Reduced Order Cell Models for Lifetime Assessment

- out of Field Data

Hans-Michael Koegeler (AVL), Georg Engel (AVL)

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"We are driven by a **passion** to examine the science, mechanics and philosophy of movement. To help create a world that is climate-neutral and one that makes **safe, comfortable, green mobility** a reality for everyone."

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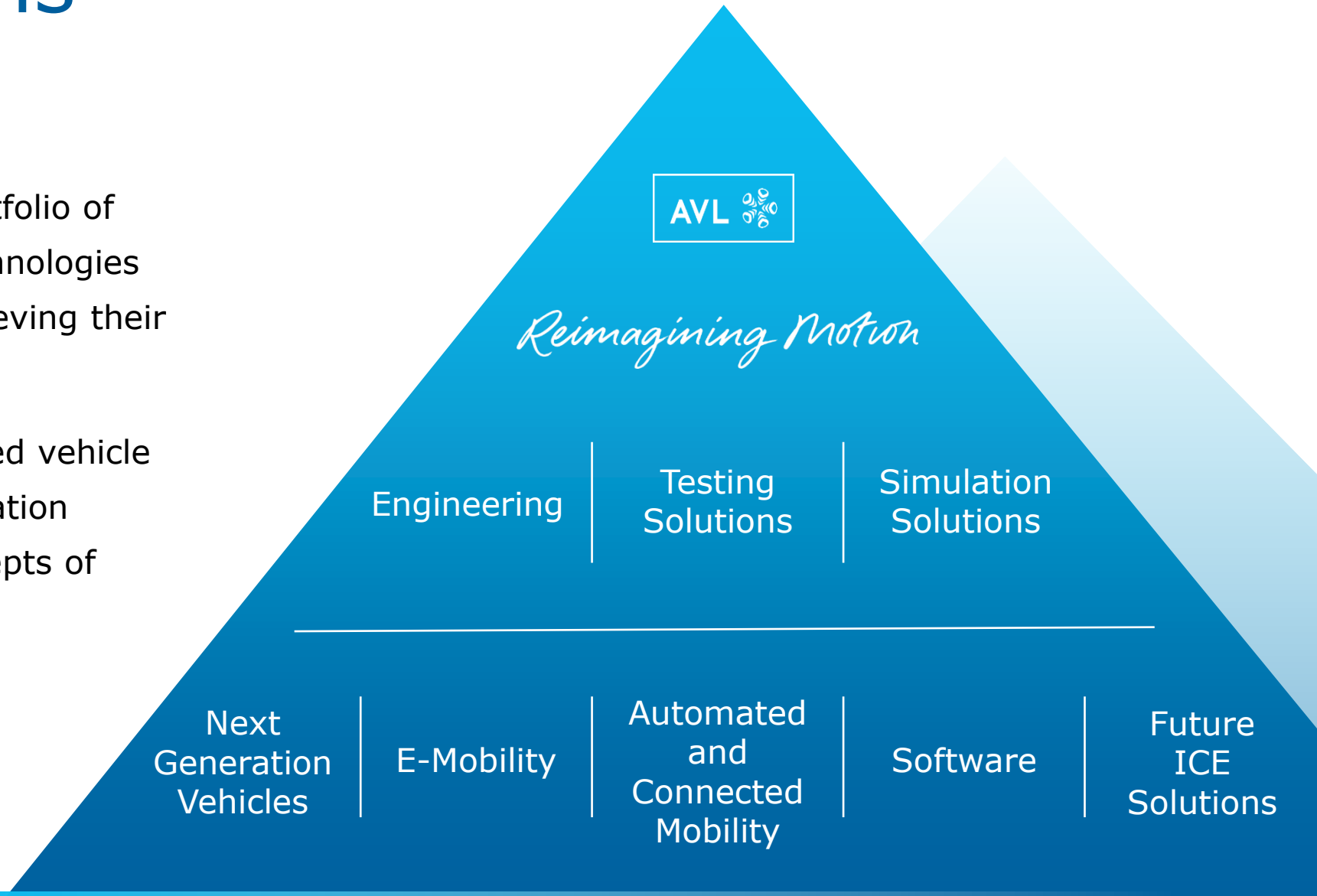
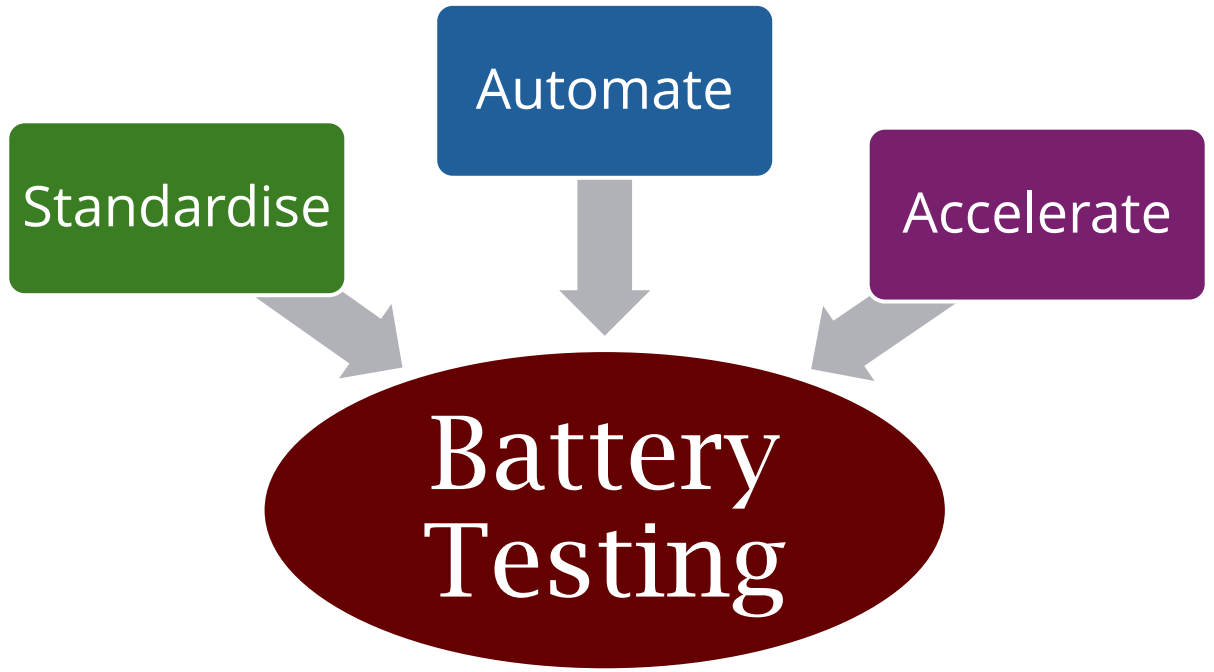
We constantly transform our portfolio of high-end methodologies and technologies to support our customers in achieving their ambitions.

From future fuels to the connected vehicle ecosystem, we are driving innovation today, to build the mobility concepts of tomorrow.



DigiBatt – European Research Project

DigiBatt = "Digital Solutions for Accelerated Battery Testing"



"Establish a ***novel, open, multi-scale digital toolbox to accelerate the testing and development of batteries"***

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Why Reduced Order Cell Models?

- **Emulating** real-time **battery behaviour** in **test environments**

  Based on **battery test data:** → **Established**, industrialized and supported by AVL-Products

- In DigiBatt: “To be delivered by WP6 to WP7”
  - WP7: Battery Simulation Model → to estimate lifetime, optimize battery system layout
  - BMS calibration to increase usable lifetime
  - Challenges / Research Questions:

    Possible to **identify RC-parameters** out of **field data?**

    How are **RC-parameters changing** over **time?**
    SoH identifiable?

    If being able to **identify RC-parameters** in field data**,**
    → **useable** for **Diagnosis? → Safety observation?**

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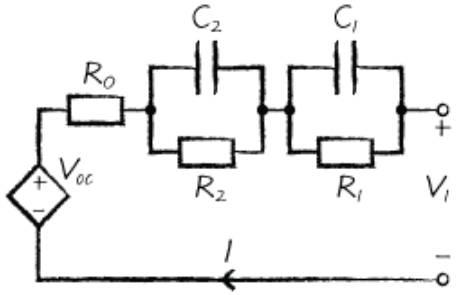
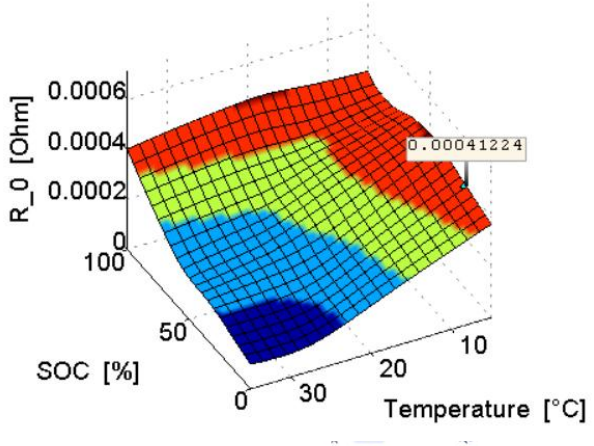
How? Proven Hybrid Modeling: RC-Model + Look-Up Tables

- Refine accuracy: Data model on top of RC-model
- Introduce dependence on state of charge (SoC) and temperature (T):

$$R = R(SoC, T)$$

- Generalize parameters, From a scalar to e.g. a look-up table





AVL MoBat & AVL E-Storage: Battery emulation on testbeds

Hybrid Model:
Refined accuracy
&
physics laws still obeyed

AVL Virtual Studio

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Which field data to fit?

