6GBRAINS: Multiband Channel Sounding and RT Modelling in Industrial Scenarios

6G BRAINS
WP3

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Outline

- Motivation
- Workflow
  - RT Modelling
  - Multiband Channel Sounding
  - RT Model Validation
- Conclusions

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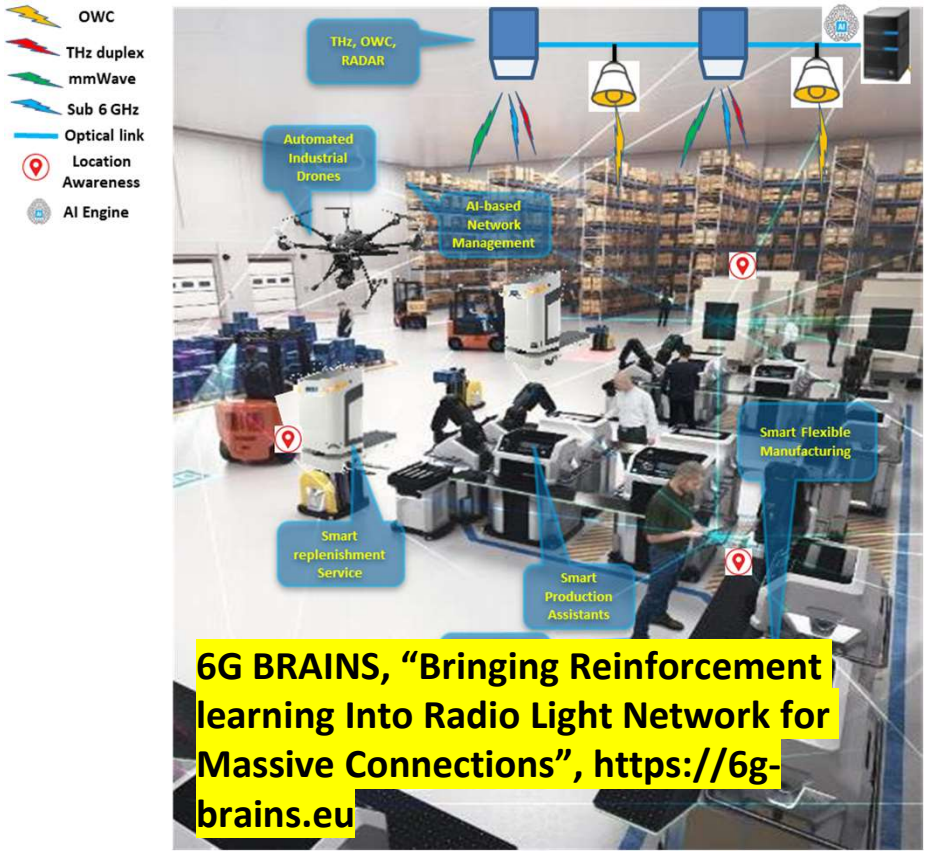
Motivation

Industry 4.0

- Requirements on **eMBB** (enhanced Mobile Broadband), **URLLC** (Ultra Reliable Low Latency Communications), and **mMTC** (massive Machine Type Communications)
  - High density and coverage → 1,000,000 IoT devices per km2
  - High accuracy:
    - 1 cm location accuracy for AGVs and Drones
    - 1 mm localization accuracy for aligning real and virtual worlds in Augmented Reality
  - Low latency → Real time remote control of machine
  - High data-rates → **Real time analysis of video** for product inspection and collision avoidance of AGVs and drones
- Heterogeneous networks



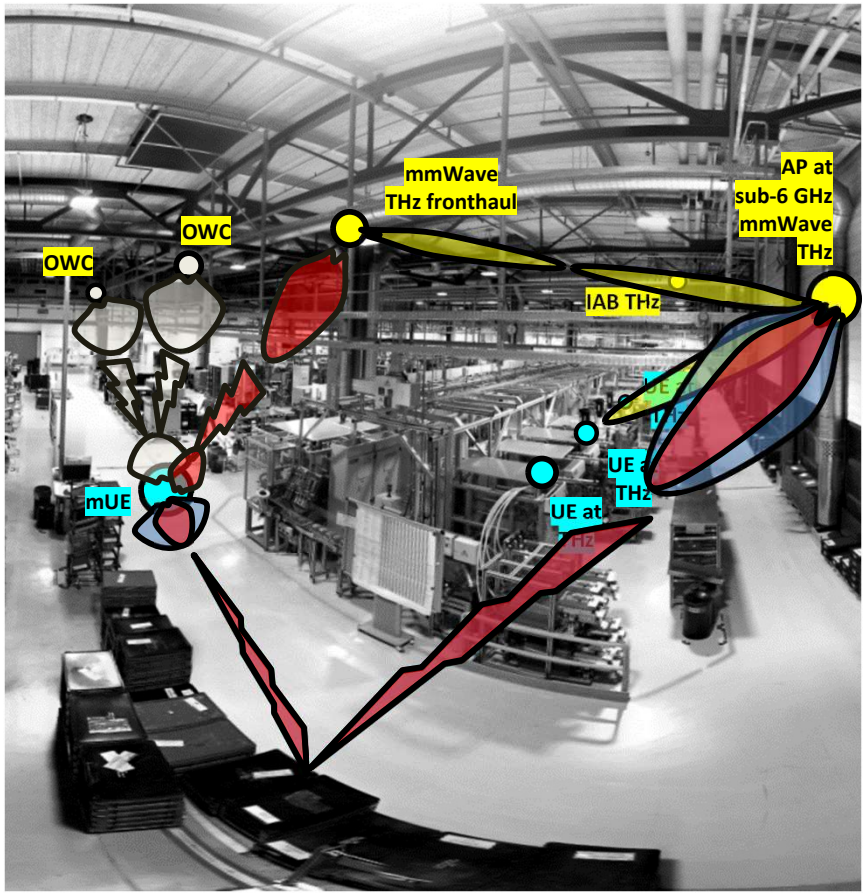
6G BRAINS, "Bringing Reinforcement learning Into Radio Light Network for Massive Connections", https://6g-brains.eu

Channel Modelling

Applications

- Heterogeneous networks
  - Simultaneous multi-band simulations for inter-band applications
- ICAS
  - Sensing
  - Localization
  - Mapping
- Channel model requirements…

Figure: *picture from the Bosch plant in Blaichach industry hall scenario.*

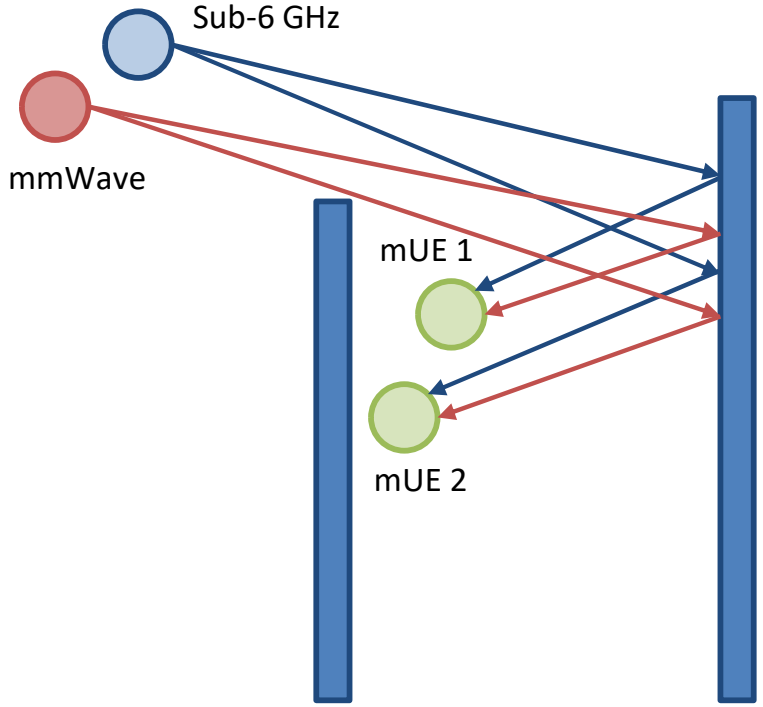


D. Dupleich, A. Ebert, and R. Thomä, ***"Measurement-Based Analysis of Multi-Band Assisted Beam-Forming at mmWave in Industrial Scenarios,"*** *17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, March 2023 - Accepted*

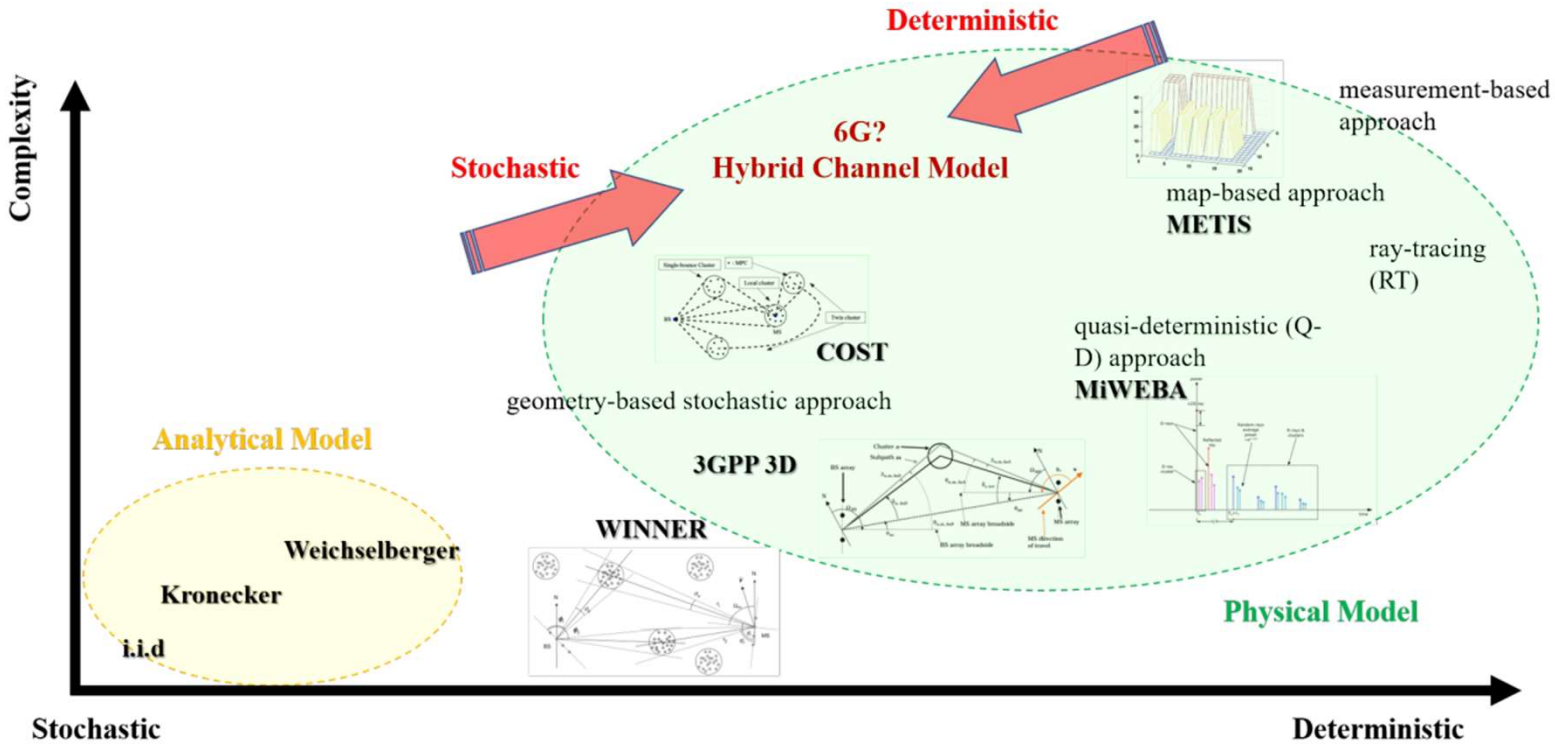
Requirements on Channel Modelling

Accurate multi-band physical channel model

- Spatial consistency
  - Intra-band
  - Inter-band → Correlation of propagation parameters over the different bands of interest
- Accurate (deterministic) information of the multipath components
  - For beam-steering (high gain radio-interfaces for high frequency)
  - For ICAS applications
  - Digital twin of the environment under test

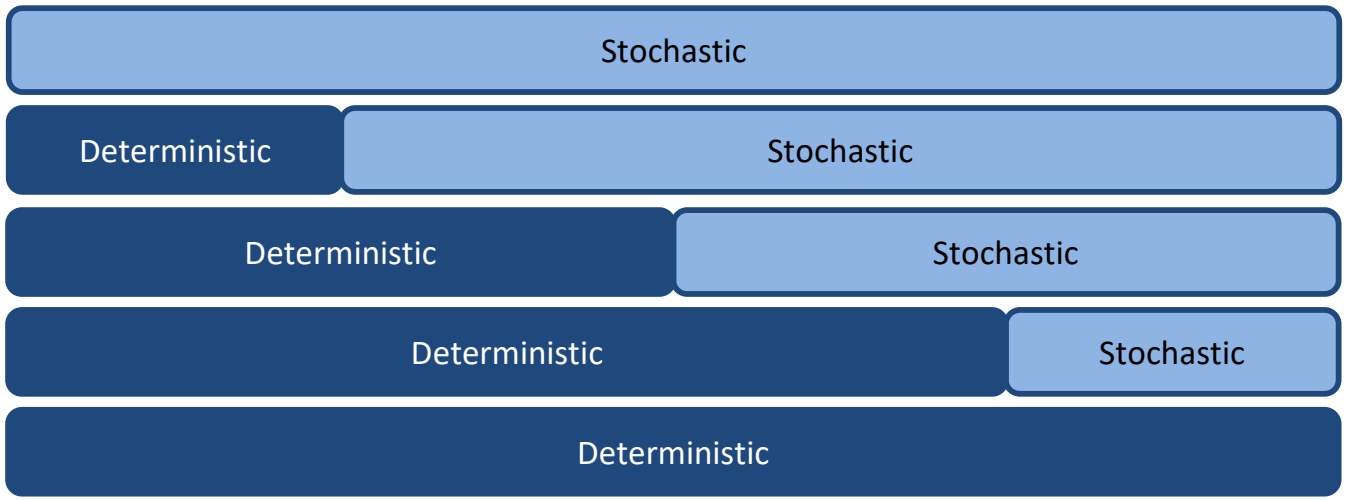


Channel Modelling



C. Han, Y. Wang, Y Li, Y. Chen, N. A. Abbasi, T. Kürner, and A. Molisch, ***"Terahertz Wireless Channels: A Holistic Survey on Measurement, Modeling, and Analysis,"*** *https://arxiv.org/abs/2111.04522*

