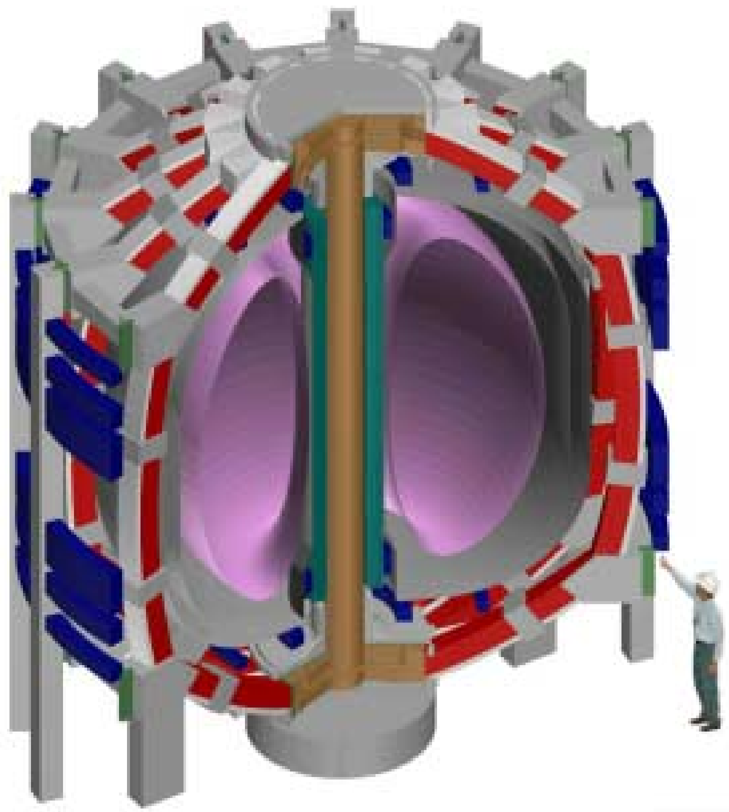
Design Innovations of the Next-Step Spherical Torus Experiment-NSST *



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For the NSST Design Teams

International and US-Japan ST Workshop
PPPL, Nov. 18 - 21, 2002

Supported by

Talk Outline

- Motivation
- Mission and Basic Device Parameters of NSST
- NSST Engineering Design Considerations
- NSST Physics Opportunities

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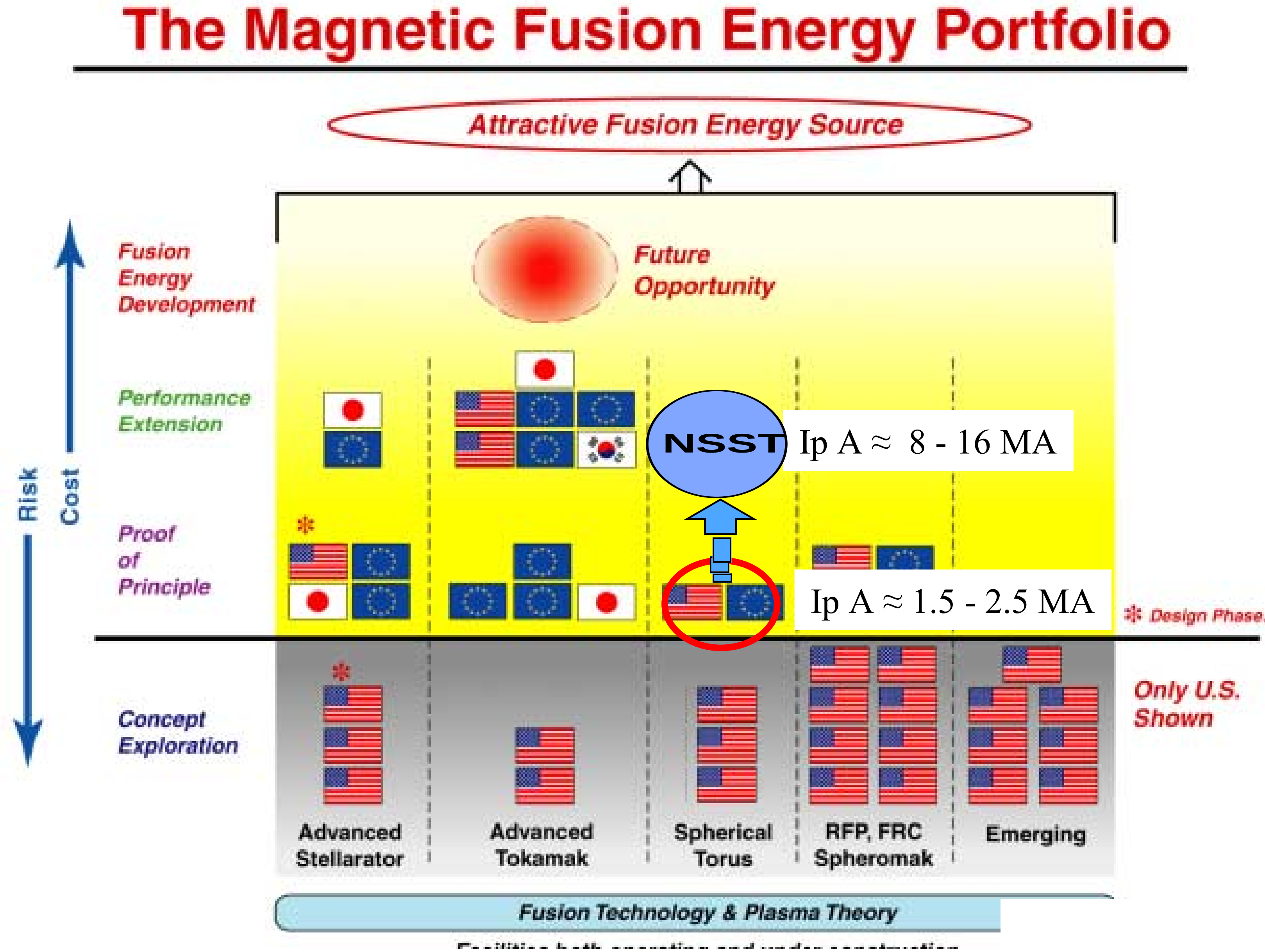
Rapid Progress Achieved In Spherical Torus Physics

