National Spherical Torus Experiment at the Cutting Edge of Fusion Plasma Science Research

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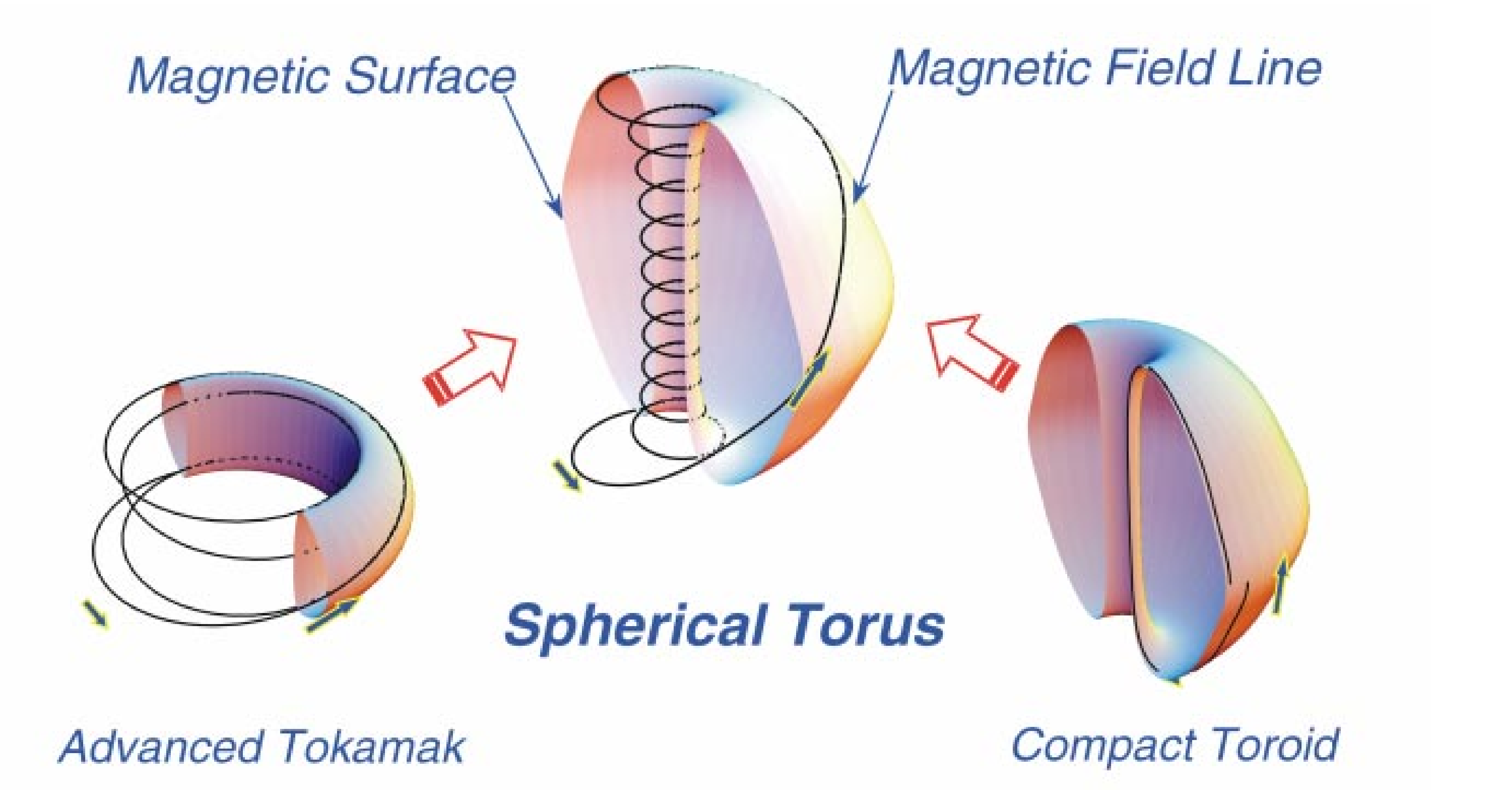
Princeton Plasma Physics Laboratory

NSTX at the Cutting Edge of Fusion Plasma Sciences Research

- What is a Spherical Torus?
- Status
- Science Goals
- Development Path

Spherical Torus Magnetic Configuration Combines Tokamak and Compact Toroid Strengths

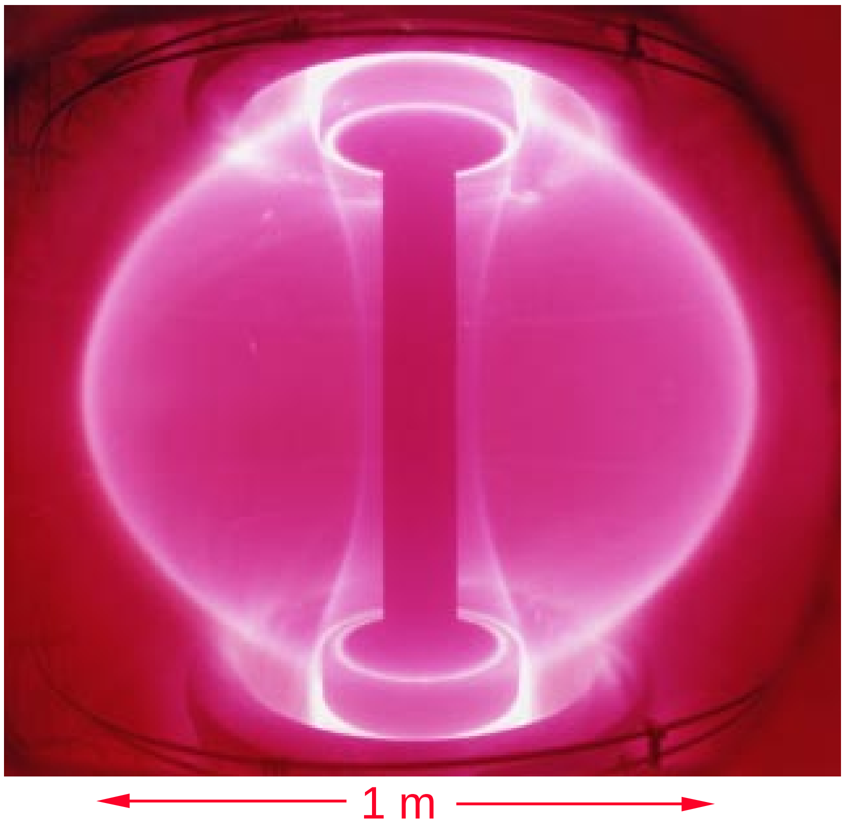
NSTX

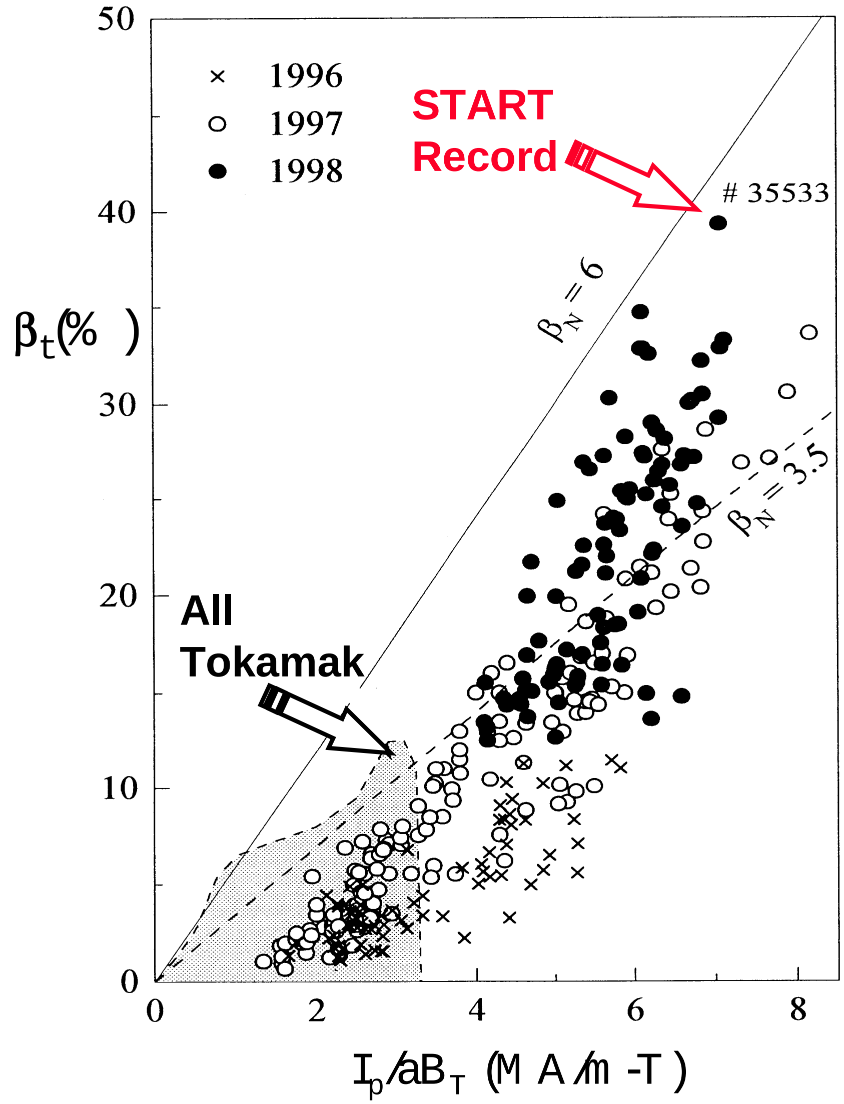


Concept Exploration Experiments Confirm Promise of ST Stability and Confinement

START

(Courtesy of START Team, U.K.)





- *Average toroidal $\beta_T \rightarrow 40\%$ ($\langle\beta\rangle \rightarrow 15\%$)*
- *Good confinement*
- *~1/3 of NSTX Plasma Size*

NSTX Responded Vigorously and Successfully to 1996 FESAC Recommendations

NSTX

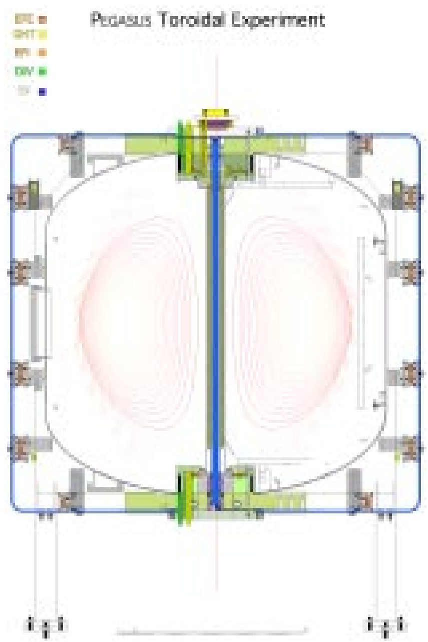
1996 | 1997 | 1998 | 1999 | 2000

- **Phase-I runs begin (8/99)**
- **First plasma (2/99)**

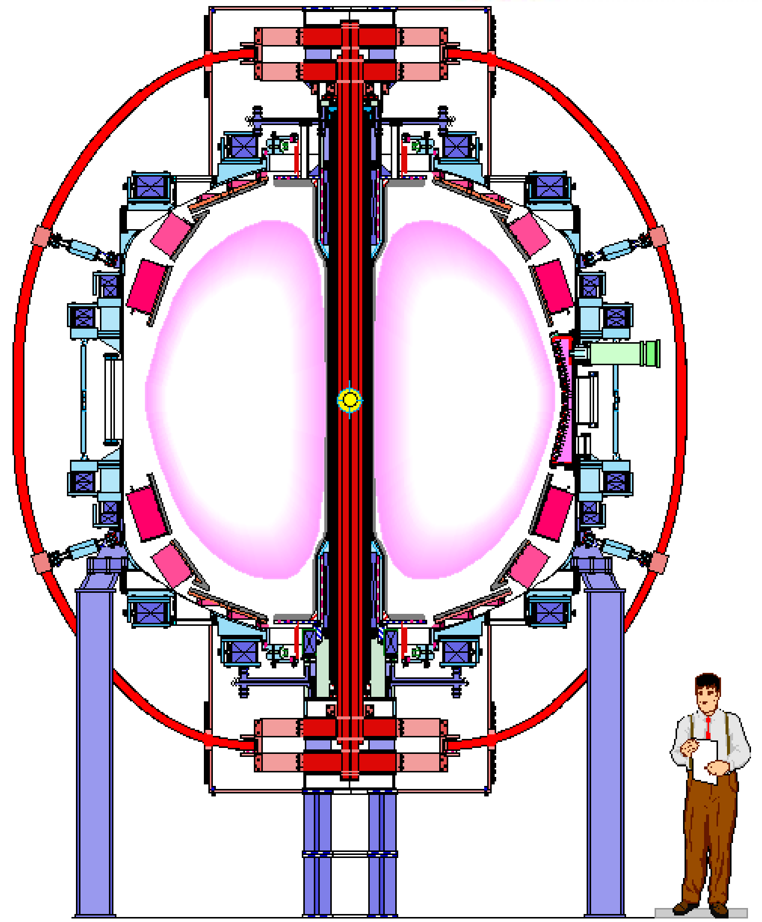
- **Pump down**
- National Research Team formed
- Assembly begins
- Research Forum

