NSTX Upgrade BPM Presentations:

- **NSTX-U Research Plans for FY2012-14 – J. Menard**
- **NSTX Upgrade Progress Overview – R. Strykowsky**
- **NSTX-U Project Plans for FY2012-14 – M. Ono**

FY2014 FES Budget Planning Meeting
Germantown, MD
March 15, 2012

NSTX-U

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NSTX-U Research Plans for FY2012-14

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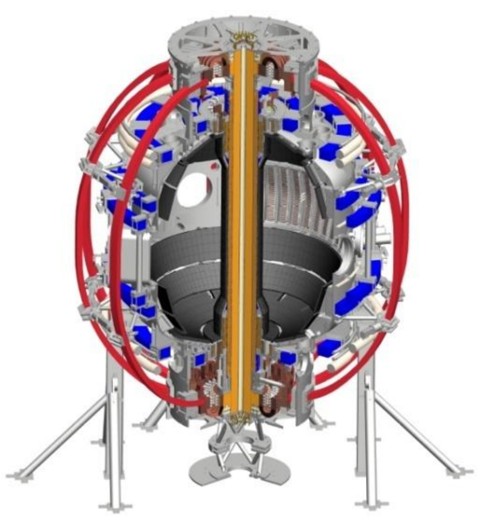
J.E. Menard, PPPL
NSTX-U Program Director

FY2014 FES Budget Planning Meeting
Germantown, MD
March 15, 2012



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CIEMAT
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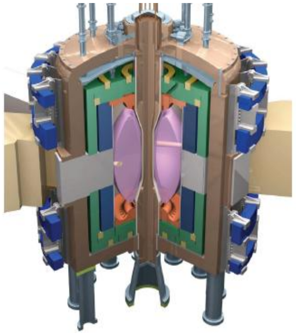
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- NSTX-U mission elements, long-term planning
- FY12-14 research plans, milestone summary
  - Transport and Turbulence
  - Macroscopic Stability
  - Energetic Particles
  - Solenoid-Free Plasma Start-up (Coaxial Helicity Injection)
  - Wave Heating and Current Drive
  - Advanced Scenarios and Control
  - Boundary Physics and Lithium Research
- Summary

NSTX Upgrade Mission Elements

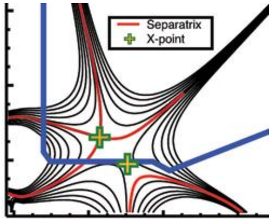
- **Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)**



ST-FNSF

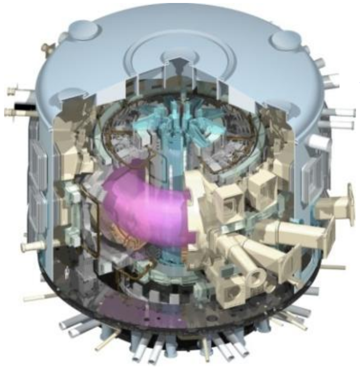
- **Develop solutions for plasma-material interface**

Lithium



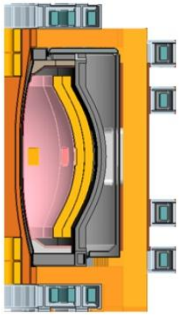
"Snowflake"

- **Advance toroidal confinement physics for ITER and beyond**



ITER

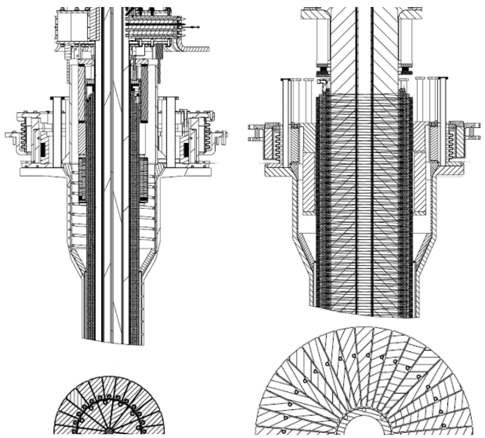
- **Develop ST as fusion energy system**



ST Pilot Plant

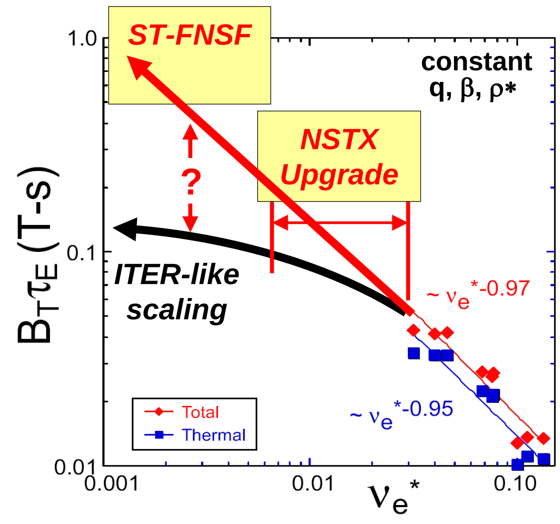
NSTX Upgrade will address critical plasma confinement and sustainment questions by exploiting 2 new capabilities

Previous center-stack	New center-stack

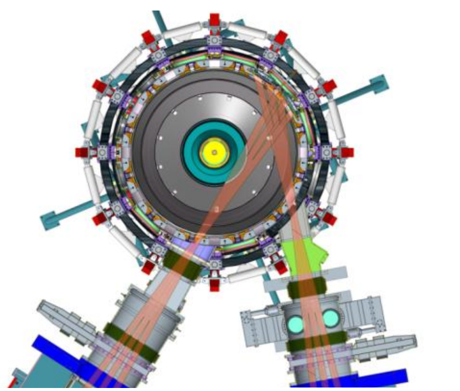


TF OD = 20cm	TF OD = 40cm

- Reduces ν^* → ST-FNSF values to understand ST confinement
  - Expect 2x higher T by doubling B_T, I_P, and NBI heating power
- Provides 5x longer pulse-length
  - q(r,t) profile equilibration
  - Tests of NBI + BS non-inductive ramp-up and sustainment



Normalized e-collisionality $\nu_e^* \propto n_e / T_e^2$

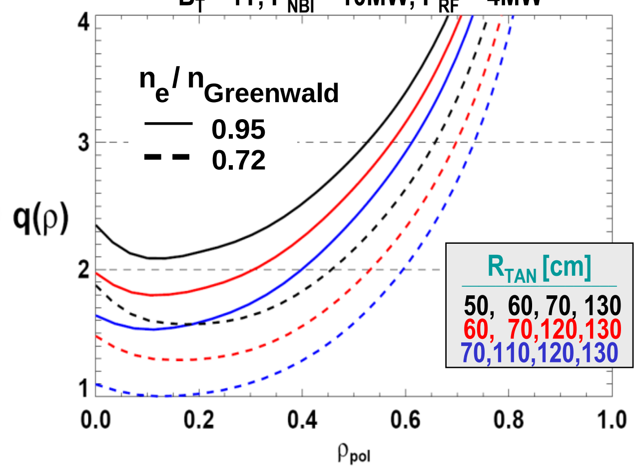


Present NBI	New 2nd NBI

- 2x higher CD efficiency from larger tangency radius R_{TAN}
- 100% non-inductive CD with q(r) profile controllable by:
  - NBI tangency radius
  - Plasma density
  - Plasma position (not shown)

I_P=0.95MA, H_{98y2}=1.2, β_N=5, β_T = 10%

B_T = 1T, P_{NBI} = 10MW, P_{RF} = 4MW



NSTX Upgrade research goals and milestones strongly support development of basis for ST-based FNSF

ReNeW Thrust 16: "Develop the ST to advance fusion nuclear science" consists of 7 prioritized Thrust Elements:

1. Develop **MA-level plasma current formation and ramp-up**
2. Advance **innovative magnetic geometries, first wall solutions**
3. Understand **ST confinement and stability** at fusion-relevant parameters
4. Develop **stability control techniques** for long-pulse, disruption-free ops
5. **Sustain current, control profiles** with beams, waves, pumping, fueling
6. Develop normally-conducting radiation-tolerant **magnets** for ST applications
7. **Extend ST performance** to near-burning-plasma conditions

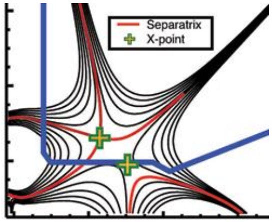
These elements motivate near-term research, and the prioritization of proposed follow-on upgrades in the next 5 year plan (next slide)

Presently formulating FY2014-18 5 year plan to access new ST regimes with NSTX Upgrade + follow-on upgrades

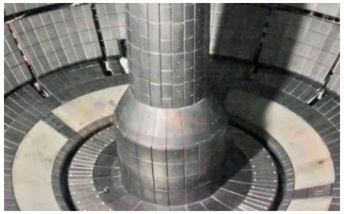
2009	2010	2011	2012	2013	2014	2015	2016	2017	2018

1 MA Plasma | **Upgrade Outage** | **1.5 → 2 MA Plasma**

- HHFW Upgrade
- LLD
- Moly-tile
- CHI Control Coils

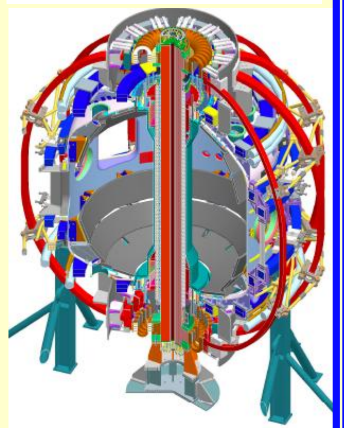


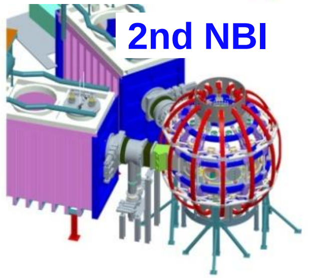
"Snowflake"


Lithium

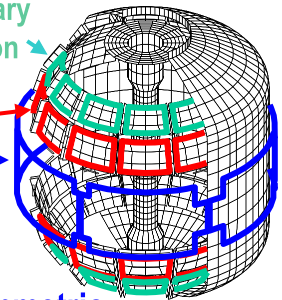
- New Center-Stack
- 2nd NBI

New Center-stack




2nd NBI

- ECH/EBW 1MW → 2 MW
- 0.5 MA CHI
- 1 MA CHI / Plasma Gun
- 0.5 MA Plasma Gun
- Long–pulse Divertor
- NCC Upgrade



Non-axisymmetric Control Coils (NCC)

NSTX Upgrade research goals in support of FNSF and ITER

- Low collisionality plasma regimes
- 100% non-inductive operation
- Long-pulse, high power divertor
- Advanced high-β scenarios

NOTE: Upgrade operation would be delayed ~1 year to mid-2015 w/o incremental, other follow-on upgrades are further delayed

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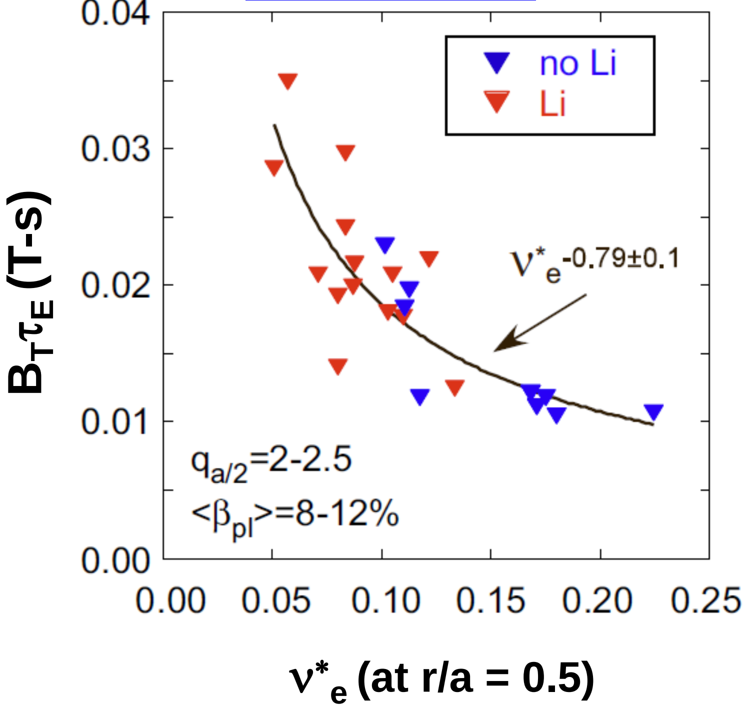
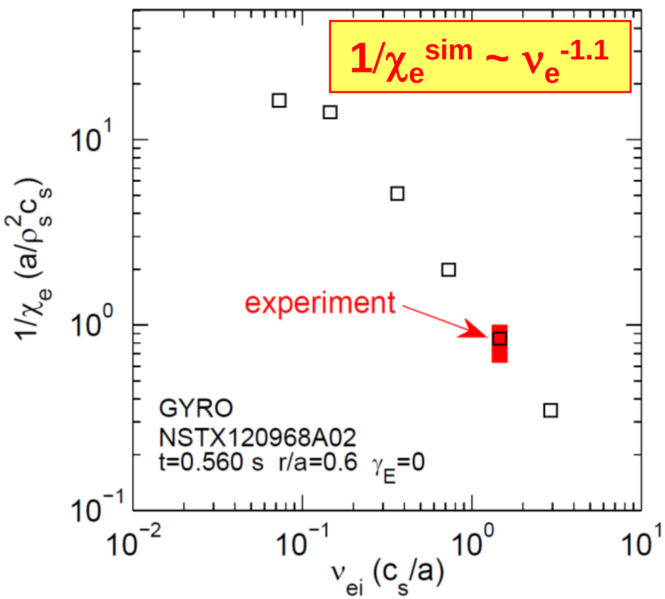
First successful nonlinear microtearing simulations for NSTX predict reduced electron heat transport at lower collisionality

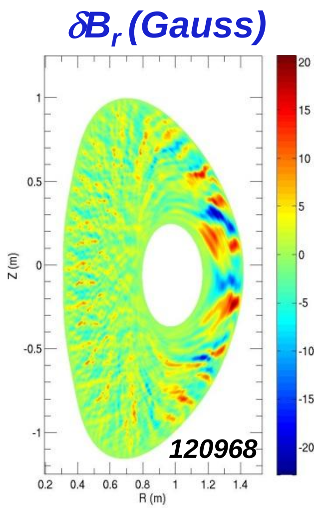
Experiment



- Increase in τ_E as ν^*_e decreases
- Trend continues when Li is used

Theory





W. Guttenfelder, et al., PRL 106, 155004 (2011)

- Predicted χ_e and scaling $\sim \nu_e^{1.1}$ consistent with experiment ($\Omega\tau_E \sim B_t\tau_E \sim \nu^*_e{}^{-0.8}$)
- Transport dominated by magnetic "flutter"
  - $\delta B_r/B$ ~ 0.1% - possibly detectable by planned UCLA polarimetry system (being tested on DIII-D)

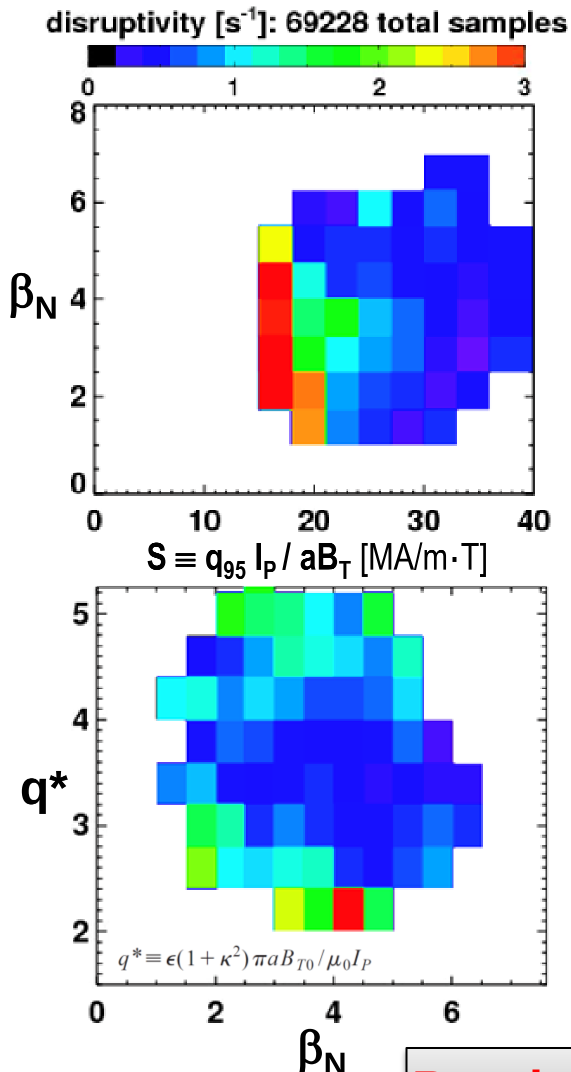
- NSTX-U will extend studies down to ~ 2-5 x lower ν^*, study full turbulence wave-number spectrum: low-k (BES, polarimetry) + high-k (μ-wave scattering)

Transport and Turbulence Research Plans for FY2012-14:

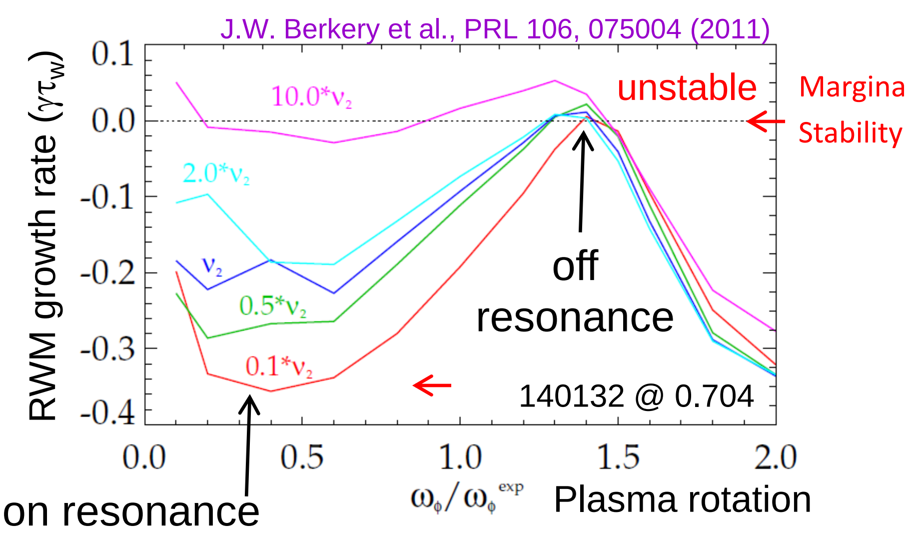
Develop advanced turbulence diagnostics, reduced transport models

- FY12/JRT: Simultaneous comparison of electron thermal and particle/impurities transport channels in NSTX, coupled with turbulence measurements and gyro-kinetic simulations
  - First testing of TGLF code with NSTX discharges (with GA)
- FY12-13: Identify diagnostics for micro-tearing, intermediate $k_\theta \rho_s \sim$ 1-4 turbulence as possible drive for e-transport
  - Work/collaborate with DIII-D (polarimetry), C-Mod (PCI, polarimetry)
- FY13: Develop integrated physics and optical design of the new high-k_θ FIR scattering system
  - Investigate micro-tearing mode by varying relevant parameters (β, ν, Z_{eff}) and using BES diagnostics on MAST
- FY14: Develop and validate reduced transport models using ST data and linear and non-linear gyro-kinetic simulations

Resistive wall mode studies and systematic disruption analysis inform control requirements for FNSF, ITER



- NSTX disruptivity is minimized for S > 30, q* > 2.7
  - Weaker dependence on β_N (confinement limited)
- NSTX-tested kinetic RWM stability theory shows dependence on rotation and collisionality
  - Reduced ν strongly stabilizing "on-resonance"
  - Expect NSTX-U, tokamaks at lower ν (e.g. ITER) could have stronger RWM stability dependence on rotation



Results motivate high κ, δ + control of ω_ϕ, q profiles for ST-FNSF

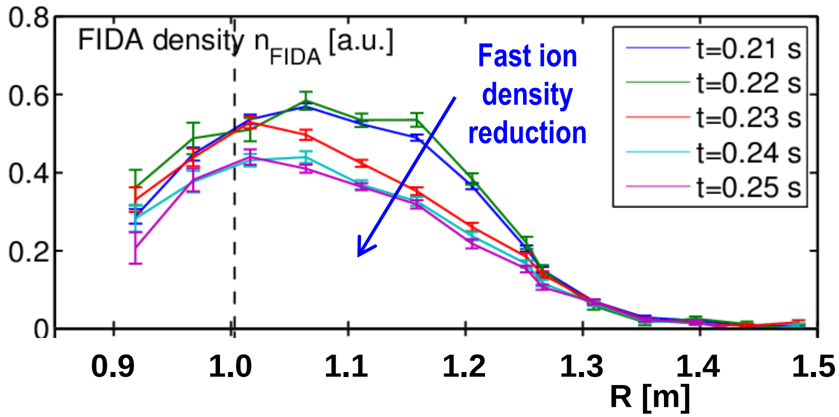
Macroscopic Stability Research Plans for FY2012-14:

