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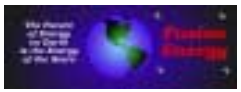





# NSTX Facilities and Upgrade Possibilities

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Princeton Plasma Physics Laboratory

**For the National NSTX Team**

**NSTX Five Year Plan Ideas Forum**
**June 24 - 26, 2002**

*Columbia U*
*Dartmouth U*
*GA*
*JHU*
*LANL*
*LLNL*
*Lodestar*
*MIT*
*Nova Photonics*
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*Hiroshima U*
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*Niigata U*
*Tsukuba U*
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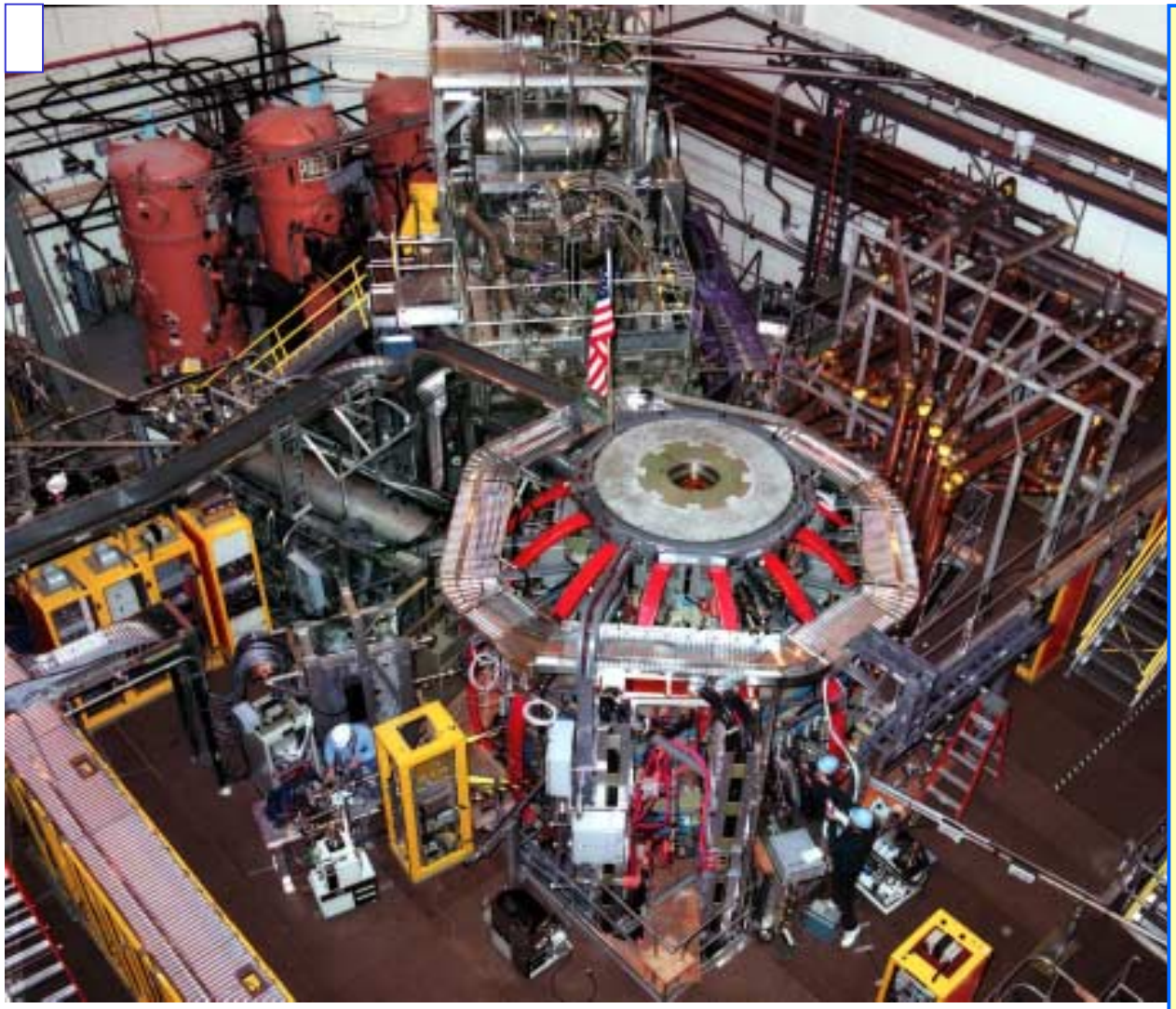
*KAERI*

