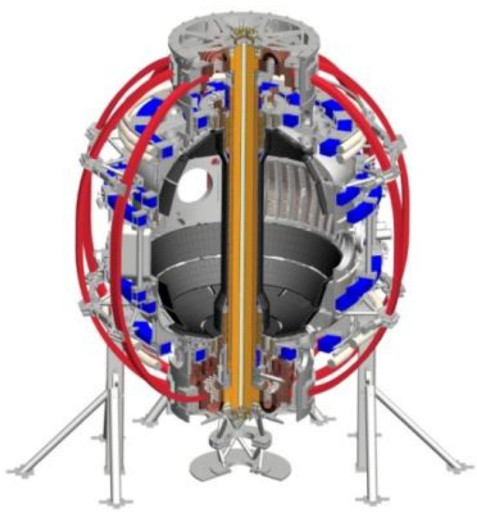
NSTX Project Plans for FY2013-15

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 and Jon Menard

for the NSTX-U Team

FWP 2015 Budget Planning Meeting
Germantown, April 10, 2013



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
Tsukuba U
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
SNU
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Talk Outline

- FY 2012-13 Operations Summary and Status
- FY2013-15 Facility / Diagnostic / Operations Plans
- Budget
- Summary
- Back-up Slides: NSTX-U Facility and Diagnostic Enhancement Detail

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.**

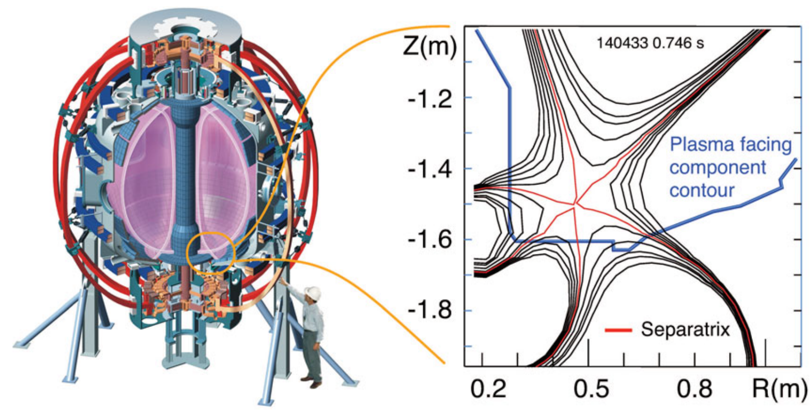


Image courtesy of Vlad Soukhanovskii

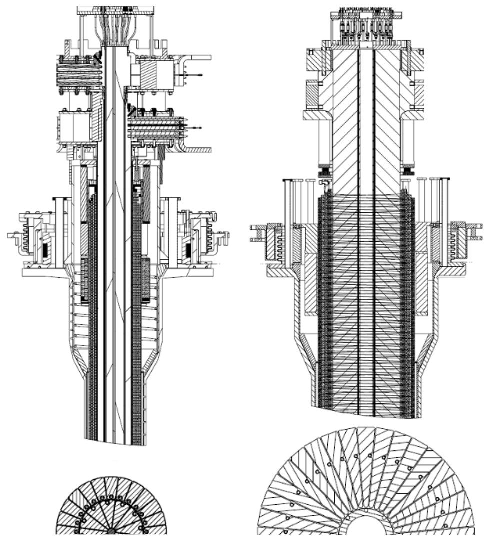
The National Spherical Torus Experiment Device at Princeton Plasma Physics Laboratory (left), and a schematic of magnetic field lines in the snowflake divertor configuration (right).

- **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 56 papers in refereed journals in 2012.**

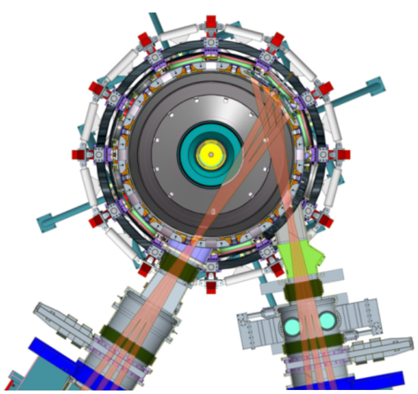
Substantial Increase in NSTX-U Device / Plasma Performance

Higher performance requires facility / infrastructure enhancements

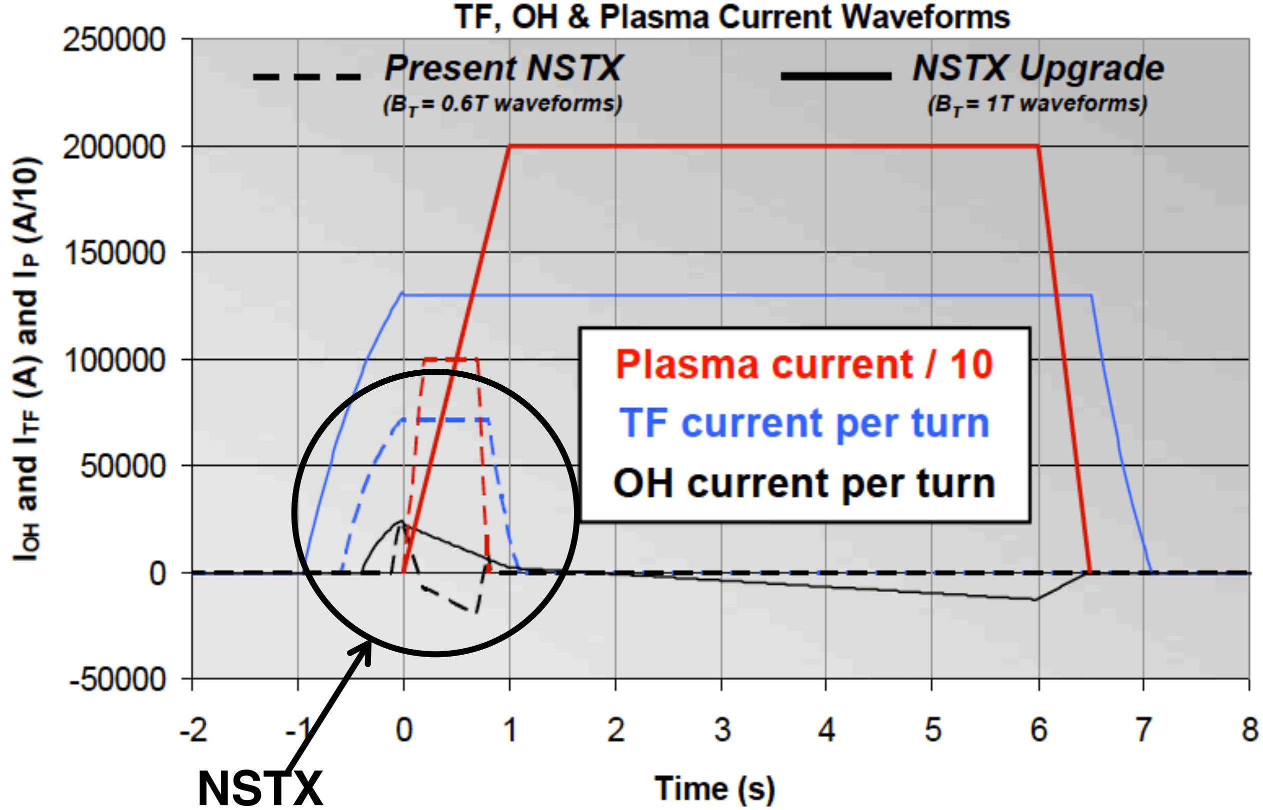
Previous center-stack | New center-stack



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

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.

NSTX-U diagnostics to be installed during first 2 years
Half of NSTX-U Diagnostics Led by Collaborators

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

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

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

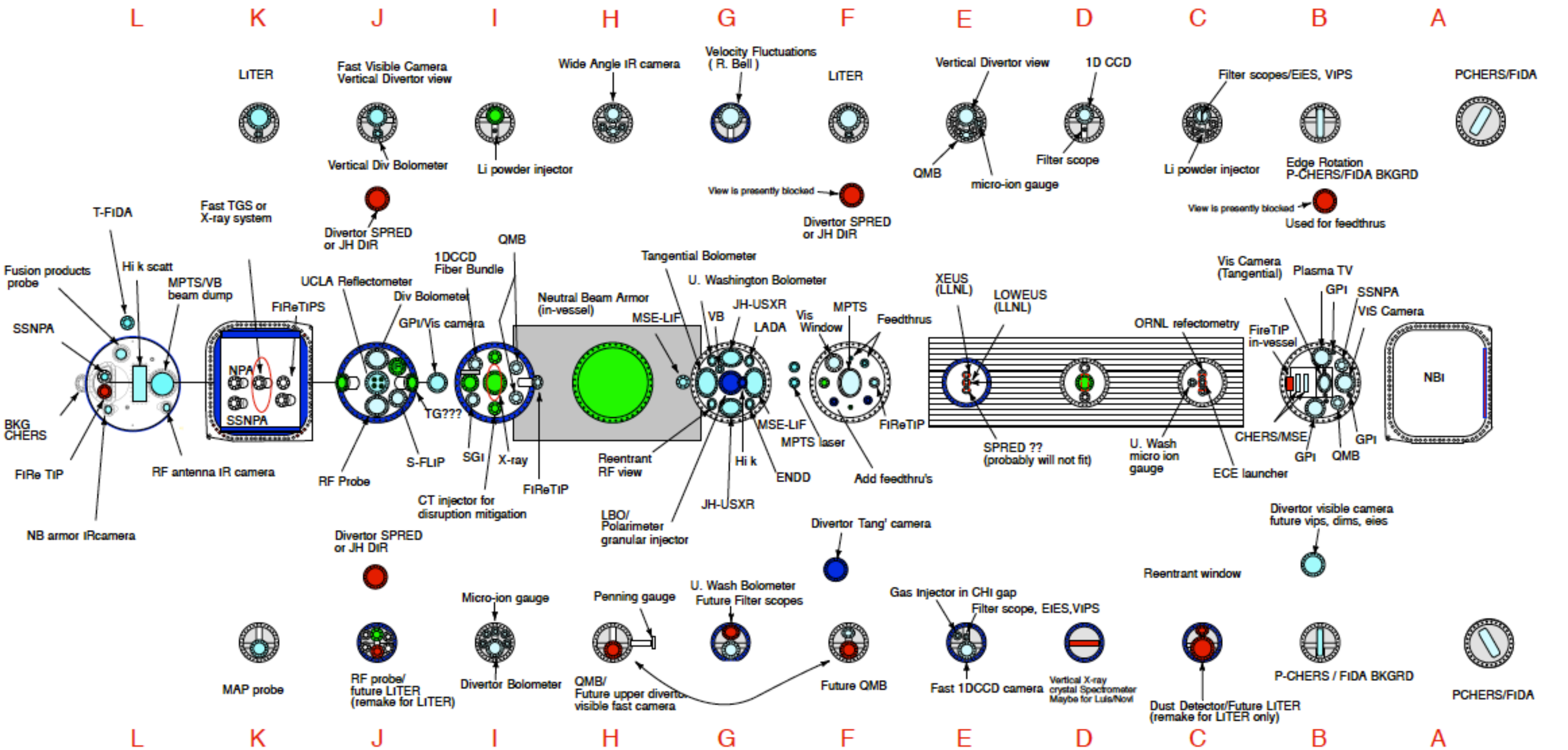
Energetic Particle Diagnostics
- *Fast Ion D_α profile measurement (perp + tang)*
- Solid-State neutral particle analyzer
- Fast lost-ion probe (energy/pitch angle resolving)
- Neutron measurements
- Neutral particle analyzer (single channel)

