NSTX-U

NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

NSTX-U Milestone R18-2: Develop simulation framework for ST breakdown and current ramp-up

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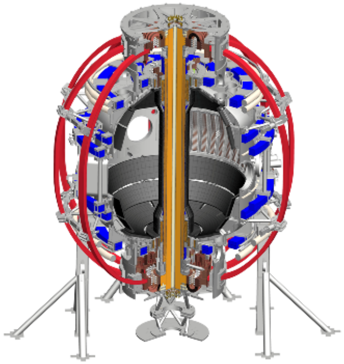
FY2018 Q2 Research Milestone Status
March 9, 2018

PPPL



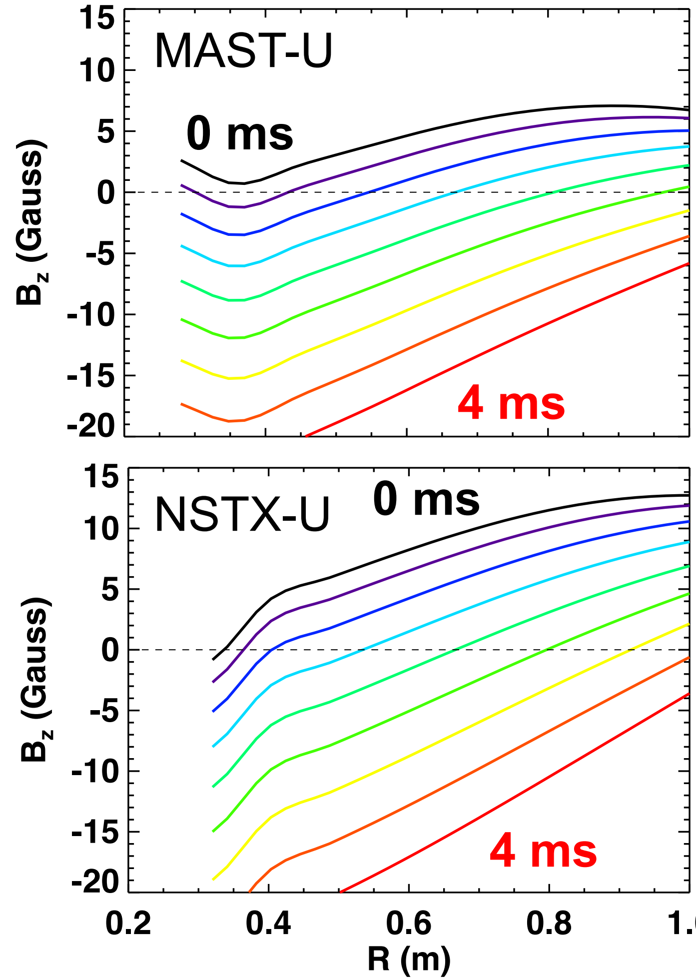
Main elements of FY18 milestone

- Inductive startup calculations using LRDFIT
  - Quantify difference between model and experiment
  - Identify impact of V_{loop} and dI_p/dt on the null quality and field index
  - Includes NSTX-U and MAST-U analysis
- Control modeling focusing on IWL → DN transition
  - Using TOKSYS code from General Atomics
  - Reproduce vertical oscillation at time of diverting in model
  - Investigate control solutions for earlier time of diverting, eliminating vertical oscillation and test resiliency to scenario perturbations
- TRANSP calculations for heating and current drive
  - Compare predictive calculations to NSTX and NSTX-U ramp-up
  - Investigate impact of outer gap, density, NBI, dIp/dt …

Status of LRDFIT breakdown modeling

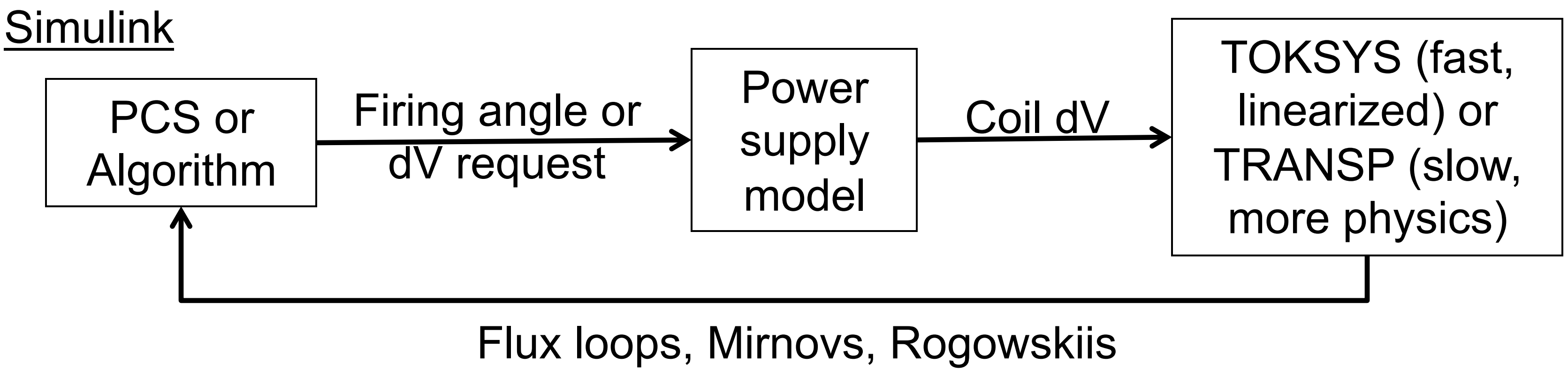
- Inductive breakdown simulations for NSTX(-U) and MAST(-U)
  - Demonstrated MAST-U can achieve similar breakdown metrics to NSTX-U within the voltage limits of PF coils
- Remaining goals for FY18:
  - [Q-3] Investigate potential sources of up-down asymmetry that scaled with I_{OH} on NSTX-U
  - [Q-4] Quantify impact on null quality and field index with V_{loop} and dI_p/dt on NSTX-U and MAST-U
    - Can we ramp I_p faster following breakdown?

Midplane B_Z evolution over first 4 ms



Overview of TOKSYS and SIMULINK development

- FY18 goal: demonstrate a simulation framework for developing and testing shape control in ramp-up



- Aim is to establish closed loop test with PCS
  - End-to-end test and valuable for shot planning work
  - Ability to test algorithm outside of PCS will be maintained

- Simulink connects PCS to TOKSYS or TRANSP
  - TOKSYS provide fast (~ minutes) solution, enables large parameter scans

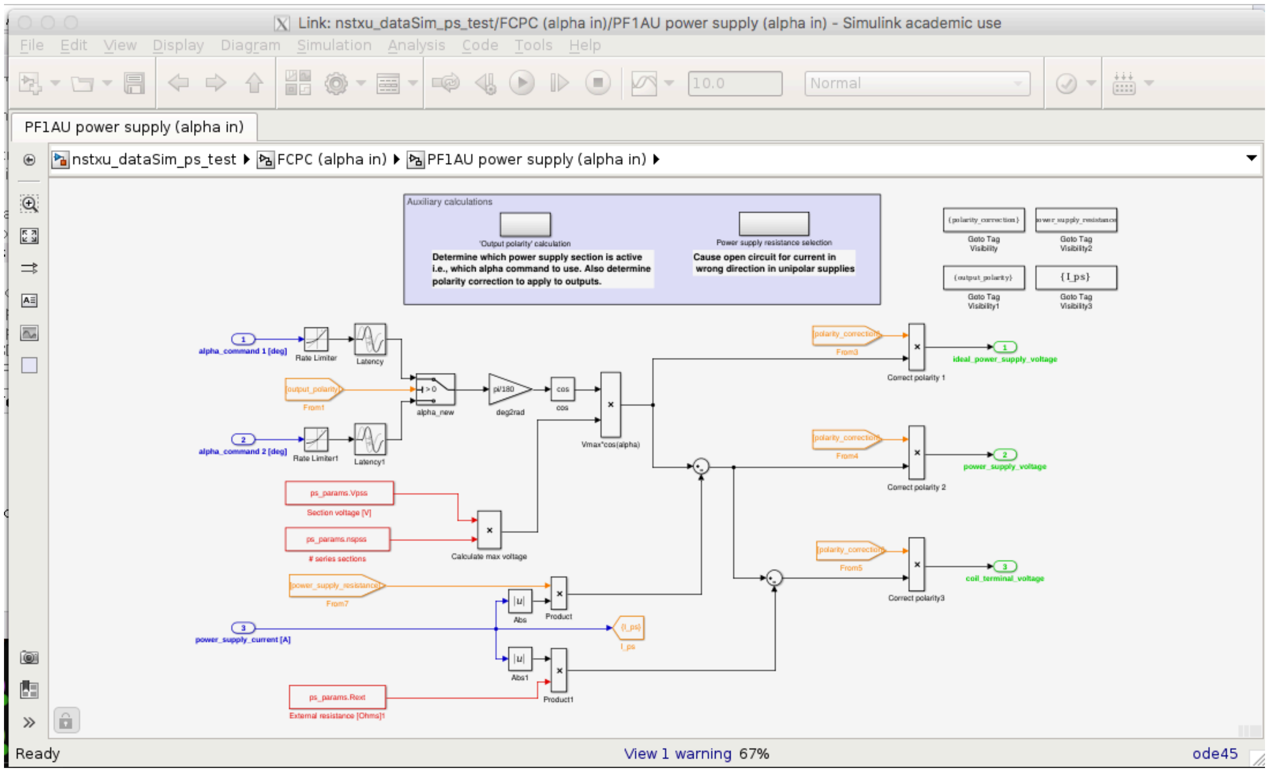
Q2 activities on TOKSYS and SIMULINK development

- PCS works in SIMULINK evironment
  - Can pipe in archived data, PCS outputs commands into MATLAB work space
  - Issue with number of outputs. Limited to 128 outputs→ gets us what we want.