- **Test Cell cleared**
- Research Forum
- NSTX Project begins
- **FESAC endorses ST PoP**

New U.S. ST Experiments - Affordable Attractive Steps for Concept Exploration and Proof of Principle



PEGASUS

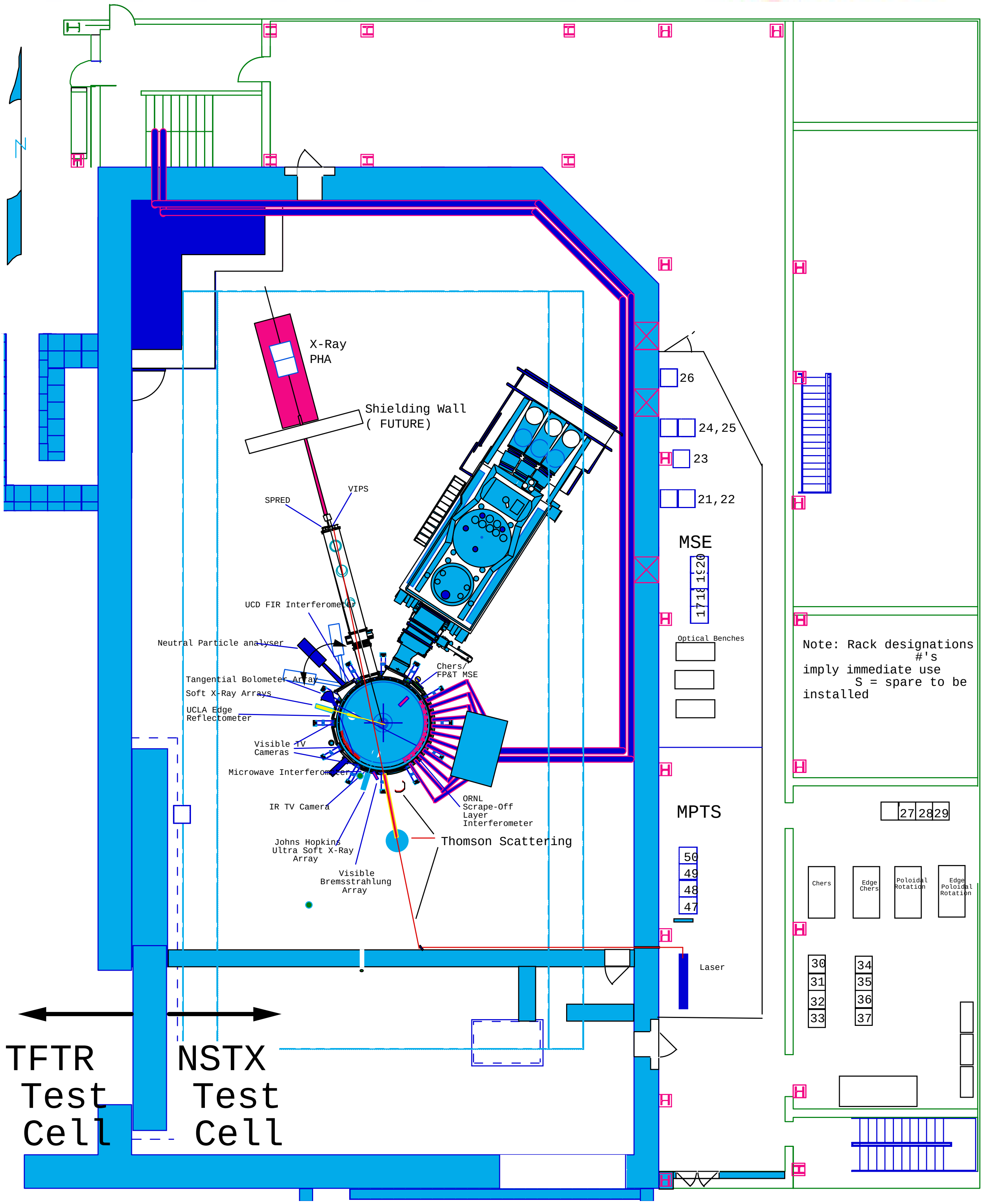


NSTX

Concept Exploration
of extreme low aspect ratio, R/a → 1.1; connections with spheromaks and FRC

Proof of Principle
testing β-limits, confinement, startup, sustainment

NSTX Test Cell Arrangement

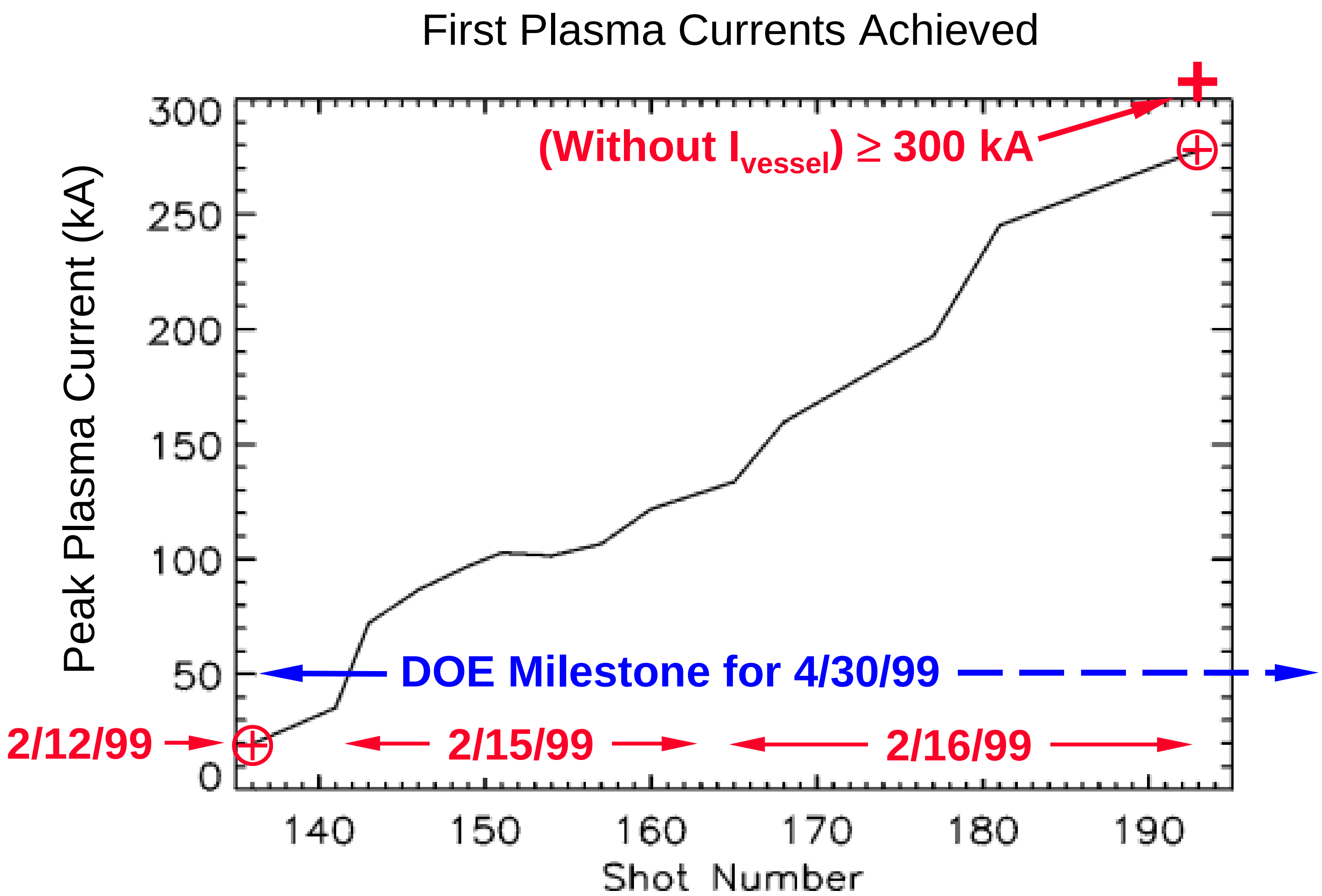


ıe platform

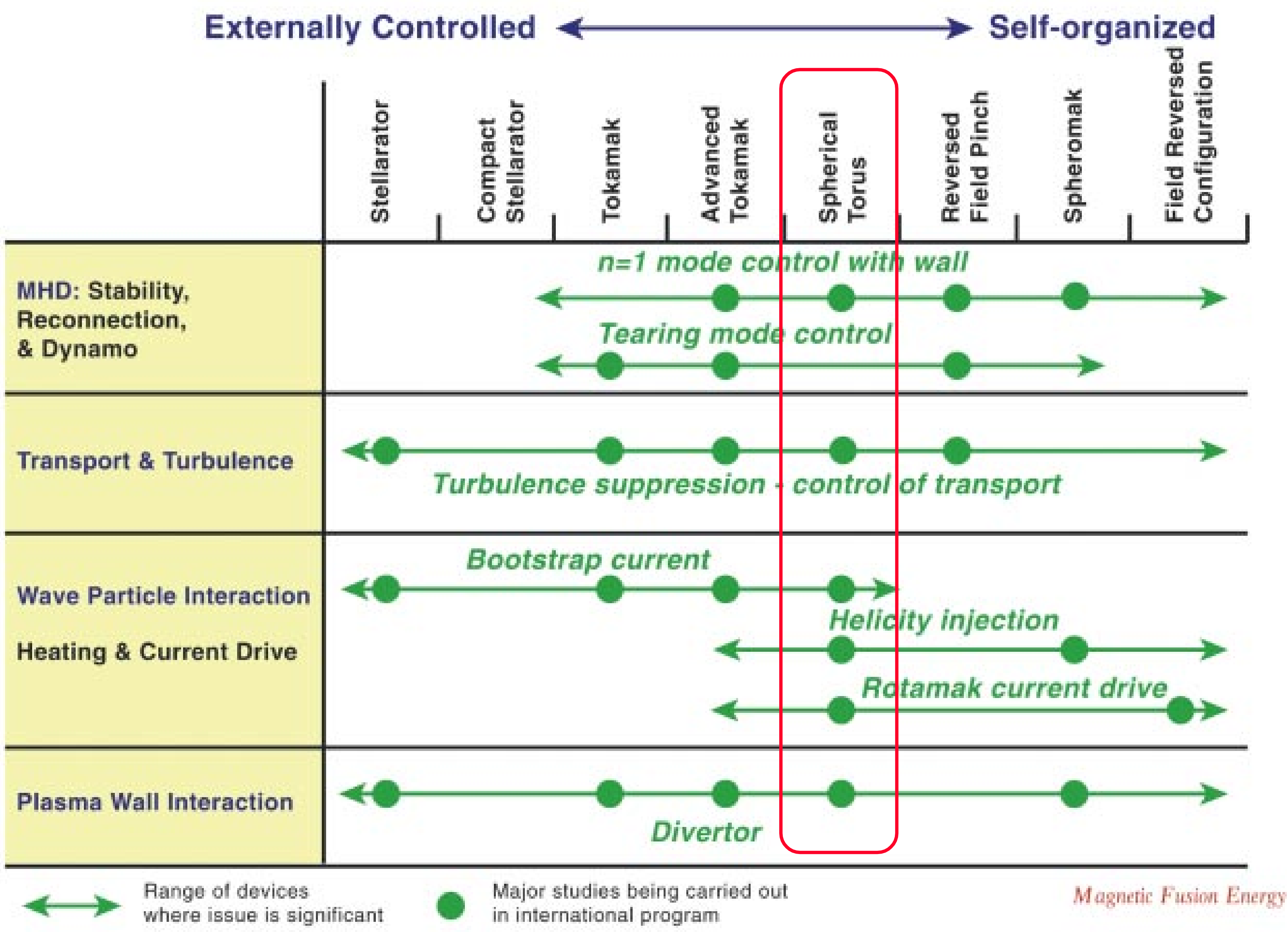
DOE Assembled Excellent National Research Team with Broad Expertise

