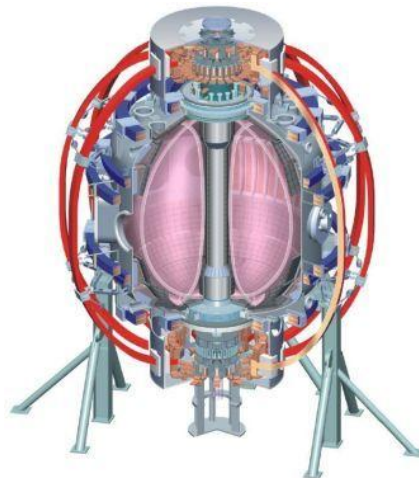


NSTX Project Plans for FY2011-13

College W&M
 Colorado Sch Mines
 Columbia U
 CompX
 General Atomics
 INEL
 Johns Hopkins U
 LANL
 LLNL
 Lodestar
 MIT
 Nova Photonics
 New York U
 Old Dominion U
 ORNL
 PPPL
 PSI
 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

M. Ono, PPPL
 NSTX Project Director
 For the NSTX Research Team

FY2013 FES Budget Planning Meeting
Germantown, MD
April 11, 2011



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
 KBSI
 KAIST
 POSTECH
 ASIPP
 ENEA, Frascati
 CEA, Cadarache
 IPP, Jülich
 IPP, Garching
 ASCR, Czech Rep
 U Quebec

Outline

- **FY 2010 Operations Summary and Status**
- **FY2011-12 Facility and Diagnostic Plans**
- **NSTX Upgrade Project Status**
- **Budget**
- **Summary**

Productive FY10 Plasma Operations Completed

- **All of the NSTX FY2010 Milestones completed on or ahead of schedule including the Joint Research Target**
 - Final year-end reports submitted to DOE-FES
 - Latest NSTX results presented at IAEA and APS
- **15.4 run weeks: total 2941 plasma shots, highest total plasma shots and plasma shots per week (191/week) for NSTX due to lithium conditioning**
 - FY09: 16.8 run weeks: 2748 shots or 163 plasma shots / week
 - FY08: 16.5 run weeks: 2571 shots or 156 plasma shots / week
- **50 XP/XMPs performed: ~ half of XPs led by collaborators**
- **New capabilities in FY10 contributed to science productivity**
 - Liquid Lithium Divertor (LLD) installation and commissioning
 - Two-Color Fast IR camera for lithium surface heat flux measurements
 - Beam Emission Spectroscopy for low k fluctuation/MHD modes
- **4.2 run weeks completed in October for FY 2011**
- **New significant facility/diagnostic capabilities readied for FY2011:**
 - 2nd SPA supply for non-axisymmetric feedback coils, extra MPTS channels, MSE-LIF, Tangential fast ion D-alpha diagnostics, multi-color dense x-ray edge array

NSTX had active community contributions and recognition

Strong collaborator contributions

- ***The NSTX research team actively participated in 26 ITPA joint experiments in 2010.***
- ***The NSTX research team participated in ten ITPA and ITER workshops***
- ***The NSTX team members served in the leadership positions in the T&T, dust, Energetic particles, Operations and Control for ITPA/ITER and the US BPO management.***
- ***Three NSTX young researchers (LLNL, Purdue U, and PPPL) received 2010 DOE OS Early Career Awards.***
- ***S. Sabbagh (Columbia University) was honored at IAEA (Daejeon, Korea) for his Nuclear Fusion Paper Award.***
- ***J. Menard and S. Sabbagh (Columbia University) were selected to become the APS-DPP Fellows .***
- ***J-K Park received the 2010 Marshall N. Rosenbluth Outstanding Doctoral Thesis Award.***
- ***Governor's Safety Award: Continued Excellence Award from NJ State for working nine (9) consecutive years (1.7 million hours) without an away from work lost time injury/illness case***

NSTX had strong publications and conference participation

Growing Number of Highly Capable Young Researchers

- 57 NSTX scientific papers published in refereed journals including four PRLs in 2010 (three PRLs thus far in 2011)***
- The NSTX team members presented twenty-five IAEA papers with eight oral presentations and ten Invited Talks at the APS-DPP meeting last fall. (the most for NSTX)***

Nurturing junior researchers:

- Strong contributions from young researchers : 23 post-docs (2 ARRA, 2 ORISE Fellows) and 24 students**
- Two Presidential Early Career Award and three DOE OS Early Career Research Program Award recipients**

NSTX Research Team Membership

	PPPL	Non-PPPL
Researchers	58	195
Post Doc.	6	17
Grad. Students	5	8
Undergrad.	1	10

Leadership in Growing World Lithium Experimental Program **(NSTX, LTX, FT-U, T11M, TJ-II, EAST, RFX, KTM)**

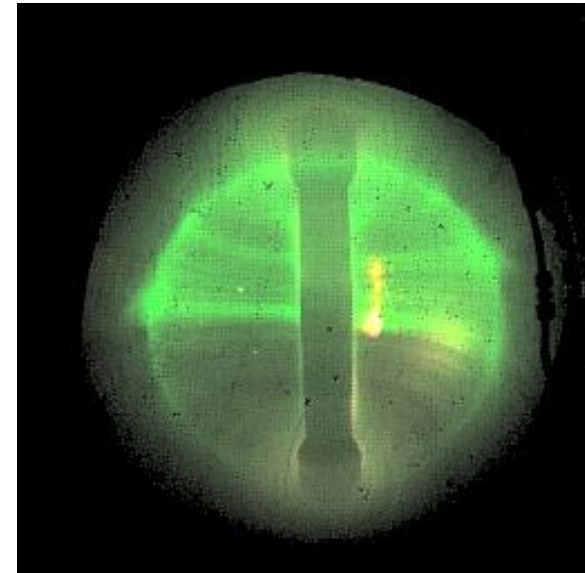
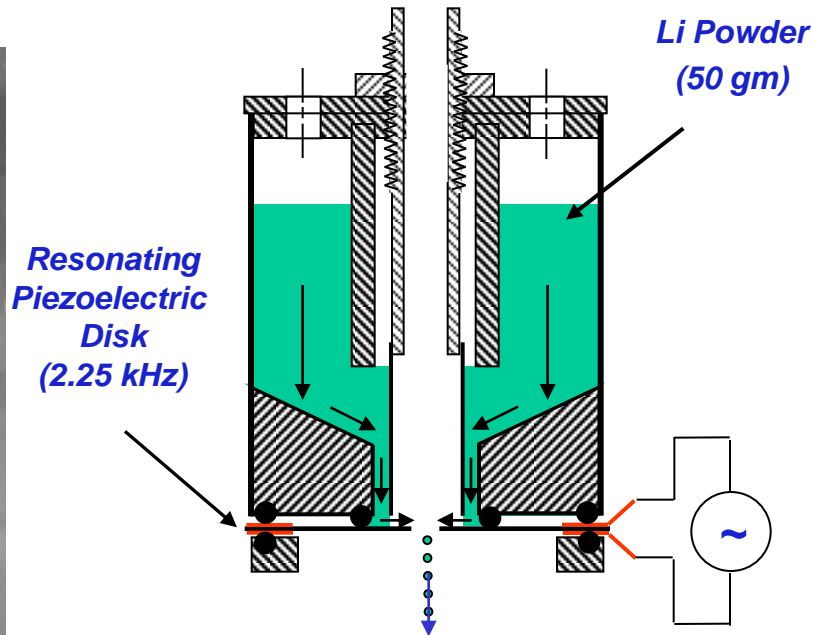
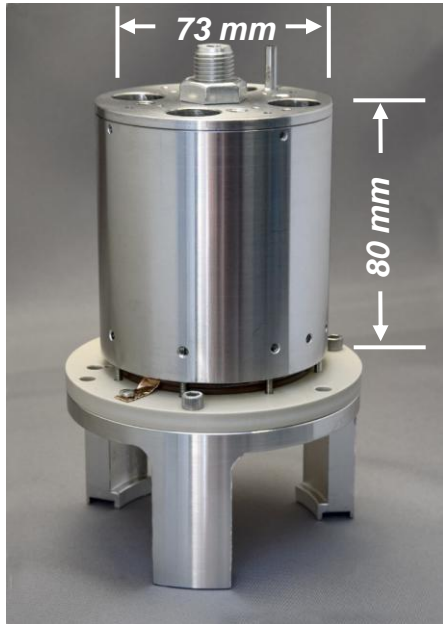
NSTX Goal: To investigate effectiveness of lithium for heat and particle control while enhancing plasma performance in H-mode.

