Progress and Plan of KSTAR Plasma Control System Upgrade

Sang-hee Hahn[1], Y.J.Kim[1], Minho Woo[1], Hyunsun Han[1], J.W. Juhn[1], M. Joung[1], J.H. Jeong[1], J.S. Kim[1], J.G. Bak[1], H.S. Kim[1], W.R. Lee[1], J.S. Hong[1], Y.M. Jeon[1], D. Mueller[2], N.W. Eidietis[3], M. Lanctot[3], A. Hyatt[3], R.D. Johnson[3], J.R. Ferron[3], D.A. Humphreys[3], B.G. Penaflor[3], B.S. Sammuli[3], A.S. Welander[3], M.L. Walker[3], P.G. Milne[4]

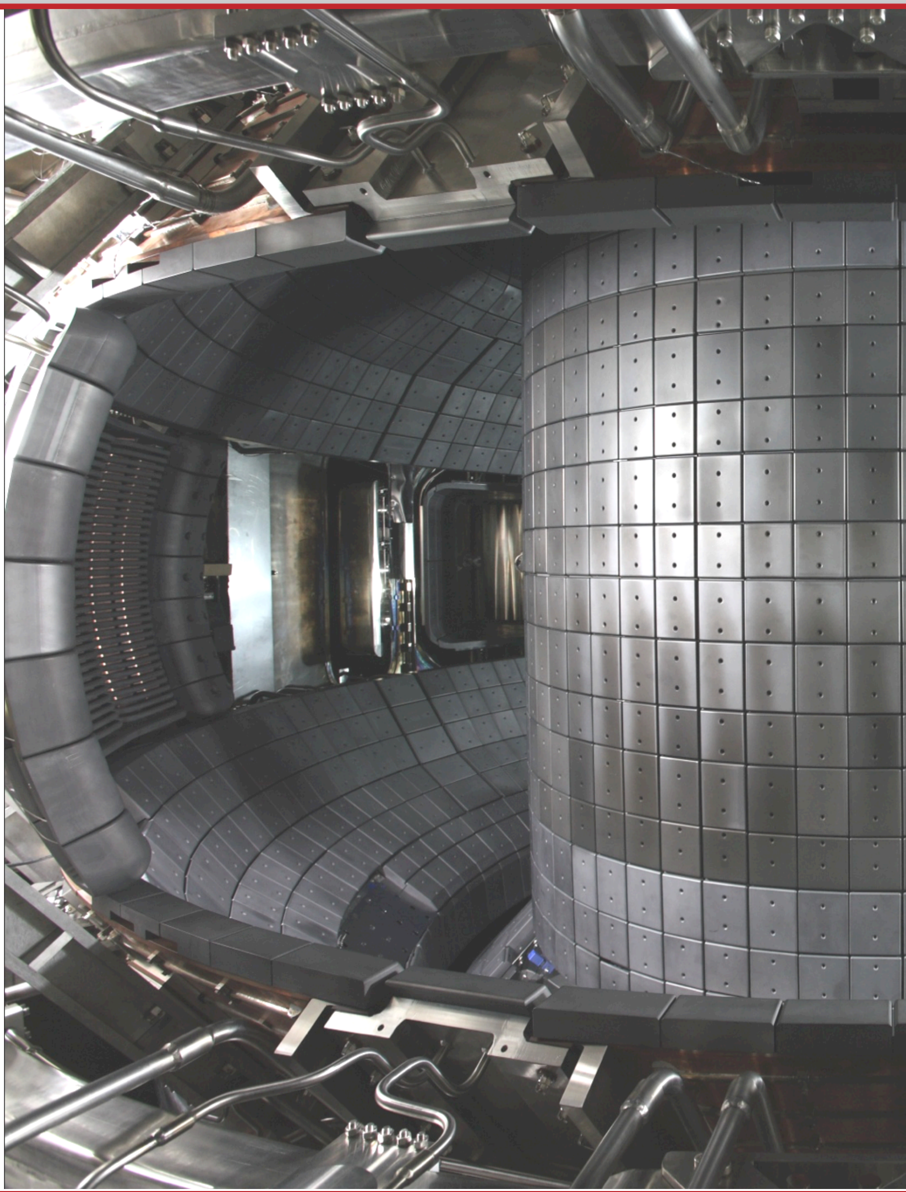
[1]*National Fusion Research Institute, Daejon, Korea*

[2]*Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA*

[3]*General Atomics, San Diego, CA, USA*

[4]*D-TACQ co. Ltd, Scotland, UK*

Email: hahn76@nfri.re.kr



ACHIEVEMENT ON PLASMA CONTROL @ KSTAR

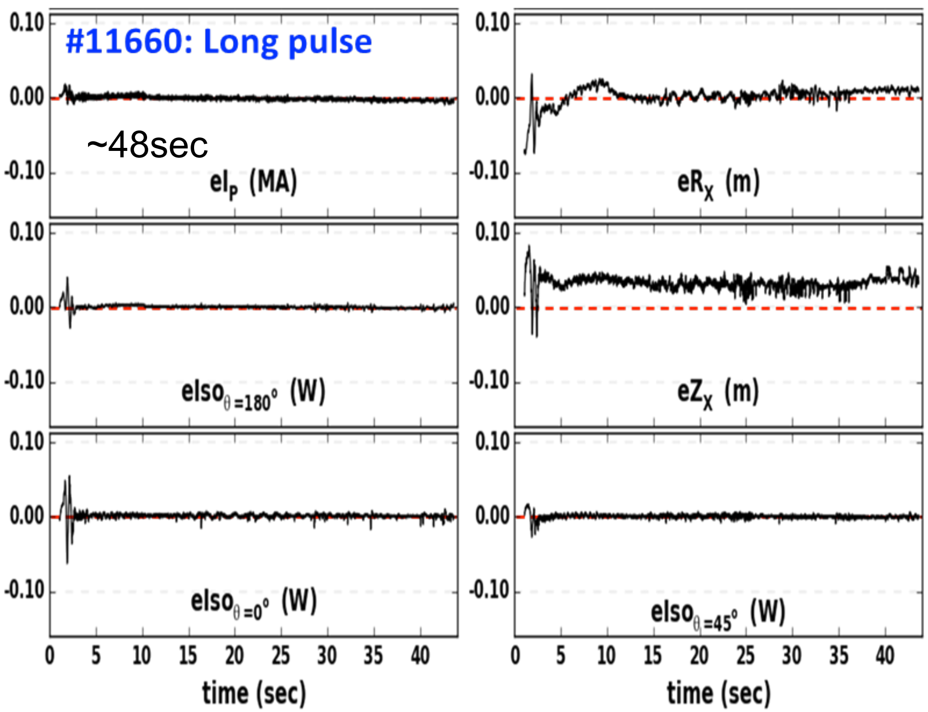
Plasma control system @ KSTAR has evolved since 2007

