Cost-Effective Spherical Torus Steps Toward Fusion Power

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on assignment from
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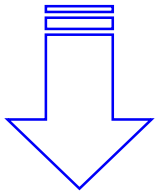
The Spherical Torus Innovation

- New DOE Facility and First Plasma
- Exciting New Science
- Cost-Effective Development

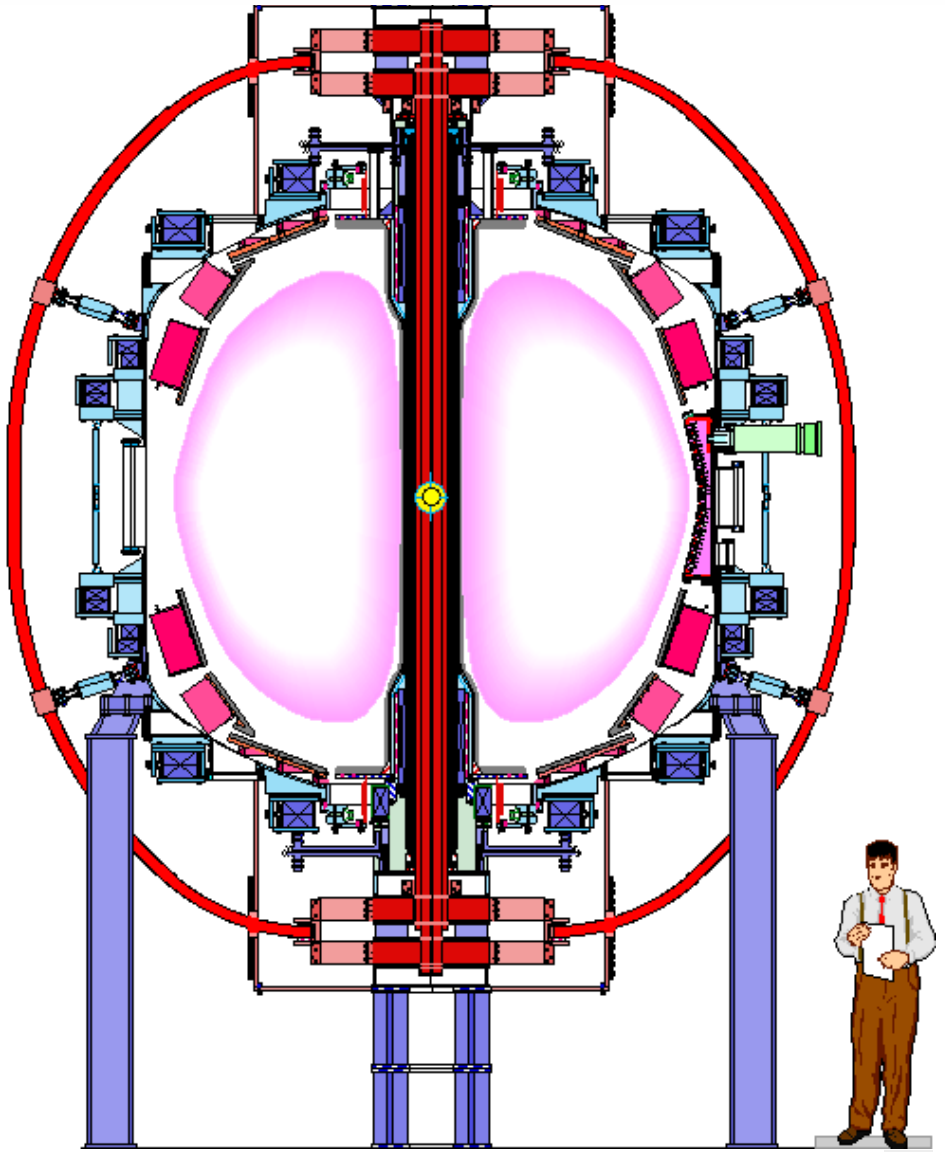


"better, faster, cheaper"

Potential Attractive Fusion Energy

A World-Class Innovative Fusion Experiment

NSTX



Baseline Parameters

- Major radius
  ≤ 85 cm
- Minor radius
  ≤ 68 cm
- Plasma current
  1 MA
- Toroidal field
  0.3–0.6 T
- Heating and current drive
  6–11 MW
- Flat-top time
  5–1.6 s

Joint Project of: Columbia University ORNL PPPL Princeton Plasma Physics Laboratory UW


Toroidal Coil ASSEMBLY
Dec. 10, '99
Ready to Test First Plasma
Feb. 12, '99

DOE Assembled Excellent National Research Team from 14 Institutions

Columbia University

Fusion Physics & Technology, Inc.

