NSTX

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NSTX Project

Facility Operations, Enhancements and Budget Plans

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Masa Ono

For the NSTX Team

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U St. Andrews
York U
Chubu U
Fukui U
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CEA, Cadarache
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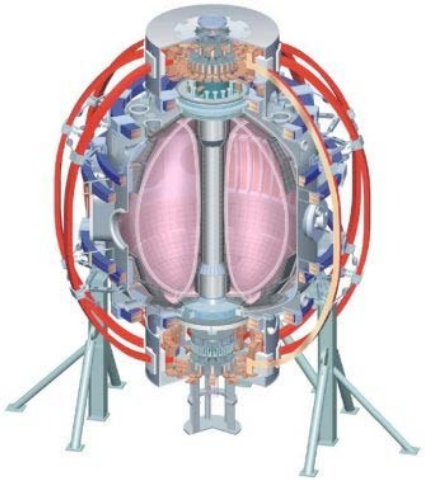
IPP, Garching
ASCR, Czech Rep
U Quebec

FY 2012 Field Work Proposal Presentation
Germantown, March 11 - 12, 2010



Successful FY09 operations completed

- 17 run weeks: 2750 good plasmas out of 2900 attempts (~95% reliability): more plasma shots than any other year for NSTX; Lithium evaporator contributed to increased plasma shots as well as enhanced plasma performance
- Over 50 XP/XMPs performed: more than any other year
- All DOE Milestones met on schedule
- 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
  - Feedback control of NBI power
  - CHI absorber coil energization
  - Reversed B_T

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*
- *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)*

NSTX is producing high quality collaborative research and training the next generation of fusion researchers

Exciting research conducted by the collaborative team:

- Six PRLs on timely research topics: 1. ELM stabilization with lithium, 2. On demand ELM triggering by 3-D fields, 3. Flow-shear stabilization effect on electron gyroscale fluctuations, 4. Kinetic effects on RWM stability, 5. Electron transport by energetic particle induced shear Alfvén modes, 6. Ohmic flux saving demonstration with CHI.
- 2009 Nuclear Fusion award on high beta physics
- Collaborators have led half of the NSTX invited papers and refereed journals

Nurturing junior researchers:

- Increasing presence of young researchers : 17 post-docs (2 ARRA, 2 ORISE Fellows) and 28 students
- Two Presidential Early Career Award and three DOE OS Early Career Research Program Award recipients

NSTX Research Team

	PPPL	Non-PPPL
Researchers	65	195*
Post Doc.	5	12
Grad. Students*	5	12
Undergrad.	1	10

*25 on-site collaborators

NSTX Near Term Facility Plan

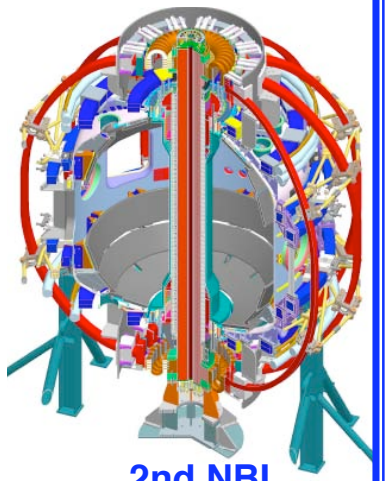
ARRA Funding Significantly Enhances Research Capability

● ARRA

	FY 10		FY 11		FY 12	
Run Weeks						
Base / Increment	14	1	14	6	14	6
Heating & CD	● HHFW Antenna Upgrade		● HHFW ELM Avoidance			
MHD and ASC	● β control (NBI)		● 2nd SPA Supplies* ● Real Time Rotation Diagnostic			
T&T	● Upgraded FIReTIP (UCD) ● BES (U. Wisconsin)		● Extra 10 MPTS Chs* ● MSE/LIF* (Nova Photonics)		● Real Time Rotation Control	
Boundary / Li	● LLD (SNL) ● PMI Probe ● Lithium CHERS		● Enhanced LLD* ● Materials Analysis Particle Probe (MAPP) (Purdue)			
Energetic Particles	● Divertor Spectrometer (LLNL) ● Two-Color Fast IR Camera (ORNL) ● Upgraded reflectometry (UCLA)		● Tangential FIDA(UCI)			
Start-Up	● CHI Absorber Control Coils (U. Washington)					

