Symposium II: New Developments in Current Drive and Current Profile Control in Toroidal Systems

S203

Tokamak Operation without the Use of Center Solenoid Coil

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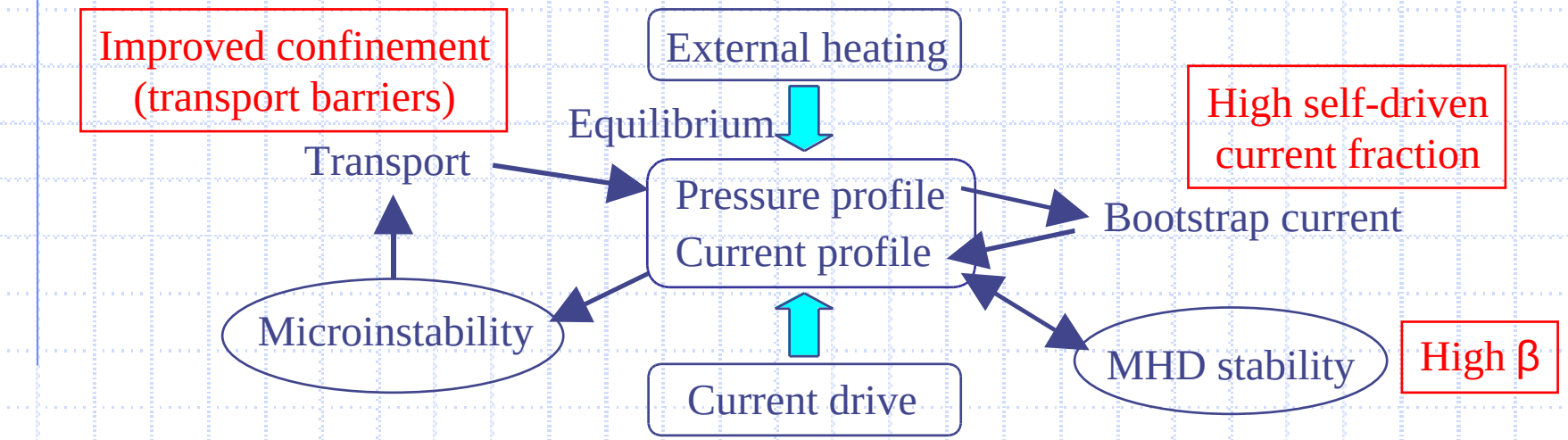
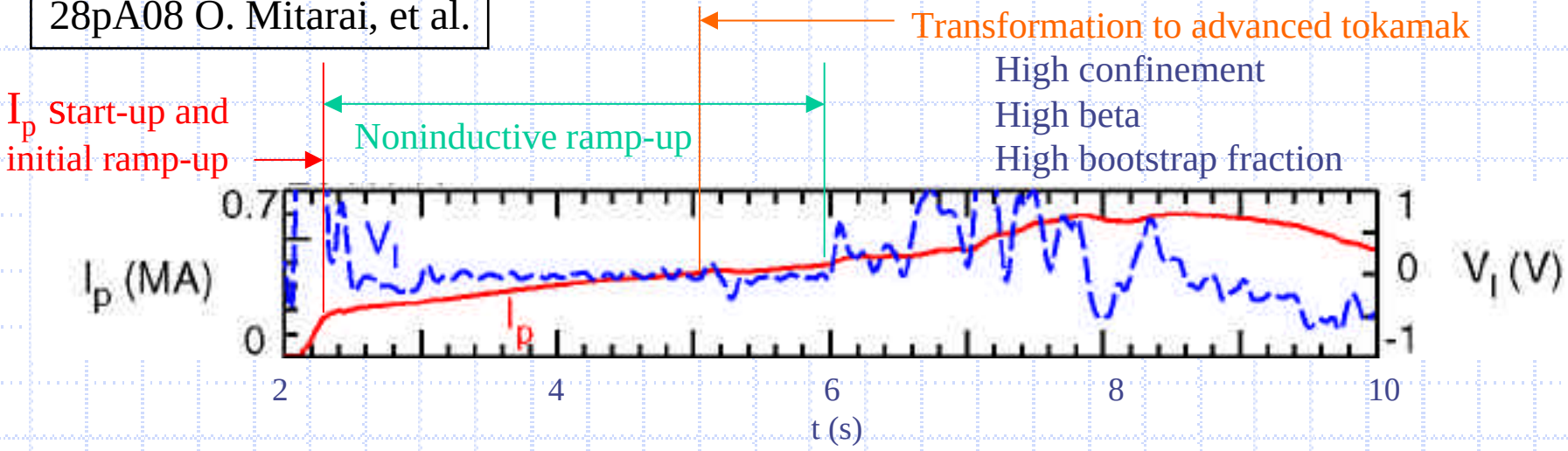
Externally driven advanced tokamak plasma

