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NSTX

XP-811 Results

Vertical Stability - ΔZ_{max} Measurement

presented by

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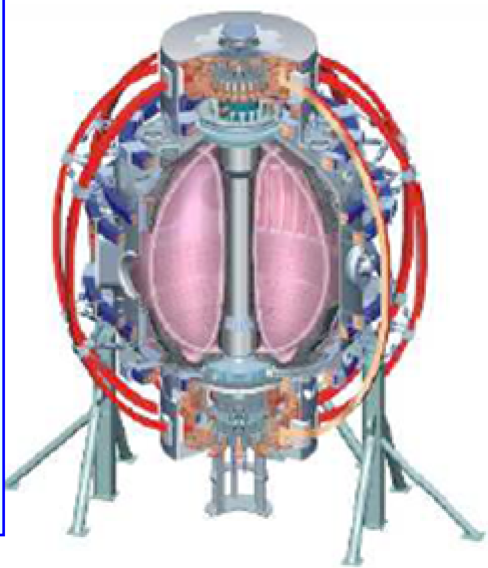
For the NSTX Team

at

NSTX ASC-TSG Meeting

March 3, 2008



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Experiment Run Plan

- The shot numbers in the experiment were 1207064 through 127087.
- In the experiment we used:
  - Helium plasma to keep the density constant, enabling reproducible results.
  - Ohmic discharge.
  - 600 kA current.
  - $B_T \sim 5$ kG
  - $l_i \sim 1.4$
  - Lower, upper gap ~ 45 cm
- Experiment run time was 1 run day.

Measure κ_{max}

- First measured κ_{max} – maximum controllability threshold in elongation.

- We increased the elongation starting from 1.8 and determined maximum robustly controllable growth rate.

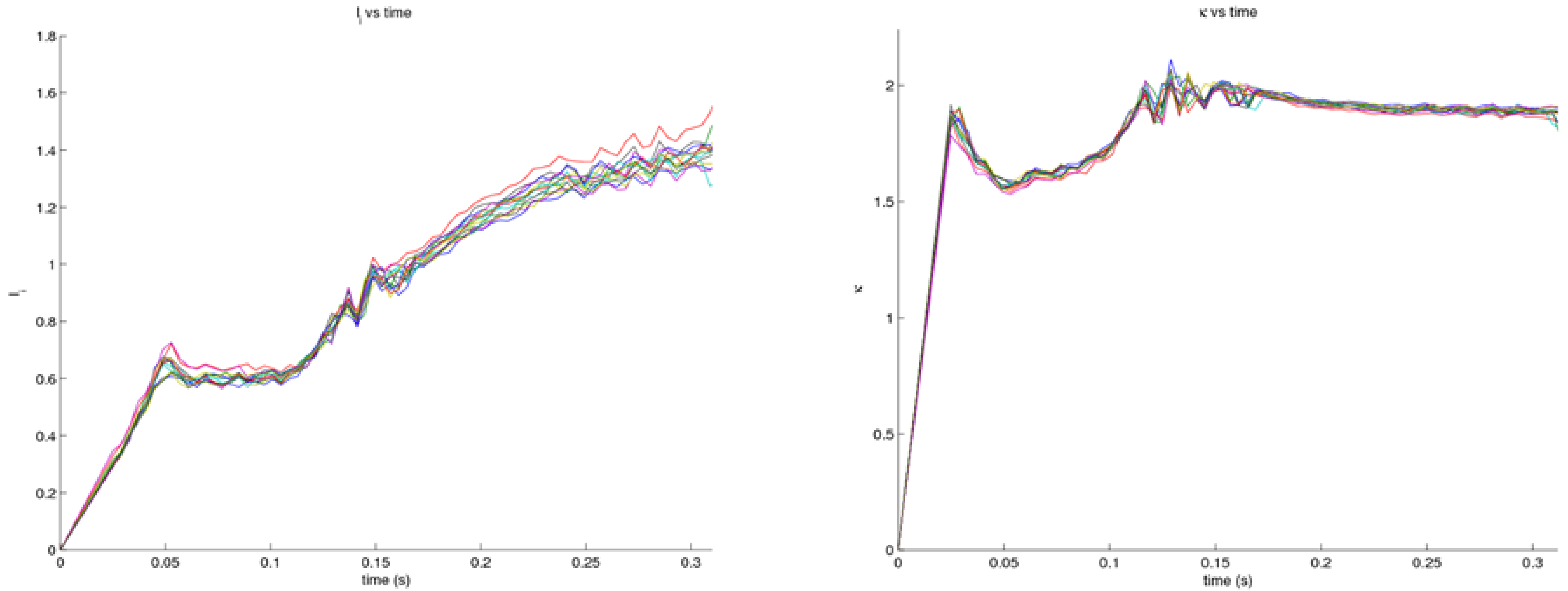
- Scanned κ values showed that for $\kappa > 1.9$ the plasma is not controllable.

