PROJECT of the PEGASUS FAMILY

VERIFICATION VALIDATION METHODS

Mid-Term Presentation 15 / 16 March 2022

# Validation of Test Infrastructure – from cause trees to a validated system simulation

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Supported by:

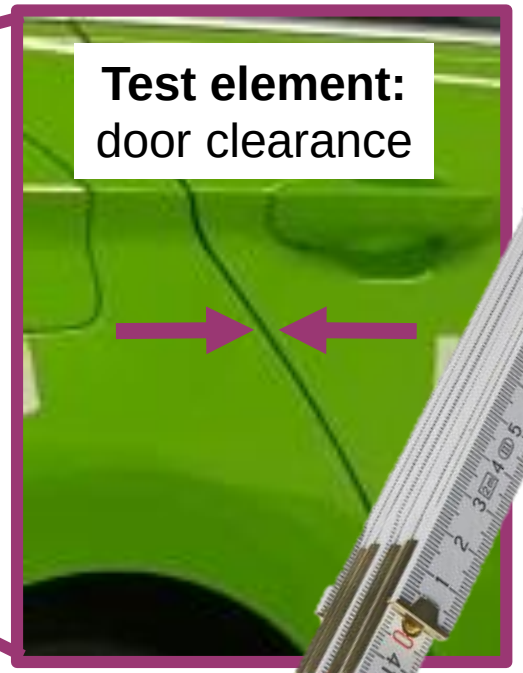
Federal Ministry for Economic Affairs and Climate Action

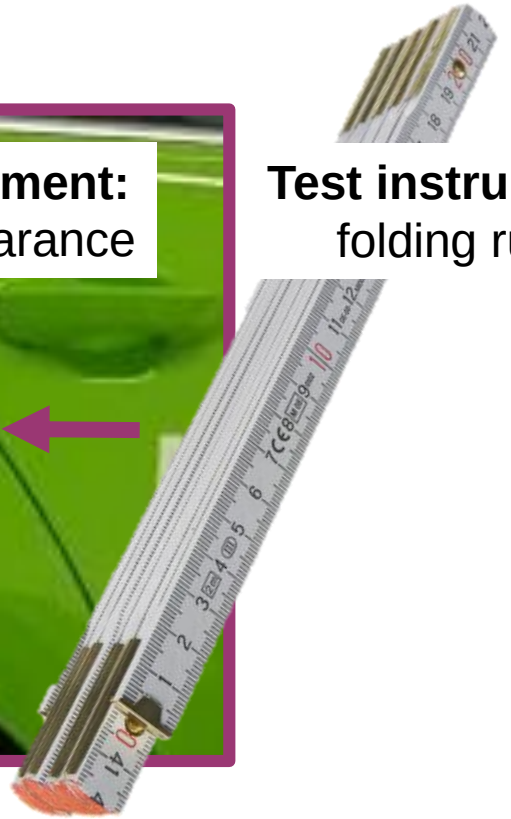
on the basis of a decision by the German Bundestag

# How to validate a test instrument?

# Motivation

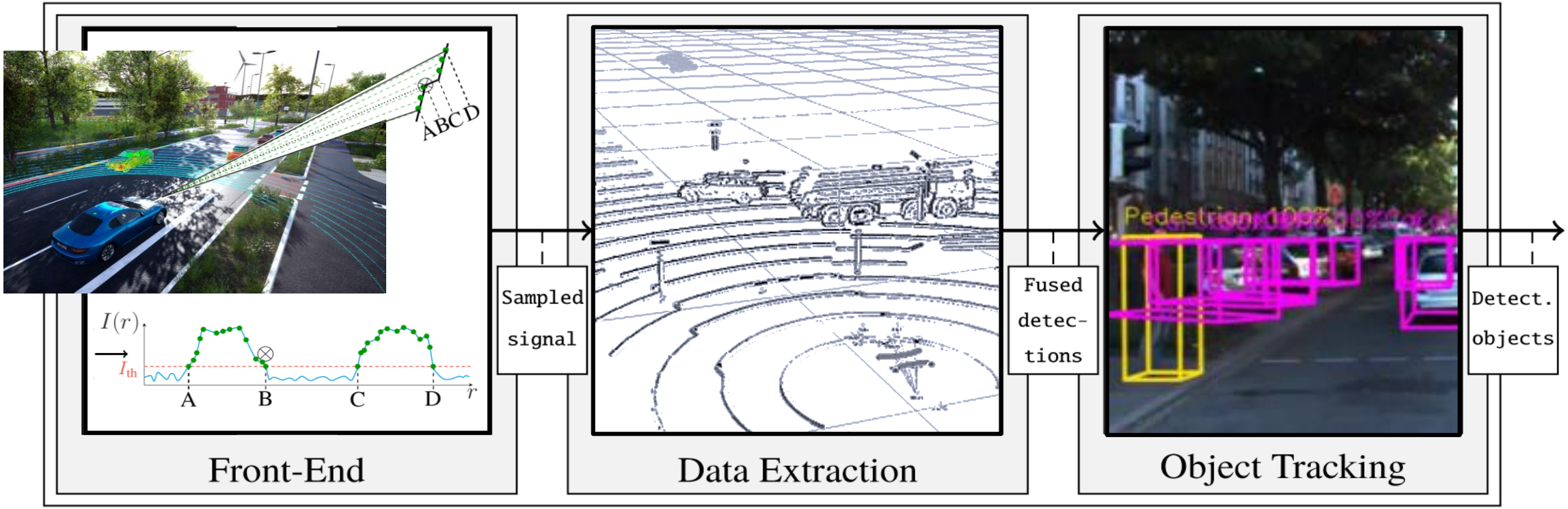
- **Test object:** automated driving vehicle
- **Test Case:** width of door clearance

