Reflector Shape Measurements

Solar Mirror Shape

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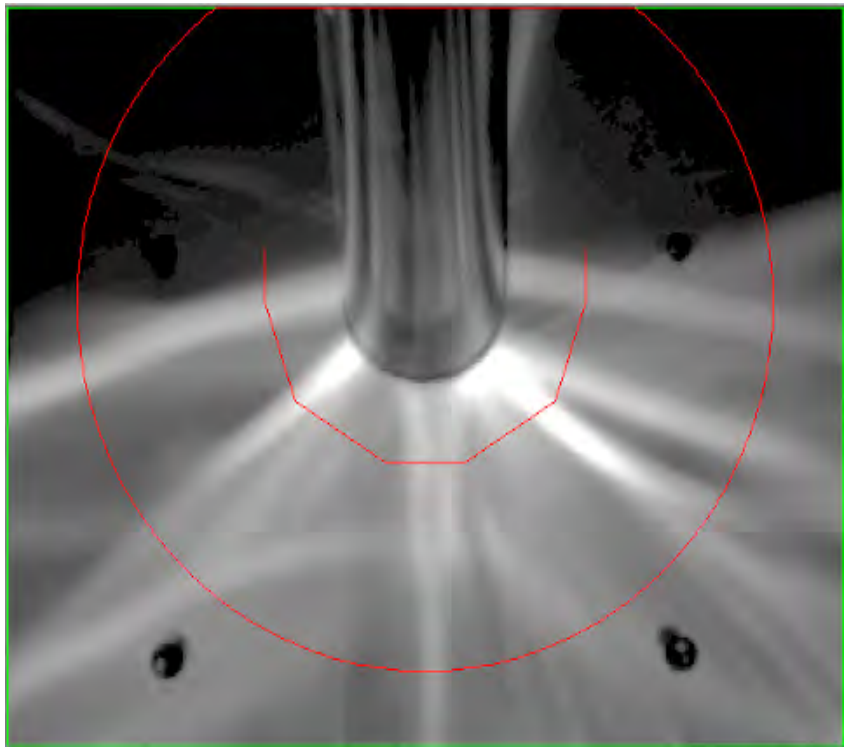
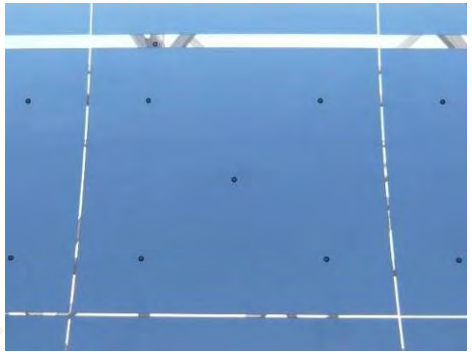
Reflector Shape is a Key Property of Concentrating Solar Systems

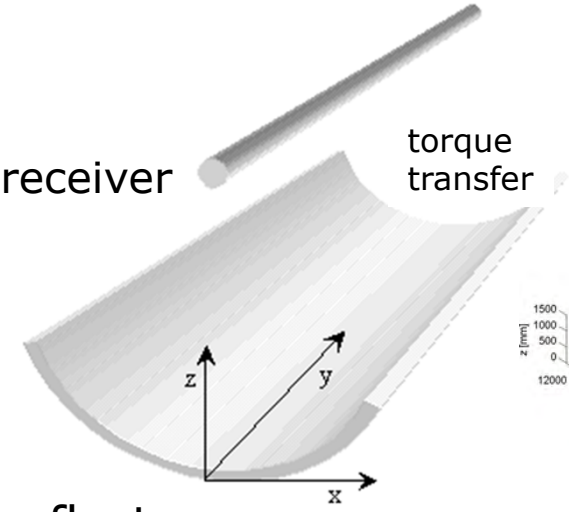
How does the focal area look like?

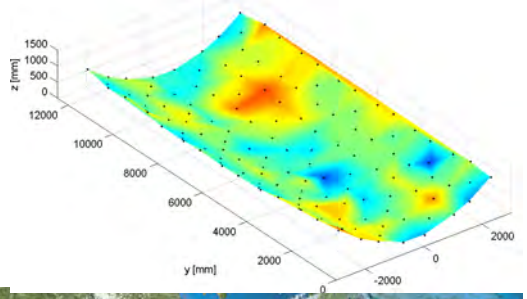


Collector Geometry Qualification

- Geometry
- Module reference
  - mirror alignment
  - receiver alignment
- Collector reference
  - alignment between modules and drive
  - in all collector angles
- Also in series production quality control







Mirror and Concentrator Geometry

- Mirror shape (component level, assembly level)
- Concentrator structure
- Collector assembly
- Performance is related to geometry accuracy
- Performance figure is the intercept factor

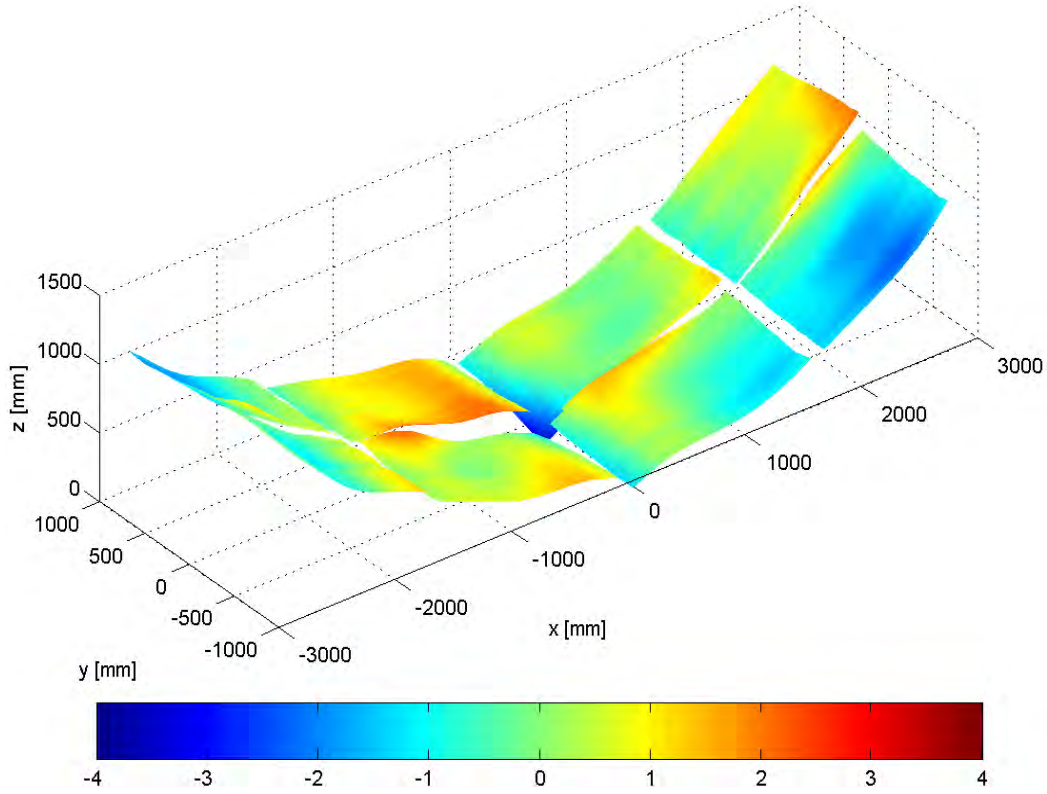
- Intercept factor is only applicable to assembly under operation conditions
- Intercept factor is not applicable to individual components

- Needed: easy-to-handle figure of merit
  (Answer will be: Slope deviation, Focus deviation)

Mirror Shape Measurement Methods

- Laser reflection count
- High-Density Close-Range Photogrammetry
- Deflectometry (Fringe Reflection)

