SIMPACK User Meeting 2014
October 8 – 9, Augsburg, Germany

Ostfalia
University of
Applied Sciences

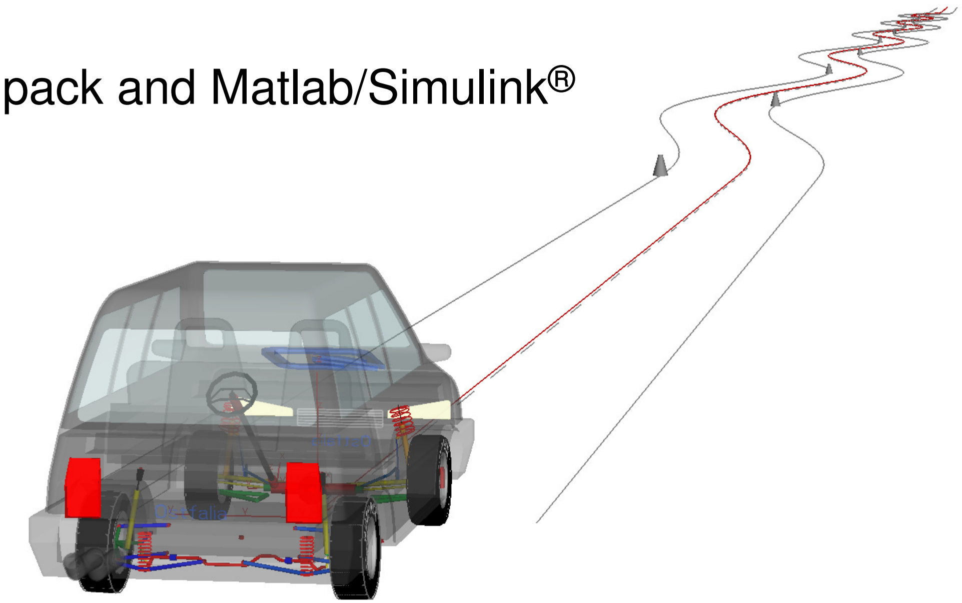
# Simulation of Vehicle Dynamics Control by active Steering Systems

Volker Dorsch, Faculty of Mechanical Engineering

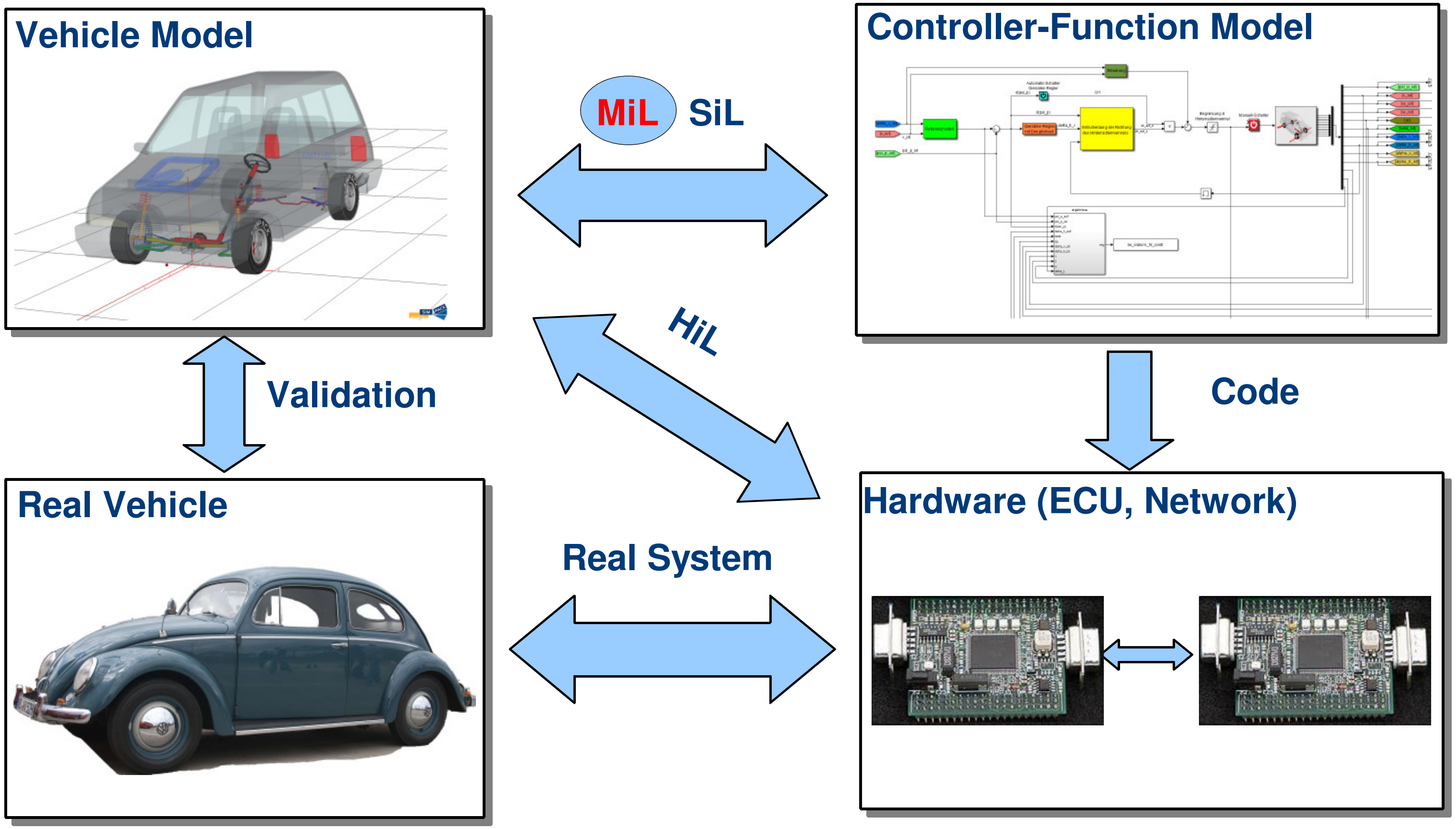
Salzgitter
Suderburg
Wolfenbüttel
Wolfsburg

# Overview

- Development scenario
- Validated mechanical multibody simulation (MBS) vehicle model
- Implementation of active steering at rear and front wheels
- Control strategy
- Co-Simulation of Simpack and Matlab/Simulink®
- Simulation Results
- Conclusions

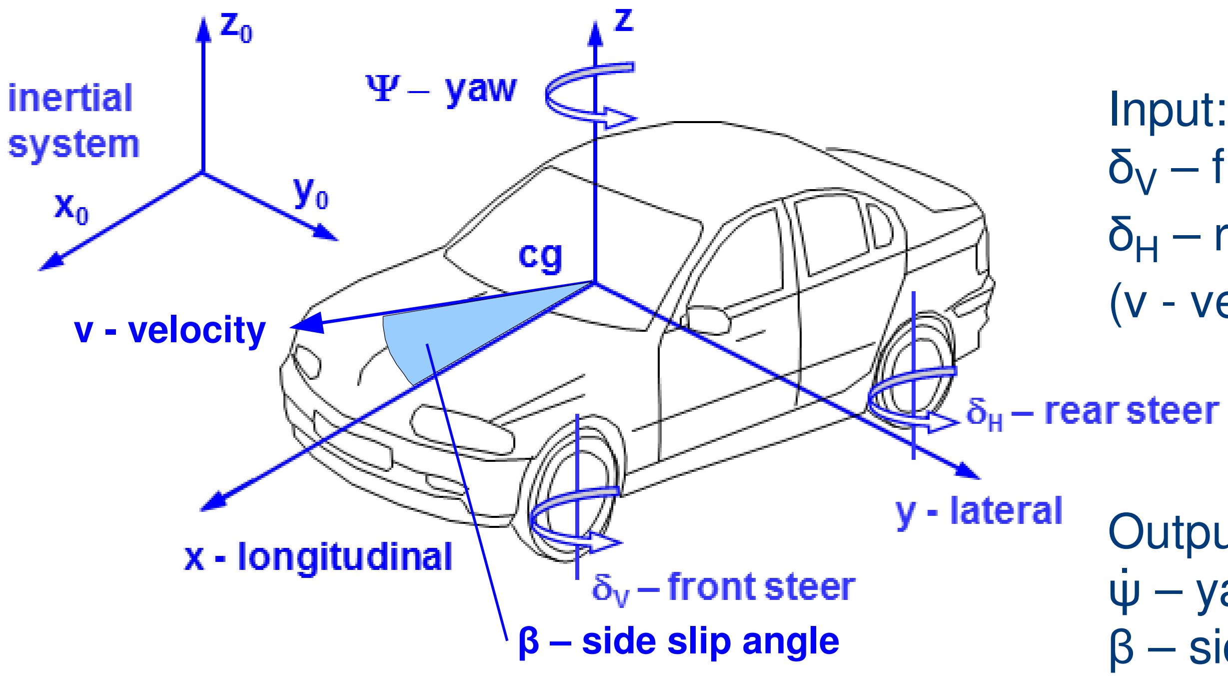


# Development Scenario



# MBS Model: Coordinates






Input:
$\delta_V$ – front steering angle
$\delta_H$ – rear steering angle
(v - velocity)

Output:
$\dot{\psi}$ – yaw rate
$\beta$ – side slip angle
$a_y$ – lateral acceleration

# Validation

Ostfalia University of Applied Sciences

Wolfenbüttel

Suspensions: simulation of Kinematics and Compliance (K&C) measurements

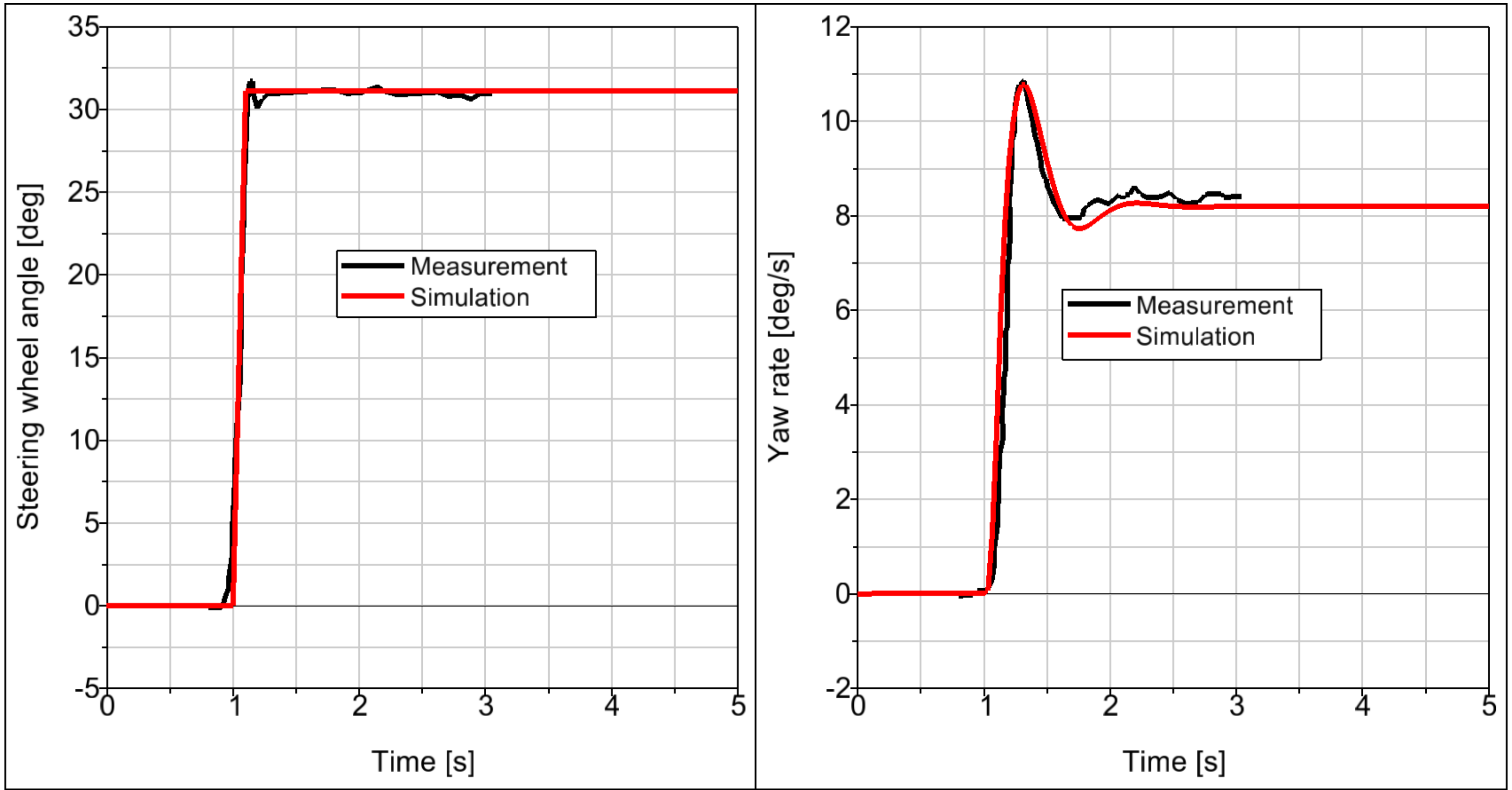
Complete vehicle model: step steering input maneuver

| | |
|---|---|
| driver | objective, no driver influence |
| velocity | 100 km/h |
| front wheel steering angle | sudden steering angle with more than 200 deg/s<br>steady-state lateral acceleration is 0.4 g |
| road surface | dry, $\mu$ = 0.9 |