**Test instrument:**
folding rule

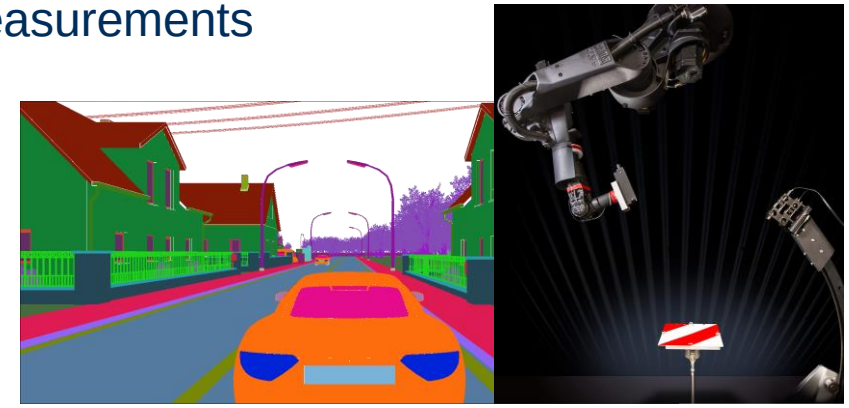
# Simulated lidar sensor system as test instrument



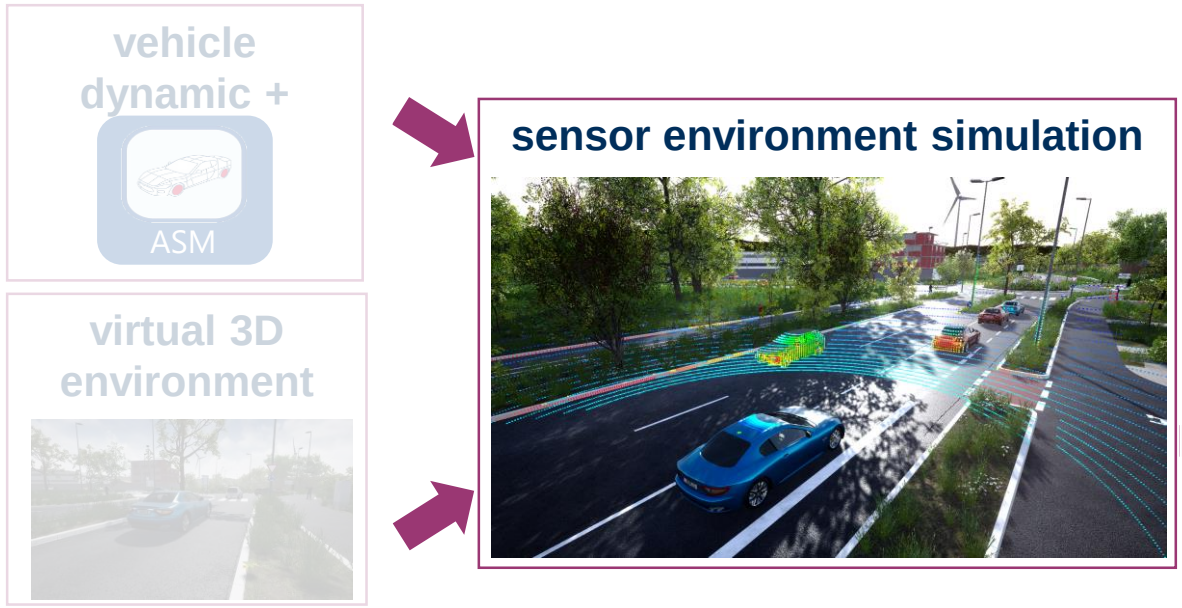

Source: C. Linnhoff, P. Rosenberger, M. F. Holder, et al.: *Highly Parameterizable and Generic Perception Sensor Model Architecture*. In: Bertram T. (eds) Automatisiertes Fahren 2020. Proceedings. Springer Vieweg, Wiesbaden. https://doi.org/10.1007/978-3-658-34752-9_16