General Atomics

Johns Hopkins University

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

Massachusetts Institute of Technology

Oak Ridge National Laboratory

Princeton Plasma Physics Laboratory

Sandia National Laboratory

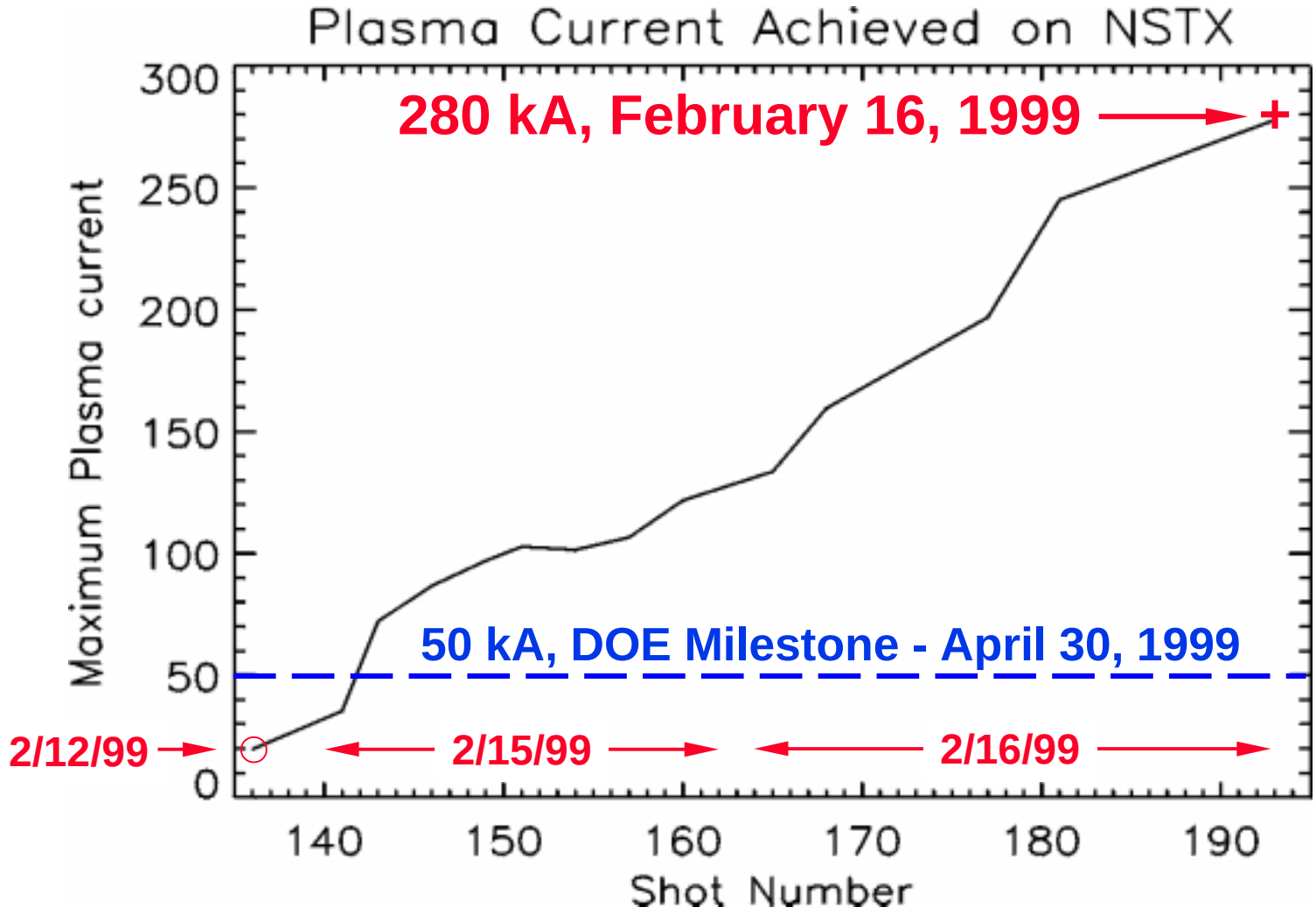
University of California at Davis

University of California at Los Angeles

University of California at San Diego

University of Washington

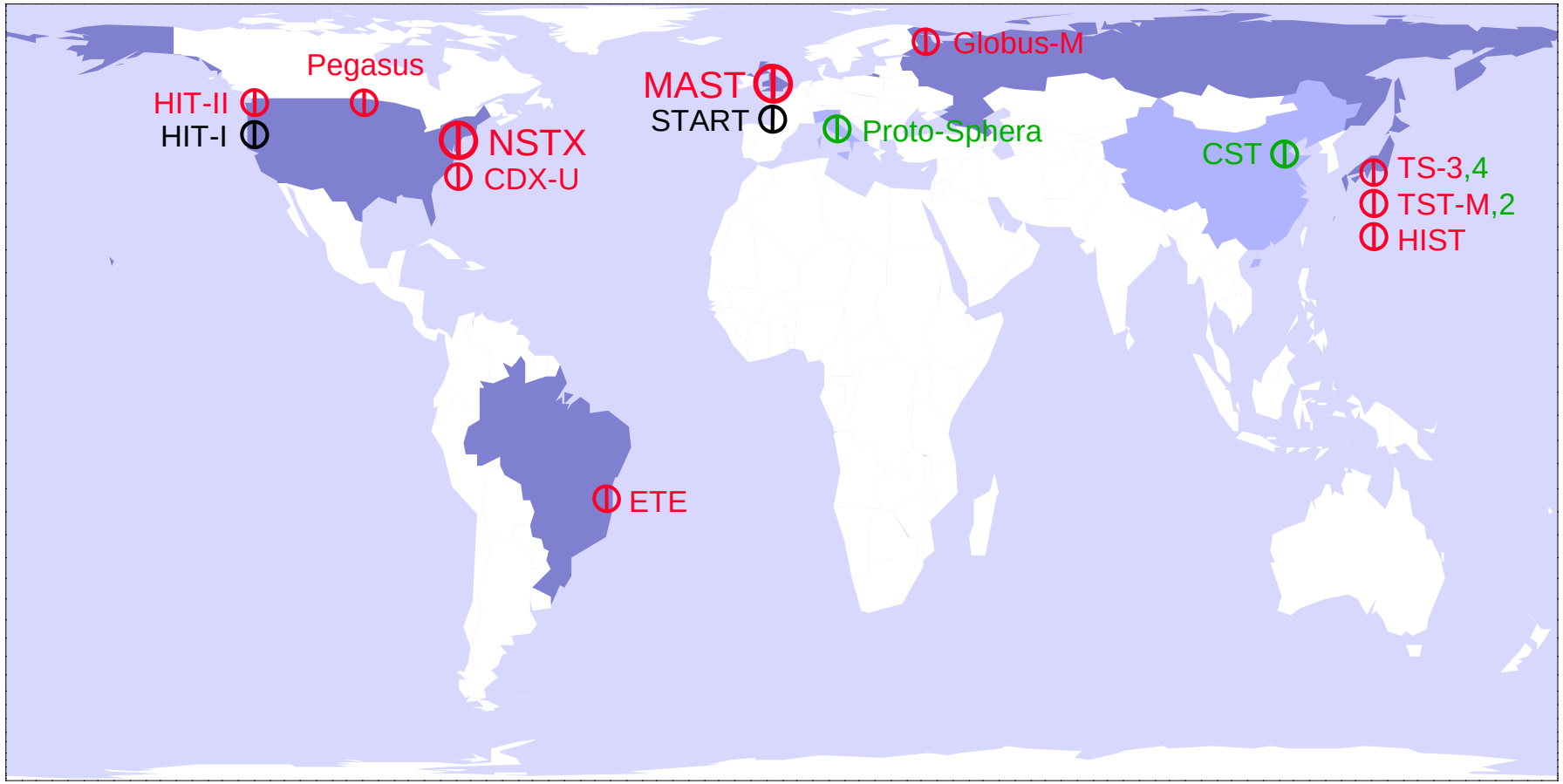
NSTX Exceeded DOE Milestone 10 Weeks Ahead of Schedule



