NSTX-U

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Analysis and modeling of current ramp-up dynamics in NSTX and NSTX-U

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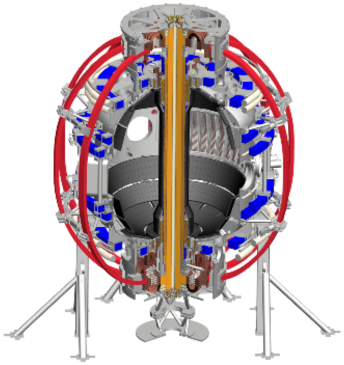
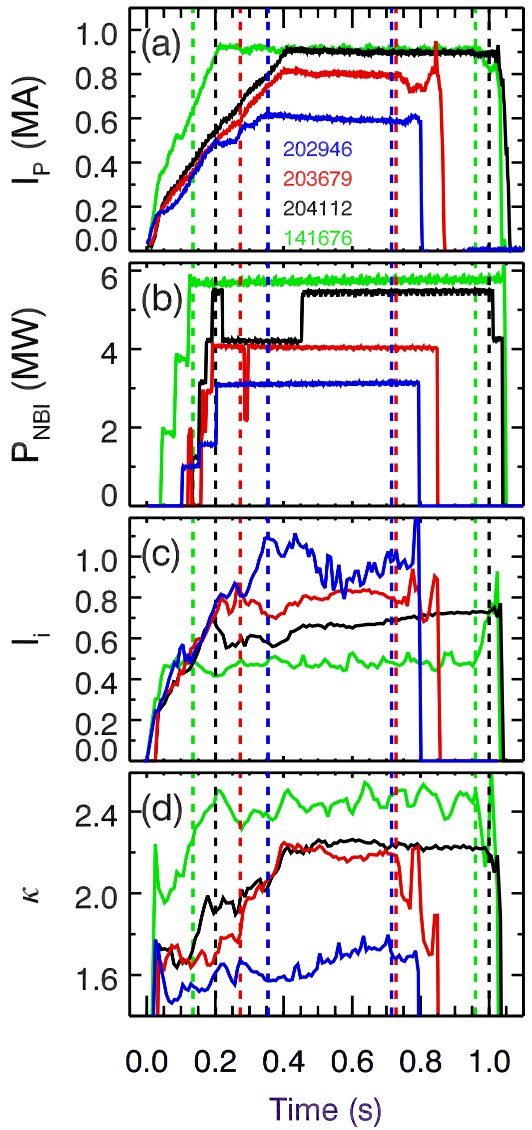
PPPL



H-mode flattop performance depends on the I_p ramp-up

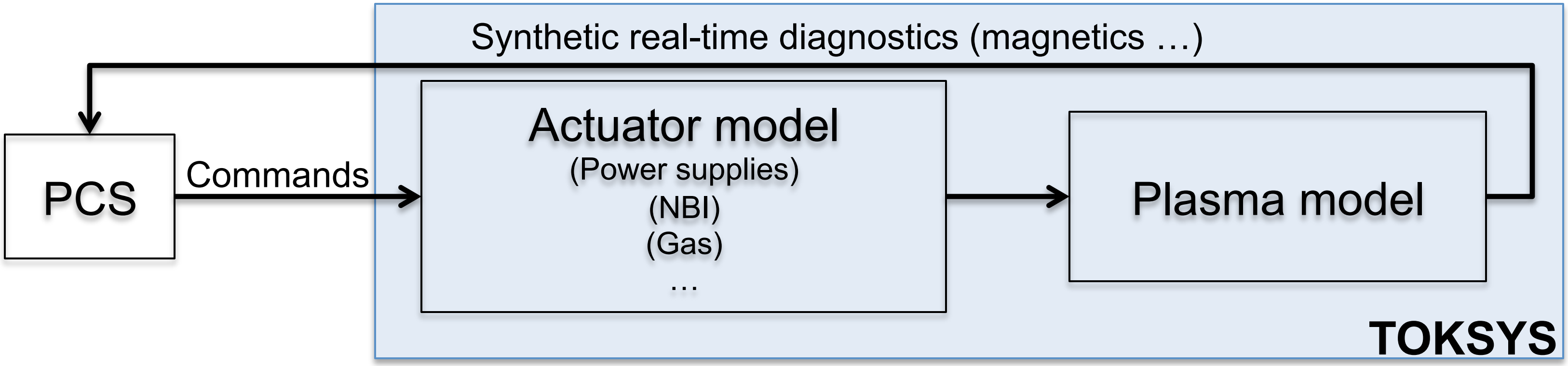
- **NSTX fiducial** had L-H transition before 150ms
  - $l_i \sim 0.5$, $\kappa \sim 2.4$ with $P_{NBI} = 5.8$ MW
- NSTX-U: progress in obtaining early L-H transition, higher I_p and κ
  - **202946 → 203679 → 204112**
  - Enabled by increase in P_{NBI}, improvements in shape control, EFC
- Access to higher I_p (> 1.6 MA) and κ (> 2.4) requires further ramp-up development during next run