# Facility Outline

- **Present Status**
  - Device
  - Operations
  - Diagnostics
- **Plans from the FY 04 FWP**
  - Facility needs by research topics
- **Opportunities for the 5-year plan**

# NSTX Facility Has Continued Rapid Progress in Operational and Experimental Capabilities



**Baseline Parameters**
(Achieved)

Major Radius 0.85 m

Minor Radius 0.68 m

Elongation = 2.2 (2.5)

Triangularity = 0.6 (0.8)

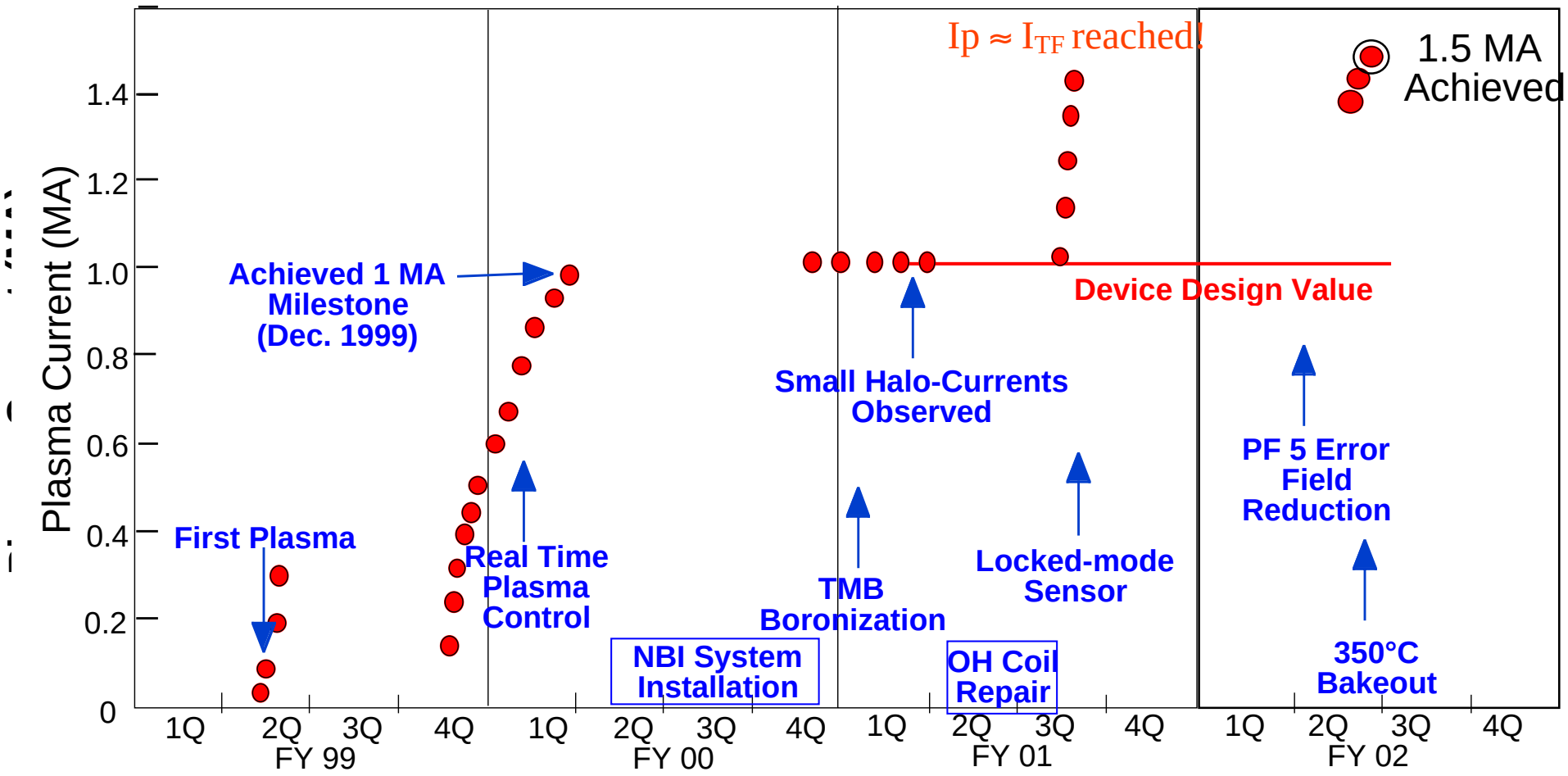
Plasma Current
1 MA (1.5 MA)