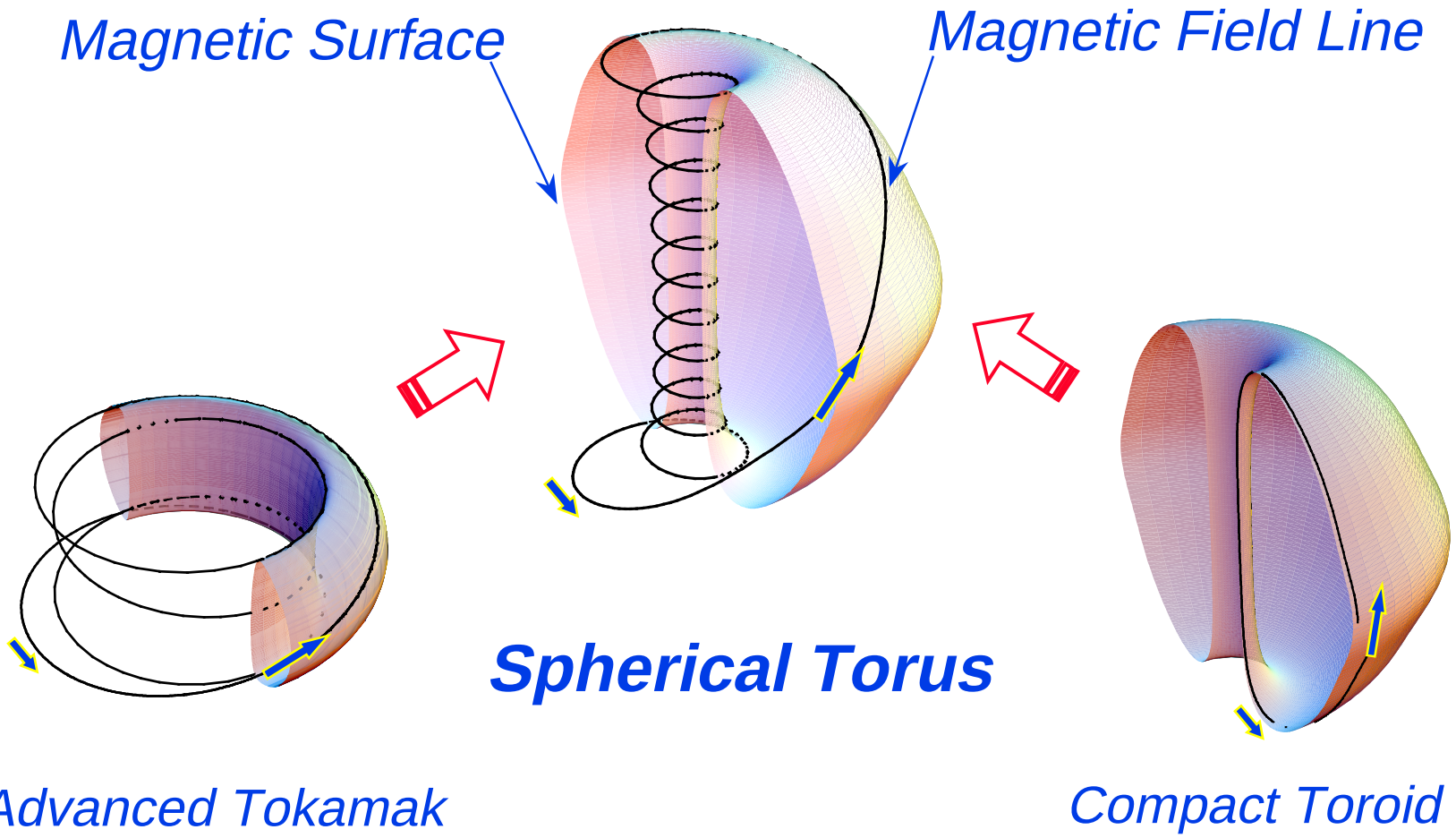
World Spherical Torus Experiments and Collaboration Have Grown Rapidly Since 1990

WORLD

Proof of Principle Concept Exploration Planned Shutdown



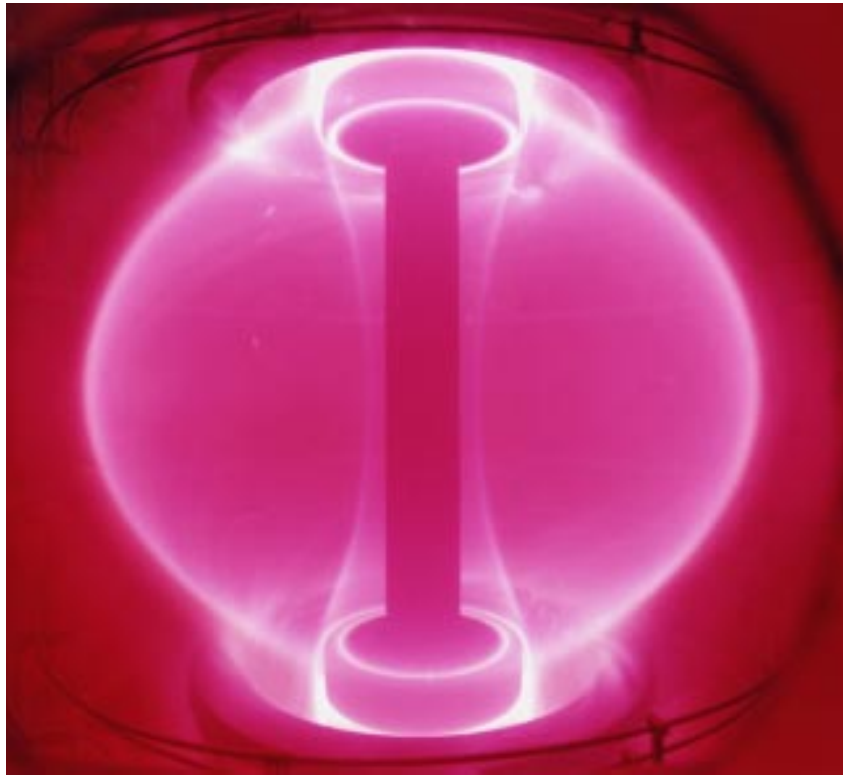
Spherical Torus Magnetic Configuration Builds on Tokamak and Compact Toroid Knowledge



Concept Exploration in U.K. Reached New Record (~40%) in Average Toroidal β_t (1/98)