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*

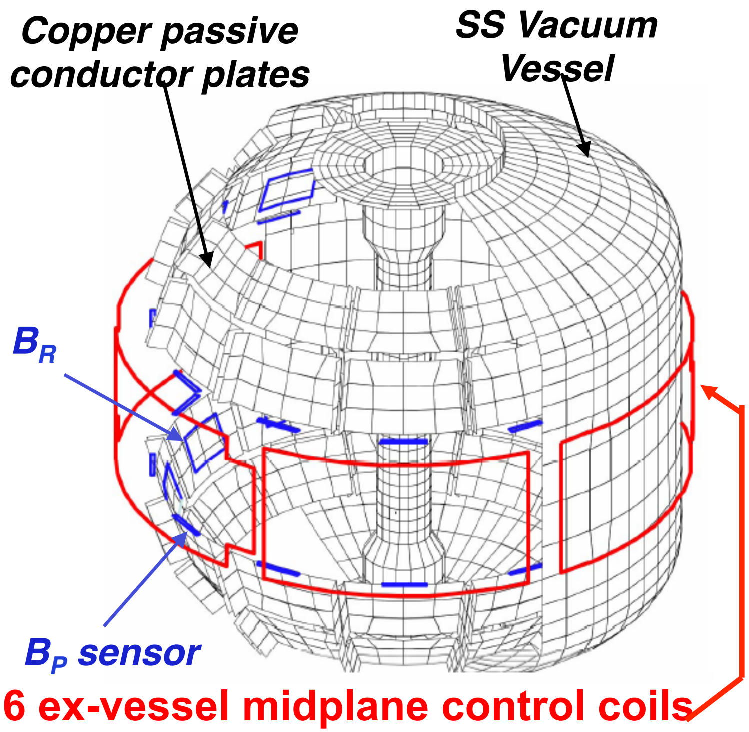
Plasma Monitoring
- FIReTIP interferometer
- Fast visible cameras
- Visible bremsstrahlung radiometer
- Visible and UV survey spectrometers
- VUV transmission grating spectrometer
- Visible filterscopes (hydrogen & impurity lines)
- Wall coupon analysis

New capability

NSTX-U facility/diagnostics port assignment
Port flanges designed and ordered



New MHD and Plasma Control Tools Available for NSTX-U
Sustain β_N and Understand MHD Behavior Near Ideal Limit



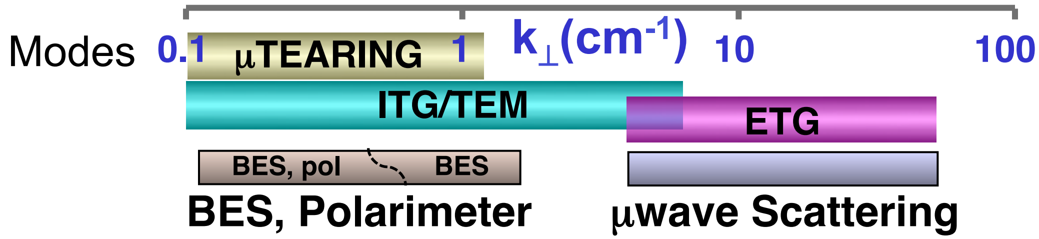
2nd 3-channel Switching Power Amplifier (SPA) commissioned in July 2011 powers independent currents in six EFC/RWM coils for simultaneous control of n = 1, 2, 3 field harmonics

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

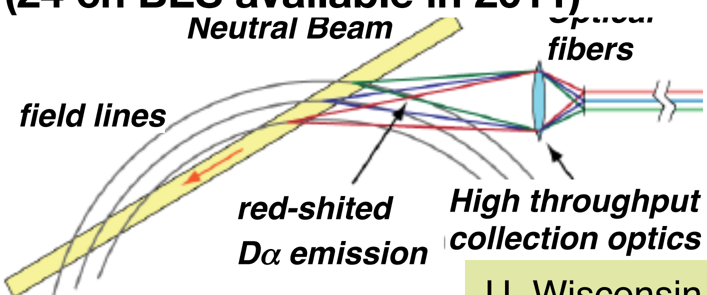
- A Real-Time Velocity (RTV) diagnostic (commissioned in 2011) to be incorporated into the plasma control system for feedback control of the plasma rotation profile using the NBI and non-resonant magnetic braking as the actuators.
- A new Plasma Control System (PCS) platform with increased capabilities (e.g., 64-bit operating system) to support increased NSTX-U rt-control requirements.
- Disruption mitigation system with massive gas injection at multiple poloidal location.

Transport and Turbulence

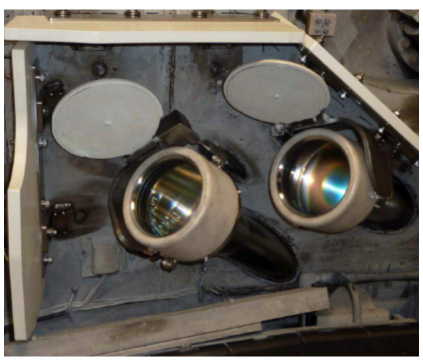
BES together with high-k to provide comprehensive turbulence diagnostic



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

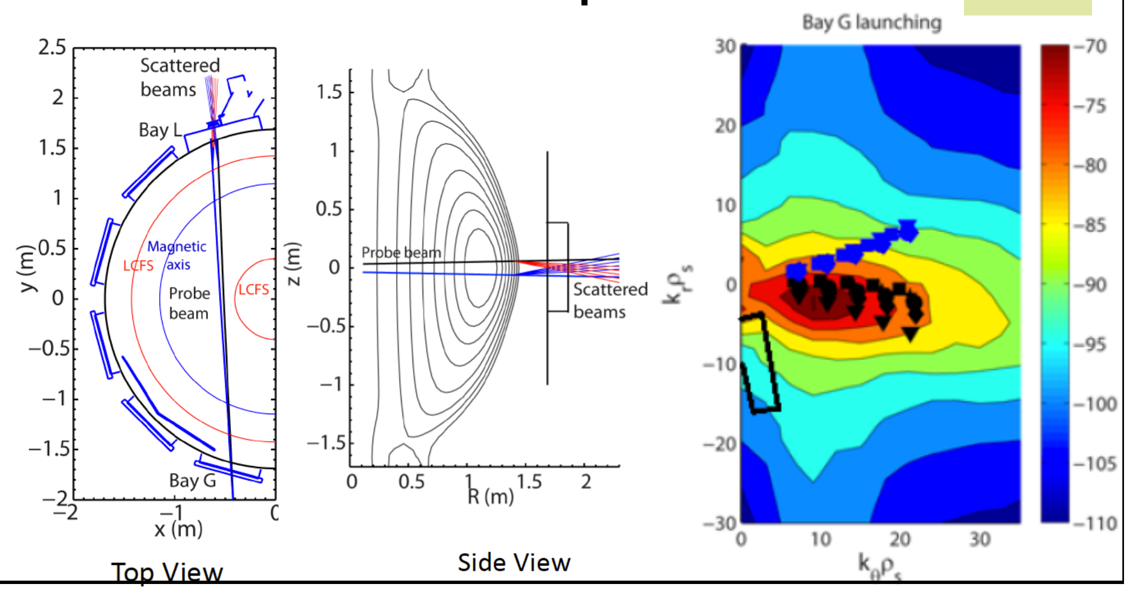


U. Wisconsin



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

UCD

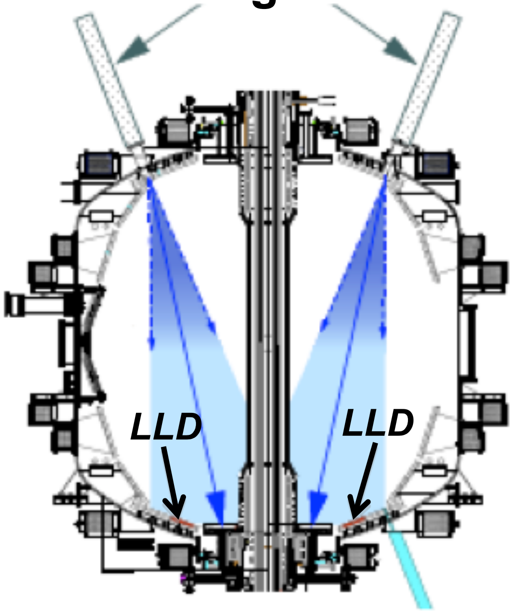


A 288 GHz polarimetry system for magnetic fluctuation measurements is being tested on DIII-D.