Investigate kinetic RWM and disruption physics, assess new 3D coils

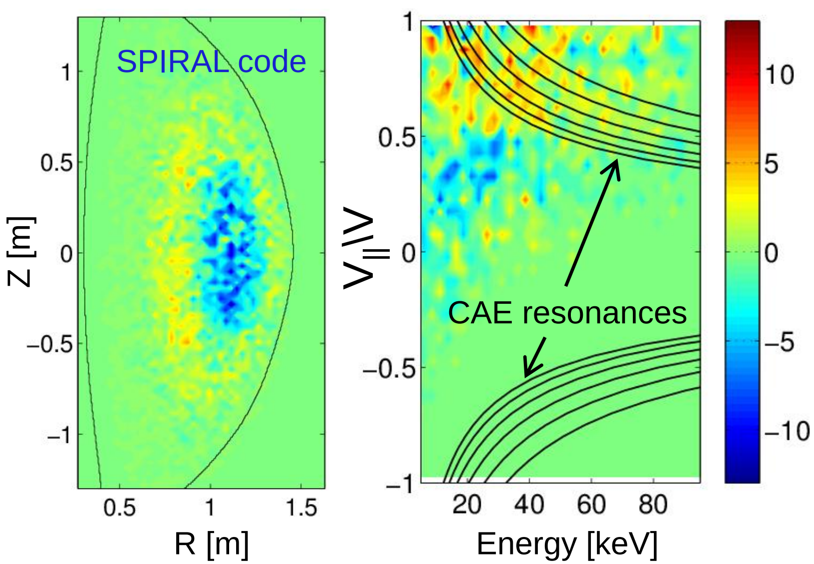
- FY12-13: Investigate RWM kinetic stability w/ MISK for NSTX & NSTX-U + experimental (DIII-D and KSTAR) and computational (MARS-K, HAGIS) RWM collaborations
- FY12-13: Compile NSTX disruption database, study NSTX disruptions, combine various precursors/signals for disruption characterization and prediction
  - Develop disruption mitigation + avoidance strategies for NSTX-U, ITER
- FY13-14: Assess access to reduced density and collisionality by investigating RWM, tearing mode physics, and 3D physics including error field + magnetic braking in NSTX-U scenarios
  - Collaborate with DIII-D, KSTAR, and MAST
- FY13-14: Assess utility of new Non-axisymmetric Control Coils (NCC) for RWM, TM, RMP, EFC, NTV/v_ϕ control for NSTX-U
  - Collaborate with DIII-D, KSTAR, MAST to identify optimal coil set

Fast ion redistribution associated with low frequency MHD measured by fast ion D_α (FIDA) diagnostic

- Caused by kink-like, global instabilities
  - Primarily n = 1, weaker n = 2 present
- Redistribution can affect stability of *AE, RWMs, other MHD
  - CAE activity observed *after* onset of low frequency MHD
- Full-orbit code (SPIRAL) shows redistribution in real and velocity space
  - Radial redistribution from core plasma
  - Particles shift towards $V_{||}/V = 1$
- Measured CAEs (reflectometer) examined as possible cause of enhanced core χ_e
  - Mode #, frequency measured: modes peak in core, resonant with electron orbit frequencies
- **Developing comprehensive fast-ion predictive capability for ITER, FNSF**



Change in distribution due to kink mode



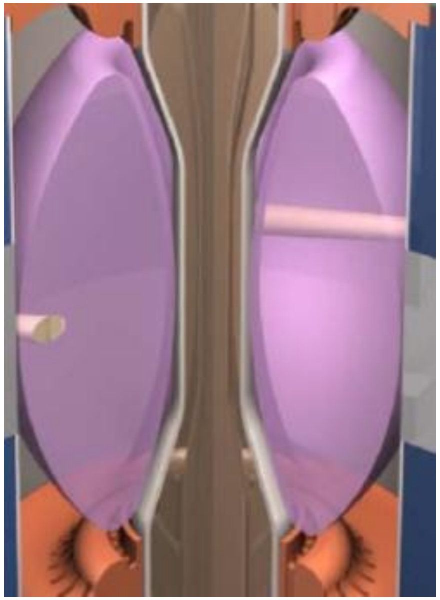
Energetic Particle Physics Research Plans for FY2012-14:

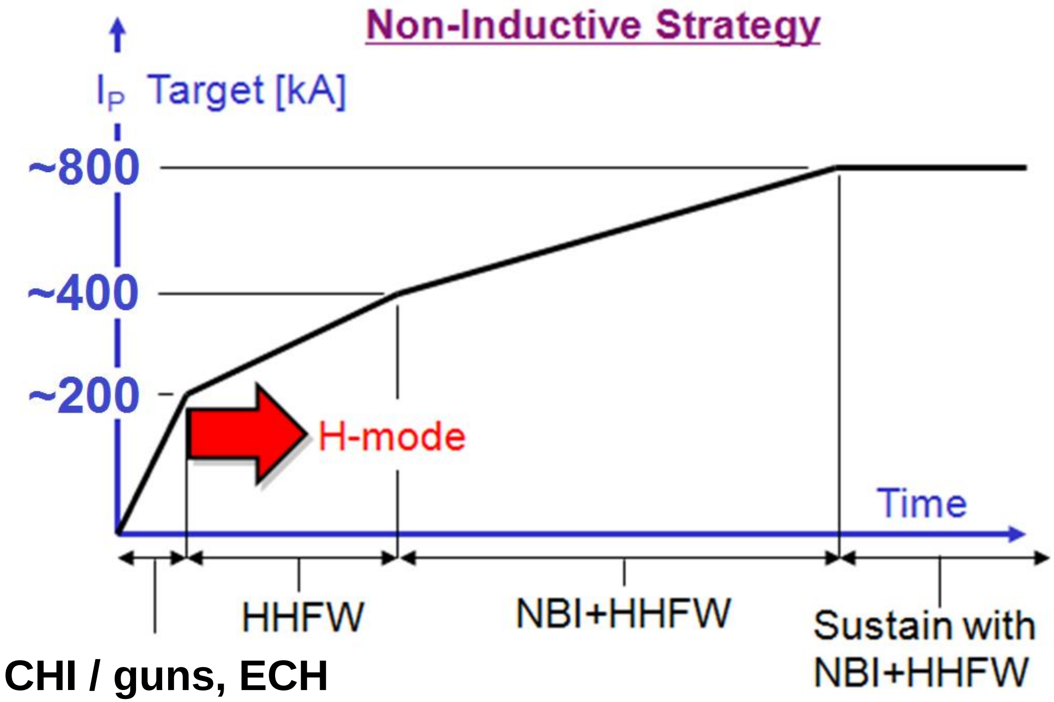
Develop full and reduced models of fast-ion transport, f(v) diagnostics

- FY12: Model TAE stability for NSTX, project to NSTX-U H-mode plasmas w/ NOVA & M3D-K codes
- FY12: SPIRAL modeling of high-frequency GAE/CAE modes, develop interface with HYM code
- FY12-13: Collaborate with MAST and DIII-D on AE experiments, ID optimal FI diagnostics for NSTX-U
- FY13-14: Develop reduced model for AE-induced fast ion losses – needed for NBICD in STs/ATs/ITER
- FY13-14: Finalize design of prototype AE antenna and of upgraded ssNPA diagnostic

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

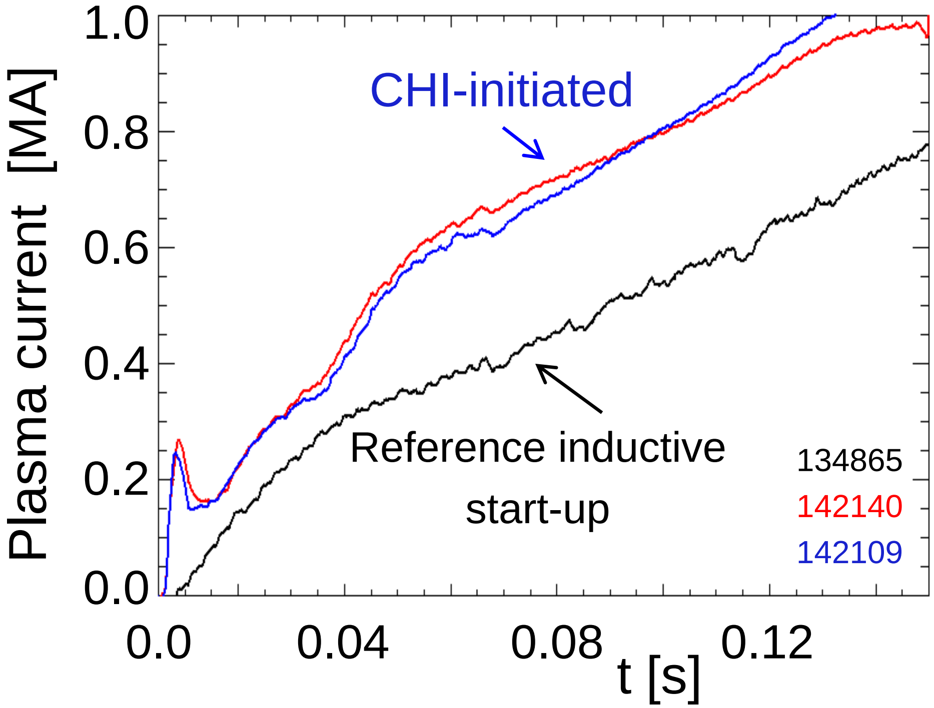
ST-FNSF has no/small central solenoid



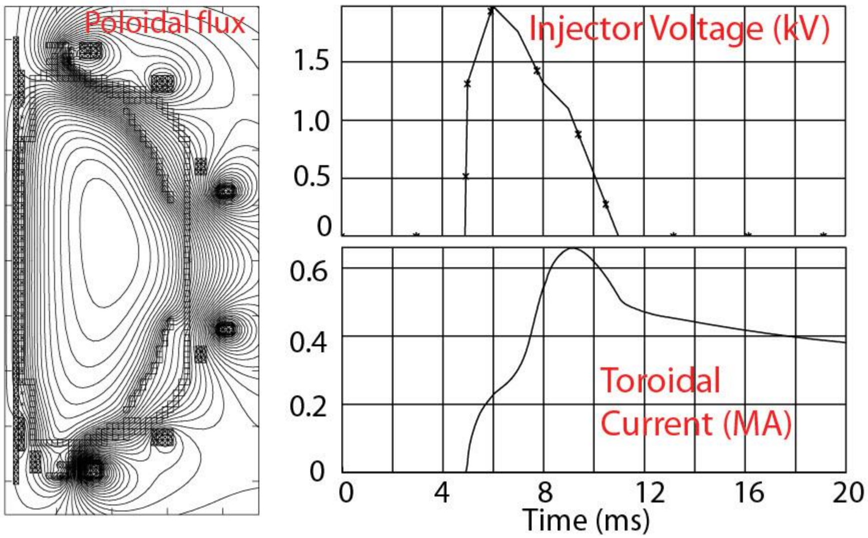


- **NSTX-U goals:**
  - Generate ~0.3-0.4MA full non-inductive start-up with helicity injection + ECH and/or fast wave heating, then ramp to ~0.8-1MA with NBI
  - Develop predictive capability for non-inductive ramp-up to high performance 100% non-inductive ST plasma → prototype FNSF

CHI-initiated discharge in NSTX requires 1/3 less flux to ramp to 1MA than OH-only standard L-mode plasma



TSC simulation using 25% of full injector flux capability in NSTX-U



- Reference inductive discharge:
  - Uses 400 mWb to get to 1MA
- CHI-initiated discharge:
  - Uses 260 mWb to get to 1MA → 140 mWb less flux to get to 1MA

- Double the closed flux current targeted for NSTX-U
  - **Estimated CHI startup $I_P \geq 0.4$MA, possibly up to 1MA**

R. Raman, D. Mueller T.R. Jarboe et al. PoP 18, 092504 (2011)

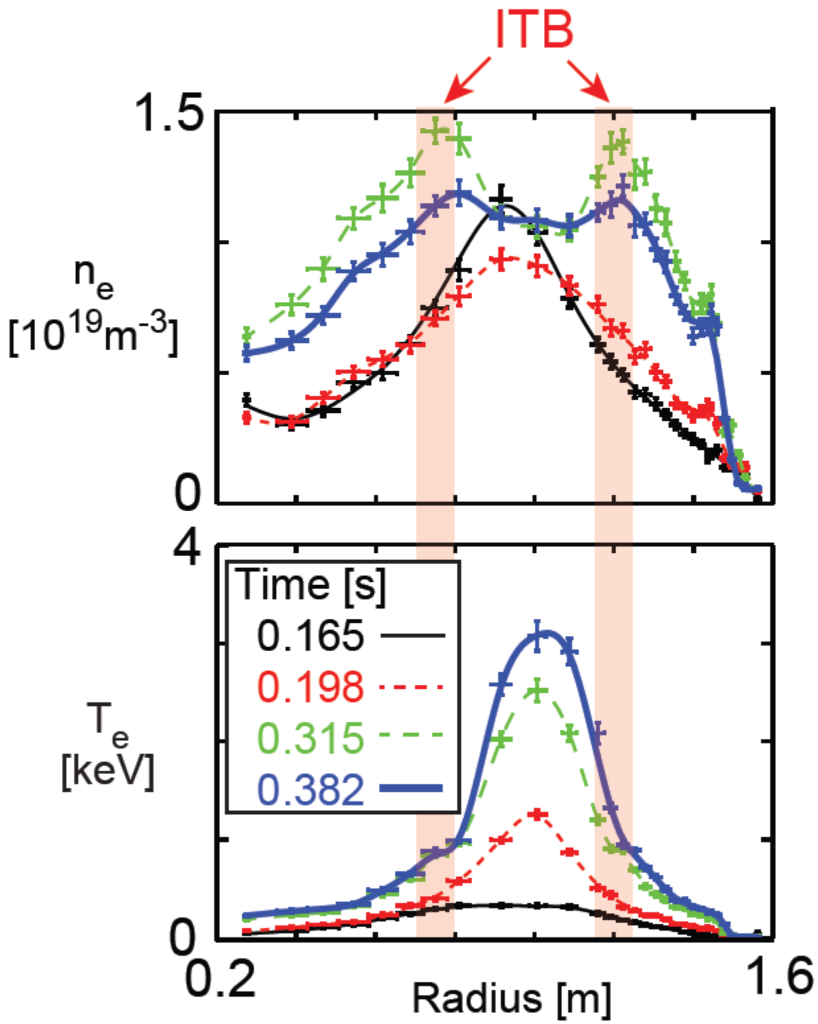
Solenoid-Free Start-up and Ramp-up Research Plans for FY2012-14:

Simulate CHI start-up/ramp-up, prepare CHI/guns for NSTX-U

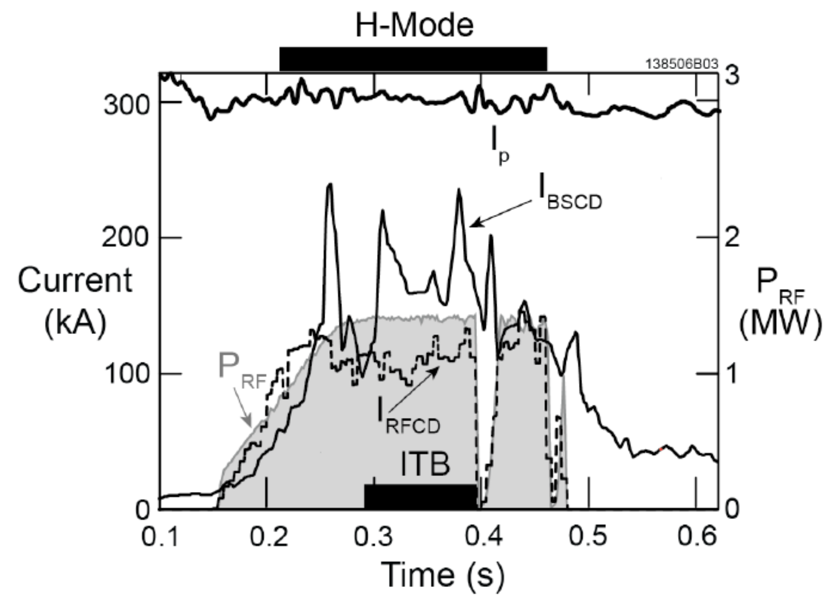
- FY12-13: Model CHI start-up → HHFW+NBI ramp-up scenarios using the NSTX-U vessel + coil geometry
  - Use TSC simulations w/ free-boundary capabilities, identify and develop CHI experiments using FY14 reduced coil set
  - Use TRANSP to vary I_P, T_e, n_e and study how NBI couples to these plasmas with low and zero loop voltage
- Design (FY12) and implement (FY13) upgrades to CHI capacitor bank and diagnostics for NSTX-U
- FY12-13: Participate in PEGASUS plasma gun start-up experiments to identify hardware requirements for implementation on NSTX-U
- FY13-14: Finish CHI design study for QUEST, work with QUEST group for possible CHI usage on QUEST

HHFW promising for heating low current target plasma for NBI non-inductive ramp-up

Can heat I_P ~ 300kA plasma to T_e = 3keV w/ low P_{RF} ~1.4MW



- Form core + edge transport barriers
- Non-inductive fraction of 65-85%
  - 40-50% bootstrap, 25-35% RF-CD
- Projects to 100% non-inductive at P_{RF} = 3-4MW in NSTX-U
  → Target for NBI I_P ramp-up



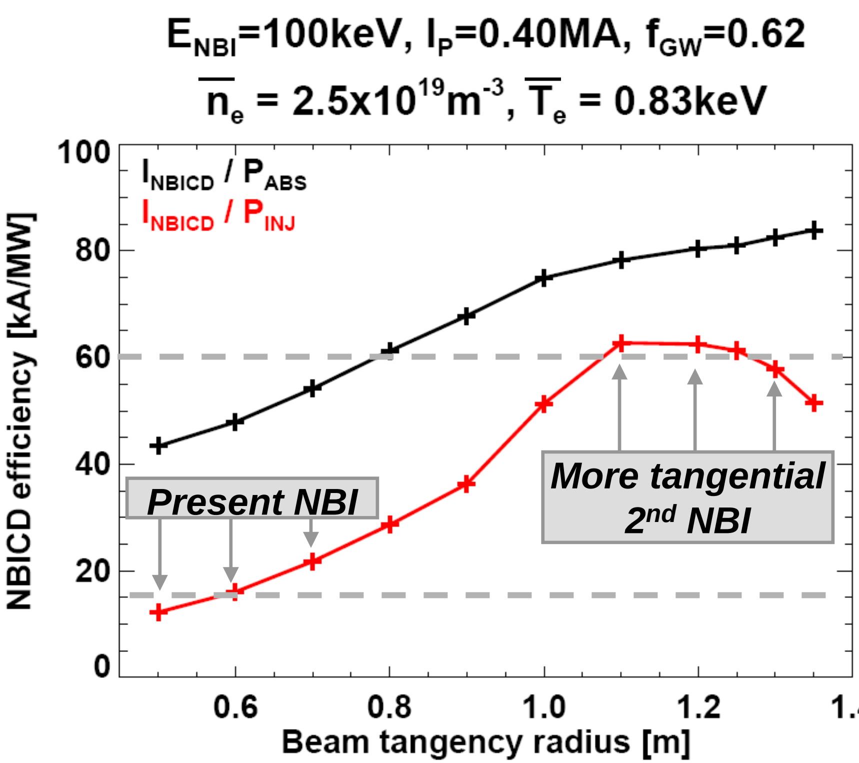
Wave Physics Research Plans for FY2012-14:

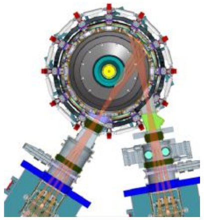
Simulate & develop reliable ICRF H-mode, prepare ECH/EBW/EHO design

- FY12-13: Extend HHFW coupling/heating calculations to higher I_P, B_T NSTX-U equilibria, including fast-ion interactions
- FY12: Collaborate w/ MAST on EBW start-up
- FY12-13: Collaborate on development of reliable ICRF-heated H-mode scenarios for NSTX-U and ITER
  - ICRF H-mode on EAST - extend work on NSTX RF-only H-modes
  - ICRF + NBI H-mode experiments on DIII-D to further study NSTX SOL power loss mechanisms with application to ITER
- FY13-14: Physics design for ECH/EBW system (28GHz, 1→2MW) for start-up heating and sustainment CD
- FY13-14: Physics design of EHO excitation system, assist in antenna design for AE spectroscopy

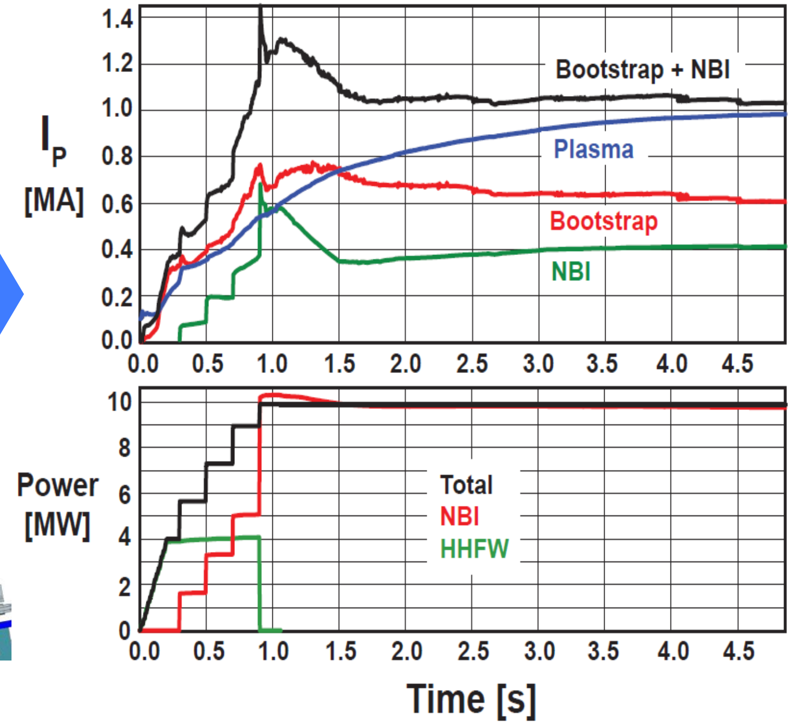
Non-inductive ramp-up from ~0.4MA to ~1MA projected to be possible with new CS + more tangential 2nd NBI

