U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Results of using the NSTX-U plasma control system for scenario development

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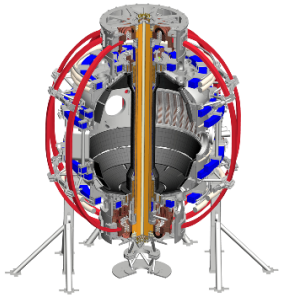
PPPL



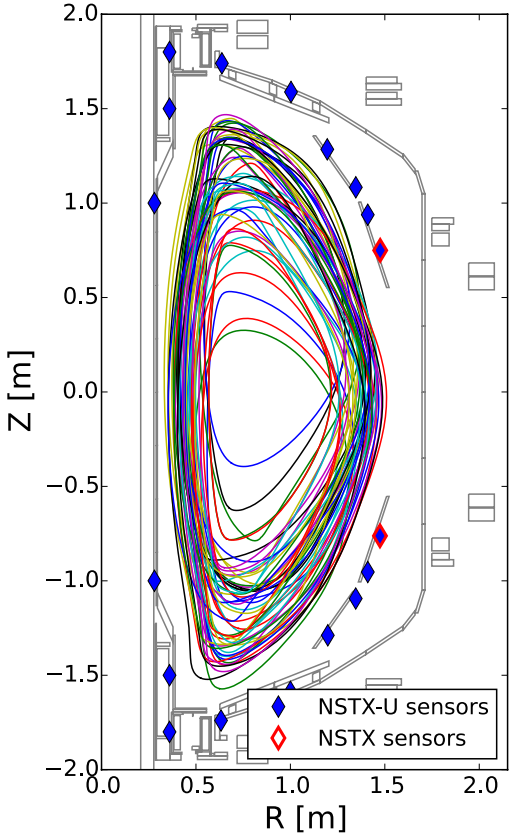
Advanced control will be required for achieving many of the research goals of NSTX-U

- High-beta operation and non-inductive scenarios
  - Maximizing elongation
  - Shaping and profile control
- Heat flux handling
  - X-point, strike point control
  - Snowflake control
- Disruption detection/mitigation
  - Real-time plasma monitoring
  - Event-handling

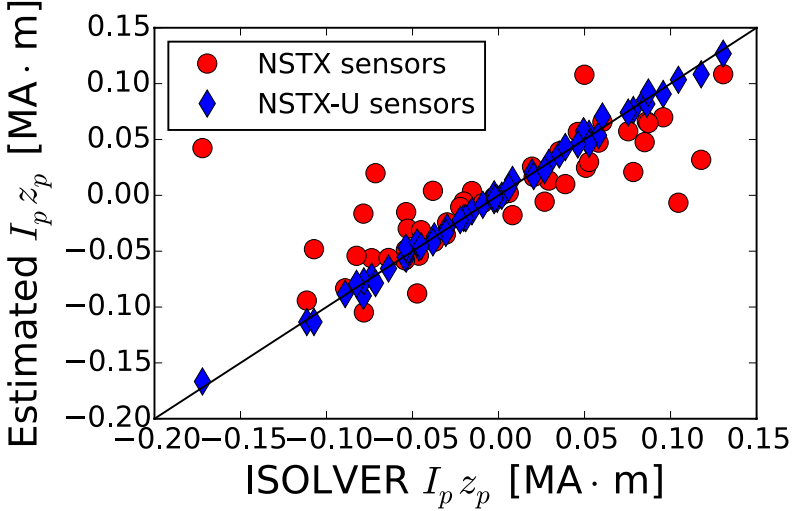
This talk will cover:

- Vertical control
- Shape control
- Plasma shutdown handler
- Near-term plans

Increased aspect ratio of NSTX-U makes vertical control more challenging



- **Added sensors and noise rejection** to improve estimation of vertical position/velocity
- Sensor weights determined by **least squares fit to IpZp** of free boundary equilibria
- Filtering removes **noise, power supply ripple,** and spurious signal due to **MHD events**



Mueller
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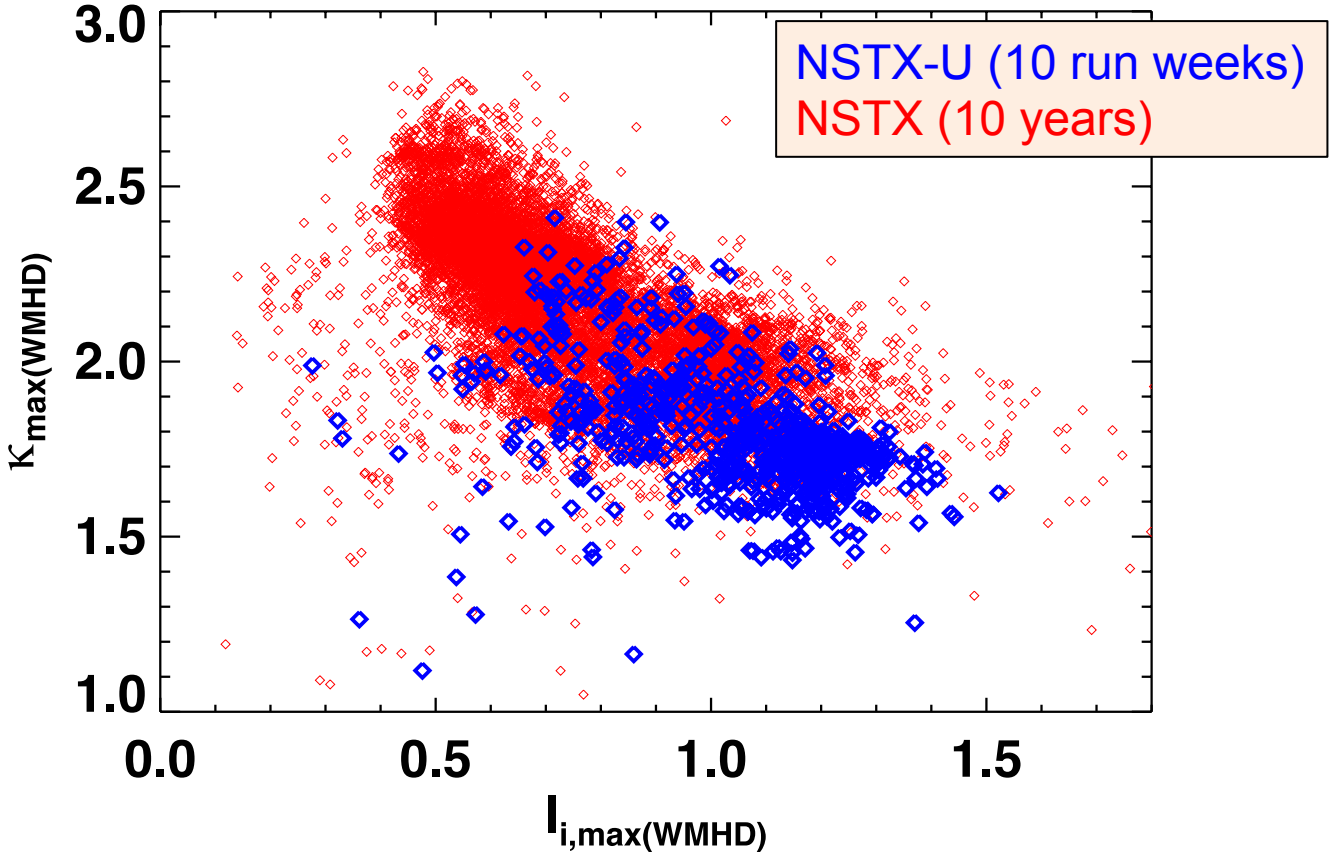
Scenarios similar to NSTX were achieved at higher aspect ratio using new vertical position/velocity estimator



