Prototyping and Validation of Two Low-Cost Inline CPV Module Efficiency Characterization Methods

Michael Sinclair, Stephen Caelers, Pascal Dufour,
Stefan Myrskog, John Paul Morgan

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The Problem

- Quantifying CPV performance is challenging!
  - Requires a collimated solar simulator (CSS) to test to Concentrator Standard Test Conditions (CSTC)
  - High CAPEX and high operating costs
  - Hard to maintain calibration
  - Requires highly trained operators and technicians
  - Repeatability σ = 2.8% (current system at MSI)

Is there another way?

The Solution

- Prototype new tools for low cost in-line efficiency estimation

- Use standard automation equipment to reduce complexity and minimize sources of variation

- These alternative techniques will estimate optical efficiency (I_{sc}) for individual optics
  - Module P_{mp} can be calculated based on an average cell model (Future work!)

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The Solution

- Key Question:
  - How accurate does the estimate need to be?

Agenda

1. Laser Solar Simulator
    i. Approach
    ii. Experimental Set-Up
    iii. System Performance
    iv. Results

2. Electroluminescence Imaging
    i. Approach
    ii. Experimental Set-Up
    iii. System Performance
    iv. Results

3. Conclusions

LSS: Approach

1. The output beam from a fibre-coupled laser system is collimated over the area of one optic
2. A two-axis translation stage shuttles the sample under the collimated beam
3. I_{sc} is directly measured for each individual optic

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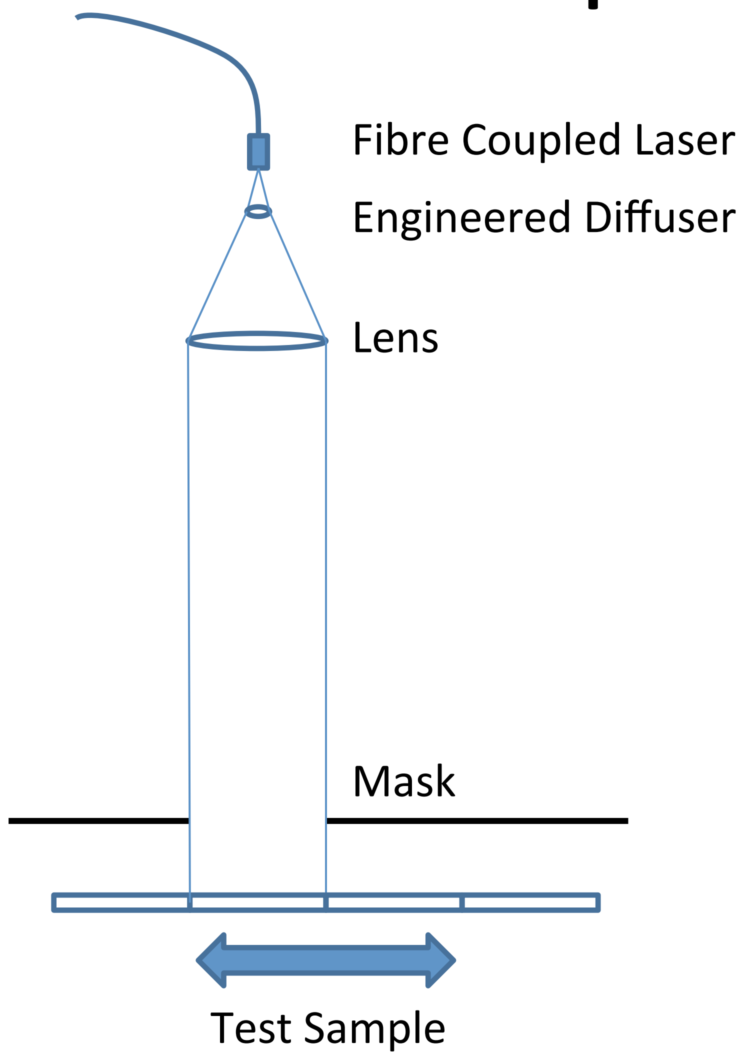
LSS: Experimental Set-Up