- Improved power supply model in SIMULINK
  - Dan showed slides on SIMULINK model of power supplies, beam model and neural network equilibrium solver
    - See next slides
  - Next step: test PS model with vacuum discharges

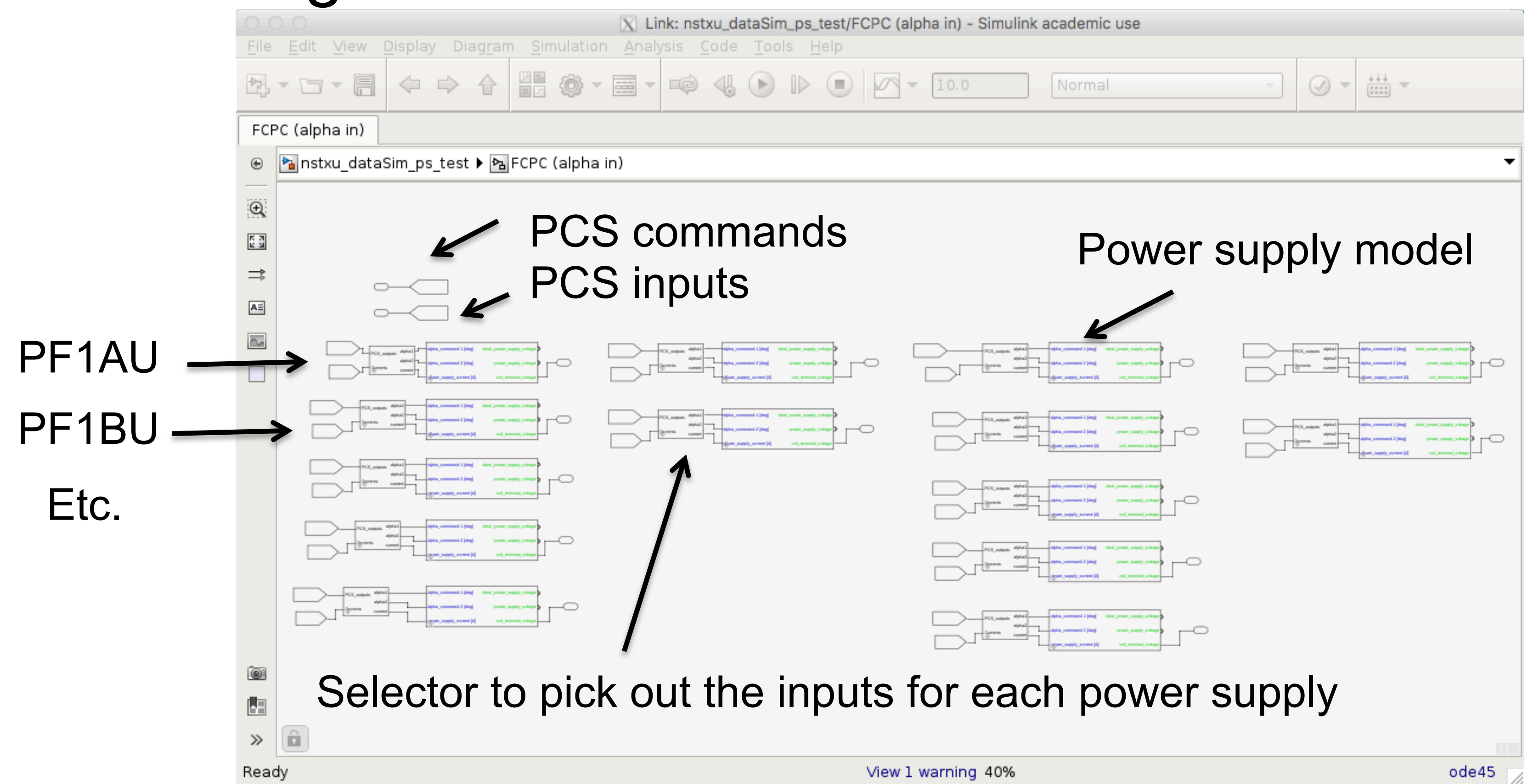
Simulink model of power supplies

- Set-up script gets configuration (polarity, number of supplies, power supply resistance, etc.) from MDSplus
- Model accounts for polarity, resistive drop, and rate limits, and latency
  - May need inductance or fine tuned resistances to perfectly match measured voltages
- Resistance increased when current goes the wrong way in unipolar supplies
- Two versions - alpha commands or system voltage requests as inputs



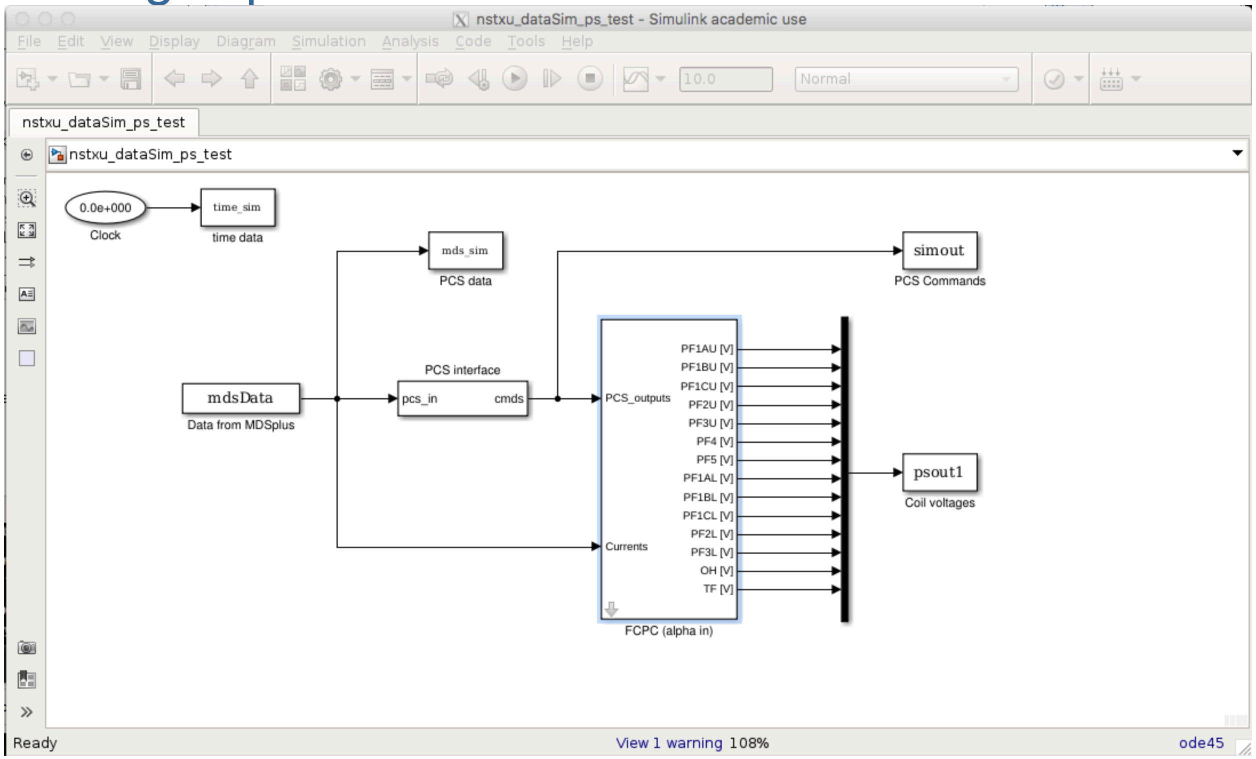
Simulink block made for FCPC

- How to handle power supply enable windows automatically?
- Planning to add SPA model next



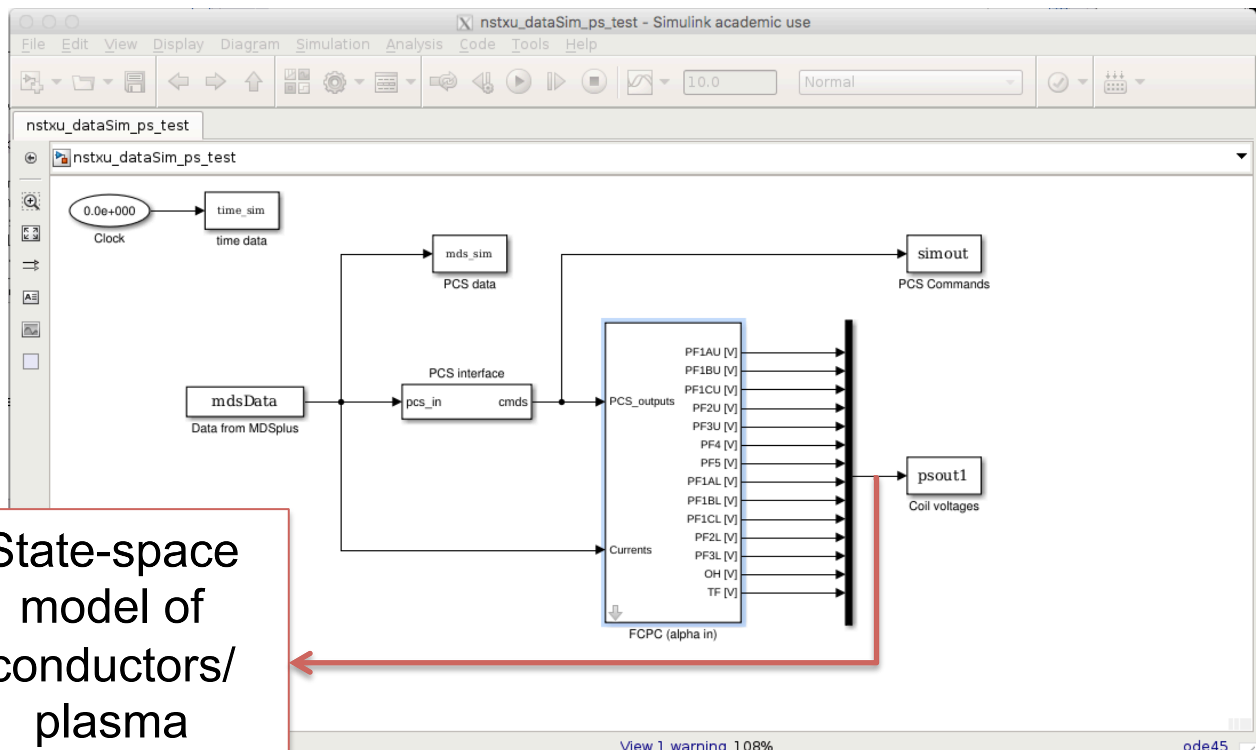
Tested connection between PCS and FCPC model in a Simulink-based data simserver

- Archived data for shot sent into appropriate PCS input channels
- PCS outputs sent to power supply model
- Configured to be able to get SPA, beam, gas, and LGI outputs
  - Planning to make SPA and beam models next
  - Should work on gas plenum models too



Next step: replace data with model for conductors

- First drive conductors/plasma response model with outputs of power supply model
- Then inject ‘measurements’ from model into input datastream



