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School of
Engineering
IEFE Institute of Energy Systems
and Fluid Engineering

# BIFOROT –

# Experimental data for LCOE appraisal of bifacial systems

BIFOROT: Bifacial Outdoor Rotor Tester

M. Klenk, T. Baumann, H. Nussbaumer, M. Morf, N. Keller, F. Baumgartner

Konstanz, bifi PV 2017

# BIFOROT set-up

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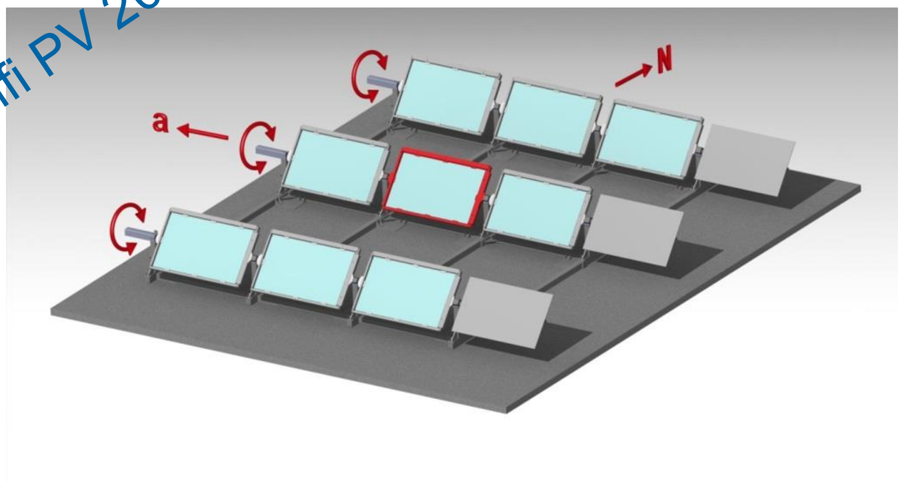
See bifi PV 2016




- Array instead of single stand-alone module
- Real world conditions as in actual bifacial PV system
- Continuously varying tilt angle (automated, 1-minute cycle 0°-90°, 12 steps)
- Variable parameters (albedo, height, distance, width - manually)
- Focus on central module(s) => Expansion of 3x3 to 3x4 array

# BIFOROT - LCOE appraisal

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- LCOE of bifacial systems (…yield, kWh/kWp…)
  - Crucial, but prediction not feasible with sufficient accuracy today

    $\Rightarrow$ Need for reliable yield prediction

$\Rightarrow$ Systematic compilation of data

  - Generation of data at system level (demo, comparison)
  - Reveal optimized installation conditions
  - Verify simulation tools and improve calculations

- Analyze specific properties of bifacial modules / systems
  - Angular sensitivity,  intensity distribution at rear, …

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# BIFOROT- Annual yield for varied tilt

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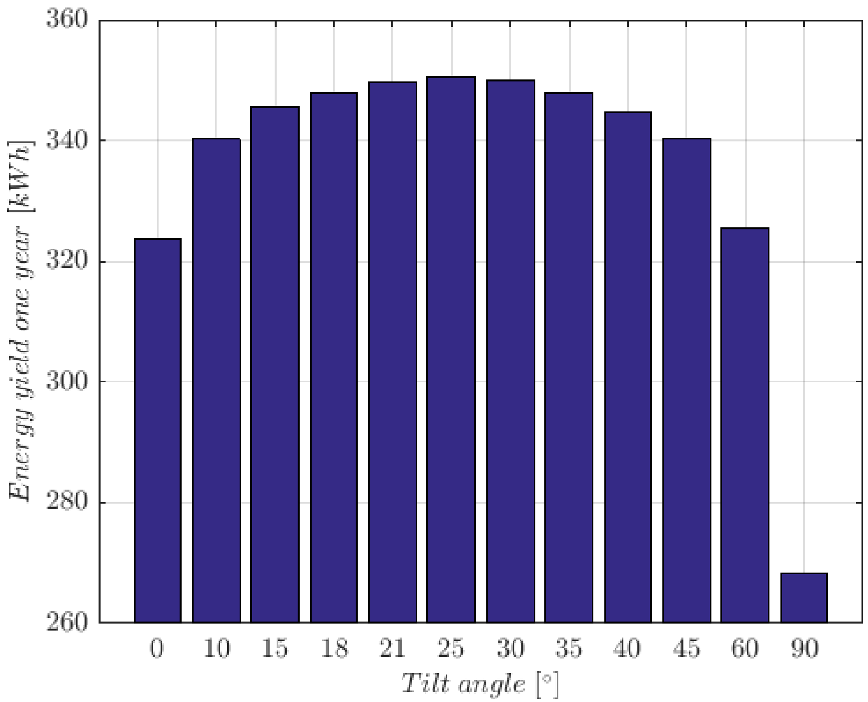
Annual yield of the center module

⇒ Prediction of PV system output for similar systems

⇒ Optimized installation conditions for given, specific installation situation




| Tilt [°] | 0 | 10 | 15 | 18 | 21 | 25 | 30 | 35 | 40 | 45 | 60 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield [kWh] | 323.8 | 340.3 | 345.6 | 348.0 | 349.6 | 350.6 | 350.0 | 347.9 | 344.6 | 340.4 | 325.6 | 268.3 |