Lithium in NSTX yielded important results in H-mode:

- Global confinement improved through electron confinement improvement by ~ 20 – 30% with strong lithium pumping. Contributed to the highest confinement H-mode with $HH98y2 \leq 1.7$ (exceeding FNSF HH).***
- H-mode power threshold significantly reduced ~ 20 – 30%***
- Completely stabilized ELMs.***
- Contributed to the non-inductive CHI start-up success by controlling impurities.***
- Improved plasma operations: shots / week increased ~ 40% over pre-lithium by controlling impurities.***

2nd Lithium Symposium to be held at PPPL on April 27 – 29, 2011
Over 50 presentations (<http://isla2011.pppl.gov/>)

NSTX Lithium Dropper was Installed on EAST ***Facilitated Wall Conditioning and H-mode Access***

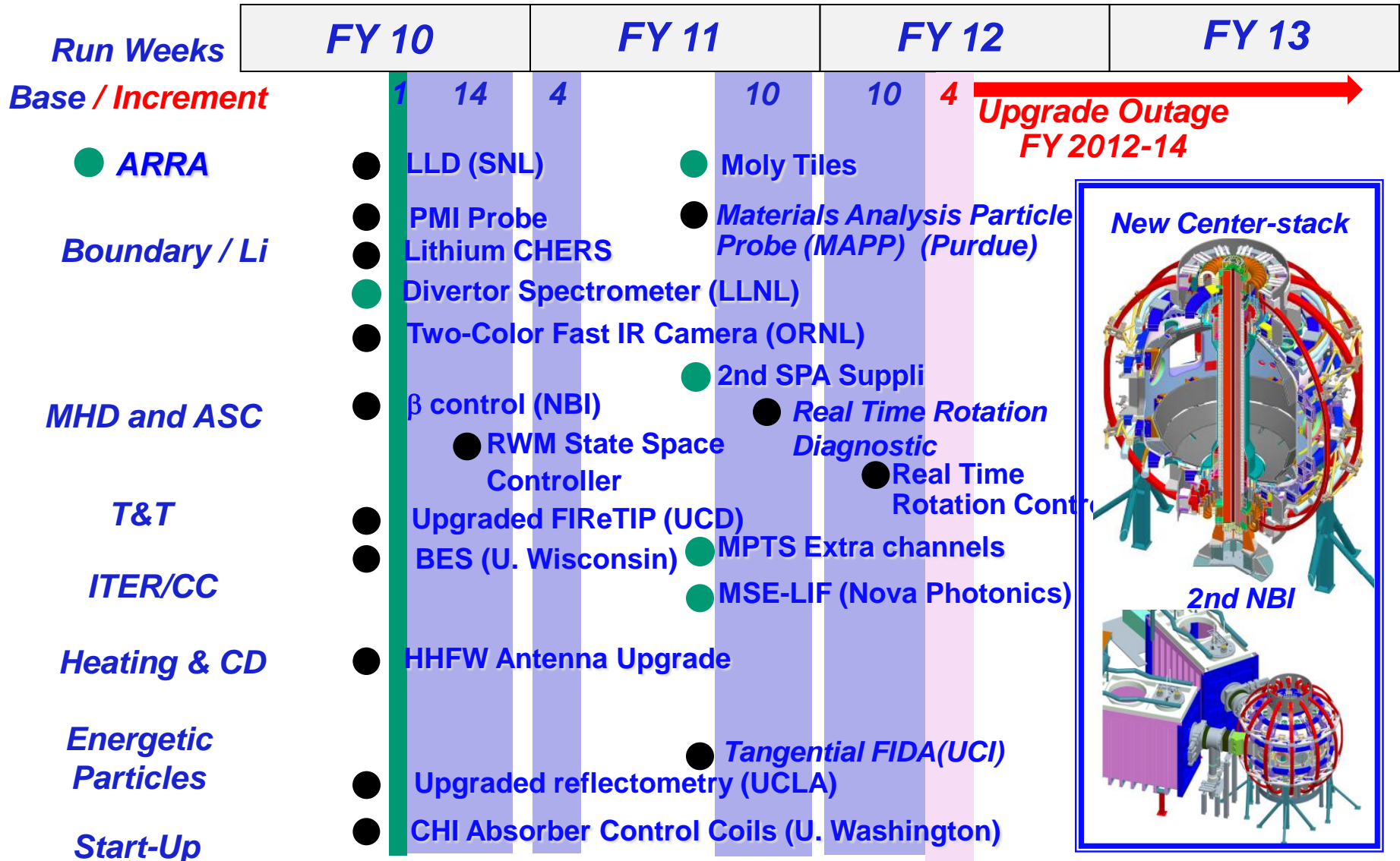


ELMy H-modes have also successfully been achieved with the combination of LHW and ICRF heating. The lithium evaporation followed by the use of the PPPL lithium dropper was used to accomplish H-mode operation. Using this scenario, EAST has produced H-modes lasting up to 6.4 seconds.

- The EAST tokamak is investigating the use of Li in much longer discharges. We will continue our collaborations with EAST in order to benefit from those experiments.
- Three EAST researchers arrived to collaborate on NSTX boundary physics.

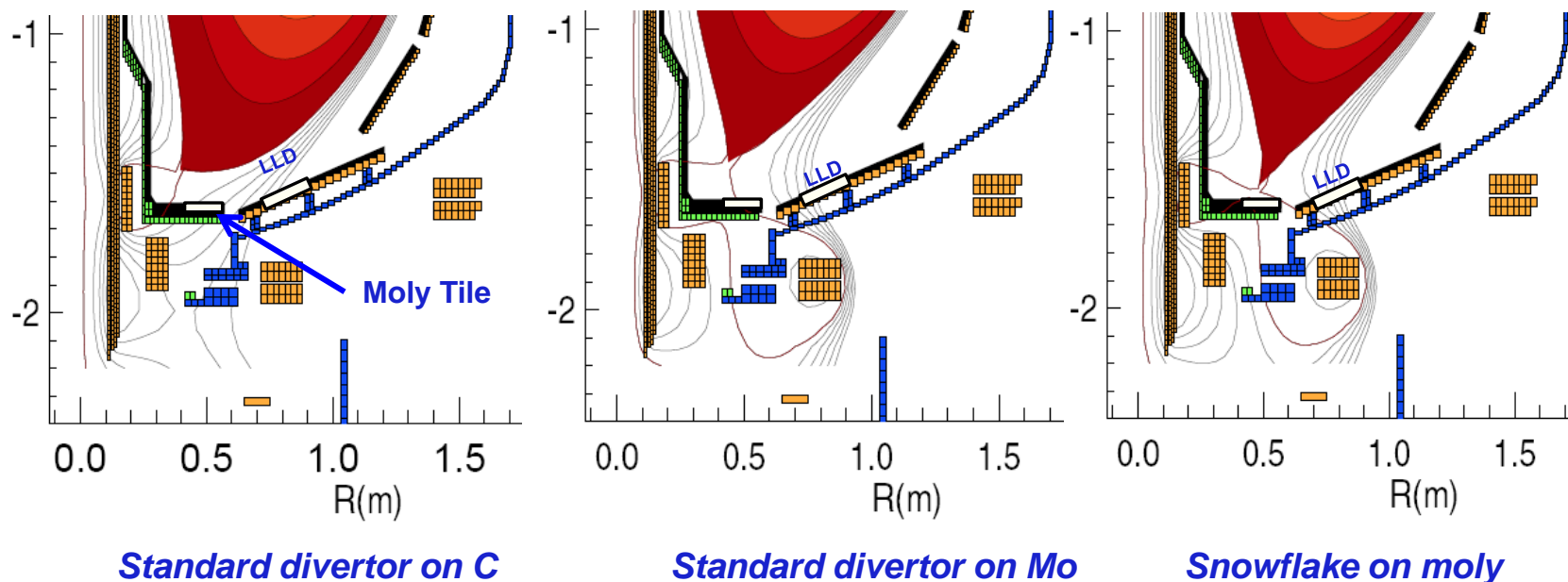
NSTX Near Term Facility Plan

Exciting New Facility and Diagnostic Upgrades in FY 2011



Addition of IBD Mo tiles would enable important divertor studies and extend liquid lithium & moly divertor research

