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NSTX

NSTX 5-Year Plan Overview

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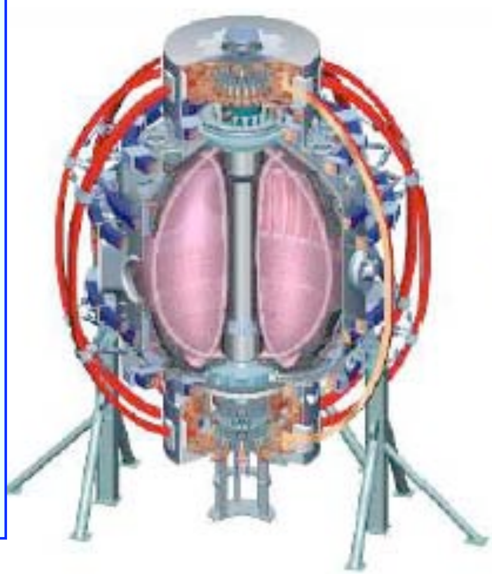
For the NSTX Team

Tokamak Planning Workshop
PSFC, MIT
Sept 17, 2007

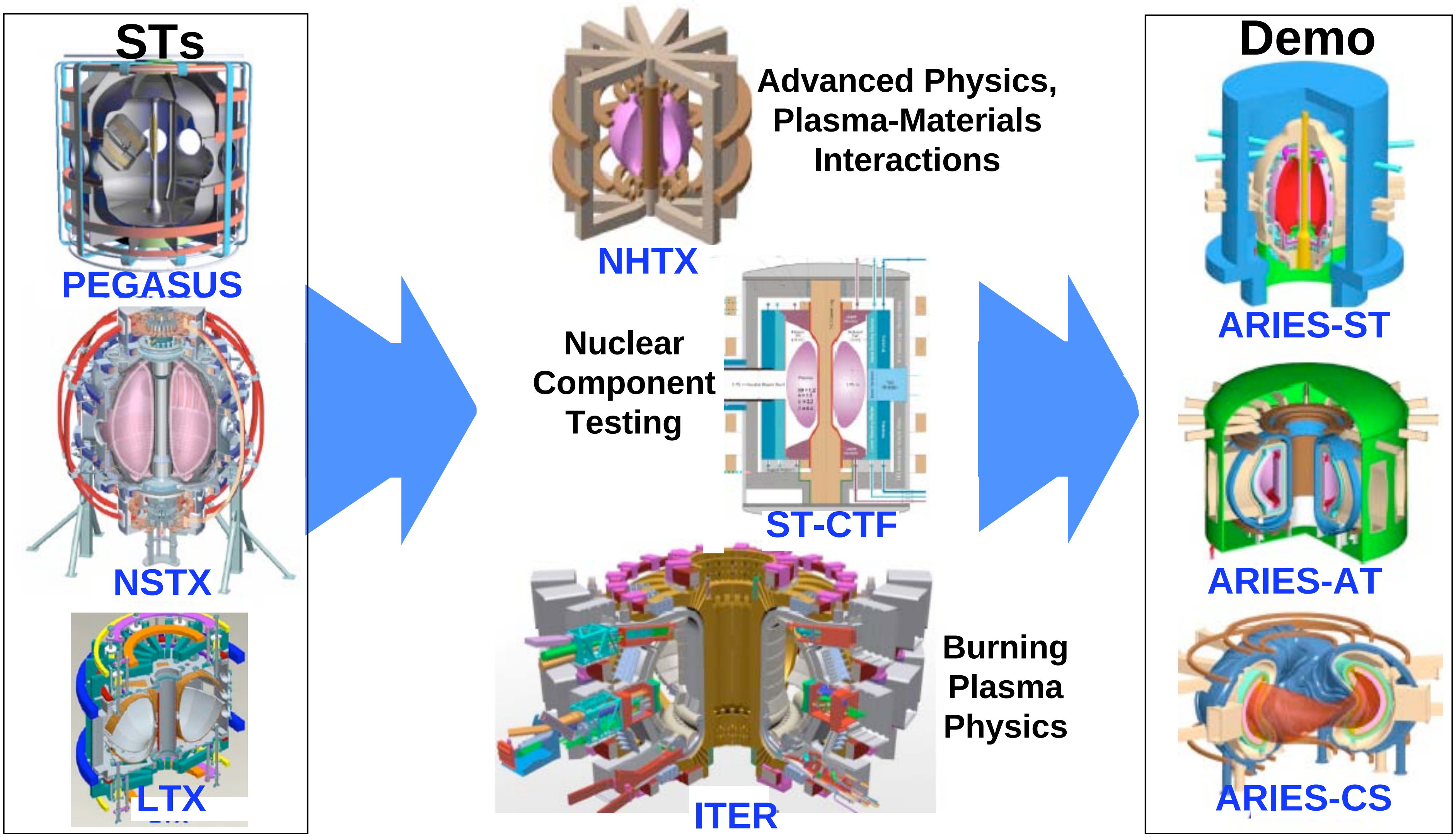
College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAERI
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NSTX Research Program Contributes Strongly to US and World Fusion Development

ST offers compact geometry + high β for attractive fusion applications



NSTX Mission Elements

NSTX

- To provide the physics basis for future ST-based devices, such as NHTX, ST-CTF and ST-Demo
- To broaden the physics basis for ITER, actively participating in ITPA and US BPO
- To advance the understanding of toroidal magnetic confinement.

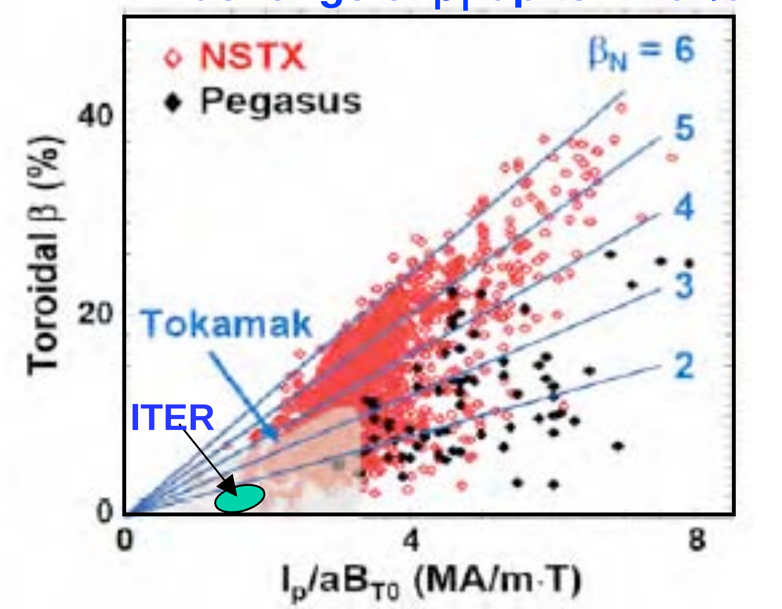
NSTX/ST Strength:

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

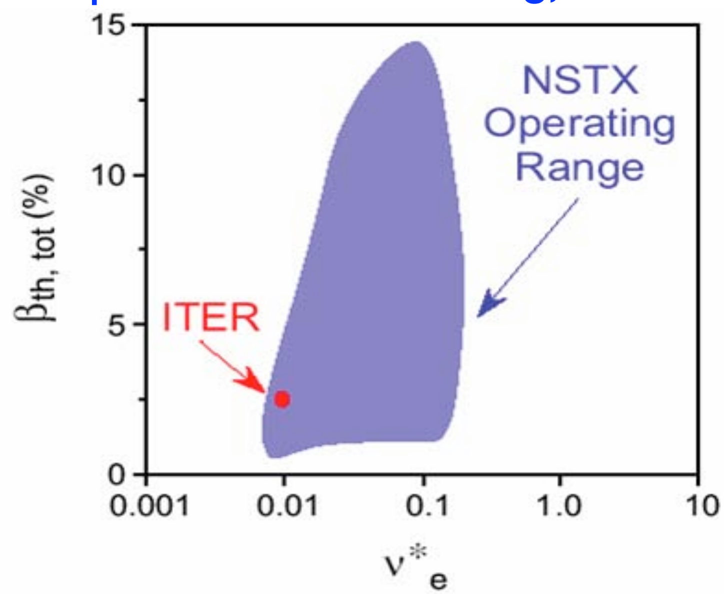
NSTX Offers Access to Wide Tokamak Plasma Regimes

