Overview of NSTX-U Research Program Progress and Plans

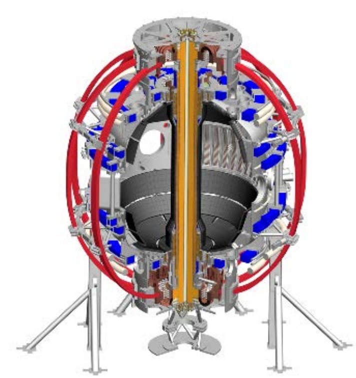
J. Menard, PPPL

For the NSTX-U Research Team

NSTX-U PAC 37

PPPL B318

January 26-28, 2016



Outline

- Events since PAC-35
- Charge Questions
- Mission and Capabilities of NSTX-U
- Research Goals and Milestones
- Key Scientific Issues NSTX-U Will Address
- Organizational Structure
- Run Coordination
- Support for FESAC / FES Strategic Goals
- Summary

NSTX-U Research Team Has Been Scientifically Productive

Very Active in Scientific Conferences, Publications, and Collaborations

- Strong APS meeting participation
  - 2014: 1 ST review talk, 5 NSTX invited talks, 44 posters
  - 2015: 3 NSTX invited talks (+4 by team-members), 54 posters
- L. Delgado-Aparicio: DOE Early Career Award for research on impurity transport and control

- Multitude of technical NSTX-U / next-step presentations at 2015 SOFE, Li Symposium, IAEA-TM on divertors
- International ST Workshop: 78 talks+posters, 50% international
- 45 refereed publications for FY2015
- 34 IAEA FEC 2016 synopses on NSTX-U + ST-FNSF

NSTX-U Research Team Has Been Scientifically Productive

Very Active in Scientific Conferences, Publications, and Collaborations

- Collaborative research contributions made in range of topics directly relevant to NSTX-U program
  - **DIII-D:** Pedestal transport, fast-ions instabilities, RWM / RFA, QH-mode TEM particle transport, Li dropper, granule injector, snowflake/X divertors
  - **EAST:** Lithium coating / wall physics, flowing liquid Li limiter
  - **KSTAR:** NTV rotation damping, error fields, RMP
  - **C-Mod:** ELM cycle / pedestal structure, high-Z spectroscopy
  - **MAST / York:** Momentum transport studies / SAMI diagnostic
  - **QUEST:** CHI + ECH start-up research, EBW-CD start-up modelling (new)
  - **ITPA** halo current data / studies: DIII-D, AUG, C-Mod (+ NSTX / NSTX-U)

Reminder: Project / Program events since PAC-35

- Successful vessel pump-down (December 2014)
- Team-wide Research Forum (February 2015)
- Commissioning for 1st plasma, OH arc fault (April)
- PAC-36 - program letter, arc fault discussion (June)
- Arc recovery, corrective actions (May)
- First test plasma: 110→140kA, 0.5T (August)
- Bake, facility / diagnostic commissioning (Fall)
- Plasma commissioning: 800kA, 0.6T (late December)
- Diverted NBI H-mode achieved (January 2016)

Just begun operating! PAC input very timely, valuable

Presentations / agenda organized to aid you / PAC-37 in addressing charge questions

- Please assess the research planned to be carried out for the NSTX-U FY2016 experimental campaign
  – Are there any major missing elements, or new opportunities?
- Please assess the alignment between the NSTX-U research plans and goals and the FESAC / FES initiatives, research opportunities, and ITER urgent research needs.
- Please comment on the progress and plans for the NSTX-U / PPPL theory partnership, and how well this partnership and the broader NSTX-U research activities support "integrated predictive capability".
- Please comment on the present team prioritization of planned facility enhancements including:
  – Divertor cryo-pump, non-axisymmetric control coils (NCC), 28GHz gyrotron, conversion to high-Z PFCs + liquid metals research

Key Presentations:

◄ Menard, Ono, Maingi, Kaye, Gerhardt

◄ All (except Ono)

◄ Bhattacharjee, Boyer, Poli

◄ Menard, Ono, Maingi, Kaye, Gerhardt, Jaworski, Sabbagh

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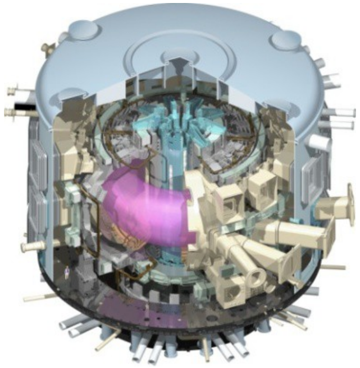
NSTX-U Mission Elements:

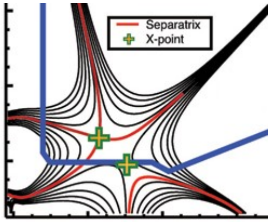
- Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond



ITER

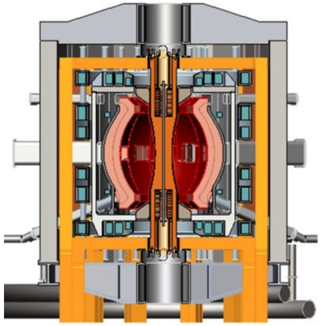
- Develop solutions for plasma-material interface (PMI)

Liquid metals / Lithium

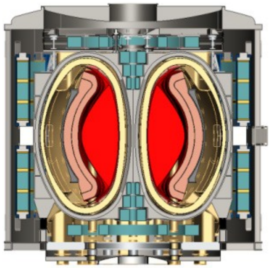


Snowflake/X

- Advance ST as Fusion Nuclear Science Facility and Pilot Plant

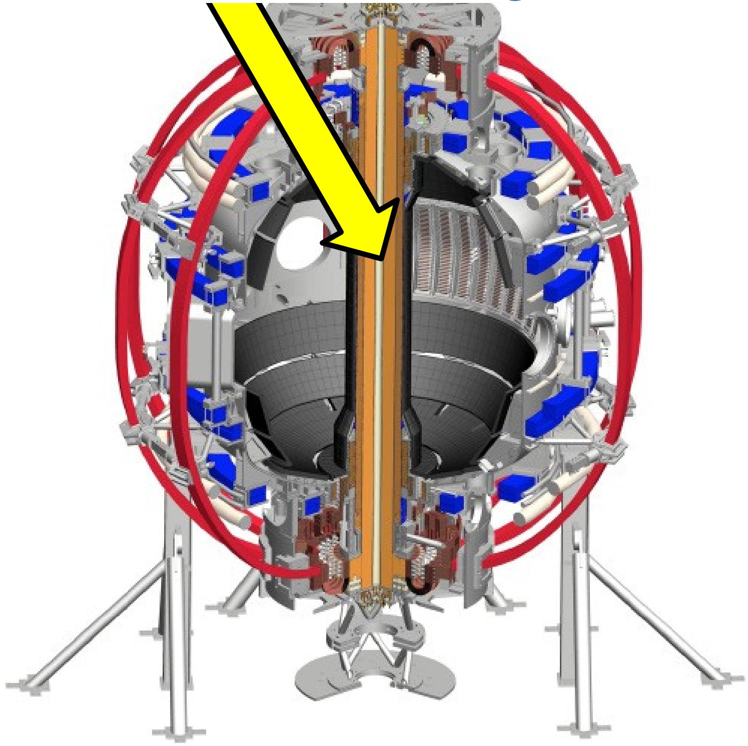


ST-FNSF / Pilot-Plant

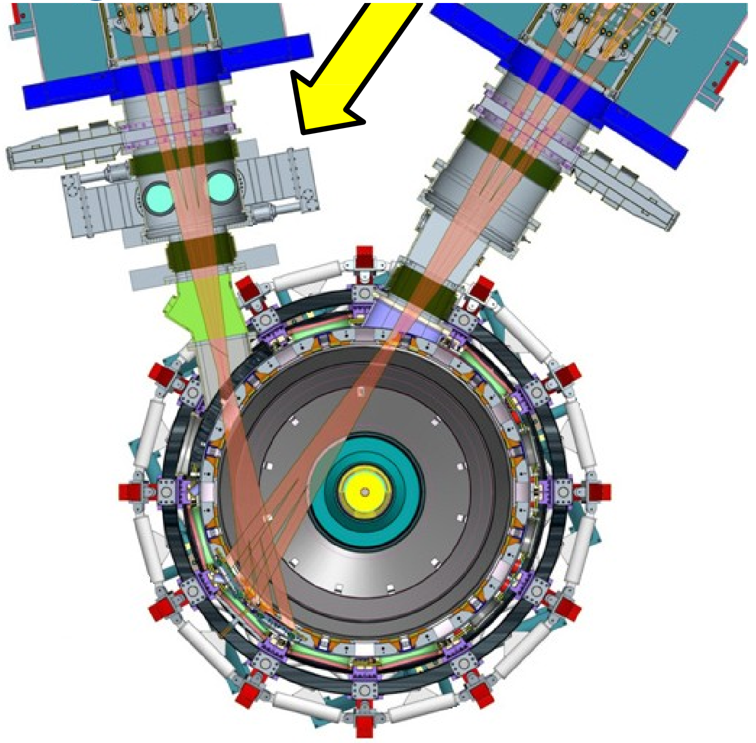


NSTX-U will access new physics with 2 major new tools:

1. New Central Magnet



2. Tangential 2nd Neutral Beam



<u>Higher T, low ν^* from low to high β</u>

→ Unique regime, study new transport and stability physics

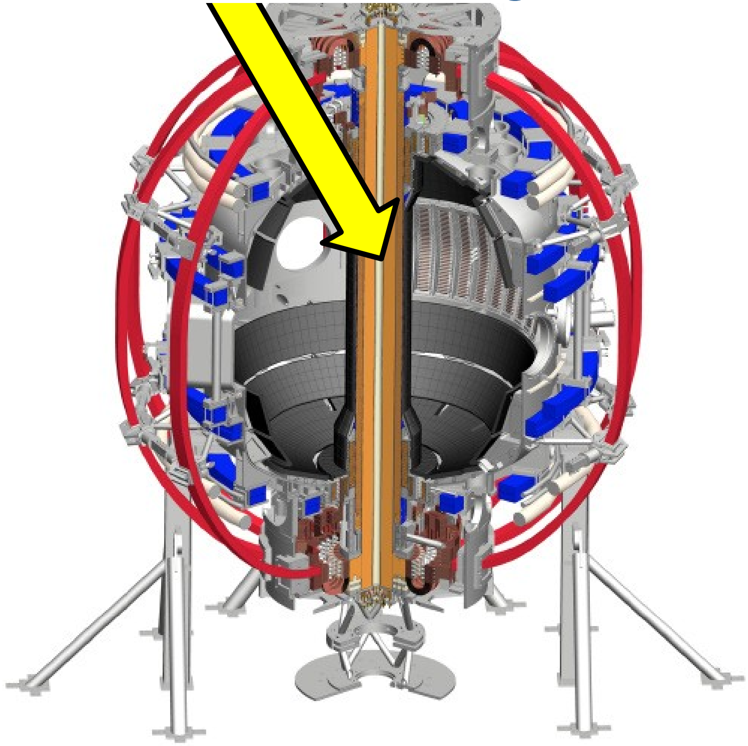
<u>Full non-inductive current drive</u>

→ Not demonstrated in ST at high-β_T

Essential for any future steady-state ST

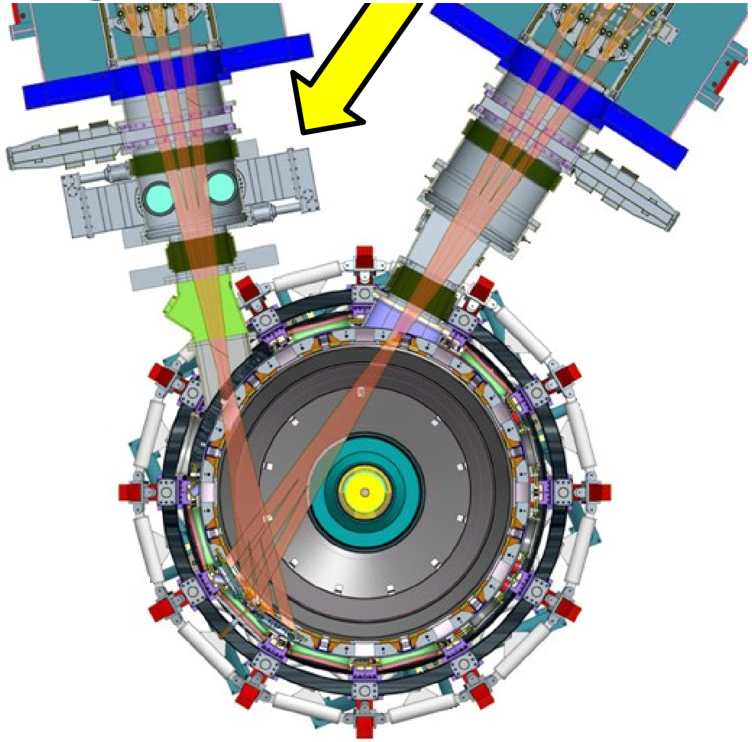
NSTX-U will have major boost in performance

1. New Central Magnet



- ➢2× toroidal field (0.5 → 1T)
- ➢2× plasma current (1 → 2MA)
- ➢5× longer pulse (1 → 5s)

2. Tangential 2nd Neutral Beam



- ➢2× heating power (5 → 10MW)
  - Tangential NBI → 2× current drive efficiency
- ➢4× divertor heat flux (→ ITER levels)
- ➢Up to 10× higher $nT\tau_E$ (~MJ plasmas)

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5 year goal: Establish core physics/scenarios for ST
10 year goal: Integrate high-performance core + metal walls

First 5 years	Second 5 years
Establish ST physics / scenarios:	**High-performance + metal walls**
• Confinement vs. β, collisionality • Sustain high β with advanced control • Non-inductive start-up, ramp-up • Mitigate high heat fluxes • Test high-Z divertor, Li vapor shielding	• Convert all PFCs from C to high-Z • Static → flowing Li divertor module(s), full toroidal flowing Li divertor, high T_{wall} • 5s → 10-20s for PFC/LM equilibration • Assess ST with high-Z, high-Z + Li
Inform choice of FNSF configuration:	**Inform choice of FNSF / DEMO plasma facing materials:**
• Lower A or higher A? • Standard, snowflake, Super-X (MAST-U)?	• High-Z consequences? need high-Z + Li? • Assess for both divertor and first-wall

Summary of FY2016-18 NSTX-U Research Milestones

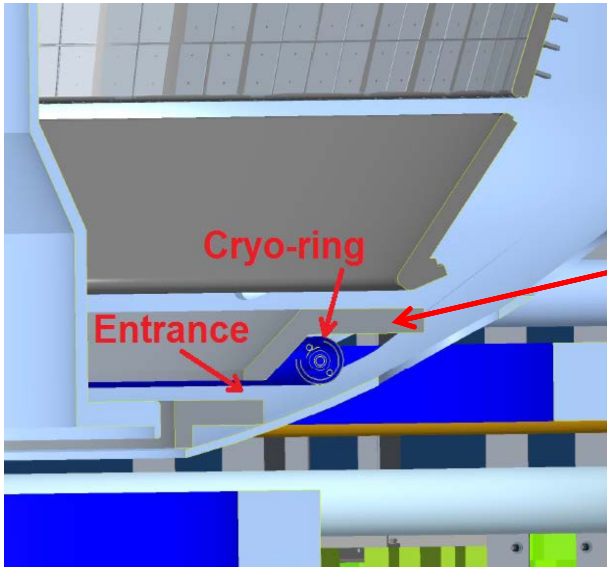
- **FY2016**
  - Obtain 1st data at 60% higher field/current, 2-3× longer pulse: — Milestone #
    - Re-establish sustained low l_i / high-κ operation above no-wall limit — ***R16-3***
    - Study thermal confinement, pedestal structure, SOL widths — ***R16-1***
    - Assess current-drive, fast-ion instabilities from new 2nd NBI — ***R16-2***
- **FY2017**
  - Extend NSTX-U performance to full field, current (1T, 2MA)
    - Assess divertor heat flux mitigation, confinement at full parameters — ***R17-1,3***
  - Access full non-inductive, small current over-drive — ***R17-4***
  - First 2D high-k scattering, test prototype high-Z tiles, HHFW — ***R17-2***, ***IR17-1***
- **FY2018**
  - Study low-Z and high-Z impurity transport — ***R18-1***
  - Assess causes of core electron thermal transport — ***IR18-2***
  - Test advanced q profile and rotation profile control — ***R18-2***
  - Assess CHI plasma current start-up performance — ***R18-3***
  - Divertor power and momentum balance (vapor shielding) — ***IR18-1***

NSTX-U Milestone Schedule for FY2016-18

	FY2016	FY2017	FY2018
Run Weeks: Incremental	**18**	**16** 18	**12** 16
Boundary Science + Particle Control	R16-1 Assess H-mode confinement, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}	R17-1 Assess scaling, mitigation of steady-state, transient heat-fluxes w/ advanced divertor operation at high power density R17-2 Assess high-Z divertor PFC performance and impact on operating scenarios	R18-1 Assess impurity sources and edge and core impurity transport IR18-1 Investigation of power and momentum balance for high density and impurity fraction divertor operation
Core Science	R16-2 Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile	R17-3 Assess τ_E and local transport and turbulence at low ν* with full confinement and diagnostic capabilities	IR18-2 Assess role of fast-ion driven instabilities versus micro-turbulence in plasma thermal energy transport Begin ~1 year outage for major facility enhancement(s) sometime during FY2018
Integrated Scenarios	R16-3 Develop physics + operational tools for high-performance: κ, δ, β, EF/RWM	IR17-1 Assess fast-wave SOL losses, core thermal and fast ion interactions at increased field and current R17-4 Develop high-non-inductive fraction NBI H-modes for sustainment and ramp-up	R18-2 Control of current and rotation profiles to improve global stability limits and extend high performance operation R18-3 Assess transient CHI current start-up potential in NSTX-U
FES 3 Facility Joint Research Target (JRT)	C-Mod leads JRT Assess disruption mitigation, initial tests of real-time warning, prediction	DIII-D leads JRT Examine effect of configuration on operating space for dissipative divertors	NSTX-U leads JRT TBD

Motivations for next major facility enhancements

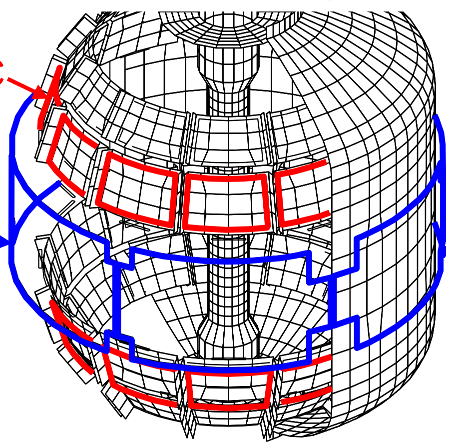
One (maybe 2) enhancement(s) feasible / affordable for FY18-19 outage



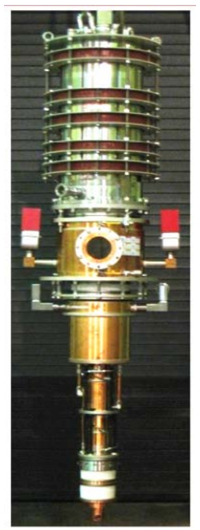
1. Divertor cryo-pump with high-Z baffle
   - Control density and ν^* without Li, compare to Li
   - Accelerate transition to high-Z PFCs, support liquid metal tests with bakeable baffle

2. Non-axisymmetric control coils (NCC)
   - Resonant, non-resonant NTV rotation control
   - RMP ELM suppression (not yet achieved in ST)
   - Enhanced RWM/EF control

Full toroidal NCC array (2 x 12)