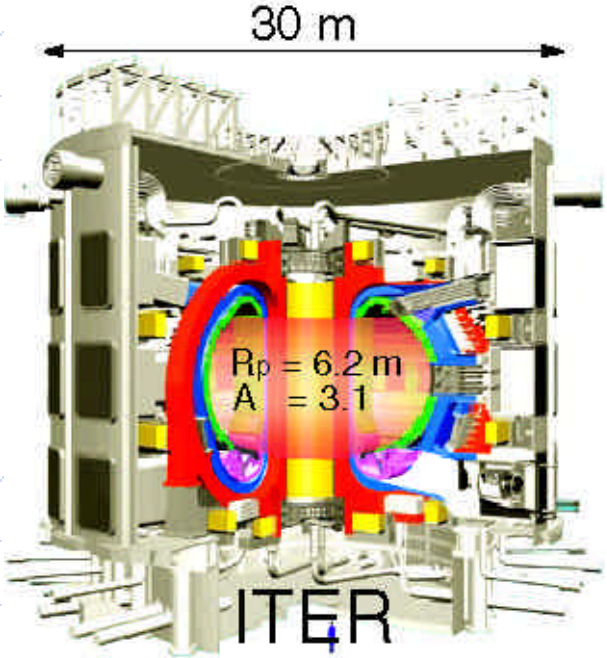


28pA08 O. Mitarai, et al.

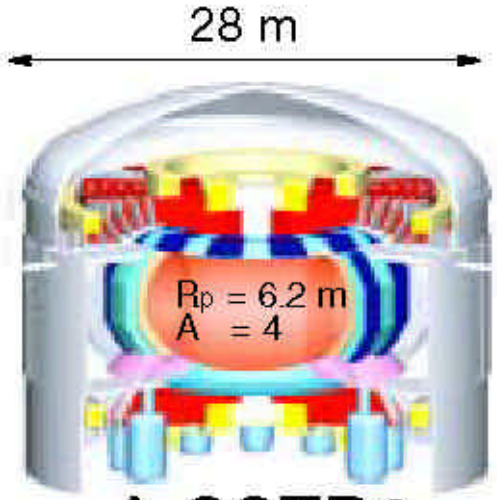


Examples of CS-less Tokamak Reactors

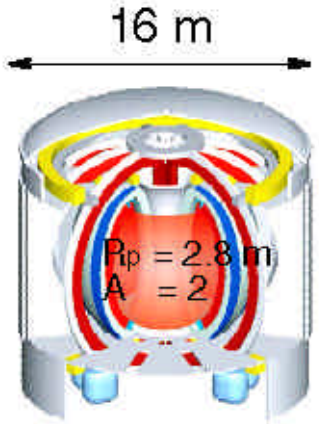
- Improved economic competitiveness may be realized by a CS-less design.



