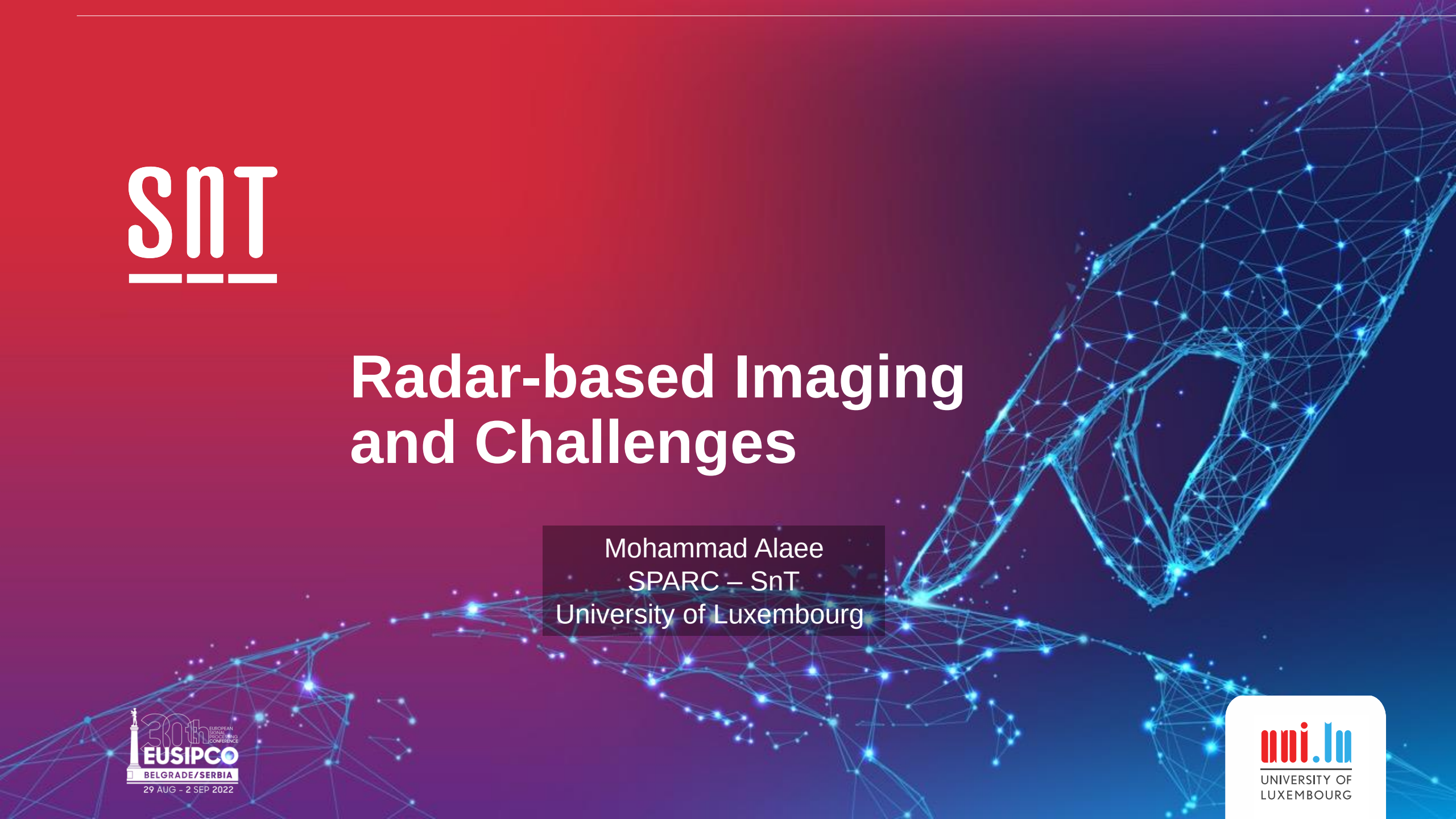

Radar-based Imaging and Challenges

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30th EUROPEAN SIGNAL PROCESSING CONFERENCE
EUSIPCO
BELGRADE/SERBIA
29 AUG - 2 SEP 2022

UNIVERSITY OF LUXEMBOURG

Model-Based Imaging Techniques and Challenges

Table of Content

Imaging Radars

Which of these are not Radar Images?

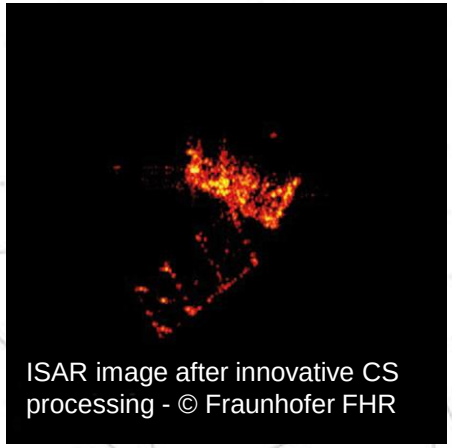
What is an image?

In the context of signal processing, an image is a distributed amplitude of color

© https://www.pinterest.com/pin/luxembourg-city-skyline-luxembourg-cityscape-painting-art--406732028727639l6/

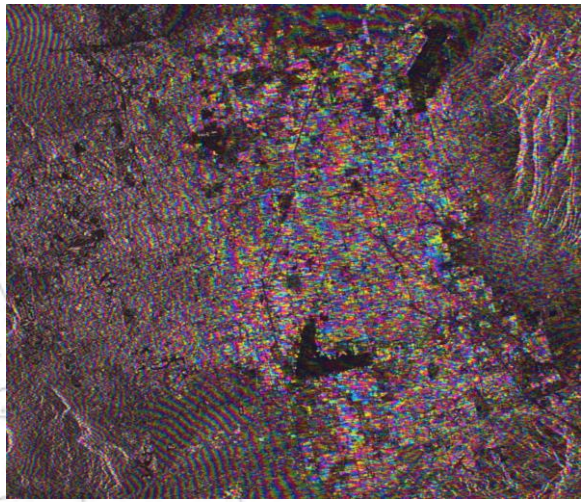
Synthetic-aperture radar (SAR) is a form of radar that is used to create two-dimensional images or three-dimensional reconstructions of objects, such as landscapes

Synthetic-aperture radar (SAR)



ISAR image after innovative CS processing - © Fraunhofer FHR

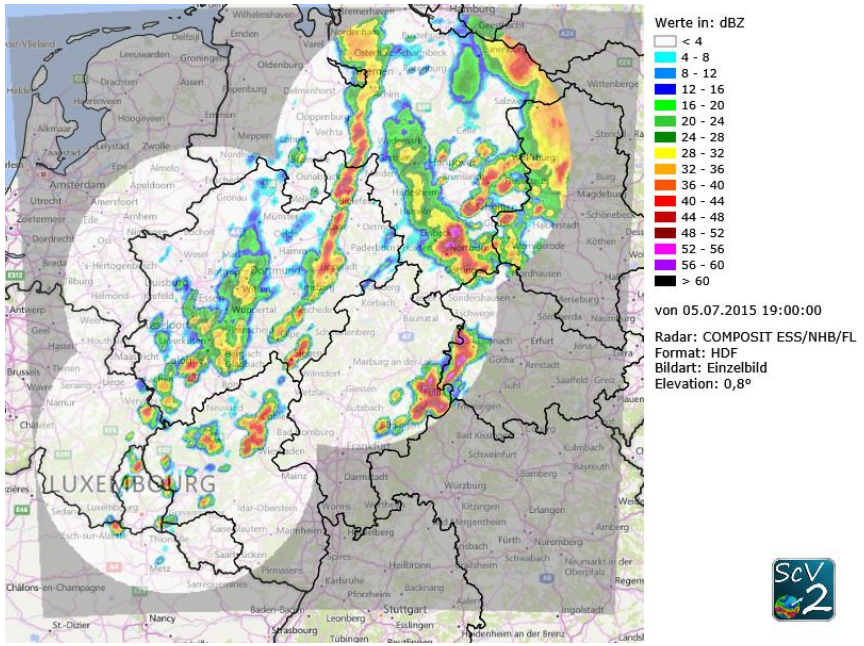
ISAR is analogous to conventional SAR, except that ISAR technology uses the movement of the target rather than the emitter to create the synthetic aperture



This interferogram used radar images from ESA's ERS-2 and Envisat satellites to show an area of approximately 30 x 35 km around the city of Las Vegas in the US

© https://www.esa.int/Applications/Observing_the_Earth/How_does_interferometry_work

Weather radar is a type of radar used to locate precipitation, calculate its motion, and estimate its type (rain, snow, hail etc.).



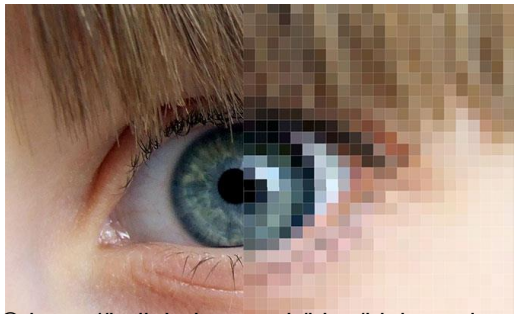
Weather Radar Image

© https://www.hydrometeo.de/index.php/en/data-analyses/weather-radar/

How can we use Radar to perform Imaging?

"Higher resolution" means more image detail

Image resolution



© https://hullabaloo.co.uk/blog/high-res-low-res-make-sure-digital-images-suitable-print/

radar resolution

The minimum separation between two targets that permits them to be distinguished by a radar

The distance between two resolvable targets must be defined in each of the dimensions of measurement, which typically for a radar are range, azimuth, elevation

Range Resolution $= \frac{c}{2B}$

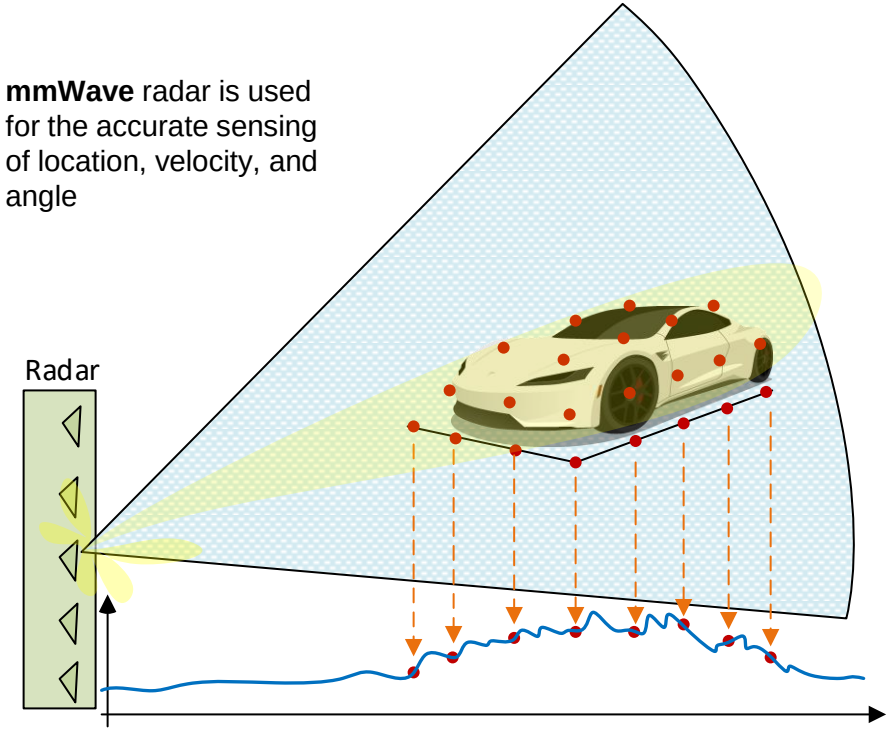
Bandwidth

Spatial Resolution $= \kappa \frac{\lambda}{D}$

(azimuth/elevation Resolution)