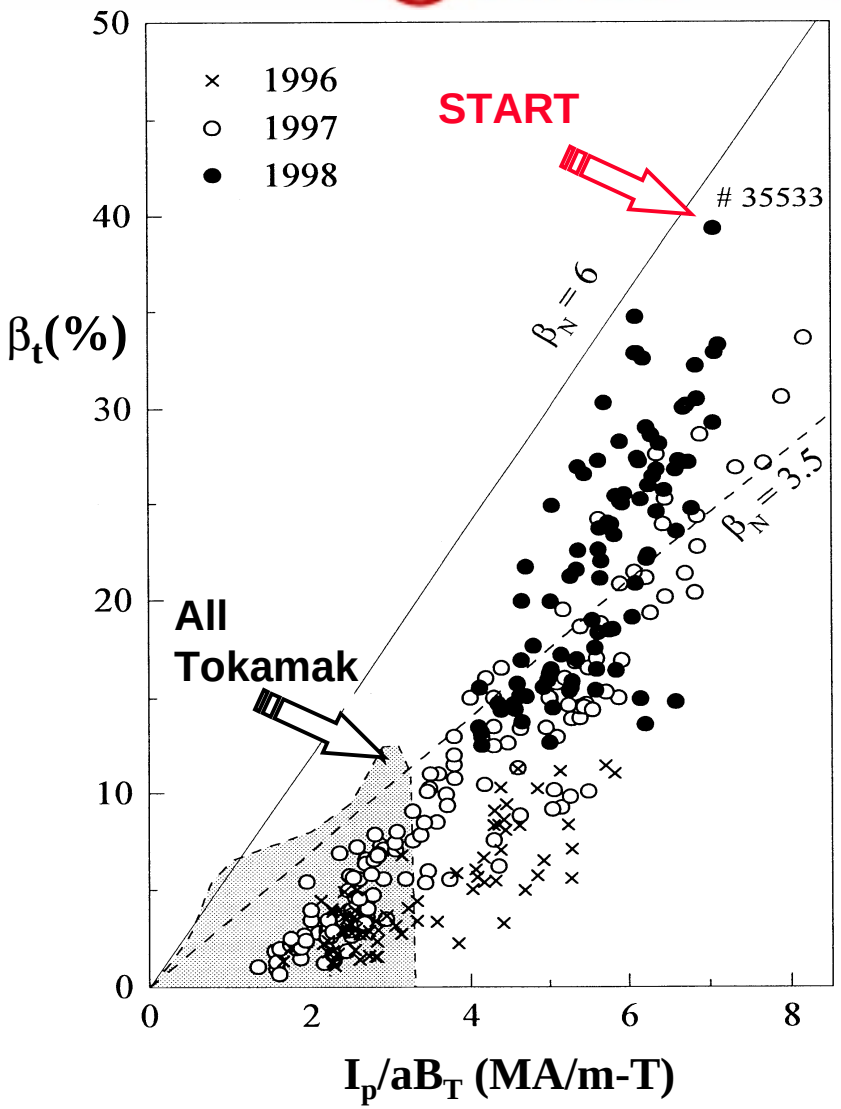
START

(Courtesy of START Team, U.K.)



1 m

- ***ORNL Beam*** *~ 0.4 – 0.7 MW*
- *Central β ~ 100%*
- *~1/3 of NSTX Plasma Size*