(NSTX, MAST, START, GLOBUS-M, PEGAUS, HIT-II, CDX-U,TST-II, TS-3, HIST...)

NSST

- **High beta**
  - $<\beta_T> \approx$ 35% at 1. 2MA
  - $\beta_N \leq 6.5$
  - 30% over no-wall limits)
- **Good heating and confinement**
  - H (98pby2) ≡ HH ≤ 1.7
  - H (89P) ≡ $H_{89P} \leq 2.5$
- **Progress on sustained CTF-relevant regime**
  - $\varepsilon\beta_p \sim 1$ at 800 kA, noninductive fraction ~ 60%
  - Good overall parameters: $<\beta_T> \approx$ 16%, $\beta_N \approx 6$, HH ≈ 1.5 ($H_{89P} \approx 2.2$)
  - Sustained over τ-skin (V-loop ~ 0.1 V)
- **Boundary Physics** H-mode power threshold (< MW) approaching scaling

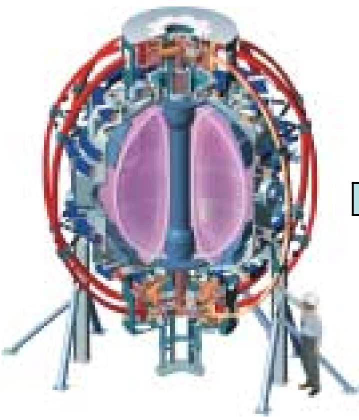
The Next-Step-ST will be in the Performance Extension Phase

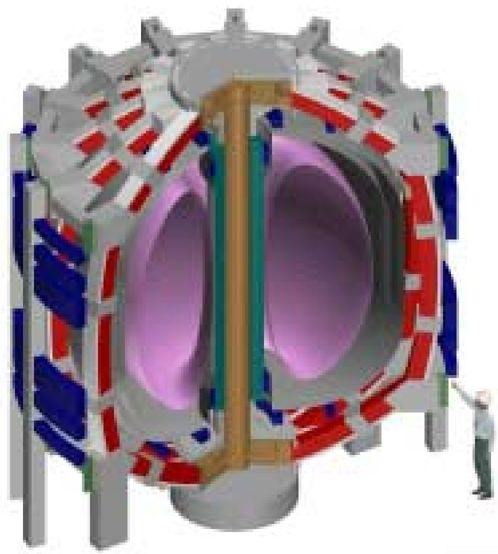


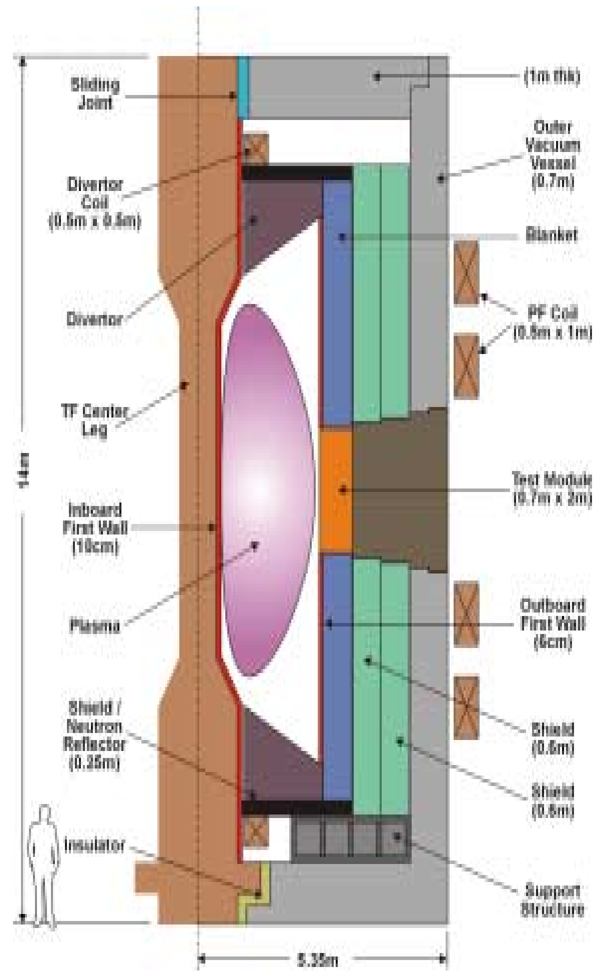
NSST: A Performance Extension Spherical Torus Physics Device

NSST

NSTX and MAST (≈ 1 MA, keV)	Next-Step ST (NSST) (≤ 10 MA, 10s keV)	Component Test Facility (CTF) (Steady-State; Nuclear Facility)