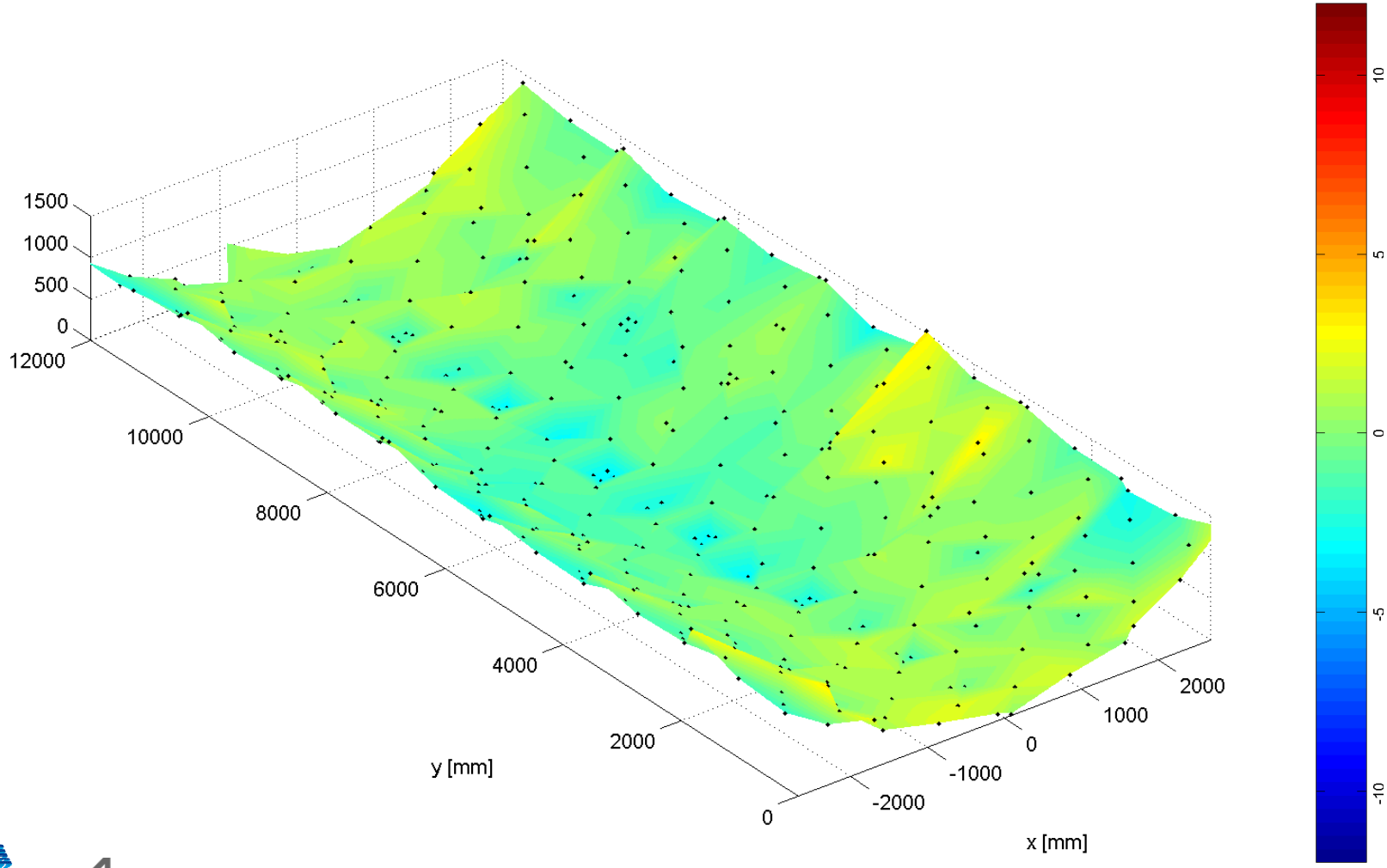
Photogrammetry on Mirrors



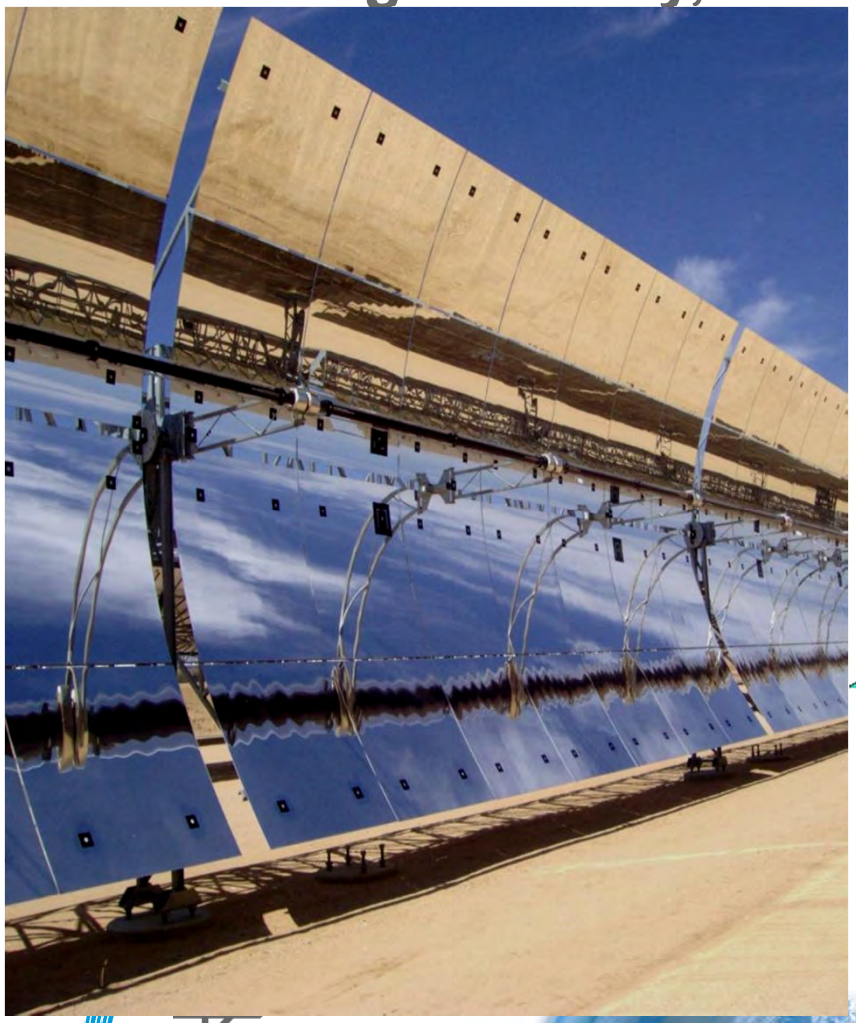
- Measure Mirror Shape
- Measure Slope and Slope Deviations
- Calculate Optical Efficiency
- Measure Deformation due to dead-load etc.

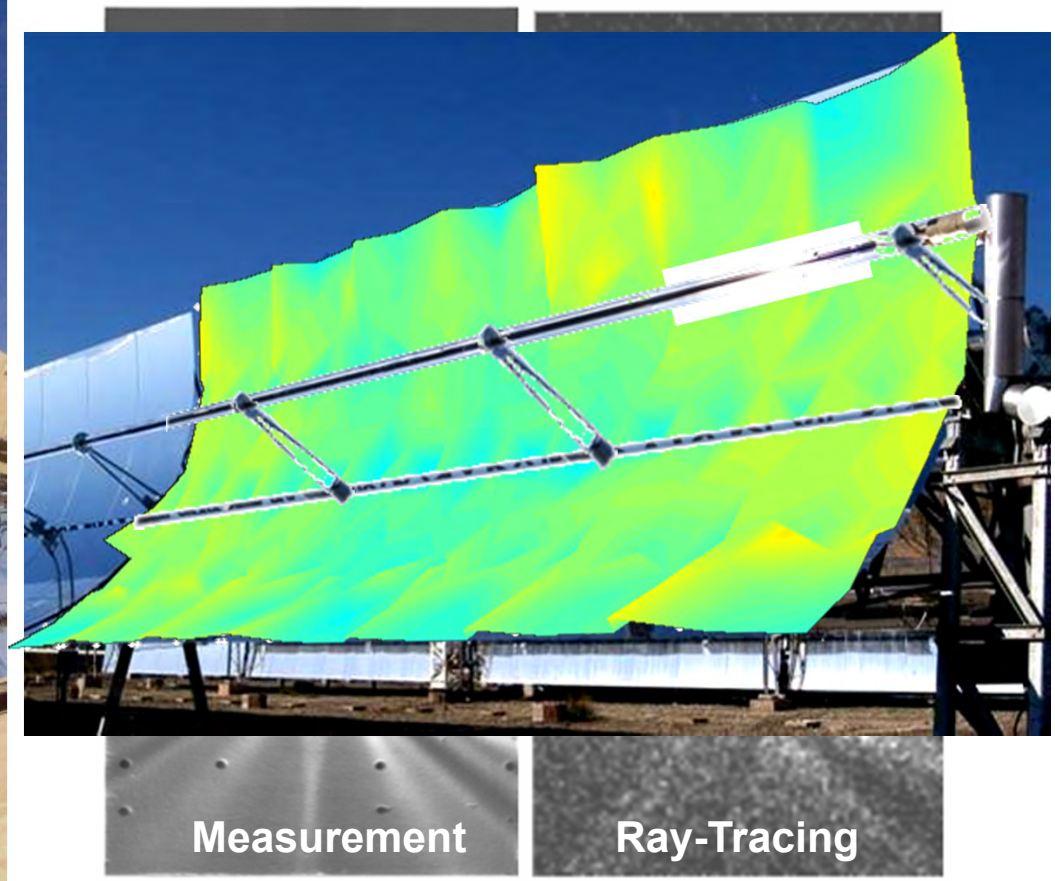
Photogrammetry on Collectors

Concentrator-Quality 3-dimensional, EuroTrough



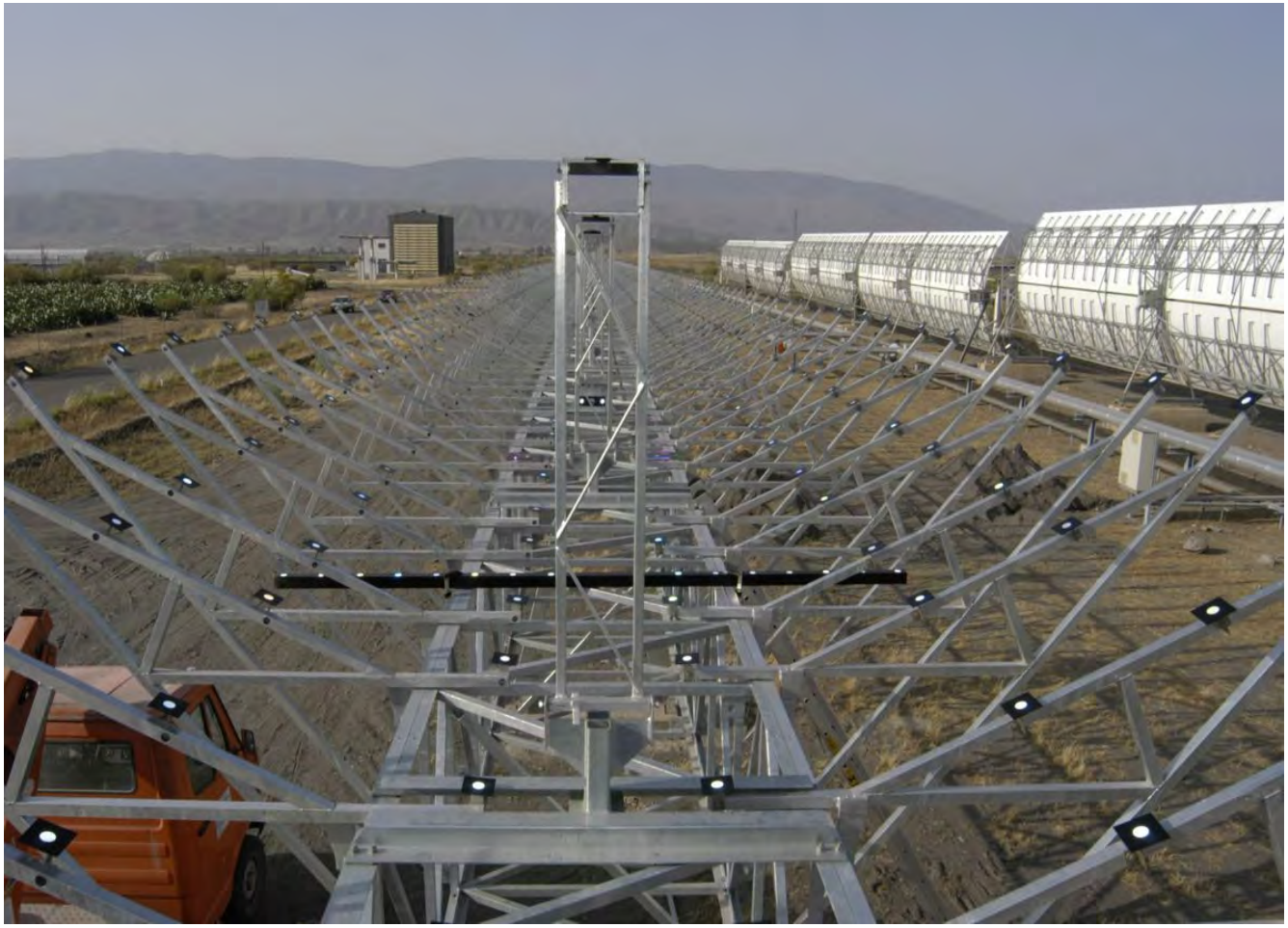
EuroTrough Skal-ET Collector Qualification Photogrammetry, Efficiency Measurement



