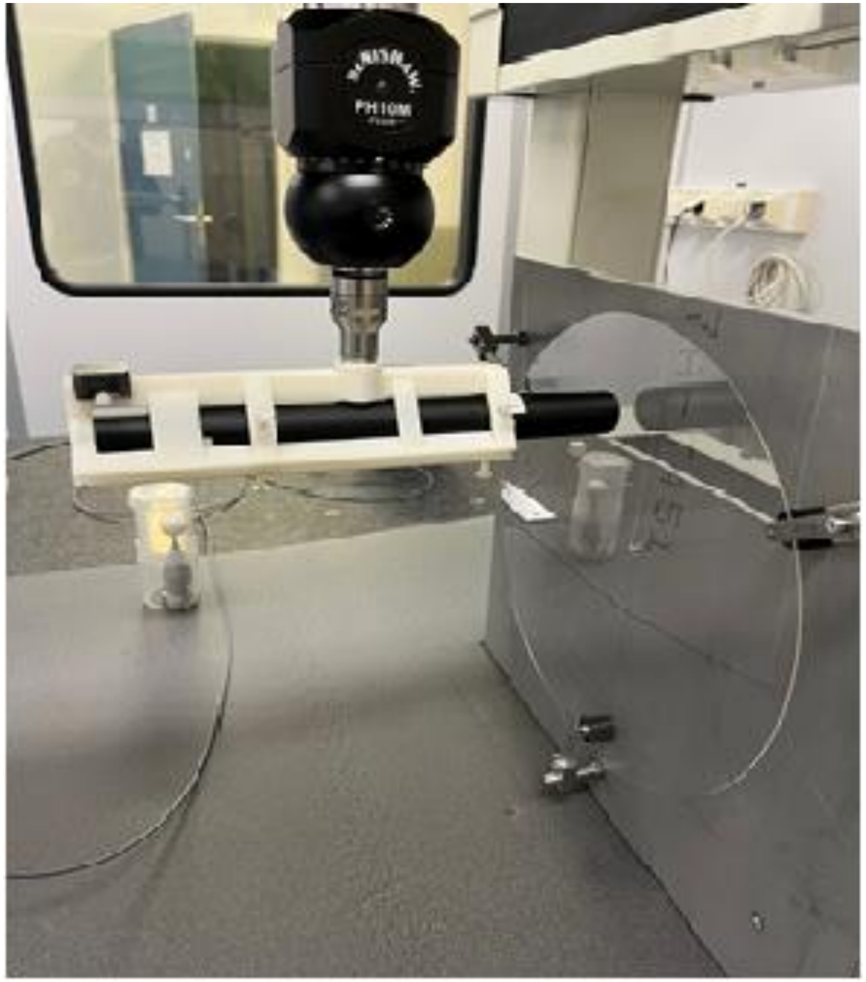
Disk planarity and simulations of OB300

Vijay Dabhi

MADMAX OB300 meeting

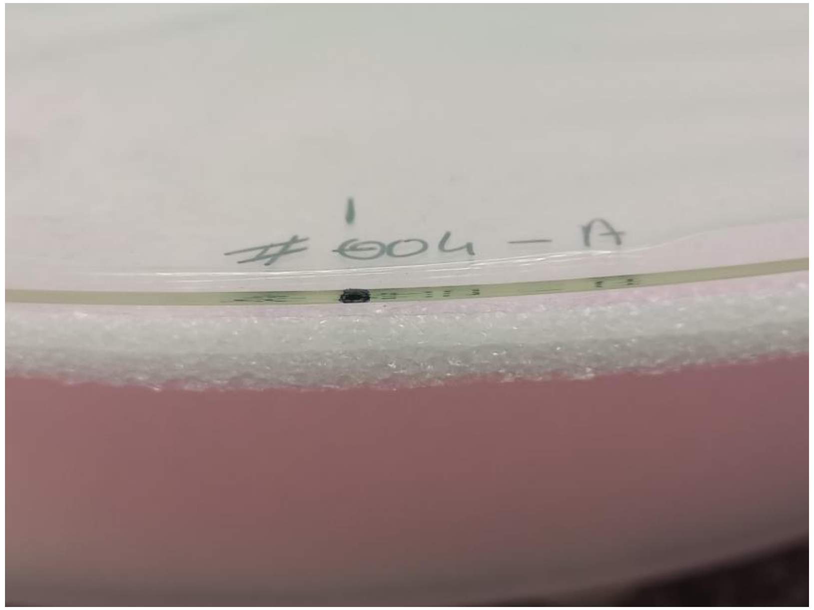
03 July 2025

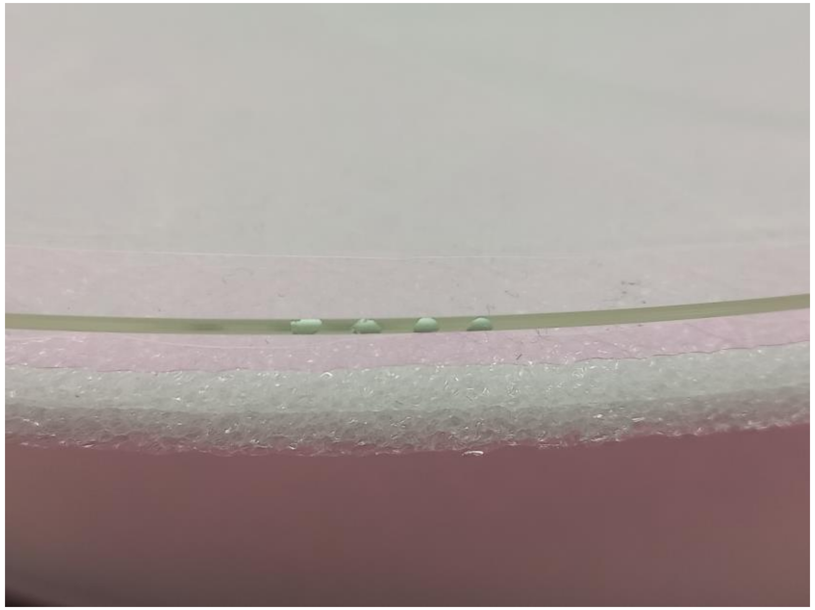
Planarity measurement at CPPM

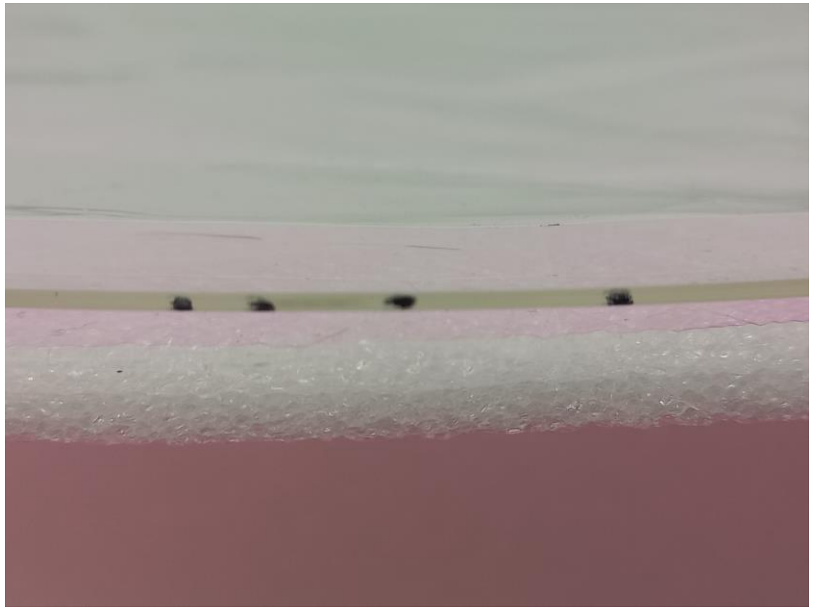


- Measurement based on reflection at different frequencies
- Accuracy is controlled by the movement apparatus
  - ~ 3 µm
- Time for 700 points measurement is ~ 1 hour using an automated script