State-space model of conductors/ plasma response

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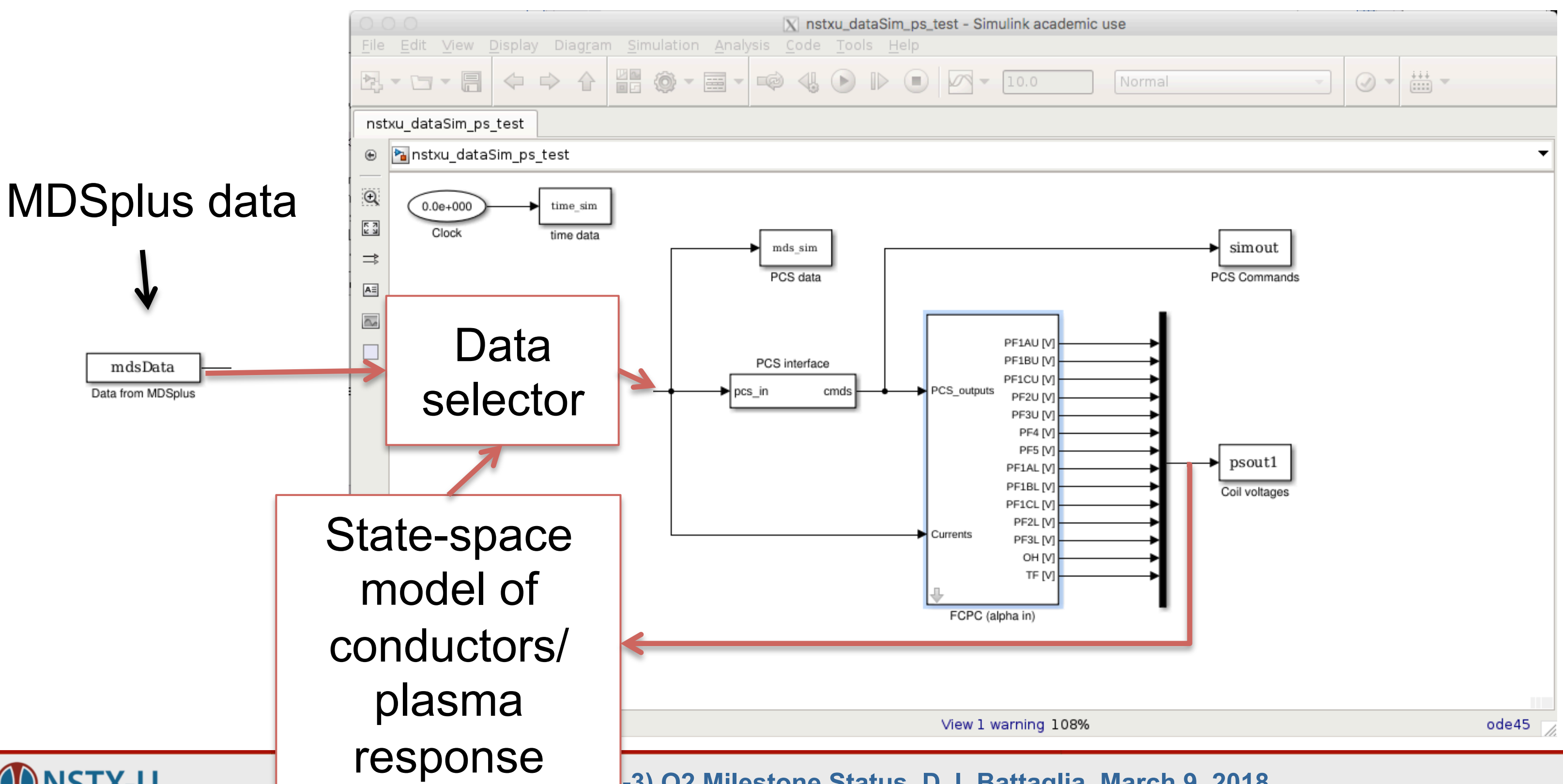
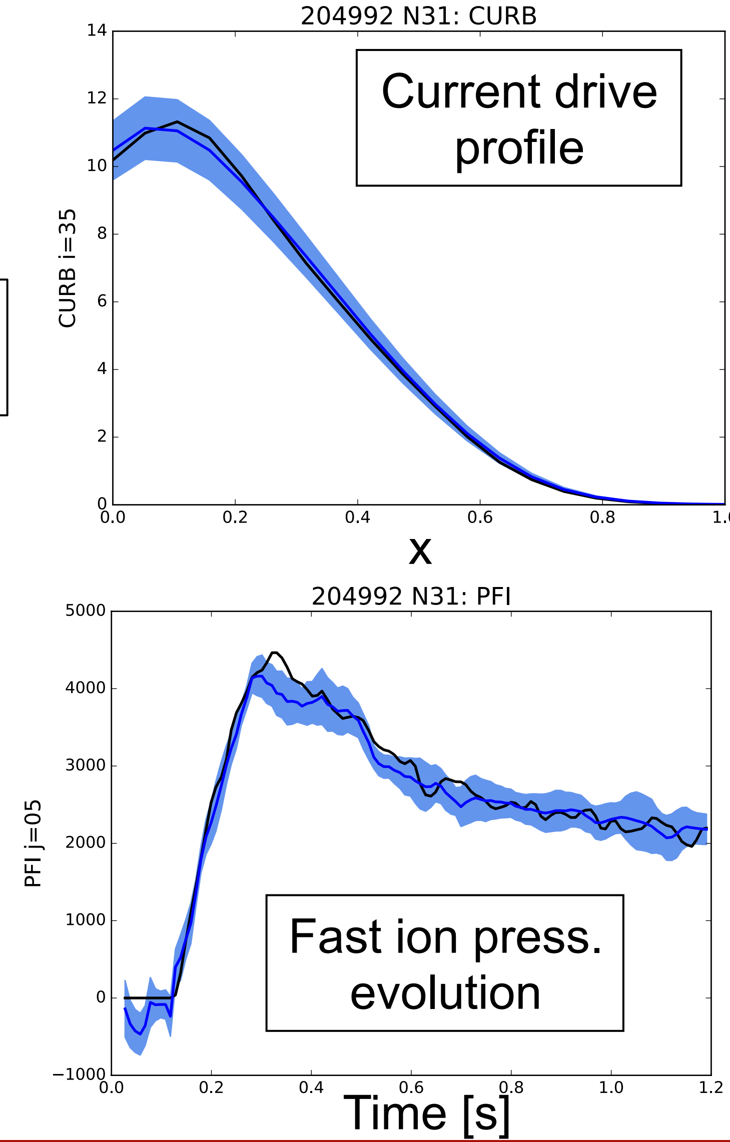


Fast, realistic beam calculations will enable real-time prediction, improve control and equilibrium reconstruction

- **NUBEAM** module provides **high-fidelity beam deposition** calculations but is **too complex for real-time** use

NUBEAM
NubeamNet

- **Machine learning** has been applied to NSTX-U TRANSP runs to create a **real-time capable** beam deposition calculator: **NubeamNet**
  - Heating, current drive, torque, fast ion pressure profiles
  - Neutron rate, beam losses



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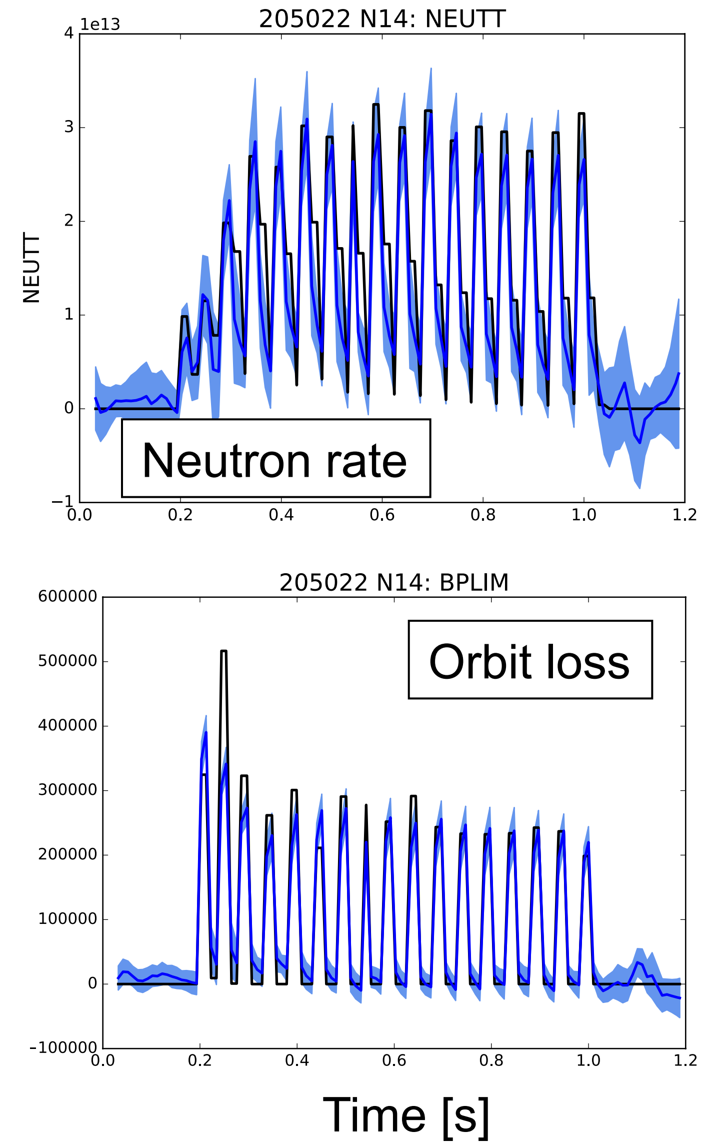
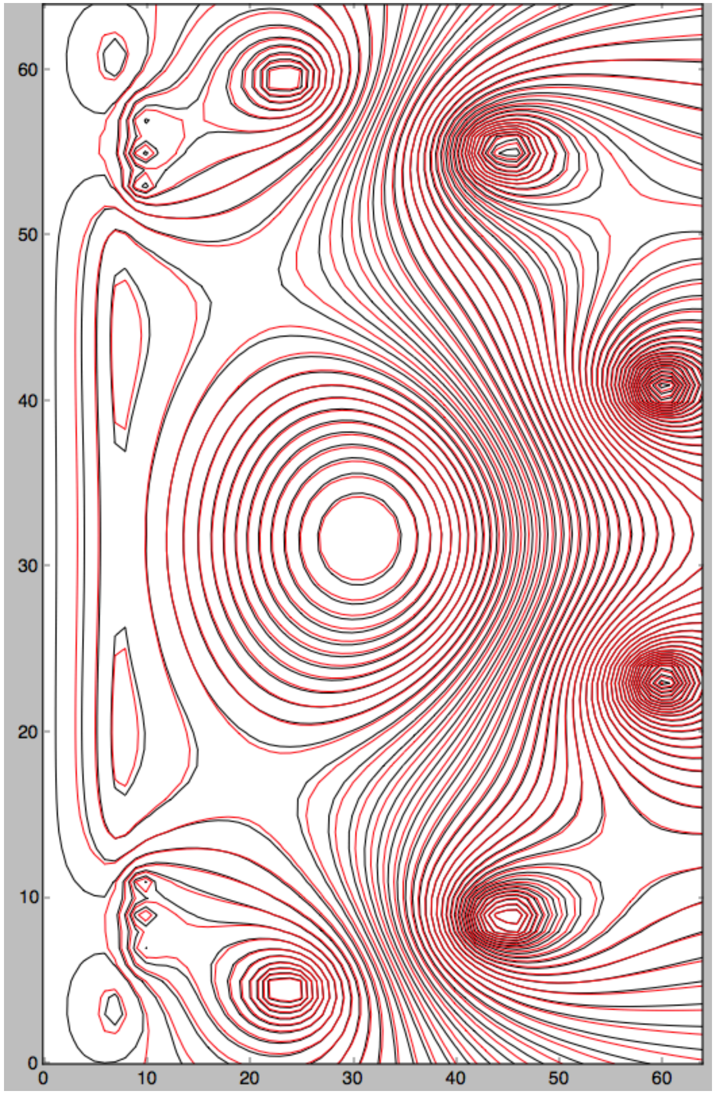


