Hello again!

Stefan Roest
CTO and co-founder of Eternal Sun
Member of IEC 60904-9 revision team

Pepijn Veling
Sales Director

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We make sunlight to accurately test the power and degradation of PV modules

A+A+A+ Flash module Pmax determination

5100XL

Temperature Controlled Lab flasher

Steady State Module degradation and tandem Pmax

Steady State Simulator

Climate Sun Simulator

A+ class Lightsoaker

UV degradation chamber

We help our customers achieve the lowest Measurement Uncertainty in the industry

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Ability to **always** trust your data

"What I value the most of the Spire flasher, is the stability. You measure a module, and after several months, you measure it again and get the same values. That enables us to do good science and research"

Dr. Bokalič, Laboratory of Photovoltaics and Optoelectronics, University of Ljubljana

http://lpvo.fe.uni-lj.si/en/members/matevz-bokalic/

Source: LPVO website

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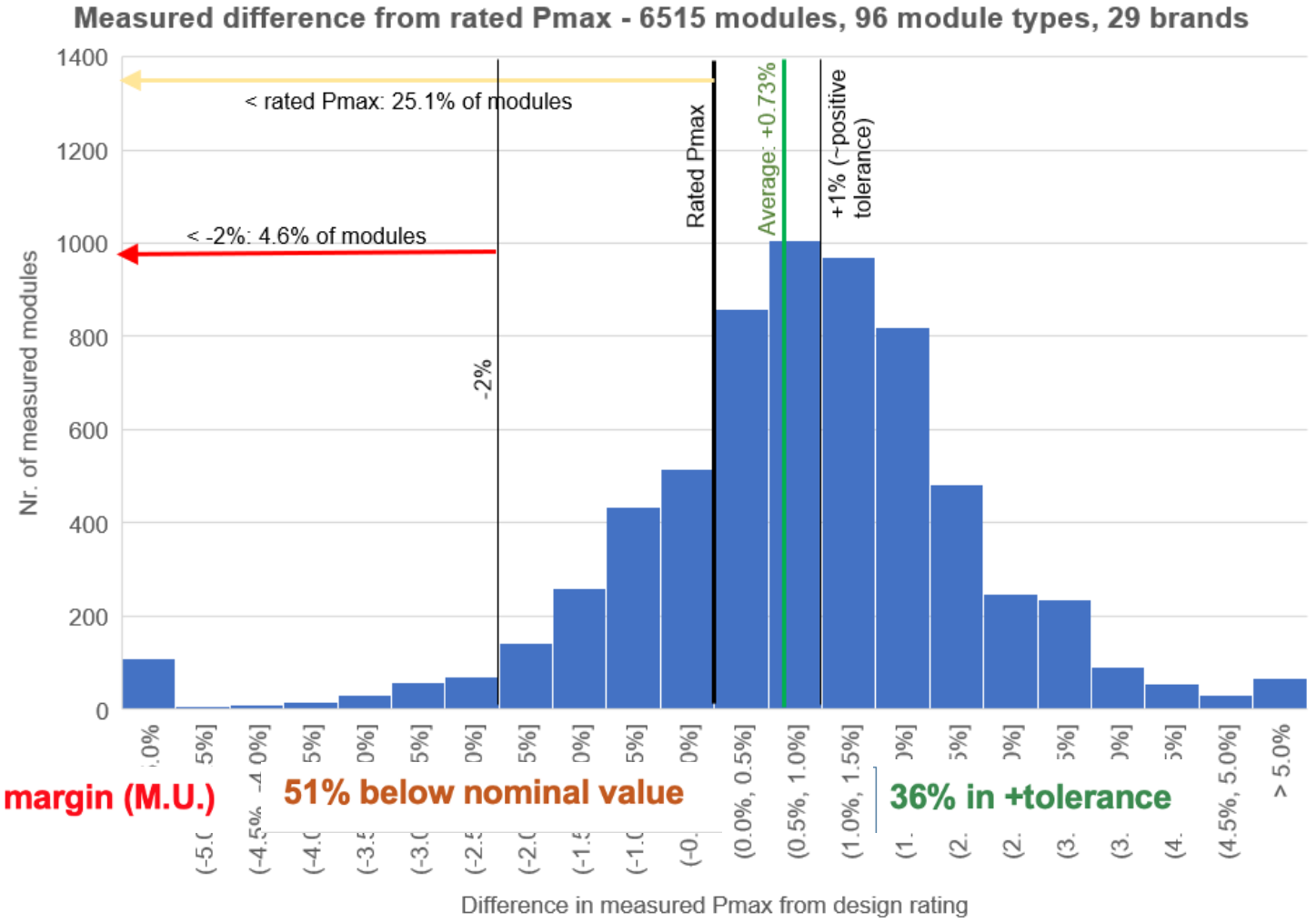
And we practice what we preach: we test ~10,000 modules per year in our Import testing labs in Rotterdam (NL) and Valencia (Spain)

- Our test labs are situated *INSIDE* the warehouses
- ~30% of PV modules imported into Europe flow through here

What do we see in the import testing centres?
→On average PV modules perform well
→More and more modules below nominal value