- The sample translates under a stationary imaging system
- Not shown: Laser source, 2-axis translation stage, LabVIEW GUI

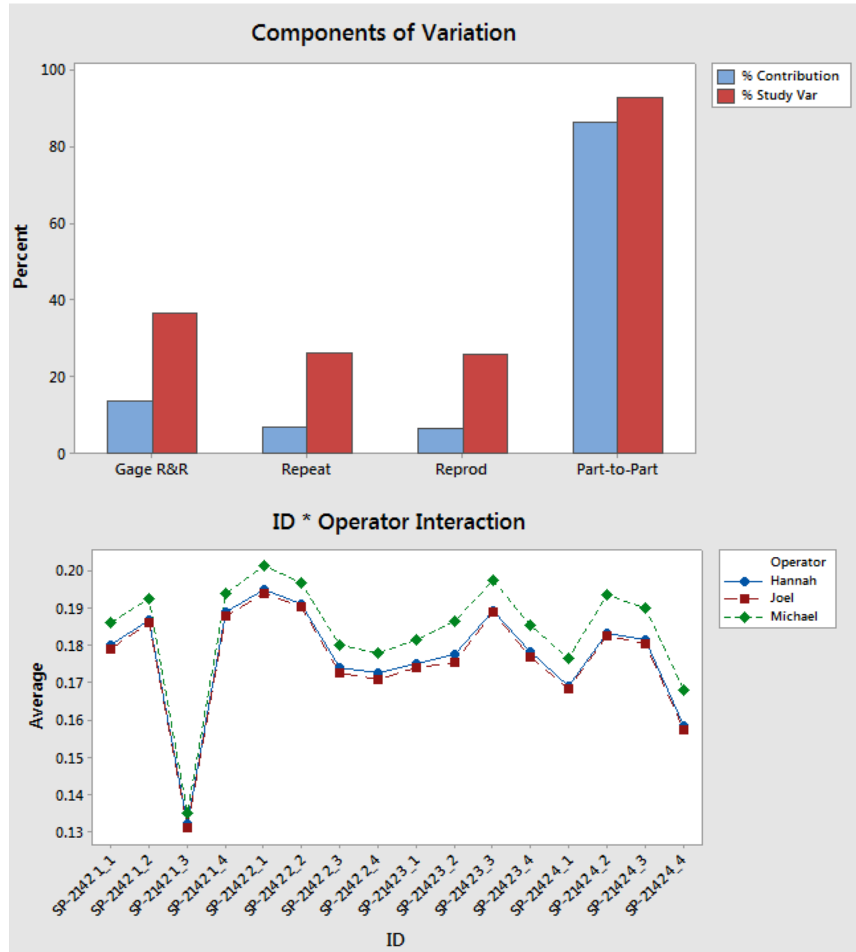
LSS: System Performance

- Collimation: ±0.5°
- Irradiation Non-Uniformity: ±5%
- Fast results: less than 2 seconds per optic

LSS: System Performance

- Gauge R&R results:
  - Not great!
  - Repeatability σ = 3.4%

Source	% Contribution (of VarComp)
Total Gage R&R	13.49%
Repeatability	6.88%
Reproducibility	6.61%
Part-to-Part	86.51%
Total Variation	100%



