Workshop on Outstanding Issues in ICRF Technology
Embassy Suites Mandalay Beach Resort, Oxnard, CA

# Experience with JT-60 ICRF System

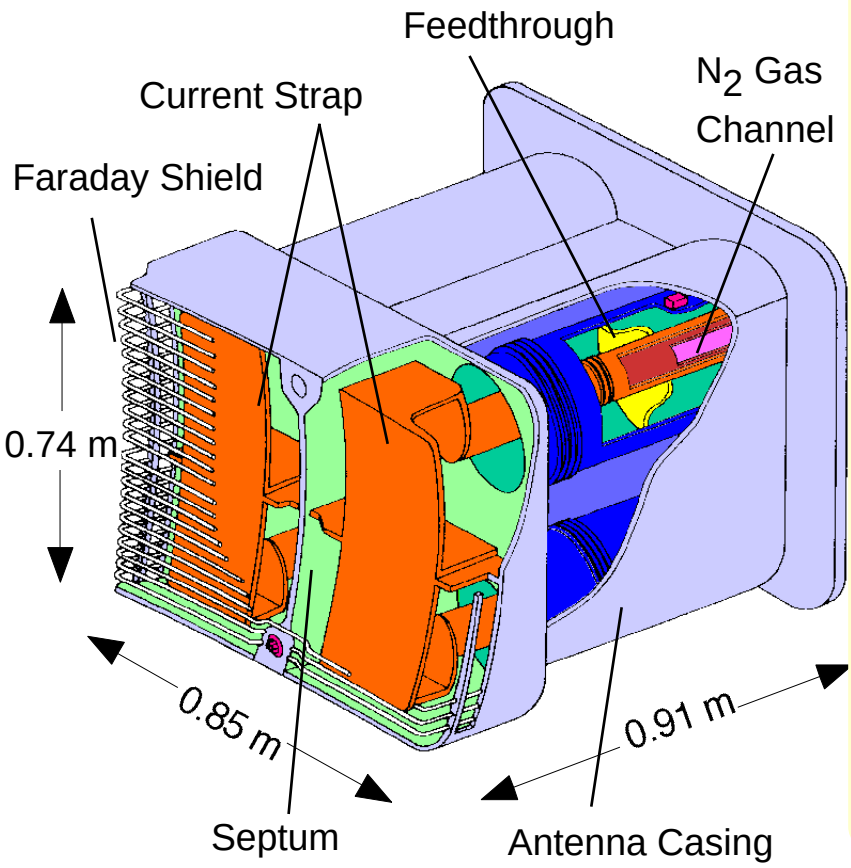
Shinichi Moriyama

Japan Atomic Energy Research Institute

Contents

1. Outline of the system and operation
2. Voltage limit with L and H-mode plasmas
3. Heat load toward the antenna
4. Trial for remote coupling
5. Summary