Institution	Lead Researchers	Research Topics
Columbia	Steve Sabbagh	MHD Studies
FP&T	Fred Levinton	MSE (Collisional)
GA	Mike Schaffer	CHI Equilibrium Reconstruction
	Bob Pinsker	RF Physics
	John Ferron	Plasma Control
JH U	Dan Stutman	Ultra-Soft X-Ray Tomography
LANL	Glenn Wurden	Fast Imaging
LLNL	Steve Allen	Edge, SOL Modeling
MIT	Abe Bers	ECH-EBW Modeling
	Paul Bonoli	ICRF Modeling
ORNL	Dave Swain	RF Experiment, etc.
	Rajesh Maingi	Edge Experiment
	Wayne Houlberg	Transport Simulation
PPPL	Mike Bell, Stan Kaye, etc.	Six Science Categories
SNL	Richard Nygren	Plasma Facing Material
UC Davis	Neville Luhmann	Tangential FIR Interferometer
UCLA	Tony Peebles	Reflectometry
UCSD	T.K. Mau	HHFW Modeling
U Wash	Roger Raman	Coaxial Helicity Injection

NSTX Surpassed First Plasma Milestone 10 Weeks Ahead of Schedule



Spherical Torus and Other Magnetic Configurations Are Mutually Beneficial



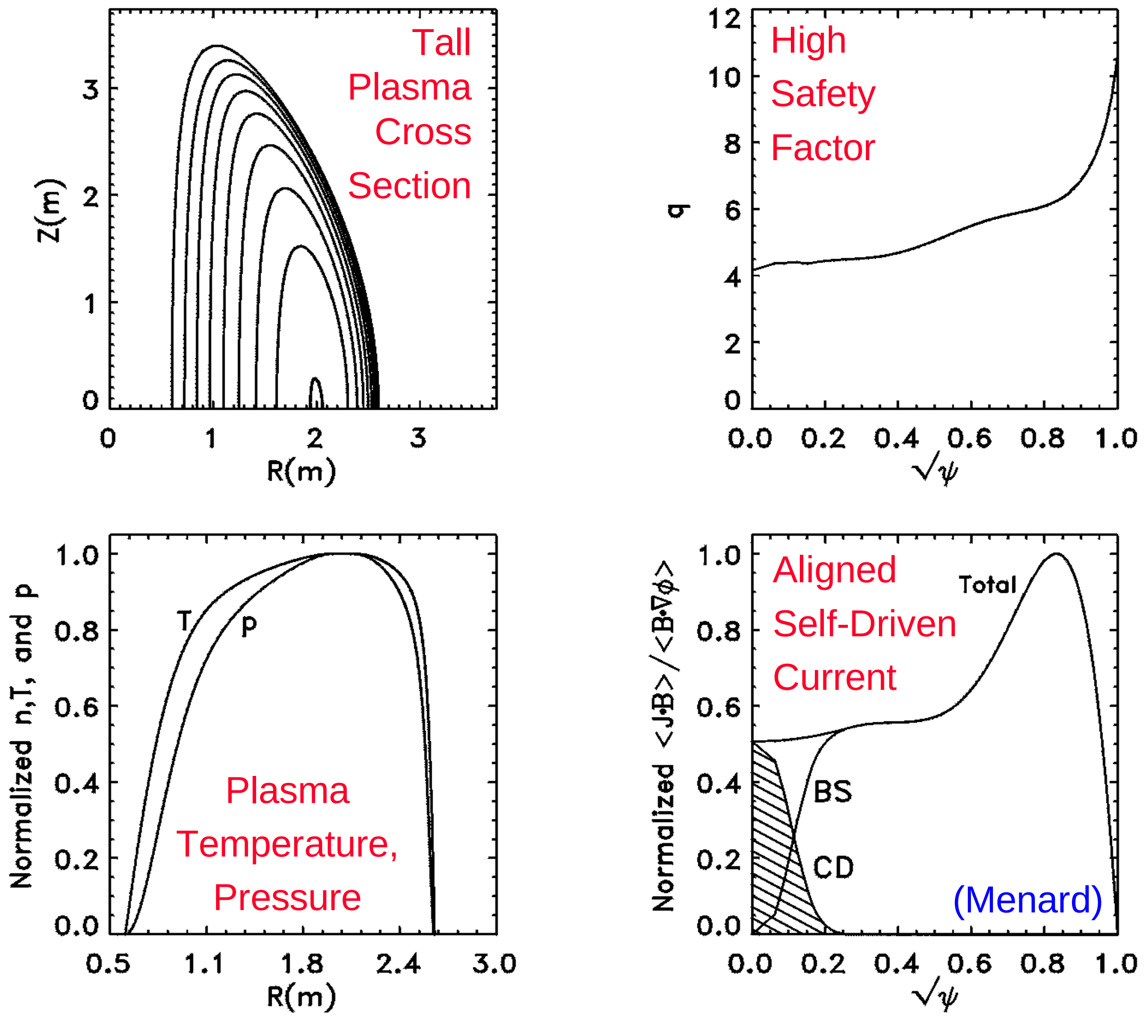
Spherical Torus Will Investigate Exciting ST Scientific Issues for Practical Fusion Energy

ST Science	→	***Fusion Energy***
Order-Unity Stable Beta-Toroidal	→	Low Device Cost
Turbulence Transport Suppression	→	Small Unit Size
Helicity Startup, Self-Sustaining Current	→	Simplified Magnets
Plasma Exhaust Dispersion	→	Reduced Wall Heat Flux

⇒ ***Also Affordable Development Steps***

ARIES Team Identified Key Issues for ST to Sustain Very High Stable Beta

$\kappa = 3.4$, $\beta_N = 8.2$, $\beta_T = 56\%$, $\langle\beta\rangle = 42\%$, $f_{Bootstrap} = 99\%$

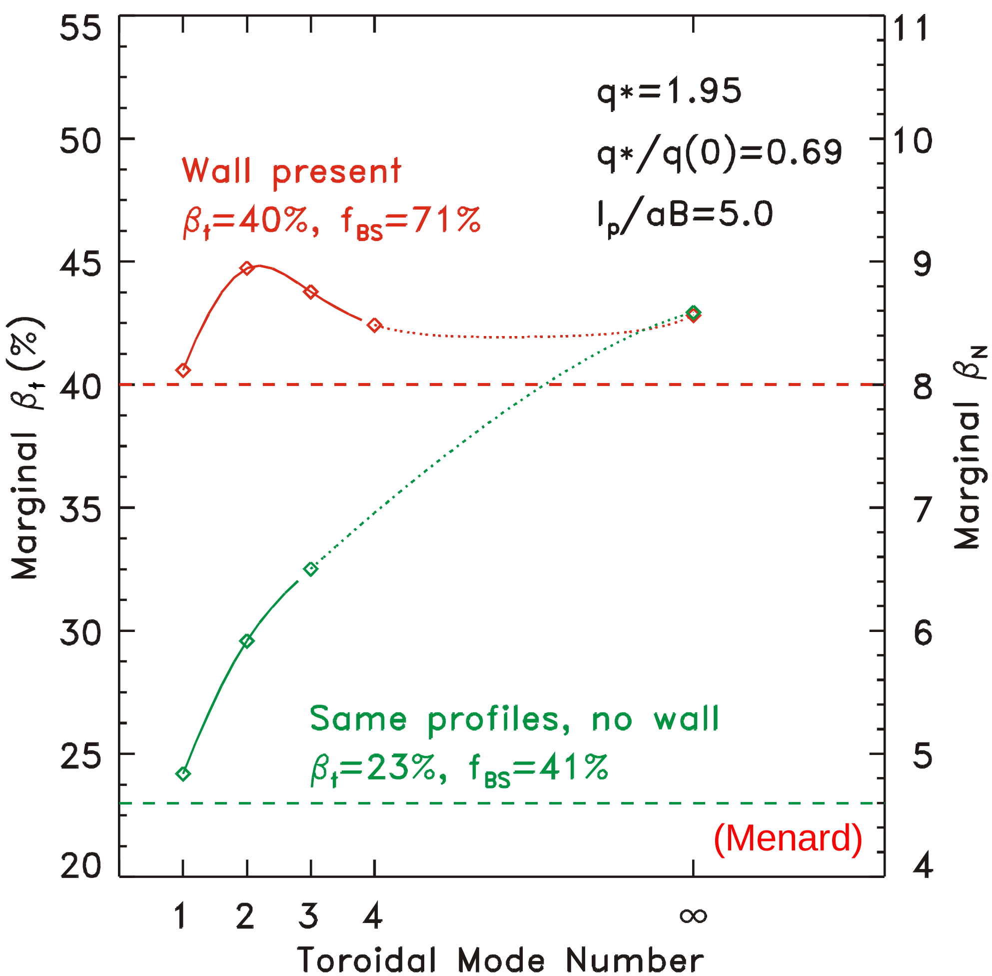


Key Issues

- Vertical stability
- Low-n kink stability
- Resistive Wall Mode stability
- Neoclassical tearing mode stability
- Bootstrap current alignment

NSTX Will Investigate No-Wall and Wall-Stabilized MHD Beta Limits for $\kappa \sim 2$

$\kappa = 2.0$, $\beta_T = 23–40\%$, $\beta_N = 4.5–8$, $f_{Bootstrap} = 41–71\%$