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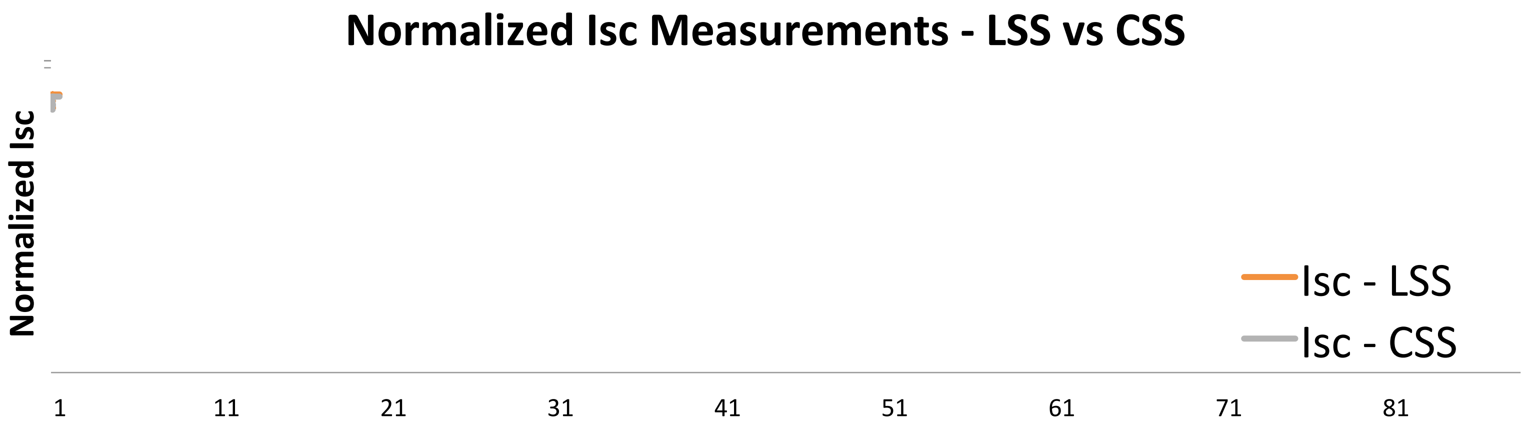
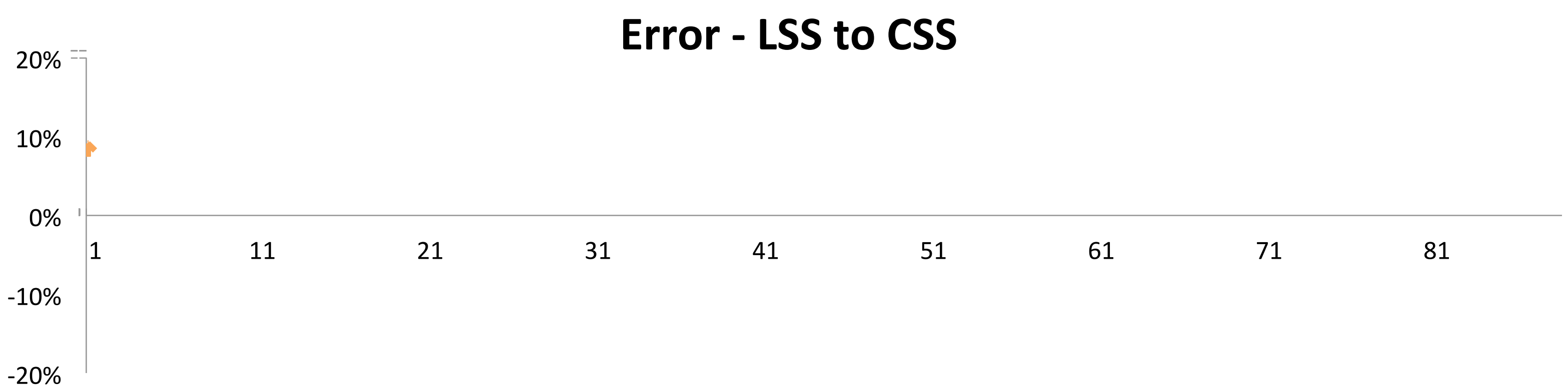
LSS: Results