Channel Modelling



WINNER II, 3GPP

COST 2100, Stochastic METIS

MIWEBA

Map-based METIS, **6G BRAINS**

RT

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Workflow

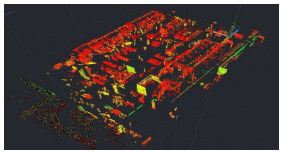
3D laser scans of scenario

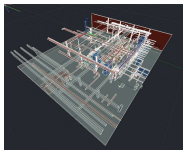
CAD model

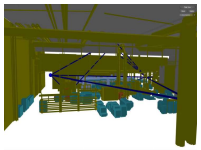
RT model

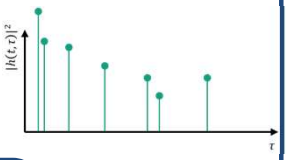
Deliverable D3.1

Simulations







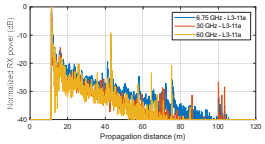


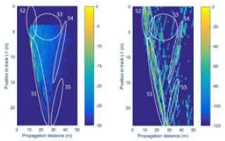
Multi-band measurements

Validation of deterministic components

Deliverable D3.3

Deliverable D3.2

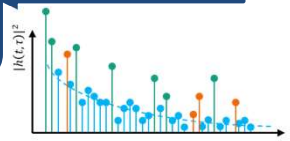




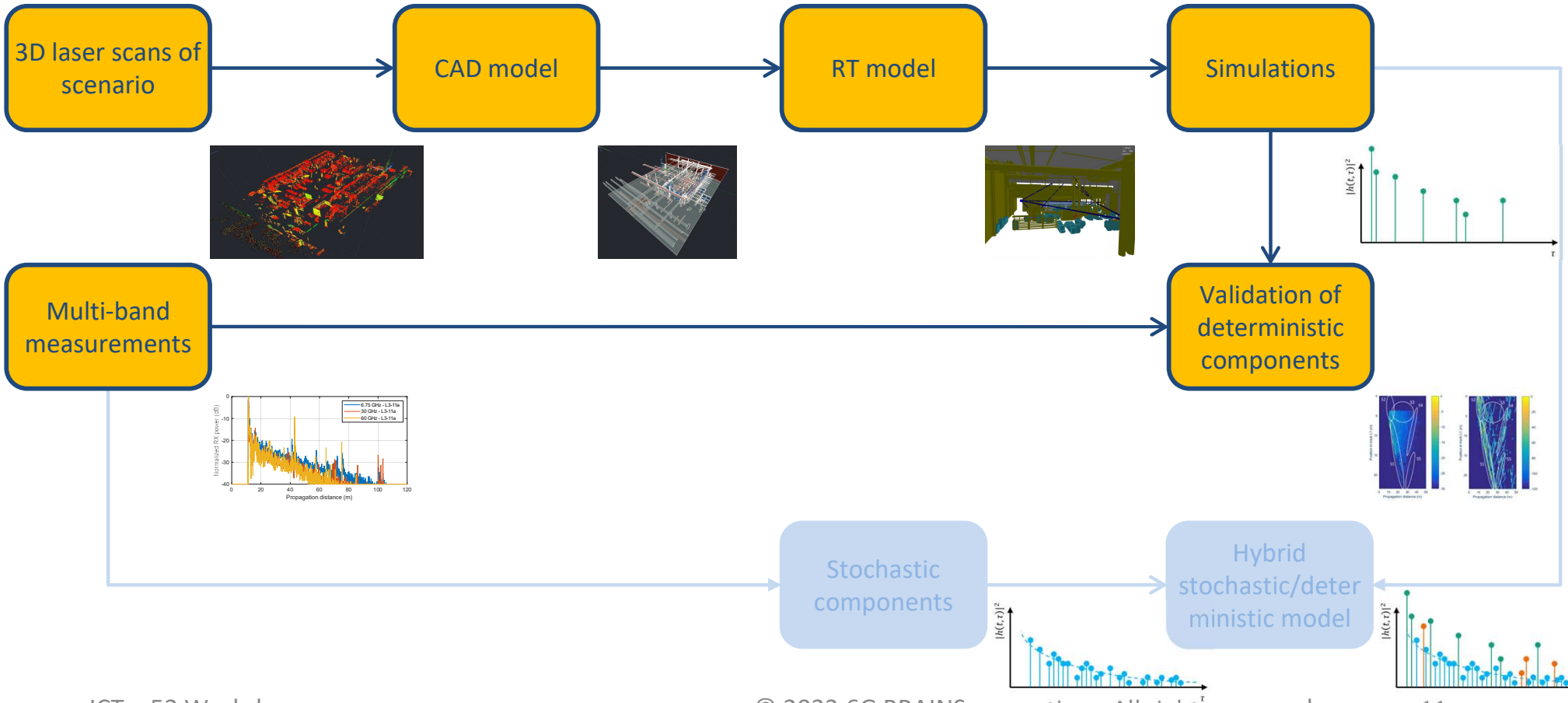
Deliverable D3.4

Stochastic components

Hybrid stochastic/deterministic model



Workflow



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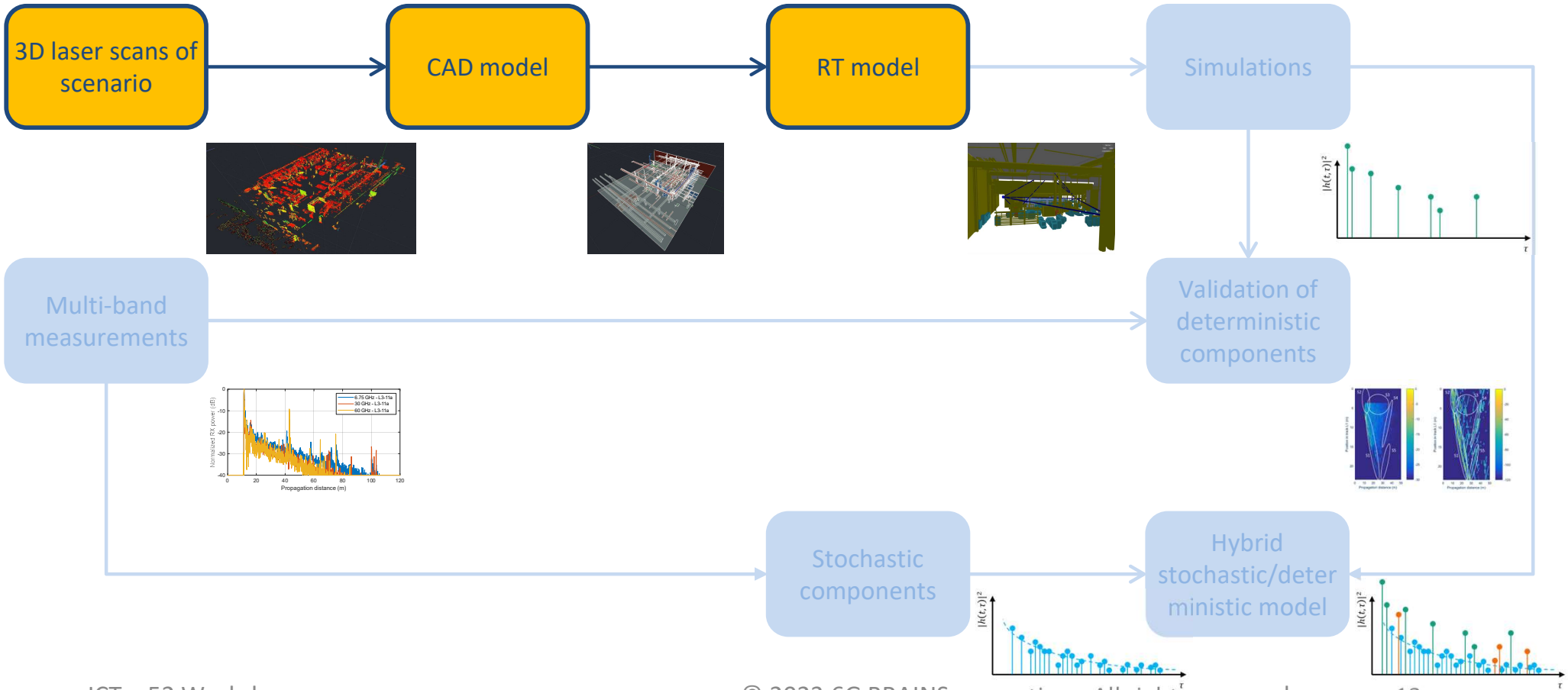

From Point-Cloud to RT Model

- Industry hall scenario (Bosch plant in Blaichach)
  - Size: 42 × 46 × 11 m
  - Number of objects: more than 10000

D. Dupleich, N. Han, J. Cosmas, G. Eappen, and K. Ali, ***"D3.1 3D Laser measurement of one factory at Bosch with 3D cloud scanner and 3D hand scanner,"*** *2021 (V1.0). Zenodo. https://doi.org/10.5281/zenodo.5786456*

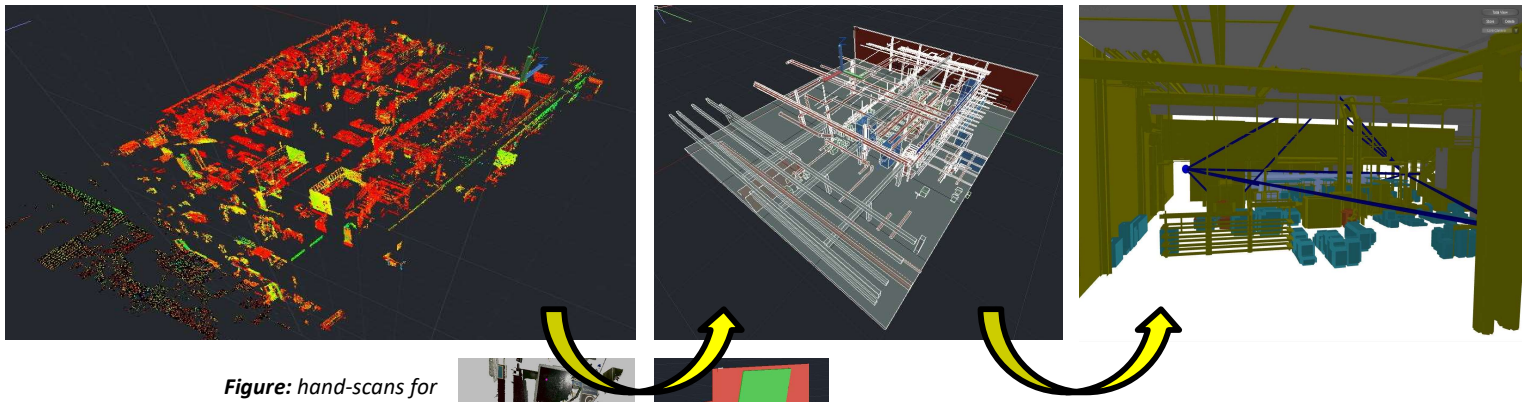

Figure: *processing from point-cloud to RT model of the Bosch plant in Blaichach (macro structure).*

Macro structure

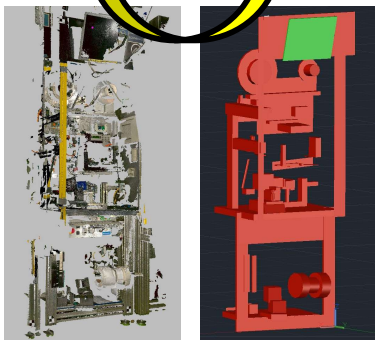

Figure: *hand-scans for modelling of the insides of the machines (Bosch plant).*

Micro-structure

From Point-Cloud to RT Model

- Machine room scenario (FhG in Ilmenau)
  - Size: 6.48 × 10.05 × 6.33 m
  - Number of objects: 16311

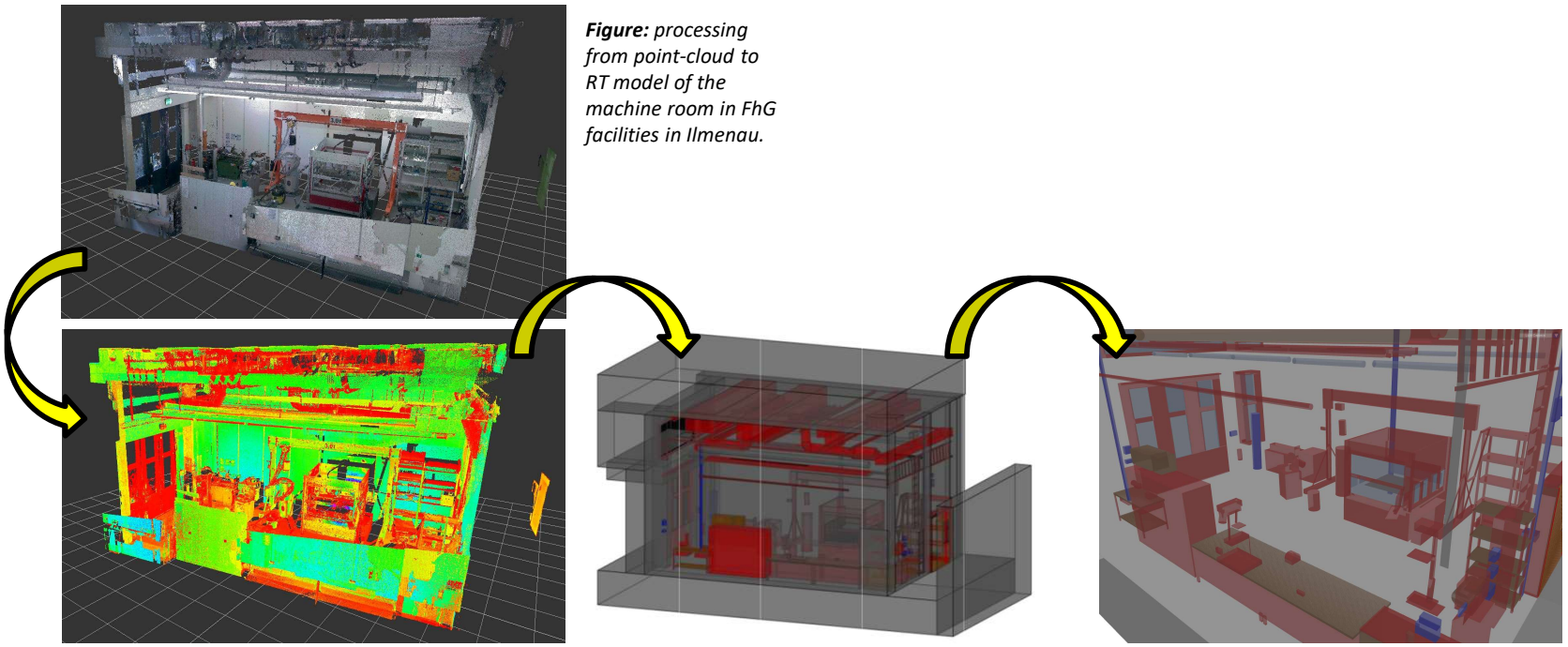

Figure: *processing from point-cloud to RT model of the machine room in FhG facilities in Ilmenau.*