- Continued the ΔZ_{max} measurement experiment with $\kappa \sim 1.9$.

Measure ΔZ_{max}

- Second part of the experiment is to measure ΔZ_{max} – maximum controllable displacement.
  - Set elongation below κ_{max} to κ=1.9.
  - Freezed coil commands to disable vertical control for a period to allow VDE.
  - Let the plasma drift for a specific period starting with 20 ms for the first experiment.
  - Restored the coil control command.
  - The control was turned back on with maximum available voltage (slew rate limited).
  - Repeated the experiment with increased drift periods [20, 30, 35, 40, 45, 50] ms.
  - Determined maximum controllable displacement for robust operation.
  - Repeated the experiment many times to get statistically sound data.

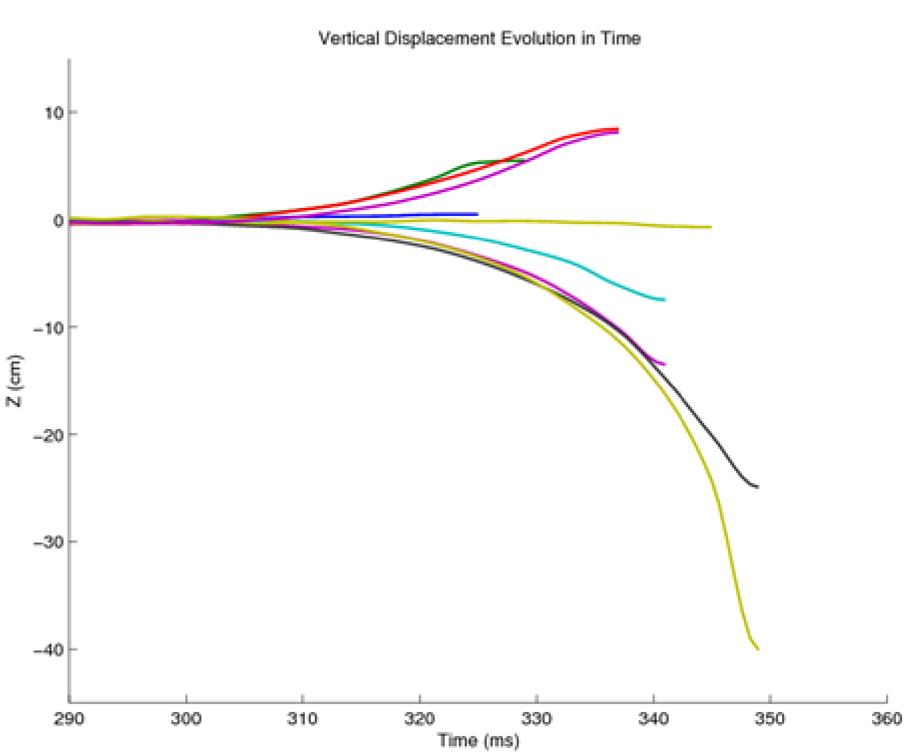
Measure ΔZ_{max}: Consistent Data



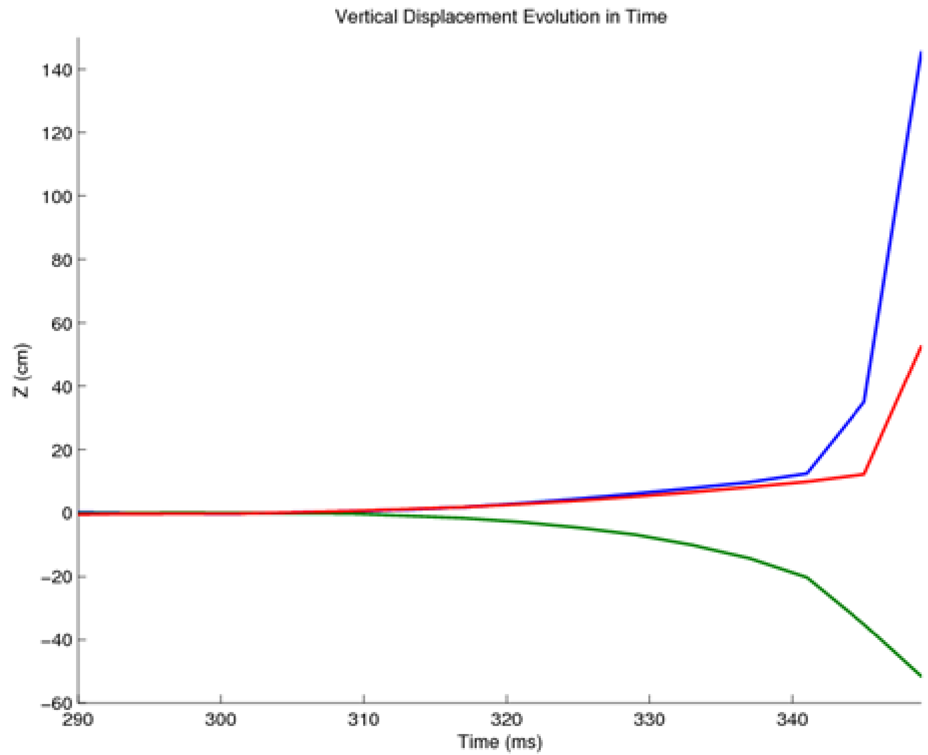
Time evolution of l_i and κ for all the shots before control is turned off

- We were able to repeat the experiment very consistently.

Vertical Displacement Measurements



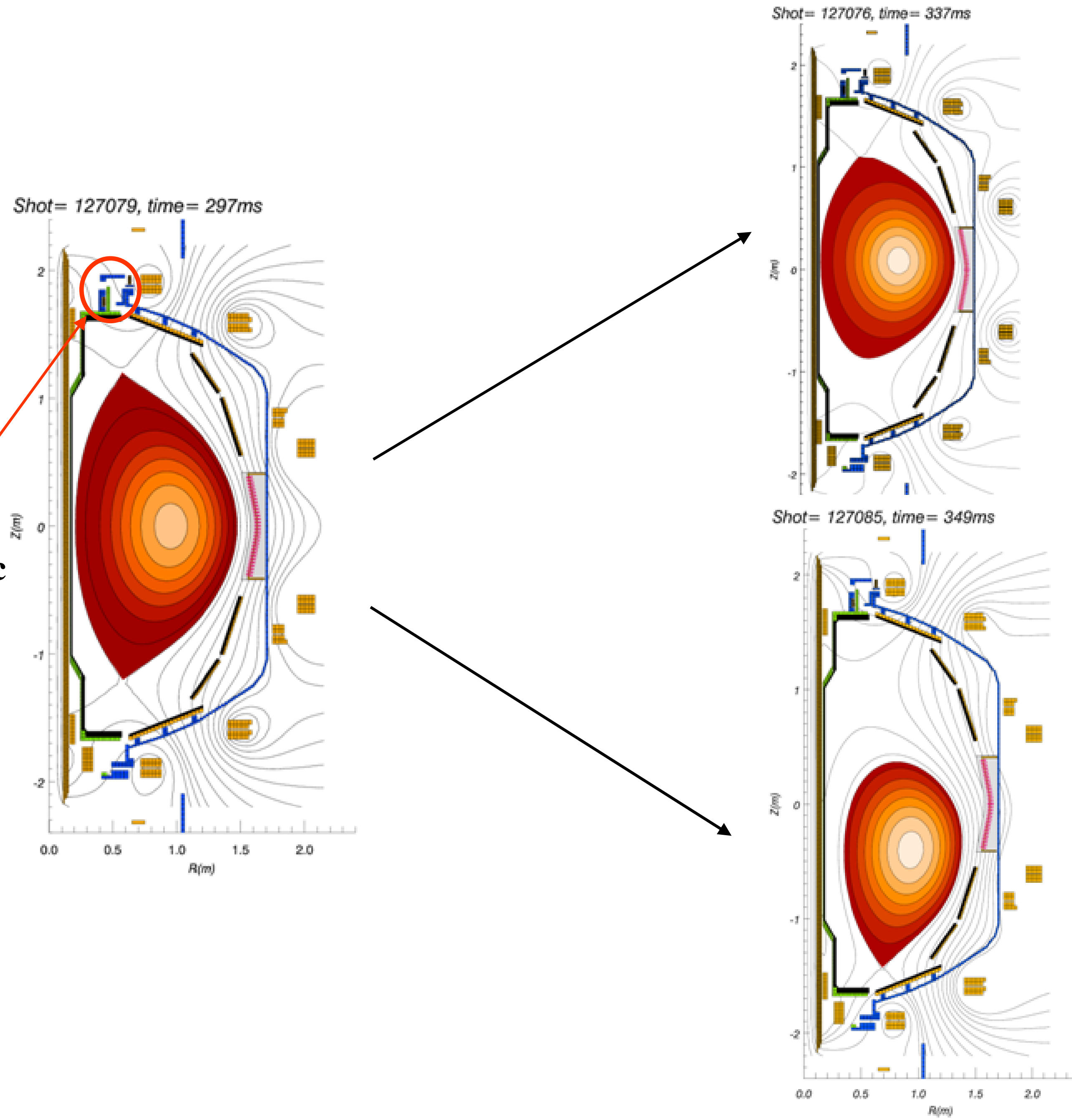
Vertical displacement for controllable shots (Cut off at the point of return)



