NSTX-U / PPPL Presentation Agenda

FY2016 Budget Planning Meeting – April 17, 2014

- **NSTX-U Research Plans**
  - 40 + 20 minutes – Jon Menard
- **NSTX-U Facility and Diagnostic Plans**
  - 40 + 20 minutes – Masa Ono
- **PPPL Institutional Issues, Incremental Requests**
  - 20 + 10 minutes – Mike Zarnstorff

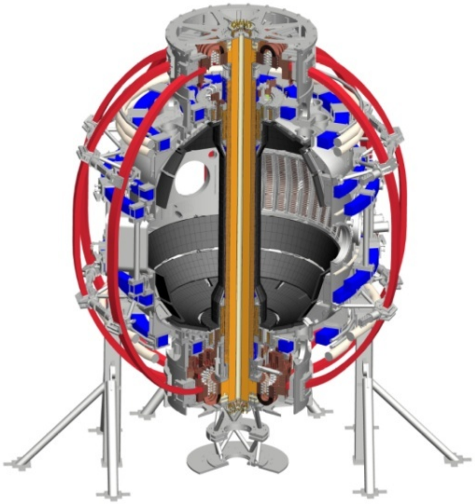
NSTX-U Research Plans for FY2014-16

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
Old Dominion
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

J. Menard, M. Ono - PPPL

For the NSTX-U Research Team

FY2016 FES Budget Planning Meeting
Germantown, MD
April 17, 2014



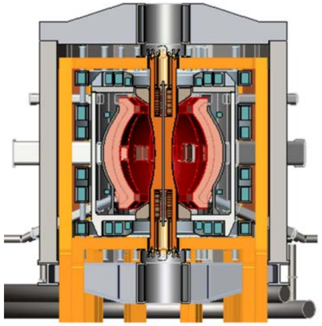
Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech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

Outline

- NSTX-U mission, priorities, FY14-16 overview
- FY14-16 research plans
- Milestone summary
- ITPA contributions
- ST-FNSF mission and configuration study
- Summary

NSTX Upgrade mission elements

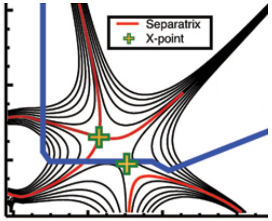
- **Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)**



ST-FNSF

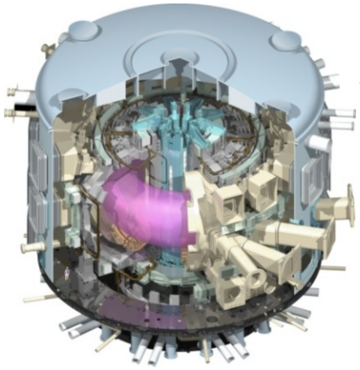
- **Develop solutions for the plasma-material interface challenge**

Lithium



"Snowflake"

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



ITER

- **Develop ST as fusion energy system**

FY14-16 planned research supports 5 highest priority goals of NSTX-U 5 year plan:

1. **Demonstrate 100% non-inductive sustainment** at performance that extrapolates to ≥ 1MW/m^2 neutron wall loading in FNSF

2. **Access reduced ν* and high-β** combined with ability to **vary q and rotation** to dramatically **extend ST physics understanding**

3. Develop and understand **non-inductive start-up and ramp-up** (overdrive) to project to ST-FNSF with small/no solenoid

4. Develop and utilize **high-flux-expansion "snowflake" divertor and radiative detachment** for mitigating very high heat fluxes

5. **Begin to assess high-Z PFCs + liquid lithium** to develop high-duty-factor integrated PMI solutions for next-steps

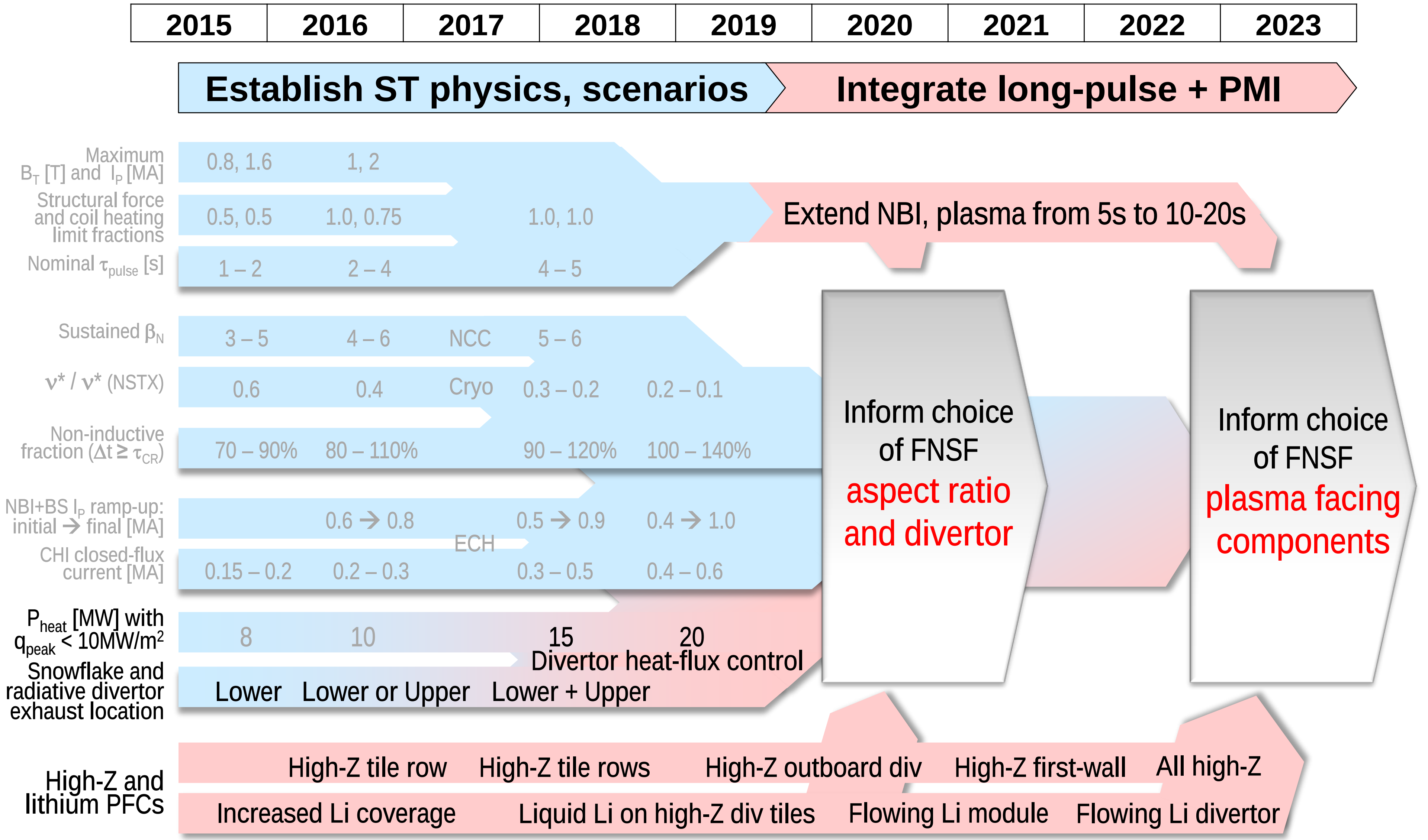
NSTX-U 5 year plan aims to develop ST physics and scenario understanding necessary for assessing ST viability as FNSF

	2015	2016	2017	2018	2019	2020
Max B_T [T], I_P [MA]	0.8, 1.6	1, 2				Inform choice of FNSF aspect ratio and divertor
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	
				Divertor heat-flux control		
Snowflake and radiative divertor exhaust location	Lower	Lower or Upper		Lower + Upper		

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

10 year goal: integrate 100% non-inductive + high β & τ_E with advanced divertor solution + high-Z solid / liquid metal walls



NSTX-U Research Team Has Been Scientifically Productive

Very Active in Scientific Conferences, Publications, and Collaborations

- Strong APS meeting (7 invited talks, 52 additional presentations) participation in the fall 2013. Three NSTX APS-DPP press releases available on the web.
- Significant collaboration research contributions are being made in diverse science areas by the NSTX-U research team.
- On-going active research collaboration particularly with DIII-D and EAST. Several activities resulted in IAEA synopses.
- All of the FY 2013 milestones were completed on schedule
- A good set of IAEA synopses (~ 30) submitted
- 61 refereed publications for CY 2013 with 4 PRLs
- Two NSTX researchers received APS Fellowship (Gates, Skinner)
- Ahmed Diallo received an Early Career Research Program Award

Overview of FY2014 NSTX-U research activities

- Collaborations supporting NSTX-U, ITER, FNSF
  – DIII-D: Snowflake/detachment control, pedestal, operations
  – C-Mod: Pedestal structure, high-Z PFC studies, RF
  – KSTAR: NTV physics, MHD stability, plasma control
  – York/MAST: Synthetic aperture μ-wave imaging (DBS, BXO)
  – EAST: Joint analysis of NSTX/EAST Li/boundary physics data

- Prepare for NSTX-U operation
  – Finish data analysis, publications from NSTX, collaborations
  – Transition off-site collaboration/researchers back to NSTX-U
  – Finalize physics design of long-term facility enhancements
    - Row of high-Z tiles on outboard divertor, divertor cryo-pump
    - ECH/EBW for start-up/ramp-up, off-midplane 3D coils
  – Prepare diagnostics, control system, analysis for NSTX-U ops

Partnering with PPPL theory to enhance NSTX-U modeling supporting high-priority research areas

(enabled by supplementary funding from FES for FY13 → FY14 covering 2.5-3FTE)

- **Energetic particle research:**
  - Use the HYM code (fully kinetic ions and drift and kinetic electrons) to study CAE, GAE, KAW effects on energy fluxes and electron transport
  - M3D-K nonlinear multi-mode TAE studies leading to avalanche production
  - Extend TAE quasi-linear model to calculate fast-ion diffusion in NSTX-U
- **Transport:**
  - Implement EM effects in GTS (for core) and XGC-1 (for edge) to enable studies of micro-tearing in NSTX/NSTX-U
  - Comparative study of role of collisionality in transport in NSTX and DIII-D
- **Stability:**
  - VDE and beta-limit disruptions using M3D/M3D-C1
  - Use stellarator tools for 3D equilibrium and coil optimization for proposed NSTX-U off-midplane non-axisymmetric control coils (NCC)

Overview of FY2015-16 NSTX-U research activities

- Resume operation, explore new regimes:
  - High β + lower ν^*, higher non-inductive w/ higher B_T, I_P, 2nd NBI
- FY2015
  – Complete CD-4 for NSTX Upgrade Project near end of CY14
  – Obtain first data at 60% higher field/current, 2-3× longer pulse:
    - Re-establish sustained low l_i / high-κ operation above no-wall limit
    - Study thermal confinement, pedestal structure, SOL widths
    - Assess current-drive, fast-ion instabilities from new 2nd NBI
- FY2016
  – Extend NSTX-U performance to full field, current (1T, 2MA)
    - Assess divertor heat flux mitigation, confinement at full parameters
  – Access full non-inductive, test small current over-drive

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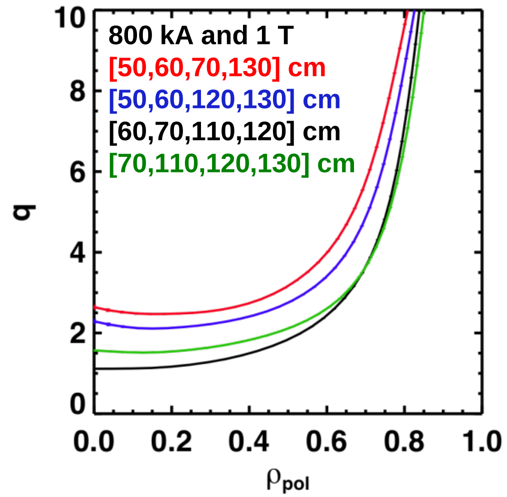
R14-3 → **Purple boxes indicate Research milestone year and number in this presentation and FWP**

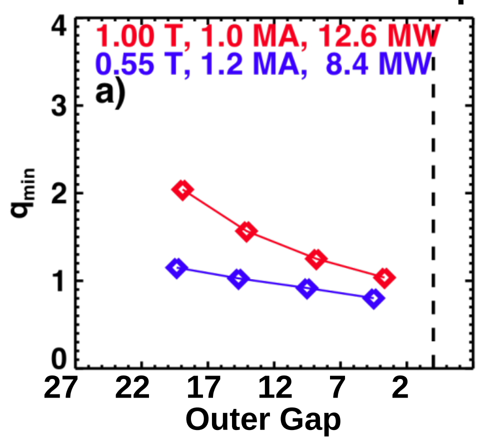
NSTX-U is developing a range of profile control actuators for detailed physics studies, scenario optimization for FNSF

q-Profile Actuators

Variations in Beam Sources
800 kA Partial Inductive, 87% < f_{NI} < 100%



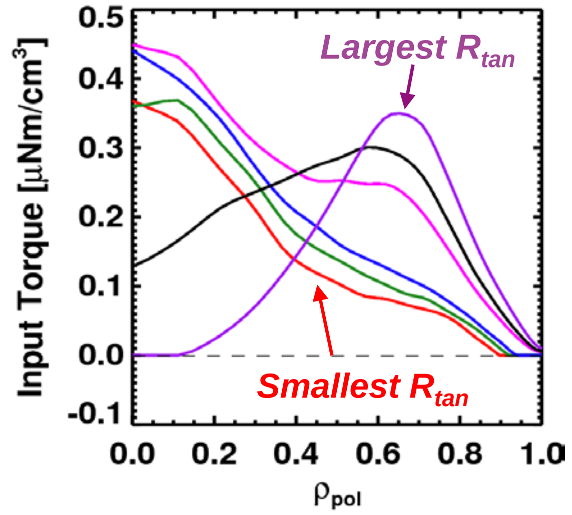
Variations in Outer Gap



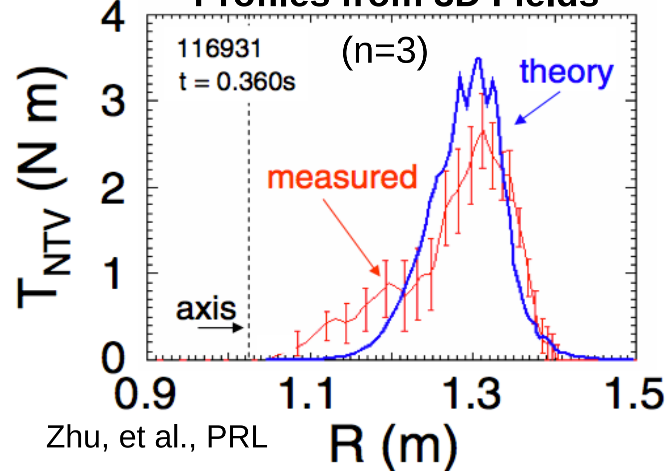
R14-3

Rotation Profile Actuators

Torque Profiles From 6 Different NB Sources

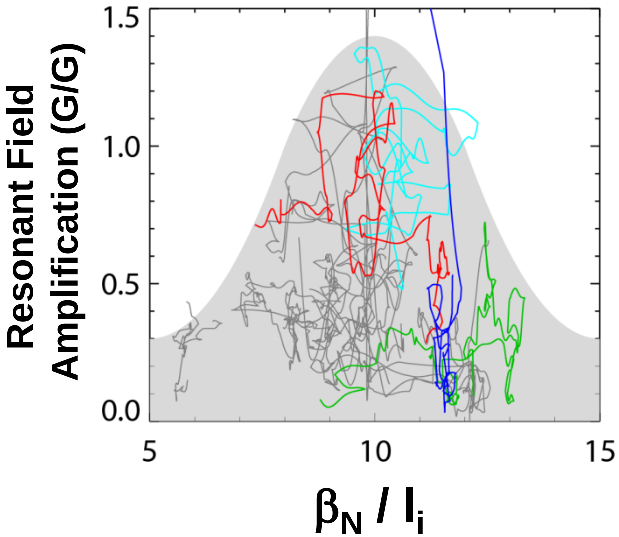


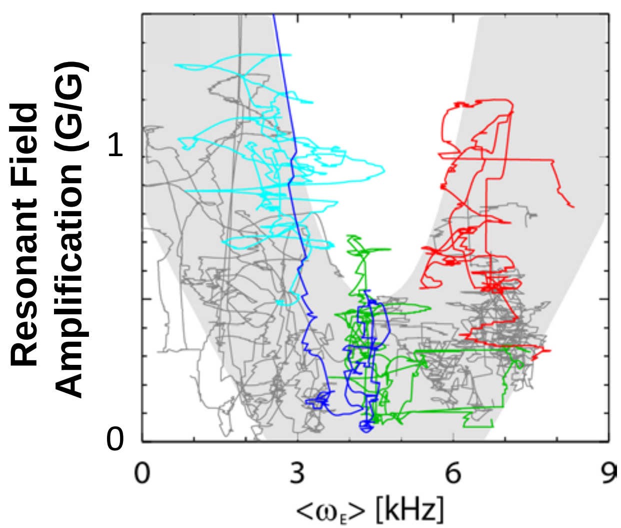
Measured and Calculated Torque Profiles from 3D Fields



Zhu, et al., PRL

Rotation profile control will be an important tool for accessing and sustaining high β





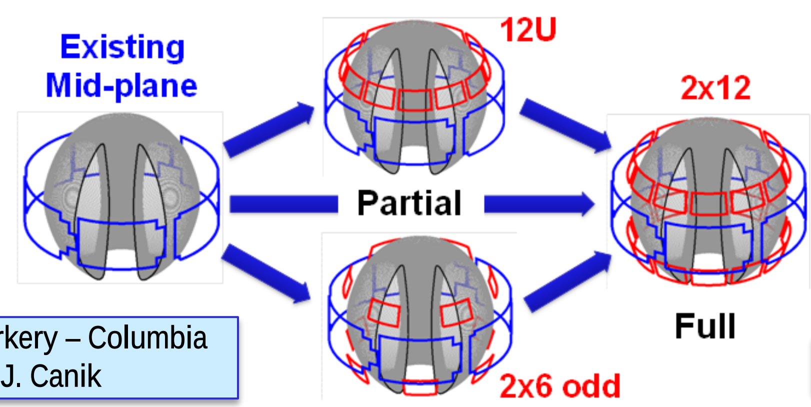
E×B rotation frequency

- n=1 MHD spectroscopy: high β_N can be more stable → important for advanced scenarios
- For these plasmas, high β_N was correlated with rotation that maximizes RWM damping
  - Largest stabilizing effect for RWM from ion precession drift resonance:

$$\delta W_k \sim \frac{1}{\langle\omega_D\rangle + \omega_E - i\nu_{eff}}$$

→ Minimize $|\langle\omega_D\rangle + \omega_E|$

- 5YP: Off-midplane 3D coils enable control of resonant vs. non-resonant torques, v_ϕ profile



S. Sabbagh, J. Berkery – Columbia
J-K Park, J. Canik

R14-1

Model-based, state-space rotation controller being designed to use Neoclassical Toroidal Viscosity (NTV) as actuator

- Momentum force balance – ω_ϕ decomposed into Bessel function states

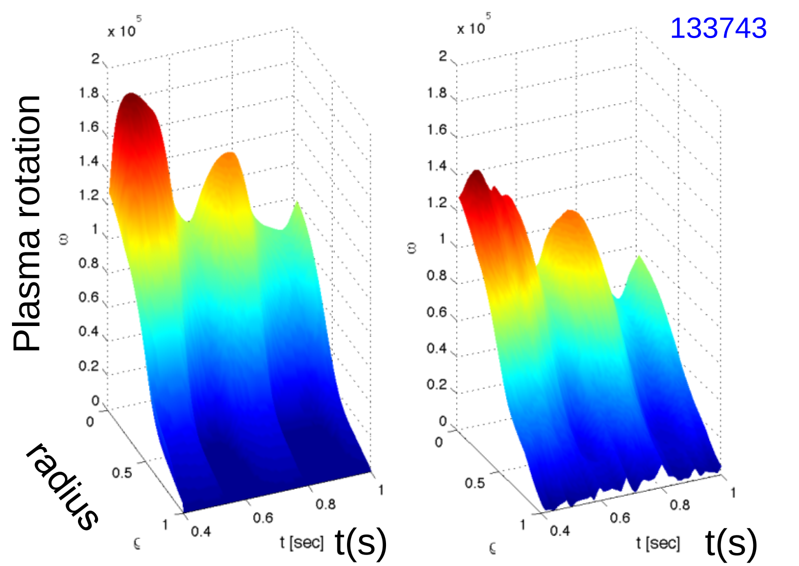
$$\sum_i n_i m_i \left\langle R^2 \right\rangle \frac{\partial \omega}{\partial t} = \left(\frac{\partial V}{\partial \rho}\right)^{-1} \frac{\partial}{\partial \rho}\left[\frac{\partial V}{\partial \rho}\sum_i n_i m_i \chi_\phi \left\langle \left(R \nabla \rho\right)^2 \right\rangle \frac{\partial \omega}{\partial \rho}\right] + T_{NBI} + T_{NTV}$$