- **Help quantify fraction of core C coming from lower divertor for high- δ shapes**
- **Potentially reduce C content of Li ELM-free scenarios**
- **Characterize Mo performance to inform choice of div/CS PFC in Upgrade**
- **Apply Li (LiTER) to divertor moly surfaces for partial/full liquid lithium**
- **Provide metal cathode surface for CHI to reduce impurity generation**



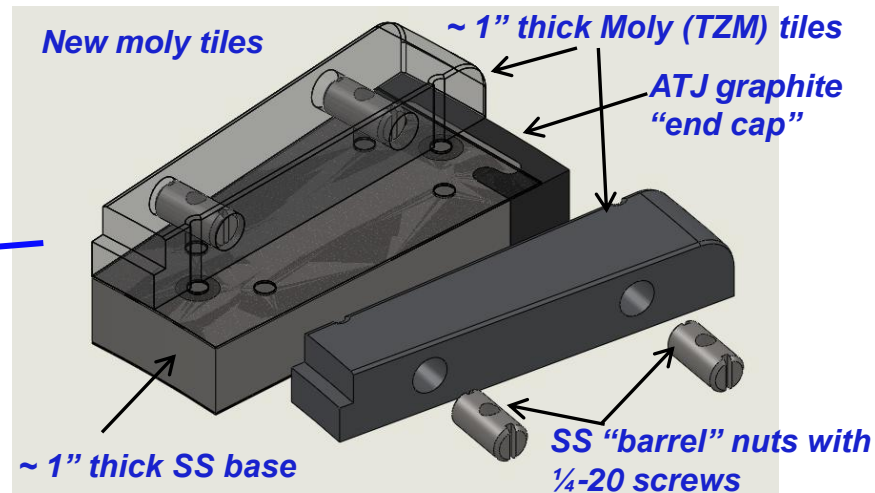
Moly-tile implementation for FY 2011-2012 run would provide valuable information for the post-upgrade PFC options

Aim to Reduce Carbon Influx with Moly-tiles and LLD

Molybdenum Tiles Installed at high priority on Lower Inboard Divertor

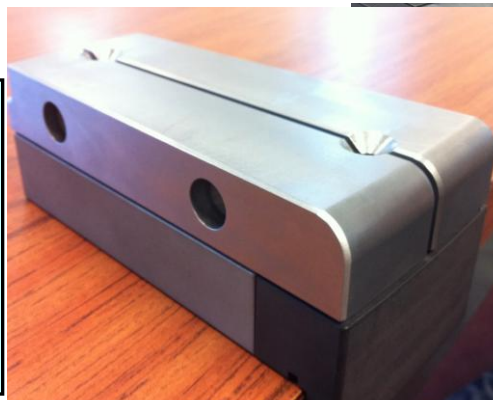


Split-top Moly on SS tile satisfies design requirements



Molybdenum tiles on inboard divertor

- Replace the second row tiles with 1" moly tiles
- All 48 tiles will be moly with three diagnostic tiles incorporated
- Lithium coating with LITER ~ 2 x outer LLD rate
- Plasma heating can lead to liquid lithium



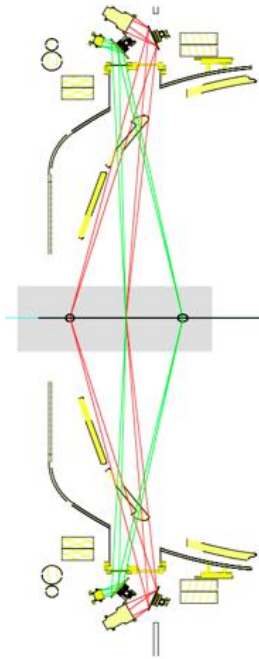
High Priority FY2013 Boundary Physics Tasks:

- Developing attractive long-pulse high power / particle handling PFCs / divertor solution.
- More moly-tiles? Closed Divertor with cryo-pump or liquid lithium tray?

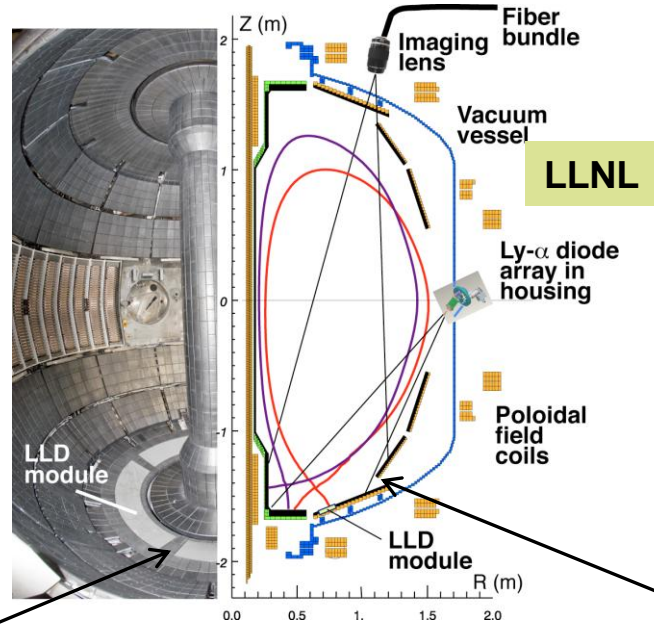
Enhanced Capability for LLD and Boundary Physics

Multi-Institutional Contributions

Lithium CHERS

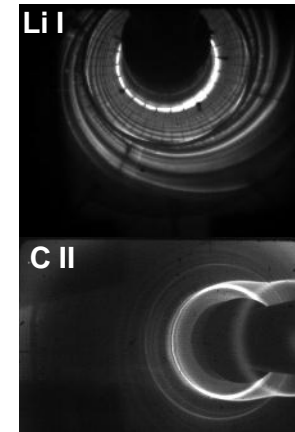


Divertor Imaging Spectrometer



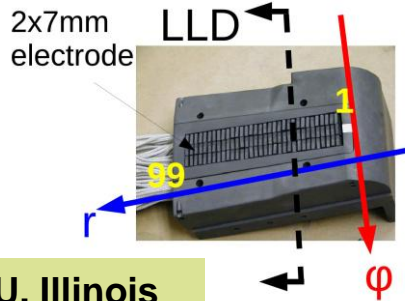
Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL



