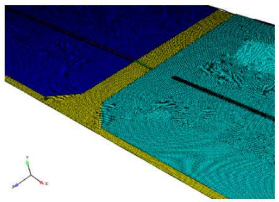
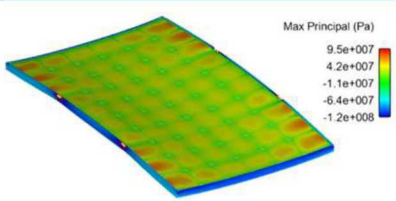
DuraMAT
Durable Module Materials Consortium

SAND2019-1937PE

DuraMAT capability area:

Multi-scale, Multi-physics Modeling for PV Reliability





PRESENTED BY

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SLAC NATIONAL ACCELERATOR LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

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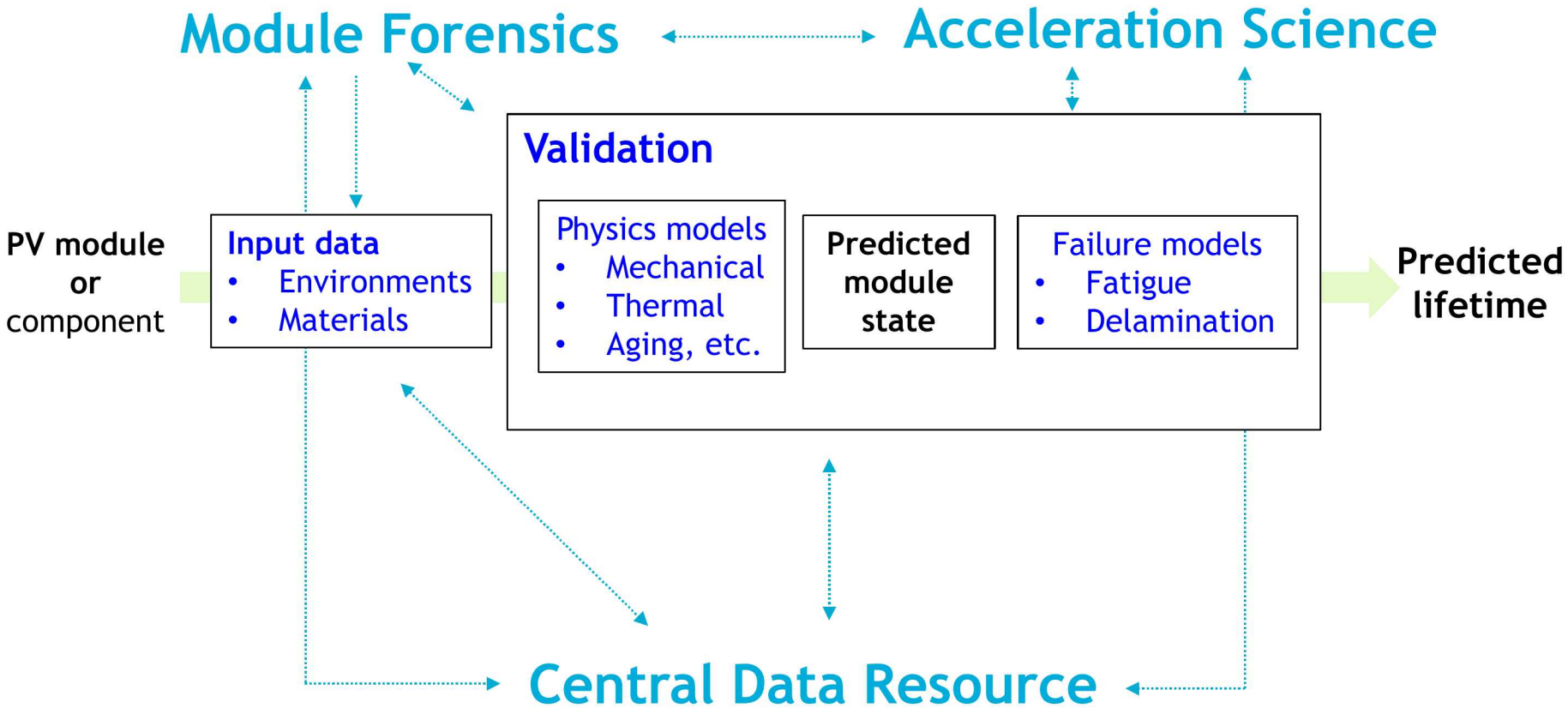
Contents

