NSTX

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Facility & Diagnostic Overview for 2010 - 12 and Beyond

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Masa Ono

For the NSTX Team

Culham Sci Ctr
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CEA, Cadarache
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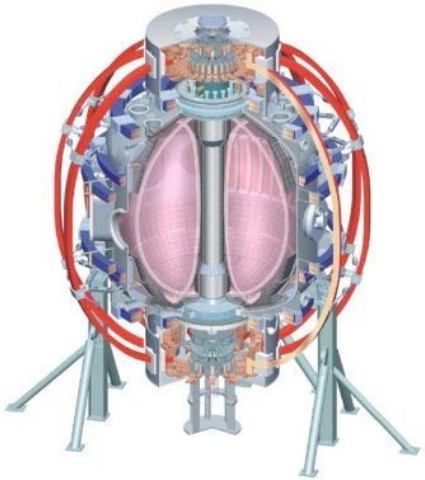
IPP, Garching
ASCR, Czech Rep
U Quebec

NSTX Program Advisory Committee (PAC 27)
PPPL, February 3-5, 2010



Talk Outline

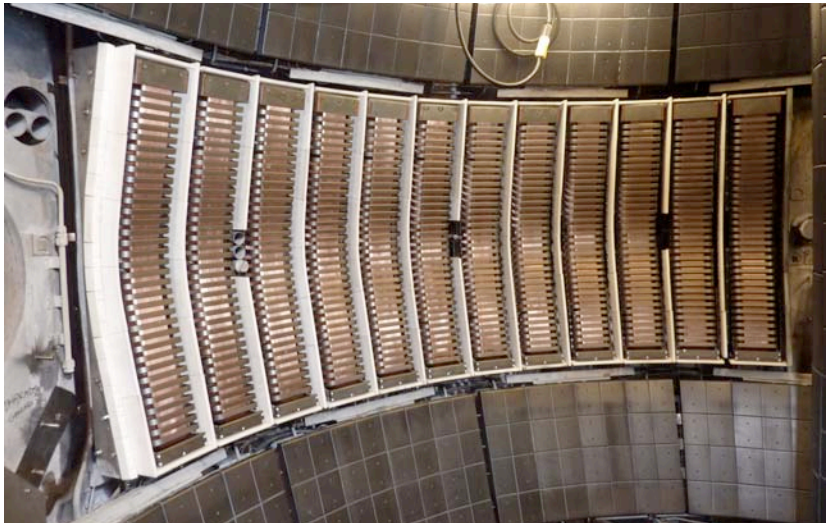
- FY 2009 Plasma Operations
- FY 2009 Outage Activities
- Facility / Diagnostic Status
- FY 2010-2012 Facility / Diagnostic Upgrade Plan and Status
- Major Upgrade Project Status: New Center-stack and 2nd NBI
- FY 2010 - 2012 Budget
- Summary

Successful FY09 operations completed

- **17 run weeks: 2750 good plasmas out of 2900 attempts (~95%): more plasma shots than any other year for NSTX**
  - **FY08: 16.5 run weeks: 2570/2760 (93%)**
  - **FY07: 12.6 run weeks: 1890/2080 (90%)**
  - **FY06: 12.7 run weeks: 1615/1930 (84%)**
- **Over 50 XP/XMPs performed: more than any other year**
- **New capabilities in FY09**
  - **HHFW upgrade allowed for lower strap voltage, higher power (up to 4 MW)**
  - **Dual Li-powder dropper system to supplement dual lithium evaporators**
  - **Sample probe for retention measurements and surface analysis**
  - **Fast IR camera for ELM-resolved heat flux measurements**
  - **NBI Feedback**
  - **CHI absorber coil energization**
  - **Reversed B_T**

Outage Completed and Preparing for FY 2010 Run

- **NSTX Outage Completed Safely**
  - Installed Liquid Lithium Divertor (LLD) and in-vessel optics for Beam Emission Spectroscopy (BES)
  - Performed diagnostic calibrations, including full neutron calibration
  - Removed lithium residue from PFCs and HHFW antenna



- **Preparing for 15 weeks of NSTX experimental operation in FY 2010**
  - Vessel evacuated
  - 3 week bake-out planned
  - Plasma operation to resume in mid-March and be completed in July-August

Diagnostic Systems Growing with Strong Collaboration Contributions

Collaboration contributions

MHD/Magnetics/Reconstruction

- Magnetics for *equilibrium reconstruction*
- Diamagnetic flux measurement
- 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*
- *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 resolvin
- Neutron measurements
- *Fast Ion D_α profile measurement*

Edge Divertor Physics

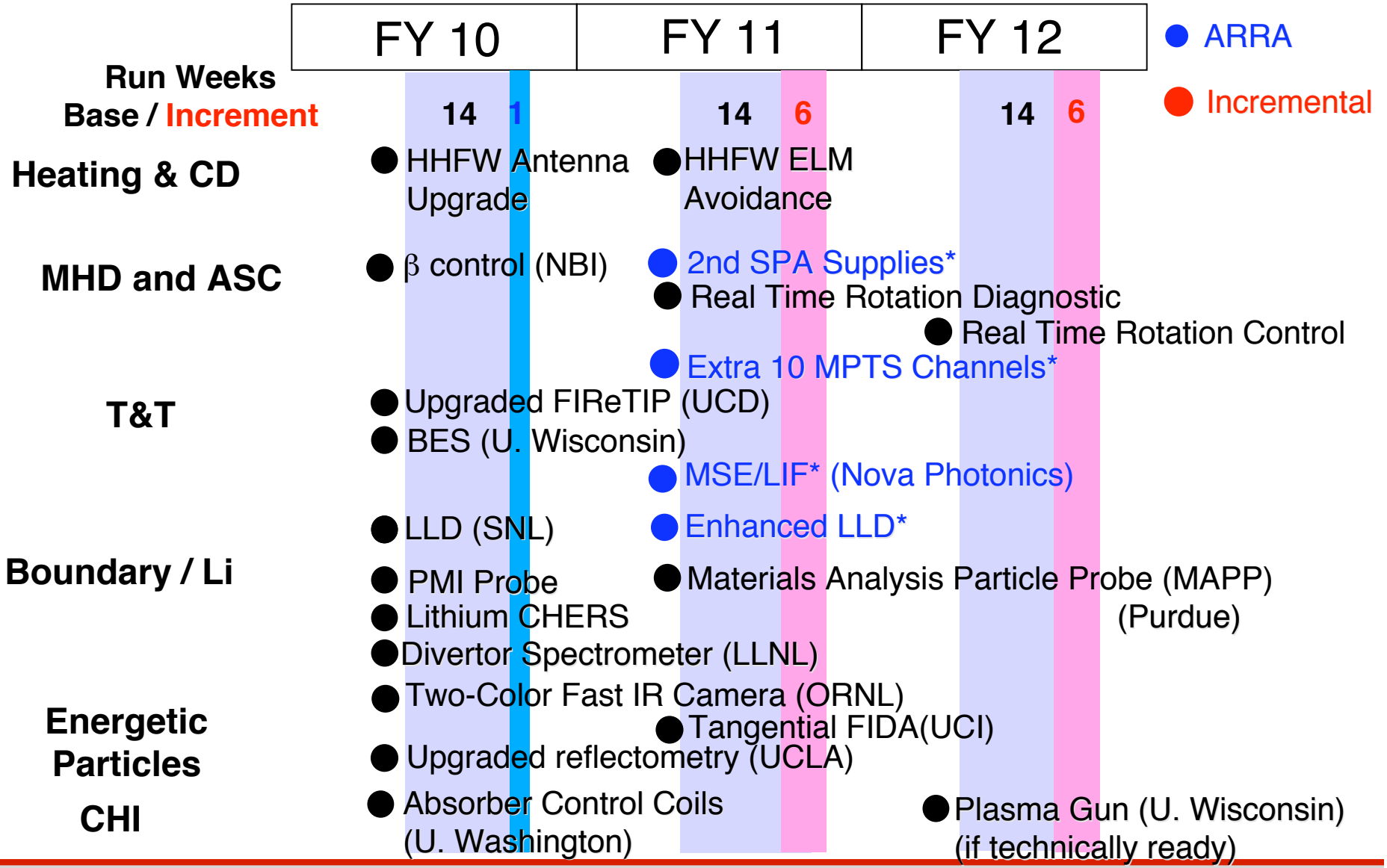
- *Gas-puff Imaging (500kHz)*
- *Fixed Langmuir probes*
- High density Langmuir probe array
- Edge Rotation Diagnostics (T_i, V_ϕ, V_{pol})
- *1-D CCD H_α cameras (divertor, midplane)*
- *2-D divertor fast visible camera*
- Divertor bolometer (20ch)
- *IR cameras (30Hz) (3)*
- *Fast IR camera*
- Tile temperature thermocouple array
- Dust detector
- Edge Deposition Monitors
- *Scrape-off layer reflectometer*
- *Edge neutral pressure gauges*
- *PMI 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)*

NSTX Near Term Upgrade Plan

ARRA Funding Significantly Enhances Research Capability



ARRA Funding Greatly Expands Research Capability

Will Significantly Increase NSTX Science Output

Enhanced operation of major fusion facilities in FY09 and FY10

- 6 extra run weeks in FY09 – 10 will enable NSTX researchers to conduct additional high priority fusion plasma experiments.

Diagnostics and Facility Upgrades in FY10 – 11 will enhance research capabilities and support the FY11 joint research milestone:

- Extra channels for the multi-pulse Thomson scattering system for improved spatial resolution in the H-mode pedestal and edge.
- Advanced Motional Stark Effect Laser Fluorescence diagnostic system for internal magnetic and electric field measurements.
- Enhancement to the lithium liquid divertor diagnostic and operational capability for improved divertor pumping to reduce edge collisionality.
- 2nd switching power amplifier system for improved error field/resistive wall mode/resonant magnetic perturbation spectra to control the edge error field.
- Post Doctoral Fellows to support targeted areas of research.

