National Spherical Torus Experiment:

A National Fusion Science Facility

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For the NSTX National Team from 14 Institutions

NSTX National Team Members

Princeton Plasma Physics Lab*
Oak Ridge National Laboratory*
Columbia University*
University of Washington*
Fusion Physics and Technology
General Atomics
Johns Hopkins University
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Massachusetts Institute of Technology
Sandia National Laboratory
University of California at Davis
University of California at Los Angeles
University of California at San Diego
University of Wisconsin

* Asterisk indicates the NSTX Construction Project Team.

Research collaboration also include researchers from Ioffe Lab., Culham Lab., University of Tokyo, and Hiroshima University

Presentation Outline

- NSTX Project Activity
- NSTX Device Operation
- Future Plans
- Summary

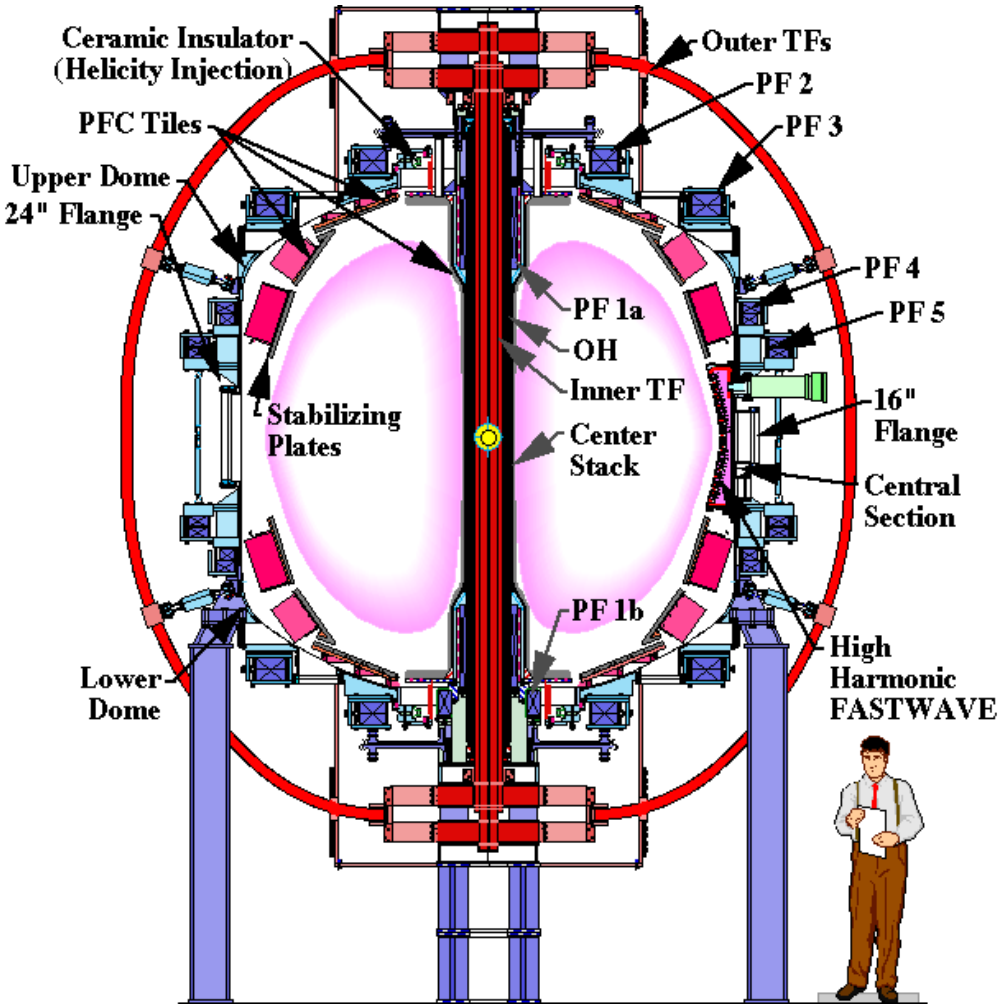


Fig. 1. A schematic of the NSTX device cross-section.

Successful Completion of NSTX Construction Project

- First Plasma "Flash" Achieved in the last day of PAC 6 (2/12)
- First Plasma Milestone (50 kA) Achieved (2/15)
- ≈ 300 kA plasma achieved with about 1/3 OH flux (2/16)
- Secretary Richardson's dedication of NSTX (2/25)
- Centerstack removed from the device to its work stand (3/10)
- HHFW antenna installed (7/7)
- All the TPC tasks completed on budget as defined in MOU (7/8)
- Center stack reinstalled with CHI ceramic insulators (7/16)
- Vacuum pump down started and leak checked (7/20)
- Power supply dummy load test completed (7/30)

NSTX is rapidly moving into new territory!