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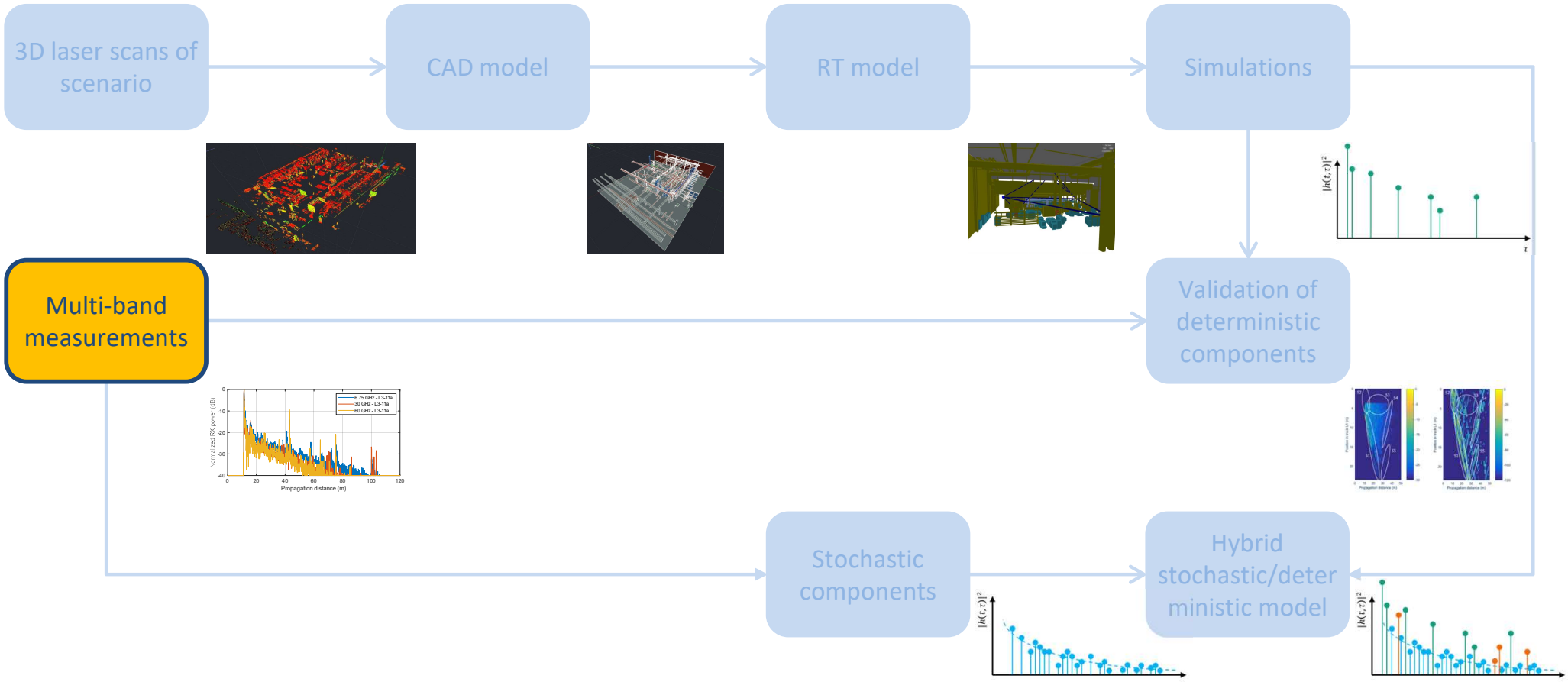

Multi-band Channel Sounding

- Simultaneous multi-band channel sounding
- M-Sequence wideband channel sounder
  - 5 GHz bandwidth after calibration
  - Bands
    - 6.75 GHz
    - 30 GHz
    - 60 GHz
- Antennas
  - Rotating (stepwise) high gain antennas for spatial characterization at the TX
    - Dual-polarized 30° HPBW antennas
  - Dipoles at RX

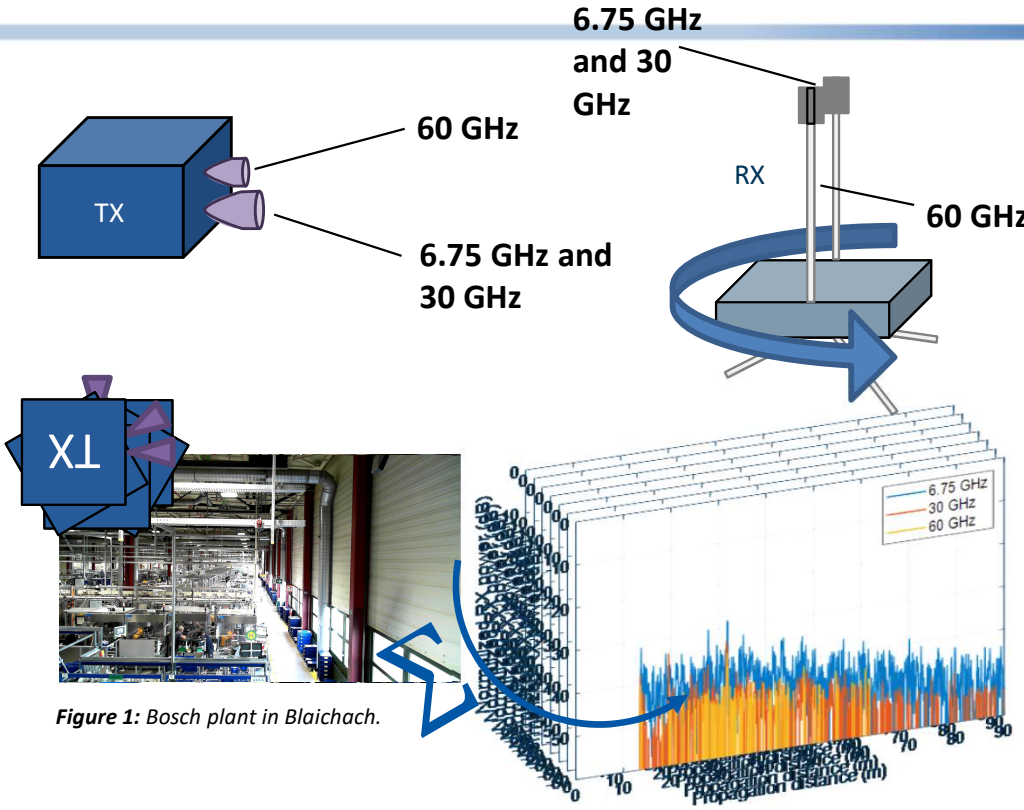

Figure 1: *Bosch plant in Blaichach.*

D. Dupleich et al., ***"From Sub-6 GHz to mm-Wave: Simultaneous Multi-band Characterization of Propagation from Measurements in Industry Scenarios,"*** *2022 16th European Conference on Antennas and Propagation (EuCAP), 2022*

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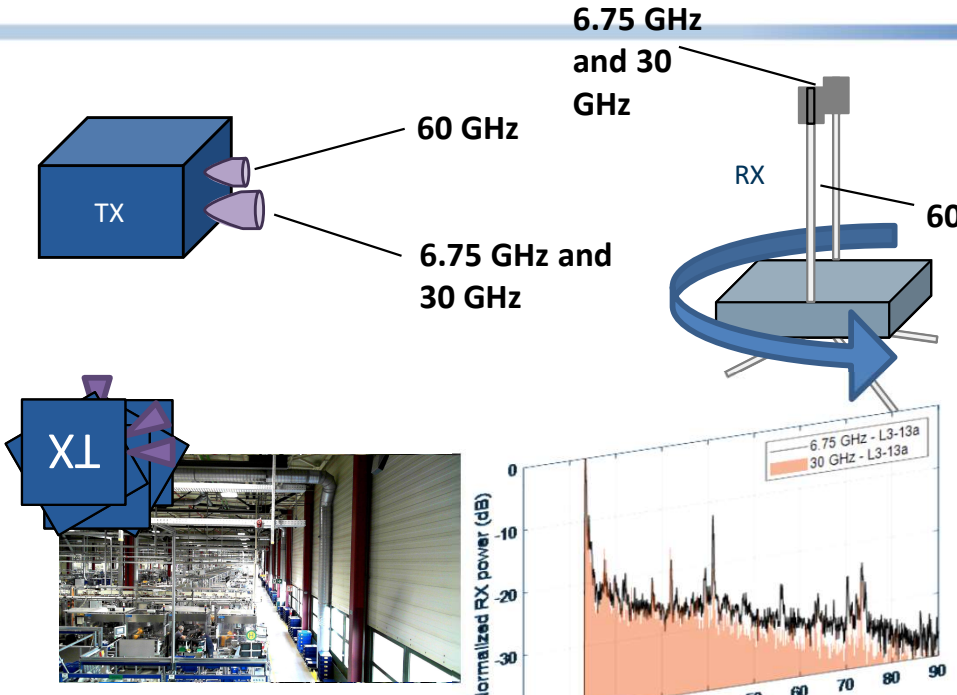
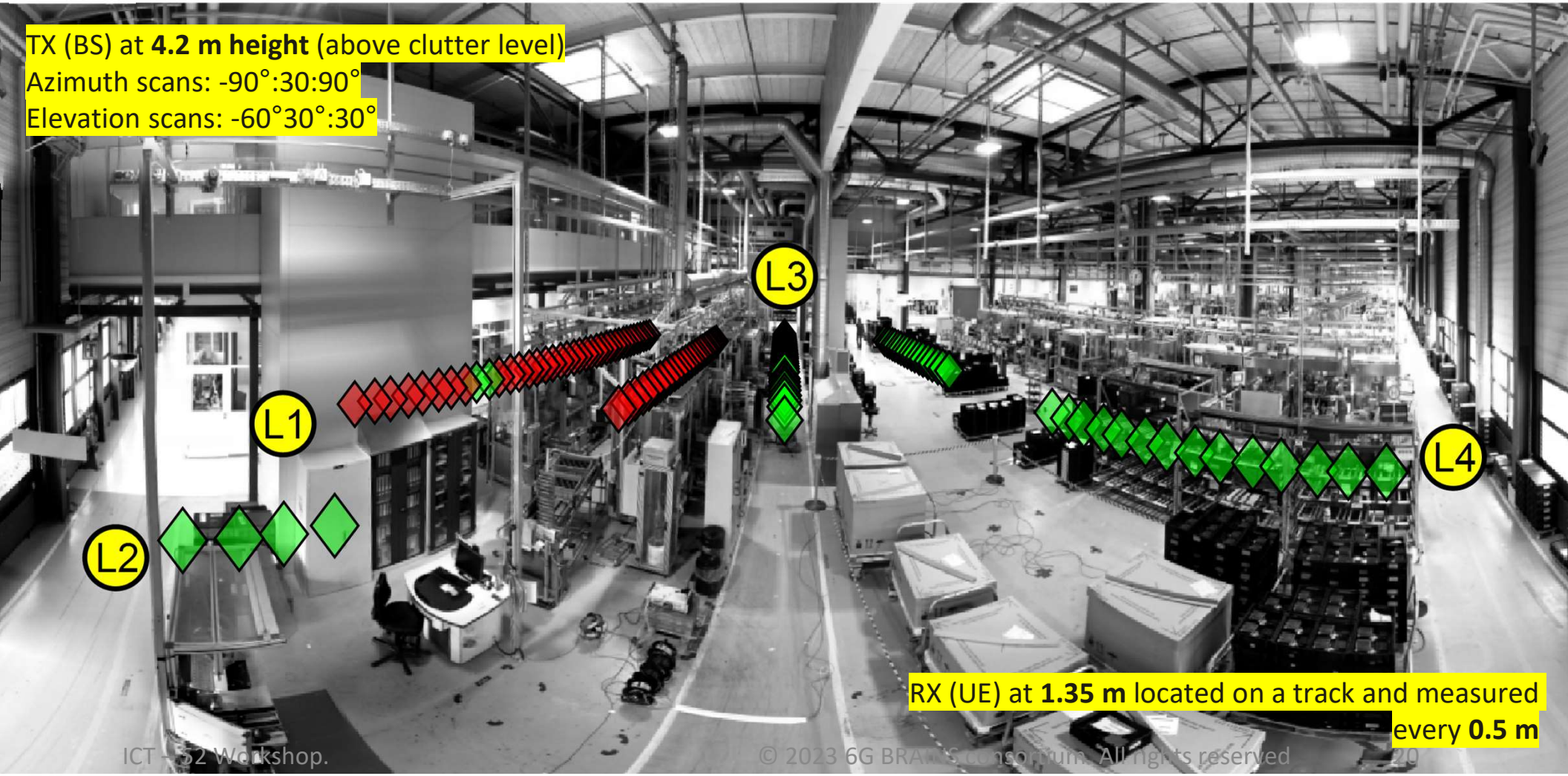


Figure 1: *Bosch plant in Blaichach.*

Figure 2: *Measured isotropic power delay profile at sub-6 GHz and mmWave*

D. Dupleich et al., ***"From Sub-6 GHz to mm-Wave: Simultaneous Multi-band Characterization of Propagation from Measurements in Industry Scenarios,"*** *2022 16th European Conference on Antennas and Propagation (EuCAP), 2022*

