

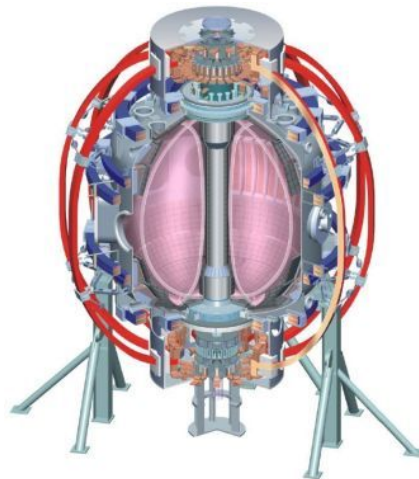
NSTX Facility & Diagnostic Plan

Masa Ono

For the NSTX Team

NSTX Research Forum
PPPL B318
March 15 - 19, 2011

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
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UC Davis
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Culham Sci Ctr
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Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
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JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
Seoul Nat. U
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Talk Outline

- **FY 2010 Plasma Operations Summary**
- **NSTX Upgrade Project Status and schedule**
- **NSTX Operations Schedule**
- **FY 2011-2012 Facility / Diagnostic Upgrade Plan and Status**
- **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/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 control coils, extra MPTS channels, MSE-LIF, Tangential fast ion D-alpha diagnostics

NSTX Upgrade Project

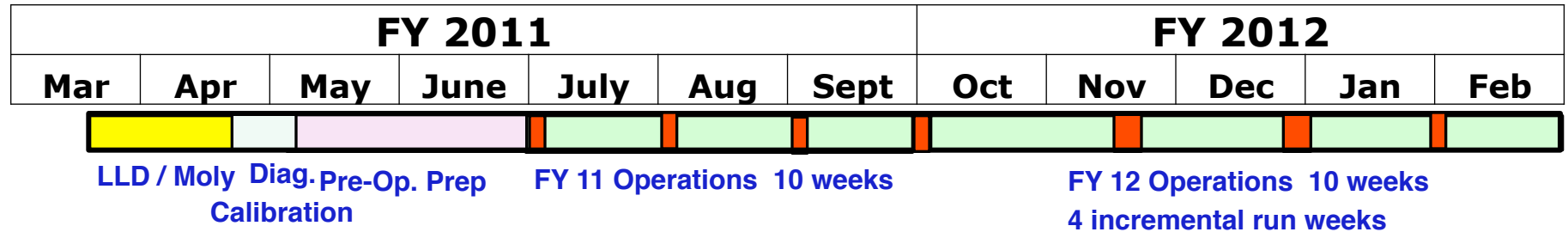
Good Progress to Date

- ☑ **CD-0 Approved - *February 2009***
 - *Approval of mission need*
 - *Begin Conceptual design*
- ☑ **Conceptual Design Review - *October 2009***
 - **NSTX FY 2010 Research Forum**
- ☑ **CD-1 Approved - *April 2010***
 - *Approval of Alternate selection and cost range*
 - *Begin Preliminary Design*
 - *Begin Capital costing*
- ☑ **Preliminary Design Review - *June 2010***
- ☑ **CD-2 Approved - *December 2010***
 - *Approval of performance baseline*
 - *Technical, cost and schedule baseline frozen!*

- In FY12, the NSTX operations team shifts to the Upgrade Project on April 1, 2012.
- It is therefore critically important to end the NSTX operation in February 2012 so that we can start the Upgrade Outage on schedule.

NSTX Operation Schedule for 2011-2012

Need to make priorities to stay on course toward the upgrade



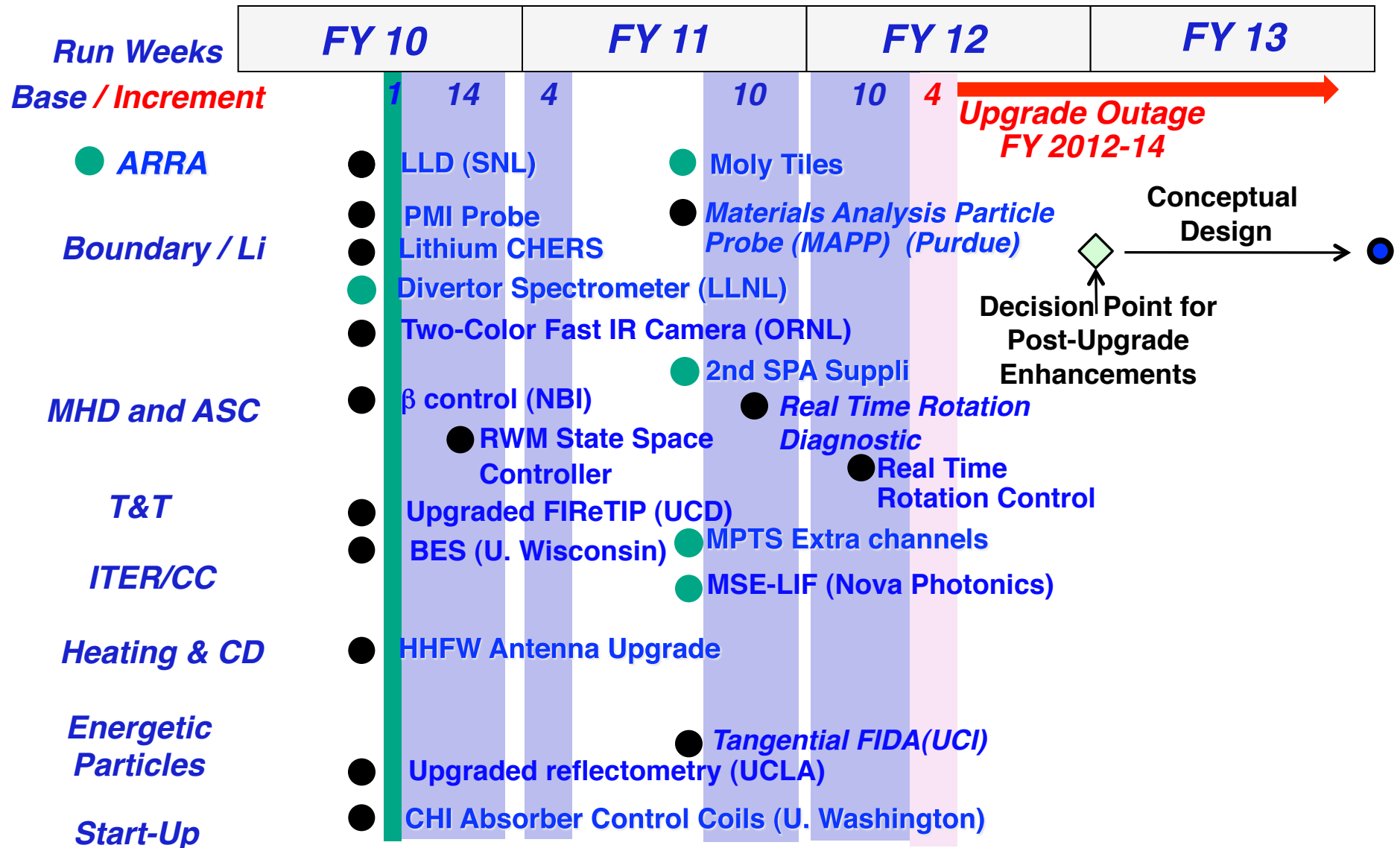
The remaining 2011-2012 run to be the last run before the upgrade.

