RECENT PROGRESS OF Q CELLS' HIGH EFFICIENCY SOLAR CELL DEVELOPMENT

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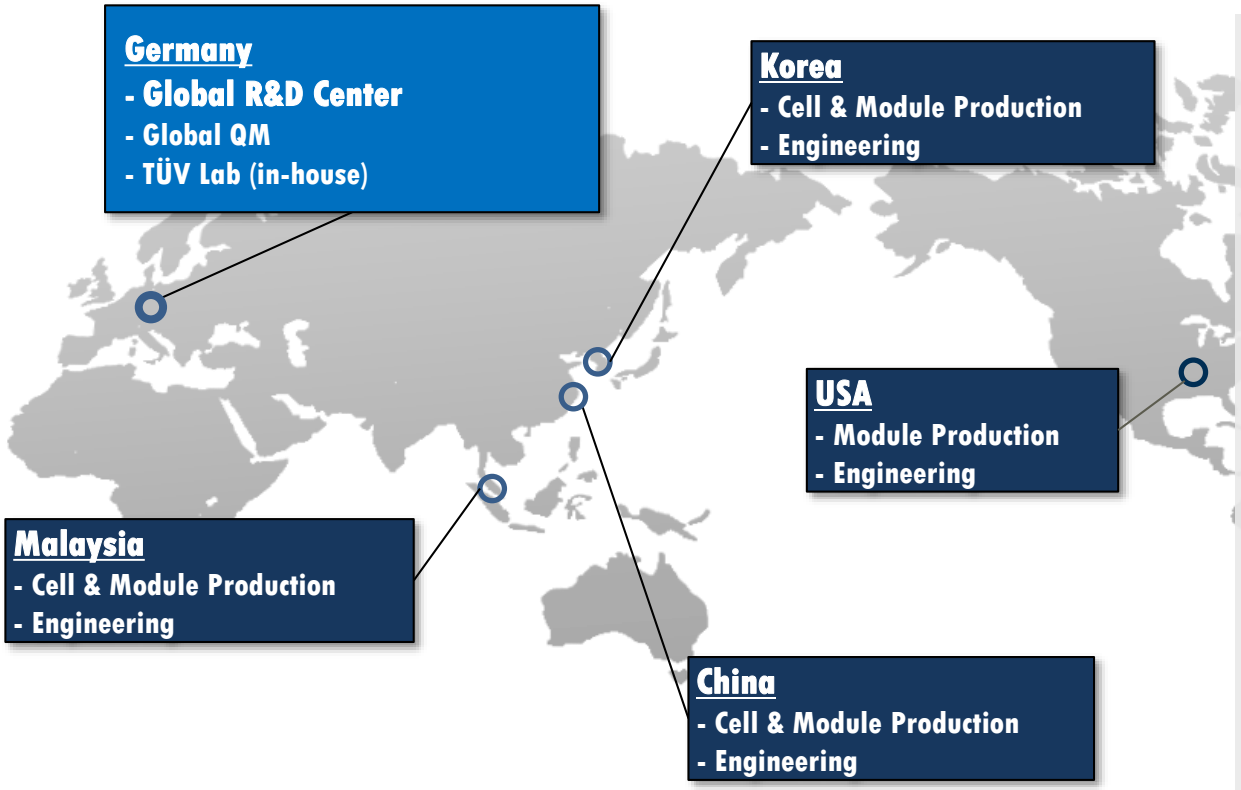
Hanwha Q Cells

Silicon PV/nPV Workshop, March 31st 2022

Q CELLS
Engineered in Germany

Hanwha Q Cells

GLOBAL OPERATION FOR R&D AND PRODUCTION

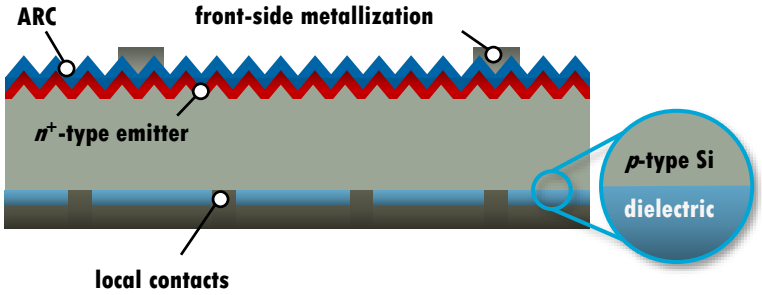


* 2021 figure

Q CELLS Q.ANTUM TECHNOLOGY

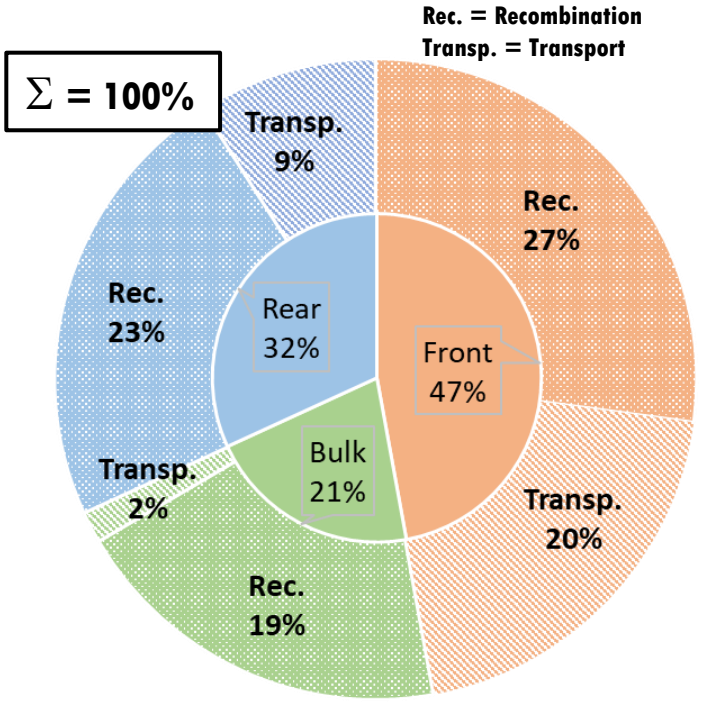
Cell structure and cell efficiency incorporating Q.ANTUM[1-3] technology

powered by Q.ANTUM



- Evolutionary development of Al-BSF cell structure
- PERC-like structure with additional features
- Patent-protected components
- Lean & cost-effective process
- Effective suppression of degradation effects (PID, LID, LeTID)
- Efficiency ~ 23.6 % in Dec. 2020

