NSTX

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

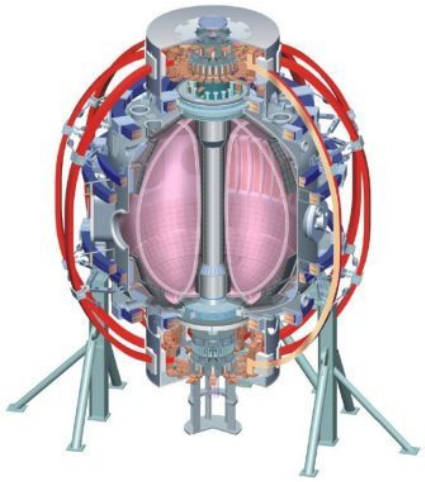
NSTX ELM Pacing Experiments: RMP Fields and Vertical Jogs

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

J.M. Canik, *S.P Gerhardt*,
R. Maingi, many others…

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Pedestal Planning Meeting, PPPL
Sept. 8th, 2010



Overview

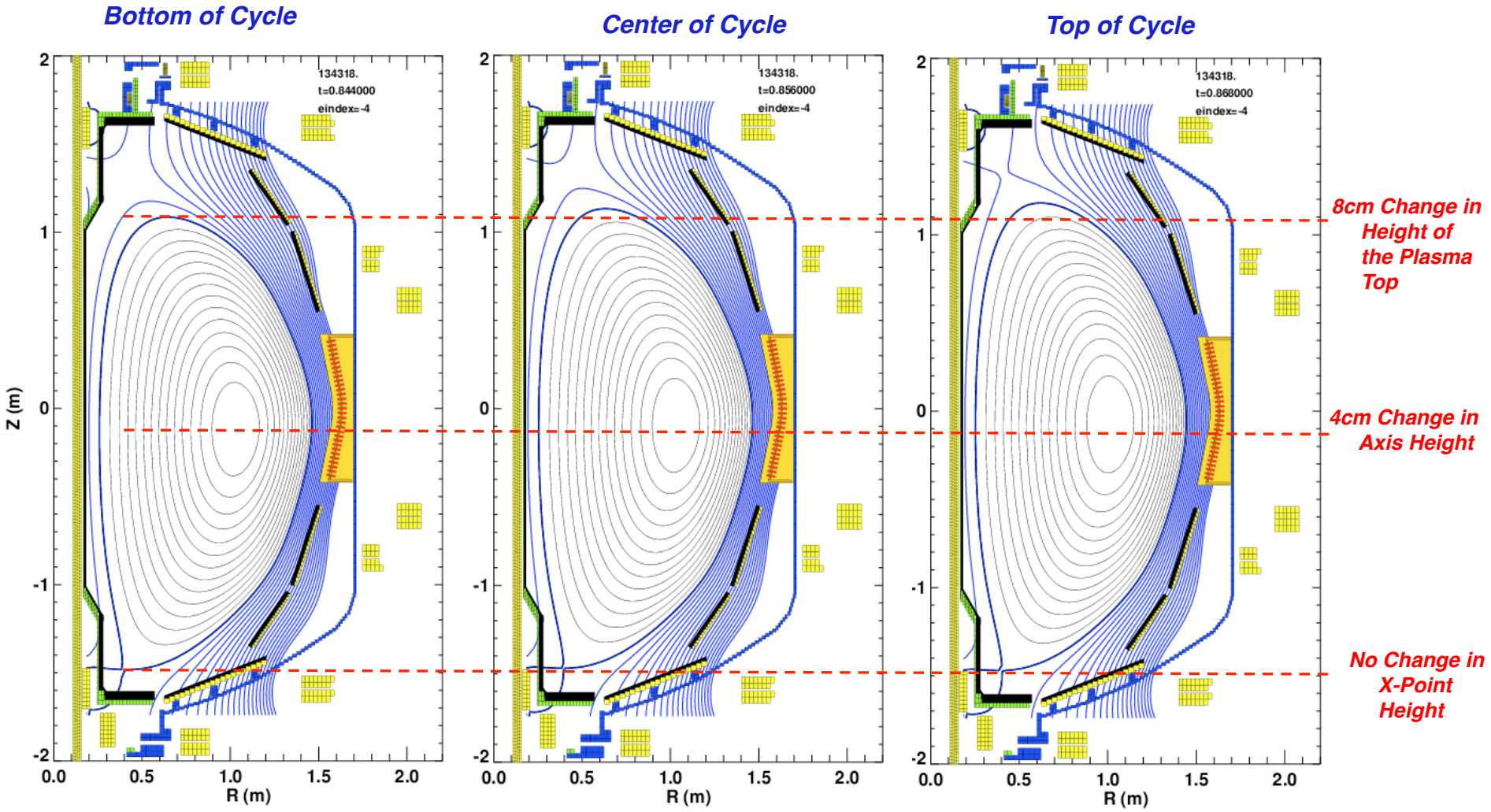
- NSTX has demonstrated ELM triggering/pacing with two different techniques.
  - Vertical jogs (“kicks”) of the plasma.
  - Pulsed and DC RMP.

- In both cases, the physics of the triggering remains obscure.
  - I’ll provide some ideas for discussion.

- There may be a useful combination of these techniques.
  - Experiment to run next week to test this in NSTX (J.M. Canik, et al.)

Vertical Jogs For ELM Pacing

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

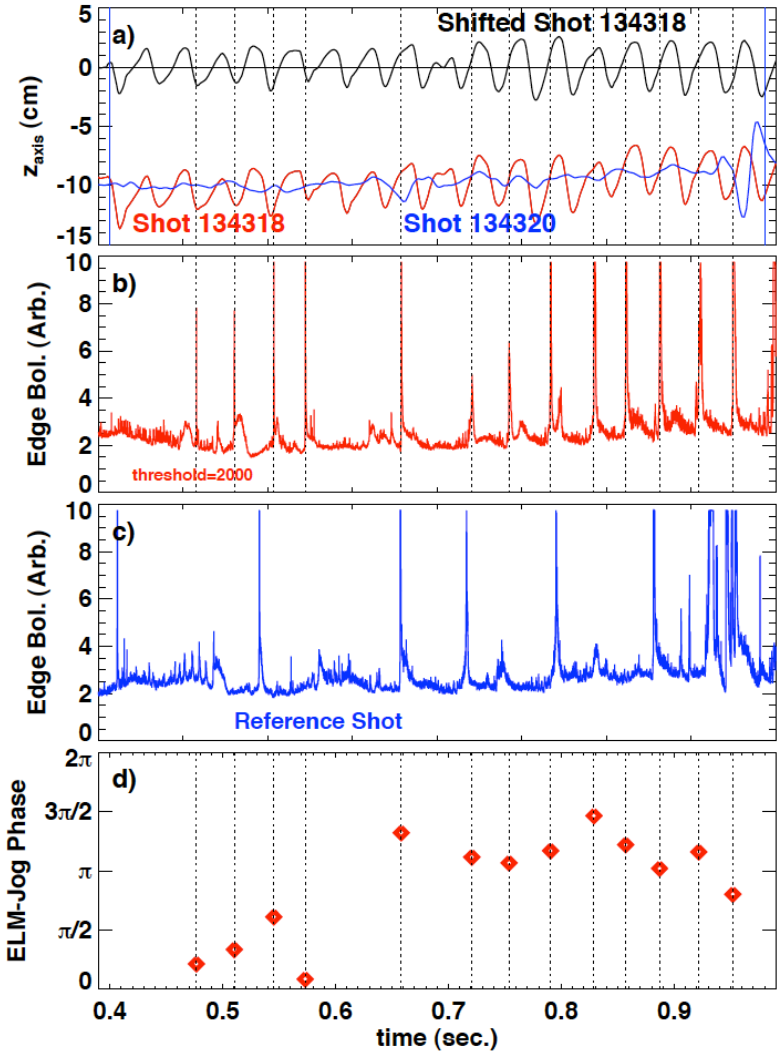


Jogs achieved by requesting large transients in either or both of Z_{maxis} and dr-sep.