2019 data of 6515 PV modules

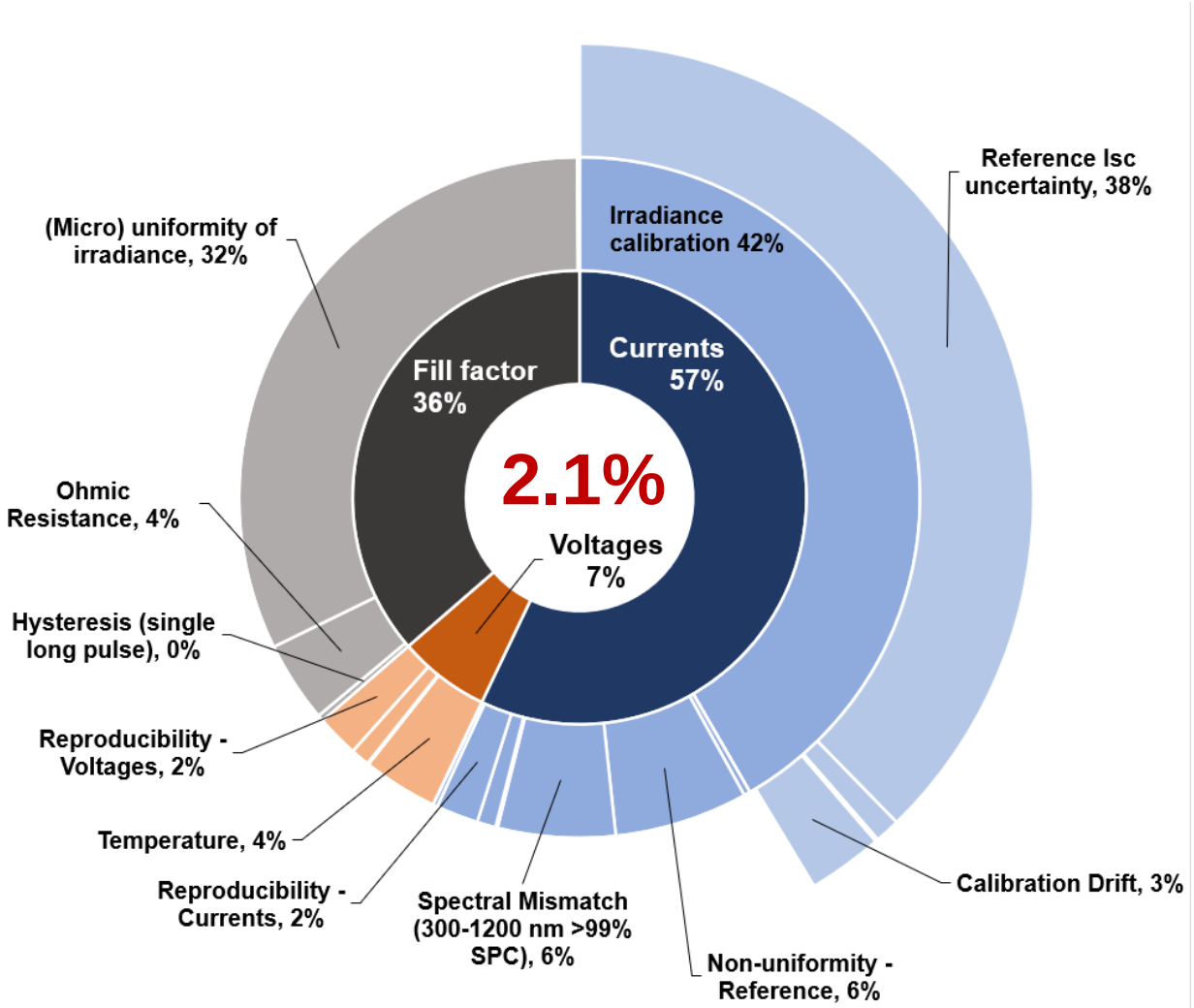
2021 update of ~35.000 PV modules:



Measurement Uncertainty is crucial in this!
→We can help

Uncertainty component	Uncertainty [%]	Cov. Factor (k)	Distribution	S.U. [%] (k=1)
Isc/Currents				**0.799997**
Effective Irradiance				**0.777101**
Calibration				0.683331
Reference device Isc	1.3	2	N	0.65
DAQ (inc. calibration tolerance)	0.2	2	N	0.1
Temperature on ref device	0.0333	1	N	0.033292
Drift of calibration device	0.3	1	R	0.173205
Calibration tolerance	0.1	1	R	0.057735
Simulator uniformity and DUT form factor	0.8	3	N	0.266667
Spectral Mismatch	0.5	2	N	0.25
Signal (DAQ)	0.2	2	N	0.1
Reproducibility + Repeatability	0.3	2	N	**0.15**
Fill Factor				**0.638566**
Sweep effects (hysteresis)	0.1	1	R	**0.057735**
Connection (adapters/wiring)	0.36	1	R	**0.207846**
Irradiance uniformity	1.2	2	N	**0.6**
Temperature uniformity	0.03511885	1	N	**0.035119**
Combined u.c.		**1**	**N**	**1.058726**
Normal Distribution				
95% confidence interval				
Combined Expanded Uncertainty		**2**	**N**	**2.117452**