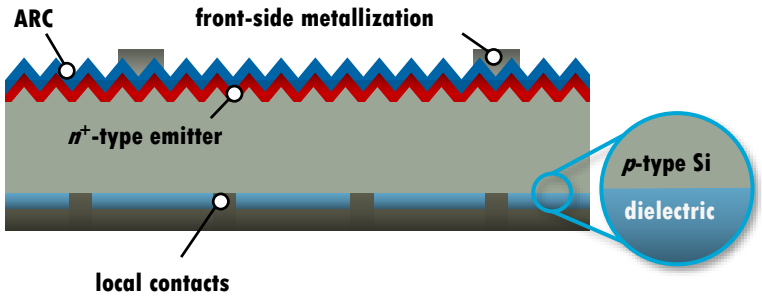
percentage of electrical power loss for different loss channels



[1] P. Engelhart *et al.* "Q.ANTUM - Q-Cells Next Generation High-Power Silicon Cell & Module Concept" in Proc. 26th EUPVSEC, 821-826, Hamburg, Germany, 2011.
[2] A. Mohr *et al.* "20%-Efficient Rear Side Passivated Solar Cells in Pilot Series …" in Proc. 26th EUPVSEC, 2150-2153, Hamburg, Germany, 2011.
[3] F. Fertig *et al.*, Energy Procedia, vol. 124, pp. 338–345, 2017.

Q CELLS EVOLUTIONARY DEVELOPMENT OF Q.ANTUM TO Q.ANTUM NEO

powered by Q.ANTUM



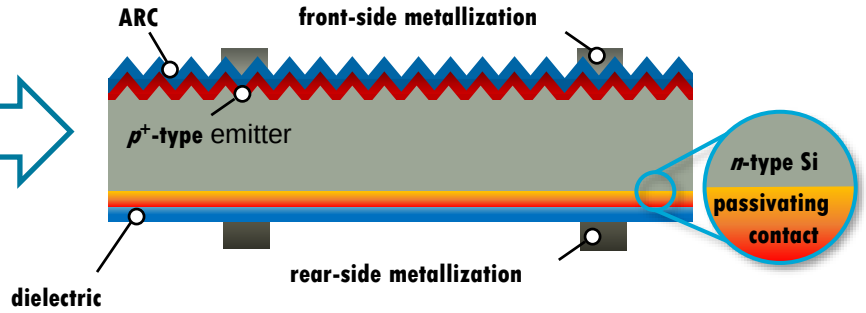
Evolution into Q.ANTUM

- 2 additional steps vs. Al-BSF
- Possible to retrofit Al-BSF lines
- Same module technology as Al-BSF

texture
diffusion
edge isolation

dielectrics + ARC
LCO + metallization

Q.ANTUM NEO



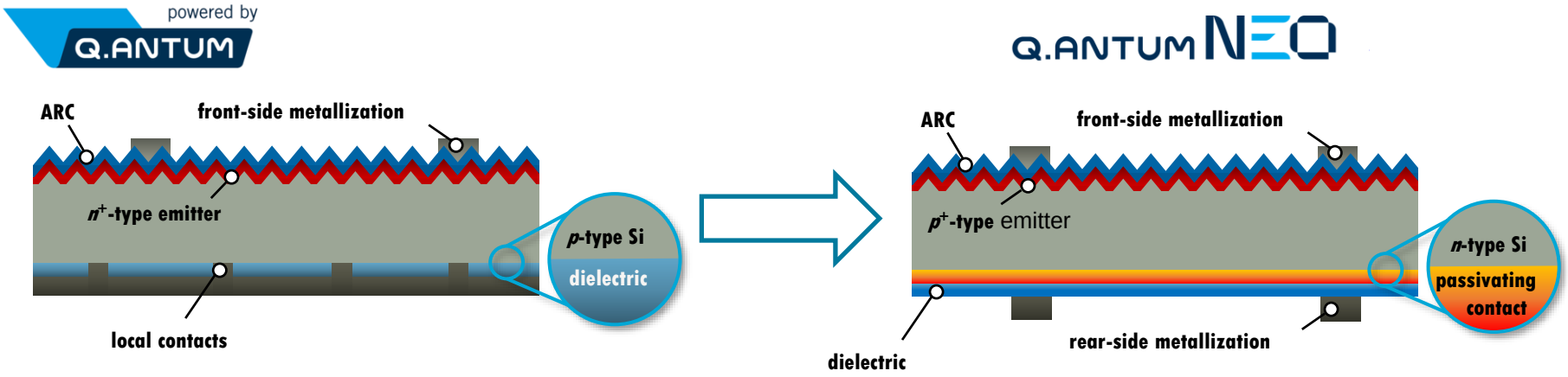
Evolution into Q.ANTUM NEO[1]