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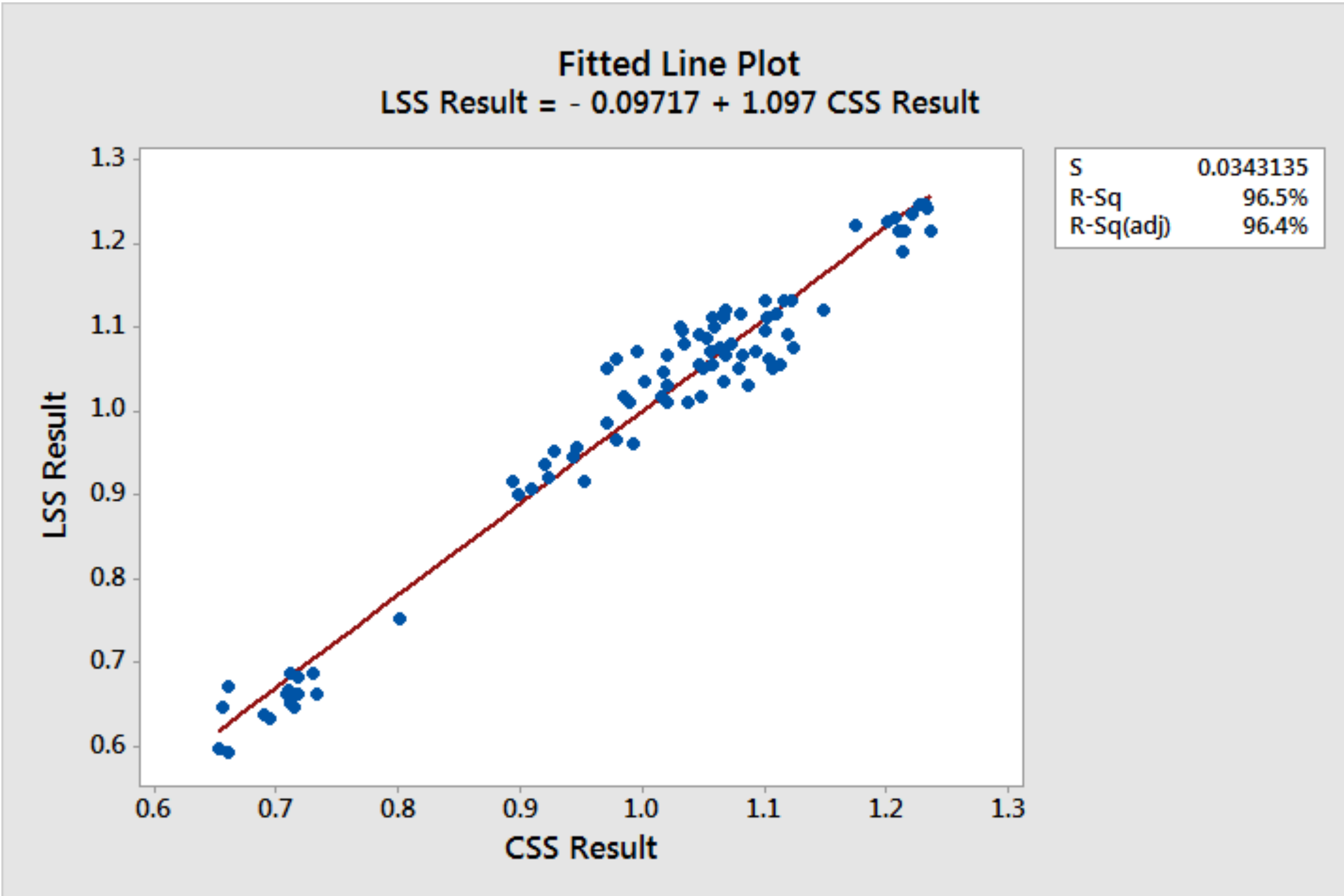
LSS: Results



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Agenda

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EL: Approach

- Electroluminescence (EL) imaging is widely used in PV manufacturing for defect detection
- Reversible Systems
  - Solar cell -> LED
  - Concentrator -> Collimator

