UNIVERSITÀ
DEGLI STUDI
DELL'AQUILA

DIIIE
Dipartimento di Ingegneria
Industriale e dell'Informazione
e di Economia

Dosimetria numerica nei sistemi WPT in ambito automotive: applicazioni

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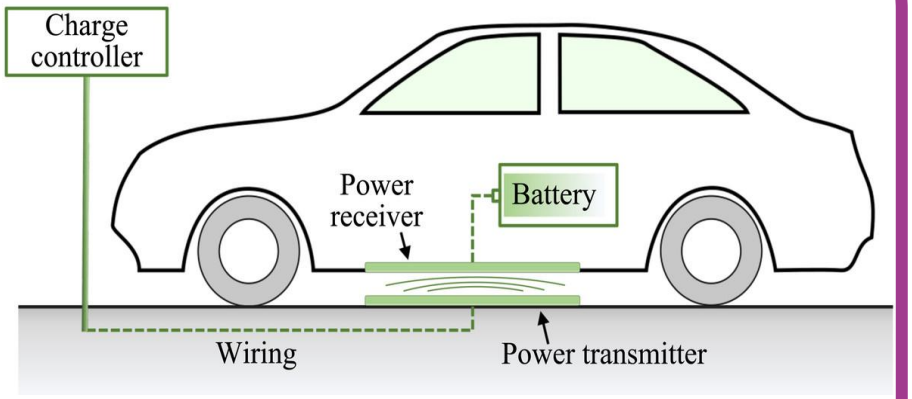
Outline

- Introduction
  - Case study 1: S-WPT system
  - Case study 2: D-WPT system
- Models and methods
  - Car-coils-human body modeling
  - Exposure scenarios
- Compliance procedure
  - Exposure assessment strategies
  - Compliance against ICNIRP RLs
  - Compliance against ICNIRP BRs
- Conclusions & future works

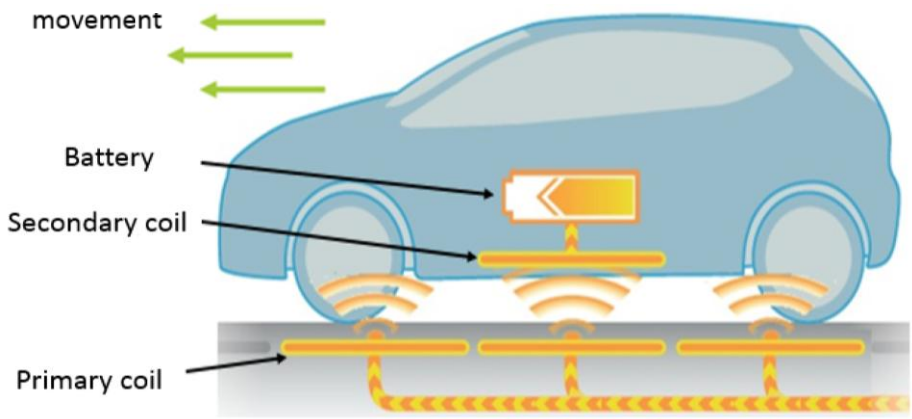
Introduction

Stationary (S)-WPT



Case study 1

Dynamic (D)-WPT



Case study 2

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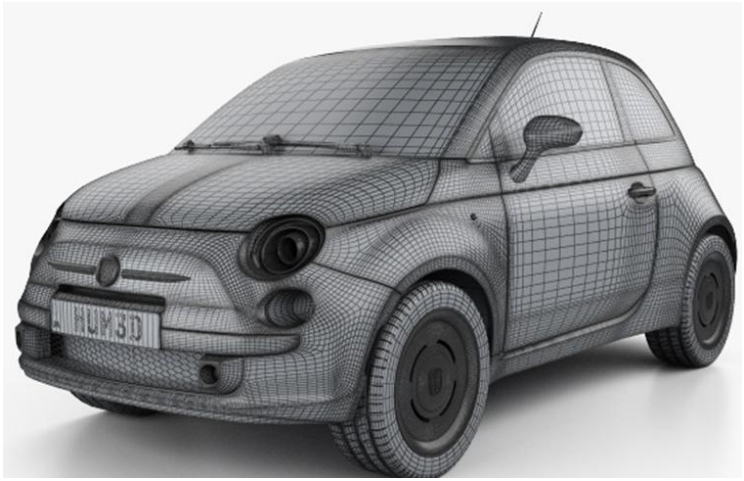
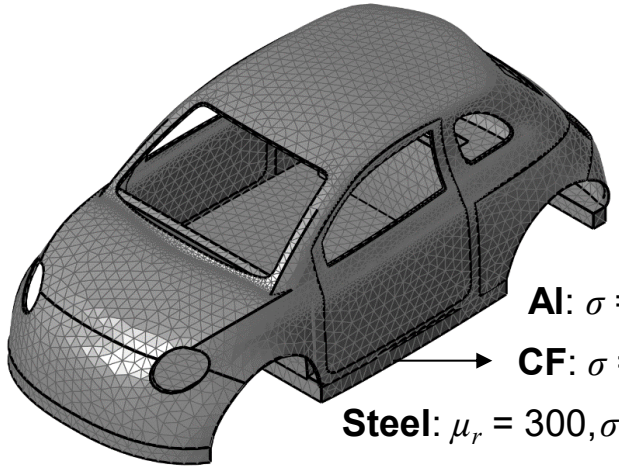
Car-coils Modeling

source CAD Model: Fiat 500e



adopted surface mesh†



Al: $\sigma = 3 \cdot 10^7$ S/m

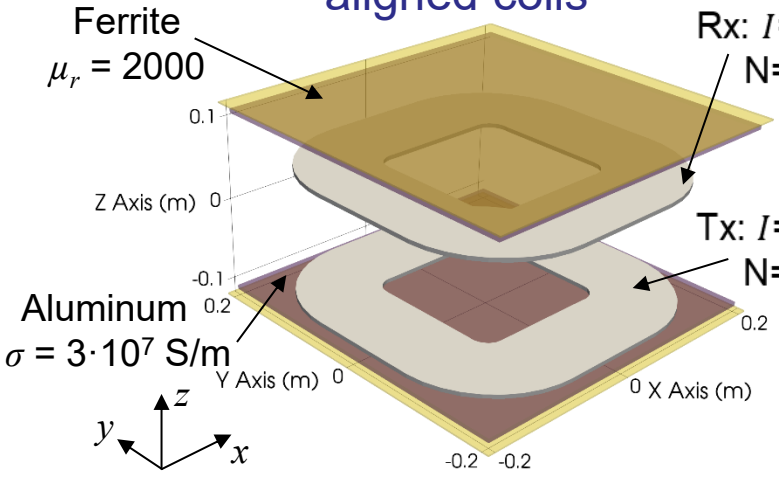
CF: $\sigma = 4 \cdot 10^4$ S/m

Steel: $\mu_r = 300, \sigma = 2 \cdot 10^6$ S/m*

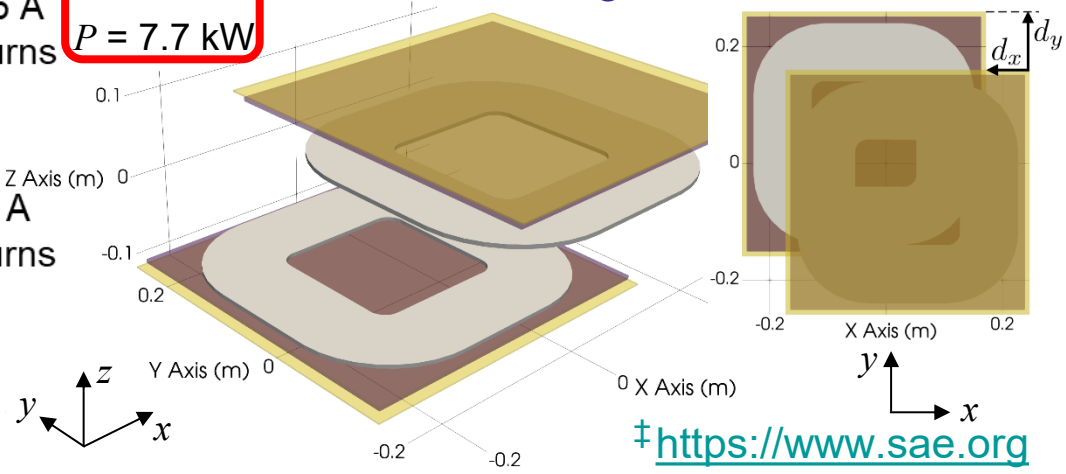
†https://github.com/cadema-PoliTO/vehicle4em

*https://www.micev.eu/

aligned coils

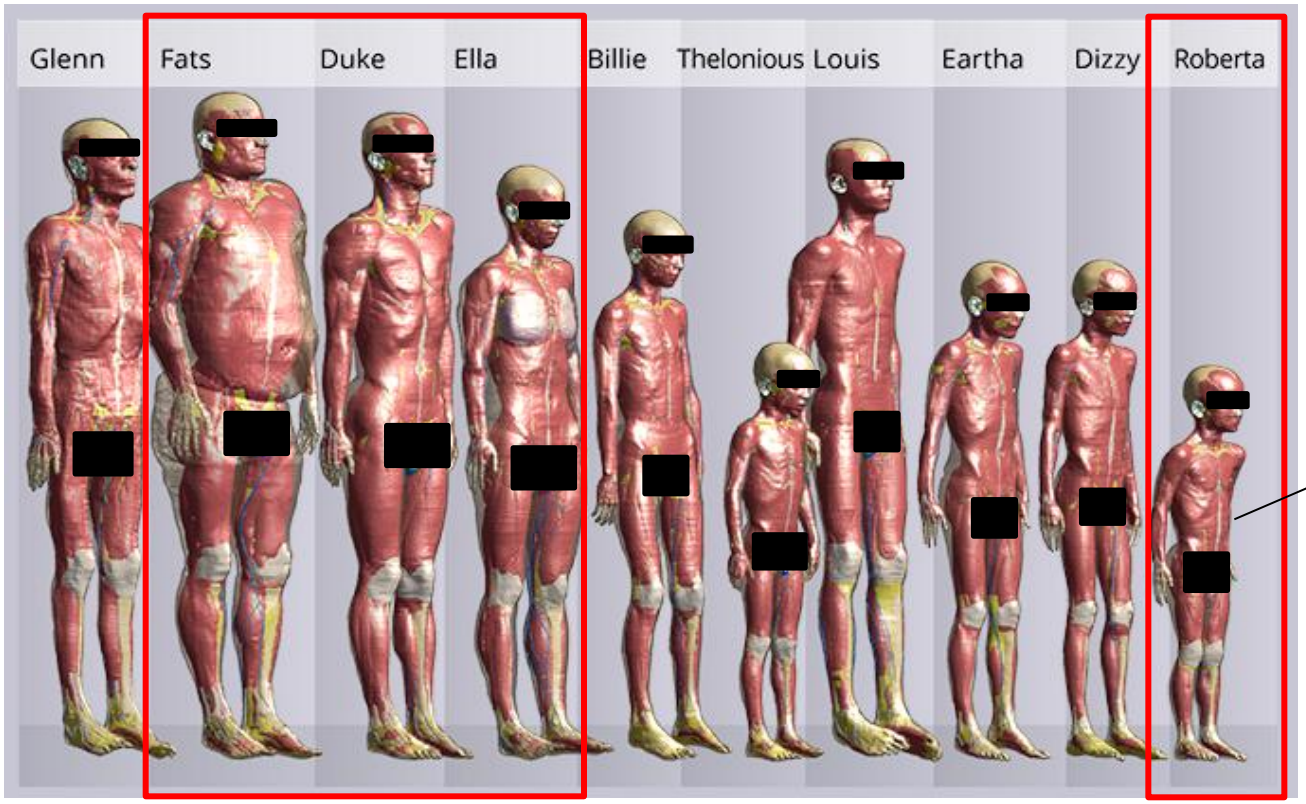


misaligned coils‡



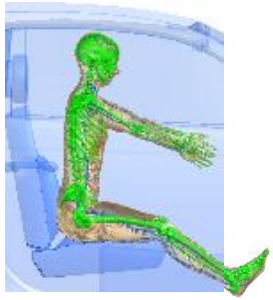
‡https://www.sae.org

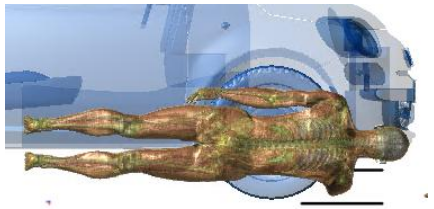
Human Body Modeling



IT'IS database, **LF/IF dielectric properties** *latest access (2021)* †

Skin: σ = 0.3 S/m*





*V. De Santis, X.L. Chen, I. Laakso, and A. Hirata, "An equivalent skin conductivity for LF magnetic field dosimetry" *Bio. Phys. Eng. Expr.*, vol. 1, 2015

