NSTX-U

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NSTX-U Initial Operations Plan
5 Year Plan for Scenarios and Control

S.P. Gerhardt

Advanced Scenarios and Control TSG

NSTX-U PAC 33
Feb. 19-21, 2013

Coll of Wm & Mary
Columbia U
CompX
General Atomics
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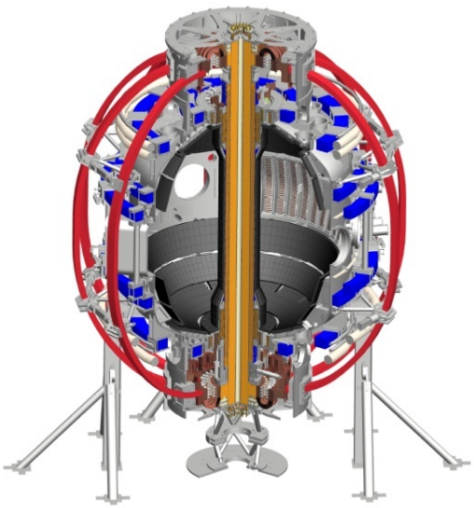

Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
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Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- Plans for Entering the First NSTX-U Operations Period
- ASC Research Plans for 5-year Period

Operations Activities Designed to Fit in the Existing NSTX-U Project Schedule

- NSTX research operations activities conducted in coordination with Upgrade project.

Time	**Activity**
May-Nov., 2013	Diagnostic Reinstallations/Calibrations In Parallel with Construction Activities
Dec. 2013 – March, 2014	Close Machine (w/o CS), Leak Checking, Prep. for CS installation.
April-May, 2014	CS Installation
June, 2014	Final Calibrations, Particularly Those Diagnostics Requiring CS for Calibration
July-Sept., 2014	Run Prep, Internal and DOE Readiness Reviews, Integrated Systems Testing, First plasma

- Schedule for diagnostic installations and calibration has been developed in 2-week increments.

Initial Operations Plans Designed to Rapidly Recover Physics Operations Capabilities

ISTP:
(Integrated Systems Test Procedure)
Establishes facility in state of readiness for operations.

Plasma Operations with:
I_p<=1.0 MA, B_T<=0.5
Develop:
- Breakdown and current ramp scenarios
- Shape & position control
- Reliable H-mode
- Diagnostic operations

Continue to add diagnostic & control capabilities while initiating physics experiments.

I_p<=1.5-1.6 MA
B_T<=0.75-0.8

~September 2014

ISTP-1 & CD-4 Prep → **CD-4 (I)** → **MPTS Calib.** → **Bake Out** → **CD-4 (II)** → **Operations Commissioning** → **Phys. Ops** → **ISTP-2** → **Phys. Ops**

~ 1 Month

Rayleigh/Raman Scattering for n_e & T_e calibrations.

ISTP-2
Required to increase the field and current for later research phase

Attempt 50 kA CD-4 plasma before bake-out. If water in vessel prevents success, then repeat.

NSTX-U Field and Current Capabilities Will Be Increased Gradually Over a ~3 Year Period

	NSTX	Year 1 NSTX-U Operations	Year 2 NSTX-U Operations	Year 3 NSTX-U Operations	Ultimate Goal
I_P [MA]	1.4	~1.6	2.0	2.0	2.0
B_T [T]	0.55	~0.8	1.0	1.0	1.0
Allowed TF I^2t [MA^2s]	7.3	80	120	160	160
I_P Flat-Top at max. allowed I^2t, I_P, and B_T [s]	~0.7	~3.5	~3	5	5

- 1st year goal: operating points with forces up to ½ the way between NSTX and NSTX-U, ½ the design-point heating of any coil
  - Will permit up to ~5 second operation at B_T~0.65
- 2nd year goal: Full field and current, but still limiting the coil heating
  - Will revisit year 2 parameters once year 1 data has been accumulated
- 3rd year goal: Full capability

NSTX-Upgrade Engineers Developing a Plan For Mechanical Diagnostics to Assess the Accuracy of the Mechanical Models Underlying Protection Levels

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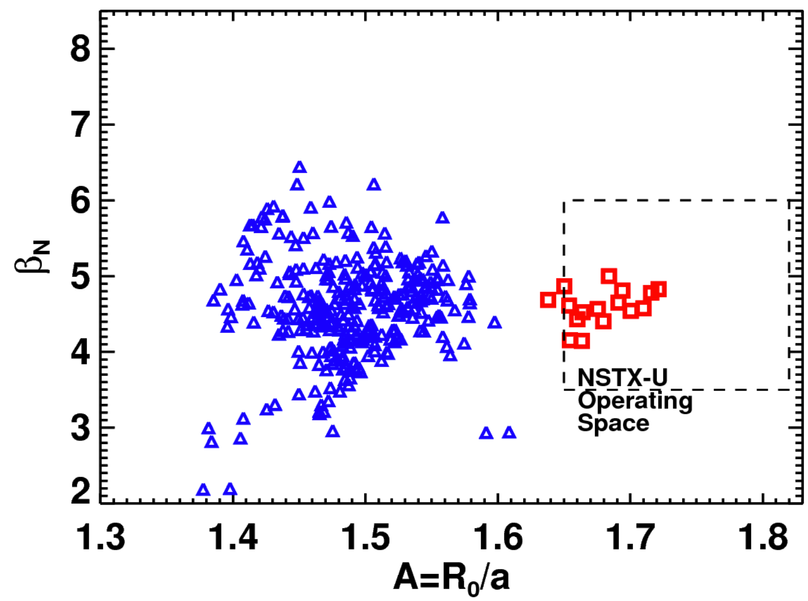
ASC Research Targets Integrated, Steady-State Scenario Needs for FNSF/CTF and ITER

Steady-state scenarios for ITER or a CTF/FNST must:

- Have full current drive with acceptable recirculating power.
  - NSTX-U ASC: Explore a range of β_N with 100% non-inductive CD.
- Control the divertor heat flux to be within acceptable material limits.
  - NSTX-U ASC: divertor geometry and radiation control.
- Simultaneously optimize confinement and passive disruption avoidance.
  - NSTX-U ASC: optimization and control of the boundary, rotation and current profiles.
- Detect and respond to disruptions and off-normal events.
  - NSTX-U ASC: disruption detection and soft-shutdowns.

NSTX Operational Space: β_N vs A
>$1\tau_E$ average for each point



Conventional NSTX Operating Space
High-A Experiment During FY-11 Run

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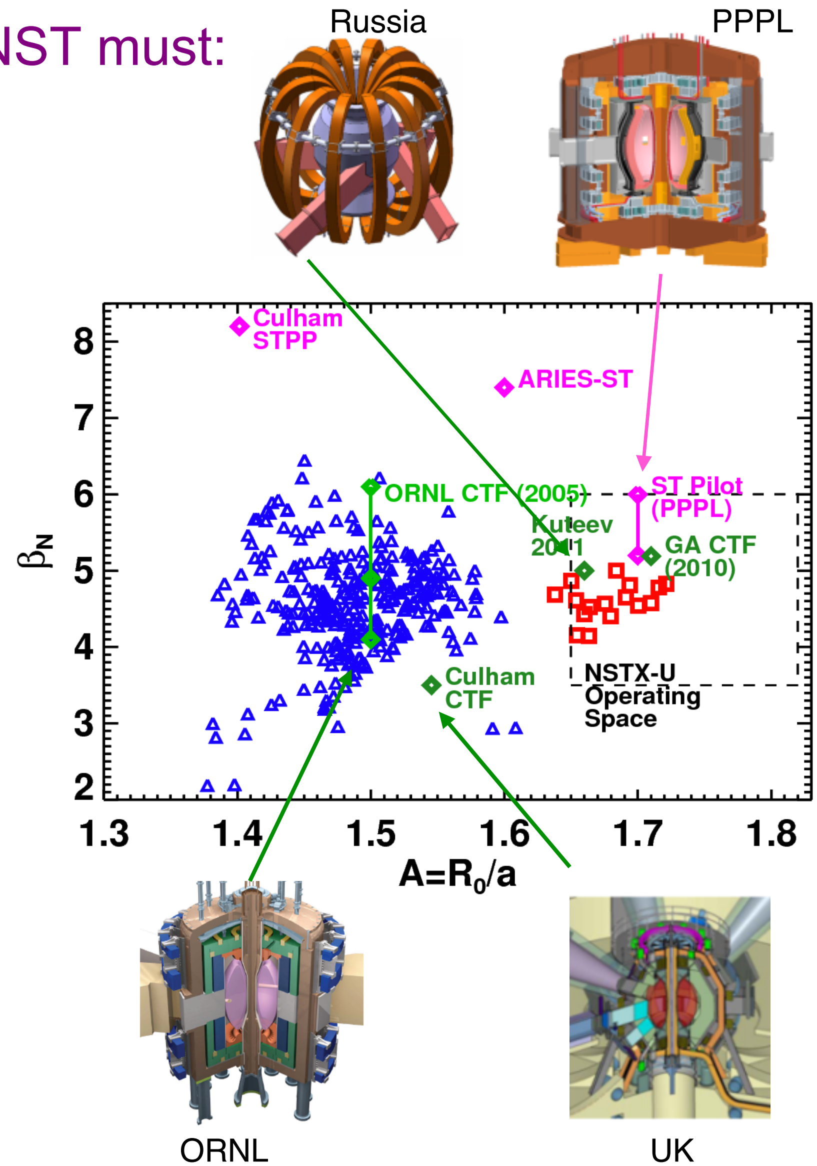

