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NSTX Facility/Diagnostics/Budget Update and Plans for FY 06 - 08

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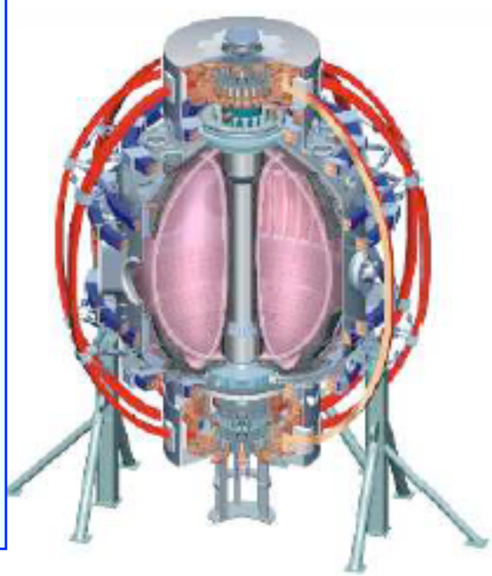
U Maryland
U Rochester
U Washington
U Wisconsin

Masa Ono

NSTX Program Advisory Committee Meeting
(PAC-19)
February 22- 24, 2006



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
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ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

NSTX Facility and Diagnostic Capabilities

NSTX

Device Parameters

R = 85 cm

a = 65 cm

κ = 1.7 - 2.7

δ = 0.3 - 0.8

B_T = 5.5 kG

τ_{TF} (3.5 kG)~ 3 sec
~ 6 τ_{skin}

I_p = 1.5 MA

V_p = 14 m^3

E_p ~ 430 kJ

P_{NBI} = 7.4 MW

P_{HHFW} = 6 MW

350°C bakeout

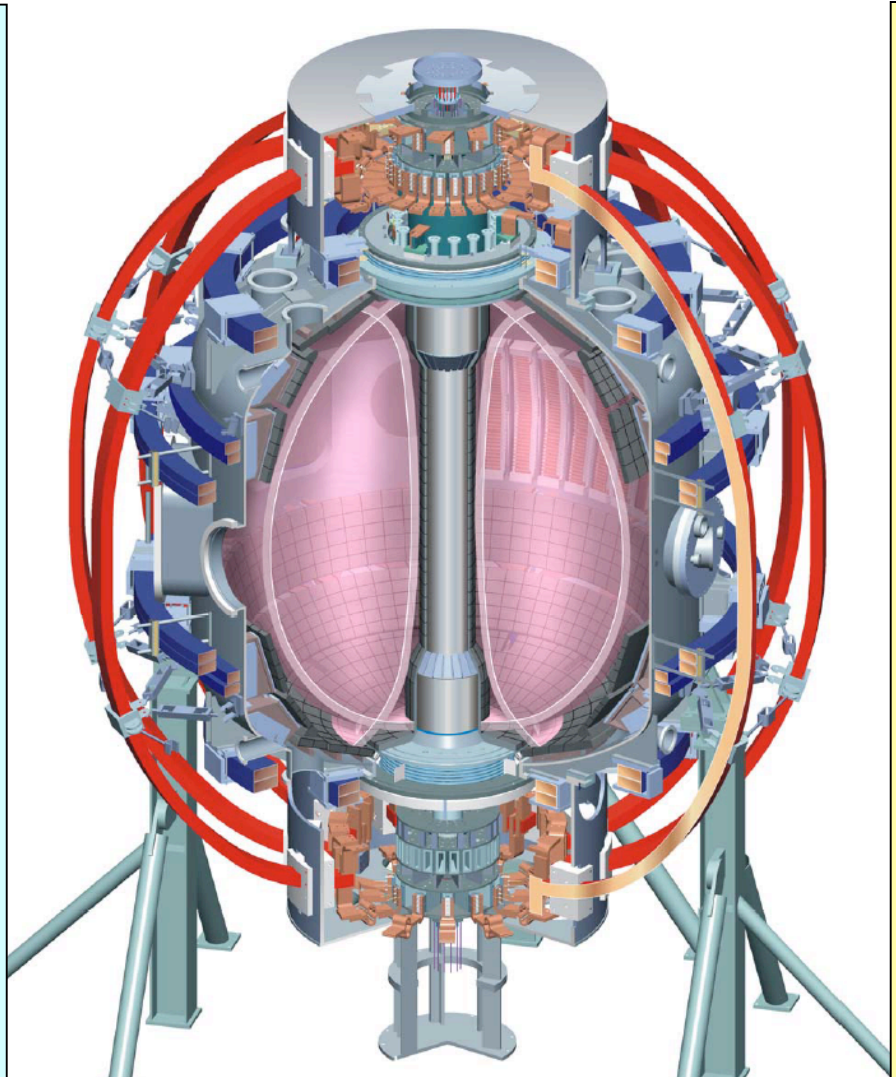
Passive Plates

RWM Coils

I_{CHI} ~ 400 kA

60 cm dia. ports

Wide tang. access



In red - collaboration
Underlined - tangential access

Major Diagnostic Systems

Confinement Studies

- Magnetics for equilibrium reconstruction
- Diamagnetic flux measurement
- Multi-pulse Thomson scattering (30 ch)
- CHERS: $T_i(R)$ and $V_\phi(r)$ (51 ch)
- Neutal particle analyzer (2D scanning)
- FIReTIP interferometer (119mm, 6 ch)
- Density Interferometer (1 mm, 1ch)
- Visible bremsstrahlung radiometer (1 ch)
- Midplane tangential bolometer array
- X-ray crystal spectrometer: $T_i(0)$, $T_e(0)$
- MSE-CIF (8ch)

MHD/Fluctuation/Waves

- High-n and high-frequency Mirnov arrays
- Ultra-soft x-ray arrays – tomography (4)
- Fast X-ray tangential camera (2μs)
- Wave reflectometers
- FIReTIP polarimeter (6 ch, 600 kHz)
- Tangential microwave scattering
- Electron Bernstein wave radiometer
- Fast lost-ion probe (energy/pitch resolving)
- Fast neutron measurement
- Locked-mode detectors
- RWM sensors (n = 1, 2, and 3)

