Supported by

NSTX FY05-06 Research in the Collaborative US & World Fusion Program

Martin Peng
Oak Ridge National Laboratory, UT-Battelle
@ Princeton Plasma Physics Laboratory

For the NSTX National and International Team

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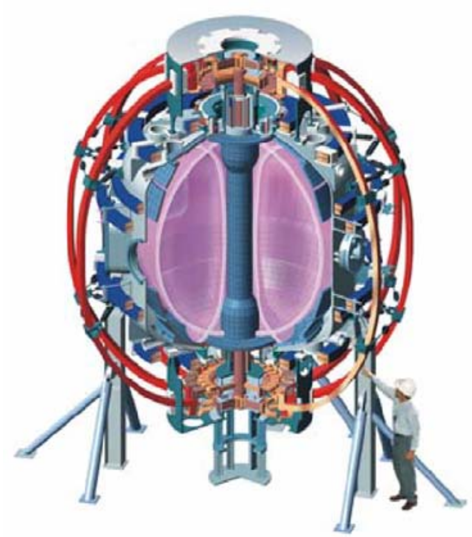
PPPL



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NSTX Can Effectively Address Overarching Scientific Issues of Practical Fusion Energy

Plasma Science Questions	NSTX Scientific Features	$\Rightarrow$	Practical Fusion Energy
1) What causes electron and ion transport?	$\gamma_{ExB}/\gamma_{ITG} \sim 10$; $\beta' \rho_i \sim 0.03$	$\Rightarrow$	Smaller unit size for sustained fusion burn
2) How are plasma pressure & bootstrap current limited?	$M_A \sim 0.3$; $\kappa \sim 2.5$; $B_p \sim B_t$ $\beta_0 \sim 1$; $\beta_N \sim 8$; $f_{BS} \sim 0.7$	$\Rightarrow$	Lowered magnetic field and device costs
3) How do energetic particles & RF power sustain plasmas?	$V_{fast}/V_{Alfvén} \sim 4$; $\varepsilon = \omega_{pe}^2/\omega_{ce}^2 \sim 50$	$\Rightarrow$	Efficient fusion a particle, neutral beam, & RF heating
4) How to convert externally directed energies to plasma magnetic flux?	$\ell_i \sim 0.3$; $\Psi \sim \mu_0 \ell_i R I_p \geq 0.3$ Wb; $K \sim 1.6 \ell_i \kappa a^2 I_{TF} I_p \geq 0.5$ Wb^2	$\Rightarrow$	Simplified smaller design, reduced operating cost
5) How do plasmas interact with materials?	$f_{Trapped} \sim 1$; $B_p \sim B_t$; Flux tube expn. ~ 10-30	$\Rightarrow$	Survivable plasma facing components

- Integration of these leads to compact CTF and practical power plant
- This is a major goal of 5-Year Plan

FY04-06 Research Aims to Advance Physics of High β, Transport, Startup, Current Drive, Boundary & Integration

NSTX

	FY04	FY05	FY06
Exp. Run-Weeks:	18	18	15
1) What causes electron & ion transport?			
	Measure low-k turbulence	Measure hi-k turbulence	
2) How are plasma pressure & bootstrap current limited?			
		Study plasmas near "with-wall" limit	Identify NTM onset conditions
3) How do energetic particles & RF power sustain plasmas?			
	Measure ΔJ from RF, NBI & ∇p	Demonstrate J_{NI} ~ 100% for ≥ τ_{skin}	Assess EBW H&CD (MAST)
	Characterize EBW emission, est. H&CD		
4) How to convert externally directed energies to plasma magnetic flux?			
	Test current initiation		Solenoid-free ramp-up to high β_p
5) How do plasmas interact with materials?			
		Characterize edge of H-mode plasmas	Assess long-pulse heat & particle control
6) How to integrate ST plasma science into attractive regimes for fusion?			
	Assess hi τ_E & hi β_T H-mode for >> τ_E	Assess combined RF & NBI effectiveness	Demonstrate J_{NI} ~ 100% for >> τ_{skin}

Research will be carried out by national & international collaborative team.

The U.S. NSTX Program Is a Highly Collaborative Effort

Institution	Research Topic
Columbia U	• MHD stability & mode control • Stellar x-ray spectroscopy*
Comp-X	• CQL-3D kinetic modeling of RF heating & current drive
GA	• CHI equilibrium, RF physics • Plasma control • Poloidal field coil start-up
INEL	• Tile surface & dust analysis*
Johns Hopkins U	• USXR tomography & diagnostics
LANL	• Visible and infrared imaging • Ultra-fast turbulence imaging • CHI plasma stability modeling
LLNL	• Edge SOL physics • Edge plasma turbulence • Stellar x-ray spectroscopy*
Lodestar	• Edge plasma stability and turbulence
MIT	• ECW-EBW modeling • HHFW modeling
U Rochester	• MHD equil. with flow modeling*

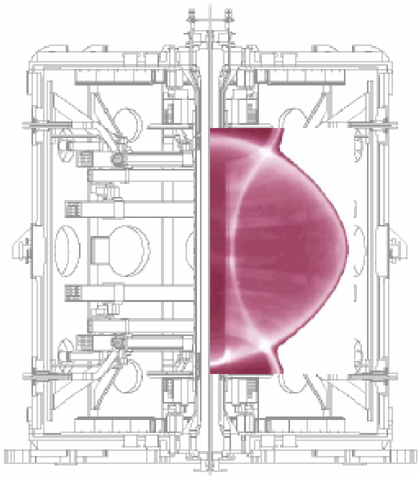
Institution	Research Topic
Nova Photonics	• MSE – CIF & LIF* • Ultra-fast imaging (~10^6 /s)* • Planar LIF*
NYU	• Transport & RF modeling*
ORNL	• HHFW & EBW physics & technology* • Boundary and H-mode physics • RF & transport modeling
PSI	• Ultrafast imaging (~10^6 /s)*
SNL	• Plasma-facing material* • Material surface analysis*
UC Davis	• FIReTIP n, B & fluctuations
UC Irvine	• Turbulence & fluctuations*
UCLA	• Reflectometry & fluctuations
UCSD	• Fast probe, HHFW modeling • Far SOL turbulent transport
U Maryland	• Transport & turbulence sim.*
U New Mexico	• Fast ion-plasma interactions*
U Washington	• CHI research
U Wisconsin	• NSTX neoclassical modeling