Vertical displacement for uncontrollable shots

- At 300 ms, we turned the controller off and let the plasma drift.
- When we turned the control back on some of the shots recovered while others hit the wall.

Asymmetry in NSTX Conducting Structure

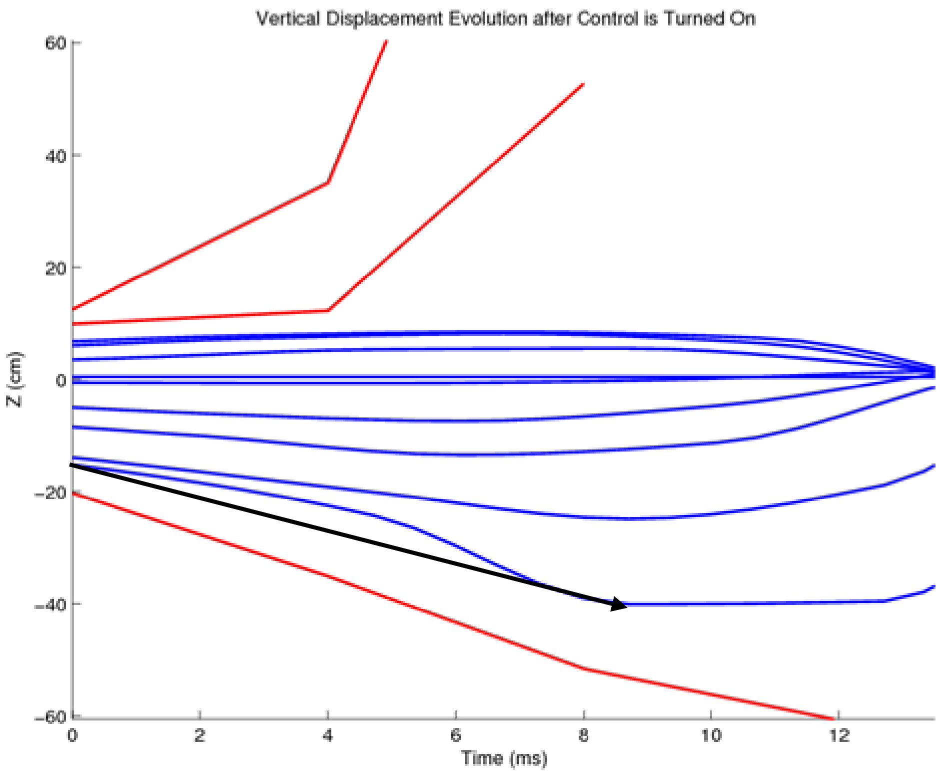


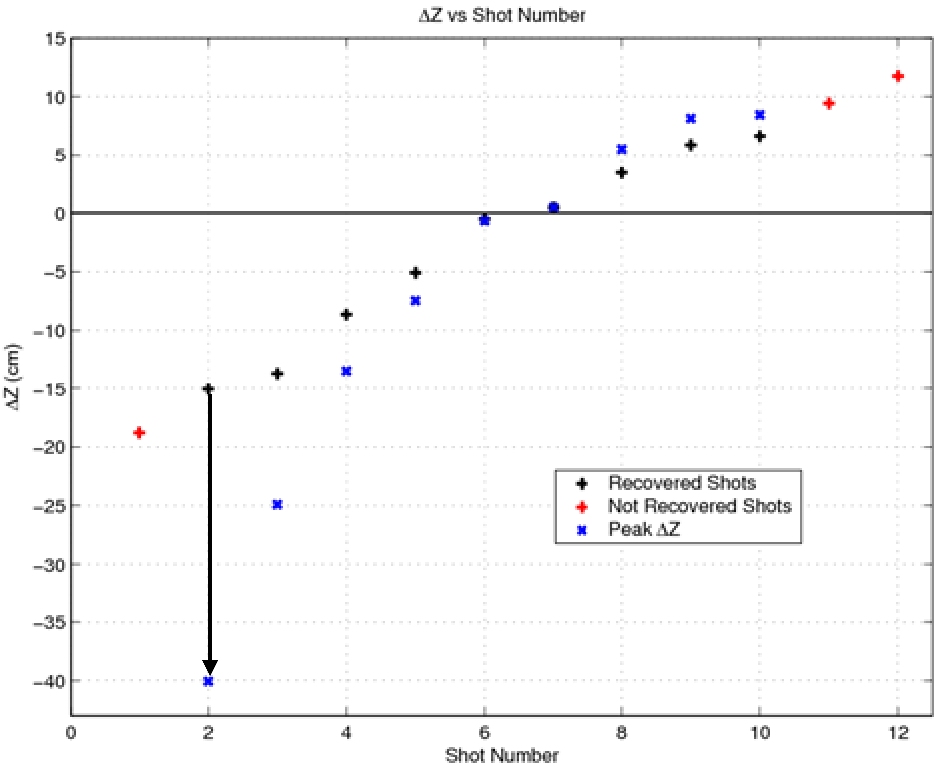
Asymmetric conducting structure

Upward Shape

Downward Shape

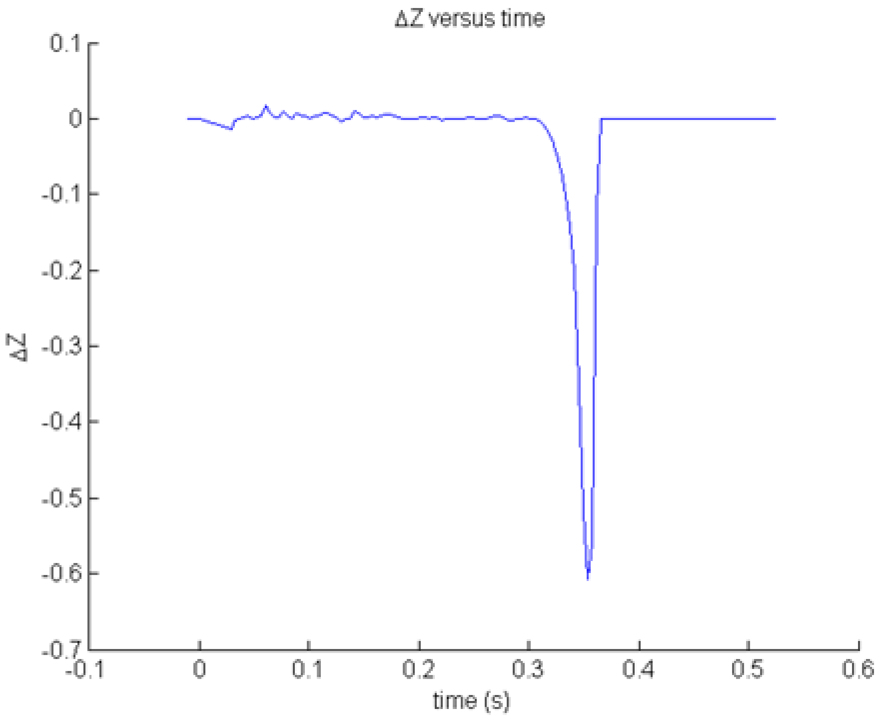