# Simpack model validation:
# Step Steering Input

Ostfalia University of Applied Sciences

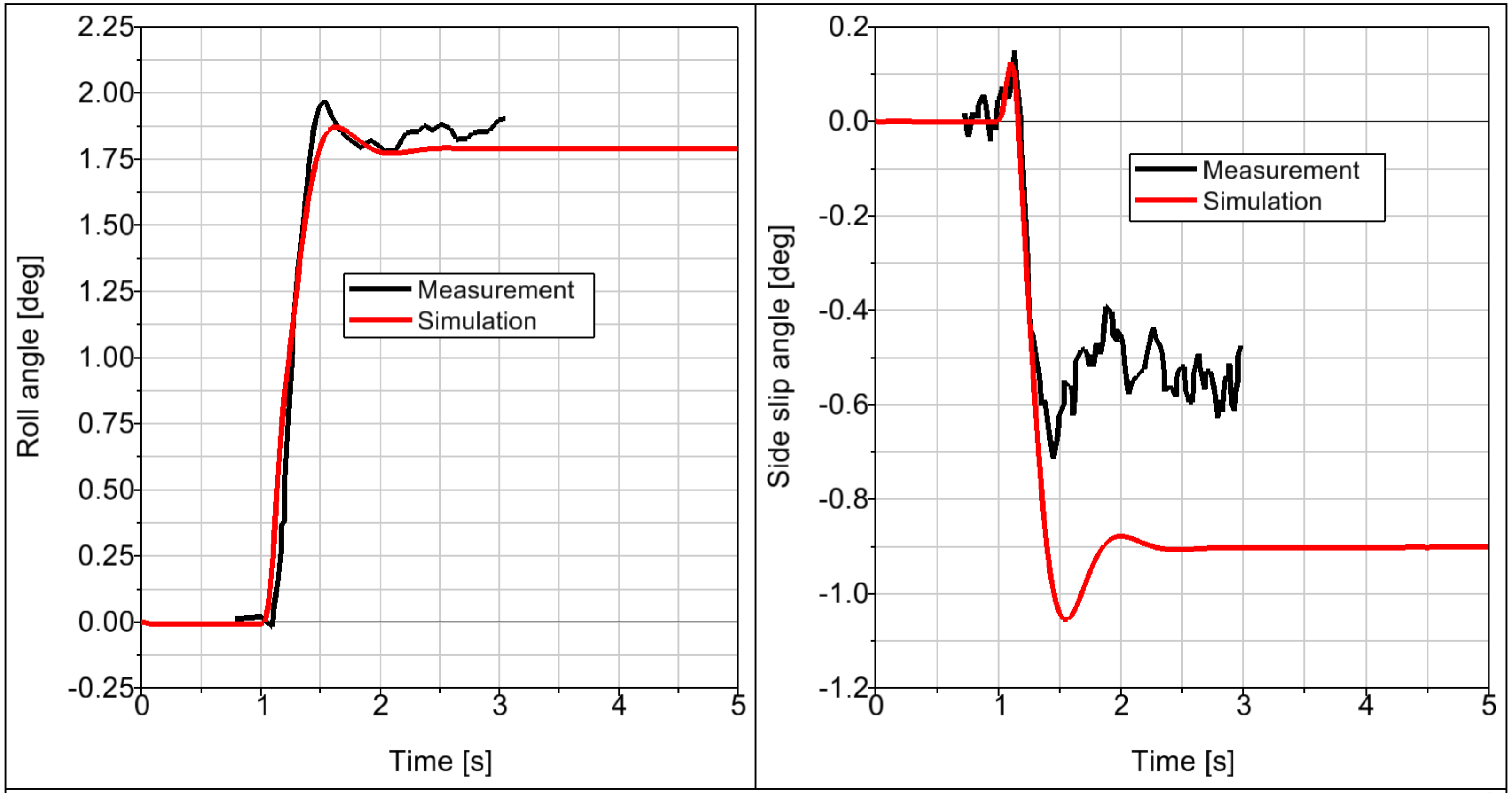
Wolfenbüttel



# Simpack model validation: Step Steering Input

Ostfalia University of Applied Sciences

Wolfenbüttel

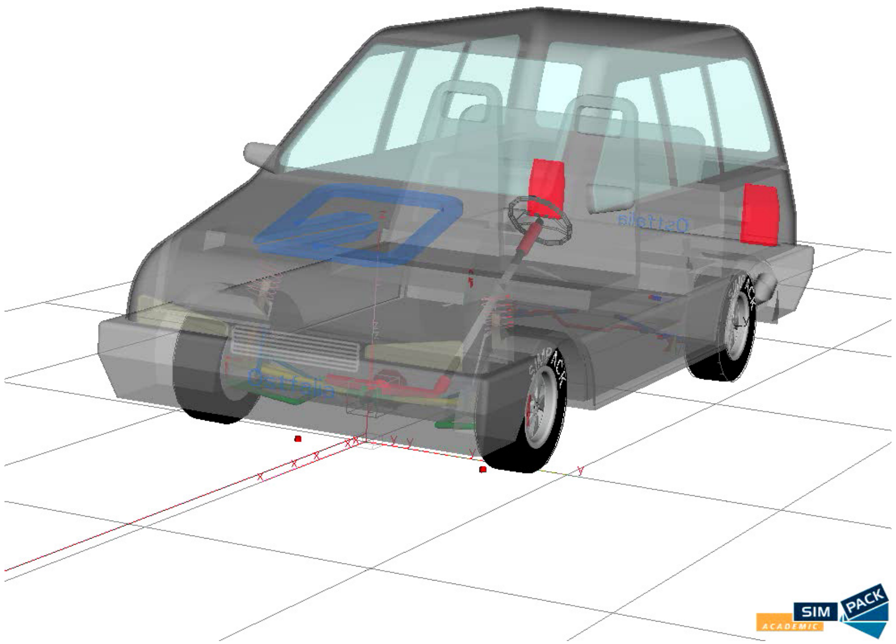



good correlation – realistic response of vehicle model

SIM PACK ACADEMIC

# MBS Model: steering systems





Active front and rear wheel steering

Simple implementation by

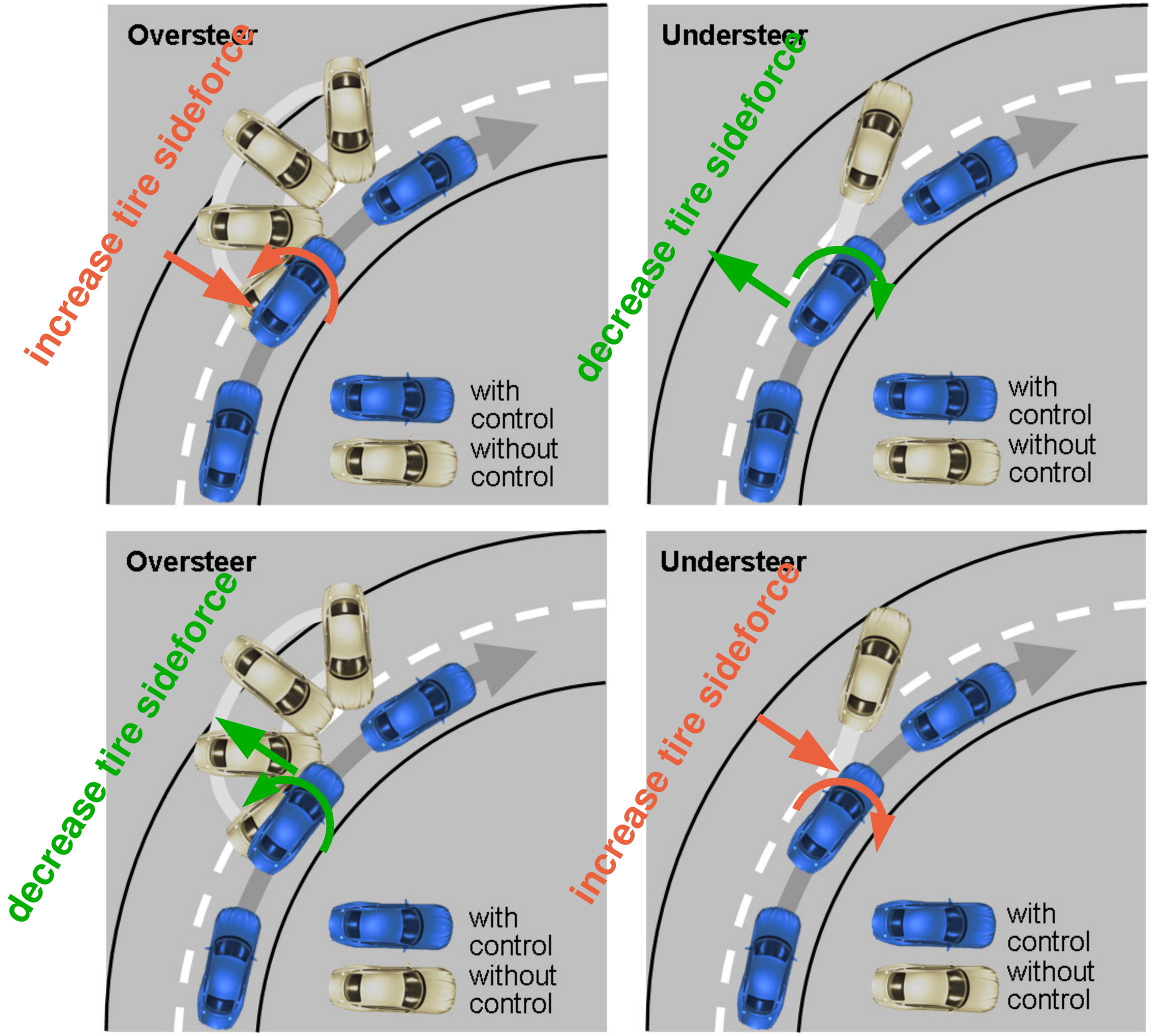
- additional rotational degrees of freedom at the corresponding wheels
- control of these degrees of freedom by external input of the co-simulated Matlab/Simulink controller model

Study of effects on vehicle dynamics

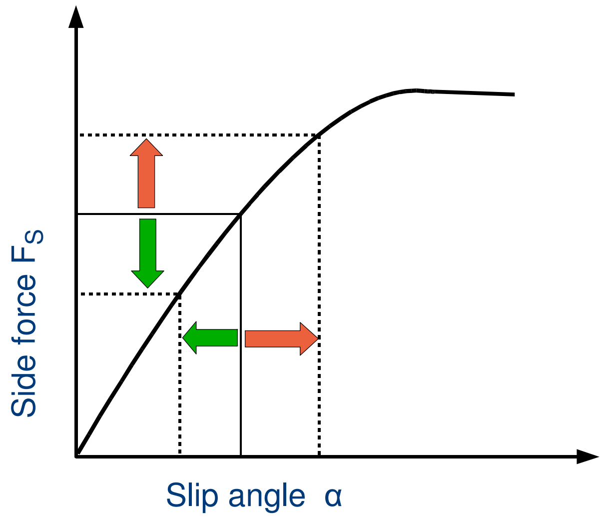
# Vehicle stabilization by adjusted steering angles

Ostfalia University of Applied Sciences

Wolfenbüttel



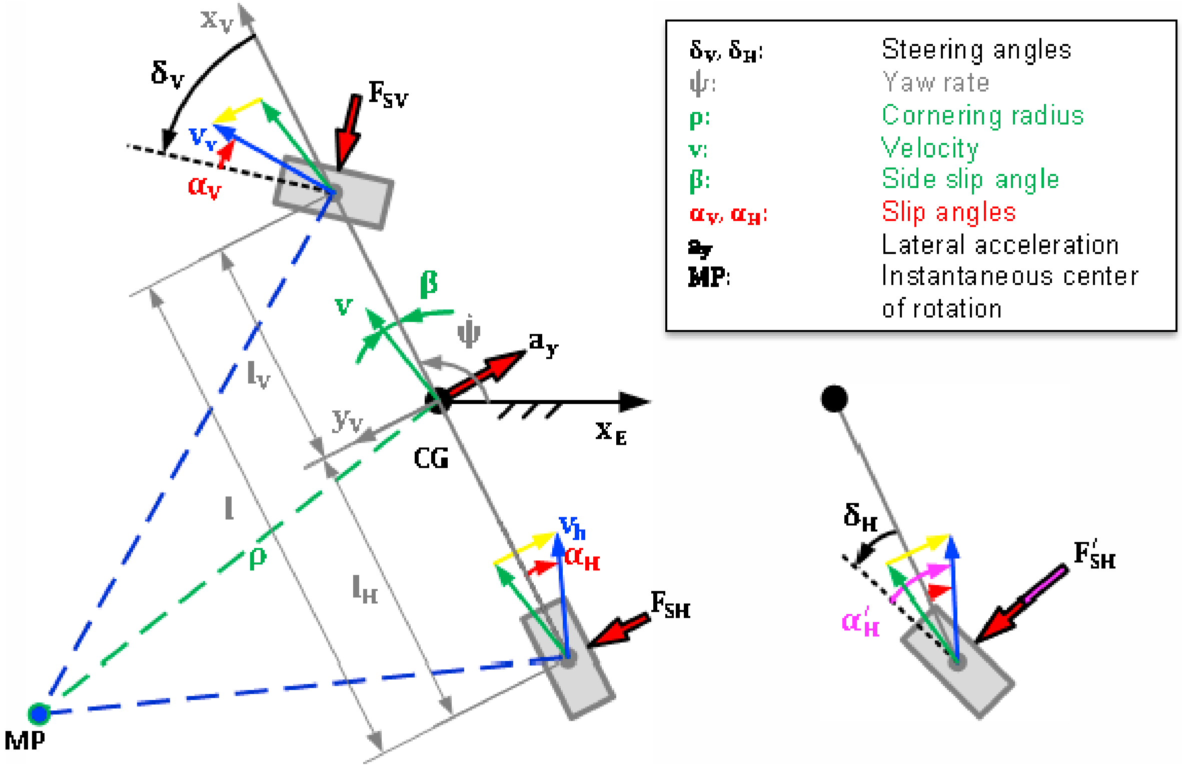

Active rear wheel steering: adjust tire slip angle α by rear wheel steering angle




