Accuracy evaluation of wavefront metrology for high N.A. EUV optics

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Outline

- Review of EUVA Project and EEI
- Relative evaluation of accuracy on EEI
  - Comparison of PDI and LSI -
- Difficulties in LSI
- Absolute evaluation of accuracy on EEI
- Summary

Goal of EUVA project

Goal

Development of the EWMS (EUV Wavefront Metrology System)

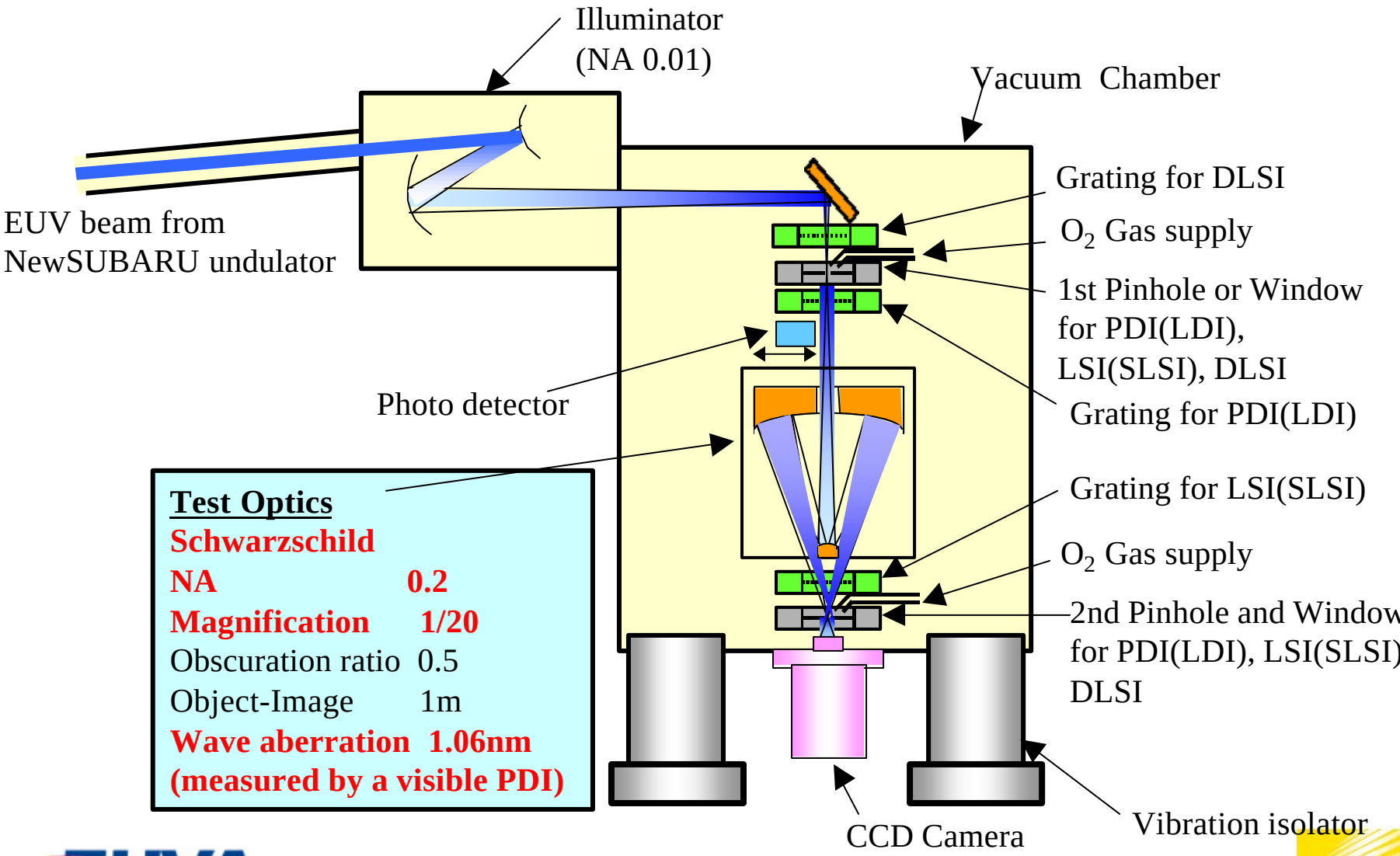
Accuracy = 0.1 nm rms

Test optics = 6-aspheric-mirror projection optics (NA0.25, M=1/4)

Schedule

2002-2003	**Basic research**
2004-2005	**EEI (EUV Experimental Interferometer)**
	Target = Schwarzschild Optics (NA0.20, M=1/20)
2005-2006/3	**EWMS (EUV Wavefront Metrology System)**
	Target = 6-mirror P.O. (NA0.25, M=1/4)

