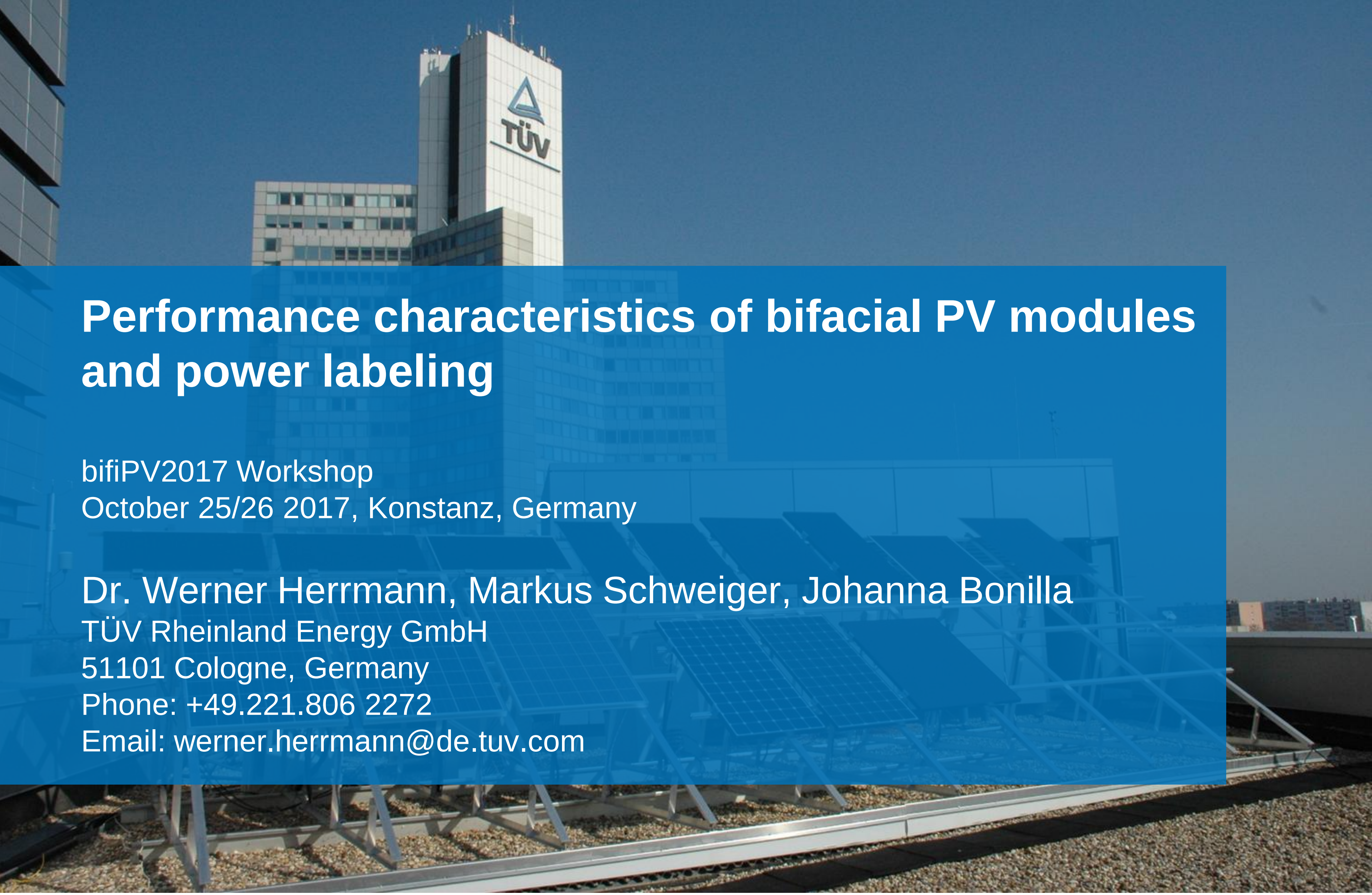


Performance characteristics of bifacial PV modules and power labeling

bifiPV2017 Workshop
October 25/26 2017, Konstanz, Germany

Dr. Werner Herrmann, Markus Schweiger, Johanna Bonilla
TÜV Rheinland Energy GmbH
51101 Cologne, Germany
Phone: +49.221.806 2272
Email: werner.herrmann@de.tuv.com

TÜVRheinland®
Precisely Right.

Performance of commercial bifacial PV modules

Introduction

- IEC test standards are written for mono-facial PV modules ⇒ How to address bifaciality in IEC 60904-X and IEC 61853-X series?

Electrical performance of 6 bifacial modules measured in the laboratory

- Power labelling of bifacial modules is not harmonized

Discussion of bifacial reference conditions

- Accurate bifacial yield simulation depends on many parameters

Preliminary results of comparative energy yield study

Performance of commercial bifacial PV modules
Efficiency curves and bifaciality factor

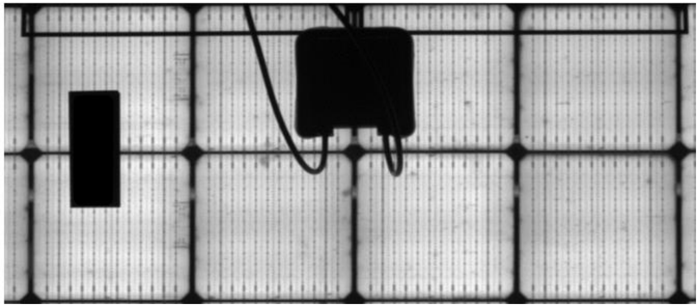
Bifaciality factor determination with one-sided Indoor method

