NSTX

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Facility, Diagnostic, and Budget Overview for 2009-13

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Masa Ono, PPPL

For the NSTX Research Team

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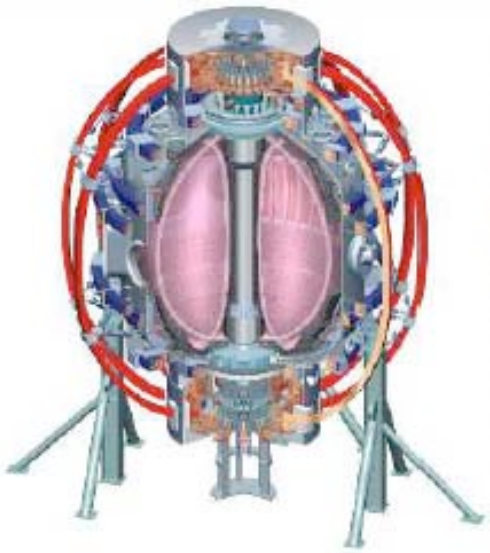
IPP, Garching
ASCR, Czech Rep
U Quebec

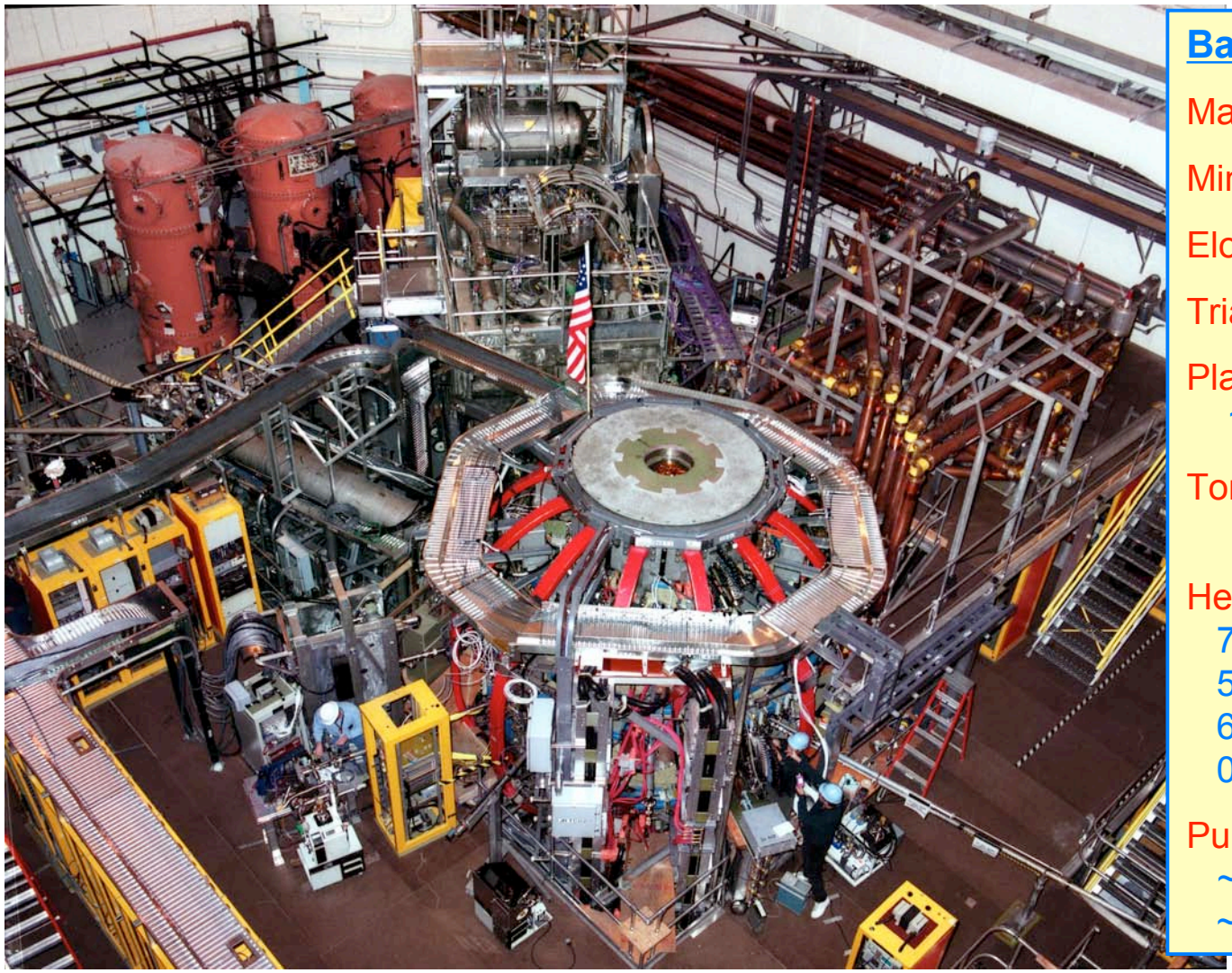
NSTX 5 Year Plan Review for 2009-13
Conference Room LSB-B318, PPPL
July 28-30. 2008



Talk Outline

- Facility / Diagnostic Status Overview
- Facility Diagnostic Plans Organized by Science Topical Areas
  - MHD
  - T&T
  - Boundary Physics
  - HHFW, EBW, and Energetic Particles
  - Start-up and Ramp-up
- New Center-stack Upgrade
- Second NBI Upgrade
- Budget scenarios
- Conclusions

NSTX Facility Overview



Baseline Parameters

Major Radius 0.85 m

Minor Radius 0.68 m

Elongation 1.8 - 3.0

Triangularity 0.2 - 0.8

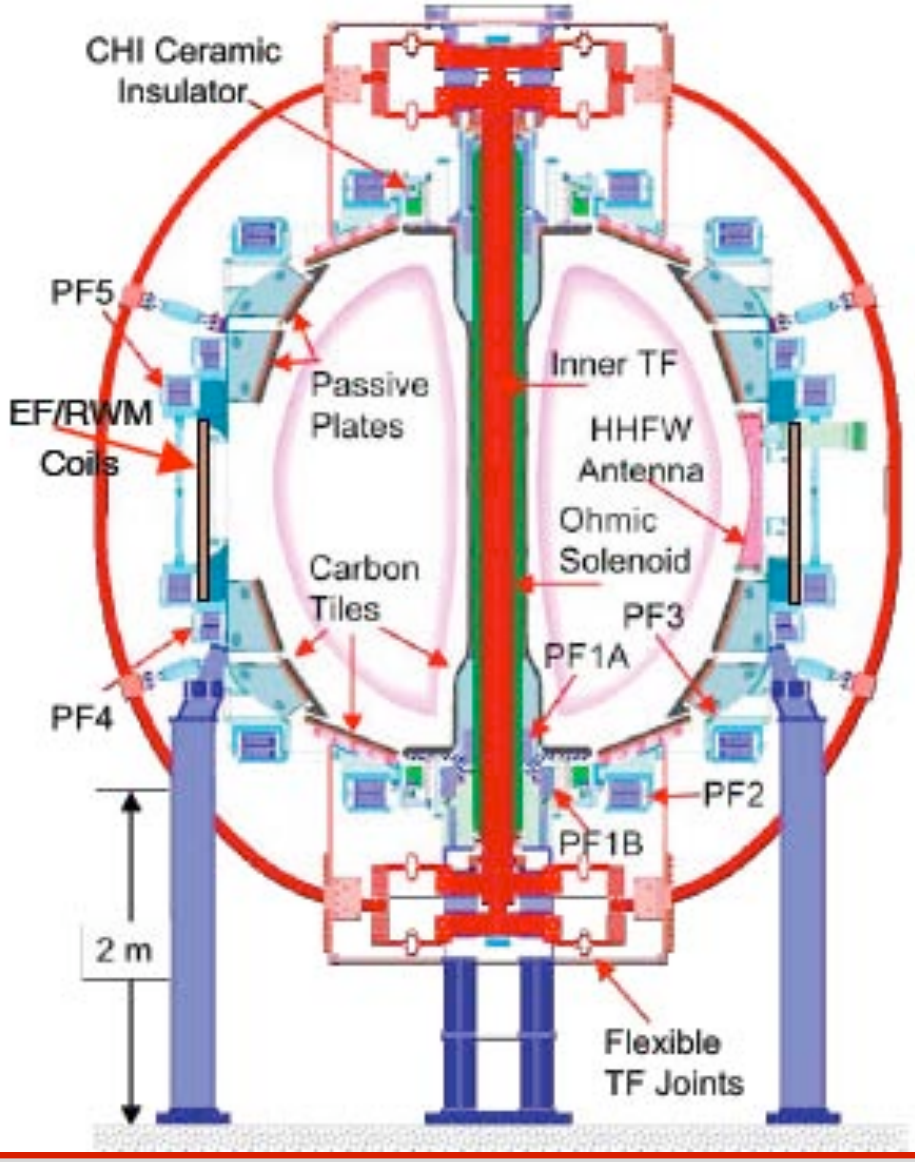
Plasma Current
1 MA (1.5 MA peak)

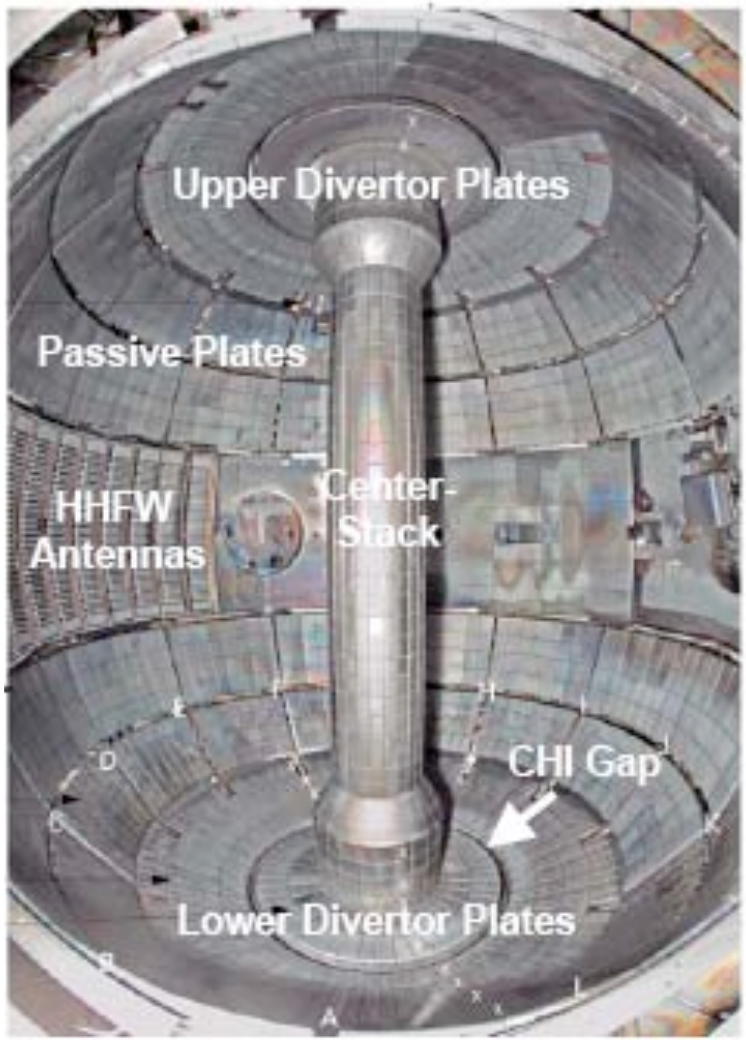
Toroidal Field
0.35 - 0.55 T

Heating and CD
7 MW NBI (2 sec)
5 MWNBI (5 sec)
6 MW HHFW (5 sec)
0.2 MA CHI

Pulse Length
~ 1 sec at 0.55 T
~ 2 sec at 0.38 T

NSTX Device Cross-Section and VV Internal Components
Removable Center-Stack Design