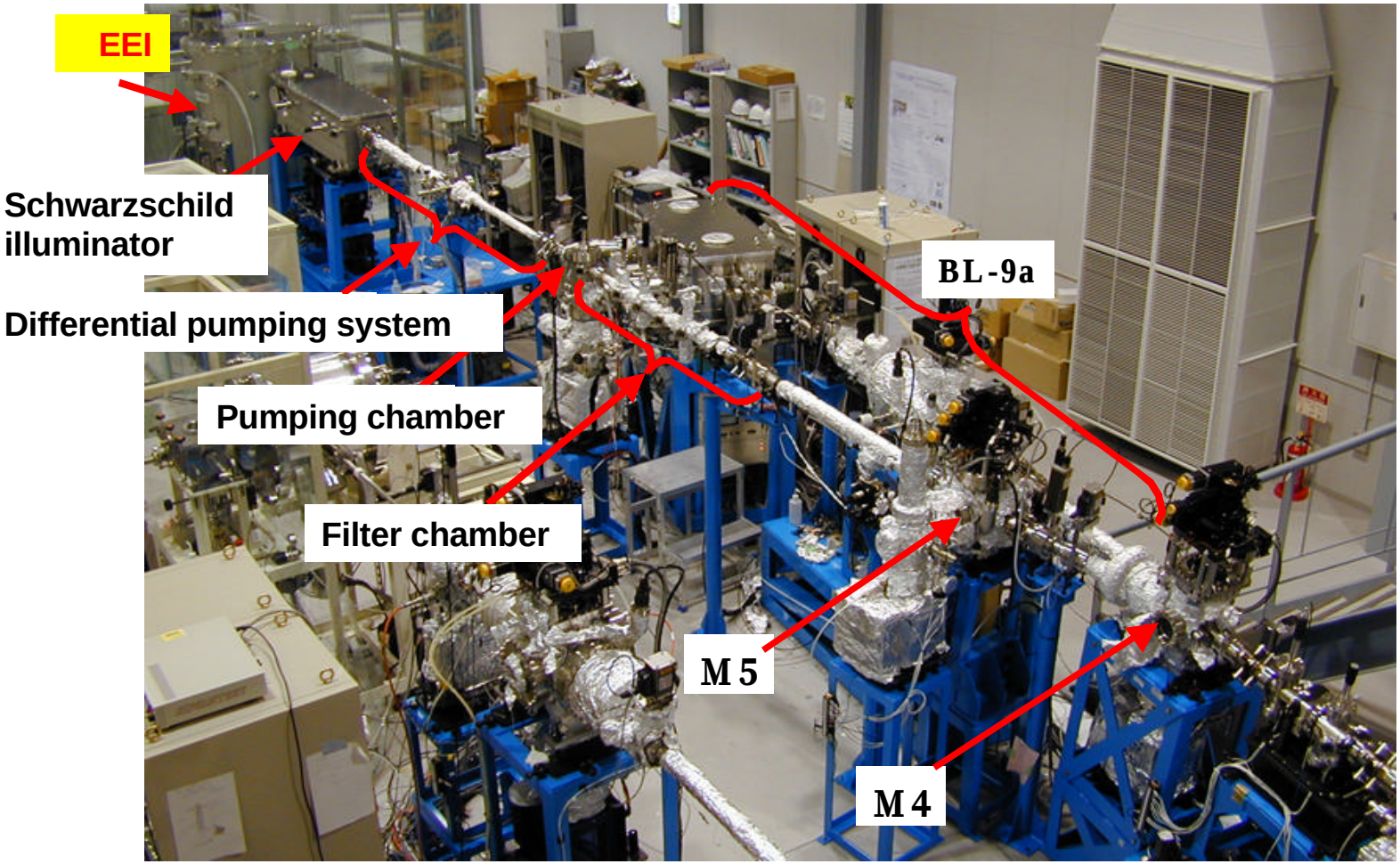
Concept of EEI



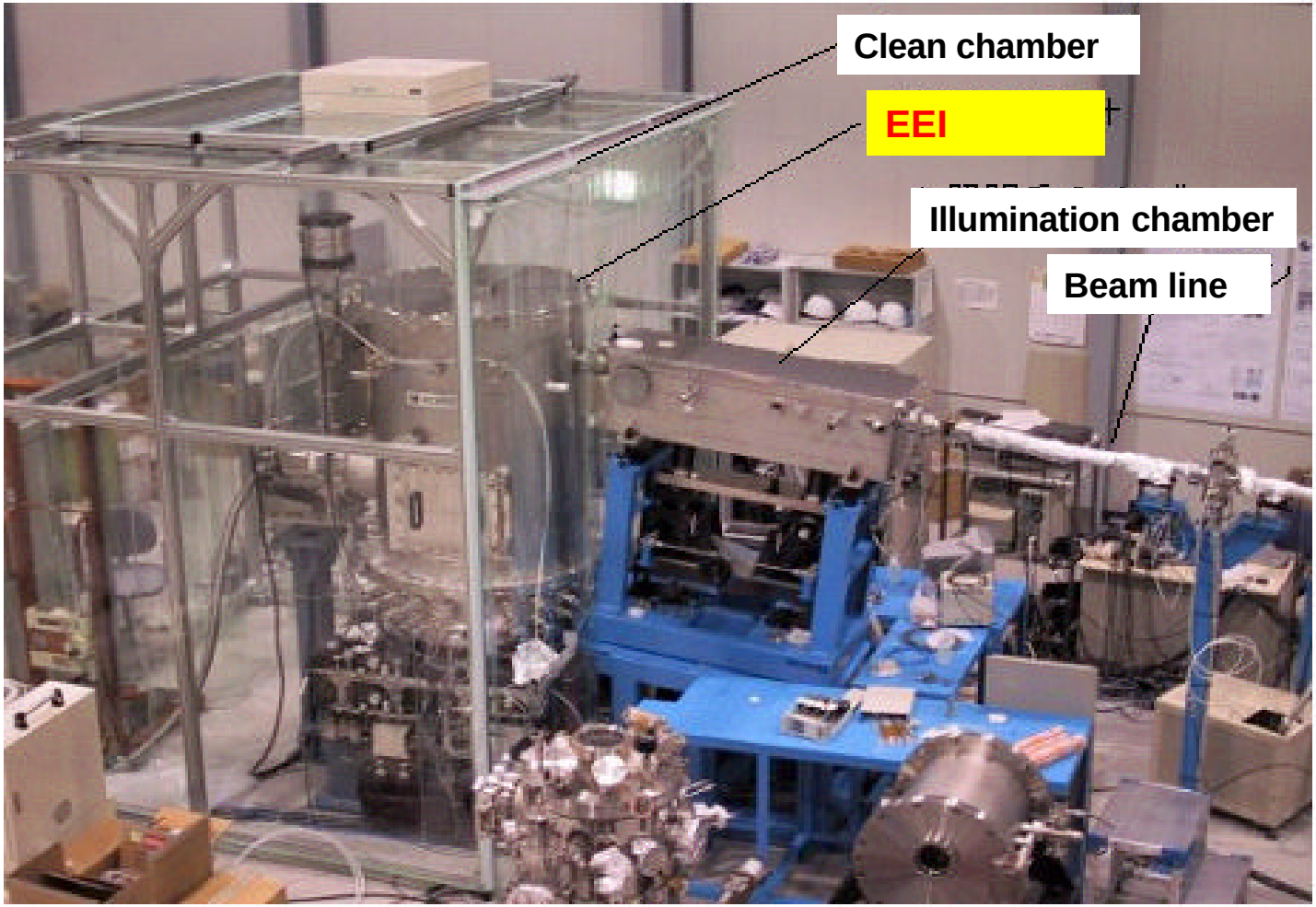
Test Optics

Schwarzschild	
NA	**0.2**
Magnification	**1/20**
Obscuration ratio	0.5
Object-Image	1m
Wave aberration	**1.06nm**
(measured by a visible PDI)	