Measurement period 1 year: 1st of Oct. 2016 to 30th of Sept. 2017

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# BIFOROT- Annual yield for varied tilt

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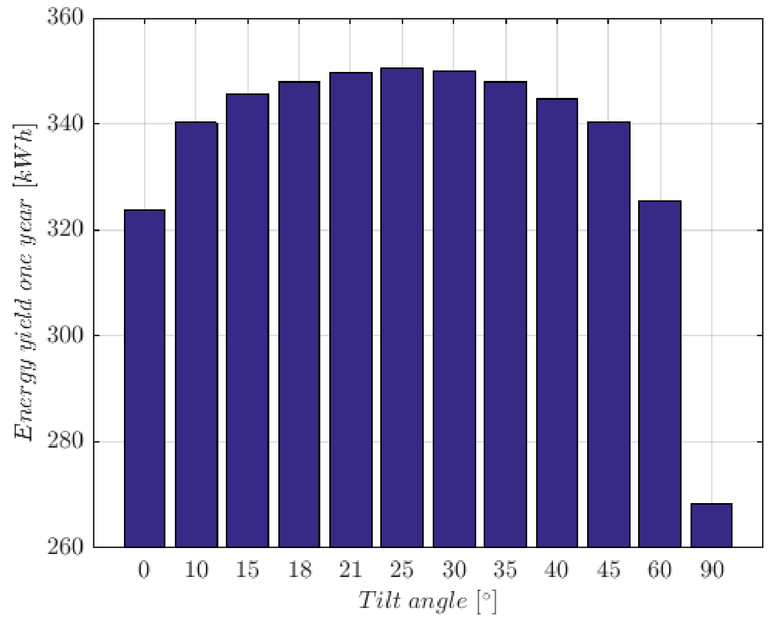
## Max.: 1292 kWh/kWp @ 25° tilt angle

(Here: net data without correction for downtime)

⇒ underestimation of actual kWh/kWp value

Unfavorable shading situation since 27th of March (see next slide)




## Specifications

- Azimuth angle: 0° (south orientation)
- Axis height: 0.75 m (axis center)
- Module height: Axis height ⇒ “lower edge” dependent on tilt angle!
- Axial spacing: 2.86 m (axis center to axis center)
- Ground albedo: 0.51 (measured at axis height on “dirty” foil)
- Location: Winterthur, Switzerland
- Module (STC): Pmpp front: 271.4 W; Pmpp rear: 188.5 W; B: 0694 (J-Box)
- Module type: Megacell MBF-GG60-270

# Challenges

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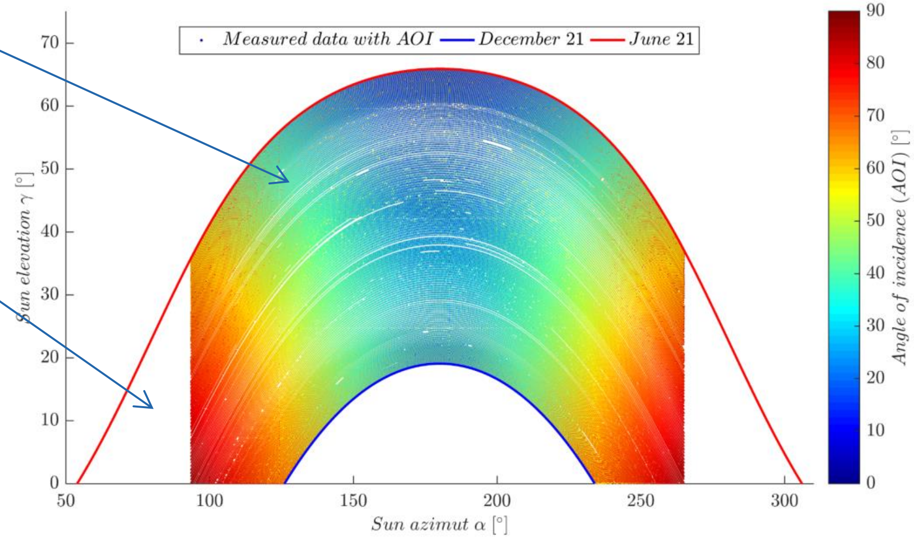
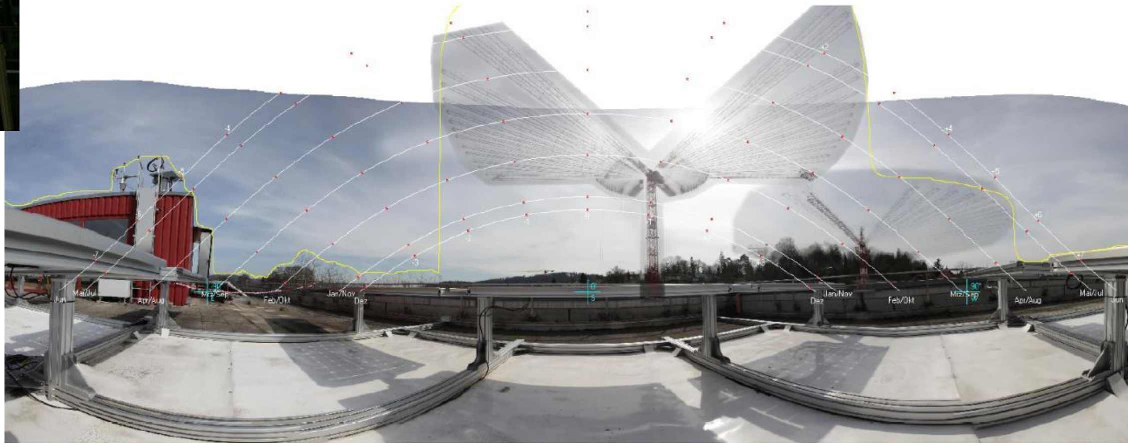
Downtime: white spaces in sun-path diagram