R14-3

- NTV torque:

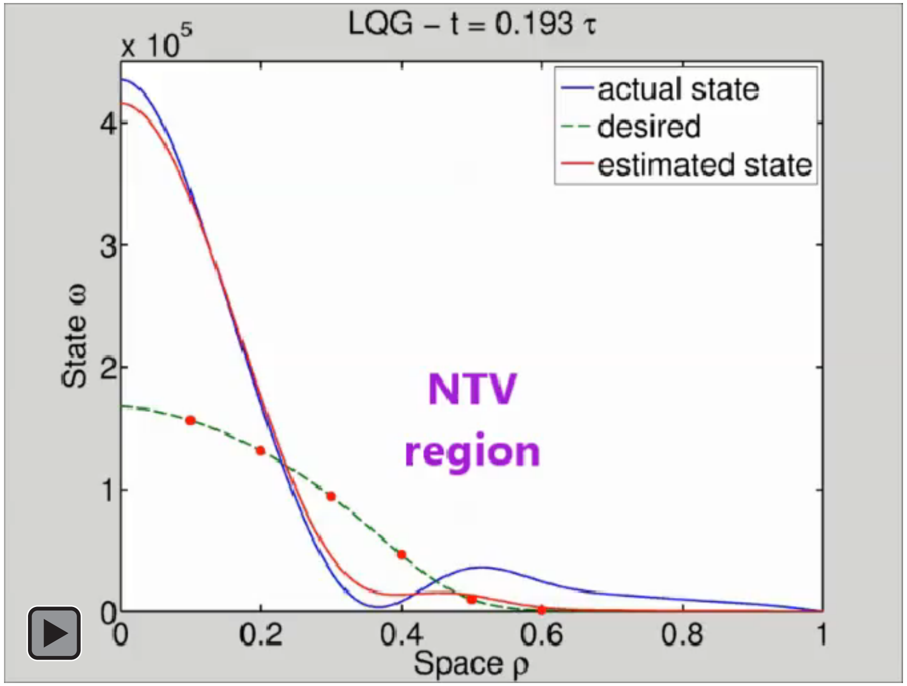
$$T_{NTV} \propto K \times f\left(n_{e,i}{}^{K1} T_{e,i}{}^{K2}\right) g\left(\delta B(\rho)\right)\left[I_{coil}{}^2 \omega\right] \quad \text{(non-linear)}$$

State-space model | TRANSP run



I. Goumiri – PU MAE grad student
(Advisors: D. Gates, S. Sabbagh – CU)

Feedback using NTV: “n=3” $\delta B(\rho)$ spectrum



Advanced Scenarios and Control Research Plans for FY2014-16:

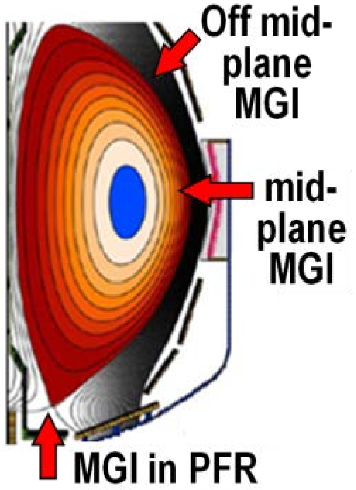
Implement advanced controls, explore high non-inductive & I_P scenarios

- FY14: Develop and implement advanced control algorithms in preparation for NSTX-U operation **R14-3**
  - Snowflake control on DIII-D (PPPL+LLNL+GA)
  - J profile control using on/off-axis 2nd NBI
    - ORISE post-doc: J profile control algorithms w/ TRANSP as plasma simulator
    - Implement rt-MSE (Nova Photonics) in rt-EFIT for q-profile reconstruction
  - Rotation control: 2nd NBI deposition flexibility + 3D fields/NTV
- FY14: DIII-D/National Campaign: test 100% NI at lower B_T
- FY14-15: Re-establish NSTX-U control and plasma scenarios
- FY15: Assess new 2nd NBI current-drive vs. R_{TAN}, n_e, outer gap
  - Push toward 100% non-inductive at higher B_T, P_{NBI} **R15-3** **JRT-2015**
- FY15: Explore scenarios (τ_E, l_i, MHD) at up to 60% higher I_P, B_T
- FY16: Explore scenarios at full I_P and B_T capability of NSTX-U
  - Goal: Access 100% non-inductive, test small I_P overdrive **R16-3**

Macroscopic Stability Research Plans for FY2014-16:

Complete 3D coil physics design, re-establish high-β ops, test MGI

- FY14: JRT - analysis for plasma response to 3D fields (J-K Park)
  - Also, complete physics design of new Non-axisymmetric Control Coils (NCC) for mode, error field, and v_ϕ control **JRT-2014**
- FY14: Understand/model low-density/ramp-up disruptions in NSTX in prep for low ν^* operation in NSTX-U scenarios **R14-1**
  - Hybrid $\nabla\Omega_\phi$ + ∇p-driven kink/TM is a leading candidate for early MHD
- FY15: Re-establish n=1-3 error-field correction, RWM control, minimize EF rotation damping, sustain operation above no-wall limit **R15-3**
- FY15: Test poloidal dependence of Massive Gas Injection (outboard vs. private flux region)



- FY16: Contribute unique MGI data (low-A, injector location) for mitigation + warning, prediction **JRT-2016**
  - Assess mitigation triggering via real-time warning in NSTX-U

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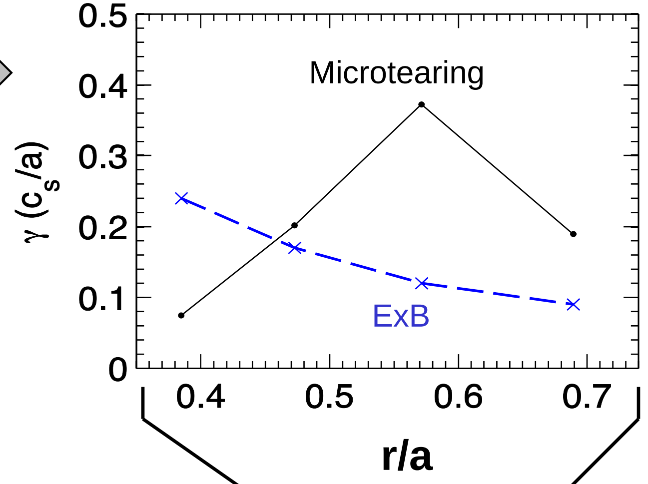
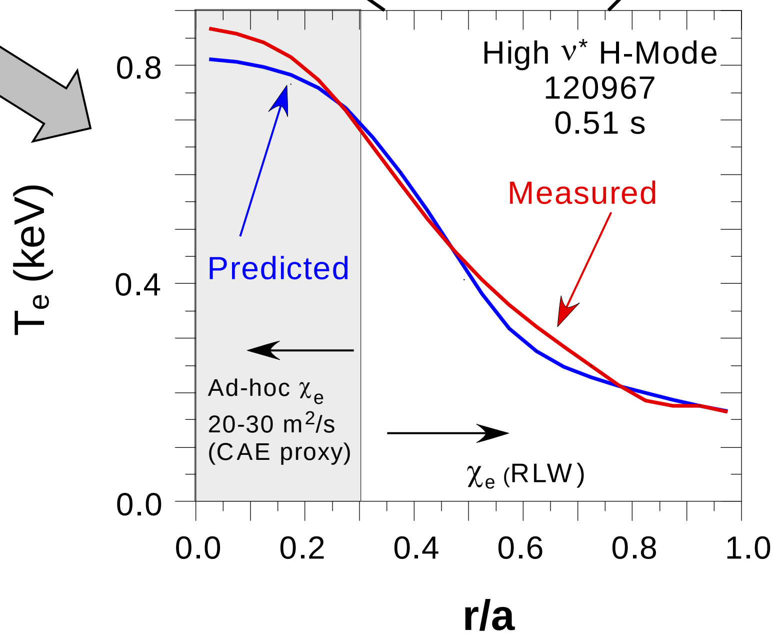
Testing predictability of T_e profiles using reduced χ_e models in regimes where single micro-instability is dominant

- Linear gyrokinetic simulations find microtearing unstable in mid-radius region of high-collisionality H-modes
  – Other micro-instabilities subdominant at this location for this class of discharge

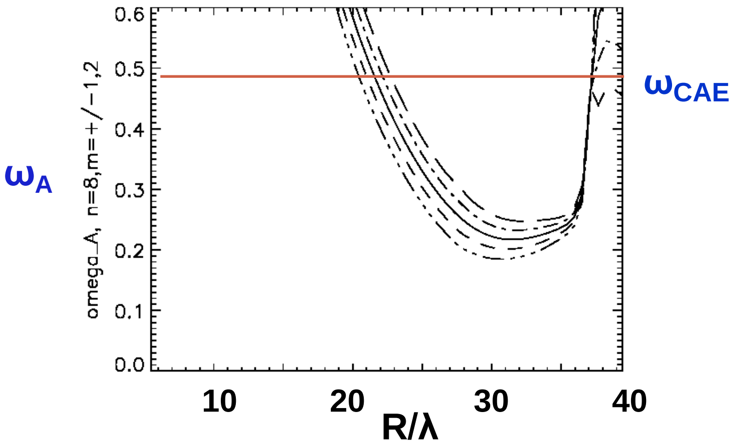


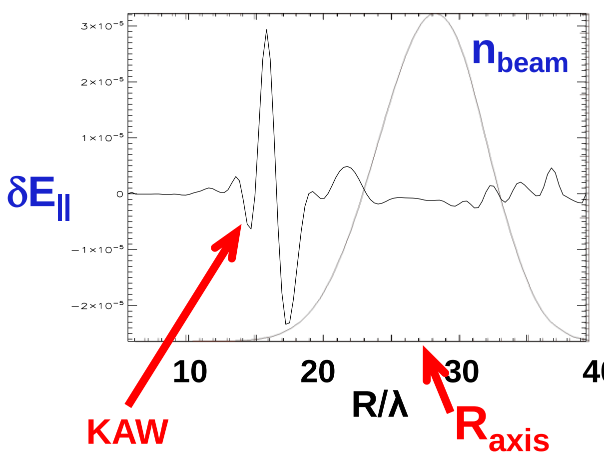
- Reduced model for microtearing χ_e (Rebut-Lallia-Watkins (RLW) - 1988) shows reasonable agreement between predicted & measured T_e for r/a > 0.3
  – χ_e much larger than RLW must be used in core to match central T_e - due to GAE/CAE?



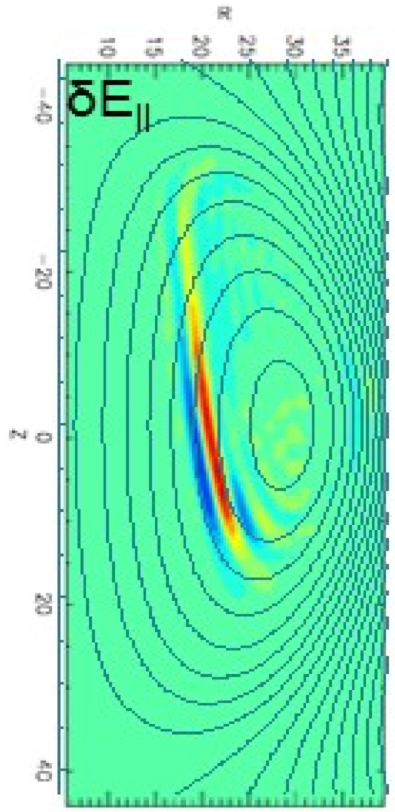
S. Kaye

CAEs show coupling to kinetic Alfvén Wave (KAW) near mid-radius → may be related to high effective core χ_e (?)





Radial profiles of Alfvén continuum and $\delta E_{||}$ for n=8. Radial width of KAW is comparable to beam ion Larmor radius



Poloidal contour plots of $\delta E_{||}$, solid line is contour of $\omega_A(Z,R)= \omega_{CAE}$, where $\omega_A(Z,R)= V_A\, n/R$.

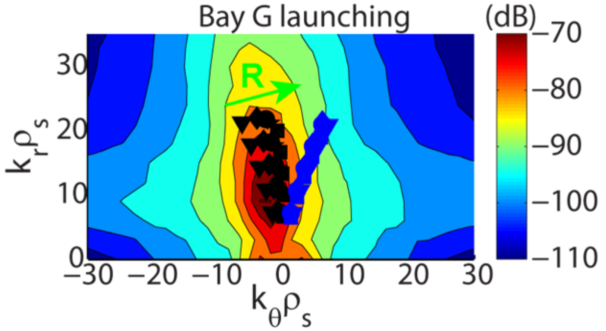
E. Belova – HYM code (Theory/NSTX-U partnership)

- **KAW can have strong effect on electron transport due to finite $\delta E_{||}$ → may transfer energy from NBI fast-ions in core to thermal electrons near half-radius**

Transport and Turbulence Research Plans for FY2014-16:

Develop reduced χ_e models, first τ_E data at higher B_T, I_P + turbulence

- FY14-16: Develop model $\chi_{e,\,AE}$ using measured CAE/GAE mode structures and HYM/ORBIT simulations (w/ EP group)
- FY14-16: Develop and validate reduced transport models using ST data + linear and non-linear gyro-kinetic simulations
- FY15: Extend ST confinement scalings and understanding with up to 60% increase in B_T and I_P **R15-1**
  - Measure low-k δn (BES w/ increased edge channel count), 1st polarimetry data
- FY16: Extend confinement studies to full B_T, I_P → 2-3× lower ν^*
- FY16: Initial utilization of new high-k FIR scattering system for ETG turbulence
  - Measure k_r & k_θ to study turbulence anisotropy

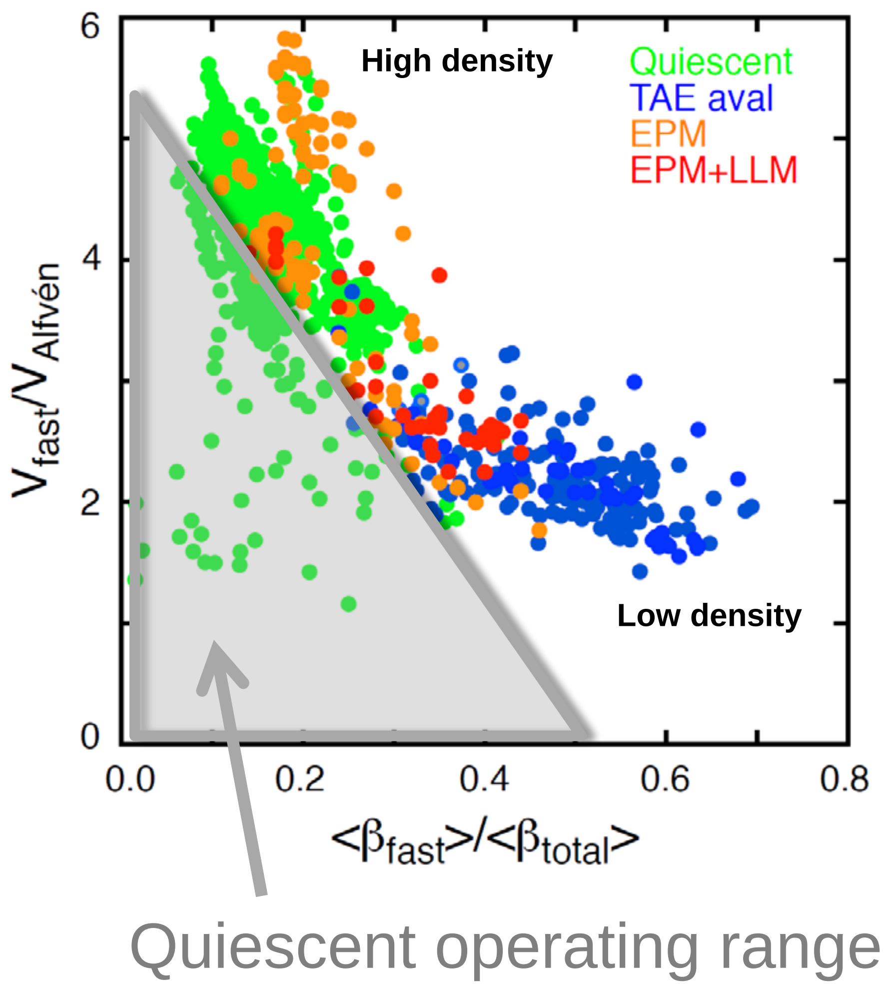


- FY16 (incremental): Study turbulence vs. ν^*, rotation, q with high-k + BES + polarimetry **IR16-1**

FY13-14: Assessed parametric dependence of TAE avalanches and energetic particle modes (EPMs) in NSTX

Identified regimes w/ small fast-ion loss: important for NSTX-U, FNSF, ITER

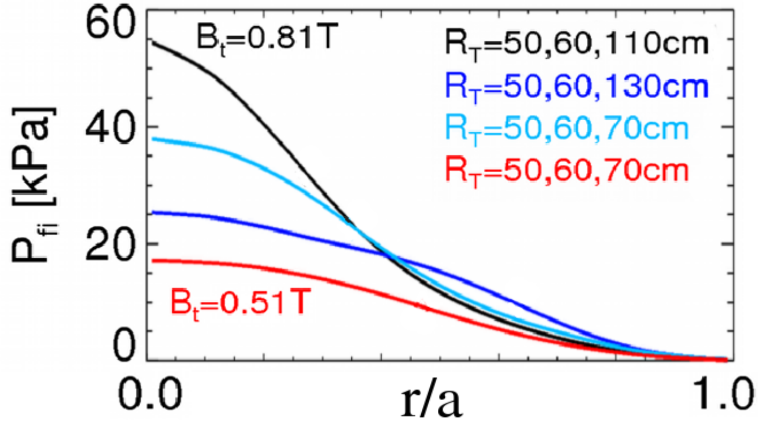
- Modes lead to neutron rate decrements up to 30%
- TAE avalanches only occur for $\beta_{fast} > 0.3\ \beta_{total}$
- Conversely, quiescent plasmas were only seen where $\beta_{fast} < 0.3\ \beta_{total}$
- Two types of EPM:
  - **Higher q_{min}~2-3 (earlier in shot), more continuous → long-lasting mode (LLM)**
  - **Lower q_{min} → 1 (later in shot), more bursty and fishbone-like, n=1-3**



E. Fredrickson

Develop full + reduced fast-ion transport models, characterize new 2nd NBI

- FY14: Collaborate with DIII-D/National Campaign studying AE thresholds & fast-ion transport vs. q_{min} and on/off-axis NBI
- FY14: Finalize design/implementation of prototype AE antenna and of upgraded ssNPA diagnostic
- FY14-15: Develop reduced model for AE-induced fast ion losses – needed for NBICD in STs/ATs/ITER **R14-2**
- FY14-15: Contribute to development of reduced model of electron thermal transport from CAE/GAE
- FY15-16: Measure fast-ion (FI) density profiles, confinement, current drive, AE stability
  - Exploit new 2nd NBI and higher B_T, access to reduced v_{fast} / v_A **R15-2**