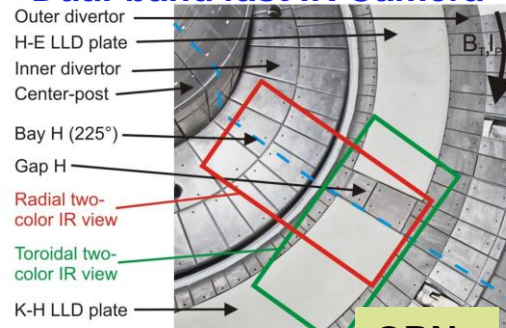
MAPP diagnostic systems

Dense Langmuir Probe Array



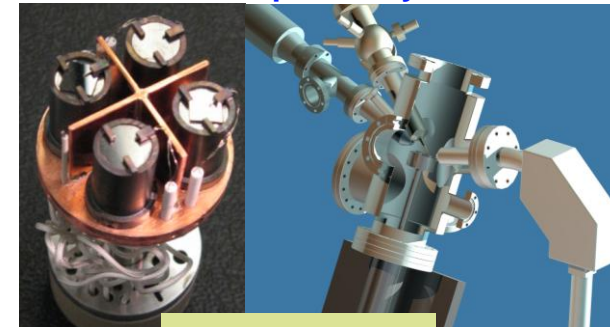
U. Illinois

Dual-band fast IR Camera



ORN

PMI Probe / to be replaced by MAPP Probe

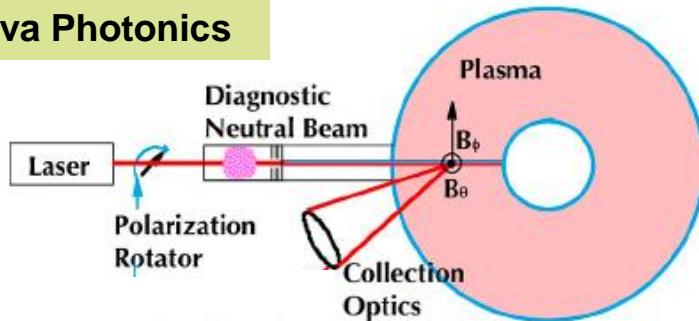


Purdue U.

Enhanced Pedestal / Profile Diagnostics for FY 2011 and FY 2012 JRT

MSE-LIF to Measure $E_r(r)$, $B(r)$

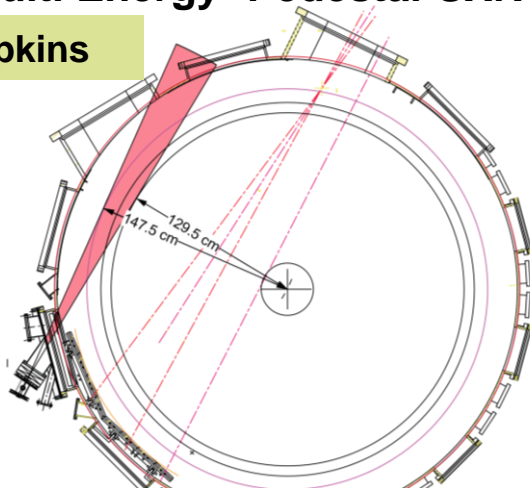
Nova Photonics



10 channels to be available in FY 2011.
Additional channels in FY 2012

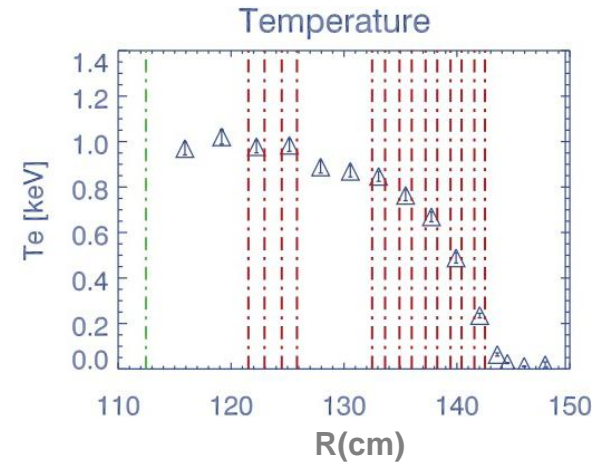
Multi Energy -Pedestal-SXR

Johns Hopkins



20 channel in the pedestal with ~ 1 cm resolution

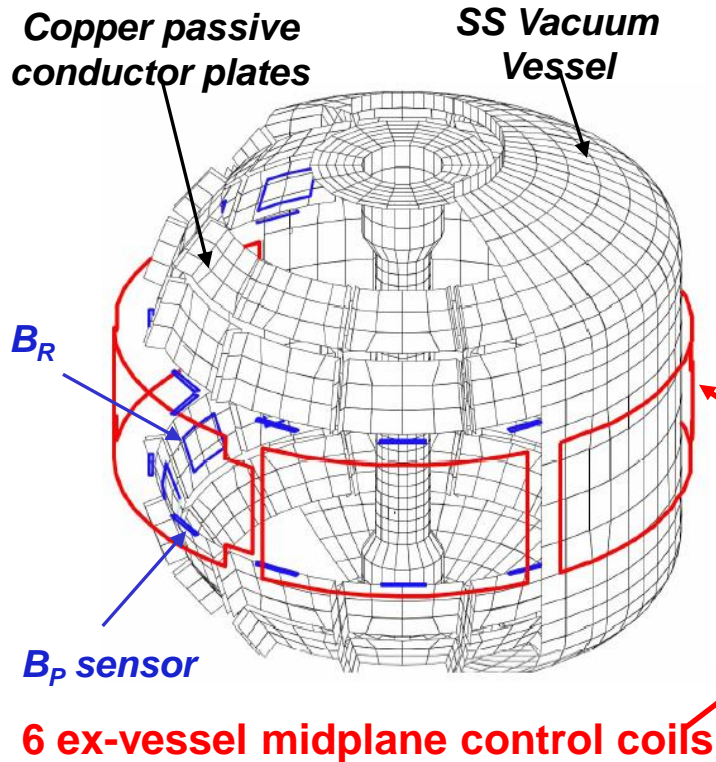
Additional 12 MPTS chs for enhanced pedestal resolution to ~ 1 cm



- NSTX profile diagnostics are maturing providing nearly all of the plasma profile information.
- All of the profile diagnostics are at mid-plane, naturally suited for rapid analyses
- In FY 2013, MPTS will be re-aimed to accommodate the upgraded center-stack

New Capabilities for Macro-stability and Plasma Control

Sustain β_N and Understand MHD Behavior Near Ideal Limit



- Install 2nd Switching Power Amplifier (SPA) to enable all six EFC/RWM coils for control of $n = 1, 2, 3$ simultaneously in FY 11
 - RWM spectrum dependence
 - Rotation and beta effects on NTMs
 - Response to 3D fields for EFC, ELM and Neoclassical Toroidal Viscosity physics
 - Disruption physics
- Columbia U, GA, ORNL

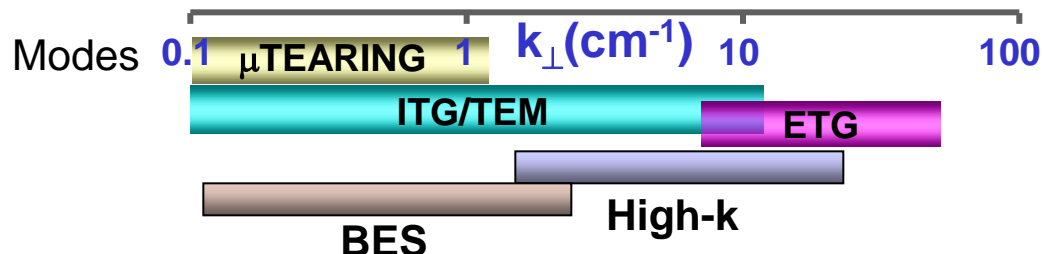
- Real Time Rotation Diagnostic Status:** Real-time measurement of toroidal rotation velocity at 4 spatial locations in plasma.
- Commissioned in FY 2011.
 - Feed into real time control system in FY 2012.