Multi-band in Industry Hall

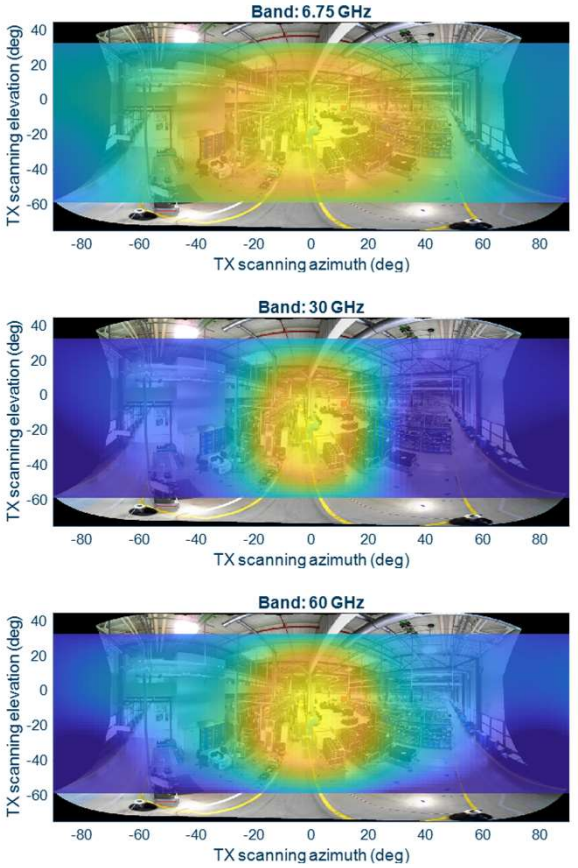


Multi-band Measurements in Industry Hall

Power azimuth/elevation profile

- RX in Line 3 in LOS

- Similar power azimuth/elevation profile in the different frequencies

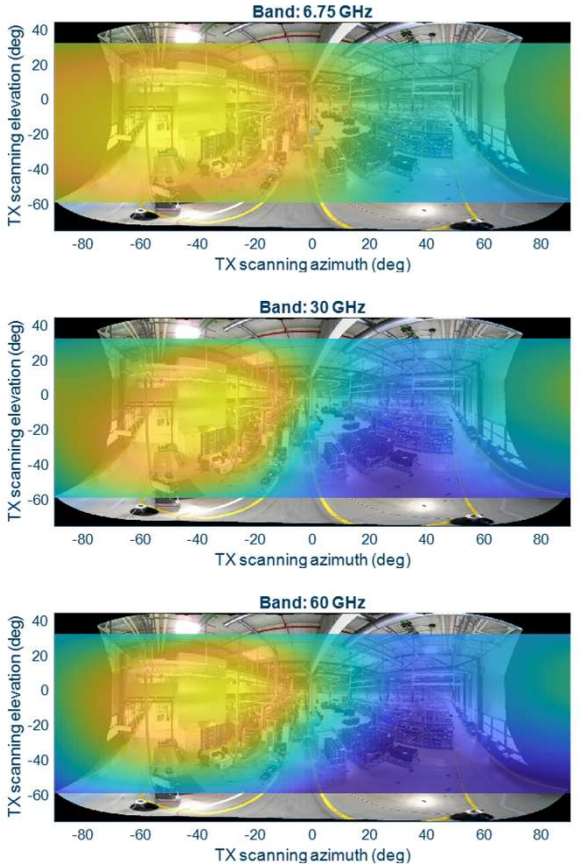


Multi-band Measurements in Industry Hall

Power azimuth/elevation profile

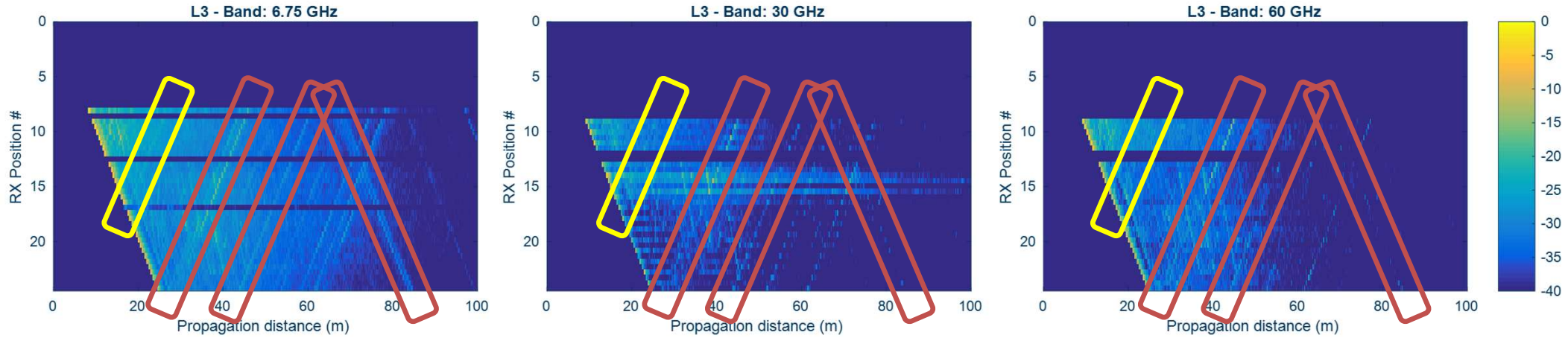
- RX in Line 1 in NLOS (behind production line)

- Similar power azimuth/elevation profile in the different frequencies **even in NLOS**



Multi-band Measurements in Industry Hall

- Example of measured isotropic PDP in LOS track
  - Dominant paths are visible with similar strength at different frequencies
  - Dominant paths describe the geometrical characteristic of the environment



Multi-band Measurements in Industry Hall

Synthetic Omni-directional power delay profile (PDP)

- ❑ Normalized to the LOS component
- ❑ Stronger clusters of paths visible at different frequencies → **<u>specular components are mostly common over frequency</u>**
- ❑ Less visible DMC with increasing frequency → also seen in [DML20]

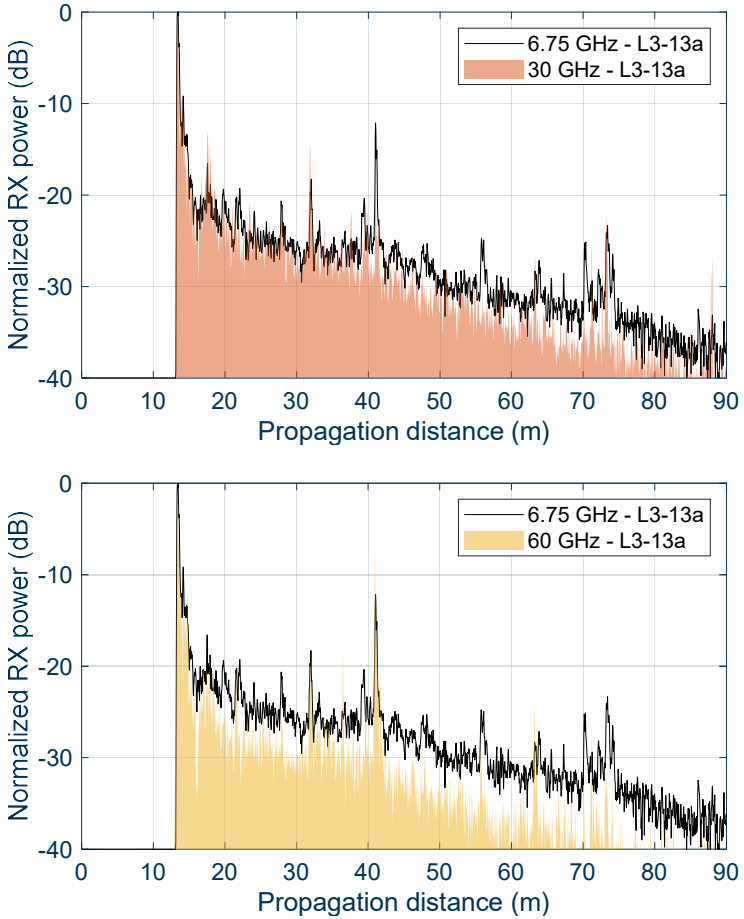


Figure: *multi-band synthetic isotropic PDP in a LOS position during the measurements in the industry hall*

[DML20] D. Dupleich, R. Müller, M. Landmann, J. Luo, G. D. Galdo and R. S. Thomä, ***"Multi-band Characterization of Propagation in Industry Scenarios,"*** *2020 14th European Conference on Antennas and Propagation (EuCAP), 2020, pp. 1-5*

Quad-band Channel Sounding

- Simultaneous RF multi-band and OWC channel sounding
- RF (Dual-polarized antennas)
  - M-Sequence wideband channel sounder
  - Bands
    - 6.75 GHz → **30°** HPBW antennas
    - 70 GHz → 15° HPBW antennas
    - 200/**300 GHz** → 15° HPBW antennas
  - 5 GHz bandwidth after calibration
- OWC
  - 940 nm
  - 100 MHz bandwidth

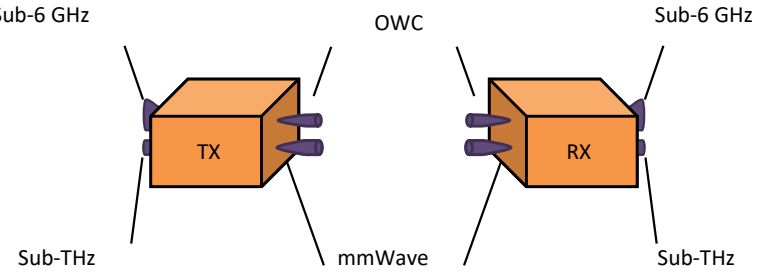


Figure 1: *Schematic of the quad-band channel sounder*

Figure 2: *Picture of the TX quad-band channel sounder*

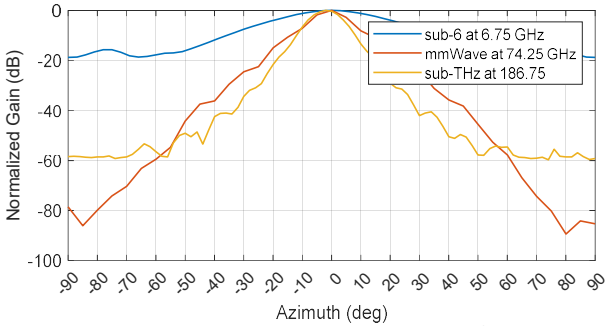


Figure 3: *Measured antenna patterns for the RF part of the sounder [1]*

Sub-THz calibration and delay resolution

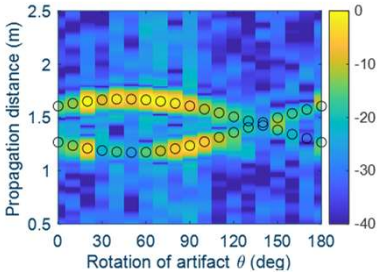
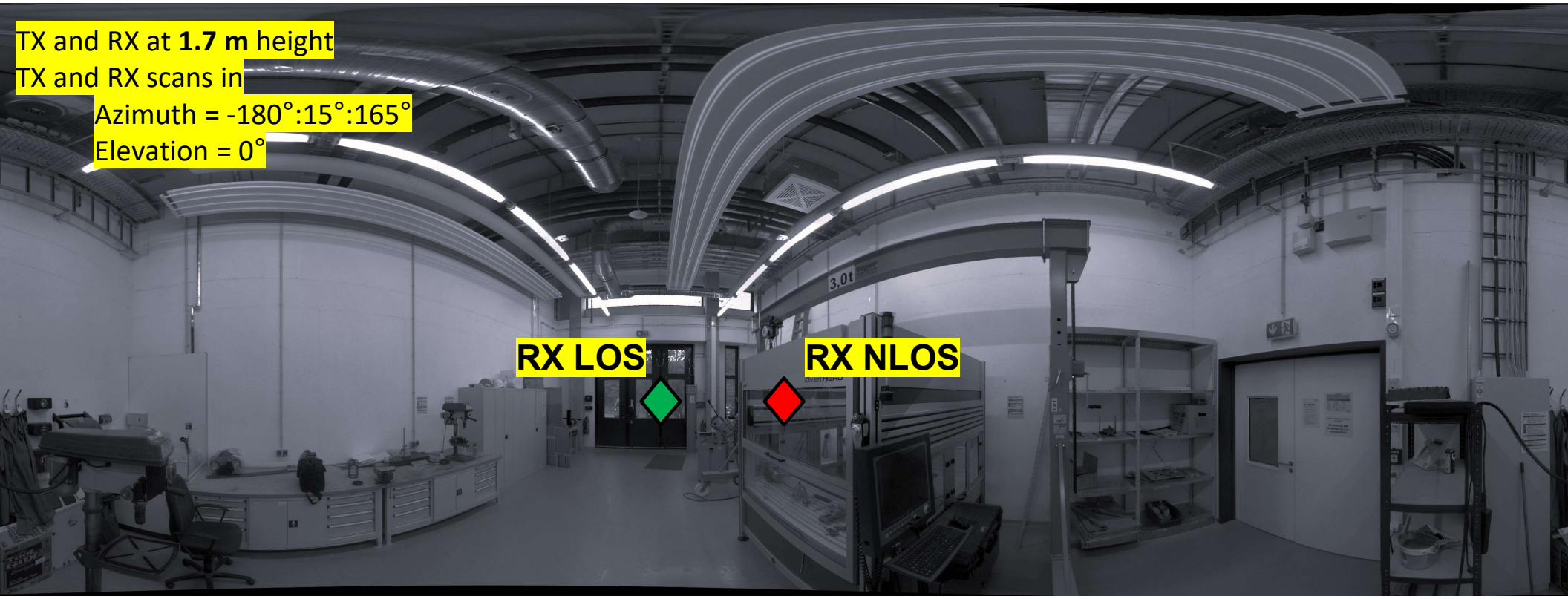


Figure 4: *Measured and estimated delay for validation of the sub-THz sounder [2]*

