PVinMotion 2023

I-V Curve Simulation of Curved PV Modules for VIPV under Various Irradiation Conditions

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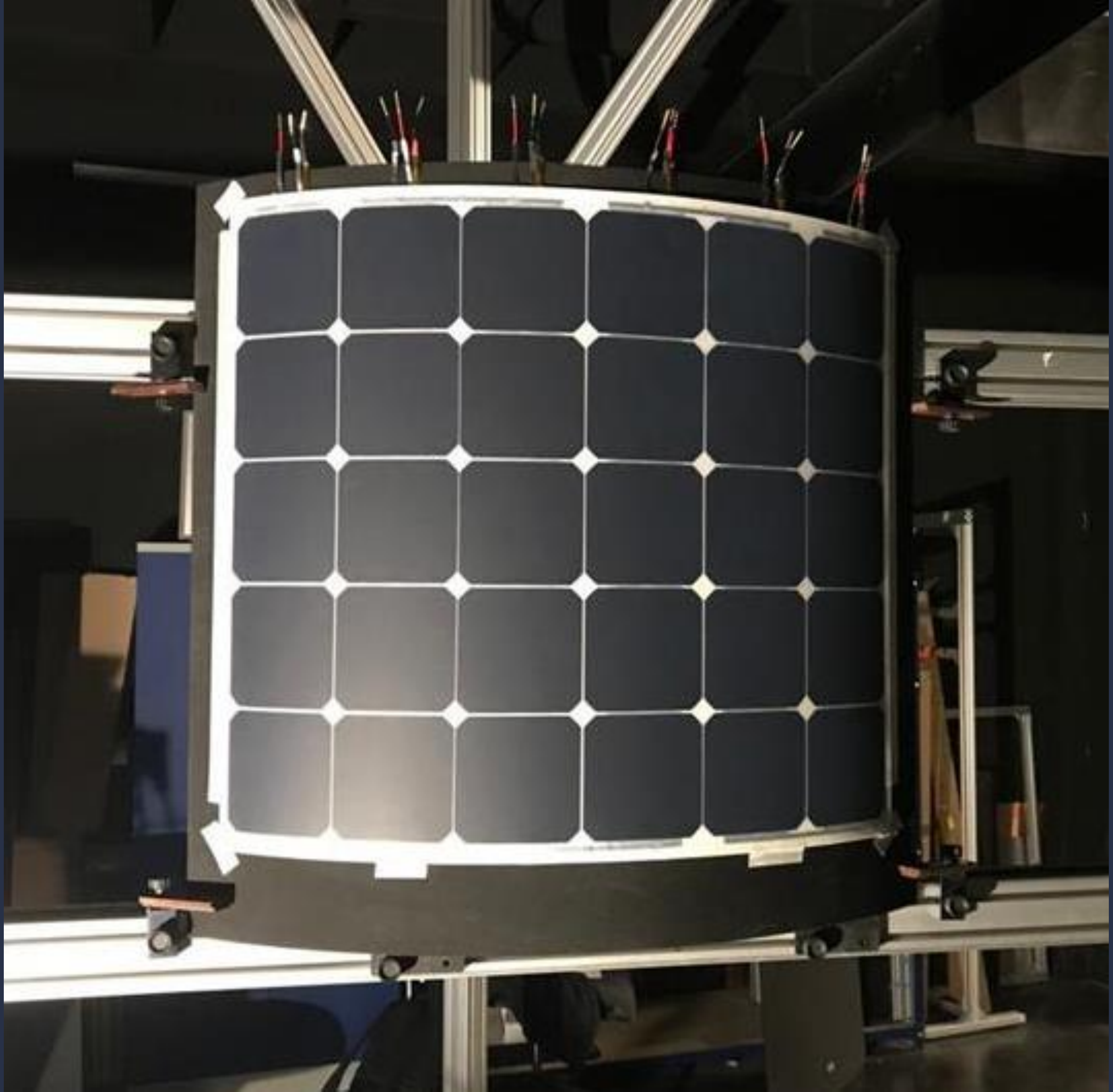
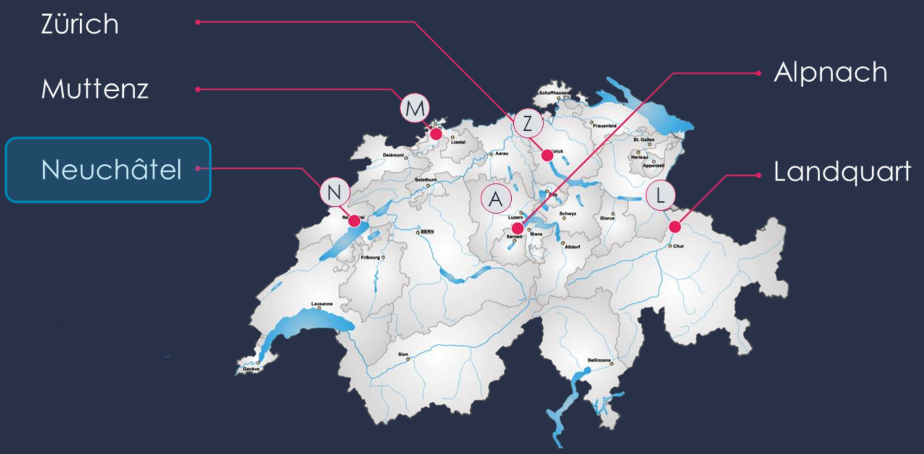


Agenda

- Introduction
- Simulation Tool: HETSIM
  - Simulation Model
- Experimental Setup
- Results
  - Impact of various parameters
- Conclusion & Next Steps

CSEM: **Innovation engine** for the industry



Pasan

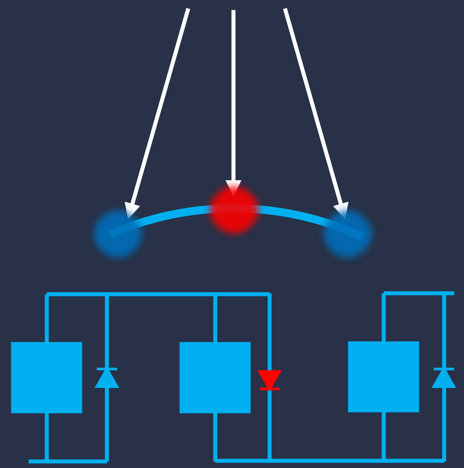
Swiss private non-profit **Research & Technology Organization (RTO)**

Development and transfer of world-class technologies **to the industrial sector**

World leader in solar panels **metrology**

Participate in project development

Implications: Curved modules



- Curvature has a great impact on performances

- Energy Yield (EY) estimations complex
- EY prediction important → range increase for VIPV !

Problematic exposition

- Can a **reproducible methodology** to flash curved modules be developed ?
    - Can we extract enough information to **precisely estimate the Energy Yield** of a curved module ?

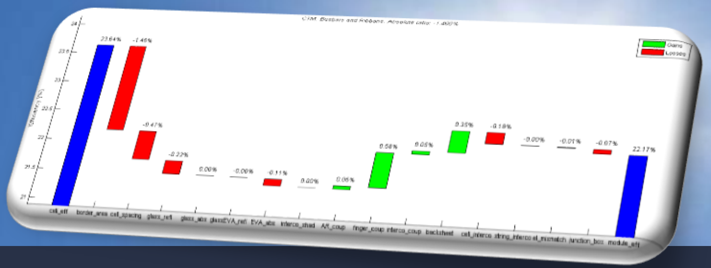
Problematic exposition

- Can a **reproducible methodology** to flash curved modules be developed ?
    - Can we extract enough information to **precisely estimate the Energy Yield** of a curved module ?

Simulation Tool

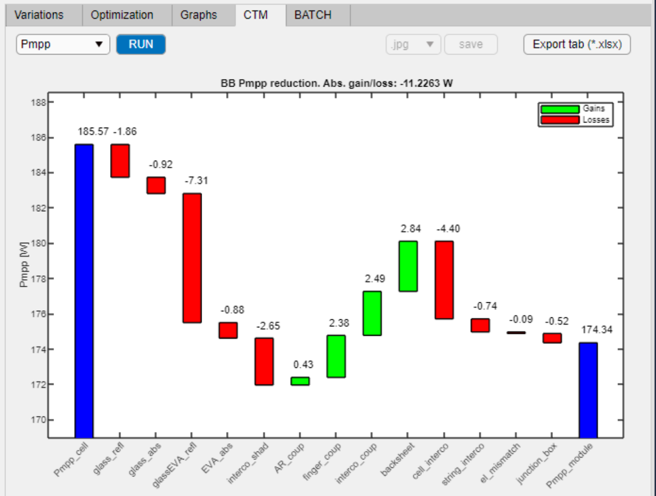
Scope of the project

- Simulation tools for curved modules
  - IV characterization
- Validation through experiments (controlled variation of light source)
  - Tunnel PASAN flashers 8m (and 4.8m)
  - Outdoor
- Characterization method study