Beam line at NewSUBARU



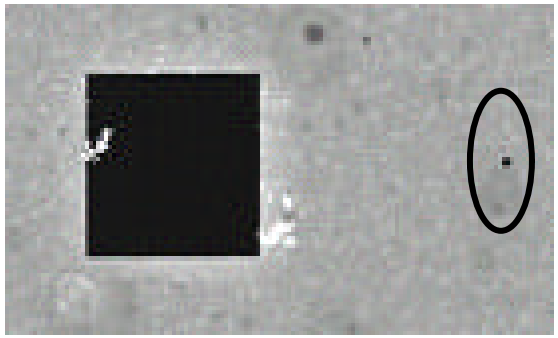
EEI at NewSUBARU

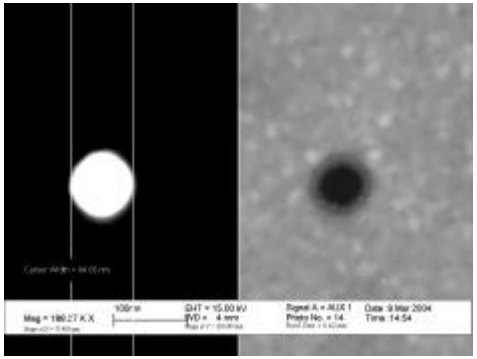


Pinhole and Slit

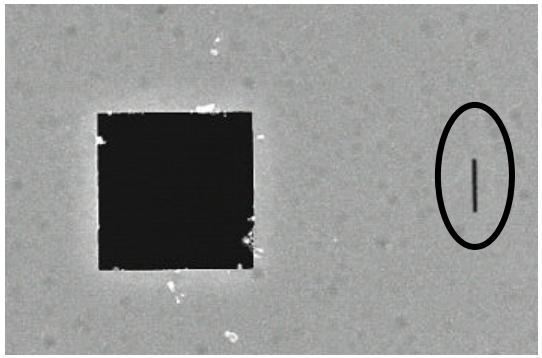
Ni-membrane by Lift-off @ LBNL

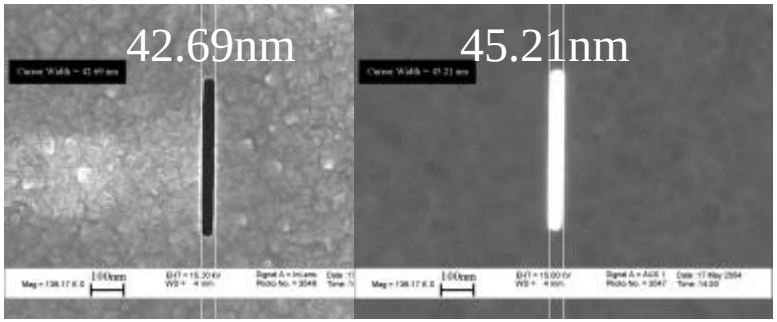
Pinhole (50nmϕ)





Slit (W=40nm)





Scheme of the EEI

6 types of interferometer were installed on EEI.

PDI : Point Diffraction Interferometer
LDI : Line Diffraction Interferometer

} 2 PDI-type Interferometer

LSI : Lateral Shearing Interferometer
SLSI : Slit-type Lateral Shearing Interferometer
CGLSI : Crossed-grating Lateral Shearing Interferometer
DLSI : Double-grating Lateral Shearing Interferometer

} 4 Shearing-type Interferometers

Scheme of the EEI

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DLSI : Double-grating Lateral Shearing Interferometer

