Long-term performance and shade detection in building integrated photovoltaic systems

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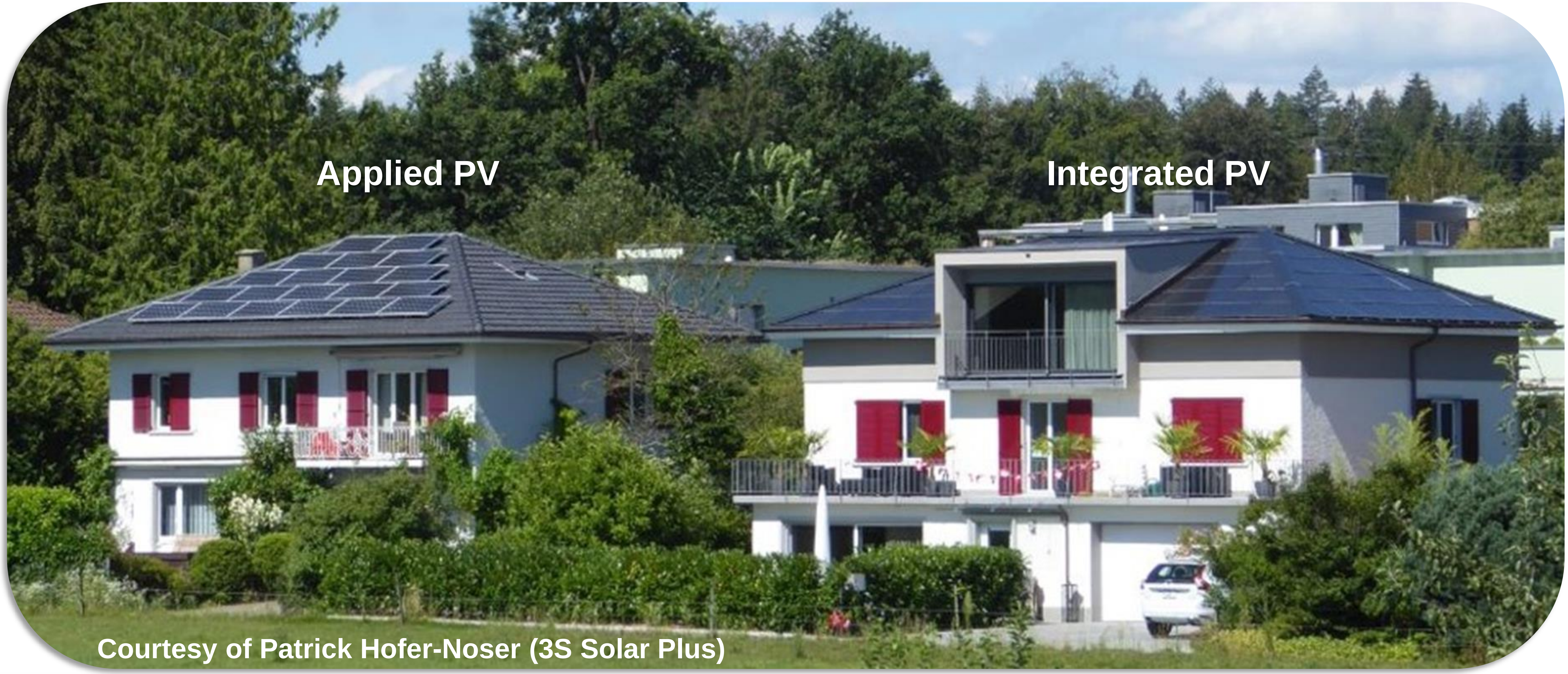
PEARL PV Workshop – 23 to 24 September 2021

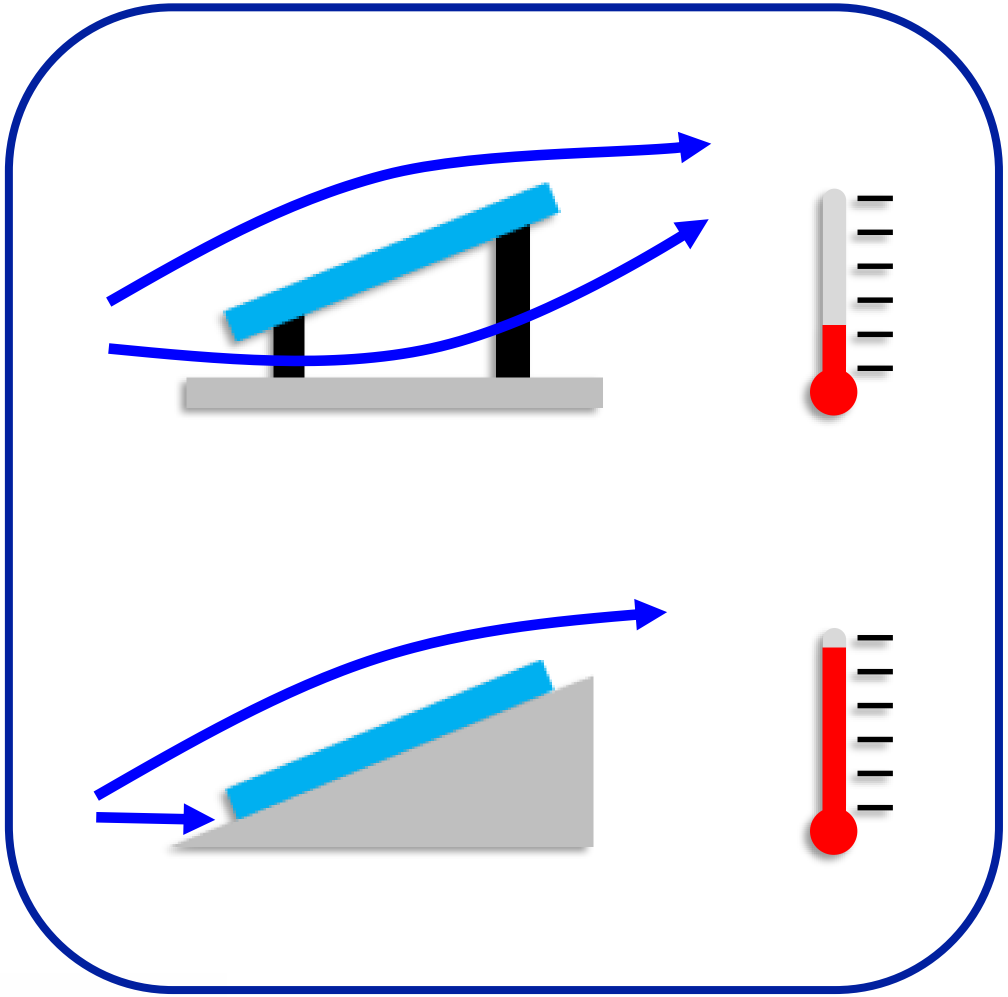
PV-lab IMT NEUCHATEL 3S Solar Plus SUPSI csem EPFL