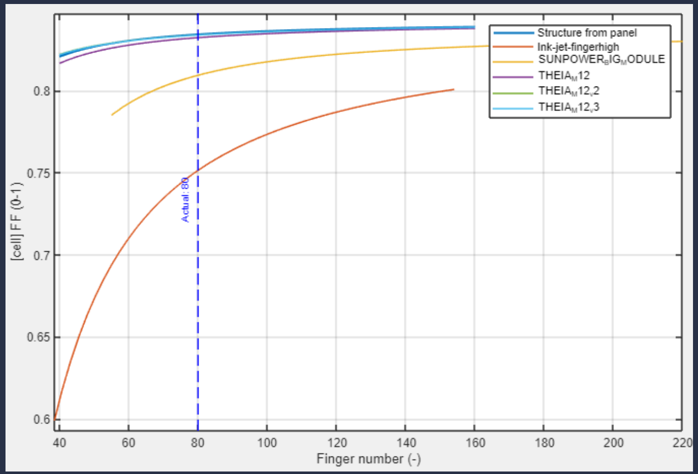


HETSIM Simulation tools: From cell to field…

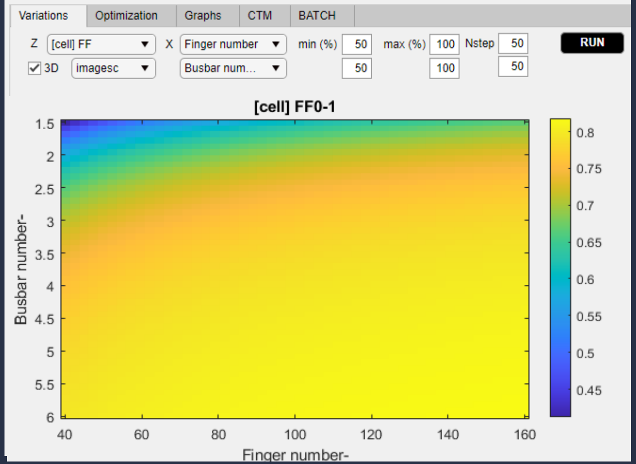
Cell to module analysis



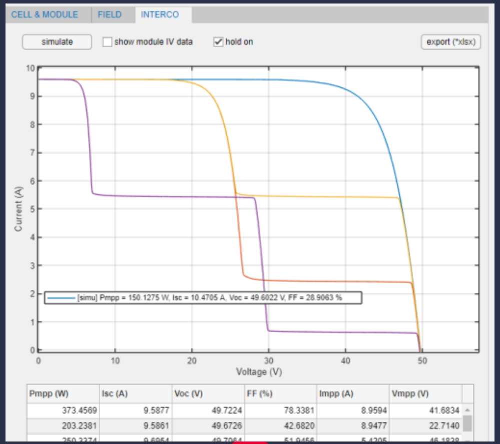
Comparisons of cells and modules BoM



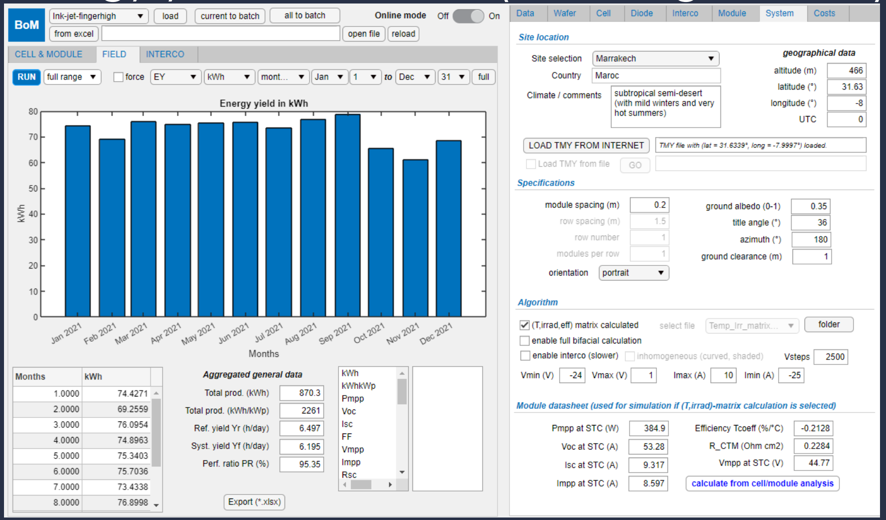
Optimization of cell/module design



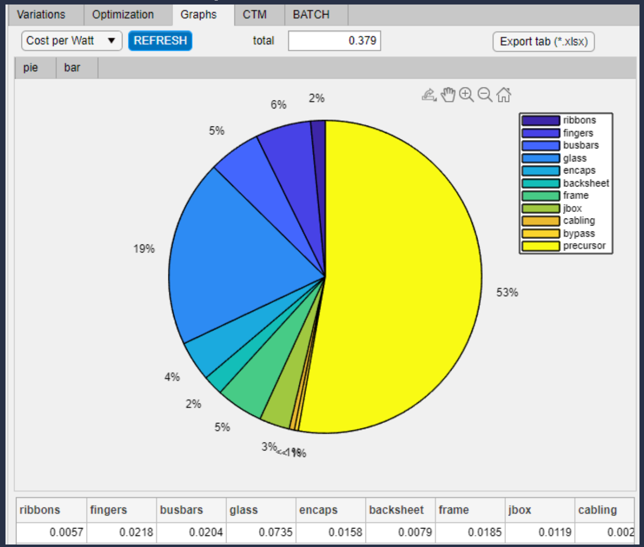
Complex module designs simulation



Energy yield of module (bifi, shingle, etc…)

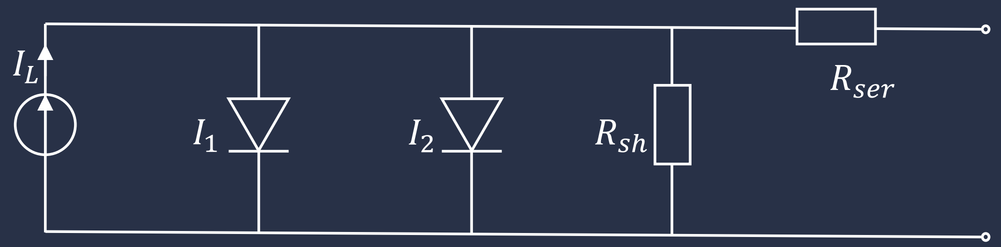


Cost analysis

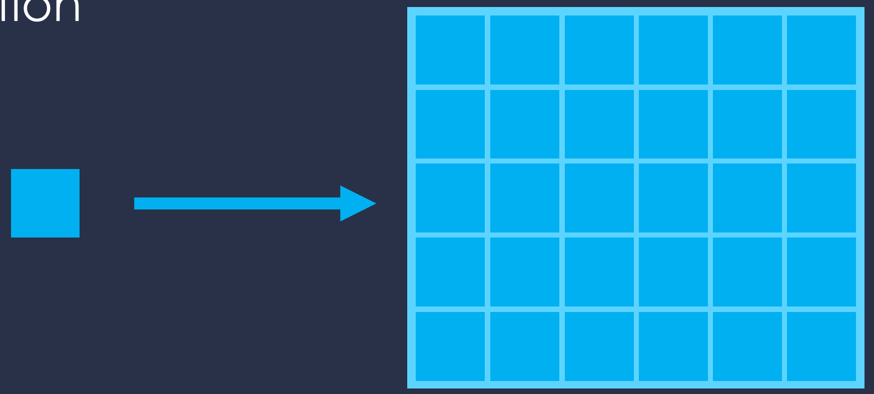


HETSIM

- Tool capable of cell and module level simulations
- Based on the two-diode model



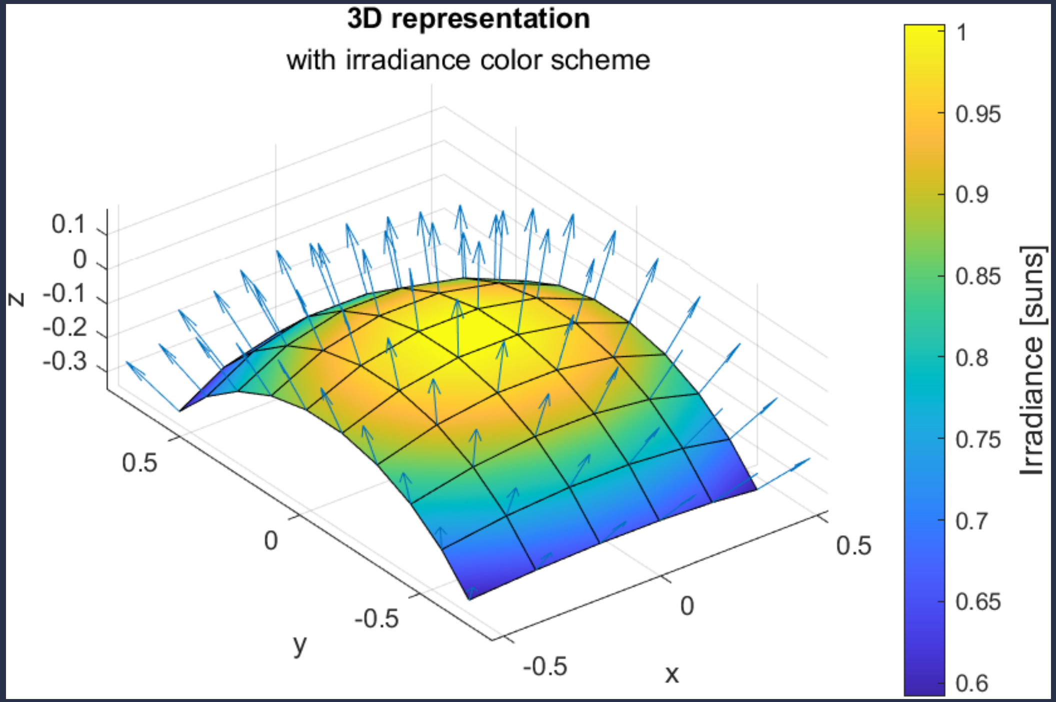
- Extract model electrical parameters from one-cell IV data
  - Simulate any arbitrary module-level configuration



