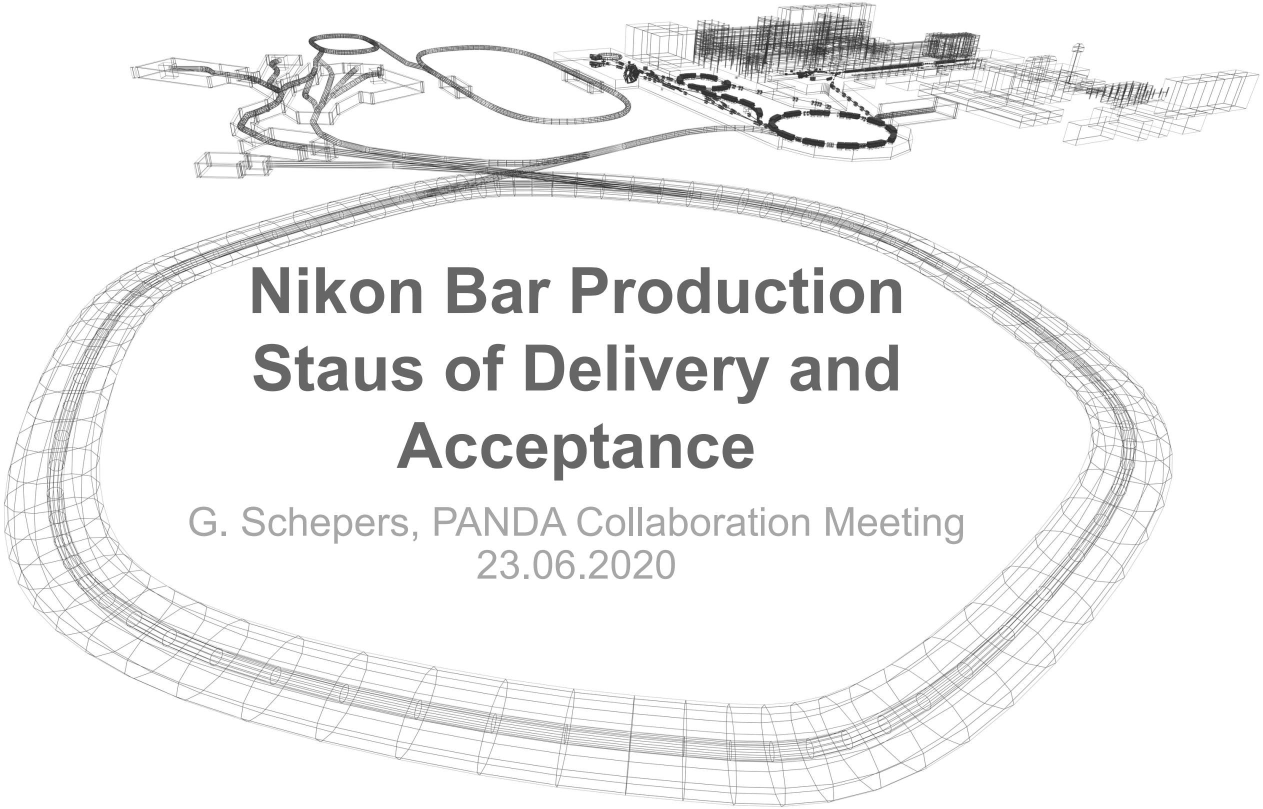


Nikon Bar Production Staus of Delivery and Acceptance

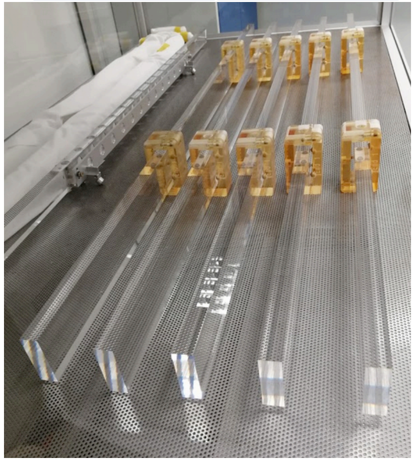
G. Schepers, PANDA Collaboration Meeting
23.06.2020

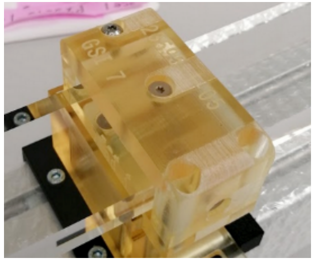
Reminder:

After more than 10 years of prototype program

- Q3 2019 — Call for tenders for Fused silica bars successful
- Sep 5, 2019 — Placed order for 98 bars with option for up to 8 more bars (need 96) with Nikon Corp, Japan.
- Sep 2019 — Production started
- March 20 — Received shipment of first lot (5 bars)

GSI	Nikon
1	P23595-1-04
2	P23595-1-08
3	P23595-1-18
4	P23595-1-19
5	P23595-1-20





Certificate of Compliance

THIS IS TO CERTIFY THAT ALL SYNTHETIC FUSED SILICA MATERIALS AND PARTS INCLUDED IN ALL SHIPMENTS ON THE FOLLOWING PURCHASE ORDER(S) HAVE BEEN PRODUCED IN CONFORMITY WITH THE REQUIREMENTS OF SPECIFICATIONS AND DRAWINGS LISTED ON THE PURCHASE ORDERS.

Customer Information			
Customer Name	GSI Helmholtzzentrum fur Schwerionenforschung GmbH		
Customer Part Name	Radiator Bar	PO No.	4500181248
Nikon Material Information			
Material Grade	NIFS-S	Lot No.	YKG04317-1
Nikon Reference No.	YKG04317	Material lot No.	P23595-1-04
		CofC Issue Date	2020/2/17
Raw Material Specifications'			
Internal Transmittance	≧99.9%/cm at 365nm		
Inclusions	No inclusions larger than 2μm		
Homogeneity	High optical homogeneity		
Striae	No significant visible striae		
Dimensional Specifications'			
Length	1200 +0/-0.5mm		
Width	53 +0/-0.5mm		
Thickness	17 +0/-0.5mm		
Parallelism	<0.5mrad		
Squareness	<0.5mrad		
TTV	<25μm		
Polished Specifications'			
Surface roughness (Faces and sides)	<5Å rms		
Surface roughness (Ends)	<10Å rms		
Edges	Sharp no bevel		
Surface quality	Total area of imperfections on bar surfaces and edges <75mm²		

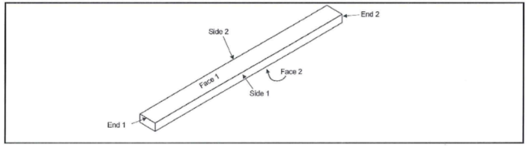
Comments :
Additional Data ((Y) / N)

Authorized Signature

NIKON CORPORATION
Production Department Production Technology Division
10-1, Asamizodai 1-chome, Minami-ku, Sagamihara-shi, Kanagawa 252-0328 Japan

Data Sheet

Date : 2020/2/17
Lot No. YKG04317-1
Material lot No. P23595-1-04
Polishing lot No. 1-1-1-1-1-1

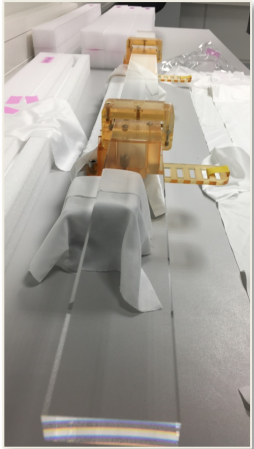


Item		Specification	tool / method	Result
Length [mm]	Side 1	1200+0/-0.5	CNC Measurement System	1199.89
	Side 2	1200+0/-0.5	CNC Measurement System	1199.89
Width [mm]	End1	53+0/-0.5	CNC Measurement System	52.91
	Middle	53+0/-0.5	CNC Measurement System	52.92
	End 2	53+0/-0.5	CNC Measurement System	52.91
Thikness [mm]	End1	17+0/-0.5	CNC Measurement System	16.95
	Middle	17+0/-0.5	CNC Measurement System	16.94
	End 2	17+0/-0.5	CNC Measurement System	16.94
Parallelism [mrad]	Face-Face	<0.5	CNC Measurement System	0.07
	Side-Side	<0.5	CNC Measurement System	0.30
Squareness [mrad]		<0.5	CNC Measurement System	Pass
Surface roughness [Å RMS]	Face 1	<5	Zygo "NewView"	3.5
	Face 2	<5	Zygo "NewView"	2.8
	Side 1	<5	Zygo "NewView"	4.9
	Side 2	<5	Zygo "NewView"	4.5
	End 1	<10	Zygo "NewView"	5.1
	End 2	<10	Zygo "NewView"	6.1
TTV [μm]	Face-Face	<25	CNC Measurement System	13.9
	Side-Side	<25	CNC Measurement System	13.0
Edges		Sharp no bevel	Visual inspection	Pass
Surface quality	Total area of imperfections on bar surface and edges	<75mm²	Visual inspection	Pass
Total				Pass

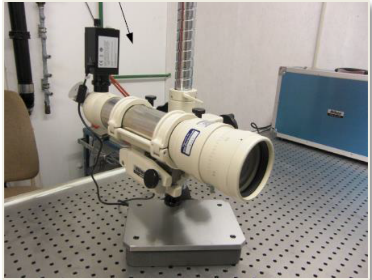
Nikon QA data looks very good, all specs are met or exceeded

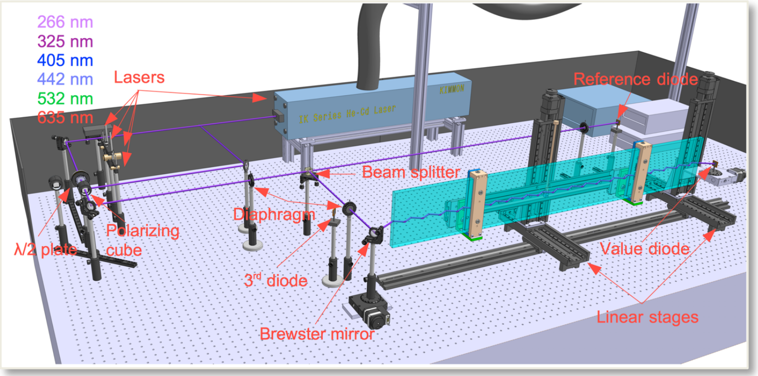
- Surface roughness
  face/side < 5Å
  end < 10Å
- Parallelism < 0.5 mrad
- Squareness < 0.5 mrad
- TTV < 25 µm