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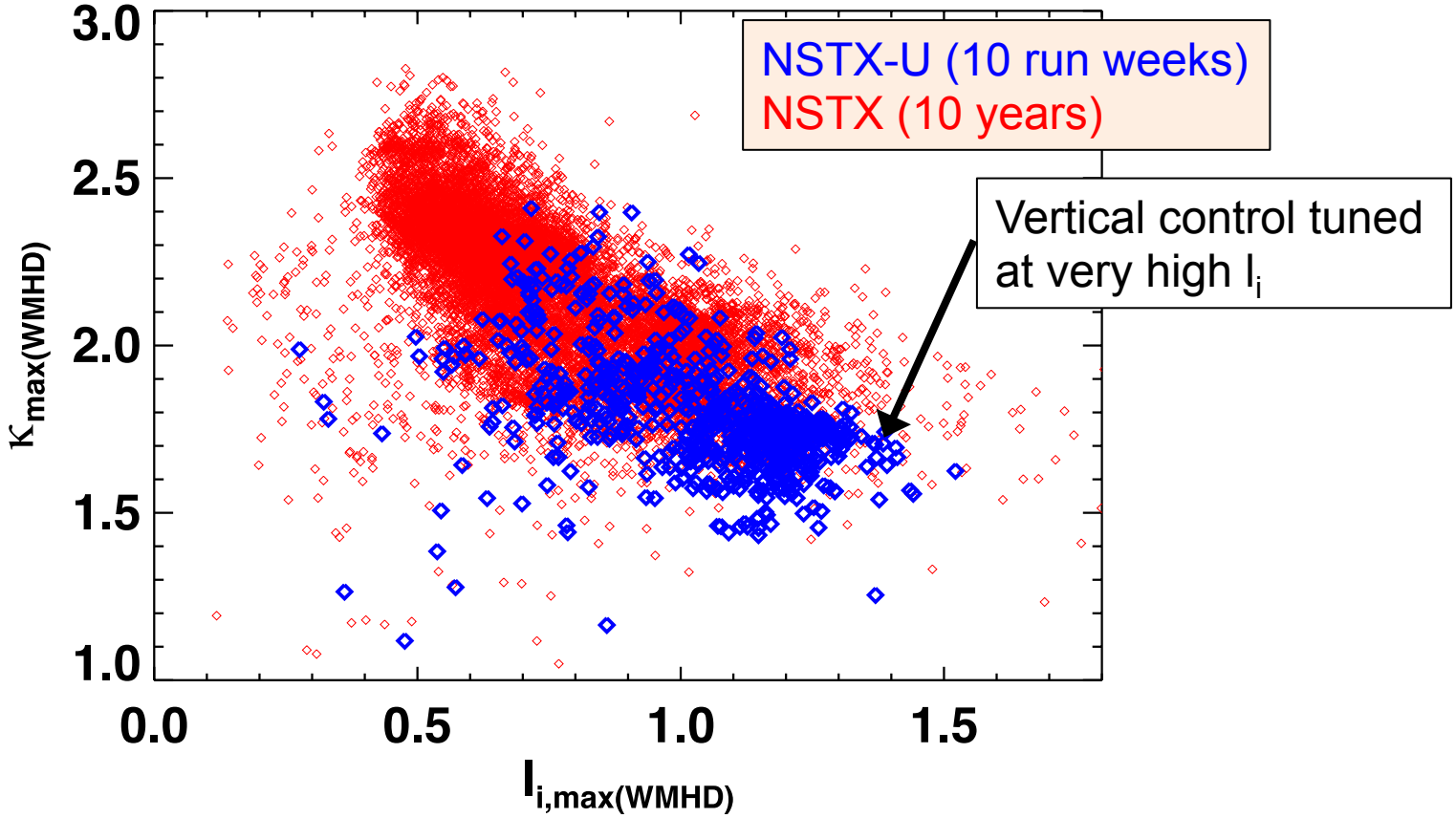