Simulation Model

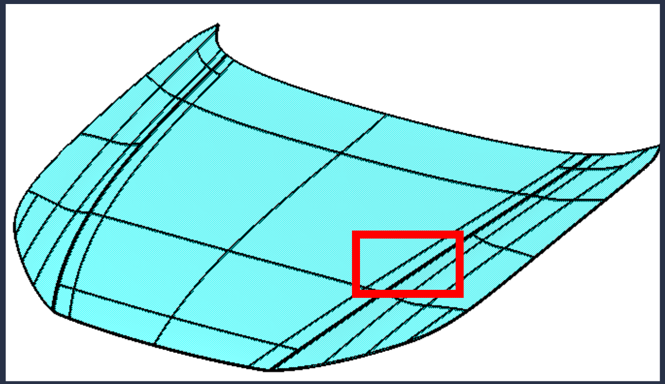
Matrices and vector-based model

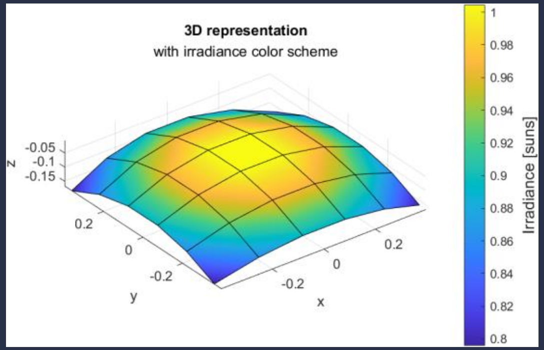
- Arbitrary surface and topology
- Flasher and outdoor simulation

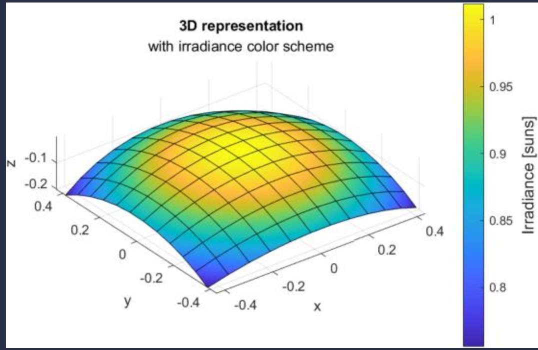


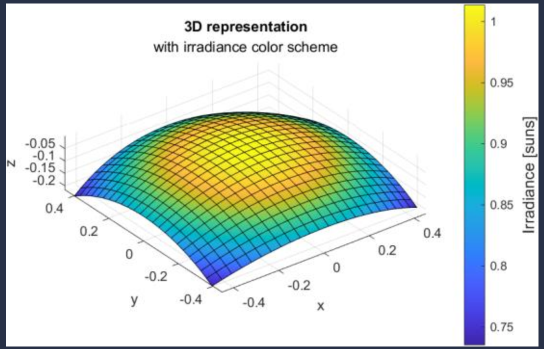
Simulation Model

- **Matrices and vector-based model**
  - Arbitrary surface and topology
  - Flasher and outdoor simulation
- Discretization of each cell for **performance vs precision** study









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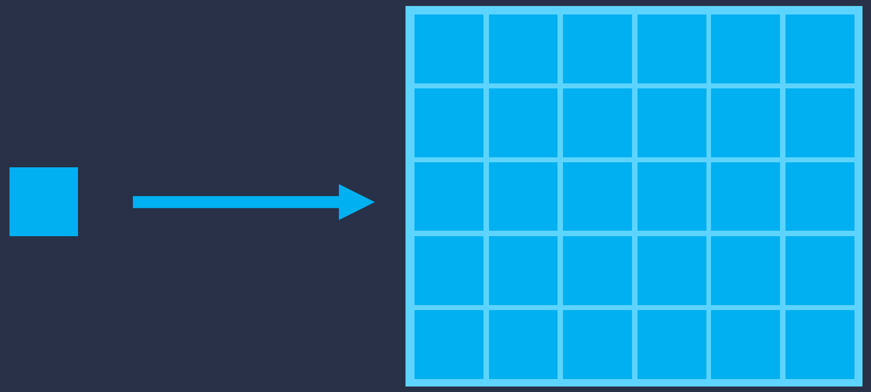
Simulation Model

- **Matrices and vector-based model**
  - Arbitrary surface and topology
  - Flasher and outdoor simulation
- **Discretization of each cell for performance vs precision study**
- **Cell to Module** (CTM) simulation, **Internal Angle Modifier** (IAM), Temperature, etc.



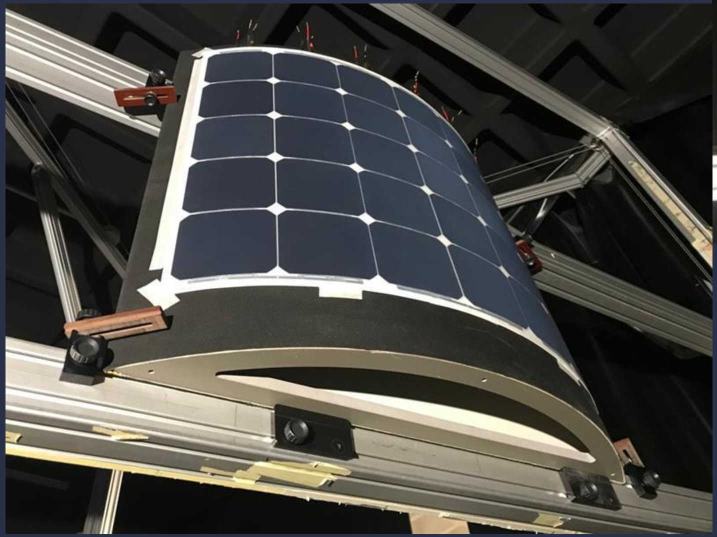
Experimental setup

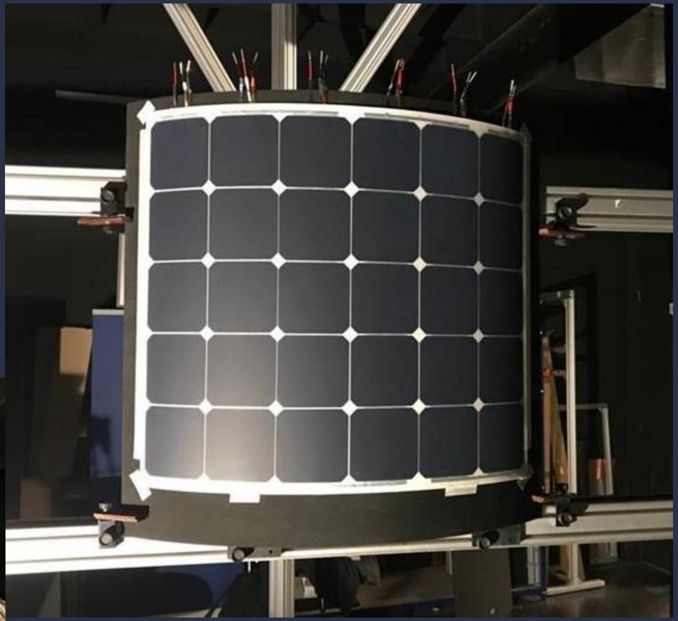
Flexible module of 6 strings of 5 cells

$$P_{mpp,string} = 15.33[W], \qquad I_{SC,string} = 6\ [A],$$
$$V_{OC,string} = 3.4\ [V]$$

Configurable Key parameters:

- Curvature
- Topology
- Bypass diodes

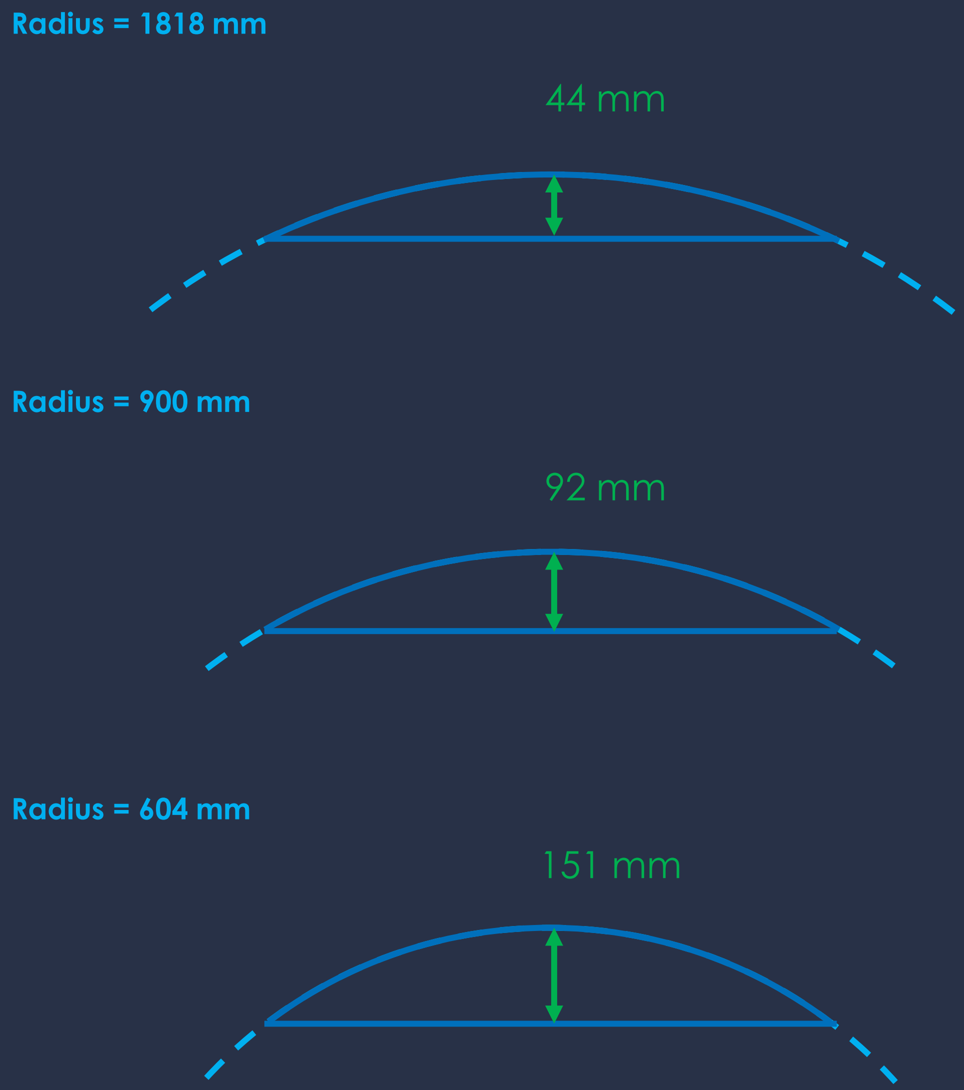




Experimental setup

Validate the simulation model by verifying:

- Impact of **curvature**



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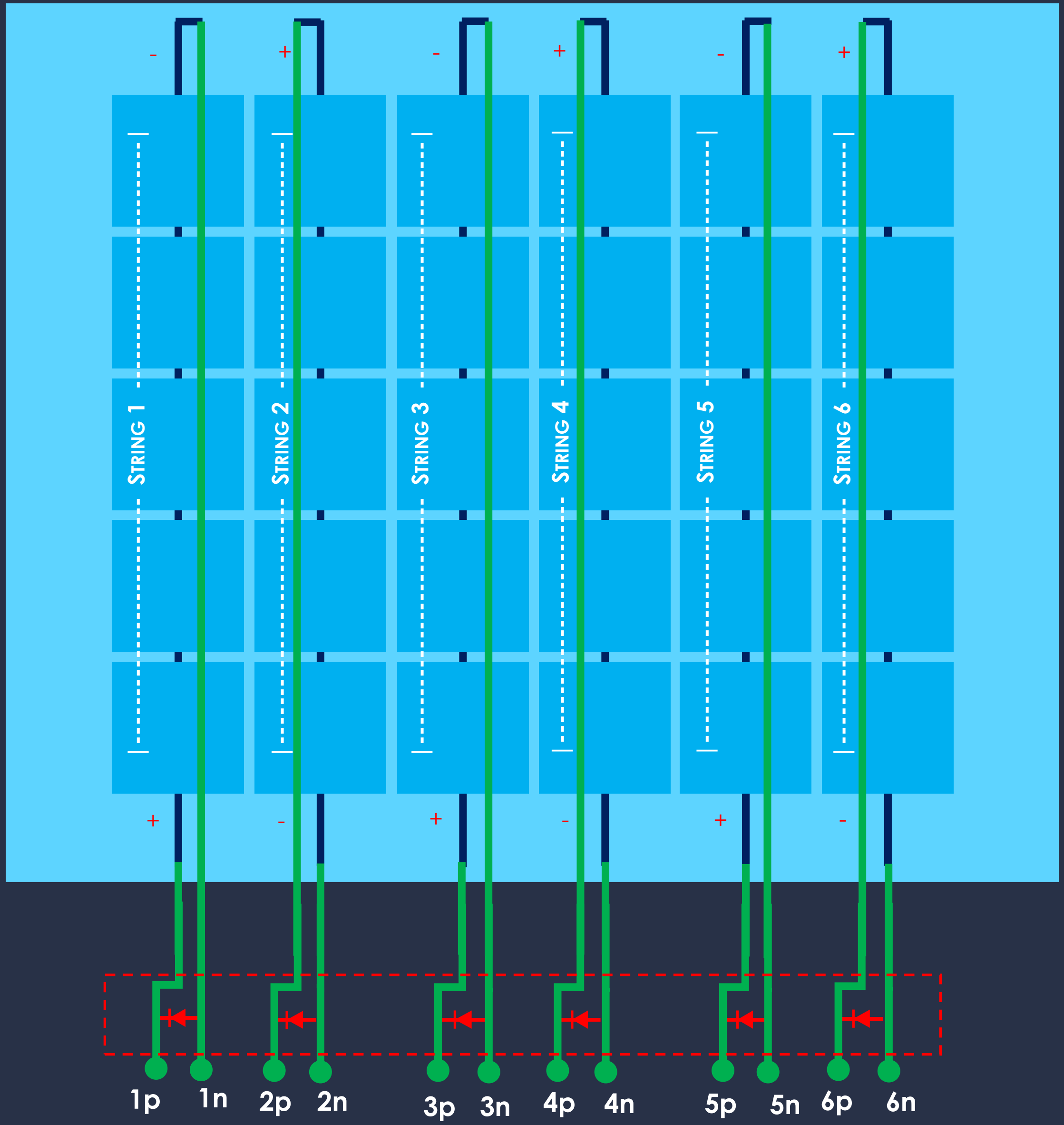
Experimental setup

Validate the simulation model by verifying:

- Impact of curvature
- Impact of **bypass diodes**



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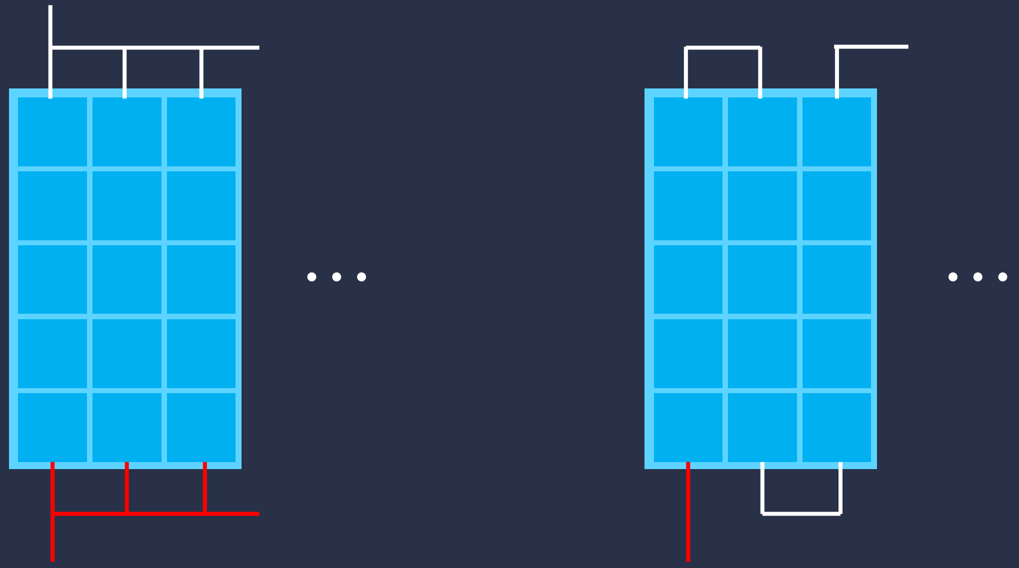
Experimental setup

Validate the simulation model by verifying:

- Impact of curvature
- Impact of bypass diodes
- Impact of **topology**



Experimental setup

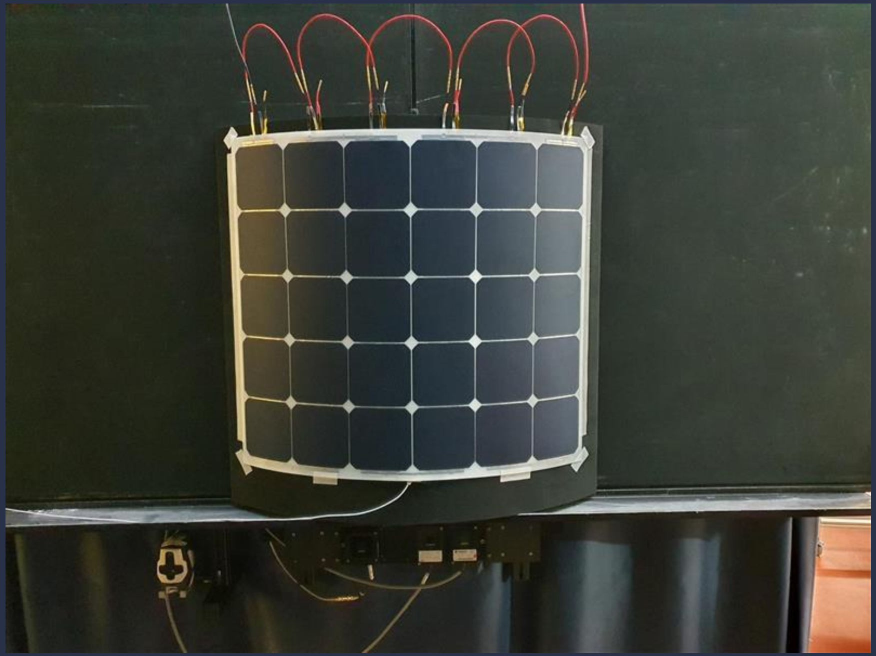
Validate the simulation model by verifying:

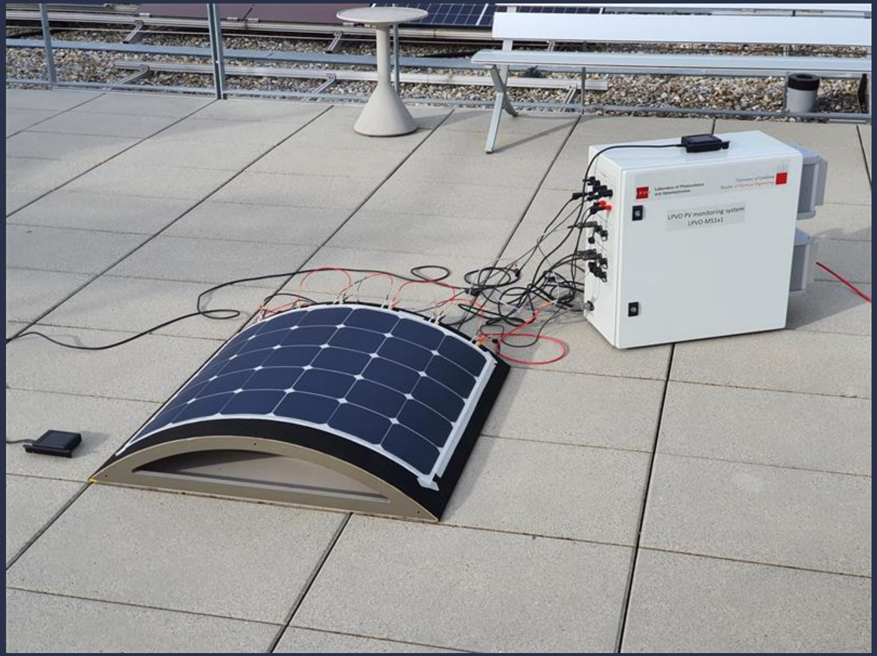
- Impact of curvature
- Impact of bypass diodes
- Impact of topology
- Impact of different **light sources**