Active front wheel steering: adjust tire slip angle α by superimposed steering angle

# Control algorithm: bicycle model






Equations of motion with linearized tire behavior: $F_S = C_\alpha \alpha$

$$\ddot{\Psi} = \frac{C_{\alpha H} l_H - C_{\alpha V} l_V}{J_z} \beta - \frac{C_{\alpha H} l_H^2 + C_{\alpha V} l_V^2}{J_z v} \dot{\Psi} + \frac{C_{\alpha V} l_V}{J_z} \delta_V - \frac{C_{\alpha H} l_H}{J_z} \delta_H$$

$$\dot{\beta} = -\frac{C_{\alpha V} + C_{\alpha H}}{m v} \beta + \left[\frac{C_{\alpha H} l_H - C_{\alpha V} l_V}{m v^2} - 1\right] \dot{\Psi} + \frac{C_{\alpha V}}{m v} \delta_V + \frac{C_{\alpha H}}{m v} \delta_H$$

# Control algorithm: bicycle model



In case of steady-state cornering (i.e. $\ddot{\Psi}=0$ and $\dot{\beta}=0$) without rear wheel angle

$$\dot{\Psi}=\frac{v_x \delta_w}{(l_V+l_H)(1+\frac{v_x^2}{v_{ch}^2})}$$

The characteristic velocity $v_{ch}$ can be computed (or be identified in tests)

$$v_{ch}=\frac{C_{\alpha V} C_{\alpha H} l^2}{m(C_{\alpha H} l_H - C_{\alpha V} l_V)}$$

Furthermore the maximum yaw rate is limited

$$|\dot{\Psi}|\leqslant\frac{a_{y,max}}{v_x}$$

The yaw rate $\dot{\Psi}$ is used as desired yaw rate in the control algorithm.

# Control algorithm: predict rear wheel steering angle

Ostfalia University of Applied Sciences

Wolfenbüttel

Setting $\dot{\beta}=0$ and $\beta=0$ in the differential equations of the bicycle model yields

$$\frac{\delta_H(s)}{\delta_V(s)}=K_{\delta_H}\frac{1+T_z s}{1+T_1 s}$$

with

$$K_{\delta_H}=\frac{C_{\alpha V} C_{\alpha H} l_H l - C_{\alpha V} l_V m v^2}{C_{\alpha V} C_{\alpha H} l_V l + C_{\alpha H} l_H m v^2},$$

$$T_z=\frac{J_z v}{C_{\alpha H} l_H l - l_V m v^2},$$

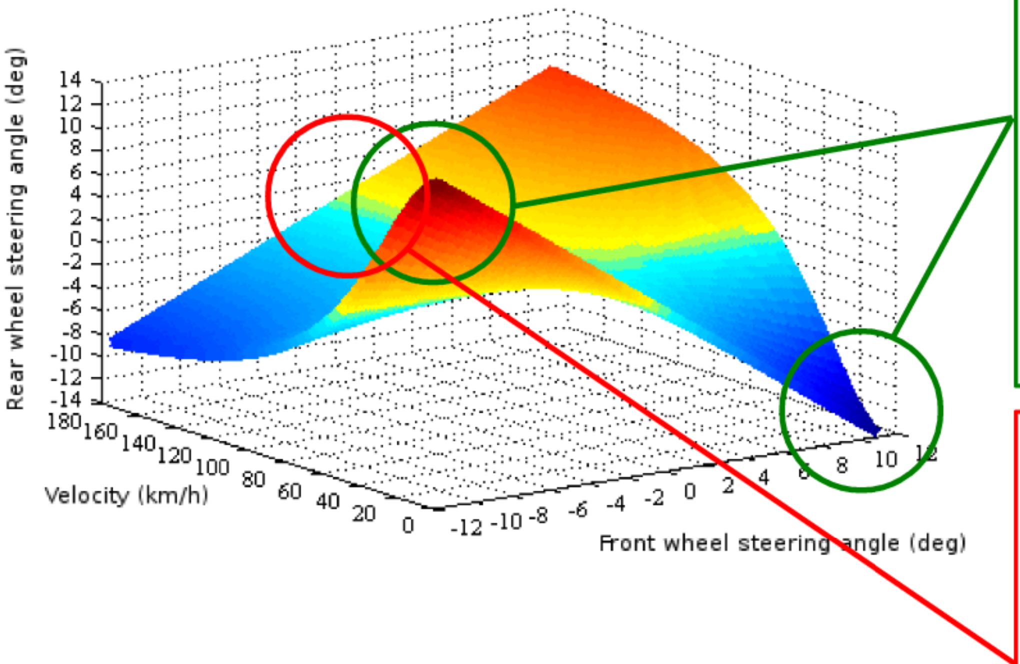
$$T_1=\frac{J_z v}{C_{\alpha V} l_V l - l_H m v^2}$$

[Woernle, C.: Fahrmechanik. Lecture notes, University of Rostock]

The steady-state case with $K_{\delta H}$ results in a characteristic diagram, that is used as a first prediction of the rear wheel steering angle.

# Control algorithm: predict rear wheel steering angle





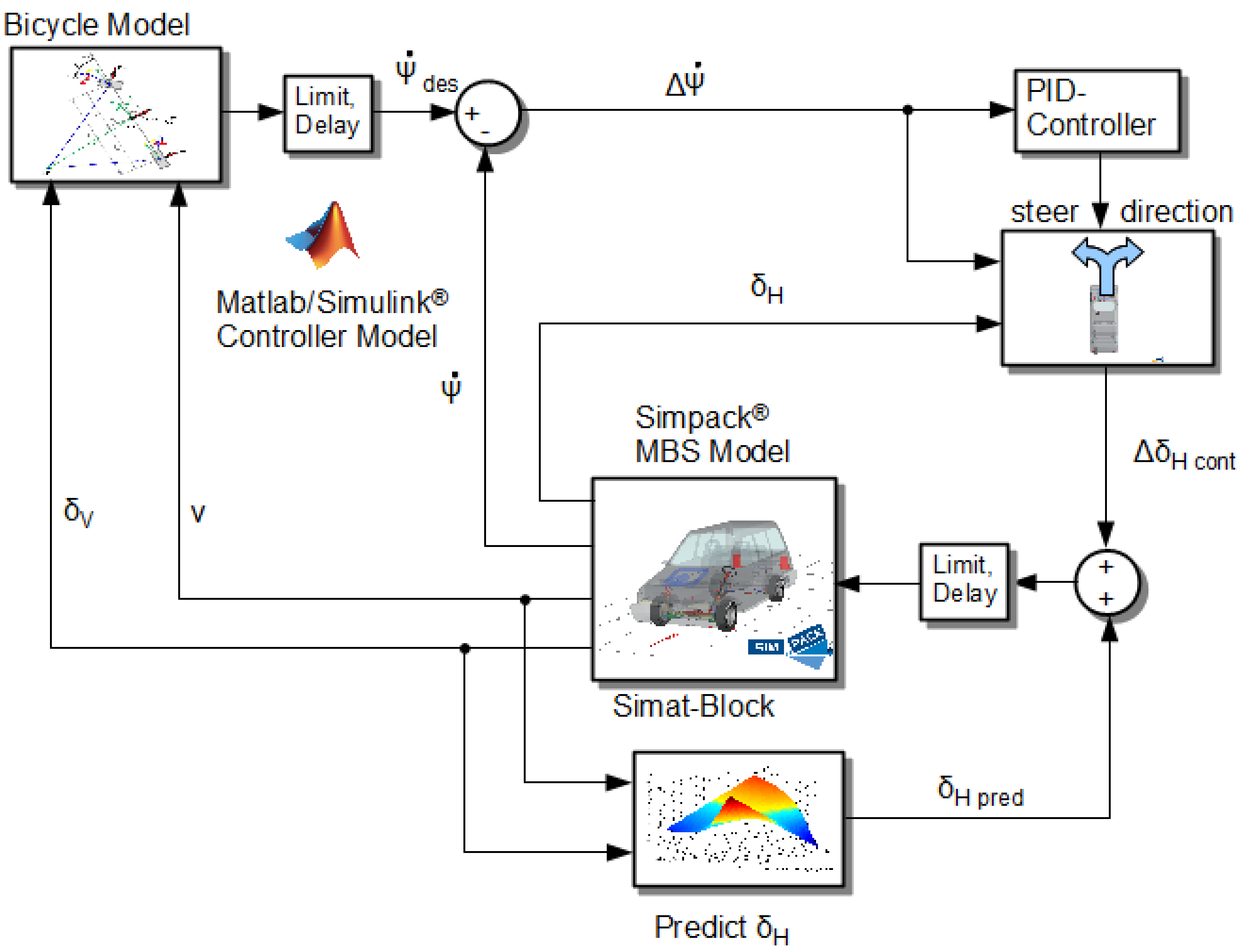

low velocities and
large front wheel steering angle:

high velocities and
small front wheel steering angle:

Open-loop rear wheel steering angle as predictor

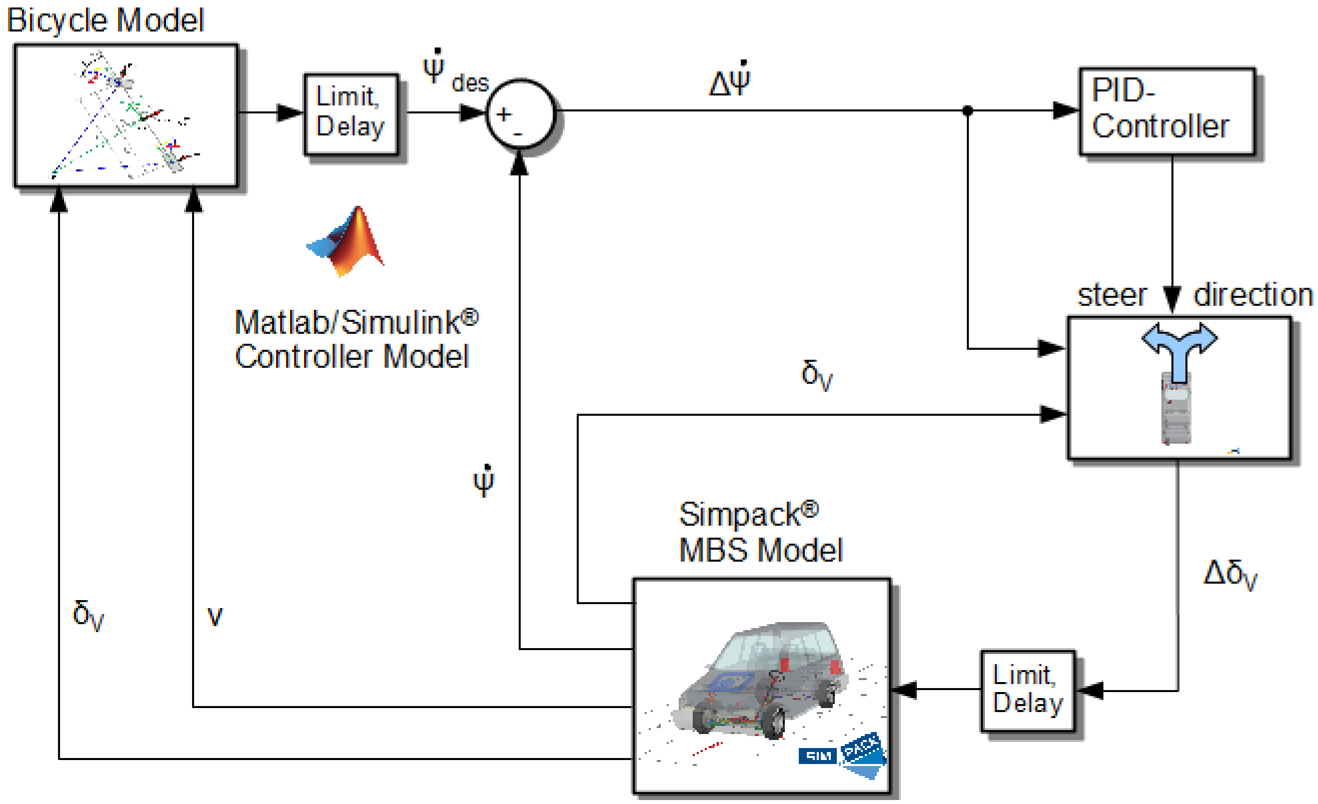
# Active rear wheel steering: Control structure with co-simulation





