Radar Chamber for Detection of UHE Neutrinos

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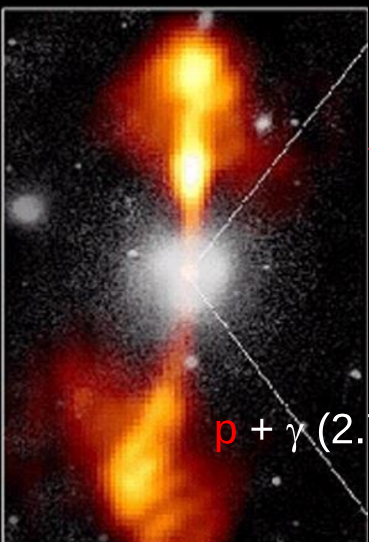
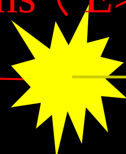
Talk at VHEPA2014 – March 20, 2014

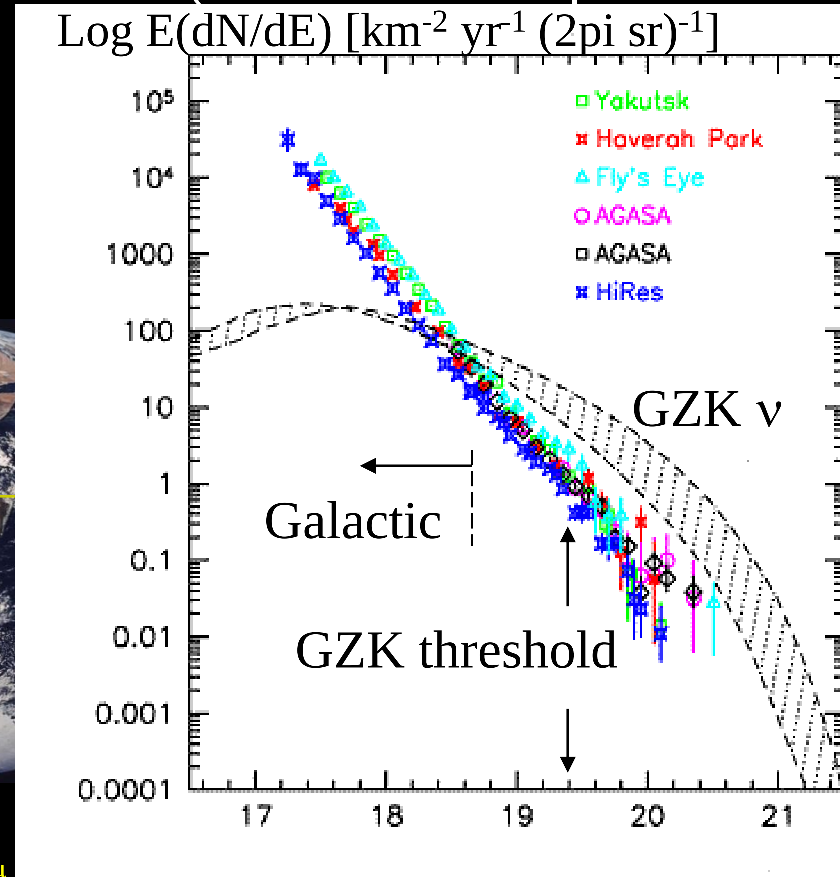
Ultra-high energy neutinos generated in GZK(Greisen-Zatsepin-Kuzmin) Process

Ultra-high-energy cosmic ray is generated in
Active Galactic Nuclei
Gamma-ray Burst etc.



Protons（ $E>4*10^{19}$eV ）





$p + \gamma\,(2.7K) \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$

$n \rightarrow p\ e^{-}\ \bar{\nu}_e$

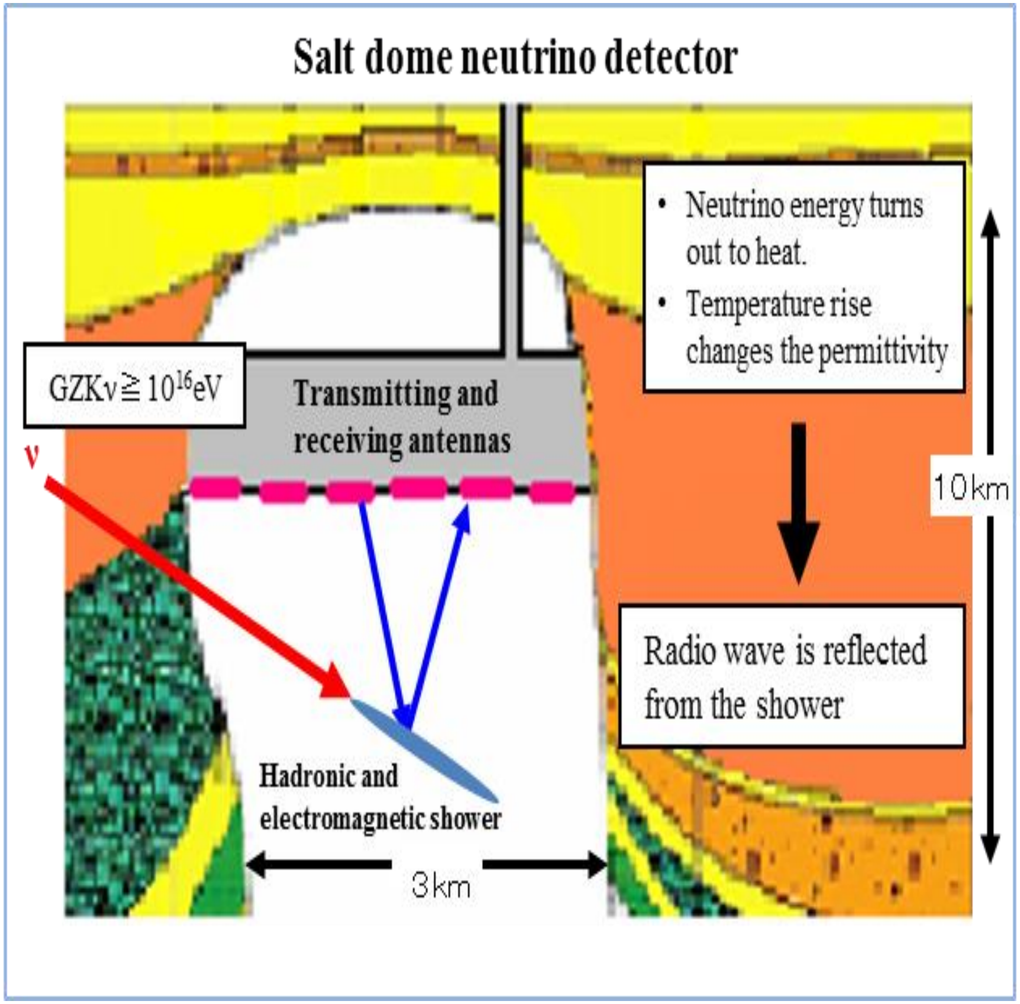
$\pi^{+} \rightarrow \mu^{+}\ \nu_{\mu}$

$\mu^{+} \rightarrow e^{+}\ \nu_{\mu}\ \nu_e$

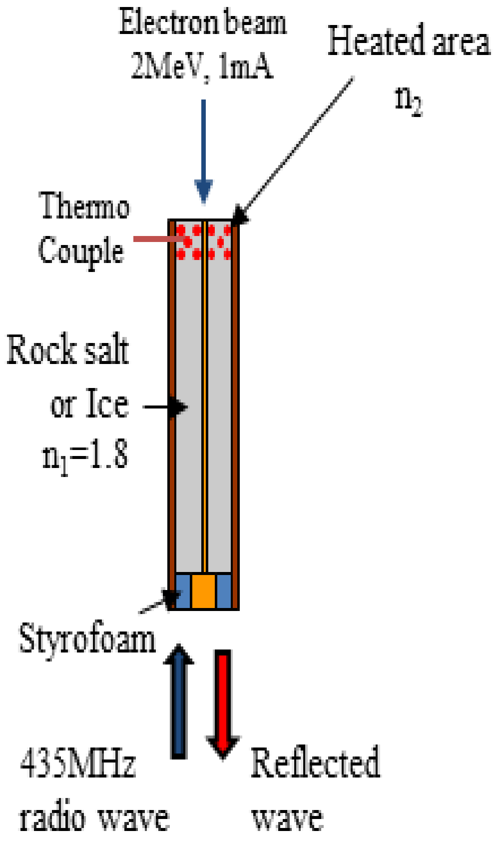
- Detection of cosmic ν（10^{16}〜10^{21}eV) using a rock salt formation or the Antarctic ice sheet

- ■The flux is extremely low (≒1/ km^2・day), we need a gigantic mass of the detection medium of 50 Gt (≒ 10 events/year) a million times as large as Super Kamiokande.

Radar method and a coaxial tube for ice and rock salt



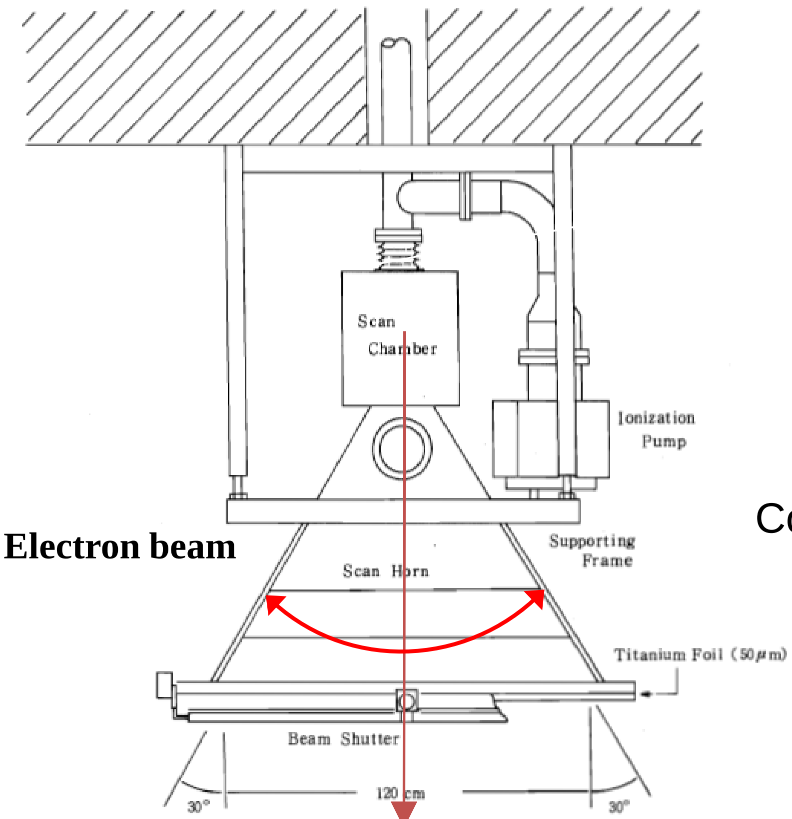
Coaxial tube with 2 cm diameter



Electron beam irradiation on ice or rock salt

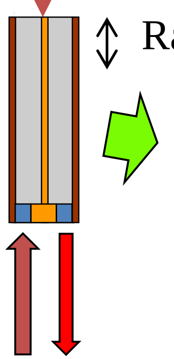
- Cockcroft-Walton accelerator located at Takasaki Advanced Radiation Research Institute, Japan Atomic Energy Agency

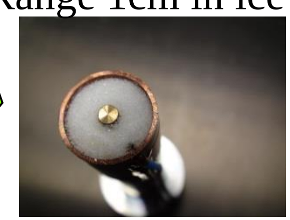
Electron beam

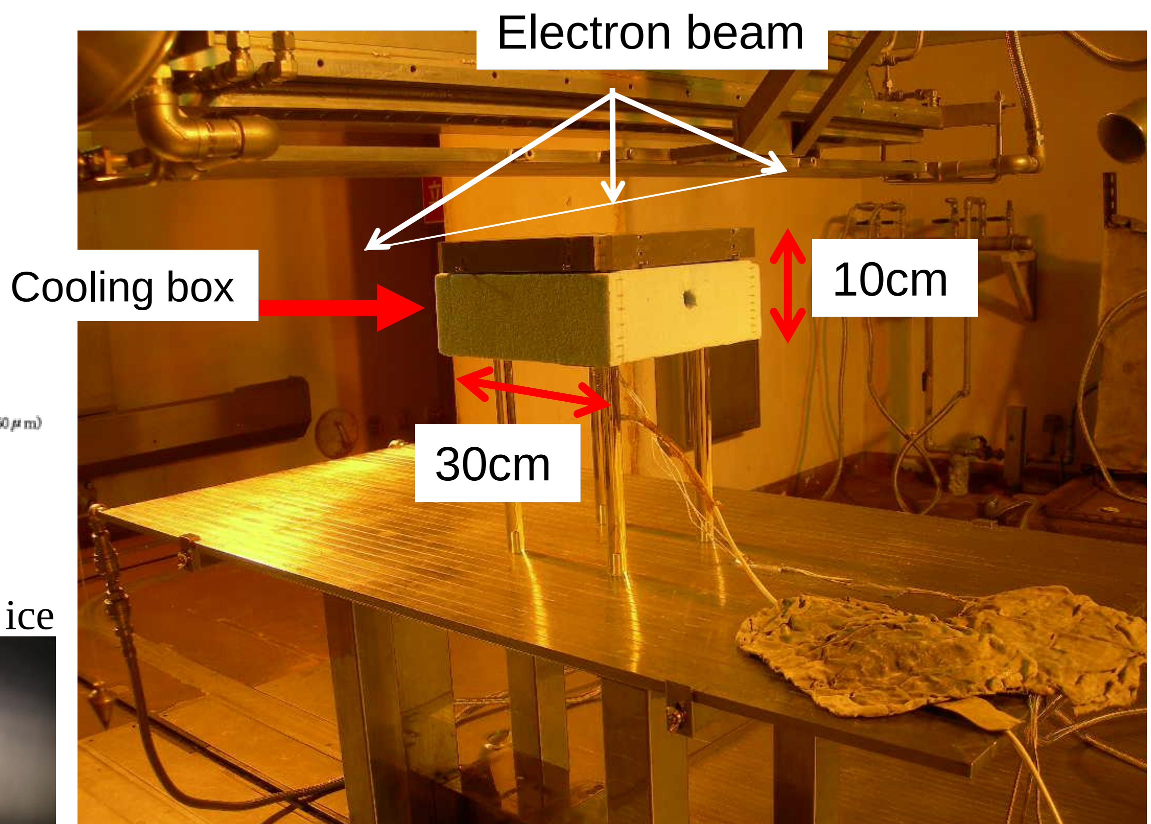


Range 1cm in ice

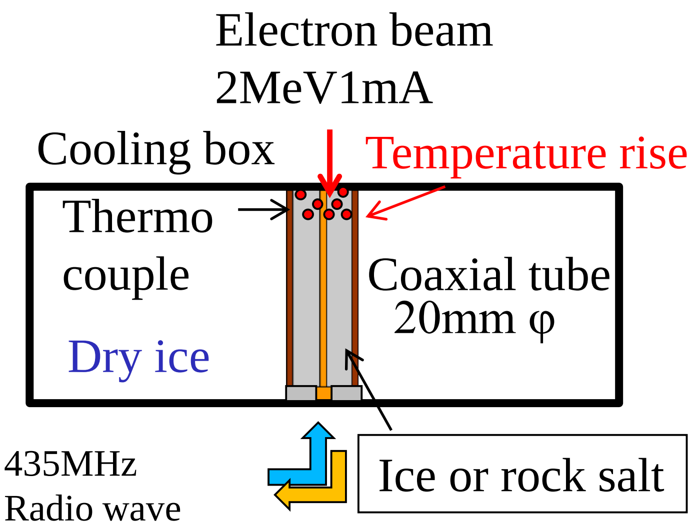
Coaxial tube







Coaxial tube and radio-wave reflection



・Coaxial tube was filled with ice or rock salt.