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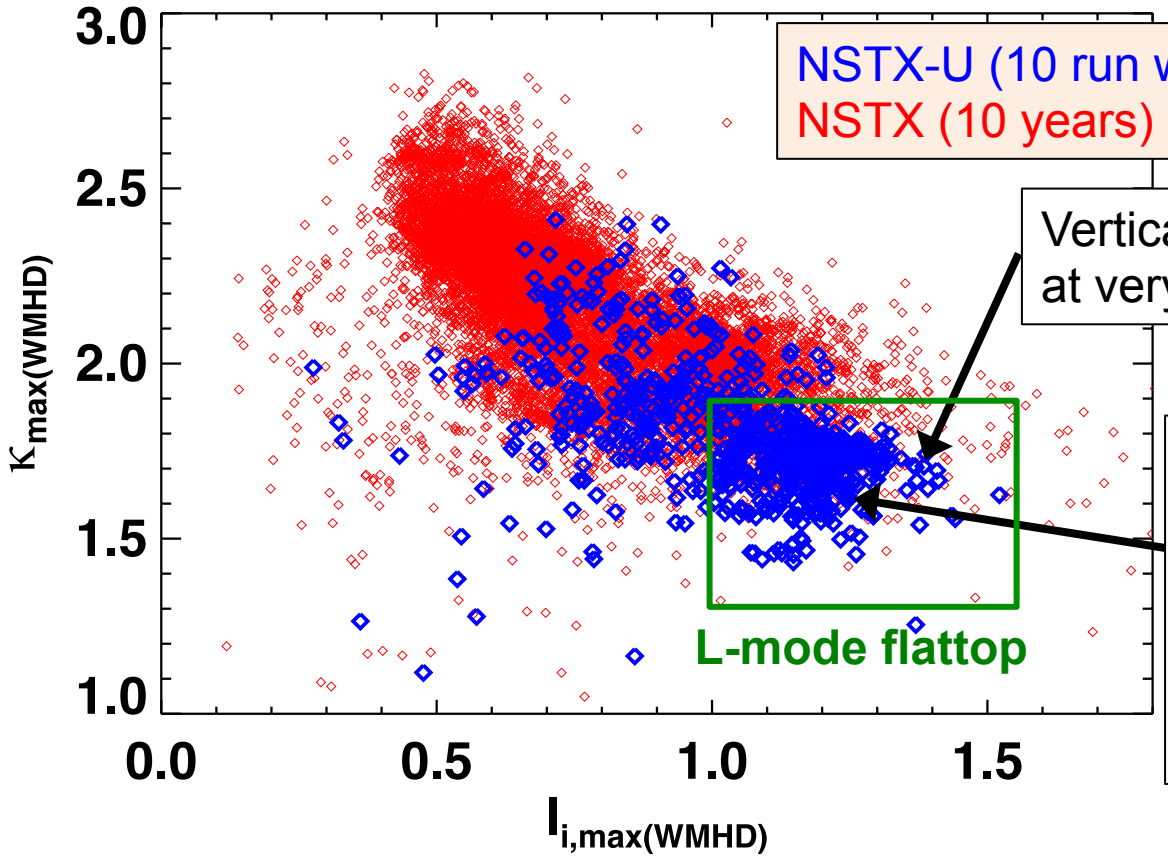

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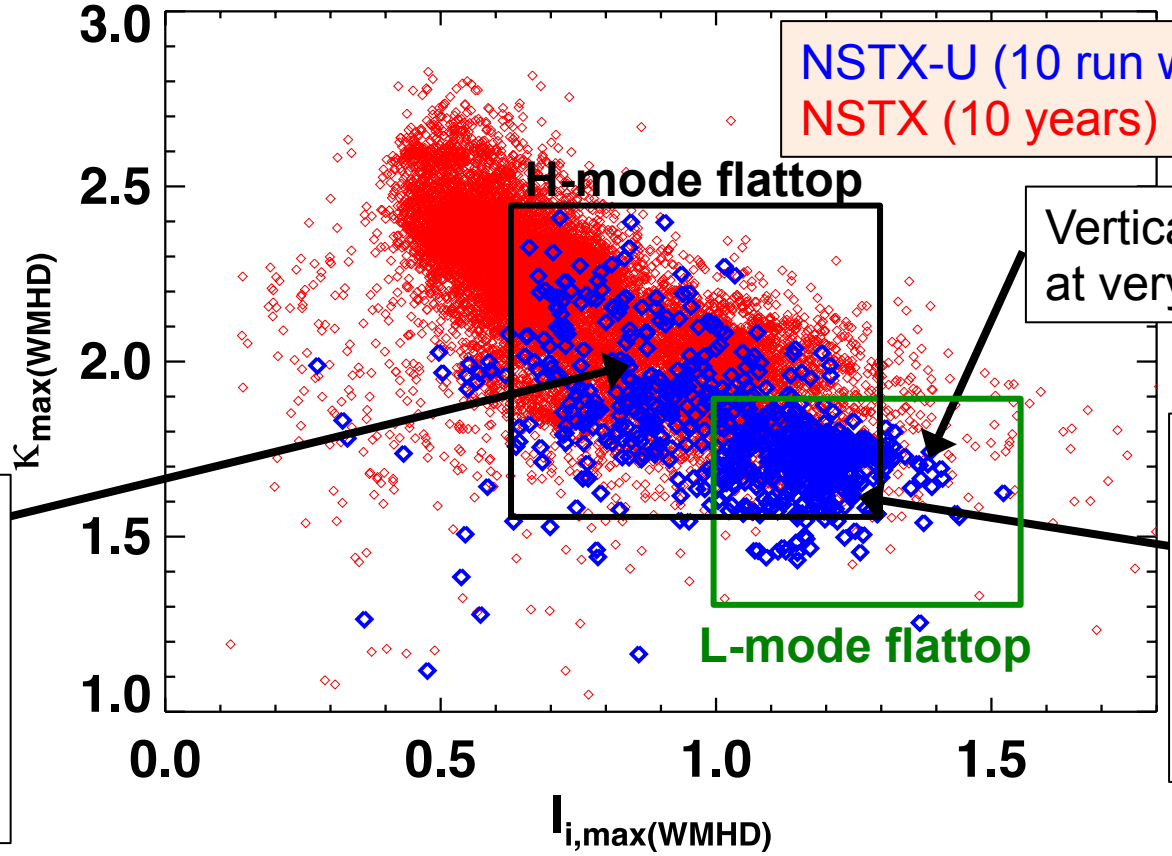