Experimental setup

Validate the simulation model by verifying:

- Impact of different **light sources**





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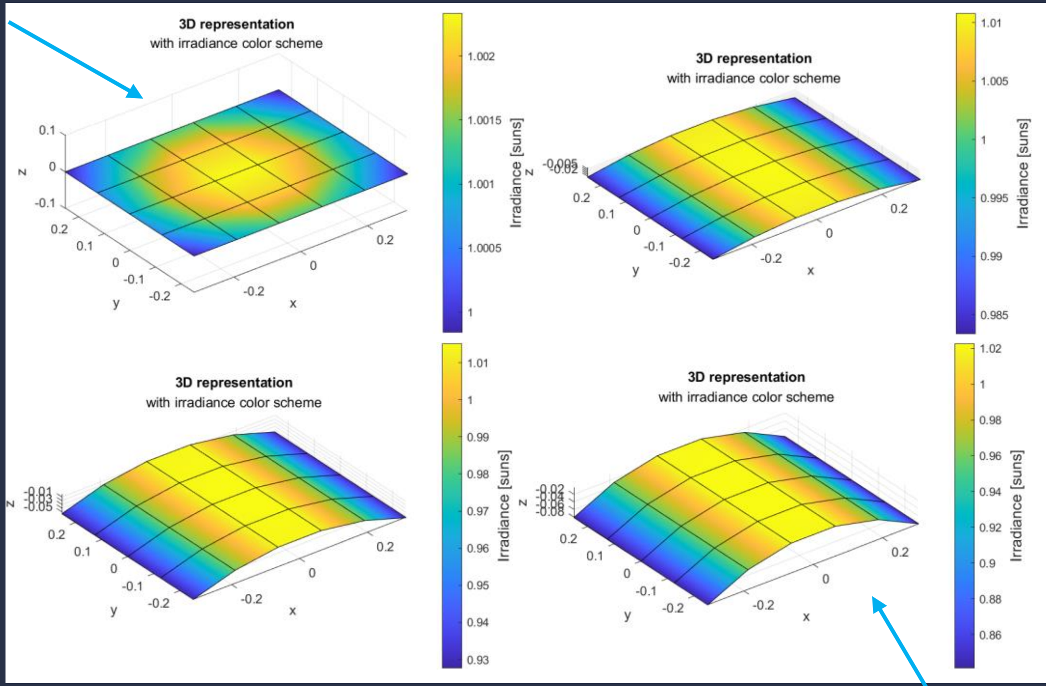
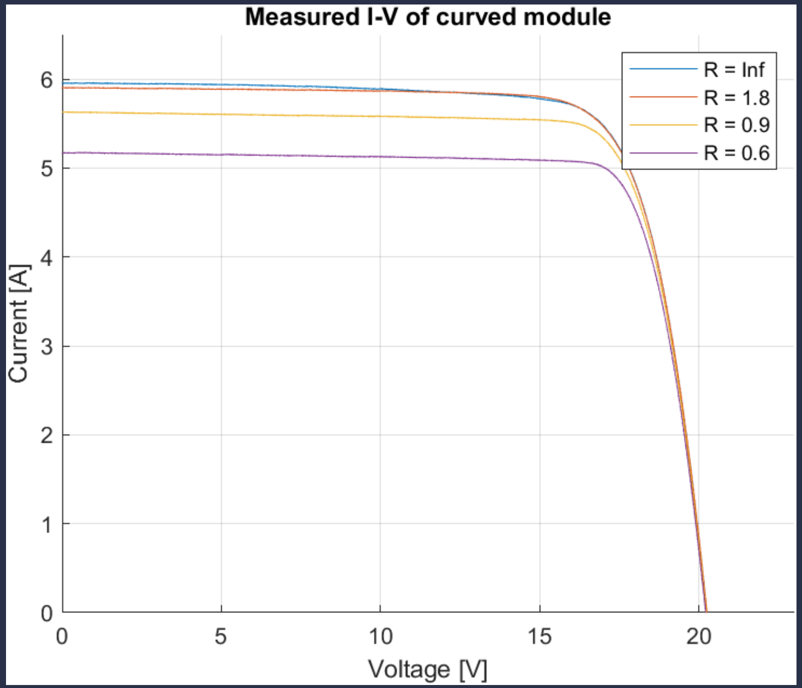
Curvature Impact – Measurements

- Without bypass diodes:

$\Delta Irrad \cong 0.2\%$





$\Delta Irrad \cong 16\%$

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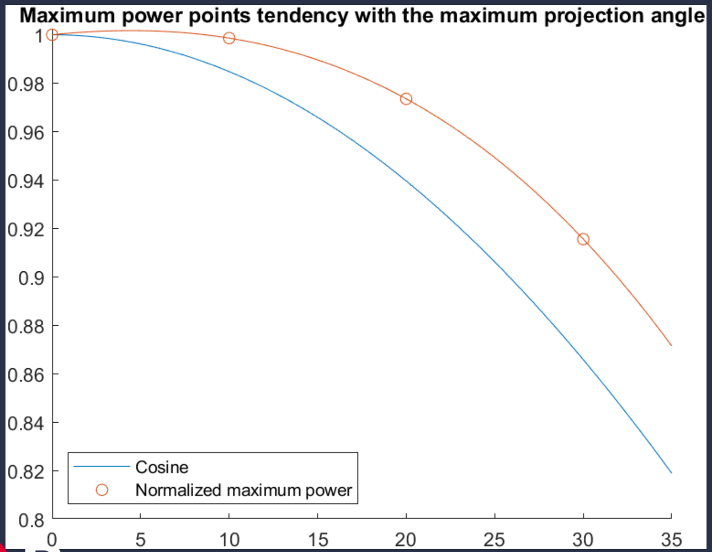
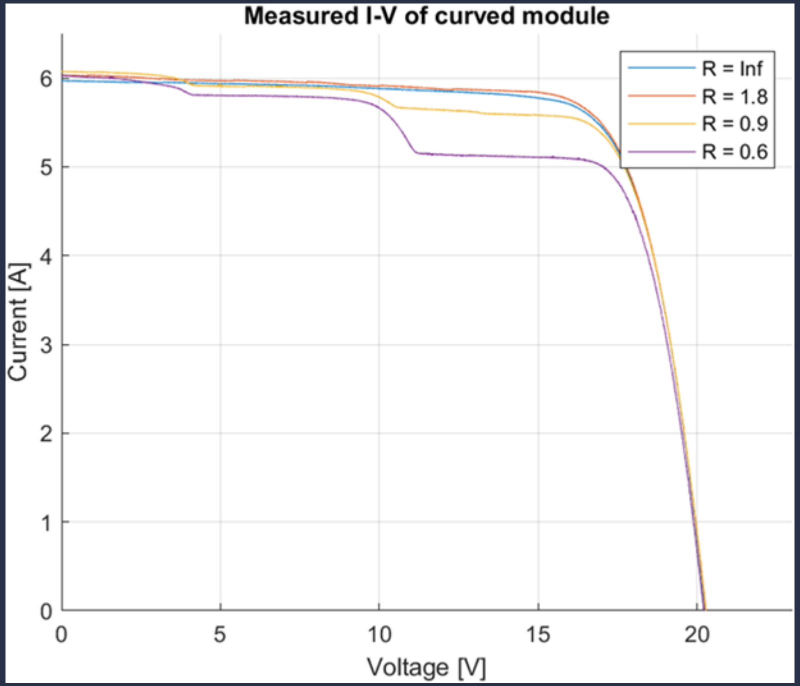
Curvature Impact – Measurements

- With bypass diodes
- Interesting maximum power trend
  - The difference might come from the nonhomogeneous irradiance





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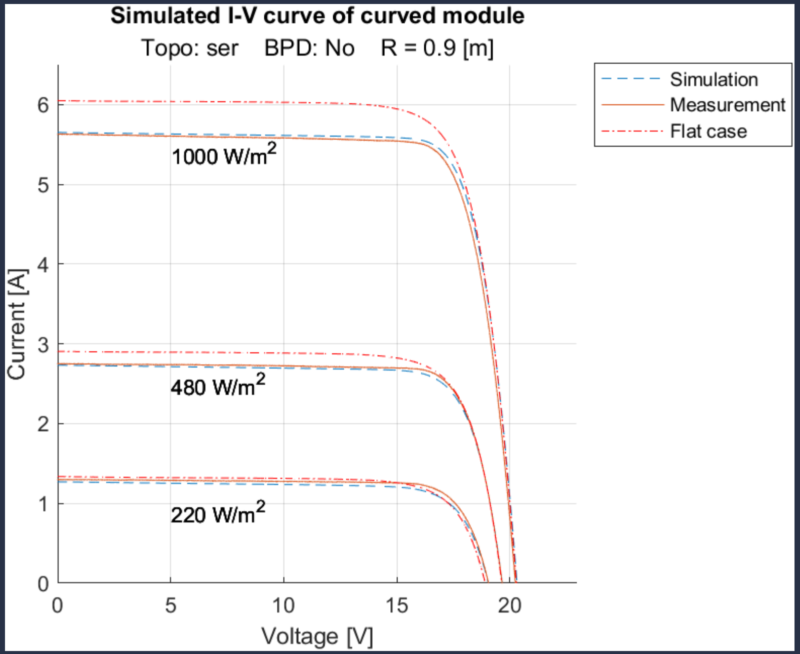
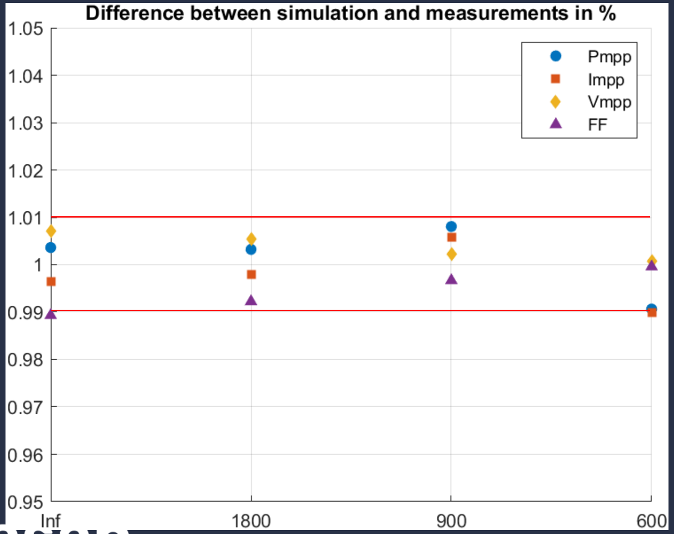
Curvature Impact – Simulation