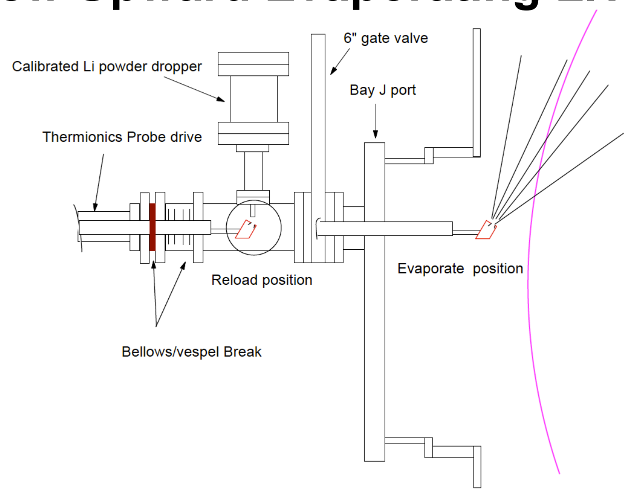
UCLA

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

Existing LITERS



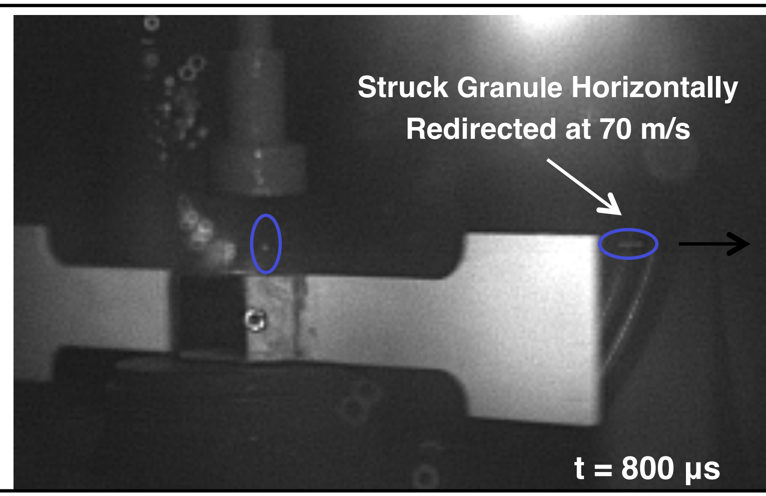
New Upward Evaporating LITER

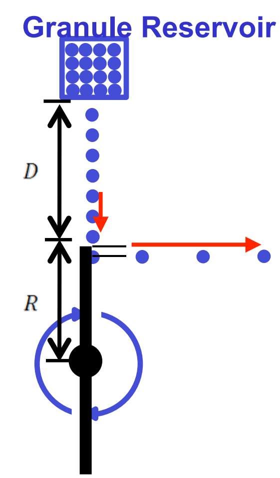


- Upward Evaporating LITER to increase Li coverage for increased plasma performance

NSTX-U lithium granular injector for ELM pacing

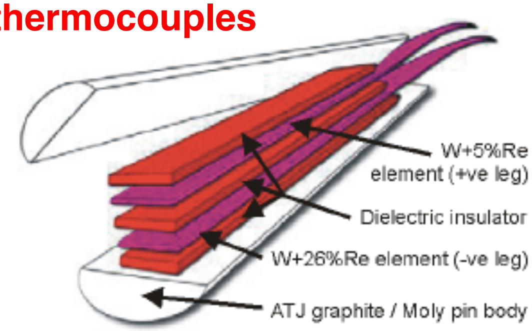
- High frequency ELM pacing with a relatively simple tool.
- ELM pacing successfully demonstrated on EAST (D. Mansfield, IAEA 2012)



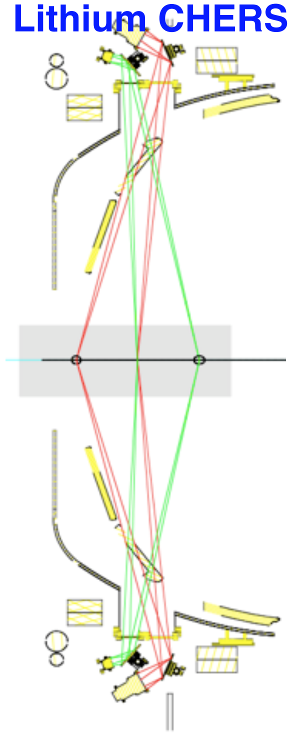


Enhanced Capability for PMI Research
Multi-Institutional Contributions

Divertor fast eroding thermocouples

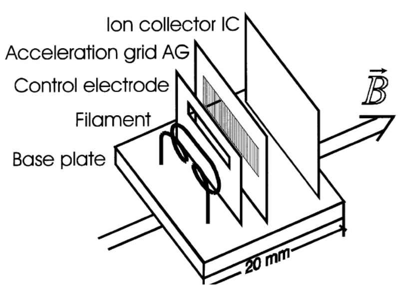


Lithium CHERS



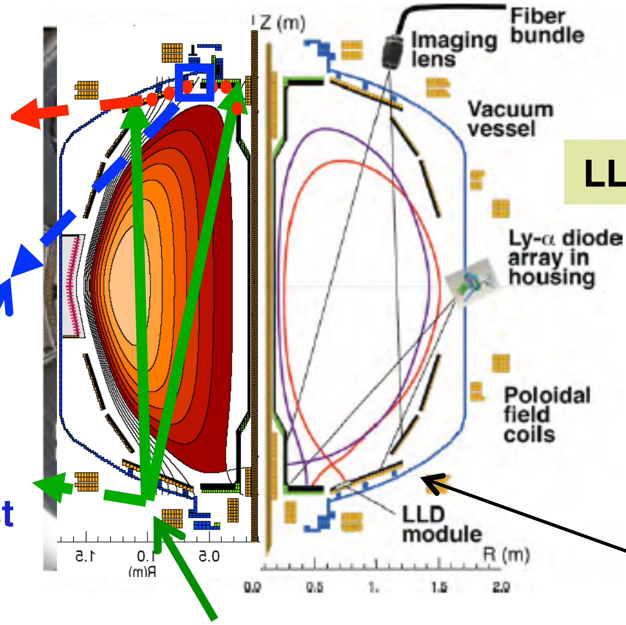
ORNL

Divertor fast pressure gauges

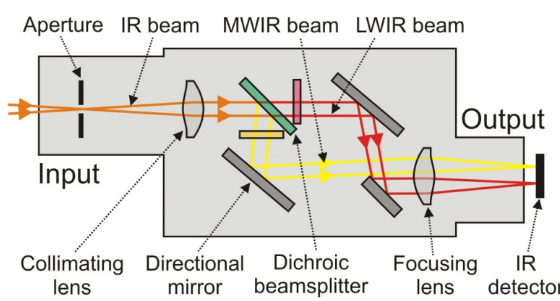


Divertor Imaging Spectrometer

LLNL

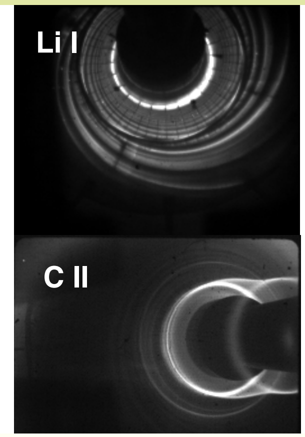


Dual-band fast IR Camera

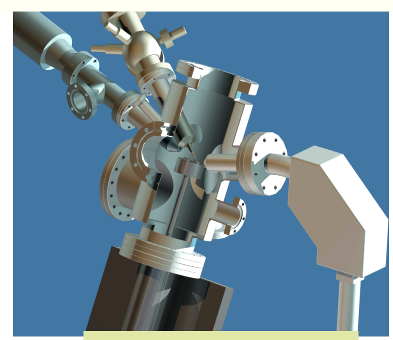


Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K



MAPP probe for between-shots surface analysis



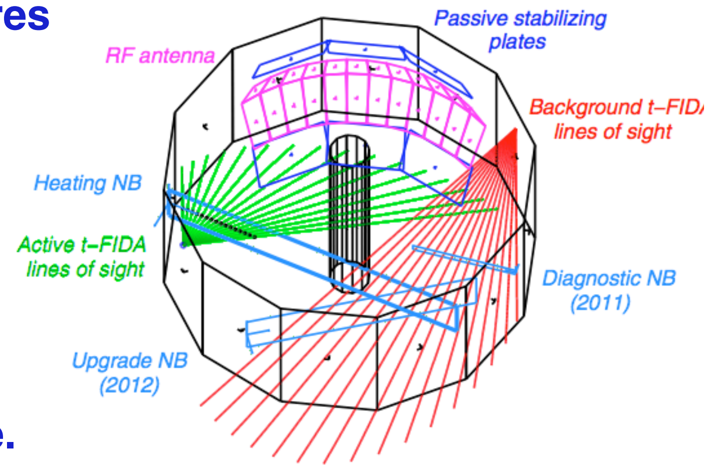
Purdue U.

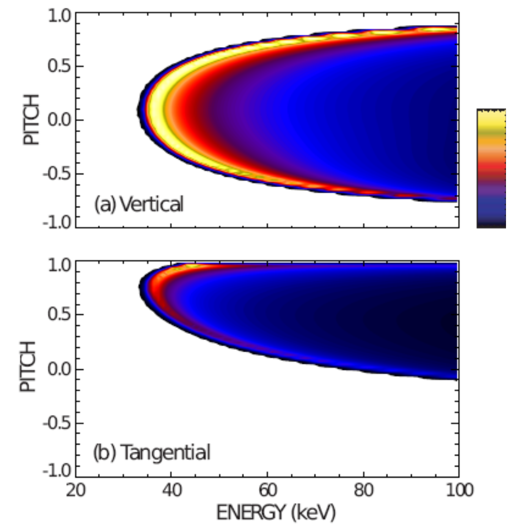
Energetic Particle Research Capabilities
For NBI fast ion transport and current drive physics

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.