* Research cooperation funded by Theory, Technology, Diagnostic Innovations, SBIR, Plasma Science Programs

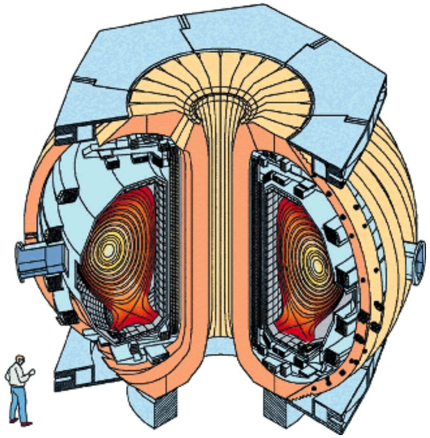
Worldwide NSTX Collaborations are Enhancing ST Contributions to ITPA-ITER

- **Extensive collaboration with MAST**
  - NBI H-mode, ITB, τ_E scaling
  - EBW H&CD, start-up (28, 60 GHz)
  - Fueling, SOL pedestal studies
  - Energetic particle characterization
- **Strong participation in ITPA**
  - **DIII-D, C-Mod**: RWM, Fast ion MHD, pedestal, core confinement, edge turbulence, x-ray crystal spectrometry
  - **A and β effects**: H-mode, ITB, ELM's & pedestal, SOL, RWM, NTM
- **Broad exploratory ST's**
  - **Pegasus**: Extreme low A, EBW
  - **CDX-U/LTX**: Li-plasma
  - **TST-2, LATE**: RF start-up, H&CD
  - **TS-3,4**: FRC-like β~1 ST plasmas
  - **HIT-II/HIT-SI, HIST**: CHI physics

MAST (U.K.)

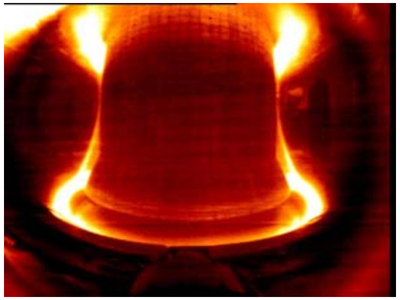


DIII-D (U.S.)



Pegasus (U.S.)

C-Mod (U.S.)



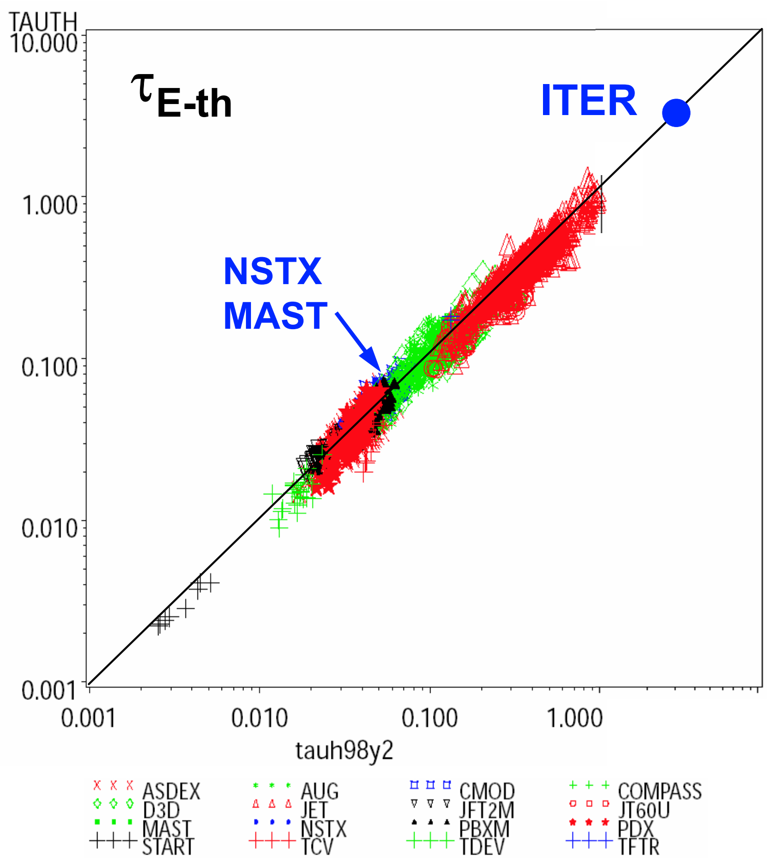
NSTX is Participating Pro-actively in ITPA Collaborations on Important Topics during FY04-06

***Mutually beneficial** joint experiments, comparisons, and database*

	Contacts:
• **Database activity**	
– Improving the condition of global ELMy H mode and pedestal databases (MAST)	S. Kaye, R. Maingi
– β degradation in ELMy H modes scaling	S. Kaye
• **Transport physics**	
– High performance operations with $T_e \sim T_i$ (many devices)	B. LeBlanc
– Dimensionlessly similar aspect ratio and core confinement (DIII-D)	E. Synakowski
– Dimensionlessly similar ITB scaling (MAST)	M. Peng
– Enhanced confinement with low momentum input	B. LeBlanc
• **MHD**	
– Joint experiments on RWM physics (DIII-D, MAST)	S. Sabbagh
– NTM physics - aspect ratio comparison (MAST,DIII-D, ASDEX-U)	D. Gates
• **Pedestal physics**	
– MAST/NSTX/DIII-D similarity	R. Maingi
• **SOL**	
– Scaling of cross-field transport	S. Zweben
• **Diagnostics**	
– Neutron/alpha source profile measurements	L. Roquemore
– First mirror lifetimes	C. Skinner