Site specific limitation / shading

⇒ azimuth angle range: 93.4° to 265.1°



Since 27th of March 2017

Building crane in front of BIFOROT

Winter (Oct. – March) unaffected

T. Baumann et al., Proceeding of the 33rd EUPVSEC 2017

# BIFOROT - LCOE appraisal

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# BIFOROT - LCOE appraisal

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- Data collection and testing of algorithms
- Project with ISC Constance / Djaber Berian just started

⇑

- Verify simulation tools and improve calculations
- Analyze specific properties of bifacial modules / systems
  - Angular sensitivity, intensity distribution at rear, …

⇓

- Some examples for more general analysis at the next slides

# Rear and front contribution

- Module 3 (M3): Rearside covered for $I_{SC,front}$ measurement
- Module 2 (M2): IV-curve measurement ($_{ISC,bifacial}$)
- Module 1 (M1): Frontside covered for $I_{SC,back}$ measurement


- Bifacial gain & rear side power contribution directly if $P_{mpp}$ measurement for M1, M3 realized
- Analysis of Irradiance/ $I_{sc}$

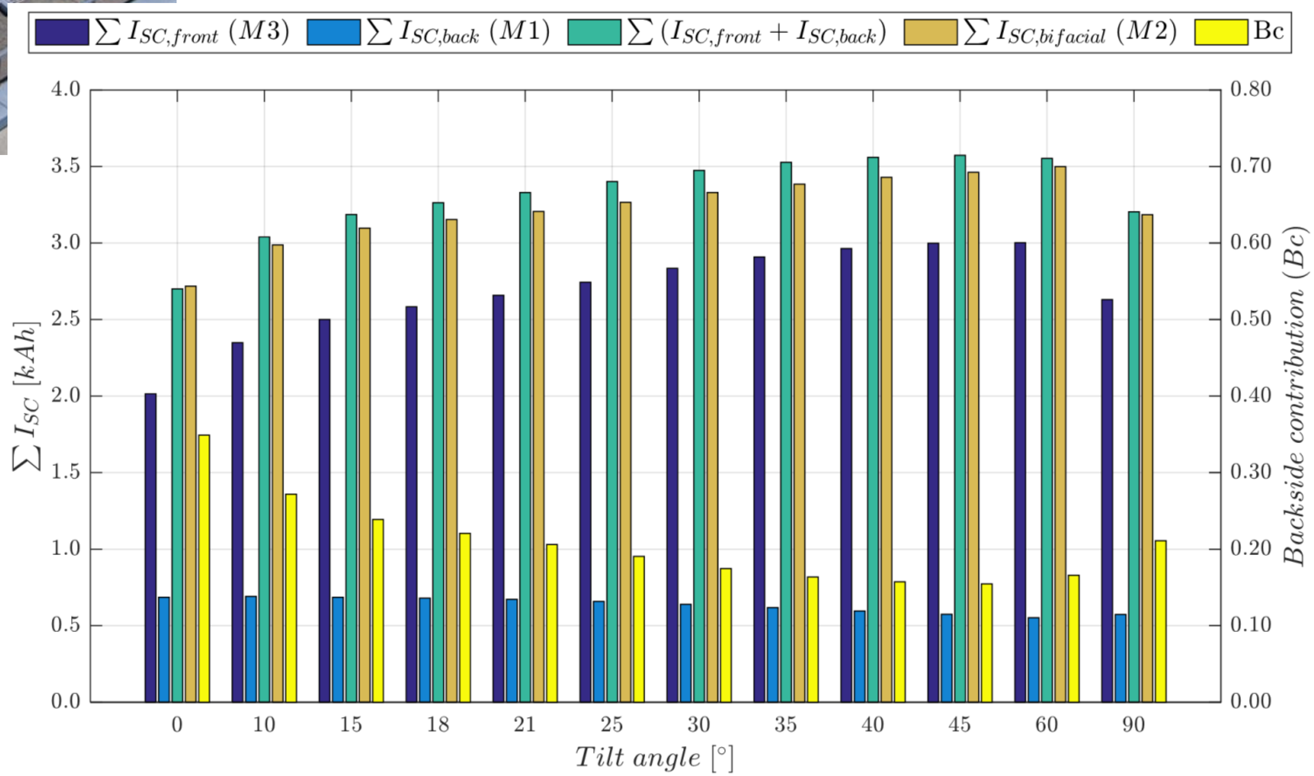
# Rear and front contribution




- M3: $I_{sc}$ front; M2: $I_{sc}$ bifacial; M1: $I_{sc}$ back
- October – March (winter season)
- Bc: Backside contribution
- Bc relative to front: 0.15 (45°) to 0.35 (0°)