Toroidal Field
0.3 to 0.6 T (≤0.6 T)

Heating and CD
5 MW NBI (7 MW)
6 MW HHFW (6MW)
0.5 MA CHI (0.4 MA)

Pulse Length
= 1 → 5 sec (1 sec)

# NSTX Facility Progressed Rapidly



# NSTX Facility Delivered Milestones

## Facility Plasma Operations Availability

| | FY 00 | FY 01 | FY 02** | FY 03 |
|---|---|---|---|---|
| # of run weeks | 15* | 15* | 12* | 21 |
| # of hours | 600 | 600 | 480 | 840 |

* Met or exceeded the run week milestones

** Over 90% of facility availability with ≈ 2000 plasma shots

## Participating Research Personnel (FY 02)

| | PPPL | non-PPPL |
|---|---|---|
| Researchers | 45 | 95** |
| Post Doc. | 3 | 7 |
| Grad. Students | 5 | 5 |
| Undergrad. Students | 3 | 5 |

** Including ≈ 20 overseas collaborating researchers from countries including Japan, Russia, Korea, UK, Ukraine, and Canada.

# Existing Diagnostic Capabilities


## Core Plasma Diagnostics

- Thomson scattering (20 ch., 60Hz)
- Charge Exchange Recomb. Spect. (CHERS): $T_i$ & $v_\phi$ (18 ch.)
- VB detector (single chord)
- Soft x-ray arrays (3) [JHU]
- Bolometer array (midplane tangential)
- X-ray crystal spectrometer ($T_i(0)$, $T_e(0)$)
- X-ray pulse height analyzer
- Electron Bernstein wave radiometer
- FIReTIP interf'r/polarim'r (2 ch) [UCD]
- GEM Fast 2D X-ray camera [Frascati, JHU]
- Tang. X-ray pin hole camera [U. Wisconsin]

## Magnetics and MHD

- Magnetics for equilibrium reconstruction
- Diamagnetic flux measurement
- High-n and high-frequency Mirnov arrays
- Locked mode coils

## Turbulence

- Edge reflectometer [UCLA]
- Edge fluctuation imaging [LANL, PSI]

## Plasma Monitoring

- Fast visible camera [LANL]
- VIPS: Visible spectrometer
- SPRED: UV spectrometer
- GRITS: VUV spectrometer [JHU]
- EFIT (Columbia University)

## Boundary Physics

- Divertor Bolometer
- Fast probe [UCSD]
- Infrared Camera [ORNL]
- Fast Ion Gauge [University of Wash]
- Divertor fast camera [Hiroshima Univ.]
- Divertor tile Langmuire probe array
- 1-D CCD $H_\alpha$ camera [ORNL]
- Visible filterscopes ($H_\alpha$, OII, CII) [ORNL
- Scrape-off layer reflectometer [ORNL]
- Fast camera (PSI)

## Energetic Particles

- Fission chamber neutron measurement
- Fast neutron measurement
- Neutral particle analyzer (scanning)
- Fast ion loss probe

FY 04 FWP

# Boundary Physics

Exciting Enhancement Opportunity in Core Fueling and Boundary Physics

| Plasma Operations | FY 02 | FY 03 | FY 04 |
|---|---|---|---|
| (Run Weeks) | 12 | 21 | 4 inc. | 20 | 5 inc. |

## Wall Conditioning

(Gas/plasma Boronization, Between-shot GDC)

- 350°C Bakeout System
- Li/Boron Pellet Injector

- Decision Point
- Base
- Incremental

**CDX-U / APEX Lithium Exp.**

## Power/Particle Control

- Recip. edge probe (UCSD)
- Divertor bolometer
- 2nd IR Cameras
- Divertor fast camera (Hiroshima Univ)