# JT-60U ICRF heating system

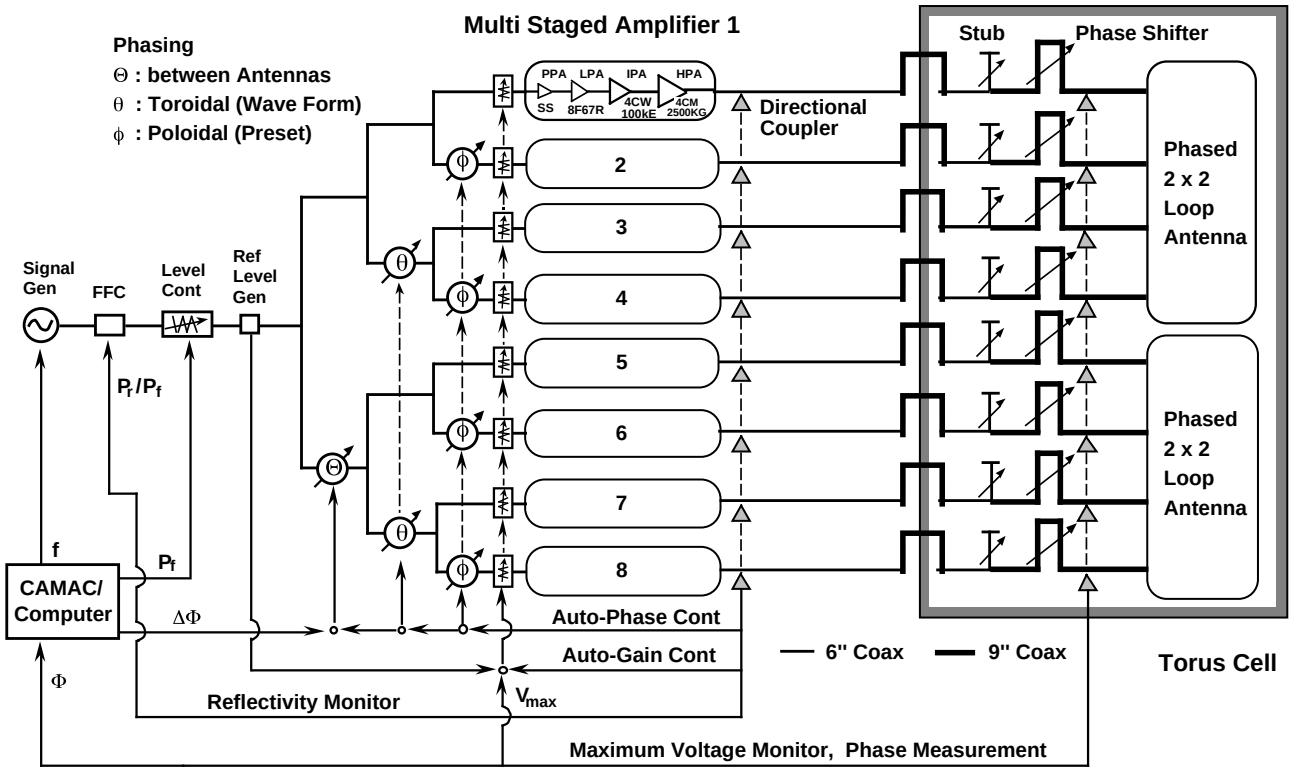



**Frequency**
102 - 131 MHz

**Generator power**
10 MW for 3 sec
6MW for 10 sec
with 8 4CM2500KG

**Achieved coupled power to the plasma**
7.0 MW for 1 sec
at 116MHz

**Number of antennas**
2



# Major changes in operating condition of the JT-60 ICRF system

**frequency**

**divertor**

**January 1996**

**116 MHz ($B_{T0}$=3.8T)**

**102 MHz ($B_{T0}$=3.3T)**

**Because of T-Coil Damage**

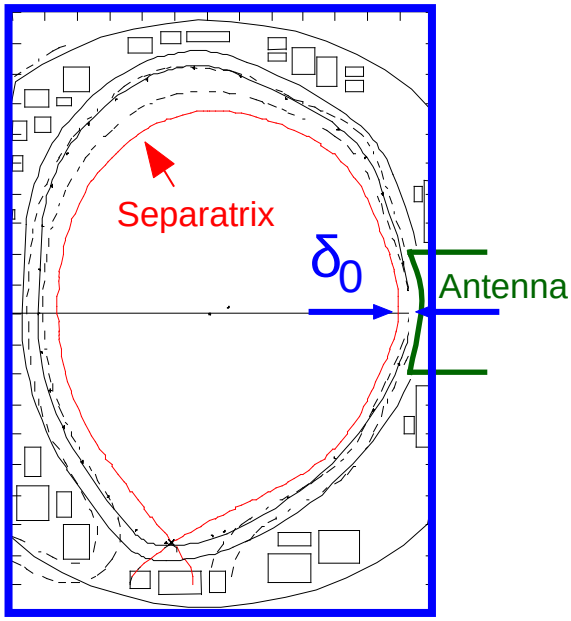
**Open**

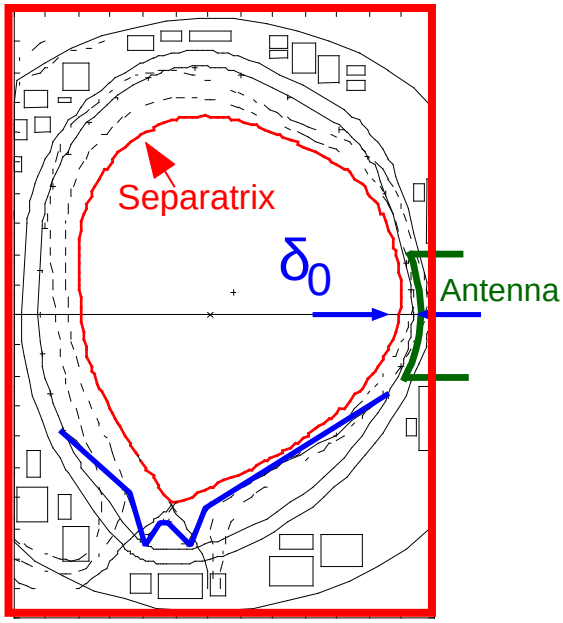
**June 1997**

**Closed**

**August 1999**

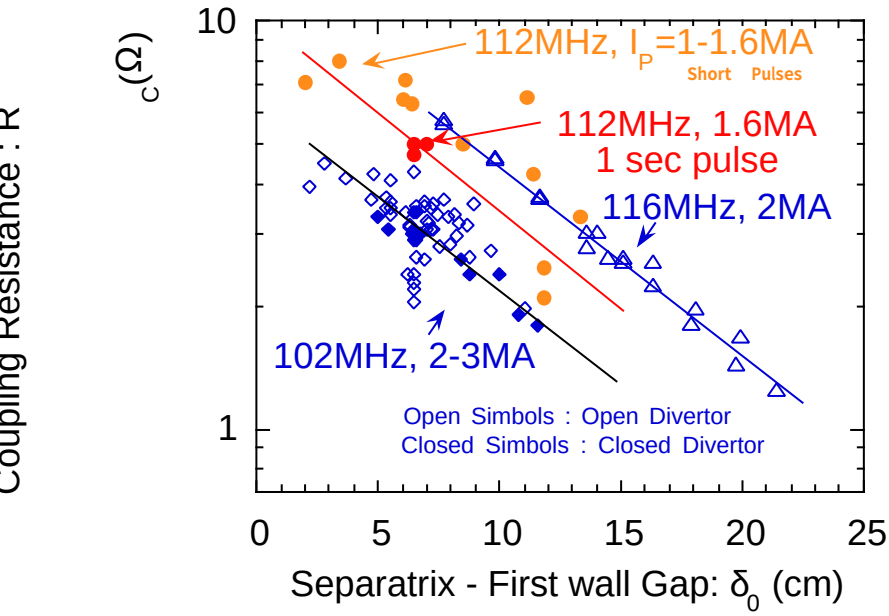
