Triggering TR in Li-ion Cells with Laser Radiation

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Agenda

- Intro
- Test Objective
- Test Configuration and Set up
- Results
  - NCR-B Cells and BP Swing 5300 (aluminum can)
- Conclusions
- Lessons learned
- Future Work
- Acknowledgements

Introduction

- The method used to initiate a cell into thermal runaway (TR) has significant impact on the TR response of that cell.
- JSC EP team has been working with multiple methods to find a method that is able to realistically initiate a cell into TR.
  - Patch heater
  - Internal short circuit device
  - Nail penetration
  - Heat to vent
  - Over charge
  - Induction
  - Laser
- One of the methods developed uses a high power laser to heat a small portion of the cell.

Test Objective

- Primary Objective:
  - Trigger a cell to go into TR minimal impacts to its interfaces within a battery design
    - Only have to apply thermally conductive coating to the laser target surface (black paint)
  - Instigate a TR response without perforating the cell enclosure at the beam spot
- Secondary objective:
  - Create a standard test bed for triggering single cells into TR
  - Create test matrix to determine various parameters needed to trigger a wide variety of cells.
  - Assess the influence of those parameters on the failure response of the cell

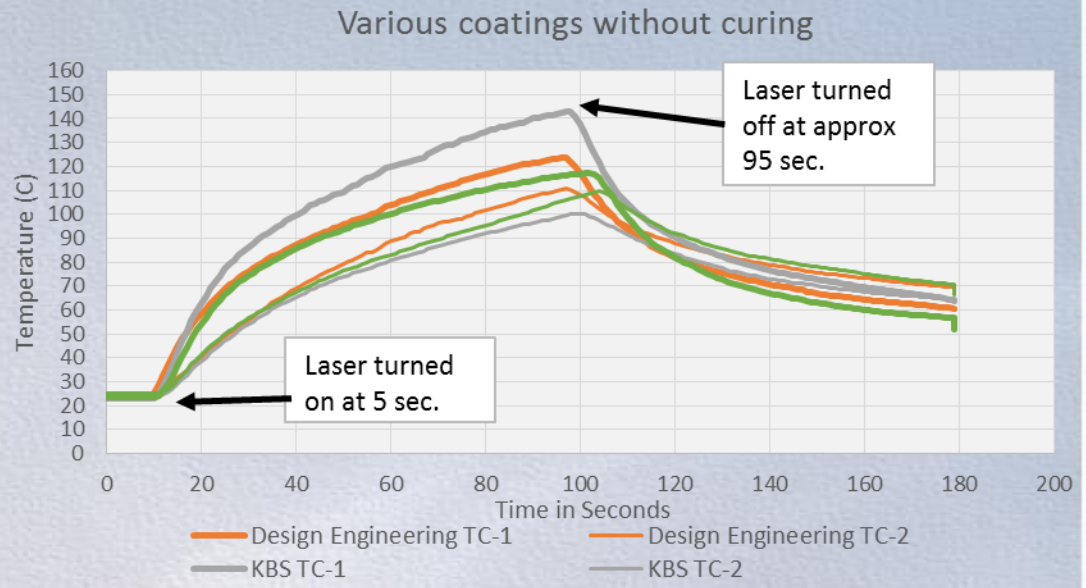
Test Materials and Configuration

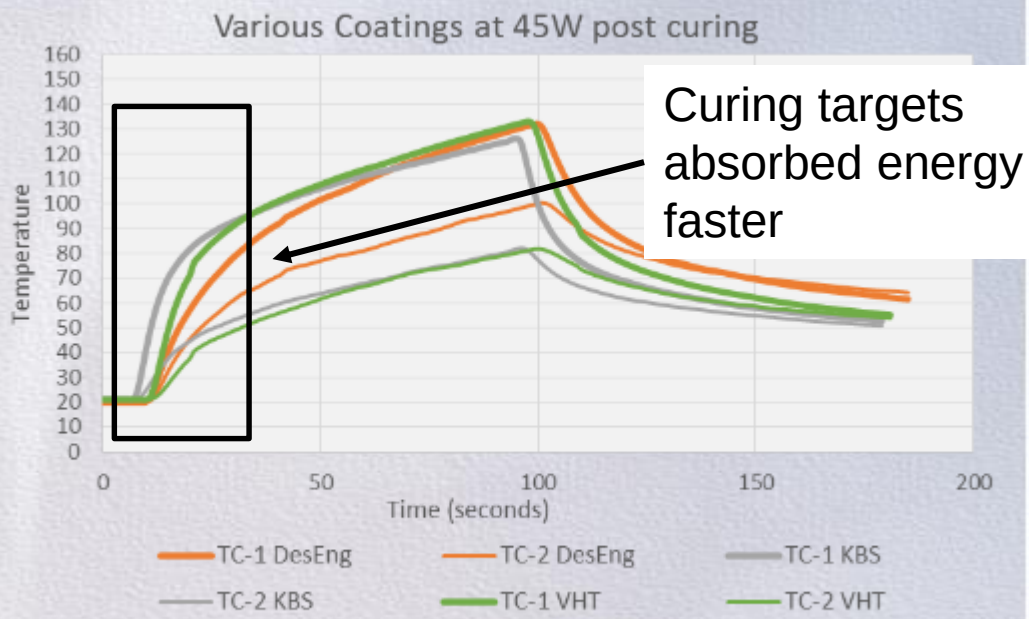
- DILAS |Coherent variable power Laser
  - 120 Watts @ 808 nm (low end IR)
  - Fiber coupled output allows for test setup to be isolated from laser
  - Coating is applied to beam spot on the can to improve beam coupling and as a result energy efficiency
    - Most carbon containing paints/coatings will ablate/off gas to fast and not be an effective transmission for the energy.
    - KBS XTC – Silicone based rated for up to ~800c