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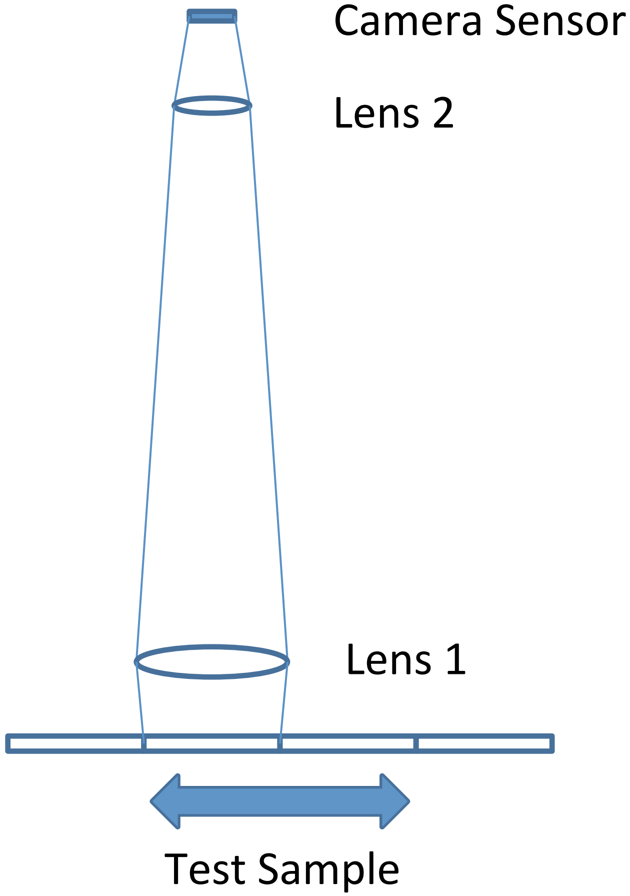
EL: Approach

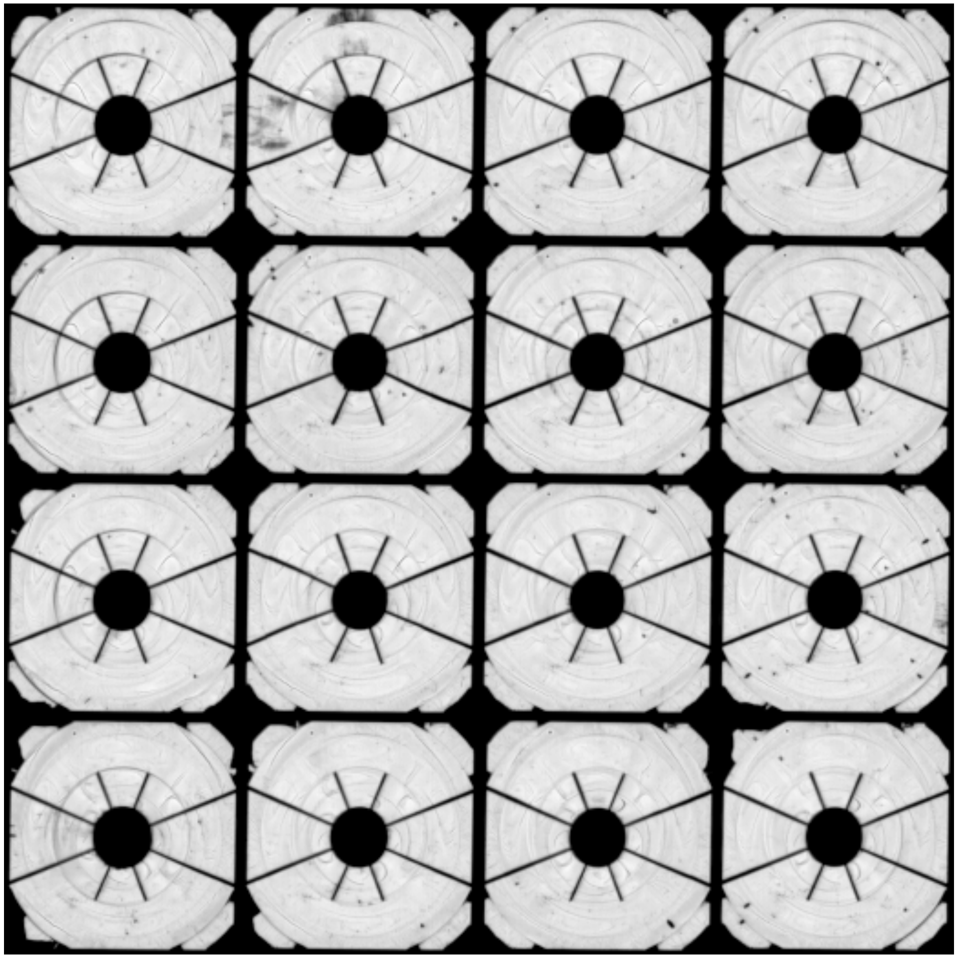
1. Constant current is applied to the test module leads
2. The collimated output beam is imaged by the test system
3. Individual optic images are processed to make I_{sc} estimate