- Independent front (f) and rear side (r) characterization with a A+A+A+ pulsed solar simulator following IEC 60904-1-2 Draft (non-reflective background)
- Performance measurement of front side at 7 irradiance levels (G_i) and 25°C constant module temperature: 100 – 200 – 400 – 600 – 800 – 1000 – 1100 W/m²
- Determination of irradiance dependence of P_{MAX} bifaciality factor

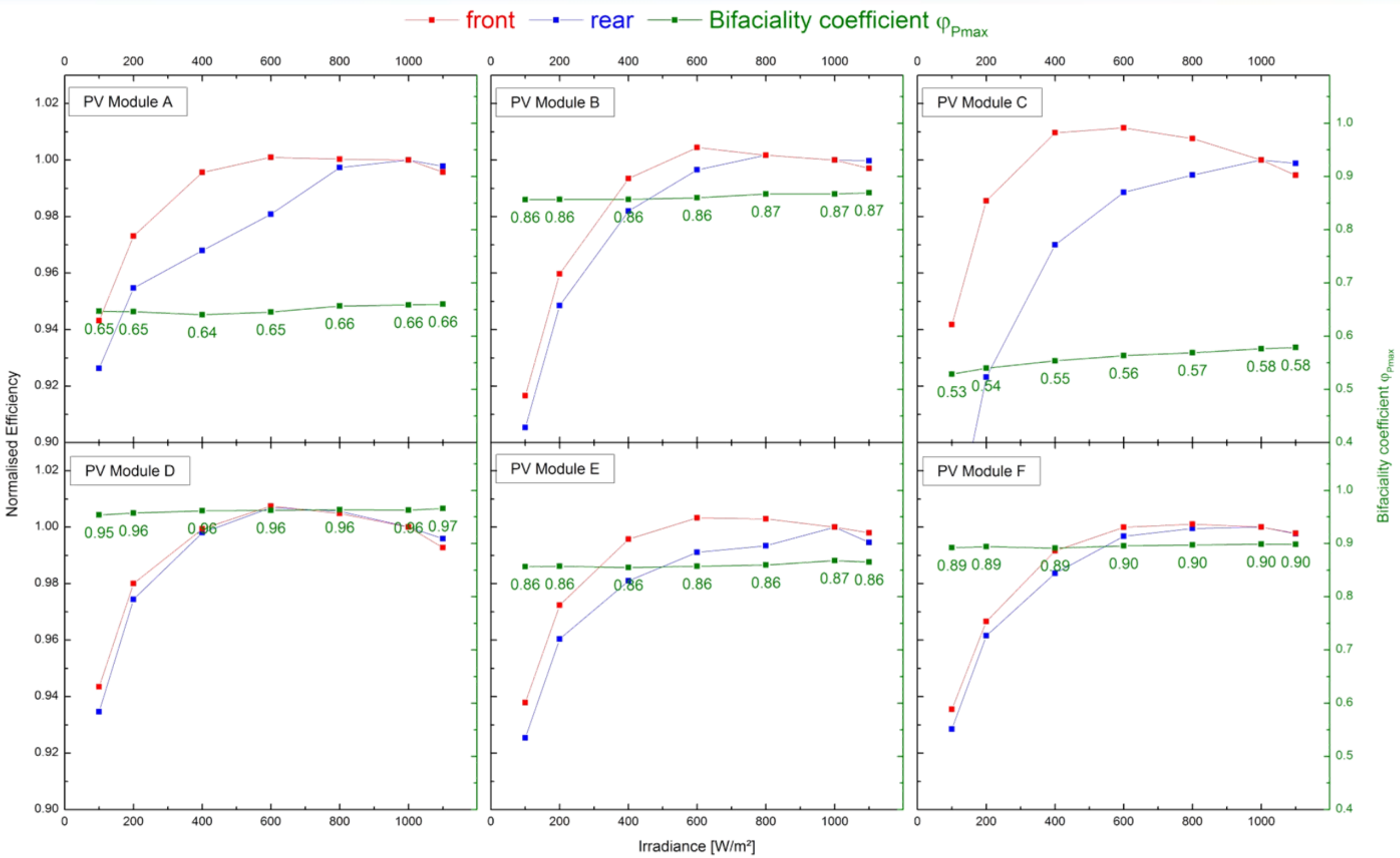
$$\varphi_{PMAX}(G) = \left.\frac{Pmax_r}{Pmax_f}\right|_G$$

Results:

- Variation in low light behavior insignificant for φ_{PMAX} >80%
- Low sensitivity of bifaciality coefficient φ_{Pmax} on irradiance level
- Shading of module rear side by label, J-boxes or cables negatively impact φ_{Pmax}

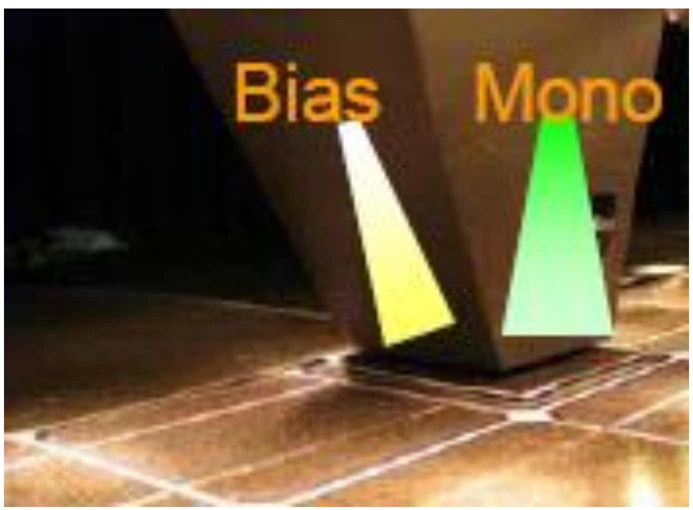


Performance of commercial bifacial PV modules
Efficiency curves and bifaciality factor