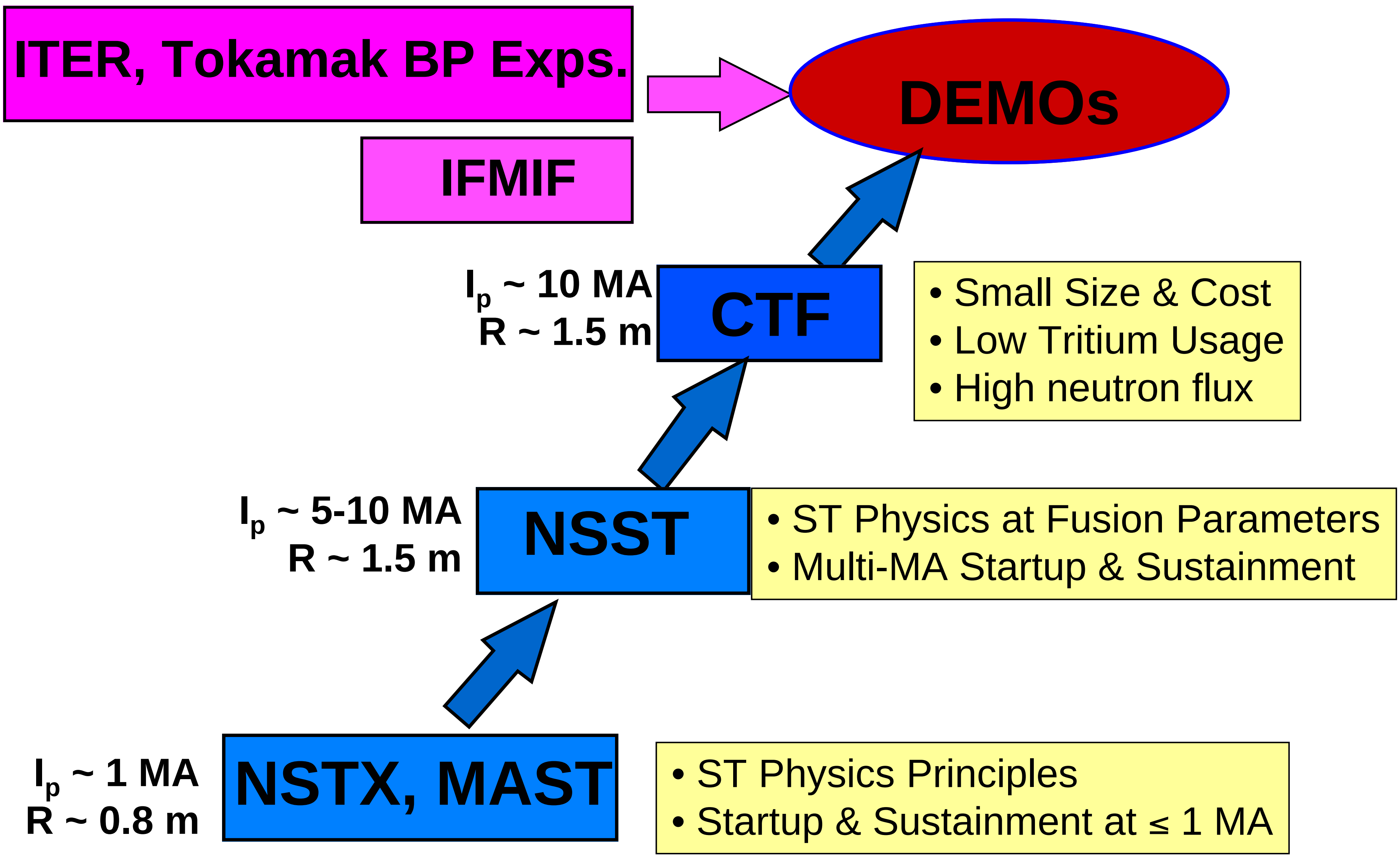




	NSTX	NSST	CTF
R(m)	0.85	1.5	1.5 - 2
a(m)	≤ 0.65	≤ 0.94	1 - 1.4
κ, δ	2, 0.8	2.7, 0.6	~ 3, ~ 0.6
Ip (MA)	≤ 1.5	5 - 10	≥ 10
B_T (T)	0.3 - 0.6	1.1 - 2.6	1.1 - 2.6
t (sec)	5 - 1	50 - 5	Steady-state
TF	Multi-turn	Multi-turn	Single-turn