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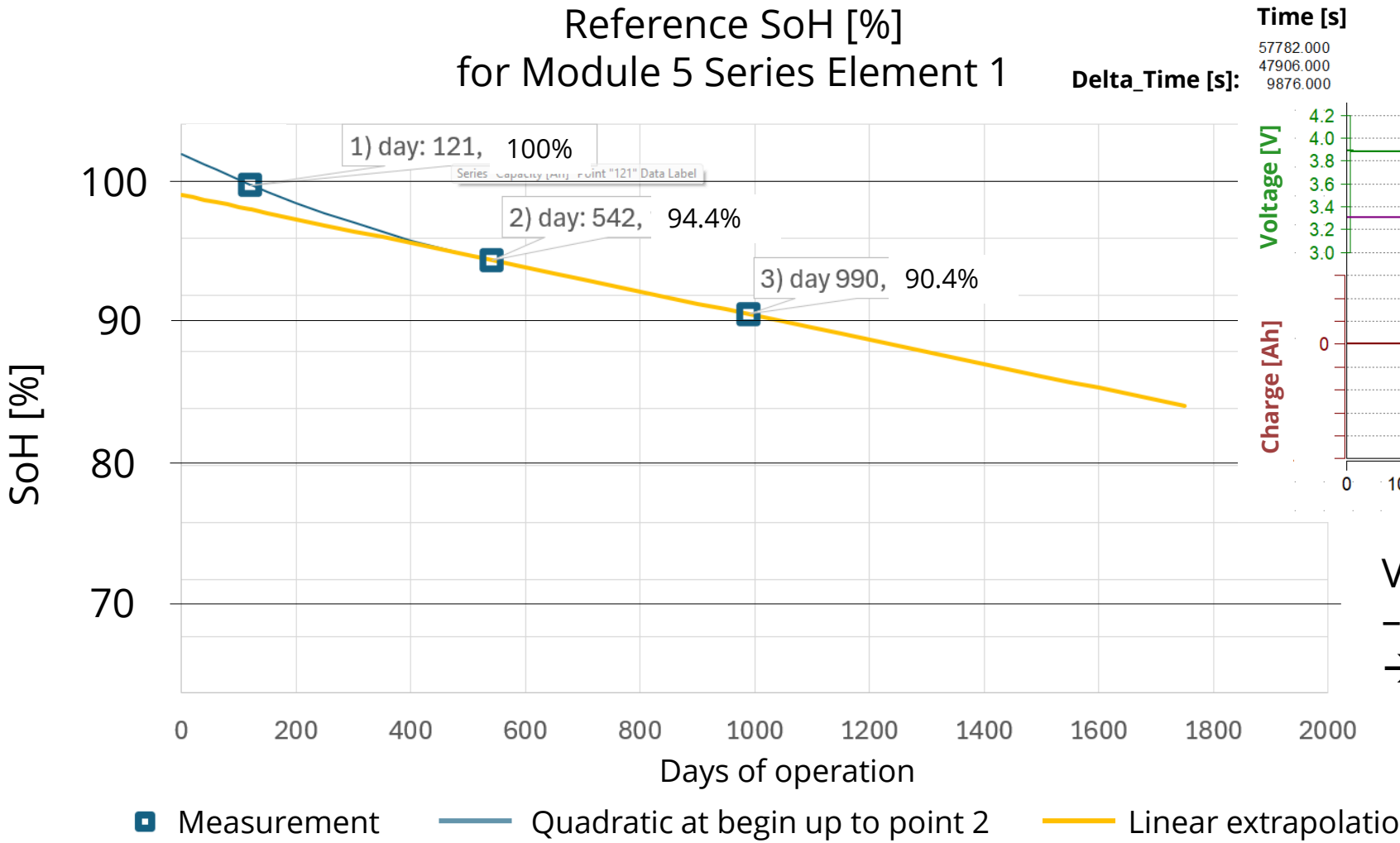
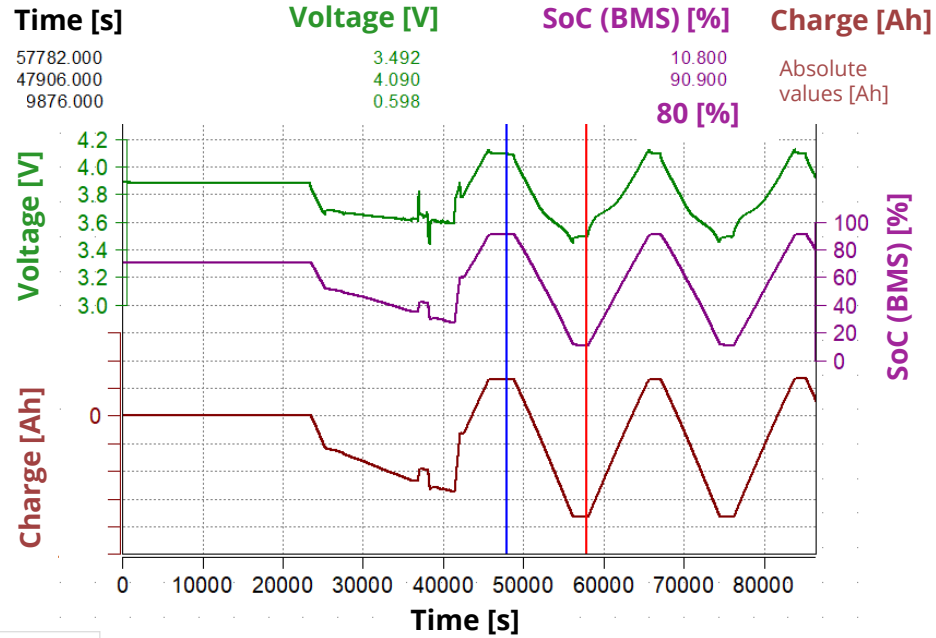
Technical Specifications | Corvus Orca ESS

Performance Specifications	
C-Rate - (Discharge / Charge)	Up to 3C / Up to 3C
System Specifications	
Battery Cell Chemistry	Lithium ion NMC / graphite
Single Module Size / Increments	5,6 kWh / 50 VDC
Single Module Capacity	128 Ah
Single Pack Range	38-136 kWh / 350-1200 VDC
Max Gravimetric Density - **Pack**	77 Wh/kg | 13 kg/kWh
Max Volumetric Density - **Pack**	88 Wh/l

1600 days of operation, 1Hz resolution, 3 Reference Check up days for Cell Capacities:





Values read out manually
– after relaxation
→ negligible dynamic remaining

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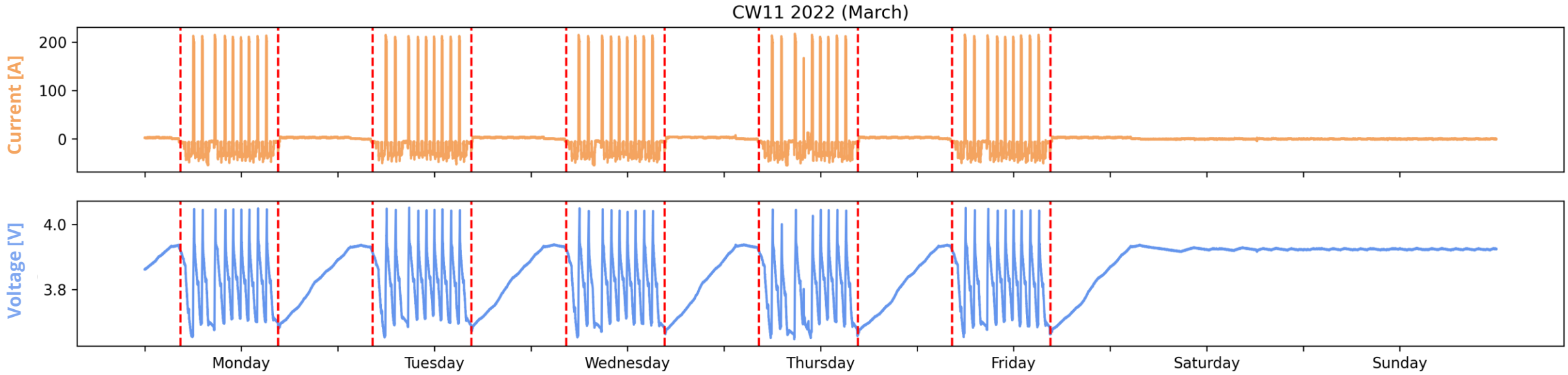
Other than these 3 days

→ typical week:



→Plus: Many similar Charging and discharging events
→Drawback for SoH estimation: “low SoC stroke” 25 to 30% only
→and some noise in data.

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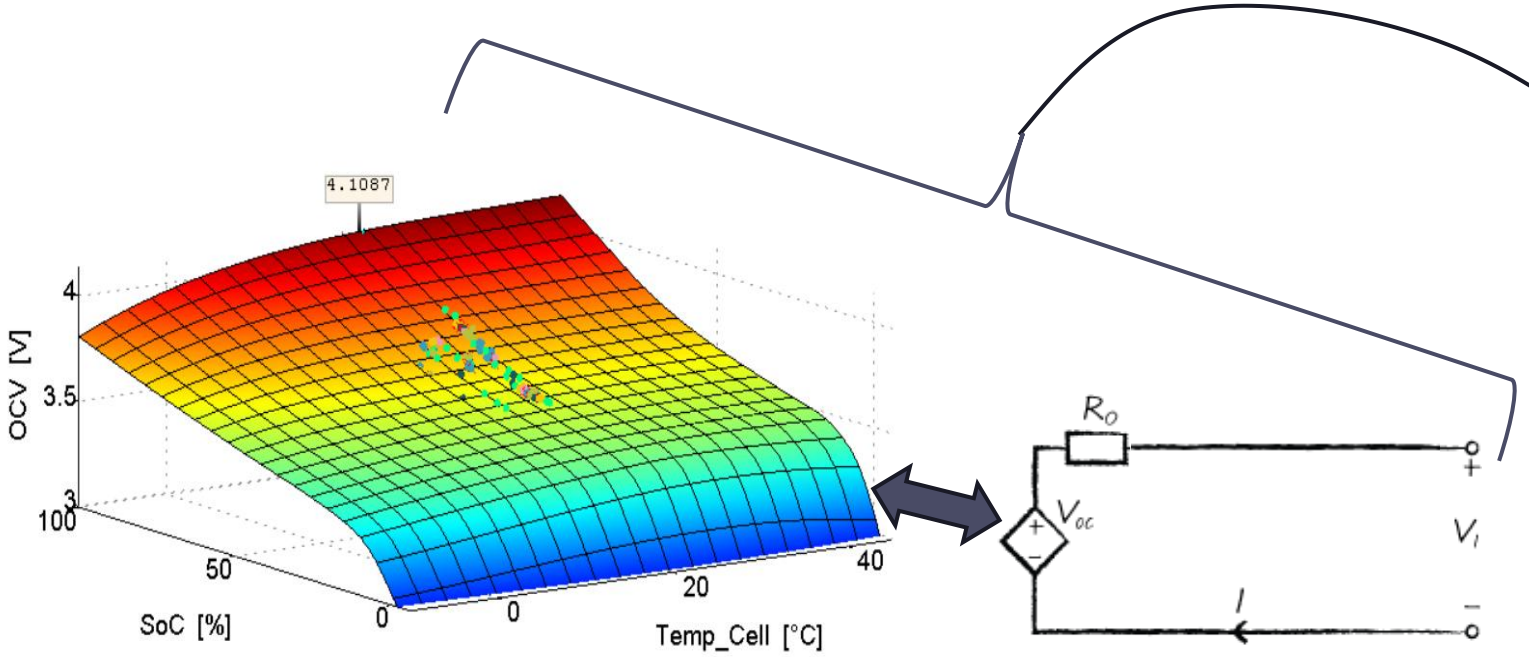
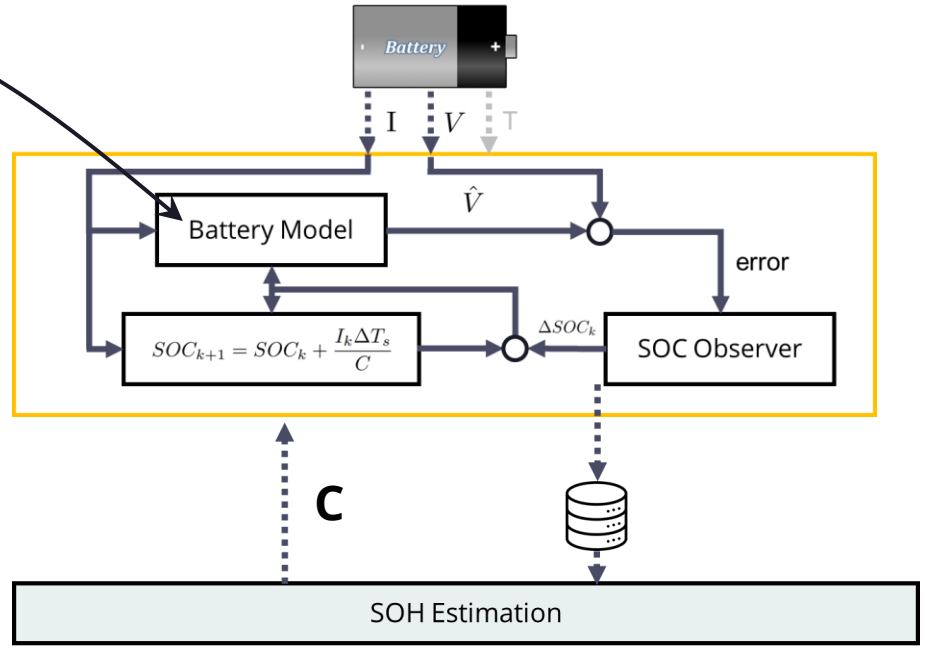
First Approach of SoH Estimation

