NSTX-U Project Status and 5 Year Plan Facility Overview

Masa Ono

for the NSTX-U Team

NSTX-U PAC 33 Meeting
February 19 - 21, 2013

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General Atomics
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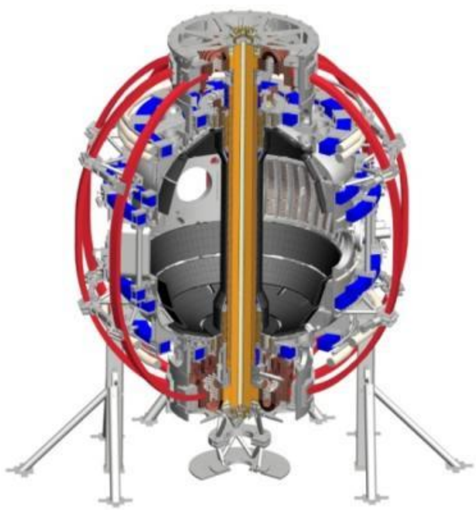

Culham Sci Ctr
U St. Andrews
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CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Talk Outline

- FY 2012-13 Operations Summary and Status
- NSTX Upgrade Project Overview
- NSTX-U Facility and Diagnostic Five Year Plans
- Budget
- Summary

NSTX-U Research Team Has Been Scientifically Productive

Very Active in Scientific Conferences, Publications, and Collaborations

- **NSTX "Snow-flake Divertor" team won the R&D 100 Award for 2012! Also featured in Oct. 2012 FES Science Highlights**

- **NSTX well represented at PSI, High Temperature Plasma Diagnostic, and EPS meetings.**

- **Strong presentations at the IAEA. Most IAEA Presentations (30) given by the NSTX-Team. Prominent contributions to the post-deadline IAEA papers.**

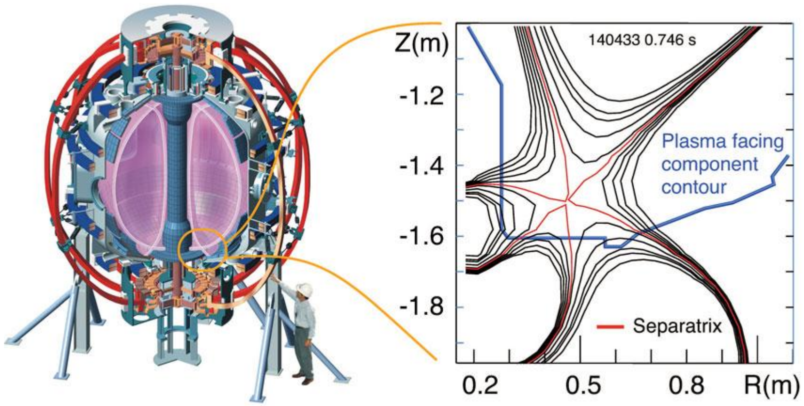

Image courtesy of Vlad Soukhanovskii

The National Spherical Torus Experiment Device at Princeton Plasma Physics Laboratory (left), and a schematic of magnetic field lines in the snowflake divertor configuration (right).

- **Strong presence at fall APS with 63 presentations. Three NSTX APS-DPP press releases are available on the web.**

- **All of the FY 2012 milestones completed on schedule.**

- **Significant collaboration research contributions are being made in diverse science areas by the NSTX-U research team. A summary is available on the web: http://nstx.pppl.gov/DragNDrop/Collaboration/**

- **NSTX-U research team published 52 papers in refereed journals.**

Engineering and Research Operations Activities
In Preparation for the NSTX-U Operations

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

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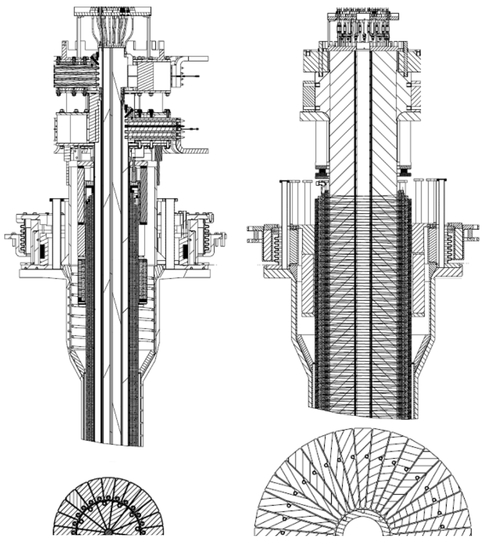
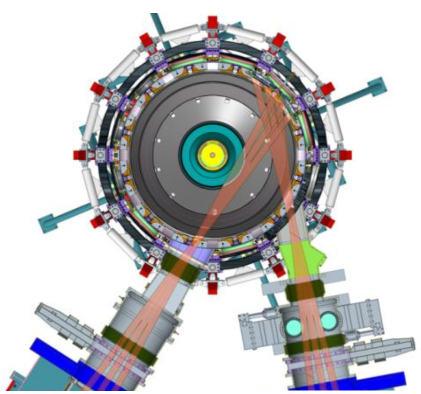
Substantial Increase in NSTX-U Device / Plasma Performance

Higher performance requires facility / infrastructure enhancements

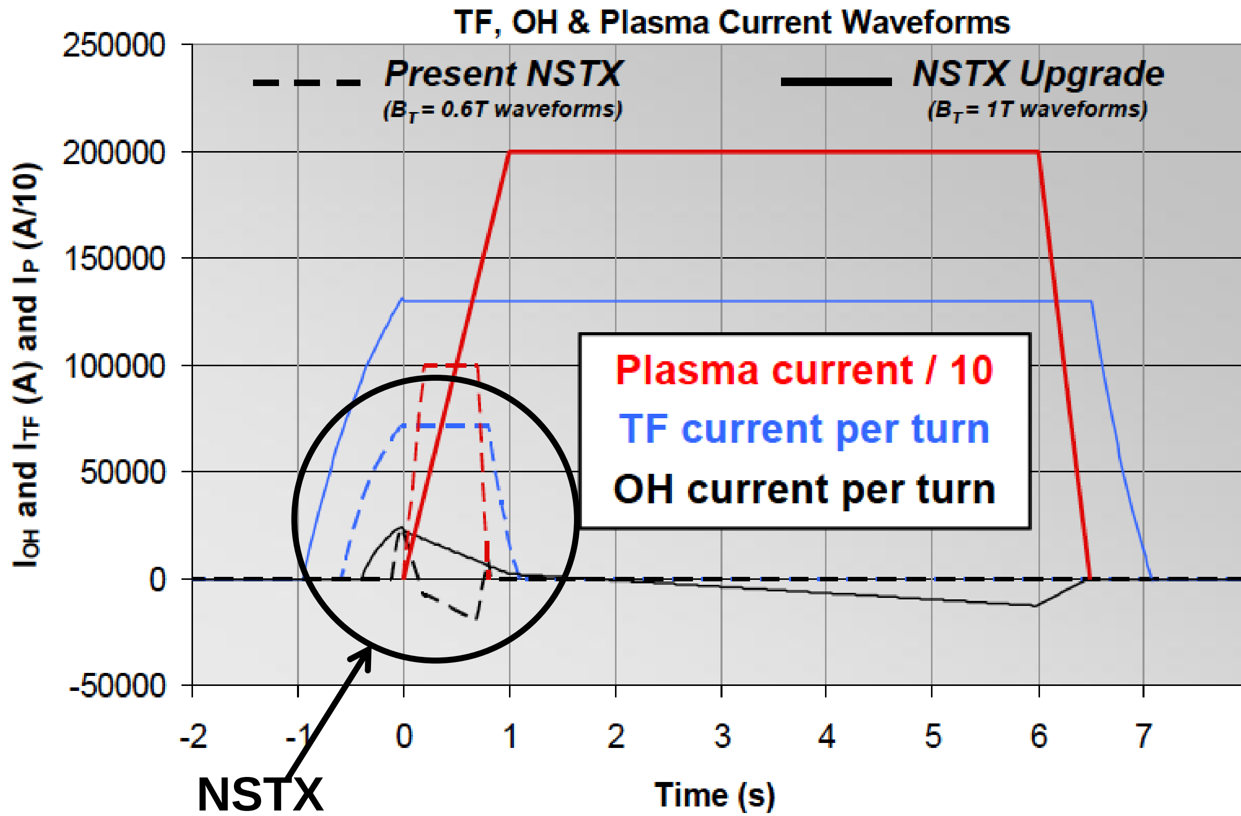
Previous center-stack | **New center-stack**



TF OD = 20cm | **TF OD = 40cm**

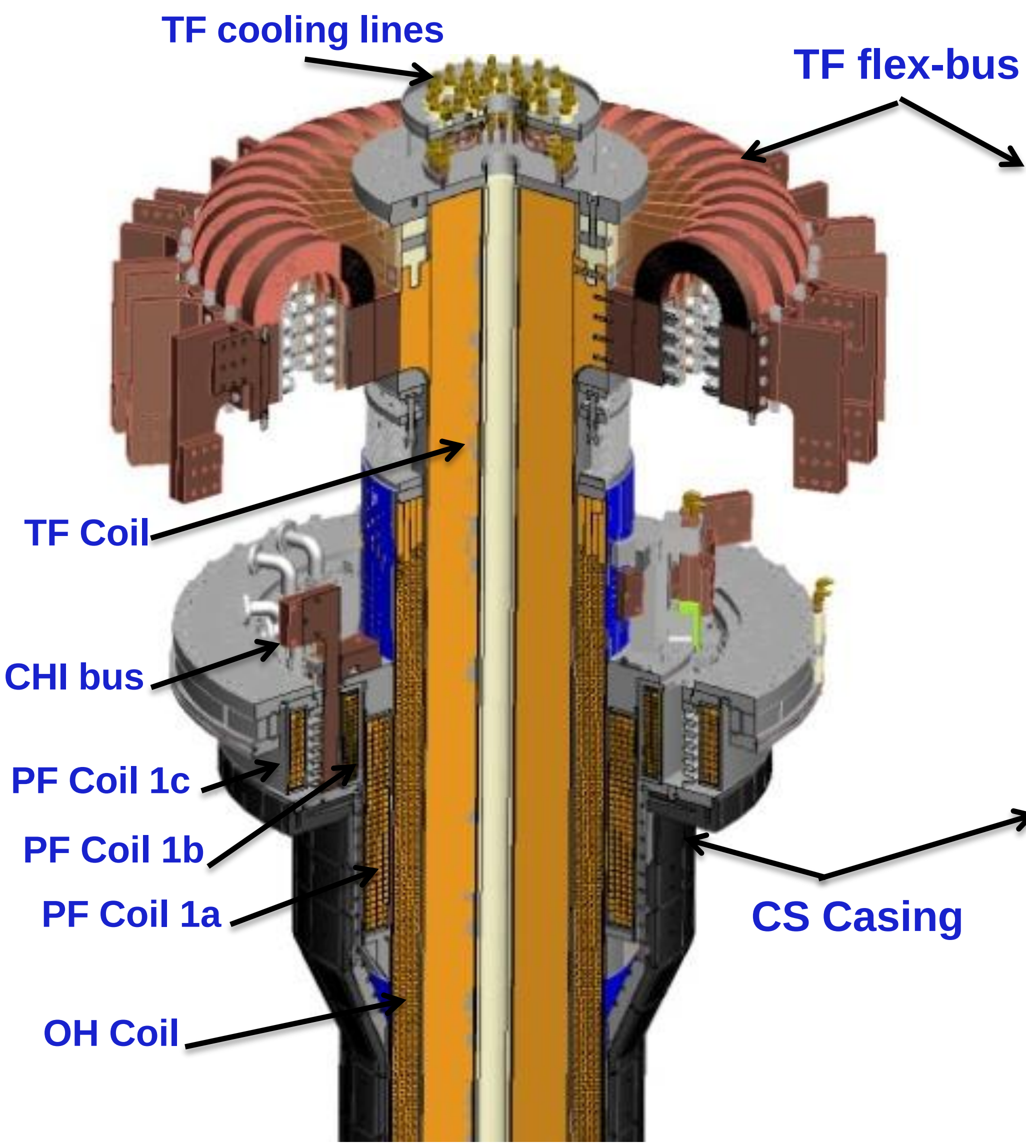


Present NBI | **New 2nd NBI**



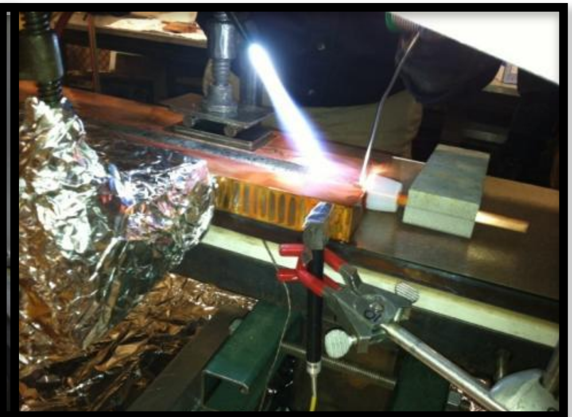
	R_0 (m)	A_{min}	I_p (MA)	B_T (T)	T_{TF} (s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	0.854	1.28	1	0.55	1	0.185	1.574	0.75
NSTX-U	0.934	1.5	2	1	6.5	0.315	1.574	2.1