NSTX Has Made Important Contributions to the ITPA Confinement and Threshold Databases

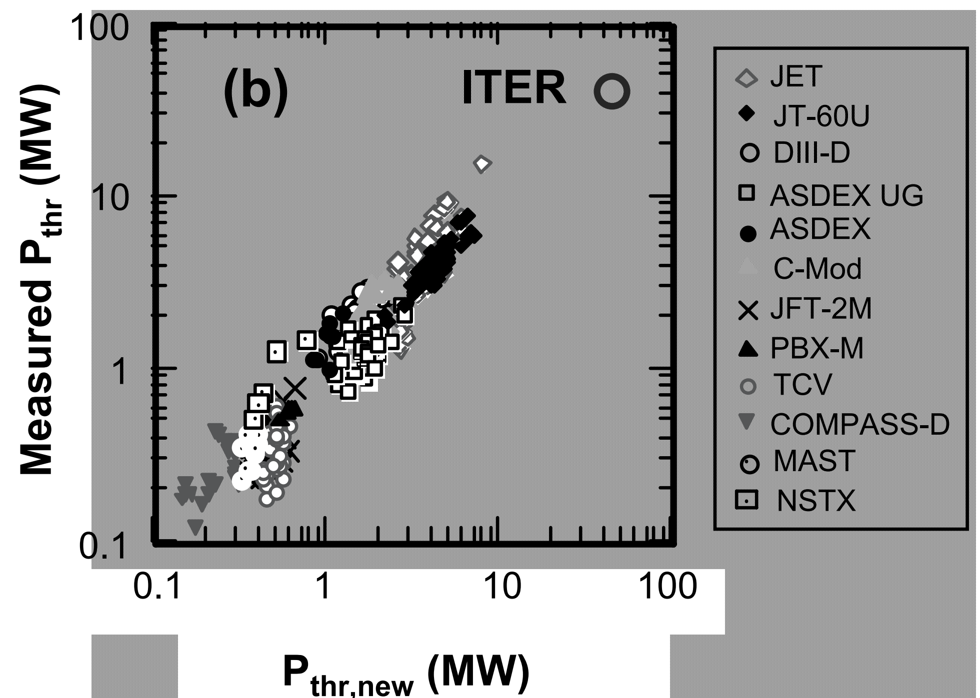
Thermal energy confinement data for both L- and H-mode ST discharges



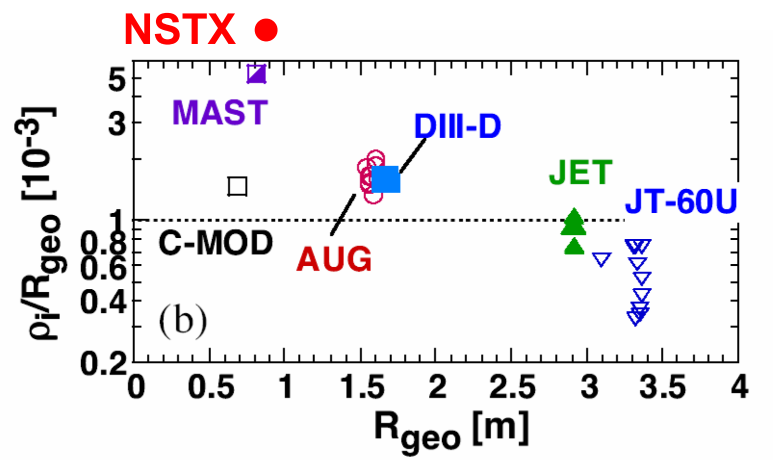
Substantially affected H-mode threshold scaling expression – inclusion of $|B|_{out}$ & A effects

$$P_{thr,new} = 0.072\,|B|_{out}^{0.7} n_{20}^{0.7} S^{0.9} (Z_{eff}/2)^{0.7} F(A)^{\gamma}$$

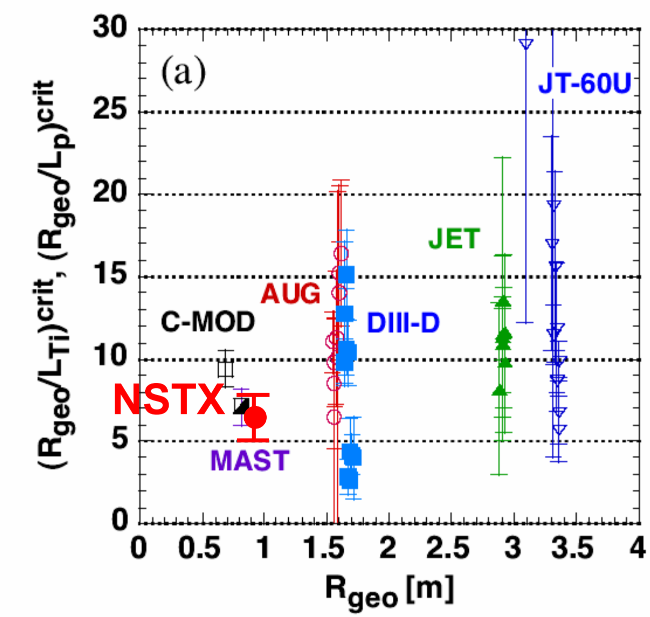
$$F(A) = 0.1A/\{1 - [2/(1+A)]^{0.5}\},\ \gamma = 0.5$$

