FY18 ASC Kickoff meeting

- Review high level results from FY17 milestone

- Define and organize tasks for FY18 milestone

Early L-H transition enables low-l_i scenario on NSTX-U

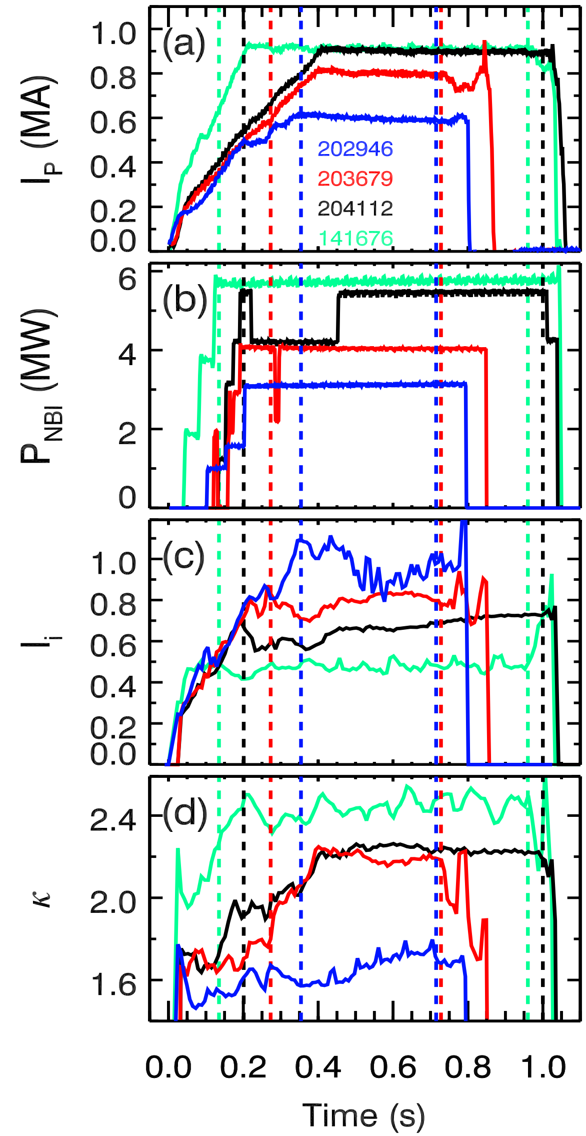
- L-H transition slows current diffusion toward axis
  - Edge pressure gradient increases edge bootstrap current
  - Higher temperature increases current diffusion time
- Stable elongation increases as l_i decreases
  - Larger κ permits larger I_p and pressure
  - Increases bootstrap current drive
  - Plot shows impact of earlier L-H timing
    - Vertical dashed lines: L-H & H-L transitions
    - I_p ramp slower on NSTX-U than NSTX