Improved Center-Stack Design to Handle Increased Forces
Identical 36 TF Bars and Innovative Flex-Bus Design

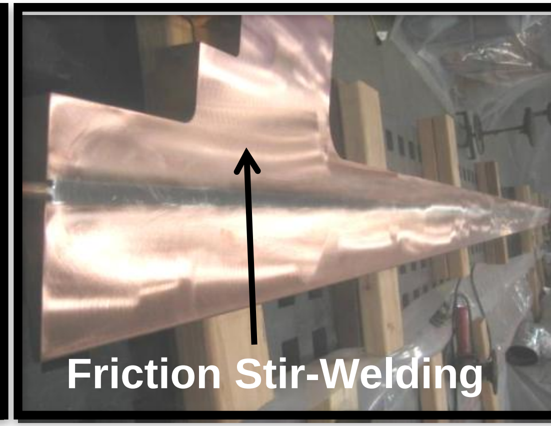


The NSTX-U Inner TF Bundle Manufacturing Stages

Friction Stir-Welding and Zn-Cl-Free Soldering Techniques Developed



Zn-Cl-Free Soldering

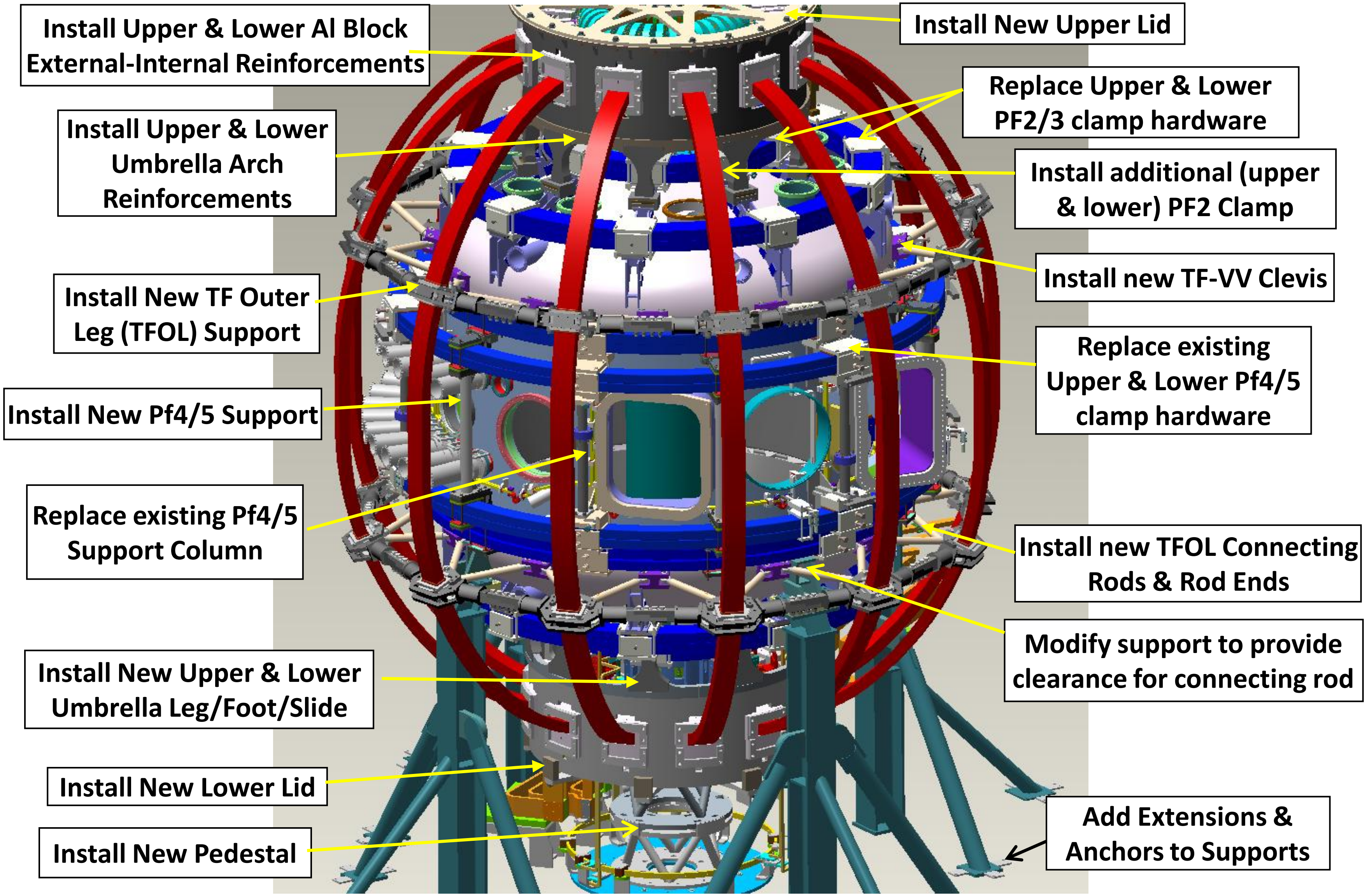


Fiber glass insulation

Conductors placed in a quadrant mold for VPI

NSTX-U Support Structures Enhanced

To Handle 4x Electromagnetic Forces



Relocation of the 2nd NBI beam line box from the TFTR test cell into the NSTX-U Test Cell Complete.

Beam Box being lifted over NSTX

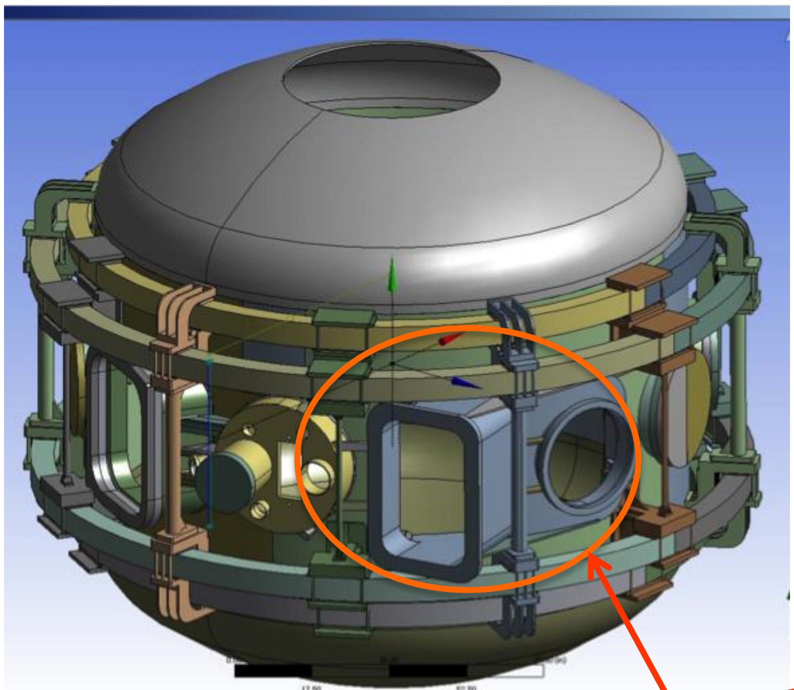
Beam Box placed in its final location and aligned

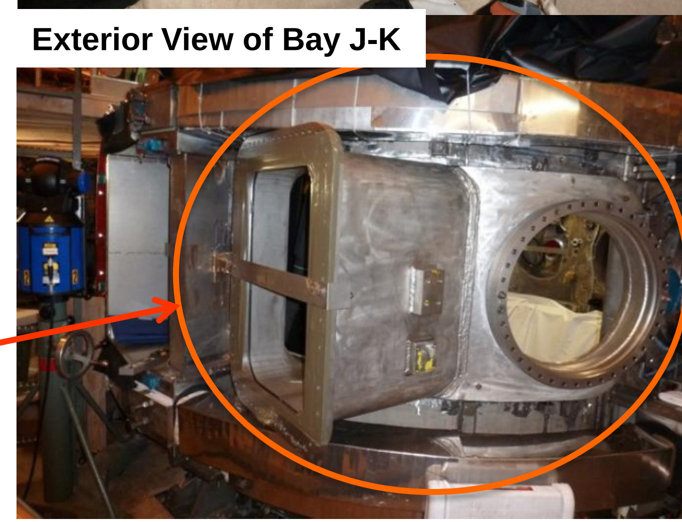
Beam Box being populated with components

Highly Tangential 2nd NBI Enabled by JK-Cap

Outer Wall Radius Moved Outward to Avoid Beam Clipping

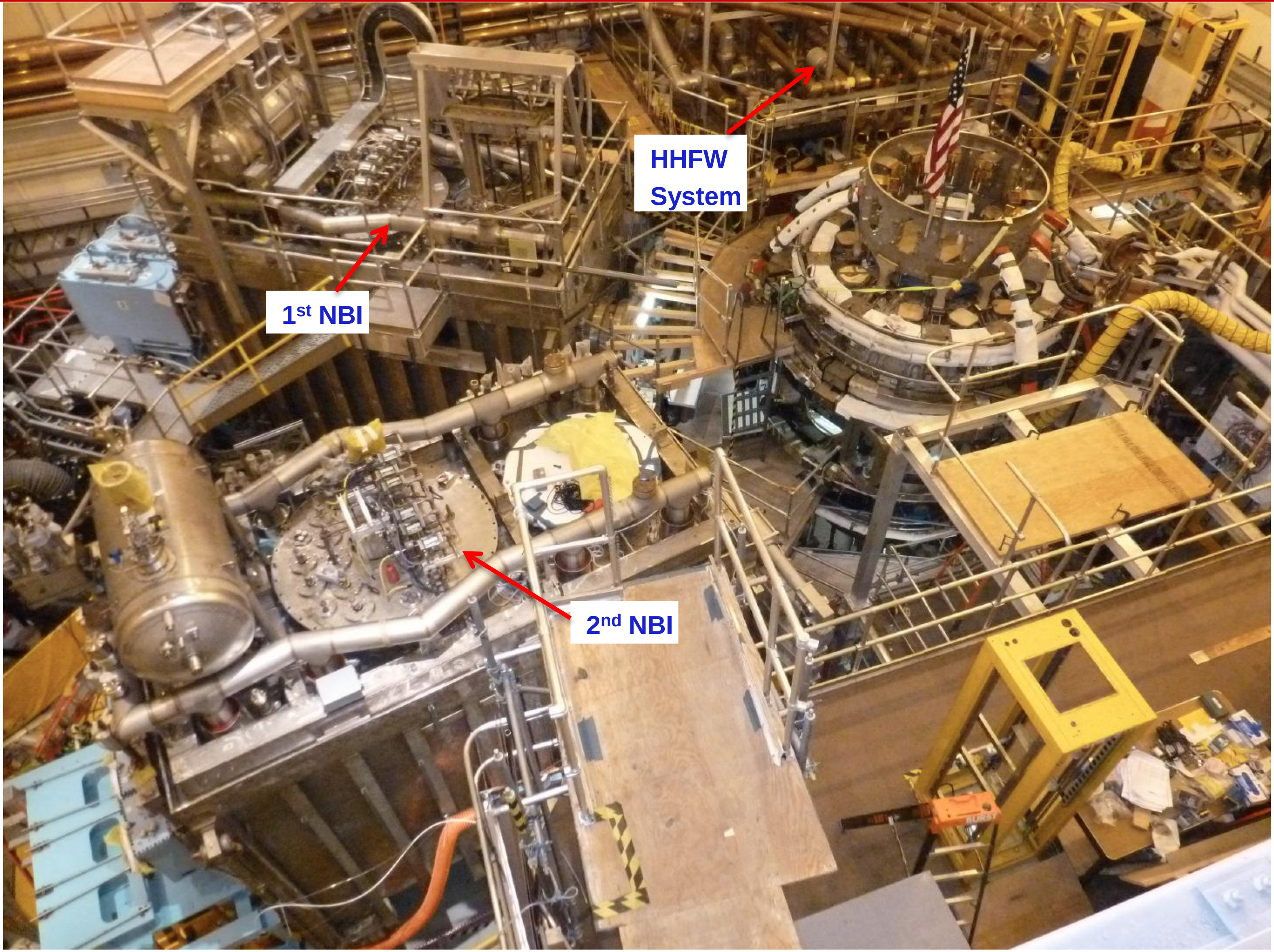
- Bay JK cap successfully welded to the vacuum vessel.
- Bay L cap is also being installed.