Starting from a single-process version in 2007, the PCS @ KSTAR has become a complex system with the following capabilities:

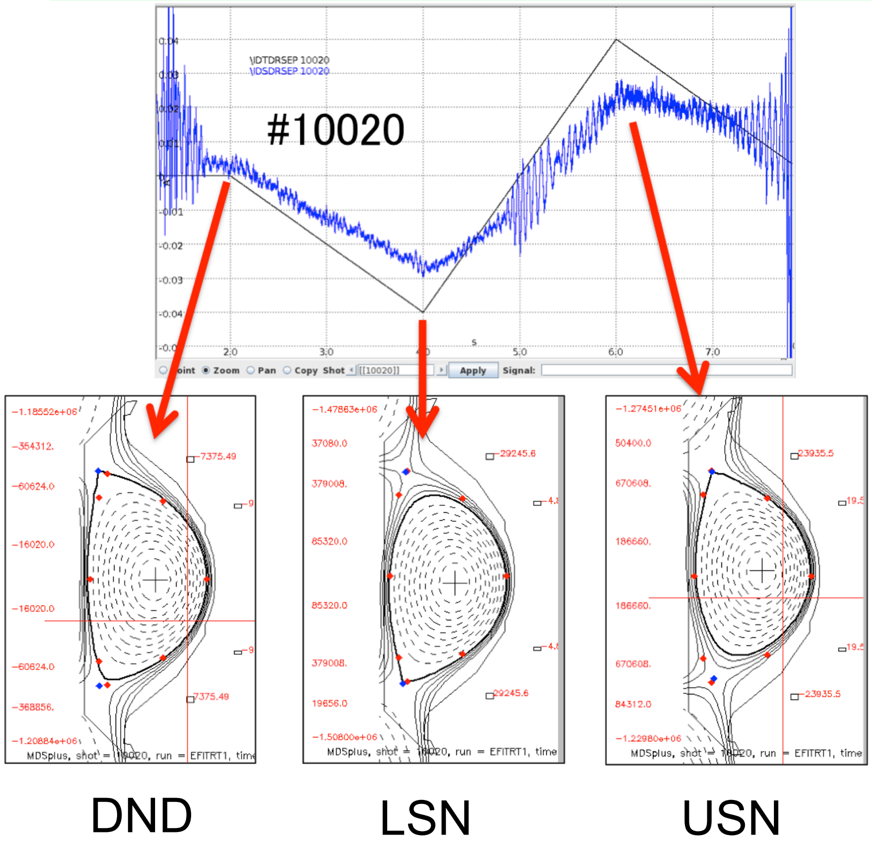
- **RTOS Cluster with 5 (+1 thread) independent real-time processes**
  - Up to 20 kHz control cycle for a single thread
- **8 separate categories of algorithms**
  - Real-time EFIT & isoflux shape controls adapted
  - Fast vertical position stabilizations with In-vessel coils
  - Kinetic control (plasma beta, density, TM/NTM…)
  - Fault detection and response
- **Real-time data communication components consisting of**
  - +180 analog inputs (AI) by dedicated digitizers
  - +600 digital I/O through the reflective memory (RFM) network
- **26 actuators directly controllable during the shot**
  - Full poloidal field coils (PF) current feedback
  - In-vessel 3D coil current feedback
  - 7 different gas injection valves
  - 2 kinds of auxiliary heating devices

Adaptation of real-time EFIT/isoflux shape control

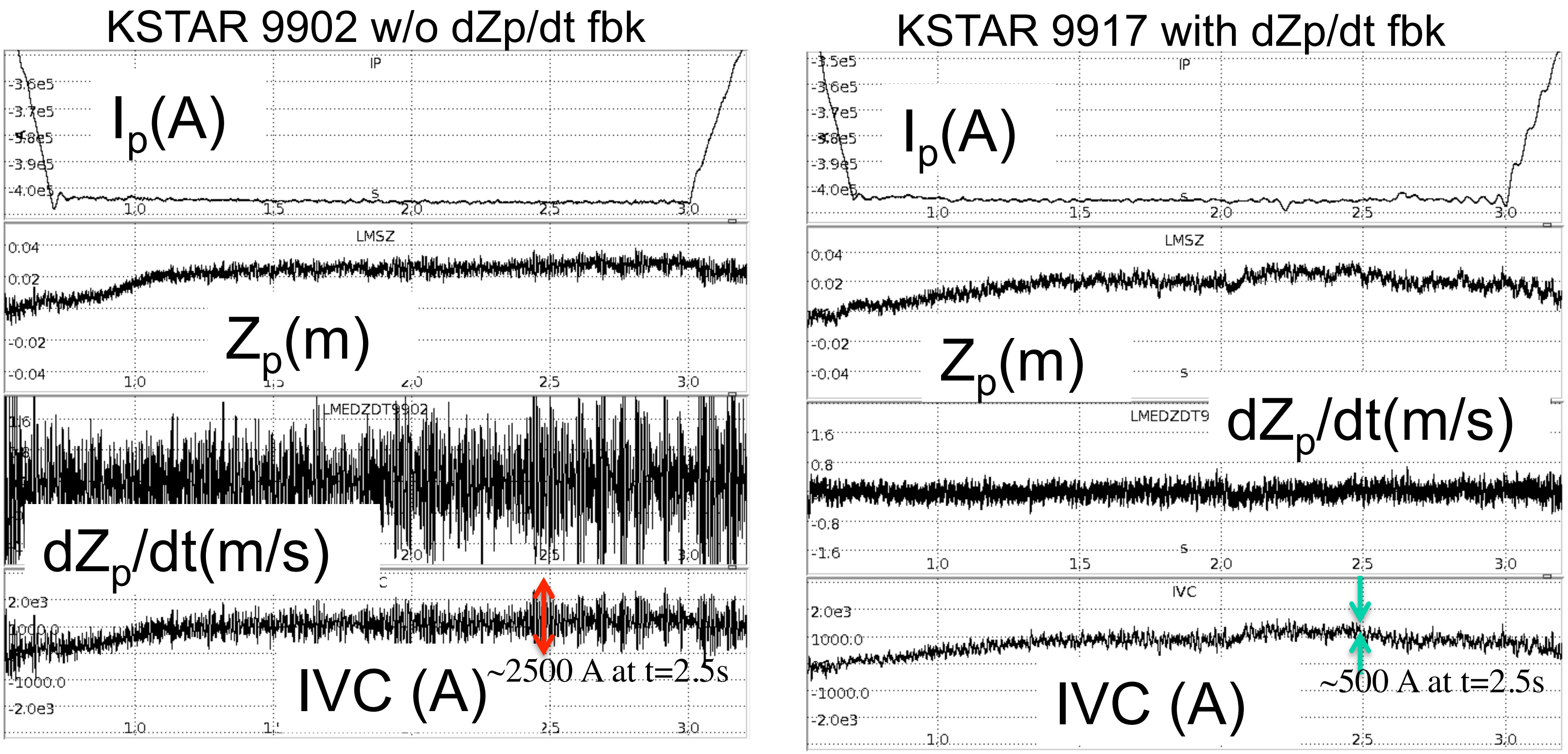
- Achieved ~48 seconds of 500 kA plasma pulses with full real-time shaping controls based on real-time EFIT measurements
- Feedback on multiple control points such as in/outboard gaps, diverting points, symmetry & squareness



