NSTX Research Forum 2000
(January 31 - February 2)

- **Goals**
  - Present opportunities for collaborative research on NSTX
  - Receive input on scientific elements of NSTX research
- **Agenda**

Monday

I. Goals, Plan, Status, Capabilities, Collaborations, Opportunities

II. Recent Experimental Results

III. Elements of Remaining Phase-I Research (7–9/00)

Tuesday

IV & V. Issues and Opportunities of Phase-II Research (10/00–3/01)

VI. Longer Term Advanced Research Concepts

Wednesday

VII. Session Summaries & Conclusion

Supported by

NSTX Research Program

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Oak Ridge National Laboratory
on assignment at
Princeton Plasma Physics Laboratory

NSTX Research Forum 2000
Princeton Plasma Physics Laboratory
January 31 - February 2, 2000
Princeton, New Jersey, USA

NSTX National Research Team

- Columbia University
- Fusion Physics and Technology
- General Atomics
- Johns Hopkins University
- Los Alamos National Laboratory
- Lawrence Livermore 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

FESAC Panel Sets Challenging Goals and Opportunities for ST Research

- **Summary:** Focus the moderate-pulse advanced tokamak program, ..., and to a lesser degree the spherical torus program, toward a 5-year assessment point; and prepare for participation in a burning plasma experiment
- **Goal 1 - Advance fundamental understanding of plasmas, ..., and enhance predictive capabilities, ...**
- **Goal 2 - Resolve outstanding scientific issues and establish reduced-cost paths to more attractive fusion energy systems ...**:

  5 years: make preliminary determination of the attractiveness of the Spherical Torus, by assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths >> energy confinement times.

  10 years: assess the attractiveness of extrapolable, long-pulse operation of the Spherical Torus for pulse lengths >> current penetration times.

FESAC Panel Sets Challenging Goals and Opportunities for ST Research (cont.)

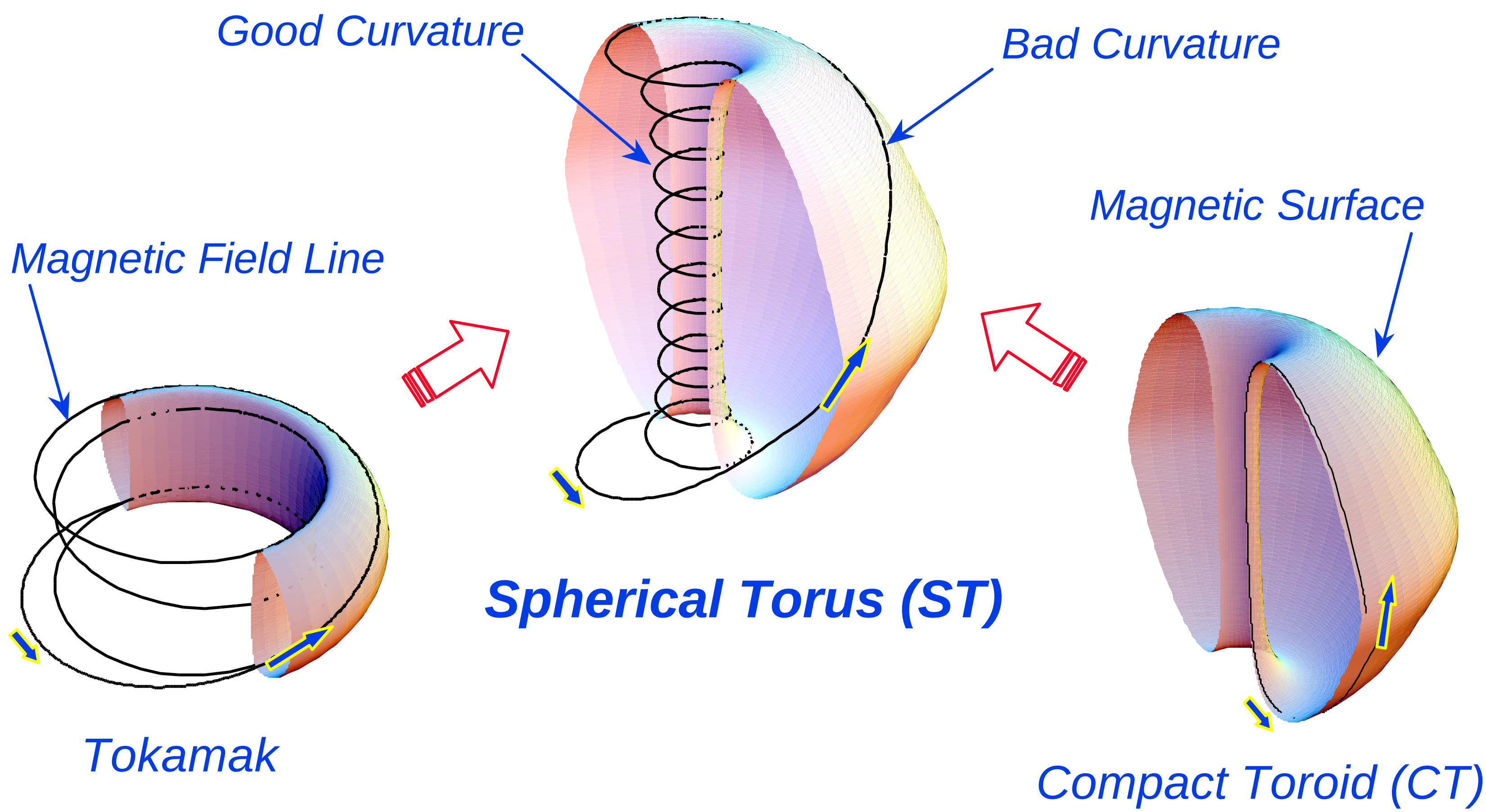
- **Goal 3 - Advance understanding and innovation in high-performance plasmas, ...**:

  ***10 years**:* assess potential of Spherical Torus as a basis for burning plasma studies and/or fusion-nuclear component testing.

- **Goal 4 - Develop enabling technologies to advance fusion science; pursue innovative technologies and materials to improve the vision for fusion energy; ...**:

  ***5 years**:* ... including advanced methods of plasma measurements, heating, current drive, flow control, and fueling. ... innovative plasma chamber technologies ...

ST Innovation: Minimizing Aspect Ratio Maximizes Field Line Length in Good Curvature



This enhances the potential for high plasma beta and confinement

Spherical Torus Introduces Both Exciting Fusion Science and a Possible Practical Route to Energy

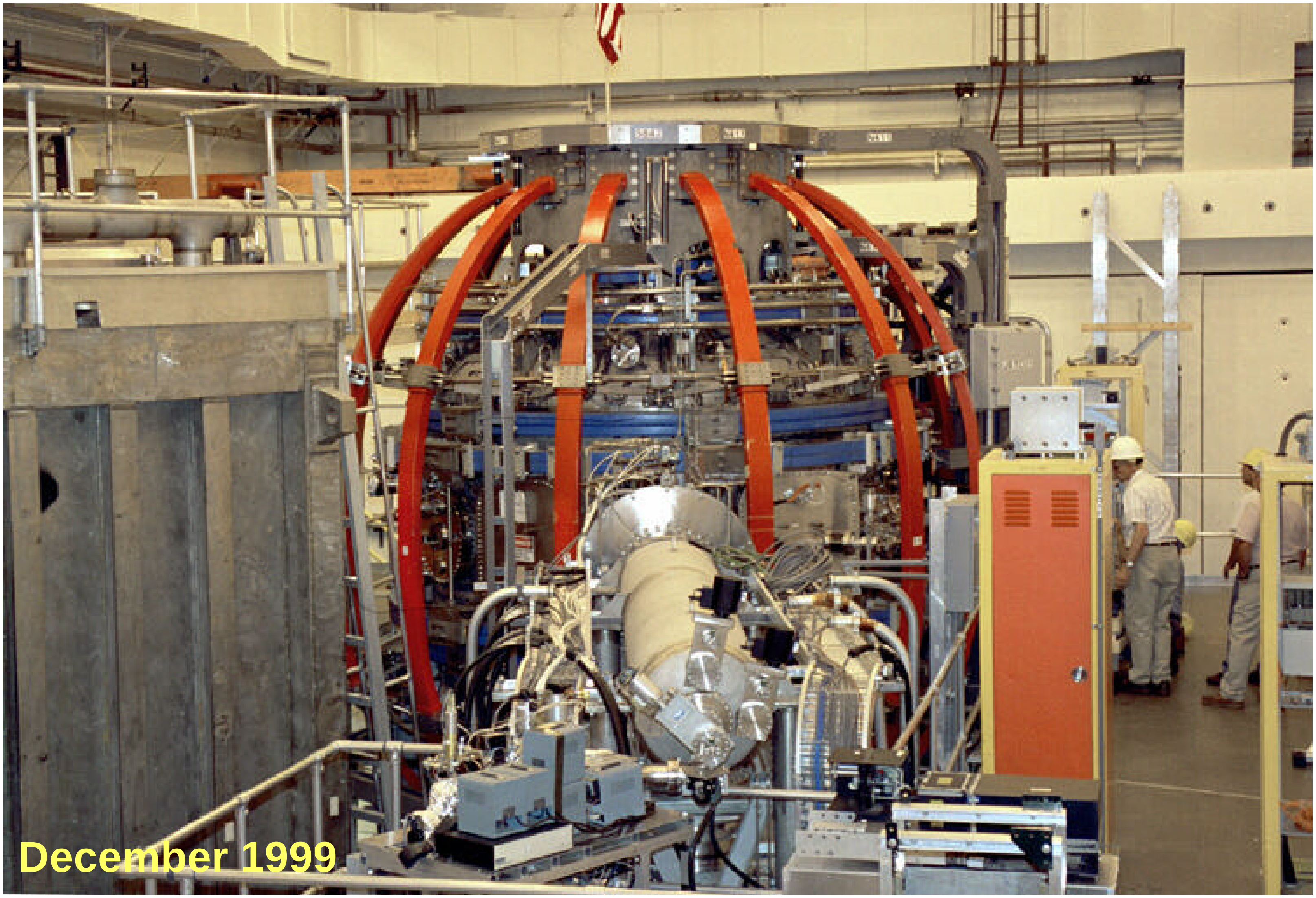
Promise: ***SCIENCE*** « ***ENERGY***

High Pressure, Low Field	↔	Low Device Cost
Suppressed Turbulence	↔	Small Unit Size
Dispersed Exhaust	↔	Reliable First Wall
Self-Sustaining Current	↔	Lowered Operating Cost
Startup Without Solenoid	↔	Simplified Compact Configuration

New Challenge: SCIENCE, TECHNOLOGY, MATERIAL

Noninductive Startup	↔	Single-Turn Center Conductor
	↔	Recirculating Power, Lifetime

NSTX is Progressing Rapidly Toward a Leading Fusion Science Research Facility



NSTX Research Program Mission and Near Term Goal Areas

- **Mission: Test Scientific Principles of Spherical Torus**
  - Understanding of broad ST fusion energy science principles
