ITALIAN NATIONAL AGENCY FOR
NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

# 3D-shape Measurement of Parabolic Trough Mirror Panels: First Results of the SFERA-III Round Robin

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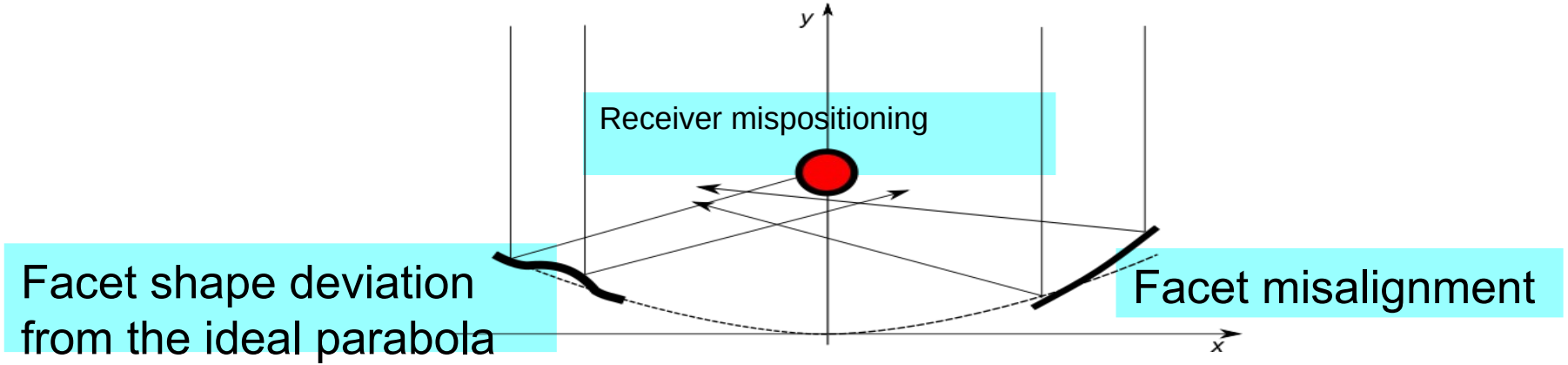
**10th October**
**11:45**
**Room G**

# Causes of degradation of intercept factor in PT collectors

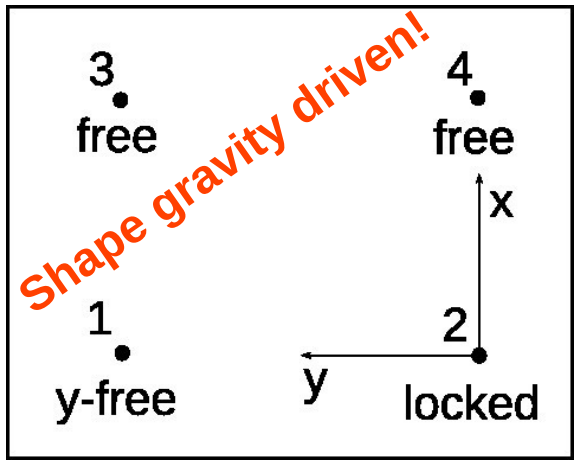



- **3D-shape measurement is fundamental to assess the panel compliance to the ideal parabola**
- **About 10 years ago a previous SolarPACES round-robin did not yeld satisfactory results because of the large deviations, thus a guideline on shape measurements is still lacking**

# 3D-shape measurement round-robin in EU project SFERA-III

- **SCOPE: comparison of the main geometric parameters, such as height and slope deviations from the ideal parabola as both RMS value and point by point**
- **PARTICIPANTS: ENEA, F-ISE, DLR, NREL, Sandia NL**
- **INSTRUMENTS: VISproPT (ENEA)**
  **deflectometry (F-ISE, DLR, Sandia NL)**
  **reflected target system (NREL)**
- **SPECIMEN KIT: 3 inner +3 outer RP3 parabolic trough panels**
  **focal= 1710 mm silvered glass 3.8 mm thick**
- **EXECUTION: 01/2023 ENEA → F-ISE → DLR → Sandia NL(NREL)**