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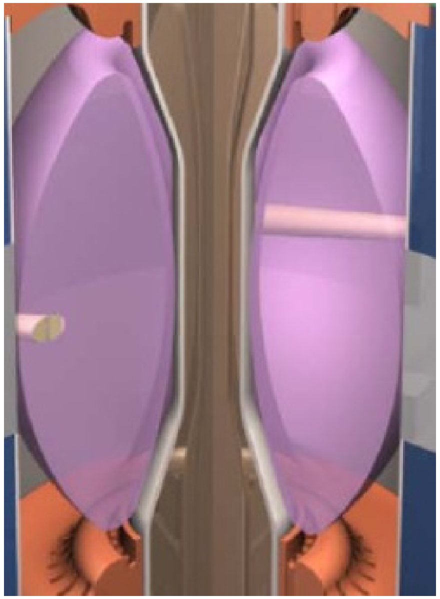
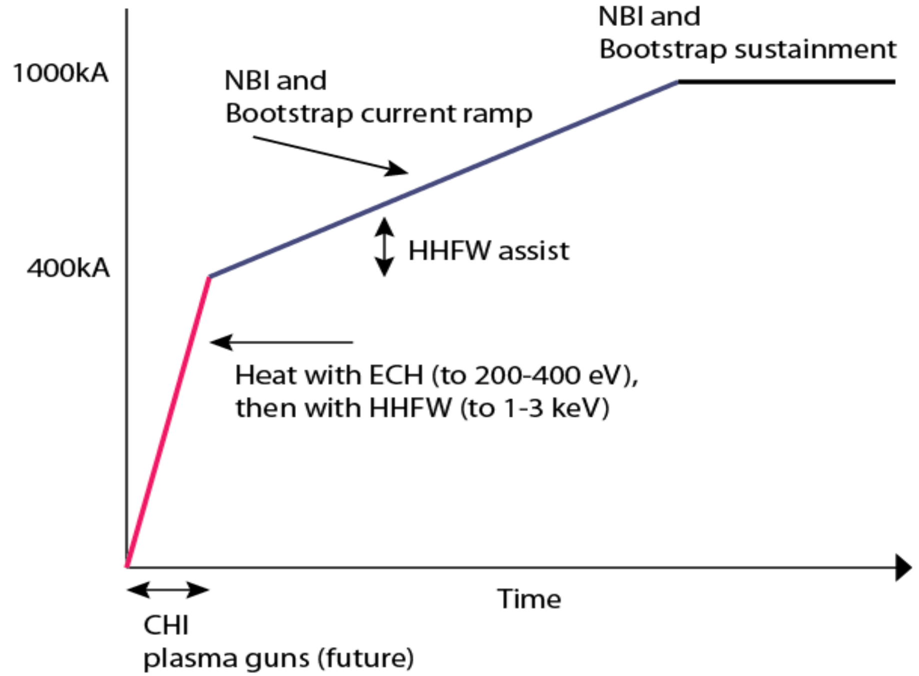
Plasma initiation with small or no transformer is unique challenge for ST-based Fusion Nuclear Science Facility

ST-FNSF has no/small central solenoid



NSTX-U Non-Inductive Strategy:

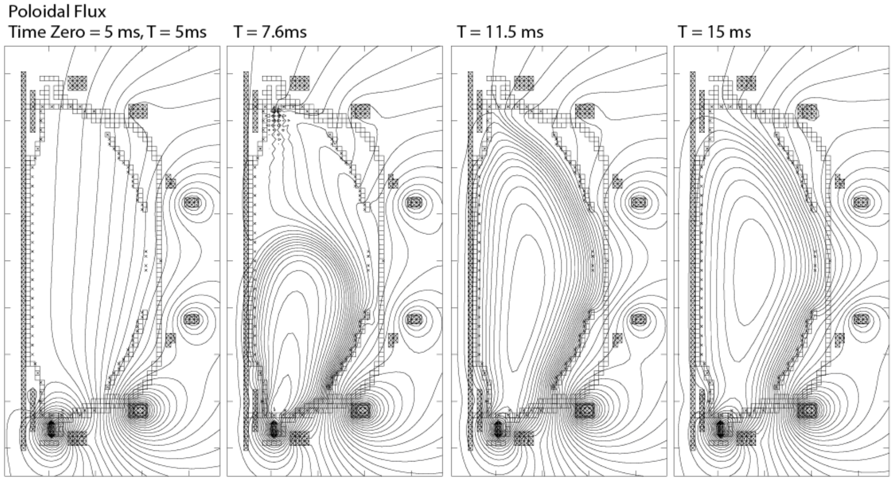


- **NSTX-U 5 year plan goal:**
  - Generate ~0.4MA closed-flux start-up current with helicity injection
  - Heat CHI with ECH and/or fast wave, ramp 0.4MA to 0.8-1MA with NBI

Simulations support non-inductive start-up/ramp-up strategy

- TSC code successfully simulates CHI I_P ~200kA achieved in NSTX

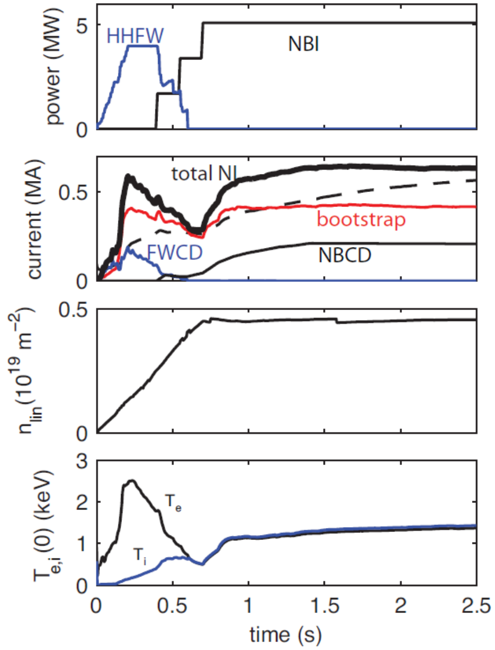
FY14: Implemented NSTX-U geometry in TSC



- TSC + tools included in 5 year plan support CHI I_P → 400kA in NSTX-U
  - 2.5 x higher injector flux (scales with I_P)
  - Higher B_T = 1T (increases current multiplication)
  - > 2kV CHI voltage (increases flux injection)
  - 1MW 28GHz ECH (increases T_e)

R. Raman (U-Wash)

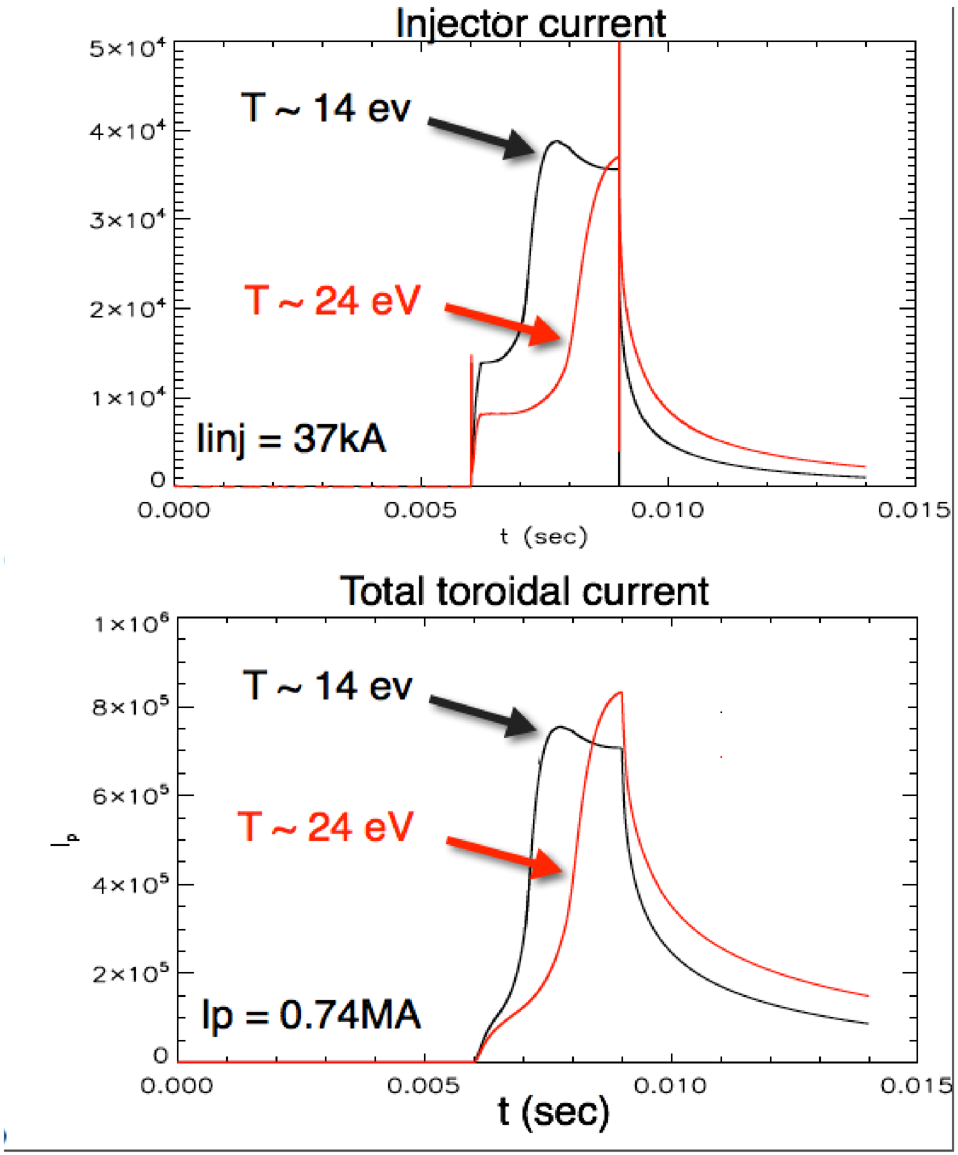
- TRANSP: NSTX-U more tangential NBI → 3-4x higher CD at low I_P (0.4MA)
  - 1.5-2x higher CD efficiency, 2x higher absorption
- TSC/TRANSP: NI ramp-up from 0.2MA→0.6MA w/ BS + (only) 2nd NBI

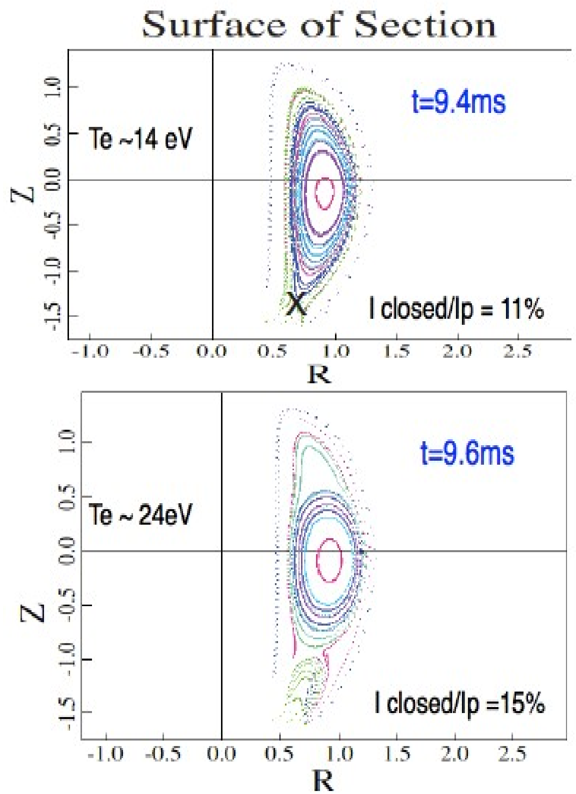


F. Poli

- Requires early RF (ECH and/or FW) heating to enable NBI coupling

NIMROD 3D-resistive MHD: CHI simulations with magnetic diffusivities similar to experiment produce flux closure



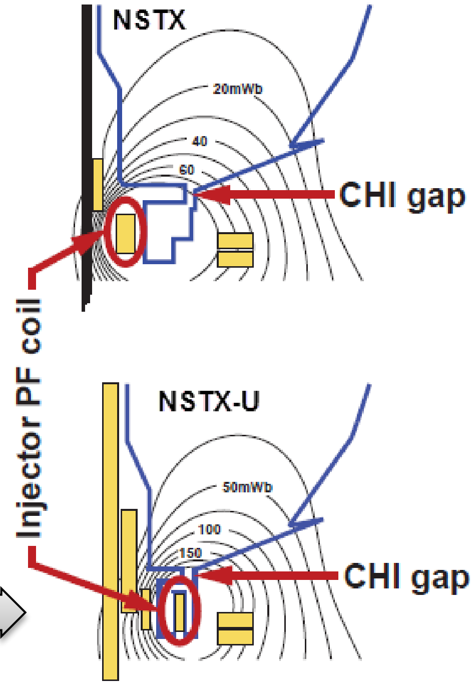


- **Closed flux fraction increases as the magnetic diffusivity is reduced (but is lower than in experiment, investigating…)**
- **e-heating increases closed-flux I_P**

F. Ebrahimi (PU), R. Raman (U-Wash)

Prepare CHI for NSTX-U, assess CHI/NBI start-up/ramp-up

- FY14: Complete design of upgraded capacitor bank and diagnostics for NSTX-U, implement CHI gap tiles
  - Also finish CHI design study for QUEST, possibly implement CHI
- FY14: DIII-D/National Campaign: test small current overdrive using NBI+BS
- FY15: Establish NSTX-U CHI, assess impact of new injector, gap, higher B_T



- FY15-16: Initial tests of small NBI+BS overdrive ramp-up using new 2nd NBI and higher B_T

R16-3

Finalize ECH/EBW design, simulate & develop reliable FW H-mode

- FY14-15: Guide 1MW/28GHz ECH/EBW engineering design
  - ECH to heat CHI, form target for HHFW/NBI
  - EBW H&CD for start-up, sustainment

- FY16: Assess fast-wave SOL losses and core thermal and fast ion interactions at increased B_T, I_P **R16-2**

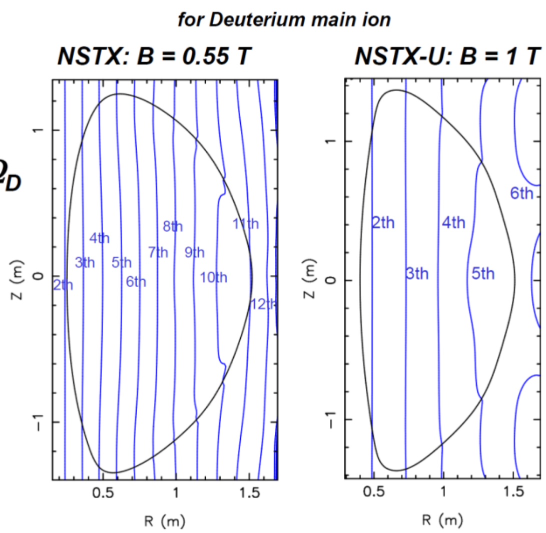
B_T → $2 \times B_T$

ω/Ω_D → $0.5 \times \omega/\Omega_D$

High harmonic regime in NSTX

↓

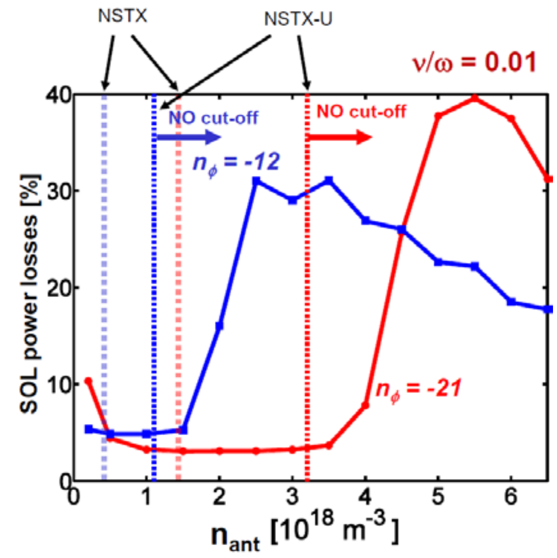
Mid harmonic regime in NSTX-U



AORSA modeling: higher B → lower SOL losses

$$n_{\mathrm{e,FWcut-off}} \propto \frac{k_{\parallel}^2 B}{\omega}$$

N. Bertelli

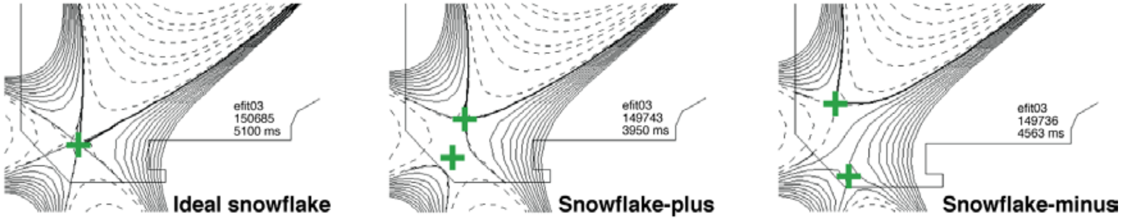


FY14-16 planned research supports 5 highest priority goals of NSTX-U 5 year plan:

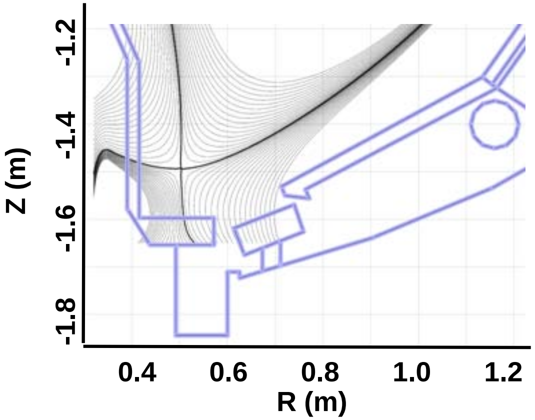
1. Demonstrate 100% non-inductive sustainment at performance that extrapolates to ≥ 1MW/m^2 neutron wall loading in FNSF
2. Access reduced ν* and high-β combined with ability to vary q and rotation to dramatically extend ST physics understanding
3. Develop and understand non-inductive start-up and ramp-up (overdrive) to project to ST-FNSF with small/no solenoid
4. Develop and utilize high-flux-expansion “snowflake” divertor and radiative detachment for mitigating very high heat fluxes
5. Begin to assess high-Z PFCs + liquid lithium to develop high-duty-factor integrated PMI solutions for next-steps

Snowflake divertor results + simulations project to favorable particle and power exhaust control in NSTX-U, next-steps

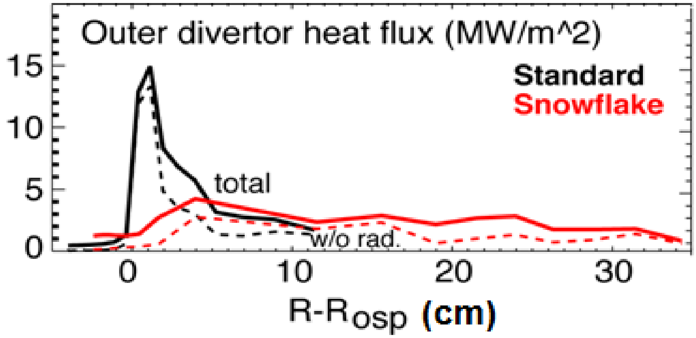
- Snowflake on DIII-D (GA+LLNL+PPPL collaboration) extended 2-3x reduction in q_{peak} to 3s duration
  - Compatible with cryo-pumping (n_e/n_G= 0.4-0.75)



- NSTX-U divertor cryo projections: $f_G \leq 0.5$ for wide range of I_P (λ_{SOL})
  - Standard/snowflake: 0.6/0.7 to 1.5/2MA
  - Maintain $q_{peak} \leq 10MW/m^2$

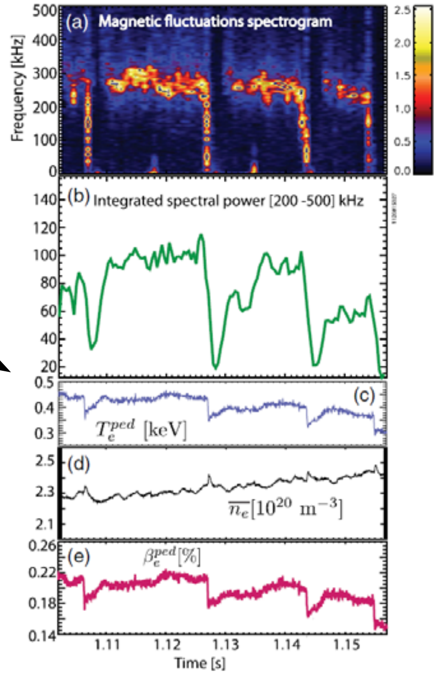


- Multi-fluid edge transport model (UEDGE) predicts factor of ~5 reduction in NSTX-U peak heat flux
  - Geometry + impurity radiation (4% C)