  - Data for optimization of confinement system
  - Data for development of affordable energy development path

- **Five-Year Goal Areas**

  Phase I. Inductive plasmas (9/99 – 9/00)

  Ohmic optimization, HHFW & CHI tests, NBI installation

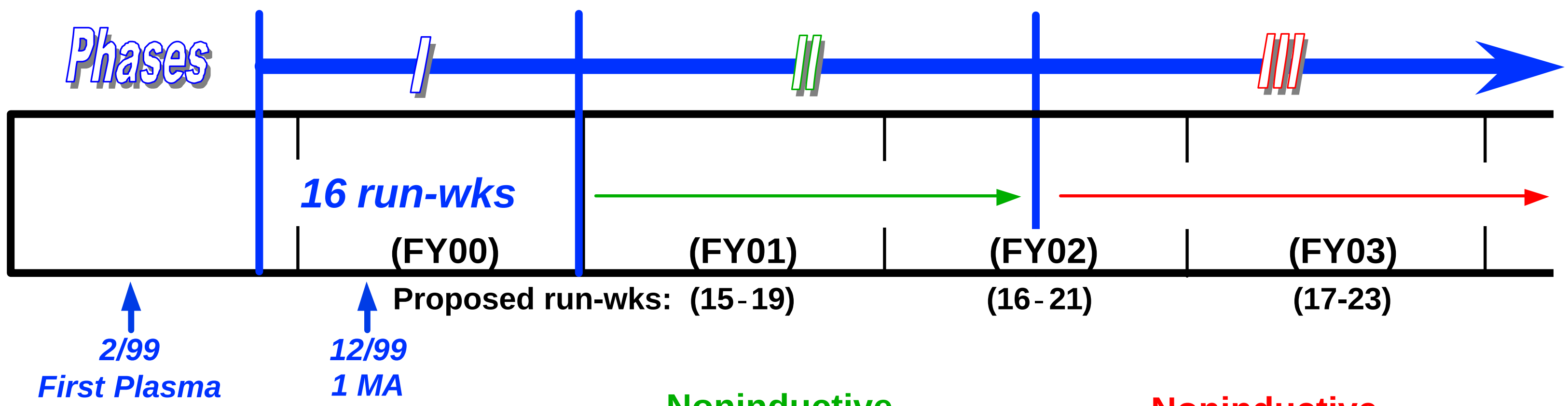
  Phase II. Noninductive assisted plasmas (10/00 – 3/02)

  Startup, heating, high beta, high confinement, edge, operations

  Phase III. Noninductive sustained plasmas (4/02 - 9/04)

  Current drive, high bootstrap, turbulence suppression, mode control, high edge power

NSTX Research Plans to Investigate in 4 - 5 Years Issues Crucial to ST Physics Principles



	Inductive	Noninductive Assisted	Noninductive Sustained
• **Toroidal Beta, b_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
• **EBW Power**	• ~ 30 kW	• → 0.4 MW (incremental)	• ~ 0.4 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, edge	• turbulence, mode control

Phase-I (9/99 - 9/00): Explore and Establish Startup and Ohmic/Low Auxiliary Power Operational Space

NSTX

ST Scientific Goals

- Characterize ohmic and low heating power confinement and operational limits (including shaping, divertors)
- Test and develop HHFW heating scenarios
- Test and develop CHI current startup scenarios

Questions for Discussion Sessions

- What has been accomplished so far?
- What analysis to complete prior to resumption of operation?
- What should be the scientific elements of the remaining experimental runs?