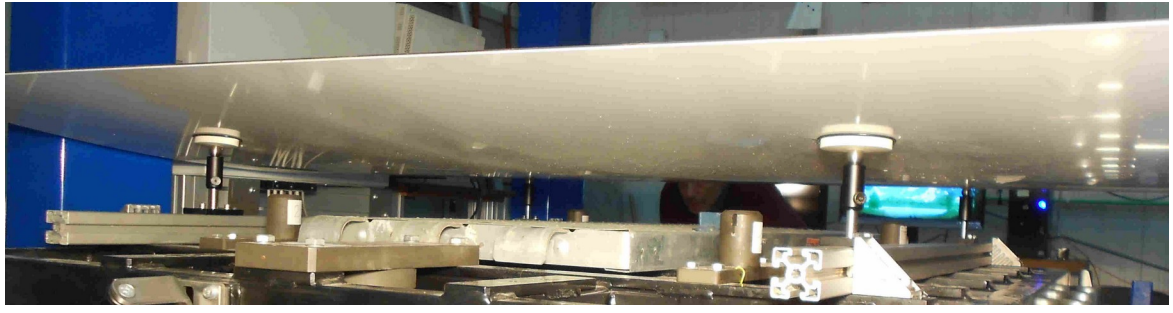
# 3D-shape RR methodology: panel mounting




**RR reference frame:**

- **Origin in the center of ball #2**
- **Z-axis vertical**
- **X-axis crossing the centers of ball #2 and #4**