- LLD reinstallation and Moly-tile installation March 14 – April 20 (this schedule could be accelerated by several days).
- Diagnostic calibration, pump-down, bake out, ISTP in April – June.
- Start of the run in July and continue the run through Sept for 10 run weeks. The schedule could be accelerated by 2 weeks. It will still be challenging to get 10 run weeks in FY 2011.
- FY 2012 run to start in October and through February 2012 for 10 run weeks but try to run as much as possible until the end of February.
- No planned vessel entry during the operations. Minimize argon vents. Lithium to be used sparingly.

Please plan vacation (whenever you can) prior to the start of the July plasma operations.

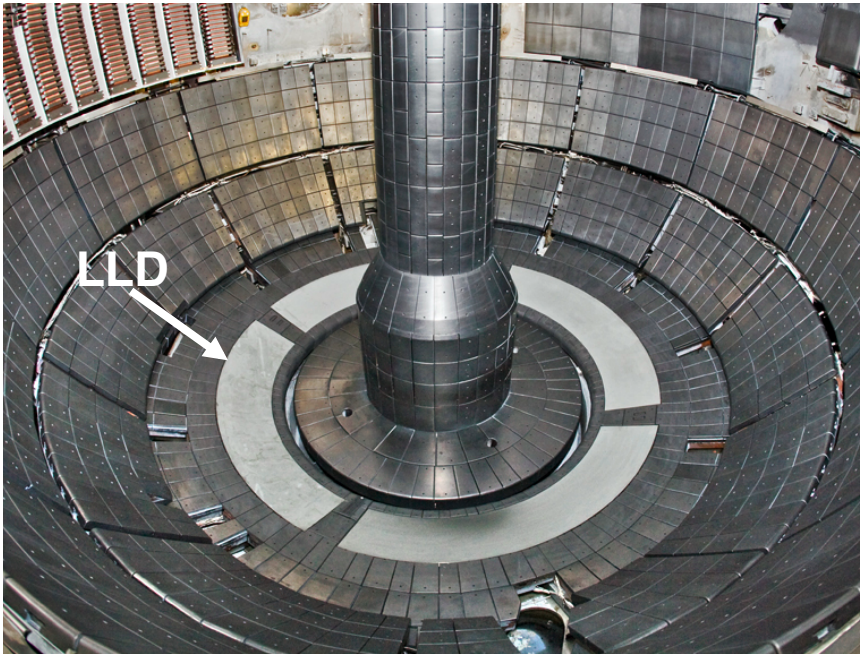
NSTX Near Term Facility Plan

Decision Point in FY 2012 for Post Upgrade Enhancements

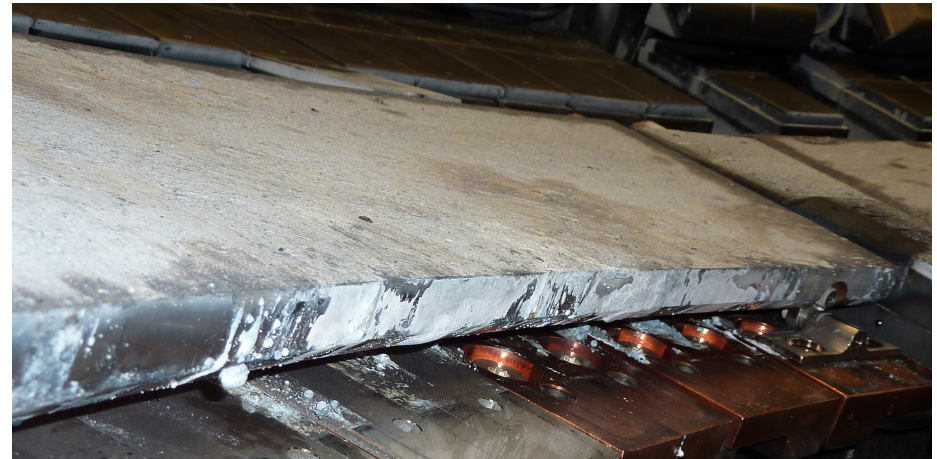


Liquid lithium divertor target system commissioned

Utilized in four LLD experimental proposals in three campaigns



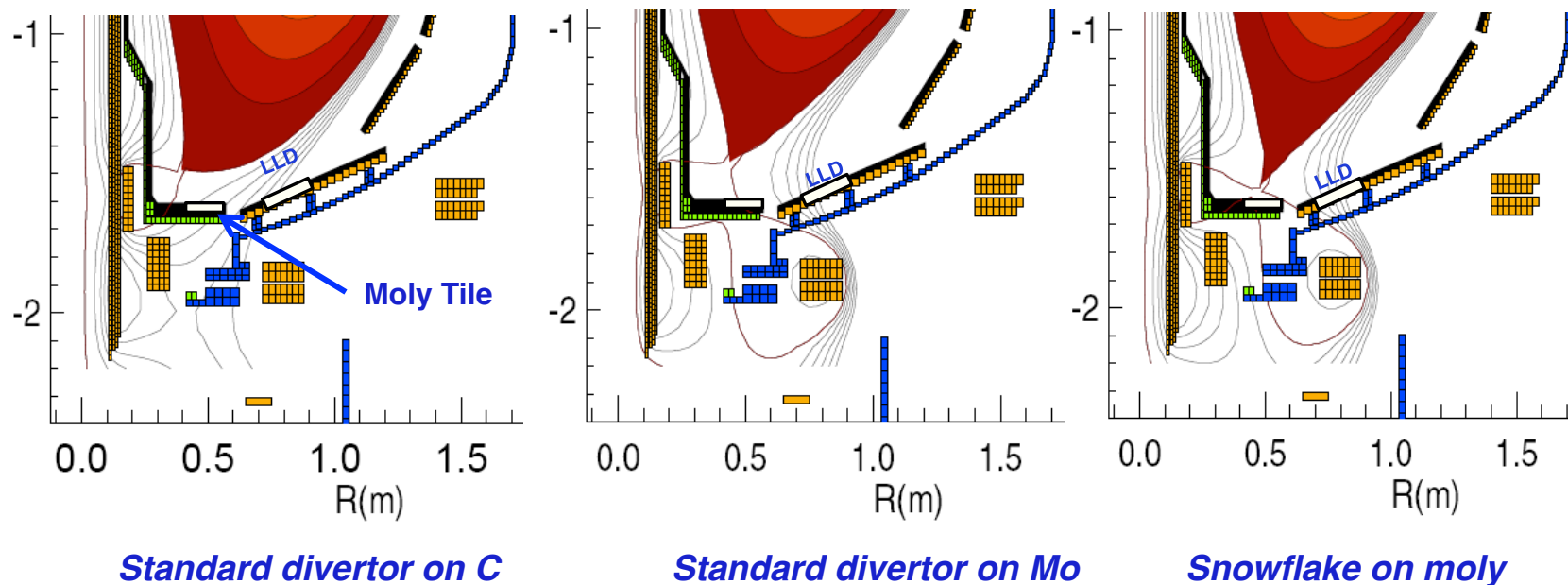
LLD plate covered with lithium
Significant over-flow evident consistent
with evaporating 2 x fill capacity