・2MeV electron beam irradiate the open end of the coaxial tube.

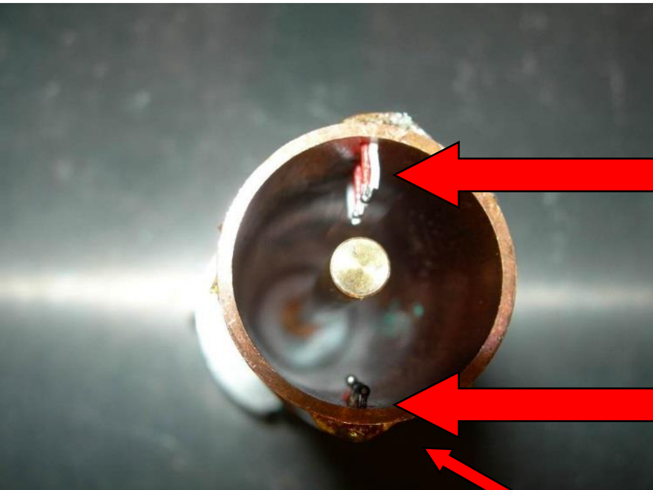
(4 J/s = 2×10^{19} eV/s at 1mA)

・Temperature rise(ΔT)

→ Increase of refractive index(Δn)

→ Radio wave reflection changes

Rock salt or Ice filled coaxial tube in a dry-ice cooling box



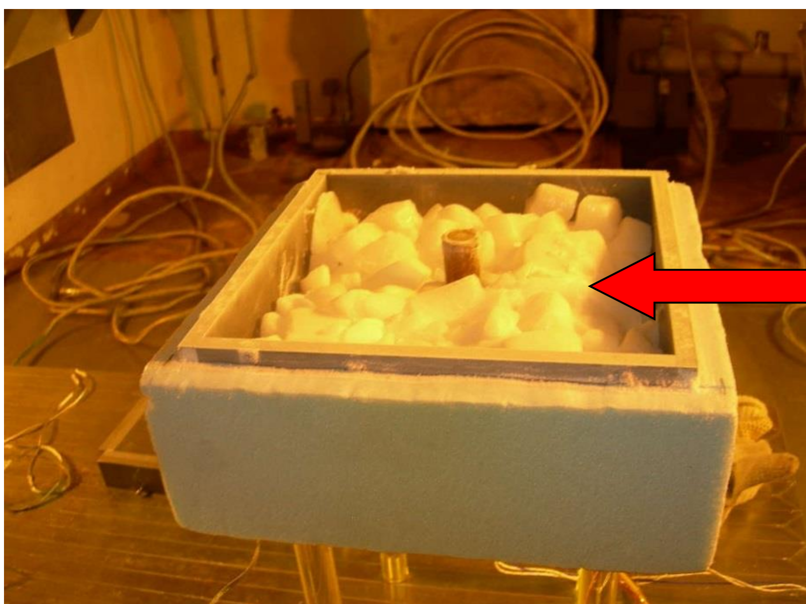
Thermocouples × 3

（r = 6 mm）

Thermocouples × 3

（ r = 9 mm）

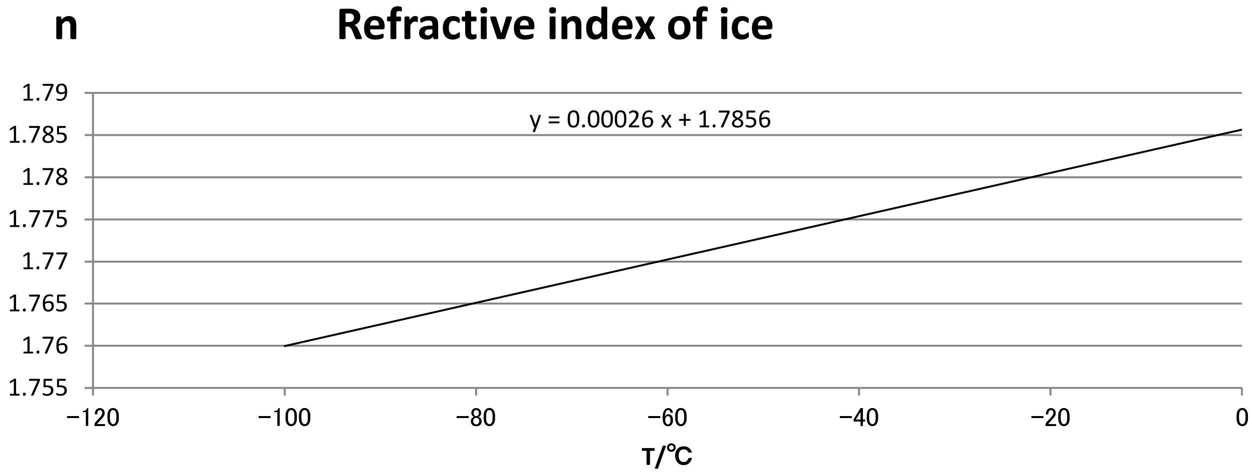
Thermocouples × 1（outside）



Dry Ice

（r = 4 mm）

Power Reflection Fraction with a Change of Refractive Index



Matzler, C and Wegmuller, U., J. Appl. Phys. 80, 1623-1630(1987)

Matsuoka,T, Fujita, S and Mae, S., J. Appl Phys. 80,5884-5890(1996)

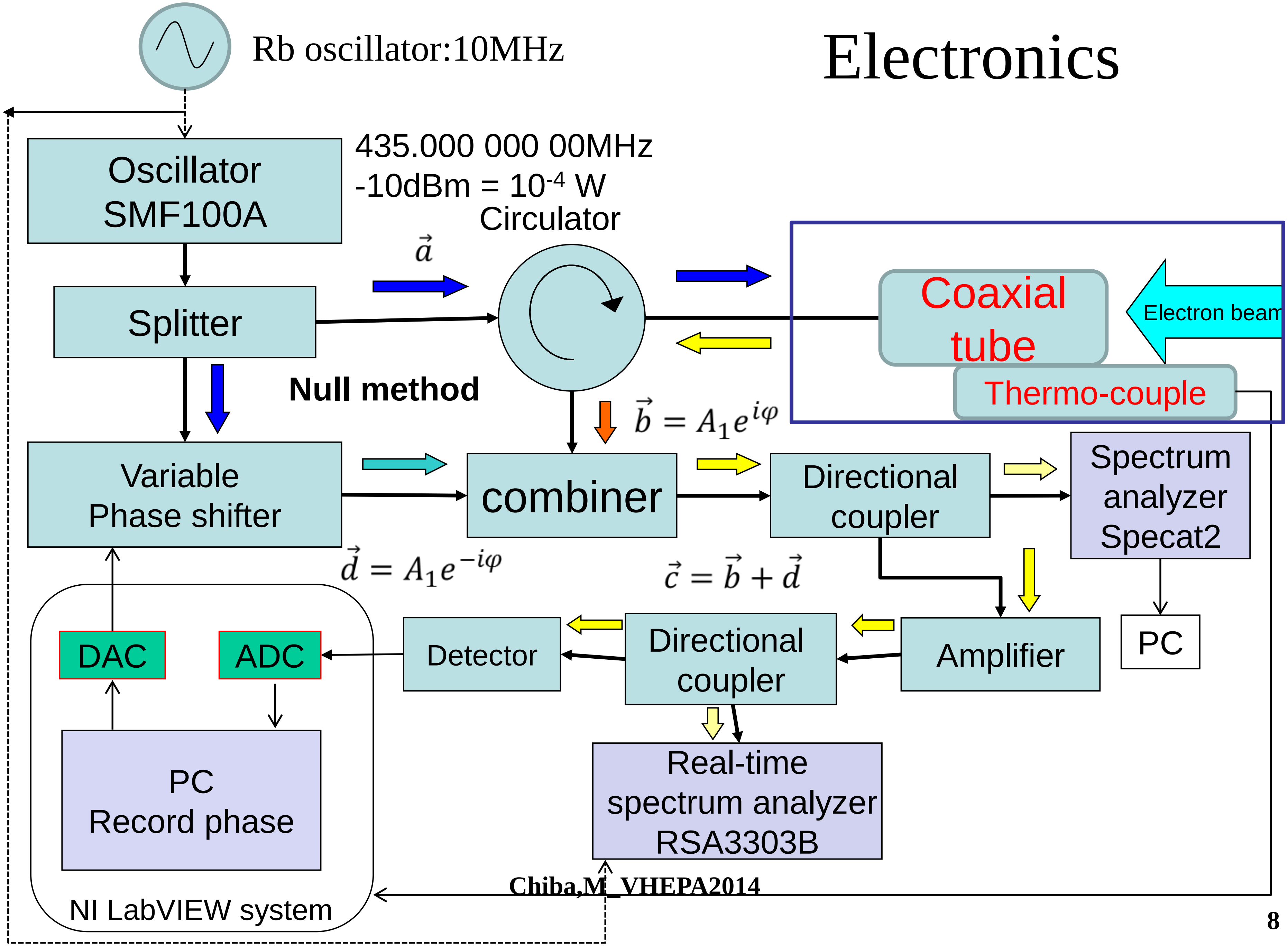
- $\Delta n \propto \Delta T$ for ice and rock salt
- Power reflection rate (Γ) is proportional to ΔT^2

Fresnel equation

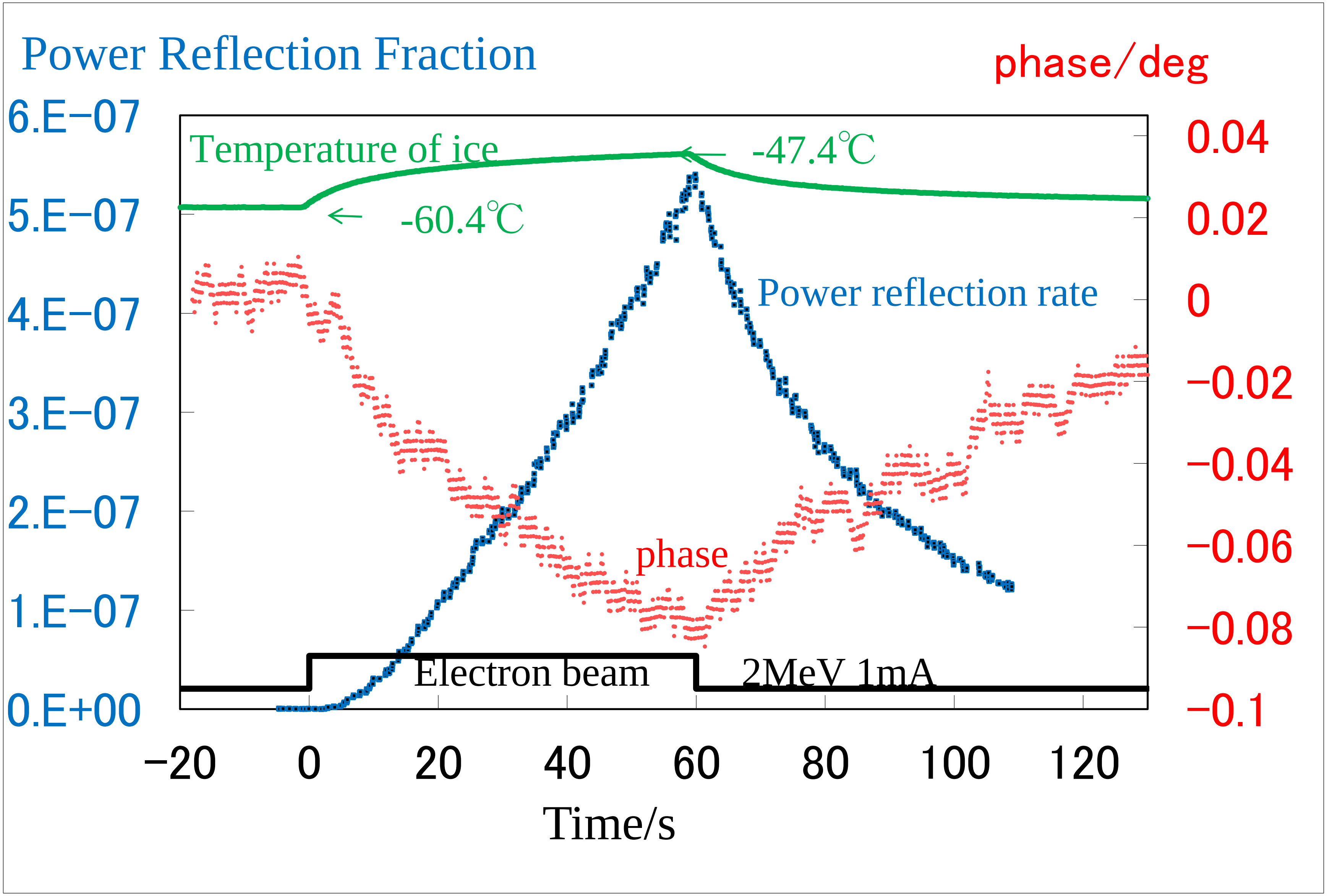
$$\Gamma = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2} \propto \Delta T^2$$