Date		bar numer		Lot	Polishing						Length		Width			Thickness			Parallelism		
Nikon QA	Received	GSI	Nikon	Material	Polishing						Side 1	Side 2	End 1	Middle	End 2	End 1	Middle	End 2	Face-Face	Side-Side	Fa
2/17/2020	3/4/2020	1	P23595-1-04	YK04317-1	1	1	1	1	1	1	1199.89	1199.89	52.91	52.92	52.91	16.95	16.94	16.94	0.07	0.30	
2/17/2020	3/4/2020	2	P23595-1-08	YK04317-1	1	1	2	1	1	2	1199.75	1199.74	52.78	52.78	52.78	16.95	16.95	16.95	0.05	0.08	
2/17/2020	3/4/2020	3	P23595-1-18	YK04317-1	1	1	2	1	1	1	1199.89	1199.89	52.90	52.91	52.91	16.95	16.95	16.95	0.01	0.04	
2/17/2020	3/4/2020	4	P23595-1-19	YK04317-1	1	1	2	1	1	1	1199.87	1199.87	52.92	52.91	52.92	16.95	16.95	16.95	0.05	0.37	
2/17/2020	3/4/2020	5	P23595-1-20	YK04317-1	1	1	1	1	1	1	1199.89	1199.90	52.91	52.92	52.91	16.95	16.94	16.94	0.10	0.12	



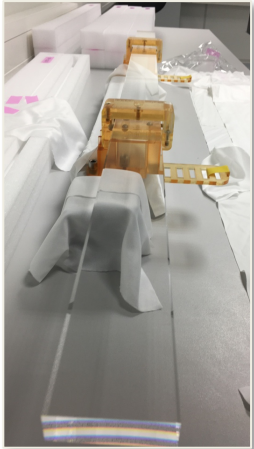
Visual inspection





Quality of internal bar surface (laser scanning system)

Bar shape (laser and autocollimator)

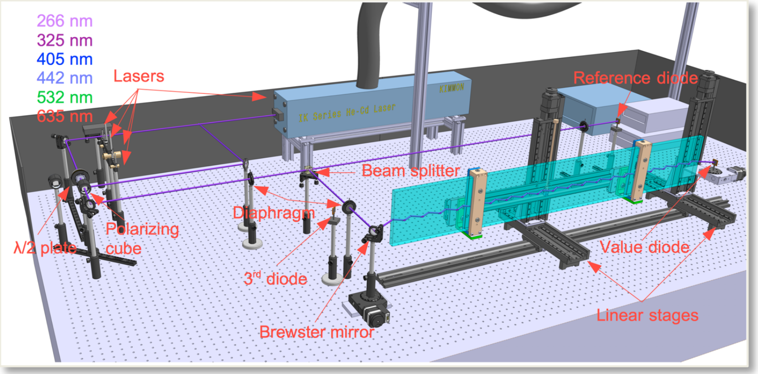


Visual inspection

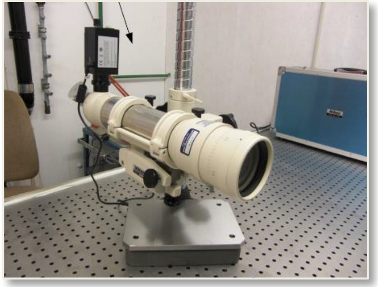
- At first glance (eye, halogen light):
- clean surfaces, no residue from cleaning or packing, very sharp corners

- At second glance (Laser scanning setup):
- shift of beam spot when bar is scanned through laser

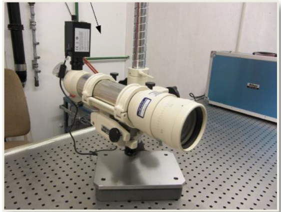
- At third glance (Autocollimator)
- “perfect” parallelism of faces
- fuzzy image for parallelism of sides



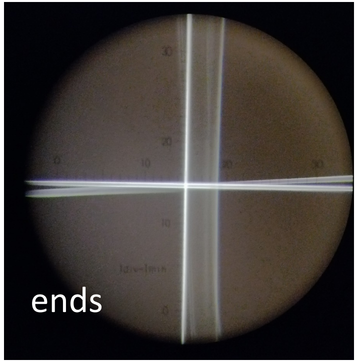
Quality of internal bar surface (laser scanning system)

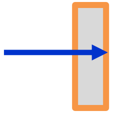


Bar shape (laser and autocollimator)

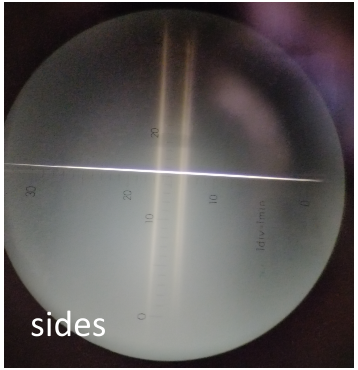


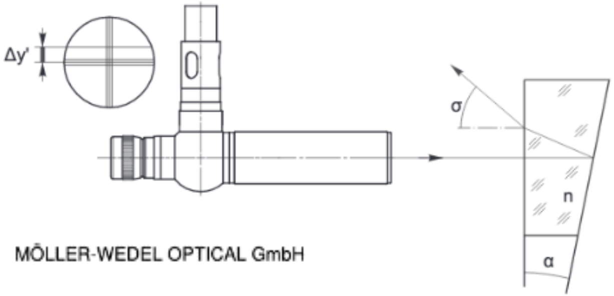
Faces show “perfect” parallelism
Crosshairs overlay each other





Ends and sides show fuzzy image
Values for parallelism and squareness can not be determined

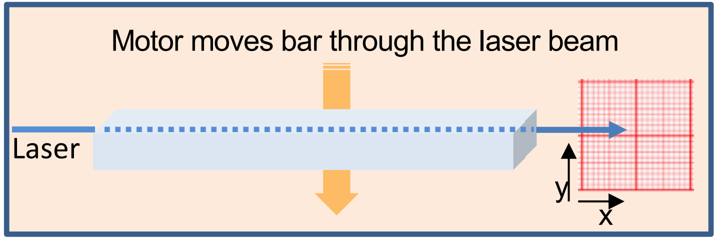


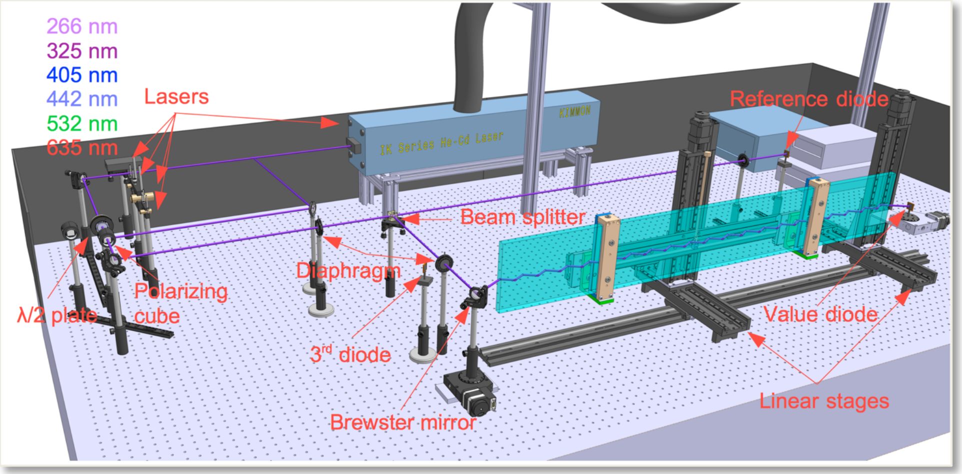


When the laser beam passes straight though the bar,
the shape of the sides has not influence.

Any deviation of the laser spot position on the wall
from the initial position provides hints regarding
refractive index variations over the bulk.

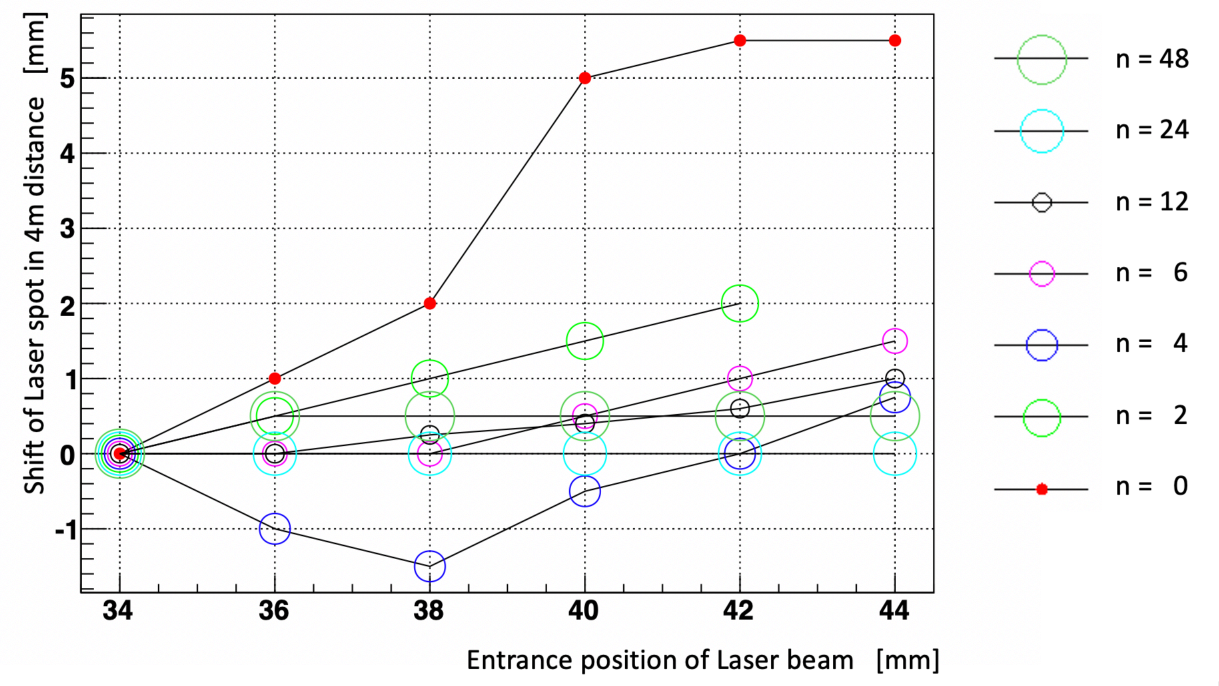
The deviation can be in the x- and/or y-direction.





Laser tests – effect after internal reflections

Primary photon propagation direction in a DIRC is along the length of the bar – check if the effect is larger or similar for photons bouncing never/few times/many times between the two bar faces



- n: number of internal reflections
- The bar was scanned over its thickness from face2 to face one
- The shift is shown relative to the spot position of each first laser entrance

Impact of effect is smaller for larger internal photon angles

Laser scanning setup – measurements

Beam steering made our usual laser scanning measurements more complicated but not impossible.