Test Materials and Configuration

- Selected aerosol based paint for better uniformity on coating
- Most “high temp” paints require curing at “medium temp”
  - Attempted curing by firing laser at 12W for 30 seconds
- Paints tested displayed few differences
  - KBS seemed to operate similar with/without curing
- KBS paint displayed least ablation and best power coupling performance

POST CURE:
DesEng, VHT targets ablated by laser.
KBS seems to hold much better





Curing targets absorbed energy faster

Initial Test Set Up and Results

- Test bed went through a long series of variations (many more to come)
  - Terminated fiber cable next to cell to trigger at close proximity
  - Stripped fiber cable next to cell (capable of being routed in tight areas)
  - Test bed with fixed fiber cable input and variable spot size
- First live run (right)
- Left- dummy cell run to measure temperature on the can
- Lessons learned
  - Terminated fibers were found to interfere with particles of ablated paint and were not used after initial testing.
  - Conventional methods of clamping the cell to a fixed angle were not sufficient to hold the cell during TR.
  - New clamping method developed

Test Set up and Results

- Similar setup as first run but using stripped fibers as the delivery method
- Results
  - Improved results compared to terminated fiber
  - Proximity of fiber to trigger cell resulted in fiber damage
  - Damaged fiber can be reconditioned post-test with polishing
  - Method could be used if cell access is via a very small opening

(23 mills/600 um to
40 mills/1000um)