Upgrade Outage FY 2013-14

New Center-stack

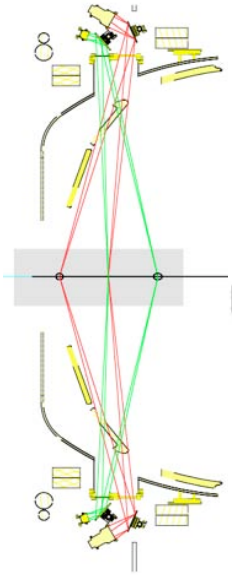


2nd NBI

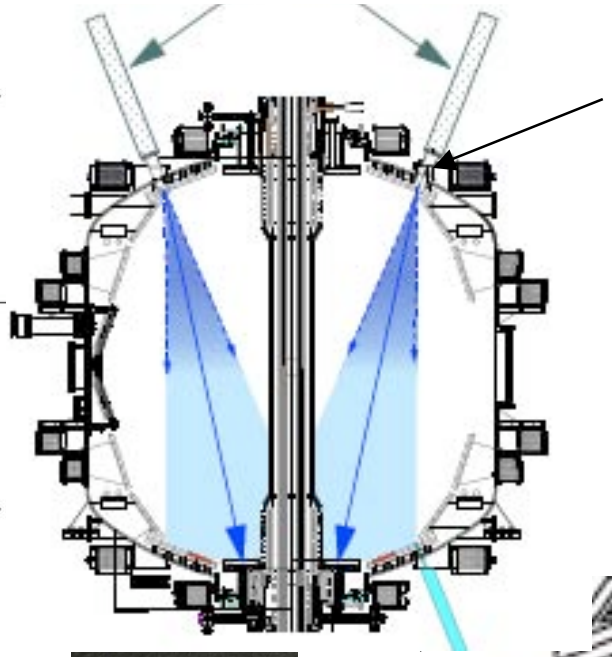
New Capabilities for Liquid Lithium Divertor and Boundary

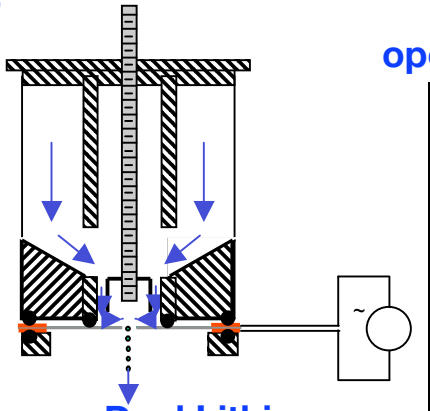
Dual Lithium Powder Dropper, Sample Probe, Fast IR Camera,

Lithium CHERS



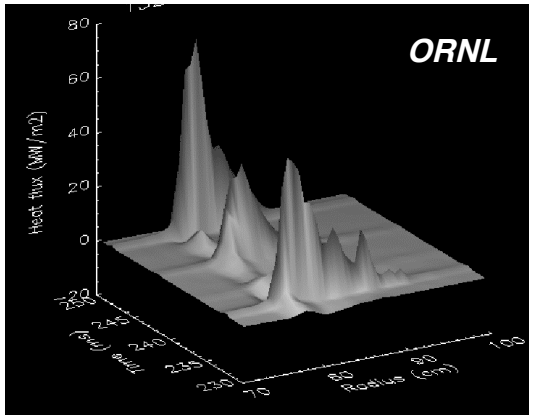
Dual Liquid Lithium Evaporator
For Li wall coatings
Now routinely used