- TF Coils tested successfully to 3 kG (from 2 kG) and all PF Coils tested to 20 kA (from 10kA). OH Coil was tested with double swing at 18 kA (3/4 if capability). (8/30)

- ECH Preionization System (ECP) became operational. (9/3)

- OH Plasma restarted with ECP. (9/3)

- Centerstack resistively baked to 208 °C for the first time. (9/8 – 9/13)

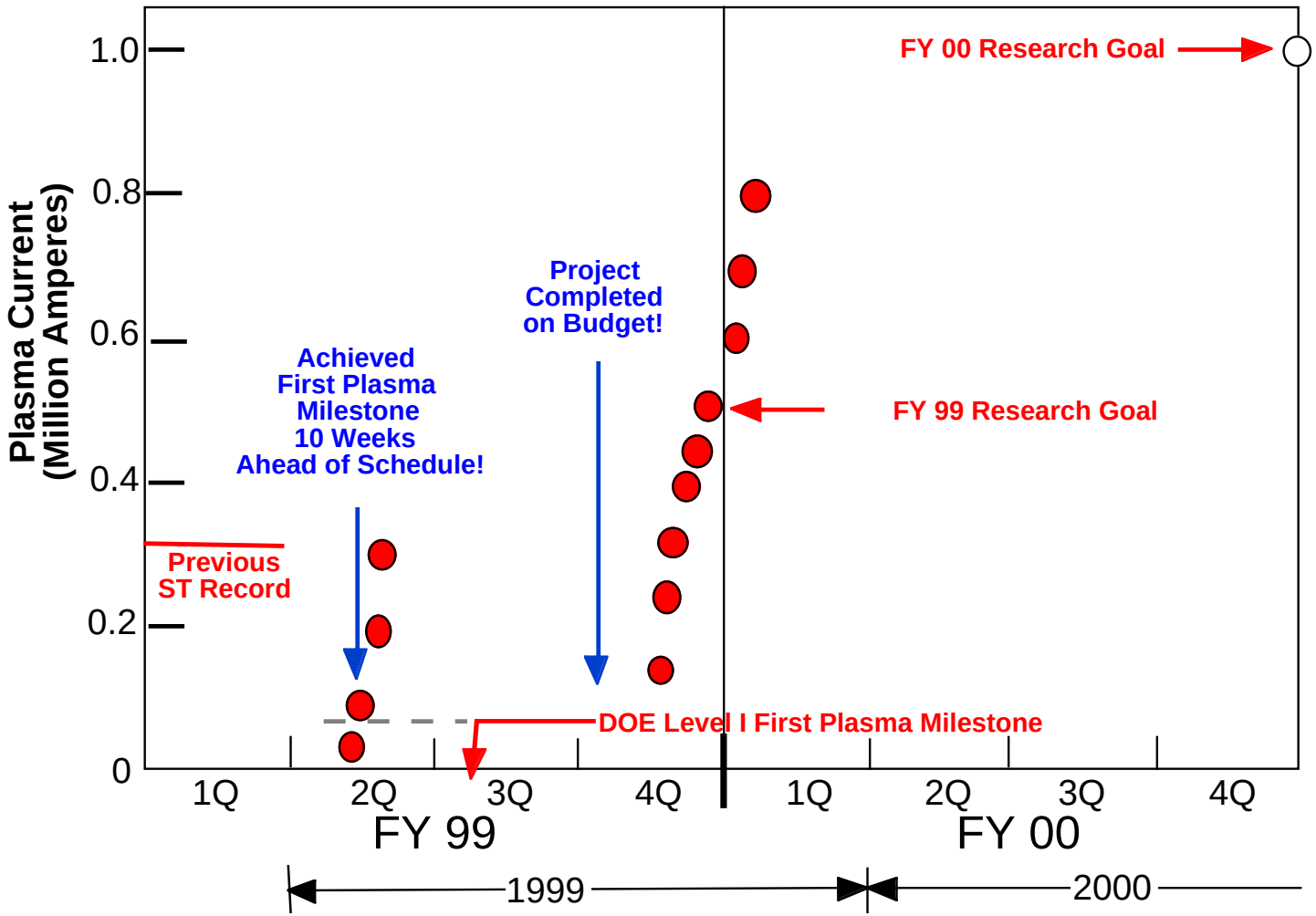
- 250 kA discharge obtained with single swing OH. (9/15)

- Vertically stable discharge of 450 kA (480 kA peaked) current was maintained for 100 msec with OH double swing for the first time. (9/20)

- Real time plasma control system was actually used to create 800 kA plasma discharges! (11/99)

Plasma is improving rapidly!

