NSTX

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ELM Pacing Via Vertical Position Jogs in NSTX

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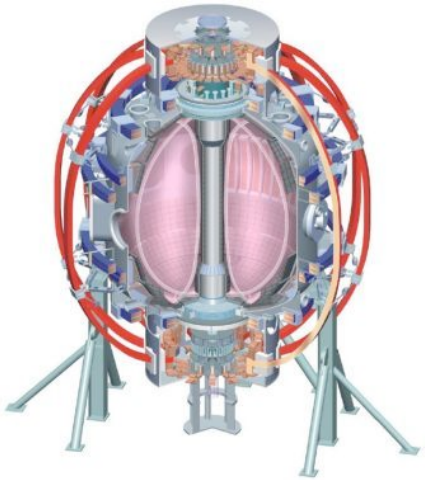
1: PPPL, 2: ORNL, 3: Columbia U.

H-Mode Workshop
PPPL



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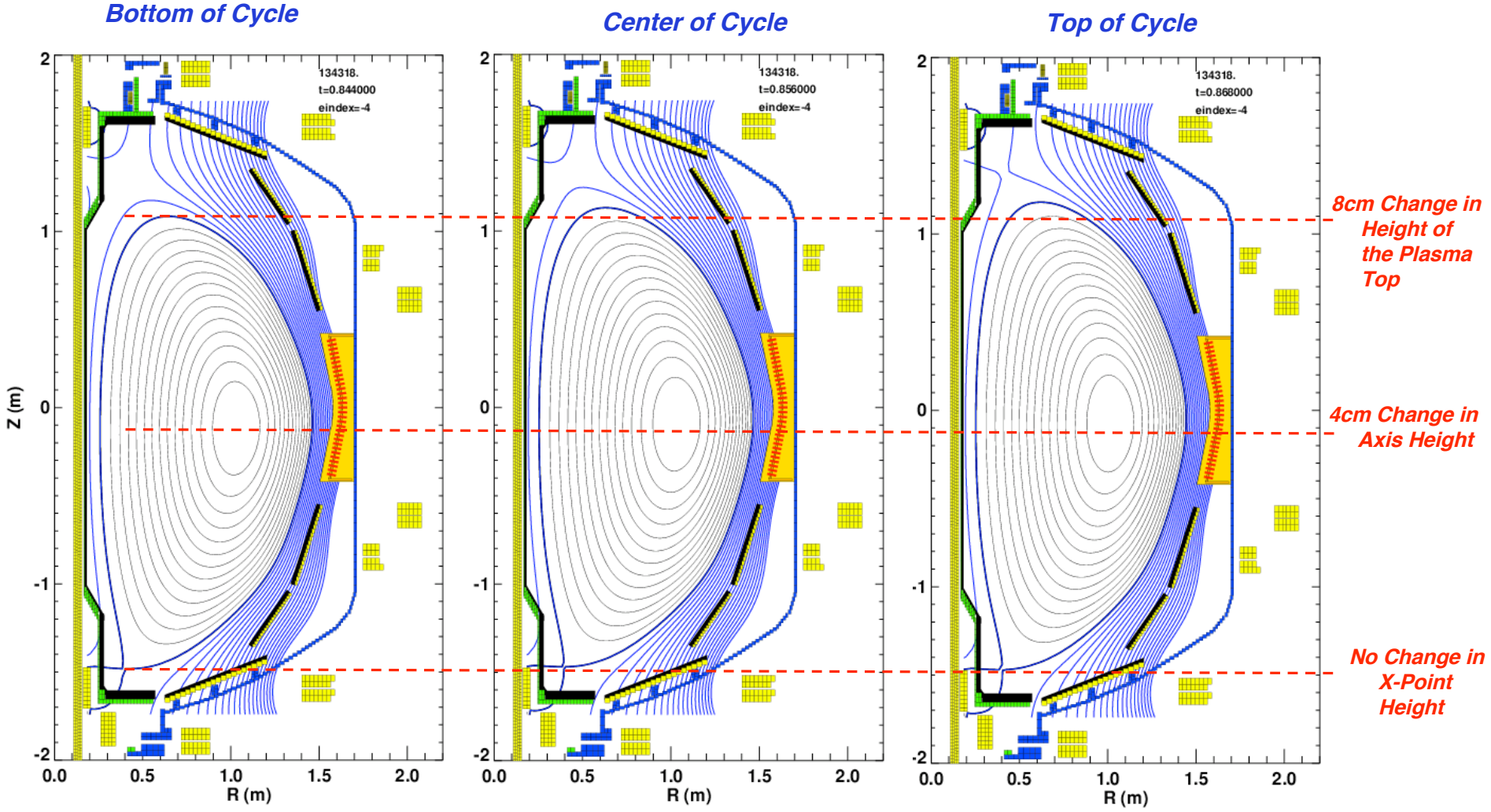
Questions & Answers

- Can the plasma be rapidly jogged in NSTX, given the thick continuous stainless steel vessel?
  - Yes: Requesting large jogs in dr_{sep} can produce rapid jogs in plasma vertical position
- Can ELMs be triggered by the jogs?
  - Yes: Discharge with ~15 Hz ELMs can have them accelerated to ~30 Hz.
- What characteristics of the equilibrium allow best triggering?
  - Preliminary: It appears that more biased down plasmas have ELMs triggered more easily.
- Do the jogs adversely impact confinement, stability, and overall performance?
  - No: stored energy and rotation are not adversely impacted as long as the average dr_{sep} is not made too negative.
- Can we learn anything about ELM physics from these experiments?
  - Maybe…