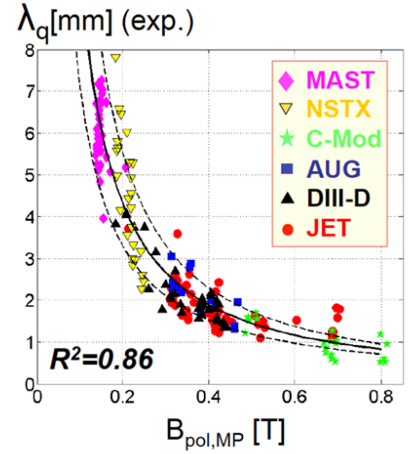


Boundary Physics Research Plans for FY2014-16:
Advance snowflake, cryo, pedestal, SOL studies, extend to higher B_T, I_P

- FY14: Complete divertor cryo physics design
- FY14: Pedestal/SOL collaborations
  - C-Mod: Measured field-aligned electromagnetic mode that clamps pedestal ∇T_e – consistent with kinetic ballooning mode (KBM) and EPED/ELITE models
    - Ahmed Diallo, et al., PRL 2014
  - NSTX-U/DIII-D: Continue analysis of enhanced pedestal (EPH) and very high confinement (VH) H-modes
    - Both obtain $H_{98y,2}$ >> 1, apparently from increased E×B shear



- FY15: Measure pedestal structure, SOL width, ELM types, snowflake performance at up to 60% higher I_P, B_T, 2× higher P_{NBI} **R15-1, IR15-1**
- FY16: I_P → 2MA → test snowflake, detachment, PFCs with $q_{||}$ up to 4-5× higher than NSTX **R16-1**

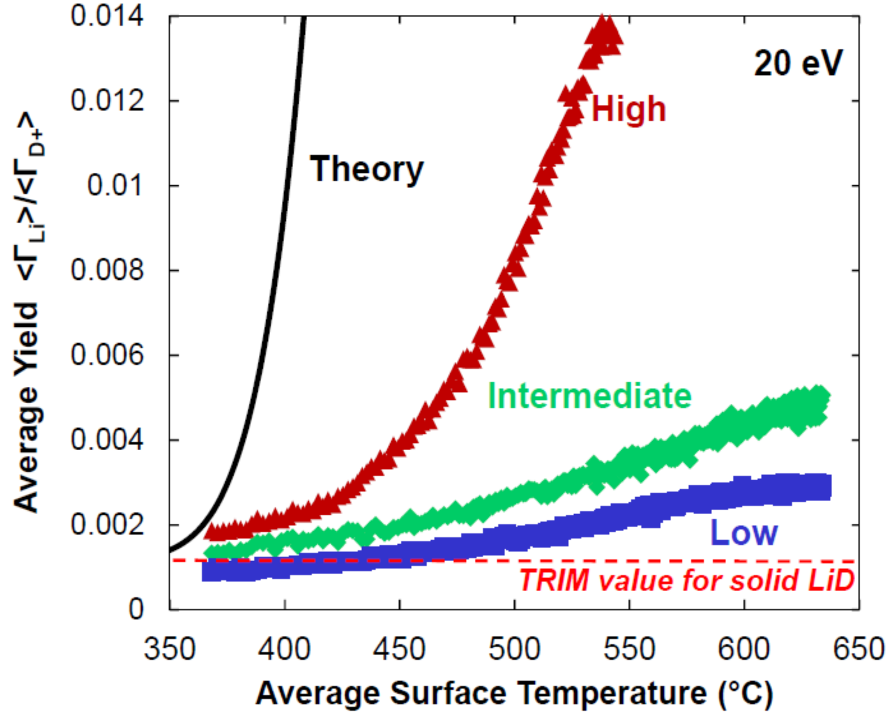


Collaboration with Magnum-PSI finds Li coatings on high-Z PFCs may have lower evaporation rates than expected

- Theory (Langmuir law evaporation + TRIM sputtering) predicts rapidly increasing yield for $T_{surface}$ > 350˚C
- Experiment shows increase in evaporation threshold $T_{surface}$ and/or significantly lower erosion
- 3 erosion regimes observed for D^+ incident on Li-coated TZM Mo:
  - **High-yield: lasts 1-2s ($\Phi_{D+} / \rho_{Li} \leq 250$)**
  - **Intermediate: ≲ 30s ($\Phi_{D+} / \rho_{Li} \leq 4300$)**
  - **Low-yield regime: Li depleted from center of sample**

M. Jaworski, T. Abrams (PU grad student)

Average Li Yield vs Average $T_{surface}$ for Li-coated TZM Mo



Φ = fluence, ρ = areal density (atoms/m²)

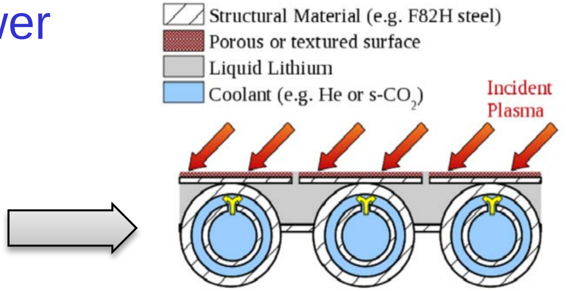
$$Y_{theory} = Y_{TRIM} + \Gamma_{evap}/\Gamma_{D+}$$

- **Suggests possible Li + (D/Mo) interactions may suppress erosion**

Advance Li understanding/technology, support NSTX-U wall conditioning

NSTX-U is key part of PPPL liquid-metal PFC development program

- FY14: Develop Li-coating tools for upper PFCs of NSTX-U to increase Li coverage of C, D pumping, thermal confinement
- FY14-15: Lab-based R&D for advanced Li PFCs
  - Study Li on metal substrates, response to plasma power and particle fluxes (MAGNUM-PSI)
  - High-heat-flux high-Z PFC design (TZM or W lamellae)
  - Flowing Li loop tests
  - Develop capillary-restrained gas-cooled Li PFC



- FY14: EAST: assess particle/impurity control w/ triggered ELMs, cryo-pumping, lithiumization, high-Z PFCs
- FY15: Test lithium granule injector (LGI) for ELM triggering and impurity control, Li coating performance in NSTX-U
- FY16: Begin to assess high-Z (+Li coated) PFC performance with 1 row of W or TZM tiles on outboard divertor (at large R)

Outline

- NSTX-U mission, priorities, FY14-16 overview
- FY14-16 research plans
- Milestone summary
- ITPA contributions
- ST-FNSF mission and configuration study
- Summary

Administration FY2015 request-level provides run-time and field + current to exploit most new Upgrade capabilities

	FY2014	FY2015	FY2016
Expt. Run Weeks:	0	18	16
Macroscopic Stability	R14-1 **Assess access to reduced density and ν* in high-performance scenarios** (with ASC, BP TSGs)		
Transport and Turbulence		R15-1 **Assess H-mode τ_E, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}** (with BP, M&P, ASC, WEP TSGs)	
Boundary Physics			R16-1 **Assess heat-flux mitigation and PFC response using advanced divertor configurations at high power density** (Joint BP and MP)
Materials & PFCs			
Waves+Energetic Particles	R14-2 **Assess reduced models for *AE mode-induced fast-ion transport**	R15-2 **Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile** (with SFSU, MS, ASC TSGs)	R16-2 **Assess fast-wave SOL losses and core thermal and fast ion interactions at increased B_T, I_P**
Solenoid-free Start-up/ramp-up			R16-3 **Develop high-non-inductive fraction NBI H-modes for ramp-up & sustainment** (Joint ASC+SFSU)
Adv. Scenarios and Control	R14-3 **Assess advanced control techniques for sustained high performance** (with MS, BP TSGs)	R15-3 **Develop physics+operational tools for high-performance discharges** (with CC, ASC, MS, BP, M&P TSGs)	
ITER Needs + Cross-cutting			
Joint Research Target	**Quantify plasma response to non-axisymmetric (3D) magnetic fields in tokamaks**	**Quantify impact of broadened current and pressure profiles on tokamak confinement and stability**	**Assess disruption mitigation and warning / prediction techniques (+ additional theory contribution?)**

Incremental (full ops) accelerates snowflake divertor and transport research, fully utilizes facility during next 2 years

	FY2014	FY2015	FY2016
Expt. Run Weeks:	0	18 **20**	16 **20**
Macroscopic Stability	R14-1 **Assess access to reduced density and ν* in high-performance scenarios** (with ASC, BP TSGs)		
Transport and Turbulence		R15-1 **Assess H-mode τ_E, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}** (with BP, M&P, ASC, WEP TSGs)	IR16-1 **Assess τ_E and local transport and turbulence at low ν* with full range of B_T, I_P, and NBI power**
Boundary Physics		**Develop snowflake configuration, study edge and divertor properties** (with ASC, TT, MP) IR15-1	R16-1 **Assess heat-flux mitigation and PFC response using advanced divertor configurations at high power density** (Joint BP and MP)
Materials & PFCs			
Waves+Energetic Particles	R14-2 **Assess reduced models for *AE mode-induced fast-ion transport**	R15-2 **Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile** (with SFSU, MS, ASC TSGs)	R16-2 **Assess fast-wave SOL losses and core thermal and fast ion interactions at increased B_T, I_P**
Solenoid-free Start-up/ramp-up			R16-3 **Develop high-non-inductive fraction NBI H-modes for ramp-up & sustainment** (Joint ASC+SFSU)
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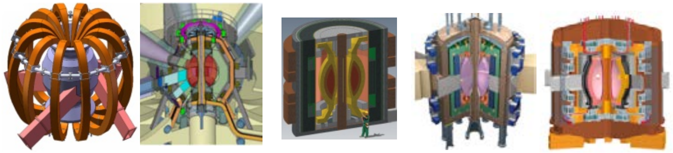
Supporting ITER through ITPA participation

- Representatives in every Task Group, leadership in several:
  - R. Maingi: chair of Pedestal and Edge Physics TG
  - S. Sabbagh: Leads WG on RWM code benchmarking, RWM stability & control
- Active in 25 JEX/JACs with many contributors from NSTX-U

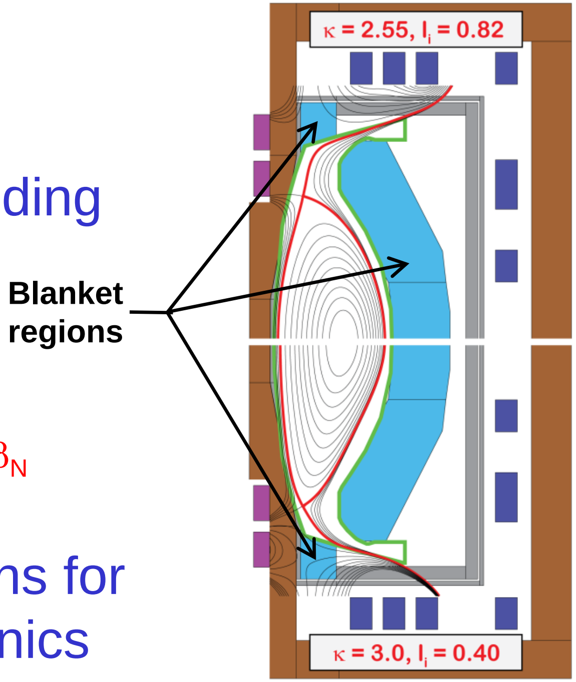
Pedestal, Scrape-Off Layer, Divertor				*Maingi (chair), Ahn, Canik, Chang, Diallo, Goldston, Jaworski*
PEP-26	Critical edge parameters for achieving L-H transitions	PEP-36	ELM energy losses and their dimensionless scaling in the context of operational parameters	
PEP-27	Pedestal profile evolution following L-H/H-L transitions	DSOL-24	Disruption heat loads	
PEP-29	Vertical jolts/kicks for ELM triggering and control	DSOL-28	Narrow heat flux widths and divertor power dissipation	
Energetic Particles				*Fredrickson, Fu, Gorelenkov, Heidbrink, Kramer, Podestá*
EP-2	**Fast ion losses and redistribution from localized AEs**	EP-6	Fast ion losses and associated heat loads from edge perturbations (ELMs and RMPs)	
EP-4	Effect of dynamical friction (drag) at resonance on non-linear AE evolution			
Integrated Operating Scenarios				*Gerhardt, Kessel, Poli, Gates*
IOS-3.2	Define access conditions to get to a steady-state scenario	IOS-4.3	Collisionality of confinement in advanced inductive plasmas	
IOS-4.1	Access conditions for advanced inductive scenarios with ITER-relevant conditions	IOS-5.2	Maintaining ICRH coupling in expected ITER regime	
Macroscopic Stability and Control				*Sabbagh, Berkery, Jardin, Park, Zakharov, Gerhardt, Menard*
MDC-2	Joint experiments on resistive wall mode physics	**MDC-17**	**Active disruption avoidance**	
MDC-14	Rotation effects on neoclassical tearing modes	MDC-18	Evaluation of axisymmetric control aspects	
MDC-15	**Disruption database development**	**MDC-21**	**Global mode stabilization physics and control**	
Transport and Turbulence				*Kaye (previous chair), Ren, Guttenfelder, McKee/Smith*
TC-9	Scaling of intrinsic plasma rotation with no external momentum input	**TC-15**	**Dependence of momentum and particle pinch on collisionality**	
TC-10	**Experimental identification of ITG, TEM and ETG turbulence and comparison with codes**	**TC-17**	**ρ^* scaling of intrinsic torque**	
TC-12	**H-mode transport at low aspect ratio**	**TC-24**	**Impact of resonant magnetic perturbations on transport and confinement**	

NSTX/ST researchers contributing to LDRD-funded study of Mission and Configuration of an ST-FNSF

- Overarching goal of study:
  - Determine optimal mission, performance, size



- Goals of study:
  - Review existing designs, ID advantageous features, improve configuration
  - Develop self-consistent assessment + configuration for use by community
  - Assess T self-sufficiency, maintainability, flexibility
- FY2013-14 results/progress:
  - Tritium breeding ratio (TBR) ~ 1 likely requires breeding blanket near top+bottom of centerstack (CS)
  - Identified coil configuration compatible with:
    - Breeding in CS end region + vertical maintenance
    - Ex-vessel PF coils on outboard, can be S/C, support range of l_i and β_N
    - Divertor power exhaust: q_{peak} ~ 3-5MW/m^2, partially detached
  - Now carrying out free-boundary TRANSP simulations for NNBI+BS current drive, fusion performance, neutronics



Summary: NSTX-U FY2014-16 research plan strongly supports FES vision elements

- **Burning Plasma Science / ITER research**
  - Leading contributions to non-linear AE* dynamics, fast-ion transport, disruption warning, response to 3D δB, RWM control
- **Control science, plasma-wall interactions, FNSF**
  - Prepare NSTX-U to extend high-β + high-non-inductive scenarios to full non-inductive operation with advanced control
  - Provide critical data on SOL-widths and turbulence, novel snowflake divertors, Li-based PFCs – all for high power density
  - NSTX + Upgrade will provide critical confinement, stability, and sustainment data for assessing ST as potential FNSF
- **Validated predictive capability, discovery science**
  - Will access new & unique high-β + low-ν* regime, exploit wide variation of rotation, q, fast-ion drive to test leading models

Incremental funding needed to fully utilize NSTX-U facility and to design + implement 5YP facility enhancements

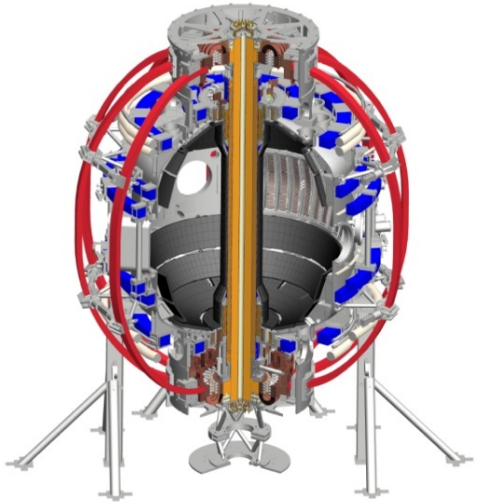
NSTX-U Facility and Diagnostics Plans for FY2014-16

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

Masa Ono, Jon Menard, Ron Strykowsky

for the NSTX-U Team

FWP 2016 Budget Planning Meeting
April 17, 2014



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
Tsukuba U
U Tokyo
JAEA
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

Talk Outline

- **NSTX Upgrade Project Update**
- **NSTX-U Commissioning and Operation Plan**
- **FY2014-16 Facility-Diagnostic Plan**
- **Budget**
- **Summary**

NSTX Upgrade Project Progress Overview

R. Strykowsky, E. Perry, T. Stevenson, L. Dudek, S. Langish, T. Egebo, M. Williams and the NSTXU Team

New Center Stack Project Scope

- ✓ Inner TF bundle
- ✓ TF Flex bus
- • OH coil
- • Inner PF coils

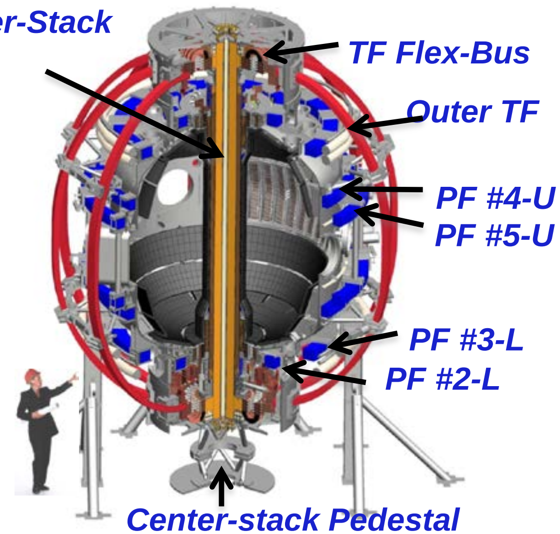
} *Center stack*

- ✓ Enhance outer TF supports
- ✓ Enhance PF supports
- ✓ Reinforce umbrella structure
- • New umbrella lids

} *Structure*

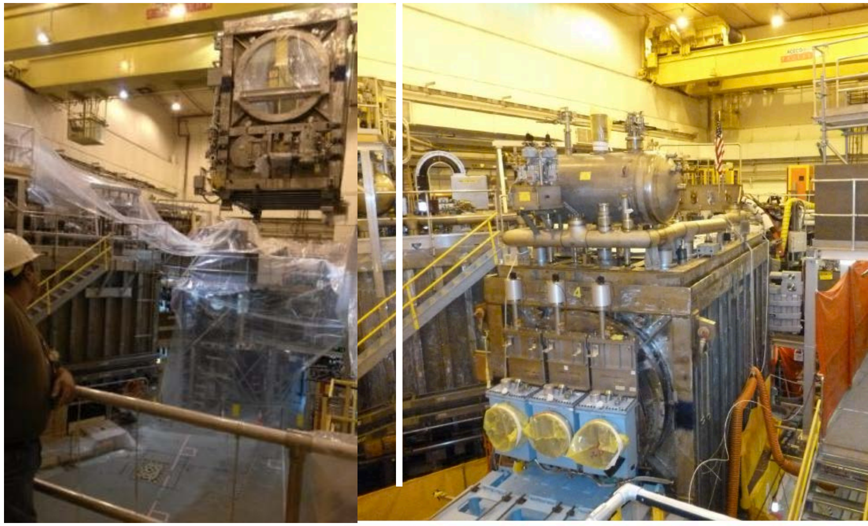
- • Power systems
- • I&C, Services, Coil protection

} *Ancillary Sys*



2nd NBI Project Scope

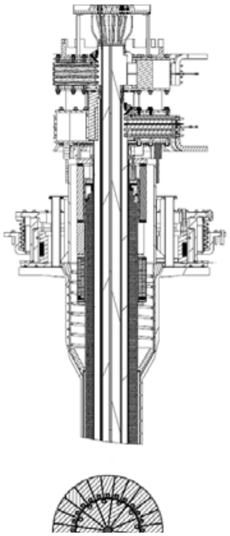
- ✓ Decontaminate TFTR beamline
- ✓ Refurbish for reuse
- ✓ Relocate pump duct, 22 racks and numerous diagnostics to make room in the NSTX Test Cell
- ✓ Install new port on vacuum vessel to accommodate NB2
- ✓ Move NB2 to the NSTX Test Cell
- • Install power, water, cryo and controls



Substantial Increase in NSTX-U Device / Plasma Performance

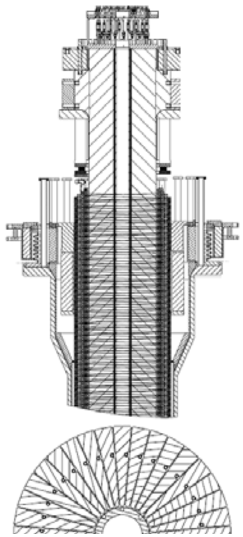
To provide data base to support ST-FNSF designs and ITER operations

