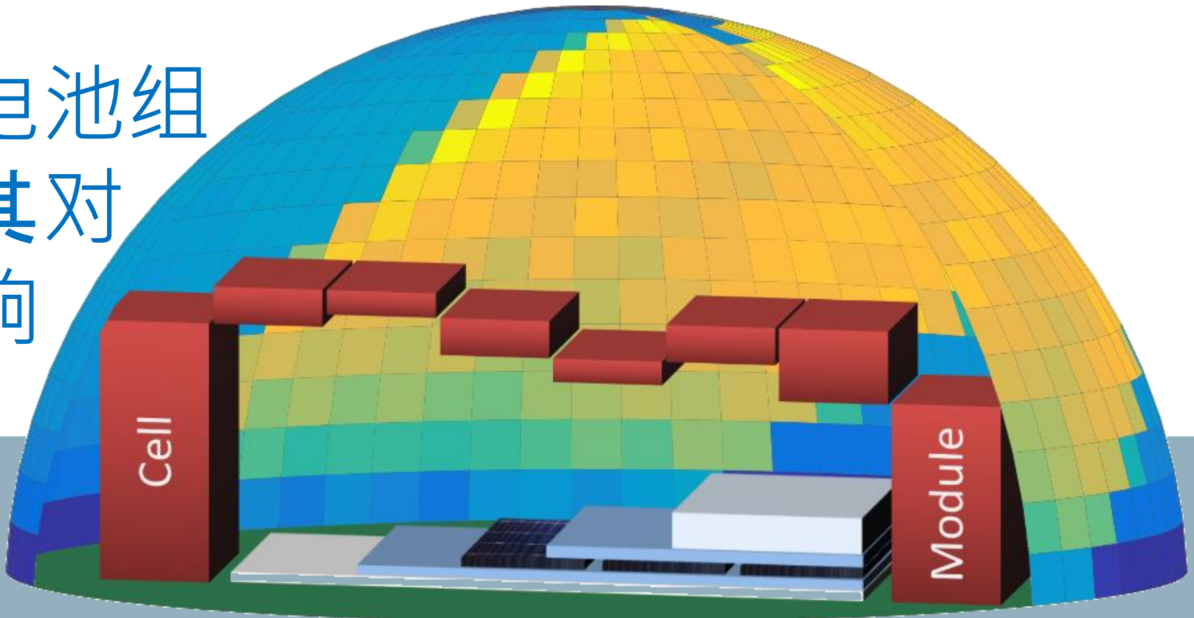
# Optimizing Busbar Design in Full and Halved Cell Modules and Impact on the Cell-to-Module Yield

优化全**片和半片**电池组**件的主栅**设计**及其**对发电量损益的影响

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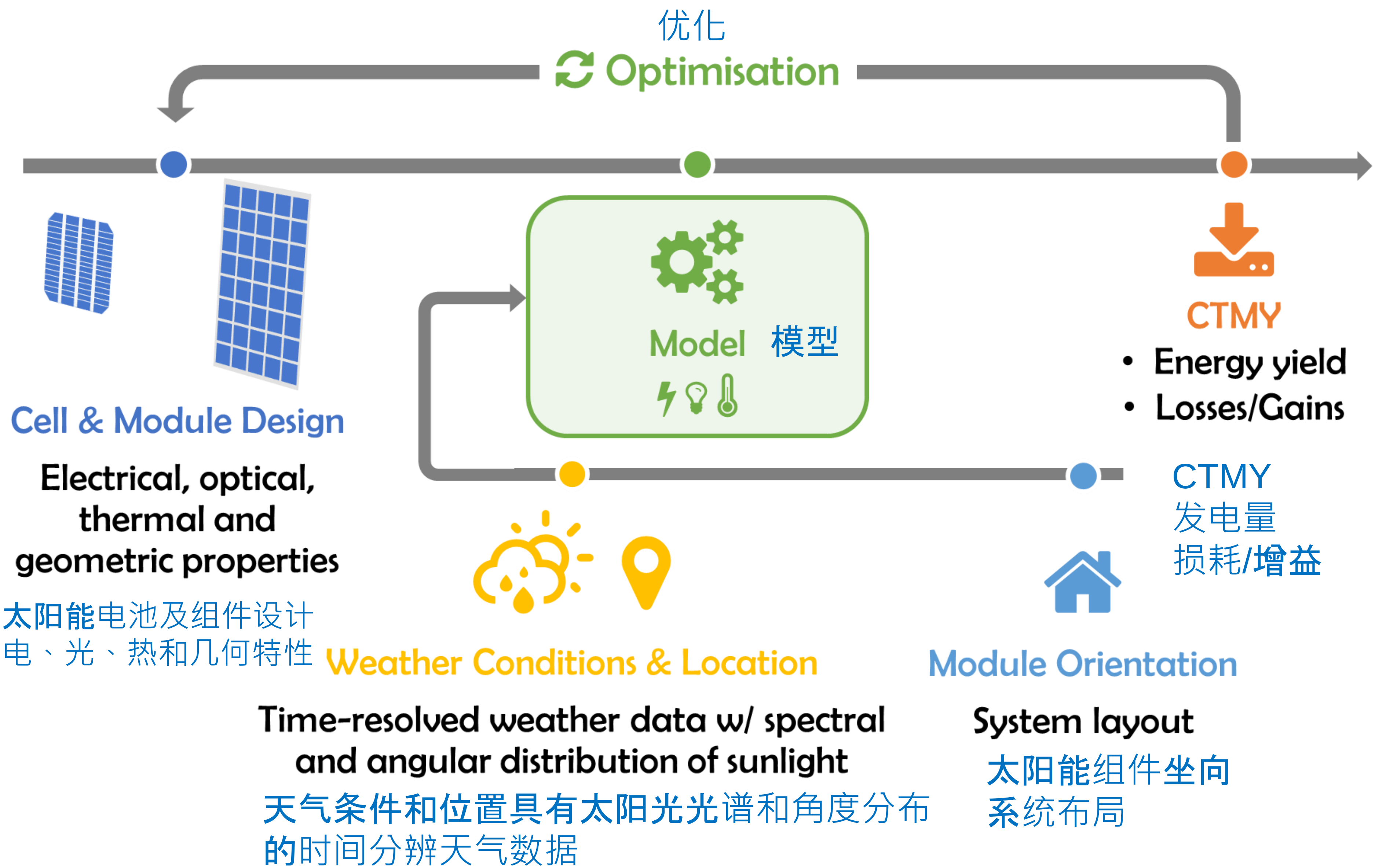
Australian National University