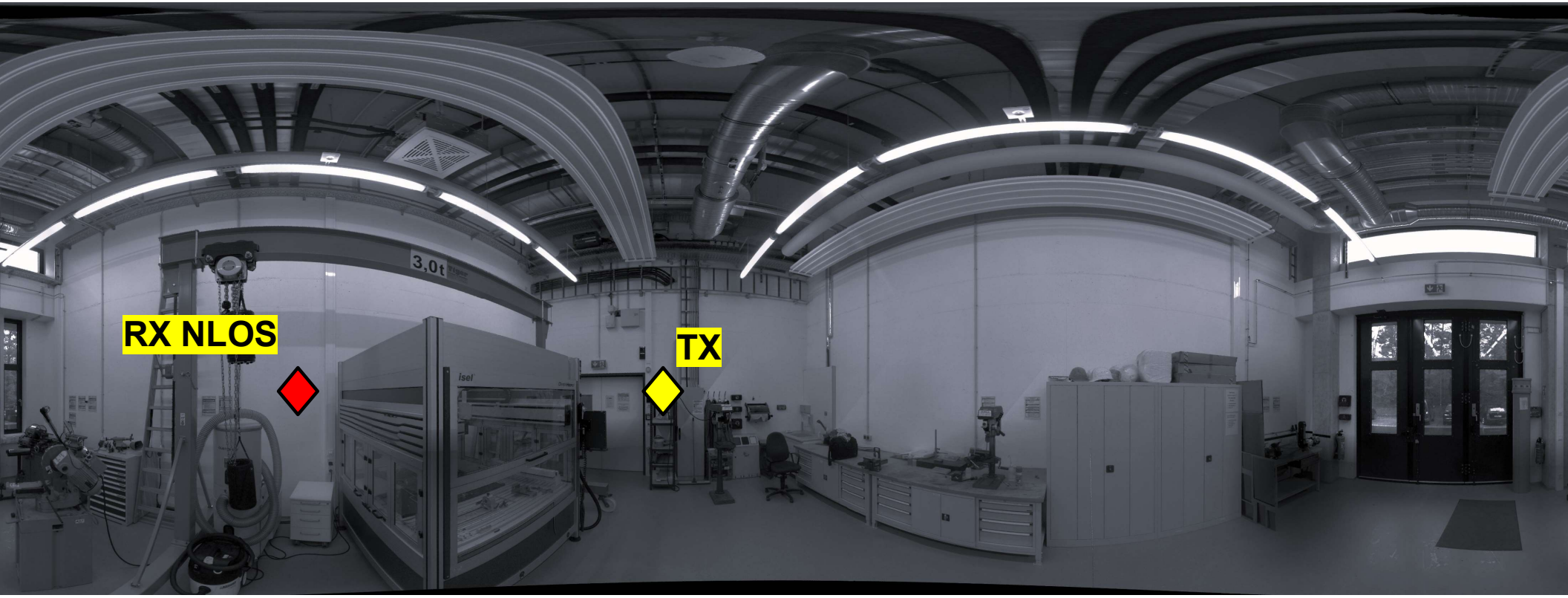
*[1] D. Dupleich et al., "**D3.2 Specifications and Upgrade of Multiband Channel Sounder for Quad-Band Measurements at Sub-6 GHz + mmWave + THz + OWC in Industry Scenarios,"** 2022, (v1.0). Zenodo. https://doi.org/10.5281/zenodo.6798252*

*[2] D. Dupleich et al., **"Verification of THz Channel Sounder and Delay Estimation with Over-The-Air Multipath Artifact,"** 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022*

Machine Room Scenario (TX View)



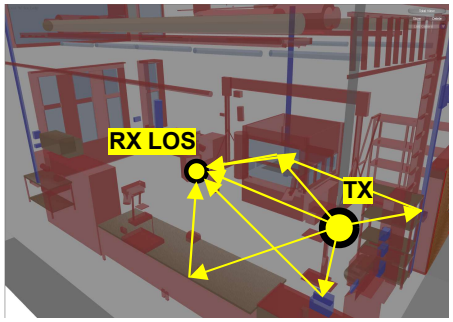
Machine Room Scenario (RX View)

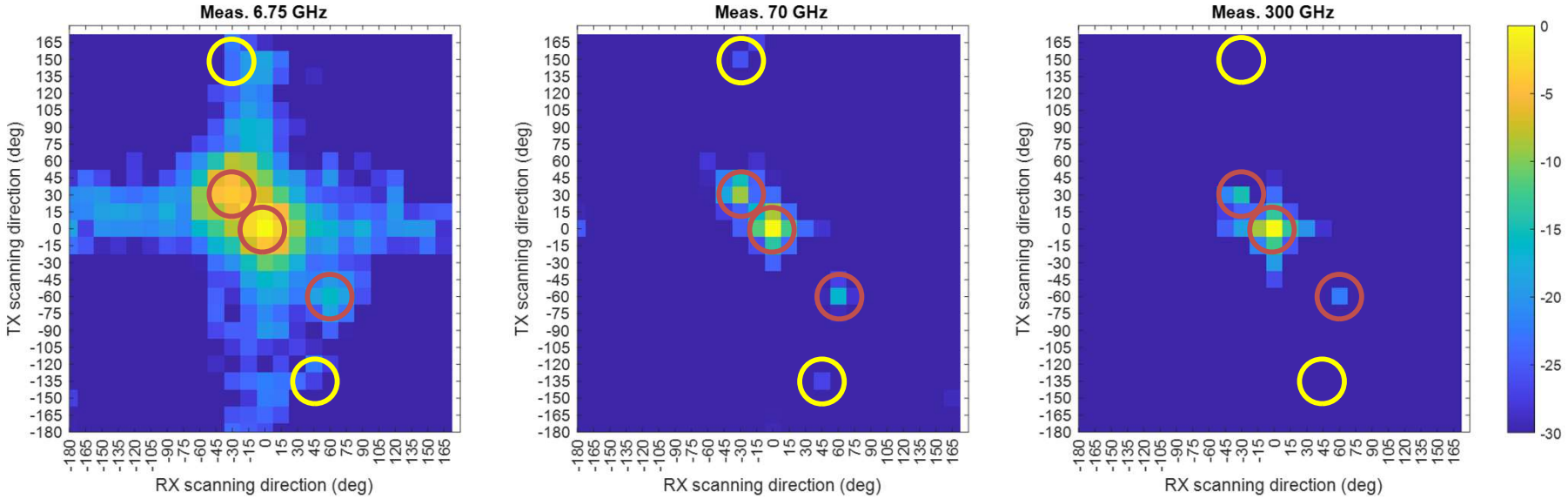


Measurements in Machine Room Scenario

Power azimuth/azimuth profile (LOS)

- ❑ Investigation of propagation properties by comparative analysis of multi-band measurements
- ❑ Identification of clusters and paths





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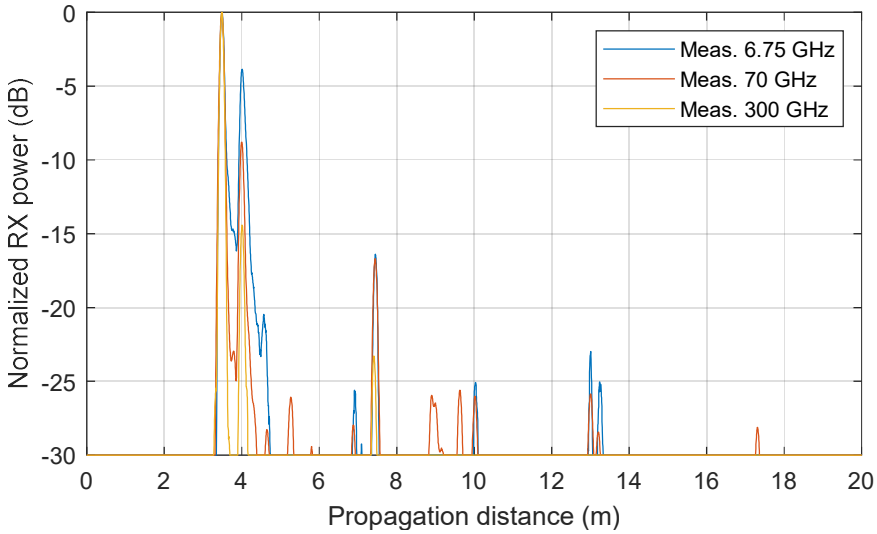
Machine room scenario (LOS)

- ❑ Power delay profile (normalized to the LOS case)
- ❑ Dominant clusters present in the different bands
  - – Different amplitudes
  - – Some clusters only visible at lower frequencies
    - Penetration losses and diffraction
    - influence of the dynamic range of the measurement system



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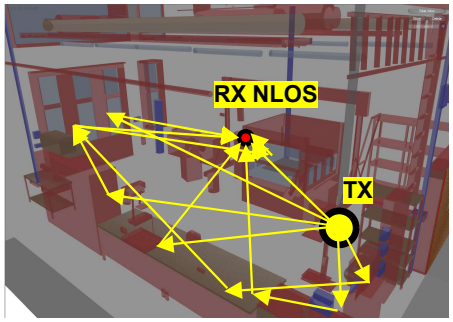

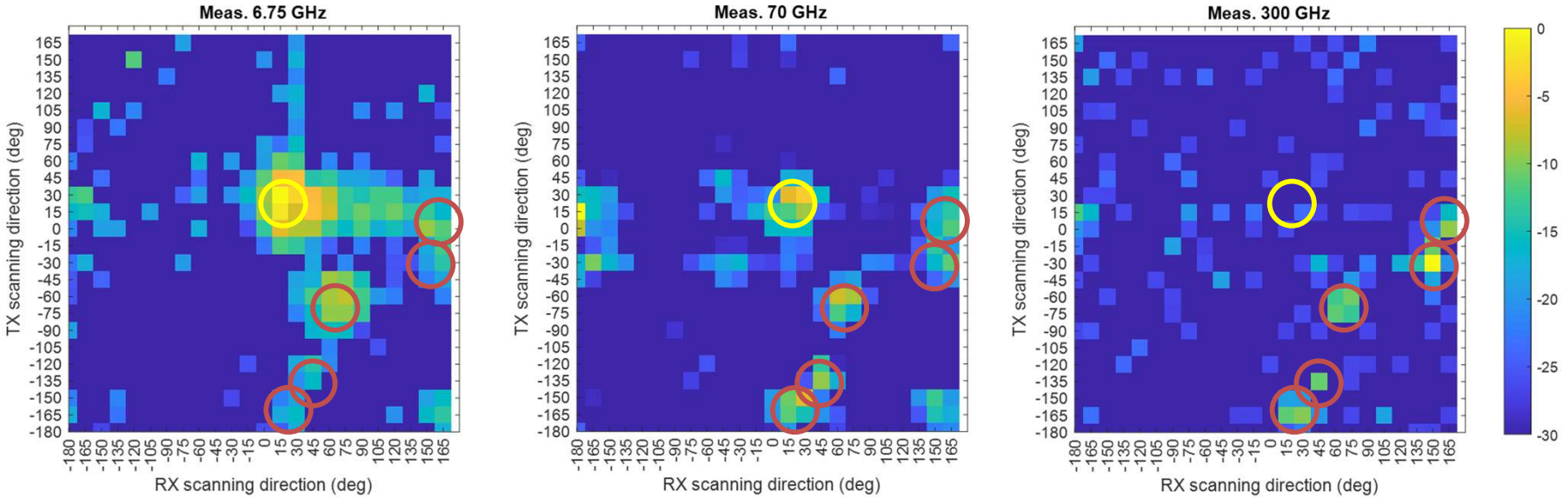

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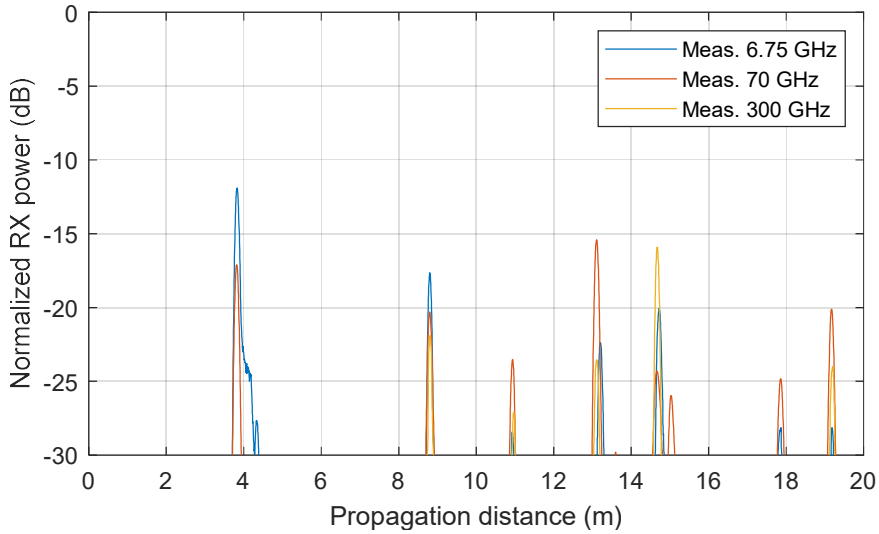

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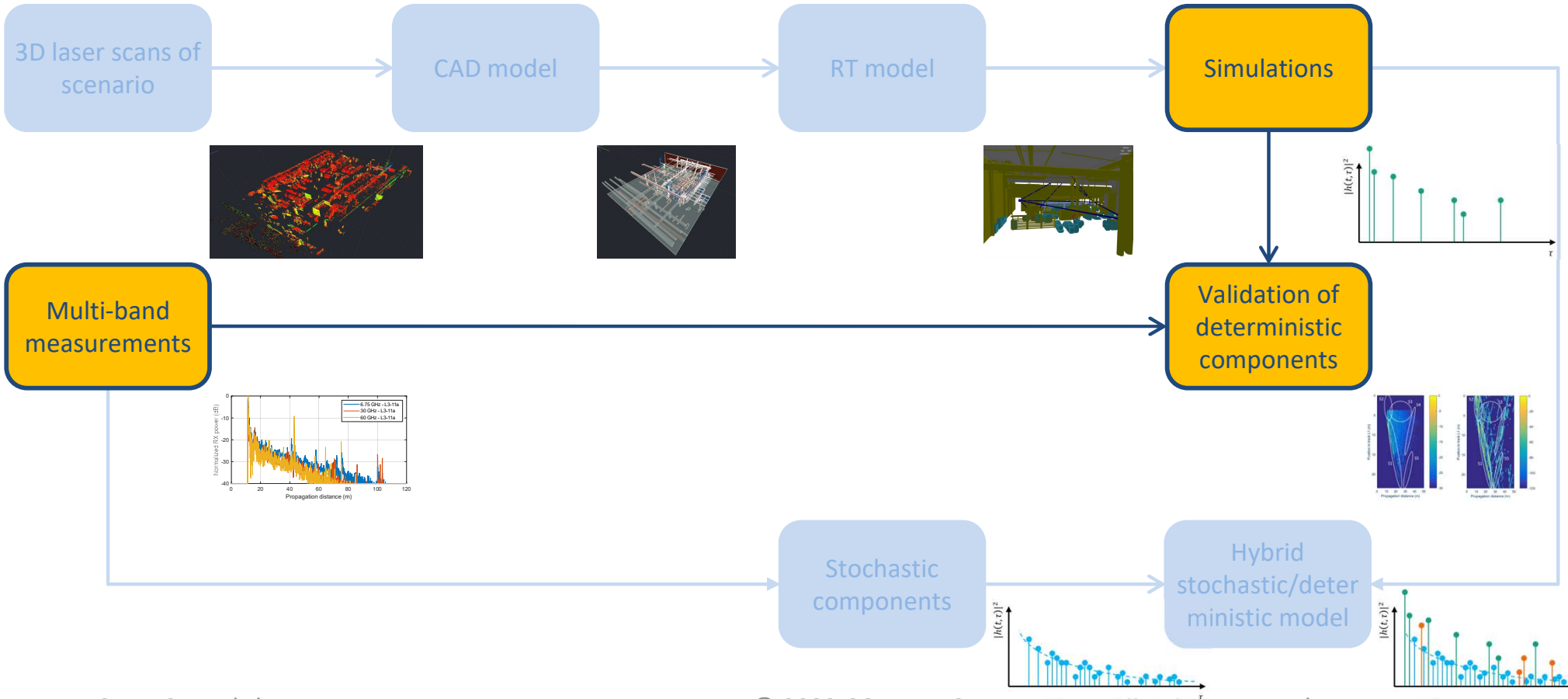
Workflow



