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Integration and Plasma Control

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PPPL

For the NSTX National Team

DOE Review of
NSTX Five-Year Research Program Proposal
June 30 – July 2, 2003

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IPPA & FESAC Have Established Ambitious Goals for NSTX

- IPPA goal 3.2.1.6:

  "integrate high confinement and high beta"

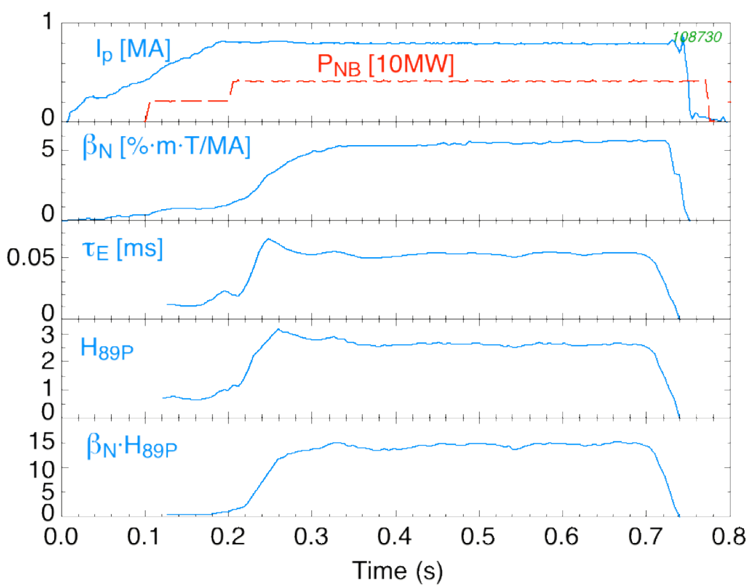
- FESAC 5-year Objective #2.1

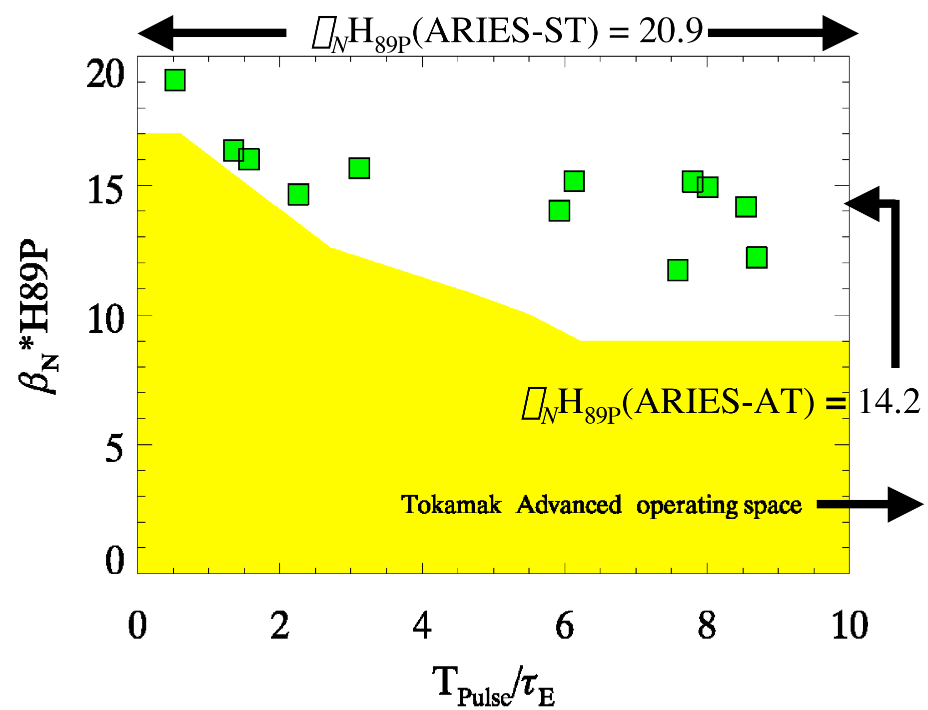
  "...assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times"