# Cell-to-Module-Yield (CTMY)

- Methodology to predict annual yield losses and gains caused by solar module design and materials under field exposure
- **太阳**电池组件设计和材料在户外工作下的年产量损**耗和增益**预测方法

- Aim:
  - Enable rapid virtual prototyping of new concepts and designs
  - Enable optimization of key design elements (e.g. backsheet, ribbon, glass) by separating individual loss/gain mechanisms
  - Enable optimizing modules for different climates under realistic conditions (angular & spectral irradiance, environmental factors)
- 目标：
  - 实现新概念和设计的快速虚拟原型
  - **通**过分离各个损**耗/增益机制**，实现关键设计元素（如背板、焊带、玻璃）**的**优化
  - **在**实际条件（角度和光谱辐照度、环境因素）下为不同气候优化组件

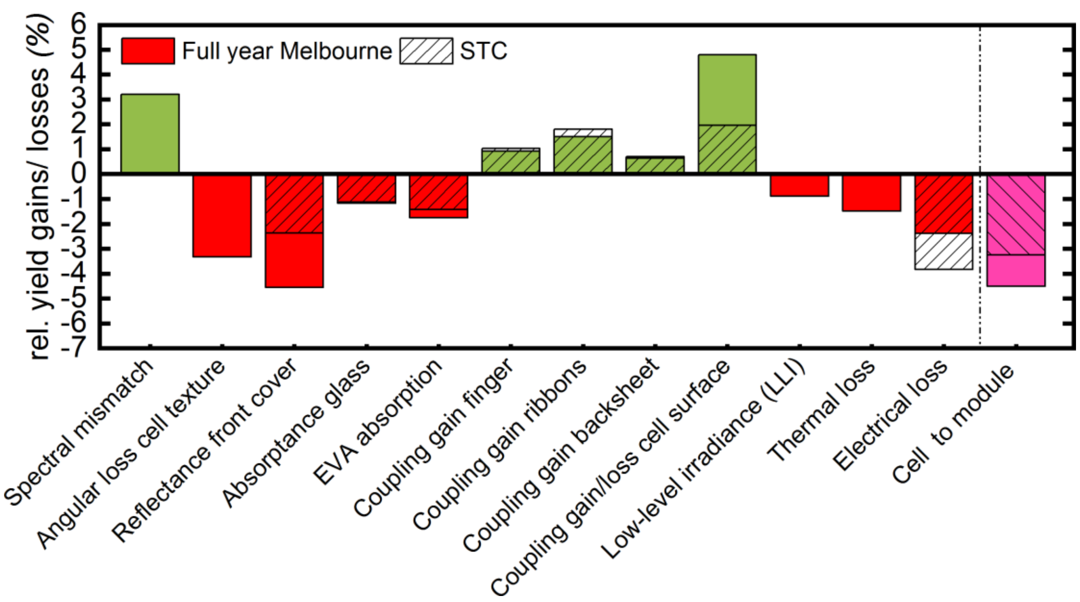
# CTMY Model Overview



# CTMY Model

- Separating 12 yield loss and gain mechanisms using timestep approach 用时间步法分离12种产量损耗和增益机制
- At each timestep:
  - Calculating optical cell-to-module losses and gains
  - Iteratively calculating cell temperature
  - Calculating electric losses

在每个时间步骤：
- 计算电池到组件的光损耗和增益
- 迭代计算电池温度
- 计算电损耗




I. Haedrich, D. C. Jordan, and M. Ernst, Solar Energy Materials and Solar Cells 202, 110069 (2019), DOI: 10.1016/j.solmat.2019.110069.

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# Model validation

## CTM (STC)

- Validation under STC conditions
- STC条件下的验证模型
- Comparison of model against measurement-based reference data [1]
- 与基于测量的参考数据的比较
- Overall in good agreement!
- 整体一致！

| Loss/Gain Mechanism from Cell to Module | Modelled values | Reference [1] |
|---|---|---|
| STC nameplate | 285.0 | 285.0 |
| Spectral mismatch to AM1.5 | 0.0 | 0.0 |
| Angular | 0.0 | 0.0 |
| Reflection front glass | -11.4 | -11.4 |
| Absorption glass | -3.8 | -3.3 |
| Absorption embedding | -3.1 | -3.5 |
| Coupling gain (CG) finger | 5.2 | 5.3 |
| CG ribbons | 0.3 | 0.3 |
| CG backsheet | 3.0 | 4.4 |
| CG cell surface | 5.0 | 3.4 |
| Low level irradiance (LLI) | 0.0 | 0.0 |
| Thermal | 0.0 | 0.0 |
| Ohmic interconnection | -9.4 | -9.0 |
| **Final module power** | **270.8** | **271.2** |

[1] I. Haedrich, et al., "Unified methodology for determining CTM ratios: Systematic prediction of module power," Solar Energy Materials and Solar Cells **131**, 14–23 (2014).