Spherical Torus Promises Exciting Fusion Science towards Practical Energy

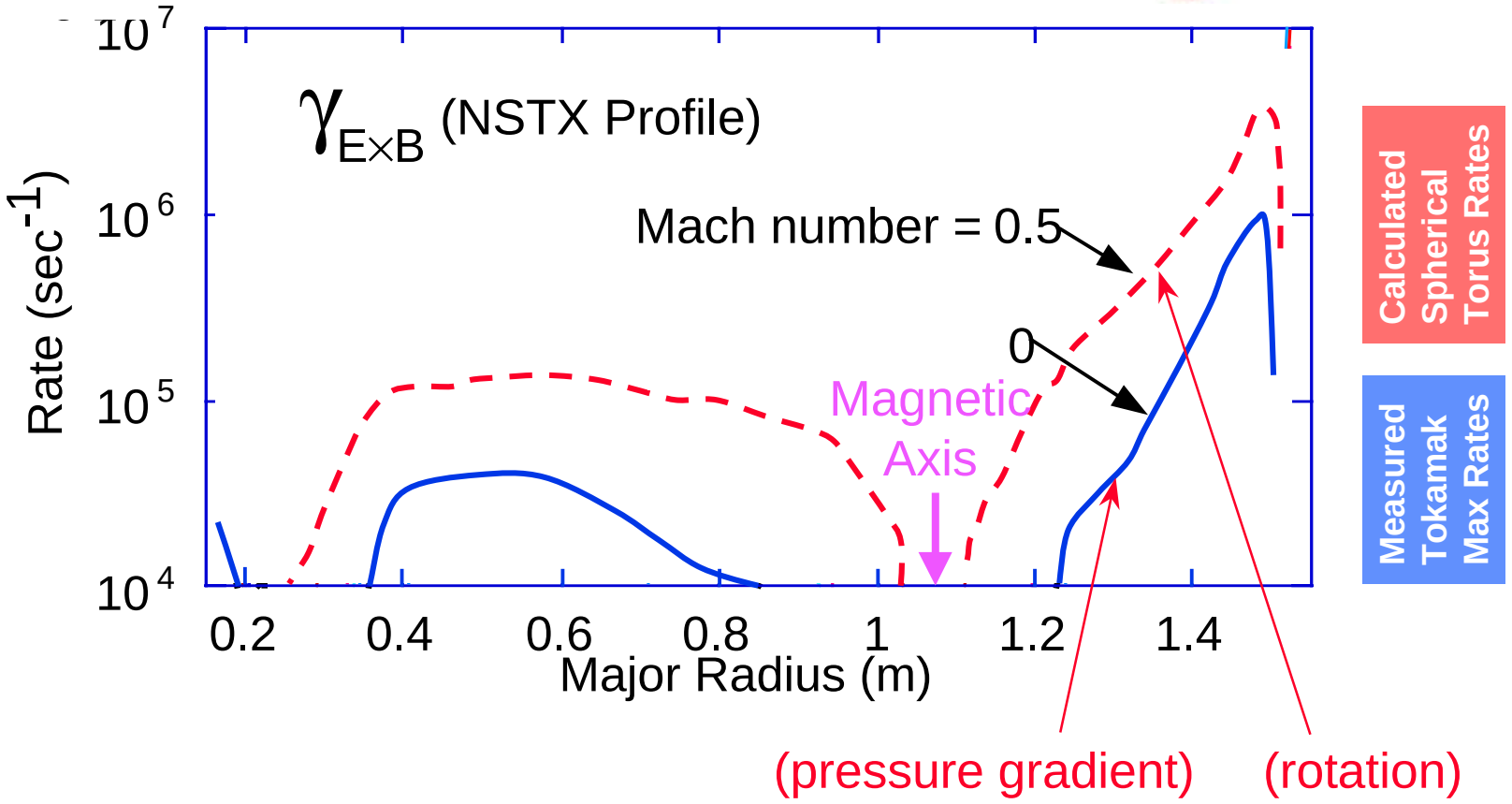
SCIENCE → ***POWER PLANT***

- New Startup Techniques → Simplified Magnets
- Order-Unity Beta → Low Device Cost
- Turbulence Suppression → Small Unit Size
- Self-Sustaining Current → Lowered Operating Cost

NSTX Research Program Aims to Test Scientific Principles for Attractive Fusion Core

- **New Startup Technique**: Coaxial Helicity Injection utilizes the mechanisms of magnetic reconnection, which is observed to be important in solar corona and geospace solar wind
- **Order-Unity Beta**: Stability of high-temperature, collisionless plasmas with such high betas is to be explored for the first time in large magnetic fusion energy experiment
- **Turbulence Suppression**: Key mechanism, so far observed in Tokamaks for Improved plasma confinement, is likely to be enhanced in ST by ~10 times $\rightarrow$ new physics
- **Self-Sustaining Current**: Magnetized "thermo-electricity" has been observed in Tokamaks; theoretically this can be extended in ST towards 100% with perfect profile alignment

Very High Flow Shear is Calculated in NSTX, Likely Suppressing Turbulence (Synakowski)



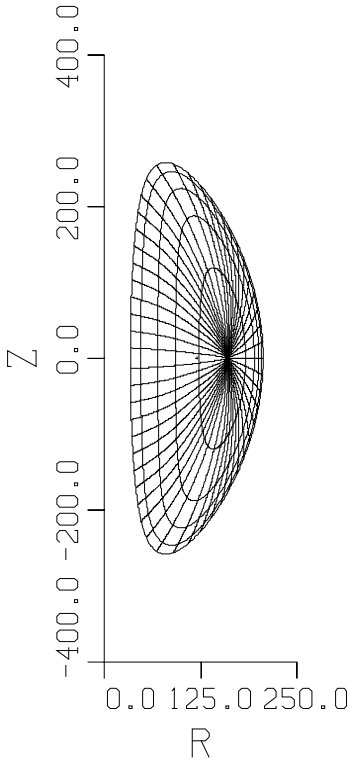
$$\gamma_{E\times B} = (RB_\theta/B)\,\partial(E_r/RB_\theta)/\partial R \approx (RB_\theta/B)\,[d(\nabla p/nZ_eRB_\theta)/dR + d(V_\Phi/R)/dR]$$

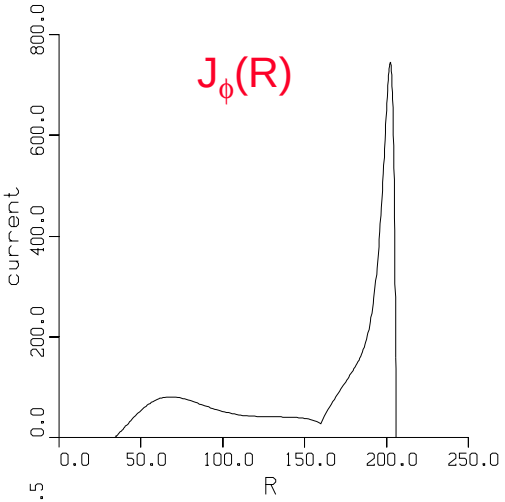
TFTR, DIII-D, JET, JT-60U, etc. observed improved confinement via sheared flow

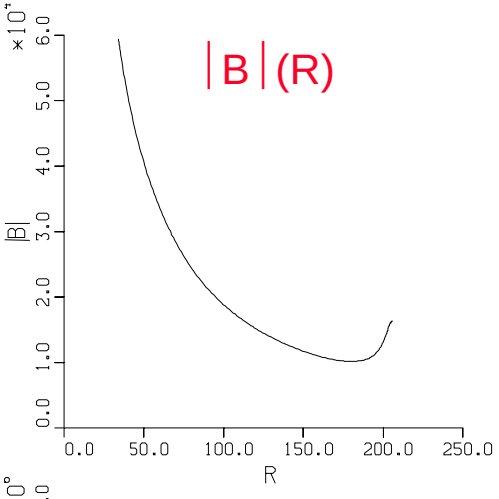
Pressure-Driven, Fully Aligned Self-Sustaining Currents Are Calculated at High Stable β (Shaing)

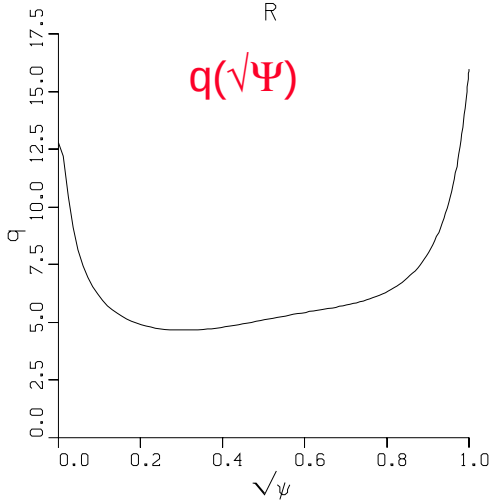
DTST

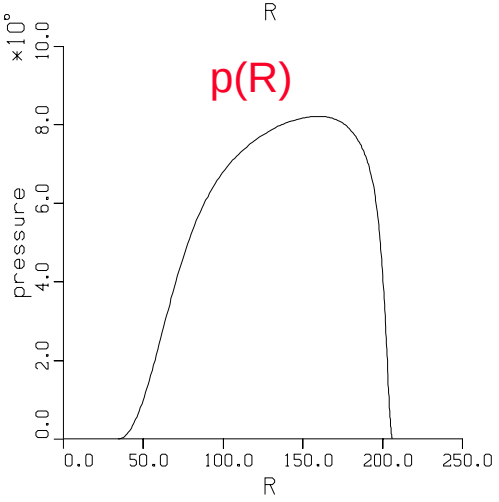
I_p = 8.6 MA ; $\ell_i(3)$ = 0.16;
β_N = 8.5; β_T = 51%;
Ballooning stable