Promising results from proof-of-principle equilibrium NN

- Calculates equilibrium from conductor currents and pressure, current profiles in ~10us
- Mismatch comparable to differences among rtEFIT, EFIT01, and EFIT02
  - Haven't optimized topology or trained on large data set yet

EFIT01
GSNet



Q2 activities on TOKSYS and SIMULINK development

- Develop TOKSYS models for ramp-up phase
  - Pat has developed and validated wall model for NSTX-U using vacuum shots
  - Pat is leading development of linearized plasma models for NSTX-U ramp-up (20 – 500ms)
    - First test is examining how the interval of updating the linearized model impacts agreement with experiment

- Near term goal: Demonstrate a SIMULINK model that can blend the different models in a time-evolving calculation

Other activities with TOKSYS and SIMULINK development

- [Q-3] Closed loop calculation of an NSTX-U discharge using PCS in simulink with TOKSYS and possibly TRANSP
  - Advances "shot simulator" capabilities
- [Q-3] Evaluate different TOKSYS models in ramp-up
  - Fixed shape, rigid shape, non-rigid linear, grad-Shafranov, NN …
    - Fixed evolution of current and pressure profile
  - How often does linearized model need to change during different phases of the discharge?
- [Q-4] Reproduce different varieties of "the bobble" at the time of diverting
  - Start to investigate proposed solutions from FY17 milestone

Status of TRANSP calculations

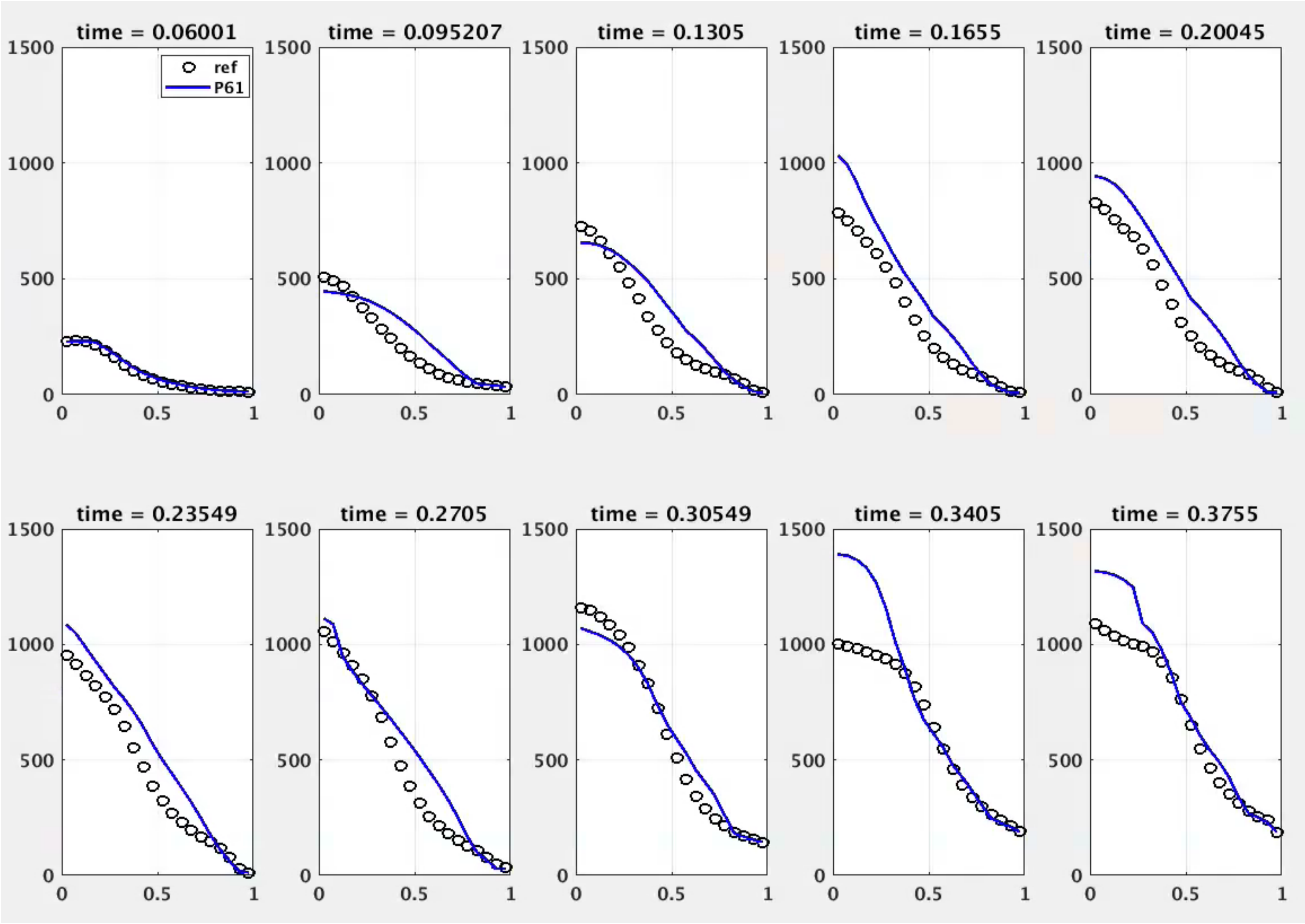
- [Q2-3] Validation of TRANSP model for ramp-up period (Doohyun, Francesca)
  - NSTX w/ MSE (139048)
    - See attached slides
  - NSTX-U w/ CHERs (204202)
    - See attached slides
  - NSTX-U early H-mode development (202946, 203679, 204112) using NBI #2
    - Underway
  - Evaluate ability of flux-driven transport models to capture evolution of discharge in L- and H-mode ramp-up

- [Q3-4] Free-boundary predictions for NSTX-U
  - Start with validated predictive model of an NSTX-U rampup
  - Examine impact of NBI, outer gap, density, dIp/dt, κ, and/or timing of L-H transition on l_i
    - Need to provide target shapes for NSTX-U cases
    - First try an NSTX-U ramp-up where everything happens earlier and faster

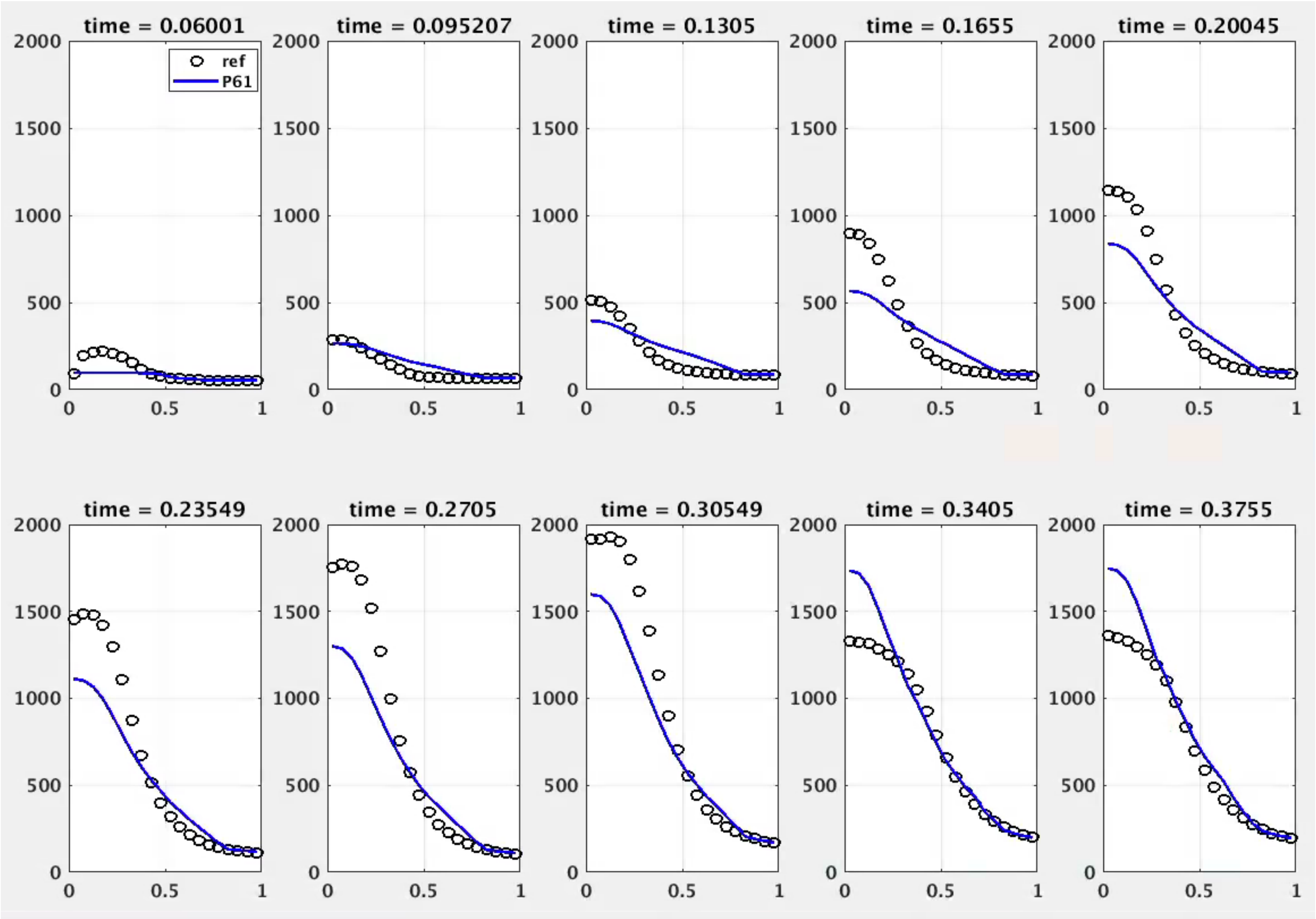
Te/Ti prediction initial test for NSTX/NSTX-U

- Transport
  - NSTX case (139048P61)
    - transport: turbulence (MMM), NC (NEOCH), ExB (TRANSPEXB)
      - MMM: Weiland (e/i), MTM (e), ETG (e)
  - NSTX-U case (204202P16)
    - Electron transport: turbulence (MMM), NC (NEOCH), ExB (TRANSPEXB)
      - MMM: Weiland, MTM, ETG
    - Ion transport: Neoclassical only (NEOCH)
  - Calculation boundary
    - Central (rho = 0 – 0.2), core (0.2 – 0.8), edge (0.8 – 1.0)
    - Te/Ti calculation in central and core regions
- Equilibrium / poloidal field diffusion
  - TEQ (fixed boundary)
  - Fixed total plasma current (ufile), calculated vloop
  - Default resistivity
- Anomalous Fast Ion Diffusion
  - Constant across minor radius (1e4)
- More test will be done for NSTX-U using 204202P16 setting