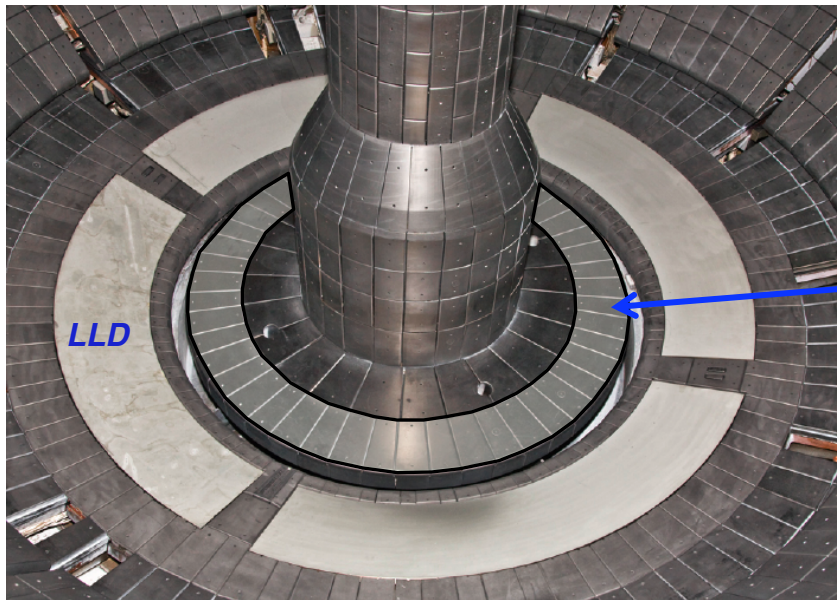
- Plasma surface heating raised the LLD surface temperature to $\sim 200 - 250$ °C.
- No significant moly surface damage or moly influx observed.
- Damage discovered after operations. Plasma disruptions caused mechanical support and arcing damages. Explains why electrical heaters failed. Air heater has worked well but the heating tubes were arc damaged.
- LLD plates being reinstalled with improvements in the mechanical support structure and grounding. No active heaters but will utilize plasma heating.

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

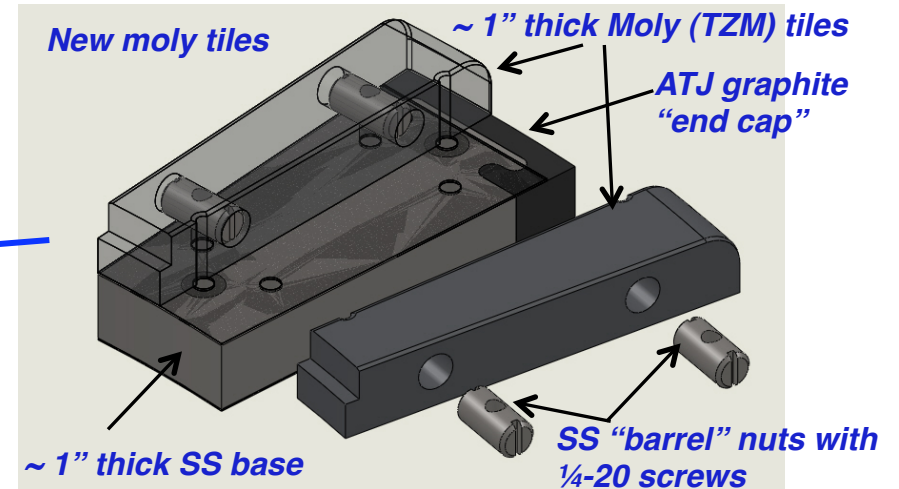
- **To quantify fraction of core C coming from lower divertor for high- δ shapes**
- **Potentially reduce C content of Li ELM-free scenarios**
- **Characterize Mo performance to inform choice of div/CS PFC in Upgrade**
- **Apply Li (LiTER) to divertor moly surfaces for partial/full liquid lithium**
-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



Installing Molybdenum Tiles on Lower Inboard Divertor for FY 2011 Run



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
- Inboard divertor area similar to the upgrade



• Plasma heating $\Delta T \sim 200^\circ\text{C}$ should be sufficient to get the moly tile surfaces to the liquid lithium temperature by controlling the strike-point location.

***NSTX leads lithium experimental program in the growing world program
(NSTX, LTX, FT-U, T11M, TJ-II, EAST, RFX, KTM)***

NSTX Lithium Program uniquely contributes to world program: Diverted H-mode experiments

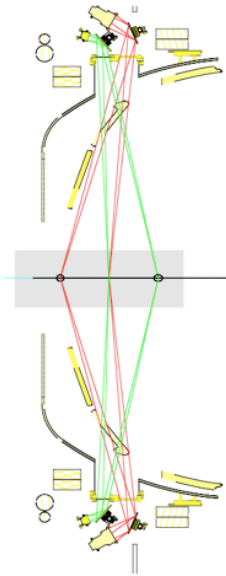
Lithium in NSTX yielded many important results:

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

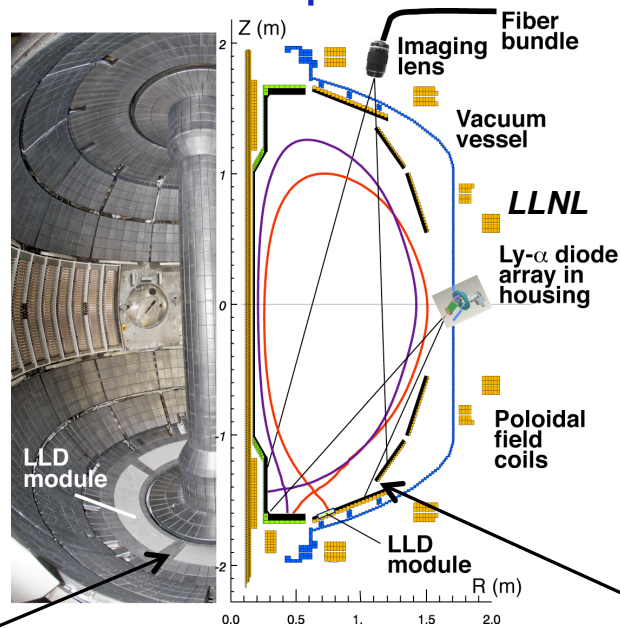
***2nd Lithium Symposium to be held at PPPL on April 27 – 29, 2011
(<http://isla2011.pppl.gov/>)***

New Diagnostic Capabilities Introduced in FY 2010 for Liquid Lithium Divertor and Boundary Physics