Up/down Symmetry control ("drSep") demonstrations
by multiple point controller (2014)



Adding analog dZ/dt signal to VS PID enhanced allowed control margin

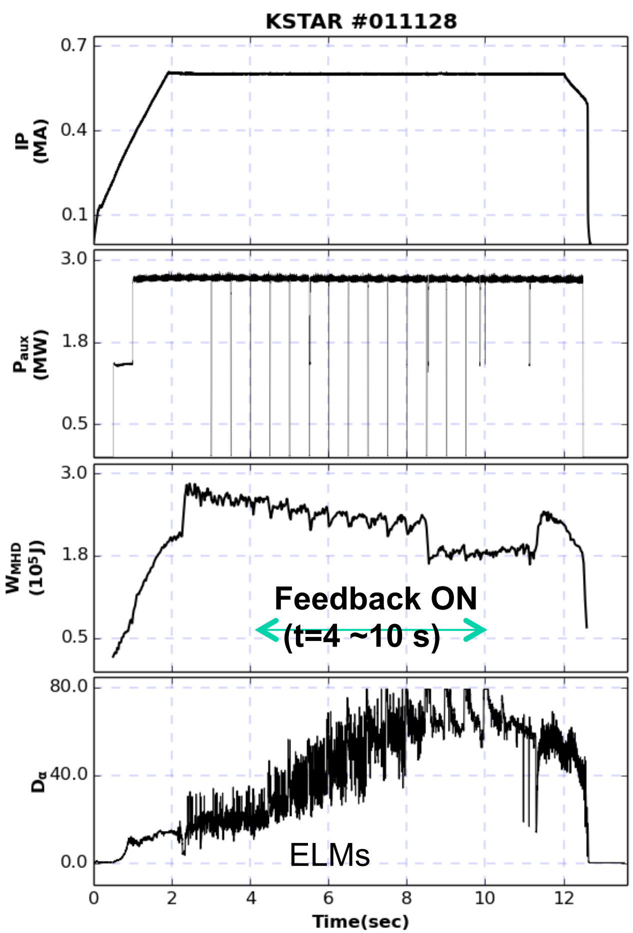


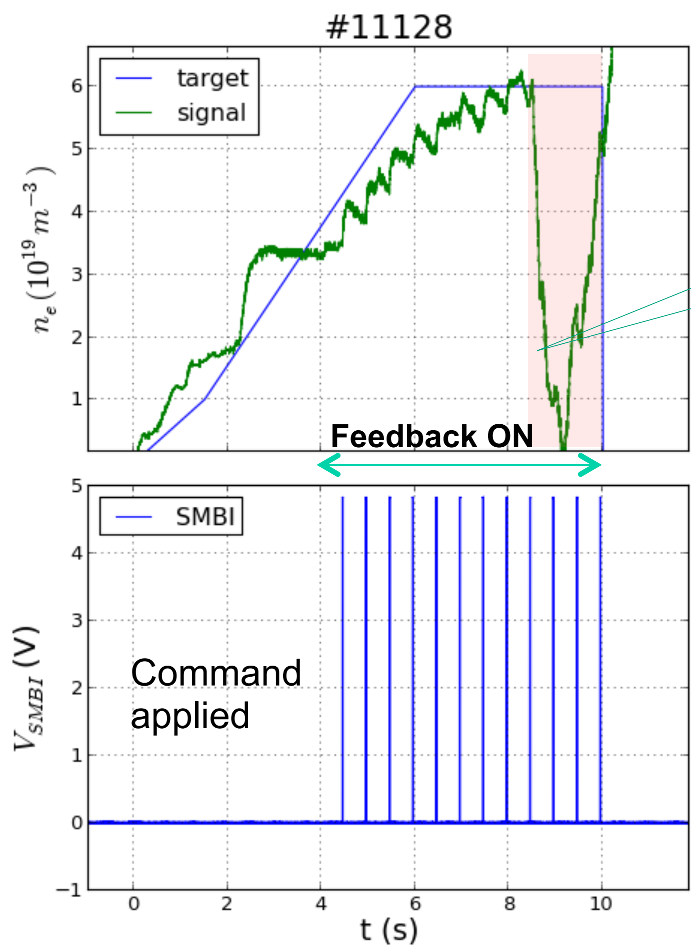
- Use of analog dZ_p/dt derived from the loop voltage signals exhibits less current request on the IVC current demand than the discharge using only Zp for PID, increase control margin available for the VS control

D. Mueller, S. H. Hahn et al. / IAEA FEC 2014

Kinetic control: Electron density feedback demonstrated by MMWI + SMBI in NBI H-mode

- Feedback loop for a single line-averaged density signal
- Preliminary result shows the pellet-type actuator [SMBI in this case] is responsive enough