# Active front wheel steering: Control structure with co-simulation





# Steering angle orientation

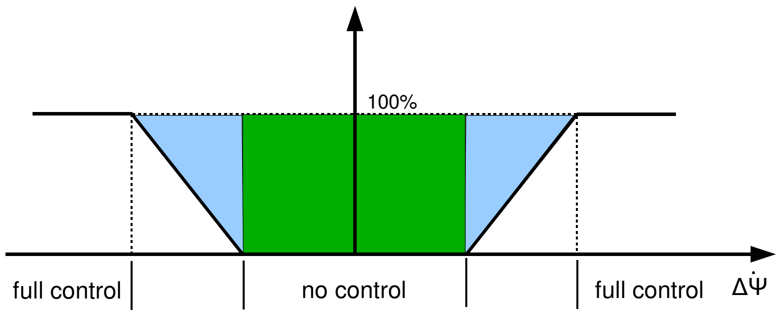


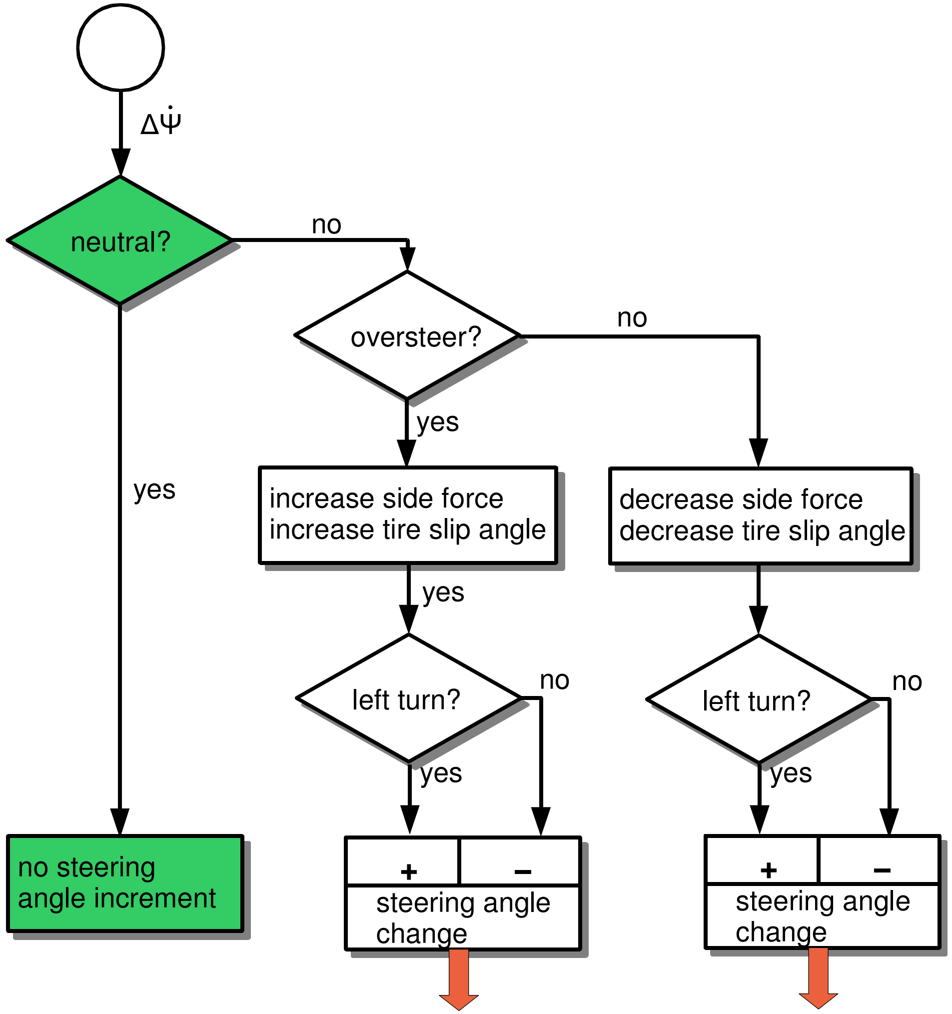
## Active rear wheel steering

$|\dot{\Psi}_{des}| - |\dot{\Psi}| < 0$ oversteer
$|\dot{\Psi}_{des}| - |\dot{\Psi}| \approx 0$ neutral
$|\dot{\Psi}_{des}| - |\dot{\Psi}| > 0$ understeer

$\dot{\Psi} > 0$ left turn
$\dot{\Psi} < 0$ right turn

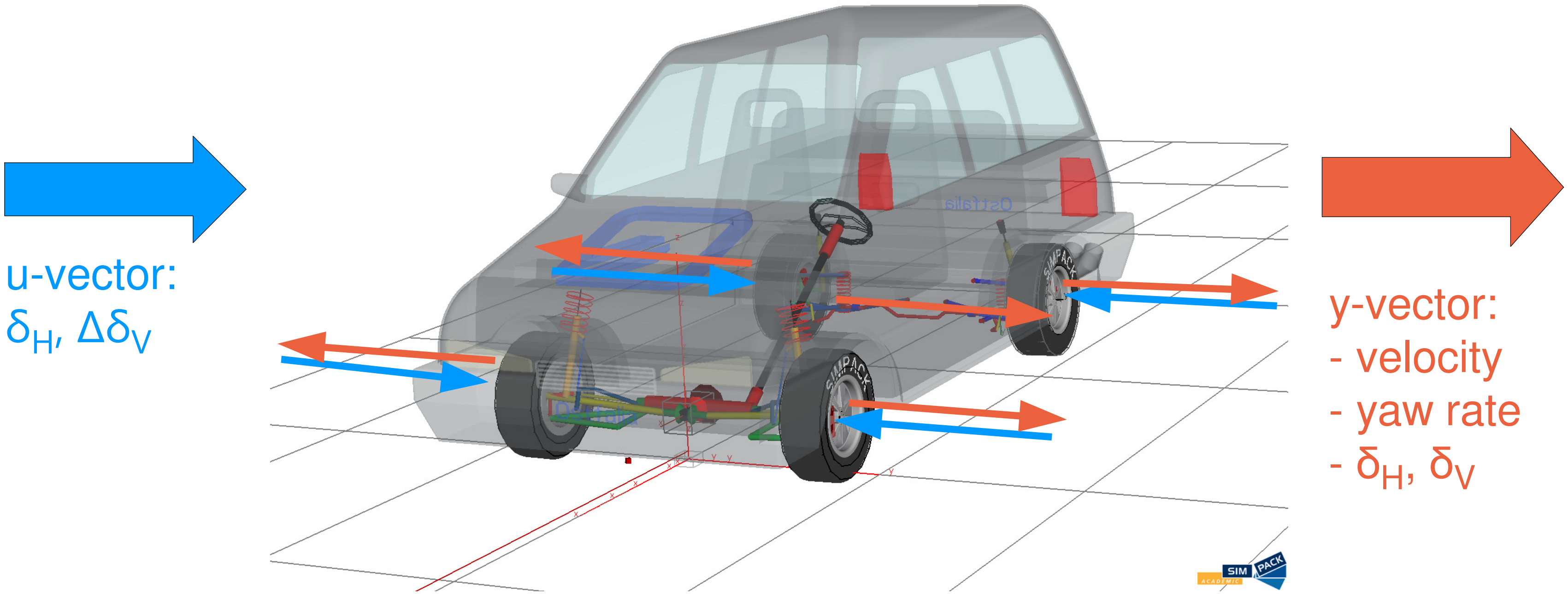
## Tolerance function to avoid hard switch on – switch off effect



# Co-Simulation: Input - Output



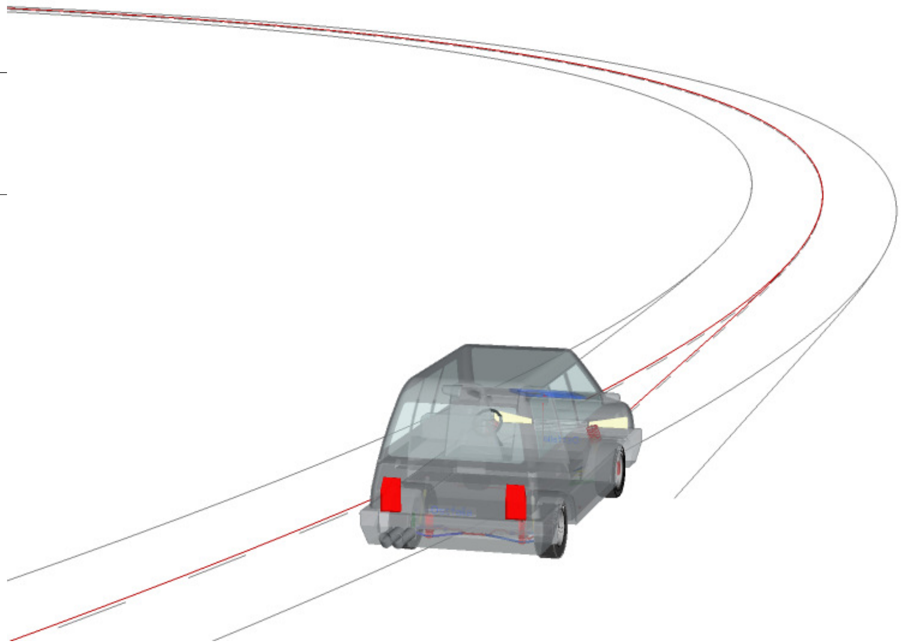



Co-simulation:
- Simpack and Matlab/Simulink® run parallel
- Data exchange at each millisecond
- Relatively slow motion of the whole vehicle: uncritical

# Maneuver steady-state cornering

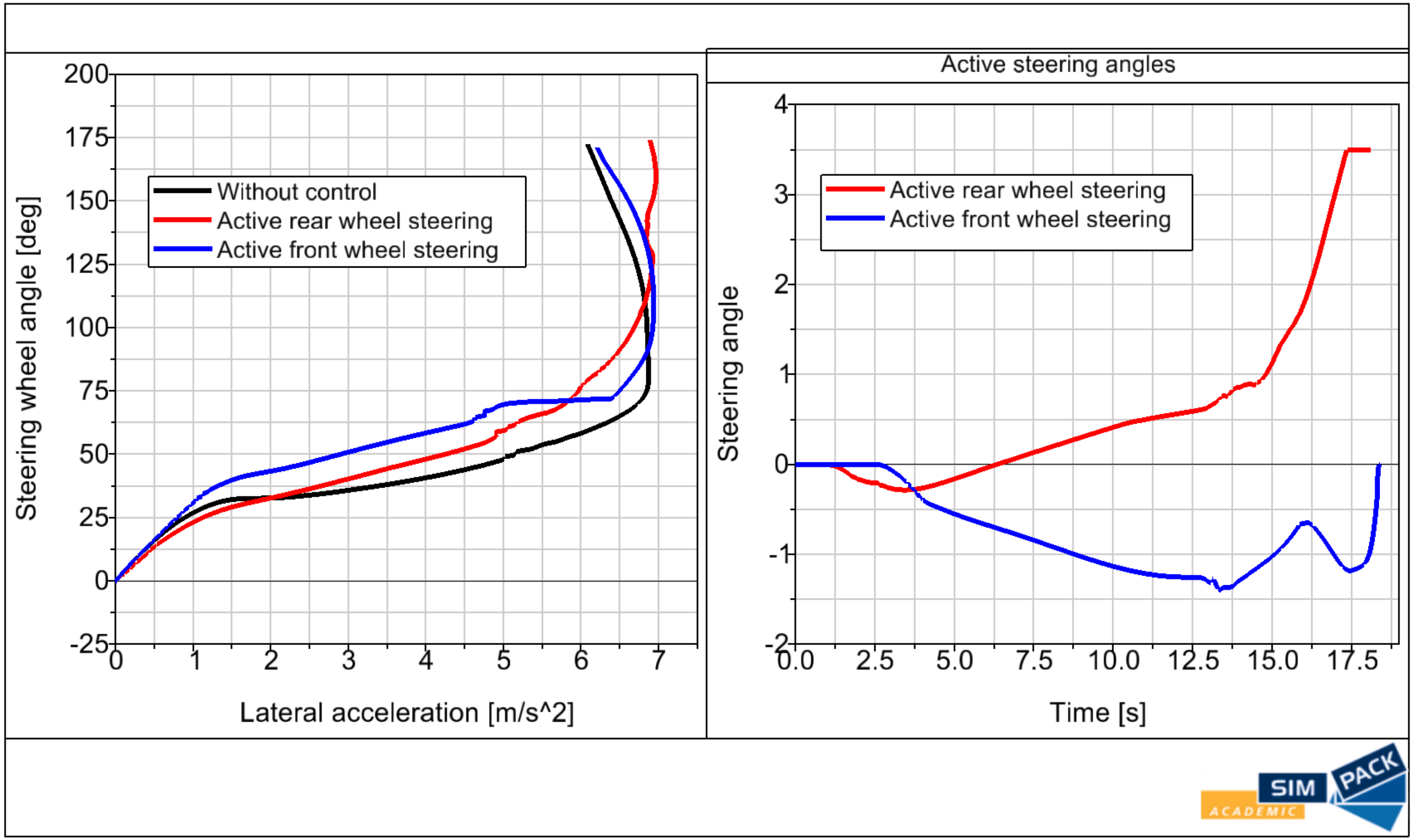


| | |
|---|---|
| Driver | Simpack driver model, driver influence |
| Velocity | increasing up to 75 km/h |
| Track | Circle with 80 m radius |
| Steering wheel angle input | closed loop, by driver |
| Road surface | dry, μ = 0.9 |



