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NSTX 5-Year Plan Overview

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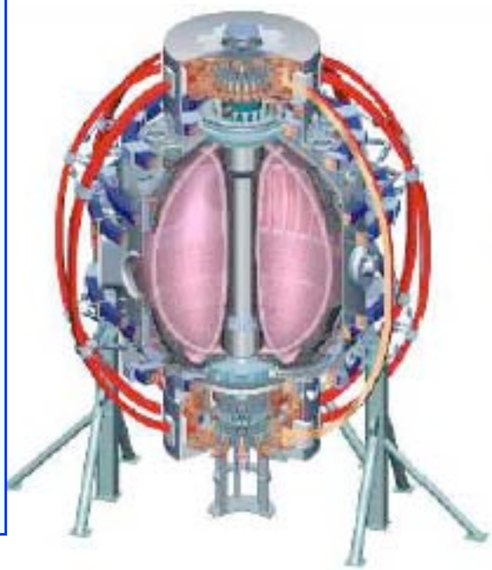
Masayuki Ono
For the NSTX Team

Tokamak Planning Workshop
PSFC, MIT
Sept 17, 2007



Culham Sci Ctr
U St. Andrews
York U
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Kyushu Tokai U
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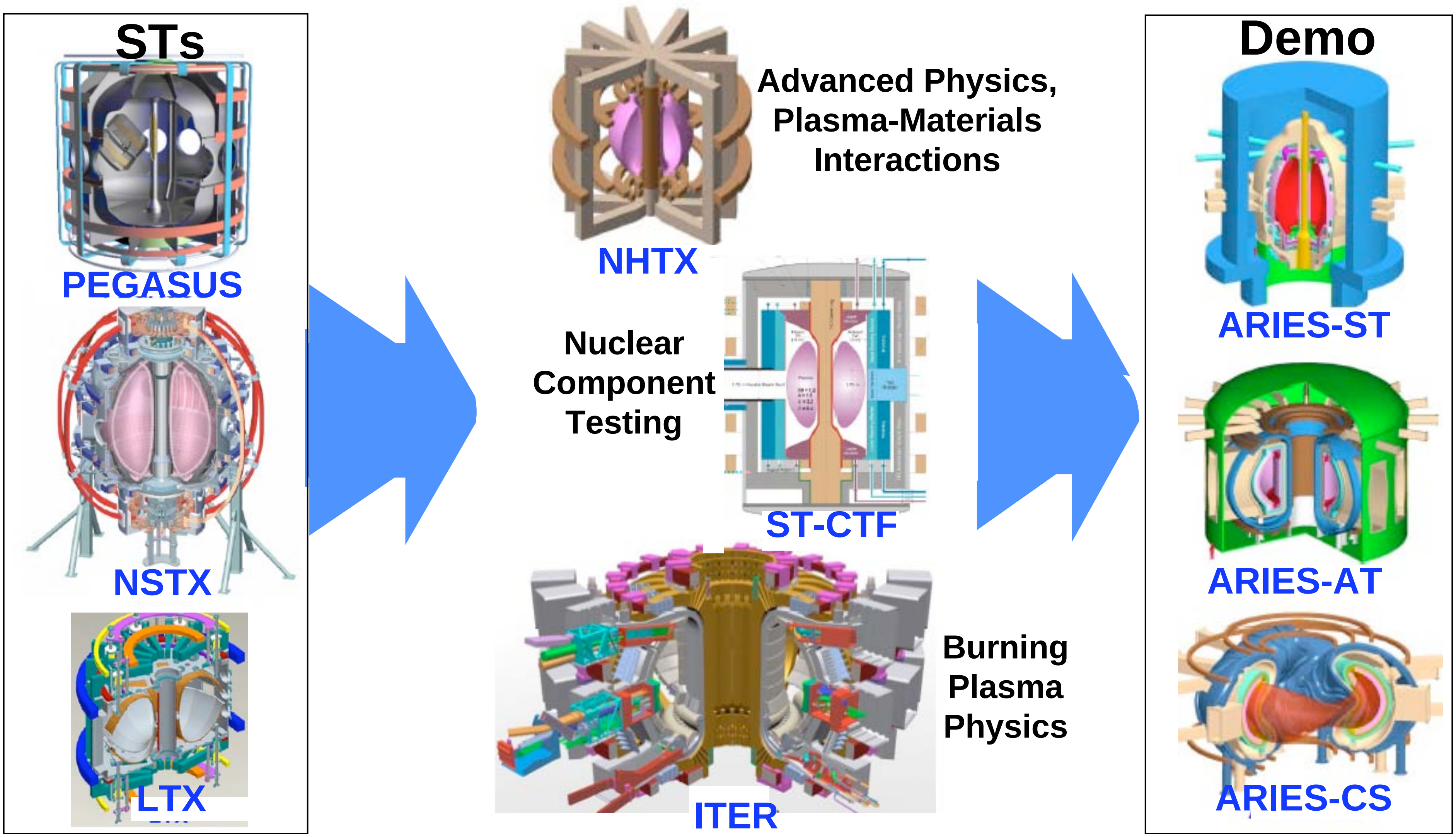
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NSTX Research Program Contributes Strongly to US and World Fusion Development

ST offers compact geometry + high β for attractive fusion applications



NSTX Mission Elements

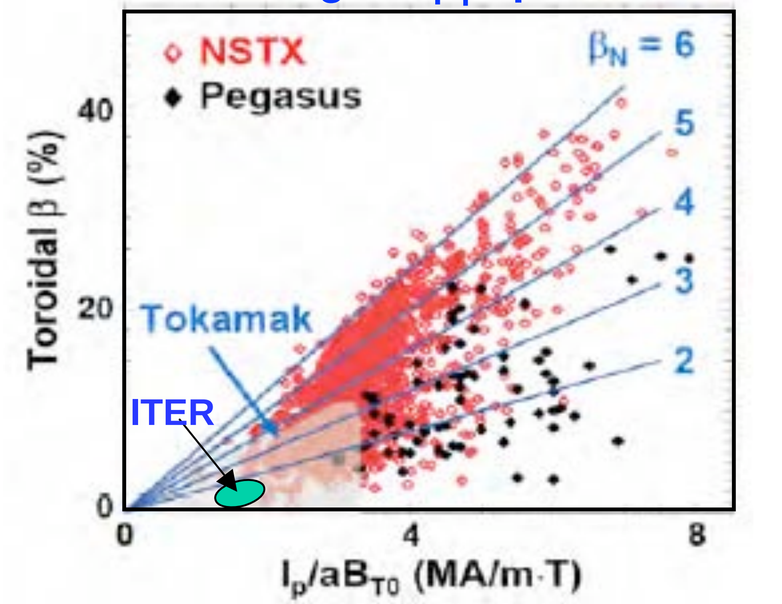
- To provide the physics basis for future ST-based devices, such as NHTX, ST-CTF and ST-Demo
- To broaden the physics basis for ITER, actively participating in ITPA and US BPO
- To advance the understanding of toroidal magnetic confinement.