Goals for R(17-5): Analysis and modeling of current ramp-up dynamics

- Evaluate elongation limits during ramp-up phase using data and calculations
  - What factors limit the elongation before, during and after diverting?
  - Identify growth rate of vertical instability to predict controllability of high-κ shapes
- Establish the dependence of the L-H transition on density, plasma shape, etc. to inform modeling of threshold criteria and scenario targets
- Perform stability analysis of experimental and modeled discharges to identify MHD limits during ramp-up
- Prepare for R18-6: establish TOKSYS framework for testing and optimizing control

Modeling framework aims to accelerate ramp-up scenario and control development



- TOKSYS: Matlab code used to develop actuator and plasma models for testing PCS algorithms (supported by GA)

- Two major development efforts
  - Design and validate plasma model using experimental data and simulations (i.e. TRANSP, DCON)
  - Develop non-linear models and/or switching between linear models
    - Flattop modeling typically uses linearized model around a reference case

- Ultimate goal: develop, test and optimize scenarios and control in the ramp-up phase in offline simulations

Recent progress in establishing TOKSYS simulations for NSTX-U

- Vessel current model, linearized axisymmetric plasma response model and synthetic magnetic signals generated
  - Supports snowflake control development and testing
  - Validation of plasma response model will begin soon
- Power supply models have been developed
  - Model includes simplified bridge rectifier model
  - Working toward end-to-end optimization of vertical stability
- Recently demonstrated coupling between PCS and the models within TOKSYS
  - Some bugs are being worked out with support from GA

Several activities are underway to study elongation limit set by vertical stability

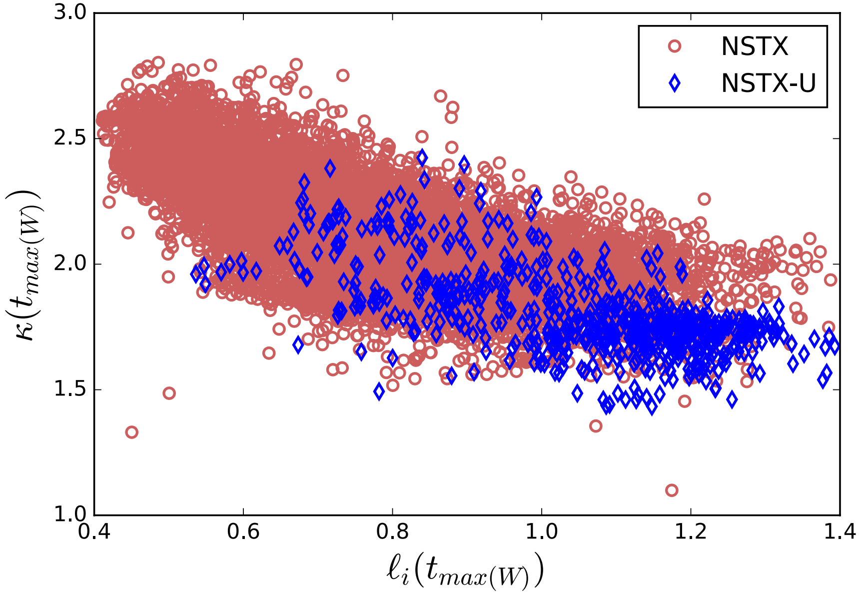
- Database of achieved elongation at time of maximum stored energy and maximum elongation

- Database of VDE times on NSTX-U and NSTX
  - Quantify disruptivity at different operating points
  - Quantify trigger mechanisms and stability boundaries

- VDE growth rate calculation
  - Evaluate dependences of growth rate (gaps, wall current …)
  - Extend calculation to planned operating points