Previous center-stack

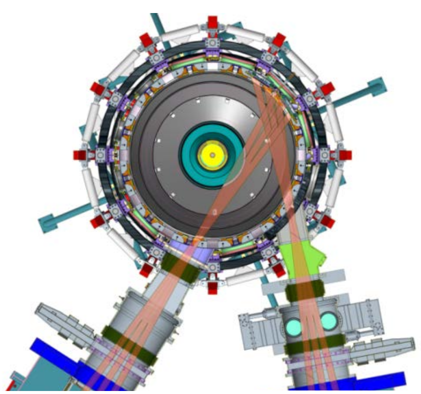


TF OD = 20cm

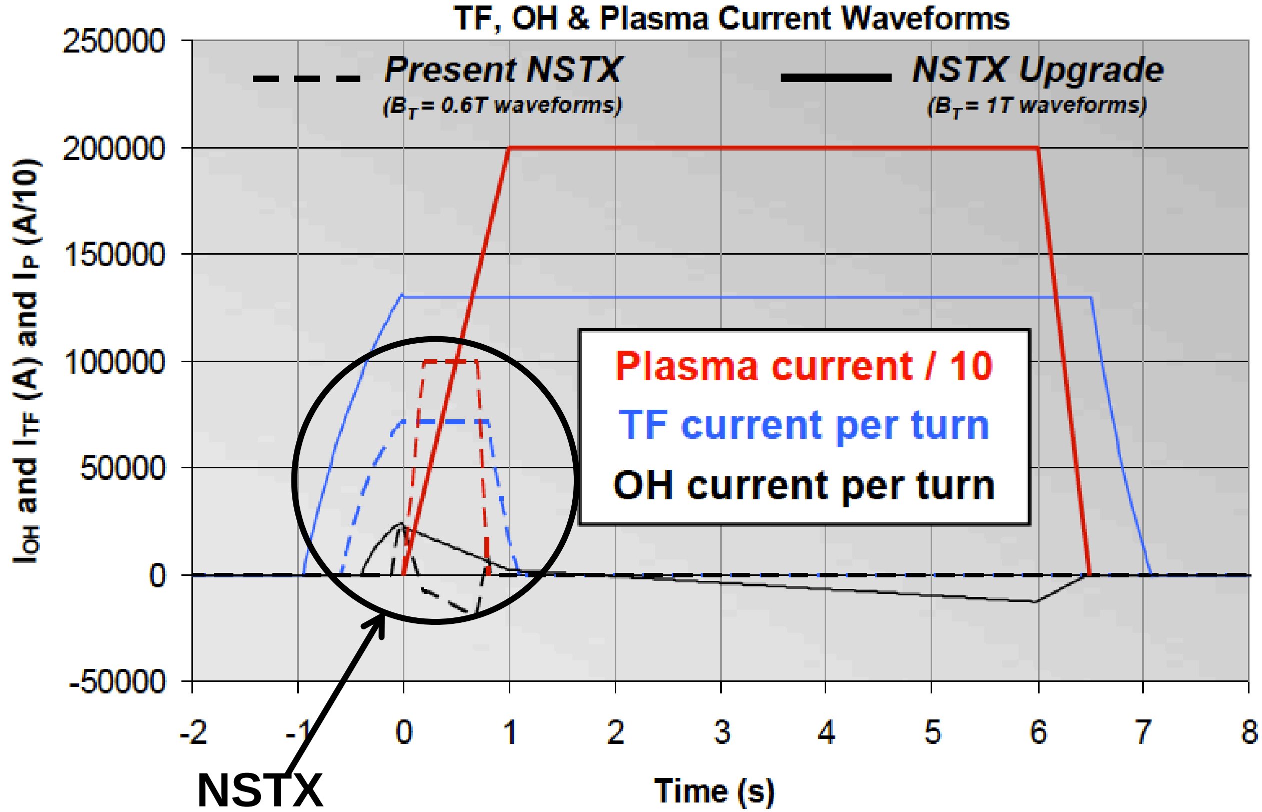
New center-stack



TF OD = 40cm



Present NBI   New 2nd NBI



	R_0 (m)	A_{min}	I_p(MA)	B_T (T)	T_{TF}(s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	**0.854**	**1.28**	**1**	**0.55**	**1**	**0.185**	**1.574**	**0.75**
NSTX-U	**0.934**	**1.5**	**2**	**1**	**6.5**	**0.315**	**1.574**	**2.1**

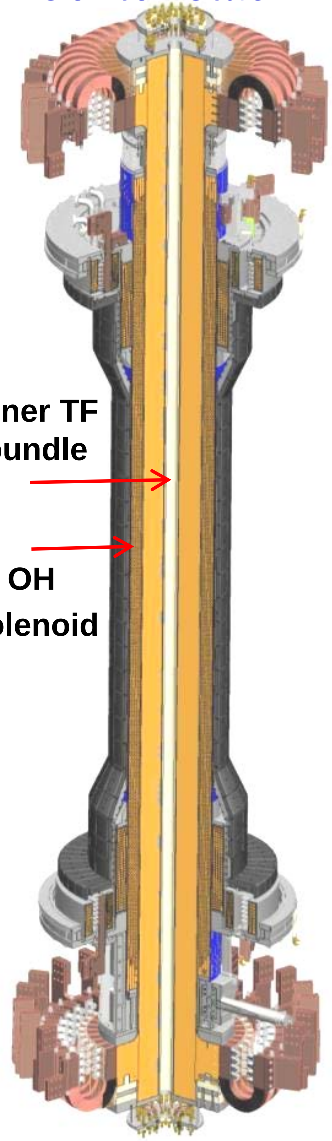
~ X 10 increase in $n\tau T$ from NSTX

NSTX-U average plasma pressure $\propto B_{T0}^2\ \beta_T (T^2\%)$ ~ TFTR, JET

OH Coil Winding Nearly Complete

Completed 3rd of 4 Layers

Center-stack



CS Casing

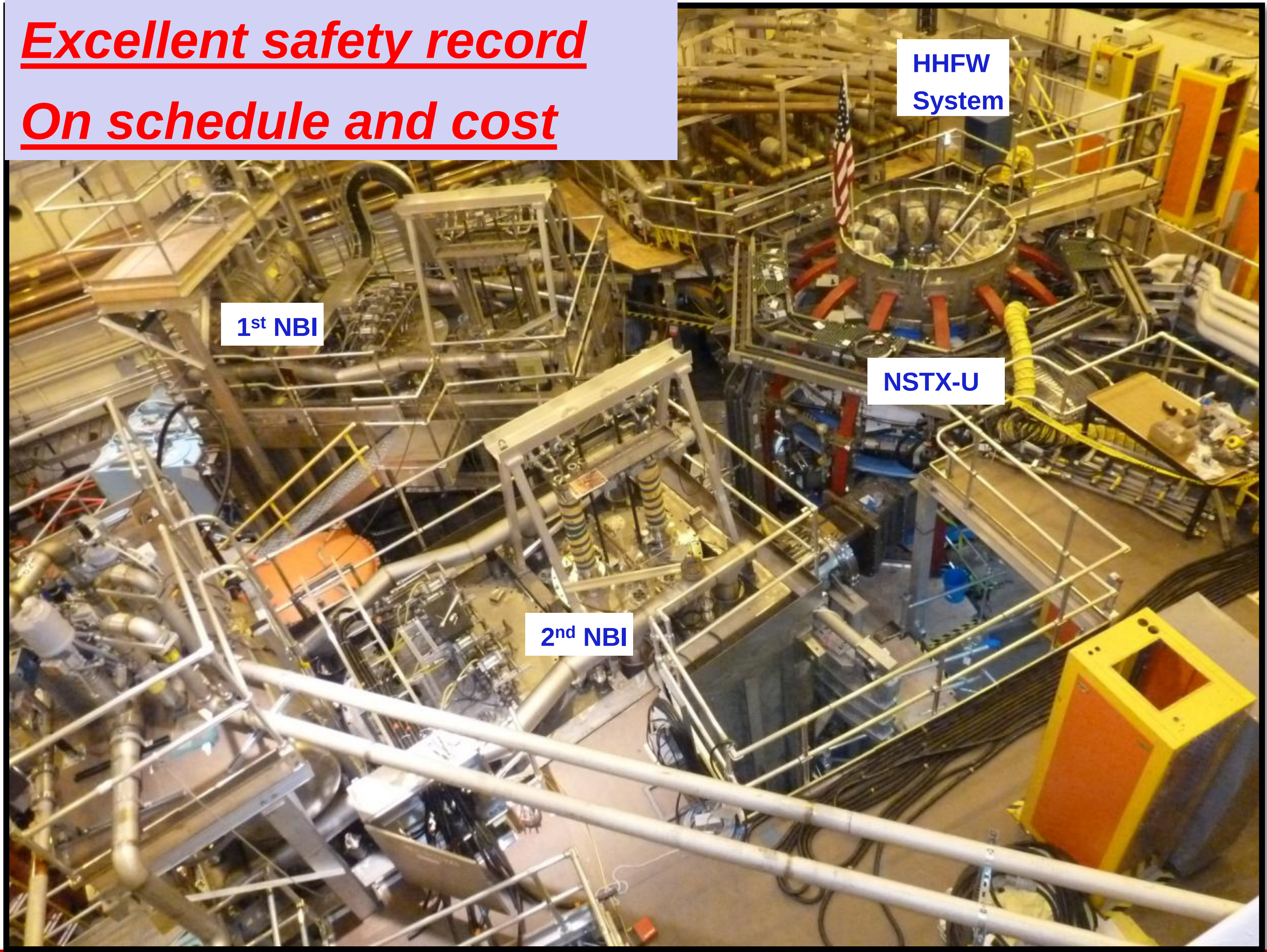
OH VPI Mold

Aquapour application

VPI Oven

NSTX-U Test Cell Aerial View (March, 2014)

2nd NBI and Structural Enhancement Nearly Complete

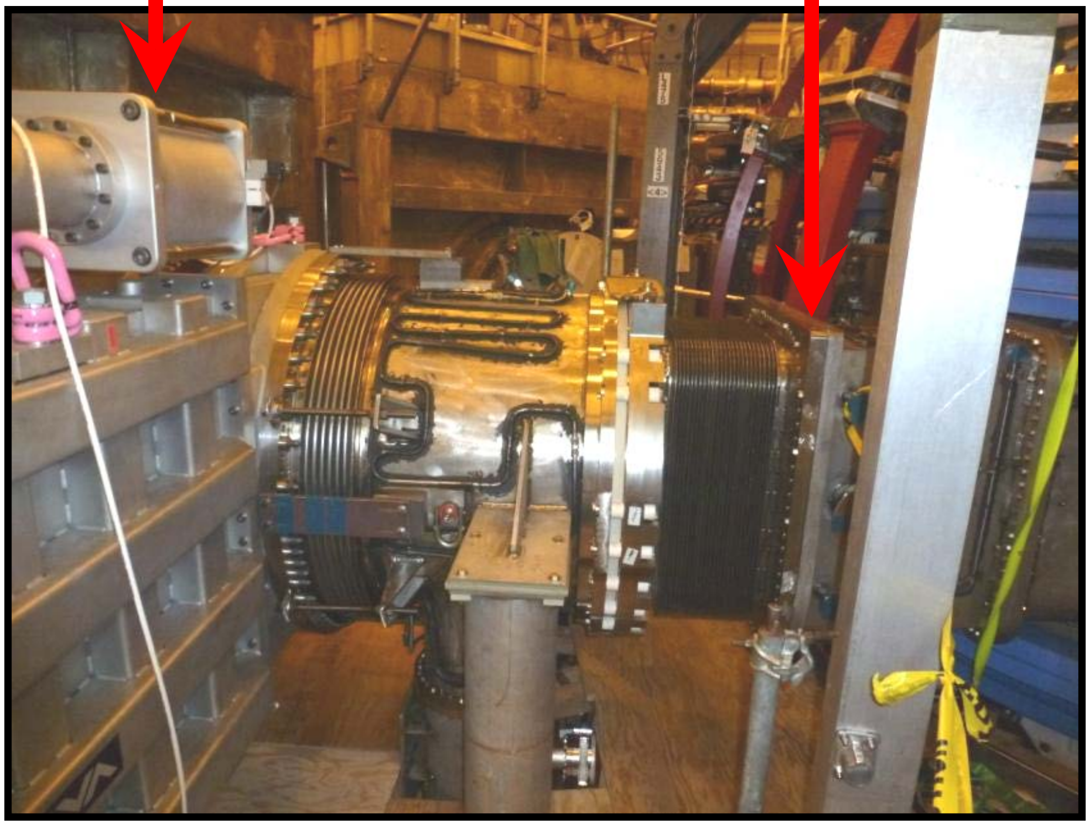


Final 2nd NBI Component being Installed

2nd NBI duct with pumping section and NBI armor installed

Neutral Beam & TIV valve

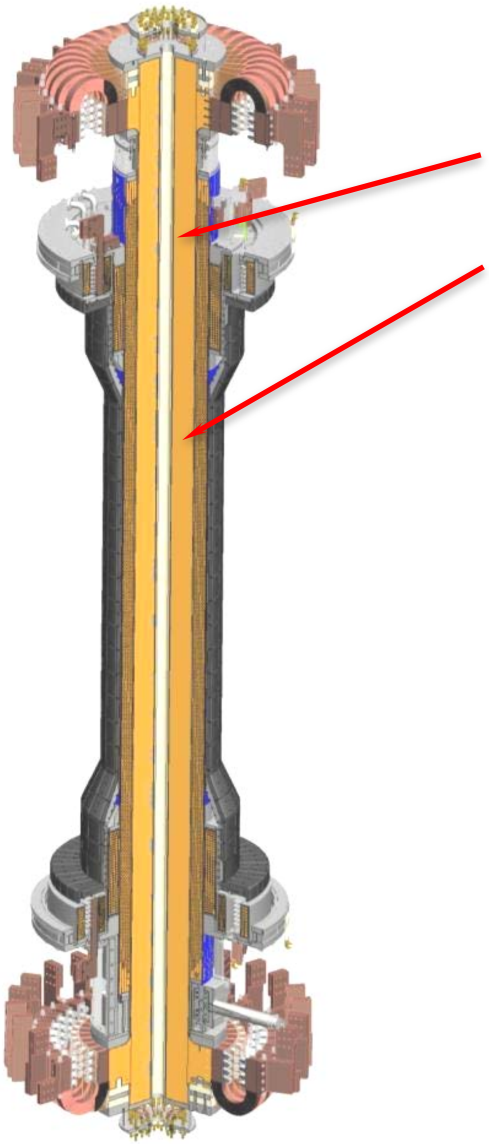
Vacuum Vessel Bay J/K port



Neutral Beam Armor Installed

Source installation planned for June

Upgrade Project 84% complete
with 30% contingency on work remaining

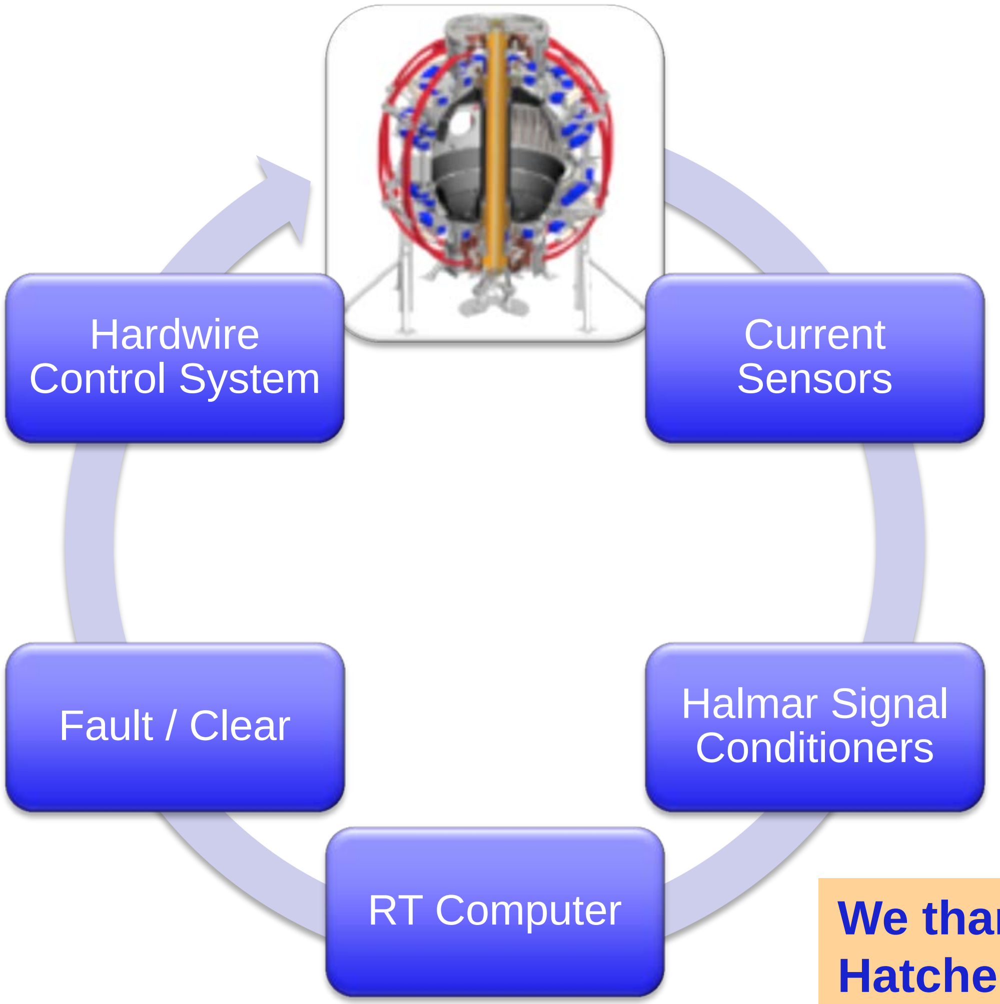


Centerstack is on the Critical Path

- **Components & Hardware**
- **Inner TF Bundle**
- **OH Solenoid**
  - OH solenoid winding- ***forecast completion April***
  - VPI OH – ***May 2014***
- **Centerstack Assembly-**
  - Delivery to NSTX TC ***July2014***
- **Install Centerstack -** ***August 2014***
- **Readiness review -** ***September 2014***
- **Pumpdown -** ***October 2014***
- **ISTP -** ***November 2014***
- **CD-4 -** ***December 2014***

NSTX-U Digital Coil Protection System

DCPS provides real time coil protection via real time computation



- **Actively protects NSTX-U by monitoring various coil currents and plasma current**
- **Triggers a fault if the algorithm output of exceeds limitations**
- **Processes many such algorithms in parallel in a deterministic fashion**
- **Faults if there exists nonzero current in the system outside of the plasma attempt**

We thank valuable contributions from Ron Hatcher who passed away on March 24.

Phase 1 testing of the DCPS software is being performed.

NSTX-U diagnostics to be installed during first 2 years

Diagnostics presently being installed prior to the center-stack installation

MHD/Magnetics/Reconstruction

Magnetics for equilibrium reconstruction
Halo current detectors
High-n and high-frequency Mirnov arrays
Locked-mode detectors
RWM sensors

Profile Diagnostics

MPTS (42 ch, 60 Hz)
T-CHERS: $T_i(R)$, $V_\phi(r)$, $n_C(R)$, $n_{Li}(R)$, (51 ch)
P-CHERS: $V_\theta(r)$ (71 ch)
MSE-CIF (18 ch)
MSE-LIF (20 ch)
ME-SXR (40 ch)
Midplane tangential bolometer array (16 ch)

Turbulence/Modes Diagnostics

Poloidal Microwave high-k scattering
Beam Emission Spectroscopy (48 ch)
Microwave Reflectometer,
Microwave Polarimeter
Ultra-soft x-ray arrays – multi-color

Energetic Particle Diagnostics

Fast Ion D_α profile measurement (perp + tang)
Solid-State neutral particle analyzer
Fast lost-ion probe (energy/pitch angle resolving)
Neutron measurements

Edge Divertor Physics

Gas-puff Imaging (500kHz)
Langmuir probe array
Edge Rotation Diagnostics (T_i, V_ϕ, V_{pol})
1-D CCD H_α cameras (divertor, midplane)
2-D divertor fast visible camera
Metal foil divertor bolometer
AXUV-based Divertor Bolometer
IR cameras (30Hz) (3)
Fast IR camera (two color)
Tile temperature thermocouple array
Divertor fast eroding thermocouple
Dust detector
Edge Deposition Monitors
Scrape-off layer reflectometer
Edge neutral pressure gauges
Material Analysis and Particle Probe
Divertor VUV Spectrometer

Plasma Monitoring

FIReTIP interferometer
Fast visible cameras
Visible bremsstrahlung radiometer
Visible and UV survey spectrometers
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis

New capability, Enhanced capability

Transition from Construction to Operation

NSTX-U Start-up Process Similar to NSTX

NSTX-U ISTP, Commissioning, and Startup will follow a similar process as NSTX initial commissioning and startup from February 1999.