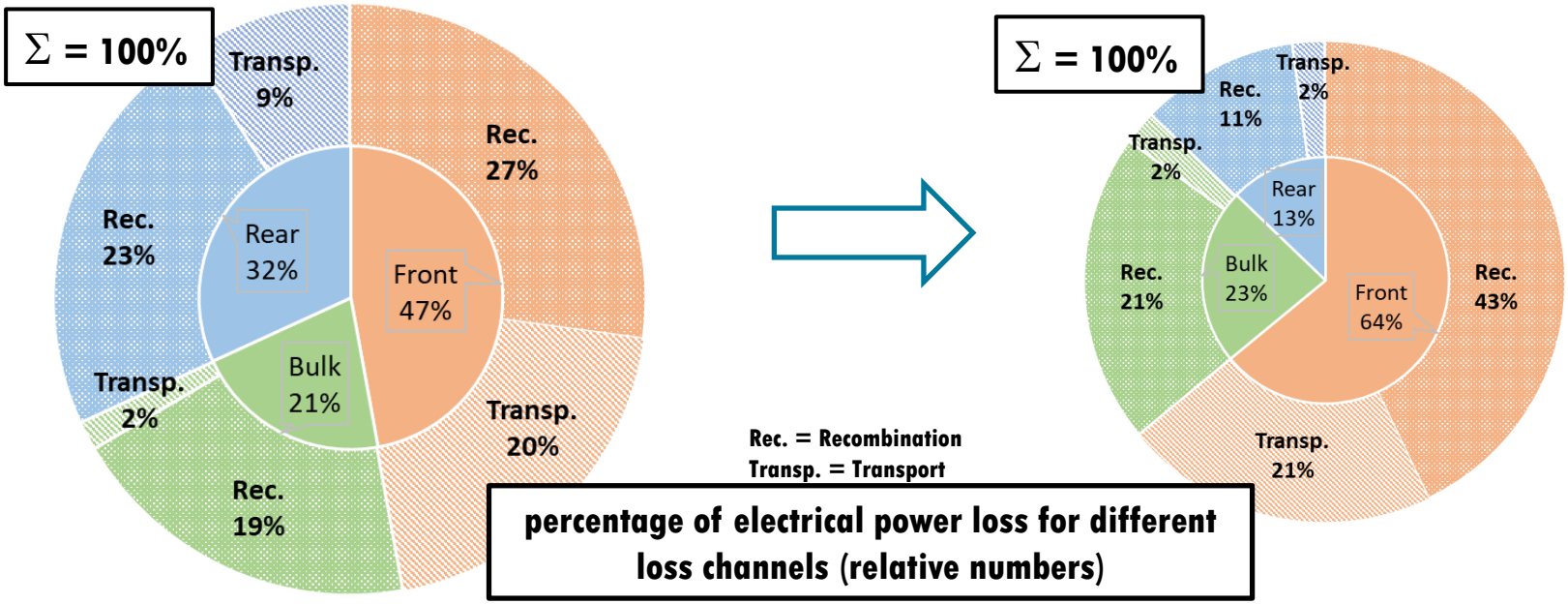
- 2 additional steps vs. Q.ANTUM
- Possible to retrofit Q.ANTUM lines
- Same module technology as Q.ANTUM

texture
diffusion
edge isolation
passivating contact
clean
dielectrics + ARC
metallization

[1] J.W. Müller *et al.*, Silicon PV 2021.

Q CELLS EVOLUTIONARY DEVELOPMENT OF Q.ANTUM TO Q.ANTUM NEO



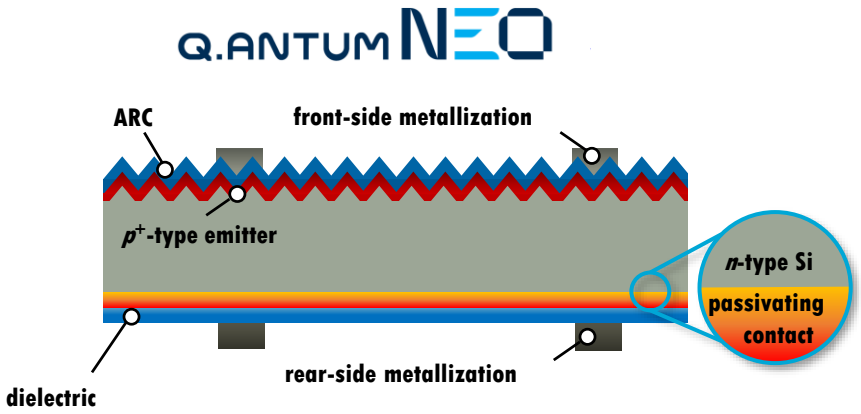


Rec. = Recombination
Transp. = Transport

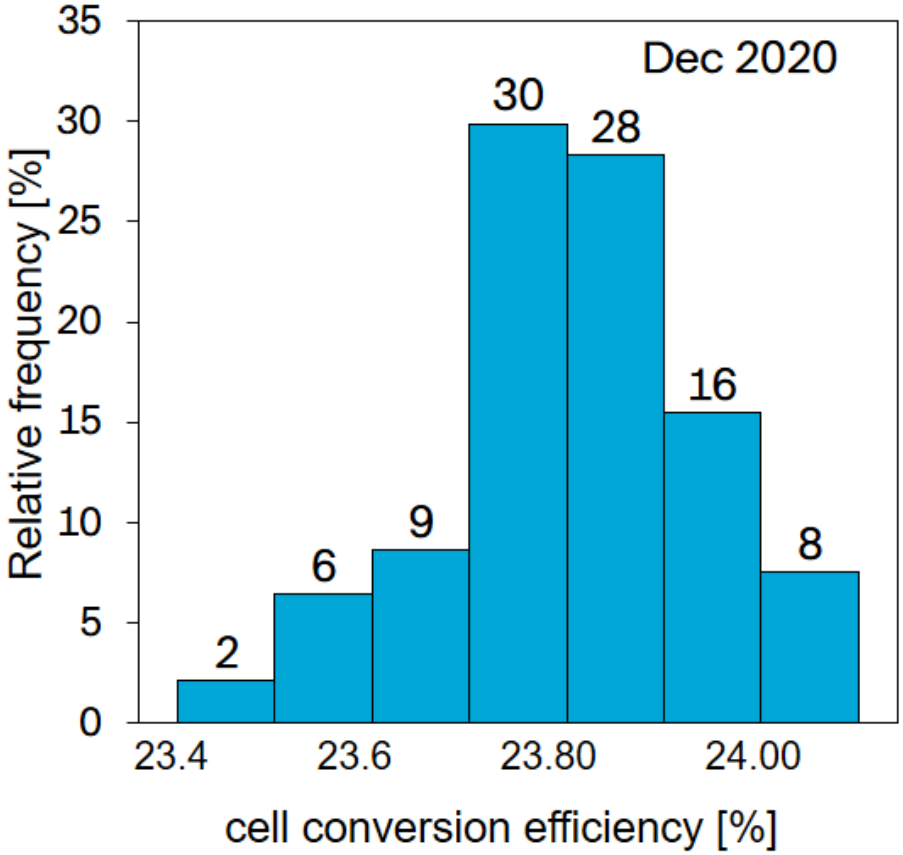
percentage of electrical power loss for different loss channels (relative numbers)