# Model validation

CTMY

POA → Temperature 温度 → Power 功率

## Three interdependent models

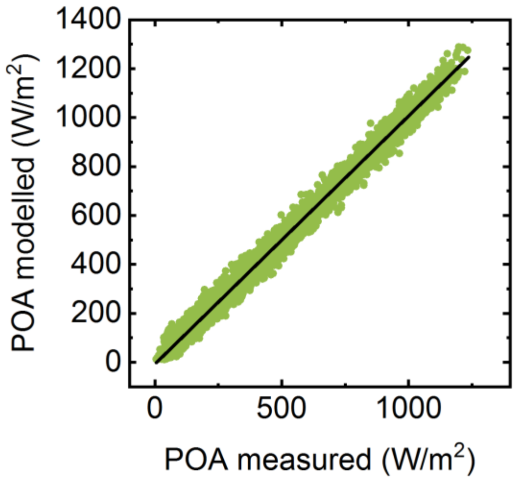
三个相互依赖的模型

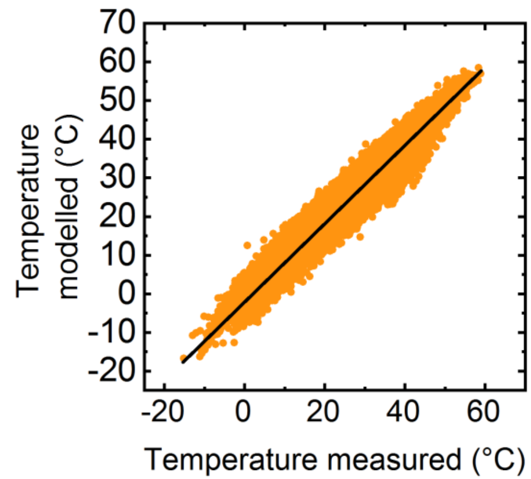
NREL, Golden, CO

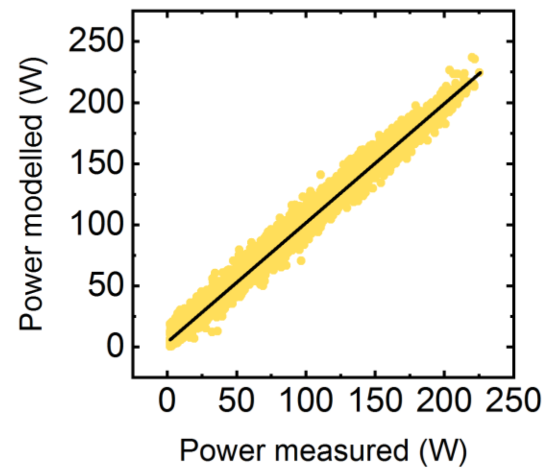
D. C. Jordan et al., "Silicon Heterojunction System Field Performance," IEEE J. Photovoltaics **8** (1), 177–182 (2018).

# CTMY model validation

POA → Temperature → Power



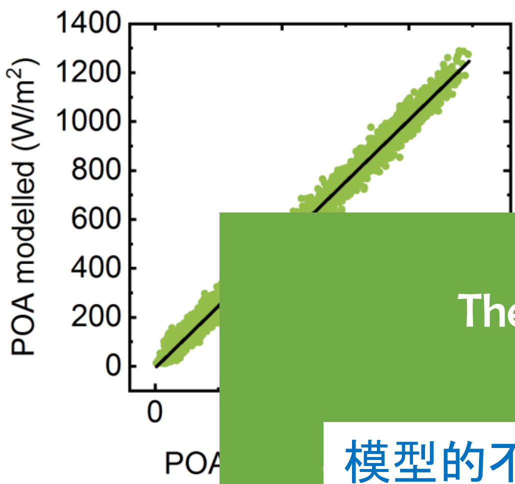



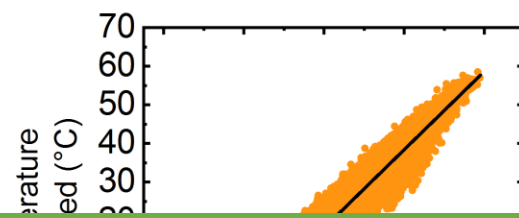



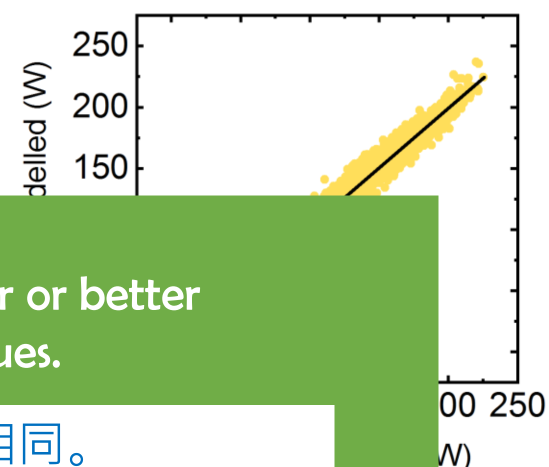

| | *Irradiance* | | *Temperature* | *Power* | |
|---|---|---|---|---|---|
| | *[W/m$^2$]* | *[%]* | *[K]* | *[W]* | *[%]* |
| Our model at location Denver (NREL) | | | | | |
| MBE | 0.55 | 0.01 | –0.03 | 0.7 | 0.8 |
| WMBE | 2.27 | 0.4 | –0.47 | 0.39 | 0.4 |
| RMSE | 22.6 | 4.2 | 2.8 | 4.6 | 4.8 |

# CTMY model validation

POA → Temperature → Power




The modelling uncertainty is similar or better compared to published values.

**模型的不确定度与文献**值相比数量级相同。

请注意，我们对三个相互依赖的参数进行了建模，而**一次只**对一个参数的参考值进行了比较

| | | | | | |
|---|---|---|---|---|---|
| Our mode (NREL) | | | | | |
| MBE | 0.55 | 0.01 | –0.03 | 0.7 | 0.8 |
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# Application of CTMY