Near new fiber

Leaking laser radiation from a damaged/unpolished fiber

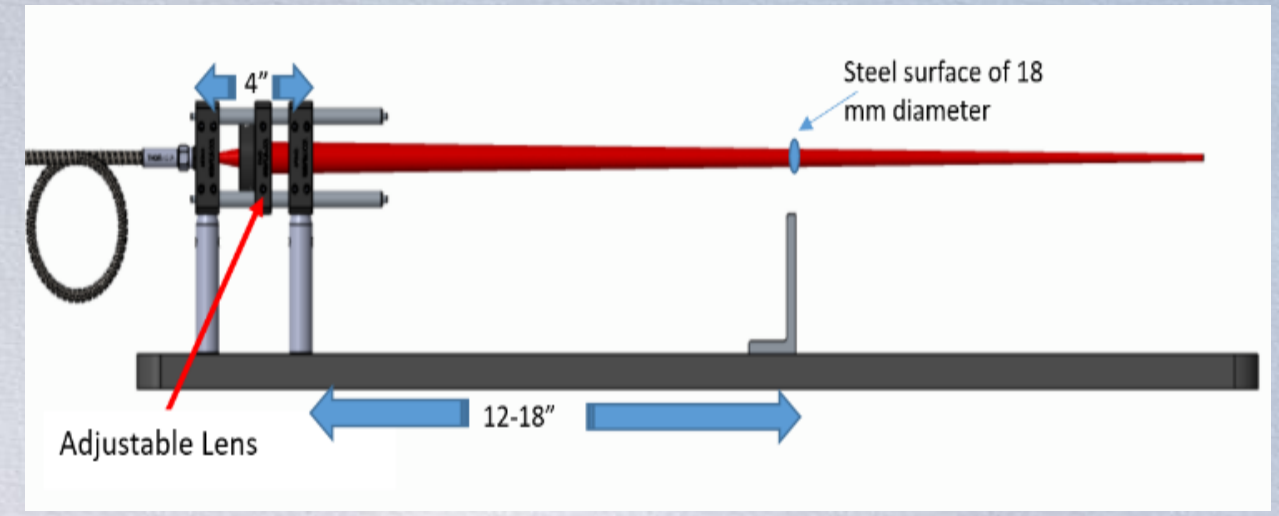
LG MJ1
Trigger Time: 90s

Panasonic NRCB
Trigger Time: 160s

Samsung 26F
Trigger Time: 115s

Current Test Set Up

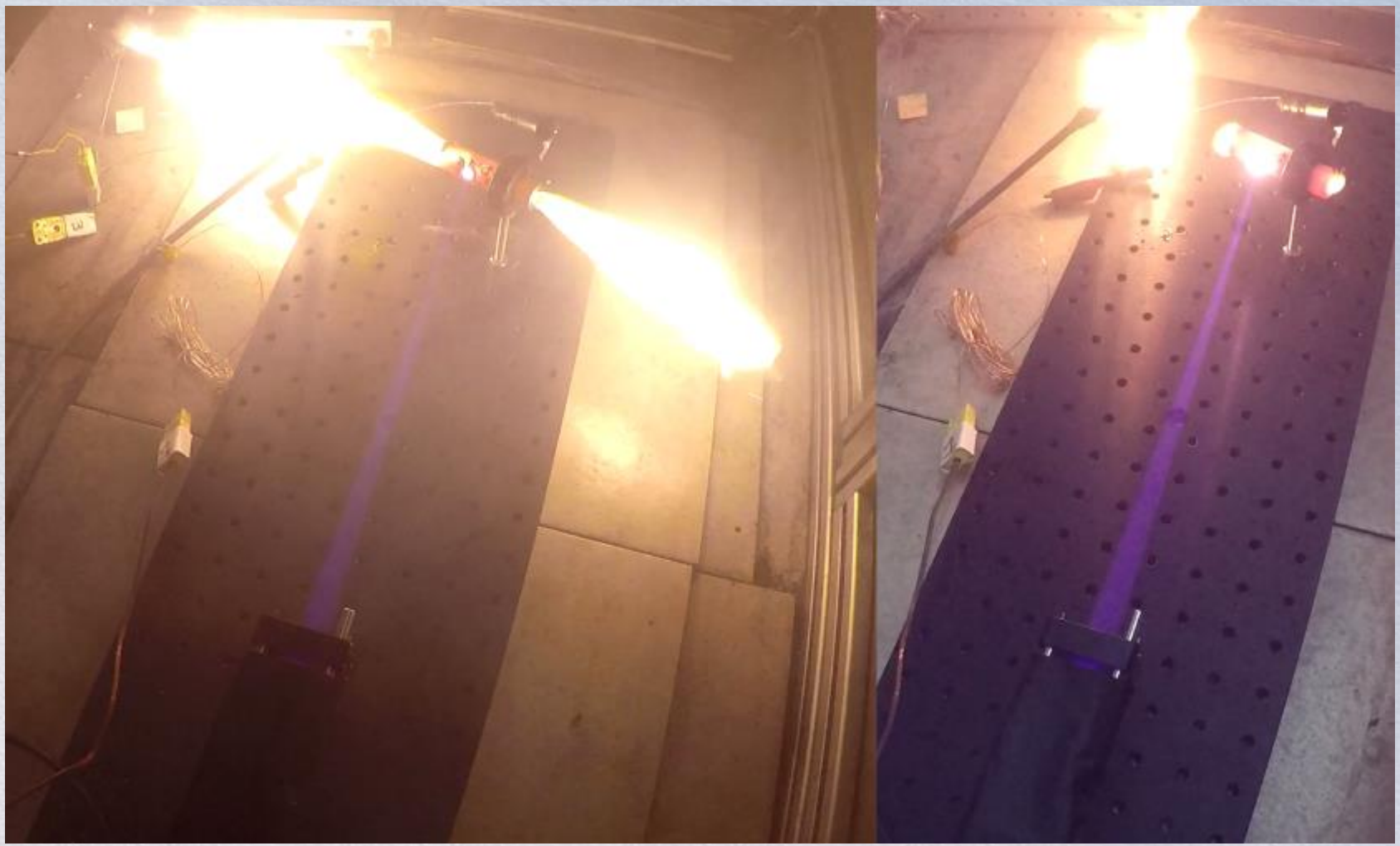
- Current setup:
- Fiber output -> long range focus ring (used as a shield) -> 100mm focus ring -> Cell
  - Cell trigger spot size can be adjusted by moving the focus ring. (smaller/bigger beam spot)
- Mid plate added to help protect from ejecta backsplash



Current Test Set Up

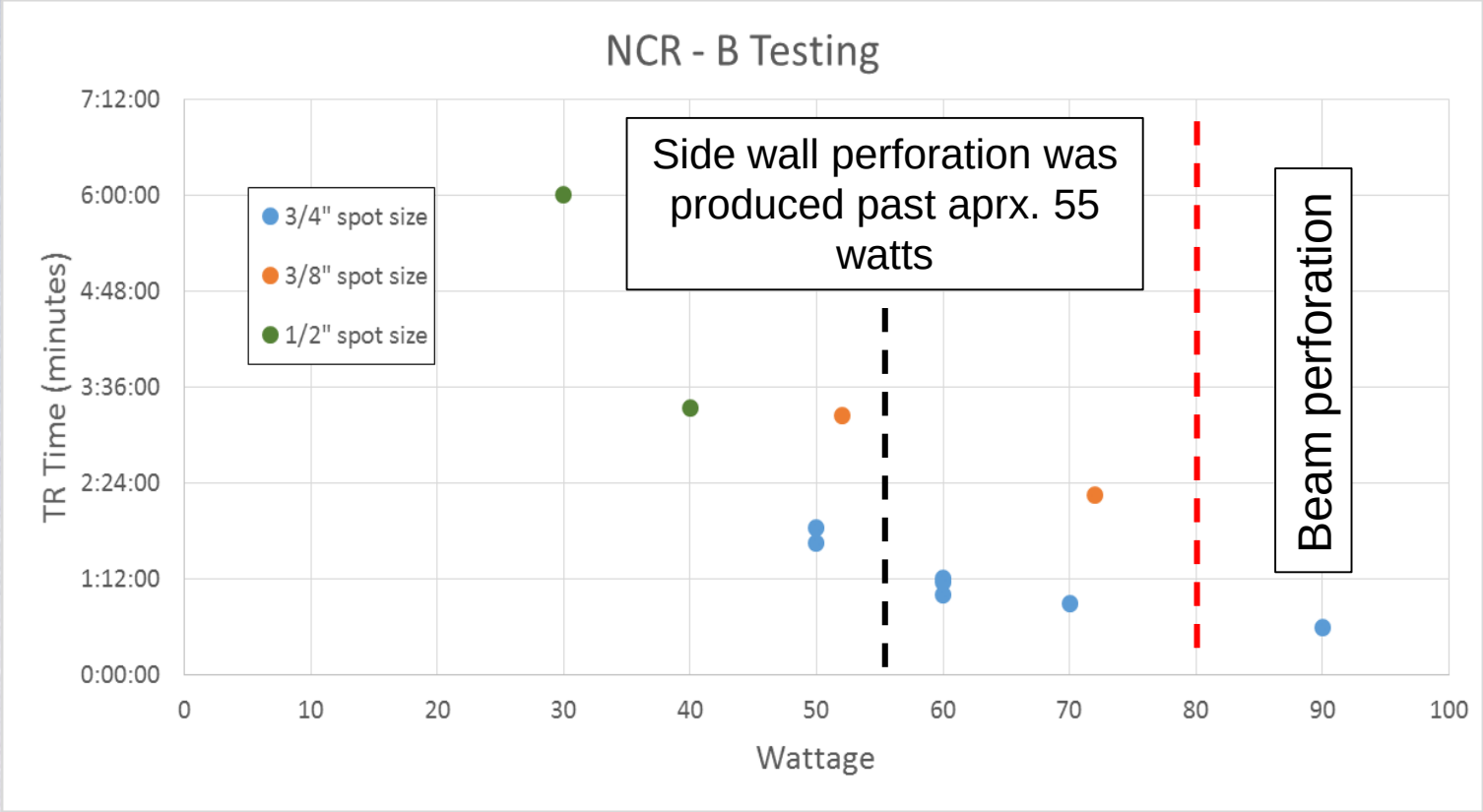
- Triggered a Panasonic NCR-BE with beam spot near the center of the length of the cell.
- Laser beam path visible due to particulates in the air
- Previous test setup (pictured) did not include ejecta shield
- Lesson Learned:
  - Ejecta shield is required
  - Ejecta from this run coated our lens

