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# Extended-creep-force model in vehicle dynamics simulation

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- Traction in curves
- Wheel-Rail-Forces

Summary


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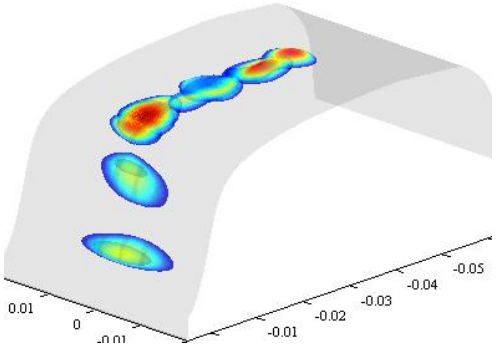
# Why is W/R-friction so important?




Friction in wheel-rail contact

**Short term**

- Vehicle dynamics
- Drive train dynamics
- Traction control
- ...

**Long term**

- Wear
- Rolling contact fatigue
- Thermal damage
- ...

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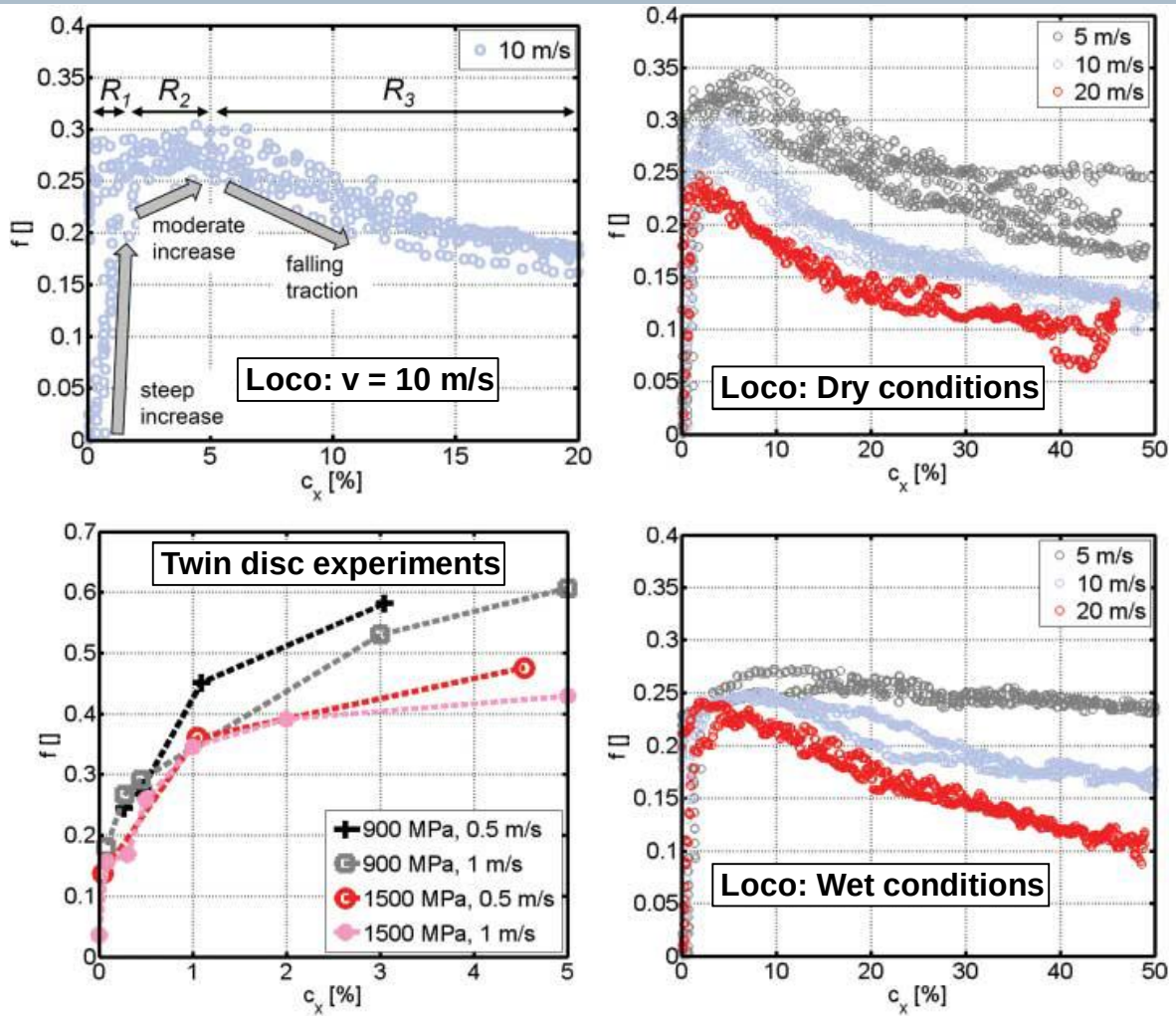
# Experimental findings

