

Supported by



Office of  
Science



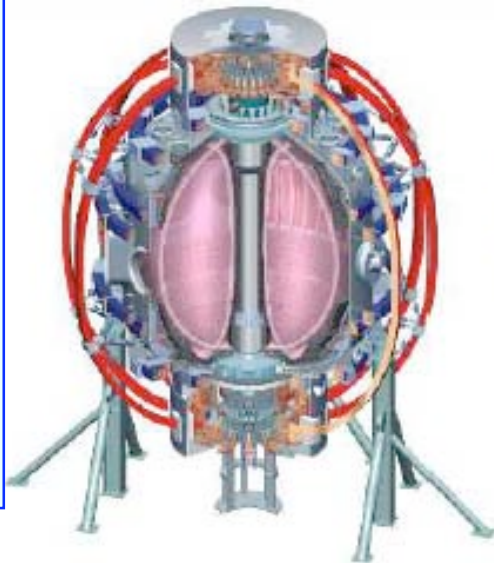
# NSTX Project Facility, Diagnostic and Budget Plan

## Masayuki Ono

### NSTX PAC Meeting

January 22- 24, 2008

College W&M  
Colorado Sch Mines  
Columbia U  
Comp-X  
FIU  
General Atomics  
INL  
Johns Hopkins U  
Lehigh U  
LANL  
LLNL  
Lodestar  
MIT  
Nova Photonics  
New York U  
Old Dominion U  
ORNL  
PPPL  
PSI  
Princeton U  
SNL  
Think Tank, Inc.  
UC Davis  
UC Irvine  
UCLA  
UCSD  
U Colorado  
U Maryland  
U Rochester  
U Washington  
U Wisconsin



Culham Sci Ctr  
York U  
Chubu U  
Fukui U  
Hiroshima U  
Hyogo U  
Kyoto U  
Kyushu U  
Kyushu Tokai U  
NIFS  
Niigata U  
U Tokyo  
JAEA  
Ioffe Inst  
RRC Kurchatov Inst  
TRINITI  
KBSI  
KAIST  
POSTECH  
ASIPP  
ENEA, Frascati  
CEA, Cadarache  
IPP, Jülich  
IPP, Garching  
IPP AS CR

# NSTX successfully completed FY 07 Run



- In June 2007 NSTX completed a 12.6 week run with 1879 plasmas, meeting the DOE facility operations Joule target of 12 weeks; 43 Experimental Proposals were conducted.
- NSTX successfully completed the DOE FES Joule Milestone of Energetic Particle Physics with a report to DOE (Sept. 2007).
- All NSTX FEAs milestones met on or ahead of schedule.
- NSTX operated routinely at 5.5kG this year: TF joints look fine.
- Evaporated ~100 g lithium with LITER in support of experiments.
- Achieved good EBW coupling in H-mode utilizing LITER.
- 27 channel interim P-CHERS commissioned.
- 30 channel MPTS operated reliably.
- Achieved efficient HHFW heating compatible with CD phasing.
- New control computer installed and demonstrated.

# NSTX to Start FY 08 Run

---



- **NSTX FY 07 Outage completed on schedule.**
- **New facility capability to be available in FY 08 run:**
  - Two LITERs with shutters to complete the toroidal coverage
  - New control system with reduced latency with more channels
  - Flexible EF/RWM/RMP configuration with n=1,2,&3 capability
  - Moly / BN protection plates on select areas
- **New diagnostic capability to be available in FY 08 run:**
  - p-CHERS 70 channel system
  - FIDA utilizing PCHERS ports (UCI)
  - Divertor bolometer: Two views - 12 channels
  - High-k mirror remote steering (UCD)
  - MPTS polarizer and internal calibration probe
  - “Halo current” sensors in lower divertor
  - 4 MHz FReTIP capability (UCD)
- **Research run to start this week with 12 run week plus possible additional 6 run weeks.**

# NSTX Facility/Diagnostic Upgrade Strategy



NSTX is a premier fusion science research facility with access to wide range of plasma parameters and the state-of-the art innovative diagnostic systems taking advantage of excellent plasma access.

- Two scenarios being considered: **FY 08-10 Plan** and **Extended Plan**
  - I. **FY 08 - 10 Plan** to cease NSTX operation in FY 11 to accelerate NCSX research operation
  - II. **Extended Plan** to operate NSTX through FY 13
- **Scenario I. FY 08-10 plan** covers the period for upcoming FWP 2010 in March, 2008
  - Select facility and diagnostic upgrades to yield maximum scientific output with the period to establish the next step ST design basis
  - Incremental funding to increase run weeks with select key upgrades
- **Scenario II. Extended plan** covers FY 11 - 13 period which enables key important upgrades to greatly reduce the next step ST design risks
  - Increment (10%) Plan enables 2nd NBI and long-pulse divertor for full non-inductive operations at high power and long-pulse.
  - Base Plan (inflation) enables MHD Feedback coil upgrade and TF sub-cooling to operate at high f-NI and long-pulse operations.

# Transport and Turbulence

Measure full k-spectrum of turbulence to better understand ion and electron energy transport

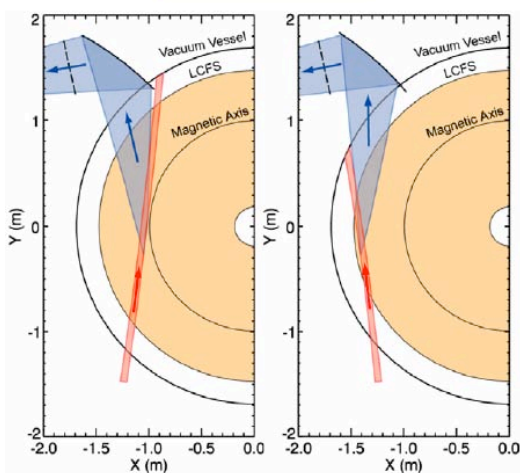
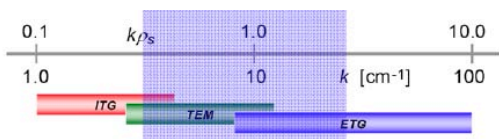


FY 08	FY 09	FY 10
-------	-------	-------

Run Weeks  
Base / Request\*

\*Note: Request is 10% enhancement over the base

Tangential High-k Scattering (3 MHz)



UC Davis  
(Ph.D. thesis)

## Profile Diagnostics

- P-CHERS(70 ch)
- MSE/CIF (16 ch) ● MSE/LIF Nova Photonics
- Multi-Color- $T_e(r)$  JHU

● MPTS Higher Spatial Resolution

## Turbulence Diagnostics

- Corr. Reflect (low-k) UCLA
- Improved High-k Scattering
- BES I

### MSE-LIF w/o heating beam

- Direct reconstruction of total plasma pressure
- Radial electric field profiles