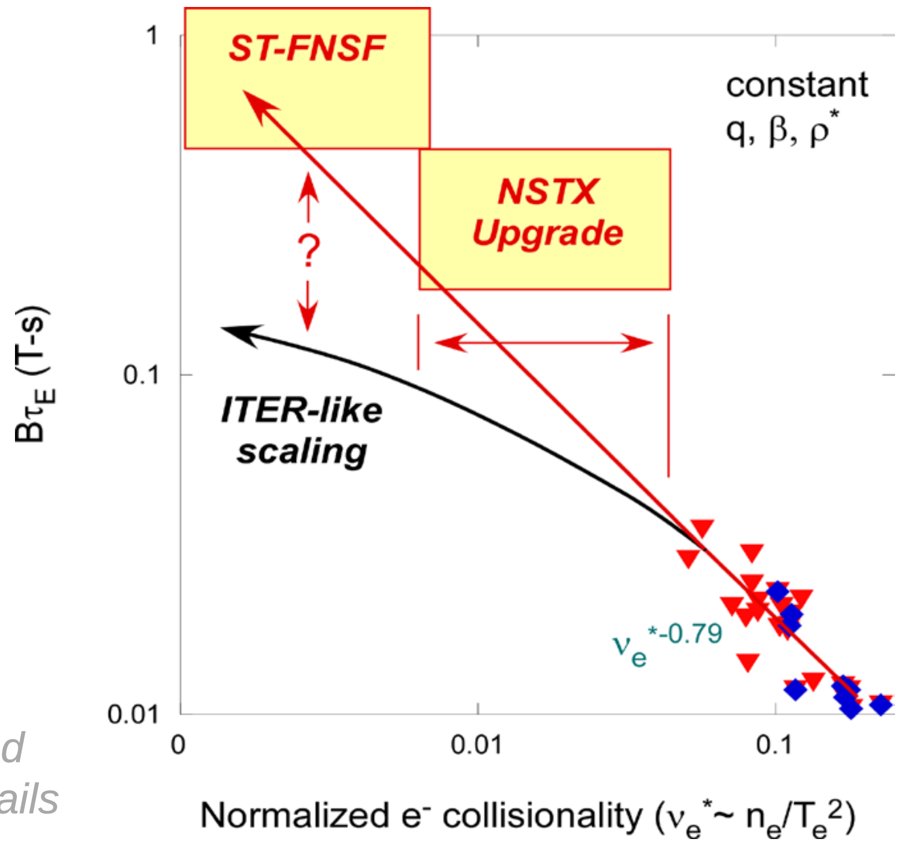
3. 28GHz / 1MW gyrotron (Tsukuba)
   - Heat CHI target w/ ECH for HHFW
   - EC/EBW-only CD for start-up
   - Longer-term: EBW CD for sustainment



Favorable confinement trend with collisionality and β found in ST experiments

ST scaling observed in NSTX and MAST: $\tau_{E,\,th} \propto \nu_{*e}^{-0.8}\ \beta^{-0.0}$

Tokamak empirical scaling (ITER 98y,2): $\tau_{E,\,th} \propto \nu_{*e}^{-0.1}\ \beta^{-0.9}$



See Bhattacharjee and Kaye talks for more details

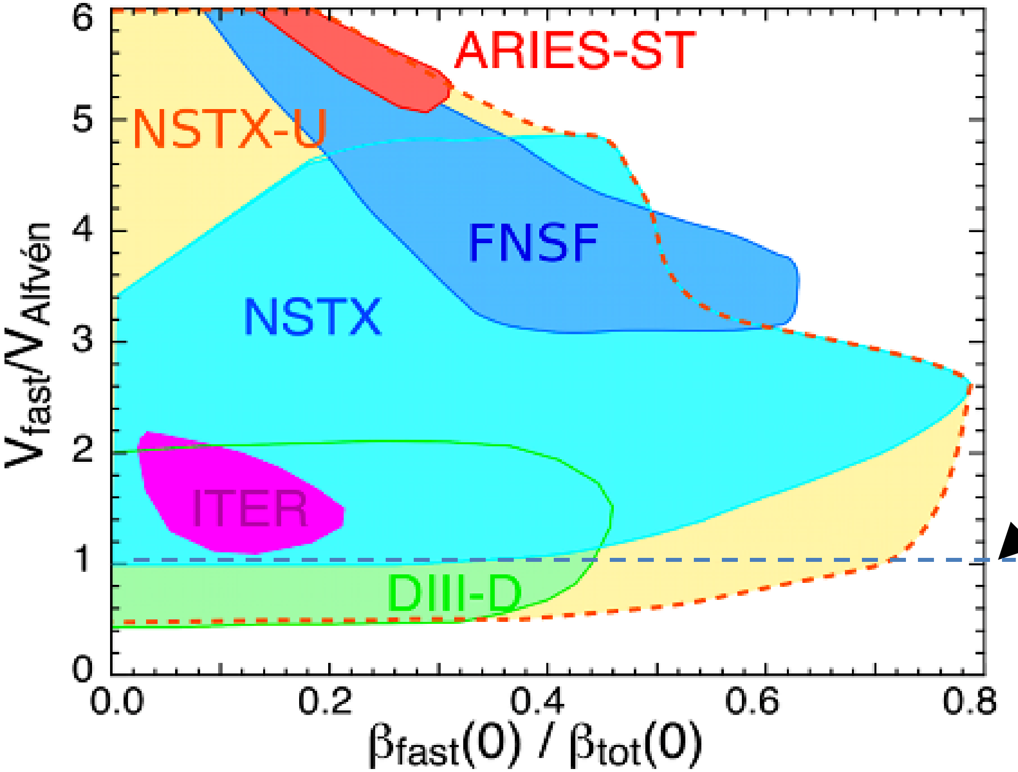
Role of enhancements:

Vary $\nu^* \leftrightarrow$ cryo, β, $\Omega_\phi \leftrightarrow$ NCC

Promising scaling to ST-FNSF / Pilot, will trend continue on NSTX-U / MAST-U?

NBI-heated STs excellent testbed for α-particle physics

- α-particles couple to Alfvénic modes when $V_\alpha > V_{Alfvén} \sim \beta^{-0.5} C_{sound}$
- $V_{fast} > V_A$ condition easily satisfied in high-β ST with NBI heating



- NSTX-U: large fast-ion dynamic range spanning ST and conventional A
  - **Toroidal field 2× NSTX →** $V_{fast} < V_A$ → stabilize modes
  - **Tangential 2nd NBI →** very flexible fast-ion distribution
    - Vary pitch angle, pressure profile

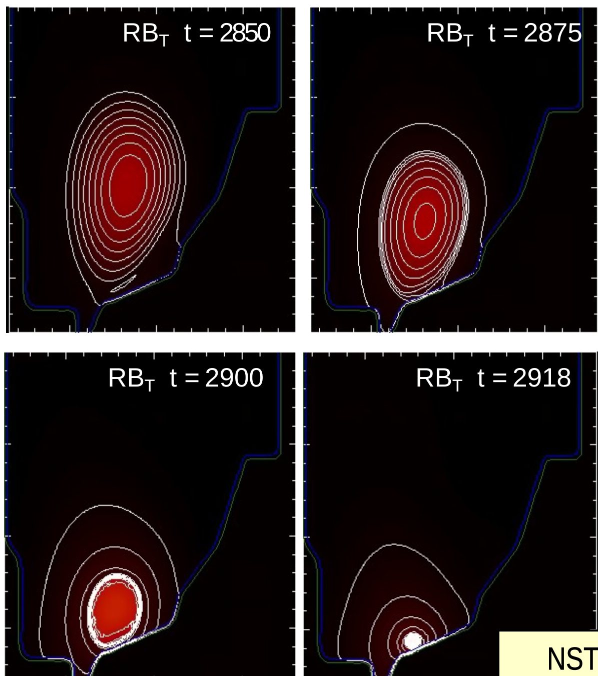
Role of enhancements:

Vary $\beta_{fast} / \beta_{tot} \leftrightarrow$ cryo, $\Omega_\phi \leftrightarrow$ NCC

Can we find TAE-quiescent, high-performance regimes in NSTX-U?

NSTX-U aims to play leading role in disruption prediction, avoidance, and mitigation (DPAM) for ITER and FNSF

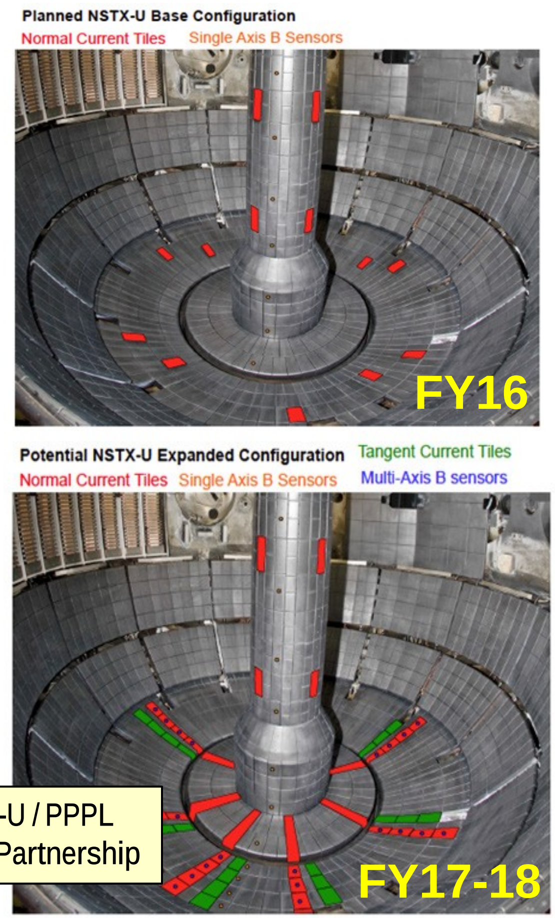
- Advanced non-linear MHD modelling of vertical displacement events (VDE) + halo currents with M3D-C[1]



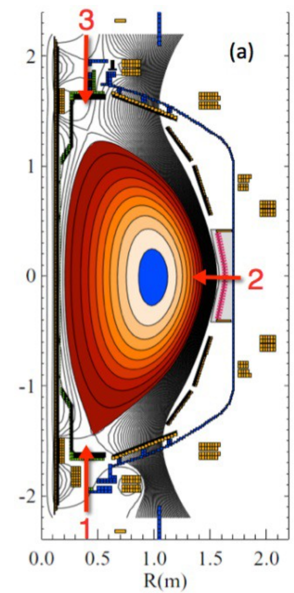
NSTX Discharge 132859

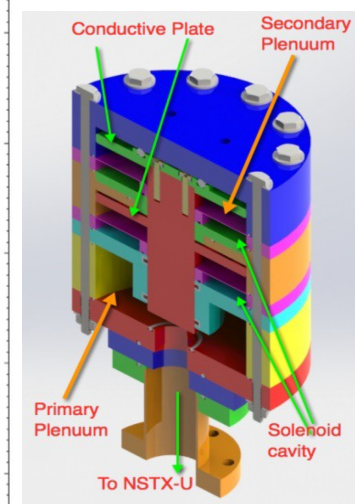
NSTX-U / PPPL Theory Partnership

- Enhance measurements of halo-current dynamics



- Test ITER-like Massive Gas Injection (MGI) valves
  - Test poloidal dependence of density assimilation
  - First data expected FY16





University of Washington

Role of enhancements:

Control $\nu^* \leftrightarrow$ cryo, β, $\Omega_\phi \leftrightarrow$ NCC

See Bhattacharjee and Sabbagh talks for more details

Design studies show ST potentially attractive as Fusion Nuclear Science Facility (FNSF) or Pilot Plant