# Exemplary validation of lidar simulation with Replay-to-Sim

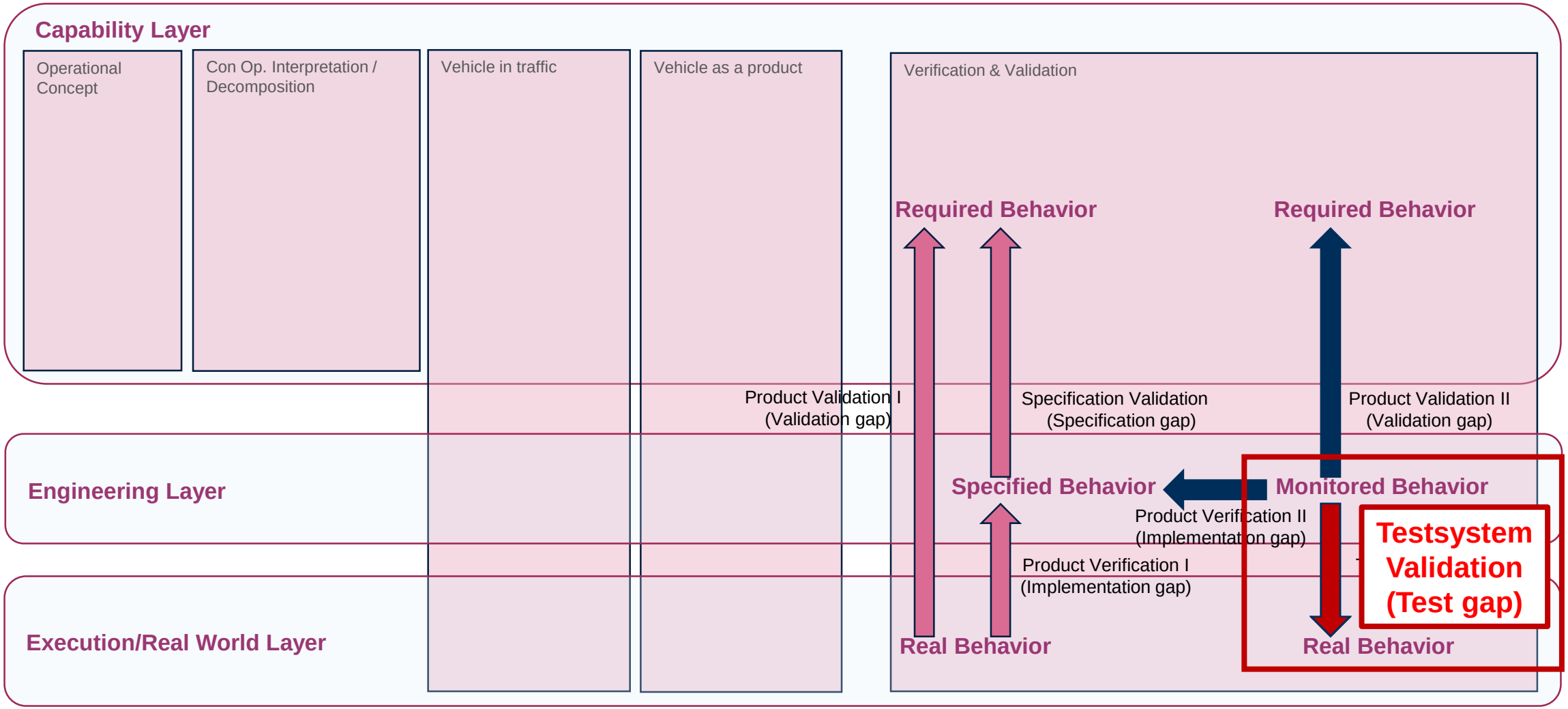
- The dSPACE SIL Environment replicates the HIL-stations measurements
  - Open and standardized interfaces for model integration
  - Validated material database



Source: Fraunhofer IOSB



# Verification & Validation in Assurance Framework



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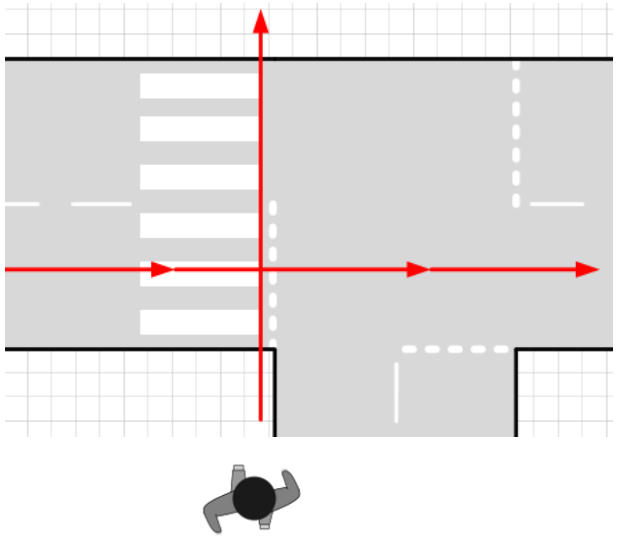
# Methodological Derivation of Sensor Model Requirements

