# Mie-Scattering Ellipsometry System for Analysis of Dust Formation Process in a Large Plasma Device

**Yasuaki Hayashi, Masahiro Kawano, Akio Sanpei**

*Kyoto Institute of Technology, Japan*

**Suguru Masuzaki**

*National Institute for Fusion Science, Japan*

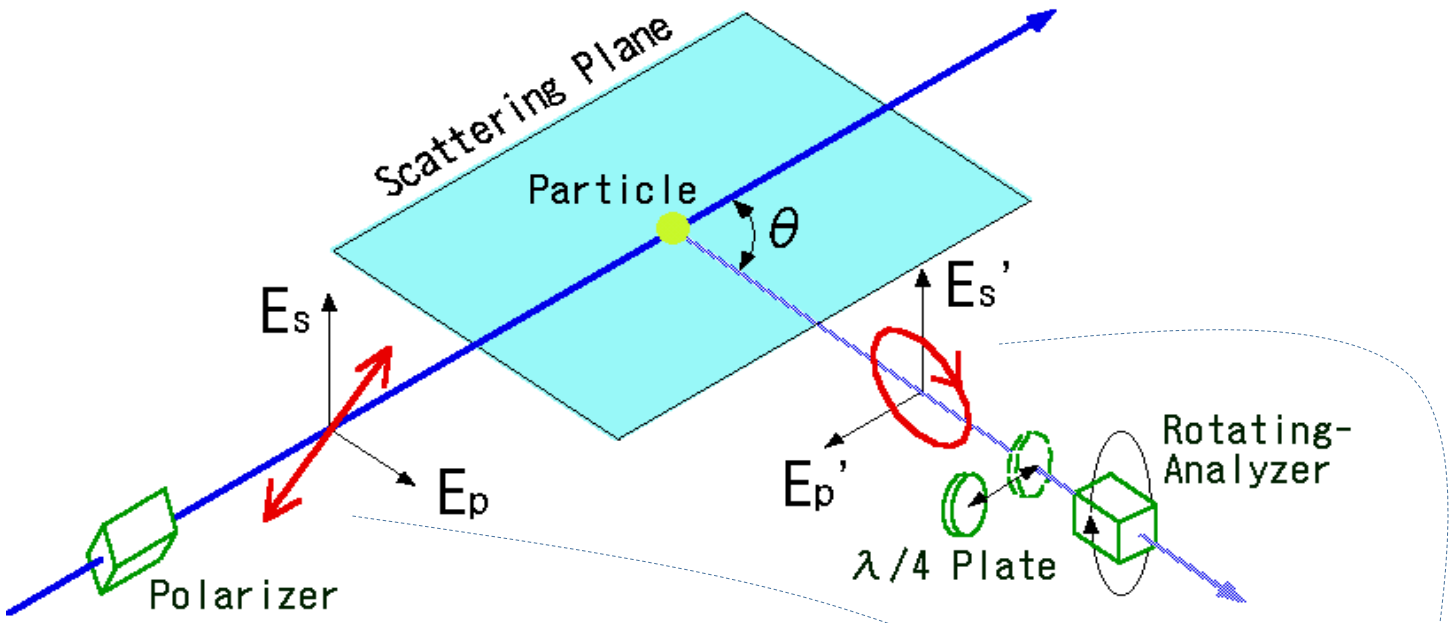
# Purpose of Research

**Dusts generated in a practical nuclear fusion reactor will bring serious problems like sources of core cooling and tritium pollution. *In-situ* measurements and analyses of dust behaviors are important issues to reduce the generation of dusts in such a reactor.**

**Mie-scattering ellipsometry developed for monitoring the growth of fine particles in a processing plasma can be a useful method for the analysis of dust growth and behavior in a nuclear fusion reactor.**

**We are developing a new system of Mie-scattering ellipsometry for the analysis of generation and transport of dusts in a large plasma device like the Large Helical Devise (LHD) at Toki in Japan.**

# Measurement Principles of Mie-Scattering Ellipsometry

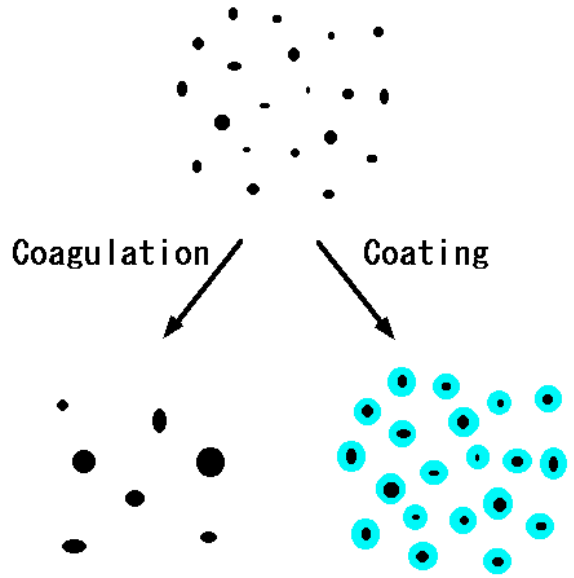



$$\tan\Psi \cdot e^{i\Delta} = \frac{Sp}{Ss} = \frac{Ep'/Ep}{Es'/Es} = \frac{Ep'/Es'}{Ep/Es}$$