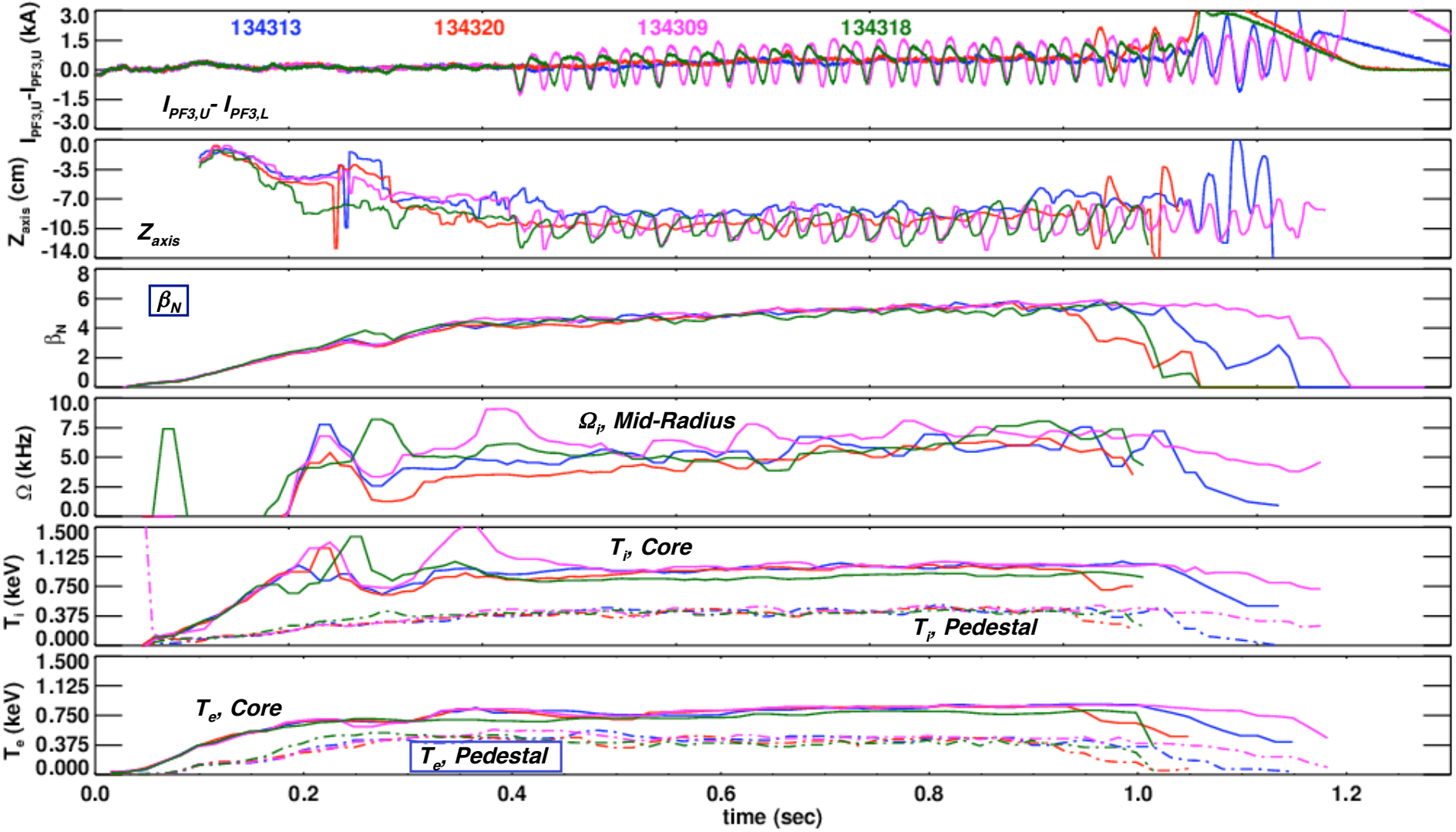
Jogs Lead To Large Shift in Plasma Top, but X-Point is Fixed