Fast IR Camera

**Advanced Power and Particle Handling Decision Point (Liquid Lithium or Cryo Panel)**

AEUV Spectrometer

Divertor Thomson Scattering

## Fueling

In-board gas injector

Realtime Gas Control

Pellet injector in "suitcase" (ORNL)

FY 04 FWP

# MHD Mode Stabilization

Opportunity Areas are Resonant Field and RWM Controls.

| Plasma Operations | FY 02 | FY 03 | FY 04 |
|---|---|---|---|
| (Run Weeks) | 12 | 21 | 4 inc. | 20 | 5 inc. |

**MHD Diagnostics**

- Locked-Mode Coils
- High Freq.Coils
- Poloidal Mirnov Array
- Ultra Soft X-ray Arrays (Johns Hopkins)
- Wall-mode sensors
- Divertor Mirnov Array

● - **Base**

■ - **Incremental**

**Resonant Field Control**

- PF 5 Realignment
- Preliminary Resonant Field Control System
- Improved Resonant Field Control System

Plasma Rotation + Wall

**+ Modeling**

MHD Mode Measurement

**+ DIII-D, HBT-EP Expt.**

■ **Optimized Resonant Field Control System**

FY 04 FWP

# Confinement and Transport

## Exciting Opportunities For Advanced Fluctuation Diagnostics


| Plasma Operations | FY 02 | FY 03 | FY 04 |
|---|---|---|---|
| (Run Weeks) | 12 | 21 + 4 inc. | 20 + 5 inc. |

**Profile Diagnostics**

- Thomson (20 ch, 60 Hz) → 51 Channel Toroidal CHERs
- Thomson (20 ch, 90 Hz)
- Poloidal CHERs
- 4 Channel FIReTIP(UCD) → 7 Channel FIReTIP(UCD)

**Energetic Particles**

- Scanning Neutral Particle Analyzer
- Fast Ion Loss Probe

**Fluctuation Diagnostics**

- Low k Reflectometer (UCLA)
- Fast Camera (LANL)
- Install Low k Imaging Reflectometer System
- Install Prototype High k Microwave Scattering System
- Complete Fabrication of Full high k Microwave Scattering System

- - Base
- - Incremental

FY 04 FWP

# Non-Inductive CD Systems

Enhancement Opportunity areas are CHI and EBW


| Plasma Operations | FY 02 | FY 03 | | FY 04 | |
|---|---|---|---|---|---|
| (Run Weeks) | 12 | 21 | 4 inc. | 20 | 5 inc. |

◆ - Decision Point
● - Base

**HHFW (6MW)**

- Pre-programmed CD Phasing
- Plasma Feed-back phase control
- 2 Channel MSE/CIF (Nova) → 10 Channel MSE/CIF (Nova)
- MSE / LIF (Nova) (Diag. Init.)

**CHI ($I_T$ = 0.5 MA)**

- New CHI Absorber Insulator Fabrication
- ⇑ Install
- Absorber field null control
- Dynamo-head For helicity transport
- ◆ **CHI in New Center Stack**

**EBW -E / -CD**

- EBWE / Edge $n_e(r)$
- Optimized EBWE Antenna (Diag. Init.)
- ◆ **High Power EBWCD System (1MW)**

# FY 04- 08 Facility Upgrade Possibilities


**HHFW**
- Real time control (being implemented)
- New Antenna (End feeds)
- Wave Diagnostics?
- Long pulse?

**EBW**
- Edge controlled EBW antenna
- Phase I EBW System (1 MW)?
- Build up toward 5 MW?

**CHI**
- New absober (being implemented)
- Null field sensors and coils (FY 03)
- Real Time Control (FY 03)
- Dynamo probe (FY 03)
- High voltage (2 kV)?
- Vacuum vessel current?
- Fast PF 2 and 3 control?

**RWM Control System**
- Phase I Sensors (FY 03)
- Phase I Feedback Coils (FY 03-04)
- Improved Sensors and Coils (FY04)
- Optimized Coils?