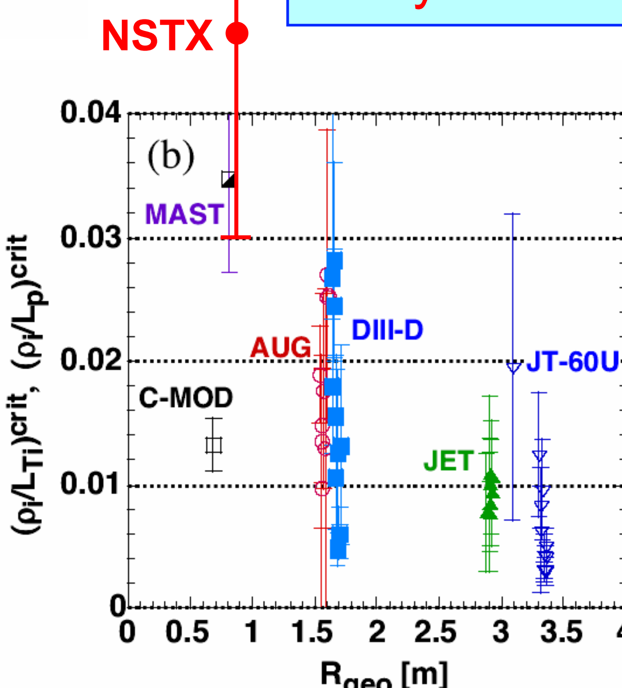


ST Exhibits ITB-Like Formation Conditions That Are Significantly Different From Those in Tokamaks



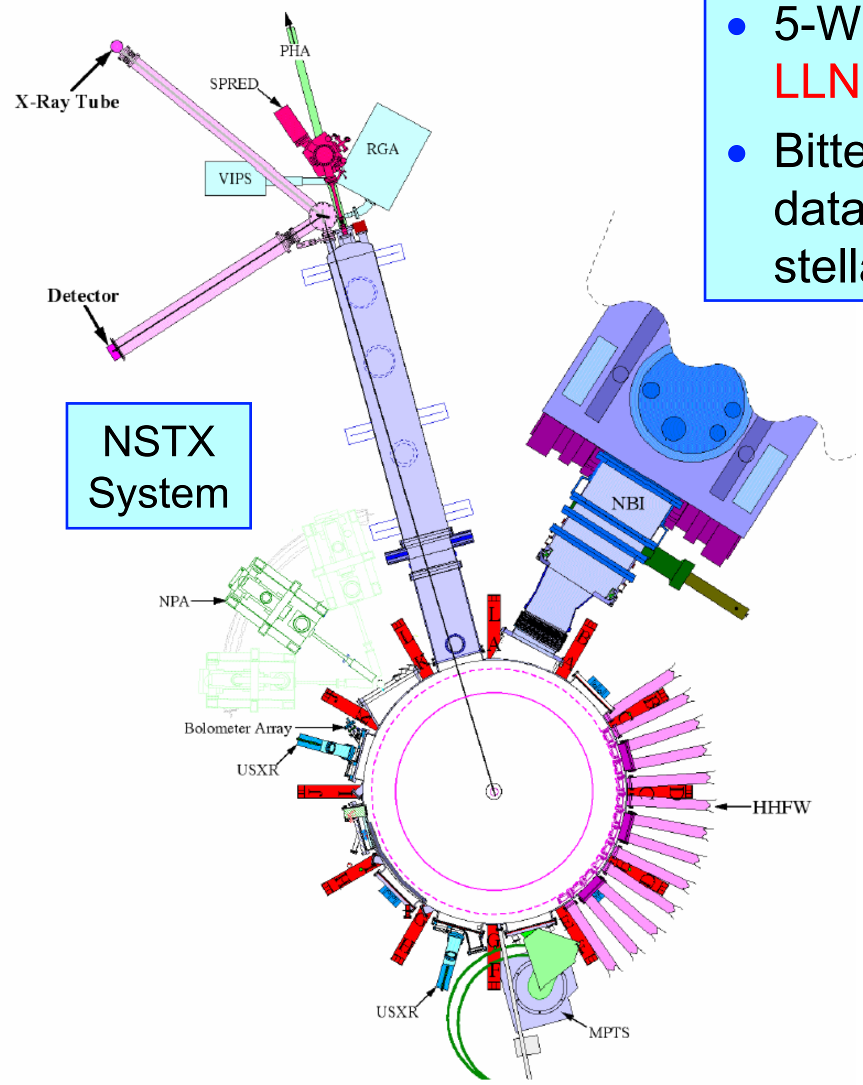
- Critical values of ρ_i/L_{Ti} depend on other quantities than ρ_i and L_{Ti}
- ST data shows high leverage in identifying key mechanisms