PV in the built environment

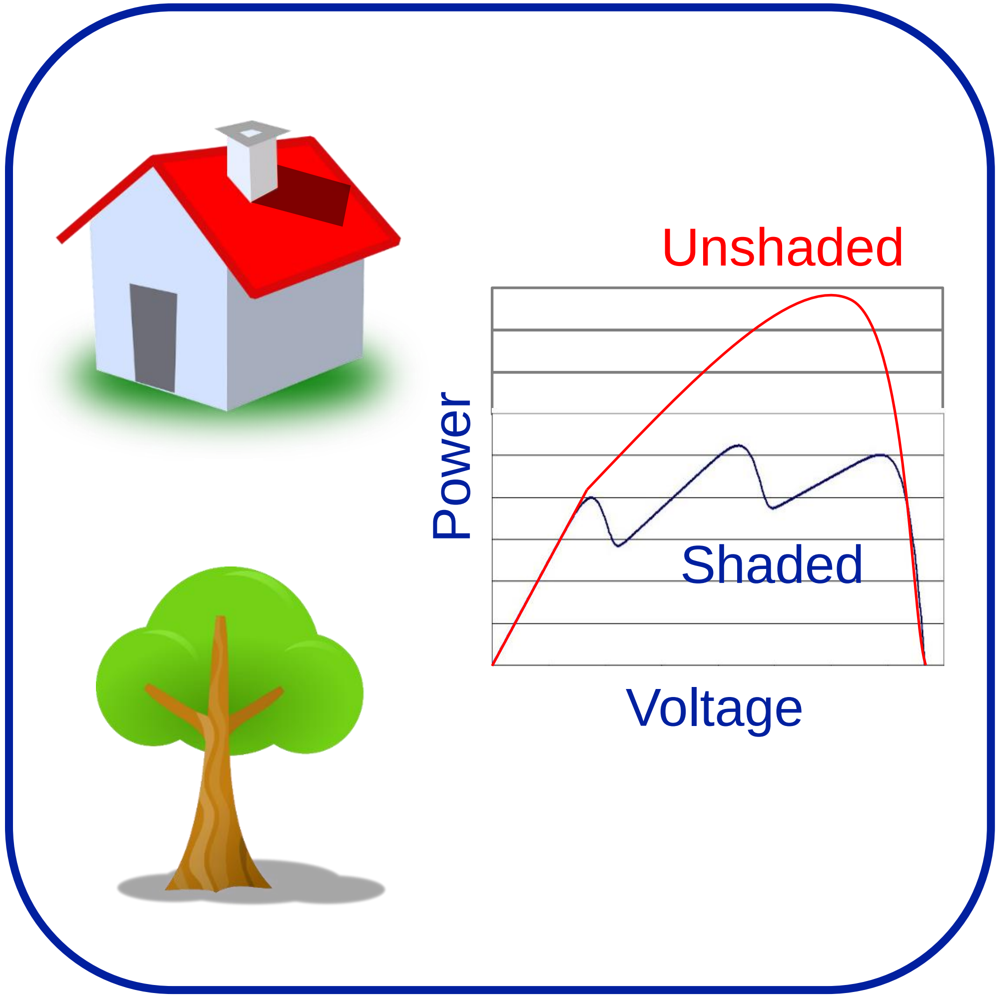


Reliability concerns for BIPV

Operating temperature

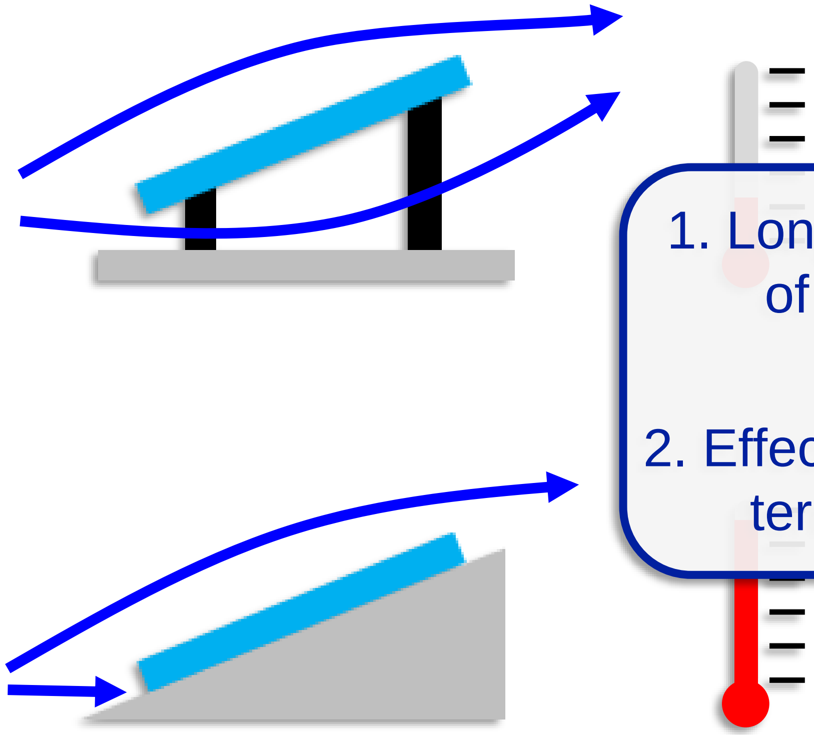


Partial shading

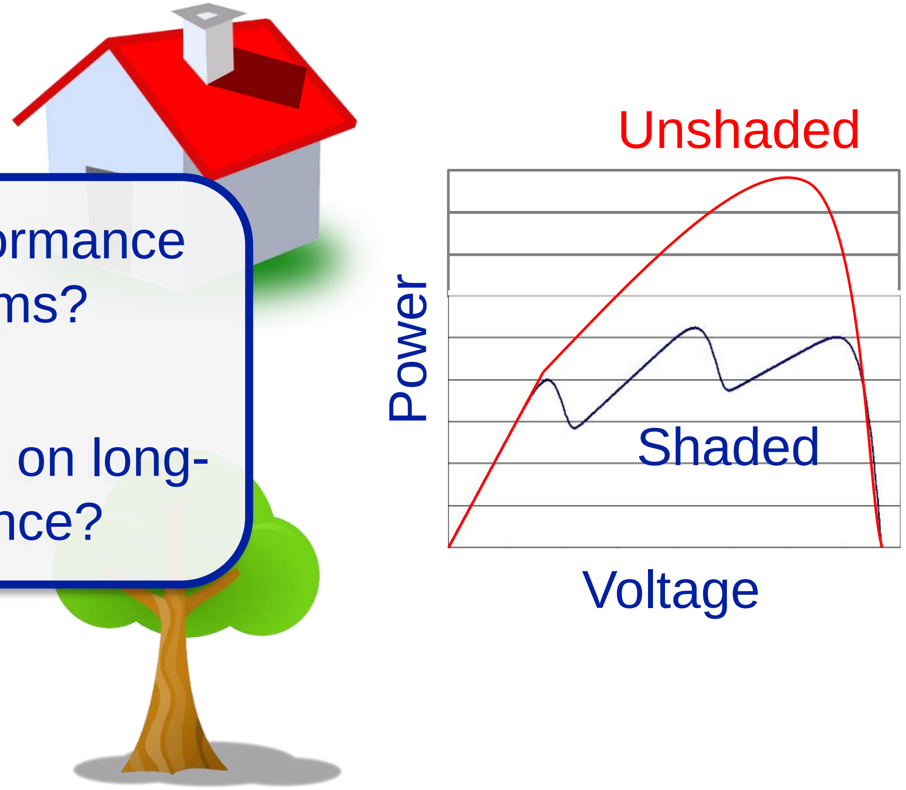


Reliability concerns for BIPV

Operating temperature



Partial shading

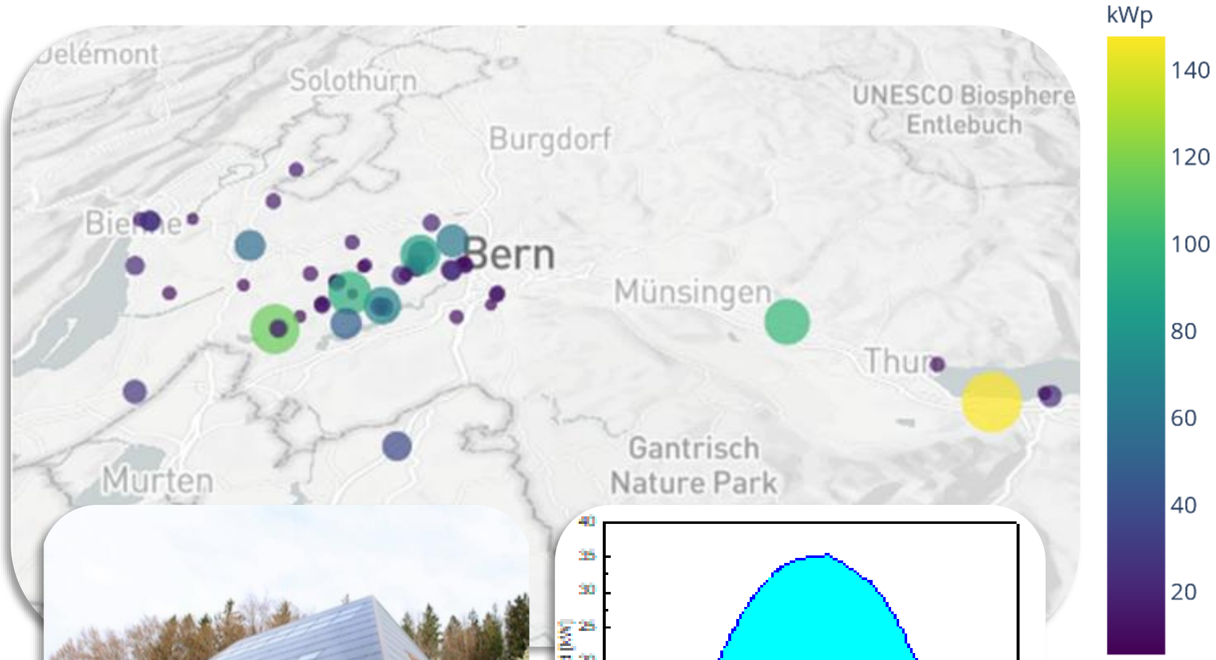


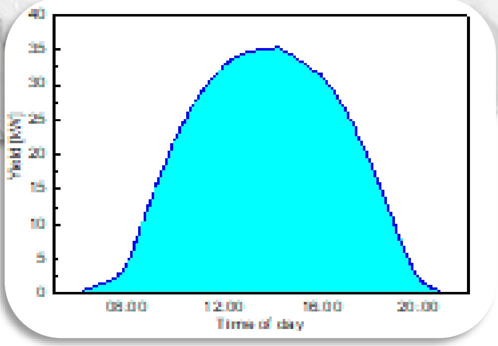
1. Long-term performance of BIPV systems?