# Steady-state cornering: simulation results

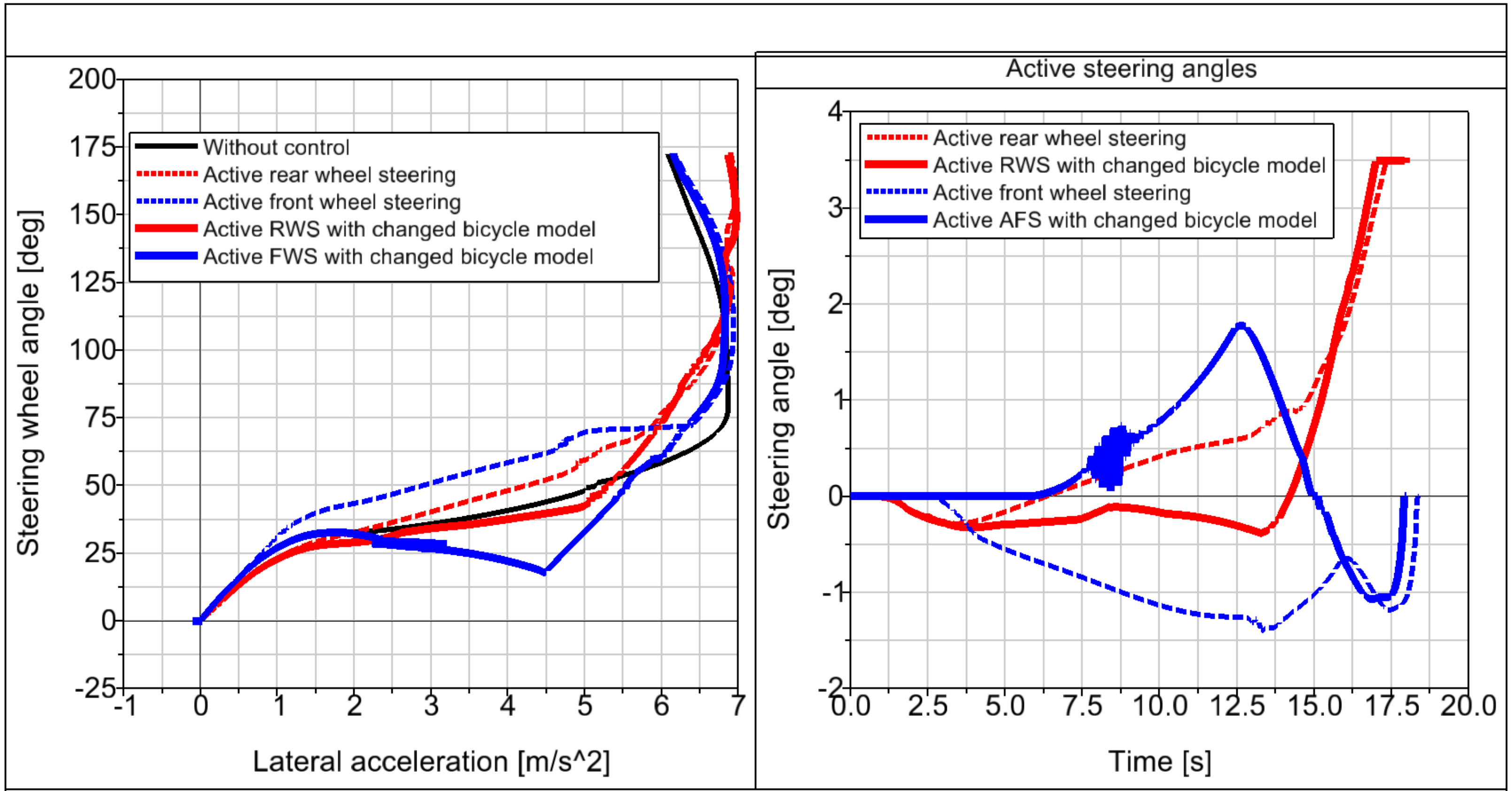




# Steady-state cornering: simulation results

Ostfalia University of Applied Sciences

Wolfenbüttel




Change of cornering behavior by change of bicycle model parameters in the control algorithm

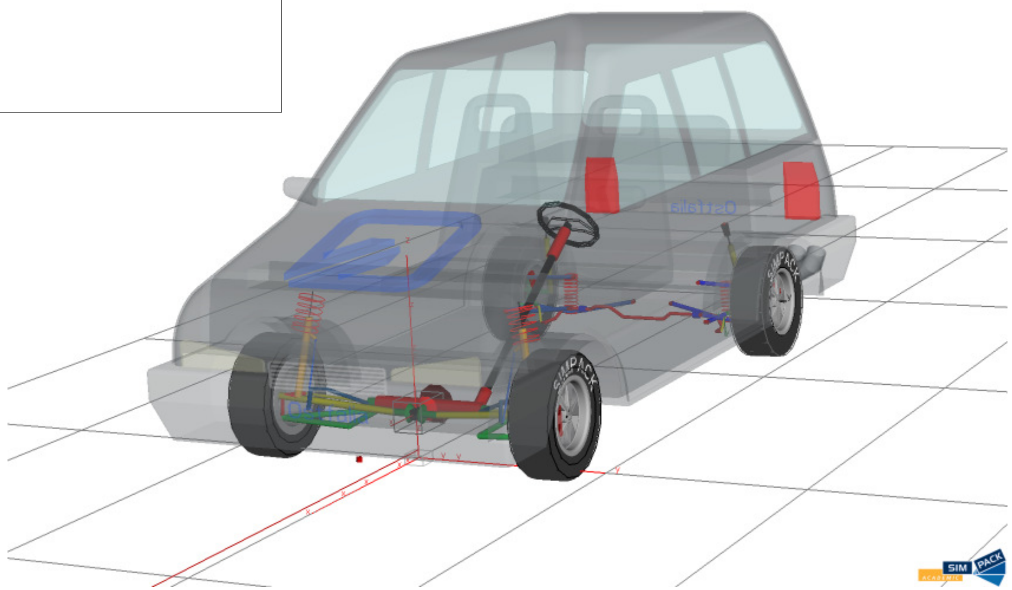
SIM PACK ACADEMIC

# Maneuver step steering input

Ostfalia University of Applied Sciences

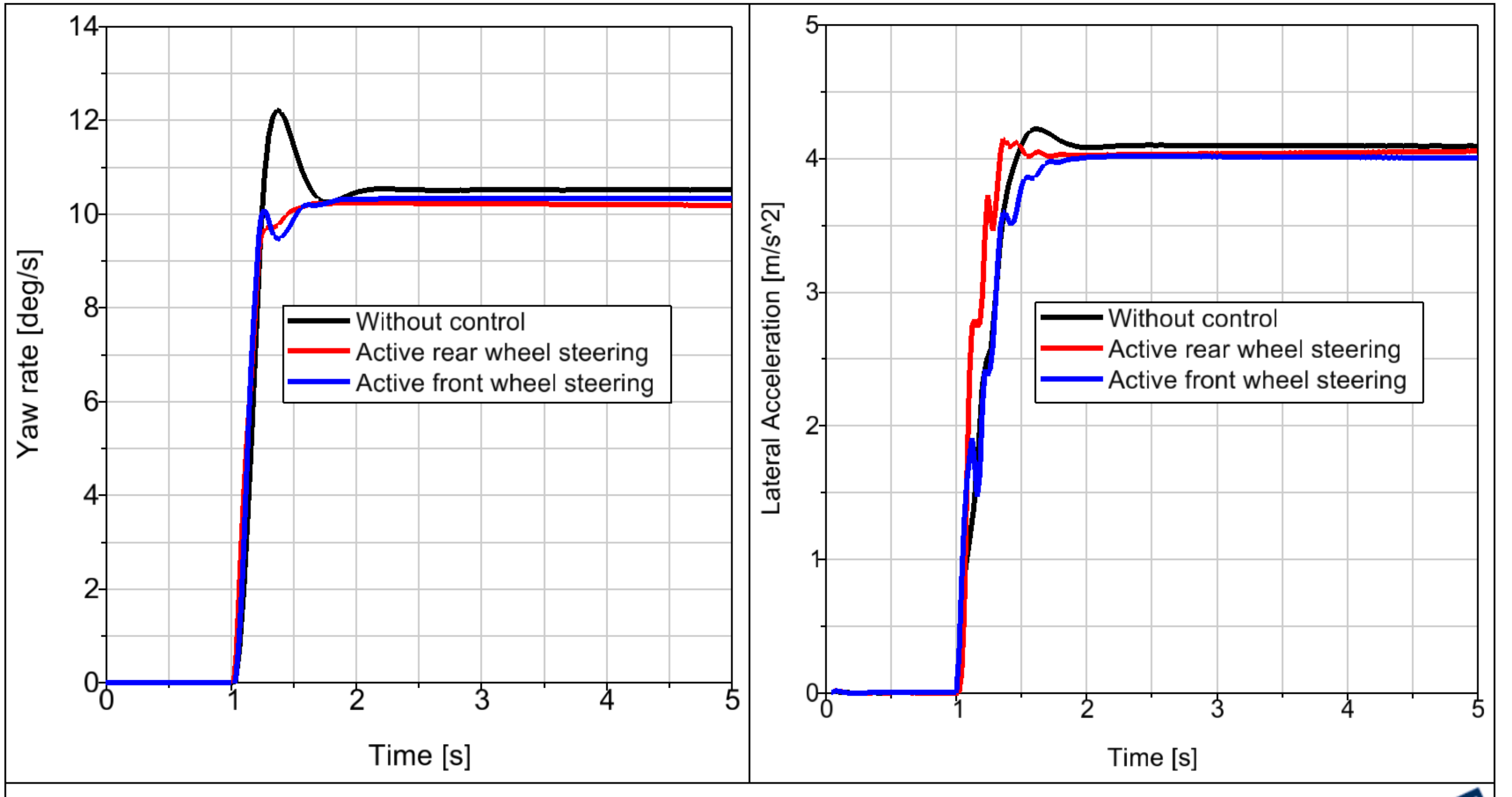
Wolfenbüttel

| | |
|---|---|
| Driver | objective, no driver influence |
| Velocity | 80 km/h |
| Steering wheel angle input | sudden steering angle step with more than 200 deg/s, steady-state lateral acceleration is 0.4 g |
| Road surface | dry, μ = 0.9 |