- Goal: Determine impact of busbar in full and halved cell modules on CTM-Yield

目标：**在全片和半片**电池组件中 **分析主栅**对电池到组件的产量的影响

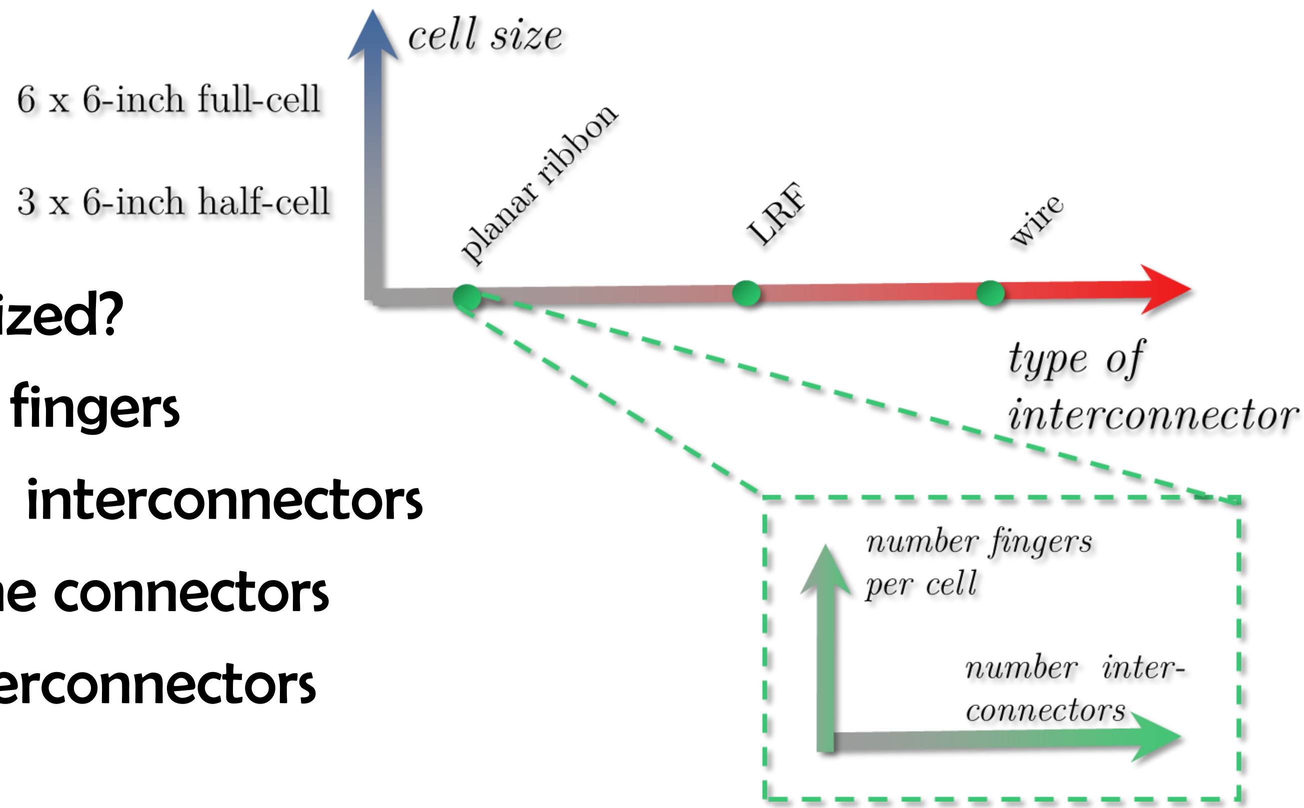
- Step 1: Optimise the cell design in combination with the cell interconnection design for an optimum performance
  - inside a module
  - under STC

步骤1：结合电池互连设计优化电池设计以获得最佳性能
- 在组件内部
- 在STC下

- Step 2: Calculation of annual yield for best performing designs

步骤2： 计算最佳设计的年产量

# Approach



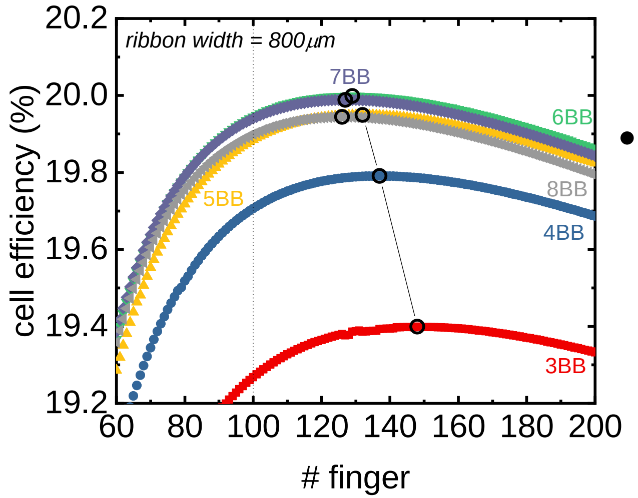

**What is optimized?**

- number of fingers
- number of interconnectors
- width of the connectors
- type of interconnectors

什么是要优化的？
- 副栅的根数
- 互连条的个数
- 互连条的宽度
- 互连条的类型

# Optimizing front metallization

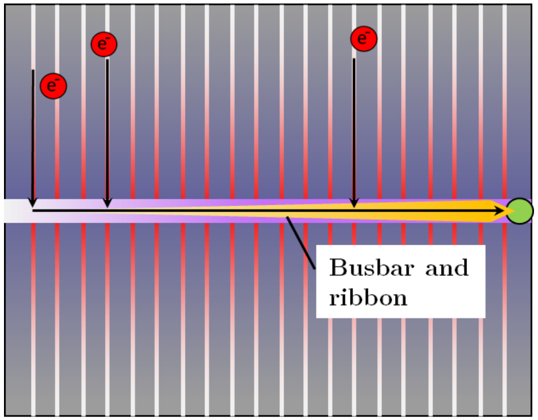
Cell in air with ribbon

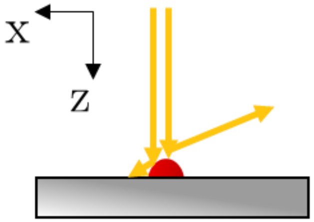



- Example of optimization for a full-cell, planar ribbons
- Cell optimization in air (including ribbon) may underestimate coupling gains, e.g. from light-redirecting films (LRF)