NCR – BE Bottom vent cell – Cell shot at middle side wall, no perforations at beam spot. Cell vented from both vents



Test Results – Panasonic NCR-B

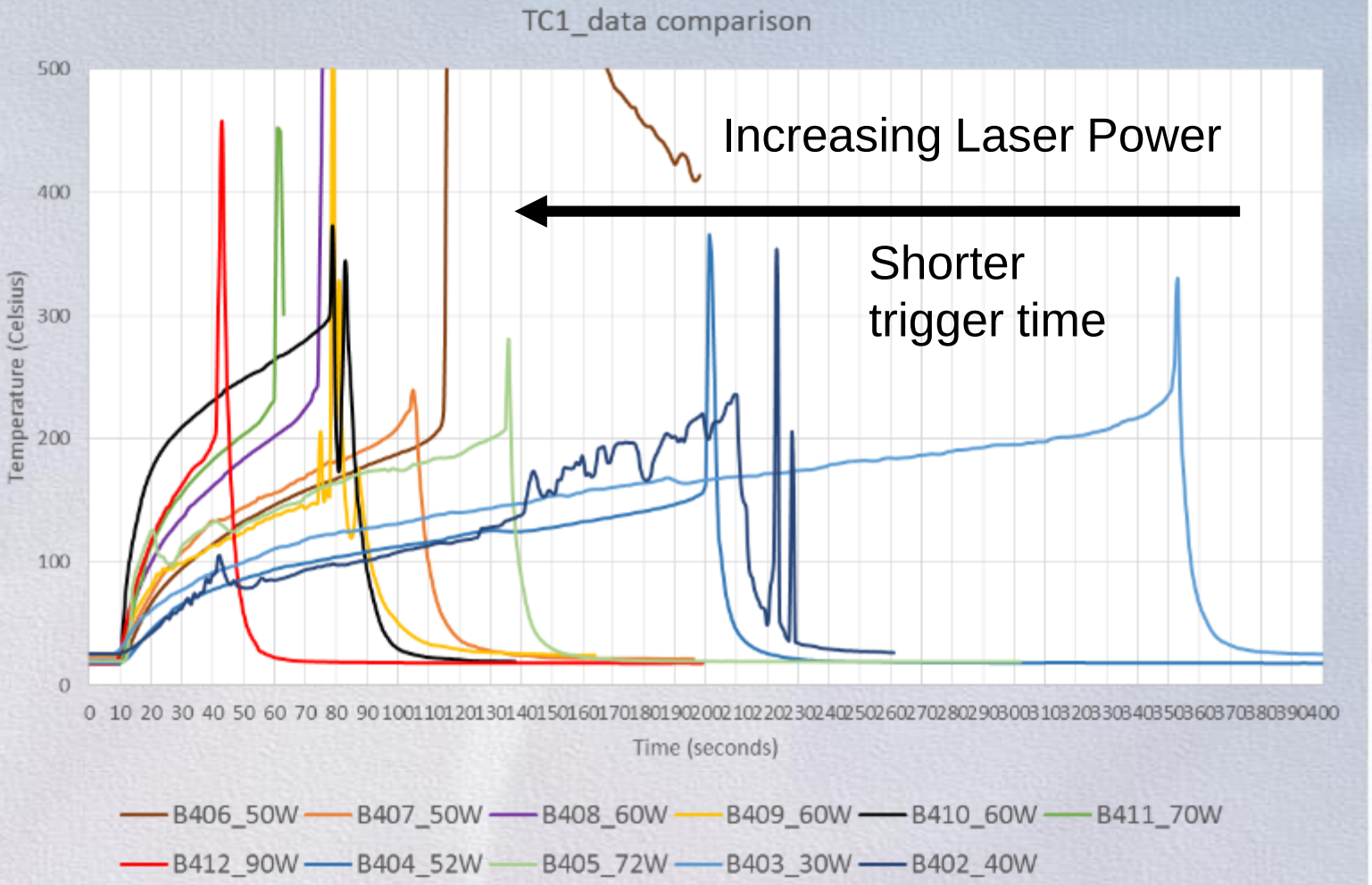
- Series of tests conducted to determine how Panasonic NCR-B cells will react to the various power levels.
- Since the NCR-B cell has thinner can walls, prediction is that any cell with marginally stronger can walls should go into a non side wall rupture TR under with the same environments.
- Samsung 26F and LG MJ1 cells are currently undergoing testing to validate parameters on thicker can walls



Triggering a cell below ~55 will likely produce a TR response without a side wall breach. Above ~80 watts will likely perforate at the beam spot.