- Accurate simulations without bypass diodes
- Manage to reach a **<1% error on the P_{MPP} estimation**





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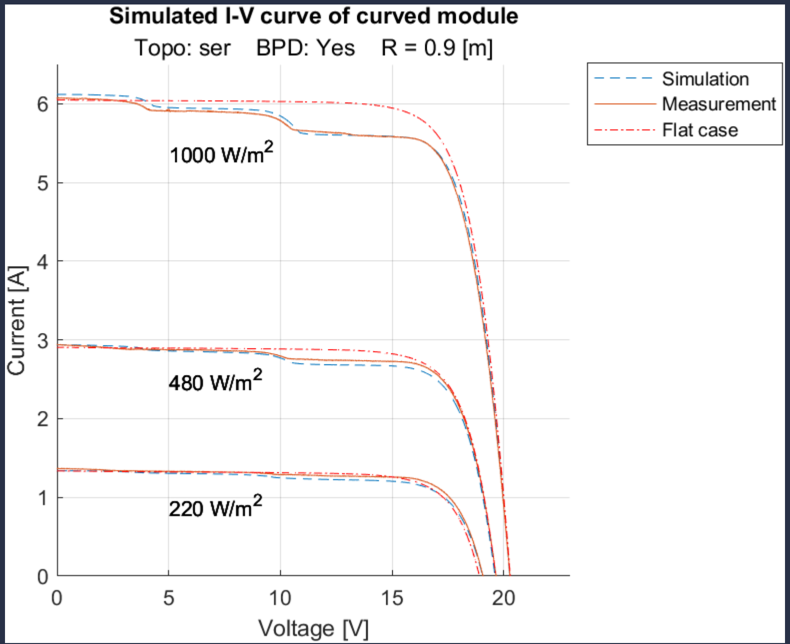
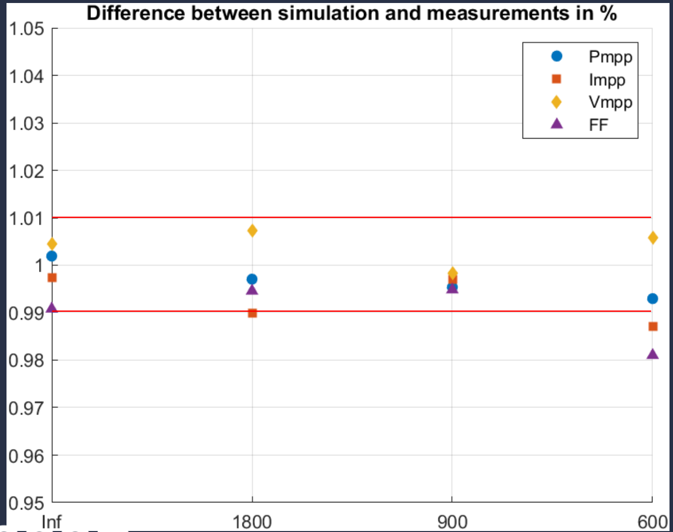
Curvature Impact – Simulation

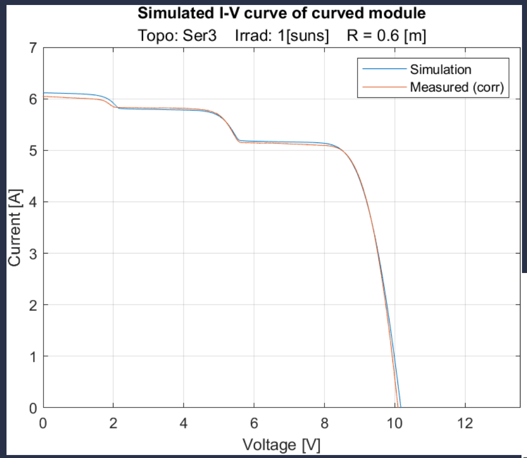
- Addition of bypass diodes create this "stairs" effect due to current mismatch
  - Modelled using their Spice model
- Simulations still within the **<1% error on the P_{MPP} estimation**

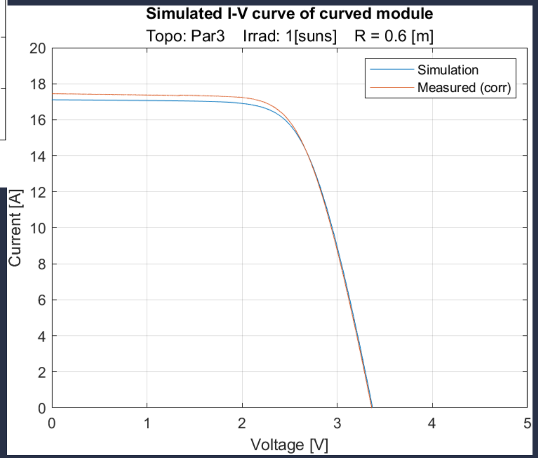




Serial vs Parallel topology – Preliminary results

- Predict Parallel strings behavior
- Comparison made at lower irradiance (220 $[W/m^2]$)





- Preliminary results indicate that parallel interco is better for higher curvature

	Measured $P_{mpp,ser}/P_{mpp,par}$	Simulated $P_{mpp,ser}/P_{mpp,par}$
$R = 1.8\ [m]$	1.0350	1.0114
$R = 0.6\ [m]$	0.9679	0.9816

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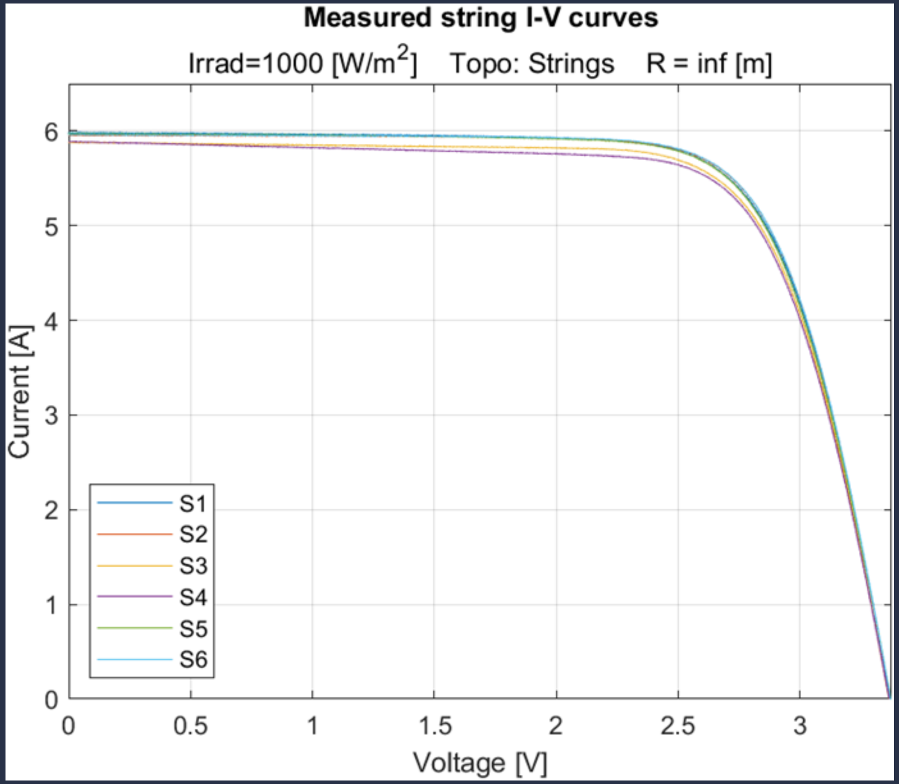
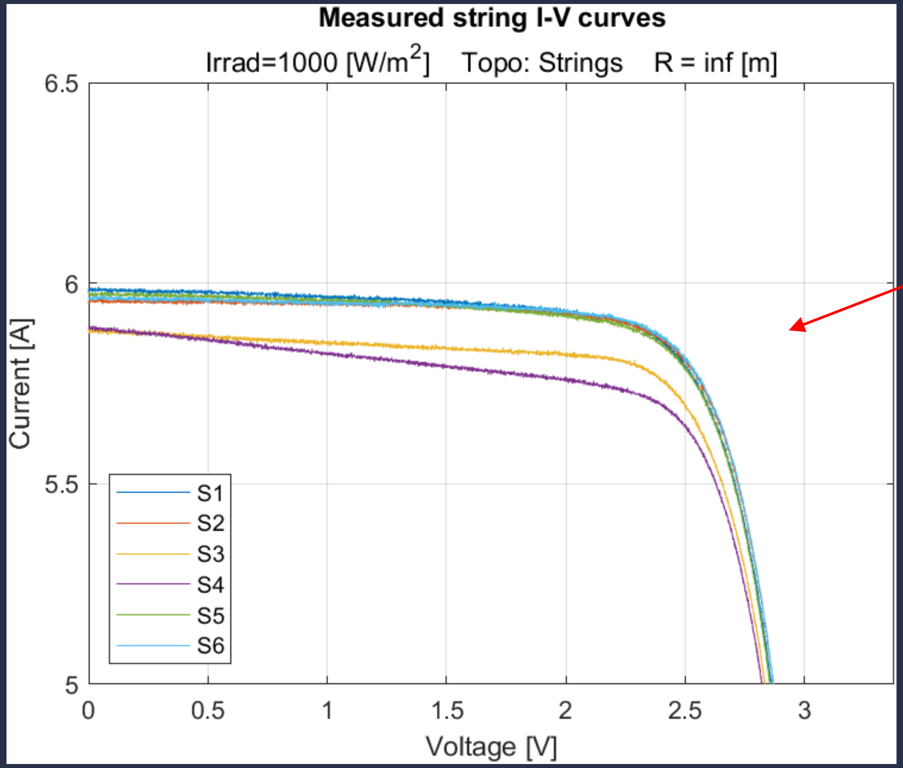
Cell mismatch modelling