# Methodological Derivation of Sensor Model Requirements

- Exemplary Use Case in VVM
- **VVM Functional Use Case 2-3:**
  Occlusion of pedestrian at T-intersection*

automated vehicle



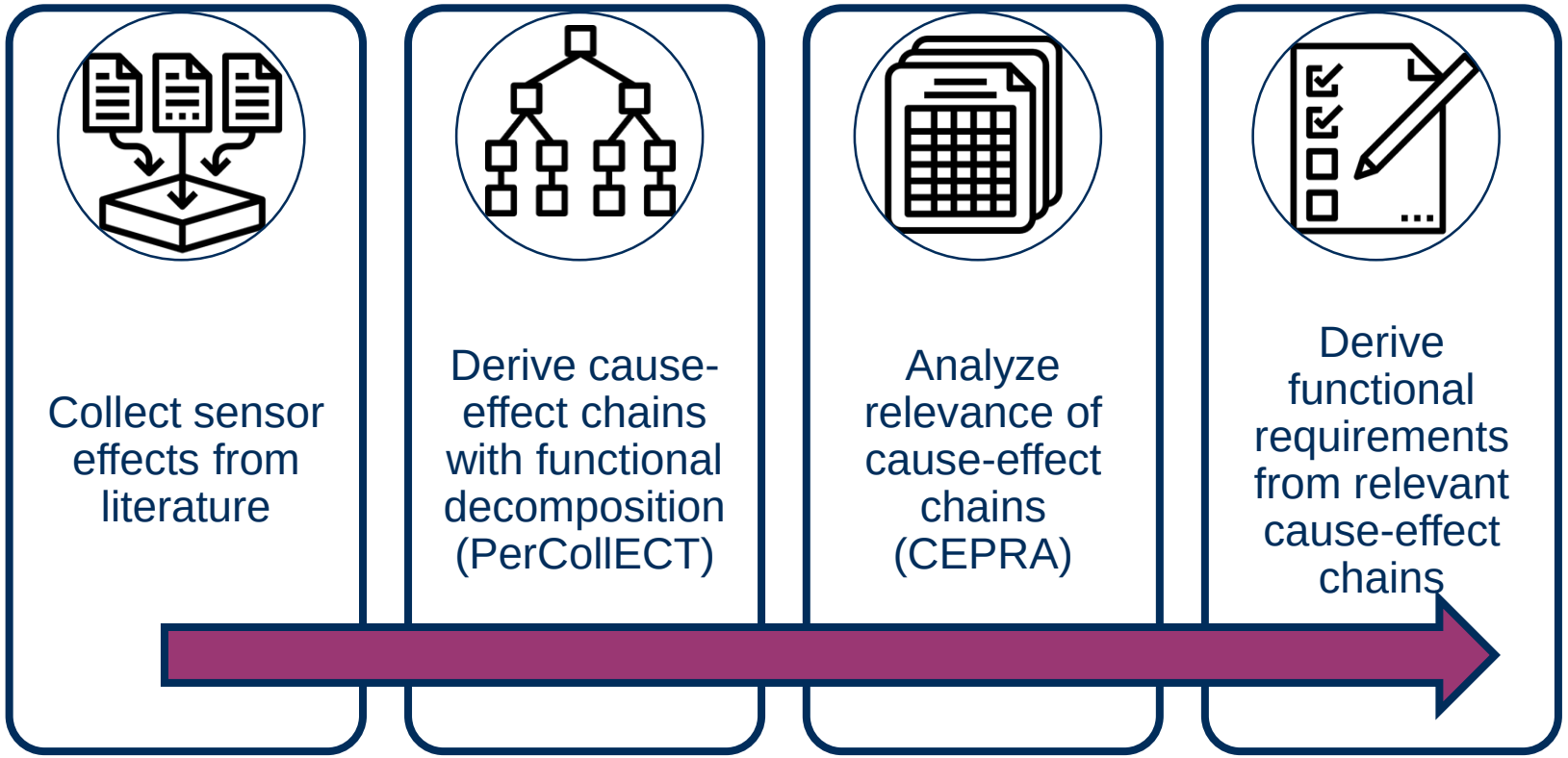
pedestrian

*occlusion by parking car not shown

- An automated vehicle is crossing a T-intersection with a crosswalk beforehand.
- A pedestrian approaches the crosswalk
- The perception of the crosswalk markings are essential for the upcoming driving decisions
- Requirements on the simulation will be based on existing requirements on the perception:

| | | |
|---|---|---|
| [illegible].1 | perception | |
| PR-1.1.2 | crosswalk marking perception | • The system shall **perceive** broad stripes on the road for *crosswalk markings*. |
| [illegible] | [illegible] | [illegible] |