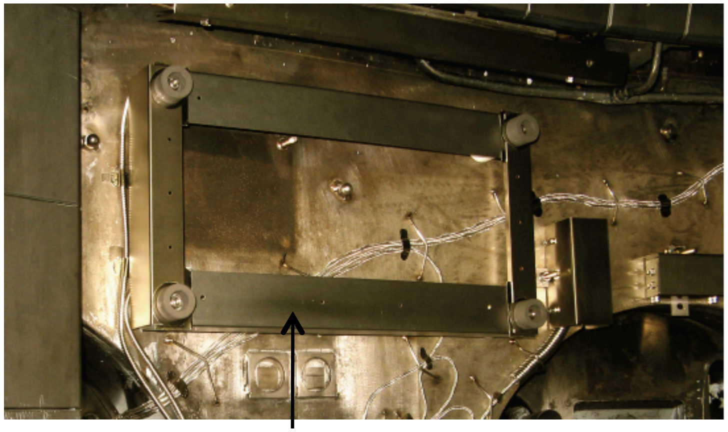
FIDA Views





FY 2013 - 14 Energetic Particle Conceptual Design and Diagnostic Upgrade

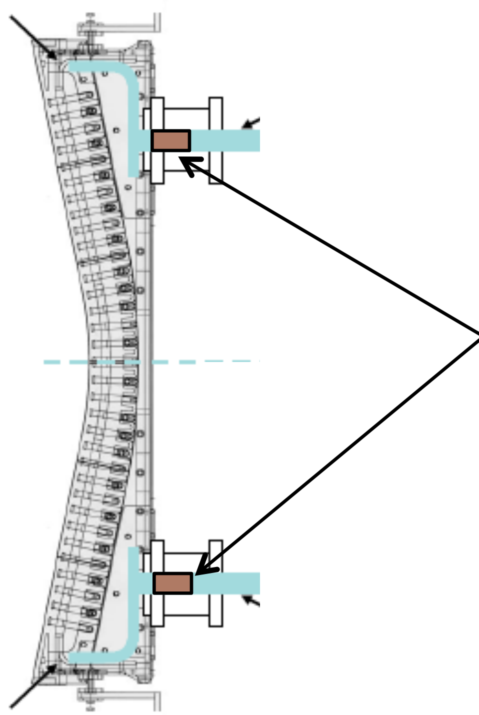
- SS-NPA enhancement due to removal of scanning NPA UCI
- Proto-type active TAE antenna



5-turn radial active TAE antenna installed in 2011

HHFW Antenna Refurbishment
To Withstand 4x Higher Disruption Loads

Double Feed Antenna



- HHFW power system to undergo structural enhancement against disruption loads in the feedthru area

A compliant section being designed

Photo courtesy of C-Mod Group

- FY 2013-2014 – Perform necessary modification
- FY 2014-2015 – Start MW-class ECH/EBW engineering design for non-inductive operations (US-Japan)

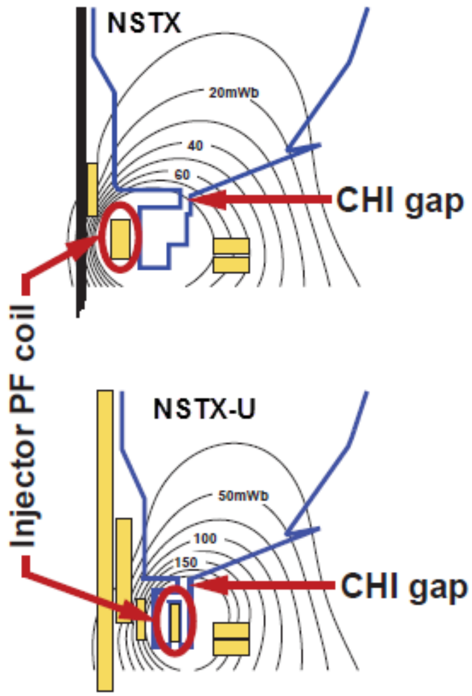
Solenoid-free Start-up

High priority goal for NSTX-U in support of FNSF

CHI Start-Up

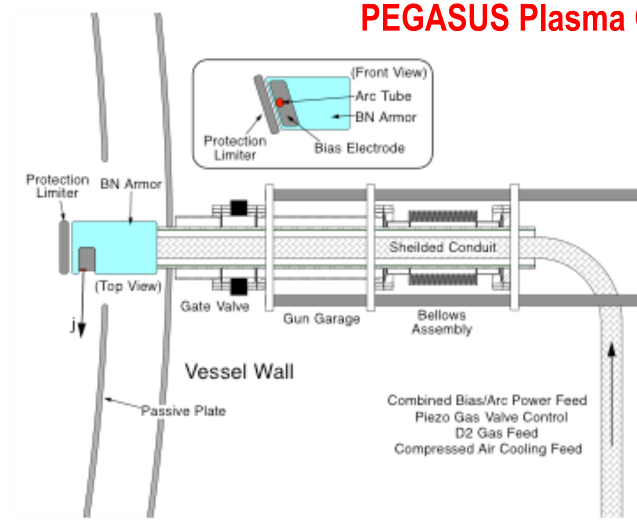
- Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX
- NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation

U. Washington



Point Source Being Developed

PEGASUS Plasma Gun



U. Wisconsin

FY 2013-15 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

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

Plans to Rapidly Recover Physics Operations Capabilities
NSTX-U Operations Team Similar to NSTX

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

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

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

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

~September 2014

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

~ 1 Month

Rayleigh/Raman Scattering for n_e & T_e calibrations.

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

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

Formulating Strategy Toward Full NSTX-U Parameters

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

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

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

* Requires motor generator weld crack repair

NSTX FY 2015 FWP Budget Summary ($M)

Base budget adversely impacts NSTX-U research operation

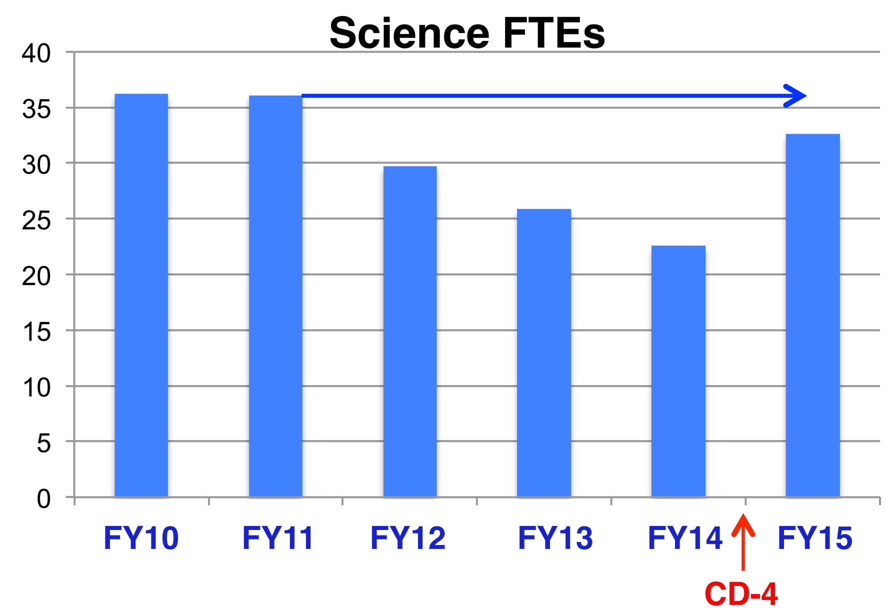
	FY2012	FY2013		FY2014		FY2015			
Budget Cases	BA	BA	Incr	Base	15% Incr	Warm Shutdown	Base	15% Incr	Optimal
Run Weeks	0	0	0	0	0	0	0 - 6	16	20
Facility Ops	$13.21	$8.82	$9.91	$8.44	$12.18	$20.48	$23.38	$25.89	$26.79
Facility Enhancements	$0.30	$0.80	$1.72	$0.04	$0.71	$0.00	$0.00	$1.75	$5.01
CS & 2nd NBI	$20.50	$22.80	$22.80	$23.17	$23.17	$3.79	$3.79	$3.79	$3.79
Facility Total	**$34.01**	**$32.42**	**$34.43**	**$31.65**	**$36.06**	**$24.27**	**$27.17**	**$31.43**	**$35.59**
PPPL Research	$10.48	$7.62	$8.96	$8.50	$10.80	$11.50	$12.63	$13.62	$14.10
Collab Diag Interf	$0.40	$0.25	$0.44	$0.2	$0.60	$0.30	$0.60	$0.70	$0.80
Collaborations	$6.10	$5.86	$5.86	$5.80	$6.40	$5.80	$5.80	$6.60	$7.26
Science Total	**$16.98**	**$13.73**	**$15.26**	**$14.55**	**$17.60**	**$17.90**	**$19.03**	**$20.92**	**$22.16**
NSTX-U Total	**$50.99**	**$46.15**	**$49.69**	**$46.20**	**$53.86**	**$41.87**	**$46.20**	**$52.35**	**$57.75**

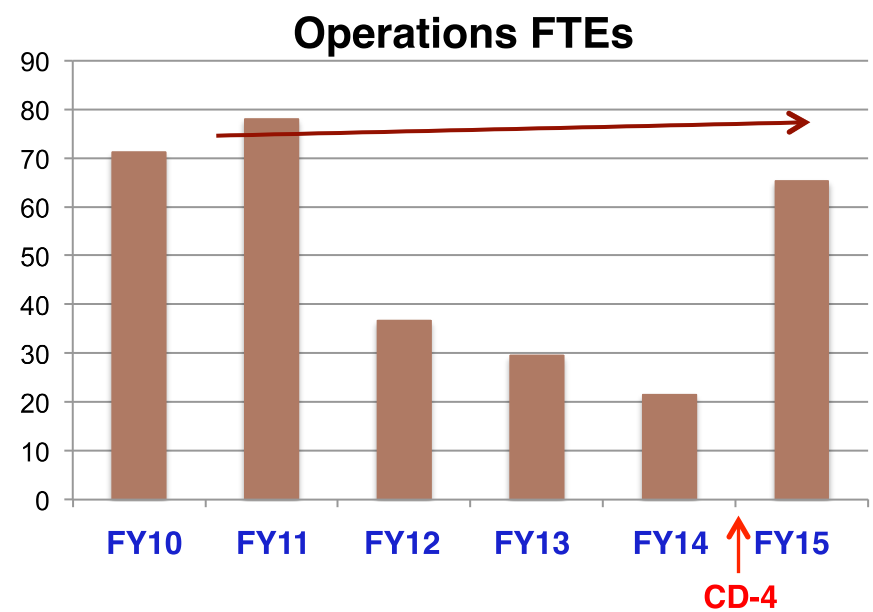
- President's base budget results in significant loss of operations and research staff and delays NSTX-U full research operation by ~ one year to FY 2016.
- FY 2014 and 2015 incremental case is equivalent to inflation adjusted FY 2012 budget case and it will restore the staff and the NSTX-U operation start to FY 2015.
- Optimal scenario will enable full NSTX-U operation and implementation of the five year plan major facility and diagnostic enhancements.
- Warm shutdown scenario completes CD-4 and put the NSTX-U facility in warm shut down mode with essential operations and research staff to enable rapid restart of the plasma operation.