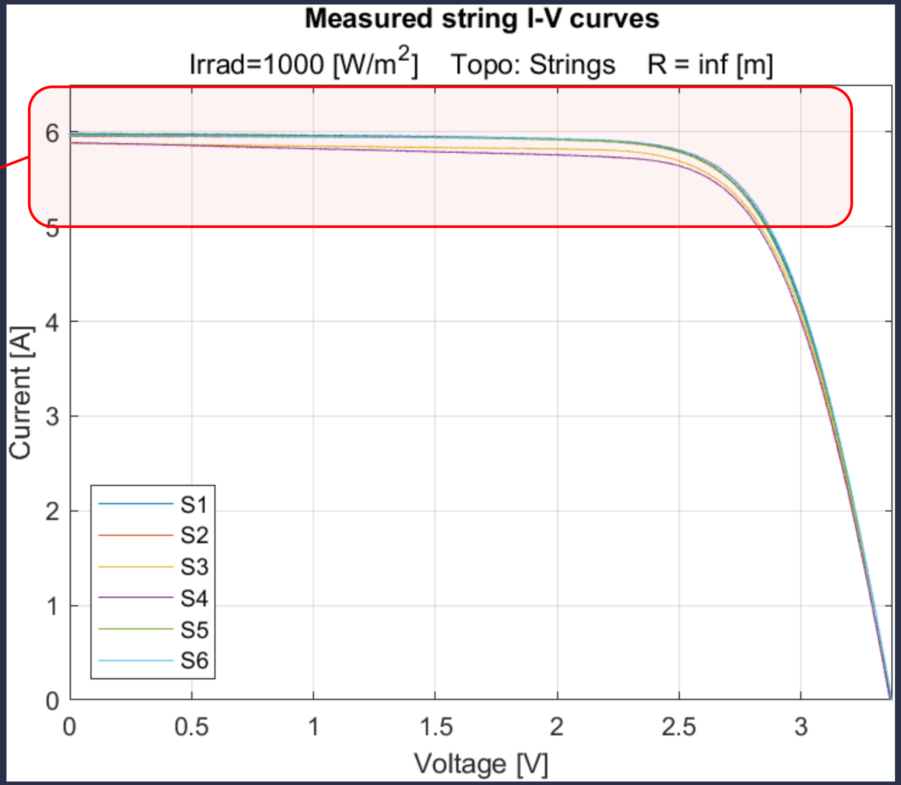
- Mismatched cells → Mismatched strings



Cell mismatch modelling

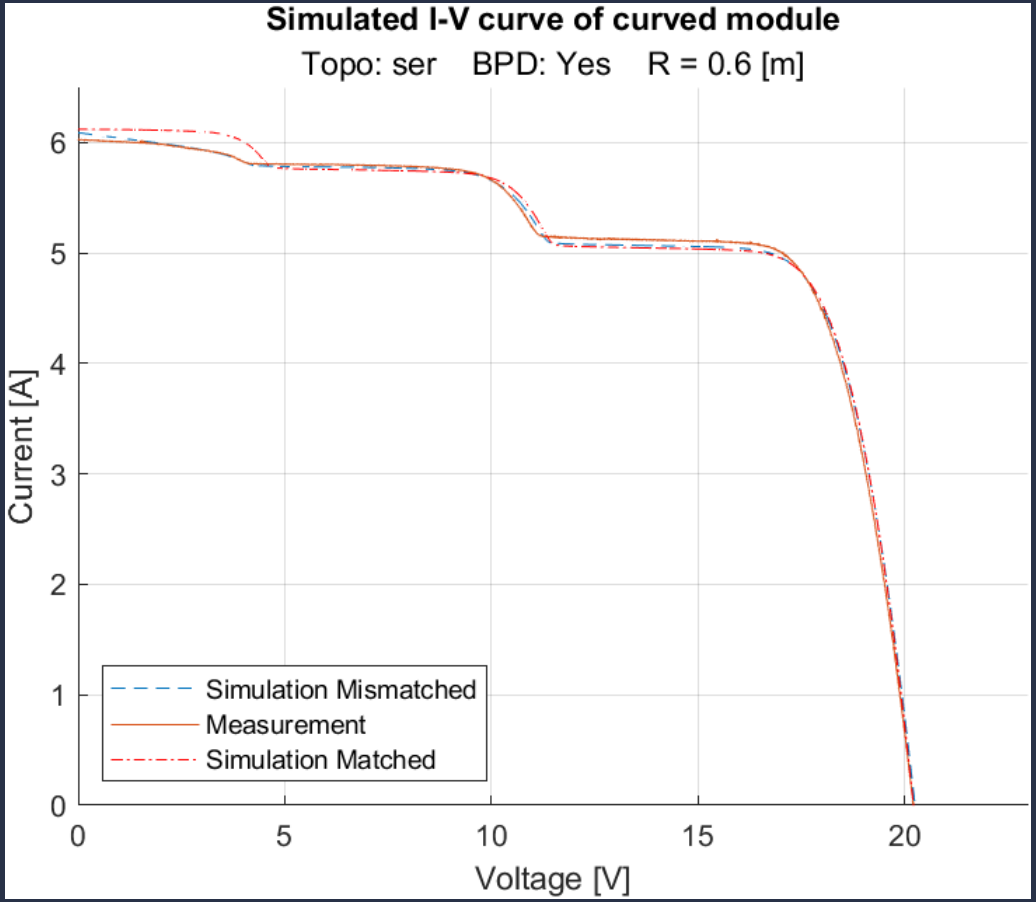
- Mismatched cells → Mismatched strings





Cell mismatch modelling

- Better estimation if needed
  - More precise estimation when performance limited by poor cells



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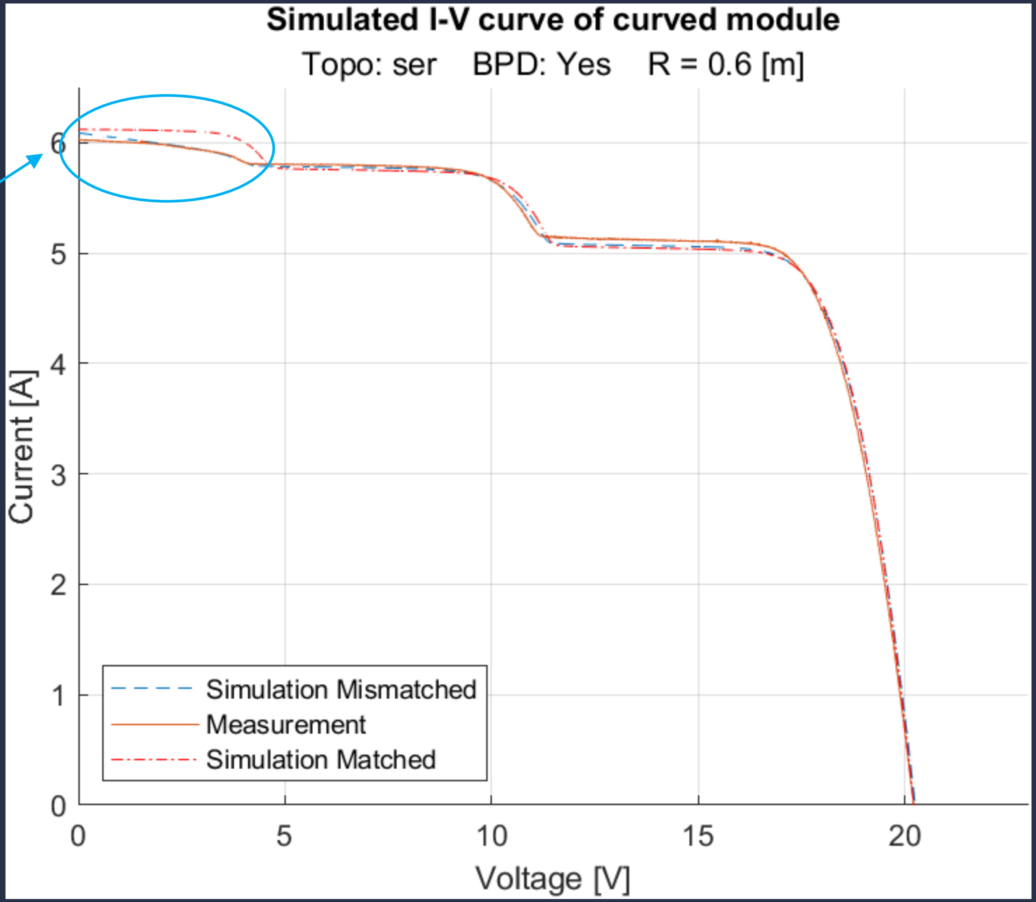
Cell mismatch modelling