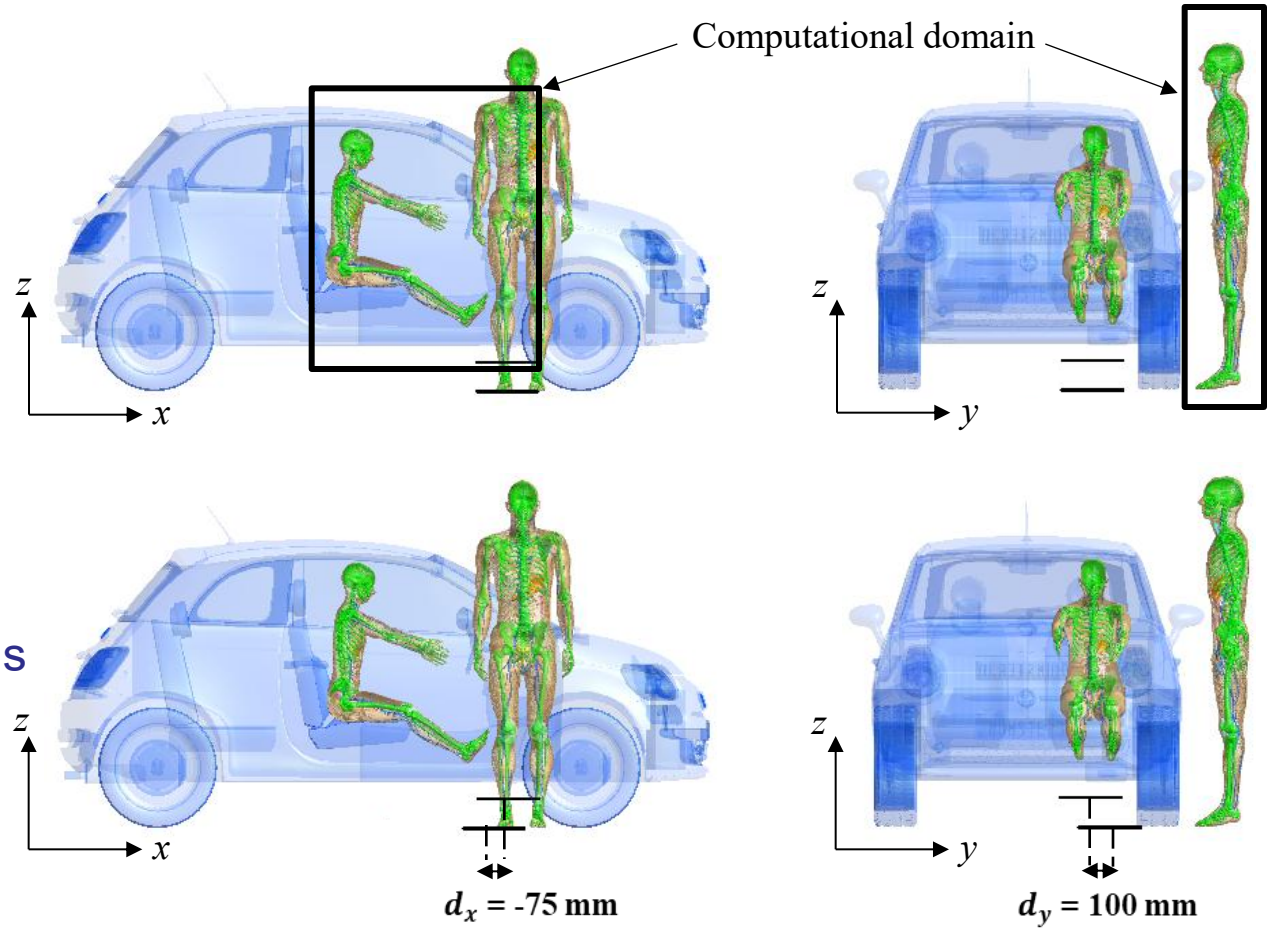
†https://itis.swiss/virtual-population/tissue-properties/database/

Exposure Scenarios

Exposure scenario #1: Ella **driving** & Duke **standing** & **middle** coils

aligned coils

misaligned coils

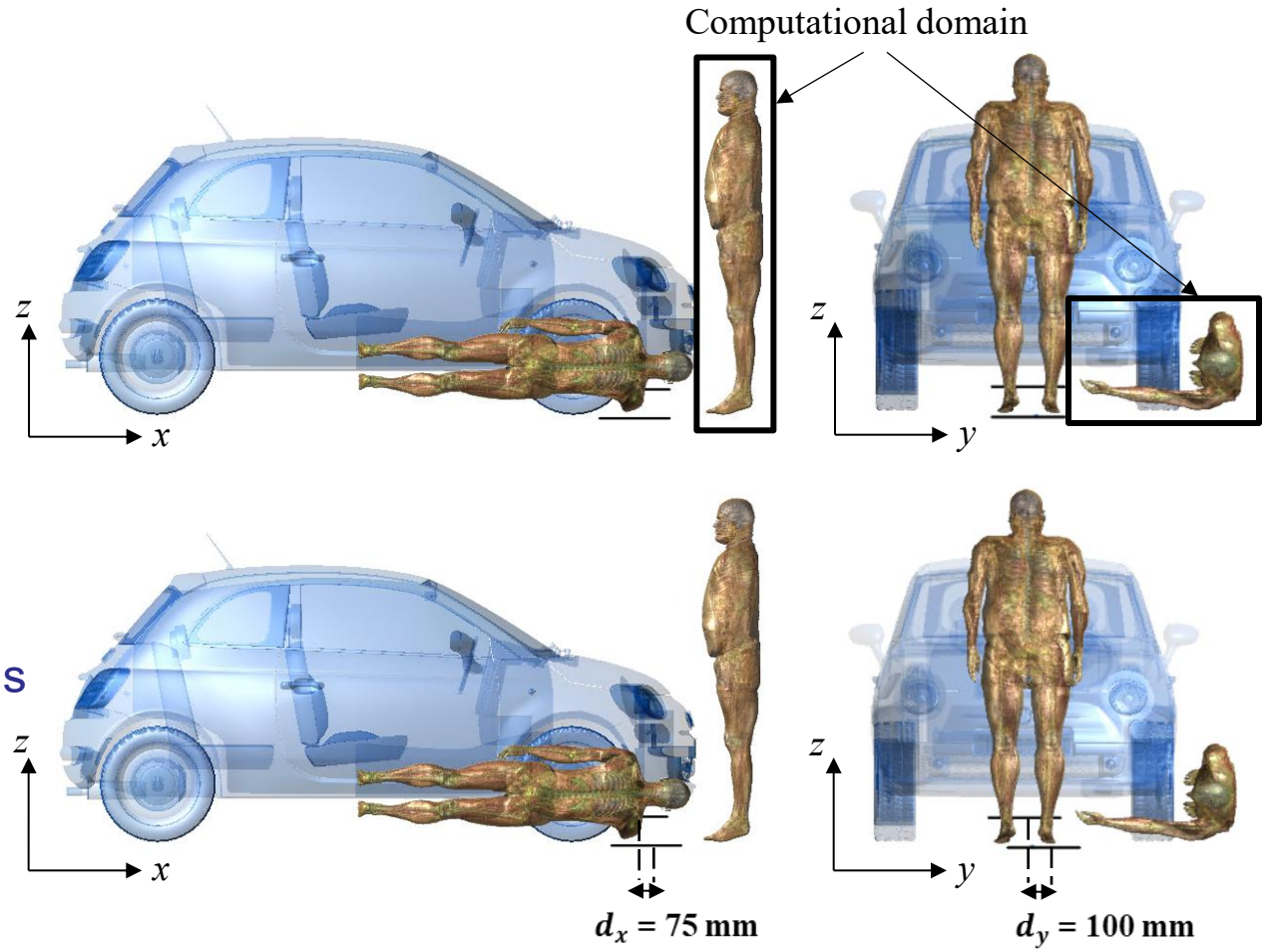


Exposure Scenarios

Exposure scenario #2: Fats **standing** & Duke **lying** & **front** coils

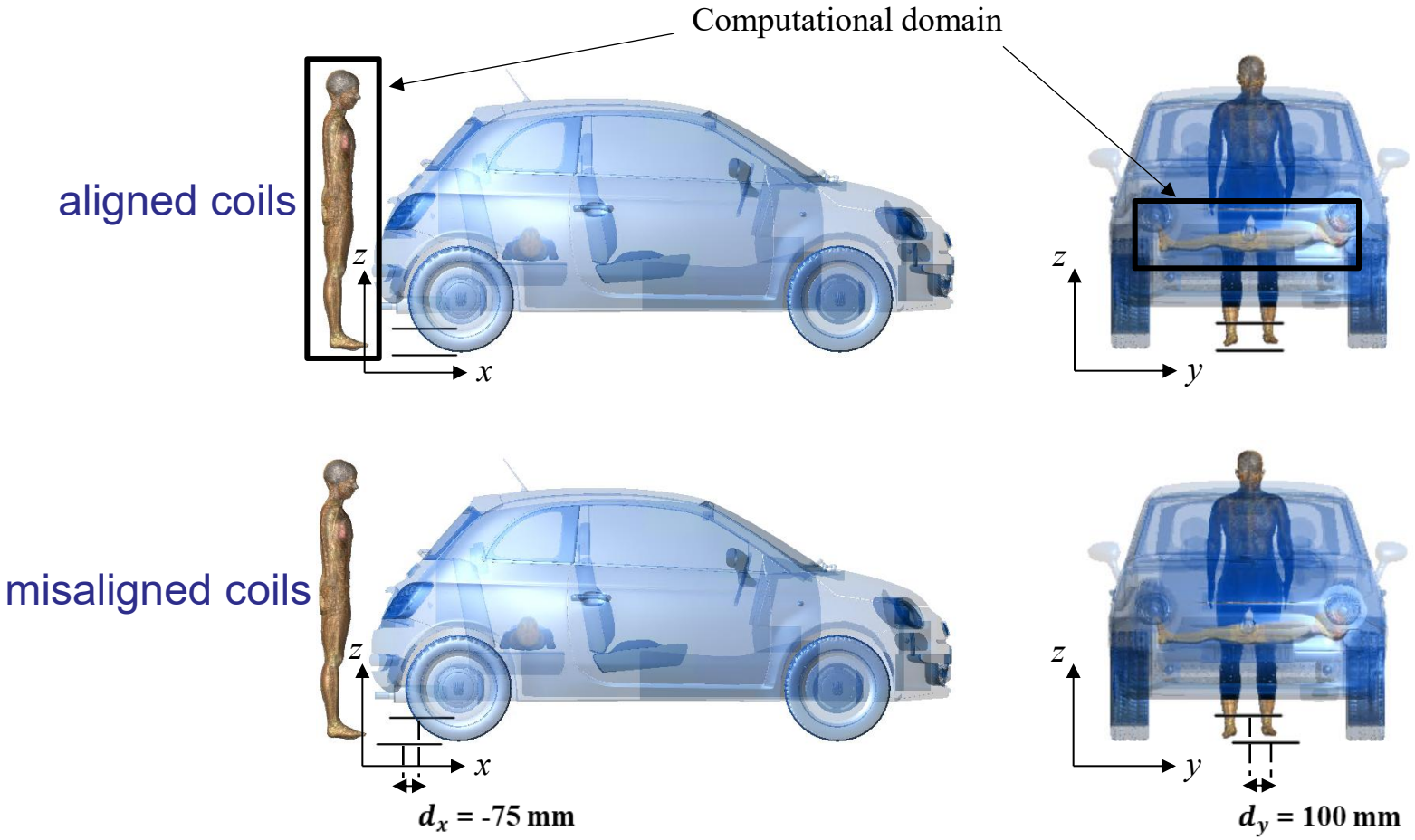
aligned coils

misaligned coils



Exposure Scenarios

Exposure scenario #3: Ella **standing** & Roberta **sleeping** & **rear** coils



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Compliance Procedure

2 step approach:

1. Measure/evaluate **external fields** in the exposed region
   - compare with ICNIRP 1998 RL → $B_{lim} = 6.25\ \mu\mathrm{T}$ (unperturbed rms)
   - compare with ICNIRP 2010 RL → $B_{lim} = 27\ \mu\mathrm{T}$ (unperturbed rms)

↓ if RL exceeded

2. Evaluate **internal fields** within anatomical models
   - compare with ICNIRP 1998 BR → $J_{lim} = 0.17\ \mathrm{A/m^2}$ ($1\ \mathrm{cm^2}$ surface avg.)
   - compare with ICNIRP 2010 BR → $E_{lim} = 11.47\ \mathrm{V/m}$ ($8\ \mathrm{mm^3}$ volume avg.) ($99-\mathrm{th}$ percentile ?)