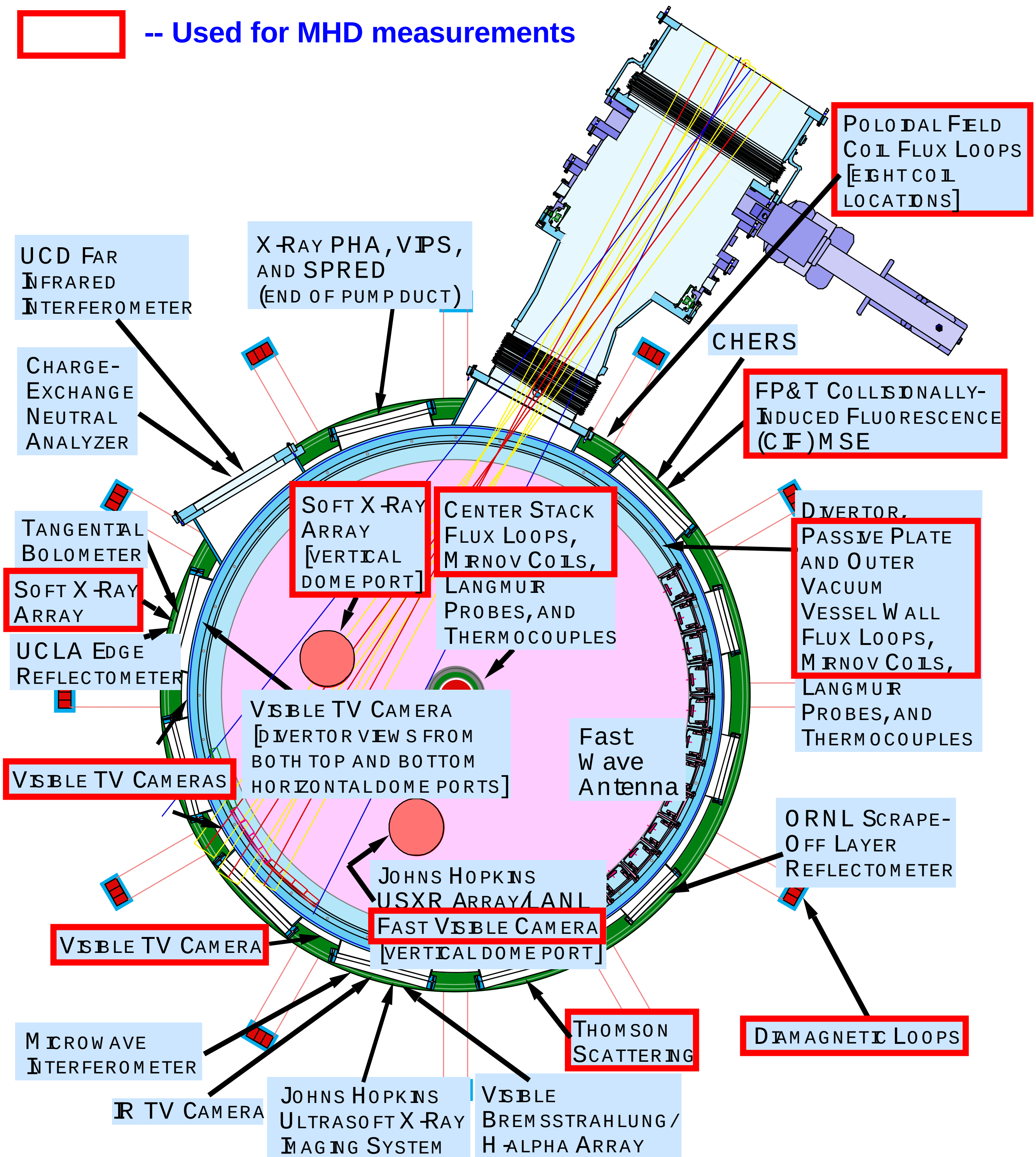


Tools

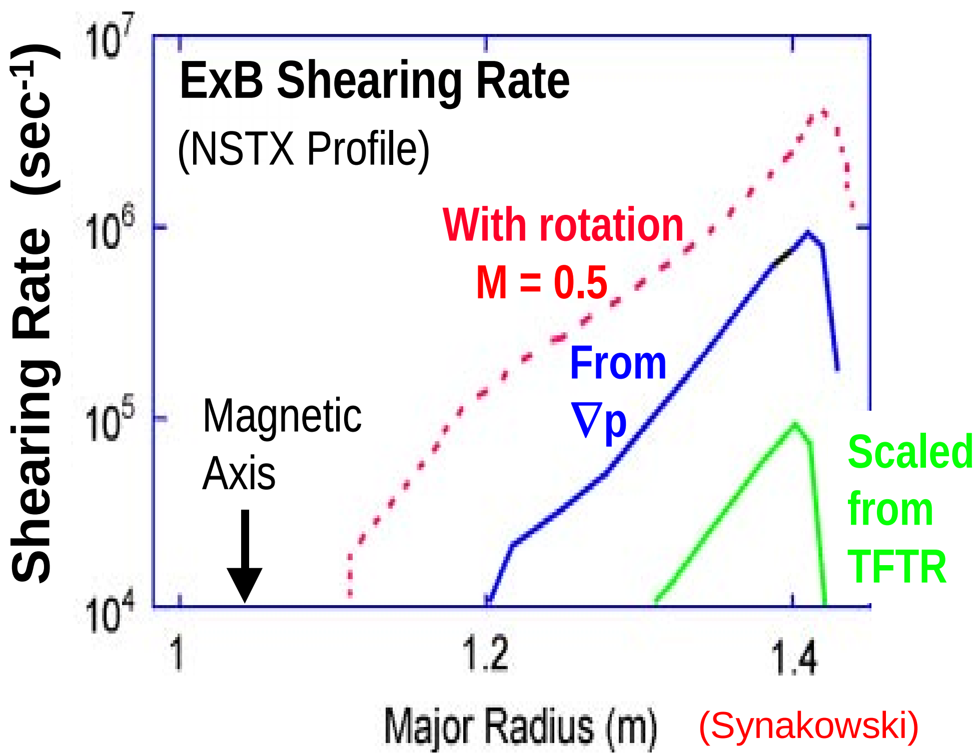
- High Power Heating
  - NBI
  - HHFW
- Plasma shape control
- Plasma profile measurements

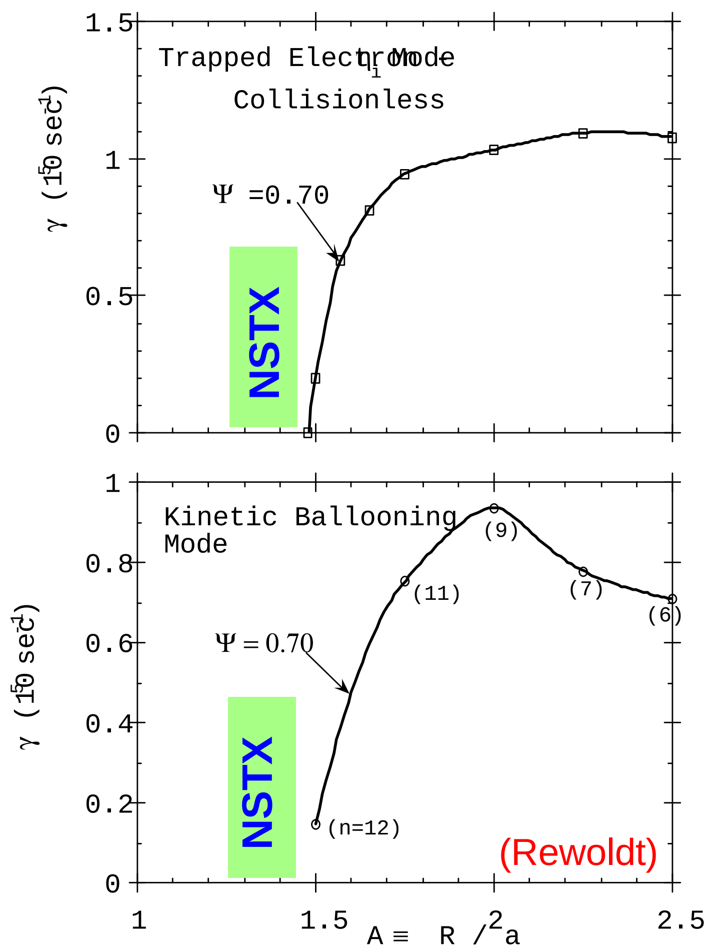
NSTX Will Have a Comprehensive Diagnostic List

-- Used for MHD measurements



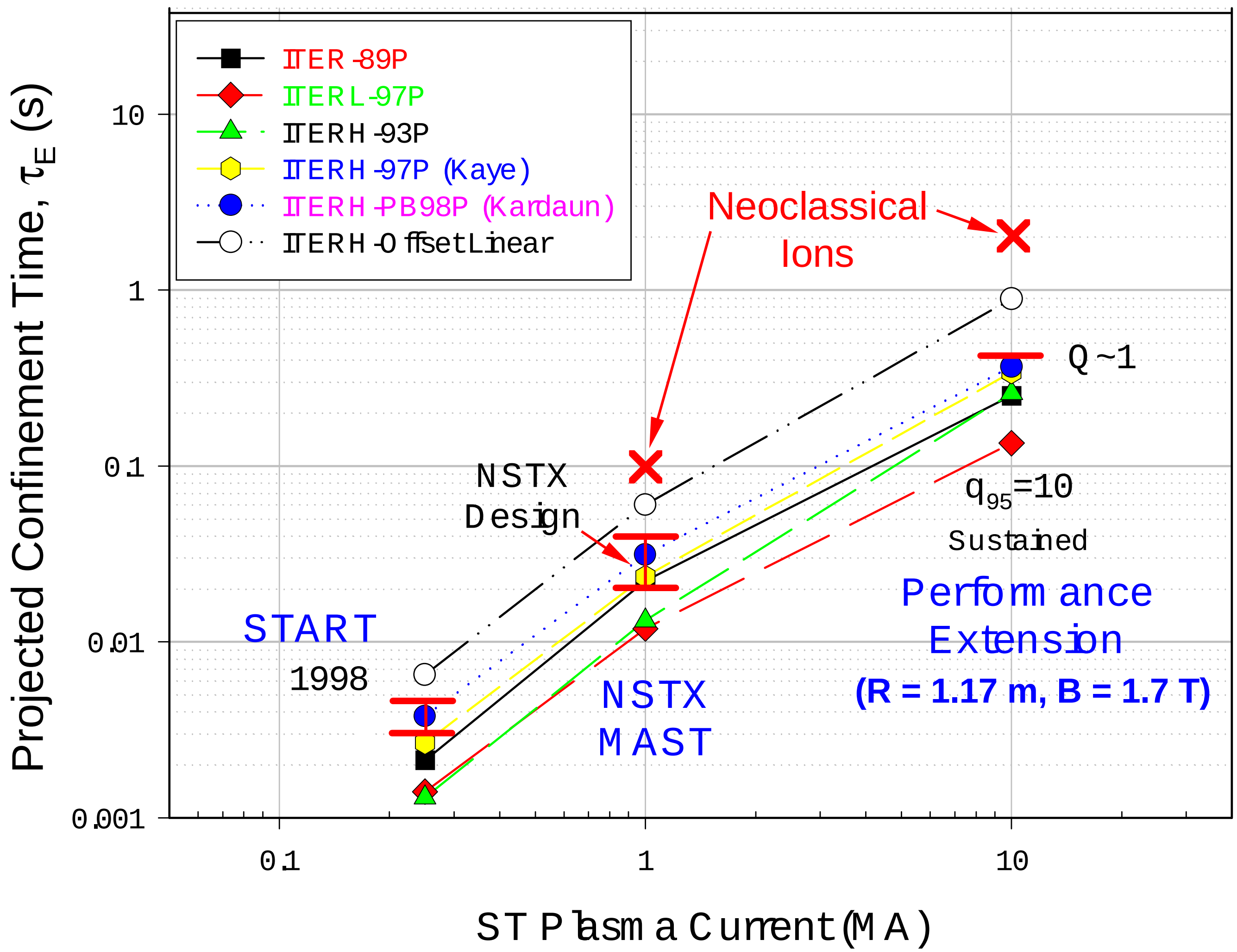
Turbulence May Be Much Reduced in NSTX Because of Large Flow Shear and Very Small Aspect Ratio



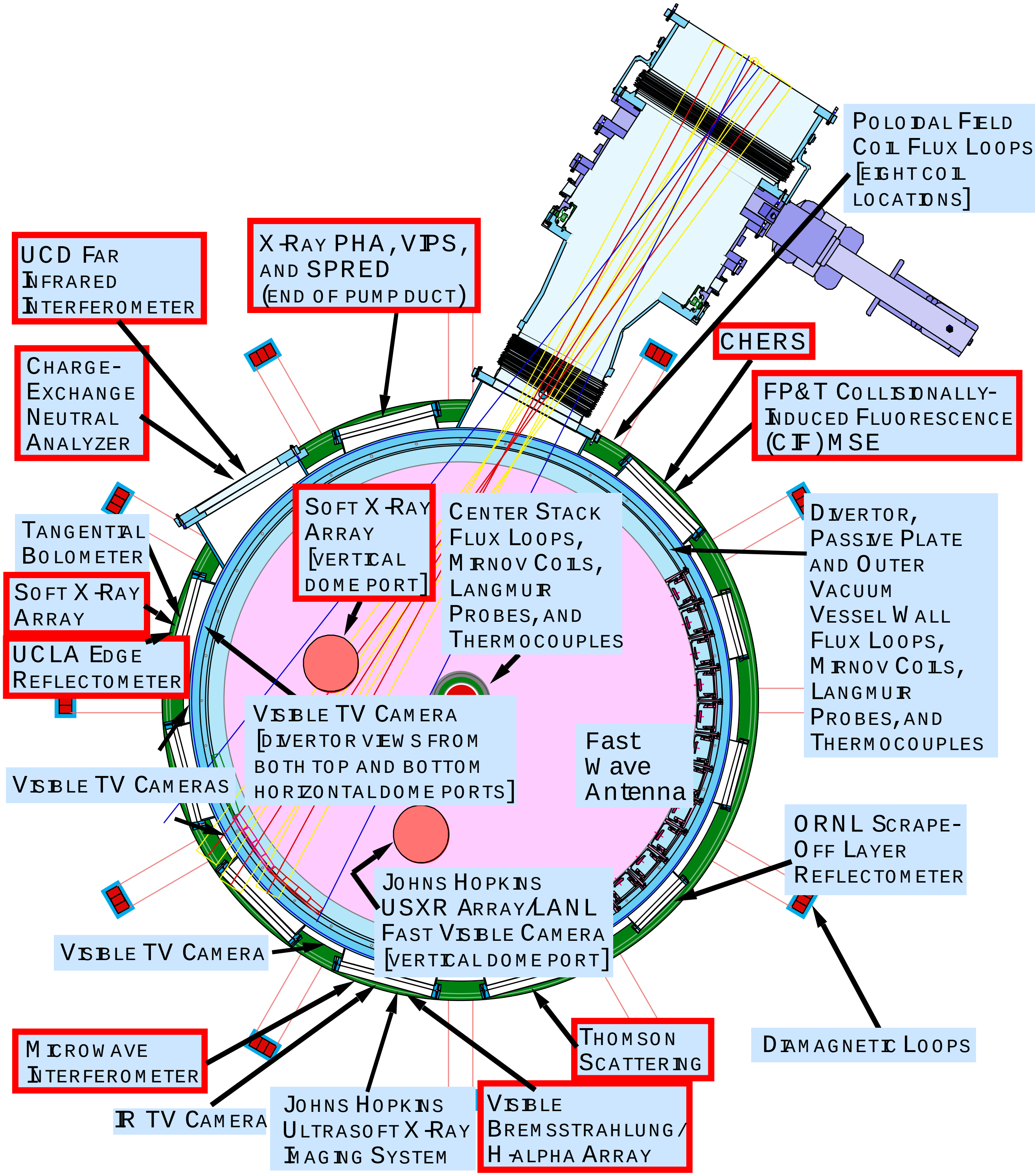


⇒ **Prospect for neoclassical ions and Ignition at I_p ~ 10 MA and R ~ 1 m has been identified** (Kotschenreuther, Dorland)