Phase-II (10/00 - 3/02): Characterize Noninductive Startup and Strong Heating Physics without Wall Stabilization

ST Scientific Goals

FY 2001

- Test and establish new methods for starting up plasma
- Determine plasma heating physics to high temperatures
- Clarify stability to large scale MHD perturbations at high β
- Characterize micro-turbulence and its suppression under intense heating

FY 2002

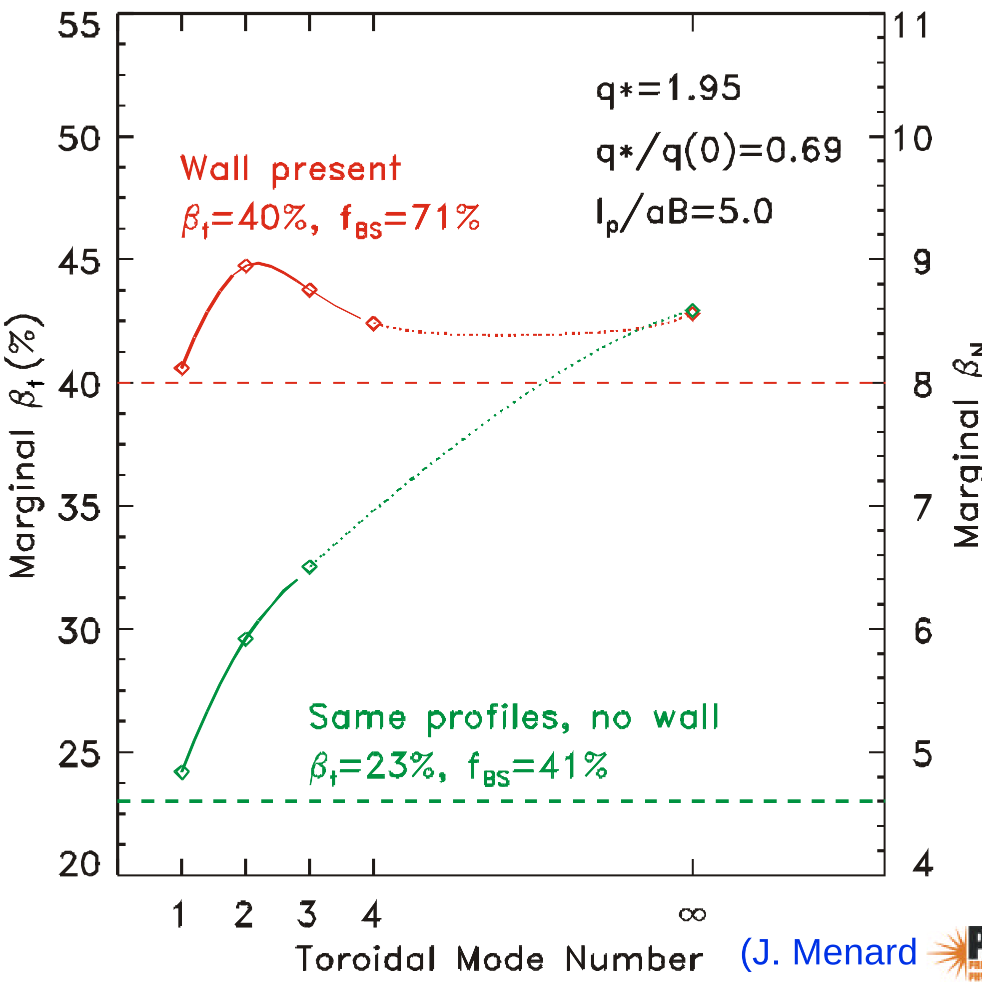
- Understand new mechanisms for dispersing plasma fluxes
- Evaluate and determine compatibility of stability at high pressure and high confinement

Questions for Discussion Sessions

- Feedback on draft NSTX scientific milestones (see WebPage)?
- What should be the scientific elements of research?
- Are the capabilities and tools adequate?
- What new diagnostics will be needed?