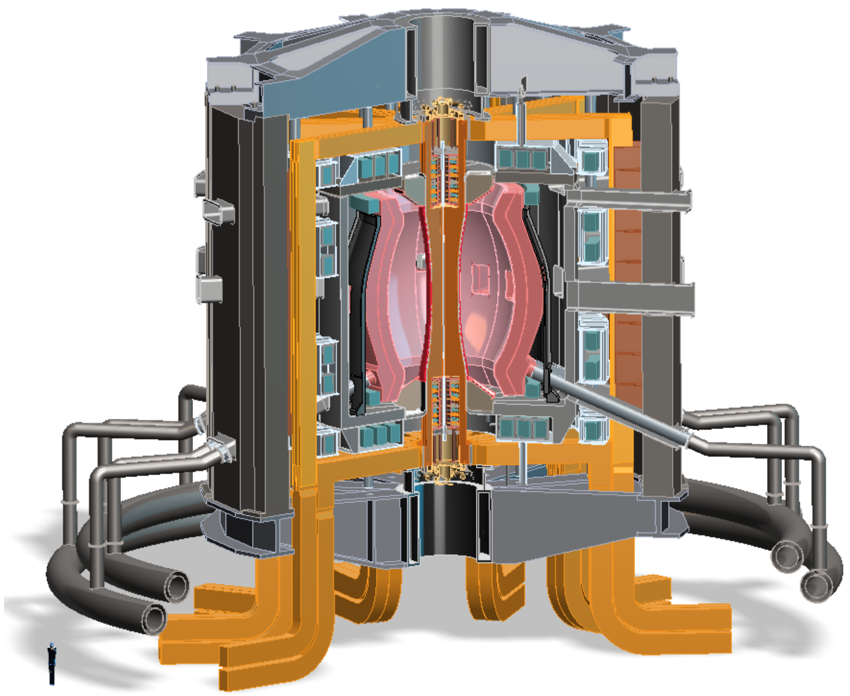
FNSF: Provide neutron fluence for material/component R&D (+ T self-sufficiency?)

Pilot Plant: Electrical self-sufficiency: $Q_{eng} = P_{elec} / P_{consumed} \geq 1$ (+ FNSF mission?)

FNSF with copper TF coils

$A=1.7$, $R_0 = 1.7$m, $\kappa_x = 2.7$

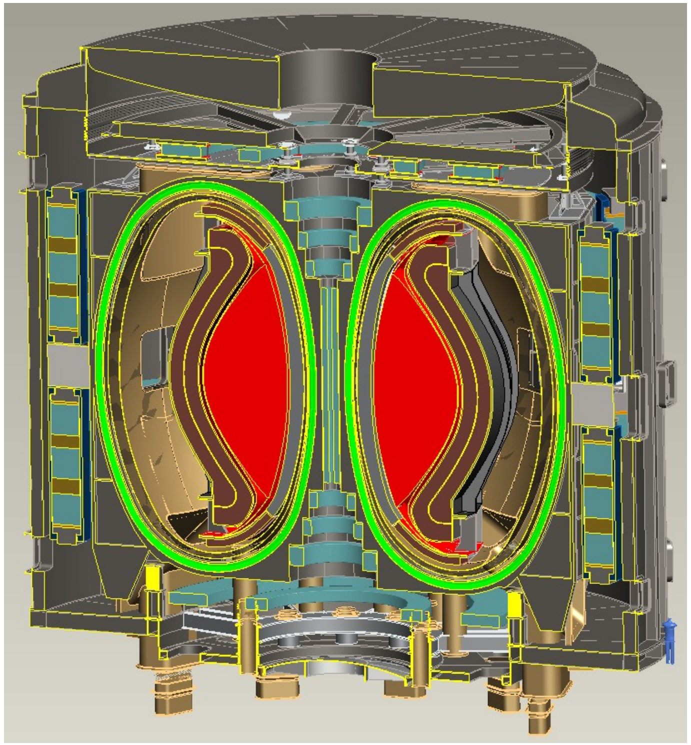
Fluence = 6MWy/m^2, TBR ~ 1



FNSF / Pilot Plant with HTS TF coils

$A=2$, $R_0 = 3$m, $\kappa_x = 2.5$

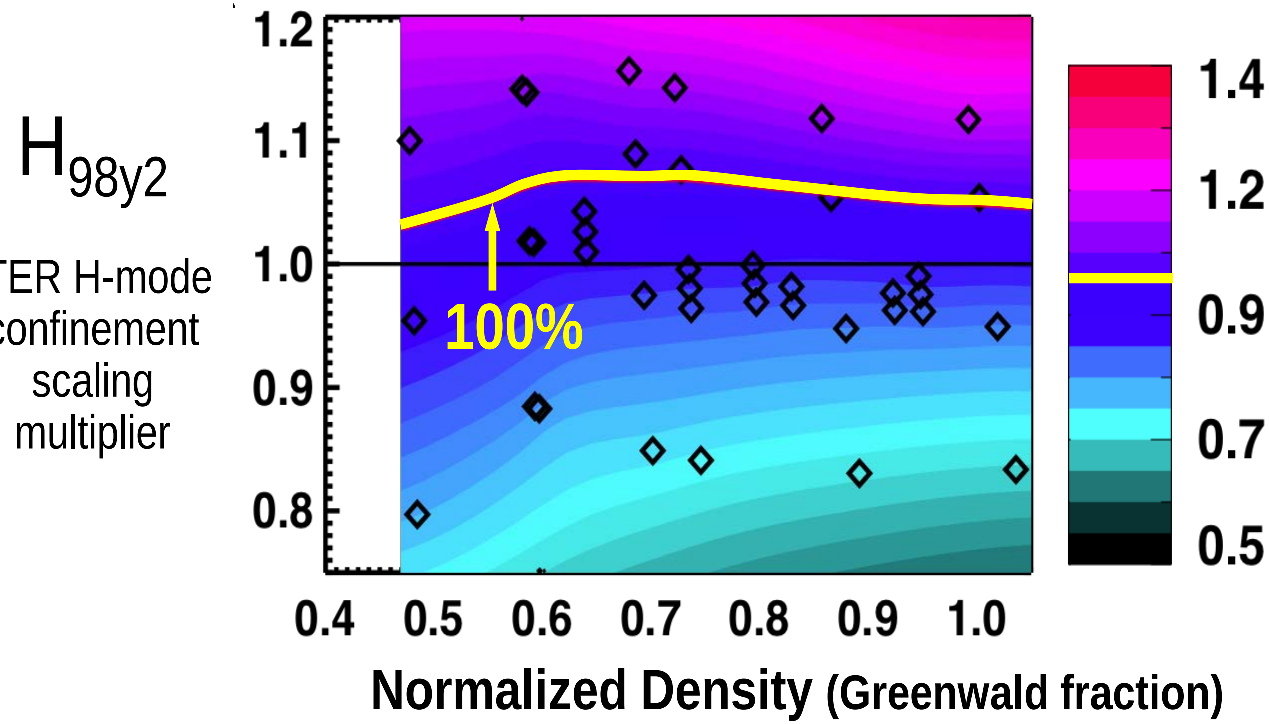
6MWy/m^2, TBR ~ 1, Q_{eng} ~ 1



Steady-state operation required for ST/AT FNSF or Pilot Plant

NSTX achieved 70% “transformer-less” current drive

NSTX-U designed to achieve 100% (TRANSP):



See Boyer and Gerhardt talks for more details

I_P=1 MA, B_T=1.0 T, P_{NBI}=12.6 MW

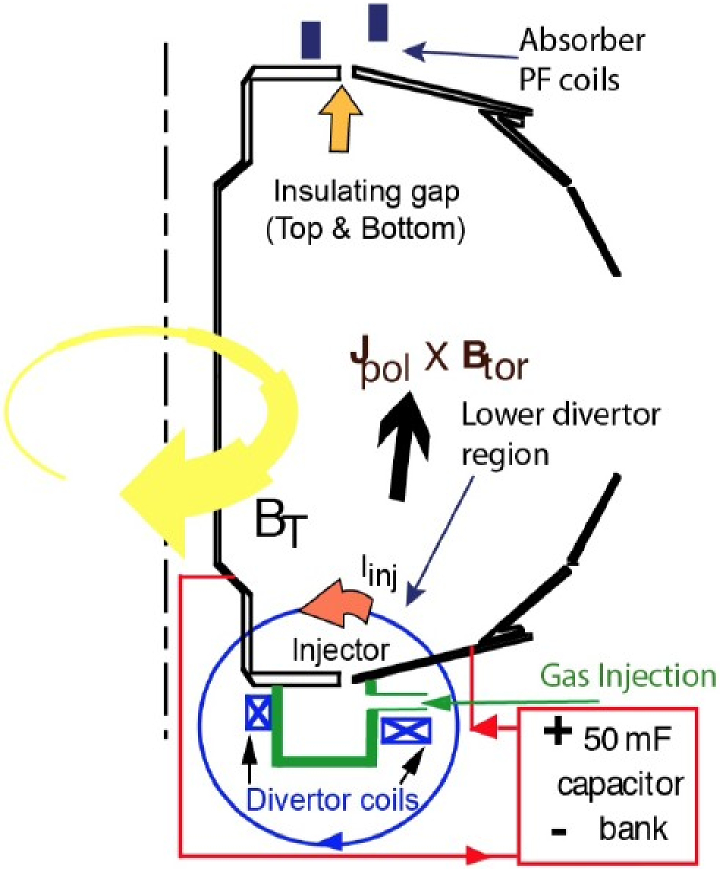
Role of enhancements:

Control n_e / n_{gw} ↔ cryo, β, Ω_ϕ ↔ NCC

Will NSTX-U achieve 100% as predicted by simulations?