ΔZ_{max} for Up and Down Directions

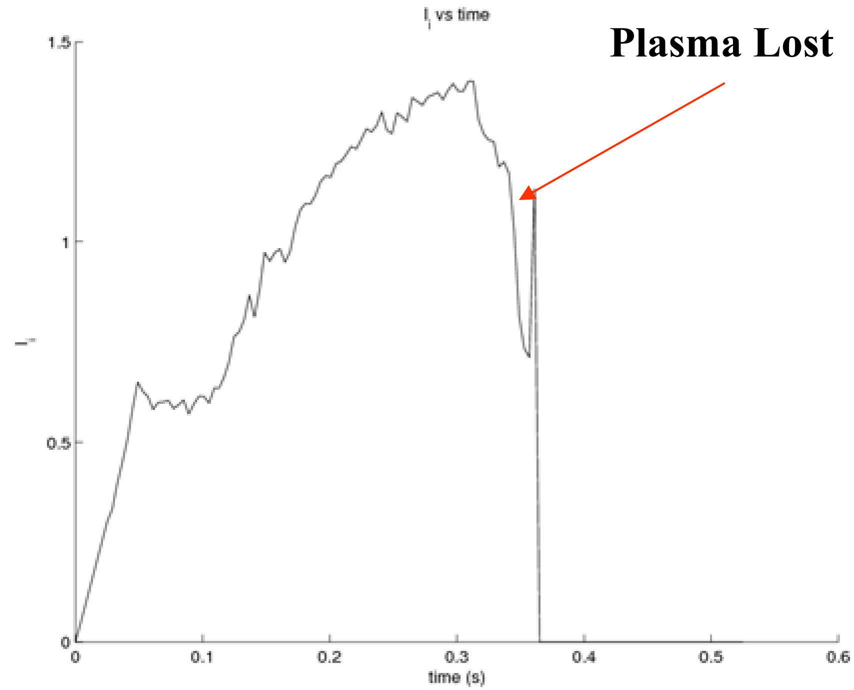




- Red lines show the shots were the vertical displacement was uncontrollable while the blue lines the controllable ones.
- NSTX is not up/down symmetric (mirror symmetry).
- ΔZ_{max} = **6.6** cm for upward motion and **15.0** cm for downward.
- $\Delta Z_{max}/a$ = **10%** for upward motion and **23%** for downward.