EL: Experimental Set-Up



- The sample translates under a stationary imaging system
- Not shown: power supply, 2-axis translation stage, LabVIEW GUI

EL: Approach



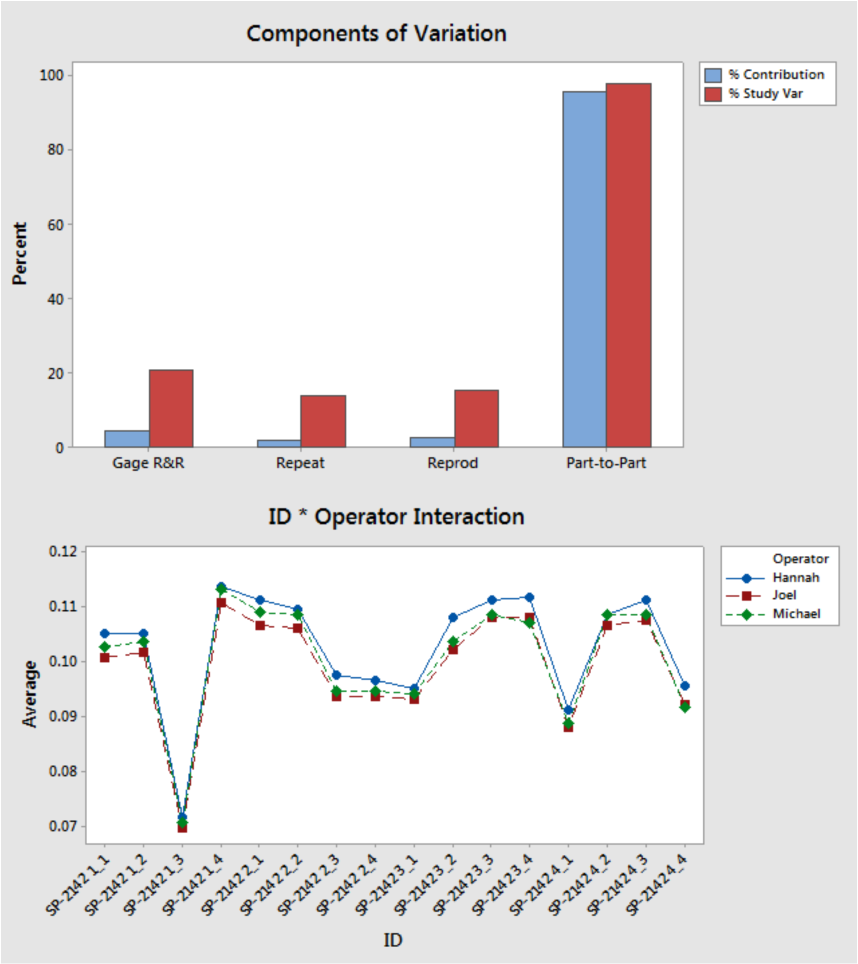
EL: System Performance

- We developed a lab-scale system which provides:
  - Fast feedback –> less than 5 seconds per optic
  - High resolution –> 40 µm
  - Meaningful test images
  - Proof-of-concept for a production test system

EL: System Performance

- Gauge R&R results:
  - Good!
  - Repeatability σ = 2.3%

Source	% Contribution (of VarComp)
Total Gage R&R	4.33%
Repeatability	1.94%
Reproducibility	2.39%
Part-to-Part	95.67%
Total Variation	100%