- $\Sigma I_{sc}$ in kAh
- $\Sigma$ front + back

  good but not perfect correspondence to bifacial
- $\Sigma I_{sc}$ back (absolute) surprisingly constant

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# Illumination intensity and homogeneity

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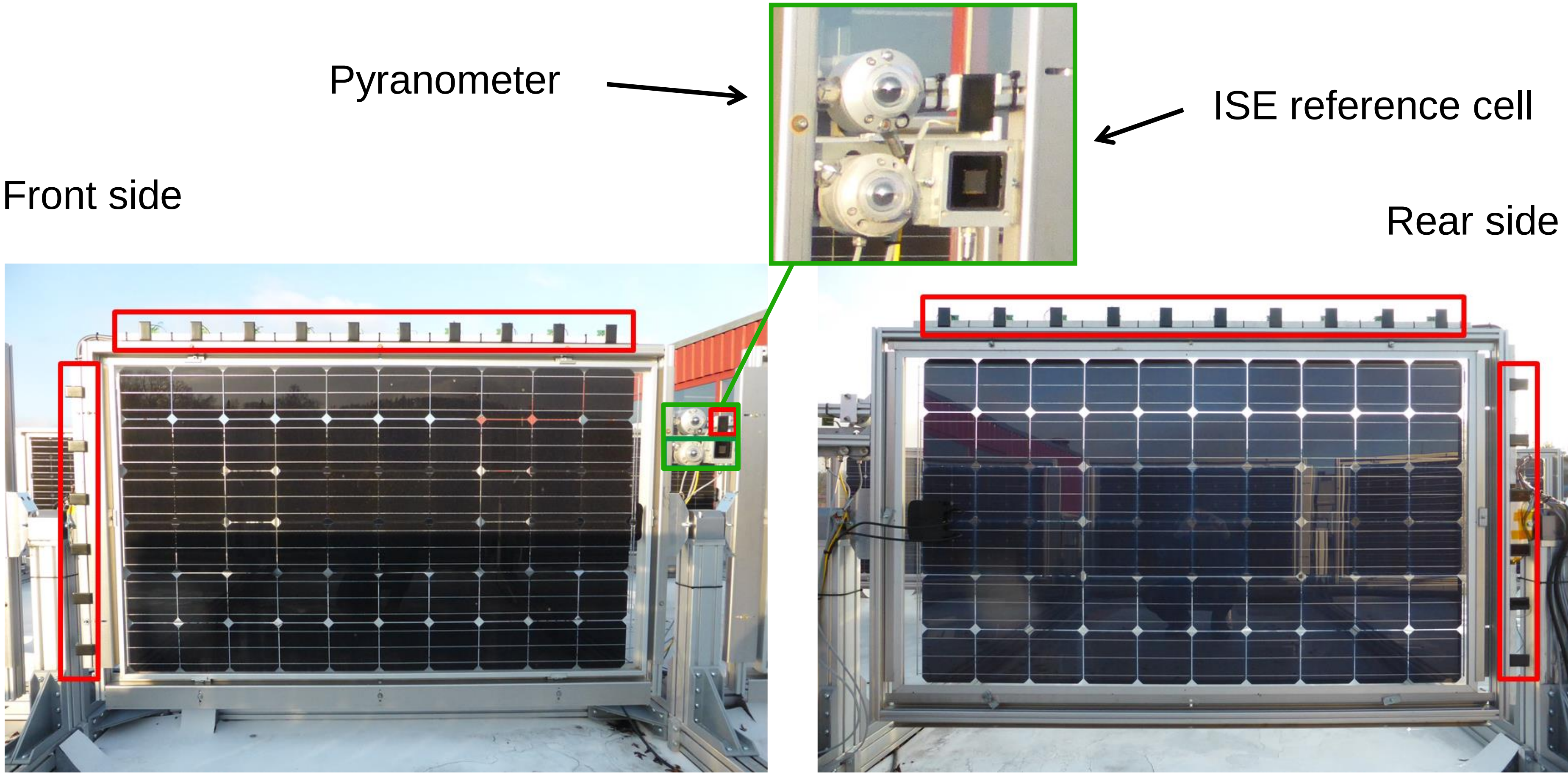


- Small irradiance sensors ☐ - crystalline silicon cells
- Sensors enable mapping of illumination intensity at front and rear side