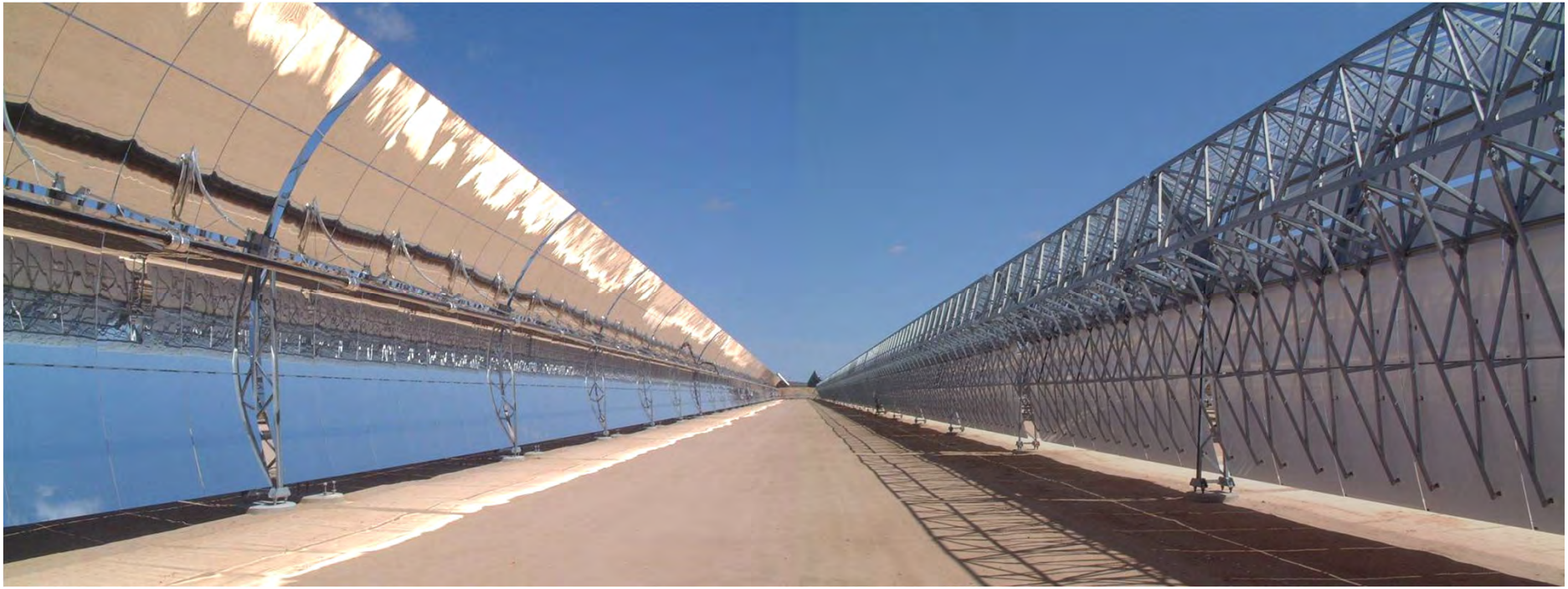


Flux distribution around absorber tube

Quality Control during Collector Assembly



Geometric Precision Study over large Collector Areas



“Distant Observer” Techniques
Reflection Image Analysis

- Receiver is imaged, thus couples receiver position/shape to concentrator optics
- Potential for large mirror areas (module level) to be characterized quickly; does not provide point by point surface measurement (i.e. suited to fast module/mirror panel/receiver alignment)
- Examples:
    - Theoretical Overlay Photographic Alignment System (TOP)
    - TARMES Reflector Analysis
    - QDec Pattern Techniques

TARMES Absorber Tube Reflection

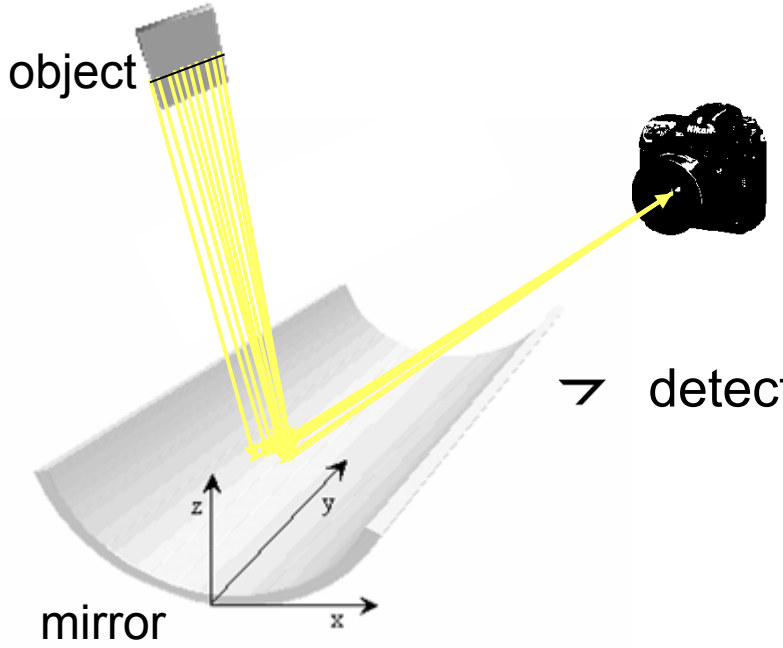
Laser Techniques (NREL)

- Laser beam reflected by the concentrator mirror
- Scanning laser
- Analysis of the position of the reflected laser on a target

- VSHOT (NREL)

QDec Reflector Analysis
"Deflectometry" or "Fringe reflection"

- Based on image recognition of a target in the reflector
- measure coordinates of many points in one step
  - ***lines/grids instead of points, for higher speed***



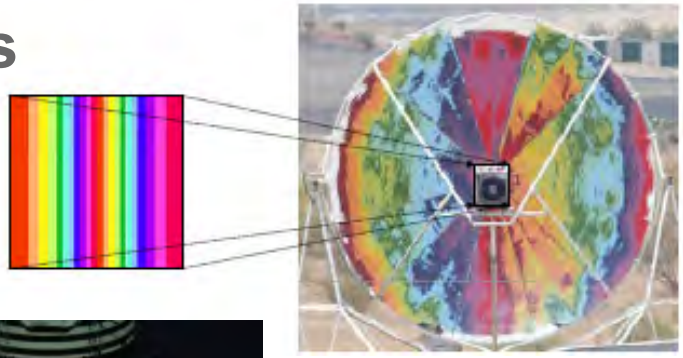
→ detector: <u>digital camera</u>

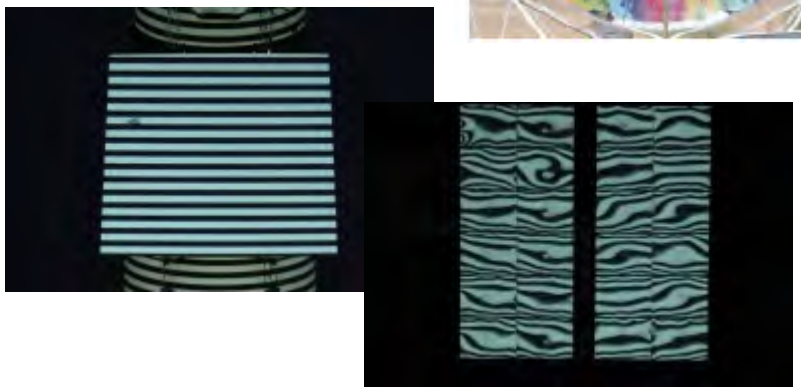
– high resolution:

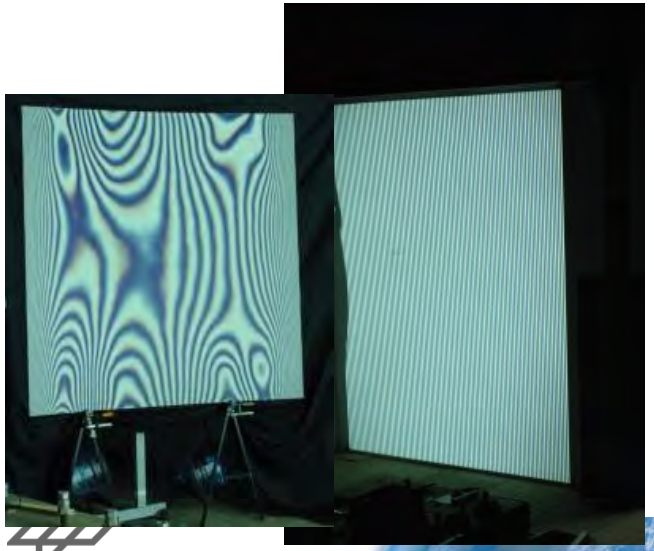
– detector data = foto

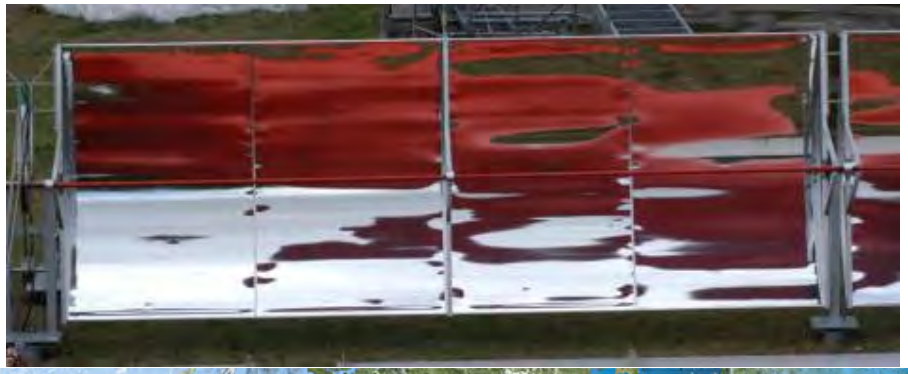
Deflectometry Application Examples

- Troughs, Heliostats, Dishes
- Mirror Facets
- flexible measurement systems
- high spatial resolution and precision
- fast
- industrial application



