Derek Robinson
and the Spherical Tokamak

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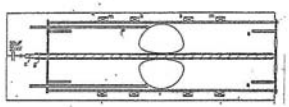
Derek Robinson Memorial Seminar
Wednesday 25 June 2003
The John Adams Lecture Theatre
Culham Science Centre
Abingdon, Oxfordshire

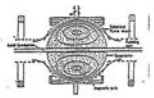
Collaboration on ST Began When Culham Commissioned Working Party to Take a Closer Look



The Heidelberg Spheromak

A = 1.1 $I_p / I_{ROD} = 2.5$

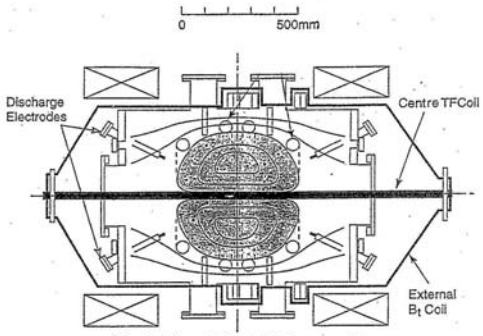
Bruhns et al, Nucl.Fus.27 (1987) 2178



The Lucas Heights Rotamak

A = 1.1 $I_p / I_{ROD} = 1.1$

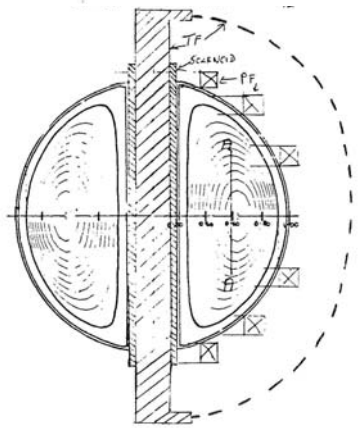
Collins et al, Nucl.Fus. 28 (1988) 255



The Tokyo TS - 3 Spheromak

A = 1.1 $I_p / I_{ROD} = 3$

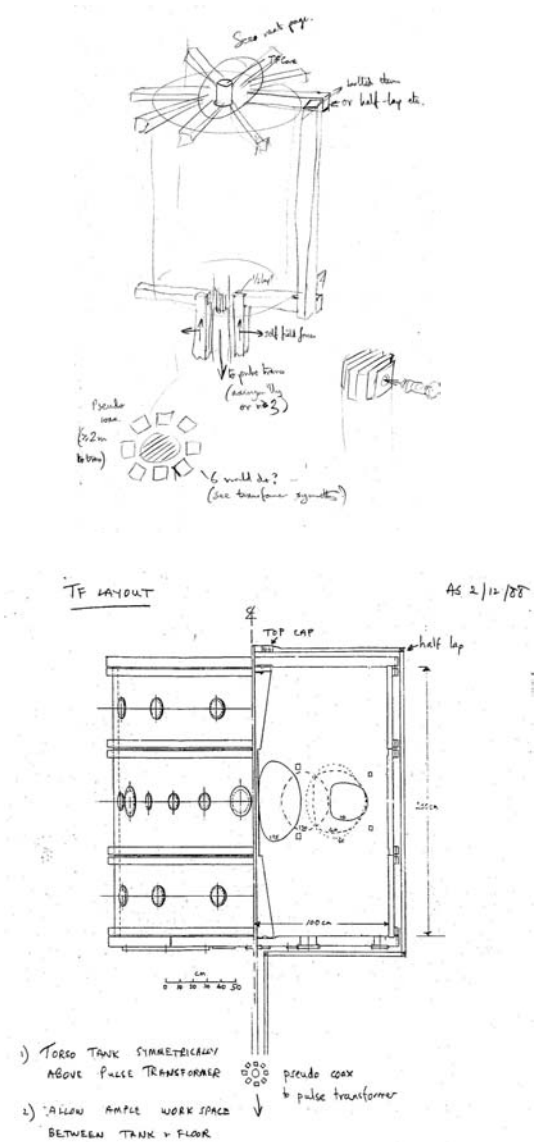
Yamada et al, Nucl.Fus.36 (1996) 1210



Initial Concept by Working Party, 1987

- Some intriguing indications from small experiments
- Study commissioned by former Director Bas Pease in 1986
- Led by Alan Sykes
- Chosen to become a new adventure at Culham in 1987
- Derek became research director at Culham