Disk identification marks





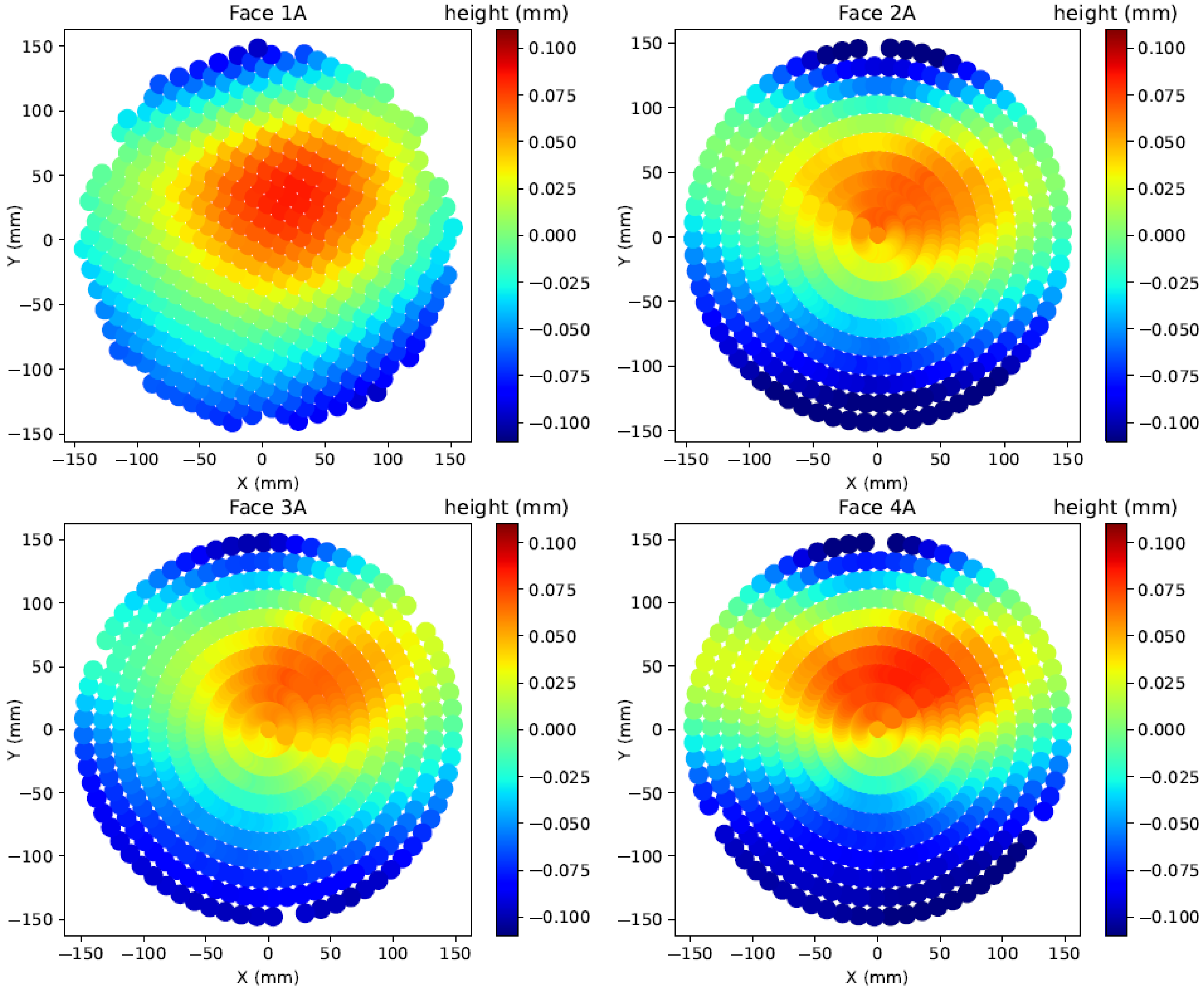


Disk number, face, and the bottom point of the disk (at the time of measurements)

Disk number (again)

Disk face indication (increasing distance on the right means the face above is face A

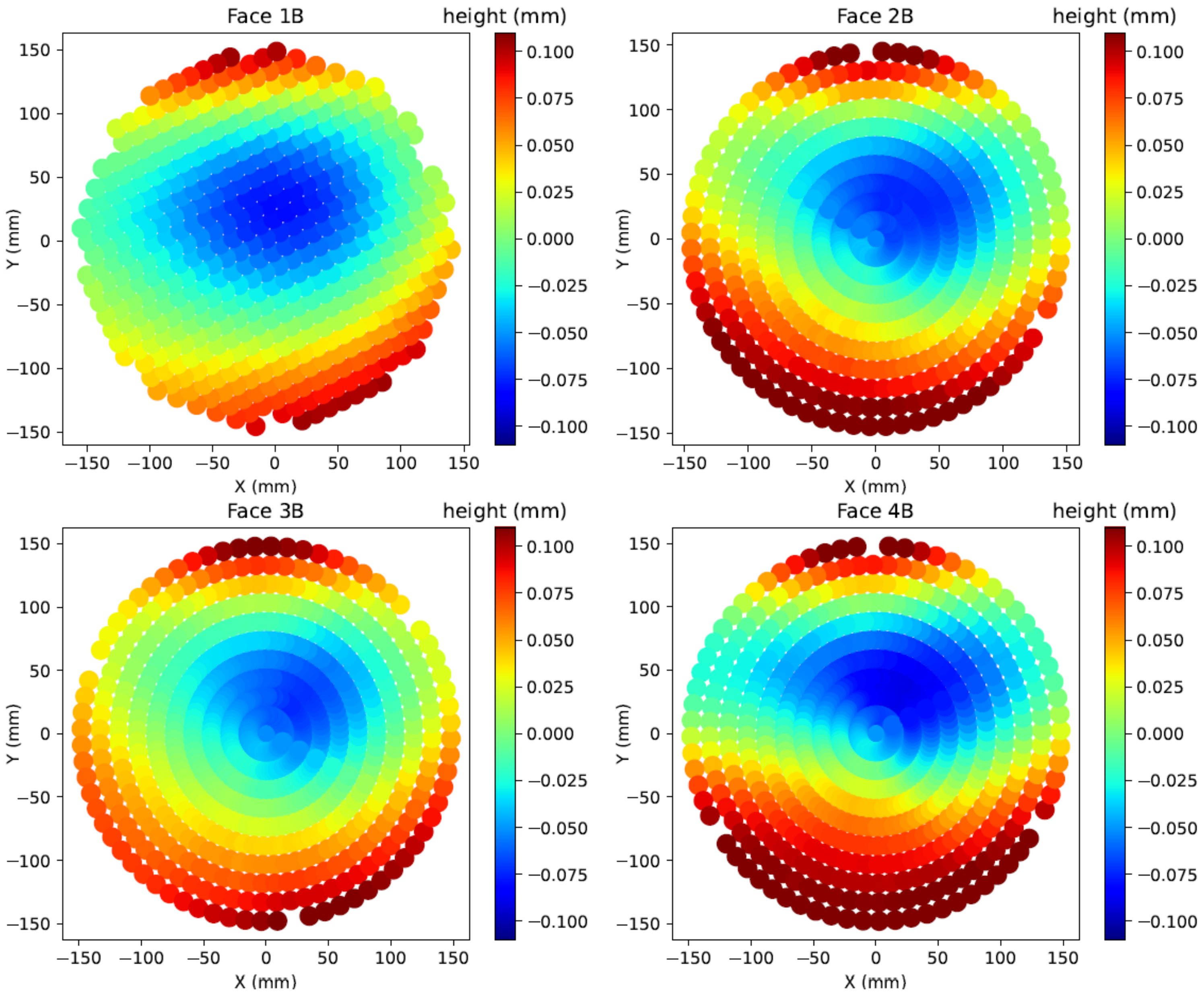
Planarity 30 cm disks



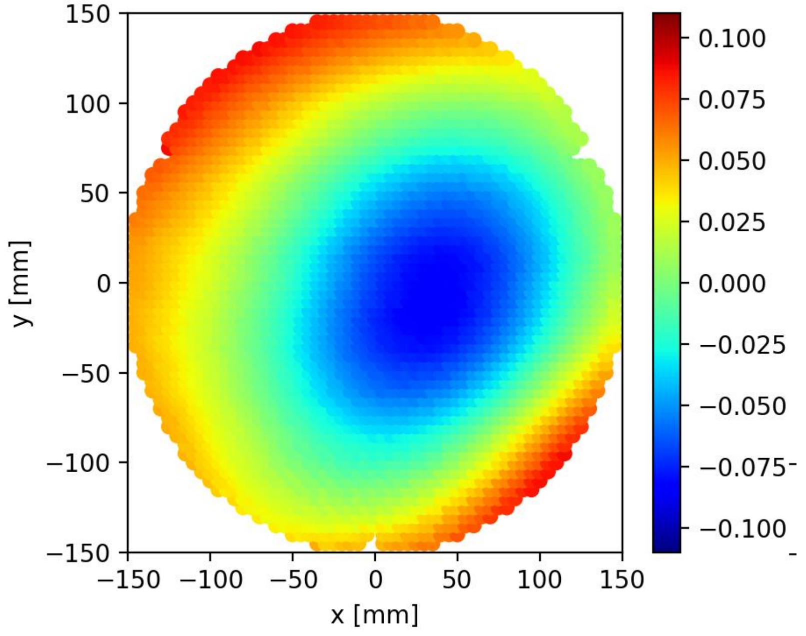
Maximum deviation in one face ≈ 0.2 mm

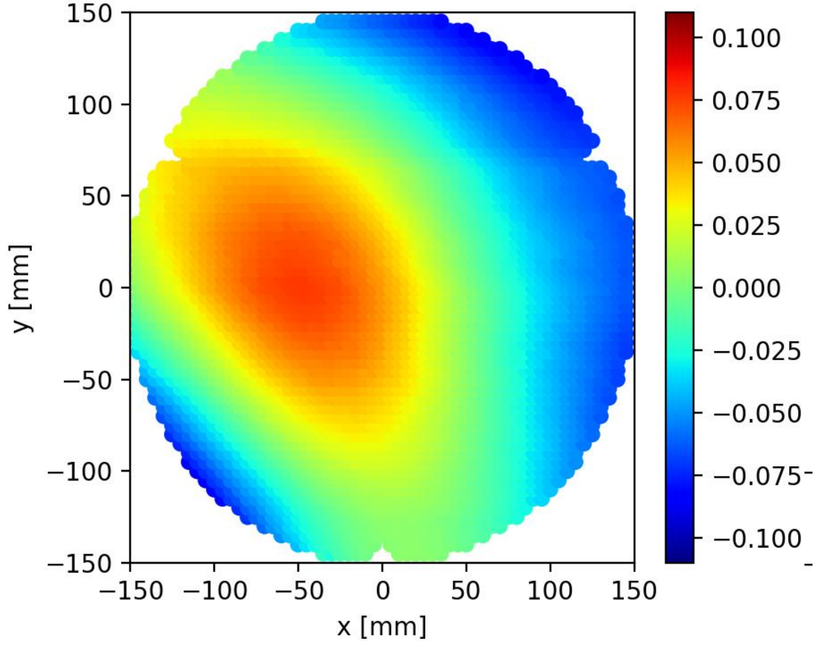
- All disks shapes are very similar
- Both disk faces are almost parallel