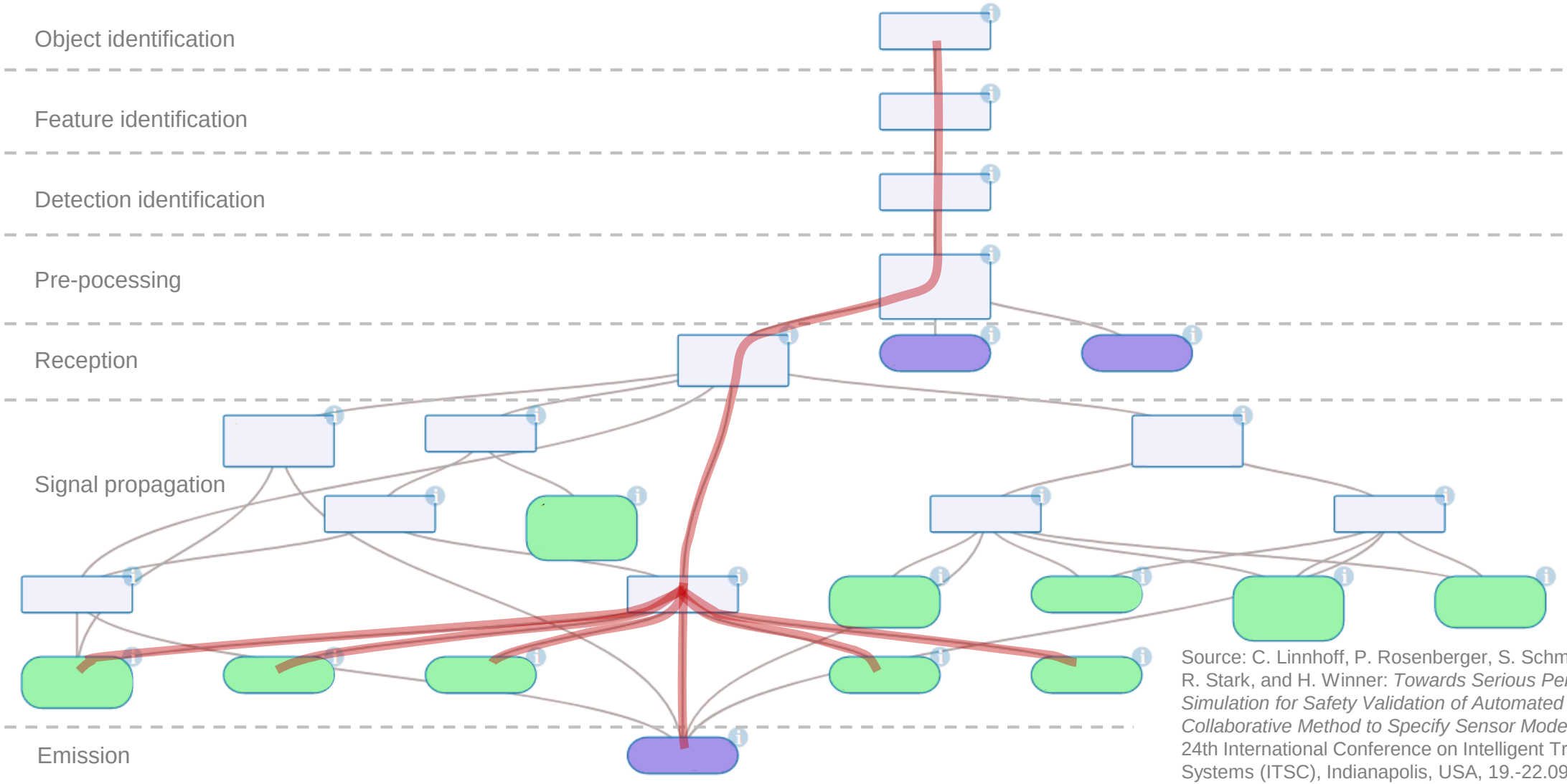
# Perception Sensor Collaborative Effect and Cause Tree (PerCollECT)




Source: C. Linnhoff, P. Rosenberger, S. Schmidt, L. Elster, R. Stark, and H. Winner: *Towards Serious Perception Sensor Simulation for Safety Validation of Automated Driving – A Collaborative Method to Specify Sensor Models*. 24th International Conference on Intelligent Transportation Systems (ITSC), Indianapolis, USA, 19.-22.09.2021

Icon source: https://www.flaticon.com/authors/becris

# Perception Sensor Collaborative Effect and Cause Tree (PerCollECT)




github.com/
PerCollECT

Source: C. Linnhoff, P. Rosenberger, S. Schmidt, L. Elster, R. Stark, and H. Winner: *Towards Serious Perception Sensor Simulation for Safety Validation of Automated Driving – A Collaborative Method to Specify Sensor Models*. 24th International Conference on Intelligent Transportation Systems (ITSC), Indianapolis, USA, 19.-22.09.2021

