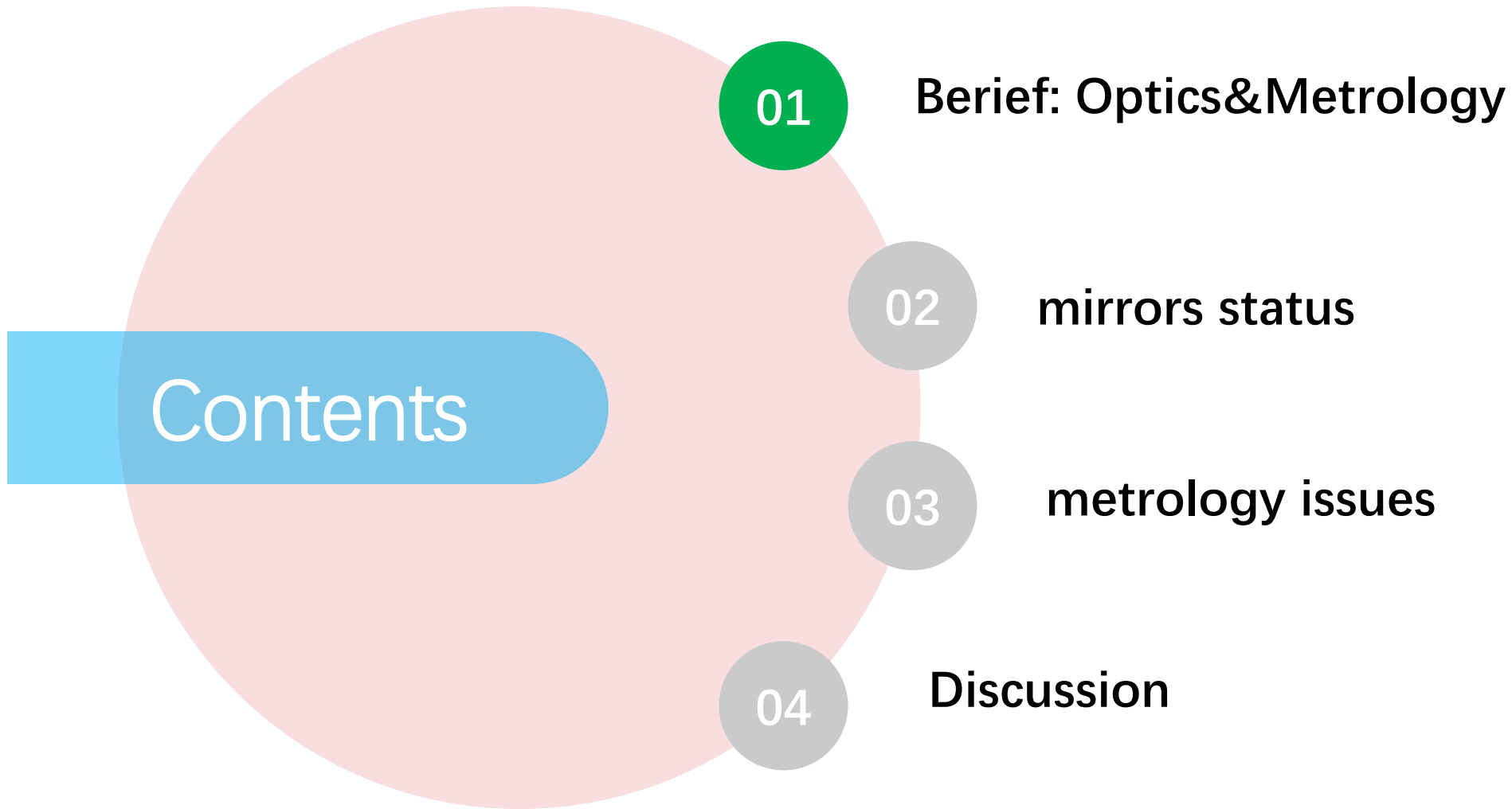


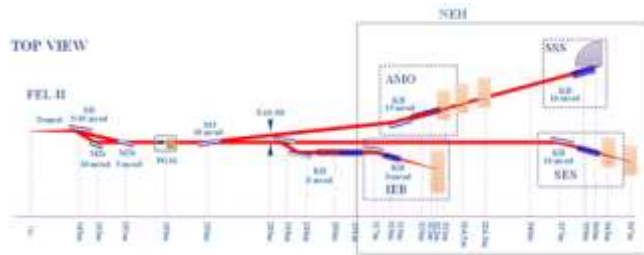
SHINE Beamline optics: issues with metrology

Speaker: Xiaohao Dong

On behalf of the beamline optics group

Tuesday, October 20, 2026

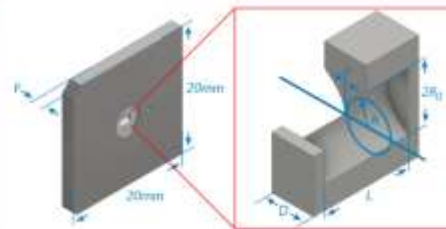
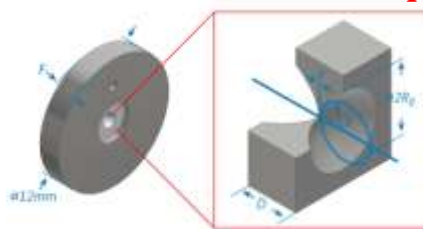




Grazing angle: 0.057°

Effective aperture: 0.5mm

Blazed grating: 0.3°

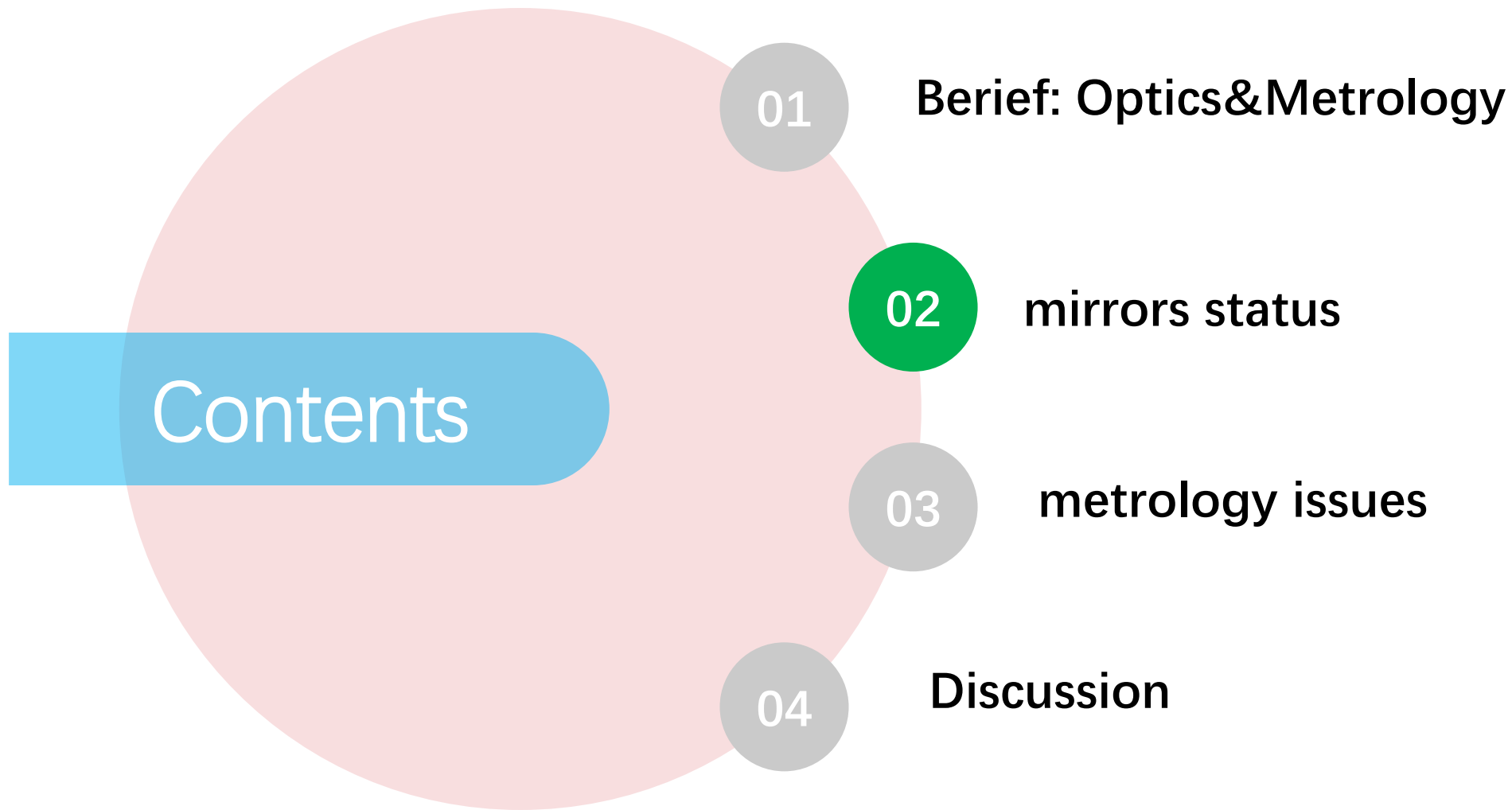


- 1) availability of optics
- 2) evaluating and calibrating of optics:
 - bare mirrors
 - mirrors with holders and benders**

