



# Status and Plan of KSTAR plasma control system

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**National Fusion Research Institute**

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**NFRI** 국가핵융합연구소  
National Fusion Research Institute



- Overview of the system
- System status
- Plasma control result in the first plasma campaign
  - ▶ Plasma creation
  - ▶ Radial position control & applications
- Plan and US-collaboration Issues
  - ▶ Development plan for upcoming 3 years
  - ▶ Progress on system upgrades
  - ▶ NFRI activities for control R&D
- Collaboration issues
- Summary

# Overview

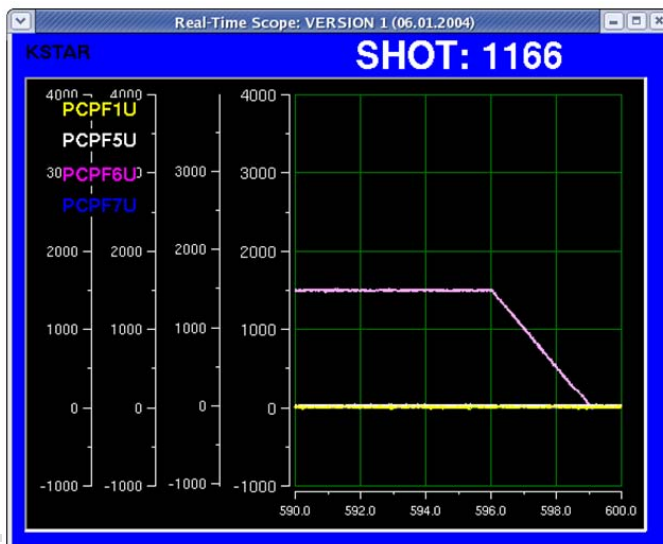


- Plasma control plays a **key role** to
  - ▶ make reproducible tokamak plasmas and enhance the plasma performances for reliabilities of the experiment
- First application on KSTAR has been successful by the **collaboration efforts with the US-participants from GA/PPPL**
  - ▶ Software / algorithms developed by GA R&D contract
  - ▶ Fast real-time hardware developed and integrated by NFRI with GA personnel support
  - ▶ Onsite experiment design performed by GA/PPPL participants
- **Substantial upgrades** are ongoing in accompany with the targets of the upcoming KSTAR program

# System Status (1/3)



- Two kinds of direct feedback loops have been developed for
  - ▶ Plasma current & major radius
  - ▶ Line density for electrons
- Time synchronization with central control system, heating and diagnostics was finished
- Real-time digital communications via reflective memory (RFM) developed for PF coil feedbacks & 1-D real-time data display



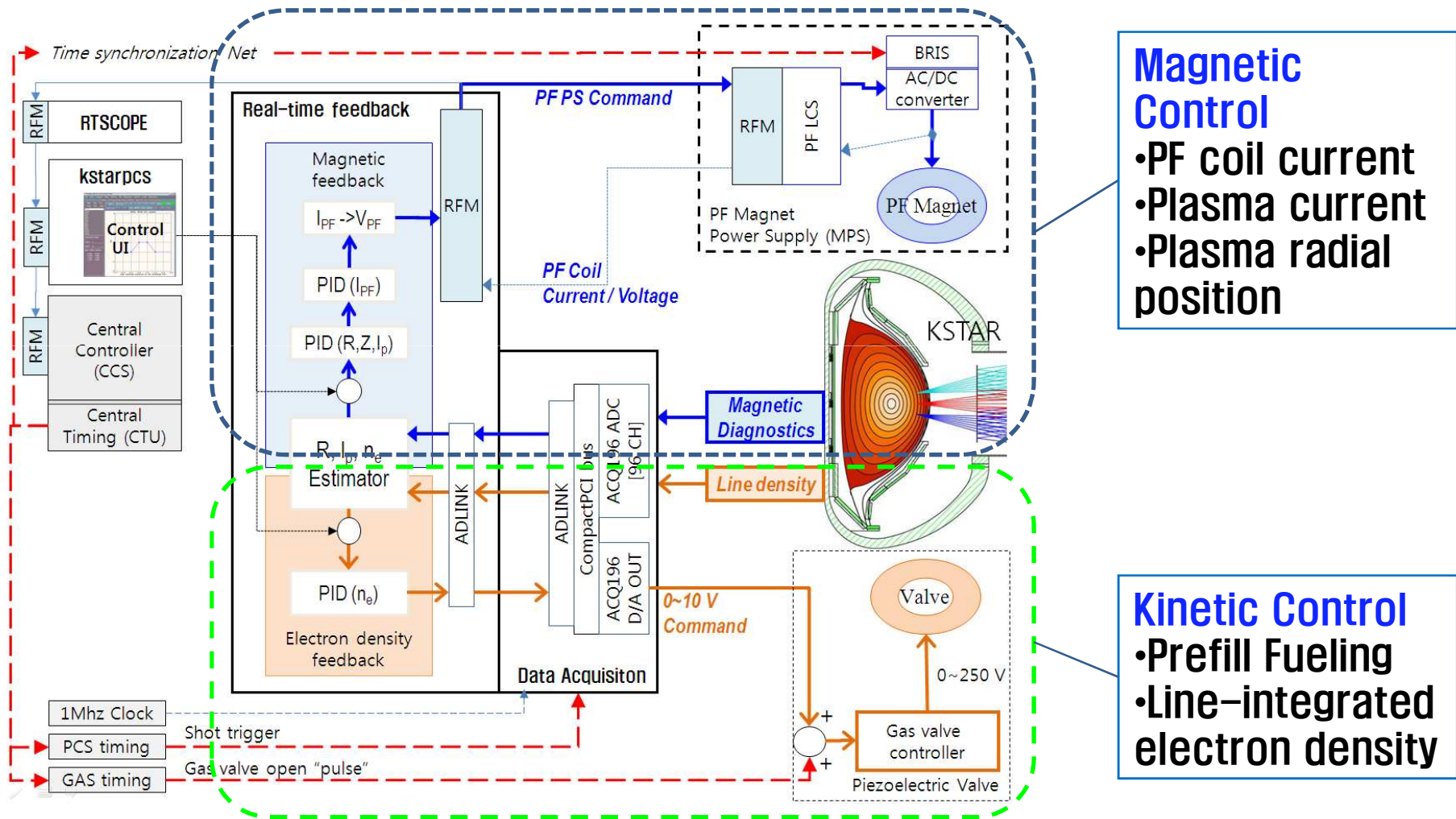
A 1200-seconds shot for PF6 feedback in the coil AC loss measurements

Diagnostics		No. of channels (with integrator)	
Flux loop		5(5)	
Loop voltage		5(-)	
Magnetic pickup coil		42(33)	
Diamagnetic loop		2(2)	
Rogowski coil		3(2)	
Vessel current monitor		3(2)	
MM interferometer		1(-)	
total		83(44)	
PF PS	Max V [V]	Max I / turn [kA]	Coil self Inductance [mH]
PF1	320	± 4.0	91.42
PF2	320	3.1	48.77
PF3	160	3.3	14.56
PF4	160	3.3	29.21
PF5	320	2.1	239.2
PF6	1000	2.3	450.9
PF7	1000	± 4.0	222.8
Main Gas		Operable pressure [mbar]	
GAS1	Hydrogen	1e-7 ~ 1e-2	