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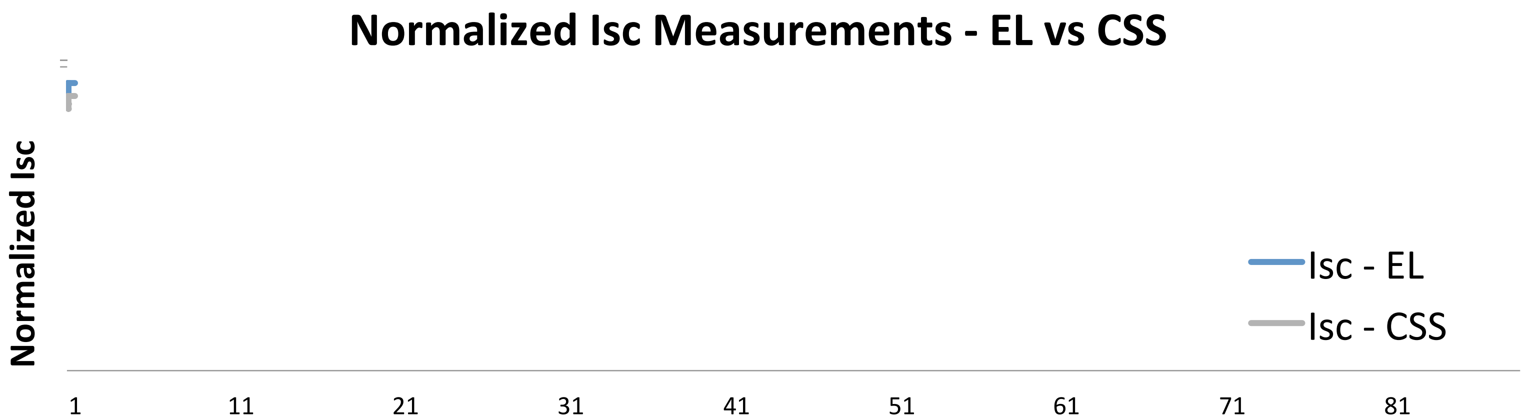
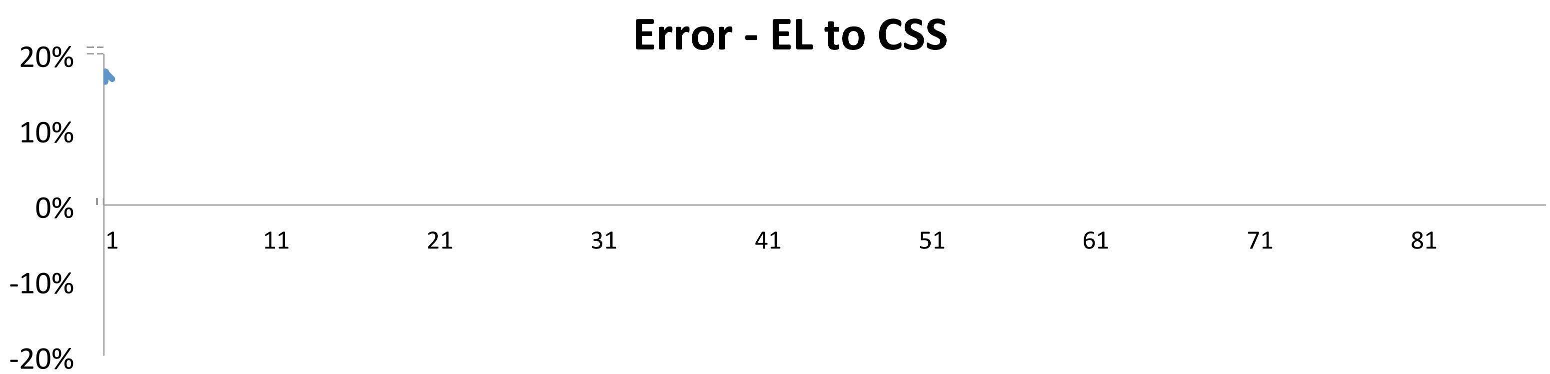
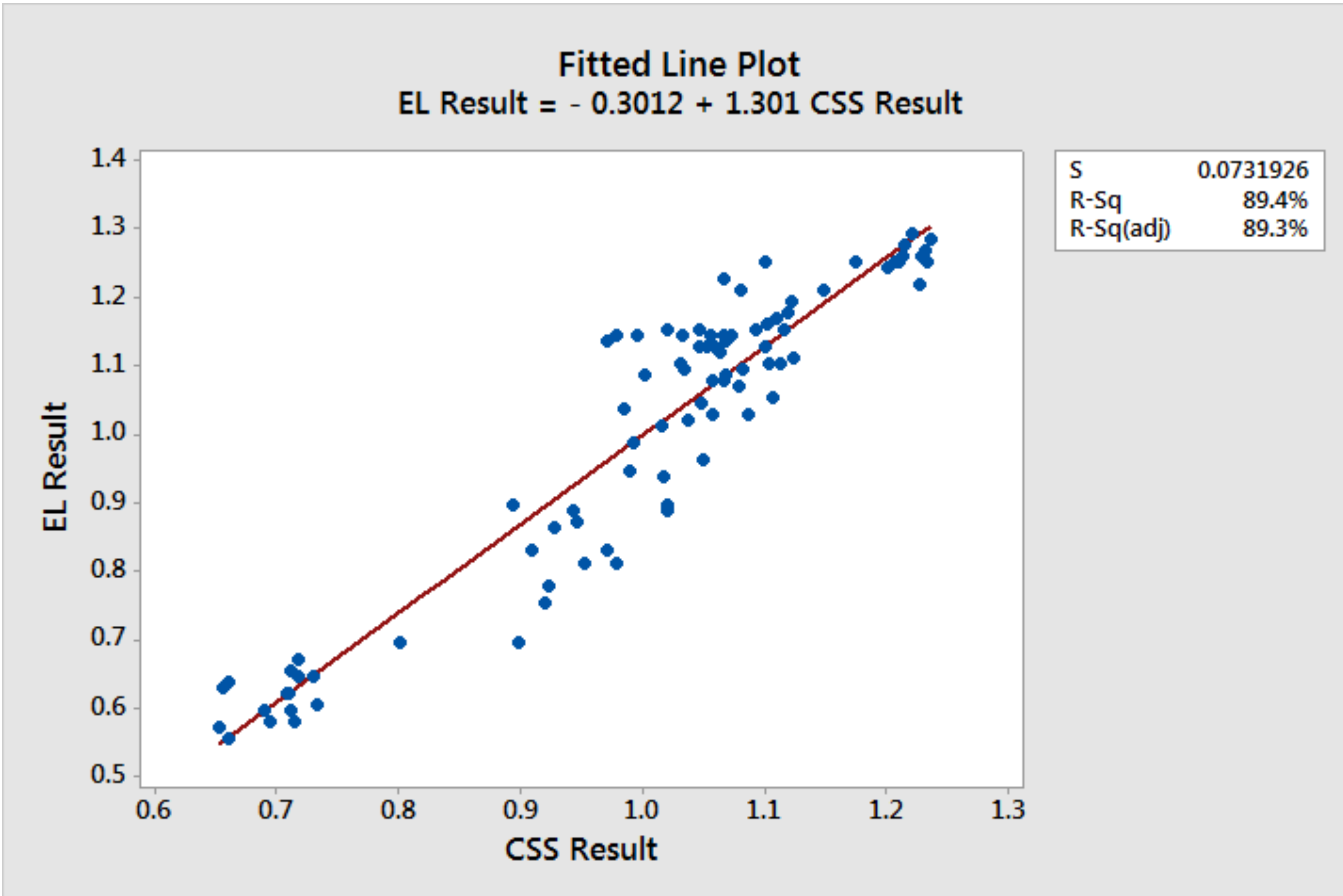
EL: Results


Normalized Isc Measurements - EL vs CSS
Normalized Isc
Isc - EL
Isc - CSS
1
11
21
31
41
51
61
71
81


Error - EL to CSS
20%
10%
0%
-10%
-20%
1
11
21
31
41
51
61
71
81

EL: Results



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Review

- Two low-cost efficiency estimation tools are in development

	CCS	LSS	EL
Repeatability (σ)	2.8%	3.4%	2.3%
Accuracy to CSS (σ)	-	3.4%	7.3%

- Further improvements are required to improve estimation accuracy

Conclusions

- Alternative solutions for quantifying CPV module performance at CSTC can be considered
  - Careful calibration of test results to CSTC is essential
  - Additional quality systems requirements can be designed to facilitate low-cost testing methodologies


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Thank You!
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