Basics of daily corrector-tuning

Peter Hartel

- Research & Development -
Corrected Electron Optical Systems GmbH,
Englerstr. 28, D-69126 Heidelberg

CEOS
Corrected Electron Optical Systems GmbH

Daily corrector alignment

- Is fast and fine-tuning against hysteresis of magnetic elements and thermal drift.
  => If possible, prepare the microscope the evening before (HT, mode, sample)

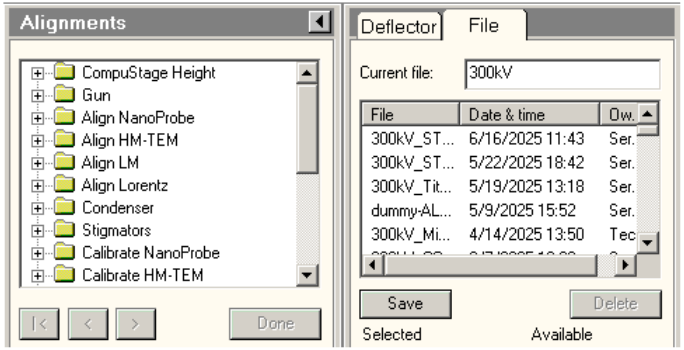
- Is never a complete realignment of the corrector.

- Timeconsuming alignments indicate:
  - Bad alignment files
  - Broken hardware
  - Tuning beyond requirements or beyond measuring accuracy
  - Omitted check points during the daily alignment procedure

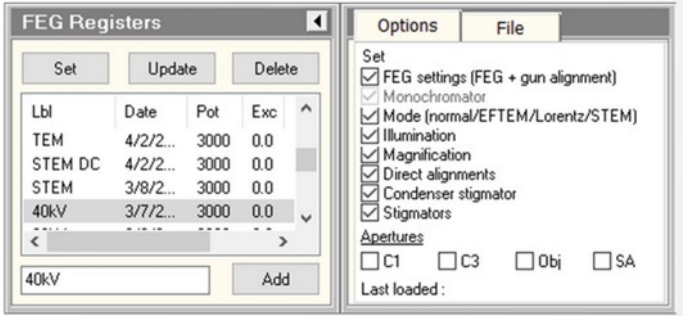
1. Load trustful alignment files and choose mode (HT, TEM/STEM)

ThermoFisher

Microscope and corrector(s)



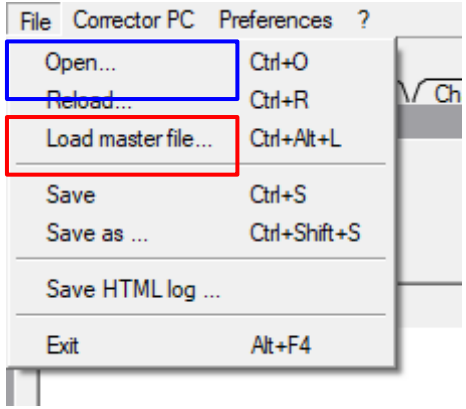
User settings



JEOL

Microscope

Corrector(s)



2. Verify fix points and do basic pre-alignments

ThermoFisher	JEOL
- Eucentric focus	- Standard focus
- Normalise all	- Lens relaxation
- Normalise correctors	
- Center beam in imaging mode:	
- Leave diffraction, use AT UserBeamShift	- Switch to ALIGN, use AT ShiftOL
- Center the right aperture on last condenser lens (or on flat area on Ronchigram)	
- Adjust with AT BeamTilt:	
- Rotation center of objective	- High tension center
- Focus (in Ronchigram) with z-height on gold cluster sample	
- Select proper magnification (FoV around 500nm)	