ITER
(18000 ton)
P_F=0.5 GW



A-SSTR2
(28000 ton)
P_F=4 GW



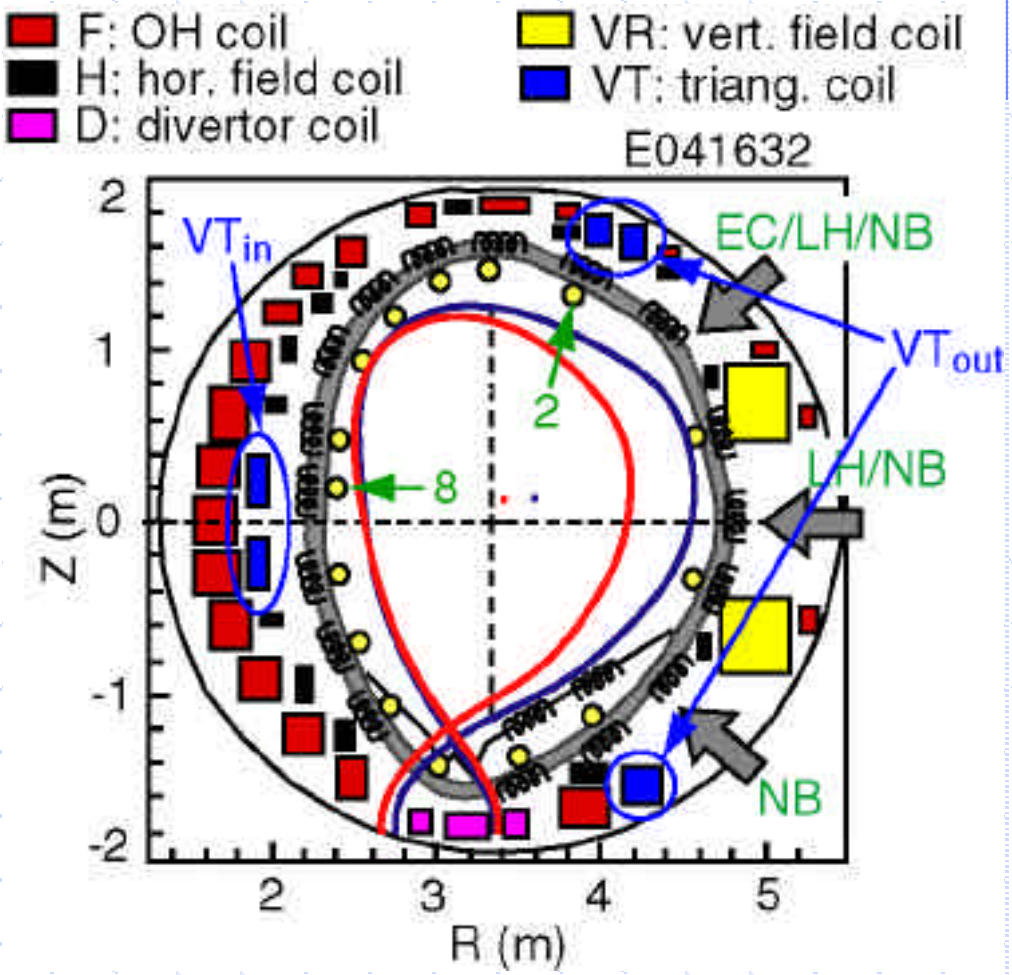
VECTOR
(~9000 ton)
P_F = 3.7 GW

S. Nishio, et al., paper FT/P1-21, 19th Fusion Energy Conference, Lyon 2002.

JT-60U Coils and Heating/CD Systems

- OH solenoid (**F**) current is kept at zero (no flux input)
- **EC/LH** preionization as well as the vertical field coil (**VR**)and the triangularity coil (**VT**) are used for I_p ramp-up
- **Full cross section divertor configuration** is used for I_p ramp-up by **LHCD**
- **Inward shifted divertor configuration** is used for the high-power **NB** heated advanced tokamak phase

Normally flux and vertical field can be controlled independently



Flux and B_v Contributions from VR and VT Coils

- Flux @ R = 3.4 m

$\Delta\Phi$ (Wb) = (30.1 + 88.1) ΔI_{VT} (MA) + 257.6 ΔI_{VR} (MA)

VT in VT out VR

In the present experiment

$I_{VT} = -7.3 \rightarrow +6.5$ kA

$I_{VR} = 0.1 \rightarrow +1.1$ kA

Flux contribution from the inner VT coil is ~20% in these experiments

- Vertical Field @ R= 3.4 m

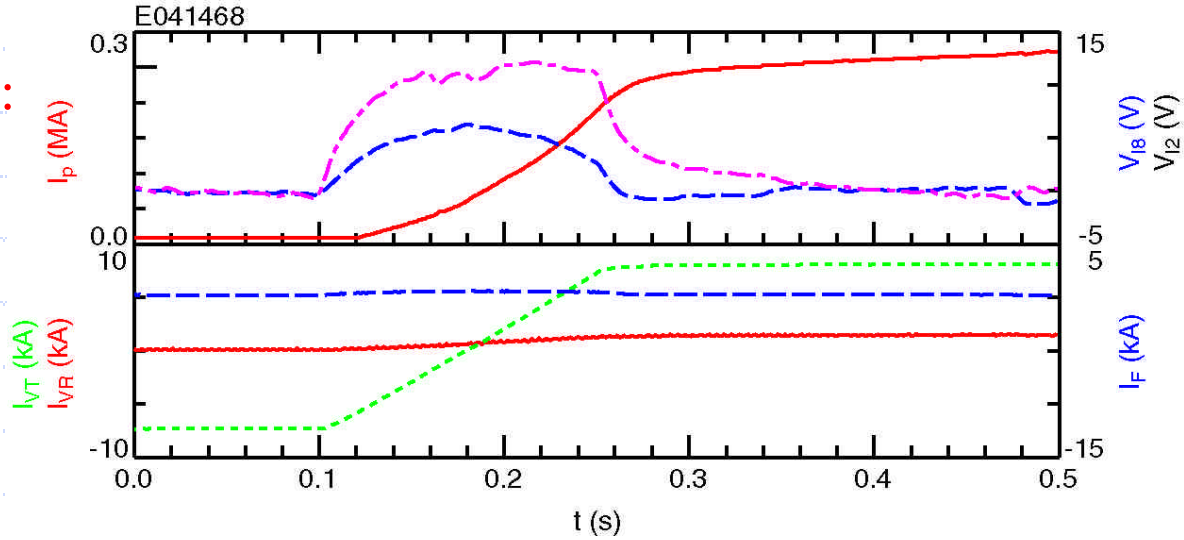
B_v(T) = (−0.537 + 1.948) I_{VT} (MA) + 8.720 I_{VR} (MA)

VT in VT out VR

Comparison with OH Start-up

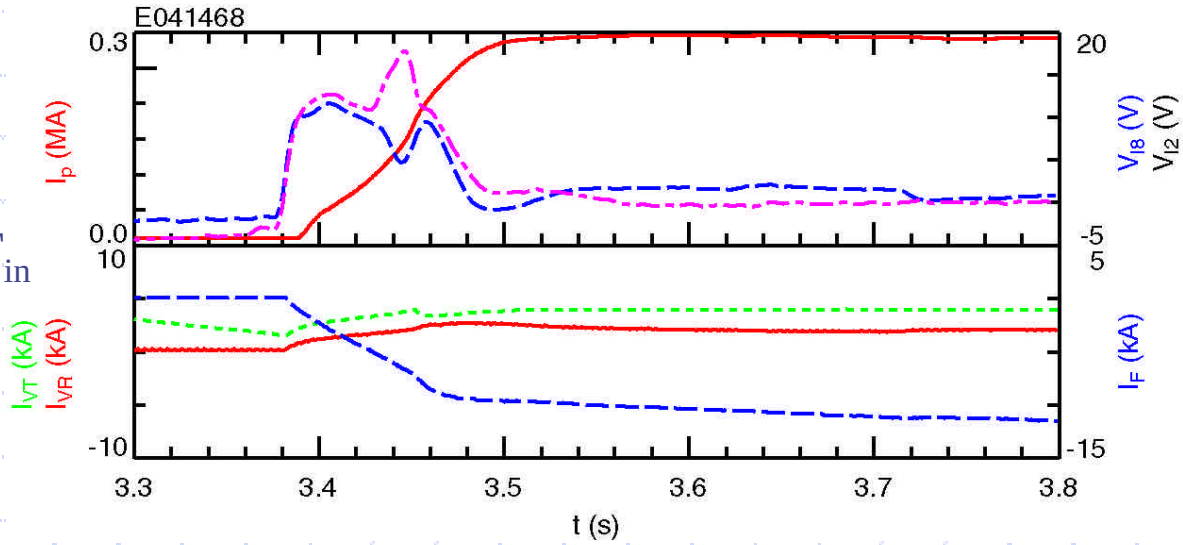
- VT/VR coil start-up:

20% flux from VT_{in}



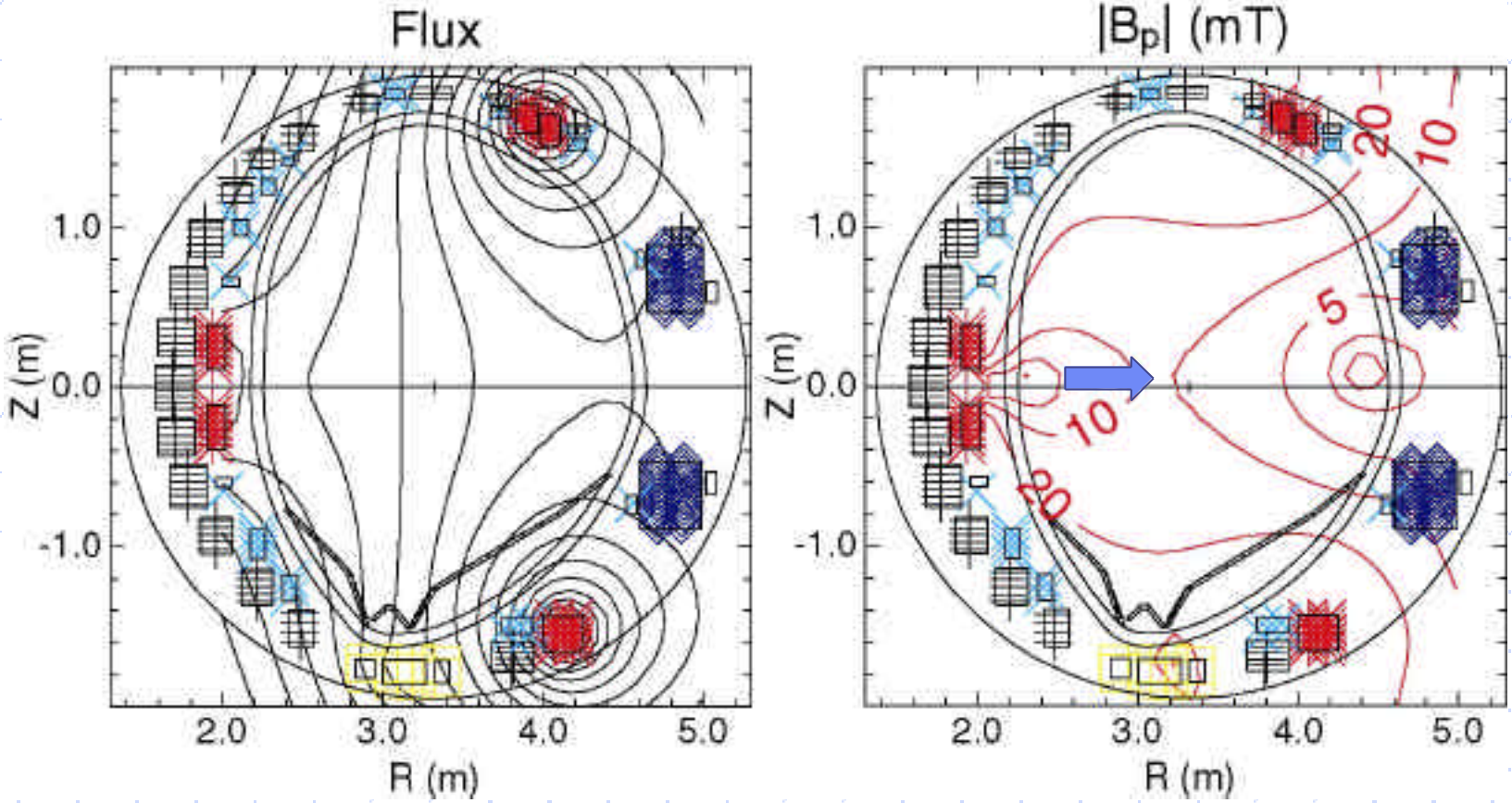
- OH coil start-up:

70% flux from $OH+VT_{in}$



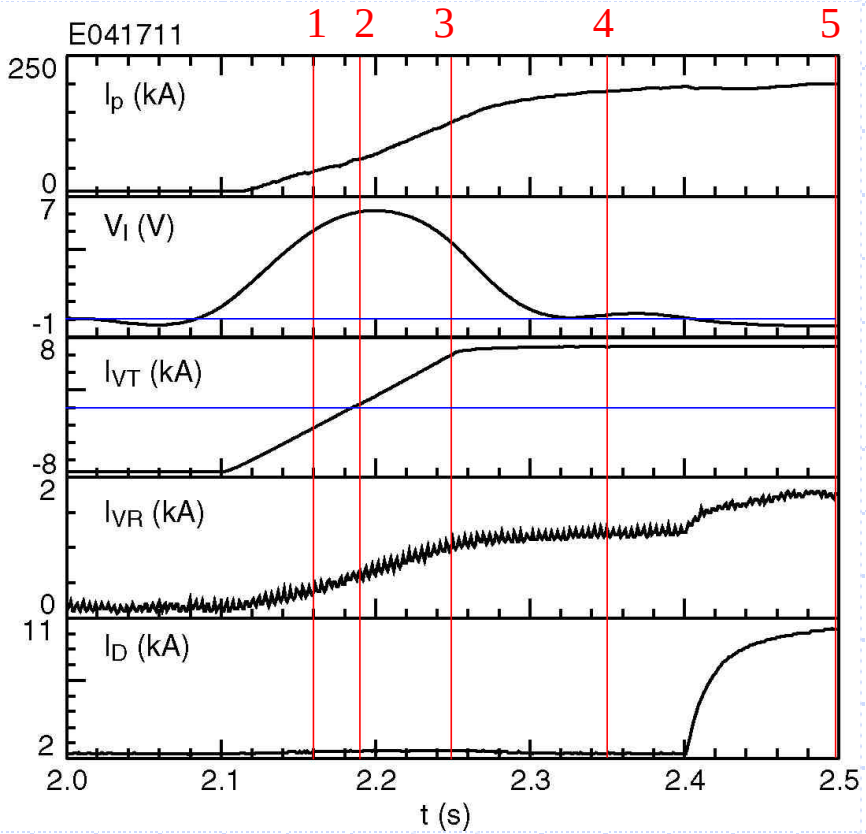
Magnetic Configuration Just Before I_p Start-up

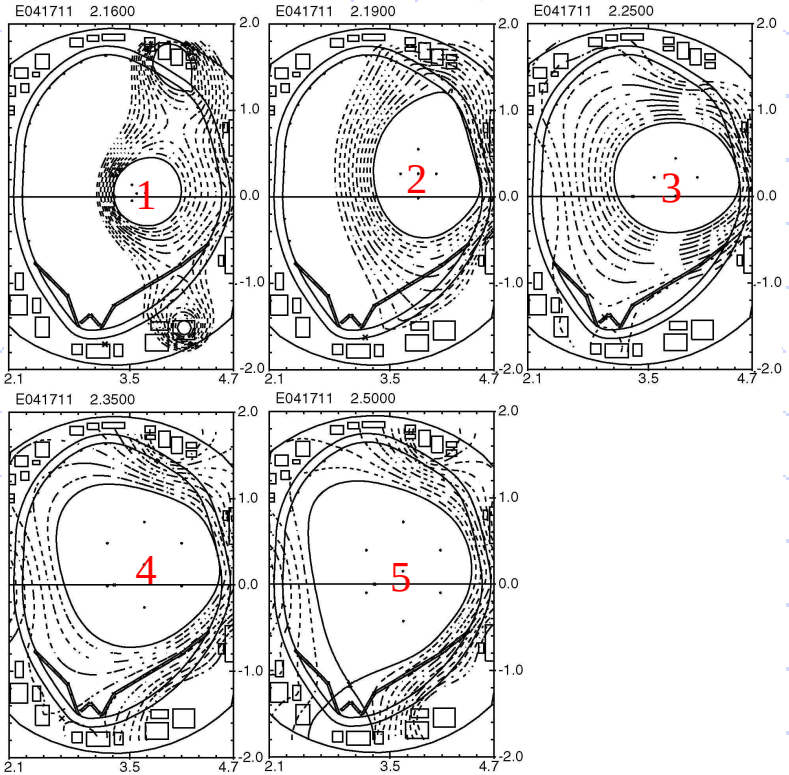
- "Field null" (minimum $|B_p|$ region) is formed by VT coil (2 locations)
- "Field null" moves radially outward by VT and VR coil ramps