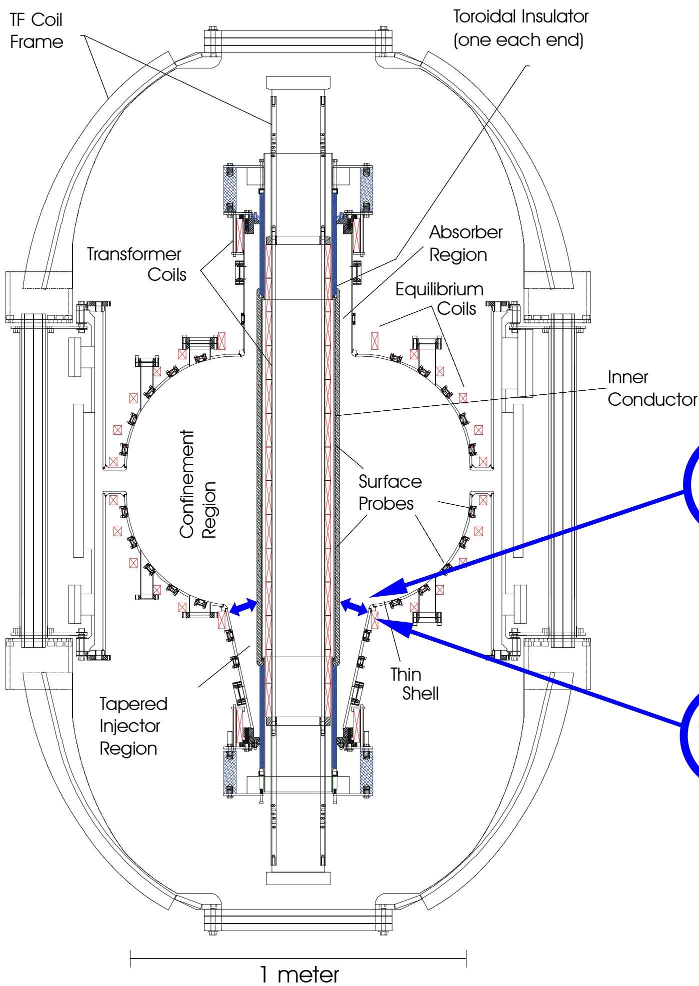
Confinement Times Obtained in NSTX Will Enable Reliable Projections to the Next Step

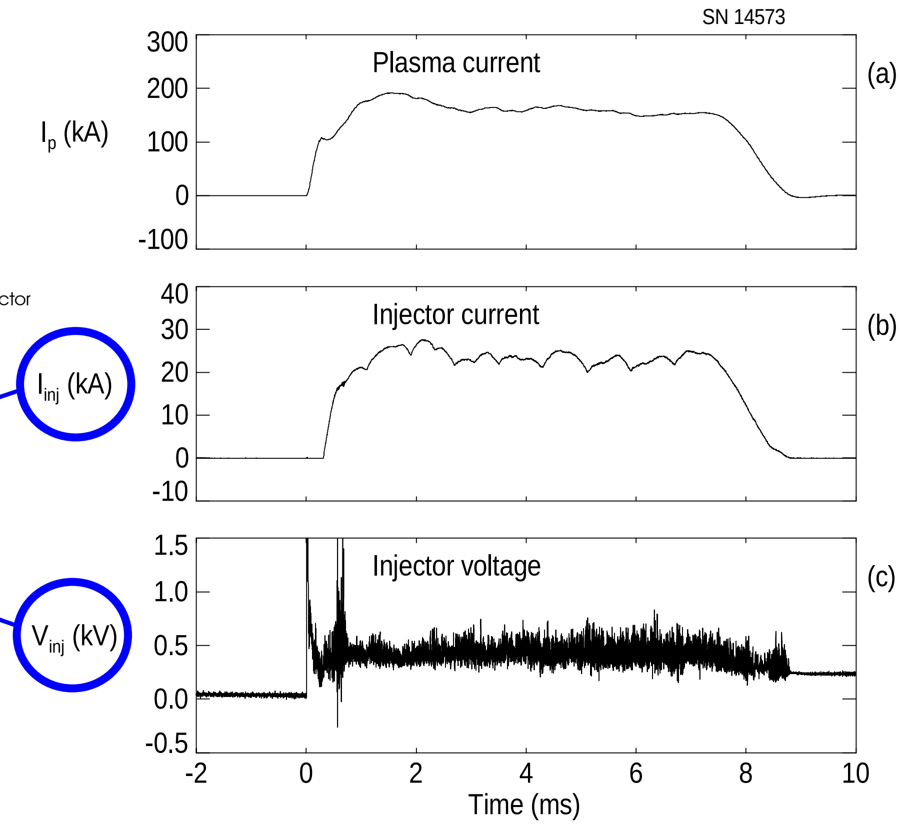


Confinement Measurements



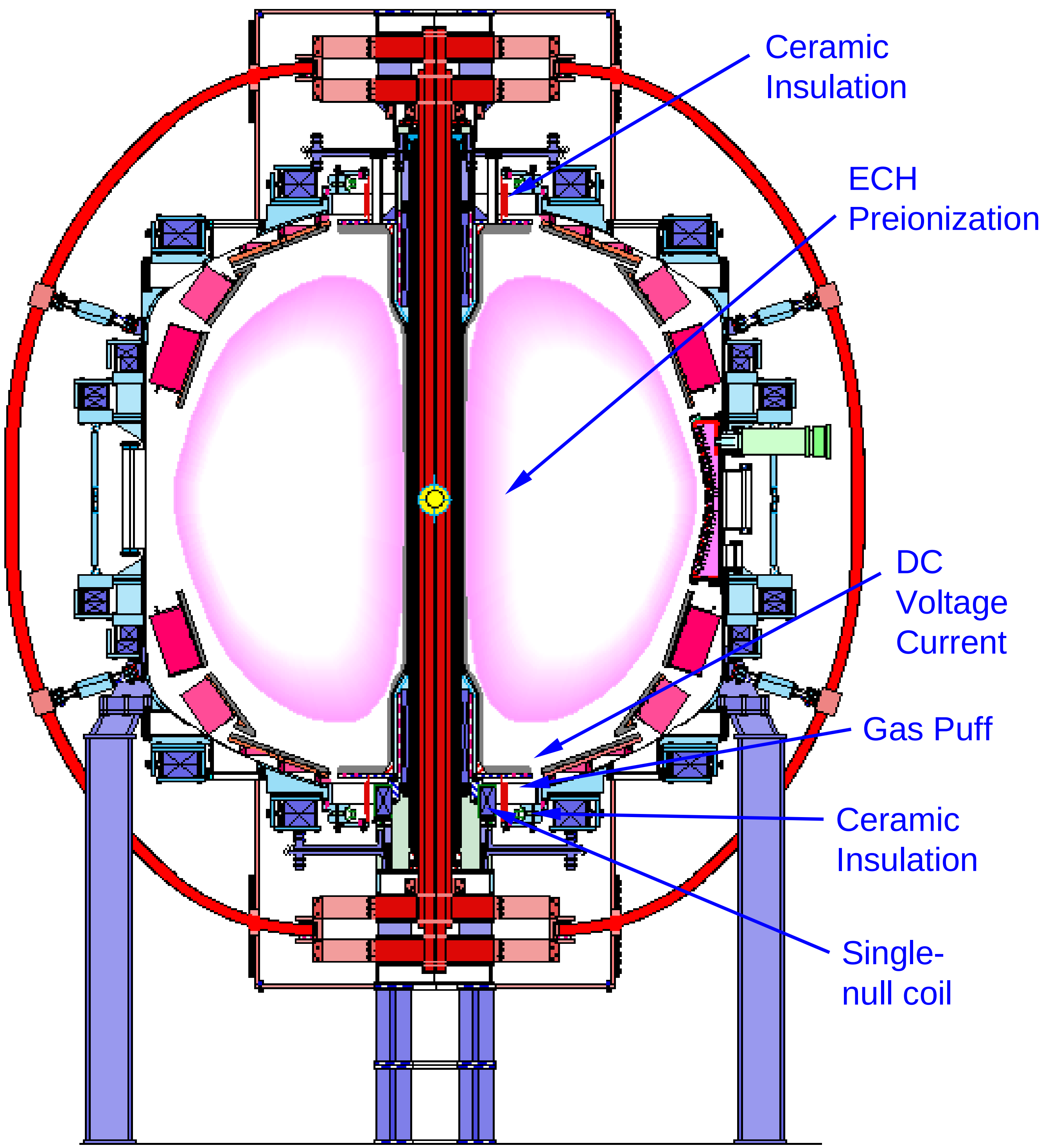
Helicity Injection Startup Was Demonstrated on HIT-II (U. Washington)