- New CS provides higher TF (improves stability), 3-5s needed for J(r) equilibration
- More tangential injection provides 3-4x higher CD at low I_P:
  - 2x higher absorption (40→80%) at low I_P = 0.4MA
  - 1.5-2x higher current drive efficiency

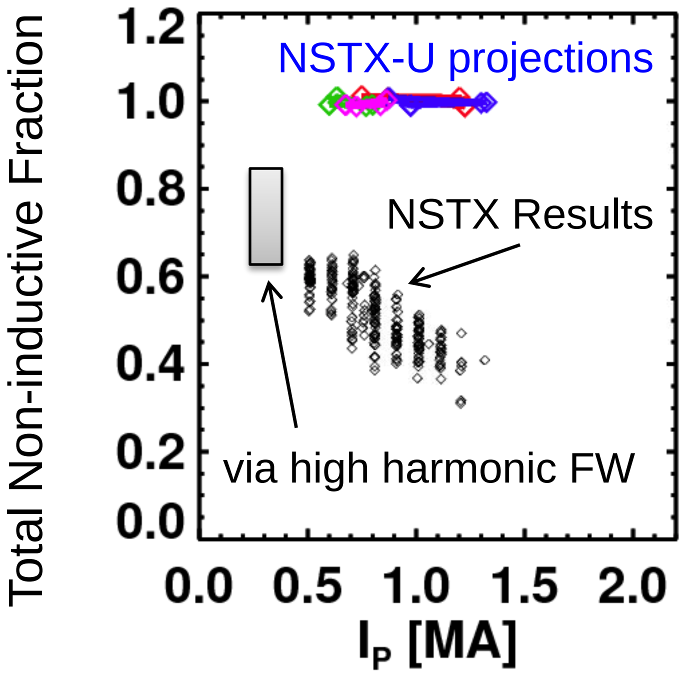


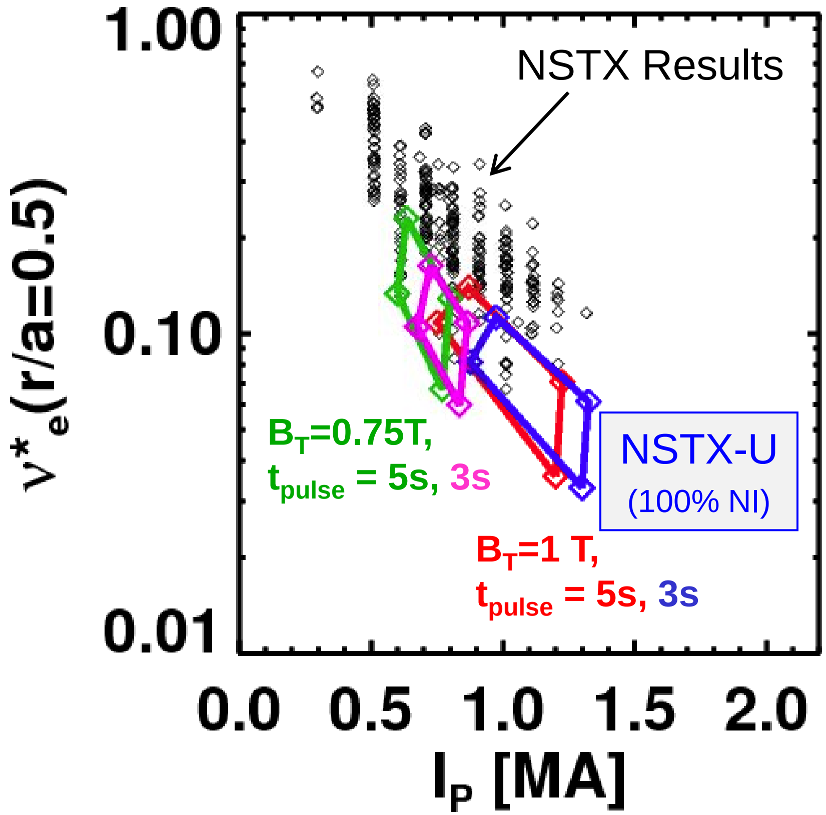


TSC simulation of non-inductive ramp-up from initial I_P = 0.1MA, T_e=0.5keV target



Non-inductive current fractions of up to 65% sustained in NSTX; Upgrade projected to achieve 100%





- NSTX: Maximum non-inductive fractions of 65% at I_P = 0.7 MA
  - Classical beam ion diffusion (< 1-1.5 m^2/s)
- NSTX: 65-85% non-inductive at I_P = 0.25-0.3MA using HHFW for bootstrap + RF current drive

- NSTX-U: project 100% non-inductive scenarios over wide operating range:
  - I_P = 0.6-1.3MA (depending on B_T, τ_E scaling, …)
  - Scenarios shown have $n_e/n_{Greenwald}$~74%

Advanced Scenarios and Control Research Plans for FY2012-14:

Simulate scenarios for NSTX-U, develop advanced control algorithms

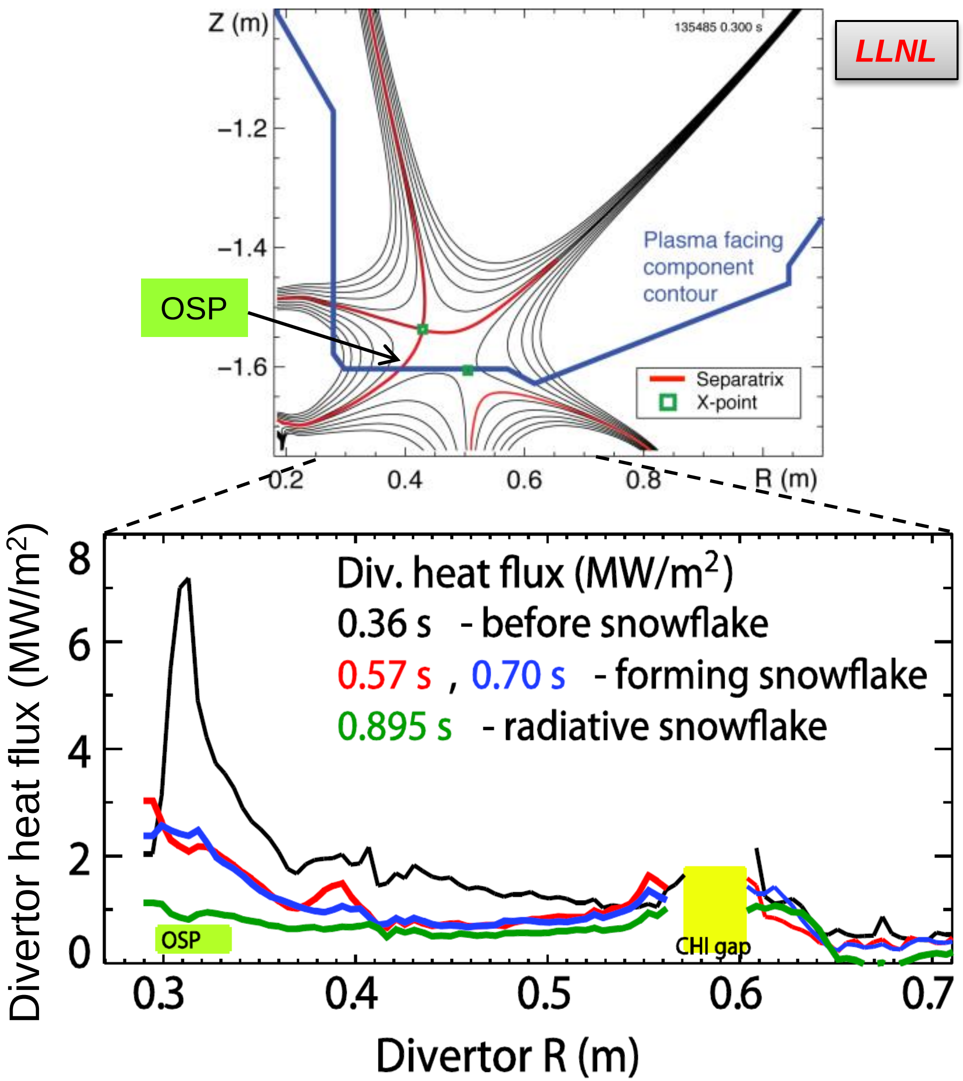
- FY12-13: TRANSP scenario/equilibrium simulations
  - RF-assisted start-up/ramp-up/sustainment simulations – w/ SFSU+WEP
  - Scenario guidance for cryo-pump design (shapes, particle inventories)
  - Provide relevant scenario targets for physics studies + diagnostic design
- JRT-2013: "Evaluate stationary enhanced confinement regimes without large Edge Localized Modes (ELMs), and to improve understanding of the underlying physical mechanisms that allow increased edge particle transport while maintaining a strong thermal transport barrier"
- FY13-14: Assess and/or implement advanced control algorithms in preparation for NSTX-U operation
  - Proposing to develop NSTX-U snowflake control on DIII-D (PPPL+LLNL)
  - J profile control using off-axis NBI on DIII-D for NSTX-U 2nd NBI
    - Implement rt-MSE (if funded) in rt-EFIT for q-profile reconstruction
  - Assess simultaneous J profile, rotation, and beta control
  - Project improvement in NSTX-U rotation control using 2nd NBI deposition flexibility + improved NTV control w/ proposed NCC coils

NSTX snowflake divertor experiments providing basis for heat flux mitigation in NSTX-U, next-steps

- NSTX, DIII-D, C-Mod (FY10 JRT):
  - Divertor heat flux width ~ I_P^{-1}
- NSTX-U at I_P = 2MA, P_{NBI} = 10-15MW with conventional divertor → up to 30-45MW/m² peak divertor heat flux
- Snowflake divertor in NSTX:
  - Good H-mode confinement
  - Up to 7x reduction in peak heat flux
  - Synergistic combination of detachment + radiative snowflake
- NSTX-U includes additional divertor PF coils for robust, flexible snowflake control

Snowflake divertor in NSTX

LLNL

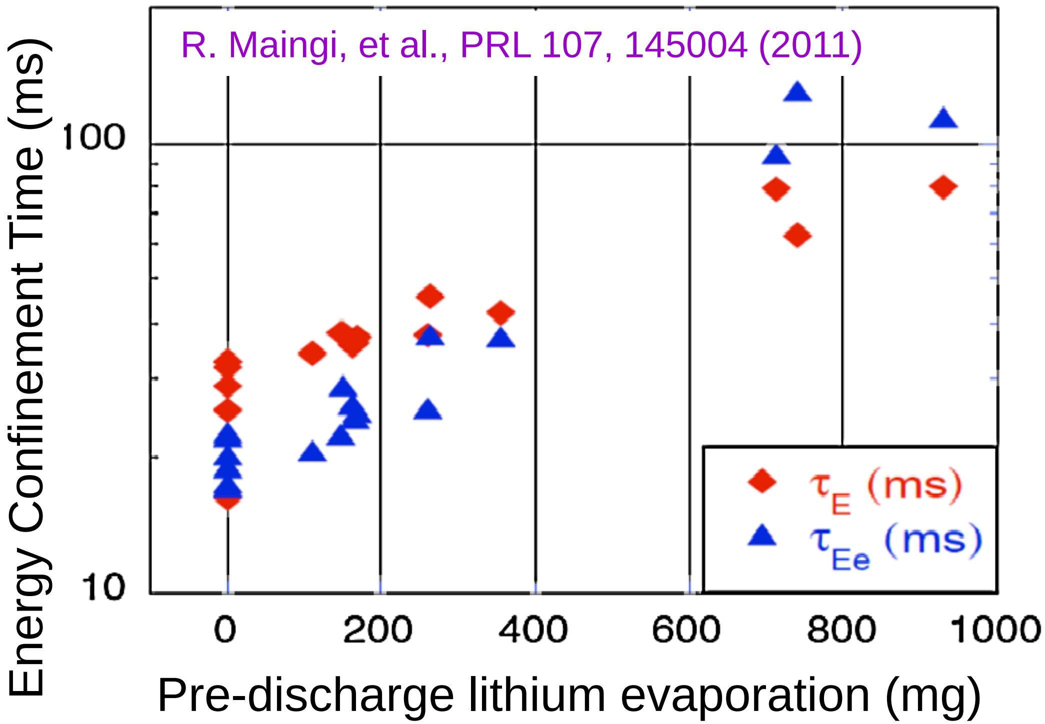


Boundary Physics Research Plans for FY2012-14:

Advance snowflake & edge turbulence understanding, plan cryo & PFCs

- FY12-13: Perform modeling of synergy of snowflake with radiative divertor in NSTX, project to NSTX-U and beyond
- FY12-13: Perform cryo-pumping physics design for NSTX-U compatible with vessel geometry and snowflake shapes
  - Use SOLPS to interpret/reproduce heat and particle flux profiles from high I_P and P_{NBI} discharges from NSTX, project to NSTX-Upgrade *(Preliminary results indicate snowflake compatible with cryo-pumping)*
- FY12-14: Study divertor power exhaust with high-Z Mo PFCs on C-Mod & EAST, assess for NSTX-U
  - Assess Mo with low-Z (B & Li) coatings, study cryo-pumping for density control with moly PFC (particle balance, supersonic gas jet fueling), possibly radiative divertor control development (C-Mod)
- FY12-14: Investigate pedestal transport & turbulence:
  - Utilize correlation reflectometer on C-Mod, EPH/VH expts + XGC0 simulations on DIII-D, SOL turbulence with GPI on EAST and C-Mod

Plasma energy confinement increases monotonically with increasing lithium evaporation inside vessel



- Confinement trends:
  - H_{97L}, H_{98} increase 50-60%
  - $\tau_{E,e}$ increases 3x, 5x
  - Improvement not yet saturated vs. amount of Li
- ELM frequency → zero
  - ELMs stabilized by inward shift of density gradient
- Edge transport declines
  - transport barrier widens, pedestal-top χ_e reduced

- Role of oxygen investigated to understand D retention of Li-coated graphite
  - Threshold lithium amount, and subsequent continuous effects investigated (Purdue)

Lithium Research Plans for FY2012-14:

Advance-Li PFC understanding and technology, R&D for flowing Li

- FY12: Model D pumping from Li coatings in NSTX, project to NSTX-U conditions, compare to cryo-pumping projections
- FY12-13: Collaborate with EAST/HT-7 on lithium research
  - Assess interplay between cryo-pumping and lithiumization, and high-Z PFC interactions/synergies with lithium
  - Study effects of Li on thermal and particle transport, further develop sustained/long-pulse lithium delivery systems (Li slapper, dropper)
- FY13: Investigate relationship between lithium-conditioned surface composition and plasma behavior using MAPP (Purdue) between-shot surface analysis capability on LTX
- FY13-14: Develop tool for Li-coating upper PFCs of NSTX-U
- FY13-14: Physics/pre-conceptual design of next-generation LLD with flowing Li and/or capillary porous system (CPS)
  - Perform lab-based R&D to develop circulation of Li in/out of divertor

Baseline: FY12-14 research milestones emphasize analysis, simulation, projection to/preparation for NSTX-U, FNSF, ITER

NSTX-U ops in mid FY2015 →

Expt. Run Weeks:	FY2012	FY2013	FY2014
Transport and Turbulence		Perform integrated physics+optical design of new high-k_θ FIR system	
Macroscopic Stability	Investigate magnetic braking physics and toroidal rotation control at low ν* (with ASC TSG)		Assess access to reduced density and ν* in high-performance scenarios (with ASC, BP TSGs)
Boundary and Lithium	Project deuterium pumping using lithium coatings and cryo-pumping	Assess relationship between lithium-conditioned surface composition and plasma behavior	
Waves+Energetic Particles		Perform physics design of ECH & EBW system for plasma start-up & current drive in advanced scenarios	Assess reduced models for *AE mode-induced fast-ion transport
Solenoid-free Start-up/ramp-up	Simulate confinement, heating, and ramp-up of CHI start-up plasmas (with HHFW TSG)		
Adv. Scenarios and Control			Assess advanced control techniques for sustained high performance (with MS, BP TSGs)
ITER Needs + Cross-cutting		Identify disruption precursors and disruption mitigation & avoidance techniques for NSTX-U and ITER	
Joint Research Target (3 facility)	Understand core transport and enhance predictive capability	Stationary regimes w/o large ELMs, improve understanding of increased edge particle transport	TBD

Incremental funding would accelerate first-plasma to FY2014, enabling access to new physics + assessment of ST for FNSF

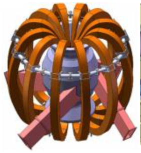
	FY2012	FY2013	FY2014
Expt. Run Weeks:			~10
Transport and Turbulence		Perform integrated physics+optical design of new high-k_θ FIR system	Assess τ_E vs. higher I_P, B_T
Macroscopic Stability	Investigate magnetic braking physics and toroidal rotation control at low ν^* (with ASC TSG)		Assess access to reduced density and ν^* in high-performance scenarios (with ASC, BP TSGs)
Boundary and Lithium	Project deuterium pumping using lithium coatings and cryo-pumping	Assess relationship between lithium-conditioned surface composition and plasma behavior	
Waves+Energetic Particles		Perform physics design of ECH & EBW system for plasma start-up & current drive in advanced scenarios	Assess reduced models for *AE mode-induced fast-ion transport
Solenoid-free Start-up/ramp-up	Simulate confinement, heating, and ramp-up of CHI start-up plasmas (with HHFW TSG)		Assess NBICD w/ larger R_{TAN}
Adv. Scenarios and Control			Assess advanced control techniques for sustained high performance (with MS, BP TSGs)
ITER Needs + Cross-cutting		Identify disruption precursors and disruption mitigation & avoidance techniques for NSTX-U and ITER	
Joint Research Target (3 facility)	Understand core transport and enhance predictive capability	Stationary regimes w/o large ELMs, improve understanding of increased edge particle transport	TBD

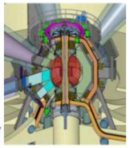
NSTX-U team continuing to strongly support ITER through participation in ITPA joint experiments and activities

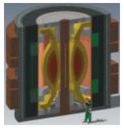
NSTX typically actively participates in ~25 Joint Experiments/Activities

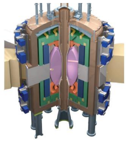
- **Advanced Scenarios and Control (4)**
  - IOS-1.2 Study seeding effects on ITER baseline discharges
  - IOS-4.1 Access conditions for advanced inductive scenario with ITER-relevant conditions
  - IOS-4.3 Collisionality scaling of confinement in advanced inductive plasmas
  - IOS-5.2 Maintaining ICRH coupling in expected ITER regime
- **Boundary Physics (10)**
  - PEP-6 Pedestal structure and ELM stability in DN
  - PEP-19 Edge transport under the influence of resonant magnetic perturbations
  - PEP-23 Quantification of the requirements of ELM suppression by magnetic perturbations from internal off mid-plane coils
  - PEP-25 Inter-machine comparison of ELM control by magnetic field perturbations from mid-plane RMP coils
  - PEP-26 Critical edge parameters for achieving L-H transitions
  - PEP-27 Pedestal profile evolution following L-H/H-L transition
  - PEP-28 Physics of H-mode access with different X-point height
  - PEP-31 Pedestal structure and edge relaxation mechanisms in I-mode
  - PEP-32 Access to and exit from H-mode with ELM mitigation at low input power above P_{LH}
  - DSOL-24 Disruption heat loads
- **Macroscopic Stability (5)**
  - MDC-2 Joint experiments on resistive wall mode physics
  - MDC-4 Neoclassical tearing mode physics – aspect ratio comparison
  - MDC-14 Rotation effects on neoclassical tearing modes
  - MDC-15 Disruption database development
  - MDC-17 Physics-based disruption avoidance
- **Transport and Turbulence (7)**
  - TC-9 Scaling of intrinsic plasma rotation with no external momentum input
  - TC-10 Experimental identification of ITG, TEM and ETG turbulence and comparison with codes
  - TC-12 H-mode transport at low aspect ratio
  - TC-14 RF rotation drive
  - TC-15 Dependence of momentum and particle pinch on collisionality
  - TC-17 ρ^* scaling of the intrinsic torque
  - TC-19 Characteristics of I-mode plasmas
- **Wave-Particle Interactions (4)**
  - EP-2 Fast ion losses and redistribution from localized AEs
  - EP-3 Fast ion transport by small scale turbulence
  - EP-4 Effect of dynamical friction (drag) at resonance on non-linear AE evolution
  - EP-6 Fast ion losses and associated heat loads from edge perturbations (ELMS and RMPs)

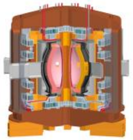
NSTX/ST researchers contributing to study of Mission and Configuration of an ST-FNSF


