NSTX

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Vertical Stability of NSTX and NSTX-U

Egemen Kolemen[1]

D. A. Gates[1], S. Gerhardt[1], D. Humphreys[2], J. Menard[1], D. Mueller[1], M. Walker[2], A. Welander[2]

[1] Princeton Plasma Physics Laboratory, Princeton, NJ 08543

[2] General Atomics, San Diego, CA 92186

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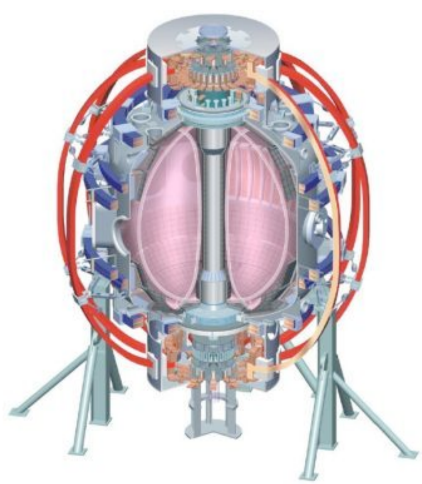

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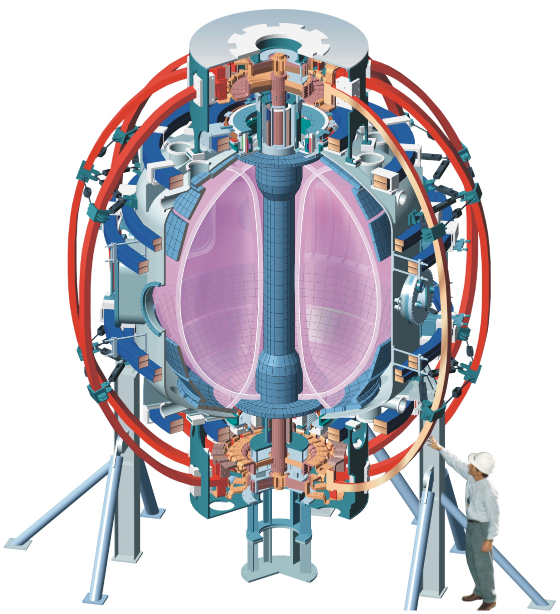
Vertical Stability of NSTX and NSTX-U

- Currently NSTX is being upgraded with a bigger center stack and an additional neutral beam, which will allow a higher toroidal field and plasma current, and a longer pulse length.

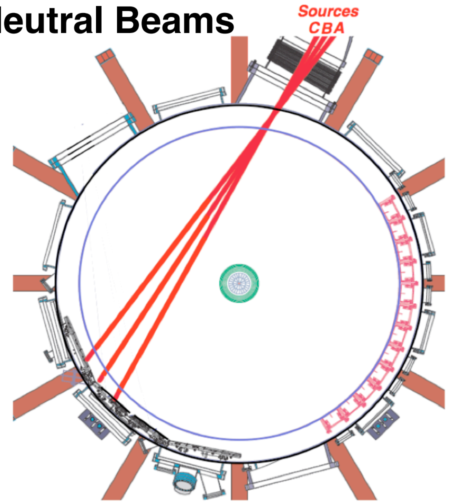
- The vertical stability of NSTX and NSTX-U is explored in this study.

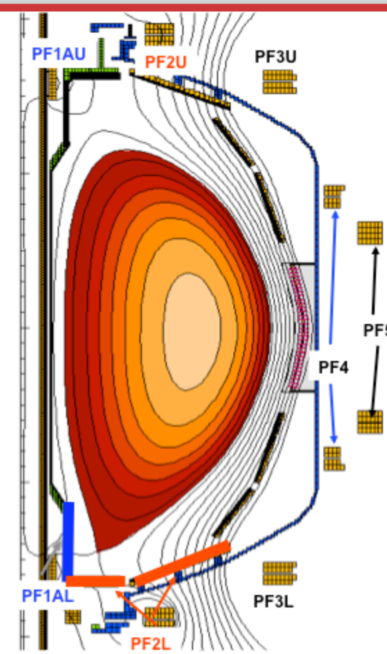
  - NSTX-U will be more vertically unstable
  - Control capabilities to overcome this increased instability have been implemented
  - Some that can stabilize Vertical Displacement Events (VDEs) are under investigation