134318: 30 Hz Jogs in dr_{sep}



Global Plasma Parameters are Remarkable Unaffected by Careful Jogs

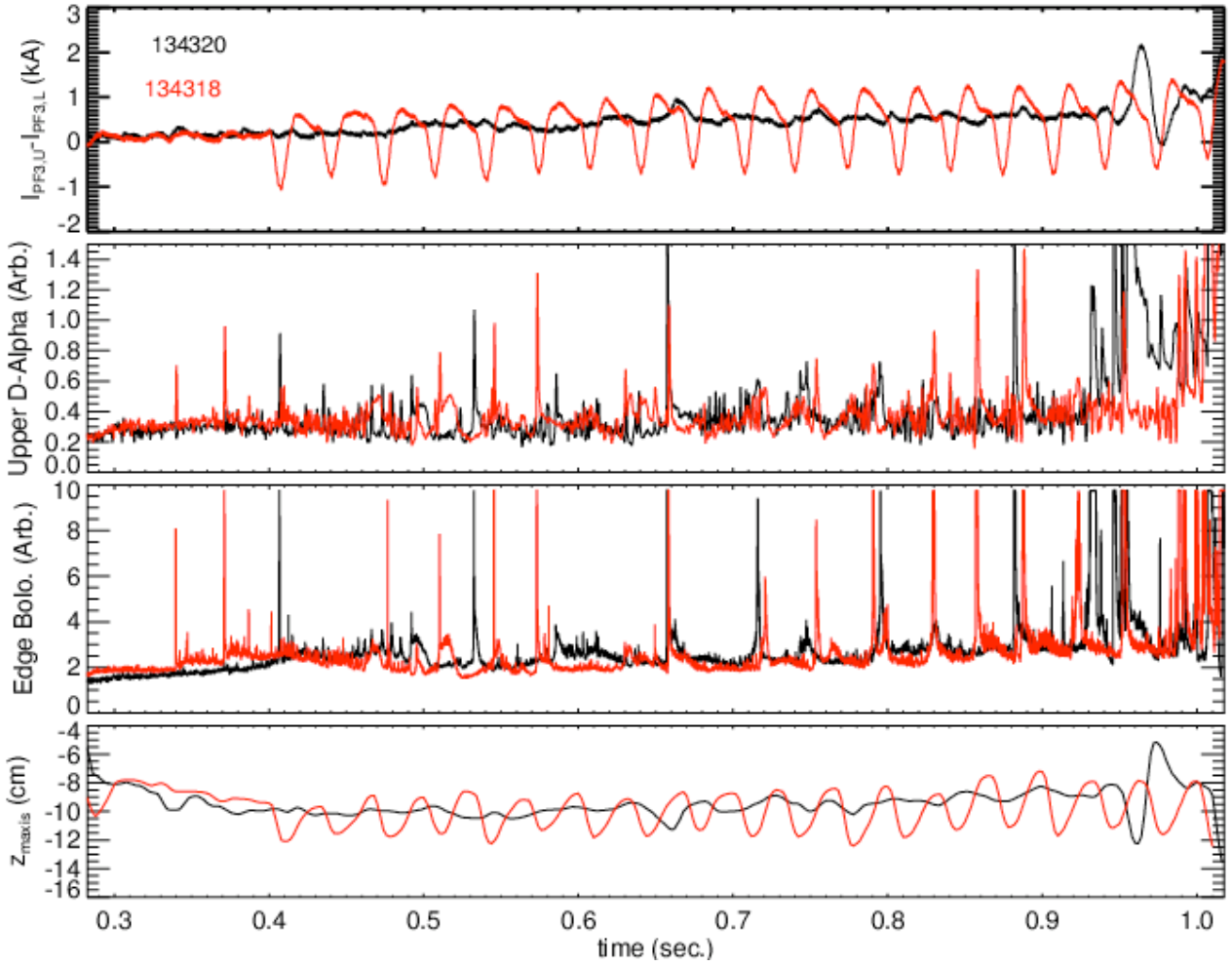
134313: Reference *134320: Reference* *134309: 45 Hz jogs* *134318: 30 Hz jogs*



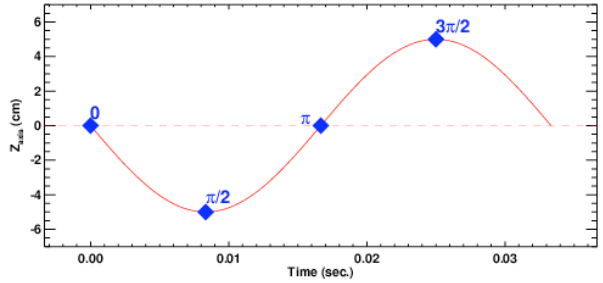
30 Hz Jogging Observed to Increase/Synchronize ELM Frequency in ELMy Discharges

134320: Reference, 6 ELMs in 0.5 sec.→f_{ELM}= 12 Hz

134318: Jogging Case , 12 ELMs in 0.5 sec.→f_{ELM}= 24Hz



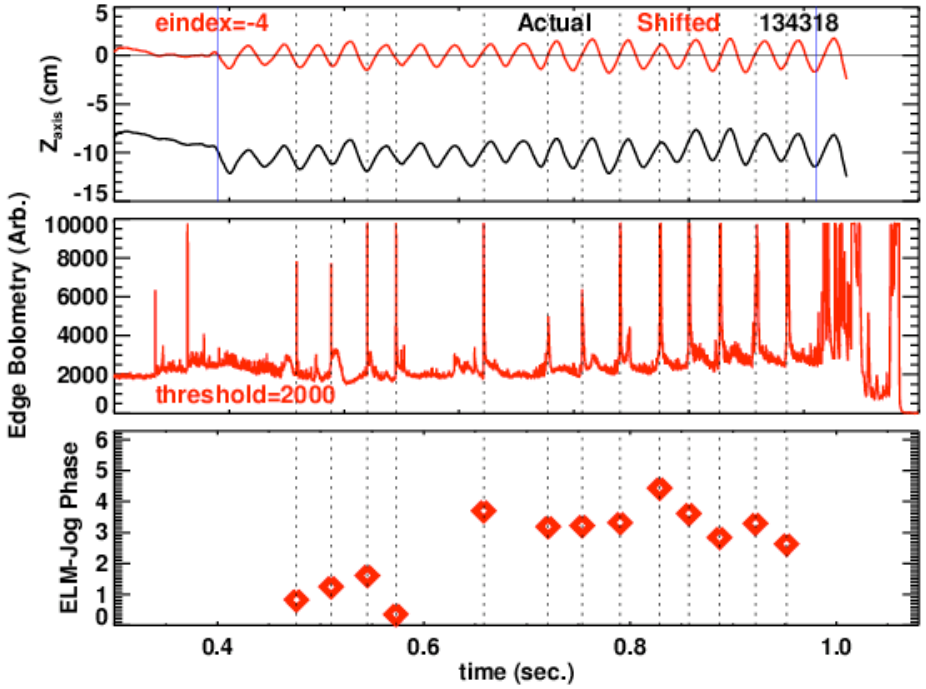
At 30 Hz, ELMs most likely to be Triggered As the Plasma Moves Up