NSTX/ST Strength:

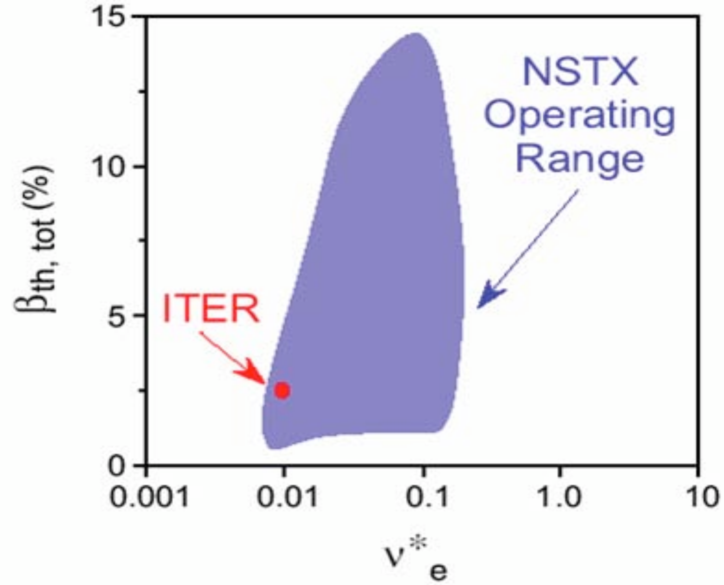
- Exceptionally wide plasma parameter space
- High degree of facility flexibility
- Highly accessible plasmas - unique diagnostics

NSTX Offers Access to Wide Tokamak Plasma Regimes

Wide range of β_T up to ~ 40 %

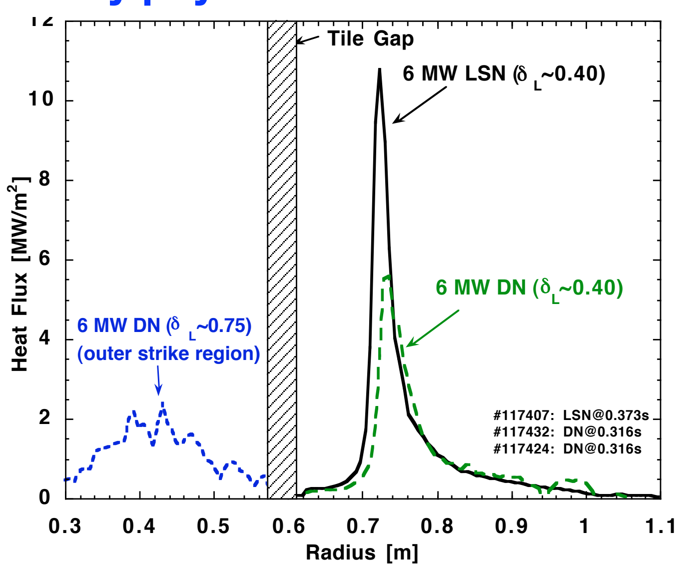


β Confinement Scaling, Electron Transport

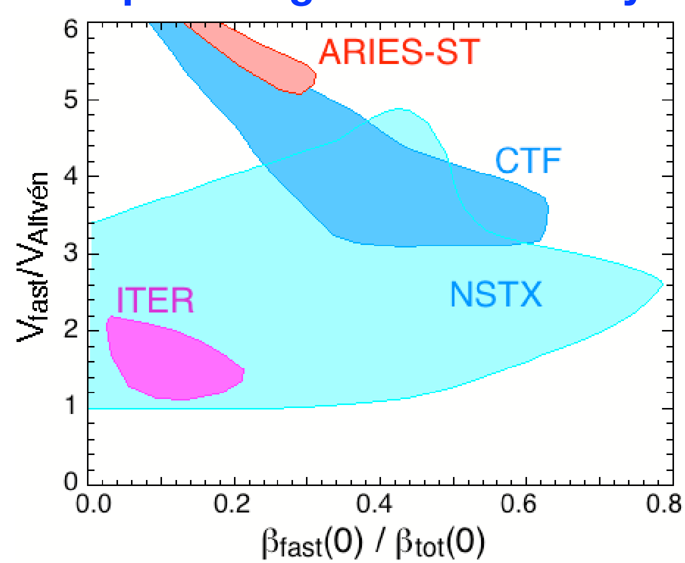


- •Confinement scaling with wide range of β_T up to ~ 40 %

Boundary physics with ITER-level heat flux



Unique Energetic Particle Physics

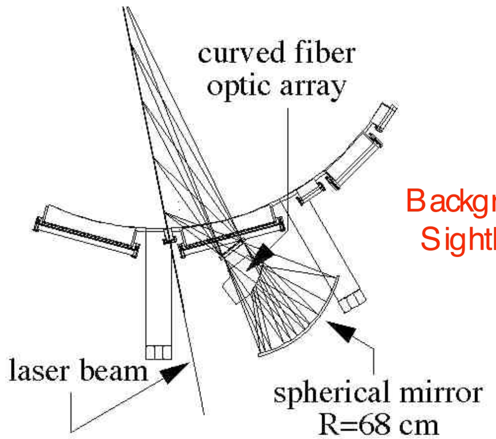


- Full set of diagnostics: including MSE for j(r)

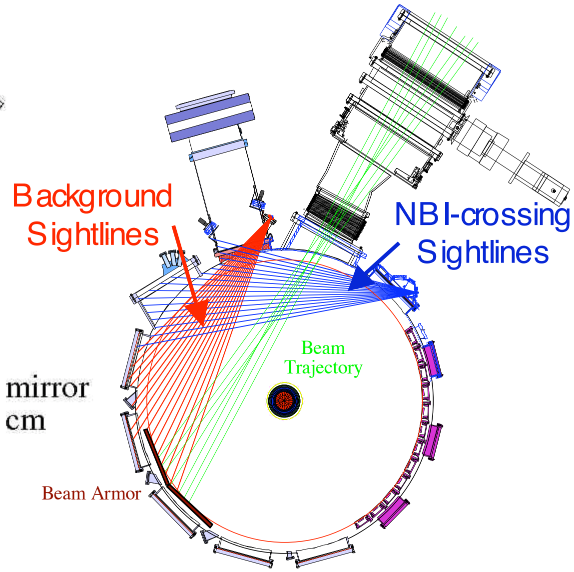
Highly Accessible Plasmas - Unique Diagnostics

