

# RF POWER MEASUREMENTS ON THE DIII-D GYROTRON INSTALLATION

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# Introduction

- The ECH injection power is not measured on each shot in many other facilities. Our goal is the development of a reliable power measurement system which can be used for every plasma shot in DIII-D.
- There are two approaches,

**Method**

Measure the gyrotron power and calculate the transmission efficiency

Measure the power just before ECH Launcher

**Problem**

- Cooling water temperature fluctuation
- Uncertainty of transmission efficiency

- Requirement to be insensitive to polarization
- Calorimetric method is not available

# Gyrotron Power Measurement

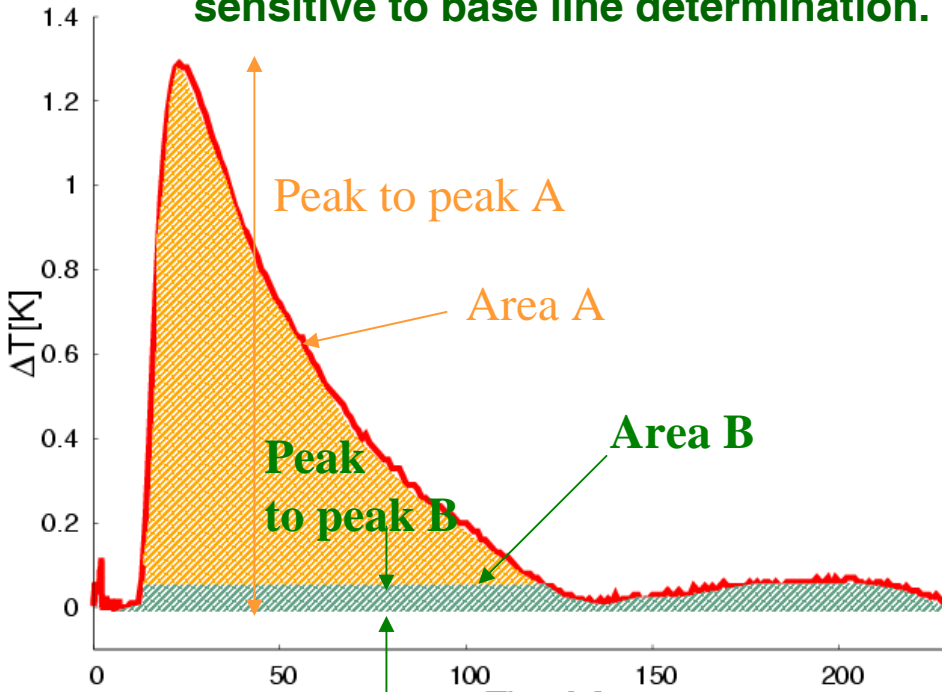
Gyrotron power is estimated by a calorimetric measurement of heating of components which have a known loss of gyrotron rf power.

## Known rf losses in DIII-D system

| Components     | Loss rate | Loss Power |
|----------------|-----------|------------|
| Diamond Window | 0.02%     | 2kW        |
| Cavity         | 2%        | 20kW       |
| Coupling Unit  | 5%        | 60kW       |
| Miter Bend     | 1%        | 10kW       |

# Effect of Temperature Fluctuation of Cooling Water

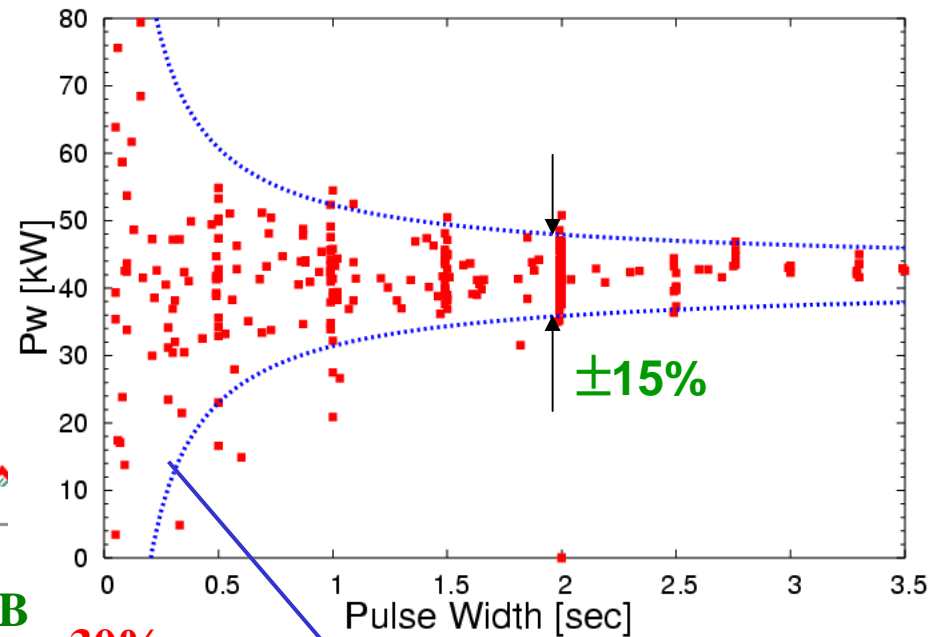
- The gyrotron power is estimated by a calorimetric measurement of heating of components which have a known loss of gyrotron rf power.
- The calorimetric power measurements have a difficulty. The obtained power is sensitive to base line determination.