NSTX was a Medium Sized Spherical Torus With Significant Capabilities for High-β Scenario Research

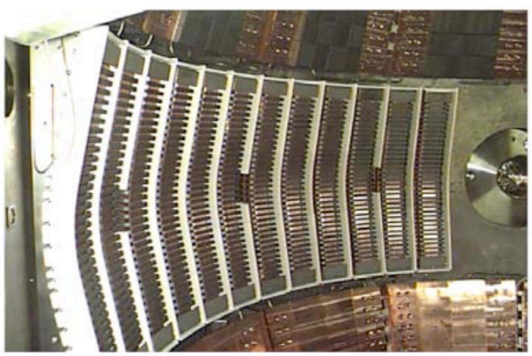


Neutral Beams





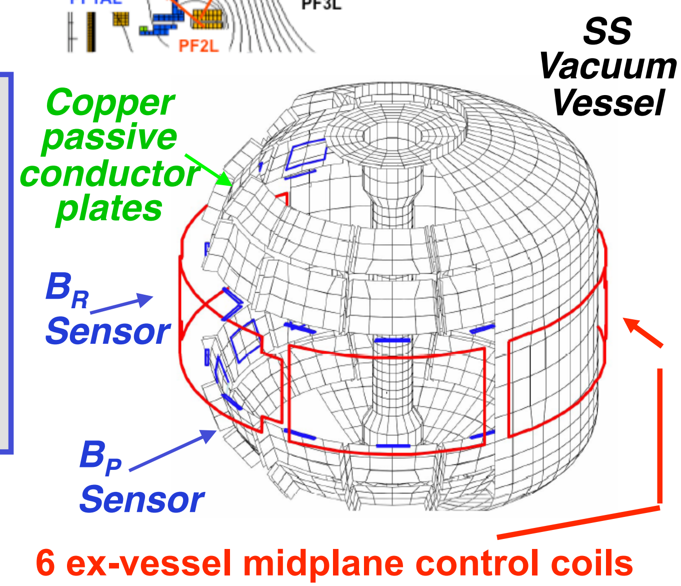
NSTX Cross Section: 11 Polodial Field coils



HHFW antenna

Aspect ratio A	1.27 – 1.7
Toroidal Field B_{T0}	.35-.55 T
Plasma Current I_p	≤1.4 MA
NBI (<100kV)	7 MW

Lithium conditioning of PFCs via a dual evaporator system

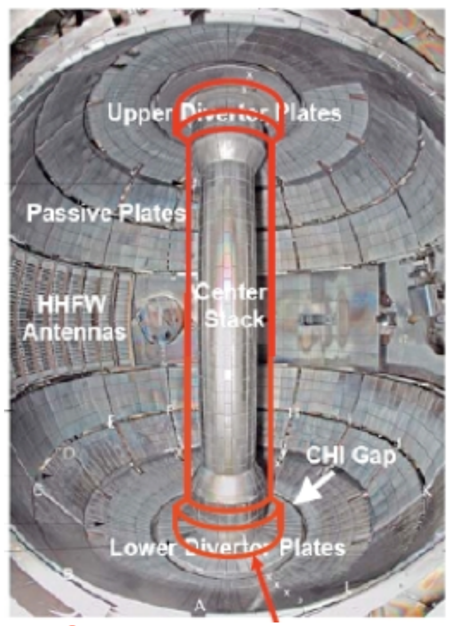


NSTX-Upgrade provides major step along ST development path (next factor of 2 increase in current, field, and power density) [1]