2. Effect of shading on long-term performance?

Long-term BIPV system monitoring

55 rooftop BIPV systems (**252 module strings**) in central Switzerland





Characteristics	Median	Low	High
Installation year	**2014**	2010	2015
Capacity [kWp]	**17**	6	148
Tilt [º]	**25**	10	55
Orientation [º]	**186 (S)**	0 (N)	310

Baur AG BAUR Bedachungen / Spenglerei / Solarstrom

3S Solar Plus

MegaSlate II

Performance loss rate analysis

BIPV system data

Baur AG/Solar-Log

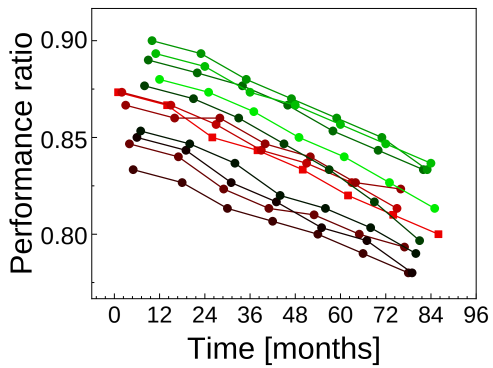
3S Solar Plus

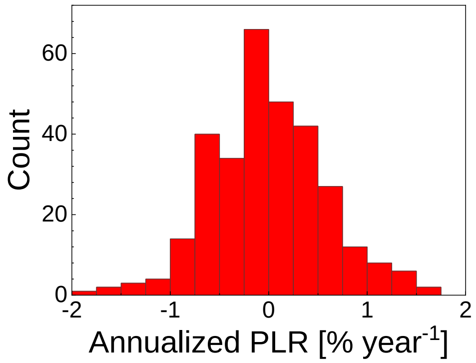
String level DC data
10 min. frequency

Performance ratio calculation

Performance loss rate calculation

RdTools
Python library
(YoY method)





Meteorological data

Solcast

Clear sky

Location specific
10 min. frequency

$$\text{Performance ratio} = \frac{\text{Actual yield [kWh]}}{\text{Reference yield [kWh]}}$$

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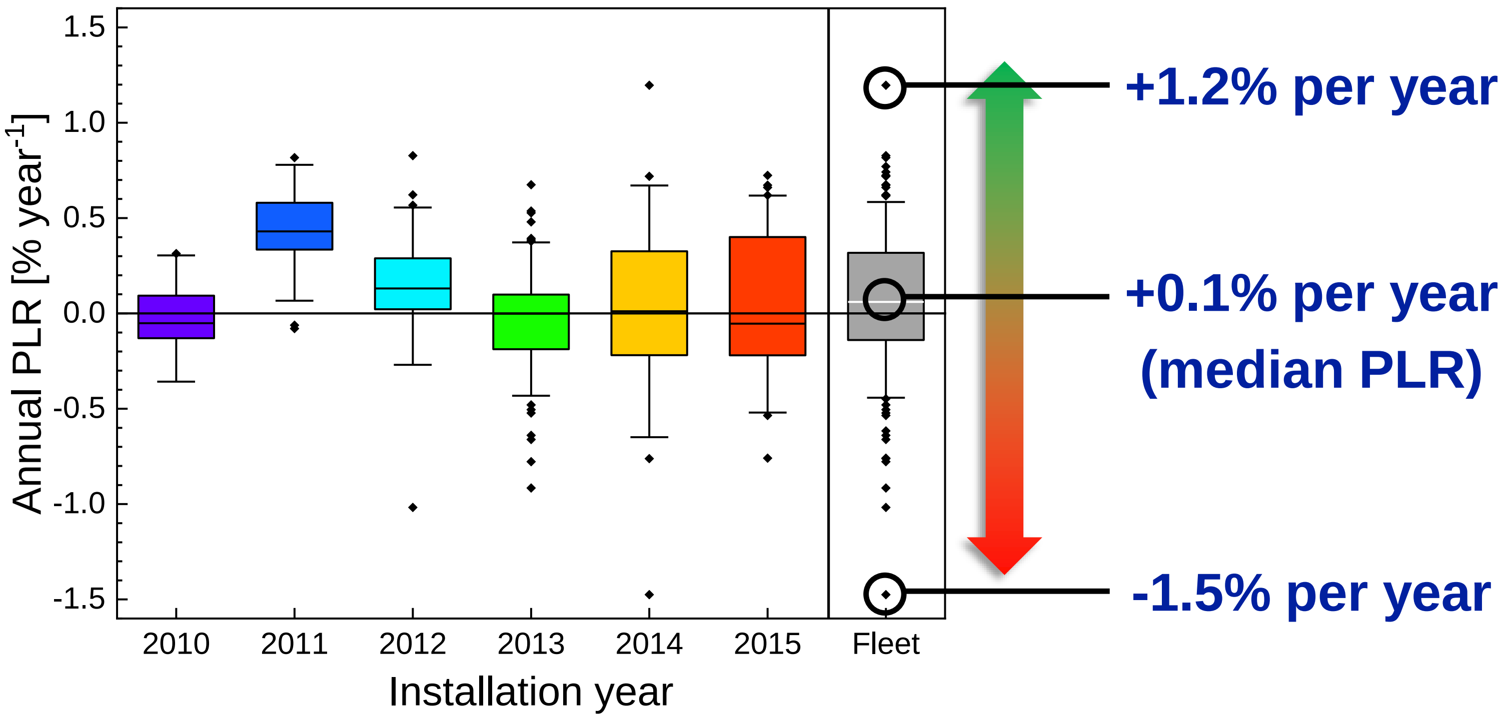
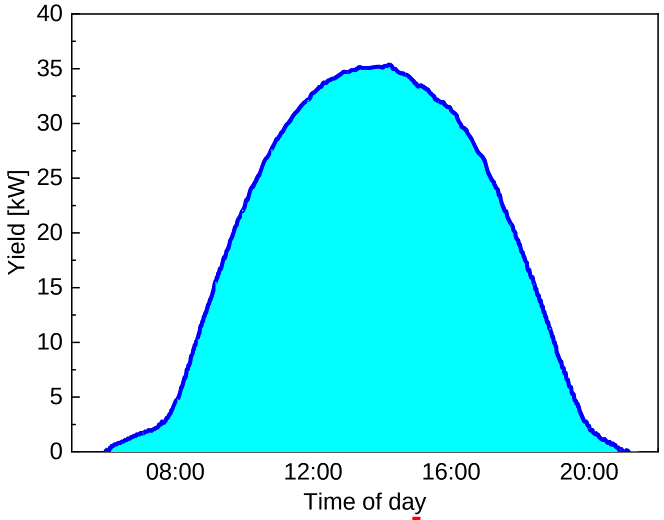
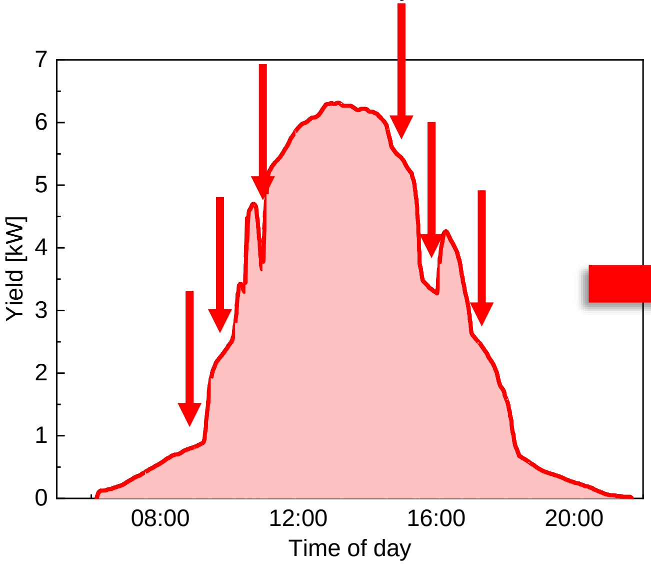
BIPV system performance loss rates