# Cause, Effect, and Phenomenon Relevance Analysis (CEPRA)

| CEPRA ID | Pheno-menon (P) | Effect chain (EC) of phenomenon | Causes of effect chains | | P&EC occurrence (O) in ODD | | P&EC impact (I) on SUT in ODD | | Relevance of P&EC |
|---|---|---|---|---|---|---|---|---|---|
| | | | Environmental causes | Design parameters | *[1, 10]* | *Rationale* | *[1, 10]* | *Rationale* | *O + I* |
| Lid_CEPRA_005 | False negative in object list | → FN features<br>→ FN detections<br>→ Not dist. from noise<br>→ Low rec. power from o.<br>→ Reflection by obj. parts | • Materials<br>• Roughness<br>• Shapes<br>• Sizes<br>• etc. | • Emitter wavelength | *9* | *filled by sensor expert* | *4* | *filled by SUT expert* | ***13*** |
| Lid_CEPRA_008 | False negative in object list | → FN features<br>→ FN detections<br>→ Not dist. from noise<br>→ Low rec. power from o.<br>→ Attenuation by atm. aer.<br>→ Absorption by atm. aer. | • Signal distance<br>• Density of atmosph.<br>• Material of particles<br>• Size of particles<br>• etc. | • Emitter wavelength | *8* | *filled by sensor expert* | *9* | *filled by SUT expert* | ***17*** |
| • • • | | | | | | | | | |

Automatically generated out of PerCollECT

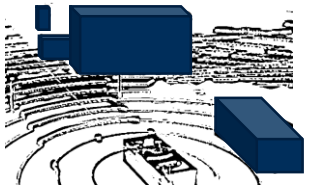
Filled by experts

ODD: Operational Design Domain
SUT: System under Test

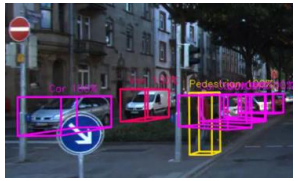
Source: C. Linnhoff, P. Rosenberger, S. Schmidt, L. Elster, R. Stark, and H. Winner: *Towards Serious Perception Sensor Simulation for Safety Validation of Automated Driving – A Collaborative Method to Specify Sensor Models*. 24th International Conference on Intelligent Transportation Systems (ITSC), Indianapolis, USA, 19.-22.09.2021

# Derivation of Requirements

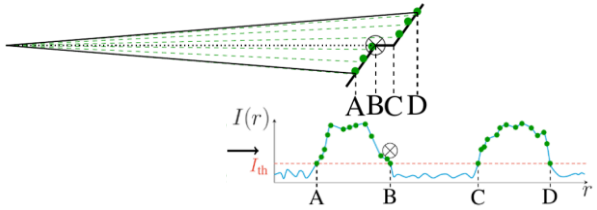
General simulation requirements



General requirements for the lidar sensor system simulation



Lidar object model requirements




Lidar detection model requirements

Acceptance Tests for the lidar sensor system simulation

Lidar sensor system experiment data

Reference data requirements per lidar sensor system experiment

Icon sources: https://www.flaticon.com/authors/becris, https://www.flaticon.com/authors/Icongeek26, https://www.flaticon.com/authors/freepik

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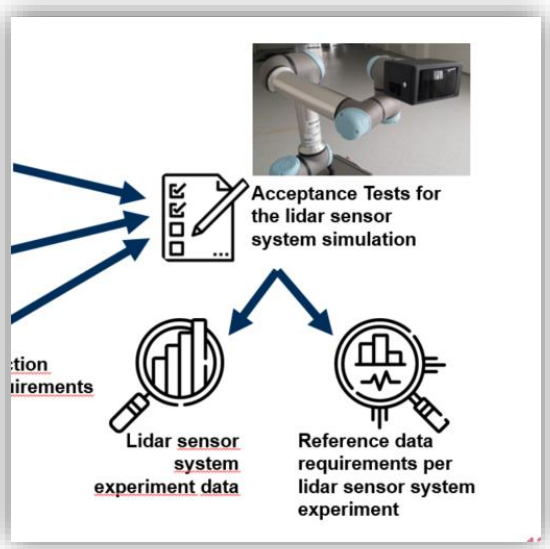
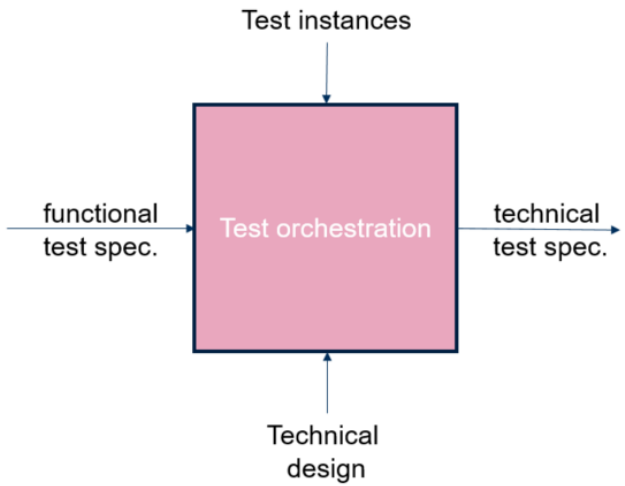
# Sample Validation