Outline

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- ASC Research Plans for 5-year Period

ASC Programmatic Goal For 5 Year Plan:
Develop the basis for integrated, steady-state operation and axisymmetric control for next-step STs, while helping resolve key scenario and control issues for ITER.

ASC Operational Goal For 5 Year Plan:
Establish stationary, 100% non-inductive operation, and partial inductive operation up to I_P=2 MA, for 5 seconds over a wide range of Greenwald fractions.

Research required to meet these goals divided into four thrusts.

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  - Thrust 1: Scenario Physics
  - Thrust 2: Axisymmetric Control Development
  - Thrust 3: Disruption Avoidance By Controlled Discharge Shutdown
  - Thrust 4: Scenario Physics for Next Step Devices

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Highly collaborative research, planned with the expectation of team-wide contributions

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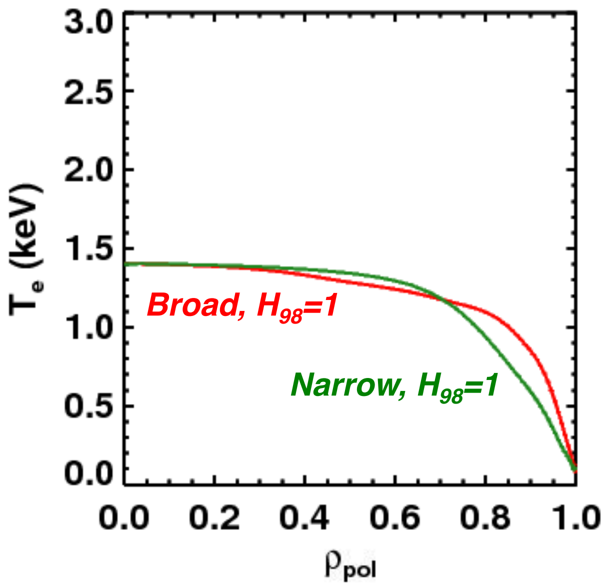
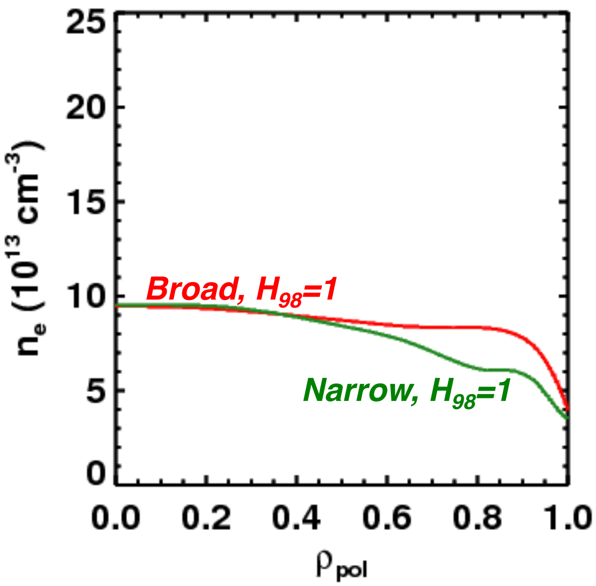
    - Study the conditions for classical beam current drive.
    - Explore & validate integrated models for projections to FNSF.

Highly collaborative research, planned with the expectation of team-wide contributions

We Anticipate The Non-Inductive Current Level at B_T=1.0 T and P_{inj}=12.6 MW To Be Between ~900 & ~1300 kA

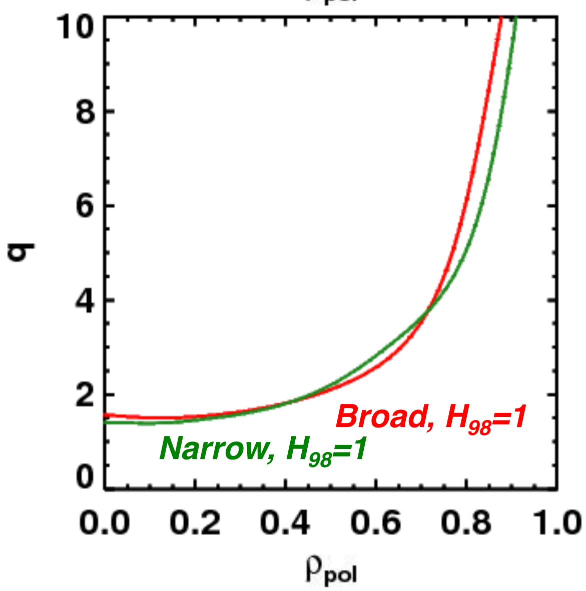
Thrust #1





Dashed: ITER-98 confinement scaling

$$\tau_{98y,2} \propto I_P^{0.93} B_T^{0.15} \overline{n}_e^{0.41} P_{Loss}^{-0.69}$$



- **Fix: 1.0T, P_{inj}=12.6 MW, f_{GW}=0.72**
- **Fix: A=1.75, κ=2.8**
- Determine the non-inductive current level for 2 confinement and 2 profile assumptions…*yields 4 different projections.*

Confinement	Profiles	I_P [kA]	β_N	q_{min}
H_{98}=1	Broad	975	4.34	1.5
H_{98}=1	Narrow	875	4.87	1.4

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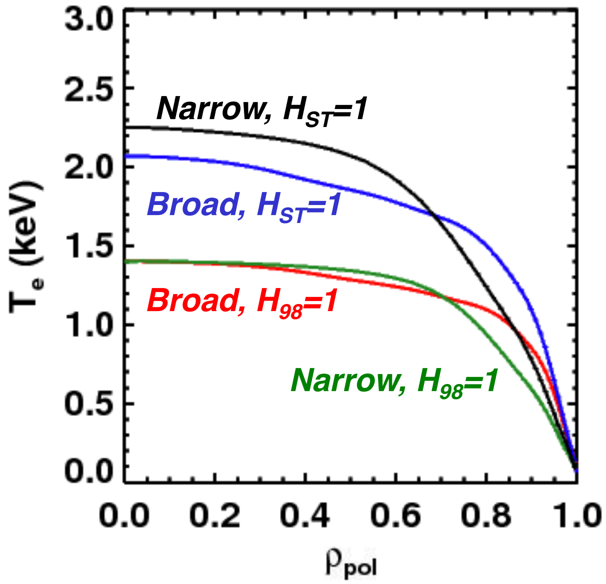
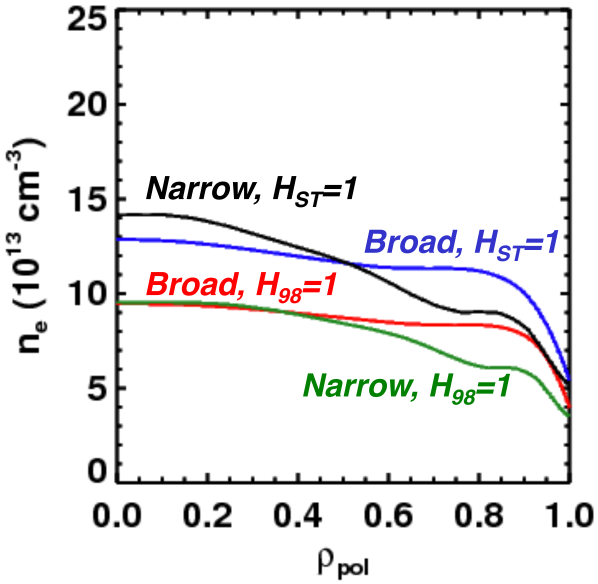