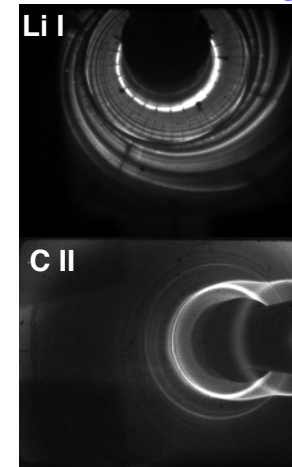
**Lithium
CHERS**



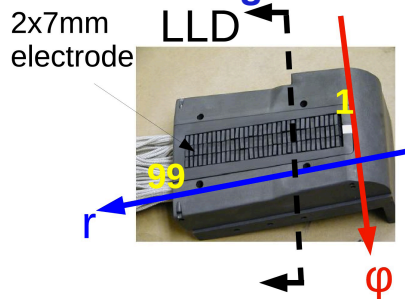
**Divertor Imaging
Spectrometer**



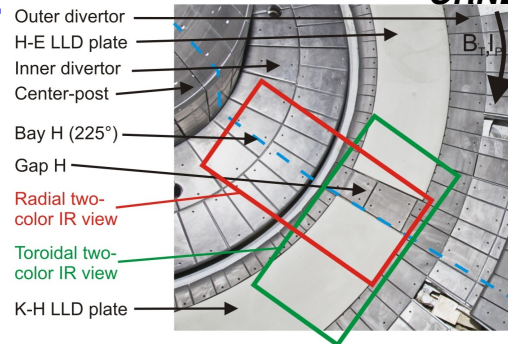
**Two fast 2D visible
cameras with full
divertor coverage**



Dense Langmuir Probe Ar



Dual-band fast IR Camera ORNL



PMI Probe

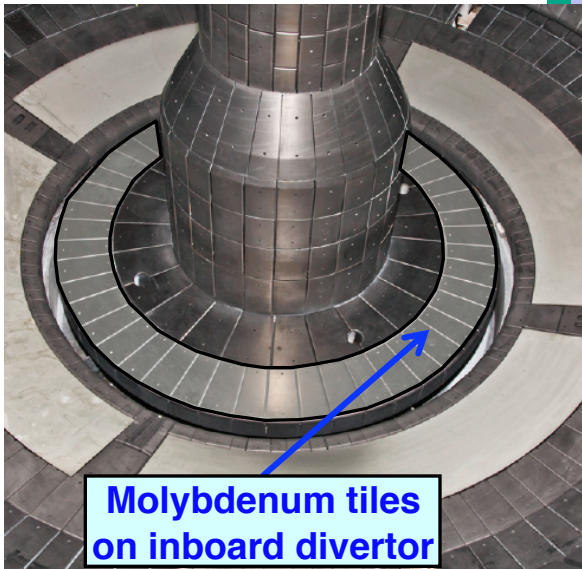


Purdue

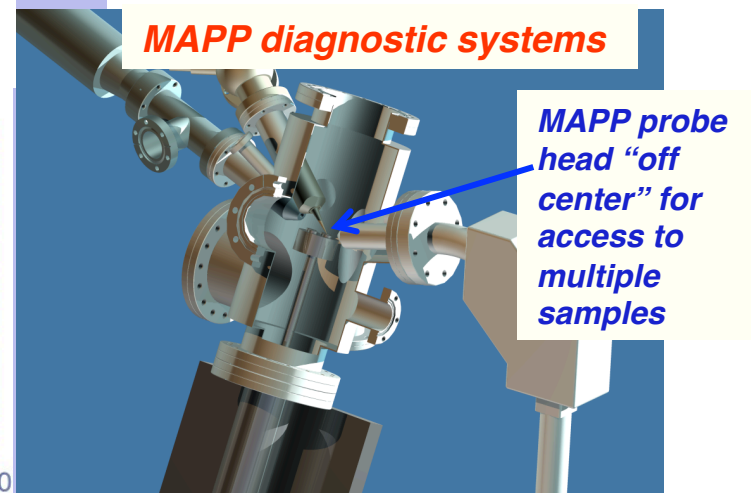
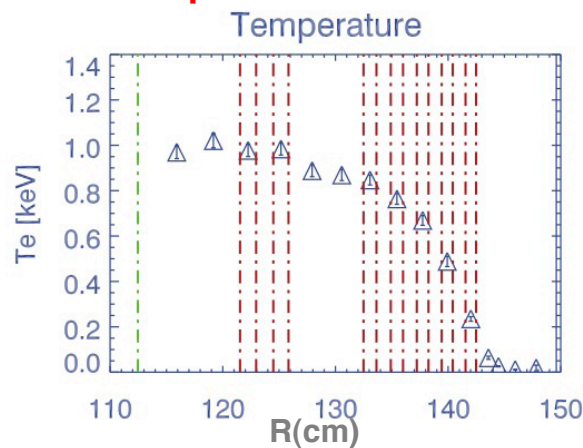
Boundary with H-Mode Pedestal Physics for JRT

MPTS Extra Channels, MSE-LIF, MAPP Probe

ARRA	FY 10	FY 11	FY 12	FY 13
Run Weeks Base	14	4	10	10
Boundary / Li / Pedestal	<ul style="list-style-type: none"> ● Upgraded FIRETIP (UCD) ● BES (U. Wisconsin) ● LLD (SNL) ● PMI Probe ● Lithium CHERS ● Divertor Spectrometer (LLNL) ● Two-Color Fast IR Camera (ORNL) 	<ul style="list-style-type: none"> ● MPTS Extra channels ● MSE-LIF (Nova Photonics) ● Moly Tiles ● Materials Analysis Particle Probe (MAPP) (Purdue) ● ME-Pedestal-20 channel SXR (Johns Hopkins) 	<p style="color: red; font-weight: bold;">Upgrade Outage</p>	

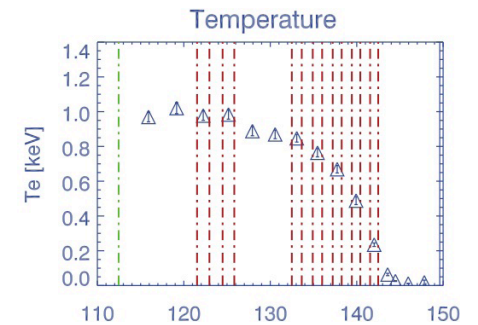
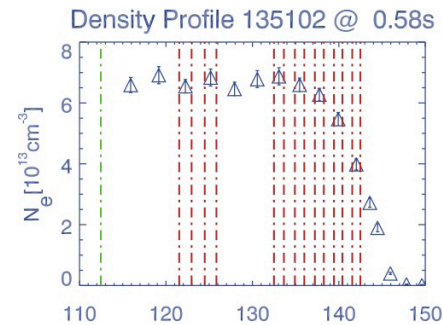