From RT to Channel Sounding Emulation

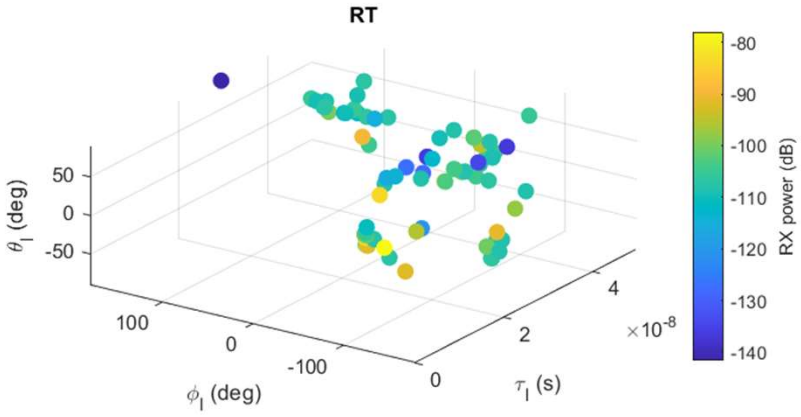
- The RT model is a discrete representation of reality (limited level of details)
- Measurement system resolution
  - Differences between simulated and real antenna patterns
  - Influence of the pattern overlapping of the scanning antennas
- RT channel equation

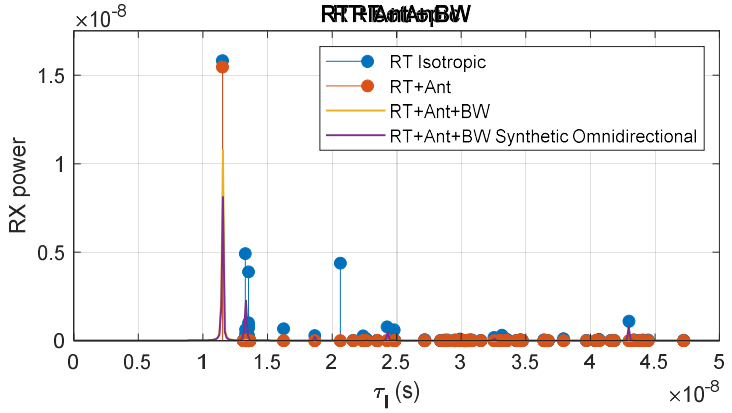
$$h_{RT}^{p}(\tau_l, \phi_l, \theta_l) = \sum_l \alpha_l^p \, \delta(\tau - \tau_l)\delta(\phi - \phi_l)\delta(\theta - \theta_l)$$

- Channel equation considering system properties:

$$H_{RT+Ant+B}^{p}(\mathrm{n}\Delta f, i\Delta\phi, j\Delta\theta) = \sum_n \sum_l \alpha_l^p \, G_{Rx}(\phi_l - i\Delta\phi, \theta_l - j\Delta\theta) e^{-j2\pi \, n\Delta f \, \tau_l}$$

$$h_{RT+Ant+B}^{p}(n\Delta\tau, i\Delta\phi, j\Delta\theta) = IFFT\left(H_{RT+Ant+BW}^{p}(\mathrm{n}\Delta f, i\Delta\phi, j\Delta\theta)\right)$$





RT Model Validation from Multi-band Measurements

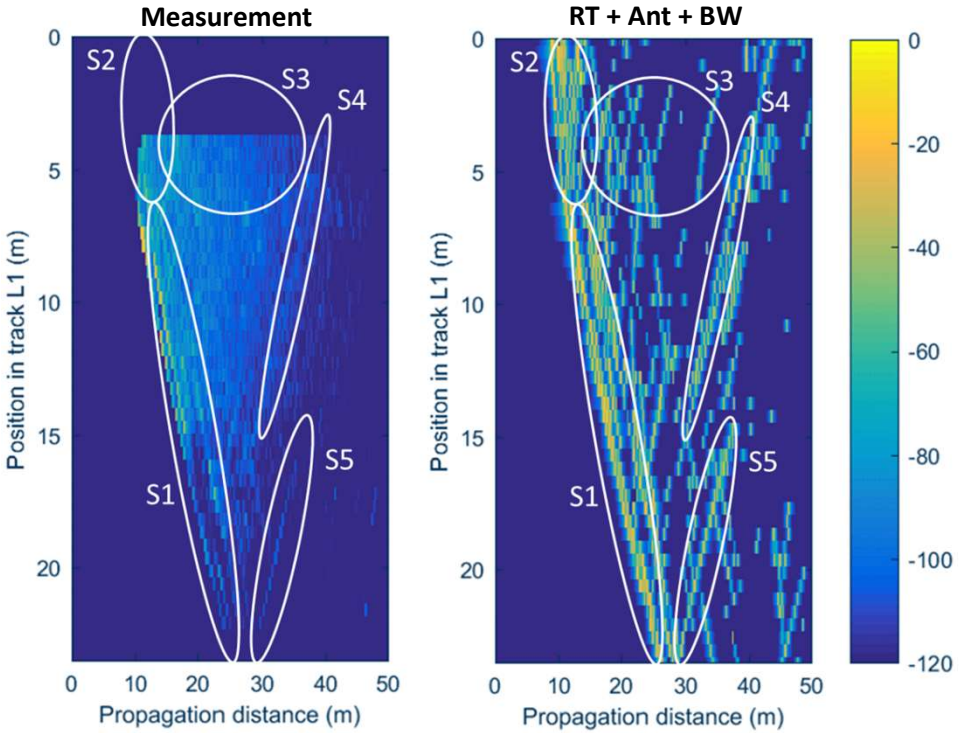
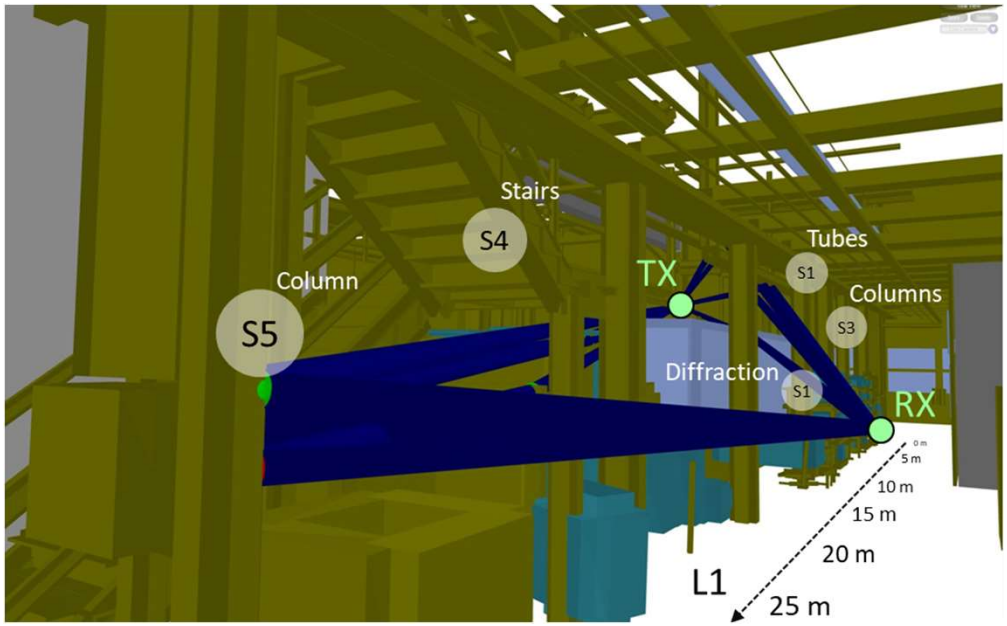


Figure: (left) *measurements and RT simulations at 6.75 GHz in the Bosch Blaichach scenario.* ***(right)*** *RT simulations and ray visualization in the Bosch Blaichach scenario.*

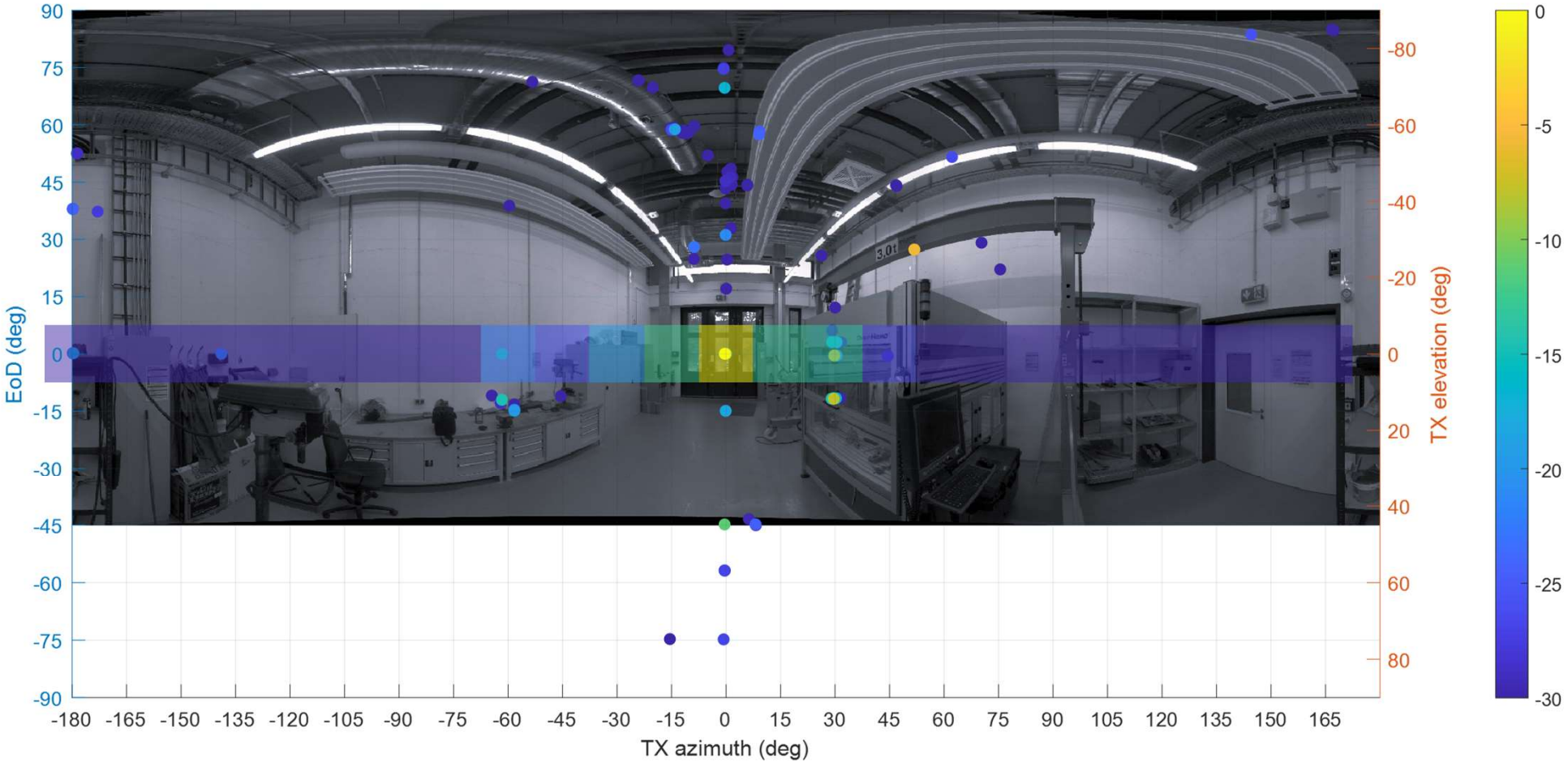


More details on:

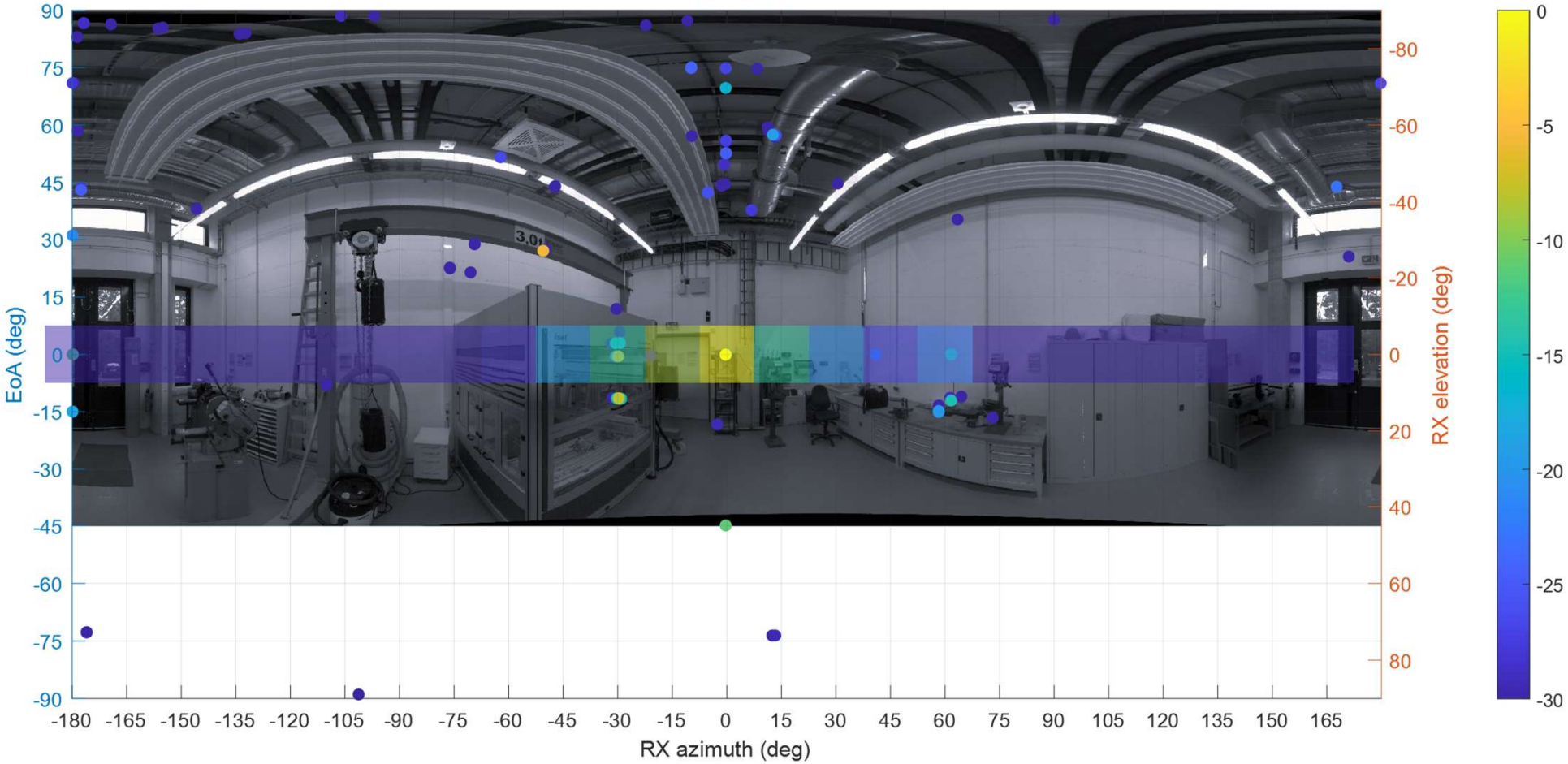
1) D. Dupleich, N. Han, J. Cosmas, G. Eappen, and K. Ali, ***"D3.1 3D Laser measurement of one factory at Bosch with 3D cloud scanner and 3D hand scanner"****, 2021, (V1.0). https://doi.org/10.5281/zenodo.5786456*