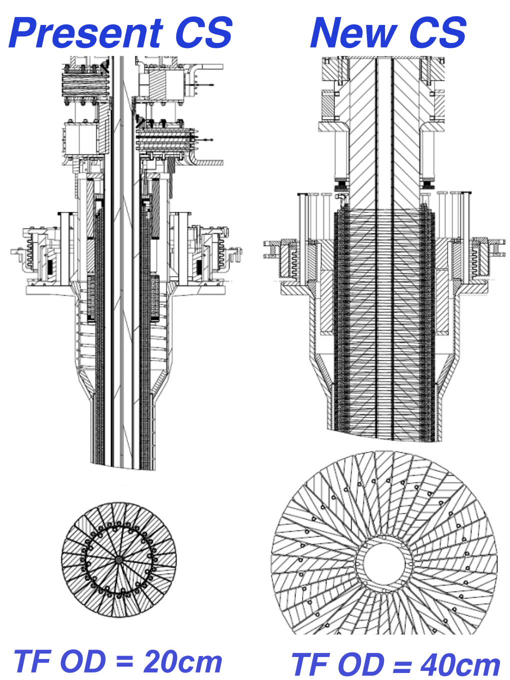
	NSTX	NSTX Upgrade
Aspect Ratio = R_0 / a	1.3	1.5
Plasma Current (MA)	1	2
Toroidal Field (T)	0.5	1
P/R, P/S (MW/m,m^2)	10, 0.2*	20, 0.4*

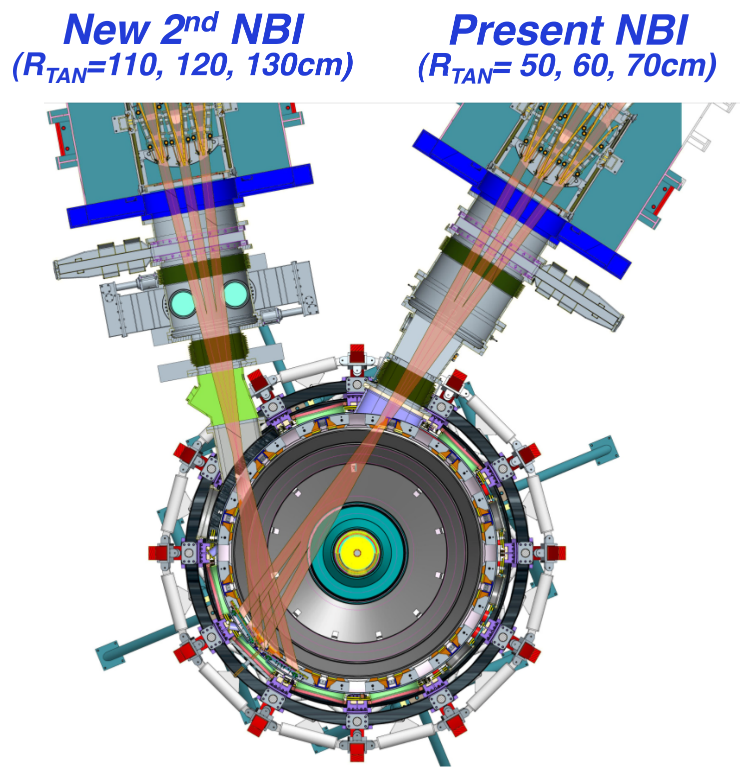
** Includes 4MW of high-harmonic fast-wave (HHFW) heating power*

Increased Aspect Ratio makes the plasma vertically unstable. Increased power makes vertical control more important for machine protection.