NSTX



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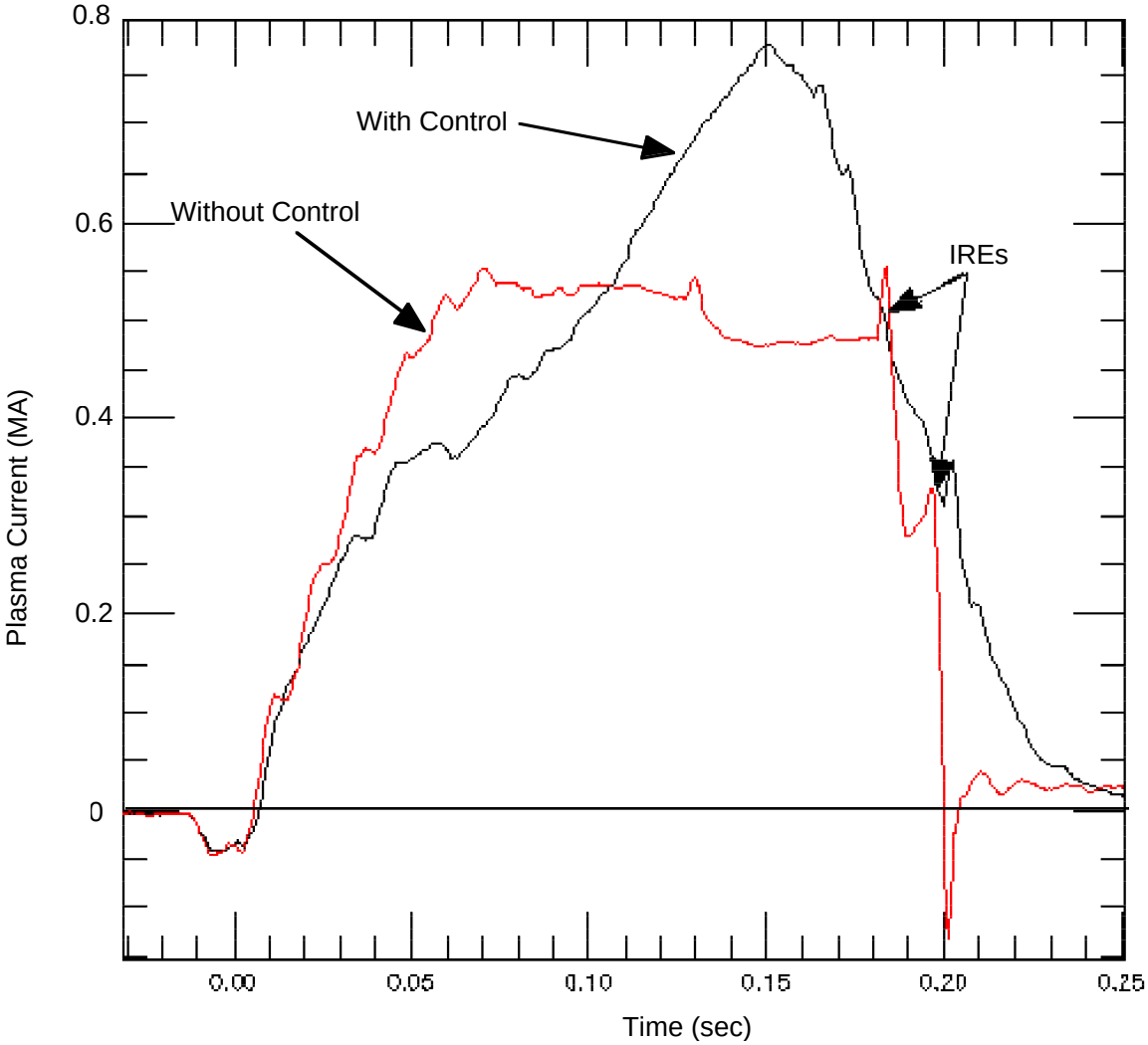
Plasma Control Works Well!

