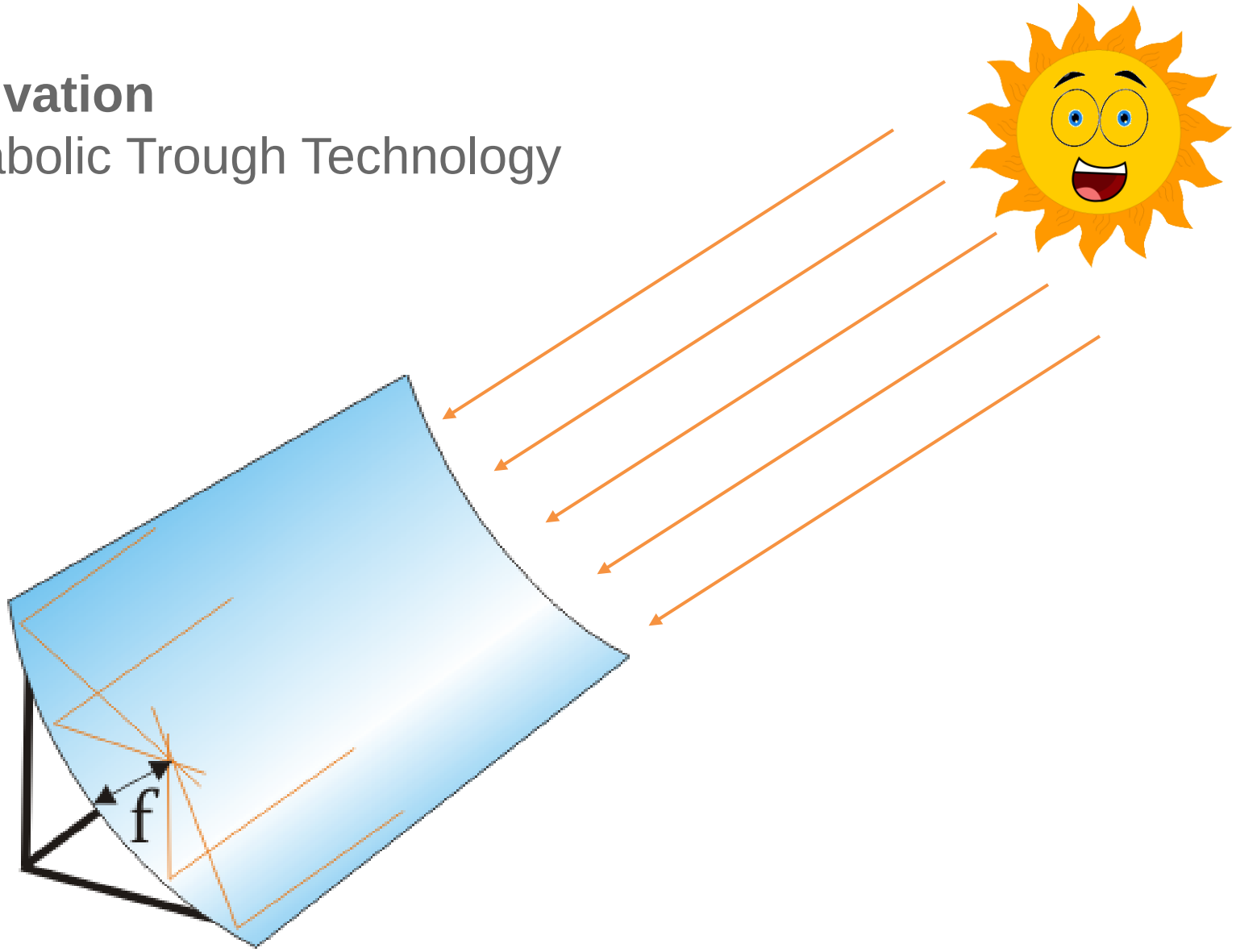
Influences on shape accuracy of parabolic trough mirror panels mounted onto solar collectors

Simon Schneider

DLR, Institute of Solar Research, Cologne, Germany

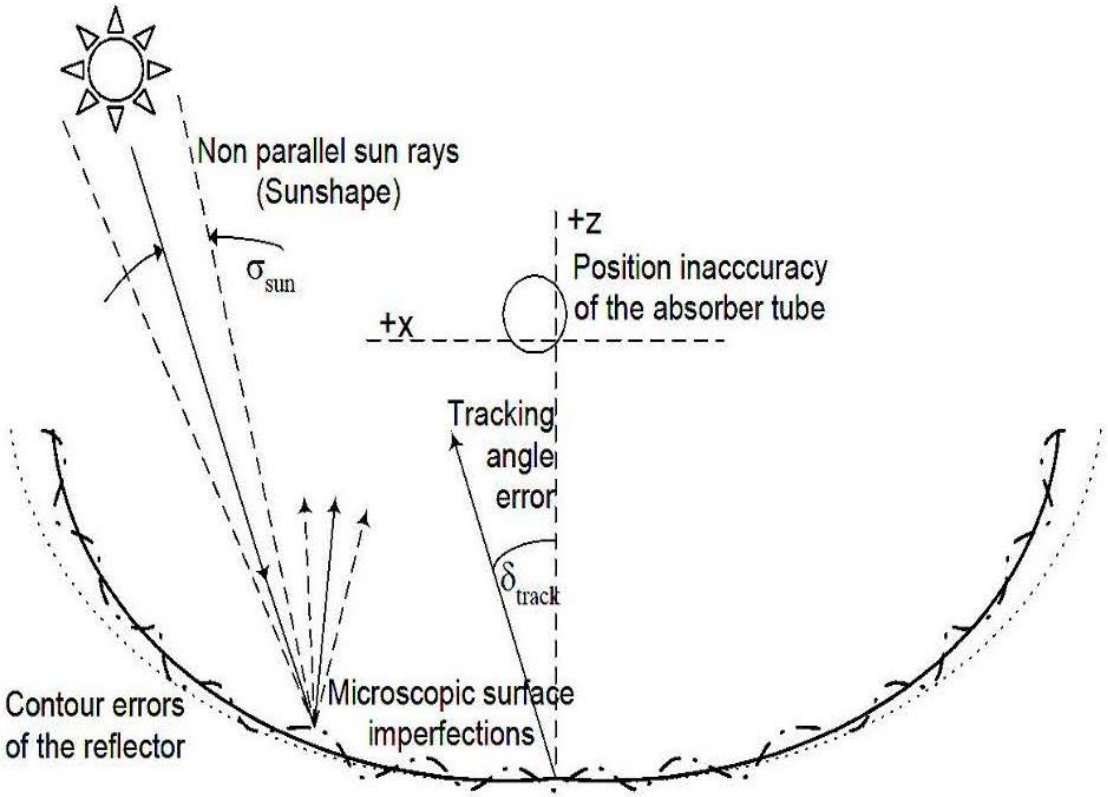
10th Sollab Doctoral Colloquium, June 2014