- High-k Scattering  $k-\theta$
- BES II U. Wisconsin

**BES - Localized low-k turbulence structures to complement high-k → full turbulence k-spectrum**

To Enable Extrapolation to Next Step ST's

# Macrostability

## Advanced Tools Enabling Cutting-Edge EF/RWM/RMP Research

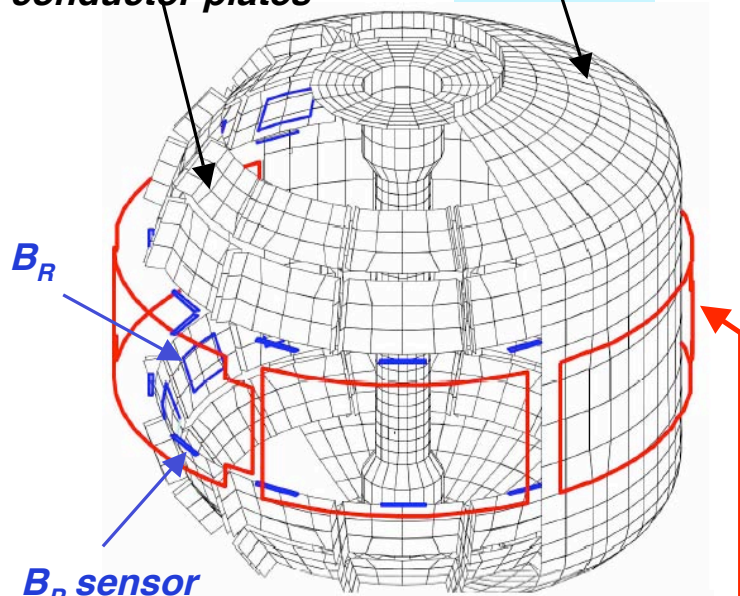


	FY 08	FY 09	FY 10
<b>Run Weeks</b>	12(18)	12	12
<b>Base / Request*</b>	12(18)	12	12
● Control system upgrade			
● Control Coil (n=1,2,&3)			
● NBI Feedback			
● Realtime CHERS			
● $V_\phi$ Feedback			
● Non-magnetic RWM-ID			

\*Note: Request is 10% enhancement over the base

Copper passive conductor plates

SS Vacuum Vessel



$B_p$  sensor

Columbia U

VALEN Model of NSTX (Columbia Univ.)

6 ex-vessel midplane control coils

### ITER design issue related activities:

- Vertical control
  - PF configuration similar to ITER
- ELM suppression
  - Attractive single row of coils test for improved RMP understanding (n=1,2,&3)
- RWM control – impact of missing control coils on feedback performance

JHU

GA

Provide basis to extrapolate high-beta operation for next-step ST's

(Ph.D. thesis)



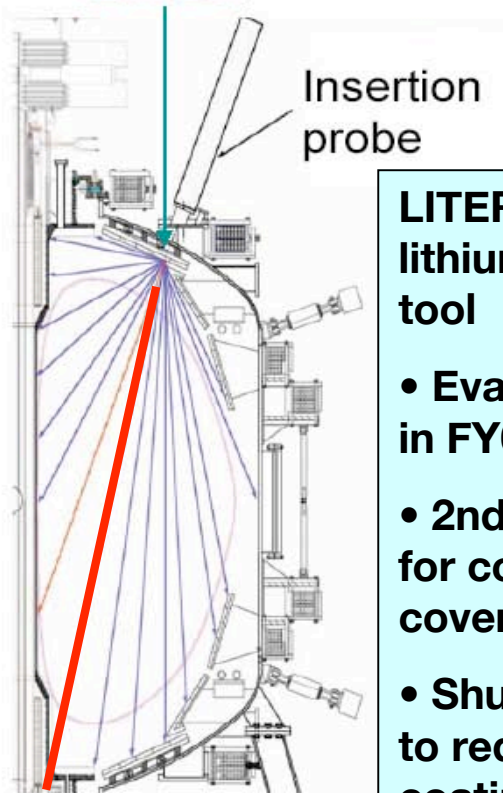
# Liquid Lithium Divertor for Particle Control

## Unique Capability for Diverted H-mode



NSTX developing lithium applications for STs/tokamaks with CDX-U/LTX since 2005

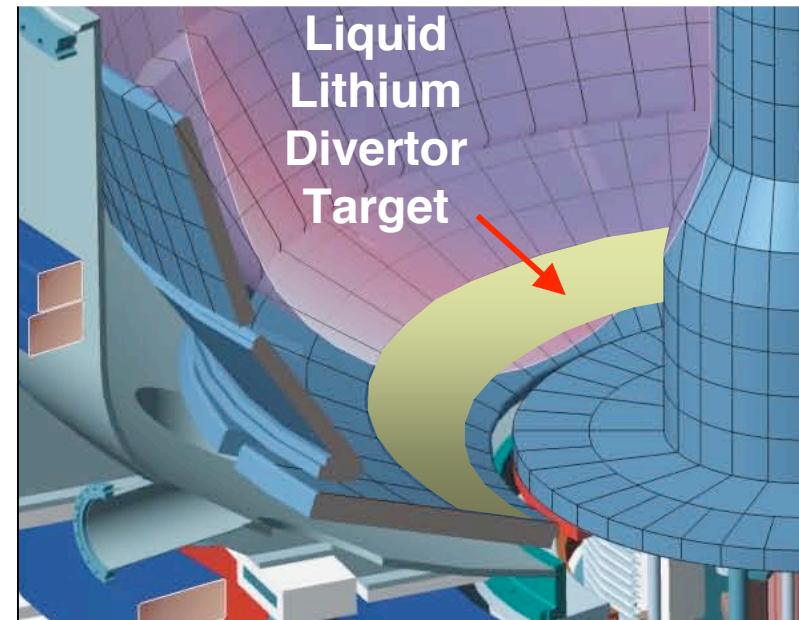
### LITER



**LITER - a reliable lithium evaporation tool**

- Evaporated ~ 100 g in FY07
- 2nd LITER in FY 08 for complete toroidal coverage
- Shutters installed to reduce window coating

The LITER System can be used for LLD to provide fresh thin liquid lithium surfaces