NSST To Address ST Physics Issues for CTF and DEMO

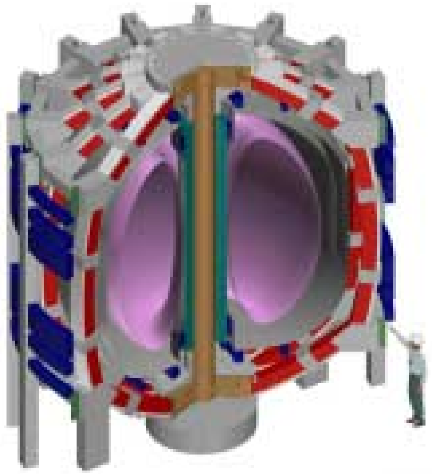
NSST



NSST Mission Elements

NSST

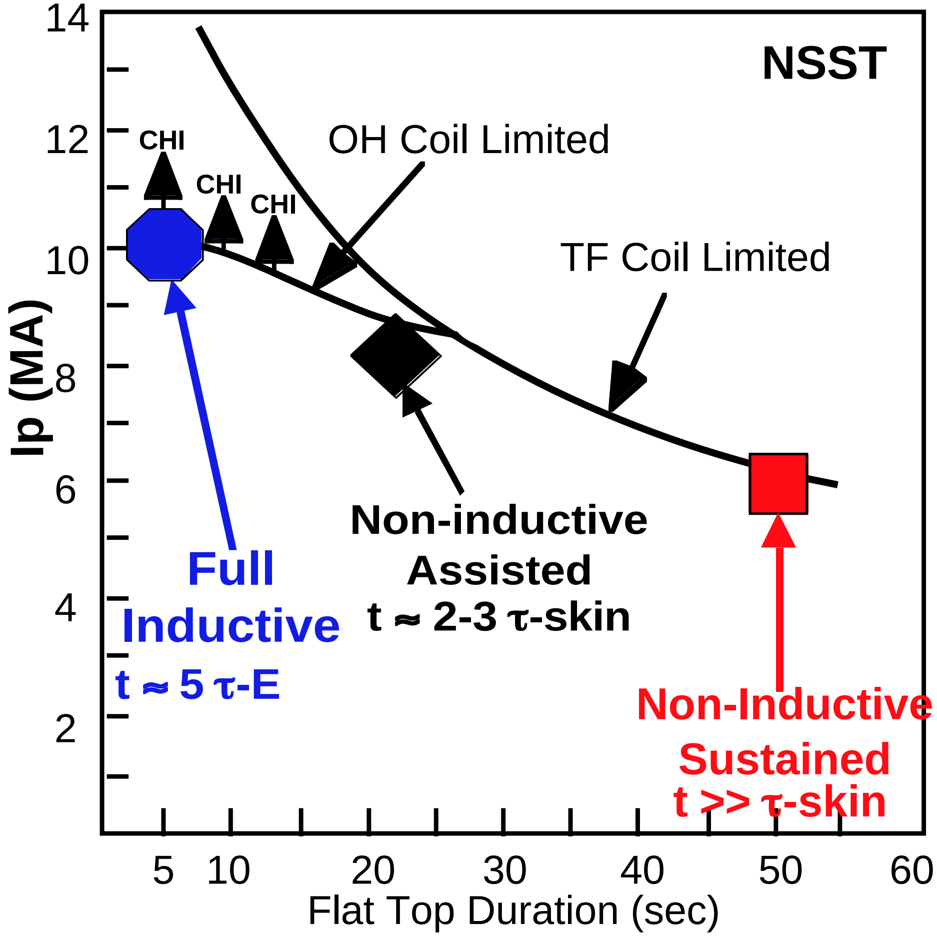
- ST Physics at Fusion Parameters
  - Non-Ohmic Start-up an Non-inductive Sustainment
  - Plasma Confinement and Stability
  - Power and particle handling
  - Alpha physics
  - Advanced ST Physics



- Provide physics basis for an ST-based compact CTF
- Develop Adv. ST Physics scenarios for CTF, DEMO, and Power Plant
- Contribute to General plasma / astrophysics/ fusion science
  - high β waves/turbulences, energetic particles, magnetic reconnections