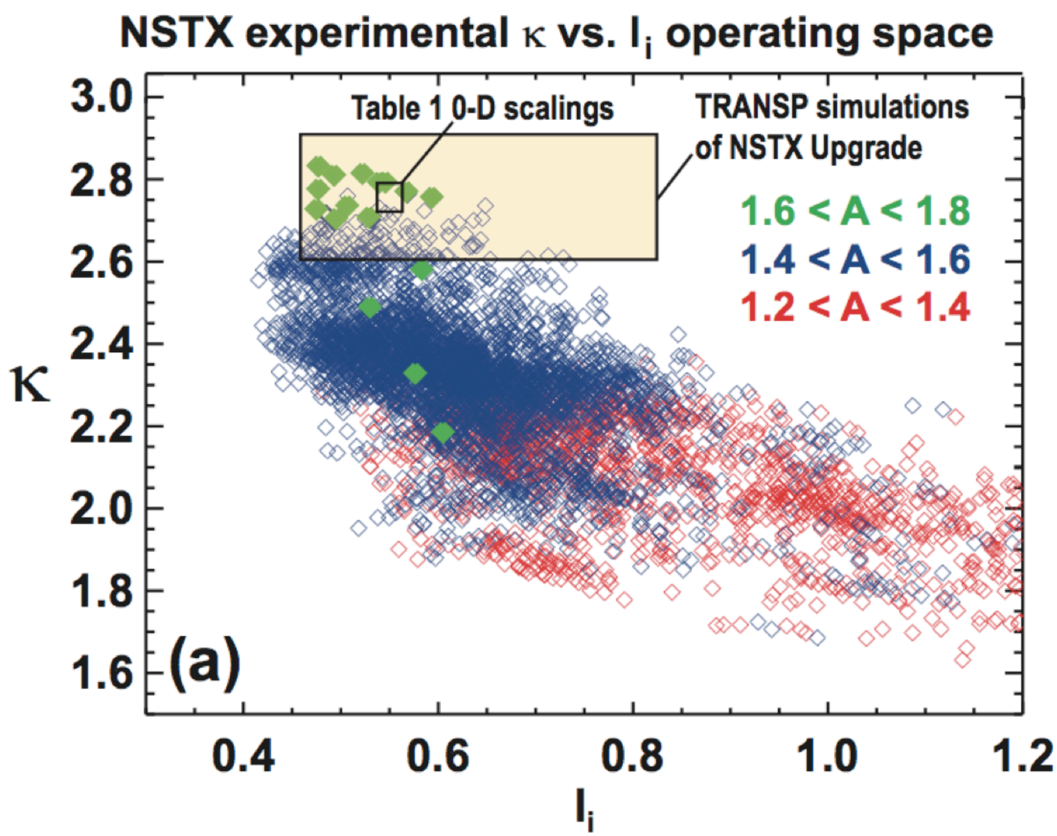


Outline of new center-stack (CS)





NSTX-U Parametric Scaling



NSTX experimental κ vs l_i operating space sorted by A. Green points are taken from the experiments dedicated to producing NSTX Upgrade-like shapes at A=1.6 to 1.8 [2]

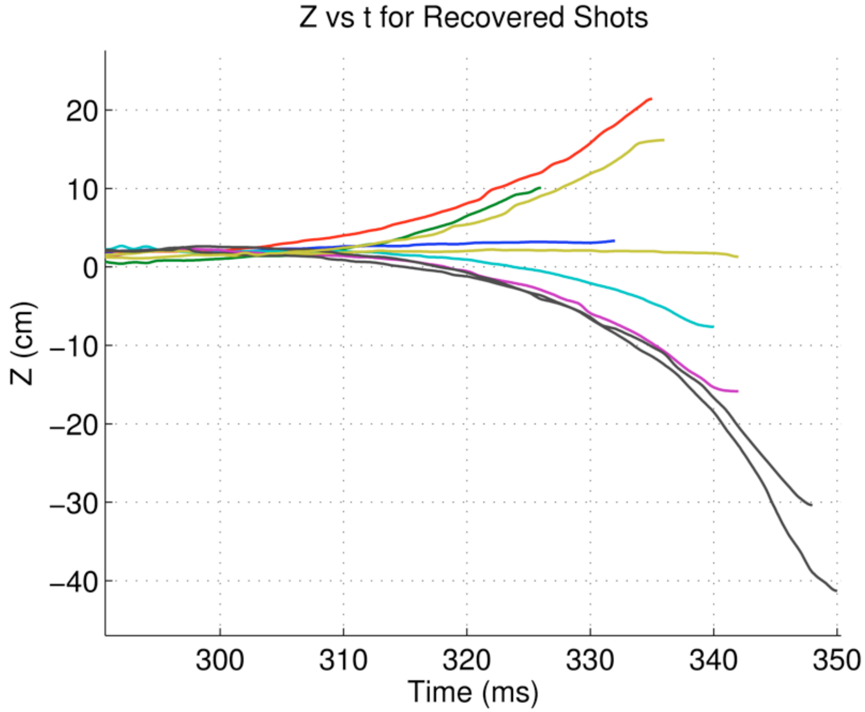
- One way of assessing the stability for NSTX-U is to look at parametric scaling from NSTX database. The green points are taken from experiments dedicated to producing NSTX Upgrade-like shapes at A=1.6-1.8