Motivation
Parabolic Trough Technology



Unfortunately, it‘s not that simple…

Optical losses

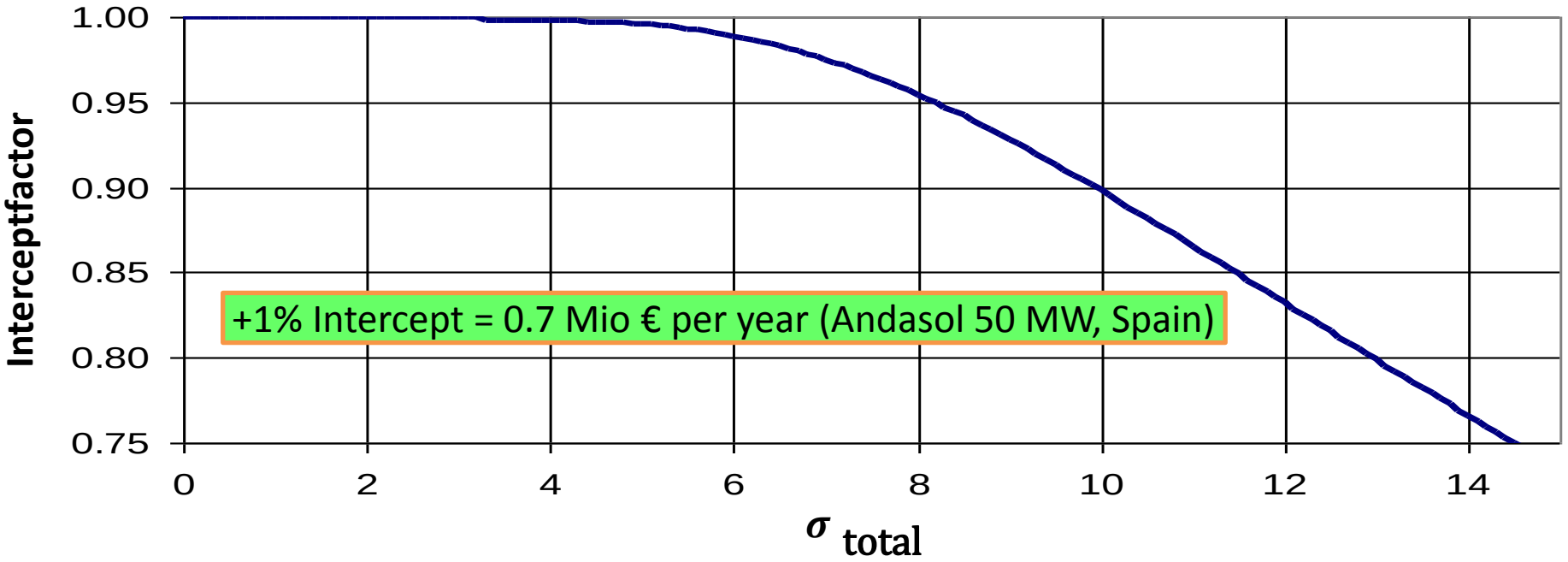


Many different effects influencing the amount of intercepted radiation, practically impossible to measure up to perfection

… That cries out for statistics!

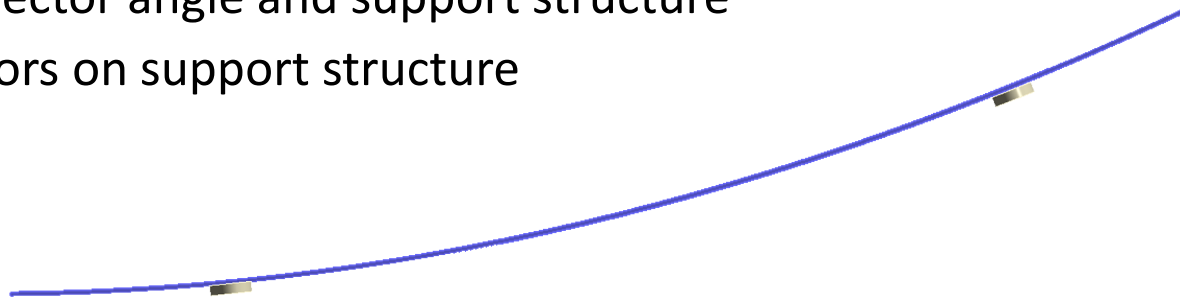
Combined Uncertainty σ_{total} (for EuroTrough)

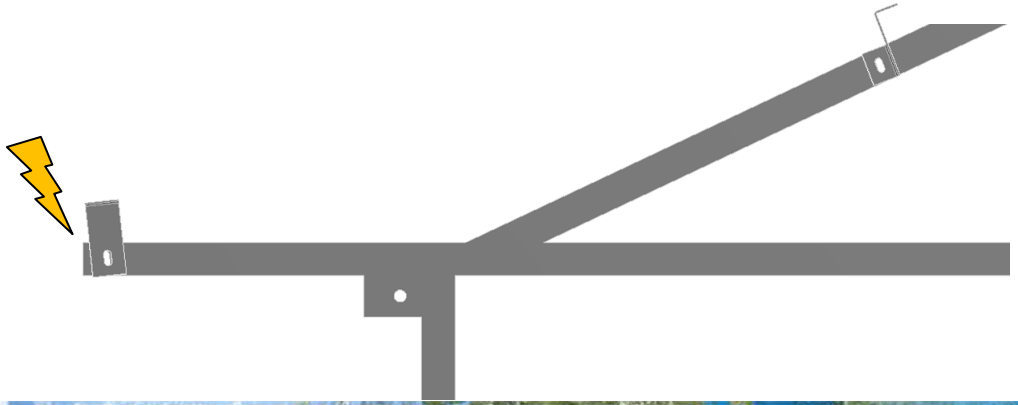
	σ in mrad
Mirror Shape*	2
Beam Spread	0.2
Mirror Support*	1
Absorber Position	1.5
Collector Torsion (Loads)	1
Module Alignment	1.5
Tracking Accuracy	1
Sun	3.5
Total	**6.24**
Intercept Factor	**98.7%**



Influences on mirror shape

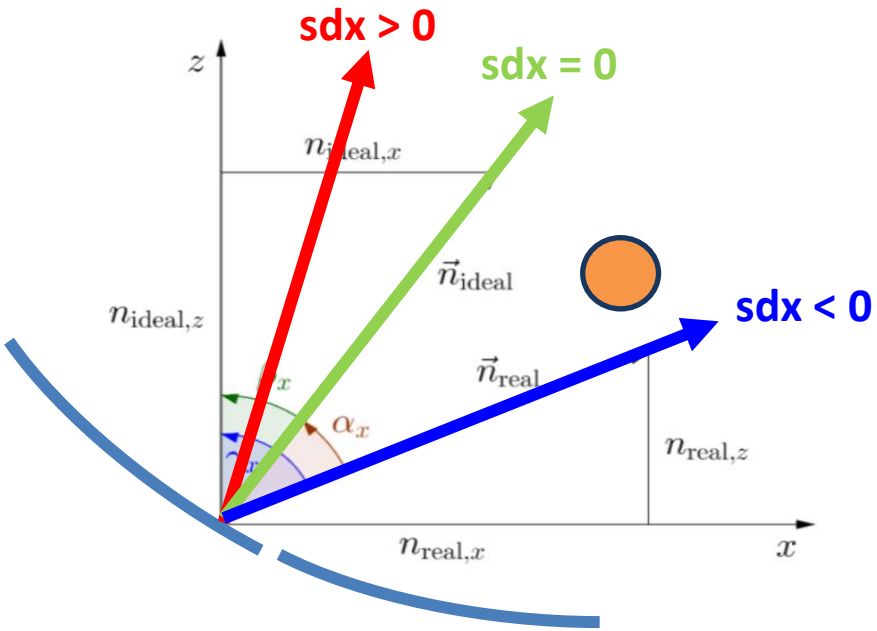
- Internal stress in mirror material due to manufacturing process
- Dead load depending on collector angle and support structure
- Inaccurate mounting of mirrors on support structure