**Demonstrate particle control in long pulse advanced discharges**

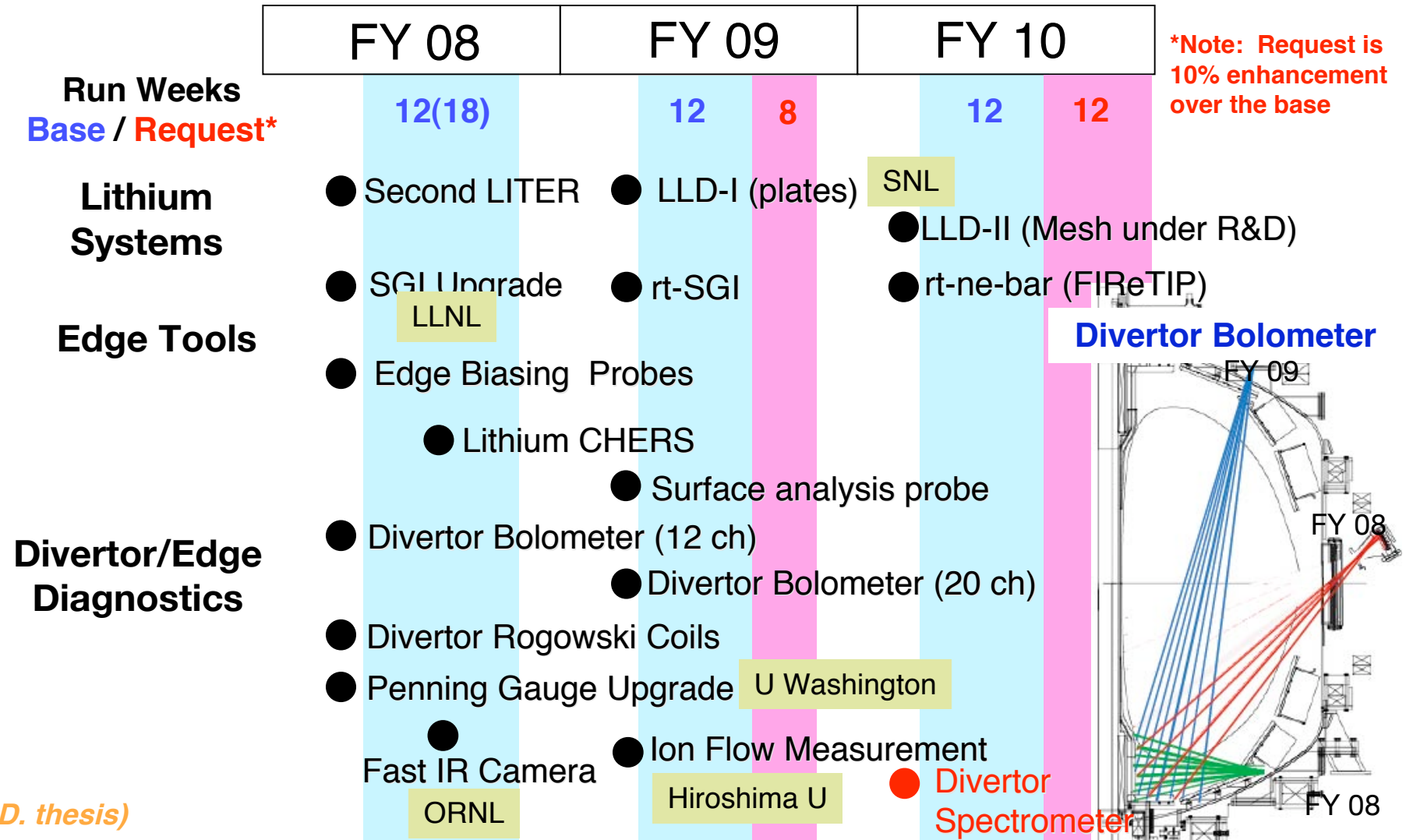
- FY 09: LLD-I - Plates with LITERS (thin lithium film to reduce operational risks)
- FY 10: LLD-II - Long-pulse pumping - mesh design under R&D
- FY 11-13: LLD-III - Long-pulse Power and Particle Handling

SNL

To Enable Particle and Power Control in Future ST's

# Boundary Physics

## Unique Facility Capability for Divertor Particle Control Using Lithium



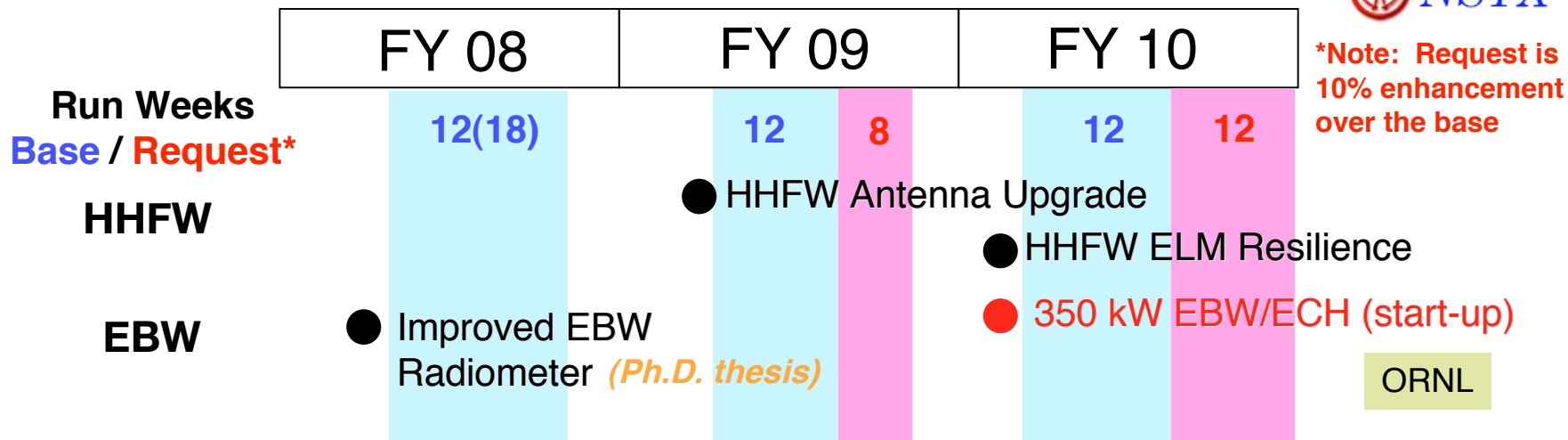
\*Note: Request is 10% enhancement over the base

To Provide Basis for Extrapolation of Edge Heat Flux in Next-Step ST's

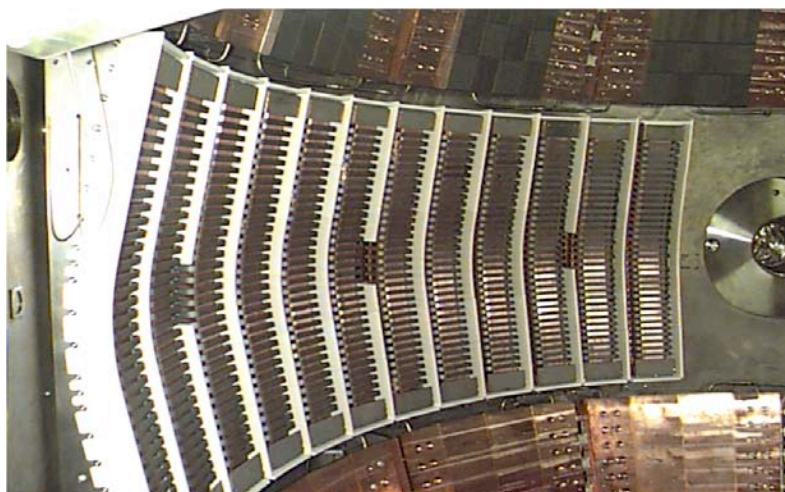
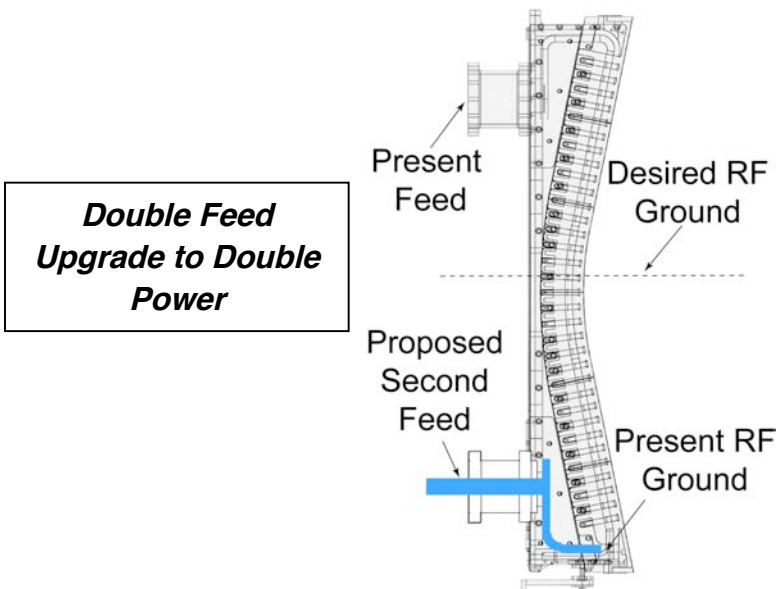