Vertical control tuned at very high l_i

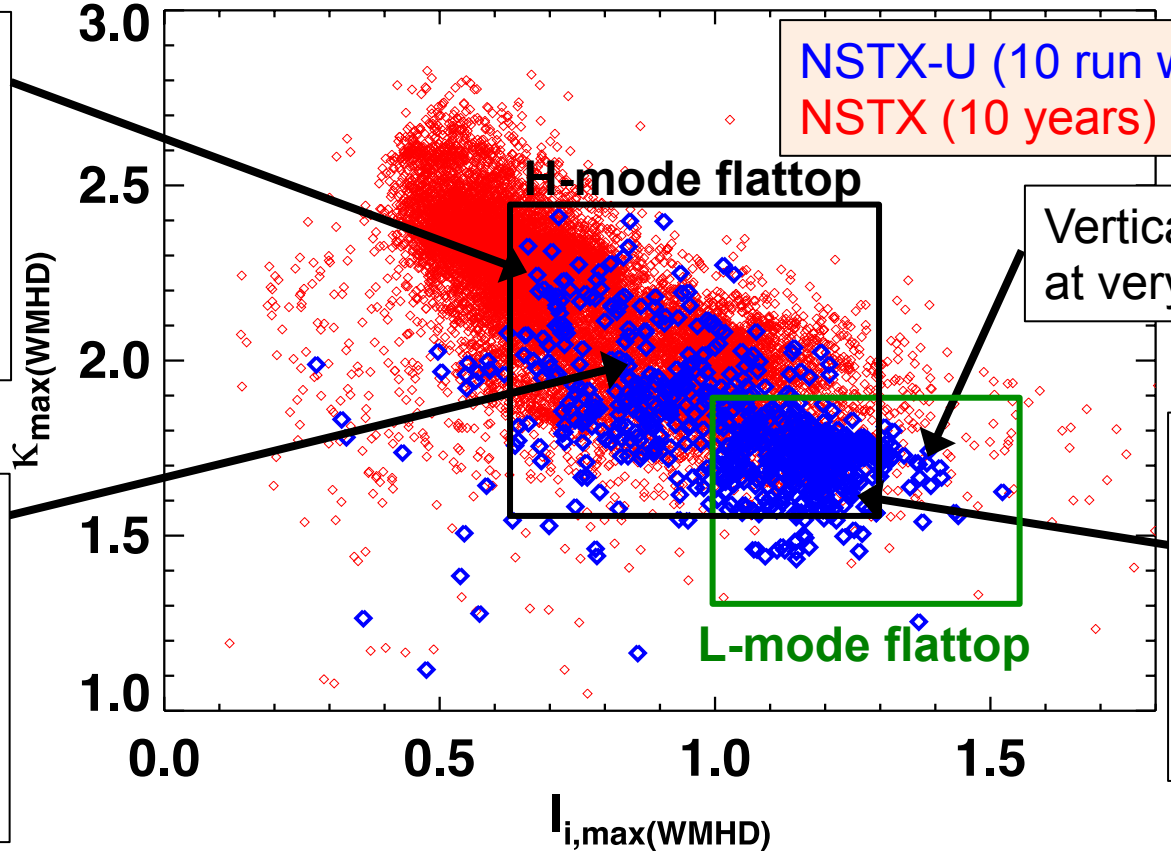
H-mode scenarios enabled access to lower l_i, higher kappa

Settled into an L-mode scenario used for many commissioning activities

Scenarios similar to NSTX were achieved at higher aspect ratio using new vertical position/velocity estimator

Vertical stability limit not reached in the H-modes ➔room to grow.

H-mode scenarios enabled access to lower l_i, higher kappa



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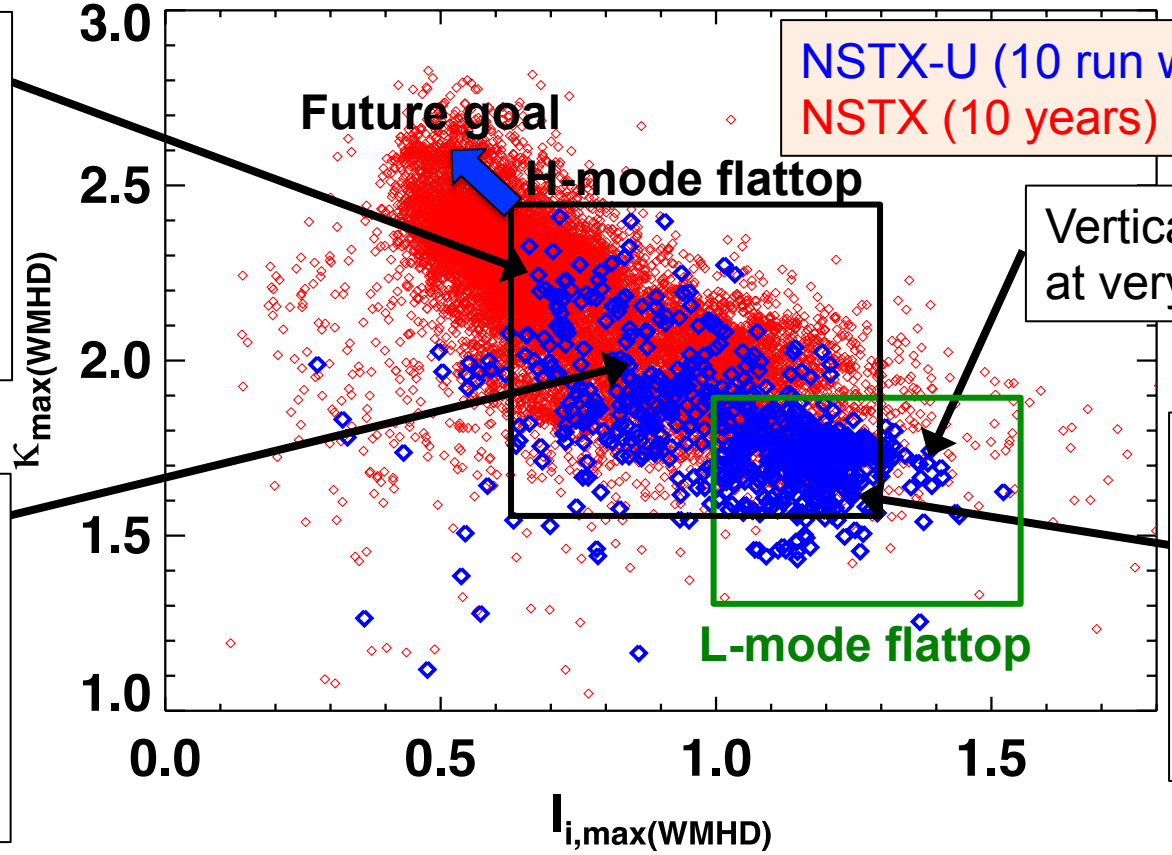
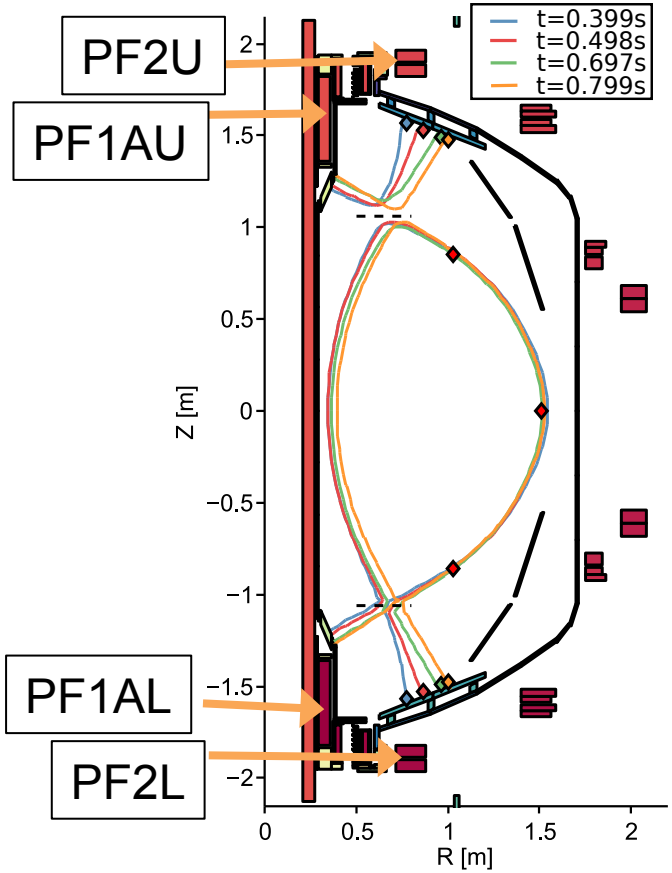