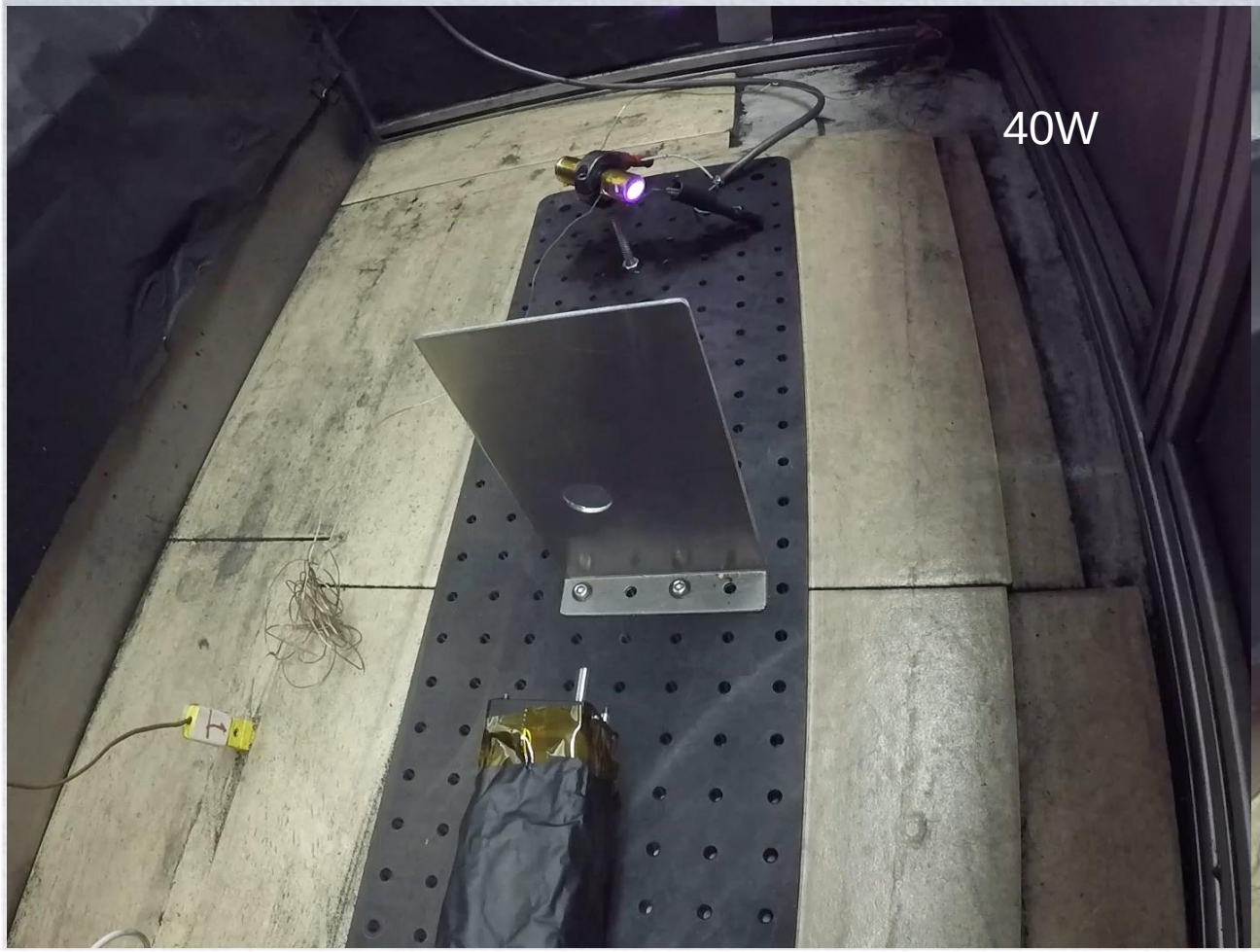
Test Results – Panasonic NCR-B

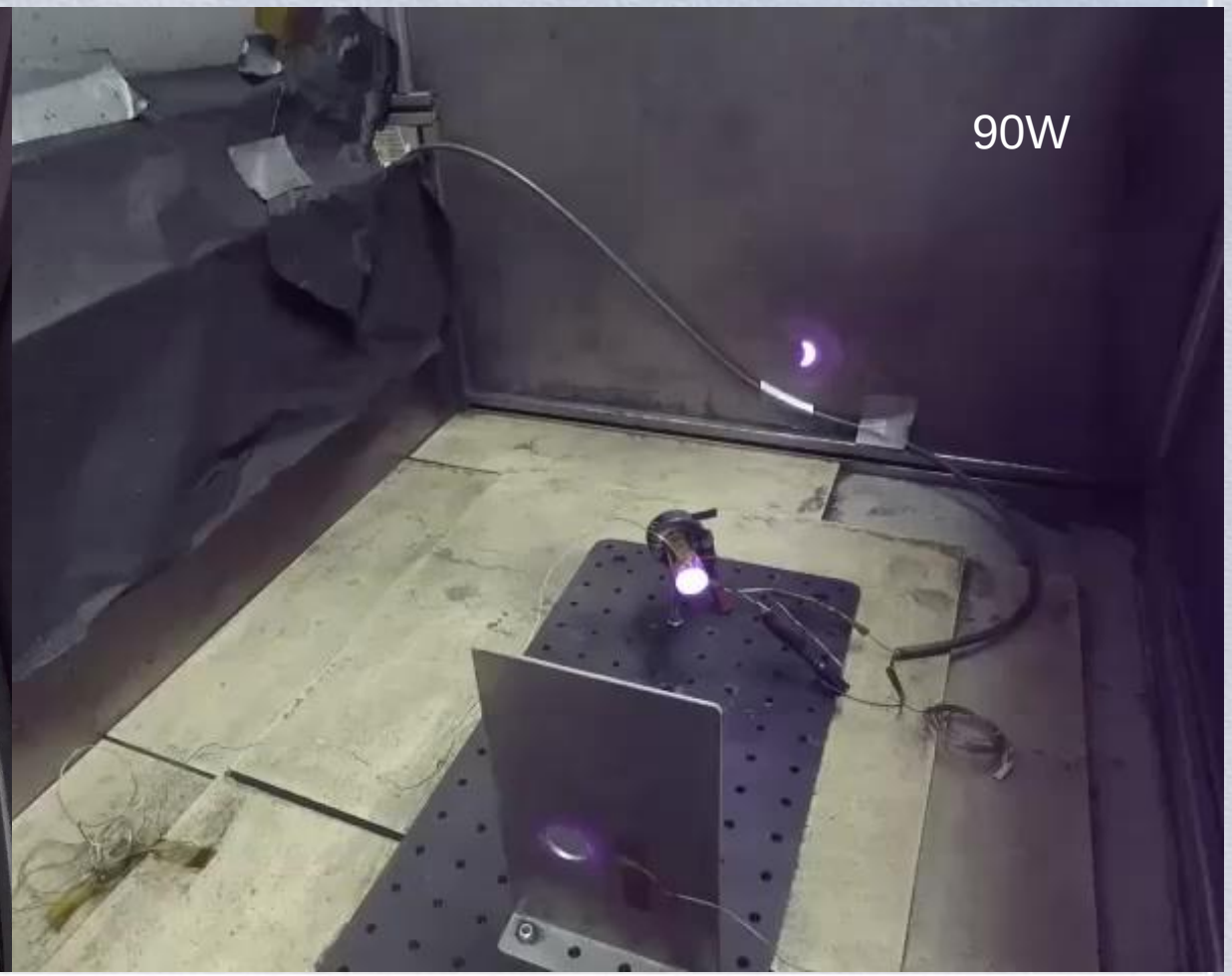
- Fixed environment (spot size, location). Varied Laser power
- Majority of the results are what we expected
- As the laser power increased, the time to TR went down.
  - Also increased likelihood of beam spot penetration/breach
- Few unexpected results where test were significantly shorter or longer than they should have been.
  - 50 watts seemed to do better than 70 watts (50 watts is also the cut off where we can start seeing a breach)
  - Likely an outlier which will be addressed with a larger sample size