Russia


Culham


UT Austin


ORNL


PPPL

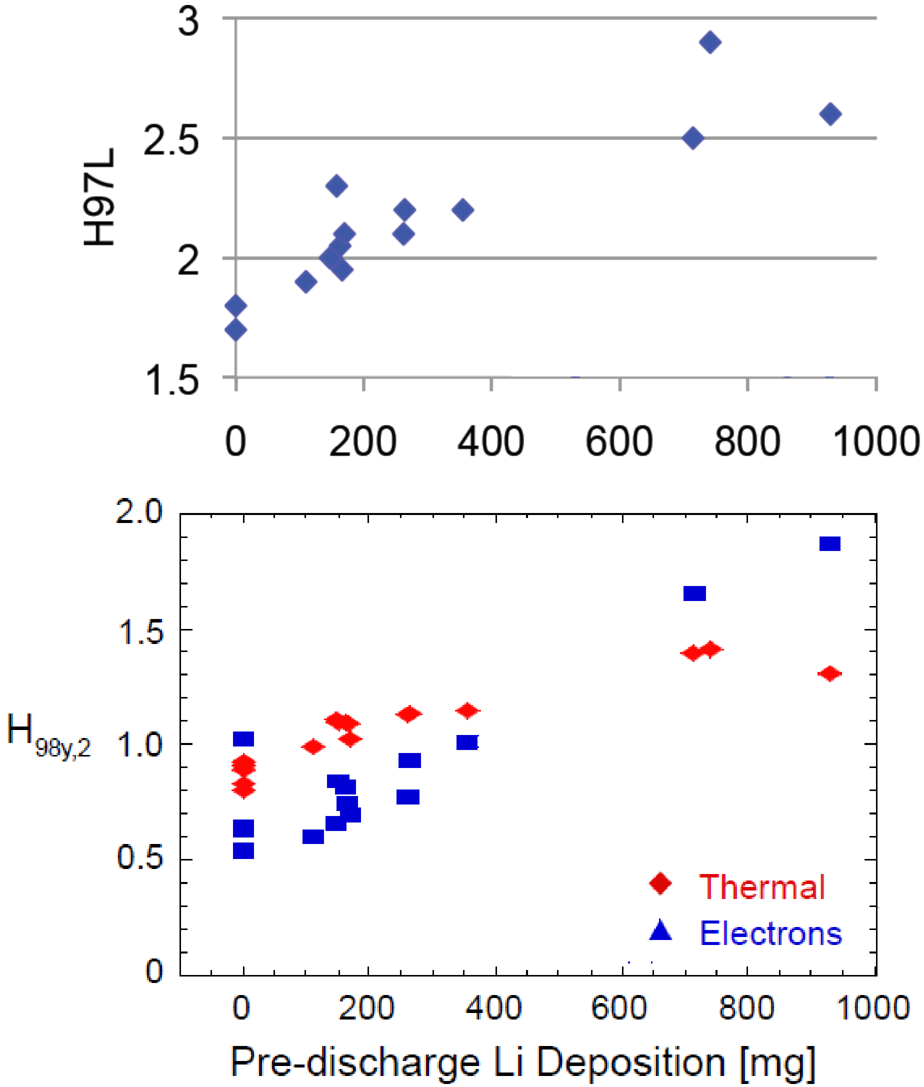
- Overarching goal of study:
  - Determine optimal mission, performance, size
- Goals of study:
  - Review existing designs, identify advantageous features, utilize these features in an updated and potentially improved configuration
  - Assess potential of designs to achieve T self-sufficiency
  - Assess maintainability and upgradeability of internal components
    - Consider divertors, shields, blankets, and identify maintenance strategies
  - Perform at least one self-consistent and detailed physics and engineering assessment for use by community
- Strong ST community participation in the study so far
  - Input from 13+ NSTX physicists + other US & UK researchers, LDRD supporting modest engineering and neutronics analysis

Summary: NSTX-U plan strongly supports OFES vision for fusion for next decade emphasizing ITER, PMI, FNSF

- **Plasma dynamics and control**
  - NSTX performed detailed measurements of turbulence, transport, core/edge stability, and integrating this knowledge to develop advanced high-β ST scenarios
  - NSTX Upgrade will extend these scenarios to full non-inductive operation with current profile control + advanced stability control w/ application to FNSF, ITER-AT
- **Plasma material science and technology, support FNSF**
  - NSTX has provided critical data on SOL-width scaling and SOL turbulence, novel high-flux-expansion divertors for heat-flux mitigation, and lithium-based PFCs
  - NSTX Upgrade will extend these studies to substantially higher heat flux, τ_{pulse}
  - NSTX + Upgrade providing critical data for assessing the ST as potential FNSF
- **Validated predictive capability, discovery science**
  - Performing leading validation efforts for turbulent transport, RWM stability and 3D MHD effects, edge turbulence, fast-ion transport from AE - **important to ITER, ST**
  - Upgrade will substantially extend range of collisionality, rotation, fast-ion drive, enabling access to a unique parameter regime of order-unity β and low ν^*
- **Incremental funding accelerates NSTX-U 1 yr for ITER, PMI, FNSF**

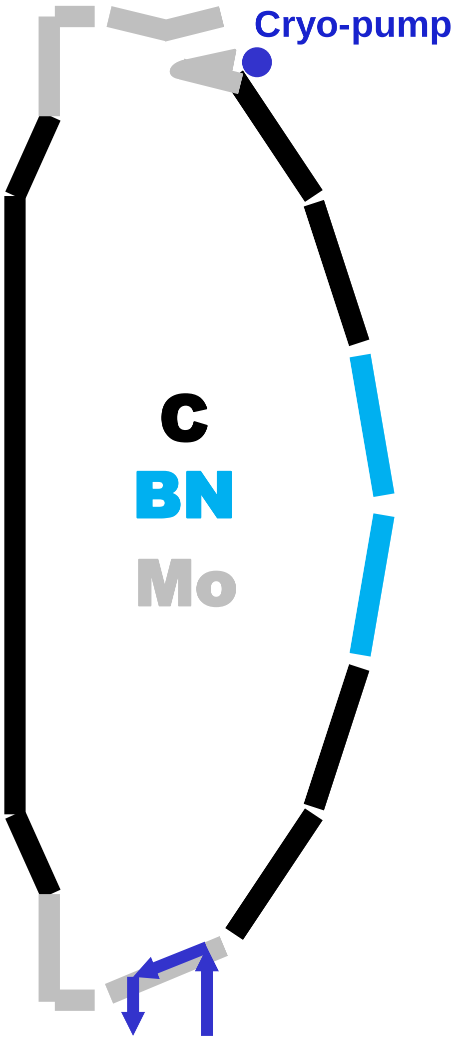
Backup material

Plasma energy confinement increases monotonically with increasing lithium evaporation inside vessel



- Confinement trends:
  - H_{97L}, H_{98} increase 50-60%
  - $\tau_{E,e}$ increases 3x, 5x
  - Improvement not yet saturated vs. amount of Li
- ELM frequency → zero
  - ELMs stabilized by inward shift of density gradient
- Edge transport declines
  - transport barrier widens, pedestal-top χ_e reduced

Direct comparison of cryo-pumping and flowing LLD by end of next 5 yr plan would inform FNSF divertor decisions



- Partially-detached snowflake + cryo-pump may provide sufficient heat-flux mitigation and particle control for NSTX-U, FNSF
- However, erosion of solid PFCs could pollute plasma, damage FNSF divertor/FW
  - FNSF at 30% duty factor → ~10^2 - 10^3 kg net erosion / year for typical FNSF size & power
  - Motivates research in flowing liquid metals
- 5 year plan for divertors (subject to revision):
  - Dedicate upper divertor to cryo-pump
  - Dedicate lower divertor to flowing liquid Li tests, materials analysis particle probe (MAPP)

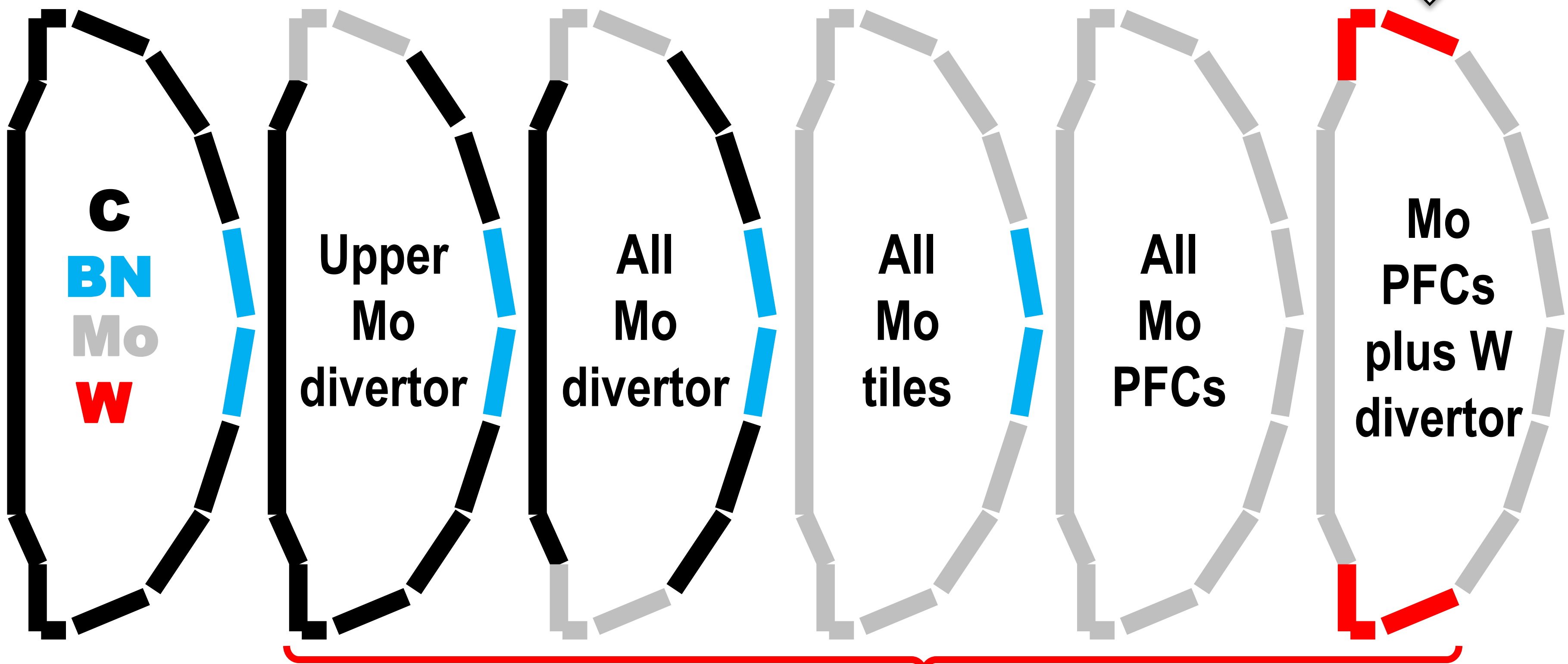
Flowing LLD, MAPP probe, possible replaceable divertor module (RDM)

NSTX-U 5 year plan goal: transition to (nearly) complete wall coverage w/ metallic PFCs to support FNSF PMI studies

- Assess compatibility of high τ_E and β + 100% NICD with metallic PFCs

Baseline

W is leading candidate material for FNSF/Demo divertor



Possible implementation plan for high-Z PFCs

Beginning of 5 yr plan → End of 5 yr plan

Backup material

Collaborations during NSTX Upgrade outage

Collaborations: Held team-wide discussion on FY12-13 opportunities and expectations in Sep-Dec 2011

- Collaboration should aim to support NSTX-Upgrade mission
  - Also support toroidal physics generally, ICCs, and non-fusion applications
- For all researchers, use Upgrade outage as opportunity to:
  - Extend and improve your ongoing and future research on NSTX
  - Learn about other facilities – bring back knowledge, best practices
  - Try or learn something new – new physics, diagnostics, analysis, …
- Aim to form small teams from NSTX (PPPL + non-PPPL)
  - Coordinate research plans, analysis, travel, and participation
- Expectations for researchers:
  - Select 1 primary and 1 secondary/backup collaboration project
  - Aim for 1st author papers, invited talks – PRL/NF/PoP, APS/IAEA
  - Present your results periodically to NSTX, PPPL research seminars
- Facilities: MAST, DIII-D, C-Mod, LHD, EAST, KSTAR, JET, more to come
- Funding: PPPL covers salaries of PPPL NSTX researchers by default
- Challenge: no additional NSTX funding dedicated to collaboration
- Working closely with PPPL off-site research department

Collaborations in materials/PMI, boundary physics

- EAST is only other divertor H-mode facility using lithium
  - Li/transport expts on EAST – D. Mansfield, J. Menard, M. Jaworski, K. Tritz
- Li surface chemistry issues on LTX, working with PU, Purdue
  - Use Purdue MAPP on LTX + surface/PMI studies – C. Skinner, M. Jaworski
  - Improve equilibrium reconstruction/control on LTX – Gerhardt, Menard
- Assess high-Z PFCs for NSTX-U through collaboration on C-Mod
  - LLNL group to assess: Mo with low-Z coatings, study cryo-pump for density control with moly PFC (particle balance, supersonic gas jet fueling), possibly radiative divertor control development
- Develop NSTX-U snowflake control on DIII-D
  - V. Soukhanovskii + E. Kolemen
- Test LLNL SPRED, NIR for NSTX-U divertor diagnosis
  - LLNL to work with Y. Raitses' LTP source
- Pedestal/SOL transport, turbulence, stability research for ITER and NSTX-U
  - Pedestal turbulence using correlation reflectometer on C-Mod - A. Diallo
    - A. Diallo also planning XPs on DIII-D (R. Groebner), possibly MAST
  - XGC0 simulations of DIII-D edge transport w/ 2D & 3D fields - D. Battaglia
  - SOL turbulence measurements with GPI on EAST, C-Mod - S. Zweben

Collaborations on core transport and turbulence

- Pursue TGLF/TGRYO studies for scenario prediction for NSTX-U and DIII-D, also DIII-D transport studies
  - W. Guttenfelder, Y. Ren, and S. Kaye
- Comparison of NSTX and MAST transport physics, BES data
  - S. Kaye, W. Guttenfelder, D. Smith/Univ. Wisconsin
- Exploration of new/needed turbulence diagnostics for NSTX-U
  - PCI for intermediate $k_\theta \rho_s$ (C-Mod) – Y. Ren
  - Polarimetry for δB from μ-tearing (DIII-D & C-Mod) – Ren, Guttenfelder
- Impurity transport studies, perturbative transport
  - Exploring use of ME-SXR on EAST for profile meas. – K. Tritz (JHU)
- 3D field effects on transport and turbulence
  - Transport simulations on LHD - D. Mikkelsen & (maybe) W. Guttenfelder

Collaborations in start-up, scenarios/control, MHD

- Plasma start-up
  - Work with Pegasus on plasma guns, possibly DIII-D to improve PF-only + EC start-up and inform proposed NSTX-U ECH/EBW – D. Mueller
  - Investigate application of CHI on QUEST – R. Raman (U. Wash)
  - EBW startup experiments on MAST - G. Taylor
- Advanced Scenarios and Control - E. Kolemen (relocated to GA)
  - Prepare for current and rotation profile control in NSTX-U through collaboration on DIII-D using off-axis NBI (and counter-NBI), NTV
  - Contribute to development of ITER plasma control specification
  - MAST vertical control analysis/experiments – prep for NSTX-U/MAST-U
  - Long-pulse tokamak ops/control experience (EAST/KSTAR) – D. Mueller
- MHD Physics
  - Assist DIII-D in new 3D δB sensors - N. Logan, J-K Park, J. Menard
  - 3D field physics in long-pulse H-mode in KSTAR – J.-K. Park, S. Sabbagh
  - RWM physics at reduced ν* on DIII-D, NTV on MAST – S. Sabbagh/CU

Collaborations in waves and energetic particles, and diagnostic development

- RF coupling and edge-loss studies in DIII-D for NSTX-U, ITER
  - J. Hosea, R. Perkins, G. Taylor
- RF-only H-mode in EAST – R. Wilson, G. Taylor
  - Supports RF-only plasma heating/start-up studies for NSTX-U
- Energetic particles and Alfvén eigenmode physics
  - Study fast-ion physics on JET (2 year relocation), prep for possible DT campaign, beam ion loss measurements on LHD - D. Darrow
  - Several fast-ion/AE physics opportunities on MAST
    - Assess operation of MAST *AE antenna, participate in expts – E. Fredrickson
    - Assess performance of neutron collimator, NBI fast-ion redistribution models – M. Podesta
    - Fusion product loss detector – D. Darrow, W. Boeglin
- Diagnostic development
  - Assist with ITER diagnostics – B. Stratton
  - Assist with MPTS on JET, LTX, maybe KSTAR & Pegasus – B. LeBlanc
  - Develop/prepare new Accurate Wavelength Lens Spectrometer (AWLS) on LTX for installation/usage on NSTX-U – R. Bell

Some statistics, and issues going forward

- Tracking 30-35 researchers, including on-site collaborators
  – ~90% of researchers have definitive plans well-aligned with NSTX-U and/or PPPL research goals
- Approximate order of collaboration emphasis by facility:
  – DIII-D, C-Mod, EAST, MAST, KSTAR, LHD, LTX, …
  – U.S. facilities most mature in diagnostics, tools, analysis, and are therefore often most attractive to researchers
- EAST and KSTAR have expressed strong interest in collaboration from PPPL/NSTX researchers
  – EAST, KSTAR still developing diagnostics, heating systems, organization for integrating collaborators – improving
- Prep for NSTX-U operation highest priority by late 2013
  – Also tracking who/what is needed for operations and diagnostics

NSTX Upgrade Progress Overview

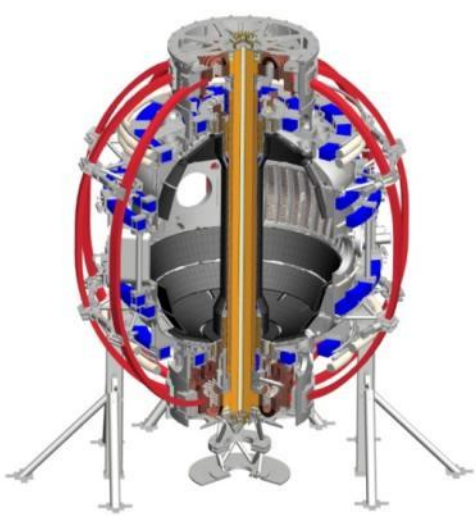
Ron Strykowsky

Erik Perry, Tim Stevenson, Larry Dudek, Steve Langish, Tom Egebo, Mike Williams

and the NSTXU Project Team

FWP FY2014 Budget Planning Meeting
March 15, 2012

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



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

- Technical Progress
- Cost and schedule performance
- Planning scenarios

Excellent progress to date

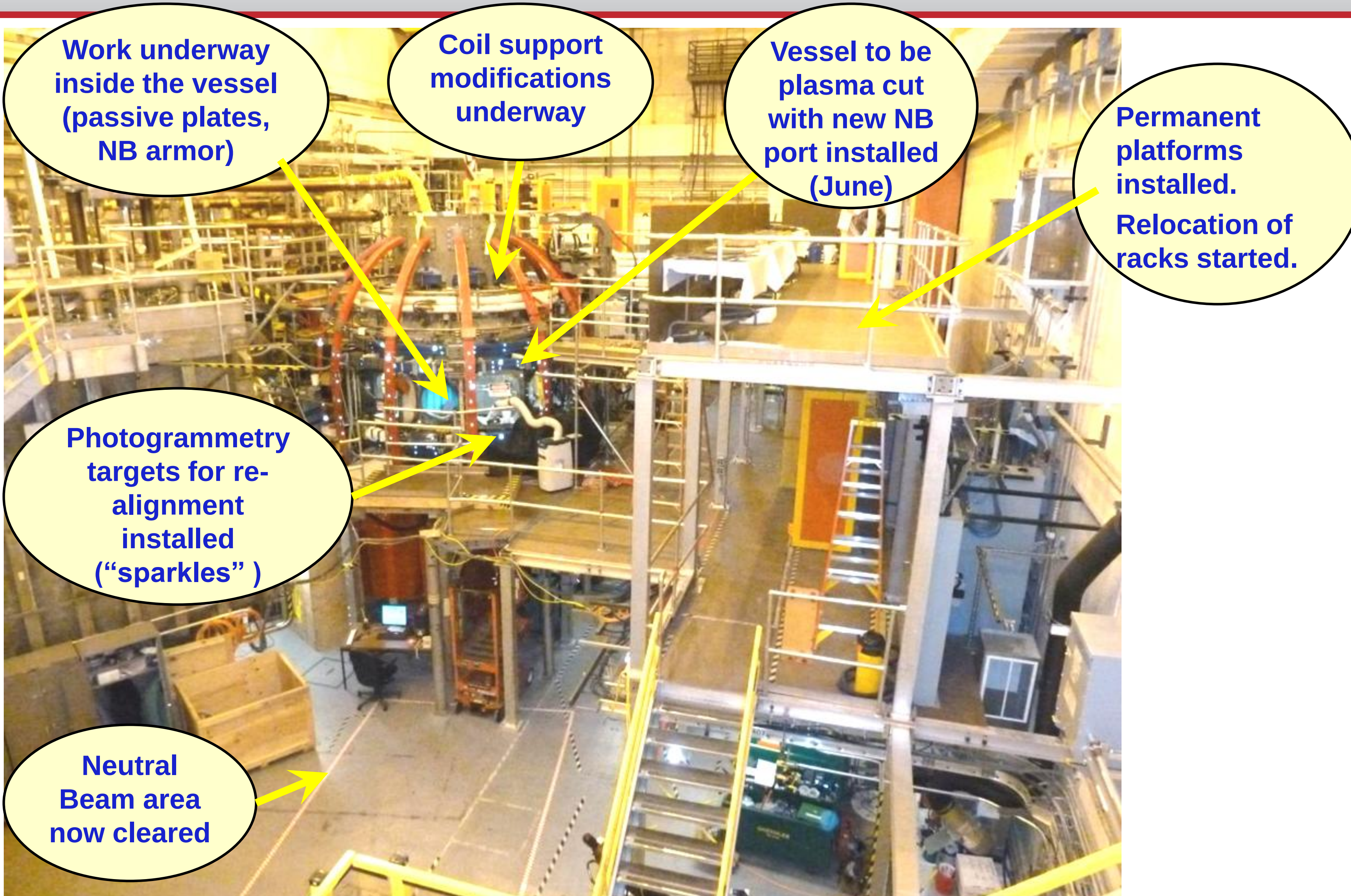
- ☑ NSTX-U Final Design Review - June 2011
- ☑ NSTX TF Bundle Failure - July 2011
- ☑ Successful independent forensic review of TF Failure - September 2011
- ☑ DOE-OFES approval to commence outage - September 2011
- ☑ EVMS Certification – December 2011
- ☑ DOE CD-3 approval received - December 2011

Excellent progress to date – *NSTX Test Cell*

- ☑ Vacuum vent
- ☑ Center Stack removed
- ☑ Pump duct removed
- ☑ LLD Removed
- ☑ Old neutral beam armor removed
- ☑ Coil Support modifications started
- ☑ Diagnostics, racks, platforms removed
- ☑ New platforms installed
- ☑ Space cleared for Neutral Beam Relocation!
- ☑ Outer board divertor installation underway
- ☑ Cabling changes underway.
- ☑ Coil support hardware deliveries ramping up.