# System Status (2/3)



## System hardware layout



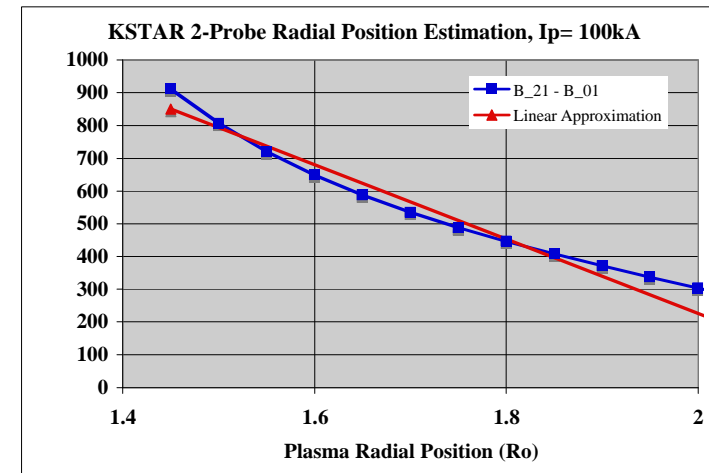
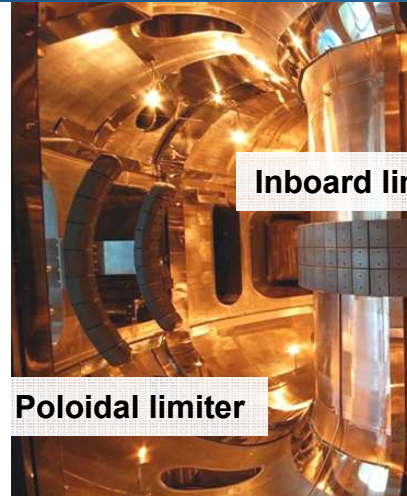
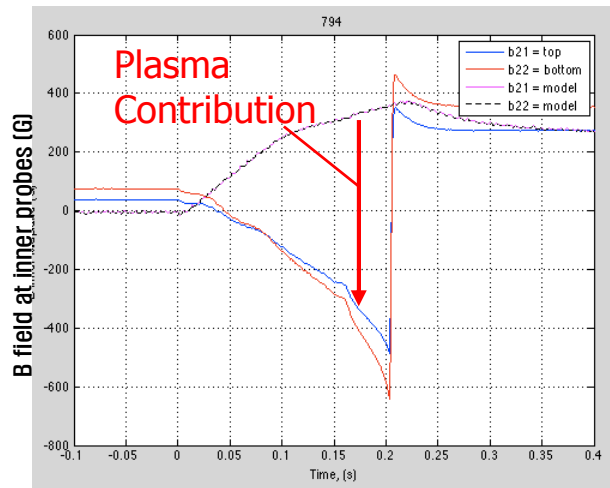
**Magnetic Control**

- PF coil current
- Plasma current
- Plasma radial position

**Kinetic Control**

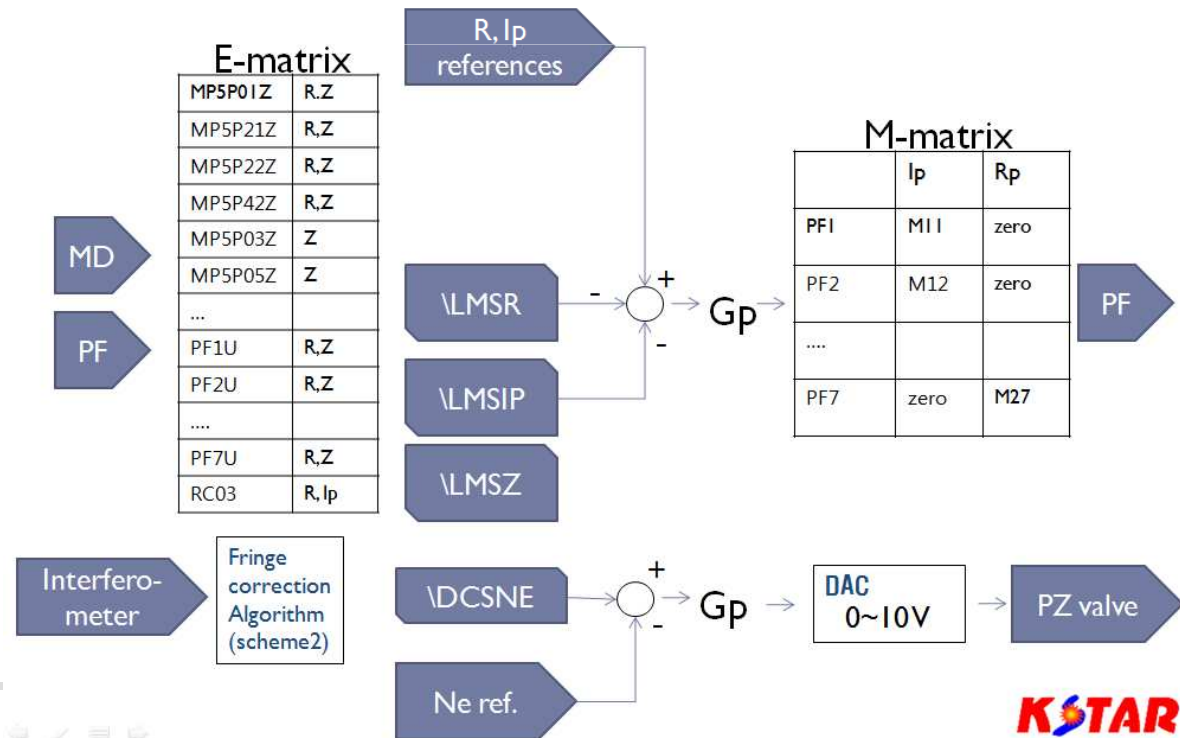
- Prefill Fueling
- Line-integrated electron density

# System Status (3/3)



- Responses of the midplane magnetic Z-probes for a rigid plasma column have been fitted for major radius ( $R_p$ ) estimations

- ▶ Plasma is assumed as a circular shape filled between inboard/poloidal limiters
- ▶ normalized by total plasma current ( $I_p$ ) measured from a Rogowski coil



# Plasma control in the first plasma campaign (1/4)



## Reproducible plasma startup

7 sets of up/down symmetric PF coils create a toroidal loop voltage by set of "blip" resistors activated at  $t=0.0$  for 100~150ms.