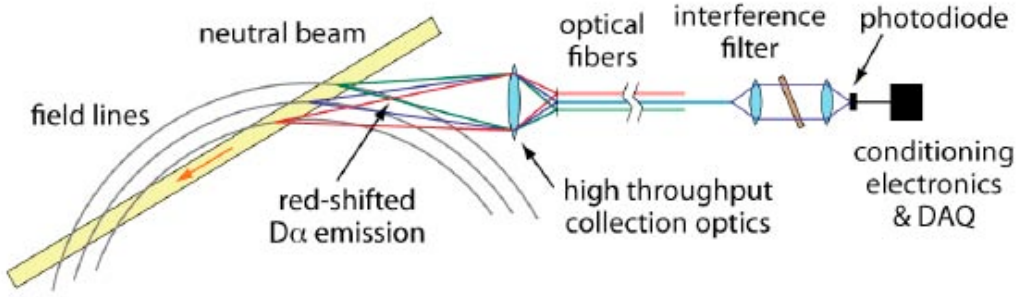
Transport and Turbulence

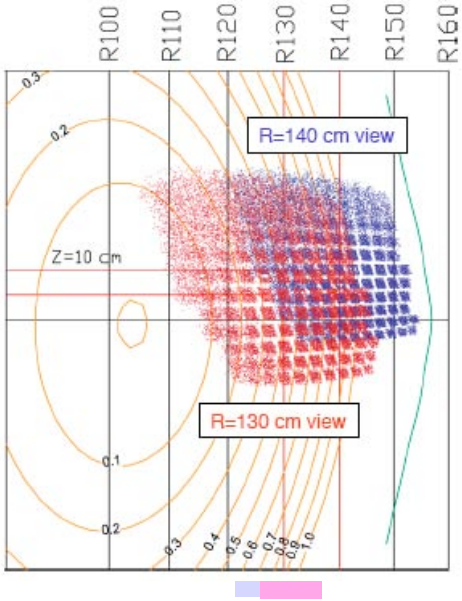
Increase and Understand H-mode Confinement at Lower n_e, ν^*

	FY 10	FY 11	FY 12
Run Weeks			
Base / Increment	14 / 1	14 / 6	14 / 6
T&T	● Upgraded FIReTIP (UCD) ● BES (U. Wisconsin)	● Extra 10 MPTS Channels* (Improve spatial resolution for e-ITBs) ● MSE/LIF (Nova Photonics)*	

● ARRA

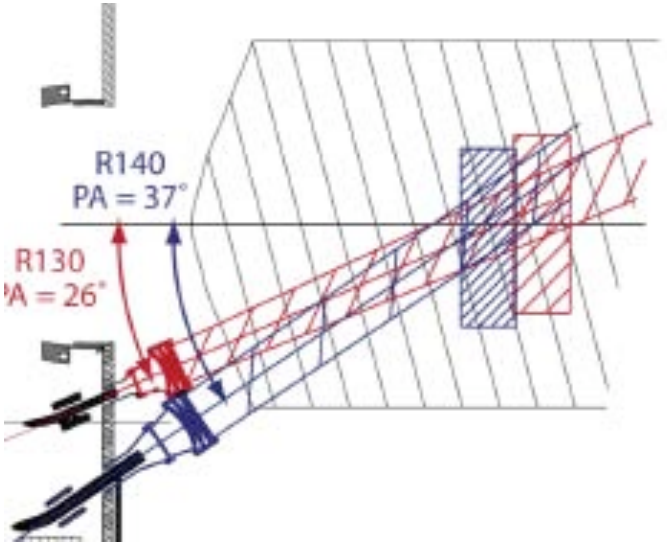
Beam Emission Spectroscopy (30 channels) configuration for 1-D (AE eigen-function) and 2-D (turbulence) together with high-k to provide a comprehensive turbulence diagnostic set





Beam Emission Spectroscopy Diagnostic

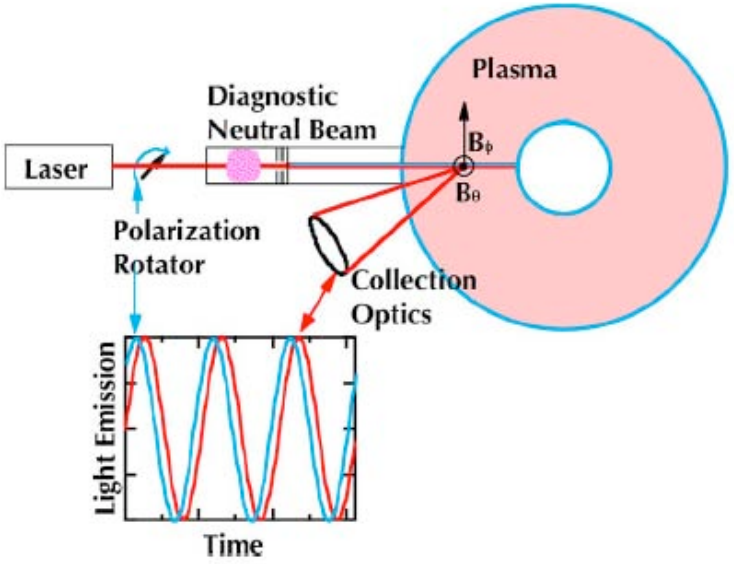
With High-k to Provide Comprehensive Turbulence Diagnostic Set

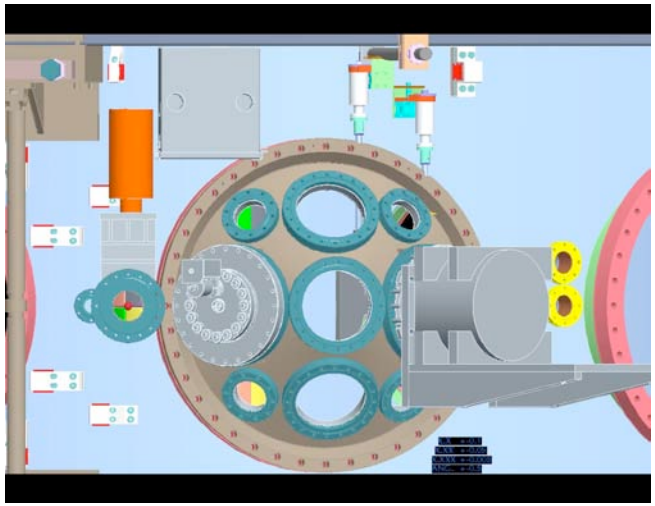


- Two re-entrant sets of optics required to match field line pitch over most of outer plasma radius (r/a=0.3-1.0)
- In-vessel BES component installation completed.
- Optics, fibers, and detectors are being installed during current outage
- Low-noise, cooled PIN photodiode detectors being fabricated by University of Wisconsin (32 channels)
- Plan to take initial data in spring 2010

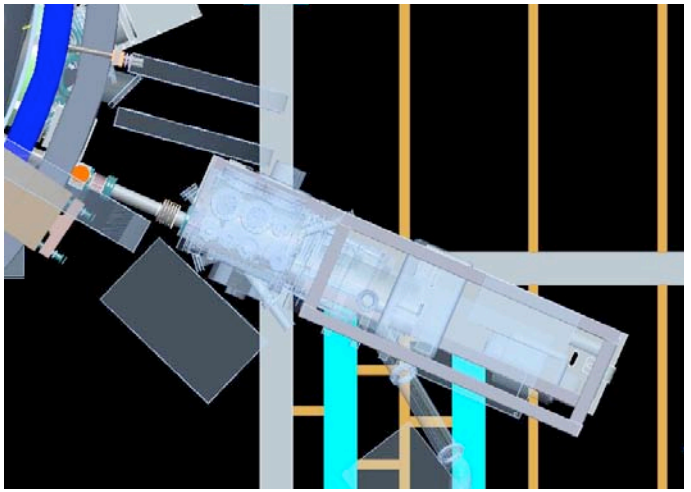
G. McKee, R. Fonck, D. Smith (U. Wisconsin), B. Stratton, G. Labik (PPPL) et al.,

Motional Stark Emission-Laser-Induced Fluorescence
Measures Field Pitch Angles and |B| and $E_r(r)$ with MSE-CIF





- **A collaboration with Nova Photonics under DOE Innovative Diagnostic Initiative**
  - **Provides DNB/laser, optics, and detectors**
  - **DNB packaged for installation on NSTX**
  - **Diode laser being tested**
- **PPPL provides diagnostic interface and infrastructure needed for DNB/laser**
- **Design nearly complete**
- **Readied for operation in FY 2011 run**

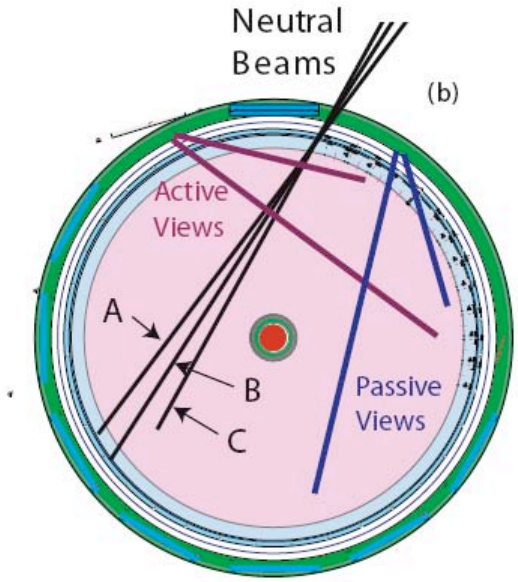


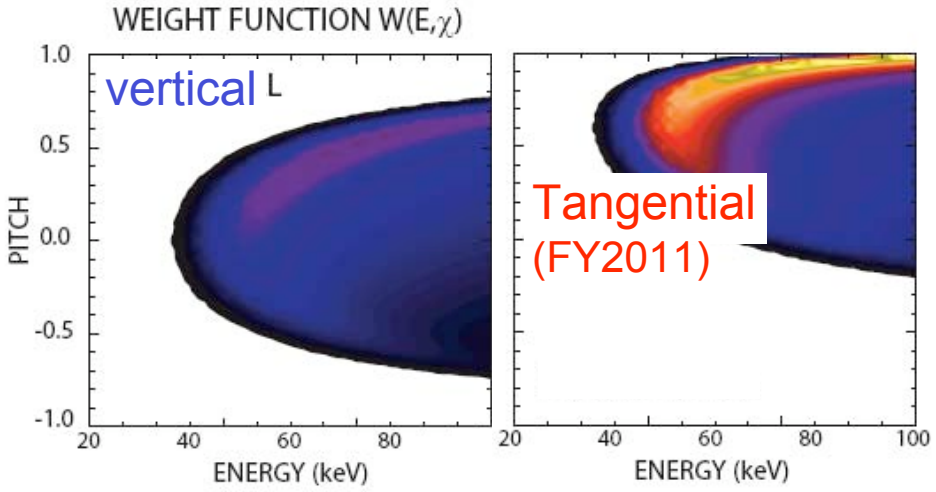
E. Foley, F. Levinton (N. Photonics), B. Stratton (PPPL) et al.,

Powerful Diagnostics for Energetic Particle Research Are Being Implemented on NSTX

	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 1	14 6	14 6
Energetic Particles	● Vertical FIDA (UCI) ● BES for AE eigenmodes (U Wisconsinl)	● Tangential FIDA (UCI) ● Upgraded reflectometry (UCLA)	