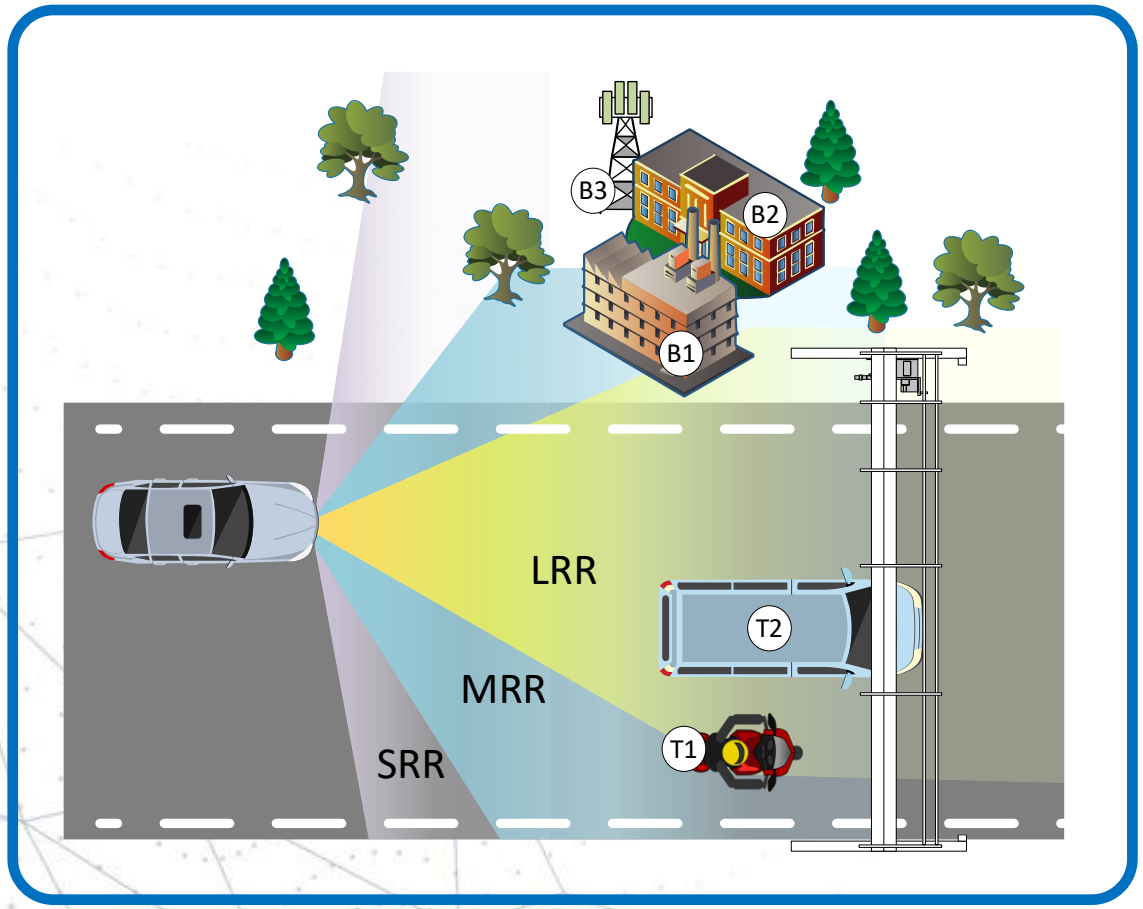
Aperture size

mmWave radar is used for the accurate sensing of location, velocity, and angle

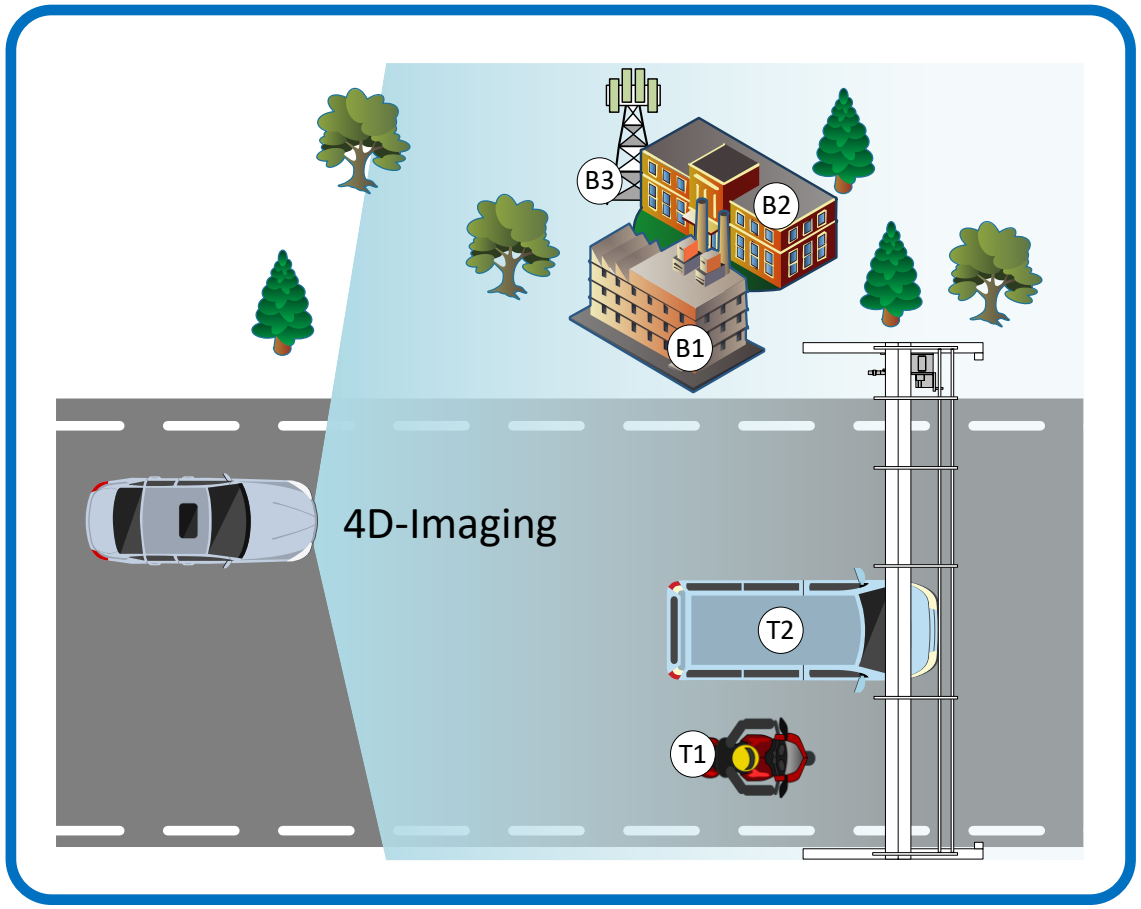


High resolution required in **Range**, **Speed**, **Azimuth**, and **Elevation**

What is 4D-Imaging Radar?



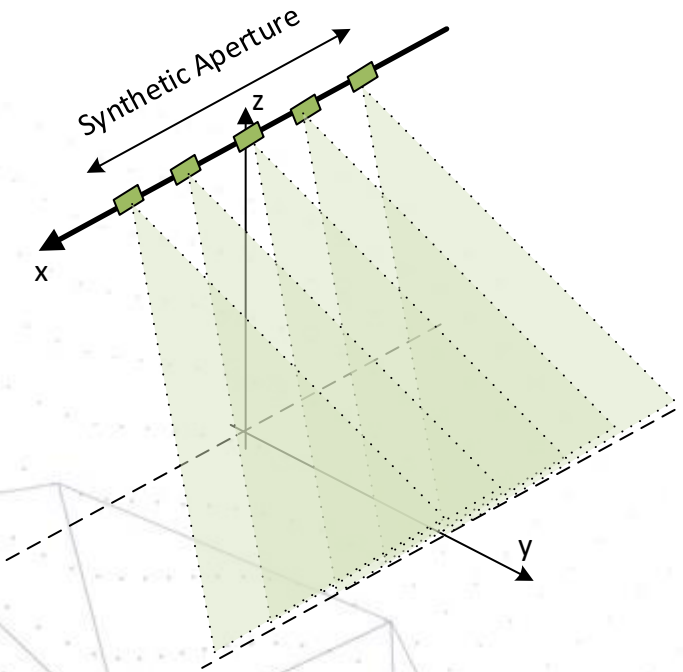
Conventional Automotive Radars

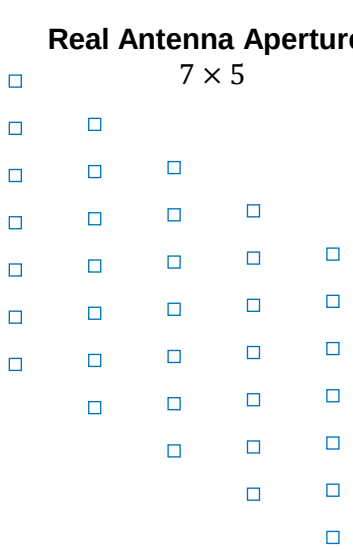


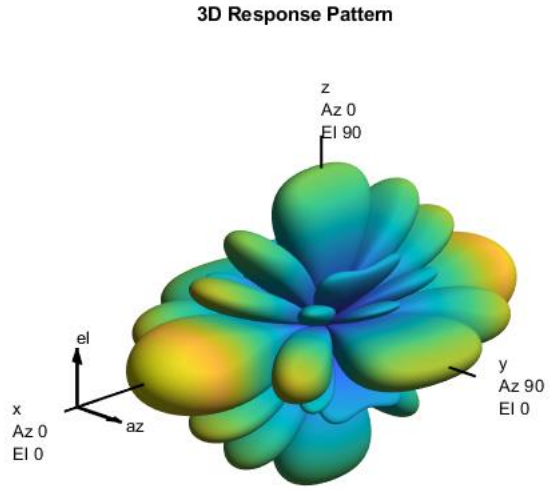
4D-Imaging Automotive Radars

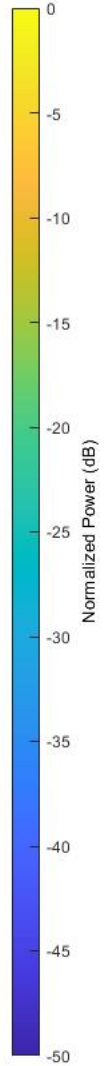
Rane, Angle (Azimuth, Election), Doppler

Synthetic Antenna Aperture vs Real Antenna Aperture





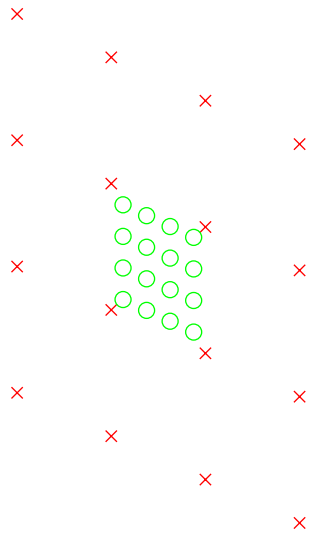


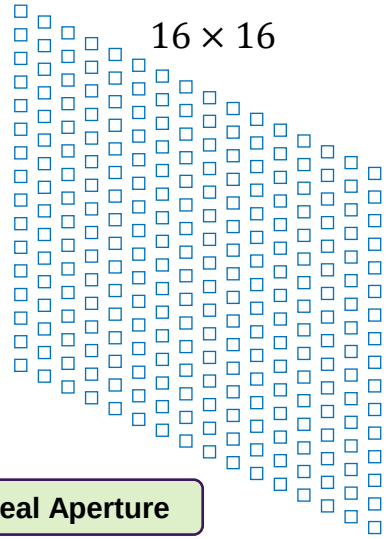


General rule to improve radar resolution

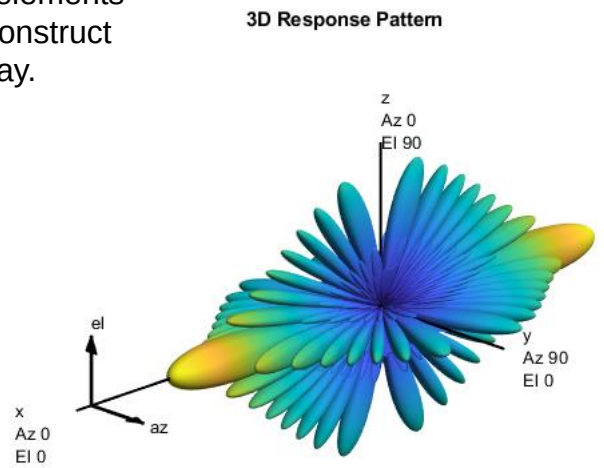
1. Increase signal Bandwidth!
2. Increase Aperture size!