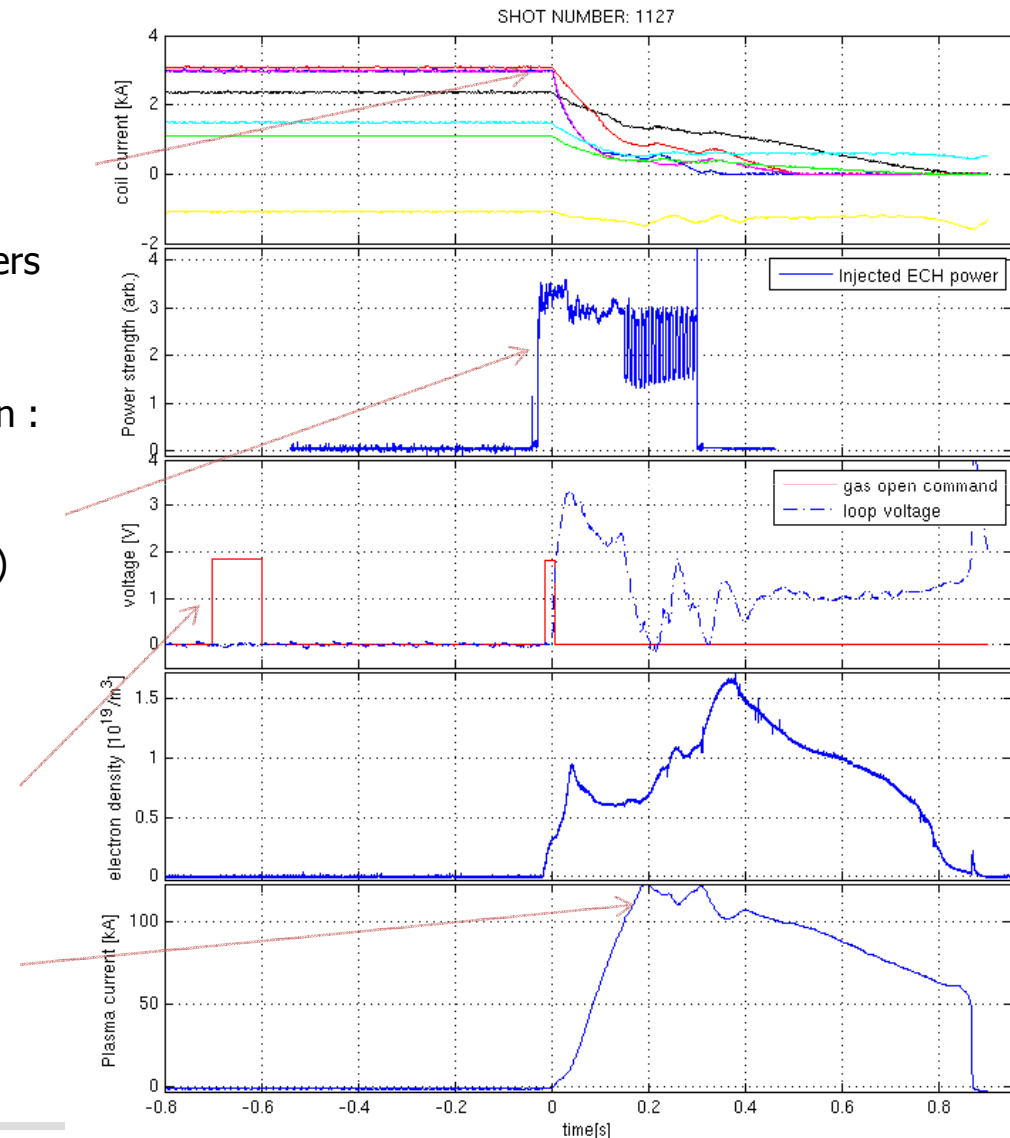
Initially available magnetic flux : 0.9~1.1 Webers

ECH injection for the 2<sup>nd</sup> harmonic preionization :  $t = -40 \sim -10$  ms.

Low loop voltages (1.5~3.5 volts @  $R=1.68$  m) have been available for successful startups

A hydrogen gas puff valve for feedforward prefill + line density feedbacks

Feedback controls started at  $t= 150$  ms for plasma current/major radius

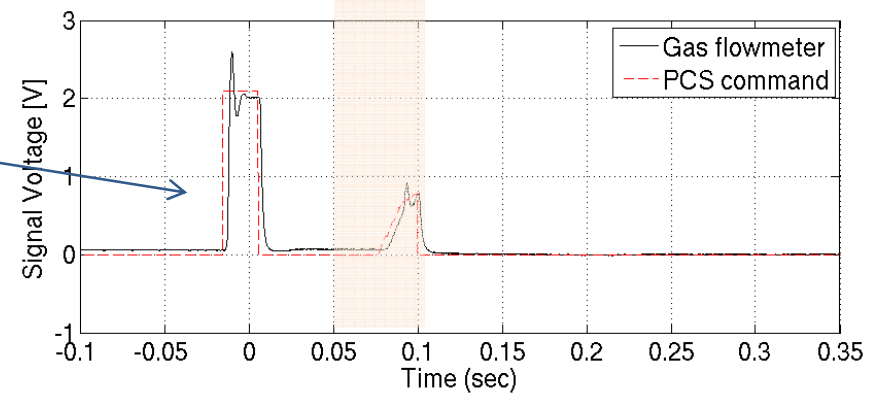
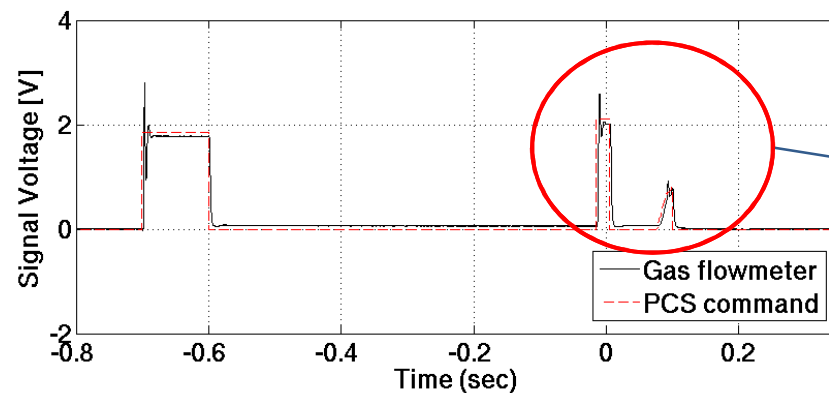
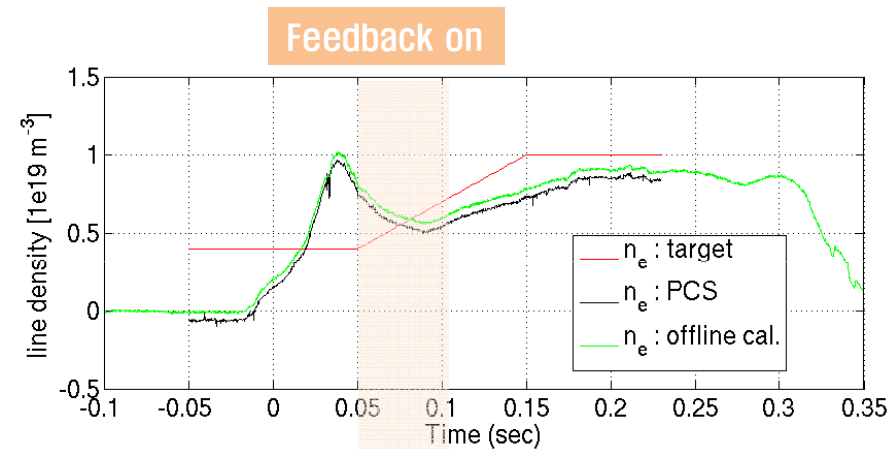
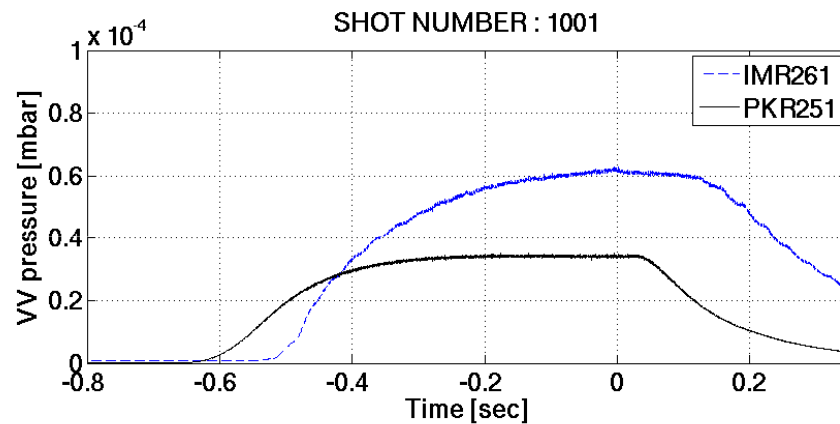