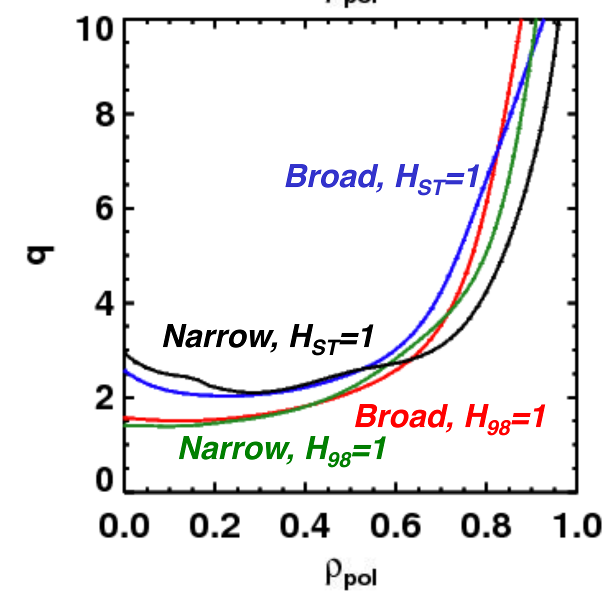
Dashed: ITER-98 confinement scaling

$$\tau_{98y,2} \propto I_P^{0.93} B_T^{0.15} \overline{n}_e^{0.41} P_{Loss}^{-0.69}$$

Solid: ST confinement scaling

$$\tau_{ST} \propto I_P^{0.57} B_T^{1.08} \overline{n}_e^{0.44} P_{Loss}^{-0.73}$$

(S. Kaye, NF 2006)



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Confinement	Profiles	I_P [kA]	β_N	q_{min}
H_{98}=1	Broad	975	4.34	1.5
H_{ST}=1	Broad	1325	5.32	2.0
H_{98}=1	Narrow	875	4.87	1.4
H_{ST}=1	Narrow	1300	5.97	2.1

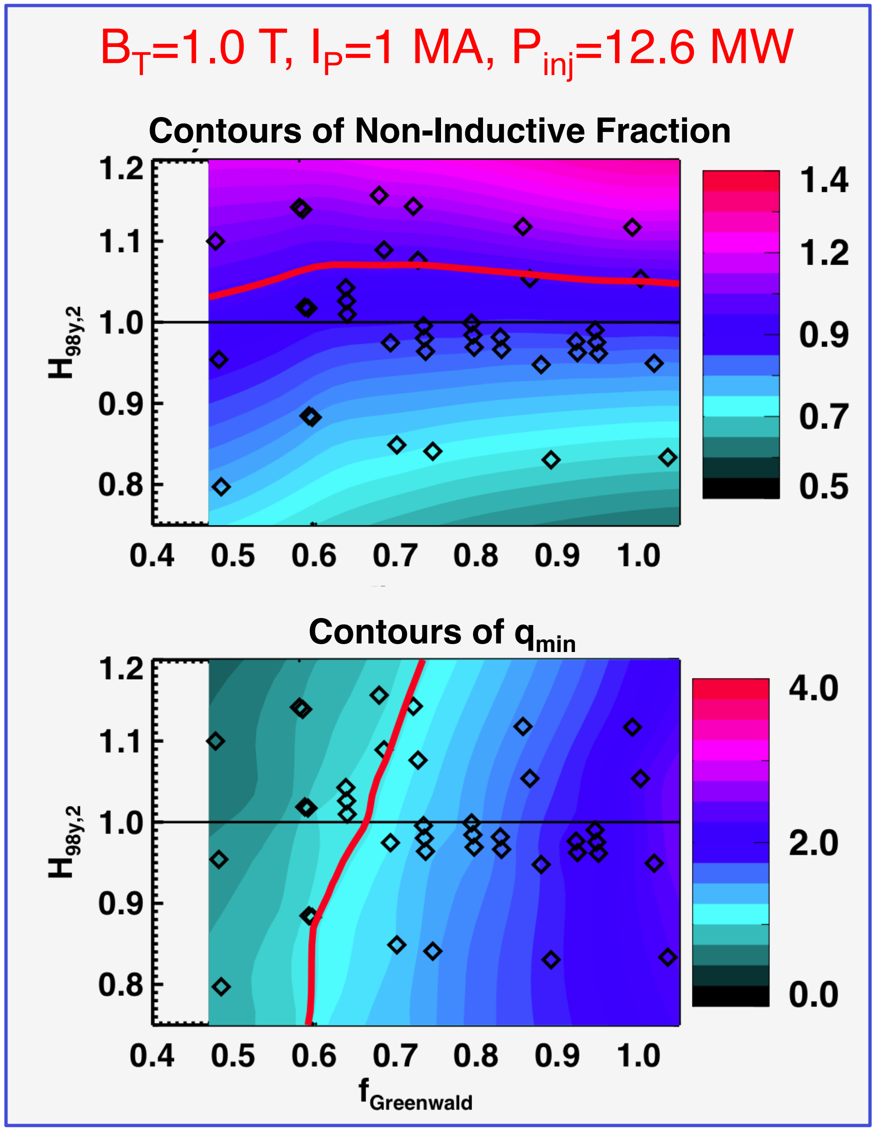
Non-Inductive Operating Points Projected Over a Range of Toroidal Fields, Densities, and Confinement Levels

- Free-Boundary TRANSP calculations of NSTX-U operations points.
  - See: S.P. Gerhardt, et al, Nuclear Fusion **52** 083020 (2012)

Research Timeline for 100% Non-Inductive Scenarios

Operation Year	B_T [T]	Current Goal [kA]	Duration Goal
1	0.75	~600-800	A few τ_E
2	0.75-1.0	~600-1000	1-2 τ_R
3-4	1	800-1300	Up to 4.5 s at lower I_P

Particle & heat flux control, NBCD tools required to realize these scenarios discussed in upcoming slides.



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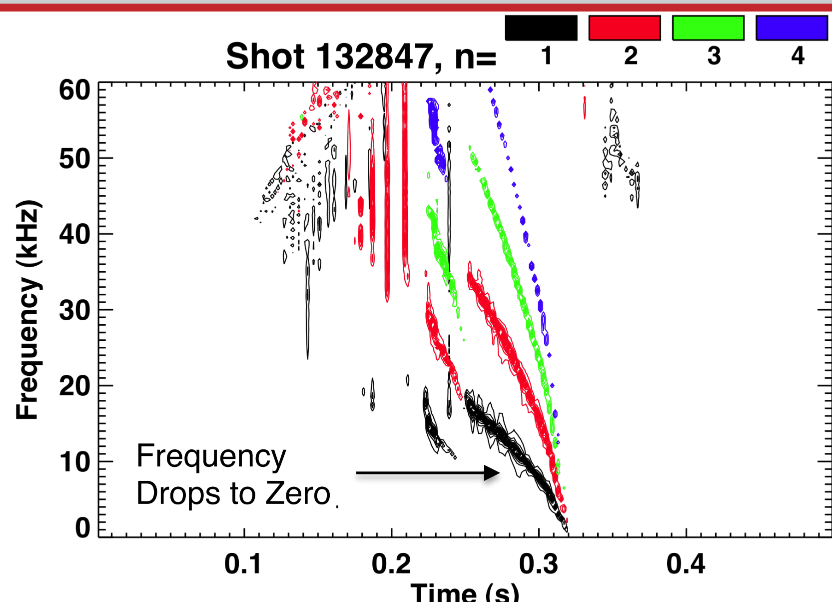
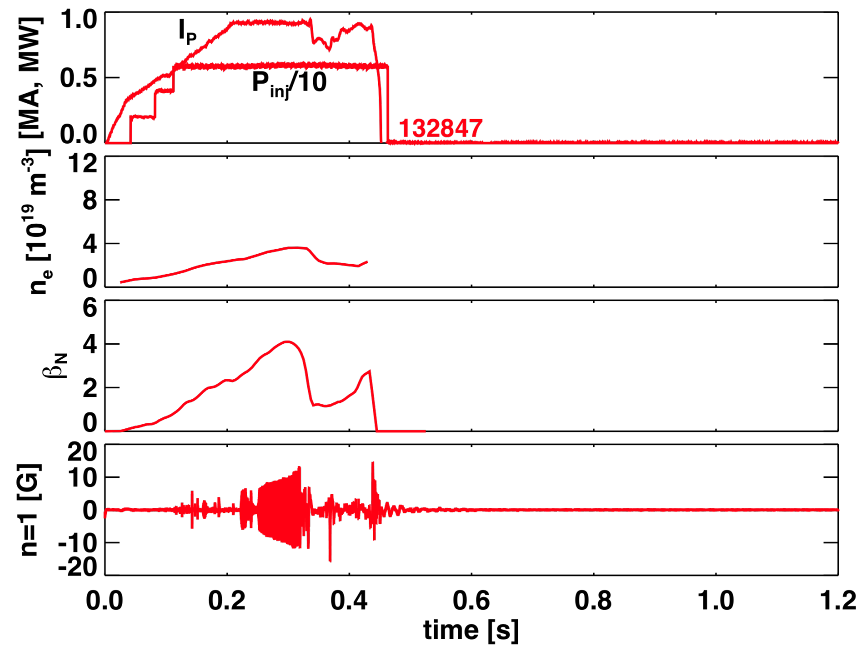
Optimizing the Early Discharge Evolution Will Play an Important Role in Achieving Low Collisionality at High-Current