NSTX

Wide range of β_T up to ~ 40 %

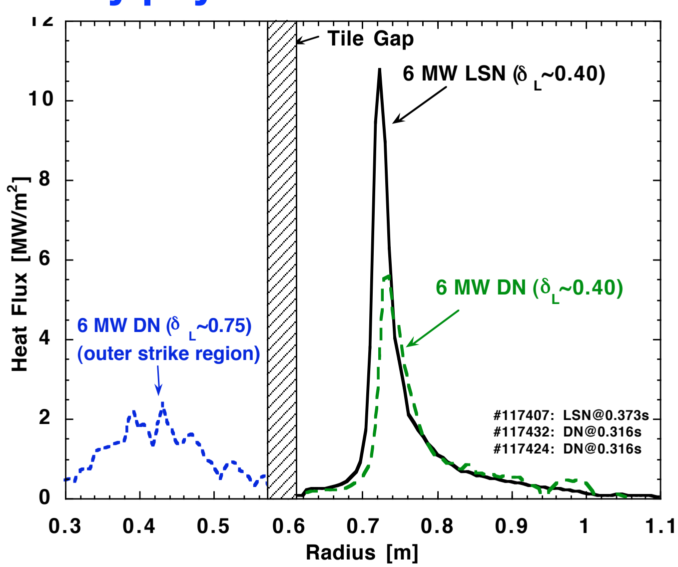


β Confinement Scaling, Electron Transport

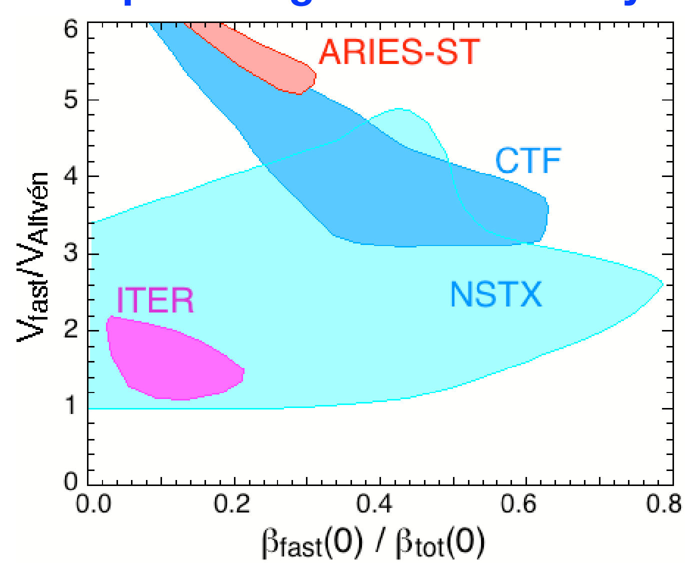


- •Confinement scaling with wide range of β_T up to ~ 40 %

Boundary physics with ITER-level heat flux



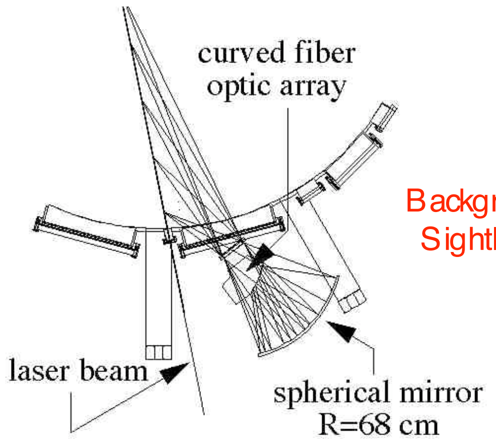
Unique Energetic Particle Physics



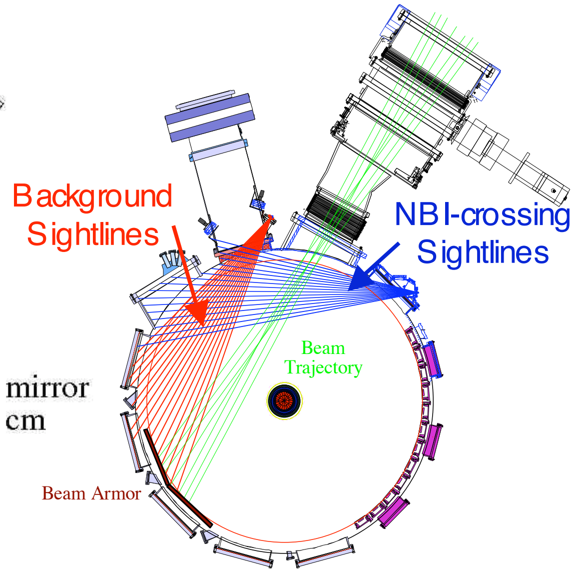
- • Full set of diagnostics: including MSE for j(r)

Highly Accessible Plasmas - Unique Diagnostics

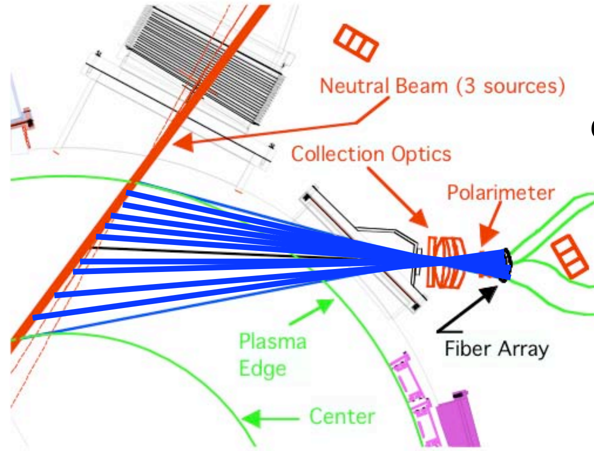
30 Ch, 60Hz MPTS for $T_e(r)$, $n_e(r)$



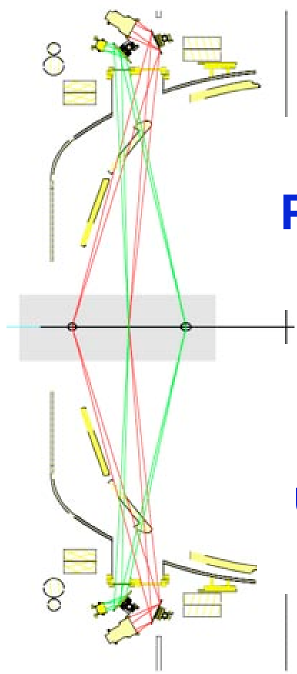
51 Ch CHERS for $T_i(r)$, $V_\phi(r)$



16 Ch MSE for q(r) (19 ch planned)

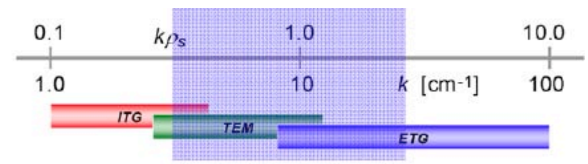


Innovative design enables MSE in kG range for the first time

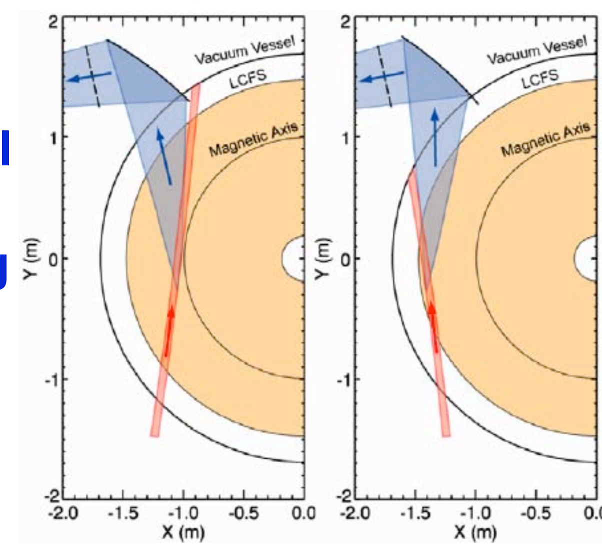


70 Ch Pololidal CHERS for $V_p(r)$

Fast Ion D-Alpha Camera using P-CHERS views



Tangential High-k Scattering (3 MHz)