Comprehensive Diagnostic Systems Operational 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: $T_i(R)$ and $V_f(r)$ (51 ch)
- P-CHERS: $V_q(r)$ (51 ch)
- *MSE-CIF (15 ch)*
- *FIReTIP interferometer (119mm, 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 (2ms)*

Energetic Particle Diagnostics

- Neutal particle analyzer (2D scanning)
- SSNPA
- Fast lost-ion probe (energy/pitch angle resolving)
- Neutron measurements
- *Fast Ion D_a profile measurement*

Edge Divertor Physics

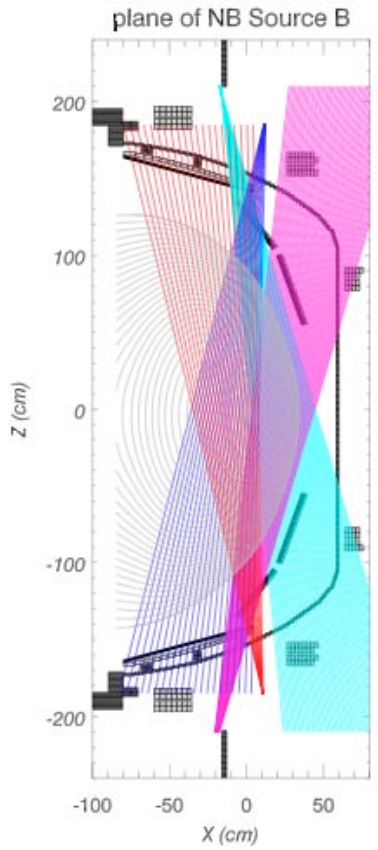
- *Reciprocating Edge Probe*
- *Gas-puff Imaging (2ms)*
- *Fixed Langmuir probes (24)*
- Edge Rotation Diagnostics (T_i, V_f, V_{pol})
- *1-D CCD H_a cameras (divertor, midplane)*
- *2-D divertor fast visible camera*
- Divertor bolometer (12 ch)
- *IR cameras (30Hz) (3)*
- Tile temperature thermocouple array
- Dust detector
- Edge Deposition Monitors
- *Scrape-off layer reflectometer*
- *Edge neutral pressure gauges*

Plasma Monitoring

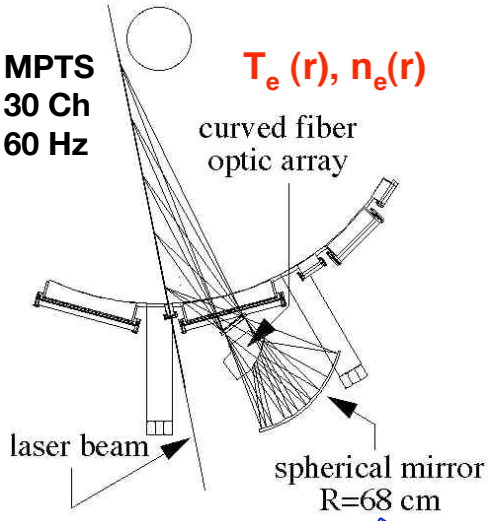
- *Fast visible cameras*
- Visible bremsstrahlung radiometer
- Visible survey spectrometer
- UV survey spectrometer
- *VUV transmission grating spectrometer*
- *Visible filterscopes*
- *Wall coupon analysis*
- *X-ray crystal spectrometer (astrophysics)*

NSTX has Excellent Diagnostic Access and State-of-the-Art Profile Diagnostics

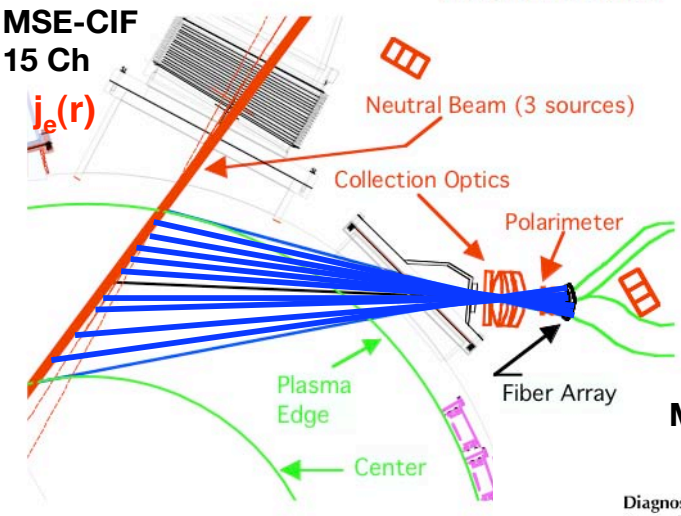
P-CHERS
75 Ch $V_\theta(r)$



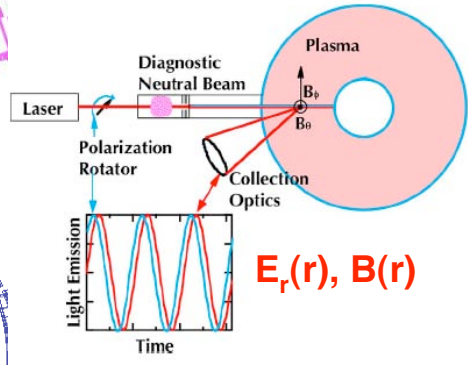
MPTS
30 Ch
60 Hz
$T_e(r)$, $n_e(r)$



MSE-CIF
15 Ch
$j_e(r)$

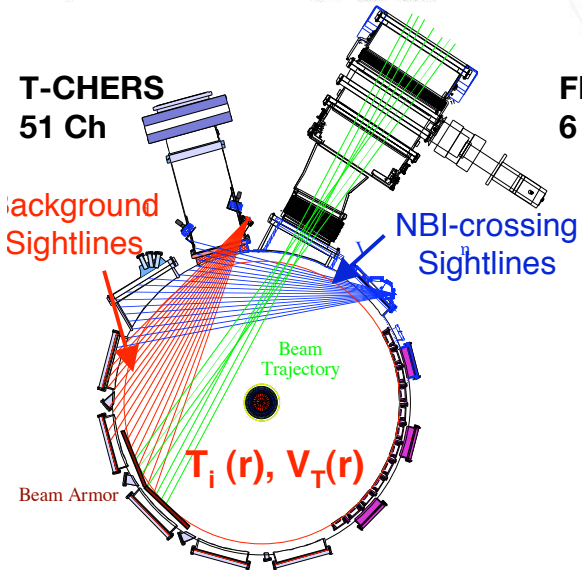


MSE-LIF (FY09-10)

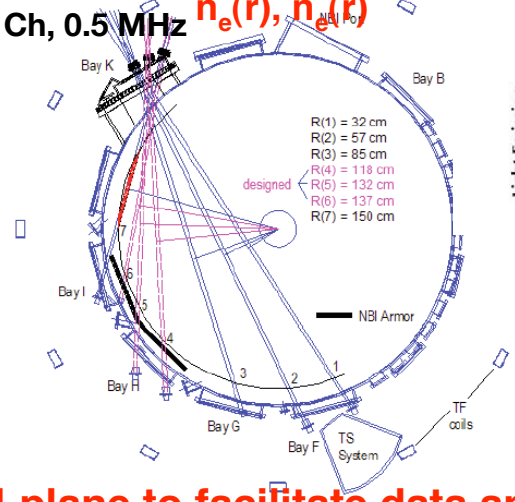


$E_r(r)$, $B(r)$

T-CHERS
51 Ch



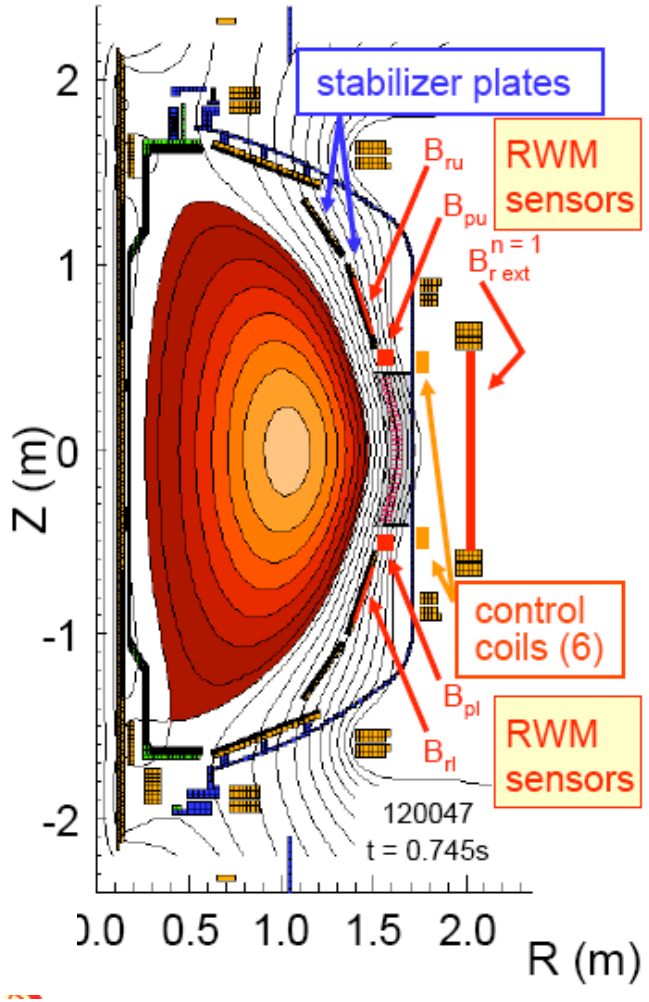
FIReTIP
6 Ch, 0.5 MHz
$\bar{n}_e(r)$, $\tilde{n}_e(r)$



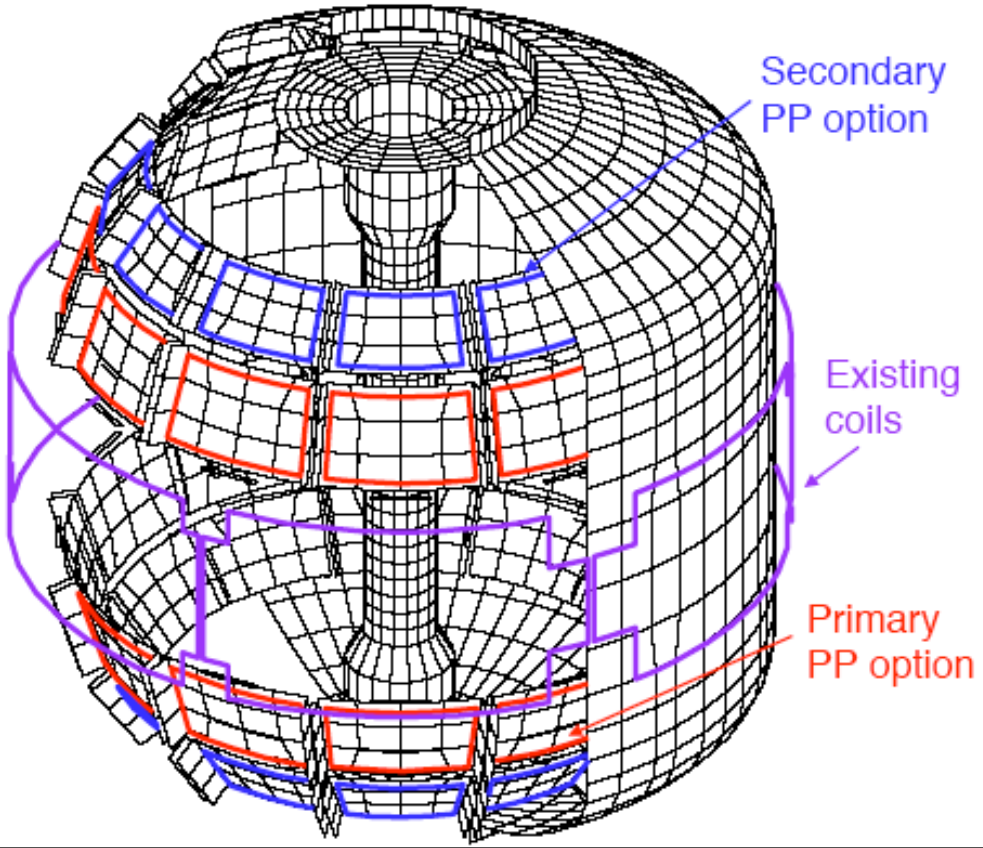
All profile diagnostics measure at mid-plane to facilitate data analyses