Edge/divertor studies

- Reciprocating Langmuir probe
- Gas-puff Imaging (2μsec)
- Fixed Langmuir probes (24)
- 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 (4 ch)
- IR cameras (30Hz) (3)
- Tile temperature thermocouple array
- Scrape-off layer reflectometer
- Edge neutral pressure gauges

Plasma Monitoring

- Fast visible cameras
- Visible survey spectrometer
- VUV survey spectrometer
- X-ray transmission grating spectrometer
- Fission chamber neutron measurement
- Visible filterscopes
- Wall coupon analysis
- X-ray crystal spectrometer (astrophysics)

FY 05 Plasma Operations Completed Successfully

NSTX

- FY2005 Joule milestone: 17 run weeks

  Achieved: 18 run weeks producing 2221 plasmas.

- All facility and diagnostic milestones completed on or ahead of schedule.

- Excellent safety record in 2005.
  - Maintaining our tradition and goal!

- New Research Capabilities introduced in FY 05 yielded exciting results:
  - New PF 1A divertor coils for strong shape control - $\kappa \sim 2.7$, $\delta \sim 0.8$;
  - Error Field / Resistive Wall Mode (EF/RWM) coils powered by Switching Power Amplifier for plasma rotation and stability control;
  - 8 channel Motional Stark Effect (MSE) diagnostic for the first current profile measurement in high beta plasmas;
  - 30 ch MPTS for detailed profile particularly in the pedestal region;
  - 1.5 kV CHI capacitor bank and direct gas/ECH feed into injector for efficient current generation with closed flux surfaces;
  - Tangential high-k scattering system for electron transport study;
  - Movable glow probe for improved particle control/boronization.

- Toroidal field coil joints operated very reliably at 4.5 kG.

New Research Capabilities for FY 06 Run

- **FY2006 Joule milestone: 11 run weeks**

- Plasma operations to resume in February 2006 and end in May.