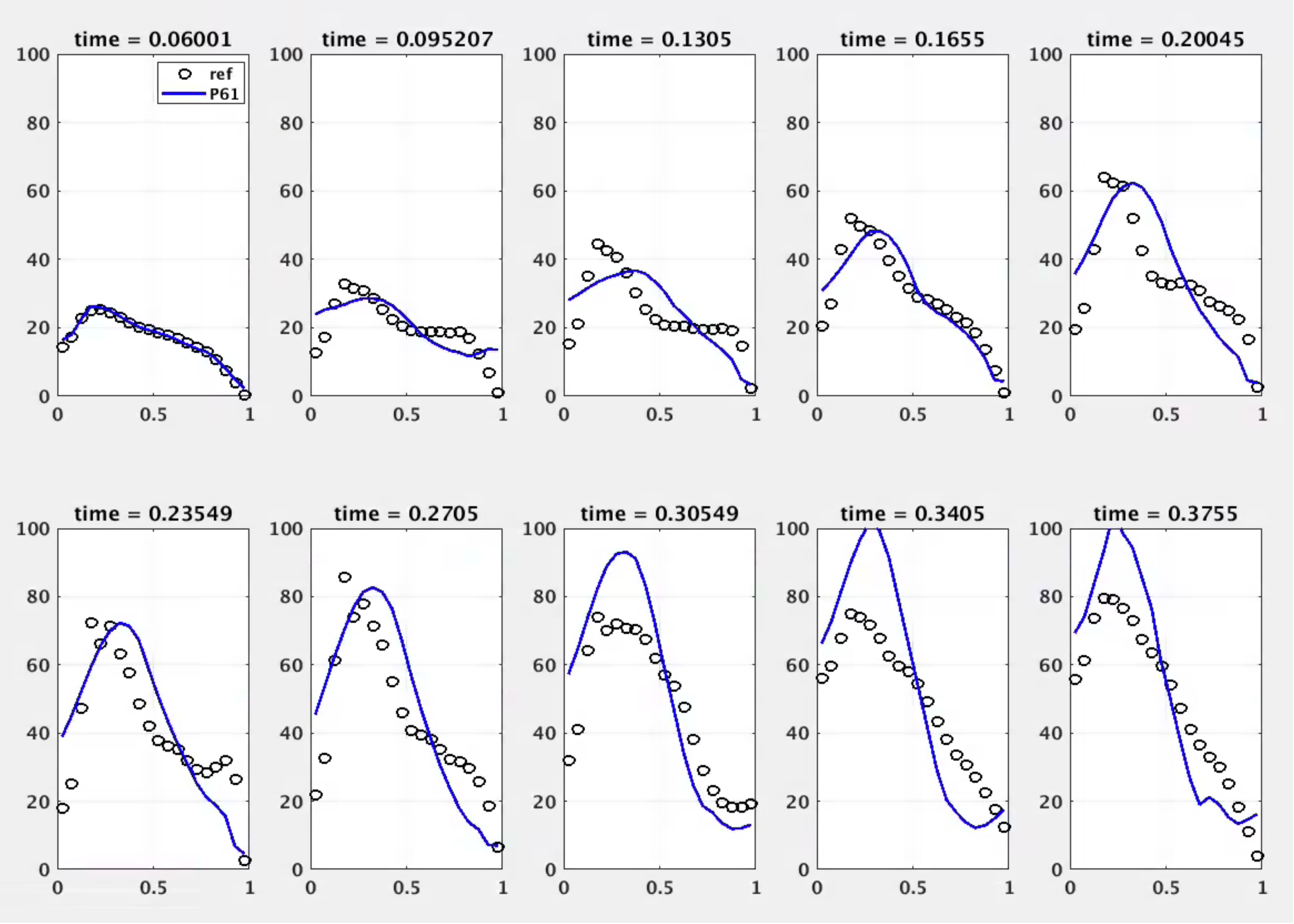
Te profiles - NSTX



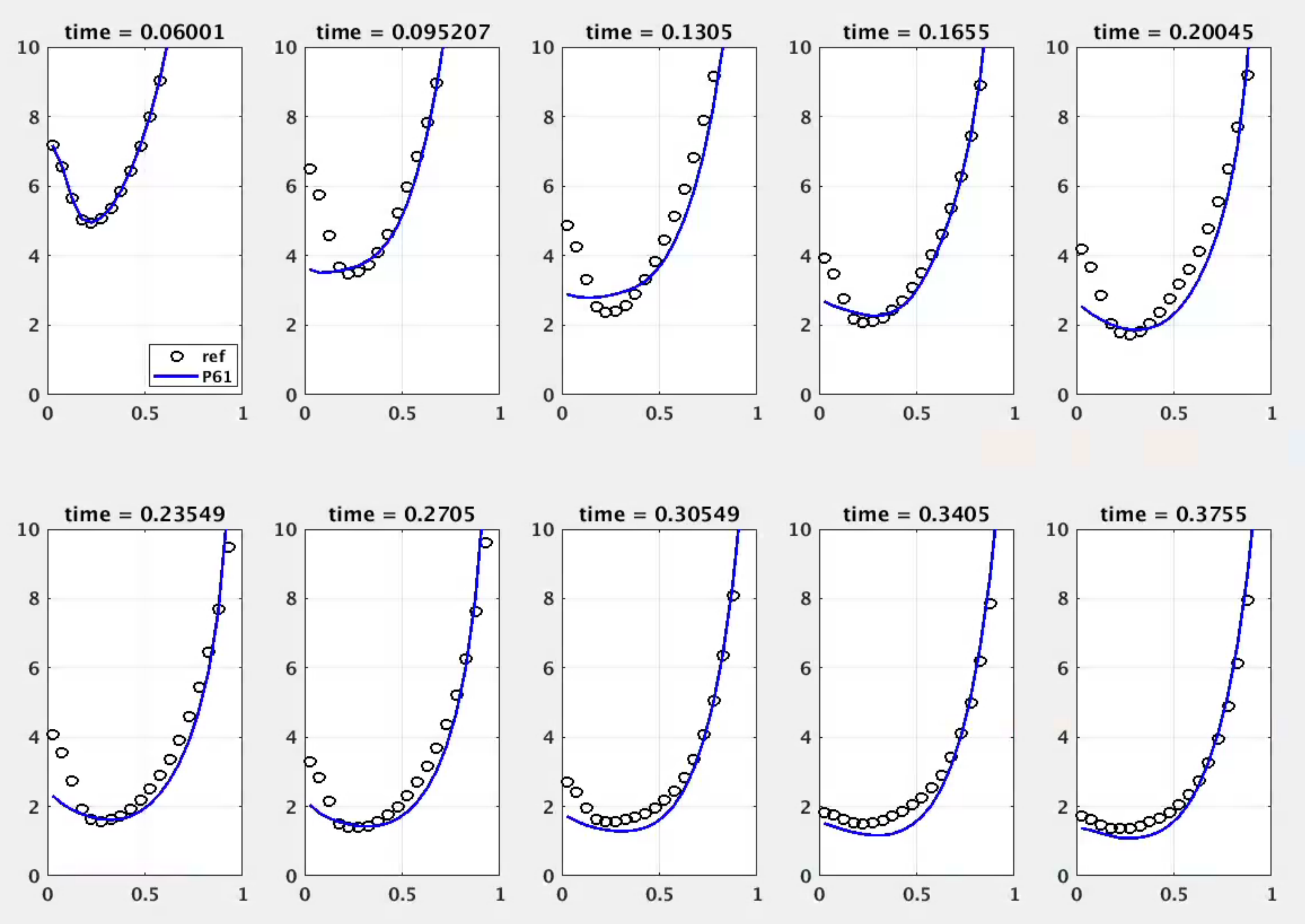
Ti profiles - NSTX



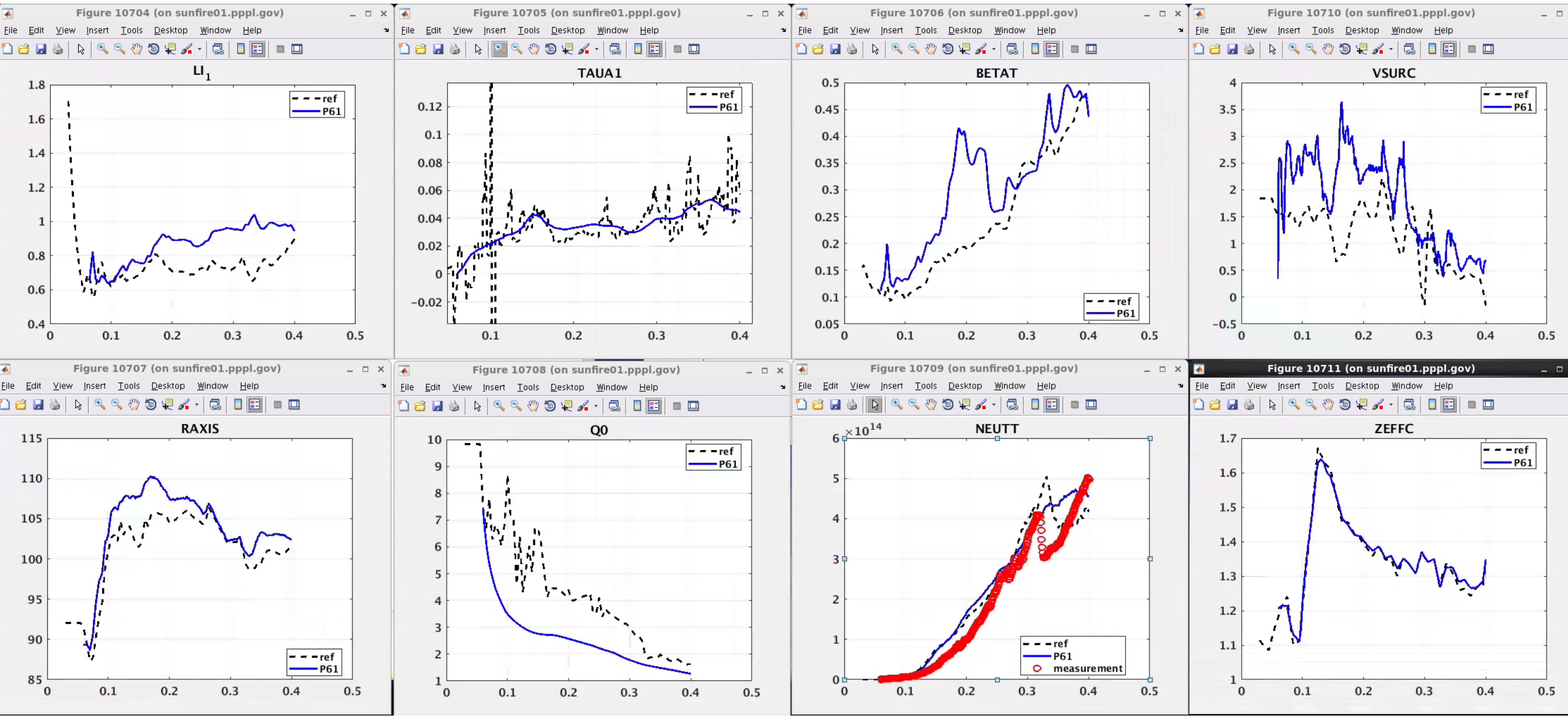
Total current profiles - NSTX



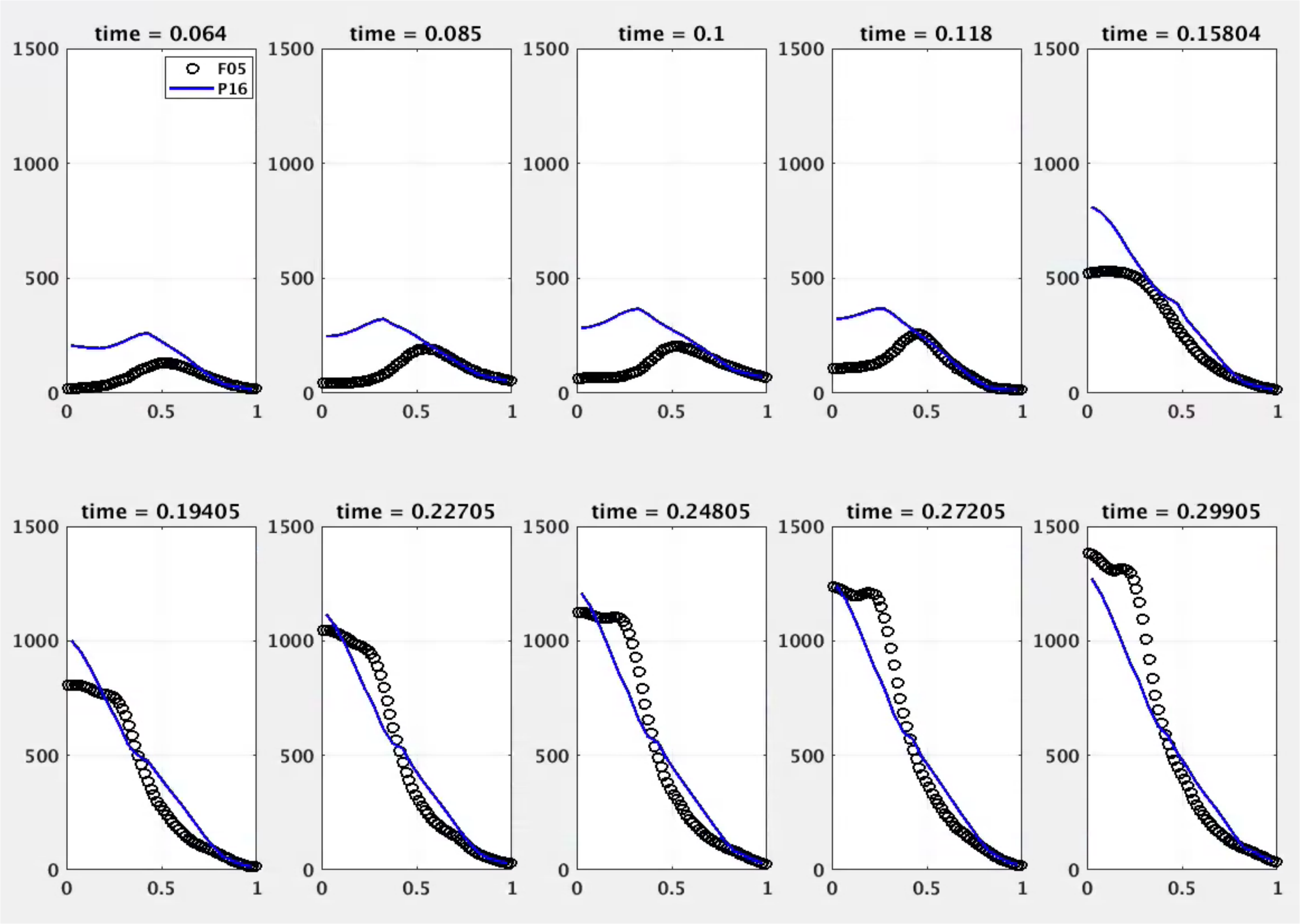
q profiles - NSTX



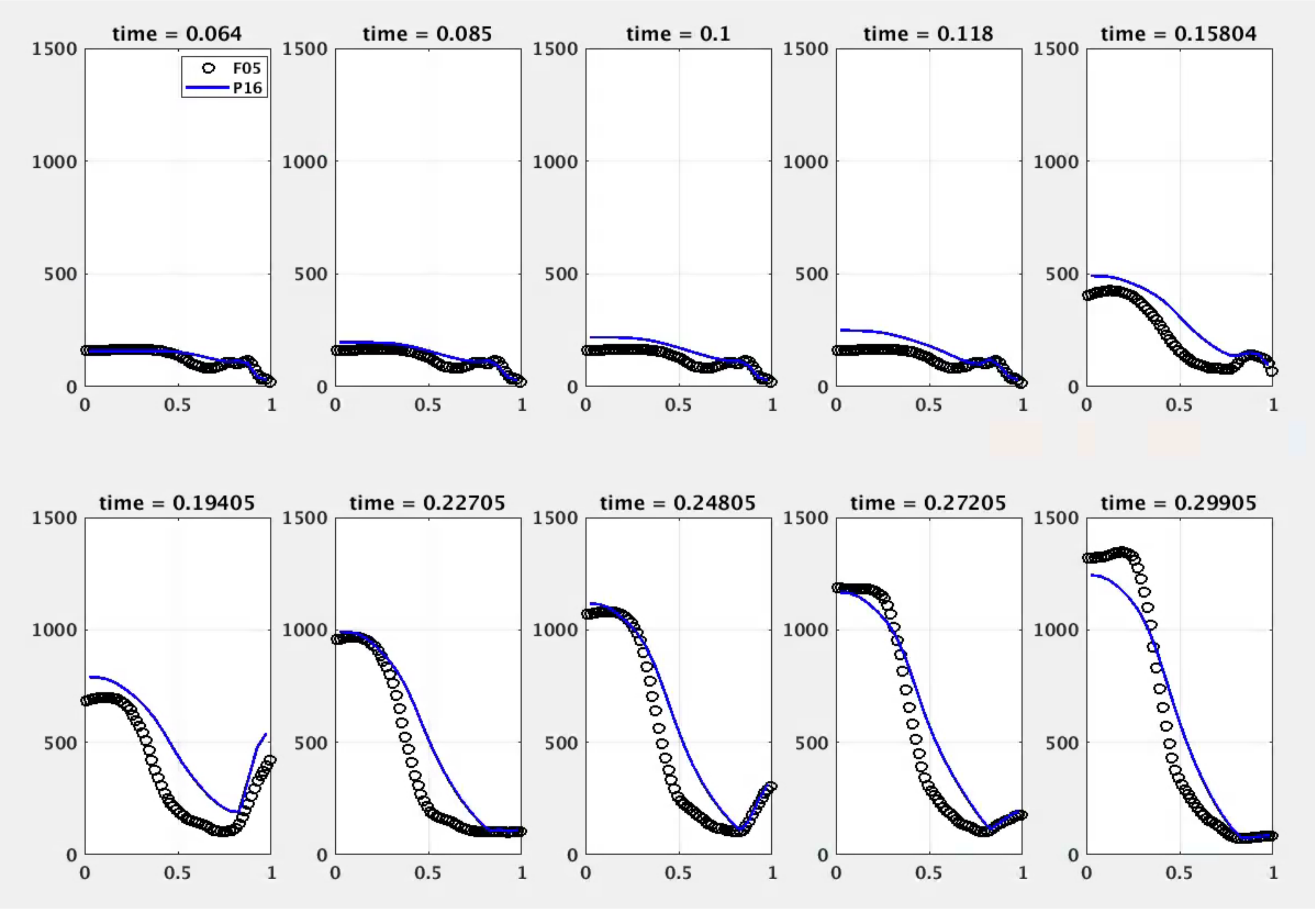
0-D parameters - NSTX



Te profiles – NSTX-U



Ti profiles – NSTX-U



Backup

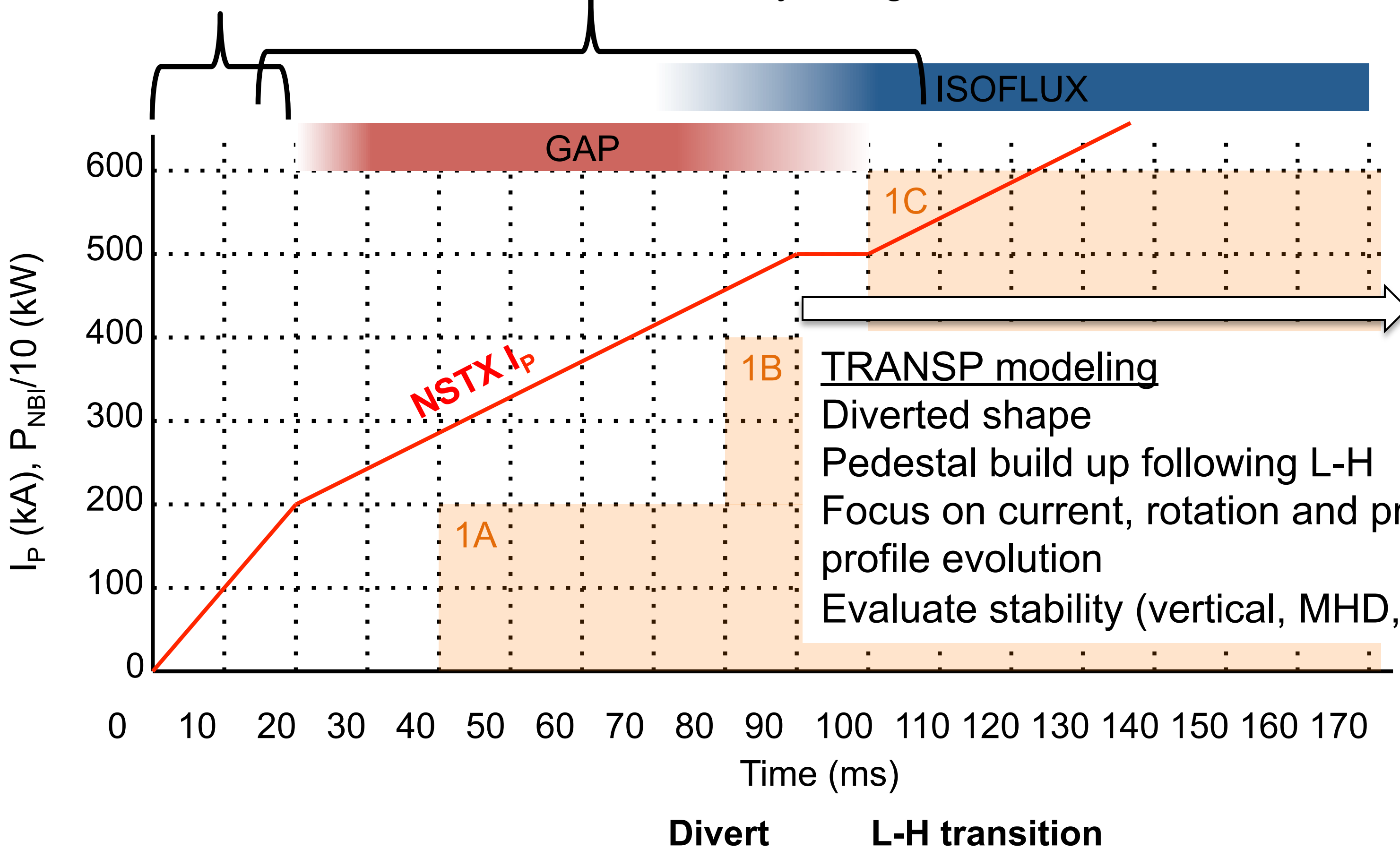
Milestone Summary

- 18-2: Demonstrate a framework for breakdown and ramp-up modeling