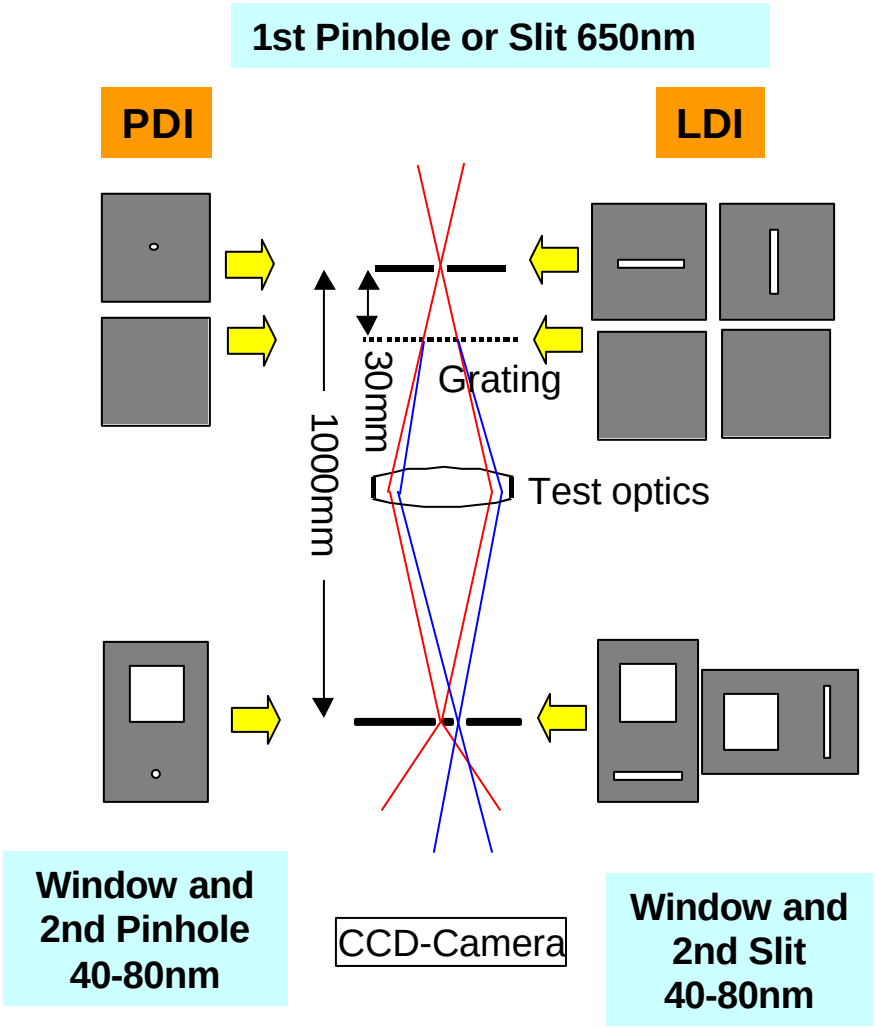
} 4 Shearing-type Interferometers

⇩

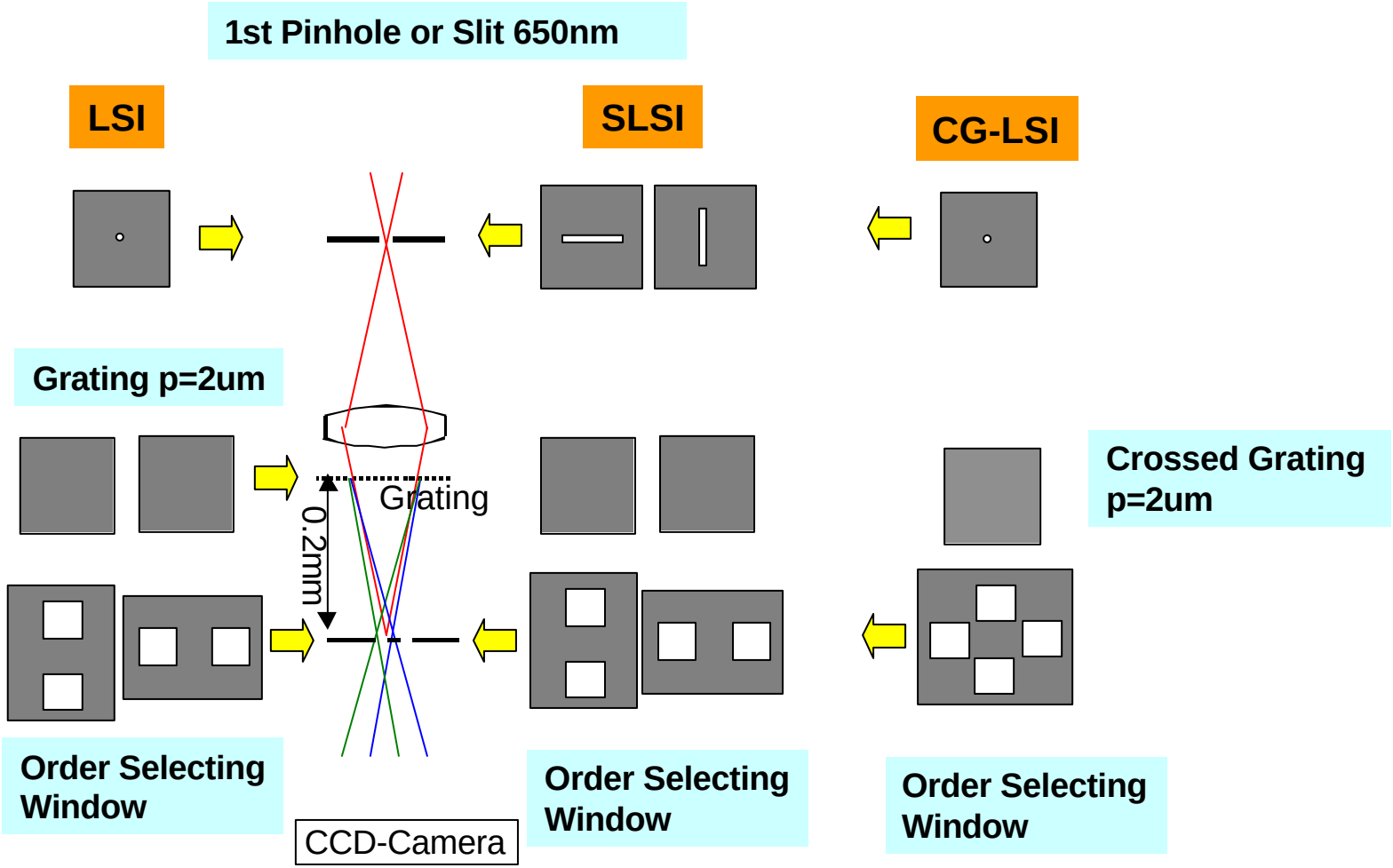
2 types will be selected.
> high accuracy/repeatability
> easy alignment/analysis/maintenance

⇨ Accuracy improving

Configuration of PDI and LDI



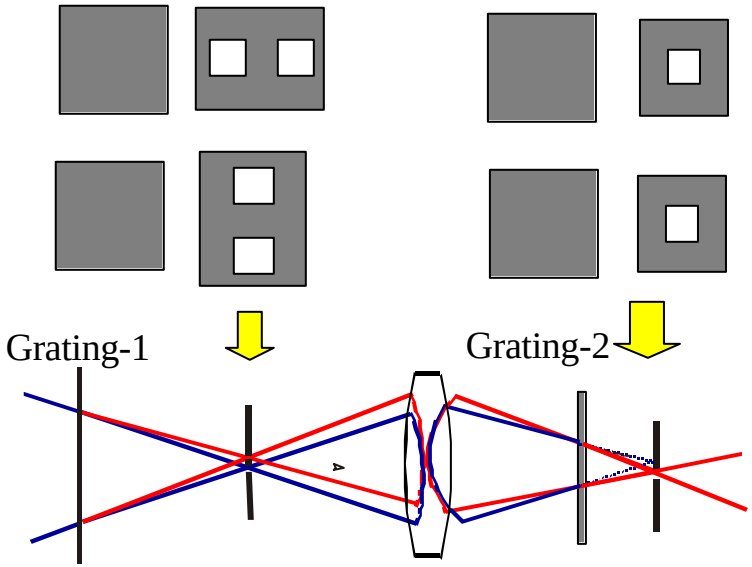
Configuration of LSI,S-LSI and CG-LSI



Configuration of DLSI

DLSI

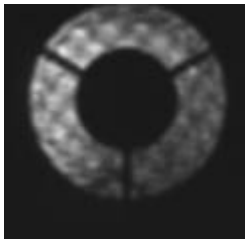
No pinhole, no slit !
→very high bright



Grating1		Grating2
+1st	→	0th
0th	→	-1st

⇨ **Interferogram**

Interferogram
(Single fringe)



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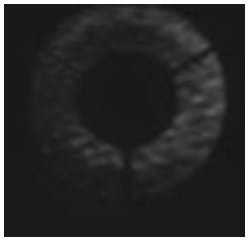

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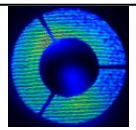
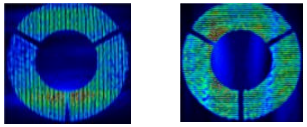
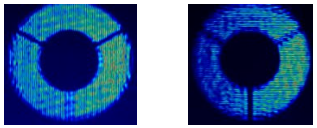
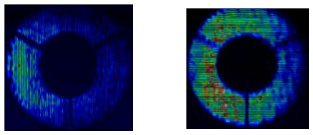
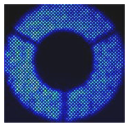
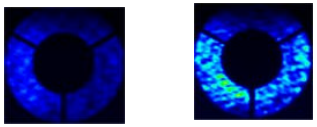
CCD-Camera

- **Single-fringe measurement**
- **Aberration free of the illumination optics (automatically compensated)**
- **No-pinhole→ Very high bright**

Current status of experiments and analyses

Wavefront differences 0.3-0.5 nm rms

	Method	Interferogram	Advantage	Status of analysis
Point diffraction	PDI		accurate	Finished
	LDI		bright	Finished
Shearing	LSI		bright	Finished
	SLSI		bright	Under analysis
	CGLSI		simple	Finished
	DLSI		very bright	Under analysis SPIE ’05.3

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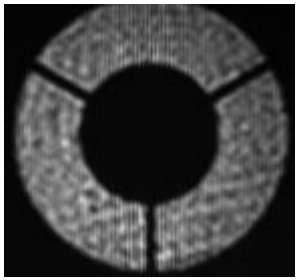
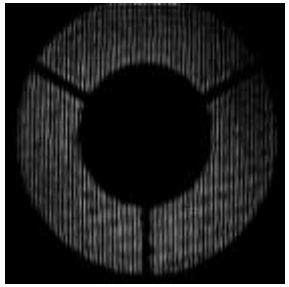
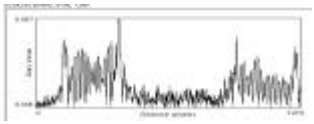
Wavefront Analysis of the PDI