全片电池**扁平**焊带组件的优化示例

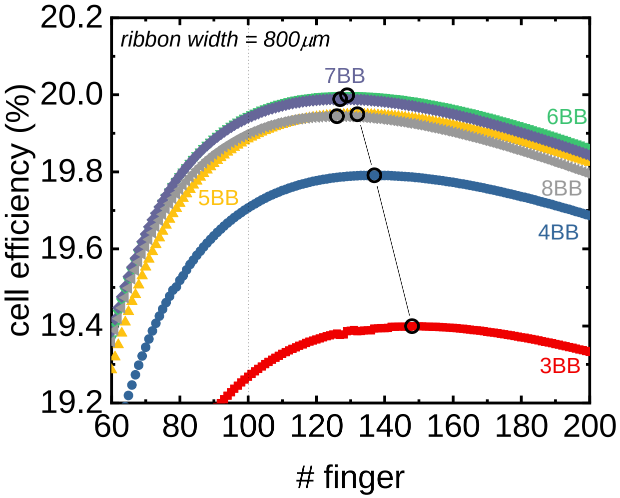
在空气中优化电池（包括焊带）可能**会低估耦合增益**，**例如使用反光**贴条（LRF）



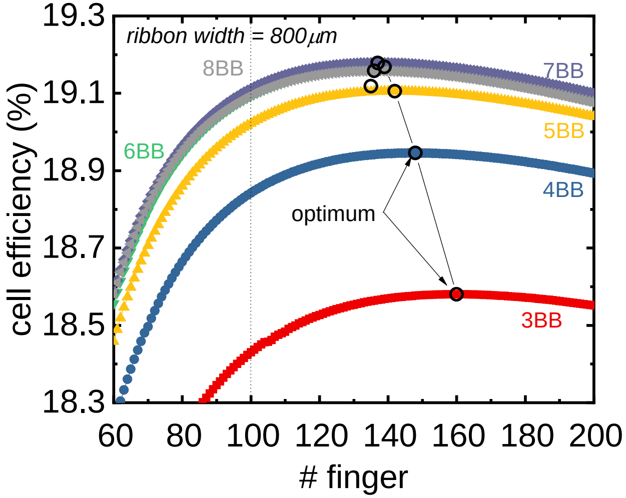



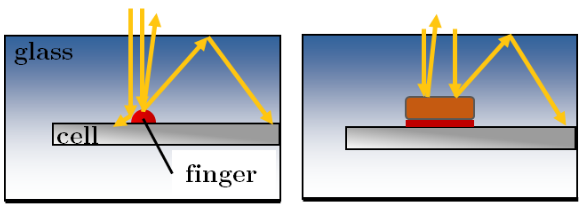
# Optimizing front metallization

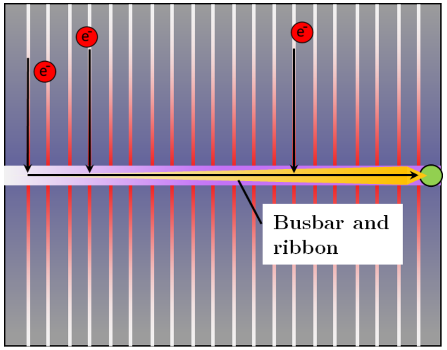
## Cell in air with ribbon




## Cell in module with ribbon




- Optimum number of fingers within module embedding slightly higher, due to
  - Reduced electrical losses (lower current)
  - Increased optical gain

在组件内优化副栅会得到更多的副栅根数， 因为

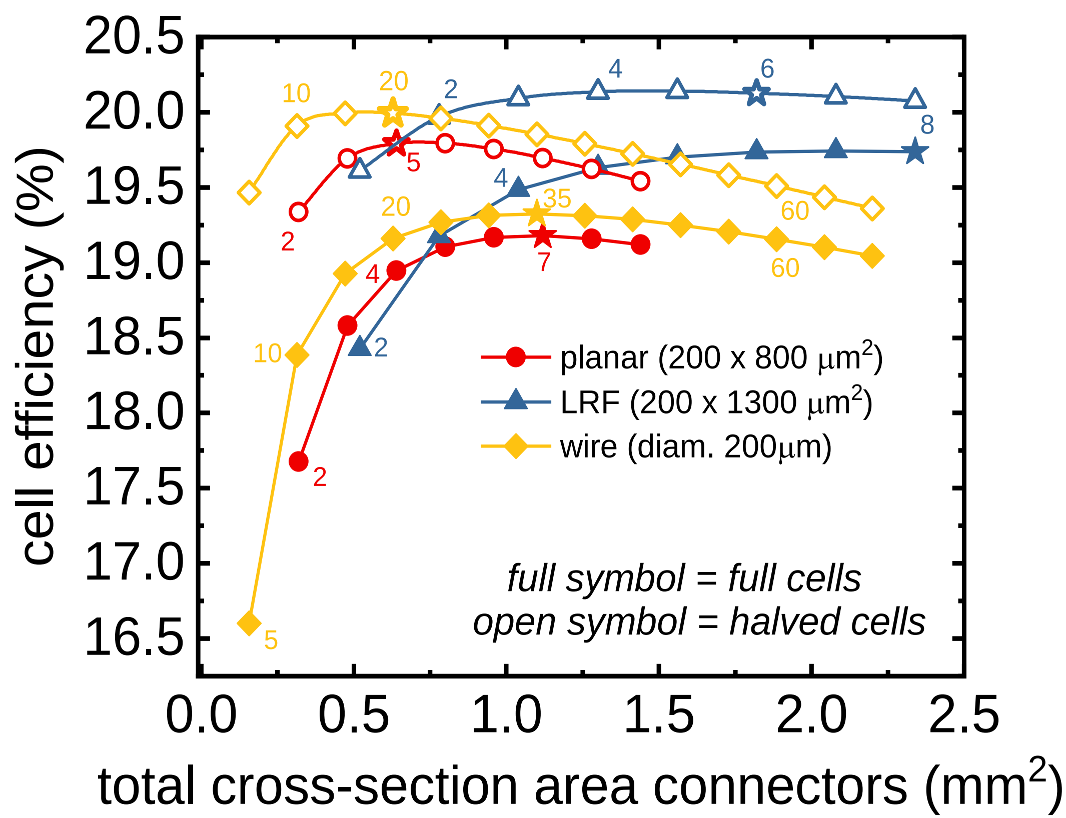
- 降低电气损耗（低电流）
- 增加的光学增益

# Optimizing front metallization

- LRF structures allow to increase the ribbon width due to the reduced optical width after embedding
- The optimized width is 1300 μm compared to 800 μm for planar ribbons