● ARRA





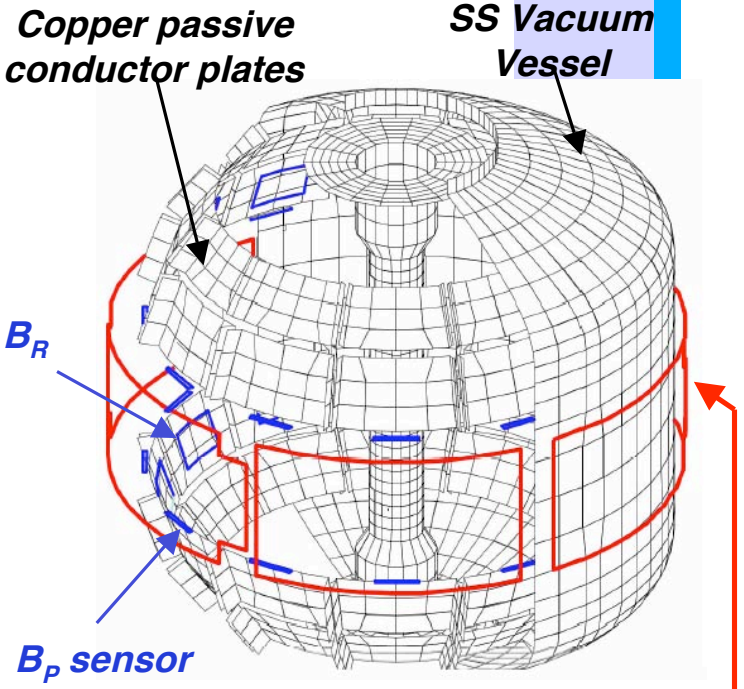
- **Utilize present FIDA system design with spectrometer: 2x16 channels**
- **Tangential views, small tilt downward, to avoid reflections from RF antennas, etc**
- **Enhanced signal, better localization in velocity space weighted toward parallel velocity**

Macrostability and Plasma Control

Sustain β_N and Understand MHD Near and Above No-Wall Limit

	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 1	14 6	14 6
MHD and ASC	● β control (NBI)	● 2nd SPA Supplies* ● Real Time Rotation Diag,	● Real Time Rotation Control

● ARRA



- **Install 2nd Switching Power Amplifier (SPA) to enable all six EFC/RWM coils for control of n = 1, 2, 3 simultaneously**
  - **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 control through NBI & magnetic braking**

To provide basis to extrapolate high-beta operation to next-step STs and to support ITER physics

Boundary / Li Capability for Joint Research Milestones

Particle transport / Divertor Heat Flux / H-mode Pedestal Physics

	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 1	14 6	14 6
Boundary / Li	● LLD (SNL) ● Enhanced LLD Diagnostics ● Dual Li Shaker ● Lithium CHERs ● PMI Probe ● Divertor Bolometer ● Two color fast IR Camera (ORNL) ● Lyman Alpha (Ly_α) Diode Array (LLNL) ● Divertor Imaging Spectrometer (LLNL)	● Enhanced LLD (Mo. inboard divertor tiles under consideration) ● Extra MPTS Channels ● MAPP (Purdue)	- **To reduce carbon influx** - **Facilitate CHI** - **Provide addition liquid lithium pumping surfaces**

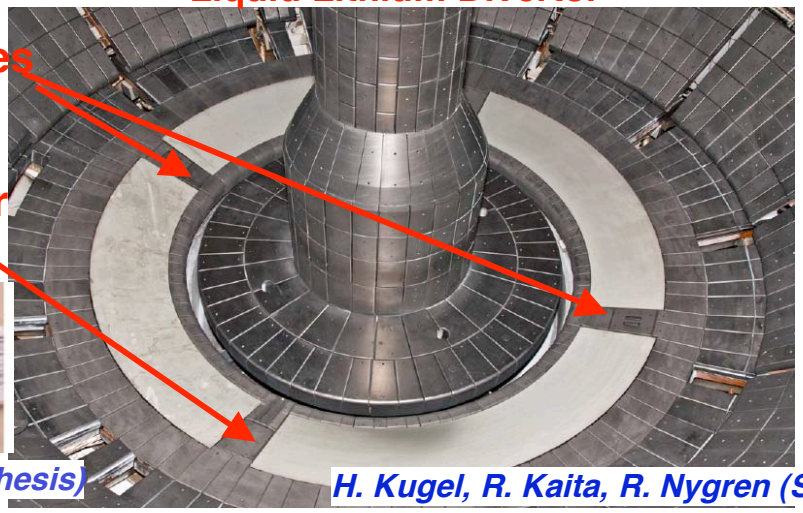
● ARRA

Liquid Lithium Divertor

Bias Electrodes

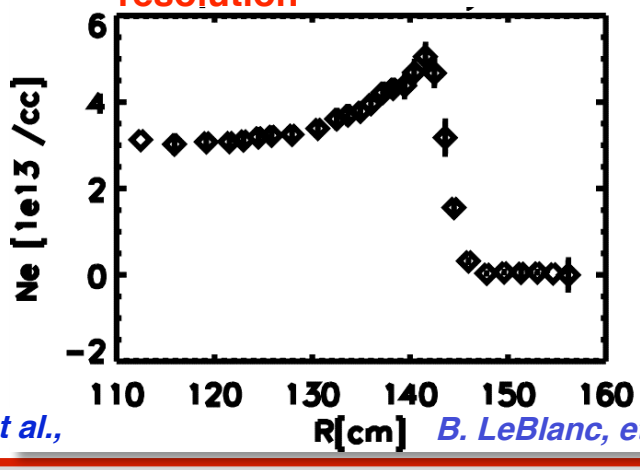
3x33 Langmuir Probe Array

J. Kallman (Ph.D. Thesis)



H. Kugel, R. Kaita, R. Nygren (SNL) et al.,

Additional 10 MPTS channels enhances H-mode pedestal resolution

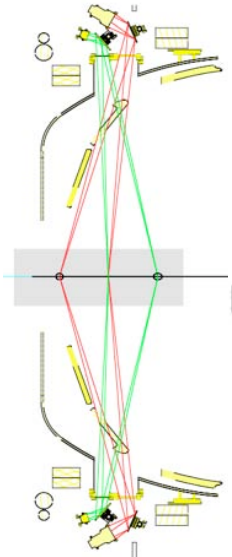


B. LeBlanc, et al

New Capabilities for Liquid Lithium Divertor and Boundary

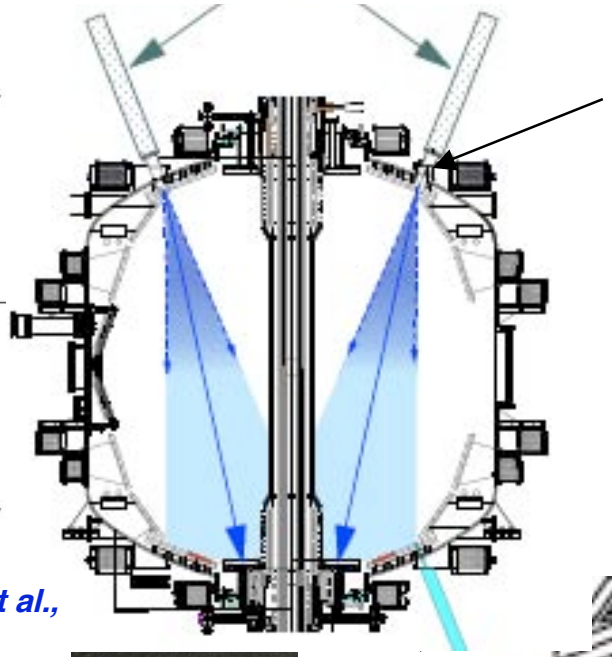
Dual Lithium Powder Dropper, Sample Probe, Fast IR Camera,

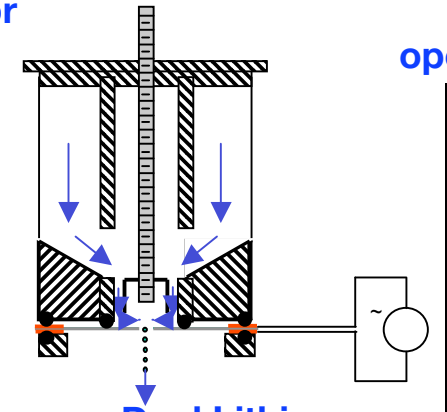
Lithium CHERS



R. Bell (PPPL) et al.,

Dual Liquid Lithium Evaporator
For Li wall coatings
Now routinely used

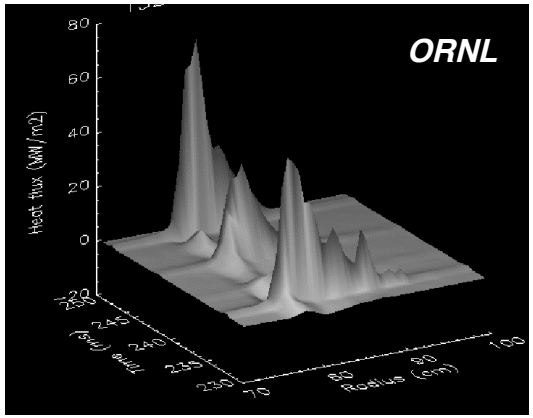




Dual Lithium Powder Dropper

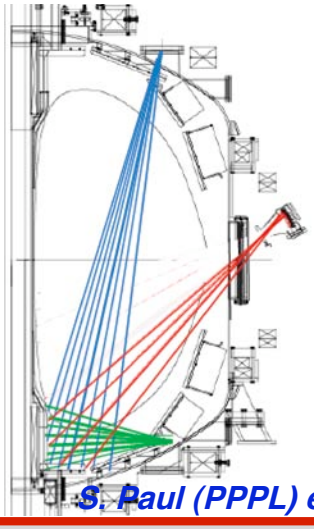
D. Mansfied (PPPL) et al.,

Two-Color Fast IR Camera
operational ELM-resolved heat flux



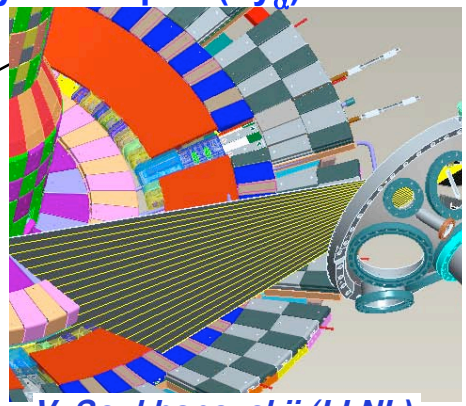
J-W Ahn et al.,

Three-view Divertor Bolometer
Installed for divertor radiation



S. Paul (PPPL) et al.,

Lyman Alpha (Ly_α) Diode Array



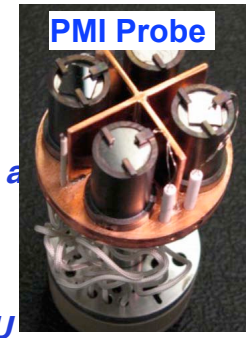
V. Soukhanovskii (LLNL)

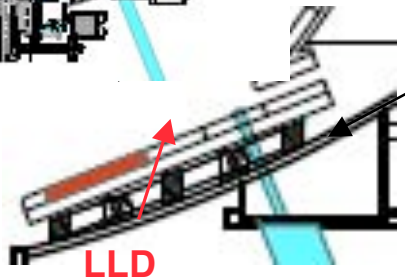
PMI Probe for retention measurements

C. Skinner (PPPL) et a

and surface analysis

J. P. Allain (Purdue U





LLD
(2010)