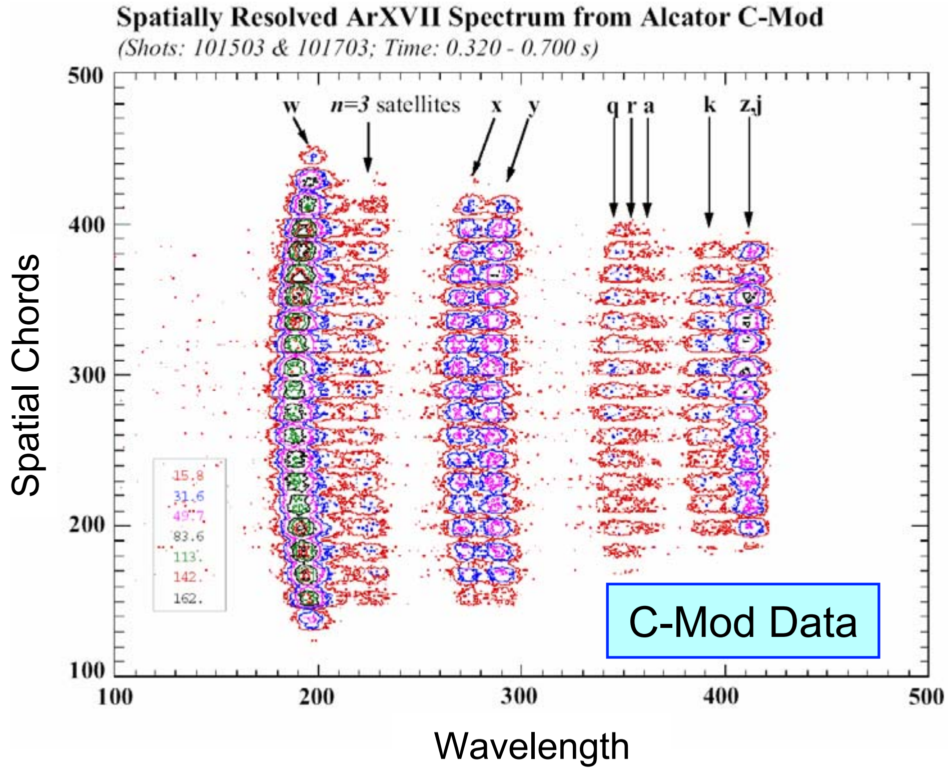




1-D & 2-D X-Ray Crystal Spectrometer of High Interest to Astrophysics Are Applied to NSTX, C-Mod & KSTAR

- 5-Way Collaboration: NSTX, C-Mod, KSTAR, LLNL, Columbia U
- Bitter et al, PRL 2003: benchmarked with TS data, and resolved key issues for comet and stellar flares





Collaboration with DIII-D Has Expanded to a Range of Topics From Operational Development …

- Plasma control (Ferron, Humphreys, Leuer, Walker, Gates, Mueller, Kessel)
  - Development of rtEFIT algorithms, MIMO feedback control
  - Optimization of vertical feedback for high-κ, high-δ operation
- Adaptation of DIII-D techniques to achieve steady-state high-$\beta\tau$ discharges on NSTX (Wade, Menard)
- CHI startup (Schaffer, Lao, Brennan, Raman, Boedo, Ji)
  - Inclusion of open field-line currents in EFIT analysis
  - Theory of helicity transport and experiments to measure it
  - Stability of CHI equilibria
- Outer PF-coil startup (West, Menard, Ono)
- Plasma heating (Pinsker, Wilson)
  - HHFW: comparison of parametric decay and edge absorption
  - EBW: study of poloidally-phased launcher for direct X-B scheme

… to NSTX/DIII-D Comparison Experiments for the ITPA

- MHD (Heidbrink, Edgell, Strait, Garofalo, Reimerdes, Fredrickson, Sabbagh, Sontag, Menard)
  - Alfvén eigenmode similarity experiments
  - Real-time RWM identification algorithms
  - Resistive wall mode physics and control
  - Non-axisymmetric effects of halo currents on stability
- Transport (Petty, Greenfield, Osborne, Snyder, Evans, Synakowski, Kaye, Maingi)
  - Comparison of core transport with matched dimensionless parameters
  - Effect of aspect ratio on the pedestal of ELMy H-mode
  - Application of NSTX RWM coils to produce a stochastic boundary layer for ELM modification
  - TRANSP analysis of discharges with comparable engineering parameters
- Boundary (Boedo, Maingi)
  - Comparison of intermittency in NSTX and DIII-D
  - Comparison of broadband turbulent transport in boundary

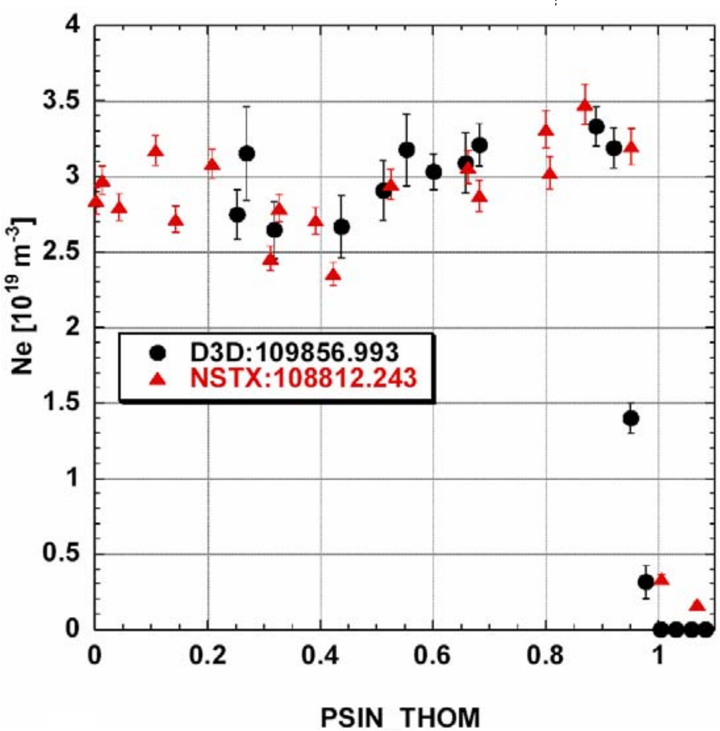
Strategies for Similarity Experiments Have Been Identified to Investigate A-Dependence of Pedestal