Planarity 30 cm disks – face B



Planarity Disk 5



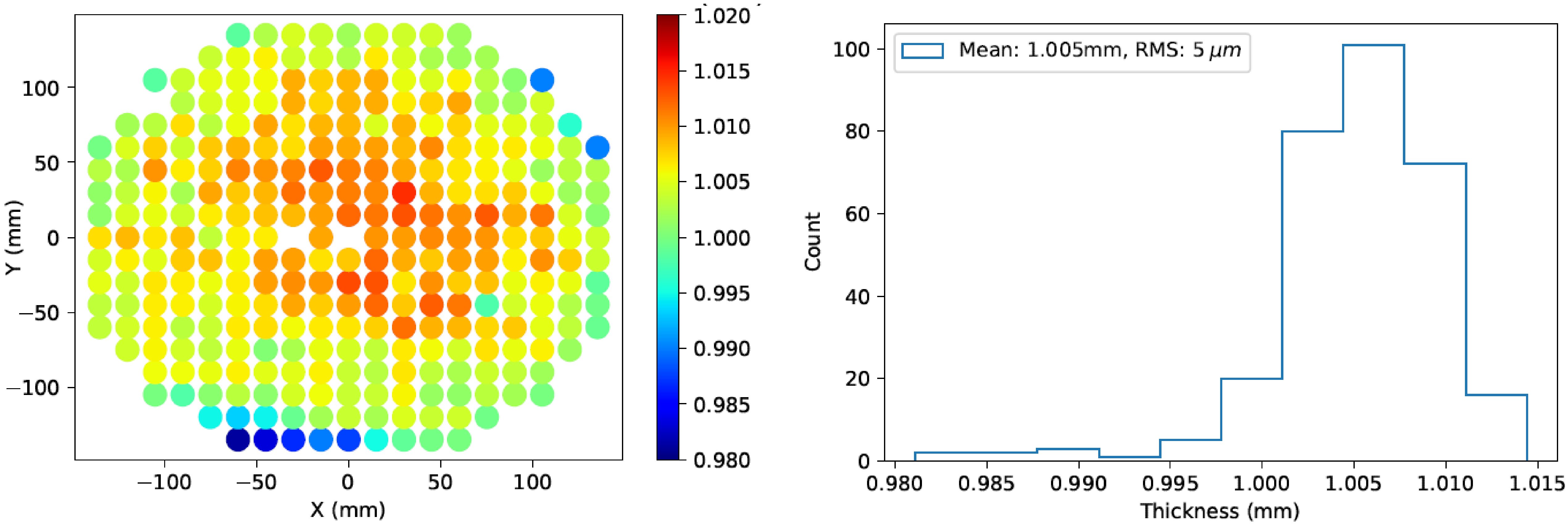


RMS: 43 μm
Min-Max: 173 μm

RMS: 41 μm
Min-Max: 160 μm

Thickness measurement

Disk 4



- Measuring both faces of the disk from one direction without turning it
- Allows to calculate the thickness distribution of the disk
  - Mean: 1.005 mm, rms = 5 µm

Planarity measurements summary

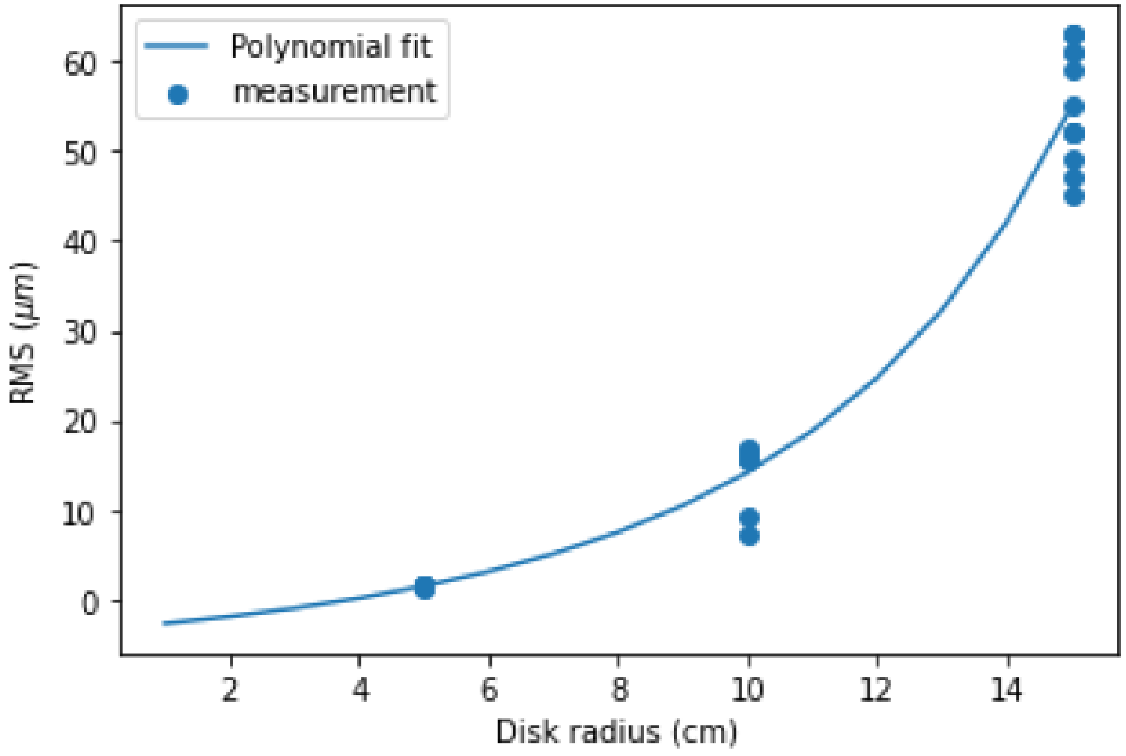
Disk face	Number of points	Raw RMS (μm)	Interpolated RMS (μm)
1A'	491	45	43
1B'	491	46	45
2A'	492	50	49
2B'	492	52	52
2A	720	52	54
2B	720	55	56
3A	715	46	47
3B	715	48	48
4A	718	56	58
4B	718	60	62
4A"	2884	55	55
4B"	2791	63	62

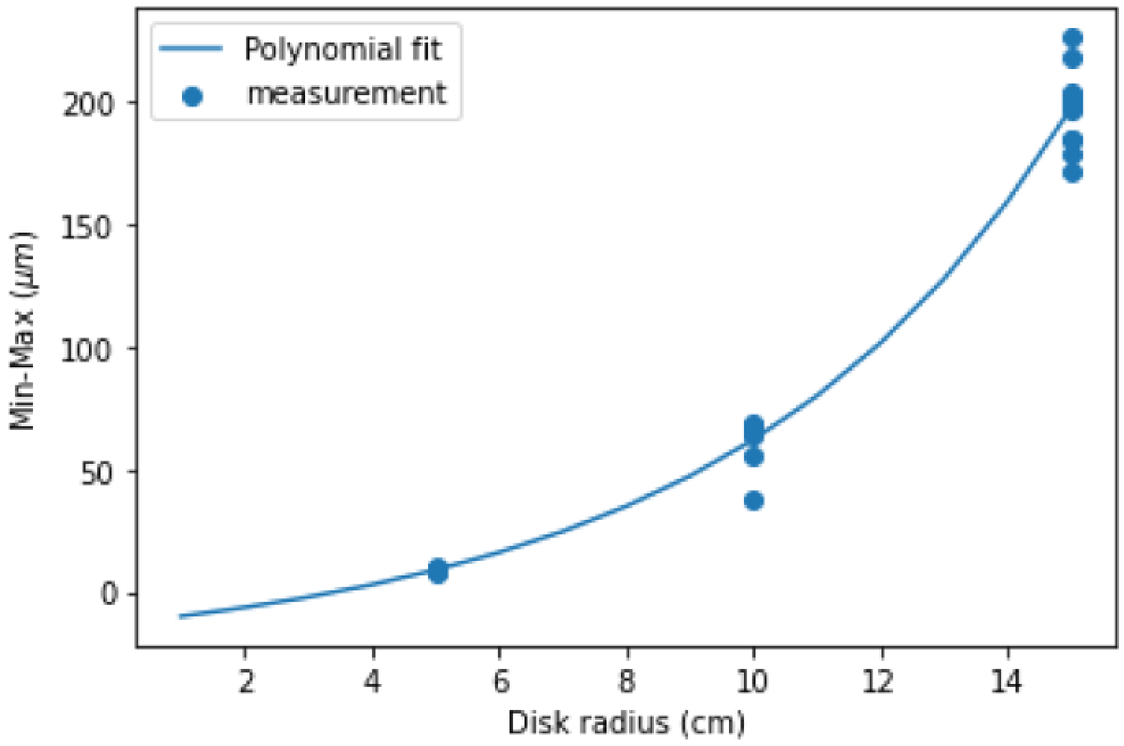
' → Contact measurment

"→ Contactless measurement with square grid sampling of points

Other measurmeents are Contactless measurement with polar grid sampling of points