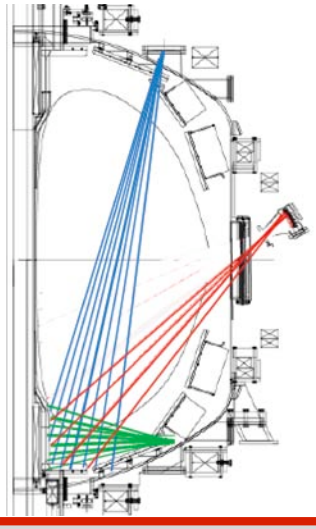


Dual Lithium
Powder Dropper

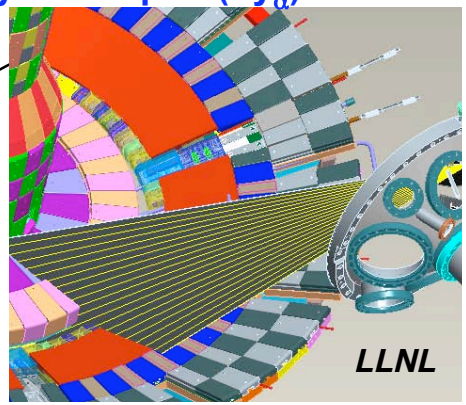
Two-Color Fast IR Camera
operational ELM-resolved heat flux



Three-view Divertor Bolometer
Installed for divertor radiation

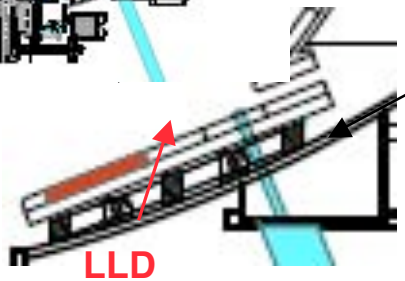


Lyman Alpha (Ly_α) Diode Array



PMI Probe for retention measurements and surface analysis

Purdue



LLD
(2010)

Boundary with Lithium Coating for Joint Research Milestones

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

	FY 10	FY 11	FY 12
Run Weeks	14 1	14 6	14 6
Base / Increment			
Boundary / Li	● LLD (SNL) ● Dual Li Shaker ● Enhanced LLD Diagnostics ● Lithium CHERs ● PMI Probe → ● MAPP (Purdue) ● Divertor Bolometer ● Two color fast IR Camera (ORNL) ● Lyman Alpha (Ly_α) Diode Array (LLNL) ● Divertor Imaging Spectrometer (LLNL)	● Enhanced LLD ● Extra MPTS Channels	

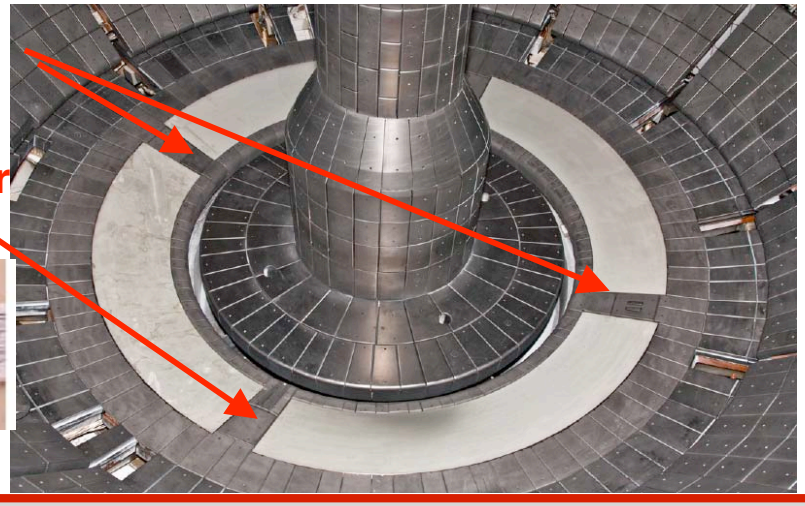
● ARRA

Enhanced LLD:
Molybdenum tiles on inboard divertor under consideration
- **To reduce carbon influx**
- **Facilitate CHI**
- **Provide additional liquid lithium pumping surfaces**

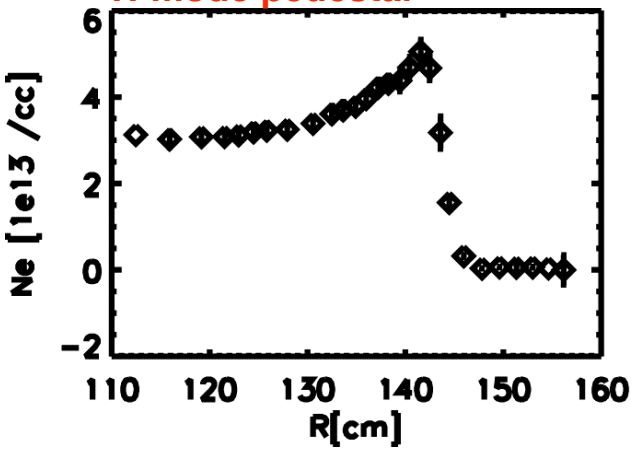
Liquid Lithium Divertor (LLD) Now Installed