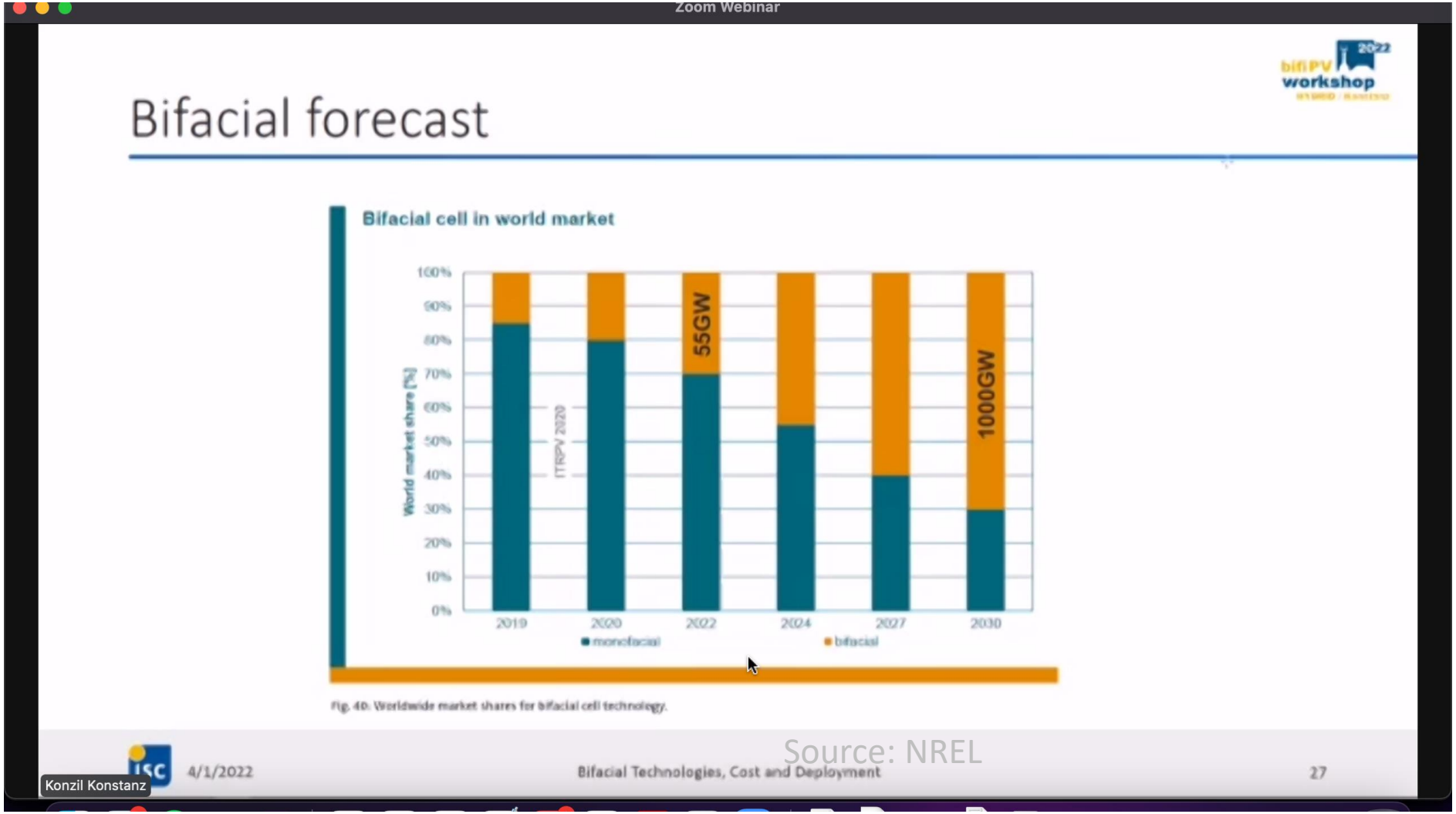
Example model



Summary of Import testing uncertainty model

Back to Bifacial: It will be dominant

→How to test high efficiency bifacial PV modules in lab and inline?



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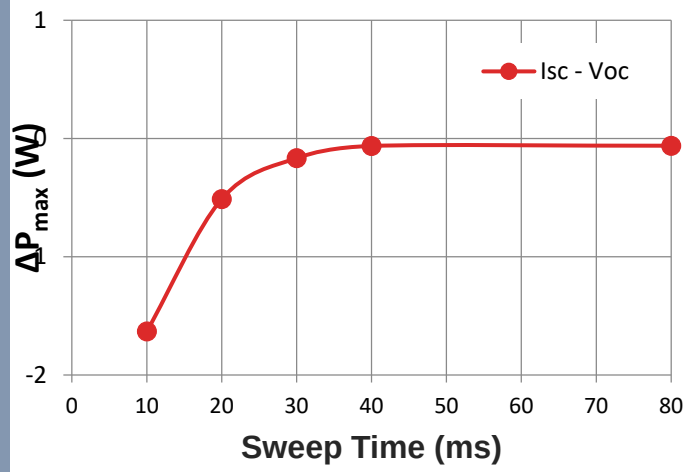
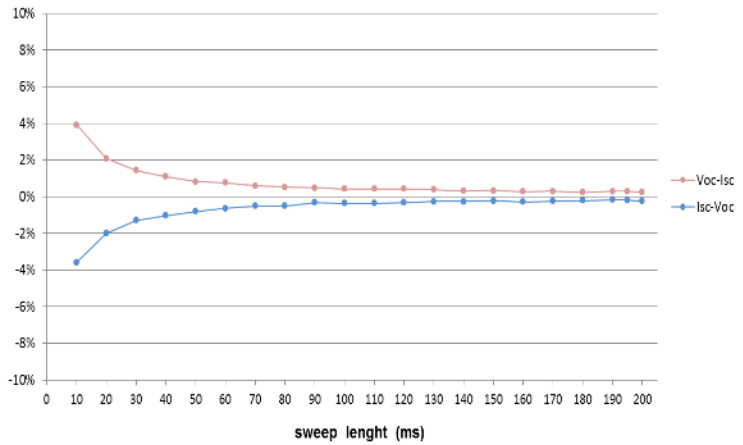
High efficiency cell technologies show increased charge built up (capacitance) during fast IV sweeps → ***Make sure you have >160ms stable pulse!***

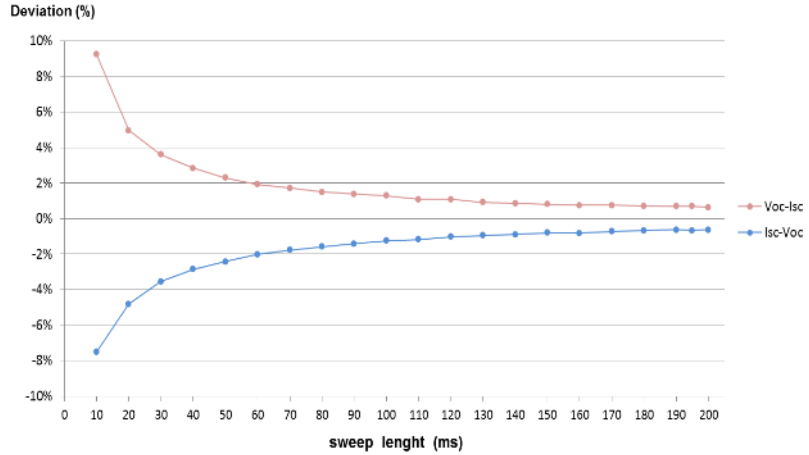
High efficiency modules effect

- *Layers such as passivation (PERC) reduce recombination of carriers resulting in higher V_{oc}*
- *Higher V_{oc} causes increased charge build-up (capacitance) during the IV voltage sweep, leading to lower P_{max} measurement*

Illustration







PERC: 40-70 ms ***TOPCon: 60-100 ms*** ***HJT: >160 ms***

Implication

- *Commonly applied 10ms pulse too short for P_{max} measurement due to capacitance*
- *For every cell V_{oc} increase of 18mV, the carrier concentration roughly doubles, which represents a doubled sweep time effect [2]*

[1] Source: Based on 3500SLP sweep time sequence measurement of PERC module (2016)
[2] Source: Smets et al., Solar Energy: the physics and engineering of photovoltaic conversion technologies and systems (2016)