MHD - NSTX Non-Axisymmetric Coil System with Fast Power Amplifiers Contributed Productively for MHD Control (n = 1, 2, 3 EF, RWM, RMP)

External midplane - 6 coils toroidally



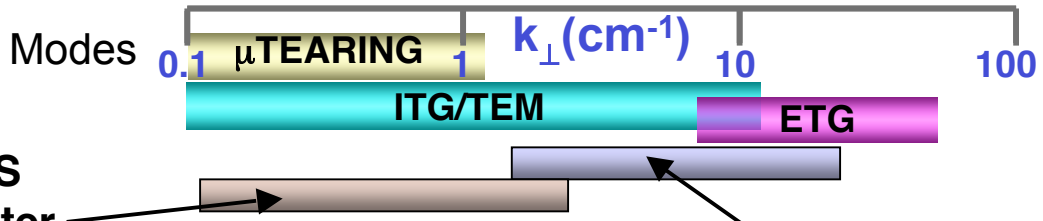
Non-Axisymmetric Control Coils (NCC)



Upgrade Plan:

- **Increase the SPA power amplifiers from 3 to 6 will allow arbitrary mix of even and odd n (2012 - base)**
- **Assess and optimize Non-Axisymmetirc Control Coils for greater EF/RWM/RMP control (2013 - Incremental)**

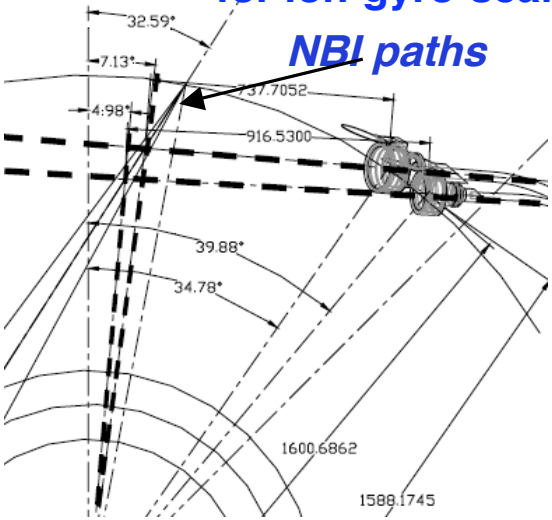
Highest Priority Turbulence Diagnostics are High-k Scattering and BES for Electron, Ion, and Momentum Transport

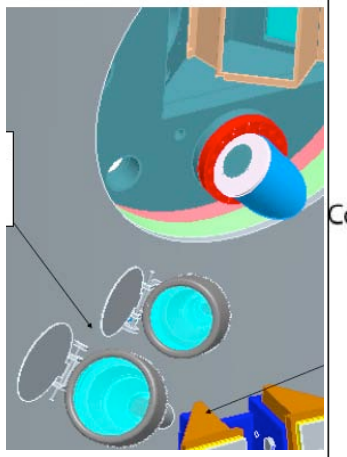


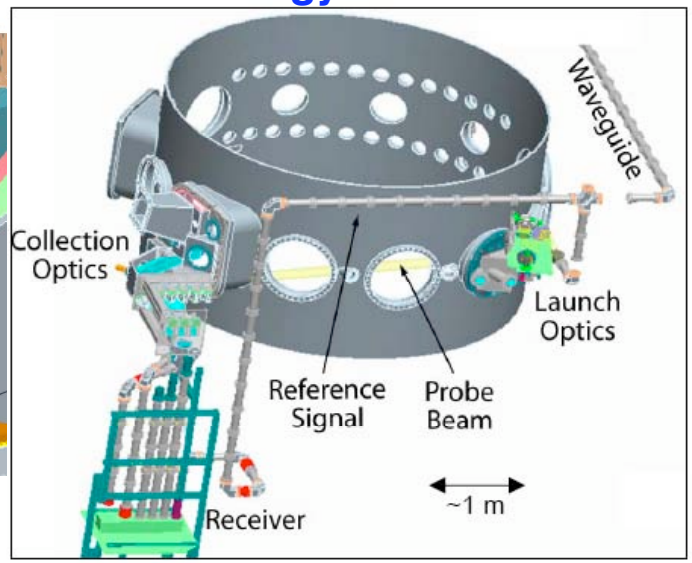
32 Ch BES Reflectometer

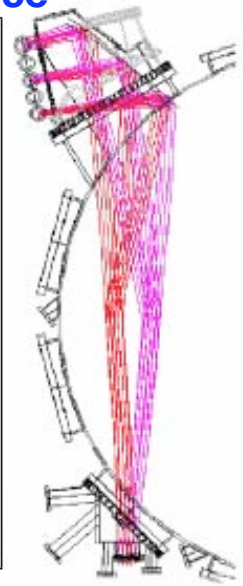
Beam Emission Spectroscopy
for ion-gyro-scale turbulence

High-k Tangential Scattering
for electron-gyro-scale turbulence









BES System Design: 0.4 < r/a < 1.0

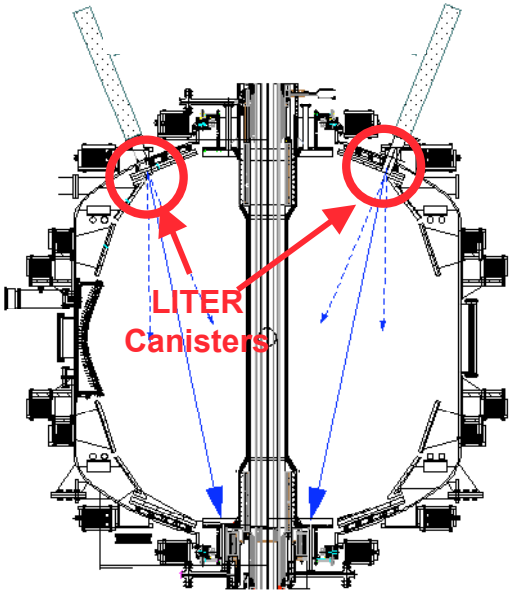
- 5 x 6 array plus 2 common modes monitors
- Fiber bundles to cover much of the plasmas
- Implement in 2009-2010

- Upgraded to 5 MHz (measured ~ 1 MHz fluctuations)
- Remote capability being implemented
- Solid-state source upgrade improve stability
- k_θ upgrade planned in 2011 (2010 incremental)

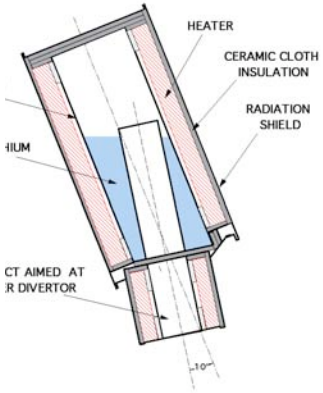
Boundary: Liquid Lithium Divertor (LLD) for Particle Control

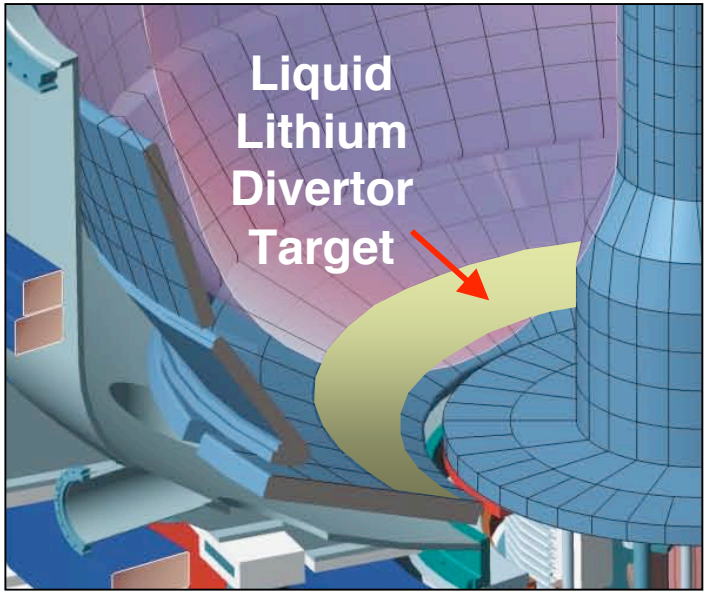
Unique Capability for Diverted H-mode

NSTX Dual "LITER"Lithium Eevaporators



LITER Canister

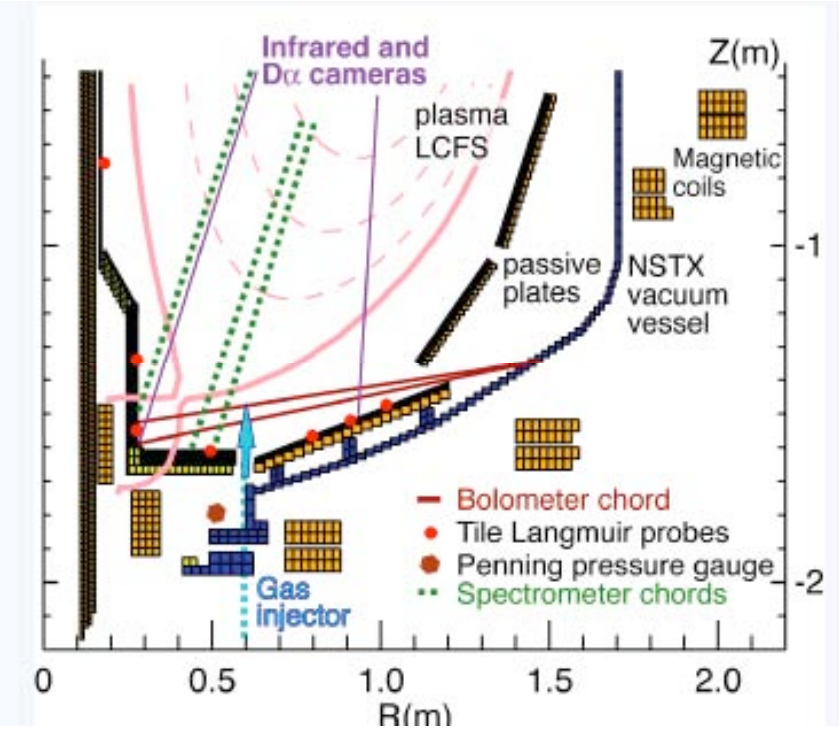




- Worked reliably in FY 08 evaporating ~ 200 g lithium
- Reloaded 3 times (takes one day to reload)
- Will be used to coat the LLD surface in 2009

- Install LLD (with SNL) with temperature control
- Start LLD operation in 2009
- Long-pulse divertor in 2012
- Core fueling in 2012
- Very high power flux divertor in 2013 (Incremental)