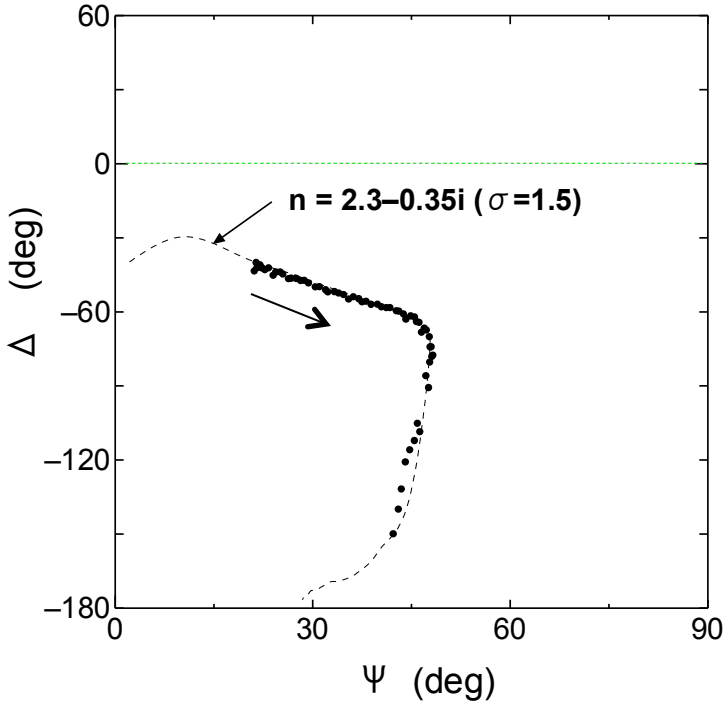
$$I = Ip + Is \propto |Sp|^2 + |Ss|^2$$

$$\frac{Ip}{Is} = \frac{|Sp|^2}{|Ss|^2} = |\tan\Psi|^2$$

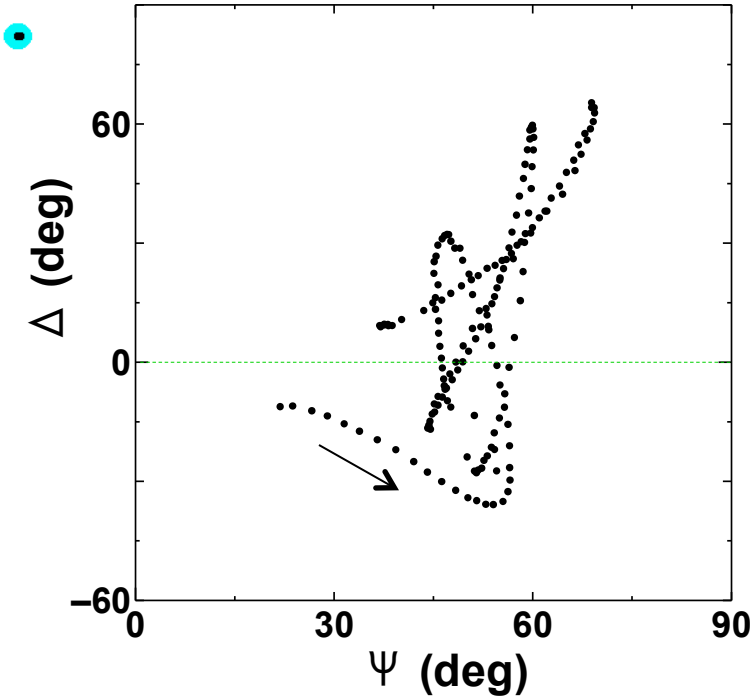
# Different Dust Growth Regimes




## in Ar plasma

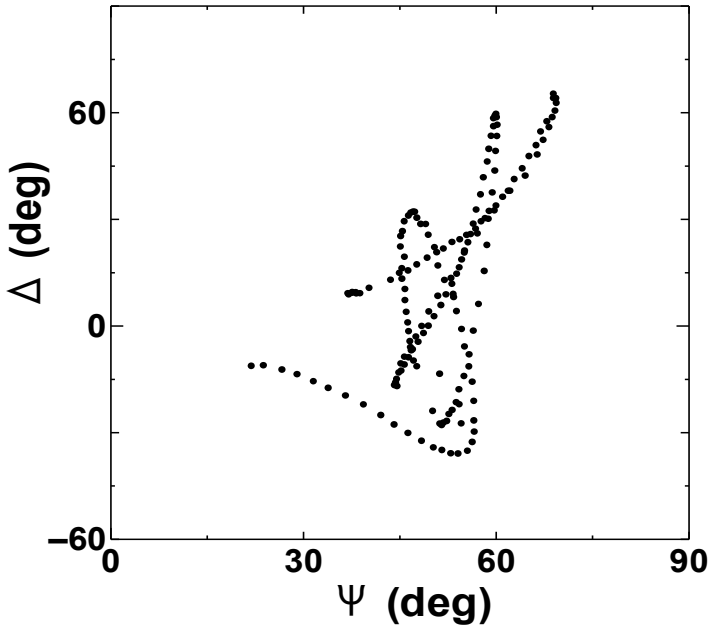