NSTX has Comprehensive and Powerful Set of Scientific Capabilities

NSTX

MHD : Passive stabilizers and Advanced EF/RWM mode stabilization tools and diagnostics

Multi-scale transport: High-k + MSE + $\chi_I \sim \chi_{i\text{-}neo}$ -> unique opportunity for understanding transport & turbulence

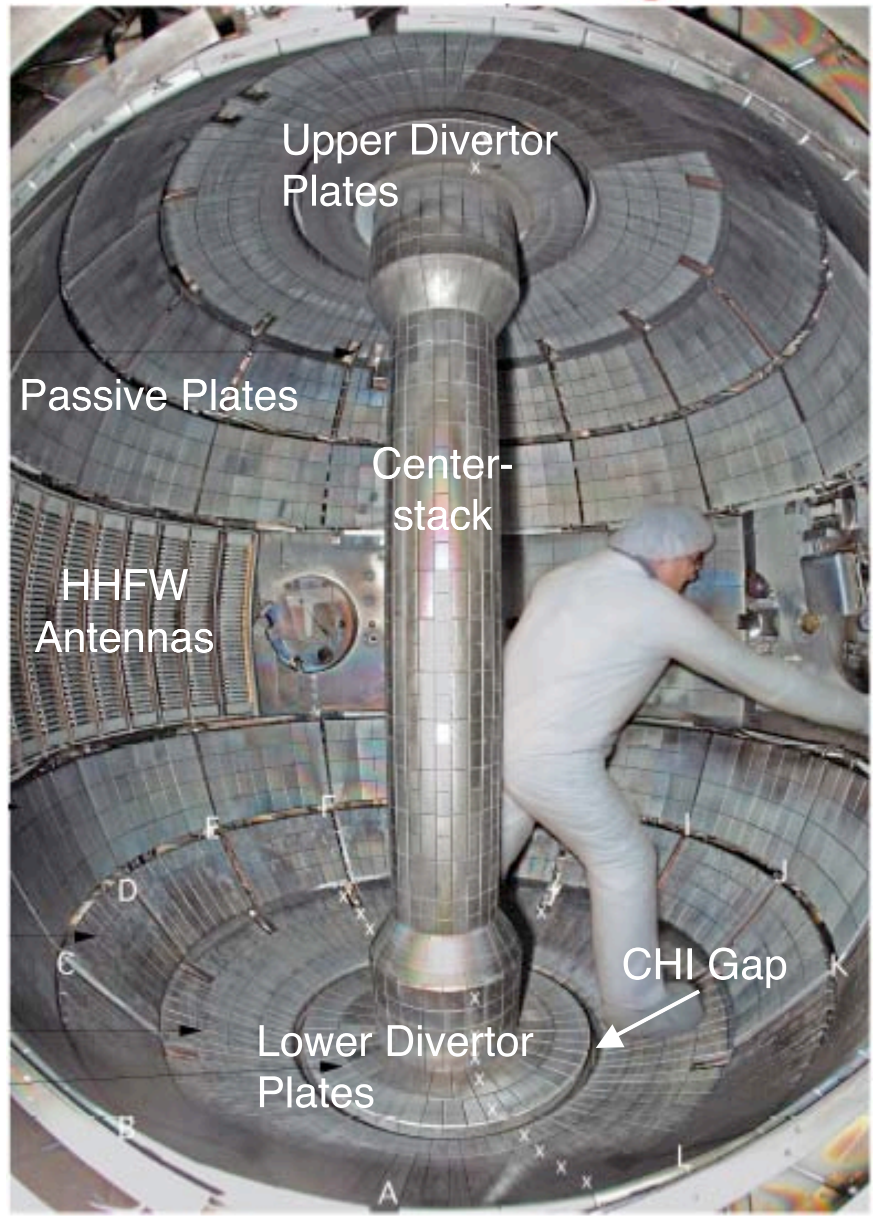
Waves: Developing unique HHFW and EBW heating and current drive tools essential for ST, useful for AT

Energetic Particles: Uniquely able to mimic multi-mode ITER fast-ion instability drive with full profile and energetic particle / mode diagnostics

Boundary Physics: High ITER-like power flux, Unique Li research,broad ITER and NHTX/ST-CTF-relevant boundary physics research

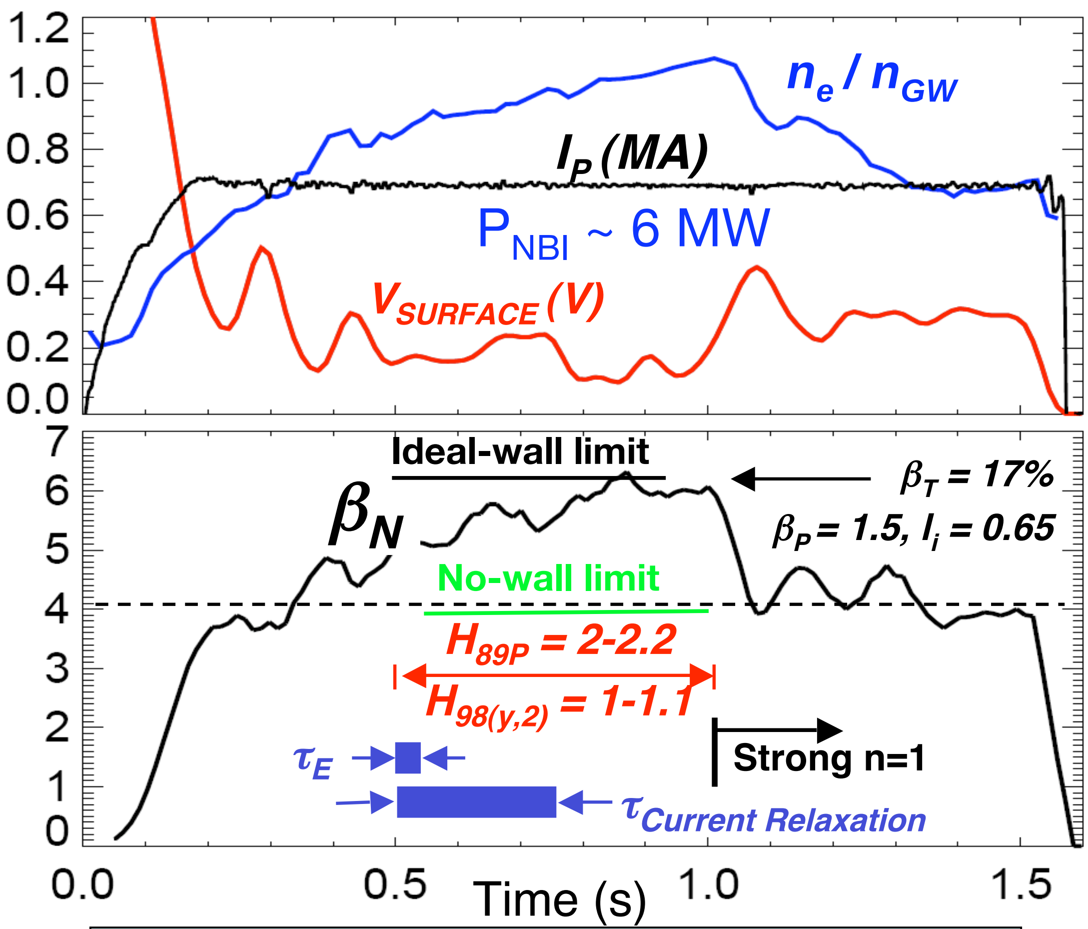
Integration: Most capable ST in world for developing high-non-inductive fraction, high β plasmas

Solenoid-free Start-up Developing unique plasma start-up and ramp-up research crucial to ST concept, useful for AT



NSTX made significant progress in developing and understanding high-performance plasmas w/high f_{NI}

NSTX



- Routine operation near ideal-wall stability limit with β_N = 5.5 - 6 for $2\tau_{skin}$.
- H-mode with H98y2 up to 1.3.
- f_{NI} up to 65%

- Utilized novel low-BT MSE
- NBICD classical w/o strong MHD
- Strong MHD redistribute fast ions

Performance goals for NHTX/CTF:

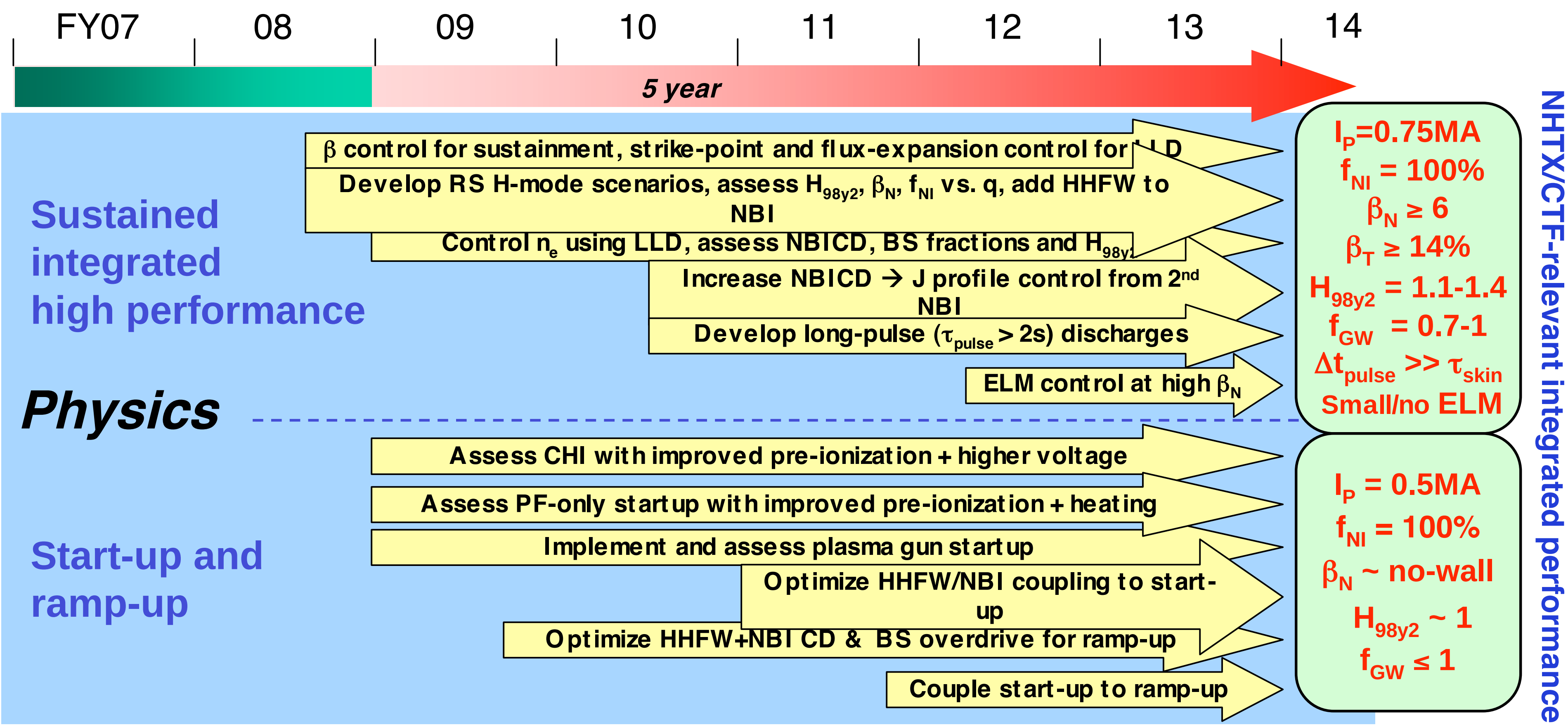
- Control density rise
- Keep q_{min} well above 1
- Increase f_{NI} with shaping
- Improve further HH and β
- $\tau_{pulse} >> \tau_{skin}$
- Small or no ELMs

NSTX 5 year integration goal to meet or exceed key dimensionless performance parameters of NHTX and ST-CTF

	NSTX full-NI target	NHTX	ST-CTF
A	1.5	1.8	1.5
H_{98y2}	1.1-1.4	1.3	1.3
κ	2.6	2.8	3.0
q*	5.3	3.8-4.5	3.3-4.2
β_T	14%	12-16%	16-25%
β_N [%-mT/MA]	6.2	4.5-5	4-5
f_{BS}	0.7-0.8	0.65-0.75	0.45-0.55
f_{GW}	0.7-1.0	0.4-0.5	0.3-0.5
	Dimensional parameters:		
I_P [MA]	0.75	3-3.5	8-10
B_T [T]	0.55	2.0	2.5
R_0 [m]	0.86	1.0	1.2
a [m]	0.58	0.55	0.8
I_P / aB_{T0} [MA/mT]	2.3	2.7-3.2	4-5

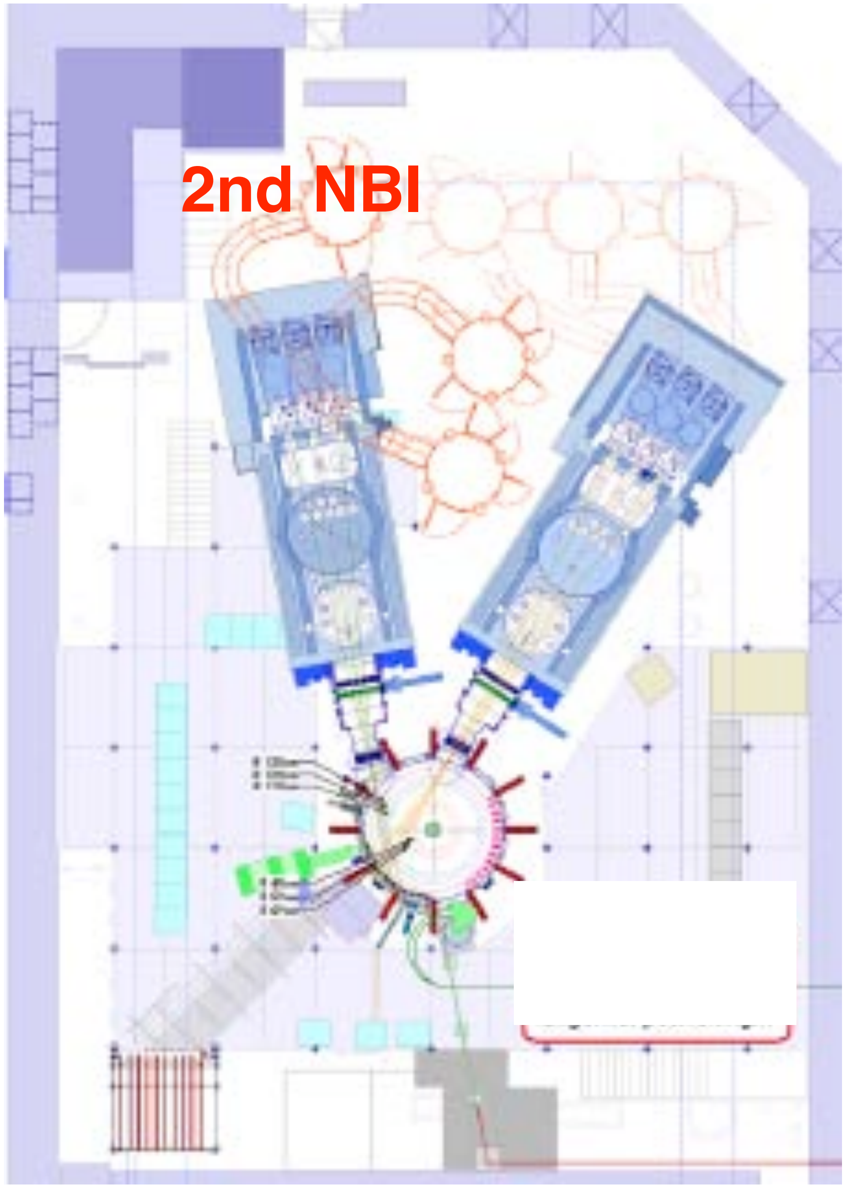
NSTX Five Year Integration Goals

Achieve and maintain fully non-inductive NHTX/CTF relevant high performance discharges