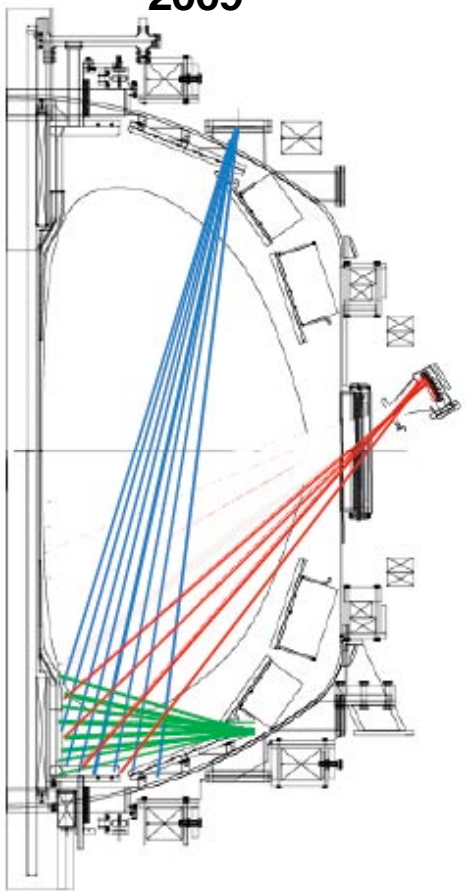
Boundary Physics Diagnostics Support Highest Priorities:
LLD, Heat-Flux Width, and Pedestal Stability



Existing Diagnostics:

- *Reciprocating Edge Probe*
- *Gas-puff Imaging (2ms)*
- *Fixed Langmuir probes (24)*
- Edge Rotation Diagnostics (T_i, V_f, V_{pol})
- *1-D CCD H_a cameras (divertor, midplane)*
- *2-D divertor fast visible camera*
- Divertor bolometer (12 ch)
- *IR cameras (30Hz) (3)*
- Tile temperature thermocouple array
- Dust detector
- *Scrape-off layer reflectometer*
- *Edge neutral pressure gauges*

Three-view divertor bolometer system 2009



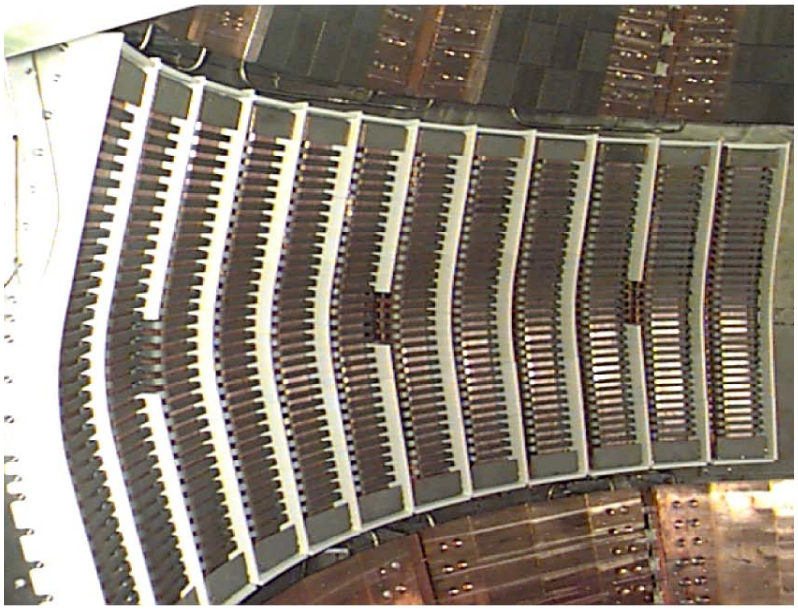
Planned Upgrades:

2009	2010	2012
Divertor Bolometer	*Ion Flow Measurement*	Divertor Thomson (Incremental)
Surface analysis probe	*Edge USXR*	
Fast IR Camera	*Divertor spectrometer*	

Collaboration contributions

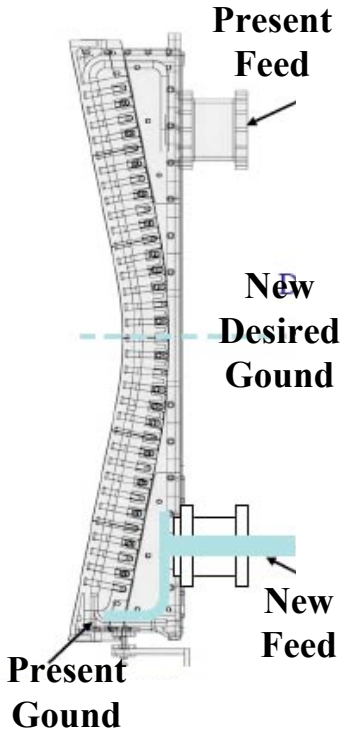
HHFW For Electron Heating and Current Drive for Start-up, Ramp-Up, and Sustainment

HHFW Antenna Array



- Twelve antennas
- Six 1 MW transmitters
- Real time phasing
- Top-fed
- Wave reflectometers
- Edge rf probes

HHFW Antenna Upgrades



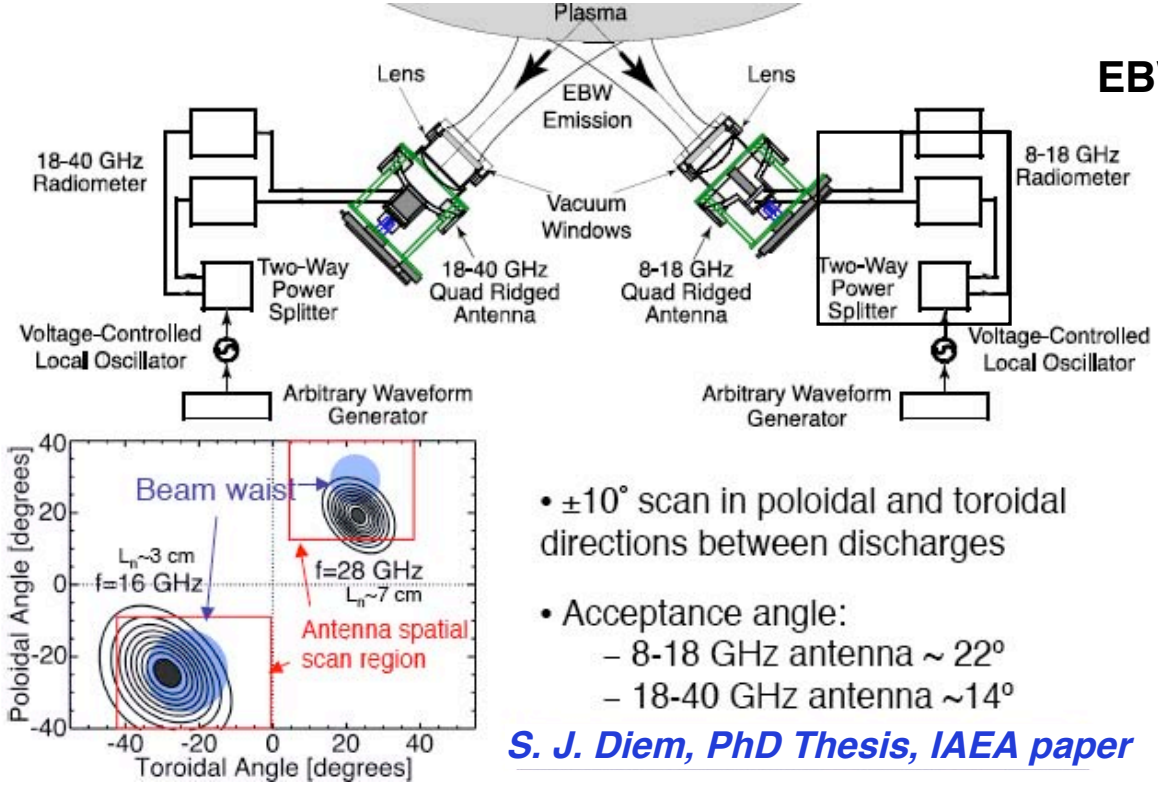
- *Feed-through voltage reduced to double power handing capability*
- *Mid-plane ground to optimize HHFW launching*

- Double-feed upgrade for higher power in 2009 to utilize full power under various load conditions
- ELM resilience system upgrade in 2010 with ORNLfor H-mode operation

Productive EBW Research

EBW Current Drive Significantly Increased ST-CTF Performance

Remotely Steered EBW Emission System for Coupling Study



- ±10° scan in poloidal and toroidal directions between discharges
- Acceptance angle:
  - 8-18 GHz antenna ~ 22°
  - 18-40 GHz antenna ~14°

S. J. Diem, PhD Thesis, IAEA paper

EBW Coupling Study

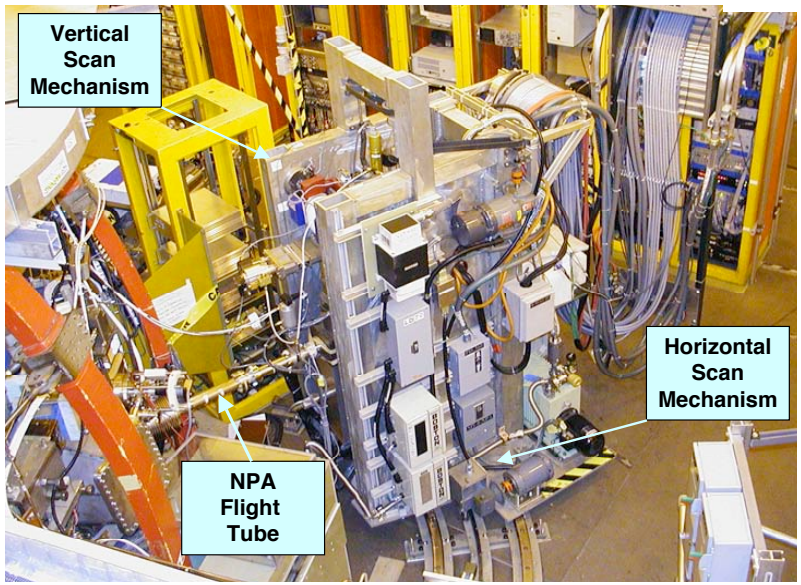
- 90% level coupling in L-mode but poor coupling in H-mode
- Lithium conditioning increased H-mode coupling from 10-20% to 50 - 60%
- Collisional damping and vertical position dependence verified
- Direct coupling experiment is a logical next step

ECH/EBW Upgrade: Utilizing ORNL system to minimize cost

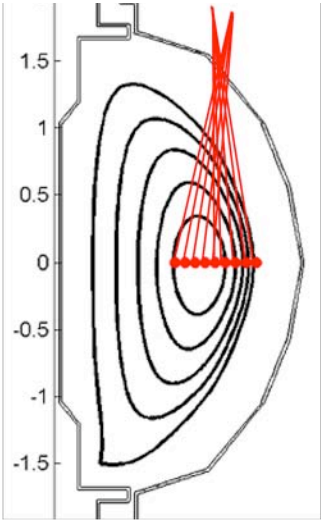
- 350 kW for Start-Up Research in 2011(short-pulse)
- 700 kW for for Start-up and EBW heating in 2012 **(Incremental)**
- Collaborate on MAST with a 350 kW system in place

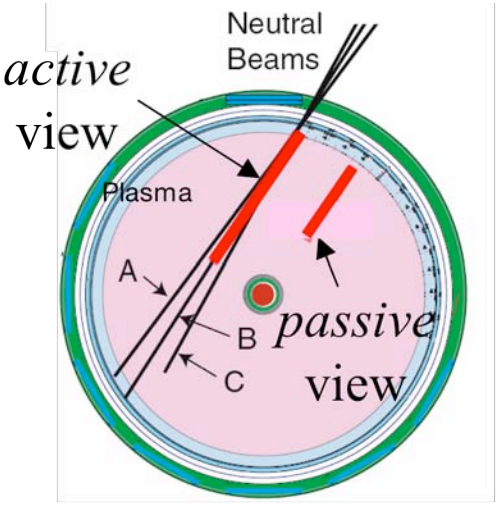
Extensive Energetic Particle Diagnostic Capability
Measures Fast Ion Properties