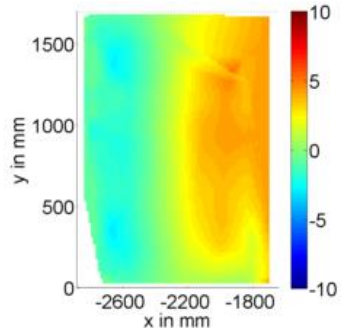


Methods

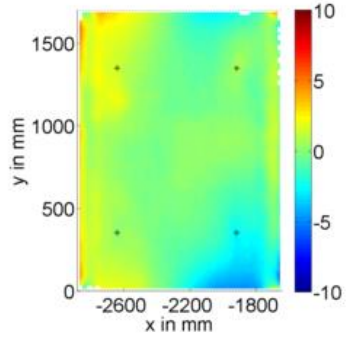
Slope Deviation – Quality of mirror surface



RP3 Outer



$SDx_{coll,meas} = 2.5\,mrad$



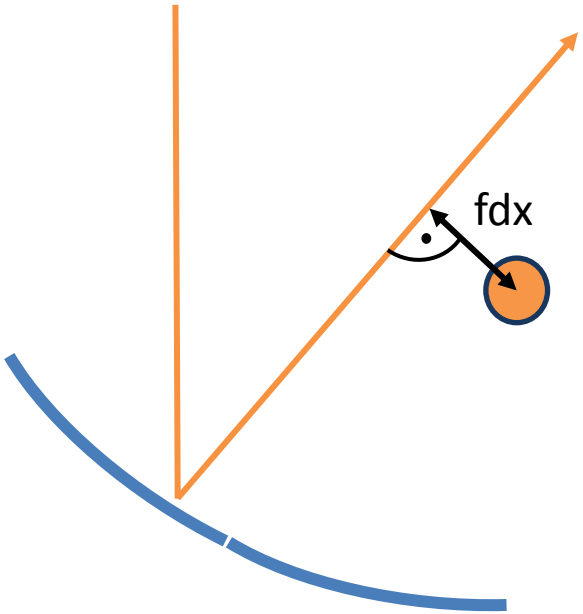
$SDx_{vf,meas} = 1.33\,mrad$

Slope Deviation (mrad)

$$sdx = \alpha_x = \gamma_x - \beta_x$$

$$SD_x = \sqrt{\sum_{k=1}^{n} \left({sdx_k}^2 \cdot \frac{a_k}{A_{total}} \right)}$$

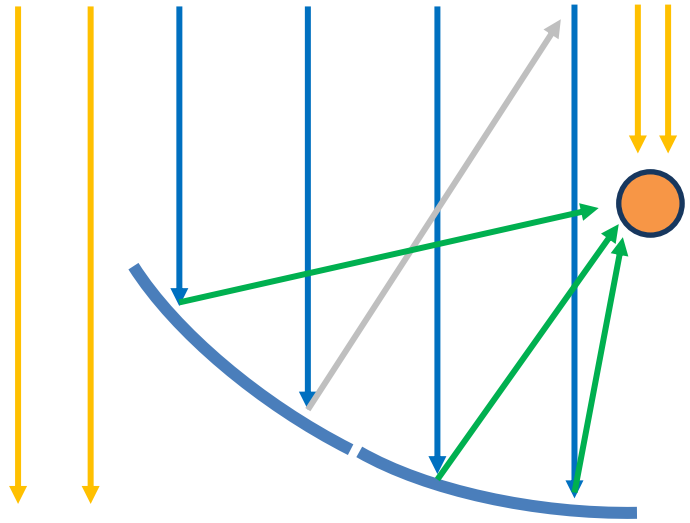
Quality assurance parameter characterizing impact on yield



Focus Deviation (mm)

$$fdx = 2 \cdot d \cdot sdx$$

$$FD_x = \sqrt{\sum_{k=1}^{n} \left(fdx_k{}^2 \cdot \frac{a_k}{A_{total}} \right)}$$



Intercept Factor (0-100 %)

Fraction of reflected power that actually reaches the receiver tube

Workflow for evaluating mirror shape accuracy

Input parameter

DEFORMATION

- **ANSYS**
- Simulation for different load cases and input parameter

SLOPE DEVIATION

- **MATLAB**
- Postprocessing of ANSYS results
- Comparison with measurement results
- Preprocessing for ray tracing

OPTICAL EFFICIENCY

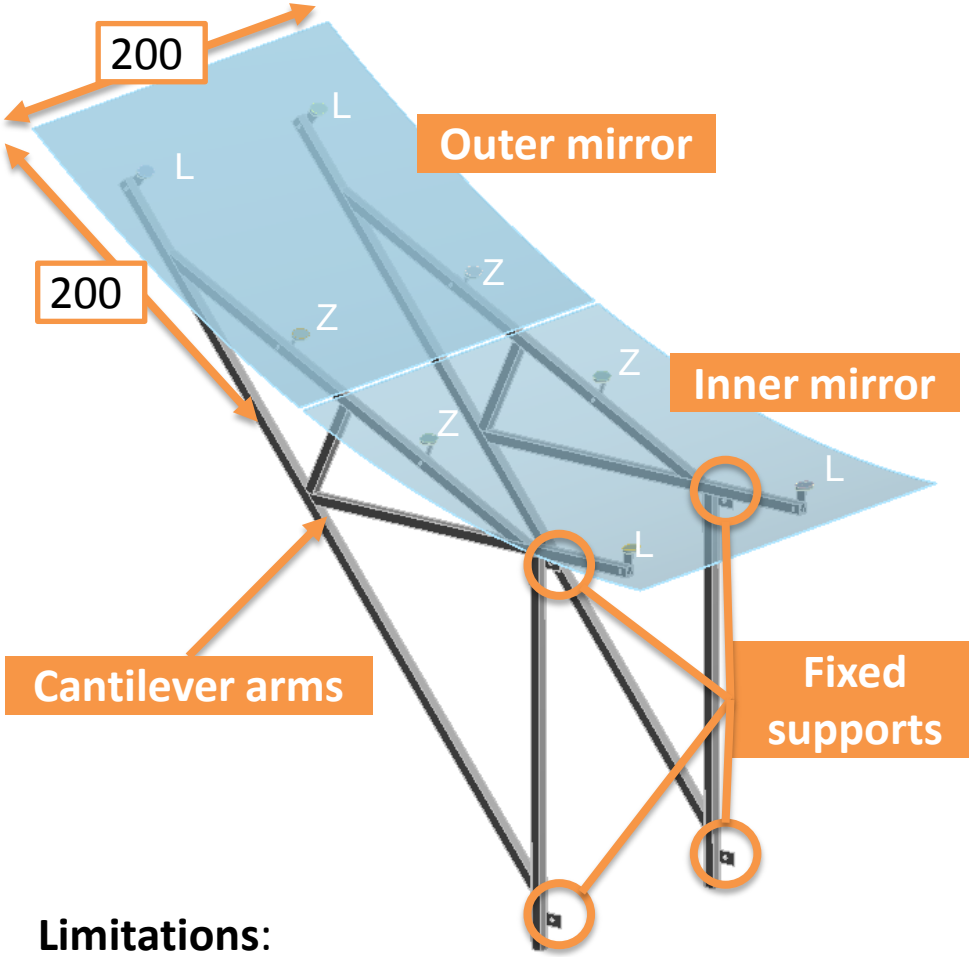
- **STRAL**
- Evaluation of optical performance via ray tracing