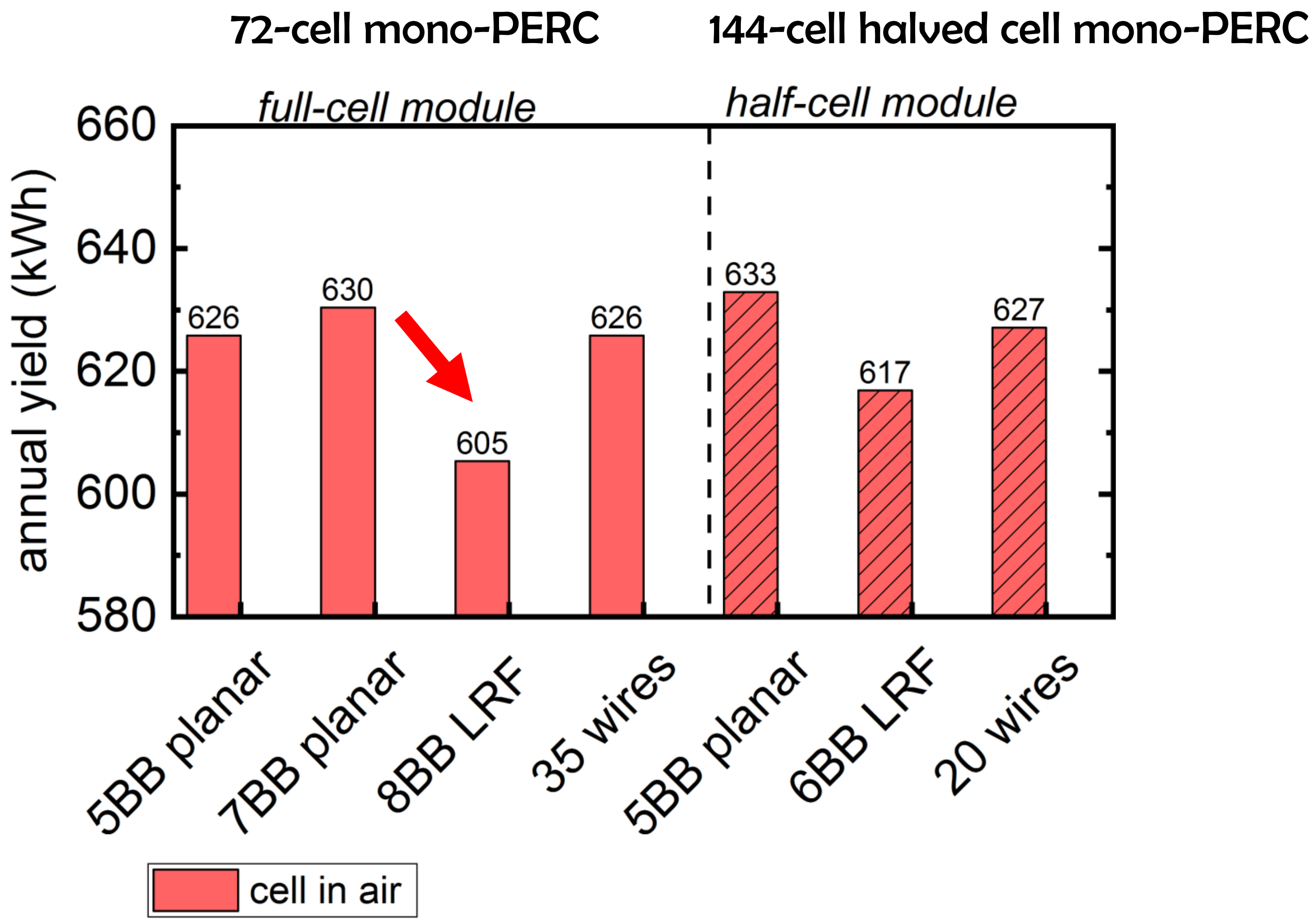
**反光**贴条**的**结构允许较宽**的**焊带由于**其光学**宽度较小

优化的焊带宽度为**1300 μm,**
**而扁平**焊带的宽度为800 μm

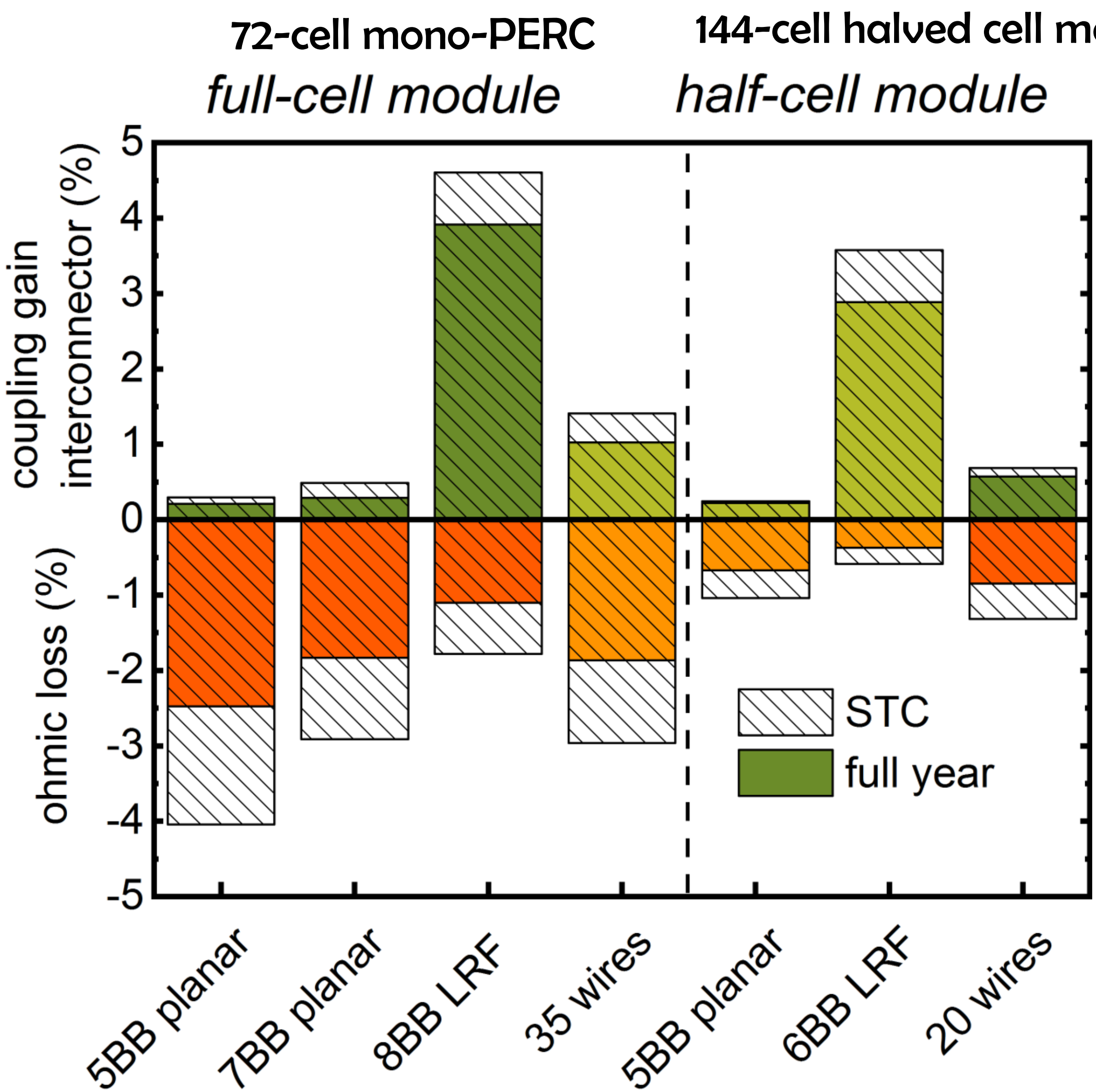


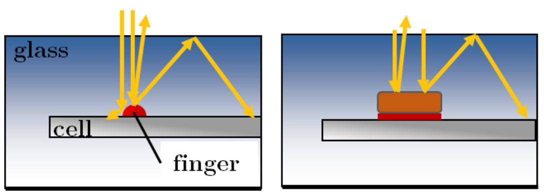
# Annual yield

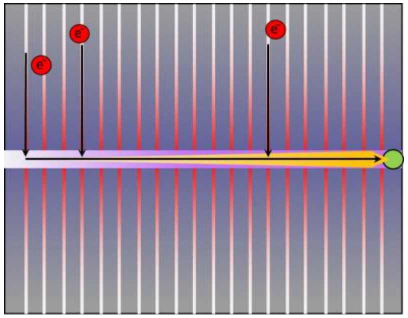