Test Results – NCR-B 40W vs 90W

- 40 Watts – nominal TR with top bent breach. 90 Watt run perforated at beam spot
- Thermal energy output of each cell could be different? Not yet measured





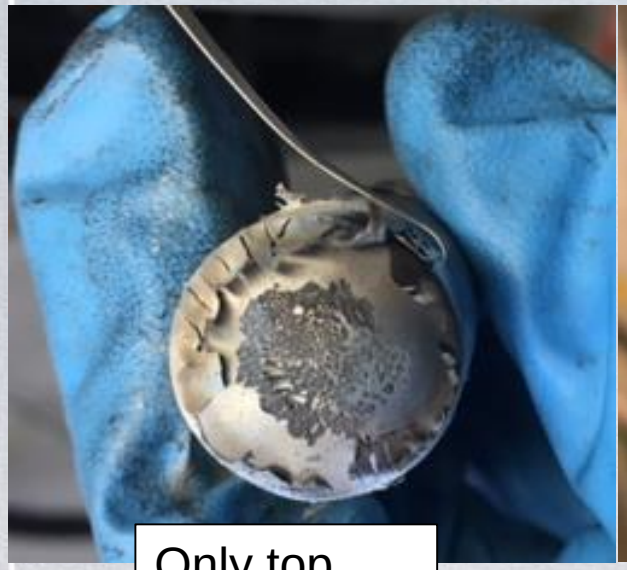
Test Results – NCR-B Pictures

~ 40 Watts
(laser not calibrated)