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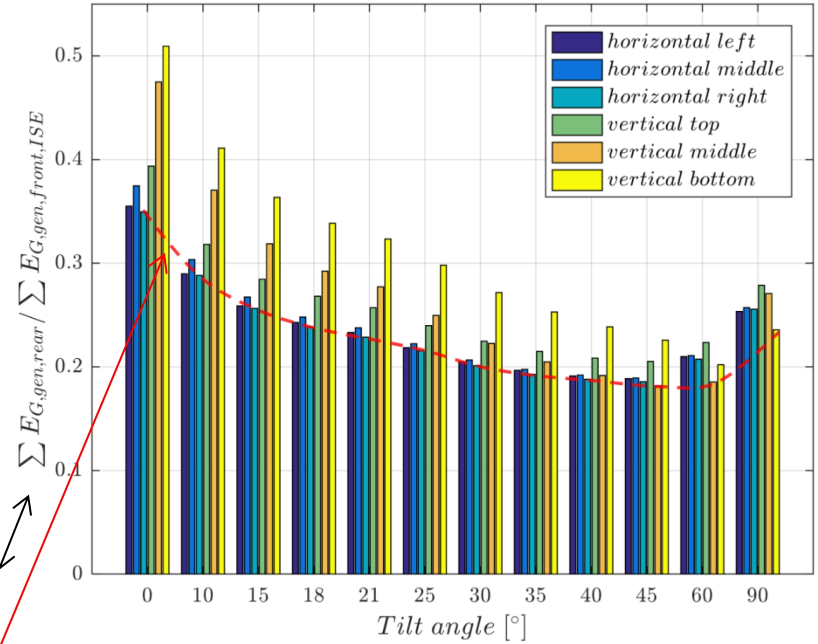
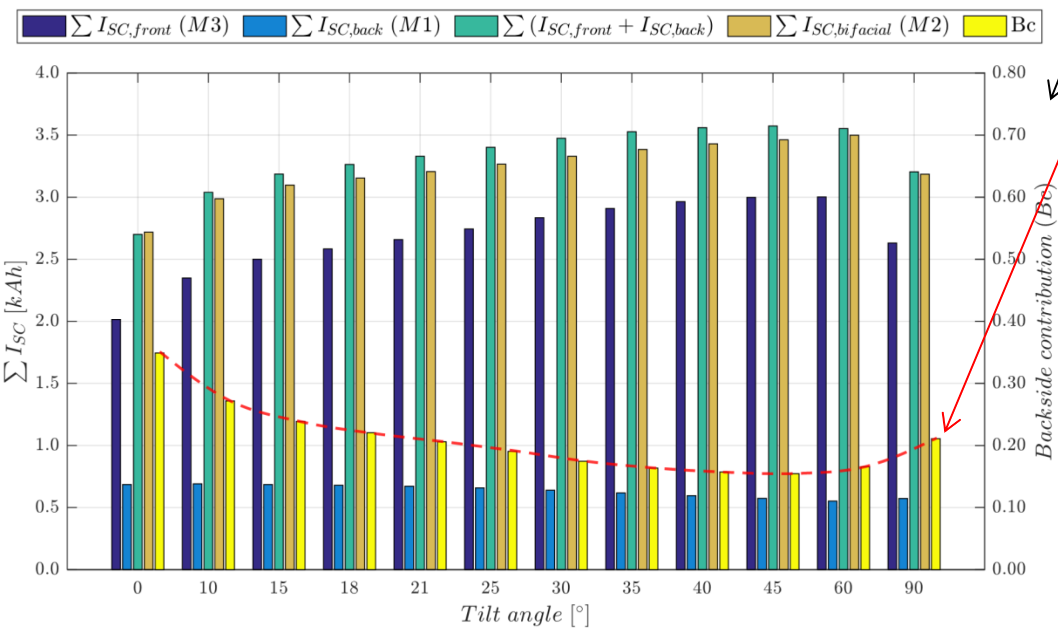
# Illumination intensity and homogeneity

- Compare M1–M3 results to small sensors
- October – March (winter season)
- Local output (rear) normalized to ISE (front)
- Compare to M1–M3 results (backside contr.)




- Lowest rear side illumination intensity determines backside contribution
- See also talk of Mr. Eisenberg/ Solaround yesterday

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# Illumination intensity and homogeneity