On average no performance loss after 5 to 10 years, **large spread of rates**



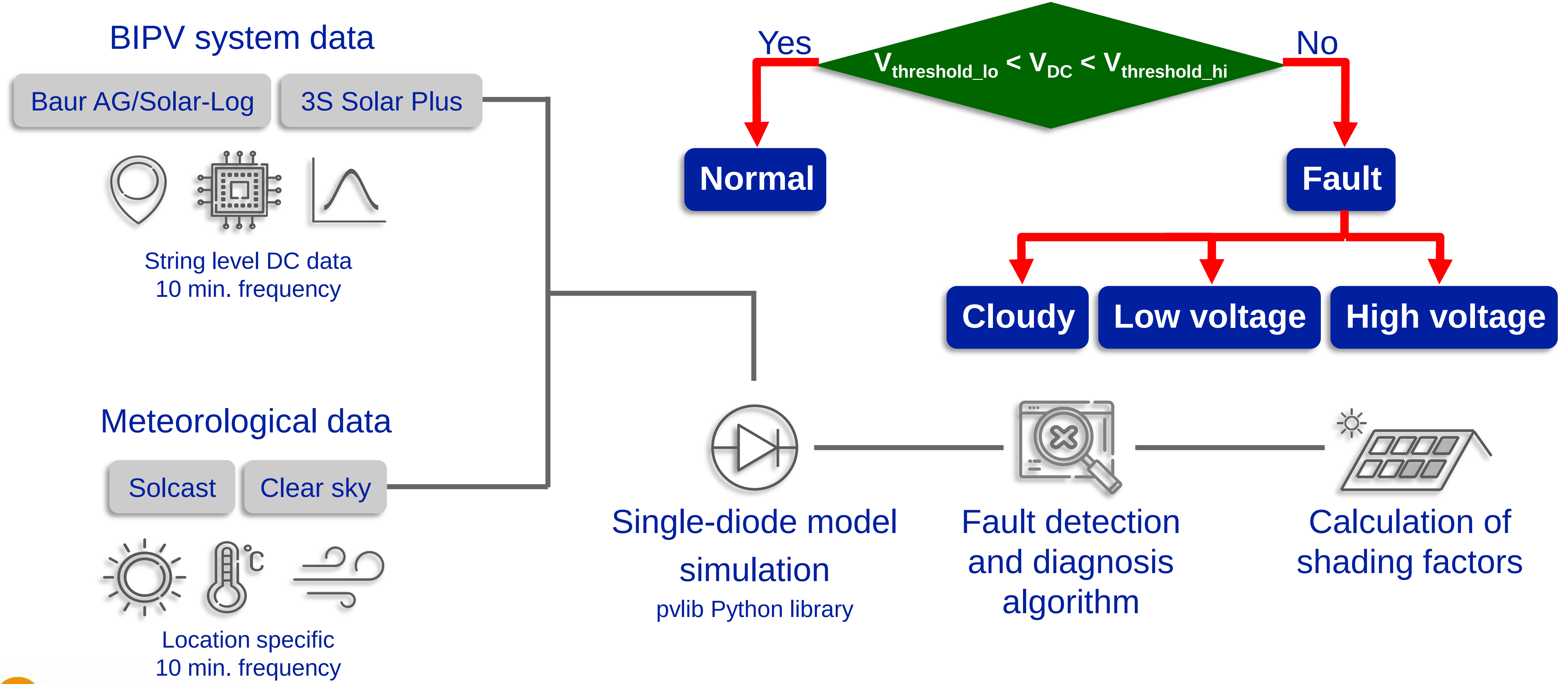
Shade detection





Fault detection and diagnosis algorithm to quantify shading severity

Shade detection analysis

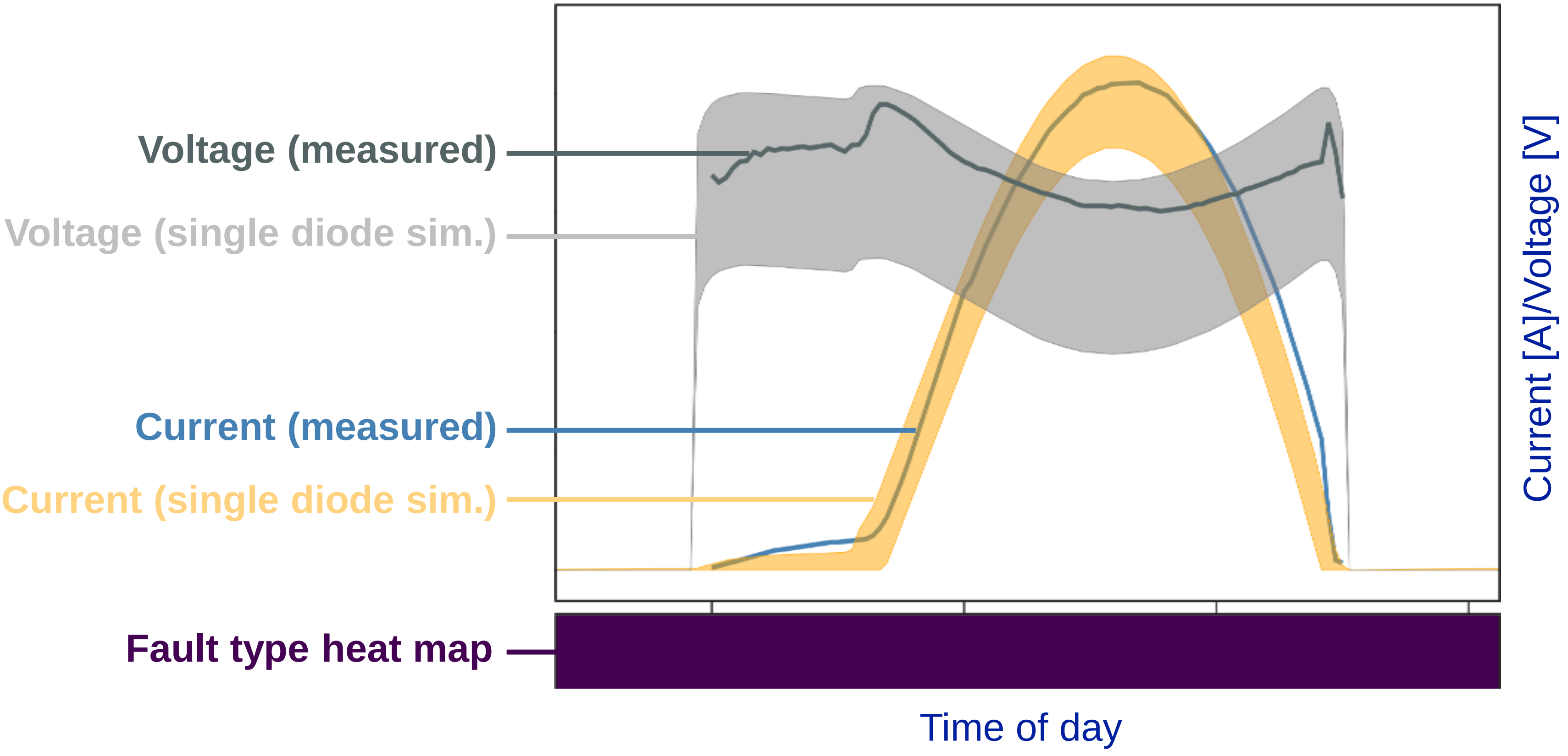


Shading fault classification

	Fault Symbol	Fault Type/ Effect	Potential Causes
	F0	Normal	---
	F1	Cloudy	Weather influence
Recurrent shading faults	F2	Low V, low I	Partial shading, connection fault, MPPT fault
Recurrent shading faults	F3	Low V	Shading with bypass diode activation, short-circuited bypass diode, connection fault
Recurrent shading faults	F4	High V, low I	High voltage MPPT, temperature effect
Recurrent shading faults	F5	High V	High voltage MPPT, temperature effect

Unshaded BIPV system

Voltage and current within simulated ranges → **normal operation (F0)**

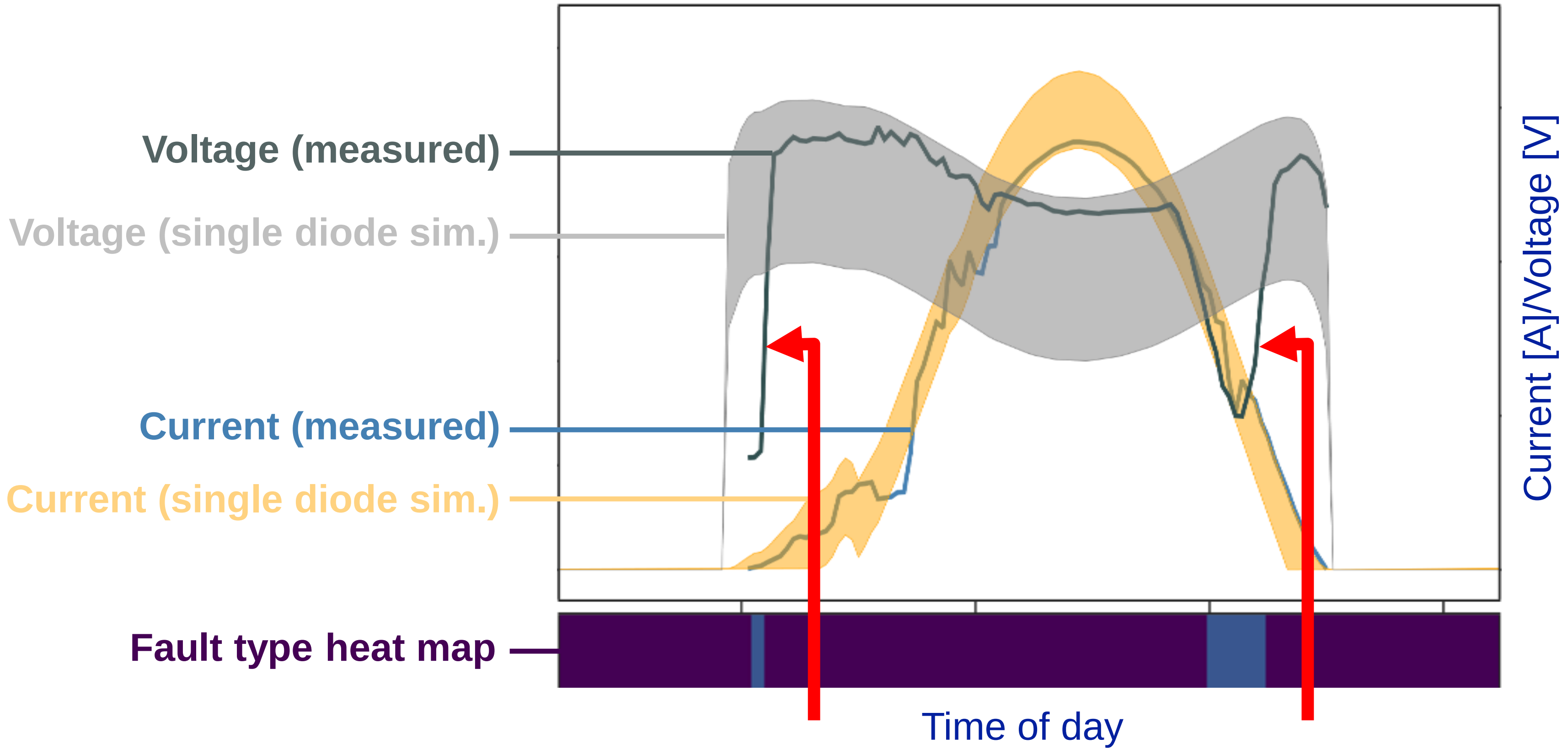


Fault type

- **F0 – Normal**
- F1 – Cloudy
- F2 – Low V, low I
- F3 – Low V
- F4 – High V, low I
- F5 – High V