# Step steering input: simulation results



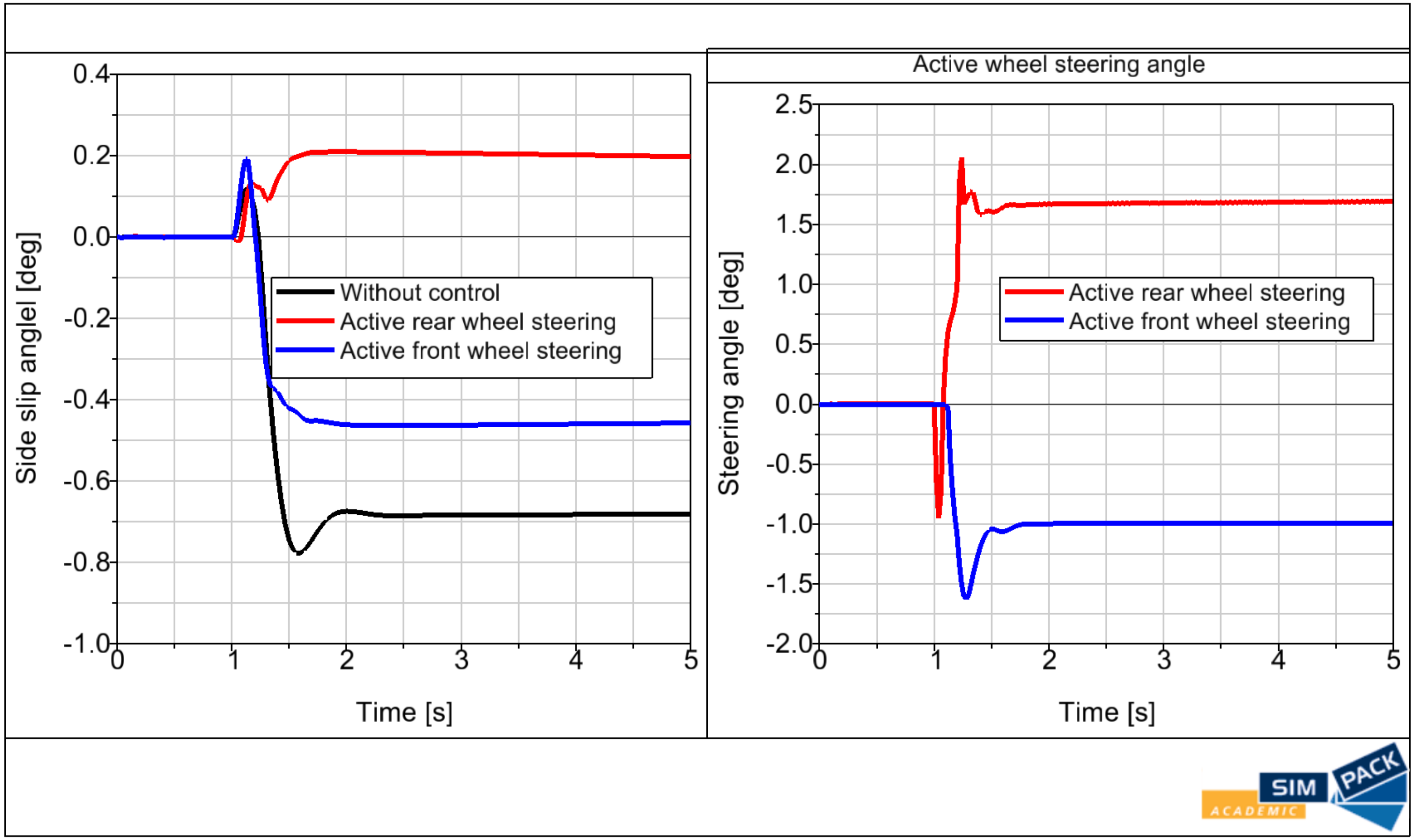



Peak reduction

# Step steering input: simulation results

Ostfalia
University of
Applied Sciences

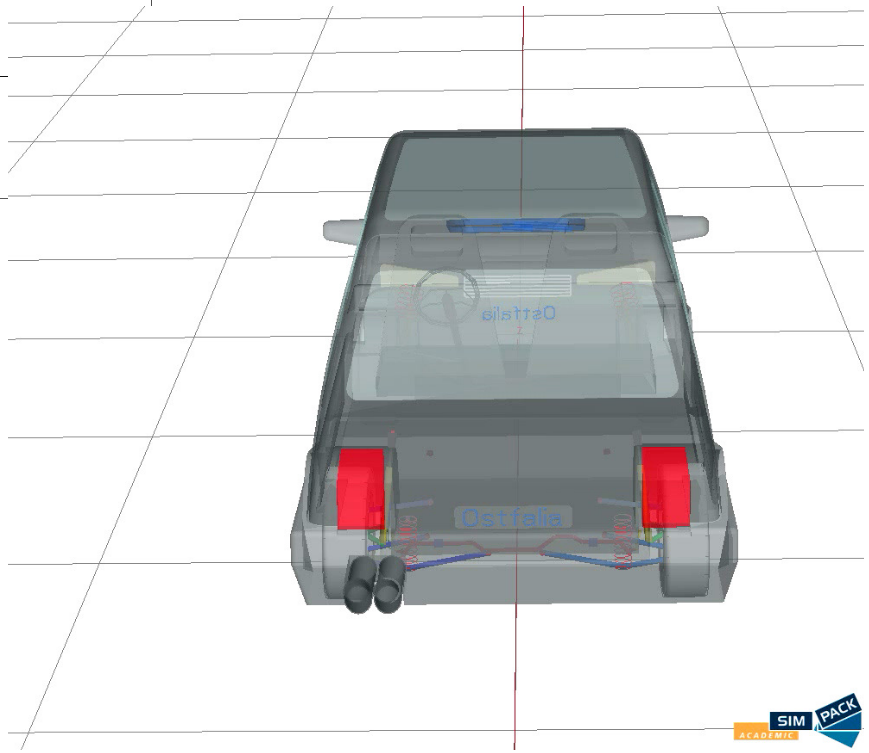
Wolfenbüttel



# Maneuver sine with dwell



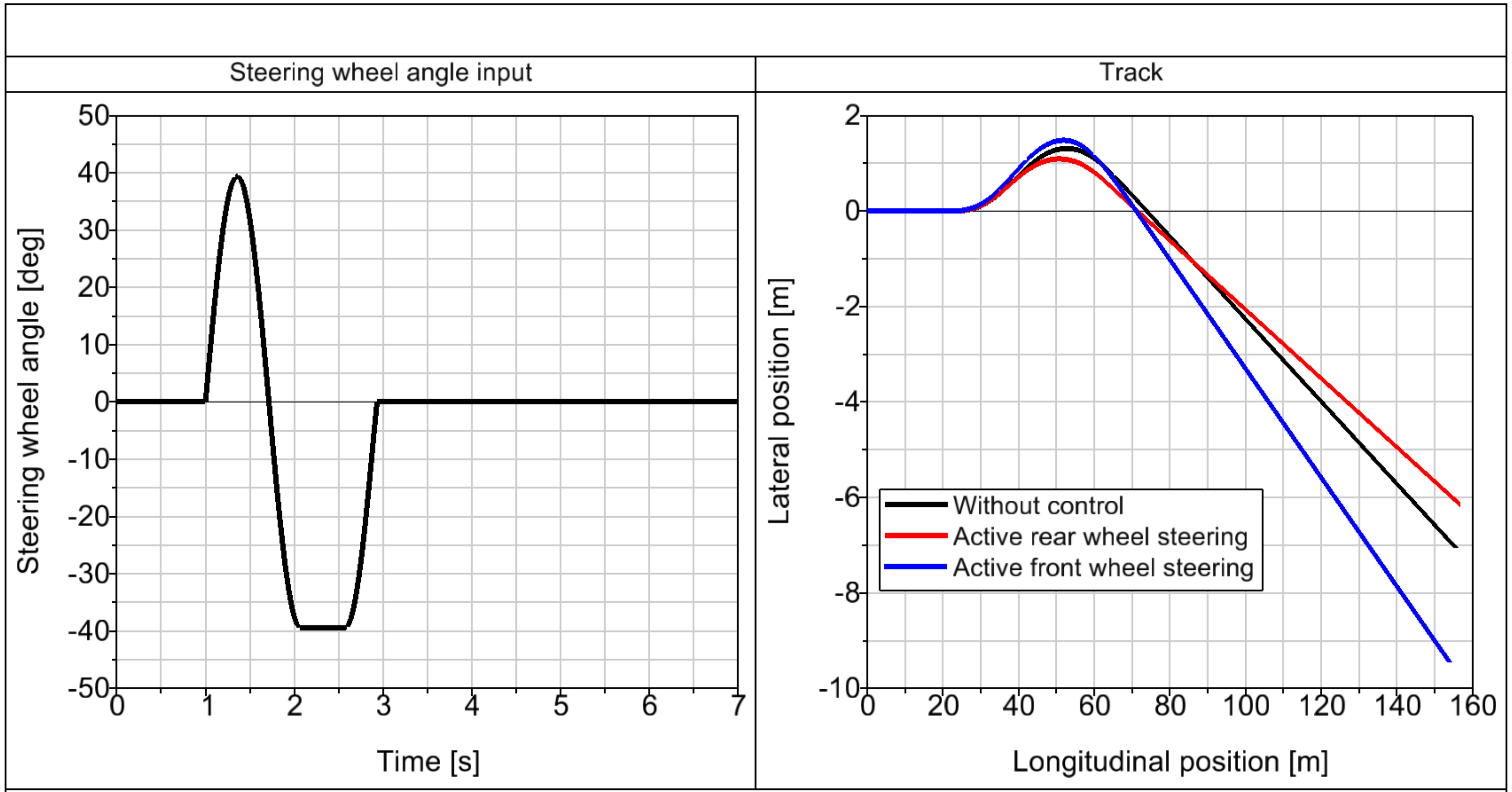
| | |
|---|---|
| Driver | objective, no driver influence |
| Velocity | 80 km/h |
| Steering wheel angle input | single sine of 0.7 Hz with dwell of 500 ms after ¾ of period, steady-state lateral acceleration of amplitude is 0.4 g |
| Road surface | dry, μ = 0.9 |