Q CELLS Q.ANTUM NEOTECHNOLOGY

Cell structure and cell efficiency incorporating passivating contact[1] technology



- Passivating rear-side contact
- *n*-type Cz silicon substrate
- Lean & cost-effective process
  (HE, ARC module optimized, screen print, …)
- comaptibile w/ standard Q.antum module technology
- Efficiency headroom > 25%



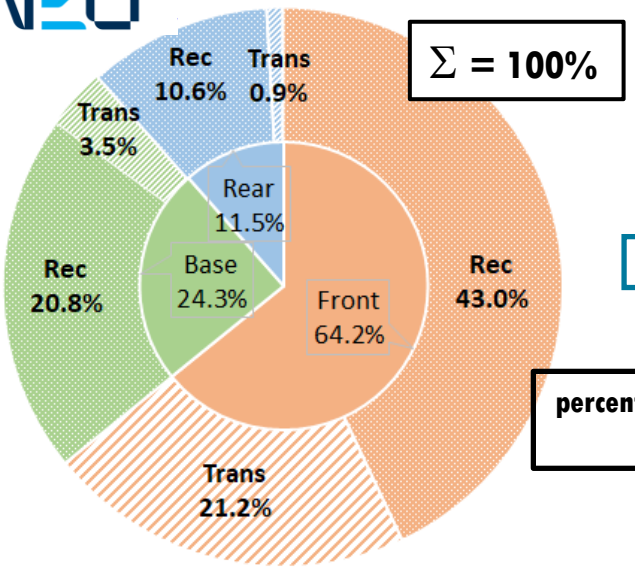
results presented @ Silicon PV 2021:
average η= 23.88%, V_{oc} > 700 mV

[1] J.W. Müller *et al.*, Silicon PV 2021.

Q.ANTUM NEO: KEY IMPROVEMENTS SINCE LAST YEAR

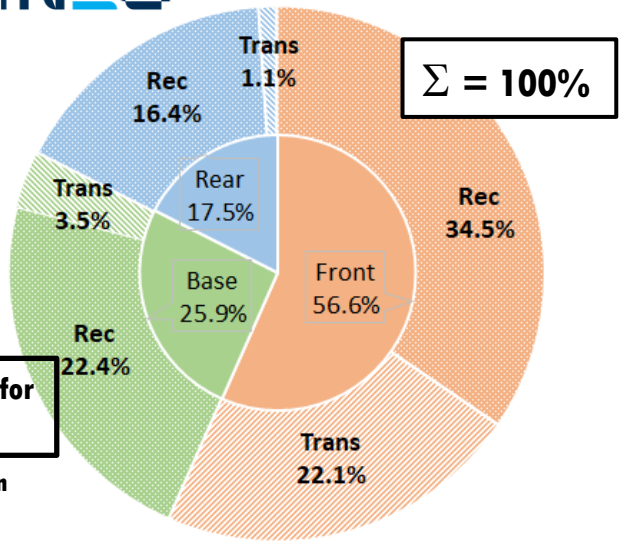
Q.ANTUM NEO

Dec 2020



Q.ANTUM NEO

Feb 2022



percentage of electrical power loss for different loss channels

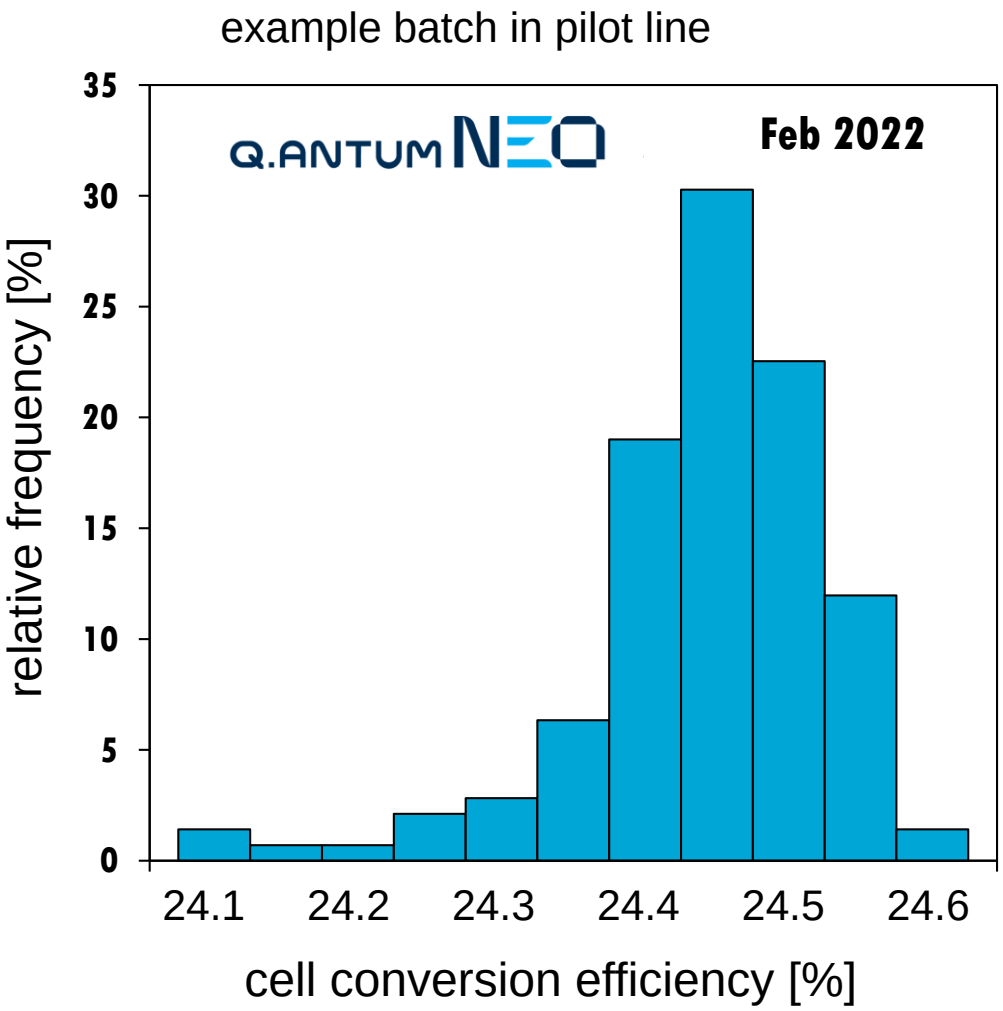
Rec. = Recombination
Transp. = Transport