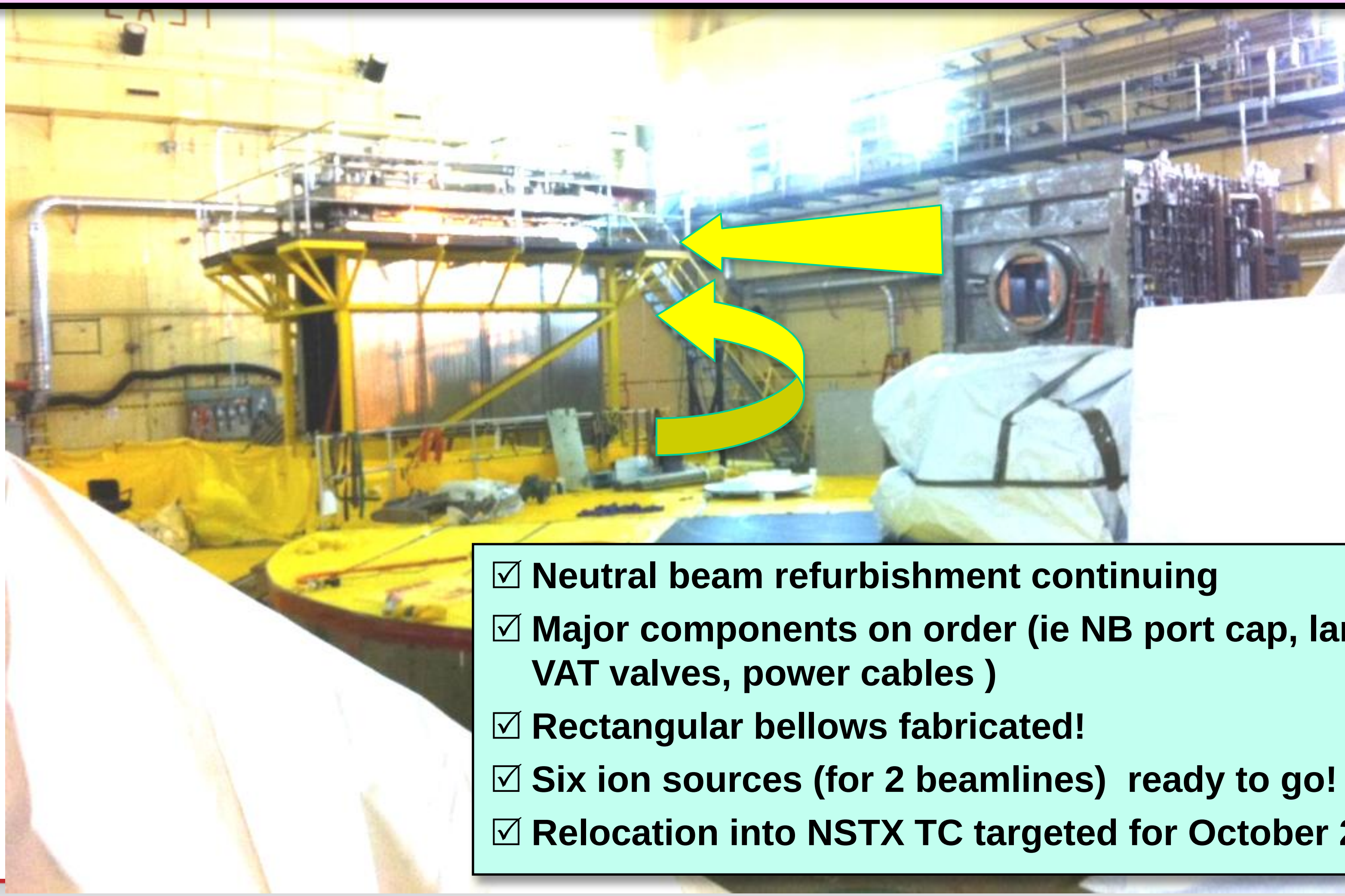
NSTXU Test Cell - October 2011

NSTXU Test Cell - March 2012



Excellent progress to date – *Neutral Beam*

Neutral Beam Almost ready to move from the TFTR TC into the NSTX Test Cell

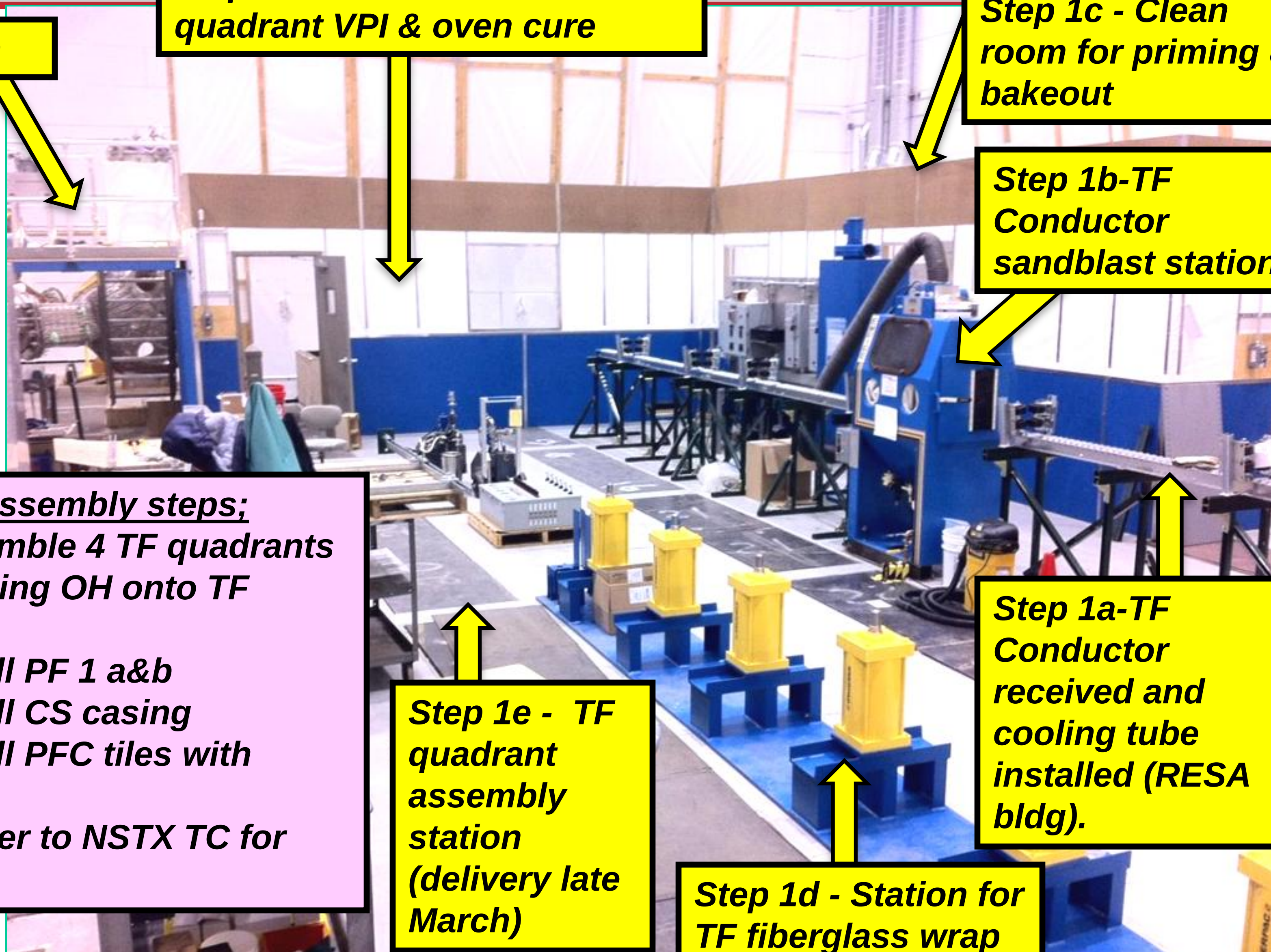


- ☑ **Neutral beam refurbishment continuing**
- ☑ **Major components on order (ie NB port cap, large VAT valves, power cables)**
- ☑ **Rectangular bellows fabricated!**
- ☑ **Six ion sources (for 2 beamlines) ready to go!**
- ☑ **Relocation into NSTX TC targeted for October 2012**

Excellent progress to date – *Center Stack Fabrication*

- ☑ Fabrication area cleared.
- ☑ Cooling tube soldering R&D complete.
- ☑ Sandblasting unit and winding station setup underway.
- ☑ Clean rooms installation incl power and HVAC complete.
- ☑ VIP Bakeout oven installed
- ☑ VIP platform installed
- ☑ TF conductor extrusions delivered.
- ☑ TF conductor machining and friction stir welding underway.
- ☑ Winding material procurements underway.
- ☑ CS Casing, PFC tiles, OH conductor, TF mold, winding machine ordered.

NSTX Center Stack Fabrication is the critical path



<u>Subsequent assembly steps;</u>

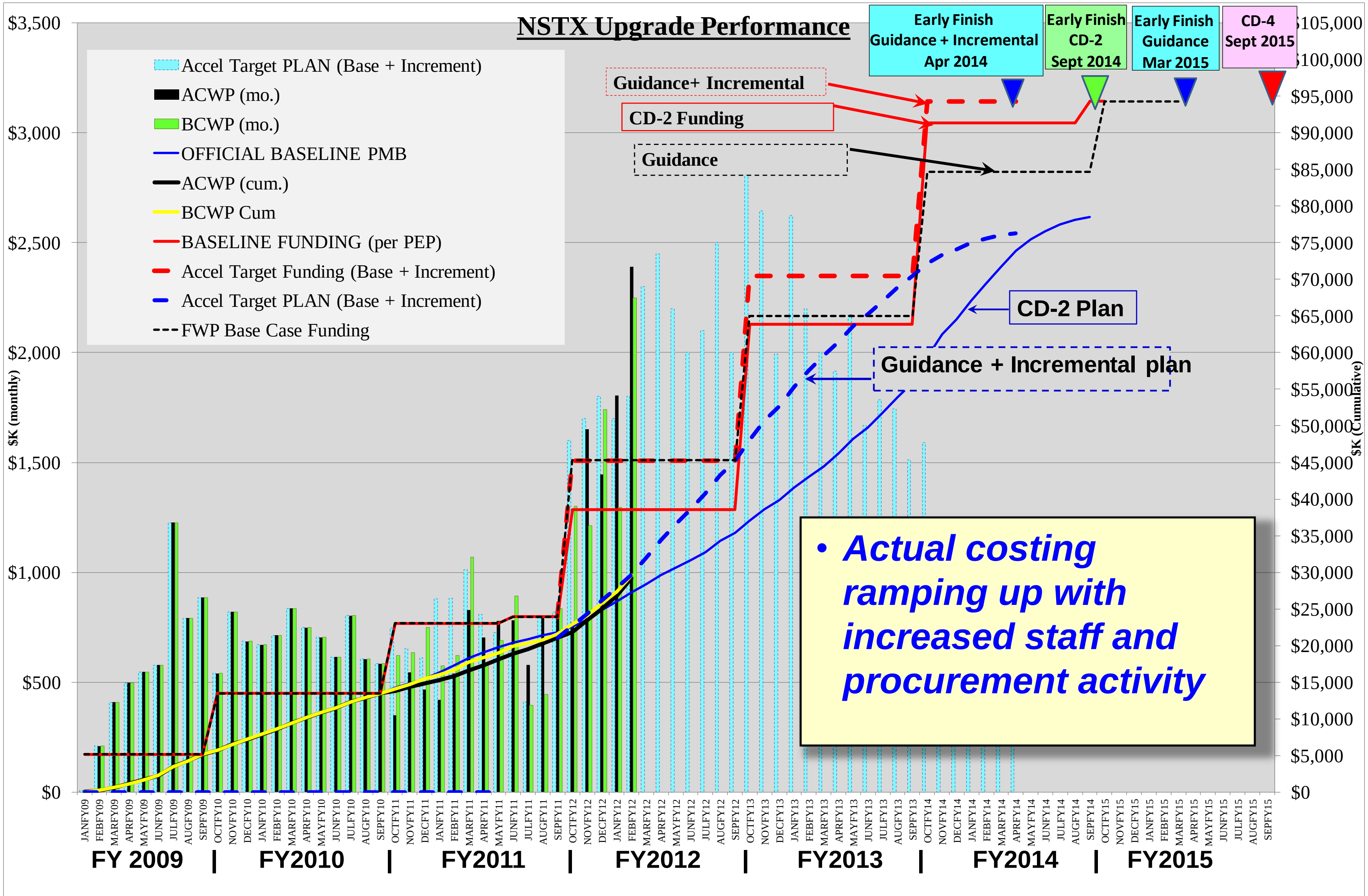
Step 2 – Assemble 4 TF quadrants
Step 3 – Winding OH onto TF bundle
Step 4 – Install PF 1 a&b
Step 5 – Install CS casing
Step 6 – Install PFC tiles with diagnostics
Step 7 – Deliver to NSTX TC for installation

Project Performance

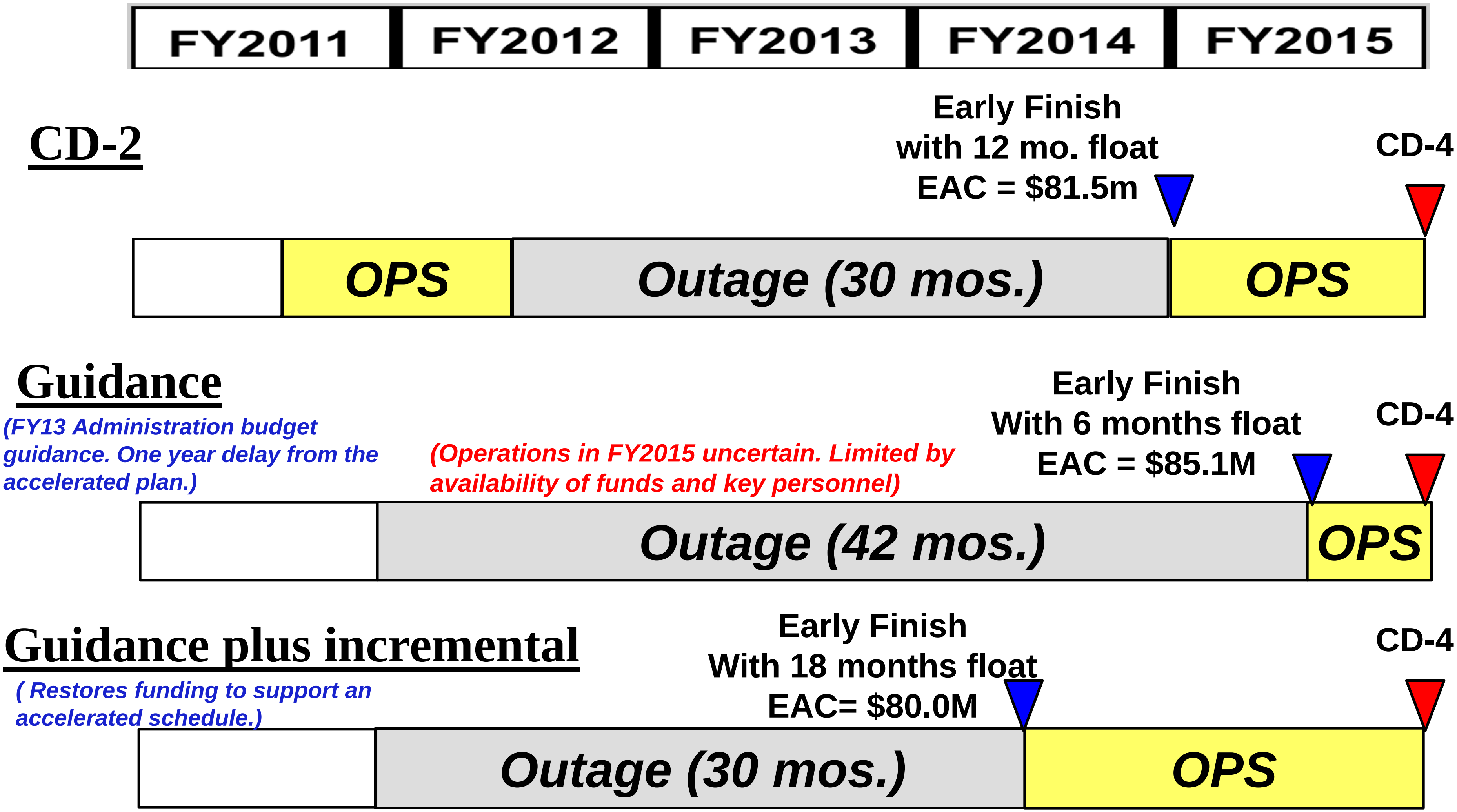
- Cost
  - *CPI=1.02 CV=+ $473K*
- Schedule
  - *SPI= 1.07*
  - *Total float = 18 months relative to CD-4 of September 2015*
- BAC =$78.4 EAC= $80.0 TPC =94.3M
  - *Project primarily funded through diversion of operations funds*
- ACWP = $29.2M ETC= $50.8M   Approx. 36% complete
- Free balance contingency 32% on remaining work and 27% on ETC (27% at CD-2)
- Risk: $2,000k retired since CD-2 Currently $3,744 remain

✓*Cost performance good*
✓*Schedule performance good*
✓*EAC tracking well*
✓*Contingency position good*
✓*Risk stable*