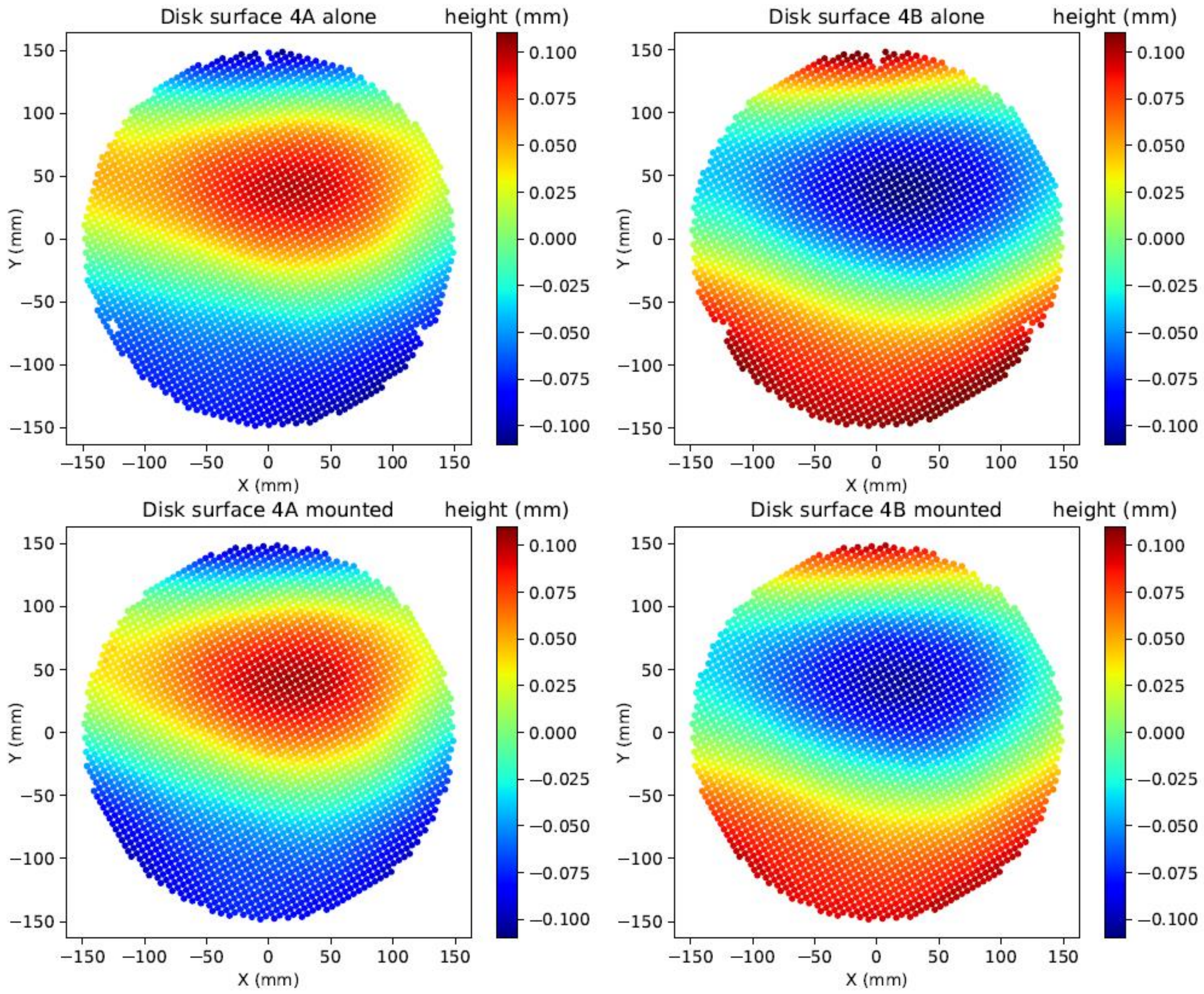
Trend in disk planarity





- All disk planarity measurements made until now at CPPM
- Non-planarity increases significantly when going from 10 cm disks to 30 cm disks

Disk ring



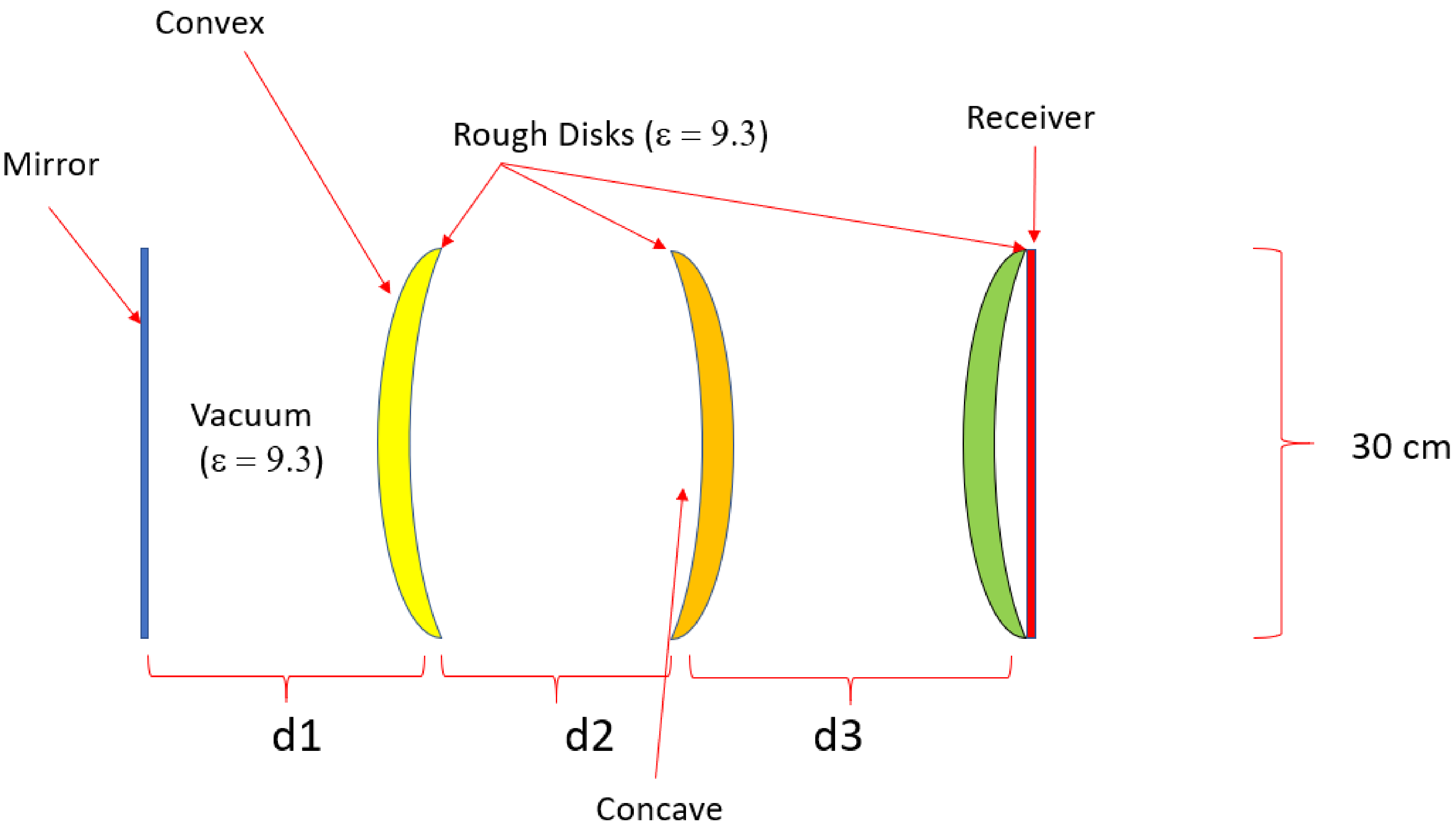
	Disk alone	Disk on ring
4A RMS	57 µm	56 µm
4B RMS	55 µm	55 µm
4A Min-Max	208 µm	206 µm
4B Min-Max	200 µm	199 µm