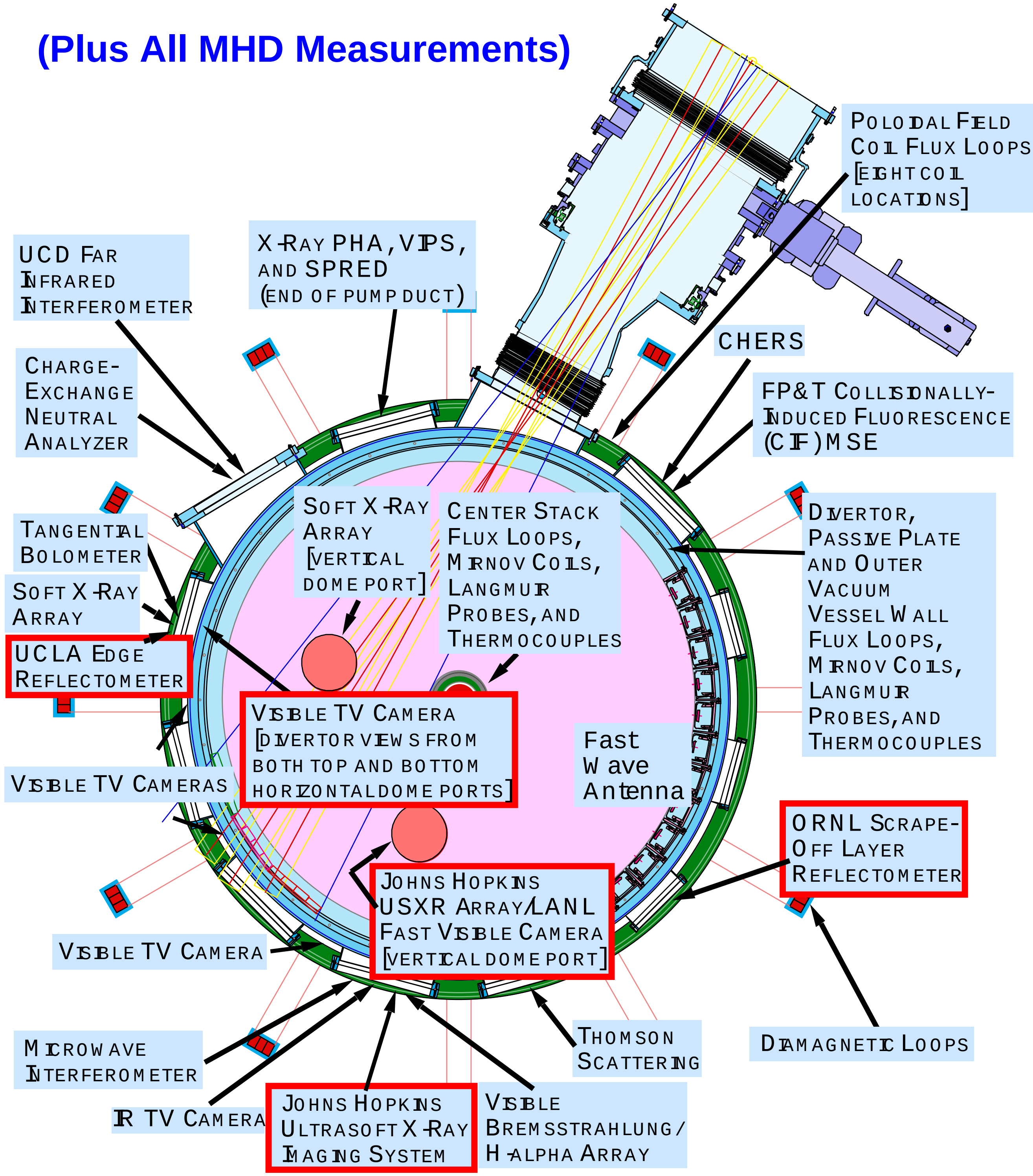
- Eliminates the need for solenoid

NSTX is Designed to Investigate Coaxial Helicity Injection Startup

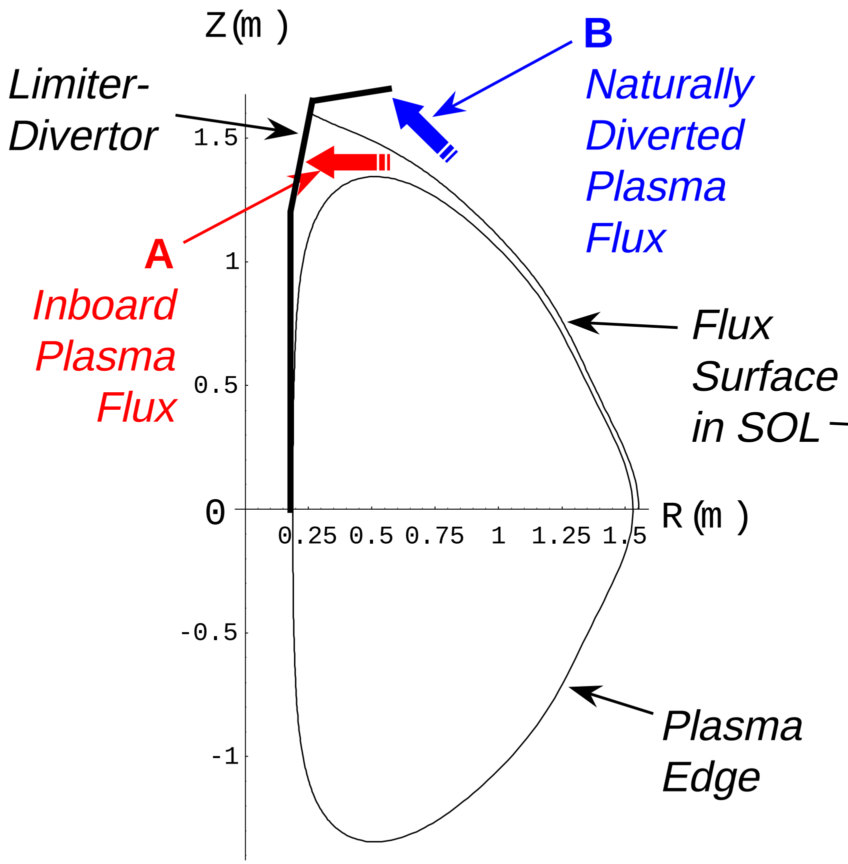


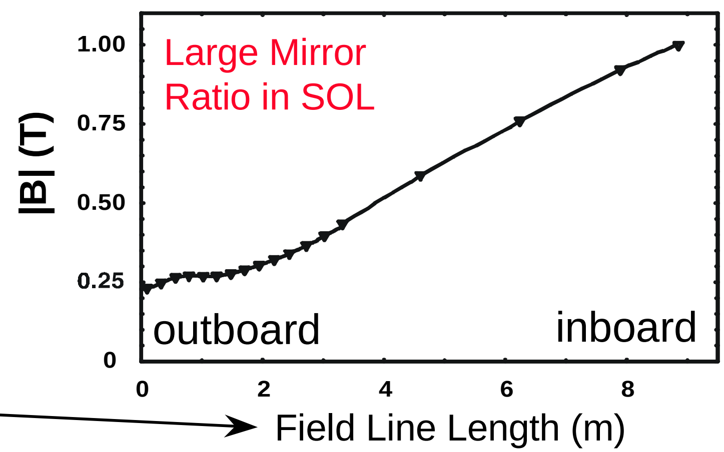
Coaxial Helicity Injection Measurements

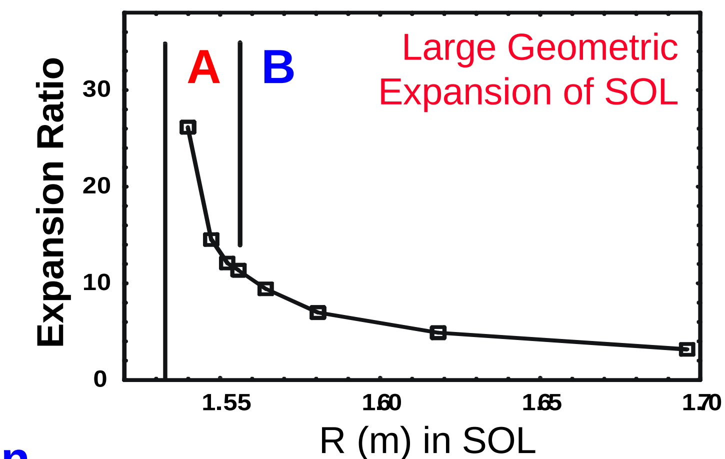
(Plus All MHD Measurements)



NSTX Inboard-Limited Scrape-Off Layer May Have Highly Dispersed Plasma Heat Flux



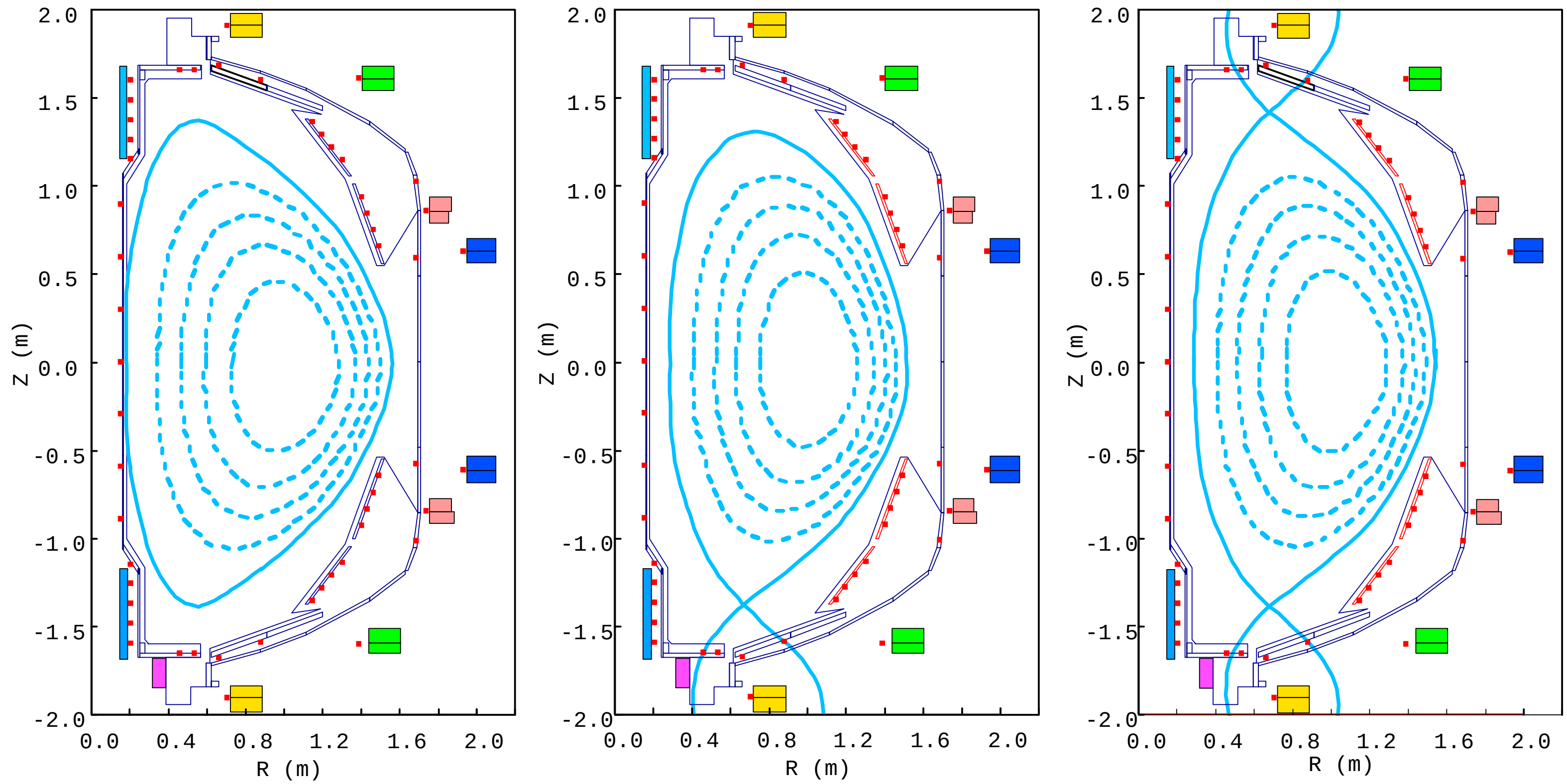




⇒ **dispersed heat fluxes due to large cross-field transport and expansion**

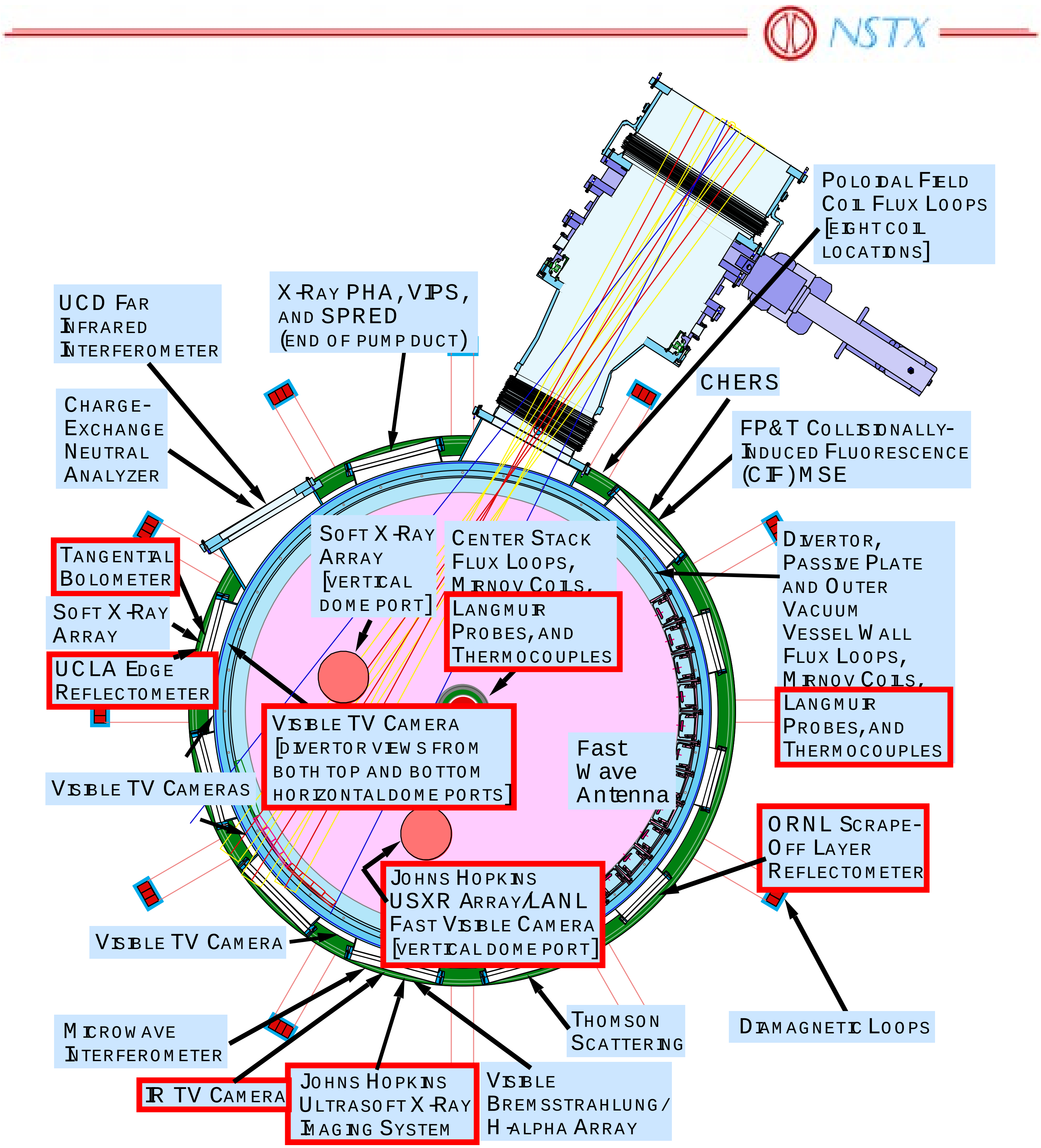
Inboard Limited, Single-Null, and Double-Null Plasma Edge-SOL Properties Will be Investigated

