Virtual Validation of Continental Radar Sensors

Gen 6 Virtual Testing, Sensor Models and VIVALDI

Sreehari Buddappagari, Sandro Reith, Hasan Iqbal
Continental

OUR VISION

Autonomous Mobility for You.

Anywhere.

Anytime.

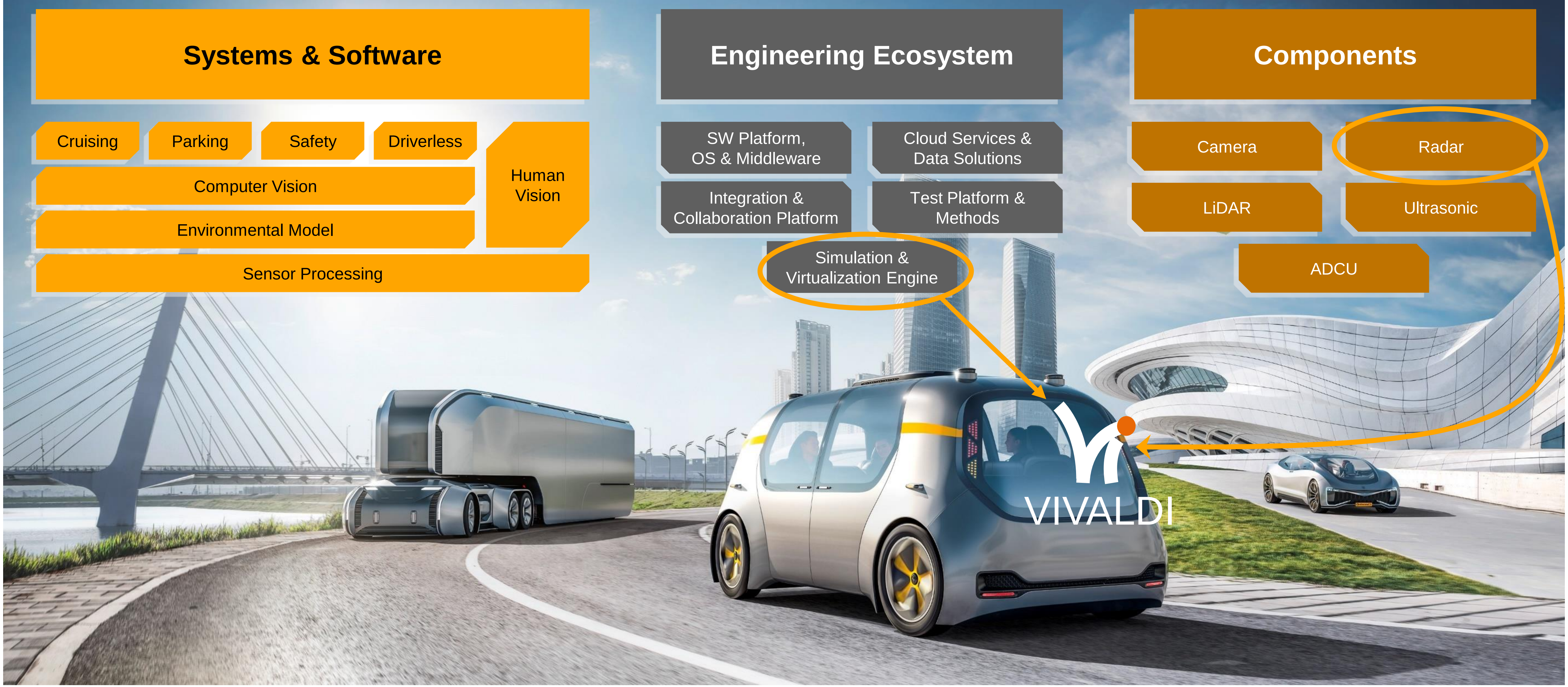
OUR MISSION

Developing the Future of Mobility.

- **High performance** radars are instrumental for autonomous mobility.
- Focus: higher **value extraction** in development process of next-gen radars.
- Modus operandi: increased importance of **virtual validation and AI**.
- Outcome: **boosted performance** of radars, increased value of sensor development chain (cost/performance optimization) and more **environment friendly**.

Core Products of Autonomous Mobility

Provider of Full Stack Solutions



Systems & Software

- Cruising
- Parking
- Safety
- Driverless
- Computer Vision
- Environmental Model
- Human Vision
- Sensor Processing

Engineering Ecosystem

- SW Platform, OS & Middleware
- Cloud Services & Data Solutions
- Integration & Collaboration Platform
- Test Platform & Methods
- Simulation & Virtualization Engine

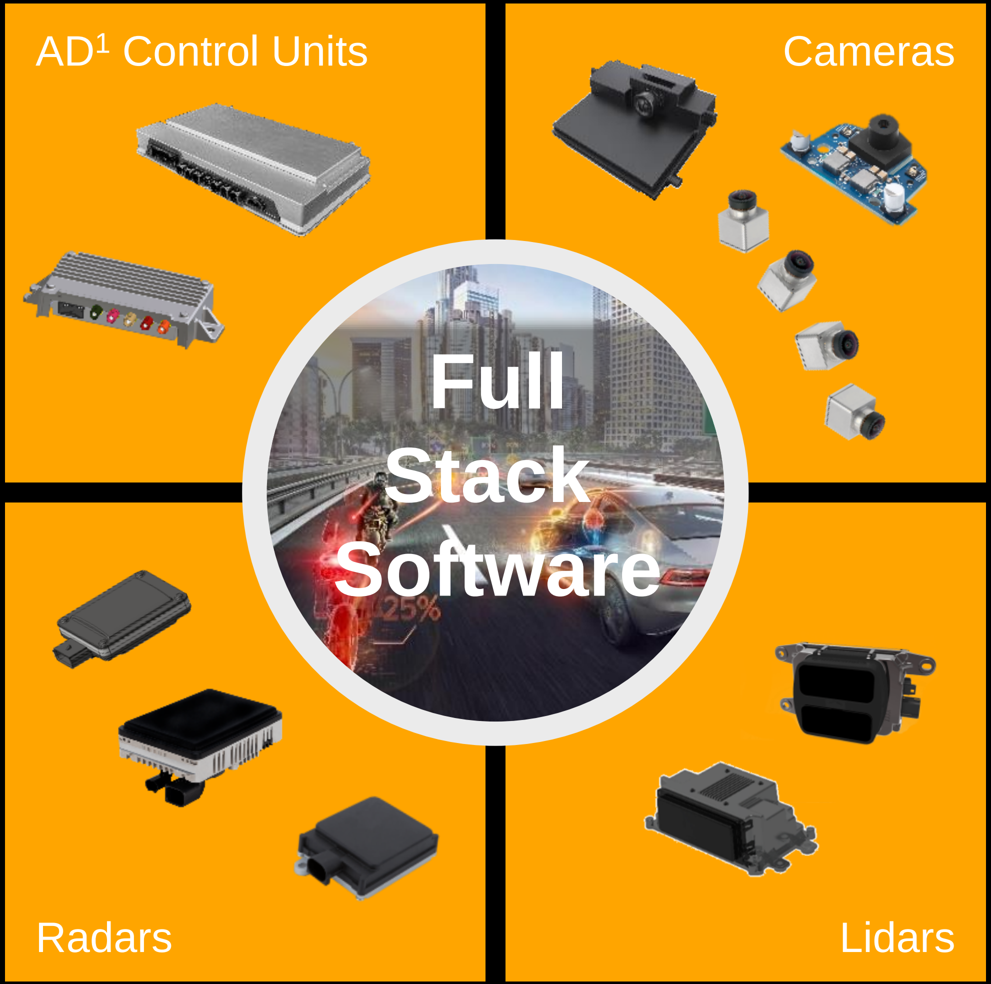
Components

- Camera
- Radar
- LiDAR
- Ultrasonic
- ADCU

Continental's Autonomous Mobility Business

Leading Player with Track Record of Profitable Growth

> 100 million
Radar sensors delivered since 1999



AD[1] Control Units

Cameras

Full Stack Software

Radars

Lidars

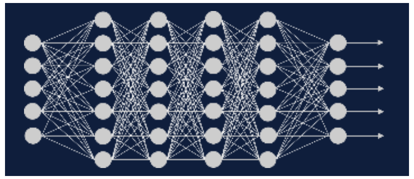
25	OEMs
50	Brands
> 300	Models

Ideally Placed for Future Challenges

AI & Virtual Validation for the Era of Autonomous Mobility

The Vital Importance of Data Quality & Efficient Data Management

Neural Network Development



Global Test Vehicle Fleet

Collecting around 100 terabytes of data each day – equivalent to 50,000 hours of movies

Synthetic Data Generation

Validation & Simulation

Strategic joint Japanese-German Partnership DIVP™/VIVALDI

jama Japan Automobile Manufacturers Association
DAIMLER
Continental The Future in Motion
内閣府 Cabinet Office
Bundesministerium für Bildung und Forschung

AI Competence Center

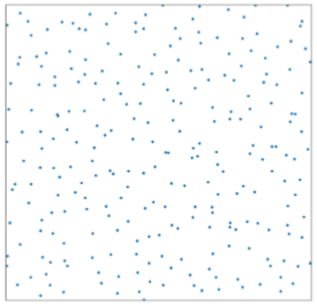
- **Core development** of AI technologies
- **Roll-out** to product development teams

Sampling Methods

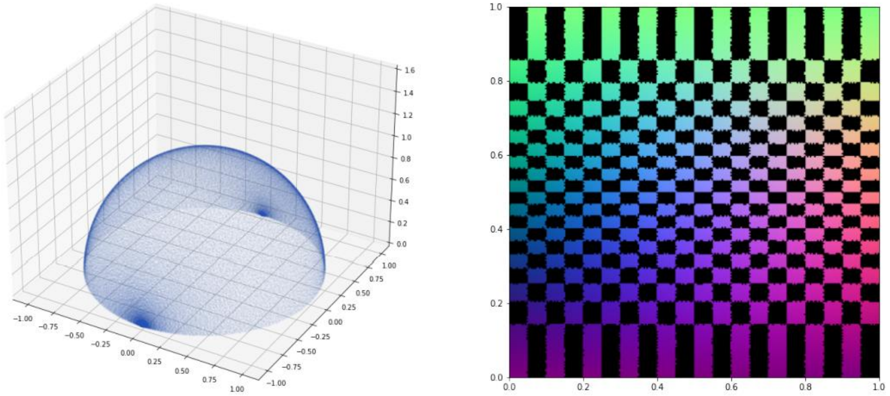
Critical Analysis of Raytracer

Investigation of ‘Smart’ Sampling – I

- Concentration of rays in areas with targets
  - Without compromising on representation of other areas in scenario
- Multiple ray ‘guiding’ algorithms were tried and rated



Uniform Sampling in 2-D (pixel based and jittered - predefined)

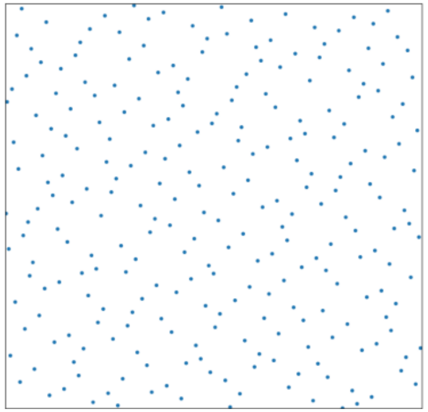


Skewed scenario sampling, inequal resolution cell dimensions

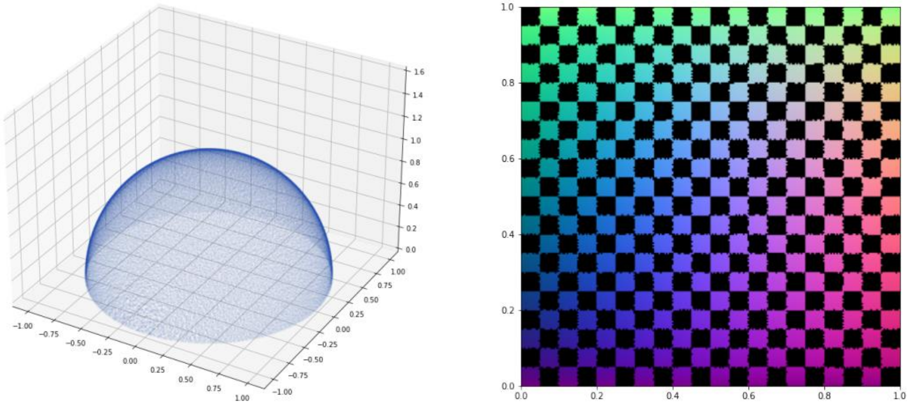
- First approach was ‘dumb’ ray guiding
  - Rays were fired in direction of positive hits
  - No mechanism to cater to uniform sampling of scenario space
- Result is a considerable distortion in the 3-D sampled representation