**The 4 spheres must lie in the same horizontal plane !!!**

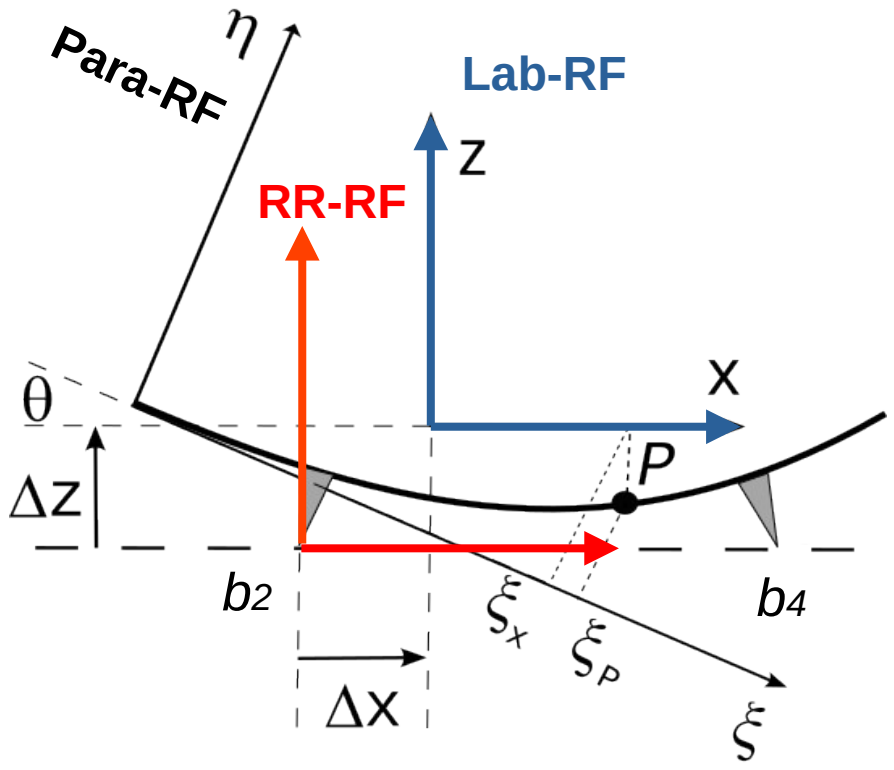


# 3D-shape RR methodology: main reference frames

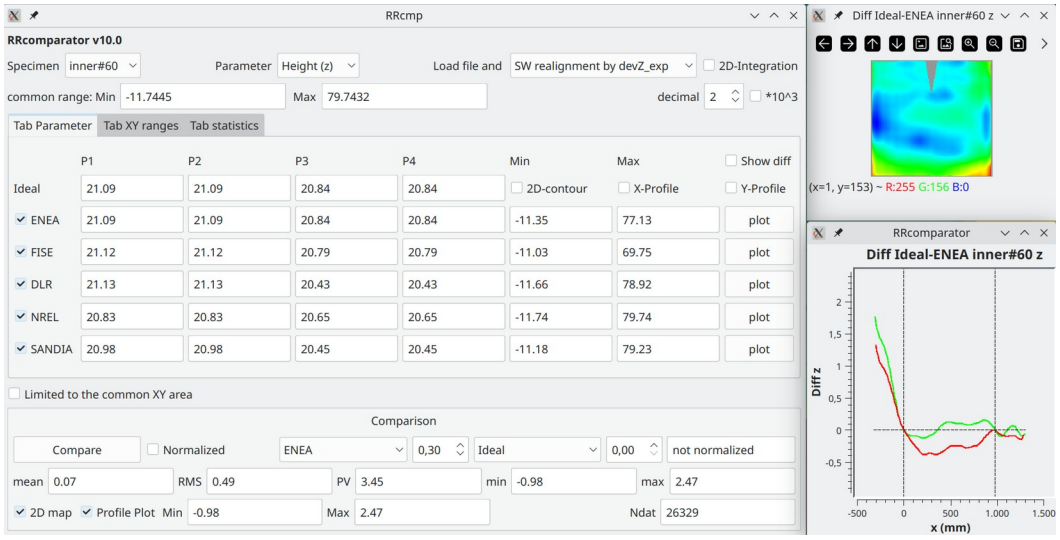
**RF=reference frame**

- **Laboratory RF**
- **Ideal parabola RF (*)**
- **Round-robin common RF** (*essential for point by point comparison!!!*)

**(*) Origin and orientation of parabola RF are evaluated by the construction drawing**



# 3D-shape RR methodology: RRcomparator software




**RRcomparator software for statistical and point-by-point comparison:**

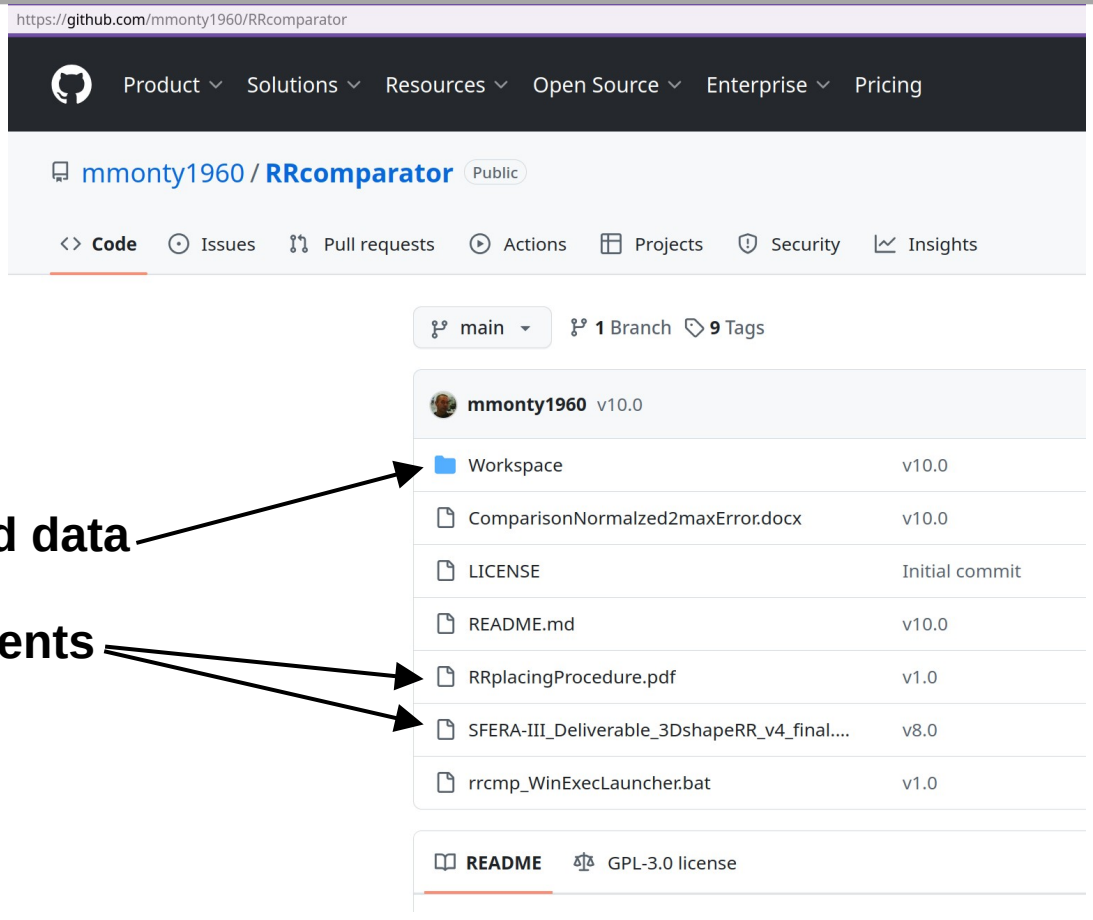
- **C++ with Qt GUI**
- **Open source**
- **MS Windows executable**
- **Resampling on common grid to allow the point-by point comparison**