I_p = 1MA; β_T = 23% | I_p = 1MA; β_T = 26% | I_p = 1MA; β_T = 27%

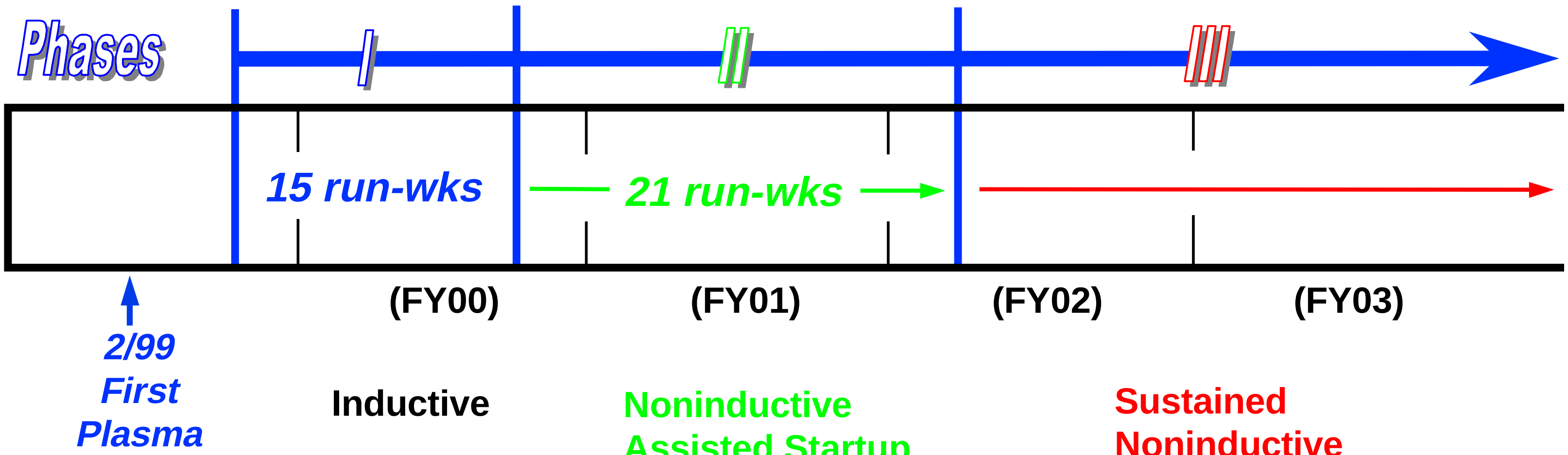


Inboard Limited | Single-Null | Double-Null

Plasma Edge-SOL Measurements



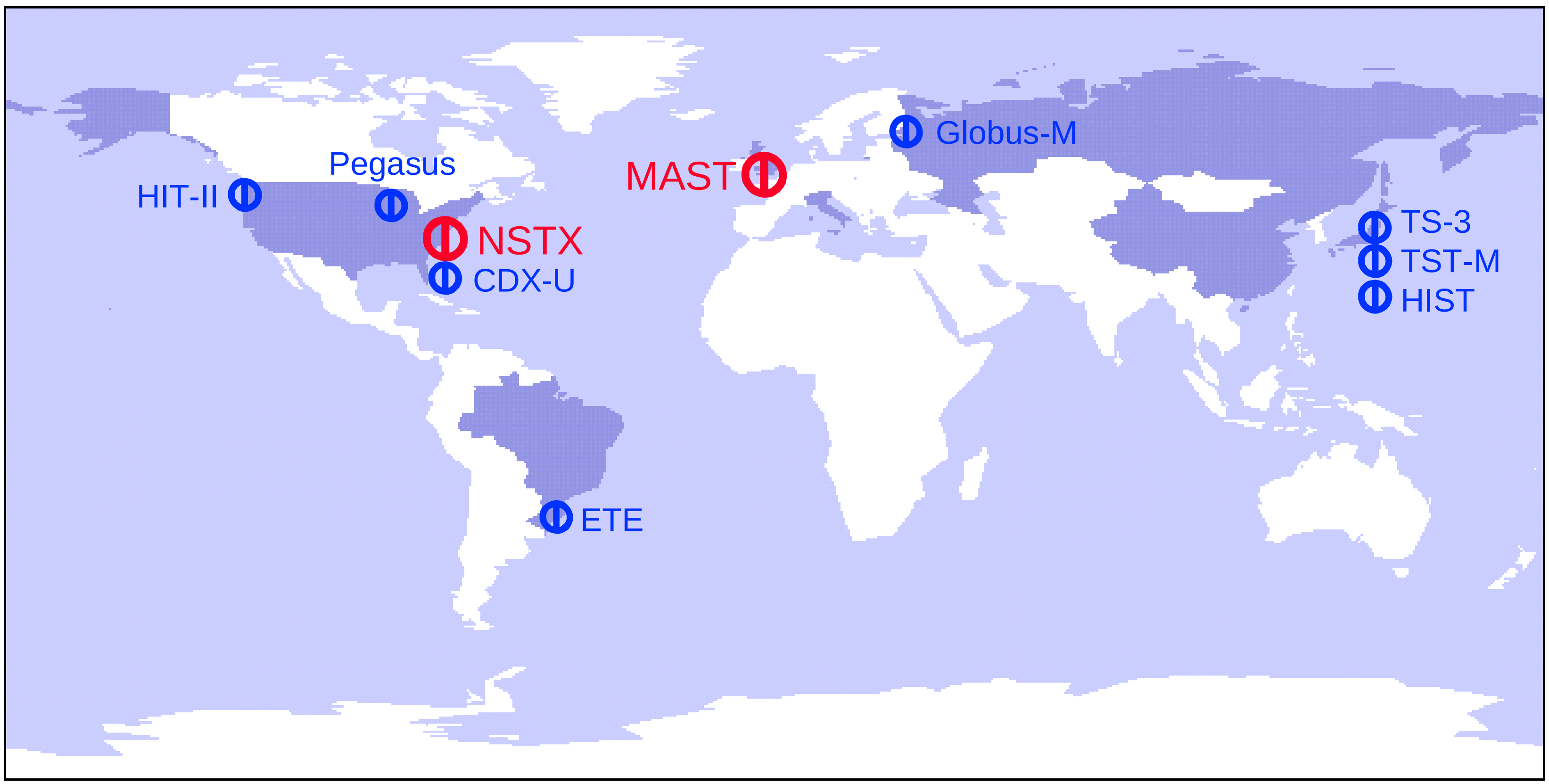
NSTX Research Plans to Investigate the Key ST Physics Issues in the Next 4-5 Years



	Inductive	Noninductive Assisted Startup	Sustained Noninductive Operation
Toroidal Beta, β_T		→ 25% (no-wall limit)	→ 40% (wall stabilized)
Bootstrap Current		→ 40% (no-wall limit)	→ 70% (wall stabilized)
Current	→ 0.5 MA	→ 1 MA	~ 1 MA
Pulse	→ 0.5 s	→ 1 s	→ 5 s
HHFW Power	→ 4 MW	~ 6 MW	~ 6 MW
NBI Power		→ 5 MW	~ 5 MW
CHI Startup	→ 0.2 MA	→ 0.5 MA	~ 0.5 MA
Measure	$T_e(r)$, $n_e(r)$	j(r), $T_i(r)$, flow	**turbulence**

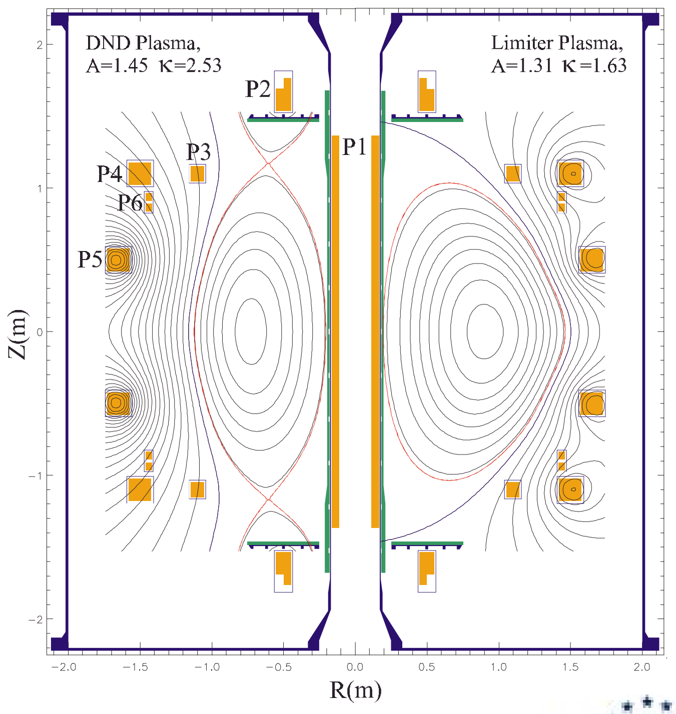
World ST Program Has Grown Rapidly Since 1990

Proof of Principle   Concept Exploration

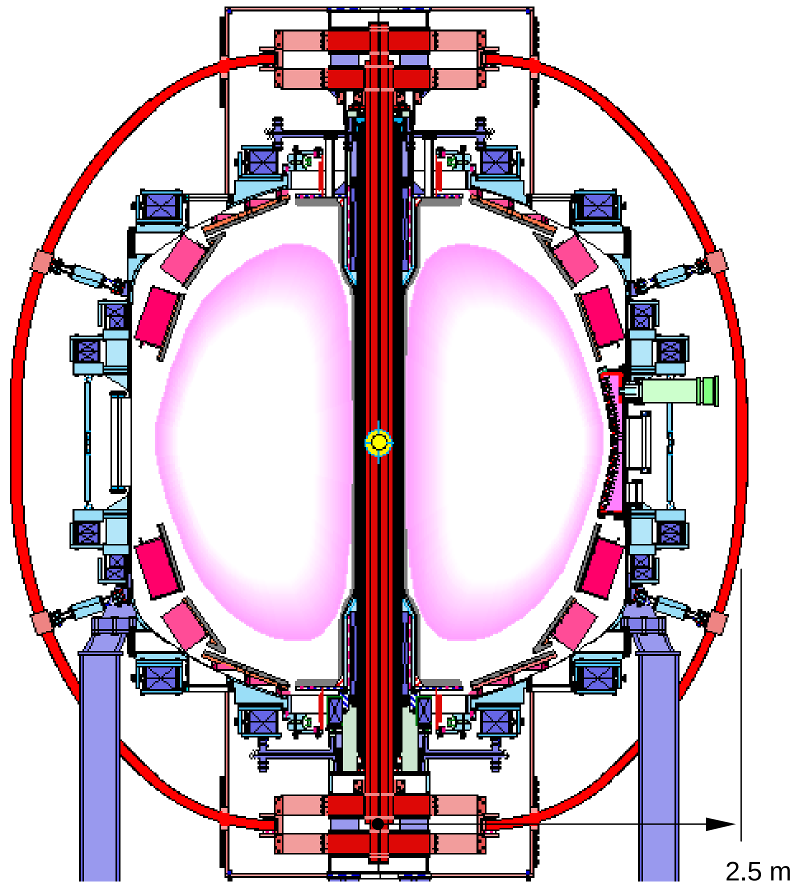


Complementing Capabilities of MAST and NSTX Strengthen World ST Fusion Research Programs

MAST (U.K.)