**Particle Control**
- Cryogenic divertor panel?
- Liquid Lithium Panel?

**Fueling**
- Ice Pellet Injector (in suitcase)?
- CT Injector?

**Center Stack for FESAC 5-10 Goal?**
- Is TF/OH optimized?
- R/a appropriate?
- 1 MA capable CHI?
- Meet $\tau$-pulse > $\tau$-skin goal?

# FY 04- 08 Diagnostic Upgrade Possibilities

## Core Plasma Diagnostics

- Thomson scattering (40 ch., 90Hz) (incremental enhancement)
- Charge Exchange Recomb. Spect. (CHERS): $T_i$ & $v_\phi$ (51 ch.) (FY 03)
- MSE-CIF (FY 03-04) [Nova]
- Soft x-ray arrays [JHU] (Supported under diag. Initiative)
- Poloidal CHERS (FY 04)
- Bolometer array (midplane tangential)
- X-ray crystal spectrometer (Supported under diag. Initiative)
- Electron Bernstein wave radiometer (Supported under diag. Initiative)
- FIReTIP interf'r/polarim'r (7 ch) [UCD] (FY 03-04)
- MSE-LIF for E(r) [Nova] (Supported under diag. Initiative)
- Fast tangential x-ray camera [PSI]
- Other B, j, and E diagnostics?

## Energetic Particles

- Fast ion loss probe (FY 03- 04)
- Diamond Detector (Ioffe)

## CoreTurbulence Diagnostics

- Low k imaging
- High k
- Medium k?
- Zonal flow?

## Boundary Physics Diagnosics

- Edge fluctuation imaging [PSI, Nova,LANL]
- Divertor bolometer (FY 03 - 04)
- Divertor Thomson?
- Edge Ti (r) ?
- Edge current?
- Edge / divertor neutral recycling?
- Edge power flow?
- Wall/material?

## MHD

- RWM Detectors (see the facility upgrade)
- Divertor magnetics(FY 03 - 04)
- Wall current sensor ?
- Higher frequency probe (FY 03)

# Particle Control

## Motivation:

- **Plasma density often rises continuously in high performance, high confinement discharges.**
- **High performance discharges including the long pulse-low voltage high beta-poloidal discharges appear to end due to some density related limit.**
- **The edge recycling appears to be quite strong resulting for example in the strong "ears" during H-mode?**
- **Strong particle pumping therefore could provide a way to achieve longer pulse and higher confinement.**

## Possible plan:

- **Consider divertor cryo-pump?**
- **Consider liquid lithium panel?**

# Tool for NTM Stabilization?

## Motivation:

- **EBW Local CD could provide an efficient tool to stabilize neoclassical tearing mode (as ECCD was shown to be effective in tokamaks) which could reduce the plasma performance and the beta limit.**
- **ECH/EBW ≈ 100 kA ST formation (1 MW) + HHFW (6MW) heating (bootstrap over-drive per ARIES-ST and AT) and CD could lead to an alternate non-inductive current start-up method to CHI (as recommended by the NSTX PAC).**

## Possible plan:

- **Establish EBW physics need & feasibility of neo-classical tearing stabilization in FY 03 (demonstration of high coupling efficiency by the edge density control EBW antenna + modeling)**
- **If assessment is promising, 1 MW EBW system to be implemented in FY 04 using existing ORNL ECH hardware to start a demonstration experiment.**
- **After 1 MW system effectiveness is demonstrated, the system up to 5 MW can be considered? RF power (≤ 30 GHz) should be readily available.**

# Looking Beyond the FESAC 5-Year Objectives


- Present center stack is designed to explore wide physics regimes including low R/a ≤ 1.27 and it is producing exciting physics results!