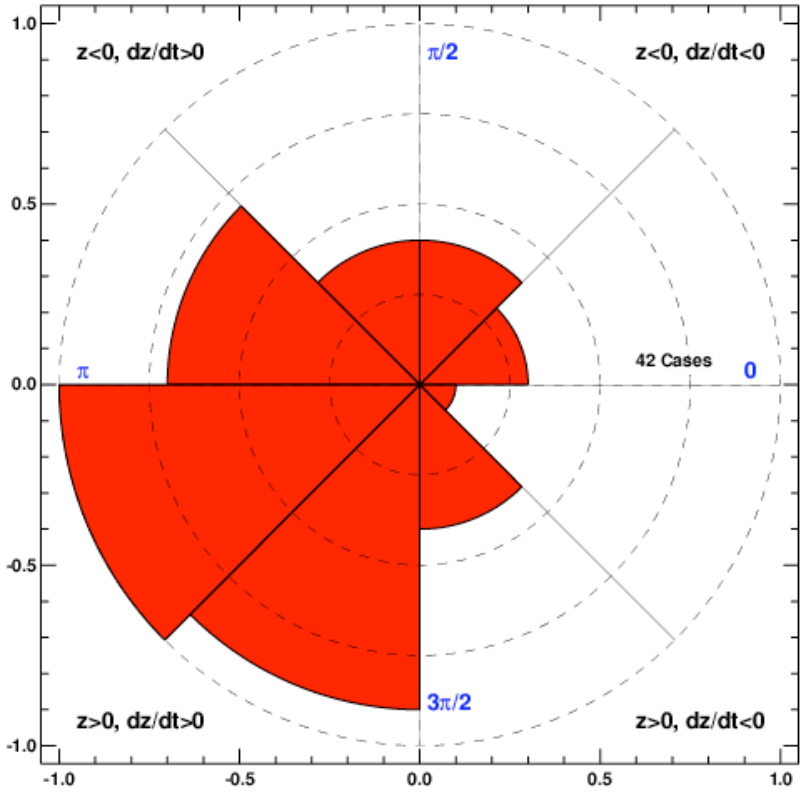


Definition of Phase Within Jog Cycle

- 42 ELMs during jogging phase of 4 shots, 30 Hz Jogging.
  - 134314,134318,134312,134310
- ELMs most likely to be triggered as the plasma moves up.
- ELMs unlikely to be triggered as the plasma moves down.

ELMs have Preferential Phase w/ Respect to Jogs after t=0.6





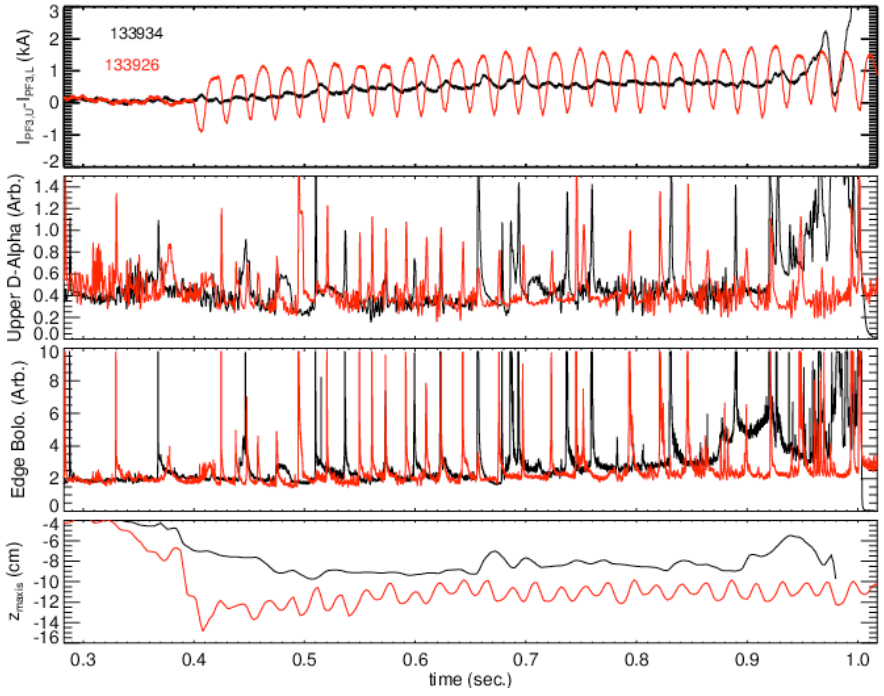
45 Hz Jogging Induces rapid, apparently random ELMs