# HHFW and EBW

Improving HHFW Coupling for Advanced Scenarios,  
Deepening EBW H-mode Coupling Understanding



HHFW Antenna Upgrade - FY 09



HHFW/ICRF and EBW can provide heating and CD for next-step ST's

# Energetic Particles

## Deepening Fast-Ion Physics Understanding

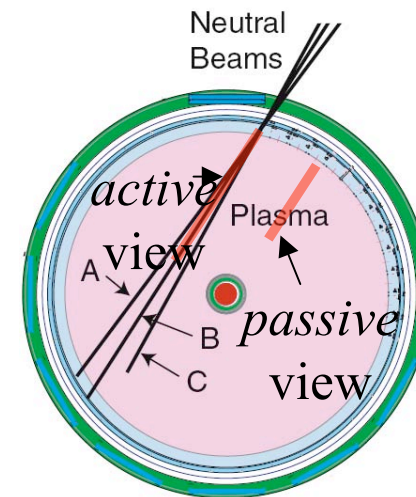
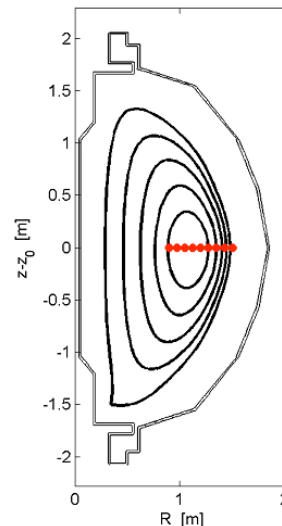


	FY 08	FY 09	FY 10
<b>Run Weeks</b>			
<b>Base / Request*</b>	12(18)	12	12
		8	12
<b>Energetic Particles</b>	<ul style="list-style-type: none"> <li>● Fast Ion D<math>\alpha</math> Camera</li> <li>● Fast SFLIP</li> <li>● Fast IR Camera</li> </ul>	UCI	<b>Other EP Diagnostics:</b> <ul style="list-style-type: none"> <li>● Scanning NPA, SS-NPA</li> <li>● MSE-LIF, Neutron detector</li> </ul>
<b>Energetic Particle Mode</b>	<ul style="list-style-type: none"> <li>● FIRETIP (3 MHz)</li> </ul>	UCD	<b>Other EP Mode Diagnostics:</b> <ul style="list-style-type: none"> <li>● High-k scattering, <math>\mu</math>- Reflectometer</li> <li>● BES, Magnetic Sensors</li> </ul>

\*Note: Request is 10% enhancement over the base

**FY 08 FIDA**  
2x16 channels

- Resolution:
- 10keV, 5cm, >5ms

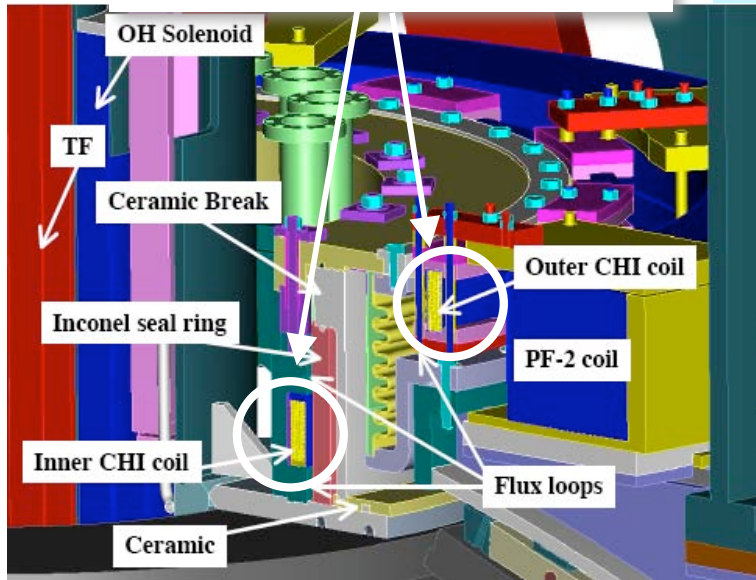
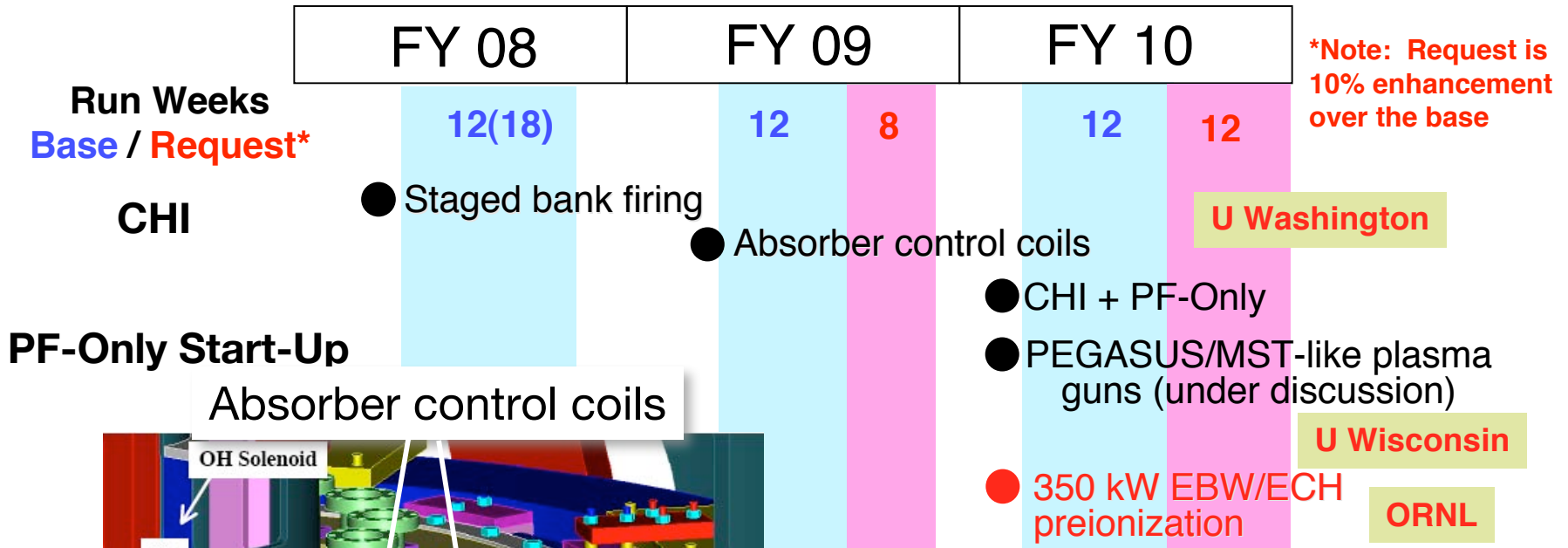