n_1: Before irradiation
n_2: Irradiation

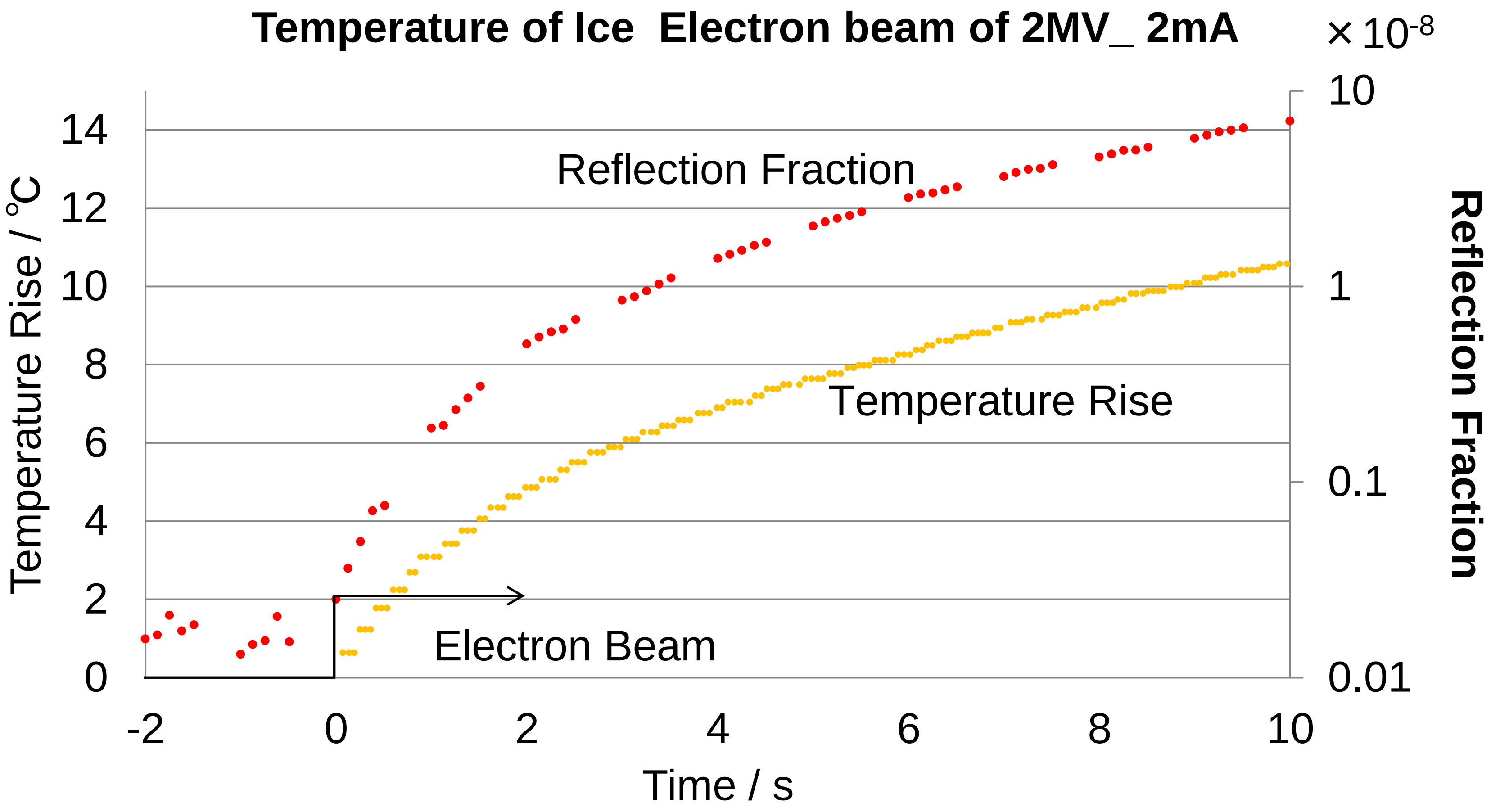
Electronics



Reflection Phase and Fraction in Ice



Reflection Fraction from Ice in Power



Simulation

- Verification of Radio wave Reflection Mechanism

1) Geant4

Energy-Deposit in detection media

2) COMSOL AB Co. Ltd.（Sweden）

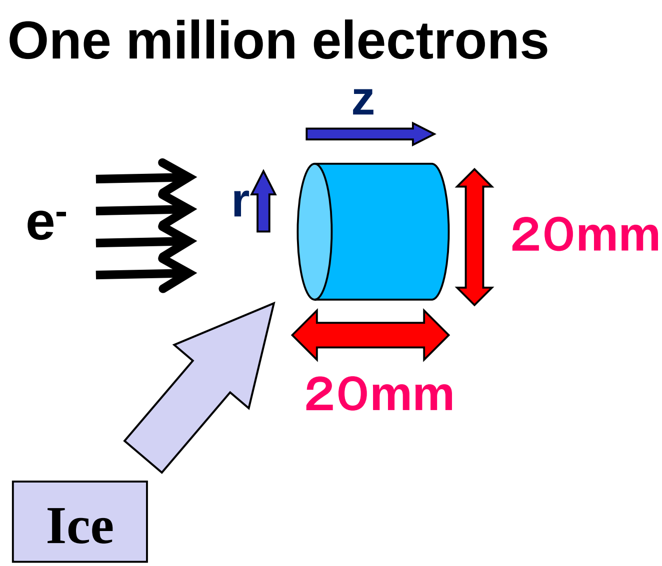
Multiphysics: 3 dimension finite element method

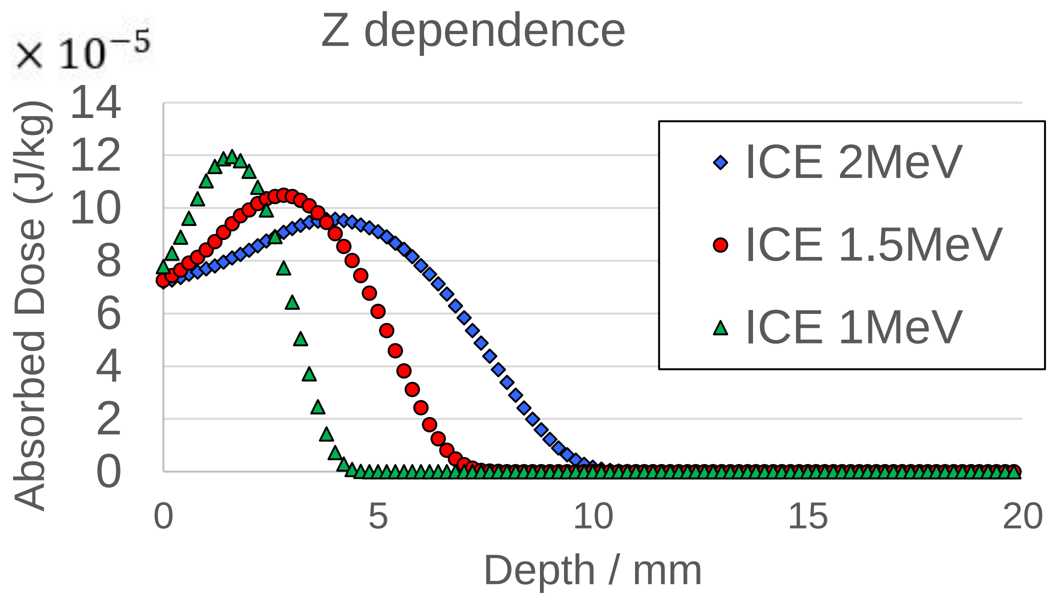
2-1) Thermal energy distribution is got by the energy deposit (Geant4).

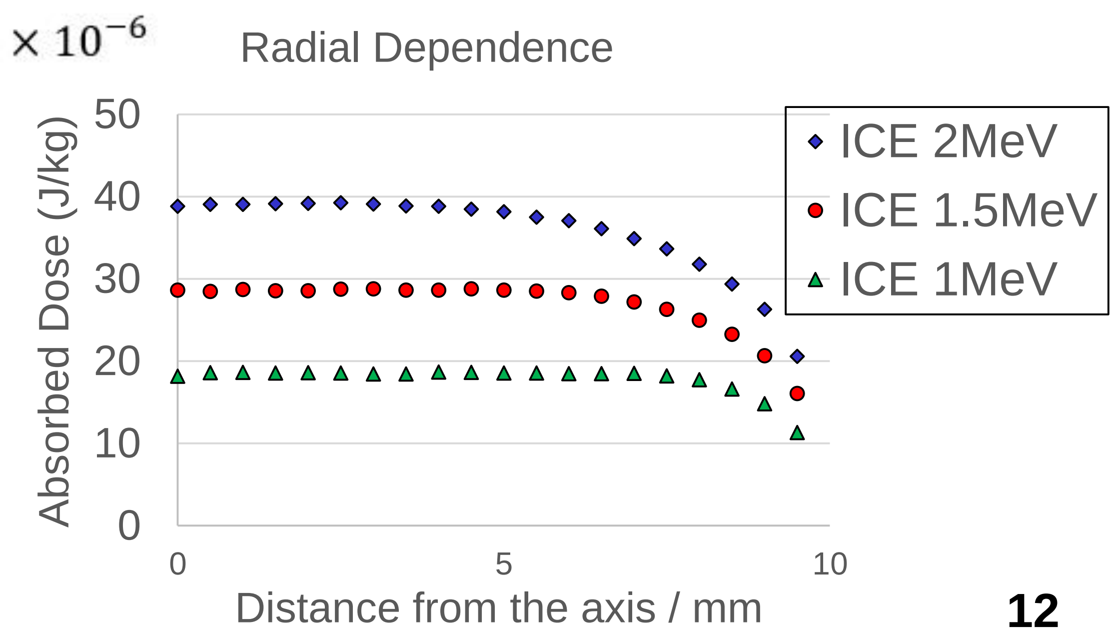
2-2) The thermal transport and the radio wave reflection inside of the coaxial tube are simulated in coupled analysis method.

2-3)120 second is analyzed from the electron beam on.

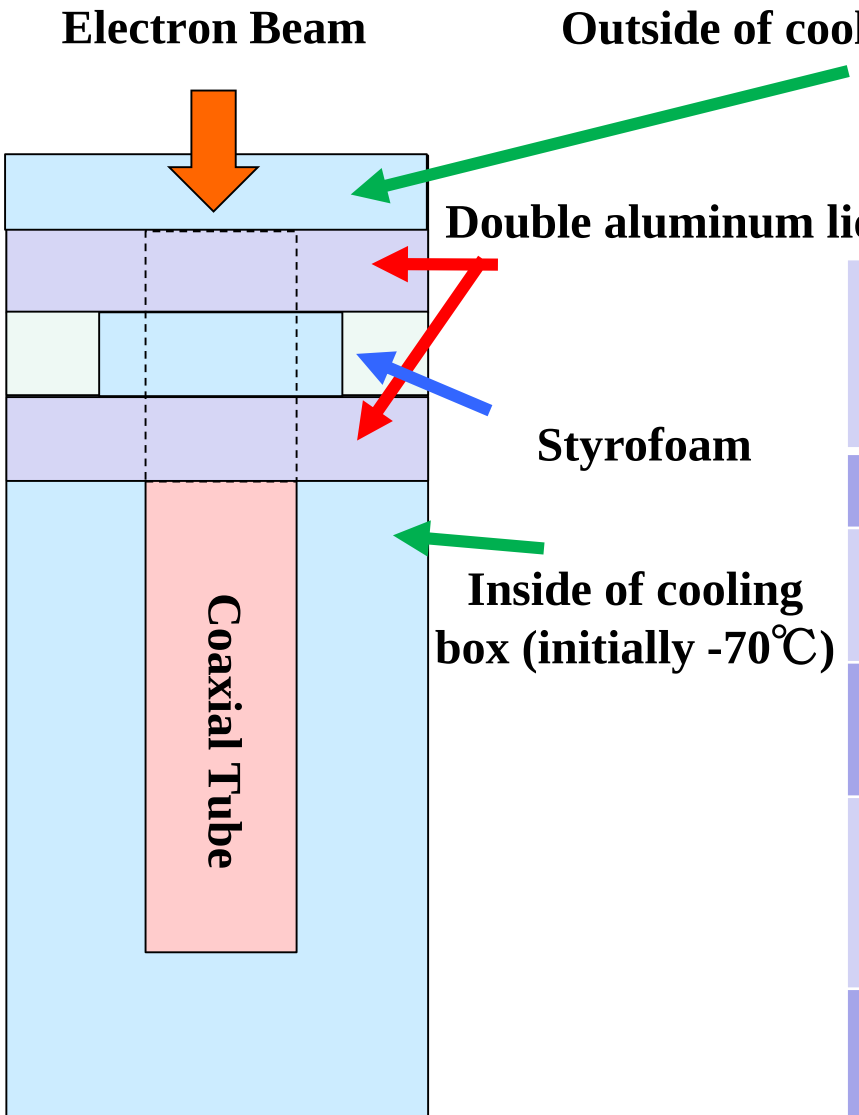
Energy Deposit in Ice (Geant4)







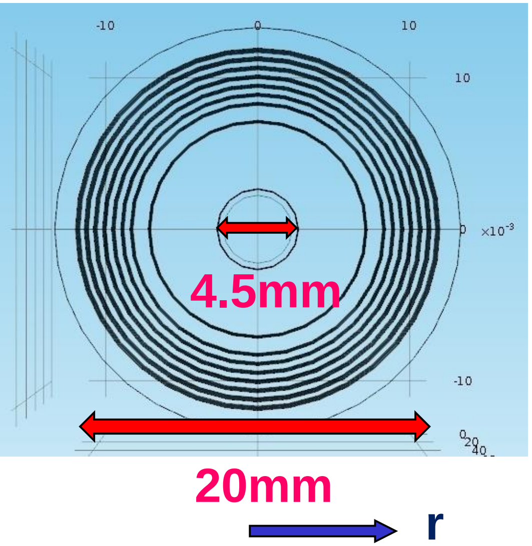
Geometry in the simulation

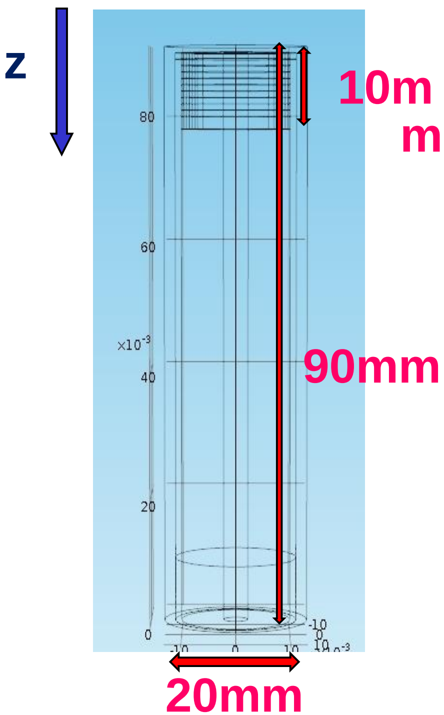


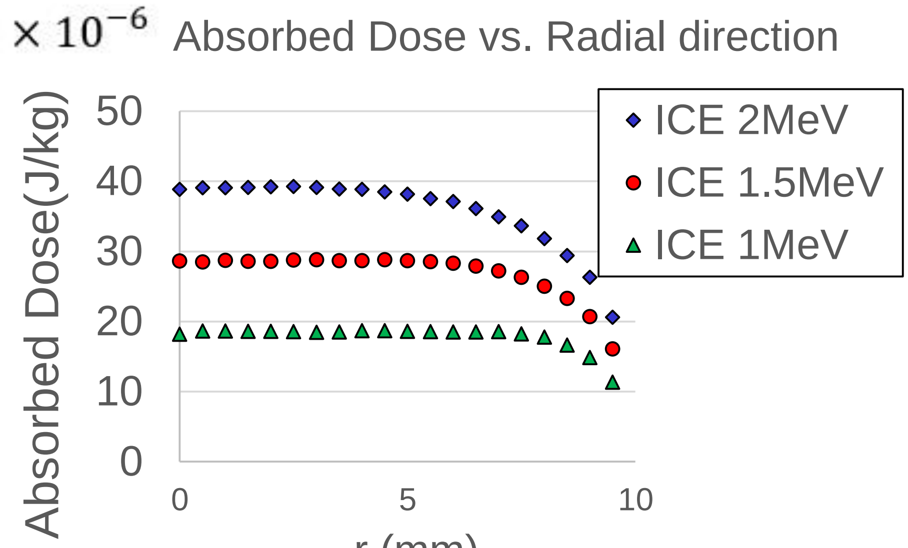
Ice

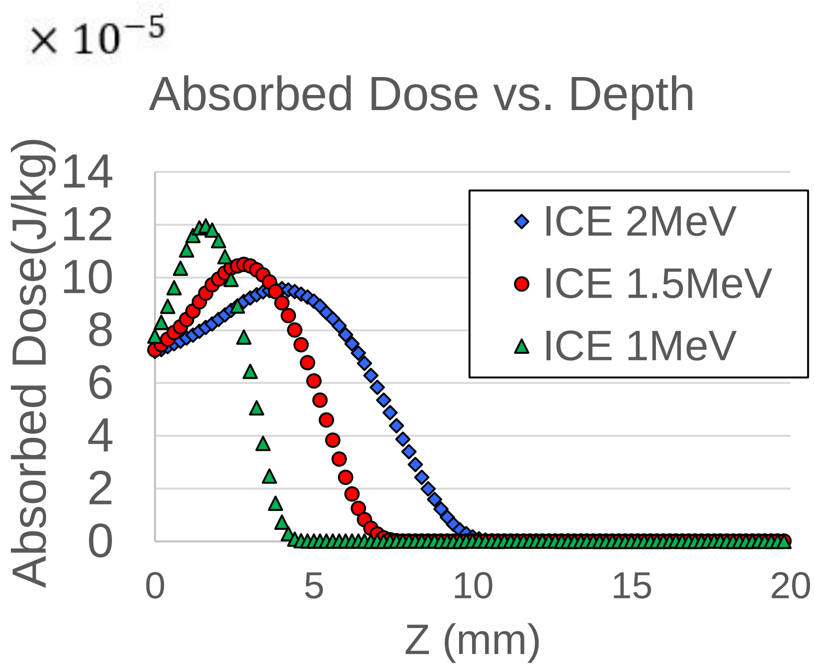
Thermal conduc-tivity	**2.2**	**W/(m･K)**
Density	0.9224	g/cm^3
Specific heat	2085	J/kg･k
Refractive index	0.000260T+1.786	1
Magnetic permiability	1	1
Electrical conductivity	0	S/m

