NSTX-U

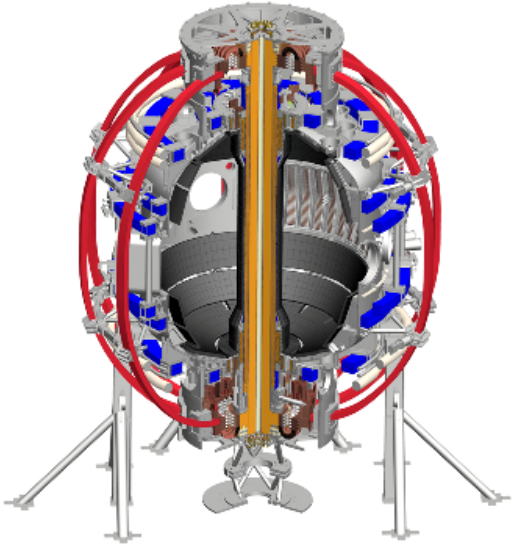
NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

Overview of Objective 2
NSTX-U 5 year plan (2021-25)

Develop operation at large bootstrap fraction and advance the physics basis required for non-inductive and low-disruptivity operation of a steady-state compact fusion device

Devon Battaglia

on behalf of the NSTX-U team



Review of Five Year Plan
February 8, 2021

PPPL

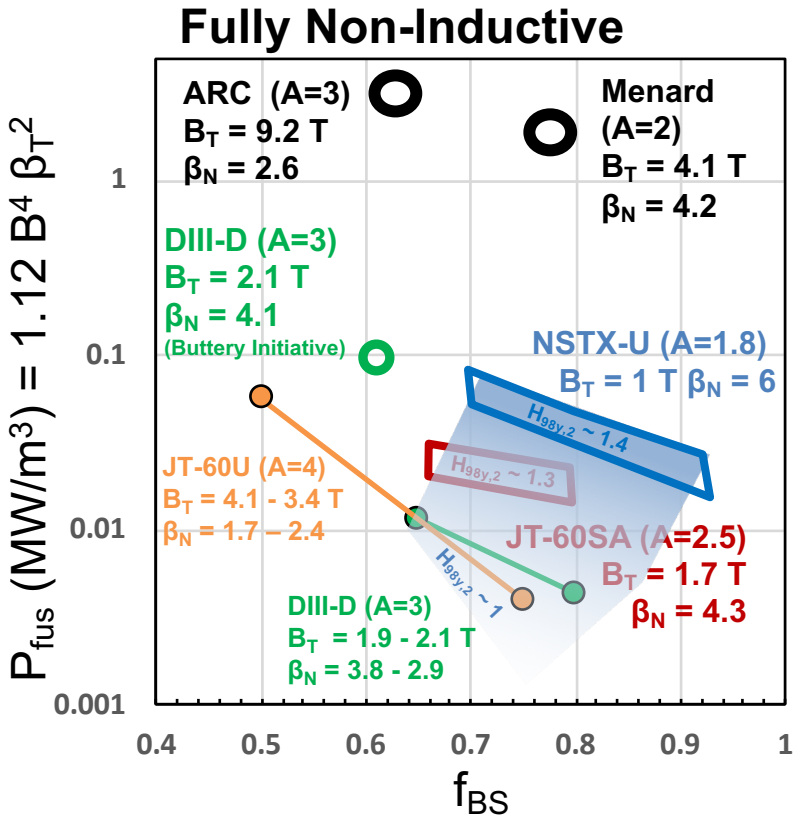
Primary deliverable and impact of Objective 2

Five-year deliverable:

Access fully non-inductive (f_{NI} = 1) and partially inductive scenarios (f_{NI} > 0.6) with good energy confinement, low disruptivity and suitable heat flux mitigation

Impact:

Provide critical data at low-A and high-β needed to optimize the configuration of next-step devices



Objective 2 is organized into three Thrusts

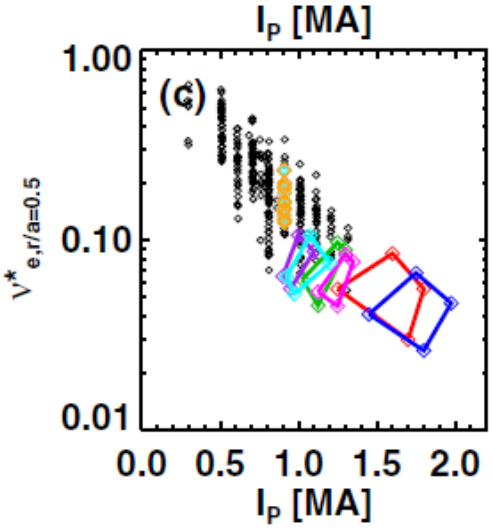
- **Thrust 1**: Achieve particle control and heat flux mitigation necessary for stationary discharges