Conceptual Design for advanced control coils and real time control system in FY 2013

- MHD: 3D coil physics design for RWM/RMP/TM/EFC/NTV/TAE
- Control: Model/plan for real-time-MSE for NBI J-profile control

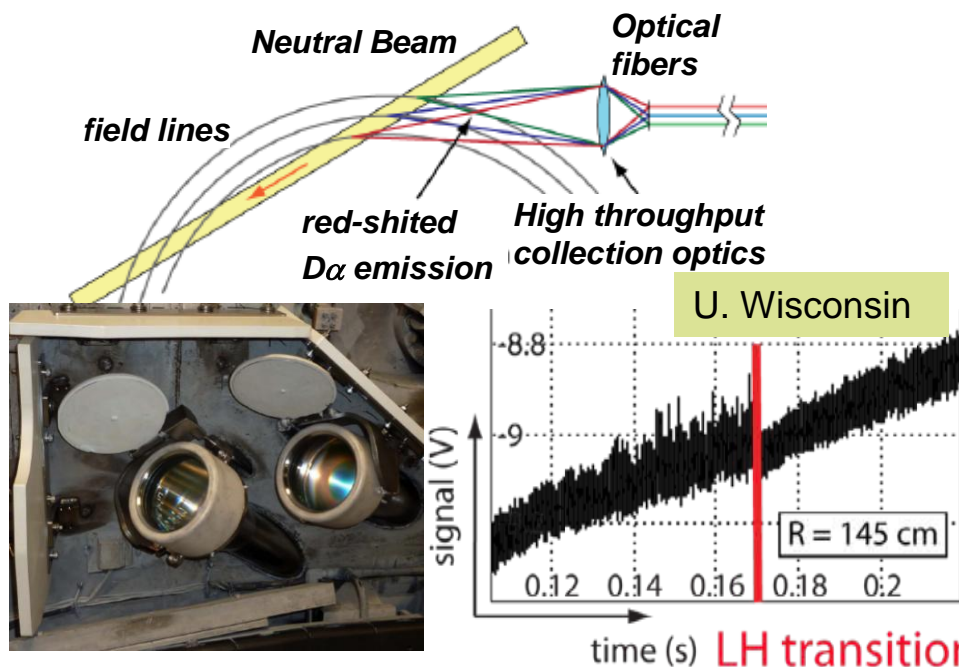
Transport and Turbulence

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

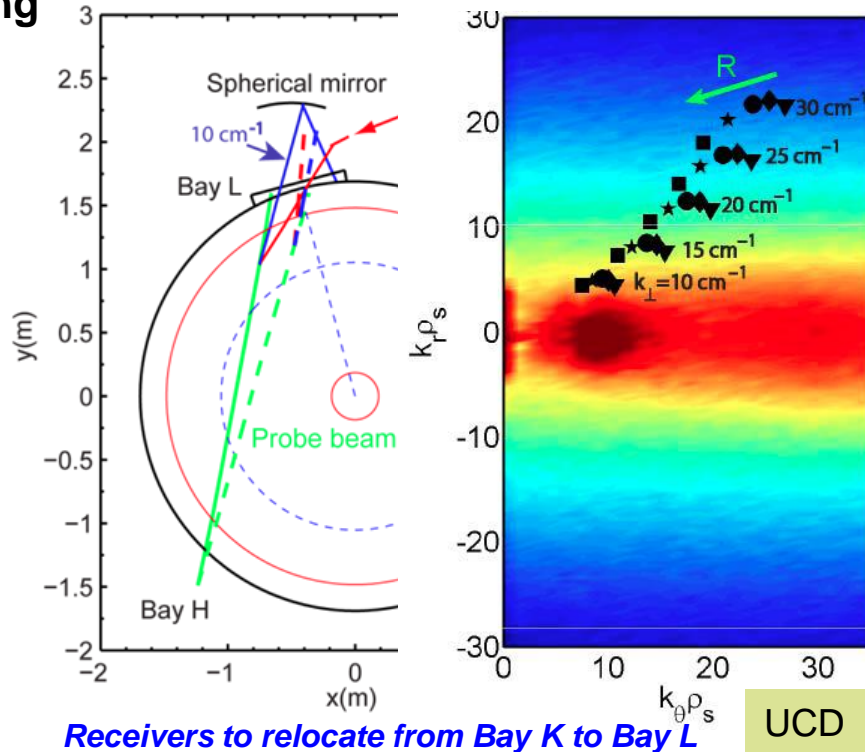


- 16 ch BES worked well in FY 2010
- 32 ch BES in FY 2011 - 2012
- Conceptual design for high-k system relocation / upgrade in FY 2013

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



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



Receivers to relocate from Bay K to Bay L

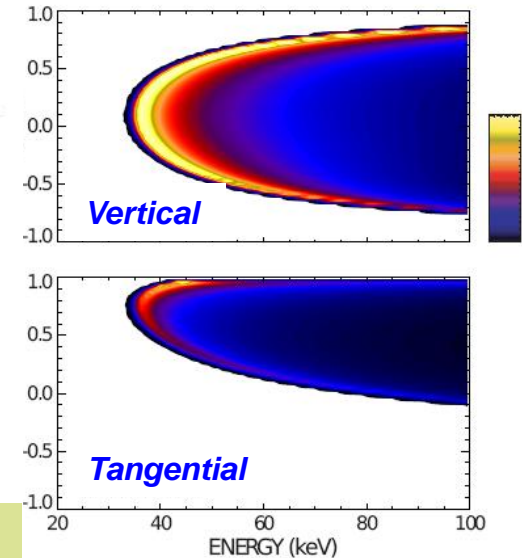
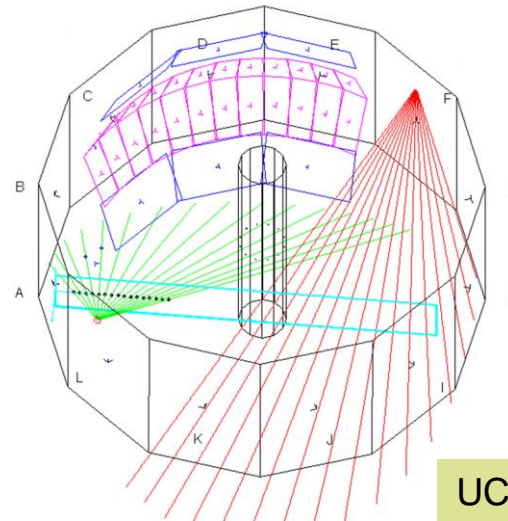
UCD

T-FIDA for Energetic Particle Research

For NBI fast ion transport and current drive physics

Tangential FIDA Views

- 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.



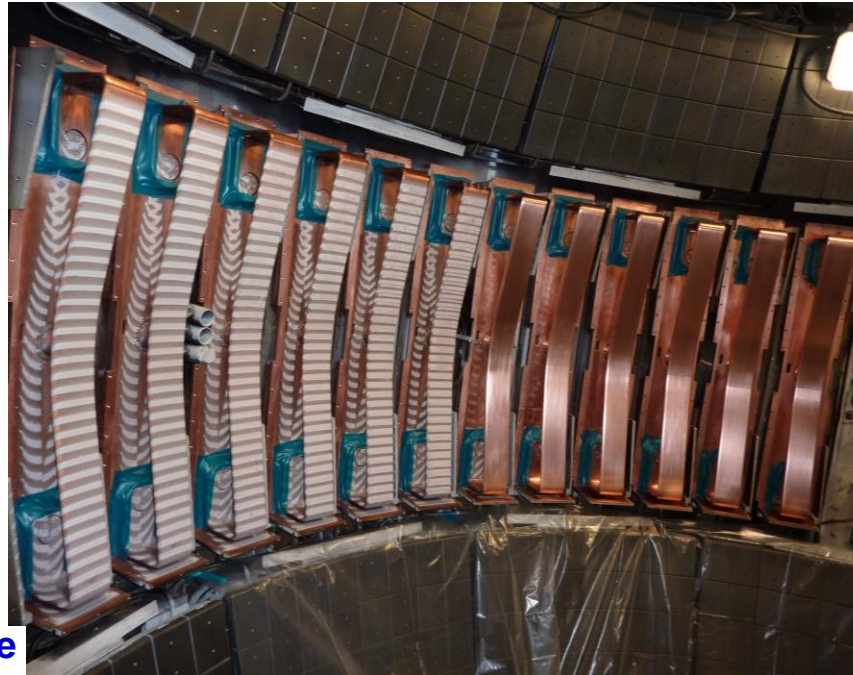
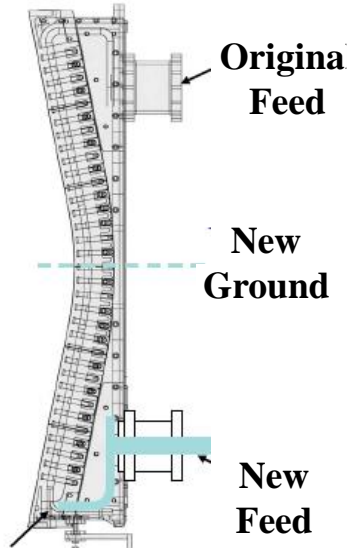
- Better localization in velocity space weighted toward parallel velocity
- Well suited to investigate NBI fast ion transport and current drive physics