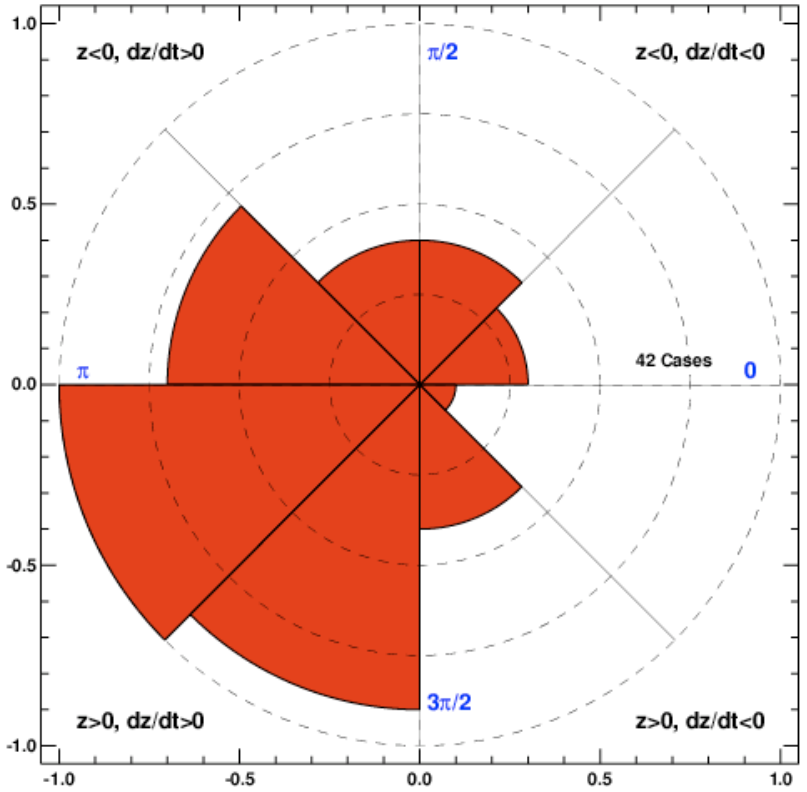
S.P. Gerhardt, et al., Nuclear Fusion **50**, 064015 (2010)

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

30 Hz Jogs

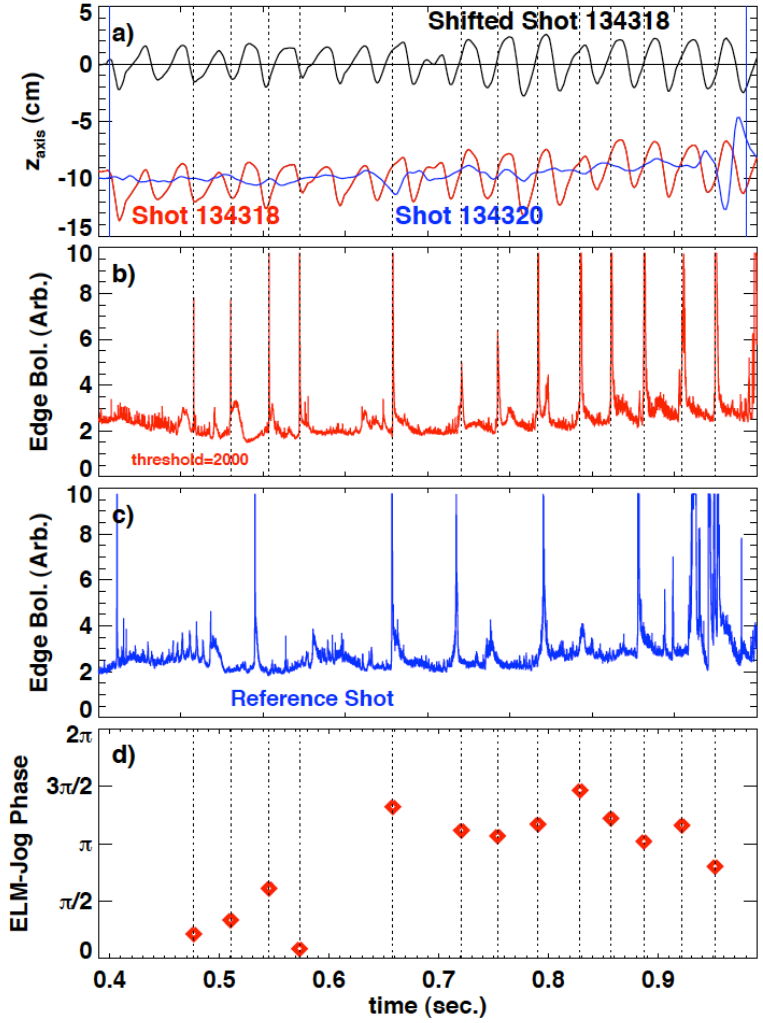


- 42 ELMs during jogging phase of 4 shots, 30 Hz Jogging.
  - 134314,134318,134312,134310
- ELMs most likely to be triggered as the plasma moves up.
- ELMs unlikely to be triggered as the plasma moves down.

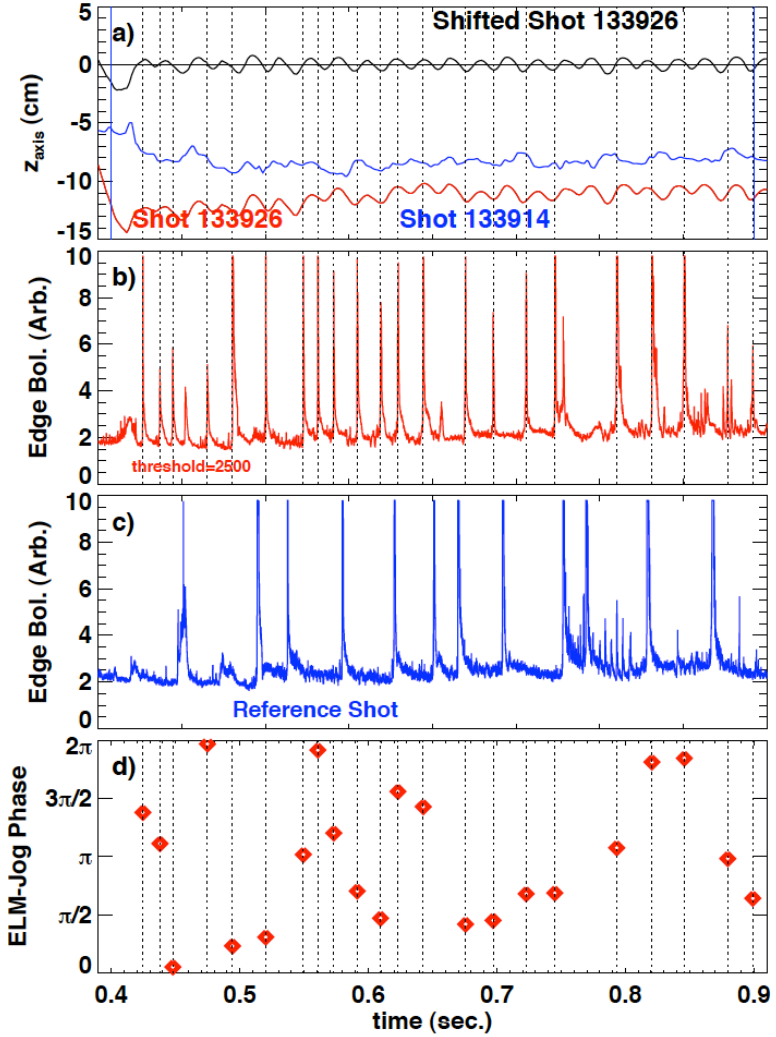


While 30 Hz Triggering was Well Synchronized with VJs, 45 Hz Triggering was NOT!