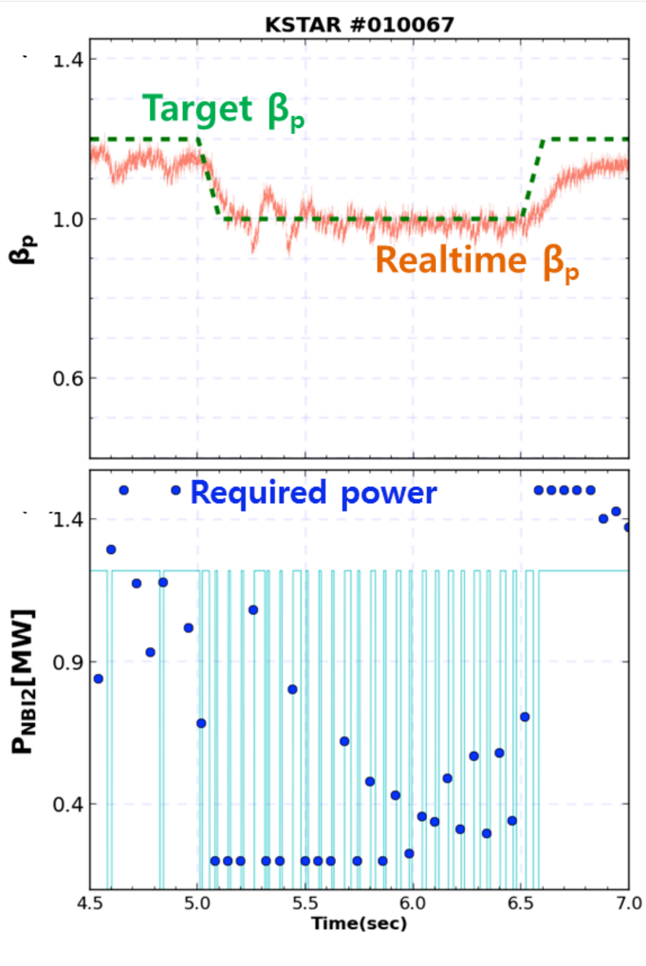




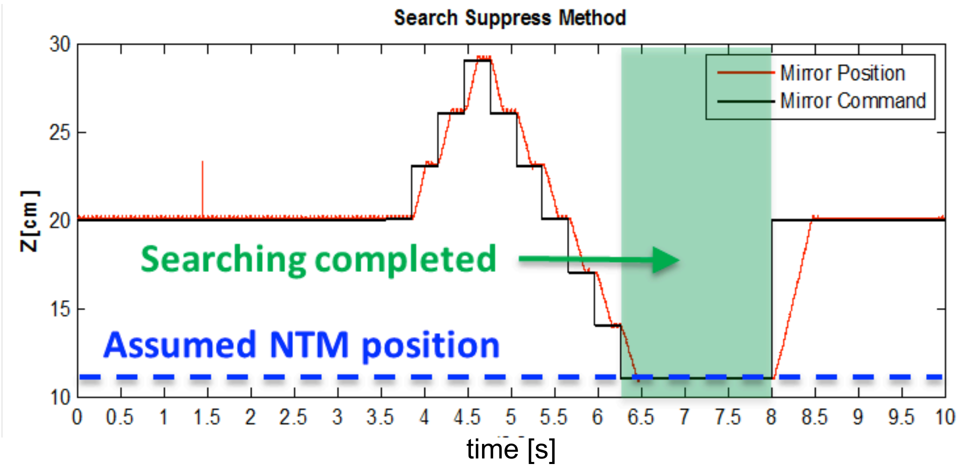
Density signal reached its diagnostic limit after t=8.0s **[6x10^{19}m^{-3}]**

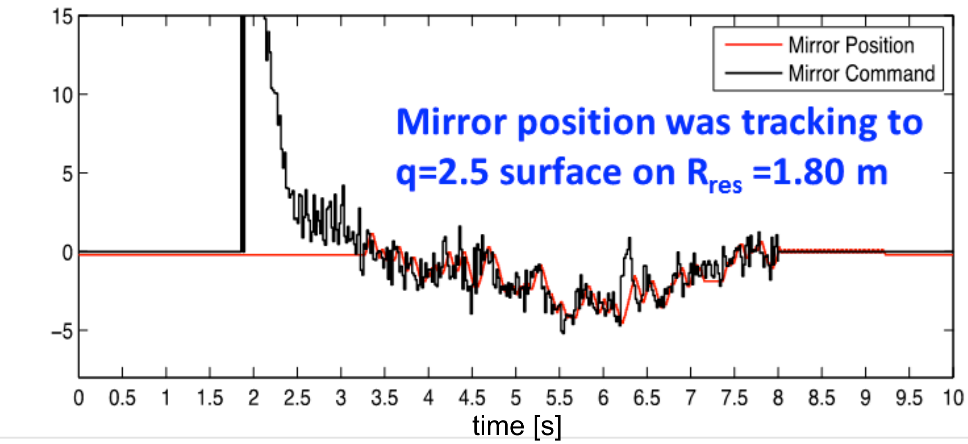
Integration of the heating devices [NB, EC] enabled more elaborate kinetic control

Demonstrations on real-time beta feedbacks using NB power modulations (2014)



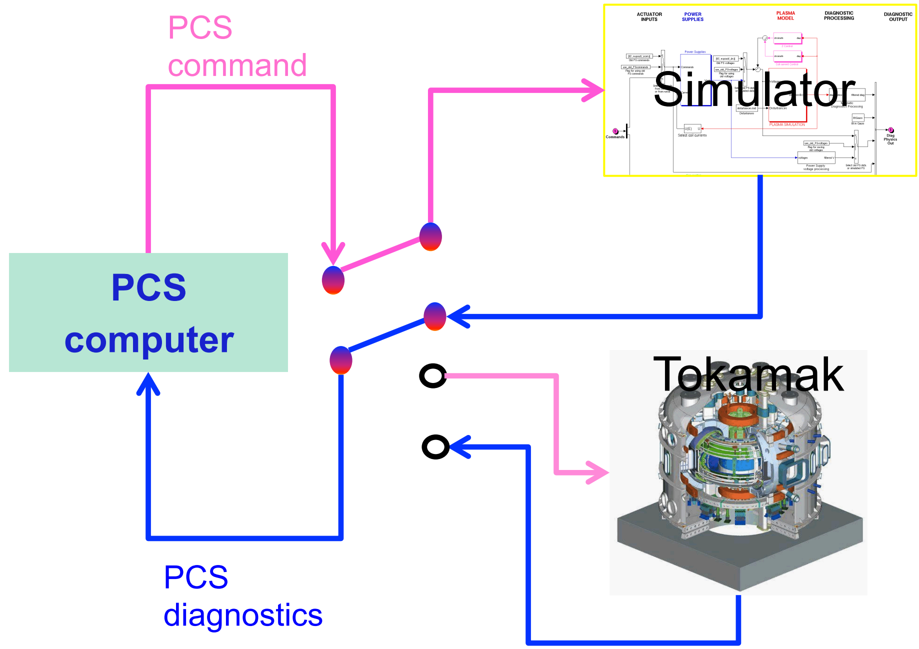
Real-time TM/NTM suppression algorithms are individually demonstrated under limited diagnostics (2013-2015)