FY 2013 Energetic Particle Conceptual Design and Diagnostic Upgrade

- Active TAE antenna
- Possible SS-NPA enhancement due to removal of scanning NPA

HHFW Operations Encountered Power Limit Due to Heavy Lithium Use in FY 2010

Double Feed Antenna modification (2009)



- Argon vent may have caused lithium dust formation resulting in arcing
- Lithium related issues need to be resolved with early HHFW operations and improved RF conditioning
- Reliable high power operation in H-mode is high priority goal

- Maximum radiation at mid-plane
- Power capability should increase by a factor of 2

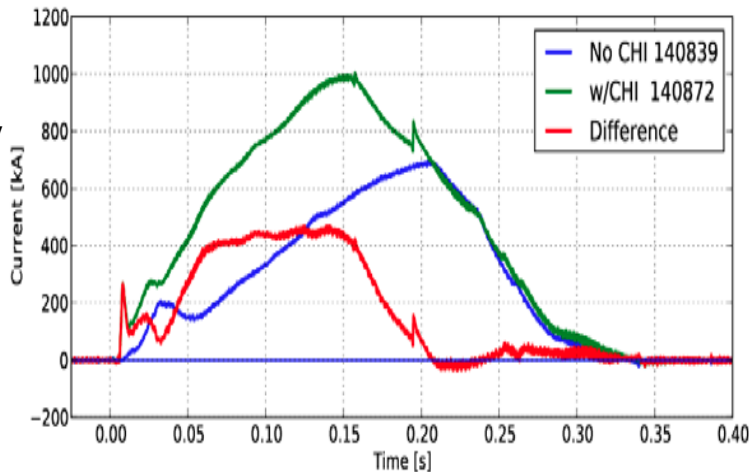
ORNL

- FY 2011 HHFW heating and current drive for start-up at low current
- FY 2012 HHFW + CHI for solenoid-free start up
- FY 2013 Conceptual design for antenna enhancement

Solenoid-free Start-up

CHI enabled lower density lower inductance start-up

Success of
CHI aided by
Low-Z
Impurity
Control



Low Z impurity reduction during CHI produced OH compatible plasmas

- Discharge cleaning of lower divertor plates or electrodes
- Avoidance of absorber arcs by control coils
- Lithium evaporation of lower divertor surfaces

U. Washington

FY 2011-2012 Operations

- Moly-surface electrodes for higher CHI current ~ 0.5 MA
- CHI + HHFW scenarios with higher Te
- Provide low-inductance target

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

- MA-class Solenoid-free Start-up Scenarios for FNSF
- Low-inductance Advanced Plasma Operations

- PEGASUS gun start-up producing exciting results $I_p \sim 160$ 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

Diagnostic Systems Growing with Strong Collaboration Contributions

MHD/Magnetics/Reconstruction

Magnetics for *equilibrium reconstruction*
Halo current detectors
High-n and high-frequency Mirnov arrays
Locked-mode detectors
RWM sensors (n = 1, 2, and 3)

Profile Diagnostics

MPTS (42 ch, 60 Hz) (*re-aim*)
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 (15 ch)
MSE-LIF (10 ch in FY 11, up to 24 ch in FY 12)
FIReTIP interferometer (6 ch) (UCI, TBD)
Midplane tangential bolometer array (16 ch)

Turbulence/Modes Diagnostics

Tangential microwave high-k scattering (upgrade)
Beam Emission Spectroscopy (24 ch)
Microwave reflectometers
Ultra-soft x-ray arrays – multi-color
Fast X-ray tangential camera (500kHz) (relocate)

Energetic Particle Diagnostics

Neutral particle analyzer (2D scanning) (*remove*)
Solid-State neutral particle analyzer (enhance)
Fast lost-ion probe (energy/pitch angle resolving)
Neutron measurements
Fast Ion D_α profile measurement (perp + tang)

Edge Divertor Physics

Gas-puff Imaging (500kHz)
Fixed Langmuir probes
High density 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
Divertor bolometer (20ch)
IR cameras (30Hz) (3)
Fast IR camera (two color)
Tile temperature thermocouple array
Dust detector
Edge Deposition Monitors
Scrape-off layer reflectometer
Edge neutral pressure gauges
Plasma-Material Interactions Probe
Divertor Imaging Spectrometer
Lyman Alpha (Ly_α) Diode Array

Plasma Monitoring

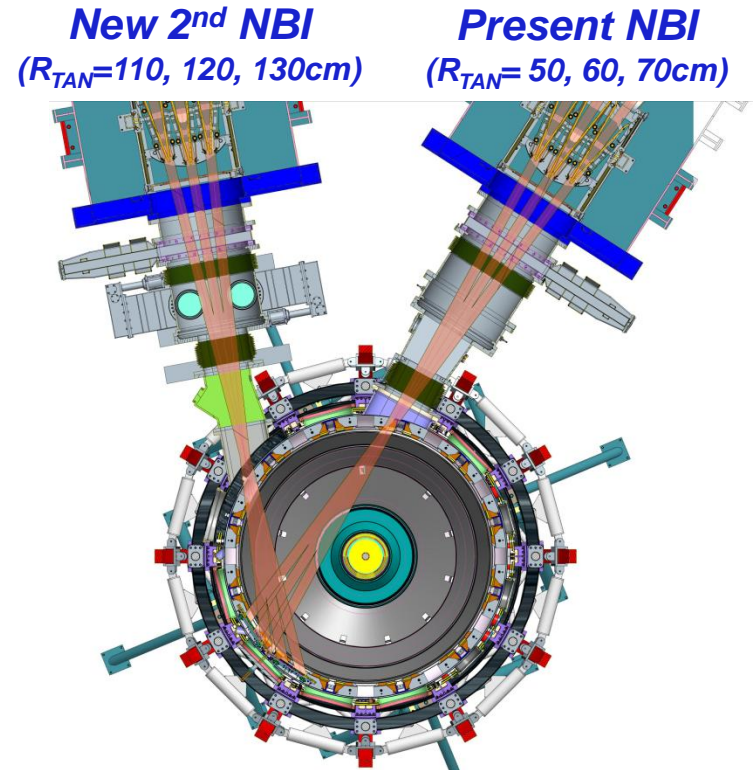
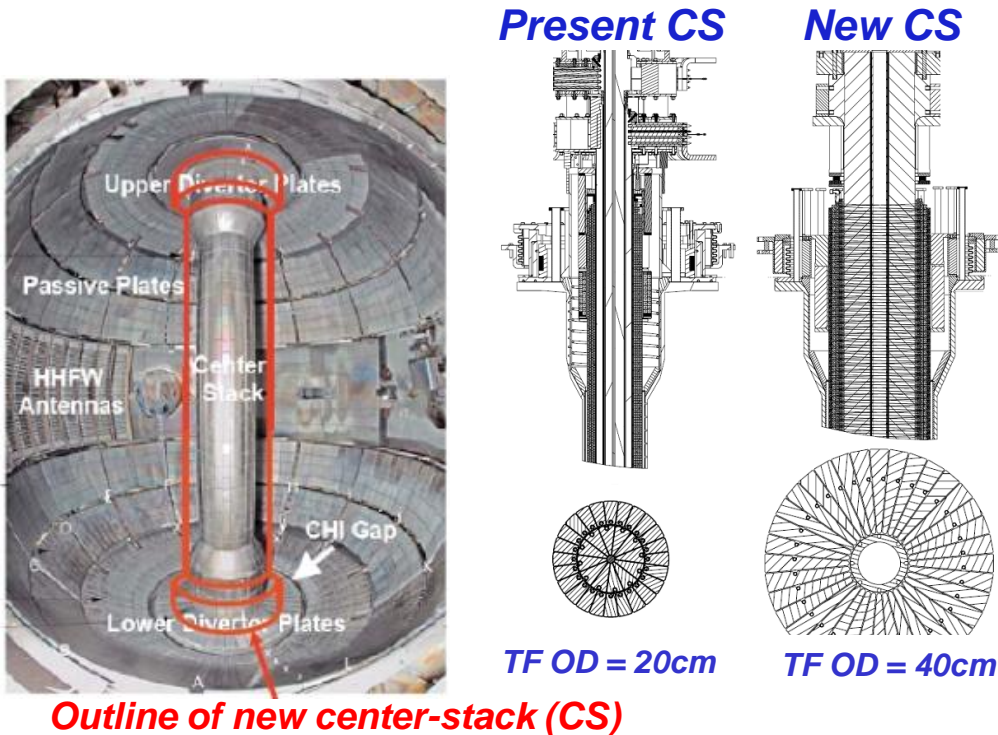
Fast visible cameras
Visible bremsstrahlung radiometer
Visible and UV survey spectrometers
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis
X-ray crystal spectrometer (astrophysics)
(Collaboration contributions) (Post upgrade changes)