- Use an SoC observer during the day
- Slow SoH observer (**C**) outside over one or several days
- Battery Model: Inner Resistance only
- Use OCV behaviour from Cell supplier + shift to qOCV measurements by CORVUS:





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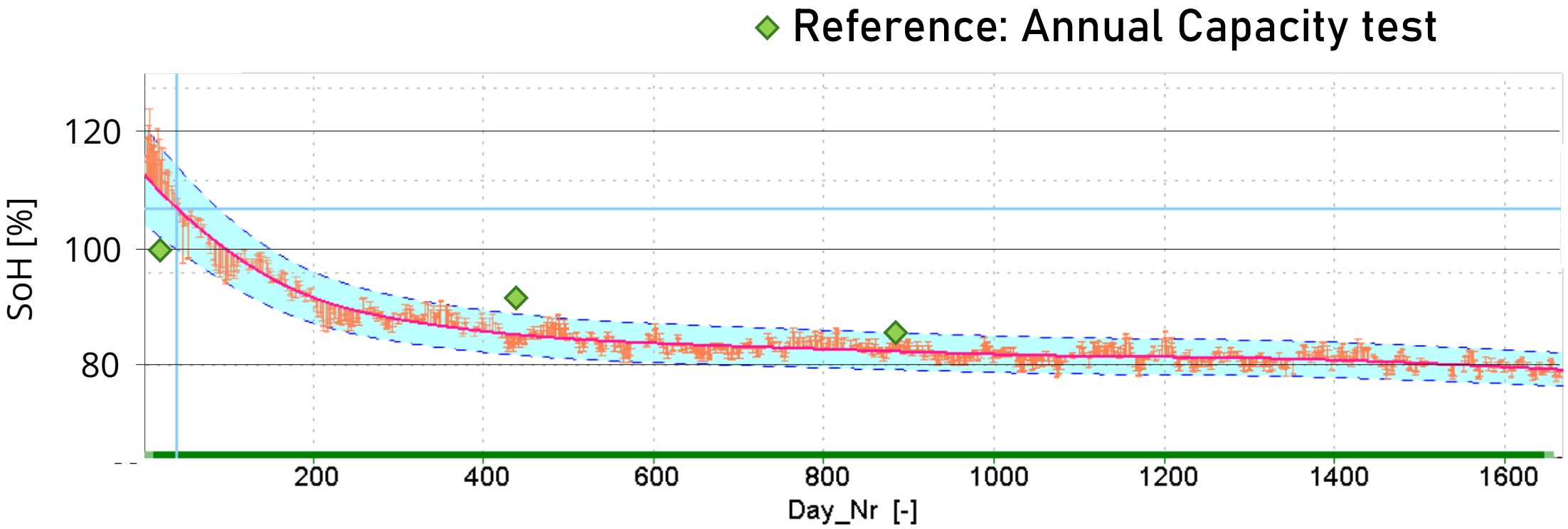
Result of First SoH Identification Run:



True? Incredibly strong decrease of capacity in the beginning.

→ Improve the Model to the intended 2 times RC

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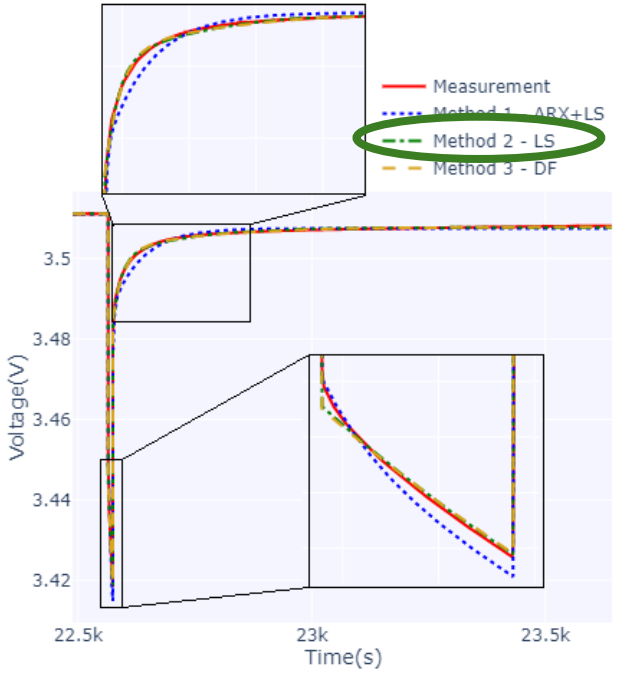
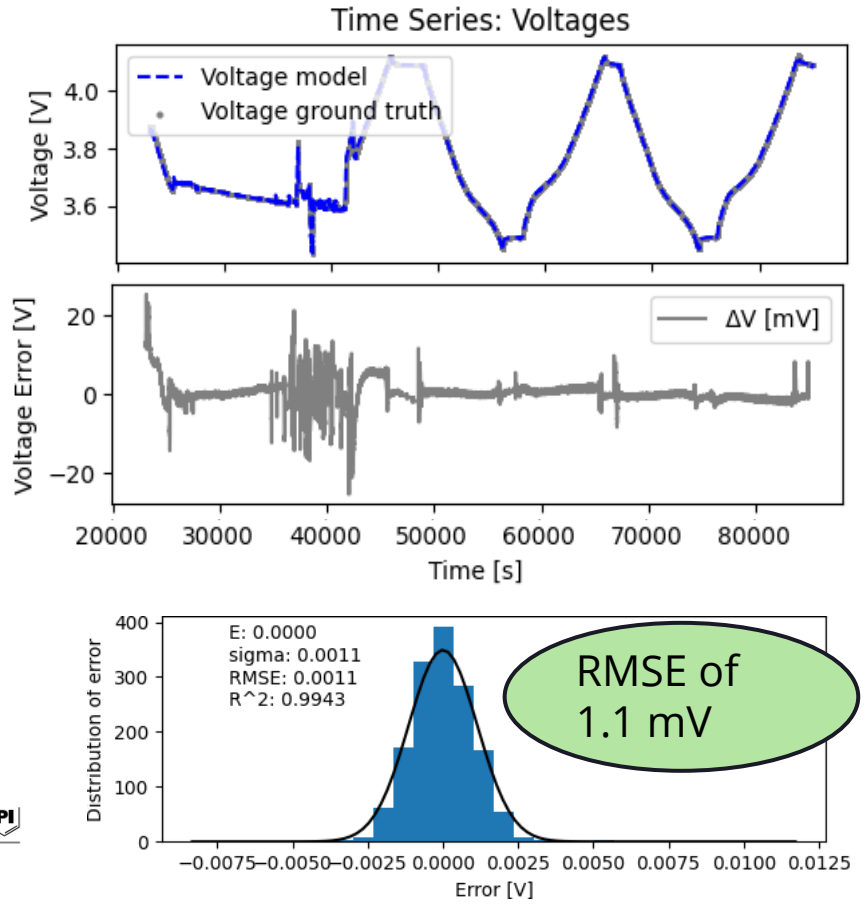
RC-Model Parameter Identification (Novel Method)