Determined transmission probability (along long bar axis) and

coefficient of total internal reflection (48 reflections)

Transmission scan examples:

T ≈ 99.6%/120cm at 442nm (bar 1)

T ≈ 98.2%/120cm at 325nm (bar 3)

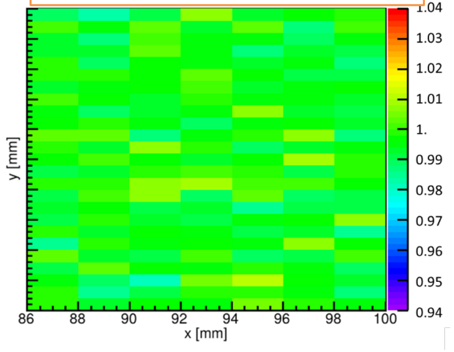
Reflection coefficient examples:

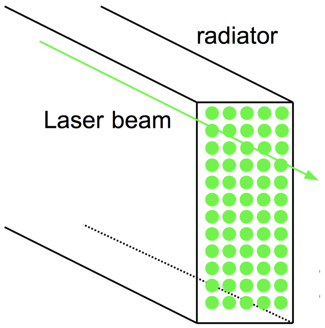
R ≈ 0.9998 at 442nm (bar 2)

R ≈ 0.9984 at 325nm (bar 3)

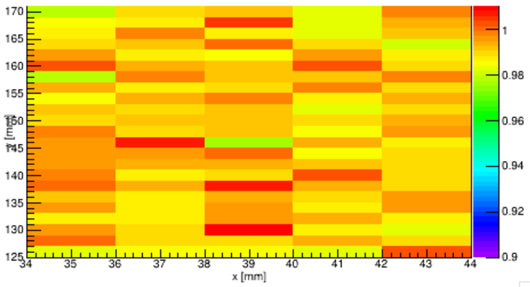
Good T/R results so far, meet DIRC requirements

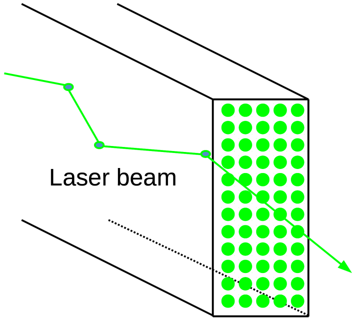
Intensity – Transmission #1





Intensity – 48 reflections #2





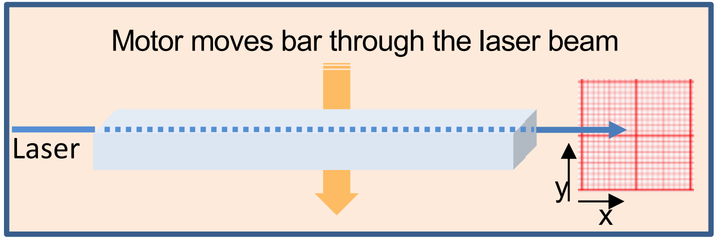
Steering of Laser Beam by the Bulk Material

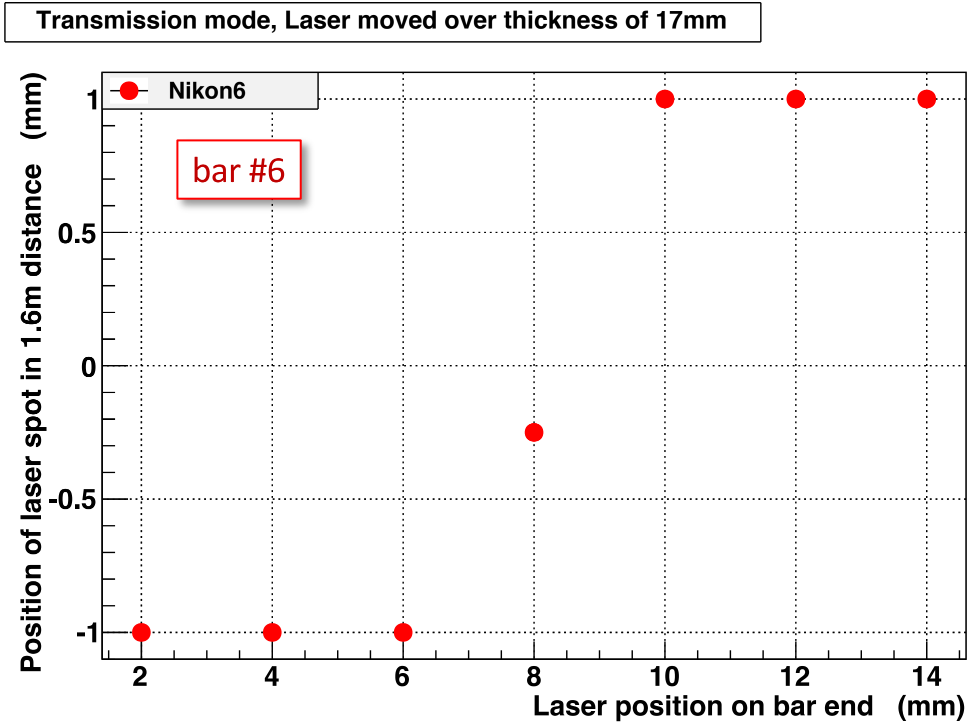
When the laser beam passes straight though the bar, the shape of the sides has not influence.

Any deviation of the laser spot position on the wall from the initial position provides hints regarding refractive index variations over the bulk.

(note that bar ends were found to be flat)

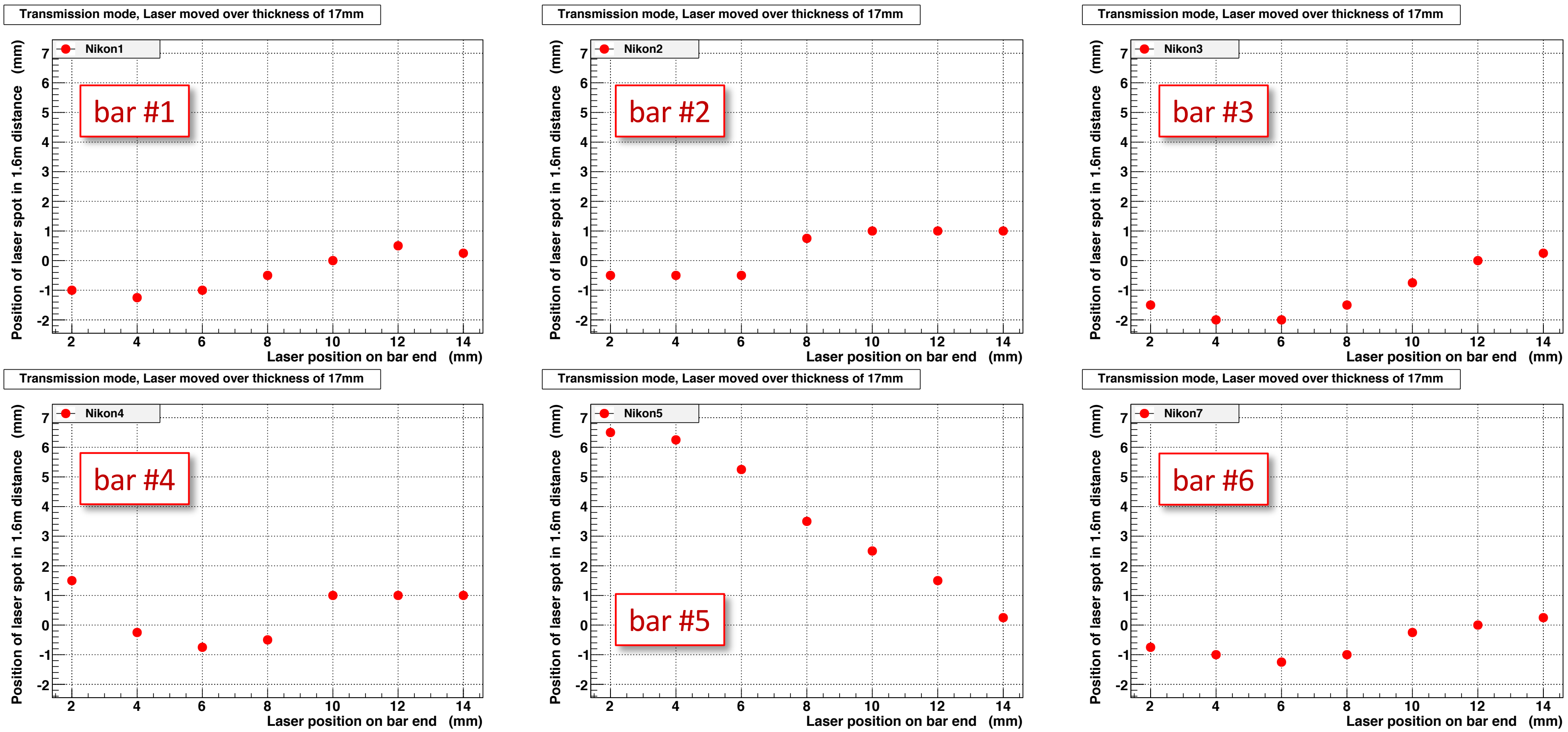
The deviation can be in the x- and/or y-direction.





Observed position shift during thickness (17mm) scan

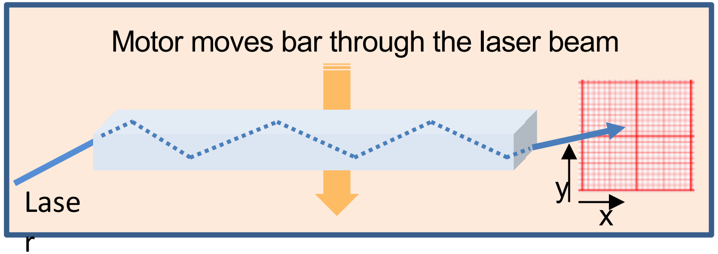
Bulk Beam Steering (thickness scan, y deflection)



Shift of Internally Reflected Laser Beam

Propagation of light inside of the bar with multiple internal reflections is the ”normal” use-case in the DIRC.