**OPTIONS:**

- **Software realignment of the 3D shape on the 4 supporting points**
- **Limit the comparison to the common XY area**
- **Differences can be computed from the ideal parabola or from another participant**
- **Normalization of the difference to the uncertainty**

# 3D-shape RR methodology: open software open data

https://github.com/mmonty1960/RRcomparator




**Software and data**

**Main documents**

# 3D-shape RR methodology: preliminary acceptance test

**Comparison of the values at the support points with the ones expected for the ideal parabola**

Tab Parameter | Tab XY ranges | Tab statistics

**Height**

| | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| Ideal | 21.09 | 21.09 | 20.84 | 20.84 |
| ENEA | 21.03 | 21.01 | 20.93 | 20.87 |
| FISE | 21.08 | 21.81 | 20.19 | 20.13 |
| DLR | 21.10 | 21.13 | 20.40 | 20.50 |
| NREL | 21.11 | 21.04 | 20.18 | 20.92 |
| SANDIA | 21.08 | 21.03 | 20.36 | 20.56 |

**No first submission passed the test !!!**

**1st lesson learned:**
**Transforming data into different reference systems is not trivial !**

Tab Parameter | Tab XY ranges | Tab statistics

**slopeX**

| | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| Ideal | -0.136 | -0.136 | 0.127 | 0.127 |
| ENEA | -0.133 | -0.134 | 0.128 | 0.129 |
| FISE | -0.133 | -0.134 | 0.126 | 0.127 |
| DLR | -0.134 | -0.134 | 0.127 | 0.129 |
| NREL | -0.136 | -0.134 | 0.127 | 0.129 |
| SANDIA | -0.134 | -0.134 | 0.127 | 0.128 |

Tab Parameter | Tab XY ranges | Tab statistics

**slopeY**

| | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| Ideal | 0.000 | 0.000 | 0.000 | 0.000 |
| ENEA | -0.002 | 0.002 | -0.001 | 0.003 |
| FISE | -0.002 | 0.002 | -0.001 | 0.003 |
| DLR | -0.002 | 0.002 | -0.001 | 0.001 |
| NREL | -0.002 | 0.002 | -0.002 | 0.002 |
| SANDIA | -0.002 | 0.002 | -0.001 | 0.002 |

# 3D-shape RR results: RMS deviations from ideal parabola-1

**The more the shape conforms to the ideal parabola, the higher the optical-geometric efficiency in terms of intercept factor of the mirror panel**

Mean and standard deviation of RMS values of **z deviations**

| | As it is (mm) | XY common (mm) | XY common and SW realignment (mm) |
|---|---|---|---|
| Inner#60 | 0.47 ± 0.11 | 0.43 ± 0.10 | 0.40 ± 0.10 |
| Inner#61* | 0.57 ± 0.08 | 0.55 ± 0.10 | 0.48 ± 0.08 |
| Inner#62 | 0.39 ± 0.10 | 0.35 ± 0.10 | 0.31 ± 0.06 |
| Outer#93 | 0.38 ± 0.14 | 0.37 ± 0.13 | 0.33 ± 0.08 |
| Outer#97 | 0.37 ± 0.12 | 0.35 ± 0.11 | 0.29 ± 0.08 |
| Outer#99* | 0.44 ± 0.16 | 0.41 ± 0.14 | 0.30 ± 0.09 |

(*) NREL data not available

# 3D-shape RR results: RMS deviations from ideal parabola-2

**The more the shape conforms to the ideal parabola, the higher the optical-geometric efficiency in terms of intercept factor of the mirror panel**