- New Research Capabilities for FY 06 experiments
  - Lithium Evaporator for improved particle recycling control for high performance long pulse discharges (March);
  - Feedback capability for EF/RWM coils powered by Switching Power Amplifier to improve and extend high performance plasmas (March);
  - 12 channels for MSE diagnostic to improve current profile determination, particularly in the outer region (March);
  - 2 kV operation of CHI capacitor bank to extend closed flux surface formation to higher current (April);
  - Dual remotely steerable, obliquely viewing radiometers for EBW emission covering extended frequency range 8 - 40 GHz (March);
  - TF qualified to 5.5 kG;
  - TF pulse length can be extended by ~20% if needed.

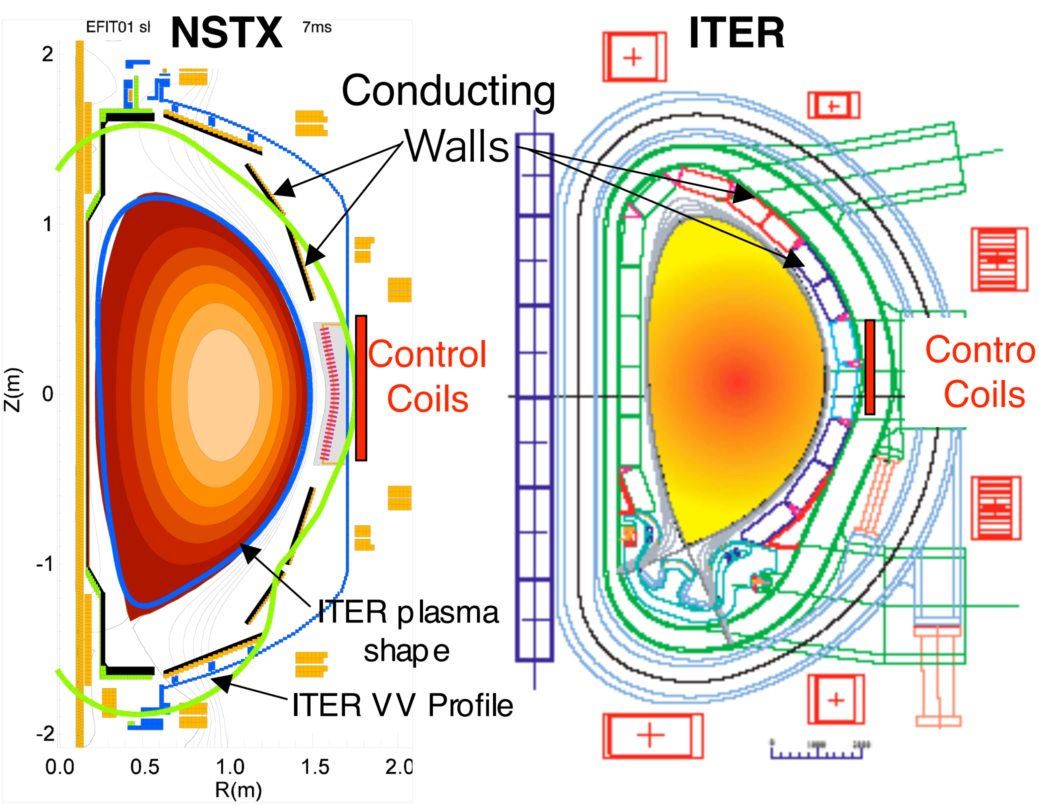
MHD

NSTX Well Positioned for Cutting Edge EF/RWM Research

Run Weeks Base / Request	FY 06	FY 07	FY 08
	11	12 / 8	10 / 10

MHD

- ● EF/RWM Feedback (Columbia)
- ● PCS Processor Upgrade (GA)
- ● Fast X-ray Camera (PSI)
- ● Fast Multi-Color-Te(r)(0.1ms, JHU)