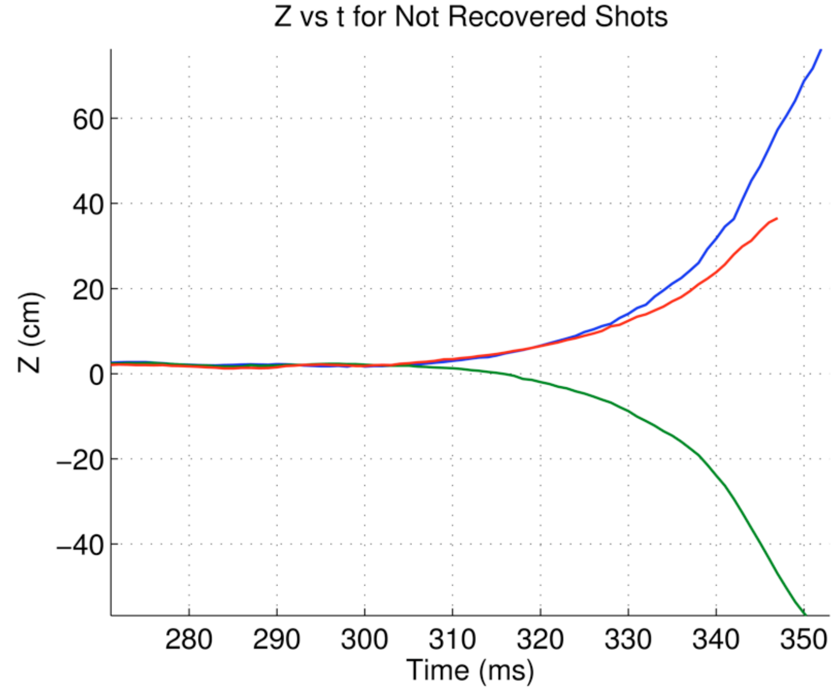
  κ≈2.7–2.8 has been sustained for l_i<0.65 across a range of aspect ratios A=1.4–1.8.

  However, for the cases with A=1.6–1.8, loss of vertical control occurred for l_i≥0.65, indicating that control of higher κ and/or high κ at higher l_i may require vertical control improvements.

  These parametric scalings motivate further study of the vertical stability and control for NSTX-U.