Mean and standard deviation of RMS values of **slopeX deviations**

| | As it is (mrad) | XY common (mrad) | XY common and SW realignment (mrad) |
|---|---|---|---|
| Inner#60 | 2.66 ± 0.35 | 2.42 ± 0.37 | 2.42 ± 0.44 |
| Inner#61* | 3.23 ± 0.49 | 3.00 ± 0.49 | 3.01 ± 0.53 |
| Inner#62 | 2.27 ± 0.25 | 2.07 ± 0.22 | 2.02 ± 0.18 |
| Outer#93 | 1.61 ± 0.22 | 1.56 ± 0.22 | 1.52 ± 0.14 |
| Outer#97 | 1.55 ± 0.20 | 1.53 ± 0.19 | 1.45 ± 0.11 |
| Outer#99* | 1.73 ± 0.24 | 1.69 ± 0.23 | 1.56 ± 0.07 |

(*) NREL data not available

# 3D-shape RR results: RMS deviations from ideal parabola-3

**The more the shape conforms to the ideal parabola, the higher the optical-geometric efficiency in terms of intercept factor of the mirror panel**

Mean and standard deviation of RMS values of **slopeY deviations**

| | As it is (mrad) | XY common (mrad) | XY common and SW realignment (mrad) |
|---|---|---|---|
| Inner#60 | 2.60 ± 0.32 | 1.61 ± 0.07 | 1.60 ± 0.05 |
| Inner#61* | 2.75 ± 0.34 | 2.32 ± 0.09 | 2.30 ± 0.08 |
| Inner#62 | 2.56 ± 0.32 | 1.61 ± 0.14 | 1.59 ± 0.13 |
| Outer#93 | 2.17 ± 0.33 | 1.85 ± 0.21 | 1.83 ± 0.20 |
| Outer#97 | 1.90 ± 0.42 | 1.61 ± 0.26 | 1.59 ± 0.25 |
| Outer#99* | 2.10 ± 0.38 | 1.87 ± 0.24 | 1.84 ± 0.26 |

(*) NREL data not available

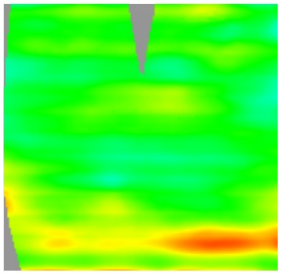
# 3D-shape RR results: RMS deviations from ideal parabola

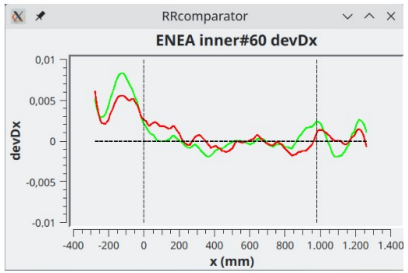
**2nd lesson learned:**

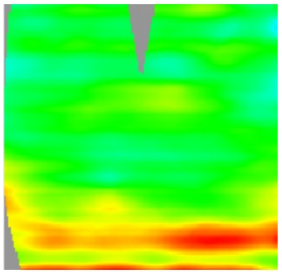
**agreement among participants improves when one applies the options**

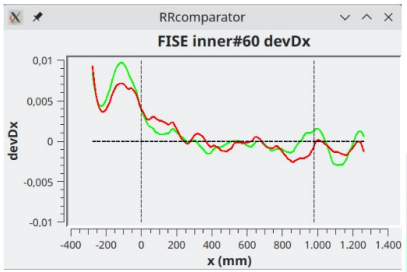
- ***Limited to the common XY area***
- ***Shape realignment on the 4 attaching points***

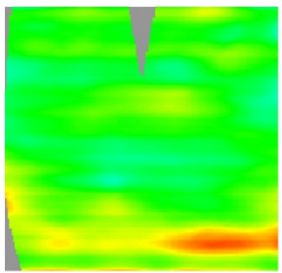
# 3D-shape RR results: Contour Maps of deviations from ideal parabola

