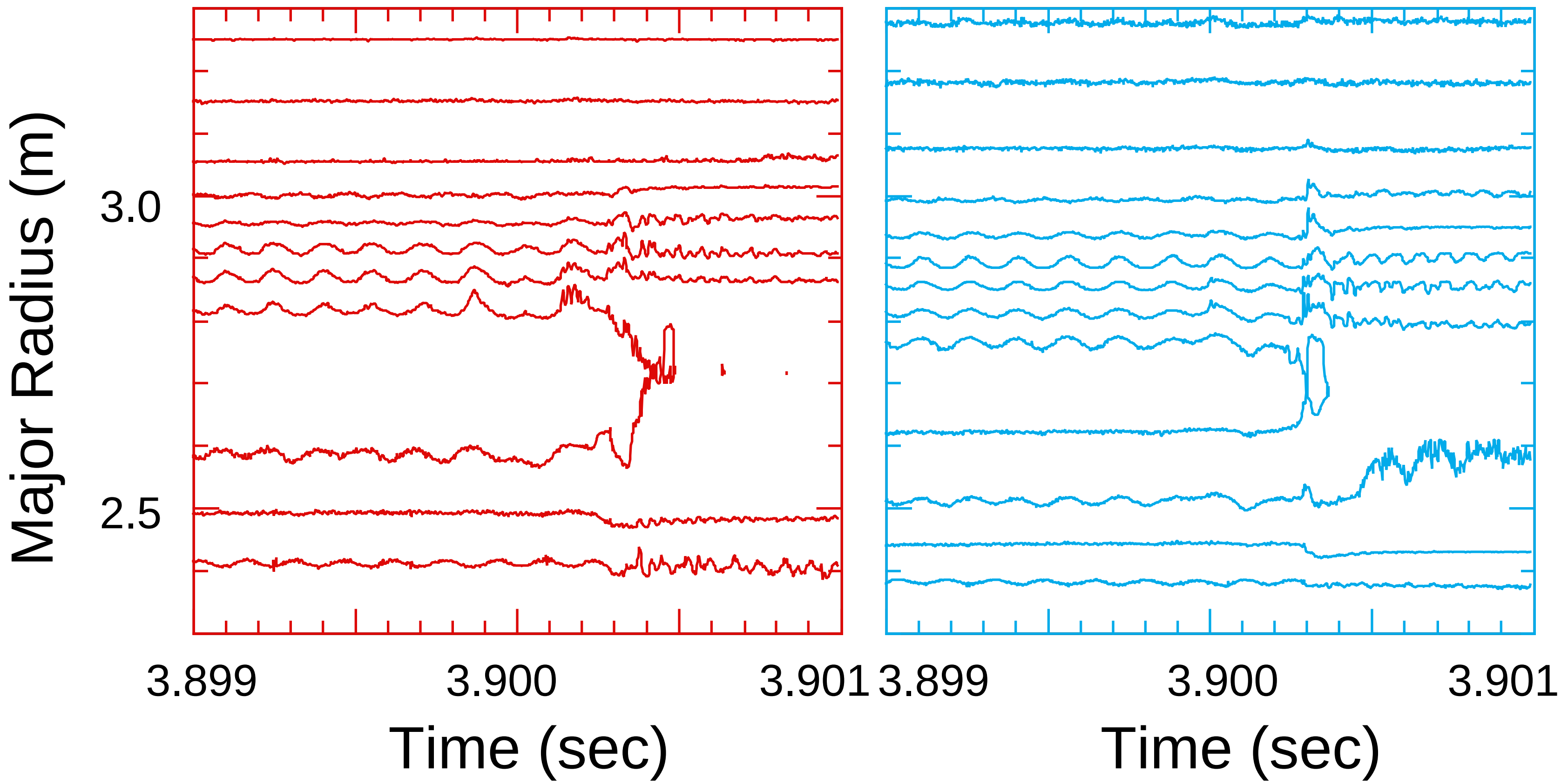
Toroidally localized ballooning precursors have been observed prior to "sawteeth"

TFTR

- Collapse is slow, very weak if any ballistic contribution.



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Summary

- Some stabilization of sawteeth was observed on DIII-D with 1.2 MW of ICRF power, the sawtooth period was lengthened during NBI by a comparable amount.
- Many features of the sawteeth and subsequent heat pulse propagation appear similar between TFTR and DIII-D.
- The most important difference is in the behavior of q during the sawtooth crash.
- Moderate n ballooning modes have been observed in sawtooth-like events on TFTR.
- The "ballistic" component of the heat pulse seems relatively much stronger on DIII-D; the origin of this effect is still unknown.

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