133934: Reference, ~12 ELMs in 0.5 sec.→f_{ELM}= Hz

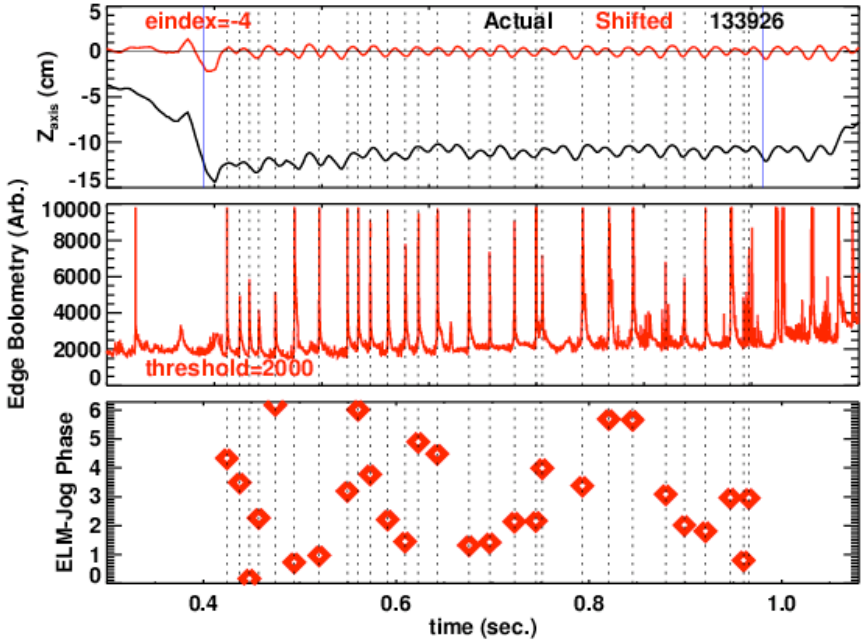
133926: Jogging Case , ~26 ELMs in 0.5 sec.→f_{ELM}= Hz

ELMs twice as rapid with 45 Hz jogs

~2 cm oscillation in the plasma centroid



Random Phase With Respect to the Vertical Motion



Jogs may trigger ELMs via more than one mechanism

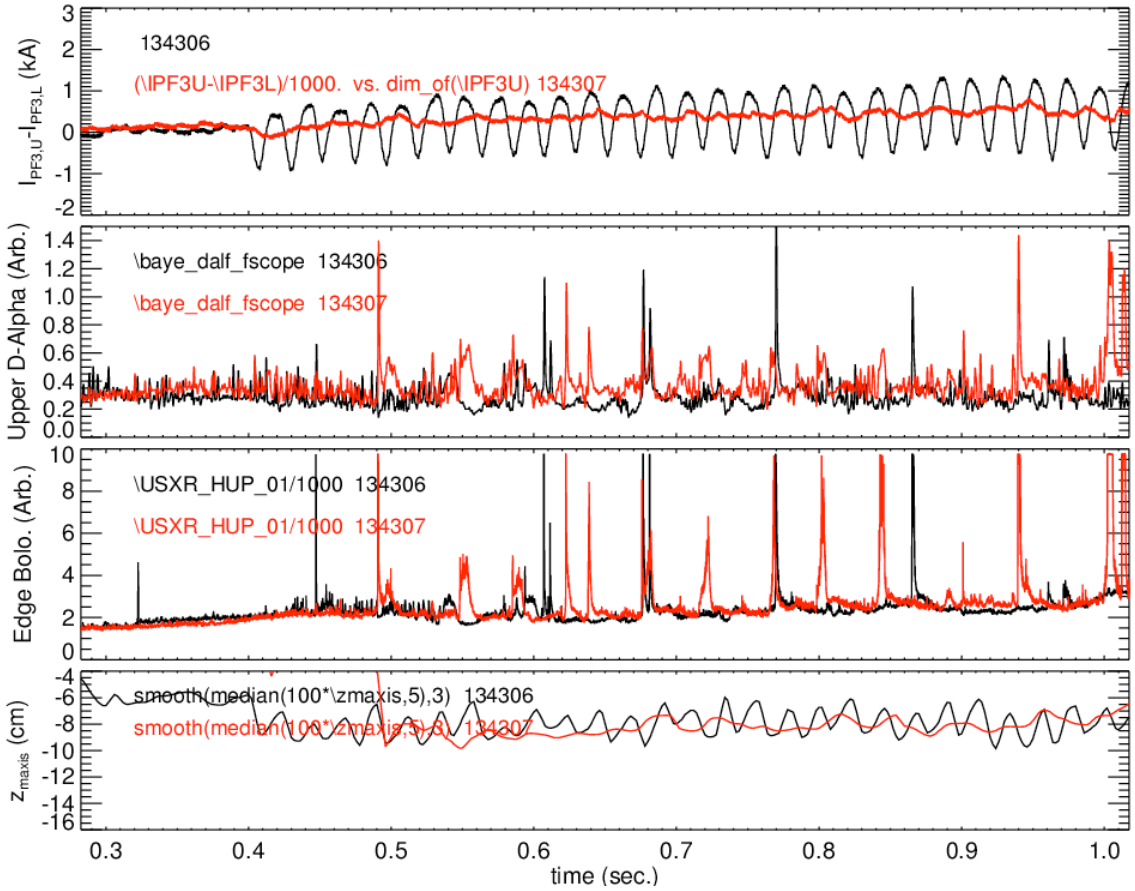
More Difficult to Trigger ELMs in When Lithium Conditioning is Present