NSTX Provides Opportunities to Study No-Wall and Wall-Stabilized Beta Limits at q ~ 10 and κ ~ 2

κ = 2.0, β_T = 23–40%, β_N = 4.5–8, q_{edge} ~ 10



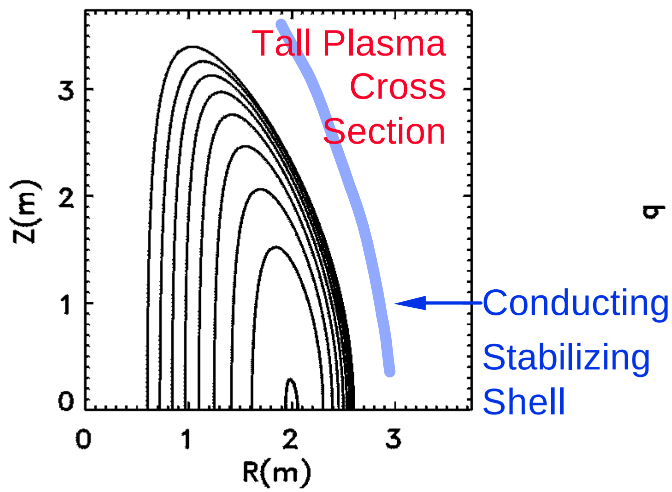
(J. Menard)

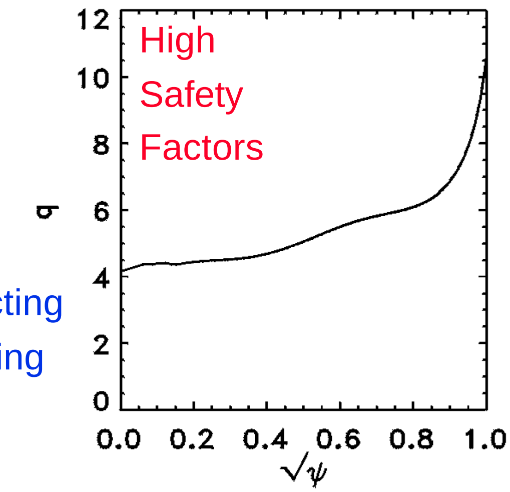
Scientific Issues

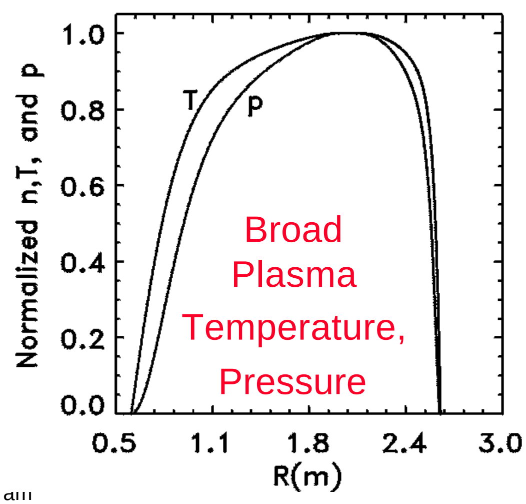
- Profile dependence
- q and κ dependence
- Heating effects
  - NBI (5 MW)
  - HHFW (6 MW)
  - ECW/EBW (0.4 MW)
- Wall effects
- Rotation effects
- Resistive wall modes
- Tearing modes
- Compatibility with high confinement

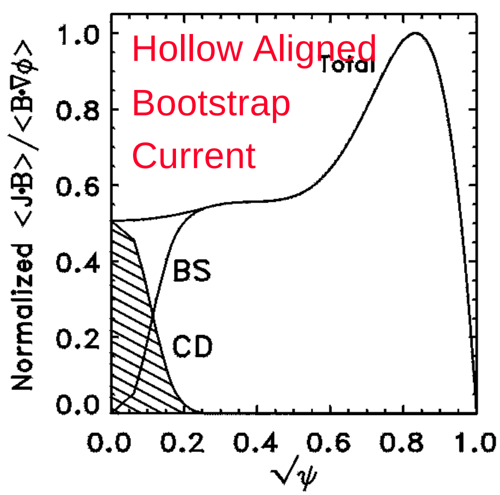
Recent Stability Calculations Suggest Route to Very High b Self-Sustaining Plasmas for Reactors

$\kappa = 3.4$, $\beta_N = 8.2$, $\beta_T = 56\%$, $\langle\beta\rangle = 42\%$, $f_{BS} = 99\%$, $q_{edge} \sim 11$