# Sine with dwell: Simulation results

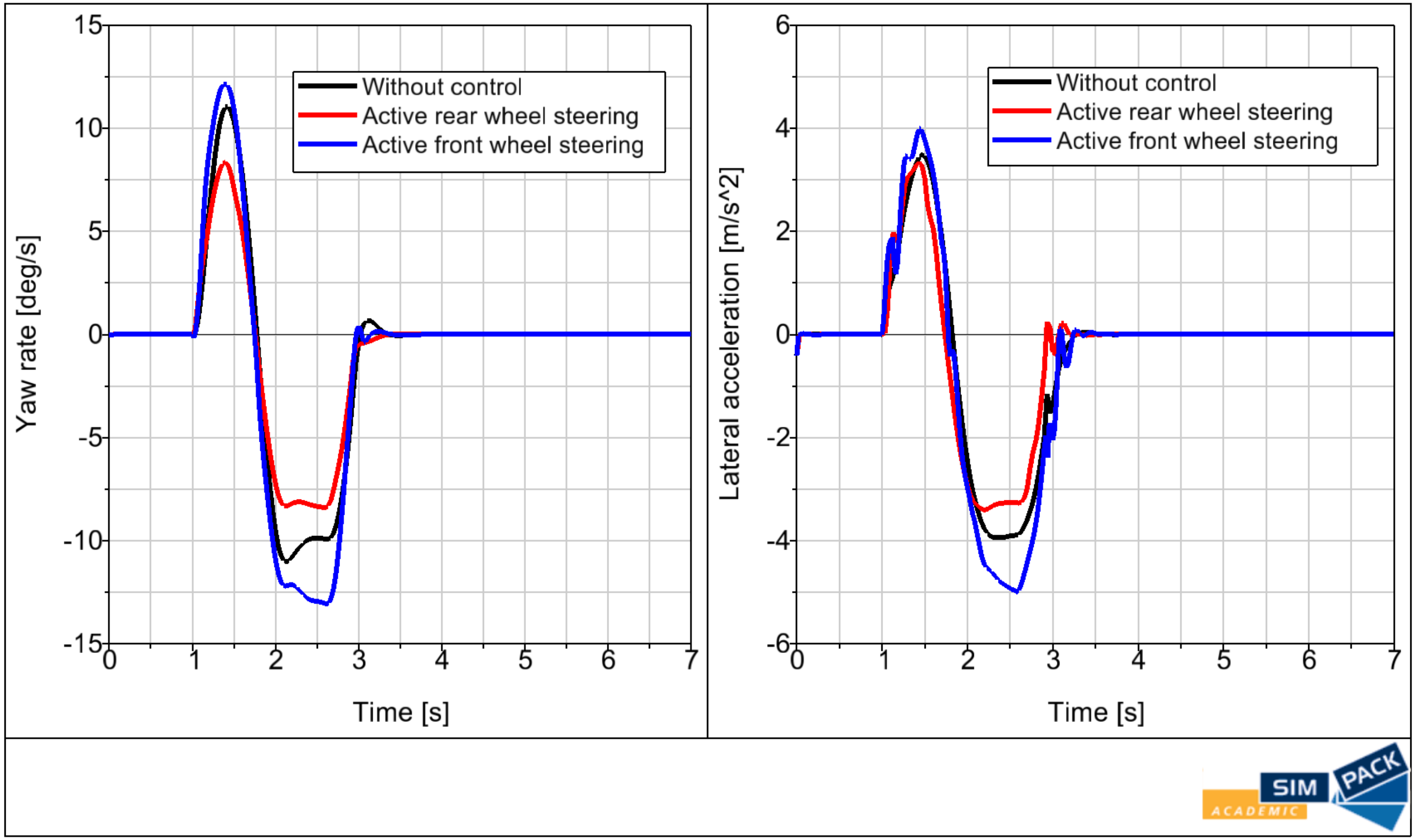
Ostfalia University of Applied Sciences

Wolfenbüttel



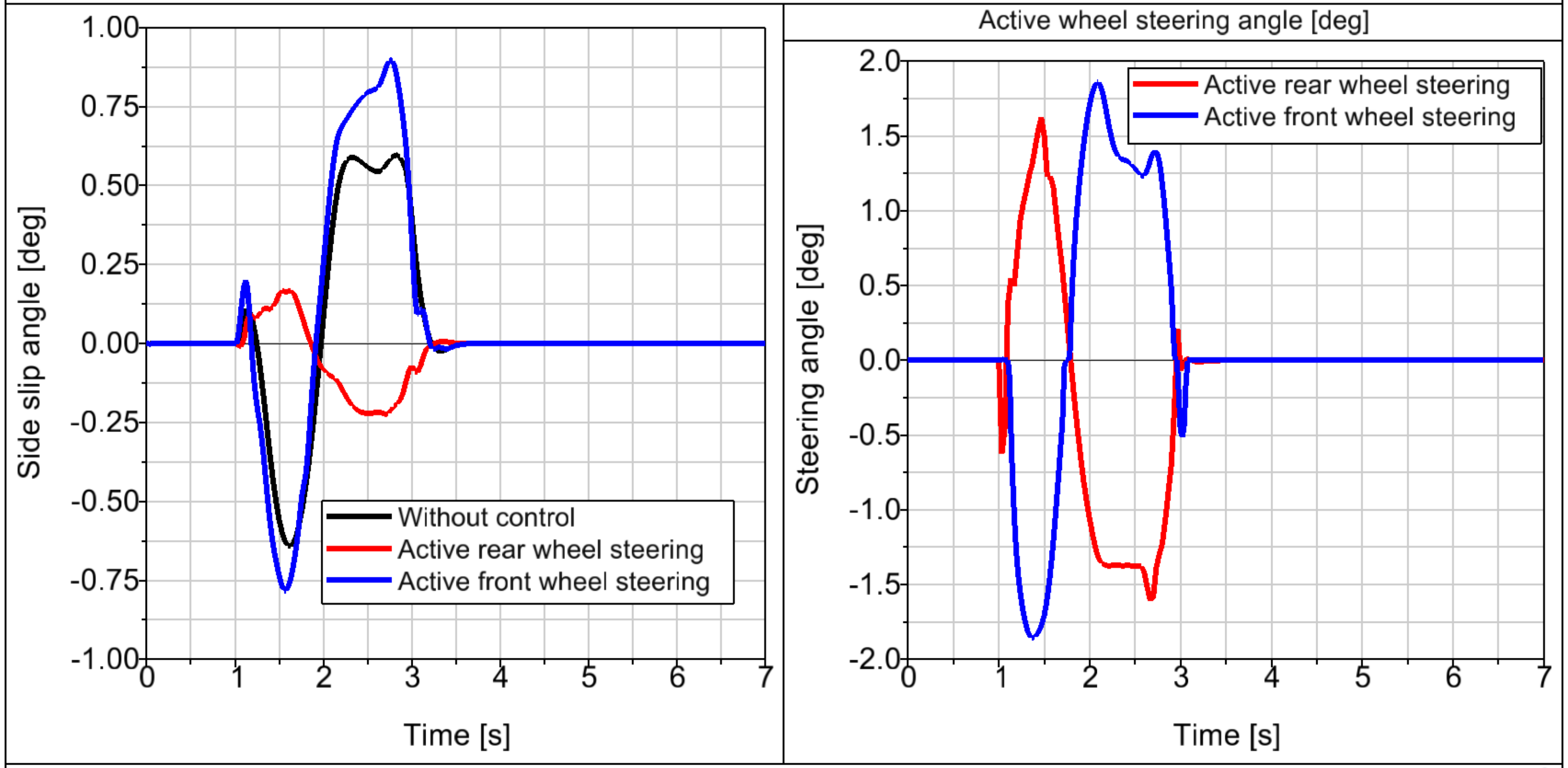
# Sine with dwell: Simulation results





# Sine with dwell: Simulation results






Active rear wheel steering seems advantageous

# Sine with dwell on slippery road

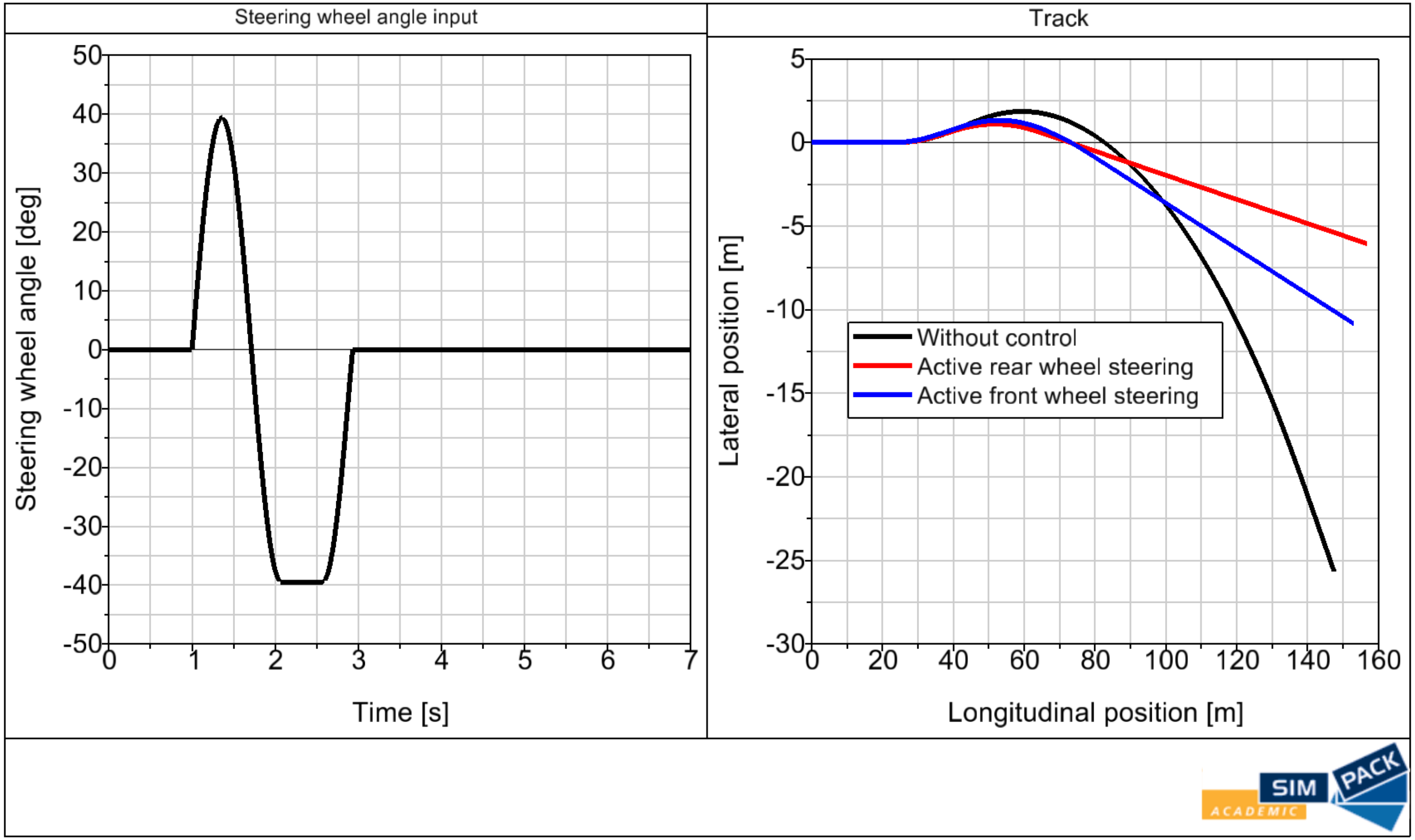
Ostfalia University of Applied Sciences

Wolfenbüttel

| | |
|---|---|
| Driver | objective, no driver influence |
| Velocity | 80 km/h |
| Steering wheel angle input | single sine of 0.7 Hz with dwell of 500 ms after ¾ of period, steady-state lateral acceleration of amplitude is 0.4 g (for vehicle without control) |
| Road surface | slippery, μ = 0.35 |

# Sine with dwell on low μ: Simulation results

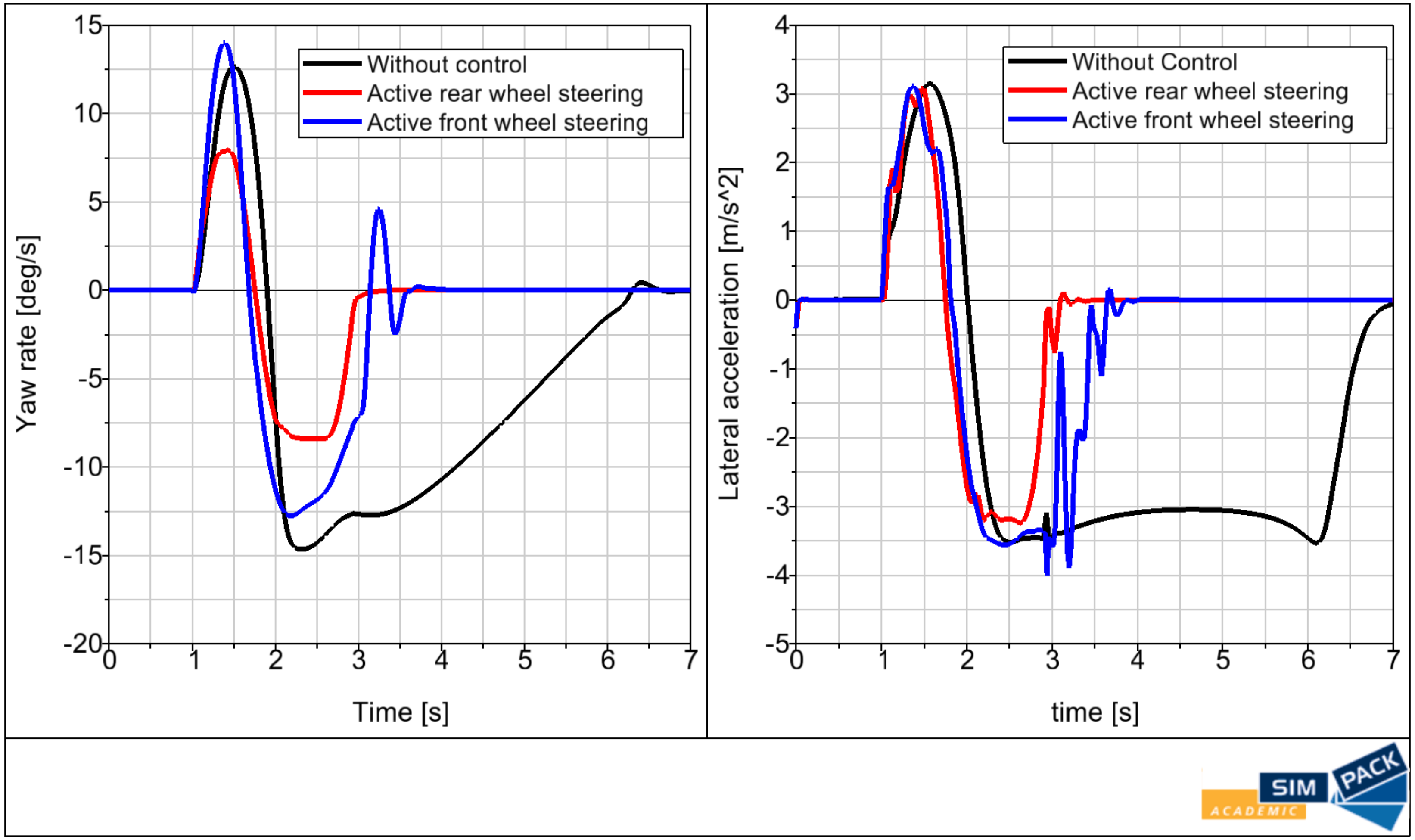




# Sine with dwell on low µ: Simulation results

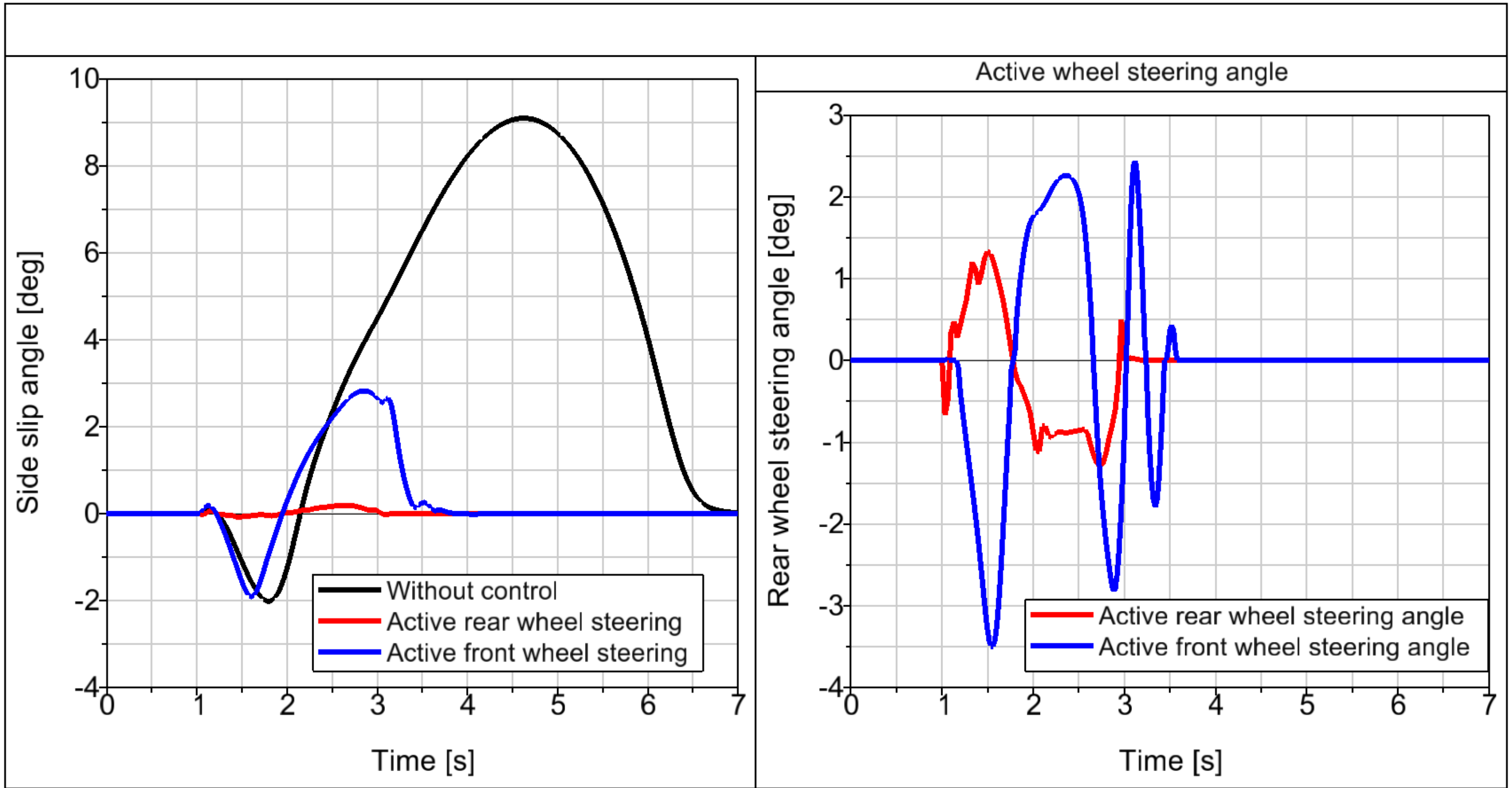
Ostfalia University of Applied Sciences

Wolfenbüttel



# Sine with dwell on low μ: Simulation results





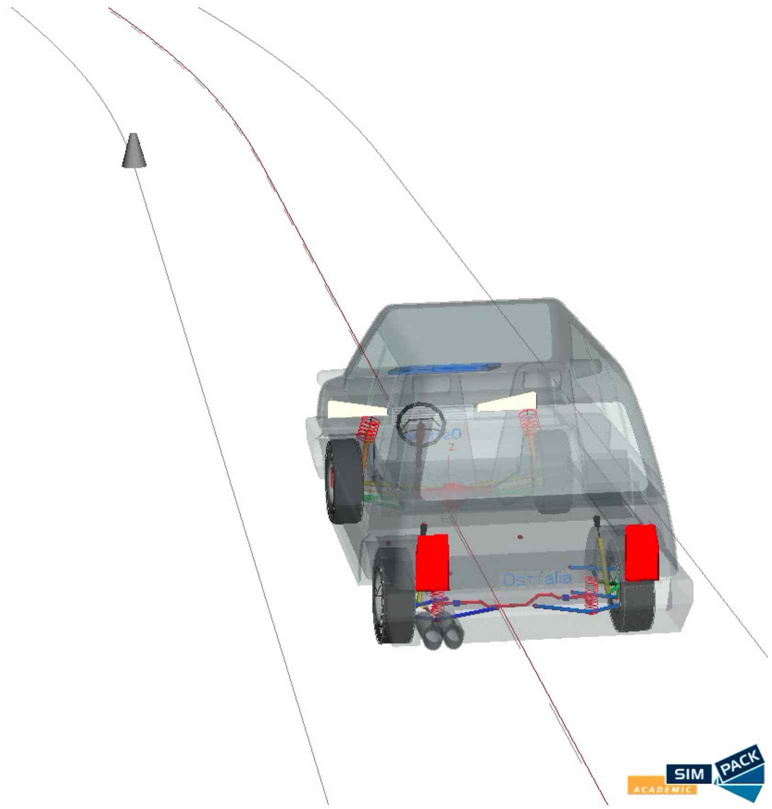

Active steering makes this maneuver driveable, rear wheel steering is most effective

