Integration and Plasma Control

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5-Year Plan Review

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IPPA & FESAC Have Established Ambitious Goals for NSTX

- IPPA goal 3.2.1.6:

  "integrate high confinement and high beta"

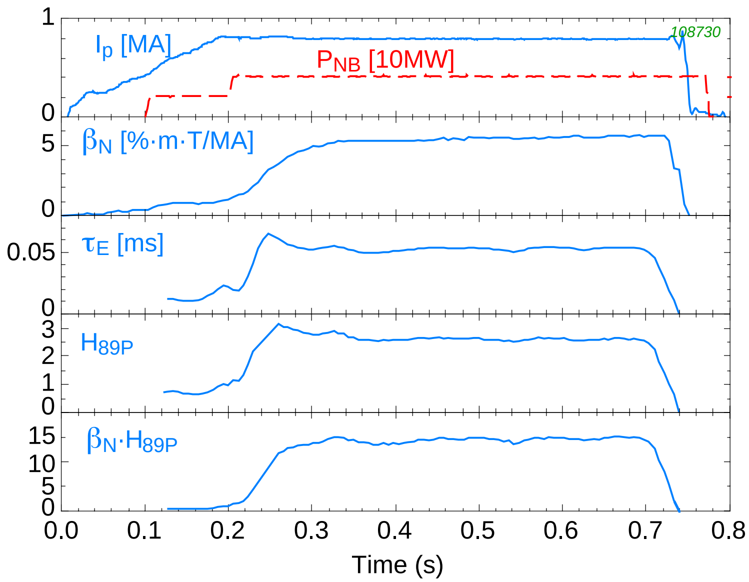
- FESAC 5-year Objective #2.1

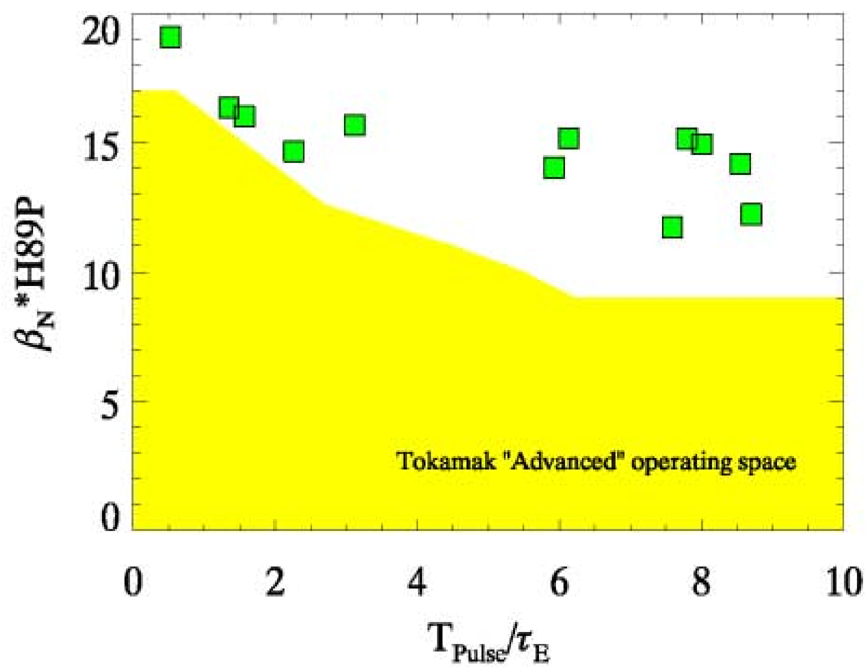
  "...assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times"

- 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, ~ $8\tau_E$





Advanced Plasma Control Necessary for Achieving "Integration Goals"