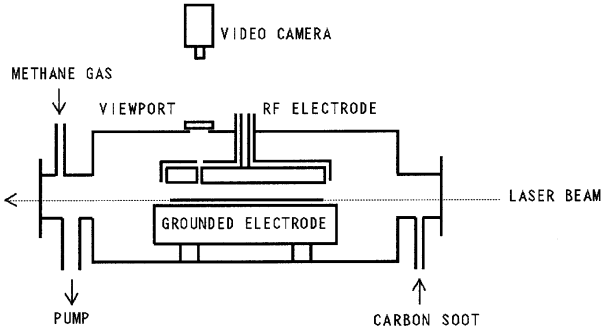

## in $CH_4$ plasma



# Analysis of Dust Growth by Mie-Scattering Ellipsometry

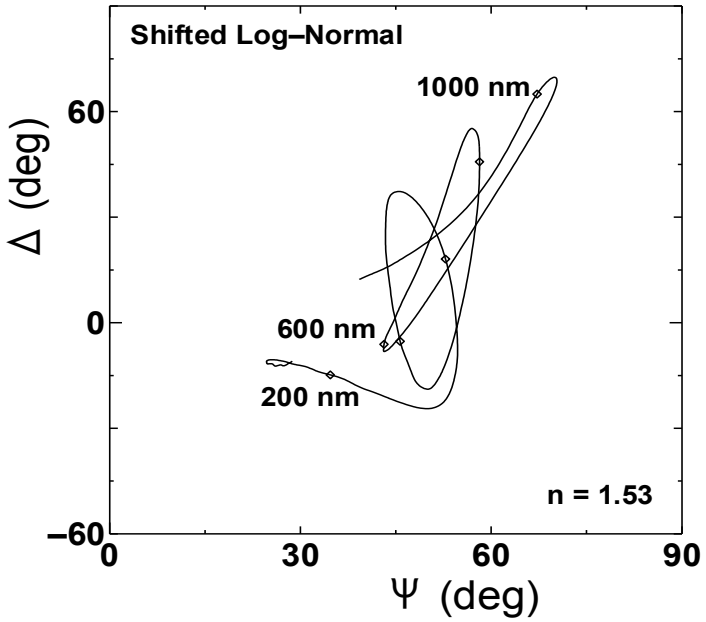
**Experiment**

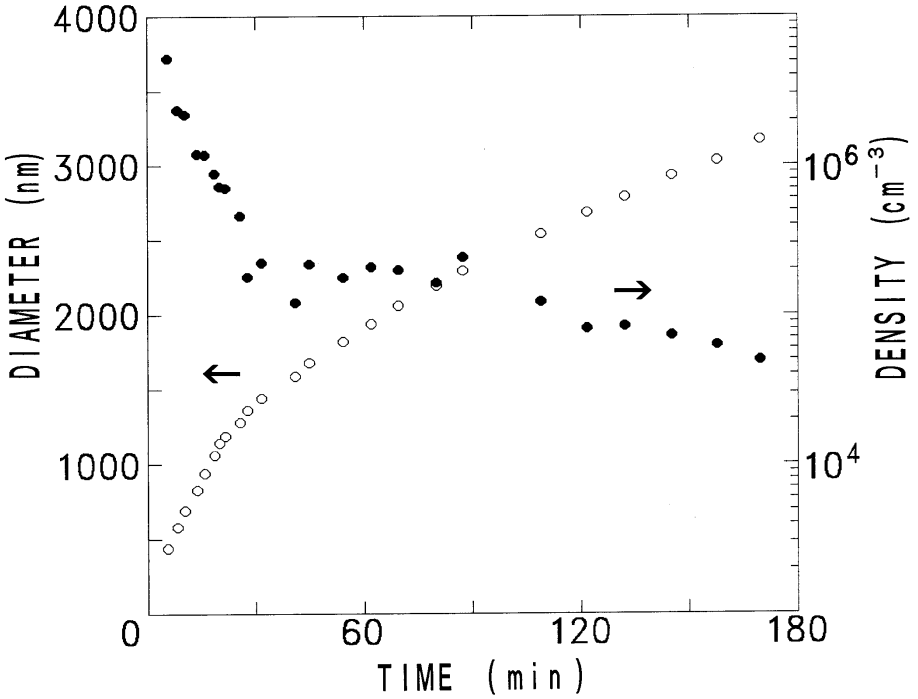


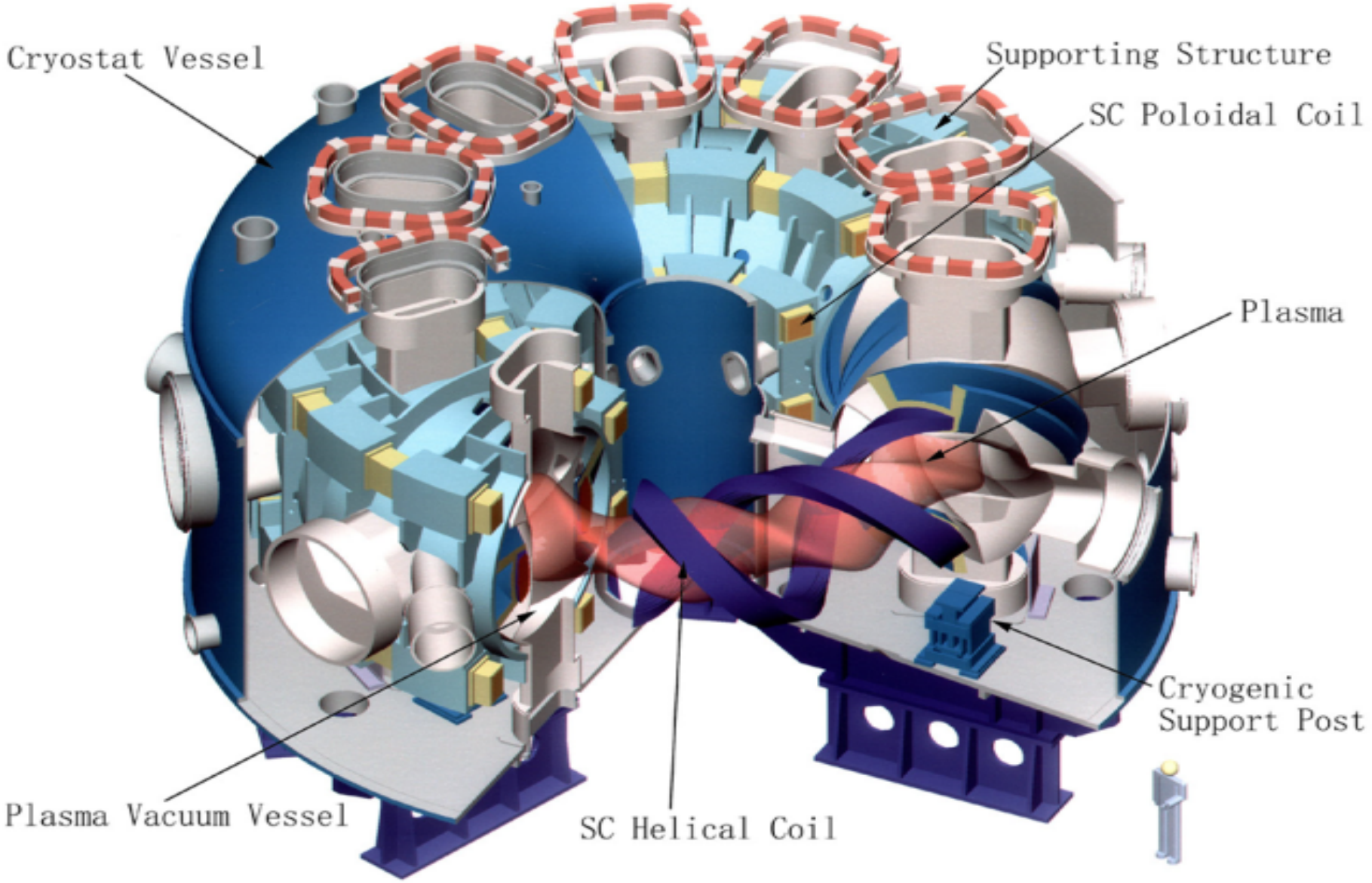