- Theoretical yield reduced for cells in air with wider LRF ribbons due to increase shading losses



# Annual yield – optical gain and ohmic loss



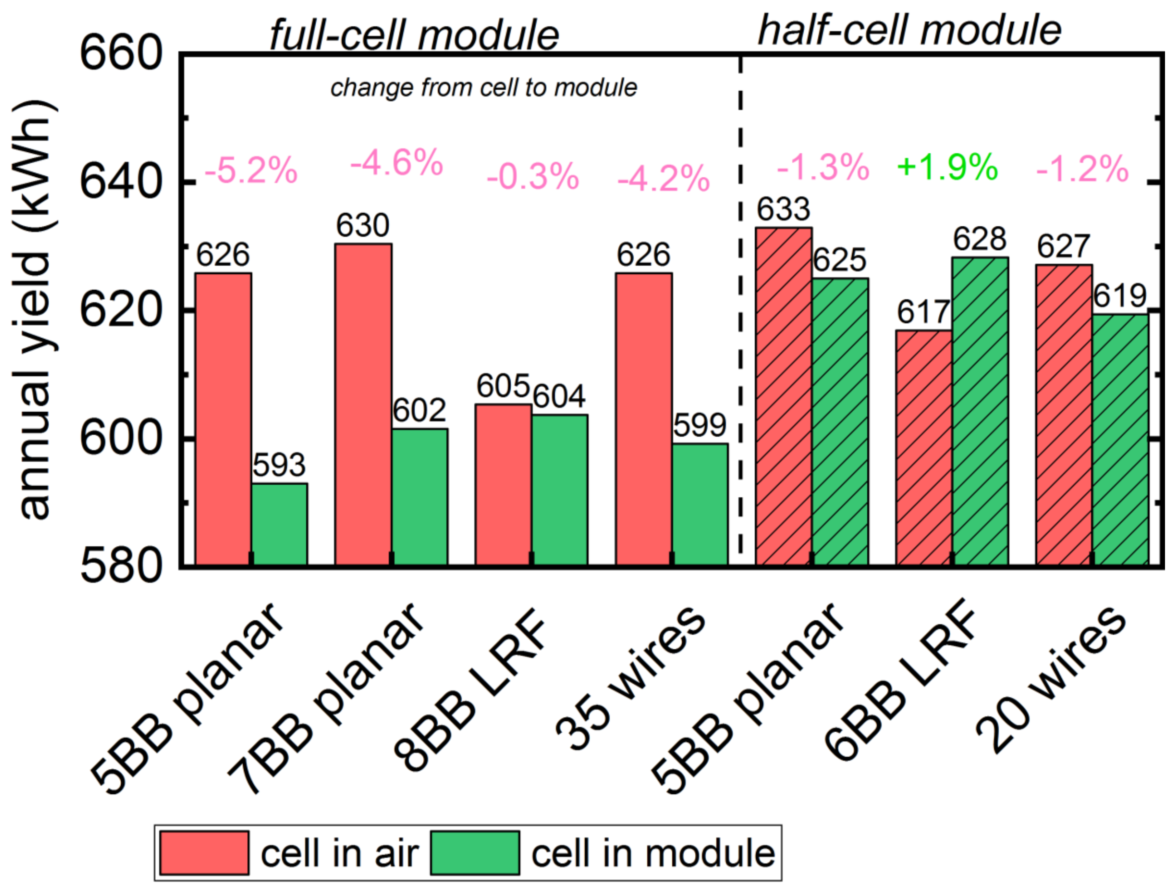



# Annual yield

- After embedding the cells with LRF ribbons perform best due to coupling gain and low ohmic losses