- Capability area introduction and goals
  - Projects in support of a multi-scale, multi-physics model
- Capability highlight: A full module-scale mechanical model
  - Purpose and applications
  - Model development process
  - Some current results
- Summary and next steps

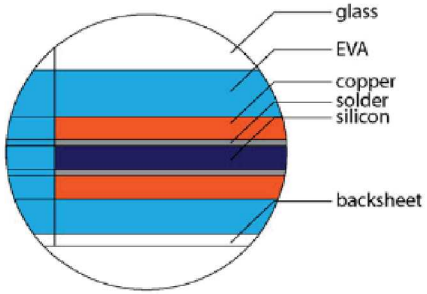
Multi-scale, Multi-physics Modeling for PV Reliability

- **Grand goal:** A modeling capability to accurately predict module lifetime
  - Applicable to multiple PV scales: From interconnects to full modules
  - Incorporating multiple degradation physics: Mechanical stress, thermal stress, materials effects, and more

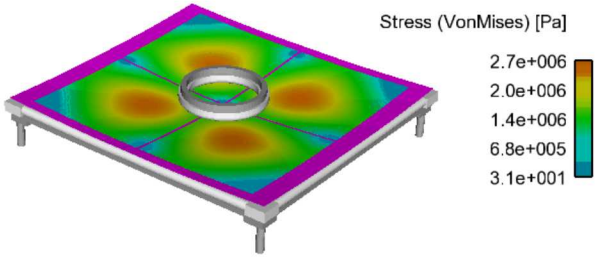


Multi-scale, Multi-physics Modeling for PV Reliability

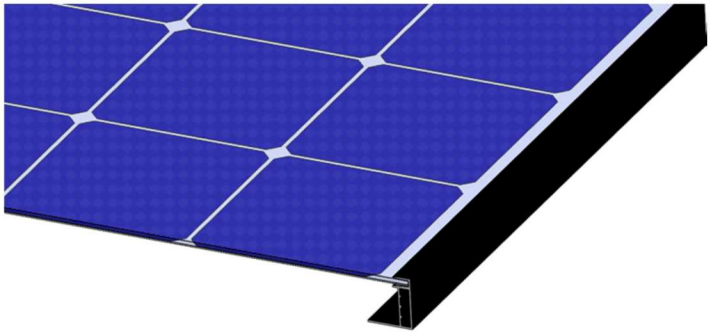
Modeling capabilities to predict stressors at various *scales* of a PV module, leveraged with projects within DuraMAT network:



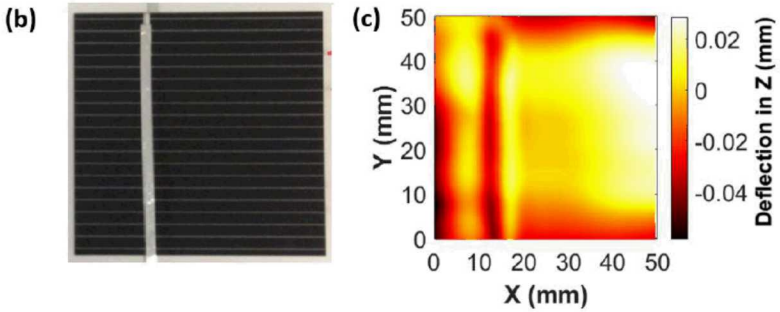
Individual Interconnections
[Bosco, NREL]