The bar is moved (by the motor) through the laser beam, the beam is reflected internally 16 times from the sides

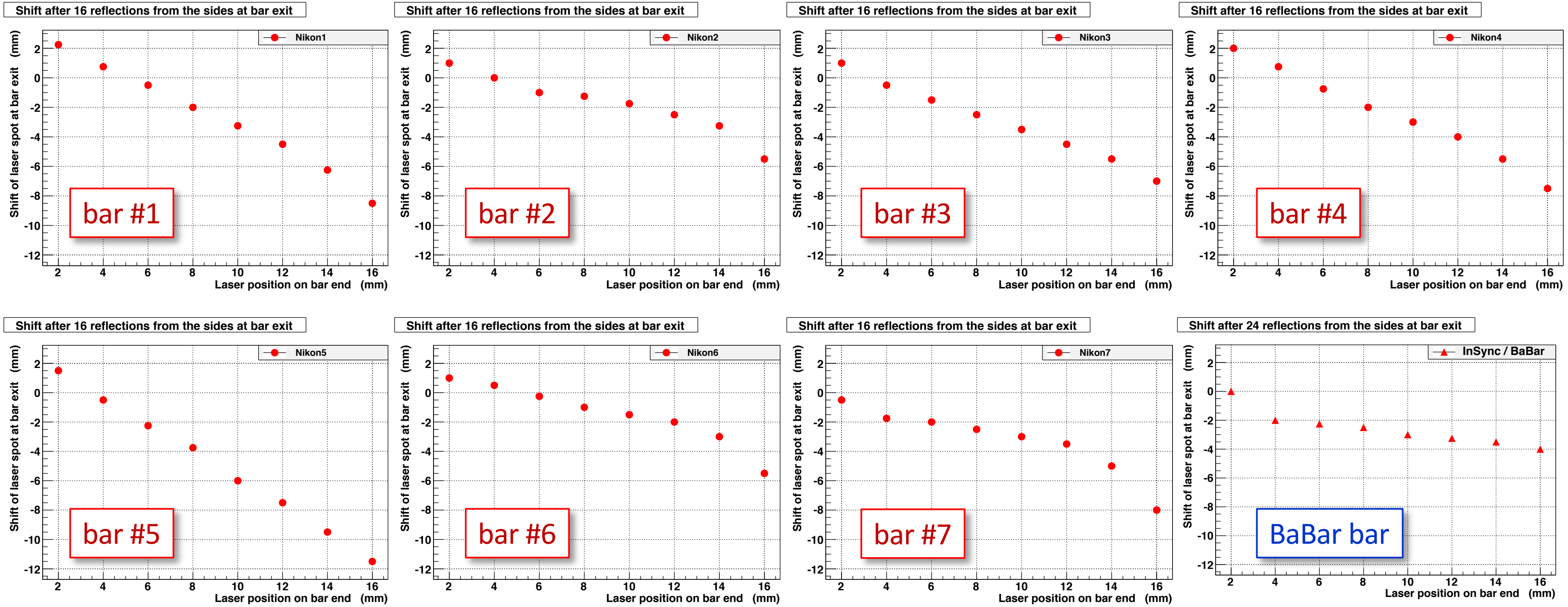


The laser beam should remain at the same height inside the bar and exit at the same height it enters the bar.

The laser spot on the wall ought to always be at the same position.

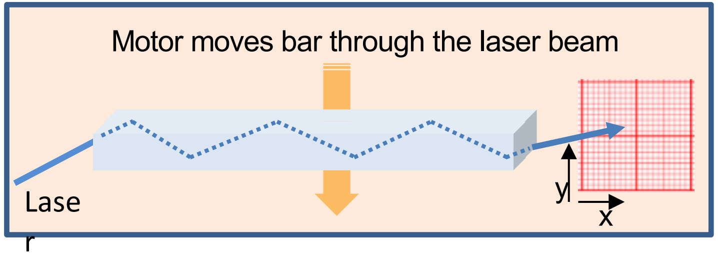
Any shift of the laser spot is a sign of reflections from a non-flat surface and/or steering from layers of varying refractive indices (striae).

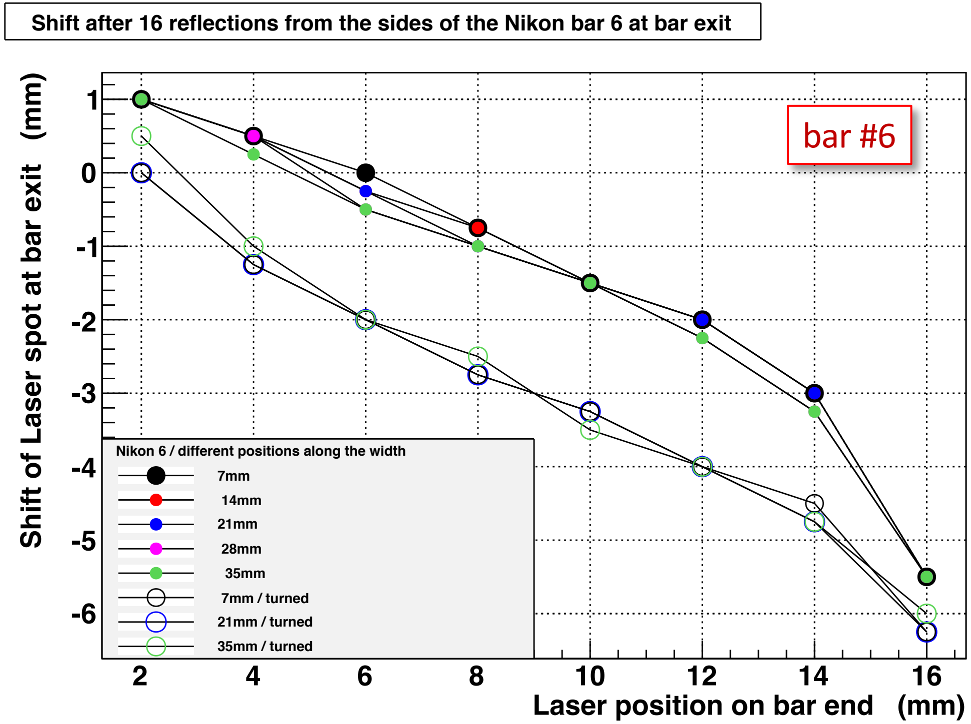
Shift of Internally Reflected Laser Beam



"bulk steering effect" from side reflections 2-3 times larger for Nikon bars than for BaBar bar

Shift of Internally Reflected Laser Beam





Detailed scan for bar #6, different laser entry positions

No significant dependence of entry position along width

Consistent result if bar is turned (end 1 -> end 2)

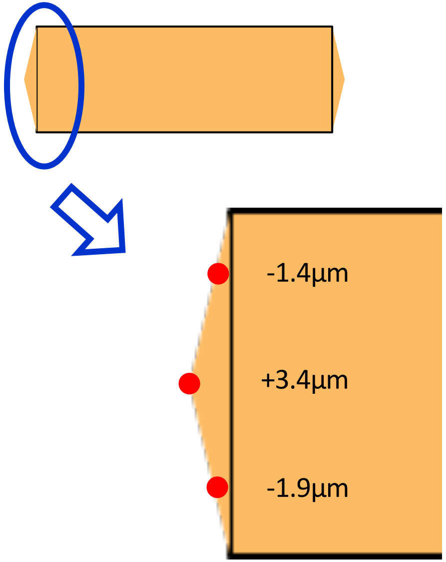
Observed "beam steering" results for all Nikon bars consistent with reflections from non-flat surfaces and/or steering from layers of varying refractive indices (striae) *(cannot be distinguished by this method)*.

Side Shape Deviation

Study of 17 mm side shape deviation

(initial impression was an approximate convex shape)

Simplified model: triangle approximation



Use spreadsheet with Nikon CMM measurement data (Apr 2020)

to visualize shape and calculate effective angle deviation

Example for side 1 of bar 3 near bar middle:

“sagitta” ≈ 4.8 µm – 5.3 µm

“local angle” = sagitta/distance

≈ +0.7 mrad at top, -0.7 mrad at bottom

● Nikon CMM example bar 3, side 1

533.7
-1.4
3.4
-1.9

Side Shape Deviation

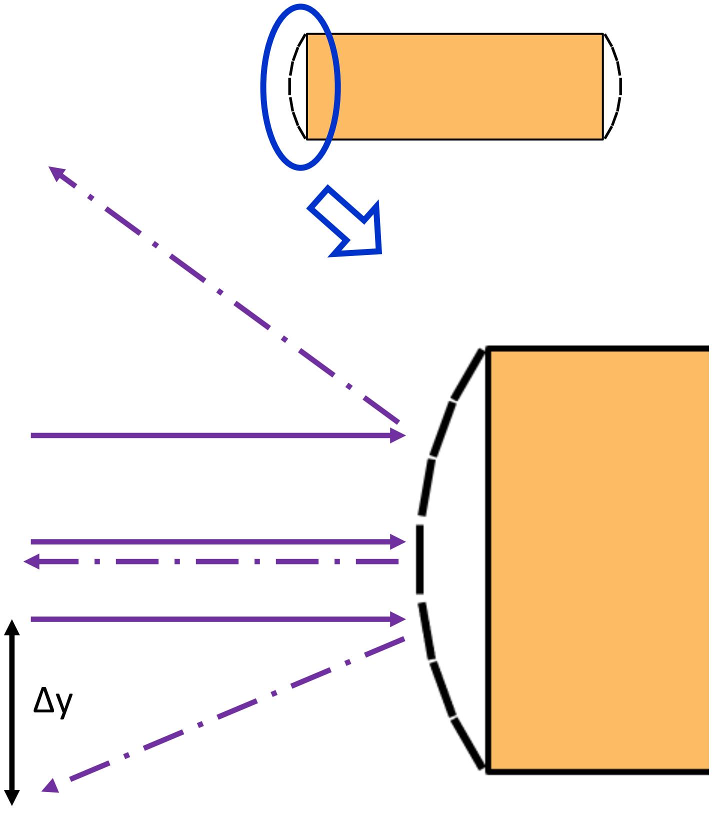
Check of deformation using external laser reflection

Simplified model: polygonal approximation

Laser beam deflected by local surface

Record laser spot displacement Δy

for different positions along 17 mm side



Side Shape Deviation

Check of deformation using external laser reflection

Example result for one position along bar length for bar 3

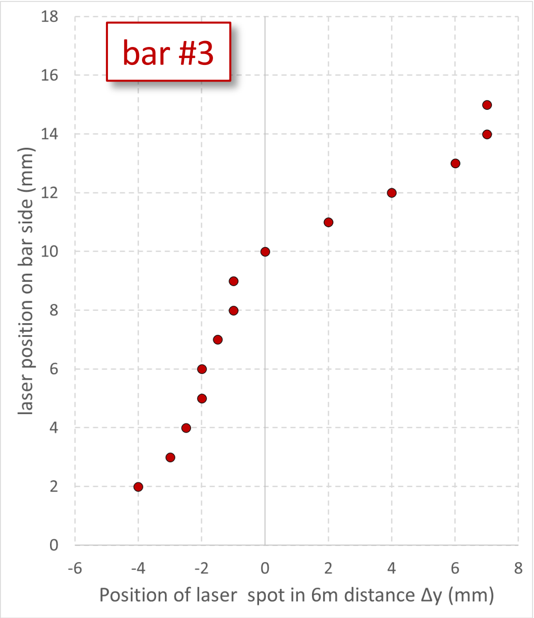
- large positive laser spot displacement near top of side
- no displacement near middle of side
- large negative displacement near bottom of side

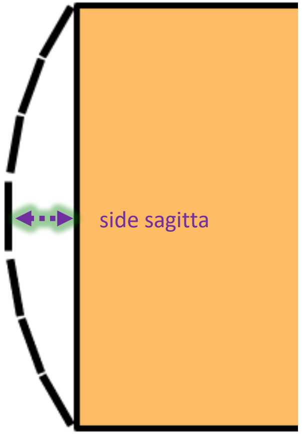
Calculate local angle θ, local sagitta Δx, side sagitta:

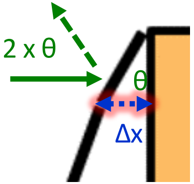
θ ≈ 0.05…0.15 mrad

Δx ≈ 0.04…0.16 µm

side sagitta ≈ 0.6 µm





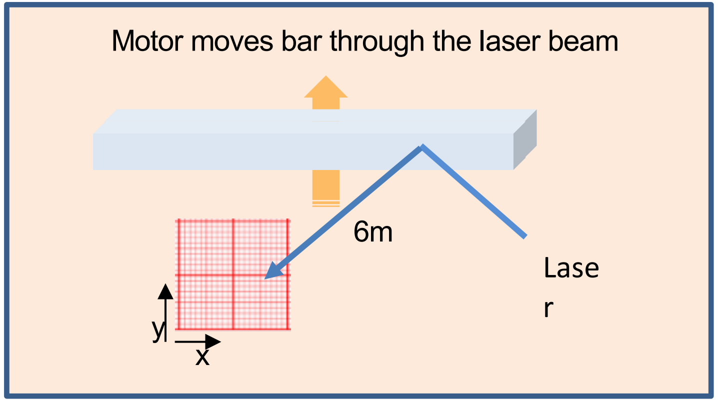


Values differ for bars and positions along length (same seen in CMM data)

Qualitative agreement: convex shape with few micron sagitta (details vary due to difference in measurement location)

Side Shape Deviation

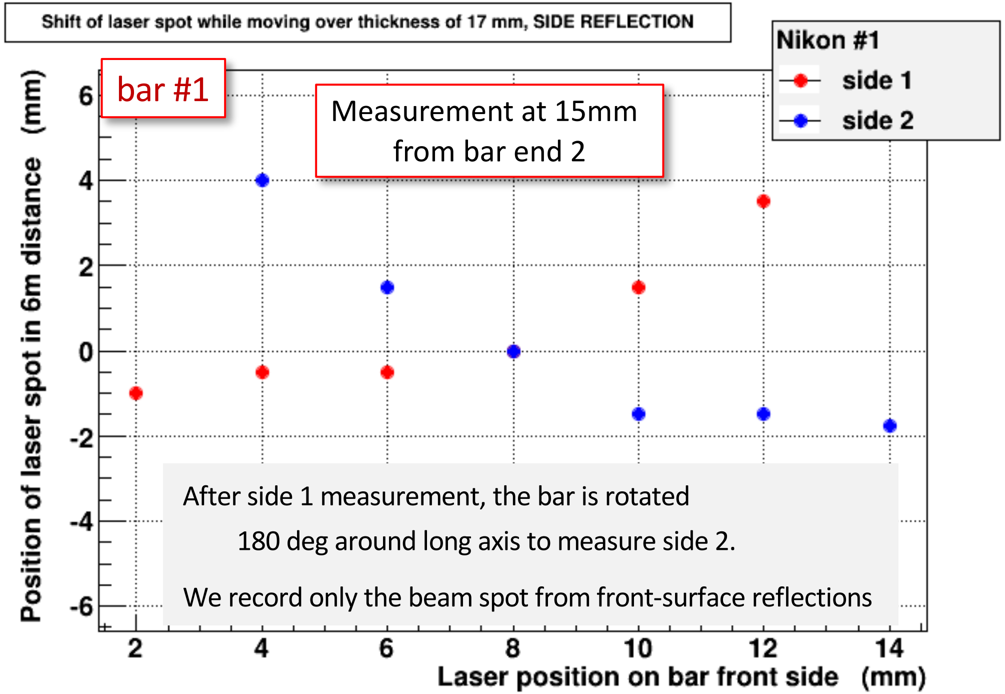
Study of laser beam deflection from the sides



A flat surface would result in a constant beam spot position across the bar side.

A slope is caused by a convex or concave surface.

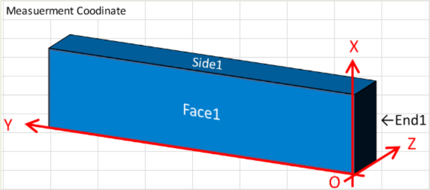
The reflection measurements from all bars (see following pages) show a slope consistent with different non-flat (convex/concave/sloped line) shapes



Side Shape Deviation

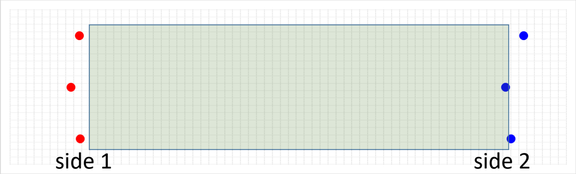
Side1		1197
z mm	15.5	1.3
	8.5	2.4
	1.5	1.2
Side2		**1197**
z mm	1.5	0.0
	8.5	-0.7
	15.5	1.6

CMM values Nikon
at 3mm from End2

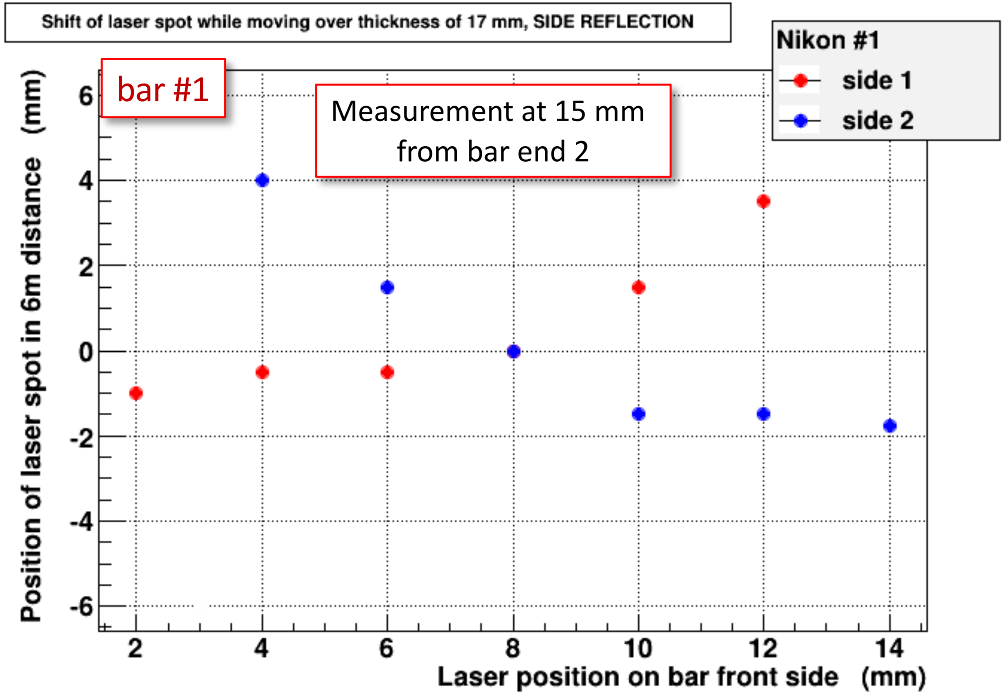


convex

concave



(positions calculated from CMM data, deviation from reference scaled by factor 1000)



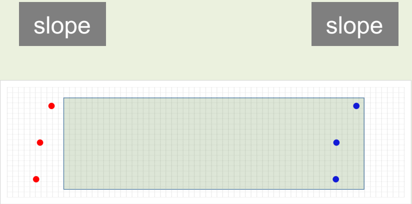
The crossed lines are consistent with
side surfaces with opposite curvature (convex plus concave)

Side Shape Deviation

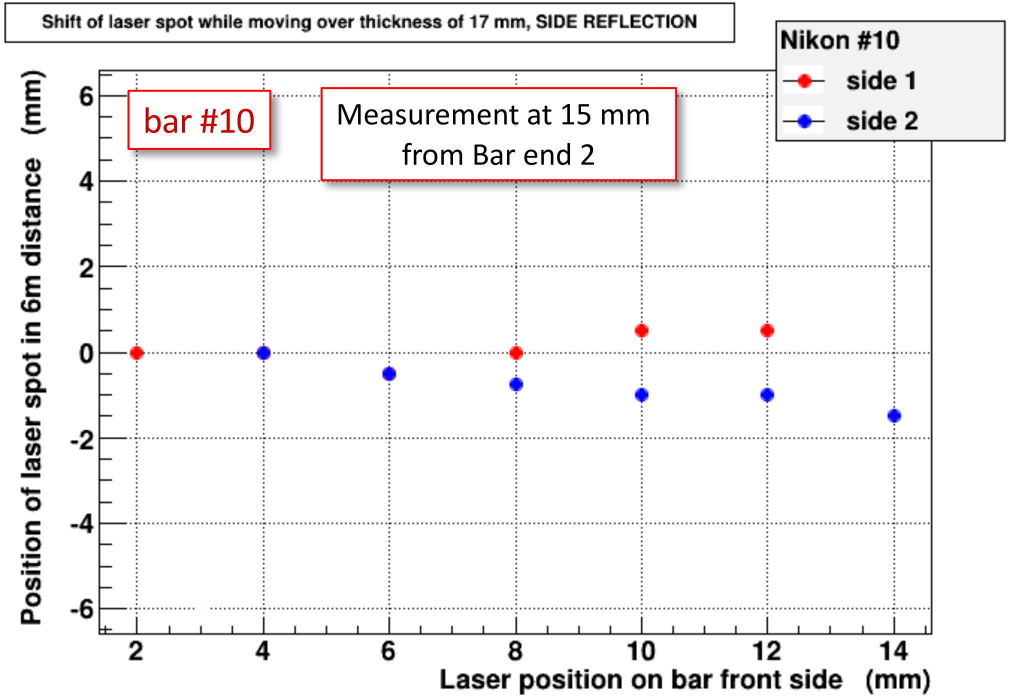
Measurements Nikon
at 3 mm from End2

Side1		1197
z mm	15.5	2.2
	8.5	4.2
	1.5	4.9

Side2		1197
z mm	1.5	-5.1
	8.5	-5.0
	15.5	-1.5



(we refer to shapes where the deviation increases across the thickness as "slope", the shape may be close to convex/concave; if the values increase, then decrease, we refer to the shape as "convex" or "concave")

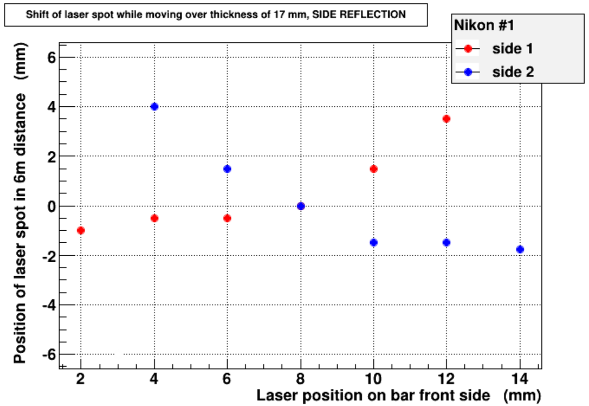


The non-crossing lines are consistent with "almost straight" slopes of the side surfaces.