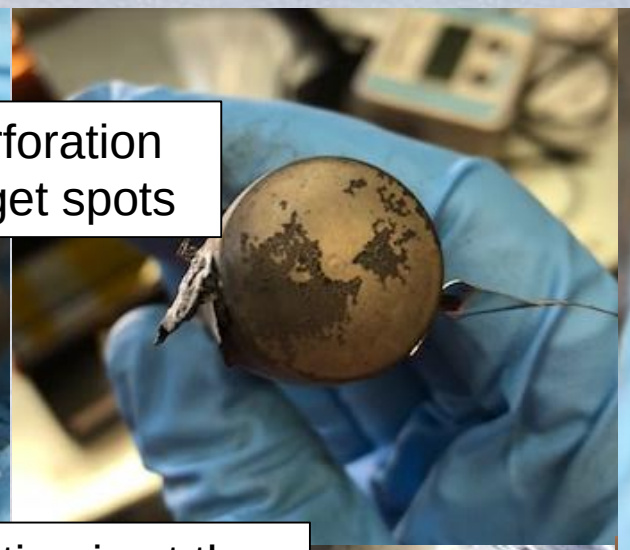
50 Watts

60 Watts

90 Watts



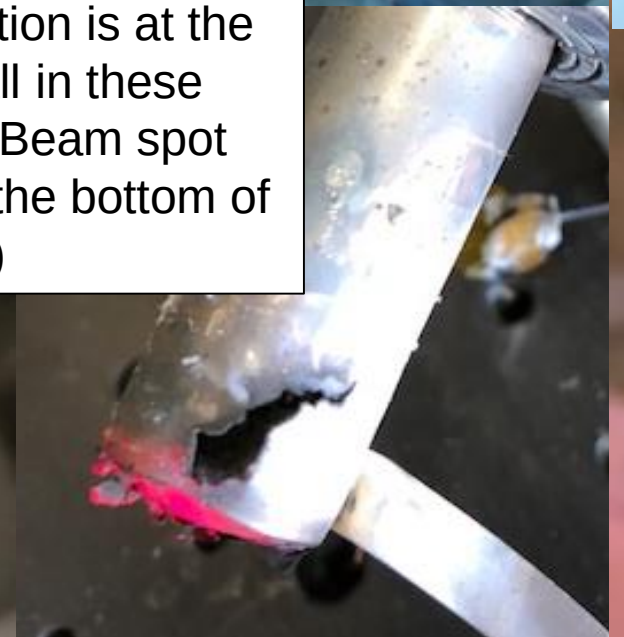
No perforation on target spots



Perforation at bottom of cell

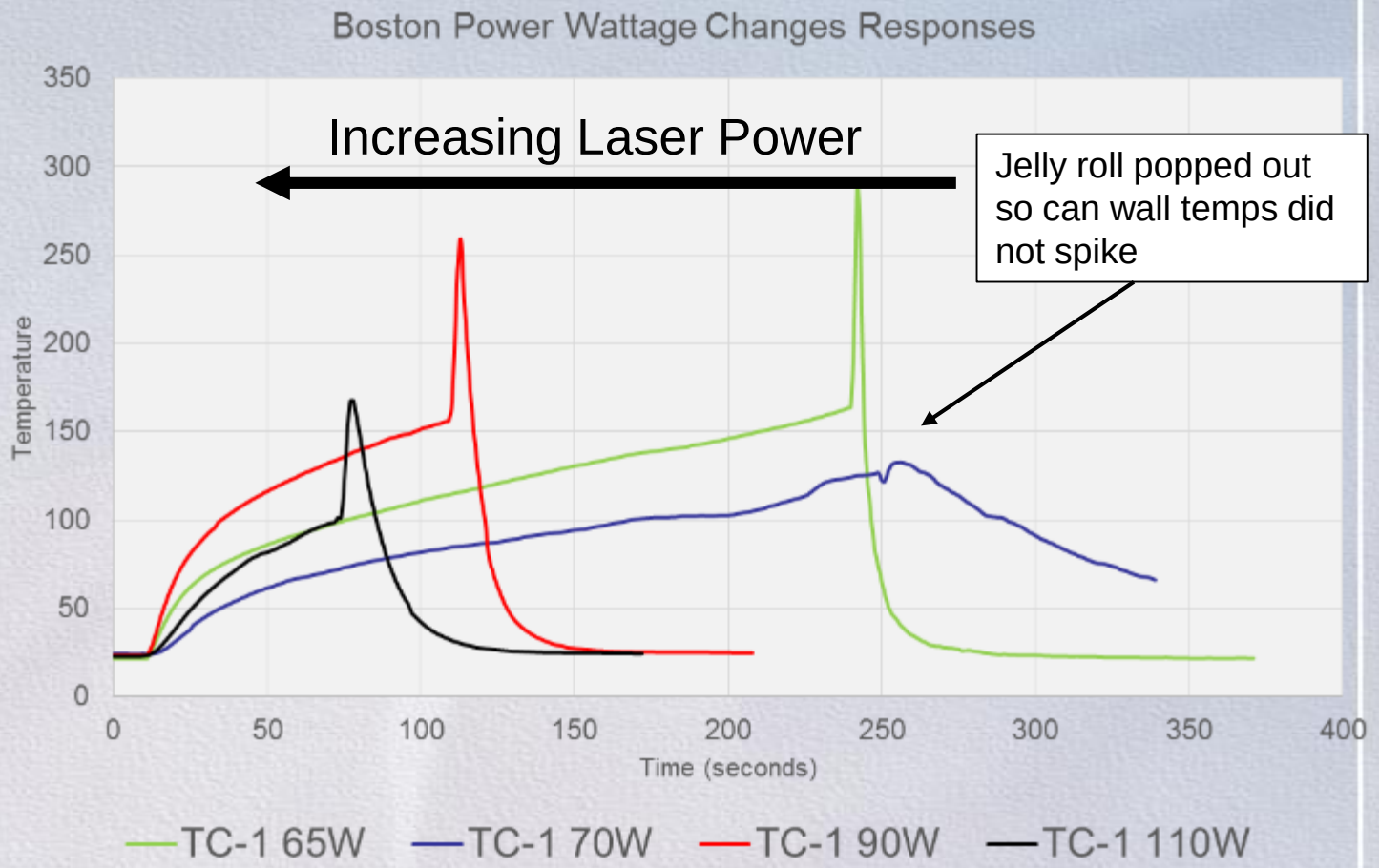
Only top vent

Perforation is at the side wall in these failure (Beam spot was at the bottom of the cell)