Vertical control tuned at very high l_i

Settled into an L-mode scenario used for many commissioning activities

rtEFIT/ISOFLUX updated to enable precise, reproducible control of shape, x-points, drsep, and strikepoints

- Real-time EFIT upgraded to more closely match offline magnetics-only EFIT:
  - Enable more precise x-point, snowflake control
  - 65x65 grid size
  - Vessel current fitting
  - Enabled by use of multiple cores to meet calculation time requirements
    - Only single core used previously
- X-point and strikepoint control with PF1A and PF2
  - Used **multi-input-multi-output control structure** to account for actuator coupling
    - Improves transient response



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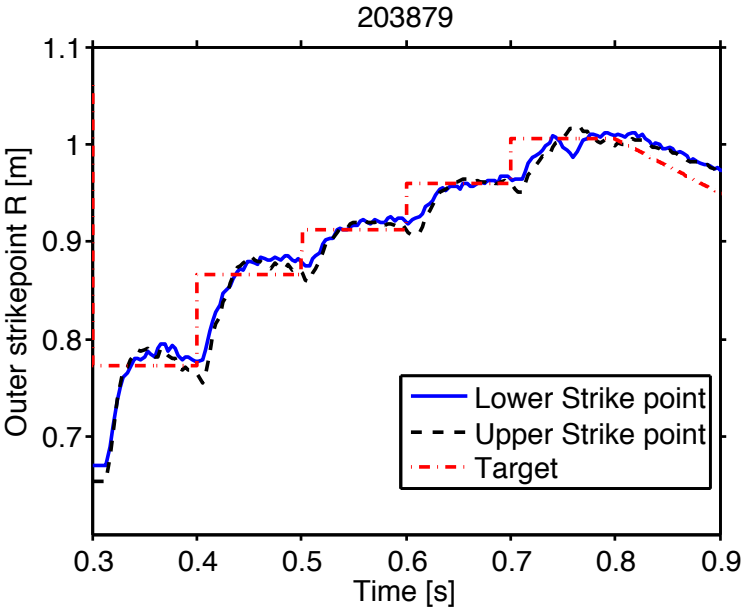
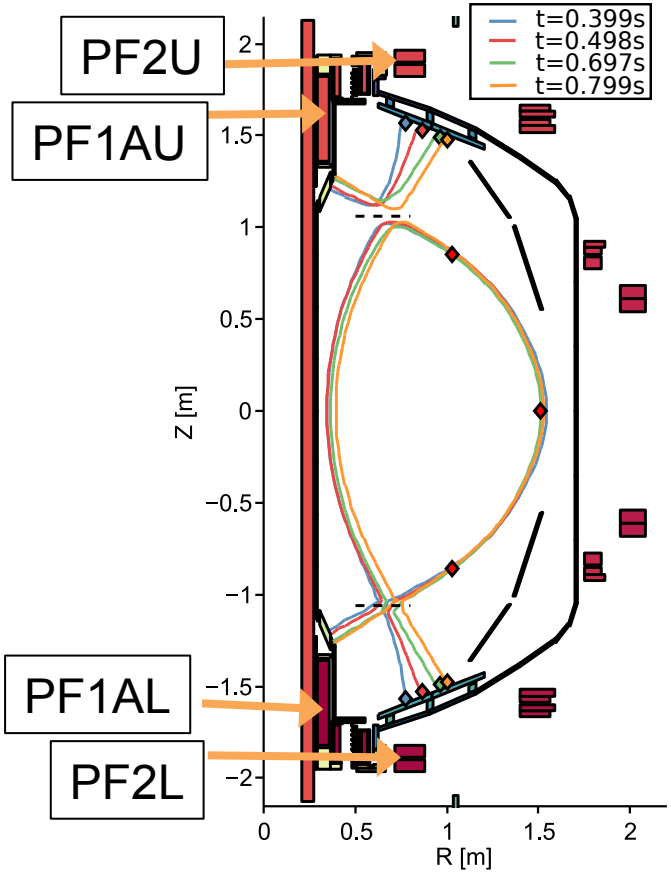
- Good tracking of step requests in strikepoint radial location
  - Fast response, little overshoot, no oscillations