NSTX
0.44 T
H-mode

NSTX-U
0.62 T
Week 3
No EFC

Week 5
EFC v1

Week 7
EFC v2



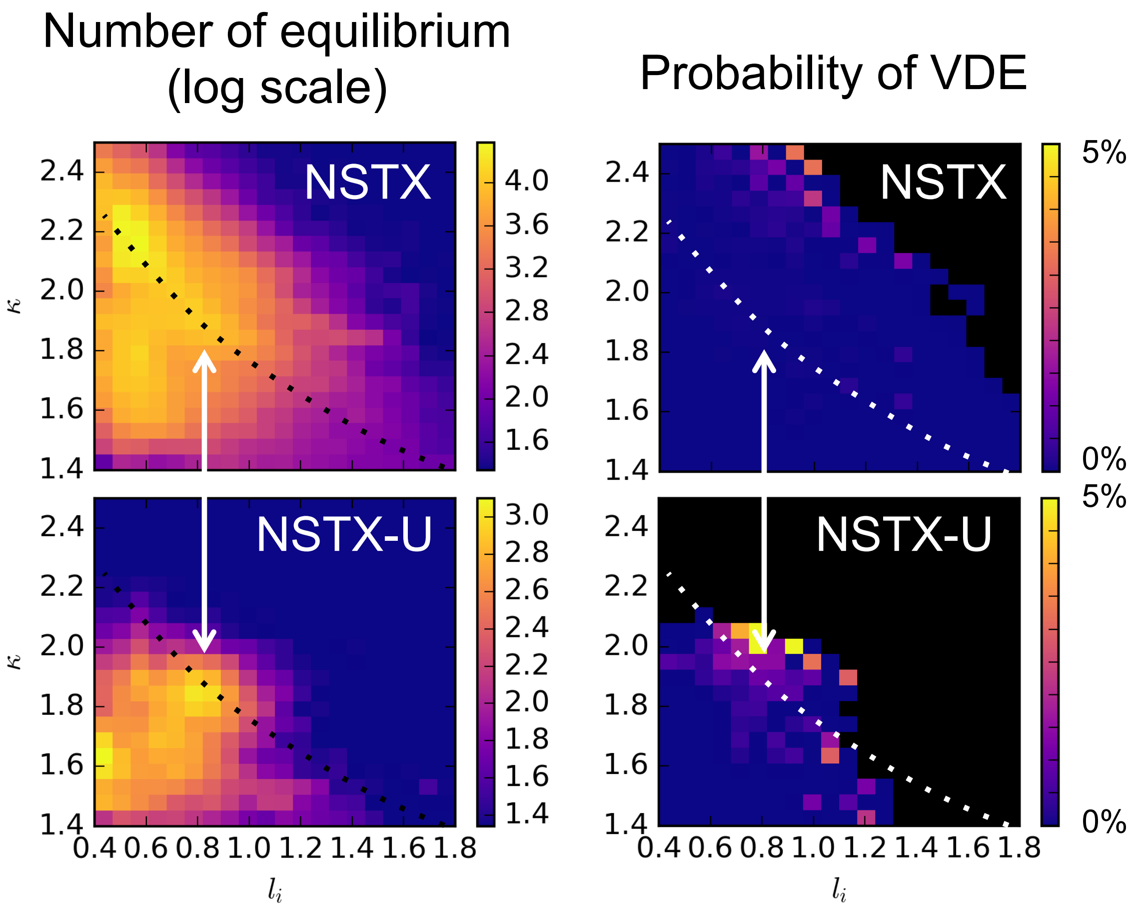
Increasing κ in NSTX-U ramp-up will require access to low-l_i

- NSTX-U achieved a similar ramp-up shape to NSTX when l_i = 0.8

- NSTX-U operated much closer to VDE limit in this condition
  - Consistent with increase in aspect ratio
  - Note: still optimizing control and EFC on NSTX-U

- Motivates lowering l_i to expand κ range

EFIT01 for t < 0.3 s



See M.D. Boyer, 11.00041 (next poster)

NSTX-U database provides guidance on target conditions for reliable L-H transition

- Why do discharges miss the L-H transition?
  - NSTX-U database of times that are diverted L-modes
    - 100 L-mode times and 68 L-H transition times = 168 entries
  - L-mode points: $P_{NBI} \geq 3$ MW for at least 50 ms
    - Beam slowing down time ~ 25 ms

- Identified four criteria for reliable L-H transition →
  - No discharges miss L-H transition if all four criteria are met
  - $P_{NBI} \geq$ 3MW can "power through" with only 3 conditions met

	Total times	L-H times	L-mode times
Satisfy all 4 criteria	39	39 (100%)	0 (0%)
Satisfy 3 criteria	57	24 (42%)	33 (58%)
Satisfy less than 3 criteria	72	5 (7%)	67 (93%)

Target conditions for a reliable L-H transition in the early ramp-up with $P_{NBI} \geq 3$ MW