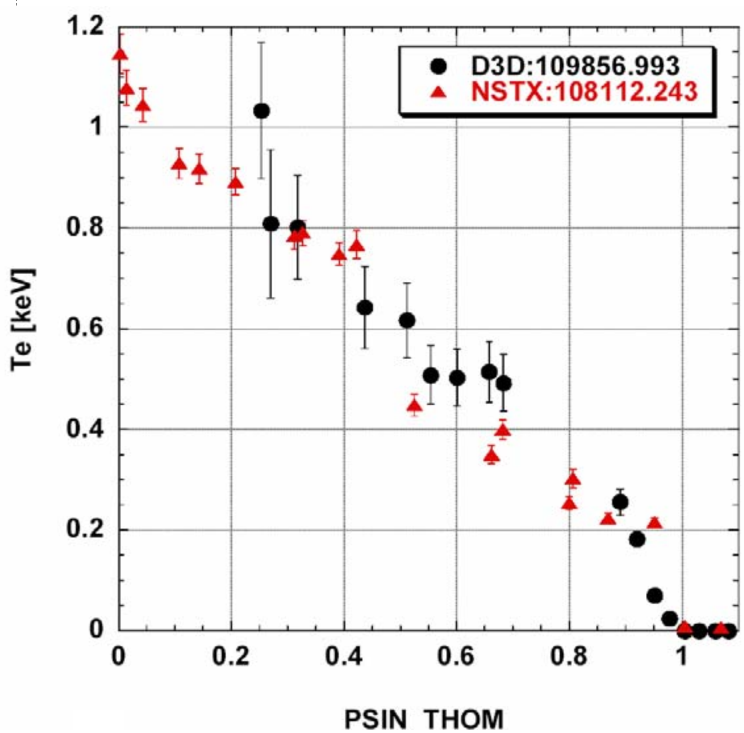
- Early after transition – nearly identical n_e and T_e profiles can be obtained on NSTX – DIII-D:

  I_p: 0.82 – 0.59 MA B_t: 0.45 – 0.62 T

  P_{NBI}: 5.4 – 1.5 MW H_{89P}: 1.8 – 1.6

- A range of plasma conditions will be explored for comparison

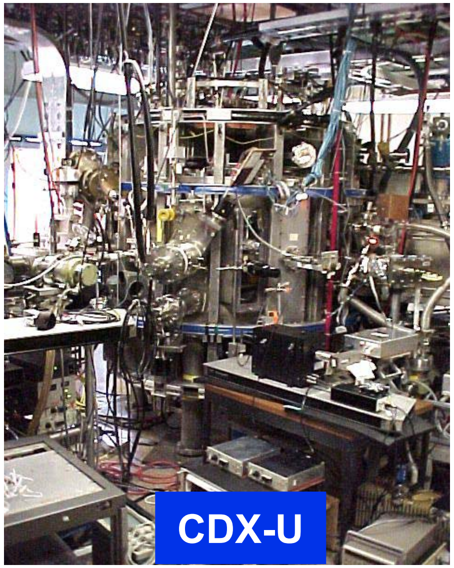


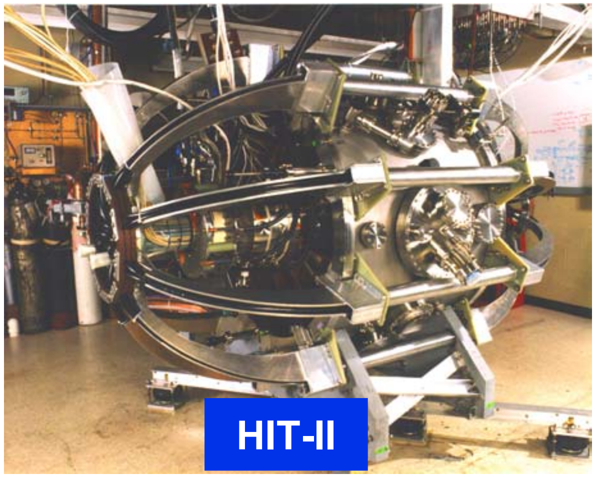


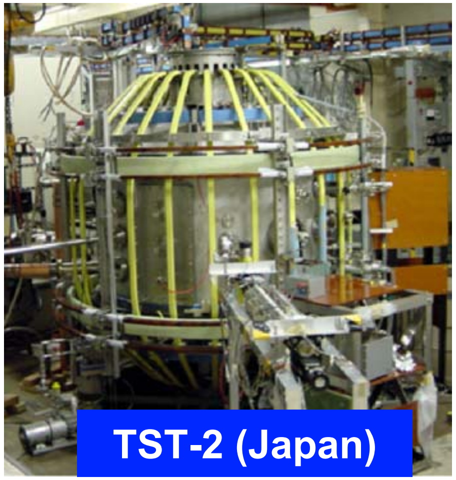
Broad ST Collaborations Will Push New Limits to ST Parameter Space and Technologies

- **Pegasus**
  - Very high I_p/I_{TF} and very small R/a ($\rightarrow$ 1)
  - Very over-dense plasmas
  - Link with FRC, Spheromak
- **HIT-II (HIT-SI)**
  - NSTX CHI improvements
  - Steady helicity injection
- **CDX-U (LTX)**
  - Lithium surface-plasma interactions
  - Upgrade to LTX to study low recycling, flat T regime beginning in FY06
- **TST-2, LATE**
  - Solenoid-free RF start-up & sustainment