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

NSTX



2nd NBI: Utilize TFTR system

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

Existing NBI

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

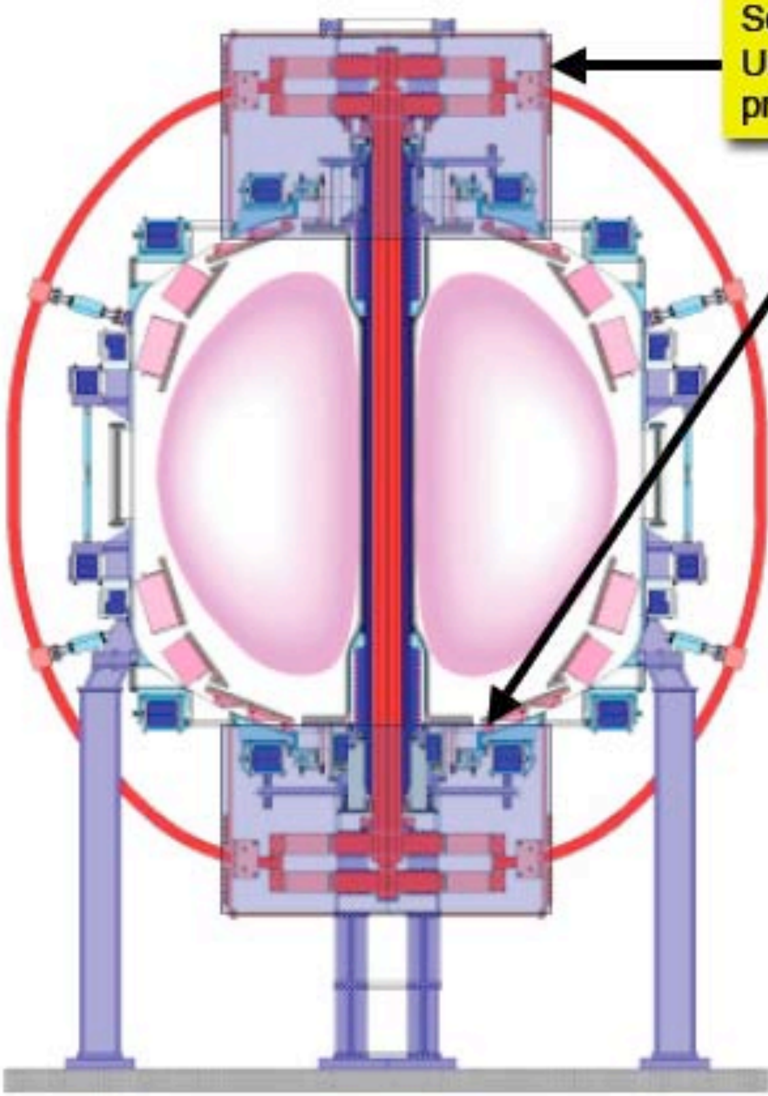
Greatly enhanced capabilities

- Doubles P_{NBI} from 7 to 14 MW
- Enables high β_T at high B_T
- Higher CD Efficiency

Aids physics investigation

- Control q and χ profile for MHD and confinement
- Thermal and energetic particle/ j(r) transport with R_{tan}
- Beta scan with B_T
- Divertor heat flux ~ 20 MW/m^2

TF Sub-Cooling Enables Physics Steady-State for NHTX/CTF Relevant Discharges

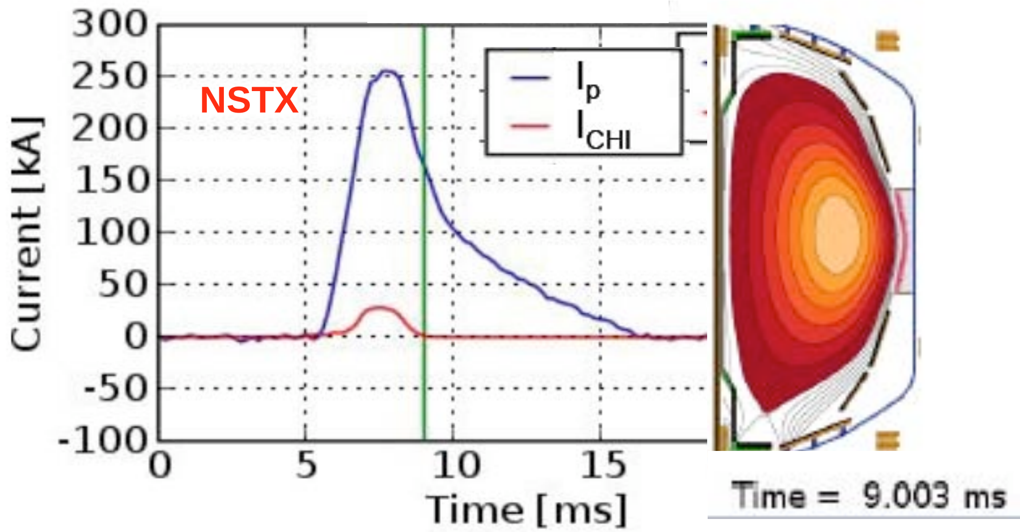


- To reach $\Delta t_{pulse} \gg \tau_{skin}$ of NHTX / CTF relevant high performance full non-inductive discharges, NSTX TF flat-top duration needed to be extended by x 2-3
  - Sub-cooling to -50°C increases TF flat top time by a factor of ~ 3 at 5.5 kG
  - Only the center stack needed to be cooled (small volume)
  - Upper and lower umbrella structure can be sealed for dry N_2

Solenoid-free Startup for ST-CTF and Demo
A number of options being developed

NSTX

CHI drove 160 kA of closed-flux current



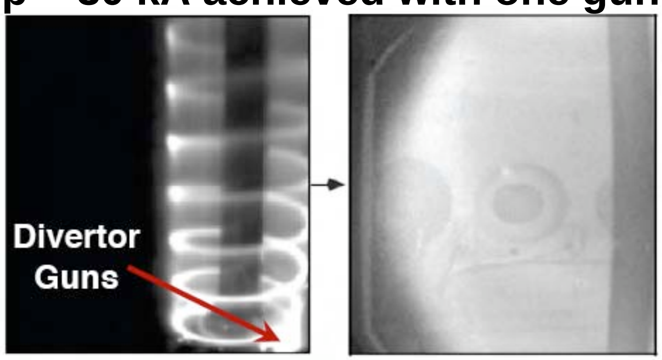
CHI to be optimized toward ~ 300 kA

Ip ~ 500 kA without OH

6 MW of HHFW Heating & CD

1 MW of ECH Preionization

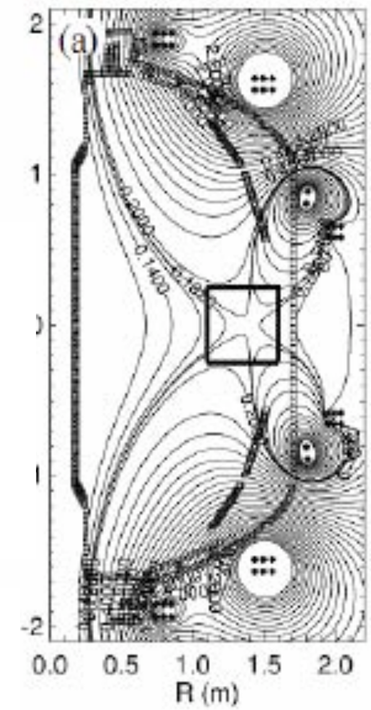
PEGASUS Gun Start-up
Ip ~ 30 kA achieved with one gun



Further improvements with improved/multiple guns

Start-up Utilizing Outer PF Flux

1MW ECH and/or Plasma Gun to assist the start-up



OH-minimized Current Ramp-up for ST-CTF and Demo

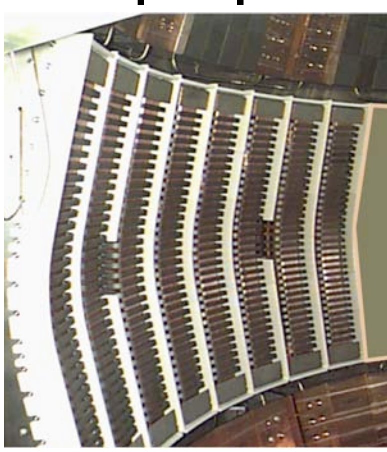
"Iron Core", high power HHFW and NBI

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

- Iron core can be used in conjunction with other start-up and ramp-up tools
- NSTX can simulate it with the existing OH solenoid
- Develop OH-minimized scenarios to reach high performance target discharges