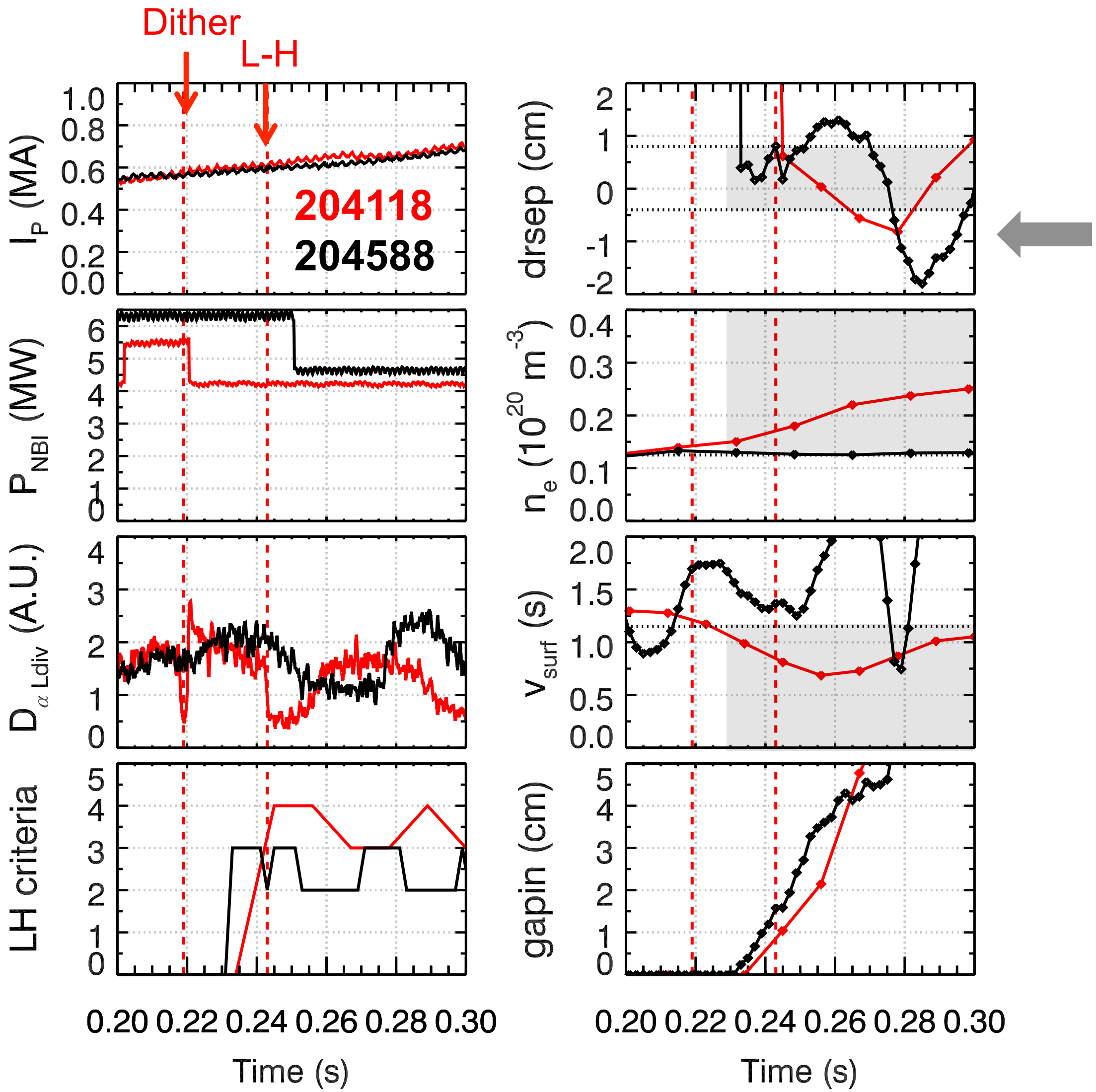
Criteria	Details
$n_e > 1.25 \times 10^{19}$ m^{-3}	Line-averaged density is above a critical value
$V_{surf} < 1.15$ V	Surface voltage (EFIT02) is below a critical value
$\lvert dr_{sep} - 0.2 \text{ cm}\rvert < 0.6$ cm	Shape is near double null (EFIT02) **
O II / $D_\gamma < 1$ (t = 0.15s)	Ratio of lower divertor filterscope channels ^^