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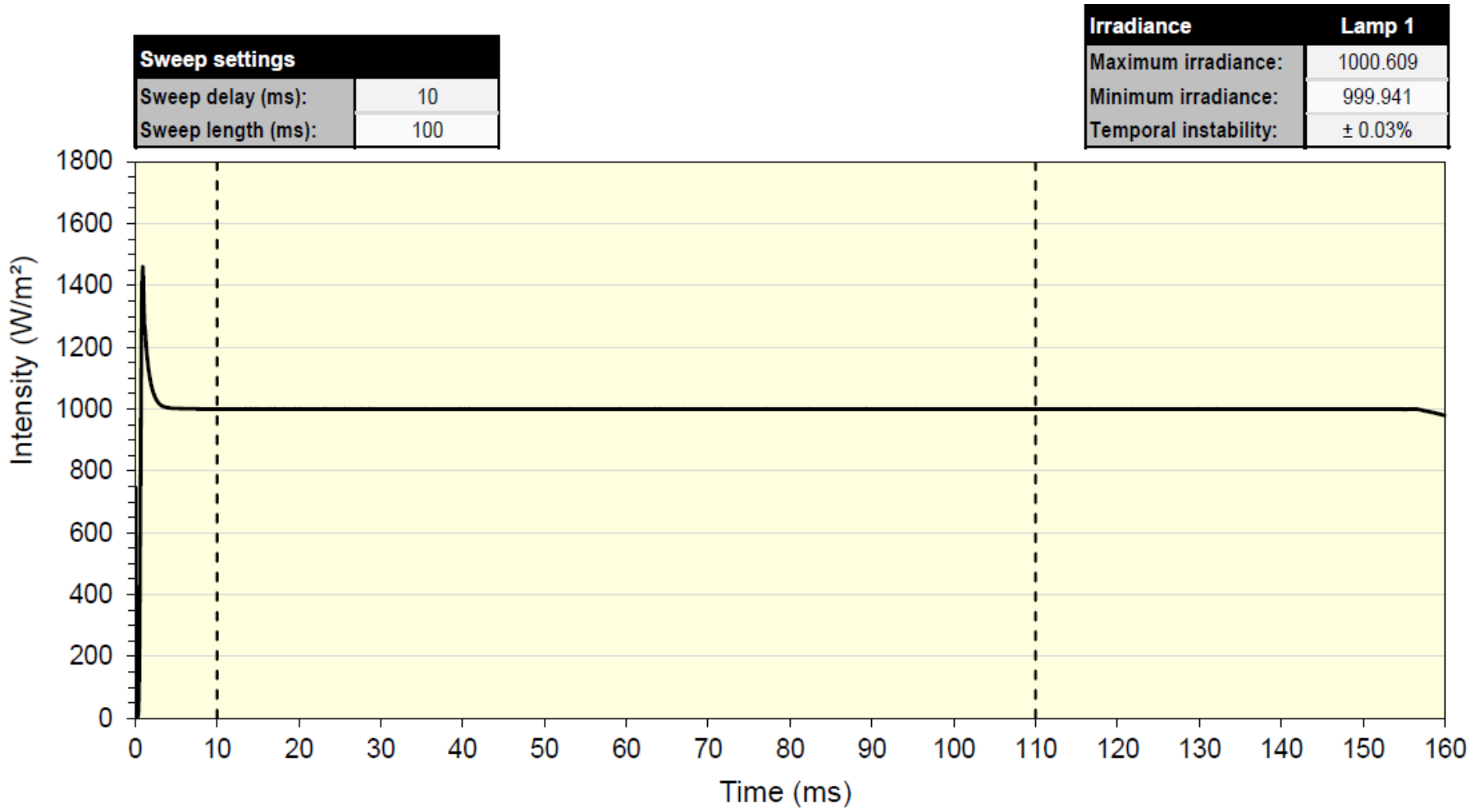
Temporal instability of basic manufacturing flasher at 1000W/m2



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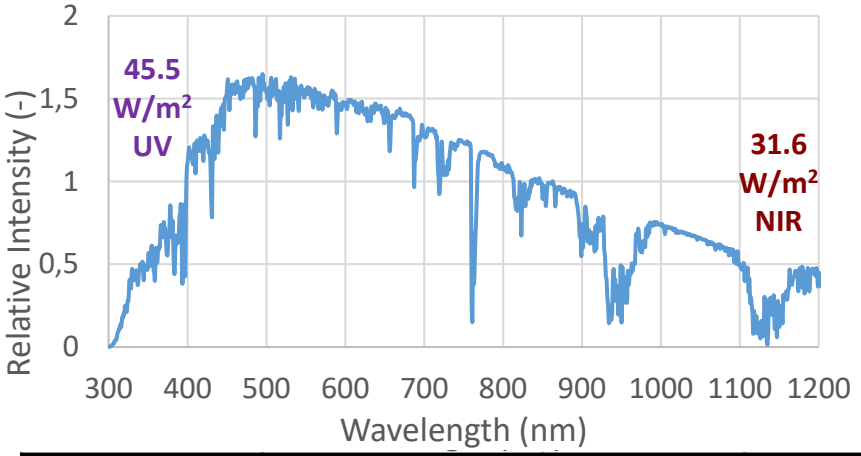
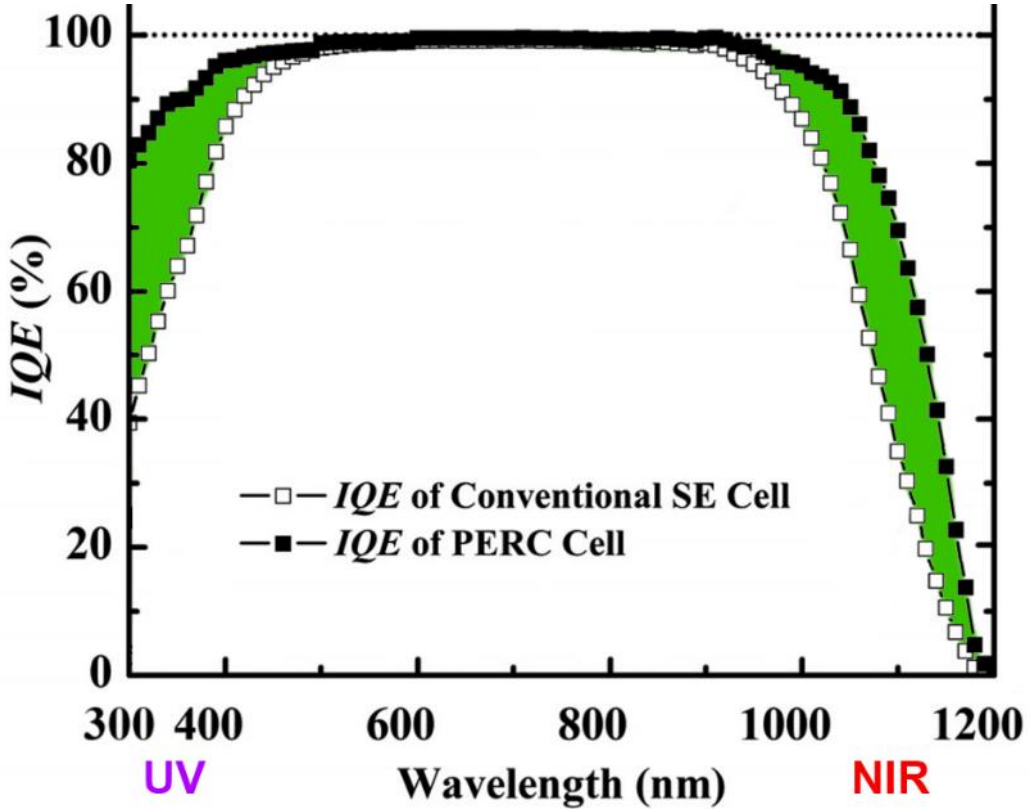
The sun has approximately 9% of its energy in the 300-400 nm UV and 1100-1200 nm NIR ranges