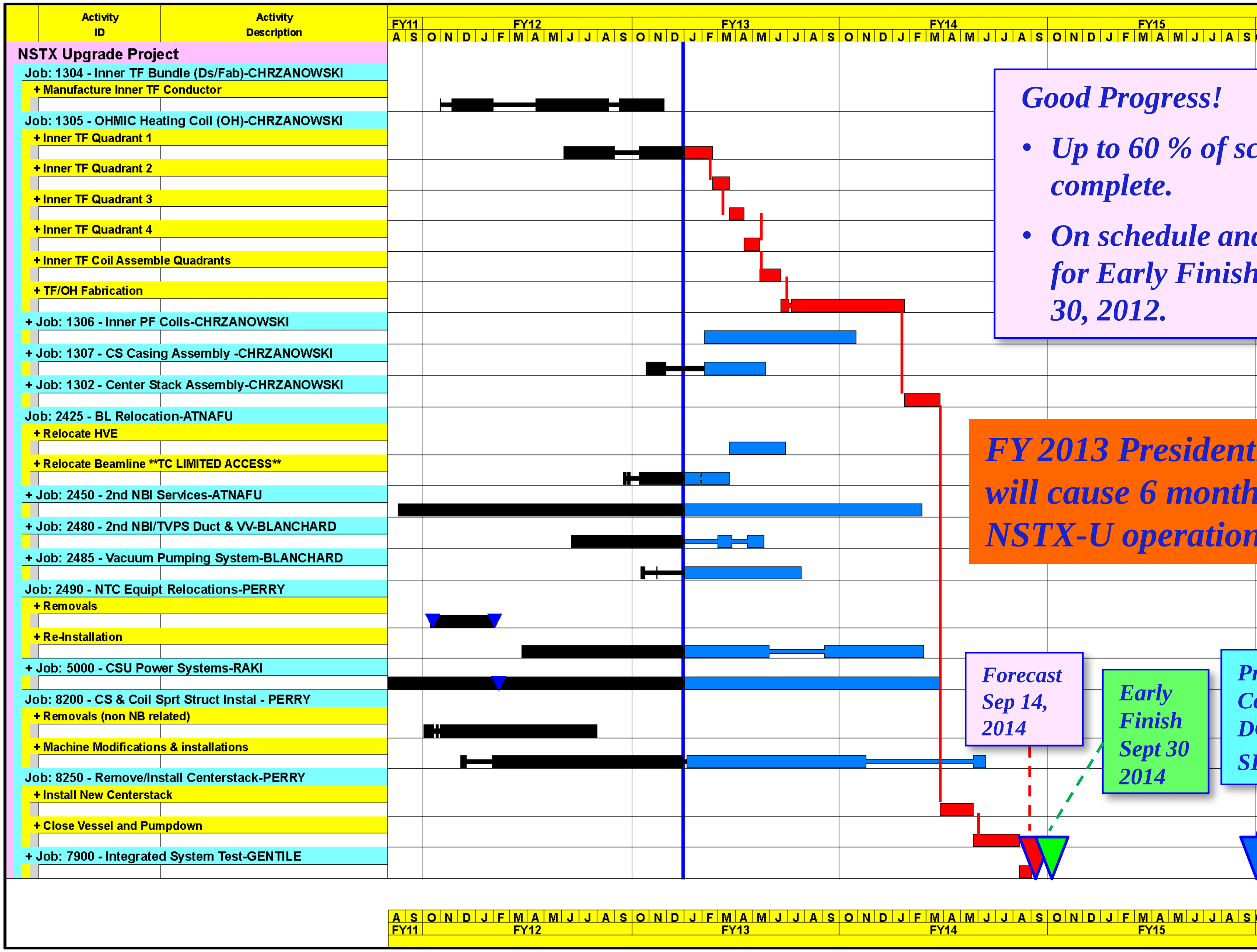
JK cap

Aerial View of the NSTX-U Test Cell (Feb. 2013)



Upgrade Schedule on track for early finish

Aiming to start research operation in FY 2015



Good Progress!

- *Up to 60 % of scopes complete.*
- *On schedule and on budget for Early Finish Date of Sept. 30, 2012.*

FY 2013 Presidential Budget will cause 6 months delay in the NSTX-U operation.

Forecast Sep 14, 2014

Early Finish Sept 30 2014

Project Completion DOE Milestone SEPT 30 2015

Formulating Strategy Toward Full NSTX-U Parameters

After CD-4, the plasma operation could enter quickly into new regimes

	NSTX	Year 1 NSTX-U	Year 2 NSTX-U	Year 3 NSTX-U	Ultimate Goal
I_P [MA]	1.4	1.6	2.0	2.0	2.0
$I_P I_P$ [MA^2]	2.0	2.5	4.0	4.0	4.0
B_T [T]	0.55	0.8	1.0	1.0	1.0
$B_T B_T$ [T^2]	0.3	0.65	1.0	1.0	1.0
$I_P B_T$ [MA*T]	0.61	1.3	2	2.0	2
Allowed TF Coil I^2t [MA^2-s]	7.3	80	120	160	160
I_P Flat-Top at max. allowed I^2t, I_P, and B_T [s]	~0.7	~3.5	~3	5	5

- **Table based on assessment of physics needs for first year of operations**
- **1st year goal: operating points with forces 1/2 the way between NSTX and NSTX-U, ½ the design-point heating of any coil**
- **2nd year goal: Full field and current, but still limiting the coil heating**
- **3rd year goal: Full capability**

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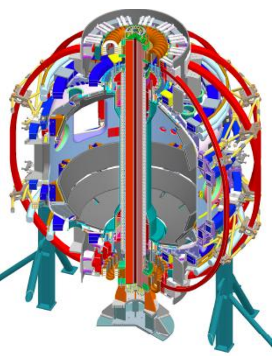
NSTX-U research program aims to establish ST physics and scenario basis, then transition to integrating long-pulse + PMI

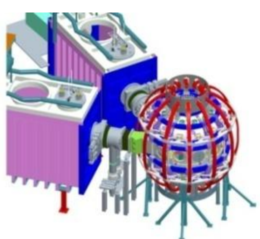
2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

Upgrade Outage | **Establish ST physics, scenarios** | **Integrate long-pulse + PMI solutions**

New center-stack



2nd NBI



Start-up and Ramp-up	Increase CHI closed-flux current → Achieve NI start-up/ramp-up; Assess plasma gun start-up at increased device size → Increase/extend ramp-up heating and off-axis current-drive for advanced scenarios; Develop/understand ECH/EBW H&CD for ST
Boundary Physics	Establish main-ion density and ν* control → Understand snowflake divertor performance → Understand high-Z first-wall erosion, migration, particle sources & sinks
Materials and PFCs	Assess baseline graphite PFC performance → Assess high-Z tile/divertor impact and performance → Assess high-Z divertor and/or first-wall → Assess impact of high-temperature first-wall
Liquid metals / lithium	Establish low impurities / Z_{eff} , assess increased Li coverage, replenishment → Test flowing liquid metal for heat-flux mitigation, surface replenishment → Assess flowing LM PFC with full toroidal coverage
MHD	Understand kinetic MHD, extend mode and disruption detection, develop mitigation → Enhance non-axisymmetric field spectrum and capabilities with off-midplane coils for control of: RWM, EF, RMP, rotation, NTM, EP
Transport & Turbulence	Understand ES and EM turbulence at high β, low ν*, emphasizing e-transport → Extend wave-number coverage of turbulence measurements
Waves and Energetic Particles	Characterize AE stability, fast-ion transport, NBI-CD, support plasma start-up, assess effectiveness of fast-wave in NBI H-modes → Prototype driving edge-harmonic oscillations (EHOs) and/or *AE
Scenarios and Control	Demonstrate full non-inductive, high I_P & P_{AUX} operation; Control: boundary, β, divertor heat flux, Ω & q profiles → Assess integrated control of long-pulse / high-performance

Inform U.S. next-step conceptual design including aspect ratio and divertor optimization

NSTX-U diagnostics to be installed during first 2 years
Half of NSTX-U Diagnostics Are Collaboration Led

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 xh)
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
Neutral particle analyzer (single channel)

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

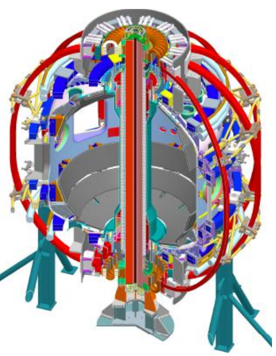
New capability

5 year plan tools with 5YP base funding

(FY2012 + 2.5% inflation)

2014	2015	2016	2017	2018

Upgrade Outage | **1.5 → 2 MA, 1s → 5s**



New center-stack

Start-up and Ramp-up
- Upgraded CHI for ~0.5MA
- Up to 0.5 MA plasma gun
- ECH/EBW 1MW

Boundary Physics
- Lower divertor cryo-pump

Materials and PFCs
- High-Z tile row on lower OBD
- High-Z tile row on cryo-baffle
- Lower high-Z divertor

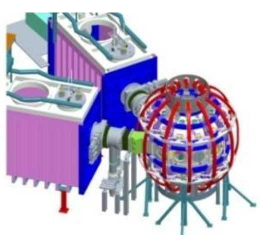
Liquid metals / lithium
- Li granule injector
- Upward LiTER
- LLD using bakeable cryo-baffle

MHD
- MGI disruption mitigation
- Partial NCC
- Enhanced MHD sensors

Transport & Turbulence
- δB polarimetry
- High k_θ

Waves and Energetic Particles
- HHFW limiter upgrade
- 1 coil AE antenna
- 4 coil AE antenna

Scenarios and Control
- Establish control of: Snowflake, $\bar{n}_e$, Rotation, q_{min}, Divertor P_{rad}



2nd NBI

Cryo-pump, high-Z tile row on cryo-baffle, and partial NCC would be installed in-vessel during ~1 year outage between FY2016 and FY2017

NSTX-U would operate 1st half of FY2016 and 2nd half of FY2017

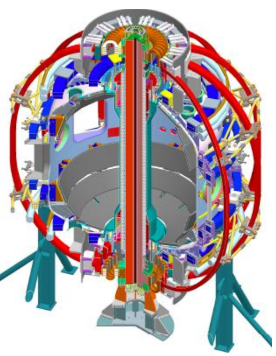
10 year plan tools with 5YP incremental funding

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

New center-stack



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

Boundary Physics
- Lower divertor cryo-pump
- Divertor Thomson
- Diagnostics for high-Z wall studies

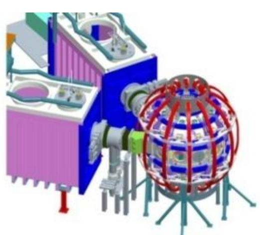
Materials and PFCs
- High-Z tile row on lower OBD
- Lower high-Z divertor
- U + L high-Z divertors
- All high-Z PFCs
- Hot high-Z FW PFCs using bake-out system