** *Offset in dr_{sep} (toward USN) may indicate a systematic error in computing dr_{sep}*

^^ *Filterscope ratio is specific to NSTX-U. It is a general metric for the oxygen content of the plasma, which increases steadily following a boronization*

- Criteria guide targets for early ramp-up
  - Fuel early to get desired n_e target and divert near DN
  - Heat with $P_{NBI} \geq 3$ MW (heating efficiency ~ 50%)
  - Then, pause or slow I_p ramp and fueling to get $V_{surf} < 1.15$V

Vertical oscillation when diverting near DN hindered shot reproducibility



Two repeat shots
(Except **204588** has larger P_{NBI})

Slight differences in shape at time of diverting lead to different behavior of vertical oscillations

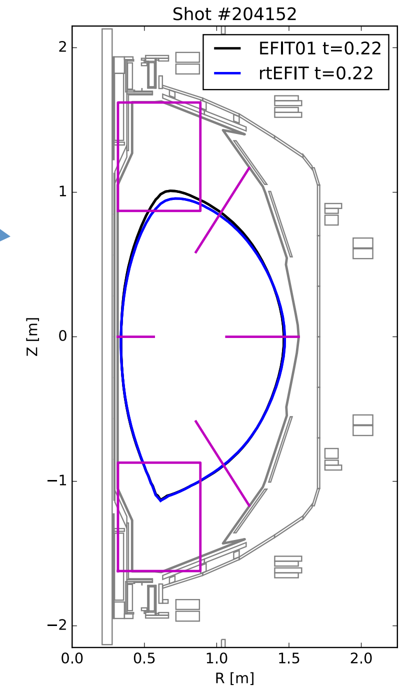
204118 has dither at 0.22s, then an L-H transition at 0.241s

204588 does not have an L-H transition despite larger heating

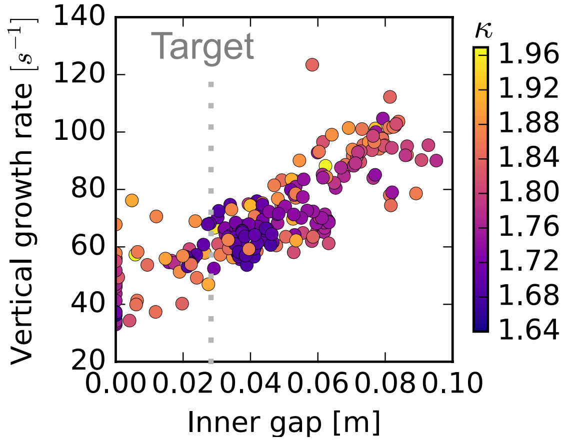
Motion away from DN shrinks plasma volume, increasing V_{surf}, hindering L-H transition from 240 – 260ms

Control and scenario solutions have been identified for mitigating the bobble

- Bobble more likely with large dZ/dt or VDE growth rates at time of diverting
  - "Kick" in dZ/dt may be driven by control algorithm transitions or errors in rtEFIT
  - Overshoot of target inner gap leads to larger VDE growth rate



- Solutions pursued in the last week of FY16 operations
  - Flux reference changes from limiter to X-point within a single algorithm
  - Inner gap feedback improves consistency of diverting time and mitigates overshoot
  - Divert SN, then allow dr_{sep} feedback to alter the shape to near DN



See M.D. Boyer, 11.00041 (next poster)