→ *Make sure your flasher matches this: >99% IEC Spectral Coverage*



AM1.5 sun spectrum

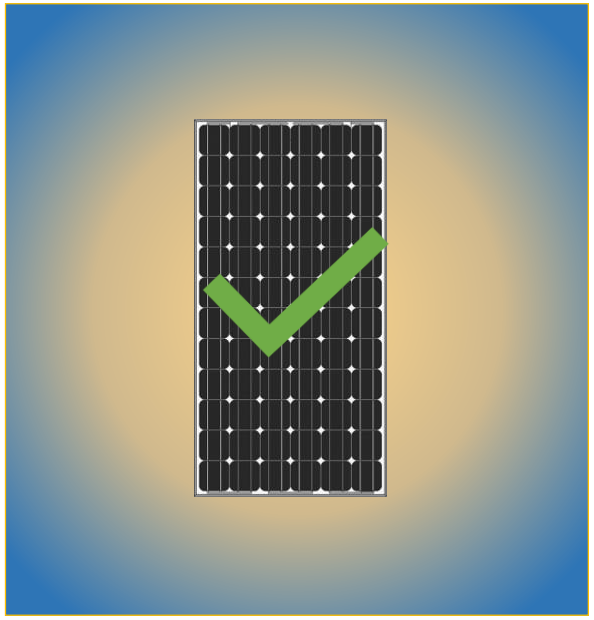
	AM1.5 content	%	AM1.5 content	%
300-400	**45.5 W/m²**	**5.4%**	**45.5 W/m²**	**5.4%**
400-500	139.4 W/m²	16.7%		
500-600	151.0 W/m²	18.1%		
600-700	139.3 W/m²	16.7%		
700-800	113.3 W/m²	13.6%	758.7 W/m²	90.8%
800-900	94.7 W/m²	11.3%		
900-1000	56.3 W/m²	6.7%		
1000-1100	64.7 W/m²	7.7%		
1100-1200	**31.6 W/m²**	**3.8%**	**31.6 W/m²**	**3.8%**



The industry has moved to larger PV module sizes

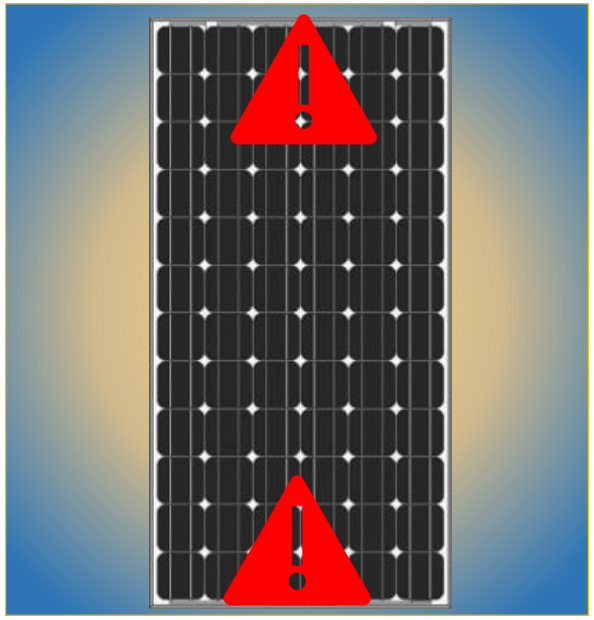
→Make sure you have A+ high resolution uniformity over entire XL test area