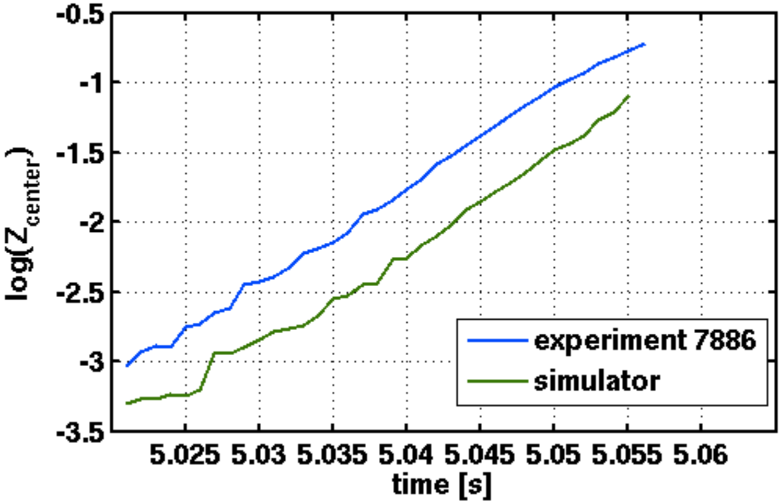


Accurate simulator enables reliable control design & cost-effective operations

- A closed-loop axisymmetric shape control simulator is developed as international collaboration activities of developing PCS
- Routinely serviced incorporating with the PCS for better control development
  - Based on nonrigid response model, reflecting shape deformation
  - Development by MATLAB/Simulink + Automatic code generation by Simulink Coder
  - Can switch/verify directly from simulation to real experiment



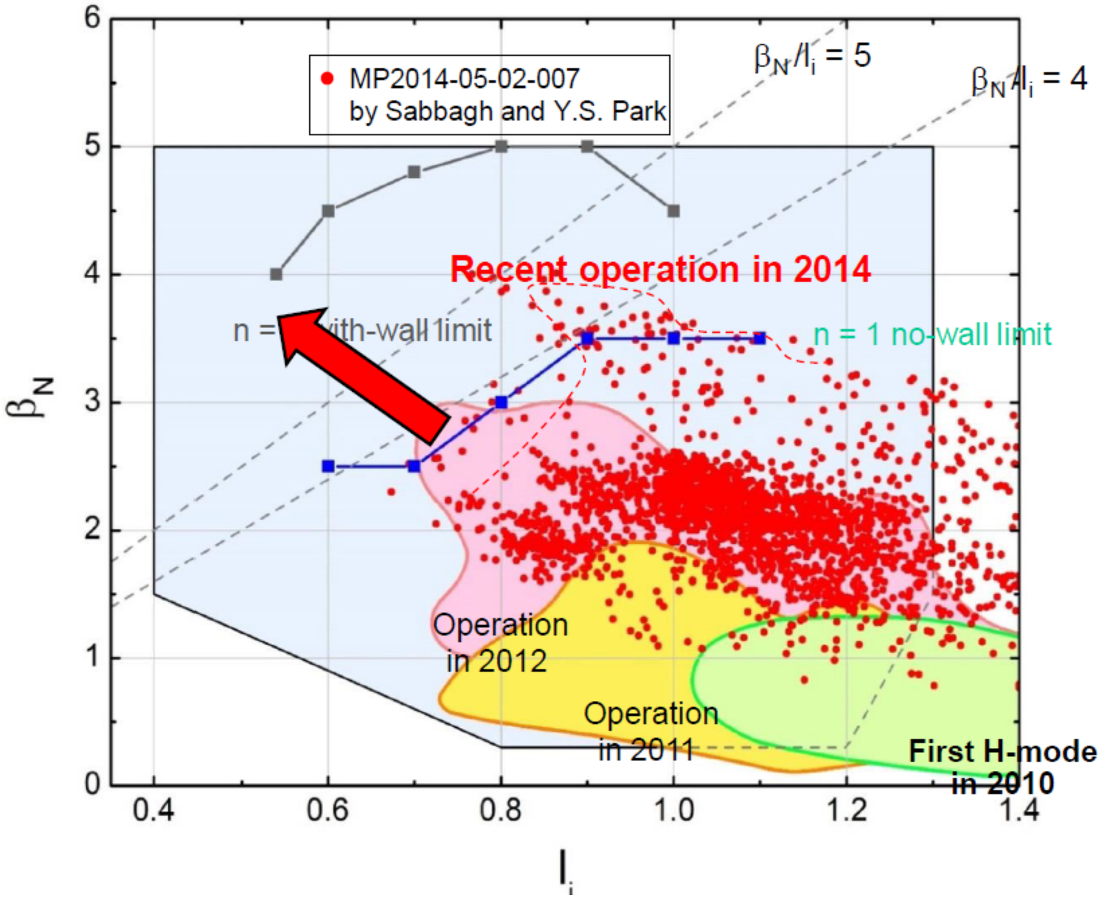
Verification: Open-loop VDE growth rate is reproduced



NEXT STEP FOR UPGRADE IN 2015-17

Plasma control system is desired to have more capabilities for advanced scenarios / steady-state operations