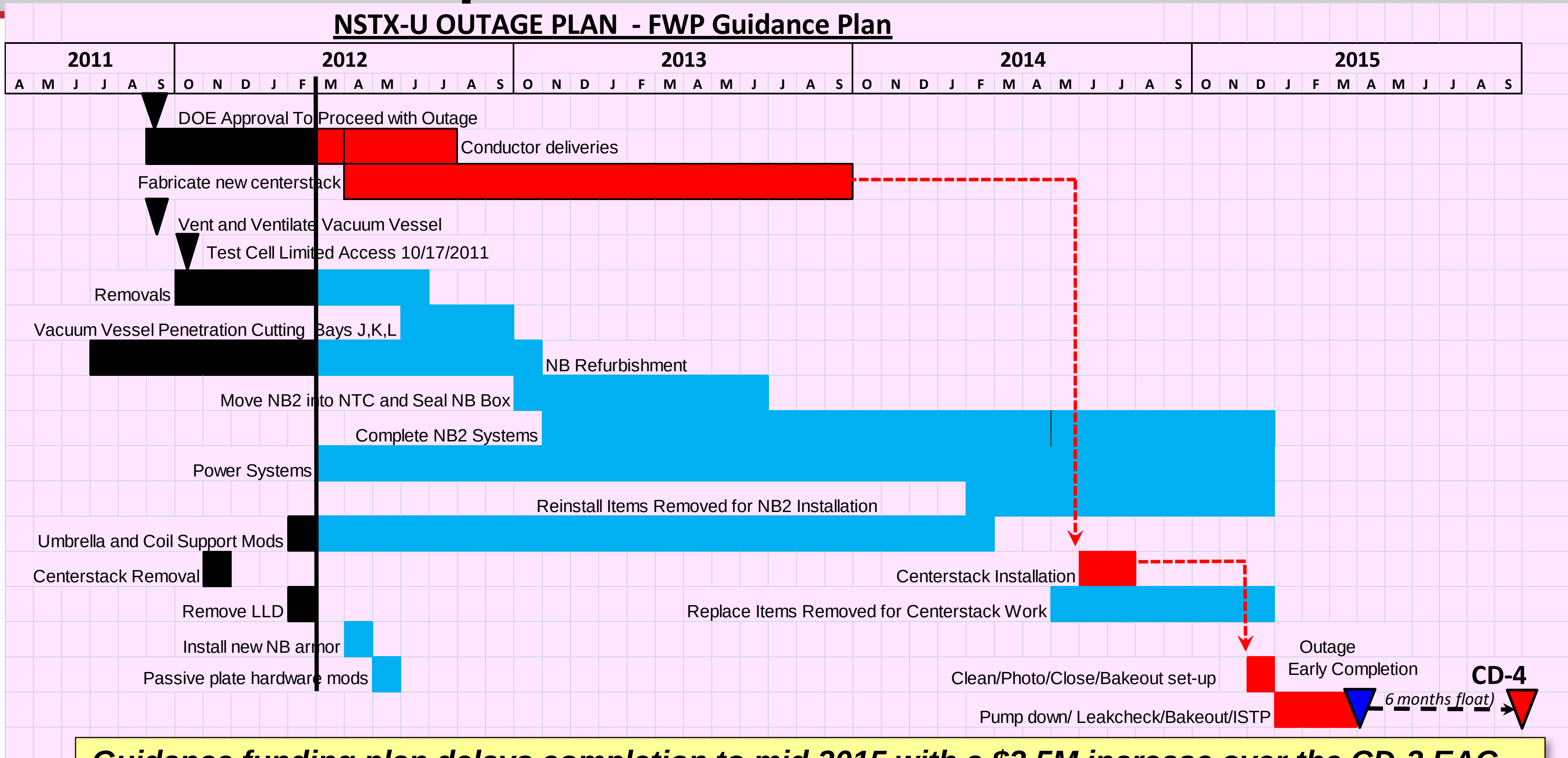
Project picking up steam



NSTX Upgrade Planning scenarios



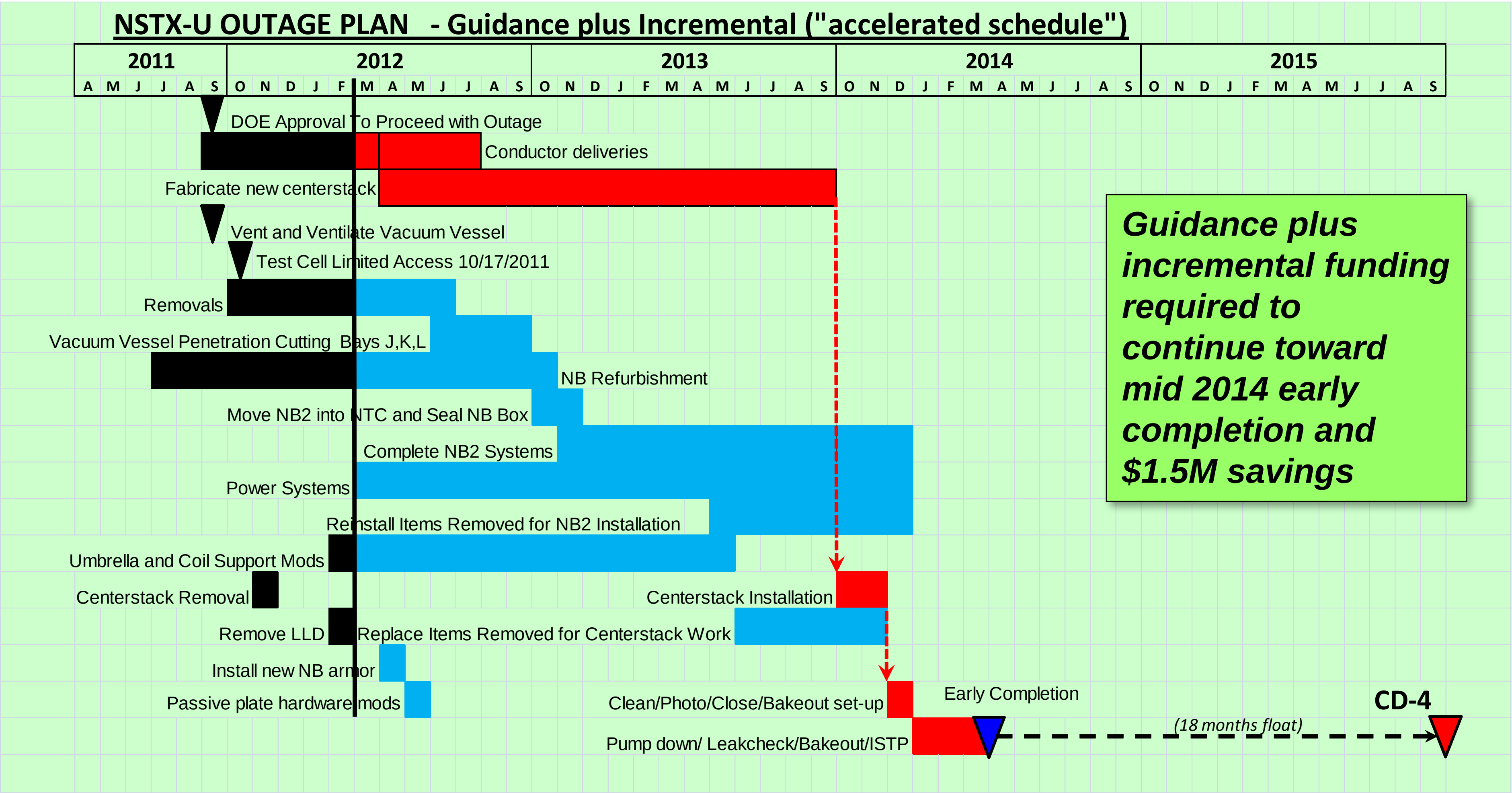
Guidance plan would delay resumption of operations to mid 2015



Guidance funding plan delays completion to mid 2015 with a $3.5M increase over the CD-2 EAC. Additional risks;

- ***Reduces schedule contingency to 6 months to CD-4.***
- ***Loss of core personnel capabilities to complete fabrication***
- ***Skill mix in-efficiencies to support construction***
- ***Overhead rates***
- ***Loss of core personnel capabilities to operate NSTX***

Well positioned for early completion with incremental funding



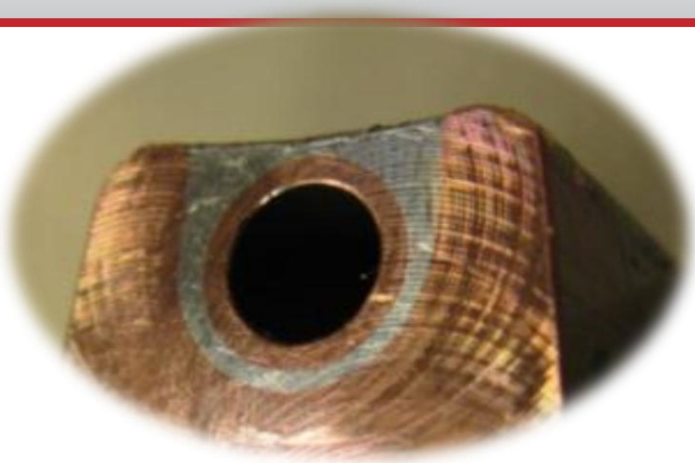
Summary

- **The project continues to make good progress!**
- **On track for meeting CD-2 baseline with FWP guidance.**
  - ***Resumption of operations, however, delayed to mid FY2015 along with increased cost and schedule risk.***
- **Currently on track for early completion in mid FY 2014 with incremental funding.**

BACKUP

Developed new soldering technique in response to TF bundle failure review

Solder paste injection over cooling tube



Close up views of solder joint

Images of tubes pull tested to ultimate strength of the solder . Note good wetting of both the tube and copper bar, indicating effectiveness of flux. Results for first specimens:

NSTX-U

Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

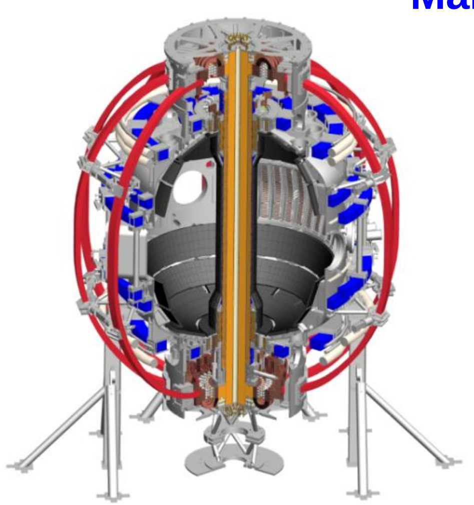
NSTX Project Plans for FY2012-14

Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
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 Washington
U Wisconsin

Masa Ono

for the NSTX-U Team

FY2014 FES Budget Planning
Germantown, Maryland
March 15, 2012

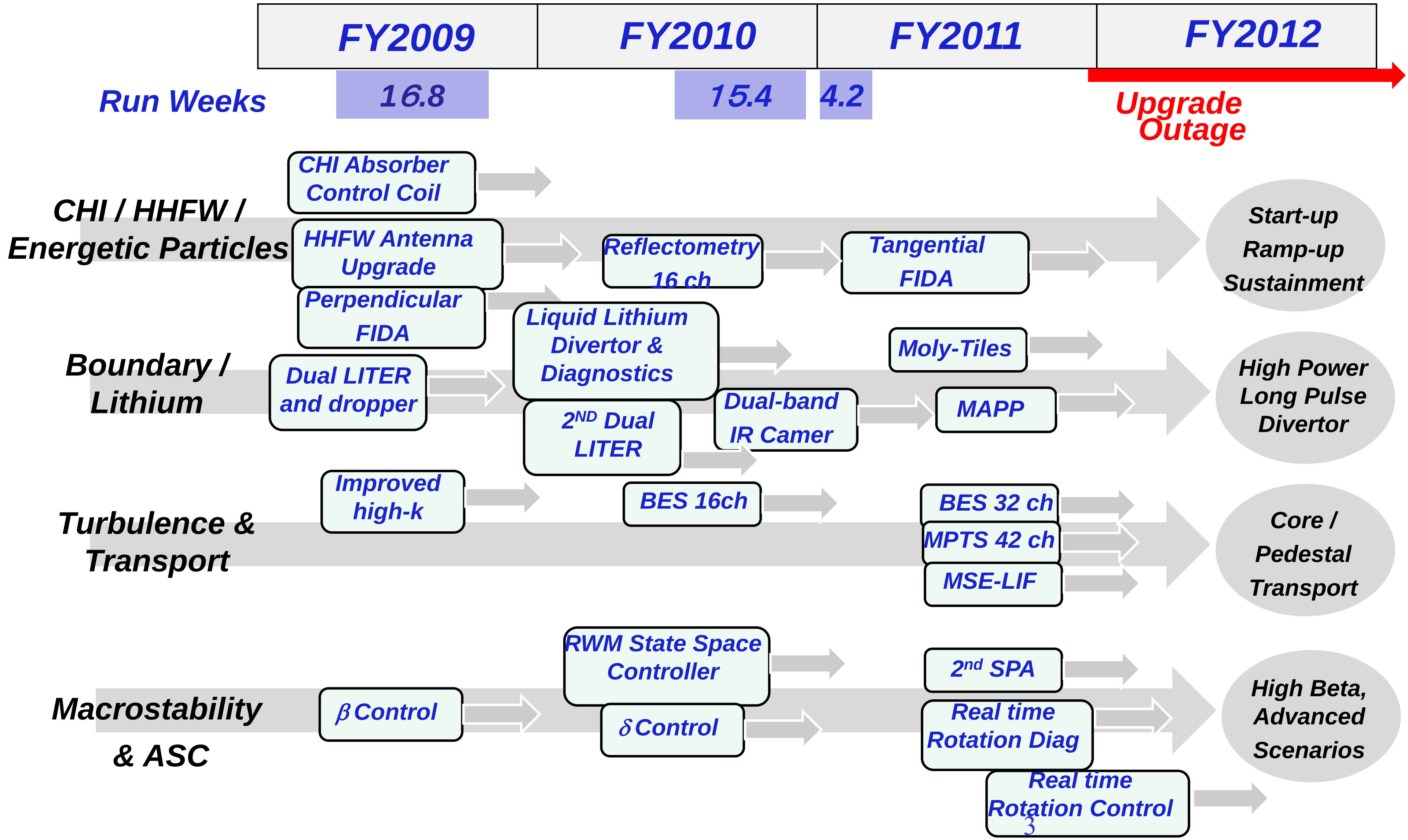


Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Talk Outline

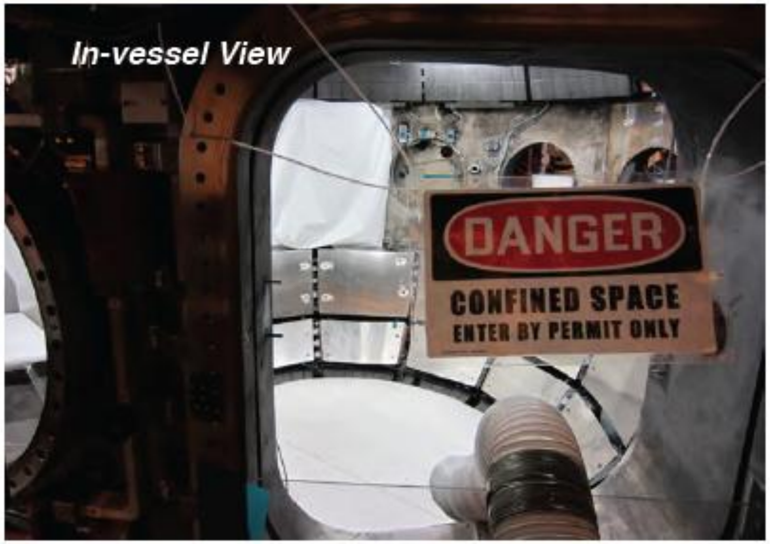
- FY 2011-12 Operations Summary and Status
- FY2012-14 Facility and Diagnostic Plans
- Budget
- Summary
- Back-up: ARRA and other Facility Activities

Significant Facility Enhancements Implemented
To Support NSTX Mission Elements and Upgrades



Recent NSTX-U Test Cell Pictures (March 9, 2012)

Steady Progress Being Made

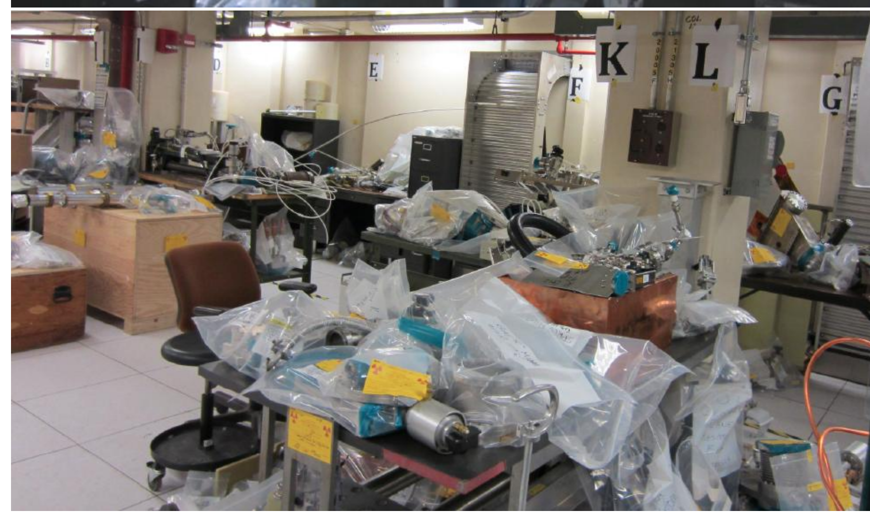


NSTX Diagnostic Removal Completed

62 Diagnostics - 49 removed, 6 partially removed, 7 remain

Beam Emission Spectroscopy (BES)
Bolometer - divertor array
Bolometer - midplane array
CHERS - poloidal
CHERS - toroidal
Edge bias & Langmuir probes - inter-LLD
Edge deposition monitors
Edge pressure gauges
Edge Rotation Diagnostic (ERD)
Fast cameras - divertor & LLD
Fast Ion D-Alpha (FIDA) Radial view
Fast Ion D-Alpha (FIDA) Tangential view
Fast lost ion probes
Filterscopes, 1-D D-alpha cameras (EIES)
FIReTIP - multi-chord interferometry
Gas puff imaging - divertor
Gas puff imaging - midplane
High-k scattering
Infrared cameras
Interferometry/forward scattering - 1 mm
Langmuir probes - PFC tiles
Langmuir probes - fast eroding
Langmuir probes (baffled) - outboard
Langmuir probes (high density) - inter-LLD
Magnetics - diamagnetism
Magnetics - flux loops
Magnetics - locked modes
Magnetics - outboard divertor halo current
Magnetics - Rogowski coils
Magnetics - RWM sensors

MAPP
Mirnov coils - high frequency
Mirnov coils - poloidal array
Mirnov coils - three-axis
Mirnov coils - toroidal array
MSE-CIF
MSE-LIF
Neutron detectors
NPA - E || B scanning
NPA - solid state
Plasma TV
Reflectometer - 65 GHz backscattering
Reflectometer - correlation
Reflectometer - fixed freq.
Reflectometer - FM/CW
RF Probe - lower dome
Spectroscopy - Divertor UV/visible
Spectroscopy - LOWEUS EUV
Spectroscopy - Lyman-alpha array
Spectroscopy - SPRED VUV
Spectroscopy - SWIFT 2D flow
Spectroscopy - VIPS visible
Spectroscopy - XEUS EUV
Spectroscopy - X-ray crystal - horizontal
Spectroscopy - X-ray crystal - vertical
Thomson scattering - MPTS
Visible bremsstrahlung
X-rays - "Optical" array
X-rays - Tangential TG spectrometer
X-rays - ultrafast pinhole camera
X-rays - Ultrasoft arrays
X-rays - bremsstrahlung spectrum



Diagnostics were stored bay-by-bay with good documentation for reinstallation

Removed *Partial Removal* *Remain*

NSTX had strong publications and conference participation

Growing Number of Highly Capable Young Researchers

- 58 NSTX scientific papers published in refereed journals including six PRLs in FY 2011. 28 engineering technical papers also published

- The NSTX team members presented six Invited Talks at the APS-DPP meeting last fall and 13 additional invited talks.

Highly regarded research team:

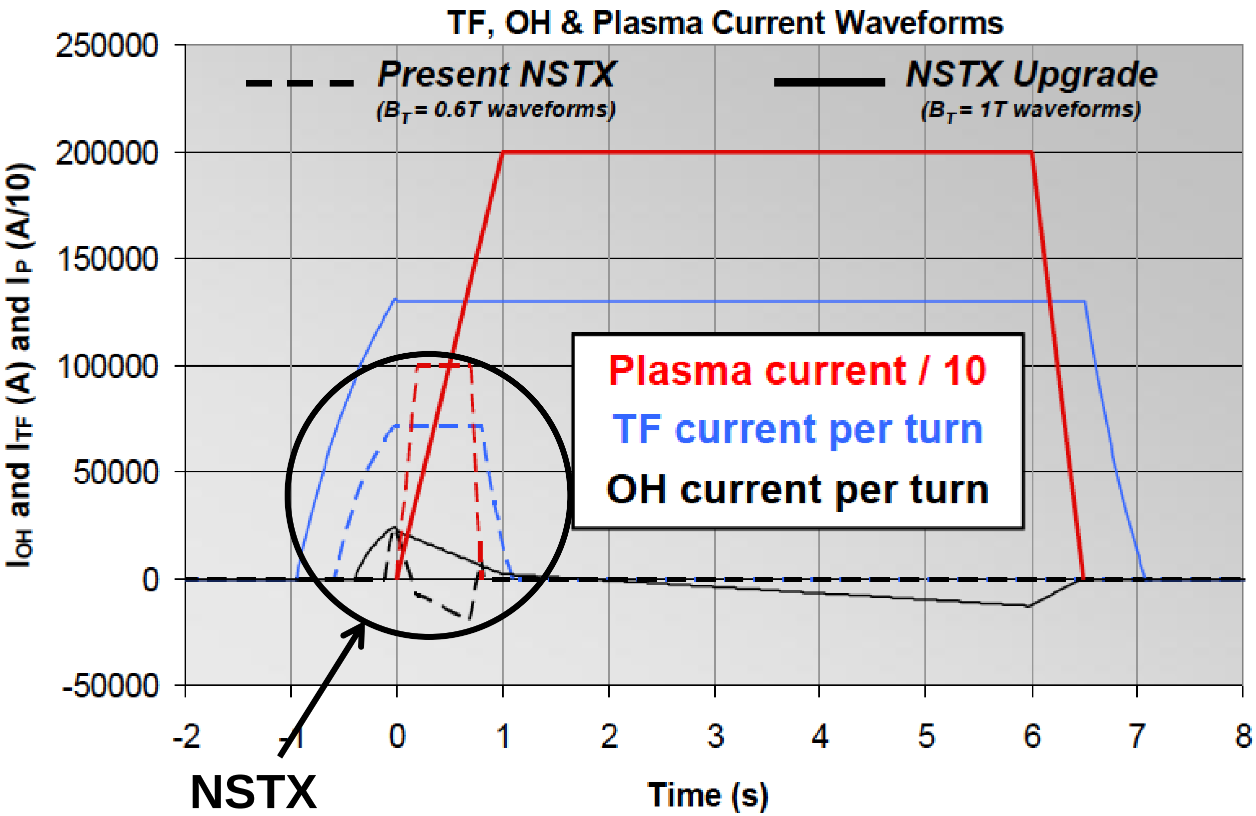
- Strong contributions from young researchers : 18 post-docs and 21 students
- Two Presidential Early Career Award and three DOE OS Early Career Research Program Award recipients
- Experienced senior researchers: 17 APS Fellows

NSTX Research Team Membership

	PPPL	Non-PPPL
Researchers	69	210
Post Doc.	6	12
Grad. Students	4	6
Undergrad.	1	10