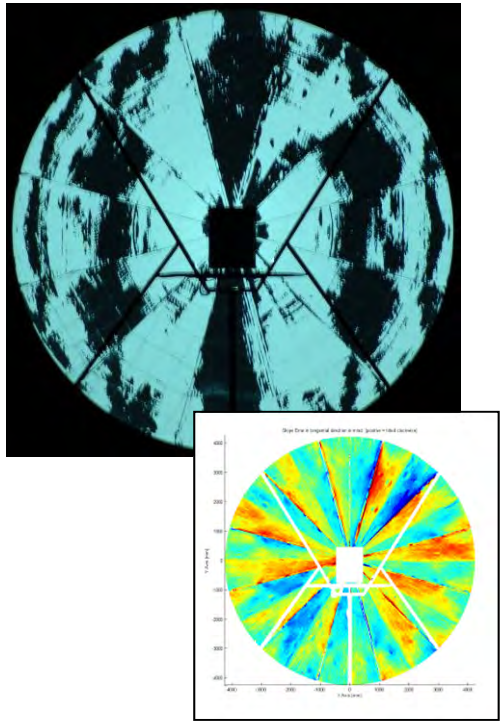




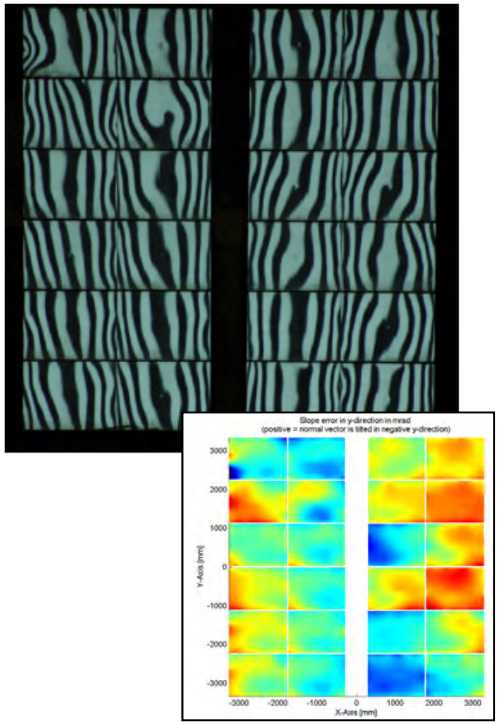


Flexible Application for all Types of Concentrator

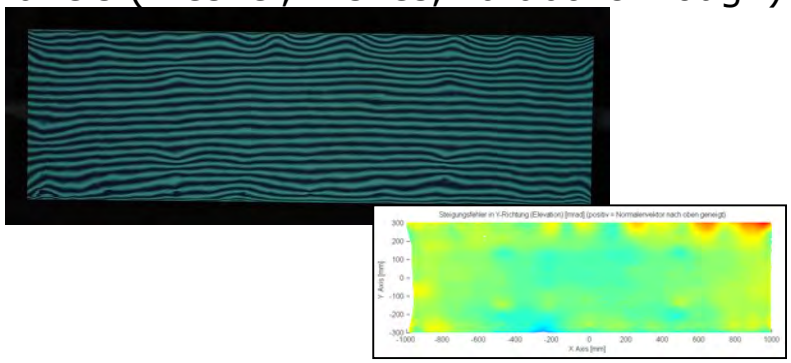
Dishes

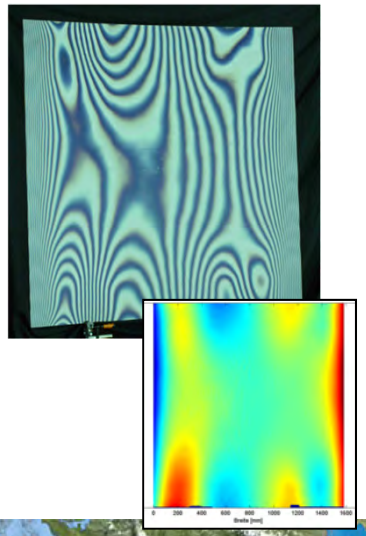


Heliostats

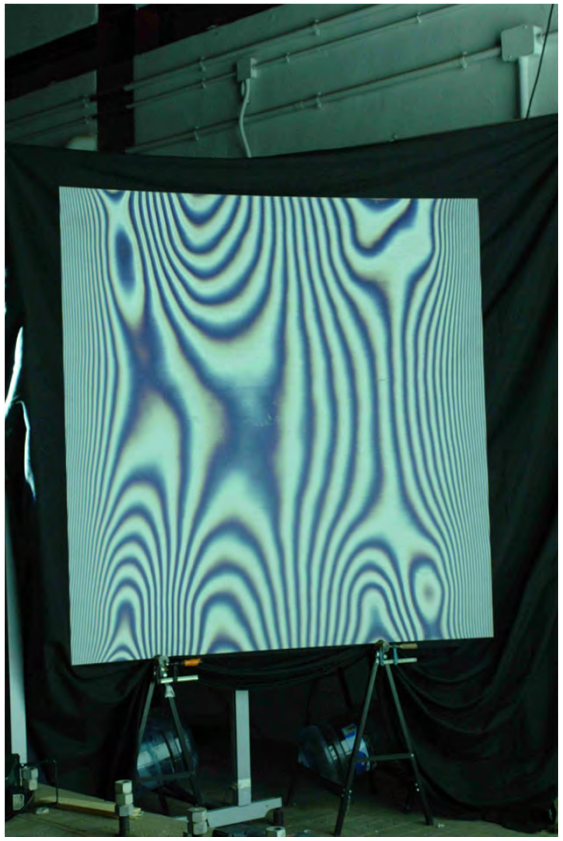


Panels (Fresnel, Dishes, Parabolic Trough)

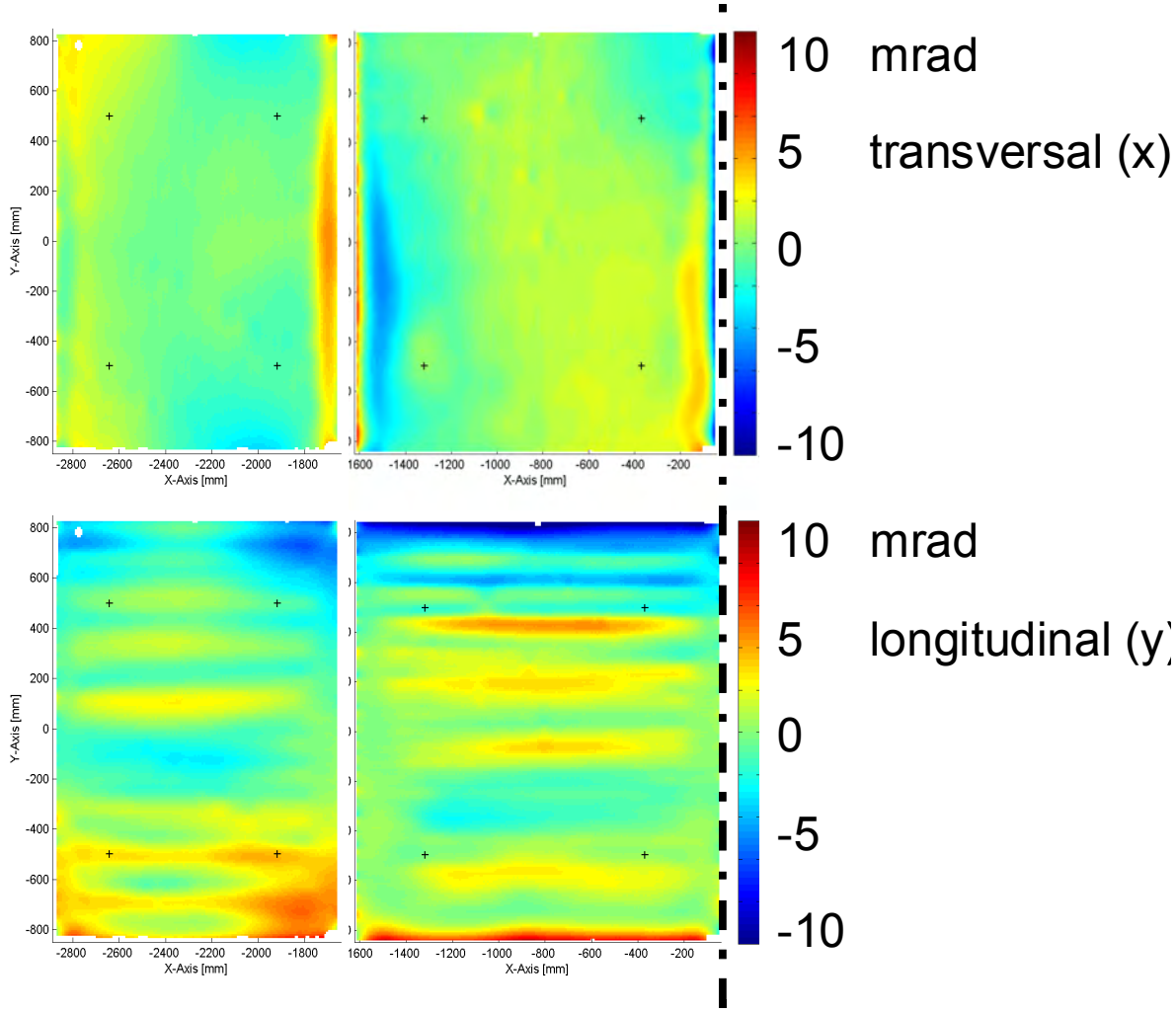




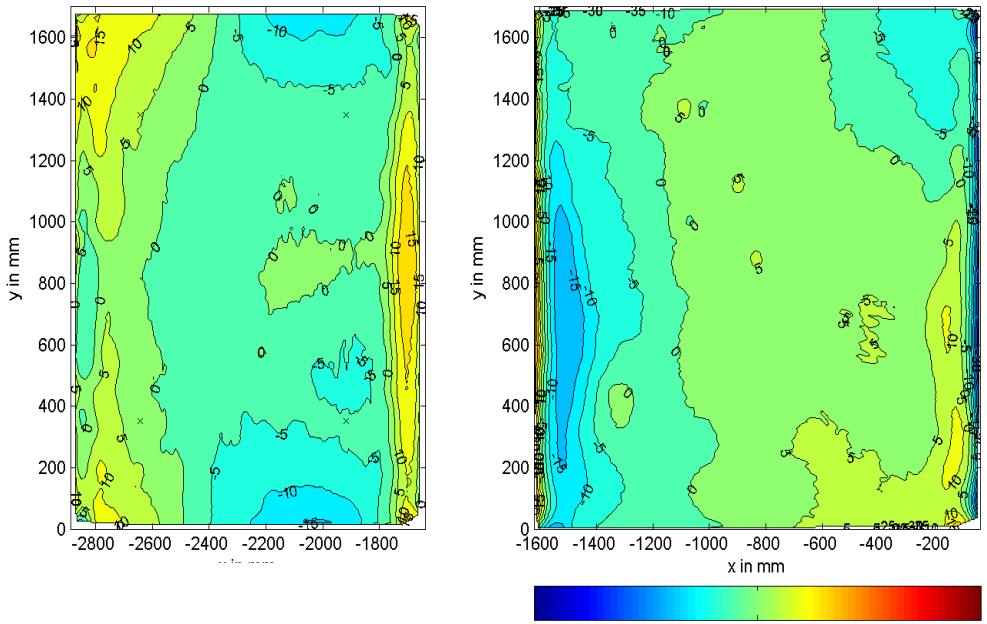
Deflectometry Measurement setup (QDec) Trough Mirror Panels