Biased Electrodes

3x33 Langmuir Probe Array



Additional 10 MPTS channels will enhance resolution in H-mode pedestal



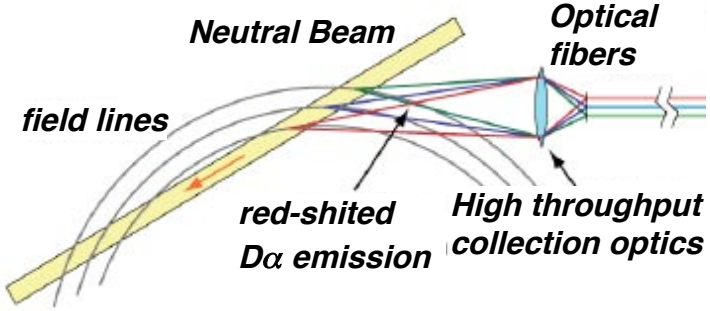
Transport and Turbulence

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

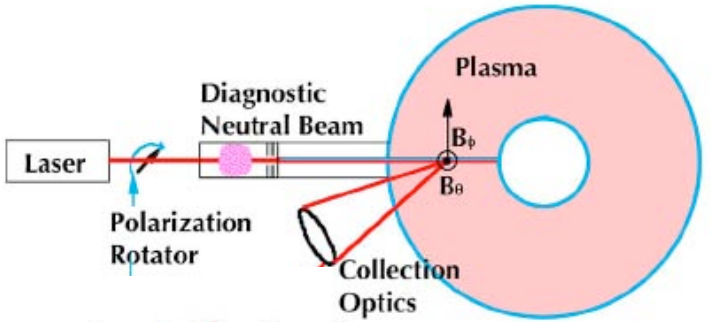
	FY 10	FY 11	FY 12
Run Weeks Base / Increment	14 1	14 6	14 6
T&T	● Beam Emission Spectroscopy (U. Wisconsin) ● Upgraded FIReTIP (UCD)	● MSE-Laser Induced Fluorescence (Nova Photonics)* ● Extra 10 MPTS Channels* (Improve spatial resolution for e-ITBs)	

● ARRA

BES together with high-k to provide a comprehensive turbulence diagnostic set



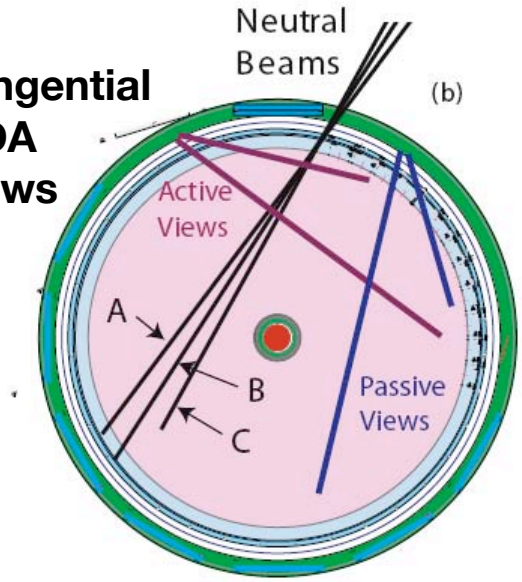
MSE-LIF to Measure $E_r(r)$, B(r)