- Shading of module rear side by label, J-boxes or cables negatively impact φ_{Pmax}
- Low sensitivity of bifaciality coefficient φ_{Pmax} on irradiance level

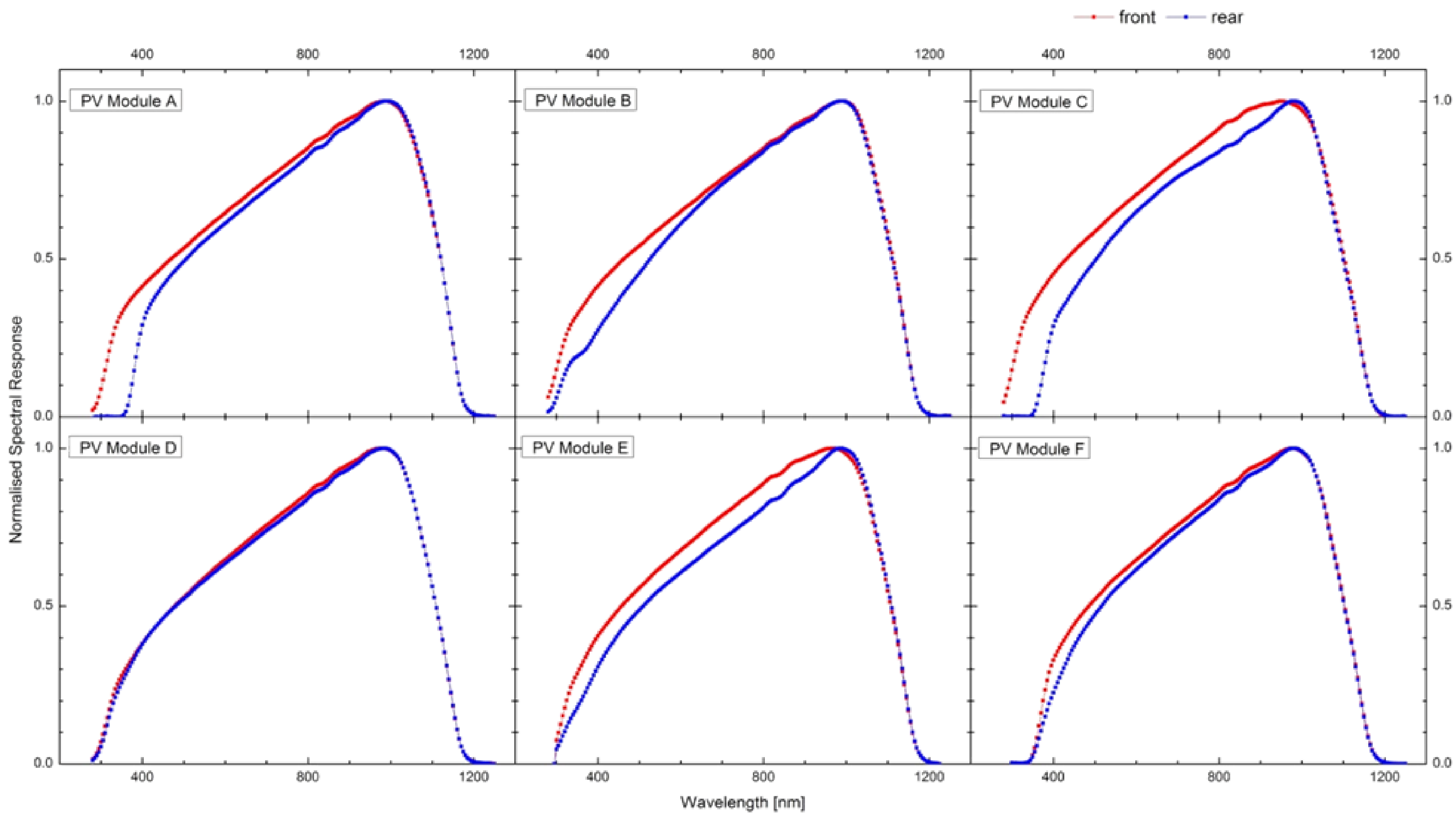
Performance of commercial bifacial PV modules
Relative spectral response



- Monochromatic light source (50 mm x 50 mm)
- Wavelength range: 300 nm – 1700 nm
- Crystalline silicon and thin-film PV modules
- Photocurrent of cell results from two module I-V measurements:
  - Fully illuminated PV module / cell-string
  - Target c-Si cell or part of thin-film module of interest shaded by mask
- Non-destructive SR measurement
  - No cut of backsheet required to contact test cell $\Rightarrow$ measurement of double glass module
- Measurement of SR non-uniformity

References:
Y. Hishikawa et al.: Spectral response measurements of PV modules and multi-junction devices, 22nd EU PVSEC, 2007
Y. Tsuno et al.: A method for spectral response measurements of various PV modules, 23rd EU PVSEC, 2008