The following measurements (next 3 pages) show that, consistent with the Nikon CMM data, the first impression of only convex shaped sides surface was too simple; bar shapes deviations are more complex and vary along bar length.

Side Shape Deviation

bar #1



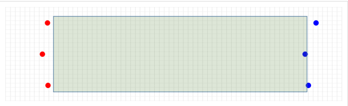
Measurements Nikon
at 3 mm from End2

Side1		1197
Z mm	15.5	1.3
	8.5	2.4
	1.5	1.2

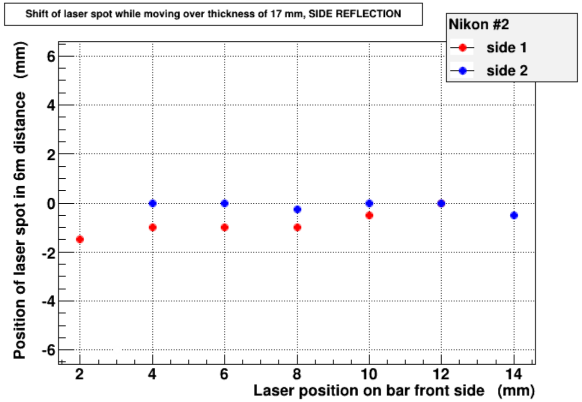
Side2		1197
Z mm	1.5	0.0
	8.5	-0.7
	15.5	1.6

convex

concave



bar #2

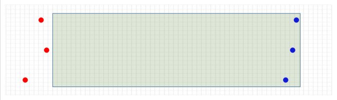


Side1		1197
Z mm	15.5	2.5
	8.5	1.3
	1.5	5.9

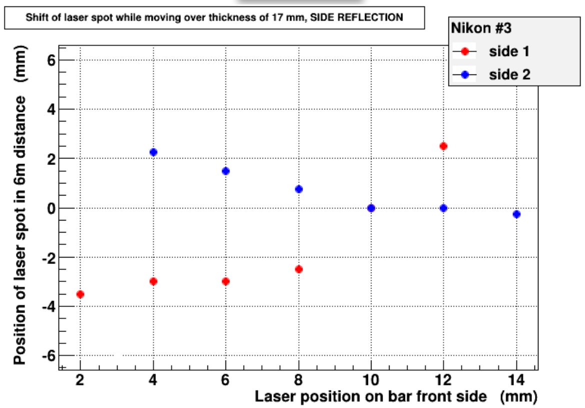
Side2		1197
Z mm	1.5	-2.9
	8.5	-1.4
	15.5	-0.6

concave

slope



bar #3

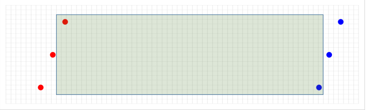


Side1		1197
Z mm	15.5	-1.7
	8.5	0.7
	1.5	3.1

Side2		1197
Z mm	1.5	-0.9
	8.5	1.1
	15.5	3.4

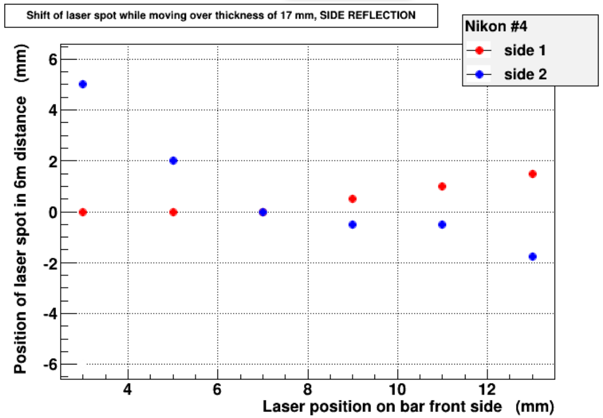
slope

slope



Side Shape Deviation

bar #4

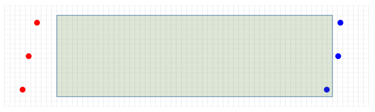


Side1		1197
Z mm	15.5	3.8
	8.5	5.4
	1.5	6.6

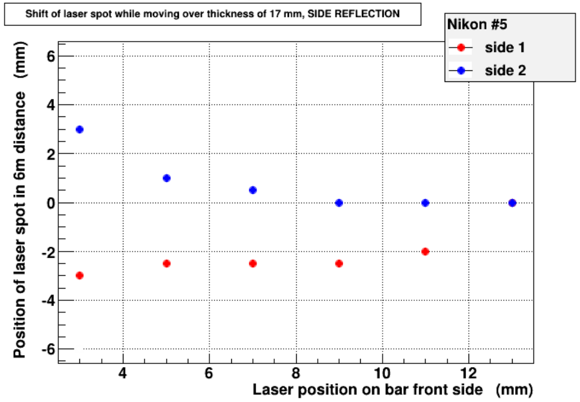
Side2		1197
Z mm	1.5	-1.1
	8.5	1.1
	15.5	1.5

slope

slope



bar #5

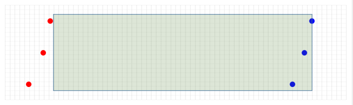


Side1		1197
Z mm	15.5	0.8
	8.5	2.2
	1.5	5.2

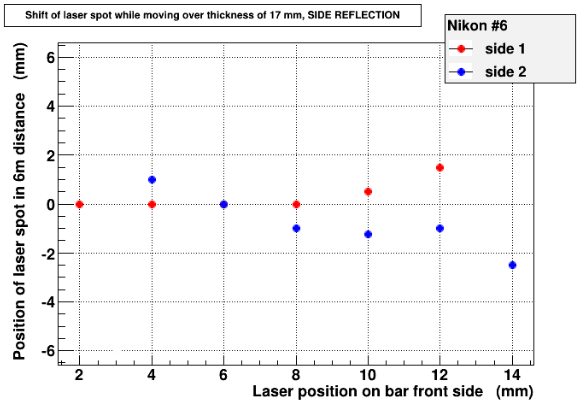
Side2		1197
Z mm	1.5	-4.1
	8.5	-1.6
	15.5	-0.1

slope

slope



bar #6

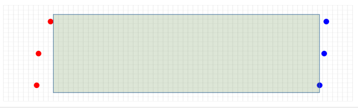


Side1		1197
Z mm	15.5	0.6
	8.5	3.0
	1.5	3.4

Side2		1197
Z mm	1.5	0.4
	8.5	1.3
	15.5	1.7

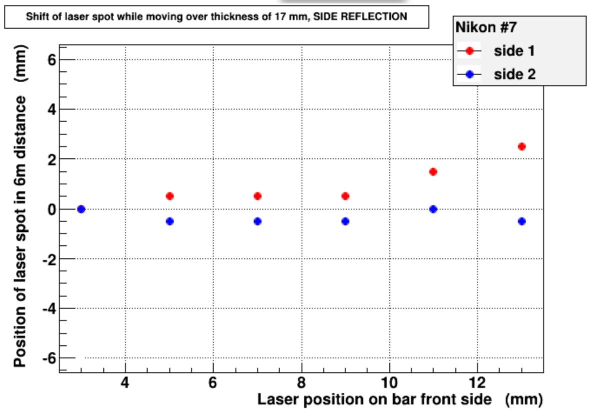
slope

slope



Side Shape Deviation

bar #7

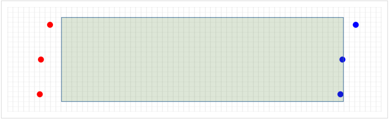


Side1		1197
Z mm	15.5	2.1
	8.5	3.8
	1.5	4.0

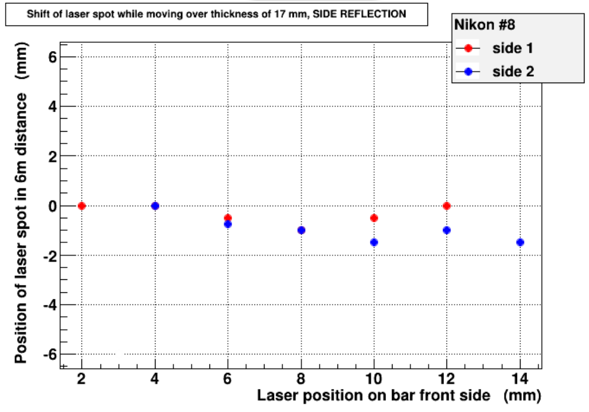
Side2		1197
Z mm	1.5	-0.7
	8.5	-0.3
	15.5	2.2

slope

slope



bar #8

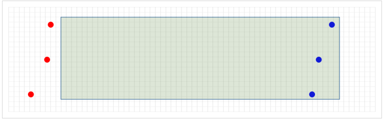


Side1		1197
Z mm	15.5	2.0
	8.5	2.7
	1.5	5.8

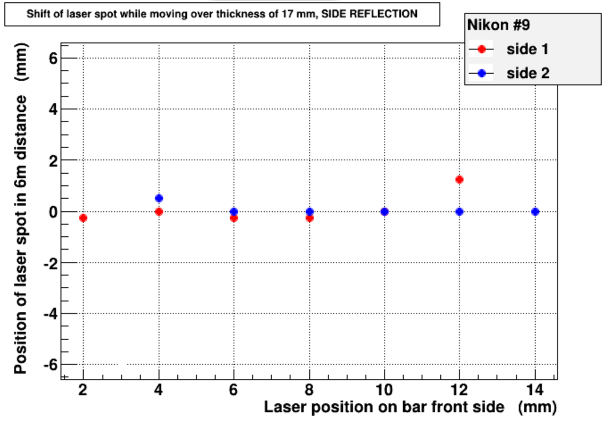
Side2		1197
Z mm	1.5	-5.1
	8.5	-3.8
	15.5	-1.3