**112 MHz ($B_{T0}$=3.6T)**

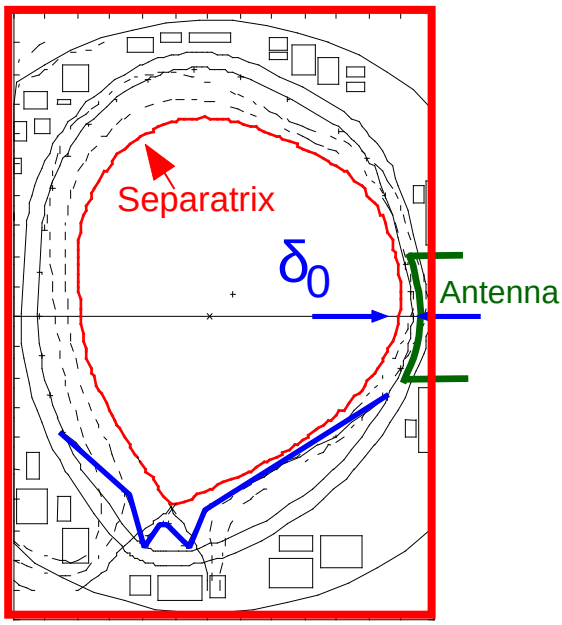



- IC & EC simultaneous heating on axis
  ← resonunce on axis at $B_T$=3.8T
- Higher power injection
- Easier remote coupling
  ← improved antenna-plasma coupling

# Antenna Coupling at 112MHz



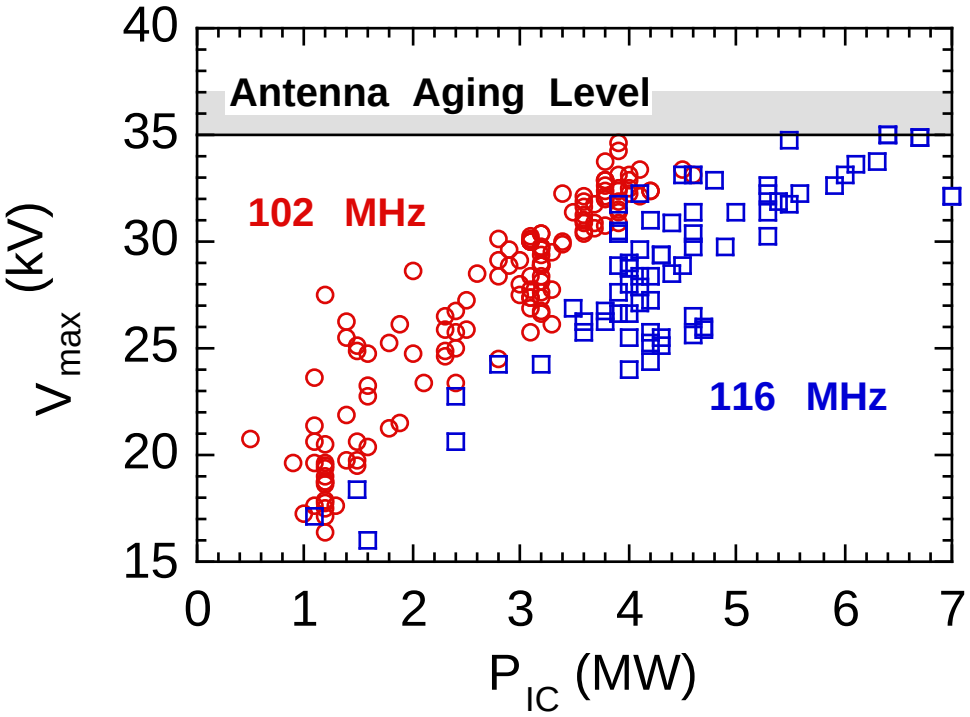




$R_C$=5Ω. was confirmed. It is not far from the predicted value and is high enough to couple ~5 MW after antenna conditioning. (estimated Vmax = 35kV)

3.6MW for 1 sec (Vmax = 28kV) was achieved at 112MHz upto now.

# The coupled power was limited by the antenna aging level (break-down voltage).

- Antenna coupling resistance decreased upon the frequency change from 116 MHz to 102 MHz.