Standard module in standard flasher



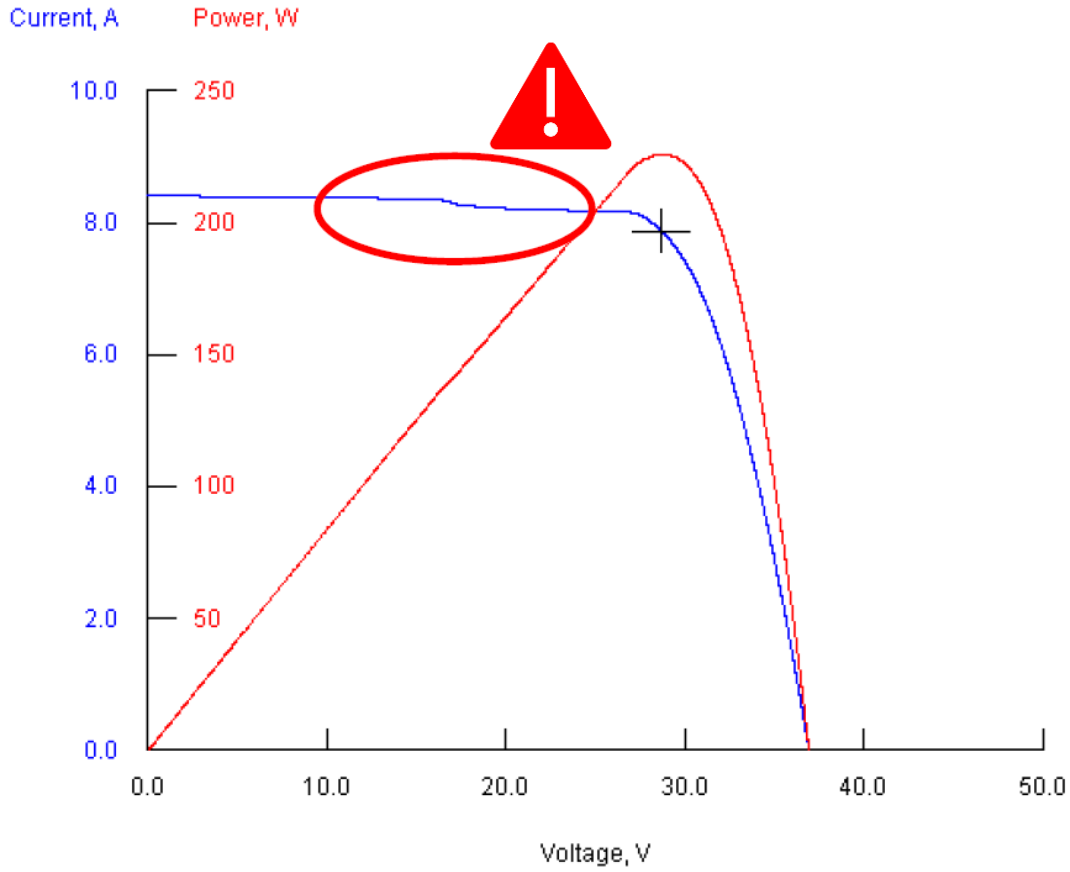
A+ uniformity

Large module in standard flasher



B/C uniformity

Result:
poor IV curves with higher uncertainty



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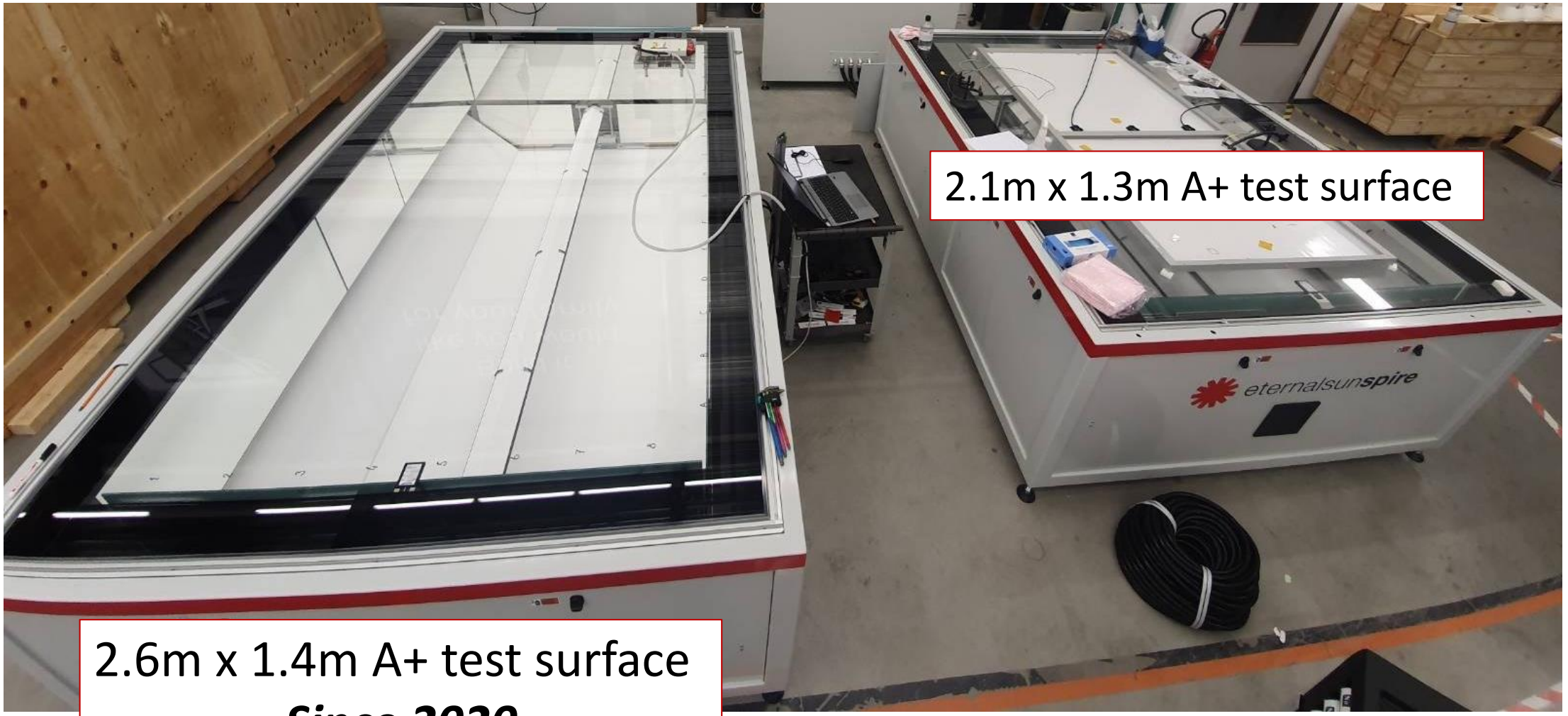
The Spire long pulse xenon flasher design allowed simple extension to XL surface