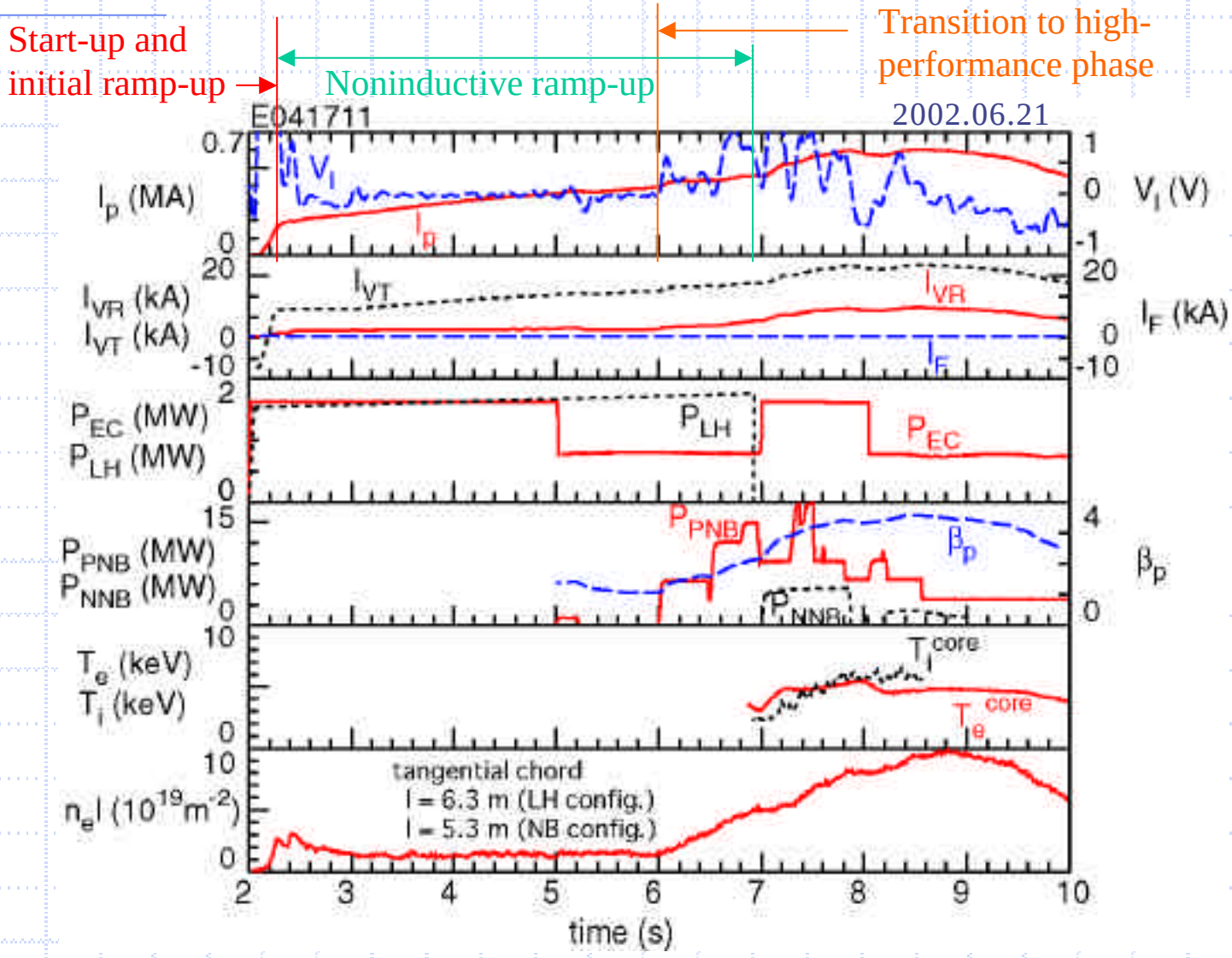
Configuration Evolution During CS-less I_p Start-up

- I_p ramp-up accomplished by EC/LH preionization and VT/VR coil ramps
- Transition to divertor configuration (5) and further I_p ramp-up by LHCD





CS-less Formation of High-Performance Plasma Demonstrated



Noninductive Ramp-up Efficiency

- $(dW_m/dt) / P_{NI} = 3.6\%$
- $(dW_m/dt - P_{ext}) / P_{NI} = 2.2\%$ (40% contribution from PF coils)

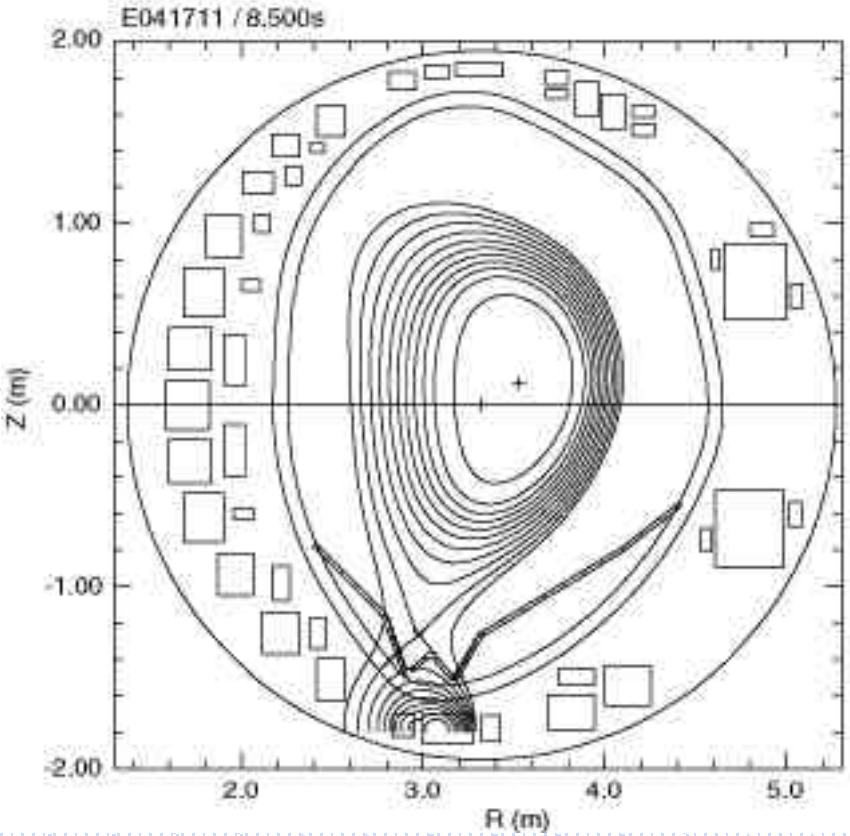
where $W_m = (L_{ext} + L_{int}) I_p^2 / 2$: total poloidal magnetic field energy