Test results – Boston Power Swing 5300 Cells – Aluminum cans

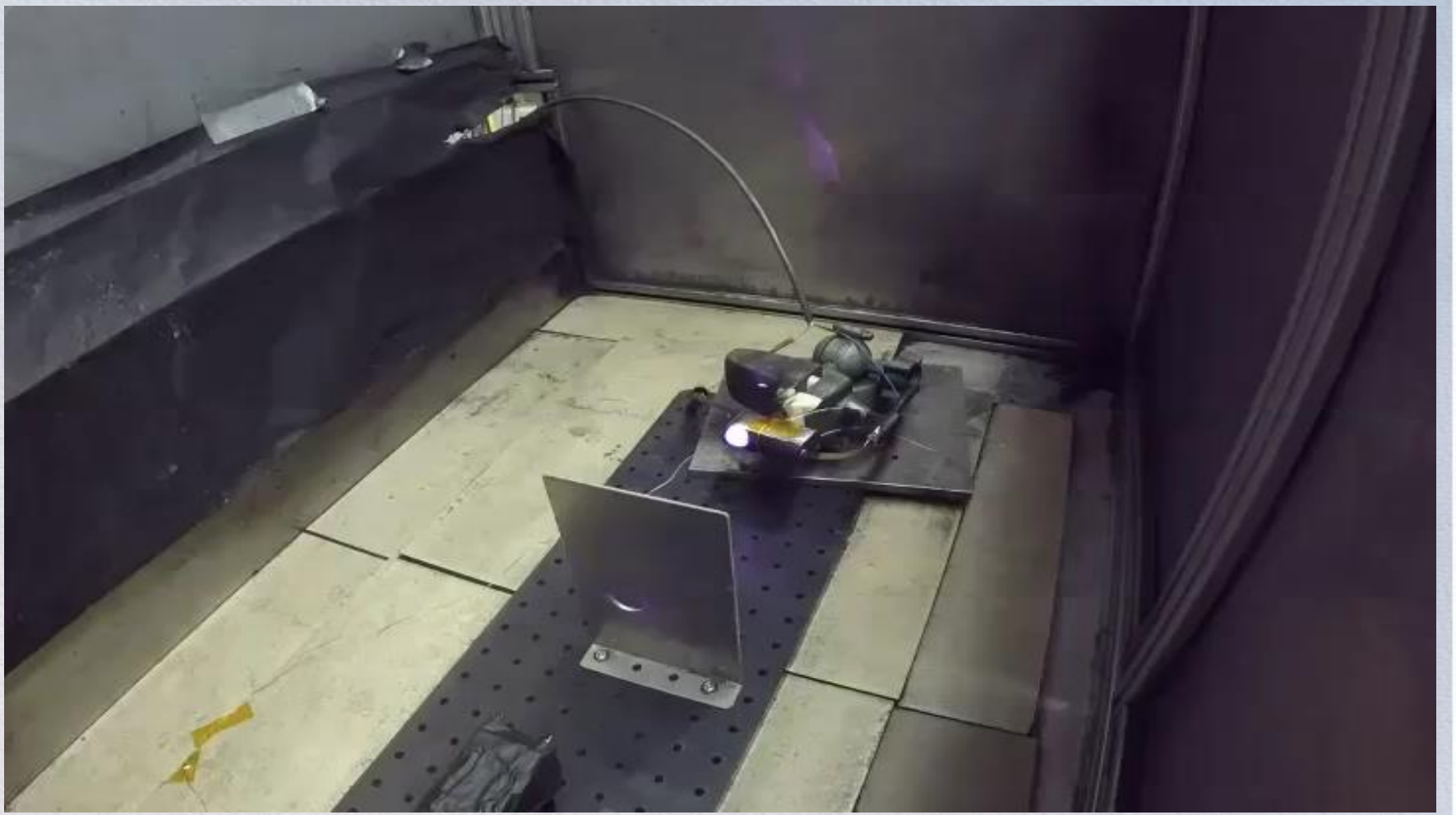
- Similar style of testing was conducted with Boston Power Swing 5300 cells
- Parameters to trigger aluminum cells are different due to higher thermal conductivity of aluminum.
  - Testing started with 50W and up to 110W
- In the 110W test, the TR was triggered much faster
  - Respective TC did not get as hot
  - Likely that TR started before the heat could transfer to the opposite side of the cell



Test results – Boston Power Swing 5300 Cells – Aluminum cans

- 70 watt (and 60W) seems to produce a higher energy thermal runaway event than the higher wattage runs on the same cell.
- Possible rationale for that is that the higher wattage ablated the paint and reflected light away;
- Seems unlikely since the runaway was triggered fairly quickly.
- Different coatings were not tested on these cells.
  - Our high temp paint might not be the best option

70 Watts



Test results – Boston Power Swing 5300 Cells – Aluminum cans

90 Watts

Beam spot

No perforations at beam spot

Conclusions

- Laser trigger method has been demonstrated capable of triggering TR without perforating the cell enclosure at the beam spot in various COTS cell designs
  - 18650 with steel can walls as thin at 125 microns
    - Data presented was with beam spots on the bottom of the cell cans. Shooting side of the cell can was captured in earlier test set up but needs to be rerun with a larger sample size.
  - Elliptical cylindrical (Boston Power Swing) cell design with Al enclosure

- TR responses produced are in family with other trigger method responses (Internal short circuit device, Patch heater)
  - Nominal top vent burst
    - The “ideal” TR
  - Crimp Seal burst
  - Jelly roll expulsion
    - Possibly – happened in various power levels, still determining cause
  - Side wall rupture
  - Bottom vent/wall rupture

Lessons Learned

- Painting style and paint selection is incredibly important
  - Most high temperature paints require curing at temperatures which would initiate TR.
  - Finding paint that will work has been troublesome.
  - Still exploring new options for paints.
- When using a bare fiber, face quality is crucial
  - Bare fibers tips should be been new or professionally cleaved/polished after every use
  - Changed to using a terminated end with a shielding lens on the fiber to protect it from any debris and maintain beam quality
- Center spot temperatures of a focused laser can often get into the 1000+ C range and an saturate your TCs or temperature measuring equipment giving false readings
  - Measure behind the trigger spot or a bit away
- IR cameras don’t go well with IR lasers.
  - IR camera wavelength was offset from IR laser
  - IR refractions + surface temps of beam spot were too high and likely damaged the camera’s sensors
  - IR shields are available to ‘cool’ the image you are looking at and also to block any stray radiation (depending on the shield you get)

Future Plans

- Continue testing various COTS cylindrical cell designs to establish breadth and reliability of method
- Fine tune laser parameters to increase propensity for certain TR responses:
  - Nominal TR, Side wall breaches, seal crimp breach, bottom vent, top vent, etc
- Integrate different bare fibers into battery packs to determine merits of method for triggering single cell TR inside in battery
- Measure the energy output of the various trigger types by the laser in comparison to other trigger methods.
  - Integrate method with our cell TR calorimeter
- Expand test matrix to include pouch and larger Li-ion cells
  - Partner with SNL

Acknowledgements

- JSC EP Battery Group
- ESTA Test Team

Questions?