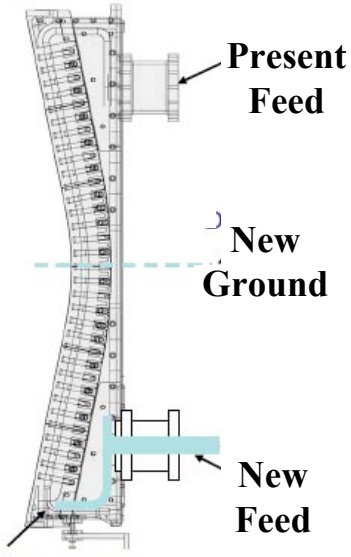
HHFW Double-Feed Antenna Upgrade Completed

Initial Operation Encouraging - Higher Power, Higher Heating Efficiency

	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 / 1	14 / 6	14 / 6
HHFW	● HHFW Antenna Upgrade	● HHFW ELM Avoidance	

● ARRA

Symmetric Antenna Main Features



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

- **Antenna Installation completed in June 2009**
- **Utilized in experiments in July, August**

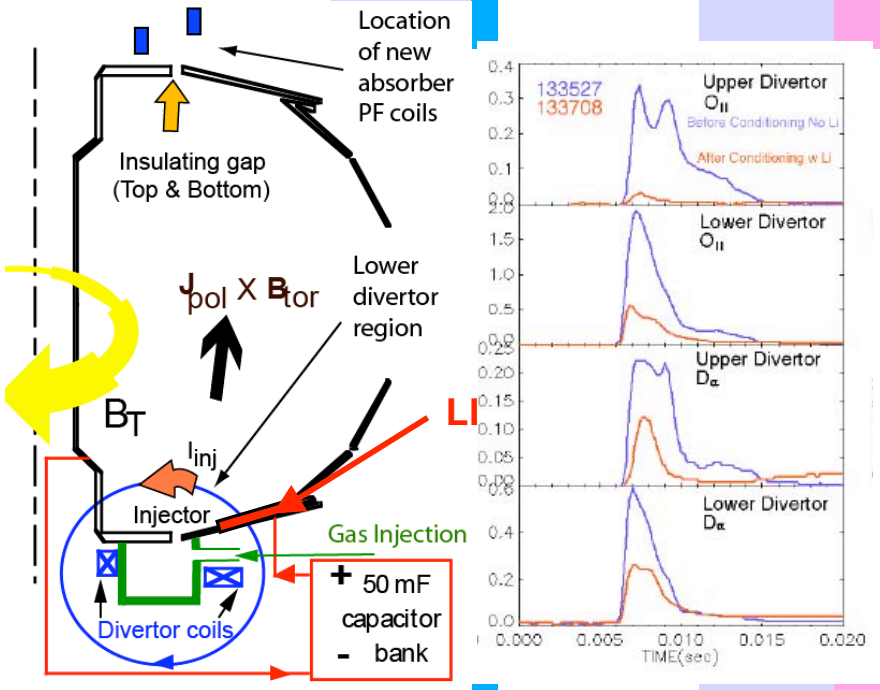
Solenoid-free Start-up

CHI Demonstrated Flux Savings Equivalent of ~ 200 kA

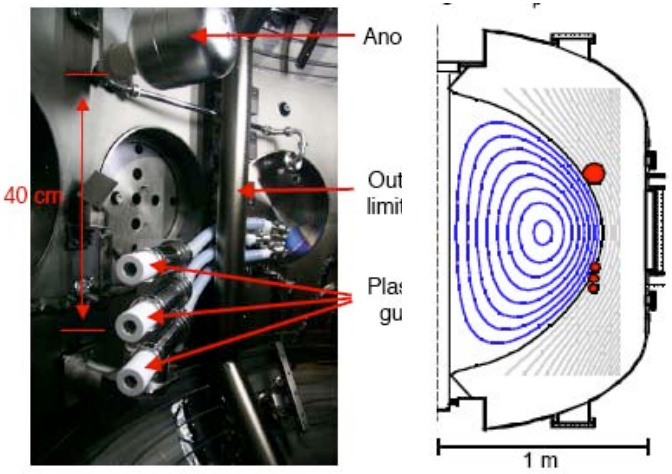
	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 1	14 6	14 6
CHI	● Partial Metal Electrode with LLD	● Metal Electrodes (Moly Div. Tiles under consideration)	
Plasma Guns			● Plasma Gun (U. Wisconsin) (if technically ready)

● ARRA

Success of CHI due to Impurity Control



PEGASUS Gun Start-up

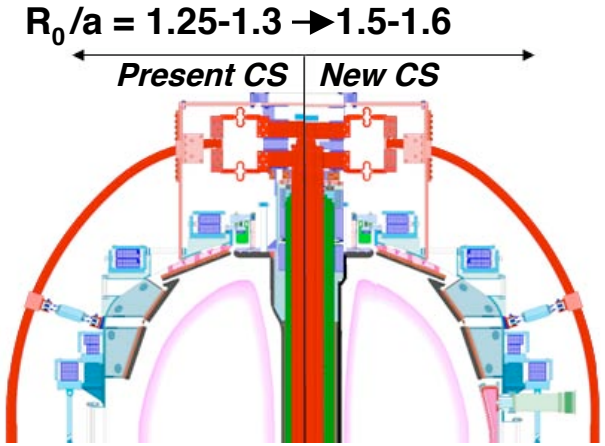


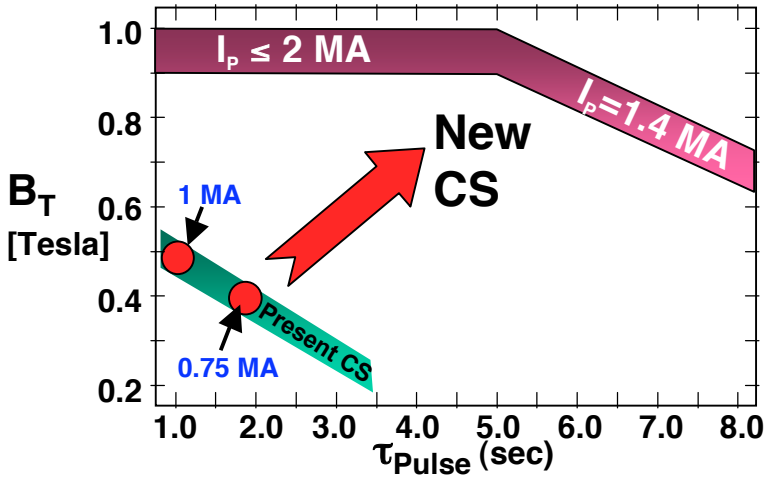
Ip ~ 150 kA achieved with three guns

Collaborating with DIII-D for PF-only start-up with ECH

Major NSTX Upgrades to Bridge the Device and Performance Gap Toward Next-Step STs

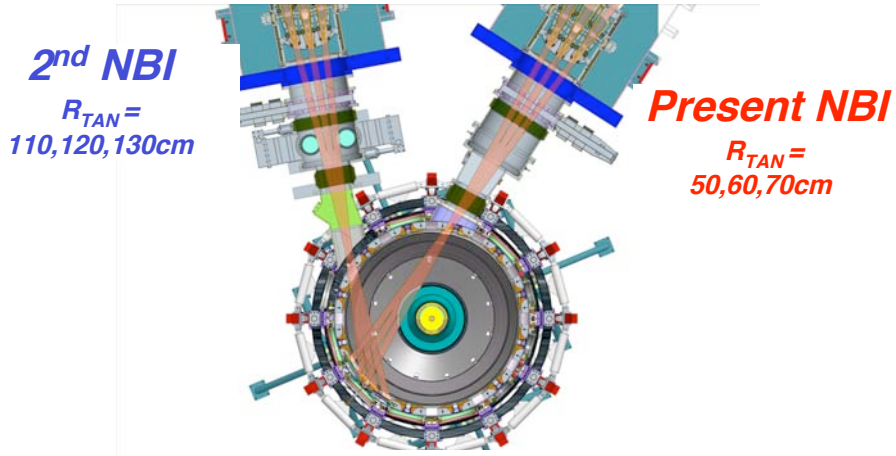
New center stack for 1T, 2MA, 5s to access reduced ν^*, 100% non-inductive ST plasmas



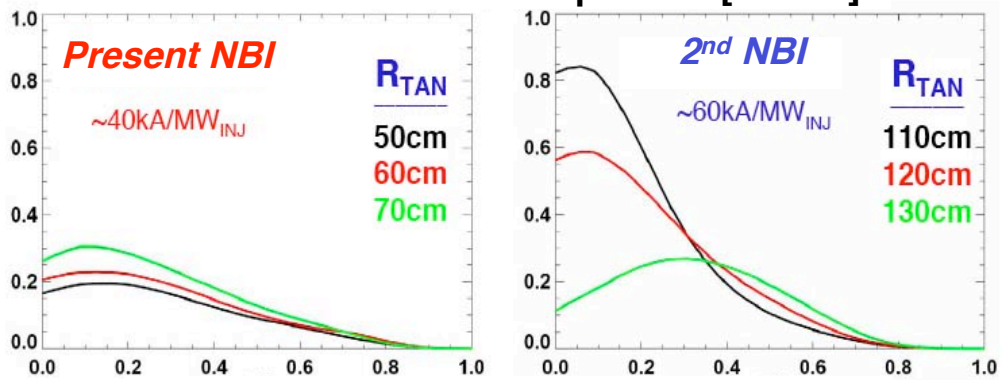


Magnet operation at ~1T (vs. 0.55T) → within a factor of 2 of next-step STs

2nd NBI with larger $R_{tangency}$ for sustained and controllable 100% NICD + high β at low ν^*



NBI current drive profiles [MA/m²]