Main losses in December 2020 from front side recombination
Key improvements actions in last year:

- **Reducing front side recombination by advanced emitter profile and passivation, reduce j_{0e} from 15 to < 10 fA/cm²**
- **Reducing front contact recombination by advanced screen printing contact, reduce $j_{0,met}$ from 650 to < 200 fA/cm²**

→ Increase Voc by ~15 mV

Q.ANTUM NEO: RESULTS IN PILOT LINE

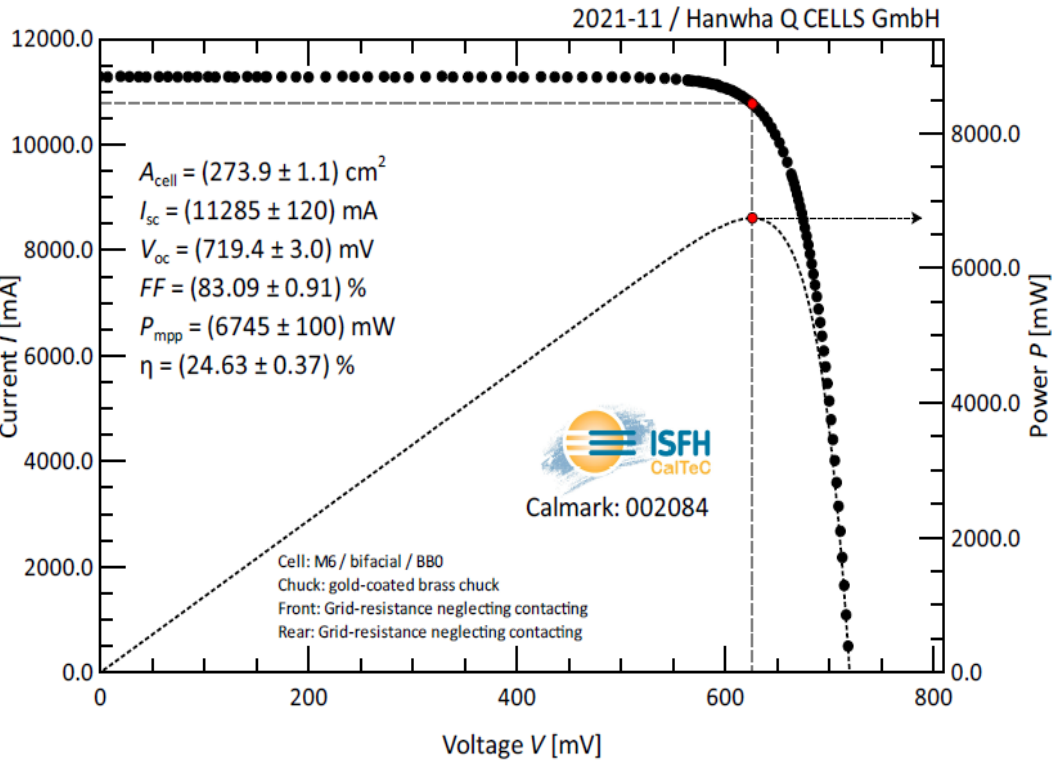


Q.ANTUM NEO achievements in Feb. 2022:

- **Tight distribution**
  - **Average η = 24.46 %**
  - **V_{oc} ~ 715 mV**
  - **Best cells η > 24.6 %**
- **Lean & cost effective process (screen printed front and rear side), using exclusively mass-production processes**
- **Standard M6 Cz-wafer**
- **12 BB, module optimized ARC (CTM ~100% with ZERO GAP technology)**

Q.ANTUM NEO: RESULTS IN PILOT LINE

Independently confirmed cell efficiency:



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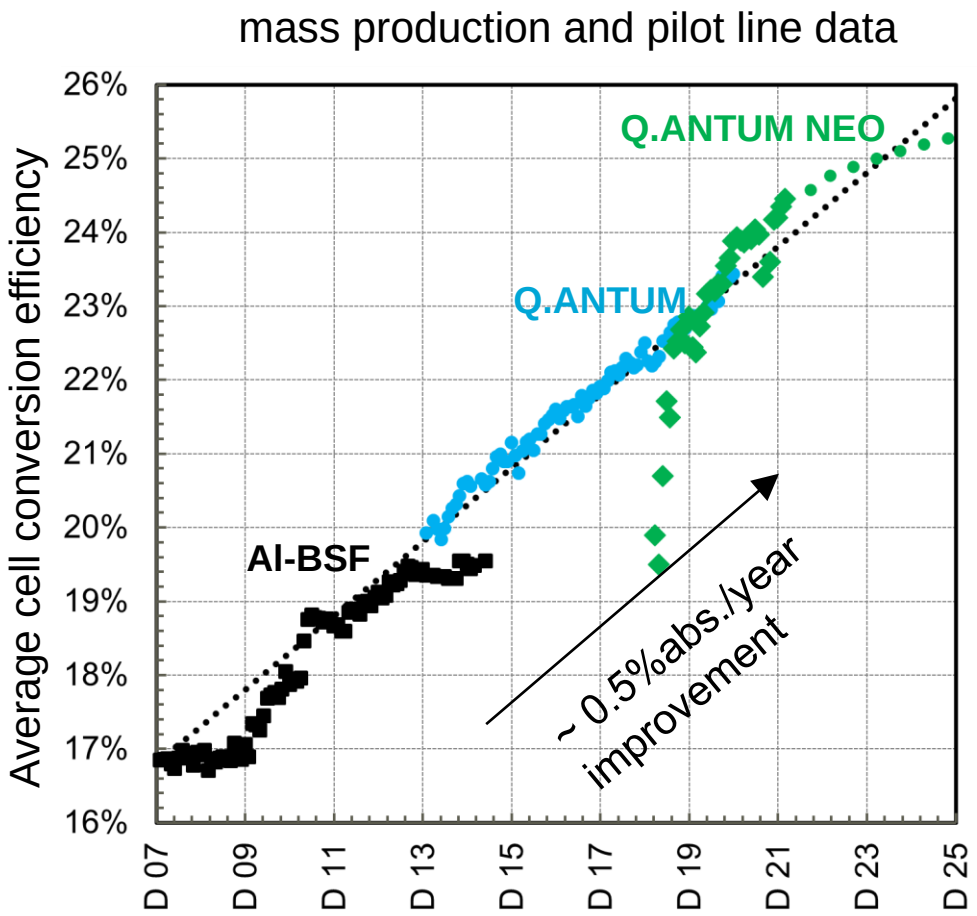
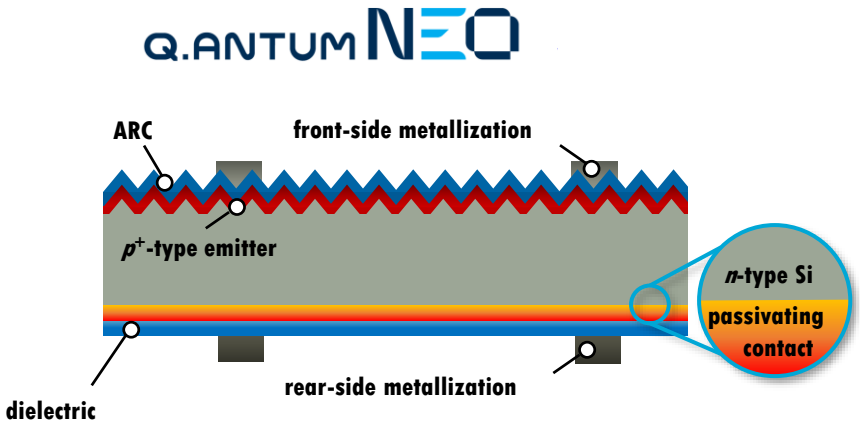
Q CELLS EVOLUTIONARY CELL EFFICIENCY DEVELOPMENT



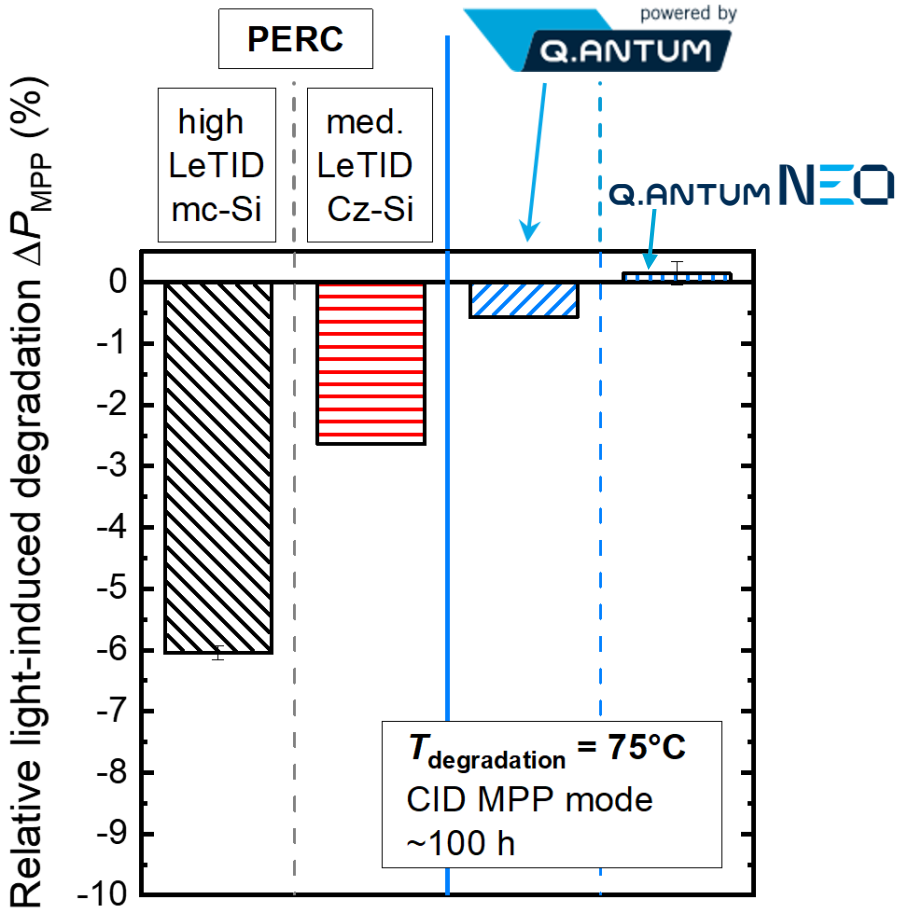
- **Q.ANTUM NEO evolutionary advancement of Q.ANTUM technology**
- **Steep learning rate in last years**
- **Average efficiency of 24.5% achieved, using exclusively mass-production processes**
- **Further improvement potential, efficiency headroom > 25 %**
- **Learning rate expected to continue for next years**

Q CELLS Q.ANTUM NEO TECHNOLOGY



- **Effective suppression of degradation effects, no PID, LID, LeTID[1]**
- **Low temperature coefficient α_{PMPP}= -0.30%/K due to high Voc**

→ **Several percent higher (location dependent) specific energy yield**



[1] F. Kersten *et al.*, Silicon PV 2022.