- Each component represents a challenge in itself
- Integration requires accommodating competing discharge requirements
  - Achieving compatibility of conditions for long pulse will be particularly challenging

Considerable Progress Achieved Towards Goal of High β and τ_E

- During 2002, NSTX achieved in a discharge
  - $\beta_N \approx 6\% \cdot m \cdot T/MA$
  - $\tau_E \approx 50ms$, $H_{89P} \sim 2.5$
  - duration ~400ms ~ $8\tau_E$ ~$1.7\tau_{skin}$





Advanced Plasma Control Necessary for Achieving "Integration Goals"

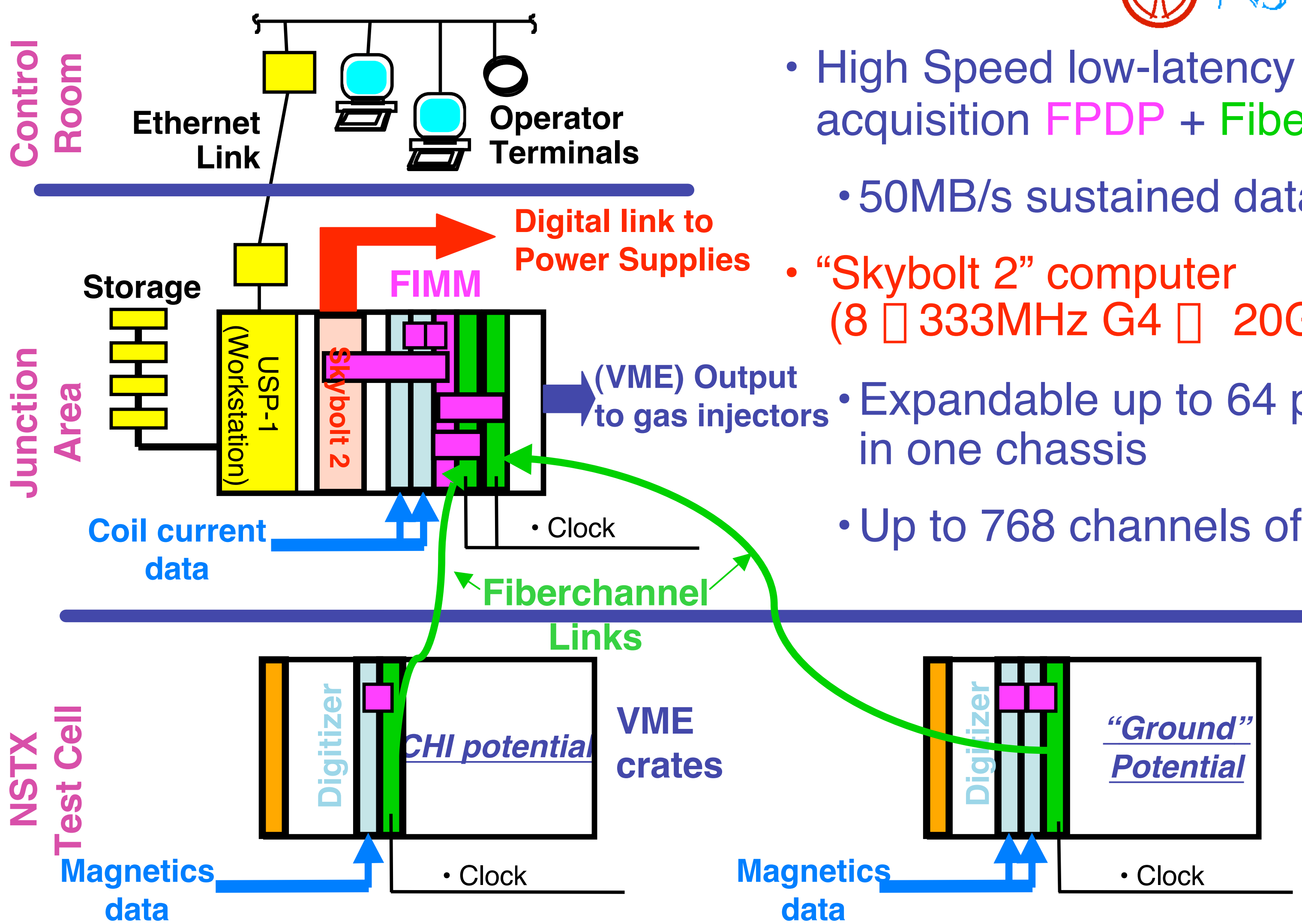
- Equilibrium
  - I_p, R_p, Z_p, □, □, stabilizer gaps
- Heating and current drive
  - $P_{NBI,}$ R_{NBI}, P_{HHFW}, $\mathbf{k}_{||}$, [J(r)], [EBW coupling]
- Fueling and density control
  - gas [supersonic], pellets, [edge pumping]
- Instabilities
  - Vertical, □, error fields and RWM, NTM
- Edge power and particle fluxes
  - Divertor strike point sweeping, edge density, divertor density, divertor radiation, [lithium module]