If  $\frac{\text{Peak to peak B}}{\text{Peak to peak A}} = 10\%$ , then  $\frac{\text{Area B}}{\text{Area A}} \sim 30\%$

It means the  $\pm 5\%$   $\Delta T$  fluctuation can make  $\pm 15\%$  error of power measurement

Coupling Unit absorbed power



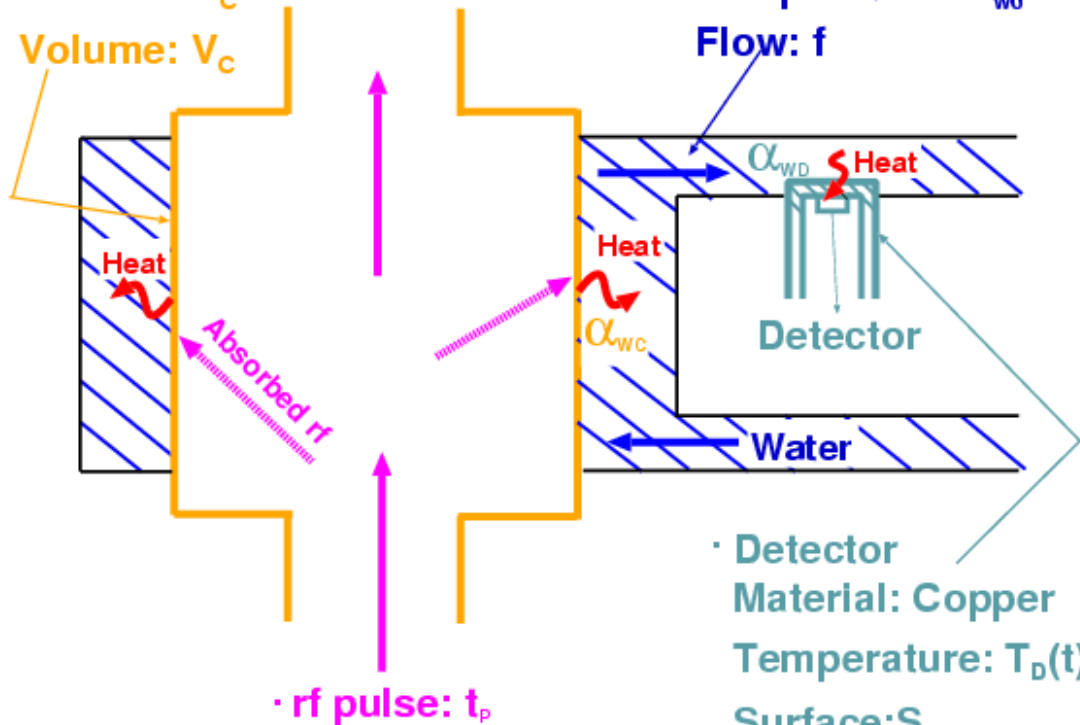
Possible measurement error by typical water temperature fluctuation 0.04K.

Note: Signal is small, for example, window temperature increase is less than 1 degree with 2 sec ECH pulse.

# Water Cooling Model for Fitting Function

In order to reduce the effect of fluctuating water temperature, a fitting function for calorimetry signal is developed.

- Component  
Material: GlidCop<sup>®</sup>  
Temperature:  $T_c(t)$   
Surface:  $S_c$   
Volume:  $V_c$



$\alpha_w$ : Heat Transfer Coefficient

- Water  
Temperature:  $T_{w0}$   
Flow:  $f$
- Detector  
Material: Copper  
Temperature:  $T_D(t)$   
Surface:  $S_D$   
Volume:  $V_D$

• Zero-dimensional model

• No heat diffusion during the transition from a component to the detector

# Simultaneous Differential Equation

During pulse

$t < t_p$

Component

$$\frac{dT_{C1}(t)}{dt} = -\frac{\alpha_{wC} S_C}{C_C} (T_{C1}(t) - T_{w0}) + \frac{1}{C_C} P_W$$