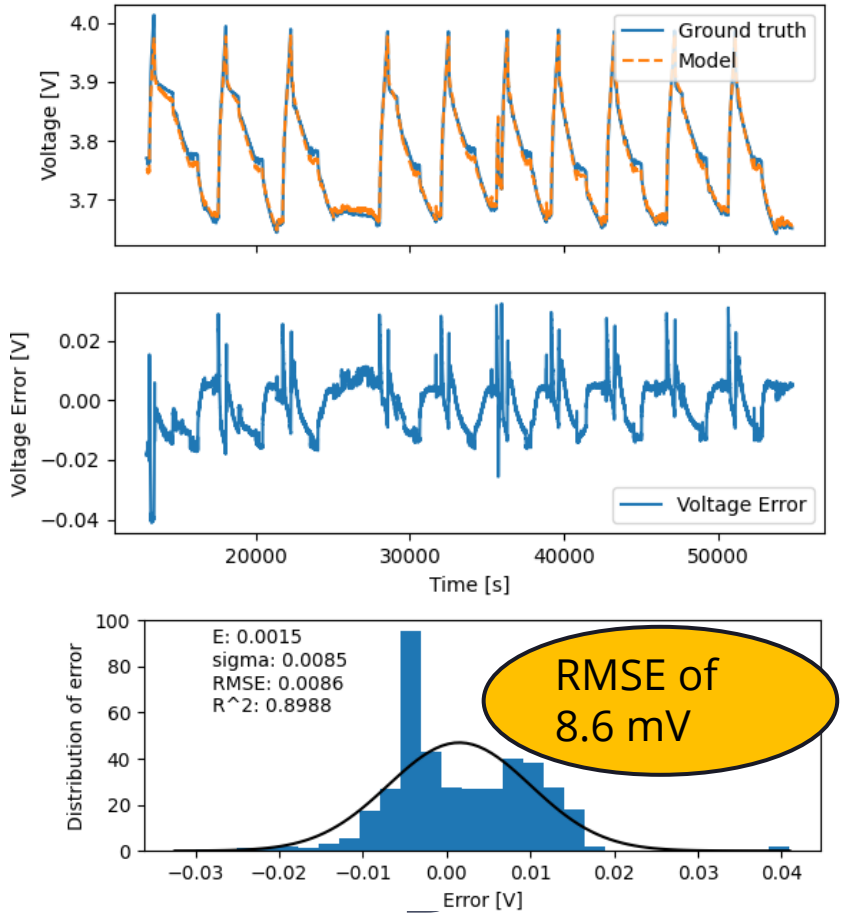
From testbed: Excellent



From field tests (high SoC stroke): Very good



From generic field data: Challenging but good



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batteries

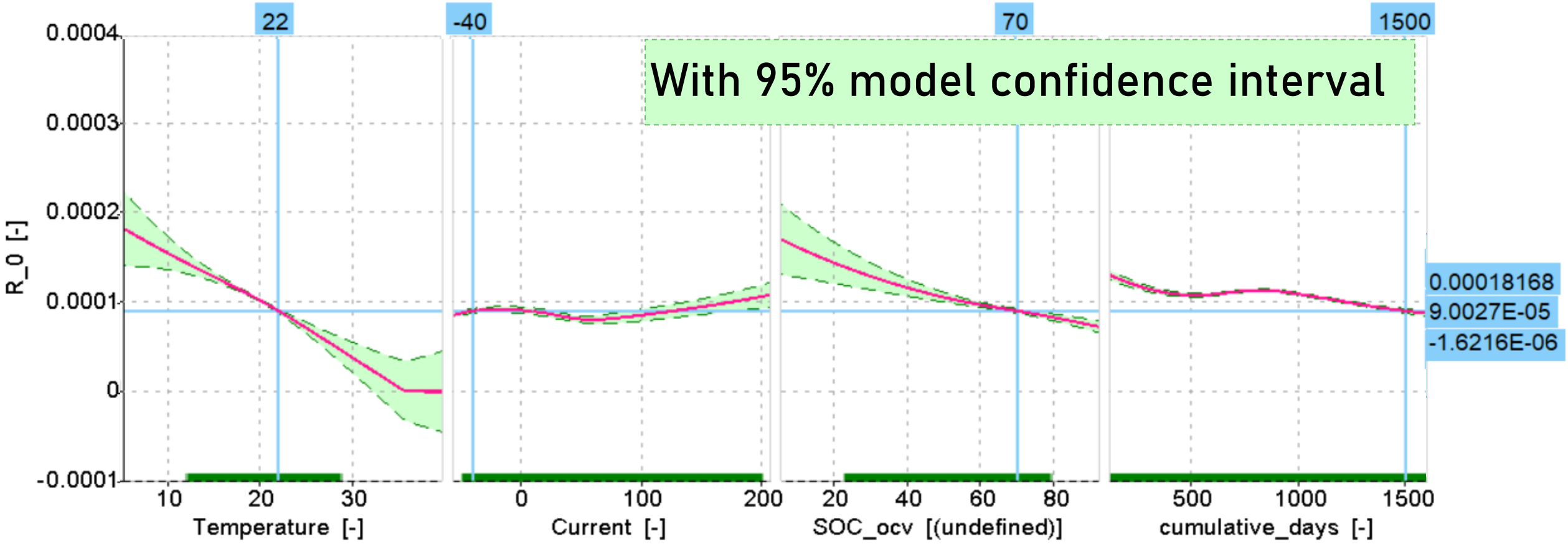
MDPI

Article

Linear Regression-Based Procedures for Extraction of Li-Ion Battery Equivalent Circuit Model Parameters

Vicentiu-Iulian Savu [1,*], Chris Brace [1], Georg Engel [2], Nico Didcock [2], Peter Wilson [1], Emre Kural [2] and Nic Zhang [1]

Fit RC-Parameters for all Days, Modelled as R_0 = F(Temperature, Current, SoC and Age)



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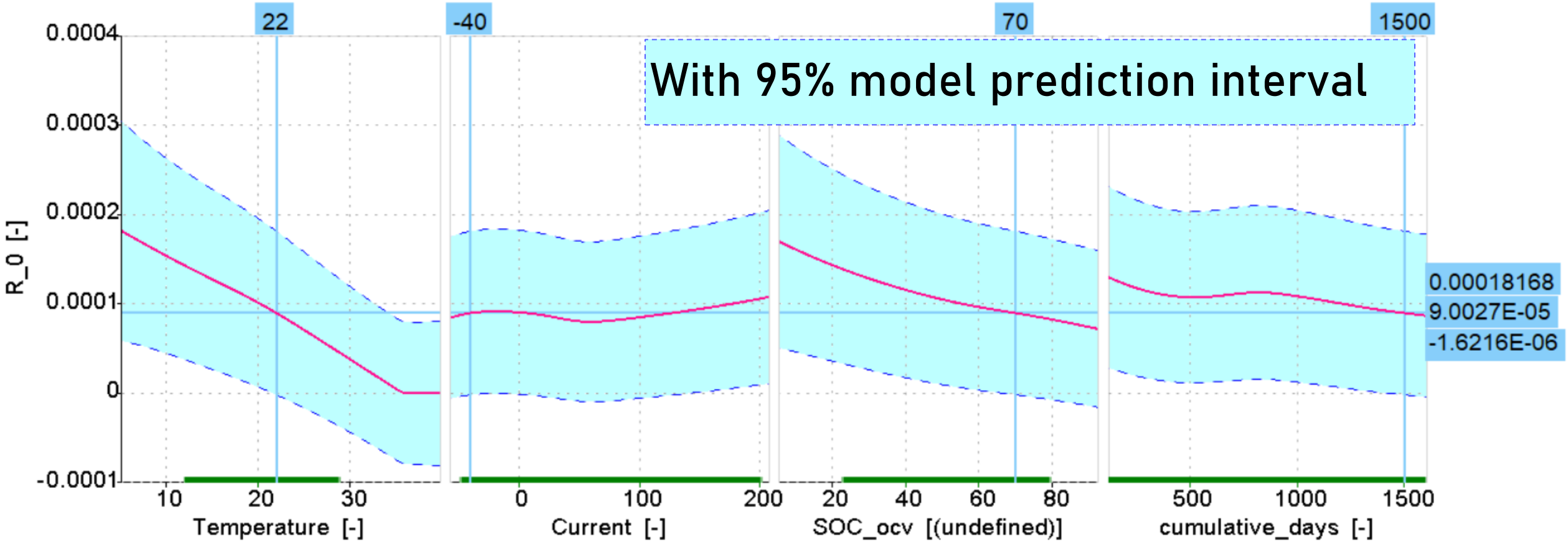

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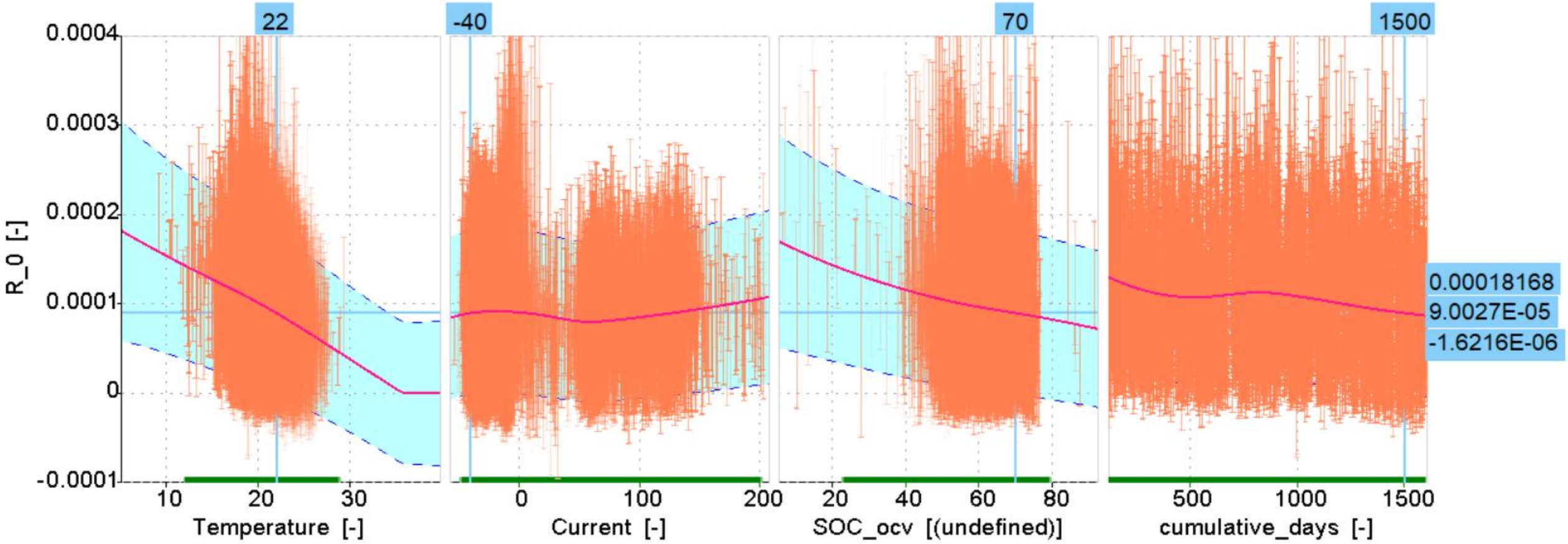