Published the same results in OB200 paper

New disk rings

Disk face	RMS (μm)	Min-Max (μm)
5A	43	173
5A on ring 5	41	172
5A on ring 6	39	154
5A on ring 8	40	159
5B	41	160
5B on ring 5	42	170
5B on ring 6	41	154
5B on ring 8	40	163

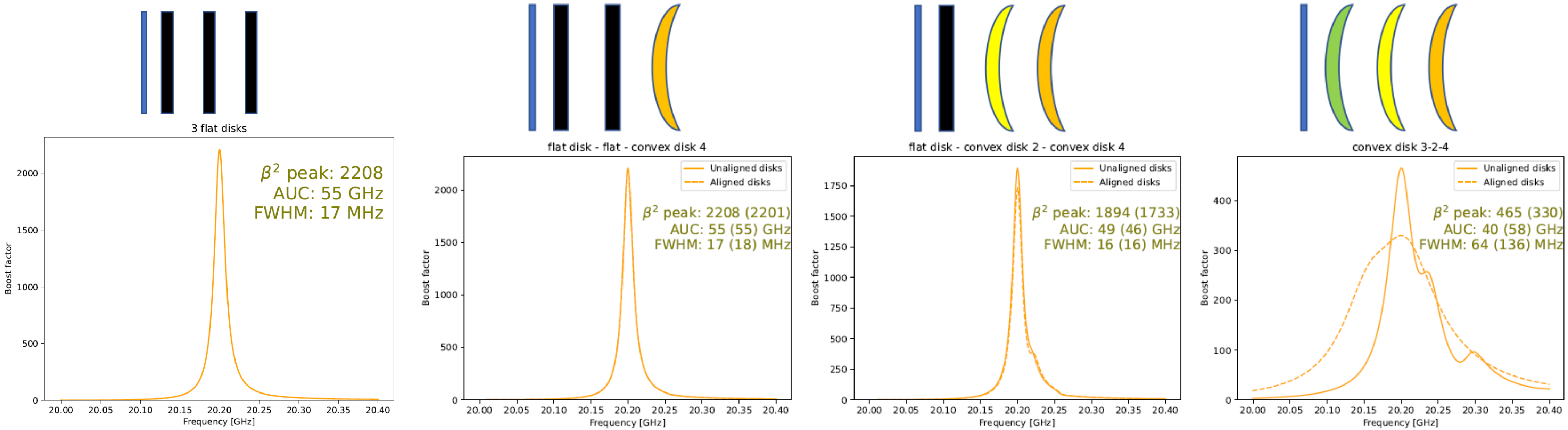
OB300v1 simulations



- Simulations to assess impact of disk ordering and orientations[boostfractor package]

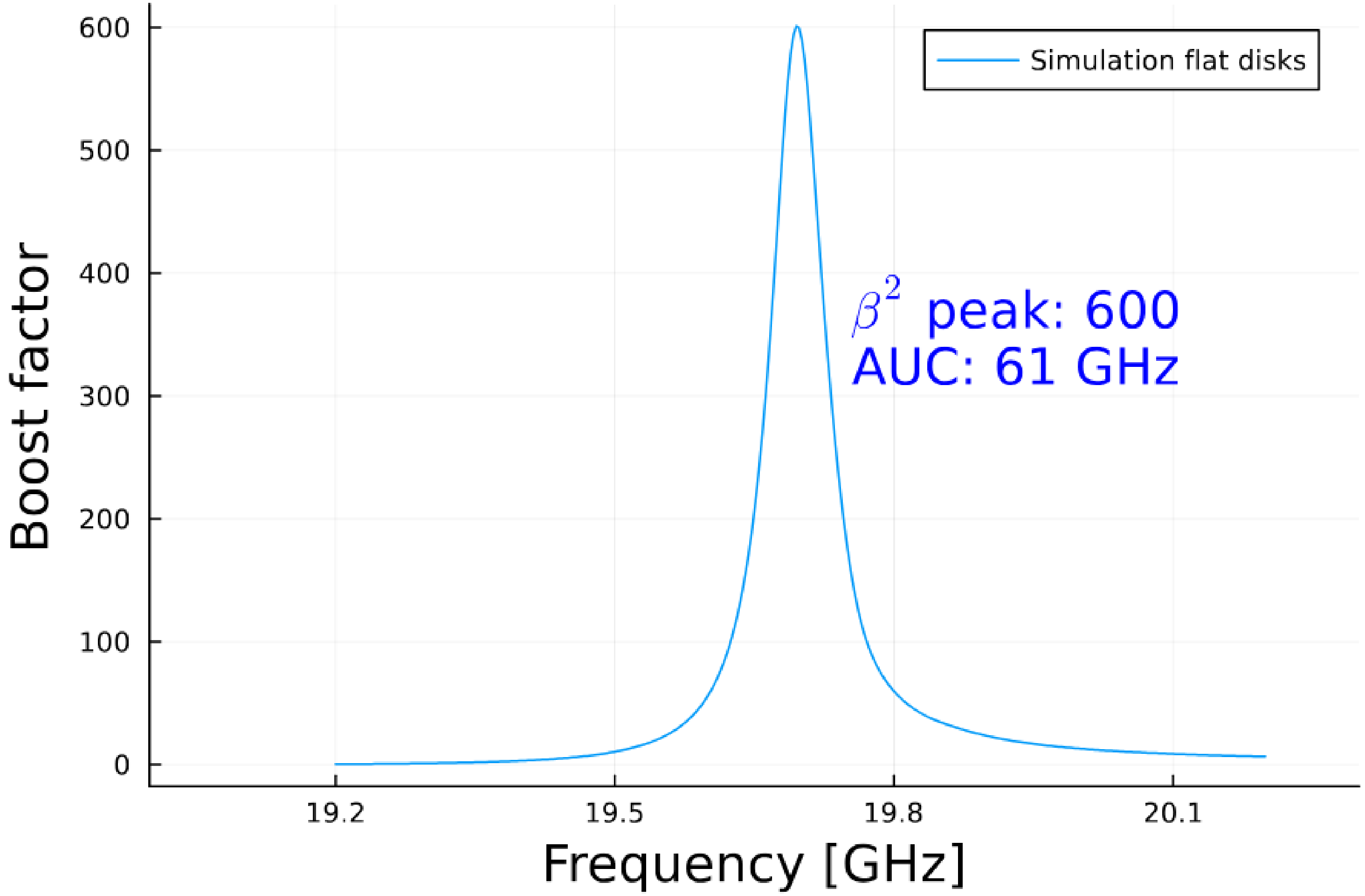
Disk alignment

narrow band @ 20.2 ± 0.01 GHz



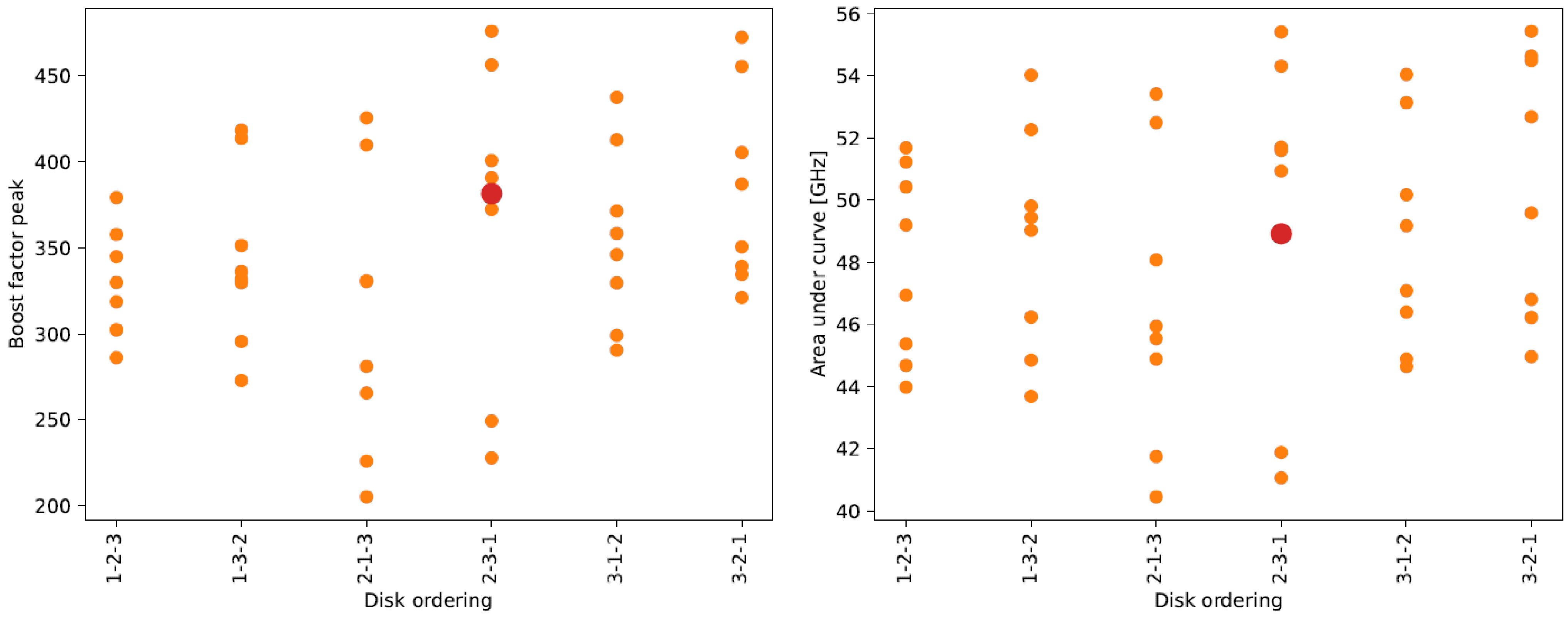
- Simulations with disks shapes aligned (as shown in slide 4) vs unaligned (in the alignment at the time of measurement)
- Calculated using optimization notebook from boostfractor package
- All simulations as well as dark photon search were performed with the disks “unaligned”