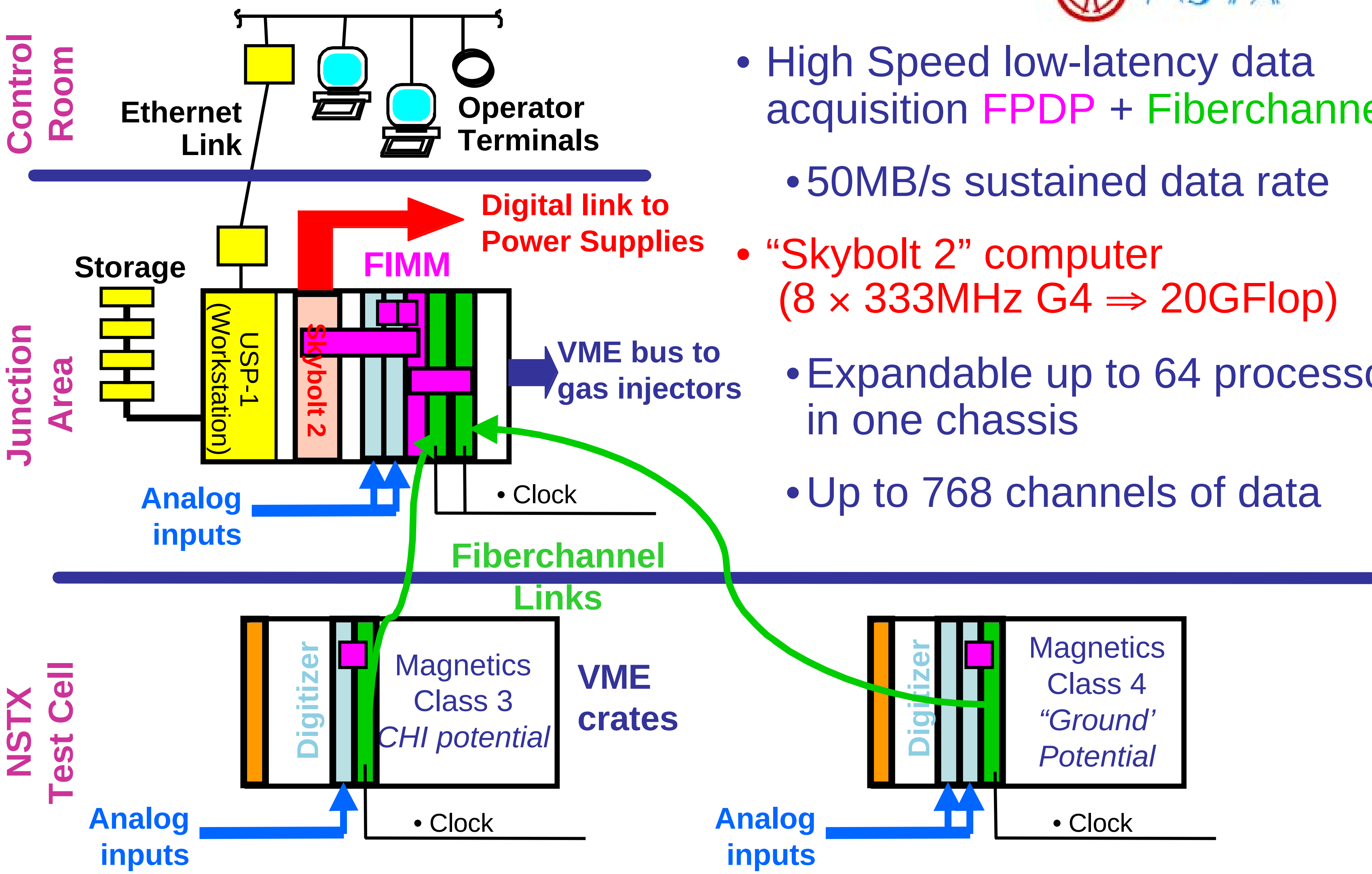
- Equilibrium
  - I_p, R_p, Z_p, κ, δ, stabilizer gaps
- Heating and current drive
  - P_{NBI}, R_{NBI}, P_{HHFW}, $\mathbf{k}_{||}$, [J(r)], [EBW coupling]
- Fueling and density control
  - gas [supersonic], pellets, [CTs], [edge pumping]
- Instabilities
  - Vertical, β, error fields, RWM, NTM
- Edge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

Elements of Control

- Diagnostics
  - Configuration, profiles (p, v_{ϕ}, 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
  - Will require upgrade of power supply data link

Control System Hardware

- High Speed low-latency 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



2003 – 2004: Control of Plasma Shaping and Heating Power

Status Plasma shape with programmed currents

- $\kappa \approx 2.5$ transiently; highest β with $\kappa \approx 2.0$, $\delta \approx 0.8$
  - higher κ would facilitate high β at high f_{bs}
- first control with rt-EFIT at end of '02 run

2003 1) Develop routine feedback control for shape (κ, δ, gaps) with rt-EFIT analysis

2) Investigate prospects for higher κ

2004 1) Upgrade control for higher κ

- faster power supply link

2) Feedback control of NB power (PWM) to control β

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 improve analysis

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

– expand real-time diagnostic data acquisition

2) Initiate real-time assessment of stability limit

– may be based on l_i, F_p in first instance

2006 Include MSE-CIF polarimetry data

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

2008 Develop real-time stability assessment

2003 – 2005: Control for Resistive Wall Modes

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

2003 Detailed measurements of RWM structure with newly installed set of B_r, B_p pickup coils

2004 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 – 2004: Control for Coaxial Helicity Injection

Status 400kA toroidal current in 300ms discharge

– Preprogrammed currents - no feedback control

– Absorber arcs terminated most discharges

• New absorber insulator and nulling coils in 2002 opening

2003 1) Assess new absorber insulator and need for local field control in absorber