# Maneuver slalom

Ostfalia University of Applied Sciences

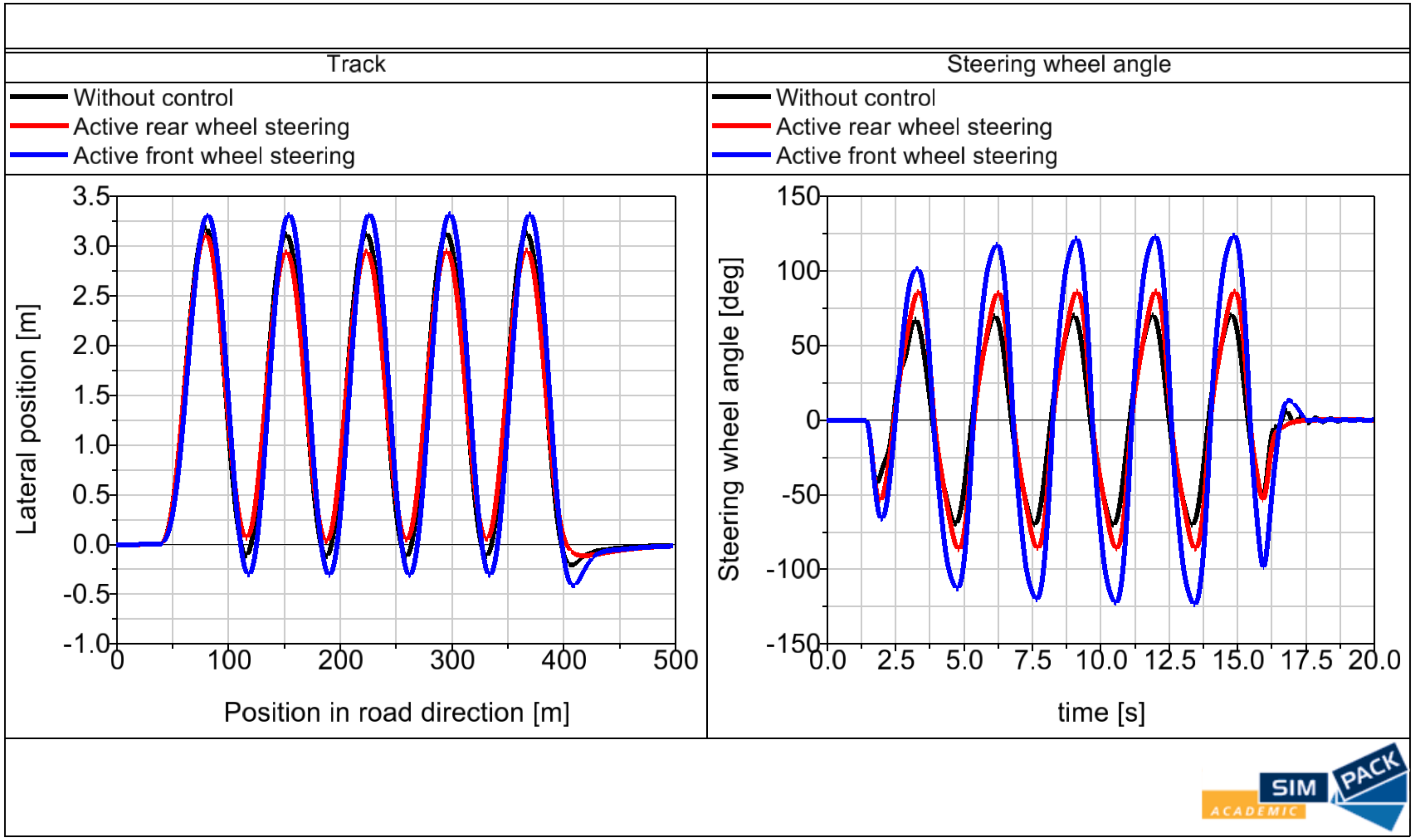
Wolfenbüttel

| | |
|---|---|
| driver | Simpack driver model, driver influence |
| velocity | 90 km/h |
| front wheel steering angle | closed loop, by driver |
| road surface | dry, μ = 0.9 |



# Slalom: Simulation results

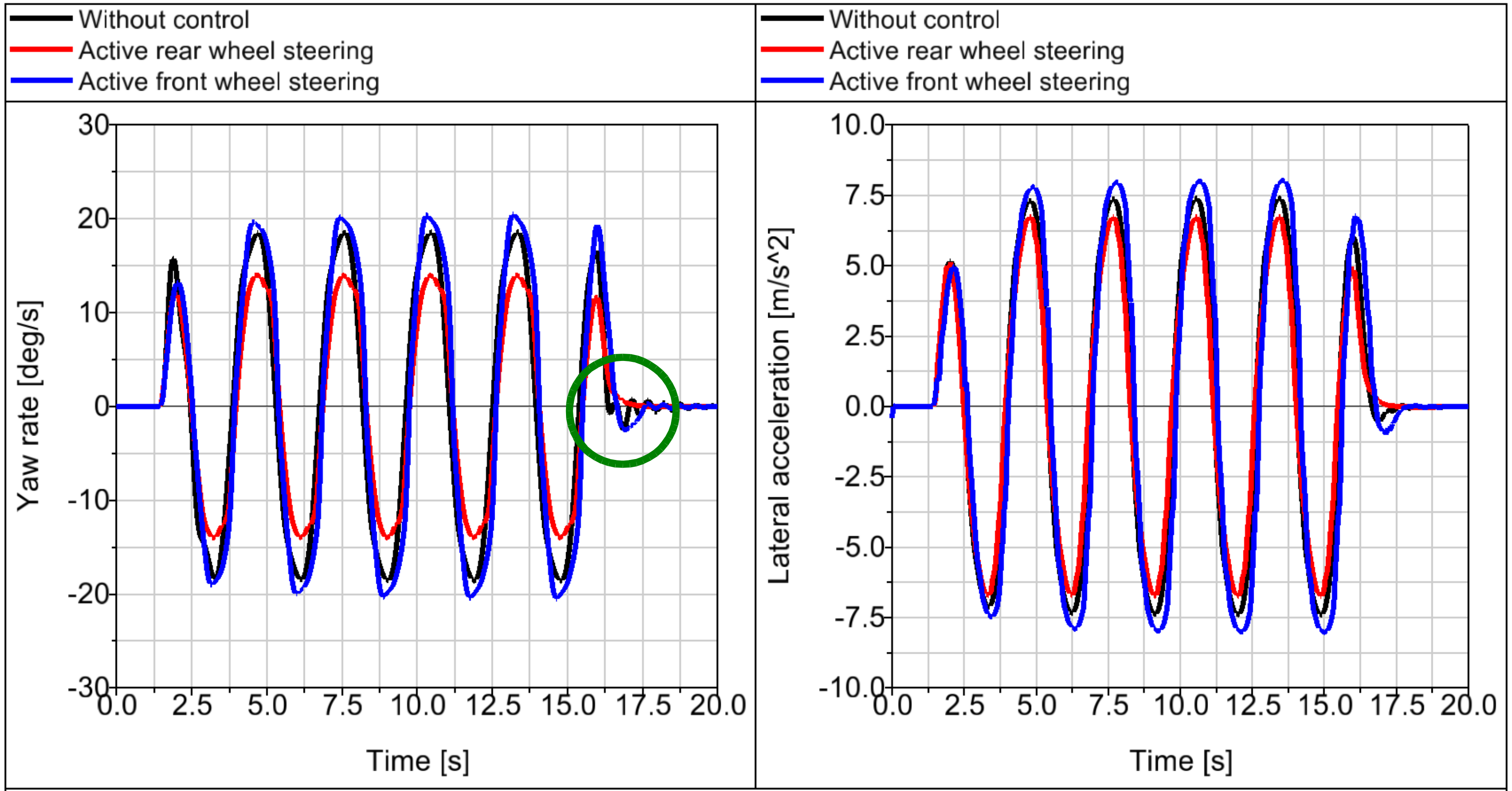




# Slalom: Simulation results

Ostfalia University of Applied Sciences

Wolfenbüttel

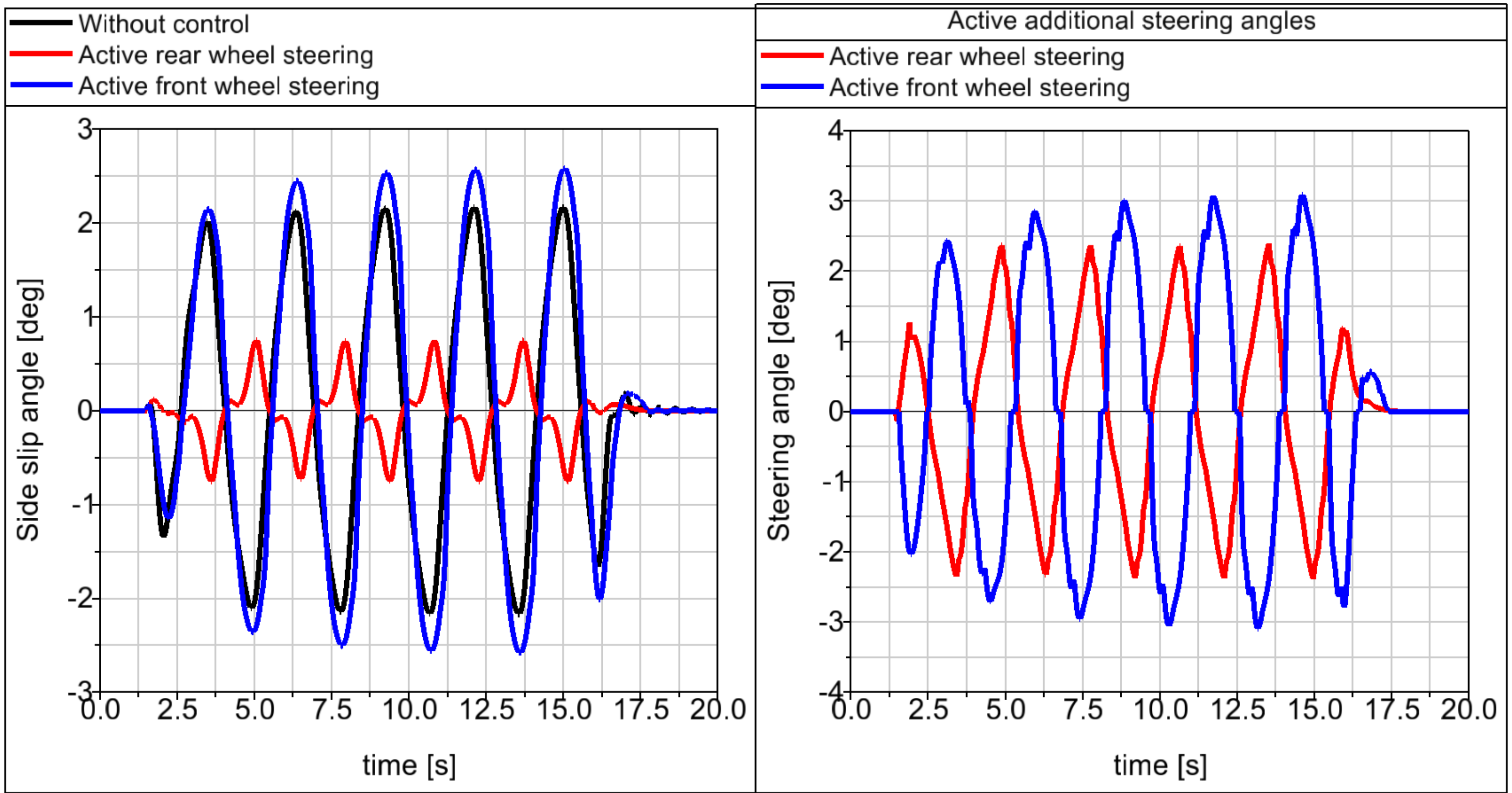



Less oscillations

# Slalom: Simulation results

Ostfalia
University of
Applied Sciences

Wolfenbüttel




Rear wheel steering is advantageous

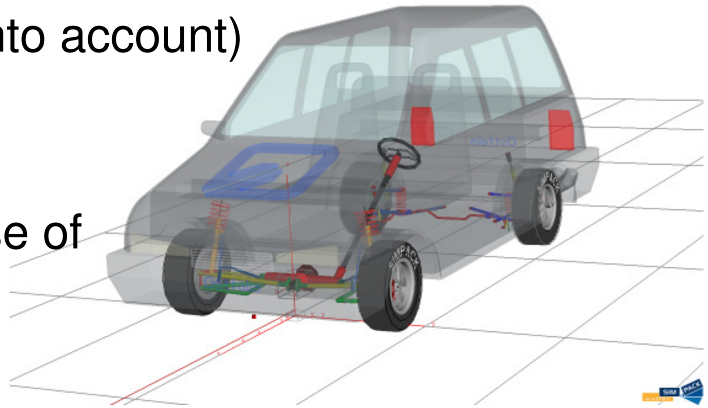
SIM PACK ACADEMIC

# Conclusion and Outlook



- Validated mbs vehicle model as a basis
- Simple implementation of active steering systems by additional dofs: rear wheel steering, front wheel steering
- Co-Simulation of Simpack and Matlab/Simulink® for integration of control systems
- Systems work effectively, effects on vehicle dynamics can be studied, active rear wheel steering seems more powerful

- Optimization of both systems still needed (optimize control parameters, take side slip limit and wheel slip into account)
- Mechanical design of rear wheel steering and implementation of an actor model
- Implementation of a steering actor model in case of front wheel steering



Acknowledgment

The author would like to thank Yangfang Yu for doing a lot of excellent modeling and simulation work.