30 Hz Jogs



45 Hz Jogs

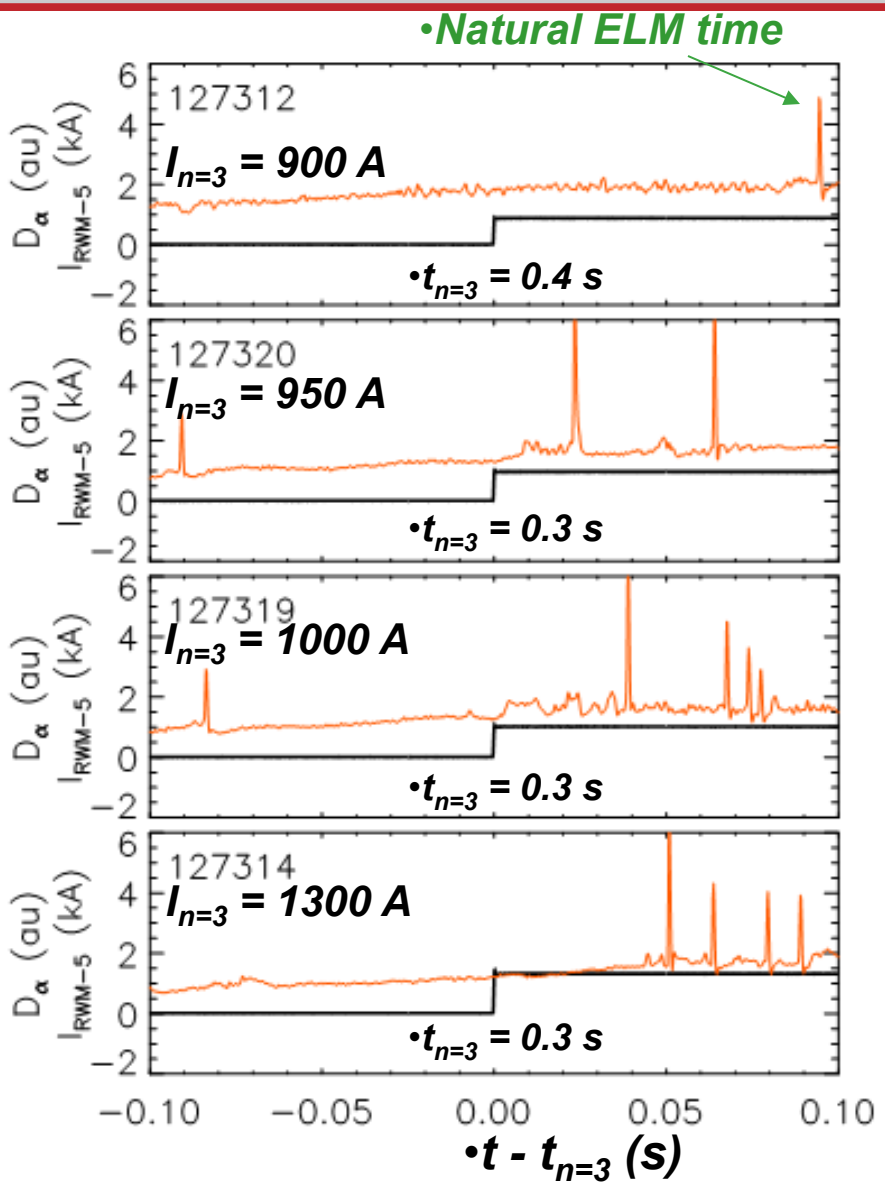


Both cases increased the ELM frequency compared to the nearby reference shot.

Pulsed and DC RMP for ELM Pacing

Midplane coil current scan shows threshold for destabilization without Li conditioning

- Threshold coil current for ELM-triggering is ~950 A ->$\Delta B/B = 6\times10^{-3}$
  - No triggering at 900 A (natural ELMs start at ~0.5s in control discharge)
  - Intermittent ELMs at 950 and 1000 A
- ELM frequency appears to increase with n=3 field magnitude
  - ELMs become more regular
  - Tendency clouded by tendency of plasma to lock:
    - high RMP currents=too much braking.



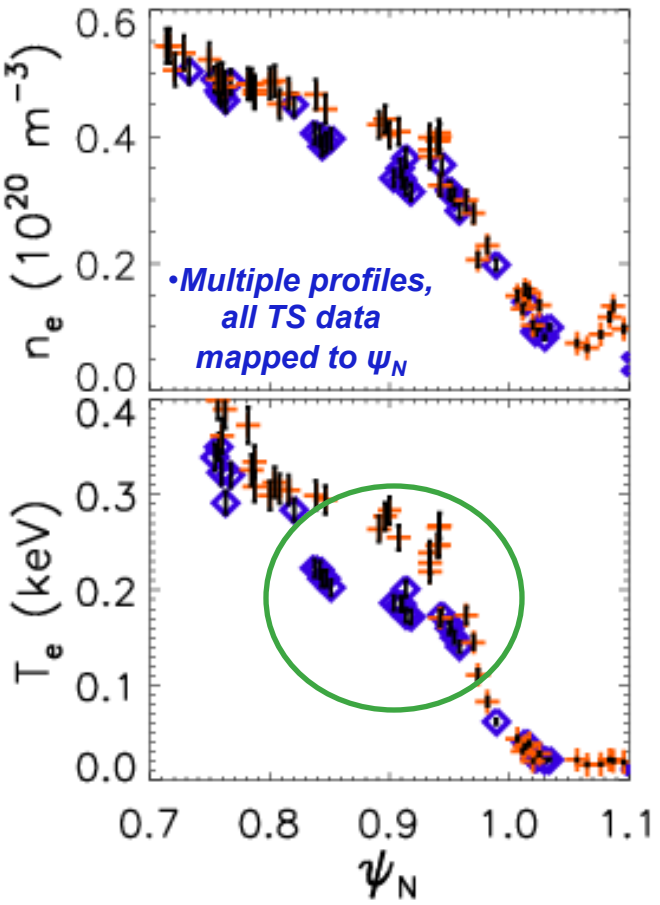
J. M. Canik, et al., Nuclear Fusion **50**, 034012 (2010)