OB300v1 with flat disks



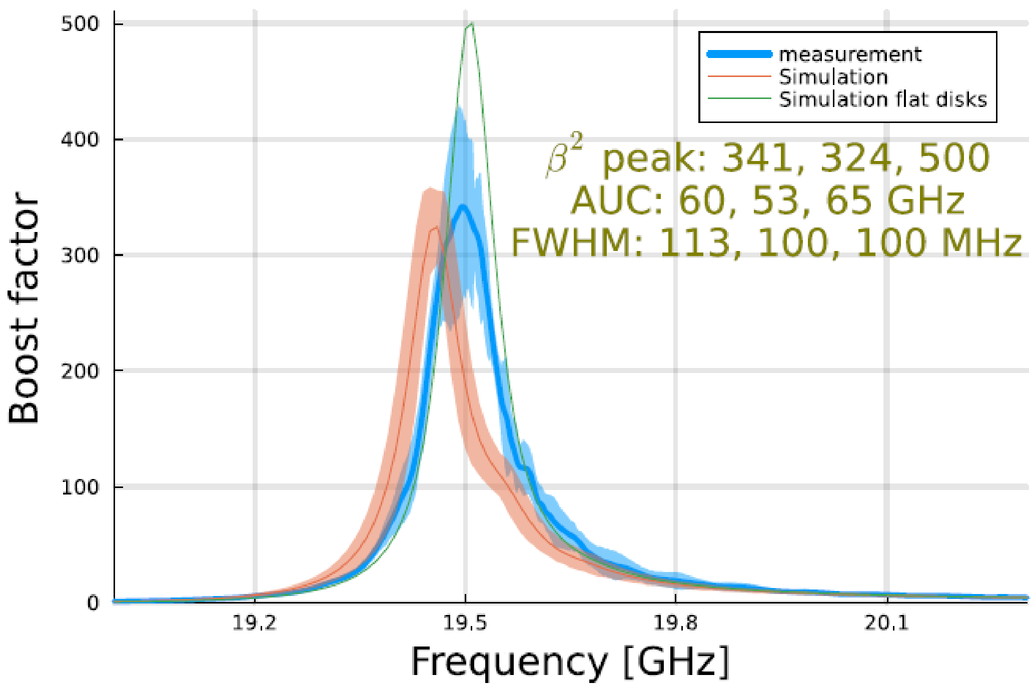
- d1, d2, d3 = 8.265, 9.813, 9.813 cm for broadband @ 19.7 ± 0.5 GHz

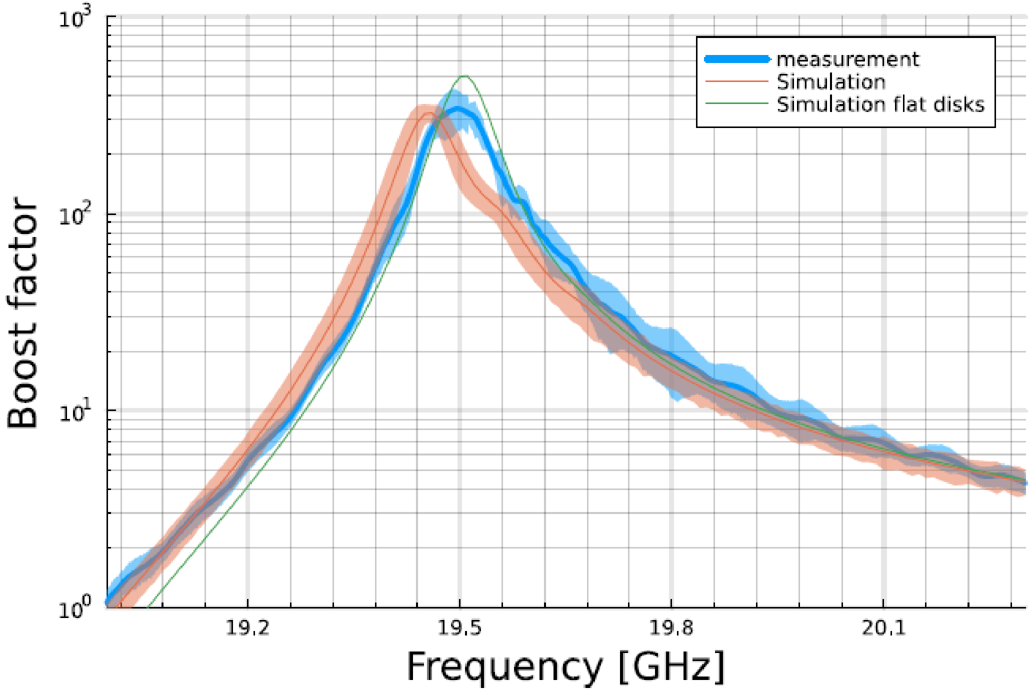
OB300v1 with rough disks



- Boost factor peak and area under curve (AUC)
  - 48 possibilities between 2 orientation for each disk (8 for 3 disks) and 6 combinations of disk order
  - d1, d2, d3 = 8.265, 9.813, 9.813 cm for broadband @ 19.7 ± 0.5 GHz
- Large spread in boost factor (200-500) and AUC (40-56 GHz)
  - 2-3-1 Concave-Concave-Concave disk configuration (shown in red) used for the DPDM search