Up to 2 times higher NBI current drive efficiency, and current profile control

Planned Upgrades to Center Stack and 2nd NBI Making Good Progress

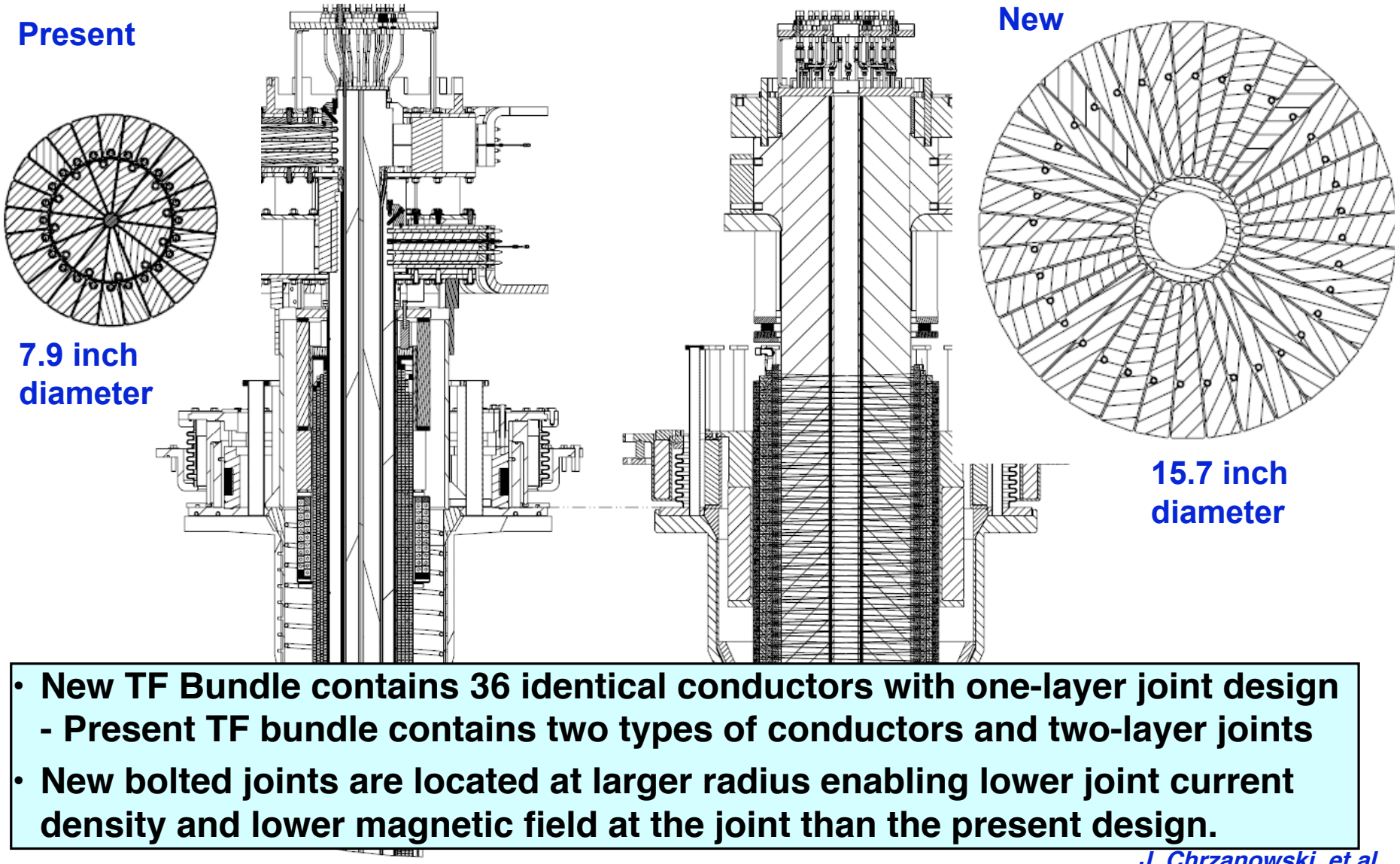
- NSTX PAC-25 Meeting (Feb 18–20, 2009)
  - Presented plan toward CD-1
- CD-0 (Mission Needs) approved Feb 23, 2009
- Successful technical peer review in June, 2009 for Neutral Beam #2
  - Disassembled TFTR BL4, evaluated hardware
  - Decontamination underway
- Successful technical peer review in August for new Center Stack
  - TF joint design selected
  - Structural Analysis report prepared
- Bottoms-up cost and schedule estimate prepared
  - 2 scenarios prepared cost range determined
- Successful independent CDR October 28–29
  - No technical, cost or schedule show stoppers

Successful NSTX Upgrade CD-1 Review Conducted

- **CD-1 documentation prepared in compliance with DOE Order 413.3**
  - **Preliminary Project Execution Plan (PPEP)**
  - **Acquisition Strategy *(design/build by PPPL. Labor =78% of cost)***
  - **Risk Registry *(no technical show stoppers)***
- **Successful OFES (Lehman) Review on December 15th–16th**
  - **Addressed all charge questions!**
  - **Recommendations**
    - **Complete FMEA**
    - **Develop a mutually agreed funding profile between OFES Program and the project**
    - **Establish project management and technical advisory committees**
  - **Review presentations and materials posted at;**
    - **http://nstx-upgrade.pppl.gov/Engineering/Reviews/Office_of_Science_Reviews/**
  - **An internal DOE review meeting (Energy Systems Acquisition Advisory Board Equivalent) which is needed for the NSTX Upgrade CD-1 approval scheduled on Feb 18th.**

R. Strykowsky, et al.,

Toroidal Field Coil Cross-Section Area Increased by ~ 4 to Support 1T, 5 sec Pulses (Present 0.55 T, 1 sec)

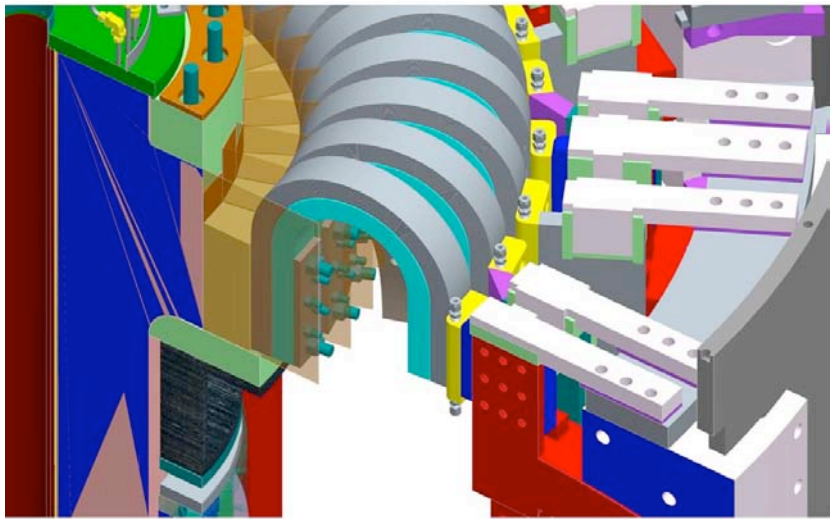


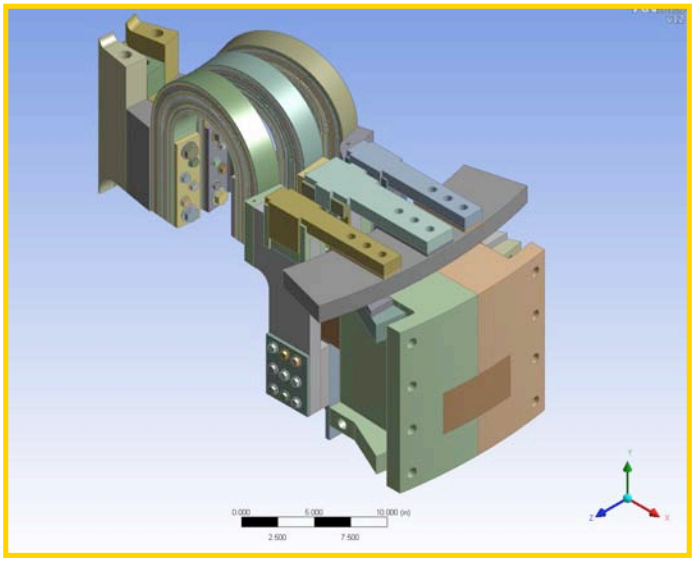
- New TF Bundle contains 36 identical conductors with one-layer joint design - Present TF bundle contains two types of conductors and two-layer joints
- New bolted joints are located at larger radius enabling lower joint current density and lower magnetic field at the joint than the present design.

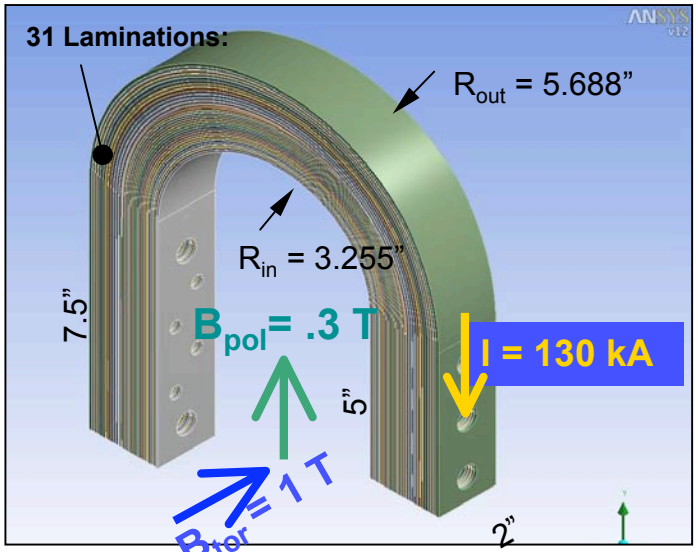
J. Chrzanowski, et al.,

Single Segment 3-Strap Assembly with Supports

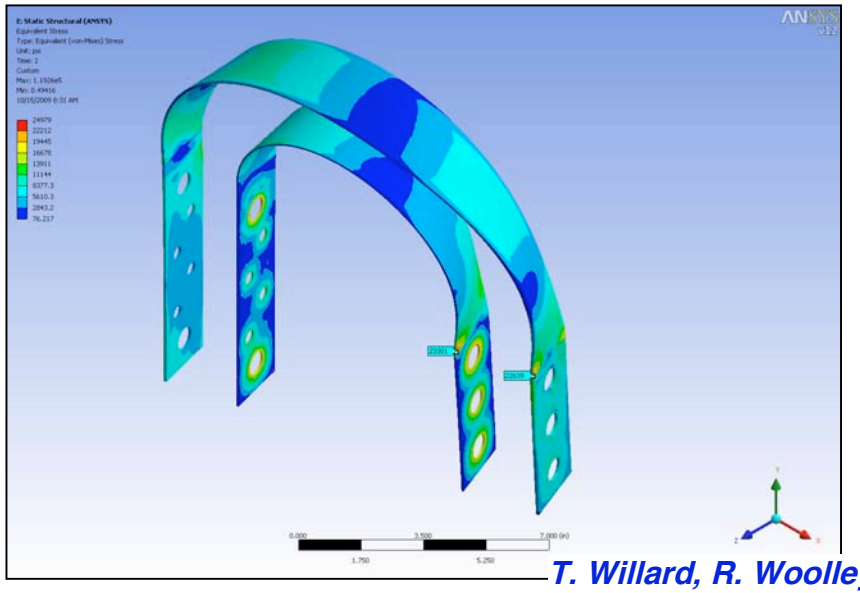
New Design Simplifies Joint and Eliminates Lift-Off