Output

Input from rf

Detector

$$\frac{dT_{D1}(t)}{dt} = \frac{\alpha_{wD} S_D}{C_D} \left( \frac{\alpha_{wC} S_C}{C_C} (T_{C1}(t) - T_{w0}) + T_{w0} - T_{D1}(t) \right)$$

Input

Boundary Condition

$$T_{D1}(0) = T_{w0}, \quad T_{C1}(0) = T_{w0}.$$

$P_W$ : Absorbed Power

$t_p$ : Gyrotron Pulse Width

$T_C$ : Temperature at component

$T_D$ : Temperature at Detector

$T_{w0}$ : Input water temperature

After pulse

$t > t_p$

Component

$$\frac{dT_{C2}(t)}{dt} = -\frac{\alpha_{wC} S_C}{C_c} (T_{C2}(t) - T_{w0})$$

Output

Detector

$$\frac{dT_{D2}(t)}{dt} = \frac{\alpha_{wD} S_D}{C_D} \left( \frac{\alpha_{wC} S_C}{C_w} (T_{C2}(t) - T_{w0}) + T_{w0} - T_{D2}(t) \right)$$

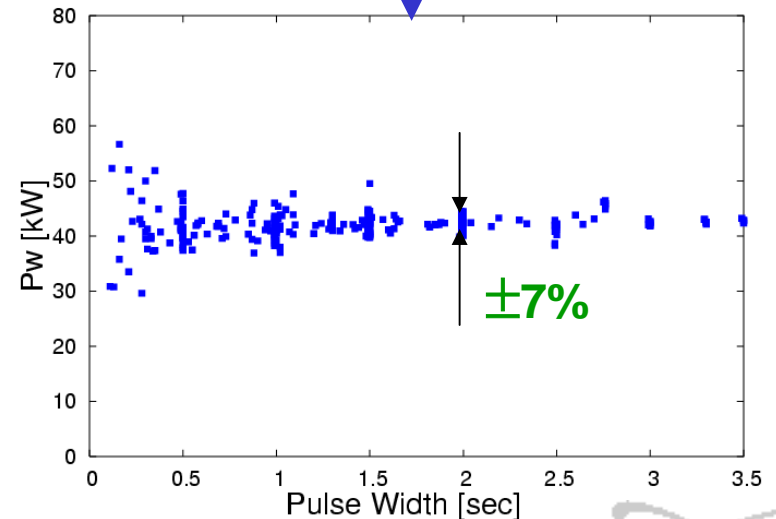
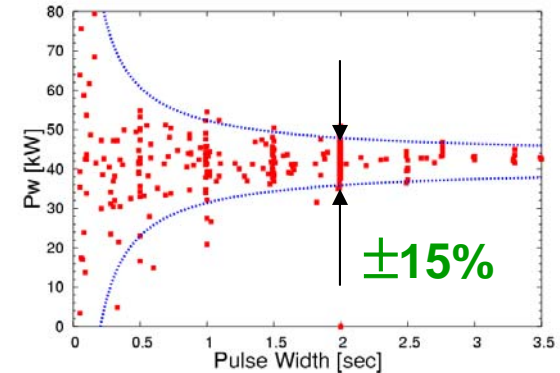
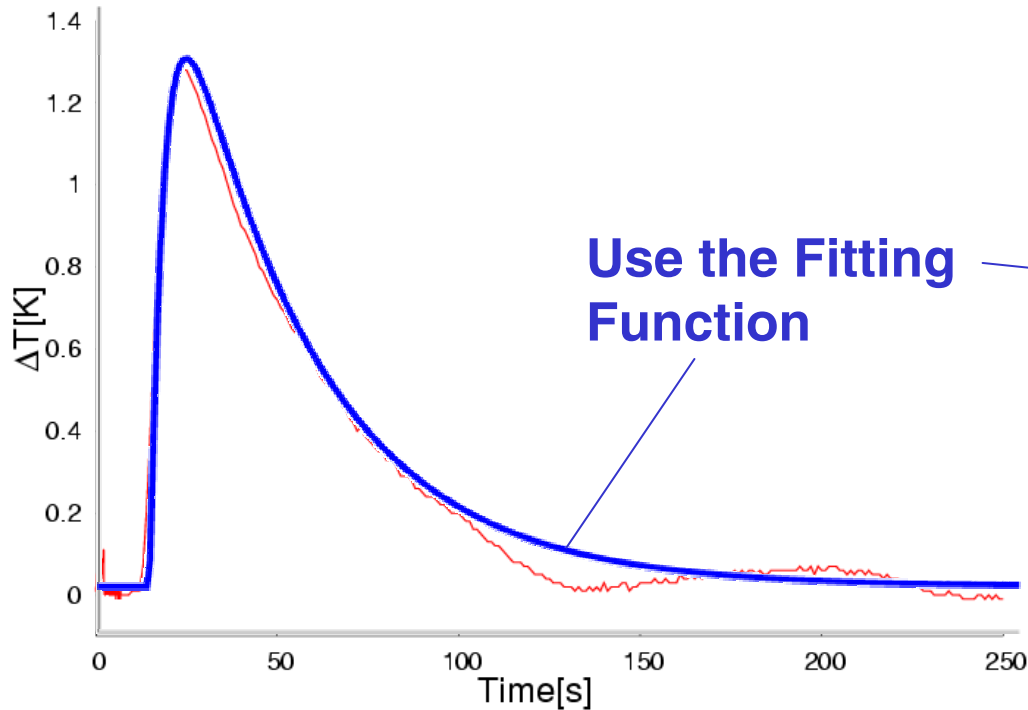
Input