**Carbon coating on fine particles in a methane plasma**

**Simulation**



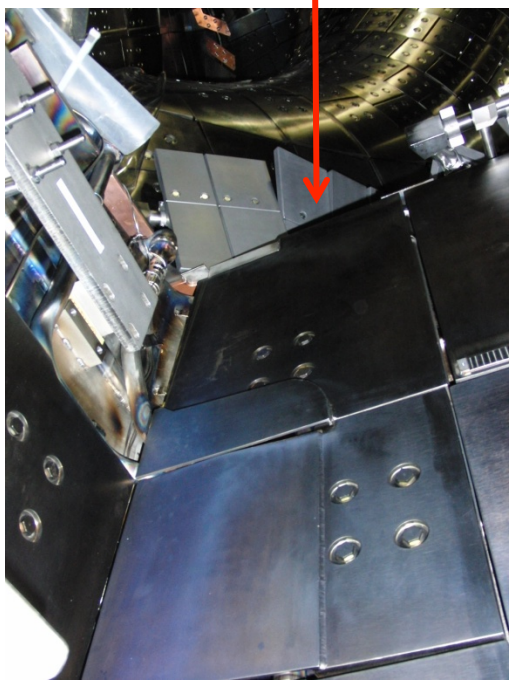
# Large Helical Device at NIFS in Japan



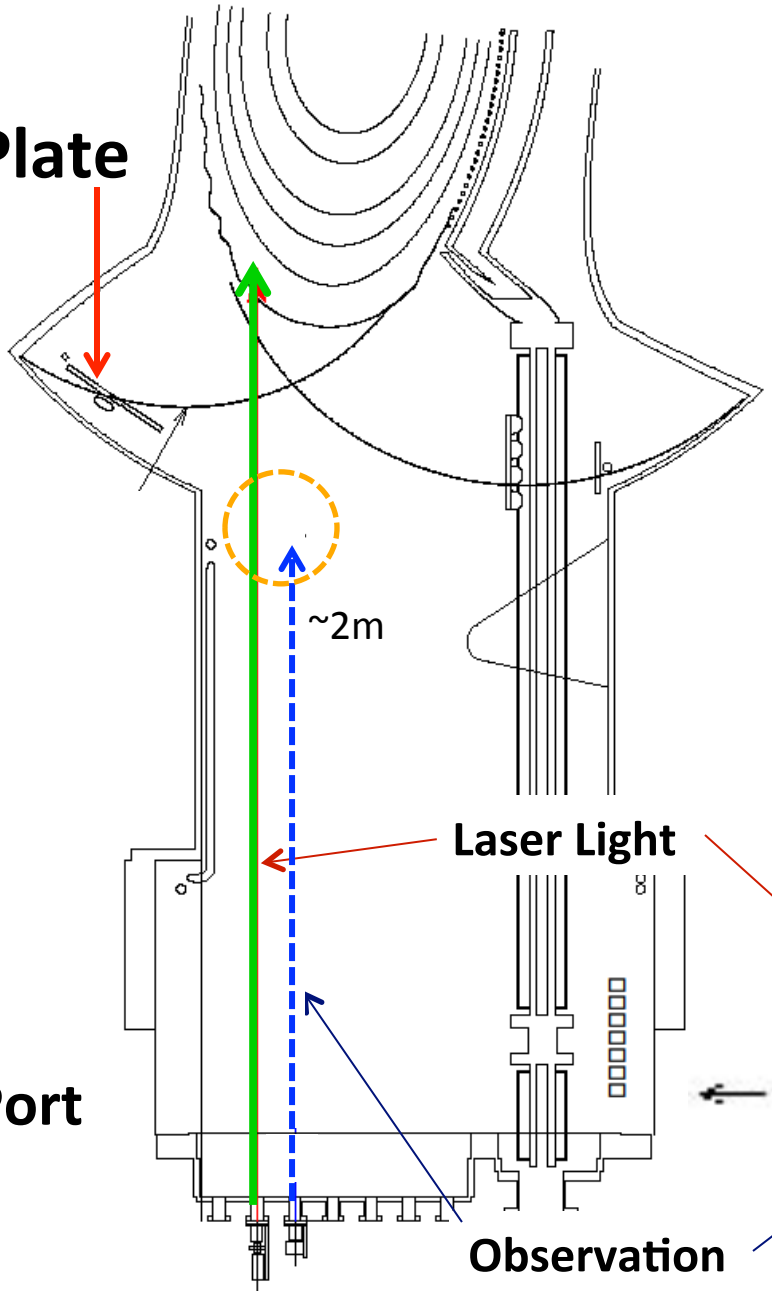

in National Institute for Fusion Science

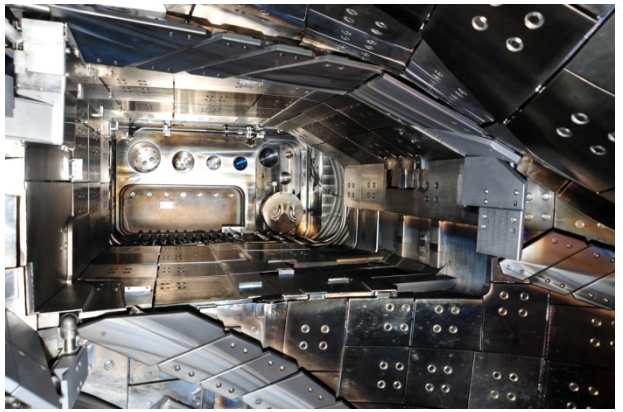
# Observation of Dusts around Diverter in LHD