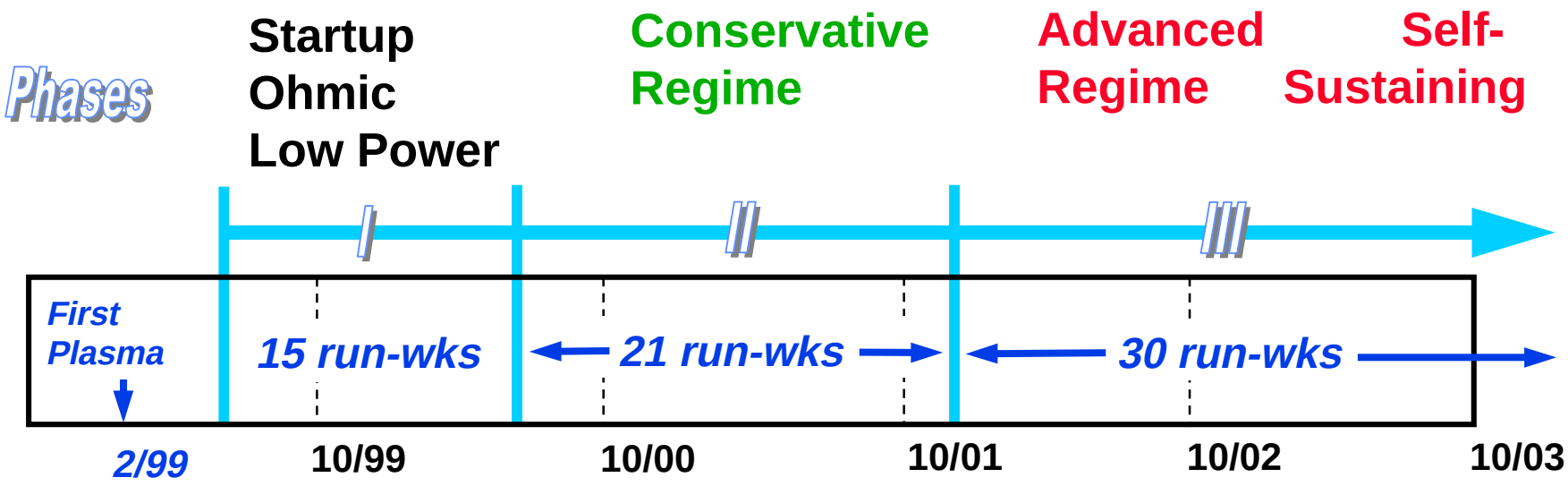






TFTR, DIII-D, JET, JT-60U, etc. observed significant bootstrap current

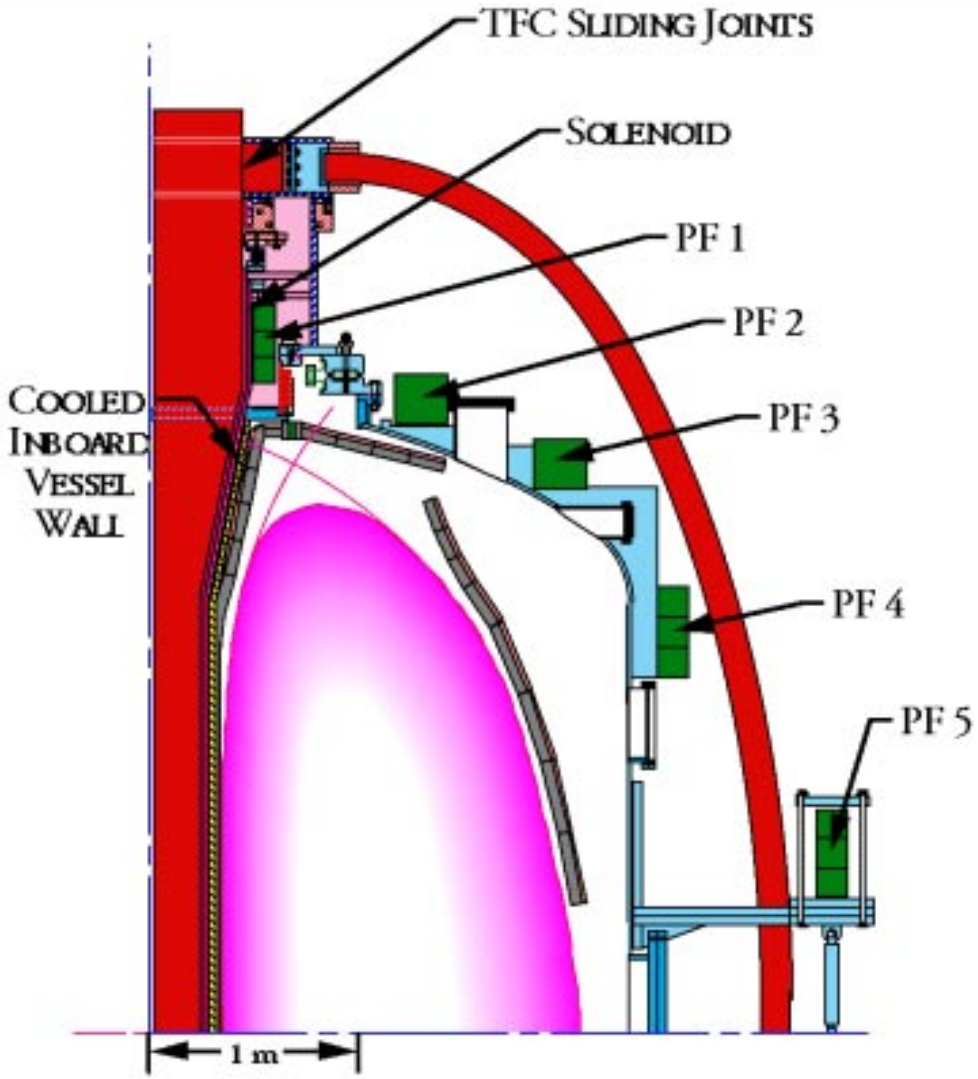
We Envision Three Phases of Proof of Principle Research for the Initial Five Years