# VVM Technical Test Specification for Lidar Model Validation

**Acceptance tests for the lidar sensor system simulation are formulized as technical test specifications**

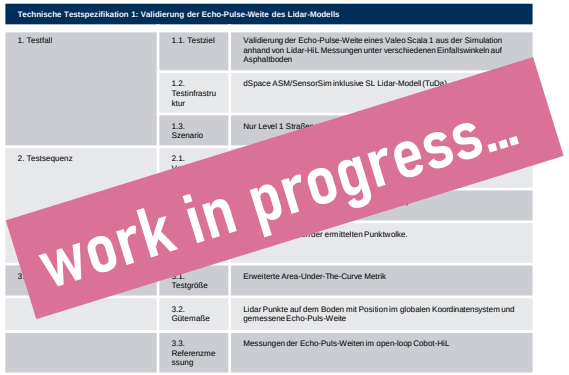



**The format of the technical test specification for validating the test infrastructure is the same as for validating the AD vehicle:**



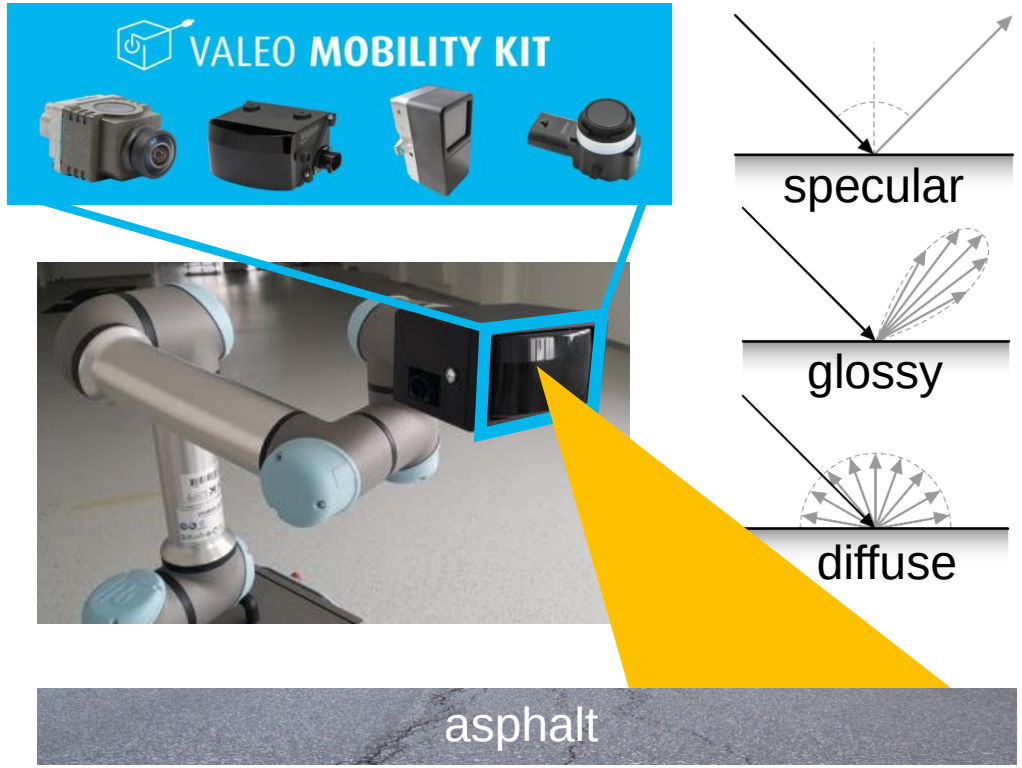

**Technical test specification:**
Validating the Echo-Pulse-Width of the Lidar Model

- 1. Test Case
- 2. Test Sequence
- 3. Test Assessment



# Measurements with High Quality Reference

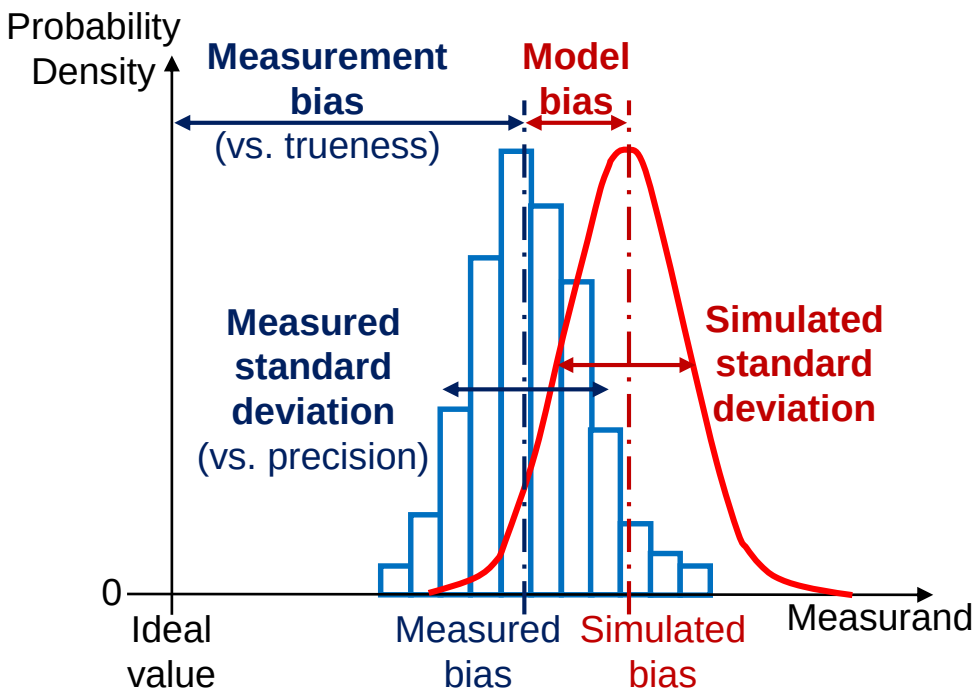
- Cobot-HiL for perception tests




wikipedia.org: bidirectional_reflectance_distribution_function

- Validation of the received echo-pulse-width (~optical power) from synthetic point clouds based on a parameterized bidirectional reflectance distribution function (BRDF)
- We use the Valeo's HiL with a collaborative robot (cobot) to collect reference data over a large parameter space:
  - mounting height
  - angle of incidence
  - type of asphalt concrete
  - specimen of lidar-sensors

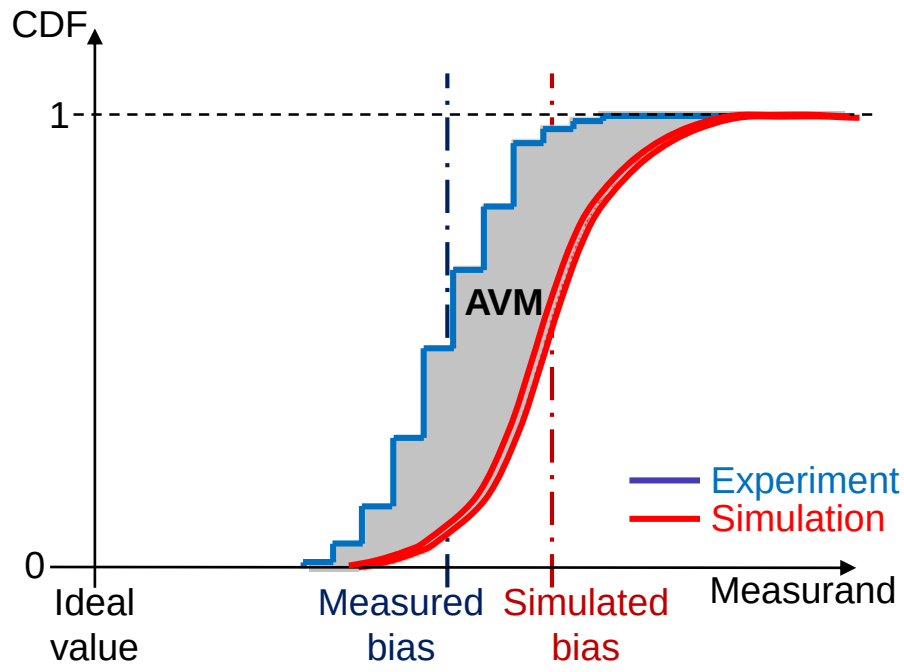
# Metric for Sample Validation




- Goals of the sensor system simulation:
- Realistic accuracy (DIN ISO 5725-1) (trueness & precision)
  - Realistic bias → no model bias!
  - Realistic standard deviation

Source: P. Rosenberger: *Metrics for Specification and Validation of Active Perception Sensor System Simulation with further Estimation of Accuracies and Uncertainties*, Upcoming PhD Thesis,TU Darmstadt, 2022