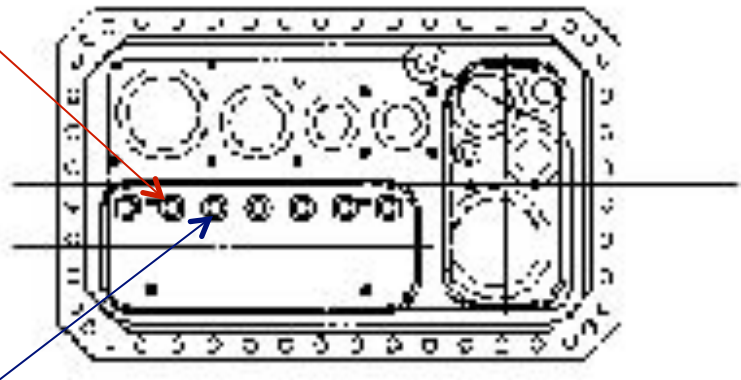
Diverter Plate



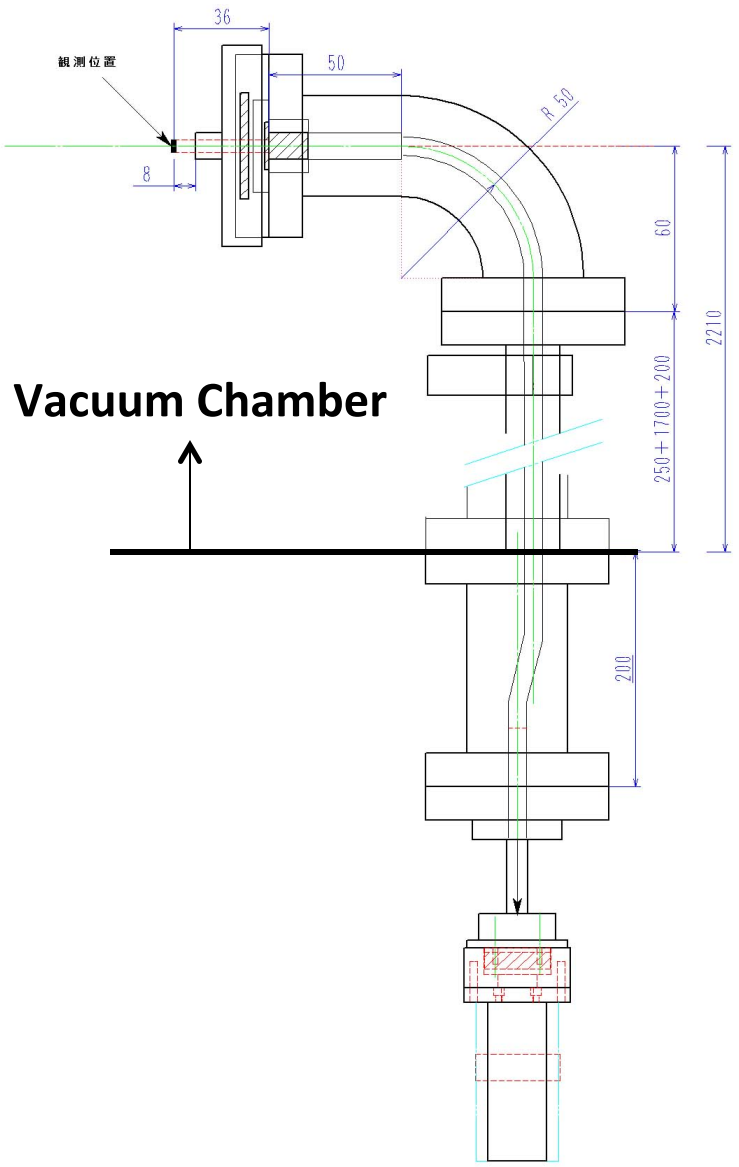
4.5-L Port

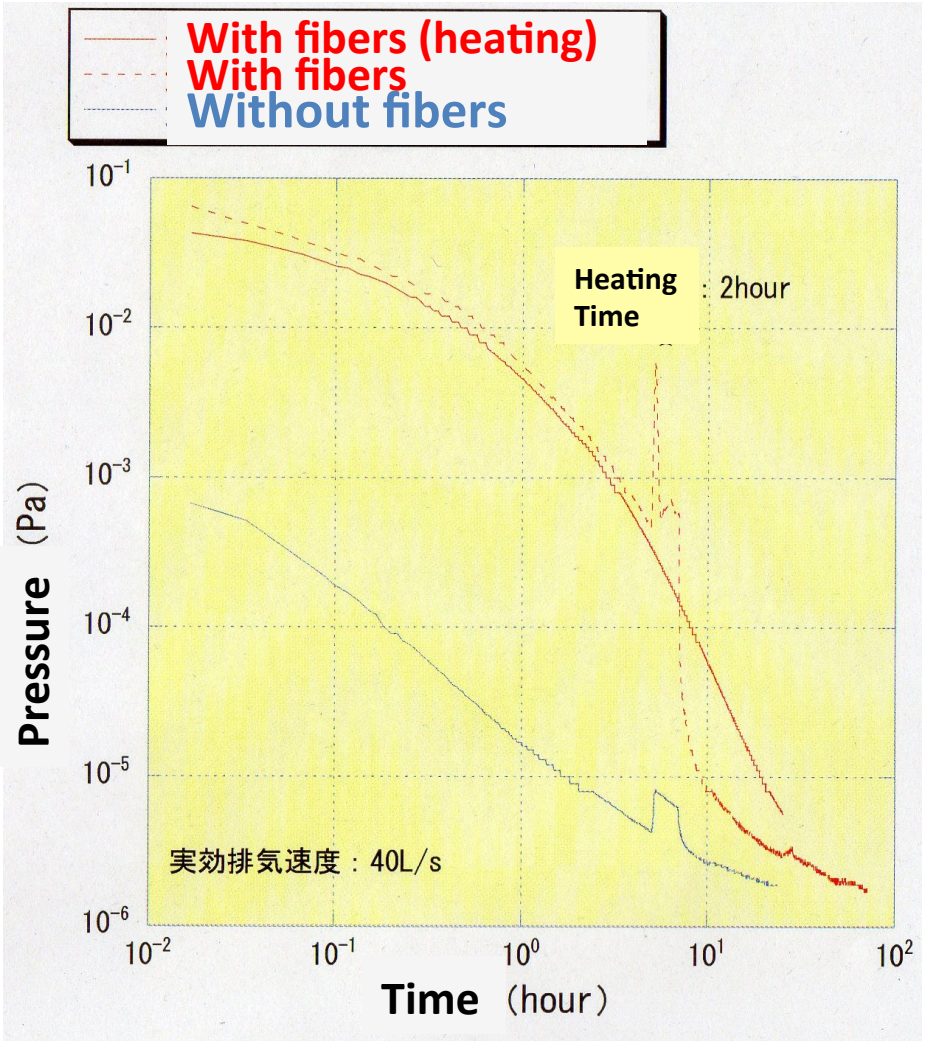


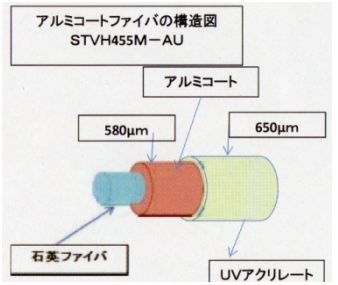





# Problem of Use of Optical Fibers in LHD

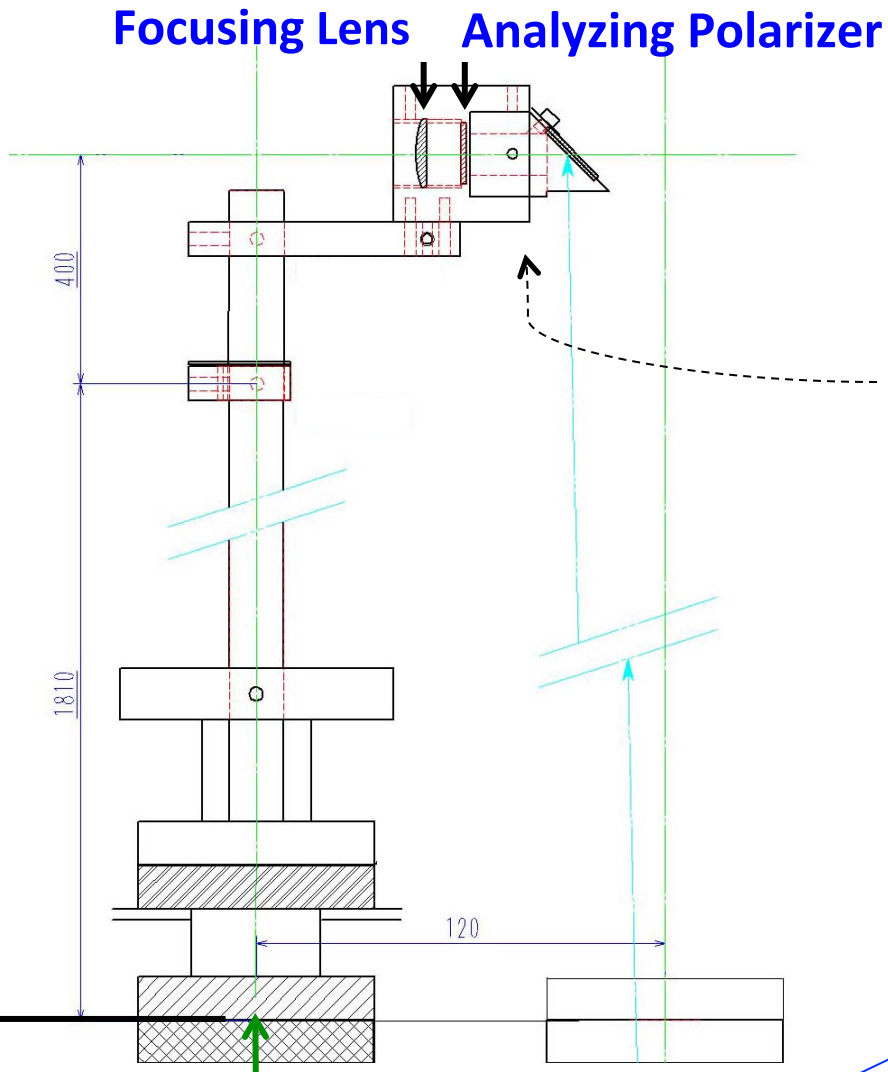