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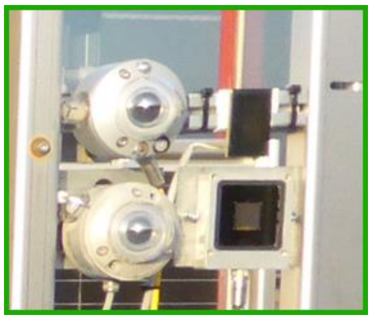
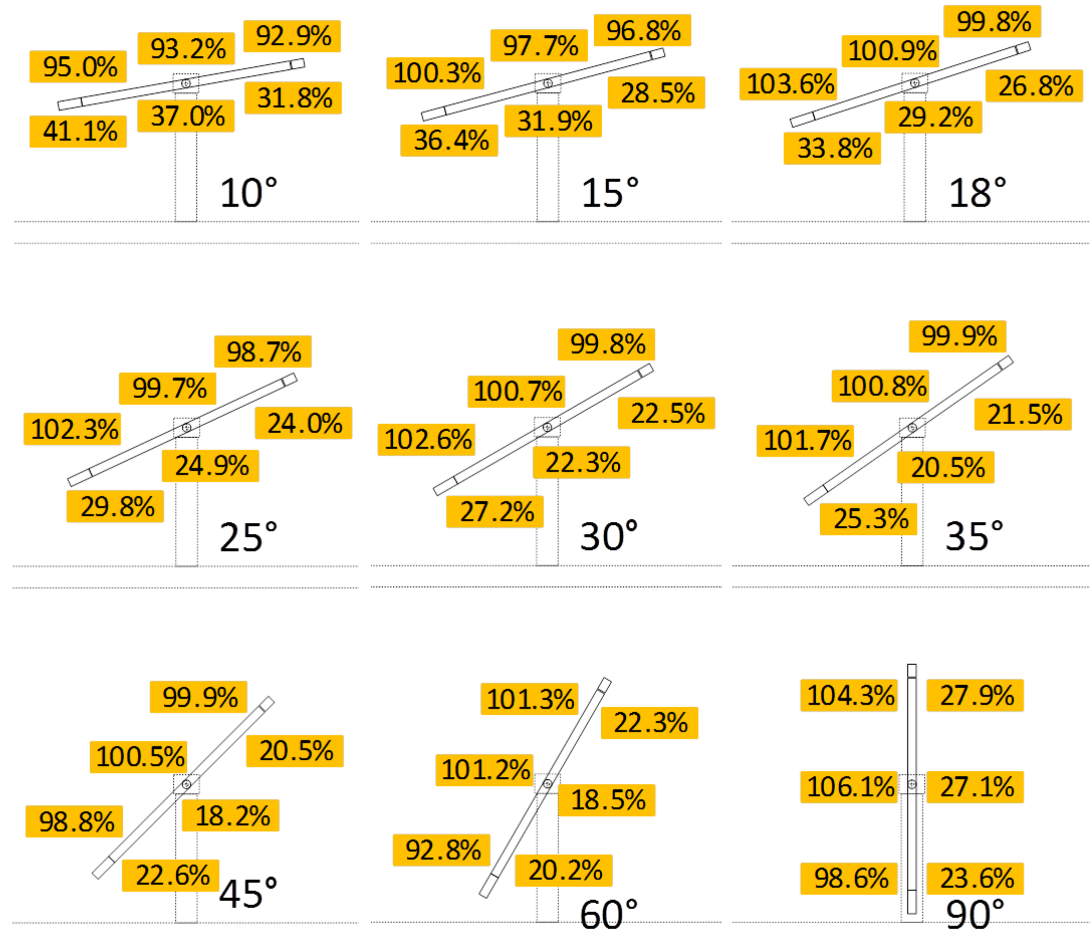
- Sensors at short side






- Normalized to ISE reference cell turning with module front
- Short-term data for test of simulation
- Here: Integrated data from Oct 2016 to March 2017

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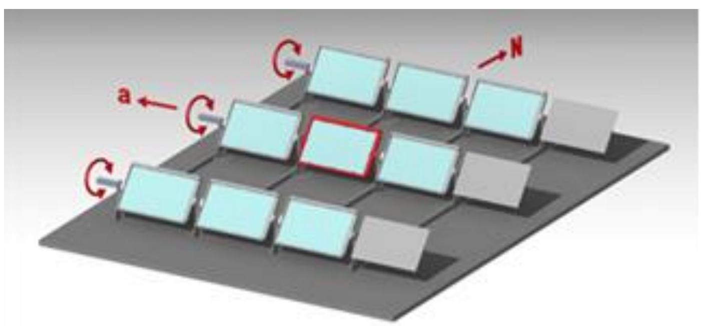
# Miniaturized test rig

# Miniaturized test rig / basic idea

## BIFOROT: Long term measurements

- Reveal yield; Compile data for simulation
- Manual adjustment (height, dist., albedo) slow




## Miniaturized rig - more flexible solution?

- Param. varied quickly→ nearly identical conditions
- **Multiple cheap rigs → vary at identical conditions !!!**
- **Multiple cheap rigs → directly compare locations !!!**