Simulation for Thermal Source









8 divisions for r

10 divisions for z

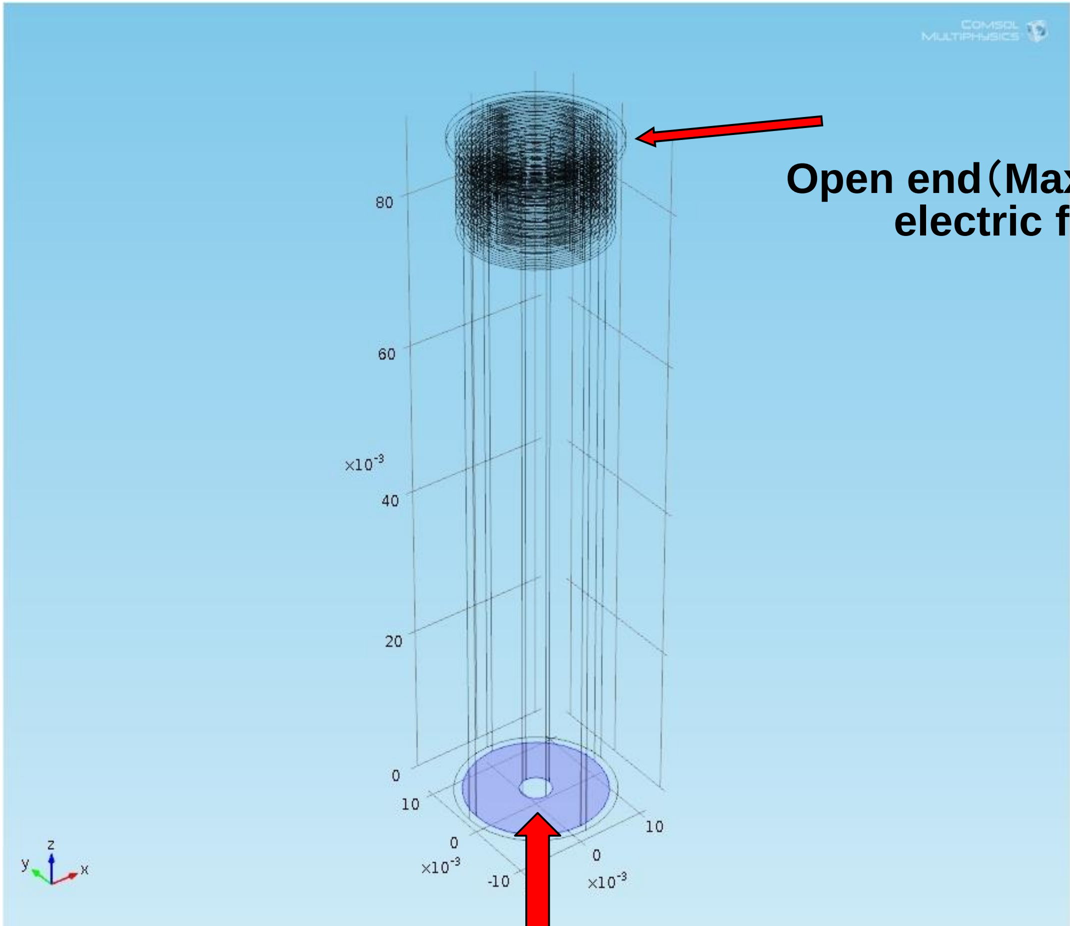
80 divisions in total

Electron beam

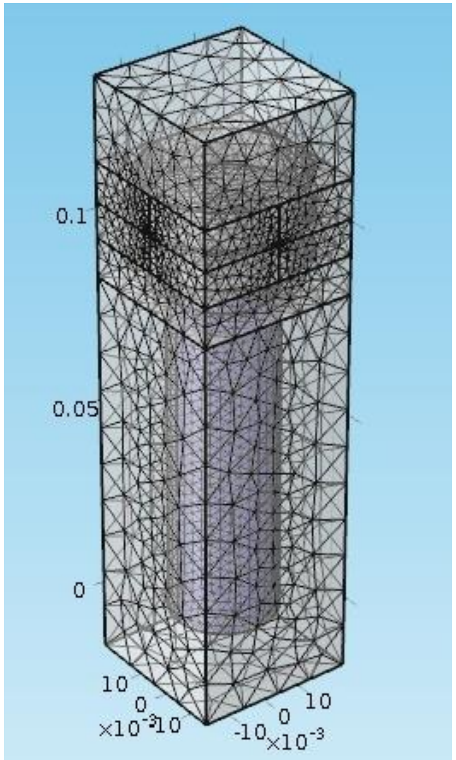
2.0MeV 1.0mA

4.3w in total

Simulation for Radio Wave



Open end（Maximum electric field）

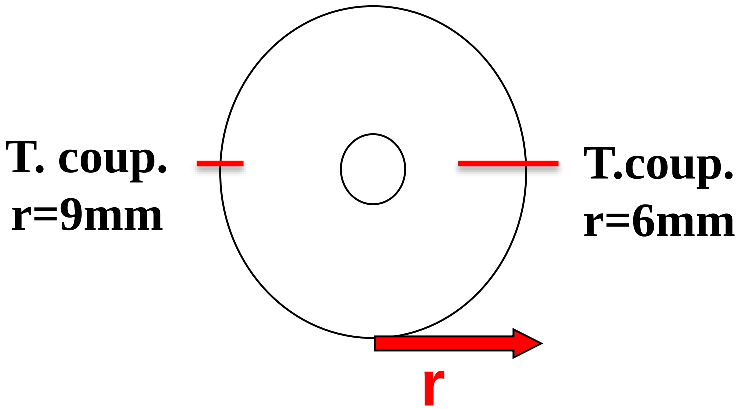


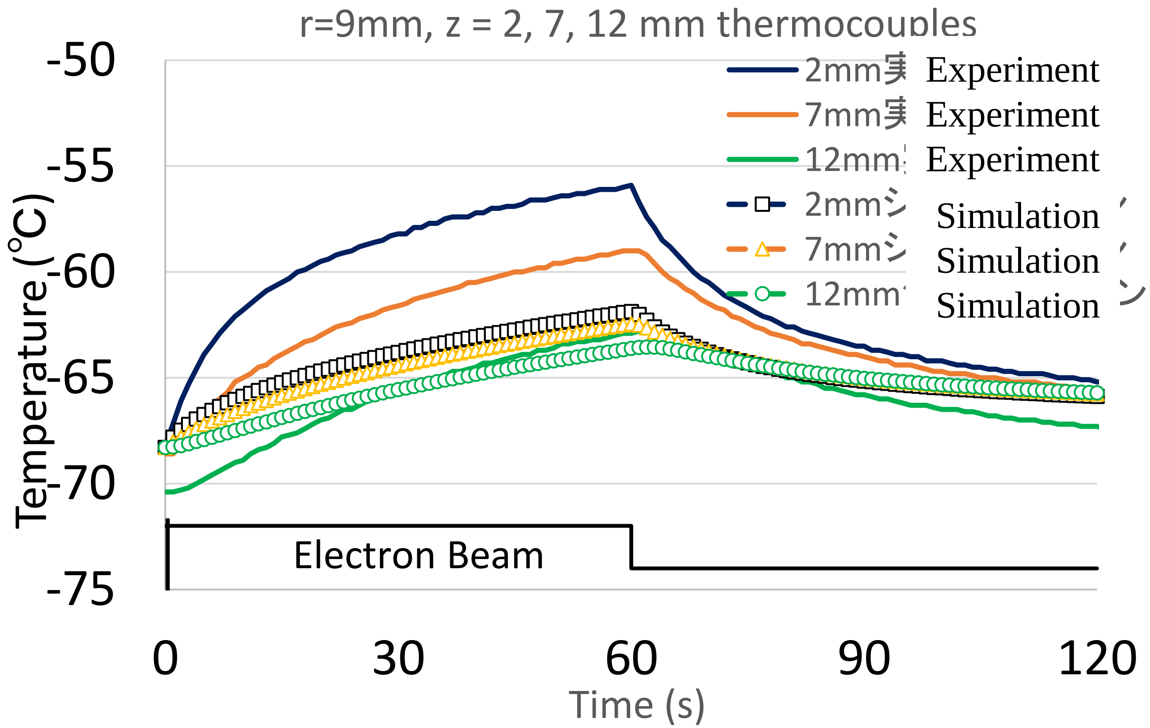
Optimum mesh sizes

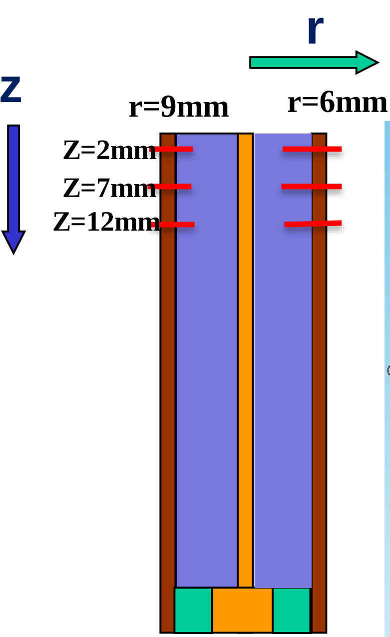
435MHz radio wave（50Ω coaxial cable）

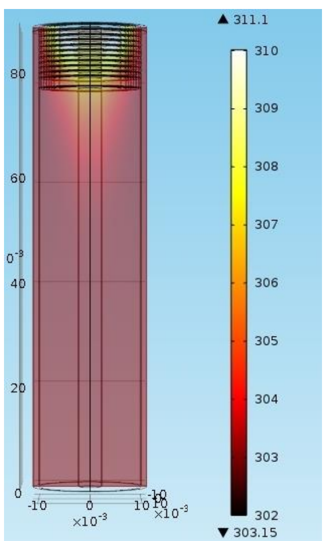
Radio wave is reflected from the inhomogeneity of the refractive indices.

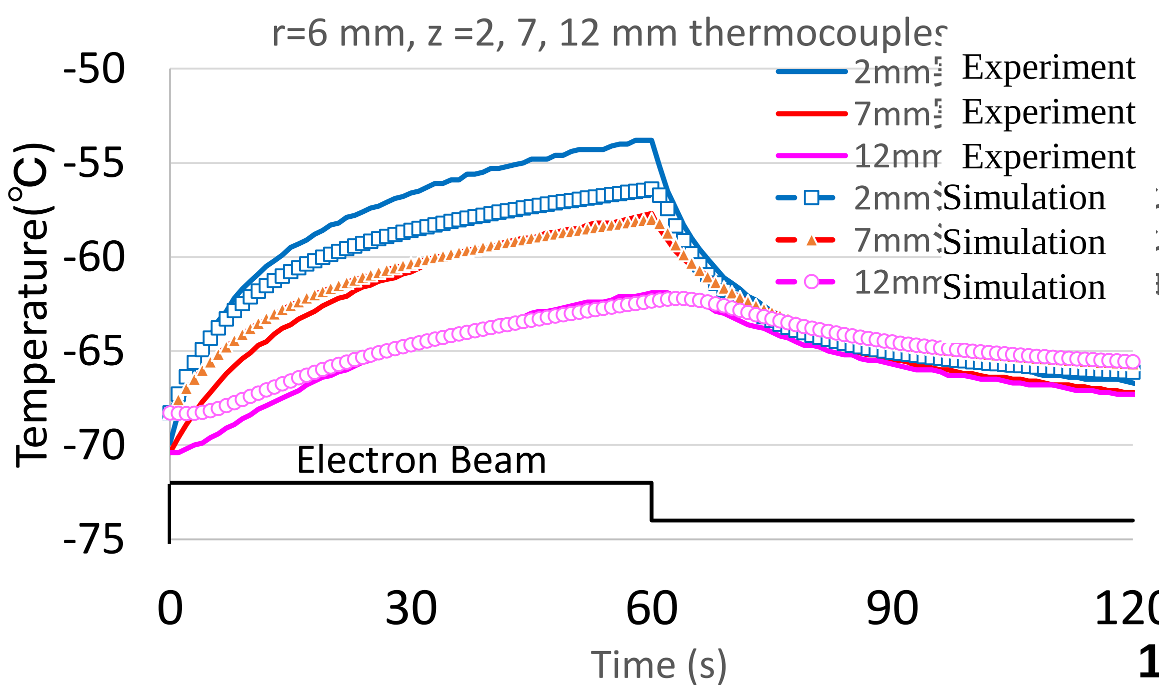
Temperature vs. time
Ice
E. Beam 2MeV,1mA