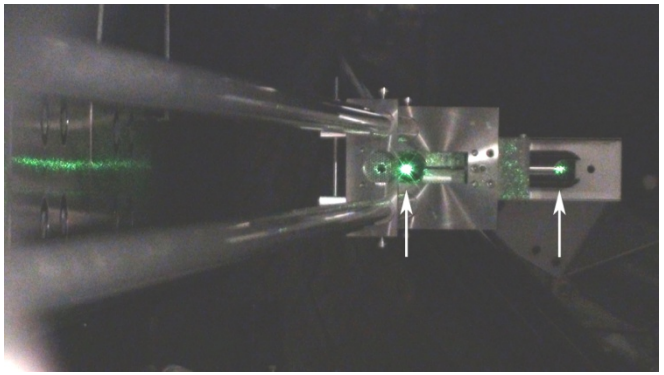



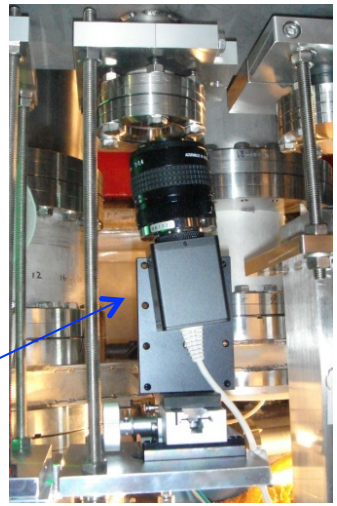




**Optical fibers cannot be used in LHD because of highly outgassing !**

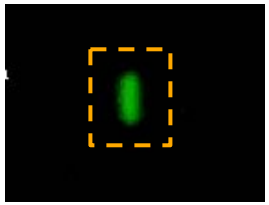
# Ellipsometery Measurement System in LHD