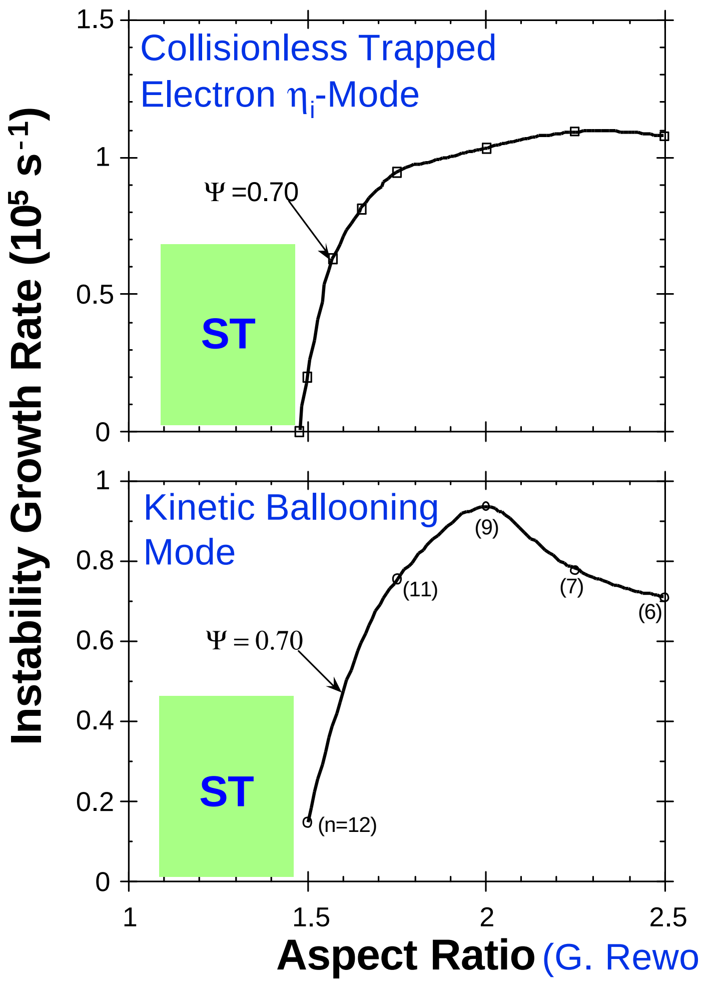
Scientific Challenges

- Vertical stability
- Disruptions
- Resistive Wall Mode stability & control
- Neoclassical tearing mode stability
- Profile tailoring
- Bootstrap current alignment

(J. Menard, PPPL)

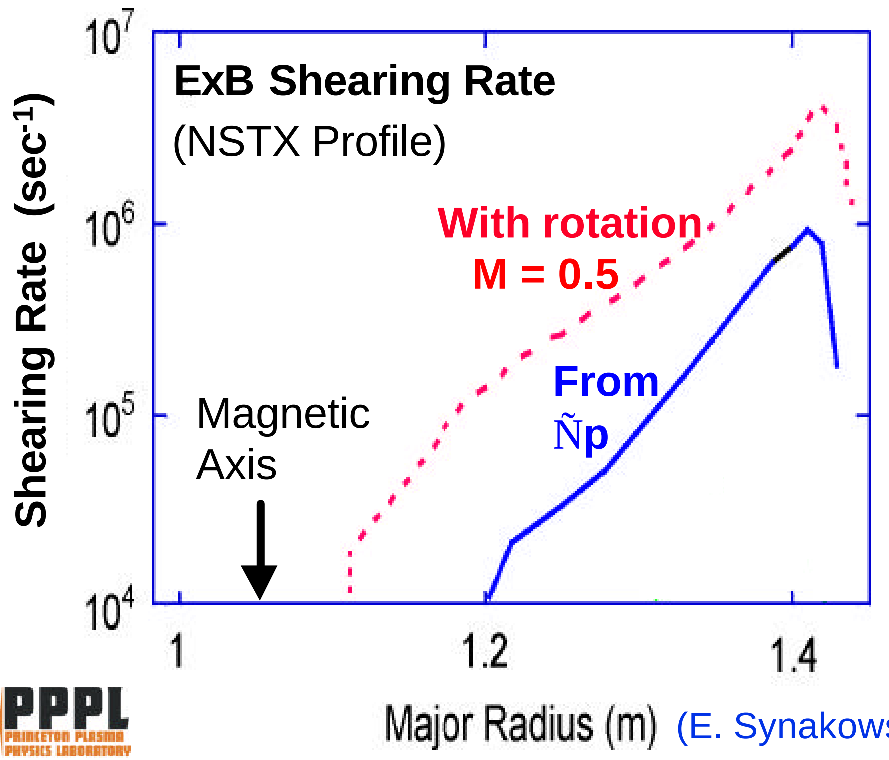
NSTX Promises Regimes Where Flow Shear Dominates over Micro-Instability Growth

Reduced Micro-instabilities



(G. Rewoldt)