Boundary Condition

$$T_{D2}(t_p) = T_{D1}(t_p), \quad T_{C2}(t_p) = T_{C1}(t_p).$$

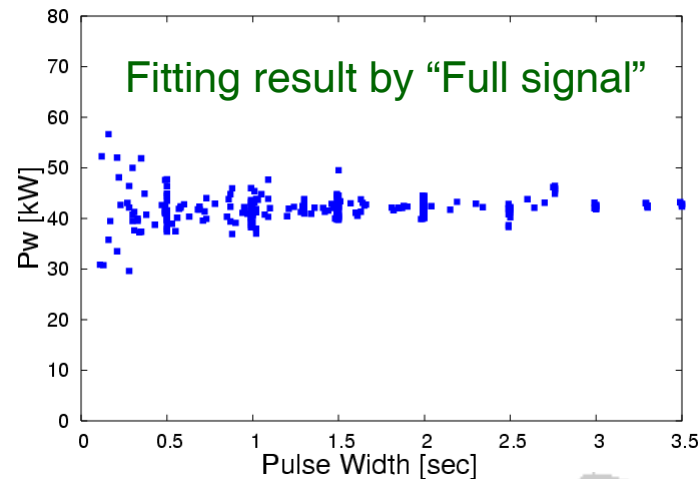
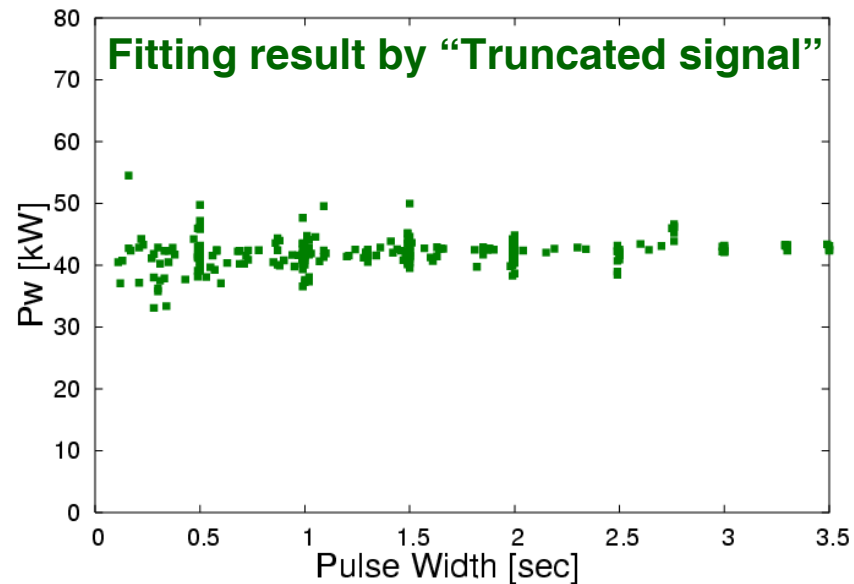
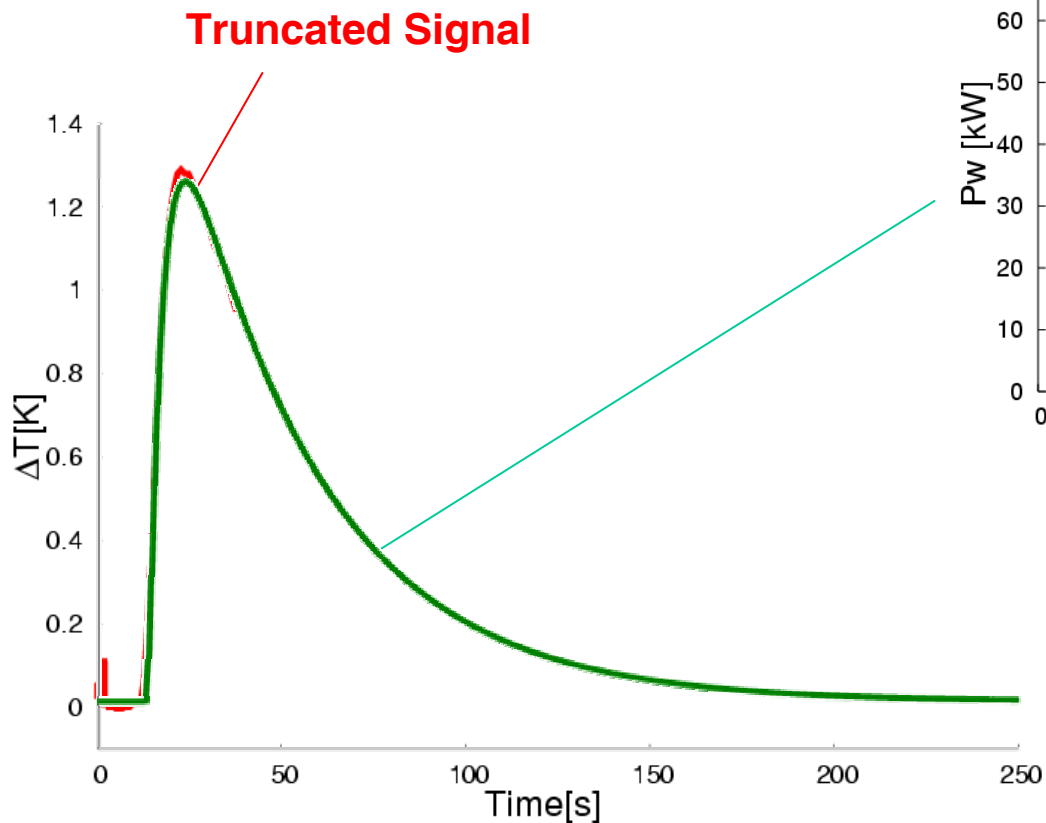
# Effect of Temperature Fluctuation of Cooling Water