Shaded BIPV system #1

Voltage outside simulated range → **low voltage fault (F3)**

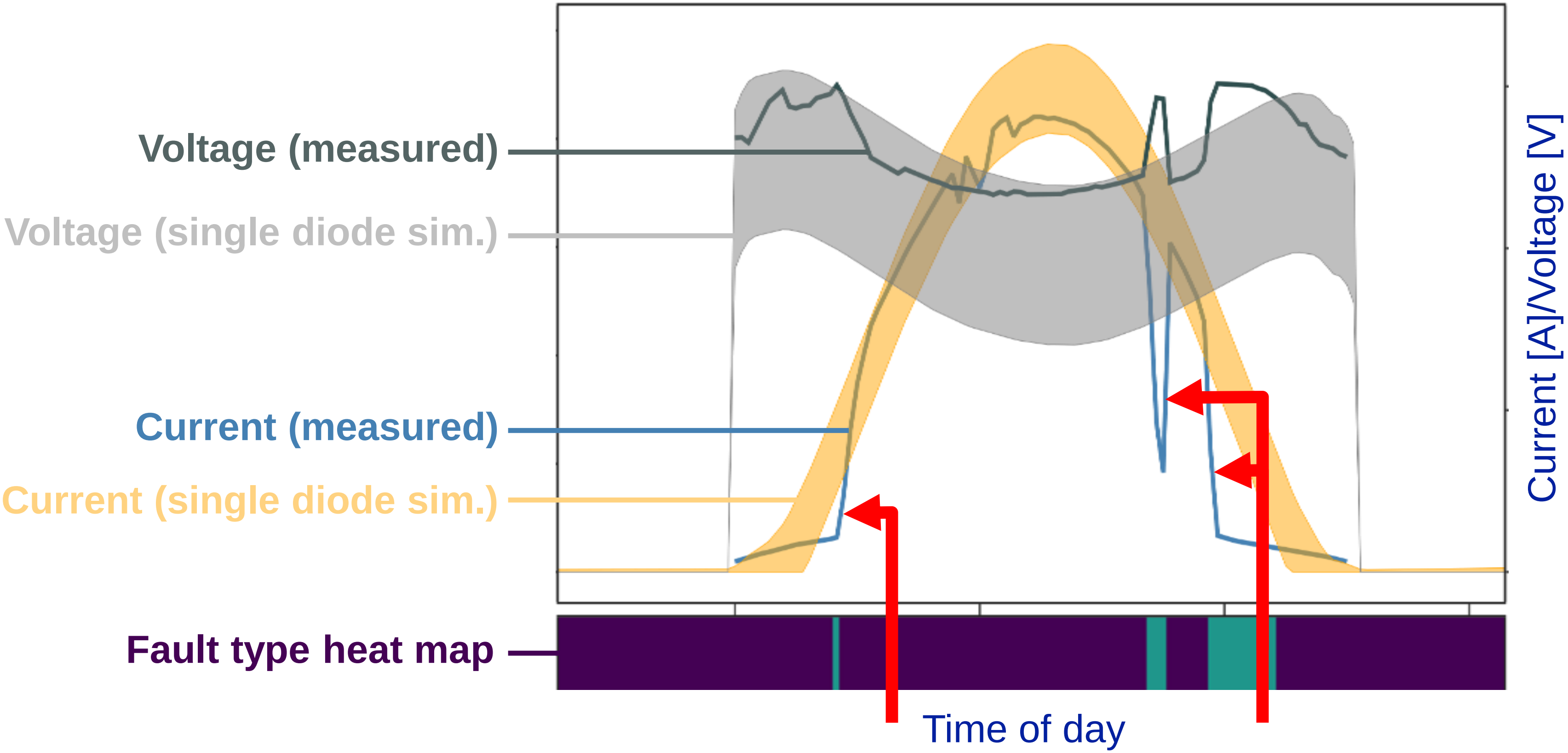


Fault type

- **F0 – Normal**
- F1 – Cloudy
- F2 – Low V, low I
- **F3 – Low V**
- F4 – High V, low I
- F5 – High V

Shaded BIPV system #2

Voltage and current outside simulated ranges → **high voltage, low current fault (F4)**

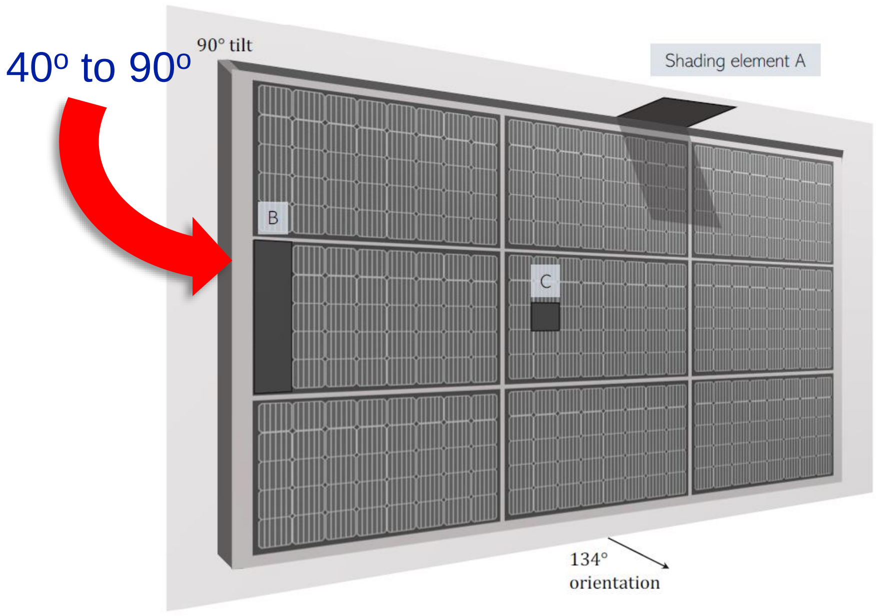


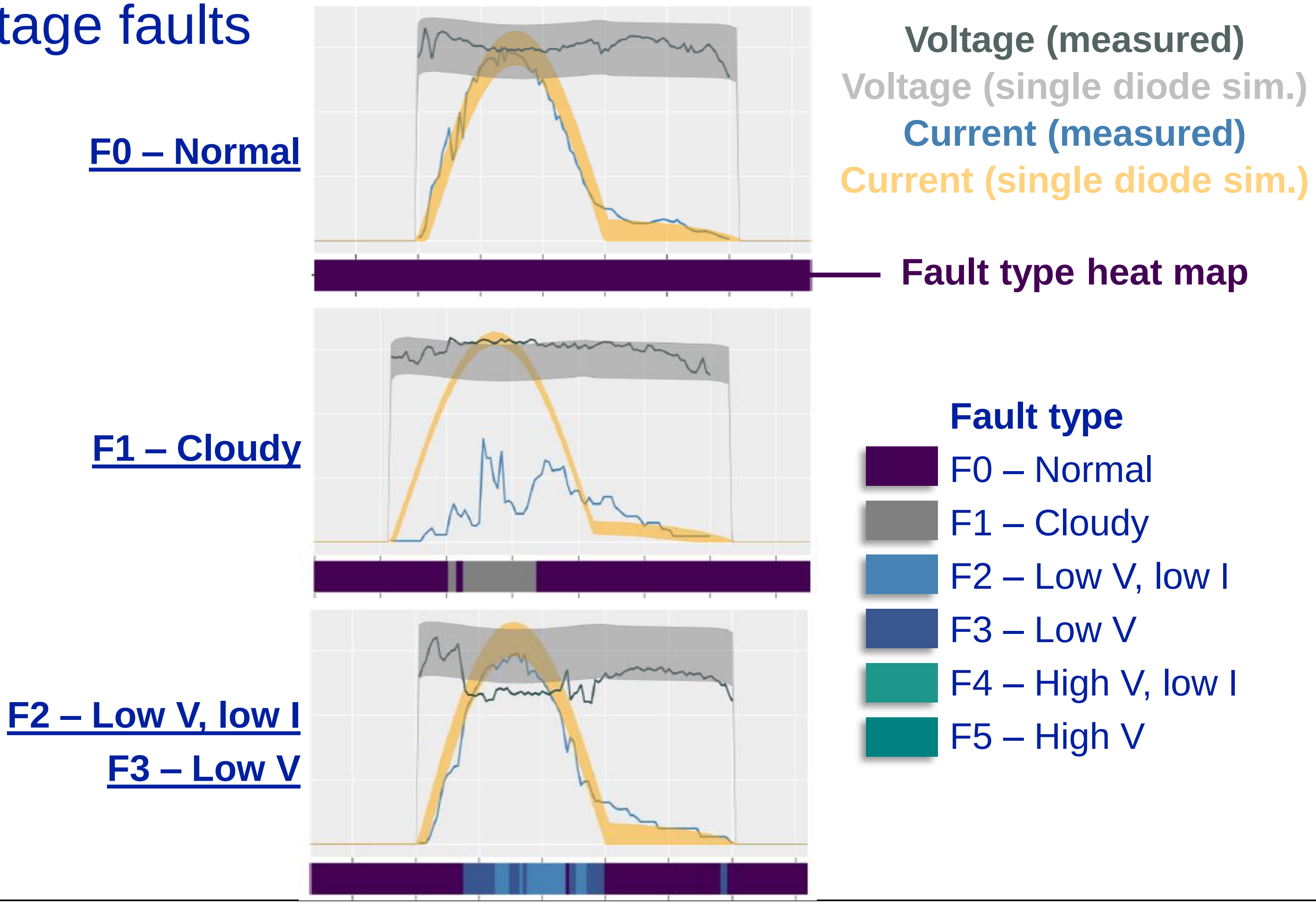
Fault type

- **F0 – Normal**
- F1 – Cloudy
- F2 – Low V, low I
- F3 – Low V
- **F4 – High V, low I**
- F5 – High V