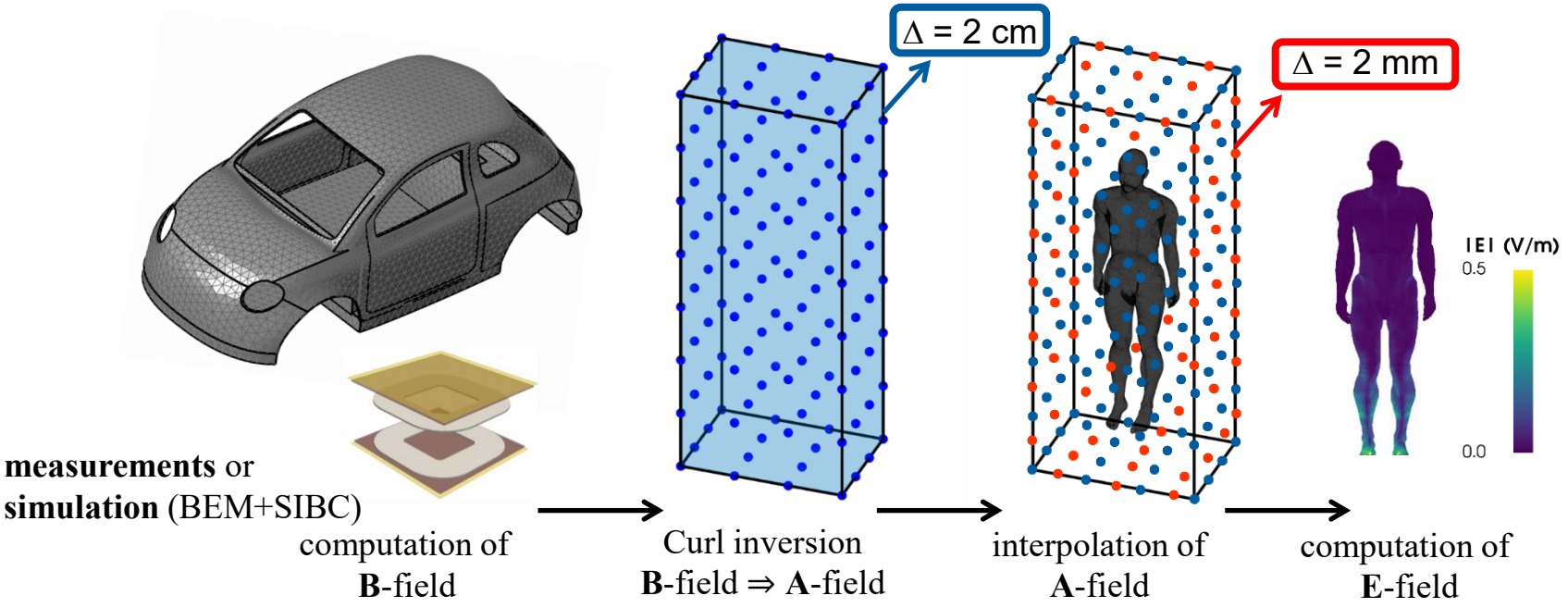
ICNIRP-1998 "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Phys.,* vol. 74, April 1998.

ICNIRP-2010 "Guidelines for limiting exposure to time-varying electric and magnetic fields for low frequencies (1 Hz-100 kHz)," *Health Phys.,* vol. 99, Dec. 2010.

Exposure Assessment Strategies

2 step approach:

1. Evaluate **external fields** in exposed region (BEM/SIBC)*



2. Evaluate **internal fields** in anatomical models (SPFE-Sim4Life)

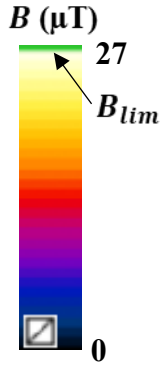
*F. Freschi, L. Giaccone, and M. Repetto, "Algebraic formulation of nonlinear surface impedance boundary condition coupled with BEM for unstructured meshes," *Eng. An. Bound. Elem.,* vol. 88, pp. 104-114, 2018.

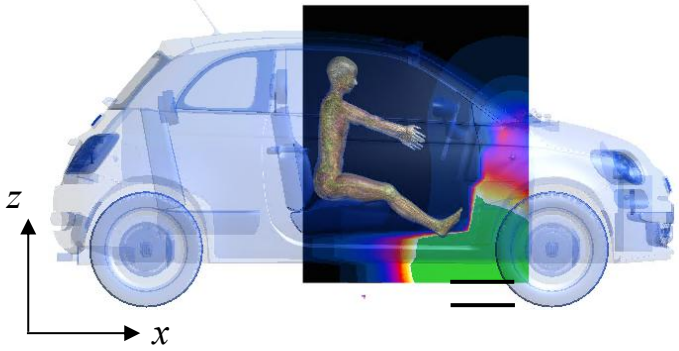
Compliance with ICNIRP RLs

Exposure scenario #1: Ella **driving** & **middle** coils

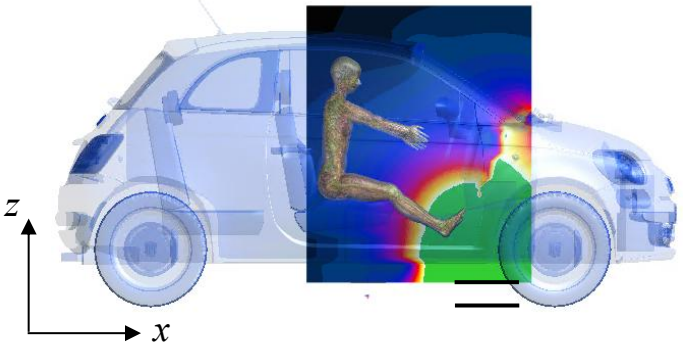
aligned coils

misaligned coils

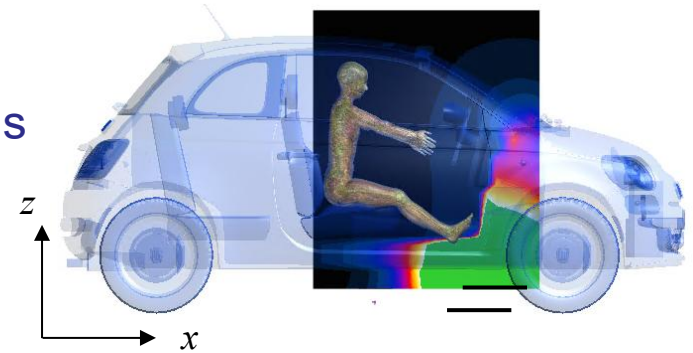


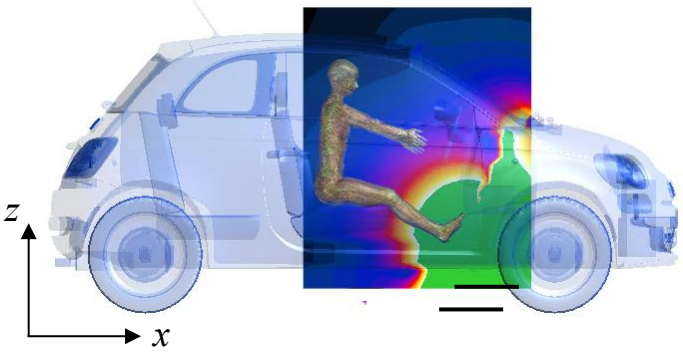


Al chassis



CF chassis





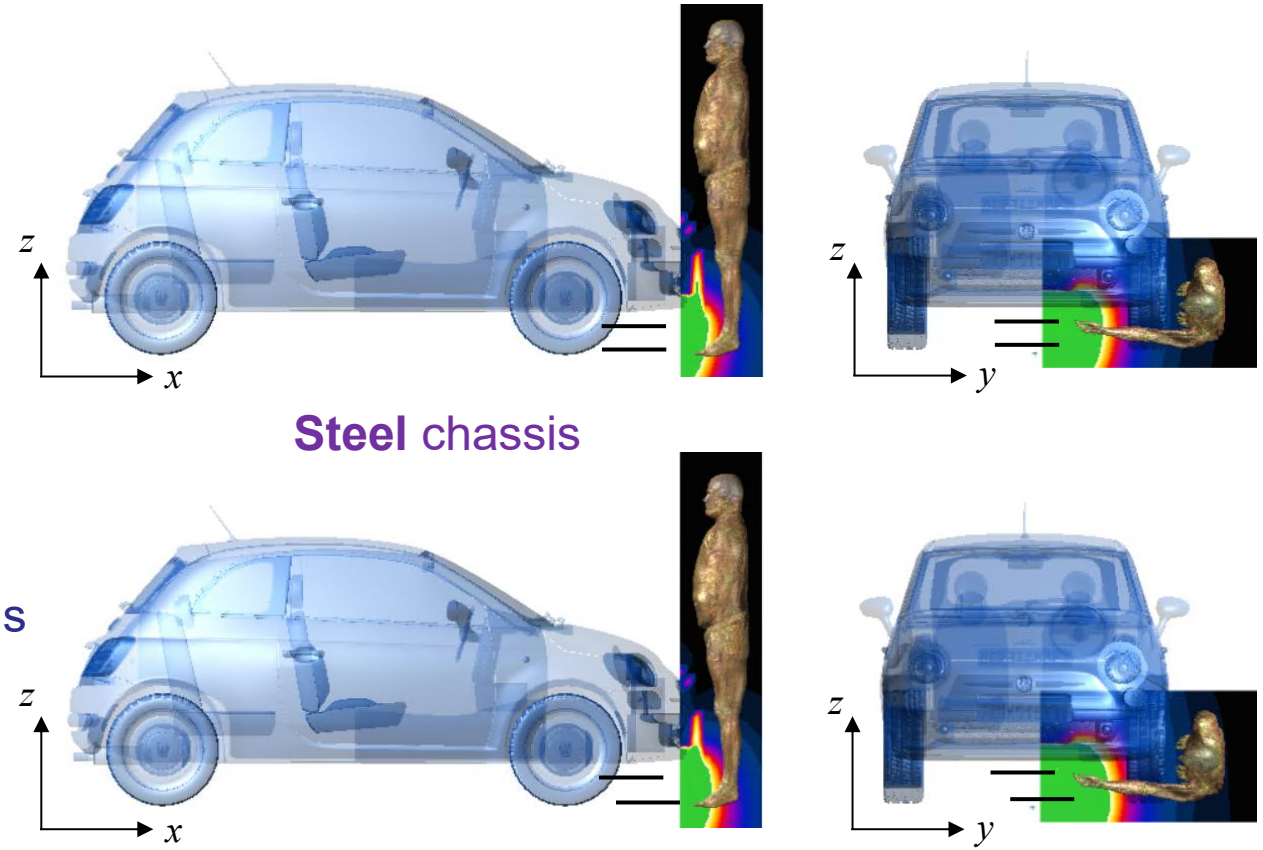
V. De Santis, L. Giaccone, and F. Freschi, “Chassis influence on the exposure assessment of a compact EV during WPT recharging operations,” *Magnetochem.*, vol. 7, pp. 1-11, 2021.