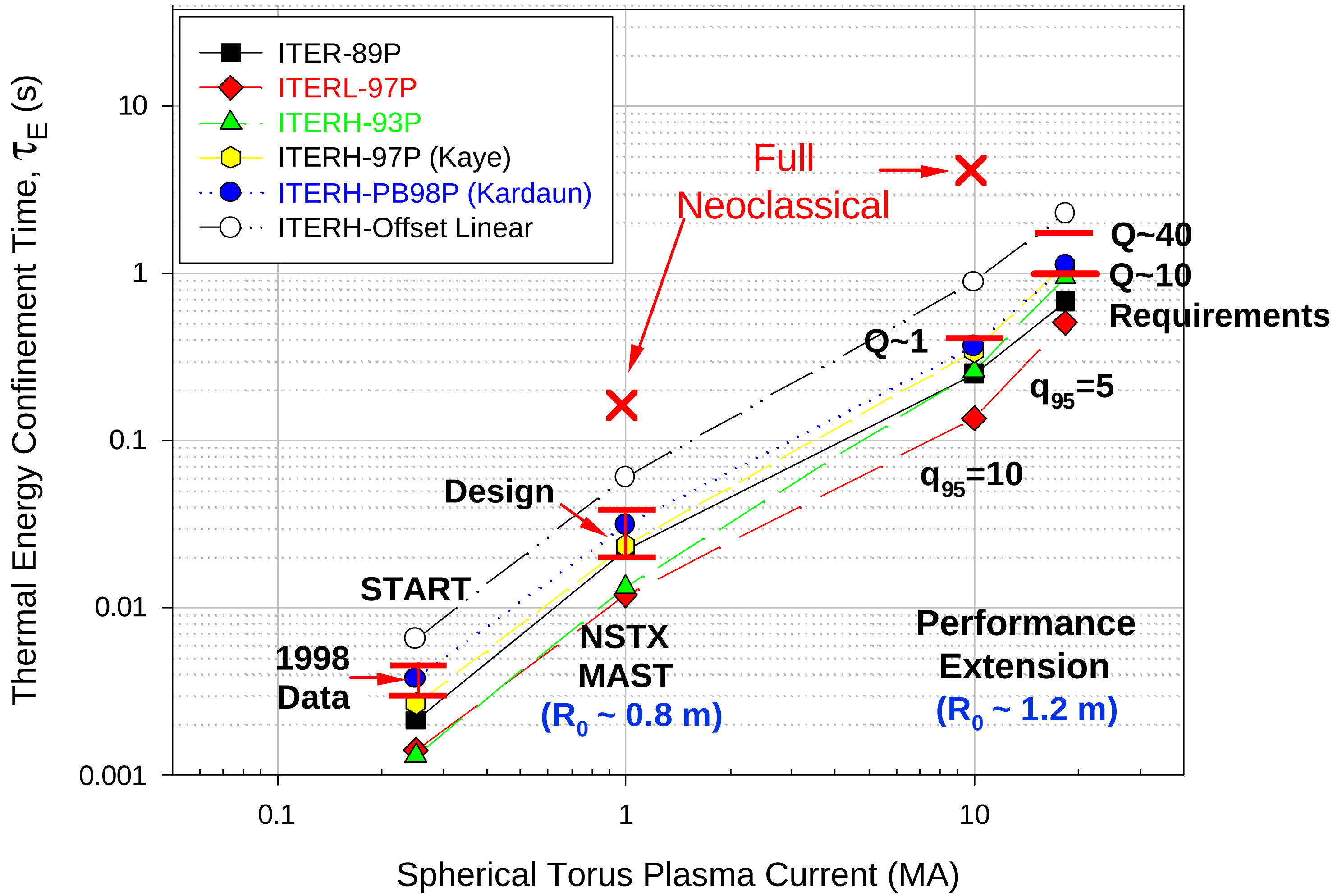
Increased Stabilization



(E. Synakowski)

- Competition between momentum input and diamagnetic flow
- Effects of strong electromagnetic and electrostatic fluctuations

Enhanced Confinement in NSTX Projects to High Performance Performance Extension Test