Mini-Modules [Hacke, Owen-Bellini; NREL]



Full Modules [Hartley, SNL]



Tabbed cells [Bertoni, ASU]

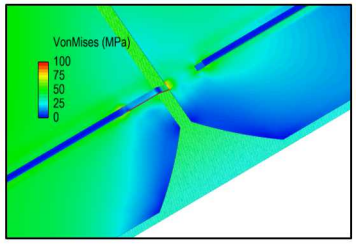
Scales NOT included are system level response (i.e. performance quantities), and molecular effects (except as manifested in material responses)

Multi-scale, **Multi-physics** Modeling for PV Reliability

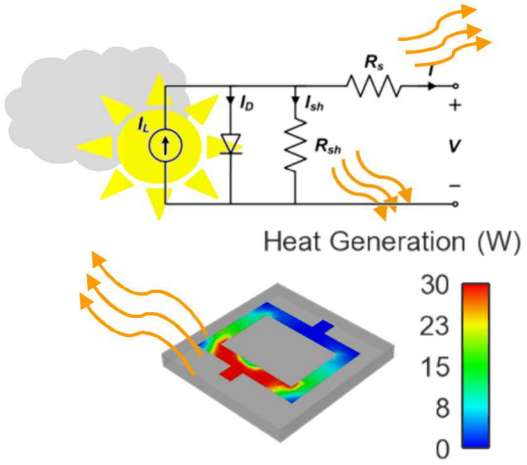
Modeling capabilities incorporate various physics causing or related to degradation:

Mechanical stress
[Hartley, SNL]

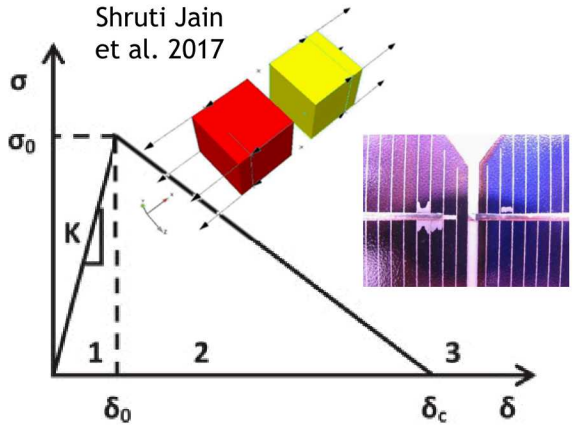
ΔT from -40°C to +85°C



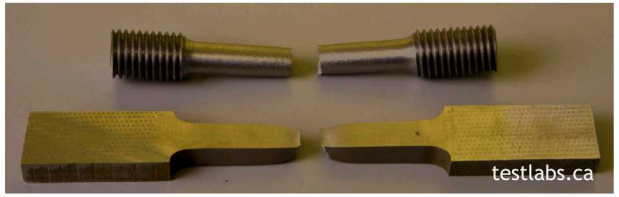
Thermal stress [SNL]



Electrical-thermal coupling [SNL]



Interfacial fracture [Bosco, NREL]



Material responses:

- Temperature dependencies [Maes, SNL]
- Viscoelasticity [Maes, SNL]
- Fatigue damage [Bosco, NREL]
- Aging effects [Owen-Bellini, NREL; Moffit, SLAC]

Additional physics could include moisture transport, corrosion chemistry, and many others!