Additional 12 MPTS chs for enhanced pedestal resolution

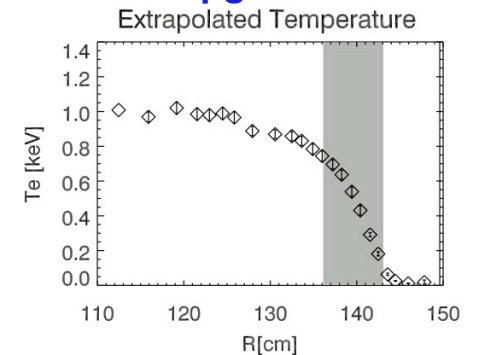
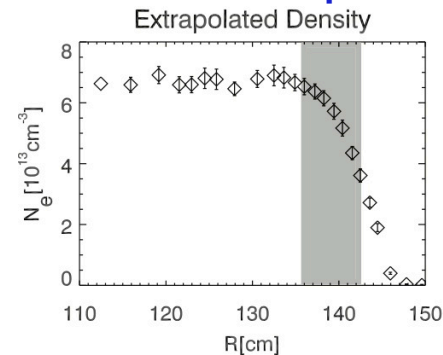


MPTS Extra Channel Upgrade Status

To support H-mode pedestal JRT milestone



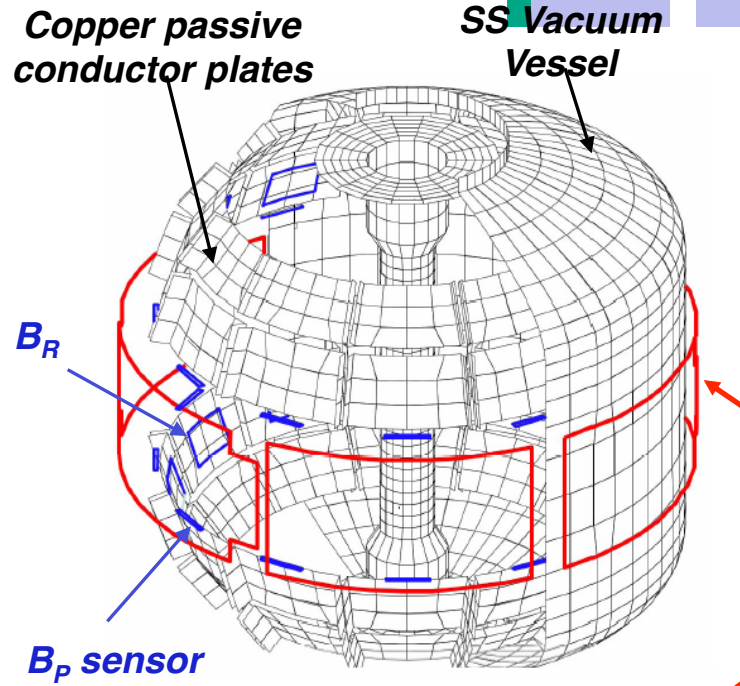
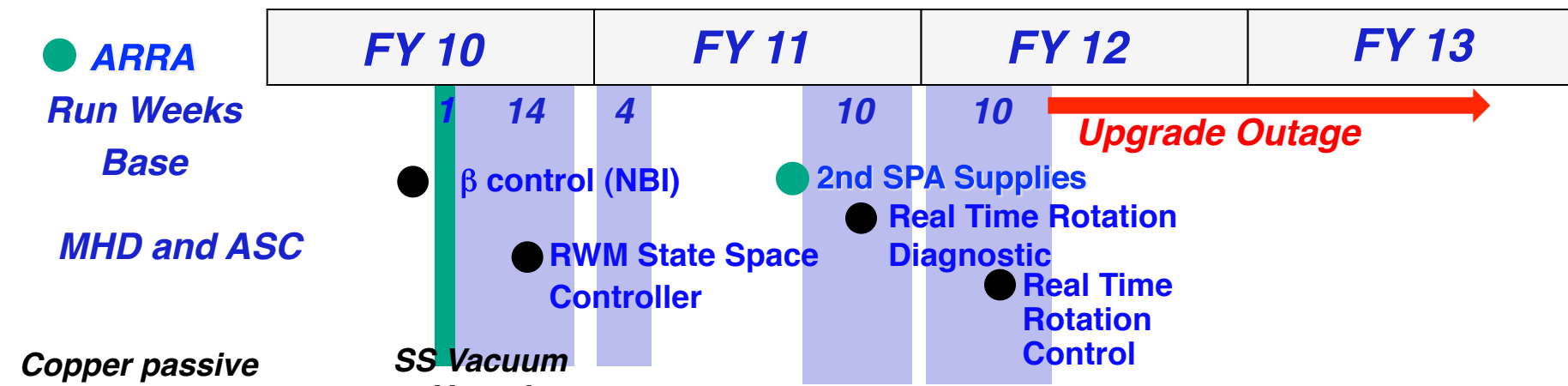
MPTS spatial locations after upgrade



- 12 new polychromators have been assembled, tested, and installed at D-site (shown above).
- Splitting of fiber bundles completed.
- **Expect to have 12 additional MPTS channels installed and calibrated by start of next run.**
- **Will provide improved spatial resolution in H-mode pedestal and ITB regions.**

New Capabilities for Macro-stability and Plasma Control

Sustain β_N and Understand MHD Behavior Near Ideal Limit



Real Time Rotation Diagnostic Status: Real-time measurement of toroidal rotation velocity at 4 spatial locations in plasma. The system will be taking data in FY 2011.

- 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

Transport and Turbulence

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

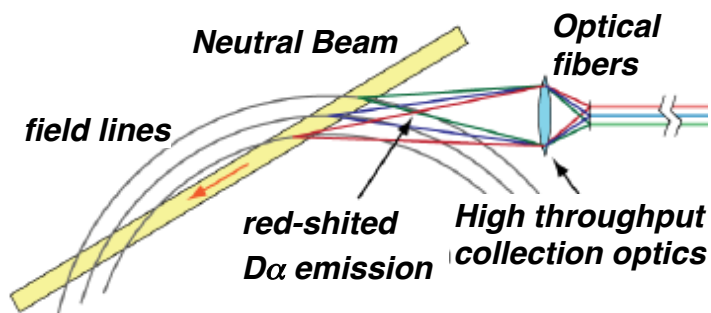
● **ARRA**

Run Weeks
Base

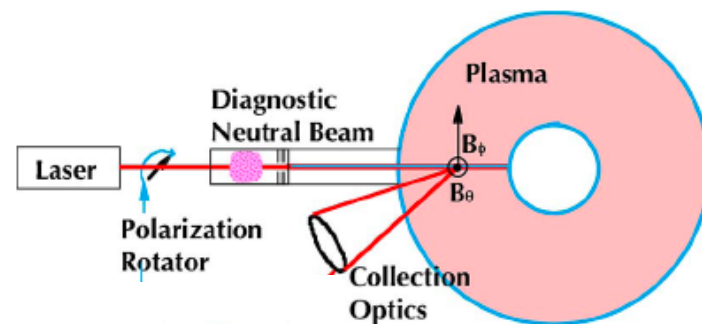
T&T

	FY 10		FY 11		FY 12		FY 13	
Run Weeks	1	14	4	10	10	Upgrade Outage →		
Base								
T&T	● Upgraded FIRETIP (UCD)		● MPTS Extra channels					
	● BES – 16 channels (U. Wisconsin)		● BES – 32 channels (U. Wisconsin)					
	● Solid-state high-k Source		● MSE-LIF (Nova Photonics)					