Results

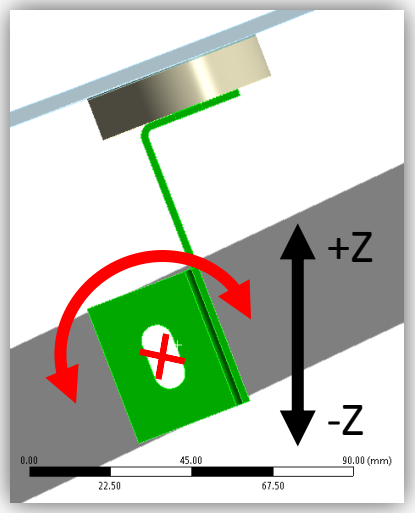
ANNUAL YIELD

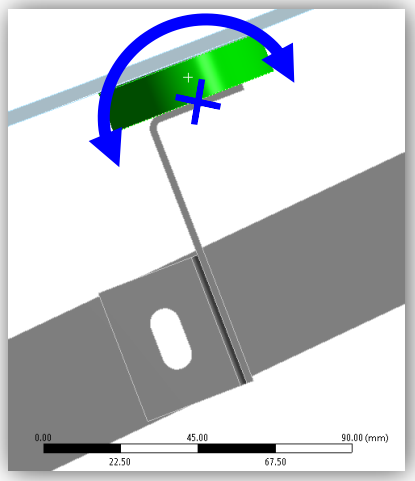
- **MATLAB**
- Postprocessing of ray tracing results for evaluating collector efficiency
- Visualisation of results

FEM EuroTrough (ANSYS WB)



Limitations:
- torque-box not included
- no screws or bolts modeled

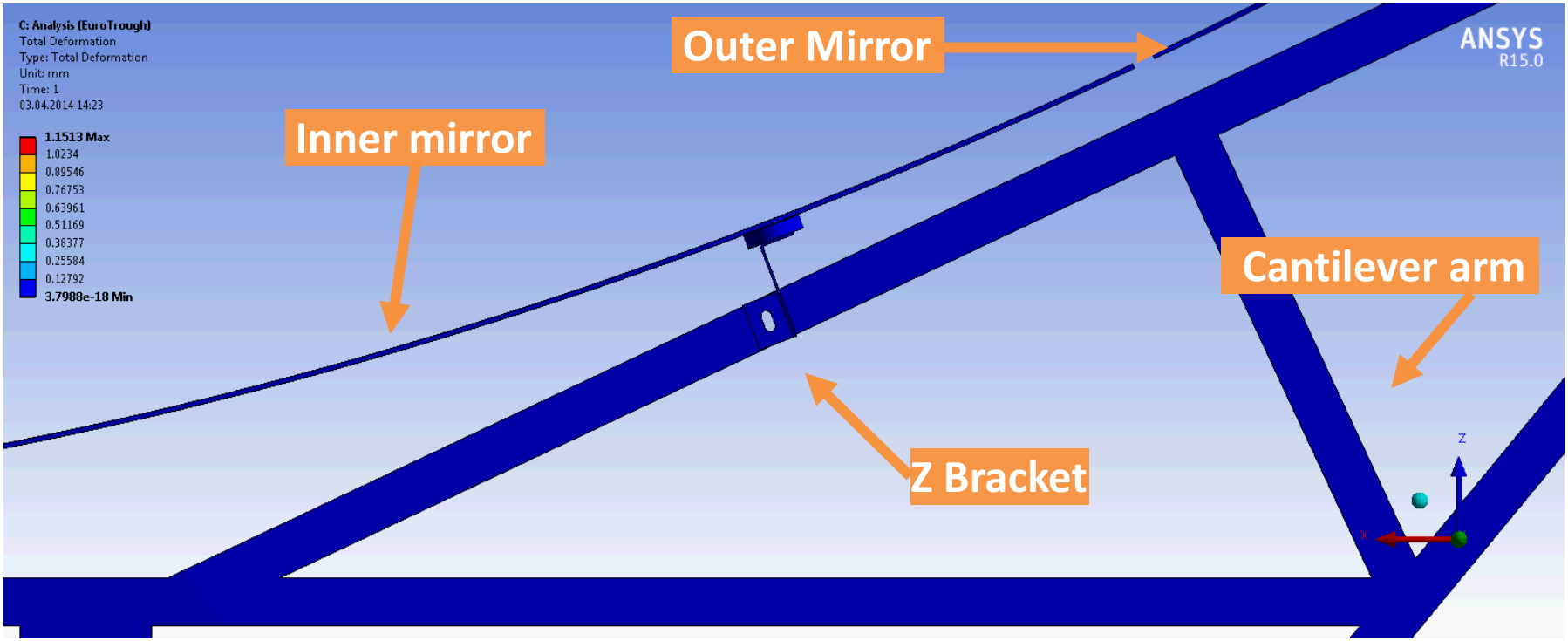




- Solid Shell hex8 elements (mirror panels)
- 20 Joints / 72 Joint Loads
- 16 Command Snippets
- 4 Substeps

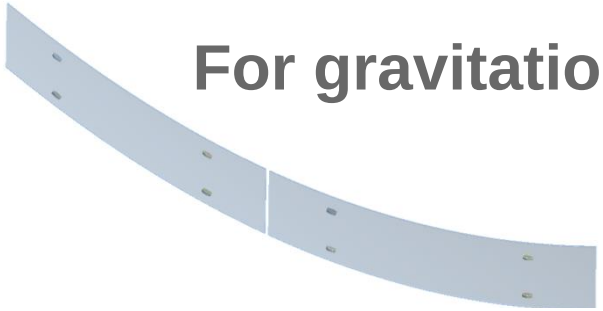
– Angular deviation of brackets
– Angular deviation of mounting pads
– Positonal deviation of brackets
– Dead-load by gravitation