How to increase Aperture Size for a 4D-Imaging Radar?



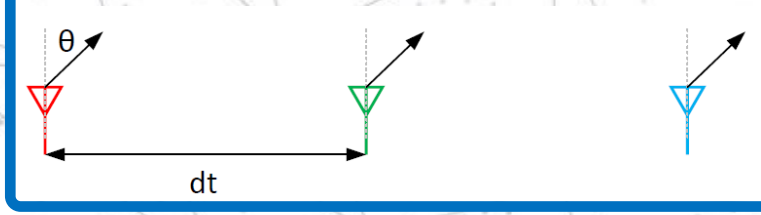


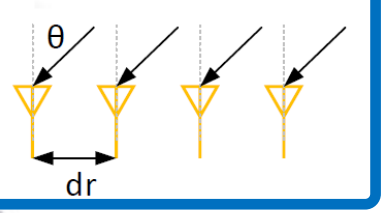
A large number of elements will be needed to construct a large filed 2D array.

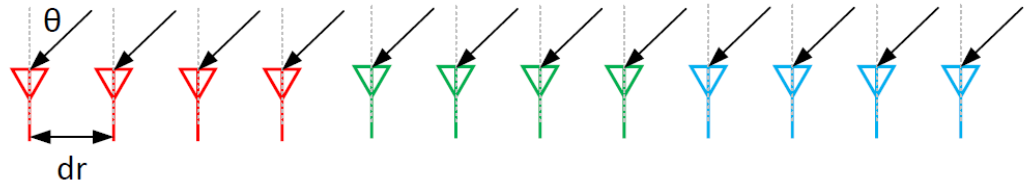


Real Aperture

Alternative solution



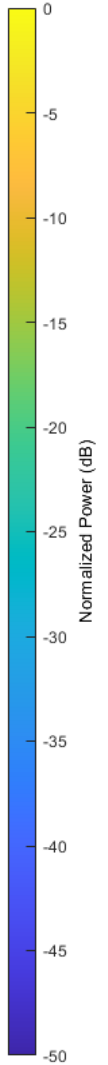




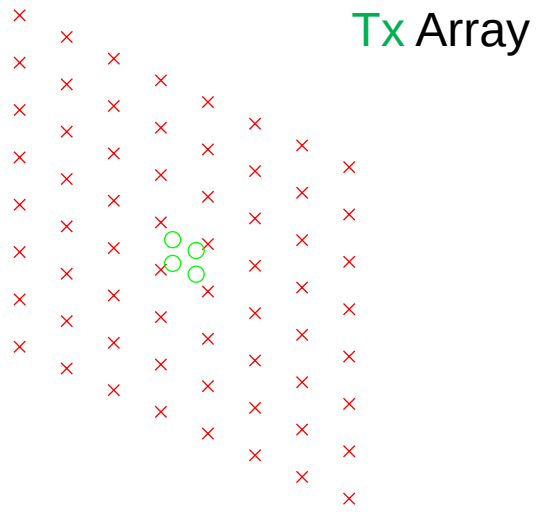
Tx Array

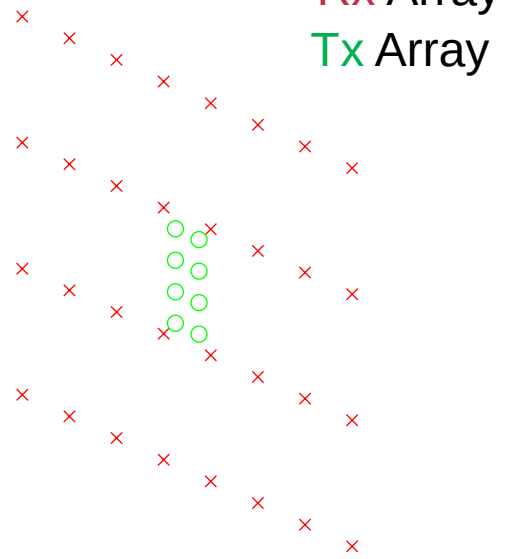
Rx Array

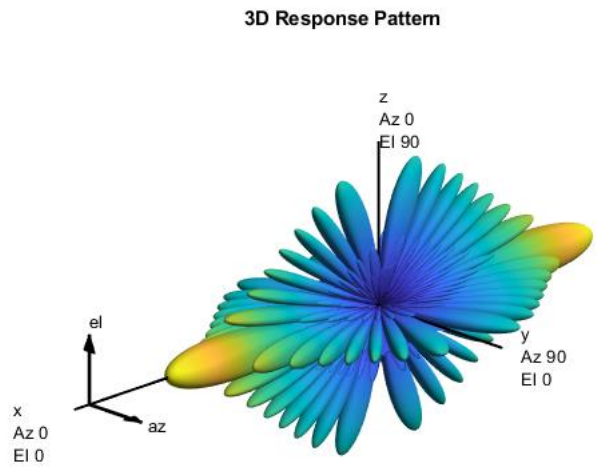
Virtual Array

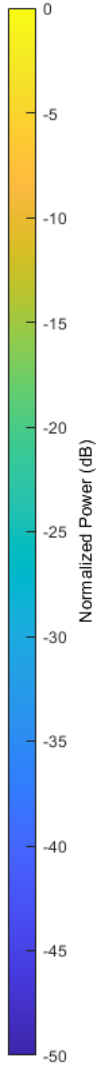


How to Select Antenna Positions for a Desired Virtual Array









To be separated in the receive side and form a virtual array without a grating lobe, the transmit waveforms must be orthogonal to each other(waveform diversity) – MIMO radars

Which Configuration is the most suitable? Price? Performance?

Orthogonal Waveforms in MIMO Radar

- ✓ **Time Division Multiplexing (TDM)**
  - *Alternative Transmitting*: transmission capabilities of all transmit antennas are not fully utilized
  - *Time-Staggered FMCW Waveform:* More efficient than alternative transmitting
  - Possibility to be implemented with dechirping technique and consequently low sampling rate ADCs
- ✓ **Frequency Division Multiplexing (FDM)**
  - Fast-time: range-angle coupling will occur after MIMO beamforming
  - Slow-time: causes that the unambiguous PRF reduced by number of antennas
  - Possibility to be implemented with dechirping technique and consequently low sampling rate ADCs
- ✓ **Doppler Division Multiplexing (DDM)**
  - Causes that the unambiguous PRF reduced by number of antennas
  - Possibility to be implemented with dechirping technique and consequently low sampling rate ADCs

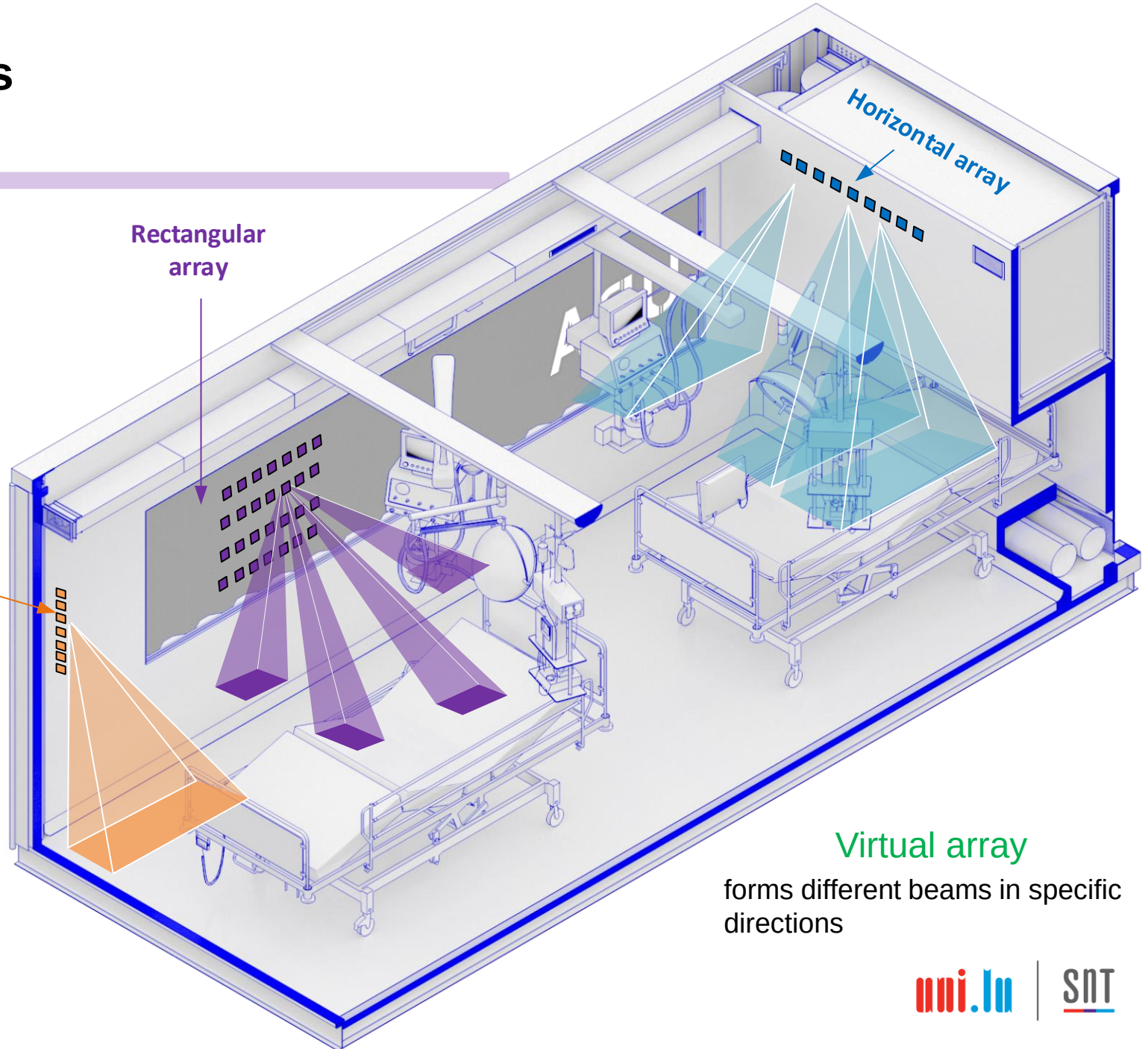
- ✓ **Code Division Multiplexing (CDM)**
  - Intra-pulse coding: high range sidelobes depending on the cross-correlation property of the code sequence. High ADC sampling rate is required – possibility to synthesize the equivalent FMCW and implemented by dechirp.
  - Inter-pulse coding: causes that the unambiguous PRF reduced by number of antennas- possibility to be implemented with dechirping technique and consequently low sampling rate ADCs

Multiple MIMO Radars

How to further enhance the performance of 4D-imaging radars?