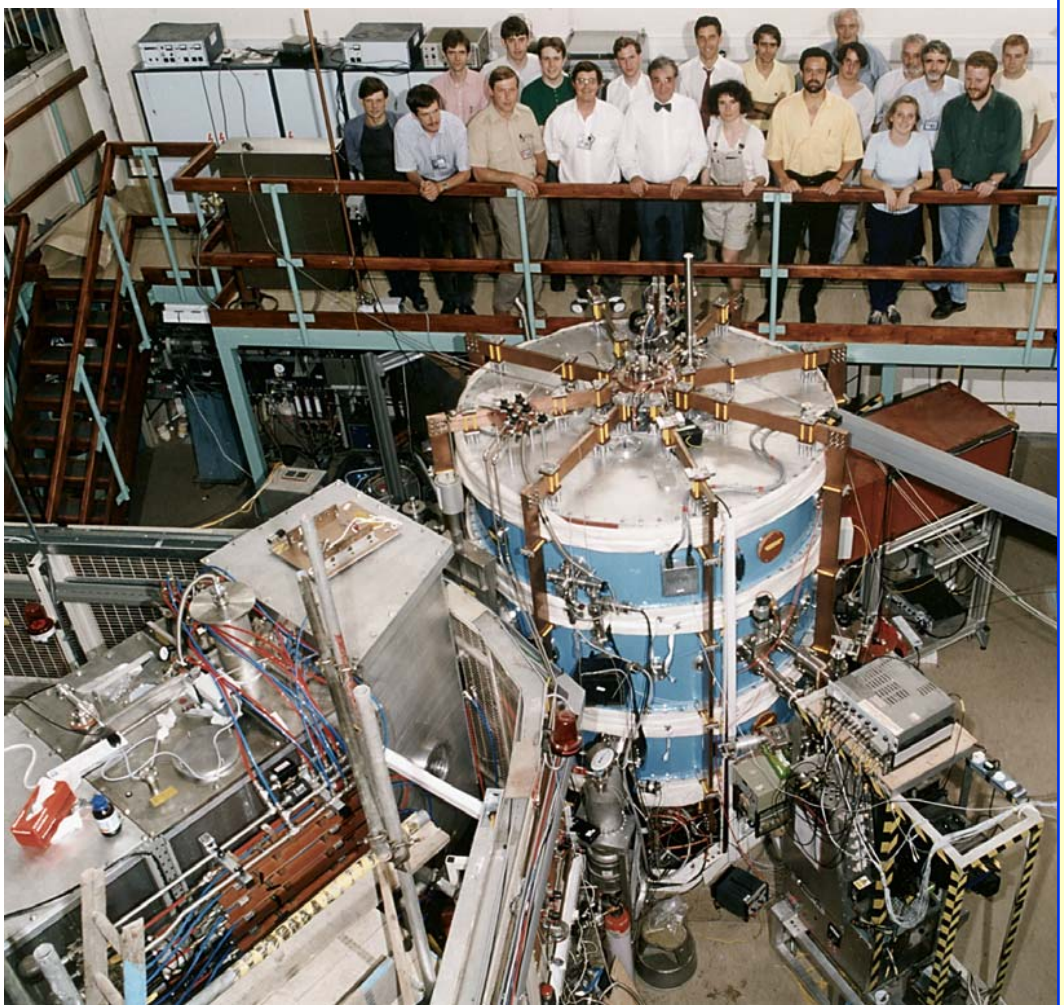
ST Research Was Envisioned to Start with START!



Creativity in Action in 1988!

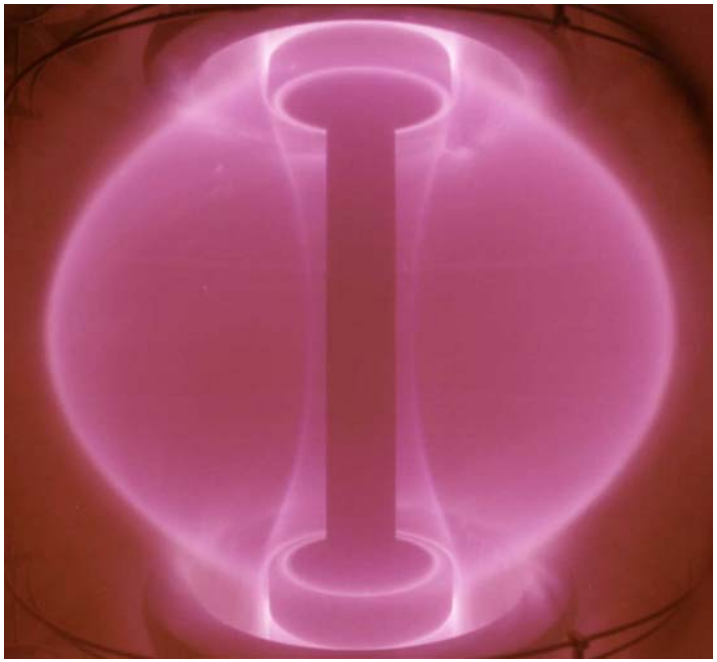
- Derek, Tom Todd et al envisioned START based on imaginative use of available equipment and funds
- A small engineering team were energized to design and build
- A small physics team “saw” what should be tested and how