1. *Pre-operational test of subsystems (PTP'S)*
2. *Activity Certification Committee (ACC) review*
3. *PU Operational Readiness Assessments (ORA)*
4. *Integrated system test procedure (ISTP) (per OP-NSTX-02 rev 14)*
5. *CD-4 Construction Project Complete*
6. *Final Preparation for Research Campaign*

- Activity Certification Committee (ACC), comprised of representatives from PPPL Engineering, Research, Safety, and the DOE Princeton Area Office, to review newly installed subsystems before commissioning. System reviews are performed at completion of construction activities.

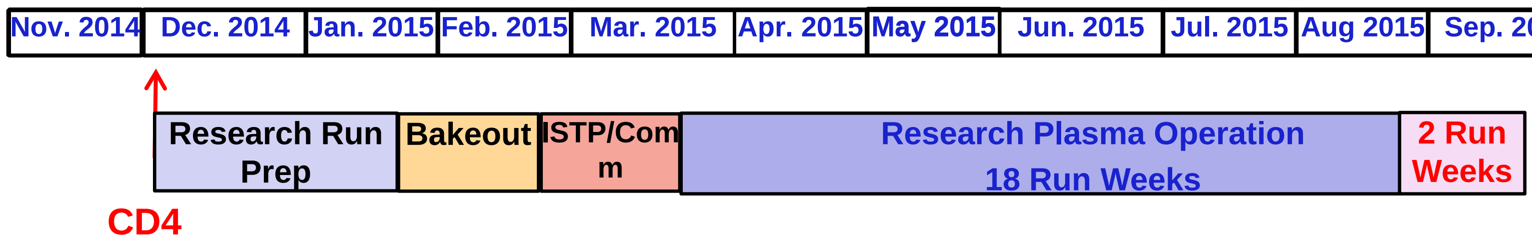
- Led by the Princeton University, an Operational Readiness Assessment (ORA) by an external committee will be made based on ACC and QA Audit reports before the project moves to start-up.

- Safety Certificates allowing Power and then Plasma Operation will be issued upon the recommendations of the ORA.

Schedule will Provide Exciting Research Operation in FY15

How to get ready for a productive research operation is a key

Run Plan for FY 2015



- **CD-4 in early December should allow scheduling of the research campaign up to 20 run weeks (Base – 18 run weeks and Incremental – 2 run weeks).**
- **The run assumes three weeks operation and one maintenance weeks. Some extended run weeks for the latter part of operation.**
- **3 - 4 month period is allocated between CD-4 and the research plasma operation.**
- **Will complete as much research run preparation tasks as possible prior to CD-4 to minimize the period between CD4 and the research plasma operation.**

Strategy for Achieving Full NSTX-U Parameters

After CD-4, the plasma operation could quickly access new ST regimes

	NSTX (Max.)	FY 2015 NSTX-U Operations	FY 2016 NSTX-U Operations	FY 2017 NSTX-U Operations	Ultimate Goal
I_P [MA]	1.2	~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]	~0.4	~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

Repair of the motor generator weld cracks to be completed June 2014 to enable full NSTX-U operation. We appreciate the funding made available this year!

10 Year Facility Plan Targets Research Goals

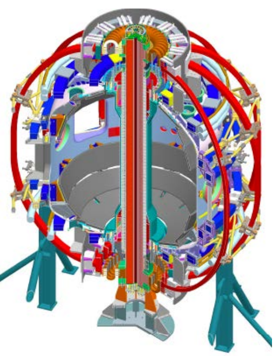
1.1 × (FY2012 + 2.5% inflation)

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

Upgrade Outage | **1.5 → 2 MA, 1s → 5s** | **Metallic PFCs, 5s → 10-20s**

Run Weeks: 20, 16, 16, 20, 22, 6, 18, 22, 22

New center-stack



Start-up and Ramp-up
- Upgraded CHI for ~0.5MA
- 0.5-1 MA CHI
- up to 1 MA plasma gun
- Extend NBI duration to 10-20s and/or implement 2-4 MW off-axis EBW H&CD
- 1 MW ECH/EBW → 2 MW

Boundary Physics
- Lower divertor cryo-pump
- Divertor Thomson
- Upper divertor cryo-pump

Materials and PFCs
- High-Z tile row on lower OBD
- High-Z first-wall + lower OBD tiles
- High-Z PFC diagnostics
- All high-Z PFCs
- Hot high-Z FW PFCs using bake-out system

Liquid metals / lithium
- Li granule injector
- Upward LiTER
- LLD using bakeable cryo-baffle
- Flowing Li divertor or limiter module
- Full toroidal flowing Li lower OBD

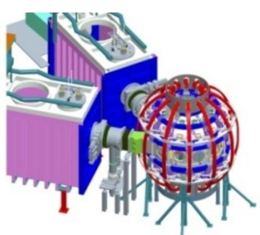
MHD
- MGI disruption mitigation
- Partial NCC
- Enhanced MHD sensors
- NCC SPA upgrade
- Full NCC

Transport & Turbulence
- δB polarimetry
- High k_θ
- DBS, PCI, or other intermediate-k

Waves and Energetic Particles
- 1 coil AE antenna
- 4 coil AE antenna
- HHFW limiter upgrade
- Charged fusion product, neutron-collimator
- HHFW straps to excite EHO
- High-power AE antenna

Scenarios and Control
- Establish control of: Snowflake, $\bar{n}_e$, Rotation, q_{min}, Divertor, P_{rad}
- Control integration, optimization
- Control integration, optimization with long-pulse and full metal wall

Inform choice of FNSF: aspect ratio, divertor, and PFCs



2nd NBI

Significant Near-Term Upgrade Scopes Are Highlighted

ECH, Cryo-Pump and NCC system require resources starting in 2015

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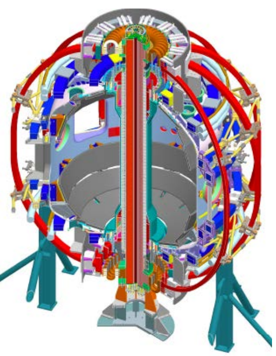

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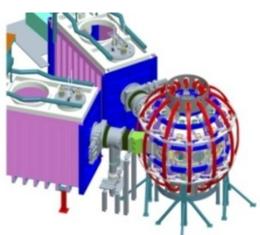
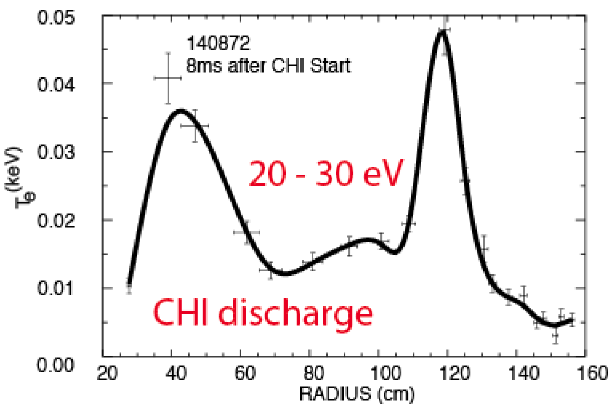
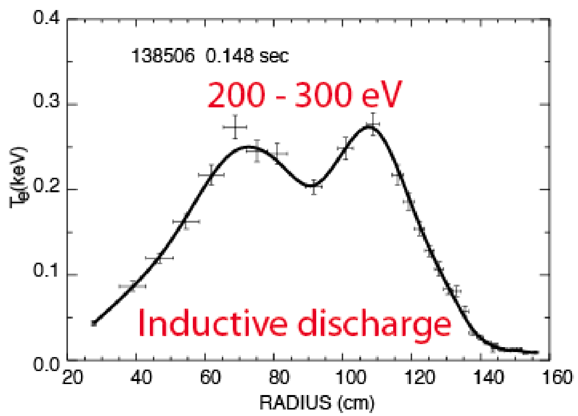


2nd NBI

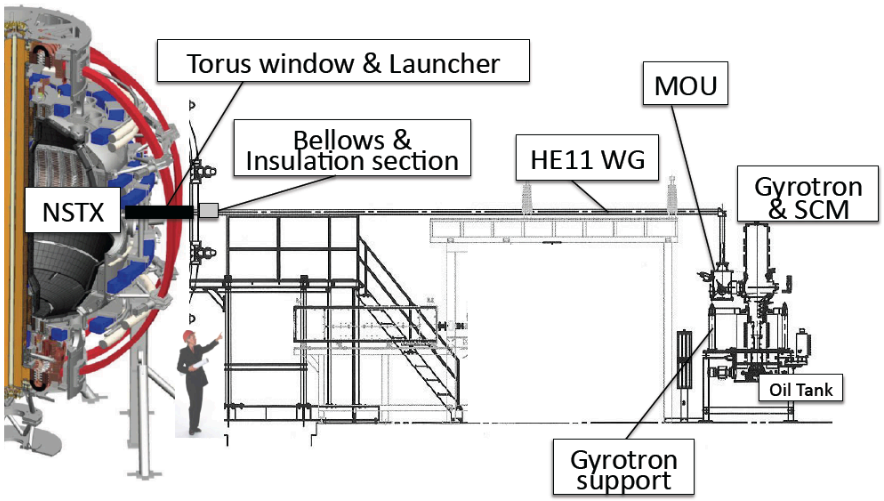
1 MW ECH system: Bridge T_e Gap Between CHI Start-up and HHFW + NBI Current Ramp-up Requirements

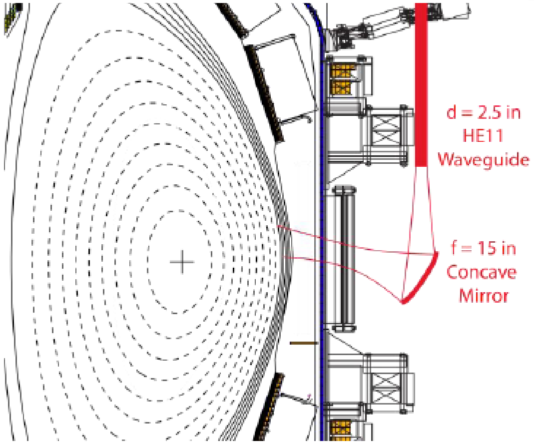


1MW ECH



28 GHz, 1.5 MW Tsukuba Gyrotron





28 GHz ECH/EBWH waveguide and mirror concept

Tsukuba U
MIT
ORNL

FY 2016 Perform MW-class ECH/EBW system engineering design for non-inductive operations. Incremental funding will enable start of engineering design and procurement in FY 2015.

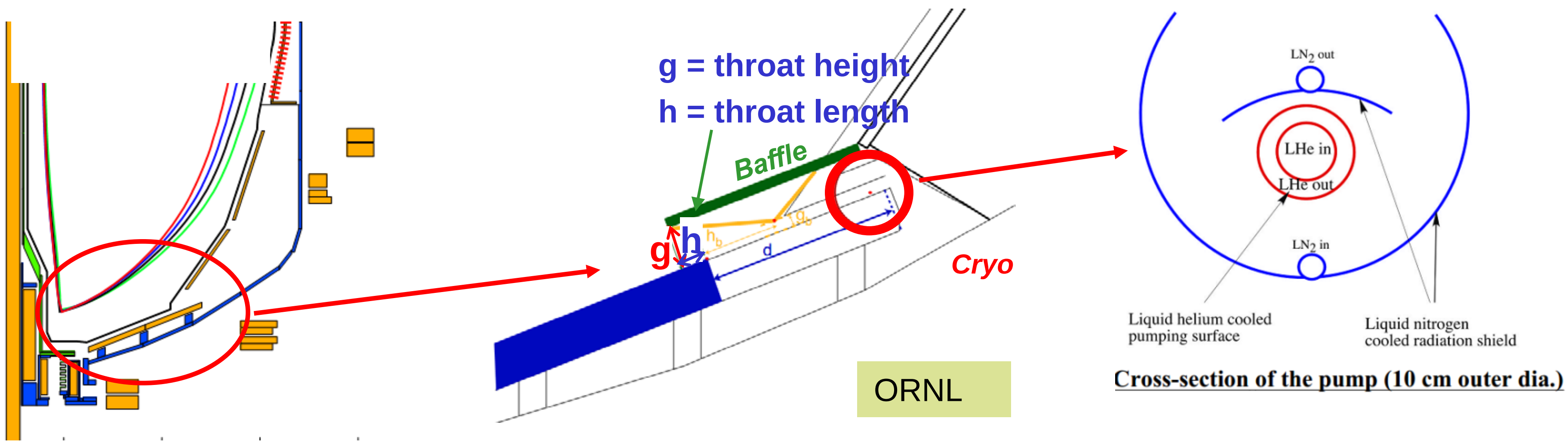
Divertor Cryo-pumping for Particle Control in Long-pulse ELMy H-mode

Cryo-pump is proven technology for plasma density control

- More conventional pumped stationary ELMy H-mode scenario
- Enables comparison with lithium based pumping

NSTX-U design will leverage DIII-D experience

- Plenum located under new baffling structure near secondary passive plates
- Pumping capacity of a toroidal liquid He cooled loop
  - S=24,000 l/s @ R=1.2m (Menon, NSTX Ideas Forum 2002)
- Need plenum pressure of 0.6 mTorr to pump beam input (TRANSP)

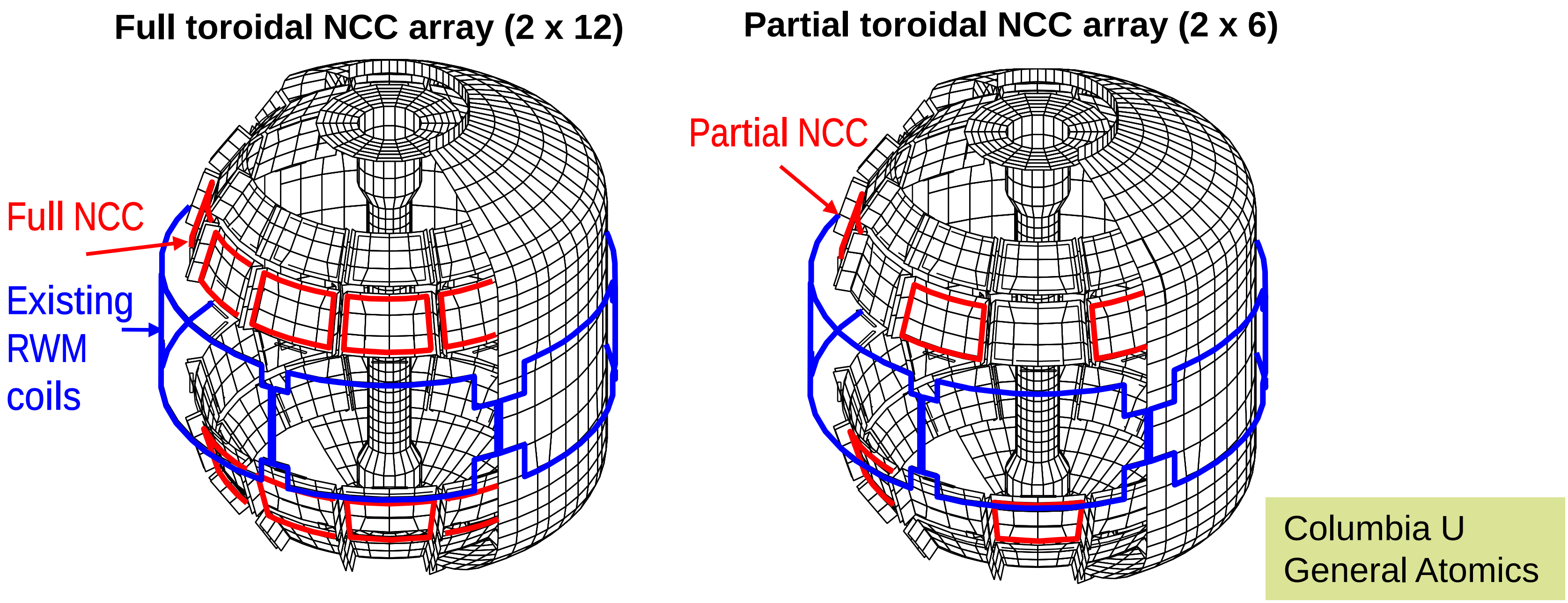


Cross-section of the pump (10 cm outer dia.)

Base - Perform cryo-system engineering design for particle control in FY 2016. Incremental funding will enable start of engineering design in FY 2015 and procurement in FY 2016.

NCC will greatly enhance MHD physics studies and control

Range of off-midplane NCC coil configurations is assessed



- NCC (a facility enhancement) can provide various NTV, RMP, and EF selectivity with flexibility of field spectrum (n ≤ 6 for full and n≤ 3 for partial)
- 6-channel Switching Power Amplifier (SPA) powers independent currents in existing EFC/RWM and NCC coils.

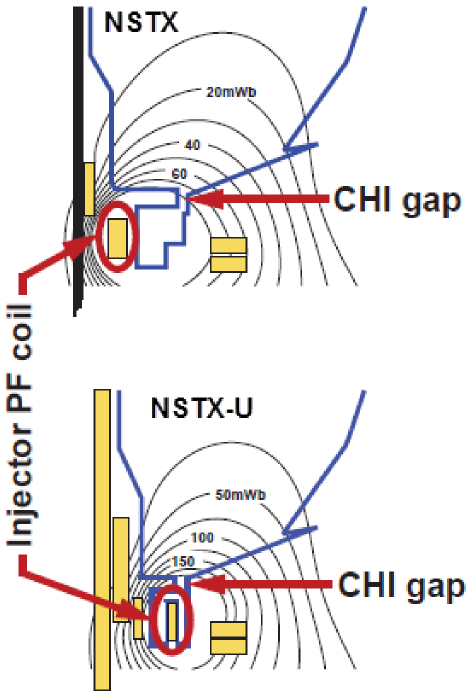
Base – No work on NCC until 2017. Incremental funding will enable start of engineering design in FY 2015 and procurement in FY 2016.

Solenoid-free Start-up
High priority goal for NSTX-U in support of FNSF

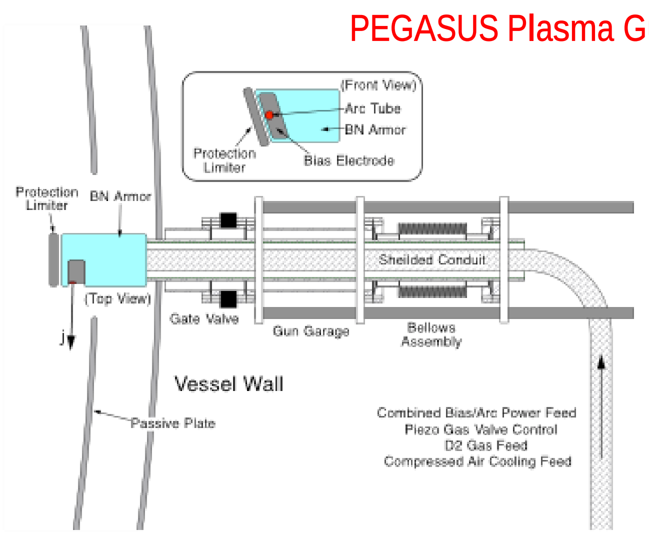
CHI Start-Up

- Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX
- NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation

U. Washington



Point Source Being Developed



U. Wisconsin

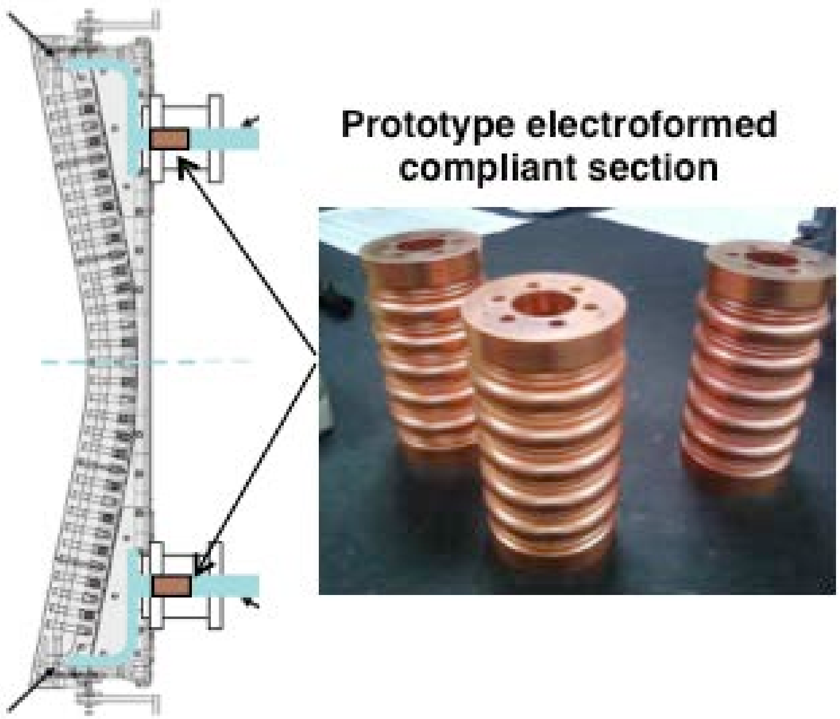
FY 2014-15 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

- CHI will start with the present 2 kV capability then enhanced to ~ 3 kV higher voltage as needed.
- PEGASUS gun start-up producing exciting results Ip ~ 160 kA. The PEGASUS gun concept is technically flexible to implement on NSTX once fully developed. High voltage gun for the NSTX-U will be developed utilizing the PEGASUS facility in collaboration with University of Wisconsin.