Slope deviation graph trough mirror panels, in mrad

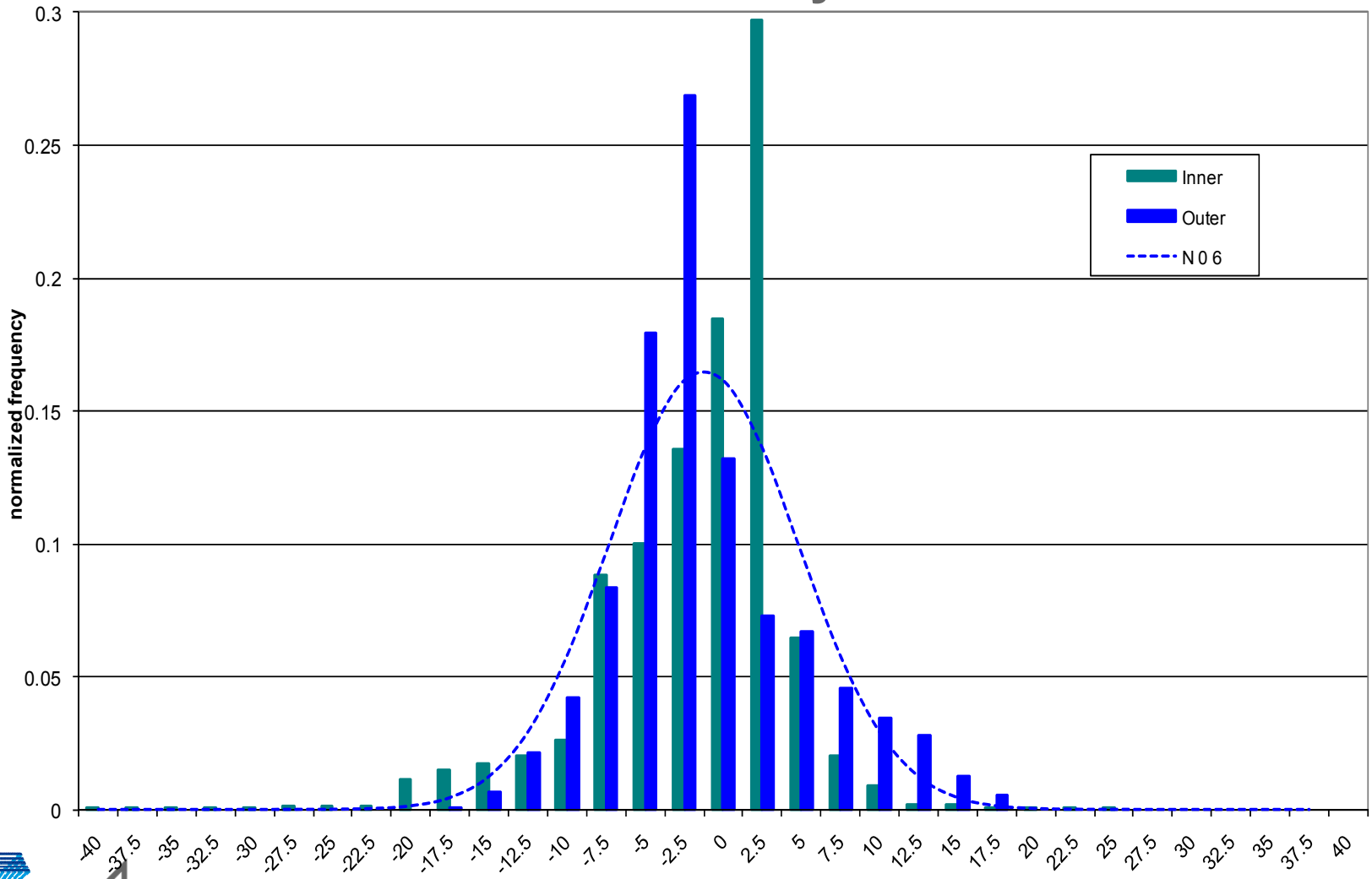


Focus Deviation Map
Deviation of reflected ray in mm



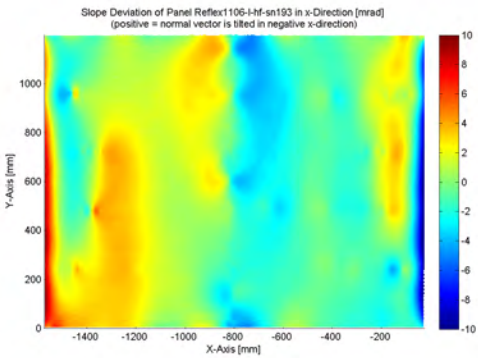
-50 0 50 mm

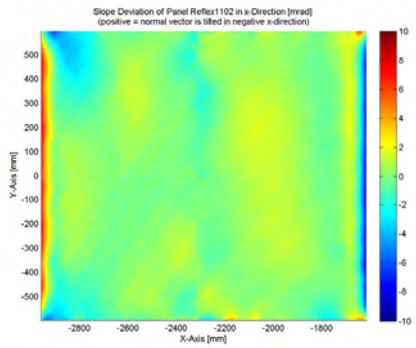
Focus Deviation Distribution Function
Standard deviation = Quality !



Measurement result (trough mirror panel)

slope

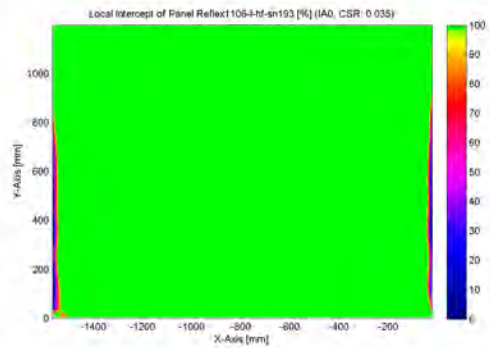


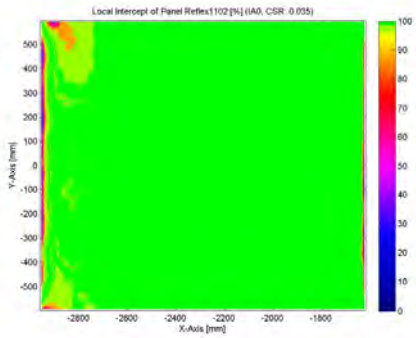


height

focus deviation

intercept





Definition of Focus Deviation and Slope Deviation based on measurement data

$$FDx = \sqrt{\sum_{i=1}^{n} \left(FDx_i^{\,2} \cdot \frac{a_i}{A_{ges}} \right)}$$

$$FDy = \sqrt{\sum_{i=1}^{n} \left(FDy_i^{\,2} \cdot \frac{a_i}{A_{ges}} \right)}$$

$$SDx' = \frac{FDx}{2f_m}$$

$$f_m = \sum_{i=1}^{n} \left(f_i \cdot \frac{a_i}{A_{ges}} \right)$$

Optical Beam Spread

statistical approach to large number of influence parameters

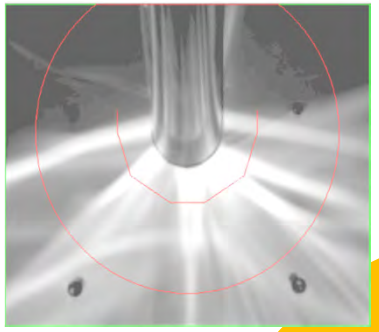
- sun, mirror shape and specularity, structure, receiver position, tracking/torsion, other mech. loads
- $\sigma^2_{total} = \sigma^2_{sun} + \sigma^2_{optical}$
- $\sigma^2_{total} = \sigma^2_{sun} + 4\sum\sigma^2_{contour} + \sum\sigma^2_{spec} + \sum\sigma^2_{structure} + \sum\sigma^2_{recpos} + \sum\sigma^2_{track}$

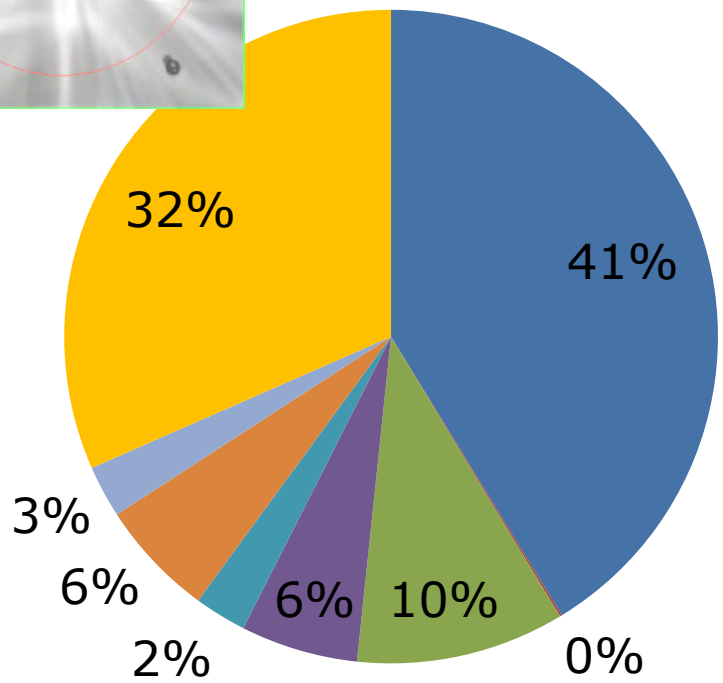
$$\sigma^2_{optical} = 4\sigma^2_{x,contour} + \sigma^2_{x,spec} + \lambda(\phi)(4\sigma^2_{y,contour} + \sigma^2_{y,spec}) + \sigma^2_{displ} + \sigma^2_{track}$$

$$\lambda(\phi) = (1 - \frac{\phi}{2\tan\frac{\phi}{2}})\tan^2\theta$$

$$\sigma_{sun,line} = \frac{\sigma_{sunshape}}{\sqrt{2}\cos\theta}$$

Quality criterion: total beam spread typical example





	σ in mrad	$a_i\sigma^2$ in mrad
Mirror Shape*	2	16
Beam Spread	0.2	0.04
Mirror Support*	1	4
Absorber Position	1.5	2.25
Collector Torsion (Loads)	1	1
Module Alignment	1.5	2.25
Tracking Accuracy	1	1
Sun	3.5	12.25
Total	**6.24**	**38.79**
Intercept Factor	**98.7%**	