No Lithium Case: T_e^{ped} Increases When n=3 Field is Applied

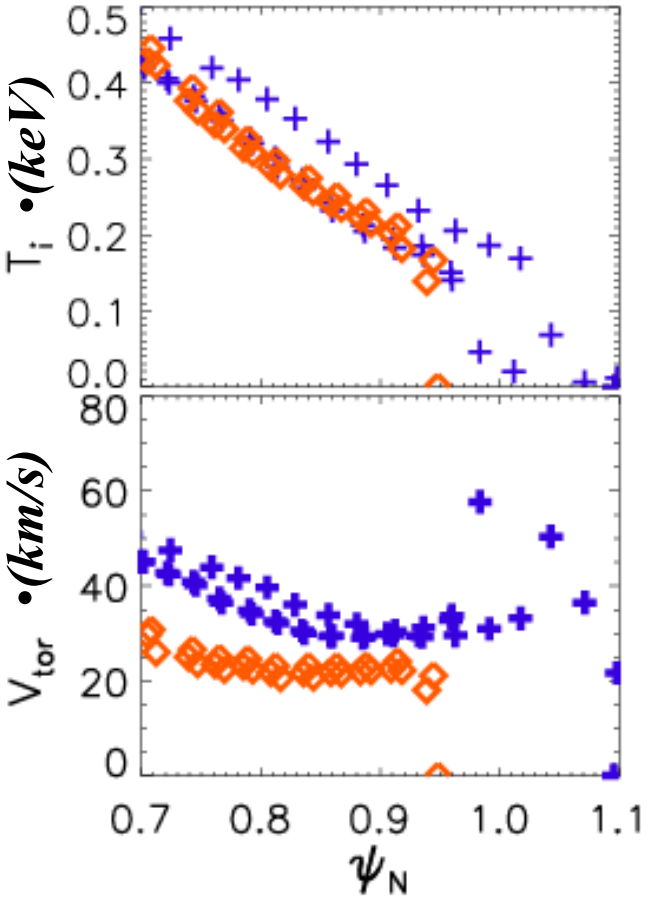
- Blue profiles: no n=3 applied
- Red profiles: 20 ms after n=3 applied (before ELMs)

•No lithium coatings in these shots

•Pedestal electron profiles



•Pedestal ion profiles



- ***No density pumpout is observed***
- ***Te, pressure gradient increases after n=3 field is applied***
  - ***Tanh fitting gives ~30% increase in peak pressure gradient***
  - ***PEST shows edge unstable after n=3 application***

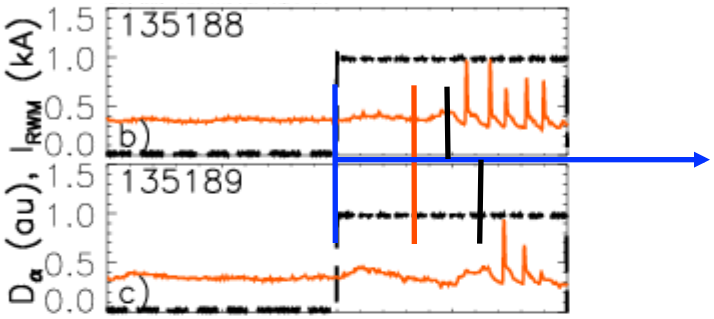
Preliminary analysis shows different pedestal response to perturbation with lithium coatings

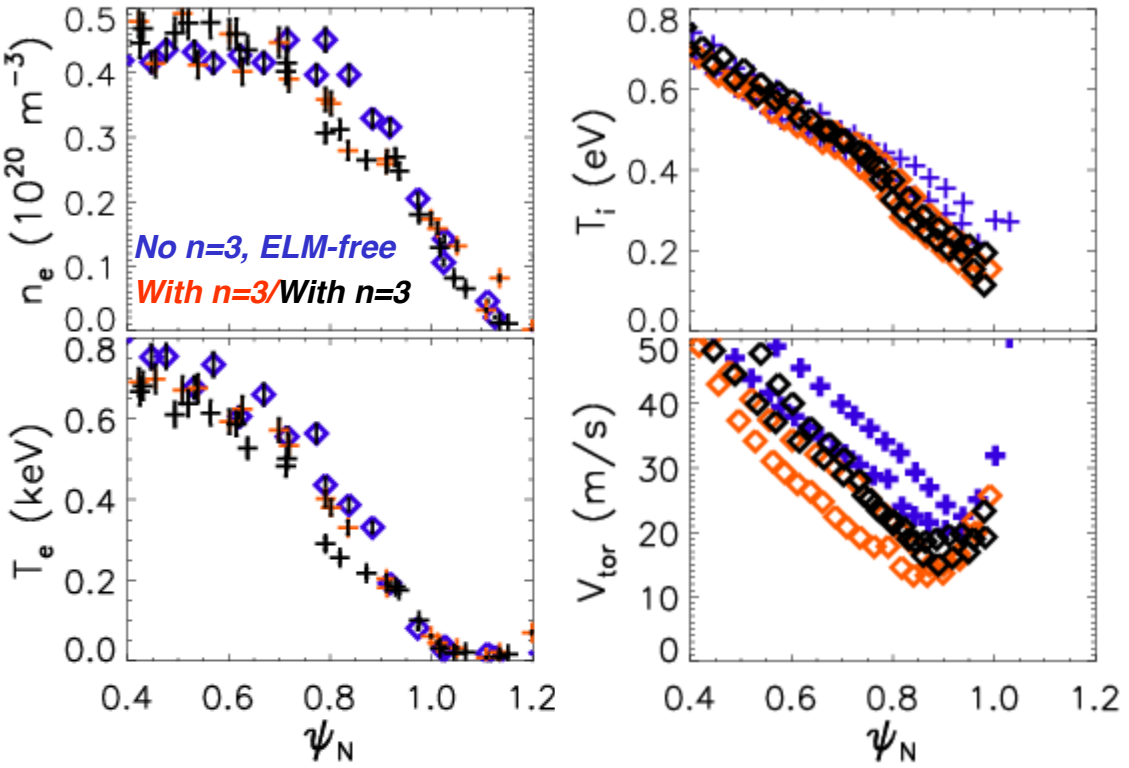
Data combined from several shots, all before ELMs start

Color code: Just before n=3, 30 ms after, ~50/65 ms after

Edge ion temperature, toroidal rotation drop after n=3 field is applied

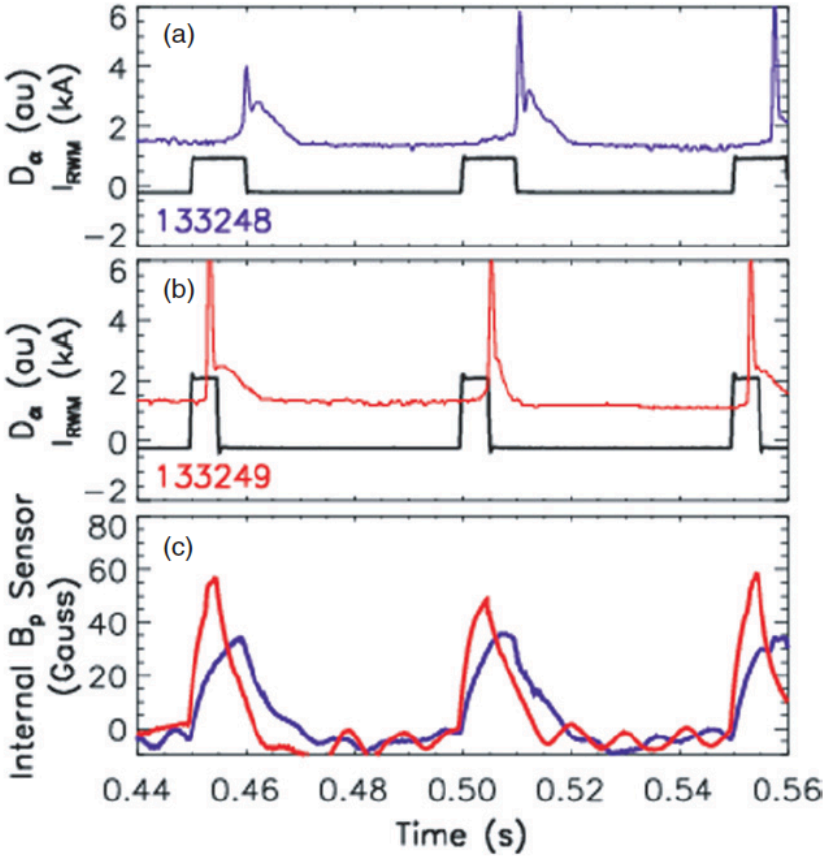
Te, ne show flattening from ψ_N ~0.8-0.9, similar gradient outside 0.9