- By using the fitting function, the scatter in the measurements is reduced from  $\pm 15\%$  to  $\pm 7\%$  with 2 sec pulse.
- The fitting function is especially useful for short pulse such as 0.5 sec shot.



# Fitting to Truncated Calorimetry Signal

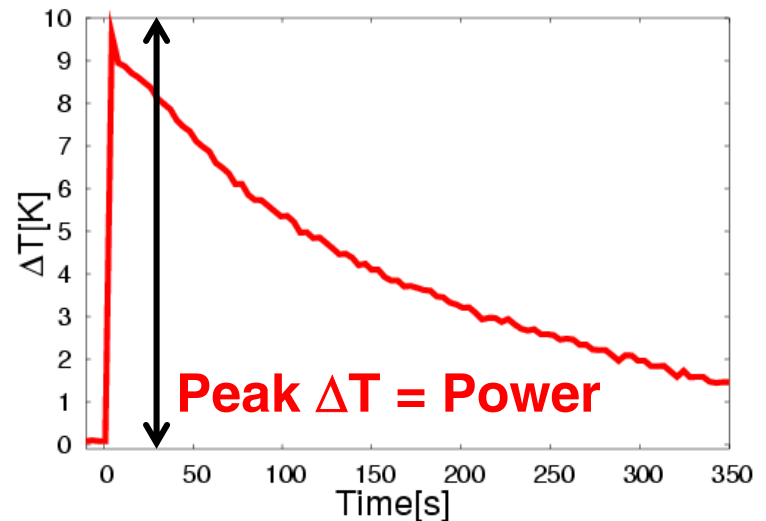
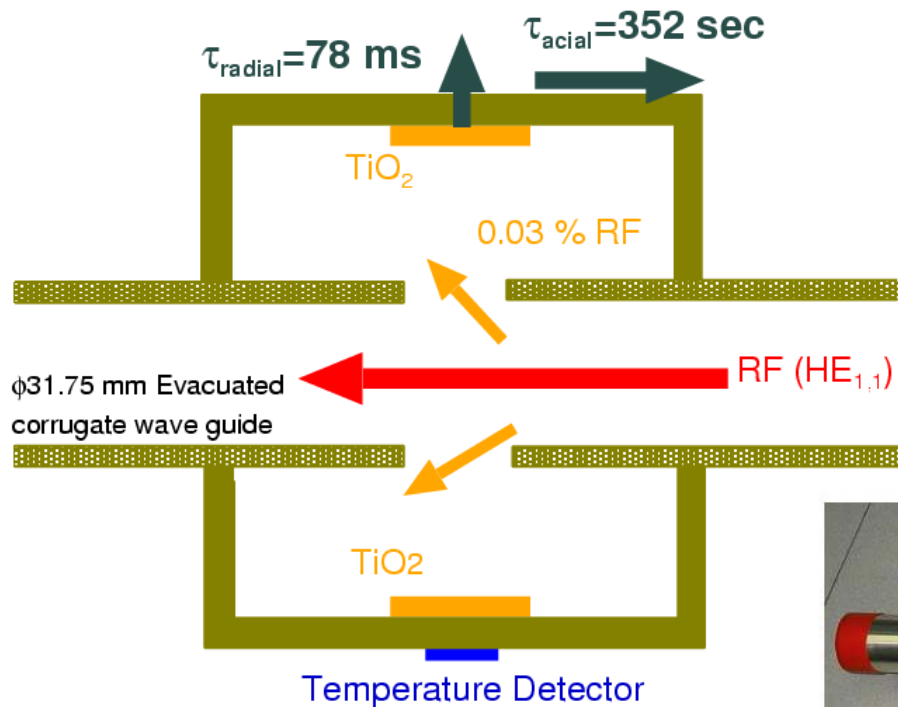
- The fitting function is working for “truncated signal” also.