Flux density distribution is characteristic for the reflector shape

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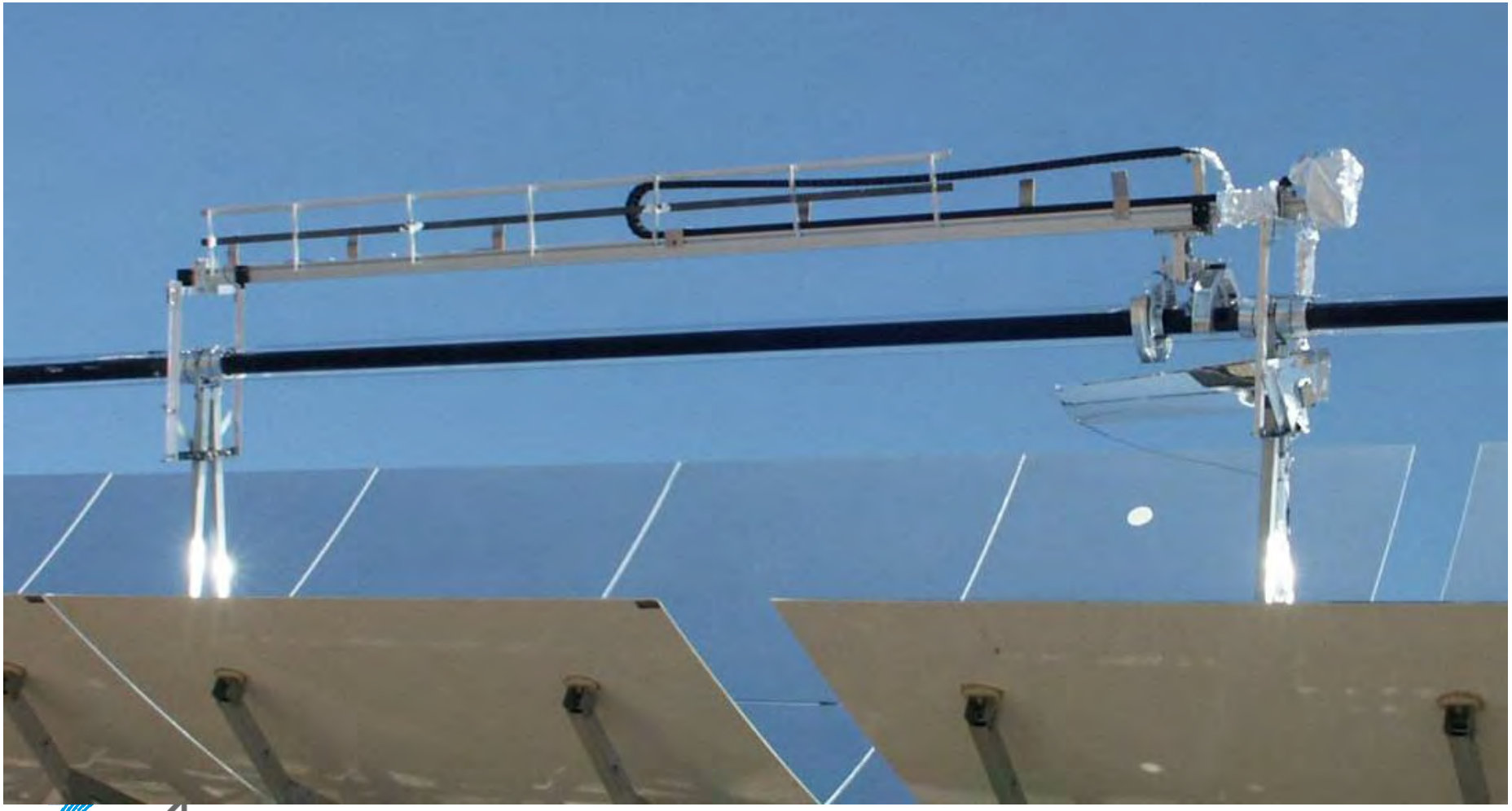
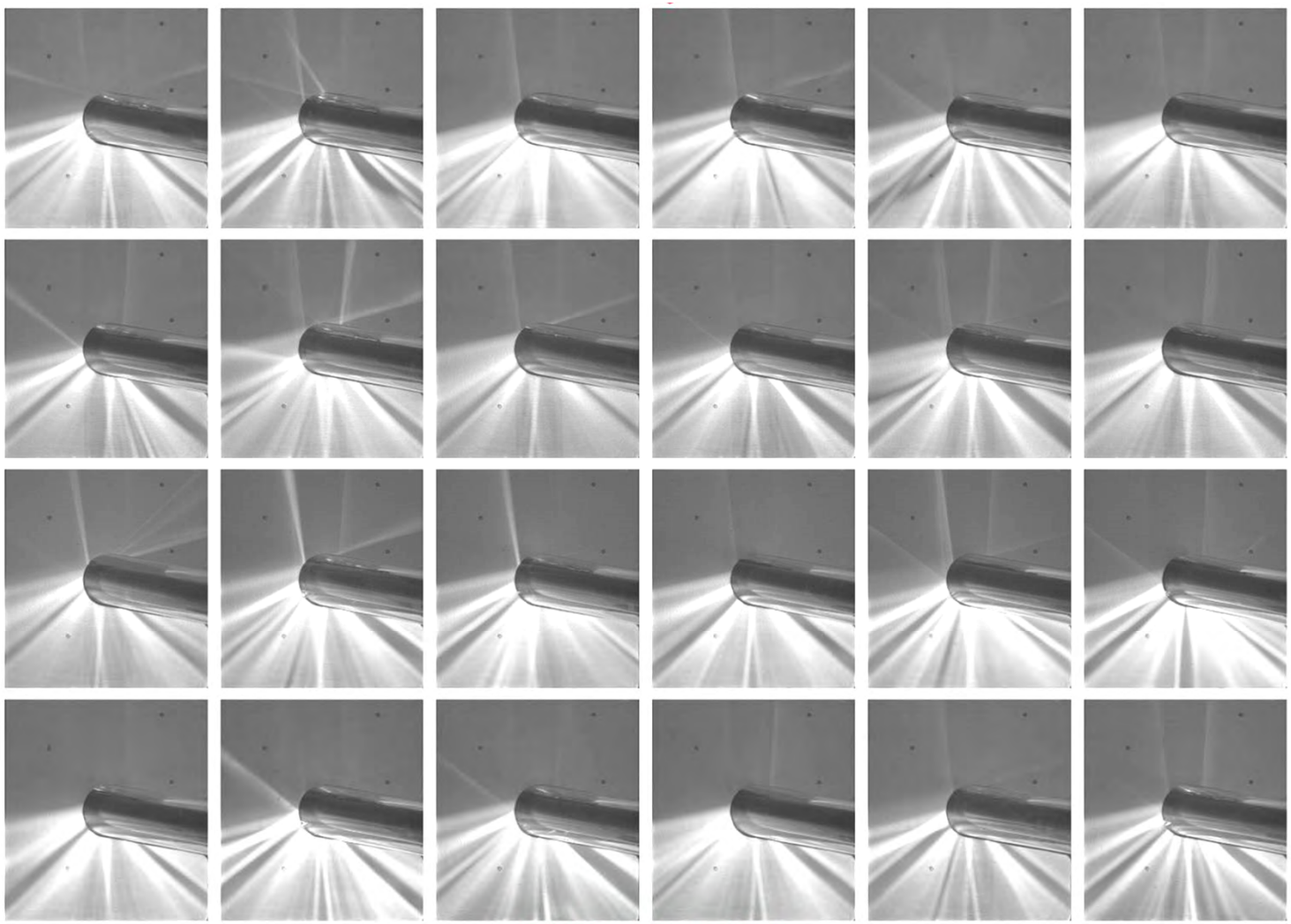
Parascan – Flux Density Measurement on Absorber Tube

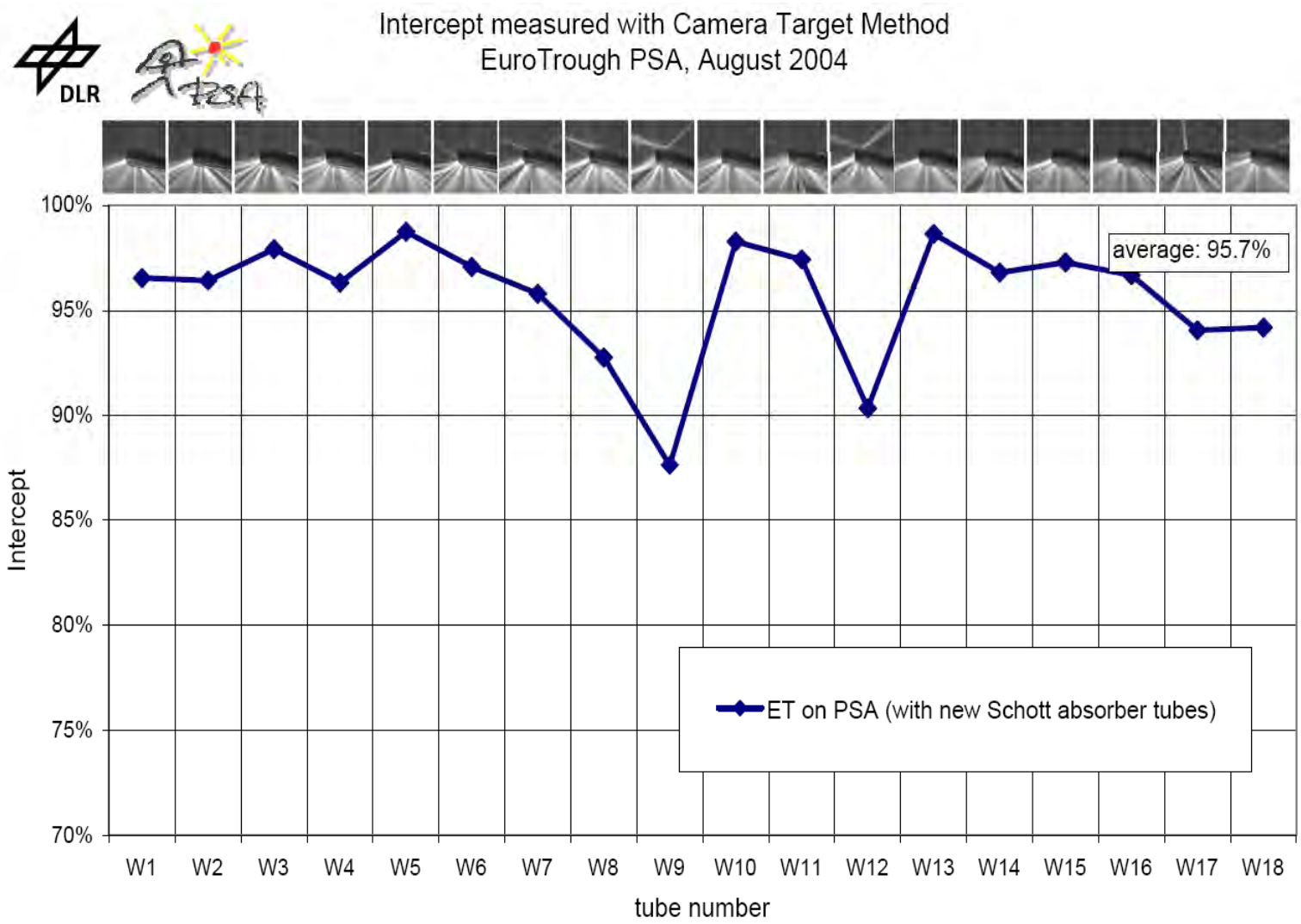


Intercept values EuroTrough Collector



Reihenfolge von Nord nach Süd

Intercept Measurement with Camera Target



Application Examples for Shape Measurements

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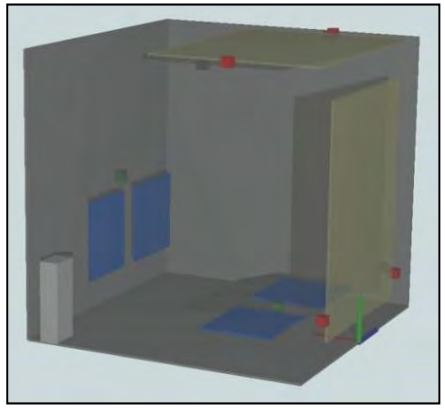
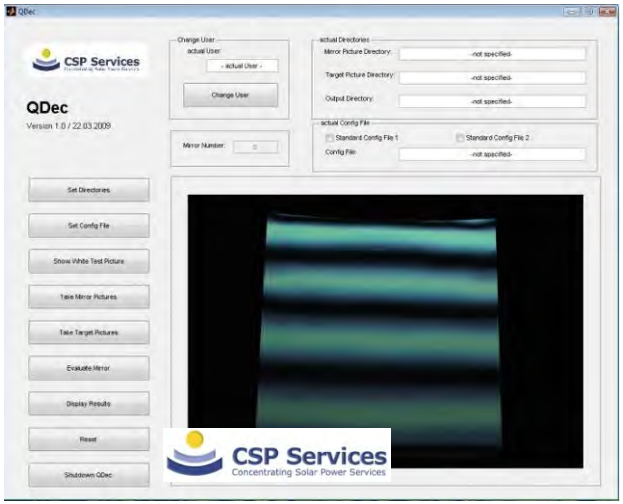
Production Quality Assurance of Concentrator Mirrors: Deflectometric Measurement System QDec