ST-FNSF may need solenoidless current start-up method
Coaxial Helicity Injection (CHI) effective for current initiation

CHI developed on HIT, HIT-II
Transferred to NSTX / NSTX-U

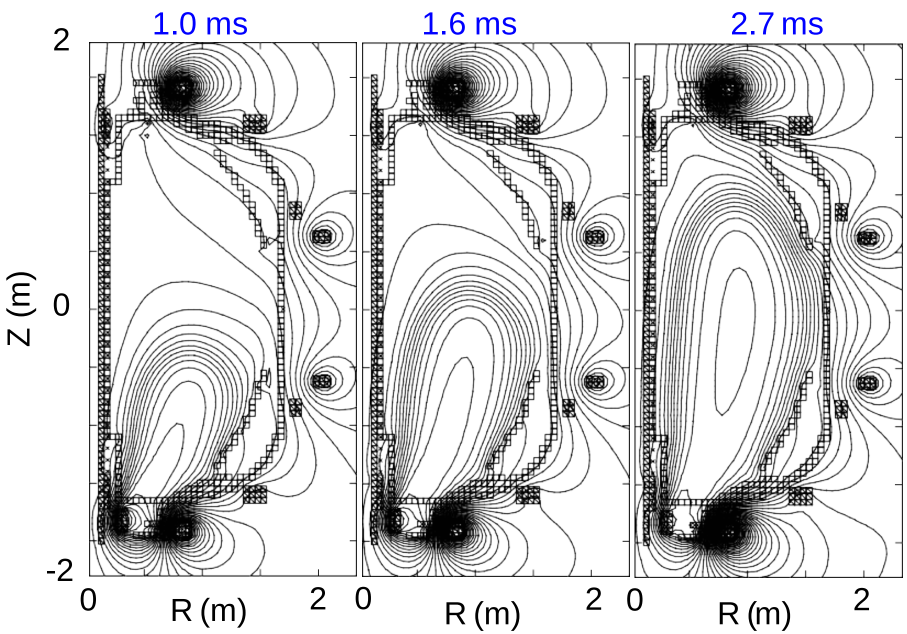


R. Raman et al., PRL 2006

NSTX: 150-200kA closed flux current

NSTX-U: CHI projects to 300-400kA

TSC axisymmetric simulation of CHI startup

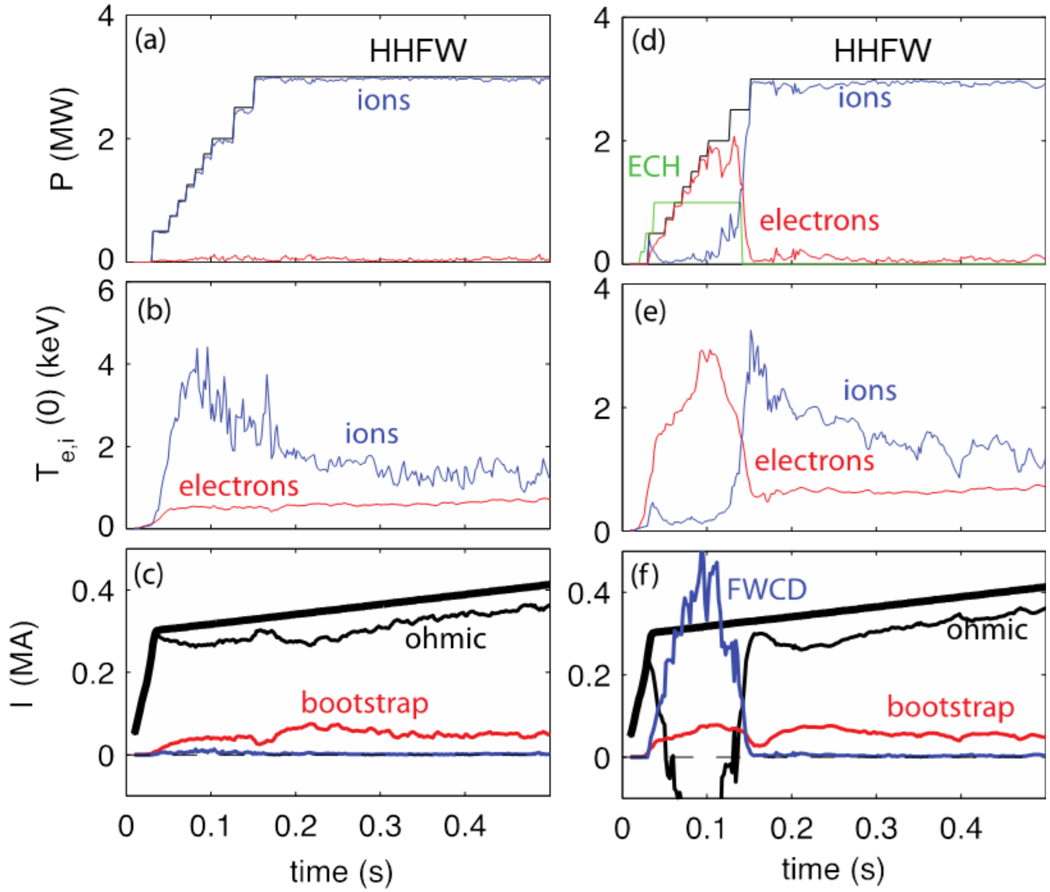


Role of enhancements:
High-Z divertor tiles ↔ reduce low-Z P_{rad}

1MW 28GHz ECH / EBW gyrotron is game-changer for solenoid-free start-up

- CHI can form I_P=300-400kA, but:
  - T_e too low for HHFW absorption
  - Density too low and I_P decay too fast for NBI absorption in CHI plasma
- Good ECH first pass absorption predicted → "bridge the T_e gap"
- Strong ECH + High-Harmonic Fast-Wave (HHFW) synergy found in TRANSP simulations of non-inductive start-up
  - Sustain I_P enough for NBI to couple (not shown)
- EBW-only start-up also promising
  - High η_{CD} ~1 A/W in MAST, QUEST

HHFW phasing: $k_{||}$ = 3m^{-1} (CD)

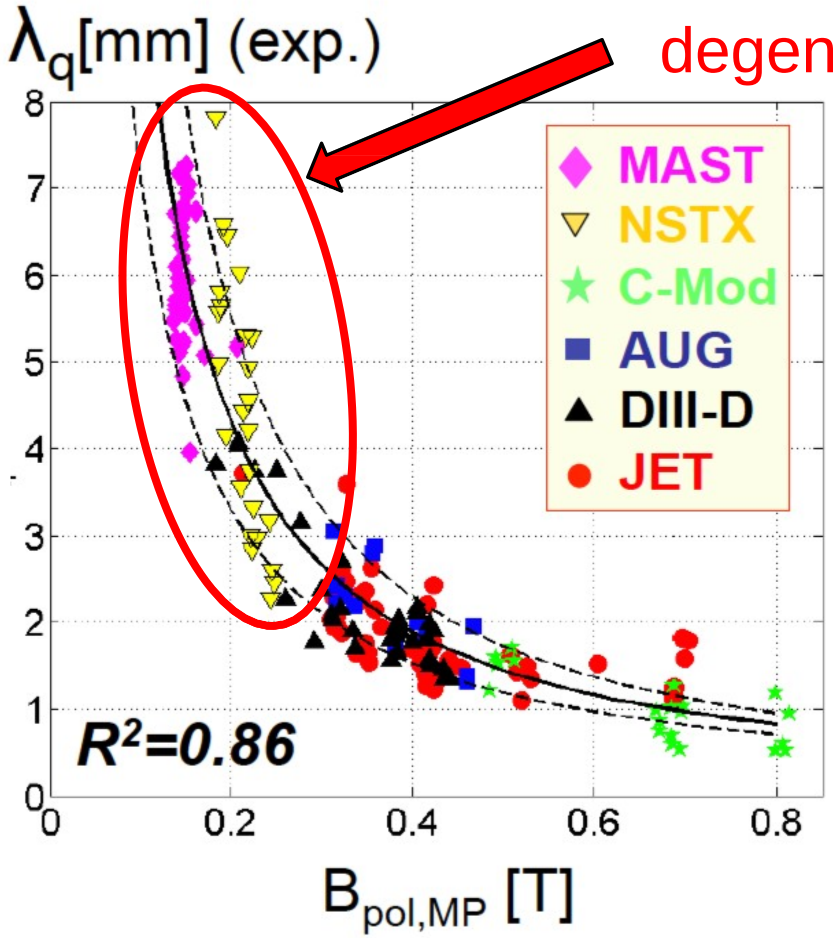


See Poli and Gerhardt talks for more details

<u>Role of enhancements:</u>
Gyrotron, also n_e control ↔ cryo

Dedicated tokamak + ST experiments found power exhaust width varies as 1 / $B_{poloidal}$

ST data breaks aspect ratio degeneracy of data set



Role of enhancements:

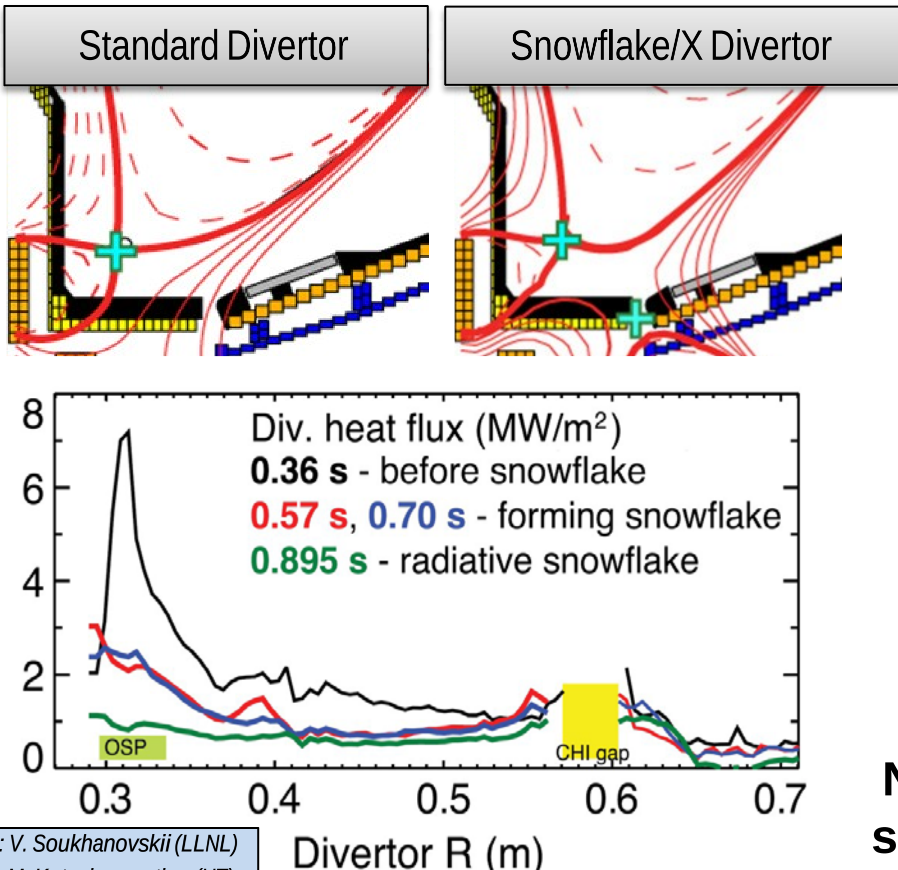
Control n_e and detachment ↔ cryo

3D/RMP effects in divertor ↔ NCC

Will 1/$B_{poloidal}$ variation continue at higher I_P? What about detached conditions?