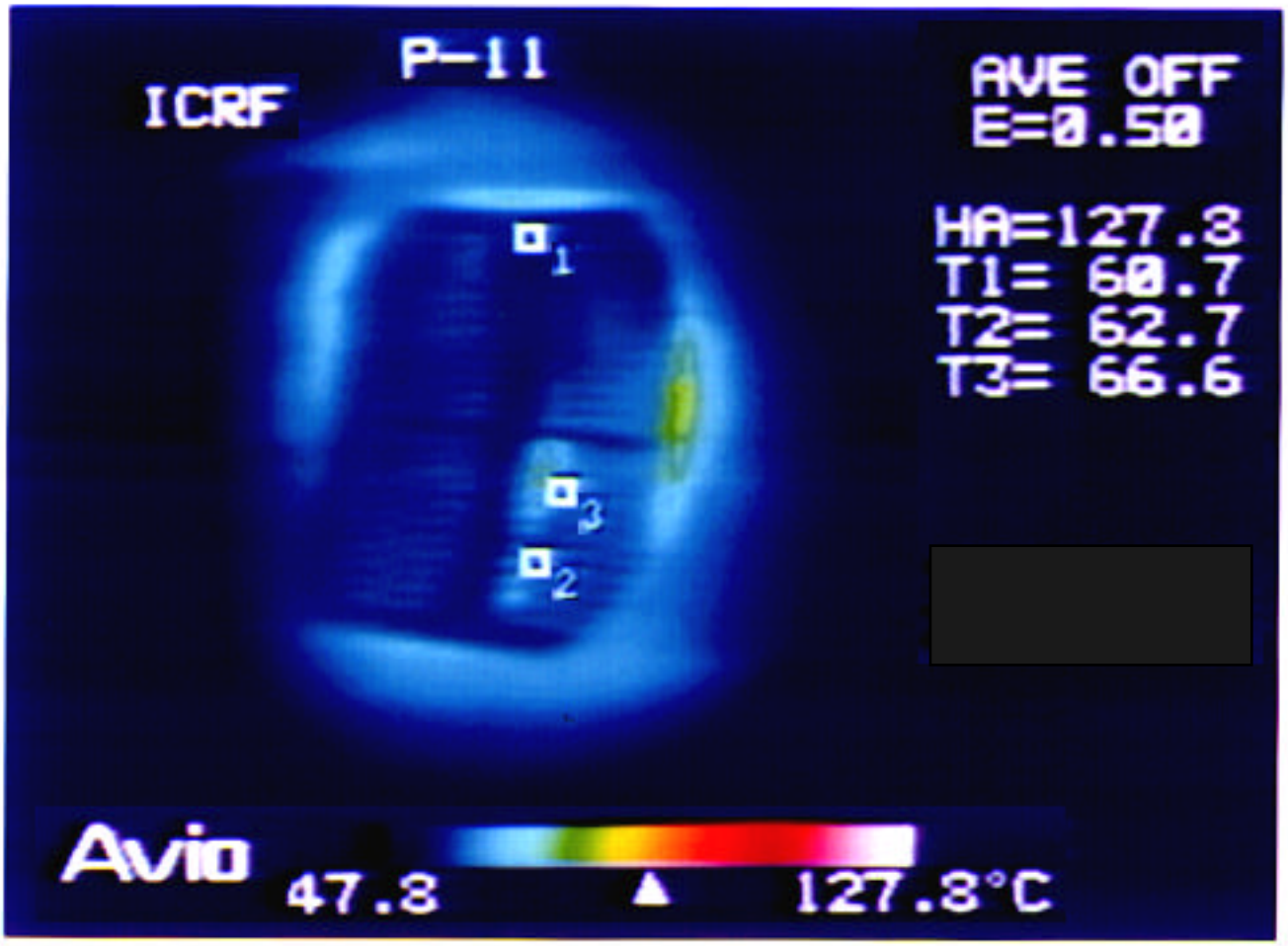

Improve antenna coupling

↓

Increase $P_{IC}$ with low $V_{max}$

$$V_{max} = \sqrt{\frac{2 P Z^2}{R_C}}$$

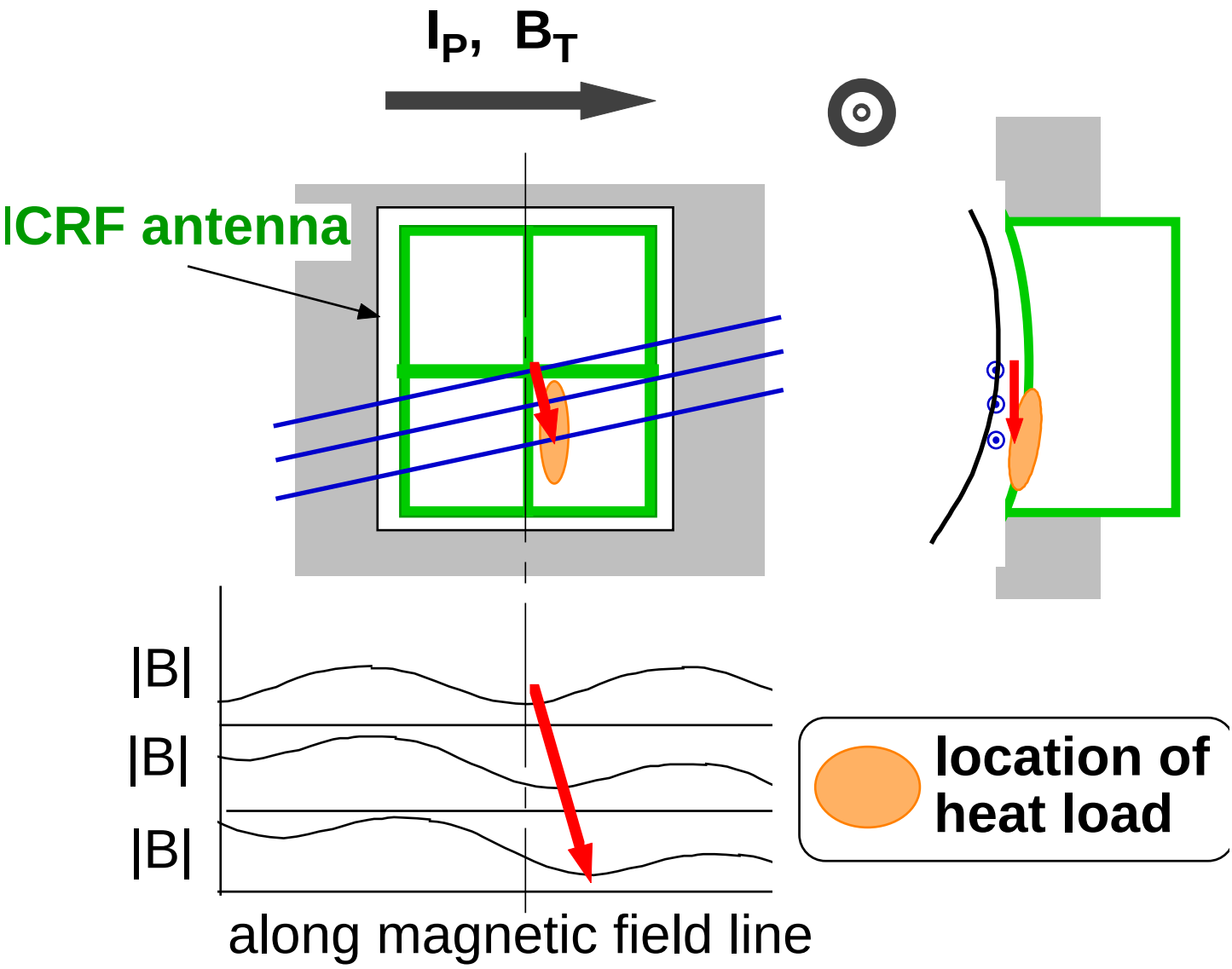
# Temperature of the ICRF antenna during ICRF heating measured by infrared camera