To Broaden ST Scientific Basis

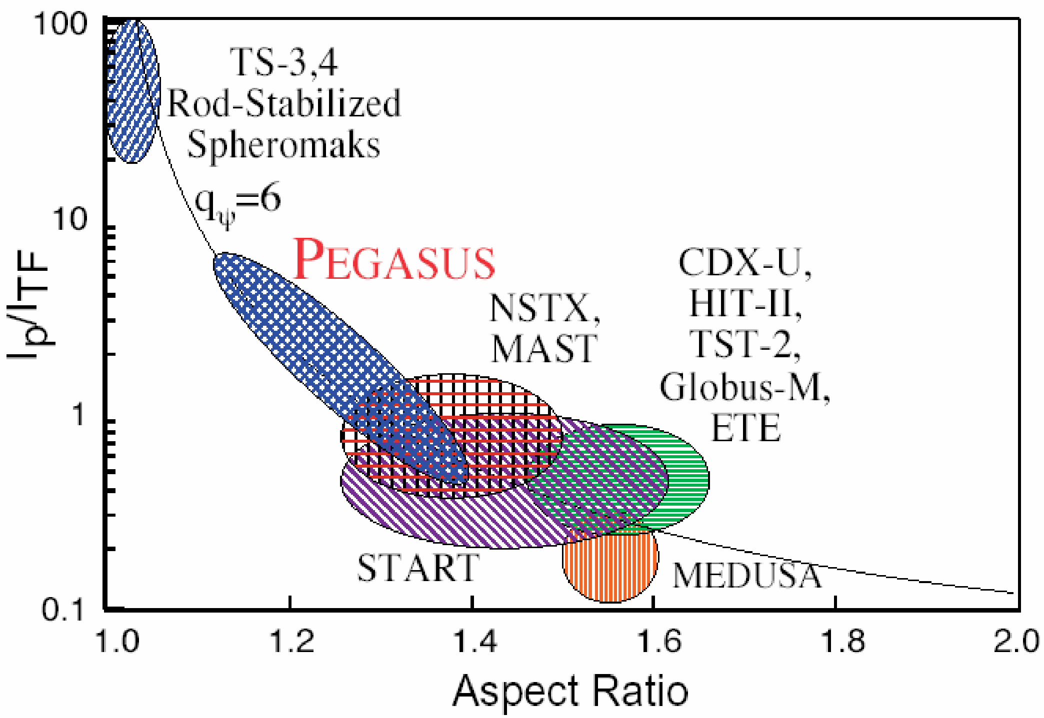






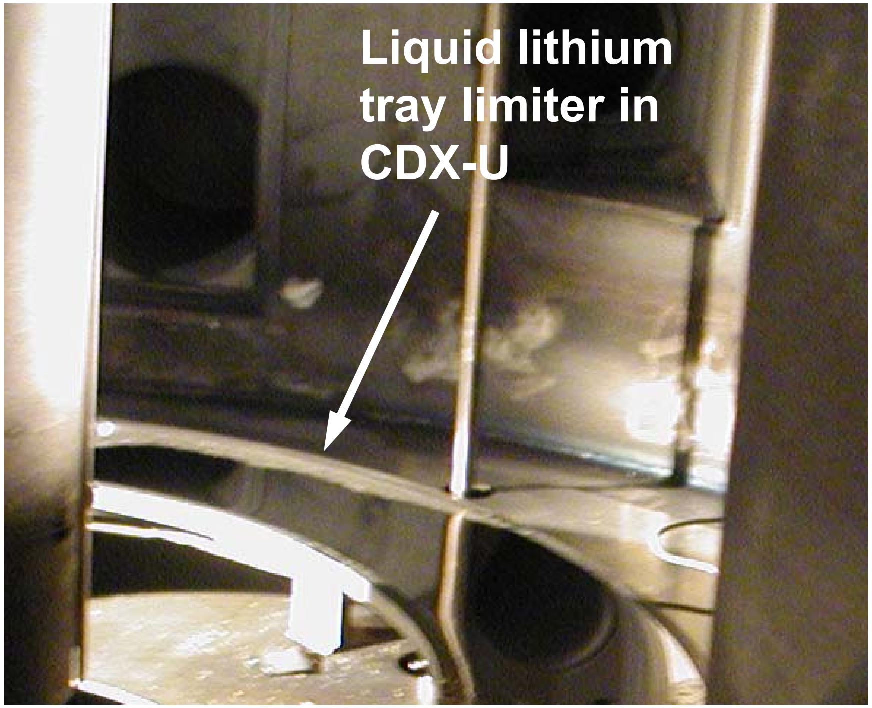
Pegasus Explores ST Regimes As Aspect Ratio → 1

- Stability, confinement at very high I_p/I_{TF} & as $A \rightarrow 1$
- Limits on β_t and Ip/I_{TF}
- EBW properties in very over-dense plasmas (ε = 200 – 1000)
- Physics connections to FRC and Spheromak