132847: Fueled from low-field side



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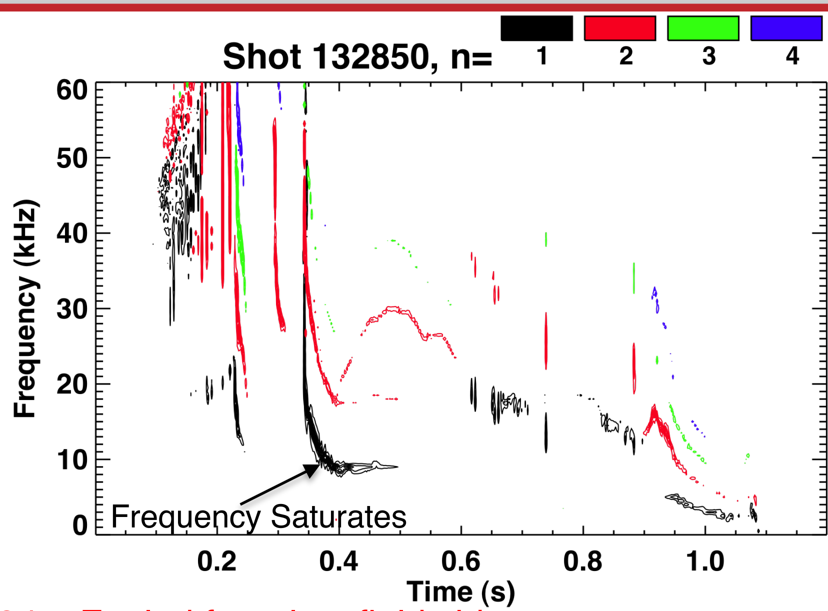
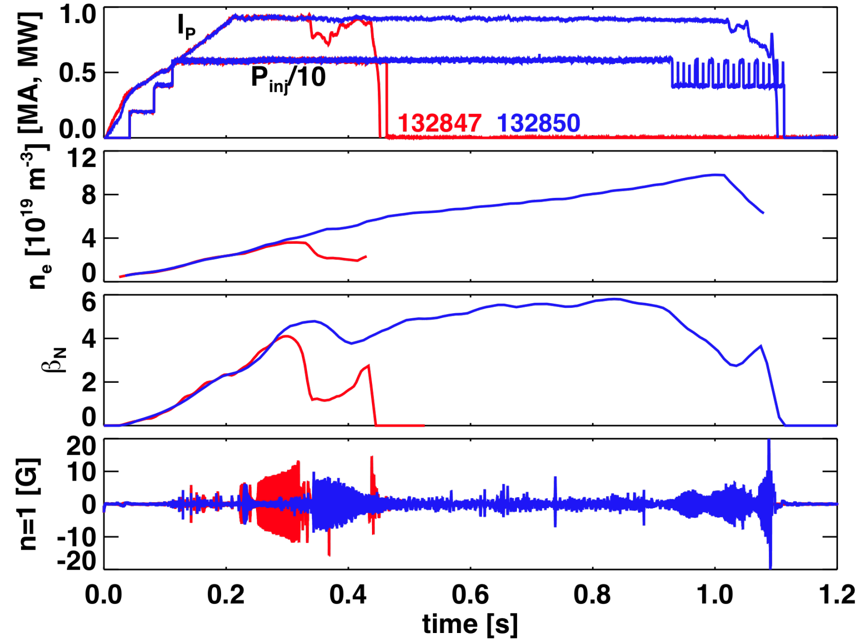




132847: Fueled from low-field side

132850: Fueled from both low- and high- field sides

- Timing and magnitude of fueling has profound impact on discharge evolution, will be optimized in NSTX-U.
  – Will slower I_P ramps w/ larger solenoid facilitate reduced fueling?
  – Will improved solenoid design and reduced error fields improve lower-density startup.
  – Will the extra torque from the new beams reduce prevalence of locking?

Milestone R14-1

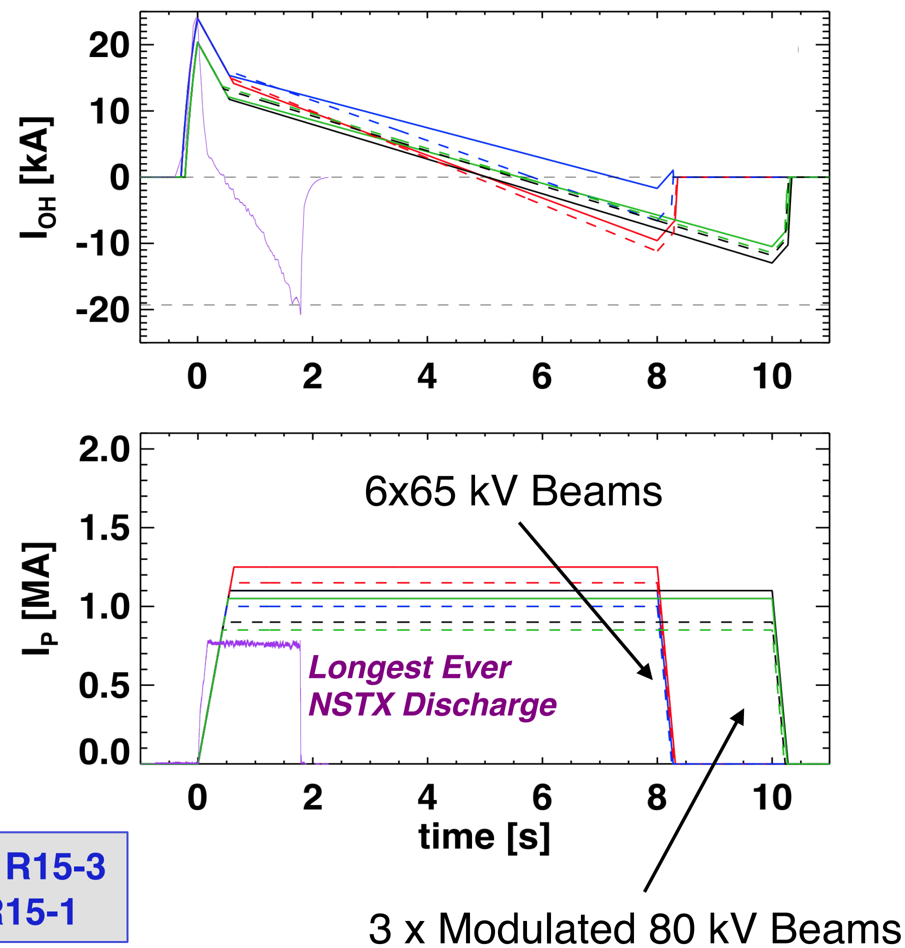
Will Develop Long-Pulse Partial Inductive Operation Up to 2 MA with High Power

Thrust #1

- Two types of partial inductive operation:
  - High-I_P operation supports collisionality scaling and divertor heat flux studies
  - Long pulse operation for particle retention and disruptivity reduction studies
- Years 1 & 2 of ops.: Re-optimize startup for reduced fueling and low collisionality.
  - Optimize fueling, ramp-rate, error field correction, torque input to facilitate reduced density
- Years 3 & 4 of ops: Performance Extension
  - Discharges up to 2 MA for 5 seconds.
  - Long pulse at ~1 MA for up to 10 seconds
- High-I_P & long pulse development will be connected to progress in:
  - Particle Control
  - Heat flux mitigation

Addresses milestone R15-3
Supports milestone R15-1

B_T=0.75 T, ***8-10 Second Discharge***
Scenarios Limited by q_{min}>1.1 or OH Coil I^2t
2 Confinement and 2 Profile Assumptions



Operation Tools for Density & Impurity Control

Thrust #1

Years 1 & 2 of ops.: Examine Wall Conditioning, Fueling, and ELM Pacing

Boronized PFC Studies

- Utilize regimes with natural ELMs to control impurity accumulation.
- Between-shot He glow for wall conditioning.
- Deuterium inventory likely to rise throughout the discharge.