NSST Can Access a Range of Operating Points Inductively and Non-inductively*

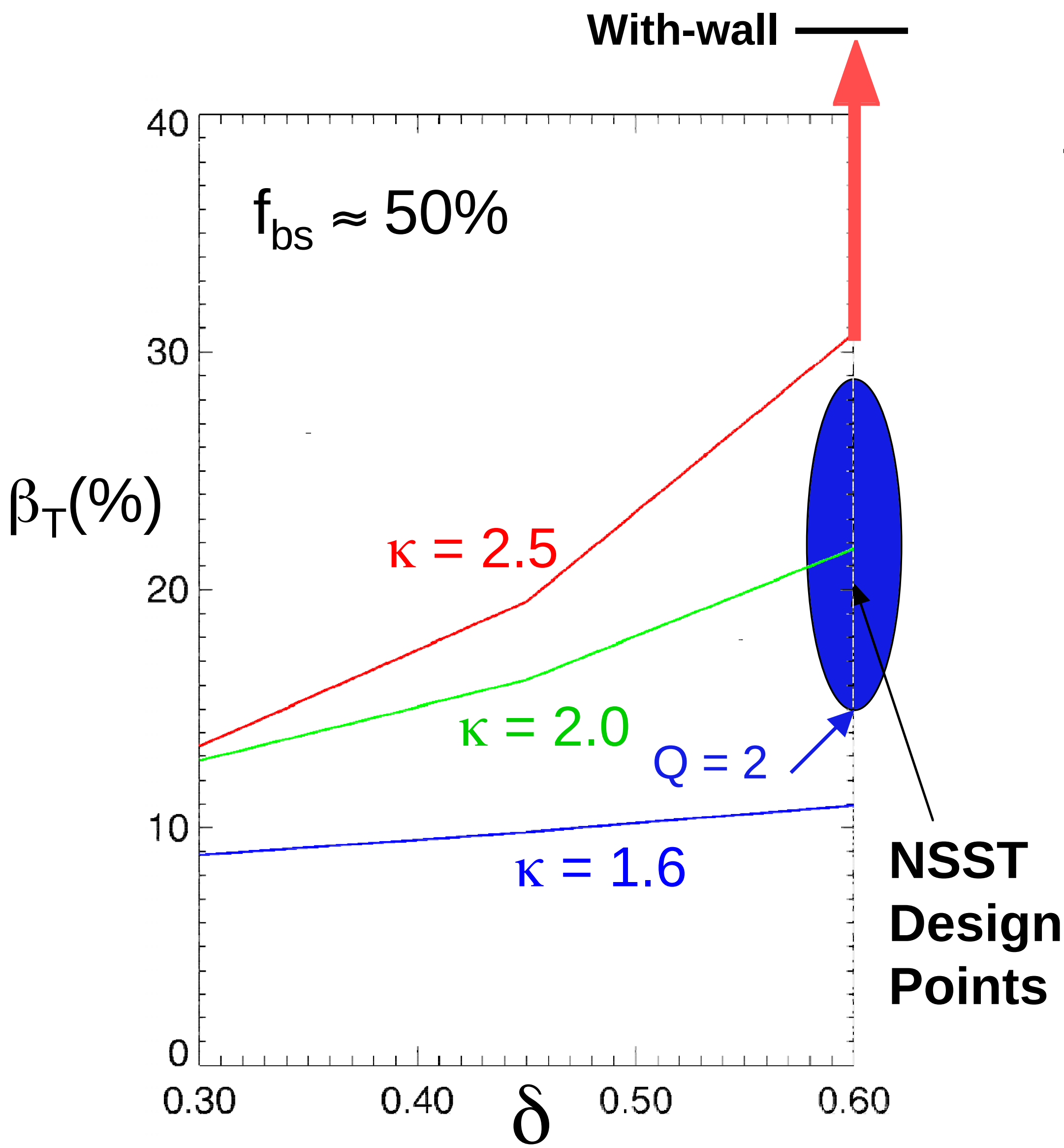
NSST

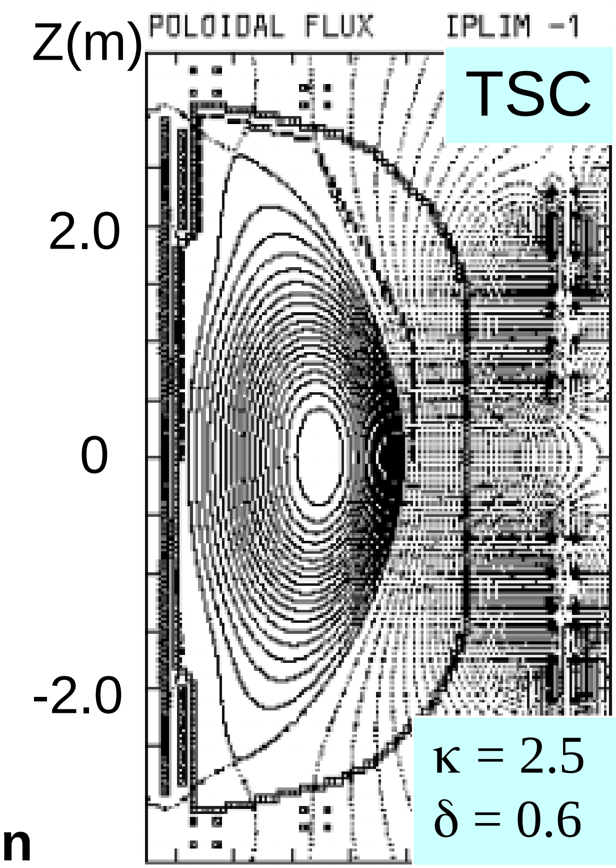


	Full Inductive	Non-Inductive Sustained
B_t (T)	2.6	1.15
β_T (%)	13.3	26.3
β_N (%)	3.2	4.64
$\langle n_e \rangle$ ($10^{20}/m^3$)	2.1	1.0
f_{GW} (%)	63.3	50.7
$\langle T_e \rangle$ (keV)	5.5	4.5
τ_{skin} (sec)	9.3	4.9
HH(98pby2)	1.4	1.4
τ_E (sec)	0.7	0.36
Q	2	0.25

*FIRE/NSST Systems Code

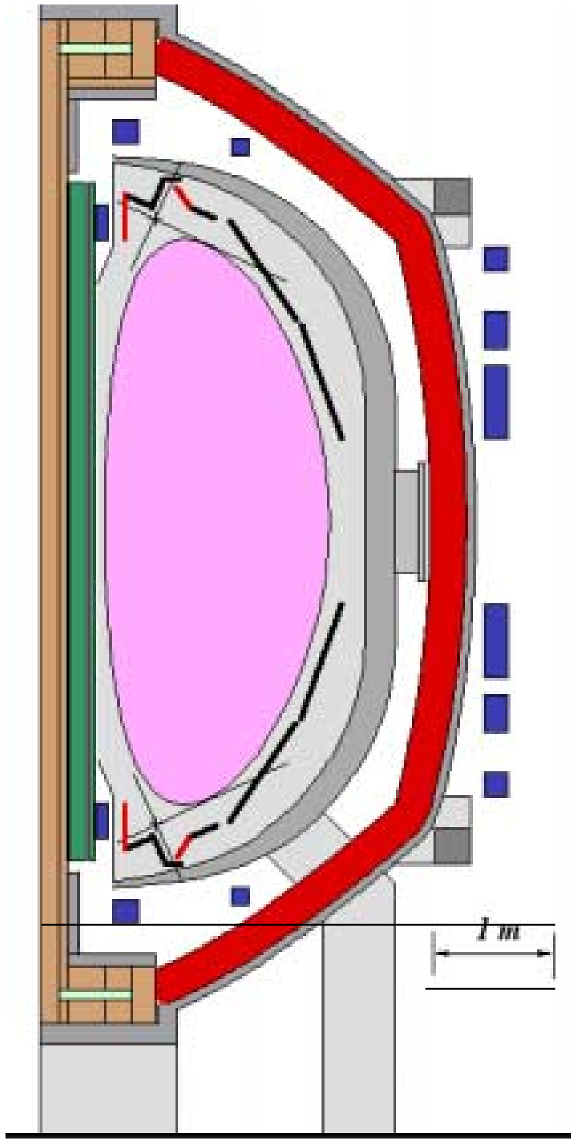
Shaping is Important for MHD Stability Limits in NSST