	LSF: Low Spatial Frequency	HSF: High Spatial Frequency
	<u>Oblique, stitching interferometry,</u>	Microscopy, scanning
Mirror Shape	Flat, elliptical, cylindrical	Flat, elliptical, cylindrical
Radius Tangential	$\geq 5\text{km}$ (oblique)	--
Mirror size	1000mm	1000mm
Height error	$PV \leq 15\text{nm}$	--
Sampling resolution	$0.1 \sim 2\text{mm}$	$20 \sim 200\mu\text{m}$

	MSF: Middle Spatial Frequency		
	stitching interferometry (Horizontal)	stitching interferometry (Vertical, upwards)	stitching interferometry (Vertical, downwards)
Mirror Shape	Flat, elliptical, cylindrical	Flat, elliptical, cylindrical	Flat, elliptical, cylindrical
Radius Tangential	$\geq 200\text{m}^*$	$\geq 200\text{m}^*$	$\geq 200\text{m}^*$
Mirror size	1000mm	1000mm	1000mm
Height error	$PV \leq 2\text{nm}$	$PV \leq 2\text{nm}$	$PV \leq 2\text{nm}$
Sampling resolution	$\sim 200\mu\text{m}$	$\sim 200\mu\text{m}$	$\sim 200\mu\text{m}$

//* 70m, Theoretical value according to calculation of the measuring system



FEL-II /I Offset and Distribution mirrors

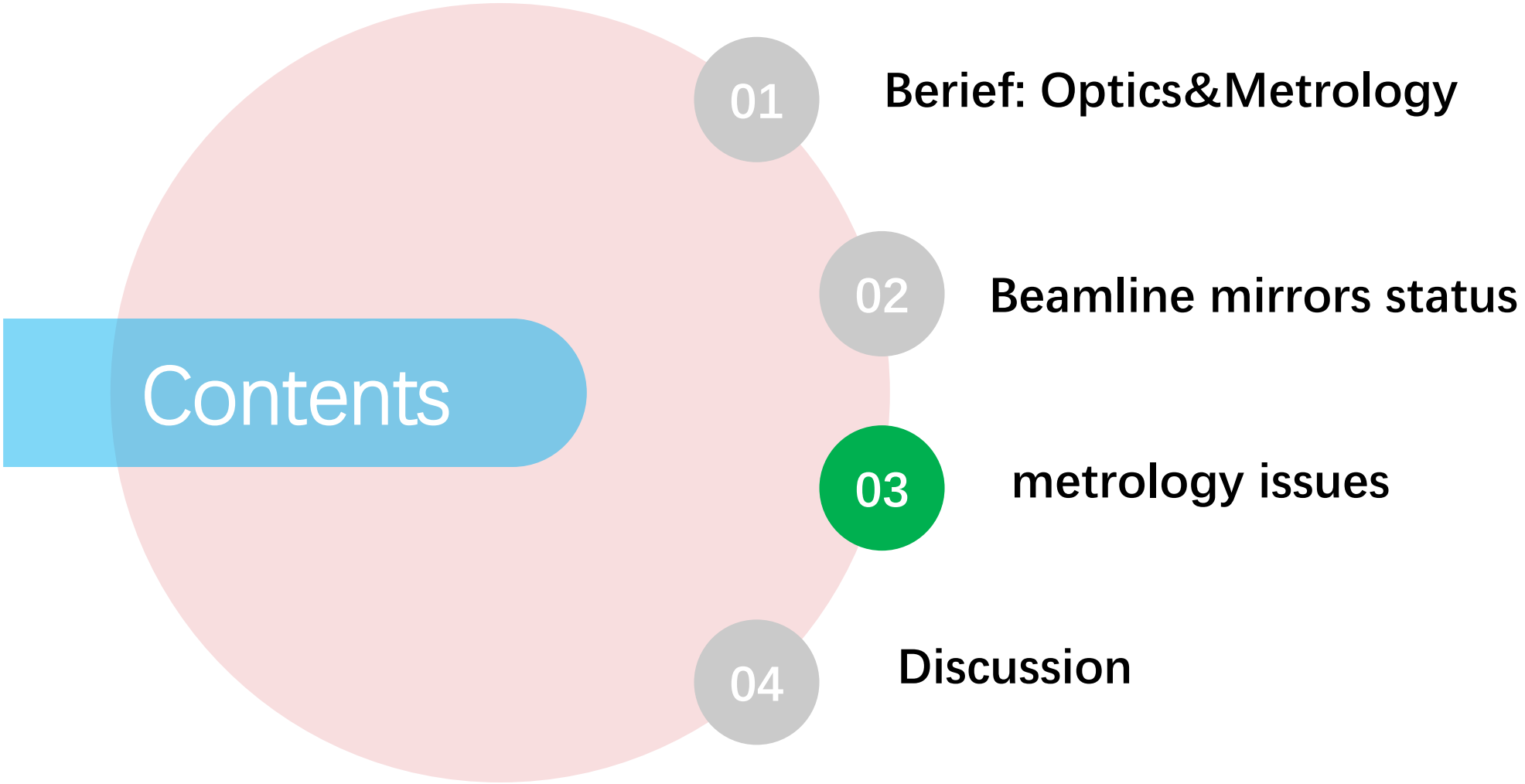
mirrors	status	remarks
FEL-II-M 1 (1x)	installed @ tunnel	flat with holder
FEL-II-M2a,b (2x)	installed @ tunnel	flat with bender
FEL-II-M3a,b (2x)	installed @ tunnel	M3a flat with holder M3b elliptical with holder: mistake of production drawing, cooling can't be implemented
account-fel-II: 5x		
FEL-I-M 1 (1x)	ready for install	to be assembled & calibrated 26.10.17
FEL-I-M2a,b (2x)	storage @4# metrology lab	to be assembled & calibrated soon(2nd half,Oct. planned)
account-fel-I: 3x		

FEL-II mono's optics

optics: mirror+grating	status	remarks
FEL-II-Mono-PM (1x)	installed @tunnel	two stripes, with B4C coating peeling defects
FEL-II -MONO-SES-ECMV (1x)	installed @tunnel	
FEL-II-Mono-PG1 (G1 1x)	installed @tunnel	inpretus grating 200mm/l; facing down
FEL-II-Mono-PG2 (G2 1x)	installed @tunnel	ZK(Hefei) grating 500mm/l; facing down
account fel-II: 4x		
FEL-II-ECMV-SSS (1x)	installed @tunnel	together with M3b, as KB pairs
FEL-II -PM-SSS (1x)	installed @tunnel	supporting configuration difference: JTEC VS Bestec
FEL-II-SSS-PG (G 1x)	installed @tunnel	
account fel-II: 3x		