- Database of vertical motion (bobble) at time of diverting

κ versus l_i at time of maximum W_{tot}

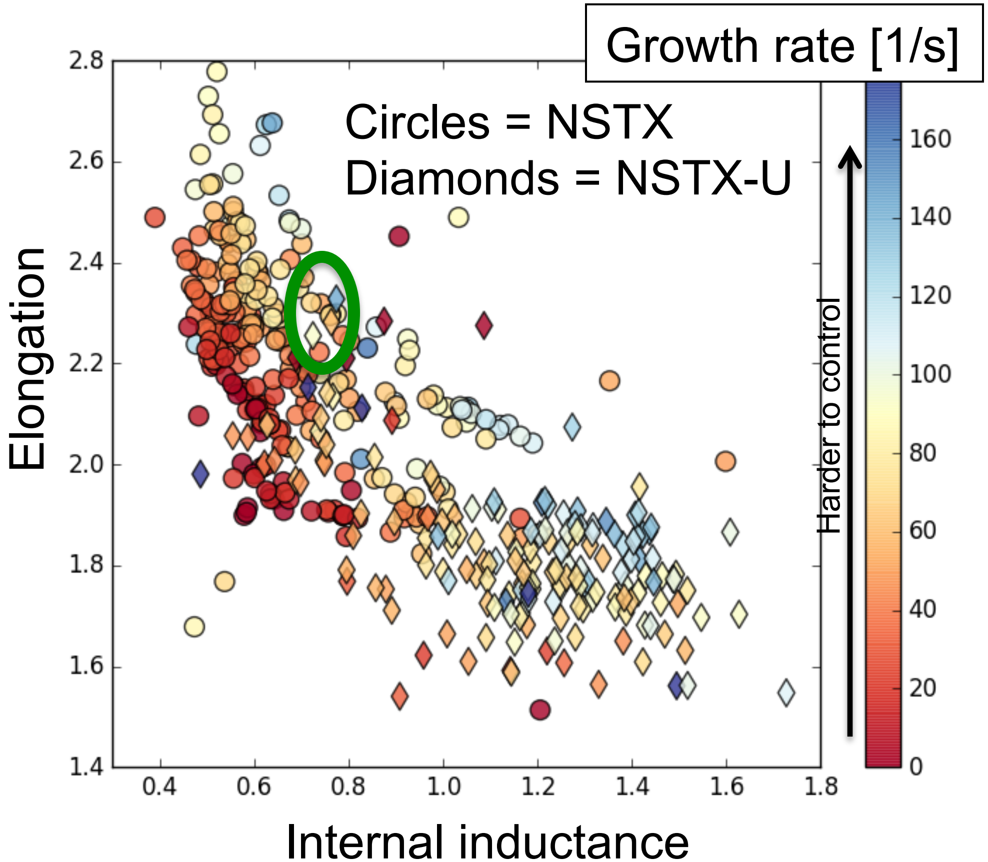


Growth rate calculations will allow projection of NSTX-U limits to lower l_i

- Calculations within ISOLVER quantify open loop vertical growth rate [Menard]
  - Evaluate growth rate just prior to VDE time

- Maximum growth rates for NSTX-U and NSTX are similar
  - Good! Suggests we can do as well as NSTX at low l_i

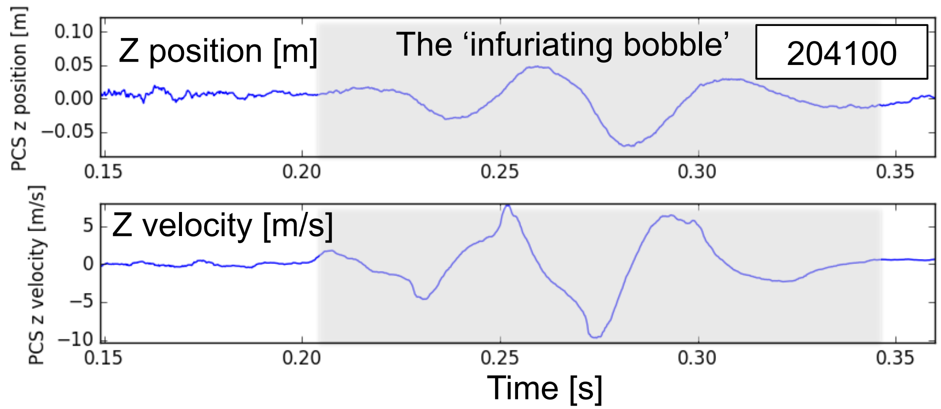
- Many 'VDEs' occur below limit ~ 140 1/s
  - Probably have different triggers, e.g., locked modes
  - Will refine filtering of VDE database (DECAF)