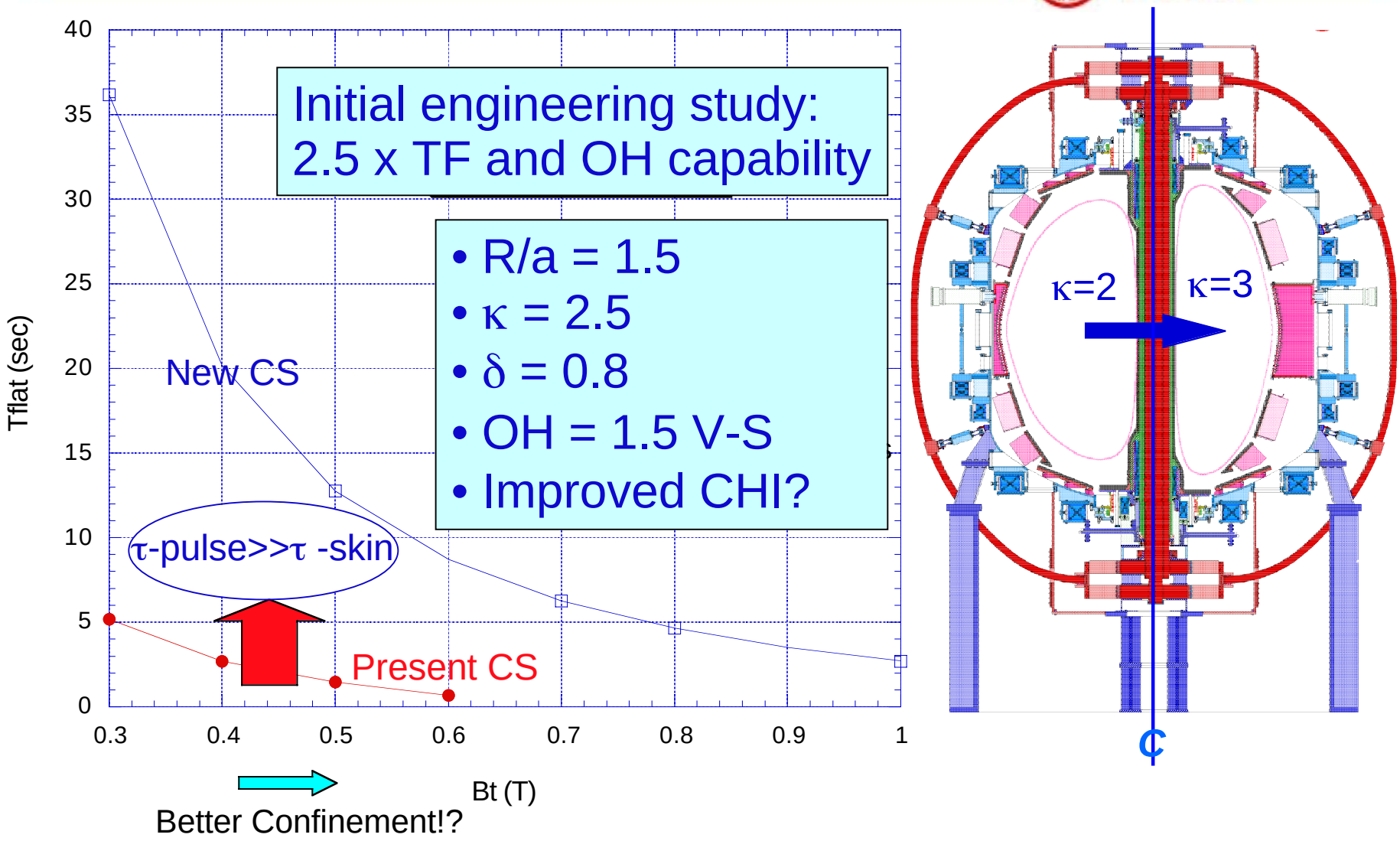
- the FESAC 5-year Objective #2.1: "*Make preliminary determination of the attractiveness of the Spherical Torus (ST), by assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times.*"

… We may actually meet the goal by FY 05-06!

Looking toward future…. What tools do we need?

FESAC 5-10 year objectives( $\tau$-pulse >> $\tau$ -skin)

# To meet the FESAC 5-10 year goal a new center stack is being considered.



# Facility Summary

**We are doing quite well!**

- **The NSTX facility has met or exceeded the original design.**
- **The facility has met or exceeded all of the major operational milestones.**
- **Every facility enhancement contributed to research output!**
- **The excellent facility availability contributed to productive research output!**

**We are excited about the future!!**

- **The facility utilization enhancement budget (21 run weeks in FY 03) will enable us to greatly increase the scientific output.**
- **The facility capability particularly the diagnostics are being enhanced.**
- **There are truly exciting facility/diagnostic enhancement opportunities!**

Let us work together to come up with the best plan!