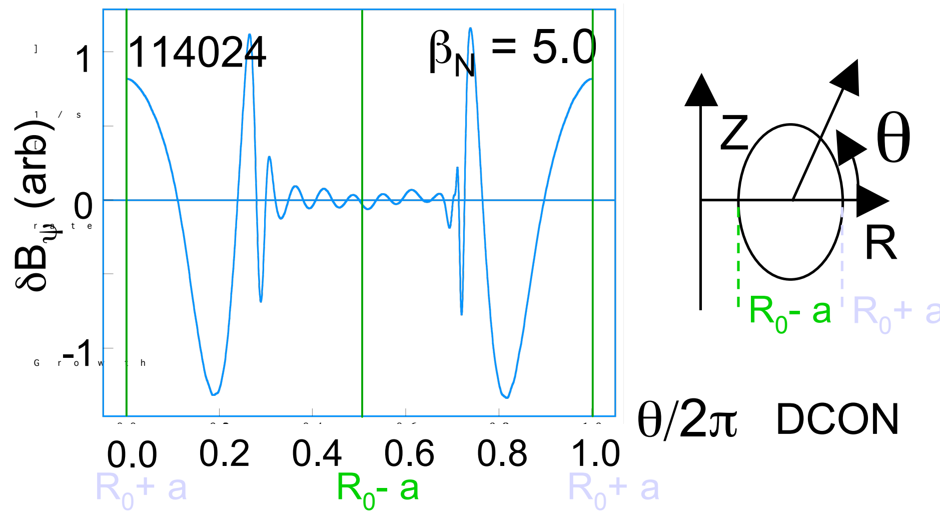


Capabilities and Plan

- EF/RWM coils powered by SPAs operated well in pre-programmed mode in FY 05
- Feedback control software written, compiled, and tested in simulation mode.
- Ready to test feedback control early in FY 06 run.
- PCS Processor Upgrade would provide faster feedback control x 3-10.

Active RWM control research on NSTX tests basic theoretical models needed for ITER and beyond

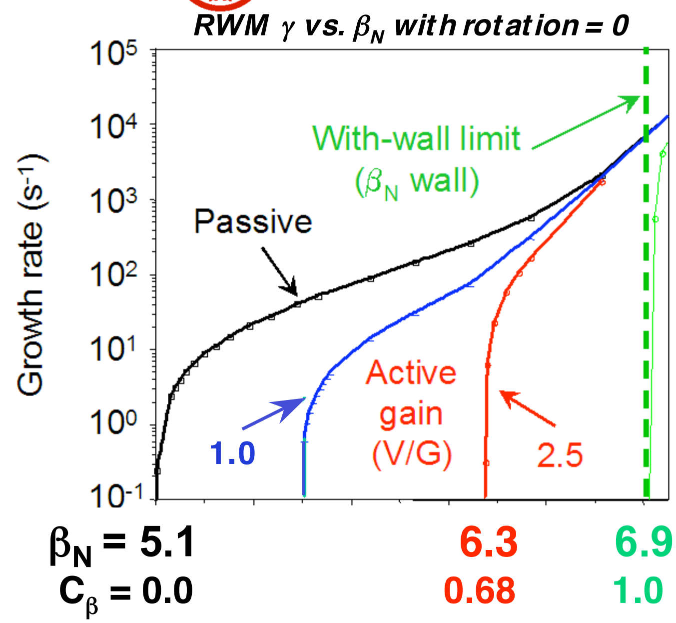
RWM eigenfunction strongly ballooning at high β, low-A → outboard coils effective



(DCON – LANL)

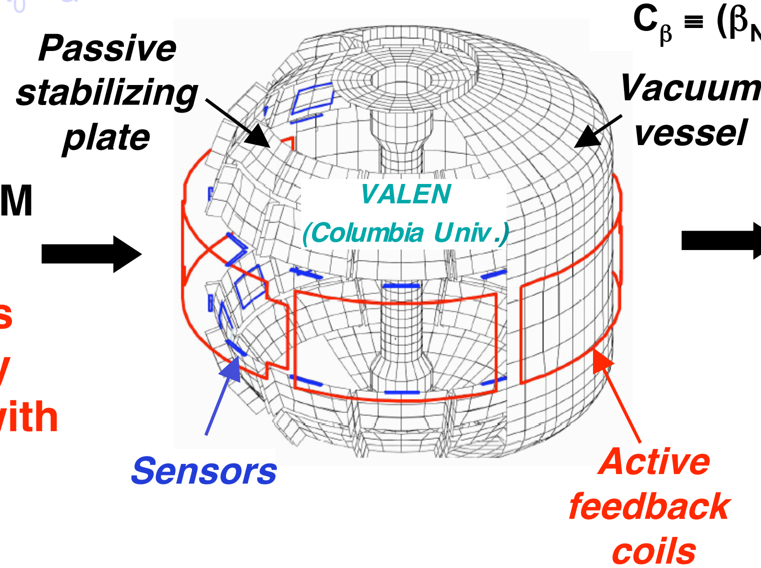
Like the proposed ITER RWM control system,