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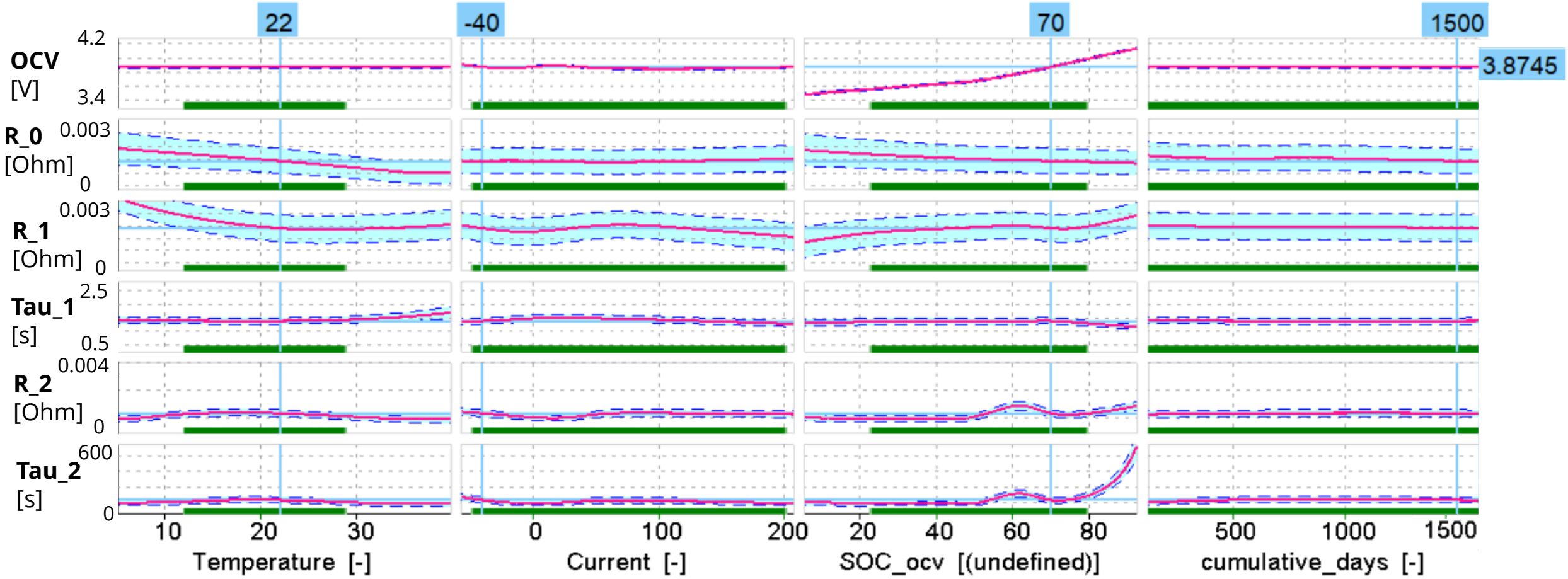
All RC-Parameters Modelled as F(Temperature, Current, SoC and Age)



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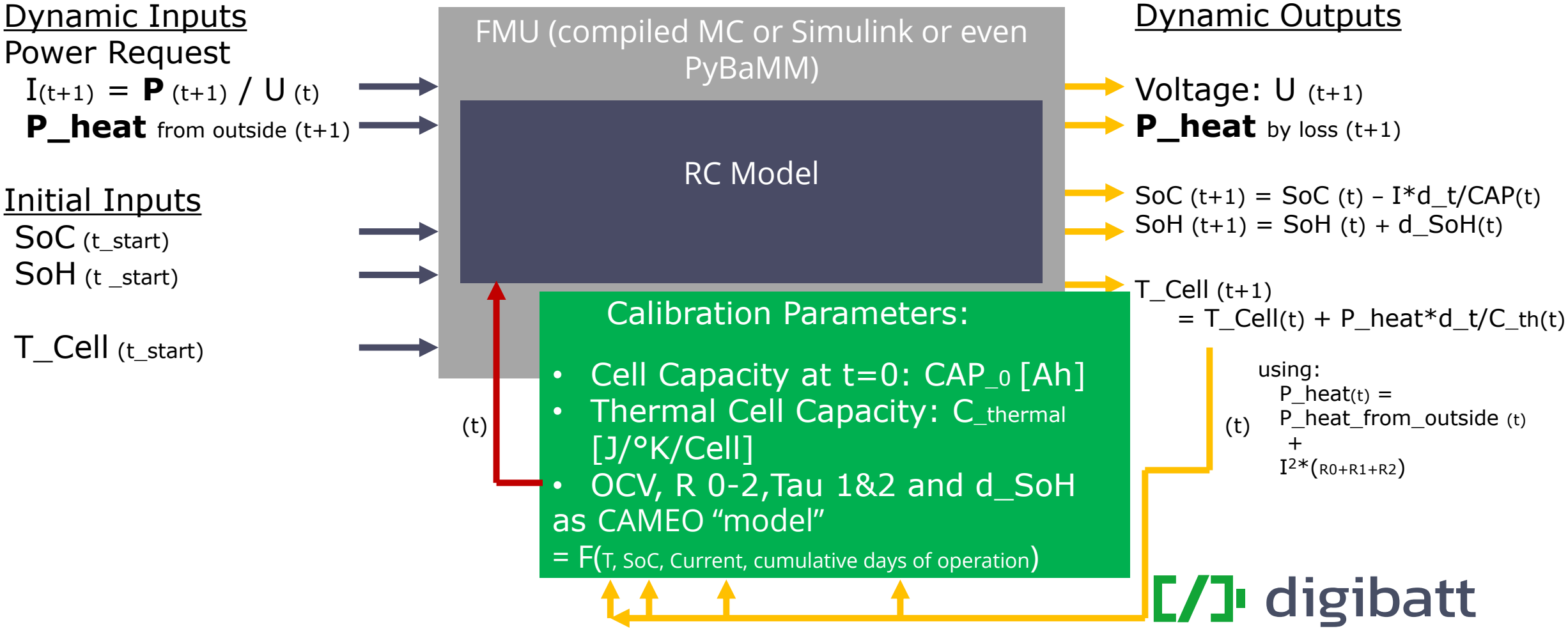
Delivered in Cell-FMU V1.0 “Calibratable Generic Cell-FMU”



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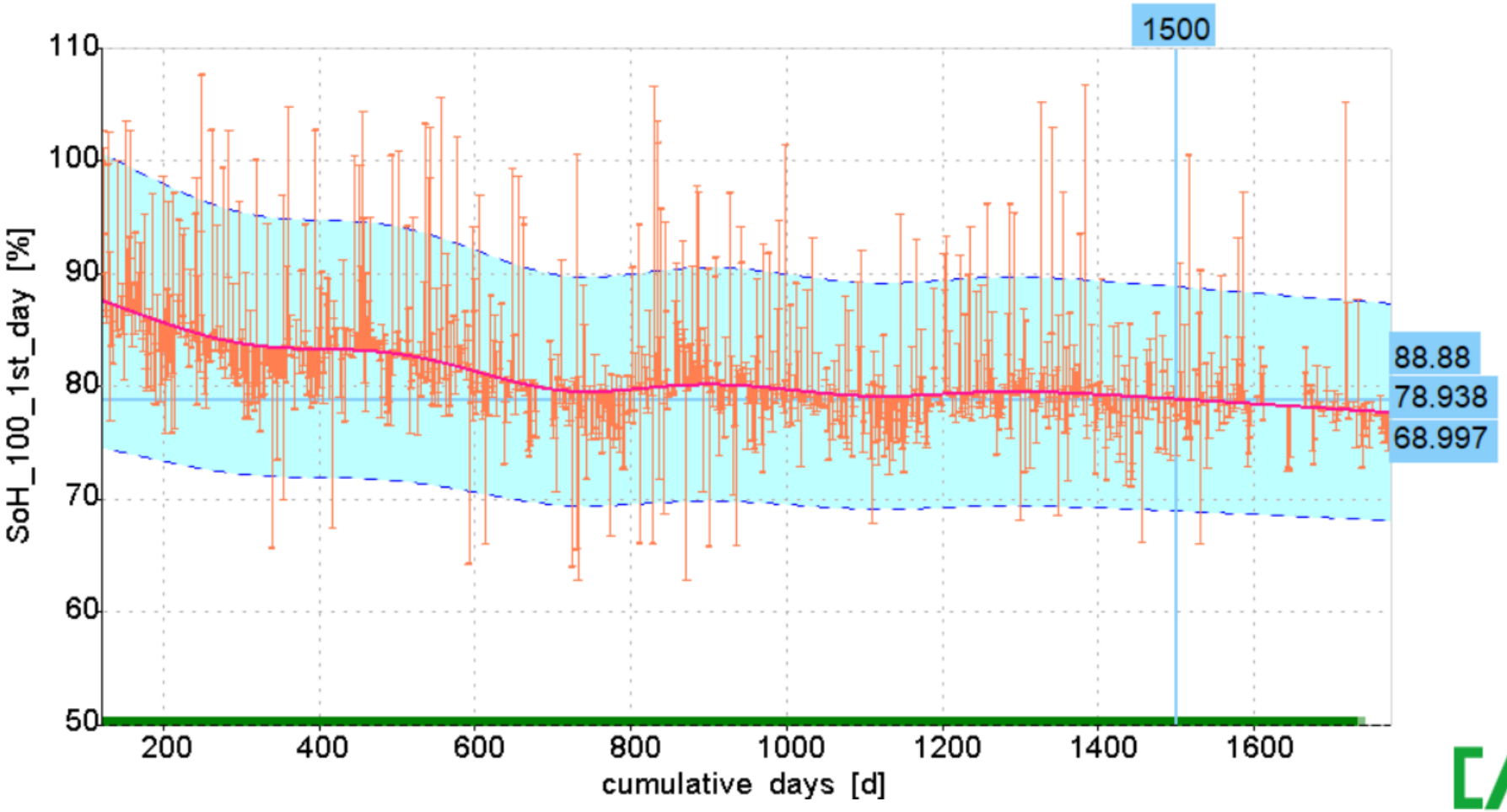
Use RC-Models in SoH Estimation plus 95% Prediction Interval:



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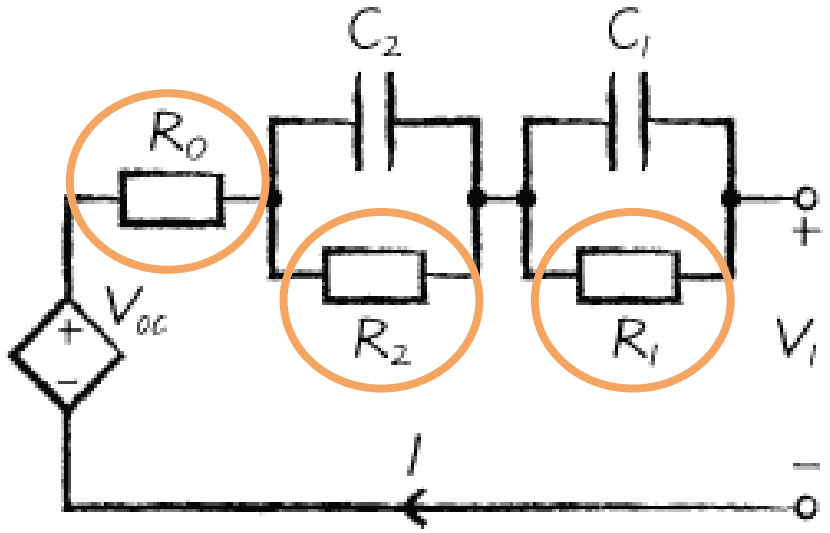
Actual 2nd Approach Under Work:

- Identify **OCV** directly out of **first Reference capacity** test day and **keep** it
- Fix further: **SoH** assumption as **linear F(days)**, Tau_1 and Tau_2
- Fit only R_0, R_1 and R_2 for each day:



- Finally use robustly fitted
  RC-Parameter for all days and
  allow SoH to adapt.