Distributed, Connected, Collaborative Sensors

1. How to place antennas?
2. How to synchronize different sensors together
3. How to avoid interference?



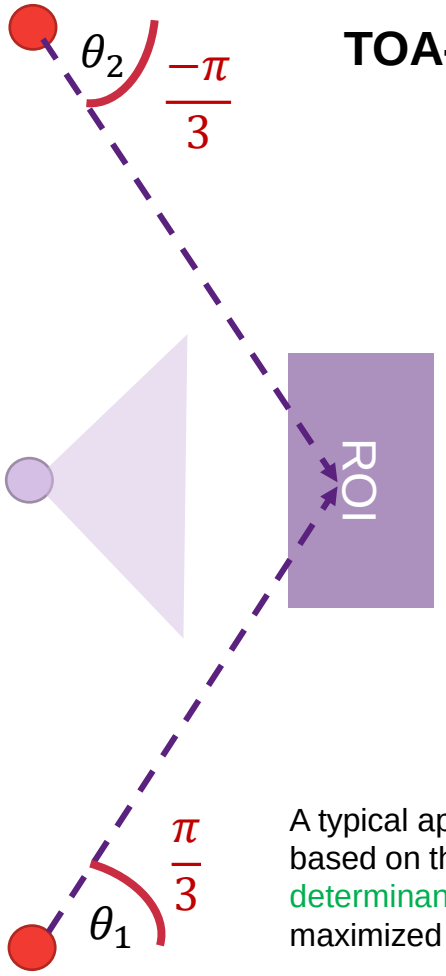
Virtual array

forms different beams in specific directions

Multiple MIMO Radars Optimal Geometries

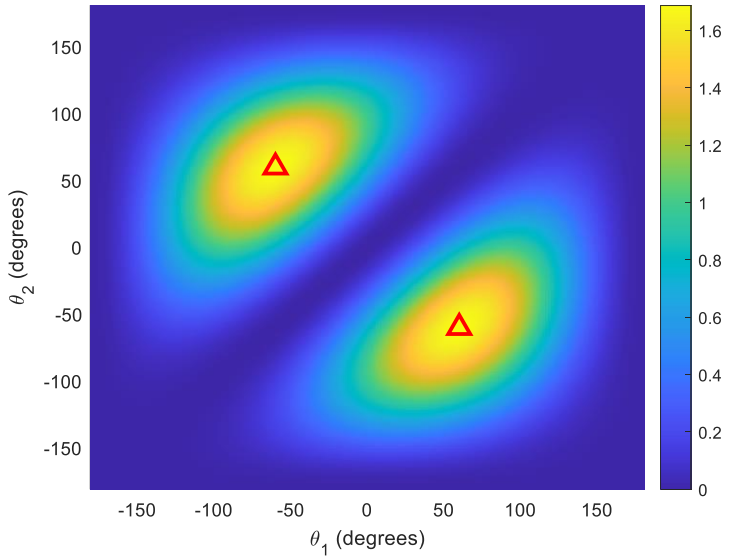
Optimal Geometries

- ✓ TOA-based localization
- ✓ AOA-based localization
- ✓ TDOA-based localization
- ✓ Doppler-based localization
- ✓ Received signal-strength based localization



TOA-based localization

D-optimality criterion



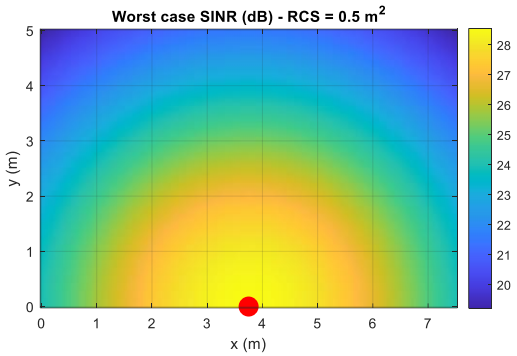
A typical approach is to characterize the target estimation performance based on the FIM which is the inverse of the CRLB. Specifically, the determinant of the FIM is utilized as the objective function to be maximized for geometry optimization.

Multiple MIMO Radars Optimal Geometries

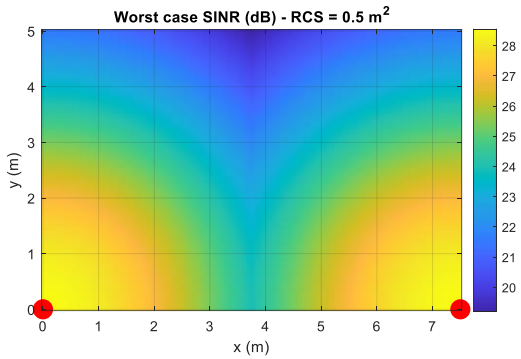
Optimal Geometries

- ✓ TOA-based localization
- ✓ AOA-based localization
- ✓ TDOA-based localization
- ✓ Doppler-based localization
- ✓ Received signal-strength based localization

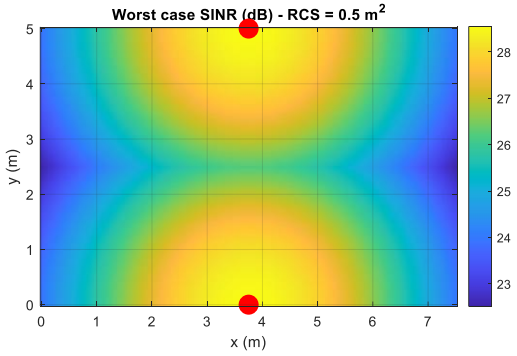
Received Signal-strength Analysis



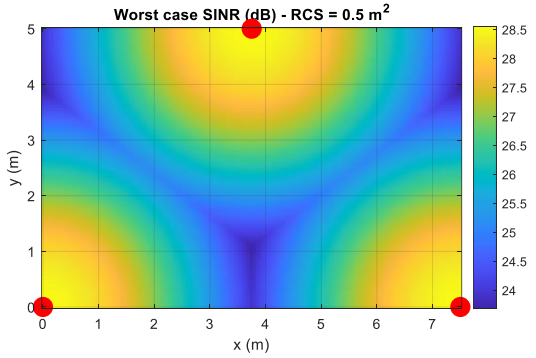
One Sensor



Two Sensors



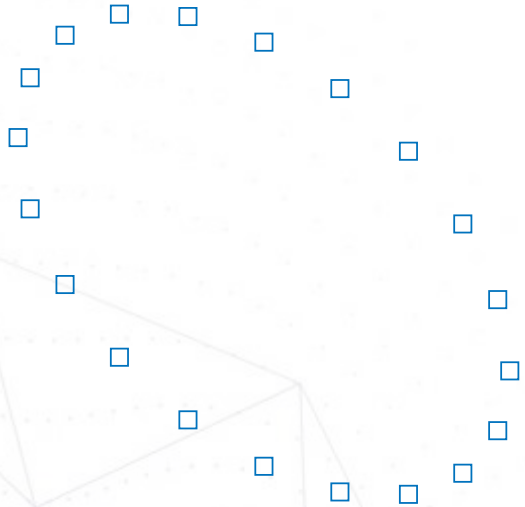
Two Sensors

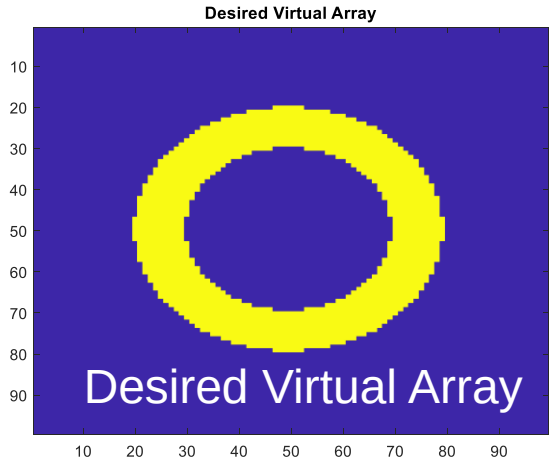


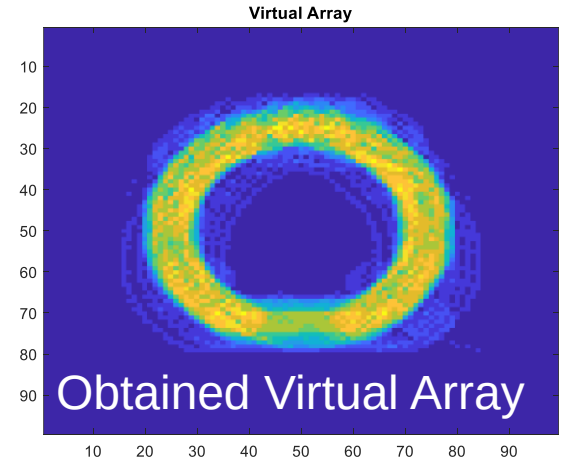
Three Sensors

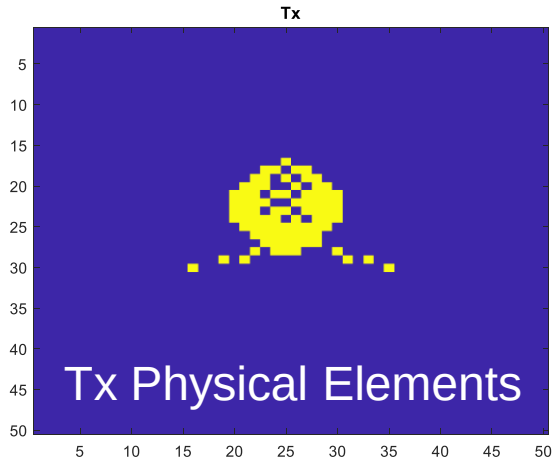
A Single MIMO Radar with Many Virtual Elements

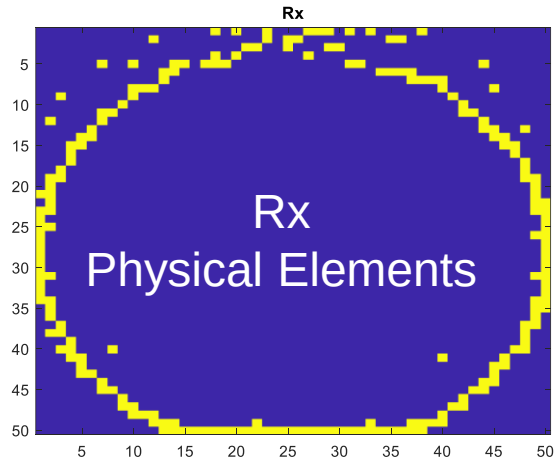
Desired: A circular array with 2500 elements





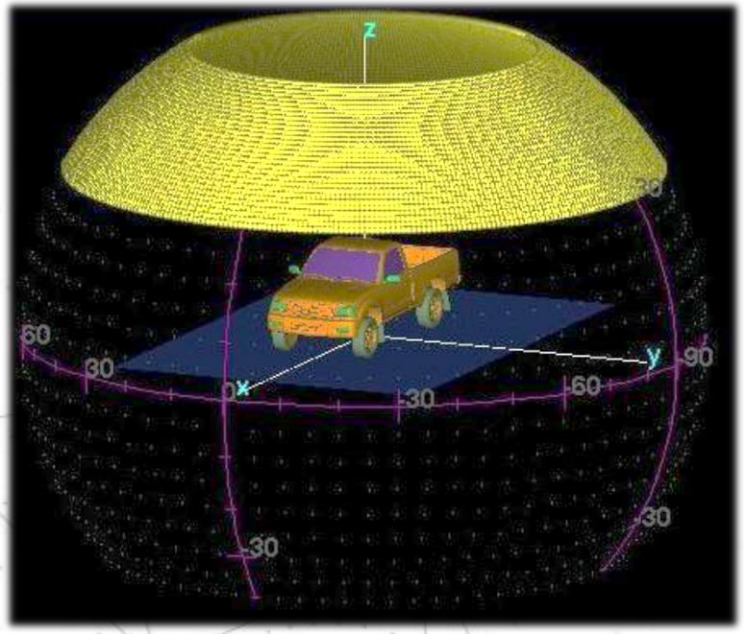






Case Study: Radar Imaging with Many Virtual Elements

CAD Based Radar Data Set



K. E. Dungan, C. Austin, J. Nehrbass, and L. C. Potter, "Civilian vehicle radar data domes," in Algorithms for Synthetic Aperture Radar Imagery XVII, vol. 7699. International Society for Optics and Photonics, p.76990P.