NSTX



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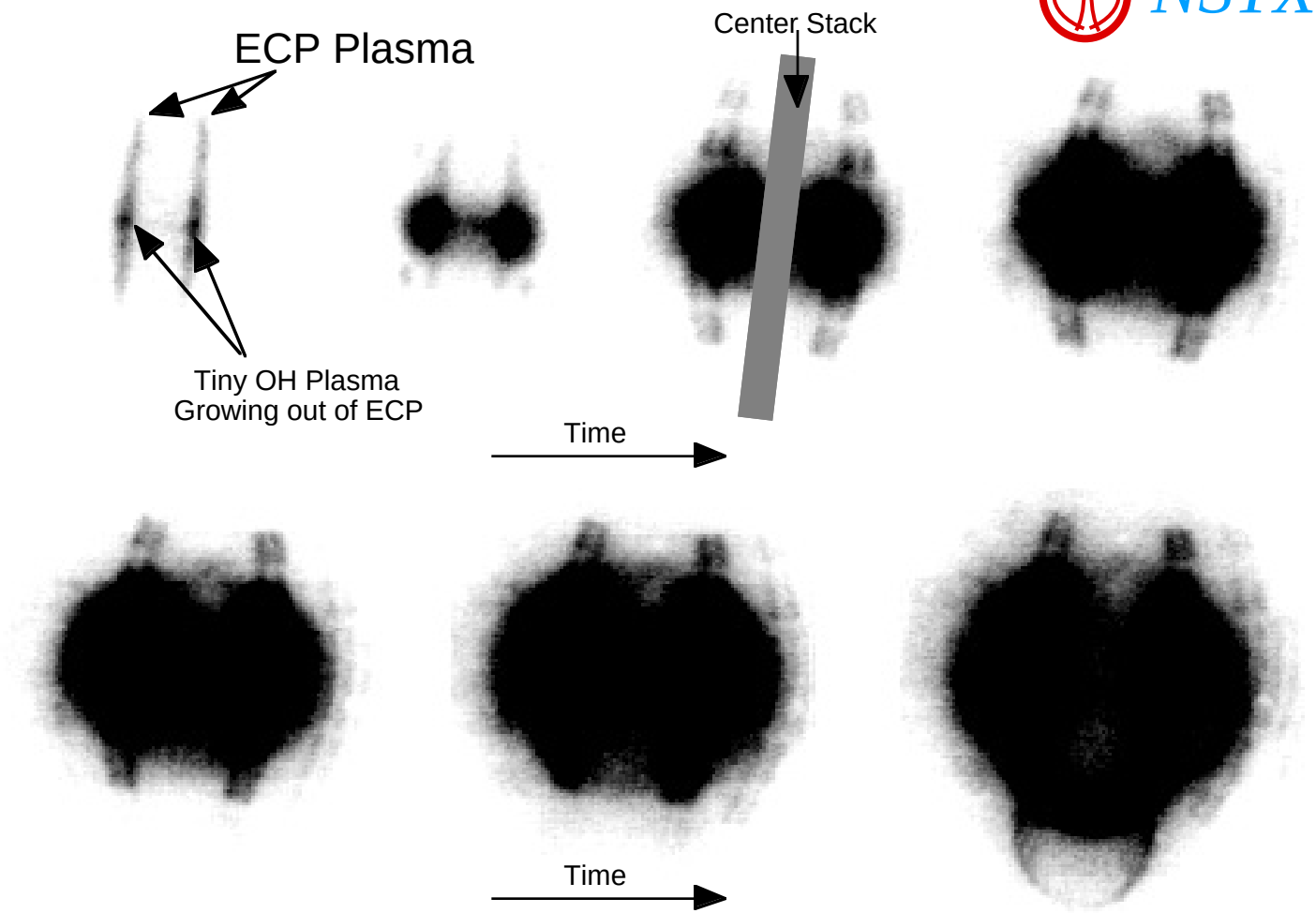
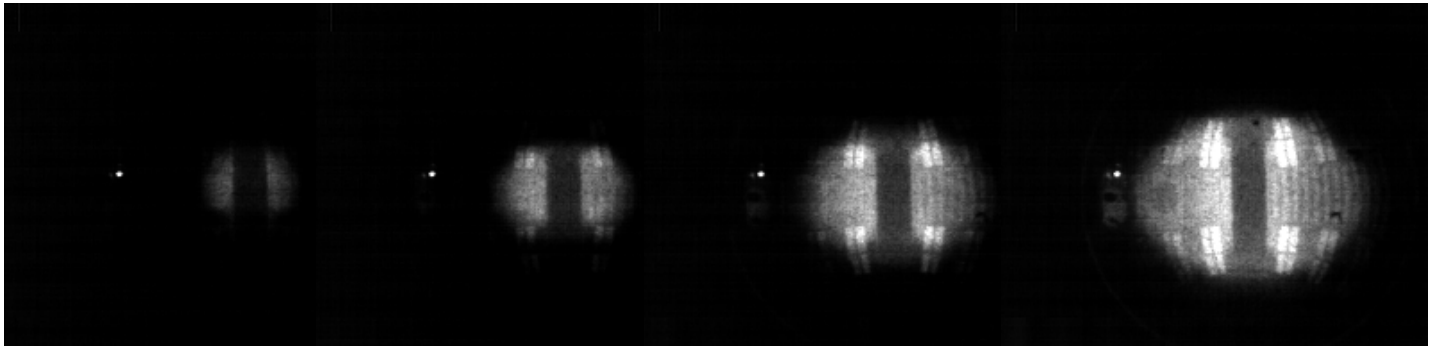
OH Plasma Growing out of ECP