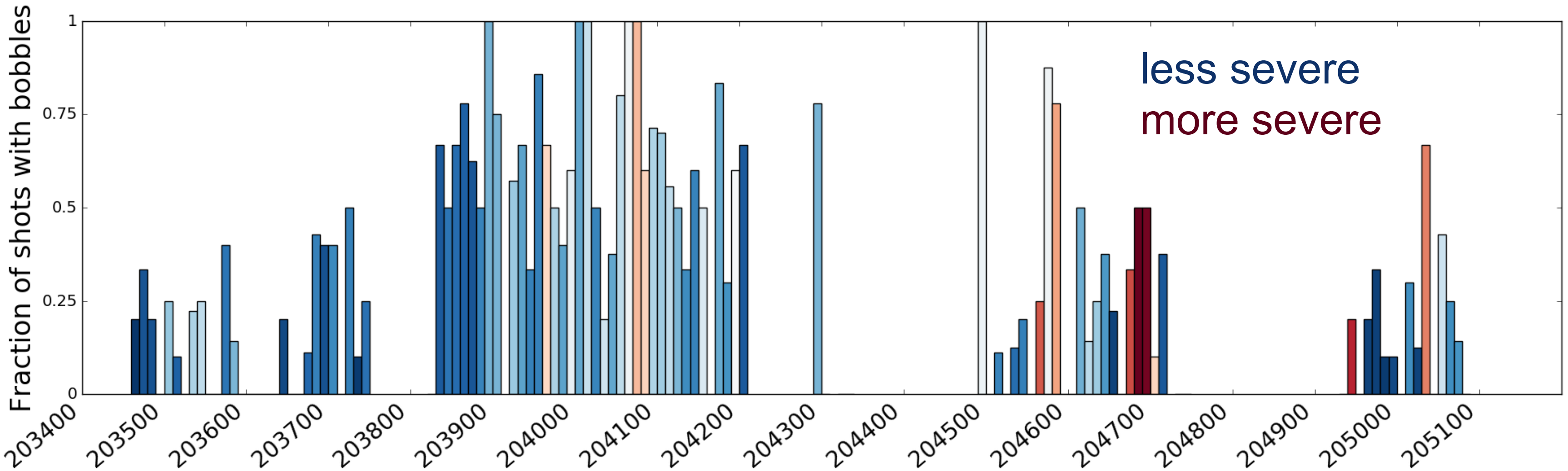
Vertical "bobble" observed near time of diverting, far away from expected κ limits

- Machine learning used to automatically identify instances of bobbles

- Using database to determine parameter regimes and/or root causes



Fraction of shots with bobbles



Database of L-H transitions and corresponding L-mode shots

- Identify important dependences of L-H transition power threshold to guide modeling and experiments

- Most shots are very dynamic around L-H transition
  - Transitioning from limited to diverted
  - Large dI_p/dt and dW/dt during ramp-up
    - $P_{LH} = \xi P_{NBI} + P_{OH} – dW/dt$
  - Many shape parameters (gapin, d_{rsep}) not stationary

- Created a database of L-H and L-mode times
  - NBI efficiency presently computed using simple model benchmarked against BEAST data for all L-mode times
    - Will need to run TRANSP runs for subset of interest to really quantify P_{LH}
  - Most useful result (so far) has been identifying range in parameters that preferentially excludes L-mode dataset

Dataset confirms experimental observation that d_{rsep} and V_{surf} influence P_{LH}

- Dataset of 68 L-H times and 101 L-mode times
  - L-H in a limited shape are excluded

- If the dataset is restricted by …
  - $n_e > 1.2 \times 10^{19}$ m^{-3}
  - $0.7 < V_{surf} < 1.2$
    - Minimum P_{LH} near $V_{surf} = 0.95$ V
    - Surprising to see P_{LH} increase below $V_{surf} = 1$V
  - $-0.4 < d_{rsep} < 0.8$
    - L-H seemed to favor USN ?
    - Minimum P_{LH} near $d_{rsep} = +0.2$

- 5 L-mode (5%) and 43 (63%) L-H times remain in constrained dataset
  - Most of L-H times removed had $P_{LH} > 3 \times$ minimum P_{LH}

Plans for Q3

- Create vertical stability probability relationship (disruptivity) from the NSTX database, compare to NSTX-U results
  - Aided by continued efforts to refine detection and classification of VDEs
- Extend NSTX-U growth rate calculations to higher κ shapes
  - Requires generating a set of target equilibria
- Continue to investigate 'The Bobble' at time of diverting
  - What parameters impact the amplitude and decay period?
- Identify subset of discharges where TRANSP runs would help identify P_{LH}
  - Expand database to include NSTX discharges
  - Strong V_{loop} dependence is of particular interest as a constraint on the scenario
- Perform stability analysis of experimental and modeled discharges to identify MHD limits during ramp-up
- Continue debugging TOKSYS and incorporate GS solver (GSEVOLVE)
  - Continue development and validation of power supply and plasma models