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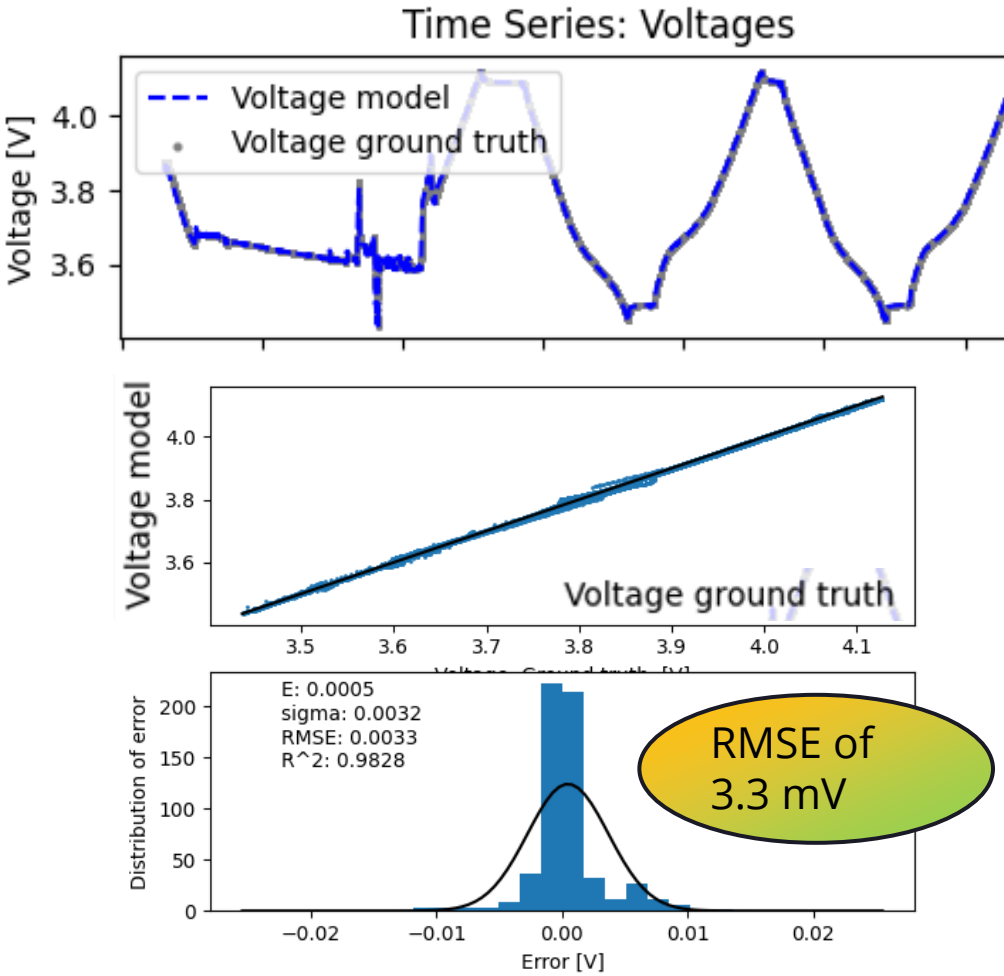
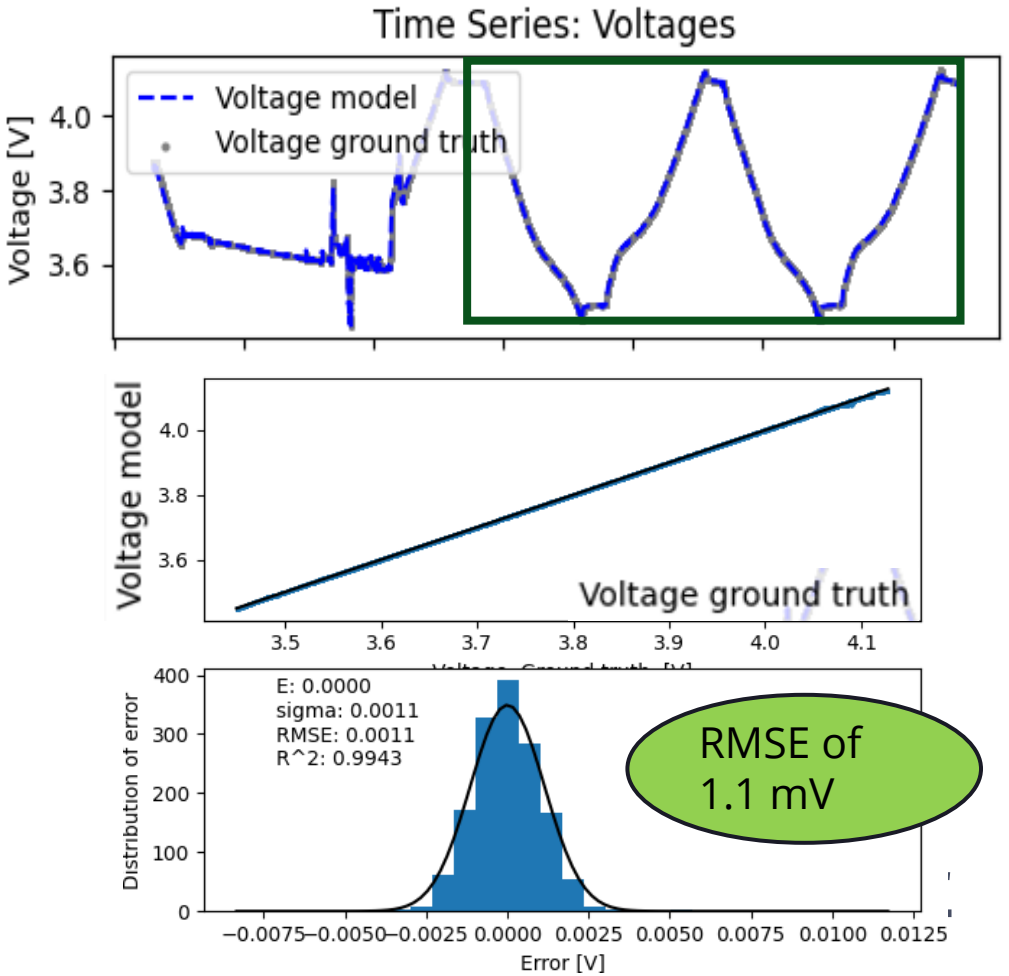
Parameters Estimated on 2020-05-01:

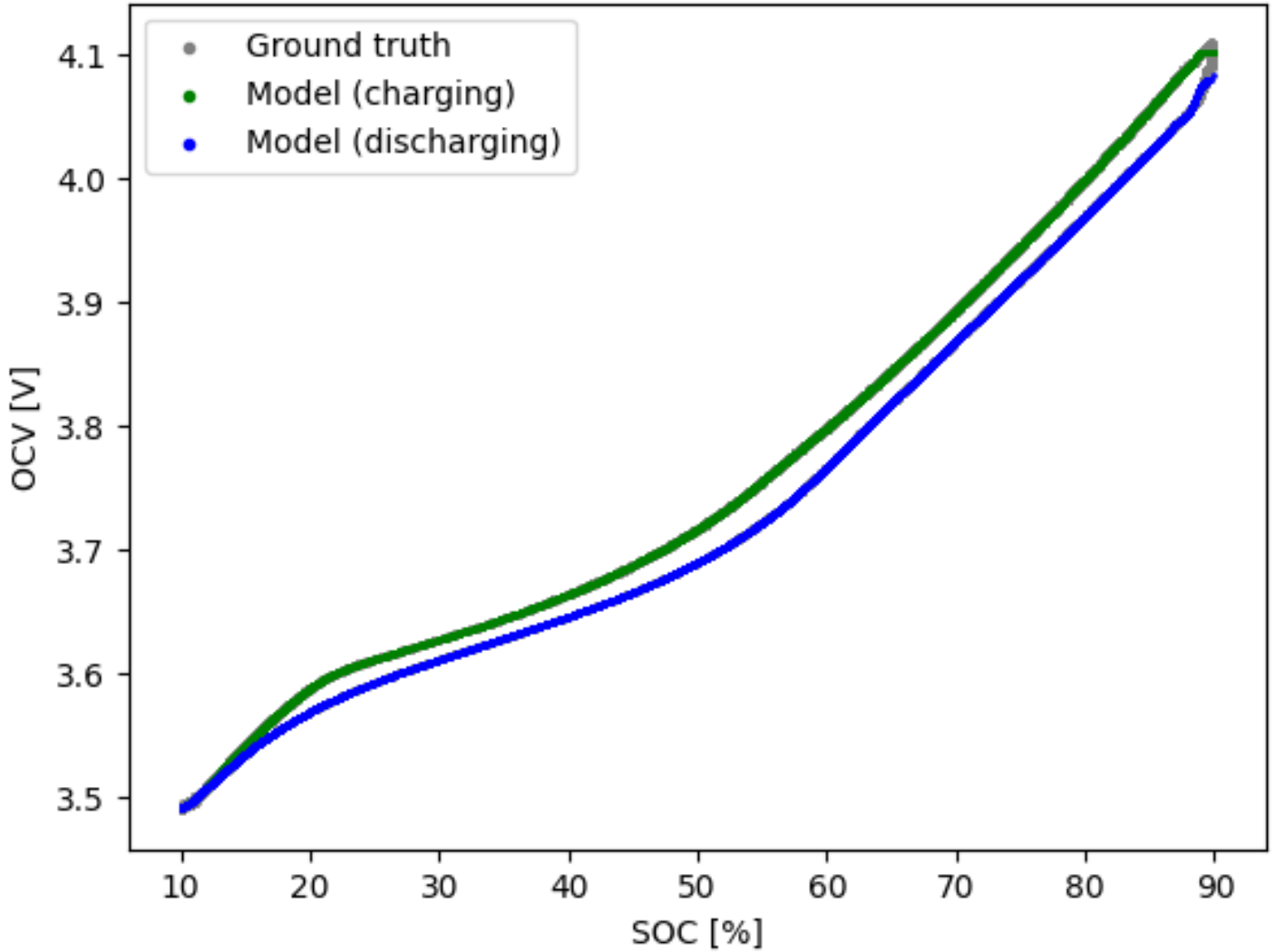
RC-params from all but idle: t=[23000, 85000]