Interferogram

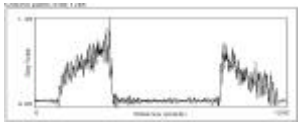


Filtering →

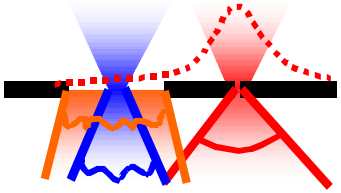


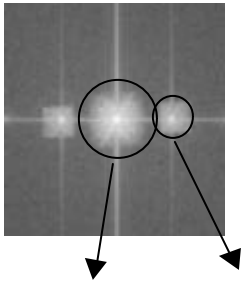


Low Modulation



High Modulation

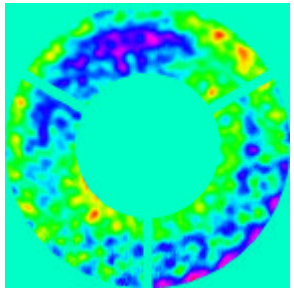




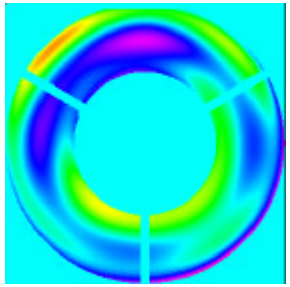
Ref+Flare Test+Flare

Retrieved WF

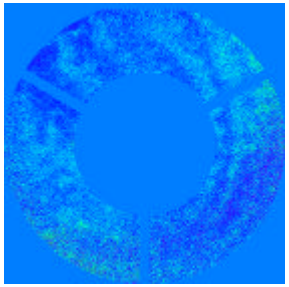
Phase Shifting →



1.339 nm rms



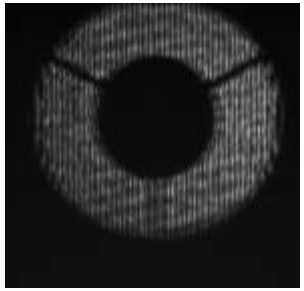
1.139 nm rms (Z1-36)

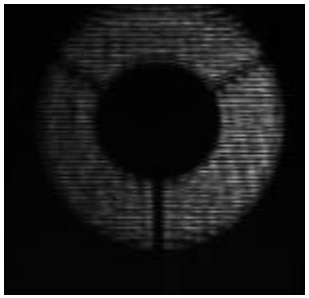


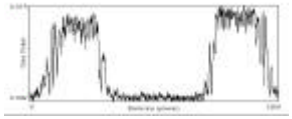
Repeatability 0.054 nm rms (Z1-36)