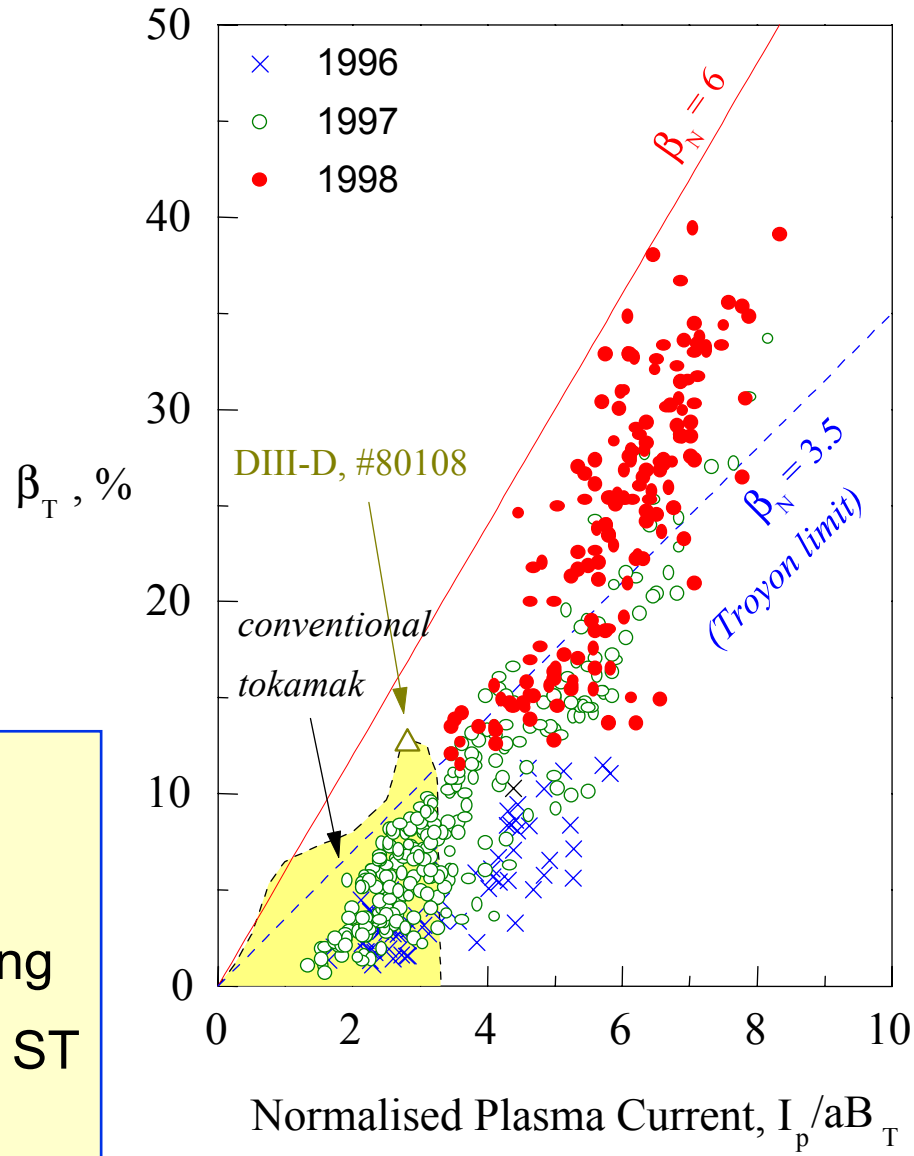
An Example of Innovation, Hard Work, Professionalism, and Collaboration



- Derek oversaw the START research, which began in 1990!
- Ohmic ST confinement was found adequate in 1991
- ORNL supplied an ATF neutral beam system in 1992-3
- Beautifully refurbished and installed on START in 1994
- START reached keV temperatures in 1995!