NSST Engineering Design

NSST



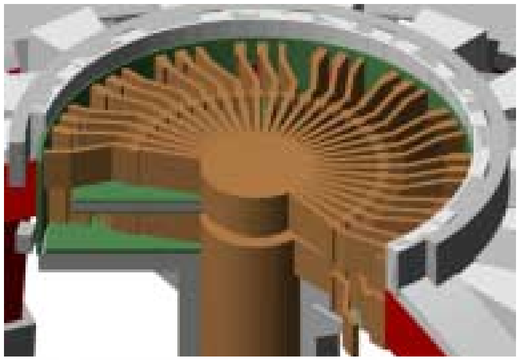
- **Flexibility/Maintainability**
  - -Demountable TF
  - -double wall VV provides shielding for DT
- **High performance**
  - -Liquid Nitrogen cooled coils
  - -Passive plates for advanced operations
- **Consistent with a TFTR-like Facility**
  - - 800MW, 4.5GJ MG system
  - - AC/DC converters, NBI & RF
  - - Test Cell
  - - cost effective, short construction time

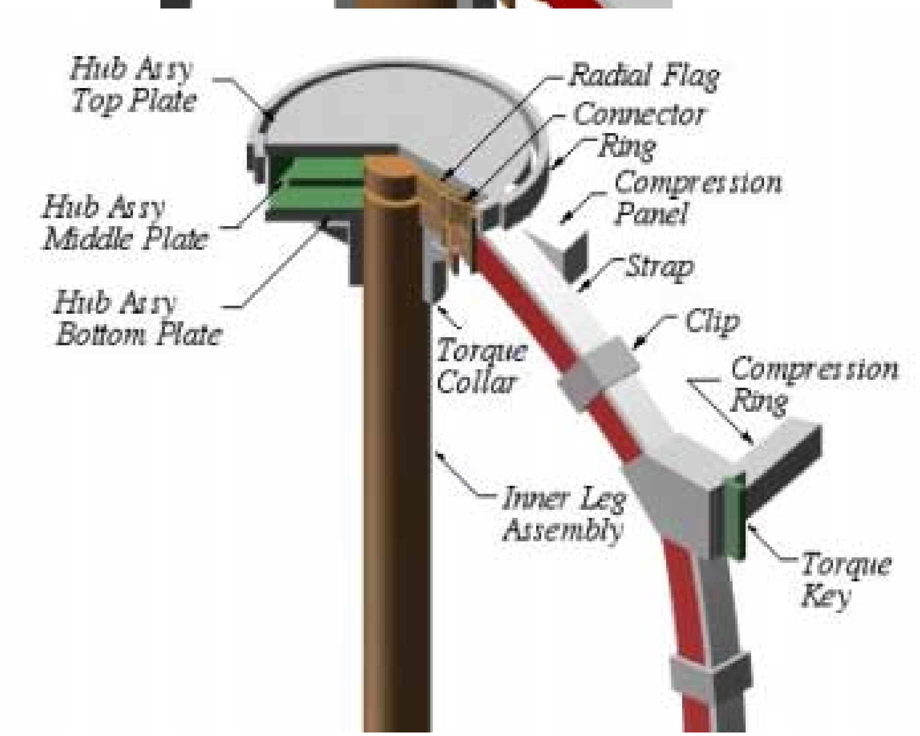
“NSTX-like” De-mountable TF Coil System

insures Device Flexibility while retaining High Performance

NSST

TF Joint View

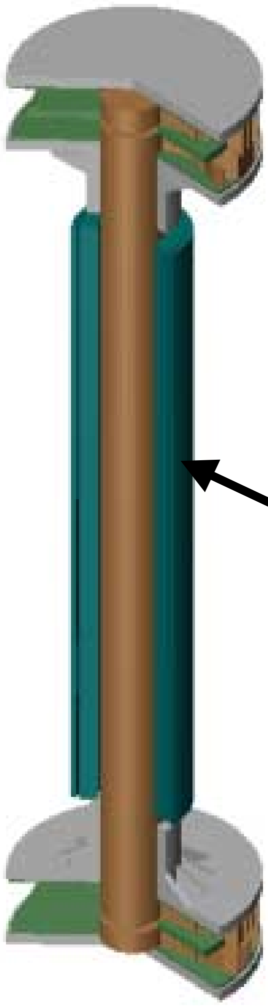




- **Structural support system**
  - -Torsional loads by OH reacted through torque collar, hub, and outer TF support
    - ✓96 standard turns
    - ✓ Removable joints
  - -Constant tension outer legs with compression rings & flexible straps
    - ✓allows inner leg thermal growth
    - ✓avoids sliding joints
- **New cyanate ester insulation**
  - -Higher shear strength and radiation resistance than standard epoxies
  - - Retains strength at elevated temperature (100 °C).