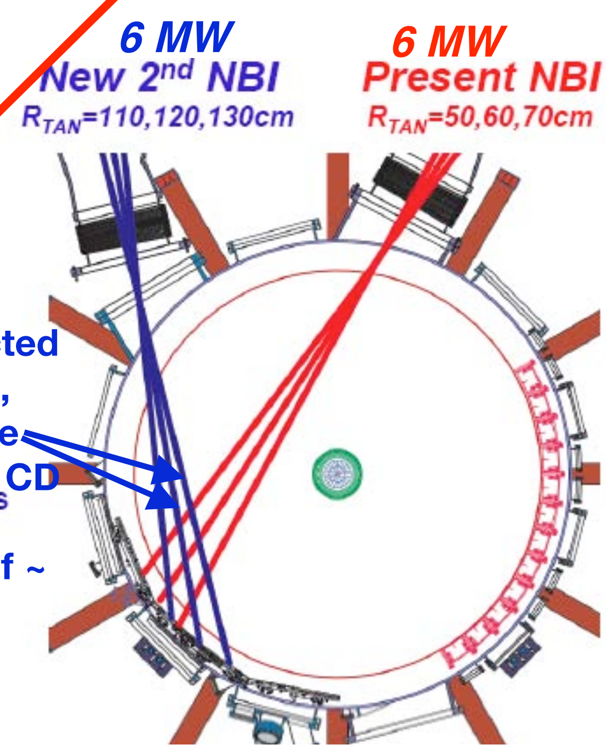
Ip ~ 1 MA with minimum OH

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



- 6 MW HHFW available

Centrally injected NBI at R = 110, 120 cm provide more efficient CD$_s$ even at lower curret range of ~ 0.5 MA



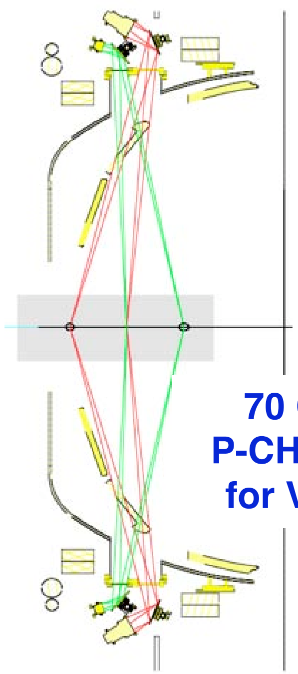
NSTX Addresses Multi-scale Transport Issues Critical to Future Devices - NHTX, CTF, and ITER

NSTX

- Measured & modeled electron, particle, and angular momentum transport
- Measured local high-k turbulence which correlated with electron energy transport at high β

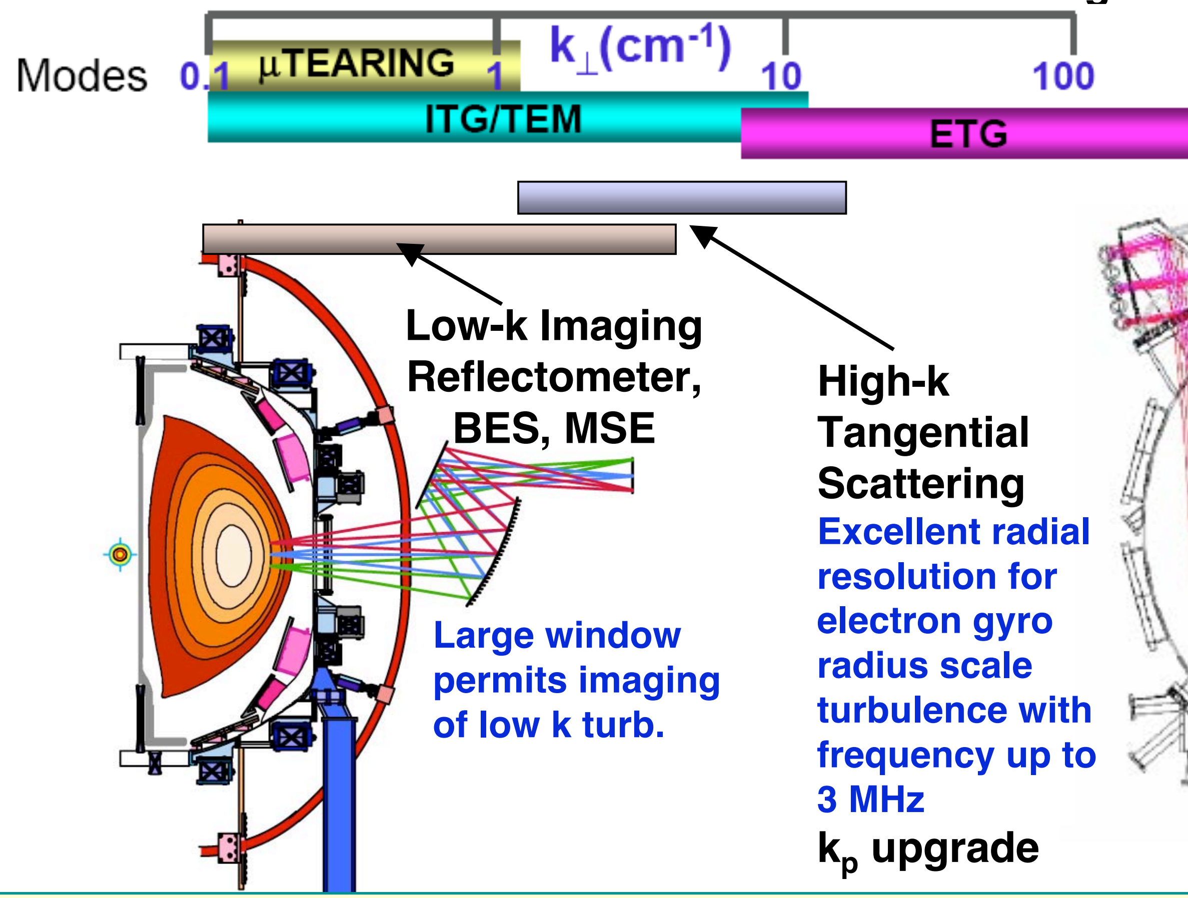
Detailed profile measurements coupled with complete turbulence measurements

Ion-gyro-scale Profile Diagnostics



70 Ch P-CHERS for $V_p(r)$

Innovative Ion-Electron Scale Turbulence Diagnostics



High-k Tangential Scattering

Excellent radial resolution for electron gyro radius scale turbulence with frequency up to 3 MHz

