Verification of COTS Li-ion Battery Cell Authenticity

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Use of Commercial Li-ion Cells in Space

- **Commercial Off-The-Shelf (COTS) cells are widely used in space batteries**
  - *Small satellites and CubeSats*
  - *Often utilize widely available 18650 cells*
  - *Other larger wound cells or pouch cells are also used*
- **Increasing incidence of counterfeit COTS Li-ion cells in the marketplace**
  - *Made by a manufacturer other than that labeled on cell*
  - *Repurposed cells (rejected or used cell made by labeled manufacturer)*
  - *Mixed cell lots (date codes modified to create appearance of single lot)*
- **Recommended methods exist in space standards to assure authenticity**
  - *Purchase cells from trusted supplier to minimize risk*
  - *Validate quality, performance, and reproducibility of all cells in each procurement*
- **Full validation to all these space standard requirements is costly**
  - *Small programs may not fully validate all cells, and thus accept risk*
- **What are some of the key methods to validate authenticity of COTS cells?**

COTS Cell Validation

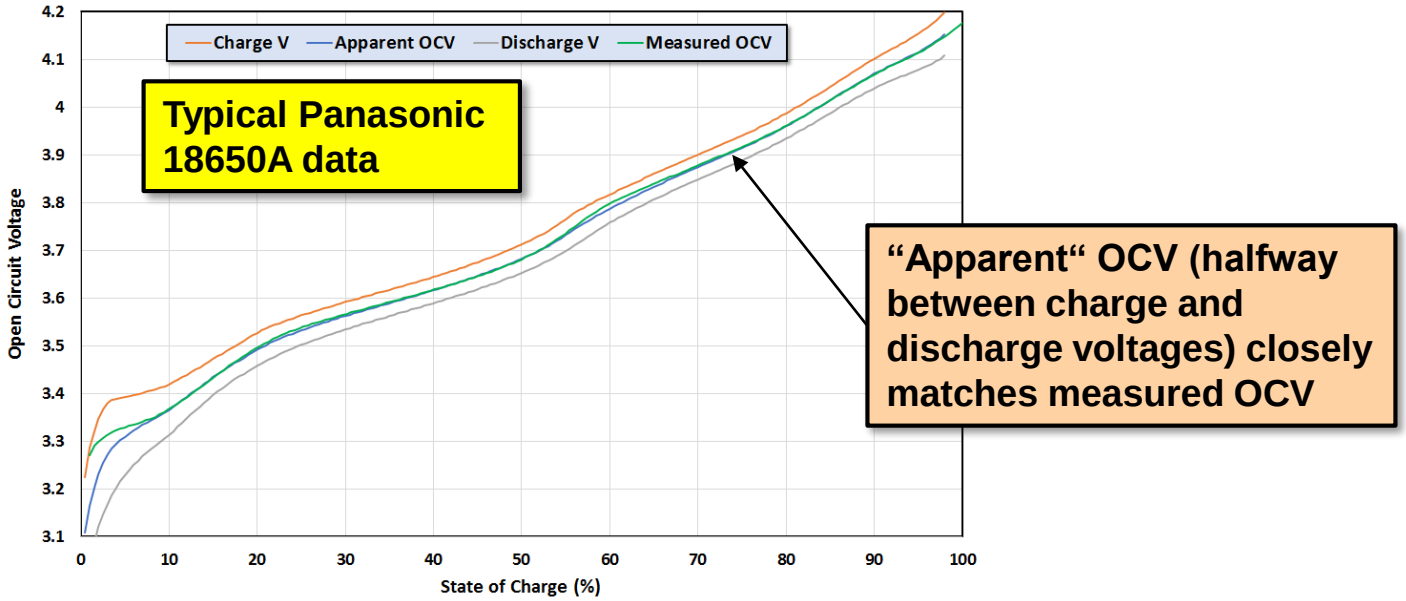
- **Standards call for extensive testing of each procurement**
  - *Inspection, environmental testing, storage testing, and DPAs*
  - *Extensive electrical tests, including life testing*
  - *Safety testing*
- **Testing to space standards provides quality assurance at many levels**
  - *None of the cells are counterfeit, repurposed, or mismarked*
  - *The manufacturer has not inadvertently changed processes or materials*
  - *The cells have sufficient performance and uniformity to meet mission needs*
- **A subset of these tests may be adequate to indicate authenticity by similarity to a trusted baseline**
  - *Cells are made with expected materials and processes*
  - *Cells are not aged by use, long-storage, or extreme environments*
  - *Cells have adequate performance reproducibility*
- **Are there simple test methods that could validate these key points for COTS cells?**

Proposed Tests for COTS Cell Authenticity

- **Results from the following tests should be compared to a trusted baseline**
  - ***Cell processes can be validated by:***
    - External inspection of weights, dimensions, markings, materials, and surfaces
    - Internal inspection by X-ray or CT for a cell sampling
  - ***Cell materials can be validated by:***
    - Measure electrical voltage response of materials in cell (OCV and capacity)
  - ***Cells are not aged, degraded, or used can be validated by:***
    - Check DC resistance as a function of state of charge
    - Peaks and transitions in resistance vs. SOC tend to broaden as cells age
  - ***Make sure that cells are not mixed or have poor uniformity***
    - Statistical comparisons within the cell batch should show good uniformity
    - Statistical comparisons should closely match the trusted baseline
- **Proposed test methods to indicate authenticity for each cell**
  - *Inspections as detailed above*
  - *Perform standard capacity cycle (C/10 or C/20 charge and discharge)*
  - *Determine OCV fingerprint based on standard capacity cycle*
  - *Evaluate DC resistance as a function of state of charge*
  - *Evaluate differential capacity fingerprint from standard capacity cycle*