- We pay attention to the point #3 which has a largest damage
- Indicated temperature needs correction with calibration data

# Higher Harmonic Resonant Ripple Trapped Ion Loss

- Higher harmonic resonant high energy ions are trapped in the local Toroidal ripple mirror field.
- The ions drift downward (ion  B) with slight shift to the direction of $I_P$ ($B_T$).



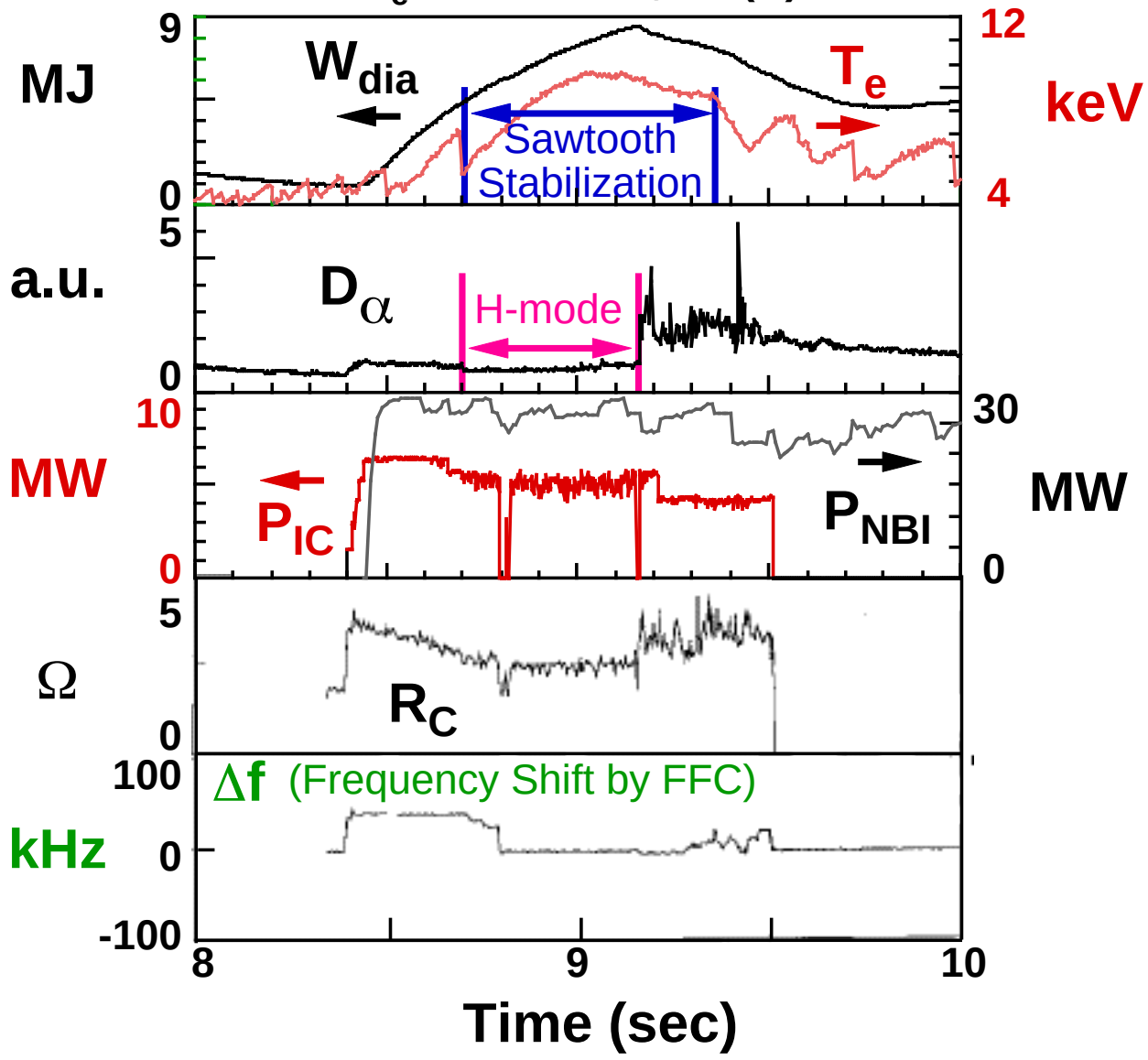