Deciding If the Plasma Recovered or Not

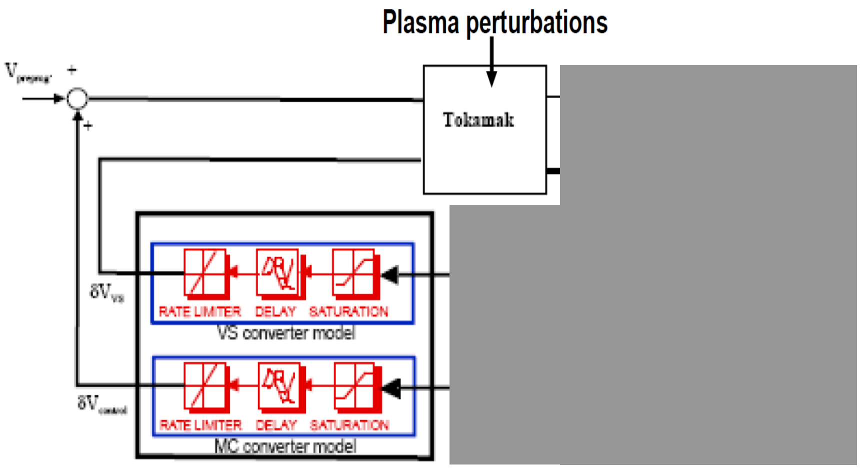




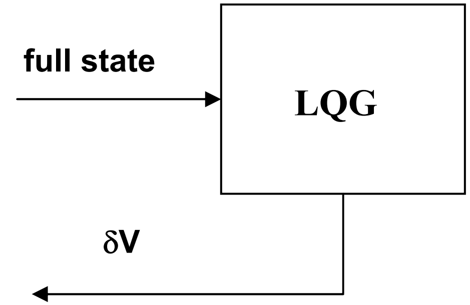
ΔZ and l_i for shot number 127084

- We were able to stop and return the motion of plasma before hitting the wall for the **all downward** vertical displacements.
- But for some of these shots most of the magnetic energy was lost before moving up.
- We considered these shots as not recovered.