NSTX feedback system has mid-plane coils and nearby (blanket-like) **passive plates with extensive RWM sensors**



$C_\beta \equiv (\beta_N - \beta_{Nnowall}) / (\beta_{Nwall} - \beta_{Nnowall})$

Columbia



Feedback stabilize RWM at C_β = 68% when $\Omega_\phi \ll \Omega_{\phi\text{-crit}}$

Testing resonant and non-resonant braking with coils to reduce/control rotation

Transport and Turbulence

World leading diagnostics to address key transport physics

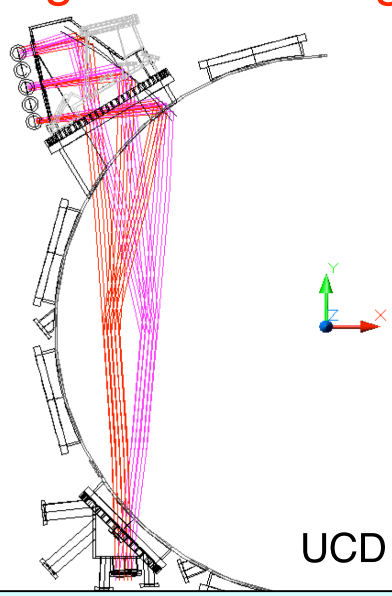
NSTX

	FY 06	FY 07		FY 08	
Run Weeks **Base** / **Request**	11	12	8	10	10

- ● MPTS 30 ch
- ● Multi-Color-T_e(r)(JHU)
- ● MSE/CIF 12 ch
- ● Corr. Reflect. (UCLA)
- ● High k Scattering (UCD)
- ● Interim P-CHERS
- ○ Full P-CHERS
- ● MSE/CIF 16 ch (Nova)
- ● Full P-CHERS
- ○ 3rd MPTS Laser
- ■ Next-step Fluctn diag

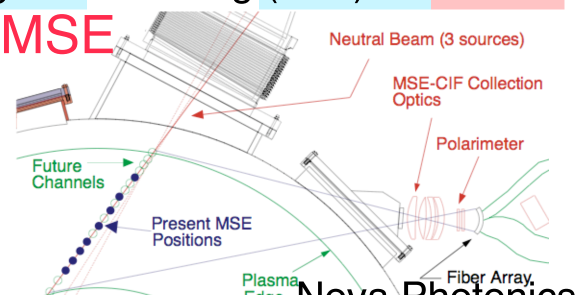
● - Base
○ - Increment
■ - Decision Pt

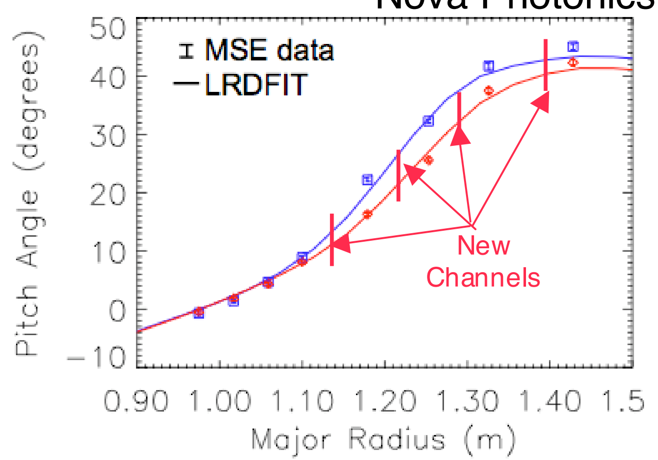
High-k Scattering



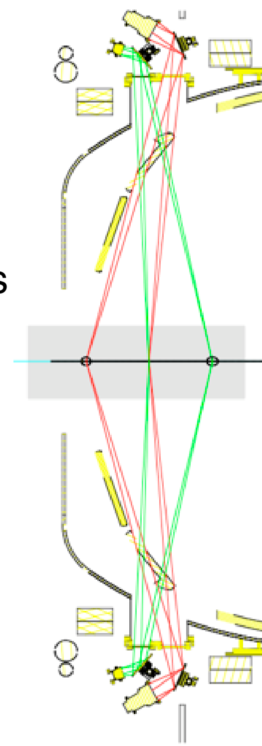
Unprecedented spatial resolution at high k