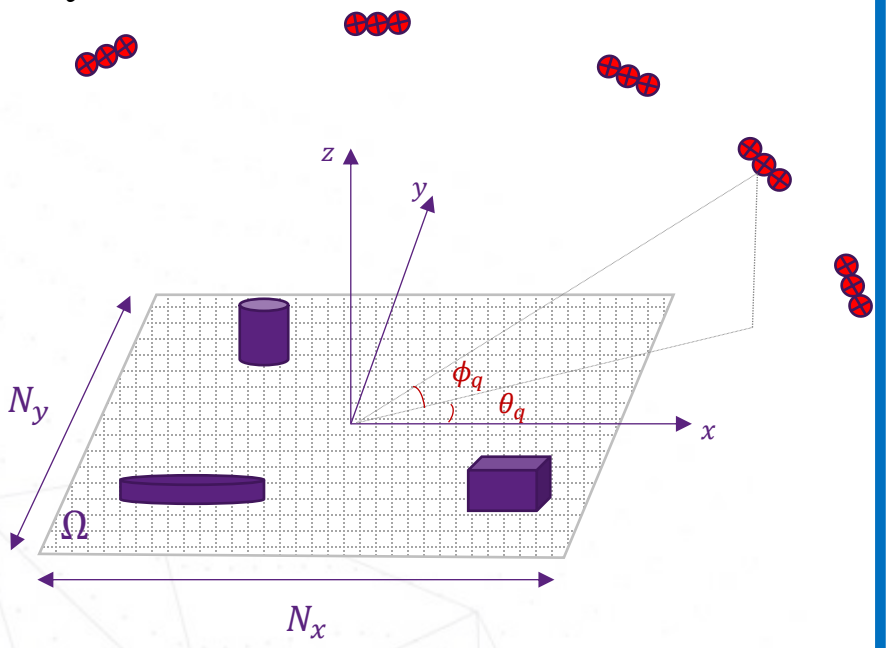
- Far-field
- Mono-static
- Range compressed (compensated)
- X-band (fc = 9.6 GHz, BW = 5.4 GHz)
- Fully-polarized (VV-HH-HV)
- Azimuth samples (16 x 360°)
- Elevation angles (30°, 40°, 50°, 60°)
- Nc = 256 x 256
- z = 1 m (imaging plane)

- Full Views – Full Bandwidth (360° - 5.4 GHz)
- Full Views – Limited Bandwidth (360° - 600 MHz)
- Limited Views – Limited Bandwidth (16° - 600 MHz)

Multiple Synchronized Monostatic Radars

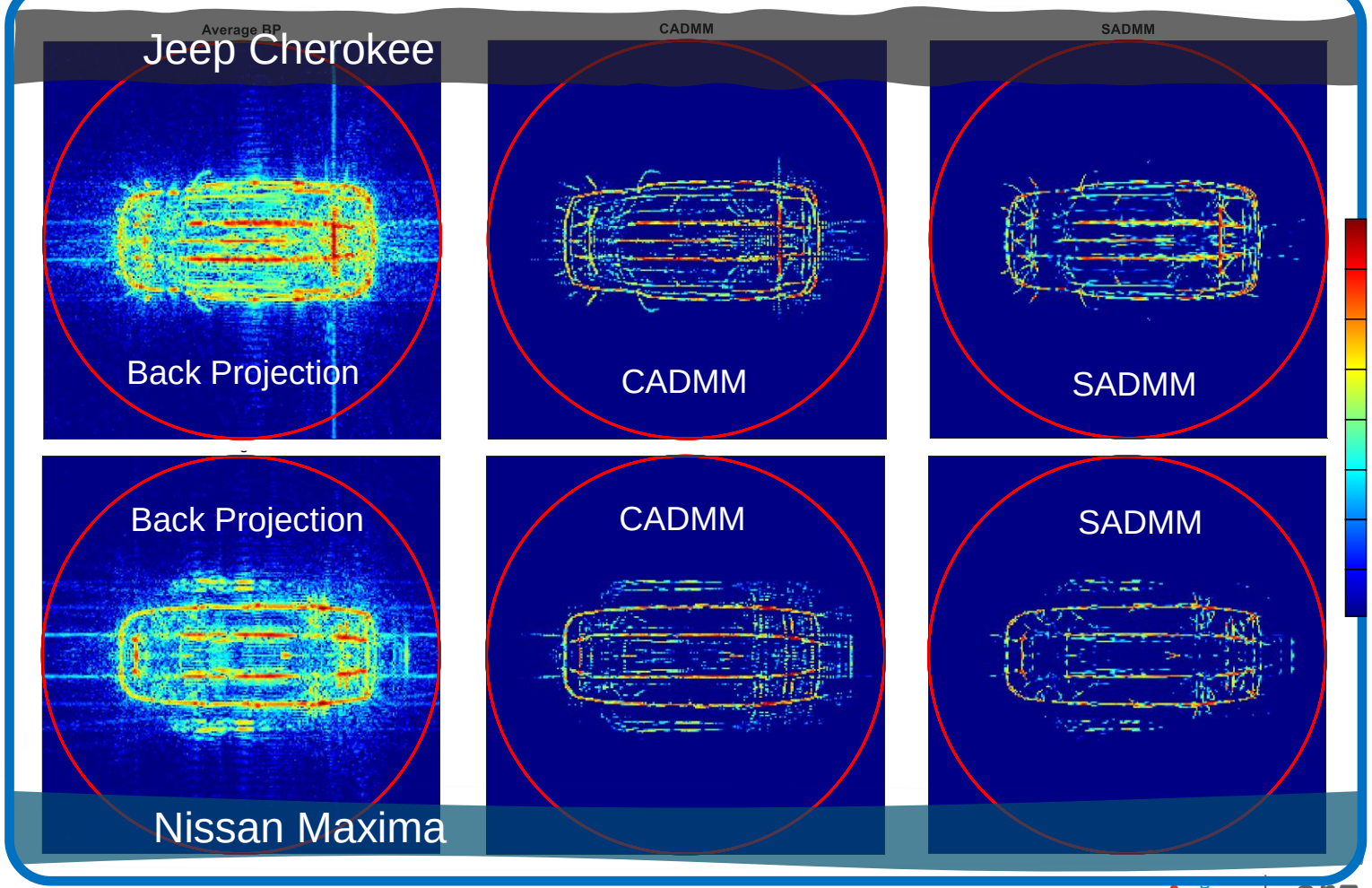
A Single MIMO Radar with Many Virtual Elements