Upgrades provide a major step toward FNSF

Access to low collisionality and fully non-inductive operations

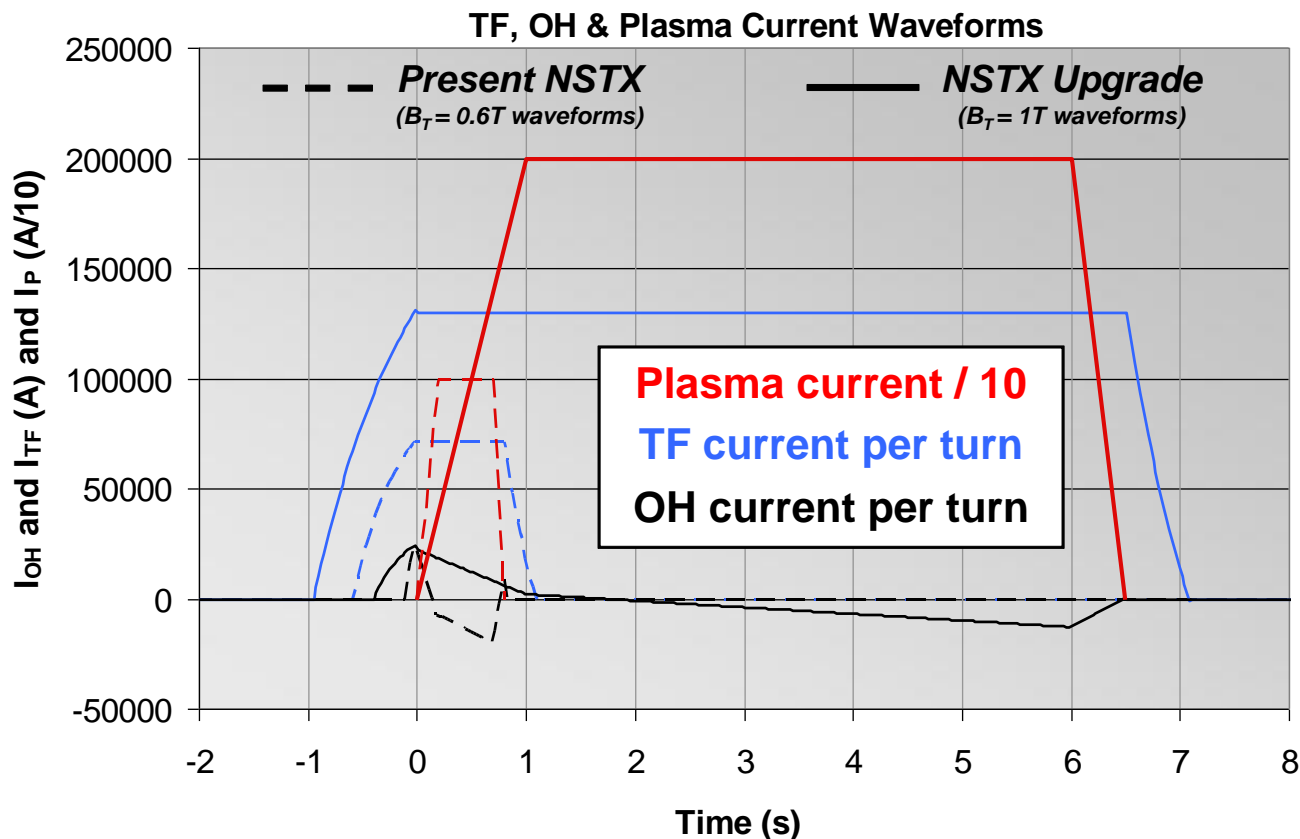
	NSTX	NSTX Upgrade	Plasma-Material Interface Facility	Fusion Nuclear Science Facility
Aspect Ratio = R_0 / a	≥ 1.3	≥ 1.5	≥ 1.7	≥ 1.5
Plasma Current (MA)	1	2	3.5	10
Toroidal Field (T)	0.5	1	2	2.5
P/R, P/S (MW/m,m ²)	10, 0.2*	20, 0.4*	40, 0.7	40-60, 0.8-1.2

* Includes 4MW of high-harmonic fast-wave (HHFW) heating power



Upgrade provides substantial increase in device performance

An order of magnitude enhancement in $n\tau T$



	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
$T_{\text{repetition}}$ [s]	600	1000
$R_{\text{center_stack}} = R_0 - a$ [m]	0.185	0.315
$R_{\text{antenna}} = R_0 + a$ [m]	1.574	1.574
Total OH flux [Wb]	0.75	2.1

Relative performance of Upgraded NSTX vs. Base:

- Center-stack radius increased 13cm $\rightarrow A=1.3 \rightarrow 1.5$
- Available OH flux increased 3x, 3-5x longer flat-top
- I_p increased 2x, B_T increased 2x at same major radius
- Plasma stored energy increased up to 4x (0.25 \rightarrow 1MJ)

NSTX Upgrade Project

Very Good Progress to Date

- ☑ **CD-2 Approved - December 2010**
 - Approval of performance baseline
 - Technical, cost and schedule baseline frozen!