Shots taken morning after heavy Li conditioning

Equilibrium dr_{sep} also less negative than other cases

134306: Jogging ***134307: Reference***

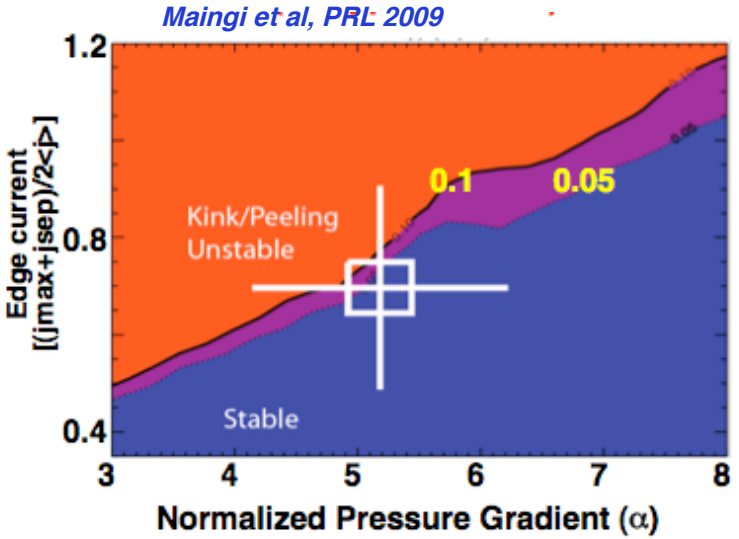
Jogs are unable to generate ELM in this cases…because of Li or dr_{sep}?

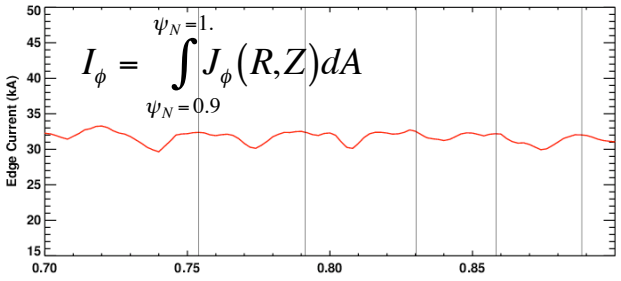


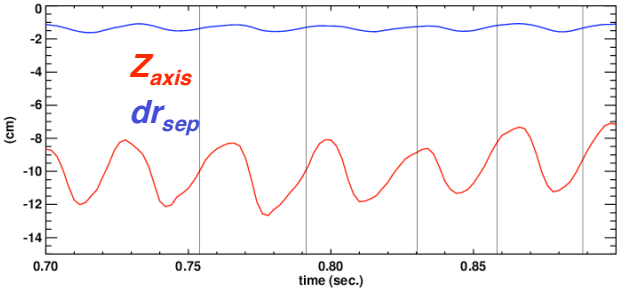
Magnetic Triggering Techniques Have Been Reliable in this Condition

A Potential Explanation From A Peeling-Ballooning Perspective

- *Peeling-Ballooning Theory*: ELMs are destabilized in NSTX when the edge current becomes too large.
- *From Reconstructions*: The jogs create perturbations in the edge current.
- *Thesis*: The sum of the temporally evolving edge bootstrap current and oscillating edge currents causes the total current to cross the stability boundary-> ELM!
- Introduces new time-scales and requirements:
  - Size of the edge current perturbations compared to the bootstrap current.
  - Time scale of jogs compared to the resistive current evolution.
- Unclear that this thesis can be proven/disproven.