slope

slope



bar #9

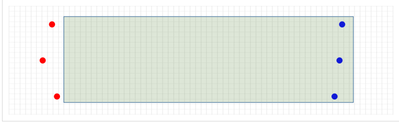


Side1		1197
Z mm	15.5	2.2
	8.5	3.9
	1.5	1.3

Side2		1197
Z mm	1.5	-3.7
	8.5	-2.8
	15.5	-2.3

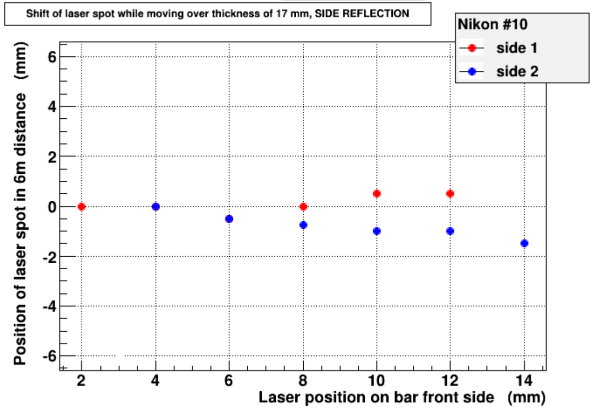
convex

slope



Side Shape Deviation

bar #10

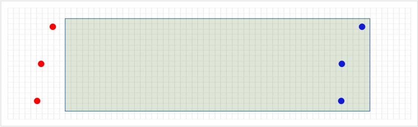


Side1		1197
z mm	15.5	2.2
	8.5	4.2
	1.5	4.9

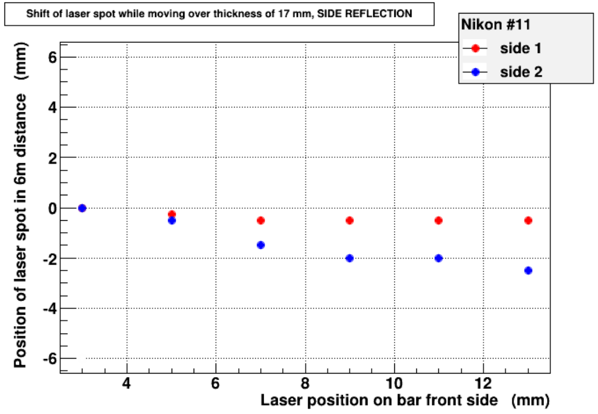
Side2		1197
z mm	1.5	-5.1
	8.5	-5.0
	15.5	-1.5

slope

slope



bar #11

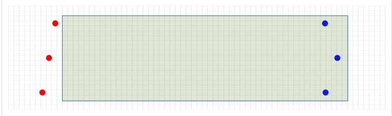


Side1		1197
z mm	15.5	1.3
	8.5	2.5
	1.5	3.7

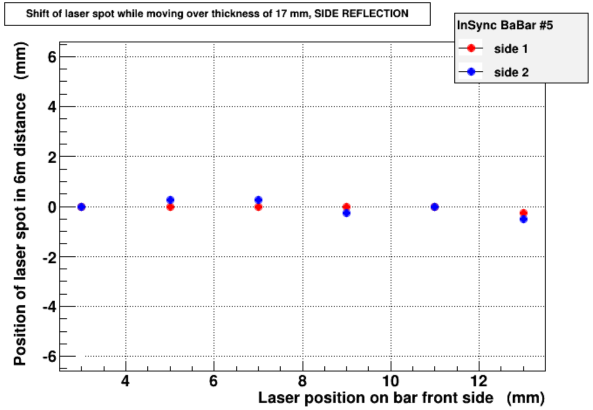
Side2		1197
z mm	1.5	-4.1
	8.5	-1.9
	15.5	-4.2

slope

convex

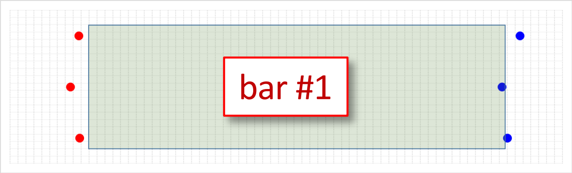


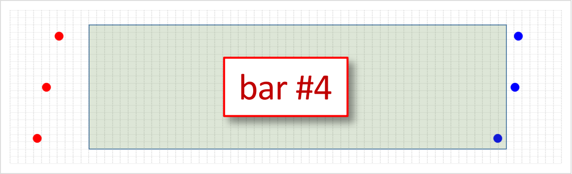
BaBar bar #5

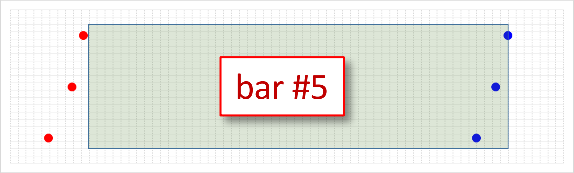


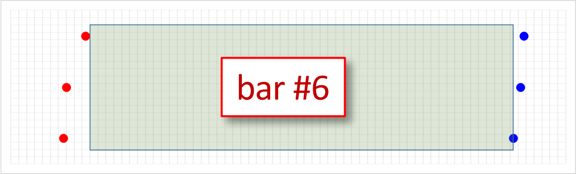
The two flat lines of the BaBar bar measurements overlap and are consistent with flat parallel surfaces.

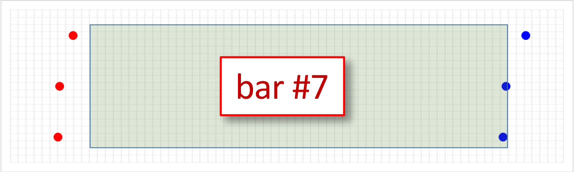
Summary of Bar Shape Examples from CMM

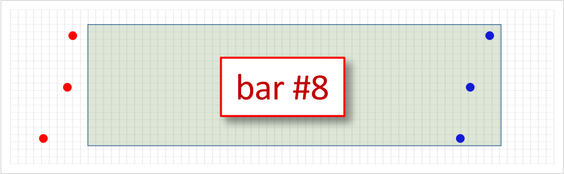


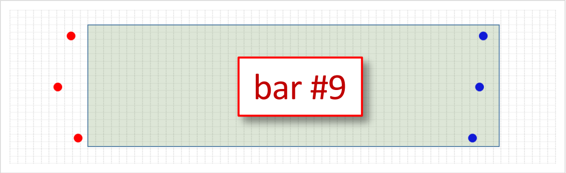












Deviations from ideal bar shape shown for narrow sides, position 3mm from End 2

(Nikon CMM data, deviation scaled by factor 1000.)

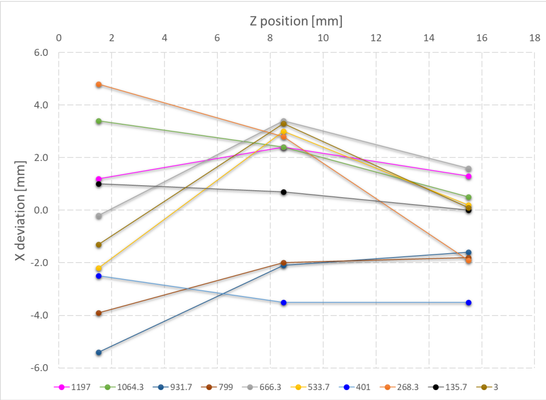
Summary of Bar Shape Examples from CMM

GSI number	Nikon number		side 1											side 2									
1	P23595-1-04		convex	slope	slope	slope	convex	convex	concave	slope	slope	convex		concave	convex	convex	convex	convex	slope	convex	convex	convex	slope
2	P23595-1-08		concave	convex	concave	convex	convex	slope	concave	slope	concave	convex		slope	convex	slope	slope	convex	convex	slope	slope	convex	slope
3	P23595-1-18		slope	slope	slope	slope	convex	convex	slope	concave	slope	slope		slope	slope	slope	slope	convex	convex	slope	slope	convex	slope
4	P23595-1-19		slope	convex	slope	slope	concave	convex	slope	slope	convex	slope		slope	convex	slope	slope	slope	slope	slope	slope	convex	convex
5	P23595-1-20		slope	slope	convex	slope	convex	convex	slope	convex	slope	slope		slope	convex	slope	slope	convex	convex	slope	slope	convex	slope
6	P23595-1-03		slope	concave	slope	slope	convex	convex	slope	slope	convex	slope		slope	convex	convex	convex	convex	convex	slope	convex	convex	slope
7	P23595-1-05		slope	convex	slope	slope	slope	concave	slope	slope	convex	slope		slope	slope	slope	convex	convex	concave	concave	concave	convex	convex
8	P23595-1-07		slope	convex	slope	slope	convex	slope	convex	slope	slope	slope		slope	slope	slope	slope	convex	slope	slope	slope	convex	slope
9	P23595-1-09		convex	convex	convex	concave	slope	convex	concave	concave	slope	slope		slope	convex	slope	slope	convex	convex	slope	slope	convex	slope
10	P23595-1-13		slope	convex	slope	slope	convex	convex	slope	slope	convex	slope		slope	convex	slope	slope	slope	slope	concave	slope	convex	convex
11	P23595-1-15		slope	convex	slope	slope	convex	convex	slope	slope	slope	slope		convex	concave	convex	slope	convex	convex	slope	slope	convex	concave
12	P23595-1-17		slope	convex	slope	convex	slope	convex	concave	slope	convex	convex		convex	convex	convex	slope	concave	slope	convex	convex	convex	convex

Illustration of the type of the side shape deviation, using the 10 CMM measurements provided across the length of the bars.

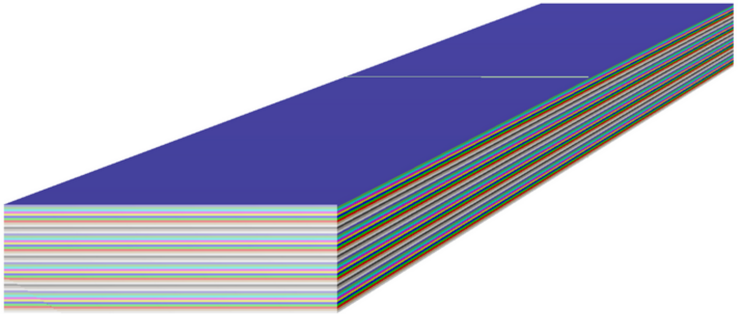
Note that the shape category changes across the length of the bar.