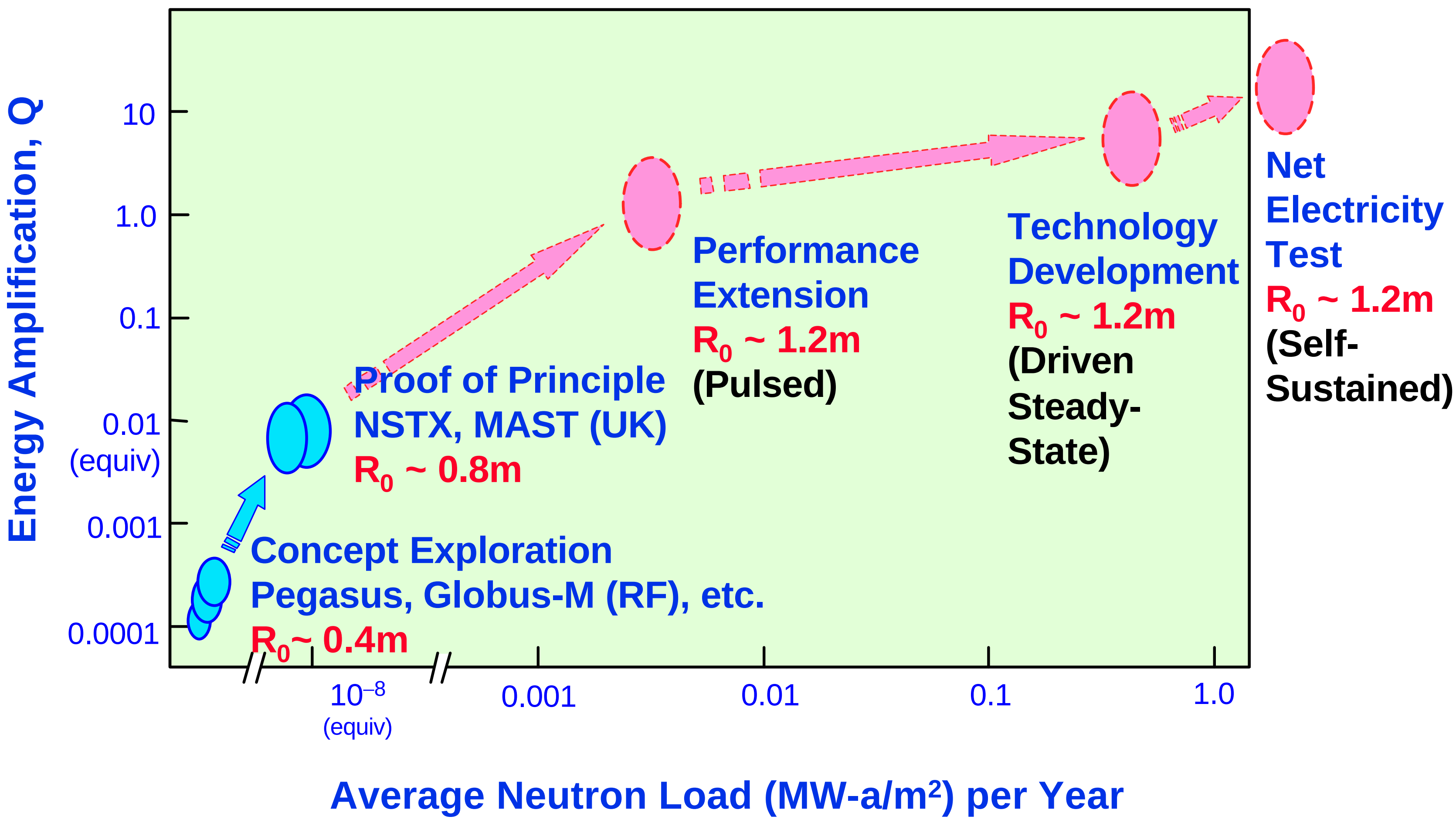


ST experiments will improve understanding of plasma transport.

ST Introduces Additional Opportunities for Advanced Concept Scientific Research

- **Strong magnetic well (~30%), near-omnigenous orbits**
  - Guiding-center orbit compression, reduced neoclassical transport?
- **Large Pfirsch-Schlüter current**
  - Stabilization of neoclassical tearing modes at high β?
- **v_{sound} ~ $v_{Alfvén,}$ where local b ~ 1**
  - “Dynamic” equilibrium with strong plasma flow?
  - Influence on stability and turbulence?
- **v_{fast} >> $v_{Alfvén}$ for fast ions or fusion a particles**
  - New classes of Toroidal Alfvén Eigenmodes, and effects?
- **Extreme low A (~1.1) – e.g., Pegasus (U. Wisc.)**
  - Connections to FRC and Spheromak?
- **Liquid wall possibilities – APEX Program (UCLA)**
  - Minimize recycling, handle large power and particle fluxes?

ST Development Path to Fusion Energy Science & Technology May Be More Affordable



NSTX Program and Teams are Working Together to Meet the FESAC Goals

- National research and operations teams performing very well
  - Already delivered 1 MA current, 2 MW HHFW power, 130 kA CHI current
- NSTX facility progressing rapidly
- Exciting new opportunities to advance fusion energy science
- Aggressive plan to address PoP issues
  - Three research phases in 4-5 years
  - Focus on FESAC 5-year goals
  - Also explore advanced longer term research concepts
    - $\Rightarrow$ Affordable fusion development path
- Research Forum a crucial component

Progress, Capabilities, Plan, Opportunities, Collaborations, and Research Elements of NSTX

- Device and Facilities (Ono)
- Research Operations (Hosea)
- Diagnostics (Johnson)
- Physics Analysis (Kaye)
- Run Coordination (M. Bell)
- Phase-I Experimental Results (3 plenary talks)
- Phase-I Remaining Research (3 parallel sessions)
- Phase-II Research (5 parallel sessions)
- Longer Term Advanced Research (1 parallel session)