NSTX

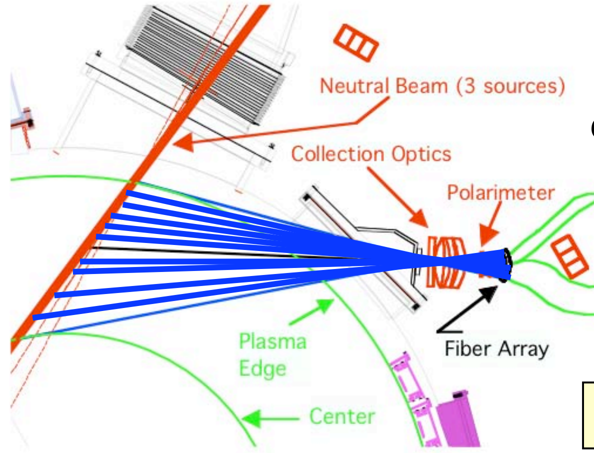
30 Ch, 60Hz MPTS for $T_e(r)$, $n_e(r)$



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

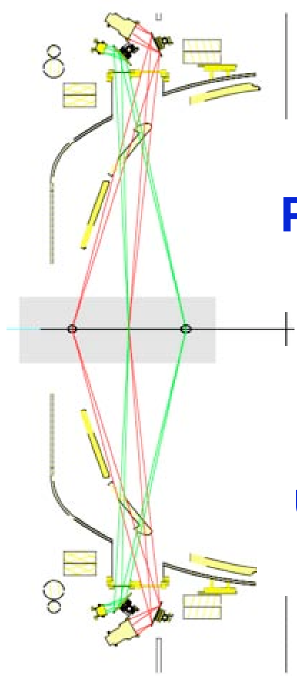


16 Ch MSE for q(r) (19 ch planned)



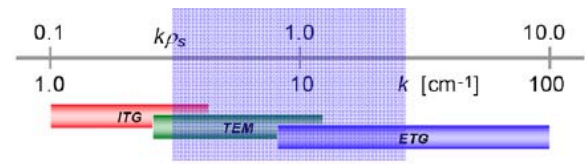
Innovative design enables MSE in kG range for the first time

Nova Photonics



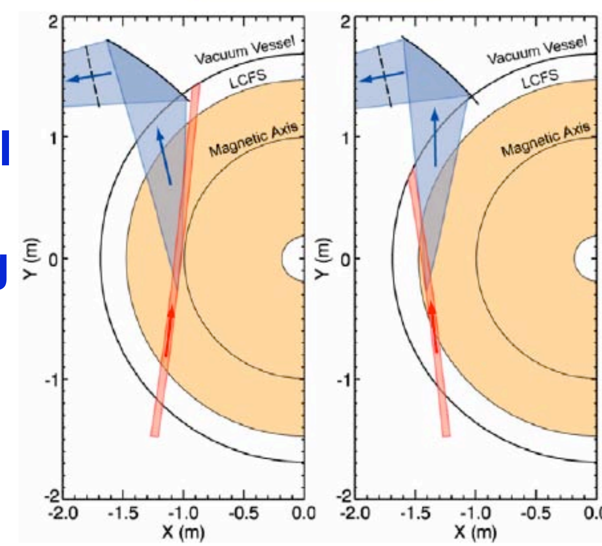
70 Ch Pololidal CHERS for $V_p(r)$

Fast Ion D-Alpha Camera using P-CHERS views



Tangential High-k Scattering (3 MHz)

UCD



NSTX has Comprehensive and Powerful Set of Scientific Capabilities

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

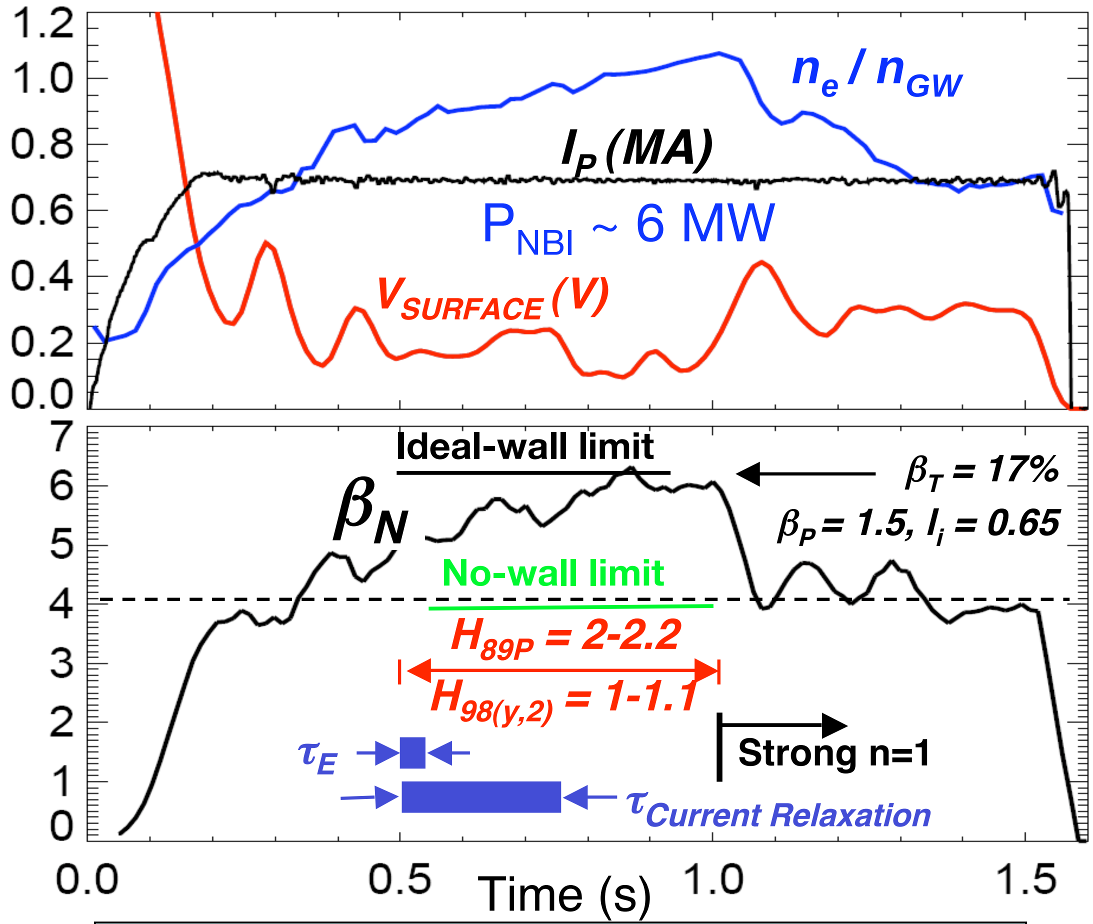
Boundary Physics: High ITER-like power flux, Unique Li research,broad ITER and NHTX/ST-CTF-relevant boundary physics research