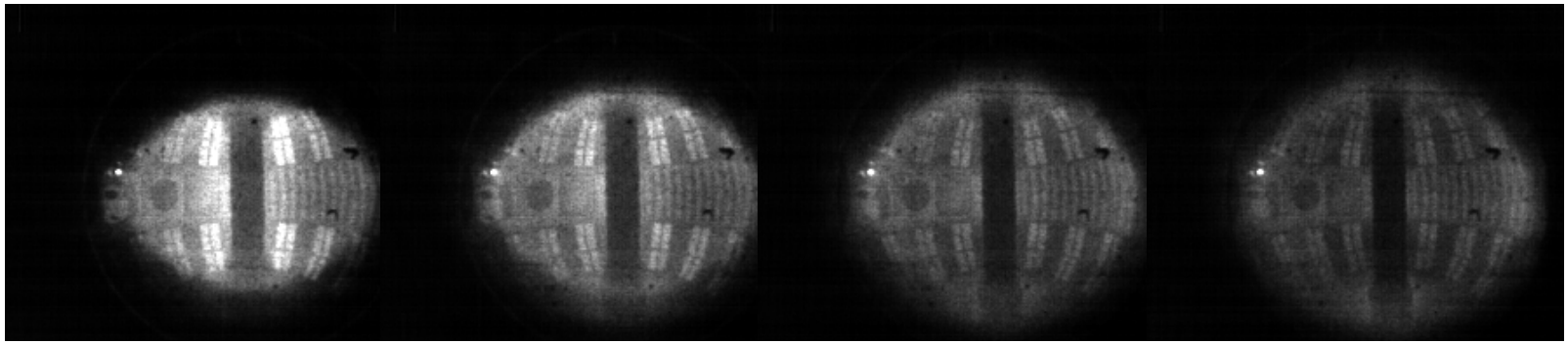


NSTX Plasmas During Start-up

t=6 msec 7 msec 8 msec 9 msec



10 msec 11 msec 12 msec 13 msec



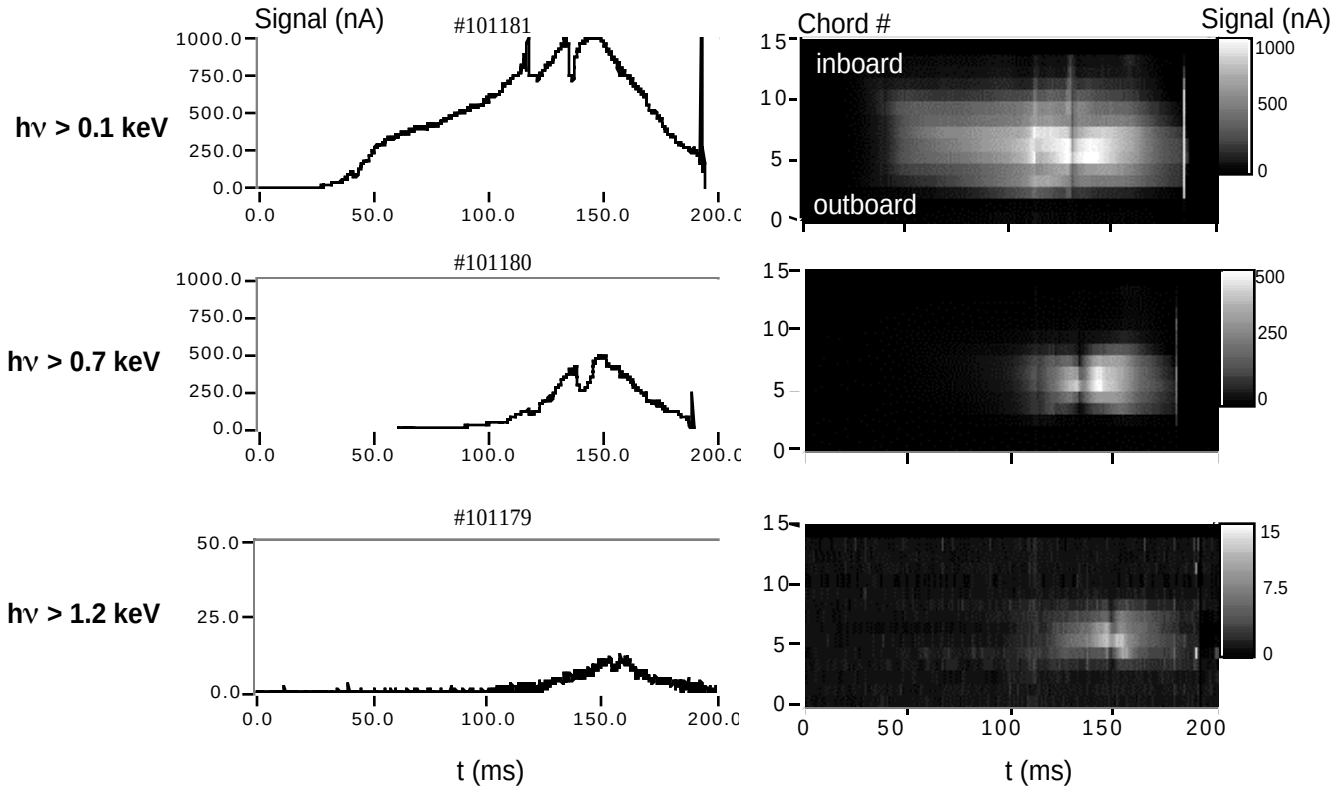
Shot 100925

Fast camera images
from R. Maqueda

Los Alamos
National Laboratory

NSTX

First data from USXR system on NSTX (top array)