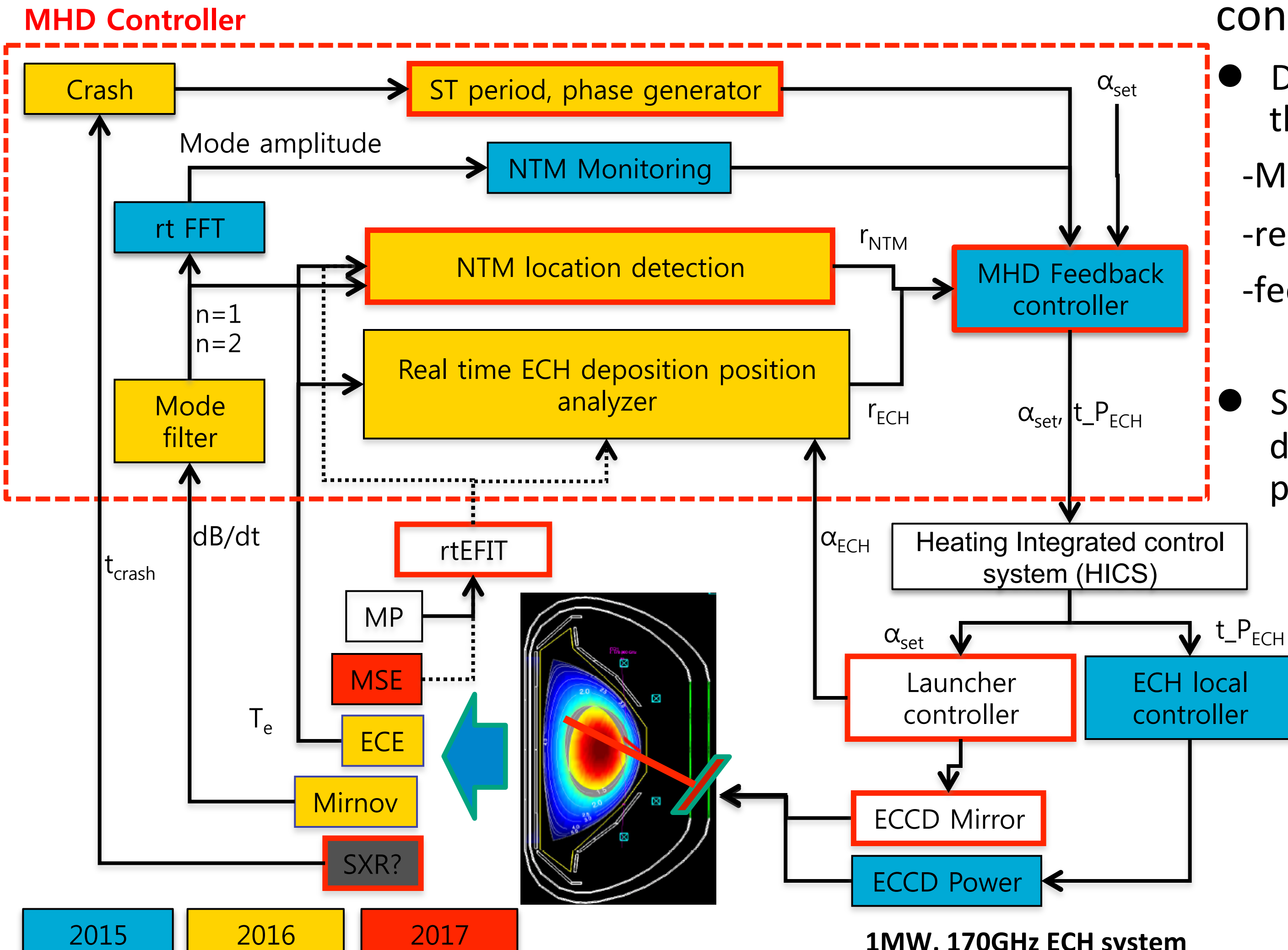
Courtesy by Y.S. Park & S.A. Sabbagh (Columbia Univ.)



For next 5 years,
KSTAR PCS is desired to have

- Capability of dealing with "advanced scenarios" beyond the no-wall limits
    - Recent attempts in 2014 reached to some points, but very short in time
- MHD/profile controls for steady-state operations

Integration of heating devices/diagnostics integrated MHD controller

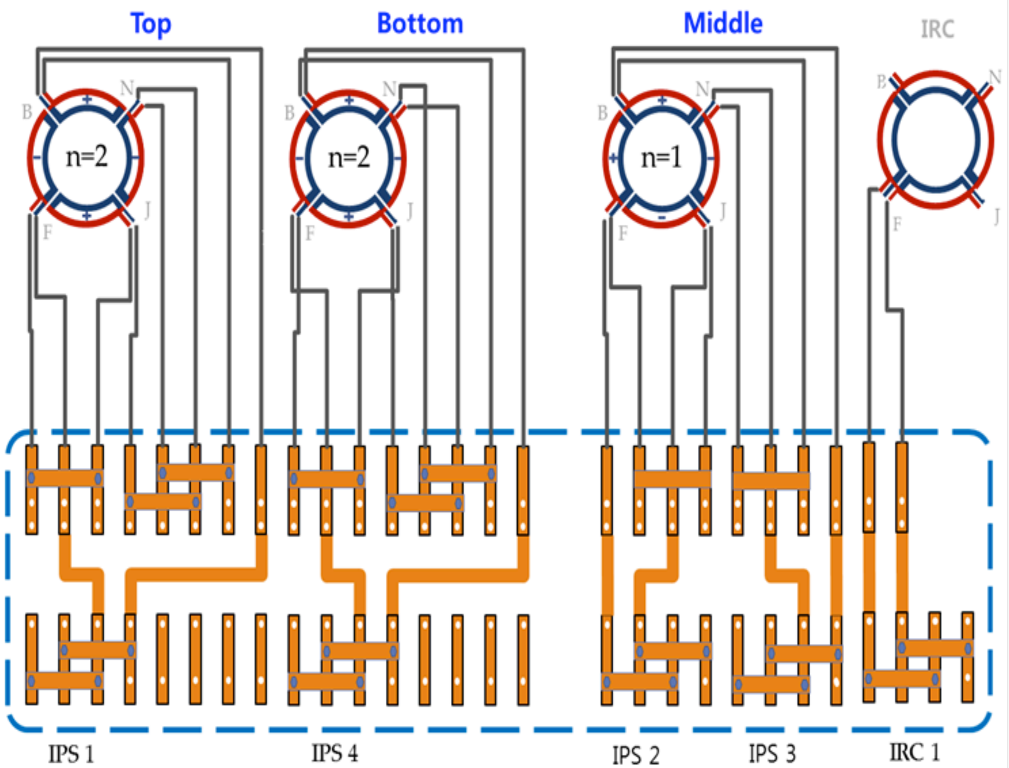


3-years plan for MHD controller:

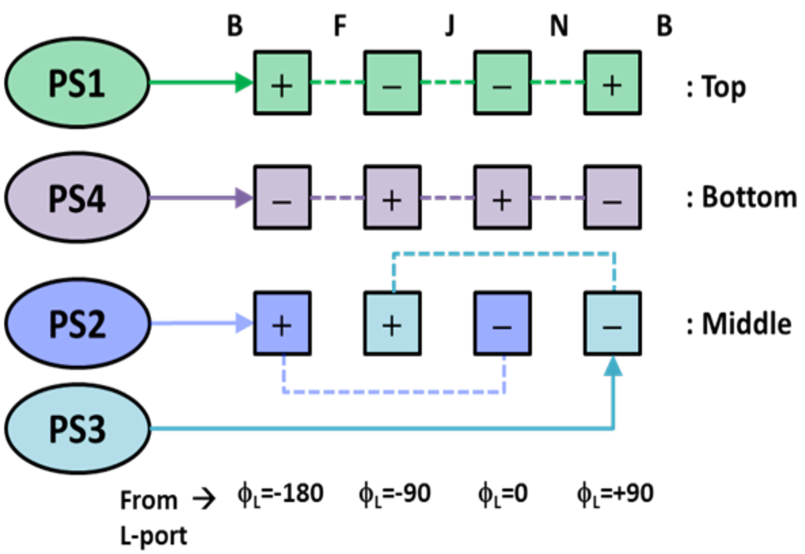
- Detect, locate and subdue the NTM by
  - -Mode location (MC/ECE/MSE)
  - -real-time EC location
  - -feedback on mode amplitude
- Simultaneous detection of different modes for multiple purposes

Need for 3D-field physics requires sophisticated controls even for actuators

- 10 stacks of In-vessel coil power supply [called as **IPS**] are introduced to KSTAR in 2015, expected to use as multi-purpose control knobs
  - proposing 8 different patch-panel connections for different physics requirements (ELM, NTV, RWM…)
  - Maximum current 5 kA/turn
  - Freq. response is DC to 1 kHz, arbitrary phasing



Example of "mixed" configurations for an ELM suppression candidate



New hardware system is expected to overcome limitations of the present system

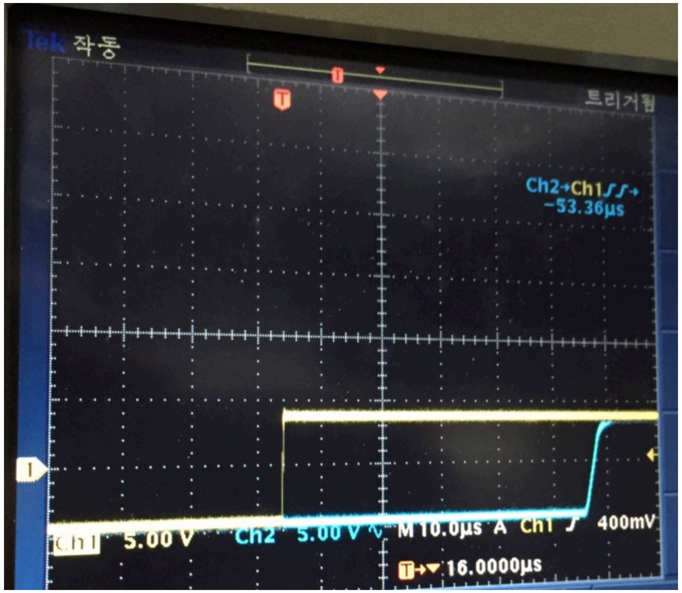
- Detections of MHD-related events need to have high frequency data acquisition @ KSTAR:
  - Data acquisition issue: high sampling rate, diagnostics spread all over the devices
    - VS, Locked mode more than 10 kHz
    - TM/NTM : more than 50 kHz
  - Current real-time scheme (GA kernel hack) isolates the system from the scheduler
    - Results in limitations on pulse length [~50s in 2014, at 4 kHz]
      - Downsampled acquisition might not be a solution[!]
    - Data streaming desired to break the pulse limits due to no. of samples

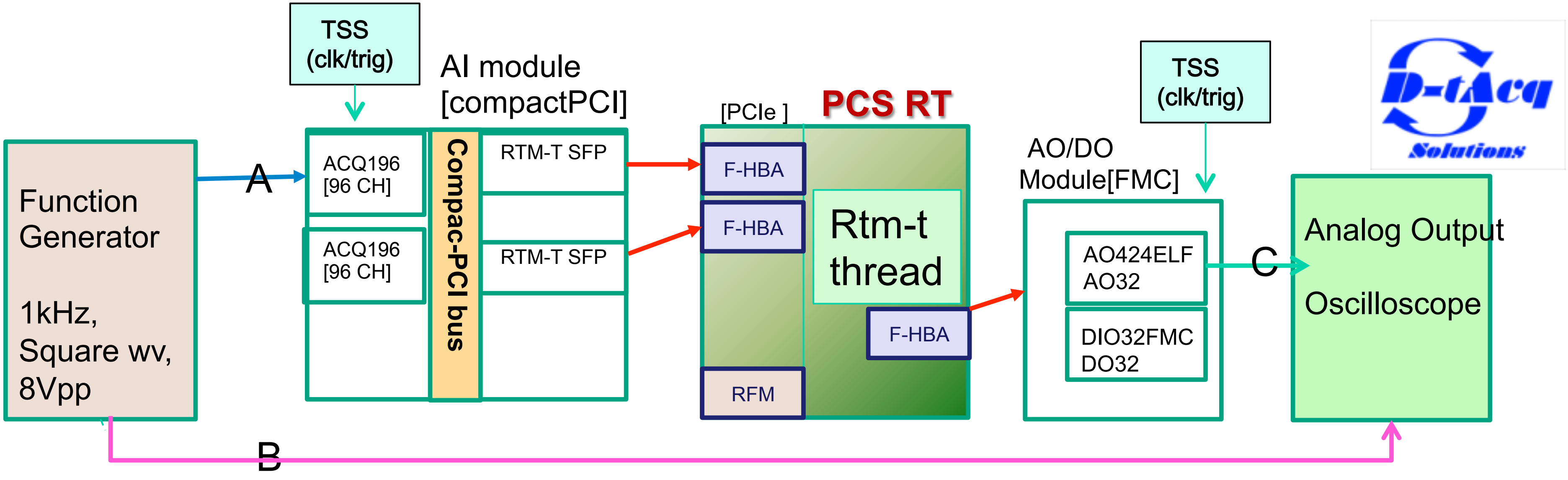
- **The CERN MRG-realtime 2.x is chosen as new real-time OS**
  - Can isolate MSI-APIC interrupts for the specified CPUs by *isolated_cpu=* boot options
    - Up to N-1 CPUs can operate simultaneously when isolated_cpu=1-N is set
  - Performance test for a single real-time process can deal with up to a *100 kHz* cycle
  - Requires software migrations to full 64-bit system