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

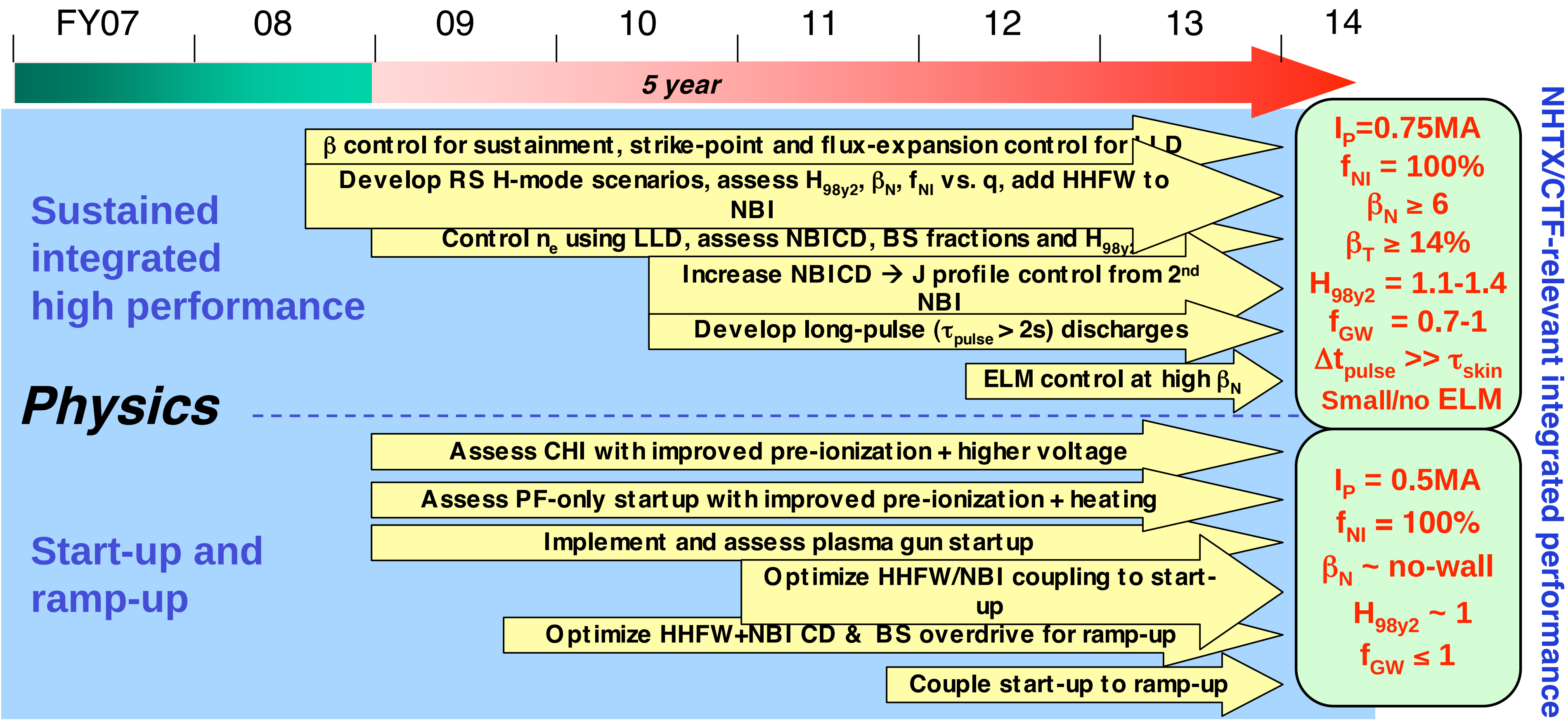
NSTX

	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

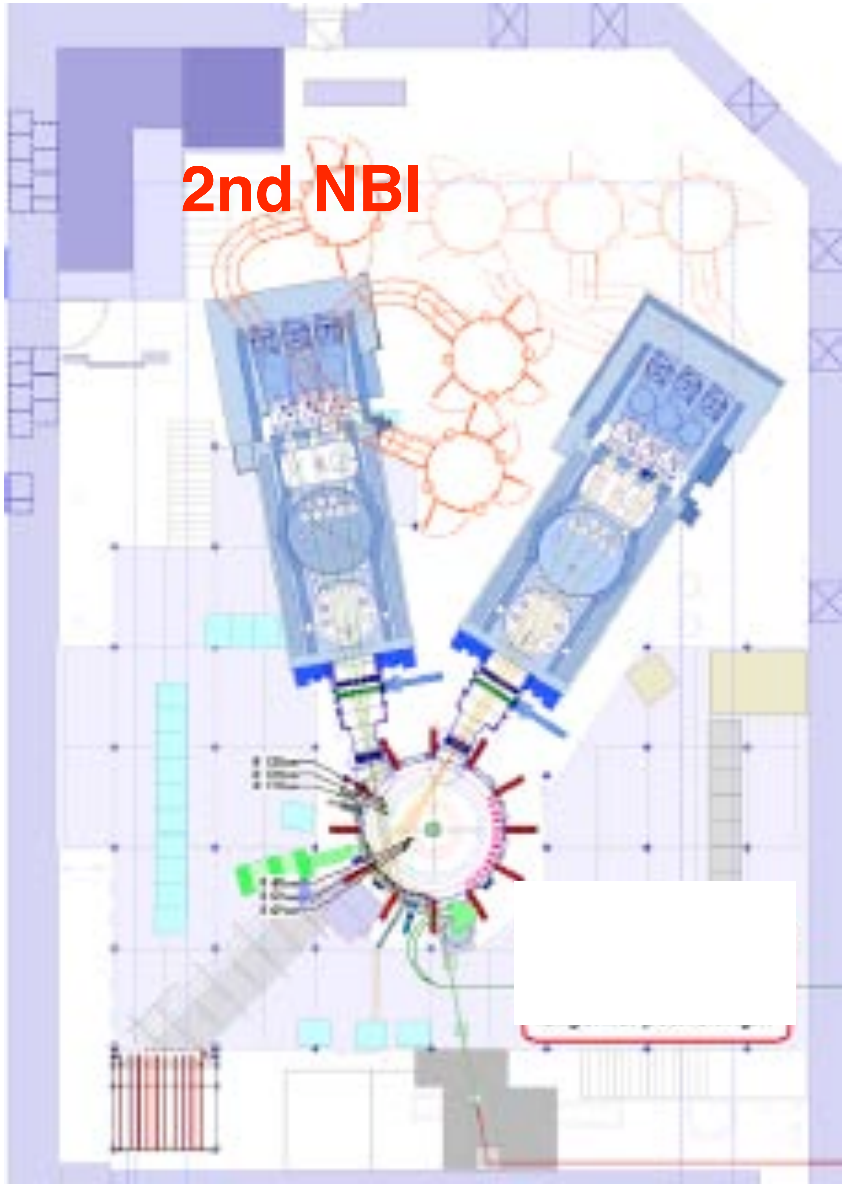
Achieve and maintain fully non-inductive NHTX/CTF relevant high performance discharges