Future Work: Model Based Optimal Control



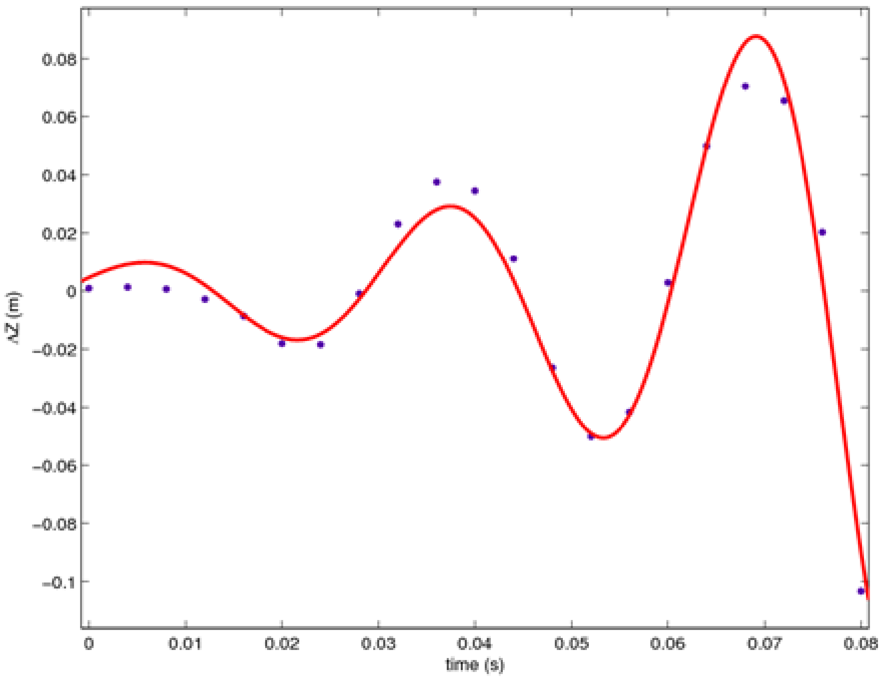
Current Control Method



Proposed Optimal Control

- Currently, PID controller is used for the vertical mode control.
- We are developing a **model based optimal control** for the vertical stability.
- **Develop low-dimensional models** of this mode of instability using the simplified models of Hofmann as a starting point.
- Use these models to **design feedback laws** using modern control techniques, such as optimal Linear Quadratic Gaussian (LQG) control.
- The experimental results will help us **validate and tune system models** that will be used for control.

Vertical Growth Rate and Frequency



Vertical displacement with control on

- Dynamics of the plasma with controller on were obtained by fitting the unstable data set.
- Vertical motion can be defined by a second order differential equation:

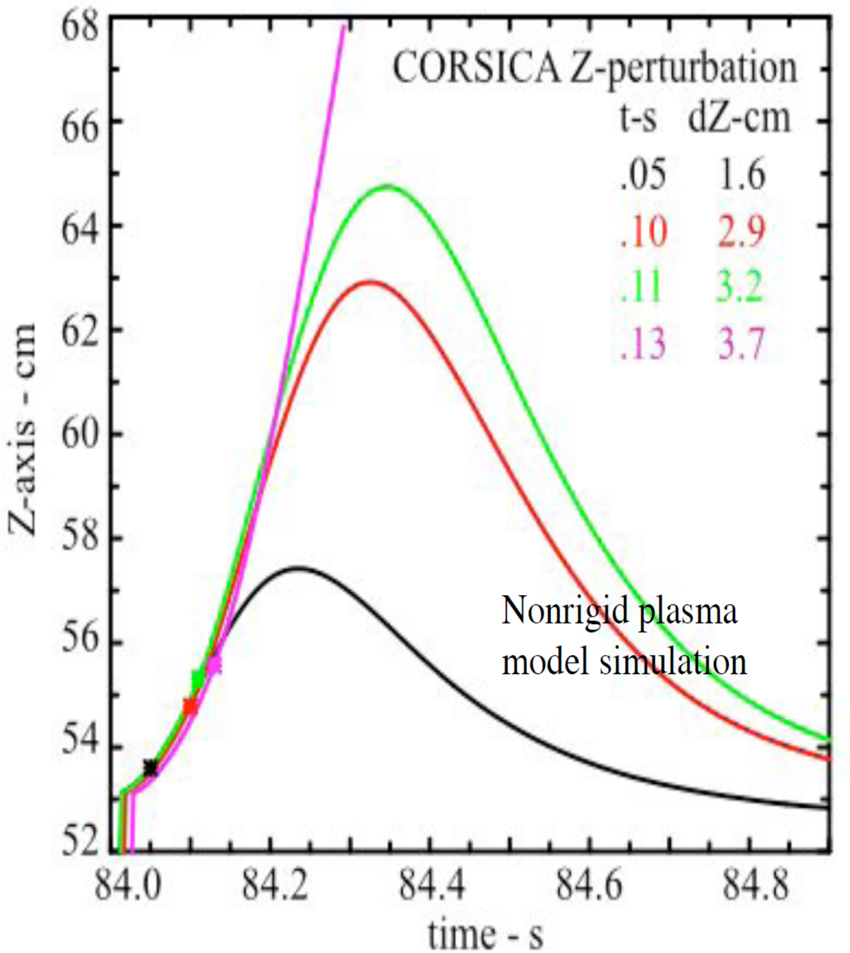
$$\ddot{Z} + a\dot{Z} + b = f(t)$$

with solution:

$$Z = e^{\gamma t} sin(\omega t + \phi)$$

- $\omega \sim 200\ s^{-1}$ and $\gamma \sim [35, 95]\ s^{-1}$ based on multiple data fits.
- **Data from the XP will be used to develop and validate low-dimensional models** of this mode of instability.

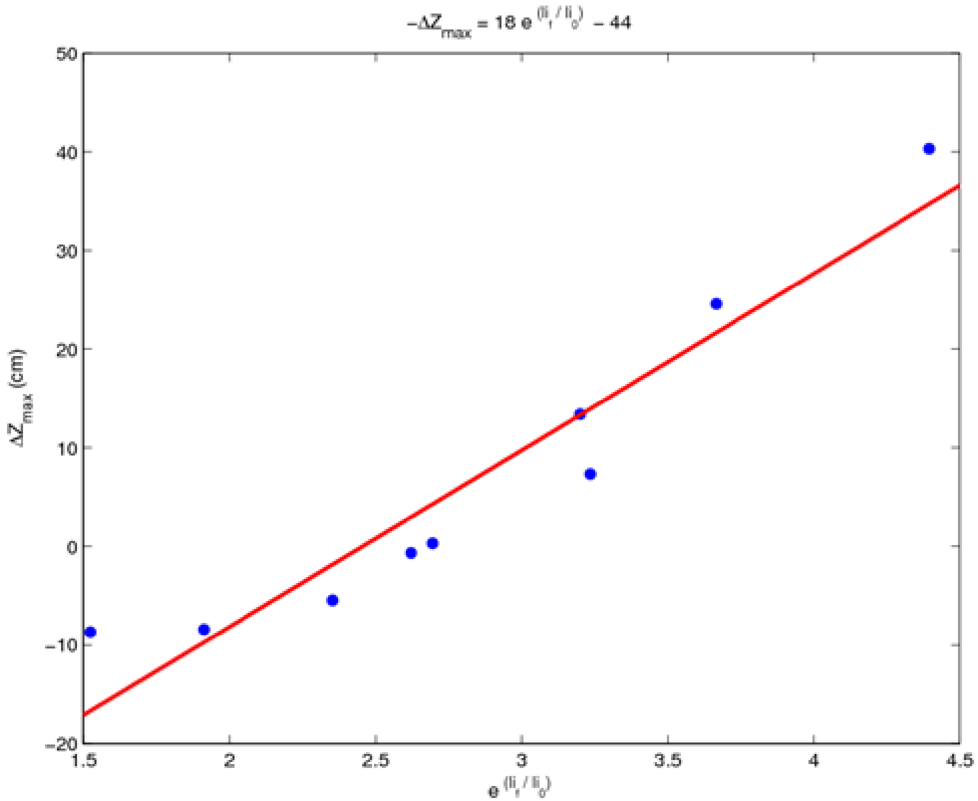
Conclusion and Future Work: Application to ITER



ITER ΔZ_{max} determination via Corsica numerical simulation

- C-Mod and DIII-D require $\Delta Z_{max}/a$ %10 or higher for robust control (Recent XP).
- We confirm these results. (Maybe even higher)
- Nonlinear Corsica ITER Simulations Find Maximum Controllable ΔZ_{max} ~3.5 cm ($\Delta Z_{max}/a \sim 2\%$)
- Future Work: Apply to these models to ITER, to validate design predictions for ITER.

Future Work: Correlation between l_i and ΔZ_{peak}



ΔZ_{peak} versus e^{li}

- There is an exponential correlation between ΔZ_{peak} and l_i.
- This is not related to time.
- The reason for this correlation will be studied further.