Scanning Neutral Particle Analyzer



FIDA diagnostic on NSTX (2008)





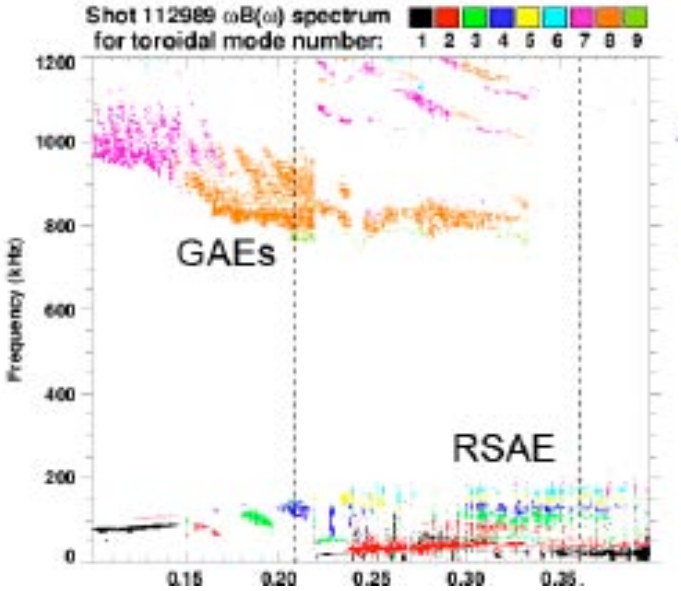
Collaboration contributions

- Fast neutron rate monitors
- Scanning NPA; high energy resolution, vertical and radial scan
- *ssNPA; 5-channel compact NPA radial array*
- sFLIP; scintillator lost ion probe, energy/pitch angle resolved, high time resolution(PMT)
- iFLIP; Faraday cup lost ion probes
- *FIDA; spatial profile, energy resolved (2008)*
- Neutron collimator; spatial profiles of fastest ion populations (2011)

Strong Diagnostic Set for Fast Ion Induced Instabilities
Physics Relevant for ITER and ST-CTF/Demo for both α-heating and NBI

- High frequency Mirnov arrays; ≈ 10 MHz bandwidth
- *Multi-channel reflectometer array; internal mode structure/amplitude*
- *Multiple view soft x-ray cameras (≈ 100 kHz bandwidth)*
- *High-k scattering 5 MHz; Kinetic Alfvén Waves*
- *FIReTIP 2MHz; internal mode amplitude/structure (2009)*
- *MSE - CIF / LIF ; internal mode amplitude/structure in δB (2010)*
- *BES; higher spatial resolution, mode structure (2010)*
- HHFW antenna may be used for active mode studies

Collaboration contributions

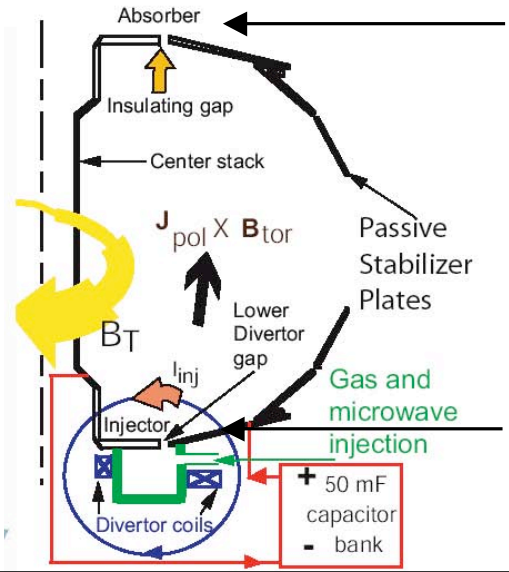


	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
Diagnostics	*FIDA, high-k, MSE-CIF*	*Firetip 2MHz, BES, MSE-LIF*	*magnetic fluctuations*			

Solenoid-free Startup for ST-CTF and Demo

Multiple options planned (NSTX-PAC Recommendation)

CHI drove 160 kA of closed-flux current



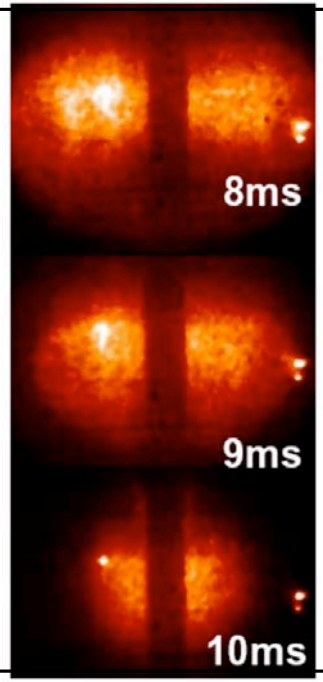
Absorber coils to be tested in 2009

LLD to be used to test metal wall in 2009

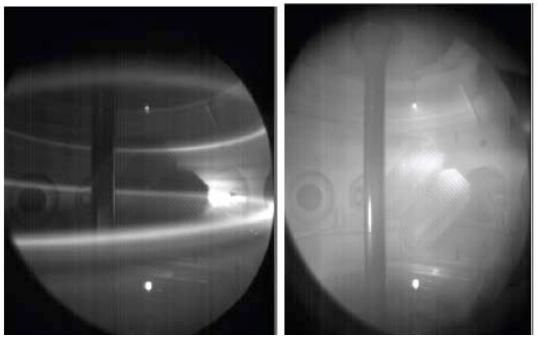
Start-up Utilizing Outer PF Flux

~ 20 kA closed flux current obtained but limited by preionization

ECH (2011), Plasma Gun (2010), and higher TF (2012) will increase the start-up current



PEGASUS Gun Start-up (2010)



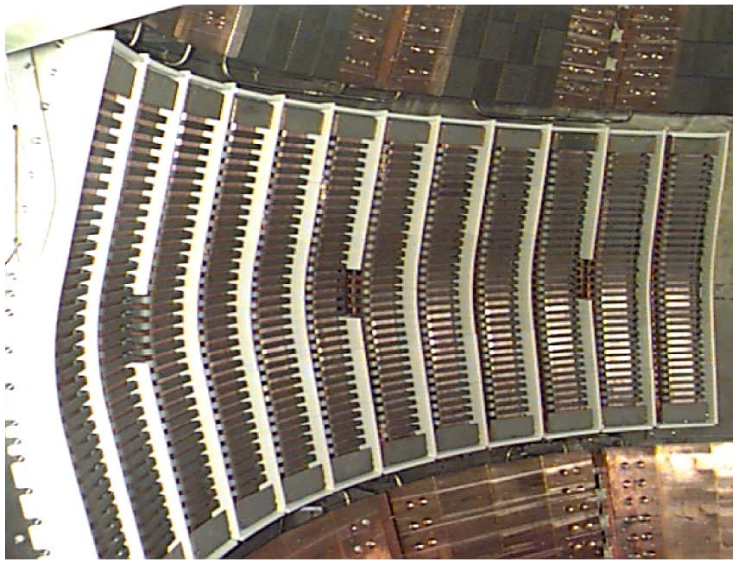
Ip ~ 80 kA achieved with ~ 2 kA gun current

Iron core provides limited but high quality ohmic flux for CTF and Demo

- Iron core or mineral insulated OH coil can be used in conjunction with other start-up and ramp-up tools if necessary
- NSTX can simulate it with the existing OH solenoid

Non-Indctive Current Ramp-up for ST-CTF and Demo
High Power HHFW and NBI to full NI plasma current ~ 800 kA

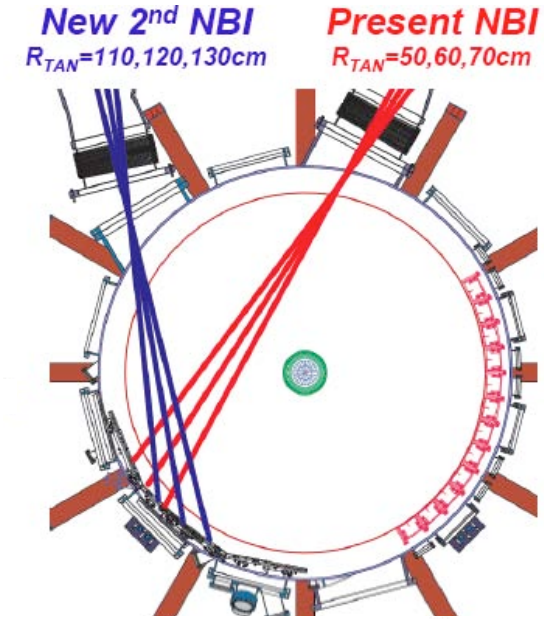
HHFW heats electrons well even at low Ip - produced ~ 80% f_{NI}



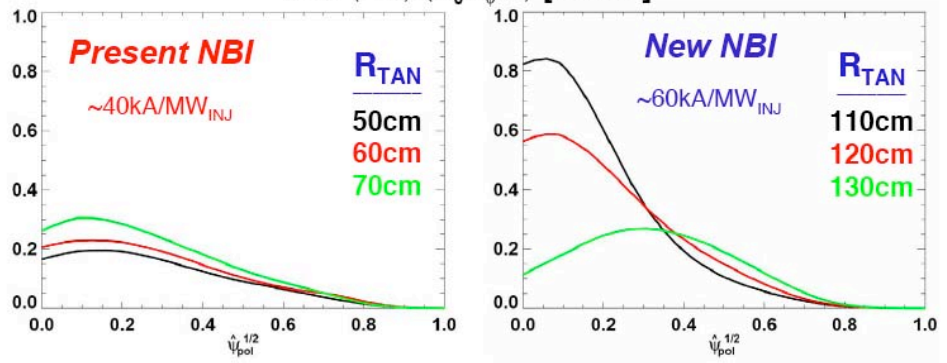
6 MW HHFW 5 sec
- **Antenna upgrade 2009**
- **Elm resilience 2010**
- **Higher B_T and 5s pulse in 2012**

Expect to bridge the current gap from start-up (~ 200 kA) and NBI (~ 500 kA)

Second NBI with more tangential injection will increase CD efficiency



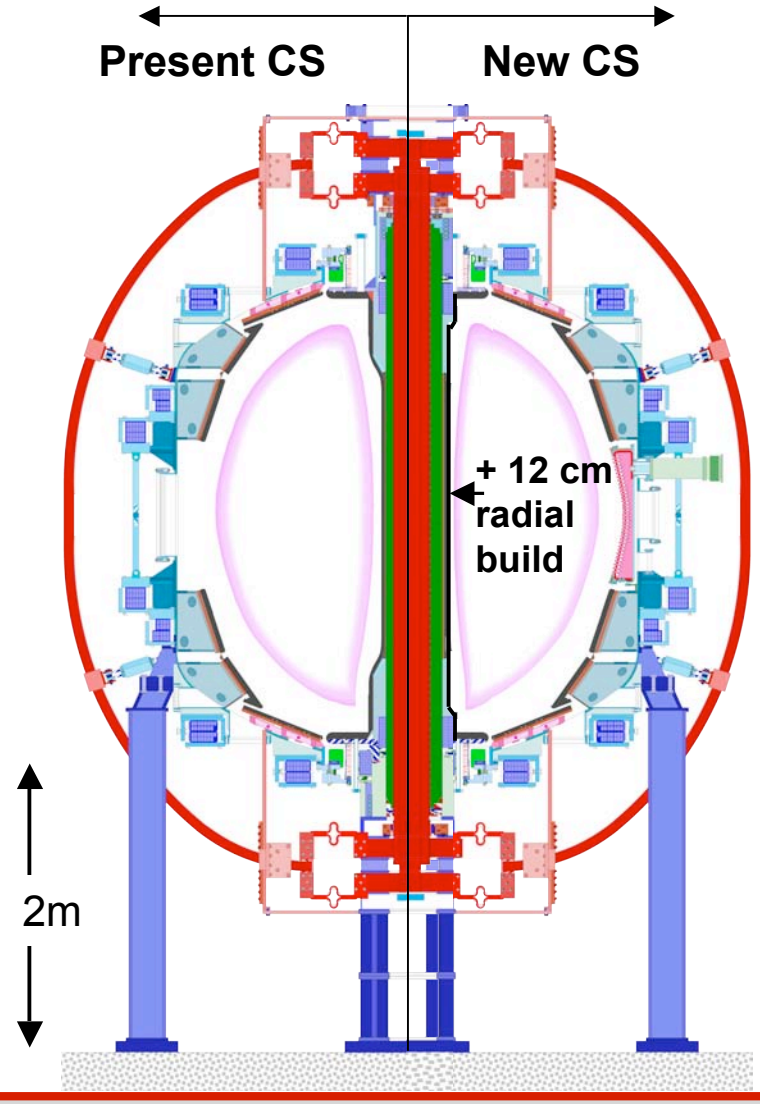
NBI $\langle J\cdot B\rangle/\langle R_0 B_\phi/R\rangle$ [MA/m^2]