17-5 Analysis and modeling of current ramp-up dynamics in NSTX and NSTX-U

- High performance H-mode scenarios on NSTX-U are enabled by achieving broad current and pressure profiles and large elongation ($\kappa > 2$) via an L-H transition early in the ramp up phase.
- A database of NSTX and NSTX-U discharges demonstrates that the maximum elongation versus l_i operation space for the two devices is similar for $l_i \geq 0.8$
- A corresponding database of VDEs shows the limit to the elongation by VDEs was more restrictive on NSTX-U than NSTX. NSTX-U achieved a similar elongation to NSTX by operating closer to the VDE stability boundary.
- Calculation of the open-loop VDE growth rate found that NSTX-U achieved stable operation at larger VDE open-loop growth rates compared to NSTX due to improvements to the active vertical position controller.
  - Consistent with achieving stable operation closer to the vertical stability limit.

17-5 Analysis and modeling of current ramp-up dynamics in NSTX and NSTX-U

- The elongation at the time of diverting was restricted ($\kappa < 2$) in NSTX-U operations by the occurrence of vertical oscillations ("the bobble") as the discharge transitioned to a diverted shape.

- Potential sources of the initial vertical motion are a mismatch at the time of transitioning between control algorithms, and a poor convergence of rtEFIT.

- An overshoot in the inner gap size exacerbates the vertical position oscillations by increasing the vertical growth rate.

- Operational and scenario development improvements were identified that would reduce the probability of the deleterious oscillations.
  - Such as: removal of an algorithm transition within ISOFLUX at the time of diverting, improved rtEFIT reconstructions using multi-threading of the real-time calculation, an inner gap control algorithm that reduces overshoot and diverting with finite δ_{rsep}.

17-5 Analysis and modeling of current ramp-up dynamics in NSTX and NSTX-U

- A database of L-H transitions was created with a corresponding database of L-mode and dithering discharges with P_{NBI} > 3 MW.

- A set of four criteria for the database was developed that excluded all of the L-mode times from the database. The criterion informs the target conditions for triggering the L-H transition during ramp-up.

- Discharges that disrupted with l_i < 0.55 were found to be due to H-L back transitions. These discharges were found to operate below the no-wall stability limit.

FY18 ASC Kickoff meeting

- Review high level results from FY17 milestone

- Define and organize tasks for FY18 milestone

Elements of FY18-2 Milestone

- Develop TOKSYS model for ramp-up
  - Power supply model, wall model, free-boundary equilibrium
  - Test shape and vertical control algorithms in ramp-up

- TRANSP calculations of heating and current drive
  - Compare predictive calculations to existing data to identify acceptable assumptions and boundary conditions
  - Investigate impact of outer gap, density and NBI sources

- Inductive startup calculations using LRDFIT
  - Optimize breakdown and early ramp-up for a range of conditions, including target shapes and dI_p/dt

Possible tasks with TOKSYS model

- Reproduce “the bobble” at time of diverting
  - Develop control that mitigates bobble
  - Extend to lower l_i, higher κ
- Reproduce VDE with wall and power supply model
  - Develop control that improves κ limits (l_i = 0.4 – 0.8)
- Reproduce transition from limited (20ms) to diverted
  - Optimize control transition strategy, X-point and dr_{sep} control
  - Develop scenarios and control that achieve an early time of diverting and an I_p pause for the L-H transition
    - What is the impact of larger V_{loop} and dI_p/dt?
    - What is a good target shape and I_p for the end of the startup phase?
    - How sensitive is the evolution to variations in the free parameters?

Near-term tasks for TOKSYS development

- Vessel model in good shape.
  - Looking at a way to automate choice of wall resistance
  - Similar format to LRDFIT
- Power supply model – simple (voltage drop, time delay and slew rate)
  - Dan is working on a more detailed model (PF supplies)
- Validation would need to be done.
- First simulations would have fixed evolution of li and betaN
- Git repository exists for eager users

Possible tasks with TRANSP

- Reproduce NSTX-U (or NSTX) beam heated ramp-up
  - Identify reasonable transport models and boundary conditions
- Examine impact of neutral beam sources, density and outer gap on evolution of l_i and q-profile in H-mode ramp-up
  - Consider MHD and fast-ion stability
  - What beams are best? Are there limits to rate that I_p, β_N, etc increase?
- Examine impact of NBI during L-mode phase