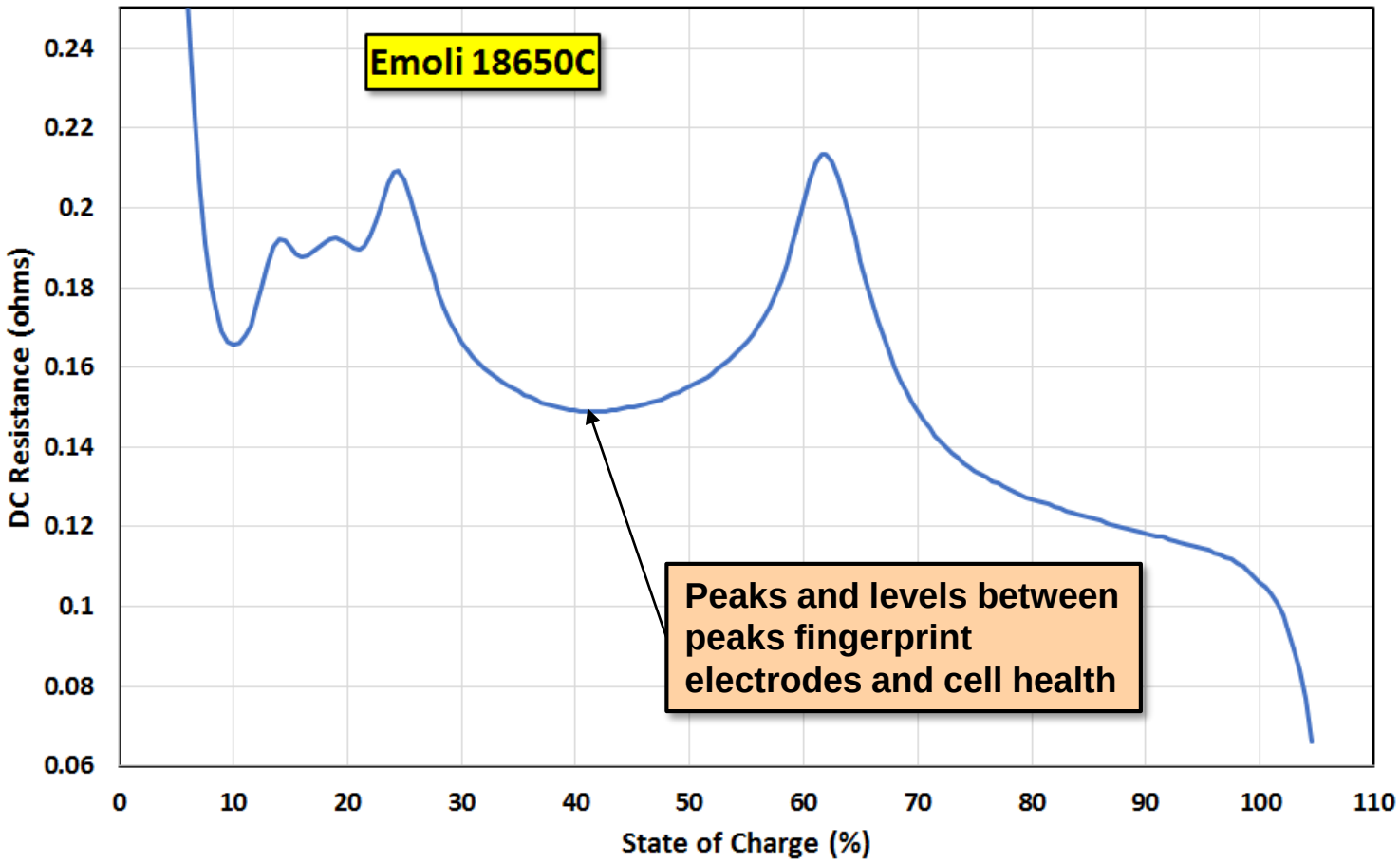
Electrical Test Methods for Authentication

- **Required data can be obtained from a stabilized standard capacity cycle**
  - *C/10 or a C/20 recharge and discharge, 20°C*
- **Apparent OCV vs. SOC found by interpolating voltage curves to zero current**
  - *Plot differential capacity vs. OCV to obtain a fingerprint for each cell*
- **DC resistance vs. SOC given by separation of charge and discharge voltages**
  - *Levels, peak positions, and peak widths should be statistically similar for all cells*
- **Differential capacity fingerprint vs. SOC given by slopes of charge and discharge voltage curves**
  - *Levels, peak positions, and peak widths should be statistically similar for all cells*