# Plasma control in the first plasma campaign (2/4)



## ▪ Electron line density controls

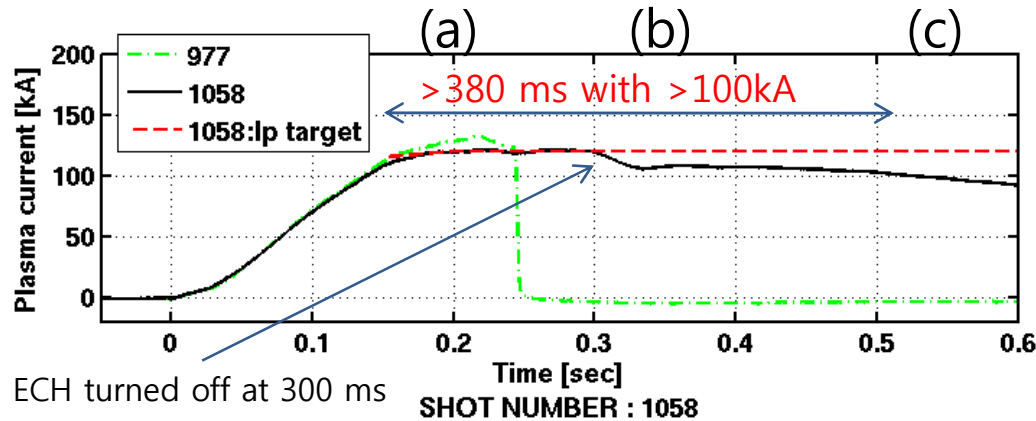
- Direct estimations on the line density from the millimeter-wave interferometer at 10 kHz
- Turned on the density feedback at  $t = [0.05, 0.1]$  seconds after two prefills
- Delay on density response for the feedback has been estimated as 100~120 ms



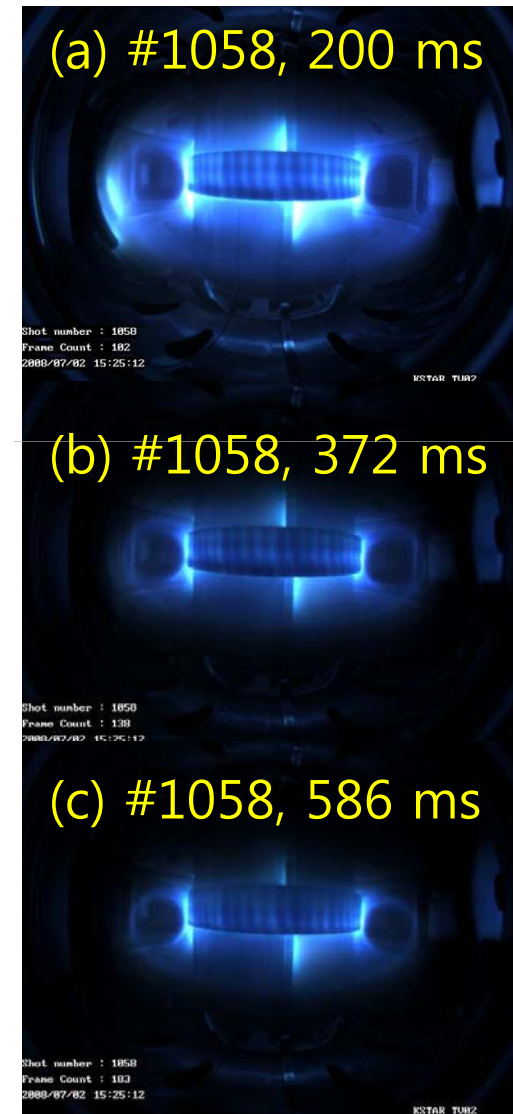
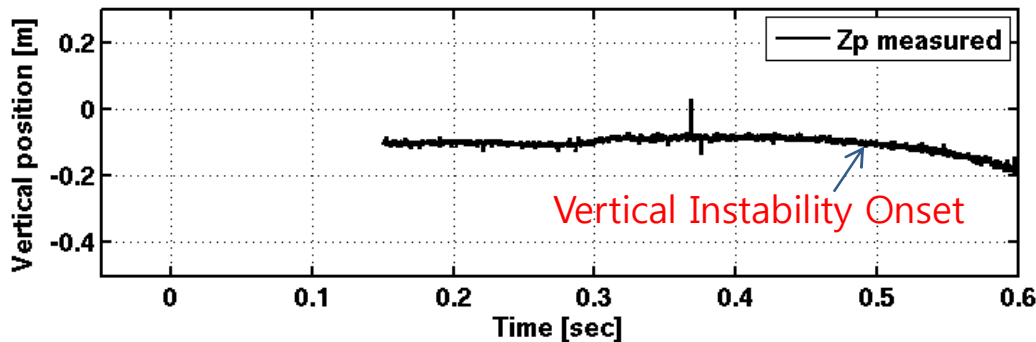
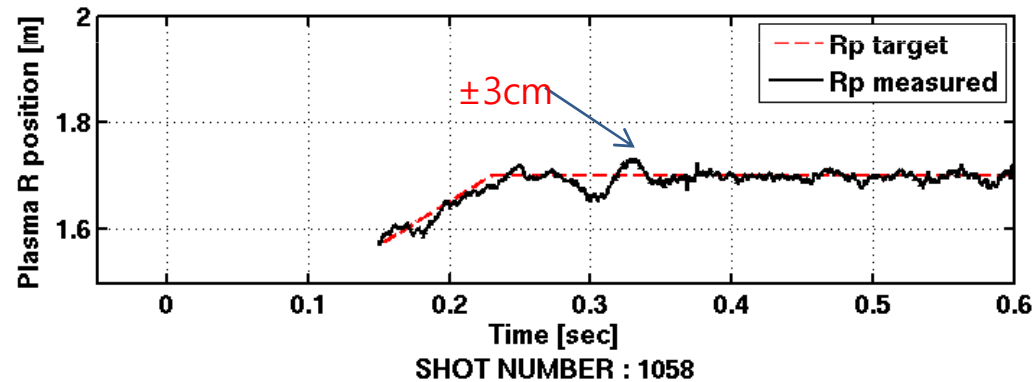
# Plasma control in the first plasma campaign (3/4)



## Plasma current / major radius control



ECH turned off at 300 ms



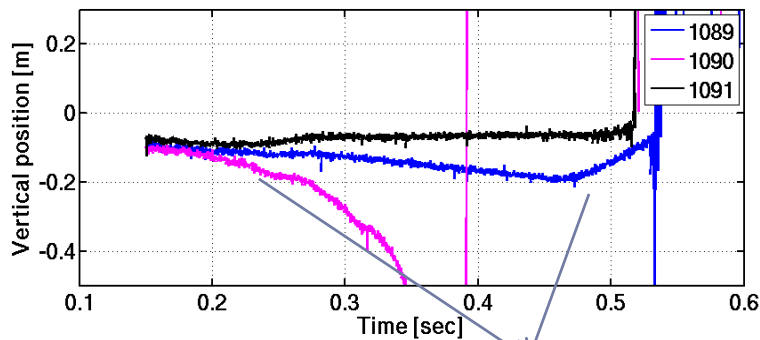
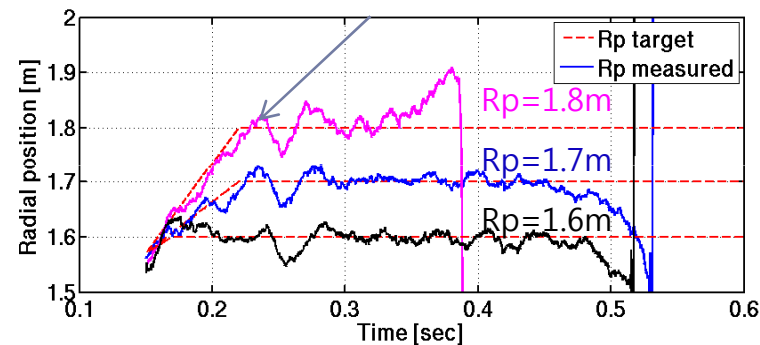
# Plasma control in the first plasma campaign (4/4)