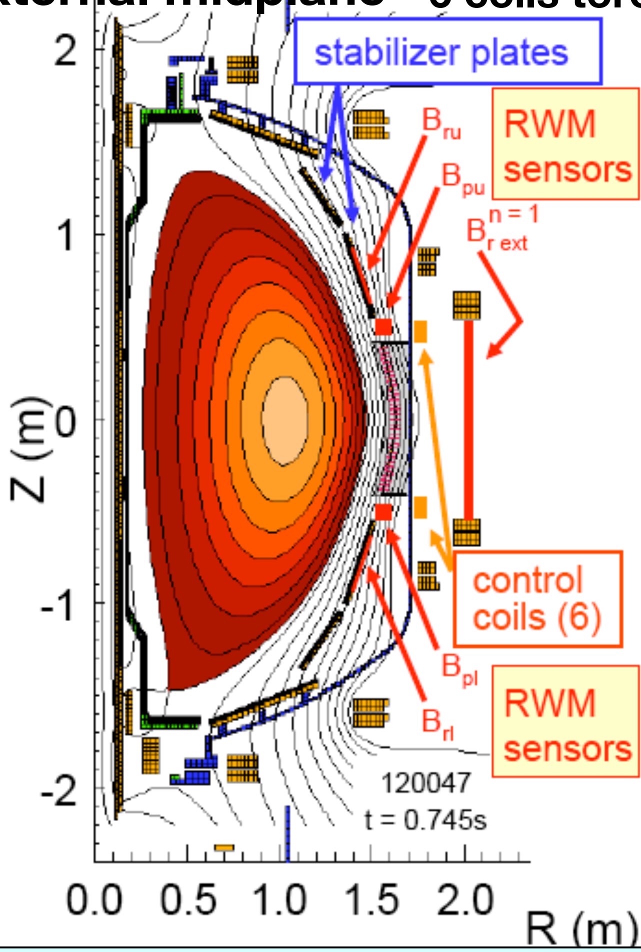
k_p upgrade

Ultimate goal: Comprehensive Understanding ⟷ Predictive Tool

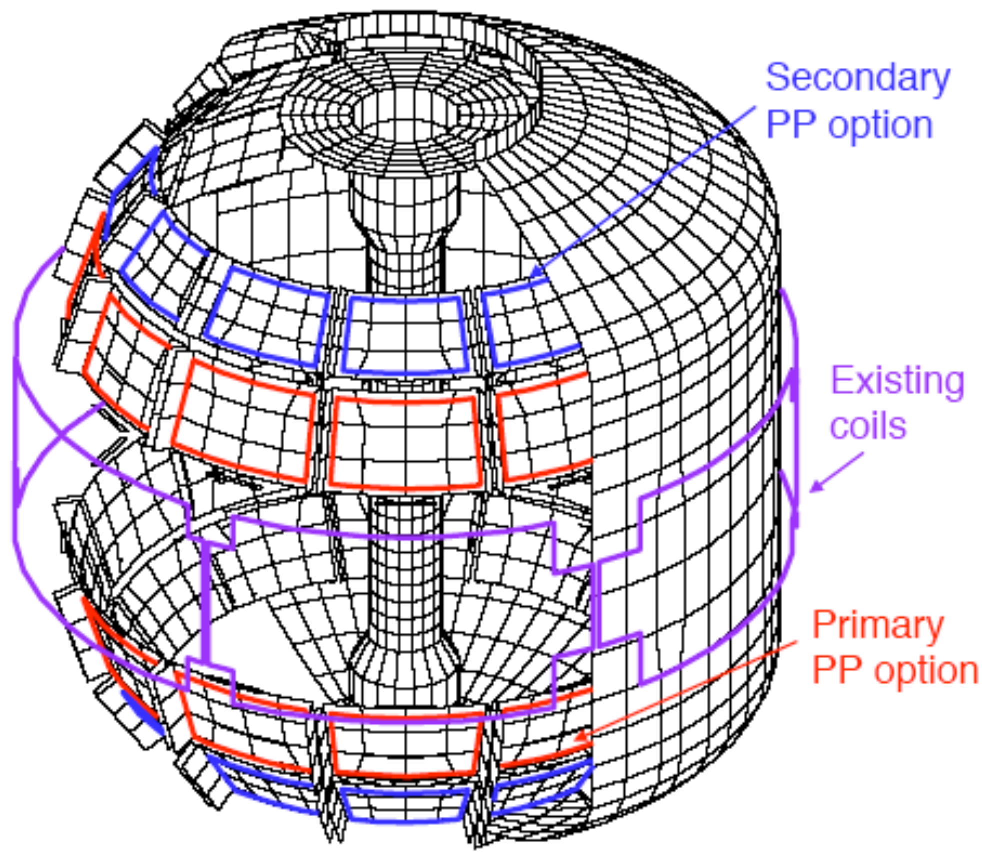
MHD - Off-midplane non-axisymmetric control coils will enable ELM suppression studies and improved RWM, EF, and rotation control

NSTX

External midplane - 6 coils toroidally



Internal off-midplane - 12 coils toroidally



- **RWM Stabilization at high β_N ~ 5.5 and low rotation fo 90 τ_{wall}**
- **Neoclassical Toroidal Viscosity**
- **Discovered n > 1 EF/RWM**

- **n = 1-6 RMP for ELM control (high-n n=6 unique NSTX capability)**
- **Improved RWM and EF control**
- **Rotation control through variable-n NTV**

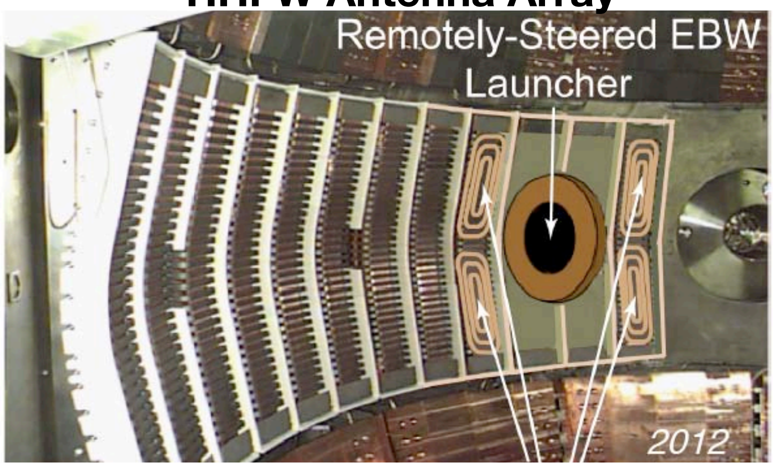
Innovative Wave Physics for Heating and Current Drive for NHTX/CTF/Demo

NSTX

- Improved understanding of HHFW coupling and produced record T_e ~ 4.6 kV with CD phasing. Possible edge loss mechanisms elucidated for ITER ICRF.
- Demonstrated good EBW coupling with L-mode and H-mode.

HHFW Research:
- Improve H-mode coupling
- Develop robust start-up assist
- NBI compatibility

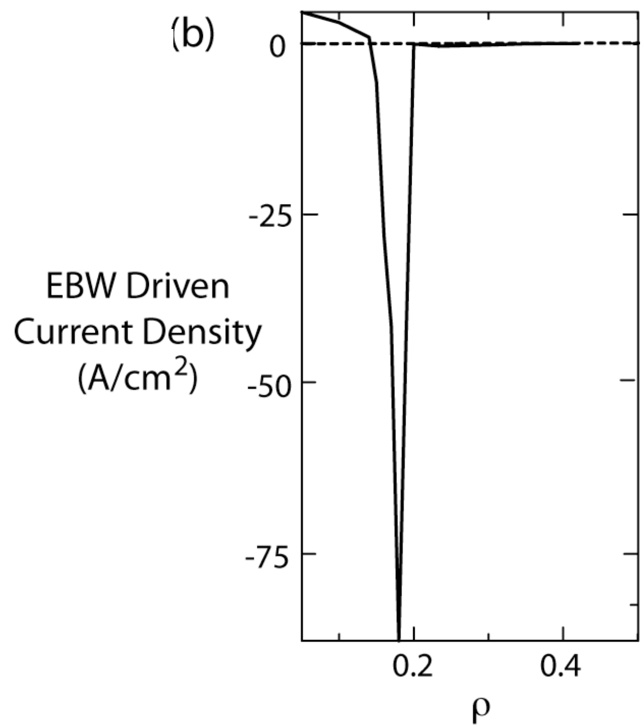
HHFW Antenna Array



CAE antenna

Antenna Upgrade: 2009-2010
- Double feeds for higher power
- Improve coupler for H-mode
- Reduce antenna to eight for EBW

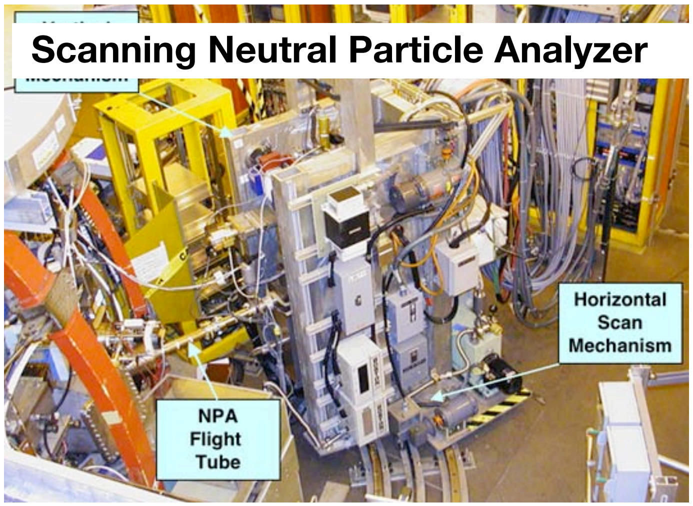
EBW Research: Utilizing ORNL system
- 350 kW for coupling physics in 2010
- 700 kW for heating in 2011
- 1 MW for CD (MSE) in 2012