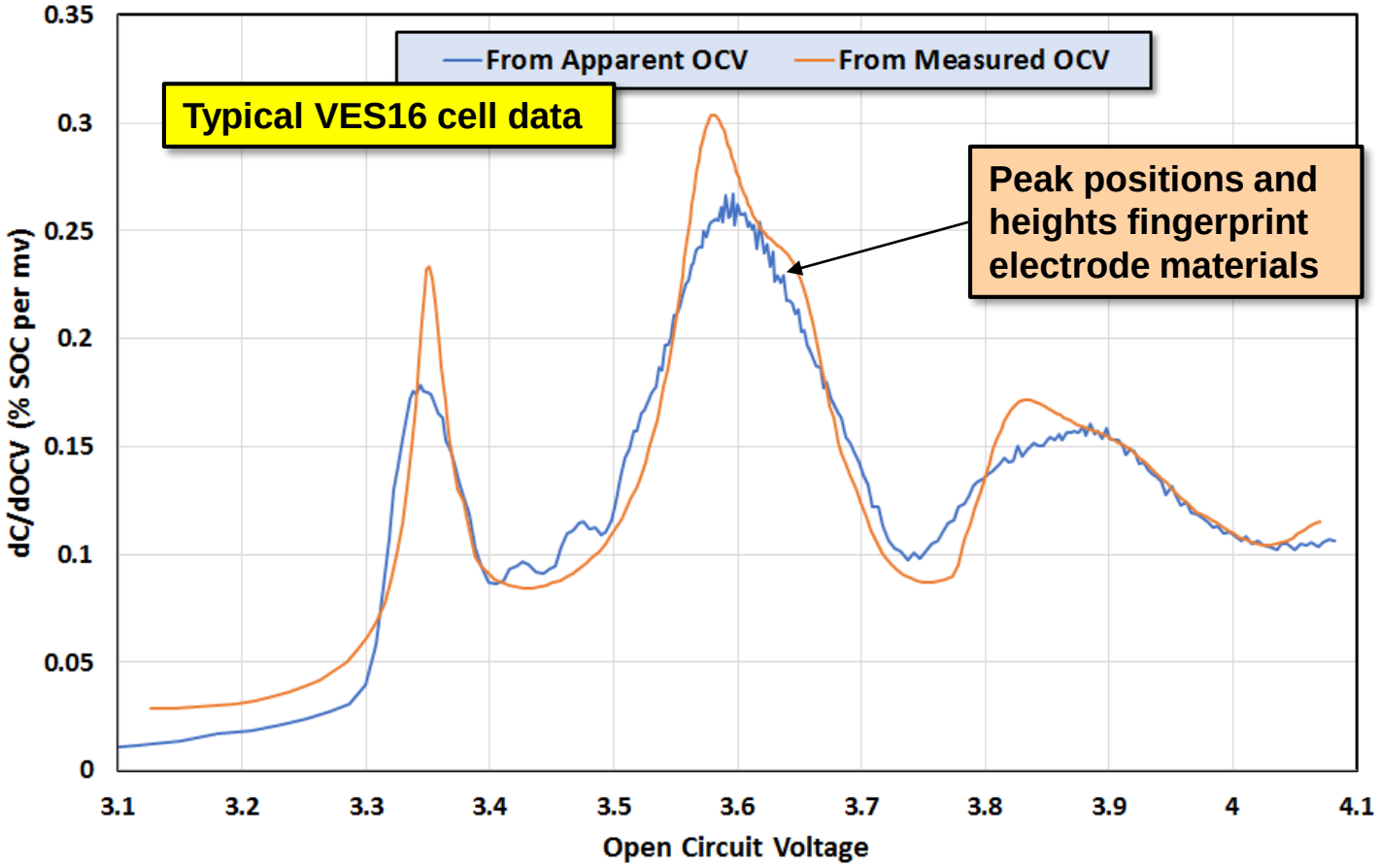
DC Resistance Determination

- DC resistance vs. SOC given by separation of charge and discharge voltages divided by current difference