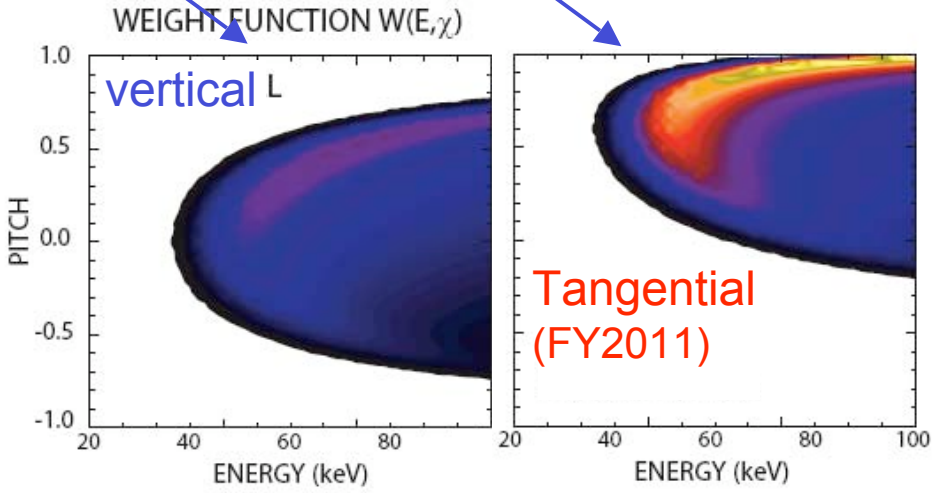


Innovative Diagnostics for Energetic Particle Research Being Implemented on NSTX

	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)	

Tangential FIDA Views





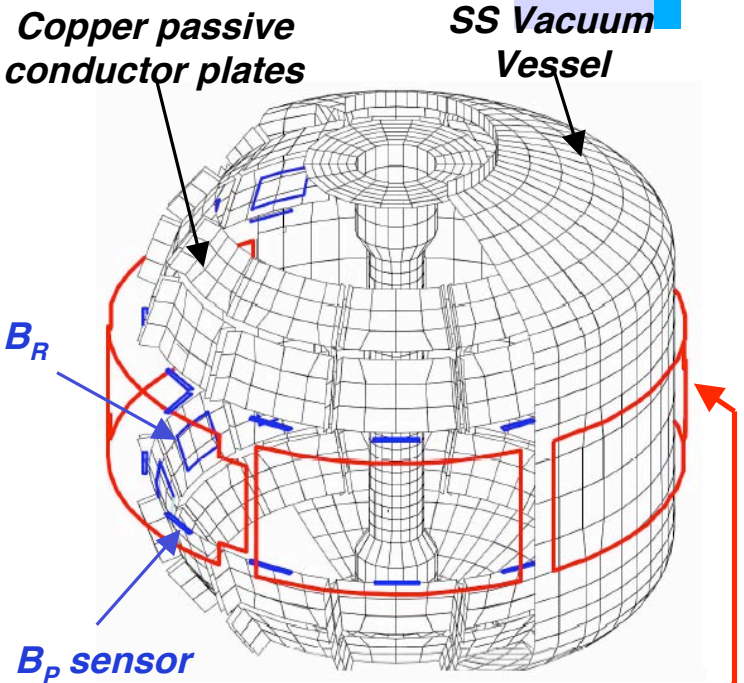
- **Utilize present Fast Ion D-Alpha (FIDA) system design with spectrometer: 2x16 channels**
- **Enhanced signal, better localization in velocity space weighted toward parallel velocity**
- **Well suited to investigate NBI fast ion transport and current drive physics**

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 Adv. Scenario & Control	● β control (NBI) ● Div. strike point control	● Real Time Rotation Diag, ● 2nd SPA Supplies	● 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 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

To provide basis to extrapolate high-beta operation for STs and to support ITER physics - with DIII-D to maintain the US leadership

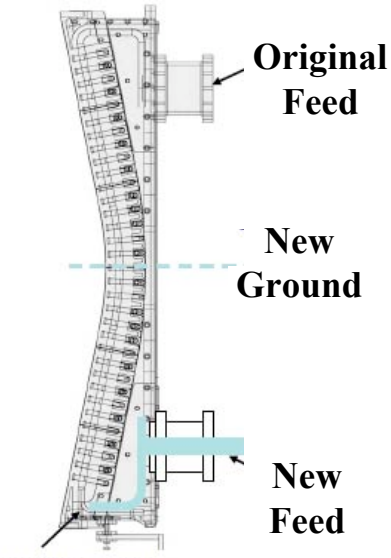
HHFW Double-Feed Antenna Modification Completed

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	● Double feed HHFW antenna modification	● HHFW ELM Avoidance	

● ARRA

Double Feed Antenna modification



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

Efficient HHFW heating / CD in H-mode plasmas will be the research focus in support of current ramp-up and sustainment