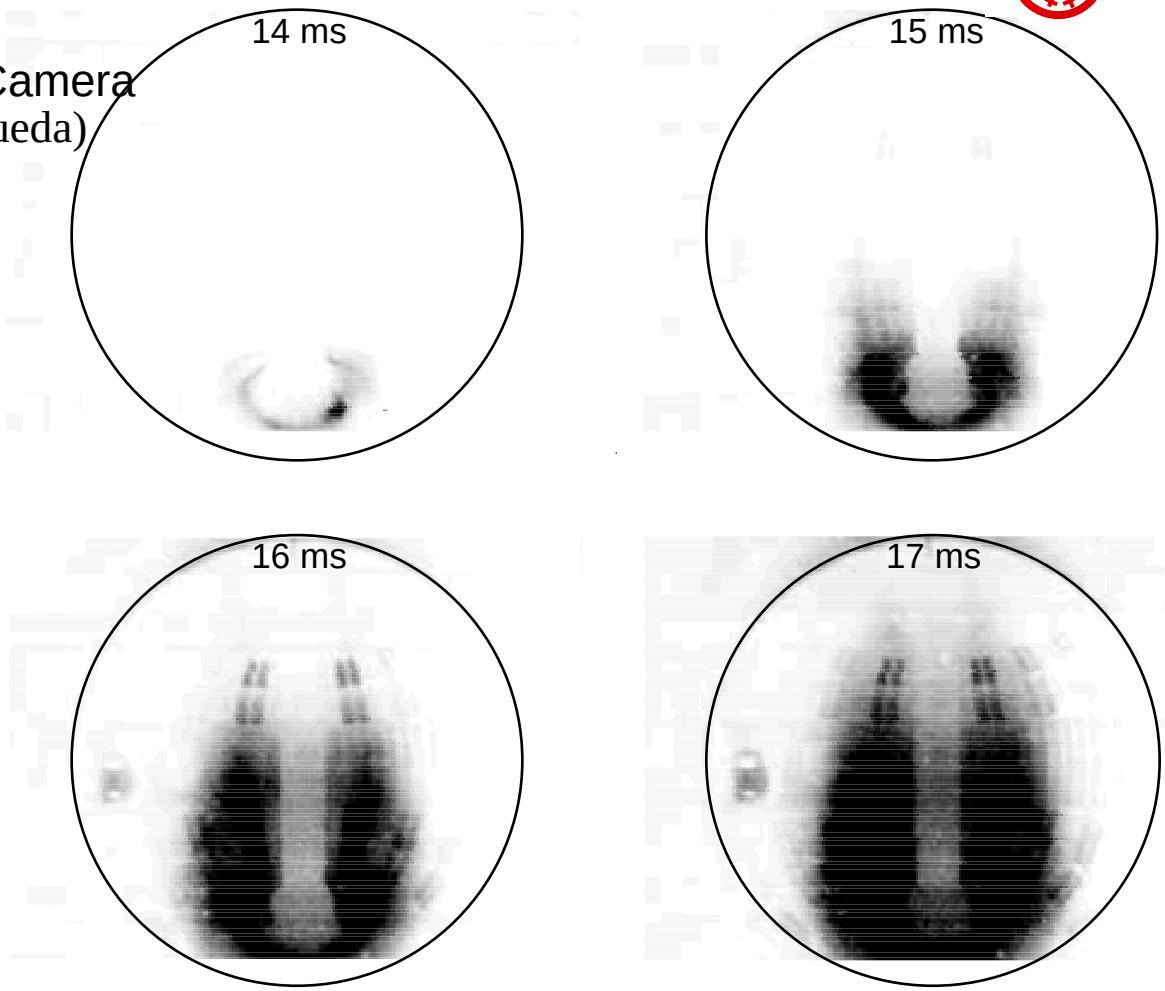
- **Substantial core emission above 0.6 keV (most probably enhanced by Δn=2-3, medium-Z line radiation) and some emission above 1.2 keV, suggest peak temperatures in the 0.5-1 keV range**

- **MHD events resembling internal disruptions are typically observed between ≈ 120-160 ms**

CHI experiment has a good start!

NSTX

101073
LANL Fast Camera
(R. Maqueda)



See also:
R. Raman et al
M. Schaffer et al

25 kA CHI discharge obtained with about 7 kW of injected current.