Q sensors/clusters



Geometry of distributed Radars

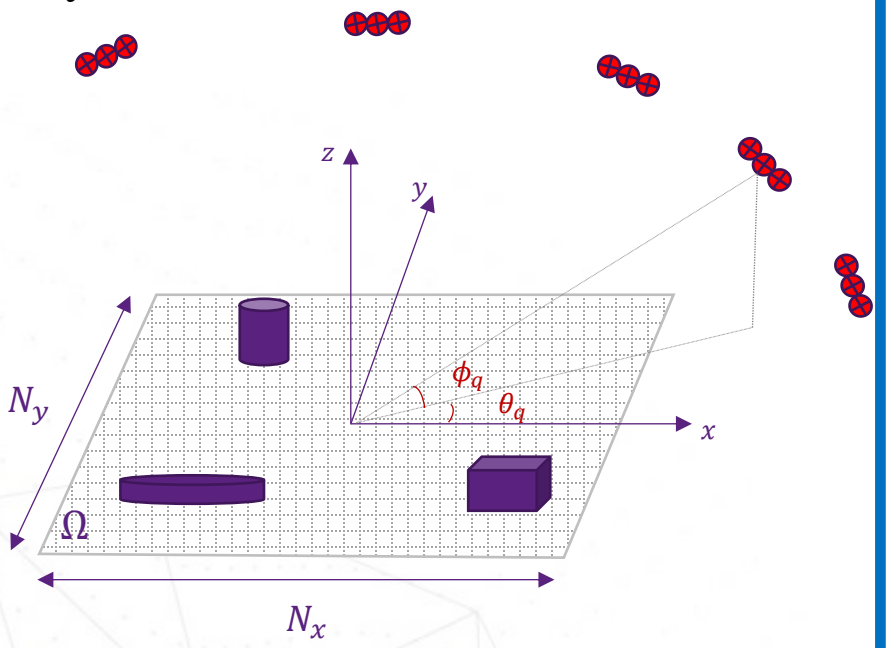
Q = 72
Cluster width = 5°
BW = 5.4 GHz



Multiple Synchronized Monostatic Radars

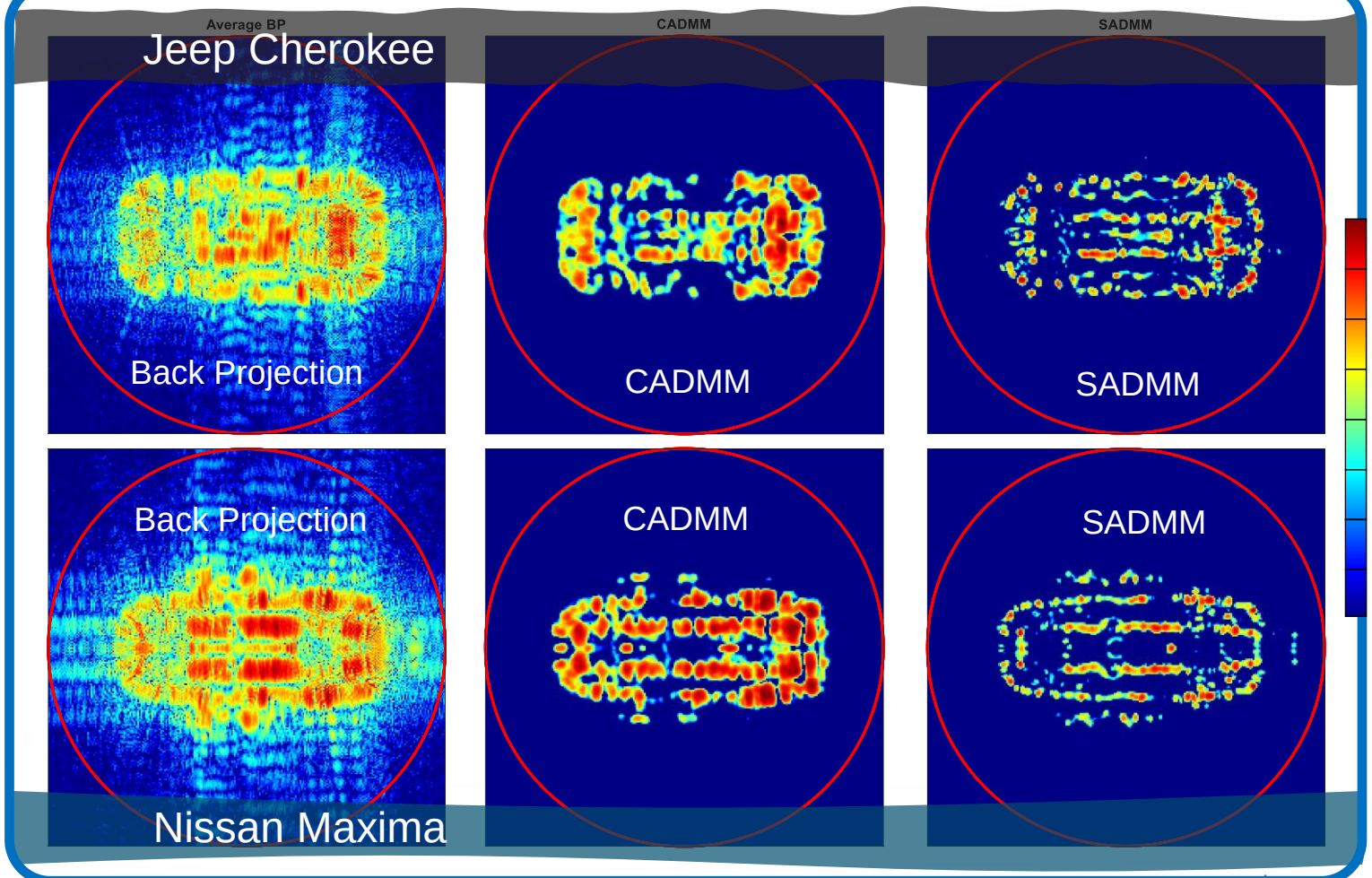
A Single MIMO Radar with Many Virtual Elements

Q sensors/clusters



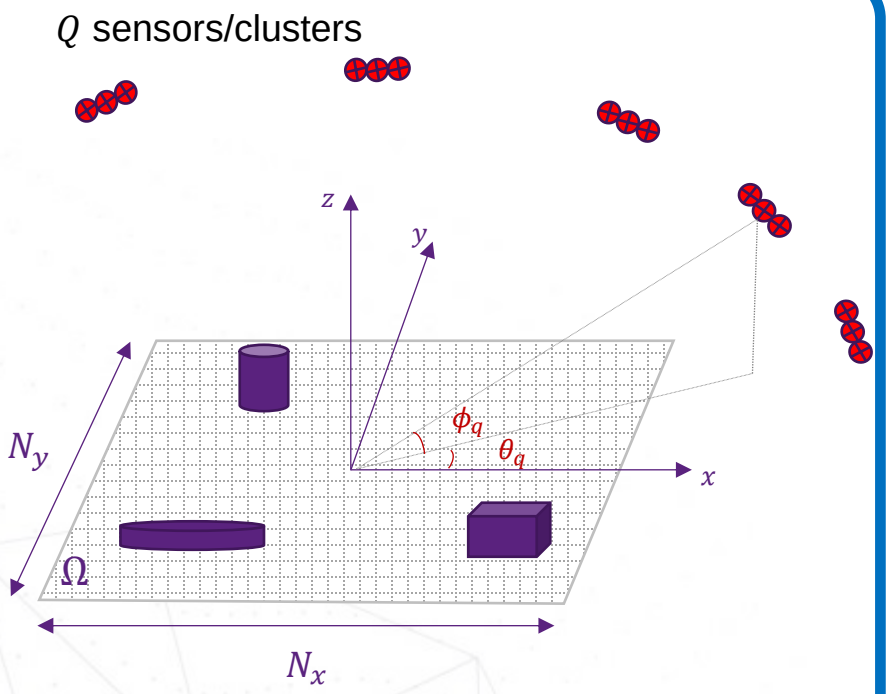
Geometry of distributed Radars

Q = 72
Cluster width = 5°
BW = 600 MHz



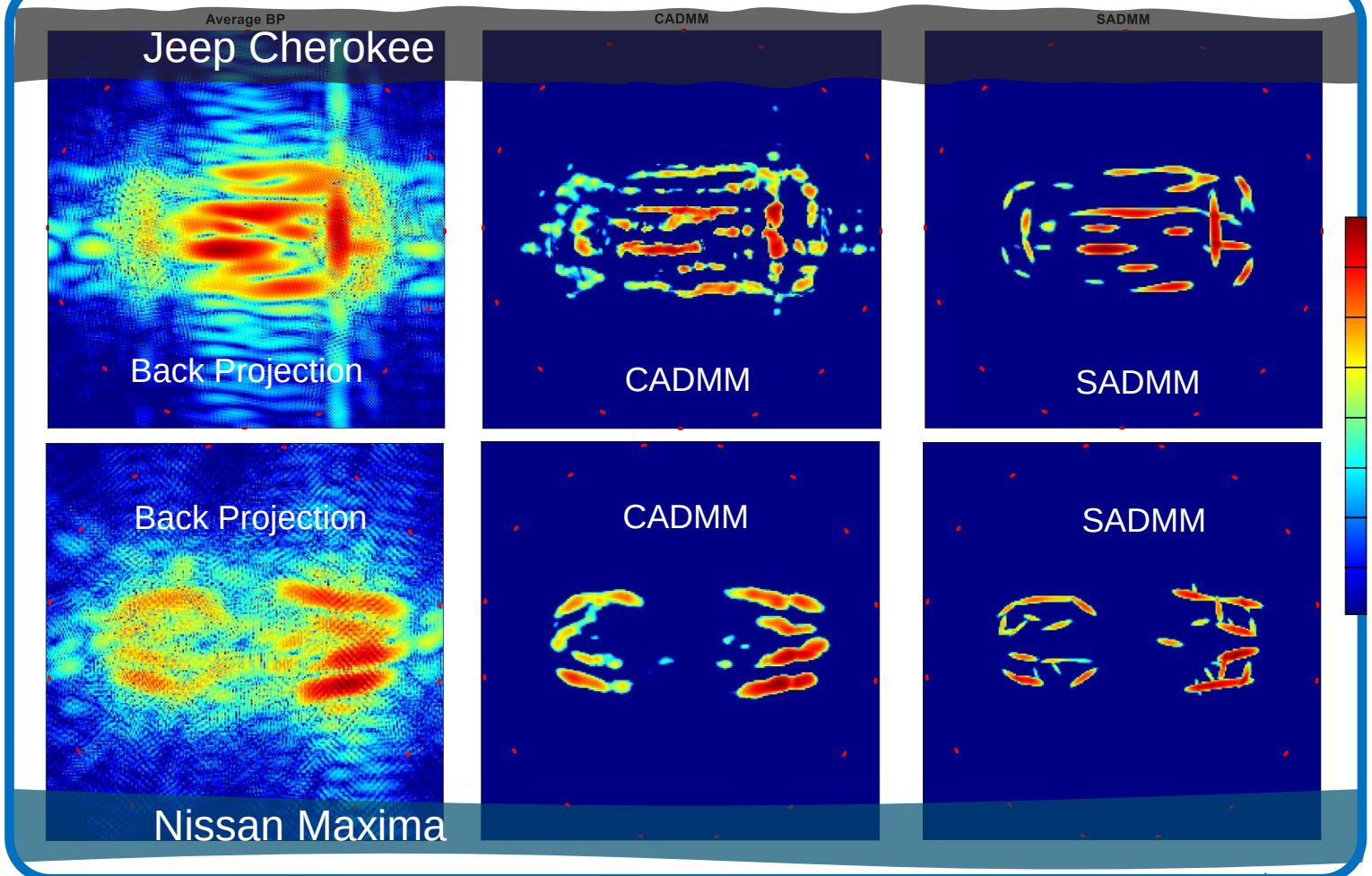
Multiple Synchronized Monostatic Radars

A Single MIMO Radar with Many Virtual Elements



Geometry of distributed Radars

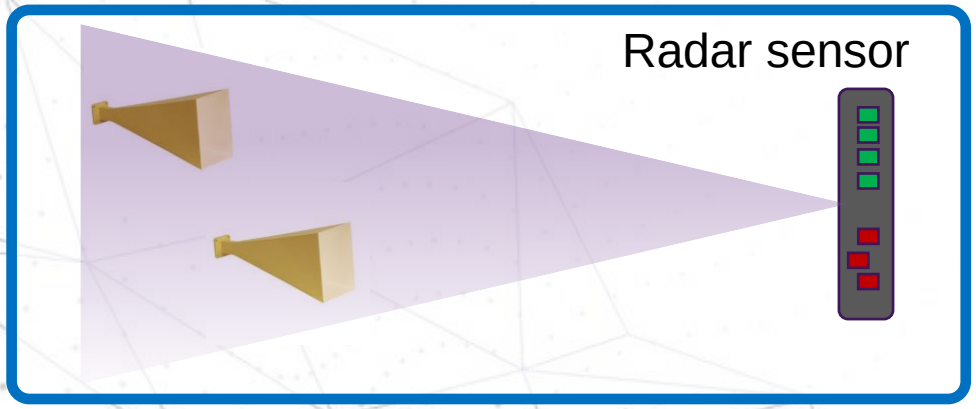
Q = 16
Cluster width = 1°
BW = 600 MHz



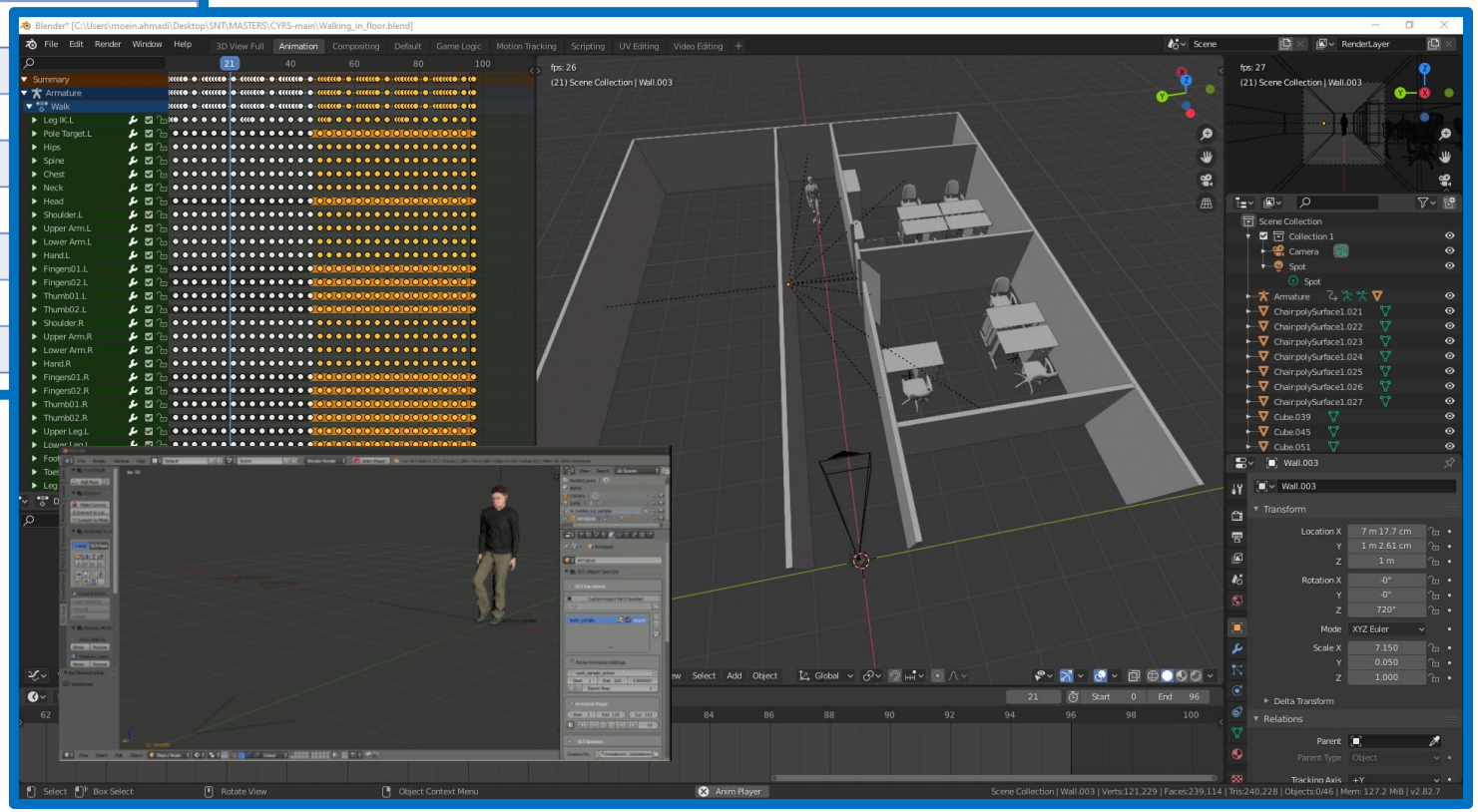
Indoor Scene Data Set

How to generate radar data set for indoor scene?