NSTX-U FY 2015 FWP Manpower Summary

Base budget adversely impacts NSTX-U research operation

	FY 2010	FY 2011	FY 2012	FY 2013		FY2014		FY 2015			
	Actual	Actual	Actual	Base	Incrementals	Base	Incrementals	Warm SD	Base	Incrementals	Optimum
Run Weeks	15	4	0	0	0	0	0	0	0-6	16	20
Science	36.2	36.1	29.7	25.9	28.7	22.6	31.3	27.9	32.6	36.8	39.3
Operations	71.1	78.03	36.7	29.5	37.2	21.5	42.3	58.6	65.3	72.2	74.2
Upgrade Project	29	25.9	69.3	70.3	70.3	73.4	73.4	11.9	11.9	11.9	11.9
Other Upgrades	13.3	7.8	0.8	0	0	0	0	0	0	8.5	18.3
Total FTEs	149.6	147.83	136.5	125.7	136.2	117.5	147	98.4	109.8	129.4	143.7



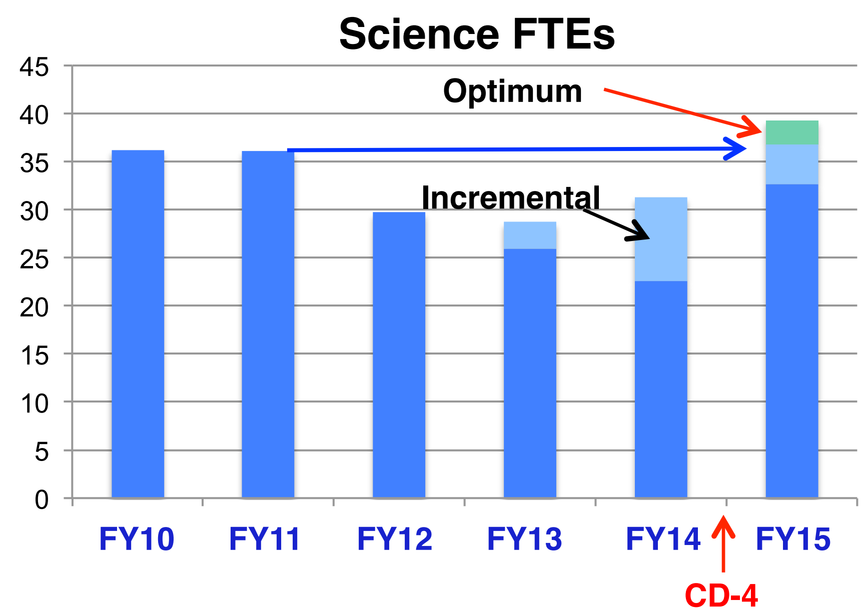


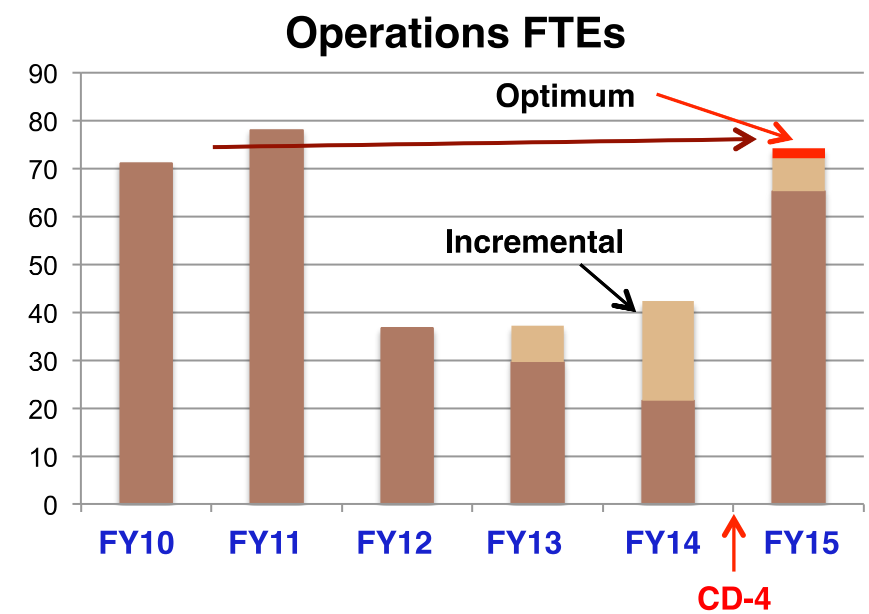
FY13 - FY15 base case delays the NSTX-U full research start to FY 2016 due to severe loss of operations and research staff.

NSTX-U FY 2015 FWP Manpower Summary

Incremental budget enables timely research operation

	FY 2010	FY 2011	FY 2012	FY 2013		FY2014		FY 2015			
	Actual	Actual	Actual	Base	Incrementals	Base	Incrementals	Warm SD	Base	Incrementals	Optimum
Run Weeks	15	4	0	0	0	0	0	0	0-6	16	20
Science	36.2	36.1	29.7	25.9	28.7	22.6	31.3	27.9	32.6	36.8	39.3
Operations	71.1	78.03	36.7	29.5	37.2	21.5	42.3	58.6	65.3	72.2	74.2
Upgrade Project	29	25.9	69.3	70.3	70.3	73.4	73.4	11.9	11.9	11.9	11.9
Other Upgrades	13.3	7.8	0.8	0	0	0	0	0	0	8.5	18.3
Total FTEs	149.6	147.83	136.5	125.7	136.2	117.5	147	98.4	109.8	129.4	143.7





FY13 - FY15 increment preserves operations and research staff needed to enable NSTX-U full research operation start in FY 2015 after CD-4.

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

	FY13I	FY14I	FY15I
Research Staff	$1.1	$2.1	$1.0
Increased Collaborator Funding		$0.6	$0.8
MG Operations	$0.2	$0.4	
HHFW Engineering	$0.3	$0.9	$0.2
Diagnostic Support	$0.2	$0.3	$0.1
Central I&C and DAS	$0.1	$0.4	$0.2
Continue-FG/SAD-II/MPTS	$0.3		
MG Weld Repair		$0.8	
Integrators/Digitizer Upgrades	$0.1	$0.3	
TMB System	$0.1	$0.3	
PSRTC (PCS Backup)	$0.1	$0.2	
Lithium Engineering Support	$0.1	$0.2	
D-Site AC Power Equip	$0.1	$0.1	$0.1
Fault Detector/HCS I/O Interface	$0.7	$0.6	
Central I&C H/W Improvements		$0.2	
Plasma Operations Support		$0.3	$1.7
5 year Plan-Facility & Diagnostic Upgrades			$1.8
Reserves e.g., Spares/Overtime			$0.5
Total	$3.4	$7.6	$6.3
Increment per Year ($46.2M Base)	7.4%	16.5%	13.6%

Incremental Cases – FY2013 +7.5%; FY2014 & 2015 +15%:

- Preserve essential operations and research staff to resume operations in FY2015 (PPPL and national collaborators).
- Restores facility enhancements necessary for reliable NSTX-U operation.
- Allows NSTX-U to be operated at its full capability.
- Increase the NSTX-U plasma operation run weeks from 0-6 to 16 run weeks.
- Start preparation for the NSTX-U five year plan facility and diagnostic tools.

Optimum Cases:

- Enables full NSTX-U operations.
- Enables initiation of the major five year plan facility/diagnostic enhancements

Optimized Plan Being Developed for FY 2013–15

Exciting Opportunities and Challenges Ahead

- **NSTX upgrade outage activities are going well**
  - Researchers are working productively on data analysis, collaboration, next five year plan and preparation for the NSTX-U operation.
  - NSTX operations technical staff are working on the Upgrade Project tasks in FY 2013 – 14.
  - Upgrade project progressing on cost and on schedule.
- **Exciting NSTX-U research plan being developed**
  - Provide new solutions to the plasma-material interface.
  - Provide necessary data base for FNSF design and construction.
  - Strong contribution to toroidal physics, ITER, and fusion energy development.
- **FY 2014 / FY 2015 base budget guidance will delay the NSTX-U research operations start date**
  - FY 2013 presidential budget is~ $ 5 M lower than FY 2012 budget which results in severe loss of essential operation and research personnel.
  - Continuing flat budget for FY 2014 and FY 2015 will delay the NSTX-U research grade plasmas by ~ 1 year into FY 2016 due to lack of personnel.
  - Incremental funding restores the budget to the FY 2012 level and enables timely start of the NSTX-U research operations in FY 2015.

Back-up Slides

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

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

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

NSTX-U Operations Staff and Resource Needs
Much of the core operations staff unchanged

While the facility capability is significantly enhanced, the core operation team and research staff however are similar for NSTX and NSTX-U. For example, the control improvements enable the NBI operations by the same number of operators.

Main Changes:

- **Additional HP (Health Physics) technician to support higher level of radiation activation and tritium levels in the NSTX-U test cell.**
- **Additional software engineer to support plasma control system due to much greater plasma control system requirements for NSTX-U.**
- **Increased consumables (electricity, liquid helium, liquid nitrogen, SF_6, etc.) due to the addition of 2nd NBI and increased magnet system power loads (x 2 higher field and x 5 pulse length) which increases the cost of incremental operating week by ~ $50k from ~ $200k/week to ~ $250k/week.**

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.

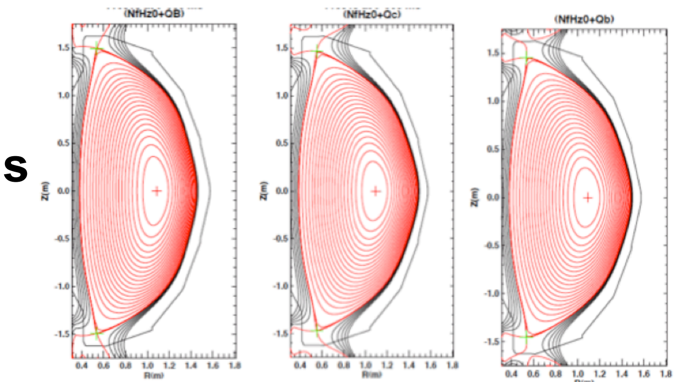
•The FD prototype has been completed in conjunction with the new FG in a Transrex rectifier.