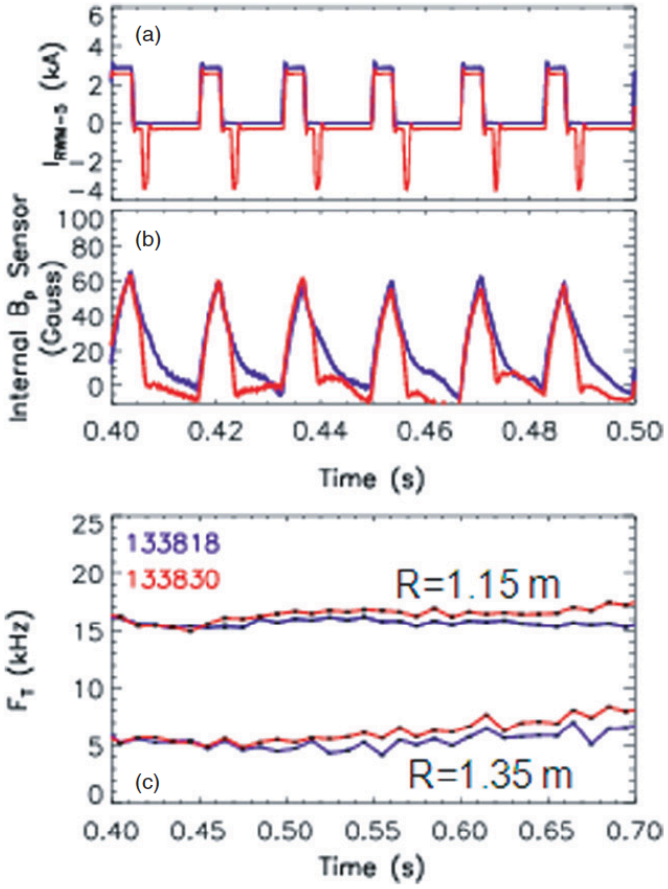


Pulsed Fields are Now Typically Used To Trigger ELMs

Positively Going Pulses Can Trigger ELMs…

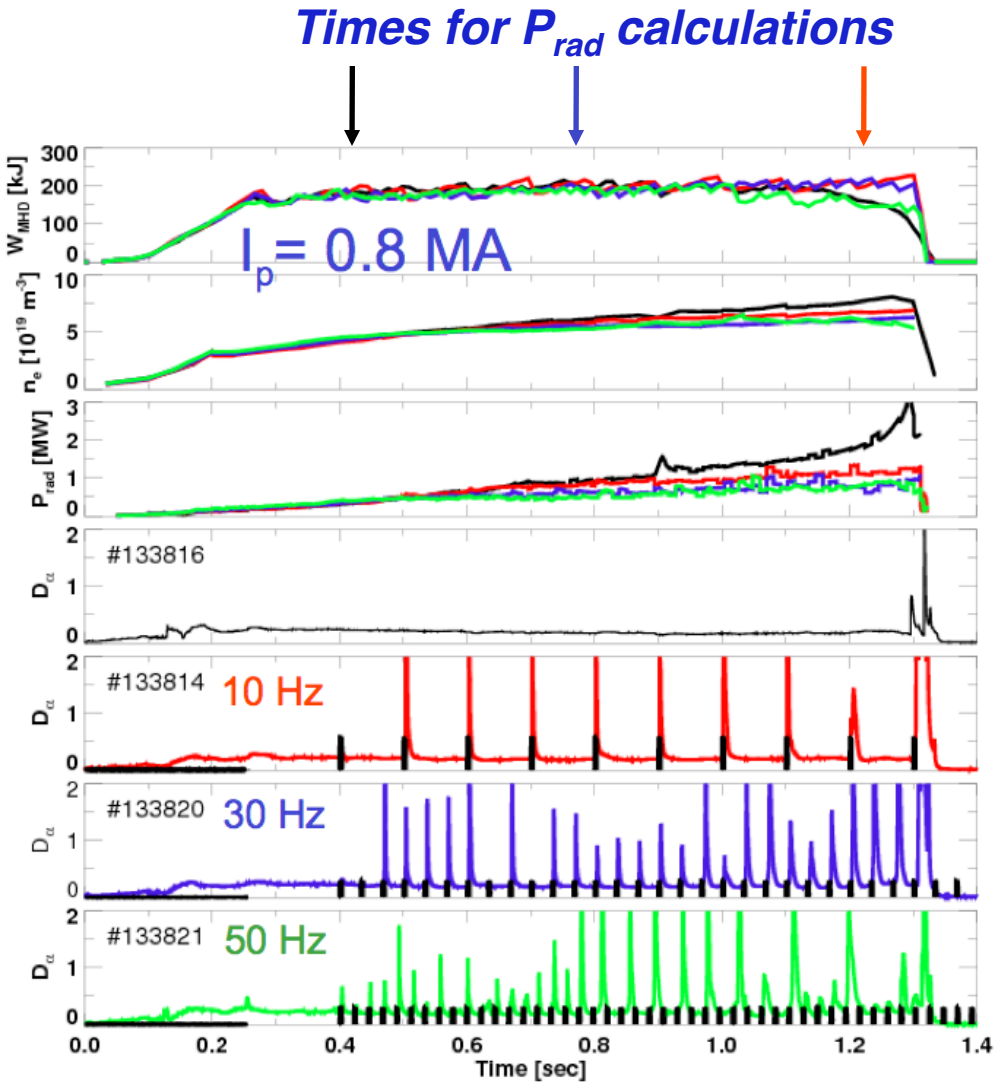


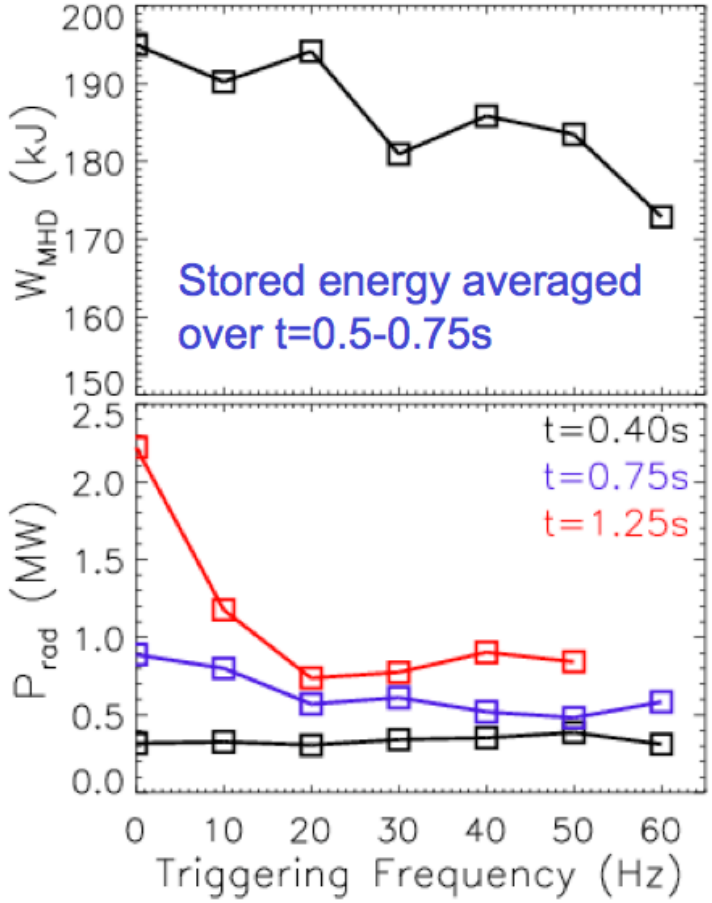
…and Adding a Negative Going Pulse Can Reduce the Time-Average RMP Field



J. M. Canik, et al., Nuclear Fusion **50**, 064016 (2010)

ELM Pacing Used To Decrease Radiated Power In Lithium Conditioned ELM-Free Discharges