  - Validate models against experimental results
  - Show simulations can be employed to improve NSTX-U rampup (don't have to solve all the problems yet)
    - Start to answer some pertinent questions (what can mitigate the bobble, how important is the choice of the beams, …)
- 19-2: Optimize ramp-up for resiliency, low l_i, and stability using predictive models
  - Use TRANSP to improve linearized models for TOKSYS
  - Use TOKSYS to refine control models in TRANSP
  - Produce a solid plan for realizing high-performance discharges when NSTX-U resumes operation

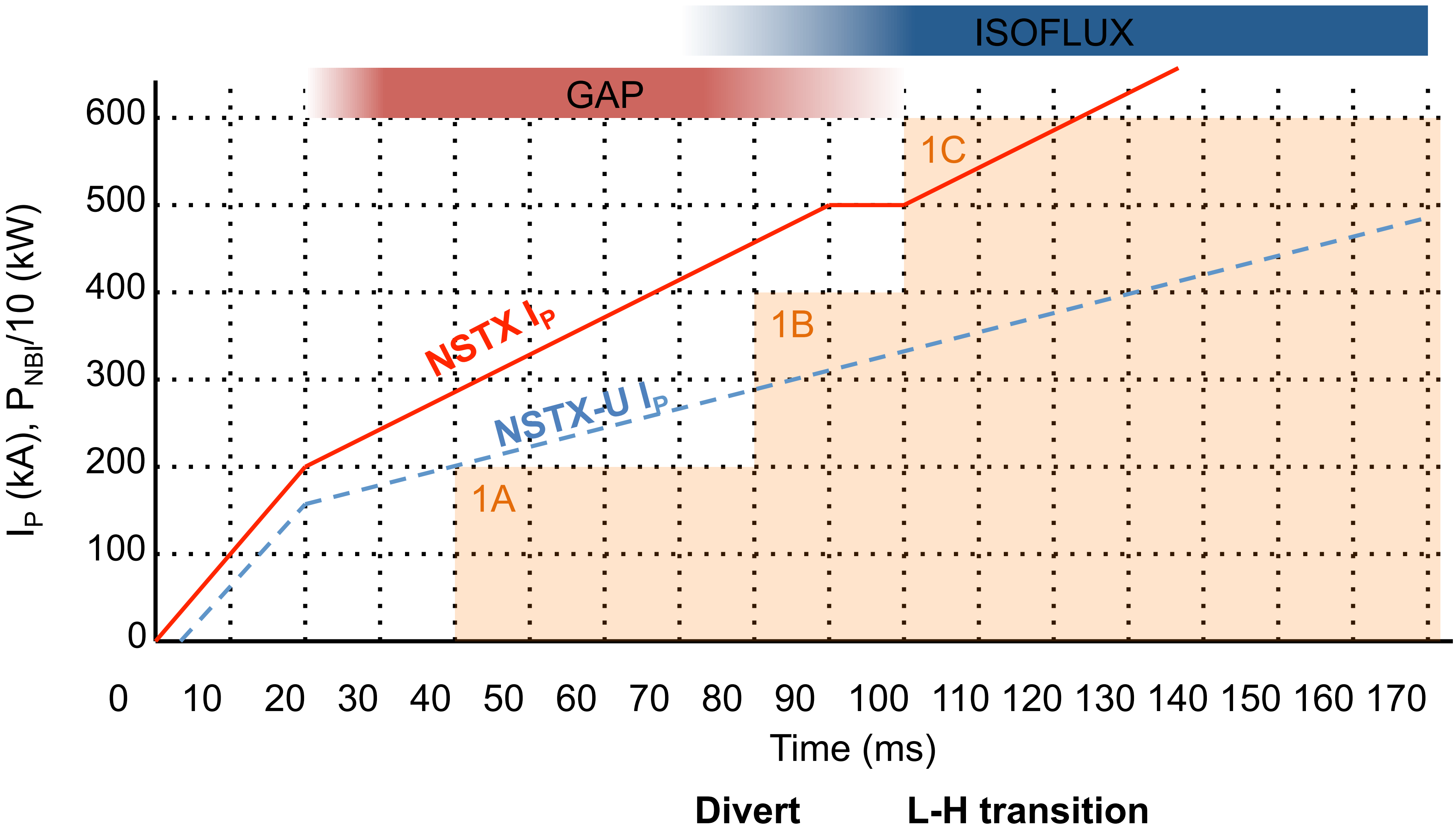
Modeling tools will focus on different challenges within the ramp-up

LRDFIT vacuum field calculations
Null formation,
dB_Z/dt with passive stability

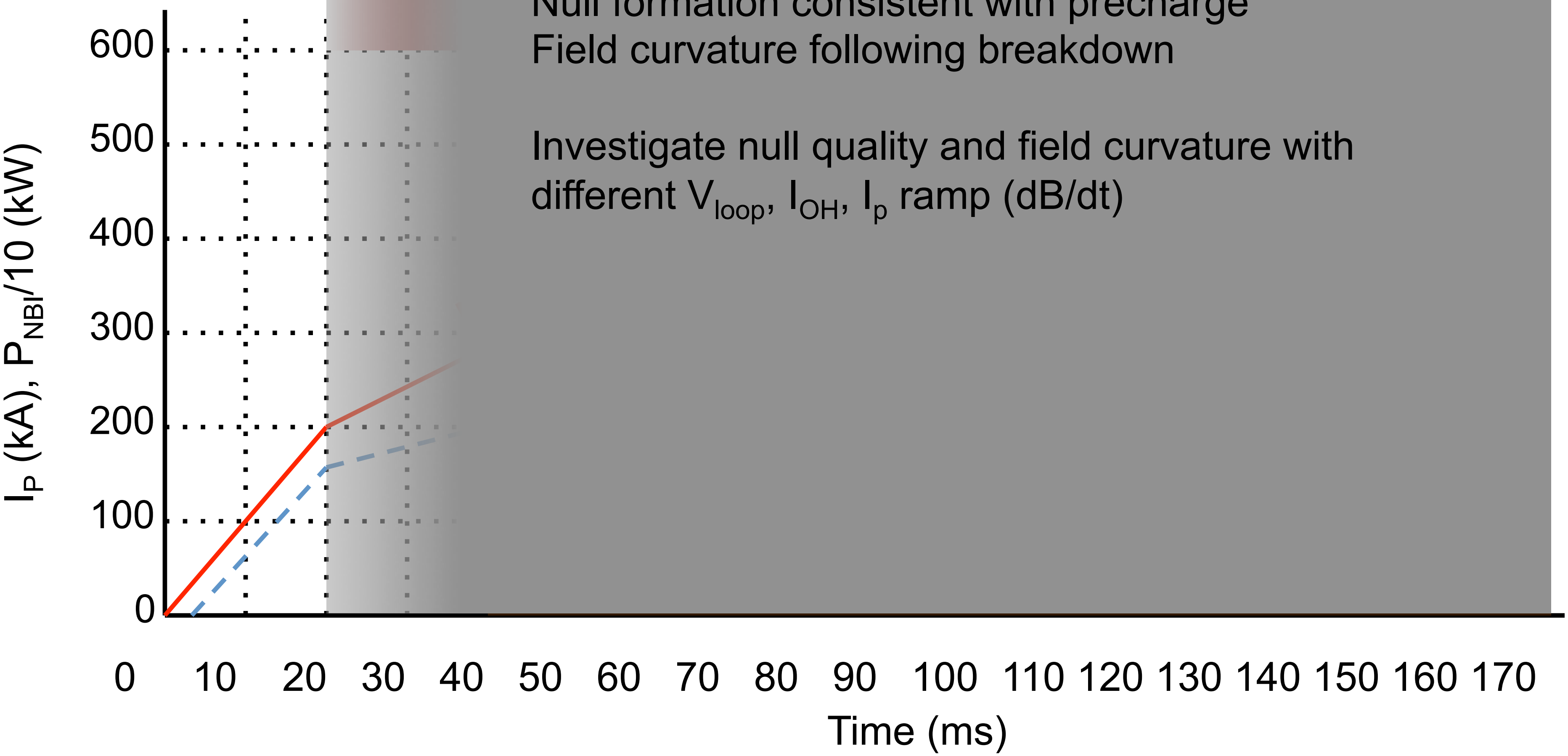
TOKSYS control modeling
Feedforward → GAP → ISOFLUX shape control
Transition from IWL → DN (L-mode)
Vertical stability at high κ