NB + IC Heating Experiment

# Coupling to H-mode Plasma

- **High power (5MW) is coupled to the H-mode Plasma, with Large S-F gap of 15cm.**
- Frequency Feedback Control (FFC) keeps good matching through L to H transition.
- Sawtooth is stabilized and highest level of the stored energy (~8MJ) among H-modes in JT-60U is achieved.

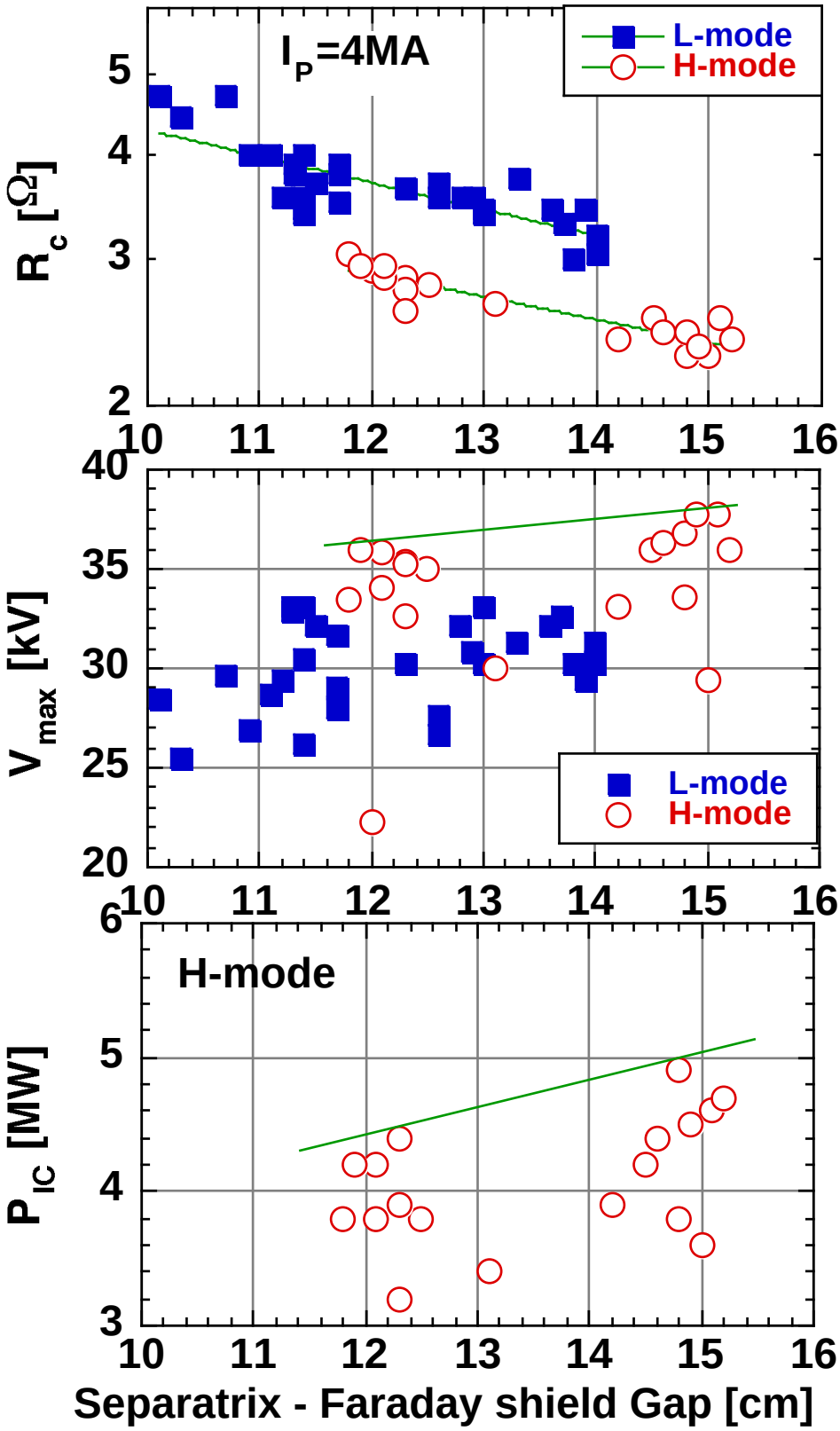
**$I_P$ = 4MA, $B_T(0)$ = 3.8T, $P_{NB}$ = 25MW**