2) H. Niu et al., ***"From 3D Point Cloud Data to Ray-tracing Multi-band Simulations in Industrial Scenario,"*** *2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), Helsinki, Finland, 2022, pp. 1-5, doi: 10.1109/VTC2022-Spring54318.2022.9861002*

RT Model Validation from Quad-band Measurements



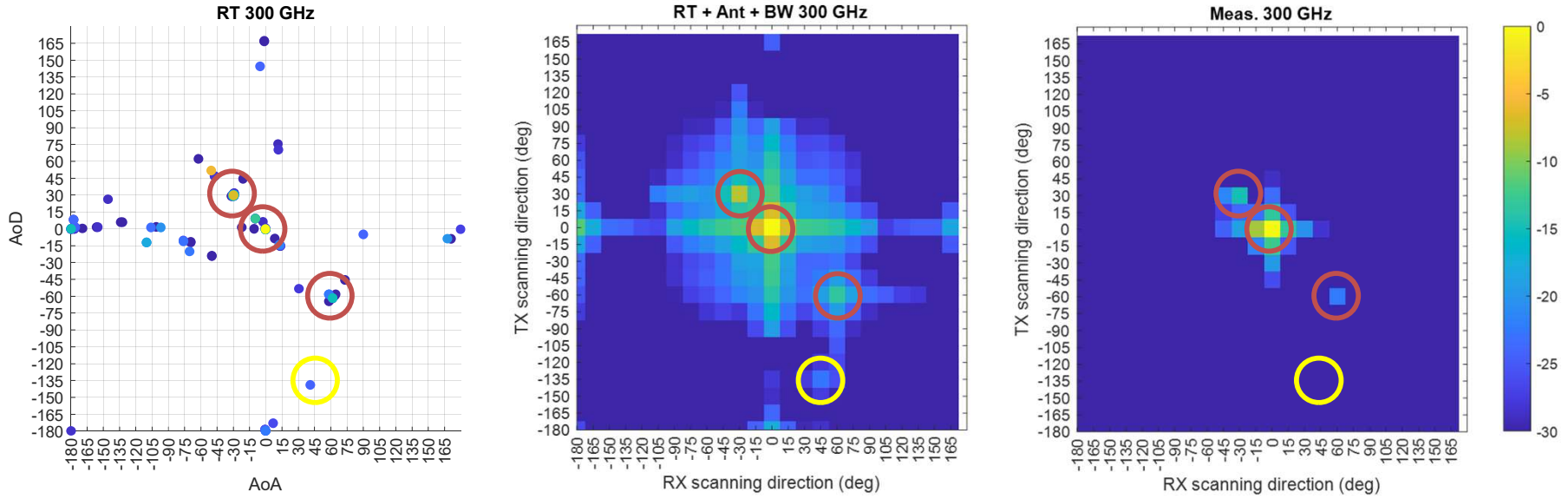
RT Model Validation from Quad-band Measurements



RT Model Validation from Multi-band Measurements

Machine room scenario (LOS)

- ❑ RT simulations: isotropic radiators and infinite bandwidth
- ❑ RT + Ant + BW: emulation of the measurement process
- ❑ Measurements: limited resolution in the angular and delay domain



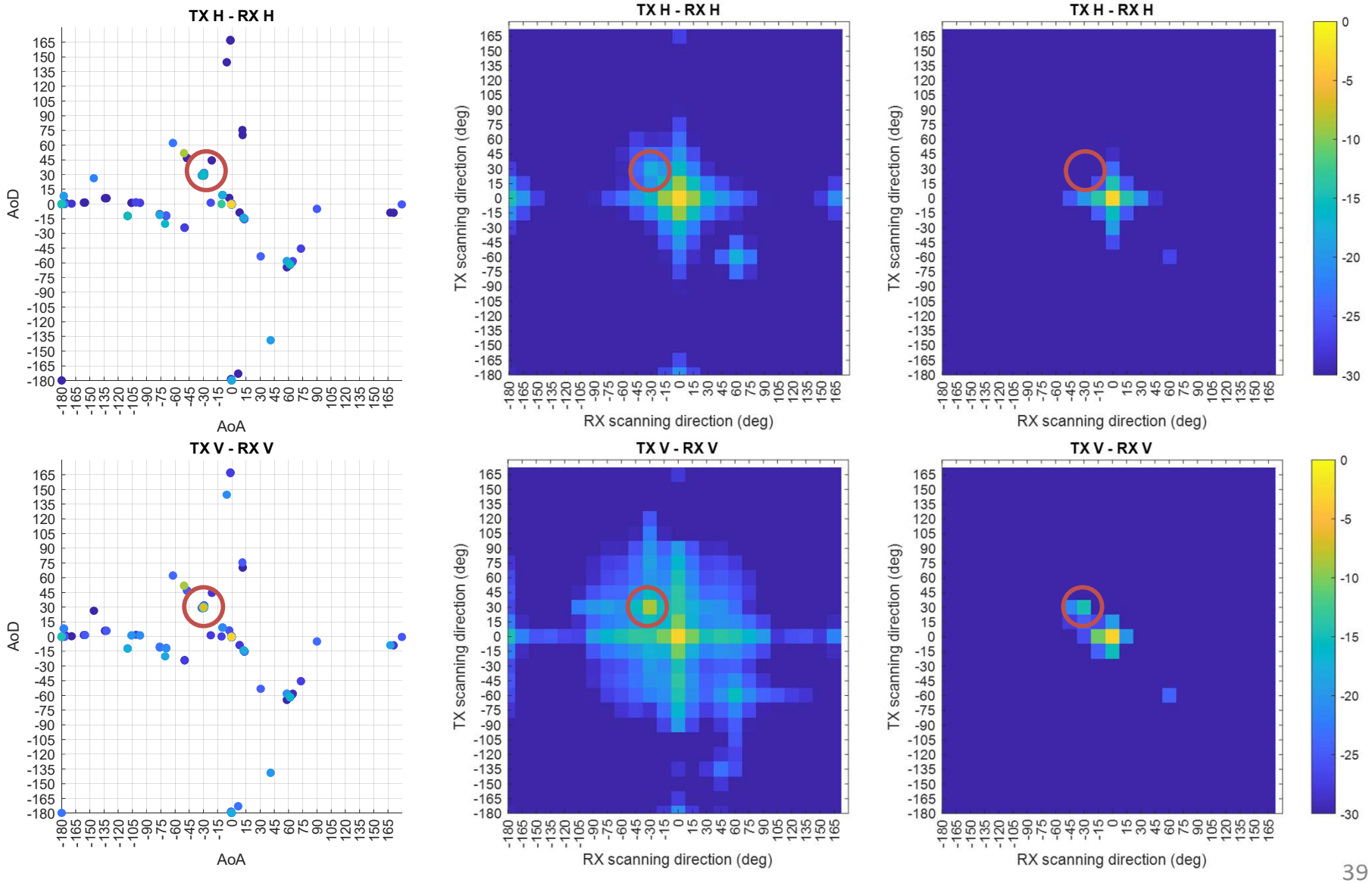
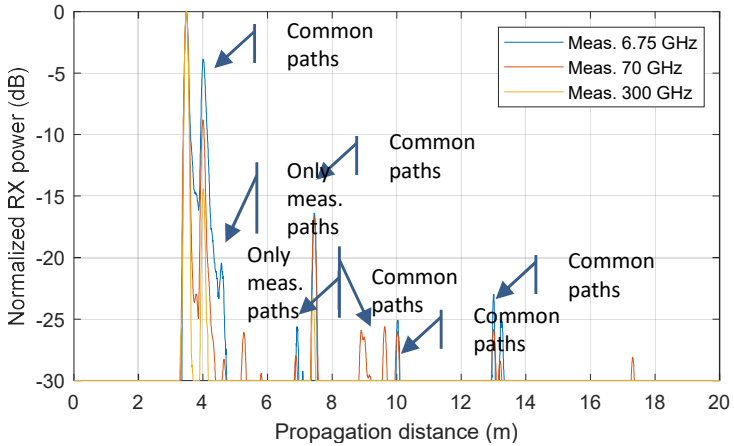


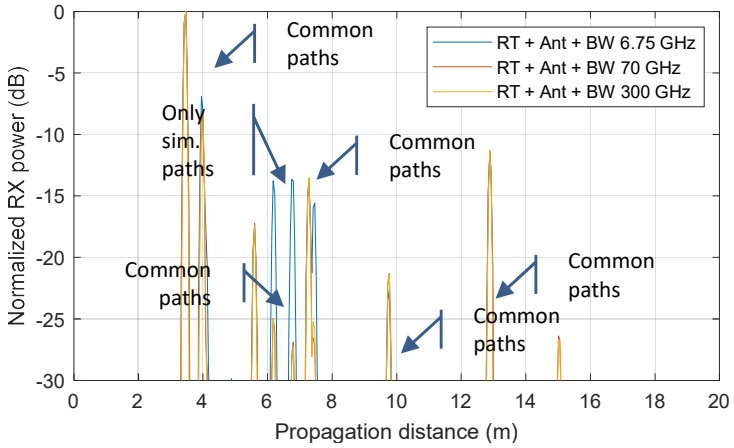
***Figure**: polarimetric decomposition of the power bi-azimuth profile of the **(left)** RT, **(center)** RT + Ant + BW simulations and **(right)** 300 GHz measurements in the machine room scenario in LOS*

Quad-band Measurements in Machine Room

Machine room scenario (LOS)

- Isotropic PDP
  - Common measurement/simulation paths
    - Different amplitudes
  - Paths only present in measurements
    - Level of details
    - Limitations on RT model
  - Paths only present in simulations
    - Shape of objects (polygons with specular surfaces)
    - Properties of materials





RT Model Validation from Multi-band Measurements

- Machine room scenario (NLOS)
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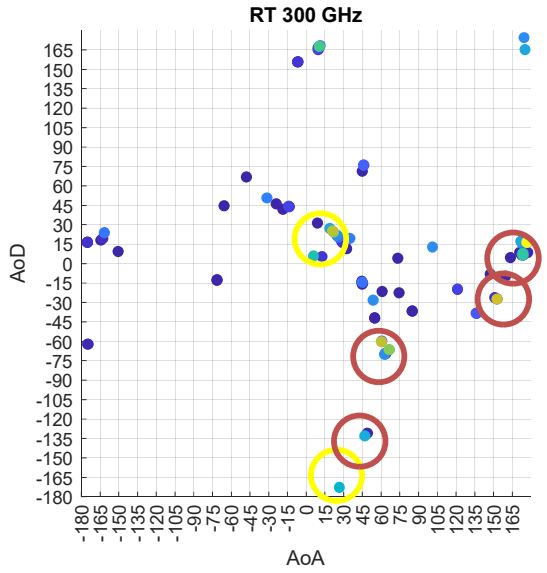