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

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

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

2nd NBI



Waves and Energetic Particles
- HHFW limiter upgrade
- 1 coil AE antenna
- 4 coil AE antenna
- HHFW straps to excite EHO
- High-power AE antenna
- Neutron-collimator, fusion source profile array

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 U.S. next-step conceptual design including aspect ratio and divertor optimization

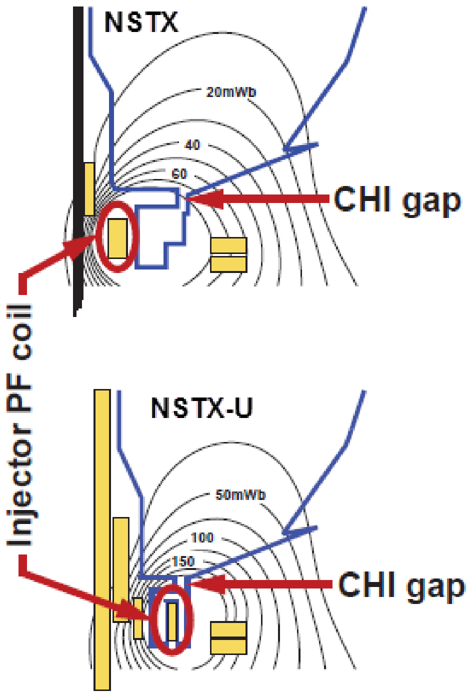
Solenoid-free Start-up

High priority goal for NSTX-U in support of FNSF

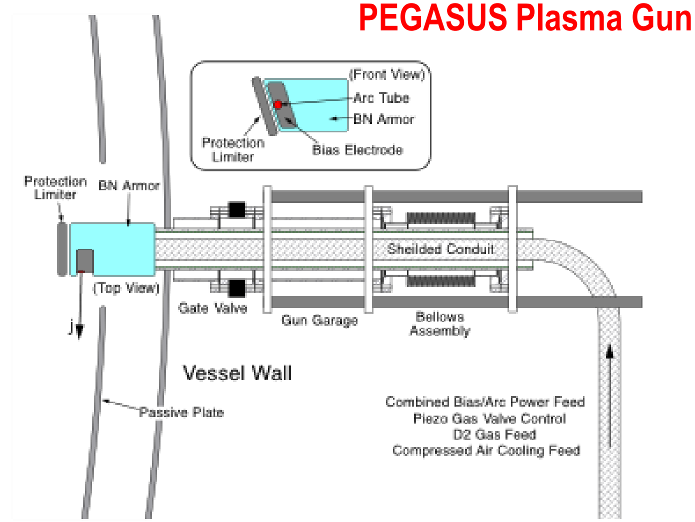
CHI Start-Up

- 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



PEGASUS Point Source



U. Wisconsin

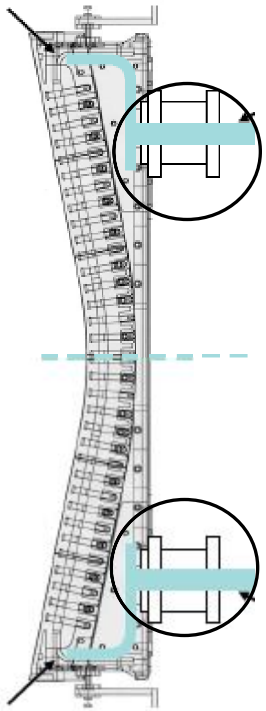
FY 2013-14 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

- 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 current gun for the NSTX-U will be developed utilizing the PEGASUS facility in collaboration with University of Wisconsin.

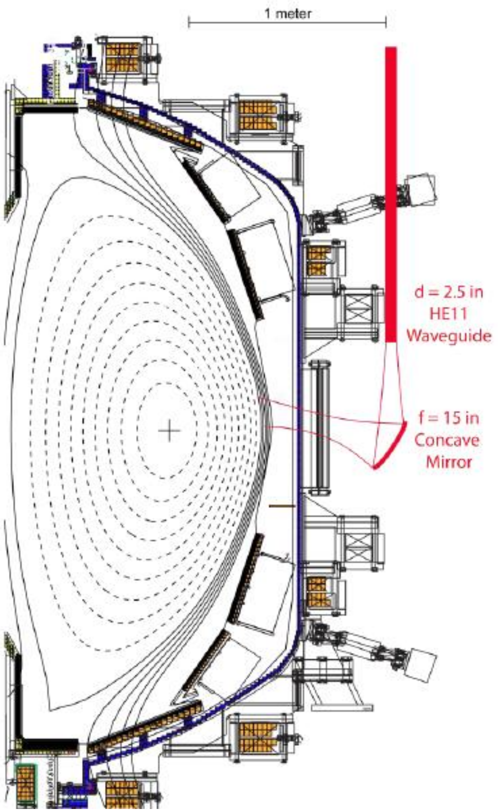
Harden HHFW Antenna Feeds for Disruption Load

A MW-Class 28 GHz ECH System for Non-Inductive Operation

HHFW antenna enhancement in the feedthru area



28 GHz, 1.5 MW Tsukuba Gyrotron

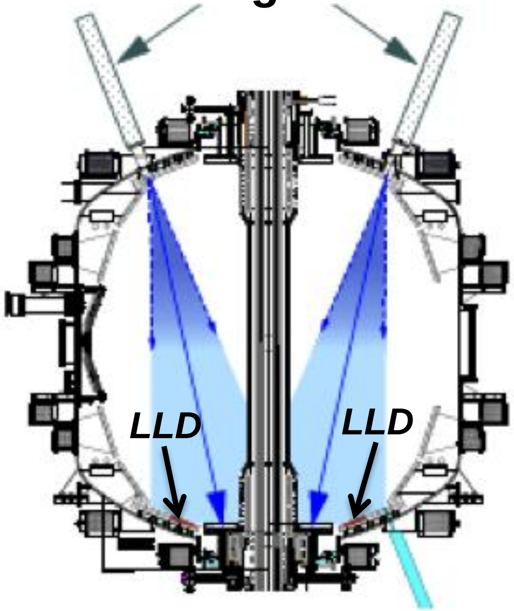


28 GHz ECH/EBWH waveguide and mirror concept

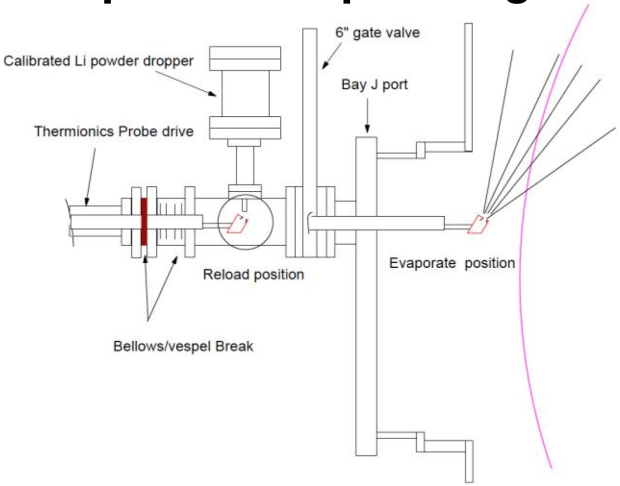
- **FY 2013/14 - HHFW Antenna feed enhancements against disruptive loads**
- **FY 2013/15 – Start MW-class ECH/EBW system conceptual design for non-inductive operations (MOU with Tsukuba University)**

NSTX-U Lithium Capability During Initial Two Years
Lithium Evaporators and Granular Injector

Existing LITERS



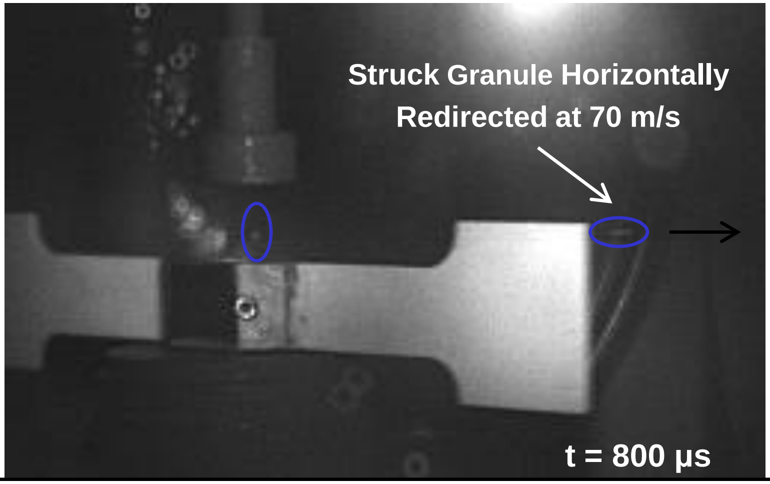
New Upward Evaporating LITER

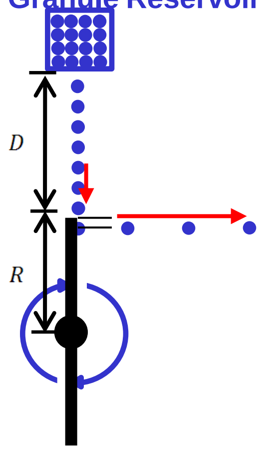


- **Upward Evaporating LITER to increase Li coverage for increased plasma performance**

NSTX-U lithium granular injector for ELM pacing

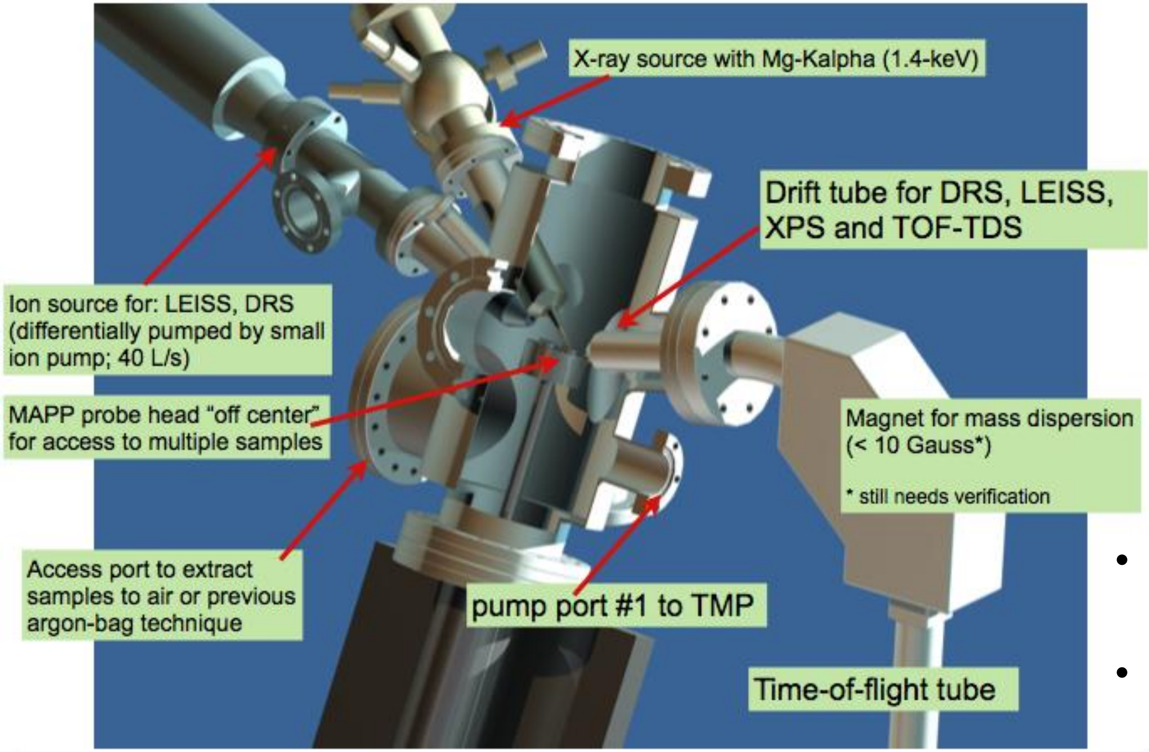
- **High frequency ELM pacing with a relatively simple tool.**
- **ELM pacing successfully demonstrated on EAST (D. Mansfield, IAEA 2012)**