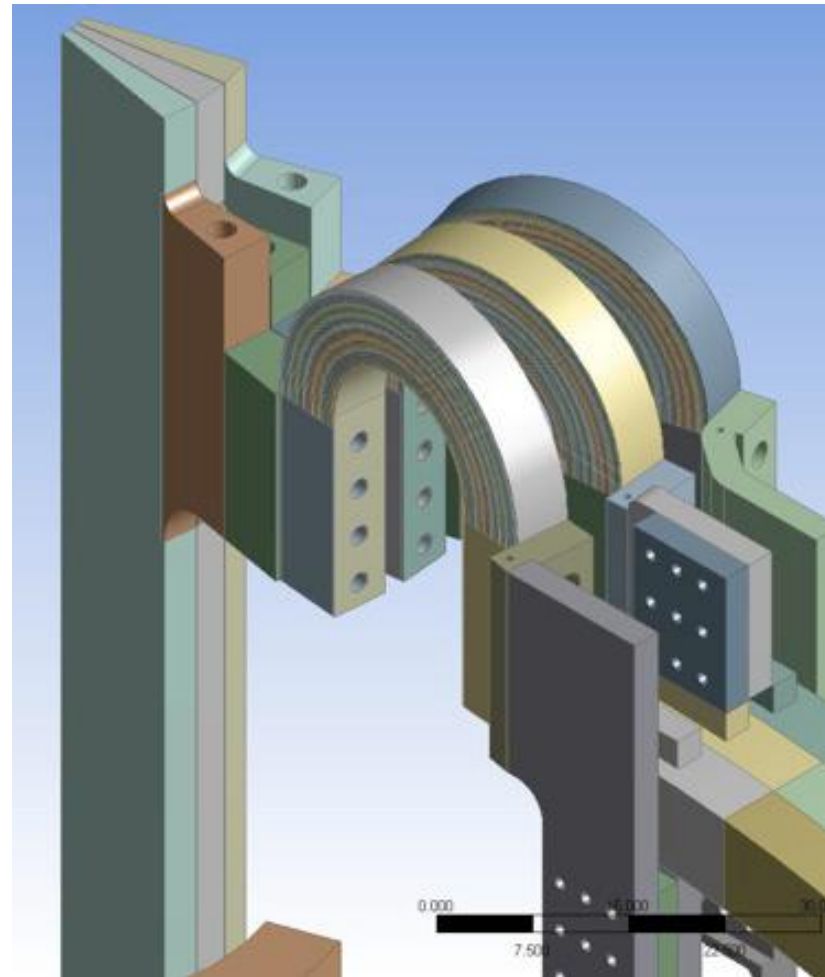
- ☑ **Complete 2nd NBI decontamination and begin refurbishment - December**

- ☐ **Award critical and long lead procurements**
 - Inner TF conductor (January)
 - TF Conductor machining (May)
 - Lead extensions (May)

- ☐ **Final Design Review - June**

- ☐ **SC-OPA (Lehman review) - August**

- ☐ **Request CD-3 Approval - September**



NSTX Upgrade Project Plans for 2012- 2013

- ❑ **CD-3 Approval - *October, 2011***
Authorization to begin procurement and fabrication

- ❑ **Begin Assembly of CS incl friction stir weld lead extensions to inner TF conductor – *January, 2012***

- ❑ **Continue NBI refurbishment**

- ❑ **Award critical and long lead procurements**

- ❑ **Begin outage – *April, 2012***

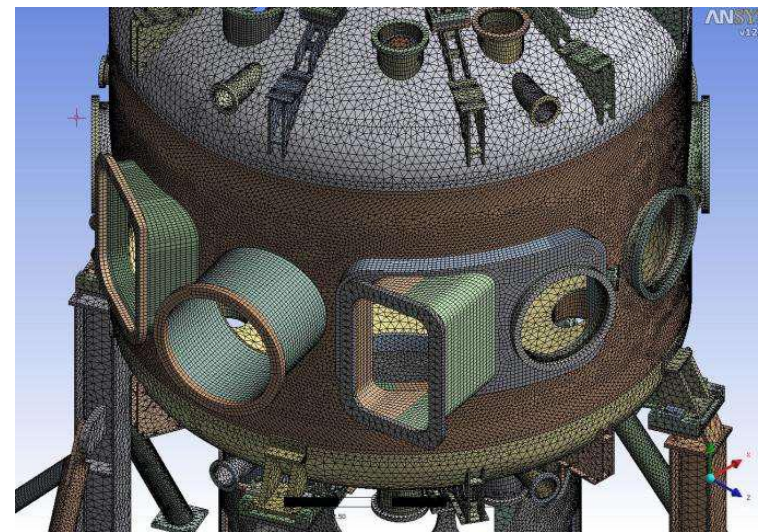
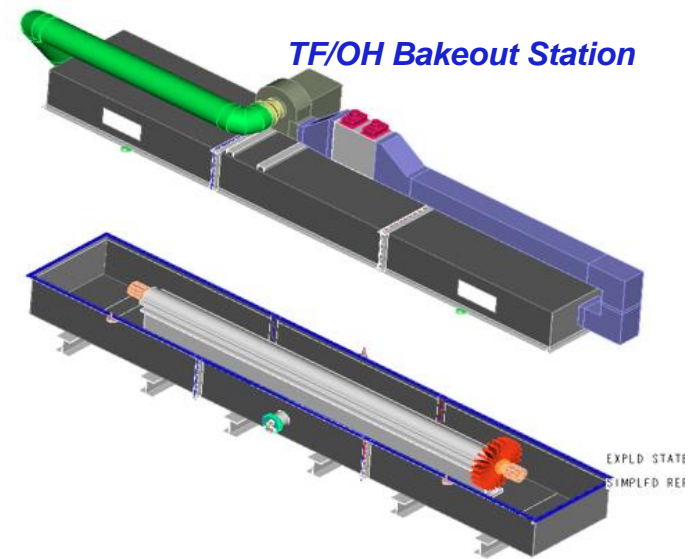
2013

- ❑ **Complete Diagnostics & Equipt removals**

- ❑ **Begin Final assembly of CS**

- ❑ **Complete refurbishment and begin relocation of 2nd NBI**

- ❑ **Begin structure and vessel modifications**



NSTX FY 2013 FWP Budget Summary (\$M)

Base and Incremental Cases

Budget cases	FY2011		FY 2012		FY2013	
	Base	ARRA	Base	Incr.	Base	Incr.
Run Weeks	14	0	10	4.0	0	0
Facility Operations	21.2	0.4	16.3	0.94	7.2	
Fac. Enhancements	0.3	2.4	1.1	1.2	1.6	1.9
CS & 2 nd NBI	9.0	0	14.6	2.5	25.3	2.5
Facility Total	30.5	2.8	32	4.64	34.1	4.4
PPPL Research	10.0	0	11.3	0.2	12.1	0.6
Collab Diag Interf.	0.4	0	0.4	0	0.4	0
Collaborations	5.9	0	6.1	0.1	6.3	0.3
Science Total	16.3	0	17.8	0.3	18.8	0.9
NSTX Total	46.8	2.8	49.8	4.94	52.9	5.3

Base Funding:

- The base facility operations resource to shift to upgrade after FY2012 operations.
- The research planning during the upgrade outage started include facility enhancements and collaborations.
- However, the conceptual design and travel funds are very much limited.

Incremental Funding:

- The upgrade project to accelerate critical path items and significantly reduce the schedule risks and overall cost, accordingly.
- Enables 4 extra run weeks in FY 2012 obtain valuable data before the upgrade outage.
- Allows significant conceptual design work in FY 2012- 2013 for facility/diagnostic enhancements in key science areas including divertor/PFCs and high-k
- Provide travel fund needed to engage in significant collaboration activities

Optimized Plan Developed for FY 2011–13

Exciting Opportunities and Challenges Ahead

- **Very productive FY2010 run with all milestones completed**
- **FY 2011 - 2012 run to start with new capabilities**
 - MAPP Probe (Purdue U)
 - Tangential soft-x ray array (JHU)
 - Tangential FIDA (UCI)
 - Real time rotation measurements and control
- **ARRA funding enables facility upgrades to support FY 2011–12 research plan**
 - MSE-LIF to complement MSE-CIF (Nova Photonics)
 - 2nd SPA for improved RMP/EF/ RWM capability
 - MPTS Extra Channel for improved pedestal resolution
 - Molybdenum In-board Divertor Tiles
- **NSTX Upgrade project is making good progress**
 - Successful DOE OFES CD-2 Approval in Dec 2010
 - Research activities in FY 2013 - 2014 are being planned
- **Incremental budget greatly enhances facility capability and output**
 - Accelerate the center-stack and 2nd NBI upgrade schedule and reduce risks
- **10% cut case causes 2 months delay of upgrade or 60% cut in research effort risking the post upgrade research operations**