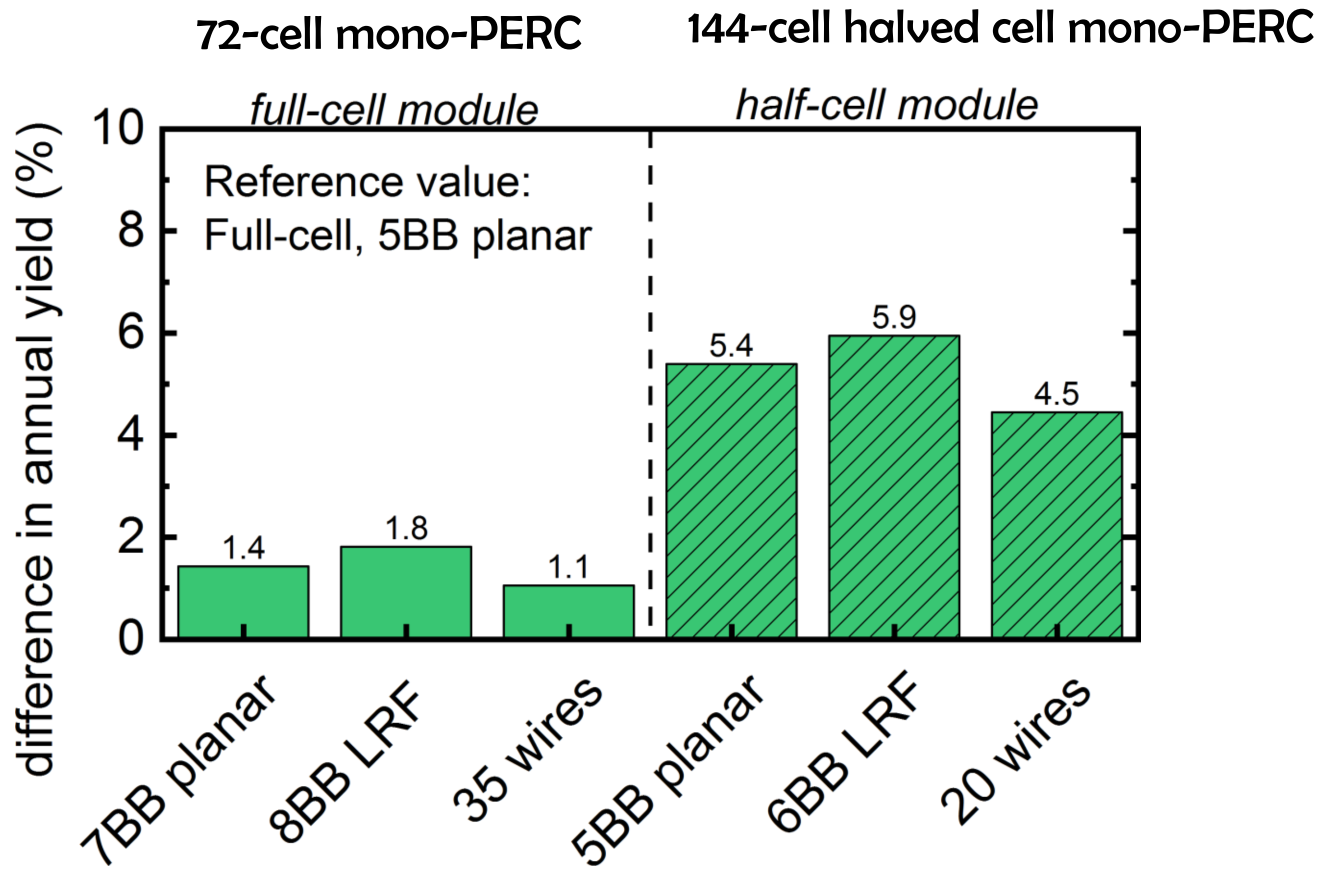
72-cell mono-PERC 144-cell halved cell mono-PERC



# Annual yield

- **Both, reduction in electrical losses and increase in optical gain contribute to an increase in the annual yield**

电损耗的减少和光学增益的增加都有助于提高年产量



# Summary

## Cell-to-Module-Yield Methodology

- Validated using module outdoor measurements at NREL

  使用NREL的组件室外测量进行验证

- Applied to busbar / metallization designs optimized for full and halved-cells after module embedding
  - Light-redirecting-films enable using much wider ribbons (optimized width of 1300 μm compared to 800 μm for planar)
  - 1.8% yield gain for full-cell 8BB with LRF compared to 5BB planar ribbon reference
  - Halved-cells further increase CTMY energy yield by 3-4%

应用于全片和半片电池在组件内优化主栅/金属化设计

- 反光贴条允许使用较宽的焊带（优化宽度为1300 mm，而扁平焊带为800 mm）
- 八主栅带反光贴条的全片电池可以比五主栅扁平焊带电池提升1.8%的产量增益
- 半片电池进一步提高 3-4% 的CTMY能量产出

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# Thank you for your attention

谢谢您的关注。

## We are open for collaboration!

我们很乐意进行合作！

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More information and free download of SunCalculator and high-time resolution TMY datasets for Australia at www.marcoernst.net

更多信息的请访问www.marcornst.net，免费下载SunCalculator和高时间分辨率的TMY数据集

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