MSE





P-CHERS



- **Unique** up/down symmetric ports along NB for optimal view
- Transport barrier physics
- Low aspect ratio accentuates the physics of poloidal rotational viscosity

Boundary
Extend high-performance discharges

NSTX

● - Base
○ - Increment
■ - Decision Pt

	FY 06	FY 07		FY 08	
Run Weeks **Base** / **Request**	11	12	8	10	10

● Lithium Pellets

● Lithium Evaporator

● 2nd Li Evap

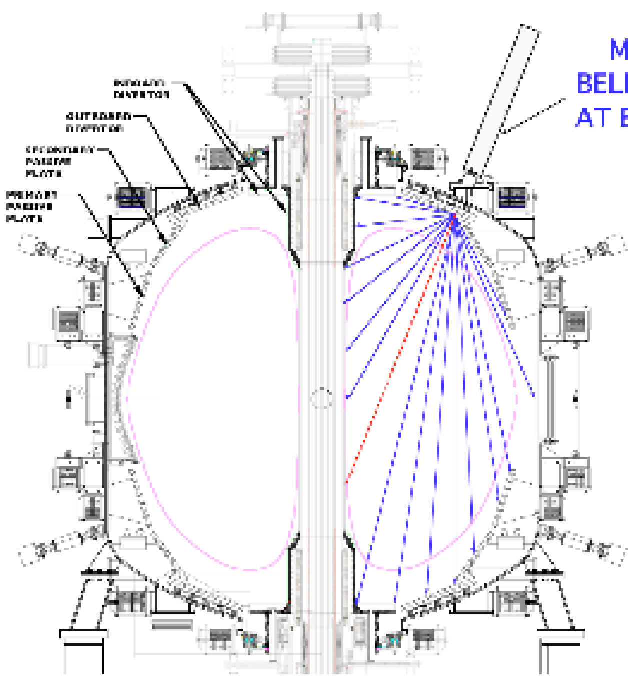
■ Core Fueling DP

■ Adv. Particle Exhaust DP

● Fast IR Camera (ORNL)

○ Pellet Injector (ORNL)

○ Divertor Dignostics (ORNL)



Li evaporation rate ~ 100 mg/min
Compare to a few mg / Li pellet

Achieving low particle recycling regime

- FY 05: ~30mg of lithium from multiple pellets reduced recycling
- FY 06: Utilize lithium evaporator LITER-1 with 50 mg/min deposition rate
- After FY 06 run, assess needs for
  - core fueling: pellets or CT injector;
  - additional particle control: second lithium evaporator, liquid lithium tray, or divertor cryo-panel.