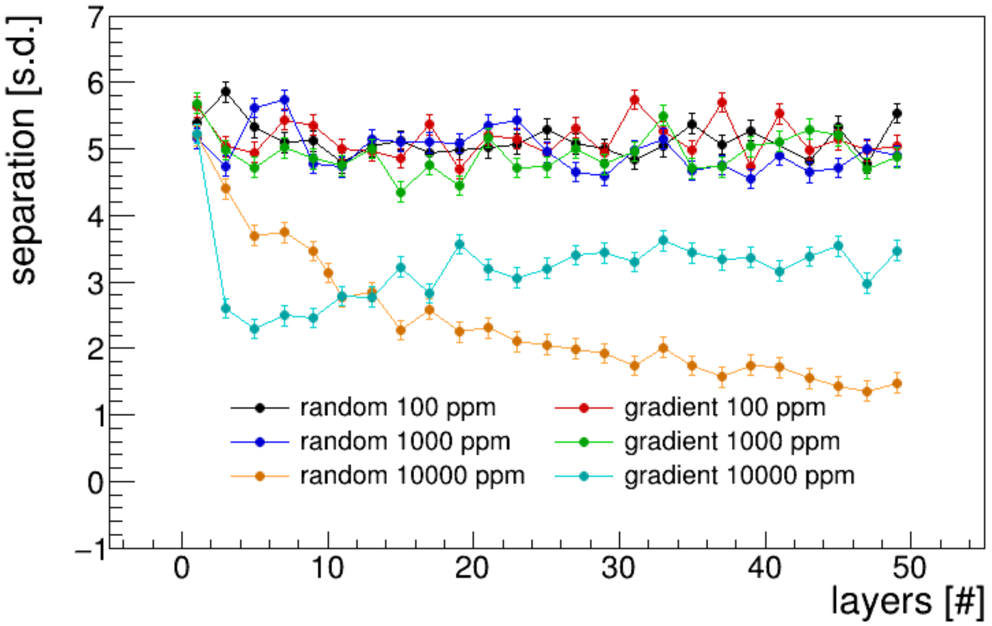
(Based on Nikon CMM data, shape definition as shown above;
"slope" may be curving inward or outward, may be close to concave or convex in shape)



Example of the side shape deviation for bar 1, side 1, for 10 positions in Y

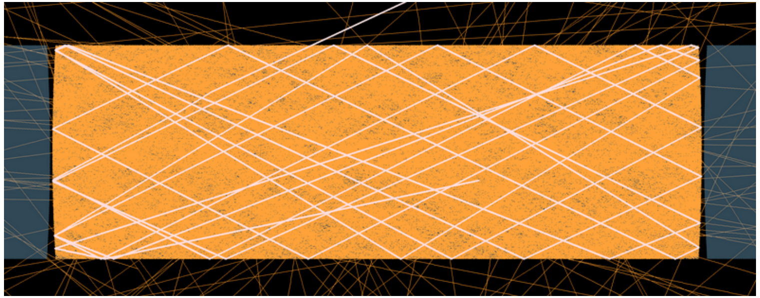
Simulation of striae on DIRC performance

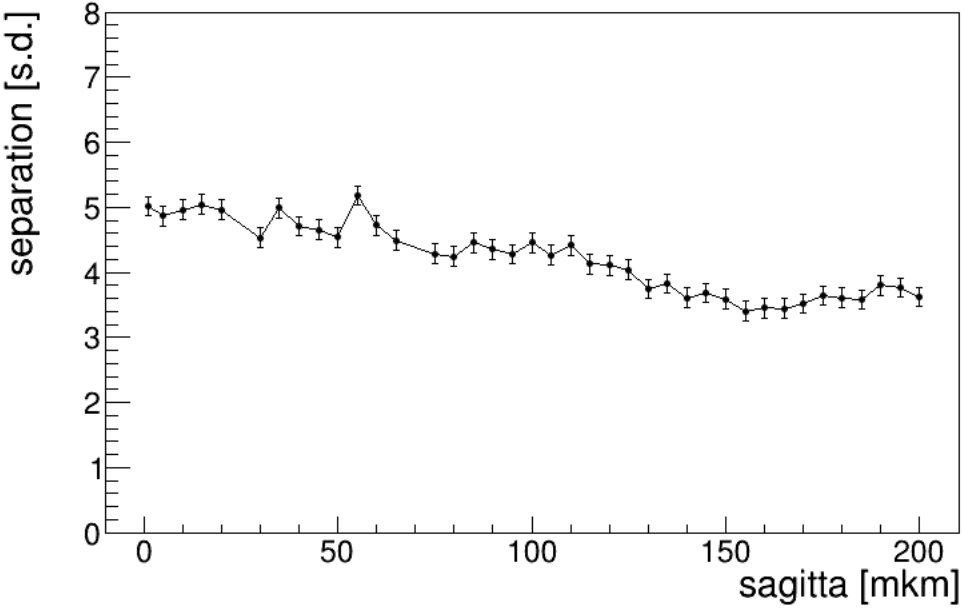




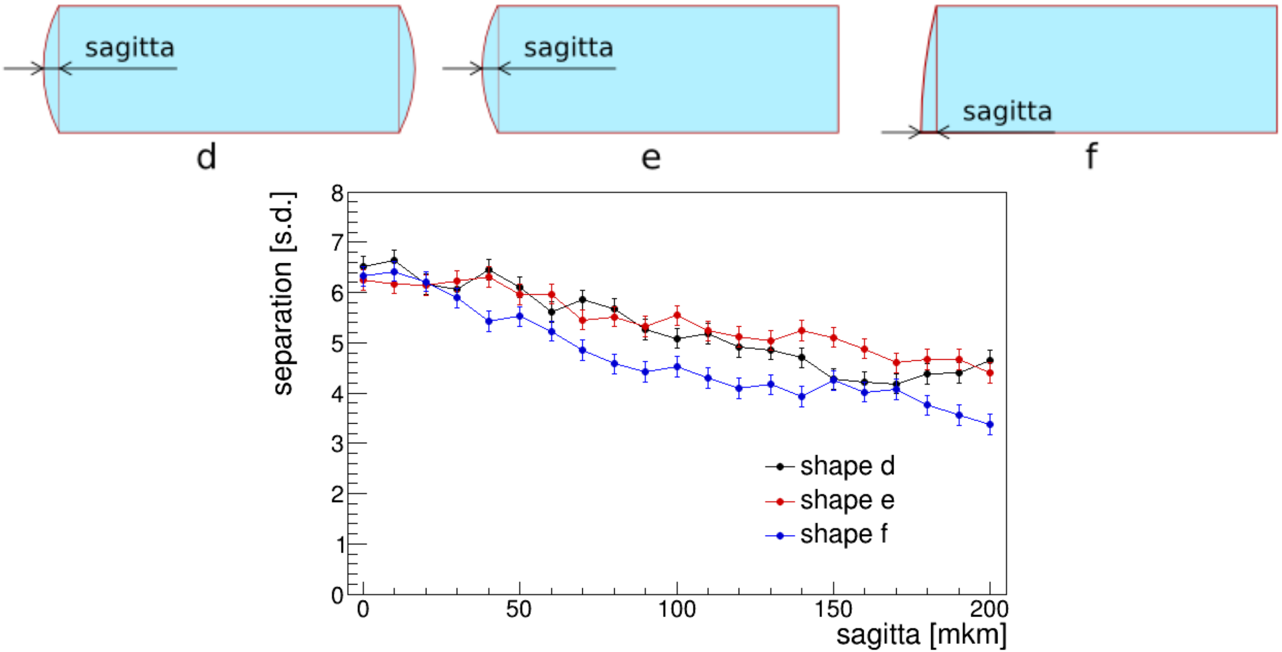
Nikon measurements: Maximal deviation of less than 7 ppm

Simulation of symmetric shape on DIRC performance





Simulation of non-symmetric shape on DIRC performance



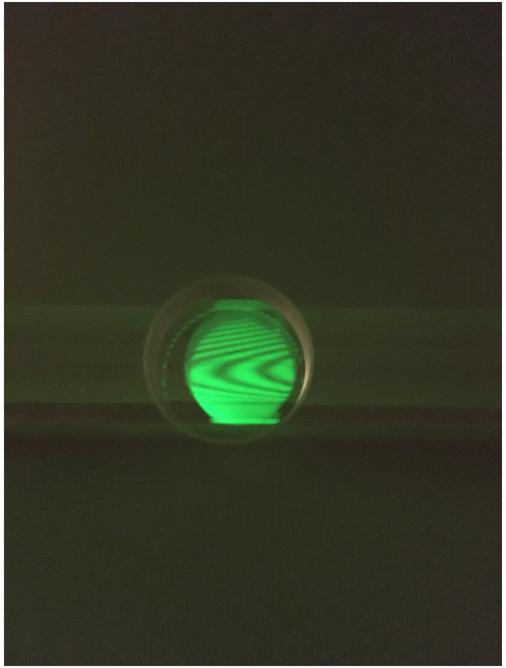
Nikon measurements: Maximum Sagitta around 10 mum

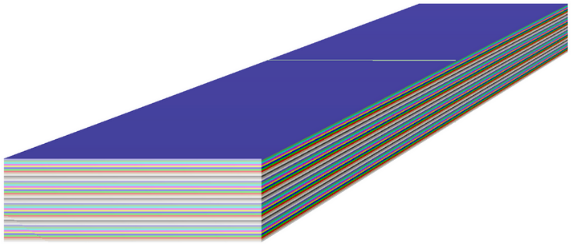
Conclusion and Outlook

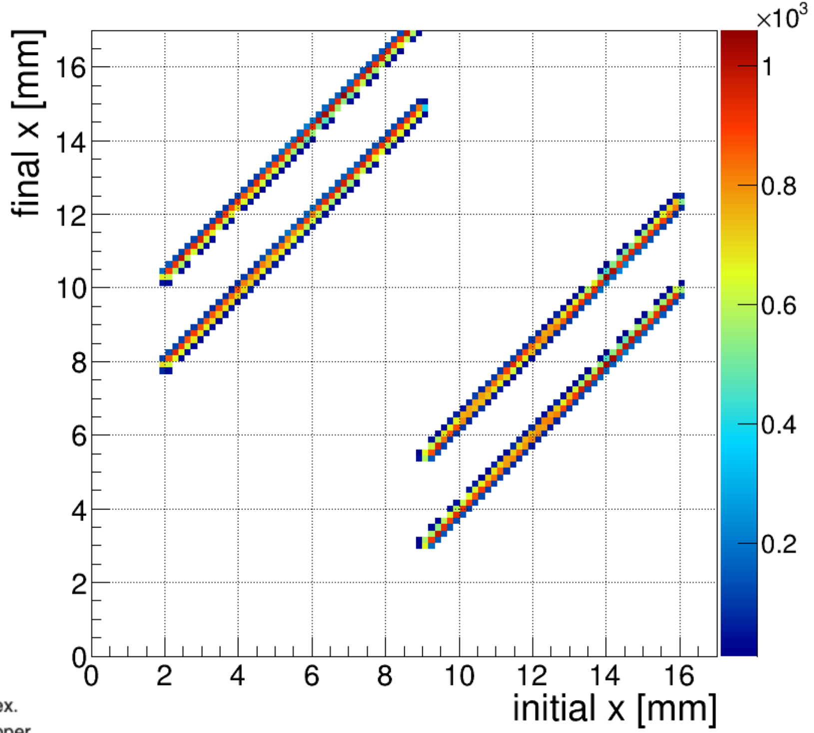
- QA for acceptance of the Nikon bar ongoing
  series of Zoom meetings with Nikon

- The Nikon CMM data and our laser measurements show combinations of convex and concave shapes and that these shapes vary across the length of the bars, not what we initially expected
- Result from Test and Simulation:
  - Striae and Deformation of Sides are no reason not to accept the bars
- Those tests delayed the determination of possible subsurface damage
- Setup needs to be prepared or adapted to ”beam steering bars”
- First results from internal reflection measurements for 442nm are promising

Thank You







Simulation of the laser beam (390 nm) along the bar. The bar has 100 layers which create 10 ppm gradient of refraction index. Position shift X along the bar thickness (outer bands for 3 mrad angle between laser beam and bar axis; inner for 2 mrad; upper two bands for photons with angle increasing in the direction of higher refraction index, lower two - opposite direction) :