Typical NSTX ramp-up



LRDFIT modeling focus

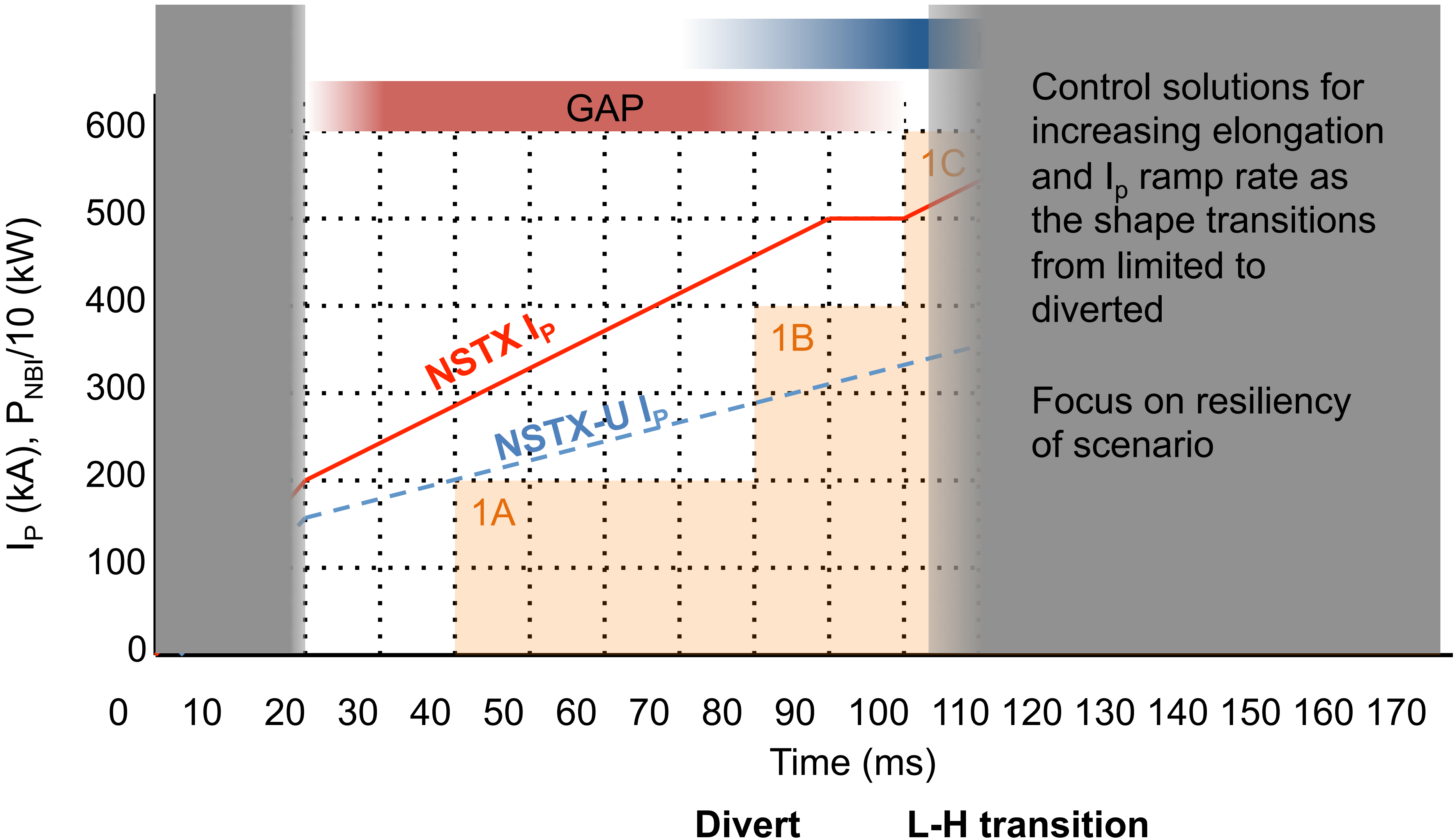


Null formation consistent with precharge
Field curvature following breakdown

Investigate null quality and field curvature with different V_{loop}, I_{OH}, I_p ramp (dB/dt)

Divert **L-H transition**

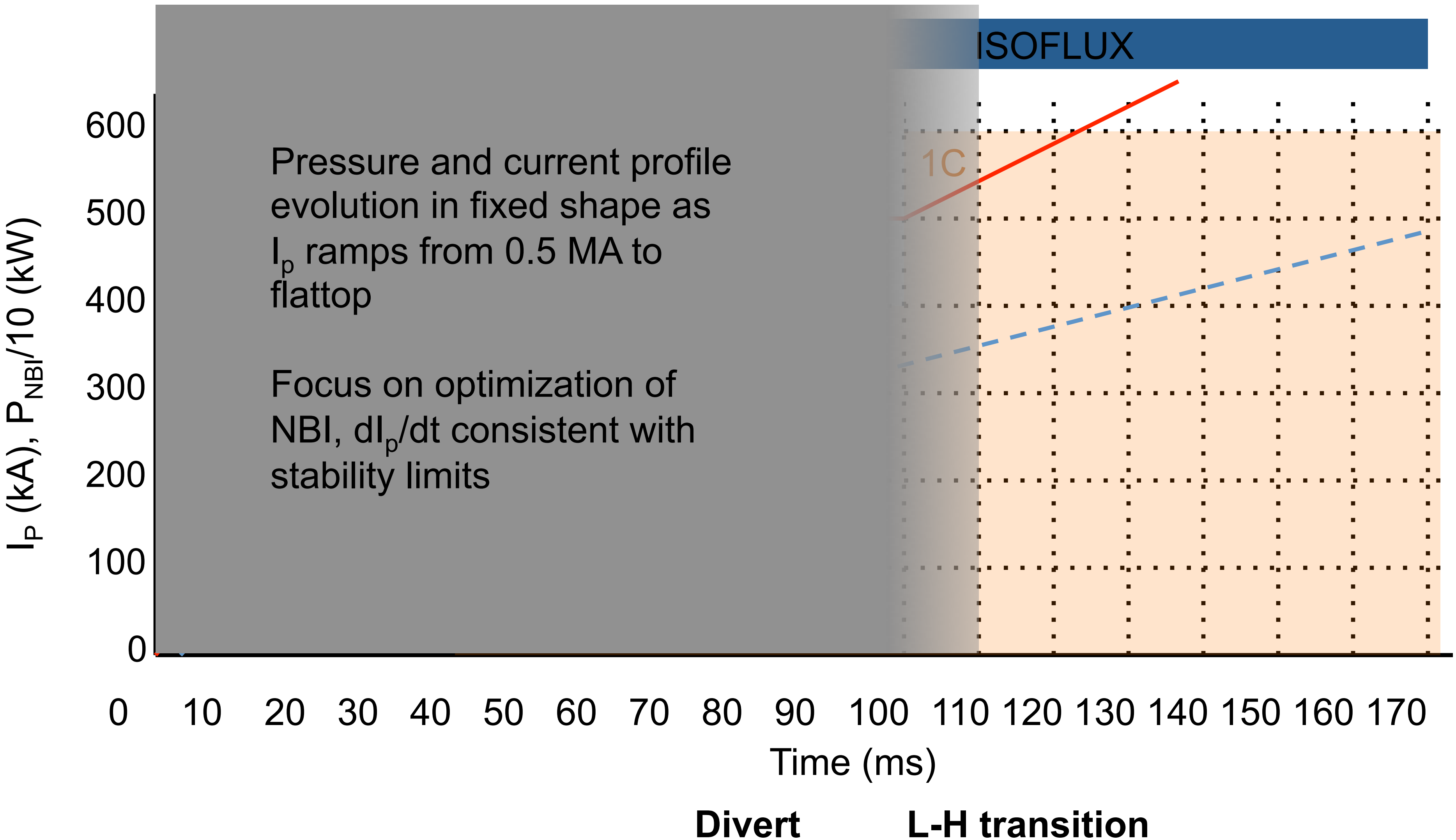
TOKSYS modeling focus



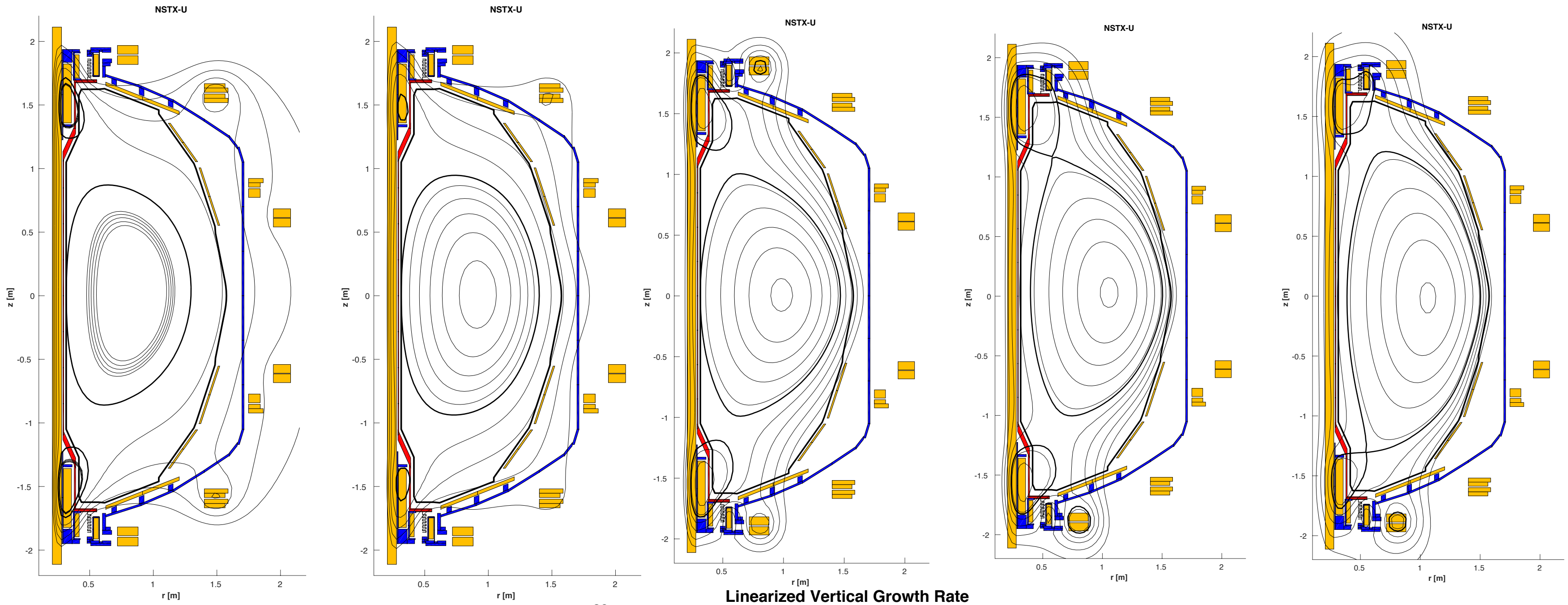
Control solutions for increasing elongation and I_p ramp rate as the shape transitions from limited to diverted

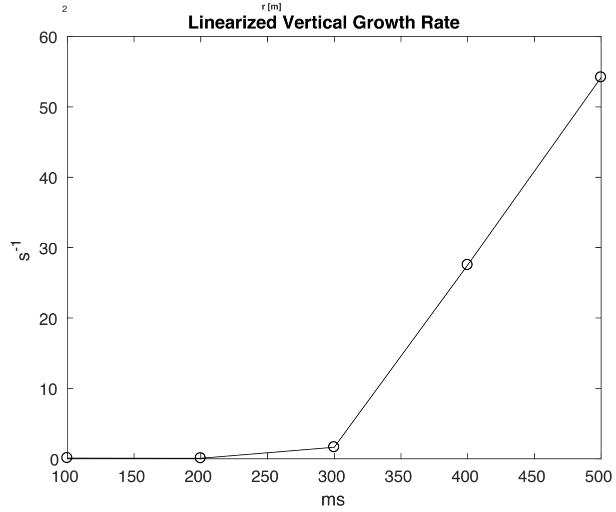
Focus on resiliency of scenario

TRANSP modeling focus



Linearized models generated for Shot 204118





TOKSYS work by Pat Vail