Contents

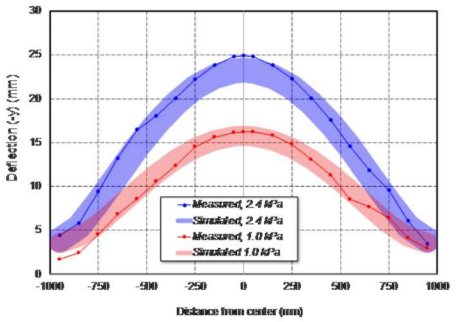
Capability highlight: A Module-Scale Mechanical Model

- **Goal:** Develop a full-module model predicting internal stresses under mechanical loads

- **Purpose and applications:**
  - Confirm applicability of finite element methods to PV modules
  - Develop best practices for simulating PV module scenarios
  - Confidence in full-module models enable:
    - Propagation of boundary conditions to smaller-than-module scale (mini-modules, cells, interconnects) tests
    - Parameter sensitivity studies for module and material design

Test module with datasheet and Bill of Materials (BOM)

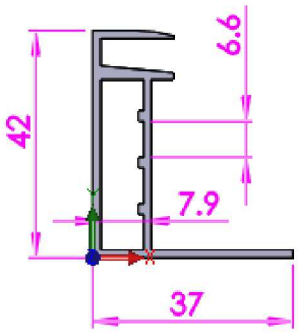
Mechanical load experiments and simulations

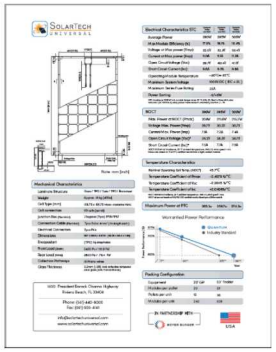


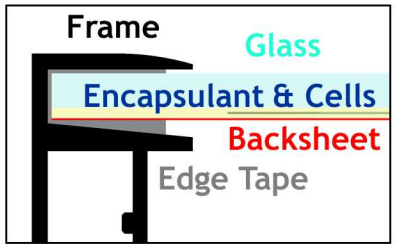
Comparison of measured vs. simulated deflections

Model Development Process

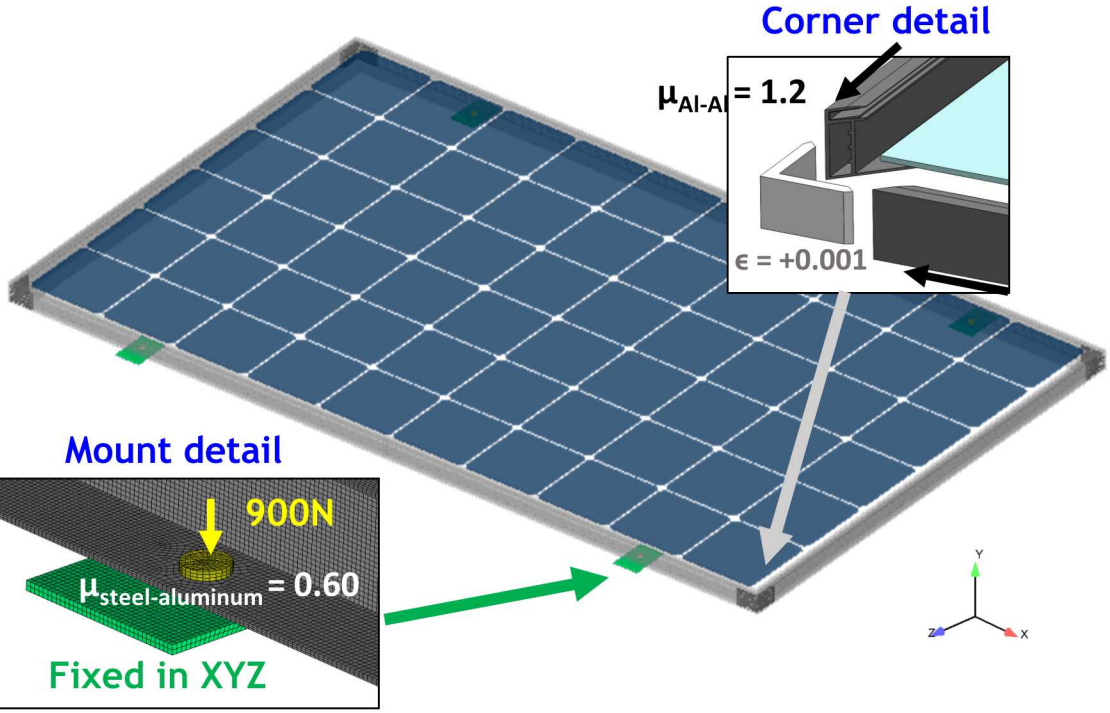
- **Test module:** SolarTech Quantum 300 Series
  - 60-cell, mono-PERC, glass-backsheet, aluminum framed
  - Chosen for representative construction and easily available example
- Computational model development mirrored actual module construction