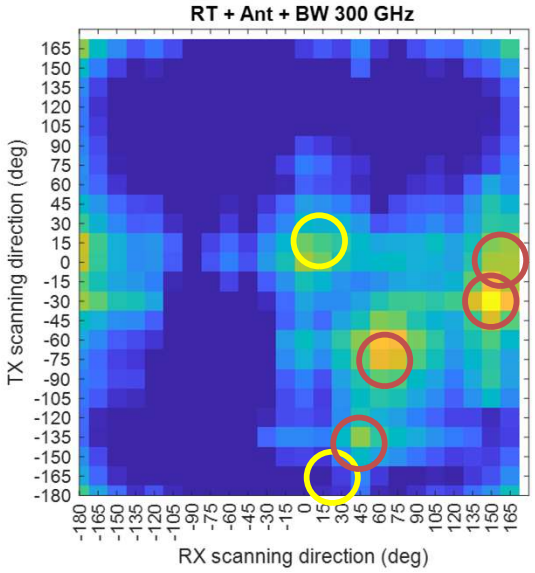

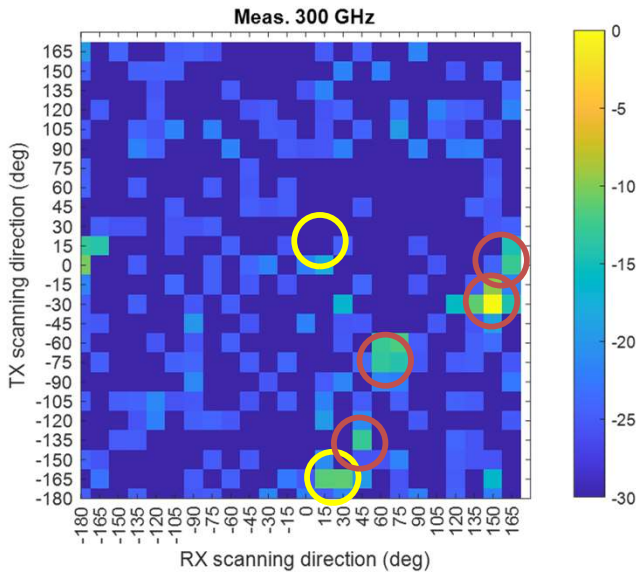

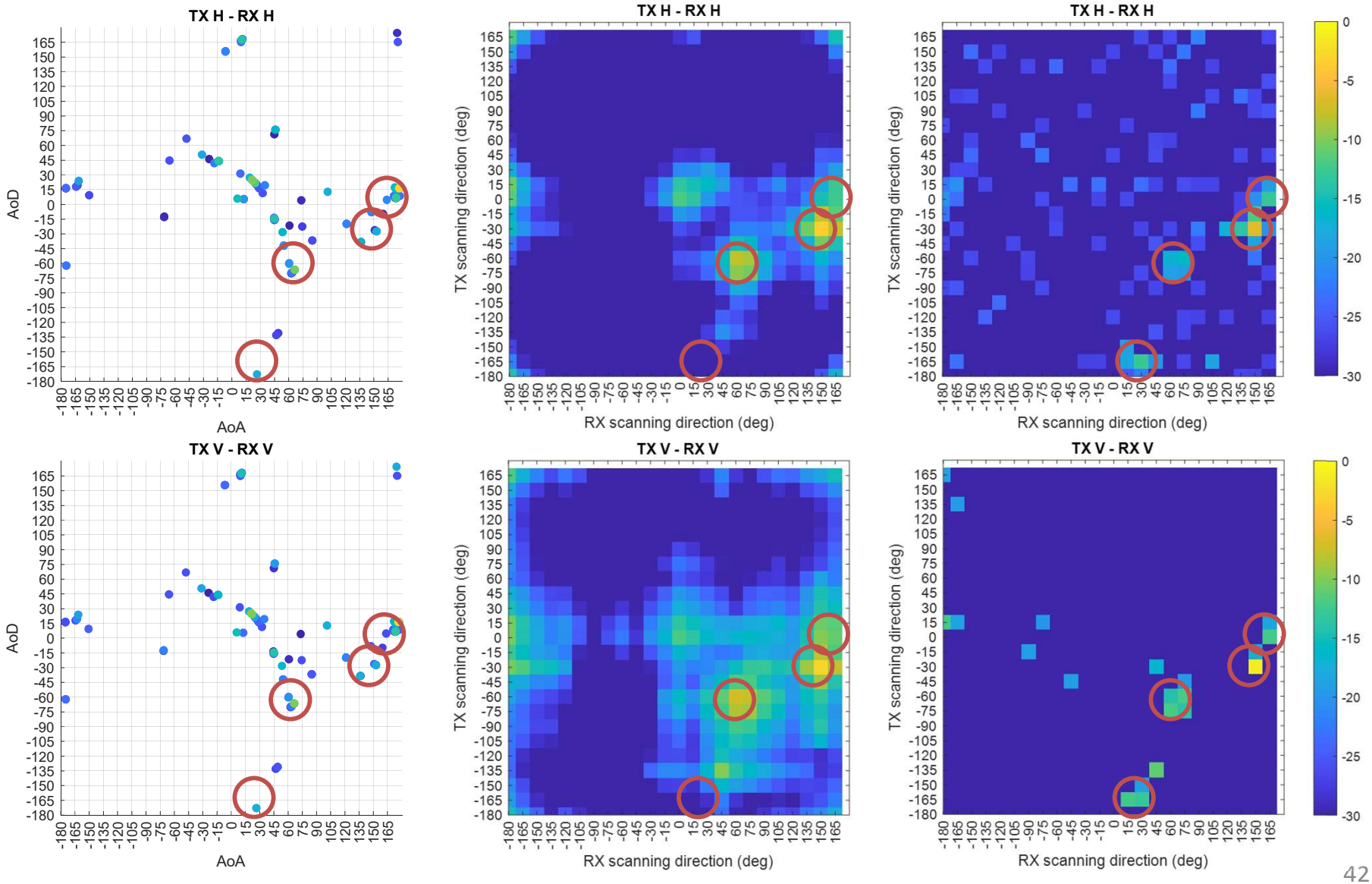

***Figure**: polarimetric decomposition of the power bi-azimuth profile of the **(left)** RT, **(center)** RT + Ant + BW simulations and **(right)** 300 GHz measurements in the machine room scenario in NLOS*

Quad-band Measurements in Machine Room

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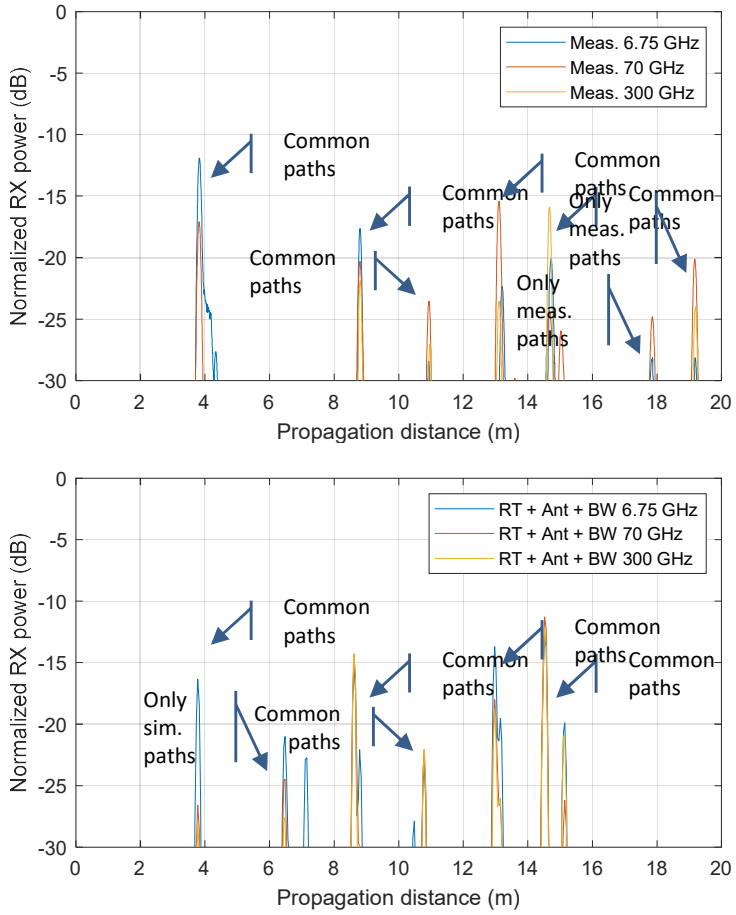
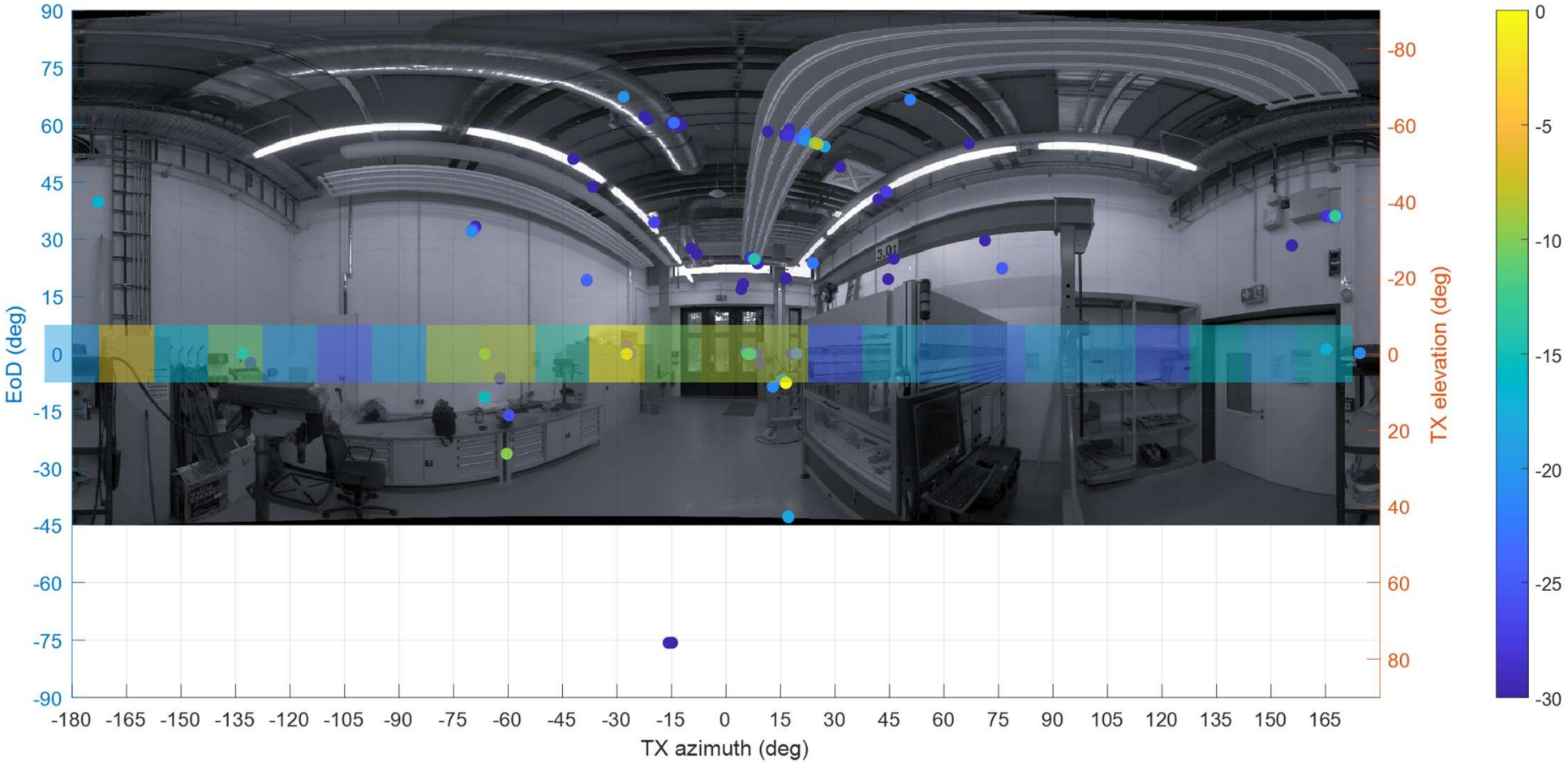
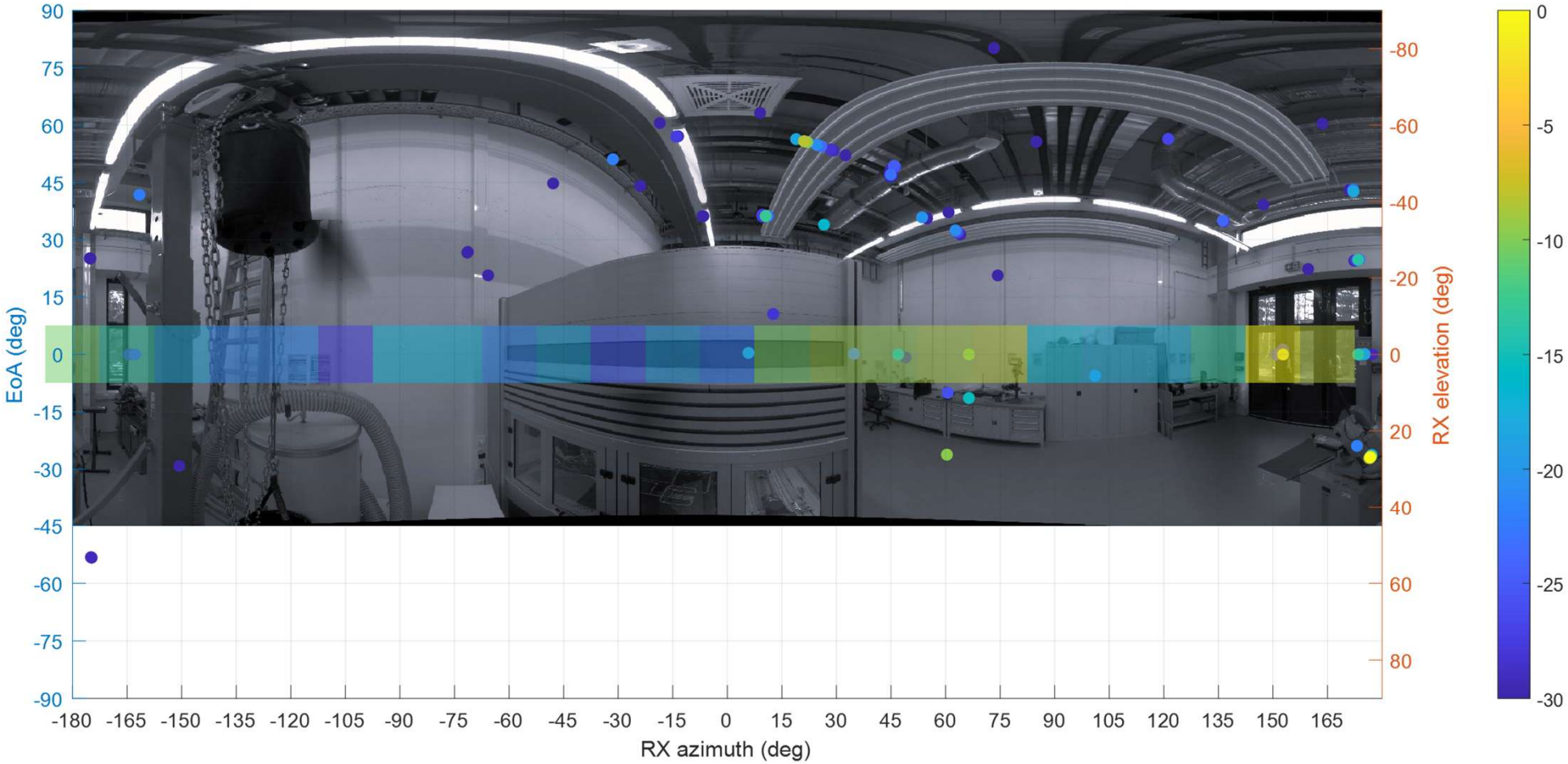


RT Model Validation from Multi-band Measurements



RT Model Validation from Multi-band Measurements



Outline

- Motivation
- Workflow
  - RT Modelling
  - Multiband Channel Sounding
  - RT Model Validation
- Conclusions

Conclusions

Conclusions

- Most of the strongest and dominant paths are visible in the different measured bands
- However, some paths are only visible at lower frequency
  - Early arriving paths: propagation properties
    - Diffraction
    - Lower penetration losses
  - Late arriving paths: influence of the measurement system (dynamic range)
- "Picture" of the geometrical properties of the scenario from the propagation properties of the measured multipath
  - Important in channel models for ICAS, localization, etc. → Validation of our RT models

Future work

- Calibration and adjustment of electromagnetic properties of the materials in the RT model to match better the simulations with the measurements

Thank you for your attention

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6G BRAINS partners

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