# Miniaturized Test Rig / Correspondence

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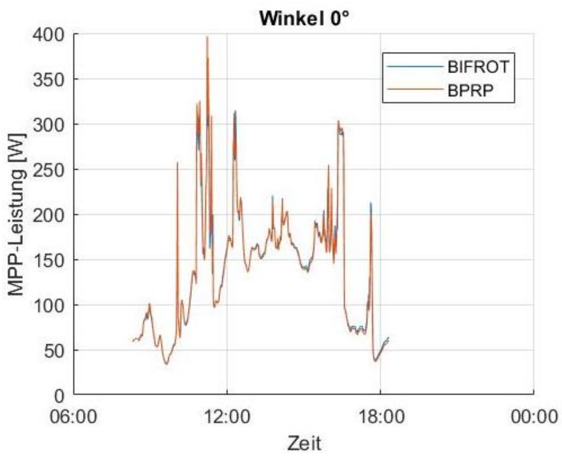
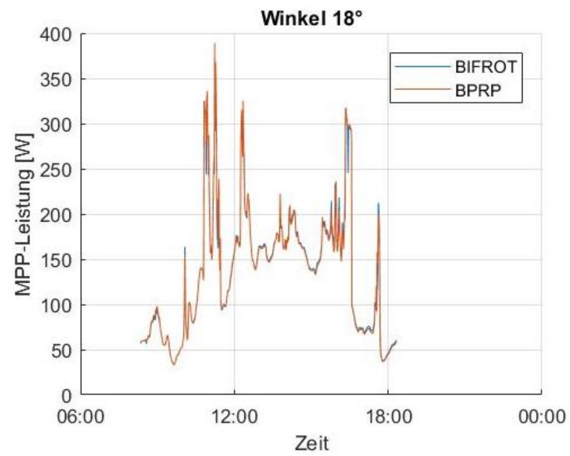
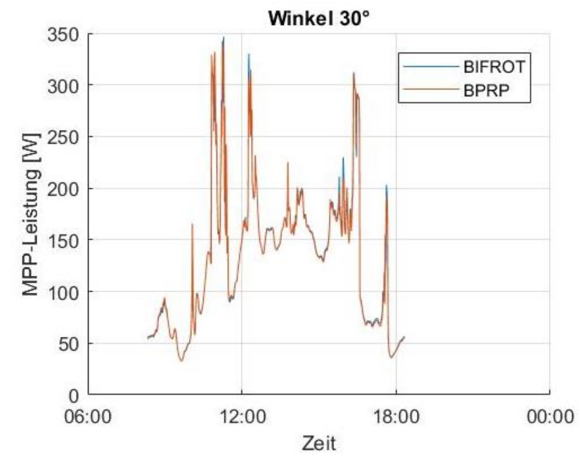
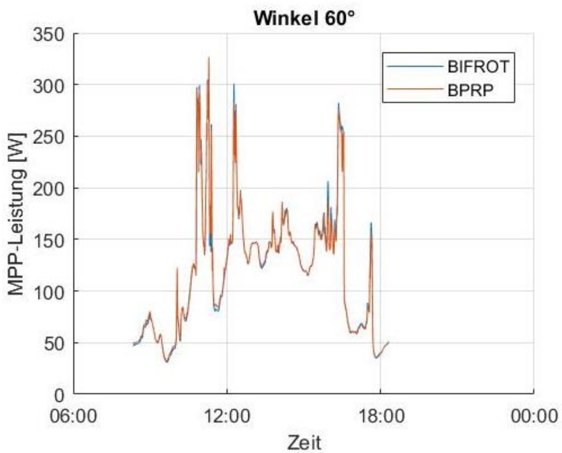
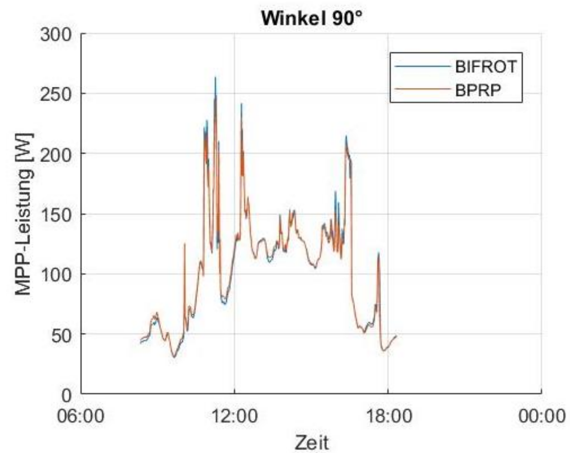
# Correlation of small and large rig