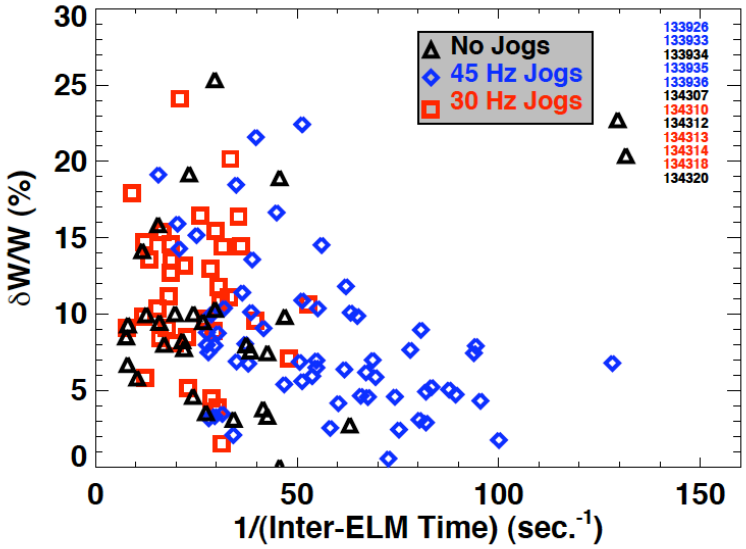




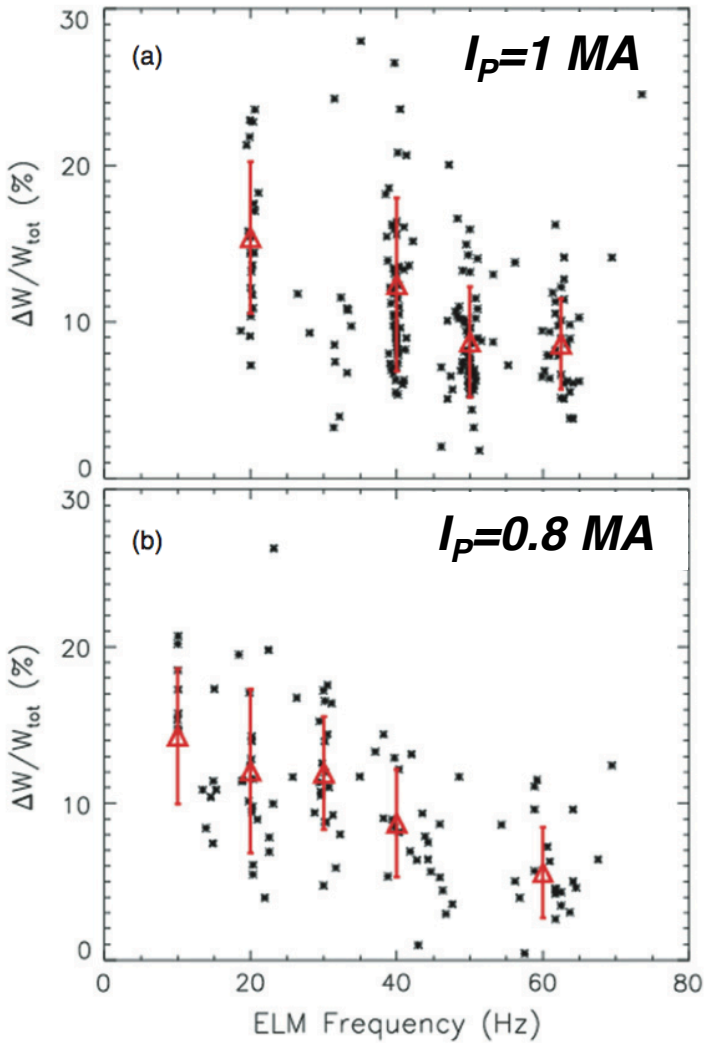
Both Techniques Were Able to Decrease the Typical ELM Size

- Faster ELMs ➔ Smaller ELMs.
  - Be careful!…small increases in ELM frequency can result in higher average ELM power.
- For RMP, it is important to maintain triggering efficiency:
  - Large ELMs often follow failed triggers.