(Ph.D. thesis)

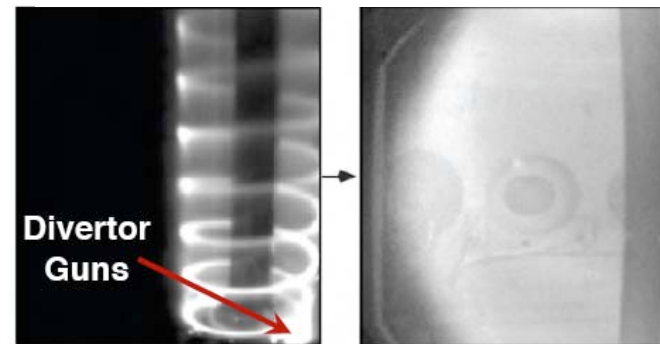
To Provide Basis for Energetic Particle Effects in Next-Step ST's

# Solenoid-free Start-up

NSTX Well Positioned for Cutting-Edge EF/RWM Research



## PEGASUS Gun Start-up



$I_p \sim 30$  kA achieved with one gun

NHTX can Test Start up Techniques, ST-CTF can have Slender Iron Core

# NSTX Budget Summary (\$M)



	FY 08	FY 09		FY 10	
Budget cases	Base	Base	Request	Base	Request
Run Weeks	12*	12	20	12	24
Facility Operations	18.7	19.3	20.9	19.9	22.3
Facility Upgrades	0.7	0.5	1.6	0.5	1.2
Diag. Upgrades	0.5	0.4	1.3	0.4	0.9
<b>Facility Total</b>	<b>19.9</b>	<b>20.2</b>	<b>23.8</b>	<b>20.8</b>	<b>24.4</b>
PPPL Research	10.1	10.4	10.4	10.7	10.7
Collab Diag Interf.	0.6	0.6	0.7	0.6	0.7
Collaborations	5.5	5.6	5.7	5.8	5.9
<b>Science Total</b>	<b>16.2</b>	<b>16.6</b>	<b>16.8</b>	<b>17.1</b>	<b>17.3</b>
<b>NSTX Total</b>	<b>36.1</b>	<b>36.8</b>	<b>40.6</b>	<b>37.9</b>	<b>41.7</b>

- 12 run week base cases in FY 09 and 10 assumes minimal upgrades.
- Requested budget ~ 10% increase allows near full facility utilization and acceleration of high priority facility and diagnostic upgrades.

• Up to 18 run weeks maybe available due to the omnibus bill

# **Modest Budget Enhancement (~ 10%)**

## **Significantly Increases Science Output**



### **Increase Operations toward Full Facility Utilization:**

- ~ 80 % increase in run weeks

### **Accelerate Key Facility/Diagnostic Upgrades:**

- Install ECH/EBW System 350 kW for pre-ionization for start-up and EBW study in FY10
- MPTS higher spatial resolution for transport and pedestal study in FY 10
- Realtime CHERS in FY 9-10 for rotation control
- Divertor spectroscopy for divertor study

### **Improves Facility Reliability and Availability**

- Better Preventive Maintenance and
- Critical spare parts



# Not Running FY 10 Devastating for FY 08 - 10 Plan

---



**FY 10 Run likely to be the most scientifically productive run due to implementation and maturing of key advanced diagnostics critically needed to enable extrapolation to Next Step STs:**

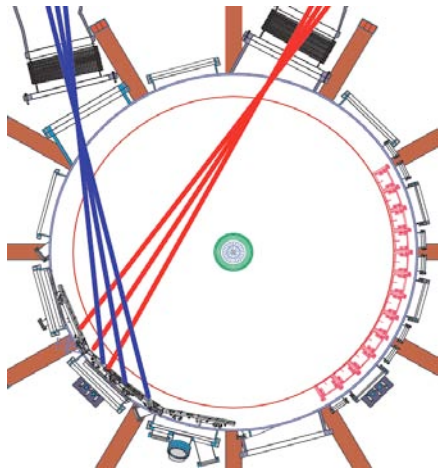
- **Not able to utilize BES and High-k- $\theta$  for full turbulence k-spectrum for electron / ion transport study.**
- **Not able to utilize MSE-LIF for Er and total pressure profile measurements for complete plasma profiles information and to support energetic particle study.**
- **Not able to test LLD-II and density feedback for long-pulse particle pumping for advanced operations.**
- **Not able to implement HHFW ELM Resilience needed for robust heating and CD in H-mode.**
- **Not able to test CHI + PF-Only start-up.**
- **Not able to implement Plasma Gun for start-up study**

# Extended Plan: FY 11 - 13

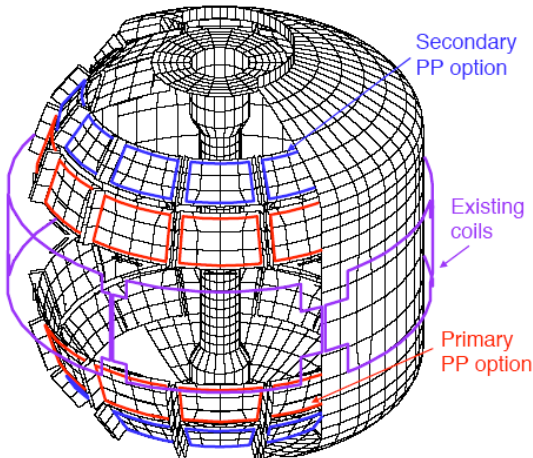
Enables key important upgrades and additional 32 run weeks to greatly reduce the next step ST design risks