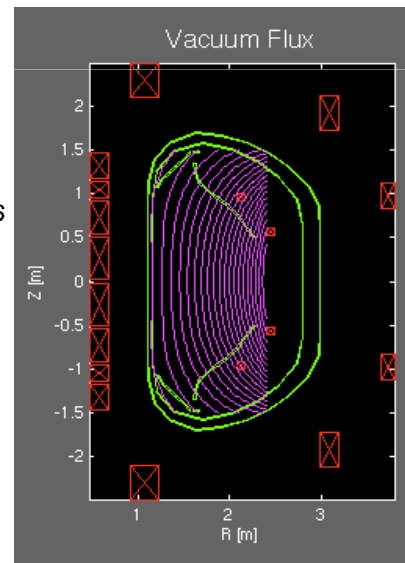
## Major radius control minimizes chances to VDE

- Vertical displacement event (VDE) has been observed (growth rate  $14.3 \pm 0.2$  rad/s)
- Concave PF field profile in the outboard makes plasma vulnerable to VDE
- A real-time adjust on the major radius to the more favorable field index made the plasma live longer below the typical disruption level - The *longest* discharge has been obtained as 866 ms @ 1.1 Wb (#1127)

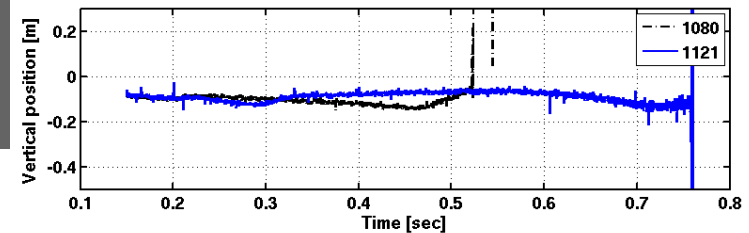
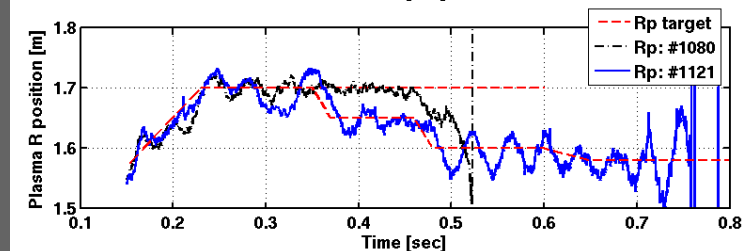
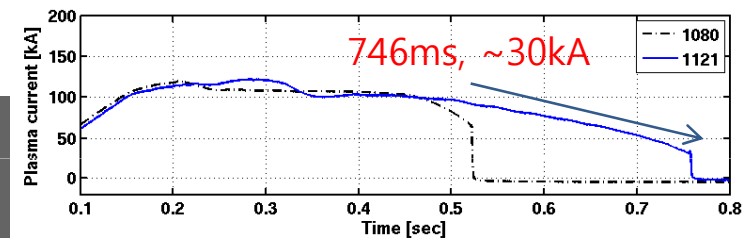
ECH turns off at 240ms



Vertical instability Onset



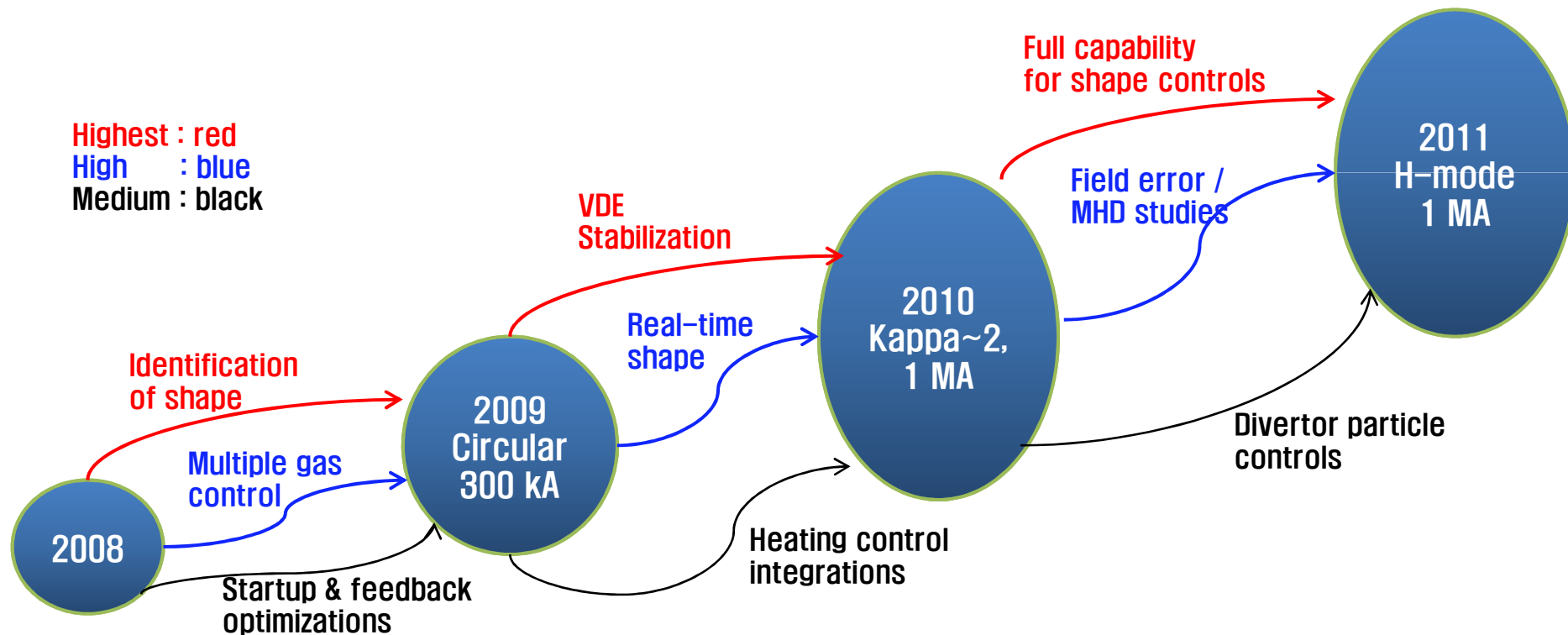
Vacuum flux profile reconstructed from the PF coil currents at  $t=650$ ms, Shot 1062



# Development plan for KSTAR D-shape/H-mode



- The importance of the D-shape target in KSTAR
  - ▶ To optimize utilizations of the 2MW ICRF heating (designed for kappa ~2)
  - ▶ H-mode target : much easier to get at the D-shape configurations
- Priorities for the upcoming PCS upgrades