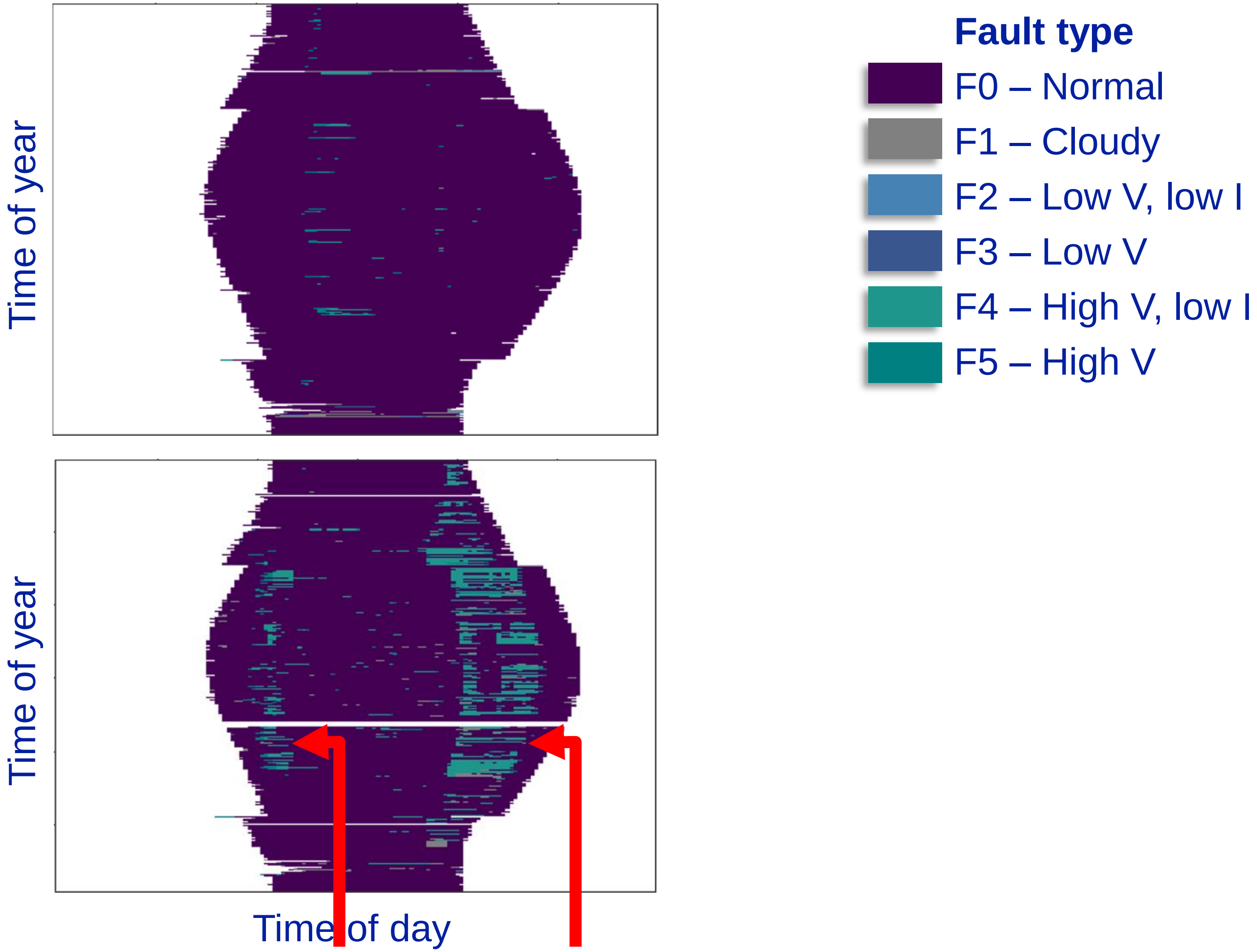
Fault detection validation

Recreation of cloudy and low voltage faults

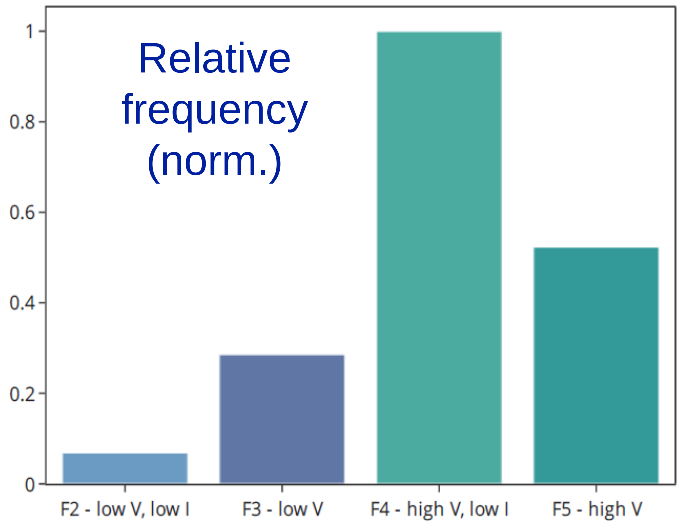


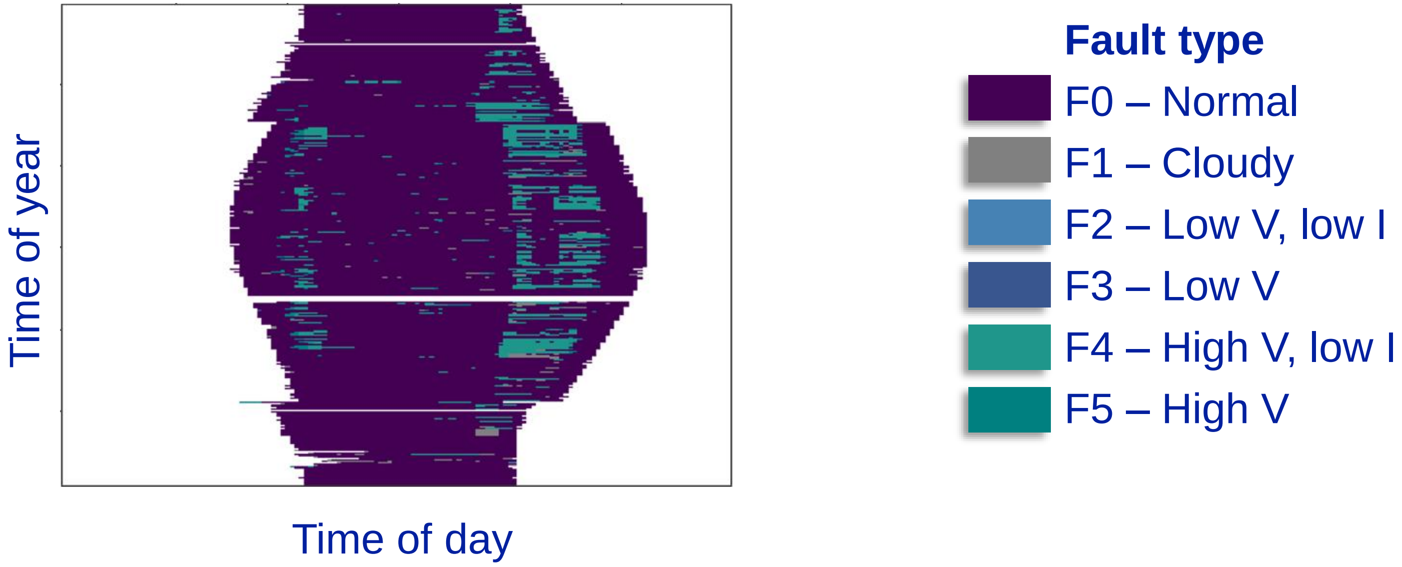


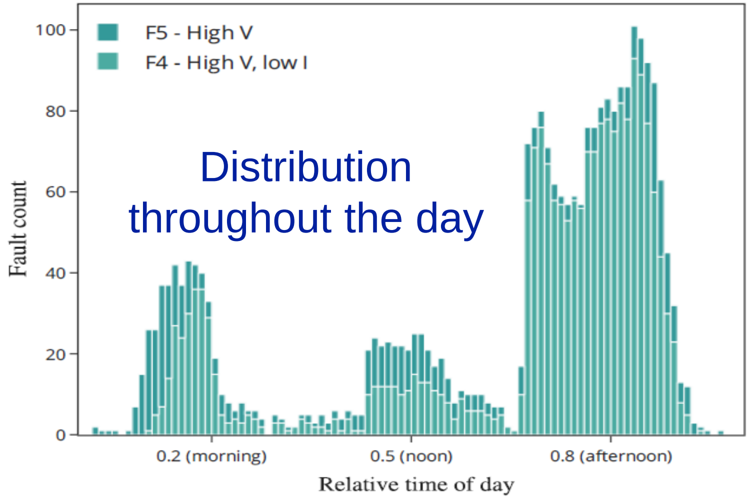
Yearly fault occurrence heat map

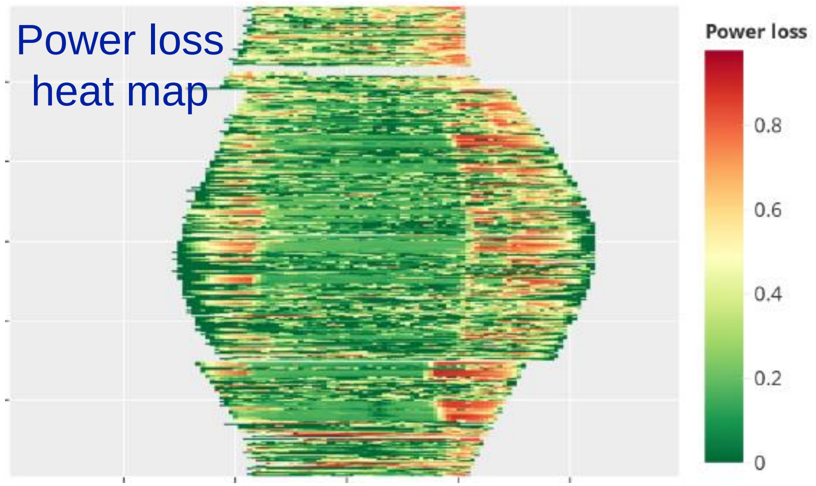


Yearly fault occurrence heat map

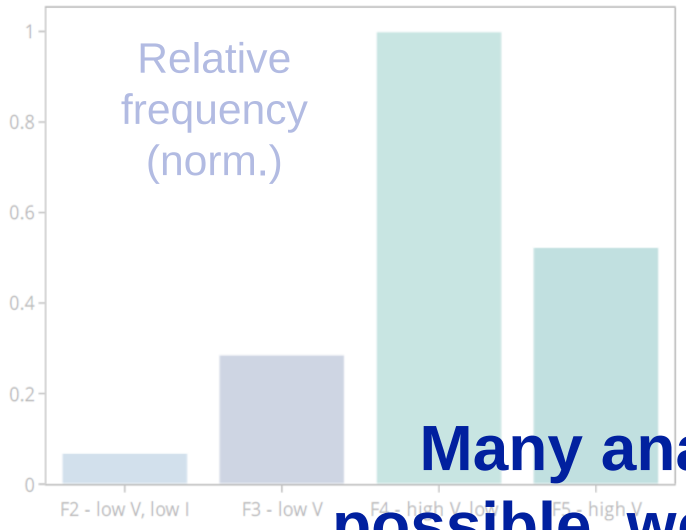




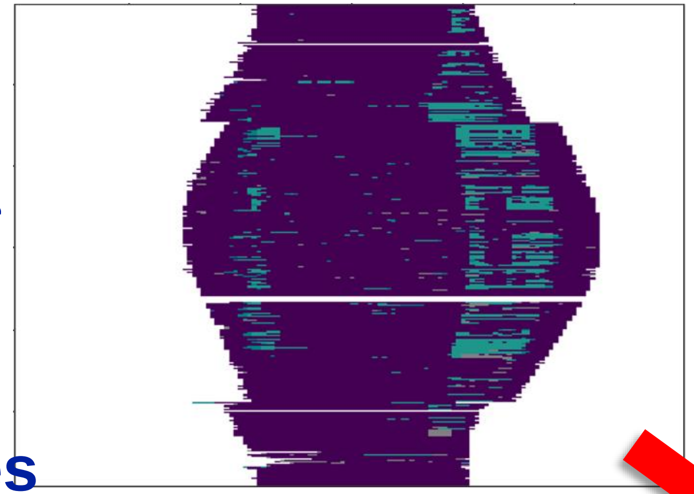