**$n_e$ ~ $3\times10^{19}m^{-3}$, D+(H)**



# Coupling with H-modes

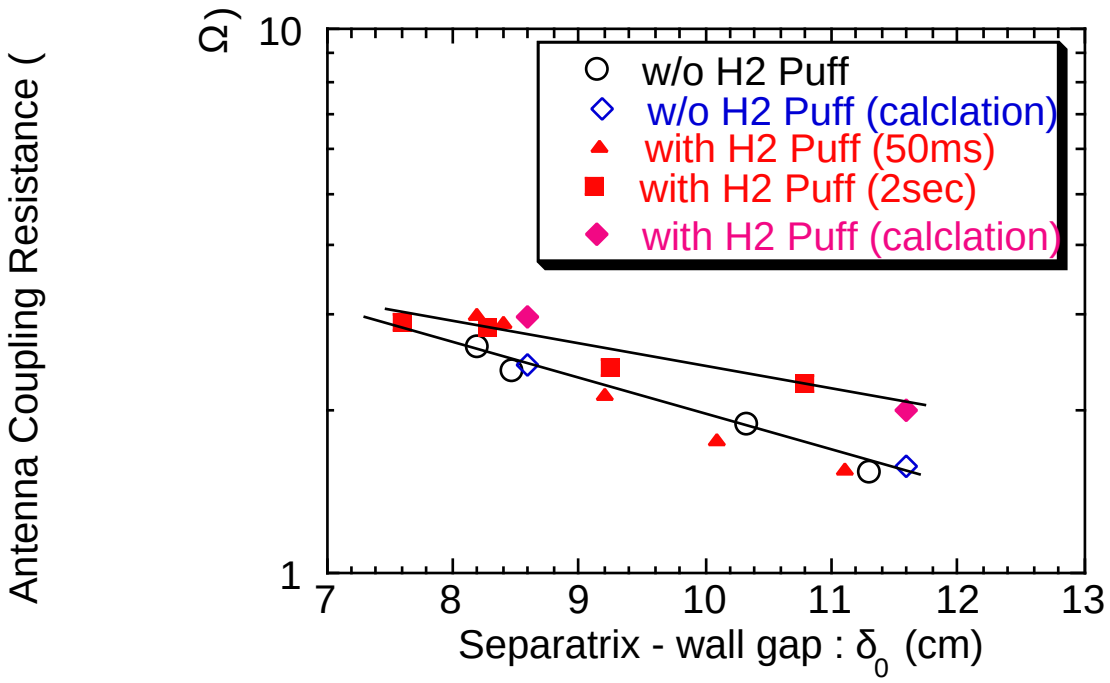
- High power ICRF injection is rather difficult with smaller S-F gap, possibly because of particles from the plasma.



# $R_C$ was increased with $H_2$ Gas Puff

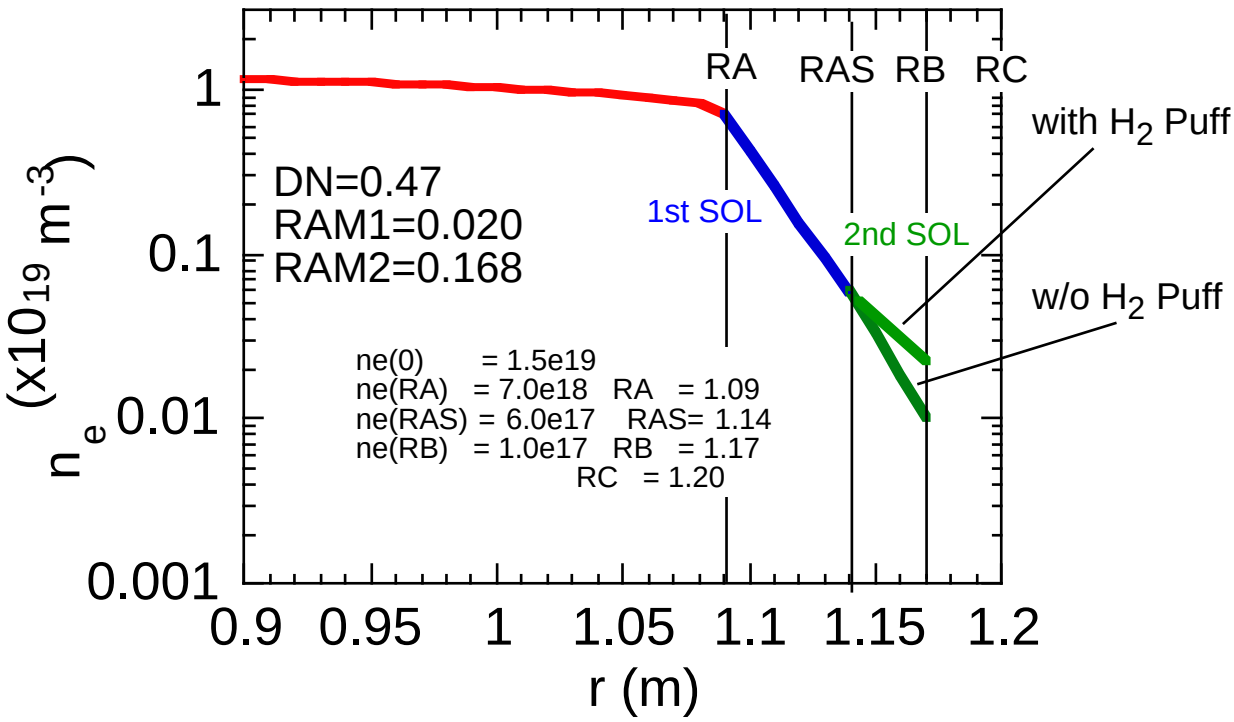
Main Gas : He  Additional Puff : 4Hz pulse $H_2$ from the top of VV (P-11).