FEL-II/I KB mirrors

mirrors	status	remarks
FEL-II- AMO KB (2x mirror)	installed @tunnel	Axilon (DE)
FEL-II –SES KB (2x mirror)	installed @tunnel	Ireclec (FR)
FEL-II SSS KB (1x mirror, KBV facing downwars)	installed @tunnel	Bestec(DE) : same chamber with pulse compressor; KBH ==M3b
FEL-I HSS KB (2x mirror)	installed @tunnel	Axilon (DE)
FEL-I CDS KB (6x mirror)		Ireclec(FR)
M3	waiting for coating	foseseen by end of 26.11
EM3	received	under inspection with support
M4	waiting for coating	foseseen by end of 26.11
EM4	under production	2027.1/2
EM7	received	under inspection with support
EM8	finishing EEM	foseseen by end of 26.10



Contents

01

Berief: Optics&Metrology

02

Beamline mirrors status

03

metrology issues

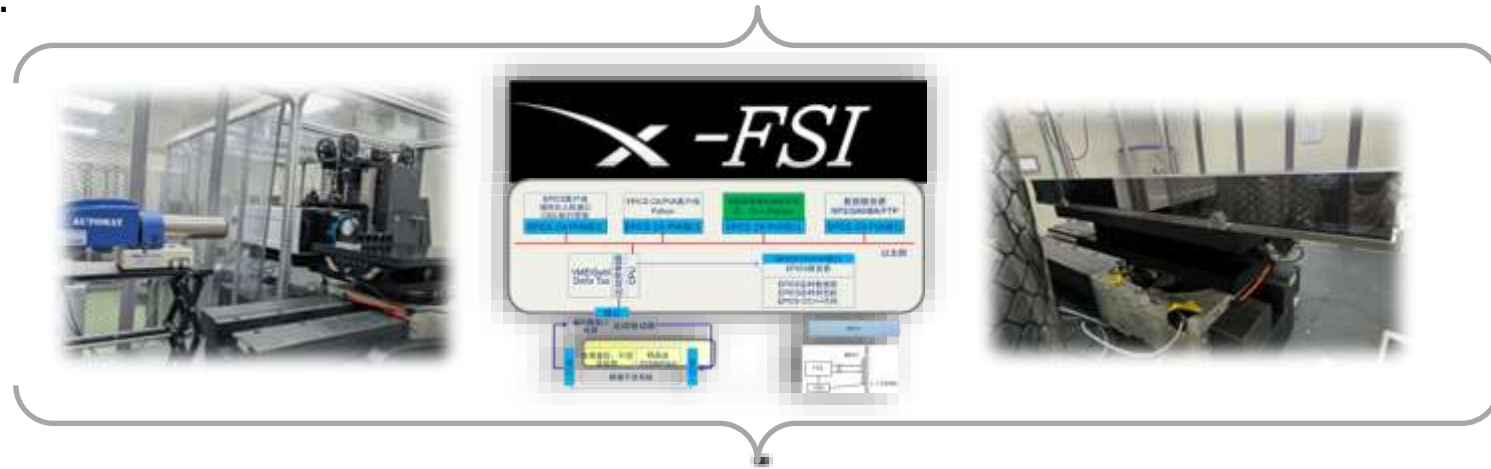
04

Discussion

Stitching interferometry system in operation

Together with in-house developed software(*X-FSI: Fizeau Stitching Interferometry for X-ray mirrors*), absolute calibration and full aperture shape errors measurements can be done in the same platform.

Stitching measuring repeatability < 0.02 nm (RMS) : STD value---point-to-point (Center line) differences of multiple (10x) measurements.

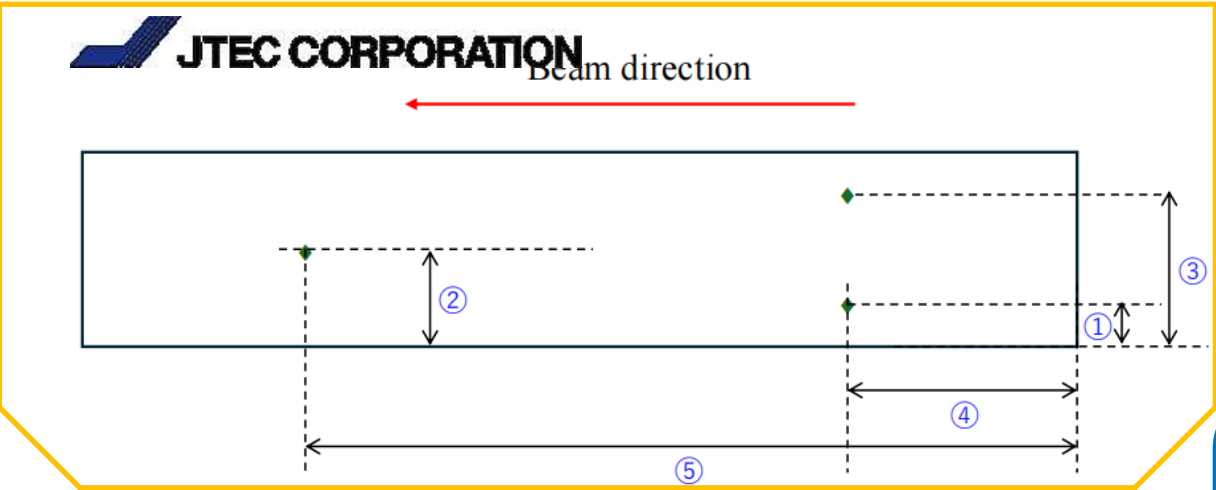


Most of the **beamline optics**, have been measured and calibrated with mechanisms and results are at the same level as the suppliers, but there is still discrepancy of the slopes due to different positioning and supporting configurations.

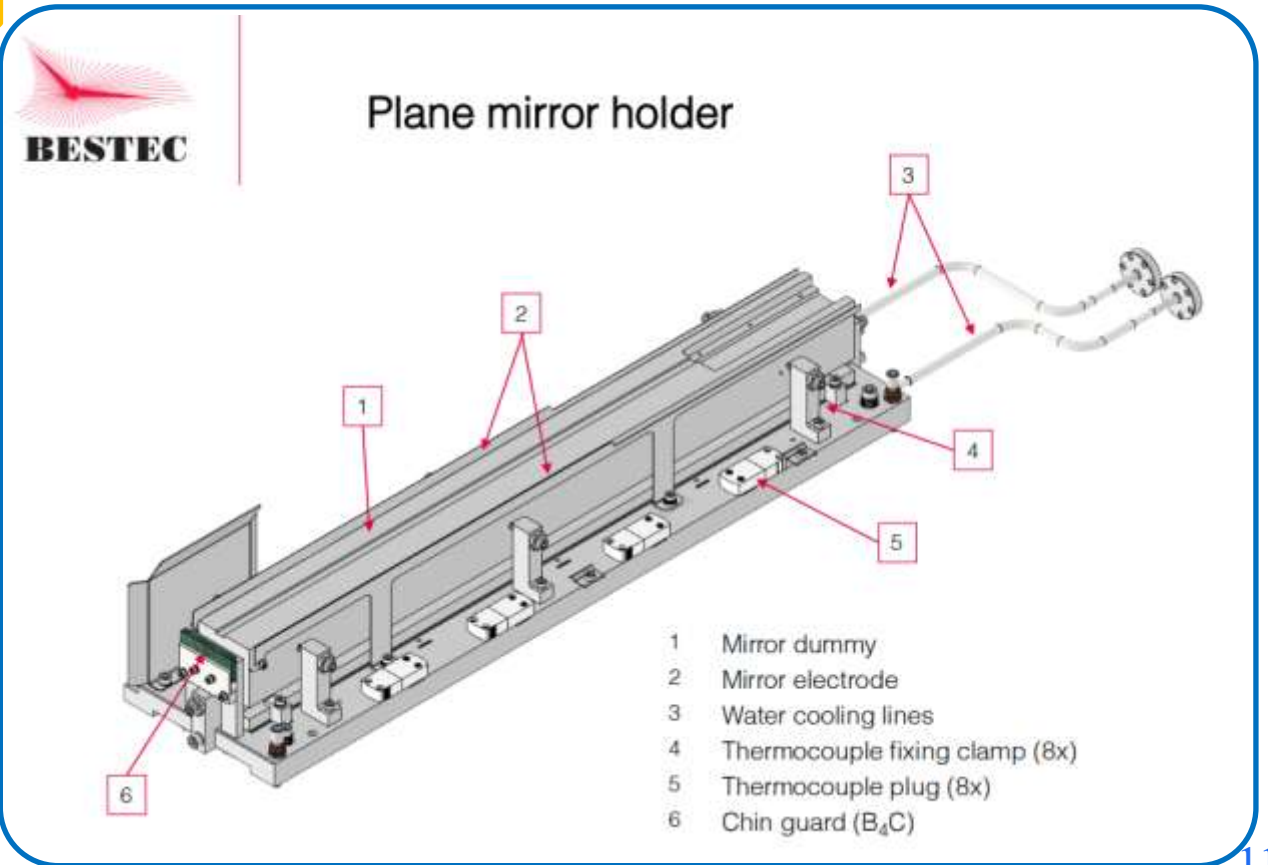
Issues with mirrors inspection:

- mirror supporting configurations
- small radius

#1 shape error due to supporting configuration: SSS-KB PM

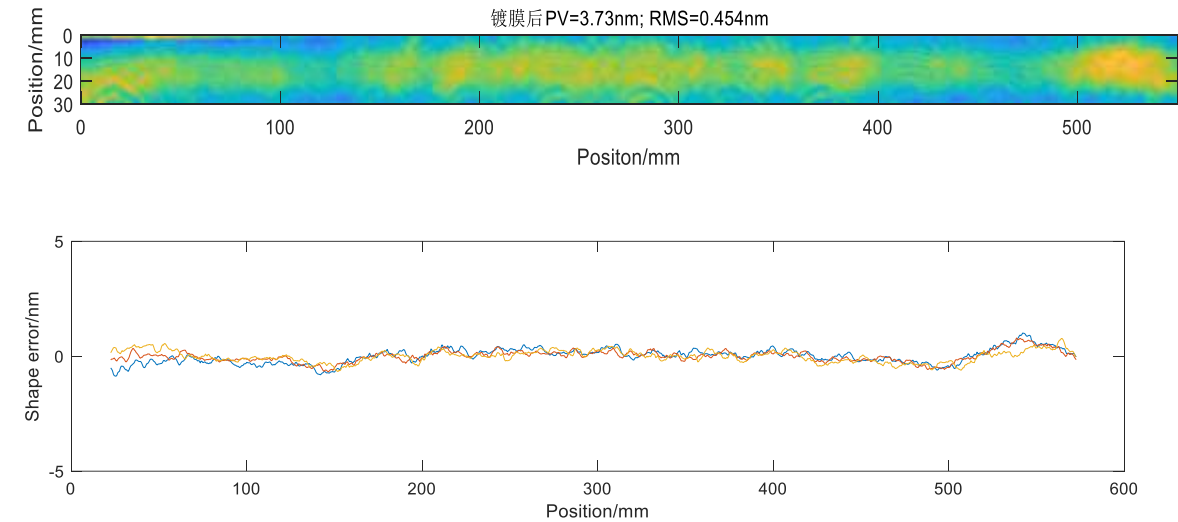


Supporting deffirences
for assmeby&adjustement



Shape error : comparison of different support (1)

Bare mirror (facing side, without gravity sag. effects)



	-7mm	0mm	7mm
PV/nm	1.9	1.5	1.4
RMS	0.32	0.25	0.26

mounted with **JTEC holder** (facing upwards): FAT results

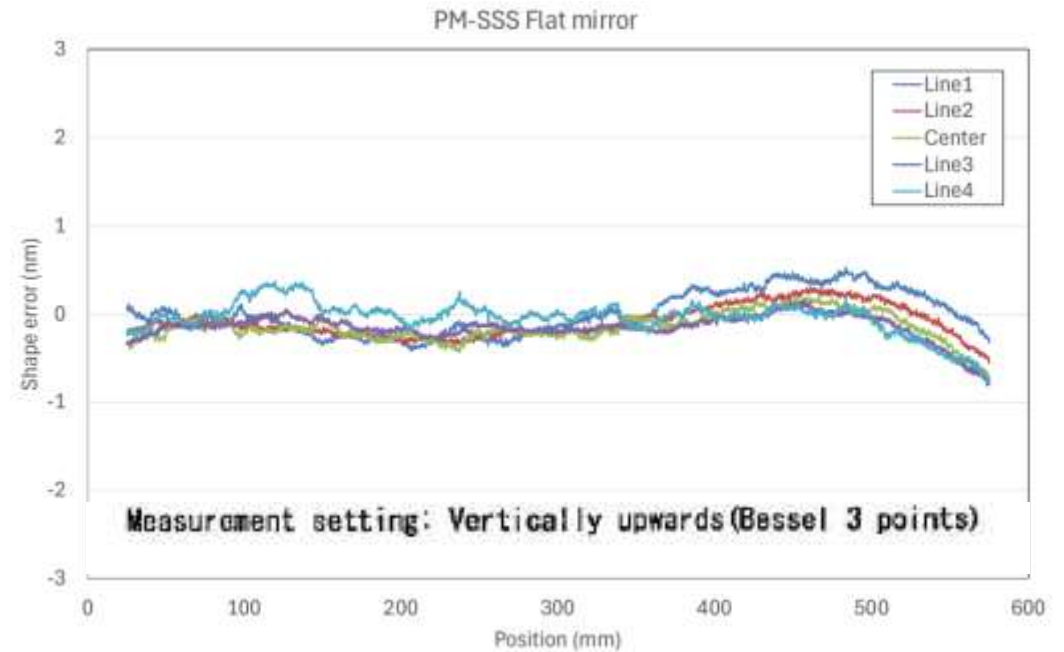
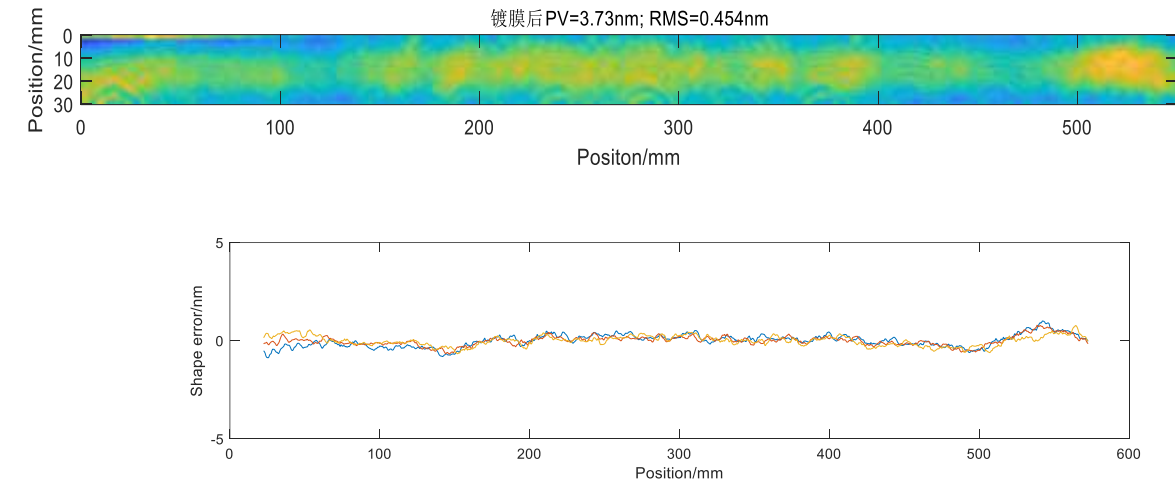


Table 1-2: Tangential shape error of SHINE PM-SSS Flat mirror (F240001)

No.	Line1	Line2	Center	Line3	Line4
F240001 (nmRMS)	0.242	0.201	0.222	0.210	0.189
F240001 (nmPV)	0.94	0.86	0.96	0.96	1.14

Shape error : comparison of different support (2)