NSTX



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

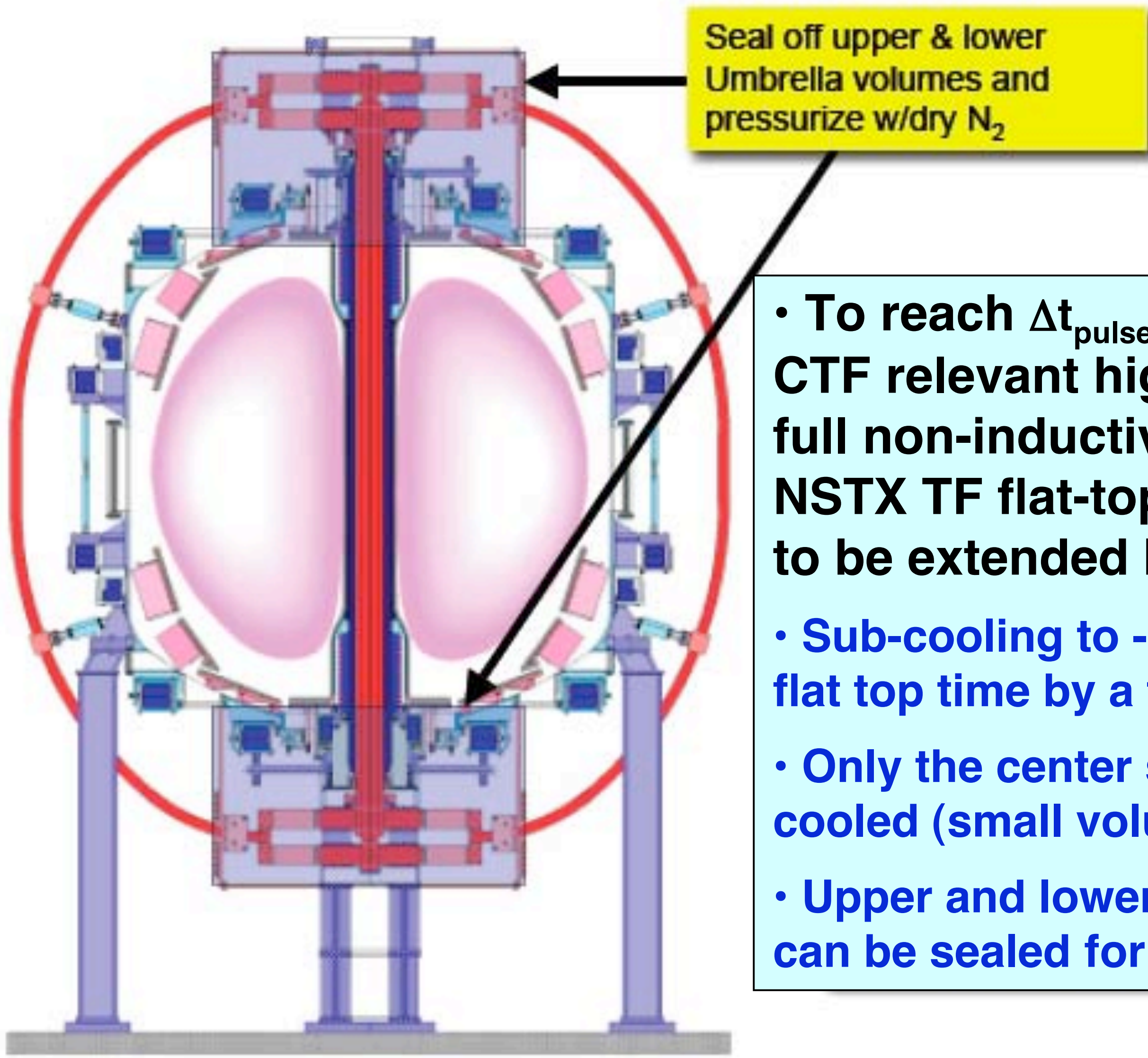
Greatly enhanced capabilities

- 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

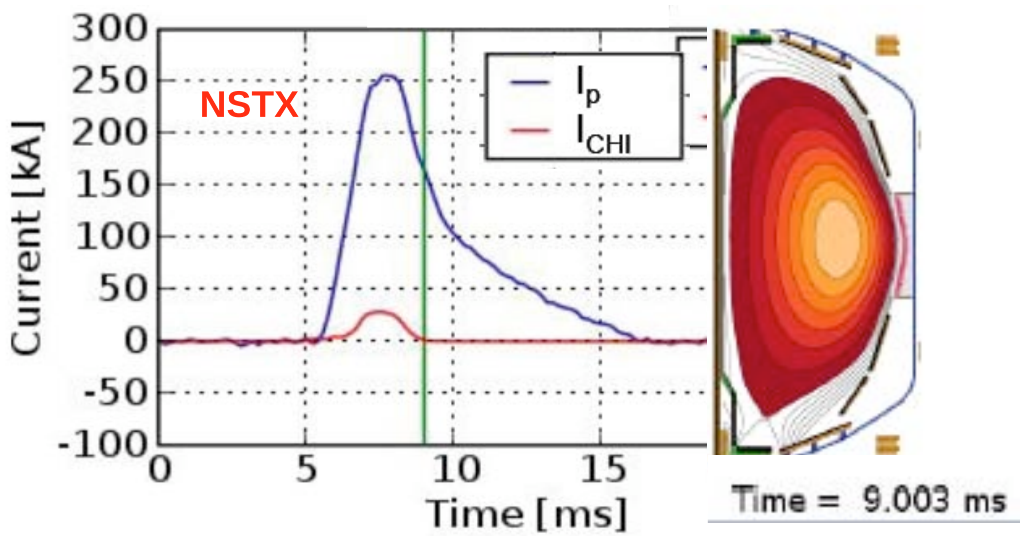


- **To reach $\Delta t_{pulse} >> \tau_{skin}$ of NHTX / CTF relevant high performance full non-inductive discharges, NSTX TF flat-top duration needed to be extended by x 2-3**
  - **Sub-cooling to -50°C increases TF flat top time by a factor of ~ 3 at 5.5 kG**
  - **Only the center stack needed to be 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