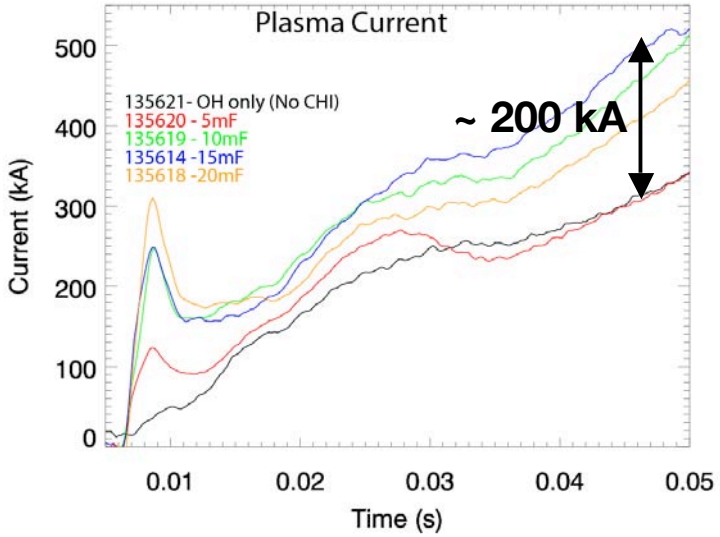
Solenoid-free Start-up - Coaxial Helicity Injection

Ohmic Flux Savings Equivalent of ~200 kA with only 20 kJ capacitor

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

● ARRA

Success of CHI due to 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**

Suggests advantage of metallic electrode surfaces to reach ~ 0.5 MA

- **PEGASUS gun start-up producing exciting results Ip ~ 170 kA. The PEGASUS gun concept is technically flexible to implement on NSTX once fully developed.**
- **Successful collaboration with DIII-D for PF-only start-up with ECH**

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	$20.6	$0.14	$21.9		$1.56	$19.5	$1.60
Facility Enhancement	$1.1	$5.33	$0.3	$1.45			
Upgrade Project	$8.0		$7.5		$4.5	$10.5	$4.5
Facility Operations Tota	**$29.7**	**$5.5**	**$29.7**	**$1.5**	**$6.1**	**$30.0**	**$6.1**
PPPL Research	$11.1		$11.4			$11.7	
Collab Interface	$0.4		$0.4			$0.4	
Collaborations	$5.7		$5.8		$0.5	$6.1	$0.5
Science Total	**$17.2**	**$0.0**	**$17.6**	**$0.0**	**$0.5**	**$18.2**	**$0.5**
NSTX Total	**$46.9**	**$5.5**	**$47.3**	**$1.5**	**$6.6**	**$48.2**	**$6.6**

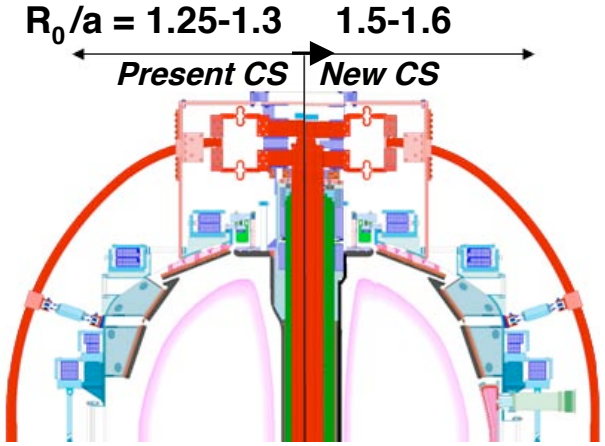
- **Incremental: Greatly enhance the science productivity near term as well as longer term**
  - **10% ($4.5M) incremental funding in FY 2011-2012 enables the upgrade project to be accelerated by 7 months reducing the total project cost by $1.5M - gain the equivalent of one run campaign.**
  - **Additional 4% ($1.6M) increases the run weeks from 14 to 20; research output greatly enhanced**
- **10% Cut case: Significant loss of research productivity and personnel**
  - **Loss of 19 Direct FTEs including younger researchers**
  - **Reduce run weeks from 14 to 9; research output significantly reduced**
  - **Delay the Upgrade by 2 months increasing the total project cost by $ 0.5M**