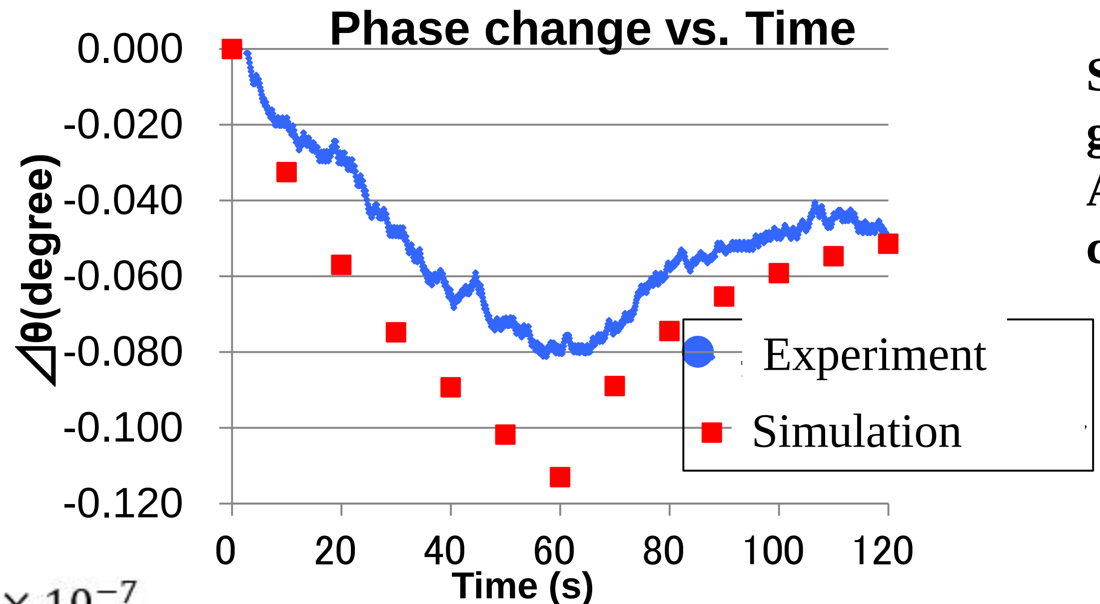




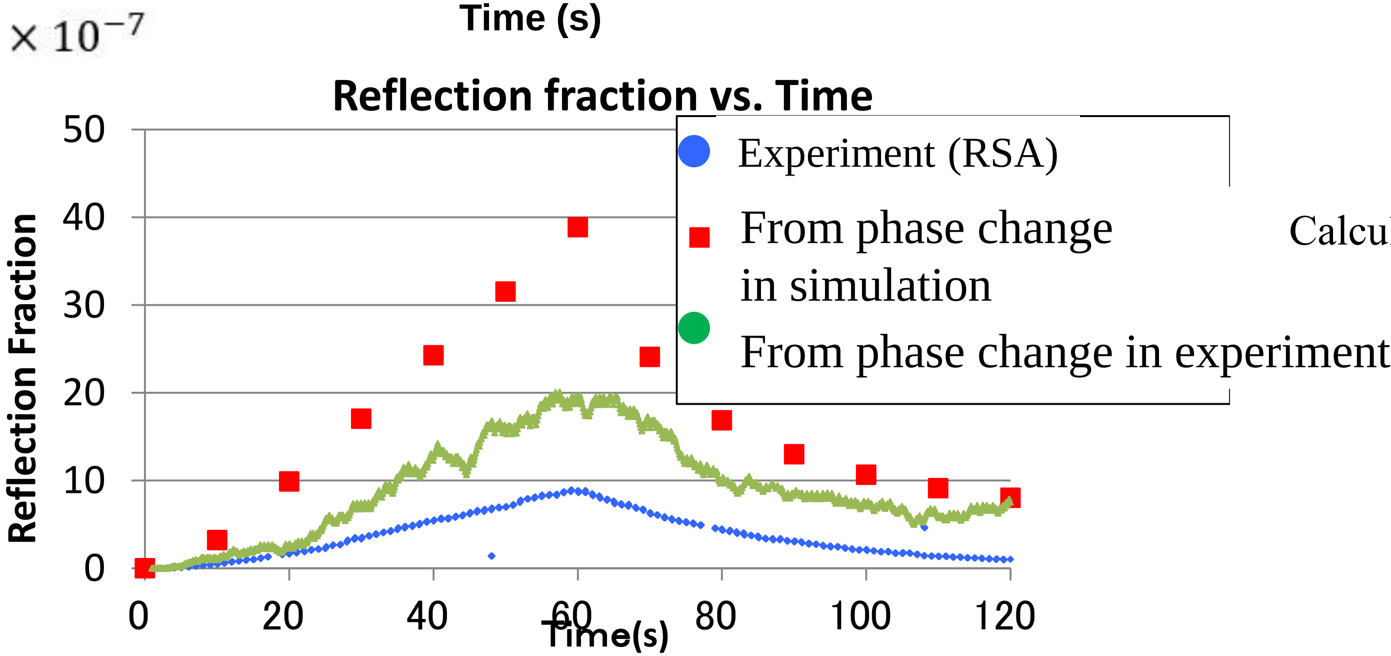




Phase Change and, Reflection Fraction in Energy in Ice Electron Beam 2MeV,1mA



Simulation presents the experiment good in shape.
Absolute values are not represented completely



Calculation of reflection fraction Γ from phase change Δθ

$$\Gamma = 2(1 - \cos\Delta\theta)$$

Radiation detectors using heat effects.

	Bolometer	**Cloud chamber**	**Bubble chamber**	**Acoustic detector**	**Radar chamber**
Inventor	S.P. Langley	C.T.R. Wilson	D.A. Glaser	G.A. Askaryan	M. Chiba, et al.
Year	1878	1911	1952	1957	2007
Medium	Solid	Gas	Liquid	Solid, Liquid	Solid
Wave length	-	～500nm	～500nm	～1m	～10m
Body	Solid	Liquid particle,	Bubble,	Heated portion,	Heated portion,
Body size	-	～0.5mm	～0.1mm	10cmφ×5m	10cmφ×5m
Reflection or emission	-	Reflection	Reflection	Emission	Reflection
Operation	-	Decompression	Decompression	—	—
Process	Heating	Super cooling	Super heating	Heating	Heating
Amplification	Small heat capacity	Growth of liquid particle	Growth of bubble	—	Coherent reflection
Sensitivity	>1eV	～100eV	～100eV	$>10^{12}$eV	$>10^{12}$eV
Position reso.	-	～0.5mm	～0.1mm	～30m	～30m
Detector size	～ 1cm	～m	～m	～km	～km
Memory time	～ 1s	～10ms	～1μs	—	～10s

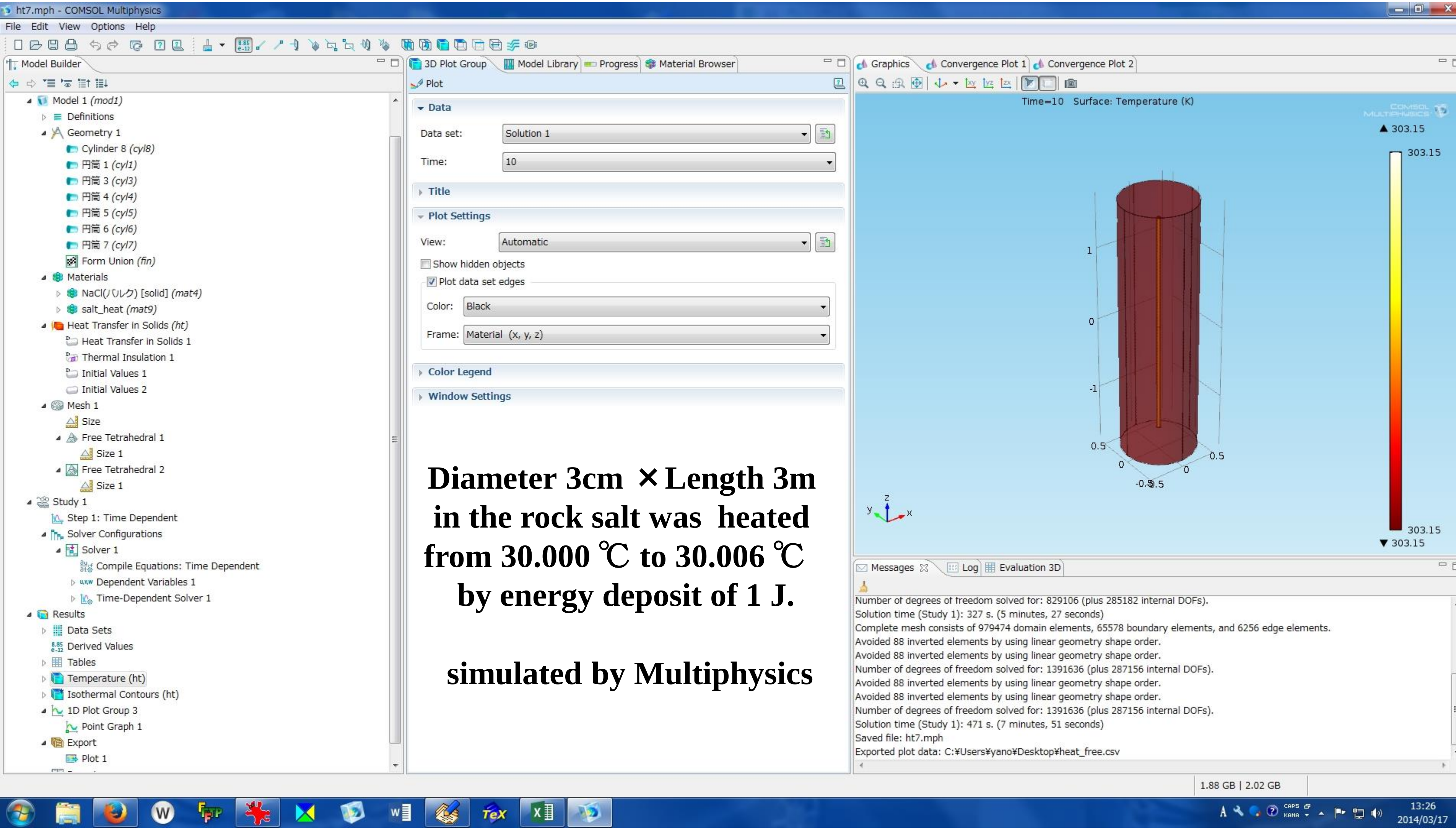
Summary

- Radio wave reflection strength with phase have been measured from ice and rock salt using a coaxial tube irradiated by an electron beam.
- Simulation of the experiment has been done using Geant4 and 3 dimension finite element method.
- The thermal transport and the radio wave reflection inside of the coaxial tube are simulated in coupled analysis method.
- Temperature change and radio wave reflection strength with time have been reproduced by the simulation.

The reflection mechanism has been verified. Temperature rise(ΔT) → Increase of refractive index(Δn) → Radio wave reflection changes

Backup

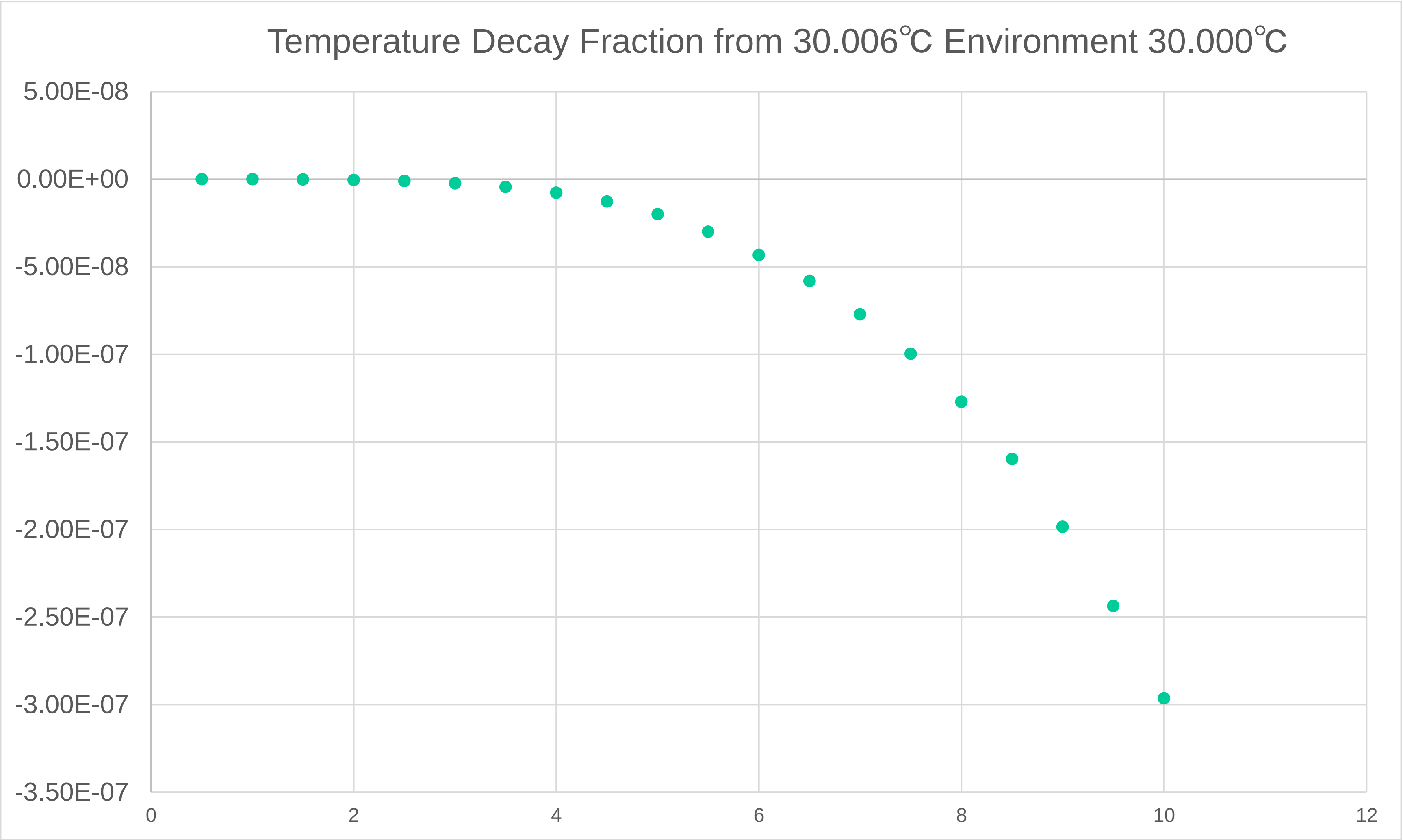
Temperature change with energy deposit of 1 J in rock salt



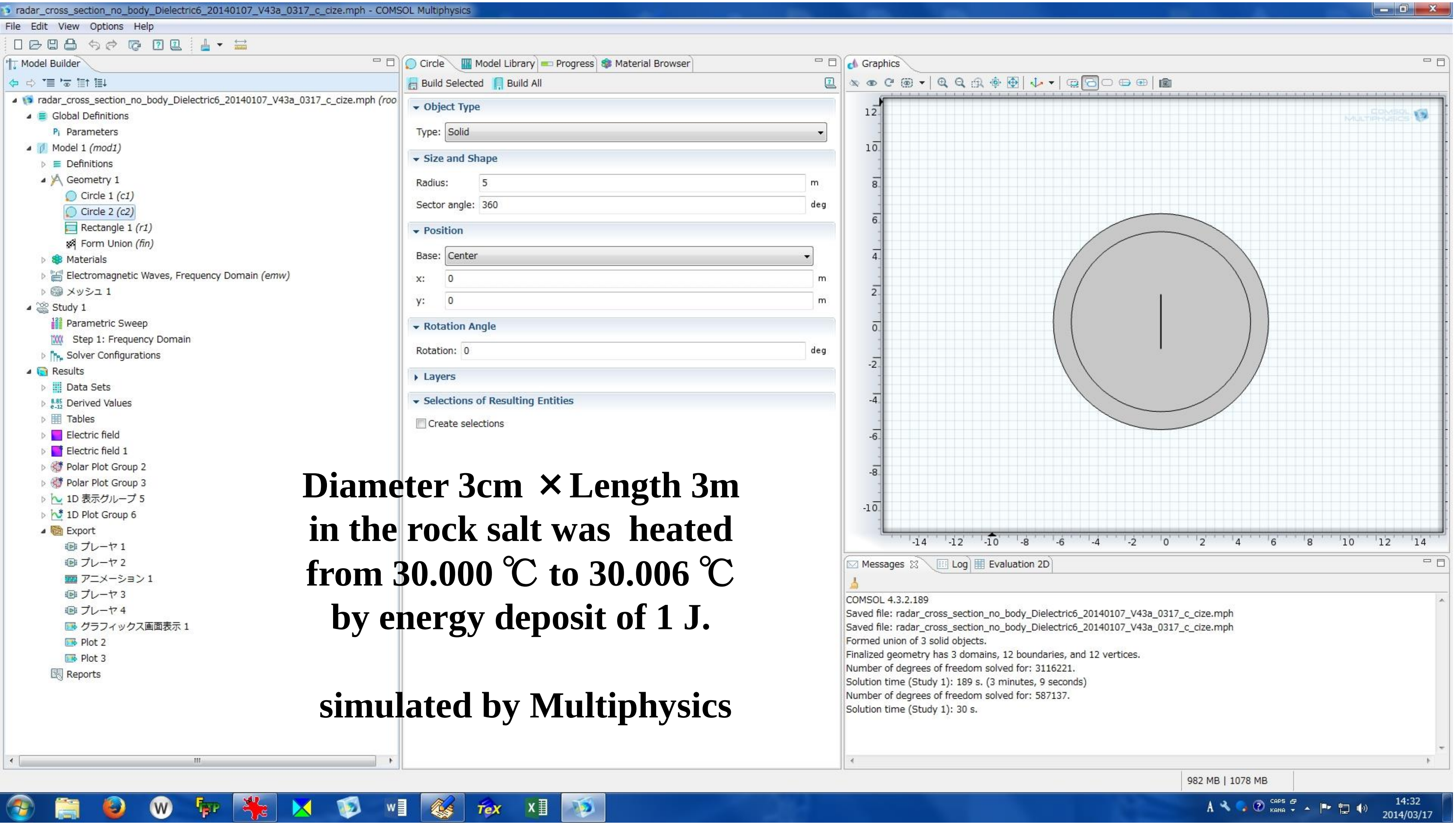
Diameter 3cm ×Length 3m in the rock salt was heated from 30.000 ℃ to 30.006 ℃ by energy deposit of 1 J.