Critical Analysis of Raytracer

Investigation of ‘Smart’ Sampling – II



Halton Sampling in 2-D
(guided sampling strategy)

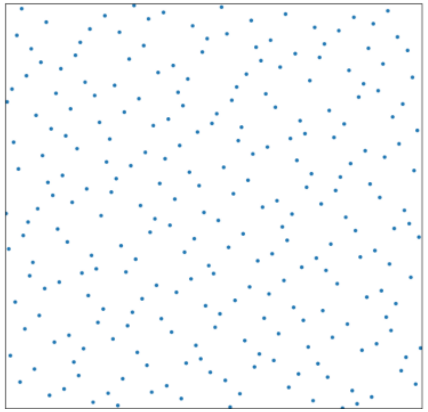


Uniformly sampled scenario space

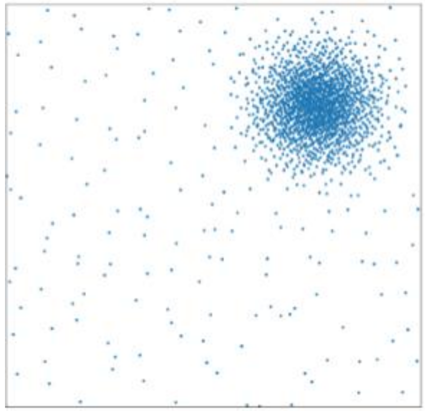
- For uniformly sampled space, pseudo random numbers should be
  i. Progressive – no of samples not fixed beforehand
  ii. Low-discrepancy – distance between samples is maximized
- This results in a uniformly sampled space and skewed cells are avoided
- Halton sampling satisfies both progressive and low-discrepancy conditions

Critical Analysis of Raytracer

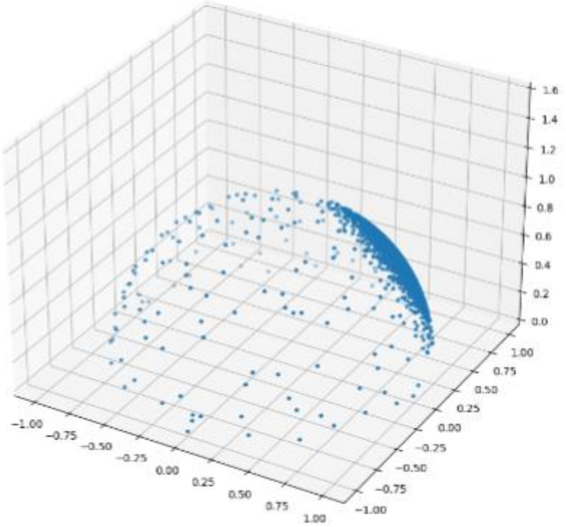
Investigation of 'Smart' Sampling – III



Halton Sampling in 2-D
(guided sampling strategy)



Importance sampling
(increase resolution – warping)

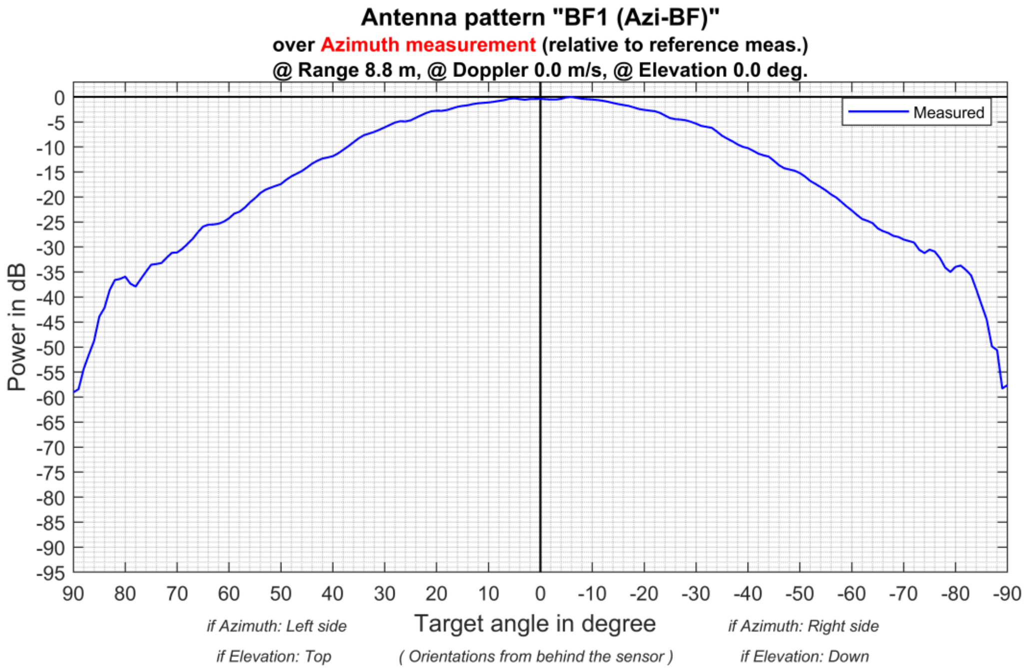


3-D scene sampling

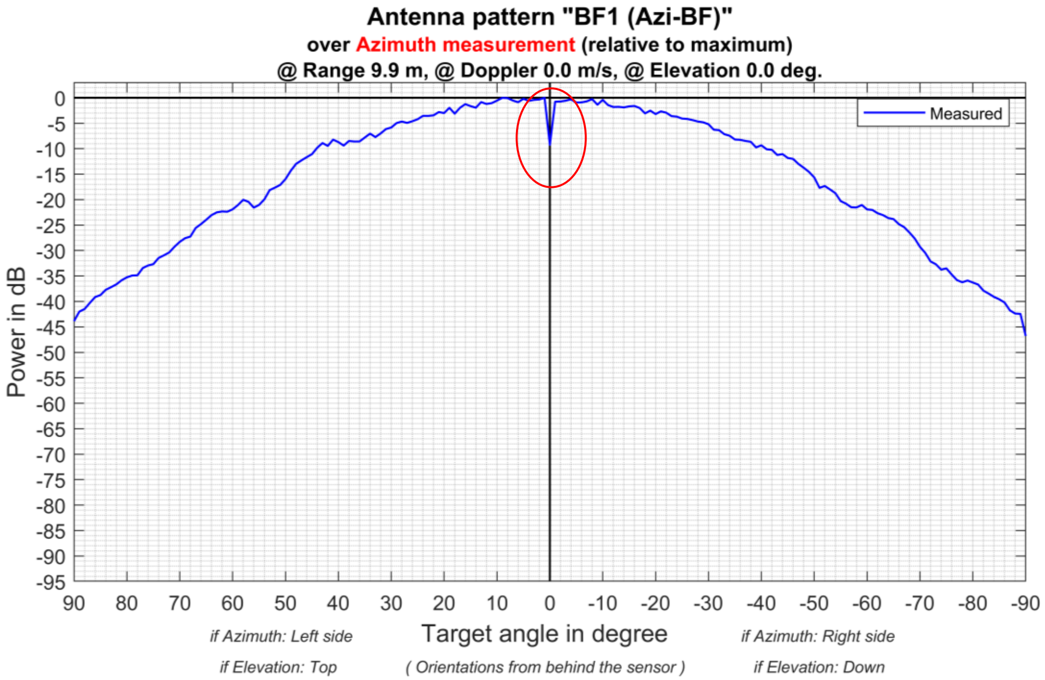
- Split the examples into training examples and rendering examples
  i. Find best parameter set for rendering sampling points
  ii. Increase the resolution at the points of interest (hit point on object) → warping

Critical Analysis of Raytracer

Scrutiny of Antenna Beam-Pattern



Measurement

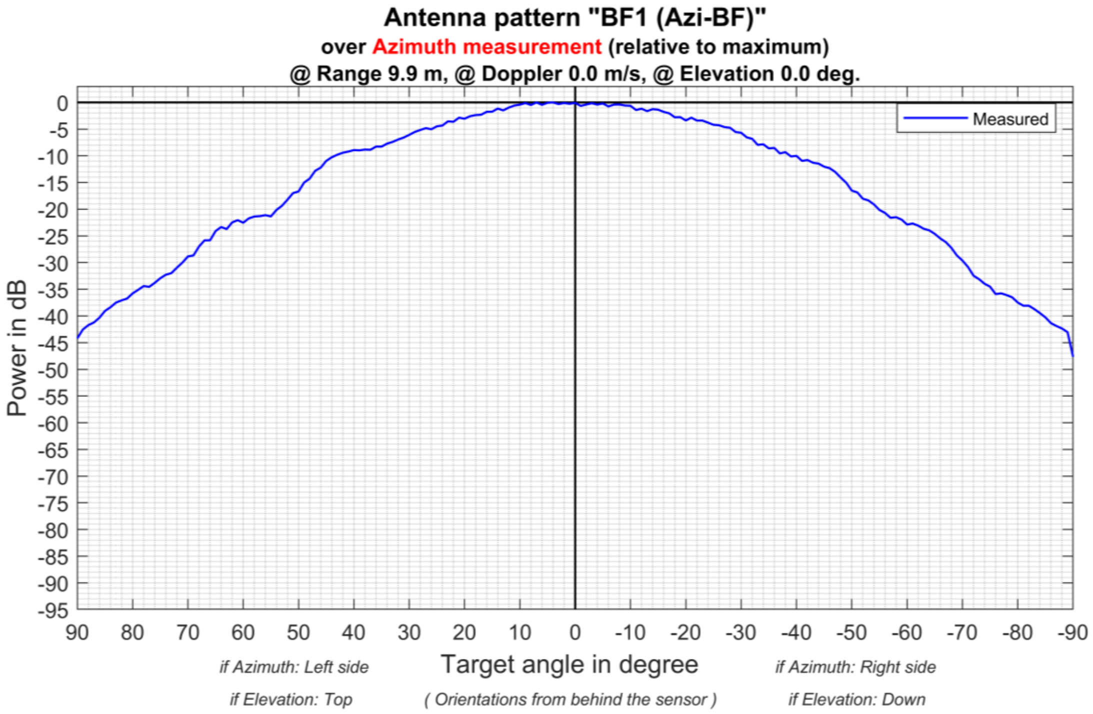


Simulation

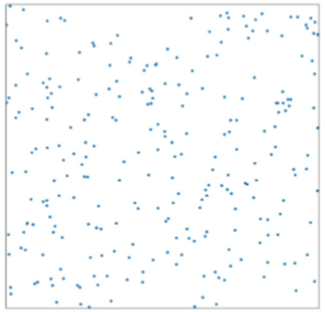
- Comparison of beam patterns
  - Sharp drop in gain at 0° azimuth angle
- Caused by extending sample in 2-D to a hemisphere in 3-D
  - Error in transformation from 2-D cartesian coordinates to 2-D polar to 3-D spherical