Wavefront Analysis of the LSI

Interferogram



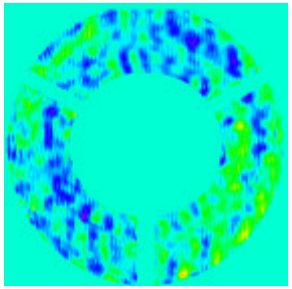


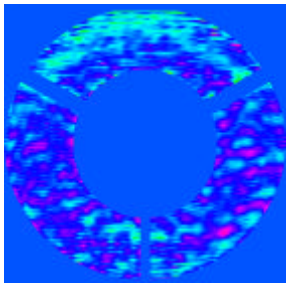


High Modulation

Phase Shifting

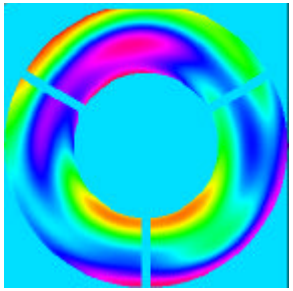
Sheared WF





Shear ratio=1/30

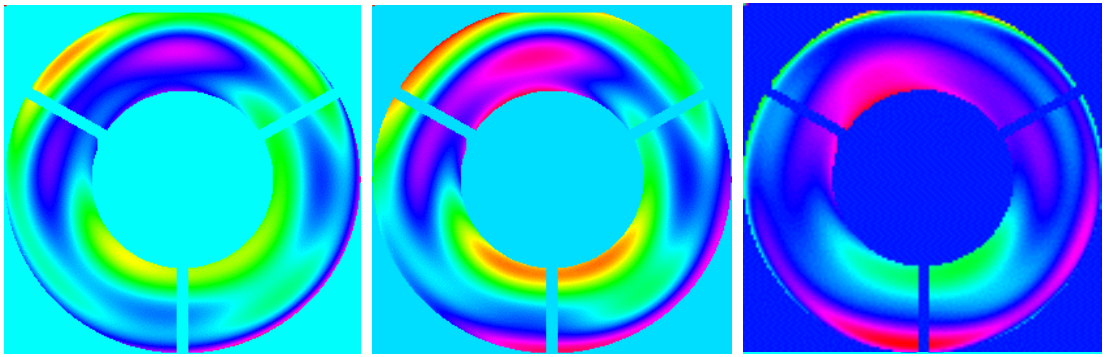
Retrieved WF



- **Differential Zernike Fitting by QR-decomp. or SVD**

- **Rimmer's method**
- **Integral method**

PDI vs LSI

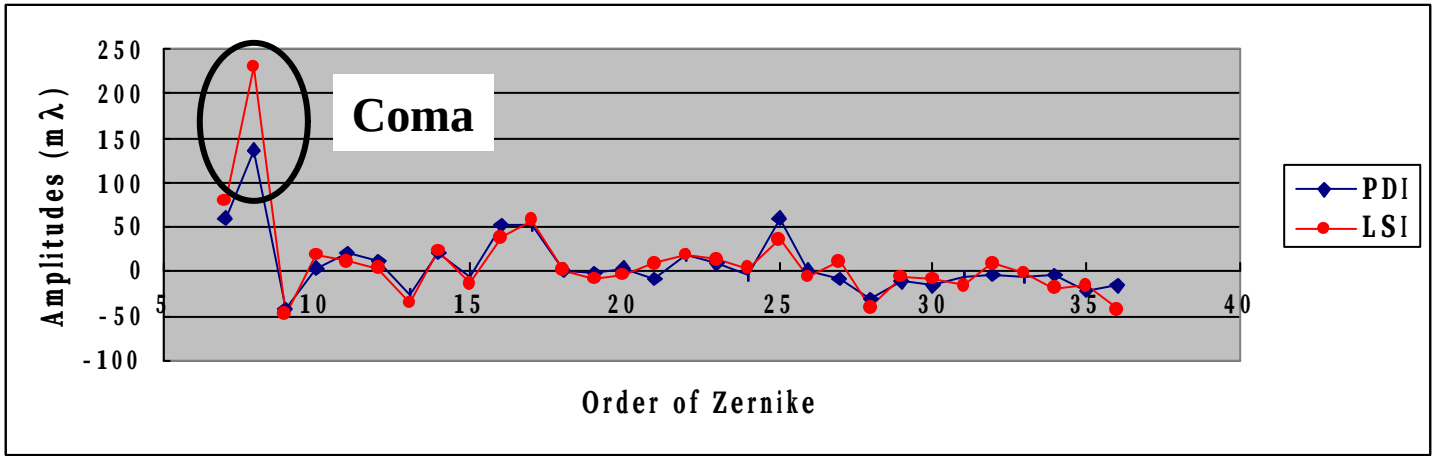


PDI
0.921nmrms

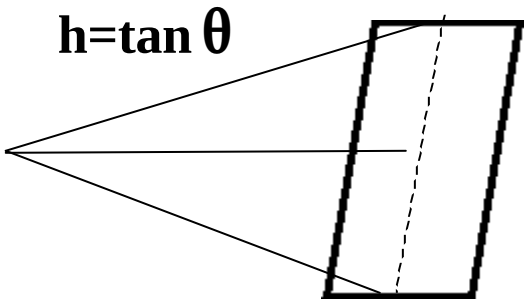
LSI
1.282nmrms

Difference
0.493nmrms

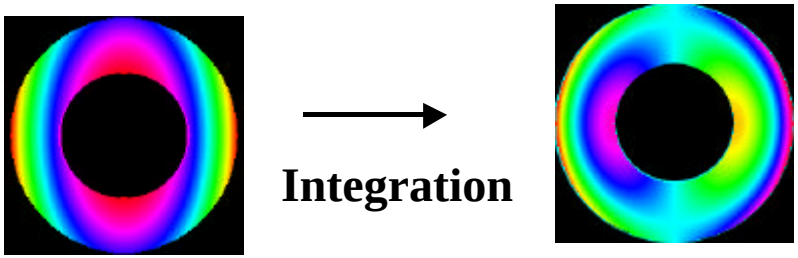
*** Z7-36**



CCD-tilt induced Coma



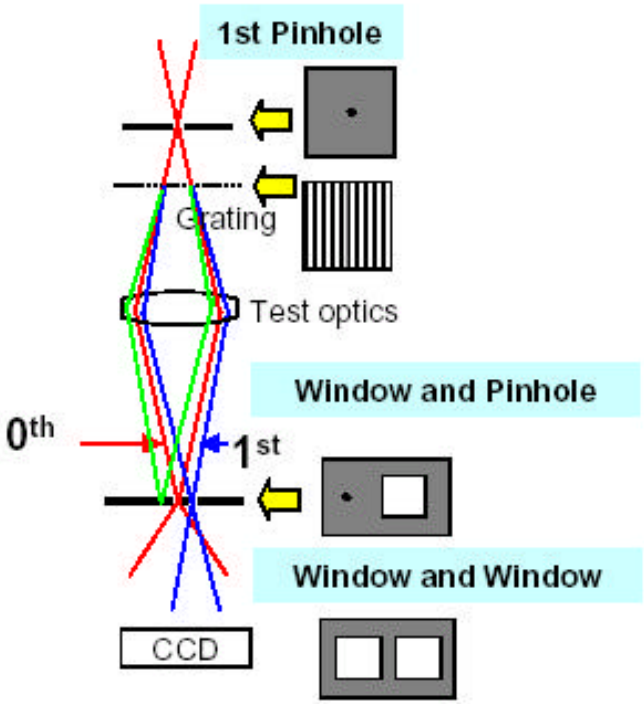
CCD-tilt
→ Astigmatism at the sheared WF
→ Coma at the retrieved WF

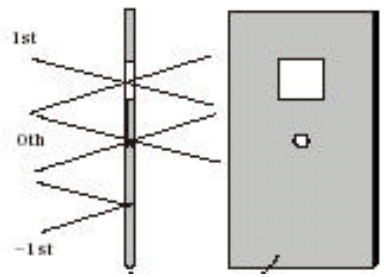


Ast. **Coma**

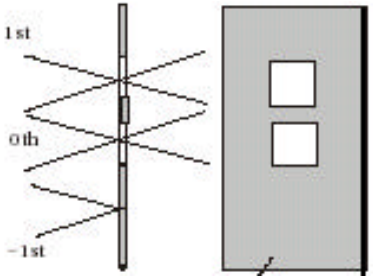
Astismatism ∝ NA^2 *tilt
Nalleau et. al. (1998)

Estimation of the CCD-tilt





(i) Pinhole+Window



(ii) Window+Window

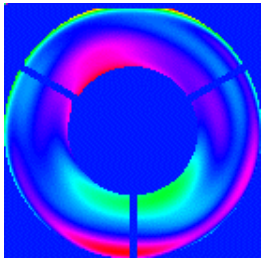
(i) W1=R0+T1+ G1+S
(ii) W2=T0+T1+ G1+S
R0=0th reference, T0,T1=0th and 1st test
G1= grating error,
S=other systematic error (CCD-tilt)
(i)-(ii)=T0-R0=Test WF
Test WF and systematic error (G1, S) can be separated.
S is estimated as coma of 0.03λ .

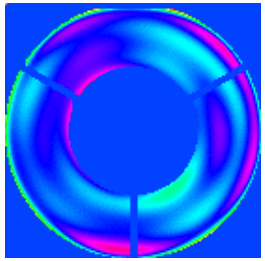
Absolute-PDI (Y. Zhu, 2004)
See poster session (MeP-14).

Compensated wavefront

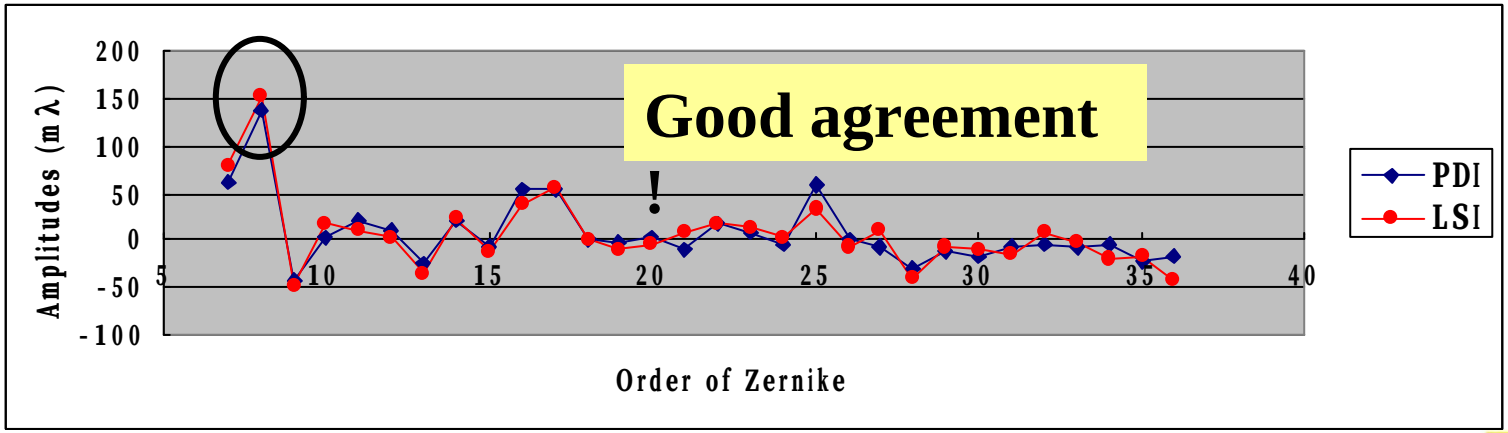
- CCD tilt =0.23 degree, Coma=0.08 λ = 0.38 nm rms
  →deviation(PDI-LSI)=0.256 nm rms
- No parameter fitting !