2. Verify fix points and do basic pre-alignments

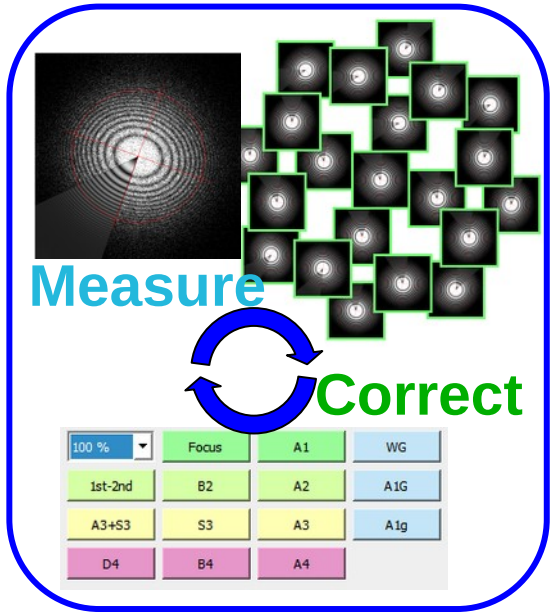
ThermoFisher	JEOL
- Eucentric focus	- Standard focus
- Normalise all	- Lens relaxation
	- Normalise correctors
	- Center beam with microscope Beam Shift - Find nice amorphous area
	- Check beam tilt pivot points (tiny changes if at all due to hysteresis of objective lens)
- Rotation center objective	- Adjust microscope BeamTilt w.r.t. specimen detail: - High tension center
	- Set slight underfocus with z-height
	- Select proper magnification (C1A1 range 1...2um)

3. Use corrector UI's measurement procedures and auto-alignment tools

Iterate:

- Continuous C1A1 measurements
  (up to second order in STEM,
  up to first order in TEM)
  - Use auto-alignment tools
    while measurement is running

- Tableau measurements:
  fast -> *standard* (-> *enhanced* if needed)
  - Use auto-alignment tools
    after accepting tableau in state of correction



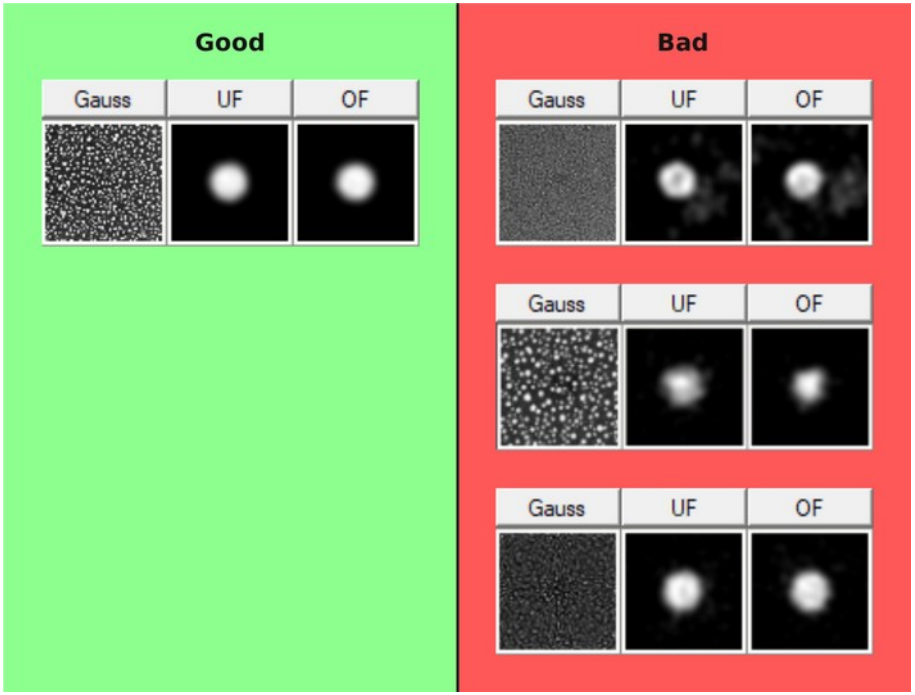
Cross-check with the instruction manual for details.

Stop iteration if experimental needs are fulfilled or measurement accuracy is limiting!