Validation with data



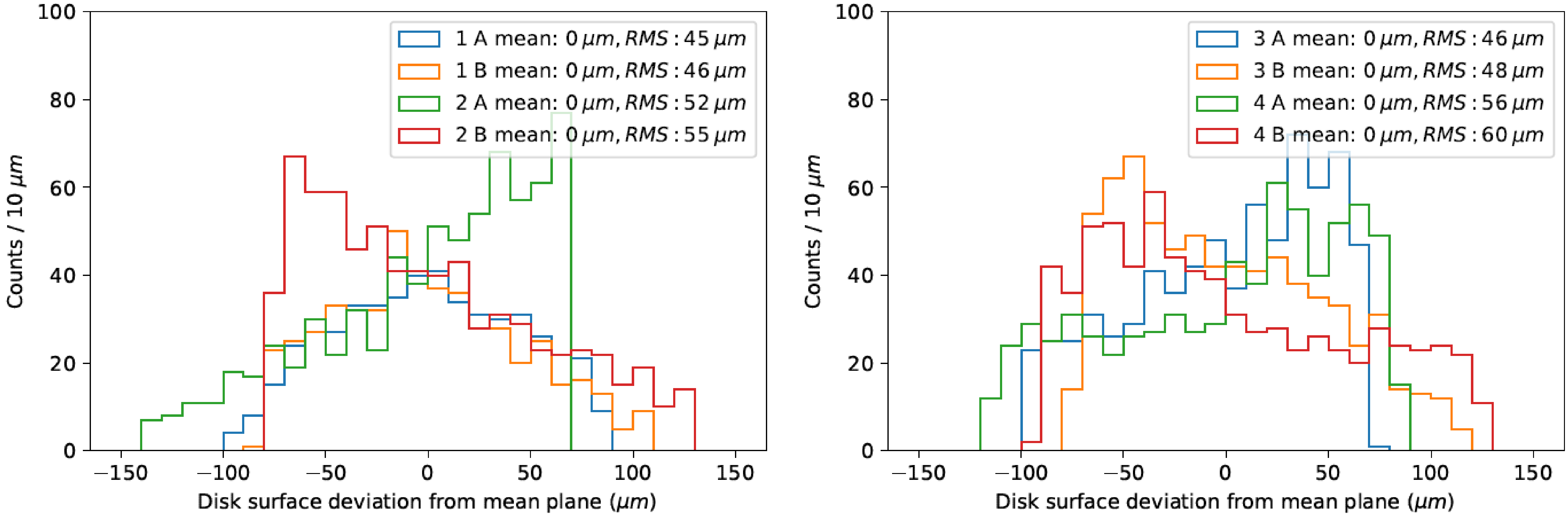


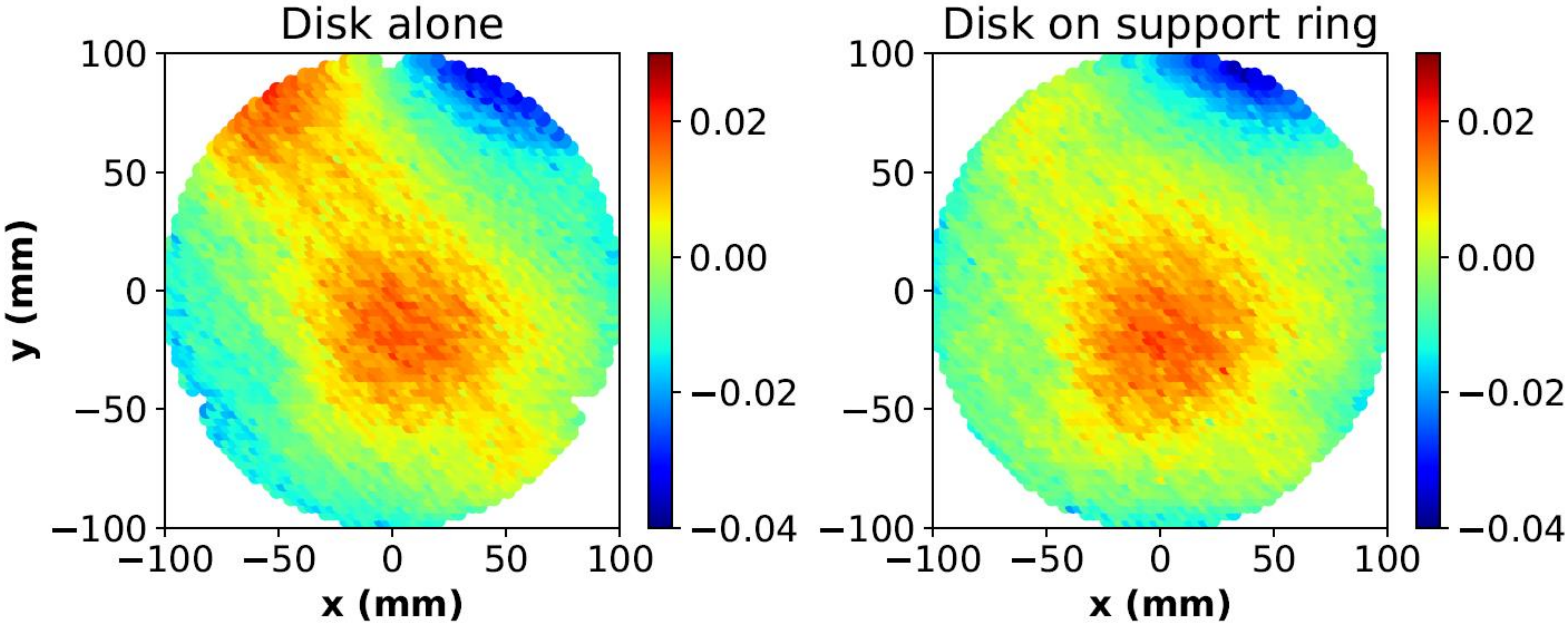
- First comparison of bead-pull measurement (without receiver chain effects) with simulation
    - Measurement is smoothened with an SG filter to remove the booster-antenna resonances not included in the simulation
    - Simulation uncertainty calculated from 100 simulations
    - d1, d2, d3 = 8.37, 9.96, 9.73 cm for broadband @ 19.5 ± 0.5 GHz

Conclusions and future outlook

- All five 30 cm disk planarity have been measured
- Disk planarity deviation increases significantly with disk radius
  - Need to find a solution for bigger disks
- The shape of the disks is affected very little by disk rings
- Booster performance largely determined by disk configuration for a given frequency and disk distances
- First simulation is able to fairly reproduce bead-pull boost factor measurement

Backup


1 A mean: 0 μm, RMS : 45 μm
1 B mean: 0 μm, RMS : 46 μm
2 A mean: 0 μm, RMS : 52 μm
2 B mean: 0 μm, RMS : 55 μm
3 A mean: 0 μm, RMS : 46 μm
3 B mean: 0 μm, RMS : 48 μm
4 A mean: 0 μm, RMS : 56 μm
4 B mean: 0 μm, RMS : 60 μm
Counts / 10 μm
Disk surface deviation from mean plane (μm)

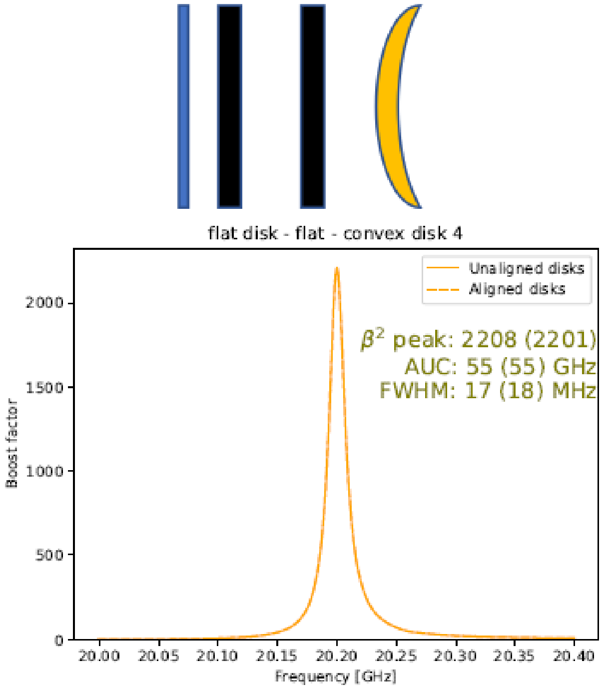


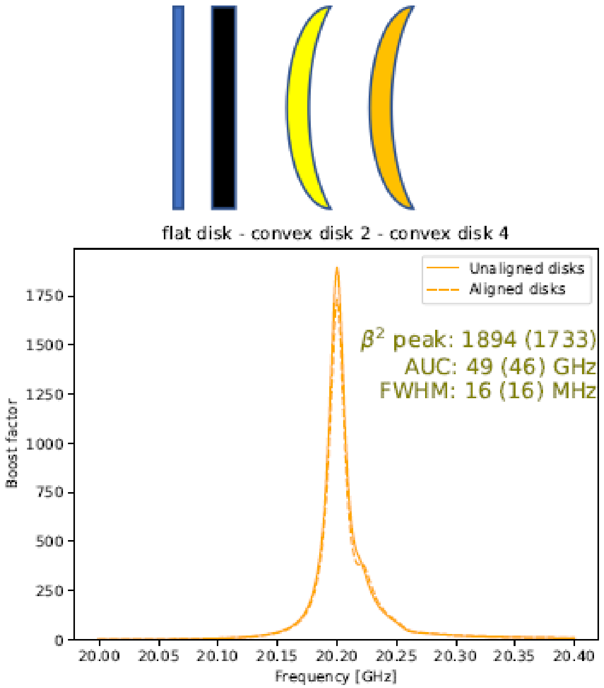
Disk alone
Disk on support ring
100
50
0
−50
−100
−100 −50 0 50 100
x (mm)
y (mm)
0.02
0.00
−0.02
−0.04

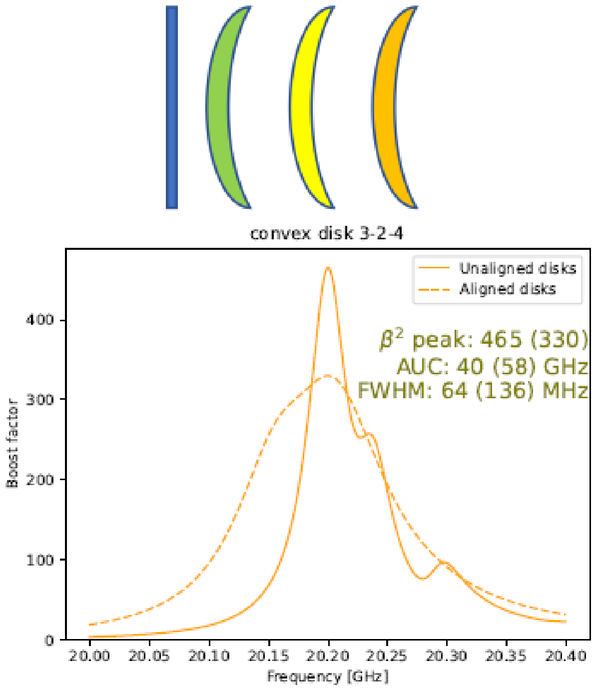
Disk rings

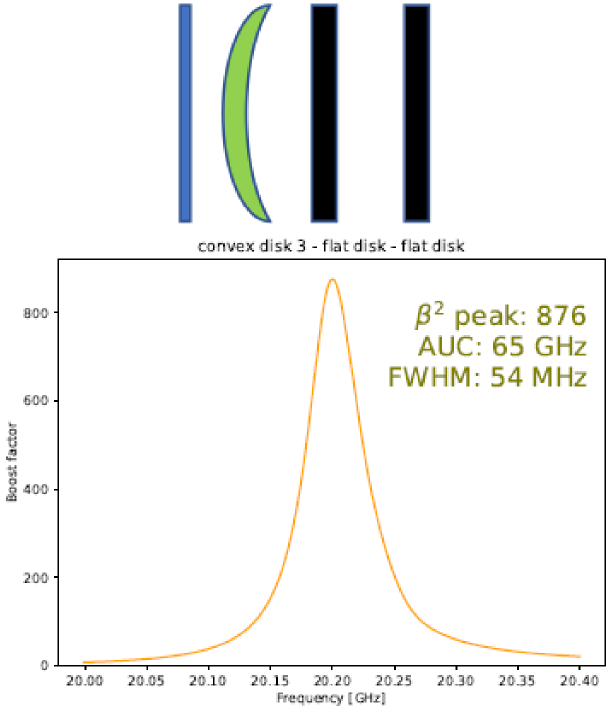
Disk4 with rings	Side	Raw RMS	Raw min-max	Interpolated RMS	Interpolated min-max
1	A	49(63)	194(226)	48(62)	194(226)
1	B	57(55)	208(204)	56(55)	206(204)
2	A	57(63)	206(226)	56(62)	204(226)
2	B	55(55)	200(204)	55(55)	199(204)
3	A	58(63)	204(226)	57(62)	203(226)
3	B	58(55)	198(204)	57(55)	197(204)
4	A	49(63)	191(226)	48(62)	187(226)
4	B	57(55)	223(204)	56(55)	222(204)