Differential Open Circuit Voltage

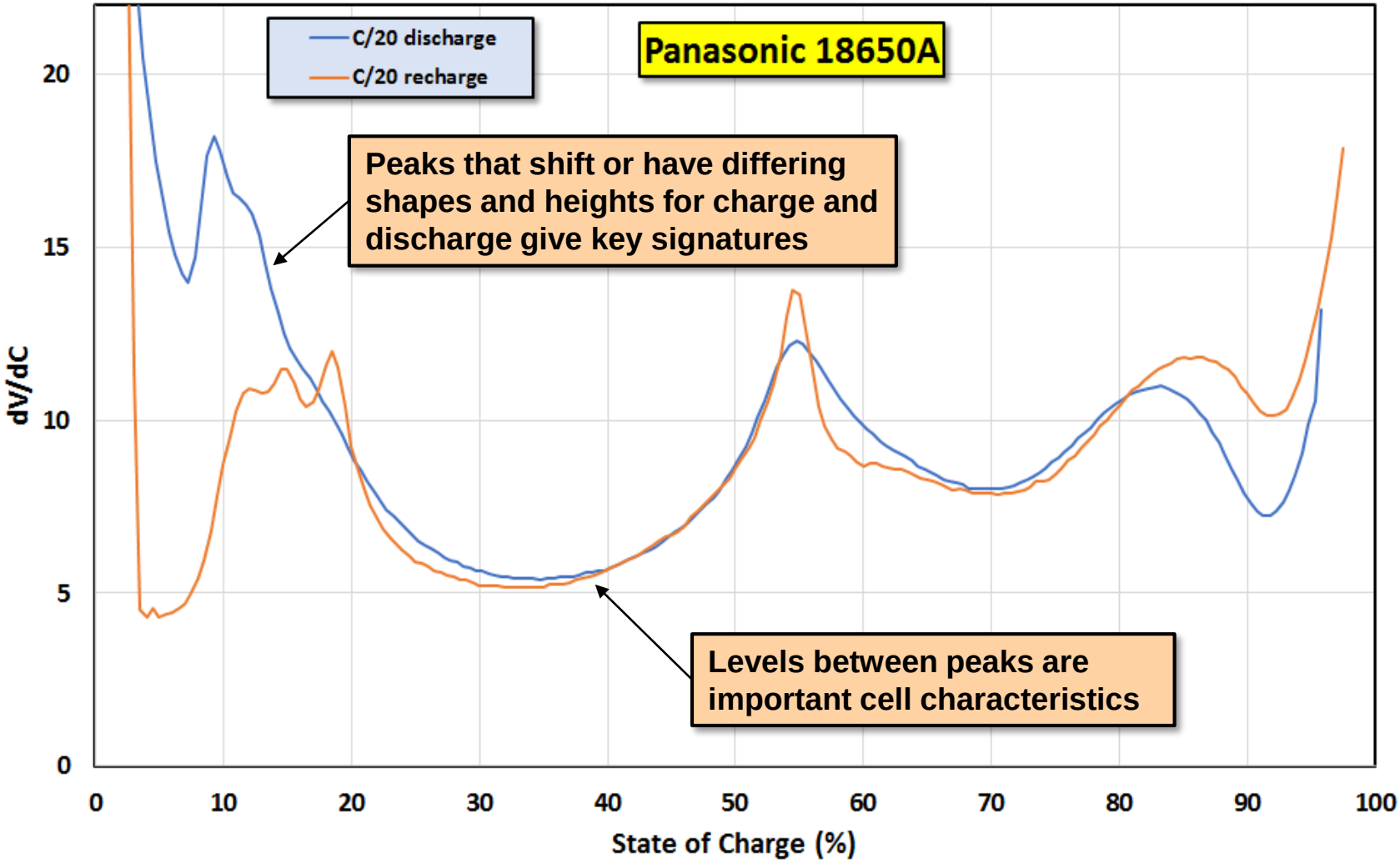
- Differential analysis of capacity *vs.* open circuit voltage gives an electrochemical fingerprint for cell
- Similar to that from a "true" OCV measurement, but not identical