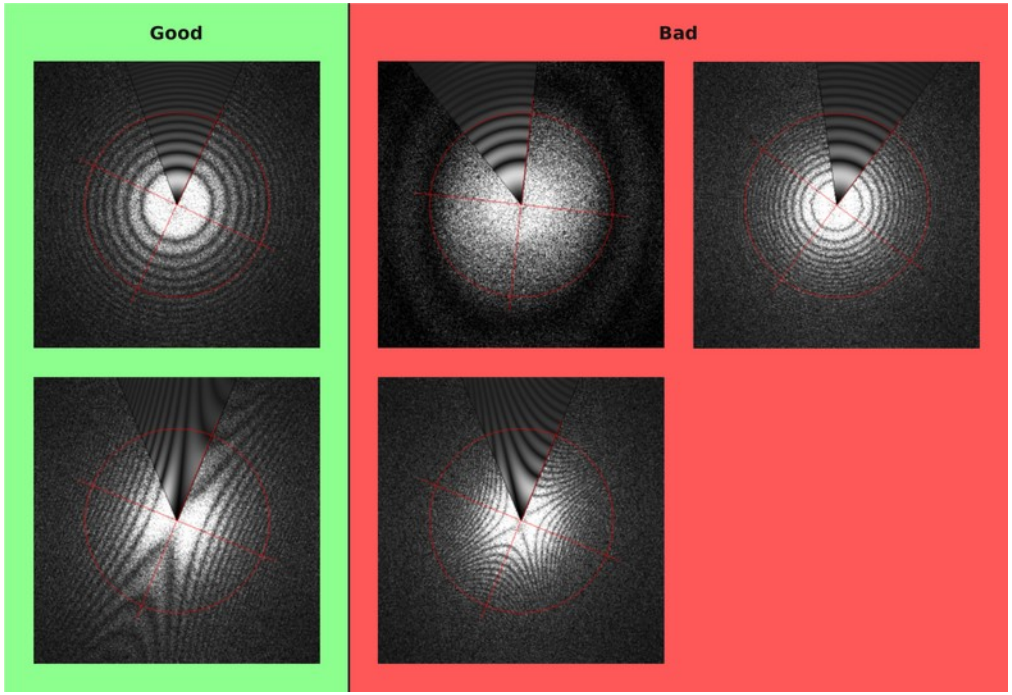
Concentrate on your experiment, not onto corrector tuning.