Lithiated PFC Studies

- High-τ_E, ELM-free regimes w/ Li conditioning
- Pulsed 3D fields or lithium granules for ELM pacing to provide impurity control.
- Deuterium inventory likely well controlled, but unclear if target Z_{eff}~2 can be achieved.

Techniques to Be Covered in Greater Detail in Talks By Maingi, Canik, Soukhanovskii, Jaworski

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Both Scenarios: Realtime Density Measurements via FIReTIP
PCS control of Supersonic Gas Inj. for Density Control

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PCS control of Supersonic Gas Inj. for Density Control

Years 3 & 4 of ops.: Utilize Cryo-pumping and Partial NCC

Cryo-pump in lower-divertor to provide deuterium inventory control

- Natural or paced ELMs to control core impurity accumulation
- Make comparisons to regimes with paced ELMs and lithium pumping

Partial NCC to aid in ELM pacing and RMP studies

- Attempt direct modification of pedestal particle transport via RMP
- Determine optimal spectrum for magnetic ELM pacing, with minimal core degradation

Techniques to Be Covered in Greater Detail in Talks By Maingi, Canik, Soukhanovskii, Jaworski

Full Utilization of the NSTX-U Will Require Heat Flux Mitigation Solutions

- Thermal stresses in target tiles can exceed ATJ graphite limits.
  - Inner horizontal target tiles qualified for 5 sec operation at Q_{ave}=5 MW/m^2
- Desire to avoid tile surface temperatures exceeding T_{max}~1200 C.
- Conservative assumption: $\lambda_q = 0.92 I_P^{-1.6}$ $\quad Q_{Pk} = \frac{P_{heat} f_{div}}{2\pi R \lambda_q f_{exp} \sin(\theta)}$ $\quad Q_{ave} = 0.63 Q_{Pk}$

Discharge Parameters			Worst-Case Standard DN Divertor f_{exp}=15 & f_{div}=0.4			
I_P [MA]	P_{inj} [MW]	Heating Duration [s]	Q_{Pk} [MW/m^2]	Time to T_{max} [s]	Q_{Pk} [MW/m^2]	Time to T_{max} [s]
0.75	10.2	5.0	6	12.6		
1.5	10.2	5.0	18	1.4		
2.0	10.2	5.0	28	0.5		
1.5	15.6	1.5	27	0.6		
2.0	15.6	1.5	43	0.25		

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- Primary solutions: Broadening the heat channel (f_{exp}) via the snowflake divertor
  Increasing the fraction of radiated power (decreasing f_{div})

Discharge Parameters			Worst-Case Standard DN Divertor f_{exp}=15 & f_{div}=0.4		f_{exp}=60 & f_{div}=0.4 or f_{exp}=15 & f_{div}=0.1	
I_P [MA]	P_{inj} [MW]	Heating Duration [s]	Q_{Pk} [MW/m^2]	Time to T_{max} [s]	Q_{Pk} [MW/m^2]	Time to T_{max} [s]
0.75	10.2	5.0	6	12.6	1.5	200
1.5	10.2	5.0	18	1.4	4.5	22
2.0	10.2	5.0	28	0.5	7	8.7
1.5	15.6	1.5	27	0.6	7	9.3
2.0	15.6	1.5	43	0.25	11	4.0

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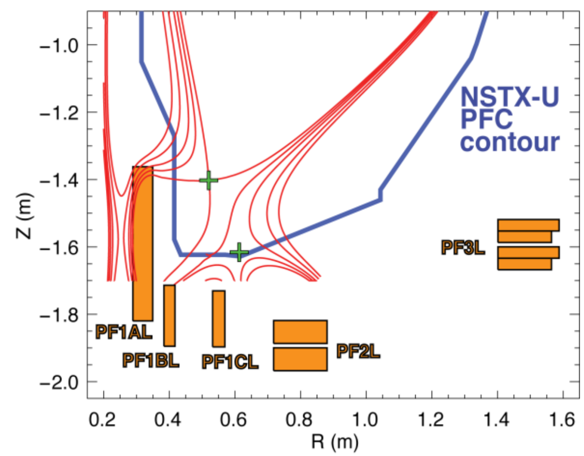
Snowflake Geometry and/or Divertor Radiation Control Required for High-Current Operation

Snowflake Divertor in NSTX-U

Increases divertor volume and flux expansion.



- Physics of these techniques to be covered in Boundary Physics talk

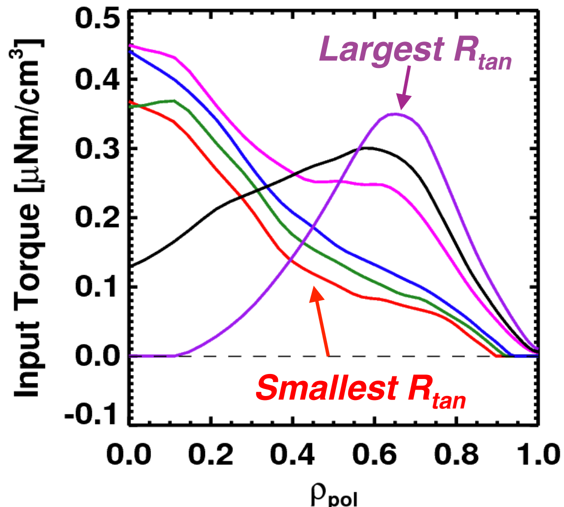
- Control development plans
  - Pre-ops year:
    - Collaborate on snowflake divertor physics and control experiments at DIII-D
  - Years 1 & 2 of ops.:
    - Develop schemes for dual X-point control using new divertor coils
    - Assess magnetic balance control in the presence of 4 X-points
    - Develop the realtime measurements for divertor radiation control
  - Between years 2 & 3 of ops: Install cryo-pump
  - Years 3 & 4 of ops:
    - Utilize cryo-pump + snowflake divertor for increasing the pulse length at higher current
    - Begin implementation of closed loop radiative divertor control

Milestone R14-3

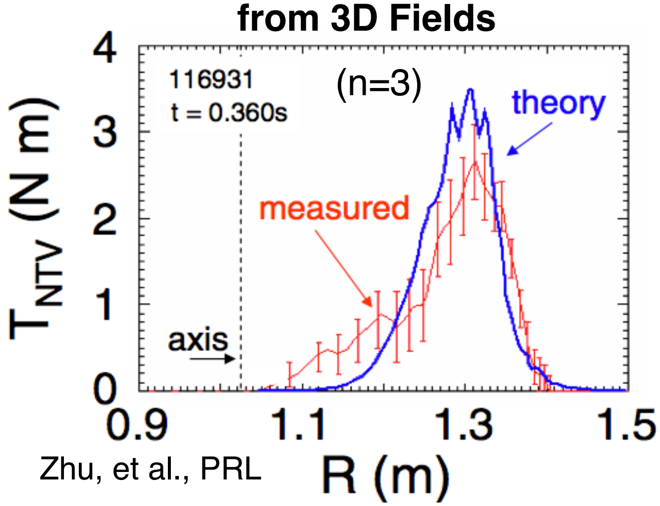
NSTX-U Will Have Significant Actuators For Profile Control Studies