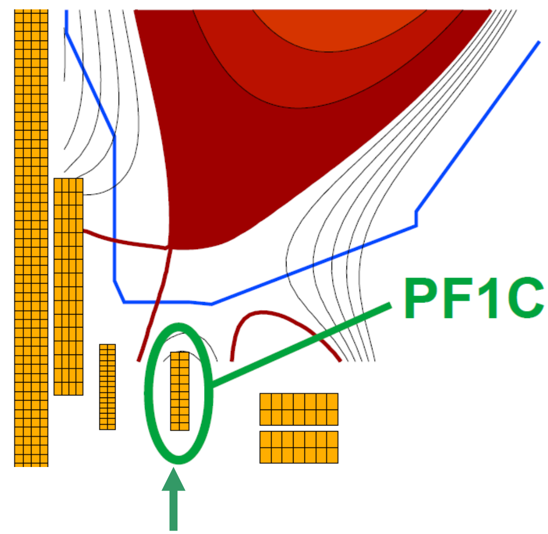
NSTX-U will test ability of radiation and advanced divertors to mitigate very high heat-fluxes

- NSTX: reduced heat flux 2-4 × via radiation (partial detachment)
- Additional null-point in divertor expands field, reduces heat flux



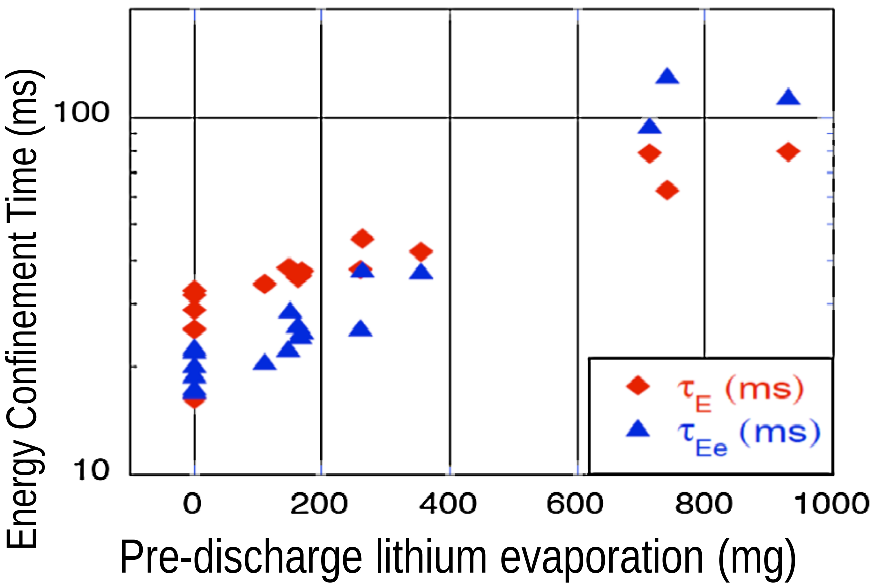
SFD: V. Soukhanovskii (LLNL)
XD: M. Kotschenreuther (UT)

NSTX-U peak heat fluxes will be up to 4-8 × higher than in NSTX



NSTX-U has additional coils for up-down symmetric snowflake/X, improved control

Plasma confinement increased continuously with increasing Li coatings in NSTX – what is limit?



R. Maingi, et al., PRL 107 (2011) 145004

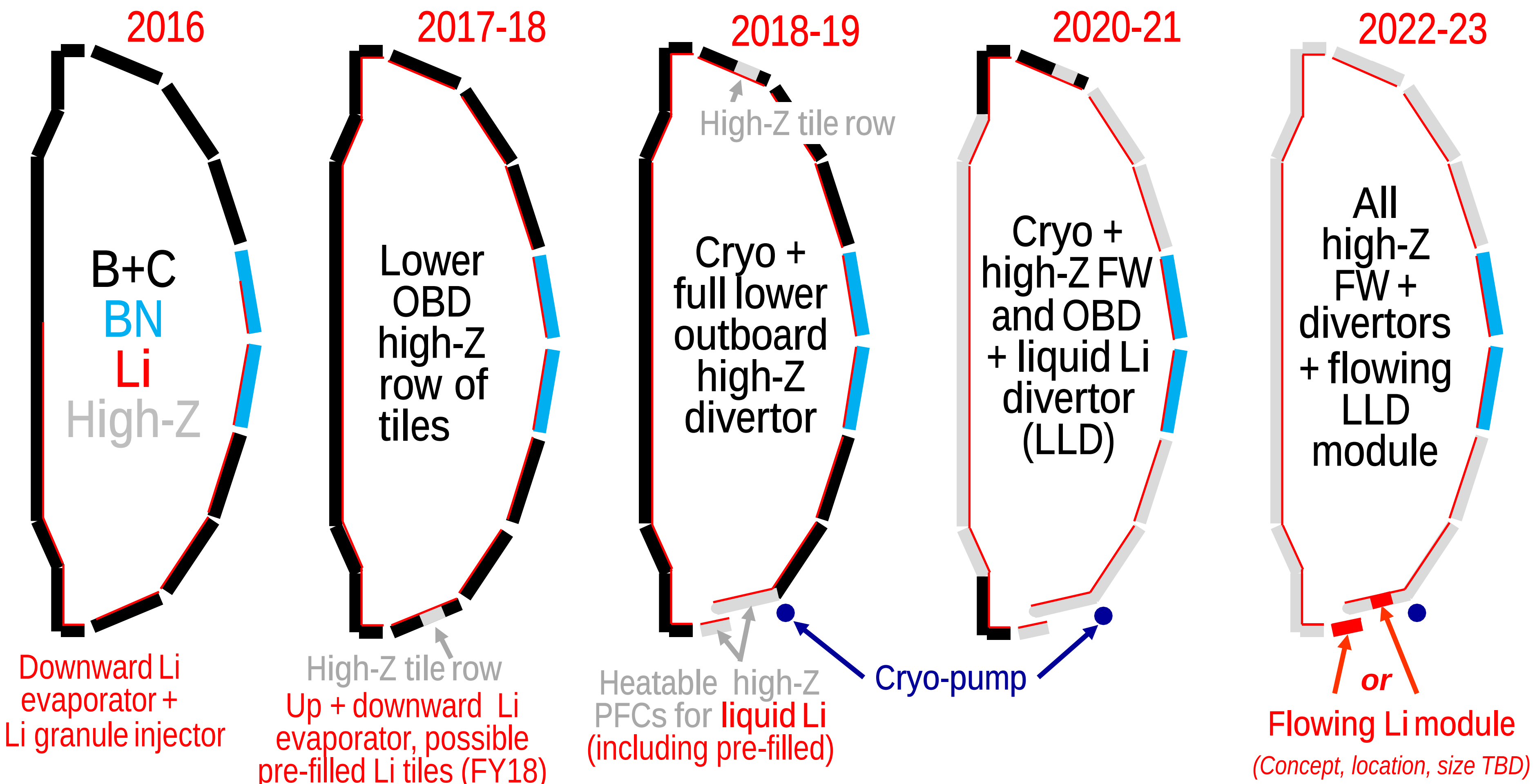
- Global parameters improve
  - H_{98y2} increases ~0.9 → 1.4
  - No core Li accumulation
- High H critical for compact FNSF / Pilot Plants

- NSTX-U will double Li-wall coverage with upward evaporators
- Will further assess contributors to confinement improvement:
  - Lower-recycling / reduced neutral source / higher T_e
  - Edge profile / turbulence changes
  - Influence of (low-Z) impurities in pedestal region

Role of enhancements:
Compare Li-wall pumping to conventional pumping ↔ cryo

NSTX-U boundary / PFC plan: add divertor cryo-pump, transition to high-Z wall, study flowing liquid metal PFCs

- **5yr goal: Integrate high τ_E and β_T with 100% non-inductive**
- **10yr goal: Assess compatibility with high-Z & liquid lithium PFCs**



See Maingi, Jaworski talks for more details

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New NSTX-U Science organizational structure for 2015-16:
3 Science Groups, 9 Topical Science Groups, 1 Task Force

Science Group (SG)

Topical Science Group (TSG)

Task Force (TF)

Boundary Science Group
R. Maingi, C.-S. Chang (deputy)

- Pedestal Structure and Control
  A. Diallo, R. Maingi
  Theory/Modelling: J. Canik[1]
  University Rep: D. Smith[2]
- Divertor and Scrape-Off-Layer
  V. Soukhanovskii[3], J.-W. Ahn[1]
  Theory/Modelling: D. Stotler
  University Rep: O. Schmitz[2]
- Materials and PFCs
  M. Jaworski, C. Skinner
  Theory/Modelling: B. Wirth[4]
  University Rep: J.-P. Allain[5]

Core Science Group
S. Kaye, S. Sabbagh[6] (deputy)

- Macroscopic Stability
  J. Berkery[6], J.-K. Park
  Theory/Modelling: S. Jardin
  University Rep: D. Brennan[7]
- Transport and Turbulence
  W. Guttenfelder, Y. Ren
  Theory/Modelling: W. Wang
  University Rep: K. Tritz[8]
- Energetic Particles
  M. Podestá, D. Liu[9]
  Theory/Modelling: N. Gorelenkov
  University Rep: N. Crocker[10]

Integrated Scenarios Group
S. Gerhardt, R. Raman[11] (deputy)

- Advanced Scenarios and Control
  D. Battaglia, S. Gerhardt
  Theory/Modelling: F. Poli
  University Rep: E. Kolemen[7]
- Solenoid-free Start-up & Ramp-up
  D. Mueller, R. Raman[11]
  Theory/Modelling: F. Ebrahimi[7]
- Wave Heating and Current Drive
  R. Perkins, J. Hosea
  Theory/Modelling: N. Bertelli
  University Rep: P. Bonoli[12]

Particle Control Task Force (FY2016-17)
Leader: J. Canik[1], **Deputy:** R. Maingi

Goal: Develop pumping and fueling tools, operating scenarios, and control systems to achieve main-ion and impurity density control for long-pulse

Collaborators in Science Program Leadership:

1	ORNL
2	University of Wisconsin
3	LLNL
4	UT Knoxville
5	University of Illinois
6	Columbia University
7	Princeton University
8	Johns Hopkins University
9	UC Irvine
10	UC Los Angeles
11	University of Washington
12	MIT

Each TSG has a leader, deputy, theory rep, and at least 1 university rep to enhance university participation

Task Force focuses resources on particle control – important for NSTX-U research goals, addresses PAC recommendations

12 collaborating institutions engaged in NSTX-U science program leadership

Motivations for restructuring science program

- TSGs provide expertise in broad range of topics, but program would benefit from better coordination between TSGs
  - SG leader responsibility: Coordinate TSG physics research plans, experimental/shot plans, diagnostic coverage & usage
- Efficient shot usage especially important during first run year (many systems need to be re-commissioned)
  - Experiments that engage multiple TSGs receive more run-time
- Incorporate much wider set University researchers/PIs in planning + coordination of research program (FES/PPPL goal)
- New - Task Force for long-pulse particle control
- New - Working Groups: Disruption PAM (Sabbagh, Raman), NCC performance spec (Park, Canik), data frameworks (Tritz, Yuh, Smith)
  - Task Forces have dedicated run-time, Working Groups do not, but recommend Program/SG/TSG actions

NSTX-U university collaborators spearheaded new outreach seminar effort –11 talks given so far

J. Berkery (CU), D. Smith (UW)

National Spherical Torus eXperiment Upgrade

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NSTX-U Web Pages:

- Home
- Overview
- Mission
- Accomplishments
- Collaboration Info
- Data Management Plan
- Diagnostics
- Five Year Plans
- Group Links / Files / Email
- Joint Research Targets
- Milestones
- Operations
- Organization
- **Outreach Seminars**
- Program
- Project
- Publications & Presentations
- Remote Connection Info
- Reports
- Research Forum - 2015
- Roles and Responsibilities
- Run Coordination
- Run Schedule Calendar
- Science Groups
- Scientific Conferences
- Software
- Surface Science
- Task Forces
- User Information Form
- Working Groups
- NSTX Upgrade Overview
- NSTX Upgrade Project

Program >

Outreach Seminars

The following NSTX-U team members are available to give seminars at your institution on the topics / titles listed below, and may also be willing to speak on other related topics as well. If you are interested, please contact the speaker directly and CC Stan Kaye (kaye@pppl.gov), or click on an e-mail link below.