Vertical Jogs



Pulsed RMP



Discussion and Future Experiments

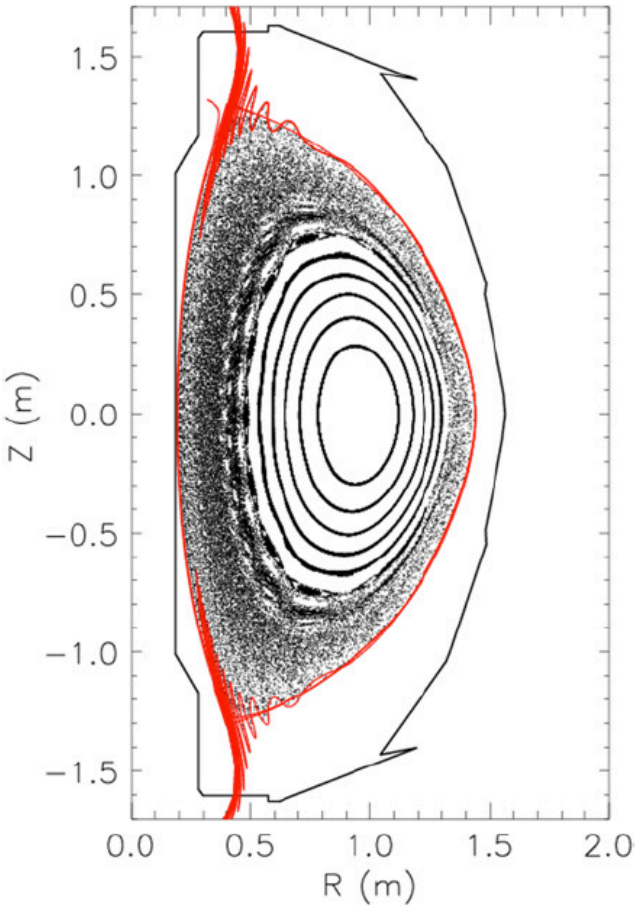
Questions And Issues: Vertical Jogs

- Upward motion is in the direction to increase edge currents.
  - Upward motion triggered ELMs in the 30 Hz jogs case.
  - NSTX typically sits near the peeling boundary…provides a cartoon explanation.
  - Need to resolve the edge current perturbation.
  - Likely needs a TSC-like code...G.-S. based reconstructions were insufficient.
- Jogs make it difficult to assemble diagnostic data.
  - Plasma is always moving!
  - Only a few kinetic profile measurements per jog, some with long time averages.
- Important physics may be 3D!
  - Lots of eddy currents driven by the radial field coil swings…have typically regarded them as 2D only.
  - NSTX has many complicated 3D conducting structures.
    - Segmented copper stabilizing plates, larger ports, beam duct and armor.
- Need to couple ELM stability calculations to accurate, time-dependent equilibrium calculations.
  - Not clear that the NSTX data properly constrains this problem.
    - Approach ignores 3D effects.

Questions And Issues: RMP ELM Triggering

- RMP increases the T_e and pressure gradients in no-Lithium case.
  - Why this RMP response?
- Pulsed RMP in Lithiated plasmas show flattening of electron profile.
  - So what triggered the ELM?
- What is the role of stochastization of the plasma edge?
  - Non-linear evolutions of ELMs can be impacted by “tangle” structure…what about the triggering/onset?
- MHD equilibrium should respond more rapidly to RMP than the profiles.
  - Assuming full shielding, NSTX becomes a stellarator…does this directly impact the stability?
  - Need 3D ELITE?

Fully Penetrated Vacuum Response



Propose To Combine the Techniques in 2010 Experiments

- JET showed that that RMP and "Kicks" could individually trigger ELMs…
  - …and that by combining them, could get the same triggering with reduced RMP or kick amplitude. (de la Luna, APS invited, 2009)

- Could eliminate the deleterious effects of the pacing techniques.
  - Smaller jogs are easier on PSs and coils, less perturbative to H-mode.
  - Jogs may be more reliable at triggering if aided by RMP.
  - Smaller RMP allows reduced magnetic braking.

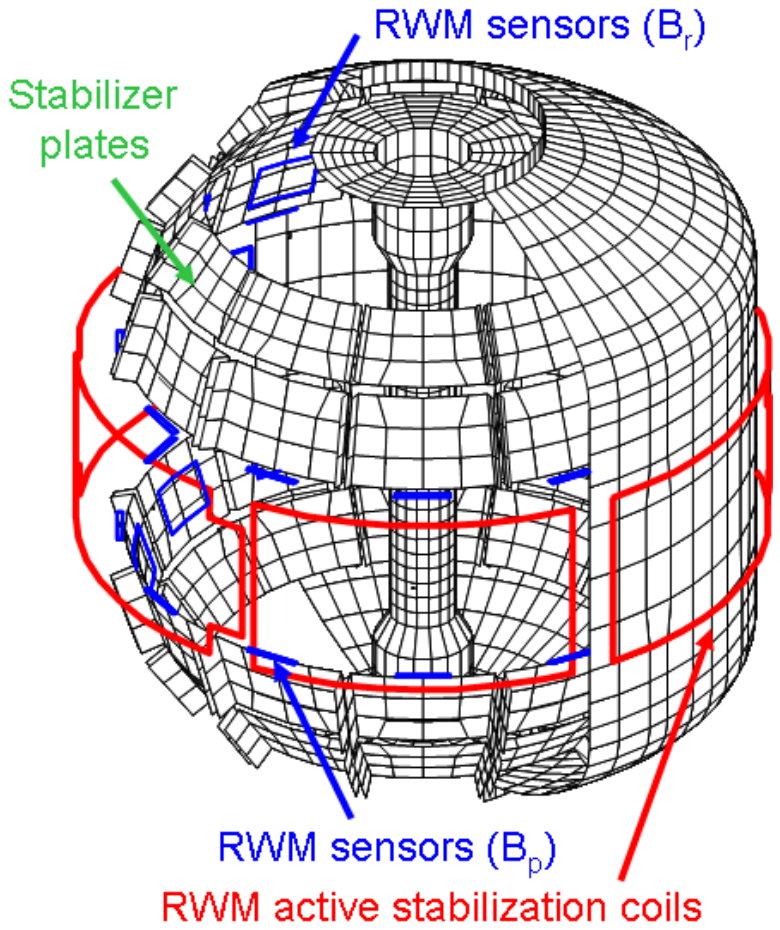
- NSTX experiment next Monday to test these effects.
  - J.M. Canik (ORNL), A. Loarte (ITER), S.P. Gerhardt (PPPL) are main authors.
  - Study if jog amplitude threshold is reduced when RMP is applied.
  - Repeat at a couple of q_{95} levels (Ip.

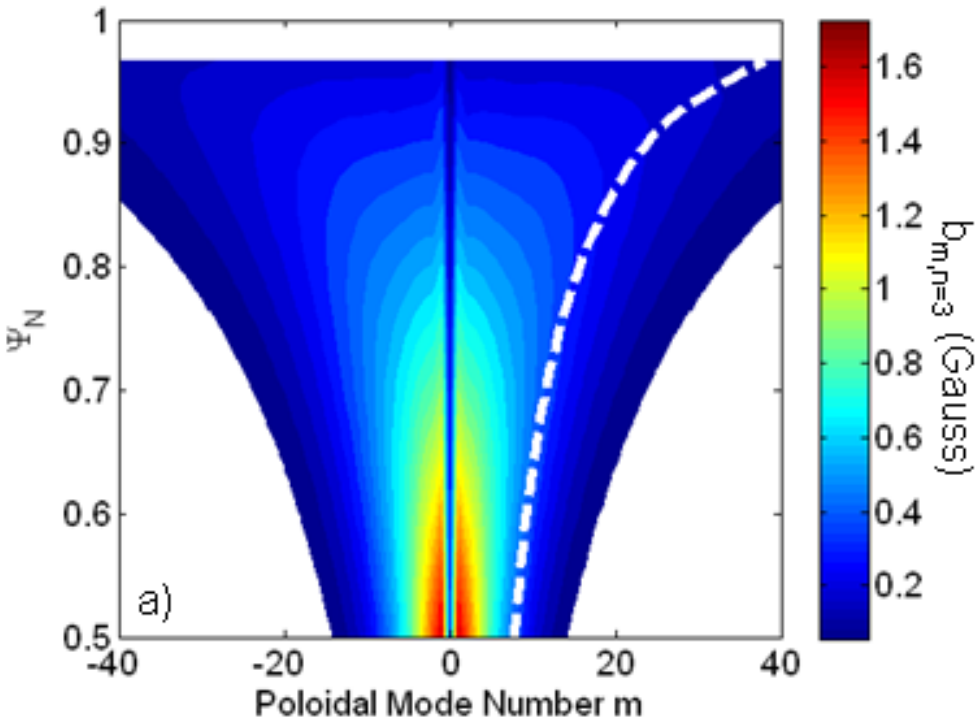
- Somewhat operational approach…not particularly designed to illuminate the important physics of the two techniques.

