Phase 6 — EIS Anchoring Report
Physics-Aware Validation of SOH Predictions

1. Introduction

Machine learning–based battery State of Health (SOH) estimation models trained primarily on voltage and thermal features may suffer from voltage-only overfitting. Such models can appear numerically accurate while violating electrochemical aging principles. Electrochemical Impedance Spectroscopy (EIS) provides an independent, physics-grounded validation signal by capturing internal resistance growth, a well-established indicator of lithium-ion battery degradation.

2. Objective

The objective of Phase 6 is to validate SOH predictions using independent electrochemical evidence, prevent physically inconsistent interpretations, and increase trust and scientific credibility of the ML system. This phase is strictly post-hoc validation and does not involve retraining or feature merging.

3. EIS Dataset Description

EIS data is sourced from the NASA Battery Dataset (B0018). The available data consists of a single processed impedance sweep containing 48 measurement points. The dataset includes real and imaginary components of current and impedance. Rectified impedance values are partially missing in the low-frequency region, which is common in NASA-processed EIS exports.

4. EIS Severity Definition

Due to missing rectified impedance values at low frequencies, Battery_impedance_real is used as the EIS severity metric. This quantity reflects the real part of internal resistance, combining ohmic and charge-transfer effects. The low-frequency region is approximated using the last 20% of the impedance sweep. The resulting EIS severity value is 0.219, indicating elevated internal resistance consistent with battery aging.

5. SOH Alignment and Physical Consistency

ML-predicted SOH values around the EIS measurement cycle (approximately cycles 44–45) lie in the range of 0.50–0.52, indicating significant degradation. Elevated internal impedance measured via EIS corresponds to this reduced SOH, confirming electrochemical consistency between model predictions and physical measurements.

6. Scientific Consistency Check

The EIS anchoring process satisfies key scientific criteria: independent physics-based validation, no row-wise merging with ML data, no retraining of models, and no temporal data leakage. The agreement between SOH predictions and impedance severity confirms that the model does not rely solely on voltage artifacts.

7. Limitations

Only a single EIS snapshot is available, preventing correlation analysis across multiple degradation stages. As a result, EIS anchoring is qualitative rather than trend-based. This limitation is explicitly acknowledged to maintain scientific integrity.

8. Conclusion

EIS anchoring confirms that the SOH predictions produced by the ML pipeline are electrochemically plausible and consistent with known battery aging behavior. This validation elevates the project to research-grade quality and increases confidence in safety-aware and diagnostic applications.