P_{NBI}=2MW E_{NBI}=90keV, I_p=0.82MA, f_{GW}=0.58 $\overline{n}_e = 4.4\times10^{19}$m^{-3}, $\overline{T}_e$ = 1.2keV

New NSTX Center Stack Builds Upon 10 Years of Design, Manufacturing, Operational Experience

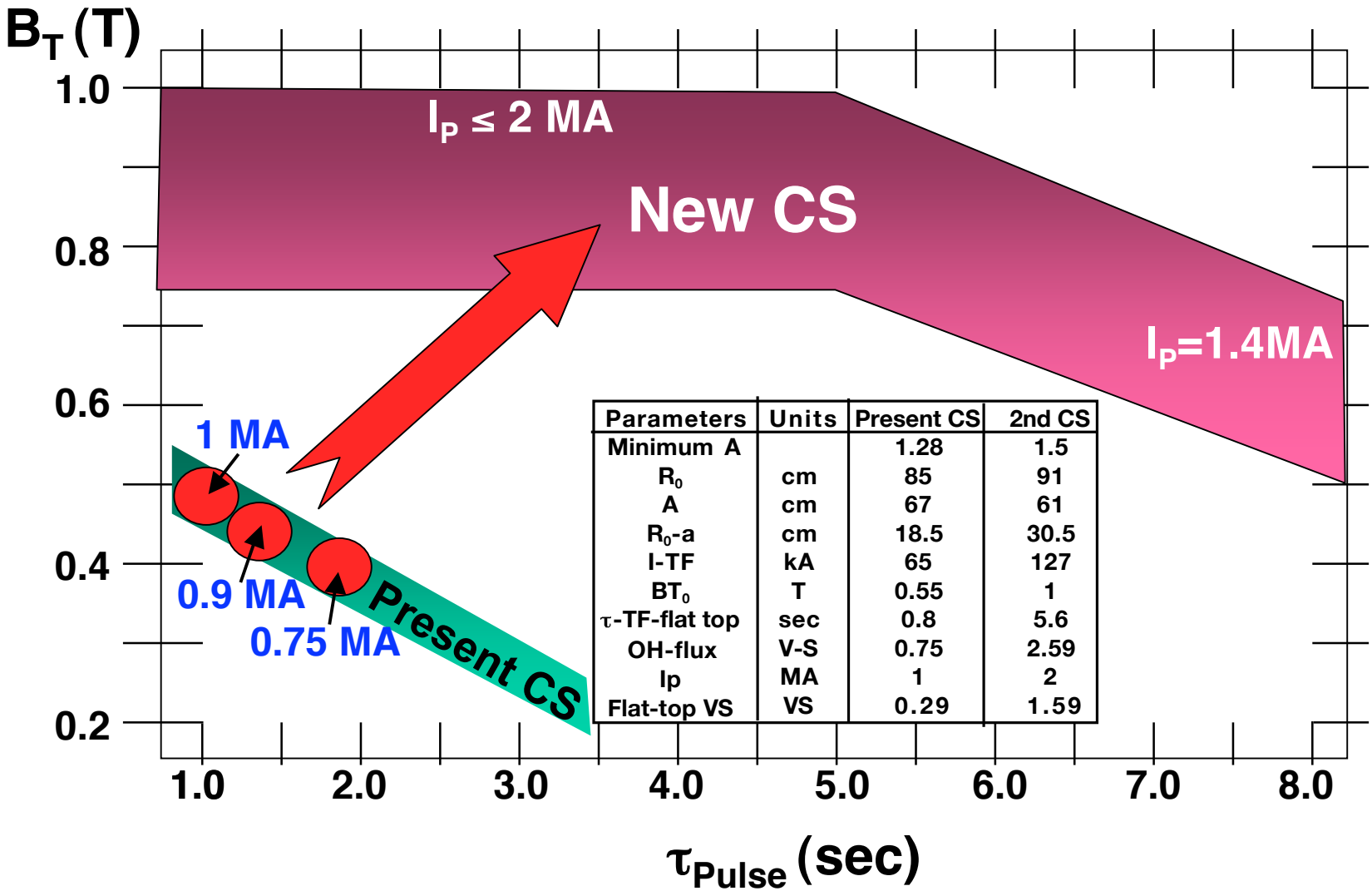
Replaceable Center-Stack Envisioned in the Original NSTX Design



NSTX center-stack magnets lifted out of device for maintenance

- **TF joints operated stably at 5.5 kG (~ design value) for last three years without major maintenance.**
- **Every TF joint monitored at all time**

New Center Stack Greatly Expands Device Operational Range

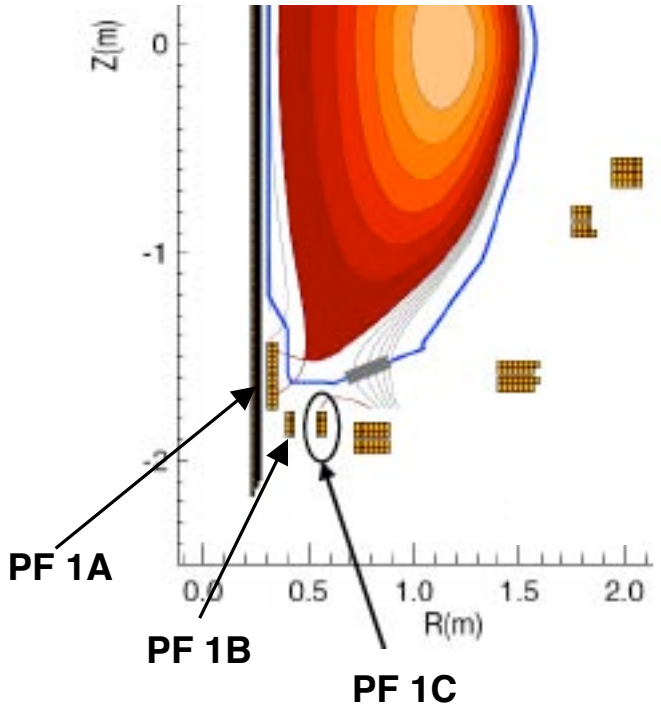


Parameters	Units	Present CS	2nd CS
Minimum A		1.28	1.5
R_0	cm	85	91
A	cm	67	61
R_0-a	cm	18.5	30.5
I-TF	kA	65	127
BT_0	T	0.55	1
τ-TF-flat top	sec	0.8	5.6
OH-flux	V-S	0.75	2.59
Ip	MA	1	2
Flat-top VS	VS	0.29	1.59

New NSTX Center Stack Utilizes Proven Design With Select Design Improvements

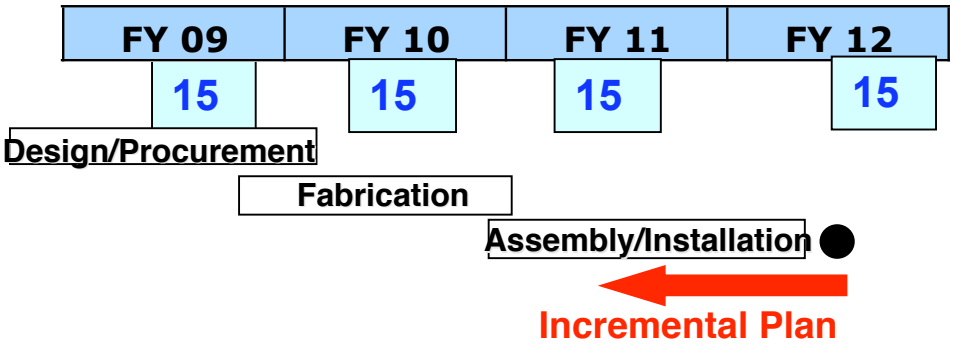
Main Design Features: Similar overall interchangeable design with key improvements:

- Improved TF joint design to minimize lift off
- PF 1A, 1B, and 1C for both top and bottom for improved divertor control flexibility (e.g. very high expansion for x-divertor)
- Incorporate additional physics capabilities (e.g. pellet guide tube)



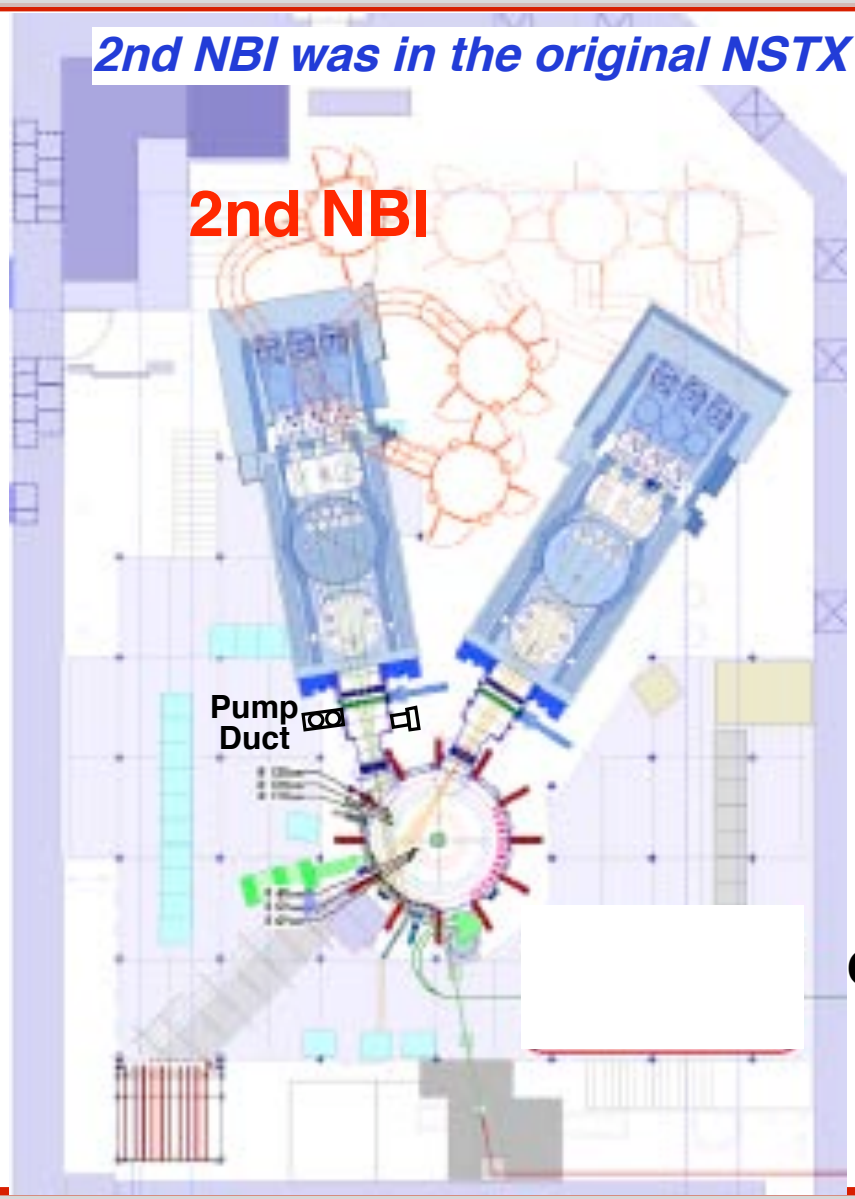
Other Related Tasks:

- Modest support structure enhancement
- Utilize PF 2-5 and outer TF as present
- Re-configure TF power supplies
- Re-align the MPTS laser path and laser beam dump



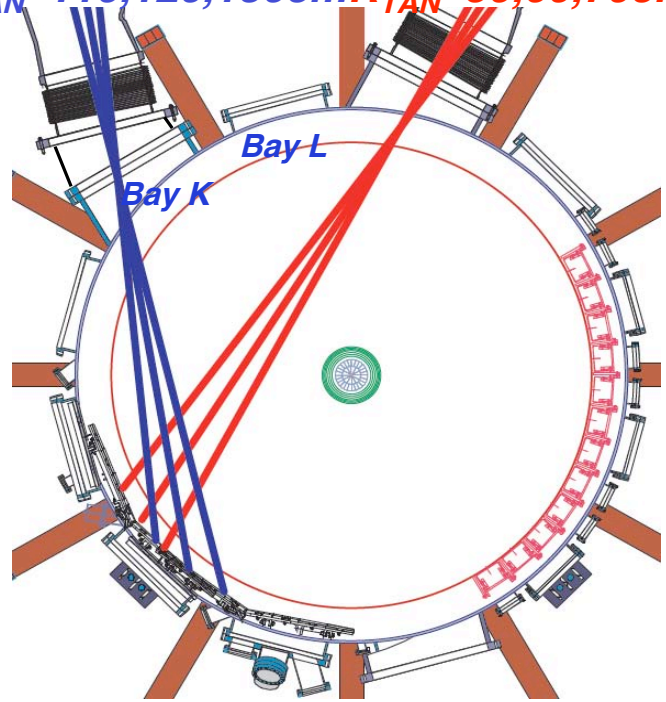
Addition of Second NBI Enables Profile Control and Full-Non-Inductive CD Scenarios

2nd NBI was in the original NSTX design for installation at Bay K



New 2nd NBI Present NBI

R_{TAN}=110,120,130cm R_{TAN}=50,60,70cm



Greatly enhanced capabilities

- Doubles P_{NBI} from 7 to 14 MW (at 95 keV, 2s), 5 to 10 MW (at 80 keV, 5s)
- Higher CD Efficiency and j(r) control

Second NBI Installation Tasks

Move one NBI Beam Box from TFTR Test Cell

- **Generic NBI tasks are very similar to the first NBI**
  - First NBI project completed on schedule on budget in about two year period
- **New Scopes above the first NBI:**
  - Assess and perform tritium cleaning tasks of the beam box
    - Some uncertainties in the level of tritium removal from various internal components
    - TFTR NBI sources cleaned and being used safely on NSTX
    - Assuming replacement of all of the copper internals in the beam box
  - Design and fabricate transition section including vacuum pump duct
  - Relocate diagnostics on Bay K to mostly to Bay L. Relocate t-CHERS background views.

NBI upgrade schedule is resource dependent:
- Available for FY 2014 operations in the base budget case
- Accelerated to FY 2013 operations in the incremental budget case

	FY 09	FY 10	FY 11	FY 12	FY 13
Run Weeks	15	15	15	15	15

2nd NBI

Design/Procurement/Fabrication/Installation ● 2nd NBI

Increment

NSTX Base Budget (15% over FY 08)*

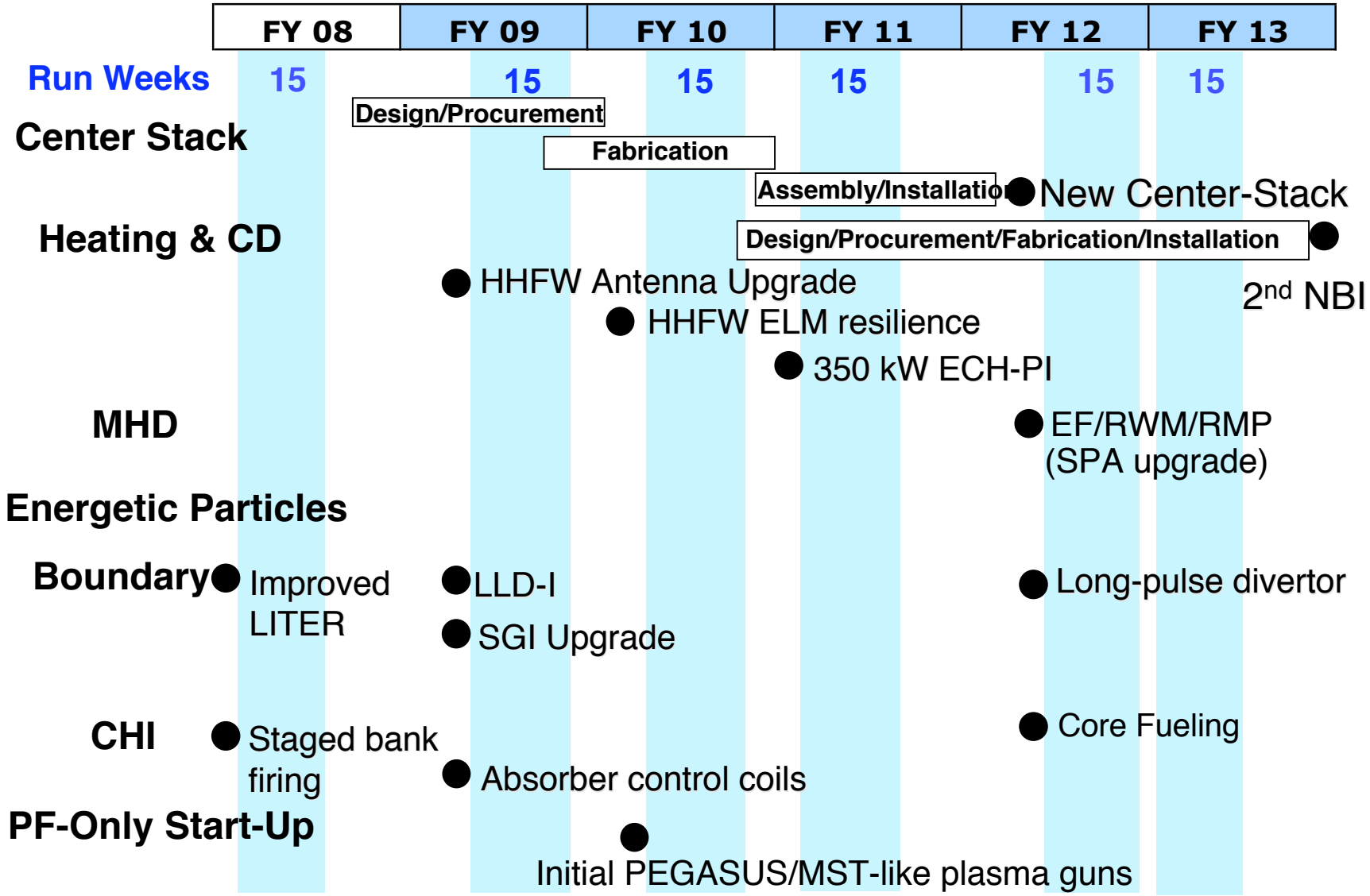
Enables Major Upgrades: New CS and 2nd NBI

	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Budget cases	Base	Base	Base	Base	Base	Base
Run Weeks	15	15	15	15	15	15
Facility Operations	19.5	20.3	20.7	21.3	22.0	22.6
Facility Ugs	1.2	1.5	1.5	0.8	1.1	1.4
Diag. Ugs	1.5	1.2	0.9	0.6	0.6	0.7
New CS		4.5	4.9	4.9	0.0	0.0
2nd NBI		1.4	1.4	2.6	7.6	7.5
Facility Total	22.2	28.9	29.5	30.4	31.3	32.2
PPPL Research	10.2	10.6	10.8	11.1	11.5	11.8
Collab Diag Interf.	0.5	0.5	0.5	0.5	0.5	0.6
Collaborations	5.9	6.2	6.3	6.5	6.7	6.9
Science Total	16.6	17.3	17.6	18.2	18.7	19.3
NSTX Total	38.8	46.2	47.1	48.6	50.0	51.5

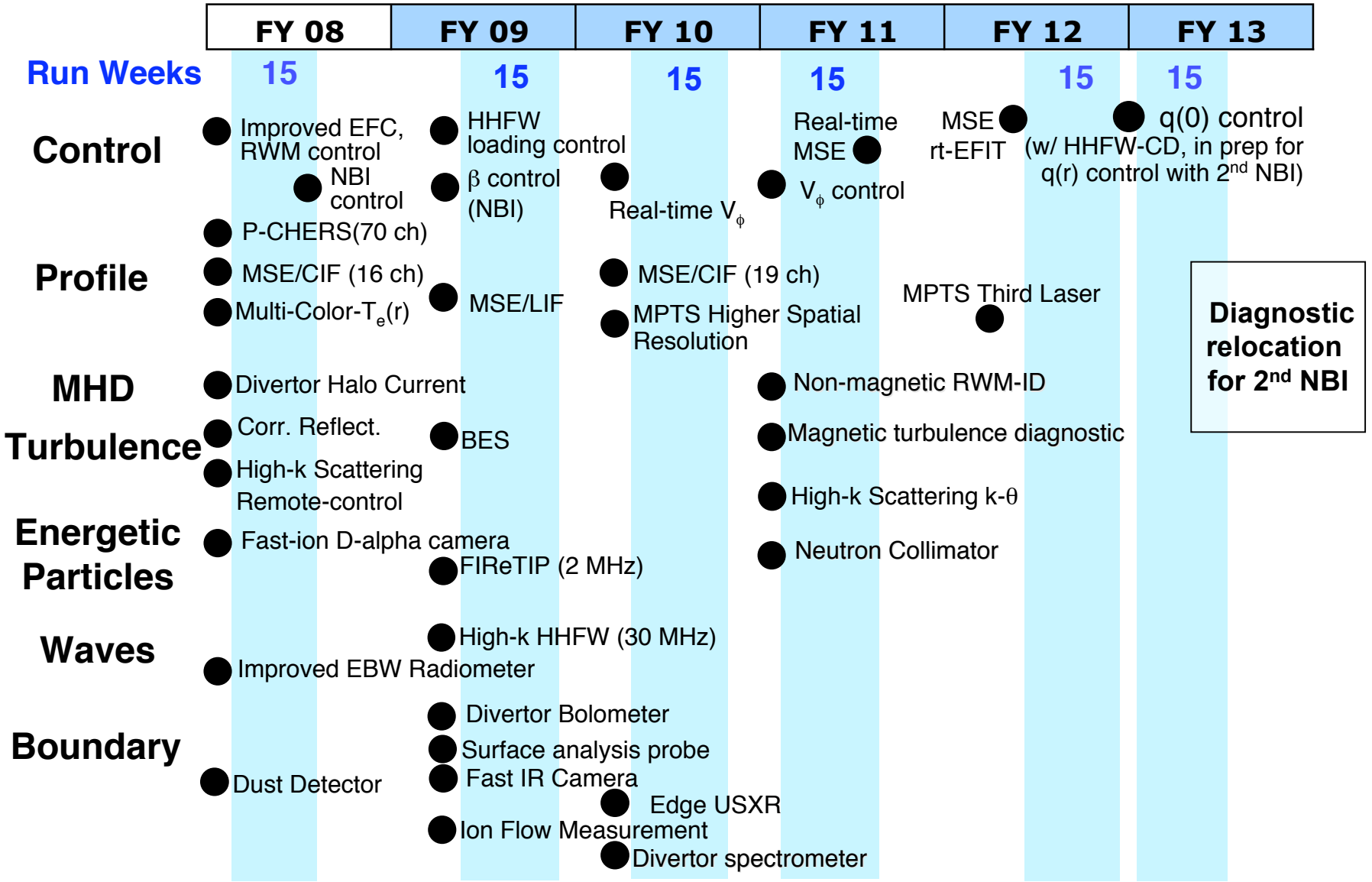
* As spent

- 15 run weeks per year to continue productive research progress
- New Center Stack in 2012 and Second NBI in 2014
- Facility upgrades: 350 kW ECH, LP-Divertor, core fueling, SPA
- Diagnostic upgrades: MPTS, divertor spectrometer, High-kθ, neutron collimator