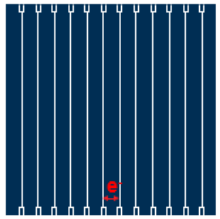
Q CELLS SOLAR MODULE TECHNOLOGY

MODULE TECHNOLOGY

powered by Q.ANTUM DUO

Improved module technology based on

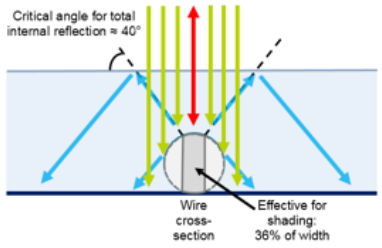
- **Half cells**
- **12 round wire**



Shorter distance reduces effect of resistance on electrons → +2.0% Power

1× full cell → ~10 Amps ~0.7 Volts

1× half cell → ~5 Amps ~0.7 Volts → +3.0% Power

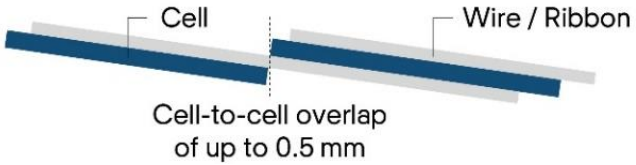


→ +2.5% Power

ZERO-GAP TECHNOLOGY

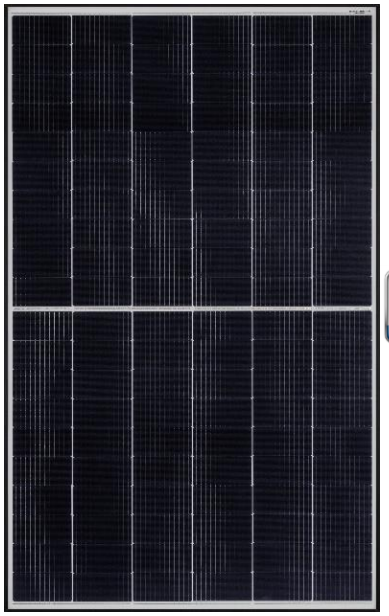
powered by Q.ANTUM DUO Z

- **No spacing between cells in string**
- **Compact module design with improved module efficiency**



Q CELLS Q.TRON MODULE TECHNOLOGY

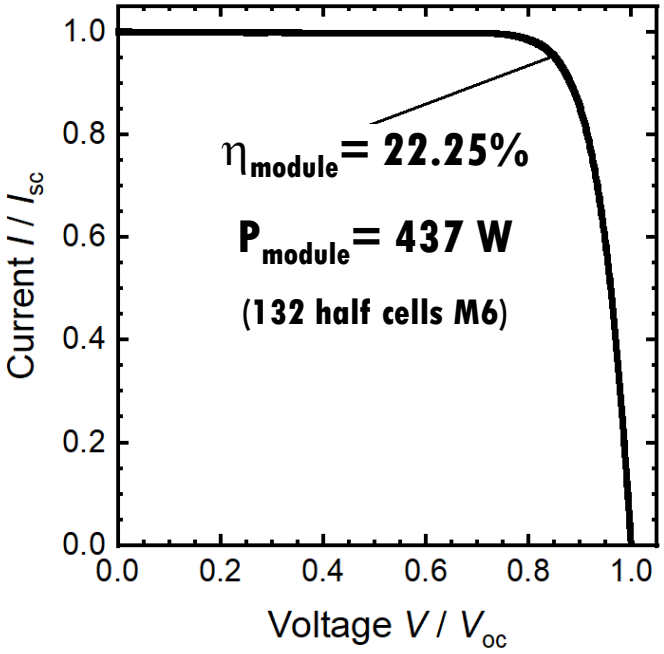
Q.ANTUM NEO



25 YR Warranty Product & Performance

Q CELLS Advanced Yield Security

TÜVRheinland CERTIFIED Quality Controlled PV

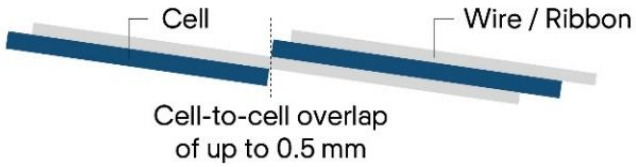


ZERO-GAP TECHNOLOGY

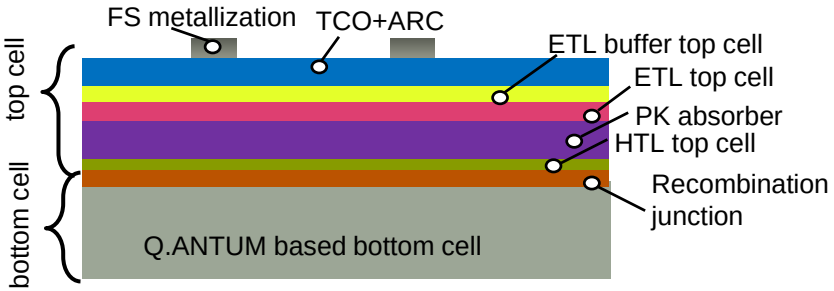
- No spacing between cells in string
- Compact module design with improved module efficiency