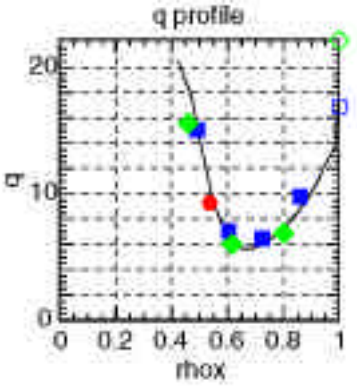
$P_{NI} = P_{LH} + P_{EC}$: total noninductive input power

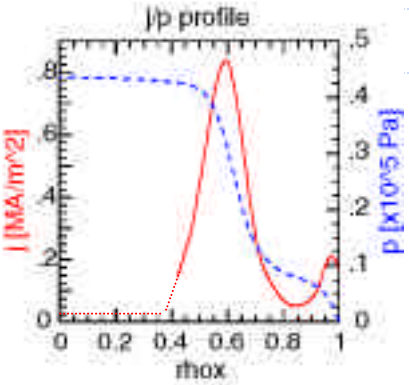
P_{ext} : Poynting flux provided by PF coils

Advanced Tokamak Equilibrium and Pressure and Current Density Profiles

- Start NB heating when I_p becomes high enough for beam ion confinement
- Deeply reversed shear configuration with “current hole” is formed
  - Current hole and ITB already formed during LHCD ramp-up





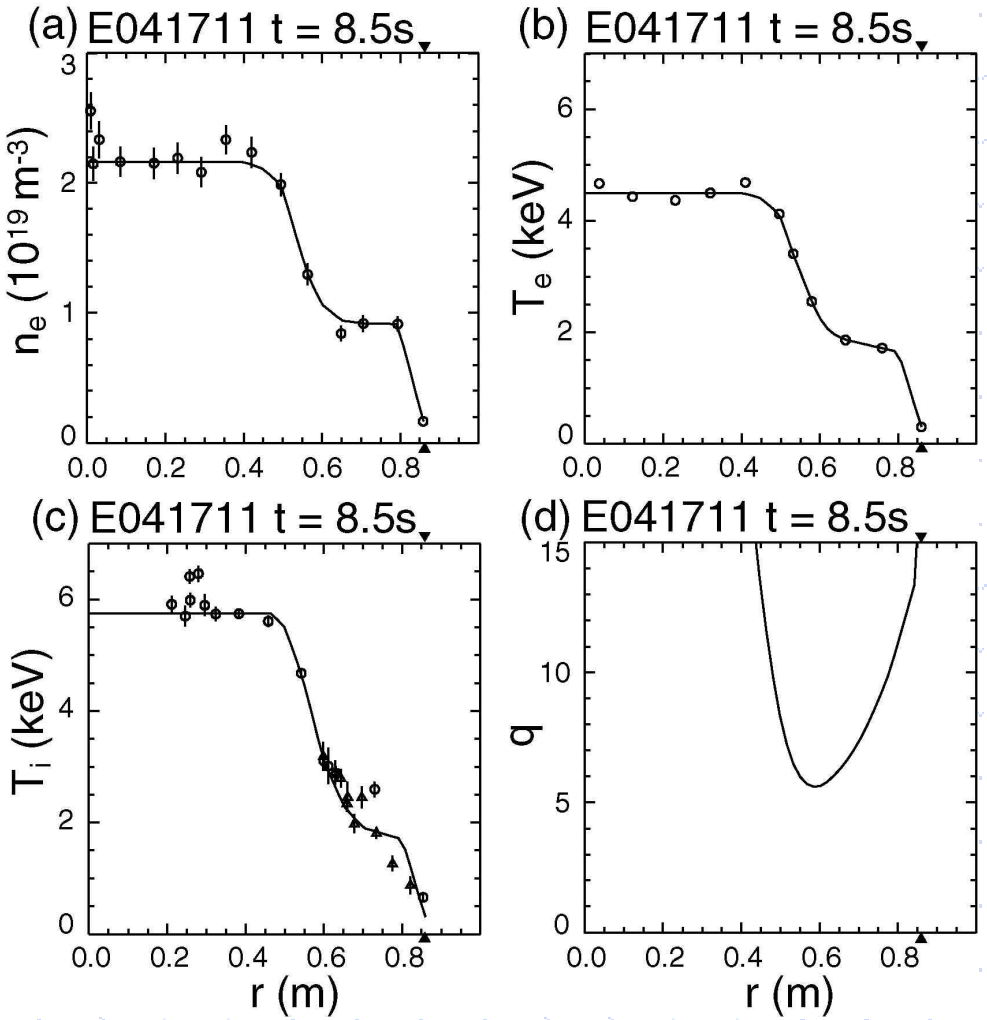


L_{ext} = 5.6 μH
L_{int} = 1.4 μH
(l_i = 0.67)