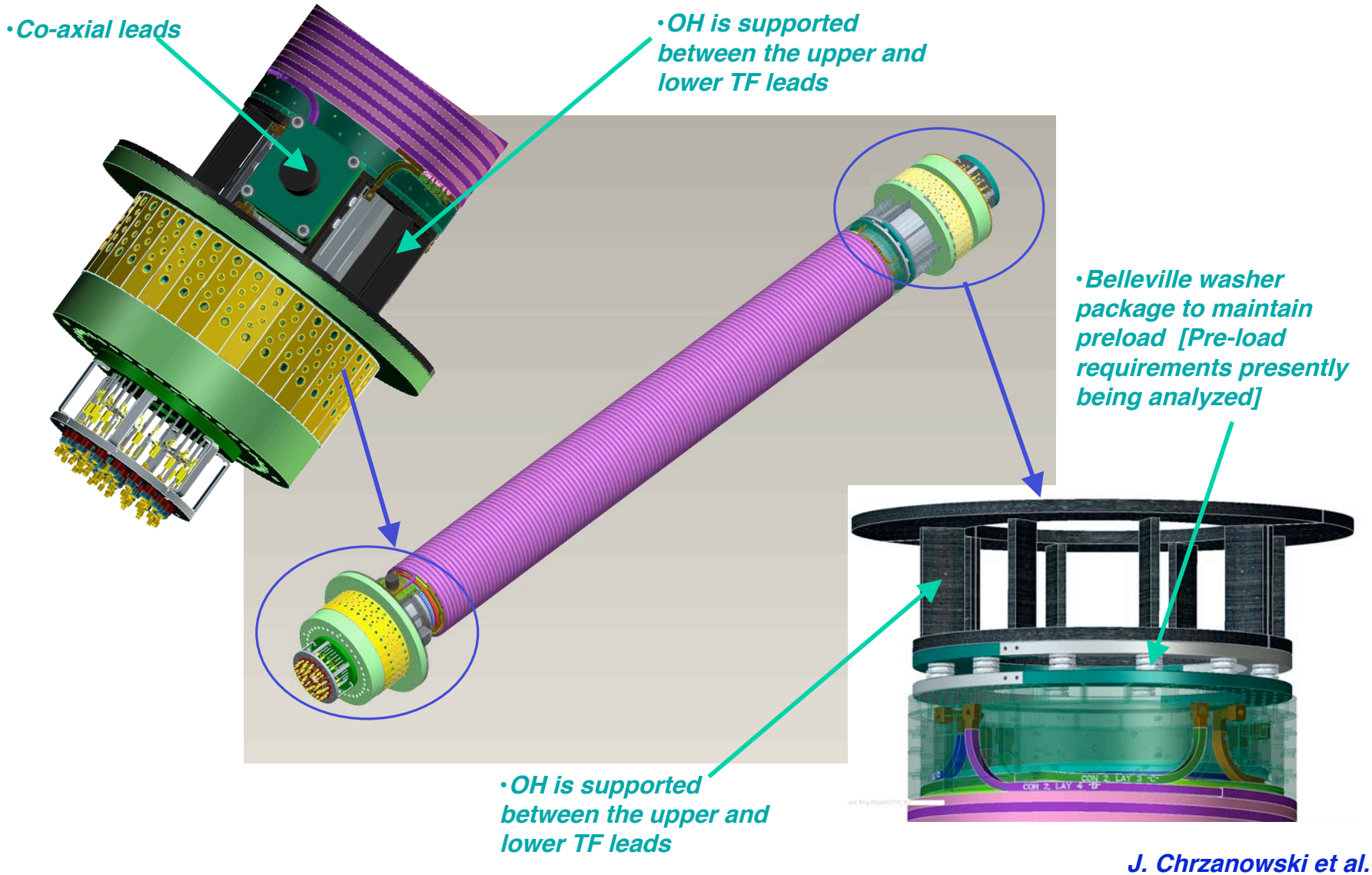


Laminated Strap Assembly with Applied Fields and Current



T. Willard, R. Woolley et al.

OH Flux Increased x 3 to Support 2 MA, 5 s Pulses (Present ~0.7 Vs ⇒ 1 MA, ~1 s)

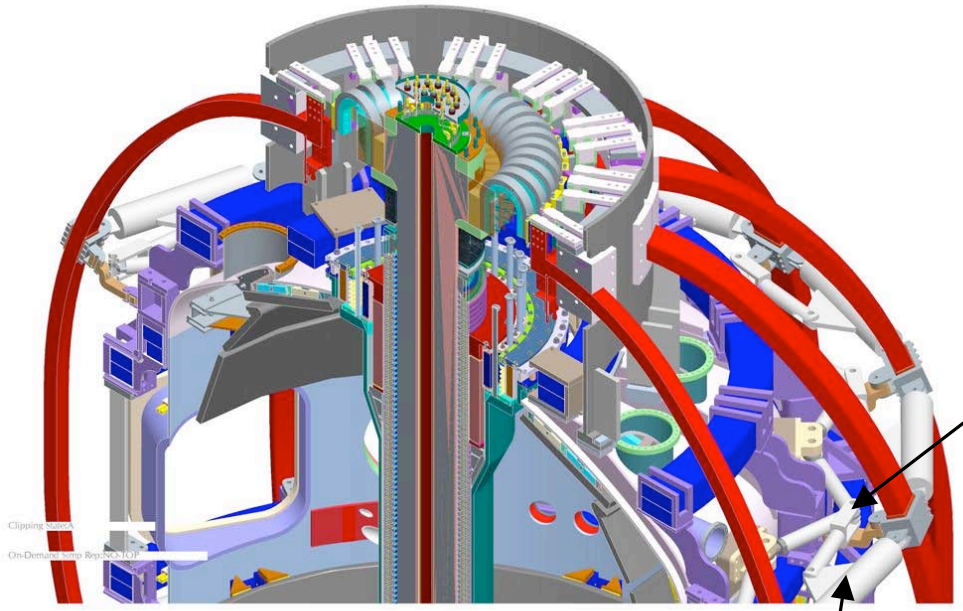


J. Chrzanowski et al.

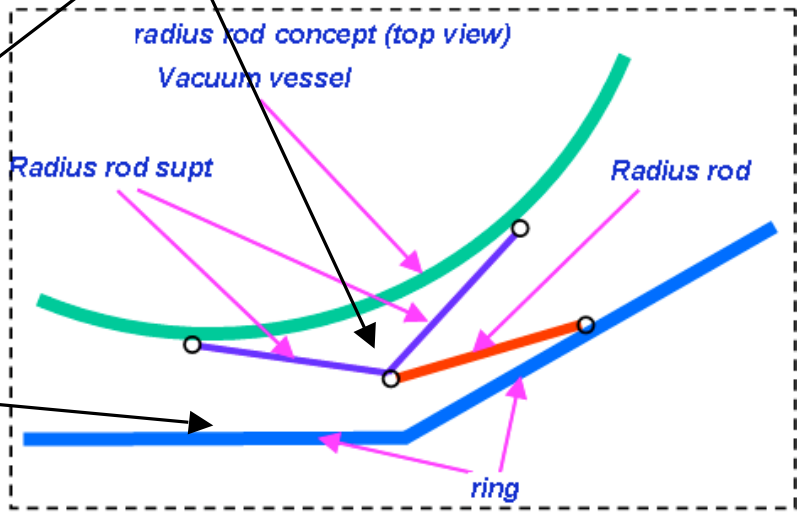
Extensive Analyses Performed Using Global and Local Codes

Static, Dynamic, Fatigue for Electro-Magnetic, Thermal, Mechanical Loads

Outer TF, Vessel, Umbrella Structure, Reinforcements



- Tangential radius-rod reacts out-of-plane loads and allows radial growth during bakeout
- Utilizes space used by present TF support truss