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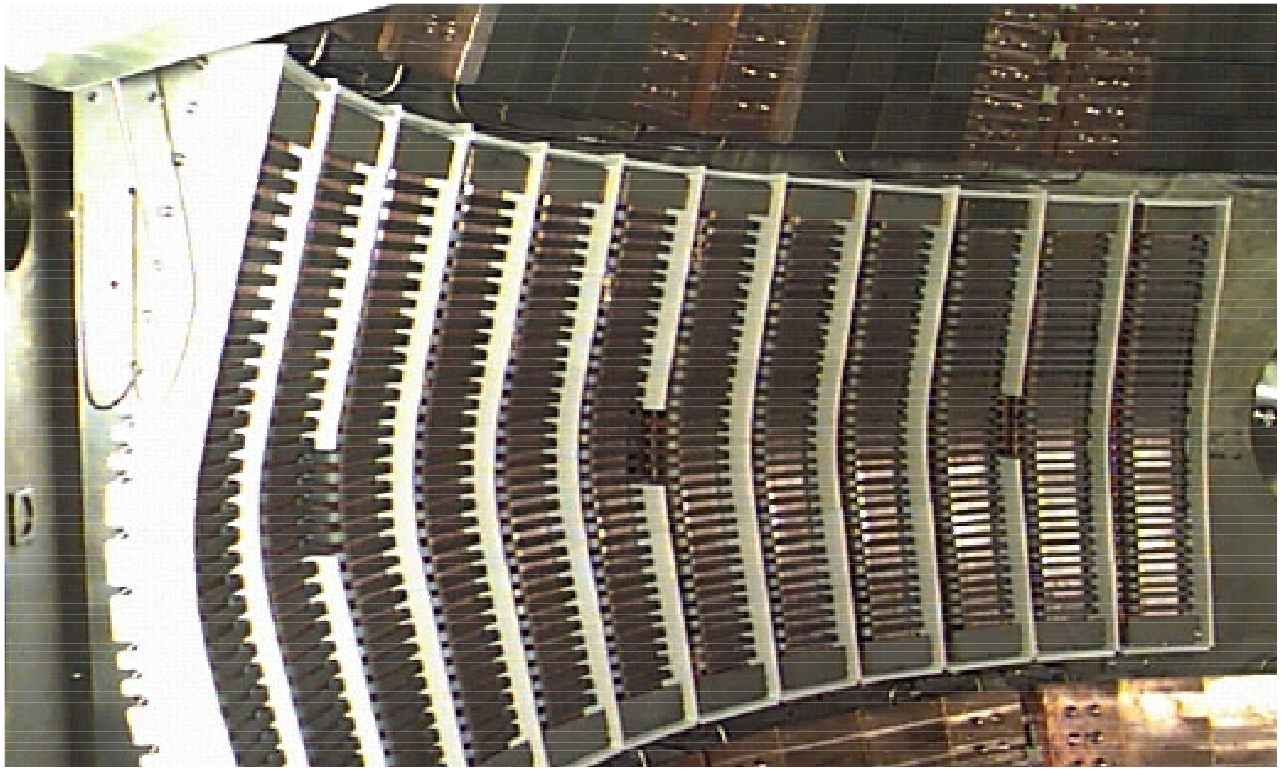
HHFW High Power Operation Started!

NSTX



- 400 kW injected into plasma with 4 antennas. (J.R. Wilson, et al)
- Near term goal: 2MW with 8 antennas.

National Research Team is working well!

On-site team members are working as a true research team (R. Maingi - ORNL, R. Raman – Univ. Washington, S. Sabbagh, F. Paoletti – Columbia Univ., D. Stutman – Johns Hopkins, F. Levinton – FP&T). The off-site team members are contributing extremely effectively.

- Columbia University, 3-D Wall Currents Modeling made a big impact and EFIT/MHD effort coming together nicely.
- LANL Fast Camera has been the workhorse of the plasma operations.
- ORNL ECH Preionization system has been working reliably.
- ORNL HHFW collaboration is a shining example of enabling technology collaboration. Edge Reflectometry is getting ready.
- GA Real Time Control System collaboration has been invaluable.
- University of Washington is leading the CHI research. GA is developing a nice analysis tool for CHI.
- Johns Hopkins University Ultra-Soft X-ray system is nearly ready for plasma.
- UCLA Core Reflectometry is coming up with impressive speed.
- RF Collaboration effort (MIT, GA and UCSD) are preparing important tools.
- SNL's Diagnostic Tiles have been installed.
- LLNL, UCD, and FP&T are addressing the longer-term needs.

NSTX Success Built Upon Fusion Assets

- Utilization of the D-site facilities (Over $100 M of site credit)

- Wealth of experienced personnel with decades of fusion experience.

- National Resources
  - ORNL, Columbia Univ., Univ. of Washington as construction partners
  - MDS-PLUS from MIT, EFIT from GA, EPICS from Argon
  - National Research Team (e.g., Fast Camera from LANL)

- Existing procedures and training programs which are well tested and developed on TFTR.

- PPPL Laboratory infrastructure, e.g., ES&H, QA & QC, Procurements, Accounting, etc.

- Constructive interactions with the DOE PG and OFES.

Near Term Plan (Next One Month):

- Bring the NSTX OH to full capability: 18 kA to 24 kA double swing
  - Flat top operation from 500 kA to 700 kA
  - Peak current from 800 kA to 1 MA

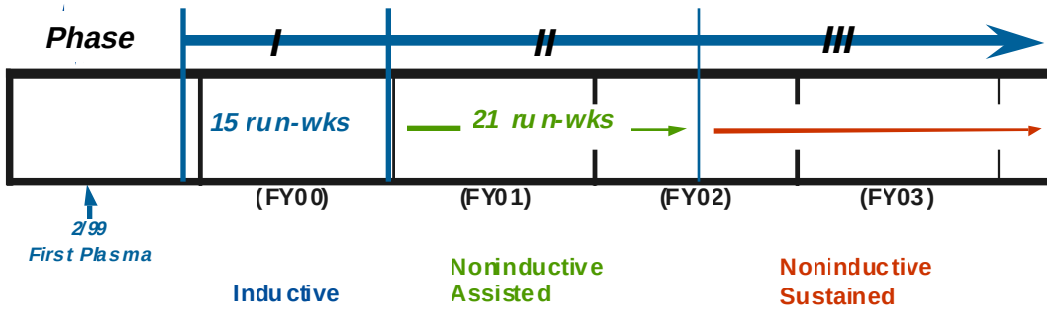
- Improve bakeout: Bring inner tiles to 300 °C, outer tiles to 200 °C, VV to 150 °C.
  Achieved to date (280 °C) (≈ 80 °C) (52°C)