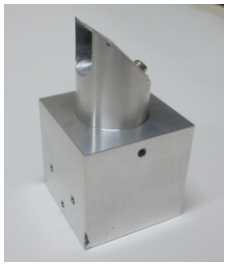



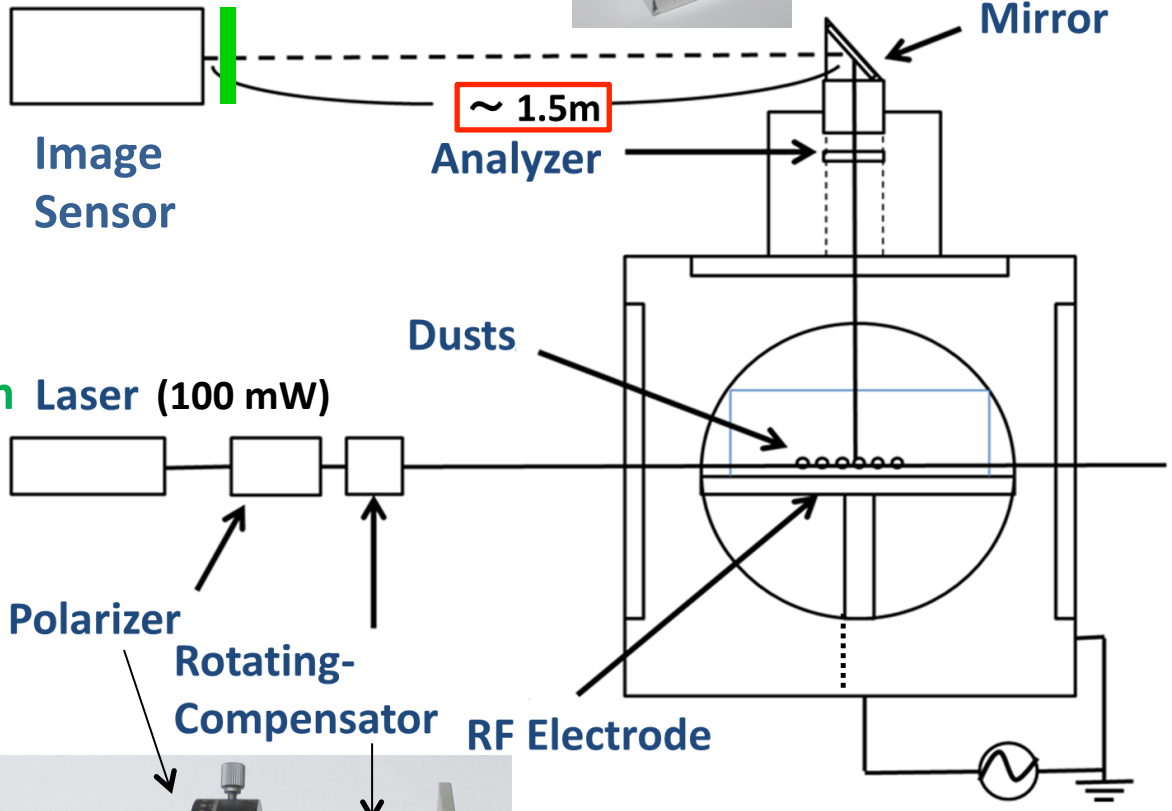


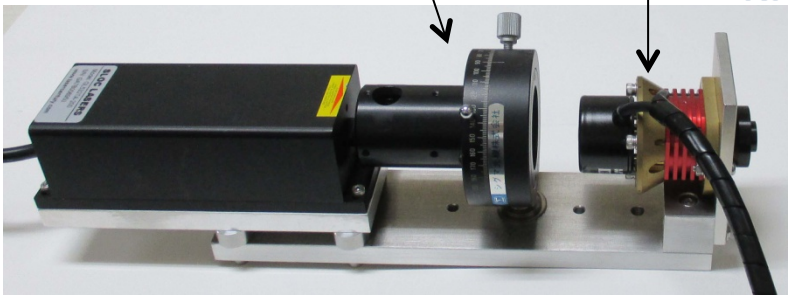
# Preliminary Experiment Using the Ellipsometer



1600 pixels





**Plasma Conditions**

Gas : Ar

Pressure : 50 Pa

RF Power : 10 W

**Dust Properties**

Material :

Divinylbenzene Polymer

(Mono-disperse and Spherical)

Size : 2.27±0.1 μm

Particle number (for measurement) :

3,000 ~ 5,000

# Ψ-⊿ Determination by Rotating-Compensator Ellipsometer

**Light Intensity Variation**

$$I(C) = A_0 + A_2 \cos 2C + B_2 \sin 2C + A_4 \cos 4C + B_4 \sin 4C$$

(C : Compensator azimuth)

for P=0°, A=45°

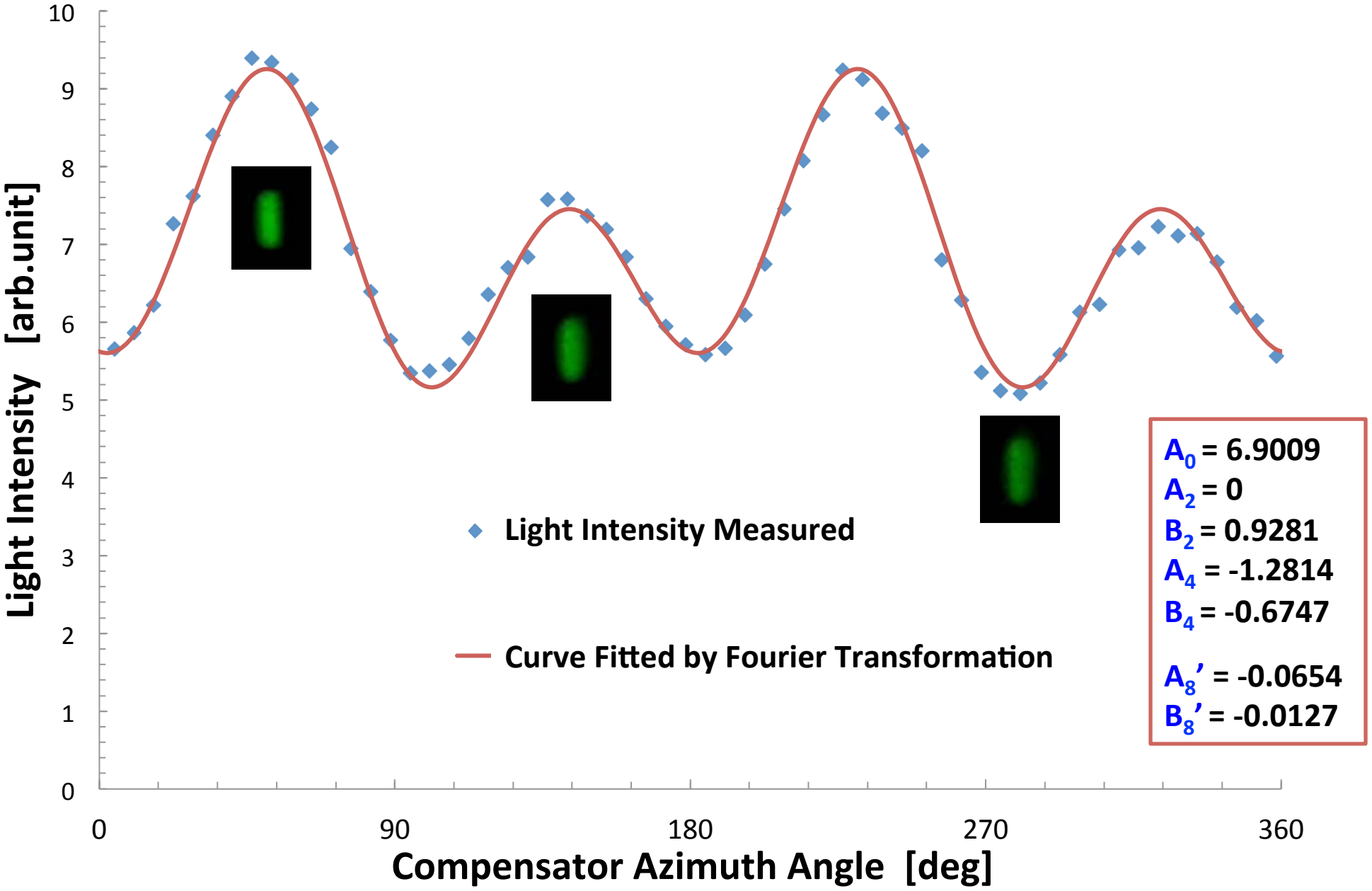
$$A_0 = 2 - \cos 2\Psi$$
$$A_2 = 0$$
$$B_2 = 2 \sin 2\Psi \sin \Delta$$
$$A_4 = -\cos 2\Psi$$
$$B_4 = \sin 2\Psi \cos \Delta$$