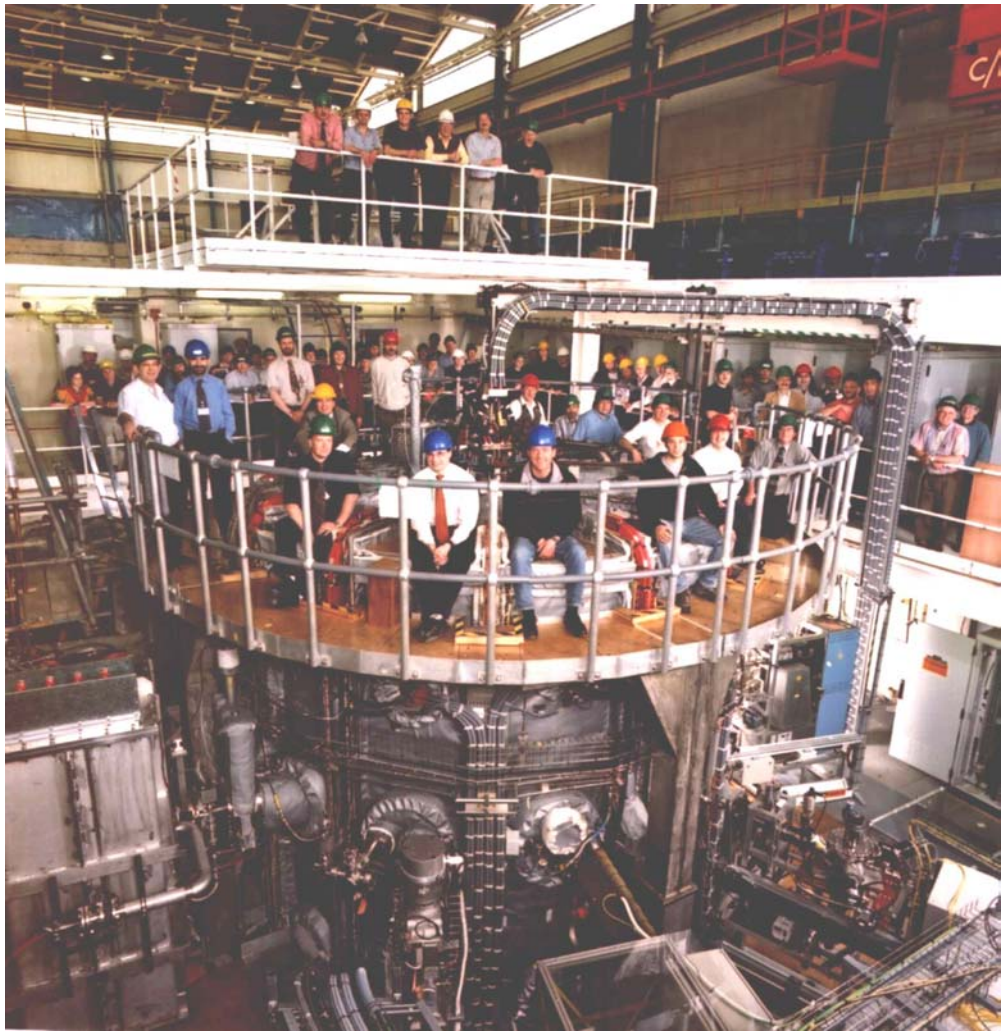
START Startled





- H-mode obtained
- Toroidal beta reached 40%
- Confinement close to ITER scaling
- Engendered the next generation ST experiments

Mega Amp ST's Came into Existence

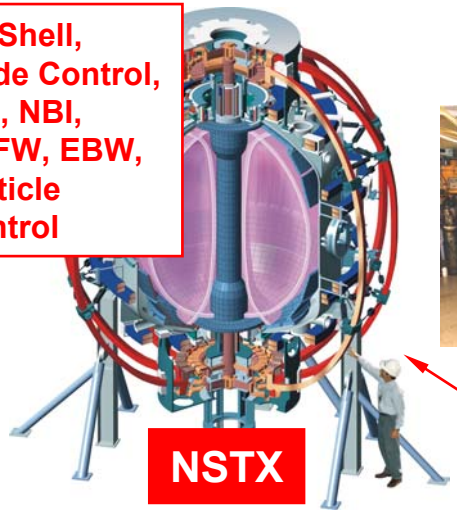


- MAST design based on the tried-and-true START
- Began in 1996
- NSTX was approved in FY1997

ST Research Blossomed in the World

Concept Exploration (~0.3 MA) **Proof of Principle (~MA)**

Cu Shell, Mode Control, CHI, NBI, HHFW, EBW, Particle Control

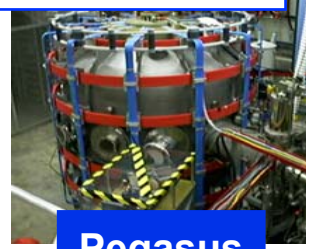


NSTX

CHI Synergy

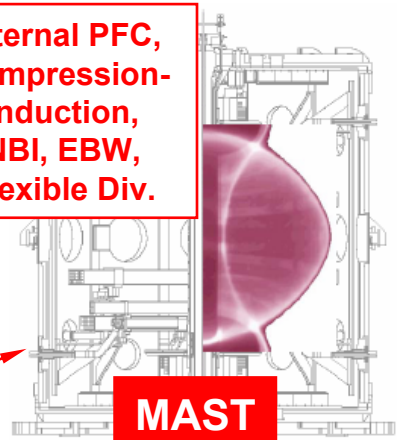
HIT-II

Extreme Low A, HHFW, EBW, Spheromak Comp.