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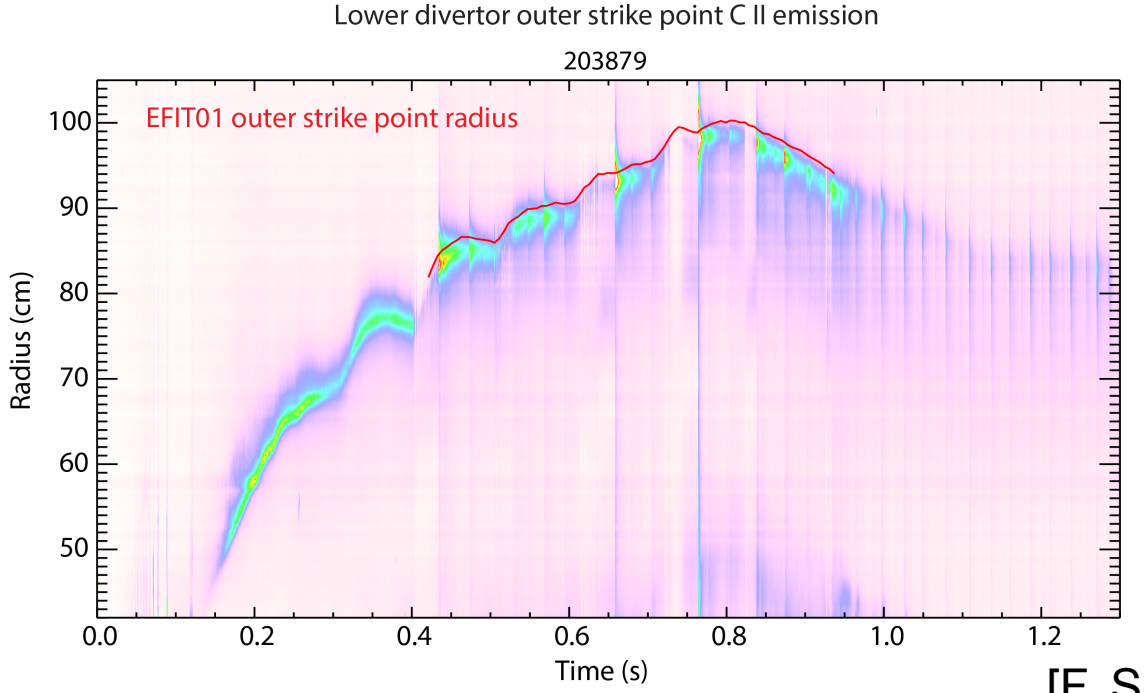
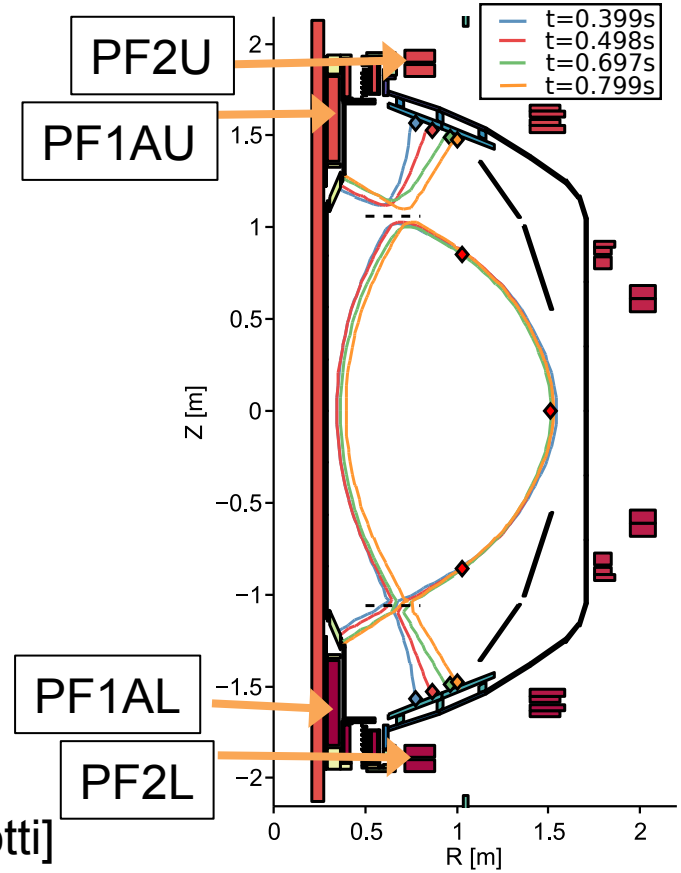
- Strikepoint tracking results confirmed by peak of CII emission

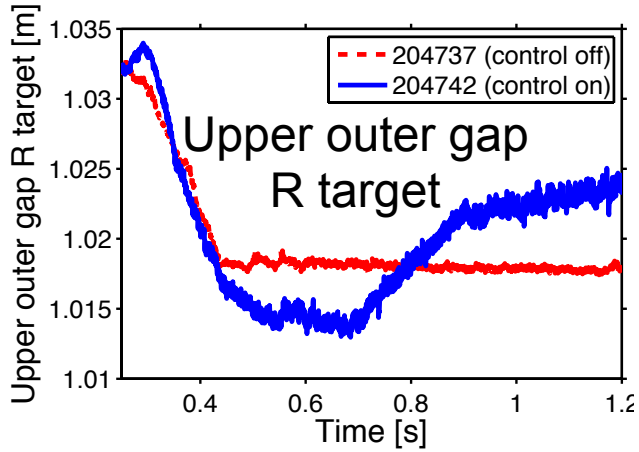


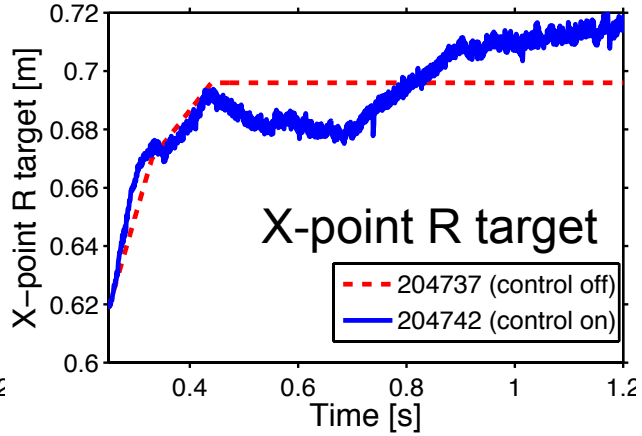


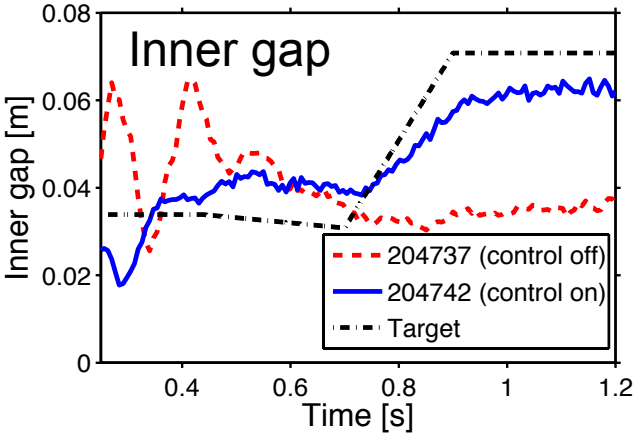
[F. Scotti]

A method for inner gap control (a challenge for ST's) has also been tested

- No way to independently control the inner gap
  - No shaping coils on inboard side, available coils already assigned…
- Approach:
  - Automatically adjust other shaping parameters based on operator provided weight matrix to achieve desired inner gap