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

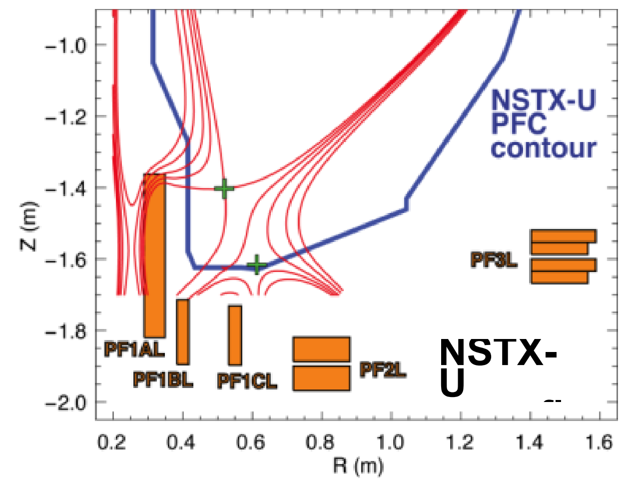
- **The first-year power supply capabilities of NSTX-Upgrade will yield considerable experimental flexibility, namely, up-down symmetric PF-1C coils compared to only at the bottom.**
- **By powering the PF-1A & PF-1C coils, it will be possible to generate up-down symmetric snowflake divertors**
  - **Capability 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:**

  - 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.



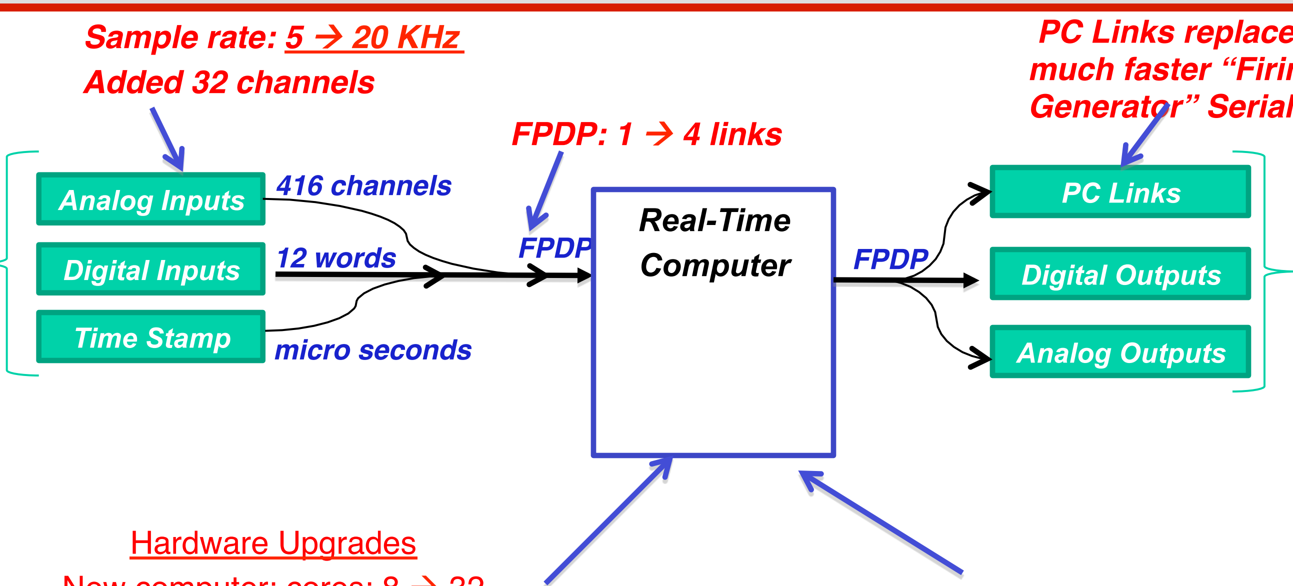
NSTX-U double-null | NSTX-U double-snowflake-plus | NSTX-U double-snowflake-minus



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.

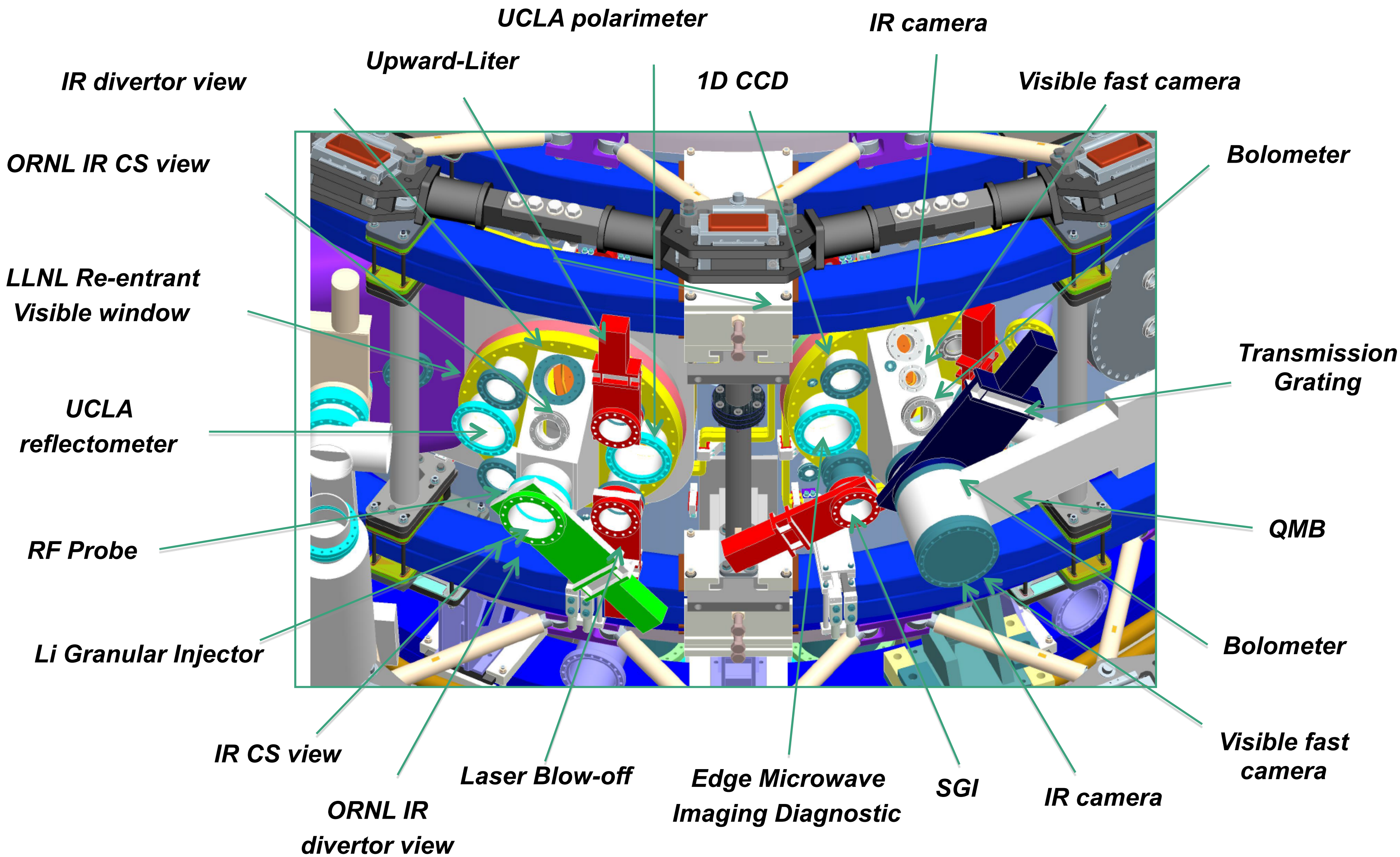
Software Upgrades
Ported PPPL code and GA PCS to 64-bit.
Generate commands for new firing generators .
Coil Protection (DCPS) functions incorporated in PSRTC.
Numerous new control algorithms.
PCS algorithms re-written using GA format.
PSRTC to be re-written.

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.**

Detailed facility/diagnostics port design developed

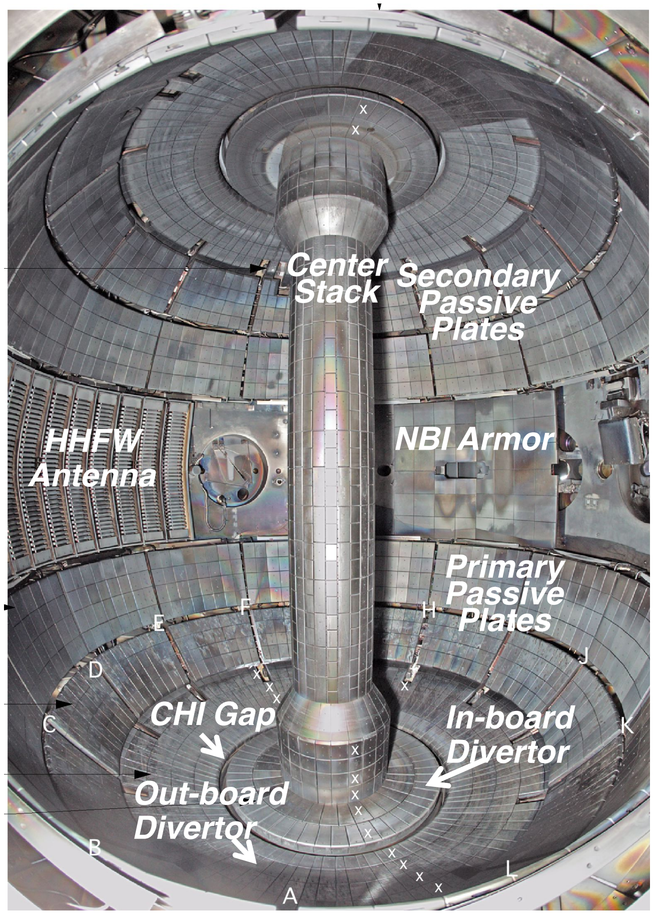
Example of Bay I and J Configuration for Day 1