Critical Analysis of Raytracer

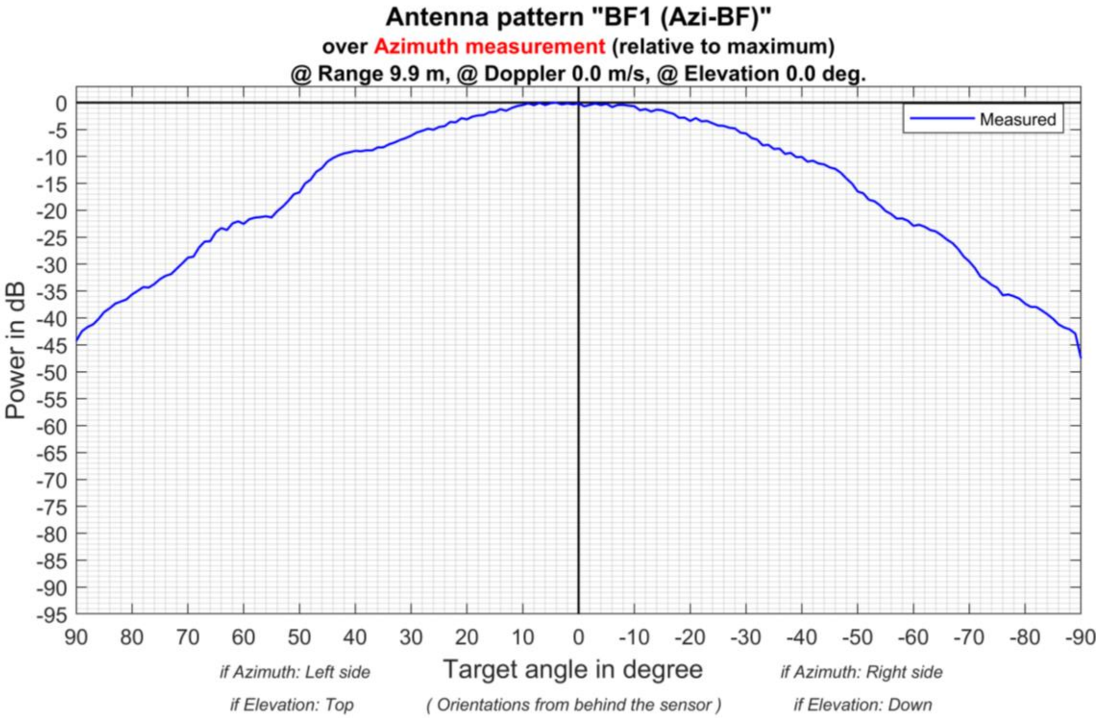
Corrected Beam-Pattern



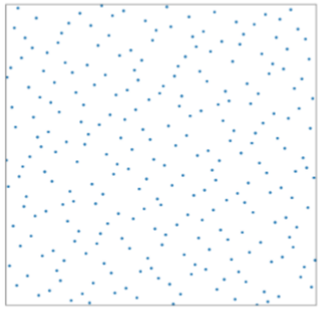
Jittered Sampling



- ➢ good low-discrepancy
- ➢ not progressive



Halton Sampling

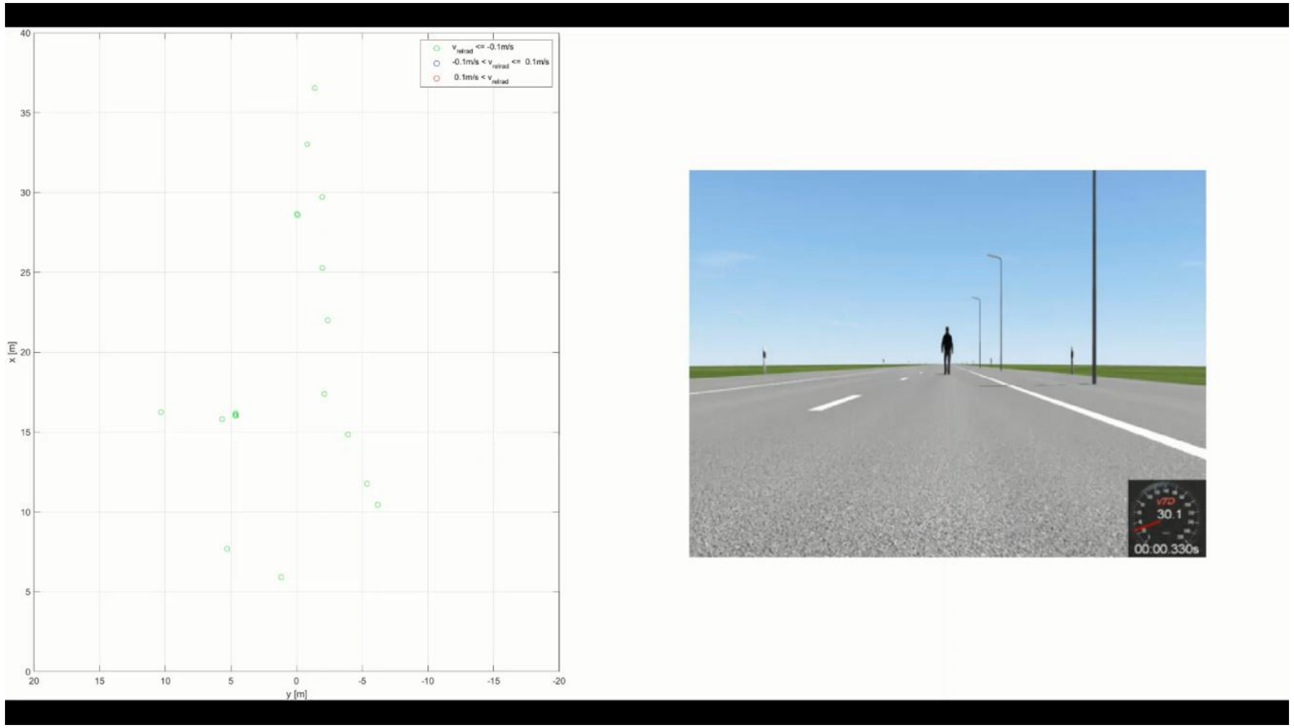


- ➢ very good low-discrepancy
- ➢ progressive

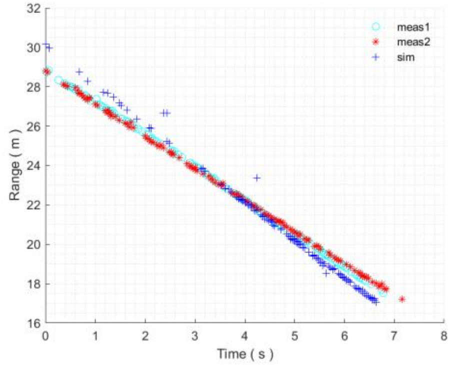
Validation of Synthetic Data

Validation of Euro-NCAP Scenarios

Chosen scenario: CPLA



- Car travelling at 30 km/h approaches pedestrian walking away at 5 km/h
- This scenario was simulated using VTD and evaluated using the ARS620 sensor model
  - The simulated sensor output was evaluated using the AE signal processing toolchain used for actual prototype sensors
  - Plot shows the simulated detections
- To evaluate quality of virtual data, set of KPIs need to be identified
  - The behavior of real data to be used as a measure for comparison

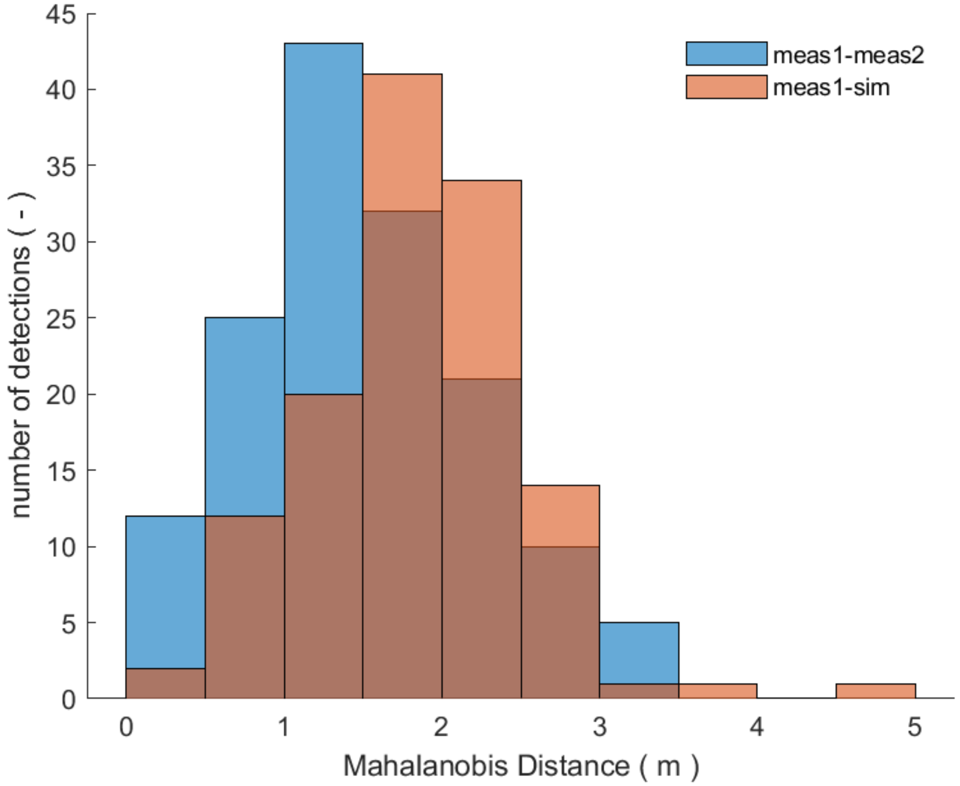


- On the left is plot of all detections against time for two measurements and one simulation
- Measured data agree well with each other
  - Larger difference to simulated data: Real pedestrian and driver cannot maintain exact speed and walk/drive in an exact straight line

Suggested KPI for Virtual Data Validation

Use of Mahalanobis Distance – CPLA Scenario

- One proposal for KPI to judge quality of virtual data: distance of detection points between measurement and simulation
- Mahalanobis distance is suitable as it accounts for correlation between datasets
  - It is used frequently with large datasets with manifold correlations (AI, statistics)
  - Simple Euclidean distance does not account for ‘data trends’
- Plot of Mahalanobis distances for CPLA plotted
  - Good initial overlap between measurement and simulation
  - Spread of distances very similar
- Some differences occur due to walking and driving ‘uncertainties’ of real people vs simulated scenarios
- Further investigation needed before a general statement can be made
- Centre of gravity for simulated data is offset by ≈1/2 m compared to measurements



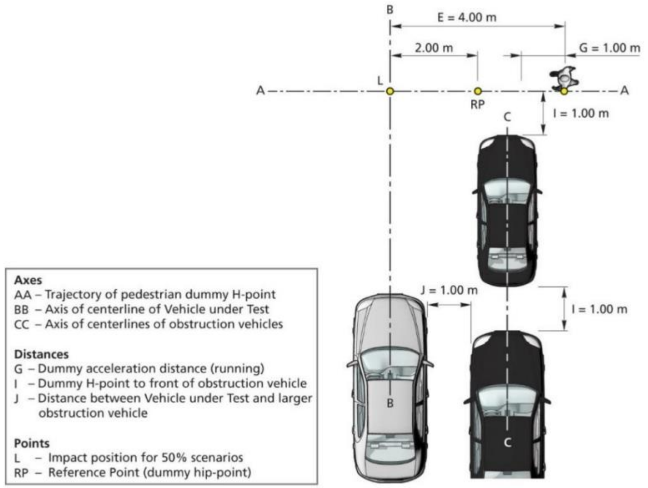
CPLA scenario parameters:
Ego velocity – 30 km/h
Pedestrian velocity – 5 km/h

Validation of Euro-NCAP Scenarios

Chosen scenario: CPNC

- Car travelling at 30 km/h approaches two longitudinal parked cars and child walking across
- This scenario was simulated using VTD and evaluated using the ARS620 sensor model
  - The simulated sensor output was evaluated using the AE signal processing toolchain used for actual prototype sensors
- To evaluate quality of virtual data, set of KPIs need to be identified
  - The behavior of real data to be used as a measure for comparison

7.2.6 Car-to-Pedestrian Nearside Child



Axes
AA – Trajectory of pedestrian dummy H-point
BB – Axis of centerline of Vehicle under Test
CC – Axis of centerlines of obstruction vehicles