Yearly fault occurrence heat map



Time of year

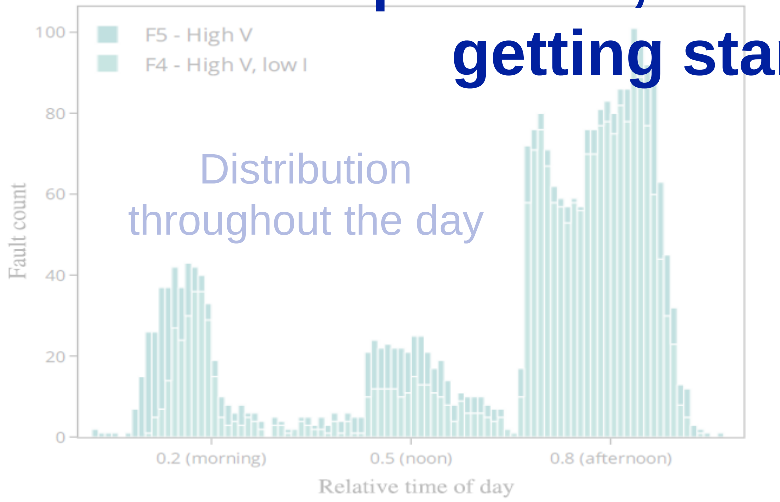


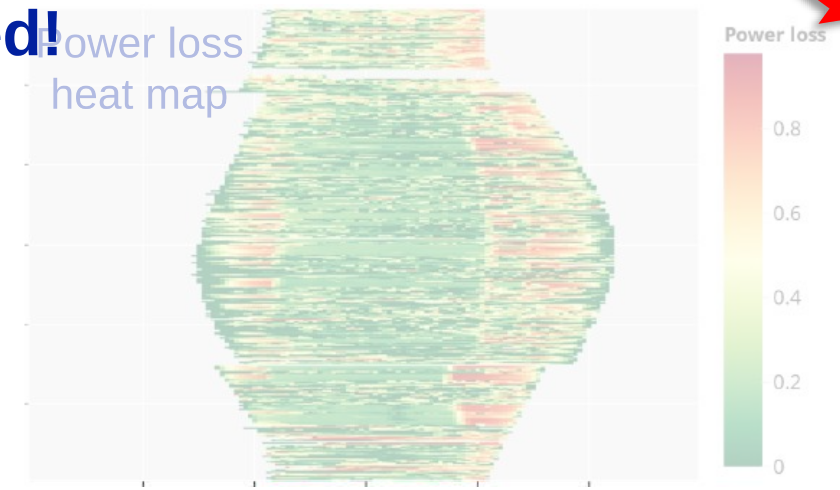
Time of day

Fault type

- F0 – Normal
- F1 – Cloudy
- F2 – Low V, low I
- F3 – Low V
- F4 – High V, low I
- F5 – High V

Many analyses possible, we are just getting started!

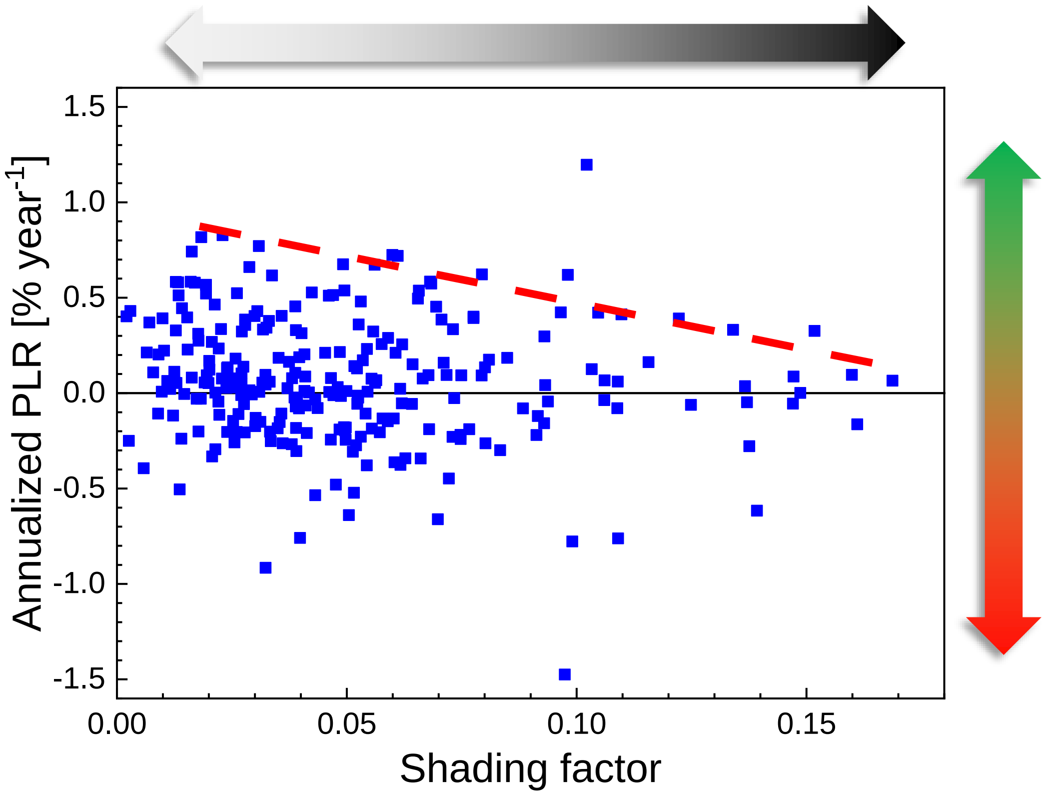




$$\text{Shading factor} = \frac{\text{Time in shading fault}}{\text{Time in operation}}$$