Goals / Tools	Startup Ohmic Low Power	Conservative Regime	Advanced Regime	Self-Sustaining
	Drive → 4 MW	→ 11 MW	~ 11 MW	
	Startup → 0.2 MA	→ 0.5 MA	→ 1 MA	
		β_T → 25%	→ 40%	→ 54%
		Self-current → 40%	→ 70%	→ 90%
	Measure: $T_e(r)$, $n_e(r)$	$J(r)$, $T_i(r)$	**Turbulence**	

Small Performance Extension Device Concept Draws From the NSTX and MAST Experience

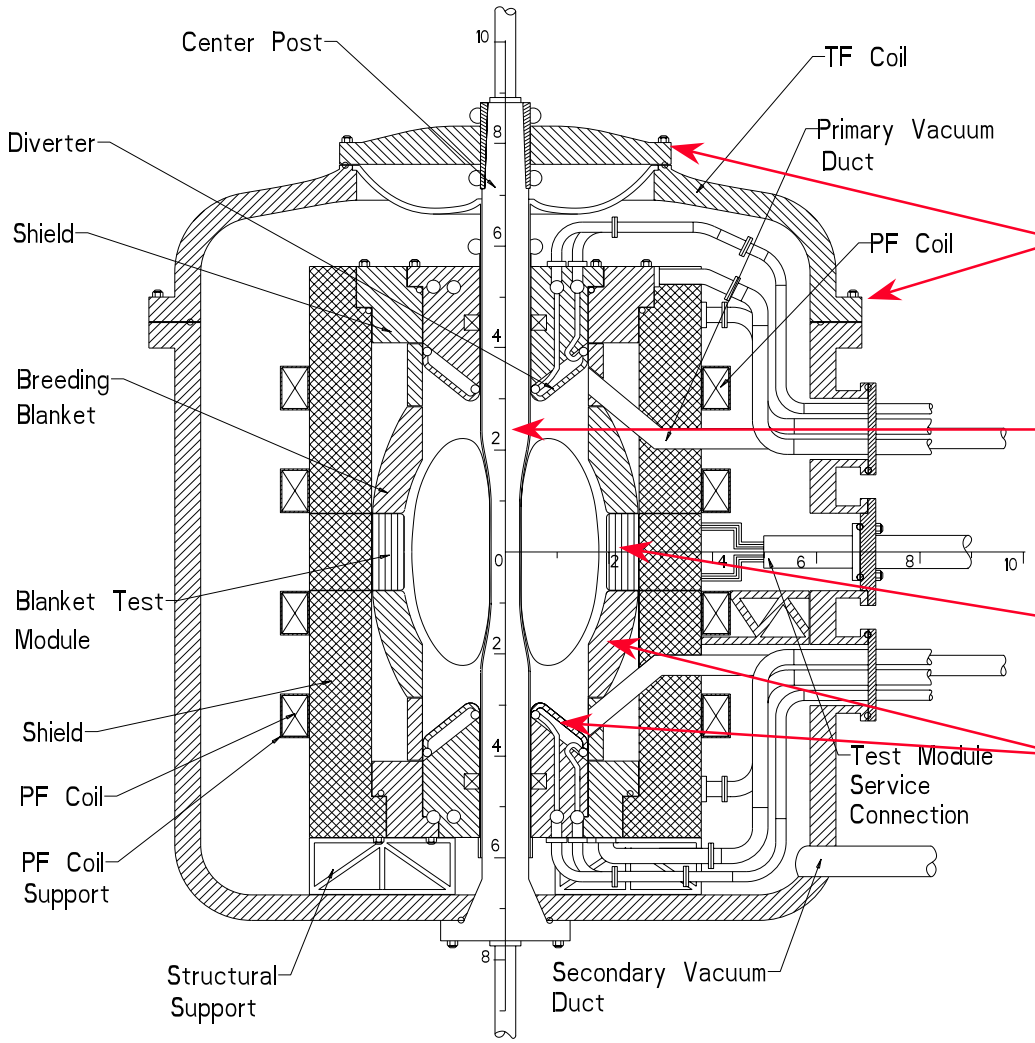
DTST



Initial Features

- **Target plasma:** ~1 MA via solenoid, CHI, and/or ECH
- **Pulse Length:** time for slow noninductive current ramp up
- **TFC Center Leg:** multiple-turns to use existing supplies
- **Tiles:** tungsten to avoid Tritium hold-up
- **NBI Energy:** existing ~100 kV D^0
- **RF Frequency:** existing ~60-80 MHz
- **PF Coil Arrangement for κ ~3:** similar to ST power core

ST Could Enable a Small Energy Technology Device, such as Volume Neutron Source (VNS)