Compliance with ICNIRP RLs

Exposure scenario #2: Fats **standing** & Duke **lying** & **front** coils

aligned coils

misaligned coils



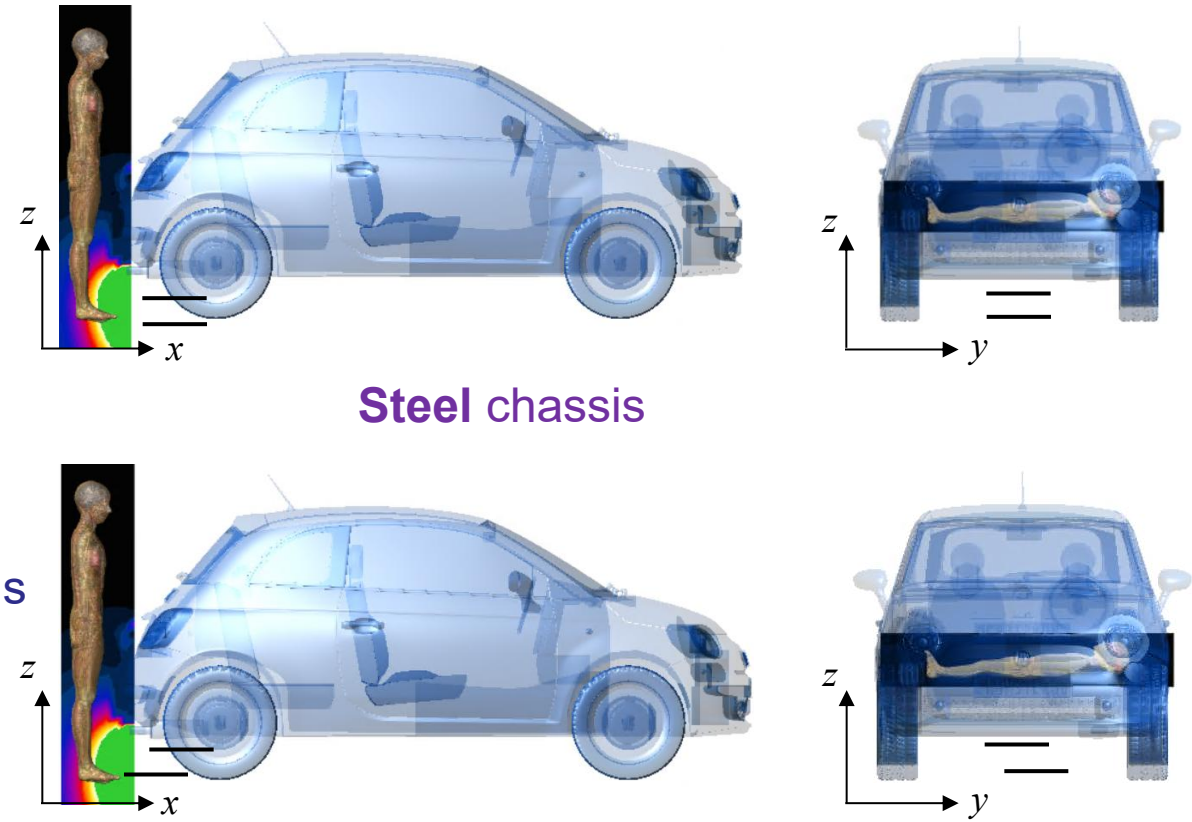
V. De Santis, L. Giaccone, and F. Freschi, “Influence of posture and coil position on the safety of a WPT system while recharging a compact EV,” *Energies,* vol. 14, no. 21, p. 7248, Nov. 2021.

Compliance with ICNIRP RLs

Exposure scenario #3: Ella **standing** & Roberta **sleeping** & **rear** coils

aligned coils

misaligned coils



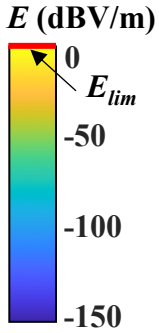
V. De Santis, L. Giaccone, and F. Freschi, “Influence of posture and coil position on the safety of a WPT system while recharging a compact EV,” *Energies,* vol. 14, no. 21, p. 7248, Nov. 2021.

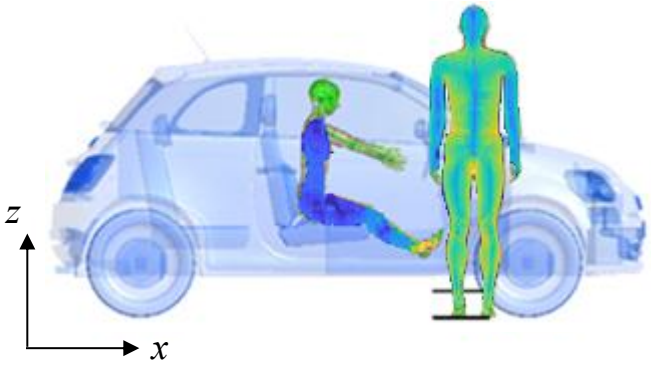
Compliance with ICNIRP BRs

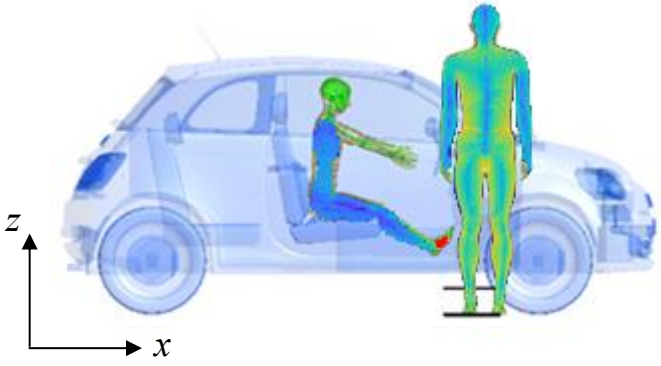
Exposure scenario #1: Ella **driving** & Duke **standing** & **middle** coils

aligned coils

misaligned coils

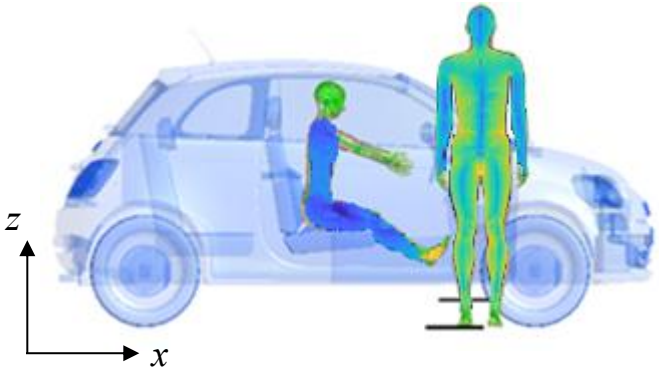


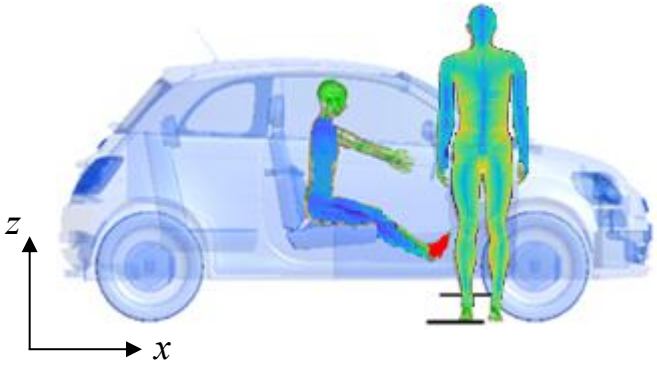




Al chassis

CF chassis





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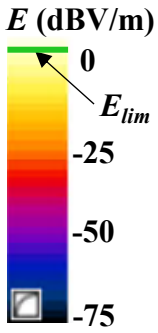
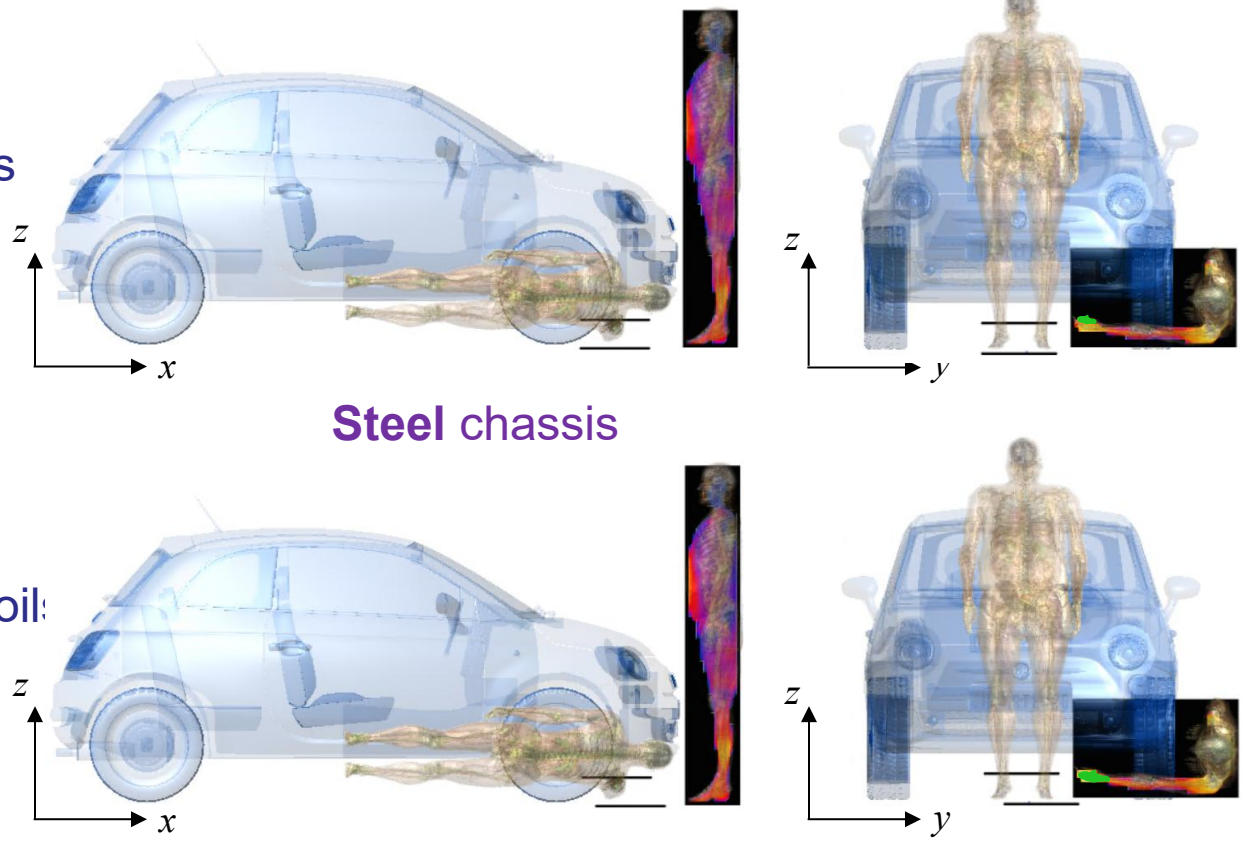
Compliance with ICNIRP BRs

Exposure scenario #2: Fats **standing** & Duke **lying** & **front** coils

aligned coils

misaligned coils





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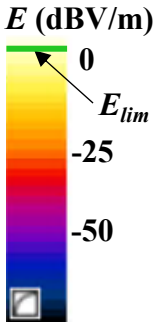
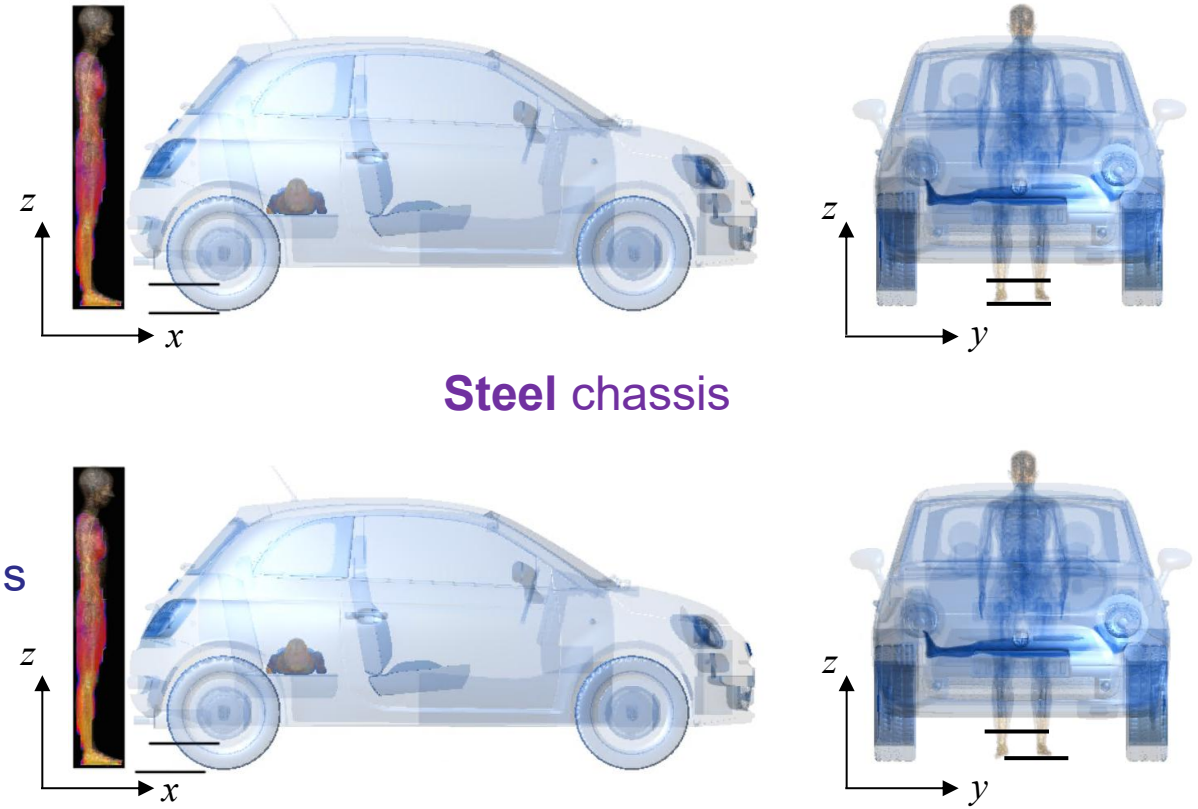
misaligned coils





V. De Santis, L. Giaccone, and F. Freschi, “Influence of posture and coil position on the safety of a WPT system while recharging a compact EV,” *Energies,* vol. 14, no. 21, p. 7248, Nov. 2021.