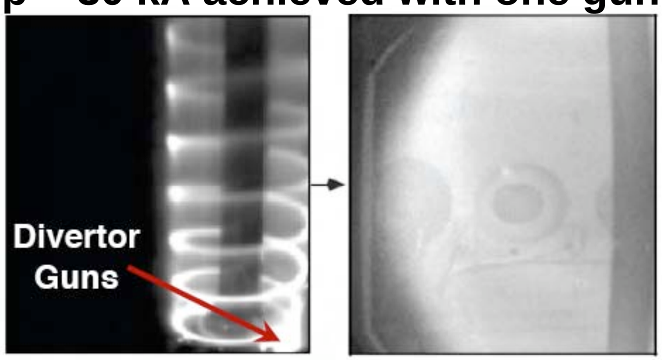
NSTX

CHI drove 160 kA of closed-flux current



CHI to be optimized toward ~ 300 kA

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



Further improvements with improved/multiple guns

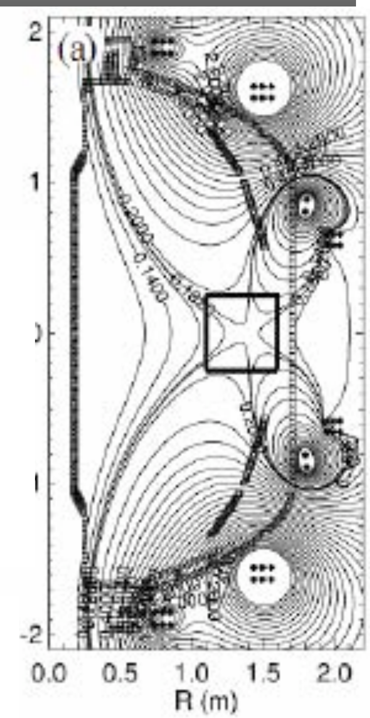
Ip ~ 500 kA without OH

6 MW of HHFW Heating & CD

1 MW of ECH Preionization

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

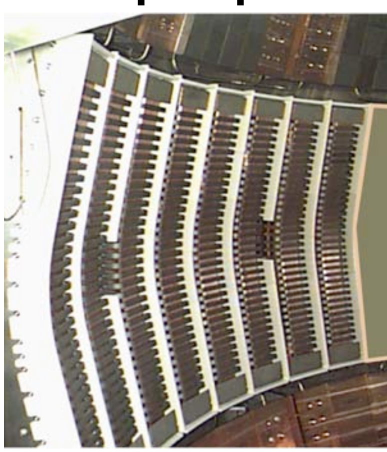
NSTX

Ip ~ 1 MA with minimum OH

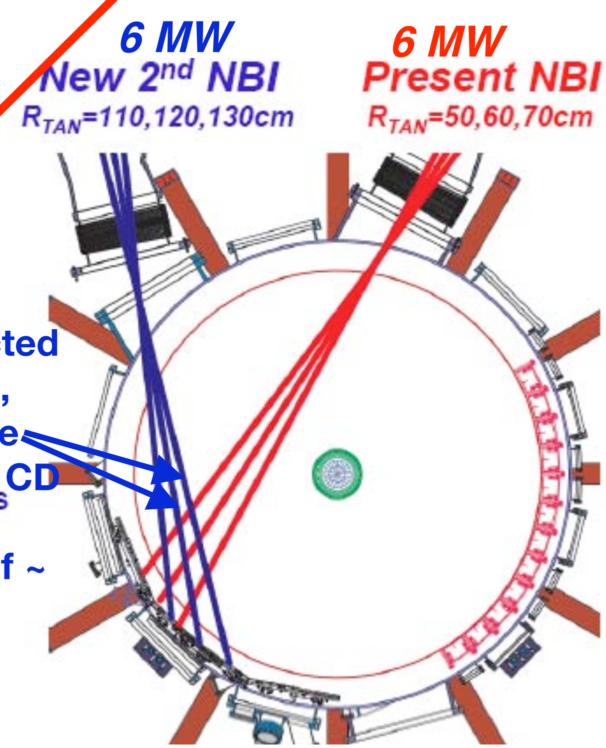
Iron core provides limited but high quality ohmic flux for CTF and Demo

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

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 CDs even at lower curret range of ~ 0.5 MA

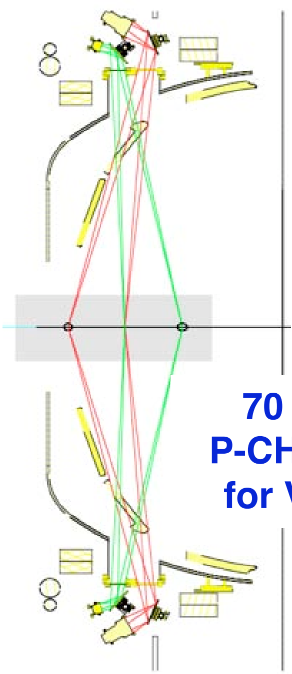
NSTX Addresses Multi-scale Transport Issues Critical to Future Devices - ITER, NHTX, and CTF

NSTX

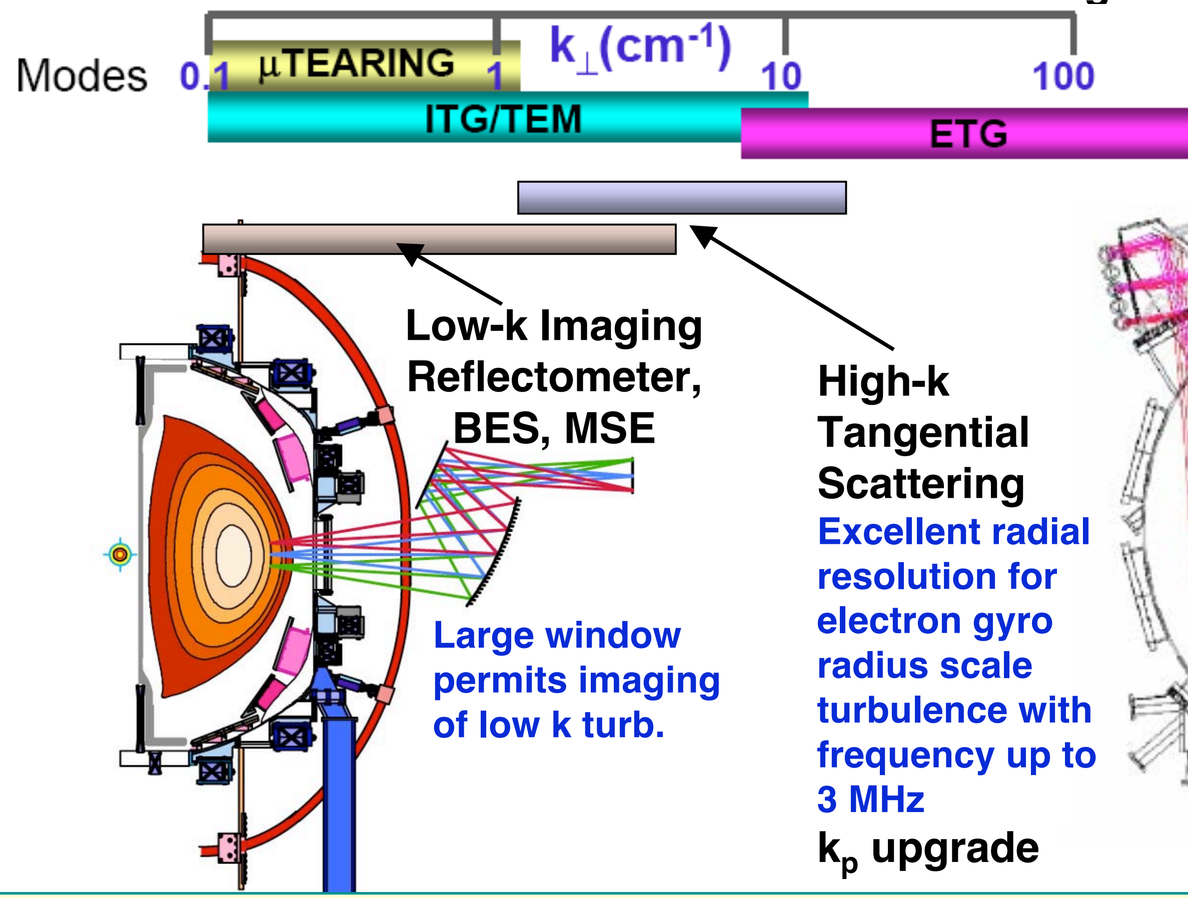
- Measured & modeled electron, particle, and angular momentum transport
- Measured local high-k turbulence which correlated with electron energy transport at high β