Backup

External midplane coils are used to apply perturbation with strong resonant *and* non-resonant components

- n=3 configuration is used in all experiments presented here

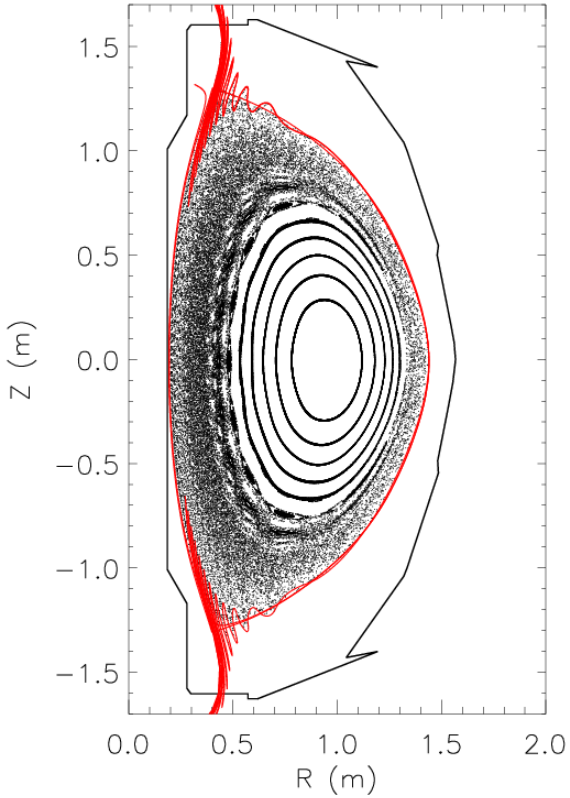




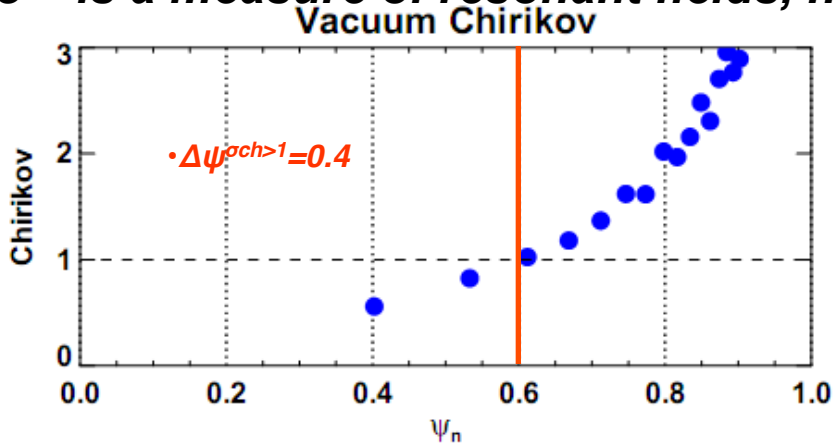
•***Vacuum Field***

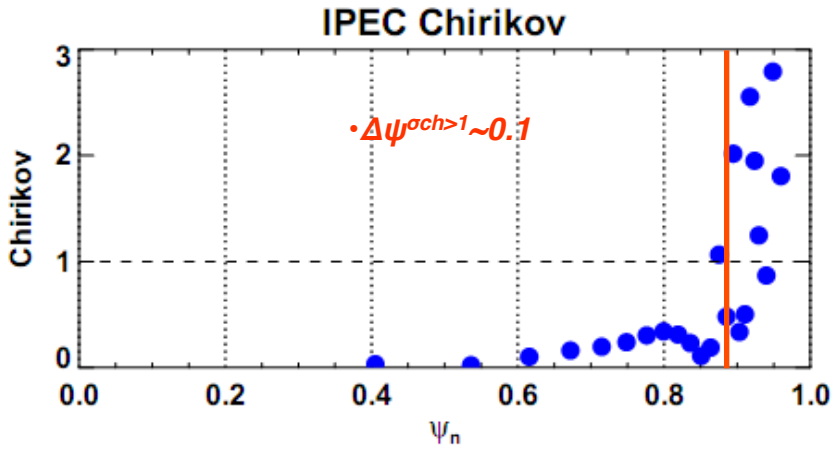
Resonant components are sufficient for edge stochasticity

- ***Vacuum and IPEC calculations give different regions of strong resonance***
  - ***Vacuum case: $\sigma^{ch} > 1$ implies overlapping islands, stochasticity***
  - ***IPEC: ideal plasma response -> σ^{ch} is a measure of resonant fields, no islands are allowed***

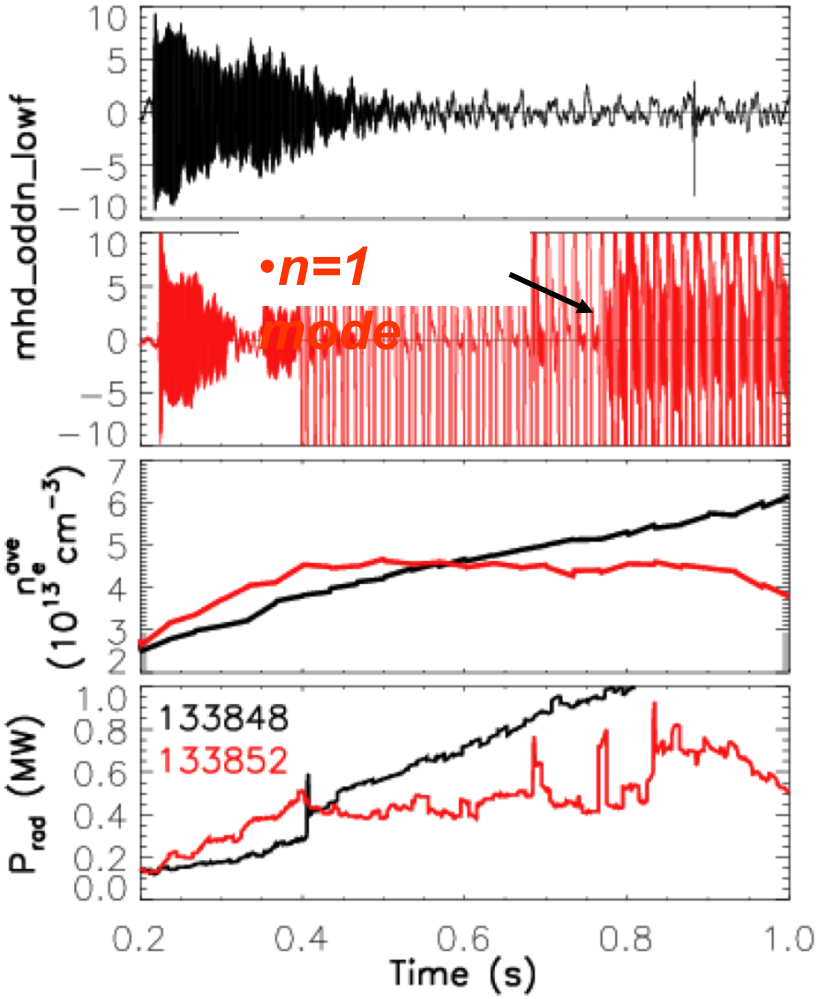


•*Vacuum fields*





Combining ELM pacing with improved fueling produces quasi-stationary global parameters, profiles still evolving



- Fueling from a slow valve on the center stack was reduced, replaced with a puff with faster response
  - Allows fuelling to be turned off quickly following startup

Applying n=3 pulses arrested the line-averaged density and total radiated power for 0.3 s

Profiles not stationary: core increasing, edge decreasing