# Metric for Sample Validation




- Goals of the sensor system simulation:
- Realistic accuracy (DIN ISO 5725-1) (trueness & precision)
  - Realistic bias → no model bias!
  - Realistic standard deviation
  - Realistic Cumulative Distribution Function (CDF)
  - Area Validation Metric (AVM) = 0!
    - Metric in unit of measurand
    - Handles P-Boxes for epistemic model input uncertainties

Source: P. Rosenberger: *Metrics for Specification and Validation of Active Perception Sensor System Simulation with further Estimation of Accuracies and Uncertainties*, Upcoming PhD Thesis,TU Darmstadt, 2022

# Summary and outlook

**Validation of the test infrastructure…**

- …is (an often neglected) part of the overall safety argumentation
- …requires in-depth knowledge of the AD system and the respective test instance

**PerCollECT and CEPRA…**

- …are filling the gap for a methodological derivation of simulation requirements
- …can be applied to object detection with lidar

**Testing the echo-pulse-width of a lidar simulation…**

- …requires the newest physical reflection models in the infrared for SiL-simulations
- …can be performed reproducibly on the new HiL-Cobot for a large parameter space
- …requires a suitable metric such as the Area Validation Metric (AVM)

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# Thank you!

**Philipp Rosenberger, TU Darmstadt; Gerhard Schunk, Valeo**

Frederik Ikemeyer, dSPACE; Tuan Duong Quang, TÜV SÜD

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