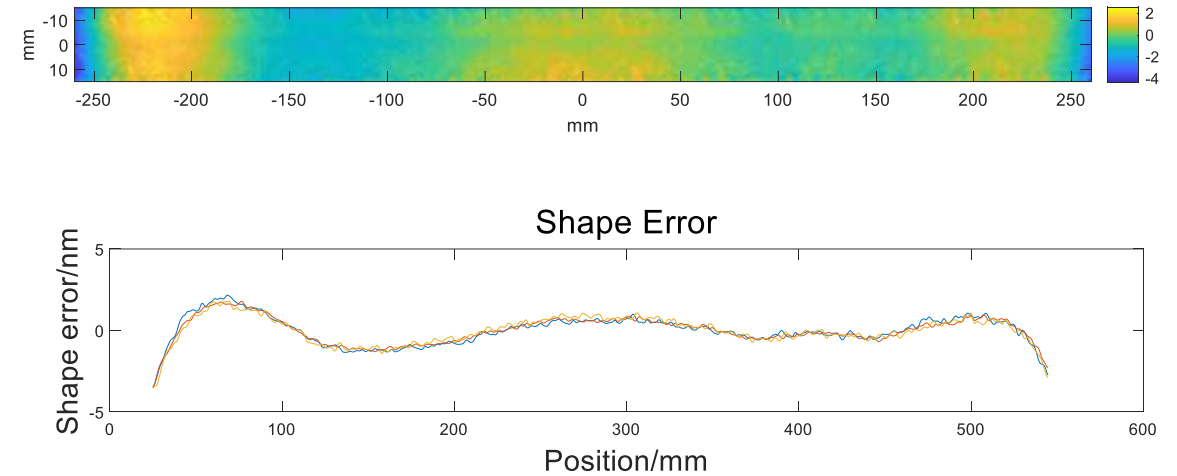
bare mirror (facing side, without gravity sag. effects)



	-7mm	0mm	7mm
PV/nm	1.9	1.5	1.4
RMS	0.32	0.25	0.26

mounted with **Bestec holder** (adjusted, facing upwards)

PV:6.9nm; RMS:0.864nm

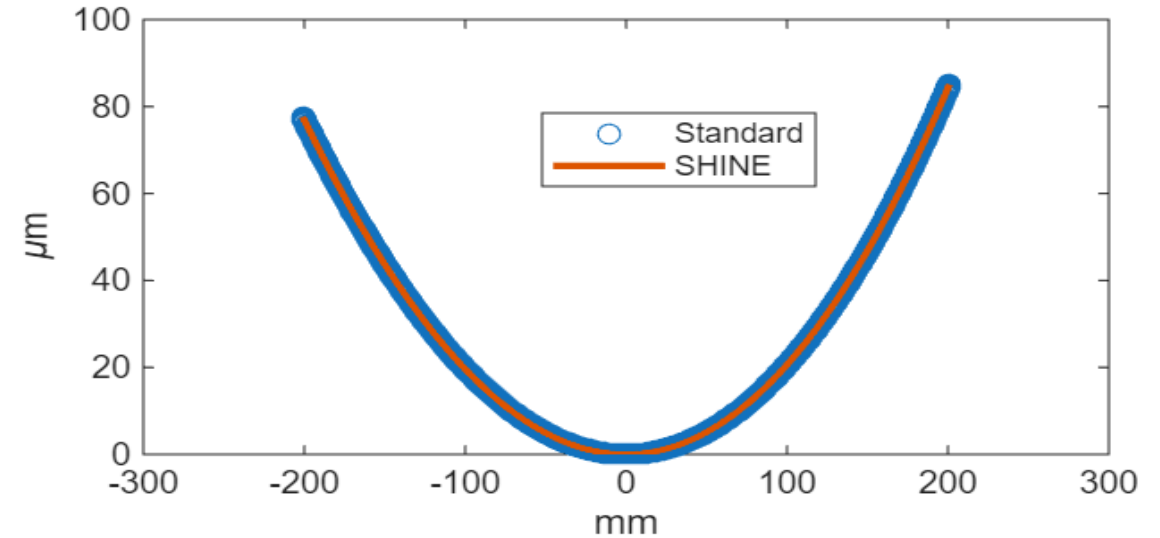


	-7mm	0mm	7mm
PV/nm	4.7	4.3	4.6
RMS	0.75	0.69	0.72

final results as installed

#2 Small radius of elliptical mirror: SSS-KB ECMV

Parameters	Specifications	Tolerance
OA /mm	≥ 450	-
p/m	28	-
q/m	2	0.5%
$\theta/mrad$	15	0.5%

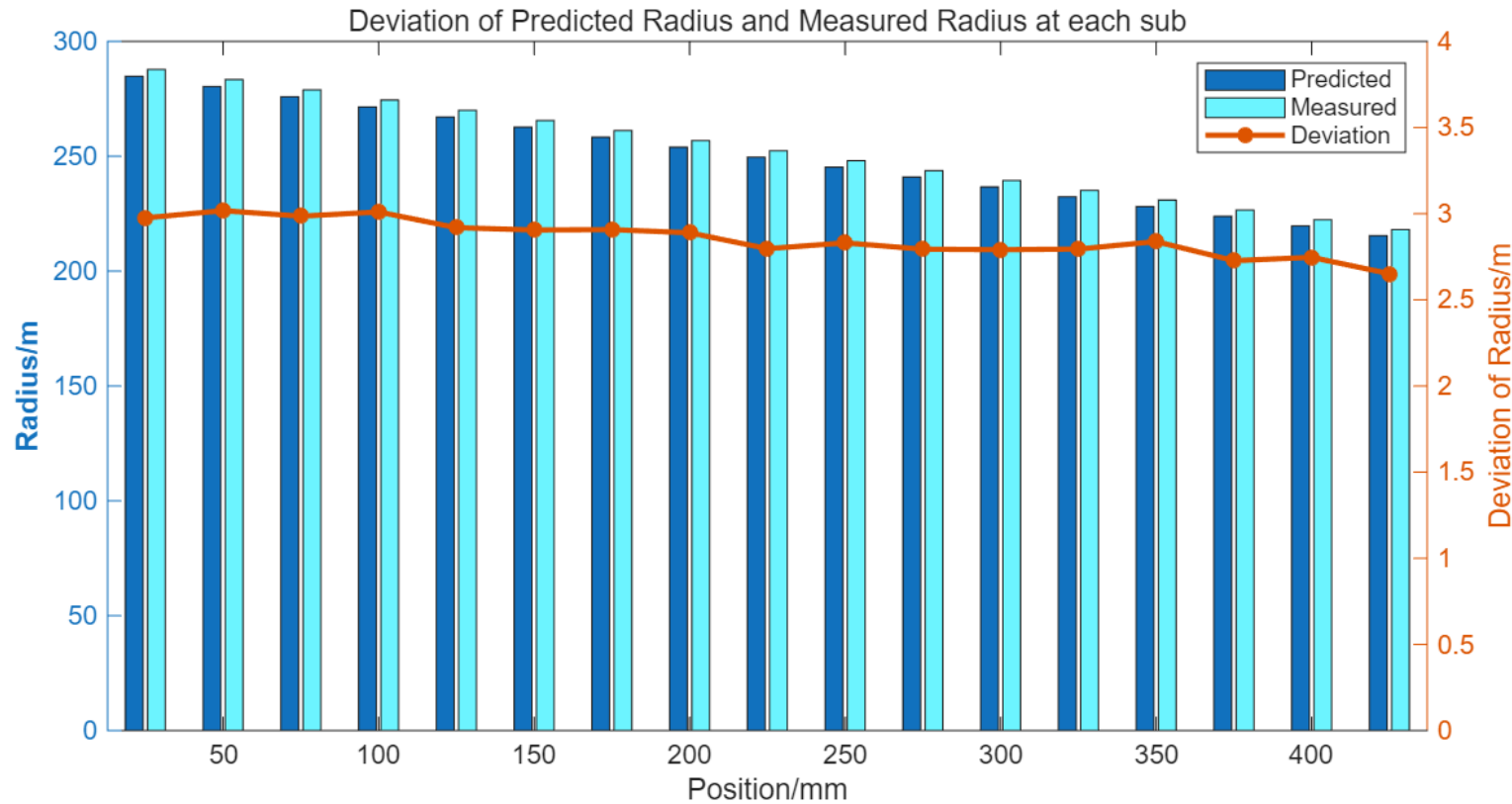


$q = 2.010000\text{m}$ (+0.500%),
 $\theta = 15.0643\text{mrad}$ (+0.429%)

Stitching Interferometry Measurement :

50mm sub-aperture, 25mm movement for each step, the overlap rate is 50%, 17 apertures to cover full optical aperture (OA).