Detailed profile measurements coupled with complete turbulence measurements

Ion-gyro-scale Profile Diagnostics



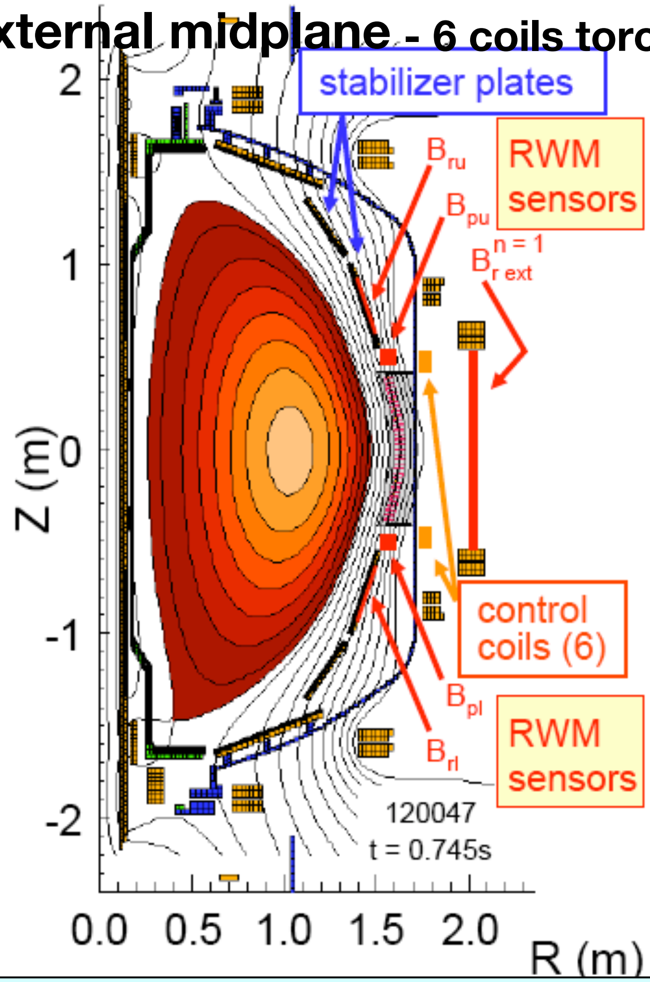
Innovative Ion-Electron Scale Turbulence Diagnostics



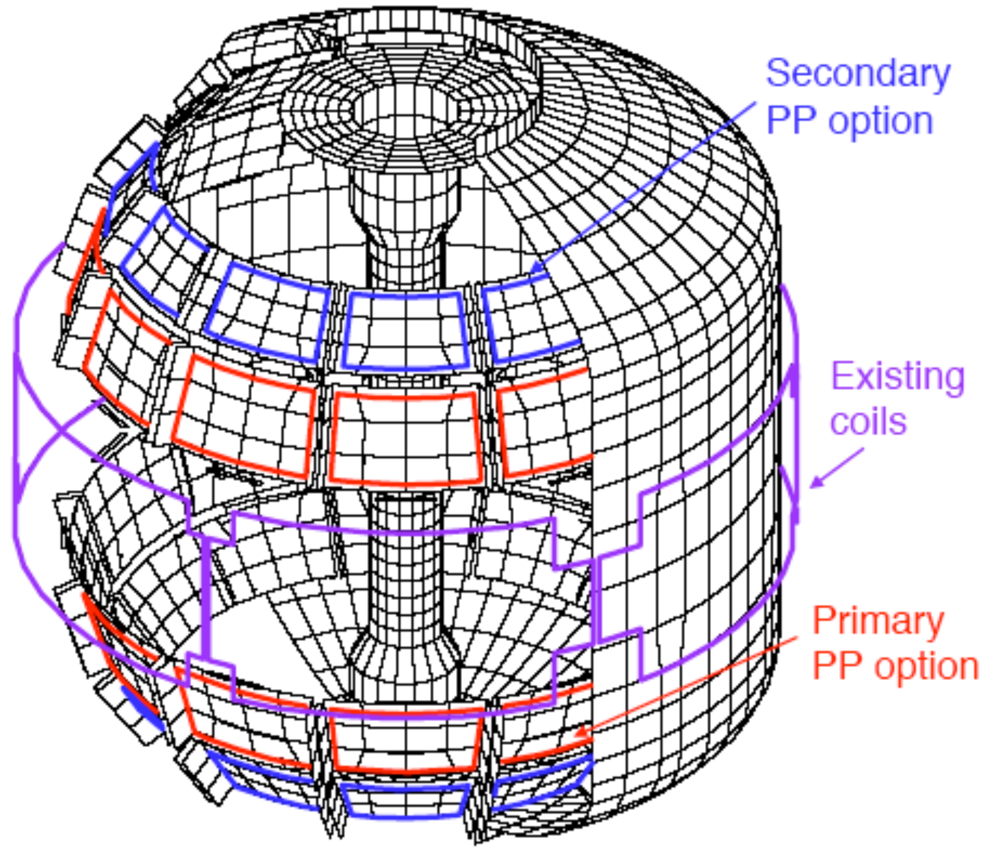
Ultimate goal: Comprehensive Understanding ⟷ Predictive Tool

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

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

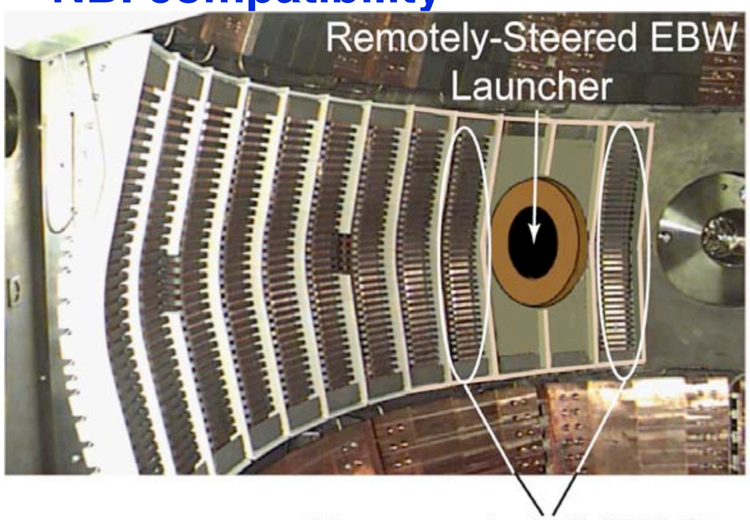
Innovative Wave Physics for Heating and Current Drive for NHTX/CTF/Demo

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:

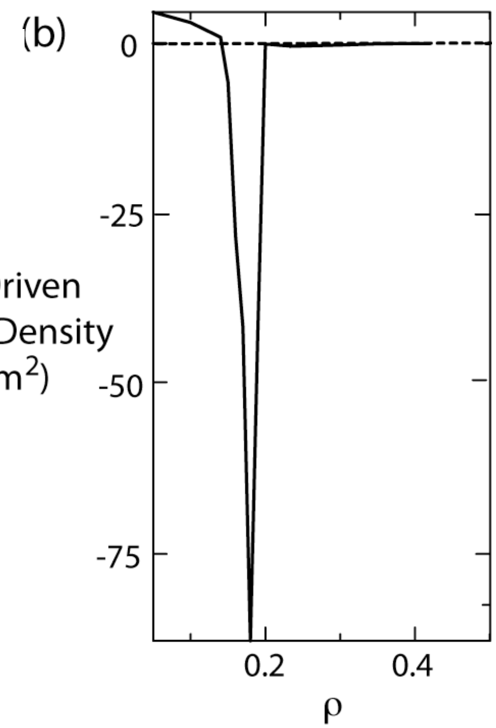
- Improve H-mode coupling
- Develop robust start-up assist
- NBI compatibility