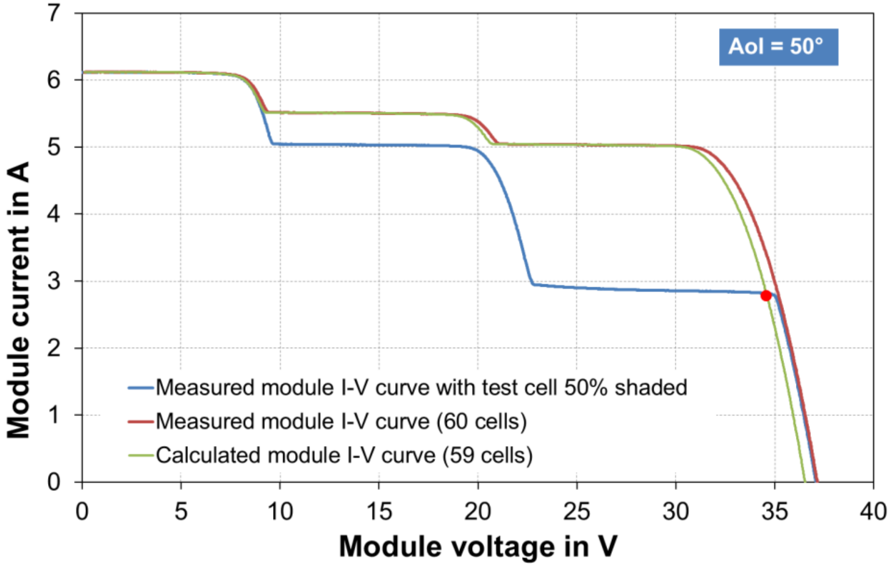
Performance of commercial bifacial PV modules
Relative spectral response



Reference:
M. Schweiger et al.: Electrical Performance of Bifacial PV Modules: Comparative Measurements of Market-Ready Products, 27th EUPVSEC, Amsterdam, 2017

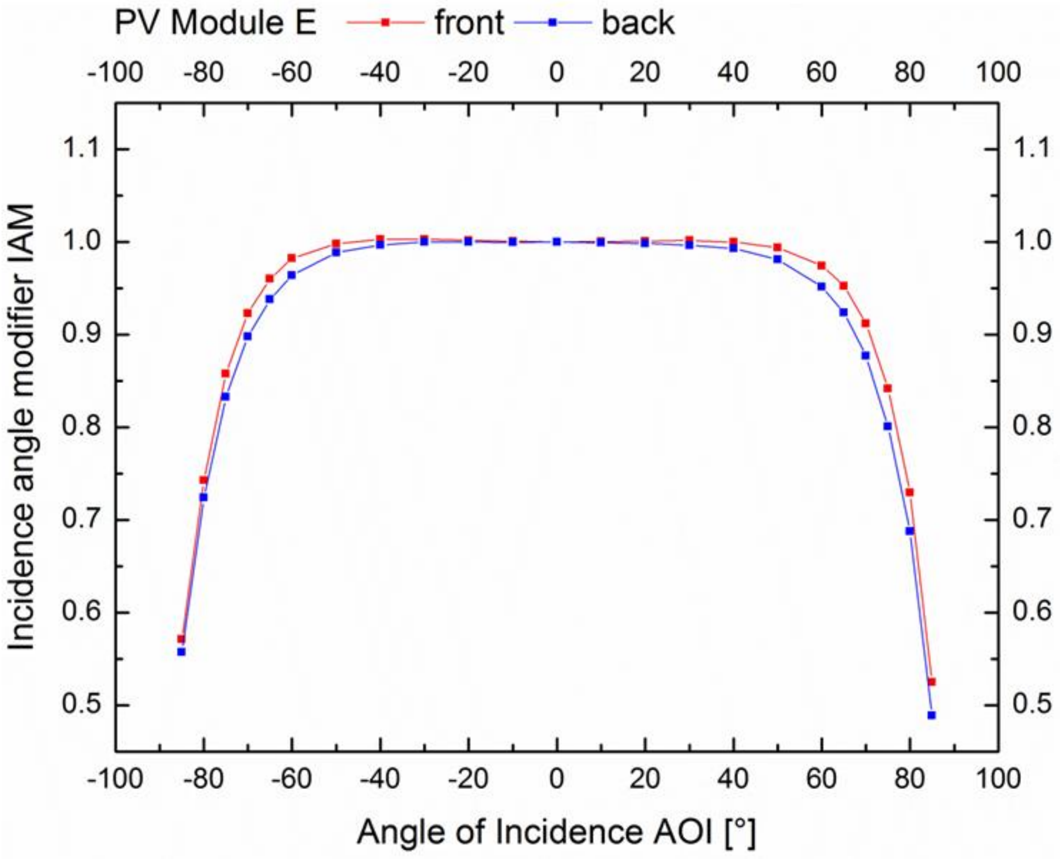
Performance of commercial bifacial PV modules
Angular response

- AR measurement requires rotation of PV module in the test area of a solar simulator
  - High non-uniformity of irradiance in the rotational volume
  - Angular measurement of c-Si modules must be performed on cell basis
- Non-destructive test method required for double glass modules
  - Isc of test cell is concluded from PV module I-V curve under partially shading



Reference:
W. Herrmann et al.: Solar simulator measurement procedures for determination of the angular characteristic of PV modules, 29th EUPVSEC, Amsterdam, 2014

Performance of commercial bifacial PV modules
Angular response



- AR response depends on type of glass, materials and AR coatings
- **Sample F:** Higher angular losses for rear side observed, but insignificant for energy yield simulation

Power labelling of bifacial PV modules
Issues

#1

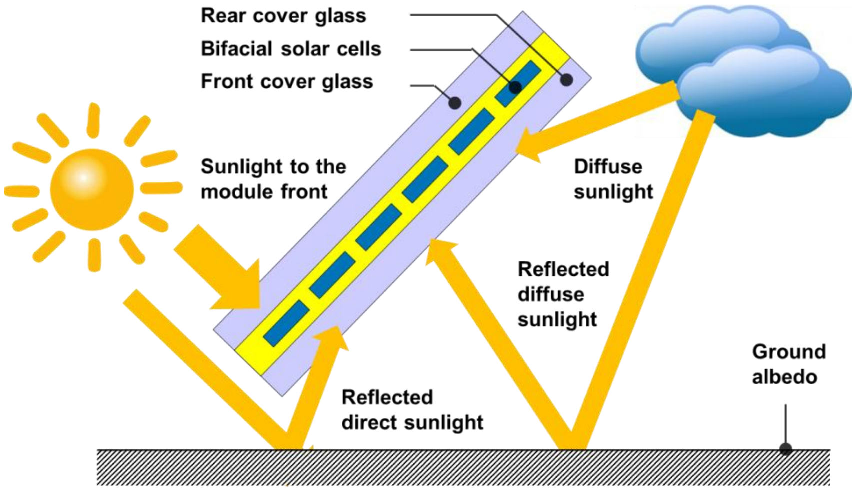
- PV modules are typically sold in price per Wp.
- How to address the bifacial gain on the PV module label or in the data sheet?