Note: smoothing of voltage data may be needed for differential capacity analysis

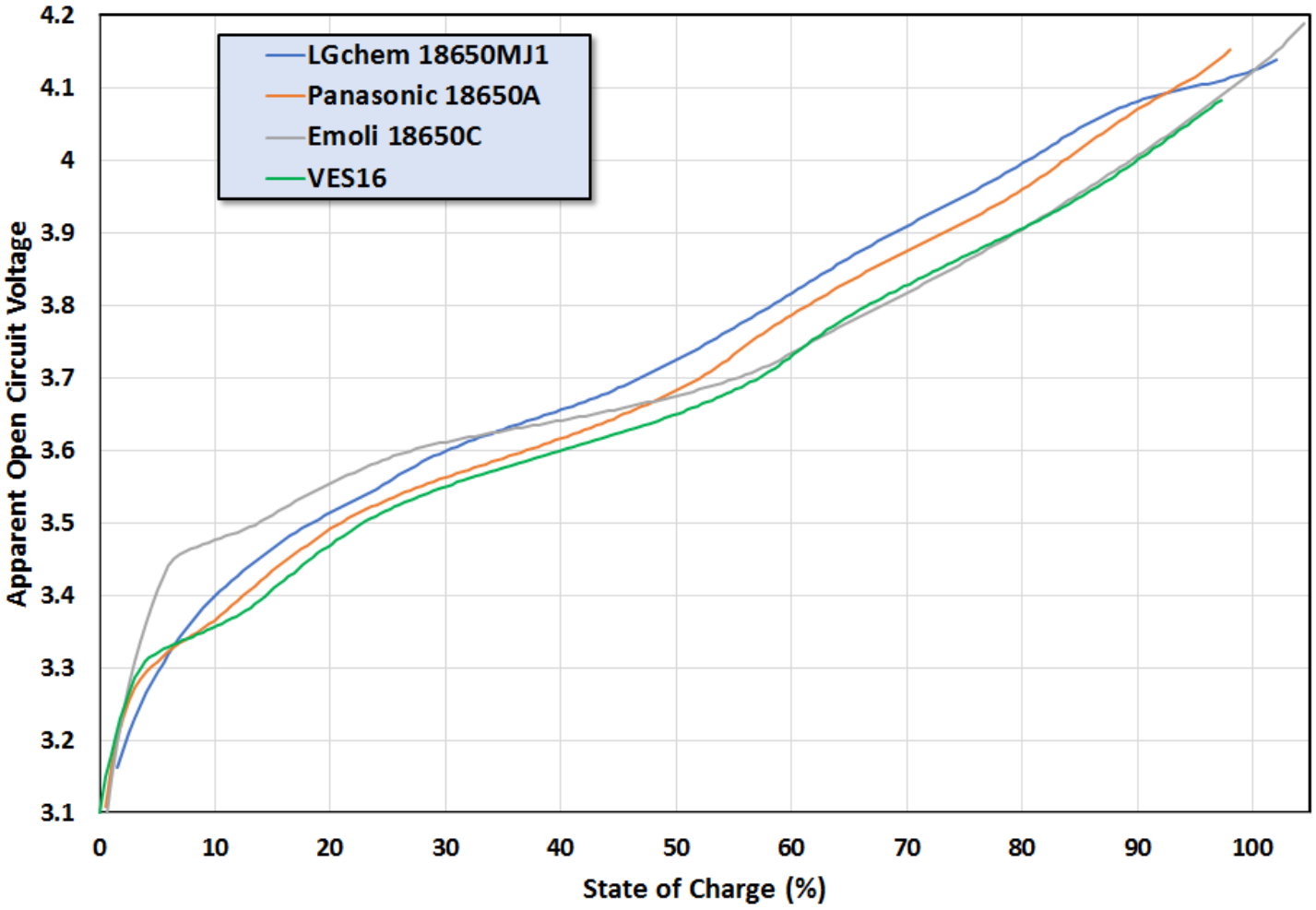
Differential Capacity Signature

- Differential capacity vs. SOC during recharge and discharge



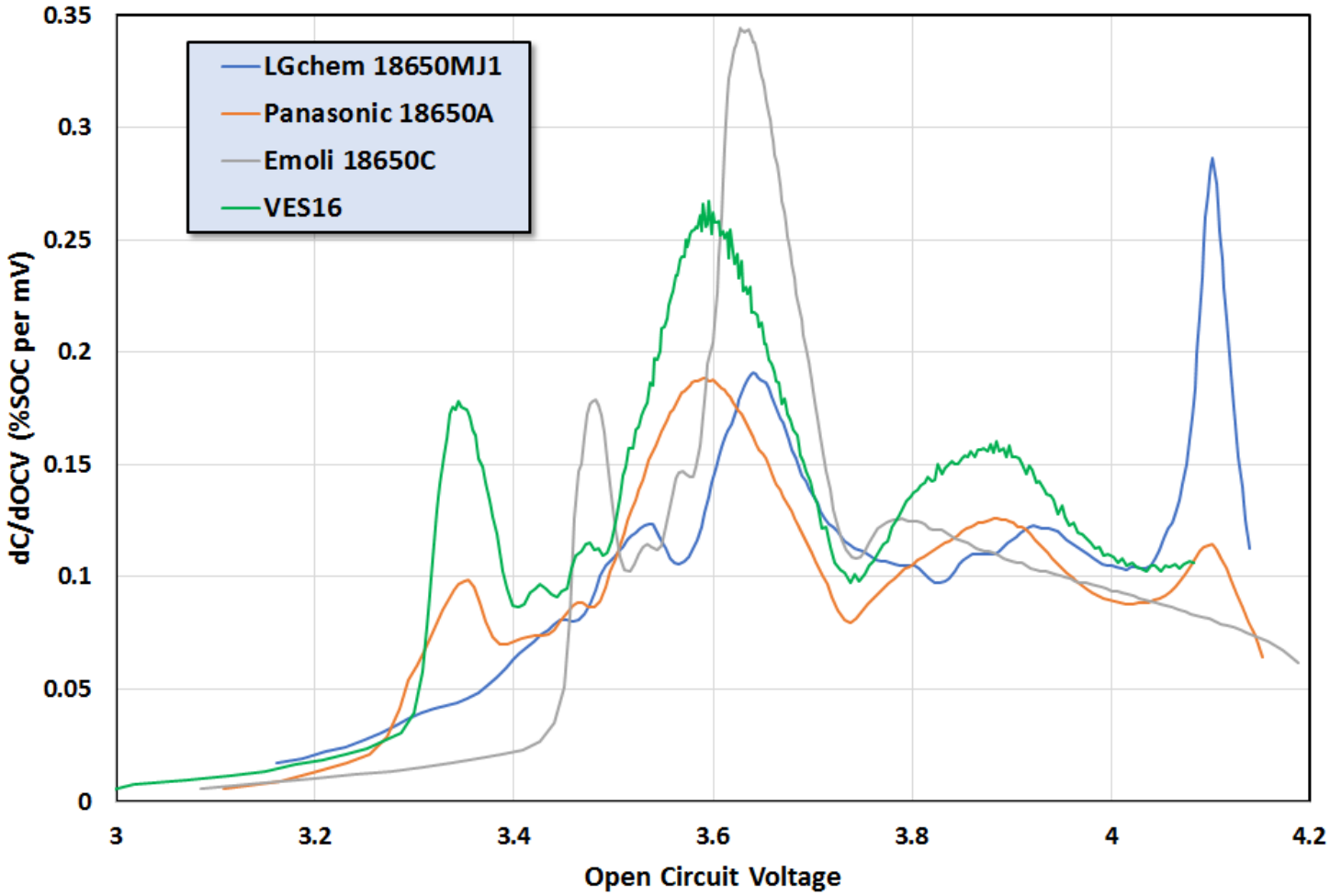
“Apparent” OCV Changes with Cell Type

- **Not surprisingly, “apparent” OCV differs significantly for different types of Li-ion cells**