- CHI with lower series resistor ⇒ Inject 25 kA ⇒ 100 - 200 kA?
  - Poloidal Field Programming
  - ECP to assist lower gas pressure initiation

- HHFW from 400 kW with 4 antennas to 2MW with 8 antennas
  - Improve antenna/plasma matching
  - Improve antenna conditions

- More diagnostics! (See Bob Kaita's plan)

- Explore various configurations and regimes



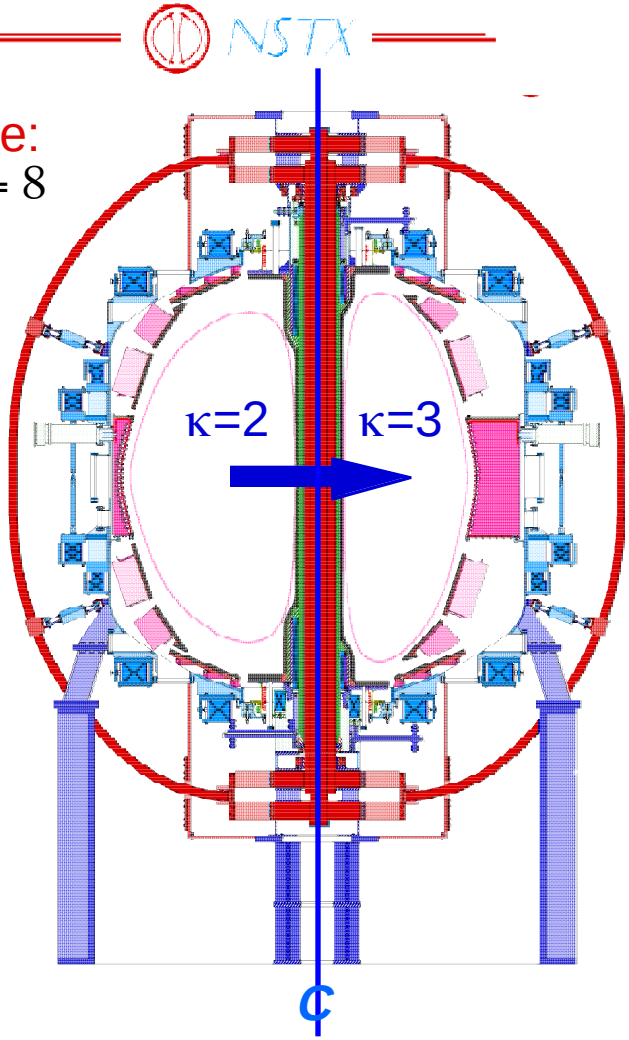
	Inductive	Noninductive Assisted	Noninductive Sustained
Toroidal Beta, β_T		≤ 25% (no-wall limit)	≤ 40% (wall stabilized)
Bootstrap Current		≤ 40% (no-wall limit)	≤ 70% (wall stabilized)
Current	≤ 0.5 MA	≤ 1 MA	~ 1 MA
Pulse	≤ 0.5 s	≤ 1 s	≤ 5 s
HHFW Power	≤ 4 MW	~ 6 MW	~ 6 MW
NBI Power		≤ 5 MW	~ 5 MW
ECH 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

κ = 3 is an important upgrade path

- ARIES-ST-like (Power Plant) regime:
  - κ = 3, R/a = 1.4, β = 50 %, β_N = 8
  - Ip ≥ 1 MA, f_{boots} = 90%.
  - NBI (7 MW, 5 sec, 90 keV)
  - HHFW (8 MW, 5 sec)

- Proposed hardware upgrade:
  - Center Stack (1T capable) with sufficient OH and CHI
  - Adv. PFC/Stabilizing Plates
  - Adv. HHFW Antenna
  - Other advanced features?
  - Interchangeablity

- Cost & Schedule: ($2M/year)
  - Design (FY 01 inc.)
  - Fabrication (FY02-03)
  - Installation and Test (FY 04)



Summary: NSTX Construction Project was a success!

• A world class fusion science facility NSTX built on budget (TPC = $23.85 M) and on schedule (First Plasma 10 weeks ahead of schedule) and with excellent safety record (New Jersey Governor's Award).

- Experienced personnel (decades of experience in all areas)
- Over $100 M of relatively modern site credit (TFTR D-site)
- Very strong community involvement (reviews, software, construction and research team members)
- Good team work at all levels (DOE-OFES-PPPL-NSTX)

• The NSTX National Research Team from 14 institutions working very well together. (Fast Camera, EFIT, MHD, ECP, HHFW, Plasma Control, Advanced Diagnostics, Edge Physics….)

• The NSTX Ohmic Operations met the FY 99 goal of 500 kA and approaching (0.8 MA achieved) the FY 00 goal of 1 MA. The Day 1 real time plasma control (Ip, R, and Z) operational and ST discharges with various shapes and configurations produced.

• The CHI non-inductive start-up and HHFW experiments have started.