Wavefront deviation (PDI-LSI)





0.493 nmrms → 0.256 nmrms



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- Absolute evaluation of accuracy on EEI
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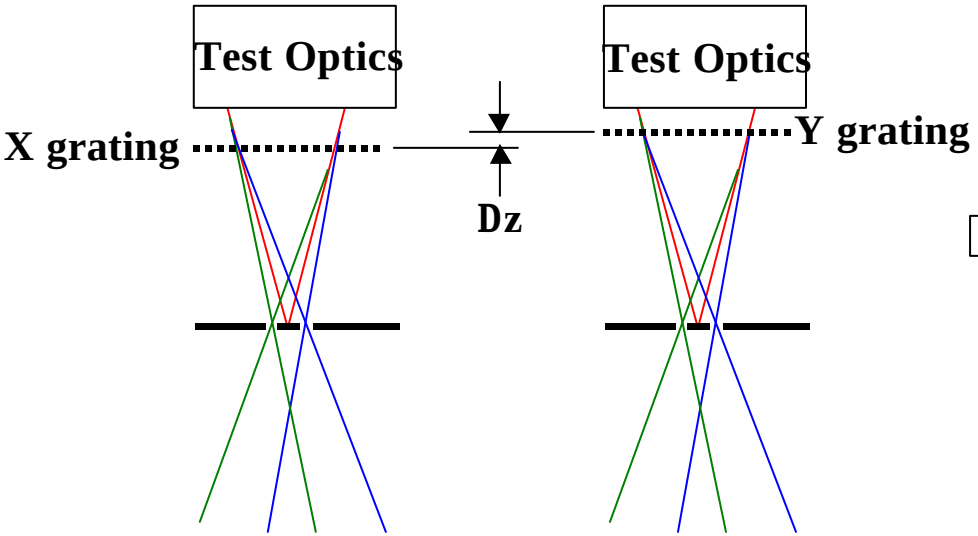
Difficulties in LSI -measurement -

Measurement of astigmatism is so difficult.

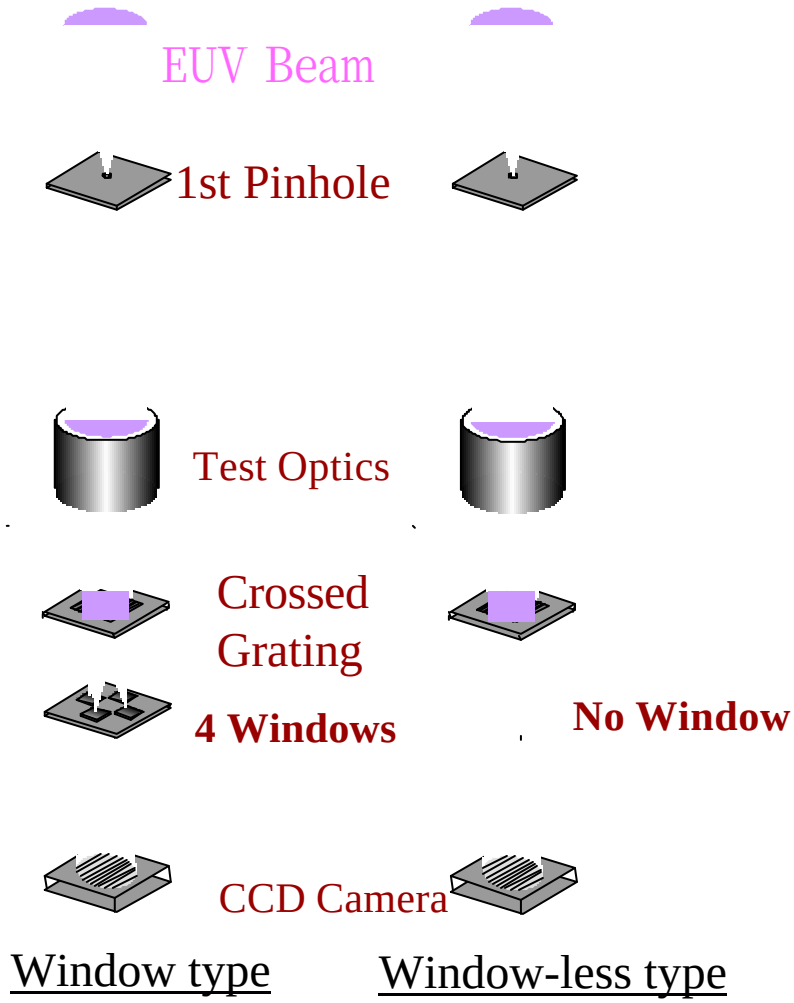
In LSI, astigmatism is sensitive to the grating position error DZ.