Rotation Profile Actuators

Torque Profiles From 6 Different NB Sources



Measured and Calculated Torque Profiles from 3D Fields



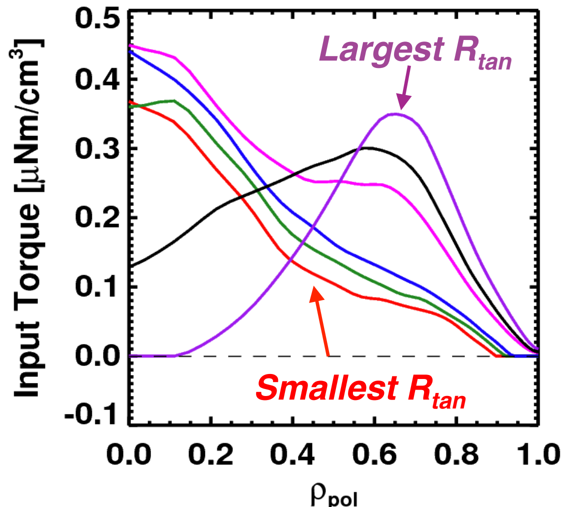
Zhu, et al., PRL

NSTX-U Will Have Significant Actuators For Profile Control Studies

Thrust #2

Rotation Profile Actuators

Torque Profiles From 6 Different NB Sources



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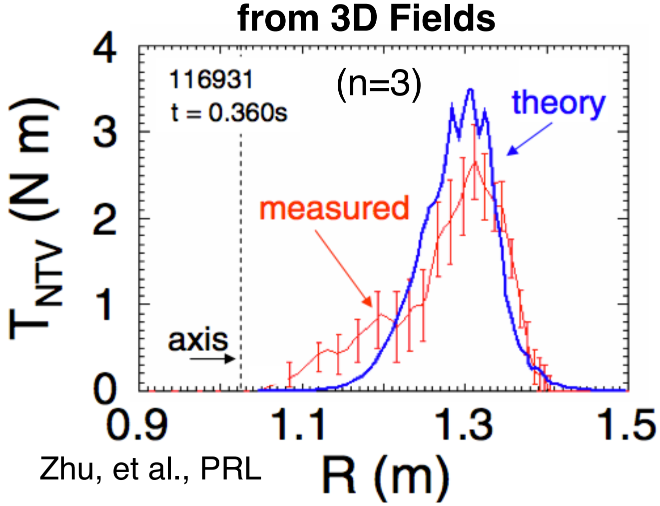
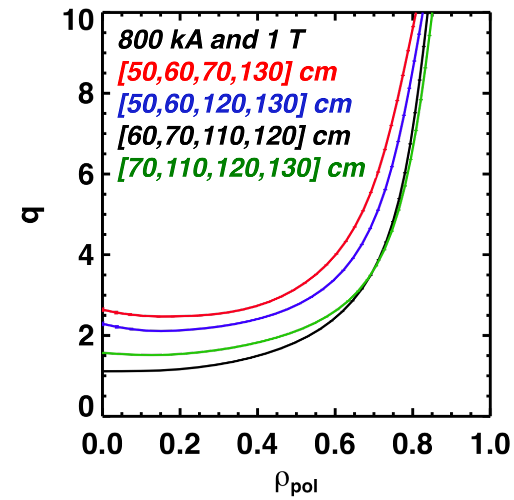


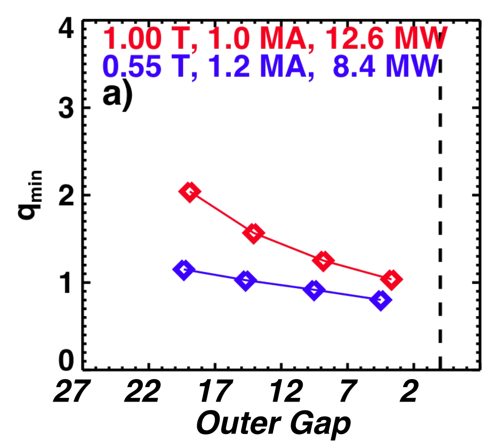
q-Profile Actuators

Variations in Beam Sources

800 kA Partial Inductive, 87% < f_{NI} < 100%



Variations in Outer Gap



Milestone R14-3

Profile Control Techniques Will be Developed To Support NSTX-U Physics Studies and Next-Step ST Designs

Thrust #2

- Pre-ops. Year: Continue developing control schemes for NSTX-U actuators.
  - Lehigh: Collaboration on q-profile control algorithms, building on their experience at DIII-D.
  - Princeton University: Collaboration on rotation profile control algorithms.
  - Continue operations collaborations on KSTAR and EAST.
- Years 1 & 2 of ops.:
  - Test ability of different NB source selection to change the q-profile.
    - Study as a function of density, fast-ion β, source voltage.
    - Assess the NBCD calculations underpinning NSTX-U and most next-step ST studies.
  - Commission rtMSE (Nova Photonics) and rtV$_\phi$ (PPPL) diagnostics.
  - Make first tests of β_N + central rotation ($F_{T,0}$) and, if feasible, β_N+q_{min} control.
- Years 3 & 4 of ops.:
  - Expand rotation control to the full profile.
  - Complete β_N+q_{min} control and assess combined control, e.g., β_N+$F_{T,0}$+q_{min}.
  - Assess NTV capabilities from NCC for enhanced rotation profile control.
  - Work with MS group to develop physics-based requests for disruption avoidance goals.

Milestone R14-3

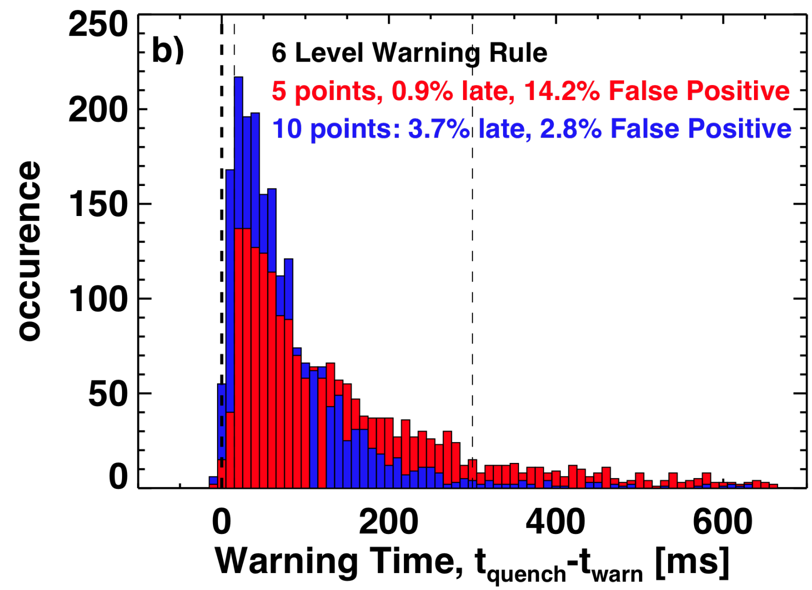
Outline

- Plans for Entering the First NSTX-U Operations Period
- ASC Research Plans for 5-year Period
  - Thrust 1: Scenario Physics
    - Development of 100% non-inductive operation.
    - Extend the high-current, partial-inductive scenarios to long-pulse.
  - Thrust 2: Axisymmetric Control Development
    - Develop methods to control the heat flux for high-power scenarios.
    - Develop rotation and current profile control.
  - Thrust 3: Disruption Avoidance By Controlled Discharge Shutdown
    - Develop detection of impending disruptions.
    - Develop techniques for the automated termination of discharges.
  - Thrust 4: Scenario Physics for Next Step Devices
    - Determine the optimal, simultaneous q- and rotation profiles.

Disruption Avoidance Via Discharge Shut-Down Will be Developed

Thrust #3

- Disruption detection algorithms have been developed using NSTX data
  - Compare diagnostic data to thresholds & assign "penalty points" when thresholds are exceeded.
  - Sum the "penalty point", and declare a warning when the point total exceeds a given threshold.
- Provides the foundation of disruption detection in NSTX-U.
- Years 1 & 2 of ops.:
  - Implement basic detector in PCS, and design architecture of control response.
  - Assess accuracy of predictor for NSTX-U disruptions, and refine as necessary.
  - Do initial tests of automated rampdowns.
- Years 3 & 4 of ops.:
  - Add additional realtime diagnostics for improved detection fidelity.
  - Optimize rampdowns for different types of alarms.
  - Incorporate closed loop MGI if it appears promising.