Two Layer OH Solenoid Gives Physics Flexibility
Enabling Both High Current and Long-Pulse Capability

NSST



• OH Half-Swing for long-pulse current sustainment research at 6 MA range in parallel with the non-ohmic start-up research.

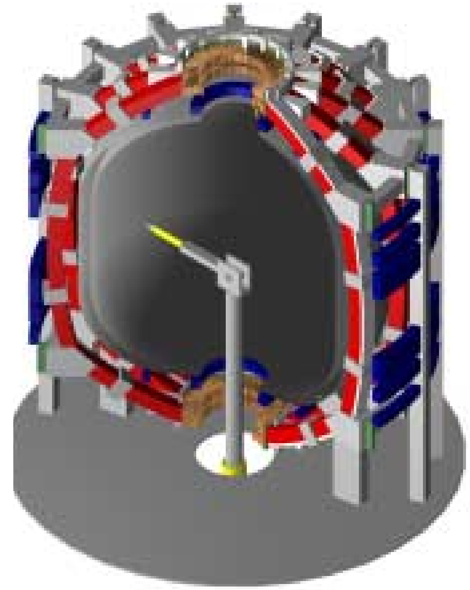
• OH Full-Swing for high performance operations up to 10 MA including α-physics.

•**Two layer winding giving 50 % more OH flux**
- Cu outer layer
  - ✓at thermal and hoop stress limit
- BeCu inner layer
  - ✓at hoop stress limit

Demountable TF Coils Facilitate Remote Handling

NSST

TFTR-like Test Cell would be a Possible Location

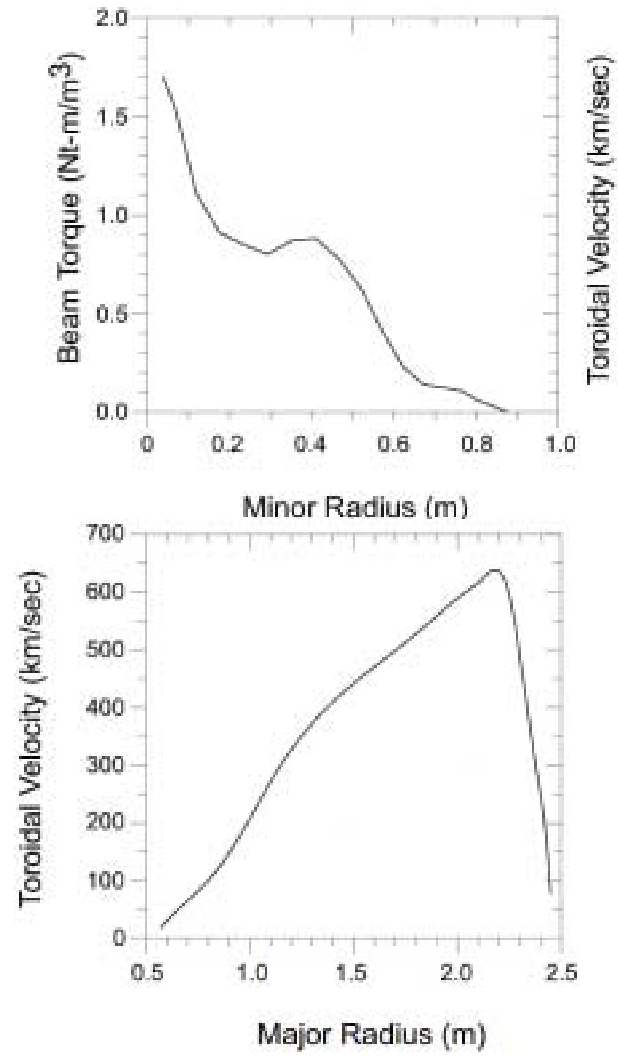


NSST Heating and CD Systems

NSST

- 30 MW NBI System
  (3 co- and 1 counter beams)
  - Heating and CD
  - Core fueling
  - Sheared flow for transport barriers
  - Toroidal rotation for wall stabilization
  - Plasma diagnositcs
- 10 MW ICRF / HHFW for Core Heating and CD
- 10 MW EBW as upgrade
- 5 MA CHI if shown feasible

High rotation (0.3 V_{Alf}) predicted by TRANSP



Multi-MA Coaxial Helicity Injection?!

NSST

- HIT-II to NSTX shows favorable scaling:

Machine	R (m)	a (m)	Bt0 (T)	Φ_T (mWb)	I-inj (kA)	V-inj (kV)	I-tor (kA)	I-Mult
HIT-II	0.3	0.2	0.5	50	30	0.5	200	4
NSTX	0.86	0.68	0.3	522	28	0.56	400	14
NSST	1.5	0.9	0.3	1,670	28	0.56	1,200?	42?
NSST	1.5	0.9	1.2	6,680	28	2.24	4,800!?	132?!

- Recent HIT-II result is very encourgaging.
- NSTX new absorber region upgrade should allow improved operations.

If sufficient understanding and predictive capability for 5 MA operations on NSST can be developed, CHI can be incorporated into the design.

Elimination of OH is essential for Compact CTF and ST Power Plant

NSST

- Several promising candidates at sub MA level:
  - Bootstrap over drive (JT60-U)
  - Poloidal field utilization (MAST, JT60-U)
  - RF/NBI CD (HHFW, EBW)
  - Coaxial Helicity Injection (NSTX, HIT-II)
- However, physics uncertainty makes the extension of these techniques to multi-MA level (as needed for CTF) <u>a great challenge!</u>

NSST with 50 sec pulse length is designed to be a good test bed for developing multi-MA non-OH plasma current start-up.