- Double feeds for higher power
- Improve coupler for H-mode
- Reduce antenna to eight for EBW

EBW Research: Utilizing ORNL system

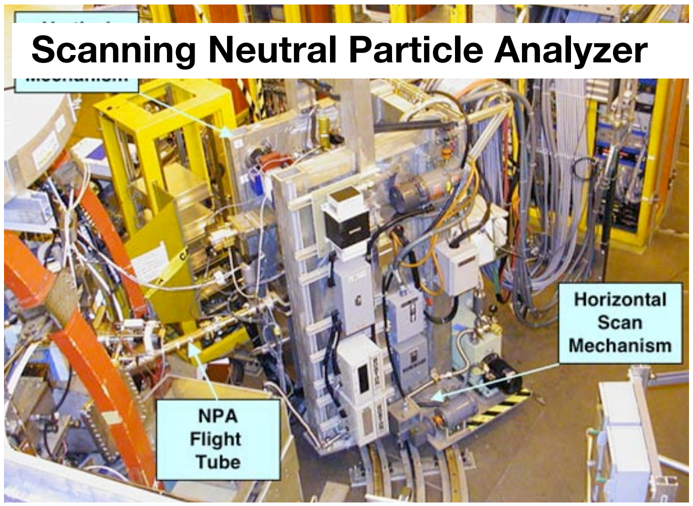
- 350 kW for coupling physics in 2010
- 700 kW for heating in 2011
- 1 MW for CD (MSE) in 2012

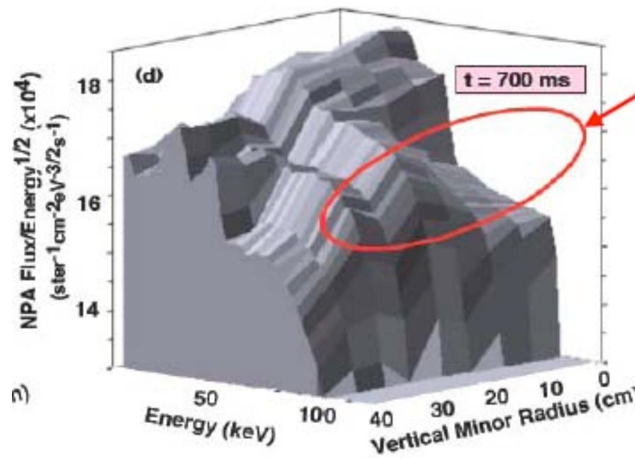


Localized CD ~ 40 kA/MW for On-Axis 28 GHz EBWCD in NSTX β = 20% Plasma

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

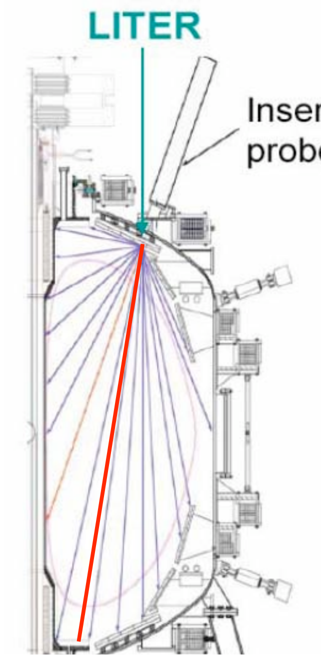
EP Modes diagnostics:
- High frequency magnetic arrays
- Soft X-ray tomography
- Tangential scattering
- FIR interferometer
- Wave reflectometers

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***

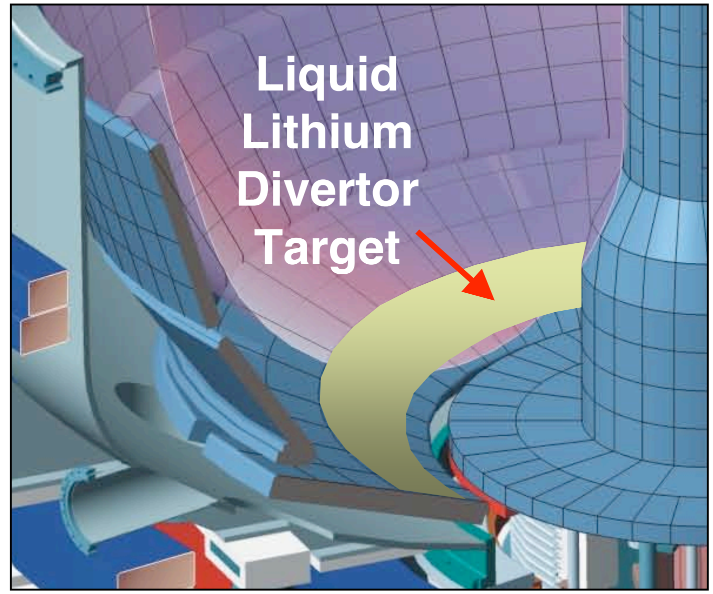
Boundary: Liquid Lithium Divertor for Particle Control

Unique Capability for Diverted H-mode

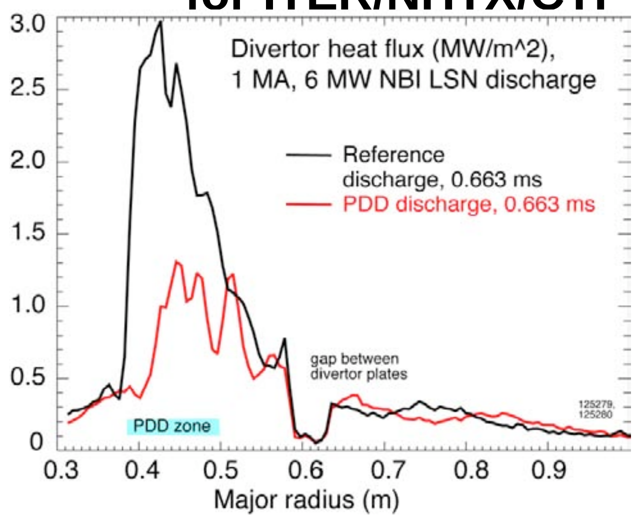


Lithium Evaporator

- 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

NSTX

	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	Core Fueling (Ice Pellets, CT Injection)	● Long-pulse Divertor upgrade	● Passive Plate Upgrade
CHI	● Staged bank firing	● Absorber control coils				
PF-Only Start-Up		● PEGASUS/MST-like plasma guns (under discussion)				

NSTX 5 Year Diagnostic Upgrade Plan

NSTX

	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!