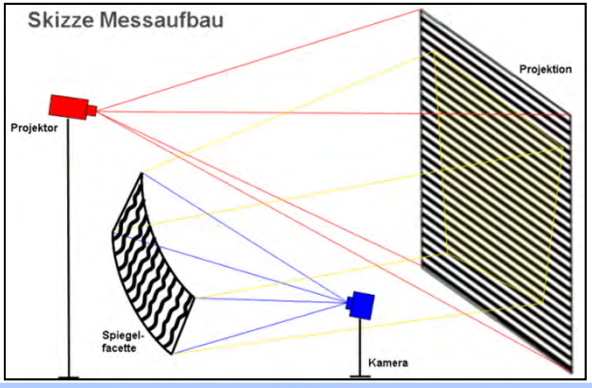
- Automatic production quality assurance of concentrator mirrors with QDec
- High-resolution, optical measurement system based on deflectometry
- Including evaluation and assessment software (failed/passed) to optimize and document production quality

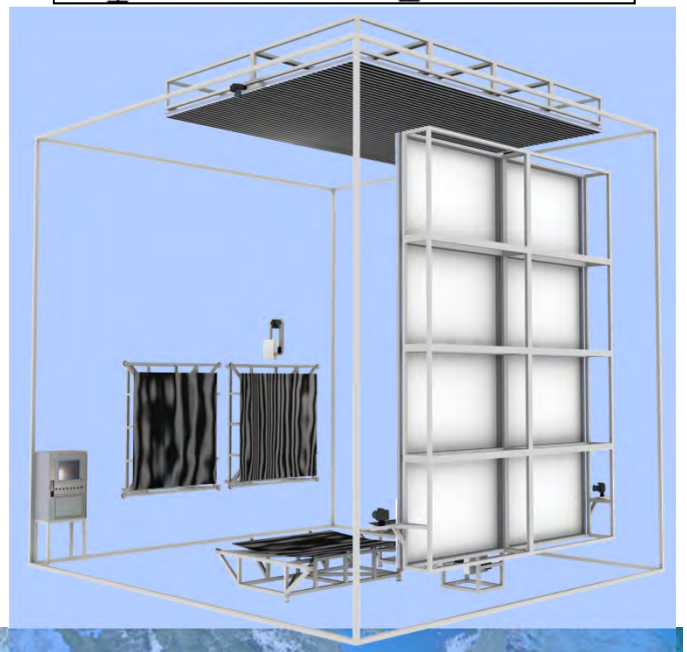


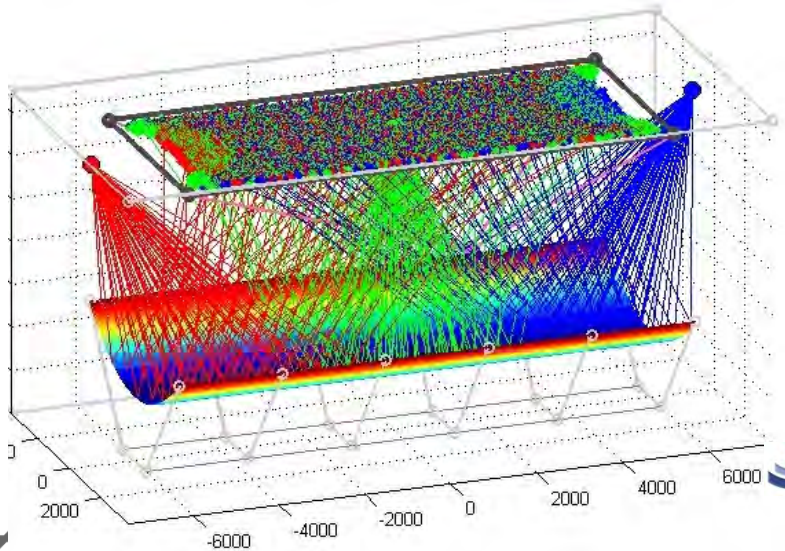


QDec Deflectometric Measurement System Quality Control in Mirror and Module Production

- Automatic production quality assurance of concentrator mirrors with QDec
- High-resolution, optical measurement system based on deflectometry
- Including evaluation and assessment software (fail/pass) to optimize and document production quality







CSP Services
Concentrating Solar Power Services

SEVENTH FRAMEWORK PROGRAMME

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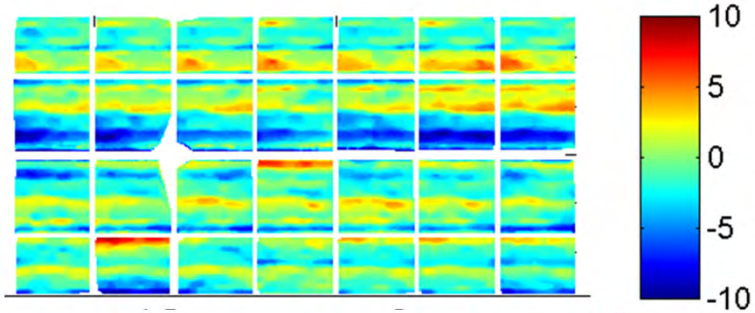
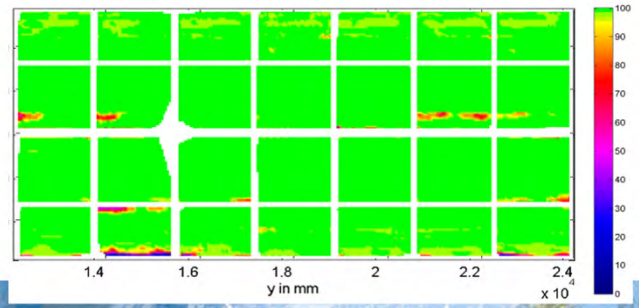
Trough Modules Shape Measurement in Field with Deflectometry