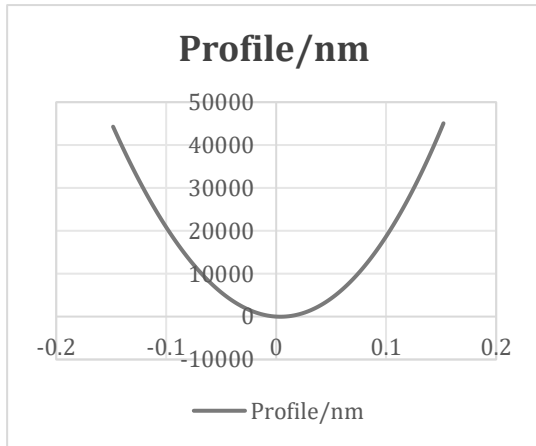
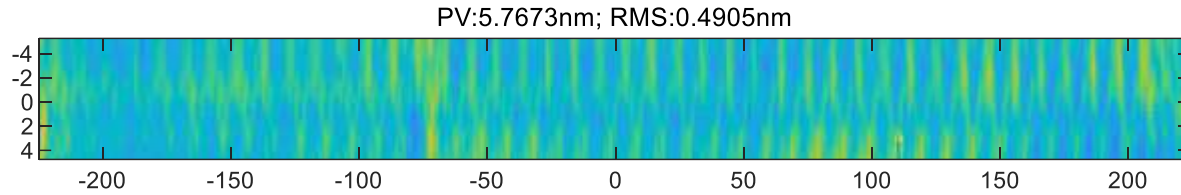
Radius deviation for measurements



Deviation of each sub-aperture Radius

number	Radius/m	number	Radius/m
sub1	2.976	sub10	2.830
sub2	3.018	sub11	2.794
sub3	2.985	sub12	2.791
sub4	3.010	sub13	2.794
sub5	2.919	sub14	2.838
sub6	2.905	sub15	2.727
sub7	2.908	sub16	2.746
sub8	2.889	sub17	2.652
sub9	2.797	mean	2.858

Shape error difference : FAT vs SAT



	as designed	as measured
$p(\text{fixed})/\text{m}$	28	28
$q(\text{fixed})/\text{m}$	2	2
θ/mrad	15	14.83

JTEC FAT Report

Table 2-2: Tangential shape error of ECMV-SSS Mirror (X362001)

No.		Line1	Line2	Line3	Line4	Line5	Avg.
X362001	(nmRMS)	0.269	0.269	0.274	0.270	0.282	0.273
	(nmPV)	1.55	1.41	1.44	1.39	1.38	1.43

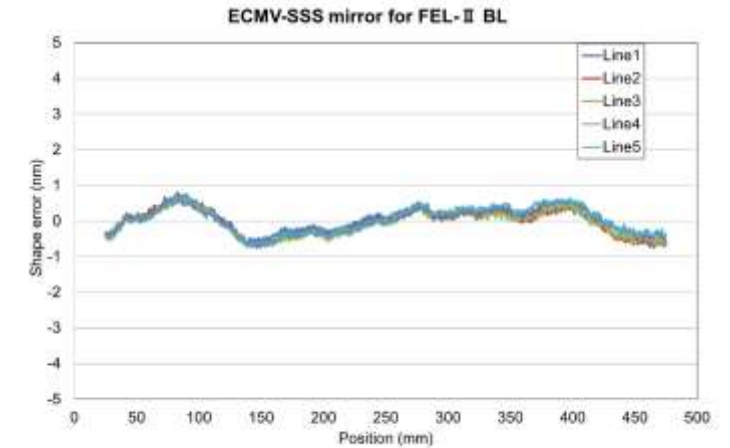
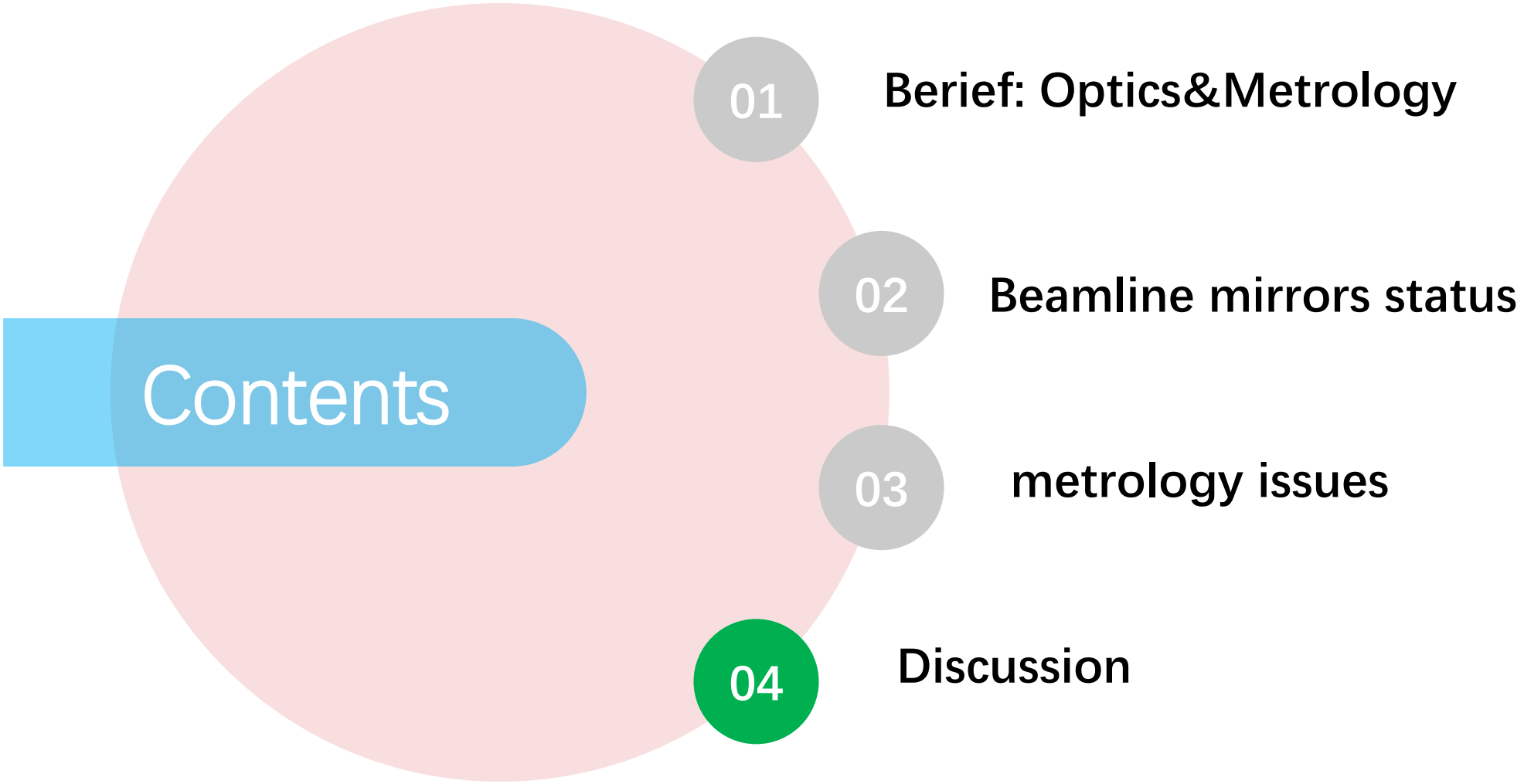


Figure 2-1: Tangential shape error profiles of ECMV-SSS mirror (X362001)

Mirror orientation: Horizontally



Contents

01

Berief: Optics&Metrology

02

Beamline mirrors status

03

metrology issues

04

Discussion

Summary and Discussion

Most of the mirrors are received but there are discrepancies between mirror makers and system integrator (FAT) and the SHINE side (SAT):

- different supporting configuration,
- small radius of curvature.

Following that:

- FEA simulation implemented for cross check. Is that sufficient for verification? any experiences on that?
- for small radius mirrors: oblique and stitching interferometry measuring are compared and evaluated for the SHINE mirrors. but still for radius $< 300\text{m}$ ones are challenging for current setup, any advice will be highly appreciated!