simulated by Multiphysics

Preliminary



Radio wave reflection from heated rod in rock salt



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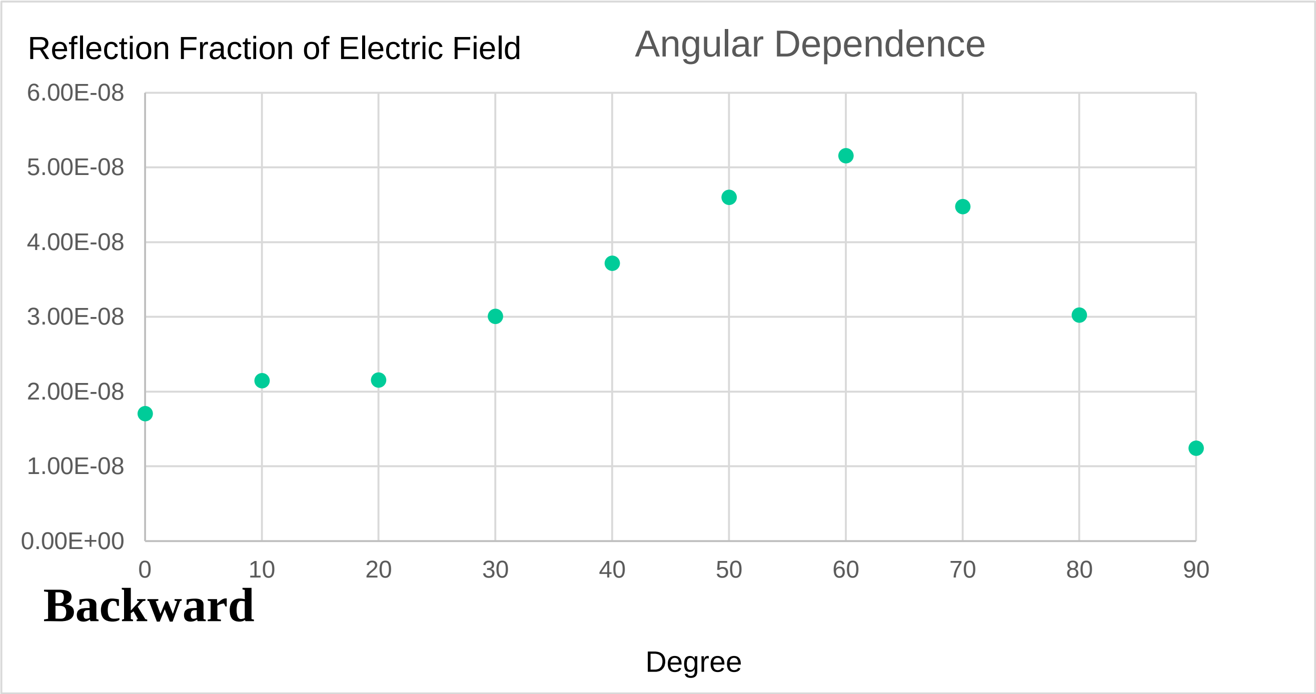
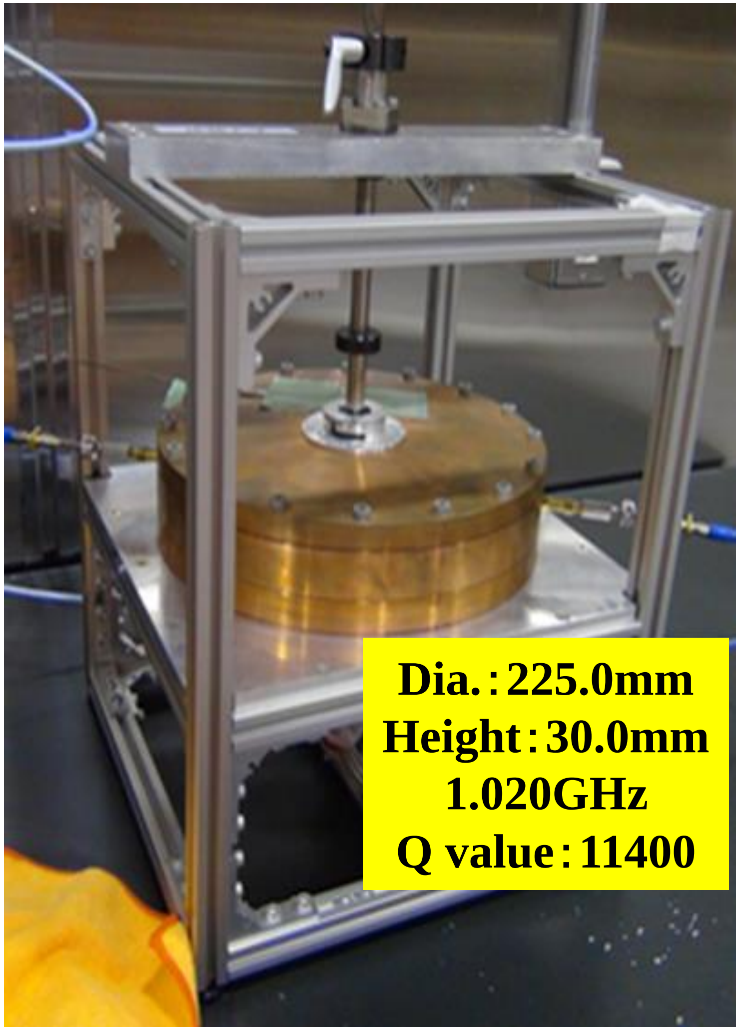
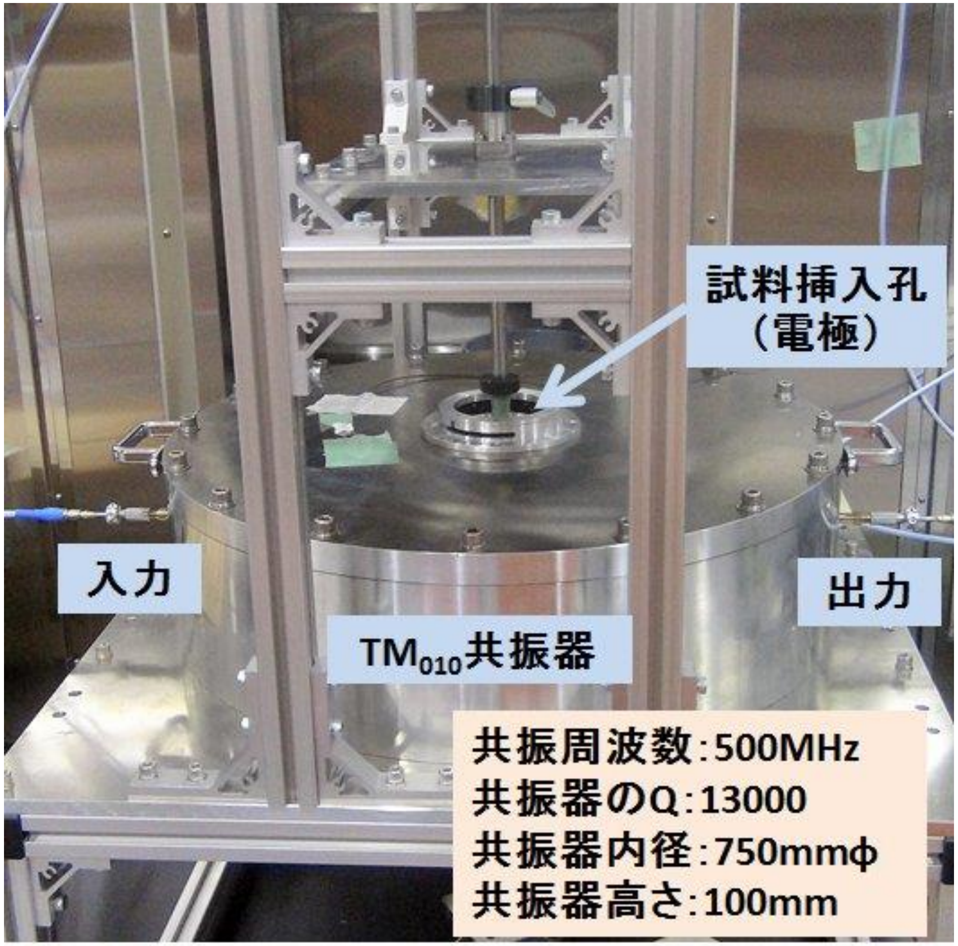
simulated by Multiphysics

Preliminary



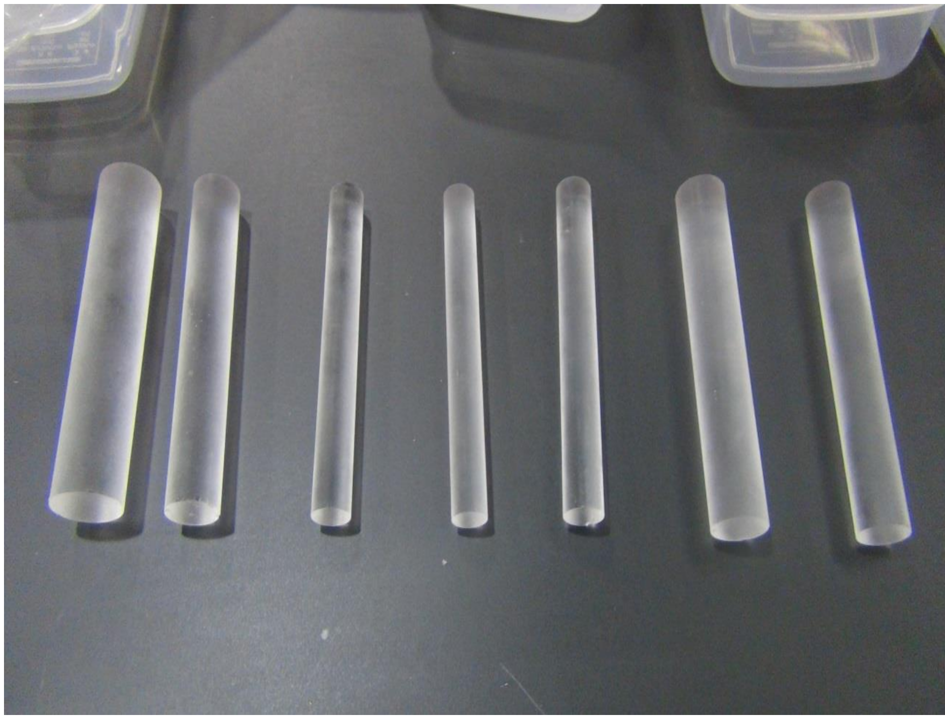
UHF Perterbation Resonance Cavity with plug at -30℃