Fit OCV only in second run
from annual capacity in range: t=[48400, 85000]



OCV Estimated on 2020-05-01
Hysteresis Clearly Detected and Kept:



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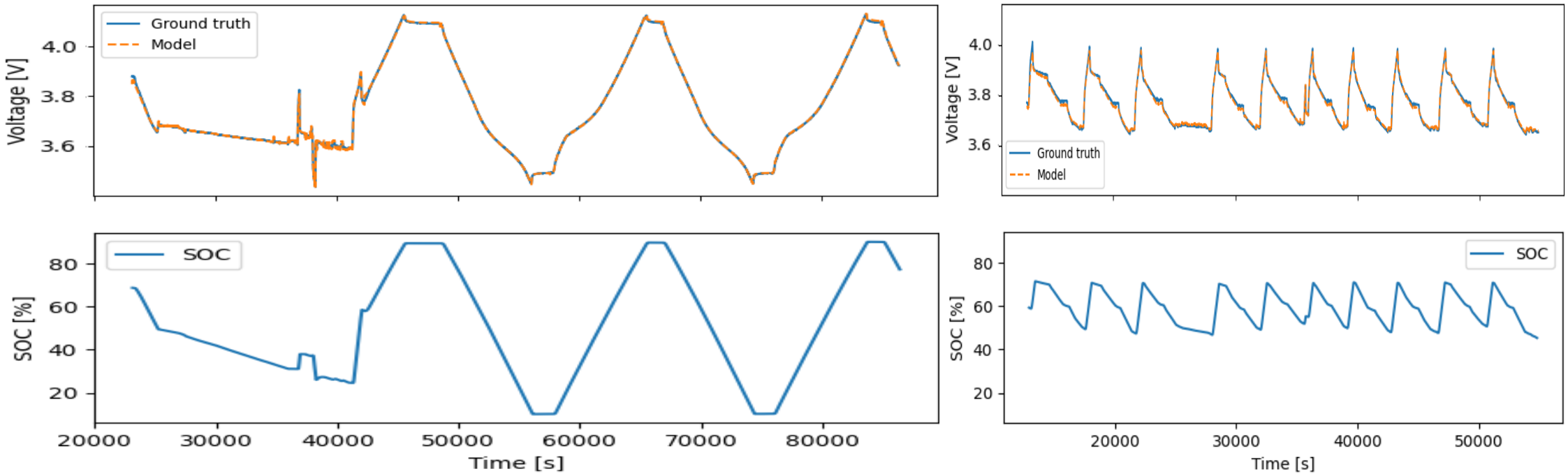
Comparison:
Capacity Check Day ←→ Regular Day



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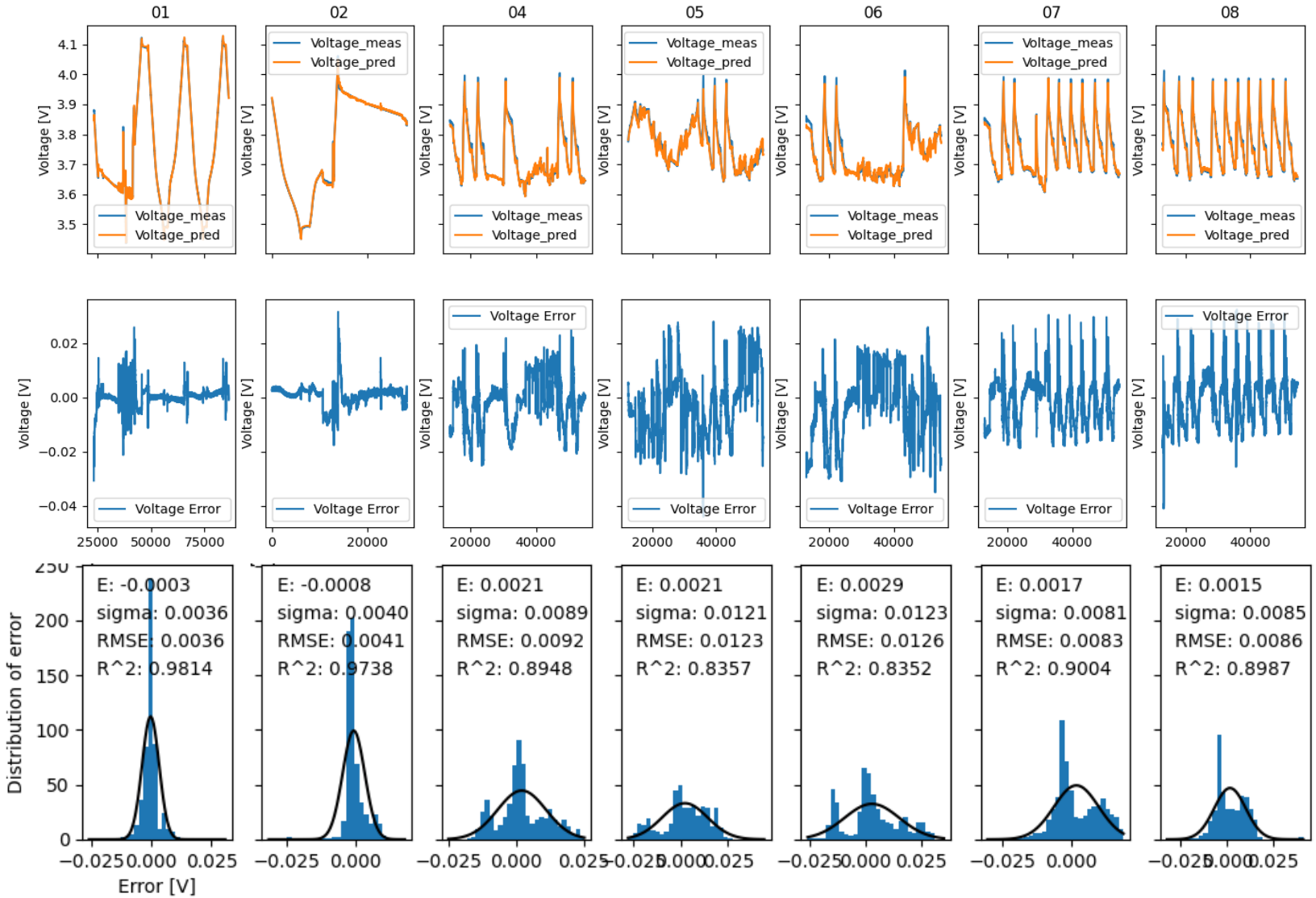
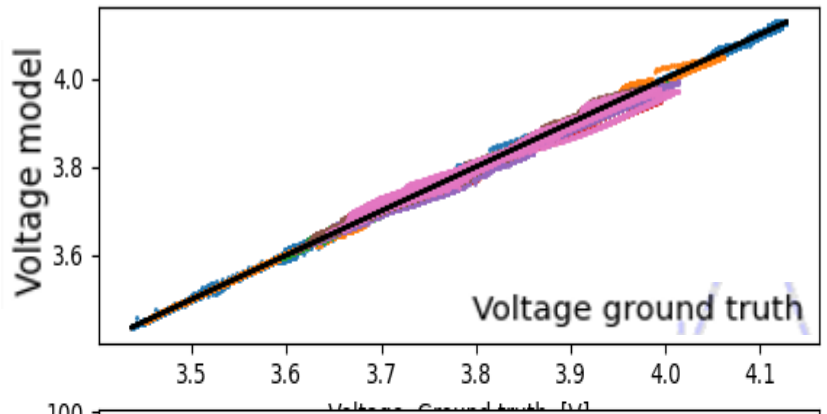
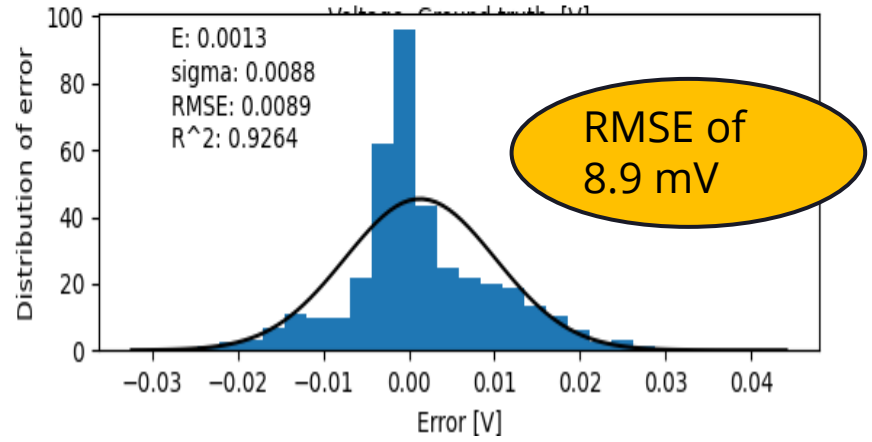
Check Parameters on Next Days (2020-05)