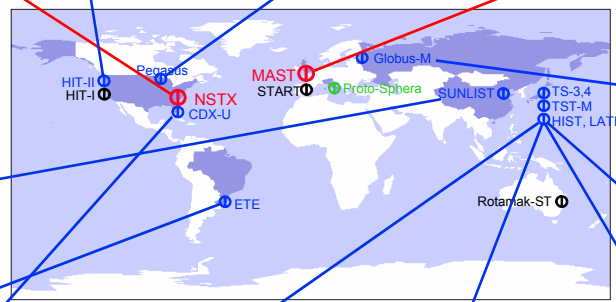


Pegasus

Internal PFC, Compression-Induction, NBI, EBW, Flexible Div.



MAST



Brand-New!

SUNLIST

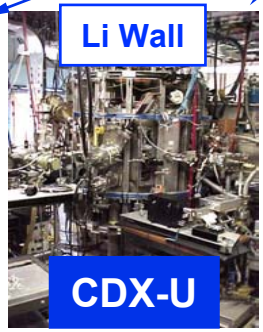
LHW, NBI, Advanced Diagnostics

Globus-M

Advanced Diagnostics

ETE

Li Wall



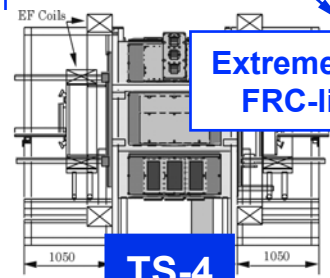
CDX-U