Good and bad continuous measurements

STEM: deconvolution

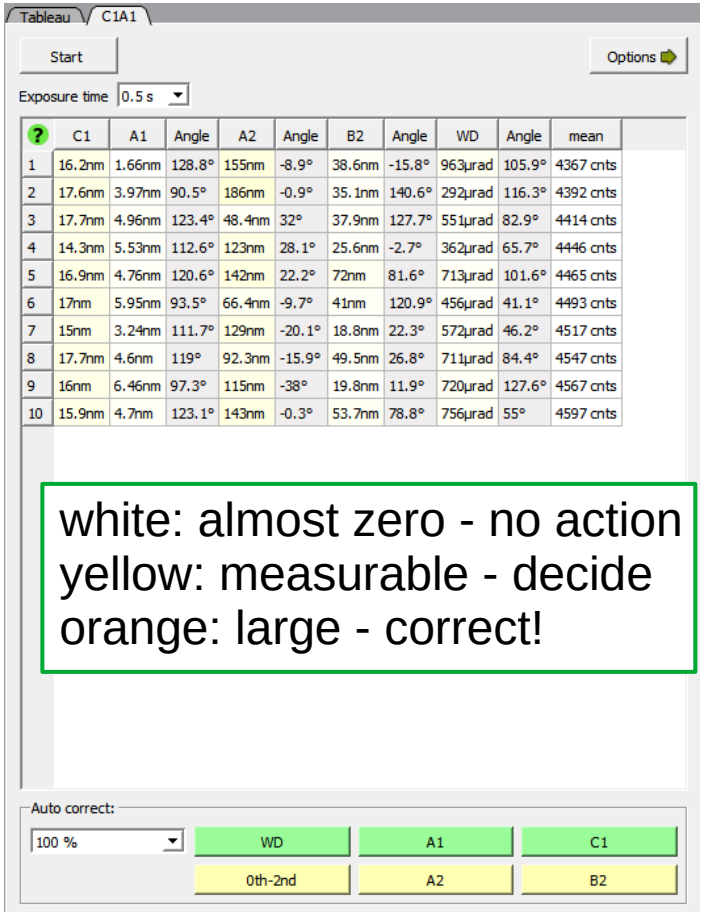


TEM: diffractogram analysis



Hints at continuous measurements

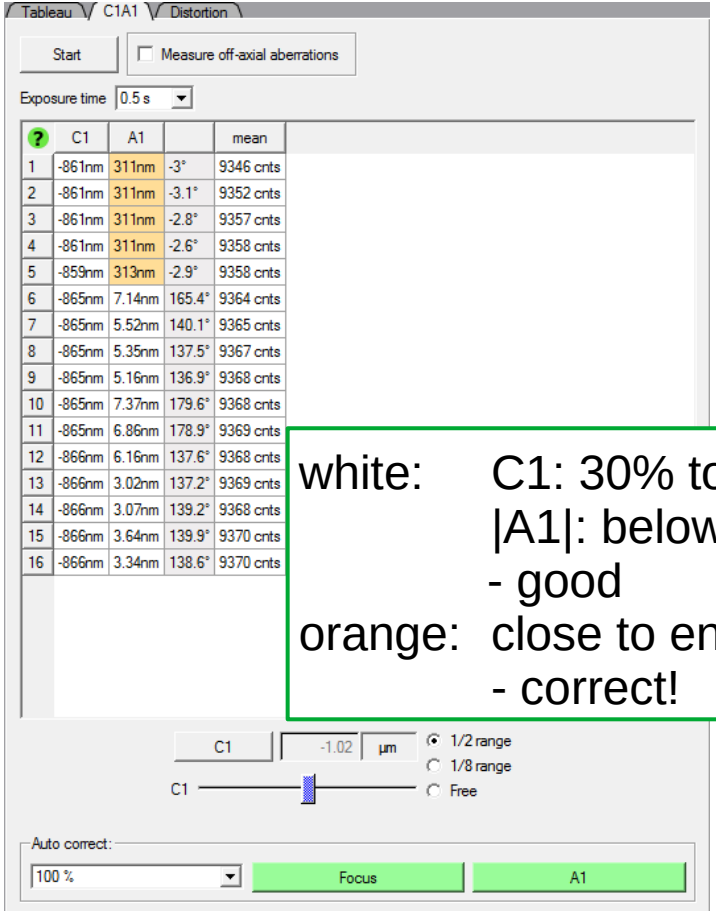
STEM: color code for size



	C1	A1	Angle	A2	Angle	B2	Angle	WD	Angle	mean
1	16.2nm	1.66nm	128.8°	155nm	-8.9°	38.6nm	-15.8°	963µrad	105.9°	4367 cnts
2	17.6nm	3.97nm	90.5°	186nm	-0.9°	35.1nm	140.6°	292µrad	116.3°	4392 cnts
3	17.7nm	4.96nm	123.4°	48.4nm	32°	37.9nm	127.7°	551µrad	82.9°	4414 cnts
4	14.3nm	5.53nm	112.6°	123nm	28.1°	25.6nm	-2.7°	362µrad	65.7°	4446 cnts
5	16.9nm	4.76nm	120.6°	142nm	22.2°	72nm	81.6°	713µrad	101.6°	4465 cnts
6	17nm	5.95nm	93.5°	66.4nm	-9.7°	41nm	120.9°	456µrad	41.1°	4493 cnts
7	15nm	3.24nm	111.7°	129nm	-20.1°	18.8nm	22.3°	572µrad	46.2°	4517 cnts
8	17.7nm	4.6nm	119°	92.3nm	-15.9°	49.5nm	26.8°	711µrad	84.4°	4547 cnts
9	16nm	6.46nm	97.3°	115nm	-38°	19.8nm	11.9°	720µrad	127.6°	4567 cnts
10	15.9nm	4.7nm	123.1°	143nm	-0.3°	53.7nm	78.8°	756µrad	55°	4597 cnts

white: almost zero - no action
yellow: measurable - decide
orange: large - correct!

TEM: color code for range “violation”