Component-by-component verifications done for the compatible operation under MRG-R

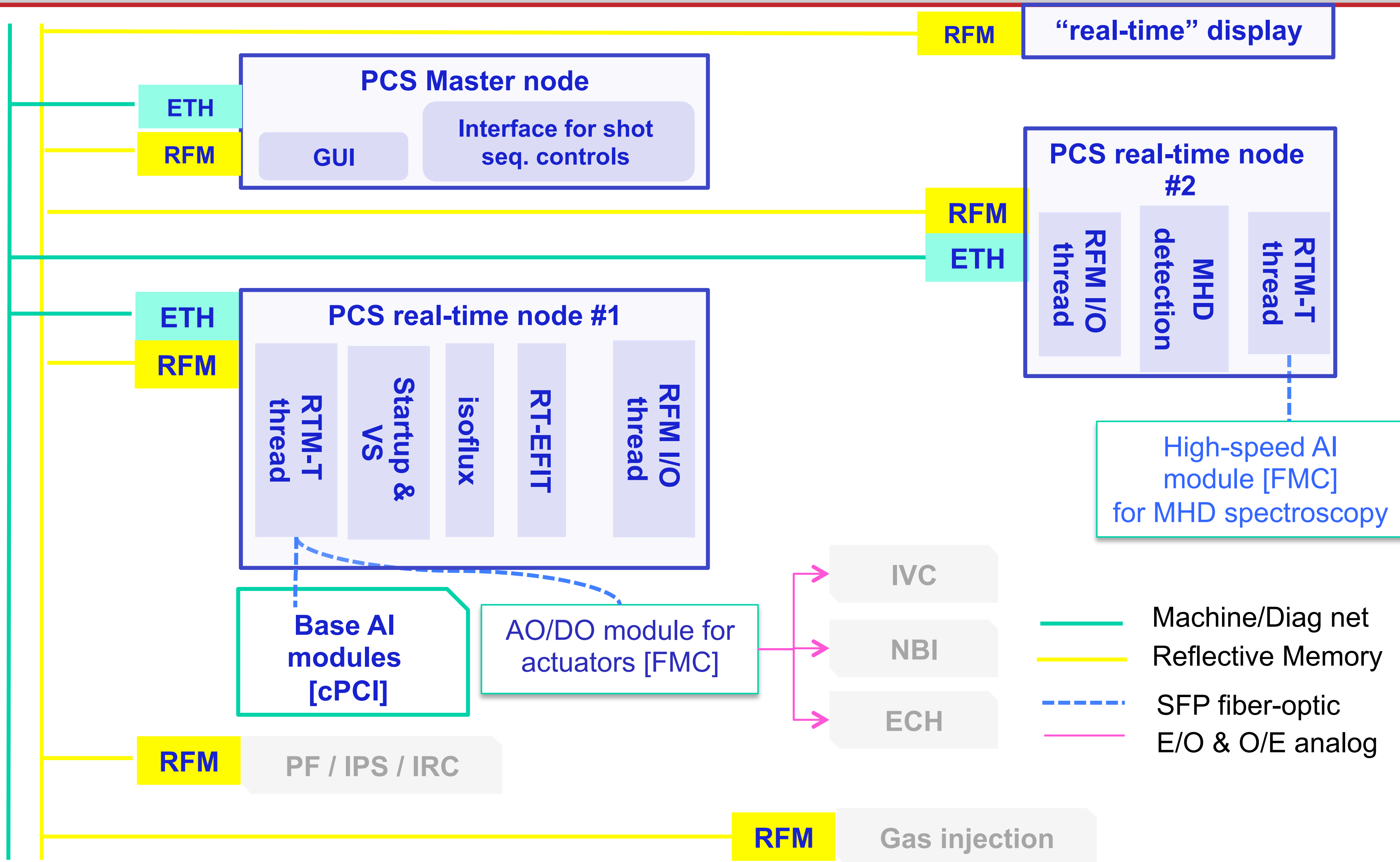
- Analog Input (AI) component test showed a single isolated process can do 4,000,000 cycles, 200 kHz, with only 1 cycle miss
- A hardware loopback test for 2 AIs, 1 AO showed that the system satisfies the requirements

AI cycle [Acq196]	AO cycle [Acq400]	Ave. delay [C-B]
100kHz(CLKDIV=10)	100kHz(CLKDIV=10)	21 ~ 29 us
50kHz(CLKDIV=20)	50kHz(CLKDIV=20)	32 ~ 53 us
20kHz(CLKDIV=50)	20kHz(CLKDIV=50)	20 ~120 us





Designed H/W configuration layout for 2015-16



Summary & Future Plan

- KSTAR plasma control system (PCS) has become an essential system for any integrated plasma operations
  - Almost every essential actuator is integrated to the real-time comm. interfaces
  - Full applications on shape control enabled long pulse within constraints
  - Basic attempts on kinetic controls accomplished

- KSTAR PCS is desired to have capabilities required for advanced scenarios research that KSTAR wants to do
  - Extensive implementations on diagnostics / actuators are required
  - New H/W platform is desired for easier extension, higher performances

- The next upgrade of the KSTAR PCS is planned in 2015-17
  - Adapted MRG-R + 64 bit to apply new ideas useful for ITER
  - Finished component-by-component tests successfully
  - First commissioning on integrations planned at 2015 May