“Apparent” OCV Changes with Cell Type

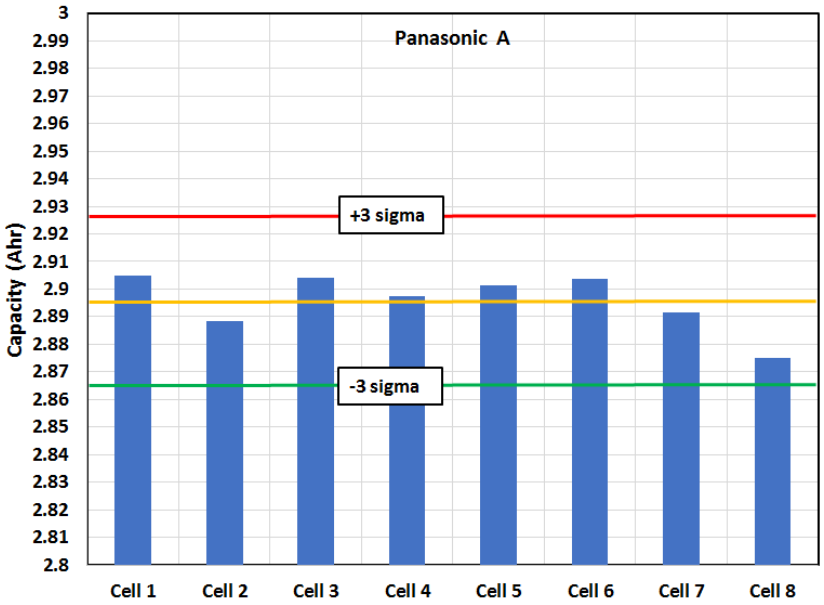
“Apparent” OCV differences can be magnified if differential capacity is examined

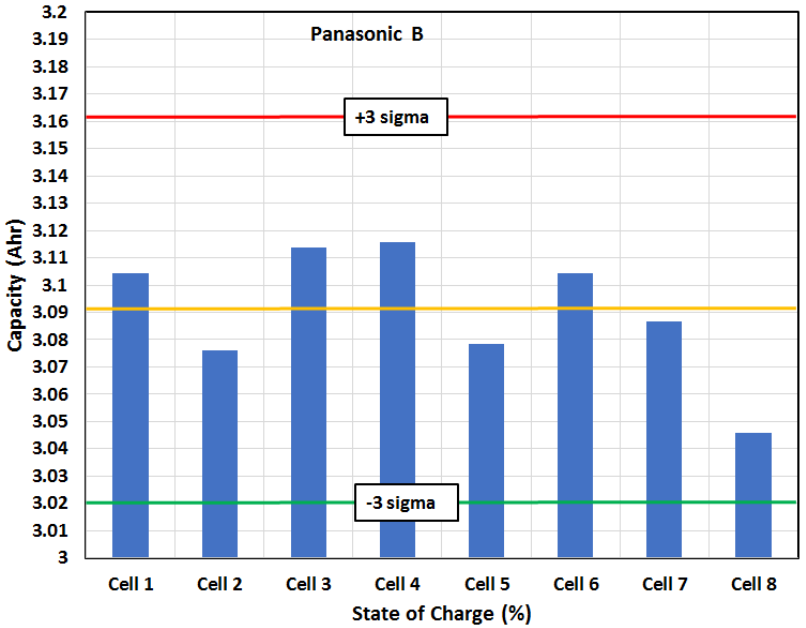


Peaks move around or even disappear for different types of cells, pointing to the detailed signatures of the materials and chemistry used in the cells