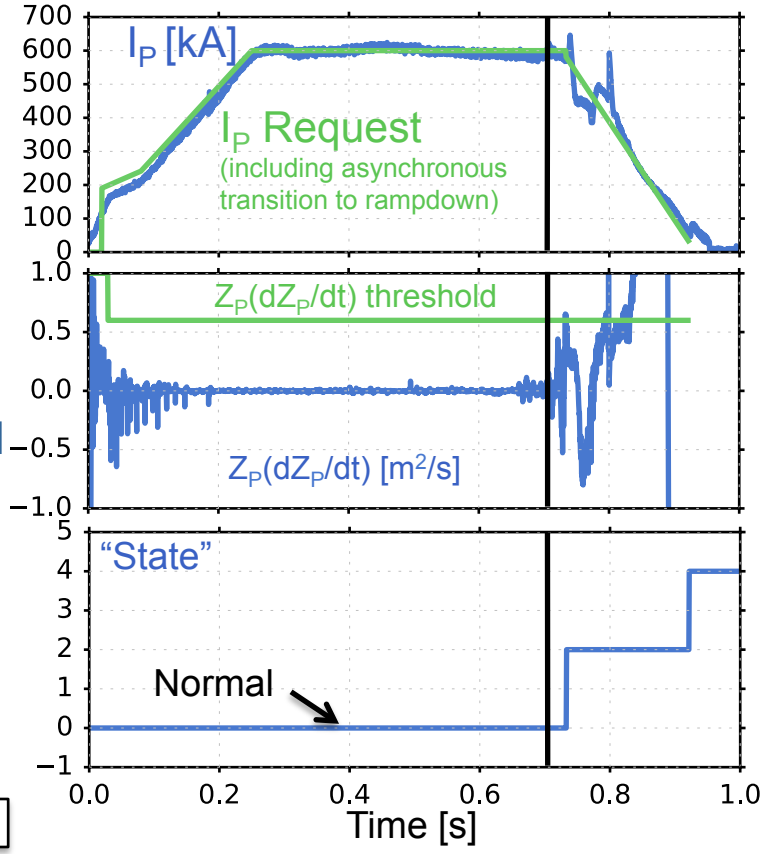


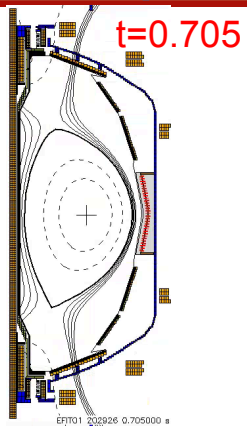


State-machine-based automated ramp-down now used routinely to limit forces and avoid disruptions

- Plasma control system detects loss of control
  - OH near max current
  - Vertical oscillations exceed threshold
  - ABS (I_p - $I_{p\ request}$) too large
  - Locked mode detected
- Feedback control switches to new "states" that attempt to gently end the discharge

Gerhardt NP10.00005





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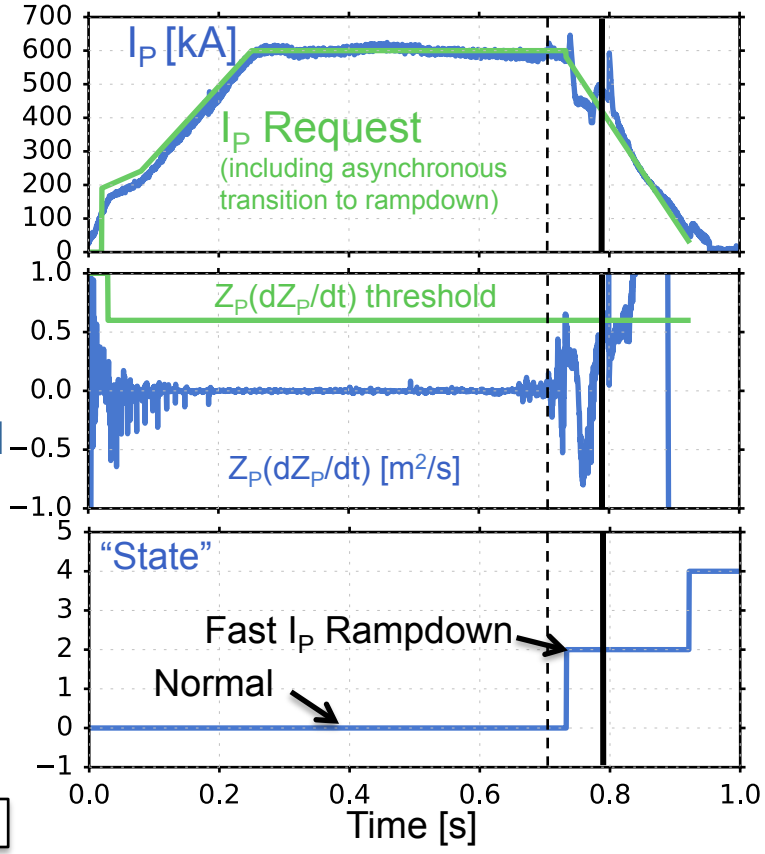

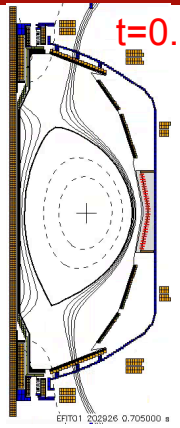

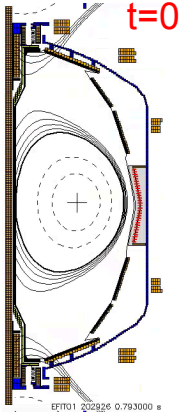

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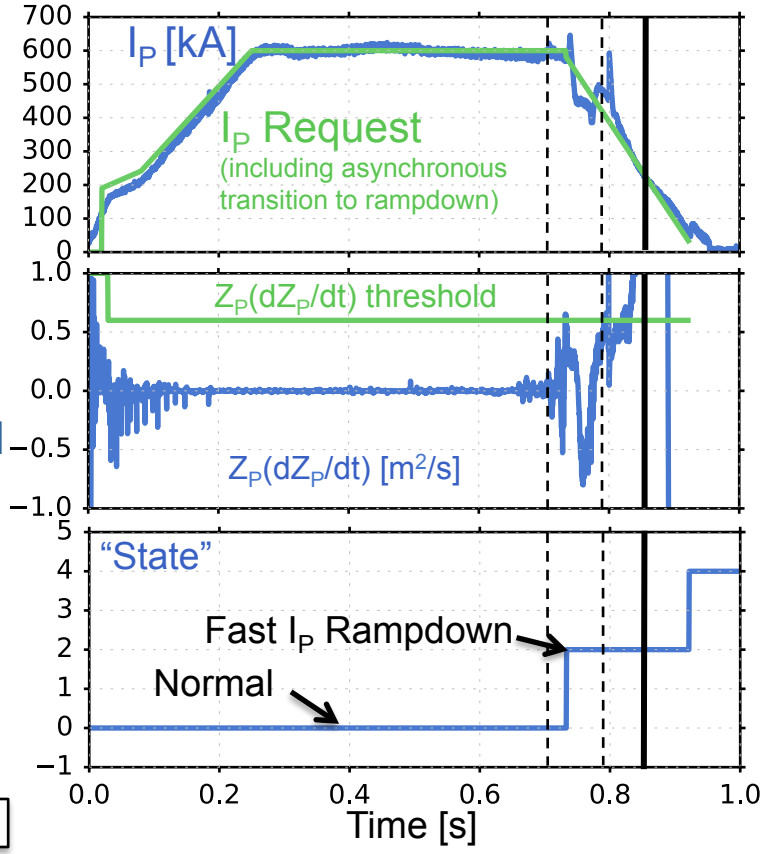