Waves and Energetic Particles

Current and Pressure Profile Control for Advanced Regimes

NSTX

	FY 06	FY 07		FY 08	
Run Weeks **Base / Request**	11	12	8	10	10

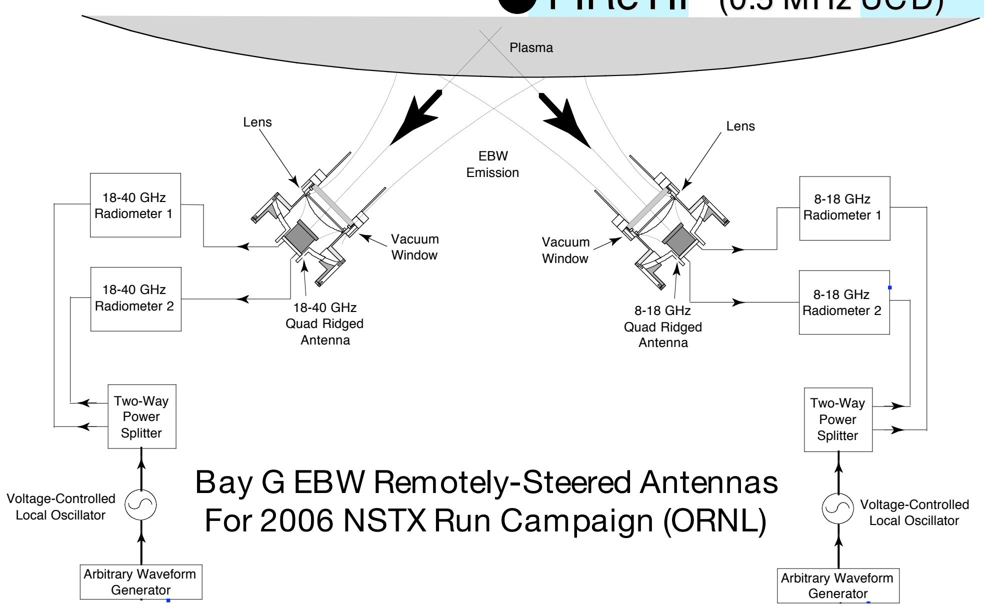
● - Base
○ - Increment
■ - Decision Pt

HHFW
- ● Edge Wave Reflectometer (ORNL)
- ● Core Wave Reflectometer (UCLA)
- ○ HHFW Antenna Upgrade

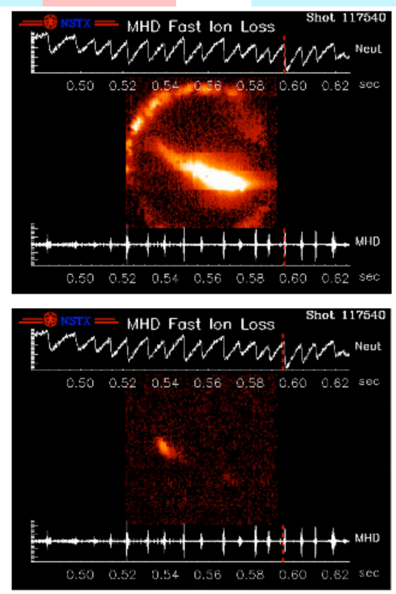
EBW emission
- ● Dual EBW Radiometer (8-40GHz, ORNL)

1 MW EBWCD
- ■ Decision Point
- ○ Complete FDR, Begin Site Prep
- ○ Complete Site Prep, Antenna Design

Energetic Particles
- ● Fast Lost Particle (JAEA)
- ● Core Reflectometer (UCLA)
- ● FIReTIP (0.5 MHz UCD)
- ● Fast-ion D-alpha camera(UCI)
- ● FIReTIP (2.5 MHz UCD)



Bay G EBW Remotely-Steered Antennas
For 2006 NSTX Run Campaign (ORNL)



New fast lost ion probe data can be used to benchmark ORBIT simulations of energetic particle loss during MHD (JAEA)

Solenoid-Free Start-Up

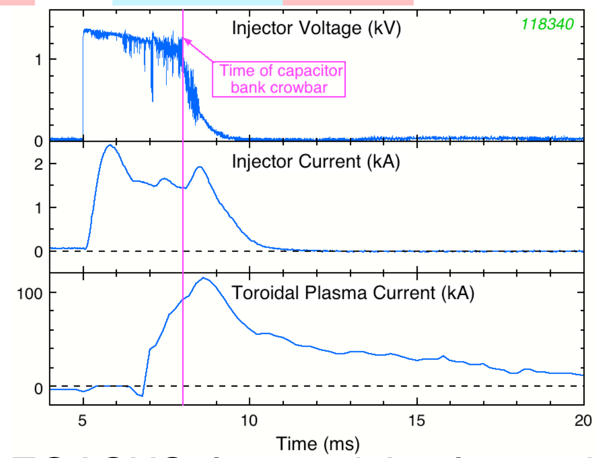
Enables ST-CTF and Attractive Tokamak Reactors