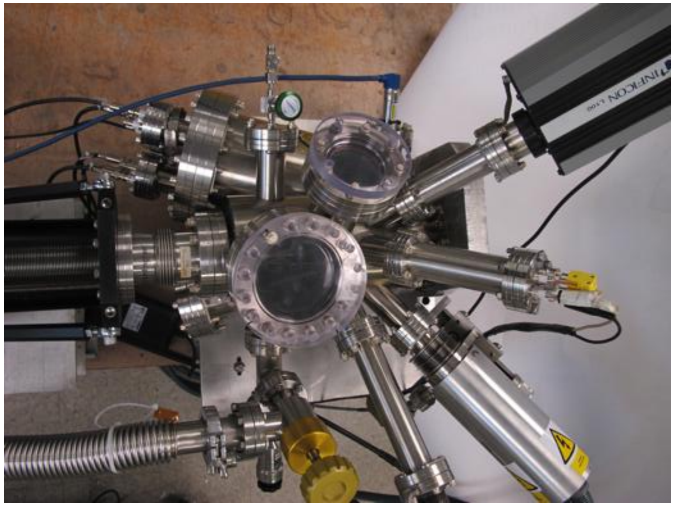




Materials Analysis and Particle Probe – MAPP –
to relate PFC surface conditions and plasma behavior in "real time"

- **PFC analysis after run is difficult to relate to plasma behavior**
  - **Reflects cumulative effect of multiple evaporations and surface compound formation**
  - **Hard to determine determine surface conditions during any specific discharge**
- **MAPP provides in-situ and between-shots solution**
  - **PFC sample can be exposed during shot and withdrawn for between-shots analysis**





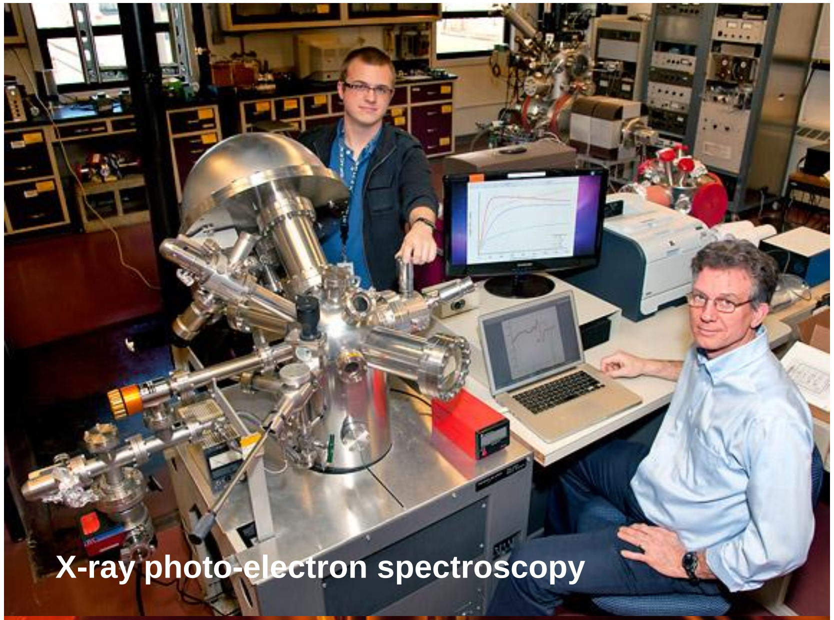
- **MAPP chamber showing diagnostics for sample analysis**
- **MAPP will be tested on LTX during outage**

J.P. Allain (Purdue), R. Kaita, et al.,

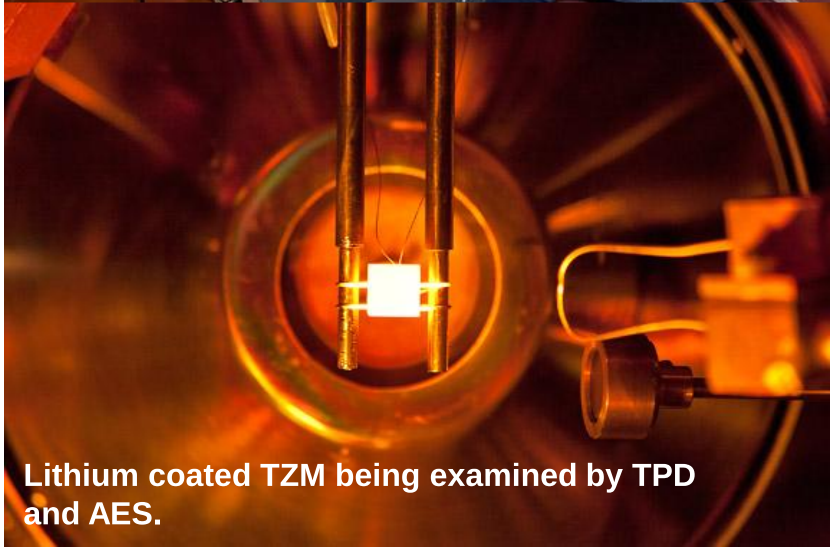
Surface Analysis Facilities to Elucidate Plasma-Surface Interactions

PPPL Collaboration with B. Koel et al., Princeton University

- **The Surface Science and Technology Laboratory (SSTL) with three surface analysis systems and an ultrahigh vacuum deposition chamber.**
- **The Surface Imaging and Microanalysis Laboratory (SIML) with a Thermo VG Scientific Microlab 310-F High Performance Field Emission Auger and Multi-technique Surface Microanalysis Instrument.**
- **Recently solid lithium and Li coated TZM were examined using X-ray photoelectron spectroscopy (XPS), temperature programmed desorption (TPD), and Auger electron spectroscopy (AES) in ultrahigh vacuum conditions and after exposure to trace gases.**
- **Experiment on SSTL determined that lithiated PFC surfaces in tokamaks will be oxidized in about 100 s in the expected NSTX-U vacuum conditions.** (C. H. Skinner et al., PSI_20 accepted to J. Nucl. Mater.)



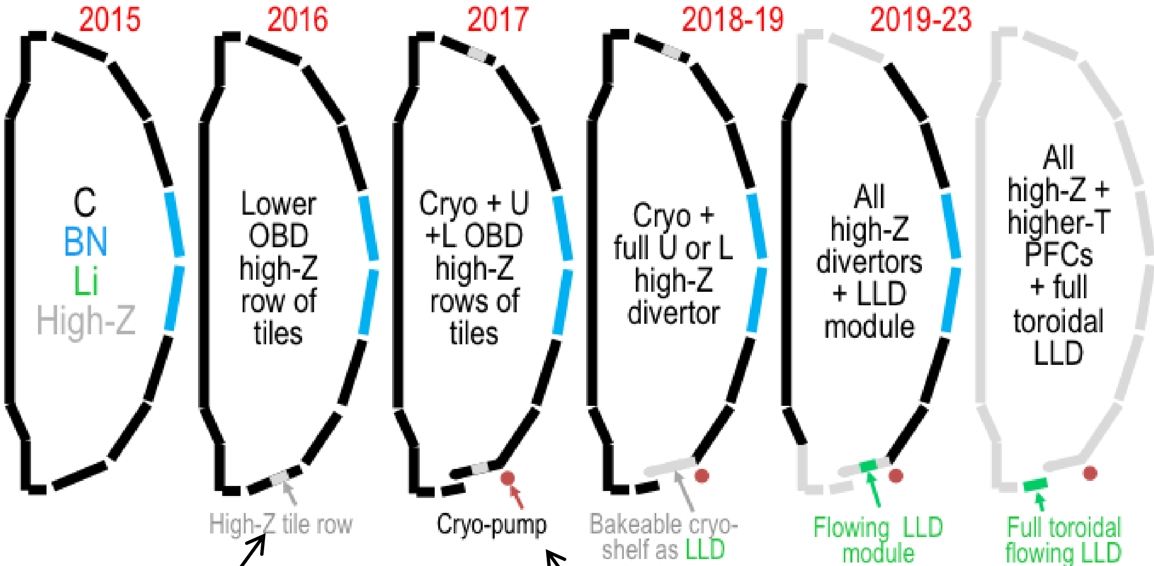
X-ray photo-electron spectroscopy

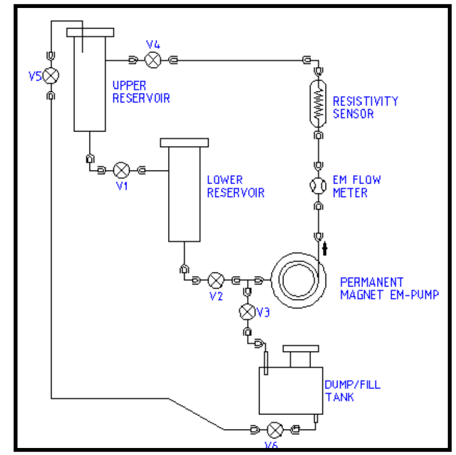


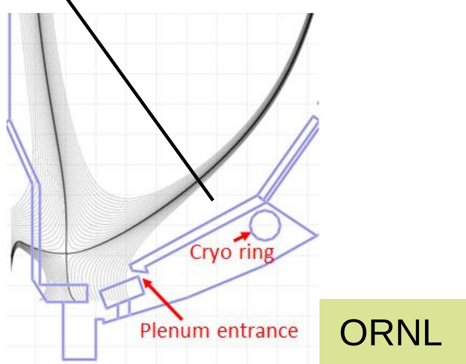
Lithium coated TZM being examined by TPD and AES.

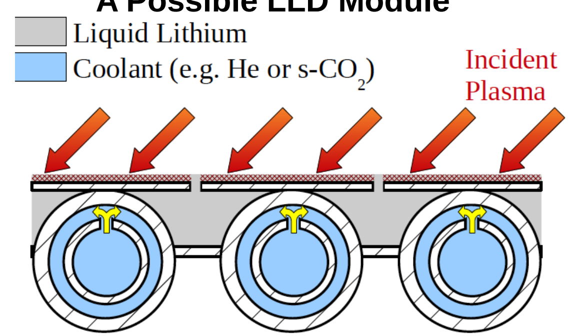
Boundary Facility Capability Evolution

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





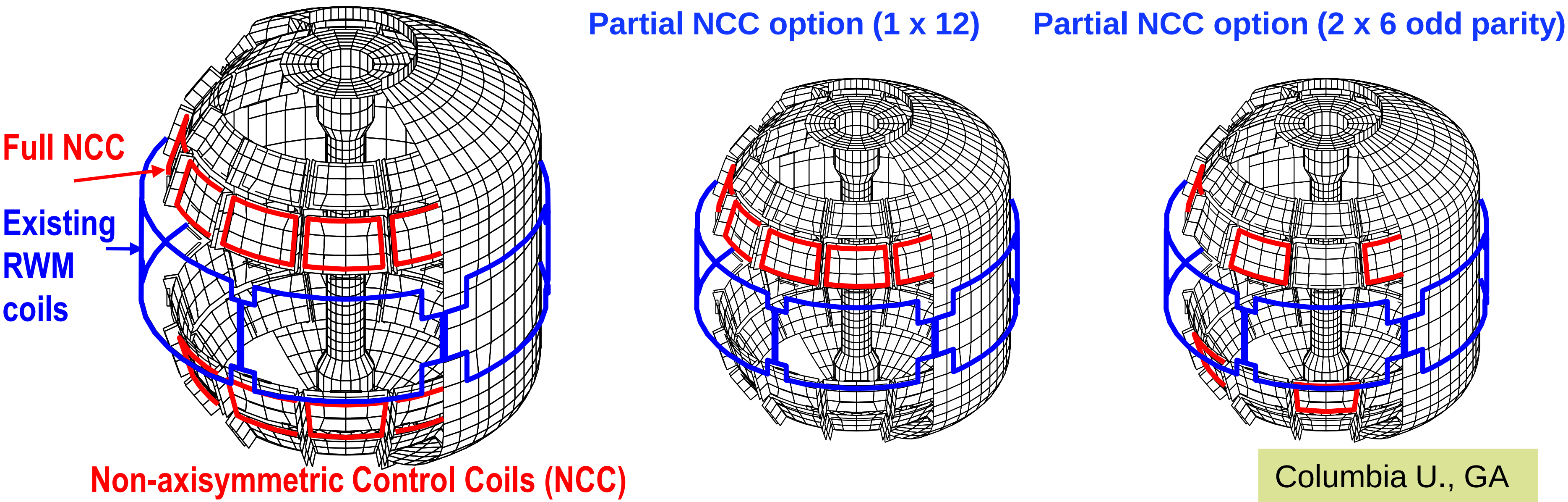




- For FY 13 - 15, advanced divertor upgrade conceptual design work will commence for moly-based PFCs, and closed divertor with cryo-pump.
- For FY 13 - 15, flowing liquid lithium PFC R&D will be conducted at PPPL.