#2

- Validation of output power specification is part of IEC 61215 product qualification testing.
- Production tolerances of rear performance are typically higher compared to front side.
- How to address the manufacturers tolerances for bifacial modules?
  - Production tolerance
  - Measurement uncertainty of production line measurement
  - Performance change due to LID

Power labelling of bifacial PV modules
Extension of STC needed?

- **Fielded bifacial PV modules** ⇒ Field parameters greatly impact rear side irradiance G_R
- **Ray-tracing simulations**:
  - ⇒ Rear side irradiance lies in the range 130-140 W/m² for parameters given in the table
  - ⇒ Height of bifacial modules >1 m above ground leads to <5% spatial non-uniformity of G_R
- Consumer view: Additional power labelling to differentiate products (B-STC)
- **Reference G_R value for B-STC?**



Field parameter	Bifacial reference conditions
Albedo	0.21 (light soil)
Height above ground	1 m
Inclination angle	37°
Front side irradiance	1000 W/m“

Reference:
C. Deline et al., Assessment of Bifacial Photovoltaic Module Power Rating Methodologies - Inside and Out, IEEE Journal of Photovoltaics Vol. 7, No. 2 (2017)

Energy yield performance of bifacial PV modules
Comparative measurements in Cologne, Germany

- Comparative energy yield measurement of bifacial, monofacial and thin-film PV modules

Installation:

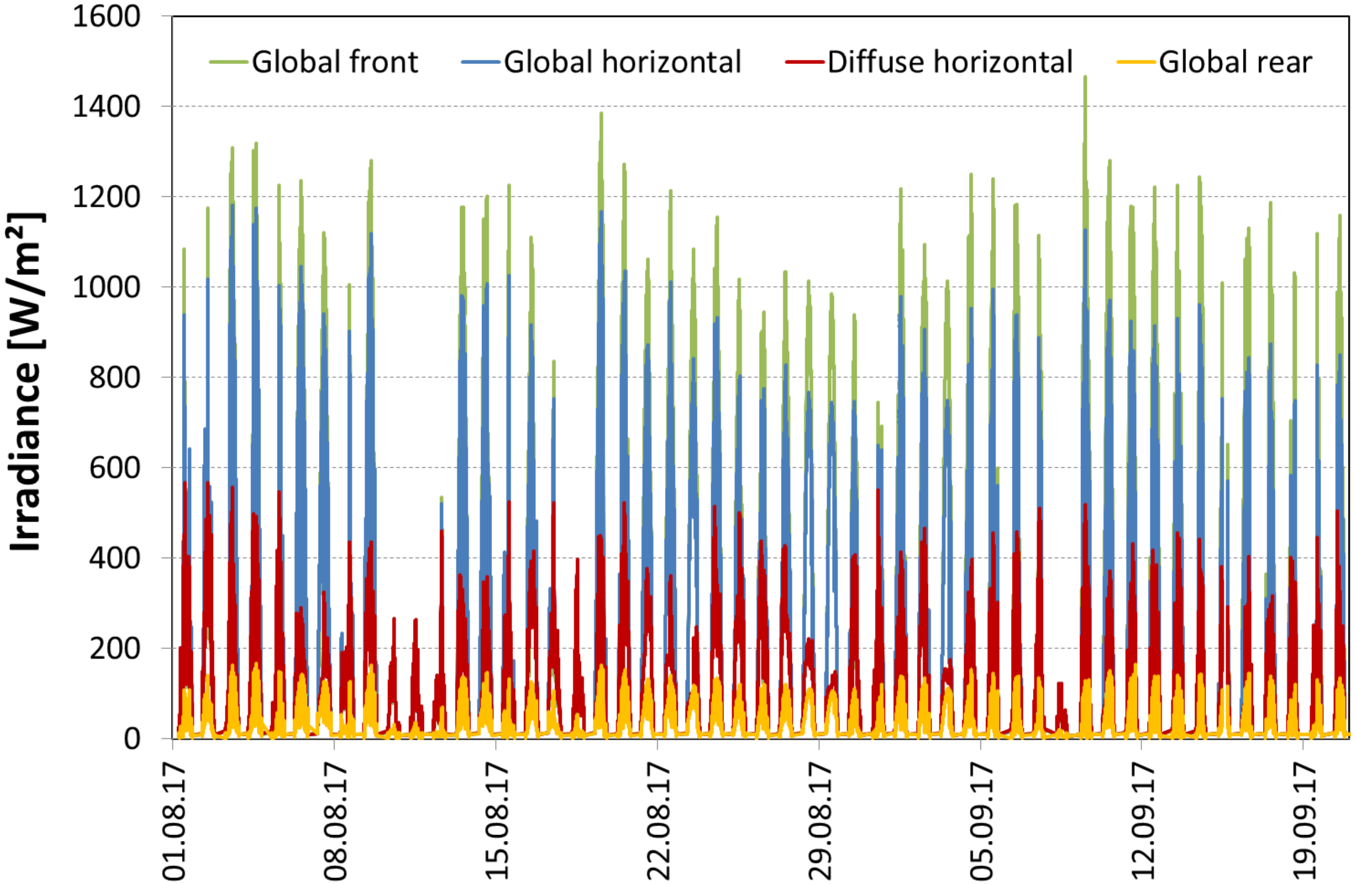
- Height above ground: 1.5m
- Tilt angle: 35° South
- Ground: gravel (albedo ~20%)