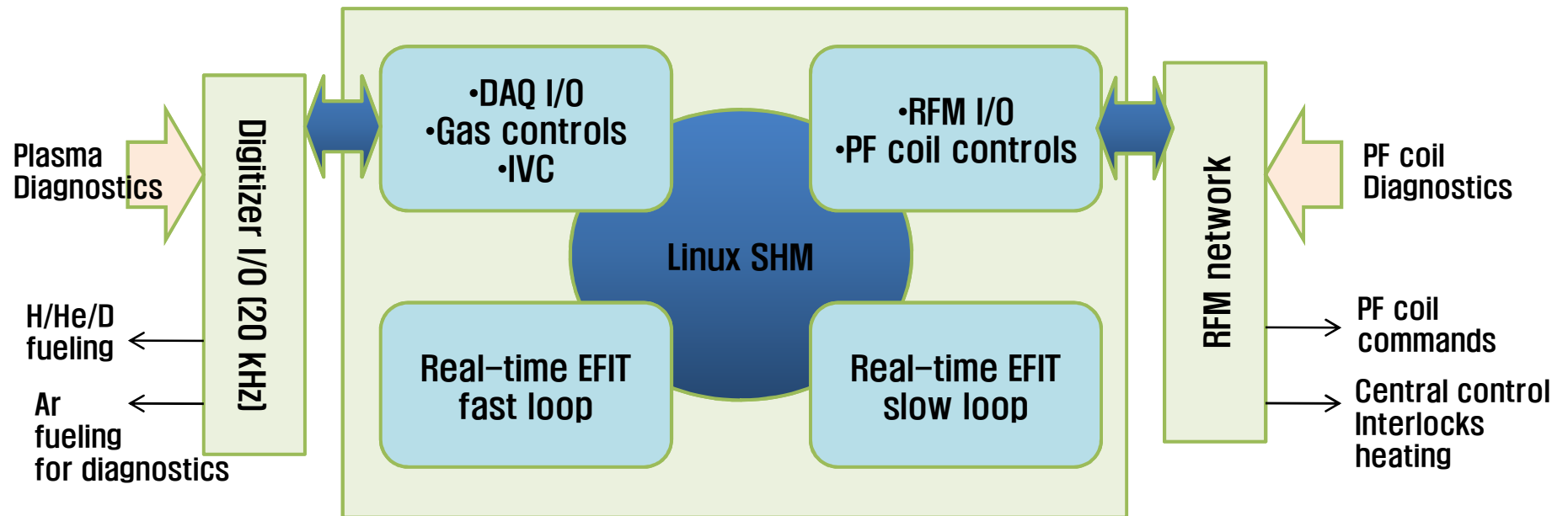
# Progress on system upgrades (1/2)



- System Upgrades in 2009/2010

- ▶ Real-time unit : 8-processes-in-a-box

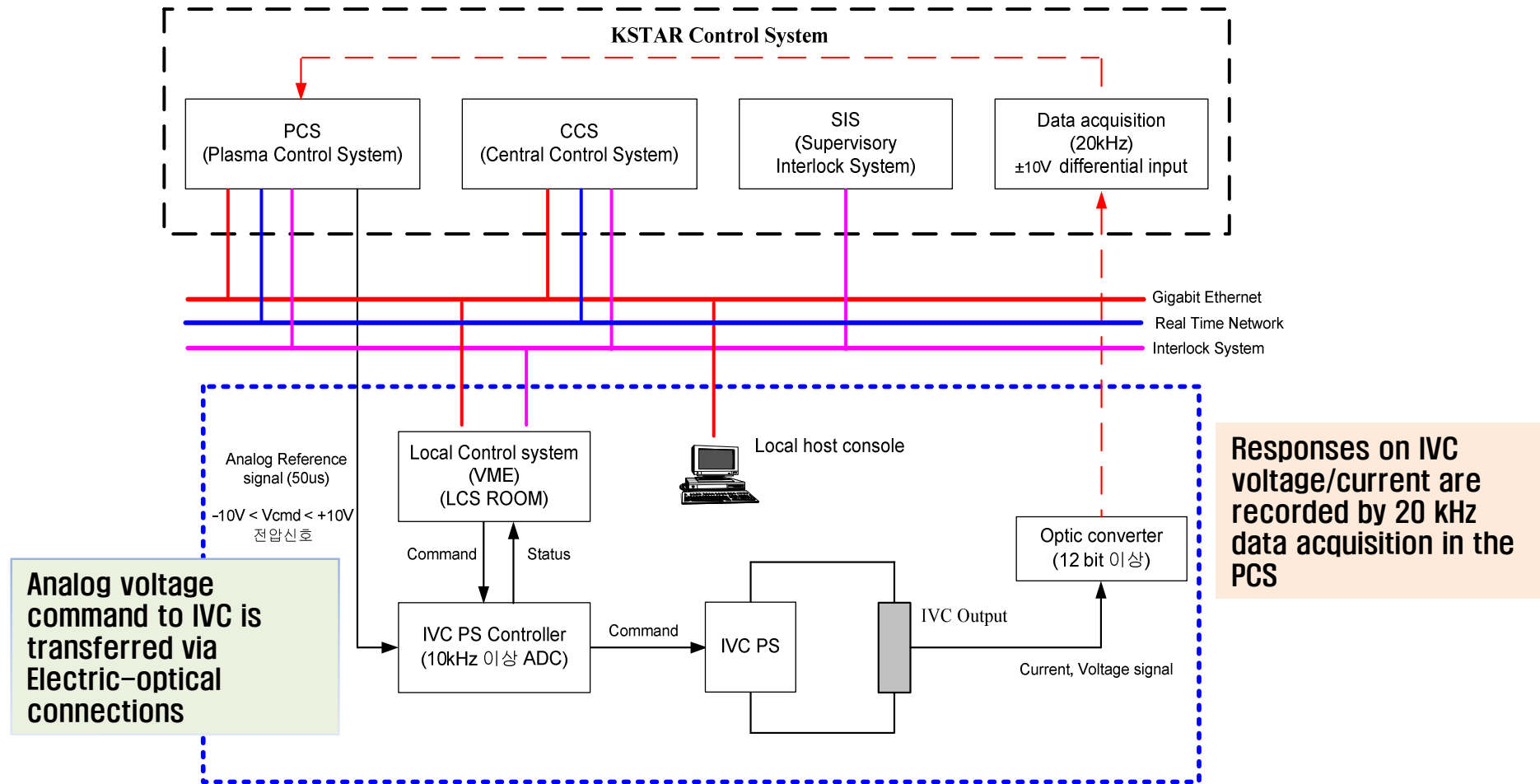
- ▶ **Done** : preparation of hardware including a brand-new 8 multicore x86 server with direct data acquisitions of 192 channels@20kHz and 128MB reflective memory (RFM) network
    - ▶ **Ongoing** : Preparations on a 4-process version, featuring dedicated Reflective memory (RFM) network I/O process



# Progress on system upgrades (2/2)



- In-vessel vertical control coil (IVC) controller design
  - ▶ Concept design for the IVC PS interfaces is finished