New MHD and Plasma Control Tools for NSTX-U

Sustain β_N and Understand MHD Behavior Near Ideal Limit

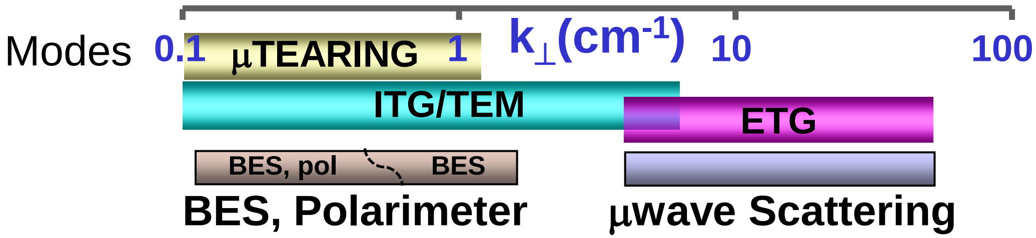


Columbia U., GA

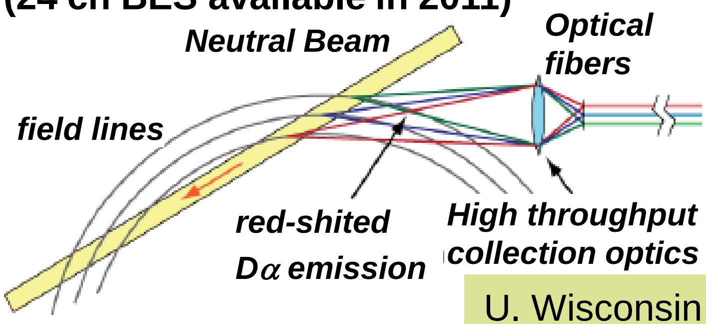
- **NCC can provide expanded RWM, NTV, RMP, and EF selectivity physics studies with more flexible field spectrum (n ≤ 6, or n ≤ 3 depending on set).**
- **2nd 3-channel Switching Power Amplifier (SPA) commissioned in July 2011 to power 6 independent currents in existing midplane RWM and NCC coils.**
- **An extended MHD sensor set to measure theoretically predicted poloidal mode structure and to improve mode control.**
- **A Real-Time Velocity (RTV) diagnostic in a new plasma rotation control system for active instability avoidance by controlling rotation profile.**
- **Multi-poloidal location massive gas injector system will be implemented.**

Transport and Turbulence

BES together with high-k to provide comprehensive turbulence diagnostic



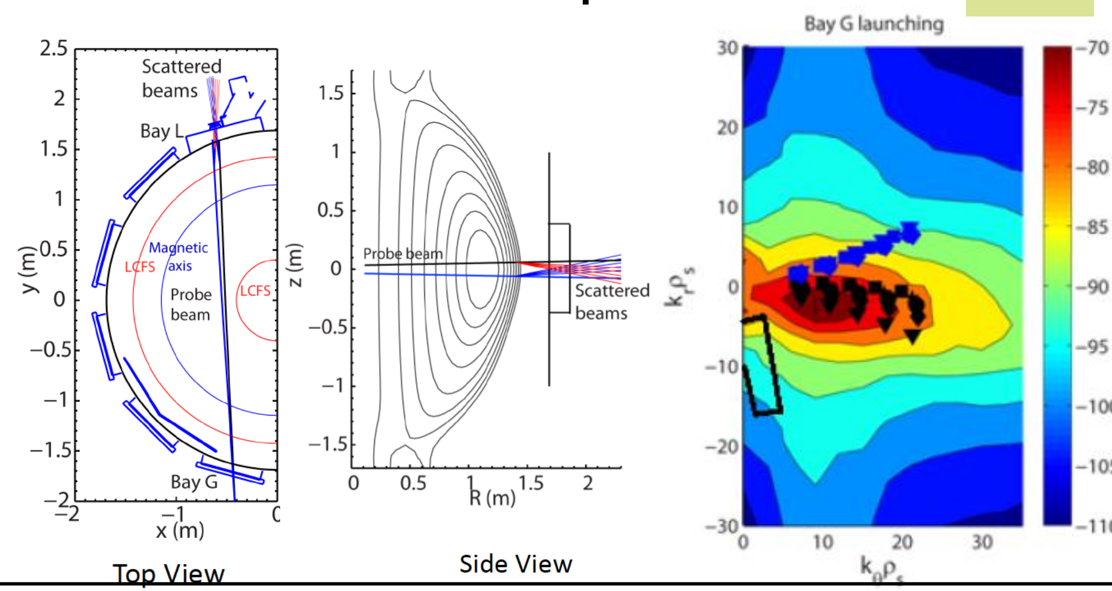
48 ch BES available for NSTX-U
(24 ch BES available in 2011)



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

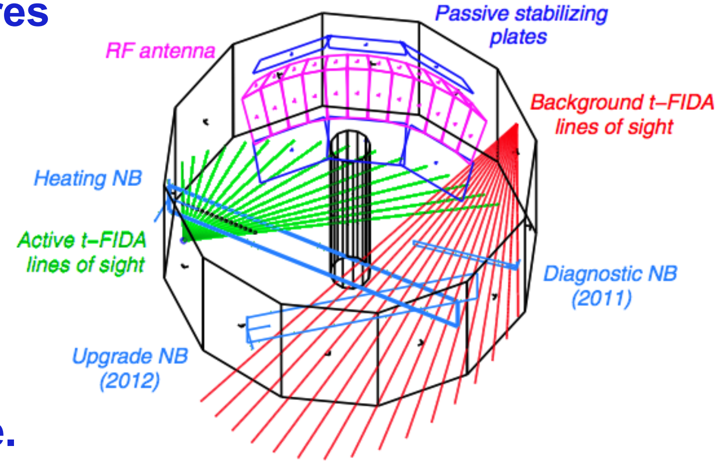
Energetic Particle Research Capabilities
For NBI fast ion transport and current drive physics

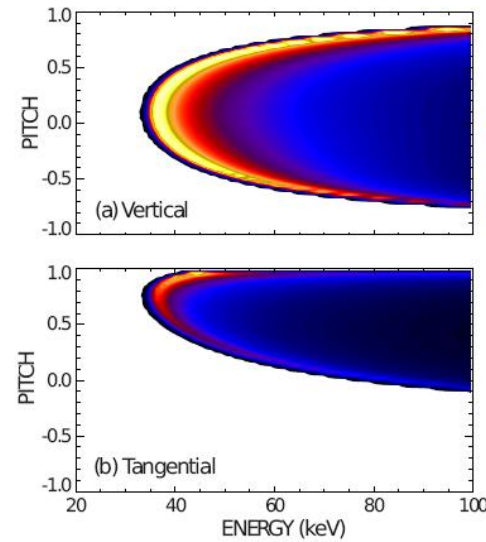
Fast Ion D-Alpha Diagnostics

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.**

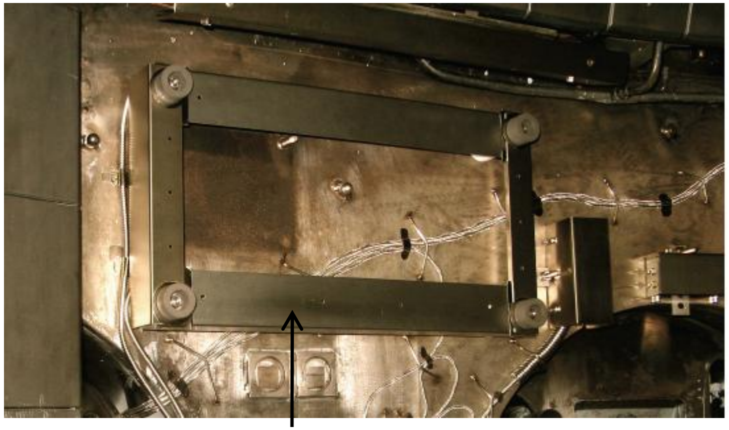
FIDA Views





FY 2013 - 14 Energetic Particle Conceptual Design and Diagnostic Upgrade

- **SS-NPA enhancement due to removal of scanning NPA** UCI
- **Proto-type active TAE antenna**



5-turn radial active TAE antenna installed in 2011

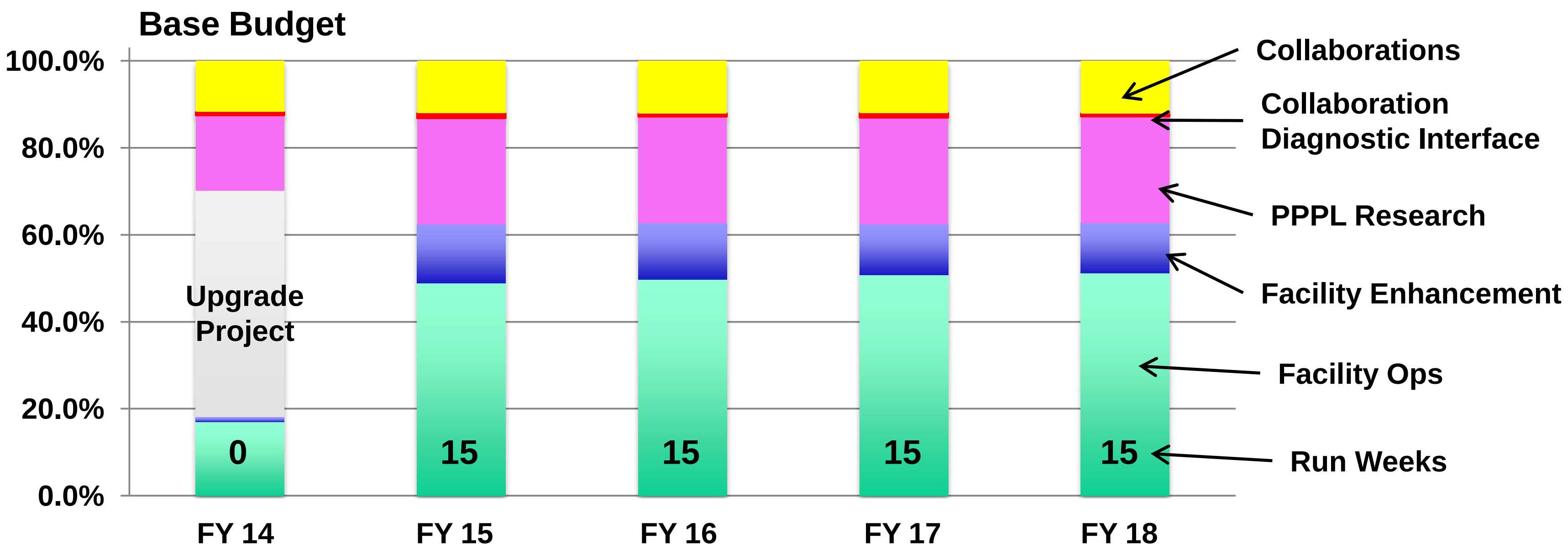
Talk Outline

- FY 2012-13 Operations Summary and Status
- NSTX Upgrade Project Overview
- NSTX-U Facility and Diagnostic Five Year Plans
- **Budget**
- Summary

Base NSTX-U Five Year Plan Budget Summary
Base Budget is Highly Constrained Particularly in FY 14