Vertical Displacement Studies for NSTX



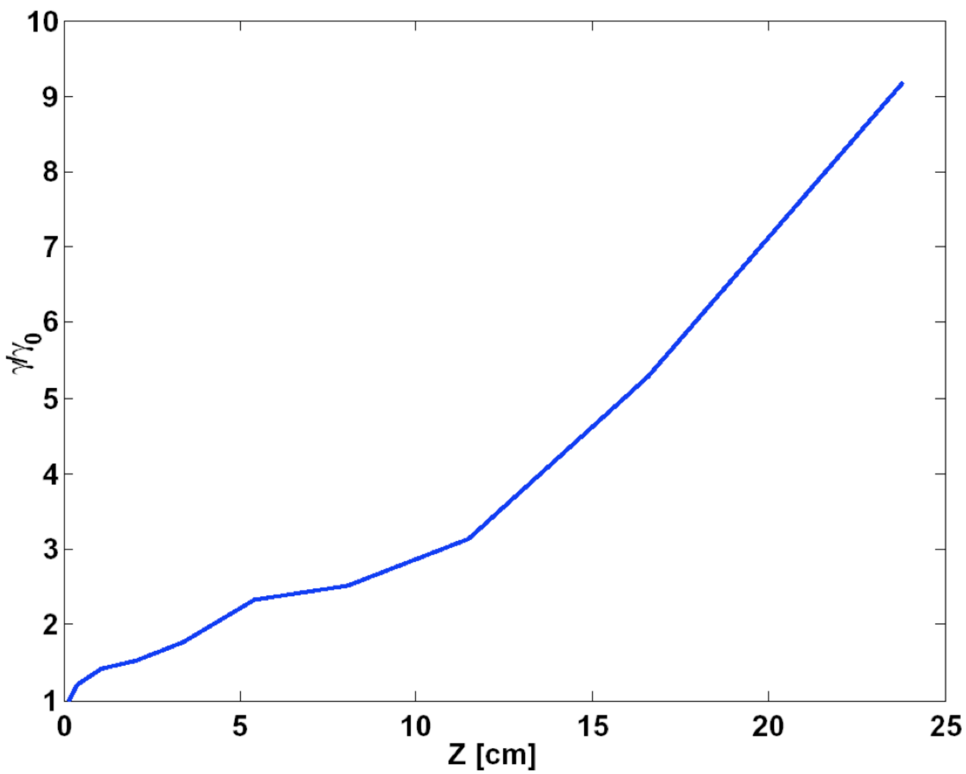


Vertical displacement for controllable shots (Cut off at the point of return)

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

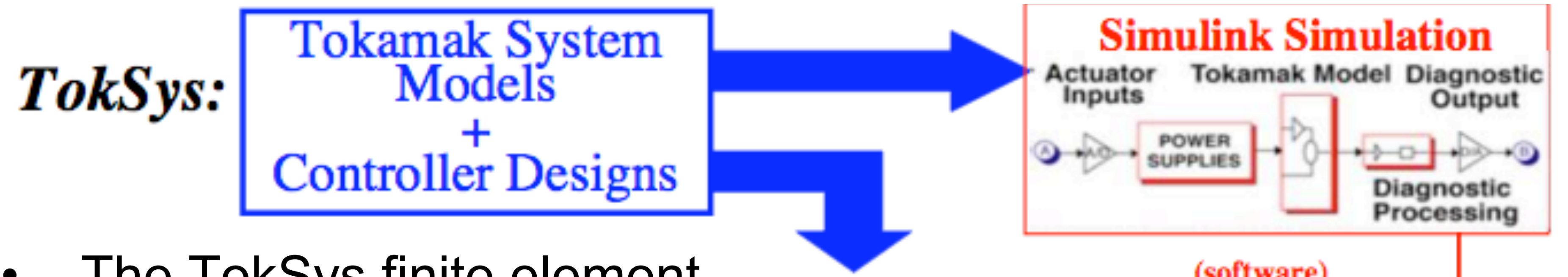
Growth Rate Increases as the Plasma Moves from Center