NSTX

	FY 06	FY 07		FY 08	
Run Weeks **Base / Request**	11	12	8	10	10
CHI	● 2 kV CHI Bank Capability; ● Dynamo edge probe (UCSD)				
PF-only Start-up		■ Pre-ionization DP		○ Improved pre-ionization	

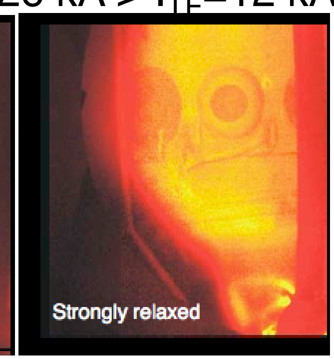
● - Base
○ - Increment
■ - Decision Pt

- CHI
  - In 2005, CHI bank operated at 1.5 kV, achieved very high current multiplication of ~60, closed flux surface plasma after decay of injector current
  - For 2006, upgrade for 2kV operation to extend toward higher current



- PF-only Start-up
  - In 2005, needs for high power pre-ioinization (e.g., ECH/EBW) was determined
  - CT-Injection, Plasma Gun (PEGASUS), and/or high-$k_{||}$ HHFW antennas may also provide efficient pre-ionization

PEGASUS: Ip = 26 kA > I_{TF}=12 kA



Opportunities to extend NSTX device performance
TF Joints are performing well

NSTX

Run Weeks Base / Request	FY 06		FY 07		FY 08	
	Base	Request	Base	Request	Base	Request
	11		12	8	10	10

FY 2005

- TF pulse extended to 1.5 sec from 1 sec at 4.5 kG due to excellent joint resistance.

FY 2006

- TF Joints already tested up to 5.5 kG.

FY 2006 - 2007

- Extend TF pulse length as needed, extend toward 2 sec at 4.5 kG.
  - take credit for TF cooling during pulse
  - increase cooling water flow rate

FY 2008

- New OH coil with potential for higher I^2t and more flux.

NSTX Budget Summary ($M)

	FY 06	FY 07	
Budget level	Actual	Base	Incremental
Run Weeks	11	12	20
Facility Operation	17.7	18.2	0.9
Facility Upgrades	0.5	0.5	2.0
Facility Total	**18.2**	**18.7**	**2.9**
PPPL Research	9.7	9.8	0.2
Diag Upgrades	0.6	0.8	0.4
Coll. Diag. Interf	0.5	0.6	0.1
Collaborations	5.0	5.2	0.3
Science Total	**15.8**	**16.4**	**1.0**
NSTX Total	**34.0**	**35.1**	**3.9**

- 11 and 12 run week cases in FY 06 and 07 include minimal upgrades.
- Incremental budget allows better facility utilization, implementation of the 1 MW EBW system and other high priority upgrades.

Facility, Diagnostic and Budget Summary

NSTX

- Very successful FY05 run:
  - 18 run weeks with all milestones completed on or ahead of schedule
  - Facility upgrades: New PF 1A coils; EF/RWM coils powered by 3 ch. SPA; 1.5 kV CHI with improved ECH/gas; Movable GDC probe
  - Diagnostic upgrades; High-k Scattering, 30 ch. MPTS, 8 ch. MSE-CIF, Edge Reflectometer, EBW Radiometer (18-40 GHz), Fast-sFLIP
- Planning for exciting FY06 run with new capabilities:
  - 11 run weeks to start in February, end in May with June as contingency
  - Facility upgrades: Lithium Evaporator; EF/RWM coil feedback; 2 kV CHI
  - Diagnostic upgrades: 12 ch. MSE-CIF; Dual remotely-steered radiometer (8 - 40 GHz) for EBW emission; Dynamo probe for CHI; 1ms Multi-color $T_e(r)$
- New capabilities planned to support FY 07 - 08 plan:
  - Facility upgrades: 2nd Lithium Evaporator (LITER), PCS Processor Upgrade
  - Diagnostic upgrades: 16 ch. MSE-CIF; P-CHERS; D_α detector; 2.5MHz FIReTIP, 100μs Multi-color $T_e(r)$,Fast IR Camera

Incremental budget would allow NSTX to contribute significantly more to Burning Plasma Physics, AT Plasma Science and Configuration Optimization