Dead Load + Angular deviation of brackets



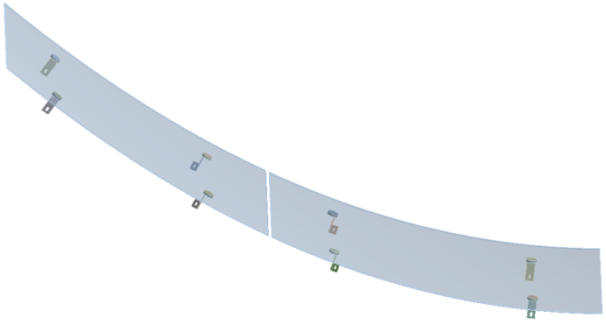
Scale factor: 190

For gravitational results – Investigated Cases



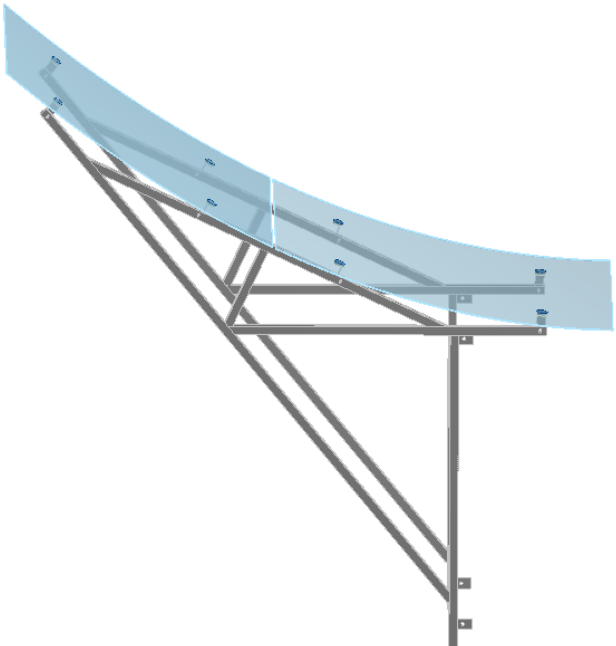
I. Ideal case

Mirrors + Mounting pads + Silicone adhesive



II. Bracket case

Ideal case + L/Z - brackets



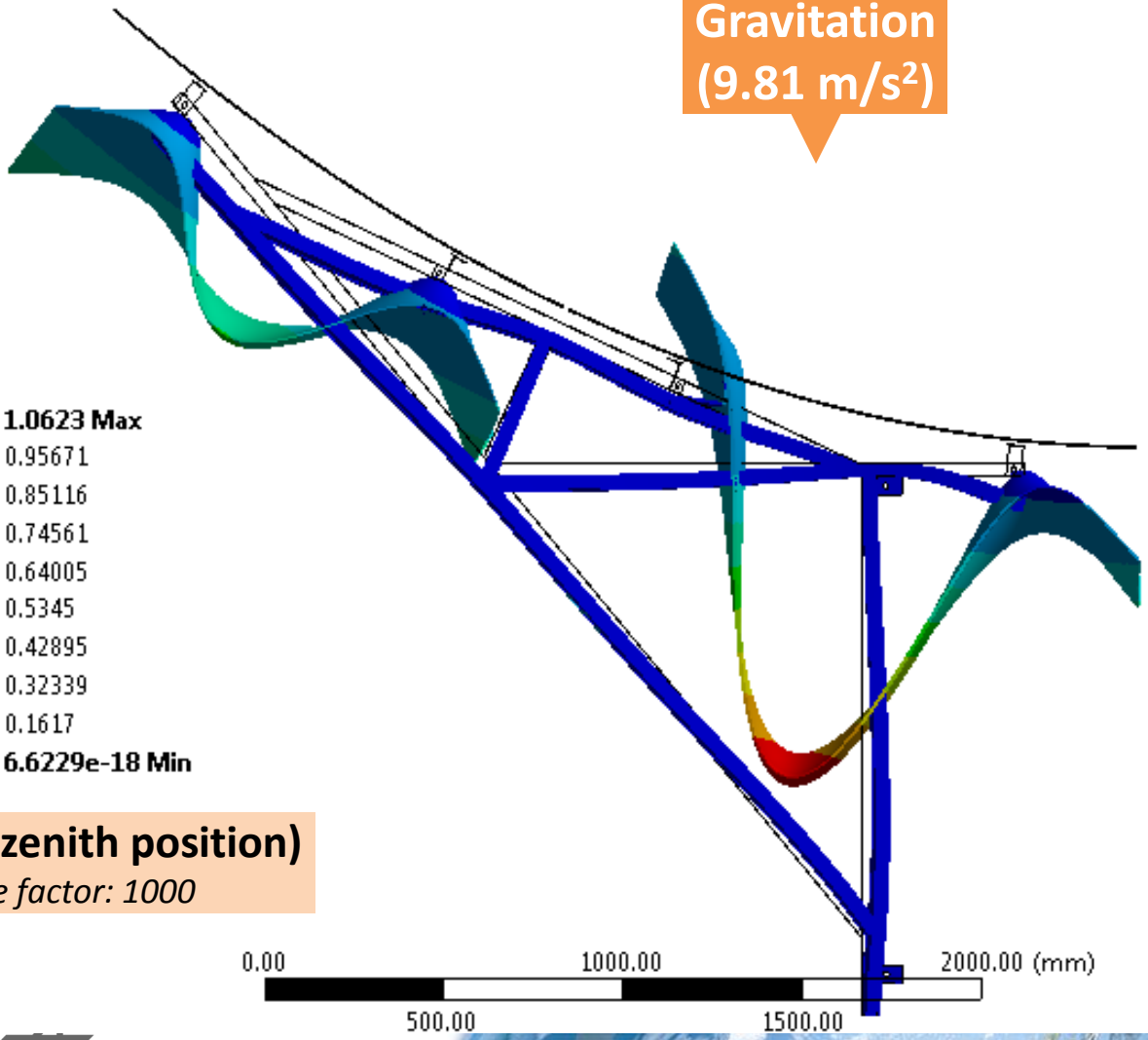
III. Cantilever case

Bracket case + cantilever arms

Results

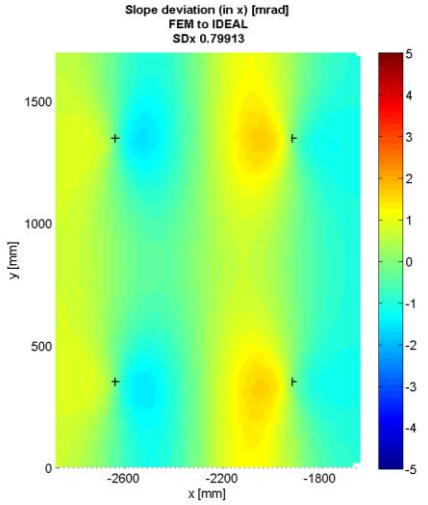
Deformation in zenith position

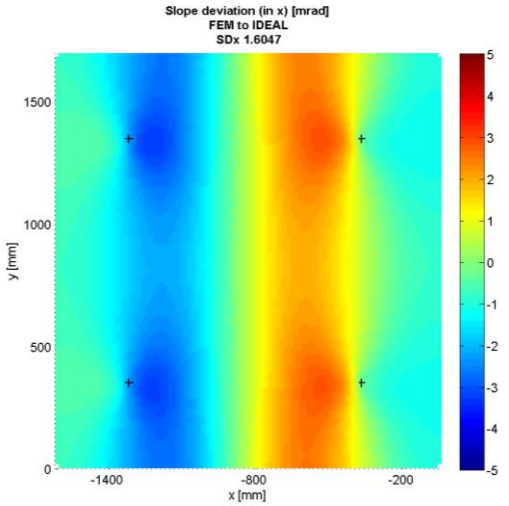
Gravitation (9.81 m/s²)