# Wave Guide Power Monitor

- A new concept built-in wave guide power are developed by J.L.Doane in General Atomics.
- Operation of the power monitor depends on the rapid heat conduction through the wall of the cylinder at the location of the  $\text{TiO}_2$  compared with the longitudinal thermal conduction. The response is linear and the peak value of the temperature vs. time can be used to determine the power. S/N ratio is good.



# Calibration Setup

- A calibration is attempted by using the long wave guide system which is comparable to the real wave guide length of ~90m in order to increase  $HE_{1,1}$  mode purity.
- There are four Resistance Temperature Detector (RTD).

To DIII-D

Tinman →  
Tinman Wave  
Guide →  
Boris Wave  
Guide → Boris  
Dummy load

Isolation  
Valve

Polarizer

Tinman  
Gyrotron

RF

Dummy  
Load

Boris  
Gyrotron

3.6 m

W/G  
Switch

## Wave Guide Power Monitor

RTD1

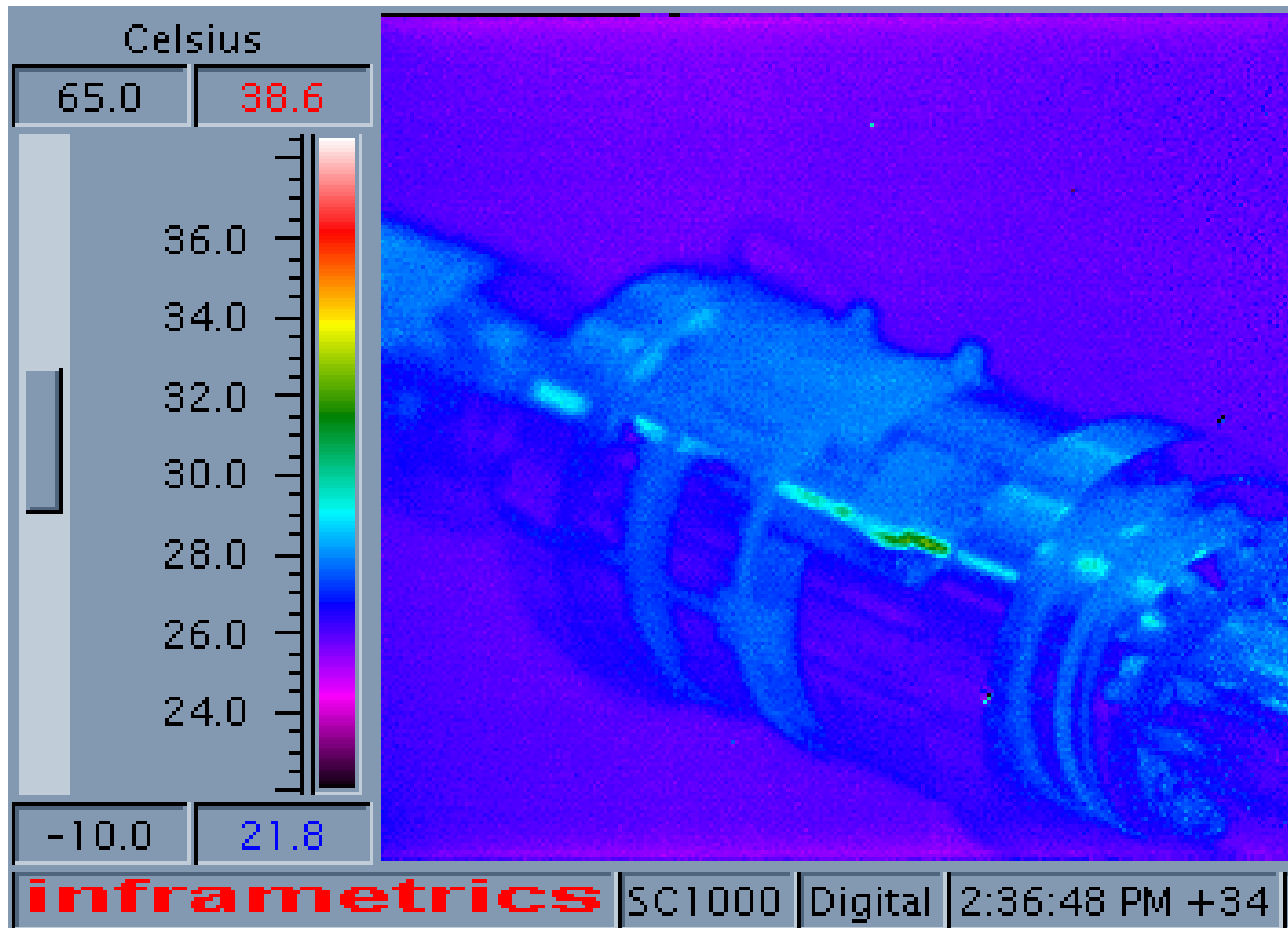
RTD4

RTD2

RTD3

# Temperature Increase of Power monitor

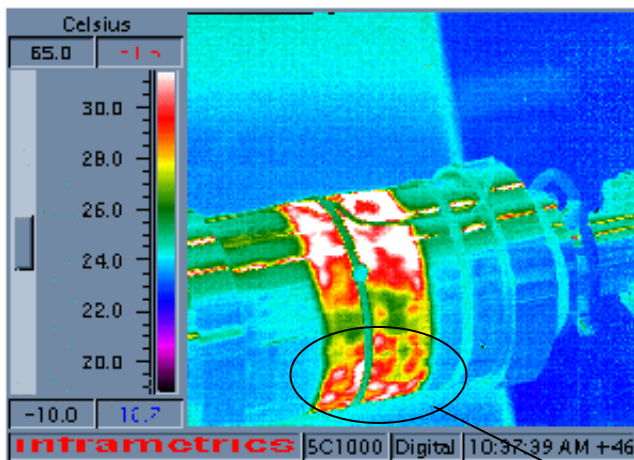
- The power monitor is very sensitive to non-HE<sub>1,1</sub> modes.
- Non-uniform temperature profile is found.



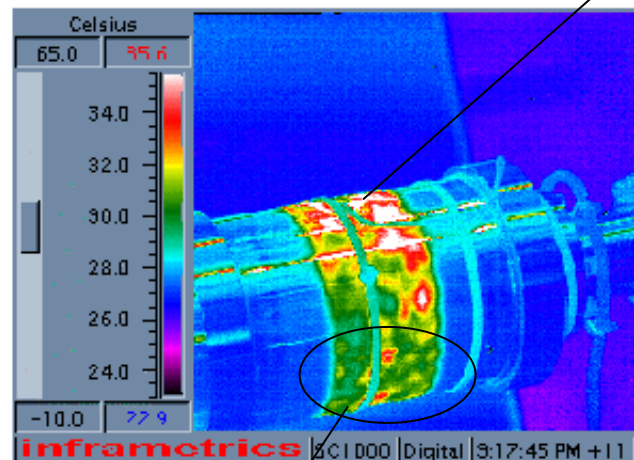
# Polarizer Dependence

- Polarization sensitivity was found due to small mode conversion at nearby miter bends in the test setup.

Polarizer 0

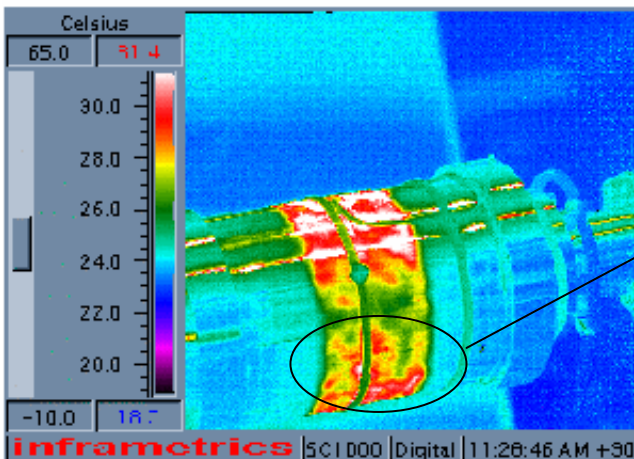


Polarizer 40



Reflection?