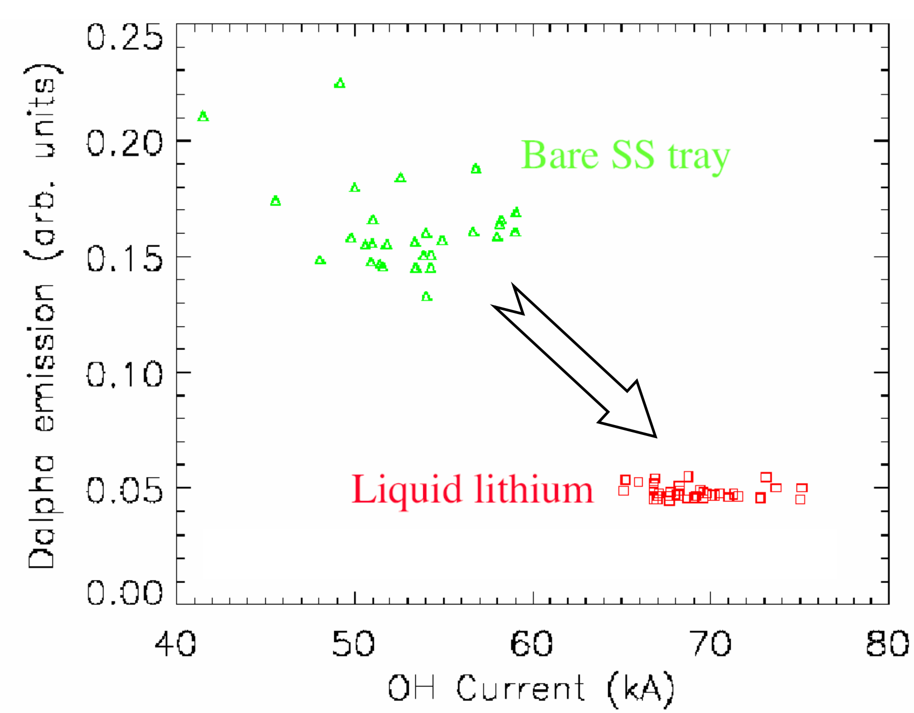


CDX-U Tested Lithium Surface-Plasma Interactions, Producing Encouraging Results

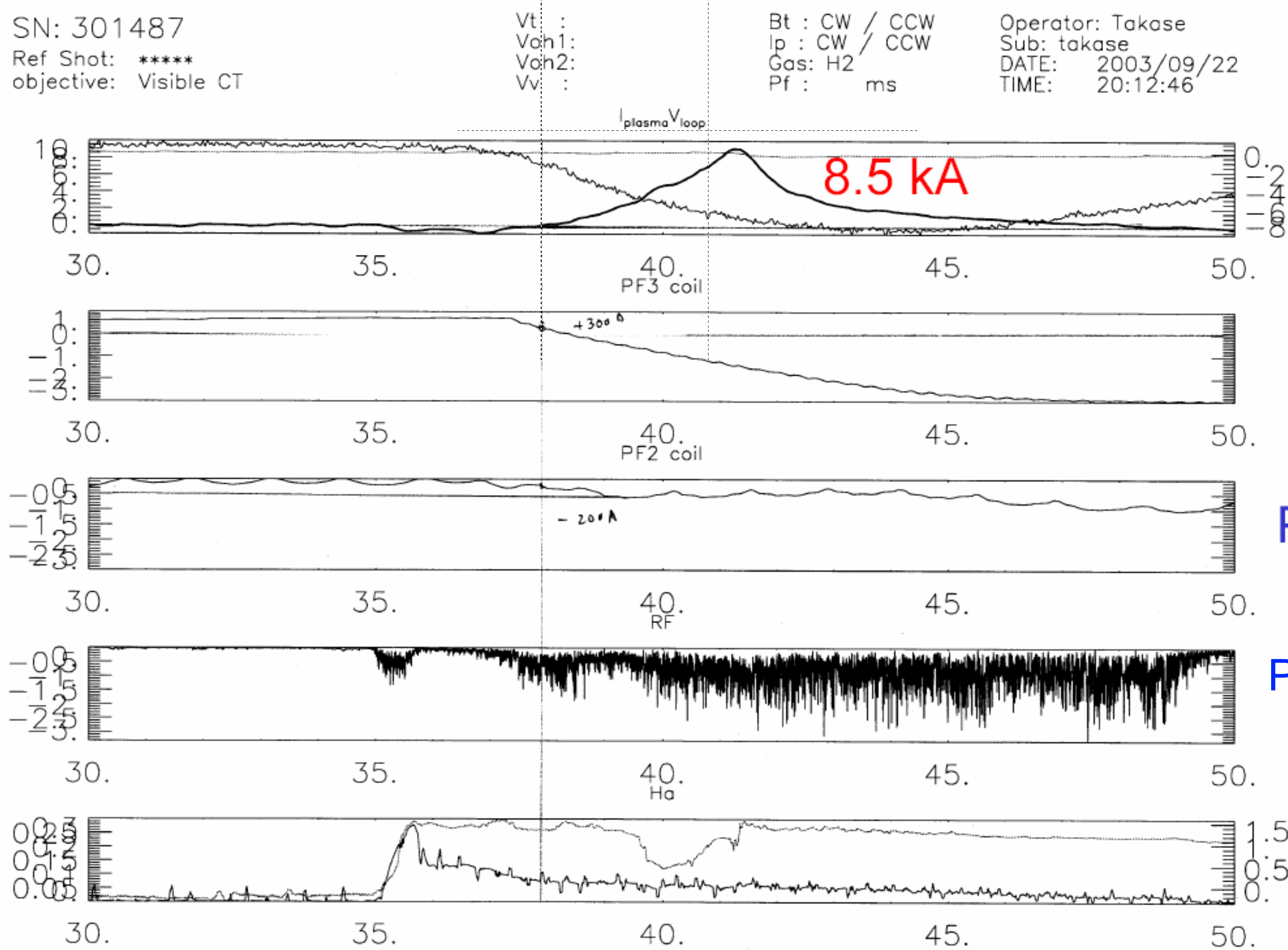
- First successful test of toroidal liquid lithium tray limiter
- Dramatic reduction in plasma edge fuel recycling, lowering impurity influx and loop voltage
- NSTX tests of lithium pellets and lithium wall coating in FY04-05



Tray after ~40 discharges.



I_p Ramp-Up to 8.5 kA Achieved on TST-2 Using “JT-60U” Solenoid-Free Scenario w/o Inboard Shaping Coil



PF3

PF2 + PF5

Pre-
Programmed

NSTX Will Work Actively with the U.S. and World Fusion Community

- Research effectively addresses overarching scientific issues of importance to fusion energy
  - FY04-06 research will make substantial progress towards the goals in the 5-Year Plan
- A national & international research team will carry out this research
  - Highly collaborative national team
  - Proactive worldwide collaboration enhances contribution to ITPA and benefits NSTX research
- DIII-D & C-Mod collaboration has expanded
  - Controls, operations, start-up, heating, MHD, transport, boundary physics, and diagnostics
- Broad ST collaboration (Pegasus, MAST, HIT-II, CDX-U, TST-2, …) will
  - Study extreme low A, CHI, Lithium coatings, and solenoid-free start-up
  - Broaden ST scientific basis for fusion