Density and Temperature Profiles of High-Performance Plasma

- Reversed shear for r/a < 0.7
- ITB + H-mode

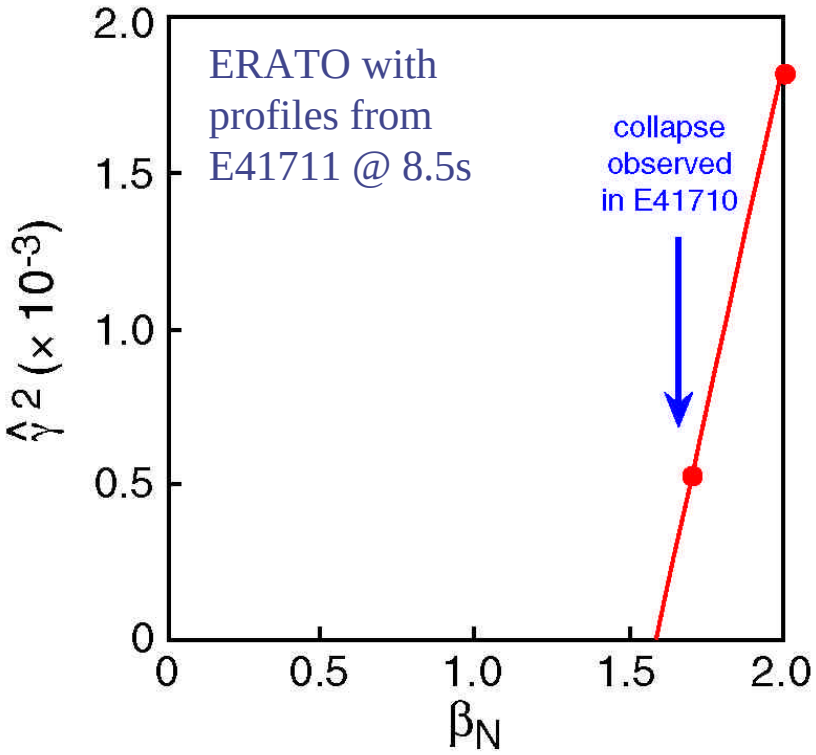
I_p = 0.6MA
β_p = 3.6
β_N = 1.6
H_H = 1.6
f_{BS} > 90%
l_i = 0.67
q_{95} = 13
q_{min} = 5.6 @ r/a = 0.7



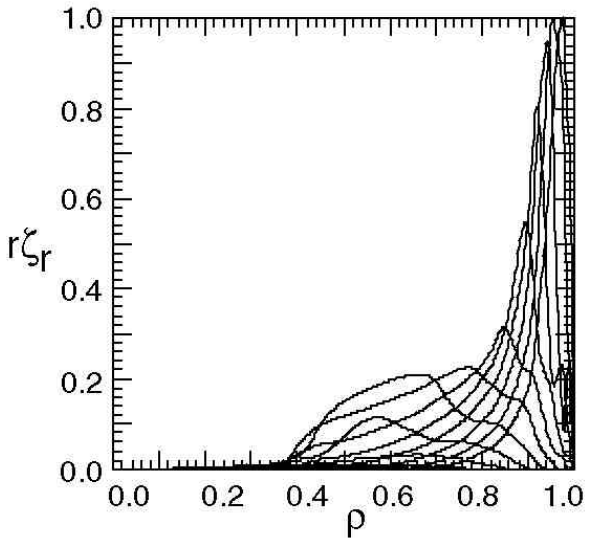
Y. Takase, et al.,
J. Plasma Fusion Res.
(Rapid Communications)
78, 719 (2002)

Stability Limited by n = 1 Kink-Ballooning Mode

- No β collapse observed at β_N = 1.6 in E41711
- β collapse observed at β_N = 1.7 in E41710



Growth rate of the n=1 kink-ballooning mode for the equilibrium at maximum stored energy of E41711.



Eigenfunctions of the n=1 kink-ballooning mode.

Summary of CS-less Ramp-up

- Inductive ramp-up by outer PF coils is effective
  - Strong preionization by EC (fundamental) and/or LH is required for effective I_p start-up with negative B_v
  - I_p start-up by VR ramp alone is possible but less effective (~ 50 kA)
  - Formation of "field null" by VT coil is effective
  - Further improvement of start-up scenario is possible
- Noninductive I_p ramp-up by LHCD (+ ECCD)
  - Decouples $\Delta\Phi$ and B_v from PF coils
    - but ramp-up efficiency is not very high (a few %)
  - Maintenance of 250 kA (but not further ramp-up) was possible by EC alone
    - I_p ramp-up by EC alone should be possible but requires higher power
- An integrated scenario with controlled I_p ramp-up, transformation to advanced tokamak plasma, and controlled ramp-down is demonstrated:
  - ITB + H-mode plasma with $\beta_p = 3.6$, $\beta_N = 1.6$, $H_H = 1.6$, $f_{BS} > 90\%$

Remaining Issues

- Inner VT coil provided 20% flux (VR and outer VT coils provide 80%)
  → Demonstrate a scenario that uses no turns on the inboard midplane (use inboard top/bottom coils)
- Extension to higher I_p, higher β_N
- Application of CS-less operation to ST
- Develop control algorithm that can react to β collapse, etc.