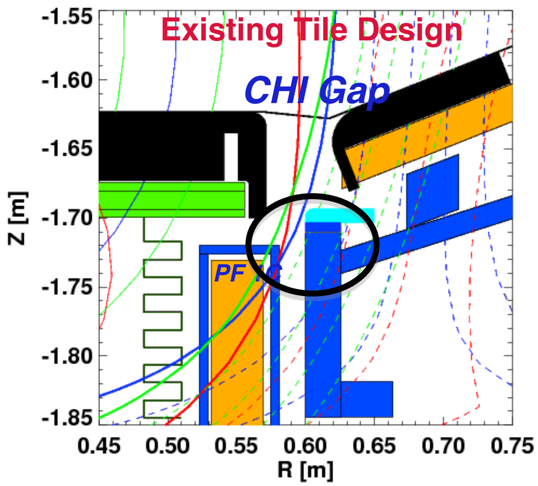


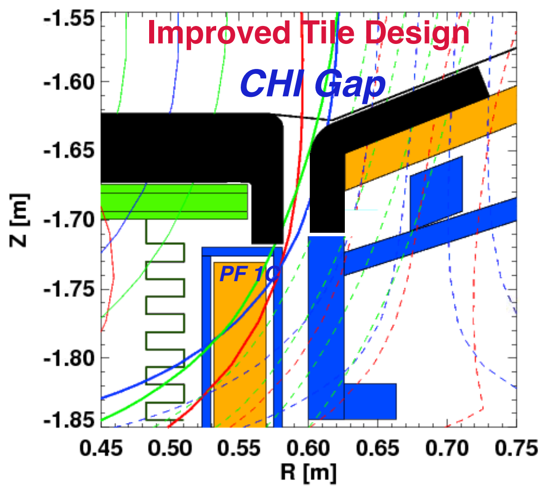
Day-1 Plasma Facing Component

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 Provide Necessary Protection**
- **Preliminary design completed**
- **5 MW/m^2 for 5 sec tolerable with ATJ but not with Poco TM**
- **ATJ graphite tile material secured**

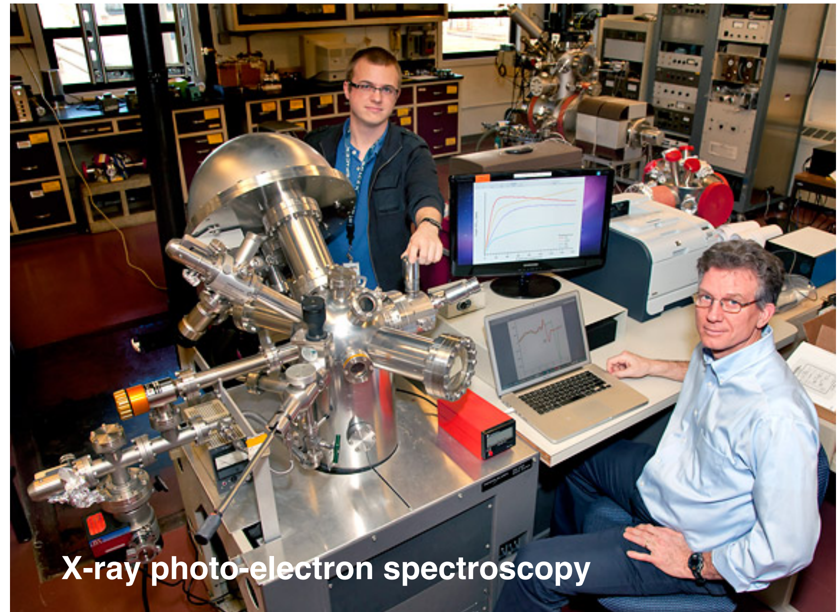
Surface Analysis Facilities to Elucidate Plasma-Surface Interactions

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

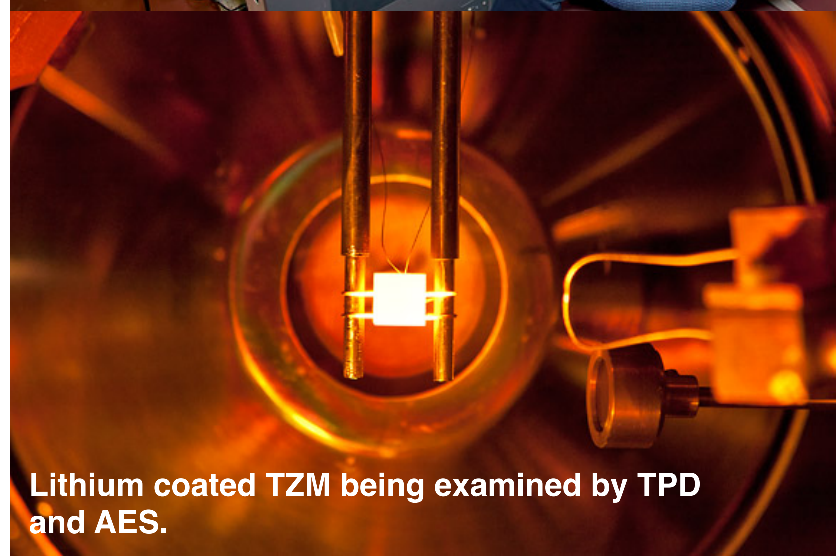
- **The Surface Science and Technology Laboratory (SSTL) with three surface analysis systems and an ultrahigh vacuum deposition chamber.**

- **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.**
  - Determined that lithiated PFC surfaces in tokamaks will be oxidized in about 100 s depending on the tokamak vacuum conditions. (C. H. Skinner et al., PSI_20 submitted to J. Nucl. Mater.)



X-ray photo-electron spectroscopy

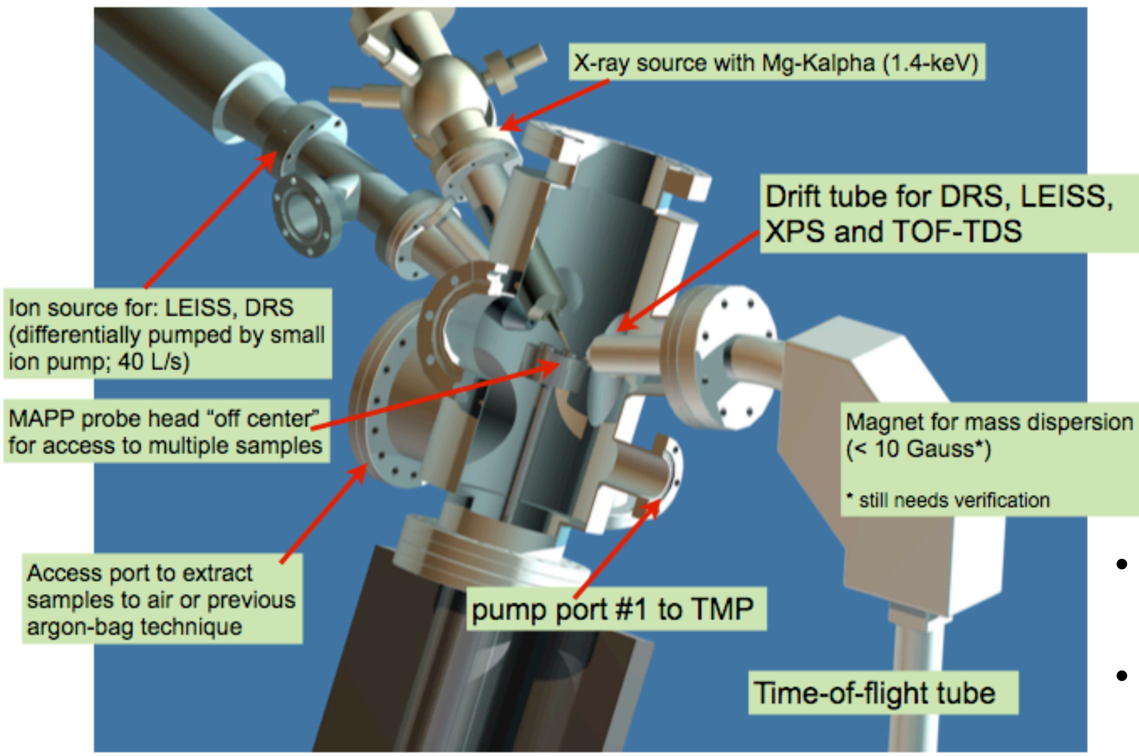


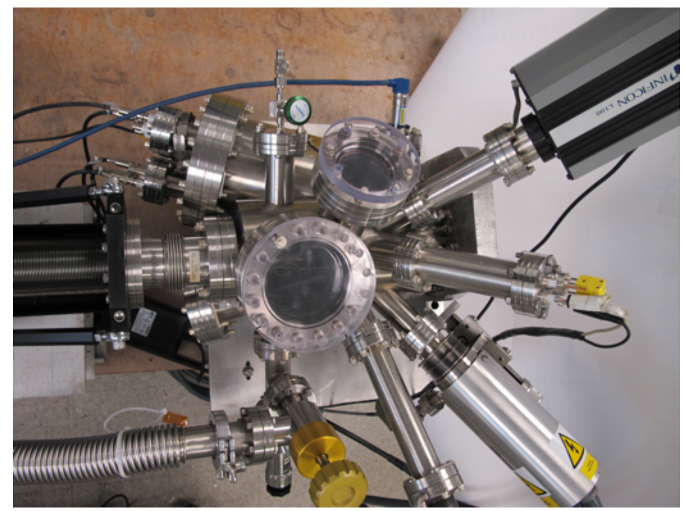
Lithium coated TZM being examined by TPD and AES.