NSTX 5 Year Facility Upgrade Base Plan (15%)



NSTX 5 Year Control/Diag. Upgrade Base Plan (15%)



NSTX Incremental Budget (25% over FY 08)*

Accelerates Major Upgrades: New CS and 2nd NBI

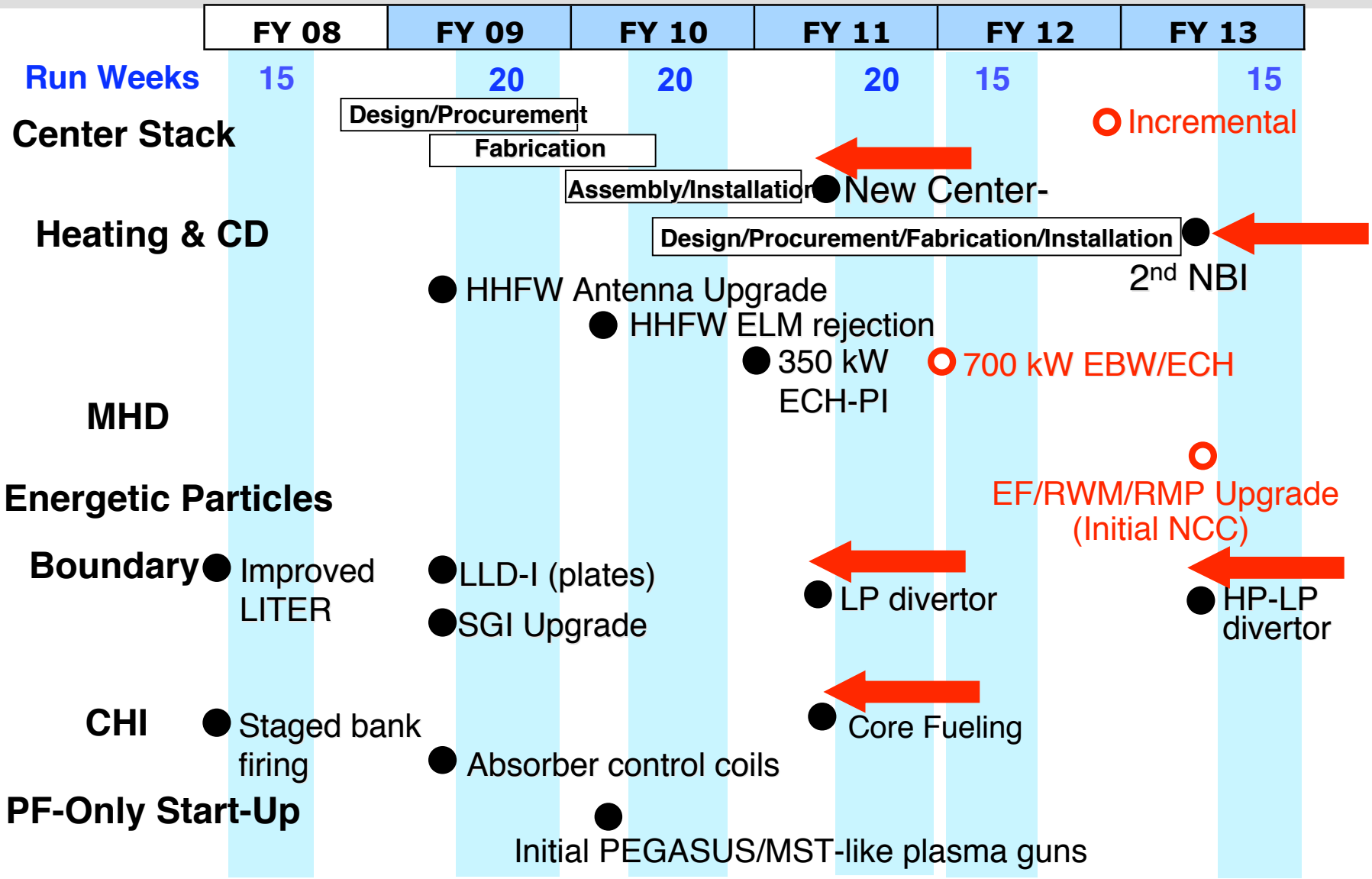
	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Budget cases	Base	Base	Base	Base	Base	Base
Run Weeks	15	20	20	20	15	15
Facility Operations	19.5	21.3	21.9	22.4	22.0	23.7
Facility Ugs	1.2	2	1.8	1.3	2.7	2.8
Diag. Ugs	1.5	1.5	1.0	1.1	0.9	0.9
New CS		5.2	6.2	3.4	0.0	0.0
2nd NBI		1.5	1.5	5.0	7.6	5.2
LP-HP Divertor					1.0	2.5
Facility Total	22.2	31.5	32.4	33.1	34.1	35.1
				0.0	0.0	0.0
PPPL Research	10.2	11.3	11.6	11.9	12.2	12.6
Collab Diag Interf.	0.5	0.7	0.7	0.7	0.8	0.8
Collaborations	5.9	6.5	6.7	6.8	7.0	7.2
Science Total	16.6	18.5	19.1	19.4	20.0	20.6
						0.0
NSTX Total	38.8	50.0	51.5	52.6	54.1	55.8

* As spent

- Run weeks increased from 15 to 20 in FY 2009-2011
- Accelerated New Center Stack and Second NBI by one year
- Second ECH/EBW tube, NCC coil, HP-LP divertor. Accelerate core fueling by one year
- Full MPTS, Divertor Bolometer. Accelerate high-k_θ and MPTS upgrades by one year

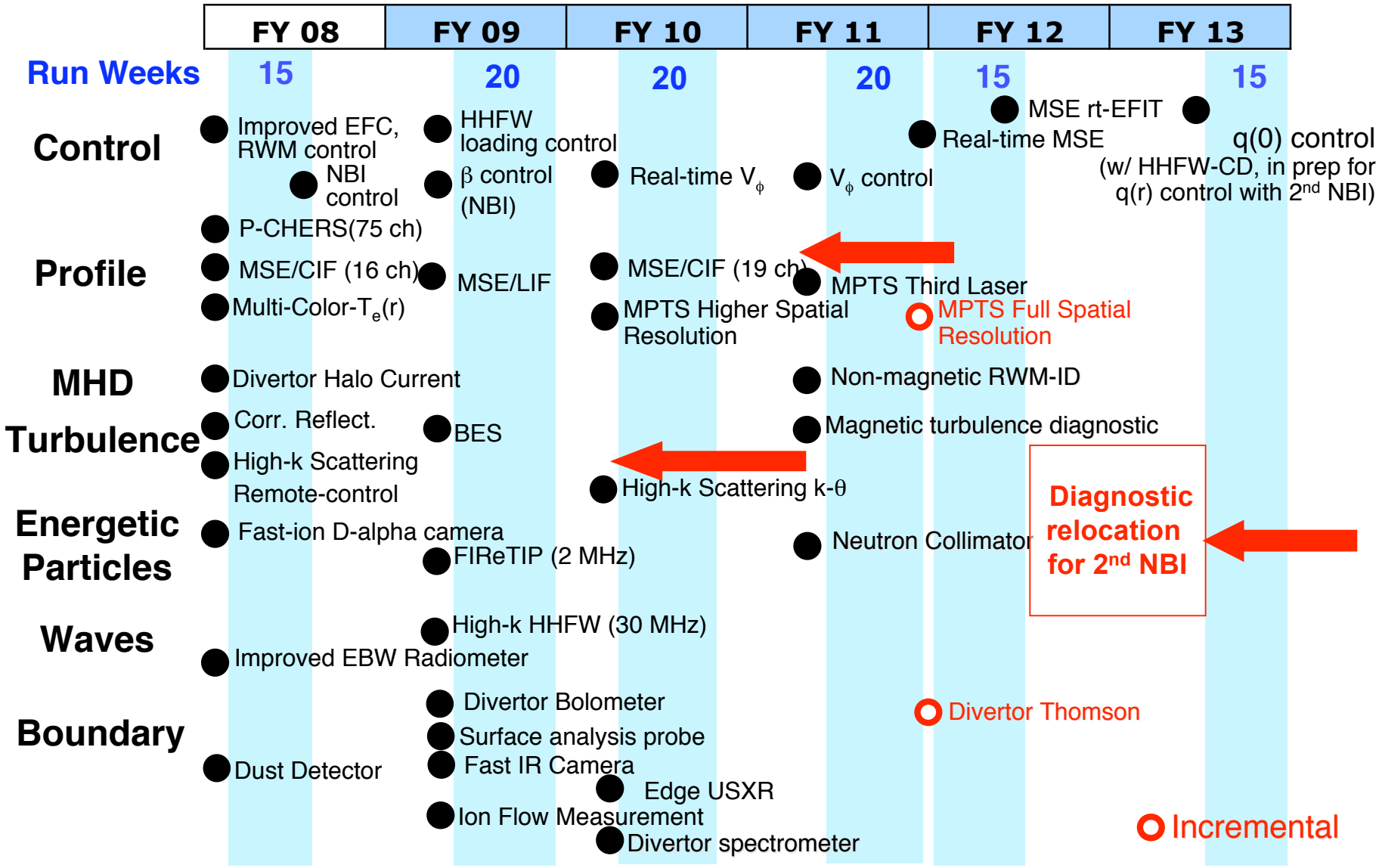
NSTX 5 Year Facility Upgrade Incremental Plan (25%)

Accelerates Major Upgrades: New CS and 2nd NBI



NSTX 5 Year Control/Diag. Upgrade Incremental Plan (25%)

Enables Full MPTS, Divertor Thomson, Accelerates MPTS Third Laser and High-k-θ



Facility and Diagnostic Plan Developed to Support Exciting NSTX Facility Five Year Plan

NSTX contributes to the US Fusion Program with unique and complementally capabilities

- Exceptionally wide operating plasma parameter space
- High degree of facility flexibility
- Highly accessible plasmas - unique diagnostics

NSTX facility and diagnostic upgrades to support the Five Year Plan

- New center-stack to greatly expand ST operating parameter regimes - double B_T, I_p for τ-pulse up to 5 sec, a significant step toward next STs
- Second NBI to double heating and CD power with current profile control for full non-inductive operations
- Important facility upgrades to support topical science areas - LLD, HHFW, ECH, RWM/EF/RMP system, Core Fueling, Start-up
- Important diagnostic upgrades to support topical science areas - BES, MSE-LIF, High-k_θ, MPTS, Real time CHERS, Boundary Diagnostics

Incremental funding will accelerate NSTX research by one year

- Increased run weeks
- Accelerate upgardes including Center-Stack and second NBI by one year
- New upgrades including full MPTS, divertor Thompson, and 700 kW ECH/EBW