Near-term tasks for TRANSP development

- Doohyun will take the lead
- Devon will provide cases of interest for ramp-up
- Francesca likes the different ramps with different heating

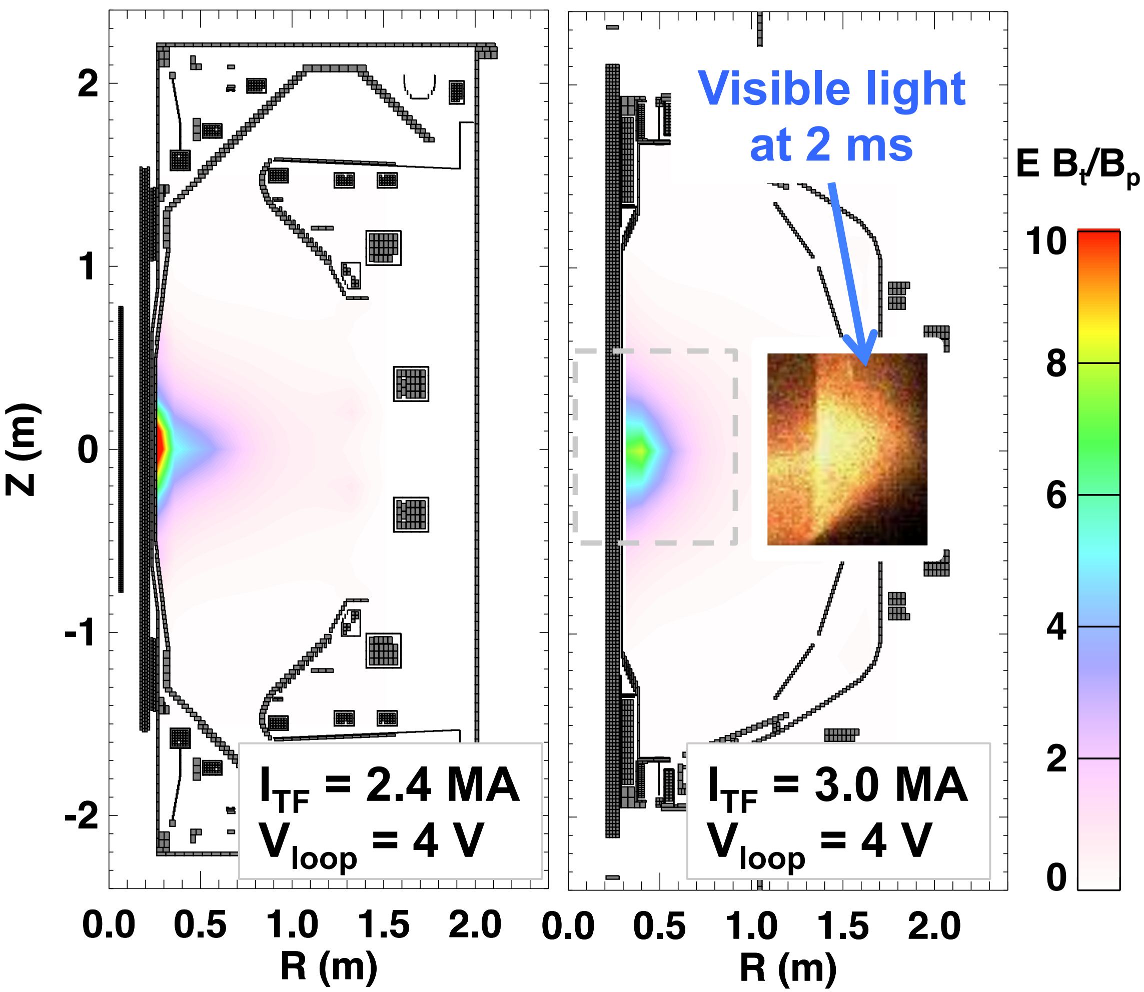
Possible tasks with LRDFIT

- Investigate impact of using additional PF coils on NSTX-U
  - What is the impact on the null quality and field index?
- Examine the limits to dI_p/dt in the startup phase