NSTX-U provides substantial increase in device performance

High performance requires facility / infrastructure enhancements



	Base NSTX	NSTX Upgrade
R_0 [m]	0.854	0.934
Min. aspect ratio	1.28	1.5
I_p [MA]	1	2
B_T [T]	0.55	1
T_{pulse} [s]	1	5
$T_{repetition}$ [s]	600	1000
$R_{center\_stack}=R_0$-a [m]	0.185	0.315
$R_{antenna}=R_0$+a [m]	1.574	1.574
Total OH flux [Wb]	0.75	2.1

With increased device and plasma performance of NSTX-U, there will be a number of challenges in facility and diagnostic areas:

- **Restore Motor Generator 2 structural welds to normal rating before the NSTX-U operation – necessary due to increased electrical demand (x 8) by NSTX-U.**
- **Implement Fault Detector and Firing Generators on NSTX-U rectifiers for better control → to reliably and safely operate with 8 rectifiers in parallel for toroidal field.**

Facility and Diagnostic Upgrade Plans for FY 2012 – 2014
In Support of the NSTX-U Operation and Research Plan

Facility and Diagnostic Milestones:

- **FY 12: Identify possible high priority facility and diagnostic enhancements for the post upgrade operations**
- **FY 13: Complete the conceptual design of high priority facility and diagnostic enhancements for NSTX-U operations**
- **FY 14: Implement high priority facility and diagnostic enhancements for TX-U operations as the resource permits (if for example, the upgrade project under runs)**

Other Related Activities:

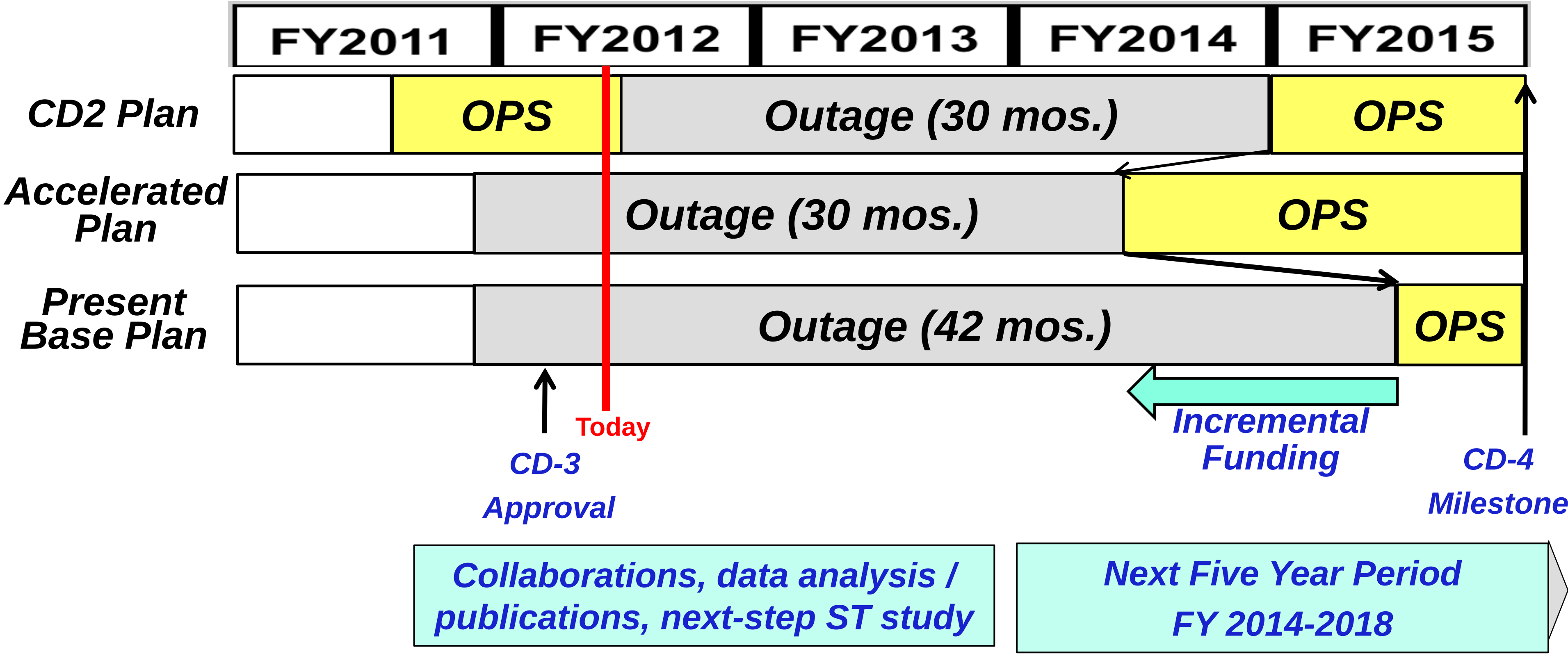
- **NSTX Team Facility – Diagnostic Upgrade Brainstorming Meetings in July 2011 and Feb. 2012 (a large numbers of great ideas!)**
- **New 2012 DOE NSTX collaboration diagnostic grants selected**
- **DOE advanced diagnostic grant solicitation and NSTX laboratory collaboration proposal solicitation in 2013**
- **NSTX physics collaboration grant solicitation in 2014**

NSTX FY 2014 FWP Budget Summary ($M)
Base Budget is Highly Constrained

	FY2012	FY 2013		FY2014	
Budget cases	Base	Base	Incr.	Base	Incr.
Facility Operations	9.5	8.8	3.9	8.8	2.9
Fac. Enhancements	0.4	1.7	1.0	0.5	0.7
Upgrade Project	24.2	19.7	5.7	19.8	3.9
Facility Total	**34.1**	**30.2**	**10.6**	**29.1**	**7.5**
PPPL Research	10.2	10.0	0.3	11.1	0.4
Collab Diag Interf.	0.3	0.3	0.3	0.3	0.3
Collaborations	6.0	5.8	0.5	5.8	0.6
Science Total	**16.5**	**16.0**	**1.1**	**17.2**	**1.3**
NSTX Total	**50.6**	**46.2**	**11.7**	**46.2**	**8.8**

- **NSTX-U Project has the highest priority and funded largely from the base program. However, budget reduction directly impacts the upgrade construction.**
- **The present base plan is $6.6M lower for FY 2013 and $8.1M lower for FY2014 compared to the CD-2 NSTX National Program budget profile.**
- **Under the base plan, NSTX-U Project still needs ~ $10M in FY 2015 to complete.**

The Base Plan Delays NSTX-U Operation to FY2015
Incremental Budget Restores Accelerated Schedule



- The base plan delays the NSTX-U first plasma to mid FY 2015.
- Incremental funding restores funding to the level necessary to support accelerating the NSTX Upgrade Project first plasma date to mid FY 2014 and maintaining optimum operations staffs necessary to support NSTX-U Program.

Base Budget Presents Special Challenges Both for NSTX-U and Institutionally

Present base budget will result in a significant loss of staff at PPPL. Impacts of the manpower reduction on NSTX-U is not yet fully assessed.

FES FY2013 Guidance: PPPL NSTX Base Budget = $40.4M

- **NSTX-U is given priority; reduce FY2013 non-labor expenses as much as possible to have least impact on maintaining staff necessary to resume operations, however at this funding level PPPL staff reductions are necessary.**
- **Provides NSTX-U with FY 2013 budget consistent with CD-2 commitment**
  Fabrication, assembly & testing of TF/OH coil bundle will be completed and final assembly of CS will begin. Structural modifications to the device will be completed and 2nd NBI system & associated infrastructure will be completed.
- **Research Staff support collaborations and 5-year plan**
- **<u>If sufficient funding is provided in FY2014 we can meet the Sept 2014 NSTX-U 1st Plasma date</u>**

FES FY2014 Guidance: PPPL NSTX Base Budget = $40.4M (level with FY2013 guidance)

- **In FY 2014, the newly fabricated center stack will be installed on NSTX-U and connected to the utilities. The 2nd NBI system will be also readied for operations however at this funding level PPPL staff reductions are necessary.**
- **Based on the NSTX-U FY 2014 flat funding guidance and the need to fund NSTX Program Research and Facility Operations Caretaking activities NSTX-U cannot commit to resuming plasma operations until mid FY 2015 at this funding level.**
- **Research Staff support collaborations, and develop NSTX-U operation plans for the FY2015 first plasma.**

Facility Operations Budget
Non-Upgrade scopes are being pared down to minimum

- Facility Operations resources shifting to the NSTX-U Project in FY 2012
- Cover the site utilities (electricity, etc), allocations, and caretaking
- Provide engineering management and supervision
- Support NSTX-U operations
  - Refurbish aging rectifier controls: fault detector and firing generator
  - Migrate plasma control system to modern processors
  - Enhance HHFW antenna feed-thru conductor support against disruption forces
  - Realign Multi-Pulse Thomson Scattering System
  - Re-install high priority diagnostics
  - Support preparations toward NSTX-U operations
  - Most NSTX facilities and diagnostics are in caretaking and maintenance state
- Support NSTX-U research team activities
  - Support in-coming collaborators (e.g. diagnostics)
  - Support outgoing collaboration activities

Incremental Funding Summary ($M)
Enabling NSTX-U Acceleration and Enhancements

Incremental scopes: in order of programmatic priority	FY13 Increments	FY14 Increments
NSTX-U need to get back on Accelerated Schedule	$5.61	$3.95
Restore Planned Collaborators Funds	$0.50	$0.60
Accelerate Fault Detector/Firing Generator (Rectifiers)	$0.40	
Repair MG welds	$1.08	
Plasma Control System Hardware	$0.06	$0.06
Plasma Control System Engineering Enhancement	$0.09	$0.10
Central I&C Critical Staff/Improvements	$0.43	$0.49
HHFW-Critical Staff/Update Sources, RFTF/Probe Work, Antenna Improvement	$1.72	$1.62
Collaborator Interface Support	$0.31	$0.32
High Priority Facility/Diagnostic Enhancements	$0.62	$0.65
Restore Research	$0.33	$0.36
Replace Boundary Physics-Chemist	$0.35	$0.38
NBI Drawings	$0.20	$0.22
Total	$11.69	$8.74

Enhanced Case – FY2013 +25% ; FY2014 +17%

- FY2013 PPPL @ $51.7M National Program @ $57.9M
- FY2014 PPPL @ $48.6M National Program @ $54.7M

- Restores NSTX-U (PPPL and national collaborators) to Accelerated Plan – allows NSTX-U to be ready for 1st Plasma mid-FY2014 – allows preserving optimum staff necessary to resume operations in FY2014 and enables necessary facility enhancements to fully take advantage of NSTX-U capability

Note: under the Enhanced Case the amount of run-weeks NSTX can perform in FY2014 is dependent on the amount of un-used contingency NSTX-U can turn back to operations.

NSTX FY 2014 FWP Budget Summary ($M)
Termination case has huge institutional implications

NSTX Program Termination Assumption:

- NSTX Notified in FY2013 that Program will be terminated in FY2014
- Systems are already in safe shutdown state
- NSTX Engineering Staff on-board (~ 87 FTEs) at 9/30/13 will close out construction packages by the end of the 1st quarter
- Caretaking estimate (Jan-Sep) : 2 Engineers and 4 Technicians plus misc. expenses

  Note: Indirect Staff reduction assumption contemplates that the laboratory will undergo a significant restructuring to accommodate a laboratory approximately half its current size.

- Research Staff Supported through September 30, 2014
- PPPL Budget Need - $33.9M. Reduction of 139 FTEs (111 Direct Staff plus 28 Indirect Staff) 103 on 12/31/13 - 36 on 9/30/14. Severance of $10.0M ($2.8M less if researchers were not terminated in FY 2014) is included in the $33.9 M.

Optimized Plan Being Developed for FY 2012–14

Exciting Opportunities and Challenges Ahead

- **NSTX started the upgrade outage in FY 2012 six months earlier**
  - Diagnostics were stored and secured for the upgrade activities
  - Researchers are working on data analysis, collaboration, next five year plan and preparation for the NSTX-U operation
  - NSTX operations technical staff are being shifted to the Upgrade Project tasks in FY 2012
- **NSTX Upgrade Project is making excellent progress**
  - Successful DOE OFES CD-3 Approval in Dec 2011
  - Upgrade activities are ramping up rapidly in all areas, currently in pace to complete in April, 2014 well ahead of the Sept 2015 CD-4 completion target
- **FY 2013 / FY 2014 budget guidance will delay the NSTX-U start date**
  - Upgrade project to continue as the original schedule through FY 2012
  - FY 2013 presidential budget is $ 6.6 M lower than the CD-2 budget profile will delay the NSTX-U start date to end of FY 2014
  - FY 2014 flat budget guidance is $ 8.1 M lower than the CD-2 budget profile will delay the NSTX-U start date further to mid FY 2015.
  - Incremental funding restores the budget to the CD-2 profile level and accelerates the NSTX-U first plasma date accordingly with enhanced capabilities

Backup Slides

ARRA Funding Greatly Enhanced Research Capability

Planned ARRA Upgrades Completed on Schedule

Extra 12 channels for the multi-pulse Thomson scattering system for improved H-mode pedestal and plasma edge spatial resolution to support the FY 11 joint research milestone.

Enhancement to the liquid lithium divertor target capability for modifying edge collisionality, including two lithium evaporators, and LLD diagnostics.

Post Doctoral Fellows to support the enhanced research capabilities.

2nd switching power amplifier system for improved error field/resistive wall mode/resonant magnetic perturbation spectra to control the edge error field.

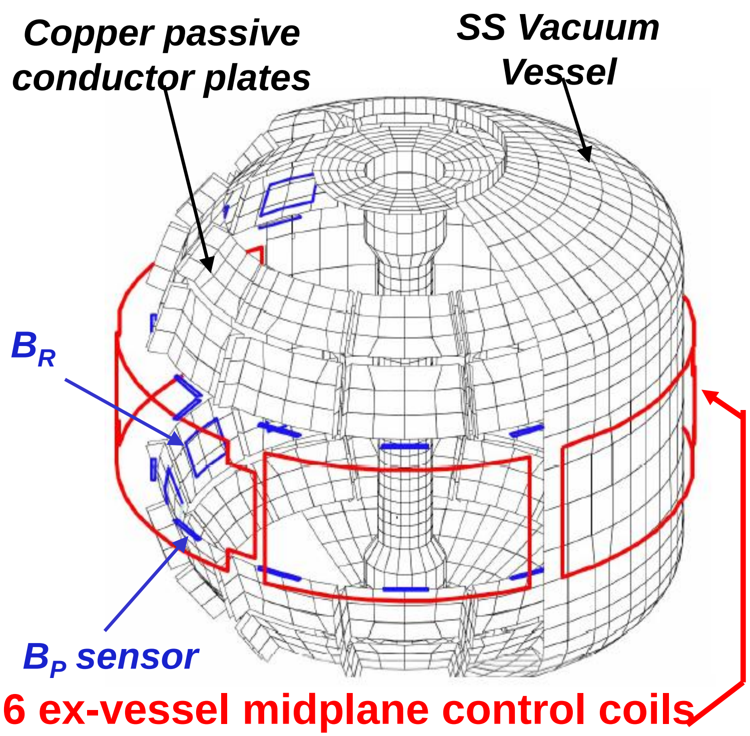
Motional Stark Effect Laser Fluorescence advanced diagnostic system for internal magnetic and electric field measurements was installed and commissioned.

Inboard Divertor Molybderum Tiles for assessing the viability of molybdenum tiles as a divertor PFC for NSTX-U (upper divertor being considered).

Li Granule Injector for triggering ELMS in a controlled manner. Commissioned and planned to be tested in RFX (Italy), EAST and possibly on DIII-D

2^{nd} SPA Successfully Installed and Commissioned

Sustain β_N and Understand MHD Behavior Near Ideal Limit



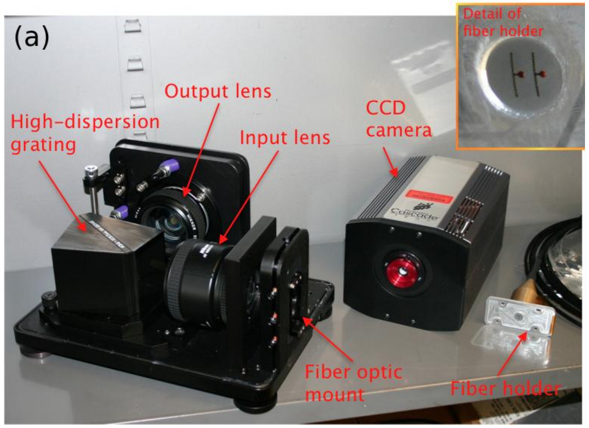
2nd 3-channel Switching Power Amplifier (SPA) comissioned in July 2011 powers independent currents in six EFC/RWM coils for simultaneous control of n = 1, 2, 3 field harmonics

- **RWM spectrum dependence**
- **Rotation and beta effects on NTMs**
- **Response to 3D fields for EFC, ELM and Neoclassical Toroidal Viscosity physics**
- **Disruption physics**

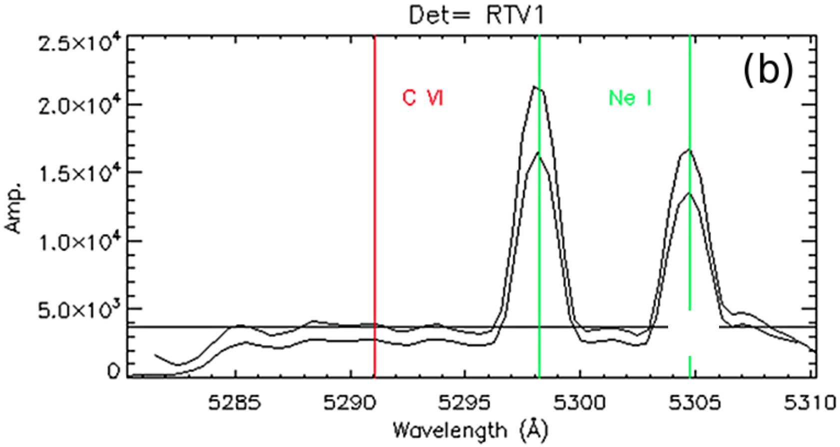
Real Time Velocity Diagnostics – An Important Tool for Advanced Plasma Control

A Real-Time Velocity (RTV) diagnostic will be incorporated into the plasma control system for feedback control of the plasma rotation profile using the NBI and non-resonant magnetic braking as the actuators

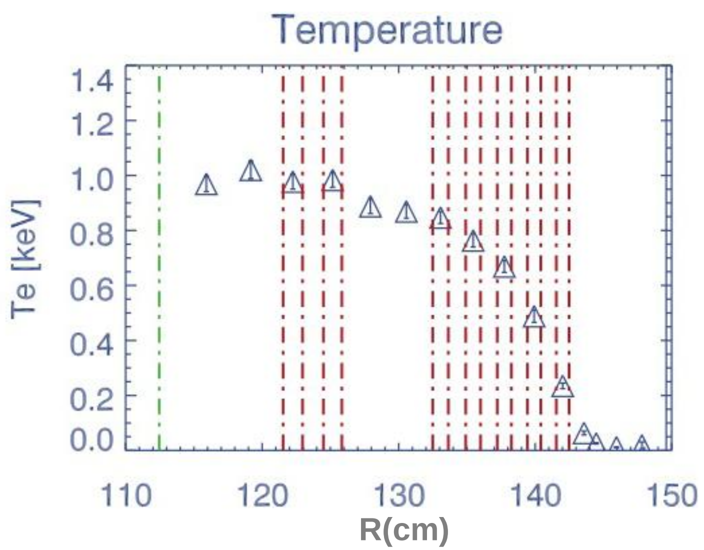
- **Based on active charge-exchange recombination spectroscopy (CHERS)**
- **Measures at six radial locations and a sampling rate of 5 kHz.**
- **Uses two toroidally separated views to distinguish the heating NB view from the background (intrinsic) contribution.**
- **Installed and commissioned on NSTX in July 2011**



RTV hardware including CCD camera & spectrometer



Example of spectra measured on two channels during a Ne glow.



Additional 12 channels enhance resolution in pedestal to ~1 cm and improve diagnosis of ITB in plasma core

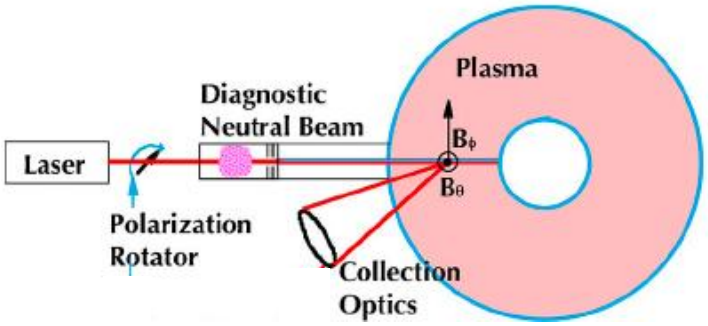
Polychromator assembly

- **Twelve additional channels for the multi-pulse Thomson scattering (MPTS) system were installed and commissioned in July, 2011.**
- **Calibration was performed in situ by employing Rayleigh and Raman scattering of the light from the MPTS laser system by nitrogen and argon introduced into the vacuum vessel**

MSE-LIF Installed for Enhanced Pedestal / Profile Diagnostics Commissioned and field calibration performed on NSTX

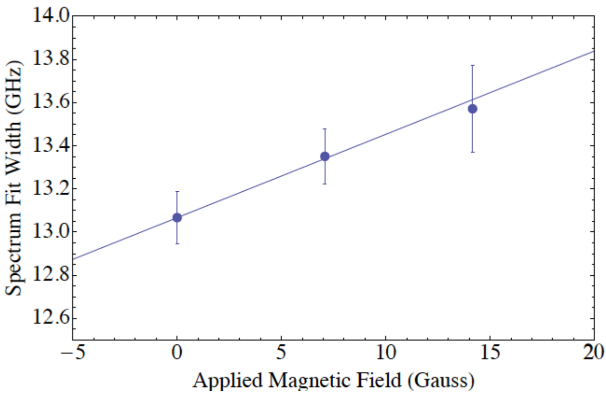
The Motional Stark Effect measurement based on Laser Induced Fluorescence (MSE-LIF) diagnostic will provide measurements of the field line pitch angle profile without requiring injection of the heating neutral beam.