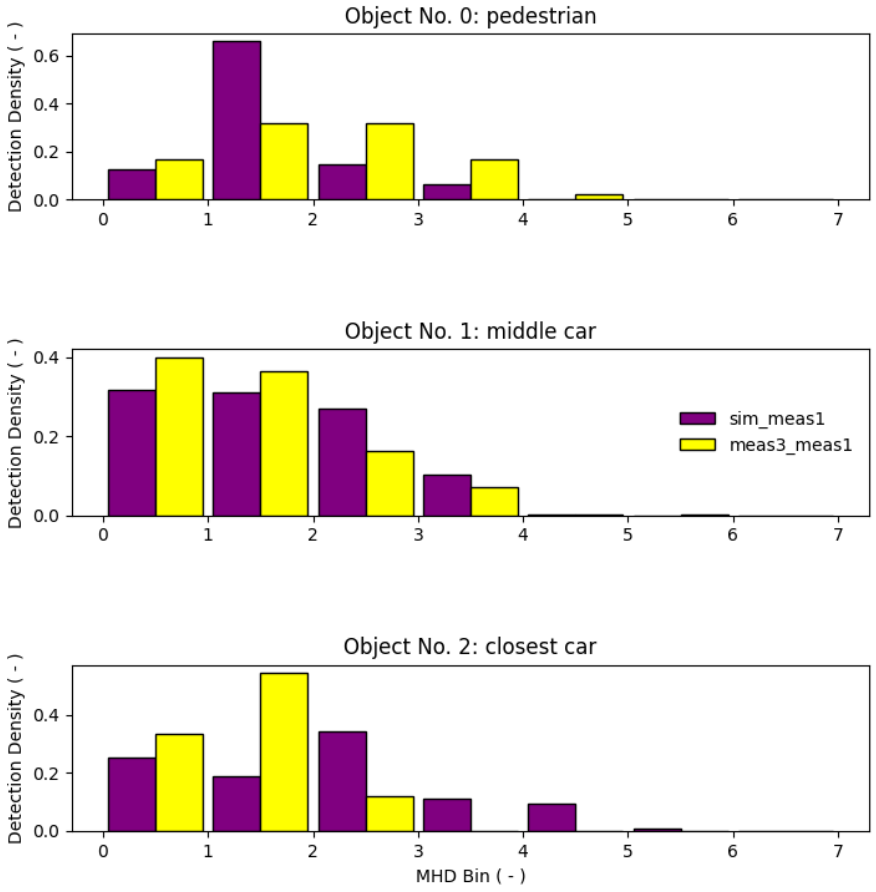
Distances
G – Dummy acceleration distance (running)
I – Dummy H-point to front of obstruction vehicle
J – Distance between Vehicle under Test and larger obstruction vehicle

Points
L – Impact position for 50% scenarios
RP – Reference Point (dummy hip-point)

Suggested KPI for Virtual Data Validation

Use of Mahalanobis Distance – CPNC Scenario

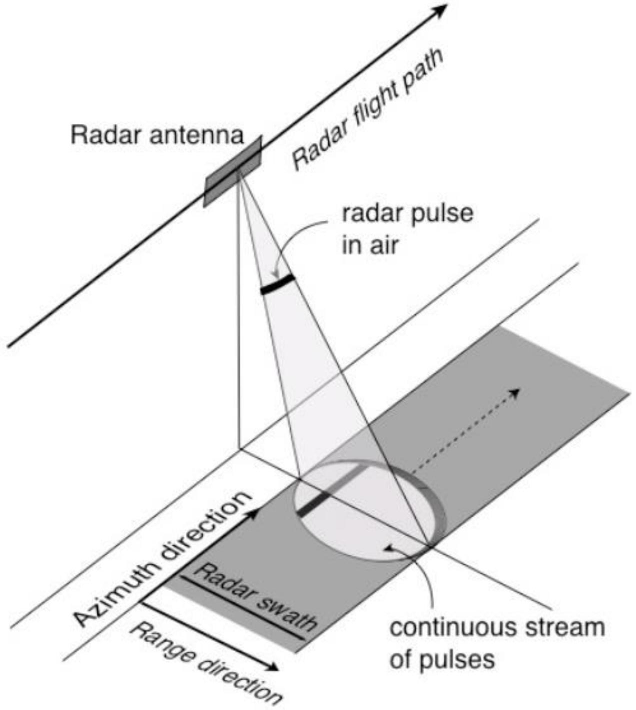
- All objects have the same material
- Euro-NCAP dummy is not a good reflector, but metal human in the simulation is a very good reflector
  - No moving parts of the simulated child
  - Simulated child has very slim shape (width), therefore many detections with narrow MHD distance distribution
- Detections on middle car are most likely distributed on the visible side, same as for simulation → good coverage by model
- Outer surface of cars is reflecting → difference on first object due to viewpoint
  - In the simulation, majority of the energy is reflected from the outer surface of the car
  - No reflections from inside and the underside of the car in the simulation
- Further investigation needed before a general statement can be made
- Mahalanobis distance is sensitive against offsets and different distributions → small differences have big impact → all 3 comparisons show a good alignment



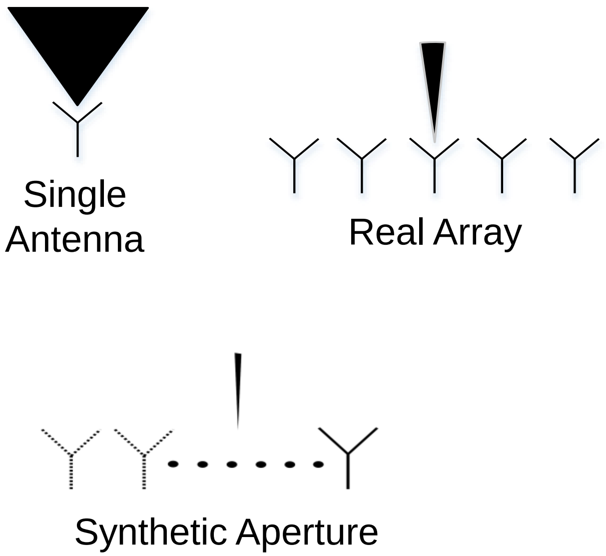
Benchmarking of Simulated Data

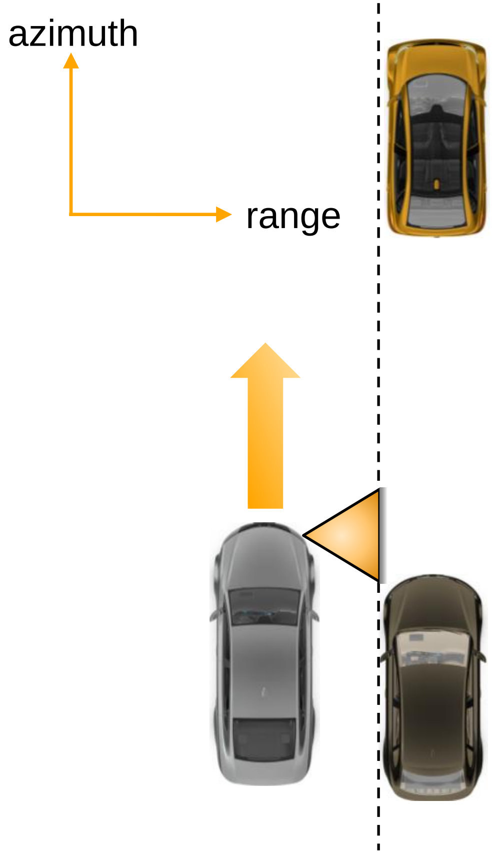
Benchmarking the Raytracer

Basics of Synthetic Aperture Radar (SAR)



Aerospace SAR*





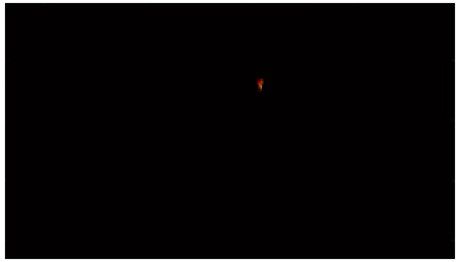
Automotive SAR

- Synthetic aperture radar (SAR) used in remote sensing for half a century
- Used to generate high-resolution radar images of Earth
- In the automotive industry it is used for imaging stationary objects
  - Moving objects can be tracked using Doppler

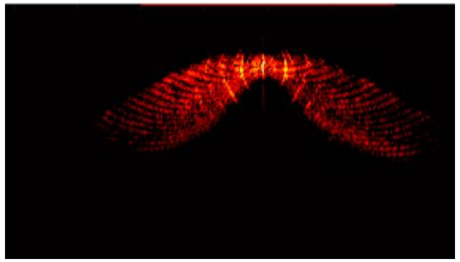
*Image taken from JPL (NASA)

Benchmarking the Raytracer

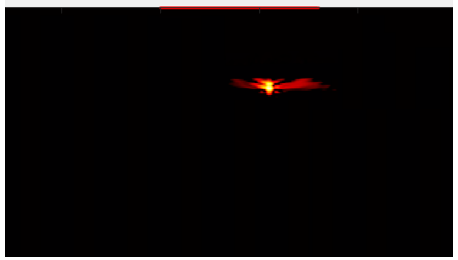
SAR Processing using Virtually Generated Data – One Corner Reflector



Expected result



Phase error due to defective doppler & carrier frequency

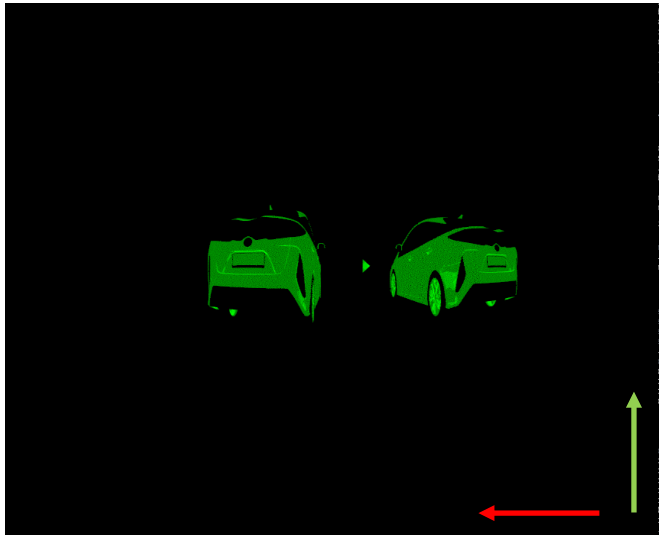


Phase error due to defective carrier frequency

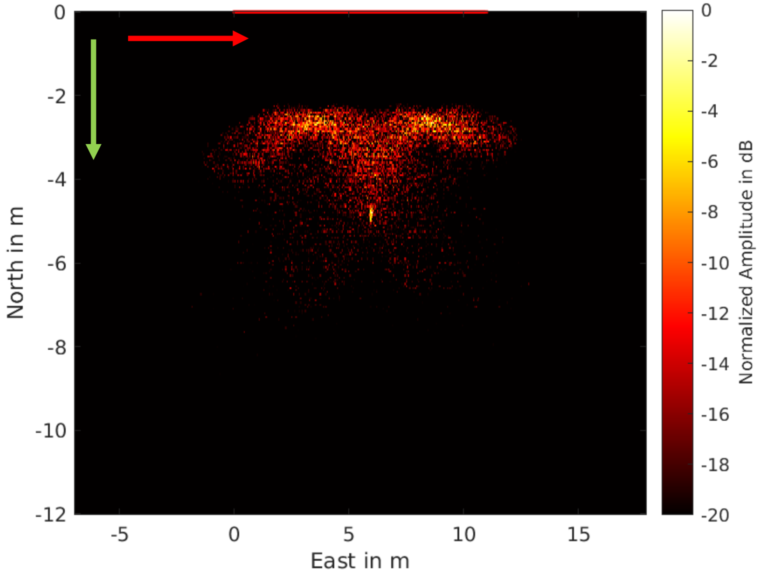
- Synthetic Aperture Radar (SAR) requires precise phase information of targets for correct processing
  - Accuracy of trajectory and range need to be in the order of ≈ λ/2
- SAR can thus be used for benchmarking the quality of virtual data
  - Not only the amplitude with respect to RCS of target needs to be correct
  - But the phase information also needs to be accurate over many hundreds and thousands of cycles
- Finally, the virtual radar returns are coherently integrated to form a SAR image of the target scenario
- Using SAR significant phase errors were uncovered
  1. Phase inaccuracies were introduced due to inaccurate doppler shift for higher level of reflection
  2. A false simulated carrier frequency added phase noise → blurring in image