- **Thrust 2**: Demonstrate high-β, low-l_i discharges at low disruptivity

- **Thrust 3**: Establish and optimize high non-inductive fraction operation

Thrust 1: Achieve particle control and heat flux mitigation necessary for long-pulse discharges

- Major deliverables:
  - Demonstrate full performance discharges (I_p = 2 MA, B_T = 1 T, P_{NBI} = 10MW for 5 s) with suitable particle control and heat flux mitigation
  - Develop high-f_{BS} scenarios that operate with stationary density profiles and without large ELMs
- Impact:
  - Lowest pulse-averaged collisionality and largest divertor energy flux projected to occur at full performance
  - Core/edge integration solutions compatible with high-f_{BS} scenarios are critical for next-step devices



All: f_{GW}=0.7, 1.1<q_{min}<1.2
6x80 kV, B_T=1 T, 15 cm outer gap
6x100 kV, B_T=1 T, 15 cm outer gap
4x80 kV, B_T=0.75 T, 15 cm outer gap
4x90 kV, B_T=0.75 T, 15 cm outer gap
4x90 kV, B_T=0.55 T, 20 cm outer gap
4x100 kV, B_T=0.55, 20 cm outer gap

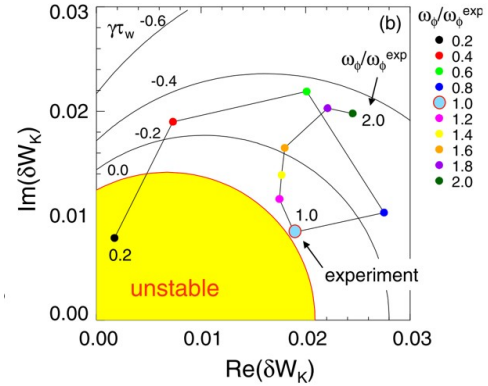
S. P. Gerhardt, et al, Nucl. Fusion **52**, 083020 (2012)

Thrust 2: Demonstrate long-pulse, high-β, low-l_i discharges at low disruptivity

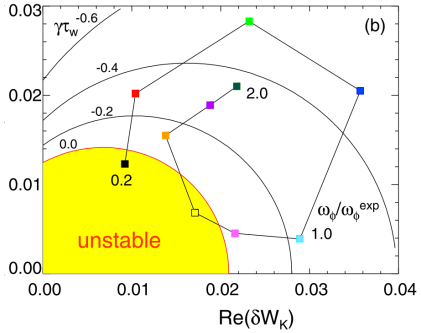
- Deliverables:
  - Test prediction that kinetic stabilization of RWM at high-β improves at lower-collisionality
  - Evaluate disruptivity and controllability at high-f_{BS} and high-β
  - Demonstrate real-time disruption prediction and avoidance techniques suitable for advanced tokamak regimes operating at high- β and large f_{BS}

- Impact:
  - Expands physics basis needed for stable long-pulse, high-f_{BS} discharges that enable next-step devices
  - Advance capabilities for disruption prediction and avoidance that are applicable for next-step tokamaks such as ITER

NSTX kinetic stabilization of RWM



Projection for passive stability at lower ν



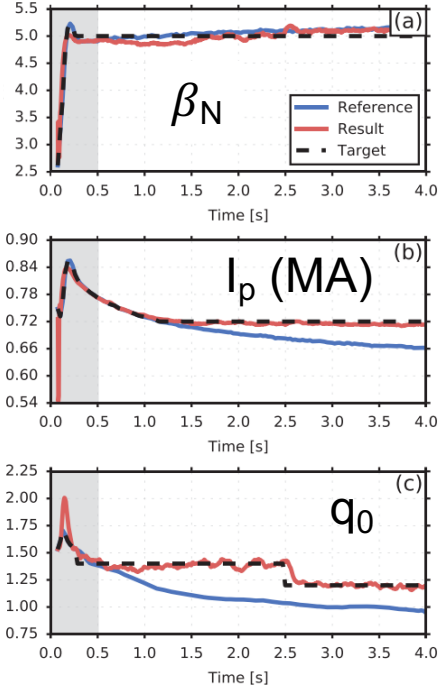
S. A. Sabbagh, et al., Nucl. Fusion **50**, 025020 (2010)