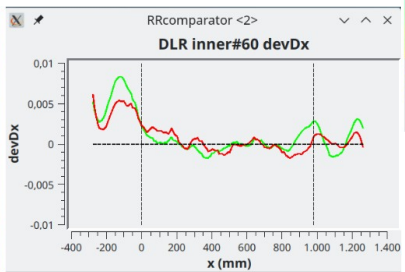




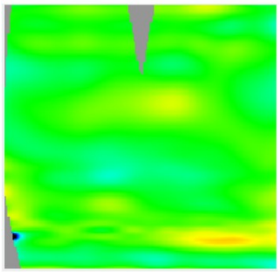



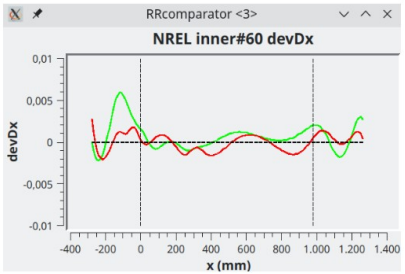


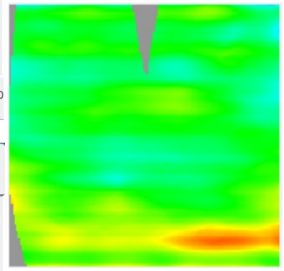



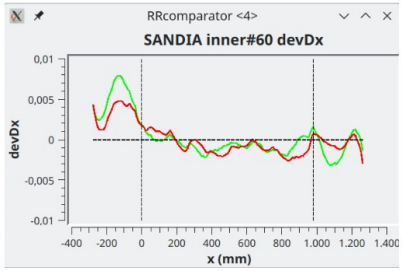



## SlopeX deviation








The narrow distribution of the RMS deviations as well as the similarity of contour maps and shape profiles prove a **reasonable agreement** in this RR

This represents an important improvement with respect to the previous round-robin

# 3D-shape RR results: comparison between pairs of evaluators

## Difference between pairs of evaluators normalized to the error (3 sigma) - inner#60

**z**

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | 0.05 ± 0.22 | -0.04 ± 0.08 | 0.00 ± 0.26 | 0.13 ± 0.36 |
| F-ISE | | -0.14 ± 0.37 | -0.09 ± 0.50 | 0.11 ± 0.51 |
| DLR | | | 0.05 ± 0.33 | 0.21 ± 0.50 |
| NREL | | | | 0.13 ± 0.45 |

**slopeX**

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | 0.01 ± 0.65 | 0.09 ± 0.31 | -1.38 ± 4.16 | -2.32 ± 2.86 |
| F-ISE | | 0.02 ± 0.52 | -0.65 ± 1.75 | -0.89 ± 1.31 |
| DLR | | | -0.95 ± 2.62 | -1.41 ± 1.77 |
| NREL | | | | -0.51 ± 4.75 |

**slopeY**

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | -0.06 ± 1.22 | -0.20 ± 0.89 | -0.64 ± 1.71 | -0.76 ± 1.33 |
| F-ISE | | -0.08 ± 1.42 | -0.27 ± 1.46 | -0.45 ± 1.43 |
| DLR | | | -0.25 ± 1.08 | -0.23 ± 0.95 |
| NREL | | | | 0.07 ± 1.82 |

# 3D-shape RR results: comparison between pairs of evaluators

Difference between pairs of evaluators normalized to the error (3 sigma)

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | 0.05 ± 0.22 | -0.04 ± 0.08 | 0.00 ± 0.26 | 0.13 ± 0.36 |
| F-ISE | | -0.14 ± 0.37 | -0.09 ± 0.50 | 0.11 ± 0.51 |
| DLR | | | 0.05 ± 0.33 | 0.21 ± 0.50 |
| NREL | | | | 0.13 ± 0.45 |

Z

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | 0.01 ± 0.65 | [illegible] | -1.38 ± 4.16 | -2.32 ± 2.86 |
| F-ISE | | 0.02 ± 0.52 | -0.65 ± 1.75 | -0.89 ± 1.31 |
| DLR | | | [illegible] | -1.41 ± 1.77 |
| NREL | | | | [illegible] |

slopeX

| | F-ISE | DLR | NREL | SANDIA |
|---|---|---|---|---|
| ENEA | -0.06 ± 1.22 | -0.20 ± 0.89 | -0.64 ± 1.71 | [illegible] |
| F-ISE | | -0.08 ± 1.42 | -0.27 ± 1.46 | -0.45 ± 1.43 |
| DLR | | | -0.25 ± 1.08 | -0.23 ± 0.95 |
| NREL | | | | 0.07 ± 1.82 |

slopeY

Good for ENEA&DLR; NREL and Sandia NL are the most deviating

The disagreement seems to be caused by imperfect data localization on XY plane

Further investigation is going on!

# 3D-shape RR: the future

- **The Round-Robin is still going on: NREL and SANDIA are checking the correctness of their data location in the XY plane**
- **Optionally the Intercept Factor will be included**
- **SolarPACES will fund the next activity with the project *3D-shape measurements for quality assessment of parabolic-trough reflective panels***
- **The lessons learned will feed into a new draft of the SolarPACES shape-guidelines**