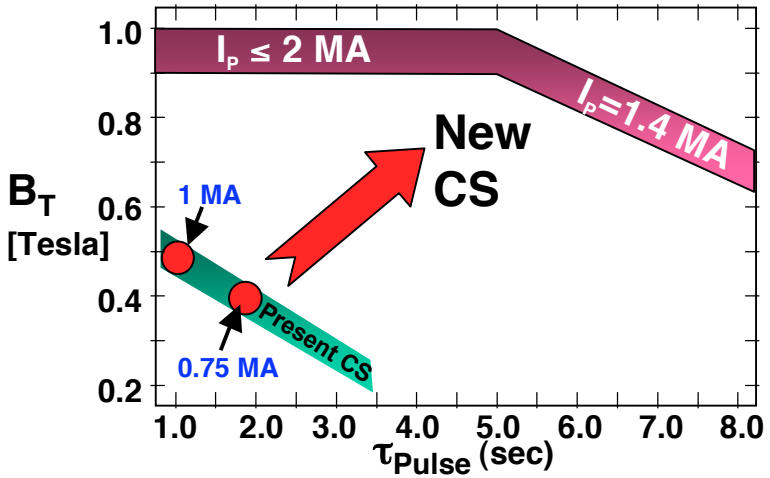
Optimized Plans Developed for FY 2010–12
Present Exciting Opportunities and Challenges

- 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 7 months
  - Increase the run weeks from 14 to 20 significantly increasing science output

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

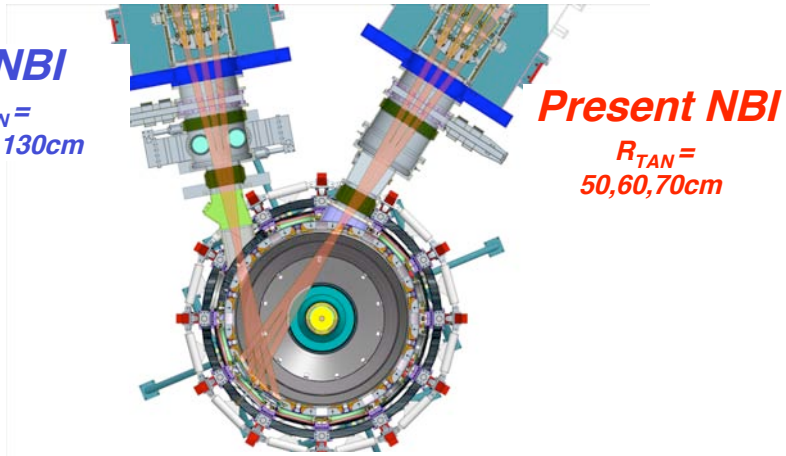
New center stack for 1T, 2MA, 5s



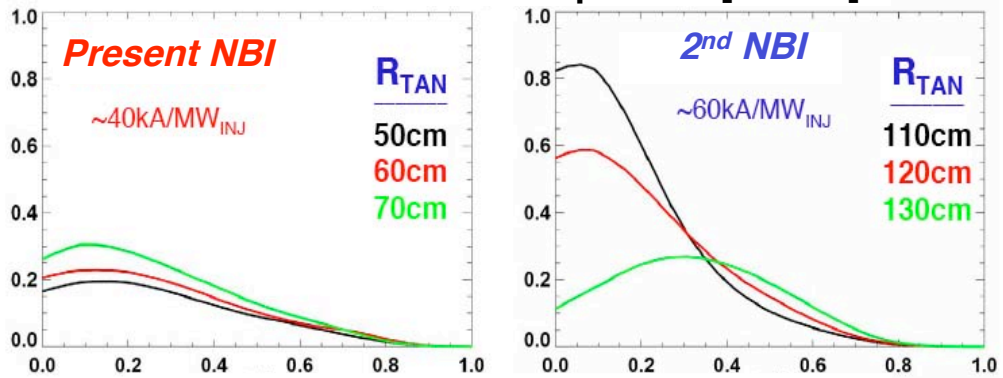


Magnet operation at ~1T (vs. 0.55T) within a factor of 2 of next-step STs

2nd NBI with 5 MW, 5s at larger R_{TAN}



NBI current drive profiles [MA/m²]



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