Summary of the Results

Exposure Index (EI): $EI_{peak} = \frac{E_{peak}}{E_{lim}}$; $EI_{99} = \frac{E_{99}}{E_{lim}}$; $E_{lim} = 11.47$ V/m

Exposure Scenario	Chassis Material	Coil Position	E_{peak} (*) (V/m)	E_{99} (V/m)	EI_{peak}	EI_{99}
#1	Al	Aligned	8.26	0.71	0.72	0.06
		Misaligned	7.69	0.57	0.67	0.05
	CF	Aligned	19.21	1.71	**1.67**	0.15
		Misaligned	24.01	1.76	**2.09**	0.15
#2	Steel	Aligned	31.84	5.65	**2.77**	0.49
		Misaligned	31.51	5.73	**2.75**	0.50
#3		Aligned	1.30	0.21	0.11	0.02
		Misaligned	2.68	0.28	0.23	0.03

(*) induced E-field averaged over a $2 \times 2 \times 2$ mm^3 cubic volume

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Conclusions & Future Works

- **Compliance** of a specific S-WPT system **against ICNIRP-RLs** has been assessed for a wide range of posture and coil positions
  - Car body **material** plays an important role
  - RLs are **exceeded** inside the car only for composite materials
- **Compliance** of a specific S-WPT system **against ICNIRP-BRs** has been assessed for a wide range of posture and coil positions
  - BRs are **slightly exceeded** on few areas of the feet (Ella driving)
  - BRs are **slightly exceeded** on few areas of the wrist (Duke lying)
- Some strategies to **reduce the exposure** are under investigation
  - better EV-WPT **shielding** performances
  - better characterization of the vehicle **chassis**
- Some strategies to **reduce numerical artefacts** are in progress

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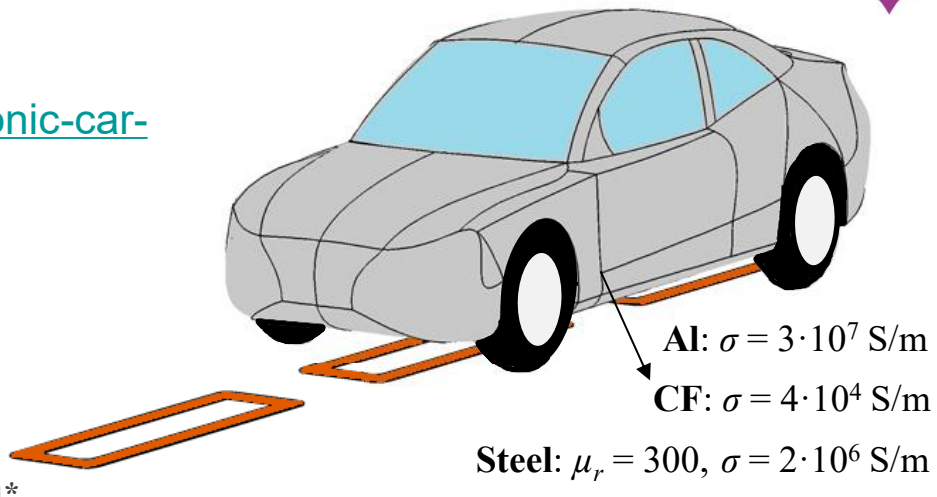
Car-Coils Modeling

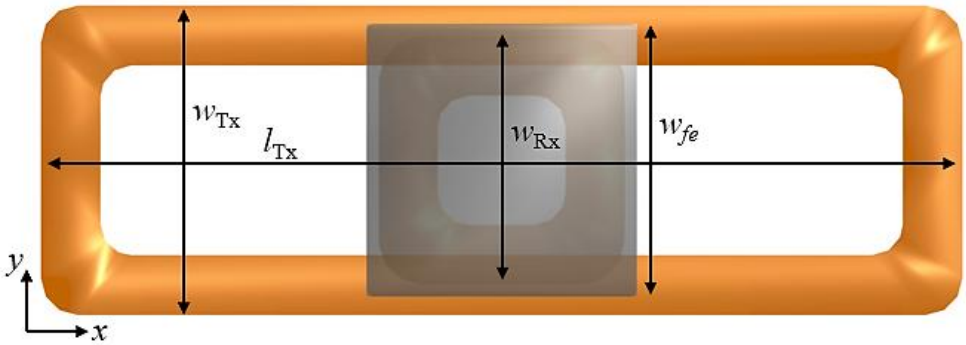
Car Model: Compact Chevrolet†

† https://www.comsol.com/model/ultrasonic-car-parkingsensor- 68041

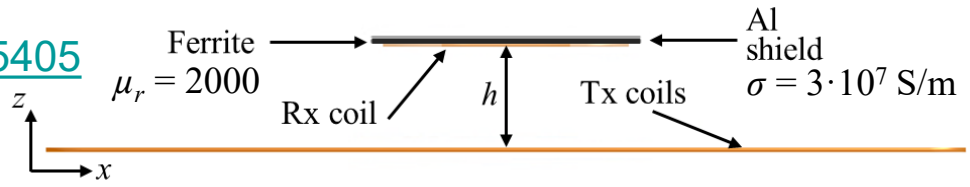


Coils configuration

- Tx coil based on **EU Fabric project** ‡
  $l_{Tx} = 150$ cm, $w_{Tx} = 50$ cm, $N_1 = 10$
- Rx coil based on **SAE J2954 standard***
  $w_{Rx} = 40$ cm, $N_2 = 14$
- Shield: $w_{fe} = w_{Al} = 45$ cm
- Clearance $h = 20$ cm
- Frequency $f = 85$ kHz
- Power Transfer = 10 kW

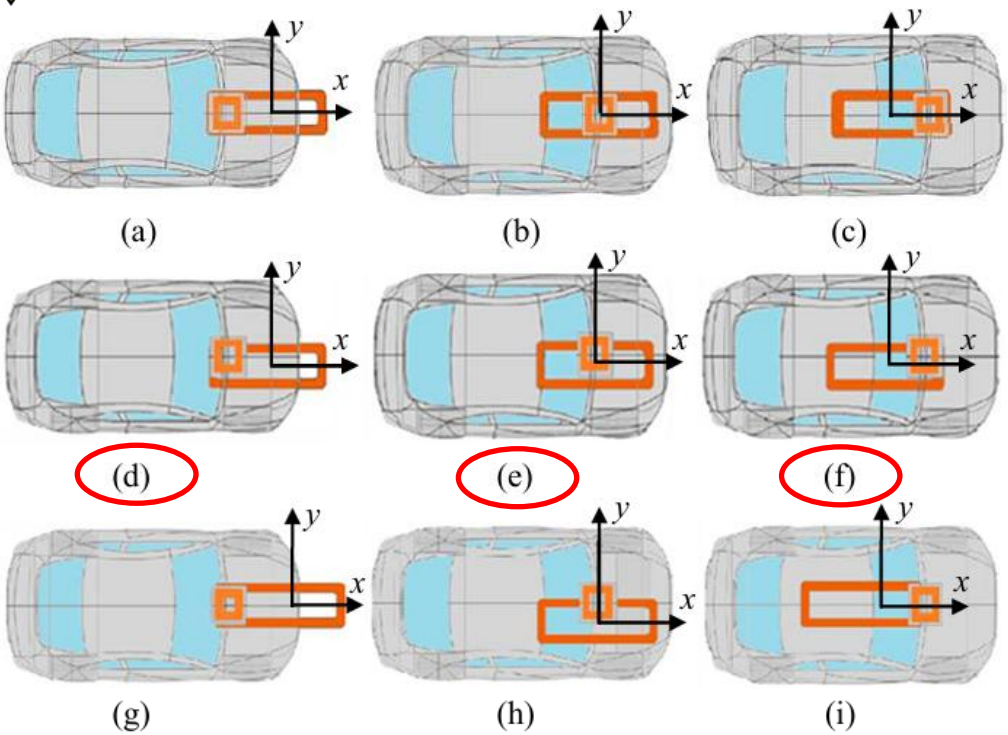


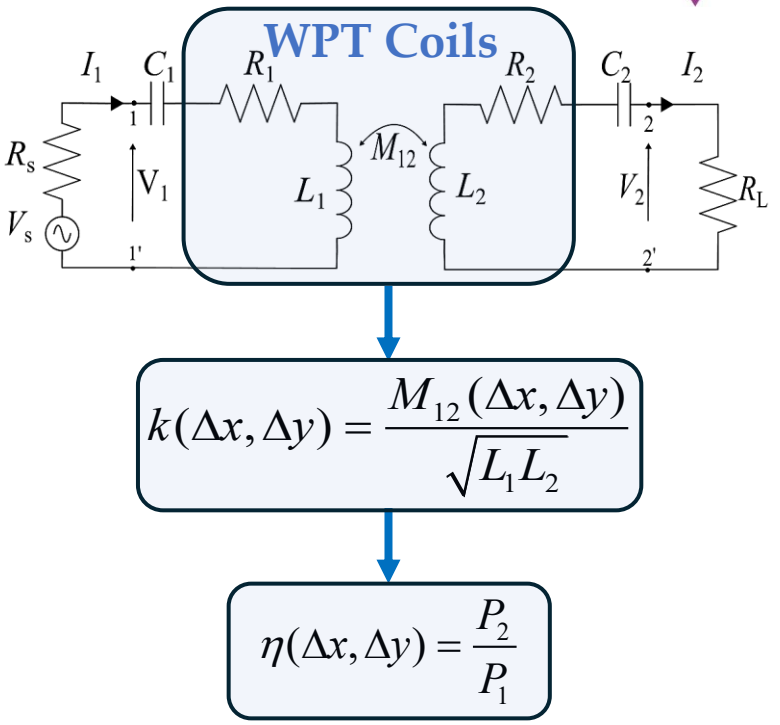
‡ https://cordis.europa.eu/project/id/605405



* https://www.sae.org

Exposure Scenarios





(a): Δx = -50 cm, Δy = 0 cm	(b): $\Delta x = \Delta y = 0$	(c): Δx = 50 cm, Δy = 0 cm
(d): Δx = -50 cm, Δy = 10 cm	(e): Δx = 0 cm, Δy = 10 cm	(f): Δx = 50 cm, Δy = 10 cm
(g): Δx = -75 cm, Δy = 0 cm	(h): Δx = 0 cm, Δy = 20 cm	(i): Δx = 75 cm, Δy = 0

W. Boumerdassi, M. Feliziani, T. Campi and V. De Santis, “EMF Safety Assessment of a Dynamic Wireless Power Transfer System for e-Mobility,” in Proc. *WPTCE-2025,* 3-6 June 2025, Rome, Italy.