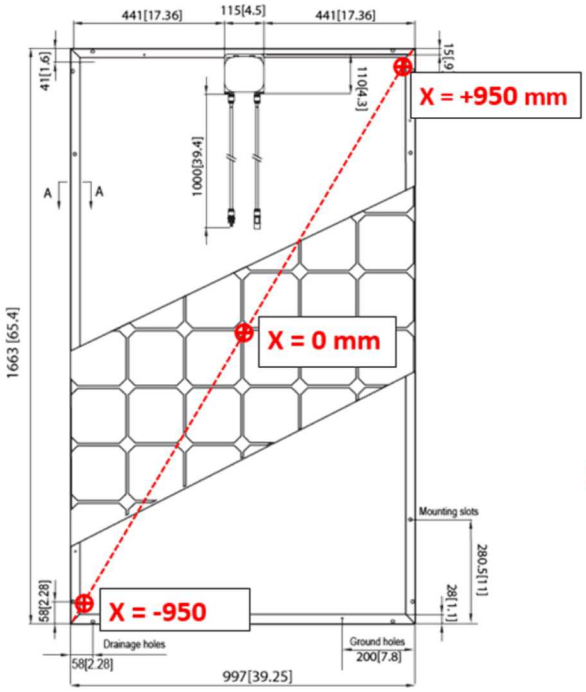
Dimensions and materials derived from module & datasheet



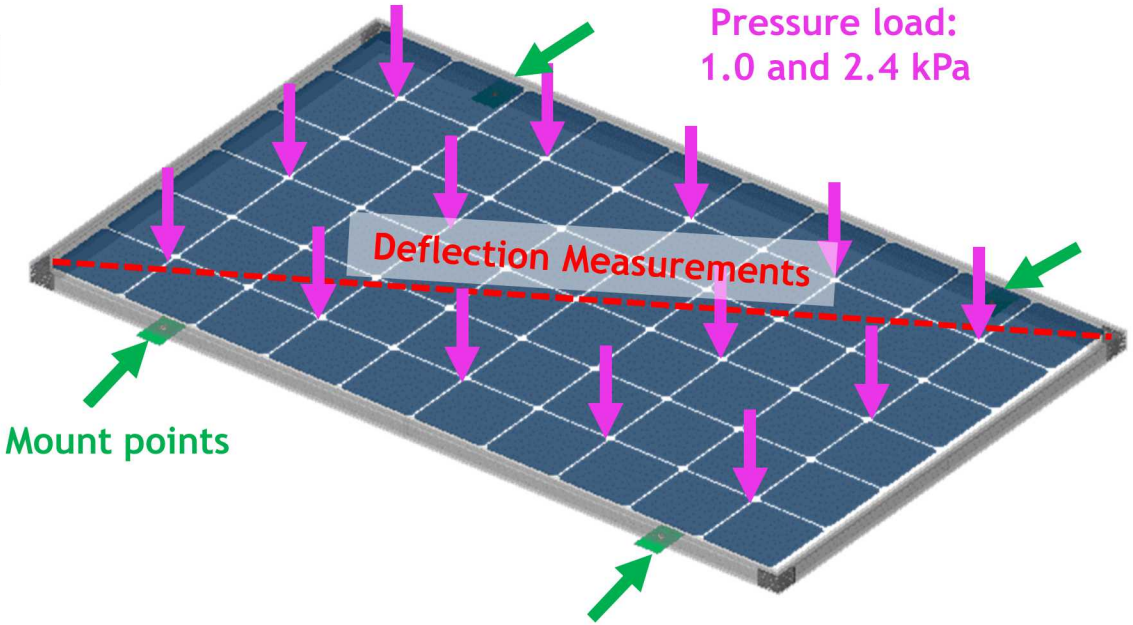
Finite element model developed to match actual features