Distinguishing Between Similar Cells

Panasonic A and B cells can be distinguished by capacity and statistics

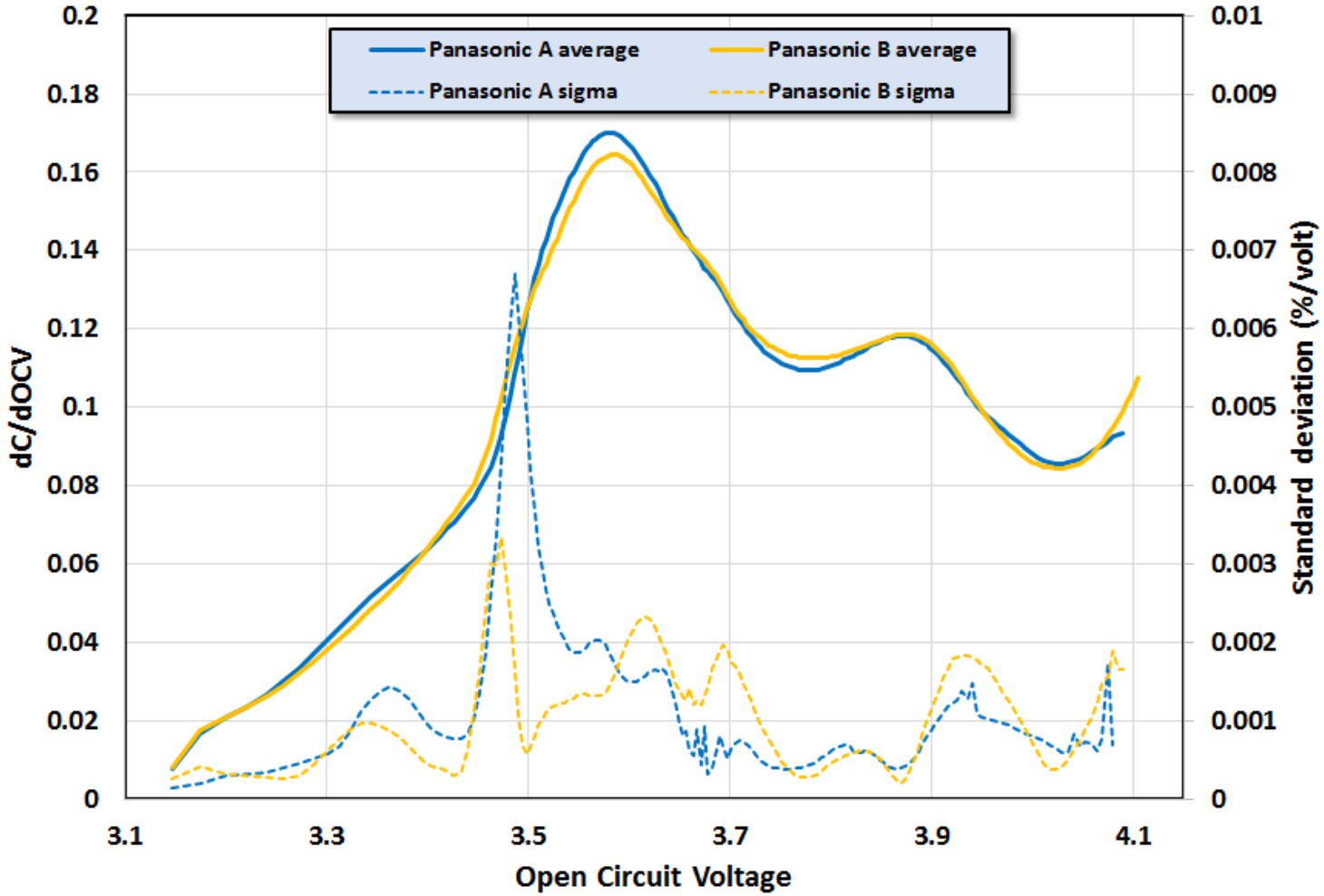




- **Are the poorer statistics for Panasonic B just because these cells were less well matched, or do the cells have greater intrinsic variability?**
- **Are the likely causes for the differences suggested by DC resistance or differential voltage/capacity analyses?**

“Apparent” OCV for Panasonic A and B Cells

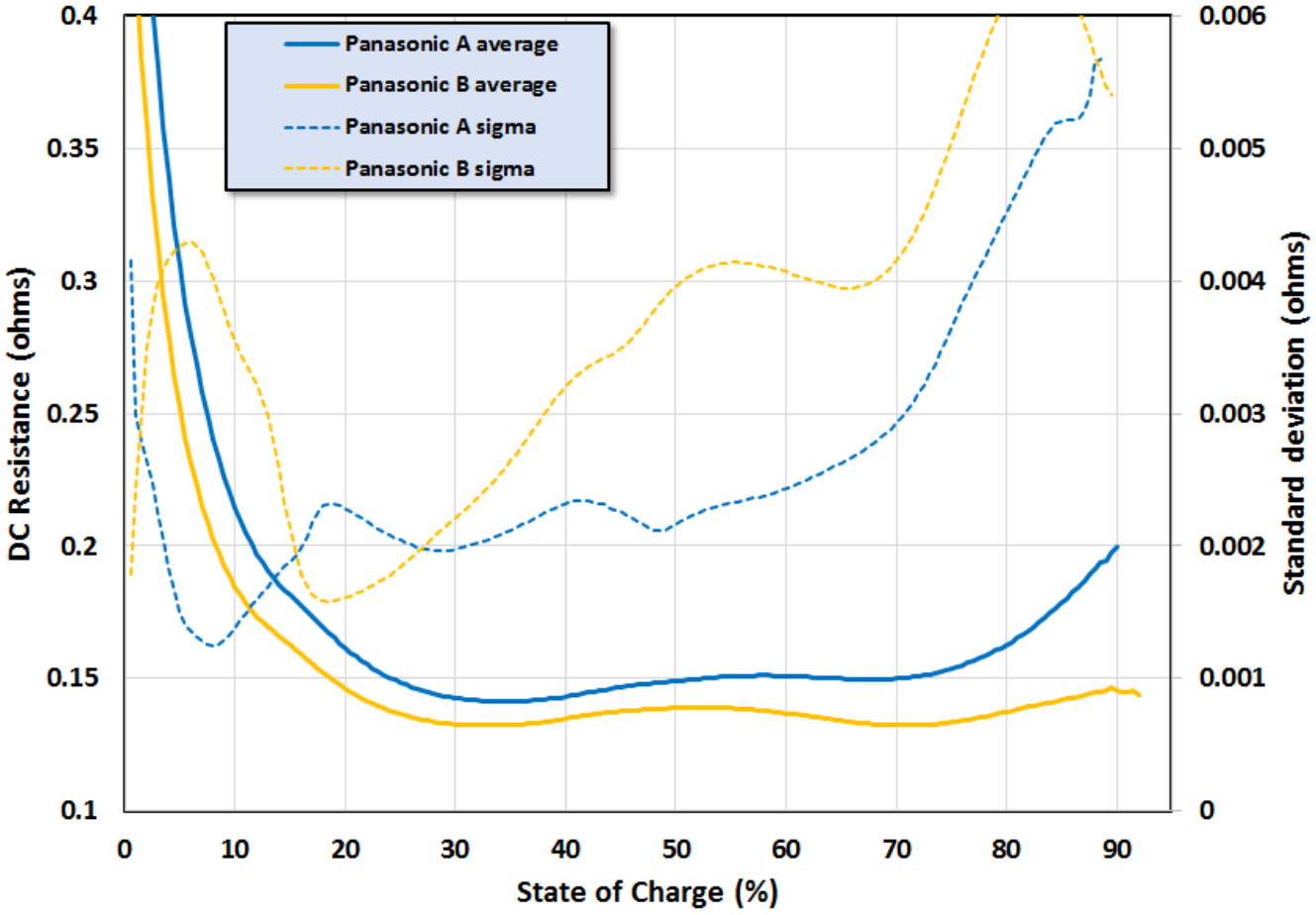
Little differences in either OCV or statistics seen