→

$$\Psi = -\mathrm{Tan}^{-1}\left[\sqrt{\left(B_4^2 + B_2^2/4\right)} / A_4\right] / 2$$

$$\Delta = \mathrm{Tan}^{-1}\left[B_2 / (2B_4)\right]$$

# Result of Measurement by the Ellipsometry



# Ψ-⊿ Determination from Fourier Coefficients

$A_0' = 6.9009$
$A_2' = -0.5825$
$B_2' = 0.7225$
$A_4' = 0.3876$
$B_4' = -1.3953$

$\delta C = -19.438°$

→

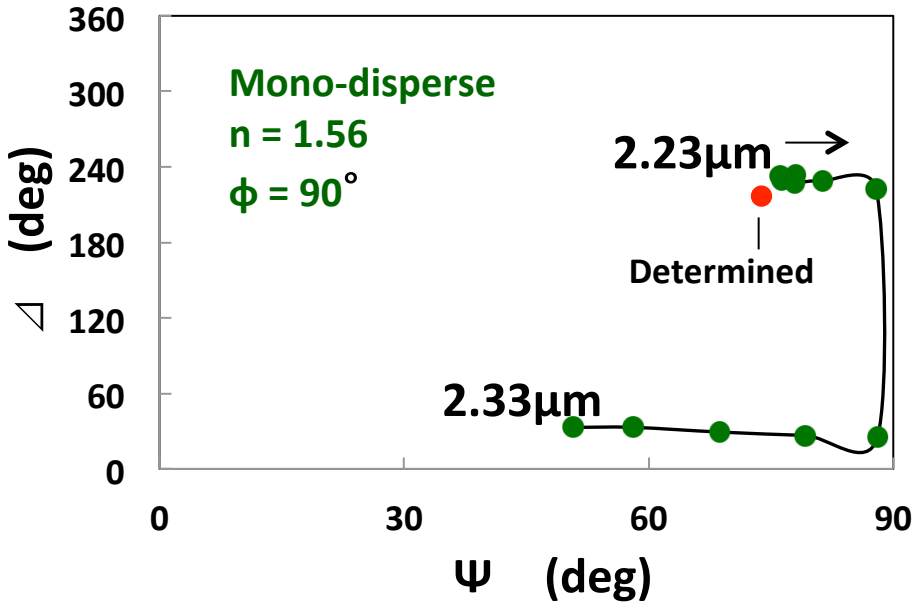
$A_0 = 6.9009$
$A_2 = 0$
$B_2 = 0.9281$
$A_4 = -1.2814$
$B_4 = -0.6747$

→

$\Psi = 73.7°$
$\Delta = 214.5°$

for the measured divinylbenzene polymer fine particles :

n = 1.56 ~ 1.59
d = 2.27 ± 0.1 μm



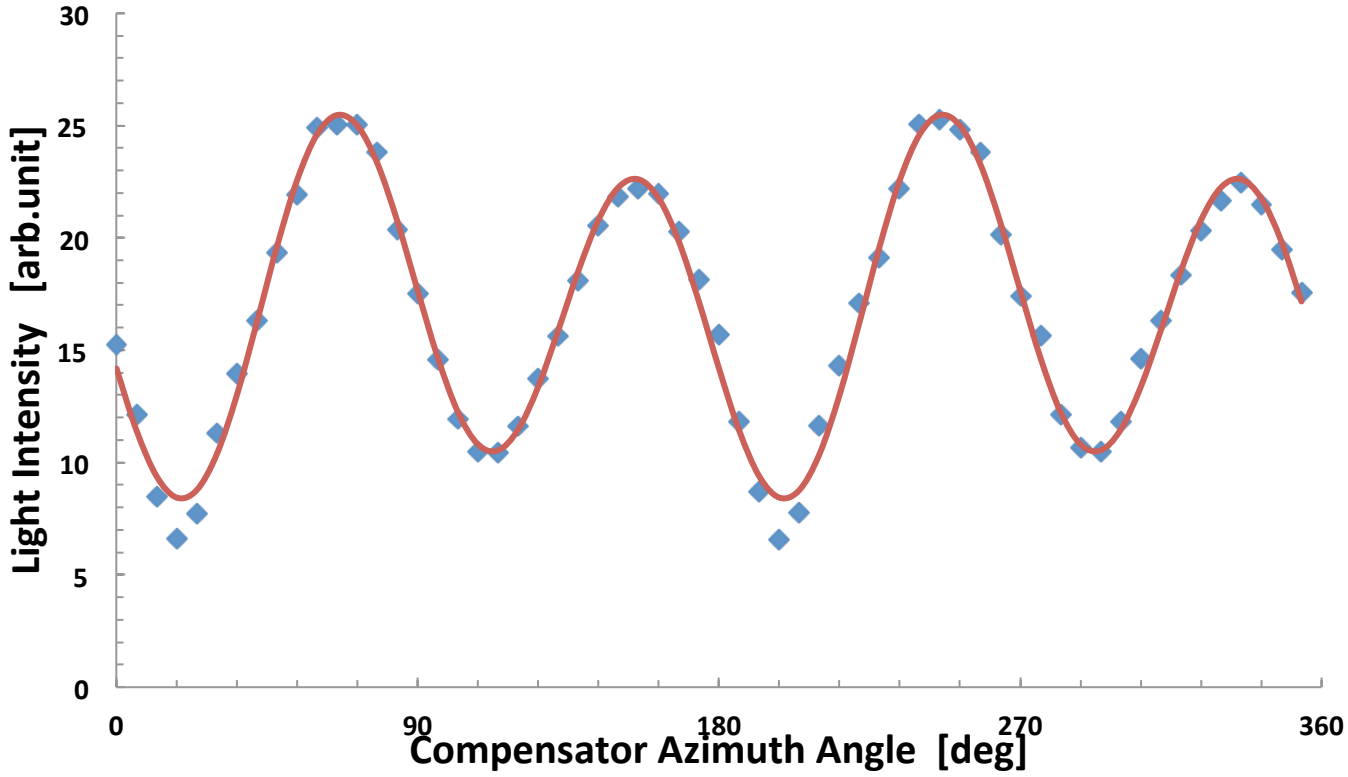
# Summary

- A new system of Mie-scattering ellipsometry was developed for the observation in a large plasma device like the Large Helical Device.

- Ellipsometric parameters were determined for monodisperse spherical polymer particles, and their values fairly agreed with calculated ones.

- The developed new ellipsometric system can be used for monitoring of growing dust at a distant position in a large plasma device.

# Ψ－⊿ Determination on Silicon Wafer




$A_0'$ = 16.7574
$A_2'$ = -1.7315
$B_2'$ = 0.36724
$A_4'$ = -0.8296
$B_4'$ = -7.2295

δC = -39.013°

↓

**Ψ = 36.36°**
**⊿ = 172.7°**

## Calculation of Ψ and ⊿ on $SiO_2$/Si

- Complex refractive index of Si at 532 nm ・・・ 4.15 – j 0.04
- Complex refractive index of $SiO_2$ at 532 nm ・・・ 1.46
- Thickness of $SiO_2$ ・・・ 15 nm

at φ (incidence angle) = 45°

↓

**Ψ = 35.23° ⊿ = 172.3°**