Name	e-mail	Research interest / specialty	Prospective Talk Title
Jack Berkery	jberkery@pppl.gov	Fusion plasma stability	"Resistive wall mode stability in NSTX"
Walter Guttenfelder	wgutten@pppl.gov	Turbulence in magnetized fusion plasmas	"Understanding turbulence at 100 million degrees"
Ahmed Diallo	adiallo@pppl.gov	H-mode pedestal, diagnostics	"Taming the plasma edge for optimum fusion performance"
Devon Battaglia	dbattagl@pppl.gov	Tokamak startup, H-mode physics, high-performance computing	"Physics operations and scenario development on NSTX-U"
Jon Menard	jmenard@pppl.gov	Research program, next-step devices, MHD physics	"NSTX-U program overview" ***or*** "Prospects for next-step STs"
David Smith	drsmith@pppl.gov	Plasma turbulence and instabilities, turbulence diagnostics	"Characterizing edge instabilities with machine learning ..."
Clayton Myers	cmyers@pppl.gov	Tokamak disruptions and error fields, laboratory astrophysics	"Two Challenges ... Operation: Error F... "Bringing the Cos... Astrophysical Pro...
Rory Perkins	rperkins@pppl.gov	Radio frequency heating	"Fast wave powe... field lines in NST...
Steven Sabbagh	sabbagh@pppl.gov	Tokamak plasma stability and control for disruption prediction and avoidance	"Global Mode Stal... in Tokamaks"
Matt Reinke	mreinke@pppl.gov	Plasma diagnostics, impurities and exhaust	"Fusion Plasma D... Measurements a...
Keith Erickson	kericksо@pppl.gov	Real-time Linux solutions	"Real-time plasm...
Roger Raman	rraman@pppl.gov	Coaxial helicity injection, non-inductive plasma formation	"Solenoid-free Pla...
Rajesh Maingi	rmaingi@pppl.gov	Boundary physics, lithium program	"The Benefit of C... Fusion Research...

Past NSTX-U Outreach Seminars

Date	Presentation Location	Speaker	Title
1/17/2016	General Atomics	Mike Jaworski	NSTX-U upgrade plan for liquid-metal plasma-facing components
11/03/2015	The College of New Jersey	Clayton Myers	Bringing the Cosmos Down to Earth: Studying Astrophysical Processes in Laboratory Experiments
10/30/2015	MIT / PSFC	Clayton Myers	Laboratory study of ideal MHD solar instability eruption mechanisms
10/26/2015	University of Washington	Jack Berkery	Progress and Plans for NSTX Upgrade and Kinetic Resistive Wall Mode Stability
10/24/2015	APS Mid-Atlantic Section Morgantown, WV	Jon Menard	Progress and plans for NSTX Upgrade and prospects for next-step spherical tori
9/16/2015	Fermilab	Jon Menard	Brief overview of PPPL, fusion, and NSTX-U
9/14/2015	University of Wisconsin	Jon Menard	Progress and plans for NSTX Upgrade and prospects for next-step spherical tori
9/4/2015	University of Rochester	Devon Battaglia	The Mission of NSTX-U Toward the Development of Fusion Energy
9/3/2015	West Virginia University	Rajesh Maingi	The Benefit of Coating the Plasma Facing Surfaces of Fusion Research Chambers with Low-Atomic-Number Materials in Keeping Plasma Hot, Confined, and Fusing
5/8/2015	Columbia University	Steve Sabbagh	Global MHD Mode Stabilization for Disruption Avoidance in Tokamaks
4/20/2015	Cornell University	Rajesh Maingi	The Benefit of Coating the Plasma Facing Surfaces of Fusion Research Chambers with Low-Atomic-Number Materials in Keeping Plasma Hot, Confined, and Fusing

Research Forum held February 2015

Experimental proposals prioritized using several criteria:

- Viability of proposal given available NSTX-U capabilities
- OFES Joint Research Targets / Milestones
- NSTX-U Research Milestones, Facility Enhancement design
- ITER: Direct IO requests, ITPA: NSTX-U is leader / prominent
- Experiments leading to high-profile publications/presentations:
  - PRL, Science, Nature   Invited talks: **IAEA**, **APS**, EPS, Sherwood, …
- Career development: PhD thesis, post-doctoral research
- Any good idea generated during run – potential "break-thru" ?
- Maximize institutional / researcher breadth of XP leadership

Very strong interest in NSTX-U research

Requested research time exceeds available time by factor of 4

Forum guidance / plan (Feb 2015): 16 run weeks
Recently incremented to 18 run weeks = 90 total run days

Requested / Available Run Time:

Total: 273 / 90 = ~3×

Research: 243 / 60 = ~4×

TSG / TF run-time guidance for FY16:

Baseline # run weeks:	18
Estimated total # run days:	90
Estimated XMP run-days	30 — Cross-cutting commissioning, shot development, calibrations
Reserve for multi-TSG XPs	10
Contingency / director's reserve	5
Nominal total days for TSG/TFs to prioritize	55
Minimum # run days per TSG / TF	3.2
Milestone weighting for FY16 and FY17 runs	0.8 (FY16), 0.2 (FY17)
Priority #1 fraction	0.75

	TSG / Task Force	FY 16 Milestones	FY17 Milestones	Nominal TSG / TF run days for all XPs	Nominal Priority 1 XP run time	Nominal Priority 2 XP run time
Boundary	Pedestal	R16-1		5.5	4	1.5
	Divertor and SOL	R16-1	JRT-17, R17-1	6	4.5	1.5
	Materials and PFCs		R17-2	4	3	1
Core	Macroscopic Stability	JRT-16, R16-3		6.5	5	1.5
	Transport & Turbulence	R16-1	R17-3	5.5	4	1.5
	Energetic Particles	R16-2		5.5	4	1.5
Scenarios	Advanced Scenarios and Control	Notable, JRT-16, R16-2,3	JRT-17, R17-4	8.5	6.5	2
	Solenoid-Free Start-up		R17-4	4	3	1
	Wave Heating and Current Drive		IR17-1	4	3	1
Task Forces	Particle Control	R16-3		5.5	4	1.5
				55	41	14

~85% of requested time

84 unique lead author names

#	Institution	Run Days Requested	Fraction
1	Princeton Plasma Physics Laboratory	112.1	41.1%
2	Oak Ridge National Laboratory	28.5	10.5%
3	Princeton University	20.5	7.5%
4	Lawrence Livermore National Laboratory	18	6.6%
5	General Atomics	17	6.2%
6	ITER (France)	12	4.4%
7	University of Washington	11.5	4.2%
8	Columbia University	10.5	3.9%
9	University of Wisconsin	9	3.3%
10	University of California - Irvine	7.5	2.8%
11	Nova Photonics	6	2.2%
12	University of Illinois	4	1.5%
13	Massachusetts Institute of Technology	4	1.5%
14	University of California - San Diego	3	1.1%
15	Johns Hopkins University	3	1.1%
16	University of Tennessee	2	0.7%
17	Lehigh University	1	0.4%
18	Florida International University	1	0.4%
19	University of California - Los Angeles	1	0.4%
20	University of York (United Kingdom)	1	0.4%
		272.6	100%

Experimental proposal preparation and execution well underway

- 29 eXperimental Machine Proposals (XMP) for commissioning / calibration identified and/or written
  - 11 of the 29 already being executed (see Battaglia listing)
  - Expect ~5-6 run weeks of XMP
- 27 eXperimental Proposals (XPs) written, reviewed for highest priority (P1a) experiments ~6 run weeks

►~1/2-2/3 of FY16 run-time has XMP/XP ready

- Additional allocations:
  - High priority experiments - P1b,c ~3.5-4 run weeks
  - Priority P2a,b ~ 1.5-2 run weeks
  - Reserve ~1 run week
- For more info see: Master Spreadsheet of XMPs and XPs

Research Operations Goals for first 2 run-months
(still consistent with Forum guidance / assumptions)

- Machine Commissioning – ~1 month (run weeks 1-4)
  - Develop basic breakdown, current ramp, shape/position control, diverted plasmas, H-mode access, basic fuelling optimizations.
  - Diagnostic commissioning
  - Boronized PFCs
  - Mostly XMPs
  - Goal: 1 MA, 0.5 T, NBI-heated H-mode (i.e. ~NSTX fiducial levels)

We are here at ~2.5 run weeks

- 1st Month of Science Campaign (run weeks 5-8)
  - Boronized PFCs, possibly begin Li coatings (end of period)
  - Operations and basic profile diagnostics, neutron rate,…
  - HHFW available for commissioning
  - 6 beam sources up to 90 kV
  - Operation up to 1.4 MA and 0.65 T, 2 seconds

M. Ono talk will cover operational readiness

Outline

- Events since PAC-35
- Charge Questions
- Mission and Capabilities of NSTX-U
- Research Goals and Milestones
- Key Scientific Issues NSTX-U Will Address
- Organizational Structure
- Run Coordination
- Support for FESAC / FES Strategic Goals
- Summary

Substantial leadership and participation in FES workshops by NSTX-U, collaborators, PPPL