Exposure Scenarios

Exposure Scenario	Δx (cm)	Δy (cm)	k	I_1 (A)	η %
(a)	-50	0	0.091	51	95.4
(b)	0	0	0.082	59	94.8
(c)	50	0	0.094	50	95.6
(d)	-50	10	0.073	63	94.2
(e)	0	10	0.063	78	92.4
(f)	50	10	0.072	65	94.1
(g)	-75	0	0.019	243	60.7
(h)	0	20	0.018	248	59.6
(i)	75	0	0.030	150	62.2

V_2 is set to 400 V → I_2 = 25 A to keep constant P_2 = 10 kW

I_1 reaches extremely high levels in exposure scenarios (g), (h), and (i)

These scenarios with $k \leq 0.05$ must be avoided to prevent performance degradation and ensure compliance with EMF safety standards

Two main approaches

Keeping constant I_1

Keeping constant P_2

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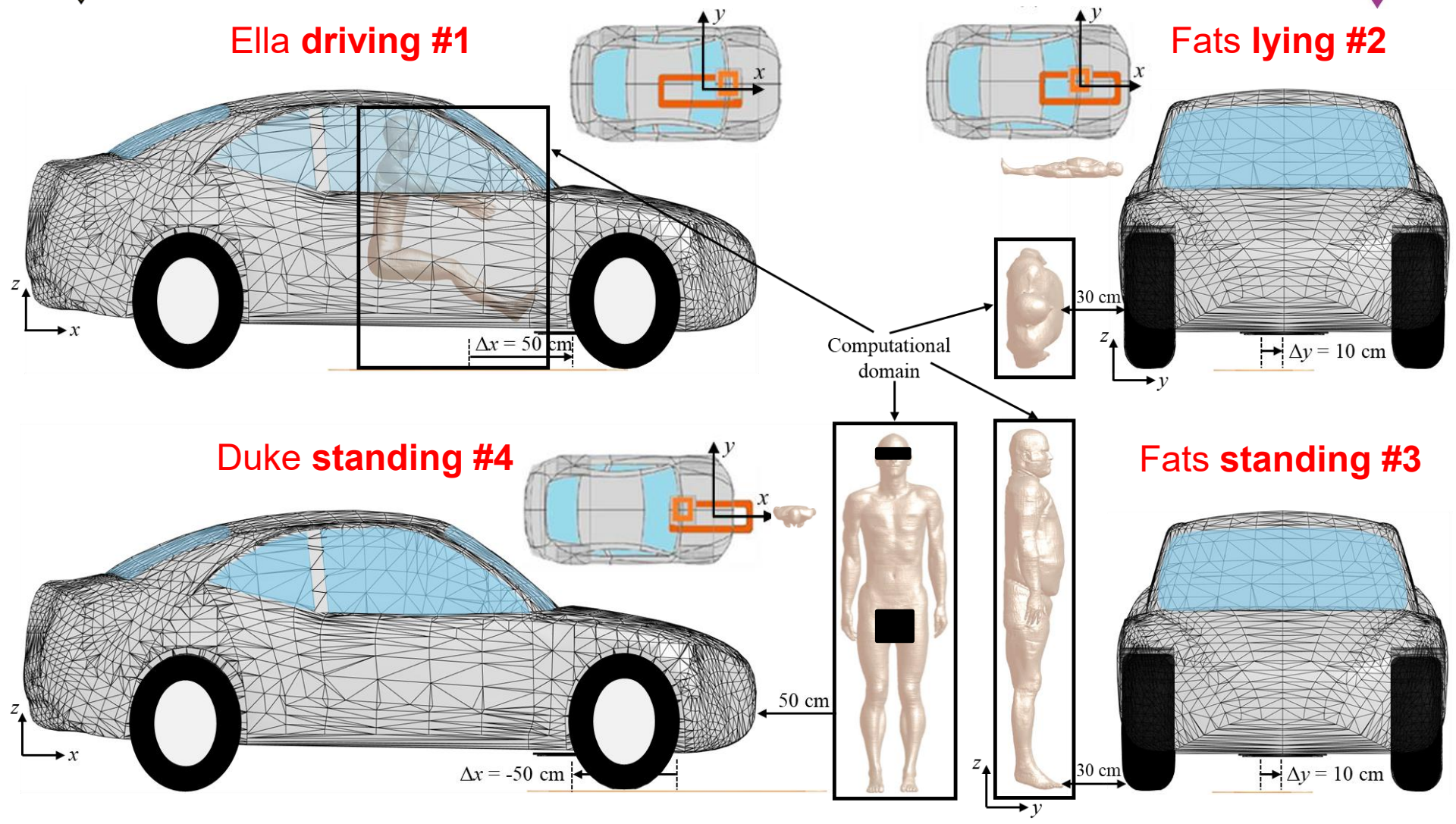
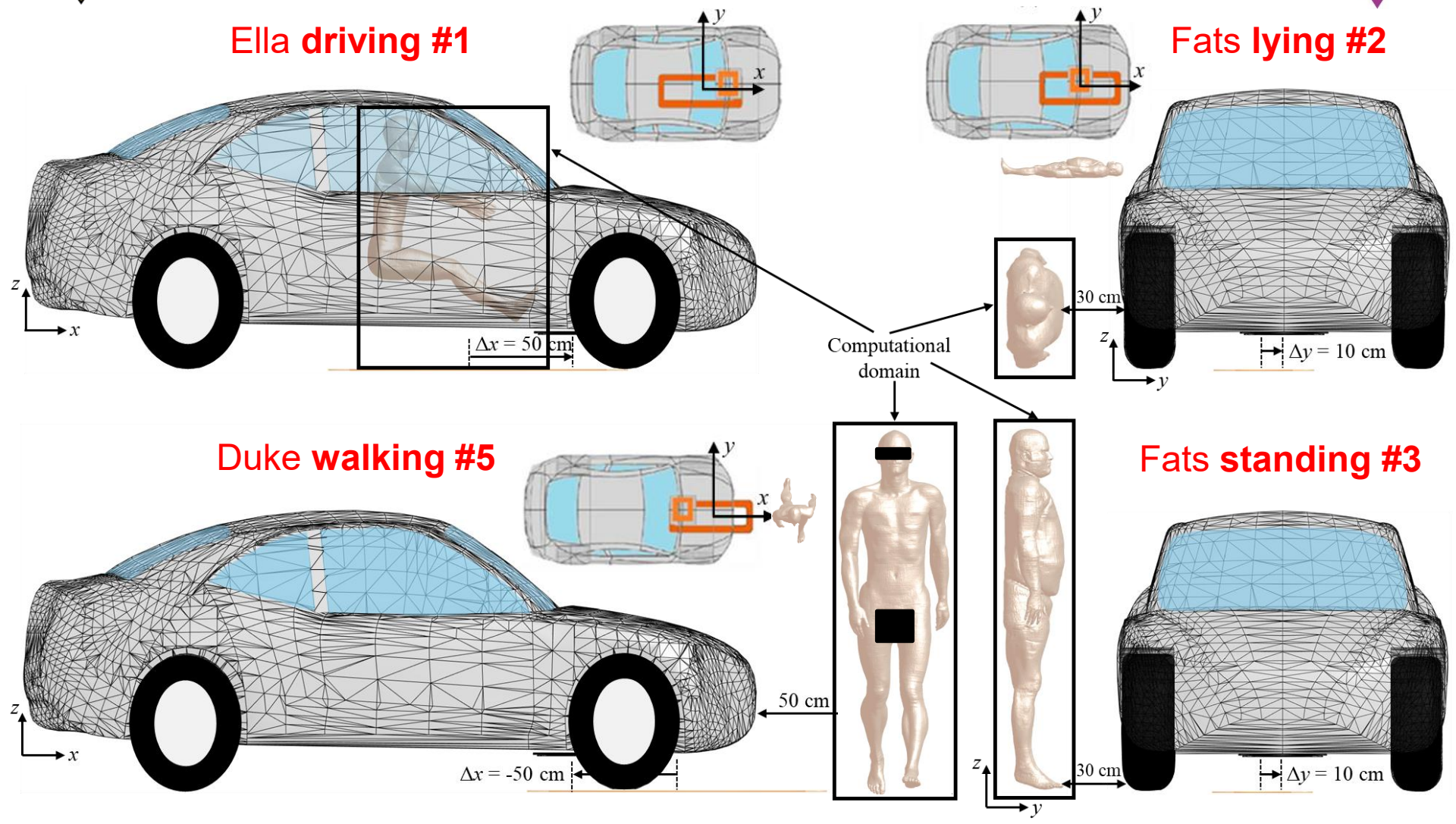
Exposure Scenarios



Exposure Scenarios



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- Compliance procedure
  - Exposure assessment strategies
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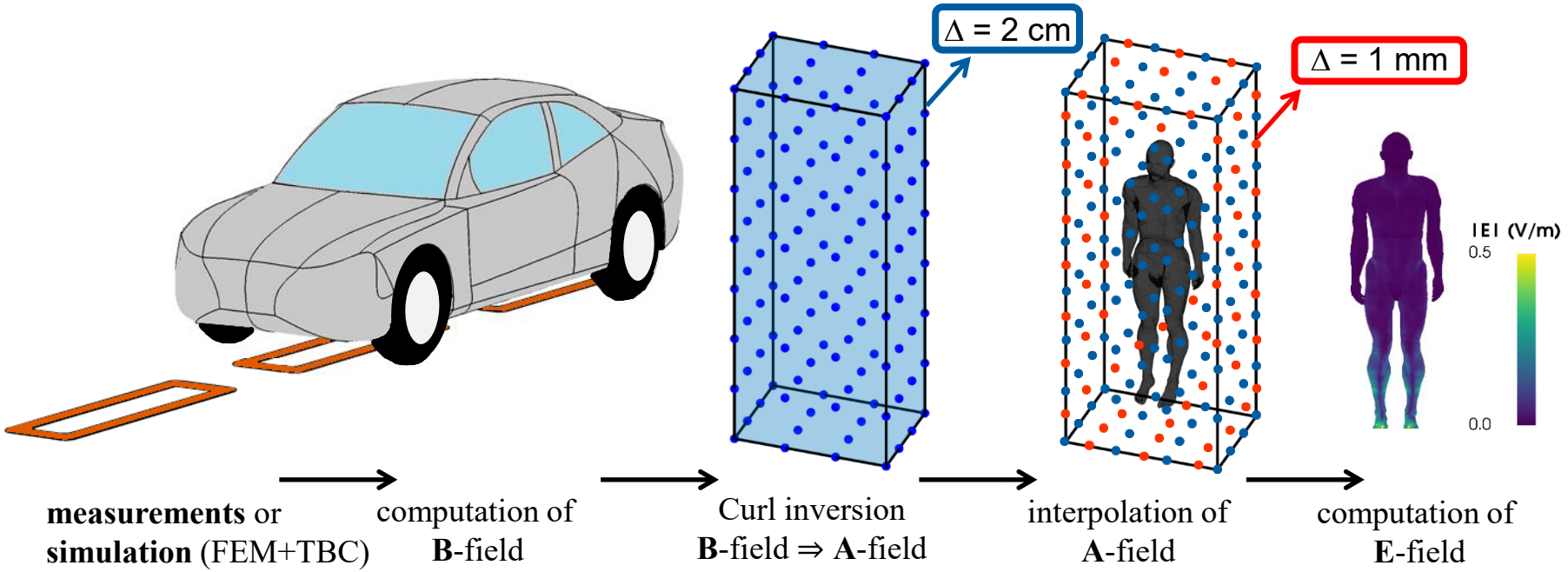
  - Compliance against ICNIRP BRs
- Conclusions & future works

Exposure Assessment Strategies

2 step approach:

1. Evaluate **external fields** in exposed region (FEM/TBC)*



2. Evaluate **internal fields** in anatomical models (SPFE-Sim4Life)

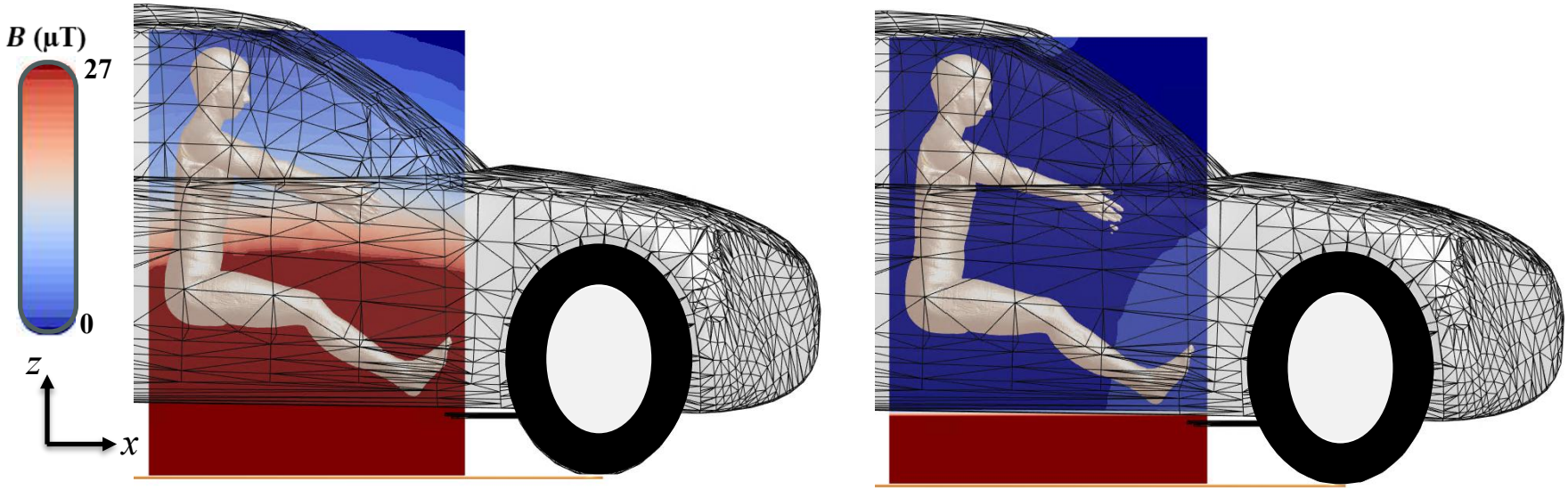
*T. Campi, S. Cruciani, V. De Santis, F. Maradei, and M. Feliziani, "Numerical characterization of the magnetic field in electric vehicles equipped with a WPT system," *Wireless Power Transfer*, vol. 4, pp. 78-87, 2017.