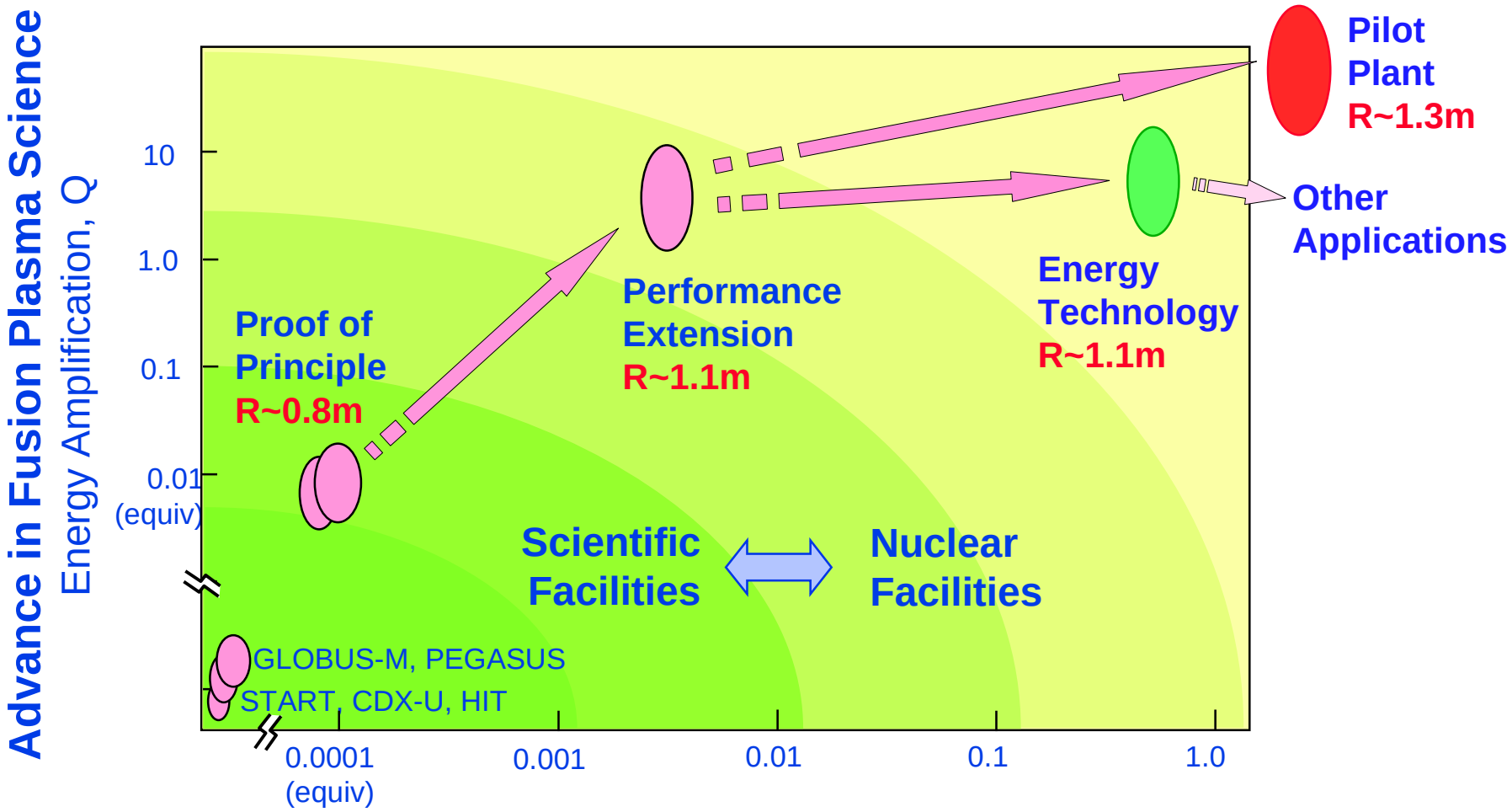
VNS

Features

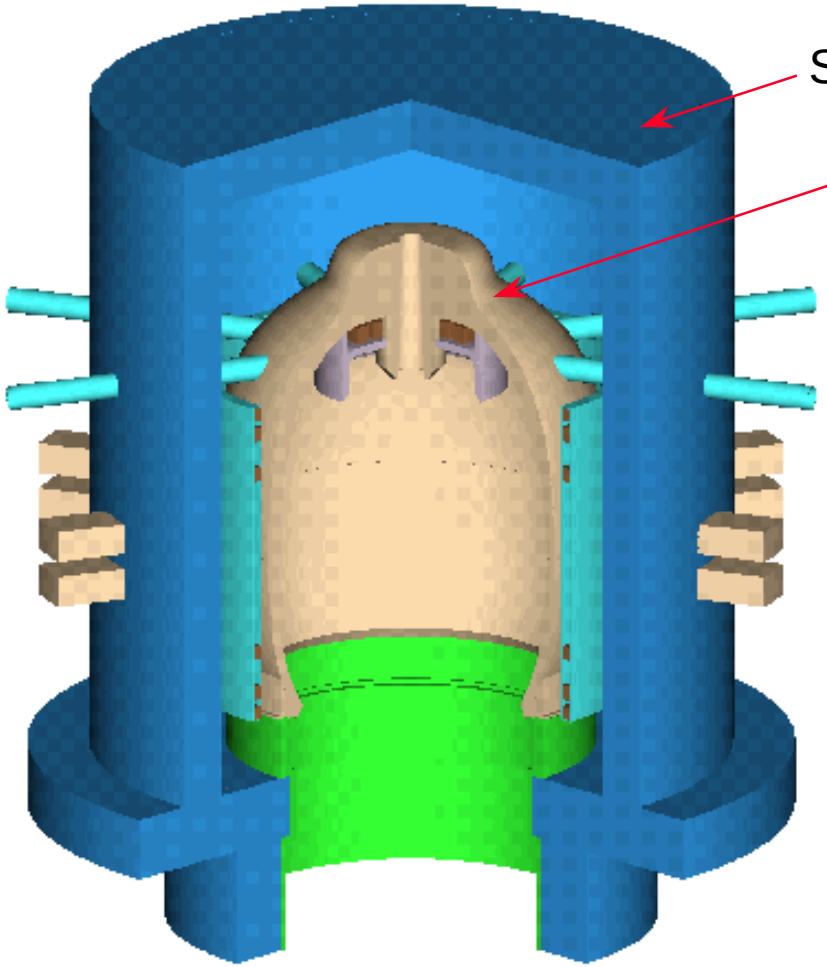
- **Remote maintenance** for activated first-wall, divertor, blankets
- **Demountable single-turn** toroidal field magnet center leg
- **Full access** to test blanket modules
- **Modular** design

ST Offers Cost-Effective Steps for Developing Fusion Plasma Science and Energy Technology

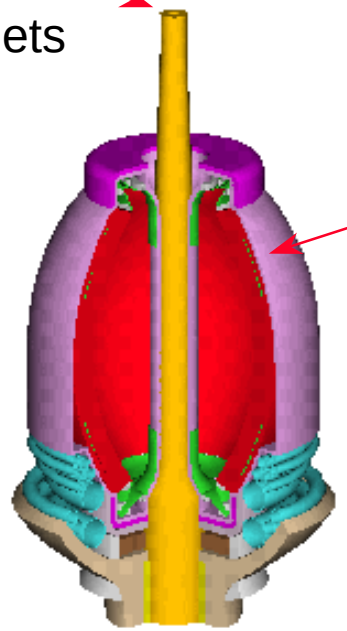
Roadmap



Highly Modular Designs Are Envisioned for Future Spherical Torus Power Plant (UCSD)



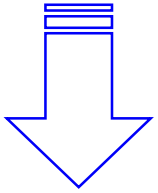
Fixed Components



Replaceable Components

Spherical Torus Fusion Research Is Exciting, Timely, and Affordable

- New NSTX Has Achieved First Plasma
- Exciting New Fusion Energy Science Will Be Explored
- Cost-Effective Development Path Has Been Identified



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