Extreme Low A, CHI, Spheromak

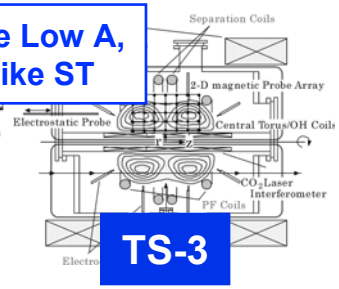
HIST

ECH startup, HHFW Innovation

TST-2



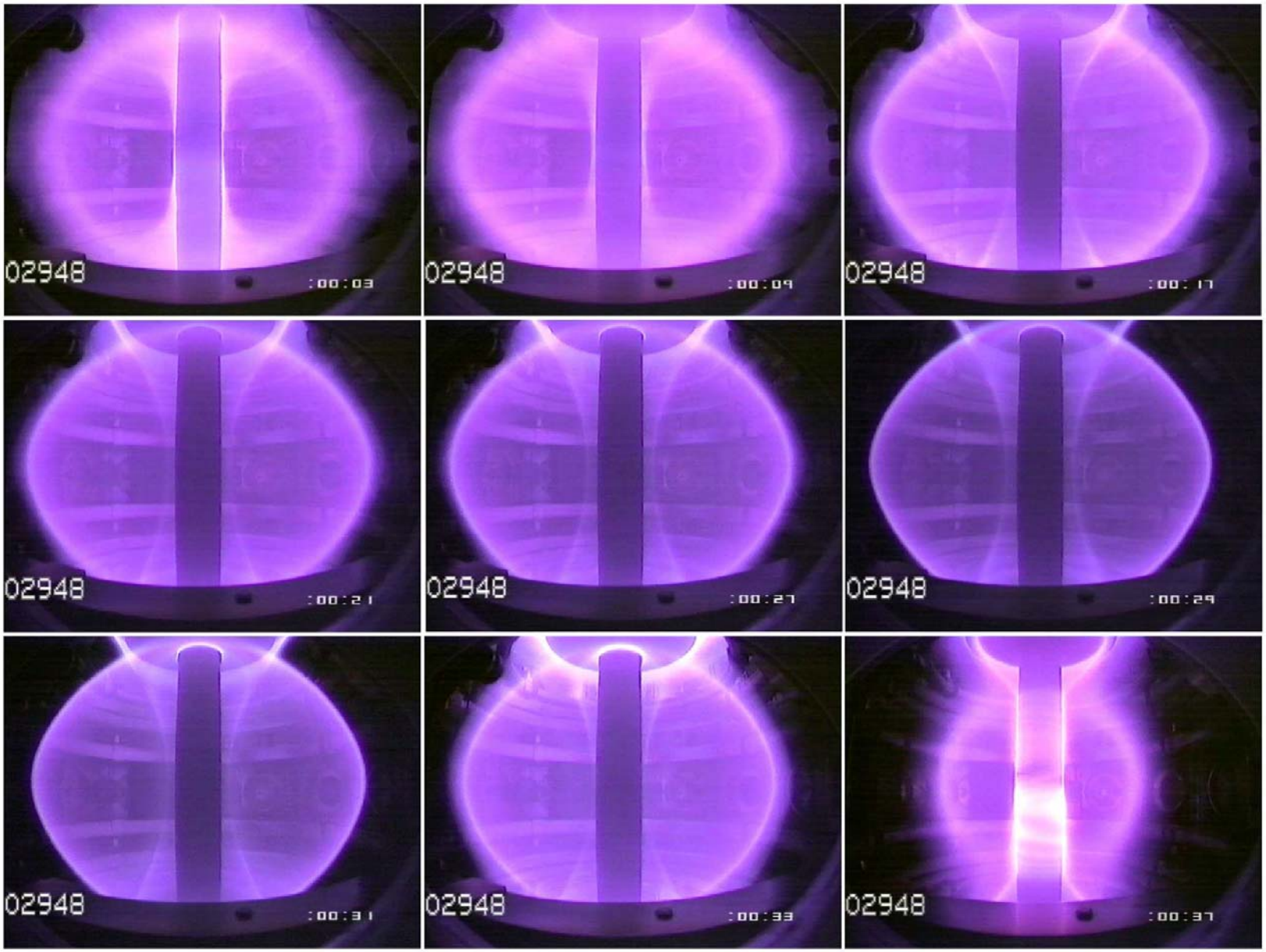
Extreme Low A, FRC-like ST



TS-4

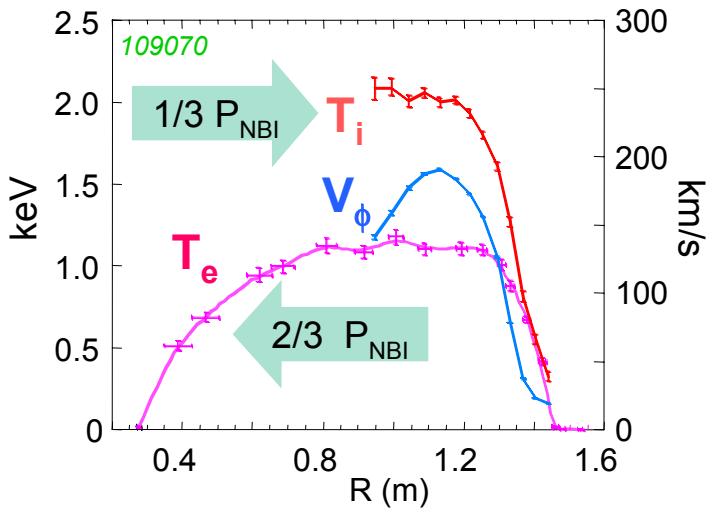
TS-3

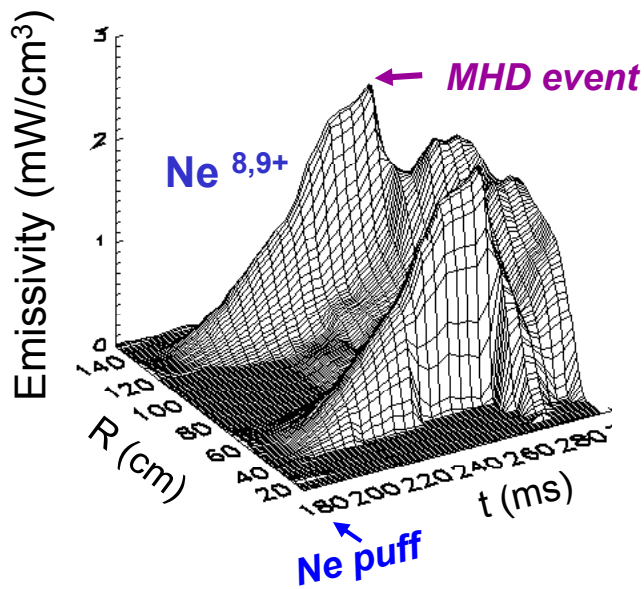
High-Quality H-Mode Plasmas Routine in MAST