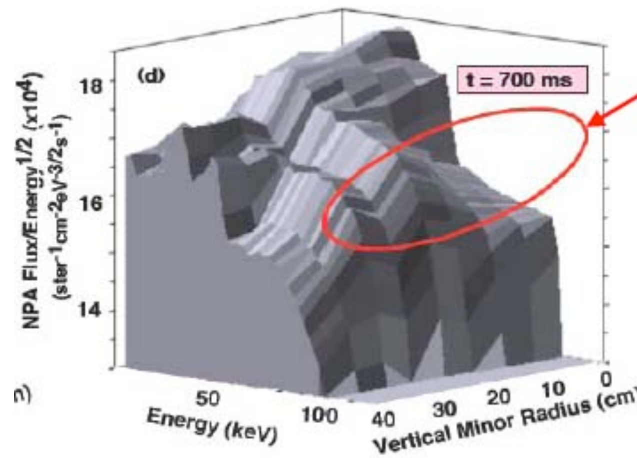


Localized CD ~ 40 kA/MW for On-Axis 28 GHz EBWCD in NSTX β = 20% Plasma

NSTX Contributes Strongly to Energetic Particle Physics Relevant for ITER and Demo with Unique Capability

Measured & modeled fast ion redistribution, TAE stability, beta evolution of AC and GAM coupling, discovered CAEs and BAAEs





NPA showing outward core energetic particle diffusion due to bursting TAEs

EP diagnostics:
- FLIPs (Fast Lost Ion Probes)
- Scanning NPA
- FIDA (D-alpha)
- Fast neutron measurement
- Neutron collimator

EP Modes diagnostics:
- High frequency magnetic arrays
- Soft X-ray tomography
- Tangential scattering
- FIR interferometer
- Wave reflectometers

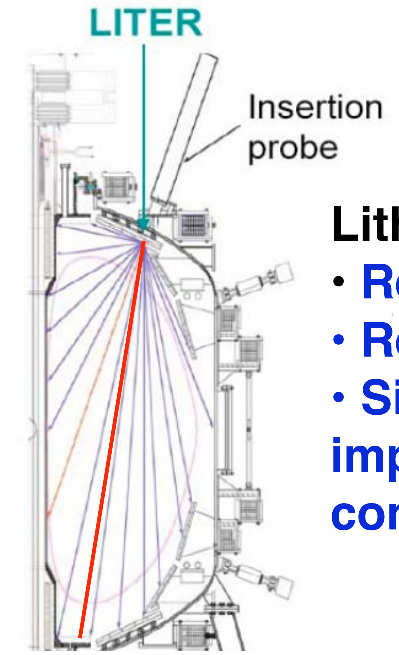
Verification and validation of theory and models at all levels!

Ultimate goal: ***Evaluate role of EP-driven modes in EP transport and confinement, predict EP confinement in ITER/ST/ tokamak reactors***

Boundary: Liquid Lithium Divertor for Particle Control

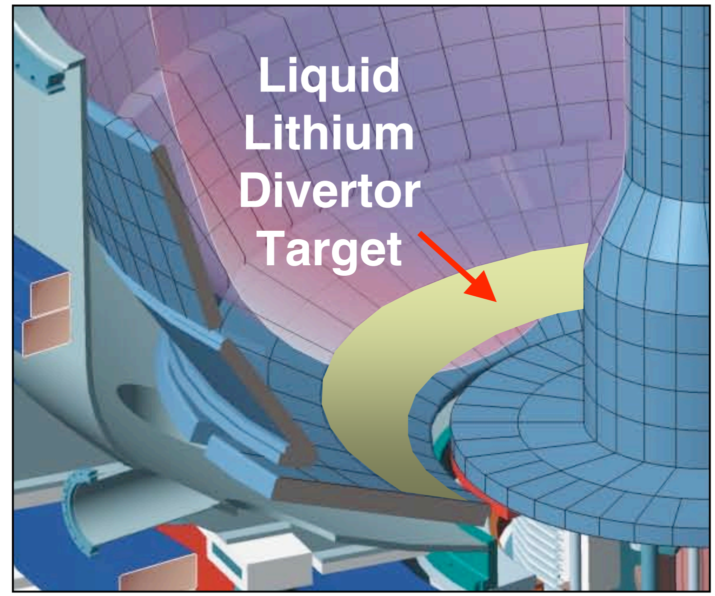
Unique Capability for Diverted H-mode

NSTX

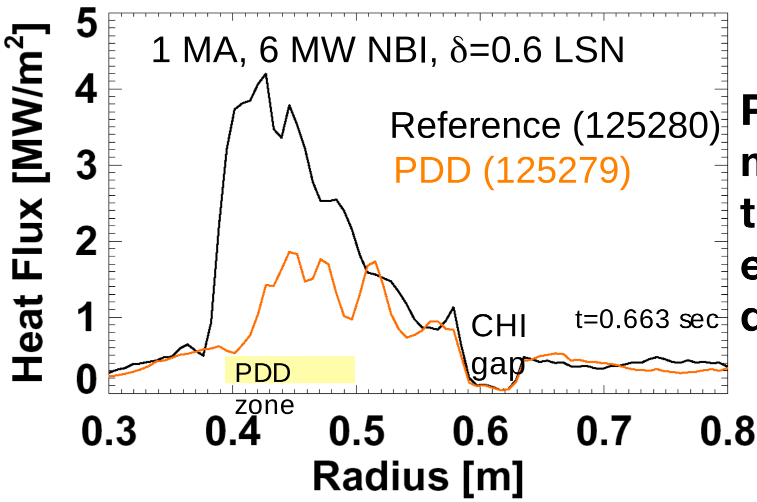


Lithium Evaporator

- Reduced O2
- Reduced recycling
- Significantly improved H-mode confinement



Elucidated Divertor Heat Flux for ITER/NHTX/CTF



Power management through flux expansion and detachment

- Install LLD (SNL)
- Start LLD operation in FY 2009
- Improve LLD in FY 2010
- Optimized Divertor in FY 2012
  - High power flux
  - Longer pulse
  - Core fueling

NSTX 5 Year Facility Upgrade Plan

	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
Run Weeks	12	24	24	24	24	
Machine		● Improved OH	● TF-OH sub-cooling			
Heating & CD		● HHFW antenna upgrade ● 350 kW EBW/ECH	● NBI Upgrade ● 700 kW EBW/ECH ● EBW Launcher		● 1MW EBW/ECH ● EBW Remotely Steered Launcher	
MHD					● Off-midplane "NCC" for EF/ELM control	● "NCC" for RWM and Rotation control
Energetic Particles					● 1MW CAE Drive	
Boundary	● Improved LITER	● Liquid Lithium Divertor ● SGI Upgrade	● LLD upgrade		● Long-pulse Divertor upgrade	● Passive Plate Upgrade
				Core Fueling (Ice Pellets, CT Injection)		
CHI	● Staged bank firing	● Absorber control coils				
PF-Only Start-Up		● PEGASUS/MST-like plasma guns (under discussion)				

NSTX 5 Year Diagnostic Upgrade Plan

	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
Run Weeks	12	24	24	24	24	
Profile	• P-CHERS(70 ch) • MSE/CIF (19 ch) • Multi-Color-T_e(r)		• Real time Vϕ • Real time MSE • MPTS High Resolution pedestal		• Full MPTS (46 ch, 100 Hz)	• Fast CHERS
MHD	• Divertor Halo Current		• Non-magnetic RWM-ID		• Real-time Non-magnetic RWM-ID	
Turbulence	• Corr. Reflect. • Improved High-k Scattering		Fluctuation diagnostics (Low-k, High-kp, MIR) (FY 10 – FY 13)			
Energetic Particles	• Fast-ion D-alpha camera • FIReTIP (2 MHz)	• Fast inboard Mirnovs /High density troidal array	• Neutron Collimator			
Waves	• High-k HHFW (30 MHz) • Improved EBW Radiometer					
Boundary	• Divertor Bolometer • Penning Gauge Upgrade	• LLD Diagnostics • Fast IR Camera • Ion Flow Measurement	• X-point Fast Probe • Edge USXR	• Divertor Imaging Spectrometer	• Divertor Thomson • 2-D Divertor Spectroscopy	

Exciting NSTX Facility Five Year Plan being developed to achieve Mission Elements

NSTX

- To provide the physics basis for future ST-based devices, such as NHTX, ST-CTF and ST-Demo
- To broaden the physics basis for ITER, actively participating in ITPA and US BPO
- To advance the understanding of toroidal magnetic confinement.

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**

We look forward to working with C-Mod and DIII-D to develop the best possible integrated five year plan for the US Fusion Energy Science Program!