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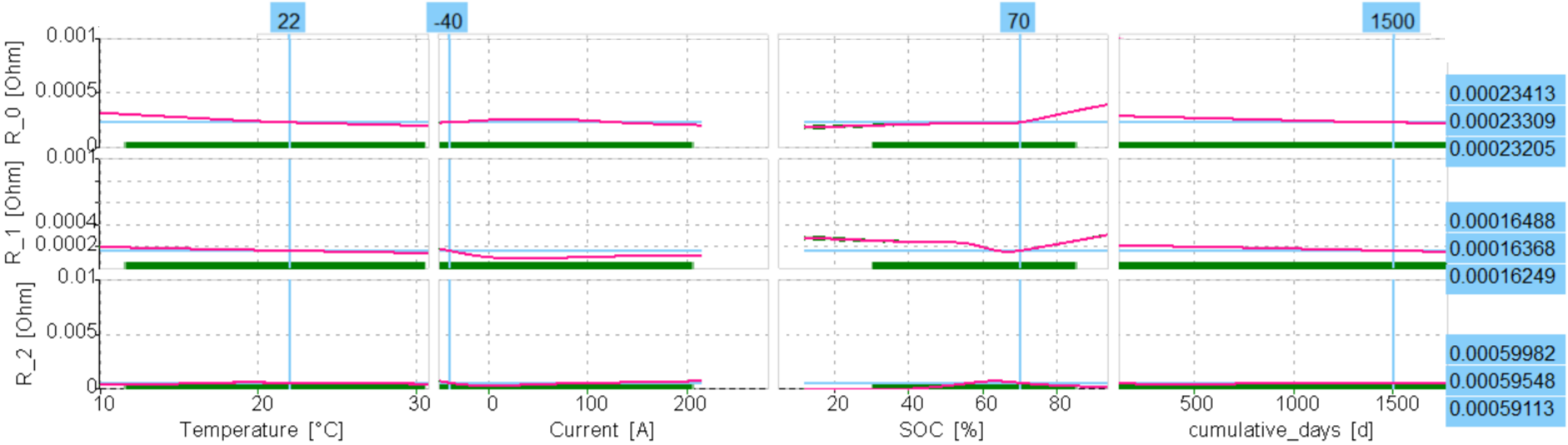
R_0, R_1 and R_2 Estimated for All Days, Behaviour Models:

With 95% model confidence interval



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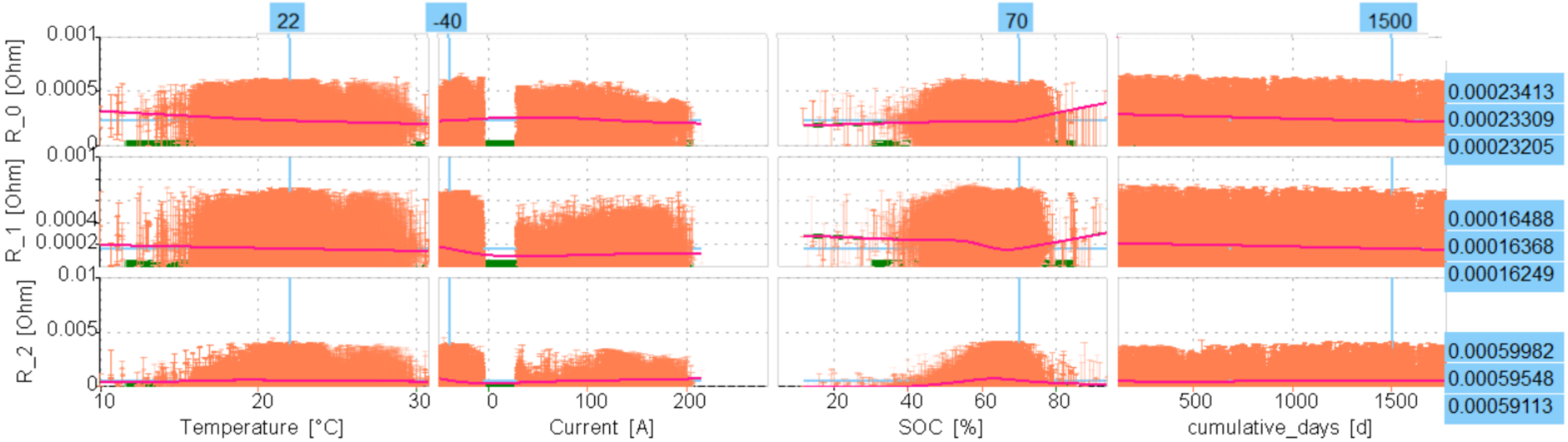
R_0, R_1 and R_2 Estimated for all Days, Behaviour Models:



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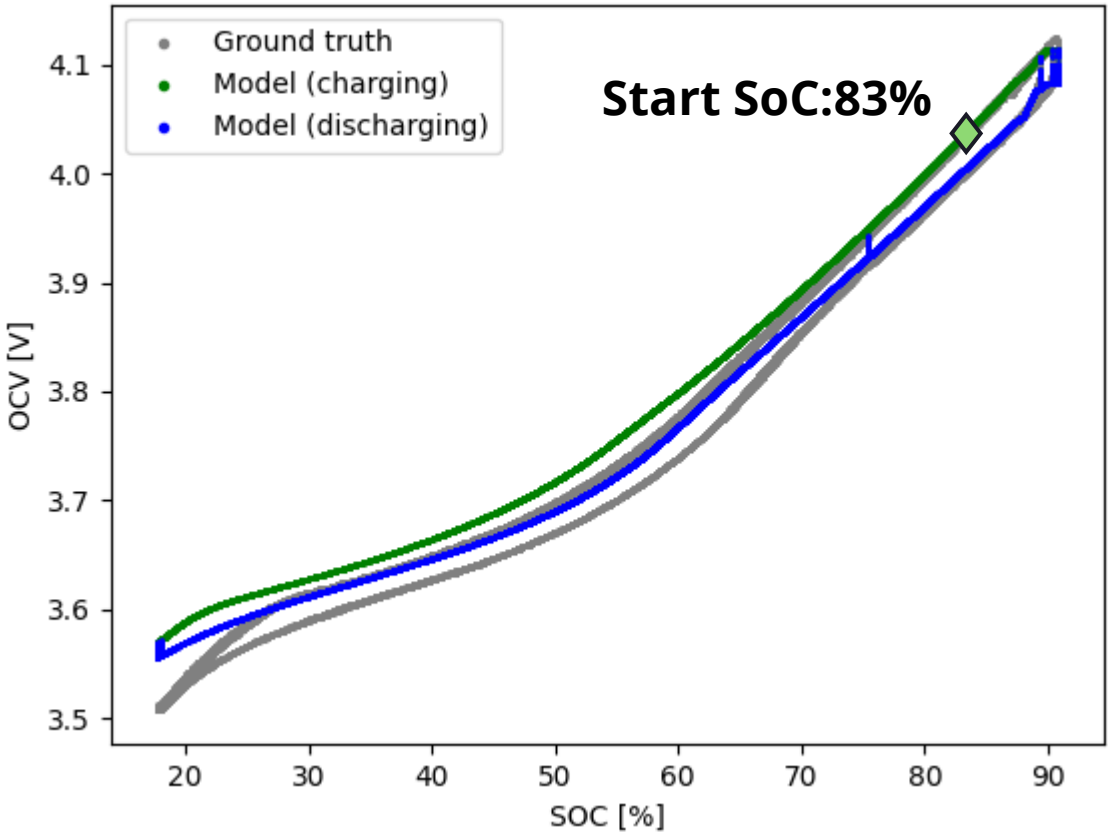
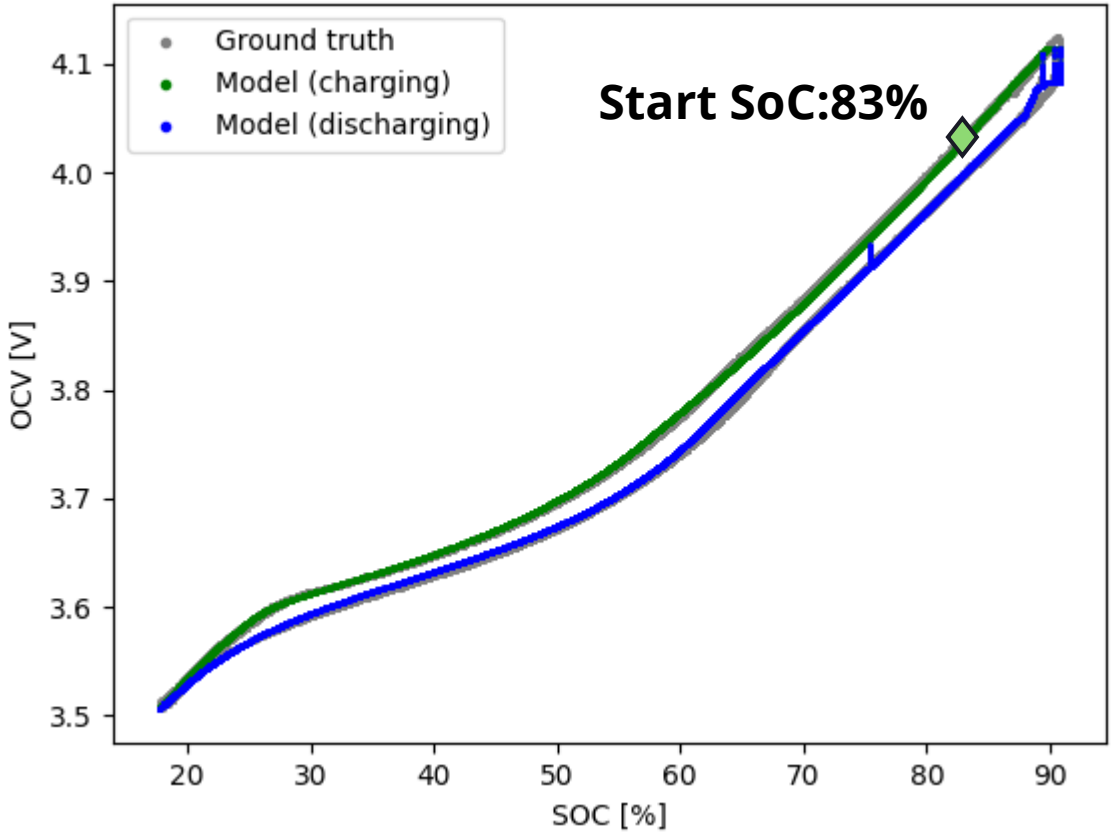
Approach Validated so far on 3rd Capacity Check Day 2022-09-17:

→ ca. 2.4 years from BoL: 2020-05-01: SoH=100%

Ignoring degradation (**SoH = 100%**)



Accounting for degradation → **SoH = 92%**
SoH Reference = 90.4 %



Next Steps to be Done:

- Use this parameter to estimate Capacity (or **SoH**) for **all days**
- Generate **SoH Model** over time
- Export all together as **Cell FMU V 2.0**
- Document **fast way** to get there for a **new dataset**.

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Conclusions / Summary

- RC-Models seem to be quite powerful
- Parameter estimation **out of field data** is a challenge:
  a) All parameters are **interacting** strongly
  b) **OCV** as F(SoC) is **dominant, Hysteresis** is **relevant**
     → Plausible **SoC and SoH** estimation is key
  c) RC parameters are changing slightly over time
  d) Influence of measurement noise can be reduced by **robust behaviour modelling**.
- Cell model – calibrated with RC=F(Temp, Current, SoC and SoH_start)
  → comparable **simple recalibration** to other battery use cases

→ to be discussed: Integrate RC-Parameter estimation
into WP4-check up tests for **lifetime cycling**

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