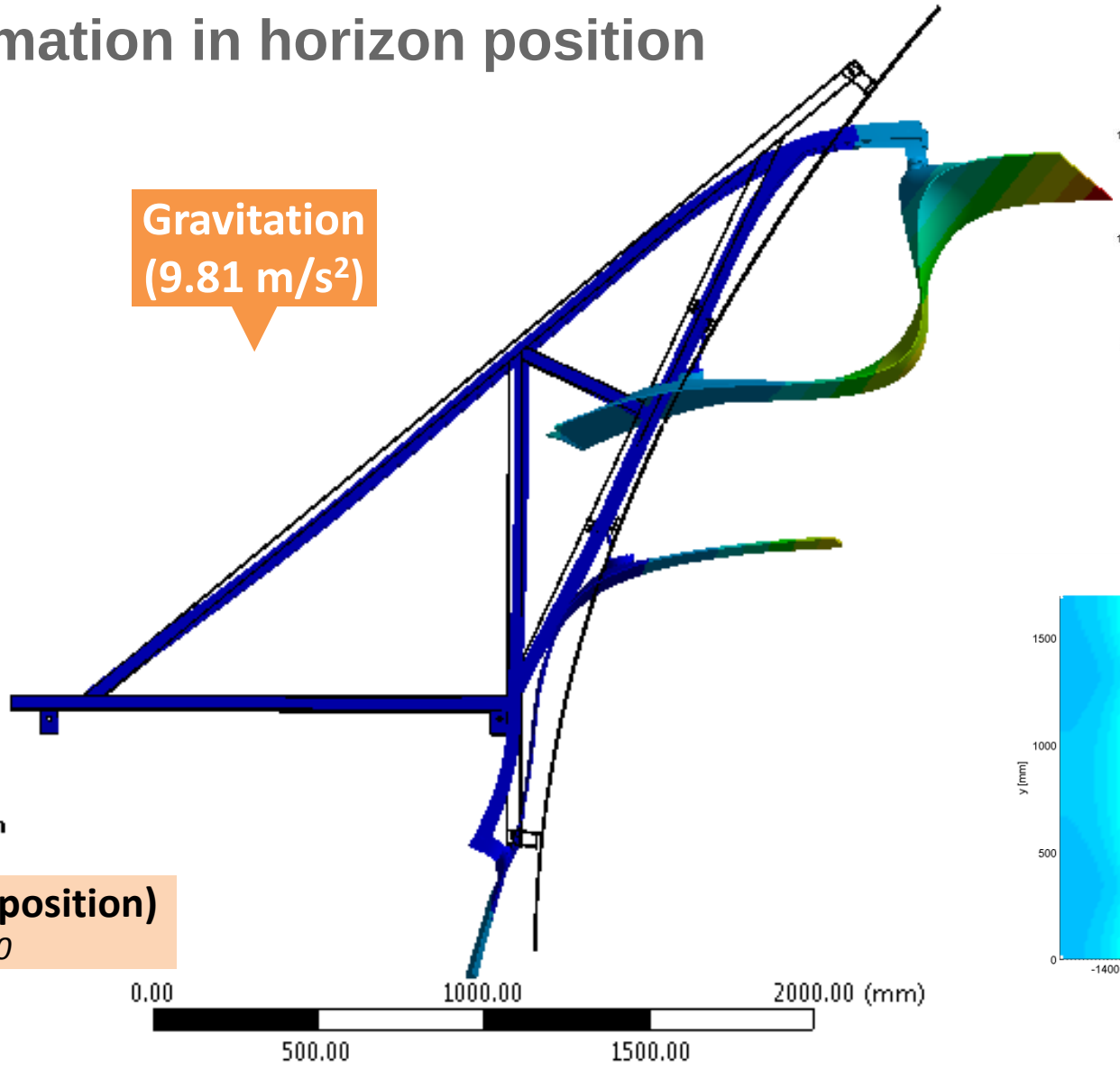
0° (zenith position)

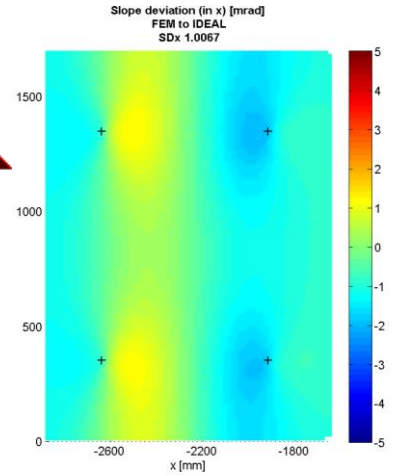
Scale factor: 1000

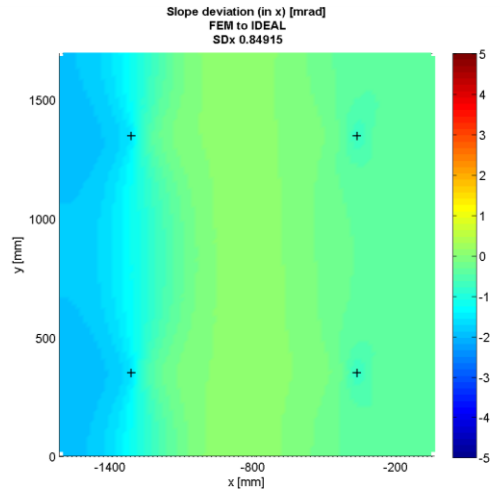




Deformation in horizon position



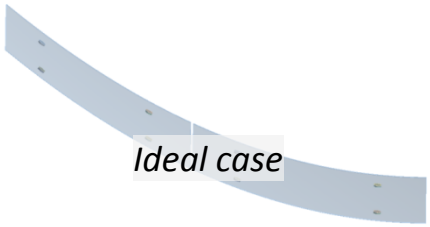


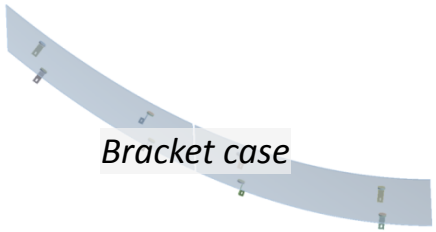


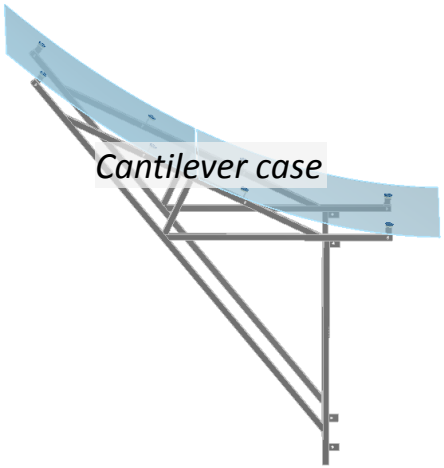
90° (horizon position)