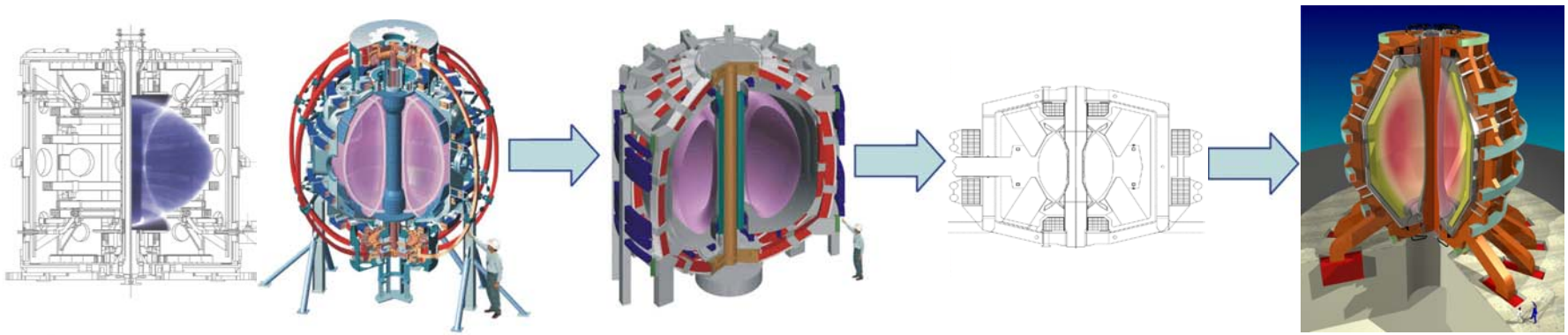
Under Intense Neutral Beam Heating, Ion Energy and Particle Diffusivities are Found Very Low

Core Transport Physics	NSTX Results
Thermal Conductivity	• $\chi_{ion} \sim \chi_{neoclassical}$ • $\chi_{elec} >> \chi_{ion}$
Impurity Diffusivity	• $D_{imp} \sim D_{neoclassical}$
Micro-instability turbulence theory	• Driven by T and n gradients • $k_\theta \rho_i < 1$ (ion gyro-scale) stable or suppressed by V_ϕ shear • $k_\theta \rho_i >> 1$ (electron gyro-scale) strongly unstable