S.P. Gerhardt, et al., submitted to Nuclear Fusion

Connections of MS TSG:
- n>=1 control, including disruption avoidance scenarios, covered by MS TSG.
- MGI physics covered by MS TSG

Milestone R13-4

Outline

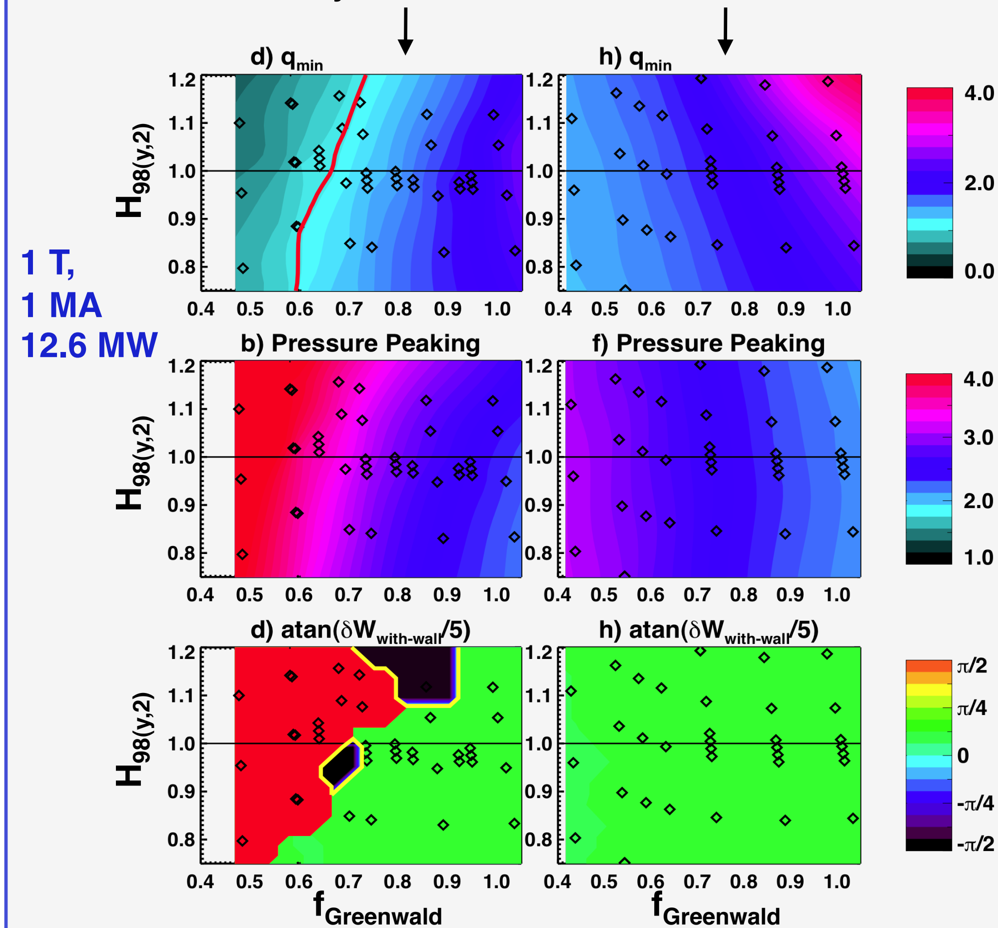
- Plans for Entering the First NSTX-U Operations Period
- ASC Research Plans for 5-year Period
  - Thrust 1: Scenario Physics
    - Development of 100% non-inductive operation.
    - Extend the high-current, partial-inductive scenarios to long-pulse.
  - Thrust 2: Axisymmetric Control Development
    - Develop methods to control the heat flux for high-power scenarios.
    - Develop rotation and current profile control.
  - Thrust 3: Disruption Avoidance By Controlled Discharge Shutdown
    - Develop detection of impending disruptions.
    - Develop techniques for the automated termination of discharges.
  - Thrust 4: Scenario Physics for Next Step Devices
    - Determine the optimal, simultaneous q- and rotation profiles.
    - Study the conditions for classical beam current drive.
    - Explore & validate integrated models for projections to FNSF.

Explore Optimal Scenarios for Next Step STs
All Topics in Collaboration with Other TSGs

- Study optimal profiles for confinement and stability.
  - Optimization of the current profile for best confinement and core stability.
  - Explore alternative optimal scenarios, such as EPH or w/ ITBs.
- Study the conditions for classical beam current drive
  - Study what parameters determine when *AE modes lead to anomalies in the fast ion diffusion and NBCD.
  - Can anomalous diffusion be used for scenario optimization?
- Assess integrated models for projections to FNSF.
  - Compare NBCD & q-profile predictions from integrated codes to NSTX-U.
  - Project scenarios to ST FNSF devices.

Milestone R15-2

Fast Ion Diffusivity: 0 m²/s 1 m²/s



Red: Internal Modes Unstable
Green: stable
Blue/Black: External modes unstable

ASC Research Supports Development of High-Performance Integrated Scenarios for NSTX-U, FNSF & ITER

- Plans for initial NSTX-U operations have been formed, in support of physics program objectives
- ASC 5-year plan designed to provide solutions for
  - the operations needs for the NSTX-U research program
  - physics needs for ITER and next-step ST scenarios
- Research will address outstanding needs by
  - developing stationary scenarios over a range of non-inductive fractions, plasma currents, and collisionalities
  - developing measurements, algorithms, and actuators for control of
    - the current & rotation profiles,
    - the core density,
    - the divertor geometry and radiation,
  - validating models for NBCD & thermal transport to enable projections for next-step STs

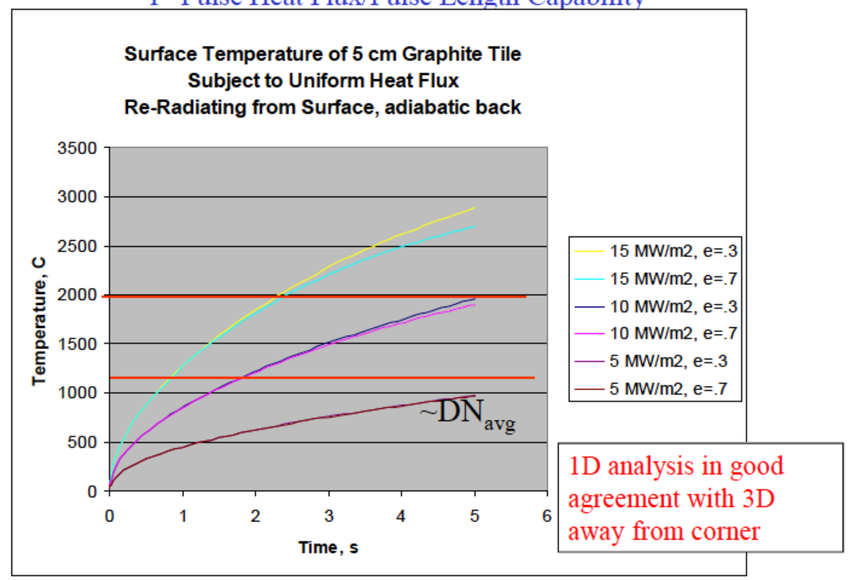
Backup!!!!!

Criterion For Heat Flux Limits

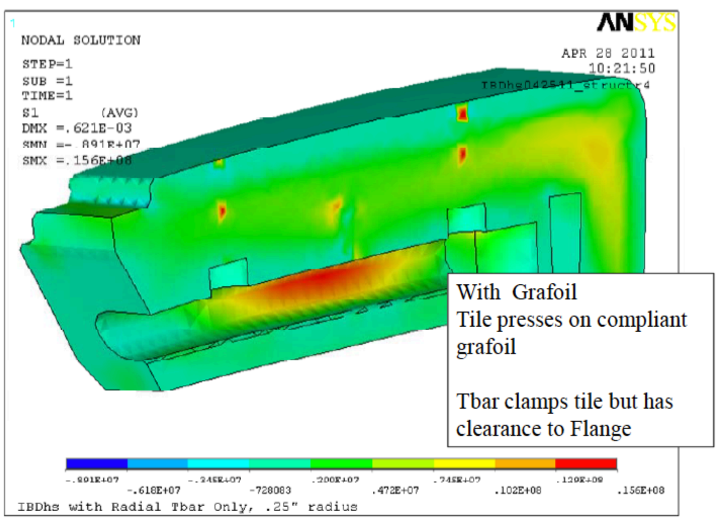
- Calibrate expression for tile surface temperature against engineering models:
  - $T_{surf}=CQ_{ave}t^{1/2}$
  - Use T_{surf}=1000 C, t=5 s, Q_{avg}=5 MW/m^2.
    - Derive C~90 Cm^2/MWs$^{1/2}$
- Derive heat flux Q from simple scalings:

$$Q_{peak} = \frac{P_{heat} f_{div}}{2\pi R \lambda_q f_{exp} \sin(\theta)} \qquad \lambda_q = 0.92 I_P^{-1.6}$$