Elements of Control

- Diagnostics
  - Configuration, profiles (p, $v_{\square}$, J), instabilities, fluxes
- Real-time processing
  - Equilibrium, stability limits, mode structure, driven current
- Actuators
  - Coils & power supplies, NBI, HHFW, [EBW], CHI, fueling, pumping
- Telemetry
  - Fast, flexible, expandable data communication

Control System Hardware

- High Speed low-latency (4μs) data acquisition FPDP + Fiberchannel
  - 50MB/s sustained data rate
- "Skybolt 2" computer (8 × 333MHz G4 ⇒ 20GFlop)
  - Expandable up to 64 processors in one chassis
  - Up to 768 channels of data



2004 – 2005: Control of Plasma Shaping and Heating Power

Status Plasma shape with programmed currents

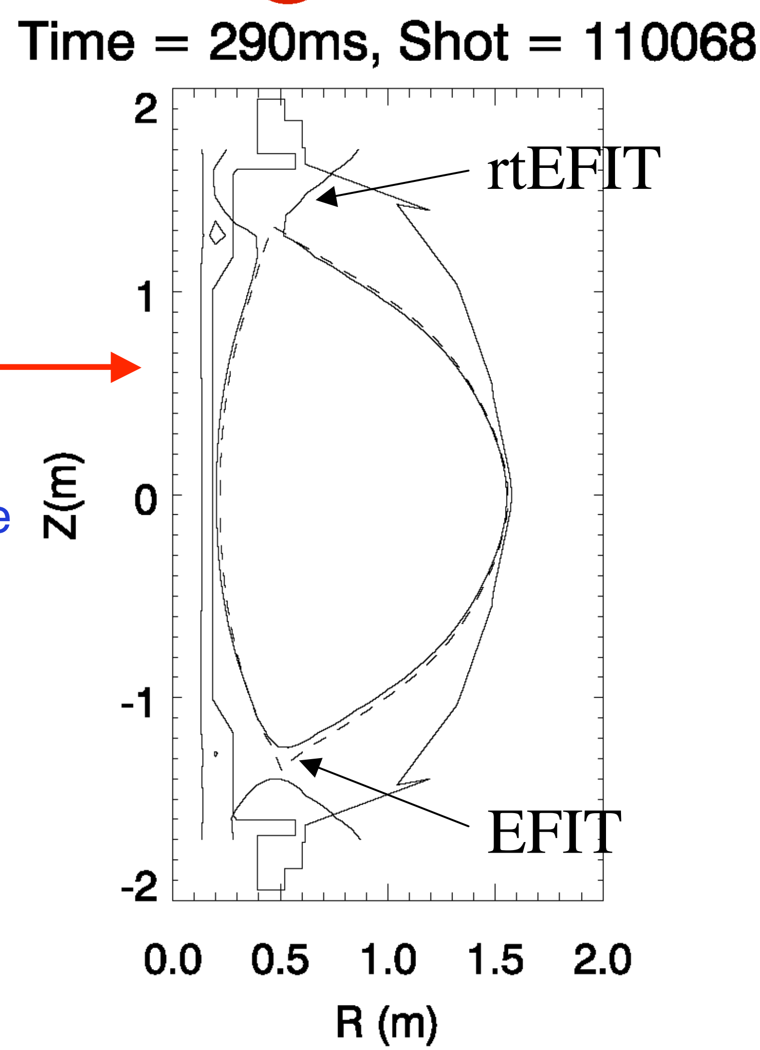
- highest □ with □ ≈ 2.0, □ ≈ 0.8
  - □ ≈ 2.5 transiently
  - higher □ facilitates high □ at high f_{bs}
- full control with rtEFIT during '03 run