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**



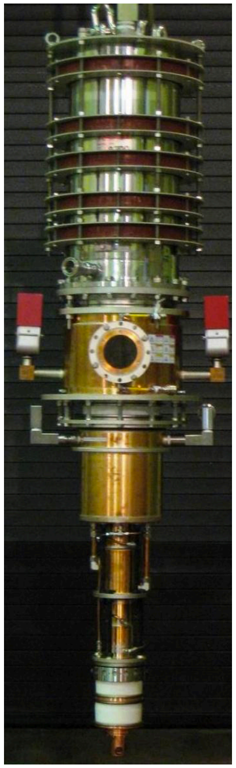


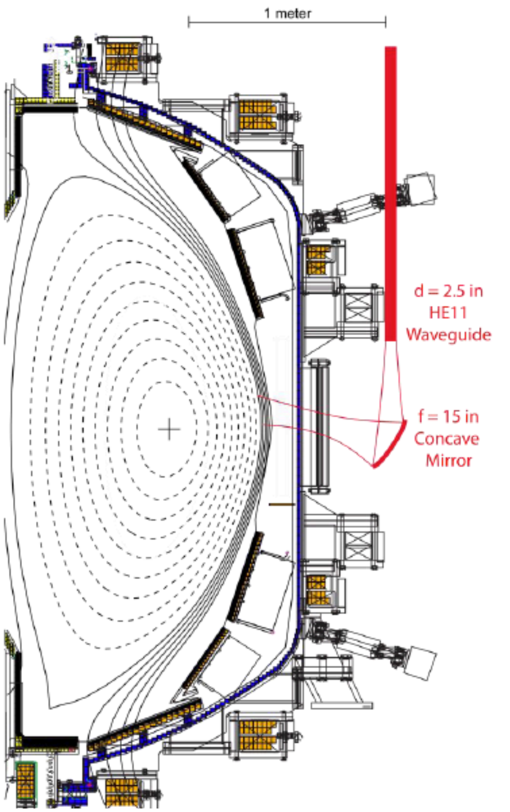
- **MAPP chamber showing diagnostics for sample analysis**
- **MAPP will be tested on LTX during outage**

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

A MW-Class ECH/EBW System for Non-Inductive Operations
To bridge the temperature gap between CHI and HHFW

28 GHz, 1 – 2 MW
Tsukuba Gyrotron



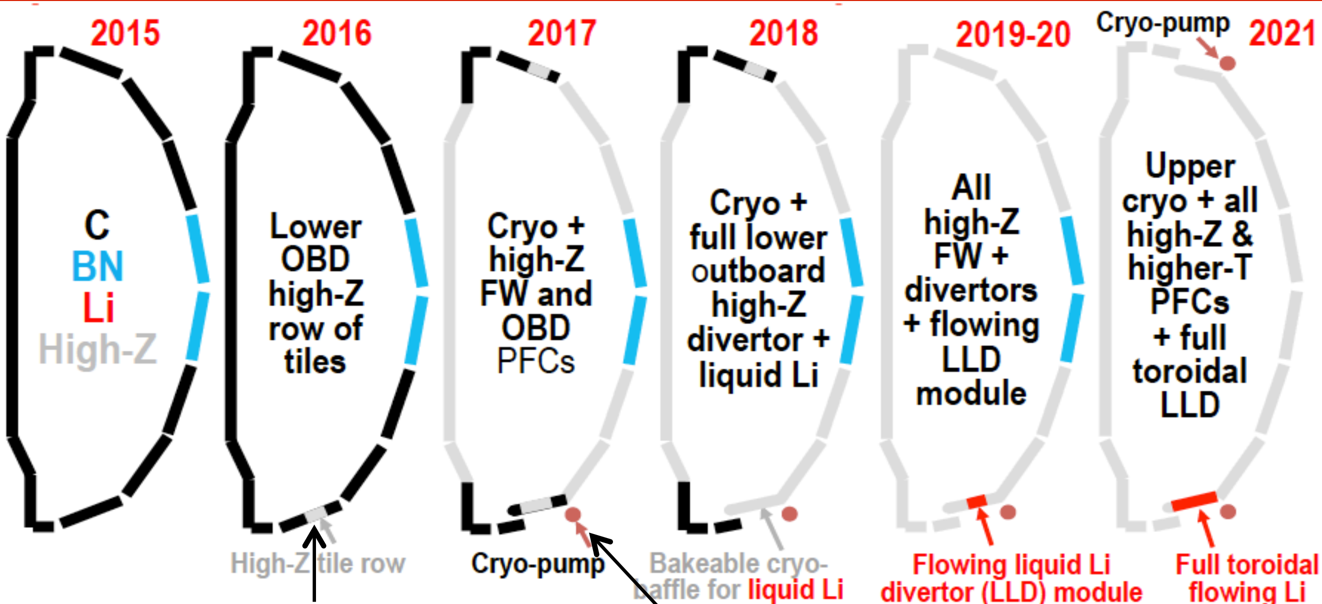


28 GHz ECH/EBWH waveguide and mirror concept

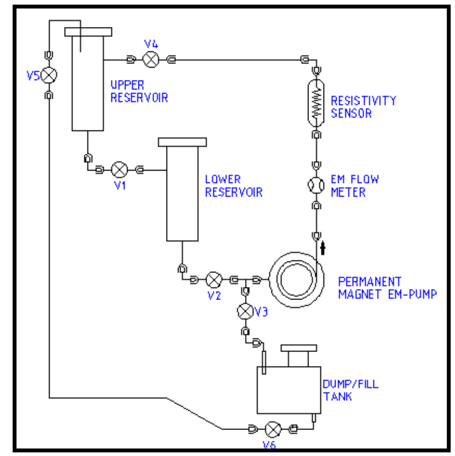
- FY 2014-15 - Start MW-class ECH/EBW system design for non-inductive start-up and CD operations (US-Japan)
- FY 2016-17 – Implement the ECH/EBW system utilizing the NBI infrastructure

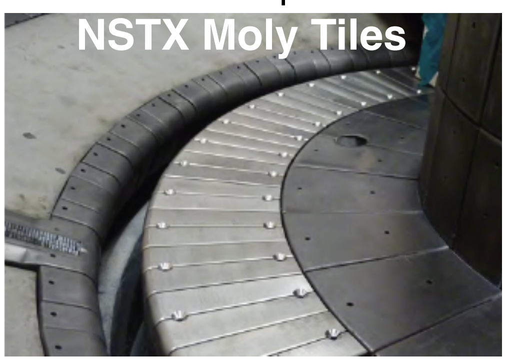
Boundary Physics Evolution

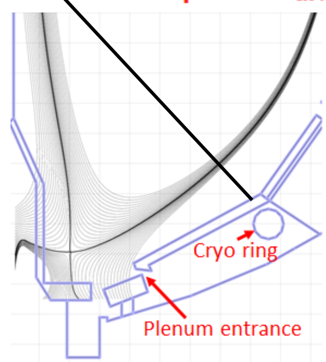
High-Z PFC, Cryo-pump, and flowing LLD



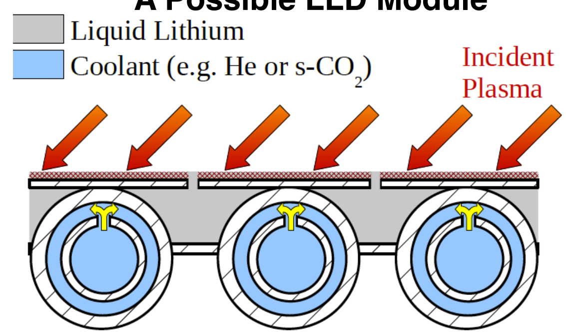
Flowing LL Test Loop





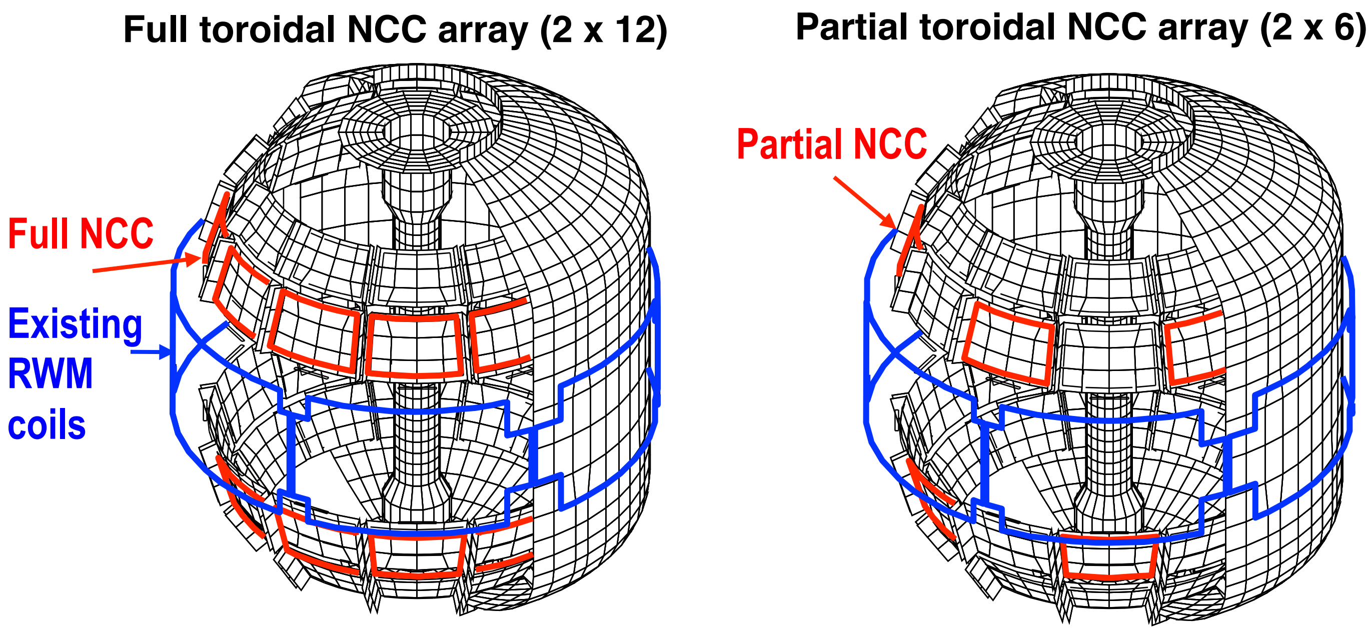


A Possible LLD Module



- **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.**

New MHD and Plasma Control Tools for NSTX-U
Sustain β_N and Understand MHD Behavior Near Ideal Limit



- **NCC can provide various NTV, RMP, and EF selectivity with flexibility of field spectrum (n ≤ 6 for full and n≤ 3 for partial) as synergy with the existing EFC/RWM system.**
- **2nd 3-channel Switching Power Amplifier (SPA) commissioned in July 2011 powers independent currents in existing EFC/RWM and NCC coils.**
- **A Real-Time Velocity (RTV) diagnostic will be incorporated into the plasma control system for feedback control of the plasma rotation profile.**
- **Multi-poloidal location massive gas injector system will be implemented.**