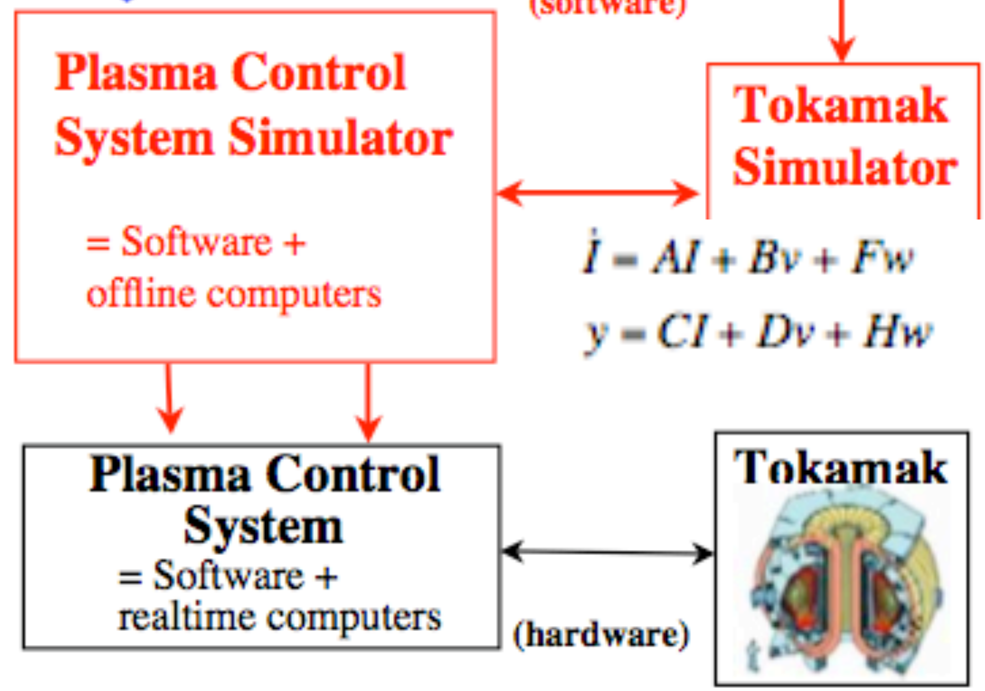


Change in γ versus the displacement in the plasma vertical location (#127077).

- We have extensively studied vertical motion in NSTX
- In these studies it was observed that the growth rate, γ, increased as the plasma moved away from the center
- This non-linear vertical plasma motion is consistent with previous spherical tokamak data from MAST[3]