  - Requires larger voltage on power supplies
  - Larger dI_p/dt tends to reduce null quality
  - Larger V_{loop} increases wall currents, reduces null quality
- May get some experimental results from MAST-U collaboration
- Extend predictive LRDFIT to include plasma current
  - Either as filaments or a free-boundary solution (ISOLVER)

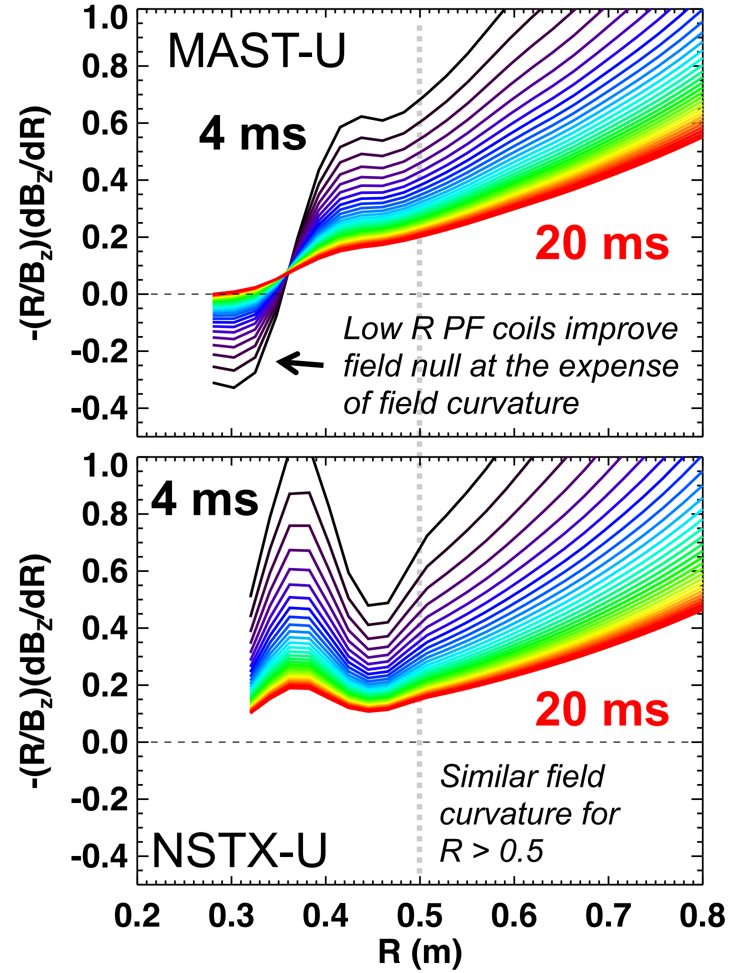
MAST-U breakdown and ramp-up metrics similar to demonstrated NSTX-U scenario