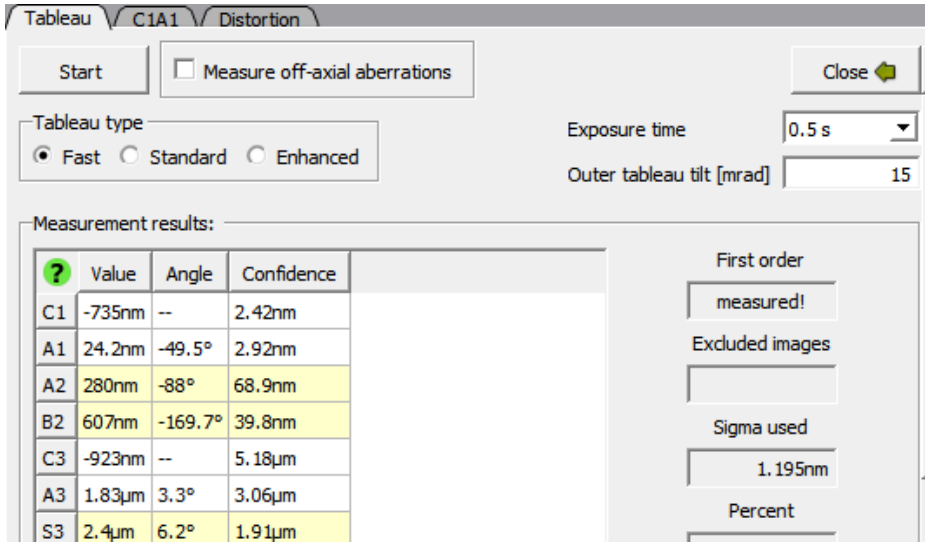


	C1	A1		mean
1	-861nm	311nm	-3°	9346 cnts
2	-861nm	311nm	-3.1°	9352 cnts
3	-861nm	311nm	-2.8°	9357 cnts
4	-861nm	311nm	-2.6°	9358 cnts
5	-859nm	313nm	-2.9°	9358 cnts
6	-865nm	7.14nm	165.4°	9364 cnts
7	-865nm	5.52nm	140.1°	9365 cnts
8	-865nm	5.35nm	137.5°	9367 cnts
9	-865nm	5.16nm	136.9°	9368 cnts
10	-865nm	7.37nm	179.6°	9368 cnts
11	-865nm	6.86nm	178.9°	9369 cnts
12	-866nm	6.16nm	137.6°	9368 cnts
13	-866nm	3.02nm	137.2°	9369 cnts
14	-866nm	3.07nm	139.2°	9368 cnts
15	-866nm	3.64nm	139.9°	9370 cnts
16	-866nm	3.34nm	138.6°	9370 cnts

white: C1: 30% to 70% of range
|A1|: below 25% of range - good
orange: close to end of range - correct!

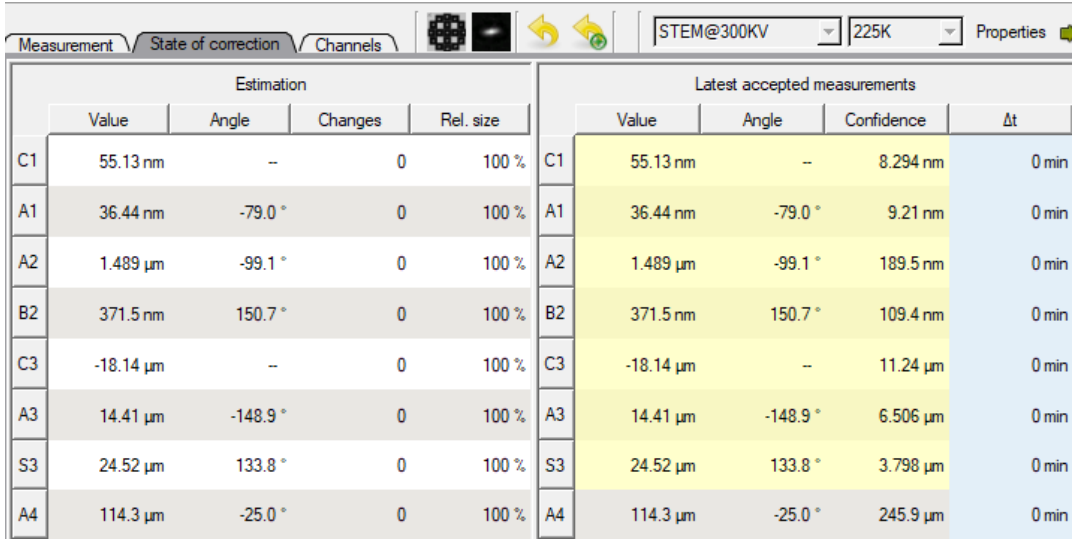
TEM and STEM: color code for well measurable aberrations

Tableau



	Value	Angle	Confidence
C1	-735nm	--	2.42nm
A1	24.2nm	-49.5°	2.92nm
A2	280nm	-88°	68.9nm
B2	607nm	-169.7°	39.8nm
C3	-923nm	--	5.18µm
A3	1.83µm	3.3°	3.06µm
S3	2.4µm	6.2°	1.91µm