Mechanical Tests and Simulations

- **Test condition:** IEC61215 pressure load, 1.0 kPa and 2.4 kPa
  - **Experimental case:** Mounted where specified, loaded with sandbags
  - **Simulated case:** Constrained as shown, pressure loads applied
- Deflection measured across the diagonal vs. fixed beam



Deflection measurement points

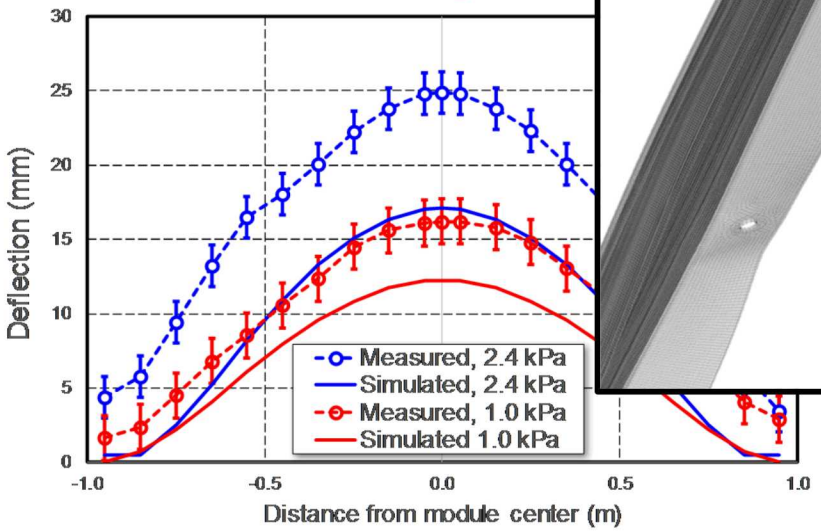


Load case boundary conditions

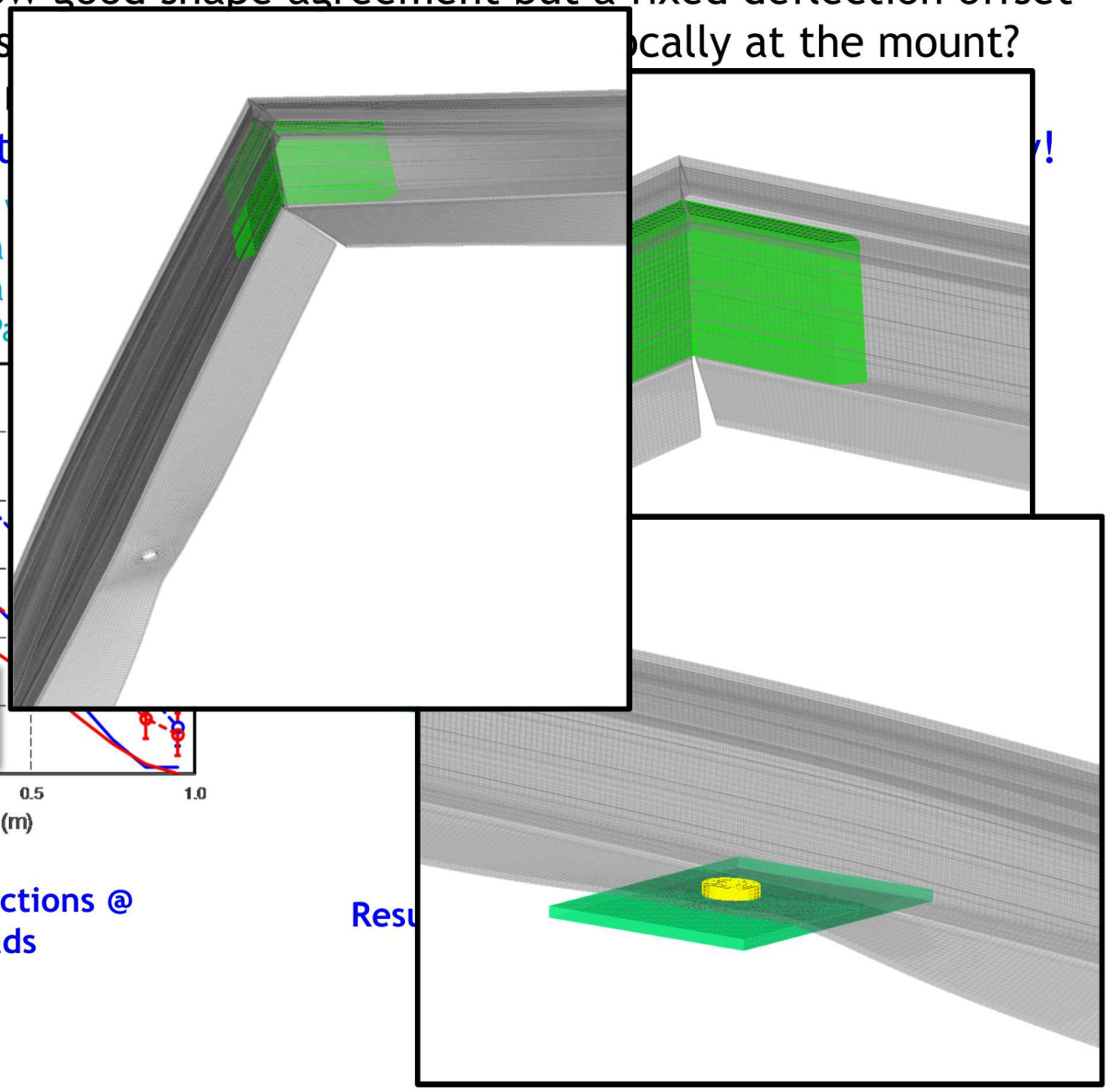
Mechanical Tests and Simulations: Results

- Results comparisons show good shape agreement but a fixed deflection offset
  - **Causes:** Deflections
    - 2.4 kPa on 1.6
- Module construction det

Assume offset increases linearly
0 mm offset @ 0.0 kPa
2 mm offset @ 1.0 kPa
4.8 mm offset @ 2.4 kP



Measured vs. Simulated Deflections @ 1.0 kPa and 2.4 kPa loads



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Mechanical Tests and Simulations: Results and Next Steps

- Parameter sensitivity studies and what-if analyses are in progress- answers questions such as:
  - What if a weaker glass is used?
  - What if a stronger glass but weaker edge tape is used?
- With enough samples, correlations and sensitivities can be found
  - Analyzed for this module model + a glass-glass thin-film module design
    - Full results at IEEE PVSC 2019!