2004

- Develop routine feedback control for shape (□,□, gaps) with rtEFIT analysis
- Investigate prospects for higher □

2005

- Upgrade control for higher □
  - faster power supply link may be required
- Feedback control of NB power to control □



2005 – 2008: Inclusion of Profile Data in Real-Time Equilibrium Analysis

Status rt-EFIT has operated with only magnetic data

– inclusion of profile data will substantially increase utility of analysis → **profile control**

2005 1) Include MPTS data for p_e (*c.f.* offline EFIT)

– expand real-time diagnostic data acquisition

2) Initiate real-time estimate of stability limit based on l_i, F_p

2006 Include MSE-CIF polarimetry data

2007 Include MSE-LIF |**B**| data

2008 Develop accurate real-time stability assessment

2004 – 2005: Control for Resistive Wall Modes

NSTX

Status RWM growth inferred from development of kink-like perturbations for □ above no-wall limit and rapid slowing of plasma rotation

2004 Detailed measurements of RWM structure with newly installed set of B_r, B_p pickup coils

Installation of RWM control coils (B_R) and power supplies

– null “average” B_R perturbation with preprogrammed currents

2005 Implement feedback control to counteract mode drag and maintain plasma rotation

2003 – 2005: Control for Coaxial Helicity Injection

Status 400kA toroidal current in 300ms discharge

- Preprogrammed currents - no feedback control
- FY02 absorber arcs terminated most discharges
  - New absorber insulator and nulling coils in 2002 opening

2003 1) Preliminary assessment of new absorber insulator and need for local field control in absorber
2) Began assessment HIT-II "forced reconnection" scheme

2004 Feedback control of I_p, *R*, *Z* of CHI plasma to

- promote reconnection
- diagnose profiles and MHD activity

2005 Implement absorber field null control, if needed

2004 – 2008: Control of Neoclassical Tearing Modes

Status – NTMs identified at high β_P with $q_{min} < 3/2$

- *But* not seen in recent high β_P plasmas with higher q_{min}

– Expect control through localized current drive

2004 Assess conditions for and impact of NTMs

–Develop NTM detection & localization methods

2005 Develop control of HHFW-CD $\Rightarrow$ NTM avoidance

2006 Assess EBW for localized current drive

Use EBW for controlling NTMs

2007 Feedback on EBW-CD for NTM control

2003 – 2009: Integrating Techniques for Particle & Power Flux Management

Status - Continuous density rise during H-mode

- Divertor heat fluxes probably acceptable for 2s but marginal for 5s pulses at full power