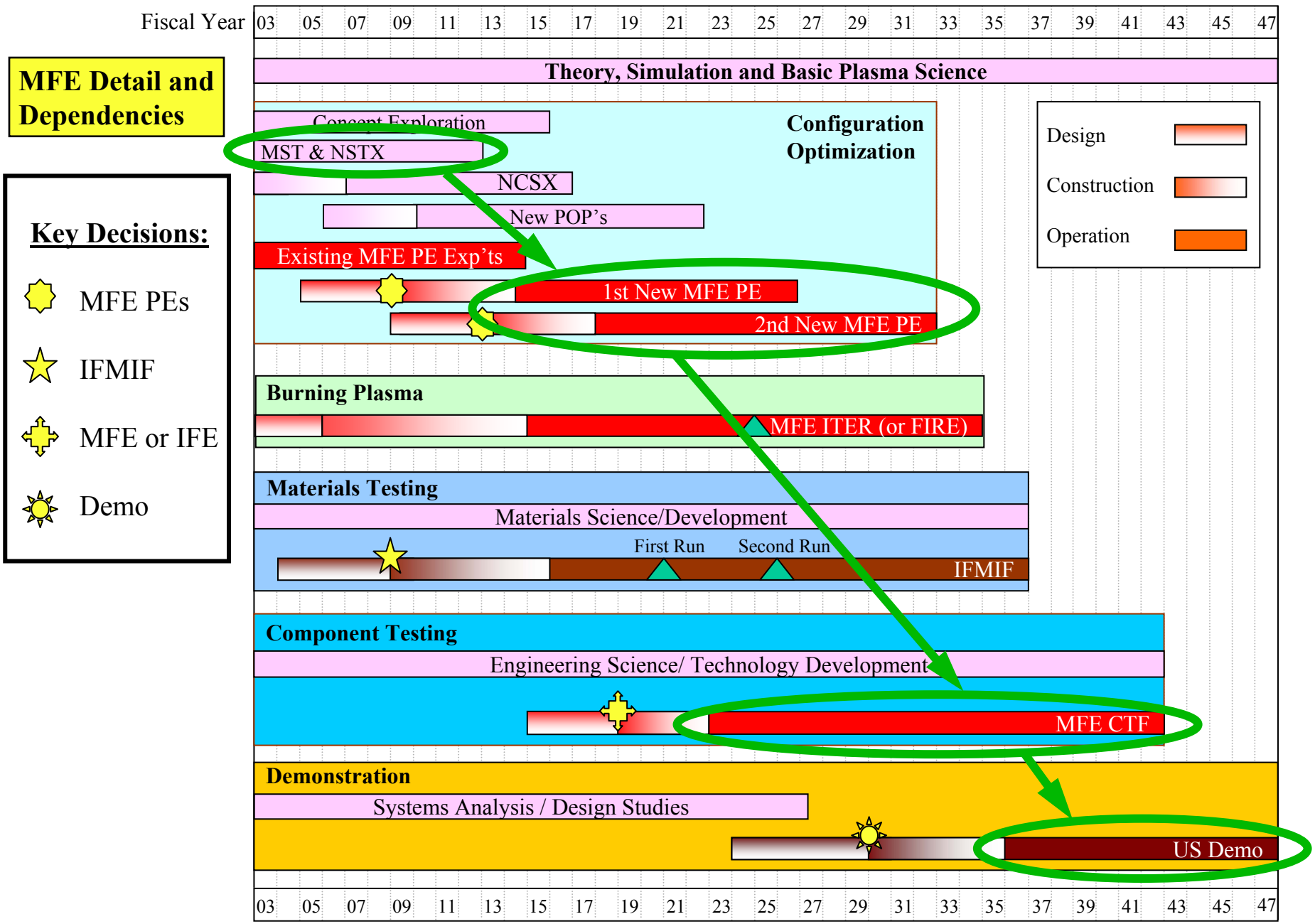


An Interest Grows in the Way Forward



Device	MAST-NSTX		NSST		CTF		DEMO
Mission	Proof of Principle		Performance Extension		Energy Development, Component Testing		Practicality of Fusion Electricity
R (m)	~0.85		1.5		0.8 – 1.2		~3.4
a (m)	~0.65		0.9		0.6 – 0.8		~2.4
κ, δ	2.5, 0.8		2.7, 0.6		~3, ~0.4		~3.2, ~0.5
I_p (MA)	1.5	1	10	5	8 – 11		~30
B_T (T)	0.6	0.3	2.6	1.1	~2		~1.8
Pulse (s)	1	5	5	50	Steady state		Steady state
P_{fusion} (MW)	–		50	10	30 – 70	120 – 280	~3000
W_L (MW/m^2)	–		–		~1	~4	~4
TF coil	Multi-turn		Multi-turn		Single-turn		Single-turn

ST Becomes an Integral Part of a U.S. Development Plan

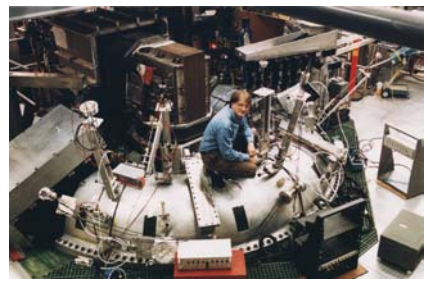


Extended ST Plasma Science Connects NSTX-MAST to the Broad Fusion & Plasma Science Portfolio

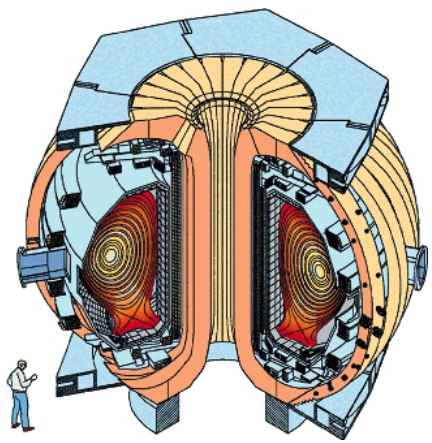
- **ICC Physics: SSPX, MST, FRC**
  - Magnetic reconnection – CHI
  - EBW H&CD – over-dense plasmas
  - Electromagnetic turbulence micro-tearing – $\beta \sim 1$ plasmas
  - TAE's – supra-Alfvénic fast ions
  - FRC-like diamagnetic plasmas
- **Burning Plasma – ITPA**
  - A and β effects: H-mode, ITB, ELM's & pedestal, SOL, RWM, and NTM
- **Tokamak Physics: DIII-D, C-Mod, JET, AUG, JT-60U, etc.**
  - RWM, Fast ion MHD, pedestal, core confinement, edge turbulence, core temperatures

SSPX

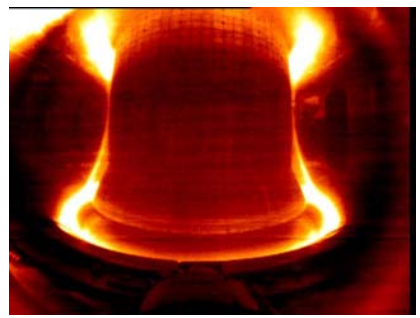
MST



DIII-D



C-Mod



Derek Robinson Has Been a Persistent Force Behind ST R&D

- Derek's hand prints from the beginning
- Caused almost the impossible to happen
- Strengthened our confidence in practical fusion energy
- His vision to support tokamak development and enable ST development lives on