Compliance with ICNIRP RLs

Exposure scenario #1: Ella **driving**

CF chassis

Al chassis

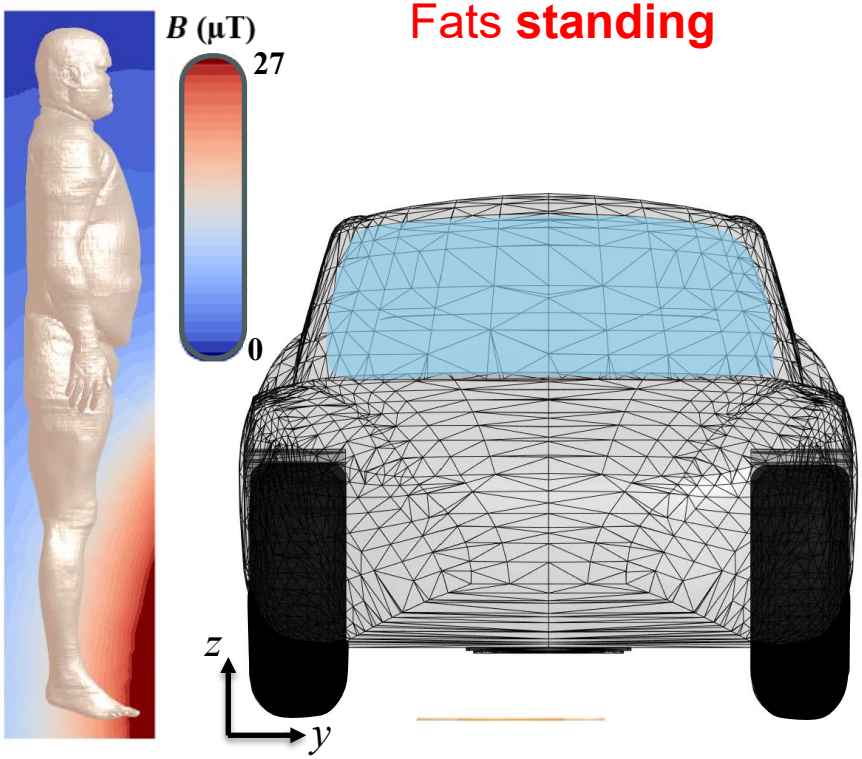


V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Compliance with ICNIRP RLs

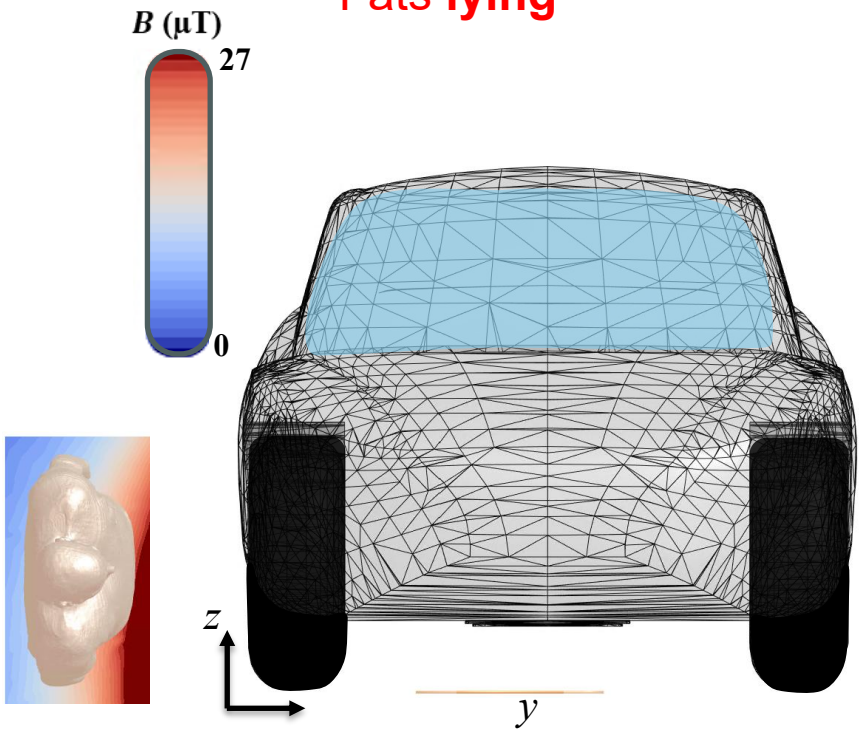
Exposure scenario #2:

Fats **standing**



Exposure scenario #3:

Fats **lying**

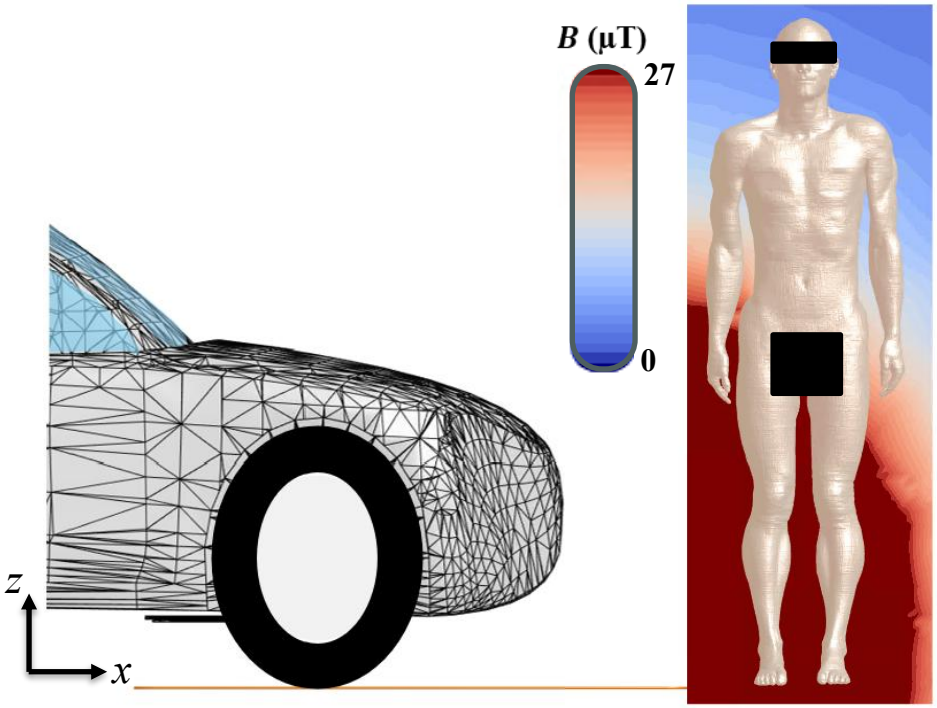


V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Compliance with ICNIRP RLs

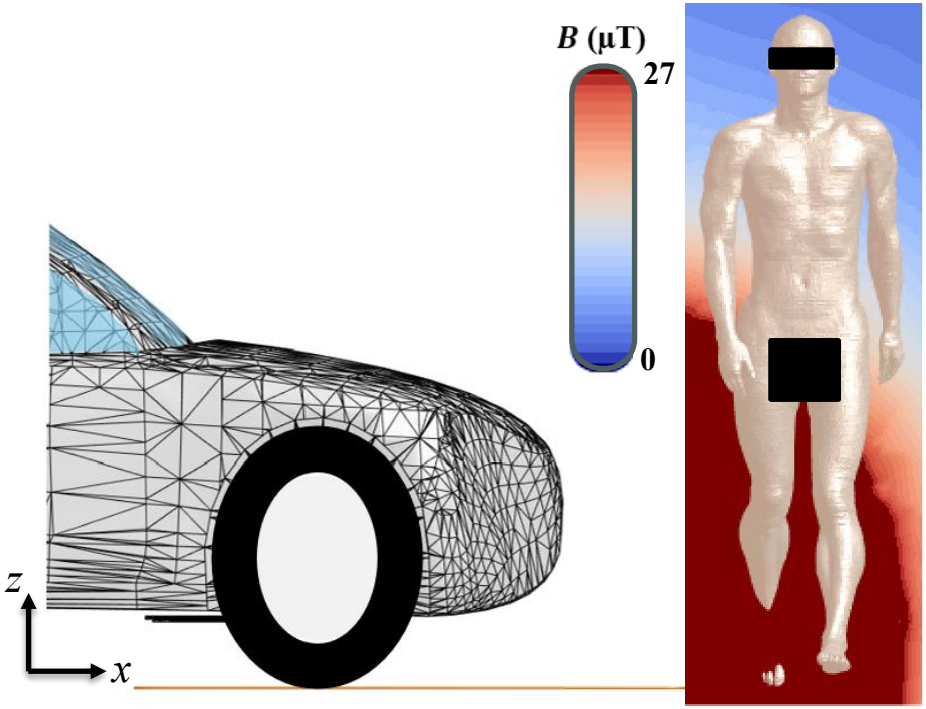
Exposure scenario #4:

Duke **standing**



Exposure scenario #5:

Duke **walking**



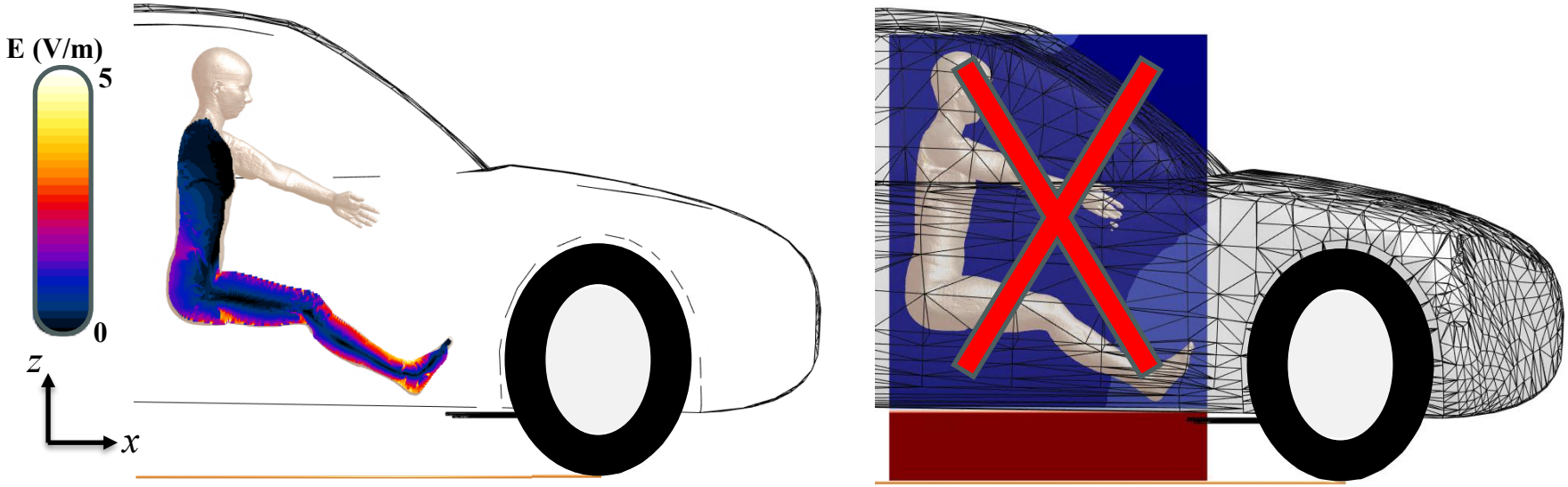
V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Compliance with ICNIRP BRs