MSE-LIF DNB system on NSTX



Schematic of the MSE-LIF system

Nova Photonics



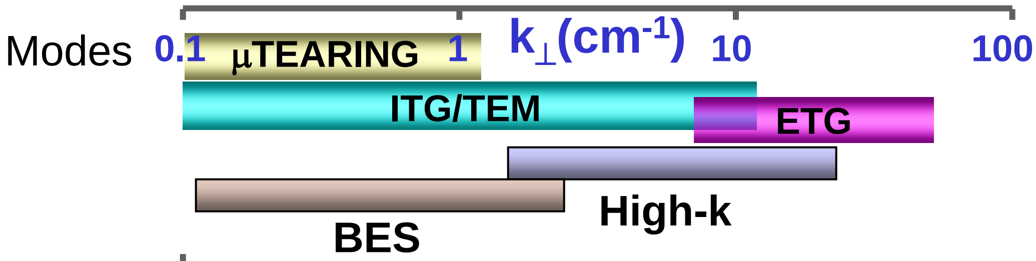
MSE-LIF Magnetic Field Calibration Scan with ~ 10 Gauss resolution on NSTX

MSE-LIF provides unique capabilities

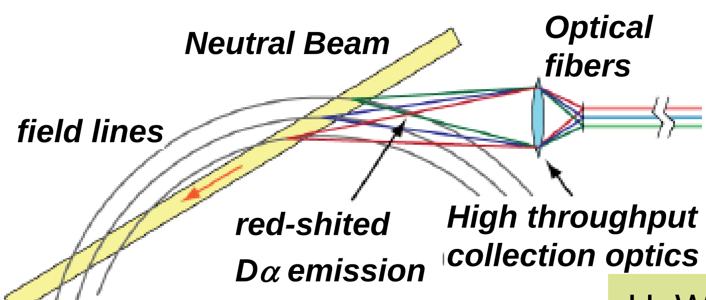
- **Measure RF-driven current without the heating neutral beam.**
- **Measure total magnetic field in plasma to reconstruct total plasma pressure.**
- **Together with MSE-CIF, yield radial electric field profile**

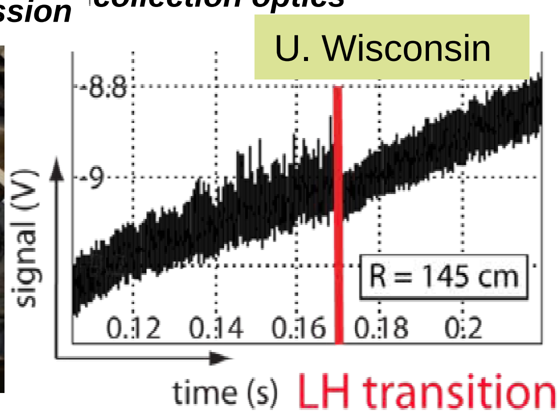
Transport and Turbulence

Increase and Understand H-mode Confinement at Lower n_e, ν^*



- **BES together with high-k to provide a comprehensive turbulence diagnostic set.**
- **High-k with a new solid-state source is running reliably.**

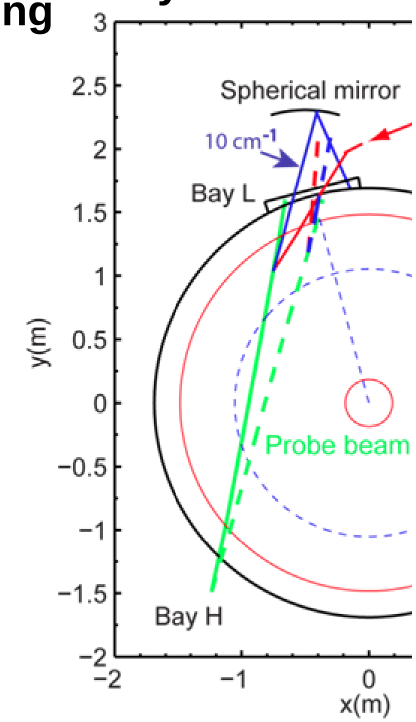


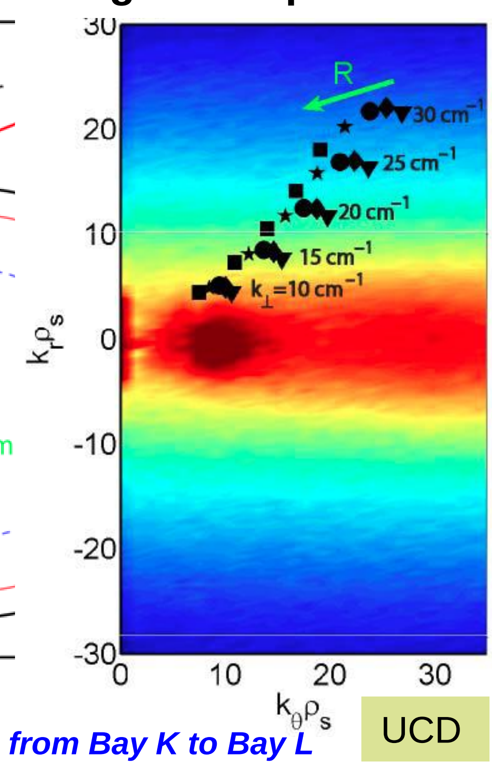


• BES - 16 ch BES worked well in FY 2010 and at least 32 ch BES available for NSTX-U

• High k Upgrade - Upgraded system with 2-D k spectrum for NSTX-U

A candidate new high-k scattering system for allowing 2 D k spectrum.

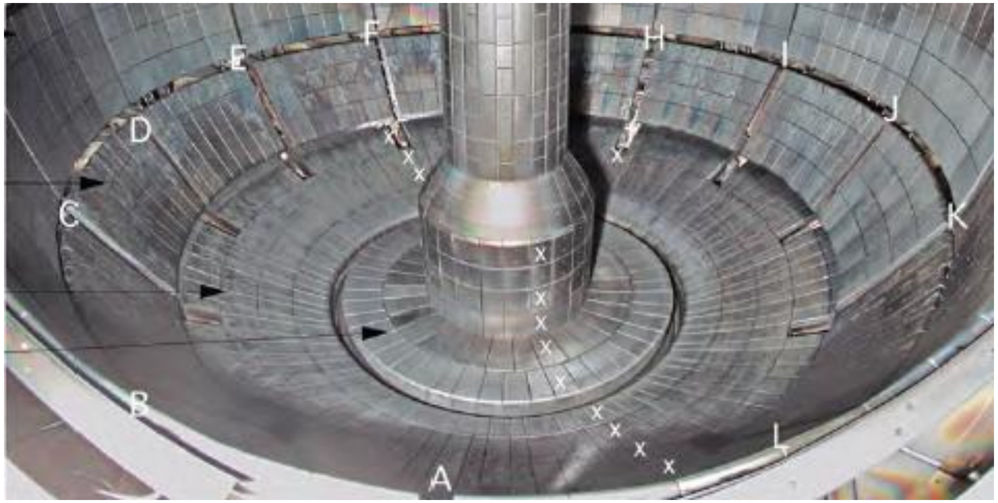




Receivers to relocate from Bay K to Bay L

Boundary Physics

Need to Assess Heat and Disruption Loads for Advanced Divertor



- **LLD removed due to the heat and disruption loads concerns**
- **Lower divertor to start with all graphite tiles for NSTX-U**
- **LITER system will be available for lower divertor as before**

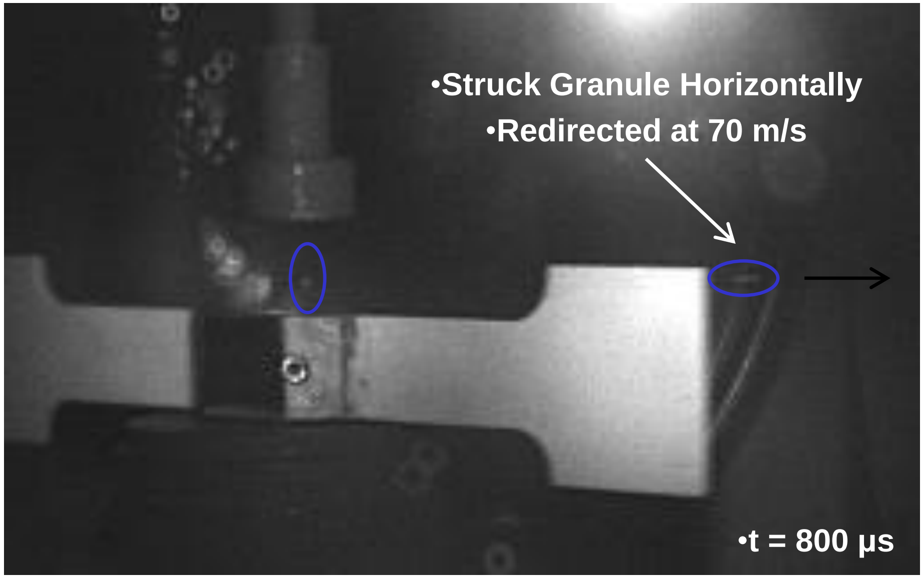
- **Assessing installation of inboard divertor moly-tiles for upper divertor and associated upper divertor LITER system**
- **Moly armor for exposed SS flange surfaces in CHI gap being considered during the**

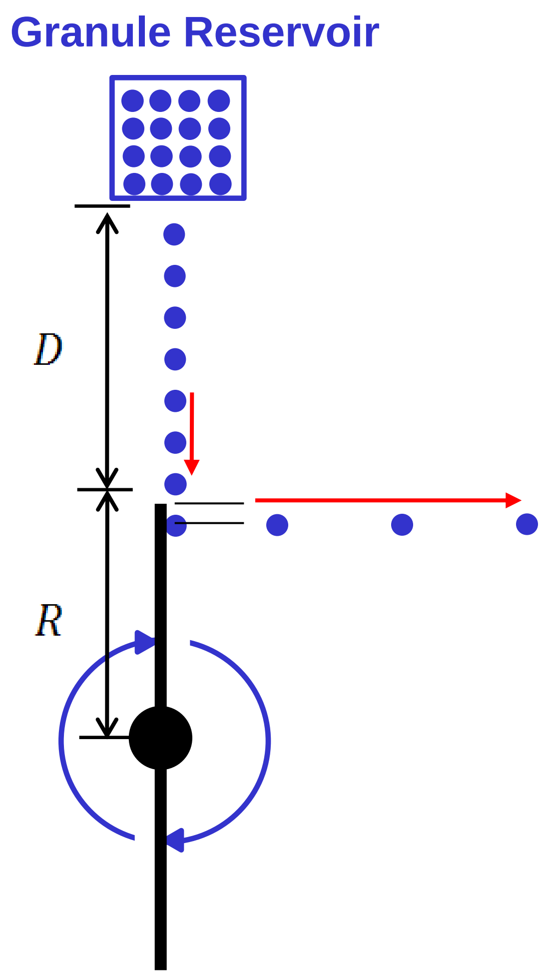
• For FY 12-14, advanced divertor upgrade conceptual design work will commence for the five year plan – e.g., moly-based PFCs, liquid lithium divertor, and closed divertor with cryo-pump.

Lithium Granules Injector for ELM Control Completed

Tests on EAST, RFX should proceed during 2012-13.

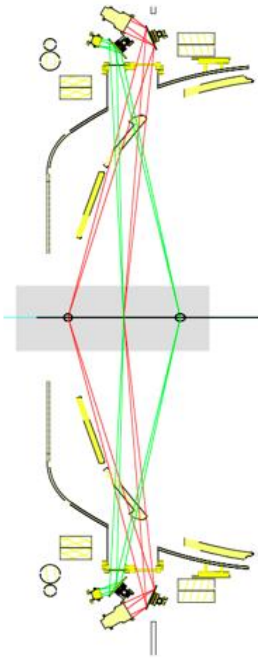
- Spherical Lithium granules (0.6 mm) have been horizontally redirected at speeds approaching 100 m/s.
- Dropping rates (pacing frequencies) of 500 Hz have been readily achieved.
- A dropper apparatus which allows the granule size to be changed between discharges has been built and is being tested.



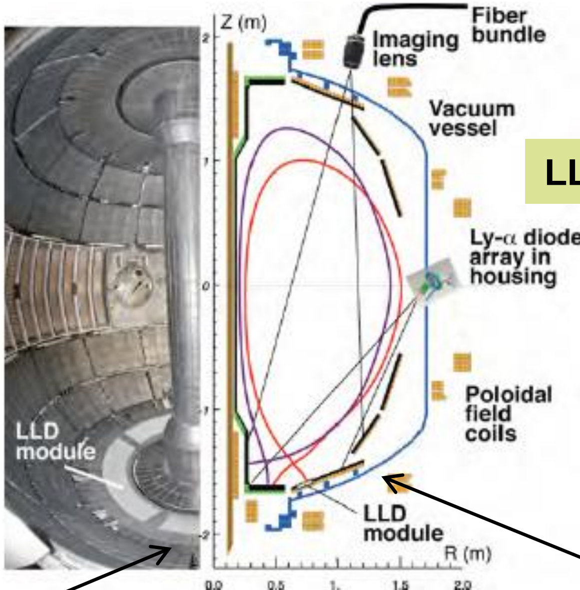


Enhanced Capability for LLD and Boundary Physics
Multi-Institutional Contributions

Lithium CHERS



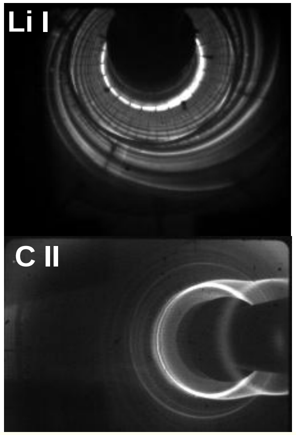
Divertor Imaging Spectrometer



LLNL

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

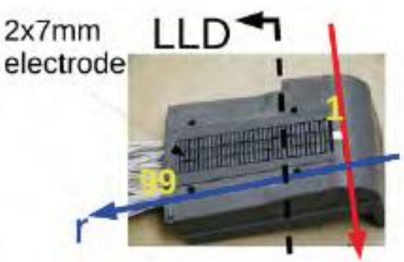
LLNL, ORNL



MAPP diagnostic systems

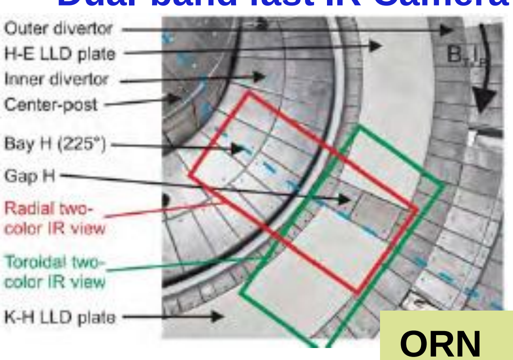
Dense Langmuir Probe Array

Will be replaced by simpler probe array



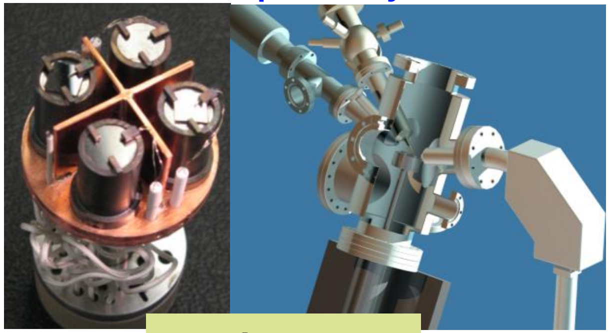
U. Illinois

Dual-band fast IR Camera



ORNL

PMI Probe / to be replaced by MAPP Probe

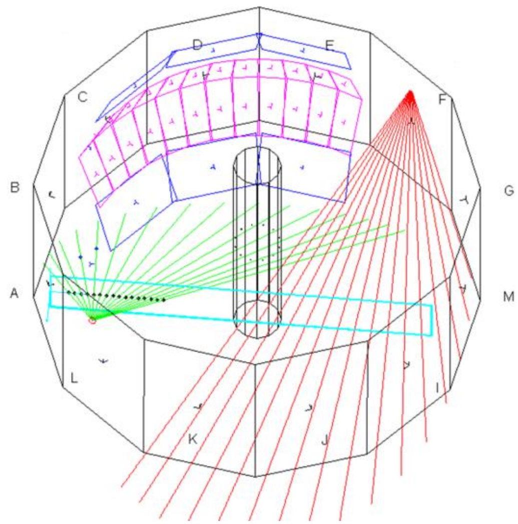


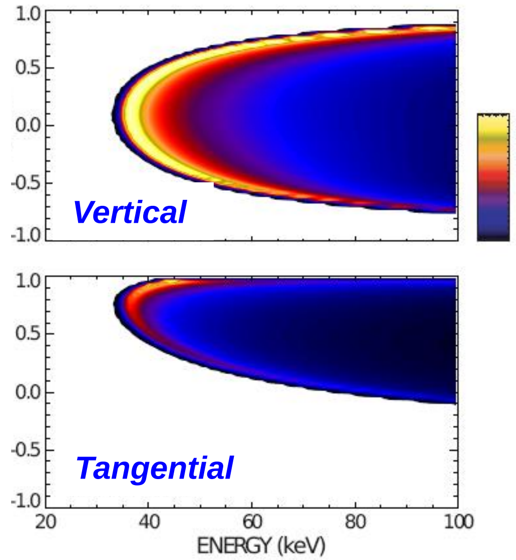
Purdue U.

Tangential-FIDA for Energetic Particle Research
For NBI fast ion transport and current drive physics

Tangential FIDA Views
UC Irvine

- **T-FIDA upgrade will provide two new views of plasma.**
- **Two new ports in vacuum vessel are being installed.**
- **Expect to have installation complete and ready for commissioning at start of next run.**





- **Better localization in velocity space weighted toward parallel velocity**
- **Well suited to investigate NBI fast ion transport and current drive physics**

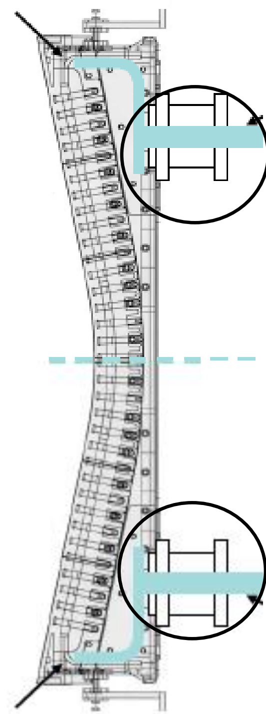
FY 2013 - 14 Energetic Particle Conceptual Design and Diagnostic Upgrade

- **Active TAE antenna**
- **Possible SS-NPA enhancement due to removal of scanning NPA (UCI)**

Possible HHFW Antenna Refurbishmet

Assess a MW-Class ECH/EBW System

Double Feed Antenna



- HHFW power system to undergo modest refurbishment
- Reliable high power operation in H-mode is high priority goal
- HHFW antenna may need structural enhancement against disruption loads in the feedthru area

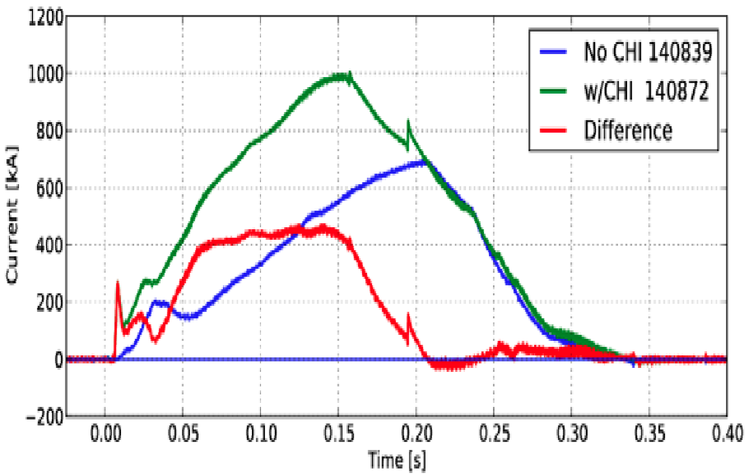
- FY 2012 - HHFW Antenna disruption load being analyzed
- FY 2013 – Perform necessary modification
- FY 2013/14 – Start MW-class ECH/EBW system design for non-inductive operations (US-Japan)

Solenoid-free Start-up

High Priority Longer Term Goal for NSTX-U

Success of CHI aided by Low-Z Impurity Control

U Washington



FY 2013-14 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

- **NSTX-U scenario development**
- **Low-inductance Advanced Plasma Operations**
- **For longer term, MW-class ECH/EBW start-up and ramp up system envisioned**

- **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 current gun for the NSTX-U will be developed utilizing the PEGASUS facility in collaboration with University of Wisconsin**
- **Conceptual design of the MA-class ECH/EBW system to be performed in FY 13-14**