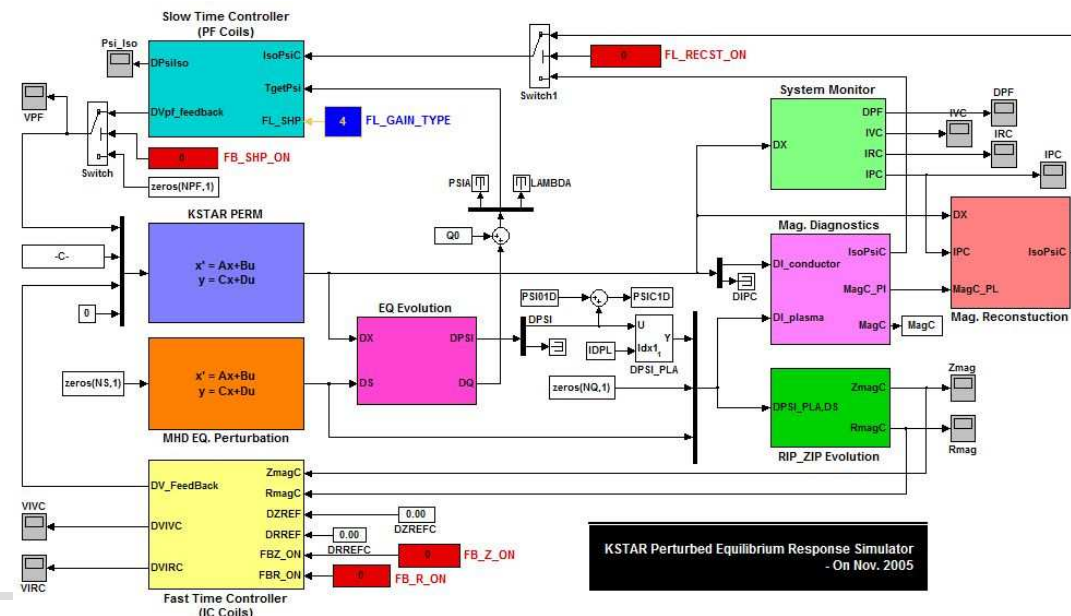
# Control R&D activities on NFRI (1/4)



NFRI Contact person :

[Yeong-Mu Jeon \(lymjeon@nfri.re.kr\)](mailto:lymjeon@nfri.re.kr)

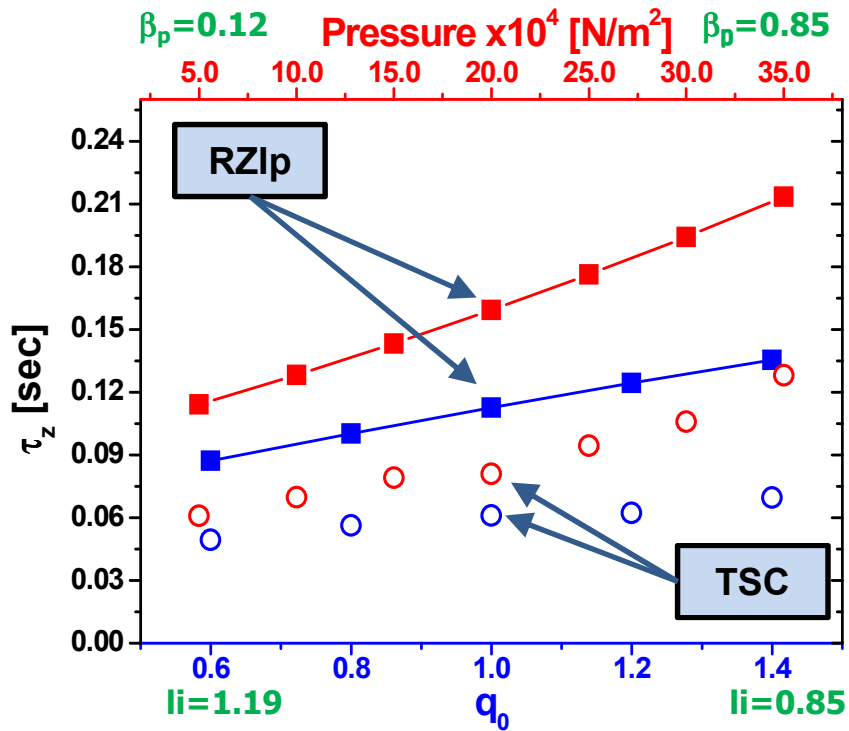
- **KSTAR-RZIp model** will be used as a basic design tool for fast position controller design
  - Comparison of RZIp model with experiments is ongoing in 2009
- **KSTAR-PERM** (Perturbed Equilibrium Response Model) model will be implemented for and applied to design of plasma position and shape controller for KSTAR
  - Comparison of RZIp (rigid), PERM (deformable), and TSC (nonlinear and inertia) model is ongoing in 2009



# Control R&D activities on NFRI (2/4)

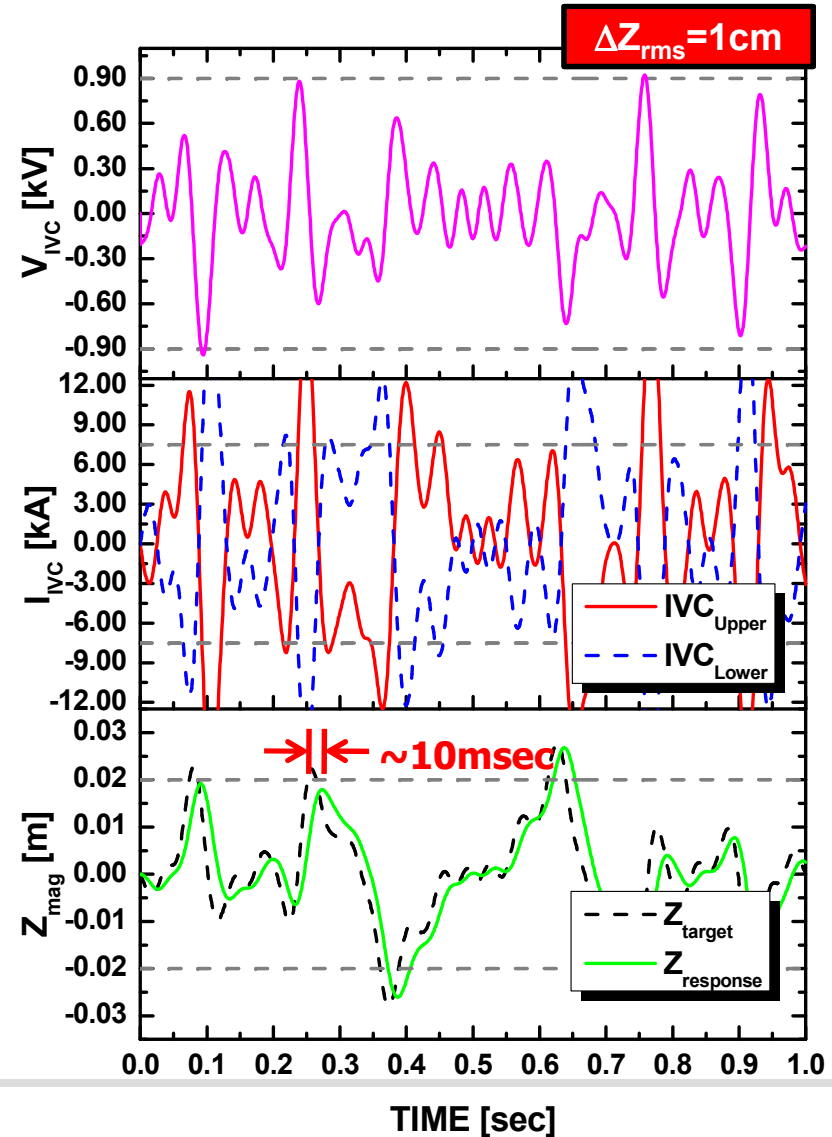


- IVC power supply design updated based on control analysis by KSTAR-RZIp modeling