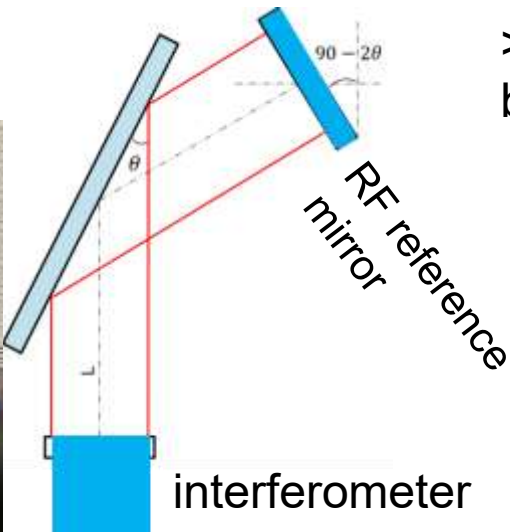


Thank you for your attention!



Metrology: oblique method

Oblique: grazing incidence interferometry

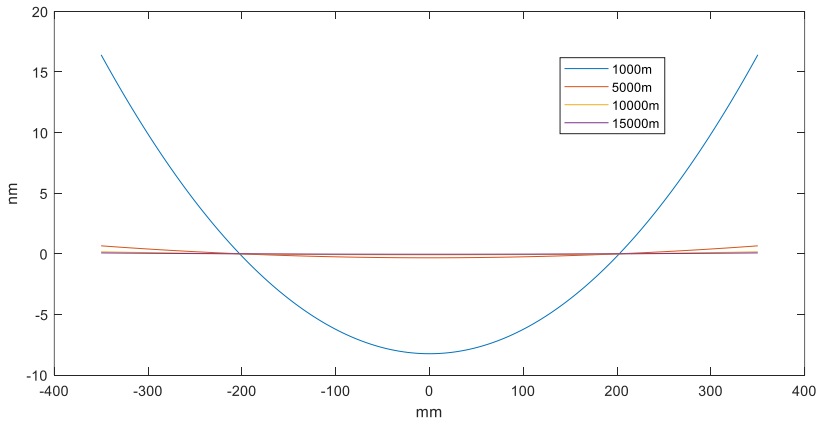
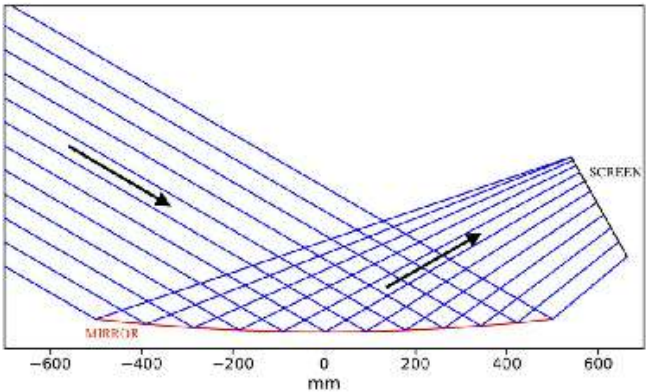
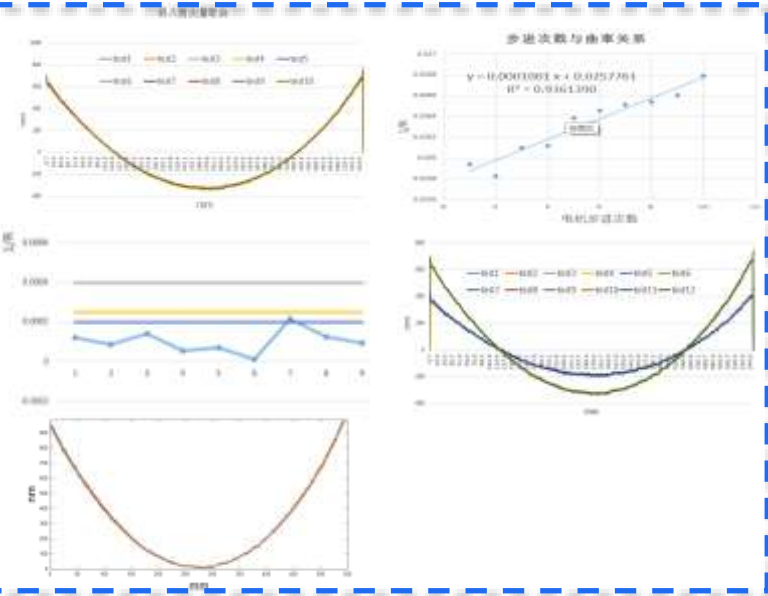


>> profile measurement, and bending “transfer function”