Benchmarking the Raytracer

SAR Processing using Virtually Generated Data – Two Cars & One Corner I



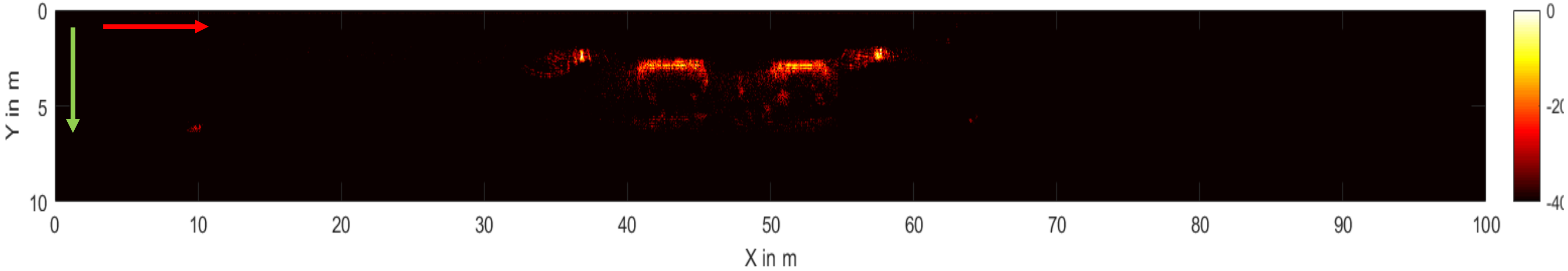
- Images on top show processed SAR images from virtual data
- Bottom image is from a real measurement
  - Presented for comparison purposes



Red arrow indicates the driving direction

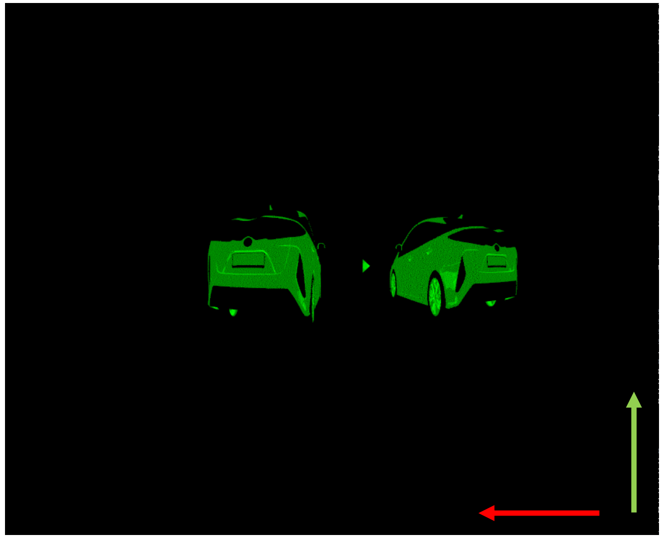
Green arrow indicates direction of radar bore-sight

- Shape of cars in simulated data not clear
  - High clutter noise present
  - Corner is focused well

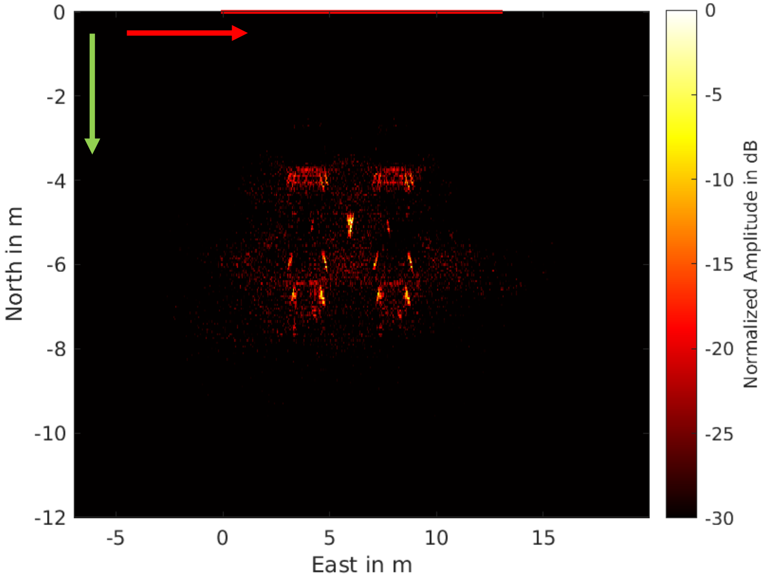


Benchmarking the Raytracer

SAR Processing using Virtually Generated Data – Two Cars & One Corner II



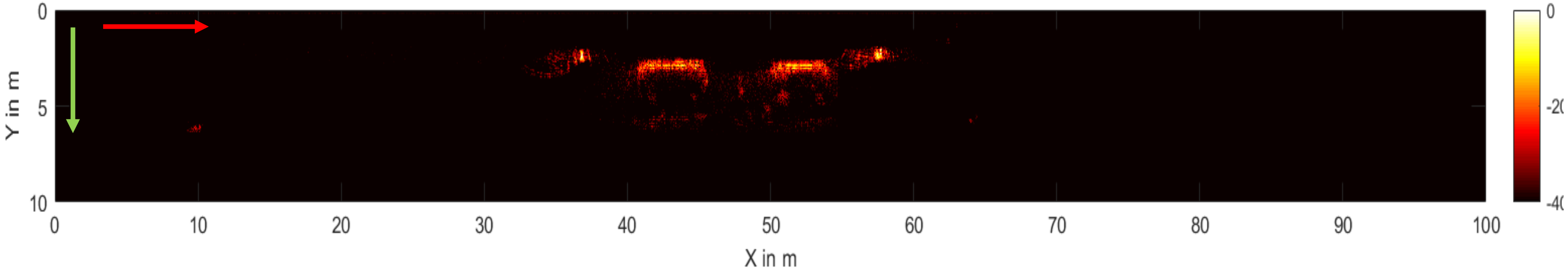
- Shape of cars very clear
- Sensor model extended to assigning multiple materials to a single object
  - Parts of car not all metallic
  - Reduced number of strong reflections
  - Presented for comparison purposes
- Material parameters from OpenMaterials implementation



- In previous iteration, all the parts of the car was composed of metallic parts
  - For example, even the tires and the windshield was metallic
  - This led to stray rays with higher ‘energy’

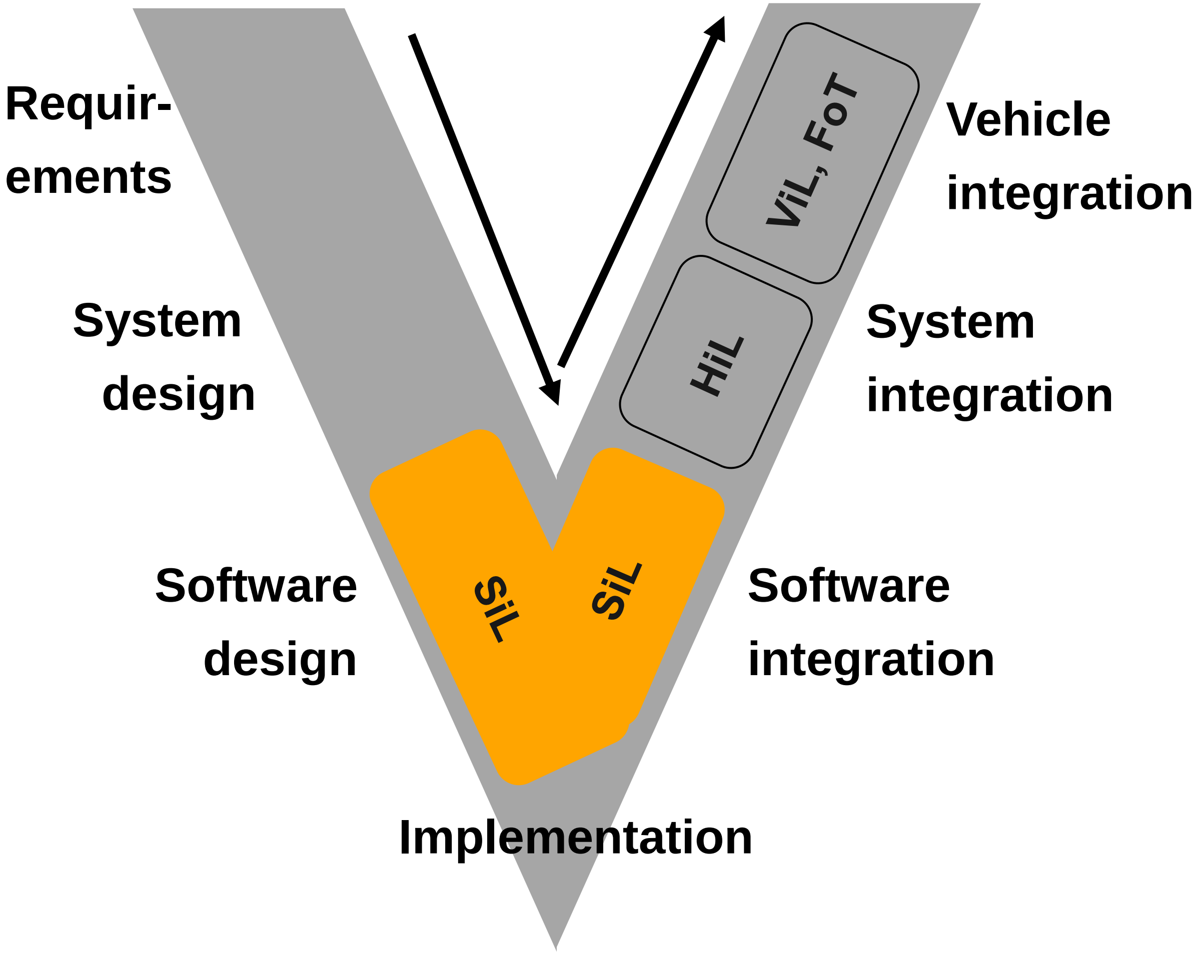
Red arrow indicates the driving direction

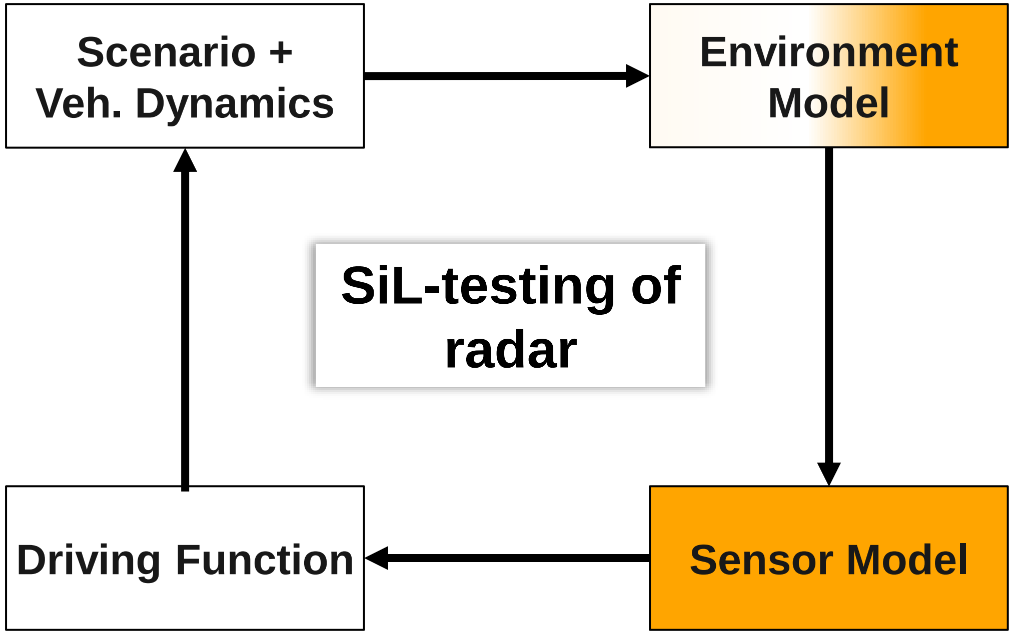
Green arrow indicates direction of radar bore-sight