1st Pulse Heat Flux/Pulse Length Capability



11 Single pulse without ratcheting with ATJ Graphite



Summary of Tile Thermal Structural Response					
	Heat Flux for 5s mw/m2	Ratcheted Temperature C	Peak Tensile Principal Stress, S1 MPa	Peak Compress Principal Stress, S3	Max Deflection mm
IBDhs, surface	5.0	1062	15.6	-58.0	0.6
Hot Spot at Corner		1512			
IBDvs, surface	1.6	425	7.0	-16.3	0.1
Hot Spot at Hole		560			
CSAS, surface	1.6	327	8.2	-10.7	0.2
Hot Spot at Hole		417			
CSFW	0.2	260	1.6	-6.5	0.01

Physics and Engineering Operations Activities Over the Next ~Year Will Provide the Baseline For NSTX-U Operations

- Upgrading the Plasma Control System (PCS) for NSTX-U.
  - Upgrading to new 32-core computer.
  - Switching to 64 bit real-time Linux with advanced debugging tools.
  - Upgrading shape-control codes for new divertor coils, gas injector controls for new/additional injectors, additional physics algorithms
  - Improving the real-time data-stream.
  - Assisting with development of a new Digital Coil Protection System (DCPS).
- Upgrading HHFW antenna feedthroughs for higher disruption forces.
- Boundary Physics Operations
  - Improving the PFC geometry in the vicinity of the CHI gap to protect the vessel and coils.
  - Developing an upgraded Boronization system.
  - Developing lithium technologies (granule injector, upward LITER).
- Diagnostic Upgrades
  - Fabricating new port covers to support high-priority diagnostics.
  - Installing additional, redundant magnetic sensors.
  - Upgrading diagnostics: Bolometry (PPPL), ssNPAs, spectroscopy (collaborators)
- Physics & Engineering Operations
  - Replacing electronics that control & protect rectifiers.
  - Upgrading the poloidal field coil supplies to support up-down symmetric snowflake divertors.
  - Developing PF null/breakdown scenario w/ new CS.

Pursue 100% Non-Inductive Current at Progressively Higher I_P and B_T

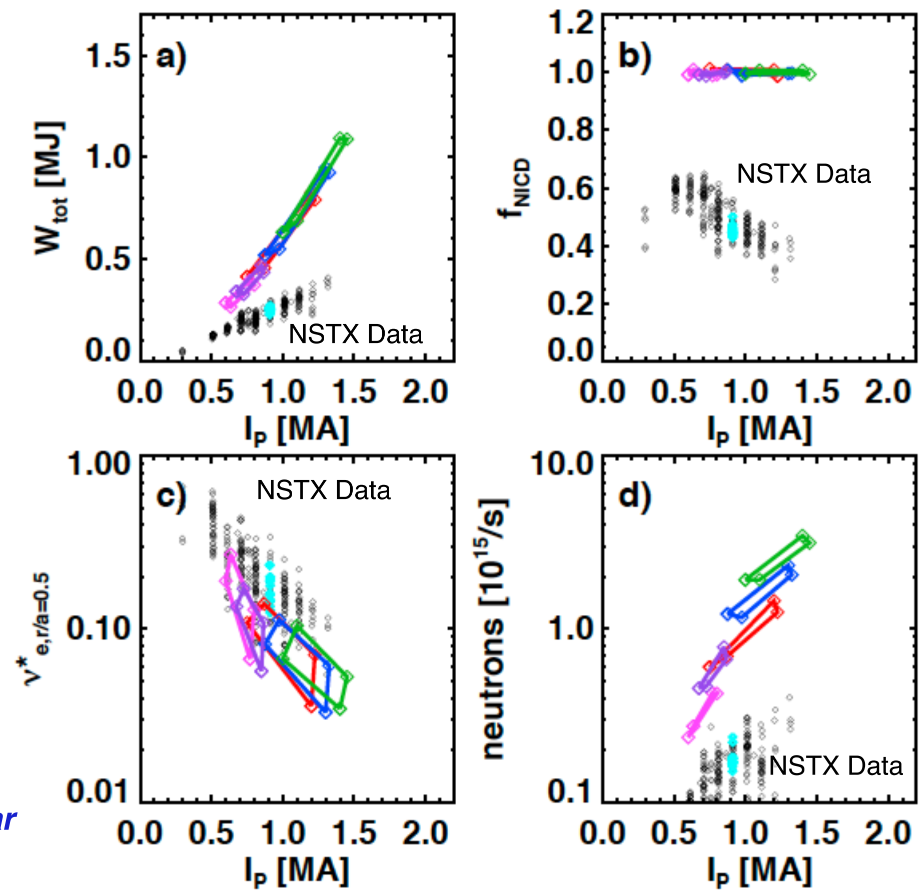
- Free-Boundary TRANSP calculations of NSTX-U operations points.
  - See: S.P. Gerhardt, et al, Nuclear Fusion **52** 083020 (2013)

Projected Non-Inductive Current Levels for κ~2.85, A~1.75, f_{GW}=0.7

B_T [T]	P_{inj} [MW]	I_P [MA]	Heating Duration [s]
0.75	6.8	0.6-0.8	5
0.75	8.4	0.7-0.85	3
1.0	10.2	0.8-1.2	5
1.0	12.6	0.9-1.3	3
1.0	15.6	1.0-1.5	1.5

TRANSP Projections for 100% Non-Inductive Scenarios

Each polygon for a given engineering configuration, multiple profile and confinement assumptions



6x80 kV, B_T=1 T
6x90 kV, B_T=1 T
6x100 kV, B_T=1 T

4x80 kV, B_T=0.75 T
4x90 kV, B_T=0.75 T
} *End of year 1 target*

NSTX-U Field and Current Capabilities Will Be Increased Gradually Over a ~3 Year Period

	NSTX	Year 1 NSTX-U	Year 2 NSTX-U	Year 3 NSTX-U	Ultimate Goal
I_P [MA]	**1.4**	**~1.6**	**2.0**	**2.0**	**2.0**
$I_P I_P$ [MA^2]	2.0	2.5	4.0	4.0	4.0
B_T [T]	**0.55**	**~0.8**	**1.0**	**1.0**	**1.0**
$B_T B_T$ [T^2]	0.3	0.65	1.0	1.0	1.0
$I_P B_T$ [MA*T]	0.61	1.3	2	2.0	2
Allowed I^2t Fraction On Any Coil		**0.5**	**0.75**	**1.0**	**1.0**
I_P Flat-Top at max. allowed I^2t, I_P, and B_T [s]	**~0.7**	**~3.5**	**~3.**	**5**	**5**

- 1st year goal: operating points with forces up to 1/2 the way between NSTX and NSTX-U, ½ the design-point heating of any coil:
  - Will permit up to ~5 second operation at B_T~0.65
- 2nd year goal: Full field and current, but still limiting the coil heating.
  - Will revisit year 2 parameters once year 1 data has been accumulated.
- 3rd year goal: Full capability

NSTX-Upgrade Engineers Developing a List of Mechanical Diagnostics to Assess the Accuracy of their Mechanical Models

Shape/Position & Fueling Control Will Be Developed to Support NSTX-U Operations

Thrust #2

- Shape/Position Control Considerations
  - Vertical control of high-A NSTX plasmas found to be problematic when l_i exceeded ~0.6.
  - Boundary and PMI research programs will require accurate control of the strikepoints.
- Years 1 & 2 of ops.
  - Assess vertical stability of NSTX-U plasmas.
  - Improve control as necessary via better algorithms or measurements.
  - Re-tune strike-point controllers for new divertor coils.
- Years 3 & 4 of ops.
  - Implement realtime n=0 stability and loss of control assessments.
    - Connection to Thrust #3.

- Fueling Control Considerations
  - Realization of lowest-collisionality will require high-efficiency fueling.
  - Full utilization of the cryo-pump will require better control of fueling
- Years 1 & 2 of ops.
  - Utilize super-sonic gas injection for improved fueling during the current ramp.
  - Develop realtime density measurements.
  - Assess closed-loop density control during the current ramp.
- Years 3 & 4 of ops.
  - Utilize cryo-pumping + advanced fueling to achieve closed-loop density control during the discharge flat-top.