2003 Control of new HFS gas injector

2004 Control supersonic gas injector

Assess density control with Li pellet coating

2005 Install & control deuterium pellet injector

Assess density control with Li evaporation crucible

2006-7 Integrate and assess cryo-pump

Strike-point control for power flux mitigation

2009 Density control with lithium wall module

2005 – 2008: Integrating Techniques for Solenoid-Free Startup & Sustainment

Status Indications of HHFW-CD, ~100kA @ 2 MW

2005 Integration and control of HHFW-CD with CHI

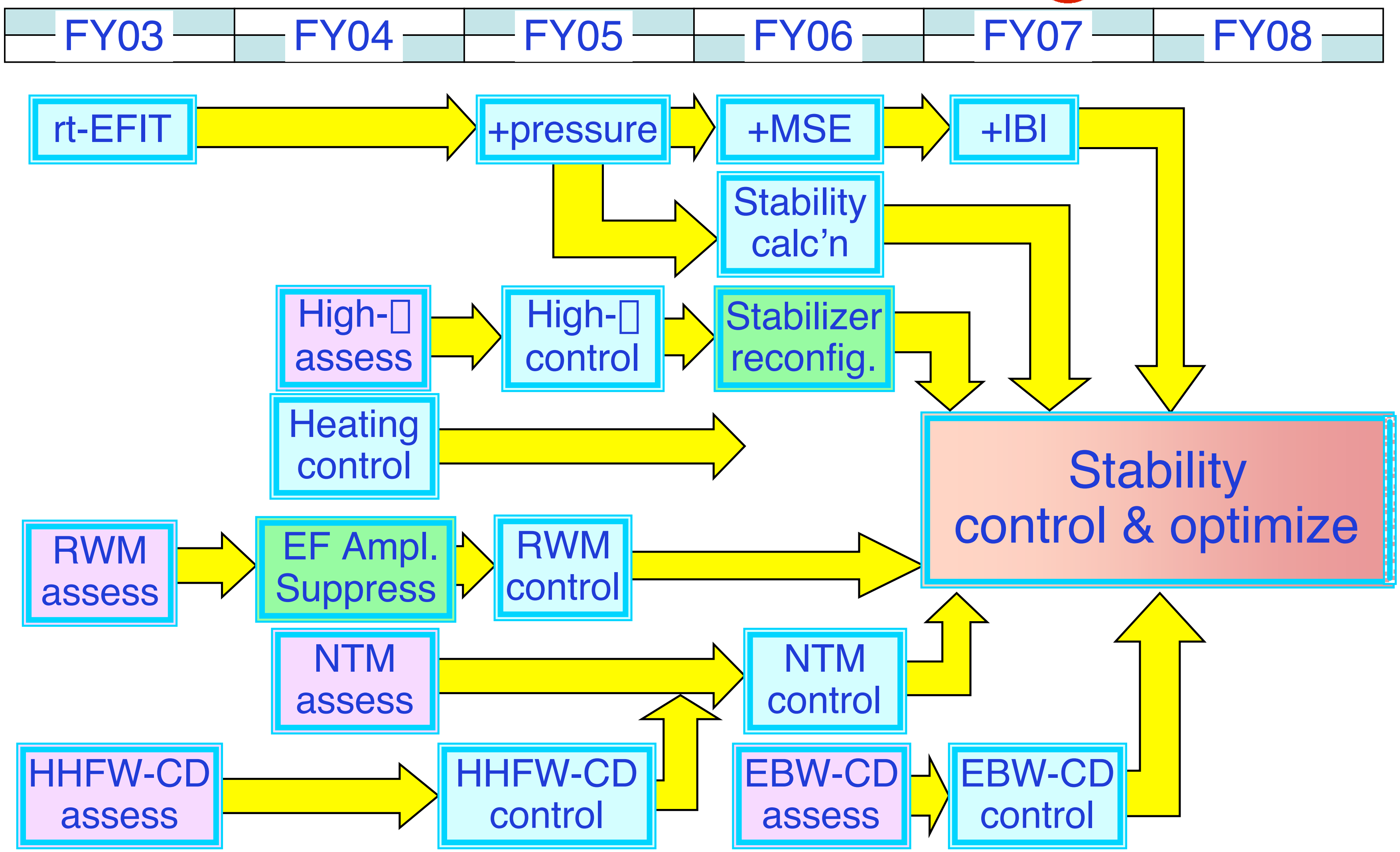
Assess PF only startup

2006 Solenoid-free ramp-up

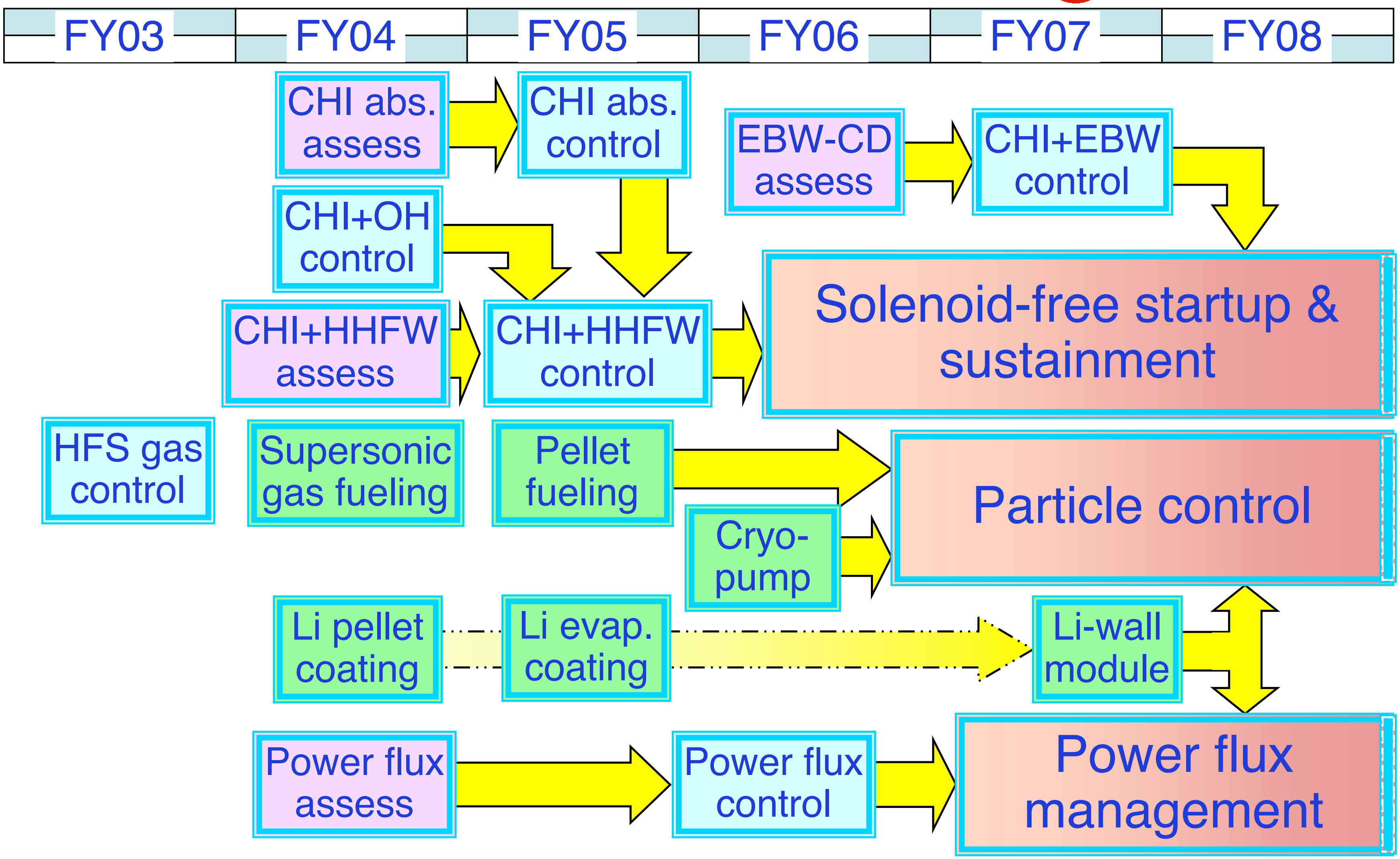
2007 Integration and control of HHFW and EBW-CD with CHI initiation

2008 Demonstration of fully non-inductive startup & sustainment with increasing pulse length

Integration & Control Builds on Progress in Facility, Diagnostics & Topical Research



Integration & Control Timeline (2)



Summary

- NSTX has already made excellent progress on IPPA integration goals
  - Control system development key to completing these objectives
- Aggressive control development strategy touches every aspect of the ST integration problem
- Utilization of high-speed parallelized real-time computation enables innovative physics based solutions to plasma control
  - Much more will be possible in the near future (processor speed has more than tripled since present computer was purchased!)