- Better estimation if needed
  - More precise estimation when performance limited by poor cells
- Allows for easy **defect/poor performances** detection



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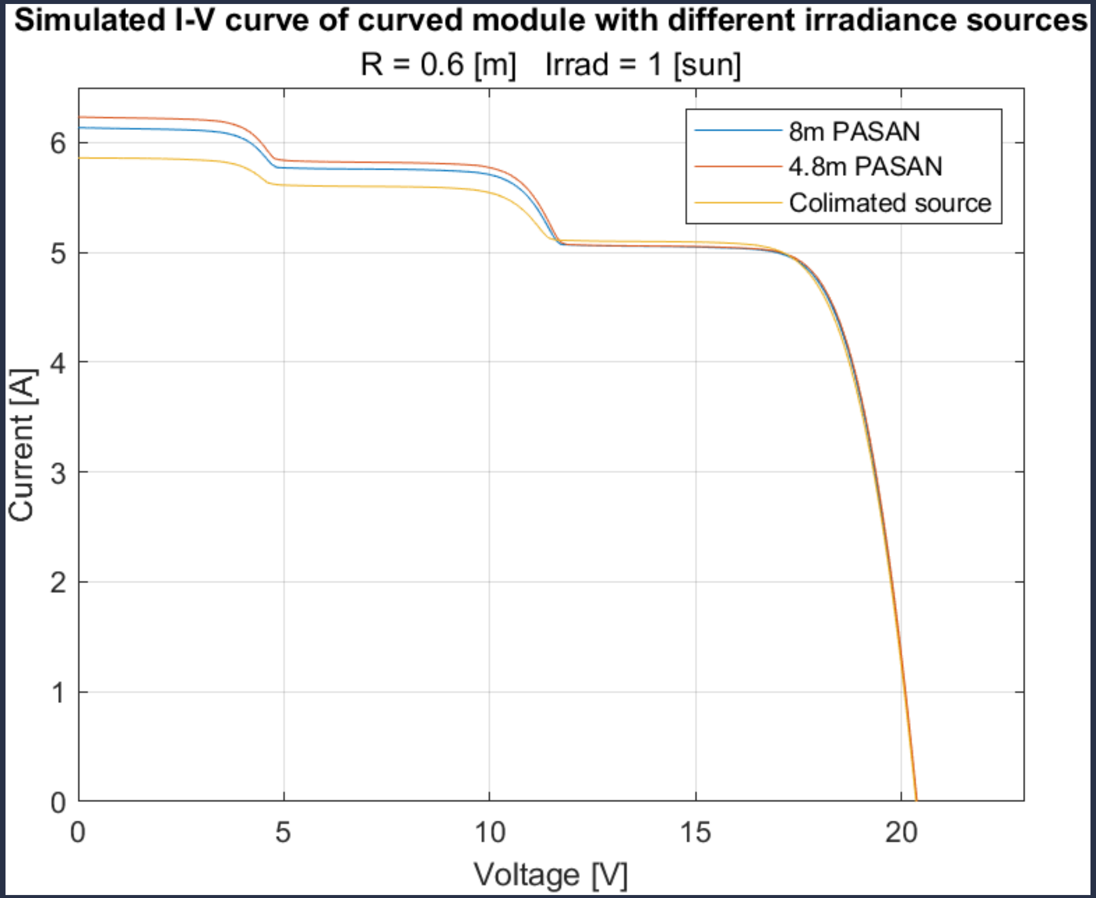
Simulation of different light sources

- Differences between the light source used
- Reference plane on the back of the module



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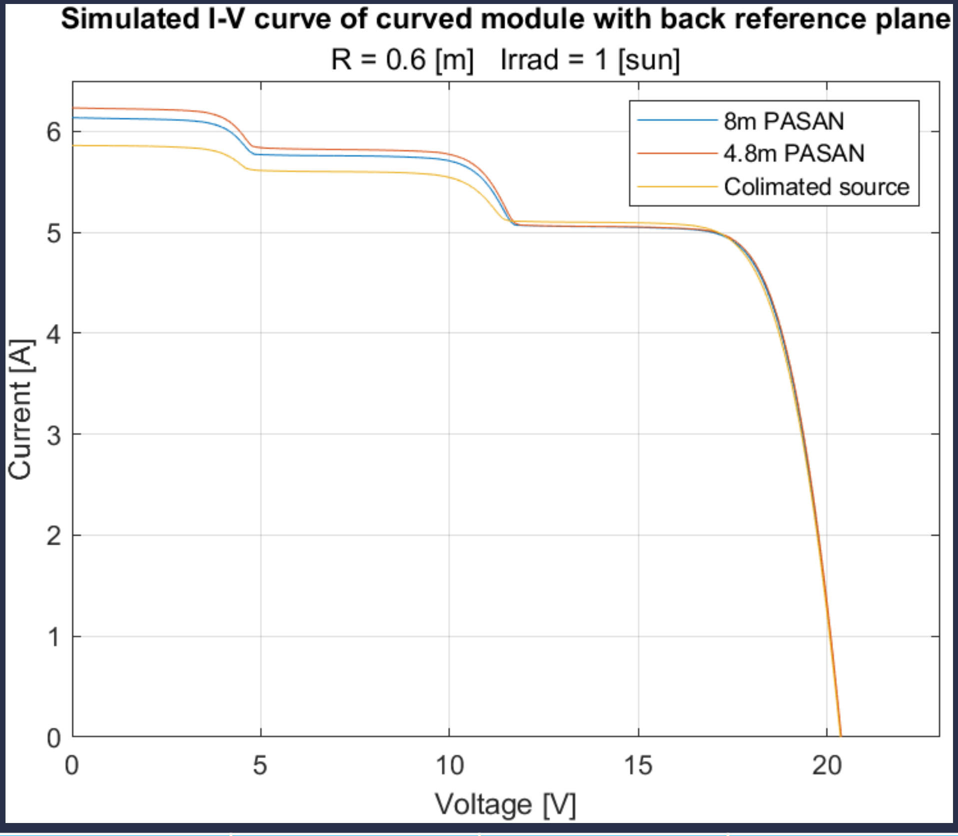
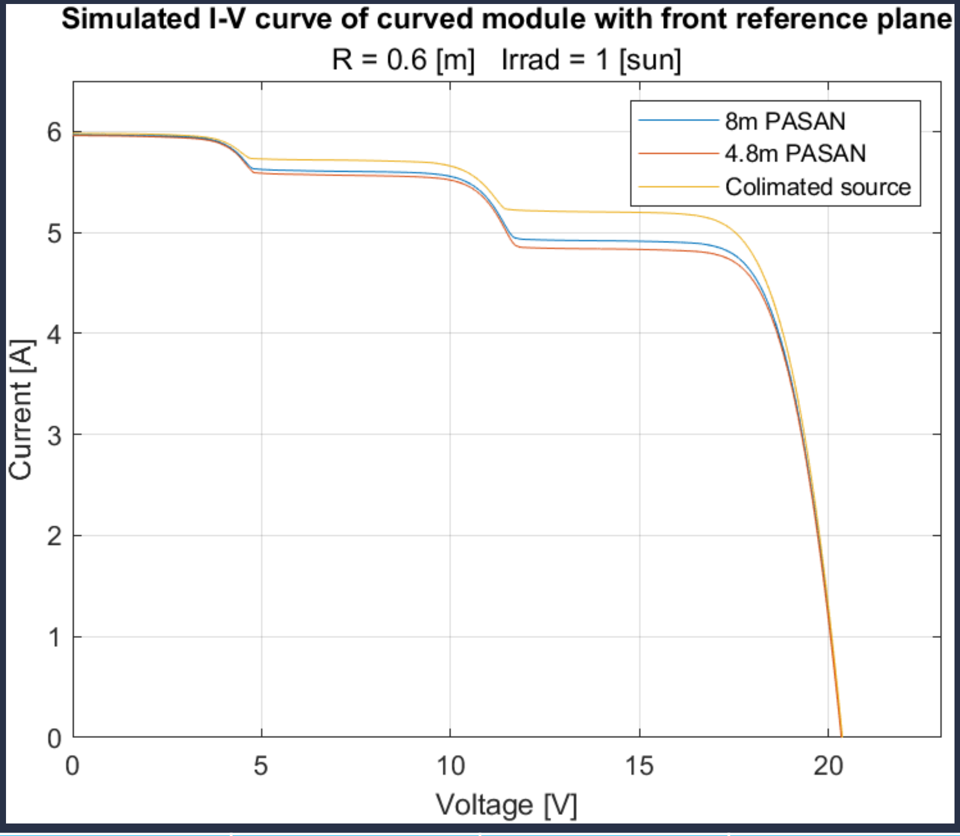
Simulation of different light sources



	4.8m PASAN	8m PASAN	Colimated
P_{MPP}	86.3455 [W]	86.0354 [W]	85.9084 [W]
I_{sc}	6.2330 [A]	6.1352 [A]	5.8606 [A]



	4.8m PASAN	8m PASAN	Colimated
P_{MPP}	83.5301 [W]	84.3302 [W]	87.7207 [W]
I_{sc}	6.0365 [A]	6.0159 [A]	5.9809 [A]

Conclusion

- We built a simultion model for different indoor irradiances conditions
  - Managed to validate the 8m PASAN condition
  - Continuing with other conditions
- We saw how this tool might
  - help us better understand critical factors of indoor measurement of curved modules
  - Complement the indoor flashing environment (poor performance detection, etc.)

Next Steps

- Finish the validation Campaign
  - New modules
  - Indoor measurements on 4.8 flasher
  - Continue collimated/outdoor measurements
- Continue simulation model development
  - Simulations of case-study
- Flashing methodology development

Thank you for listening !

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