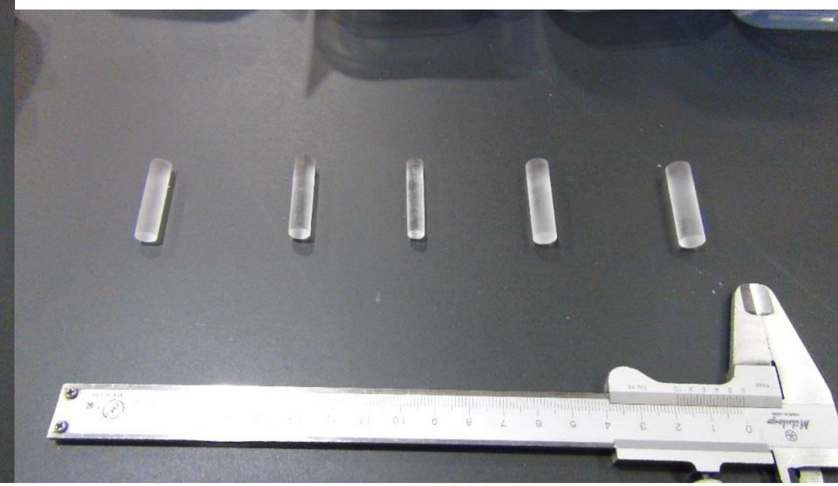




National Institute of Polar Research

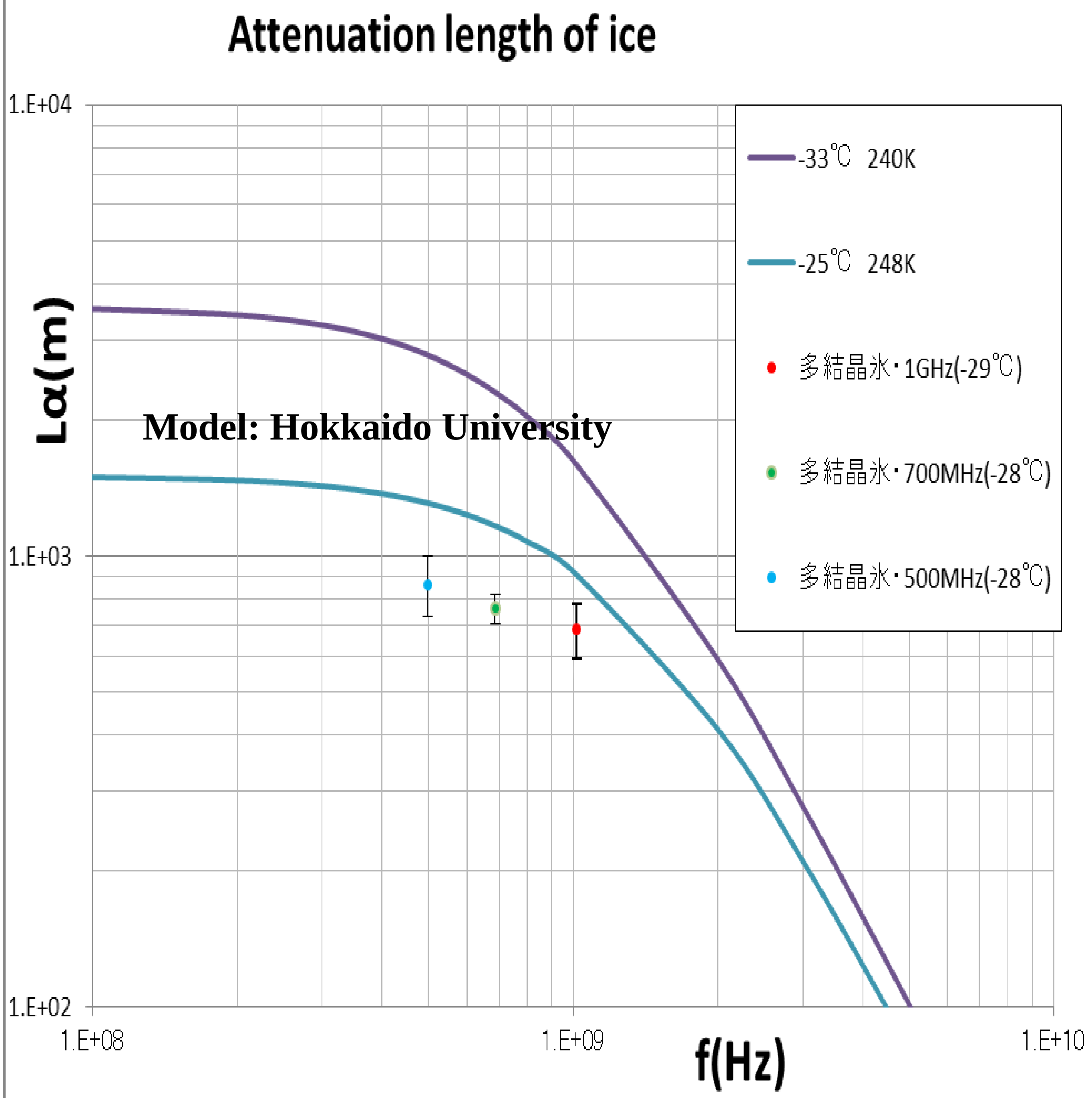
Ice samples made from pure water



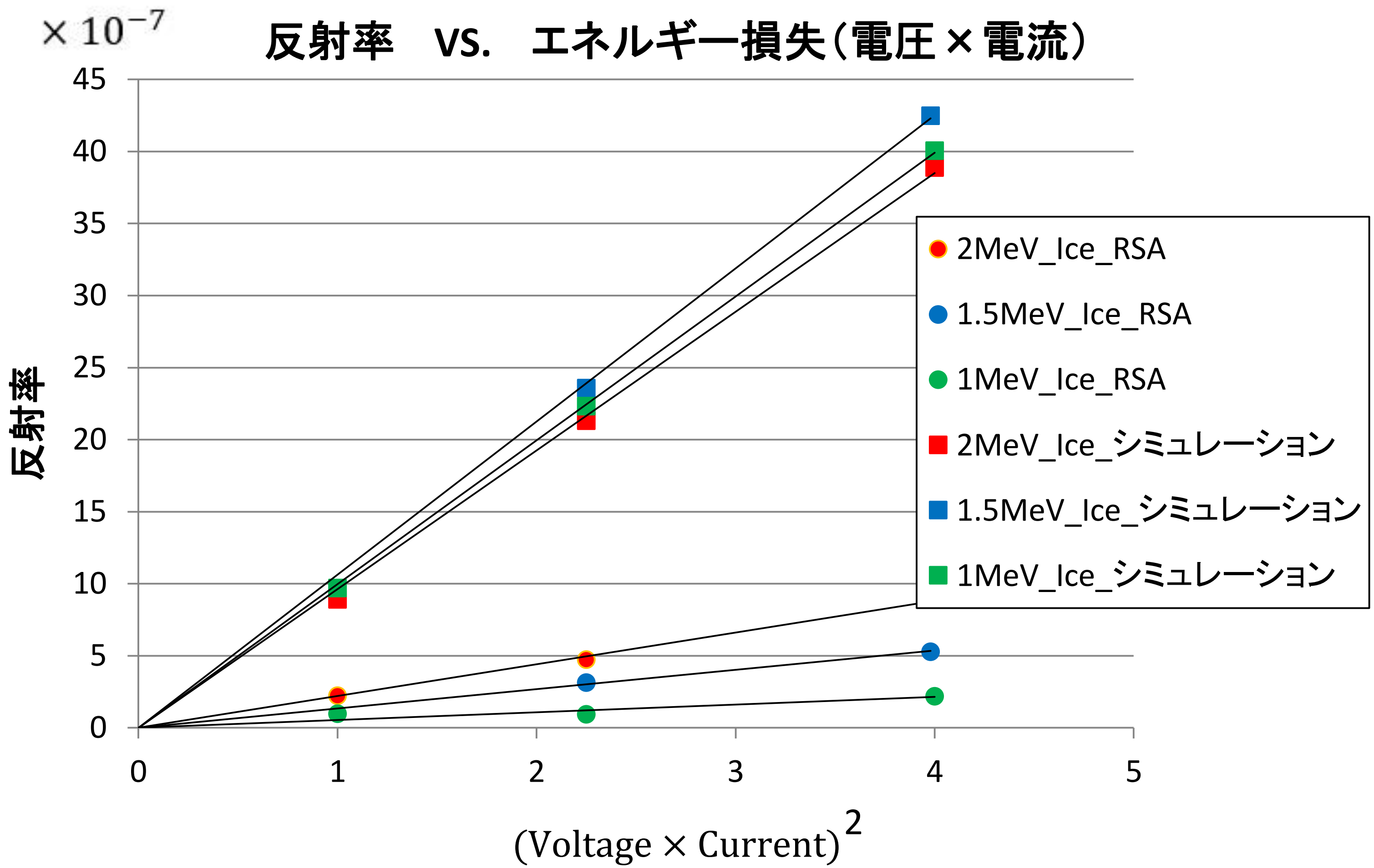


500MHz・700MHz cavity
（10～25mmφ、100mm）

cavity
（5～8mmφ、30mm）



Attenuation length of ice
1.E+04
1.E+03
1.E+02
Lα(m)
Model: Hokkaido University
1.E+08
1.E+09
1.E+10
f(Hz)
-33℃ 240K
-25℃ 248K
多結晶氷・1GHz(-29℃)
多結晶氷・700MHz(-28℃)
多結晶氷・500MHz(-28℃)



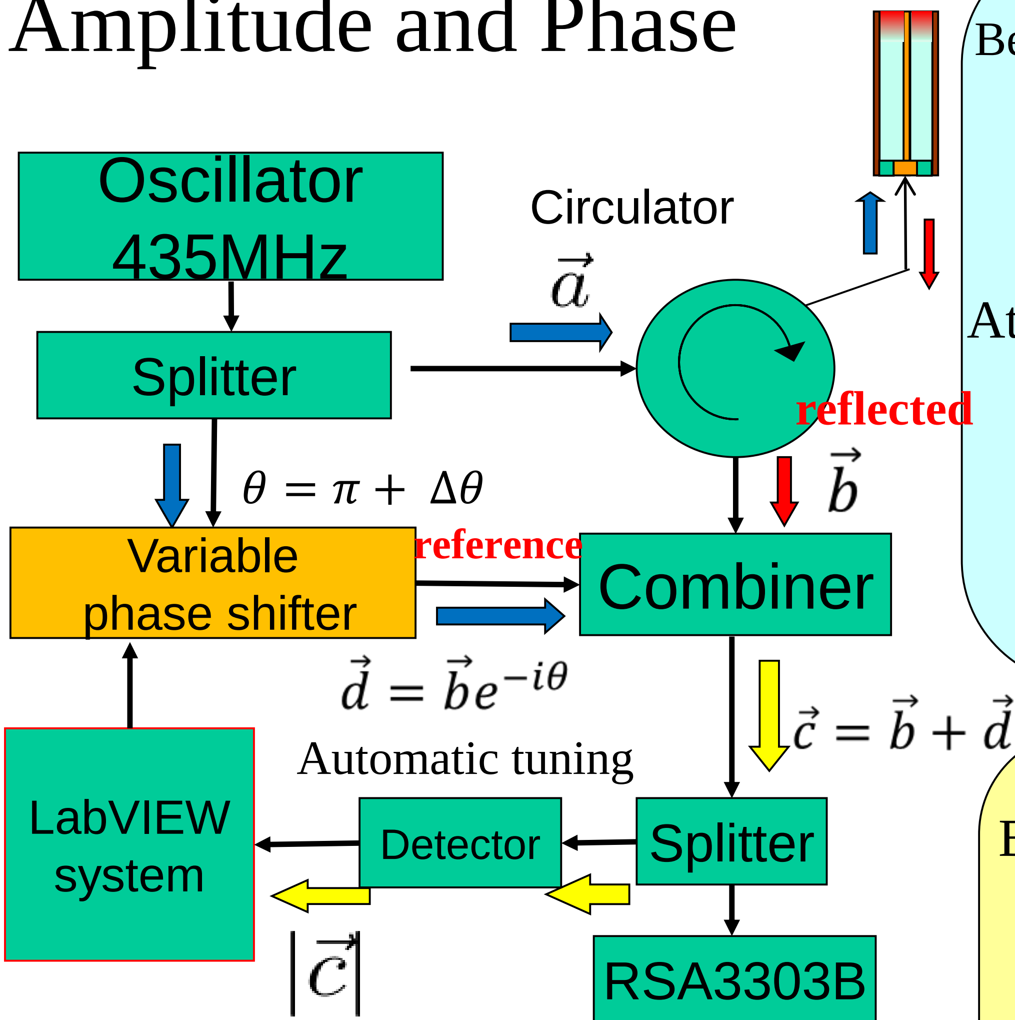
Fresnel equatior $\Gamma = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2}$ $\rightarrow \propto (\Delta n)^2$

Refractive Index ∝ Temperature Increase

Temperature Increase ∝ Energy Deposit

Reflection Fraction in Energy ∝ Squre of Energy Deposit

Amplitude and Phase



Due to open end of coaxial tube

$|\vec{a}| \,/\, |\vec{b}| = 1$

Amplitude measurement

Before irradiation: automatic tuning of θ is ON

$\vec{c} = \vec{b}e^{-i\theta} + \vec{b}$

reference reflected wave

$\theta = \pi \qquad |\vec{c}|^2 = 0$

At irradiation: automatic tuning OFF

$\vec{c} = \vec{b}e^{-i\pi} + \vec{b}e^{-i\Delta\varphi}$

reference reflected wave

$\vec{c} = \vec{b}(e^{-i\Delta\varphi} - 1)$

$|\vec{c}|^2 = 2\,|\vec{b}|^2\{1 - \cos(\Delta\varphi)\}$

Phase measurement

Before and at irradiation:

automatic tuning ON

Tuned $\Delta\theta$ is recorded

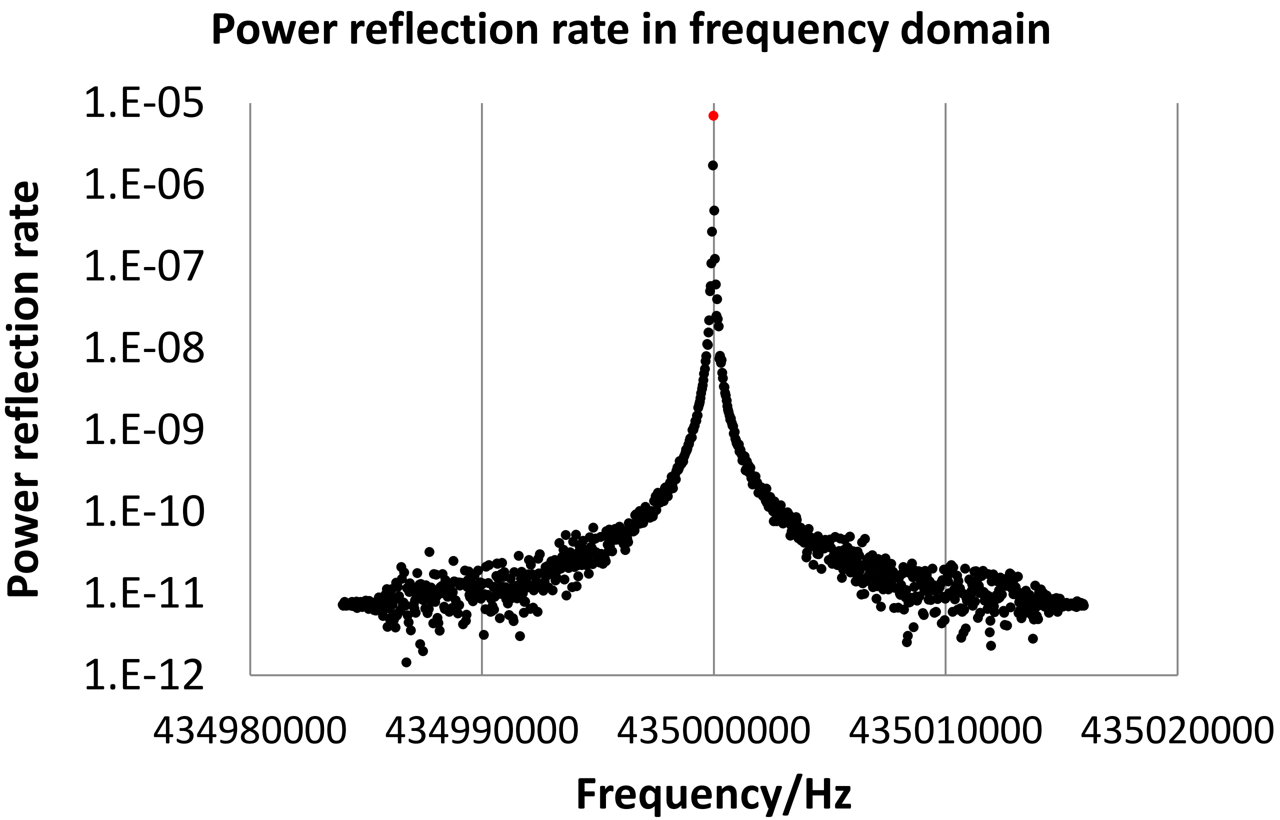
$\vec{c} = \vec{b}e^{-i(\pi+\Delta\theta)} + \vec{b}e^{-i\Delta\phi} = 0$