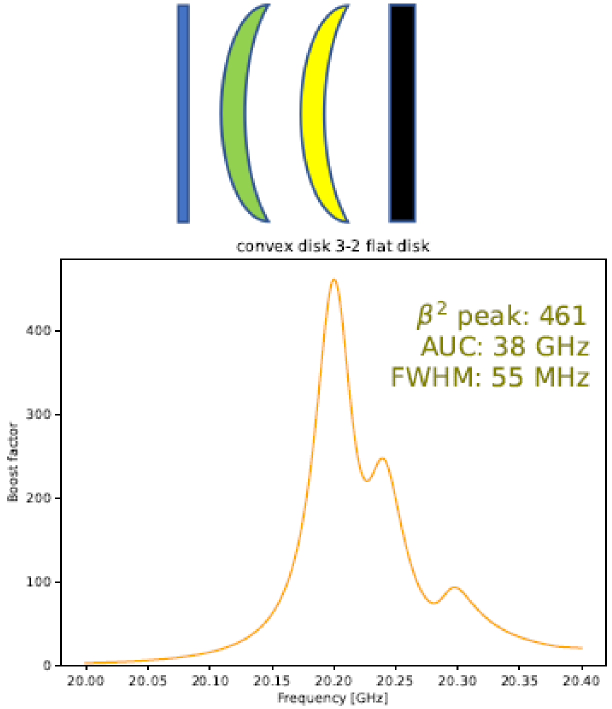
Measurements with disk mounted on ring (and disk alone)

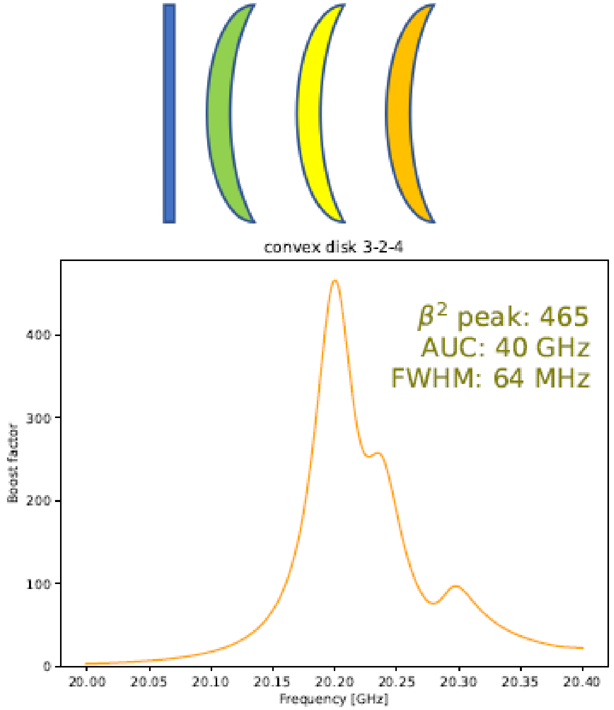

flat disk - flat - convex disk 4
Unaligned disks
Aligned disks
β^2 peak: 2208 (2201)
AUC: 55 (55) GHz
FWHM: 17 (18) MHz
Boost factor
Frequency [GHz]


flat disk - convex disk 2 - convex disk 4
Unaligned disks
Aligned disks
β^2 peak: 1894 (1733)
AUC: 49 (46) GHz
FWHM: 16 (16) MHz
Boost factor
Frequency [GHz]


convex disk 3-2-4
Unaligned disks
Aligned disks
β^2 peak: 465 (330)
AUC: 40 (58) GHz
FWHM: 64 (136) MHz
Boost factor
Frequency [GHz]


convex disk 3 - flat disk - flat disk
β^2 peak: 876
AUC: 65 GHz
FWHM: 54 MHz
Boost factor
Frequency [GHz]


convex disk 3-2 flat disk
β^2 peak: 461
AUC: 38 GHz
FWHM: 55 MHz
Boost factor
Frequency [GHz]


convex disk 3-2-4
β^2 peak: 465
AUC: 40 GHz
FWHM: 64 MHz
Boost factor
Frequency [GHz]

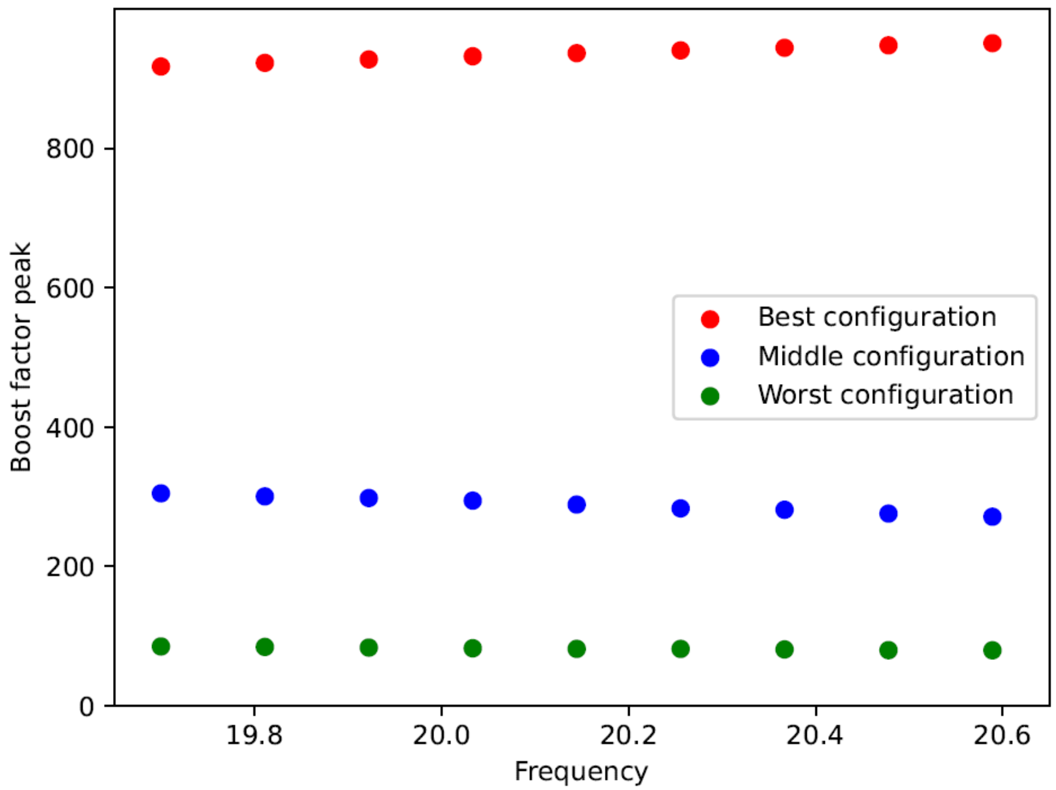
OB300 simulation parameters - original

Setup parameters	
Disk diameter	30 cm
Disk thickness	1 mm
Disk dielectric constant	9.3
Mirror dielectric constant	Nan
Mirror thickness	0
Distances array	[8.265, 9.813, 9.813] mm
Receiver distance from last interface	0
Coupling to a Gaussian antenna	Yes
Gaussian beam width	85 mm
Input parameters	
Julia version	1.6.7
Frequency	19.2-20.2 GHz
Disk grid size	0.4 m × 0.4 m
Disk grid length	2.5 mm
3D algorithm	Mode matching
Mode indices L_{max}, M_{max}	3, 3

OB300 simulation parameters - measured

Parameter	Original	Measured
mirror conductivity [S/m]	inf	$(5 \pm 1) \times 10^7$
Disk1 distance [mm]	8.265	8.3664 ± 0.0017
Disk2 distance [mm]	9.813	9.9606 ± 0.0032
Disk3 distance [mm]	9.813	9.7314 ± 0.0036
Disk thickness [mm] (3 parameters)	1	1 ± 0.005
Disk ϵ (3 parameters)	9.3	9.3 ± 0.1
Disk loss parameter $\tan\delta$ (3 parameters)	0	$(1 \pm 0.1) \times 10^{-5}$

Stability of optimized configurations



- Once a good/bad configuration is identified, it remains stable for 1 GHz