Comparison of open-loop vertical growth rate Using RZIp and TSC

Random perturbation simulation →



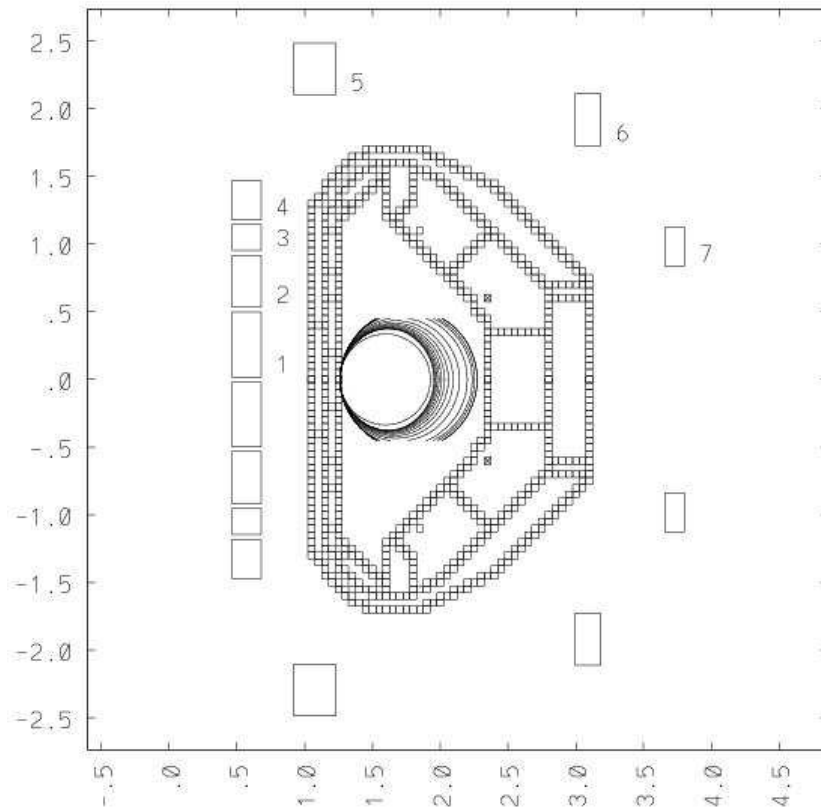
# Control R&D activities on NFRI (3/4)



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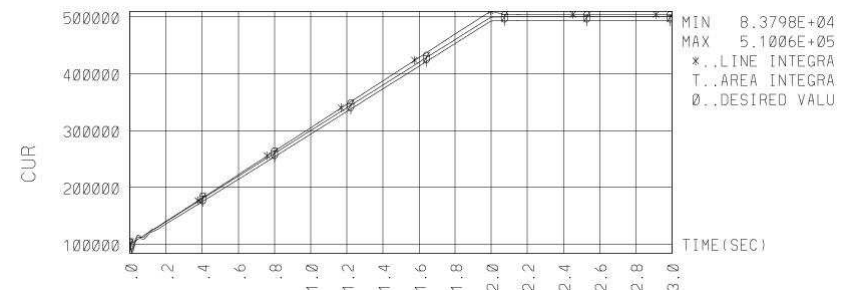
Jayhyun Kim (jayhyunkim@nfri.re.kr)

- Operation scenario development with TSC
  - ▶ 2009 KSTAR target plasma :  $I_p > 0.3 \text{ MA}$ ,  $t_p > 2 \text{ s}$
  - ▶ Circular shaped plasma : no vertical control in 2009 campaign



- 84 GHz ECH with 0.5 MW
  - ECH 1<sup>st</sup> harmonic assisted start-up
  - Auxiliary electron heating
- 45 MHz ICRH with 0.3 MW
  - Not optimized to circular shape

☞  $T_e > 0.3 \text{ keV}$ ,  $T_i \sim 0.3 \text{ keV}$



## Control R&D activities on NFRI (4/4)

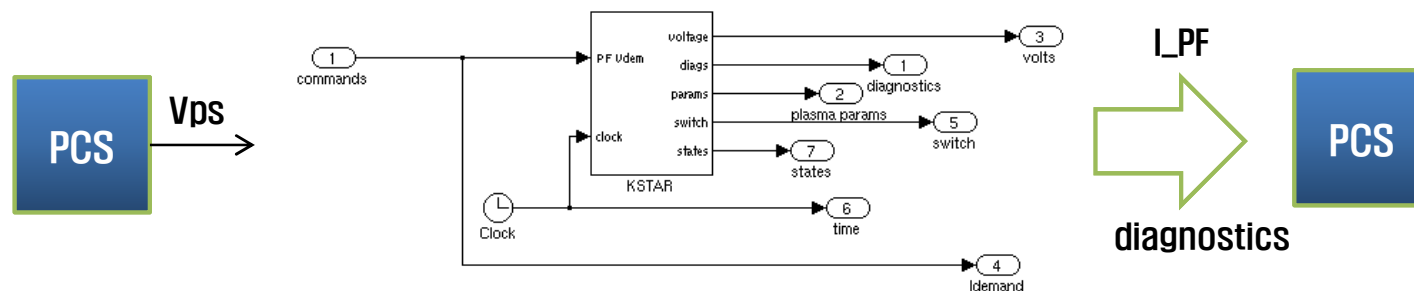


- Operation scenario development using **EVOLVE**.
  - ▶ **EVOLVE** solves 0D power and particle balance of plasma.
  - ▶ Plasma is modeled as a single filament in coupled circuits of whole system with including PF coils and vacuum vessel.
  - ▶ **EVOLVE** provides initial PF waveform before **TSC** calculation time and also gives a guideline of **TSC** run with considering ECH heating.

# Tokamak simulator development



- TokSys application on the shot analysis / rerun
  - ▶ Uses the EXACT PCS input **from the real shot**
    - Easier to compare to the real measured data
    - All the integrated / unintegrated magnetic diagnostics output is calculated and saved to the MDSplus
  - ▶ Simulators for 3 different situations have been developed so far
    - Vacuum / Plasma breakdown / gas



- ▶ **Developments on the physics operator training procedure** is ongoing for 2009 KSTAR campaign and possibly ITER applications



- Identification & Control of the plasma shape
  - ▶ Presence of the large ferromagnetic material in the KSTAR makes the identification process unique
  - ▶ EFIT result would be reliable but how exact would it be?
    - might be verified by a careful design on series of vacuum shots in 2009
  - ▶ Real-time drift correction is very difficult in the system
    - A review on the magnetic calibration process (including non-scientific ones) might be helpful
- Extension of the RFM network usages
  - ▶ Current configurations on distribution of the fast real-time data slows down the real-time unit
  - ▶ Direct distribution techniques of the data from the digitizer via the compactPCI bus communications are under consideration

# Summary



- Developments and operations of the “day-one” plasma control system have been one of the most successful collaboration cases among the US-KSTAR activities.
  - ▶ H/W developments by NFRI/KSTAR
  - ▶ Deep participations on the operation and control experiments
  - ▶ One of the key roles for achieving the first plasma goal and more
- For upcoming years, the plasma control system will evolve to the designed D-shape toward H-mode
  - ▶ System upgrades for existing controls and newly-introduced components
  - ▶ Extension of the shape controls for full kappa ( $\sim 2.0$ ) capabilities
  - ▶ Fast vertical stabilization for mega-amp plasmas
  - ▶ Future R&D for MHD studies & particle controls