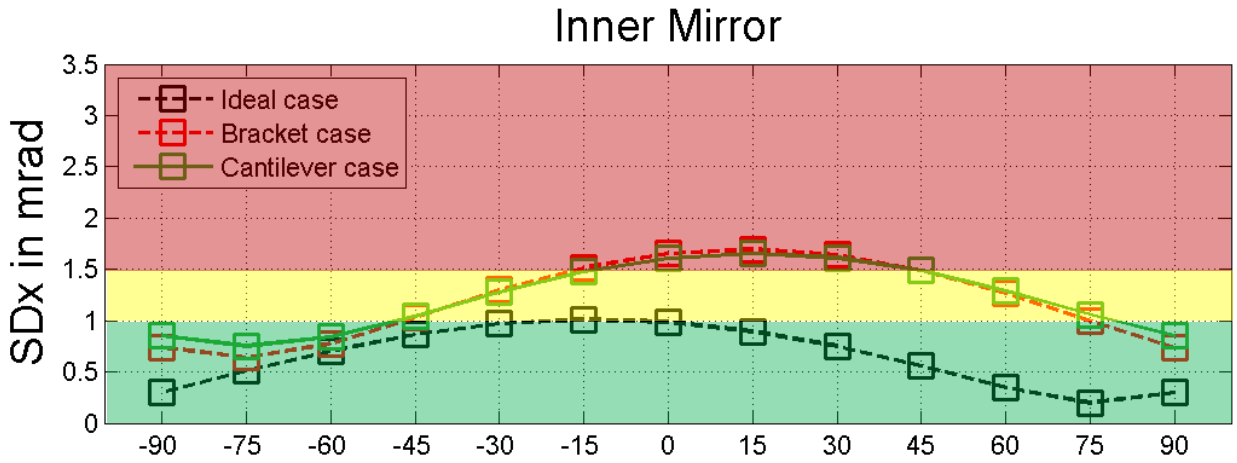
Scale factor: 1000

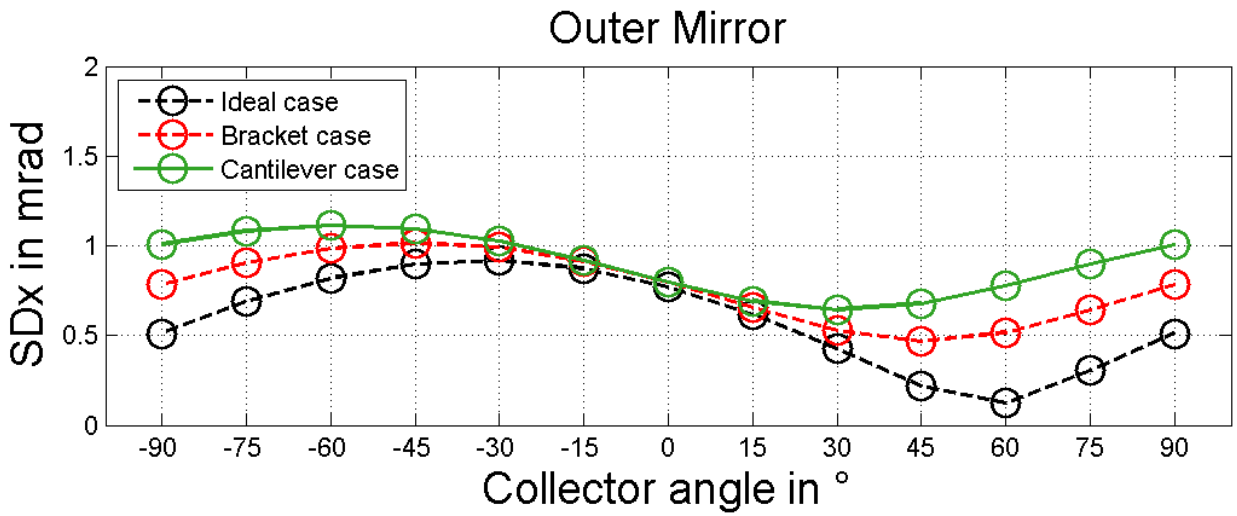
Influence of cantilever arms – Slope Deviation





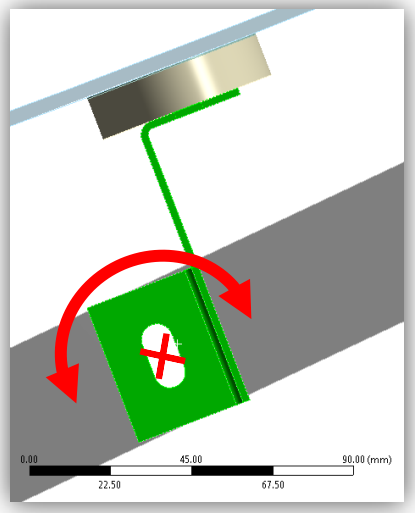


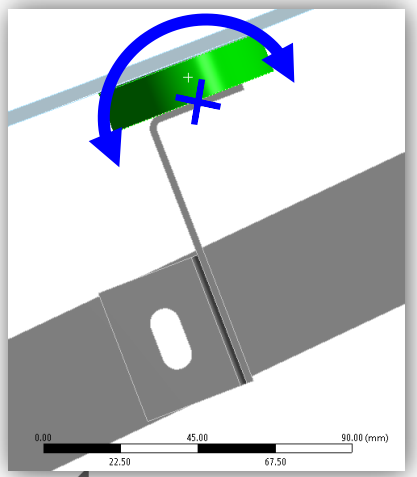


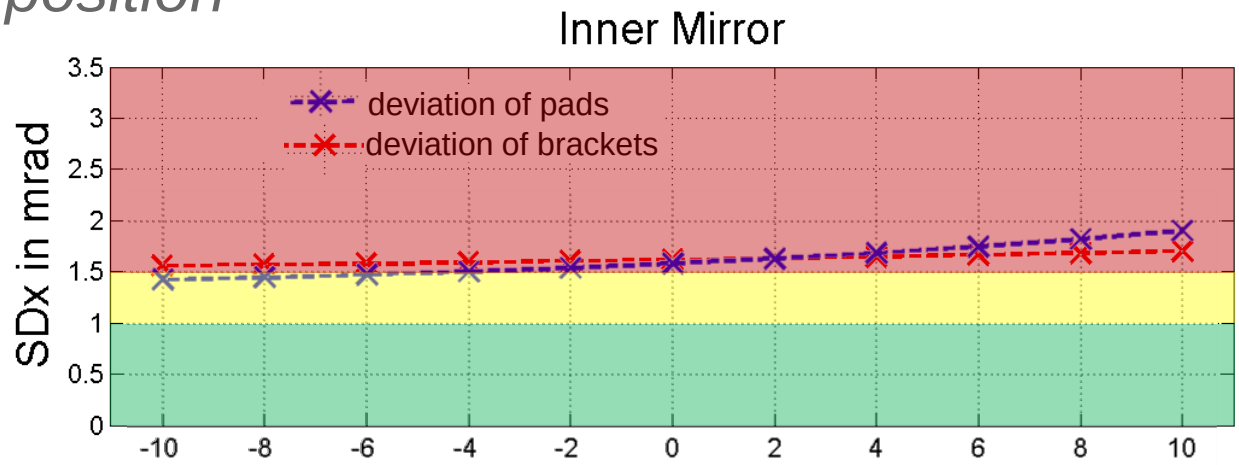


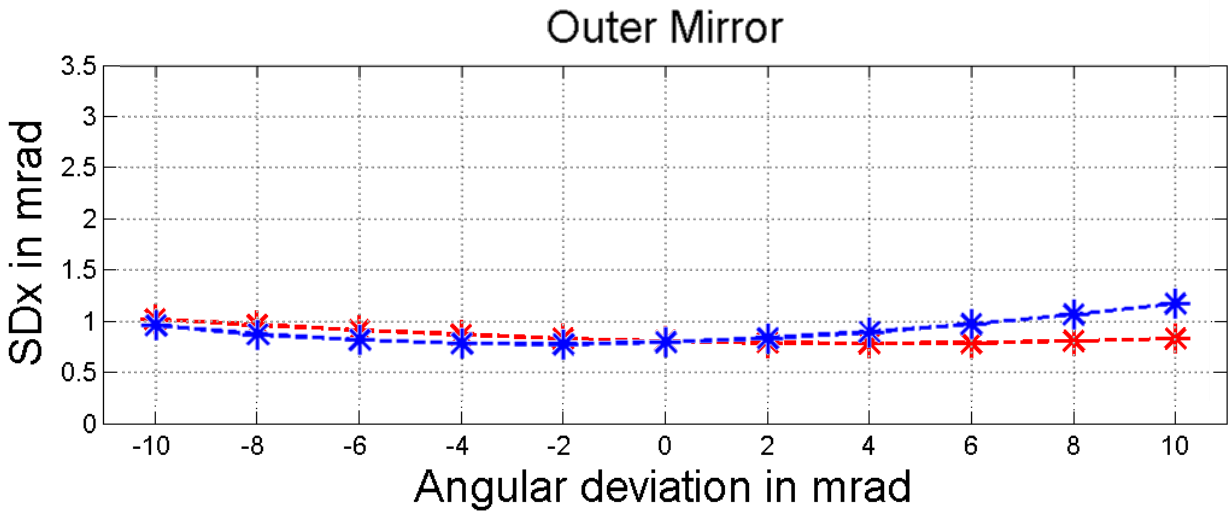
Angular deviation of brackets / mounting pads