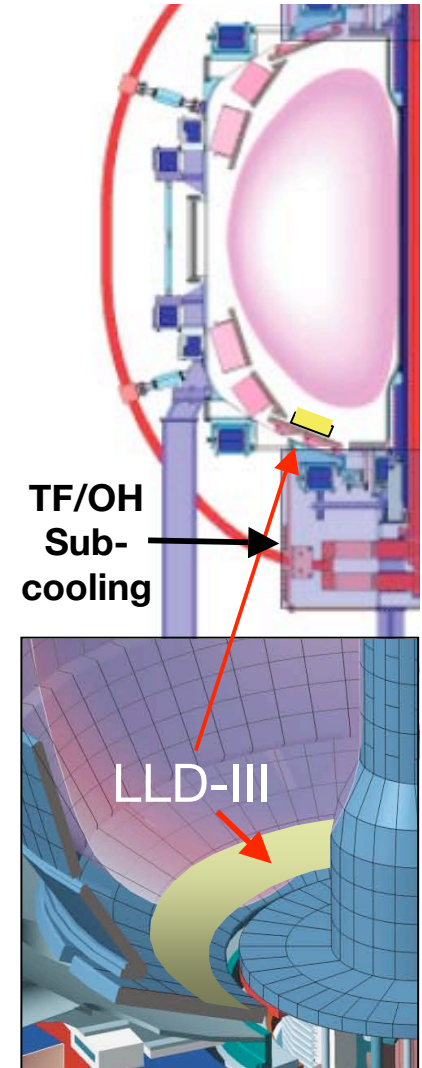
**New 2<sup>nd</sup> NBI**  $R_{TAN}=110,120,130\text{cm}$   
**Present NBI**  $R_{TAN}=50,60,70\text{cm}$



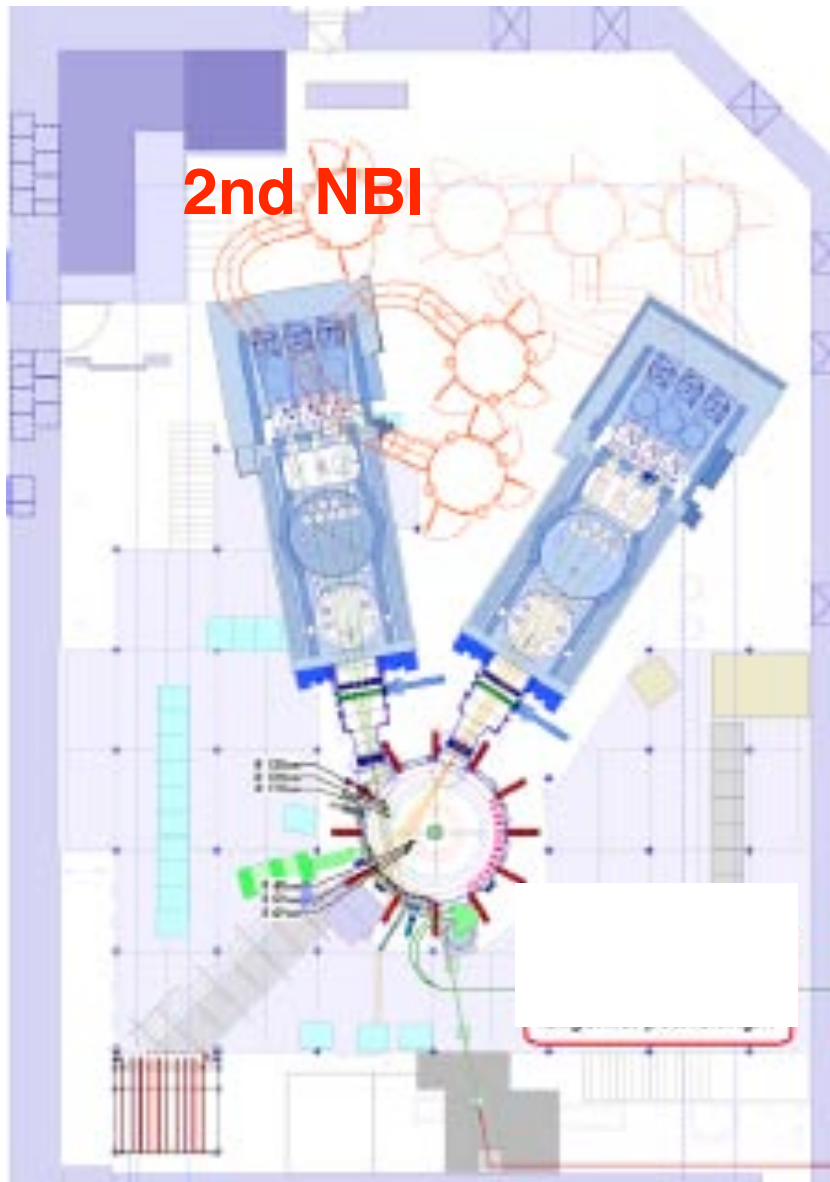
**Adv. EF/RWM/RMP coils**



- 2nd NBI for full non-inductive operations
- TF / OH sub-cooling for long-pulse operation at full field ( $\tau_{CR} \rightarrow 3\tau_{CR}$ )
- Long-pulse high-power divertor
- Advanced EF/RWM/RMP feedback coils)