Instrumentation:

- Rear irradiance measurement: pyranometer
- Rear spectral irradiance measurement as necessary
- MPP Tracking: 30 s data recording interval
- 10 min I-V curve measurement

Energy yield performance of bifacial PV modules

Irradiance conditions 1 August to 21 September



Daily insolation:

$Average_D$ = 3.3 kWh/m²

Min_D = 0.5 kWh/m²

Max_D = 6.2 kWh/m²

Diffuse radiation:

Average = 56.4%

Min_D = 23,3%

Max_D = 100%

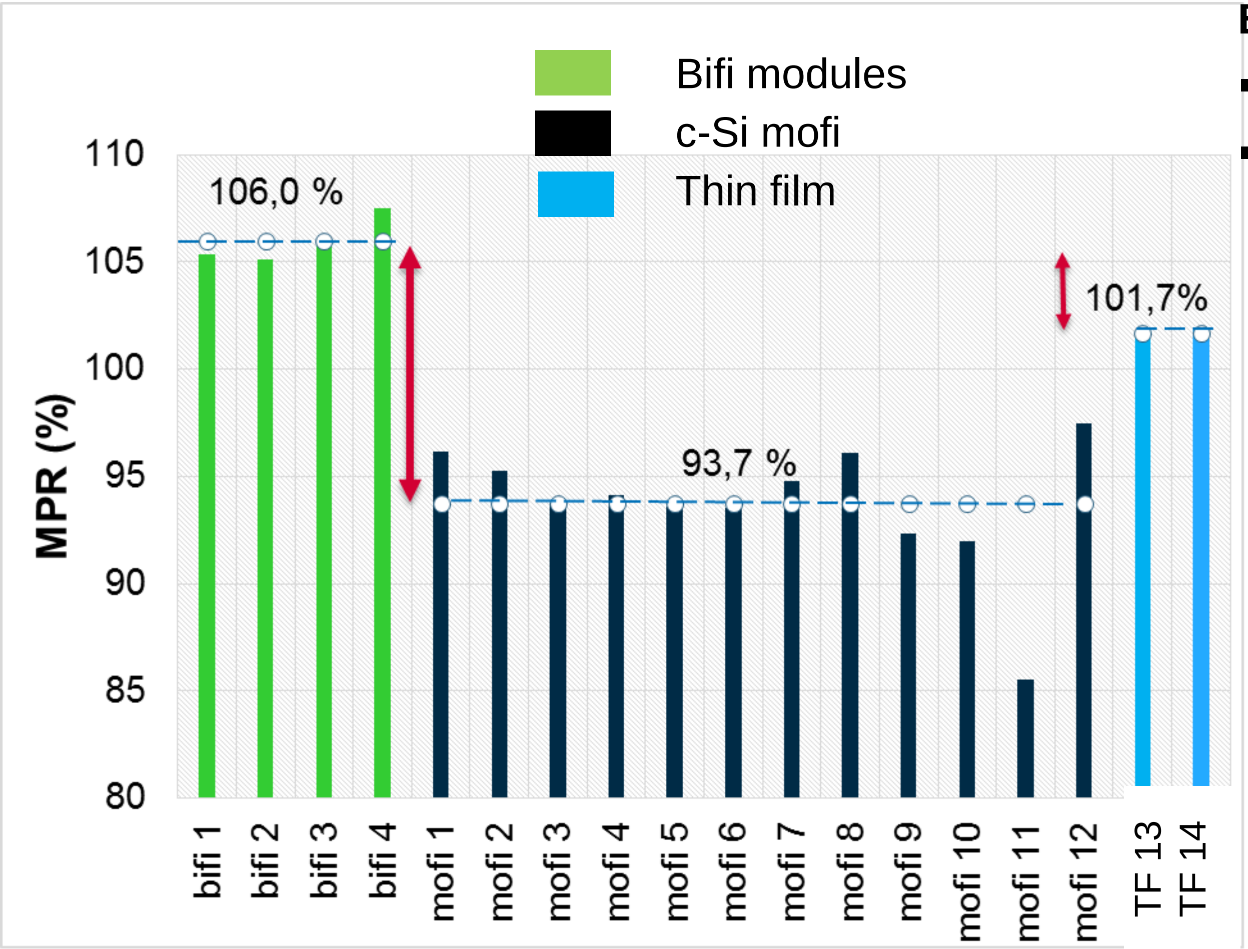
Rear/front side radiation:

Average = 13.8%

Min_D = 12.2%

Max_D = 18.3%

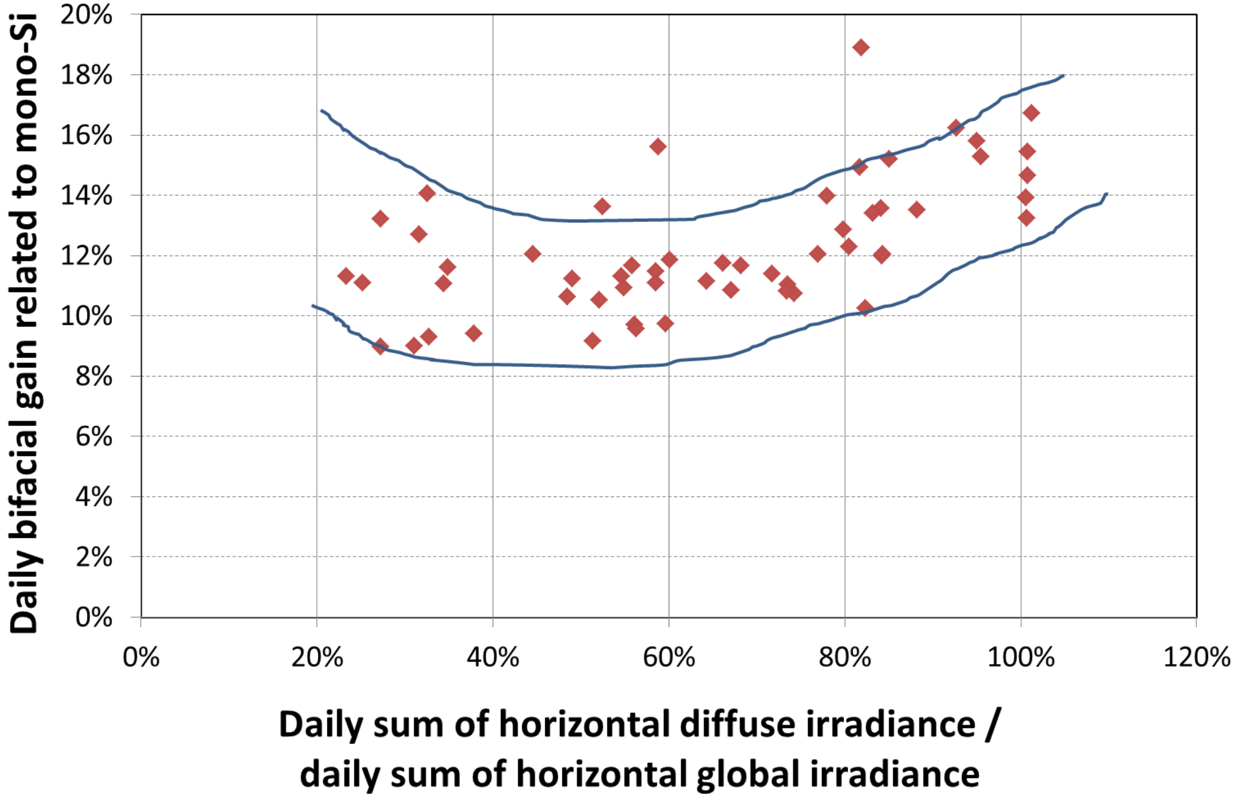
Energy yield performance of bifacial PV modules
Module performance ratio (MPR)



Bifacial gain:

- + 12,2% than mofi c-Si
- + 5% than thin-film

Energy yield performance of bifacial PV modules
Impact of diffuse irradiance on bifacial gain