Conclusions And Next Steps

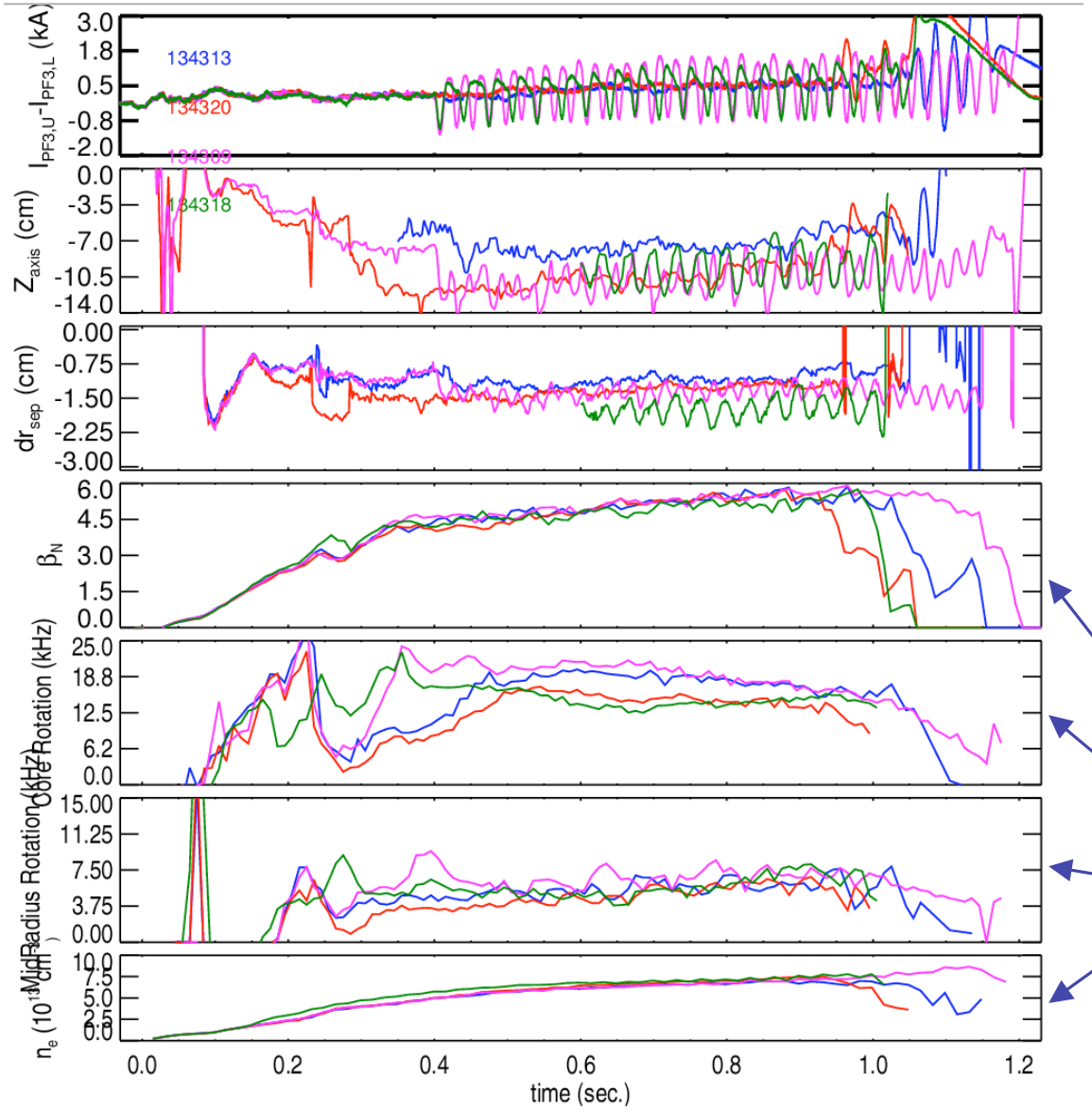
- Conclusions
  - The NSTX plasma can be vertically jogged, and the jogs can trigger and pace ELMs.
- Next Steps
  - Compare IR thermography data for natural and triggered ELMs…do the get smaller when they get faster?
  - Try to pull together the underlying physics story…can the connection to the edge current perturbation be made more concrete?
  - Assess if present "kicking" method is sufficient…do we need to add an explicit PF-3 voltage kick?
  - Present results at the H-mode workshop.
  - Design a follow-up experiment for 2010.
    - Test upward kicks?
    - Explicit scan of equilibrium dr_{sep} during kicks?
    - Try in a moderate triangularity discharge?
    - Improved profile measurements during kicks (can kicks relative to MPTS)?
    - Add explicit voltage perturbations?

Old And Backup

Goal: Use Rapid Oscillations in the Plasma Position to Trigger ELMs

- Reactor-scale tokamaks need either mitigation, or complete suppression, of ELMs:
  - Suppression techniques include some RMP results, QH mode.
  - Mitigation could mean ELM pacing with 3-D fields, small-ELM regimes, pacing via pellets, or *plasma position oscillations*.
- ELM triggering via vertical position oscillations observed in at least 3 tokamaks.
  - TCV [1]: A. W. Degeling, et al., Plasma Phys. Control. Fusion **45**, 16367 (2003)
  - AUG [2]: P.T. Lang, et al., Plasma Phys. Control. Fusion **46**, L31 (2004)
    - Above two compared in [3] S.H. Kim, et al, Plasma Phys. Control Fusion **51**, 055021 (2009)
  - JET [4]: F. Sartori, et al., 35th EPS Conference on Plasma Physics
- Physics mechanism of pacing via vertical jogs remains obscure.
  - Perturbations to edge current?
  - Modifications of the boundary shape?
  - Something else?
  - All of the above?
- Propose to test this in NSTX:
  - Support ITER needs.
  - Test concept for future ST devices.
  - Attempt to understand something about the triggering

Global Plasma Parameters are Remarkable Unaffected by the Jogs



134313: Reference

134320: Reference

134309: 45 Hz jogs

134318: 30 Hz jogs

If overdone, jogging can be highly perturbative.

Too large/long kick can drive the plasma down too far, with loss of H-mode followed by disruption at high β_N.

If done properly:

1: Normalized β_T is unaffected by jogs

2: Core rotation impacted by early mhd, but not jogs.