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

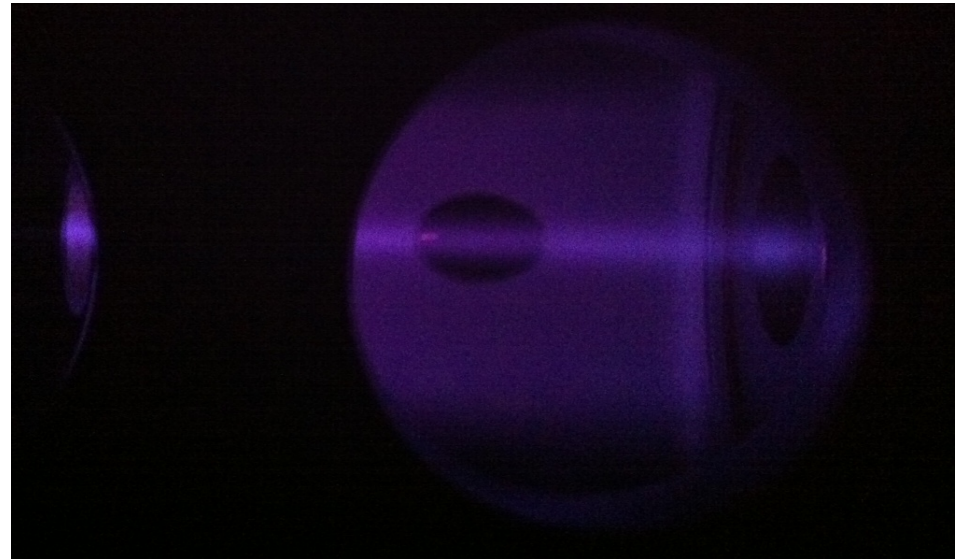
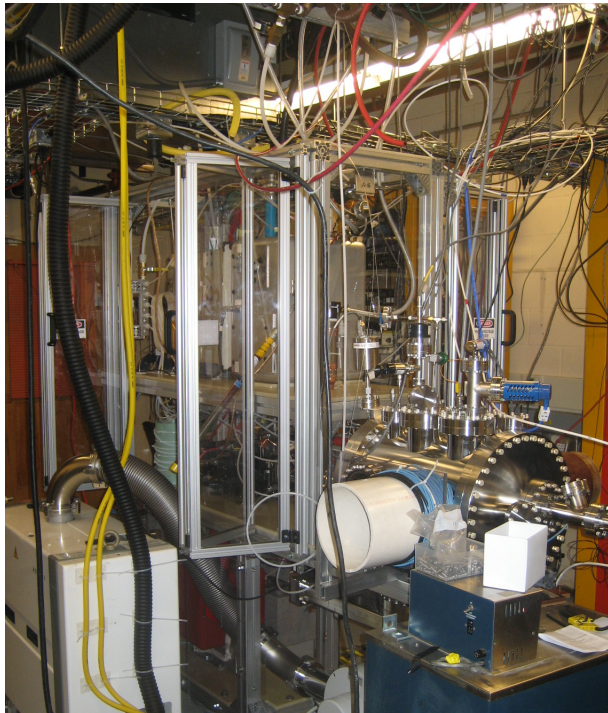


MSE-LIF to Measure $E_r(r)$, $B(r)$



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

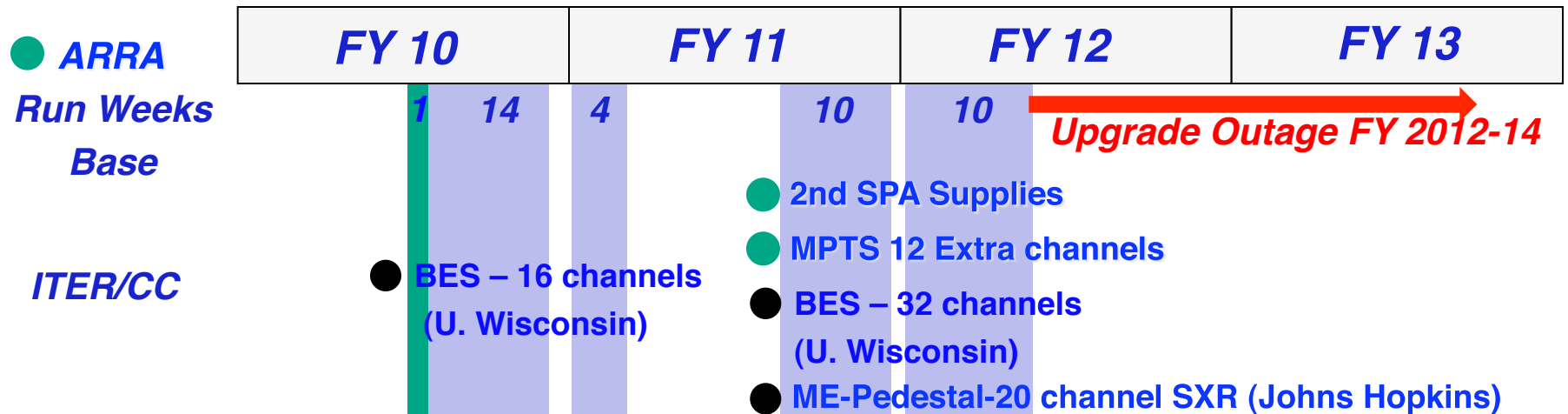
Motional Stark Emission – Laser Induced Fluorescence (MSE-LIF, Nova Photonics) Status



- Diagnostic Neutral Beam has been reconfigured for installation on NSTX and tested in lab (shown above). Laser has been tested in lab and works well.
- Modifications to NSTX infrastructure needed to support installation of DNB, laser, and viewing optics are going well.
- **Expect to have installation complete and ready for commissioning by start of next run.**
- **Initial run will start with 10 channels in FY 2011 and additional channels in FY 2012**

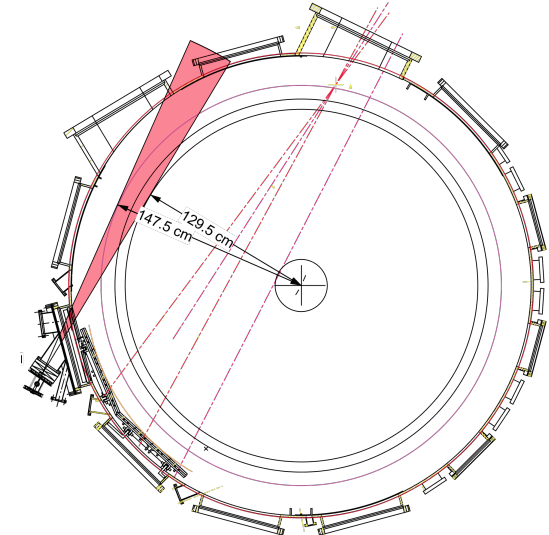
ITER and Cross-Cutting Research

3D field milestone supported by 2nd SPA, MPTS and BES



- 2nd Switching Power Amplifier (SPA) to enable n = 1, 2, 3 simultaneous control of 3D fields in FY 11
- BES to be expanded to 32 channels together with high-k to provide a comprehensive pedestal turbulence diagnostic set.
- 20 channel New Multi-Energy Soft-X-Ray Diagnostic (JHU) measures emission from the pedestal with ~ 1 cm resolution
- 12 additional MPTS channels improves the pedestal spatial resolution to ~ 1 cm