Sensor Models and Vehicle Integration Simulation

Overview – Virtual V&V of radar - SiL

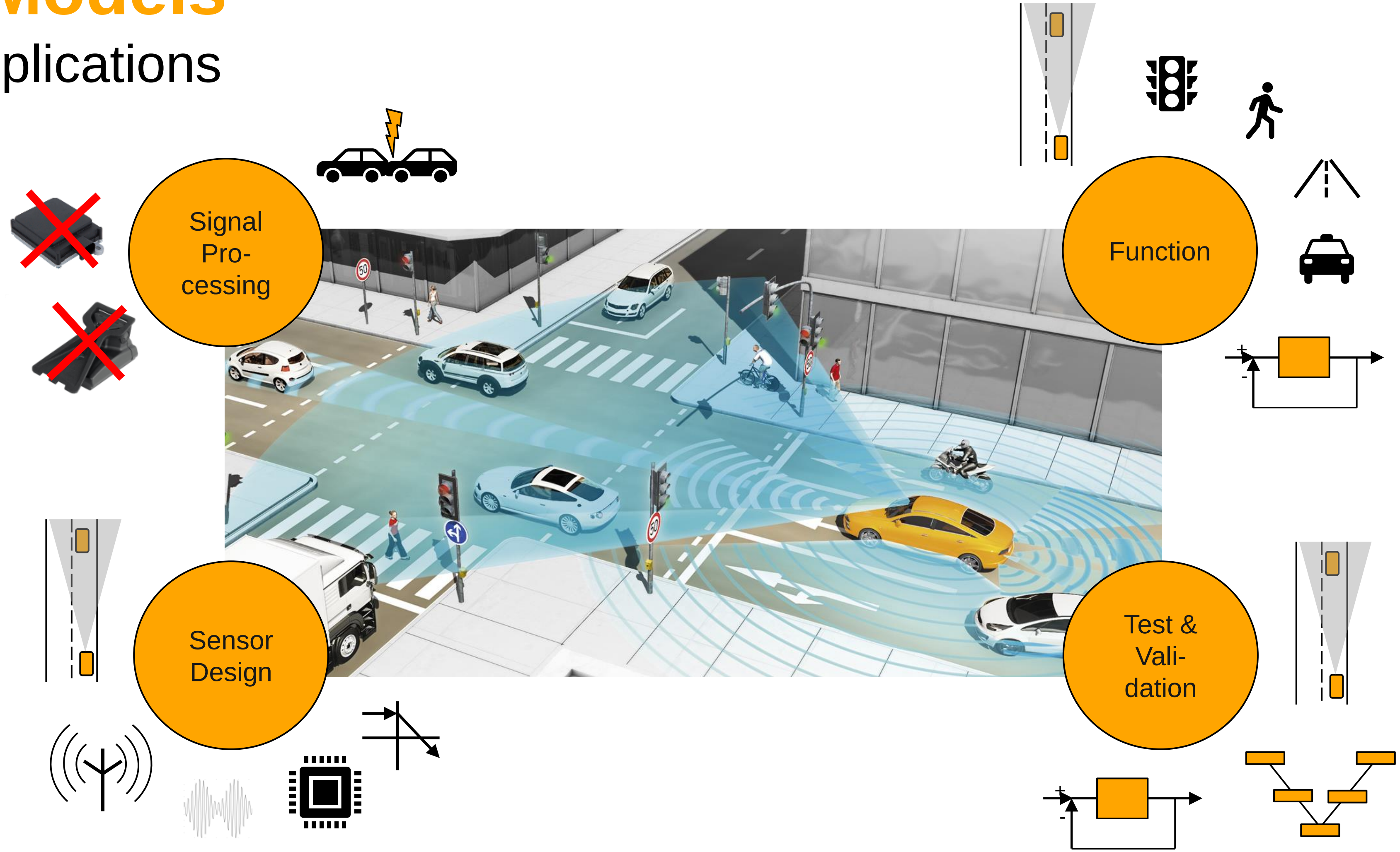




- **Virtual sensor + virtual environment**
- **Modelled and simulated in software**
- **Reduces cost, efforts, time and risks**
- **Validated with measurements**

Sensor Models

Fields of Applications



Signal Processing

Function

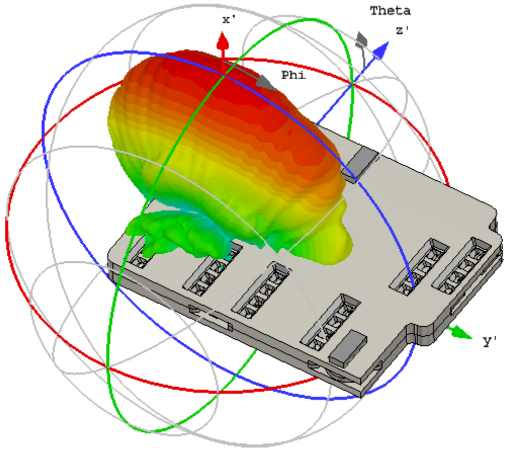
Sensor Design

Test & Validation

Credits: Dirk Ulbricht

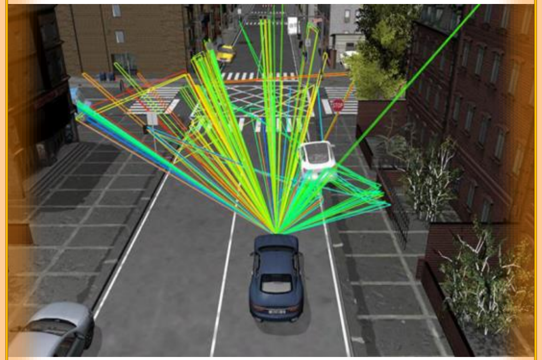
Different Automotive Model Categories

Full Wave Solver



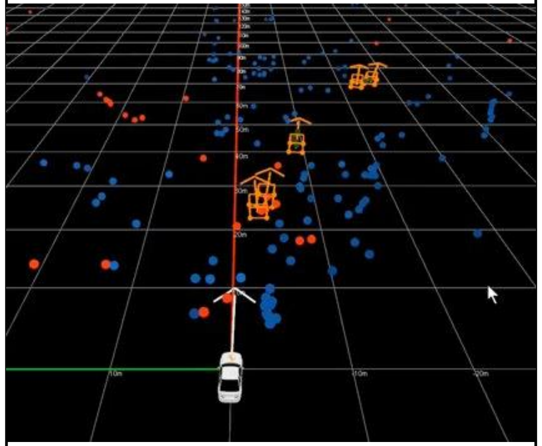
- **Advantages**
  - Physical solver
  - External Tool
  - Long time experience
- **Disadvantages**
  - Computing power
  - Environment description
  - **Calculation** time
- Tools
  - CST, Ansys HFSS

Physical/Geometrical



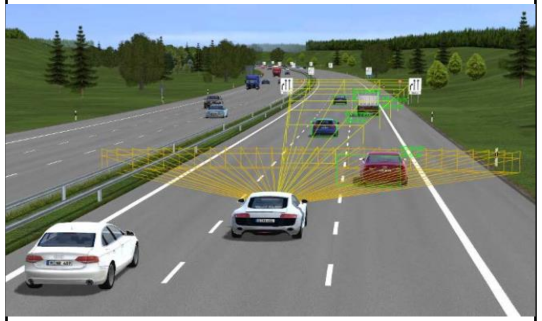
- **Advantages**
  - Fast computation
  - Physical-based results
  - 3D Environment
- **Disadvantages**
  - Approximations
  - Low number of users
  - Depends on HW
- **Tools**
  - IPG RSI, Ansys, Conti VCM

Phenomelogical



- **Advantages**
  - Fast computation
  - Easy Implementation
  - Reduced Physics
- **Disadvantages**
  - Unknown Effects
  - Masked errors
- **Tools**
  - IPG CarMaker, Hexagon VTD, Conti Pheno/Pheno+

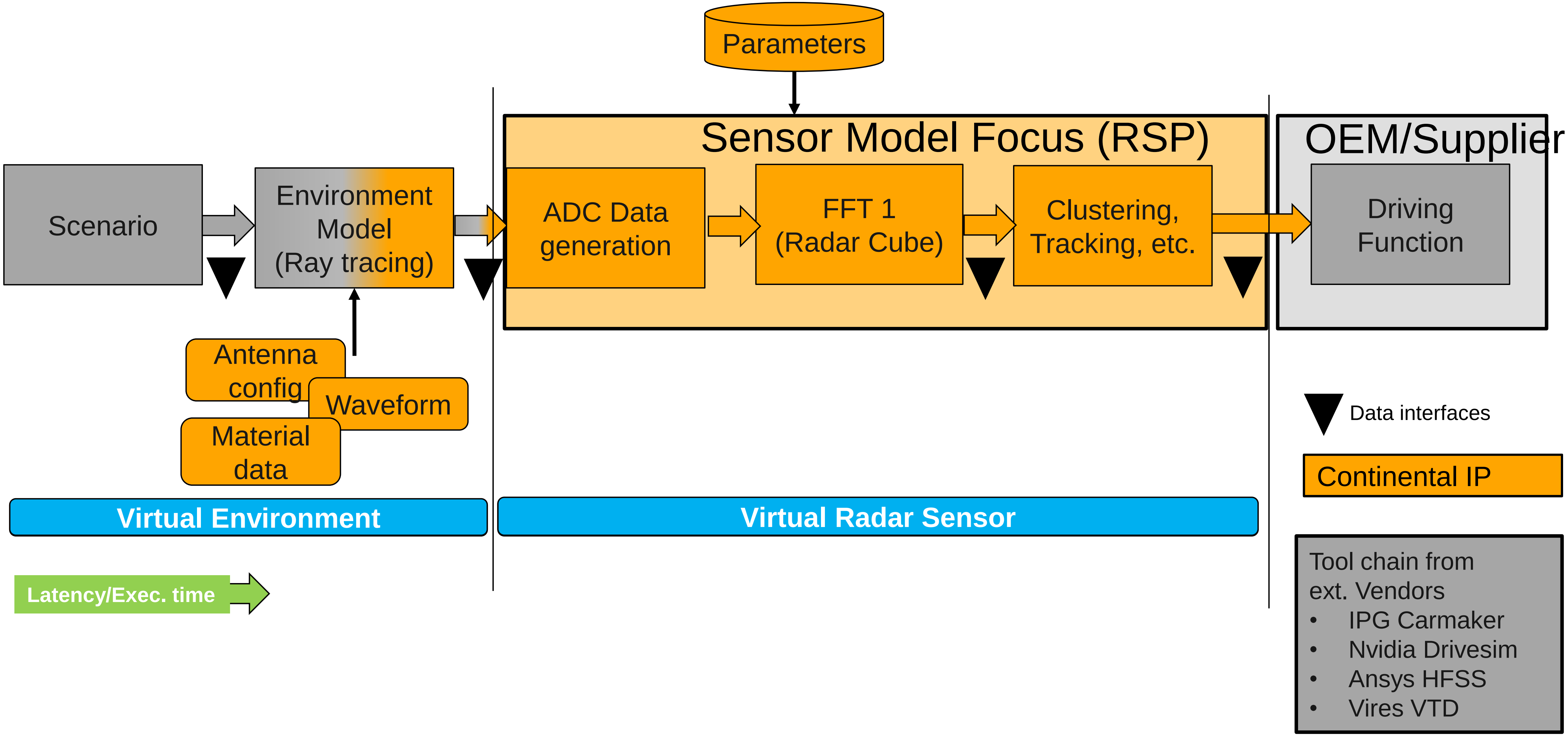
Ideal



- **Advantages**
  - Functional Test
  - Easy
  - Fast
  - Proof of Concept
- **Disadvantages**
  - Not realistic
- **Tools**
  - IPG CarMaker, Hexagon VTD

High **COMPLEXITY** **Low**

Scenario Simulation and Physical Radar Model



Parameters

Sensor Model Focus (RSP)

OEM/Supplier

Scenario

Environment Model (Ray tracing)

ADC Data generation

FFT 1 (Radar Cube)

Clustering, Tracking, etc.