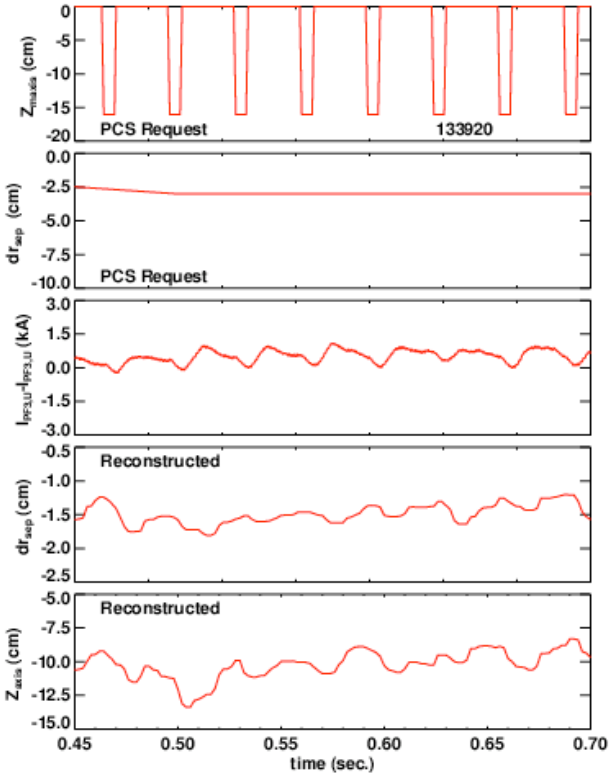
3: Mid-radius rotation identical.

4: Density evolution near identical.

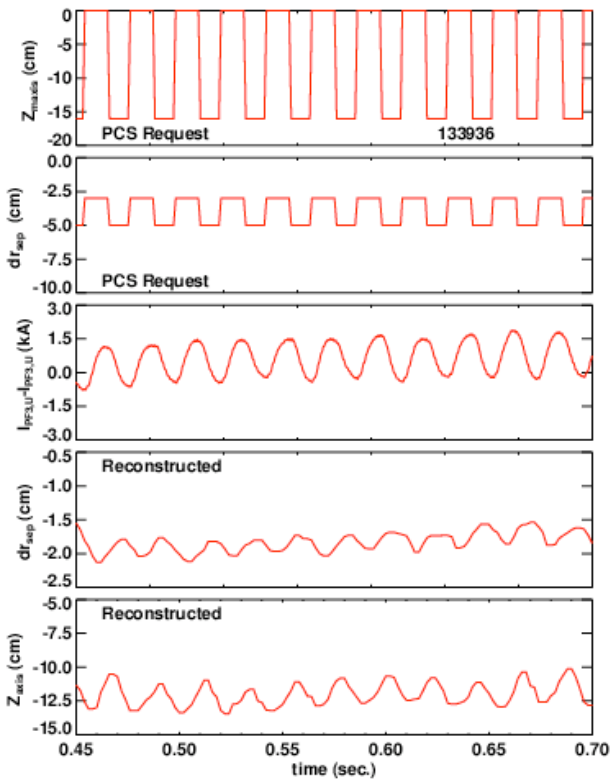
Most Type-I ELMs Do Not Cause Vertical Control

Plasma Can Be Jogged Using Step Requests in Axis Vertical Position, dr_{sep}, or Both Synchronously.

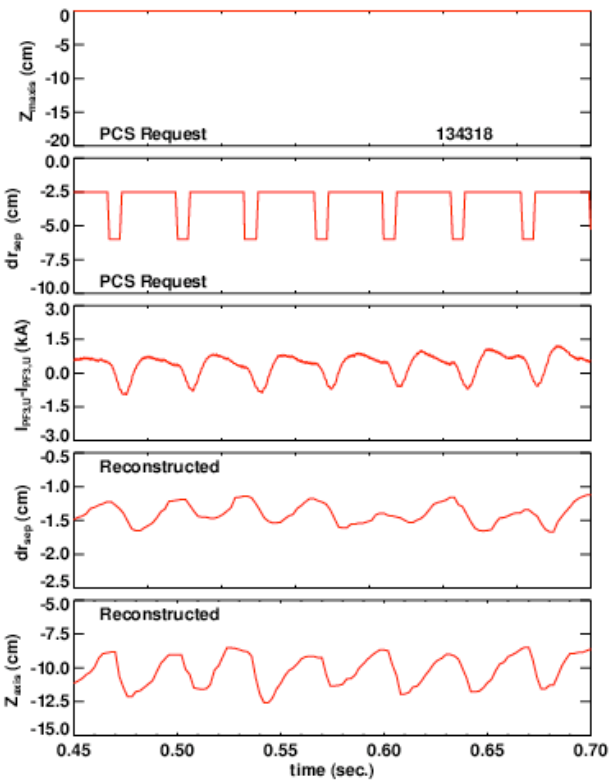
133920: Jogs in Z_{axis} alone, 30 Hz



133936: Jogs in Z_{axis} and dr_{sep}, 45 Hz



134318: Jogs in dr_{sep} alone, 30 Hz



- Final configuration used jogs in dr_{sep} alone, as these allowed a rapid response.
- Considering adding an explicit voltage perturbation for FY-10.

Background: First Attempts at ELM Triggering Via Jogs in NSTX in 2009

- Tried experiments on two days.
  - 27 shots on June 1st
    - Developed jogging technique and found evidence of pacing.
  - 20 shots on June 12th
    - This immediately after very heavy Li usage the previous evening
- NSTX has a continuous stainless steel vacuum vessel.
  - Not immediately clear that the plasma could be moved sufficiently rapidly.
- Use GA PCS with rtefit & isoflux shape control.
  - Apply jogs as square waves in requests for either dr_{sep} or Z_{axis}