- Long pulse (2sec) RF + additional puff seems to increase the 2nd SOL density
- Reduction of break down voltage due to pressure-rise in the antenna should be checked with higher power injection.




# $n_e$ profile model for the coupling calculation

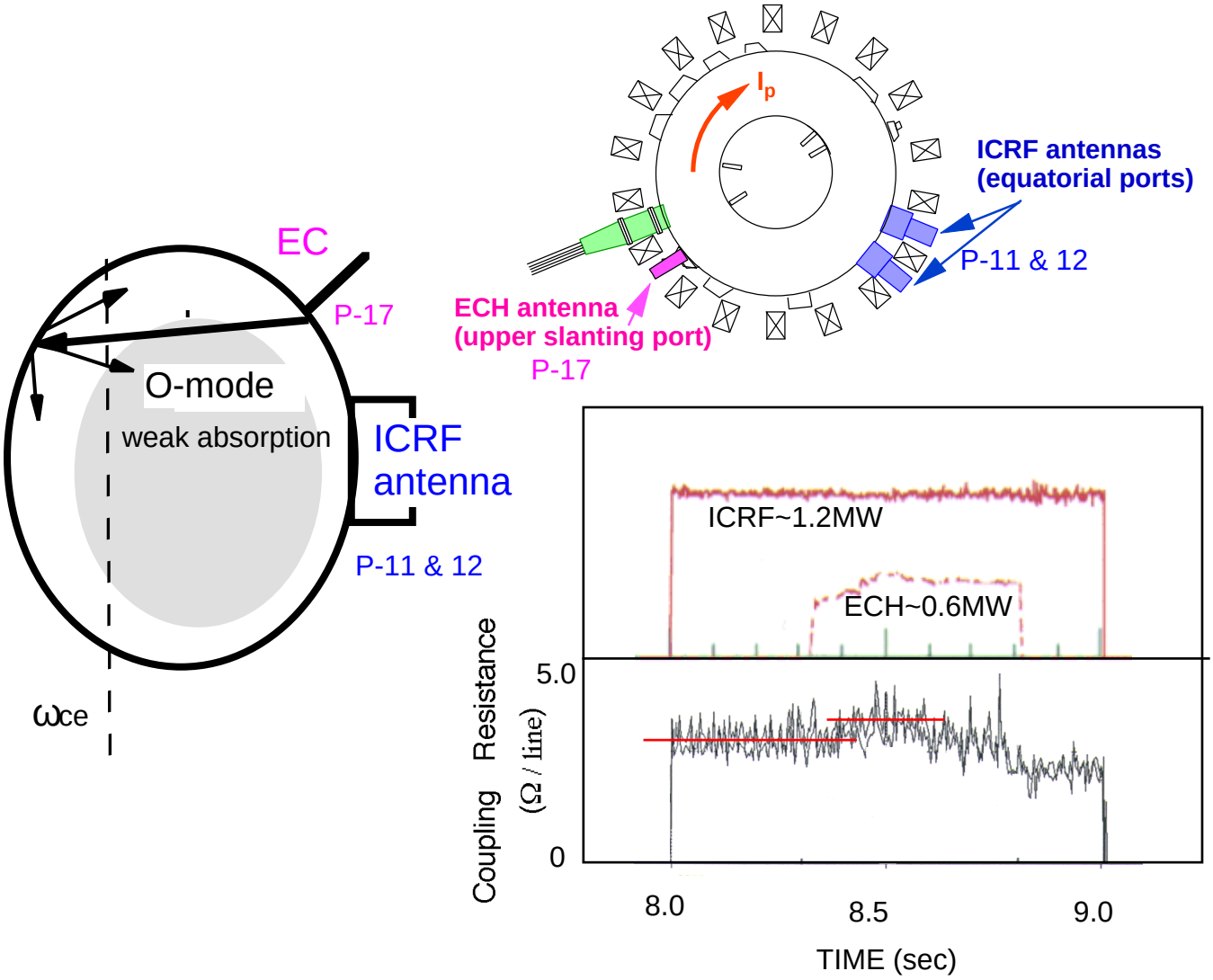
E29041/29061 1.75MA



# Remote Coupling Test with ECH

Preliminary remote coupling test with ECH were done.
Increase in SOL density by ionization by ECH was expected.

- $B_T$=3T : EC resonance at the outside of the main plasma in high field side
- ECH mirror angle : injected toward the wall
- $P_{ECH}$ ~700kw for 0.5sec, $P_{IC}$=1MW for 1sec




- Increase of the antenna coupling resistance, Rc, by 20% during ECH.
- It is possible that this is due to the ionization and also out gas from the wall.

# Summary

## 1. Obstacles to high power coupling in JT-60

Particle from the plasma

⇩

Out-gas on the particle bombardment on the Faraday shield

Limit of the coupling resistance

Voltage limit of the antenna

## 2. Efforts and ideas to break through

Improvement in the voltage limit

⇩

Antenna design
x Larger size
- High voltage feedthrough
- Local pumping
- Other Ideas

Reduction of particles from the plasma
- Remote coupling
- Low magnetic field ripple using ferrite tile (JFT-2M)

Improvement in coupling resistance

⇩

Antenna design
x Larger size
- Resonant type
- Other ideas

Modification of SOL plasma
- Local gas-puff
- Local RF injection
- Local B modification

## 3. Other obstacles in future

- Heat load and material damage by Neutron
- RF loss in steady state operation (not only for the antenna)