Exposure scenario #1: Ella **driving**

CF chassis

Al chassis

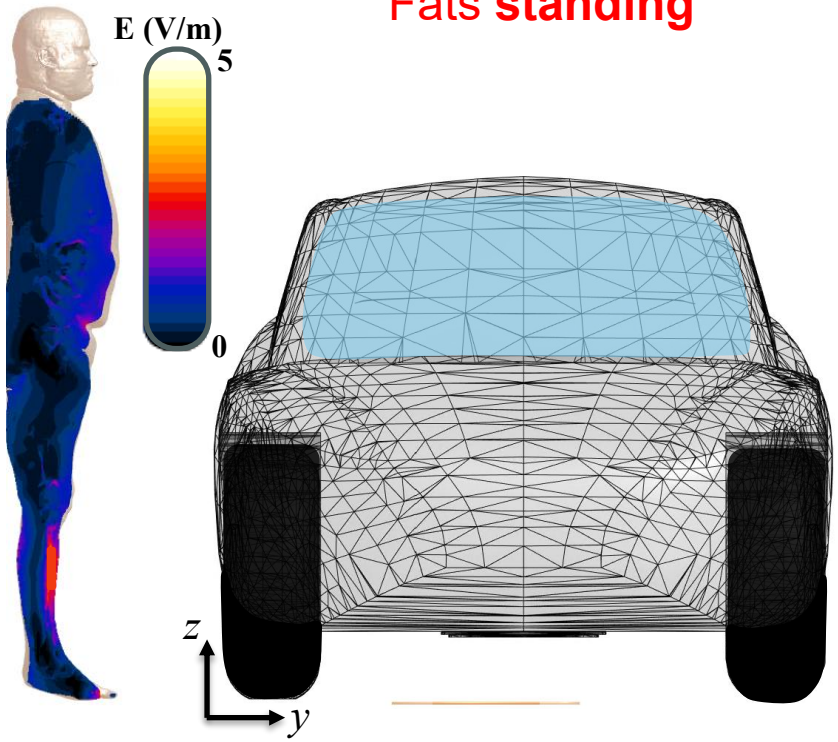


V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Compliance with ICNIRP BRs

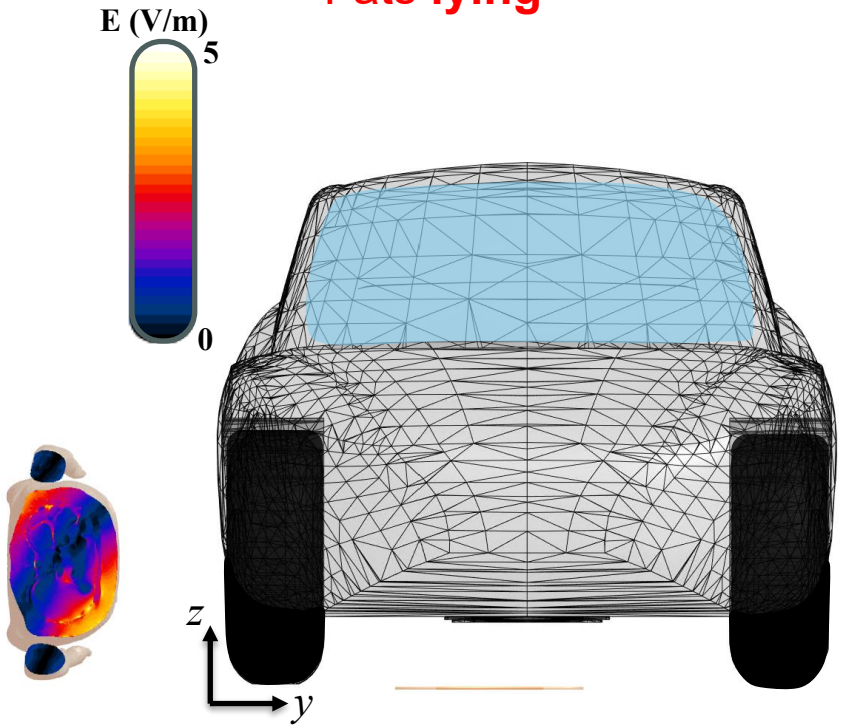
Exposure scenario #2:

Fats **standing**



Exposure scenario #3:

Fats **lying**

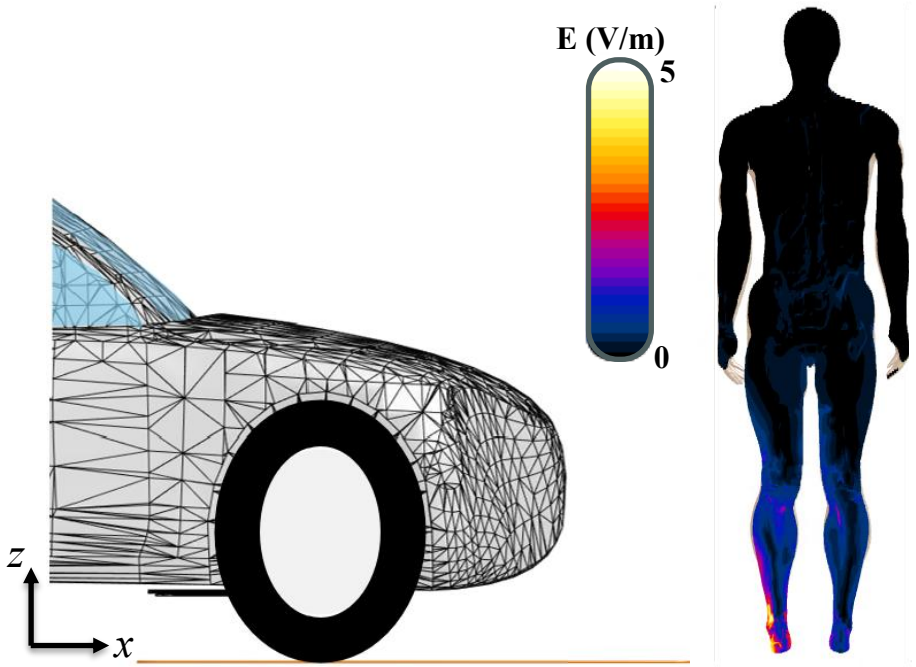


V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Compliance with ICNIRP BRs

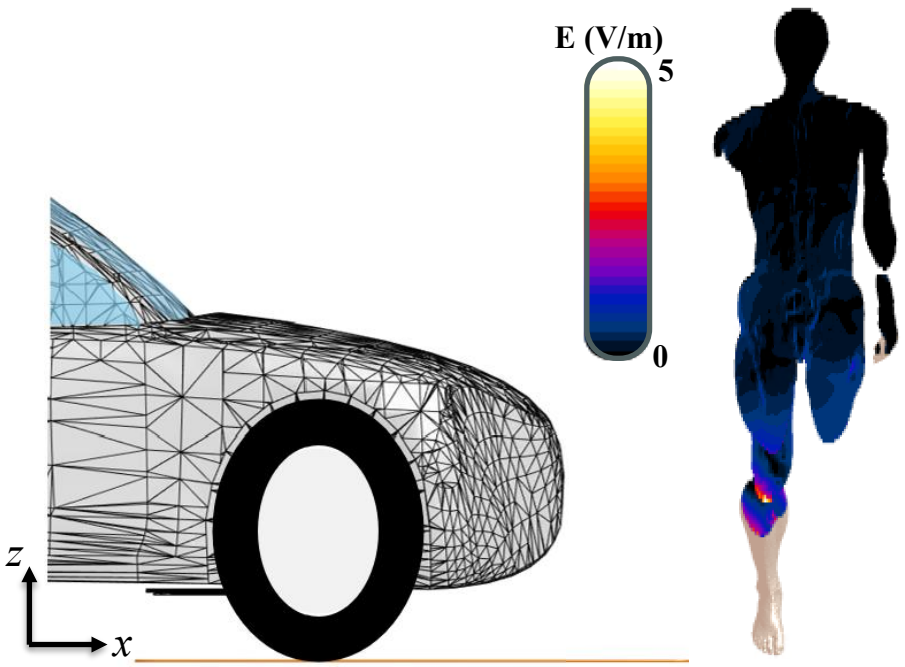
Exposure scenario #4:

Duke **standing**



Exposure scenario #5:

Duke **walking**



V. De Santis, W. Boumerdassi, T. Campi, and M. Feliziani, “Influence of Chassis Materials and Human Postures on the EMF Safety of a D-WPT System for Automotive Applications,” in Proc. *EMC Europe,* 1-5 Sept. 2025, Paris, France.

Summary of the Results

Exposure Index (EI): $EI_{peak} = \frac{E_{peak}}{E_{lim}}$; $EI_{99} = \frac{E_{99}}{E_{lim}}$; $E_{lim} = 11.47$ V/m

Exposure Scenario	Chassis Material	E_{peak} (†) (V/m)	E_{avg} (*) (V/m)	E_{99} (V/m)	EI_{avg}	EI_{99}
#1	Al	-	-	-	-	-
	CF	9.39	5.65	1.49	0.49	0.13
	Steel	-	-	-	-	-
#2	Steel	5.02	3.15	0.97	0.27	0.08
#3		8.94	5.43	1.34	0.47	0.12
#4		7.86	4.97	1.26	0.43	0.11
#5		**11.91**	8.49	1.55	0.74	0.14

(†) uniform grid resolution of $1 \times 1 \times 1$ mm^3 cubic volume

(*) induced E-field averaged over a $2 \times 2 \times 2$ mm^3 cubic volume

Outline

- Introduction
  - Case study 1: S-WPT system
  - Case study 2: D-WPT system
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  - Exposure scenarios
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  - Exposure assessment strategies
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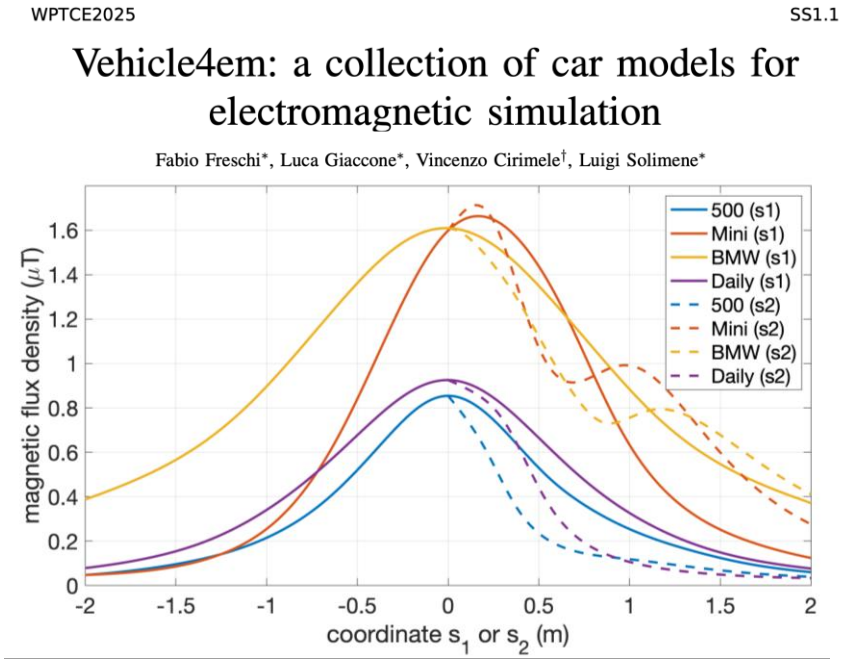
  - Compliance against ICNIRP BRs
- Conclusions & future works

Conclusions & Future Works

- **Compliance** of a specific D-WPT system **against ICNIRP-RLs/BRs** has been assessed for a wide range of postures and chassis material
  - Chassis **material** plays an important role (RLs **exceeded** only for CF)
  - **Posture** plays an important role (BRs **never exceeded** when avg.)
- Different vehicles for **intercomparisons** are under investigation

https://github.com/cadema-PoliTO/vehicle4em



Work in Progress

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

SAPIENZA UNIVERSITÀ DI ROMA

Electromagnetic modeling and design of WPT systems in compliance with EMC and EMF safety guidelines for automotive applications
PRIN 2022 scorrimento, Project N. 20224XN8RF

Politecnico di Torino

UNIVERSITÀ DEGLI STUDI DI UDINE
HIC SUNT FUTURA

Ministero dell'Università e della Ricerca

PRIN
PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE

Questions?

Thank you
for your attention !