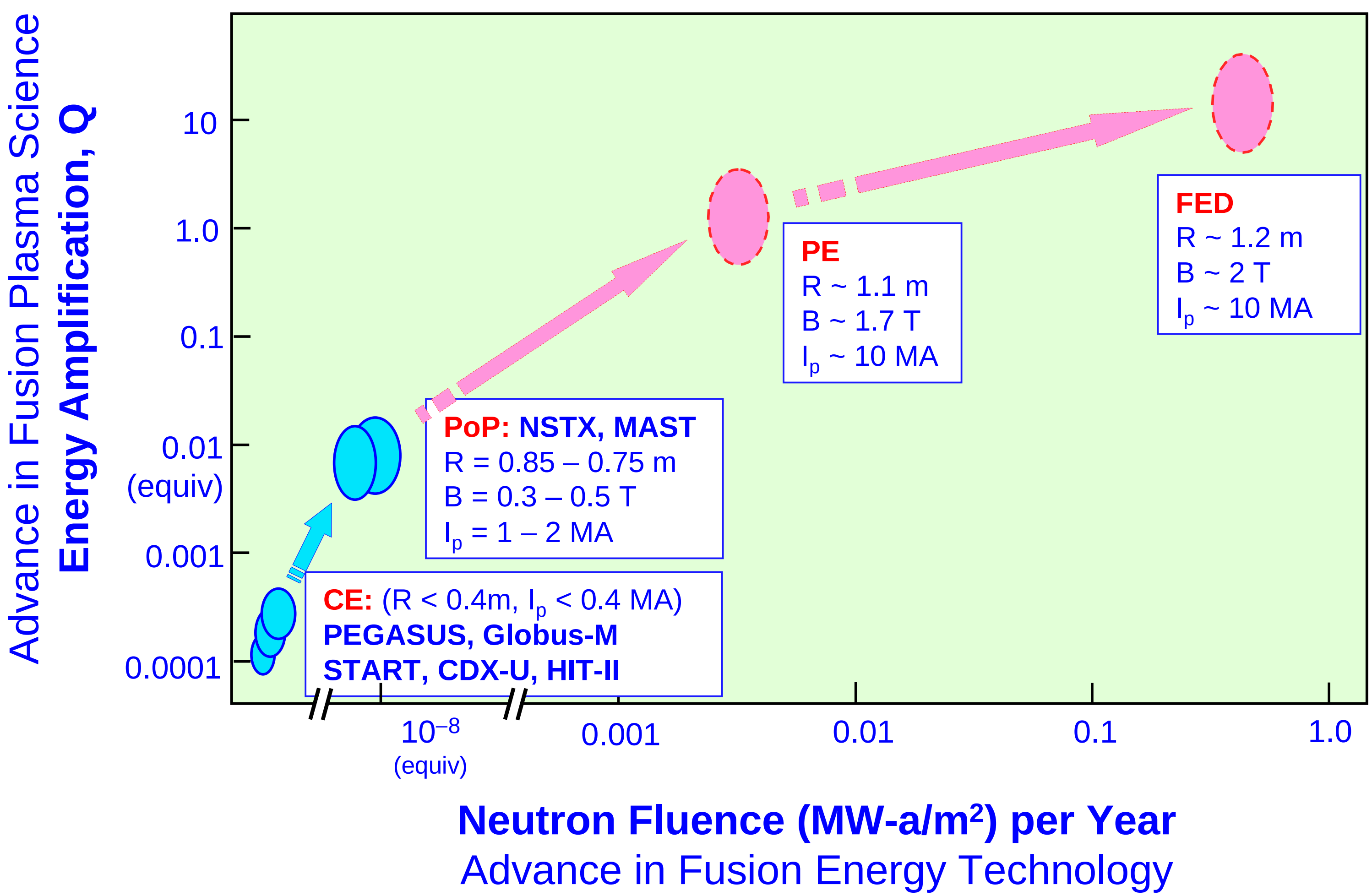
UKAEA Fusion



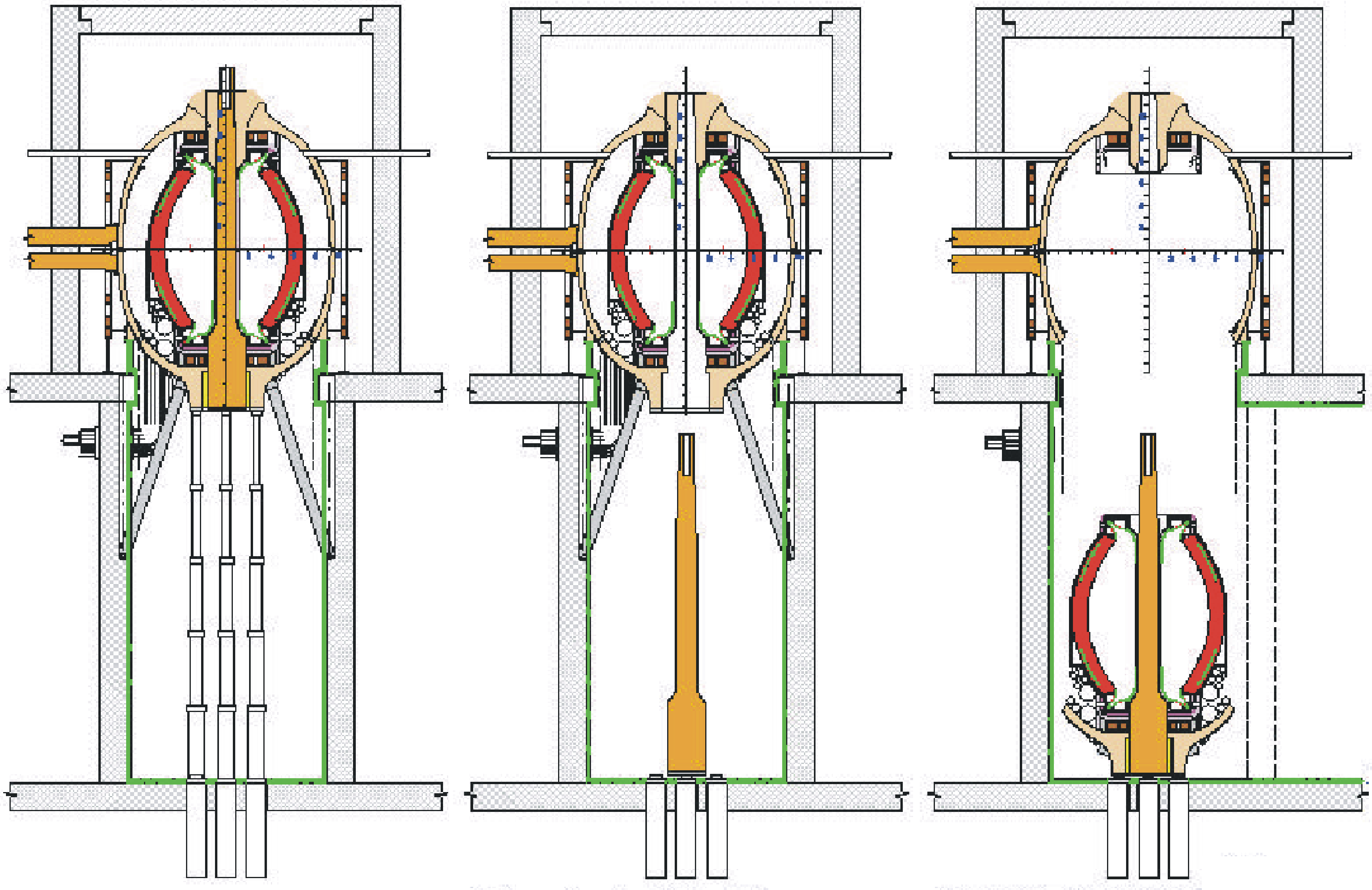
• Nearby Stabilizing Shell	No	Yes	(beta limits)
• Poloidal Field Coils	In-vessel	Ex-vessel	(plasma shaping flexibility)
• RF Heating&Current Drive	ECH	HHFW	(efficient sustainment)
• Plasma Current Startup	Compression	CHI	(eliminate solenoid)

⇒ Development of comprehensive database for Performance Extension step

ST Can Advance Fusion Science and Technology Using Small-Size Devices

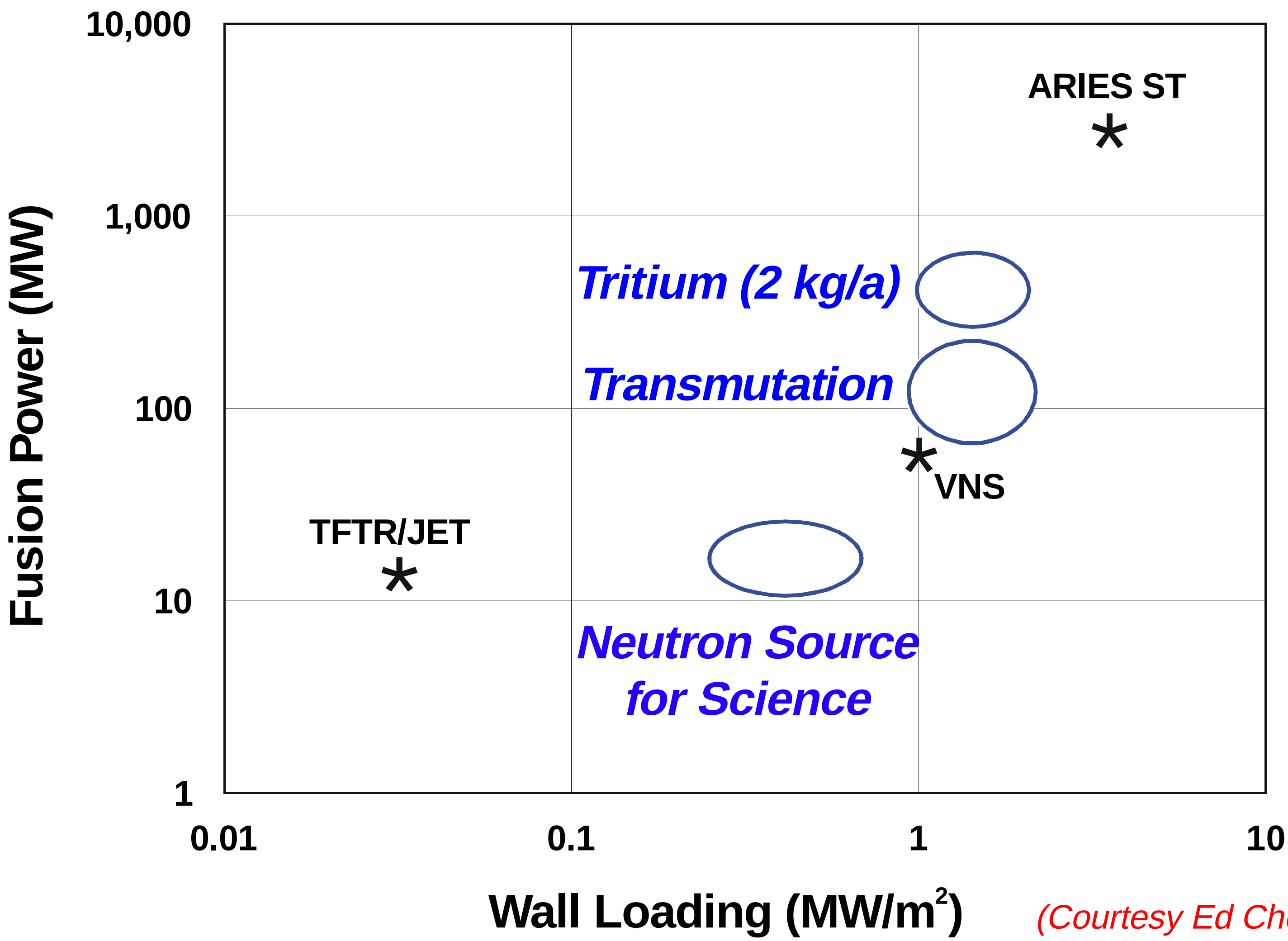


ARIES-ST Utilizes Simplified Maintenance Path



Slender and Modular Center Stack Permits Faster Installation and Upgrades

Small Powerful ST Devices Could Be Attractive in Nearer-Term Non-Electric Applications



(Courtesy Ed Cheng)

NSTX at the Cutting Edge of Fusion Plasma Science Research

- NSTX is up and running
  - First plasma ahead of schedule, built within cost
  - Experiment begins in August 1999
- NSTX & MAST world-leading ST experiments
  - → Jointly provide knowledge base for the PE step
- NSTX addresses key PoP issues
  - Strongly broadens scientific base
- ST offers attractive visions
  - Affordable development steps
  - Simplified configuration
  - Possible nearer-term application to benefit society