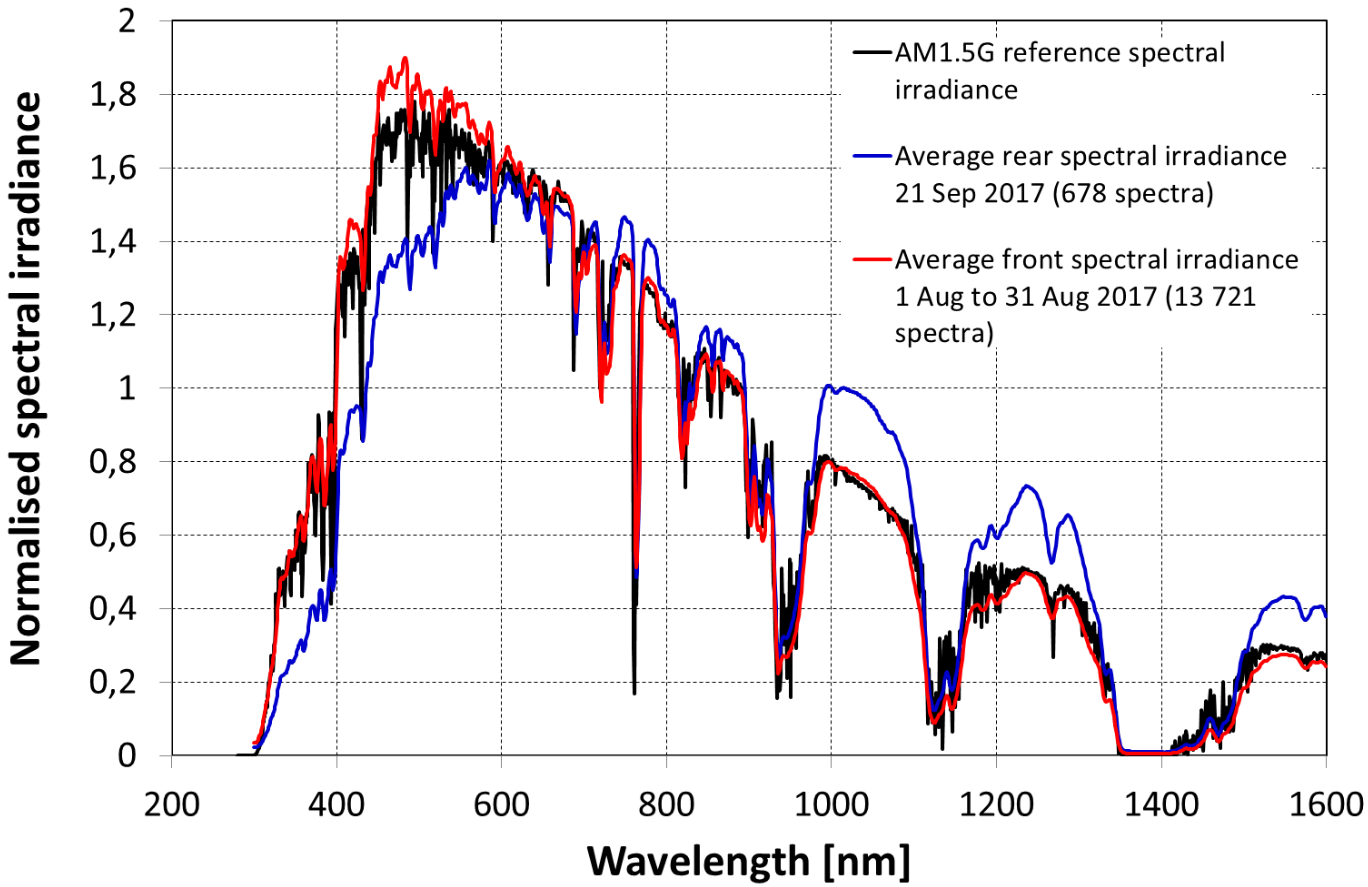


Aug/Sep 2017

- No clear correlation
- More data required

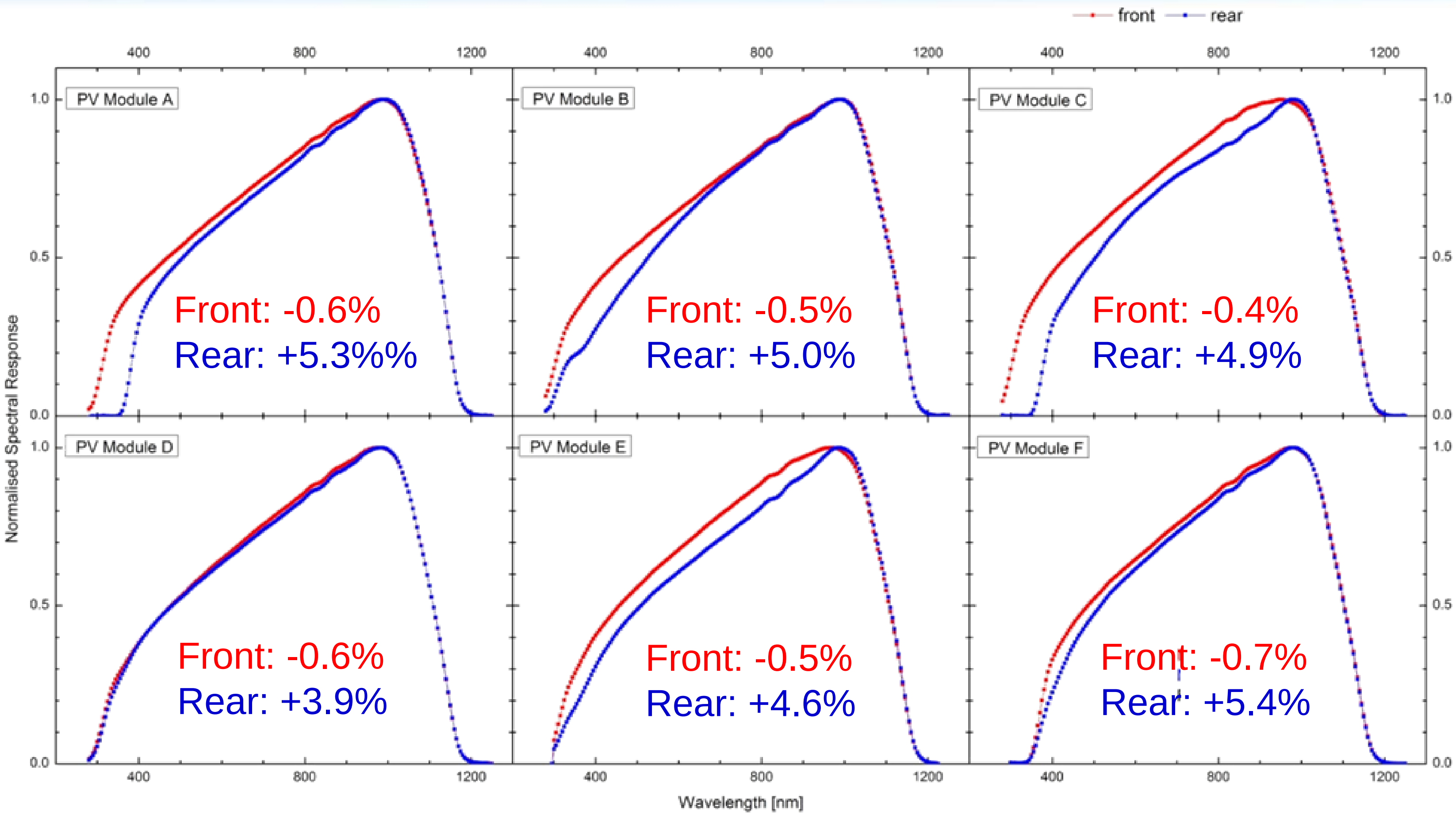
Energy yield performance of bifacial PV modules

Spectral irradiance on rear side (sunny day)



- Red shift of rear spectral irradiance distribution ⇒ depends on reflective properties of ground

Energy yield performance of bifacial PV modules
Spectral mismatch error related to pyranometer measurement



- **Pyranometer measurement:** Effective irradiance at rear cells is 3.9% to 5.5% lower

Summary and Conclusions

- Laboratory measurement procedures in place are sufficient to characterize bifacial PV modules.
- Power labelling of bifacial PV modules is an urgent matter. Sufficient knowledge is available to define bifacial reference conditions.
- Accurate bifacial gain simulation is complex and also requires accurate electrical simulation.

Thank you for your attention!