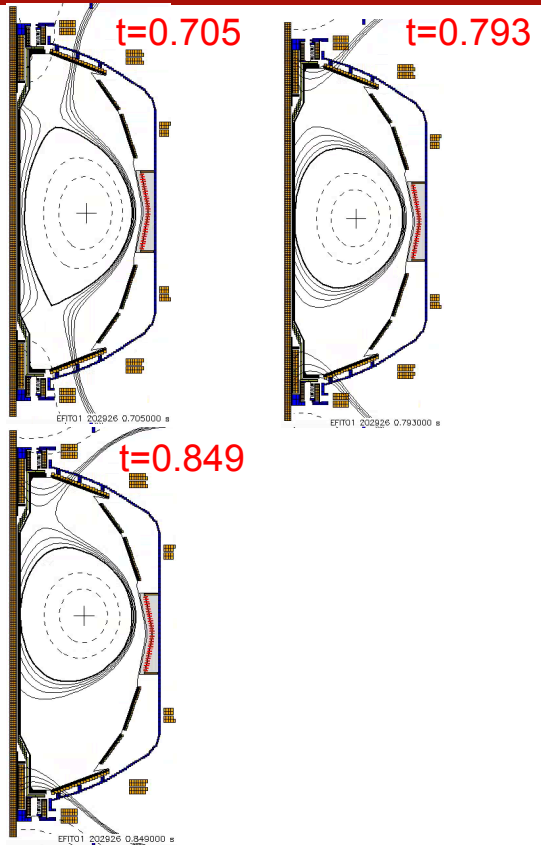

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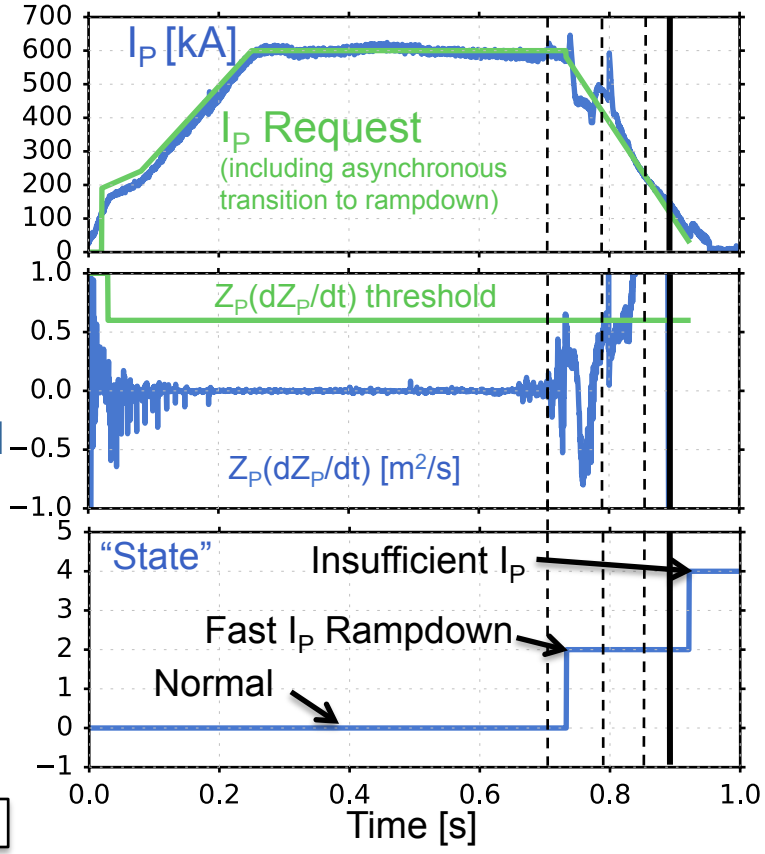

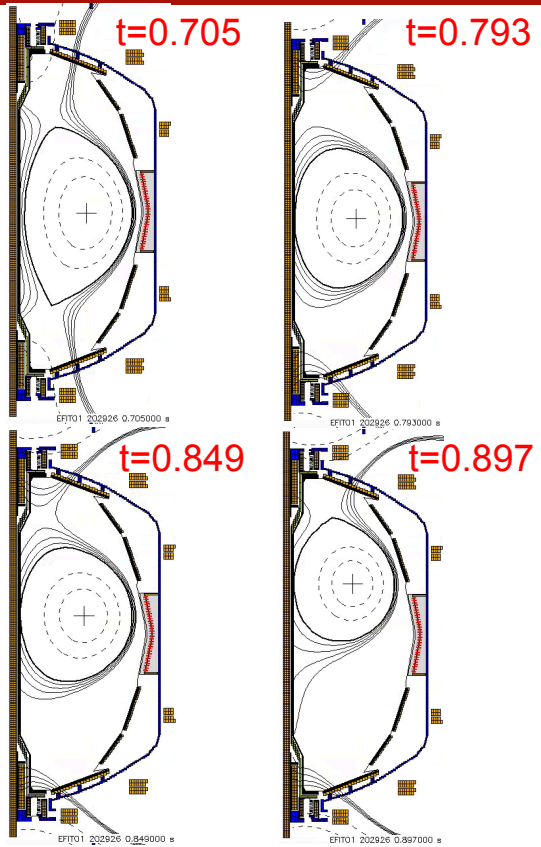

New plasma control capabilities enabled rapid development of high-performance plasmas on NSTX-U

- Early scenario development enabled by improvements in **vertical control**, and **shape control**
  - Commissioned tools to facilitate experiments (**strikepoint/inner gap control**)
- New **event handler** for reducing stress on machine and facilitating disruption detection/avoidance/mitigation studies
- **Poised to support future scientific goals** with new capabilities:
  - **Snowflake divertor control** for studying heat flux management
    - Algorithm tested in hardware-in-the-loop simulations
  - **Stored energy and l_i control, rotation and current profile control** for high-beta and non-inductive scenario development
    - Approaches tested in TRANSP simulations, PCS algorithms being implemented