Reference Reflected wave

$\Delta\theta = \Delta\phi$ then $\Delta\phi$ Is measured

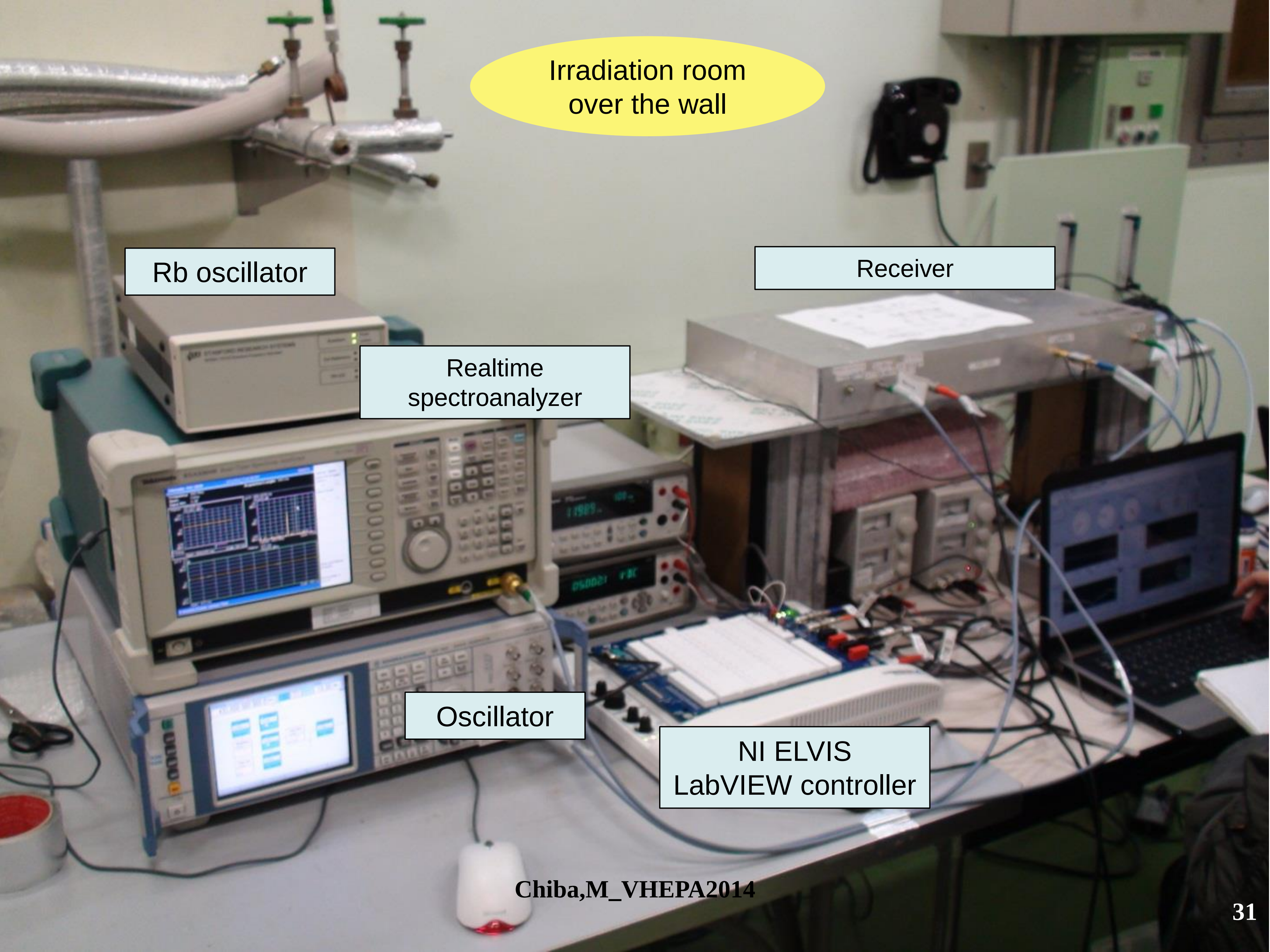
Frequency domain spectrum

- Rejection of noises from electric power source of 50 Hz.

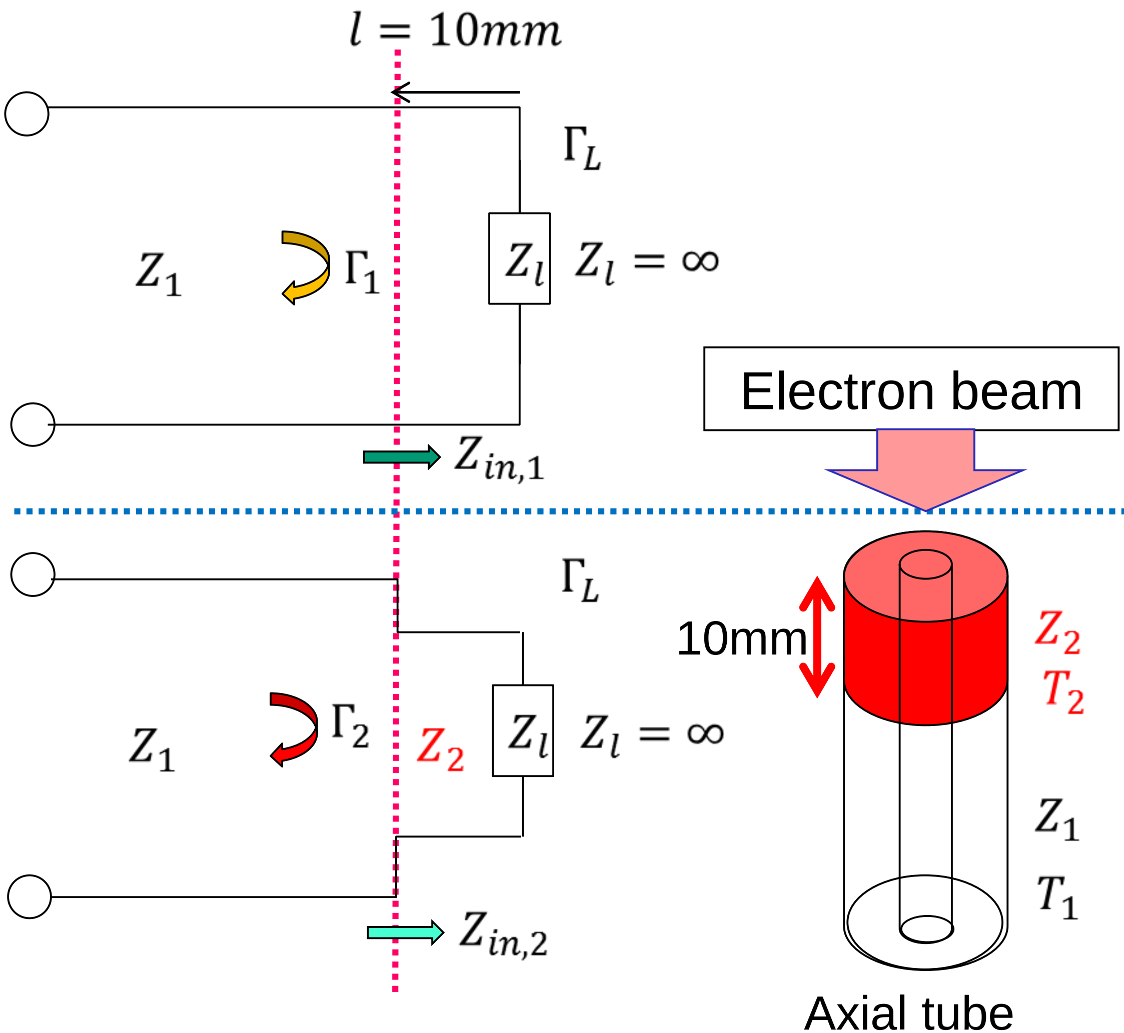


Data analysis of Real Time Spectrometer

- Time domain data of 1024points×5 for 640 ms
- 1 datum for 128ms
- Conversion of time domain to frequency domain by FFT


Irradiation room
over the wall
Rb oscillator
Receiver
Realtime
spectroanalyzer
Oscillator
NI ELVIS
LabVIEW controller

Calculation of phase difference of reflected wave by a model (based on Telegrapher's equation)



$$\Gamma_L = \frac{Z_L - Z_1}{Z_L + Z_1} = 1 \ (\because Z_L = \infty)$$

$$\beta_1 = \frac{2\pi}{\lambda}\sqrt{\varepsilon_1}$$

$$\varepsilon_1 : T_1 = -60°\text{C}$$

$$\Gamma_1 = \Gamma_L \exp(-j\, 2\beta_1 l)$$

$$Z_{in,1} = Z_1 \frac{1}{j \tan(\beta_1 l)}$$

$$\Gamma_L = \frac{Z_L - Z_2}{Z_L + Z_2} = 1 \ (\because Z_L = \infty)$$

$$\beta_2 = \frac{2\pi}{\lambda}\sqrt{\varepsilon_2}$$

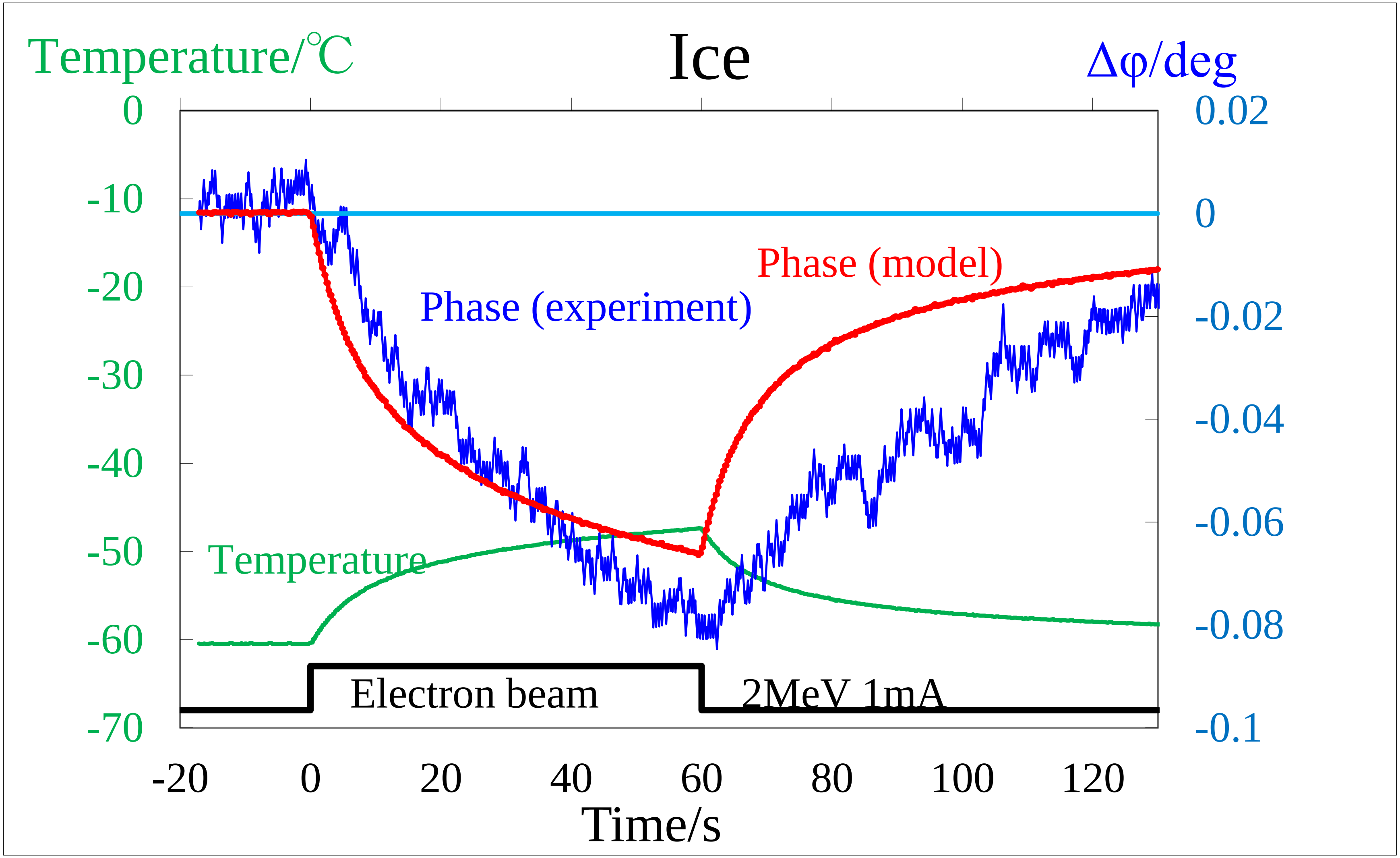
$$\varepsilon_1 : \text{T} = T_2$$

$$Z_{in,2} = Z_2 \frac{Z_L + j\, Z_2 \tan(\beta_2 l)}{Z_2 + j\, Z_L \tan(\beta_2 l)} = Z_2 \frac{1}{j \tan(\beta_2 l)}$$

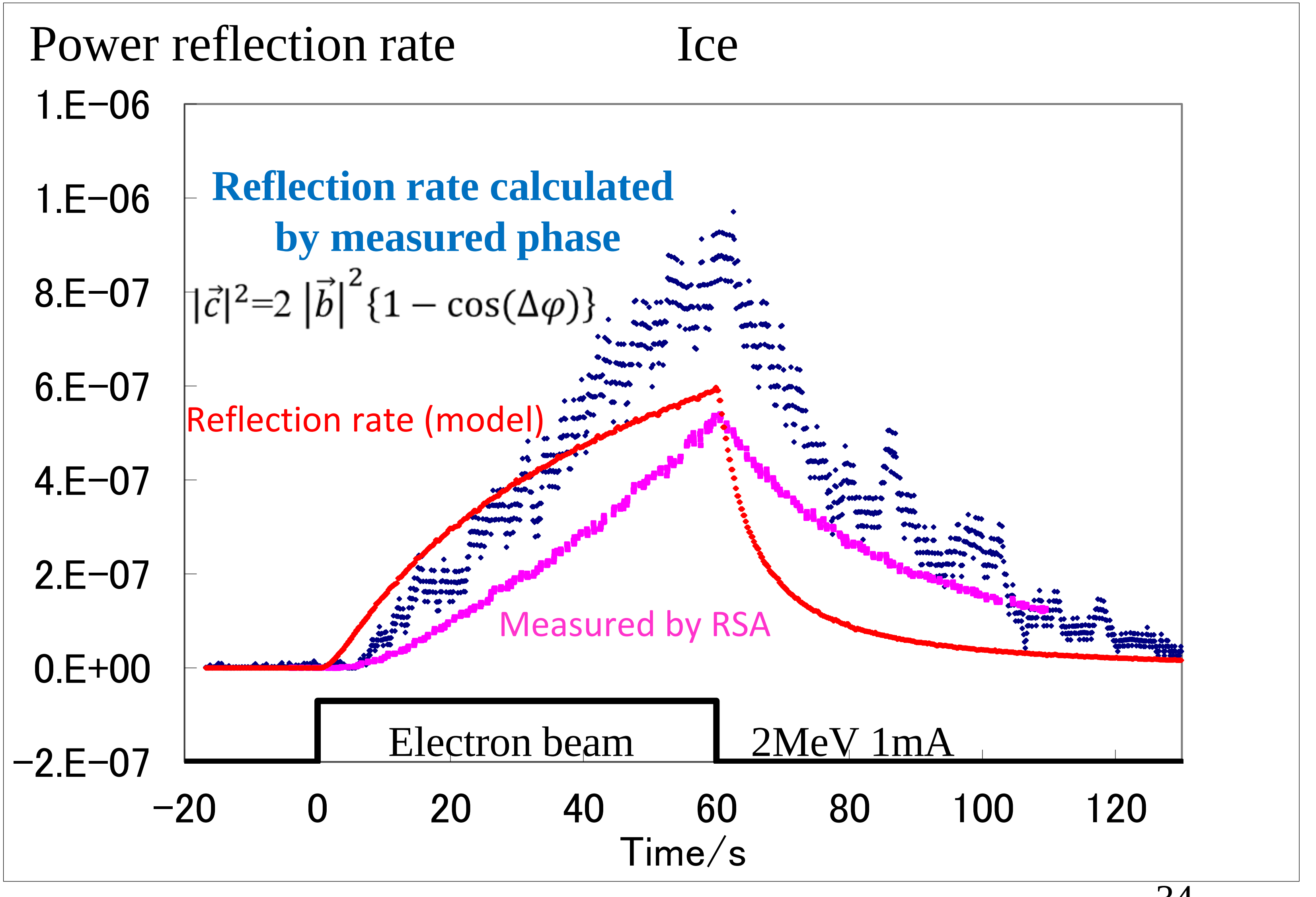
$$\Gamma_2 = \frac{Z_{in} - Z_1}{Z_{in} + Z_1}$$

Phase difference Δφ between Γ1 and Γ2

Comparison of phases between experiment and calculation



Reflection rate calculated by measured phase



Power reflection rate vs. square of temperature