Plasma Simulation:
Toksys Linearized Plasma Model



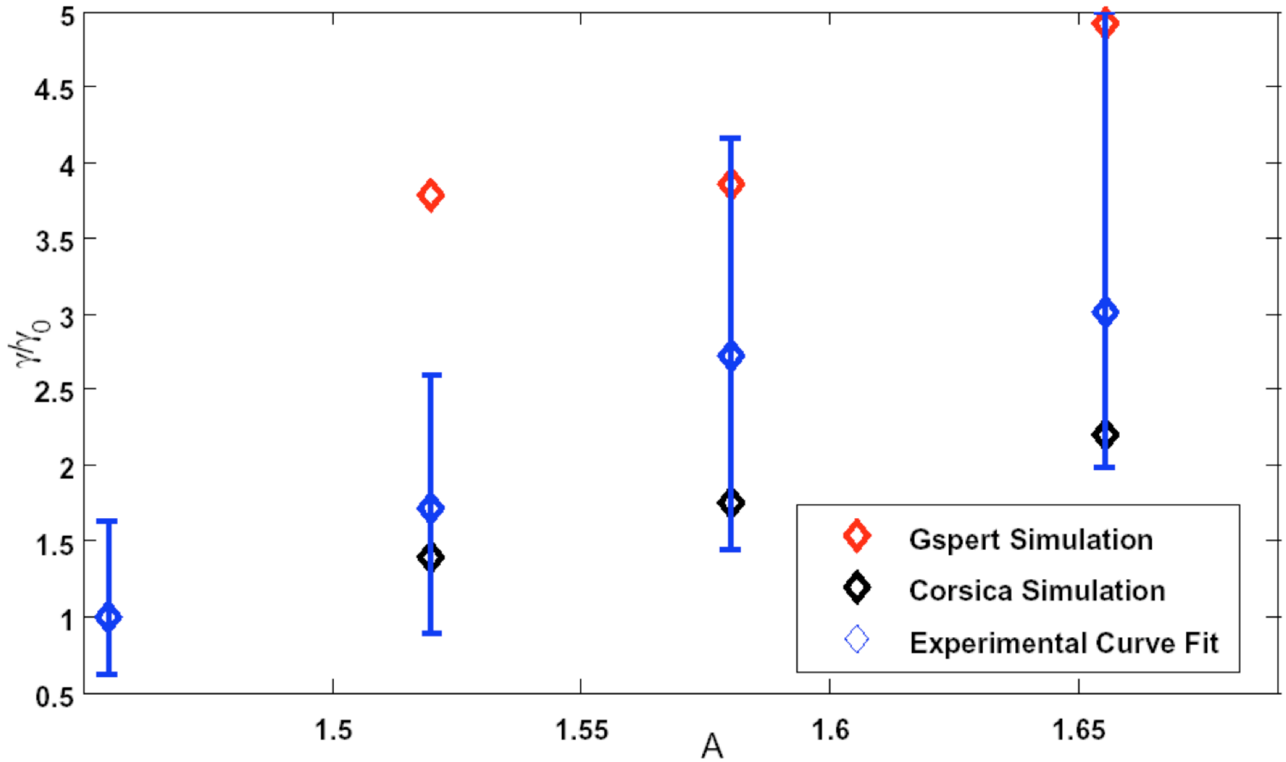


- The TokSys finite element code to solve a nonrigid plasma response model based on the linearized Grad-Shafranov equation
- Allows closed loop Plasma Control System simulation of the NSTX plasma and shape control system
- Vertical response analysis is done with Gspert module which uses perturbed Grad-Shafranov equations [4].

Plasma Simulations: Corsica Transport Code [5] with 1&½ D MHD Transport

- Equilibrium is 2D
  - Fixed boundary with inverse solver for analysis and scenario studies
  - Free boundary code for shape evolution and controller simulations
- Transport is 1D: evolve $n(\rho)$ and $T(\rho)$ with ρ=toroidal flux
  - State-of-the-art flux-surface-averaged transport models
  - Model sources for heating, fueling, current drive - control actuators
- Stability models
  - Ballooning
  - DCON ideal MHD (resistive soon to be added)
  - Neoclassical Tearing Modes (Δ'+modified Rutherford island evolution)
- At each time step, equilibrium and transport are simultaneously converged with updated source model evaluation
- Scripting-language interface
- Fully integrated with MDSplus fusion data system

Comparison of Simulation and Experimental Results



Change in γ versus A for Corsica and gspert simulations, and experimental data (#141639-141642)

- We compared numerical simulations to these experimental data. In order to study the n=0 stability of the system, we used gspert, a nonrigid plasma response model based on the linearized Grad-Shafranov equation, and Corsica, a free-boundary equilibrium and transport code

Comparison of Simulation and Experimental Results

- The simulation and the experimental results for NSTX are compared to obtain the accuracy and the statistics of the predictions
- The result of comparison between the simulations and the experimental data show a large error bar in the γ calculations due to the uncertainty that results from fitting an exponential curve to the experimental data
- Both the experimental data and the simulations show a clear trend in the increase in the γ as an increase in A. The statistical analysis of the NSTX-U vertical motion via gspert and Corsica simulations is obtained based on the results from the NSTX data. The controllability of the VDEs for a variety of parameters is assessed for NSTX-U. Results of these studies show that since NSTX-U will be operating at higher A, the vertical γ will be higher, which in turn will make control more difficult
- Acceleration in the γ as the plasma drifts leads to the prioritization of early detection and faster control over control power

Improvements to NSTX-U Vertical Control to Compansate for the Increased Vertical Instability

- With these considerations in mind, two improvements for the NSTX-U were implemented

- A new, more sophisticated vertical position estimator will enable early and more accurate detection

- RWM coils, which are much faster than the poloidal field coils, were put in the vertical control loop, which will reduce control delay against VDEs

- Communication link to the main radial filed power supplies was made faster

- Also, improvements to the vertical control algorithm are under development

References

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- [2] MENARD et al., SOFE, Chicago, IL, 26-30 June 2011
- [3] WINDRIDGE et al., Plasma Phys. Control. Fusion 53 (2011) 035018
- [4] WELANDER et al., 52nd APS/DPP Meeting, Chicago, Illinois, 8–12 November, 2010
- [5] LODESTRO and PEARLSTEIN, Phys. Plasmas 1 (1994) 90

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