Base DOE Guidance Budget – Inflation adjusted flat FY 2012 budget

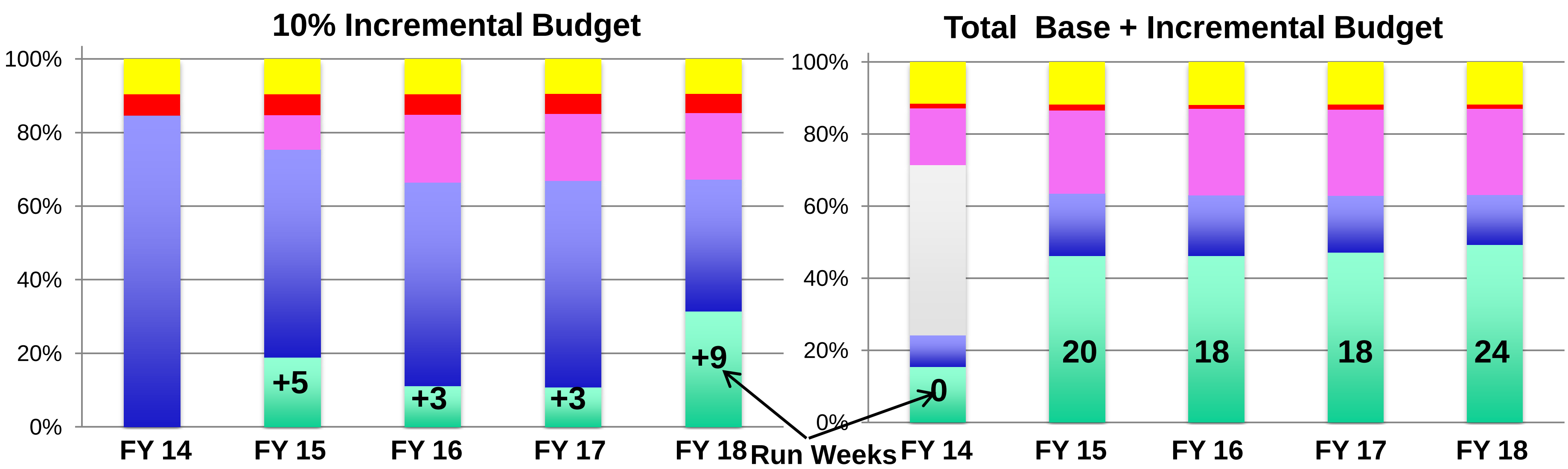
- **FY12 budget + 2.5% inflation**



- In FY 14, the Upgrade Project needs to be completed.
- In FY 14, very little budget for 5 year plan facility enhancement causing difficulty to fund long lead facility enhancements (e.g., ECH, Cryo-pump, and NCC) in a timely manner.
- For FY 15 and beyond, the budget facility operations and PPPL/Collaboration research are based on similar operations and research staff coverage to NSTX.

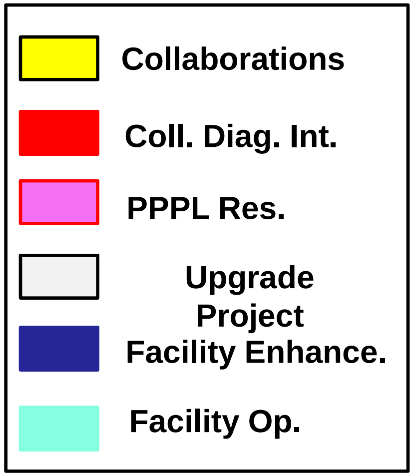
Incremental NSTX-U Five Year Plan Budget Summary

10 % Incremental Budget Greatly Enhances Facility Capability



10% Incremental Budget: 1.1 × (FY2012 + 2.5% inflation)

- Enables timely implementation of the facility / diagnostic capability to support the 5 year research plan. Particularly high leverage in FY 14 prior to the start of NSTX-U operation.
- Dedicates more resources for facility enhancements up front to make them available in a timely manner.
- Increase run weeks to take advantage of enhanced facility capability
- Enhance NSTX-U research capability for both PPPL and collaborators to support increased research activities



Large Budget Cut in FY 2013 Presidential Budget
Serious Impacts on NSTX-U Program and Staff

	FY2012	FY2013	
Budget Cases	*BA*	**BA**	**Incr**
Facility Ops	*$13.2*	$8.5	$12.7
Facility Enhancements	*$0.3*	$0.5	$1.7
CS & 2nd NBI	*$20.4*	$22.7	$24.3
Facility Total	***$34.0***	**$31.7**	**$38.6**
PPPL Research	*$10.5*	$8.3	$9.9
Collab Diag Interf	*$0.4*	$0.3	$0.4
Collaborations	*$6.1*	$5.9	$6.5
Science Total	***$17.0***	**$14.5**	**$16.9**
NSTX Total	***$50.9***	**$46.2**	**$55.5**

- **President's FY 2013 budget represents ~ $ 5M cut from FY 2012.**
- **Sufficient fund was provided for the first half of the year to make planned progress on the NSTX Upgrade Project and retain necessary staff level.**
- **Waiting for the congressional action for the final FY 2013 budget.**
- **Incremental budget was also proposed to support the preparation for the NSTX-U Operation and reduce the Upgrade Project risks.**

- **If President's FY 2013 budget is realized, it will result in a significant loss of both research and technical skills on NSTX-U.**
- **It will delay the NSTX-U research operation by about 6 months.**
- **If the FY 2013 budget can be restored to the FY 2012 level, the staff loss and NSTX-U delay can be prevented provided FY 2014 budget is also maintained at FY 2012 level.**

Optimized NSTX-U Five Year Plan Being Developed
Exciting Opportunities and Challenges Ahead

- **NSTX upgrade outage activities are progressing well**
  - Diagnostics were stored and secured for the upgrade activities.
  - Researchers are working productively on data analysis, collaboration, next five year plan and preparation for the NSTX-U operation.
  - NSTX operations technical staff were shifted to the Upgrade Project tasks in FY 2012 – 13.
  - NSTX Upgrade Project is thus far progressing on budget and on schedule.
- **Exciting 5 Year Plan (FY 2014 – 18) being developed**
  - Aiming to provide necessary data base for FNSF design and construction.
  - Strong contribution to toroidal physics, ITER, and fusion energy development.
  - 10% incremental budget would enable timely implementation of facility capabilities to support the exciting NSTX-U Five Year Plan.
- **Presidential budget guidance will delay the NSTX-U research operations and negatively impact the NSTX-U Five Year Plan**
  - FY 2013 presidential base budget is ~ $ 5 M lower than the FY 2012 budget which will result in loss of research and technical staff and will delay the NSTX-U start date to mid FY 2015.
  - Incremental funding restores the NSTX-U first plasma date accordingly with enhanced capabilities.

Back-up Slides

All of the FY12 Milestones Completed On Schedule

Through Data Analyses, Theory/Modeling, and Collaborations

FY 2012 Facility Joint Research Milestone (S. Kaye – NSTX-U Leader)

Understand core transport and enhance predictive capability: The year-end report written and the submitted to FES.

FY 2012 NSTX Milestones

Research*	Milestone Description	Baseline	Achieved
R(12-1)	Investigate magnetic braking physics to develop toroidal rotation control at low collisionality	Sep 12	Sep 12
R(12-2)	Project deuterium pumping capabilities for NSTX-U using lithium coatings and cryo-pumping	Sep 12	Sep 12
R(12-3)	Simulate confinement, heating, and ramp-up of CHI start-up plasmas	Sep 12	Sep 12

Facility**	Milestone Description	Baseline	Achieved
F(12-1)	Identify possible high priority facility enhancements for the post upgrade operations	Sep 12	Sep 12

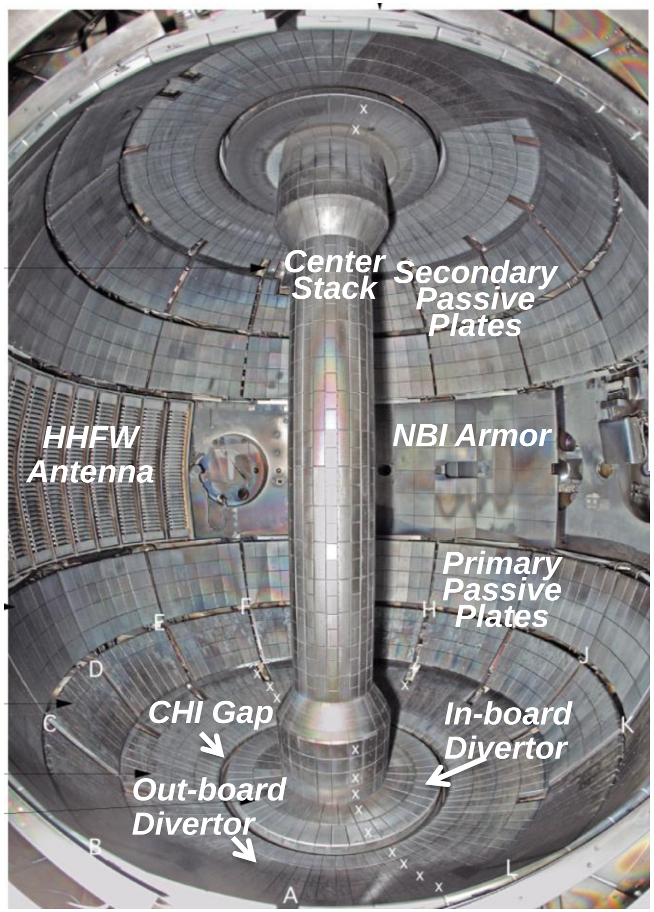
Diagnostics**	Milestone Description	Baseline	Achieved
D(12-1)	Identify possible high priority diagnostic enhancements for the post upgrade operations	Sep 12	Sep 12

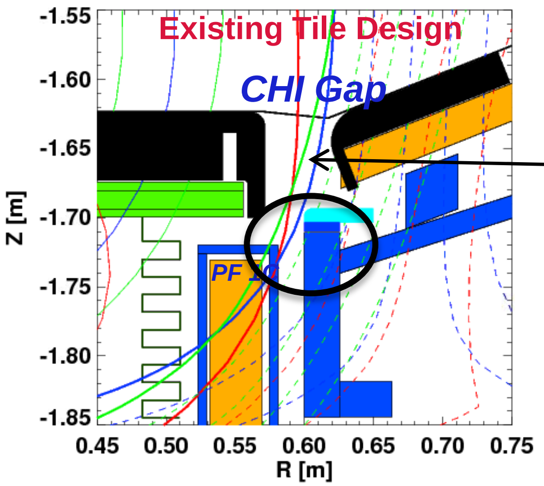
****An important part of the next Five Year NSTX Facility Plan**

- **Diagnostic collaboration grant process was completed in Feb. 2012.**
- **Brainstorming meetings were held for both facility and diagnostic enhancements.**

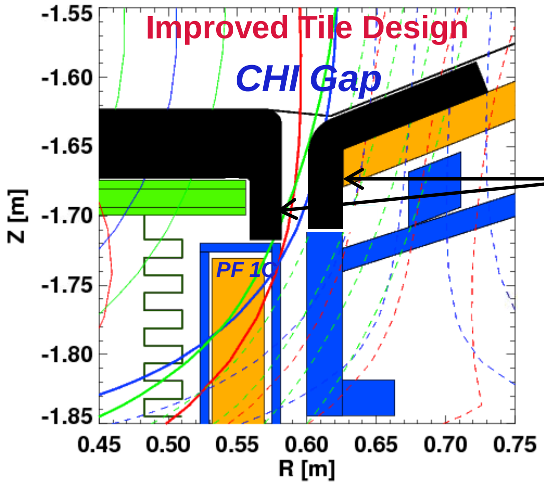
All Graphite PFC Day-1 NSTX-U Configuration

Improved gap tiles to protect PF1C and Exposed SS surfaces





- NSTX-U plasma operation may increase the gap area thermal loading by ~ x 10



- New Gap Overhung Tiles to provides necessary protection

Transrex AC/DC Convertors of the NSTX FCPC

Upgrading of Firing Generators and Fault Detectors

- **Transrex AC/DC Convertors of the NSTX Field Coil Power conversion System (FCPC) provide a pulsed power capability of 1800 MVA for 6 seconds. The modular converter concept of 74 identical (with a paired sections A & B), electrically isolated 6-pulse "power supply sections" was originally used on TFTR, and then adapted to NSTX.**
  - **Many parts from 1984 are nearing end-of-life due to age and wear, replacement parts are rare or unavailable, and that performance can be improved using more modern equipment.**
  - **Precise control of thyrister firing angles by the FCPC firing generators becomes more critical for the new 8-parallel, 130kA TF system configuration.**
  - **Ability to separately control the "A" and "B" sections of each power supply unit allows for more efficient utilization of the 74 available sections.**
  - **The new Firing Generator (FG) will deliver firing pulses with greater resolution, precision, and repeatability, and can receive and process separate commands to the A and B sections**

Status:

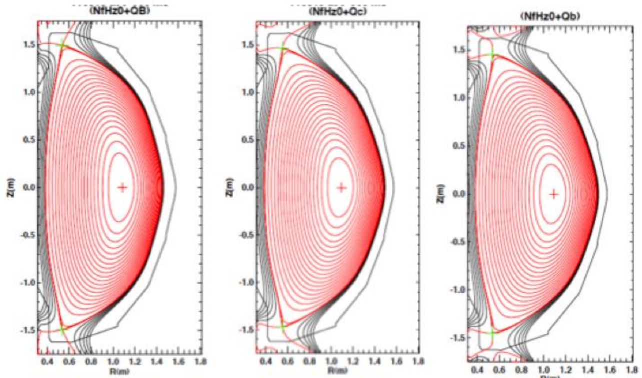
•The prototype FG has been fully tested in a Transrex rectifier, and production units are being fabricated.