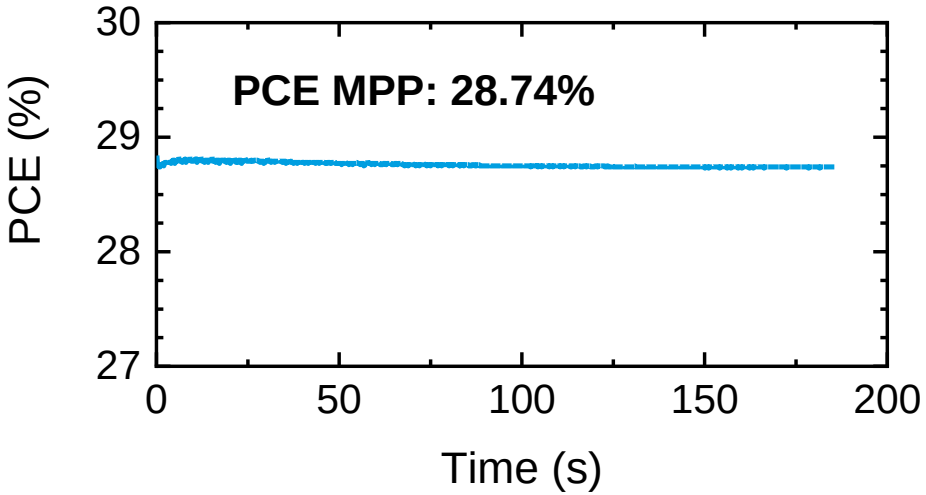
Current status module development

- State-of-the art module interconnection tech. w/ CTM ~ 100% can be applied (half-cells, multi-wire, standard encapsulants, zero-gap tech.)
- **22.25% full-area module efficiency (437 W)** achieved (full module size, 132 HC M6 layout)



OUTLOOK: PEROVSKITE-SILICON-TANDEM

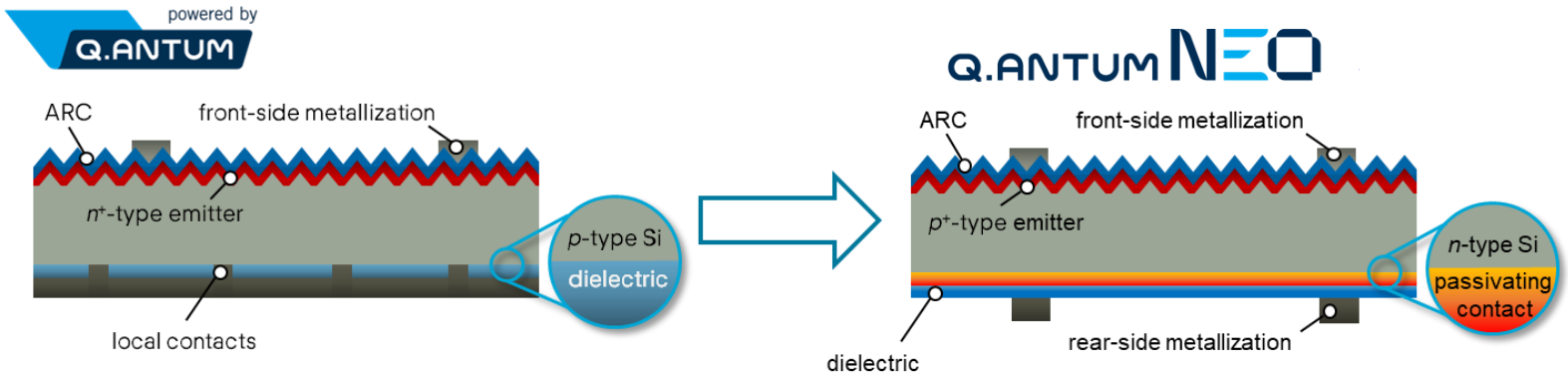




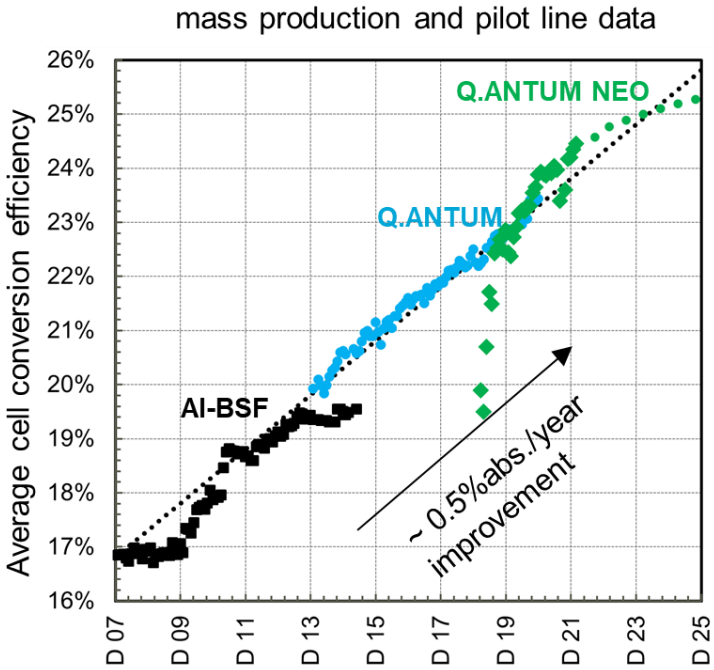
2-terminal Perovskite-Silicon tandem solar cell in close cooperation with HZB (group of Steve Albrecht)

- **Overcome practical limit of a silicon cell**
- **Bottom cell based on Q.ANTUM technology**
- **28.74 % cell efficiency, V_{OC} > 1.9 V**
- **Efficiency headroom > 30%**

SUMMARY & OUTLOOK



- **Q CELLS evolutionary development from Q.ANTUM (PERC like) to Q.ANTUM NEO (TOPCON like)**
- **Average Q.ANTUM NEO cell efficiency of 24.46% and peak efficiency > 24.6% using exclusively mass-production processes and module optimized ARC**
- **Further improvement potential within next years, cell efficiency > 25% expected within next months**
- **Full area module efficiency of 22.25%**
- **Q.ANTUM NEO with improved specific energy yield due to, e.g. low temperature coefficient, no PID/LID/LeTID**
- **Perovskite-Q.ANTUM tandem technology as next generation with efficiency headroom >30 %, current best value 28.7%**



Thank you.

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