Driving Function

Antenna config

Waveform

Material data

Virtual Environment

Virtual Radar Sensor

Latency/Exec. time

▼ Data interfaces

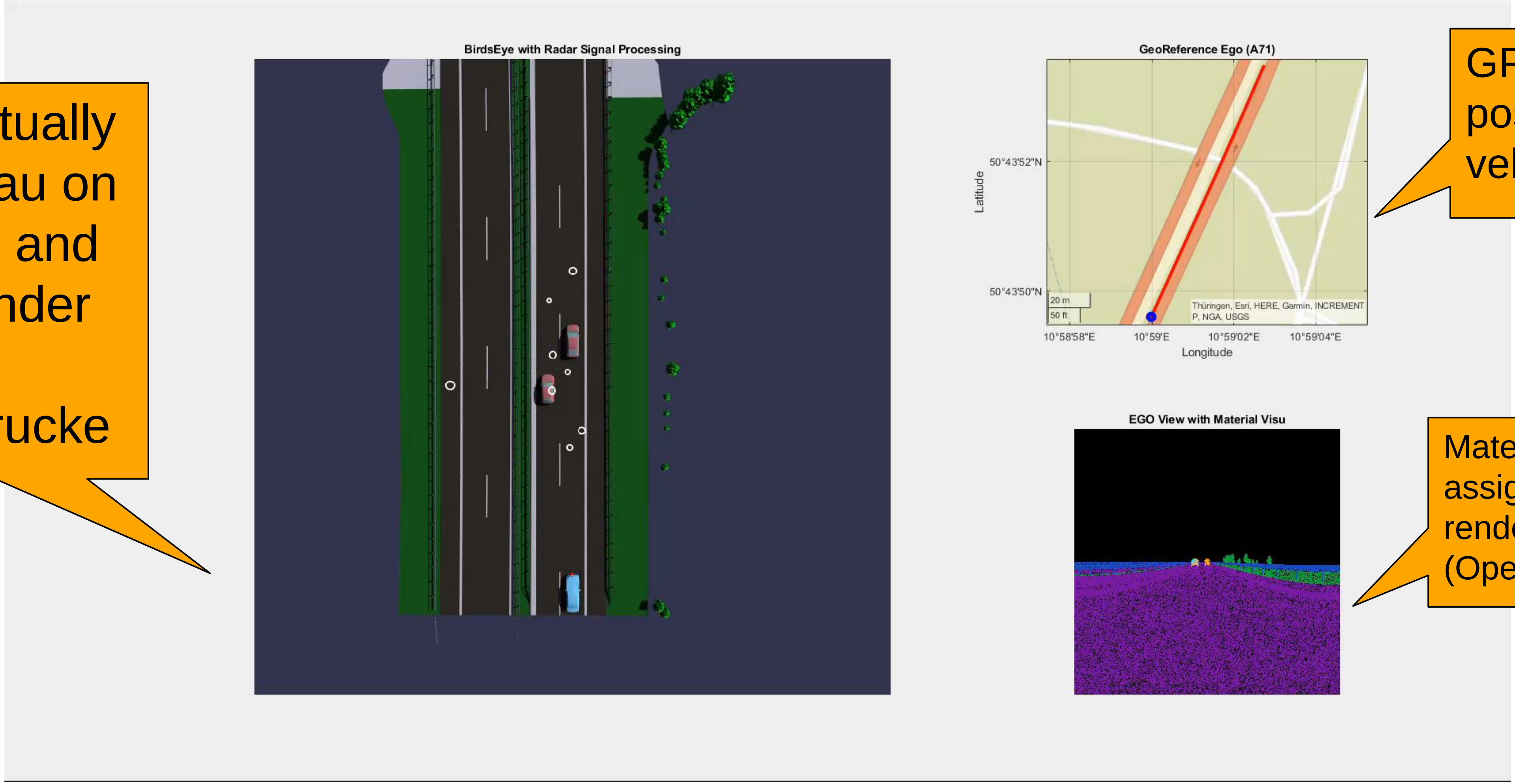
Continental IP

Tool chain from ext. Vendors
- IPG Carmaker
- Nvidia Drivesim
- Ansys HFSS
- Vires VTD

Sensor Model and Simulation of Detections

Example Scenario

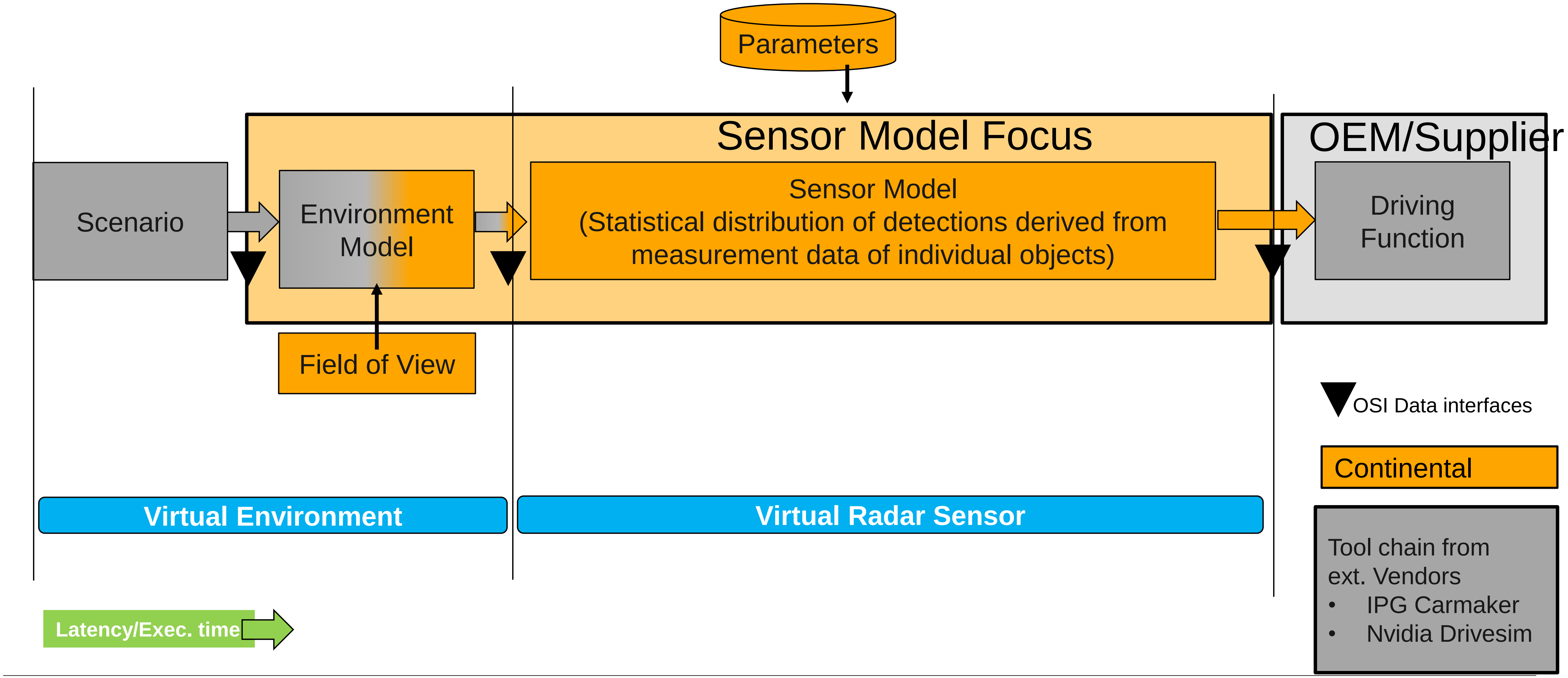
Drive virtually to Ilmenau on the A71 and drive under the Gruenbrucke



GPS position Ego vehicle

Materials assigned in render (OpenMaterial)

Phenomenological Sensor Model



Parameters

Sensor Model Focus

OEM/Supplier

Scenario

Environment Model

Sensor Model
(Statistical distribution of detections derived from measurement data of individual objects)

Driving Function

Field of View

▼ OSI Data interfaces

Continental

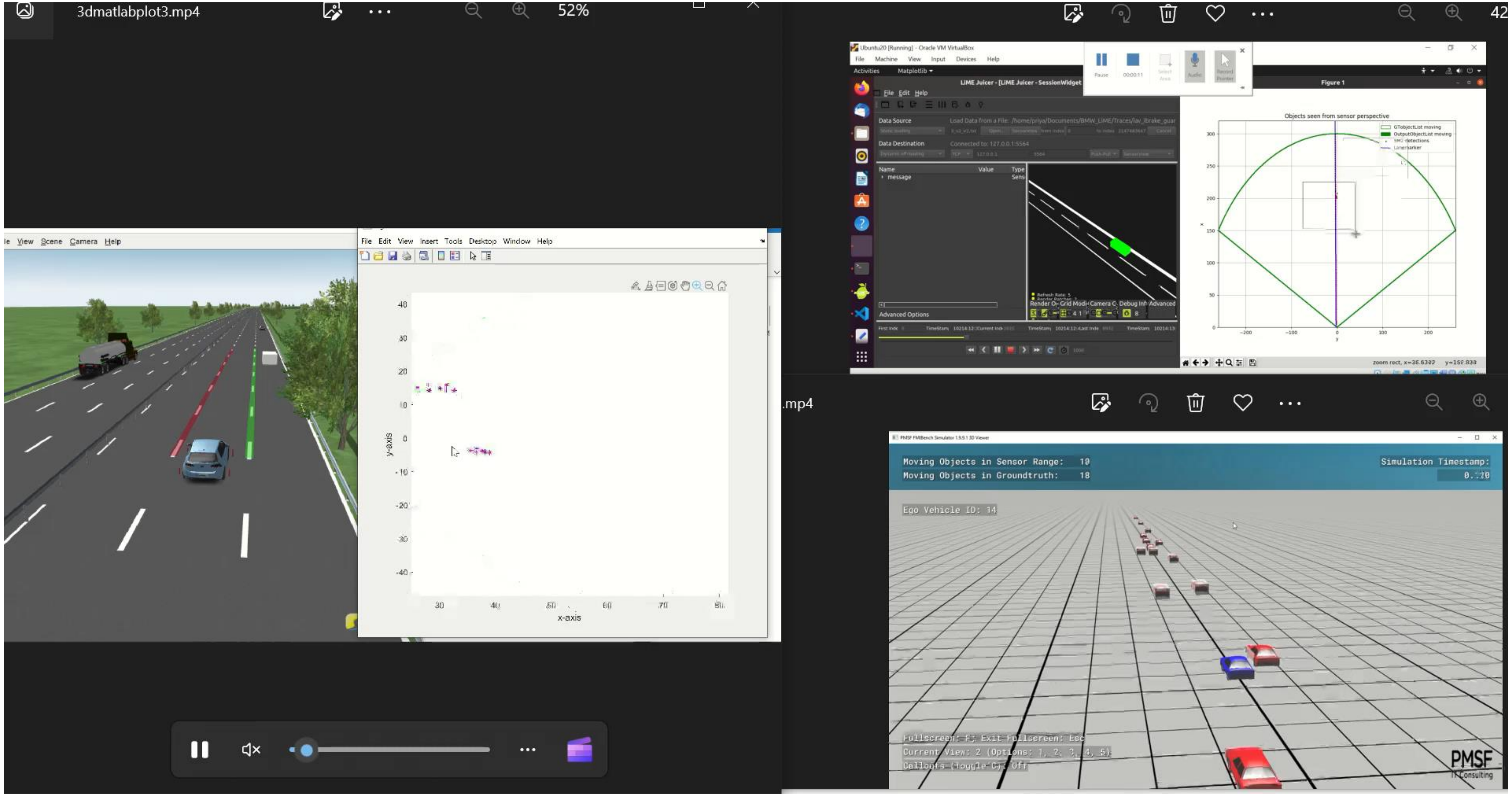
Tool chain from ext. Vendors
- IPG Carmaker
- Nvidia Drivesim

Virtual Environment

Virtual Radar Sensor

Latency/Exec. time

Radar Phenomenological Sensor Model

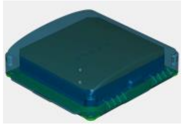


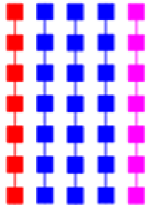
```
Moving Objects in Sensor Range:   10
Moving Objects in Groundtruth:    18
Simulation Timestamp:
0.120
Ego Vehicle ID: 14
Fullscreen: F; Exit Fullscreen: Esc
Current View: 2 (Options: 1, 2, 3, 4, 5)
Callouts (Toggle C): Off
```

Continental Radar Integration Simulation

Various Kinds of Radar Simulation environment

Antenna/ Sensor only

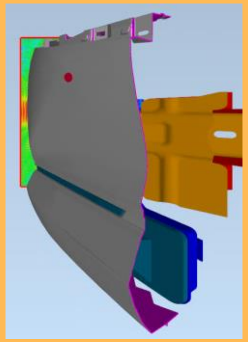




Characterize antenna, Optimize sensor design & performance

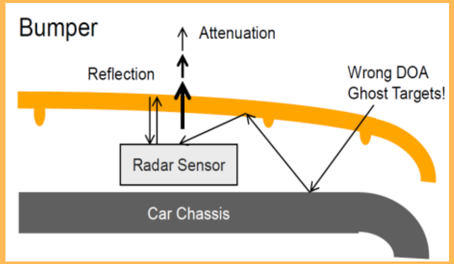
Radar Integration

(Sensor + Radome)



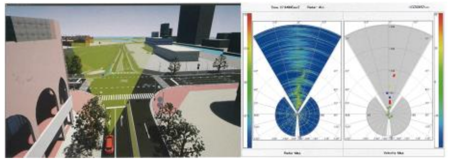
Evaluate the effect of the Radome on the radiation pattern of the sensor.