Zenith collector position





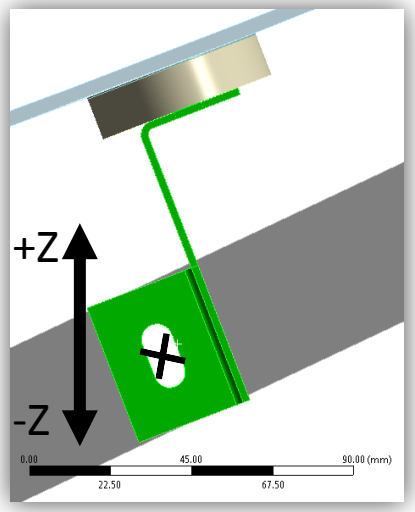


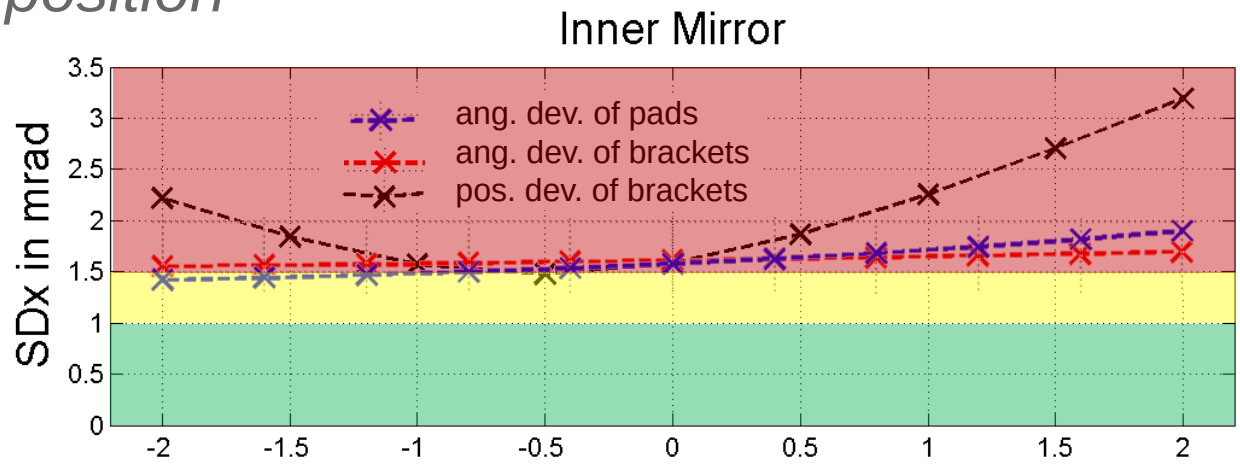


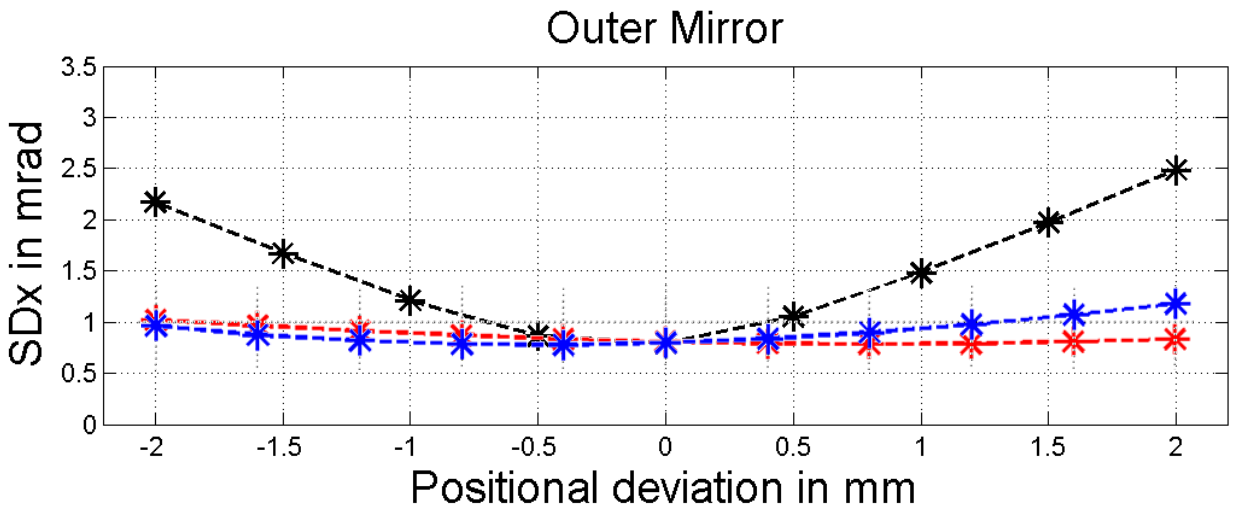
DLR

Positional deviation of brackets

Zenith collector position



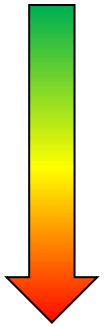




Conclusion

- Various influences on mirror shape accuracy exist (small changes = huge impact)
- Tools for investigating mirror shape accuracy have been developed
  - FE-Model in ANSYS WB
  - Specific methods to simulate different influences in the model
  - Workflow (Deformation > Mirror Shape > Optical Performance > Efficiency)

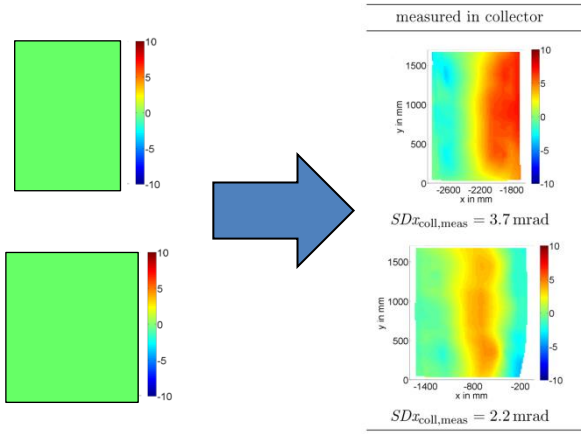
- Influence of support structure investigated (SDx inner mirror in zenith position):
  - Dead load (only pads): 0.98 mrad
  - Dead load (with brackets): 1.60 mrad
  - Dead load (with cantilever arms): 1.65 mrad
  - Dead load + Angular deviation of brackets (10 mrad): 1.70 mrad
  - Dead load + Angular deviation of mounting pads (10 mrad): 1.91 mrad
  - Dead load + Positional deviation of brackets (2 mm) 3.20 mrad



Outlook

DEFORMATION → SLOPE DEVIATION → OPTICAL EFFICIENCY → ANNUAL YIELD

- „What happens in the collector?“
  - Influence of other assembling inaccuracies
  - Forces onto the mirrors that origin from the support structure
- Long-term aims:
  - Maximum allowed forces →How to ensure that?
  - Better initial mirror shapes than ideal parabola?
- Comparative measurements at KONTAS test bench (Shape accuracy, Geometric precision, Forces)
- Transferability from laboratory to field



Thank you for your attention!