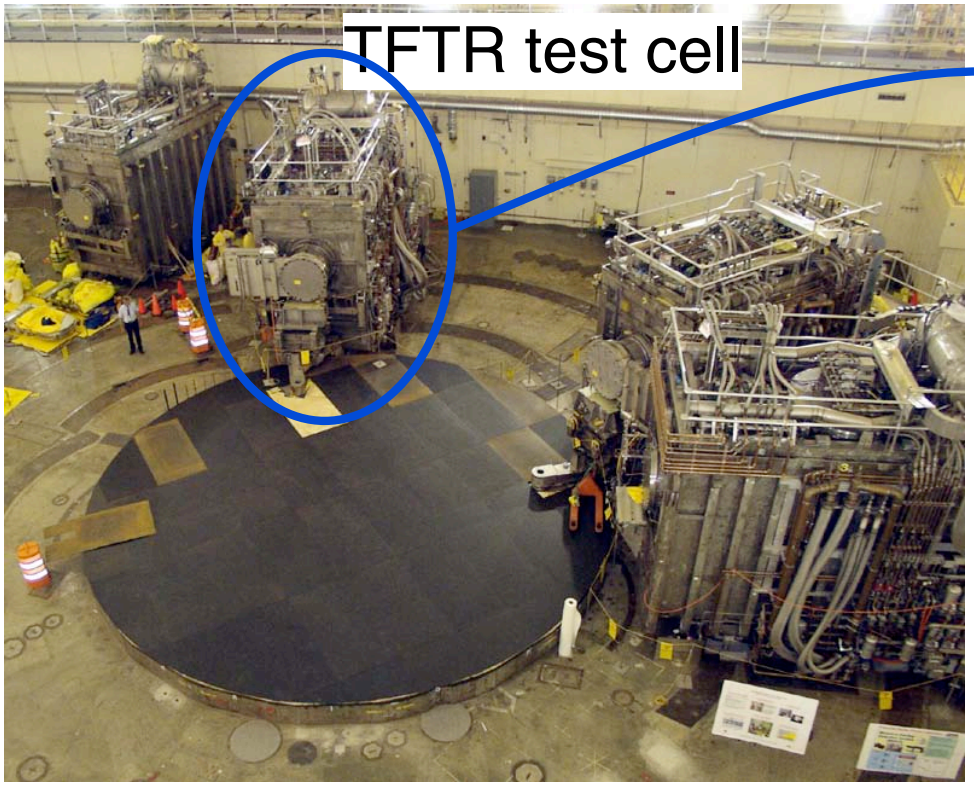


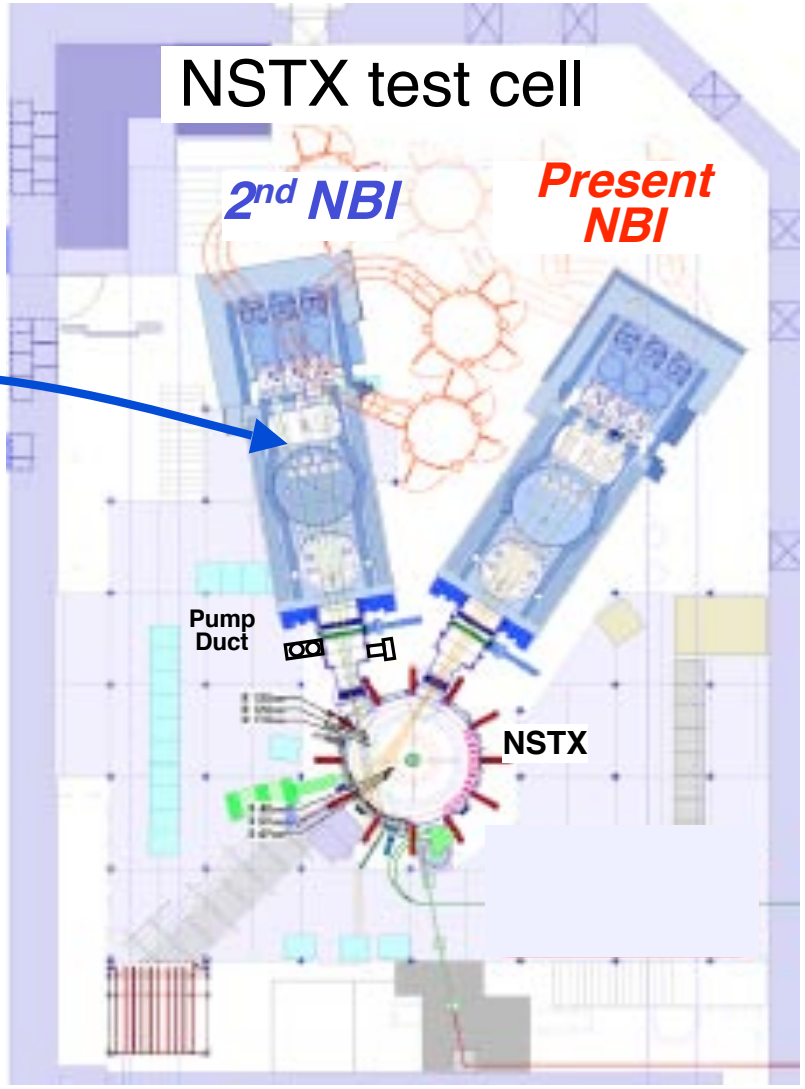
- Toroidal-Ring Supports In-Plane Loads

P. Titus, H.Zhang, S.Avasarala, A.Zolfaghari, A.Brooks, L.Myatt

A TFTR Neutral Beamline will be Moved to the NSTX Test Cell and Installed Next to the Present One

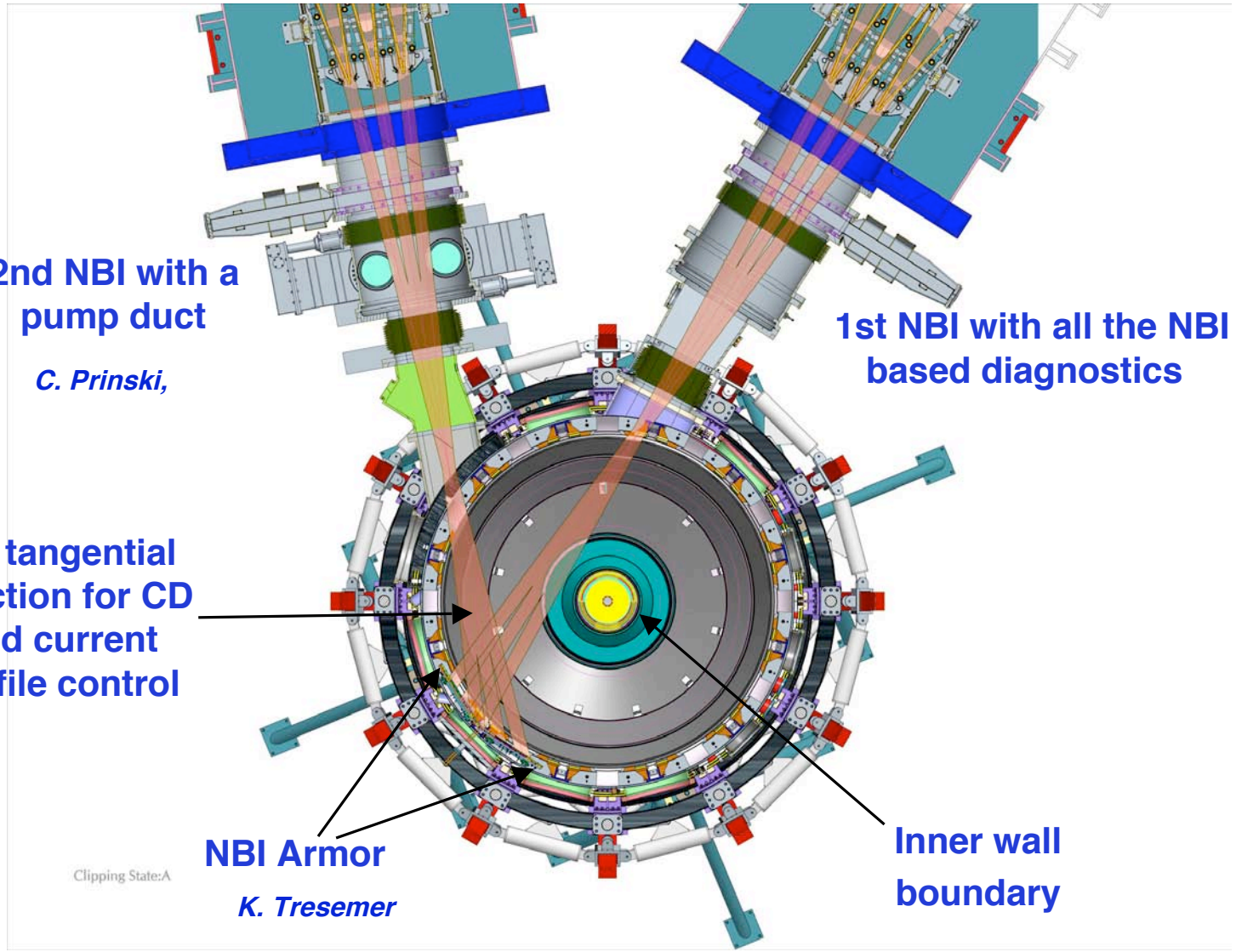
- PPPL has extensive experience operating, maintaining, refurbishing NBI
- NBI is well understood and has provided reliable heating to high β values in NSTX



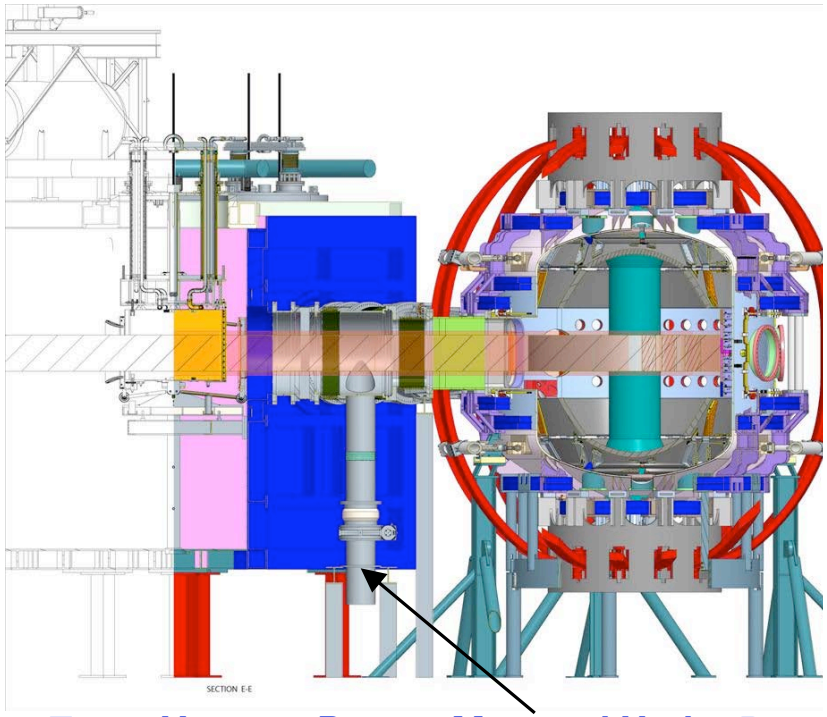


T. Stevenson, et al.

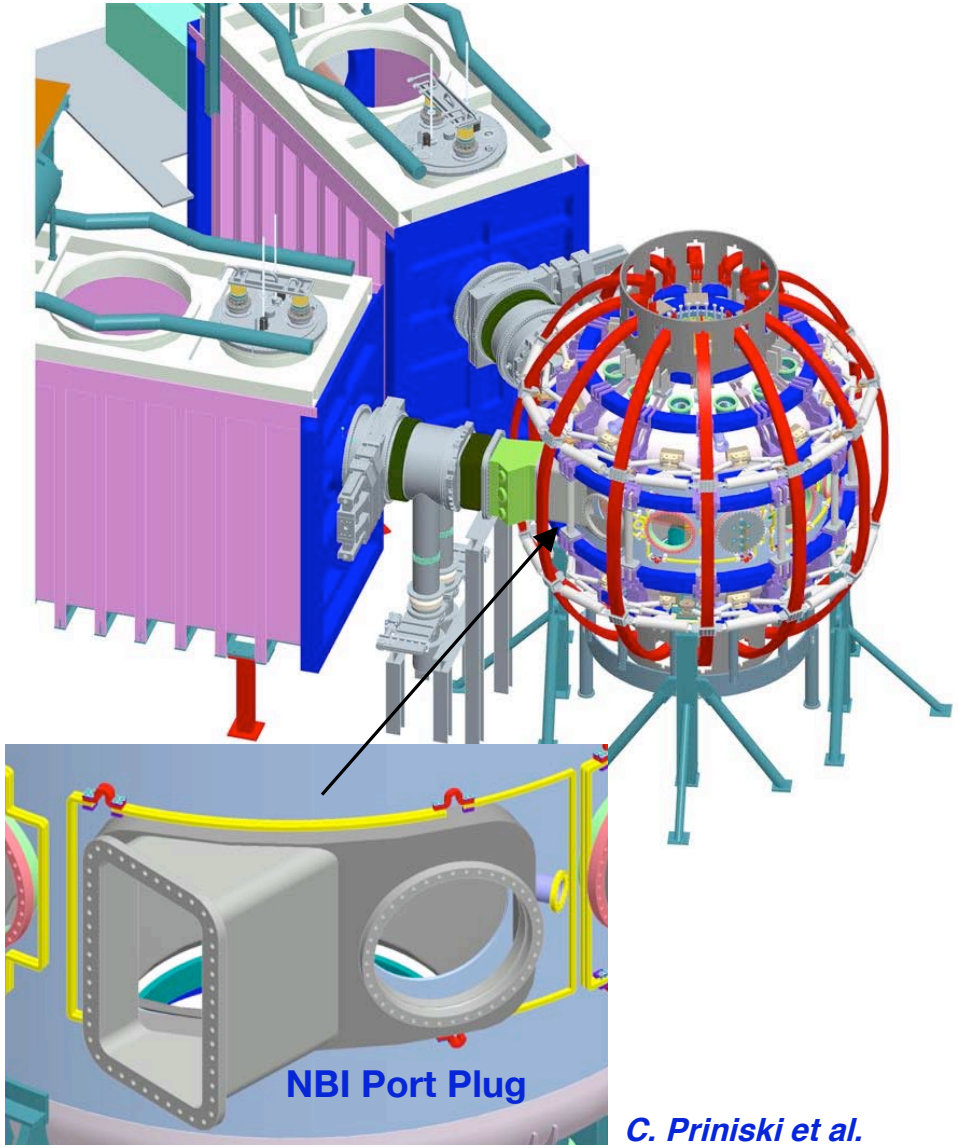
Second Neutral Beam System will Inject at Larger Tangency Radius for J(r) Control