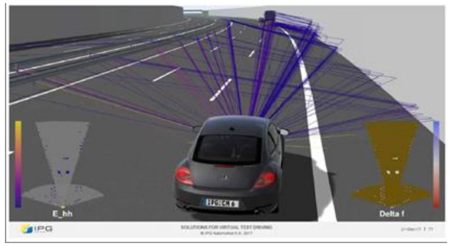
Multipath analysis (internal)



Evaluate multipath possibilities that may cause ghost targets therefore false alarms

Scenario Simulation



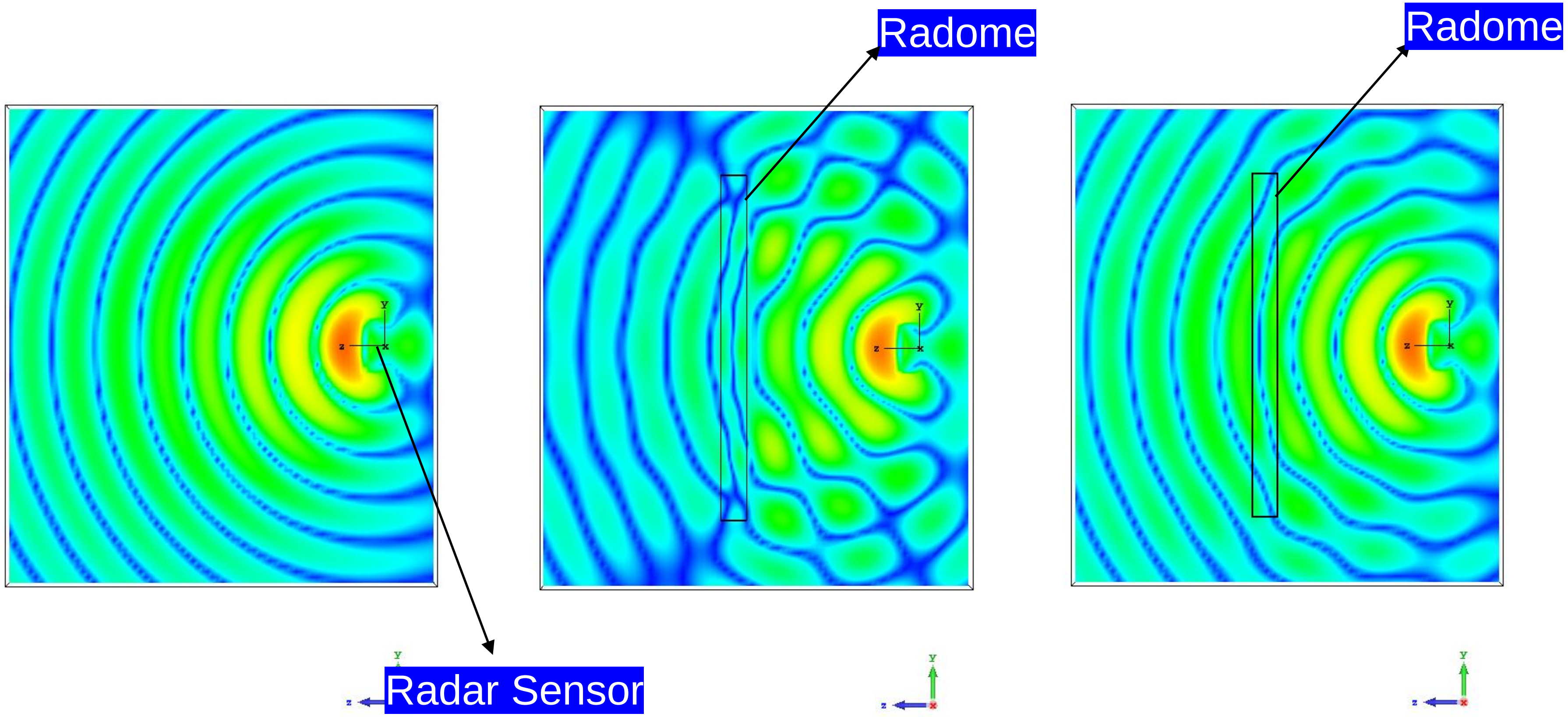


Evaluate radar detectability using a virtual world, Synthetic Data as interface to HiL and SiL

From Component to Vehicle level

Radar Integration – simulation example

2nd surface analysis – visual representation of possible effects



Radar Sensor wave propagation in Free Space

Radar Sensor wave propagation through unsuitable Radome

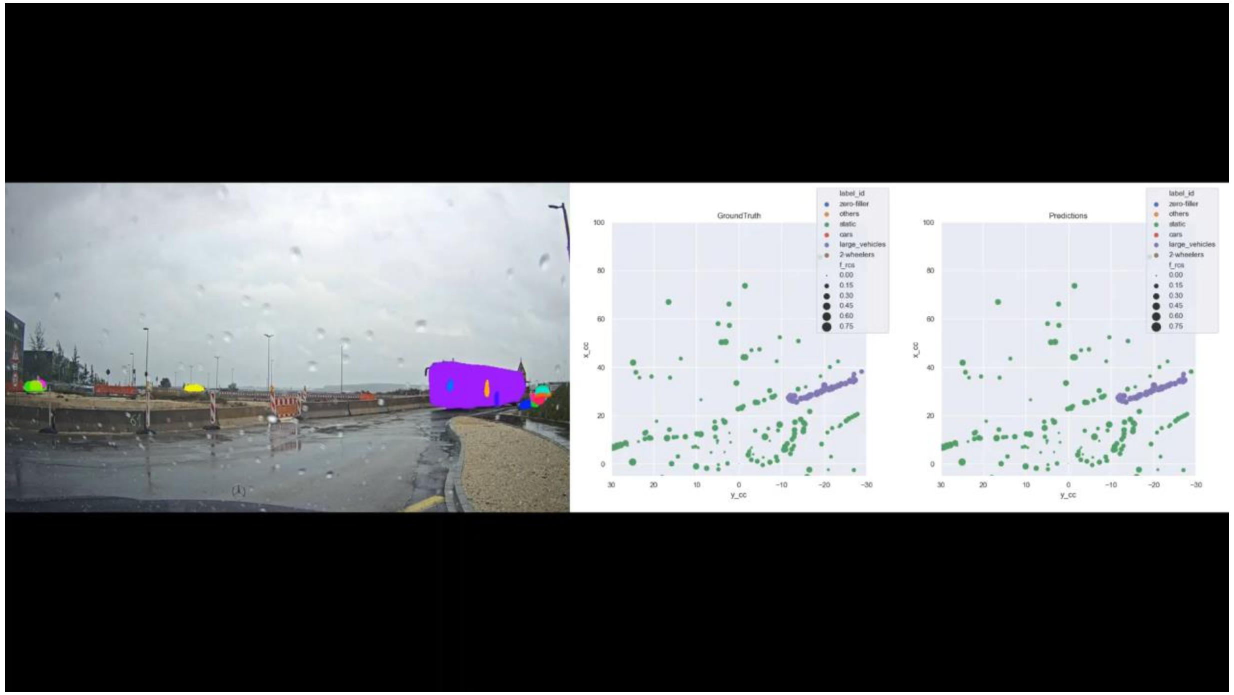
Radar Sensor wave propagation through suitable Radome

Summary and Remarks

- **Radar behavior can be simulated and estimated with radar sensor models**
- **2 types of models – Physical and Phenomenological**
- **Tradeoffs – accuracy and execution time**
- **Simulated radar performance after mounting and integration of radar in vehicle, e.g. in bumper and fascia**

Thank you!

Example AI Application: Radar Based Semantic Segmentation



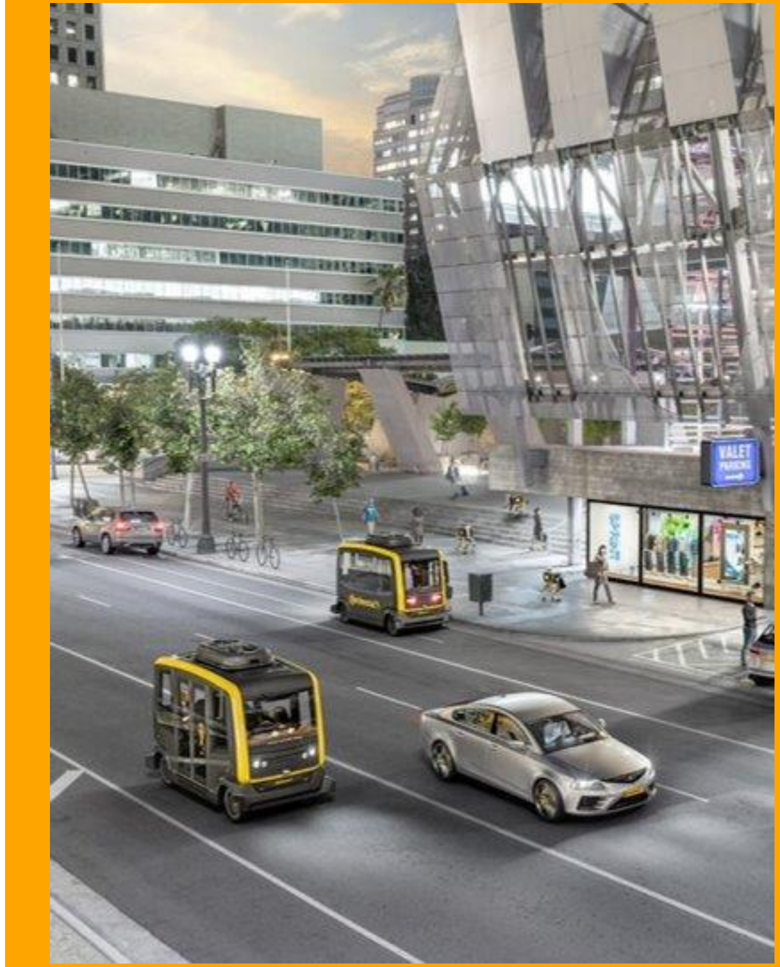
Based on the RadarScenes Dataset
(https://radar-scenes.com/dataset/about/)

- Object classification for assisted driving
- Based on open-source measurements
- Manual labelling of data involved

Current workflow

Virtual Validation in Context of AD / ADAS

Summary



- Considerable progress has been made towards improving the quality of raytracing output
- Ability to handle complex scenarios virtually is dependent on **quality** of virtual sensor data compared to real measurements
- Radar mounting and integration effects also can be estimated by simulation

- **Radar is the key technology for assisted and automated driving:** Proven technology since 1999, robust under all weather conditions and able to handle complex and highly dynamic scenarios.
- For the development of the next generation of radar sensors, **virtual validation** acts as a powerful catalyst by **speeding up antenna design and system architecture concepts.**

- Deep learning **radar CNNs** require a large amount of labeled training data. **Virtual validation will allow us to generate this training data** without the need for manual labeling of on-road test data.

Thank you!

We look forward to a fruitful cooperation.

hasan.iqbal@continental.com