Automotive radar	Surveillance/Defence	SAR/ISAR/GPR
ATRIUM [5]	dSPACE Sensor Simulation PC [6]	gprMax [7]
CarMaker [8]	FLAMES [9]	Ondulus [10]
CARLA [11] [12].	RADSim [13]	RaySAR [14] [15]
ENABLE-S3 [16]	SPx Radar Simulator [17]	
GOPOSim [18]	WinProp [19]	
OPENDS [20]	vsRAD [21]	
PreScan [22]		
TESIS [23]		
TORCS [24]		
VIRES [25]		
WaveFarer [26]		



Blender is a free and open-source 3D computer graphics software tool set used for creating animated films, visual effects, art, 3D-printed models, motion graphics, interactive 3D applications, virtual reality, and, formerly, video games.



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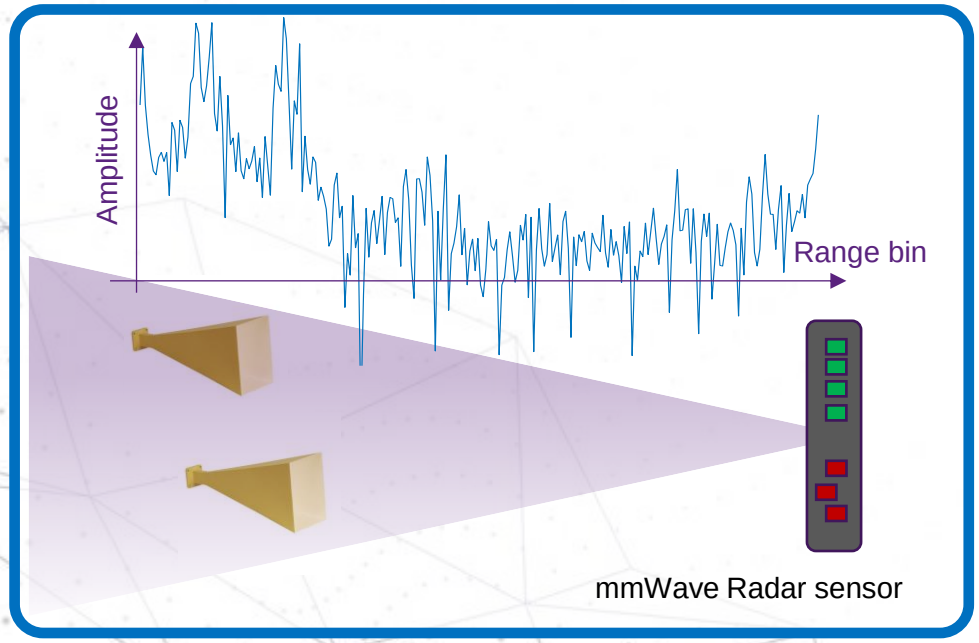
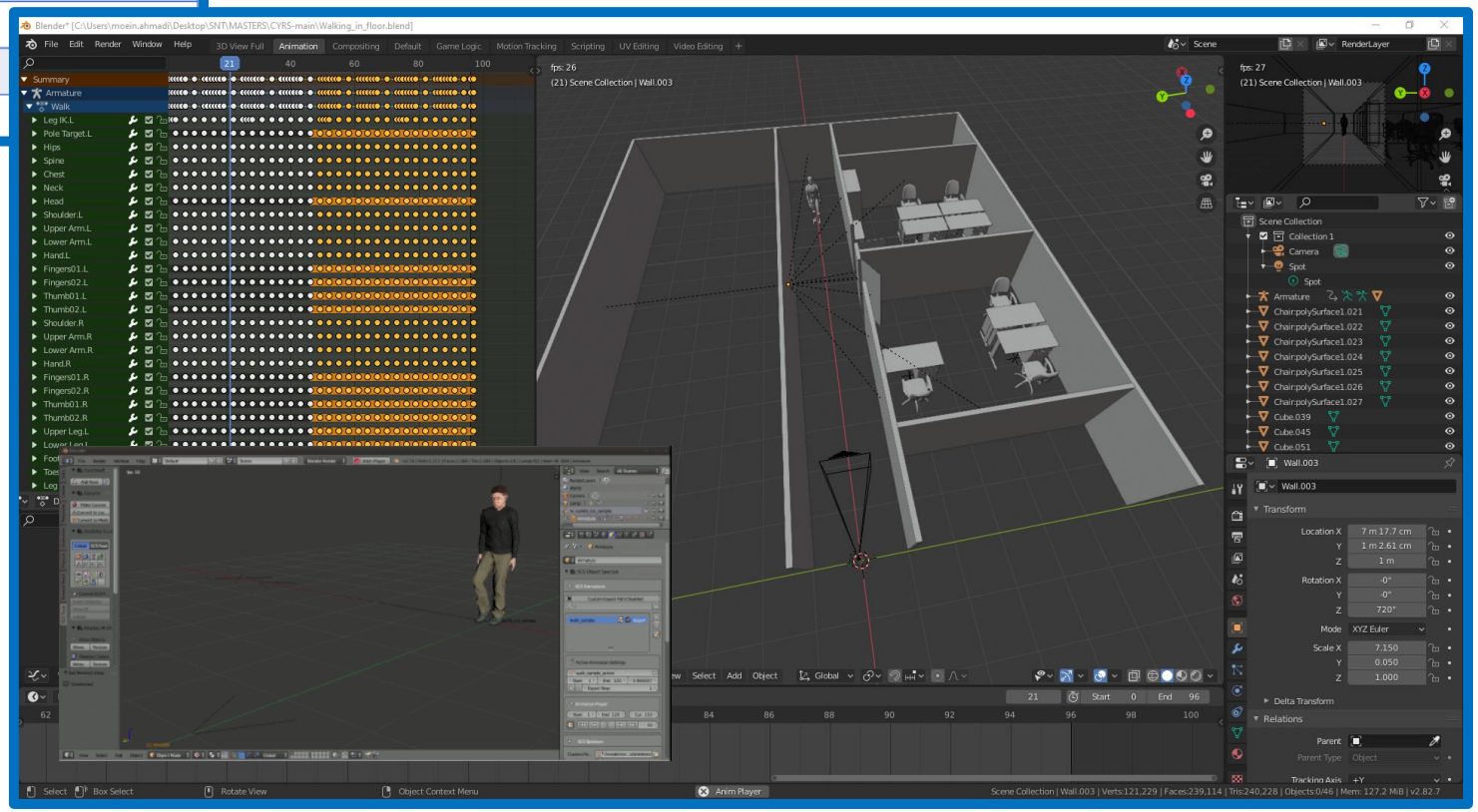
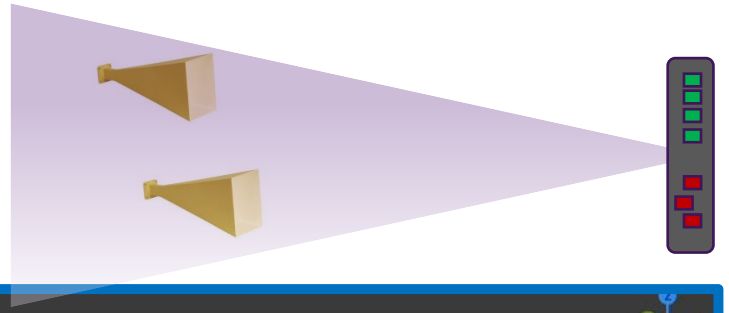
Blender is a free and open-source 3D computer graphics software tool set used for creating animated films, visual effects, art, 3D-printed models, motion graphics, interactive 3D applications, virtual reality, and, formerly, video games.