State of Correction

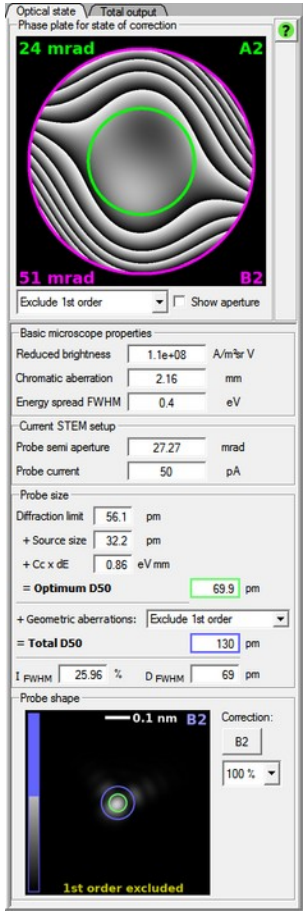


	Estimation				Latest accepted measurements				
	Value	Angle	Changes	Rel. size		Value	Angle	Confidence	Δt
C1	55.13 nm	--	0	100 %	C1	55.13 nm	--	8.294 nm	0 min
A1	36.44 nm	-79.0 °	0	100 %	A1	36.44 nm	-79.0 °	9.21 nm	0 min
A2	1.489 µm	-99.1 °	0	100 %	A2	1.489 µm	-99.1 °	189.5 nm	0 min
B2	371.5 nm	150.7 °	0	100 %	B2	371.5 nm	150.7 °	109.4 nm	0 min
C3	-18.14 µm	--	0	100 %	C3	-18.14 µm	--	11.24 µm	0 min
A3	14.41 µm	-148.9 °	0	100 %	A3	14.41 µm	-148.9 °	6.506 µm	0 min
S3	24.52 µm	133.8 °	0	100 %	S3	24.52 µm	133.8 °	3.798 µm	0 min
A4	114.3 µm	-25.0 °	0	100 %	A4	114.3 µm	-25.0 °	245.9 µm	0 min

white: almost zero - no action
yellow: above measuring accuracy - correctable

STEM: Tuning towards experimental requirements

STEM: Probe state tool



Desired optical state = “zero” aberrations

- **Reduce all aberrations sufficiently**

← Phase plate with pi/2 circle and limiting aberration, considered aberrations selectable

← Microscope properties

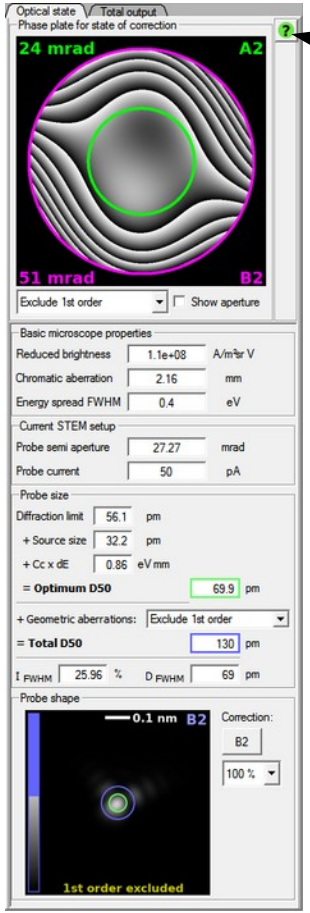
← STEM setup

← Ideal and attainable probe size

← Probe shape and most limiting aberration

Most important decision:
Good enough for desired experiment?