Second Neutral Beam Design
with Main Vacuum Vessel Turbo-Pumps Mounted Under Duct



Torus Vacuum Pumps Mounted Under Duct

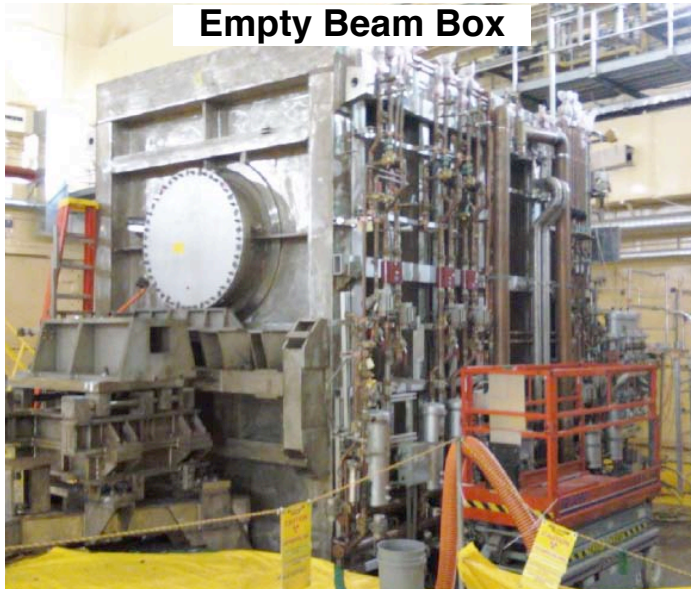


C. Priniski et al.

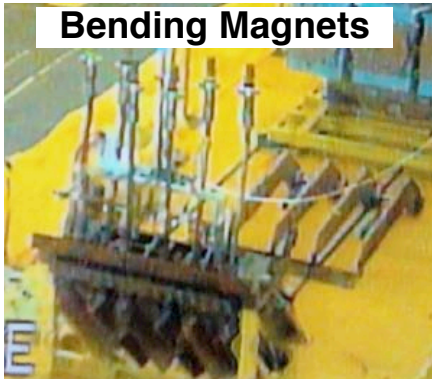
TFTR Neutral Beam Line #4 Disassembled

Tritium Contamination Level Assessed - No Re-growth Observed

Empty Beam Box

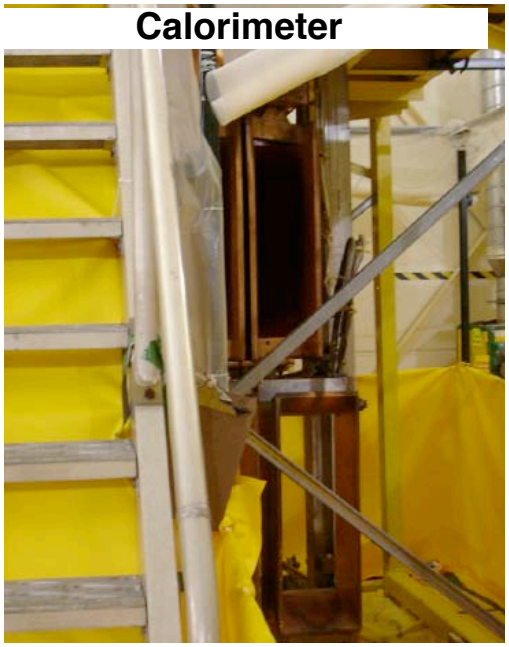


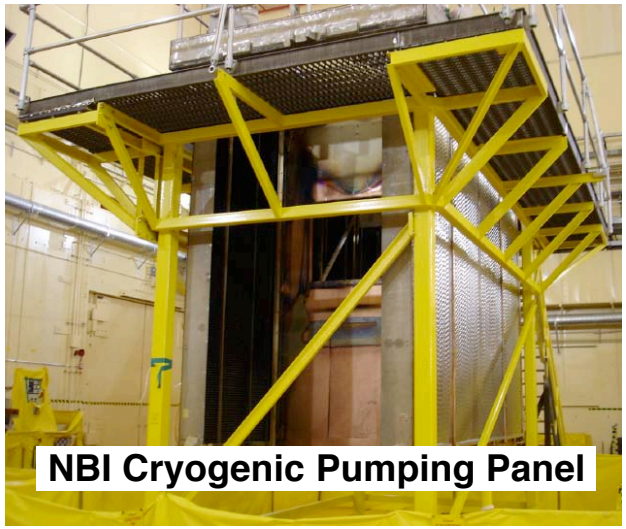
Bending Magnets



Ion Source Side Flange

Calorimeter





NBI Cryogenic Pumping Panel

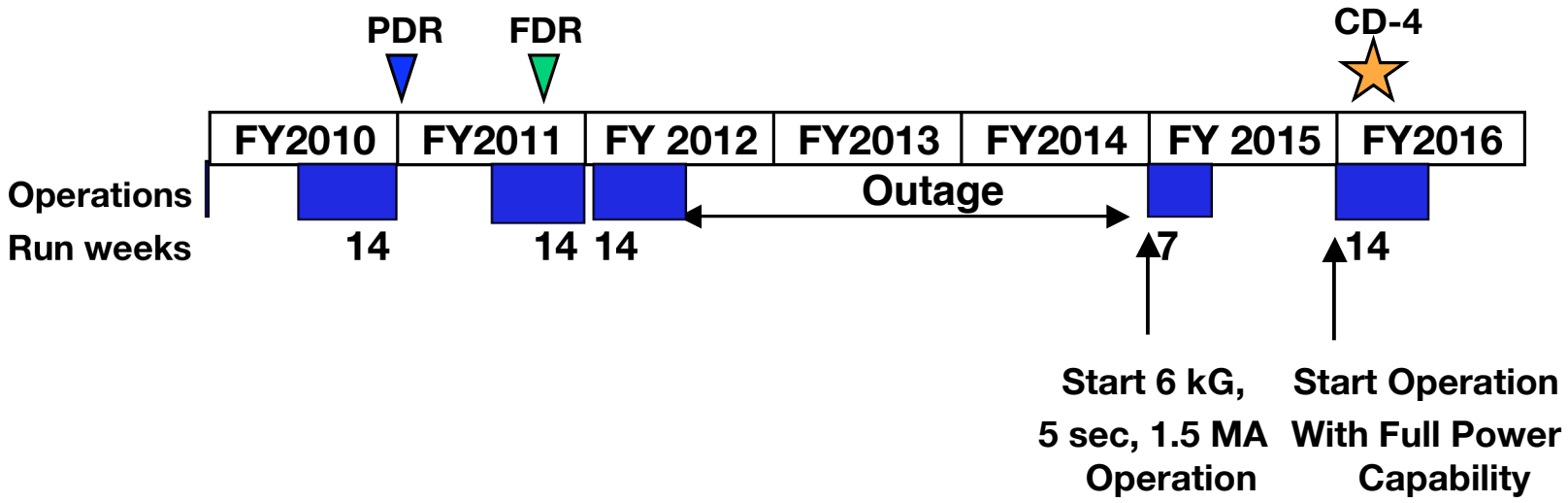
Ion Beam Dump

Radiologically Controlled Clean Area

T. Stevenson et al.

NSTX Upgrade Implementation Plan
Flat Budget Scenario

For Flat Budget with Mid-point cost



Flat budget scenario with mid-point cost:

- **FY 2013-2014 Outage to install the new CS and 2nd NBI.**
- **Complete all the inside test cell work during the outage**
- **Start plasma operation in FY 2015 with new CS with the existing power supplies**
- **Complete power supply upgrade in 2015 to be ready for FY 2016 run**

NSTX FY 2012 FWP Budget Summary ($M)

	FY2010		FY2011			FY2012	
Base cases	**Base**	**ARRA**	**Base**	**ARRA**	**Incr**	**Base**	**Incr**
Run Weeks	**14**	**1**	**14**	**0**	**6**	**14**	**6**
Facility Ops	$20.7	$0.14	$22.2		$1.58	$18.8	$1.58
Facility Upgrades	$1.1	$5.33	$0.3	$1.45			
CS/2nd NBI	$8.0		$7.2		$4.5	$10.6	$4.5
Facility Operations Total	**$29.8**	**$5.5**	**$29.7**	**$1.5**	**$6.1**	**$29.4**	**$6.1**
PPPL Research	$11.0		$11.4			$11.7	
Collab Interface	$0.4		$0.4			$0.3	
Collaborations	$5.7		$5.8			$5.9	
Science Total	**$17.1**	**$0.0**	**$17.6**	**$0.0**	**$0.0**	**$17.9**	**$0.0**
NSTX Total	**$46.9**	**$5.5**	**$47.3**	**$1.5**	**$6.1**	**$47.3**	**$6.1**

- **ARRA funding enables 2 post docs, 1 extra run weeks in FY 2010 and new upgrades - MPTS New Channels, MSE-LIF Installation, Enhanced LLD, and 2nd SPAs for EF/RWM/RMP in FY 2011.**
- **Most of the base upgrade fund shifts to high priority new CS and 2nd NBI upgrade activities. However, the base funding is not sufficient for an optimum upgrade project schedule.**
- **After FY 2012 run, the NSTX technical staff will be shifted from operations to upgrade work.**
- **Incremental budget enables acceleration of new CS and 2nd NBI upgrades by 5-8 months with power supplies and control and improved facility utilization.**

Plans Developed for FY 2010–12 Present Exciting Opportunities and Challenges

- Very productive FY2009 run with all milestones completed
- FY 2010 run to start with new capabilities in March
  - Upgraded HHFW system
  - Liquid lithium divertor with extensive diagnostics
  - BES to complement high-k
- AARA funding enables facility upgrades to support FY 2011–12 research plan
  - MSE-LIF to complement MSE-CIF
  - 2nd SPA for improved RMP/EF/ RWM capability
  - MPTS Extra Channel for improved pedestal resolution
  - Assessing possibilities and need for Molybdenum Divertor Tiles
- NSTX Upgrade project is making good progress
  - Successful DOE OFES CD-1 Review in Dec. 2009
  - DOE OFES CD-2 Review in Sept 2010
- Incremental budget greatly enhances facility capability and output
  - Accelerate the center-stack and 2nd NBI upgrade schedule by 5 - 8 months
  - Increase the run weeks from 14 to 20 toward full utilization