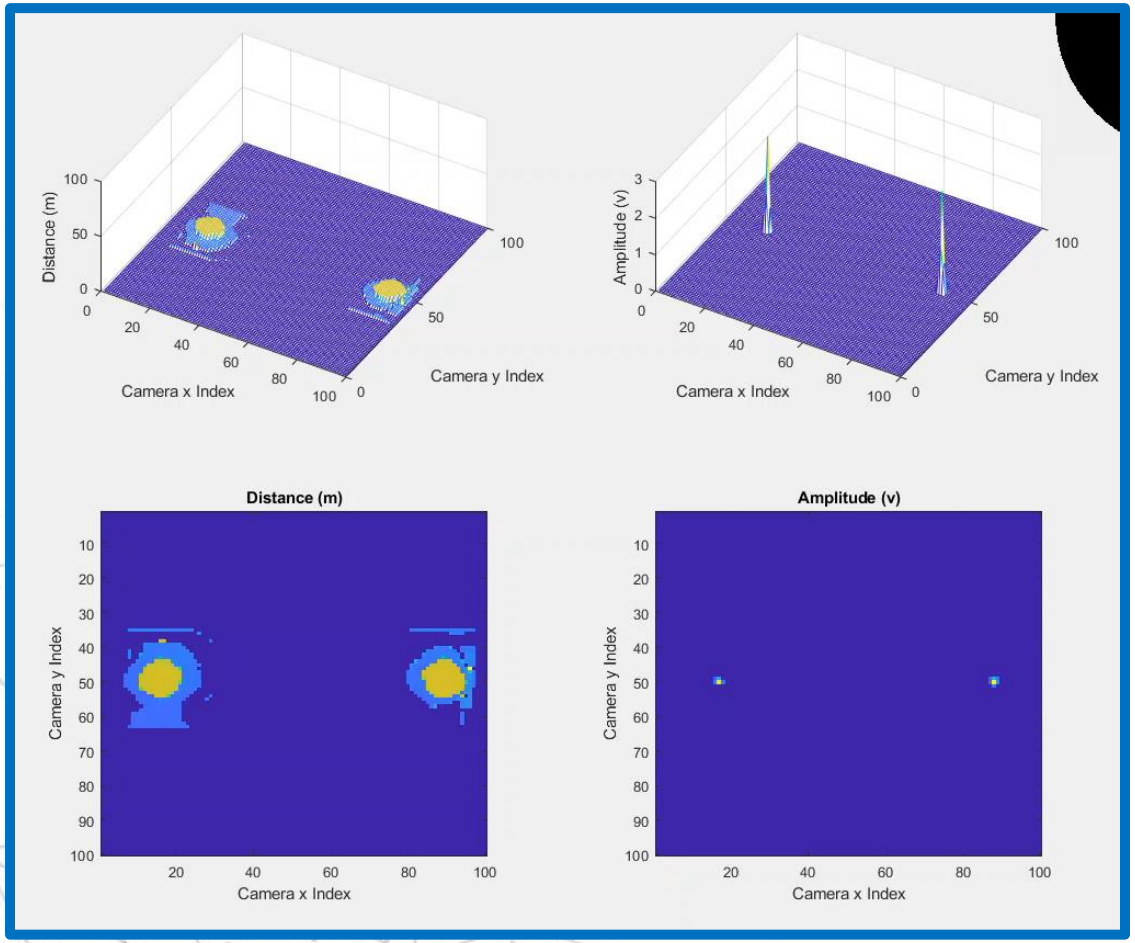


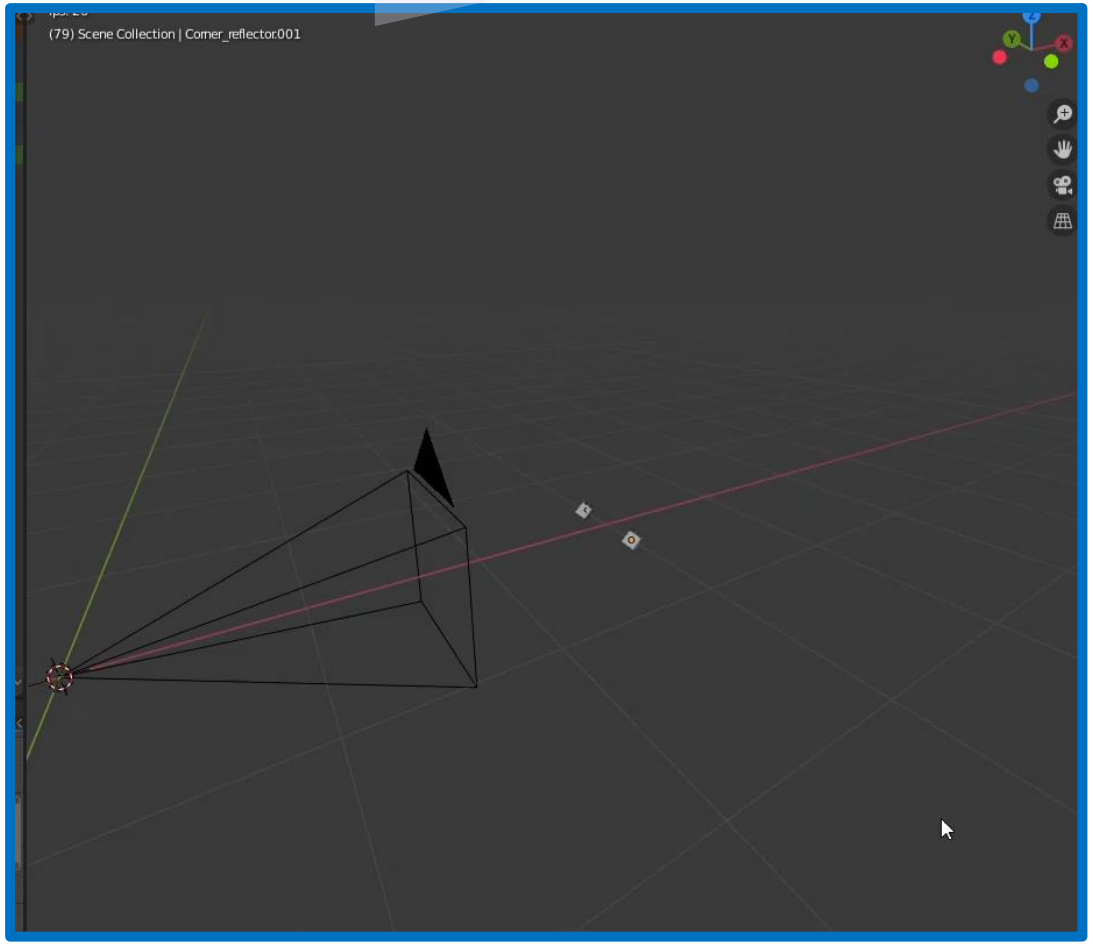


Indoor Scene Data Set

How to generate radar data set for indoor scene?

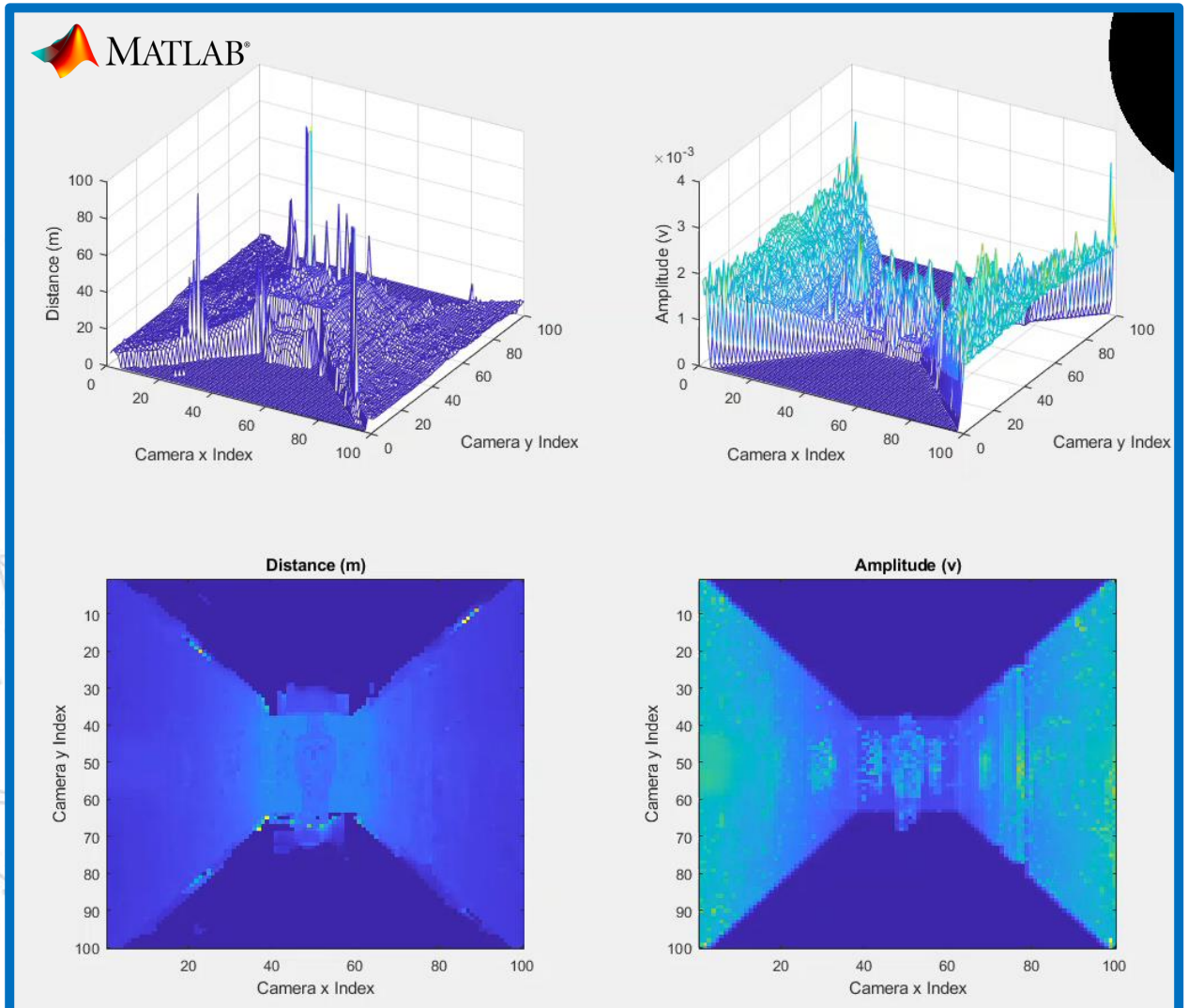


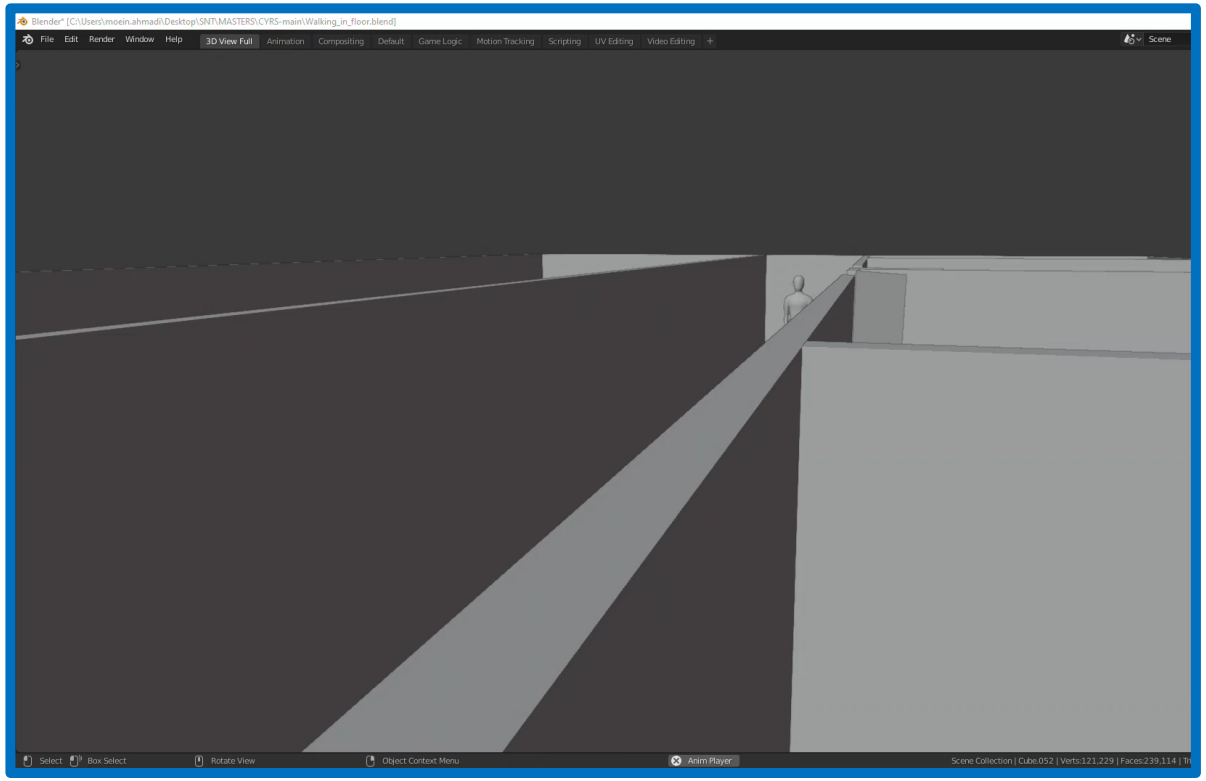




Indoor Scene Data Set

How to generate radar data set for indoor scene?





The generated radar raw data for an indoor scene can be used for image reconstruction using any antenna configuration of a single or multiple sensors.

Multiple sensors may cause interference, which can be mitigated with appropriate waveform design, as discussed in the following presentation.

Acknowledgement

Table of Content

Acknowledgement

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Question?

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