Parameter	Min	Current value	Max
Glass thickness [mm]	2.2	3.2	4
Glass modulus [GPa]	65	73	75
Edge tape modulus [MPa]	0.5	0.5	2.0
Friction coefficient	0.2	0.6	1.3
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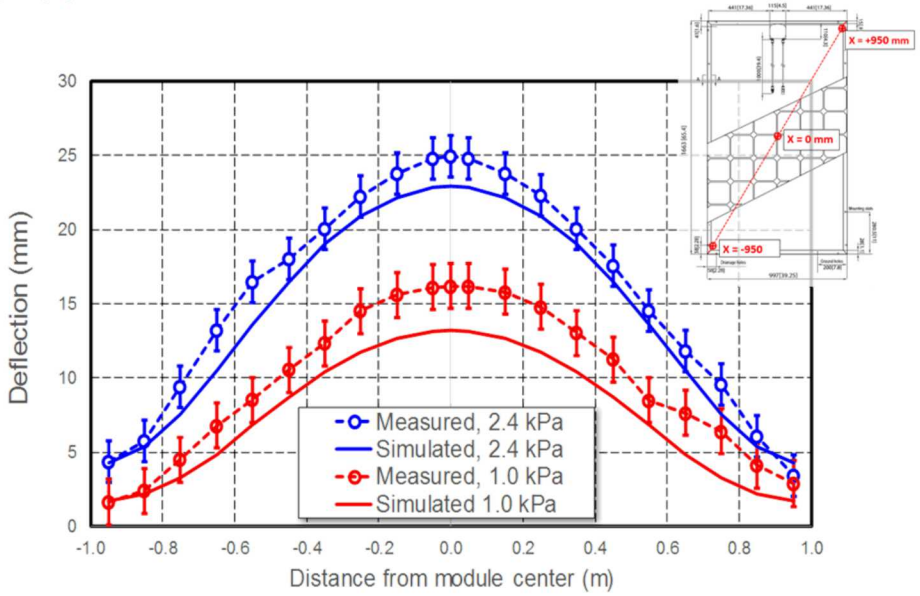

Measured vs. Simulated Deflections @ 1.0 kPa and 2.4 kPa loads with parameter adjustments

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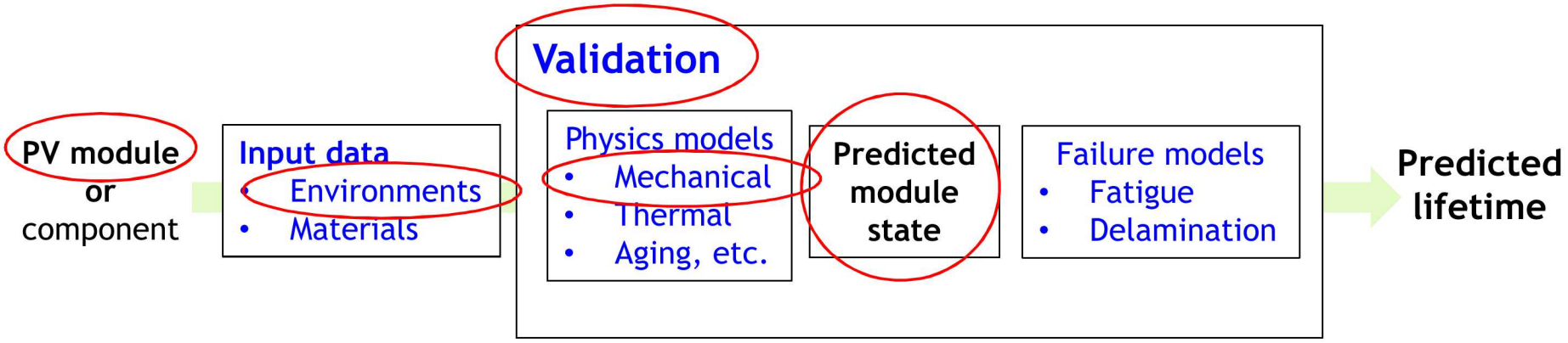
Summary

- Introduced the multi-scale, multi-physics modeling capability area



- Highlighted one capability: a module scale mechanical model, which took a:
  - Full scale PV module;
  - under mechanical pressure loading environments;
  - through predicted deflection under load with experimental validation

- Many more capabilities development! Some immediate next steps:
  - Use full module mechanical results to correlate to mini-modules
  - Incorporation of material viscoelasticity