Thrust 3: Establish and optimize high non-inductive fraction operation

- Deliverables:
  - Develop fully non-inductive (f_{NI} = 1) scenarios that are sustained for multiple current redistribution times
  - Demonstrate faster-than-real-time forecasting using reduced physics models and machine learning to improve real-time scenario optimization and resiliency to off-normal events with shared actuators
  - Optimize the I_p ramp-up scenario to support low V-s consumption using HHFW and NBI heating and current drive

- Impact:
  - Direct connection to NI operation at conventional-A enables optimization of aspect ratio in next-step steady-state devices
  - Improved real-time control for advanced tokamak concepts
  - Establish methodology for integrating non-inductive operation techniques from discharge current ramp-up through sustainment phases

Simulation of real-time control in non-inductive regime

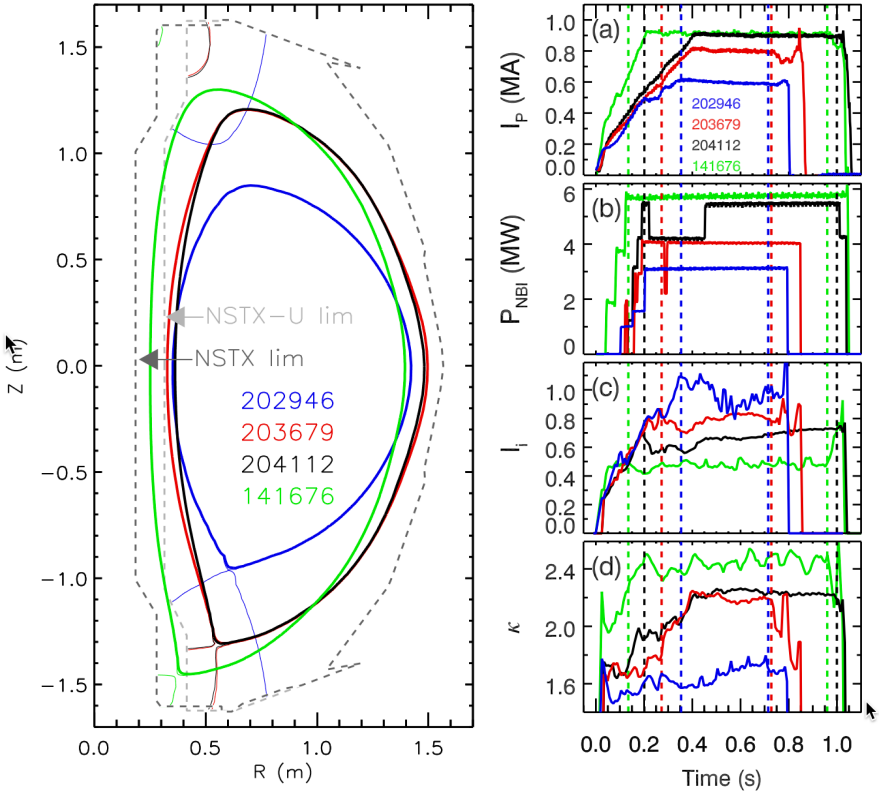


Boyer, M. D. *et al. Nucl. Fusion* **57**, 066017 (2017).

Highest priority deliverables in the first run campaign

- Achieve strong shaping at low-l_i, high-κ, β_N/β_{nowall} > 1 similar to NSTX
  - I_p = 1.4 MA, B_T = 0.85 T, 2s
  - High f_{NI} at I_p ~ 0.7 MA
- Demonstrate capabilities to:
  - Identify and correct n=1 error field
  - Characterize operation with boron and lithium wall conditioning
  - Detect and suppress RWM
  - Constrain q-profile in equilibrium
  - Characterize NBI

NSTX-U (2016) compared to NSTX



Summary

- NSTX-U will achieve high-f_{BS} regimes with unique, and potentially enhanced, energy confinement and stability properties compared to conventional-A
  - NSTX-U is the most capable ST for developing and optimizing non-inductive scenarios

- Research in Objective 2 is focused on producing high-performance long-pulse scenarios on NSTX-U, requiring:
  - Suitable particle control and heat flux mitigation
  - Low disruptivity via disruption prediction and avoidance
  - Advanced real-time control to improve access and sustainment of target scenarios