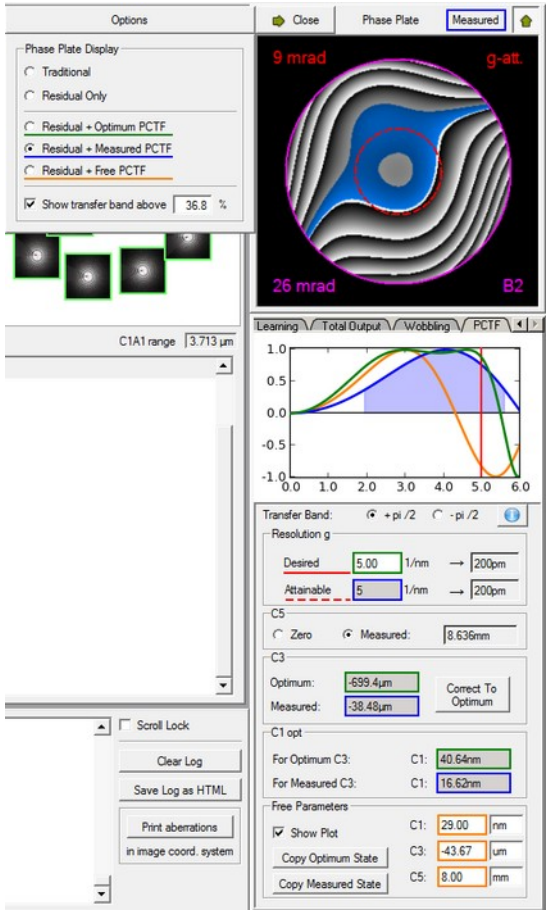
STEM: Probe state tool



See help dialog behind “Info” button for detailed instruction and complete workflow description.

TEM: Tuning towards experimental requirements

TEM: PCTF tool



Desired optical state ≠ zero aberrations

- **Shape phase contrast transfer function with round aberrations**
- **Reduce other aberrations sufficiently**

← Phase plate, considered aberrations selectable

← Phase contrast transfer function

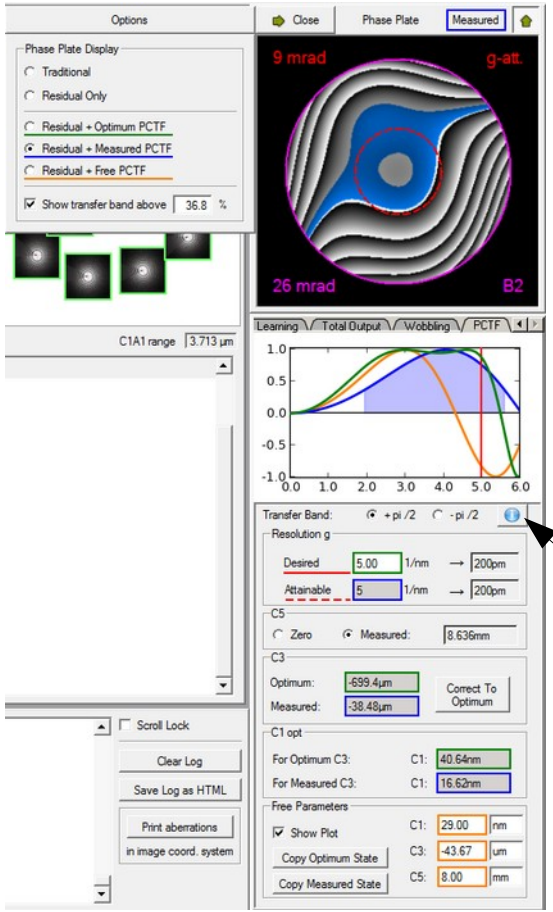
← Desired and attainable resolution

← Optimisation of spherical aberration C3

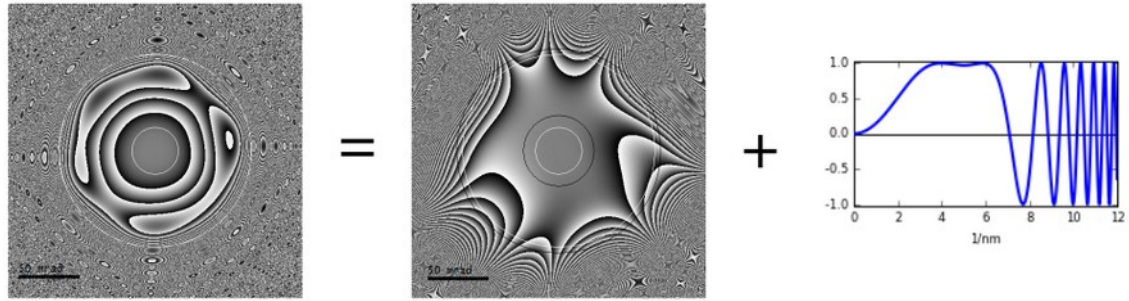
Most important decision:
Good enough for desired experiment?

TEM: Tuning towards experimental requirements

TEM: PCTF tool



total aberration = residual aberration + PCTF



correct **adjust**

See help dialog behind “Info” button for detailed instruction and complete workflow description.

Finetuning during experiment: Exported elements

Corrector GUI

➔ Channels

➔ Exported elements