Suggests that a very similar chemistry is used in both of these two cell types

DC Resistance for Panasonic A and B Cells

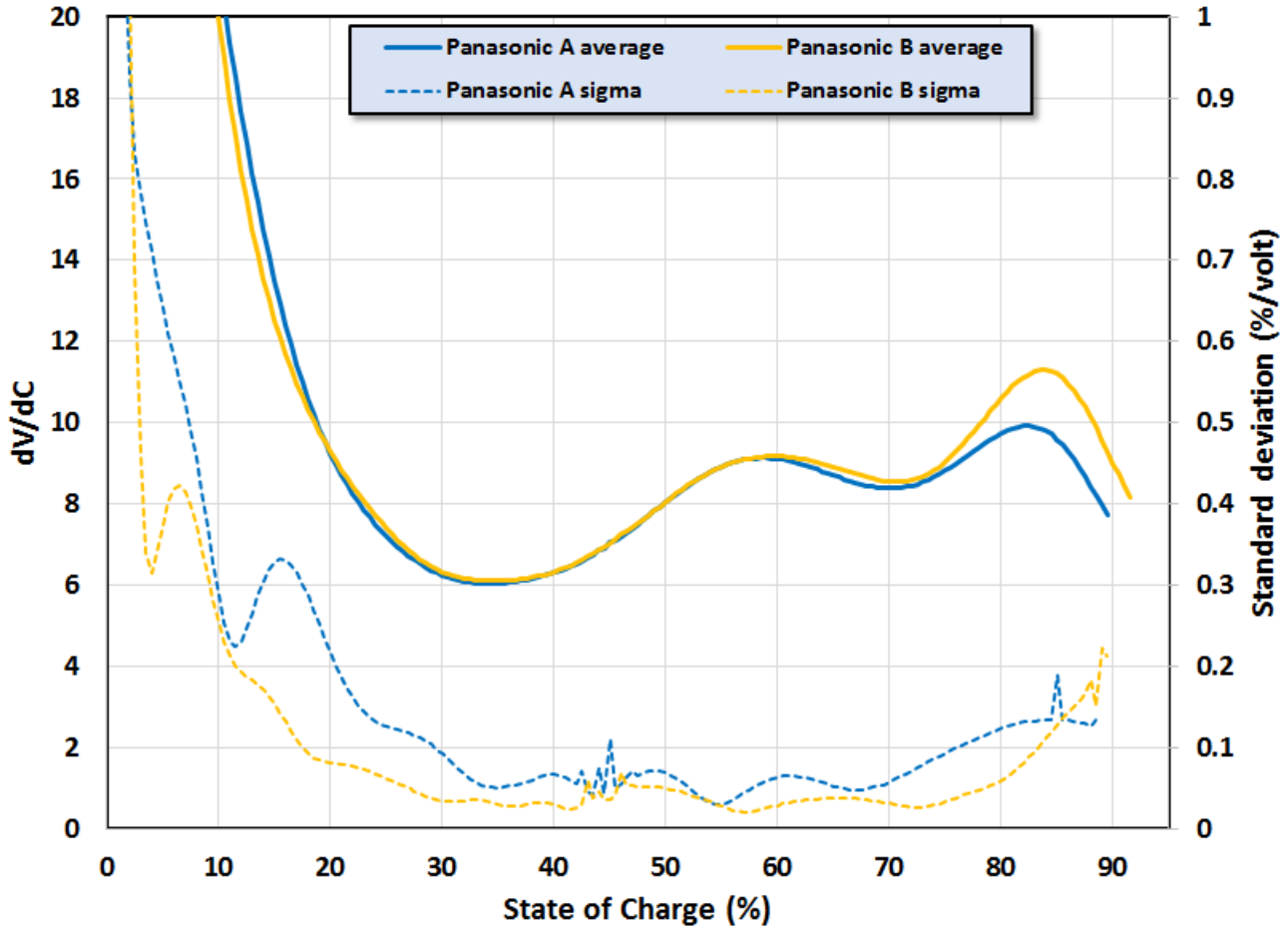
- **Resistance difference and standard deviations increase as state of charge increases**



Suggests cell design/manufacturing changes between cell types, and is primary factor in poorer cell statistics for Panasonic B

Differential Capacity for Panasonic A and B Cells

- Differential capacities separate above ~75% State-of-Charge



Suggests cycling performance above ~75% SOC may be different for Panasonic B

Conclusions

- **A group of inspection and test methods have been identified as likely to be perceptive to Li-ion cells that are non-authentic, aged, or degraded**
- **The test methods are shown to easily discern between various types of Li-ion cells**
  - *Methods can distinguish between materials, design, and process changes*
- **Validation of these methods for detecting known counterfeit cells needs to be done by comparison to a trusted baseline**
  - *Cells known or suspected to be counterfeit can be procured*
  - *Authentic cells can be intentionally aged or otherwise degraded*
  - *Cells from different batches can be intentionally mixed*
- **Methods are easy and inexpensive to apply over large batches of COTS cells**
  - *In most cases these (or similar) measurements are likely already being done as part of standard inspection and electrical screening cycles*
  - *These screening methods should be available to all small satellite and CubeSat programs*