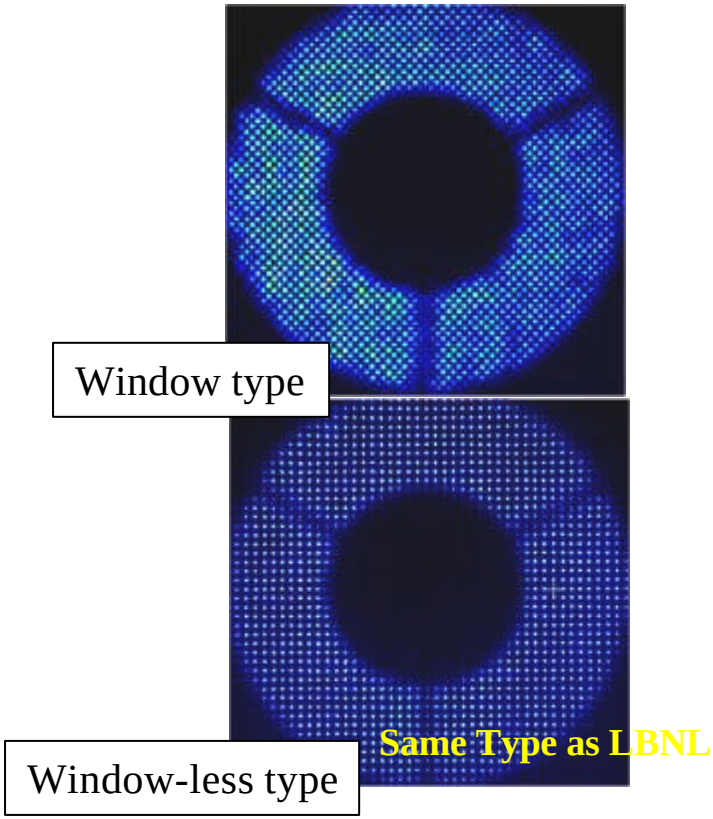
ex. DZ=14nm →Astigmatism=0.10nmrms



Crossed-Grating

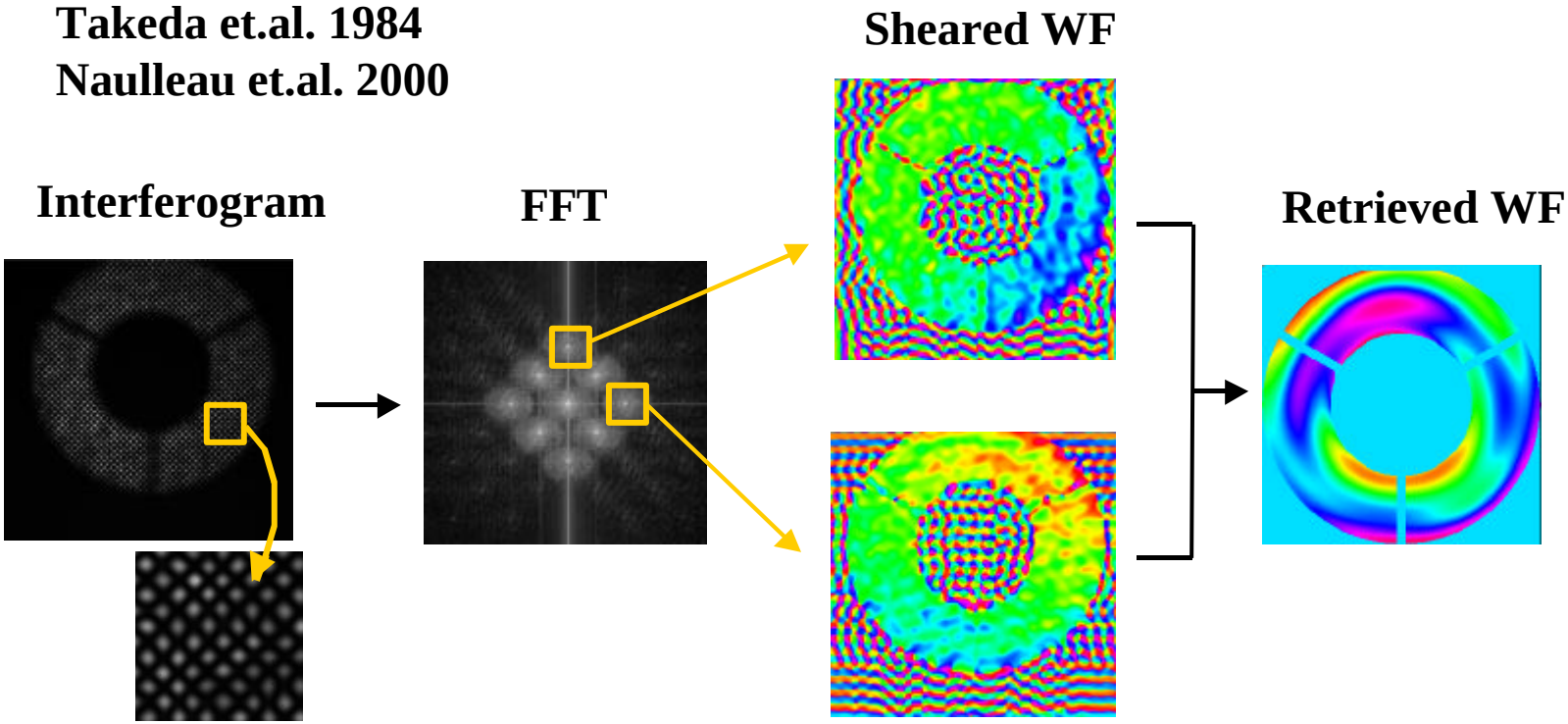
Crossed-Grating LSI





Wavefront retrieval by FFT on CG- LSI

<u>FFT Method</u>
Takeda et.al. 1984
Naulleau et.al. 2000



Please visit Mr. Kato's poster session (MeP-15)

Repeatability of PS and FFT

Which has higher repeatability ?

- **Phase shifting method (X:5 buckets+Y:5 buckets)**
- **FFT method (1bucket × 10 averaging)**

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Now analyzing

Difficulties in LSI - analysis -

Wavefront to be retrieved

$W(x,y) = \Sigma A_n Z_n(x,y)$ (n=1-36) , $Z_n(x,y)$ =Annular Zernike

Sheared wavefronts (=measured)

$W(x+s, y)-W(x-s, y) = \Sigma A_n [Z_n(x+s,y) - Z_n(x-s,y)]$ + Higher (n>36)

$W(x, y+s)-W(x, y-s) = \Sigma A_n [Z_n(x,y+s) - Z_n(x,y-s)]$ + Higher (n>36)

Non-orthogonal

⇩

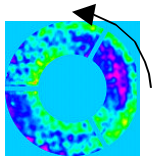
1. Ill condition → SVD
2. Cross talk from the higher components → Fitting error

Outline

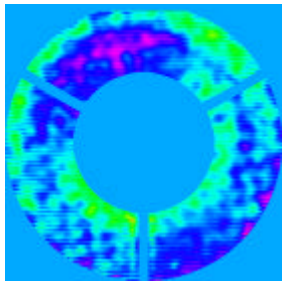
- Review of EUVA Project and EEI
- Relative evaluation of accuracy on EEI
  - Comparison of PDI and LSI -
- Difficulties in LSI
- **Absolute evaluation of accuracy on EEI**
- Summary

Absolute evaluation of the systematic error

- Deviation <PDI-LSI> ≠ absolute accuracy.
- Measured data = T + S
  T=Test wavefront
  S = Systematic error = invariable (assumption)
- Deviaiton of WF before/after P.O. Rotation
  →T and S separated
- Rotationally symmetric comp. of cannot be extracted.



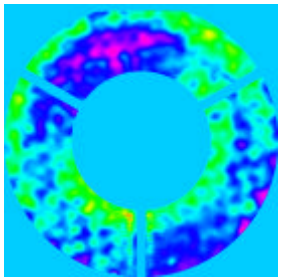
T + S0



ϕ=0deg

-

T + S90



ϕ=90 deg

→

S0 - S90

⇩

T and S are separated

Summary

- Recent advances of EEI in EUVA was introduced.
- Repeatability of 0.05 nm rms has been achieved.
- CCD-tilt induced coma aberration has been evaluated.
- Wavefront of LSI shows good agreement with that of PDI.
- Deviation of PDI and LSI was 0.26 nm rms .
- CG-LSI is effective for astigmatism measurement.
- Now continue to evaluate an absolute accuracy on EEI.

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