>> bending resolution

$$\Delta\left(\frac{1}{R}\right) = \frac{1}{R_{i+1}} - \frac{1}{R}$$

>> bending repeatability

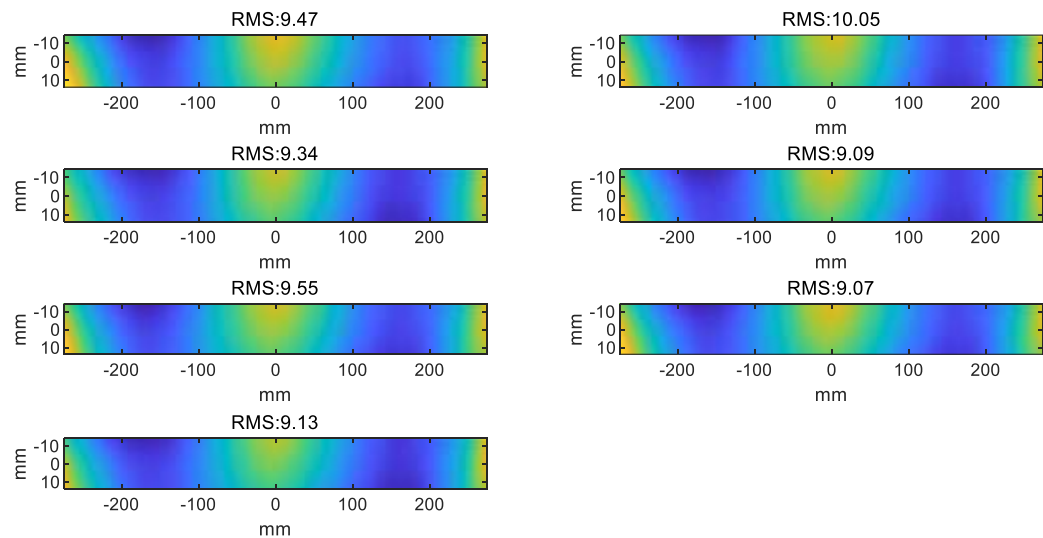


radius/m	1,000	5,000	10,000	15,000
retrace error/nm	24.66	0.99	0.25	0.11

Shape error : gravity sag. effects

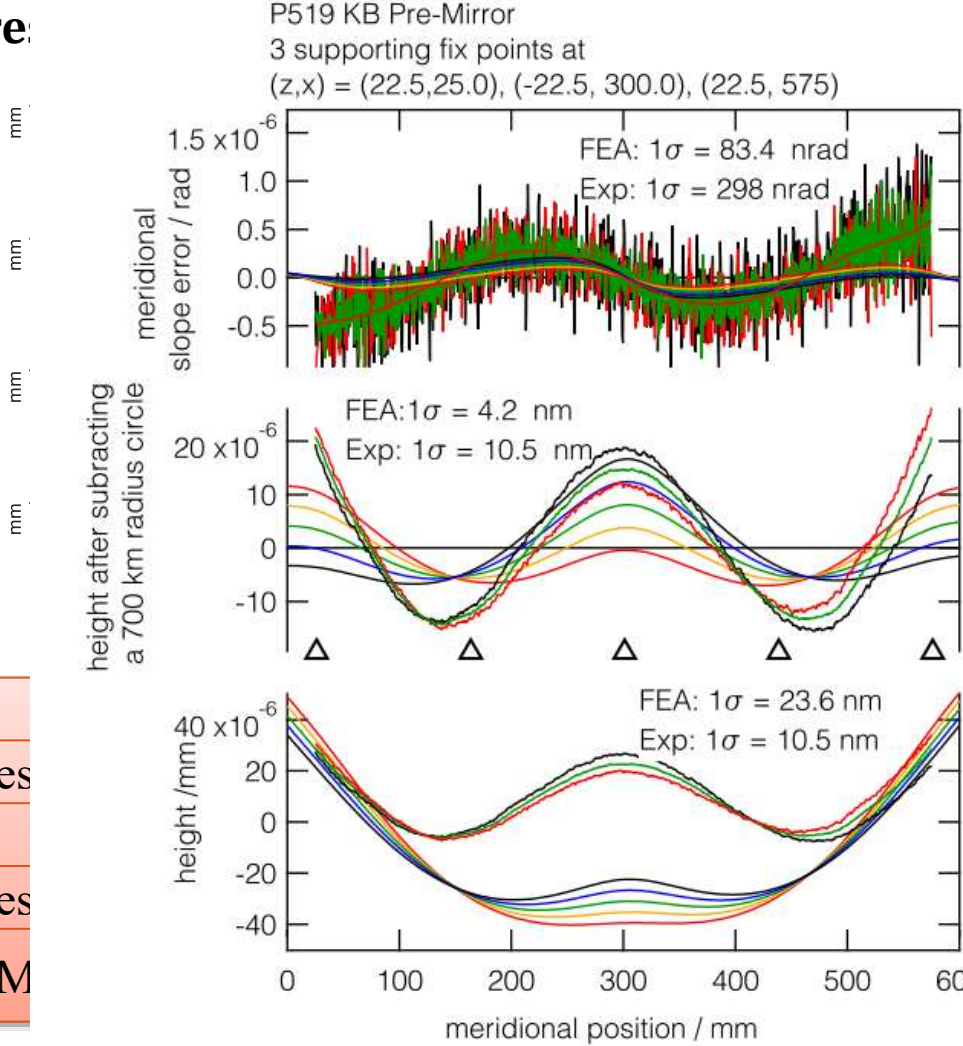
mounted with holder (without adjustment): gravity sag. NOT compensated

different measurements in the same condition



	M1	M2	M3	M4
RMS(map)/nm	9.47	10.05	9.34	9.09
	M5	M6	M7	
RMS(map)/nm	9.55	9.07	9.13	
STD of meas.	0.35 nm RMS			

re



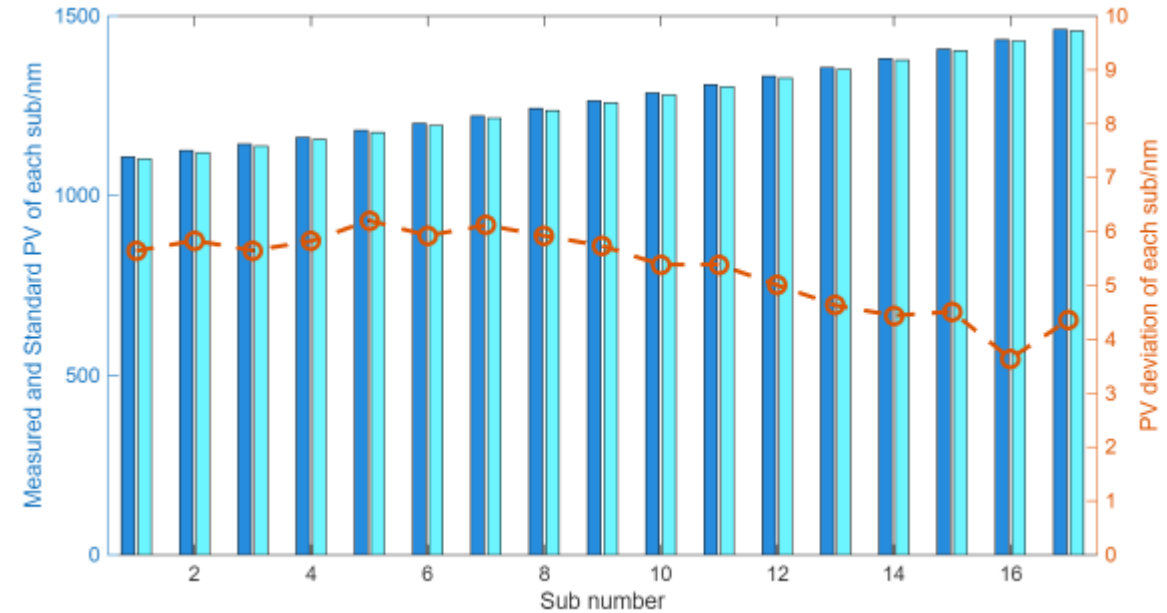
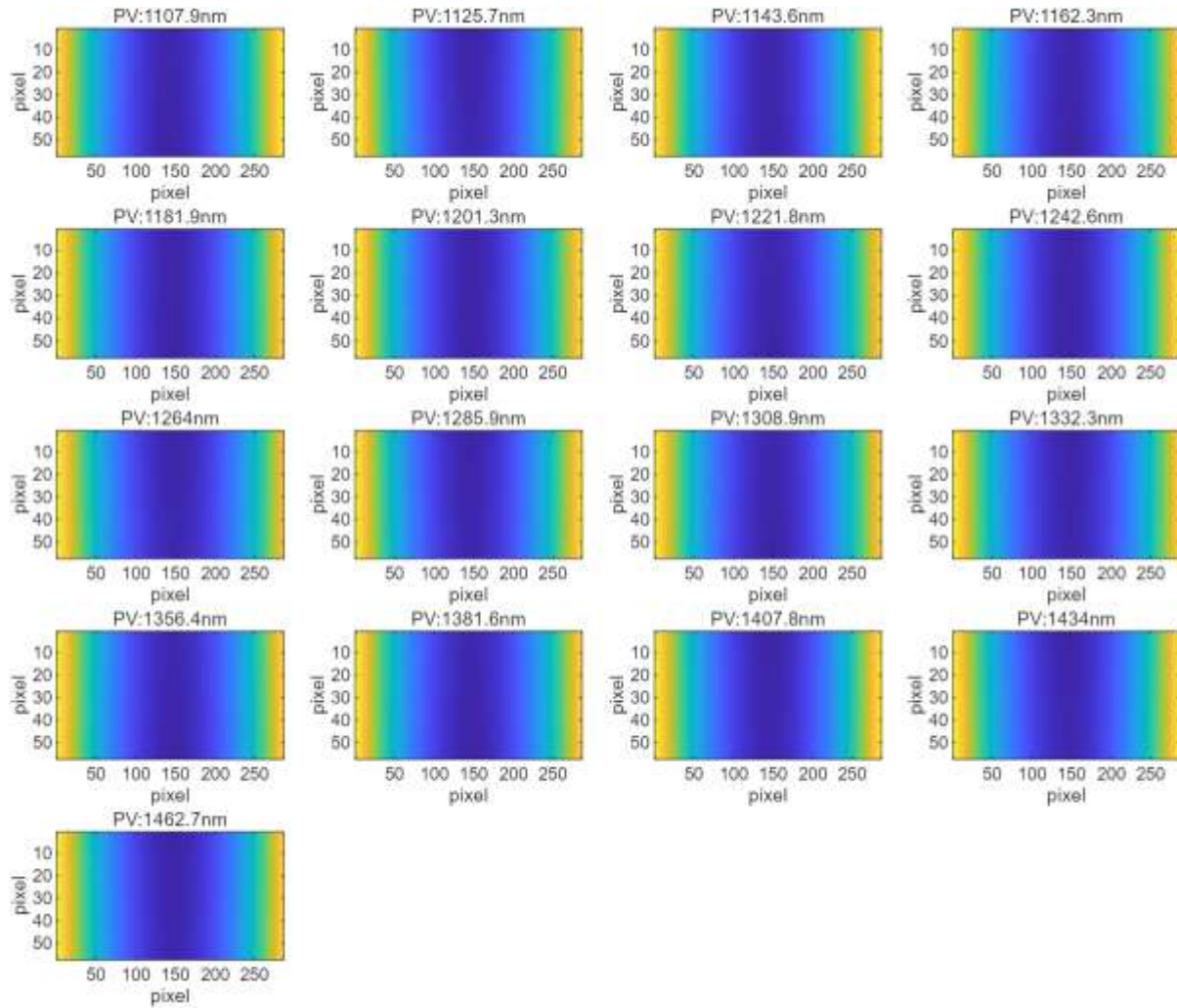
age



Res
Res
RM

M4
0.38

Measurement results of each sub-aperture (17x)



Comparison:
measured profile VS designed profile