# NBI Upgrade Enables Profile Control and Full-Non-Inductive CD Scenarios



## 2nd NBI: Utilize TFTR system

- $R_{\text{tan}} = 110, 120, \text{ and } 130 \text{ cm}$

## Existing NBI

- $R_{\text{tan}} = 50, 60, \text{ and } 70 \text{ cm}$

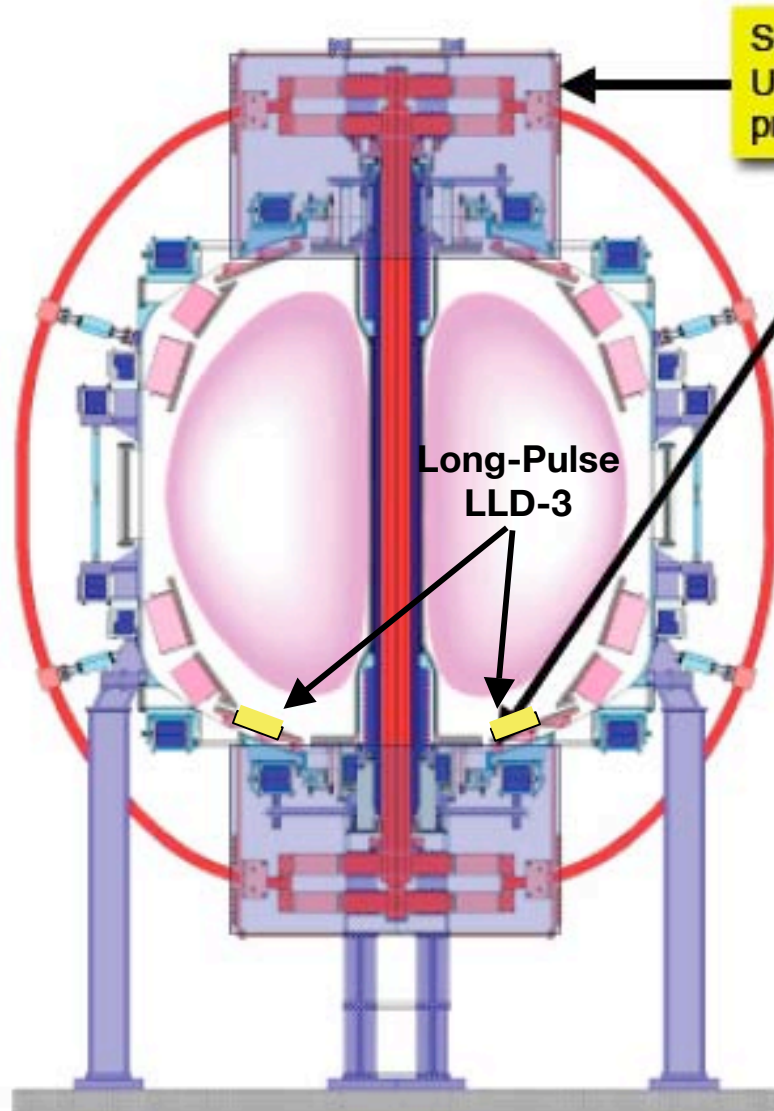
## Greatly enhanced capabilities

- Doubles  $P_{\text{NBI}}$  from 7 to 14 MW
- Enables high  $\beta_{\text{T}}$  at high  $B_{\text{T}}$
- Higher CD Efficiency

## Aids physics investigation

- Control  $q$  and  $\chi$  profile for MHD and confinement
- Thermal and energetic particle/ $j(r)$  transport vs.  $R_{\text{tan}}$
- Beta scan at full  $B_{\text{T}}$
- Divertor heat flux  $\sim 20 \text{ MW/m}^2$

# TF Sub-Cooling Enables Long-Pulse at Full Field to Better Test NHTX/CTF Proposed Operating Scenarios



- To reach  $\Delta t_{\text{pulse}} \gg \tau_{\text{skin}}$  of NHTX / CTF relevant high performance full non-inductive discharges, NSTX TF flat-top duration needed to be extended by x 2- 3
- Sub-cooling to  $-50^{\circ}\text{C}$  increases TF flat top time by a factor of  $\sim 3$  at 5.5 kG from 0.7 sec to  $\sim 2$  sec ( $1 \tau_{\text{cr}} \rightarrow 3 \tau_{\text{cr}}$ )
- Only the center stack needed to be cooled (small volume)
- Upper and lower umbrella structure can be sealed for dry  $\text{N}_2$

# ASIPP-NSTX Collaboration Activities



- **NSTX OH Spare:**
  - ASIPP is ramping up the manufacturing effort.
  - Engineering team to visit ASIPP in 1/21-25/2008 to review manufacturing plan, testing and quality control.
- **EAST diagnostic status:**
  - ECE grating polychromator and ion source are being prepared for shipment and loan agreements are in progress
  - Germanium PHA detector testing is nearly done
  - Export control is being contacted for whether or not export license is needed for neutron (He3) detectors
  - NPA testing is the next remaining task.
- **ASIPP researchers' visits to NSTX/PPPL for tokamak code training**
  - Jinping Qian, ASIPP, visited in December to learn the NSTX version of EFIT as well as the LRDFIT codes, with the intent of using LRDFIT for equilibrium reconstruction of EAST plasmas.
  - Two researchers are scheduled to visit for one year in March to learn tokamak simulation codes (TSC, pTRANSP, etc.)
- **Assist EAST operations:**
  - We send our head of NSTX plasma operation, Dennis Muller to EAST to help the EAST operation. He visited EAST to help the first plasma and the second campaign. Dennis plans to return for the third campaign planned this year.