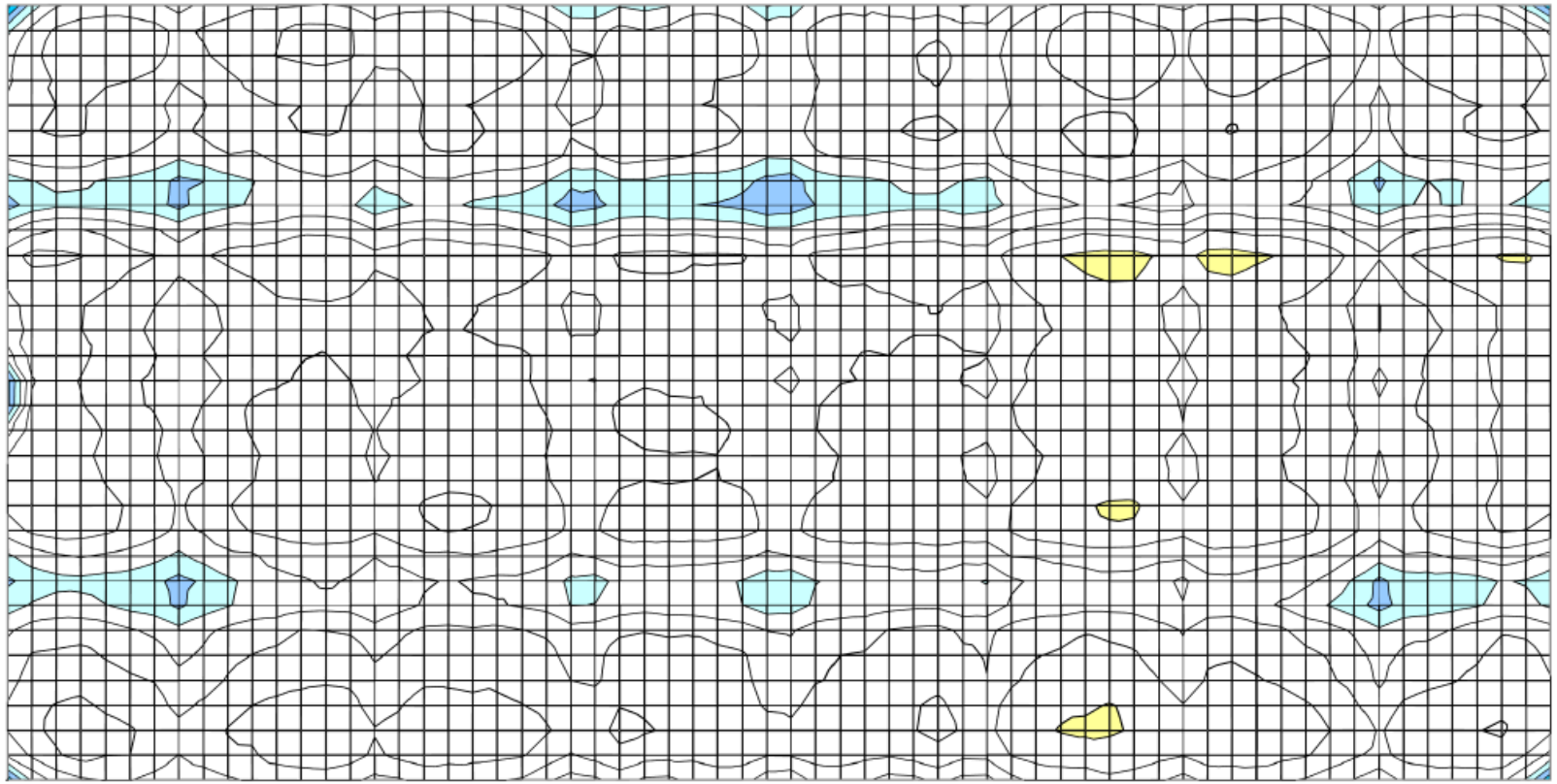


2.6m x 1.4m A+ test surface

Since 2020

Intensity pattern of 5100XL flasher:
<1% non-uniformity over 2.6 x 1.4m area

Yellow = Higher intensity White = Average intensity Blue = Lower intensity

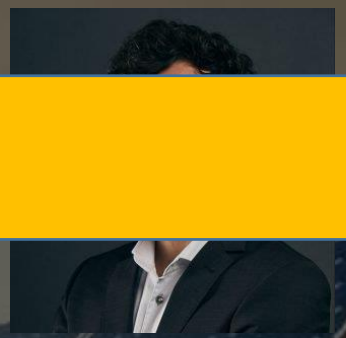


Non-uniformity: 0.77%

Bifacial Modules Webinar: Insights in Data, Modelling and Test Methods

Tristan Erion-Lorico
Head of PV Module Business
PV Evolution Labs

PVEL
MAKE DATA MATTER.



For the IEC bifacial testing protocol and PVEL field data:
→Re-watch our webinar online

Tijmen Slikker
Application Engineer
Eternalsun Spire

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Host and moderator:
Charis Dagoc
Sales manager

What does the relevant IEC norms say?

- Eternalsun Spire CTO Stefan Roest is member of Working group 2 (WG2) of IEC Technical Committee (TC) 82 → PV Module standardization

- Relevant norms:
  - IEC TS 60904-1-2:2019 → Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices

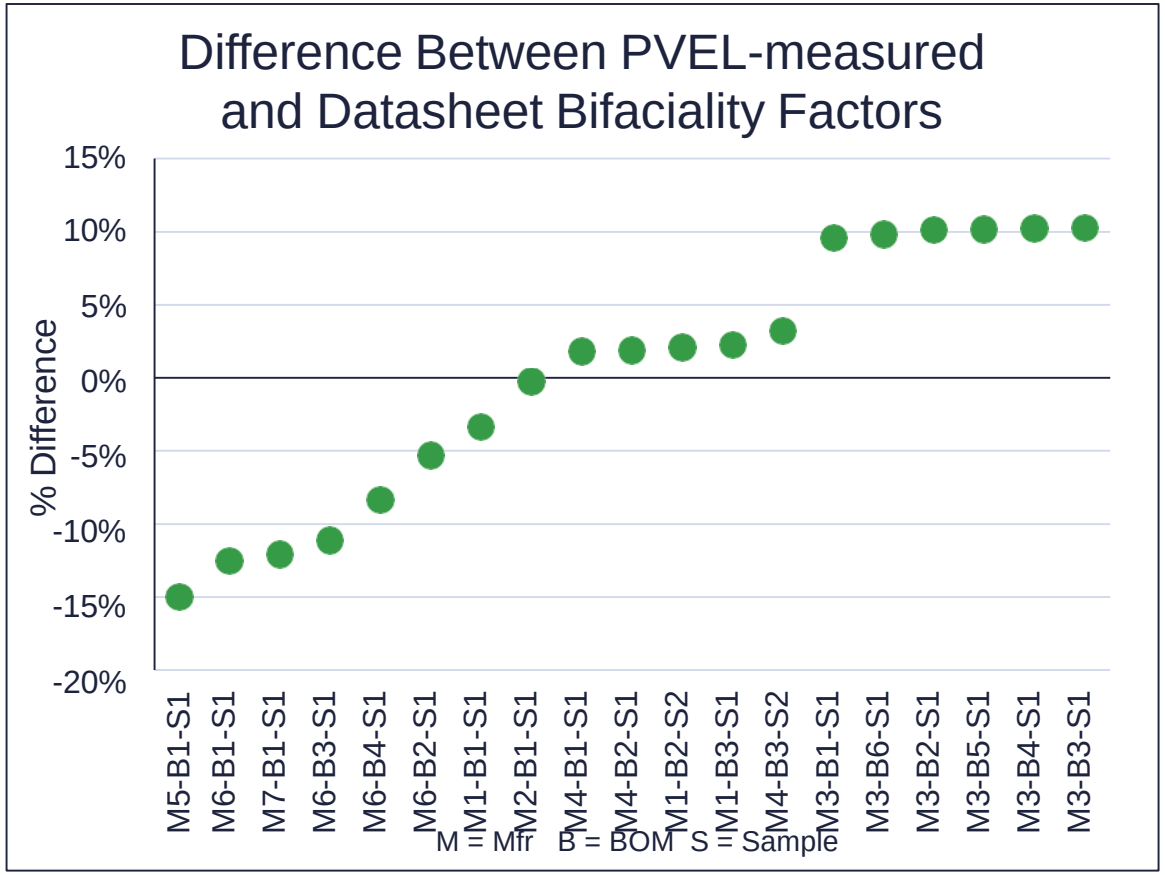
  - IEC 61215-1:2021 → Design qualification and type approval - Part 1: Test requirements
    - BNPI = corresponding to 1000 W/m2 on the module front and 135 W/m2 on the module rear
    - BSI = corresponding to 1 000 W/m2 on the module front and 300 W/m2 (may be extrapolated)
      - Worst case scenario for module reliability (hotspots, diode testing)