•The new Fault Detector (FD) provides improved external interface compatible with the NSTX-U data acquisition system.

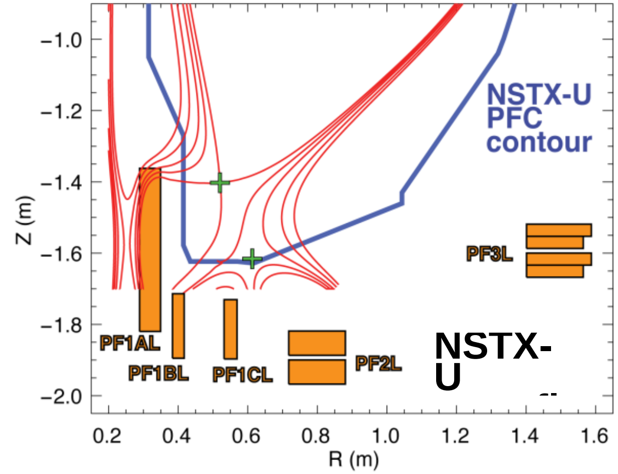
•The FD prototype has been completed in conjunction with the new FG in a Transrex rectifier.

NSTX-U PF Coil Power System Upgrade
Enables up-down symmetric divertor operations

- **The first-year power supply capabilities of NSTX-Upgrade will yield considerable experimental flexibility, namely, up-down symmetric PF-1C coils compared to only at the bottom.**
- **By powering the PF-1A & PF-1C coils, it will be possible to generate up-down symmetric snowflake divertors**
  - **Capability did not exist in NSTX.**
  - **Bipolar PF-1C allows easy comparison between snowflake and standard divertors.**
- **The new configuration should provide better control for the CHI absorber region.**
- **Longer-term, upgrades to the power supply systems may add considerable new capability:**



NSTX-U double-null | NSTX-U double-snowflake-plus | NSTX-U double-snowflake-minus



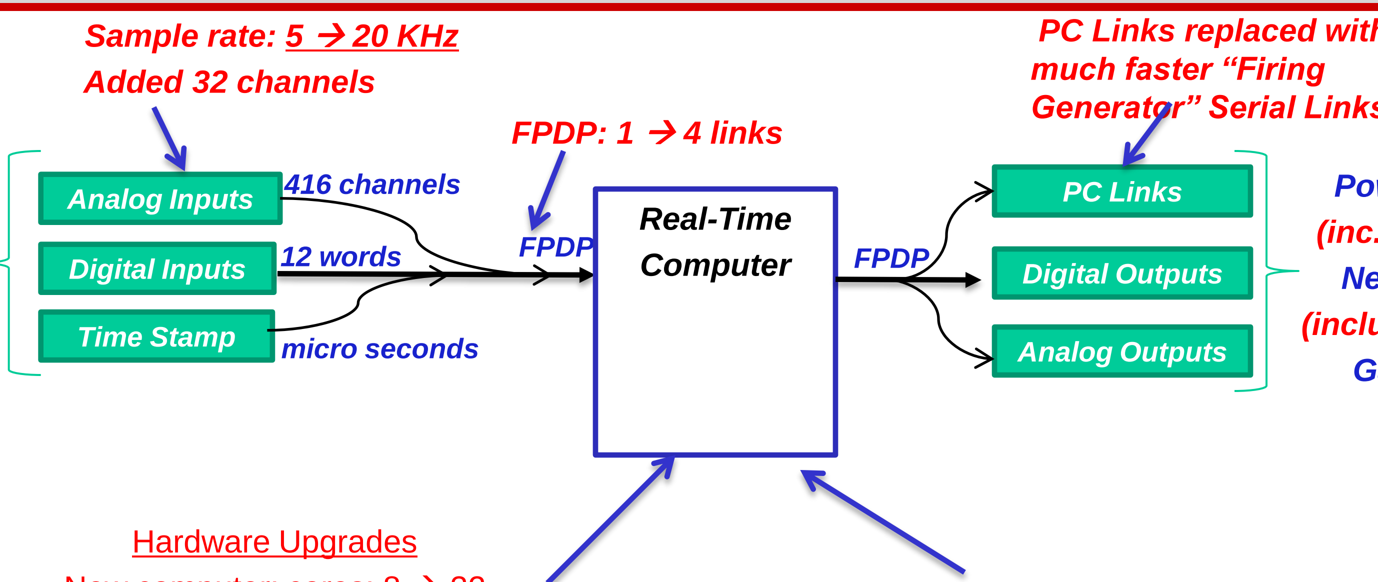
- The PF-2 coils may be upgraded to bipolar operations. This will allow those coils to either create the snowflake divertor or to control the lower plasma-wall gap in the high-triangularity shapes, without changes to the power supply links.

- The PF-1B coil, which will not be powered during initial upgrade operations, may be important for maintaining a steady snowflake divertor through the full OH swing.

NSTX-U Plasma Control System Upgrade

Migration to more modern computer for real-time applications

Analog Inputs
Coil Currents
Power Supplies
Magnetics
(including upgrades)
Neutral Beams
(1st and 2nd BLs)
Gas Injection
Vacuum
Rotation data
Pitch angle data



Power Supplies
(inc. 3 new coils)
Neutral Beams
(including new BL)
Gas Injection

Hardware Upgrades

New computer: cores: 8 → 32

Commercial Linux Real-Time operating system & advanced real-time debug tools.

New quad-port fiber optic FPDP I/O boards.

Software Upgrades

Ported PPPL code and GA PCS to 64-bit.

Generate commands for new firing generators .

Coil Protection (DCPS) functions incorporated in PSRTC.

Numerous new control algorithms.

PCS algorithms re-written using GA format.

PSRTC to be re-written.

Physics Algorithms For Development Once Hardware/Software Infrastructure is Complete

Modified shape control

Snowflake Control

Dud Detection & Soft Landings

Rotation, Current, β_N

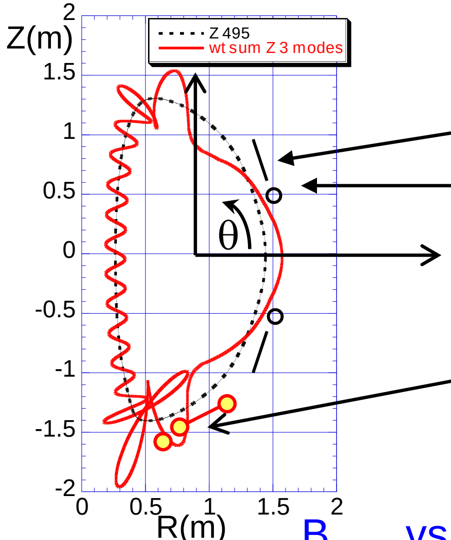
SGI and density control

new diagnostic algorithms

- **A second instance of this real-time computer will be acquired before operation providing a backup for NSTX-U operations and allowing parallel testing of control code during NSTX-U operations.**

3D analysis of extended MHD sensors show significant mode amplitude off-midplane, approaching divertor region

n = 1 ideal eigenfunction for high beta plasma

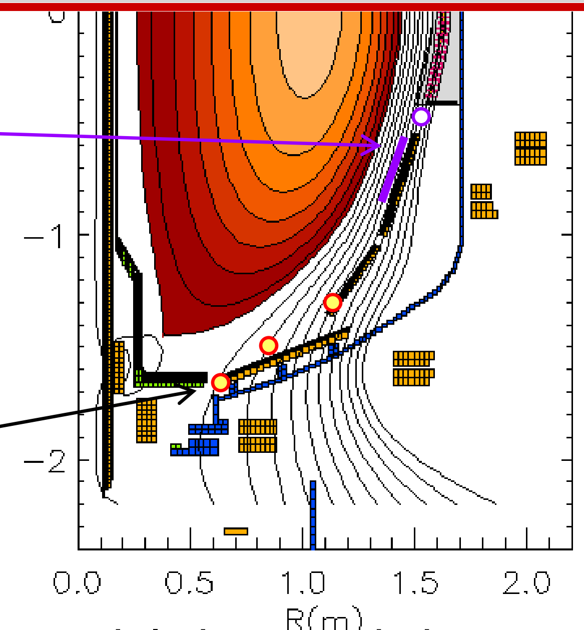


Present sensor locations

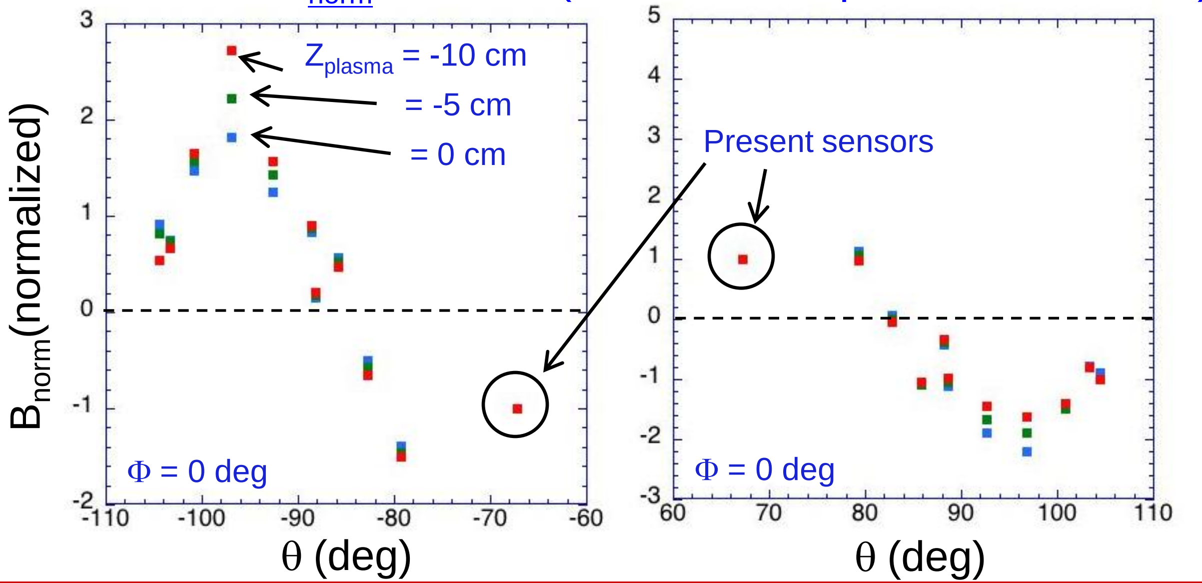
B_R sensors (nominally normal, B_{norm})

B_p sensors (nominally tangential, B_{tan})

New sensor locations (includes one new location above midplane)



B_{norm} vs. theta (normalized to present Br sensors)



- Model characteristics
  - New 3D model of divertor plate
  - 3D sensors with finite toroidal extent; n*A of existing sensors
- Results summary
  - Field amplitude up to factor of 6 larger with new sensors
  - Perturbed field reversals observed with new sensors
  - Signals sufficient with plasma shifted off-midplane