- Transients: 36% of 67 whitepapers: 13 for disruptions, 11 for ELMs
  – Co-chair: R. Nazikian
  – Disruptions: D. Brennan (co-lead), S. Sabbagh, D. Gates
  – ELMs: R. Nazikian (lead), J. Canik (co-lead), O. Schmitz, W. Solomon
- PMI: 29% of 56 whitepapers - evenly split among topical areas
  – Chair: R. Maingi ← hosted by PPPL
  – SOL / Div: R. Goldston, J. Myra, V. Soukhanovskii
  – PMI / Div. Simulators: J.P. Allain (leader), M. Jaworski, B. Wirth
  – Engineering Innovation: C. Kessel (leader), R. Ellis, R. Majeski
  – Core-edge Integration: J. Canik, M. Kotschenreuther, R. Majeski, R. Wilson
  – Cross-cutting: R. Maingi, J. Menard, H. Neilson
- Integrated Modeling: 24% of 119 whitepapers – Disruptions, WDM
  – Disruptions: D. Brennan (co-lead), S. Gerhardt, S. Jardin
  – Boundary: J. Canik, C-S Chang, G. Hammett
  – Whole Device Modelling: C. Kessel (co-lead), B. Grierson, S. Kaye, F. Poli
  – Multi-Physics, multi-scale: G. Fu, G. Hammett
  – Data Management / Software Integration: S. Kaye / F. Poli

NSTX-U research program well aligned with FESAC / FES strategic priorities

- Advancing predictive capability, model validation
  - See NSTX-U / Theory Partnership and Science Group talks
- Supporting integrated modeling, exascale computing
  - See TRANSP + Integrated Scenarios talks, XGC applications
- Mitigating / avoiding transients (disruptions, ELMs)
  - See Boundary and Core Science Group talks, DPAM talk
- Taming the PMI (Divertor, SOL, first wall, PFCs)
  - See Boundary Science and high-Z / liquid metal plan talk
- Establishing physics basis for FNSF / next-steps
  - Contributions from all talks
- Supporting discovery science, basic plasma physics
  - Reconnection / plasmoids in Partnership, Integrated Scenarios talks

Summary: NSTX-U will make fundamental and world-leading contributions to toroidal fusion science

- Investigate unique high-β, low collisionality regime for understanding transport and stability
- Explore advanced divertors, high-Z and Li walls
- Inform optimal configuration for next-steps
- **FY2016 run campaign is now underway!**

Thank you for your attention!

Backup

Run Time Guidance for XP Prioritization (January 2016)

Similar to Research Forum, but +1 week for XMP, +1 week for XP

Baseline # run weeks:	18	
Estimated total # run days:	90	
Estimated XMP run-days	30	Cross-cutting commissioning, shot development, calibrations
Reserve for multi-TSG XPs	10	
Contingency / director's reserve	5	
Nominal total days for TSG/TFs to prioritize	55	
Minimum # run days per TSG / TF	3.2	
Milestone weighting for FY16 and FY17 runs	0.8	0.2

Priority #1 fraction 0.75

	TSG / Task Force	FY 16 Milestones	FY17 Milestones	FY16 count	FY17 count	Milestone additional runtime	Forum Idea Count Increment	Nominal TSG / TF run days for single TSG XPs	Nominal TSG / TF run days for multi-TSG XPs	Nominal TSG / TF run days for all XPs	Nominal Priority 1 XP run time	Nominal Priority 2 XP run time
Boundary	Pedestal	R16-1		1	0	0.8	0.5	4.5	1	5.5	4	1.5
	Divertor and SOL	R16-1	JRT-17, R17-1	1	2	1.2	1	5	1	6	4.5	1.5
	Materials and PFCs		R17-2		1	0.2	0	3	1	4	3	1
Core	Macroscopic Stability	JRT-16, R16-3		2	0	1.6	1	5.5	1	6.5	5	1.5
	Transport & Turbulence	R16-1	R17-3	1	1	1	0.5	4.5	1	5.5	4	1.5
	Energetic Particles	R16-2		1	0	0.8	0.5	4.5	1	5.5	4	1.5
Scenarios	Advanced Scenarios and Control	Notable, JRT-16, R16-2,3	JRT-17, R17-4	4	2	3.6	1	7.5	1	8.5	6.5	2
	Solenoid-Free Start-up		R17-4	0	1	0.2	0	3	1	4	3	1
	Wave Heating and Current Drive		IR17-1	0	1	0.2	0	3	1	4	3	1
Task Forces	Particle Control	R16-3		1	0	0.8	0.5	4.5	1	5.5	4	1.5
							Total:	45	10	55	41	14

NSTX-U 5 year plan: Develop physics/scenario understanding needed to assess ST viability as FNSF/DEMO, support ITER

	2016	2017	2018	2019	2020	2021
Max B_T [T], I_P [MA]	0.8, 1.6	1, 2				
Structural force and coil heating limit fractions	0.5, 0.5	1.0, 0.75	1.0, 1.0			
Nominal τ_{pulse} [s]	1 – 2	2 – 4	4 – 5			
Sustained β_N	3 – 5	4 – 6	NCC	5 – 6		
ν^* / ν^* (NSTX)	0.6	0.4	Cryo	0.3 – 0.2	0.2 – 0.1	
Non-inductive fraction ($\Delta t \geq \tau_{CR}$)	70 – 90%	80 – 110%		90 – 120%	100 – 140%	
NBI+BS I_P ramp-up: initial → final [MA]		0.6 → 0.8	ECH / EBW	0.5 → 0.9	0.4 → 1.0	
CHI closed-flux current [MA]	0.15 – 0.2	0.2 – 0.3		0.3 – 0.5	0.4 – 0.6	
P_{heat} [MW] with q_{peak} < 10MW/m^2	8	10		15	20	
Snowflake and radiative divertor exhaust location	Lower	Lower or Upper		Lower + Upper Divertor heat-flux control		

Inform choice of FNSF/DEMO aspect ratio and divertor

Cryo: access lowest ν^*, compare to Li **ECH / EBW**: bridge T_e gap from start-up to ramp-up

Off-midplane non-axisymmetric control coils **(NCC)**: rotation profile control (NTV), sustain high β_N

NSTX-U engaged in 31 ITPA joint experiments / activities

	Advanced Scenarios and Control
IOS-1.2	Divertor heat flux reduction in ITER baseline scenario (considering)
IOS-1.3	Operation near P_{LH} (considering)
IOS-2.1	Compare helium H-modes in different devices (considering)
IOS-3.3	Core confinement for q(0)=2 (considering)
IOS-5.2	Maintaining ICRH coupling in expected ITER regime
	Boundary Physics
PEP-26	Critical edge parameters for achieving L-H transition
PEP-28	Physics of H-mode access with different X-point height (considering)
PEP-29	Vertical jolts/kicks for ELM triggering and control
PEP-30	ELM control by pellet pacing in ITER-like conditions and consequences for plasma confinement
PEP-31	Pedestal structure and edge relaxation mechanisms in I-mode (considering)
PEP-37	Effect of low-Z impurity on pedestal and global confinement
DSOL-31	Leading edge power loading and monoblock shaping
DSOL-34	Far-SOL fluxes and link to detachment (considering)
DSOL-35	In-out divertor ELM energy density asymmetries (consdiering)
	Macroscopic Stability
MDC-1	Disruption mitigation by massive gas jets
MDC-8	Current drive prevention/stabilization of NTMs (considering)
MDC-15	Disruption database development
MDC-17	Active disruption avoidance
MDC-18	Evaluation of axisymmetric control aspects
MDC-19	Error field control at low plasma rotation
MDC-21	Global mode stabilization physics and control
MDC-22	Disruption prediction for ITER
	Transport and Turbulence
TC-9	Scaling of intrinsic plasma rotation with no external momentum input (considering)
TC-10	Experimental identification of ITG, TEM and ETG turbulence and comparison with codes
TC-11	He and impurity profiles and transport coefficients
TC-14	RF rotation drive (considering)
TC-15	Dependence of momentum and particle pinch on collisionality
TC-17	ρ^* scaling of intrinsic torque (considering)
TC-19	Characteristics of I-mode plasmas (considering)
TC-24	Impact of resonant magnetic perturbations on transport and confinement (considering)
	Energetic Particles
EP-6	Fast ion losses and associated heat loads from edge perturbations (ELMs and RMPs)

Roles / Responsibilities for Task Forces

Long-pulse particle control

- Address **specific operational and/or scientific goal** that cuts across or impacts multiple SGs / TSGs
- Goal must be very high priority within research program
- **Receives dedicated run-time, and has dedicated session at Research Forum**
  - Similar to a TSG, but may not necessarily have theory/modelling or university representatives – depends on duration or scope
- **Organizes experimental proposals to achieve goal**
- Finite duration - nominally 1-2 years, renewable if necessary
- TF leadership should nominally have a leader and a deputy, and should include at least 1 collaborator if possible
- Reports directly to Program / Project

Roles / Responsibilities for Working Groups

DPAM: Prep for JRT-16, understand then avoid causes of disruptions in NSTX-U

- Respond to specific programmatic or technical charge from NSTX-U Program or Project
- Addresses issues that cross-cut more than one SG or TSG
- Nominal lifetime = 1-2 years, can be extended/renewed
- Provides points of contact between NSTX-U and other groups as necessary (e.g. PPPL theory, FESAC, ITPA, ITER)

Multi-facility and multi-institutional effort

- Does not have dedicated NSTX-U run time, but provides recommendations on XP prioritization, other resource needs
- WG leadership should nominally have a leader and a deputy, and should include at least 1 collaborator if possible

Highly collaborative research program

Domestic (33)

College of William and Mary
Columbia University
CompX
Florida International Univ.
General Atomics
Idaho National Laboratory
Johns Hopkins University
Lawrence Livermore Nat. Lab.
Lehigh University
Lodestar Research Corporation
Los Alamos National Laboratory
Massachusetts Institute of Tech.
Nova Photonics, Inc
Oak Ridge National Laboratory
Old Dominion University
Princeton Plasma Physics Lab
Princeton University
Purdue University
Sandia National Laboratory
Tech-X Corporation
U. of California - Davis
U. of California - Irvine
U. of California - Los Angeles
U. of California - San Diego
U. of California - Space Sci. Lab.
University of Colorado
University of Illinois
University of Maryland
University of Rochester
University of Tennessee
University of Texas
University of Washington
University of Wisconsin

402 team members

290 scientists

(~70% non-PPPL)

55 institutions

22 US Universities

International (22)

ASIPP
CCFE
FOM Institute DIFFER
Hiroshima University
Inst. for Nuclear Research
IPP-Czech Republic
Ioffe Physical-Tech. Inst.
JAEA
KAIST
Kyoto University
Kyushu University
NFRI
NIFS
Niigata University
Seoul National University
Tokamak Energy, LTD
TRINITI
UNIST
University of Costa Rica
University of Hyogo
University of Tokyo
University of York