Multi Energy -Pedestal-SXR

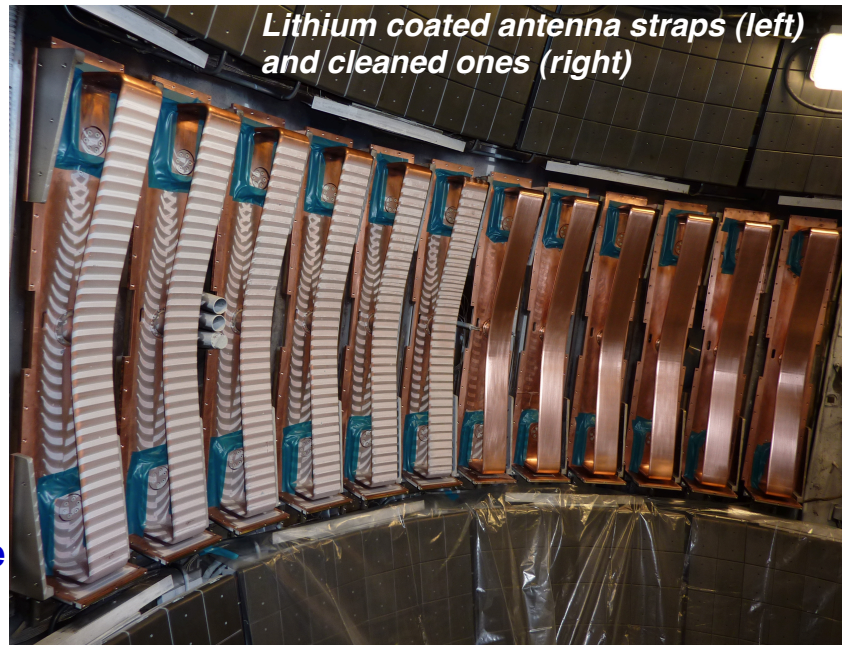
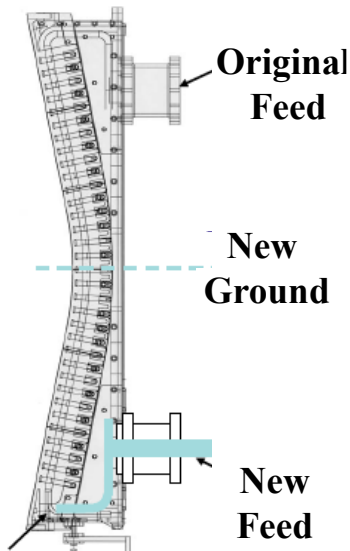
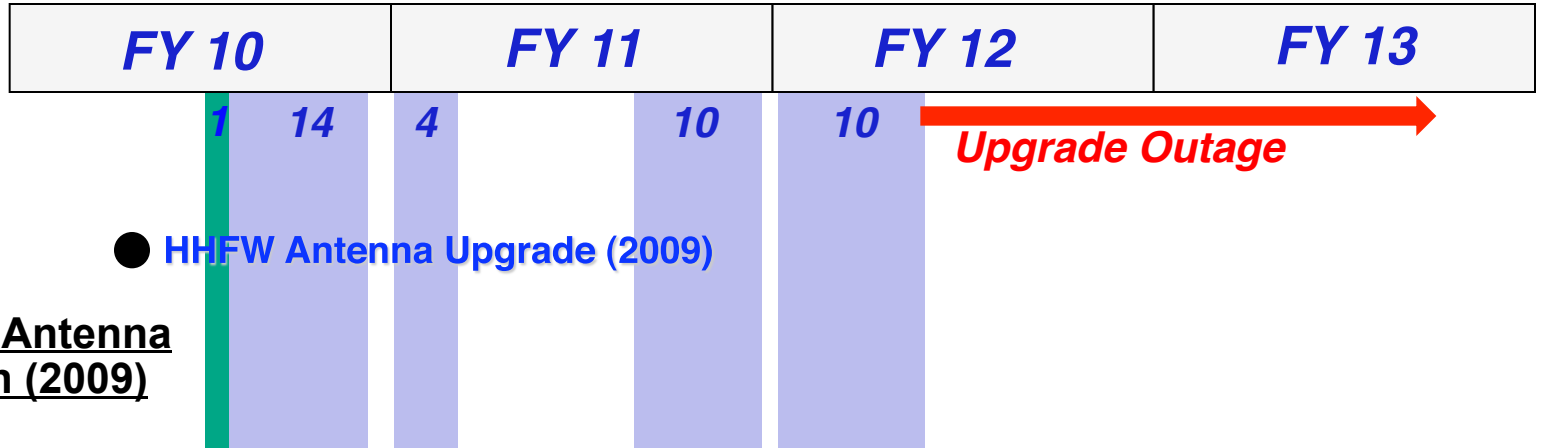


HHFW Operations Encountered Power Limit due to Heavy Lithium Use

Heavy lithium coating and lithium particulates were observed on the antenna

● **ARRA**

Run Weeks
Base



- 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

New Diagnostics for Energetic Particle Research Being Implemented in FY 2011

● **ARRA**

Run Weeks
Base

	FY 10	FY 11	FY 12	FY 13
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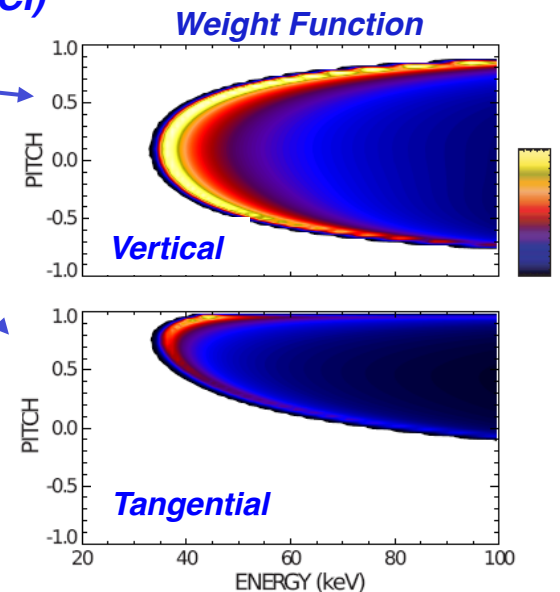
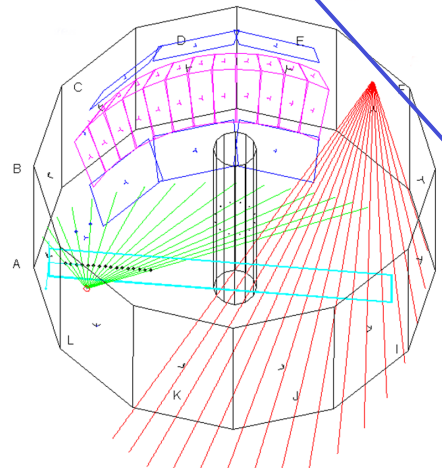