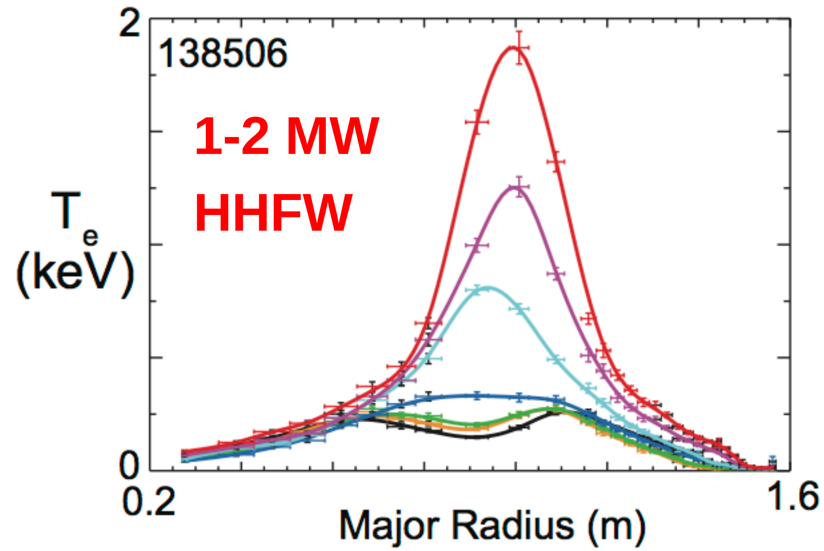
Strengthening HHFW Antenna Feeds for Disruption Loads

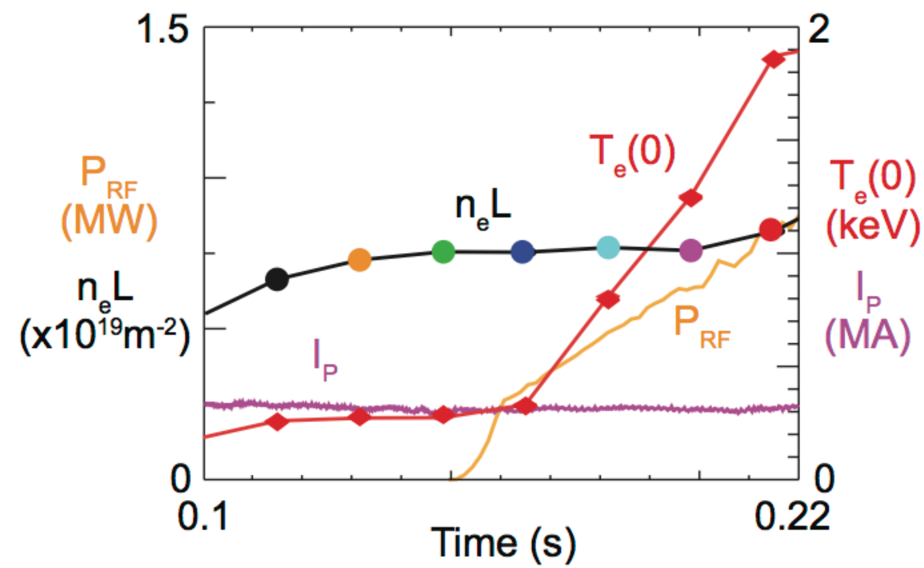
New Compliant Antenna Feeds

Will allow HHFW antenna feedthroughs to tolerate 2 MA disruptions



- **Successful CDR conducted, prototype feeds being procured.**
- **Feeds tested to 46 kV in the RF test-stand before installation in May 2014.**



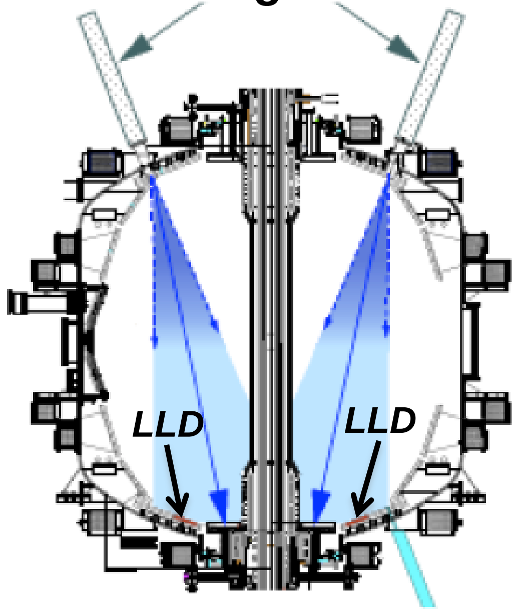


NSTX-U Lithium Capability During Initial Two Years

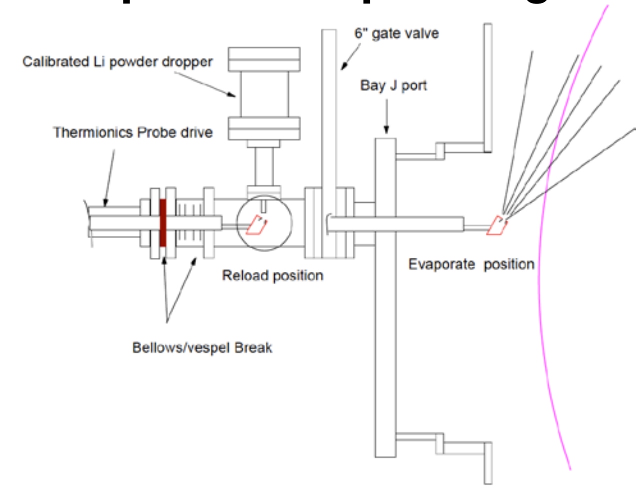
Boronization, Lithium Evaporators, and Granular Injector

NSTX-U Day 1: Boronization planned for the initial operation to establish a base plasma performance prior to turning on lithium.

Existing LITERS



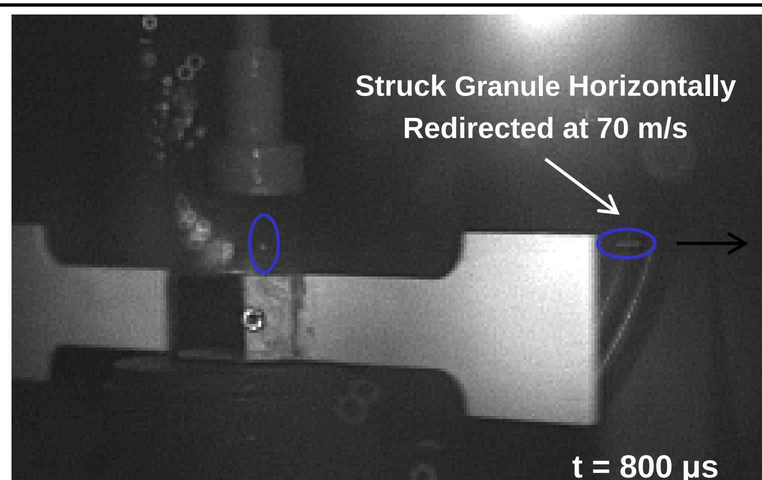
New Upward Evaporating LITER

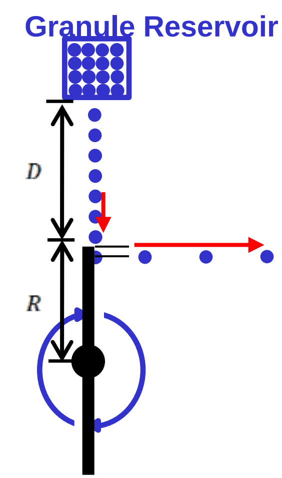


- Upward Evaporating LITER to increase Li coverage for increased plasma performance

NSTX-U lithium granular injector for ELM pacing

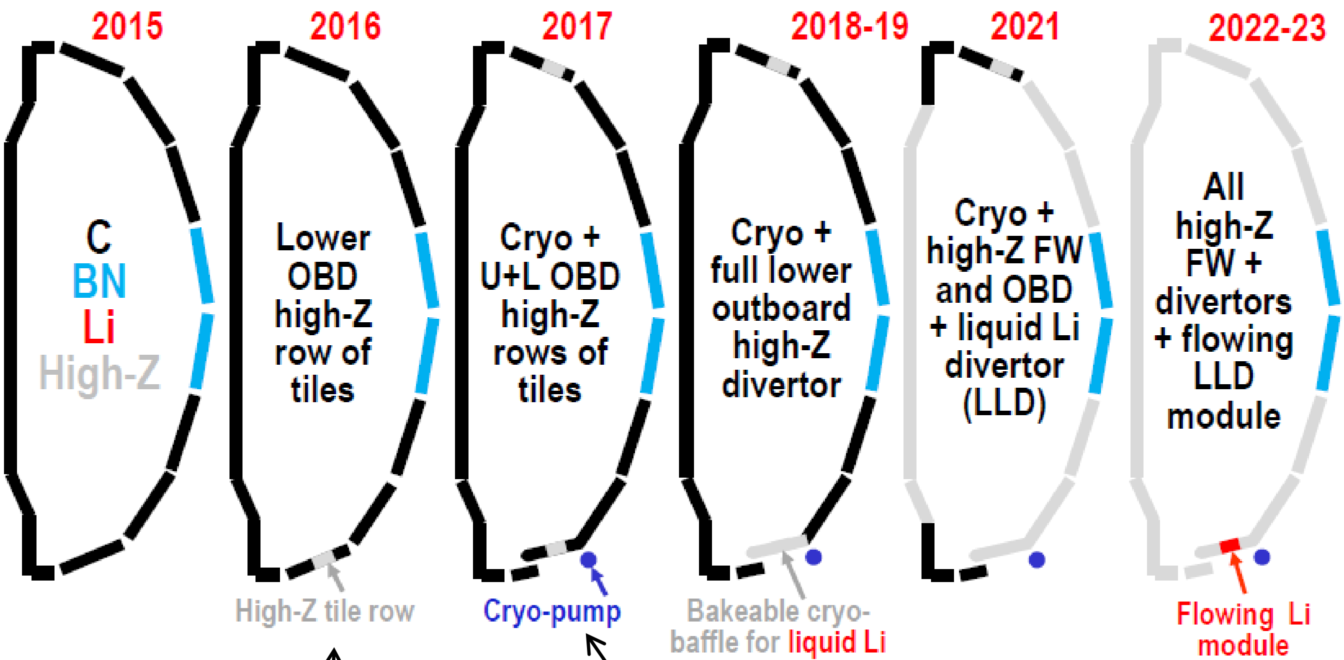
- High frequency ELM pacing with a relatively simple tool.
- ELM pacing successfully demonstrated on EAST (D. Mansfield, IAEA 2012)

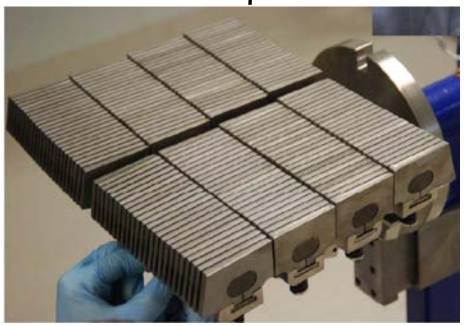




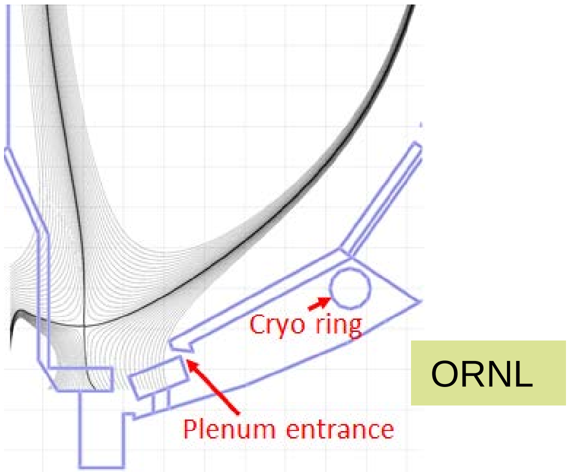
Boundary Facility Capability Evolution

NSTX-U will have very high divertor heat flux capability of ~ 40 MW/m^2





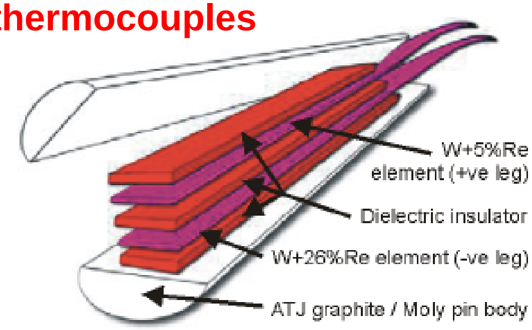
TZM or W lamellae PFC (e.g., JET)



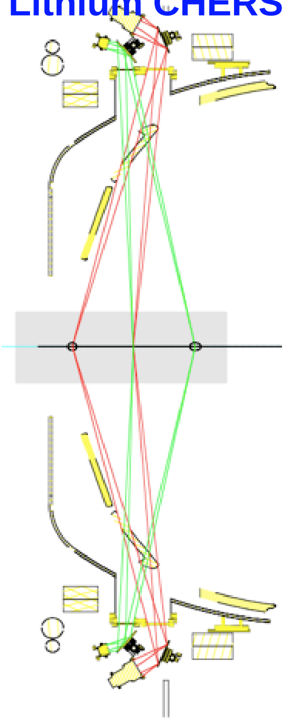
- High heat flux regions (strike-point regions)
  - TZM or W lamellae (e.g. JET)
- Intermediate heat flux regions (cryo-baffles, CS midplane)
  - TZM tiles or TZM/W lamellae
- Low heat flux regions (passive plates, CS off-midplane)
  - W-coated graphite (e.g. ASDEX-U)

Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples

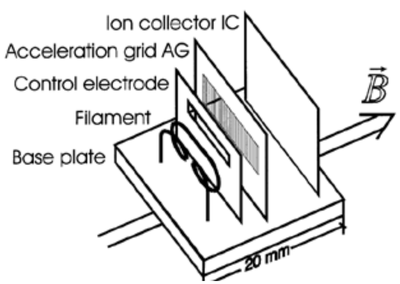


Lithium CHERS



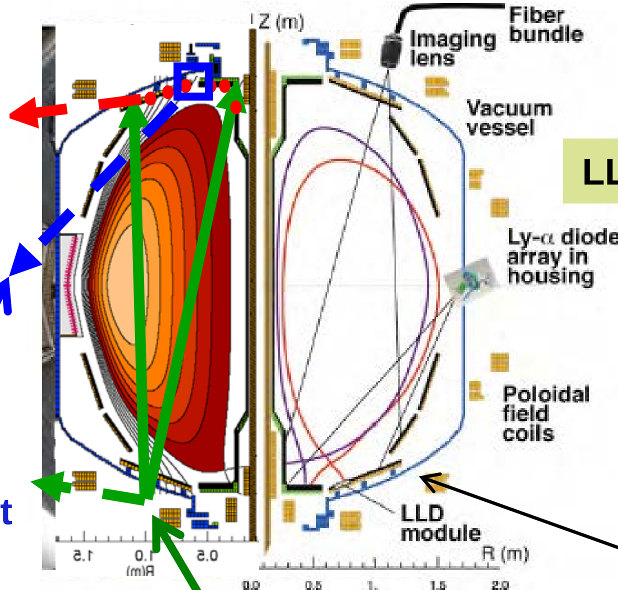
ORNL

Divertor fast pressure gauges



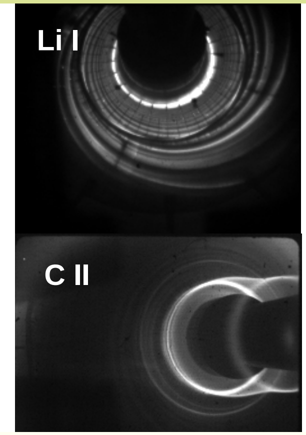
Divertor Imaging Spectrometer

LLNL

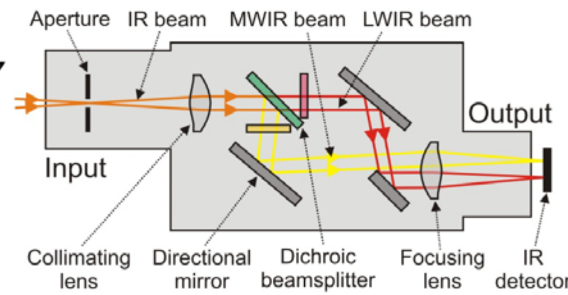


Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K



Dual-band fast IR Camera

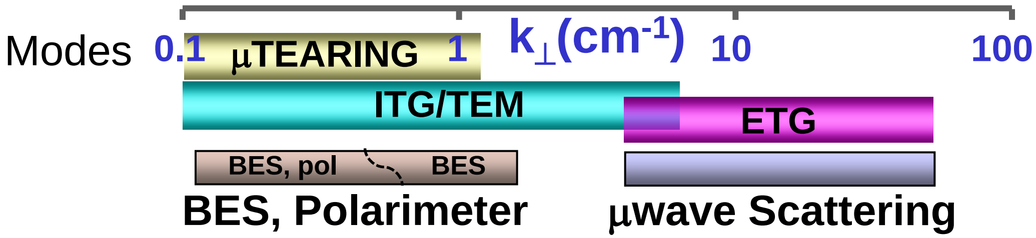


MAPP probe for between-shots surface analysis – Tested in LTX

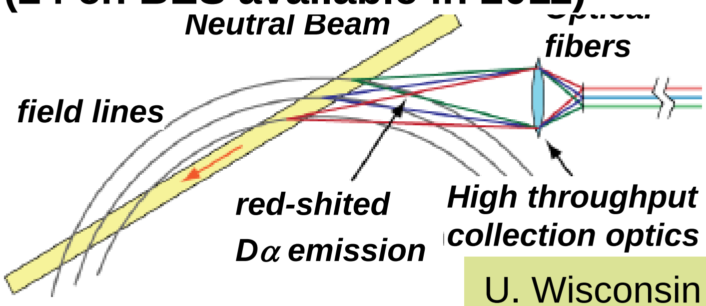
U. of Illinois

Transport and Turbulence

BES together with high-k to provide comprehensive turbulence diagnostic



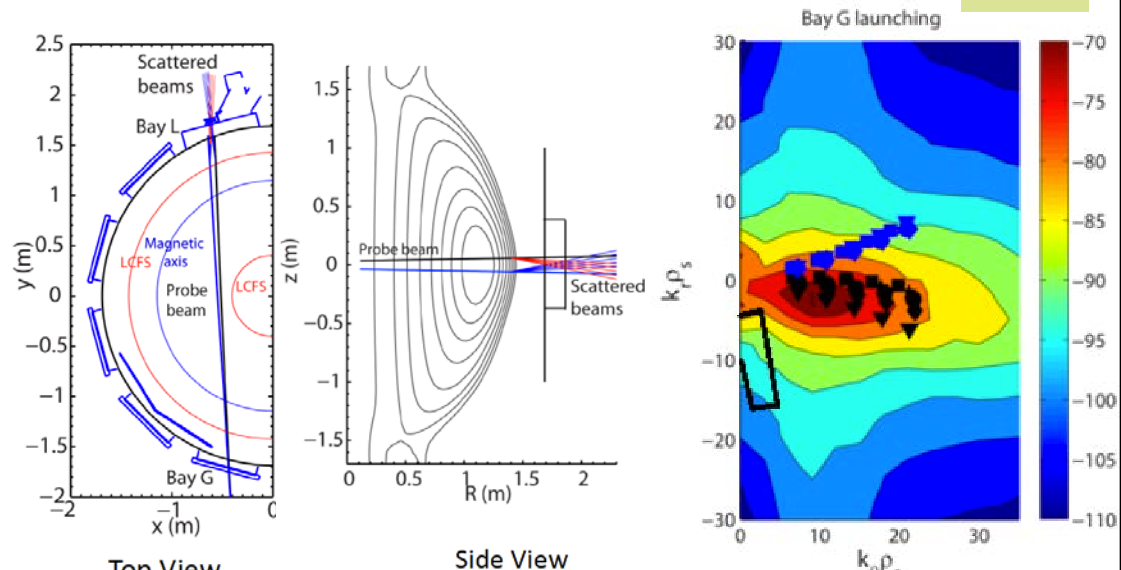
48 ch BES available for NSTX-U (24 ch BES available in 2011)



U. Wisconsin

New high-k scattering system for allowing 2-D k spectrum

UCD



A 288 GHz polarimetry system for magnetic fluctuation measurements is being tested on DIII-D.