$E_\phi B_\phi / B_\theta$ averaged over first 2 ms

MAST-U **NSTX-U**

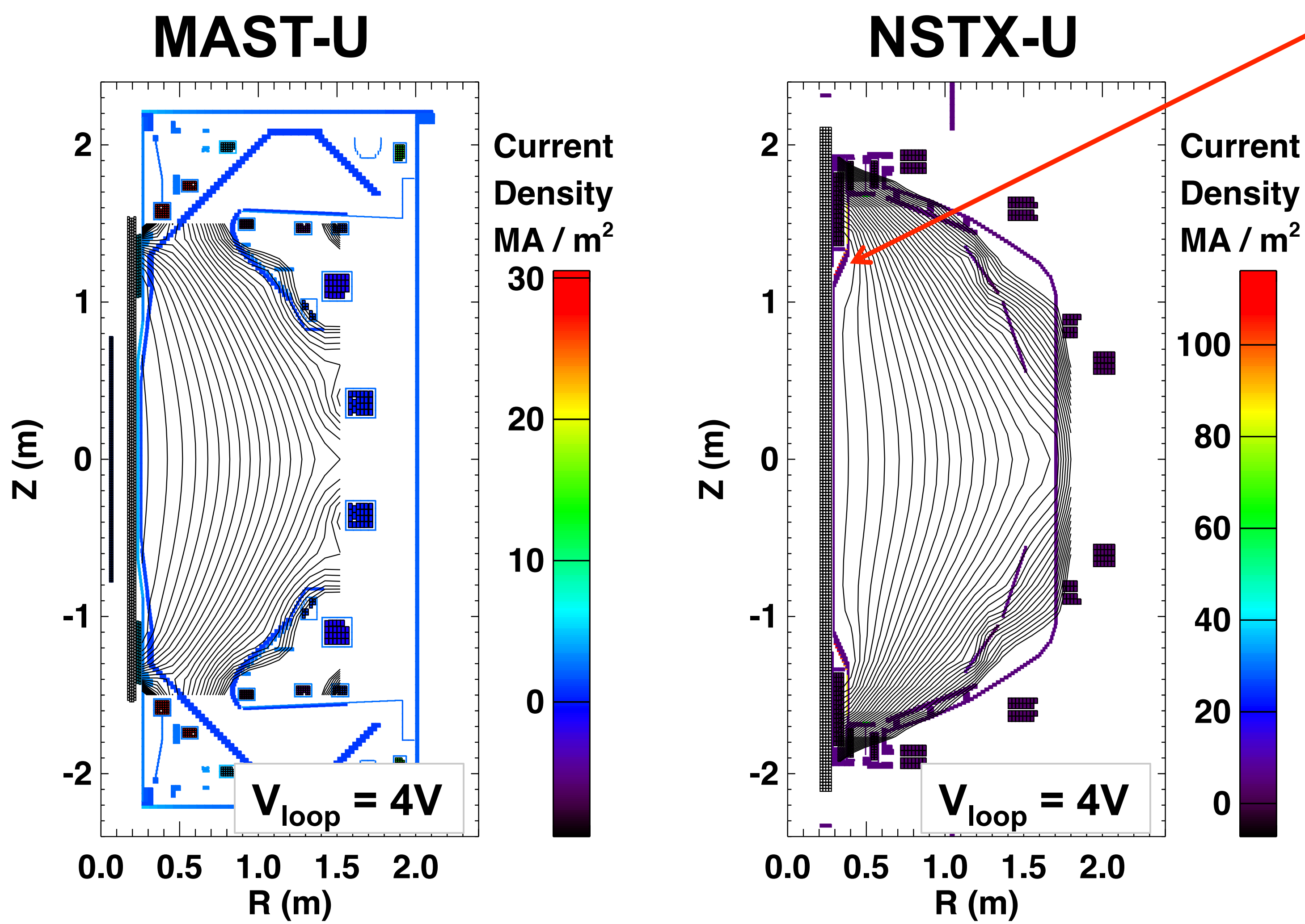


Field decay index evolution in ramp-up



Plasma elongation in ramp-up was limited by large induced wall currents on NSTX-U

Current density (colors) and flux contours at 20 ms



Large induced current in CS crown on NSTX-U limited the early elongation

MAST-U calculations predict modest induced currents

Near-term tasks for LRDFIT development

- New NSTX-U calculations could be done
  - What wall model should we use? Should we start to develop a wall model for NSTX-U-U ?

- Including Ip in predictive LRDFIT needs development
  - Can filament current be added either with a fixed distribution or with some criteria to put it in regions of low Bp?
  - Can ISOLVER be coupled to LRDFIT to evolve boundary and current distribution of a zero-β equilibrium?

Next meeting

- Aim for mid – November (one status meeting per month)