Energetic Particles

- BES (U. Wisconsin)
- Upgraded reflectometry (UCLA)
- Vertical FIDA (UCI) Available since 2009
- MSE-LIF (Nova Photonics)
- Tangential FIDA (UCI)

Tangential FIDA Views UC Irvine

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



- Utilize present **Fast Ion D-Alpha (FIDA)** system design with spectrometer: 2x16 channels
- Enhanced signal, better localization in velocity space weighted toward parallel velocity
- Well suited to investigate NBI fast ion transport and current drive physics

Solenoid-free Start-up

CHI enabled lower density lower inductance start-up

● ARRA

	FY 10	FY 11	FY 12	FY 13
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Run WeeksBase

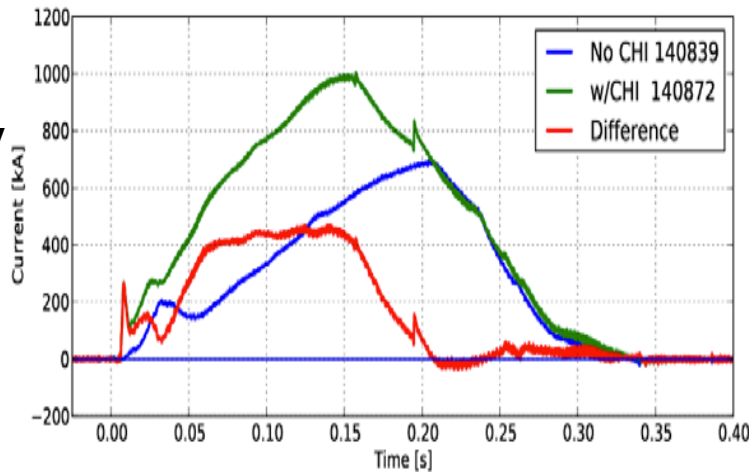


Start-Up

- LLD (SNL)
- CHI Absorber Control Coils (U. Washington)
- Moly tile cathode

Success of CHI aided by Low-Z Impurity Control

U Washington



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

Utilizing in-board moly tiles to provide cathode surfaces to reach ~ 0.5 MA

- 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

Multi-pulse Thomson scattering (30 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 (15 ch)
FIReTIP interferometer (6 ch)
Midplane tangential bolometer array (16 ch)

Turbulence/Modes Diagnostics

Tangential microwave high-k scattering
Beam Emission Spectroscopy
Microwave reflectometers
Ultra-soft x-ray arrays – tomography (4 arrays)
Fast X-ray tangential camera (500kHz)

Energetic Particle Diagnostics

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

(Collaboration contributions)

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
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 survey spectrometer
UV survey spectrometer
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis
X-ray crystal spectrometer (astrophysics)

Significant Facility and Diagnostic Capabilities Readied for FY 2011–12

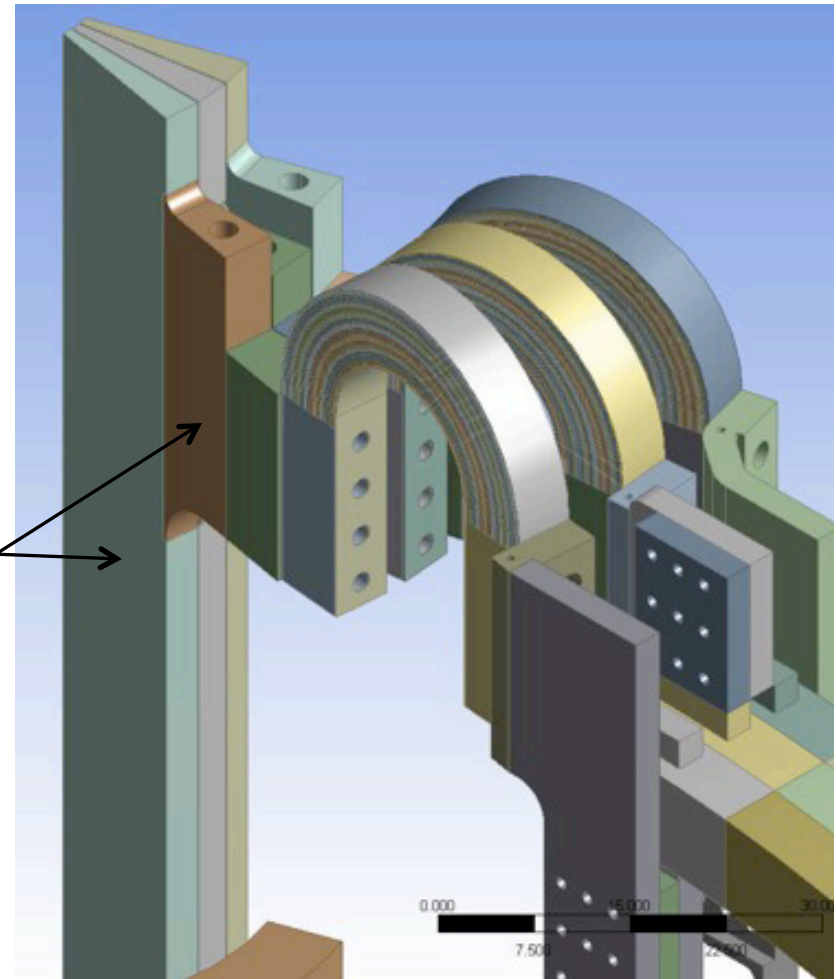
- **Very productive FY2010 run with all milestones completed**
- **FY 2011 - 2012 run to start with new capabilities**
 - MAPP Probe (Purdue U)
 - Tangential soft-x ray array (JHU)
 - Tangential FIDA (UCI)
 - Real time rotation measurements and control
- **ARRA funding enables facility upgrades to support 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 operations to begin after July 4 holiday through Feb. 2012**
- **NSTX Upgrade project is making good progress**
 - Successful DOE OFES CD-2 Approval in Dec 2010
 - FDR and CD-3 approval planned for FY 2011
 - NSTX Upgrade Outage to start in April 2012 through 2014

Let us make this last pre-upgrade run period, the best ever!

BACK-UP SLIDES

NSTX Upgrade Project Plans for 2011

- ☑ Complete 2nd NBI decontamination and begin refurbishment - **December**
- ☐ Design Peer reviews
 - CS (May)
 - NBI (March)
- ☐ 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

- ❑ **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**
 - *NB Rect Bellows*
 - *CS PFC's*
 - *Inner PF Coils*
 - *CS Casing*
 - *TF/OH materials*
 - *NBI vessel cap*
- ❑ **Complete FY12 operations campaign – *February, 2012***
- ❑ **Begin outage – *April, 2012***
- ❑ **Start Diagnostics & Equipt removals**