2) Assess HIT-II “forced reconnection” scheme and add programmed inductive drive

2004 1) Absorber field control, if needed

2) Feedback control of CHI plasma to

– promote reconnection

– diagnose profiles and MHD activity

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 localized HHFW-CD

2006 Combine real-time detection and localized HHFW-CD to control NTMs

2008 EBW-CD for NTM control

2003 – 2008: 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 improved HFS gas injector
2004	Control supersonic gas injector
	Assess density control with Li pellet coating
2005	Install & control deuterium pellet injector
2006-7	Assess and integrate cryo-pump
	Strike-point control for power flux mitigation
2008	Density control with lithium wall module

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

Status Indications of HHFW-CD, ~100kA @ 1 – 2 MW

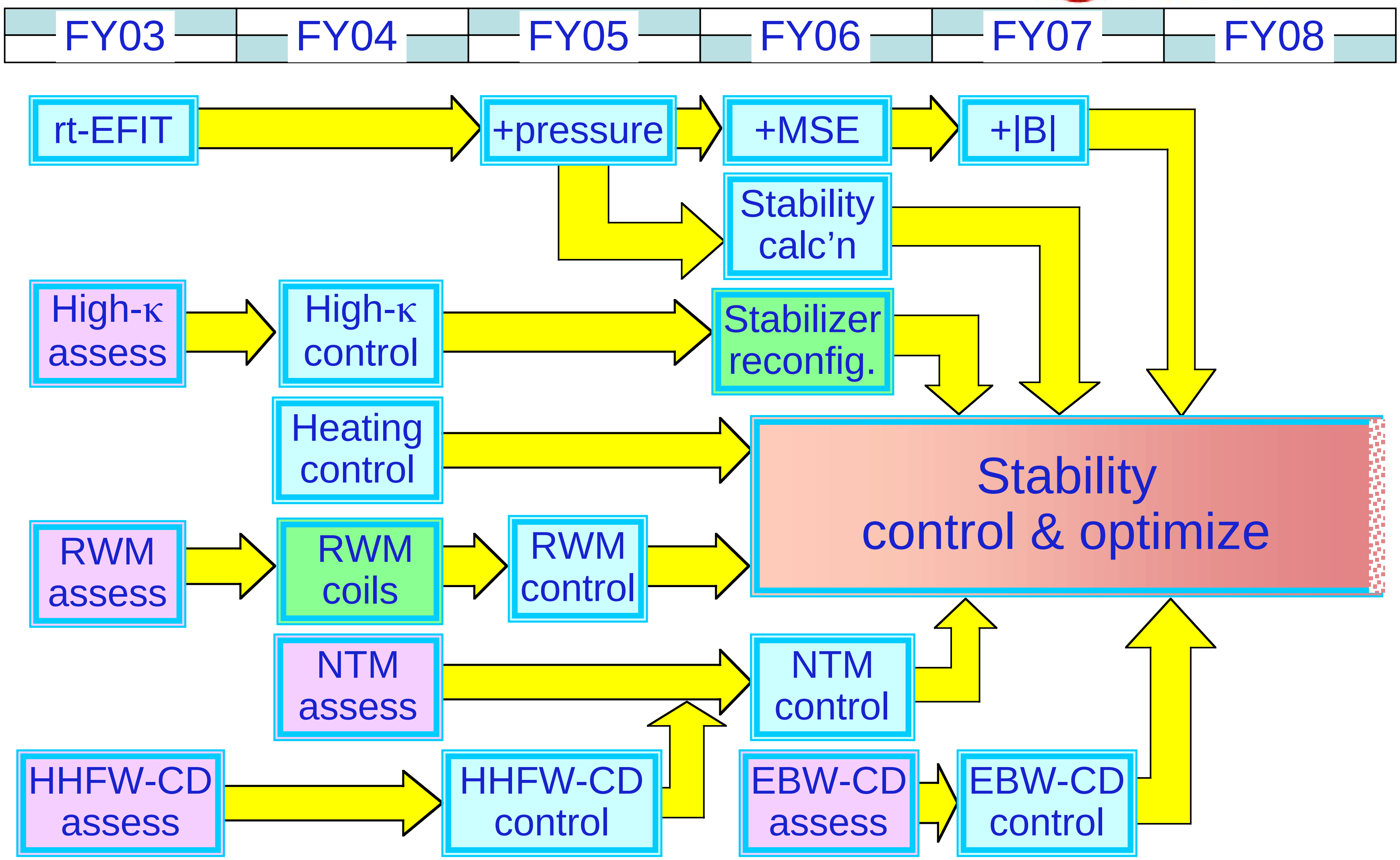
2005 Integration and control of HHFW-CD with CHI initiation

2006 Reduce role of induction for current sustainment

2007 Integration and control of 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)