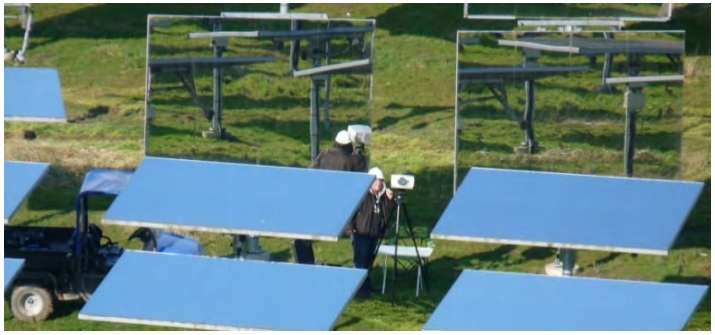
Slope Deviation in mrad



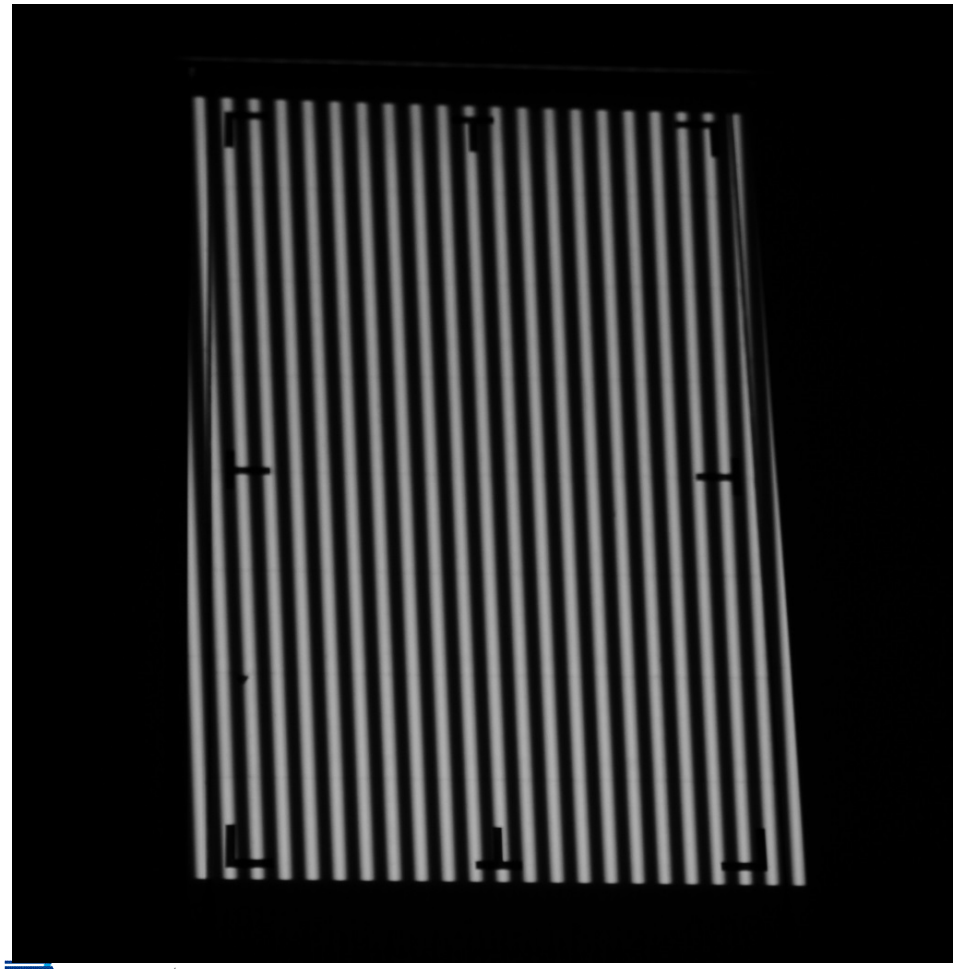
Local Intercept Factor in %

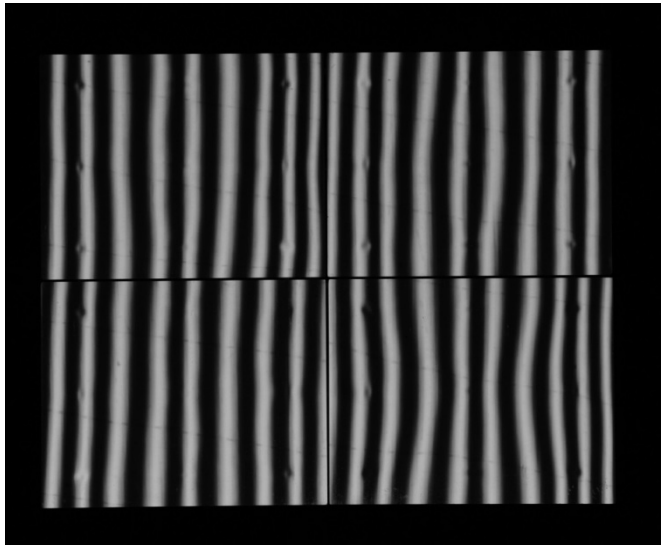


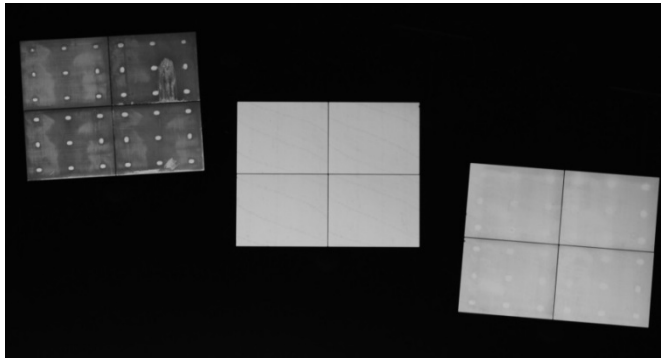
Measurement Set-up Heliostat Field Deflectometry



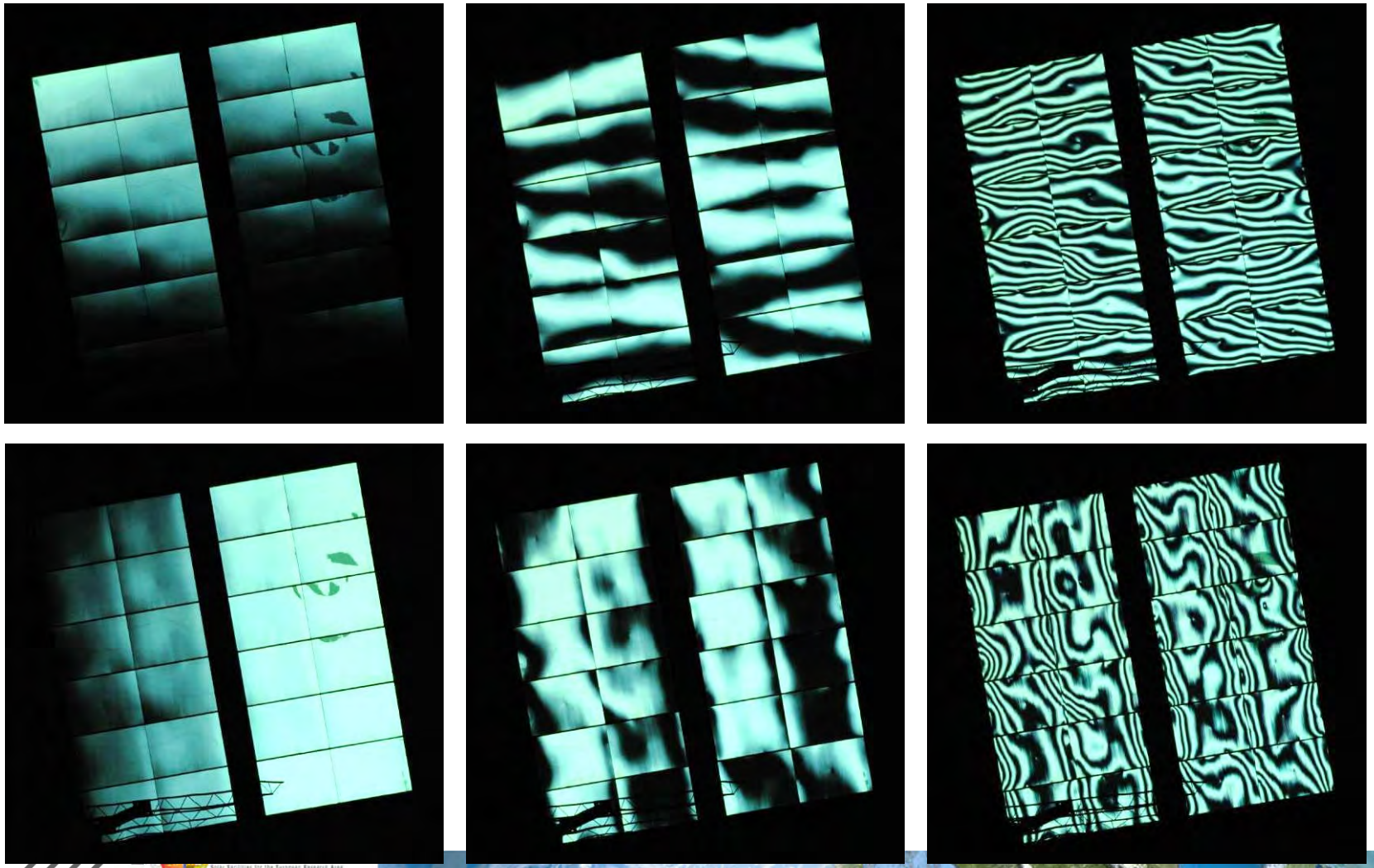
Measurement pictures



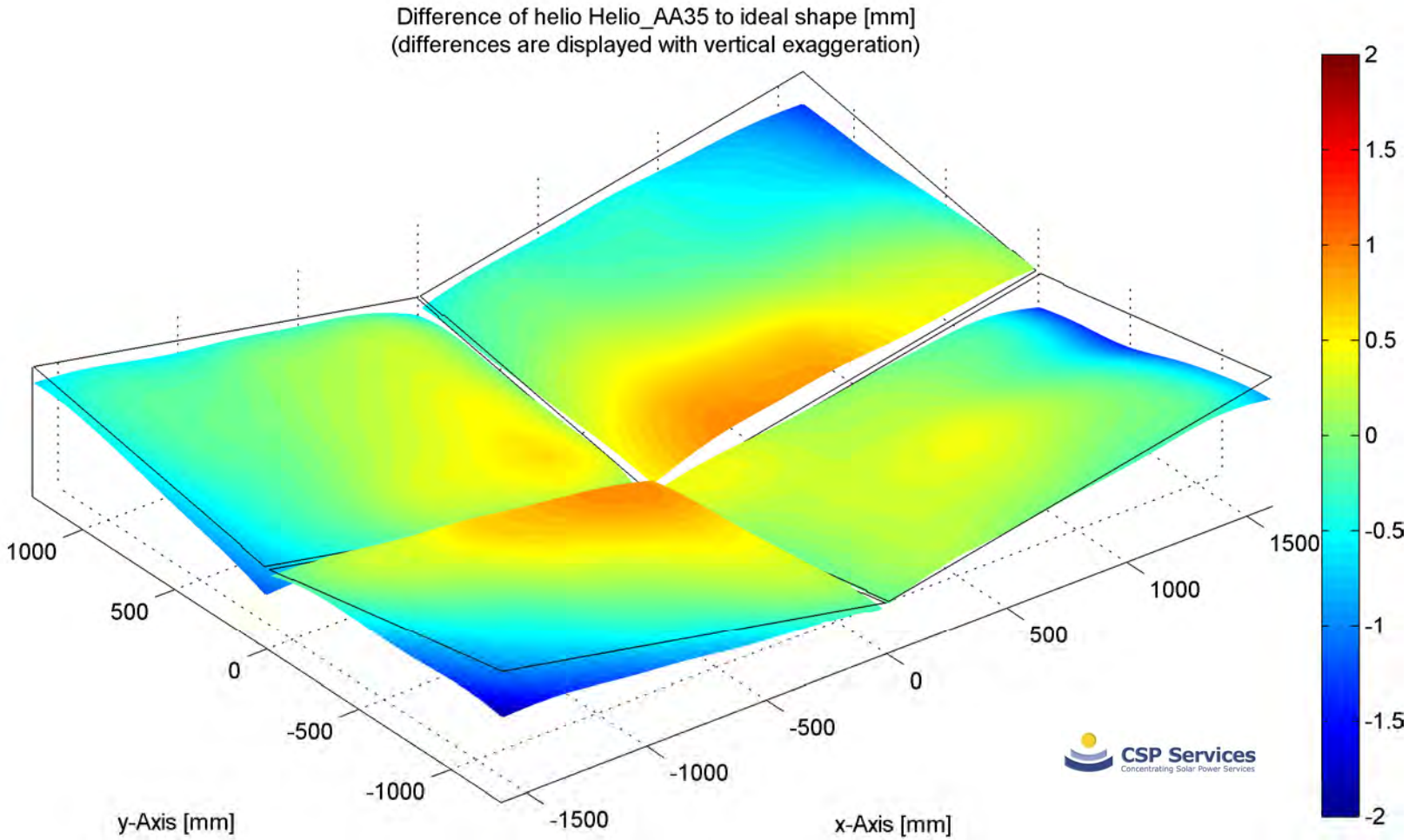




Deflectometry on Heliostats



Heliostat Shape (measured with deflectometry)



SEVENTH FRAMEWORK PROGRAMME

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What is the use of all the data?

- Ray-tracing analyses
- Intercept factor calculations
- Conclusions from achieved accuracy
  - Prediction of performance
  - Specifications for component geometry
  - Analysis of mechanical loads by dead weight, by wind
- Prototype evaluations
- Solar field evaluations
- Quality control systems
  - Mirror product specifications
  - Collector assembly accuracy

Towards standardization of mirror shape analysis

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SolarPACES Task III
Guideline on Mirror Shape (MSG)

- draft guideline for measurement of concentrator mirror shape under laboratory conditions
  - include different measurement technologies
  - different mirror geometries
  - introduce the relevant measurement configurations
  - evaluation criteria and formula

- extension of the scope to collectors under field conditions
  - transfer the same criteria and quality parameters
  - draft specifications

- Next meeting September 2013 (Solarpaces Conference USA)

Summary Reflector Shape

- Different measurement techniques available
- Contact free methods are advantageous: Laser reflection, target reflection

- Shape evaluation in terms of slope (maps)
- Shape evaluation in terms of focus deviation (maps)

- Evaluation of distribution functions
- Root-Mean-Square of Deviation Distribution (FDx)
- Product specific, system specific

- Use Focus Deviation FDx for Specs and Quality control
- e.g.: FDx ≈ 8-10 mm for EuroTrough with 70mm-receiver

- Use SDx (Slope Deviation) to describe component property
- Apply to Heliostats and Dishes accordingly (flux is more critical)