Shading factor vs. degradation rate

Shading factor sets an upper limit to PLR

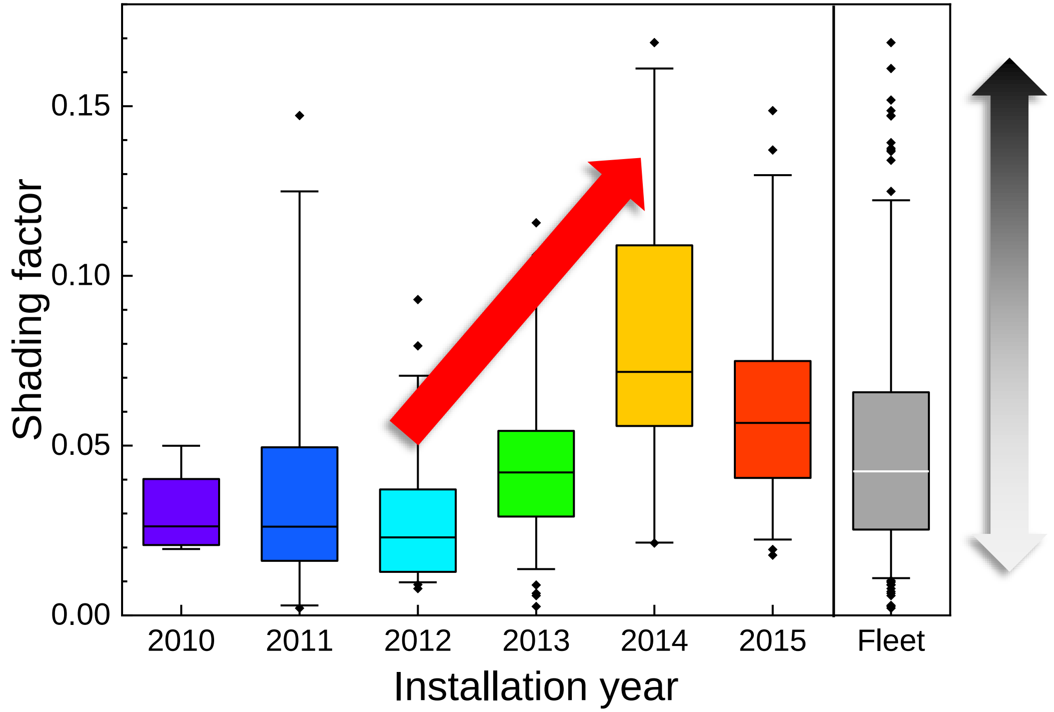


Confounding factors:

- Roof substructure
- Type of shading element/fault
- Seasonality
- Other system characteristics (tilt, azimuth, inverter…)

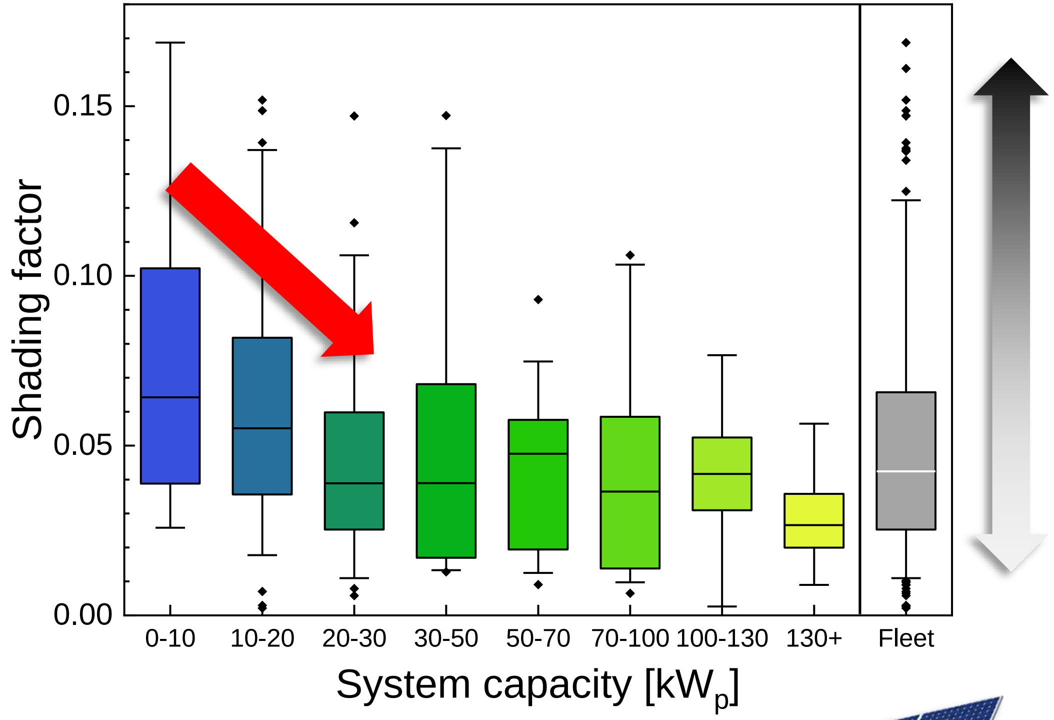
Shading factor by installation year

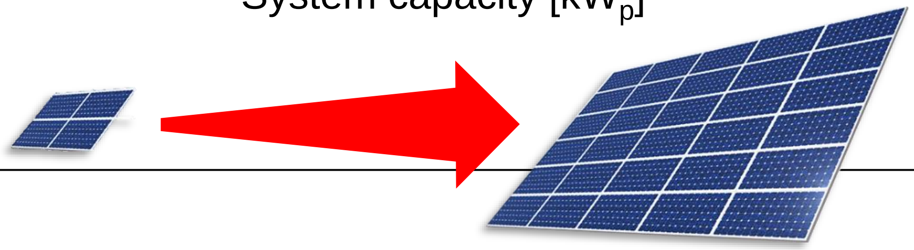
Newer systems (2012 to 2015) more shaded



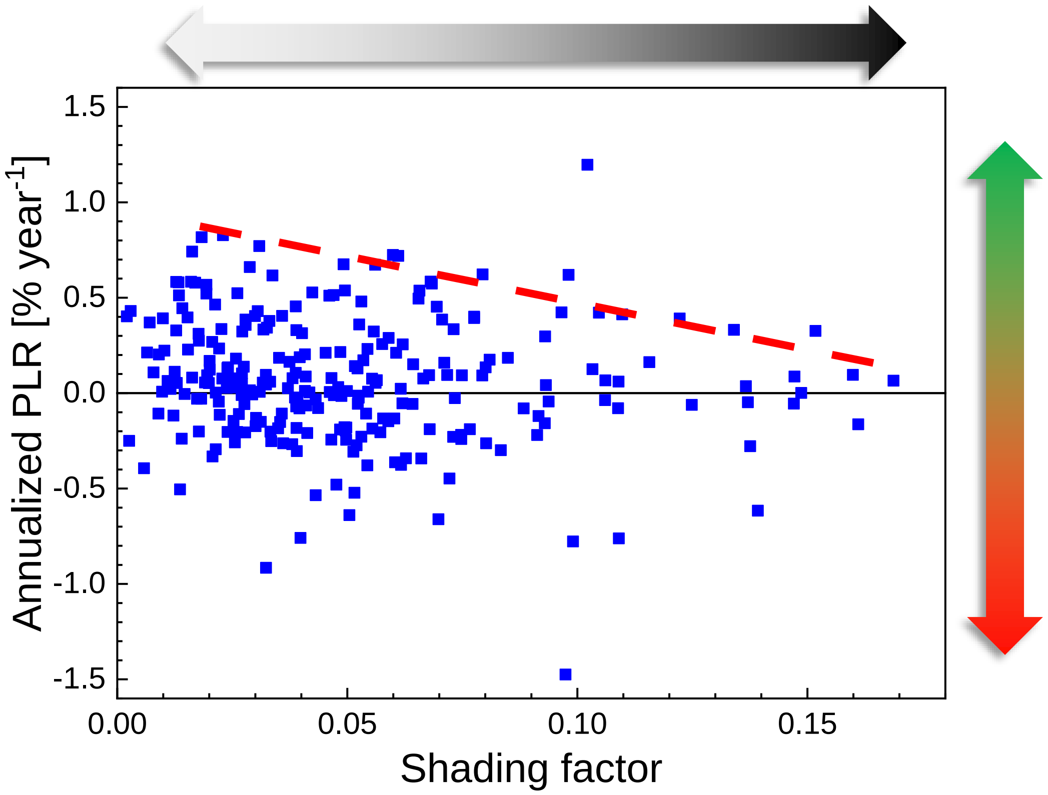
Shading factor by system capacity

Smaller systems (<20 kW_p) more shaded





Summary and conclusions



Mitigating the effect of shading:

- Design of shade-resistant modules
- Use of power optimizers or microinverters
- Precise assessment of local boundary conditions
  - Optimization of electrical layout of strings
  - Installation of dummy panels in high-shade areas

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And thank you!