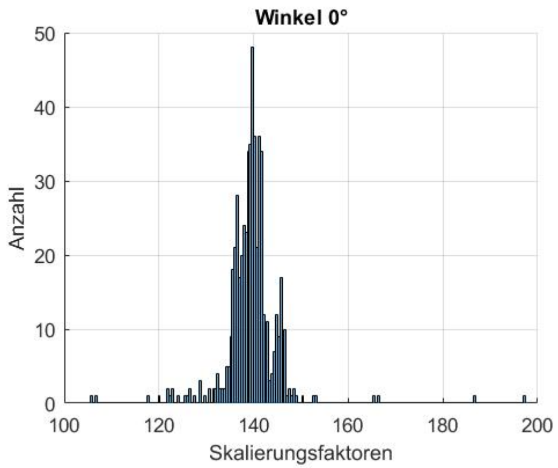



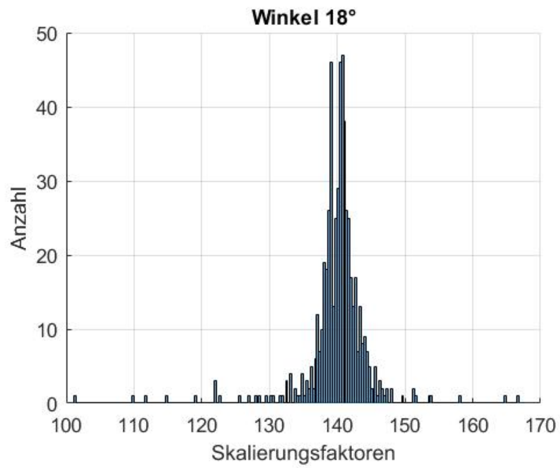



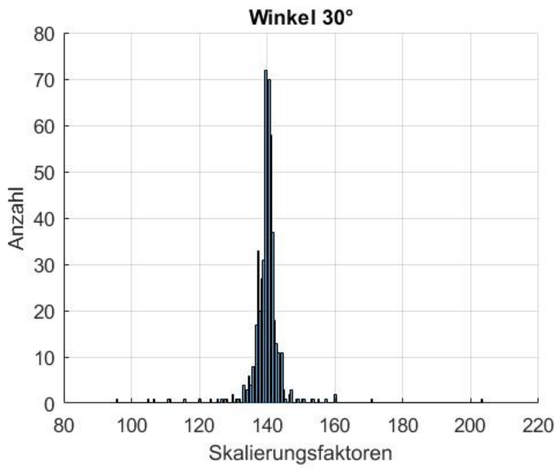

- Example 05/09/2017
- Miniaturized device: Surprising correspondence
- Determine scaling factors for each tilt angle
- Several possibilities

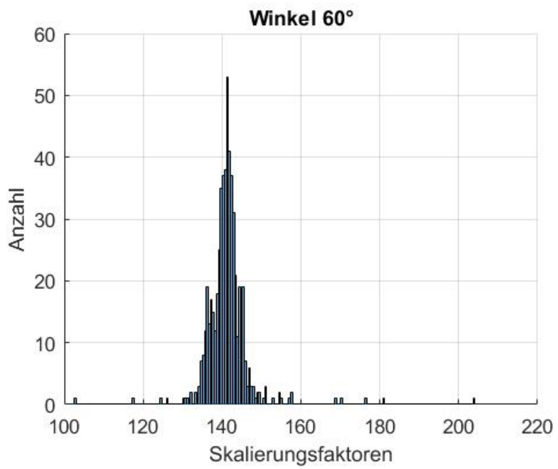
# Correlation of small and large rig

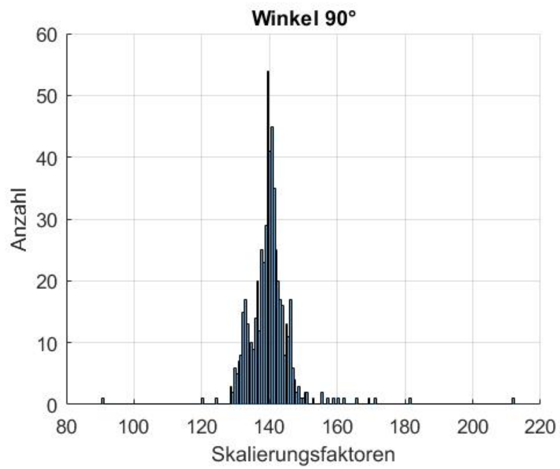





- Example 05/09/2017
- Scaling factor for each cycle (1-minute)
- Ongoing work

# Planned: Mobile test platform

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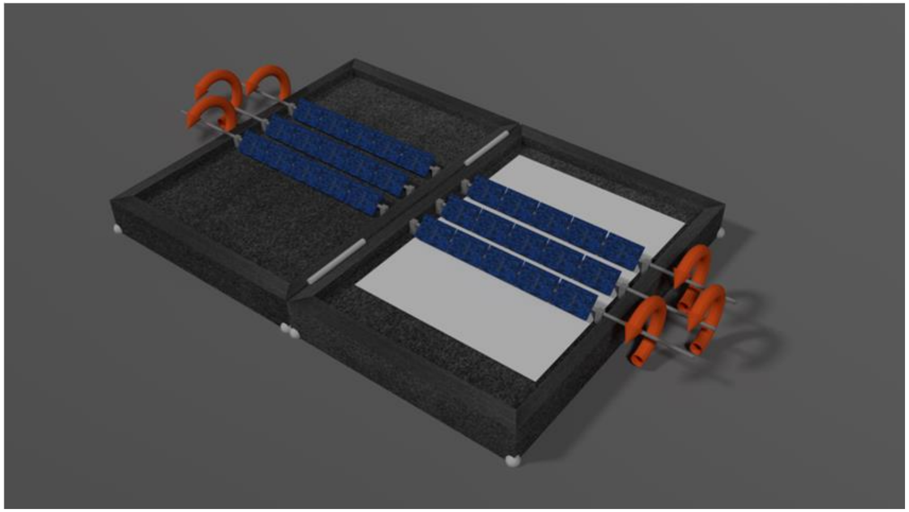
Miniaturized rig - more flexible solution

Parameters varied quickly→ nearly identical conditions

- **Multiple cheap rigs → vary at identical conditions !!!**
- **Multiple cheap rigs → directly compare locations !!!**

→ **Product for EPC`s, Institutes,...?!**



**Current plan: Improved version with two systems as mobile test platform**

# Summary and Outlook

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- BIFOROT
  - \+ Suitable tool to analyze bifacial installations
  - \+ For investors → test / demo system; Reveal optimized installation conditions
  - \+ Data generation to verify simulation algorithms
  - \+ Systematic analysis of general properties (e.g. intensity distribution at rear)
  - \- Suboptimal location at ZHAW roof
  - \- Long-term measurement

- Miniaturized test rig
  - \+ Data shows good correspondence to BIFOROT results
  - \+ More flexible than large array
  - \+ Parallel use of devices will reveal effects by direct comparison!