Key Take-Aways of webinar for bifacial workshop

- IEC norm describes both single-side illumination and double-sided illumination
- Industry agrees: The measurement results difference between the two methods is typically neglectible, especially relative to overall measurement uncerainty
- Therefore allmost all labs and manufacturer's use the single-sided flash method
  - Labs flash both front and backside according to the IEC procedure
  - Manufacturers flash all modules inline only from front-side, while periodically flipping a few modules to test backside as well
- Flasher implications: Make sure your flasher has:
  - Sufficient long pulse (>150ms) + Sufficient wide spectrum (>99% SPC) + Large area uniformity + Ge high irradicance (>1300W/m2) + Long term stability

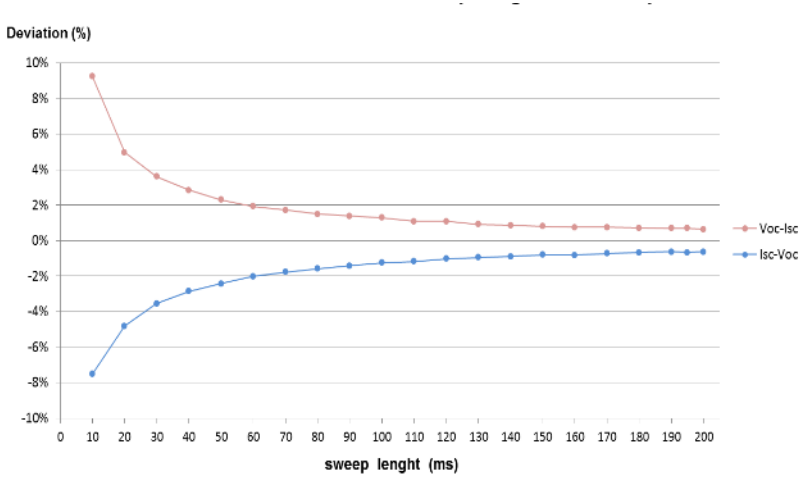
Understanding Bifacial Performance: Bifaciality Factors vs. Reality for p-type PERC Modules

- **50% of manufacturers did not list bifaciality factors on datasheets**
- Datasheet values are often inaccurate
- Measured bifaciality factors ranged from 59.5% to 83.6%
  - Median of 69.6%
- Datasheet bifaciality factors ranged from 65.7% to 75.3%
- 20% of BOMs had a measured bifaciality >5% lower than stated
  - Worst performer is 15% lower

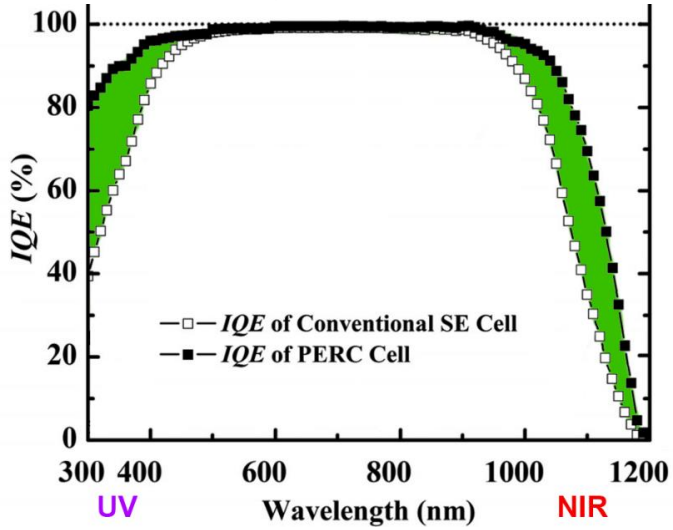


In summary, to test bifacial PV modules, make sure you have a flasher that has:

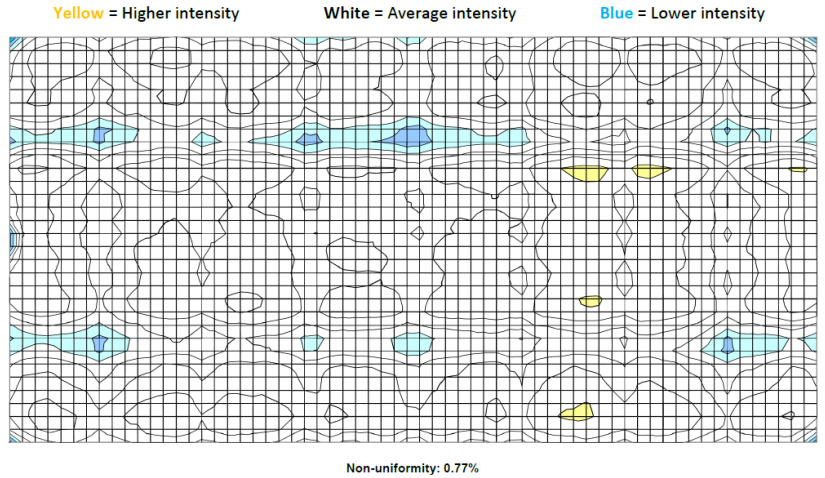
Stable long pulse (>150ms)



True wide spectrum (>99% SPC)



Large area low non-uniformity (<1%)



+ Ge high irradicance (>1300W/m2) + Long term stability

Ability to **always** trust your data ***also for Bi-facial modules***

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Source: LPVO website

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