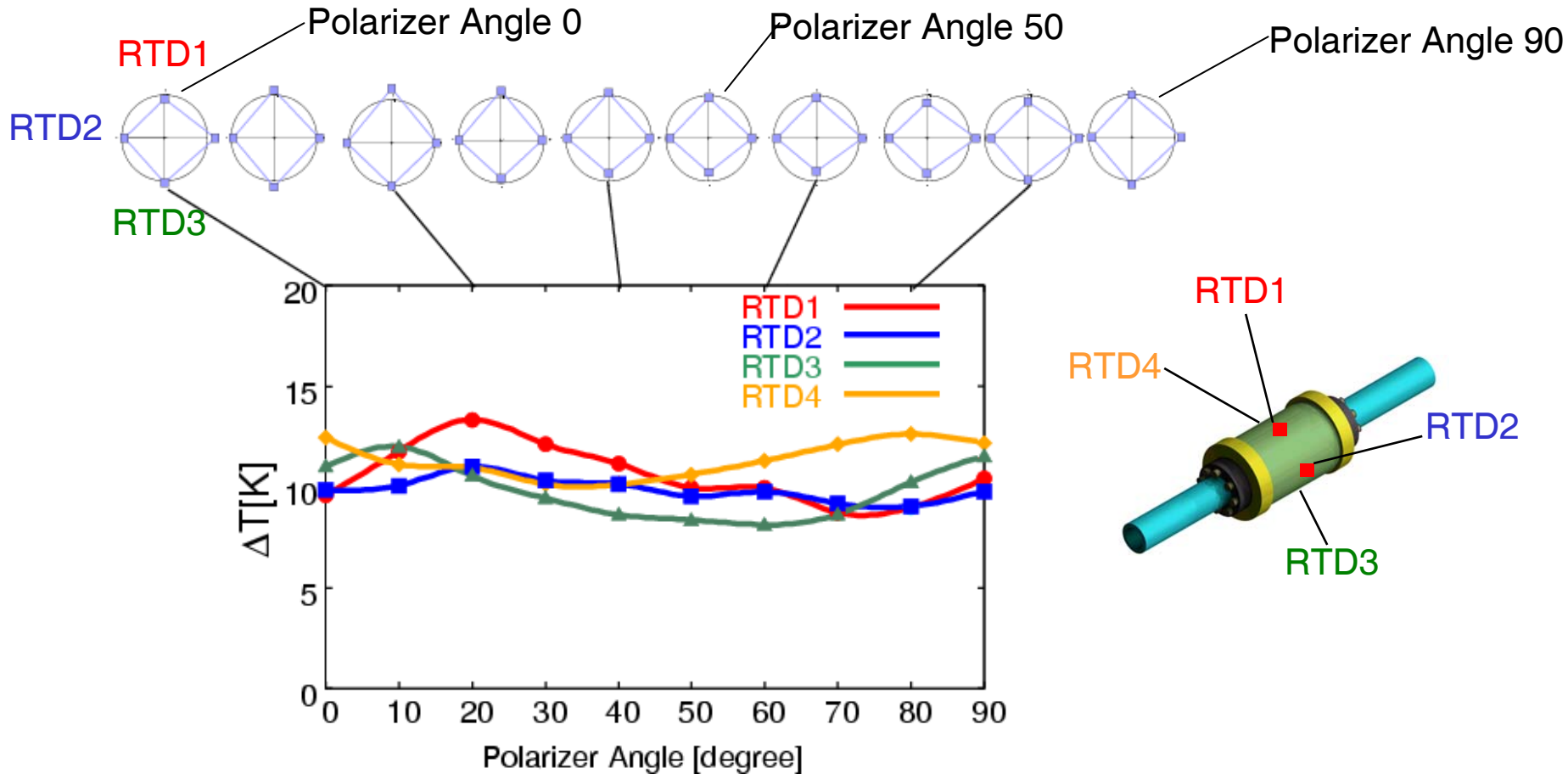
Polarizer 20



Clear Difference

# Random Change by Polarizer Setting

- The “temperature profile” is NOT rotating as polarizer rotates.



# Summary

- 1. Fitting function for calorimetry signal has been developed in order to avoid the effect of water temperature fluctuation on gyrotron power measurement**
  - 1. The accuracy of the rf absorbed power measurement is improved from  $\pm 15\%$  to  $\pm 7\%$  (case of coupling unit)**
  - 2. Fitting function has a good capability for “truncated signal”, giving improved response time**
- 2. A new concept built-in wave guide power monitor has been tested using a long wave guide system (comparable to real experimental set up)**
  - 1. Non-uniform azimuthal temperature increase is observed**
  - 2. A strong polarization dependence is found.**
- 3. The non-uniform temperature space profile does not rotate as the wave polarization rotates.**