# Exciting Opportunities and Challenges

## Optimized Plans Developed for FY 2008 - 2010

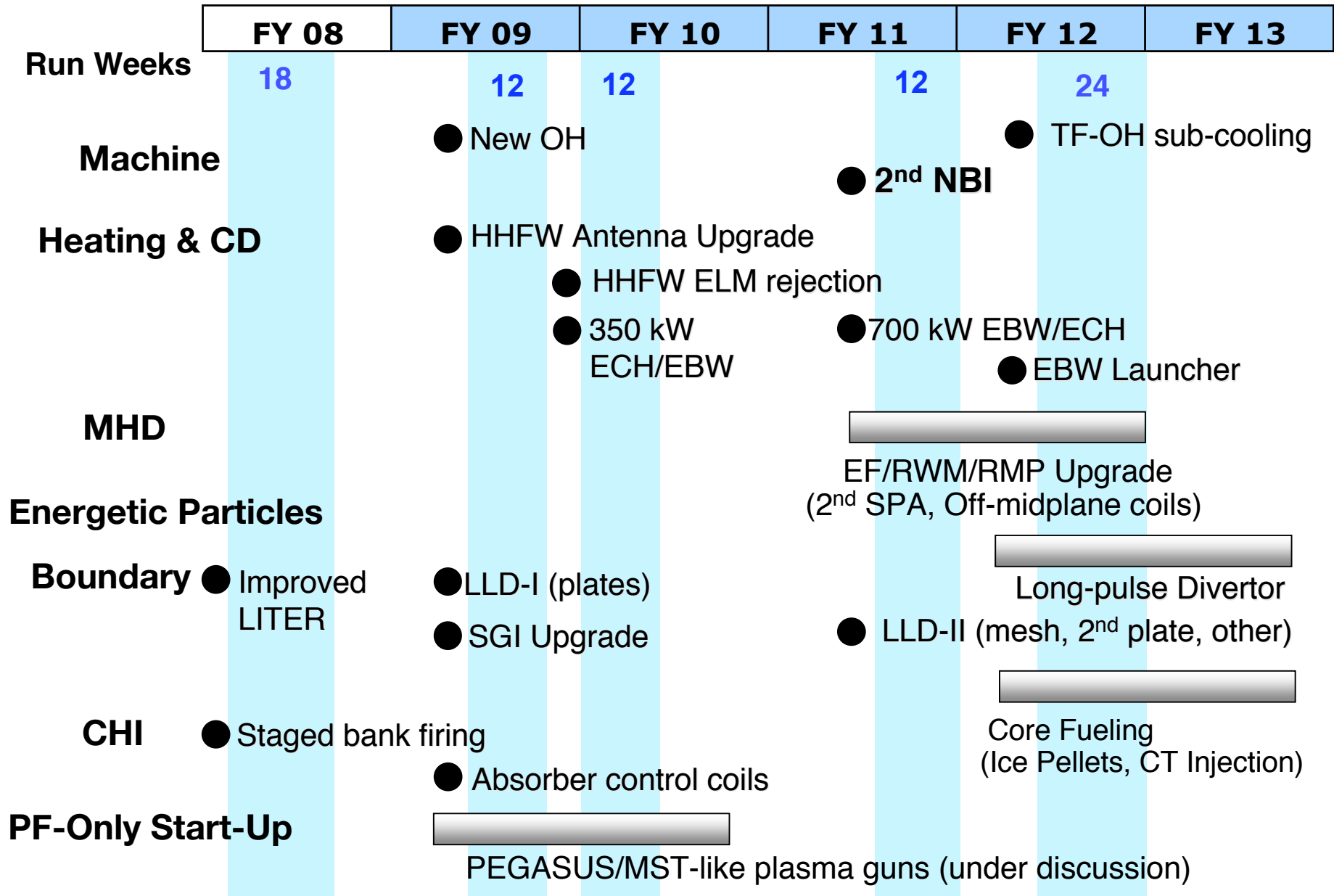


- **Very productive FY2007 run with all milestones completed.**
- **FY 2008 run started with timely new capabilities in January**
  - Two LITERS, RMP for  $n=1,2,&3$ , SGI, new rt control,
  - Two view divertor bolometer, FIDA, 70 ch p-CHERS, div. halo current
  - Improved high-k, FReTIP, MPTS, USXR, Reflectometer
- **Facility upgrades to support exciting FY 2009-2010 research plan to address next step ST device design issues**
  - Liquid lithium divertor target (Boundary) in FY 09-10
  - HHFW antenna upgrade (Waves) in FY 09
  - BES to complement high-k (T&T) FY 09-10
  - MSE-LIF to complement MSE-CIF FY 09-10
  - Three view Divertor Bolometer (Boundary) FY 09
- **~10% increase in budget greatly enhances science output**
  - Increase the run weeks by ~ 80 %
  - EBW/ECH (Waves, Solenoid-free Start-up) FY 10
  - Accelerate real time-CHERS, MPTS upgrades, Plasma gun, CHI coil

- **Extended NSTX Plan FY 11 - 13 enables fully non-inductive long pulse operation to greatly reduce the risks of future ST devices.**  
**Major Upgrades: 2nd NBI, TF sub-cooling, LLD-III and EF/RWM/RMP Coils**

# Backup Viewgraphs

# NSTX 5 Year Facility Upgrade Plan (+10%)

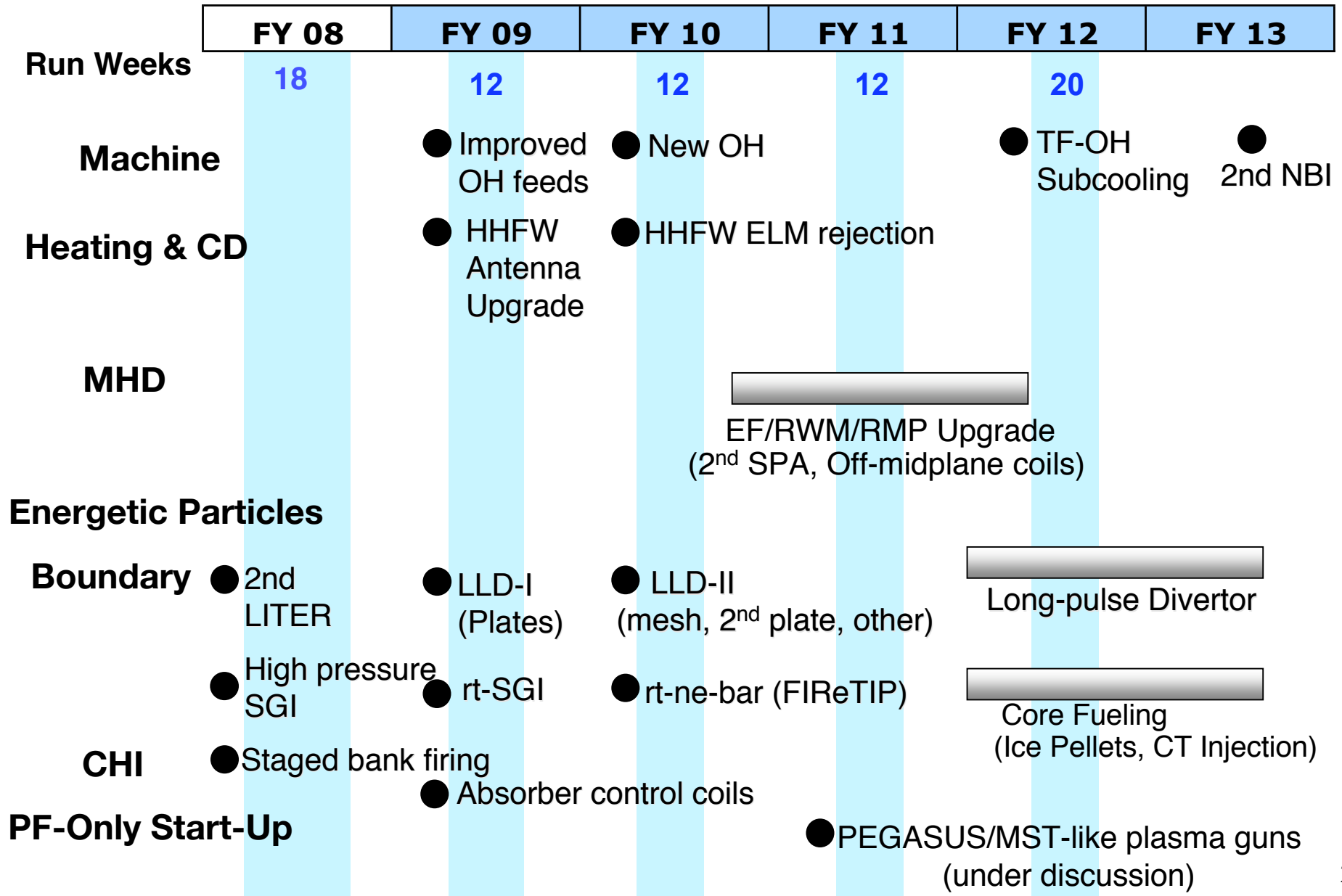


# NSTX 5 Year Diagnostic Upgrade Plan (+10%)



	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
<b>Run Weeks</b>	18	12	12	12	24	
<b>Profile</b>	● P-CHERS(70 ch)	● MSE/LIF	● Realtime CHERS	● $V_\phi$ control	● Real time MSE	● J(r) control with 2 <sup>nd</sup> NBI+rt-MSE
	● MSE/CIF (19 ch)		● MPTS Higher Spatial Resolution			
	● Multi-Color- $T_e(r)$					
<b>MHD</b>	● Divertor Halo Current			● Non-magnetic RWM-ID		
<b>Turbulence</b>	● Corr. Reflect.	● BES-I	● BES-II	● Magnetic turbulence diagnostic		
	● High-k Scattering Remote-control	● High-k Scattering k- $\theta$				
<b>Energetic Particles</b>	● Fast-ion D-alpha camera			● Neutron Collimator		
	● FIReTIP (2 MHz)					
<b>Waves</b>	● High-k HHFW (30 MHz)					
	● Improved EBW Radiometer					
<b>Boundary</b>	● Divertor Bolometer	● X-point Fast Probe	● Divertor Thomson			
	● Fast IR Camera	● Surface analysis probe				
	● Penning Gauge	● Edge USXR				
	● Improved dust detector	● Ion Flow Measurement	● Divertor spectrometer			

# NSTX 5 Year Facility Upgrade Plan (Base)





# NSTX 5 Year Diagnostic Upgrade Plan (Base)