Unique α-physics Opportunities

($V_{Ti} \leq V_{Alfven} << V_{\alpha}$ at High β)

NSST

- 10 MA in NSST enables confined α-particles orbit.

- NSST non-dim. parameters are similar to CTF/ARIES ST.

	NSTX	NSST	CTF	ARIES-ST
ν^*	0.2	0.04	0.02	0.015
a/ρ_i	35	130	108	140
$\langle\beta_T\rangle$	0.35	0.4	0.2 - 0.4	0.5
V_{NBI}/V_{Alfven}	3	0.7		
V_{α}/V_{Alfven}		4.4	5.8	5

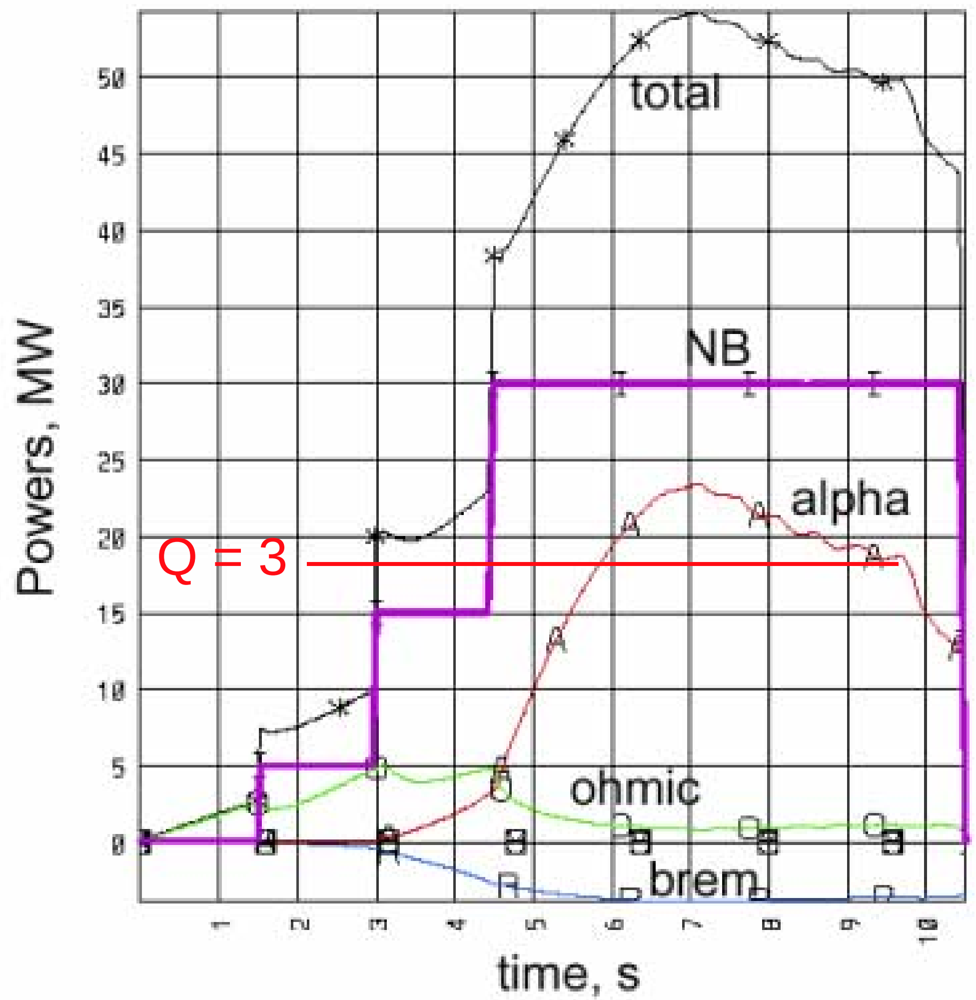
- α-driven instabilities could result in loss but also provide a channel for direct ion heating!

Moderate DT Site Capability Desirable.

TSC Simulation of NSST

NSST

- Ip=10 MA, Bt=2.6T
- R=1.52 m, a=0.94 m
- κ(X)=2.8, κ(95)=2.5, δ(X)=0.5, δ(95)=0.28
- li=0.6, βp=0.9, βN=3.5, β=15%, Wth=37 MJ
- n(0)=2.0×10^20 /m^3, n/nGr=0.5, T(0)=20 keV
- τE=0.8 s, H98(y,2)=1.3, Zeff=1.4
- P(NBI)=30 MW, P(alpha)=23 MW, Q(peak)=3.8
- I(NBI)=1.8 MA, I(BS)=3 MA
- Δψ(rampup)=18.2 V-s, Δψ(flattop)=1.0 V-s



NSST Can Contribute to Cost Effective Fusion Energy Development Path

Spherical Torus

- **NSST provides:**
  - Necessary physics (e.g., non-inductive current start-up and sustainment) basis for the ST-based compact CTF.
  - Test of advanced physics scenarios for CTF, DEMO and ST power plants.
  - Science of high beta plasmas including α-physics.

- **NSST engineering design provides flexibility to study physics.**
  - 5 - 10 MA to explore wide range of plasma parameters
  - Strong shaping, control, and stabilizing wall for advanced physics research
  - Sufficient (40 MW) of heating, CD, rotation, and sheared flow generation.
  - Sufficient pulse length (50 sec) to explore non-ohmic start-up and sustainment.
  - D-T capability to explore alpha physics at high beta.