UCLA

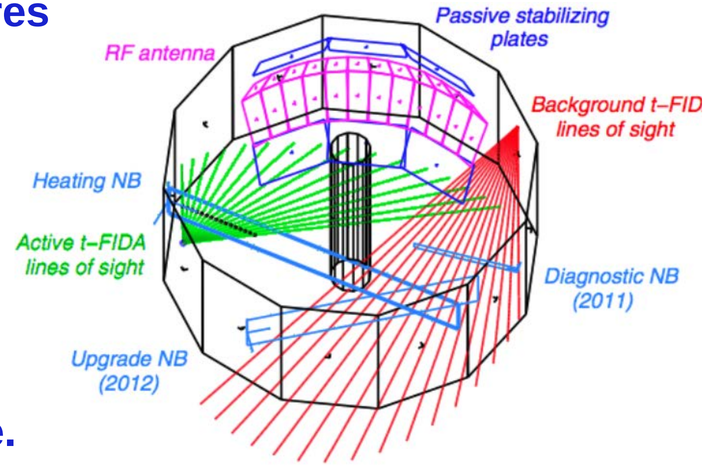
Energetic Particle Research Capabilities
For NBI fast ion transport and current drive physics

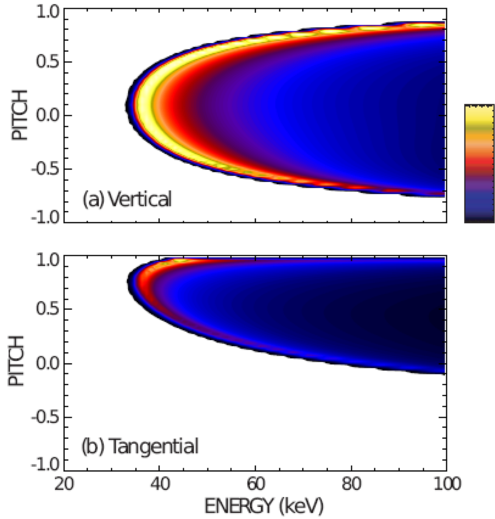
Fast Ion D-Alpha Diagnostics

UCI

- A vertical FIDA system measures fast ions with small pitch, corresponding to trapped or barely passing (co-going) particles.
- A new tangential FIDA system measures co-passing fast ions with pitch ~0.4 at the magnetic axis up to 1 at the plasma edge.
- Both FIDA systems have time resolution of 10 ms, spatial resolution ≈5 cm and energy resolution ≈10 keV.

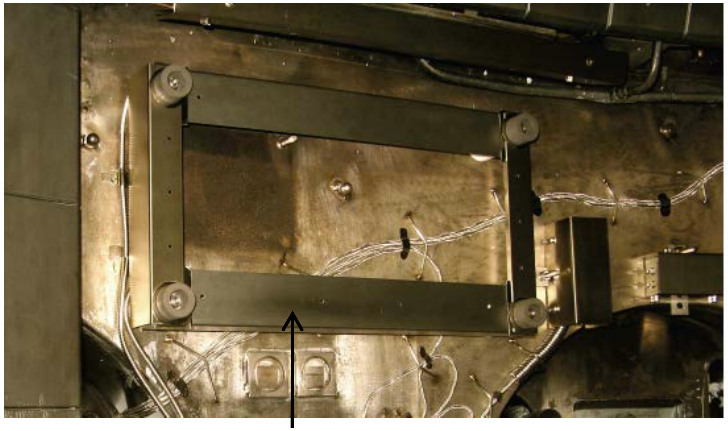
FIDA Views





FY 2014 - 15 Energetic Particle Conceptual Design and Diagnostic Upgrade

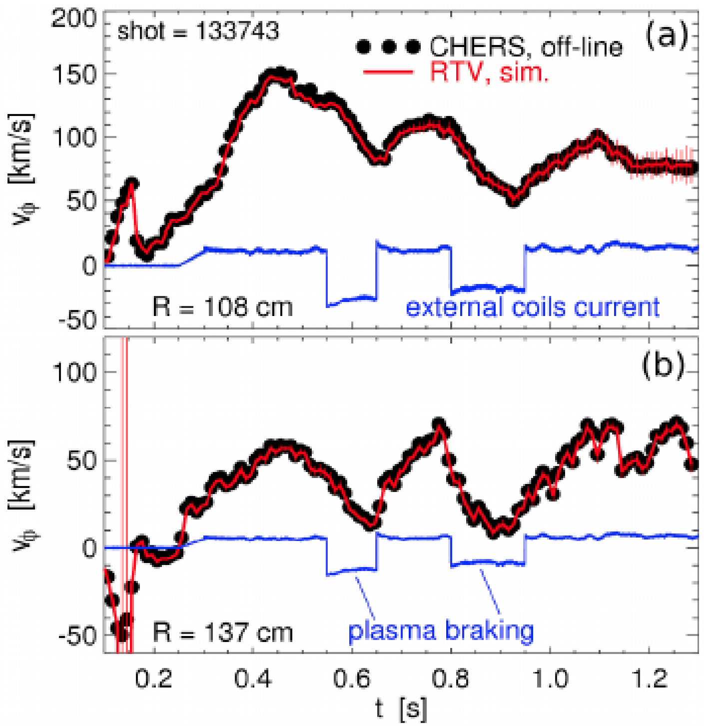
- SS-NPA enhancement due to removal of scanning NPA UCI
- Proto-type active TAE antennas and sFLIP

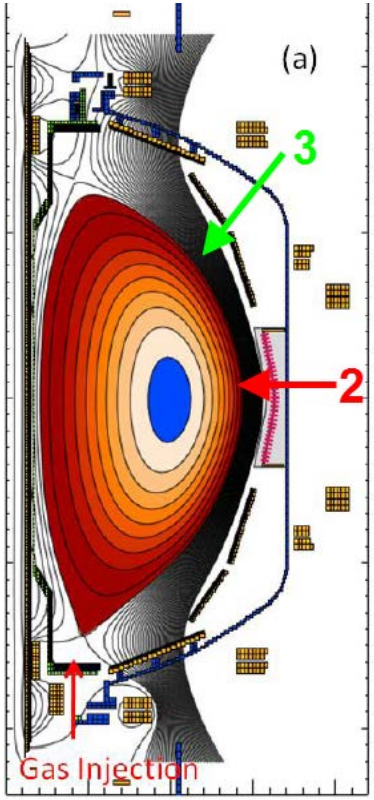


2 x 2 5-turn radial active TAE antennas installed

Advanced Scenario and Plasma Control Tools for NSTX-U
Real time rotation control and disruption mitigation

RTV fitting vs off-line CHERS data





Massive gas injector system at multi-poloidal location

U. Washington

FY 2014-15:

- **A Real-Time Velocity (RTV) diagnostic will be incorporated into the plasma control system for feedback control of the plasma rotation profile.**
- **Multi-poloidal location massive gas injector system for disruption mitigation will be implemented to test the efficiency vs location.**

Base NSTX-U Facility/Diagnostic Milestones

Crucial to complete ECH/EBW and Cryo-pump Engineering Designs in FY 2015

Facility	Milestone Description	Baseline
F(14-1)	Complete installation and testing of refurbished D-Site Rectifier Firing Generators.	Sep 14
F(15-1)	Complete 18 run week research operation	Sep 15
F(15-2)	Complete high-Z tile design and begin procurement	May 15
F(15-3)	Begin electron cyclotron heating / electron Bernstein wave (ECH/EBW) system engineering design and gyrotron procurement.	Sep 15
F(15-4)	Develop cryo-pump engineering design concept	Sep 15
F(16-1)	Complete 16 run week research operation	Sep 16
F(16-2)	Complete ECH/EBW system engineering design and begin installation	Sep 16
F(16-3)	Complete cryo-pump engineering design and begin procurement of components	Sep 16

Diagnostics	Milestone Description	Baseline
D(14-1)	Complete the Multi-Pulse Thomson Scattering (MPTS) diagnostic in-vessel modifications	Apr 14
D(15-1)	Install and commission Material Analysis Particle Probe (MAPP)	Sep 15
D(16-1)	Install and commission high k_q diagnostic system	Mar 16

NSTX-U Optimized Plan Is Proposed for FY 2014 – 16

Exciting Opportunities and Challenges Ahead

- **NSTX upgrade outage activities are going well**
  - The Upgrade Project progressing on cost and on schedule. CD-4 completion in Dec. 2014 and the research operation starting in March 2015 for 18 run weeks.
  - Researchers are preparing for NSTX-U operation while working productively on data analysis, collaboration, and five year plan.
- **Exciting 5 Year NSTX-U research plan developed**
  - Provide necessary data base for FNSF design and construction.
  - Provide new solutions to the plasma-material interface.
  - Strong contribution to toroidal physics, ITER, and fusion energy development.
- **FY 2014-15 budget guidance will enable the timely NSTX-U research operations start while completing the Upgrade Project.**
  - The base budget restores the budget to the FY 2012 level (inflation adjusted) and enables timely start of the NSTX-U research operations.
  - Incremental budget will enable full facility utilization and a timely implementation of the Five Year Plan enhancements including ECH, Cryo-pump and partial NCC.

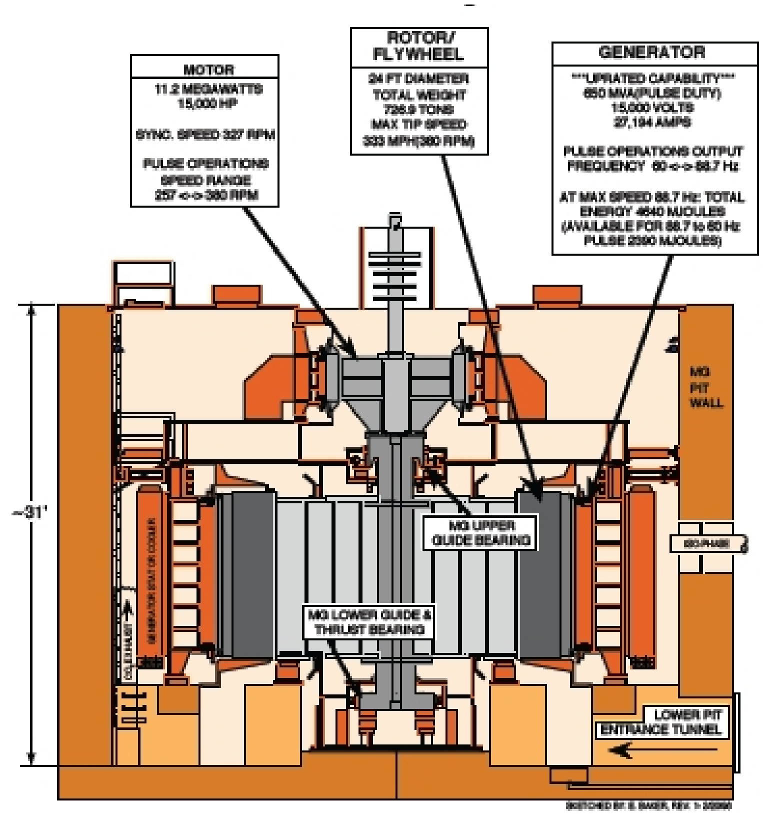
Backup Slides

Engineering / Research Operations Preparation
Ramping up for the NSTX-U Operations in Dec. 2014

- **Upgrading the Plasma Control System (PCS) for NSTX-U.**
- **Upgrading HHFW antenna feedthroughs for higher disruption forces.**
- **Boundary Physics Operations**
  - **Improving the PFC geometry at the CHI gap to protect the vessel and coils.**
  - **Upgrading gas injection system including the massive gas injection disruption mitigation system.**
  - **Boronization system will be readied to support initial research operations.**
  - **Preparing lithium systems (LITERs, granule injector for ELM trigger, upward LITER).**
- **Diagnostic Enhancements**
  - **MPTS re-alignment and laser dump relocation.**
  - **Fabricating new port covers to support high-priority diagnostics. The last large port being fabricated.**
  - **Installing additional, redundant magnetic sensors.**
  - **Upgrading diagnostics: Bolometry (PPPL), ssNPAs, spectroscopy (collaborators)**
- **Physics & Engineering Operations**
  - **Firing generators for 68 Transrex rectifiers replaced. Testing starting.**
  - **Repair of the Motor Generator radial arm weld cracks to complete in May.**
  - **Upgrading the poloidal field coil supplies to support up-down symmetric snowflake divertors on-going.**

Repair of the Motor Generator
(MG#1)

- **In 2004, Magnetic Particle Inspections identified cracking in the weld fillet of multiple joints between the radial arms of MG#1. Cracks were in primary load paths, taking that set out of service. MG#2 is in limited operations (run and monitor at reduced parameters) with cracks in "stiffener" welds intended to limit elastic deformation (not in primary load paths).**
  - **Over 250" of welds in 19 rotor spider joints will be ground out and replaced to restore MG#1 to its original design configuration.**
  - **A jacking system has been engineered to relieve all loads on the rotor assembly during the repair.**
  - **PPPL and GE engineering collaborated on the detailed repair procedure (D/NSTX-RP-MG-07).**



Status: Target completion date is June 2014

- **A Statement of Work to perform the scope described in the repair procedure has been signed.**
- **Fixed-price proposals for the weld repairs have been received. A WAF capturing all project costs (PPPL and Sub-contractor) generated.**
- **A draft Project Management Plan has been developed.**

Incremental NSTX-U Facility / Diagnostic Milestones

Accelerates ECH/EBW, Cryo-pump, NCC enhancements by one year

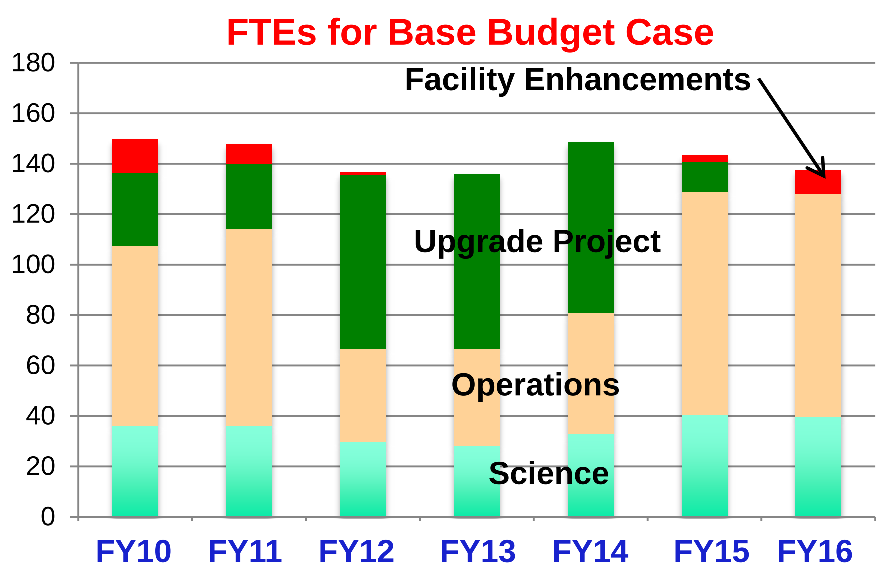
Facility	Milestone Description	Baseline
F(14-1)	Complete installation and testing of refurbished D-Site Rectifier Firing Generators.	Sep 14
IF(15-1)	Complete 20 run week research operation	Sep 15
F(15-2)	Complete high-Z tile design and begin procurement	May 15
IF(15-3)	Complete electron cyclotron heating / electron Bernstein wave (ECH/EBW) system engineering design and begin gyrotron procurement.	Sep 15
IF(15-4)	Complete cryo-pump engineering design and begin procurement	Sep 15
IF(16-1)	Complete 20 run week research operation	Sep 16
IF(16-2)	Begin ECH/EBW system installation	Sep 16
IF(16-3)	Complete procurement of cryo-pump major components	Sep 16
IF(16-4)	Develop non-axisymmetric control coil (NCC) engineering design	Sept 16

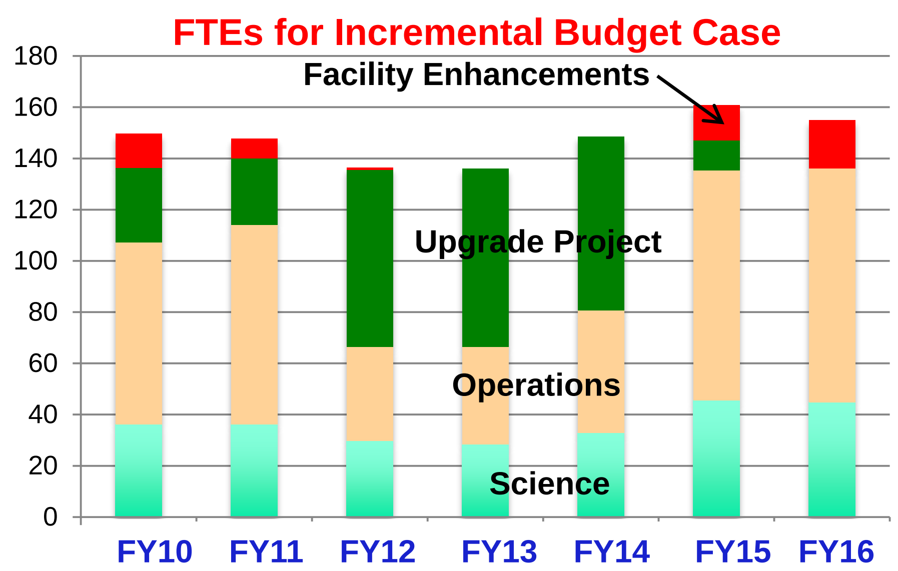
Diagnostics	Milestone Description	Baseline
D(14-1)	Complete the Multi-Pulse Thomson Scattering (MPTS) diagnostic in-vessel modifications	Apr 14
D(15-1)	Install and commission Material Analysis Particle Probe (MAPP)	Sep 15
D(16-1)	Install and commission high k_q diagnostic system	Mar 16

NSTX-U FY 2016 FWP Manpower Summary

Incremental budget enables 5 year plan implementation

FTEs	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015		FY 2016		
	Actual	Actual	Actual	Actual	Base	Base	Incr	Warm SD	Base	Incr
Run Weeks	**15.43**	**4.21**	**0**	**0**	**0**	**18**	**20**	**0**	**16**	**20**
Science	36.2	36.1	29.7	28.3	32.8	40.6	45.6	33.2	39.8	44.8
Operations	71.1	78.03	36.7	38.2	47.9	88.3	89.7	67.2	88.3	91.3
Upgrade Project	29	25.9	69.3	69.5	67.9	11.8	11.8			
Facility Enhancemts	13.3	7.8	0.8			2.6	13.7		9.4	18.8
Total FTEs	**149.6**	**147.83**	**136.5**	**136.0**	**148.6**	**143.3**	**160.8**	**100.4**	**137.5**	**154.9**





FY15 - FY16 increment ensures operations and research staff for NSTX-U full research operation and for 5 year plan enhancements.