Traction depends on:

- creepage
- vehicle velocity
- load and contact geometry
- contact conditions
- etc.

⇒complex behaviour

⇒creep force models should reproduce these effects




K. Six et al., Physical processes in wheel–rail contact and its implications on vehicle–track interaction, Vehicle System Dynamics, 2014

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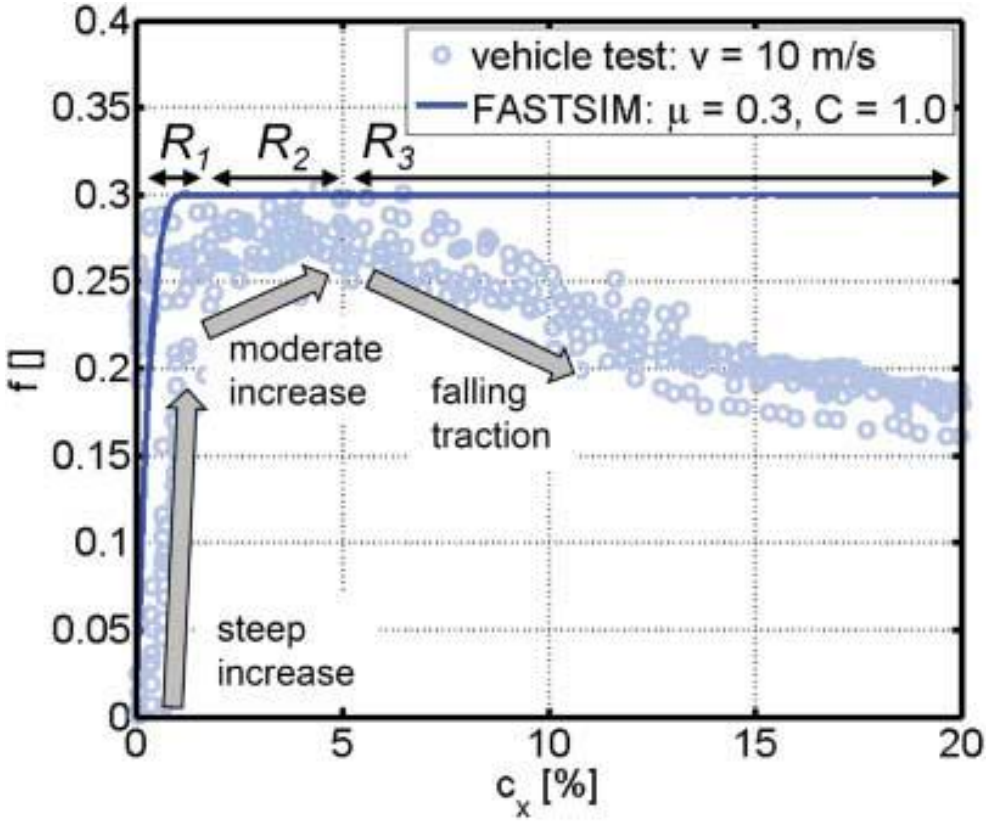
# The “classical” theory

**Assumptions**

- elastic material behaviour
- „smooth“ surfaces
- constant coefficient of friction (Coulomb law)

**Comparison to tests**

- deviations over the whole range
- no decrease at higher creepage

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# Possible implications on vehicle dynamics

Creepage

→Drive train dynamics

Vehicle velocity

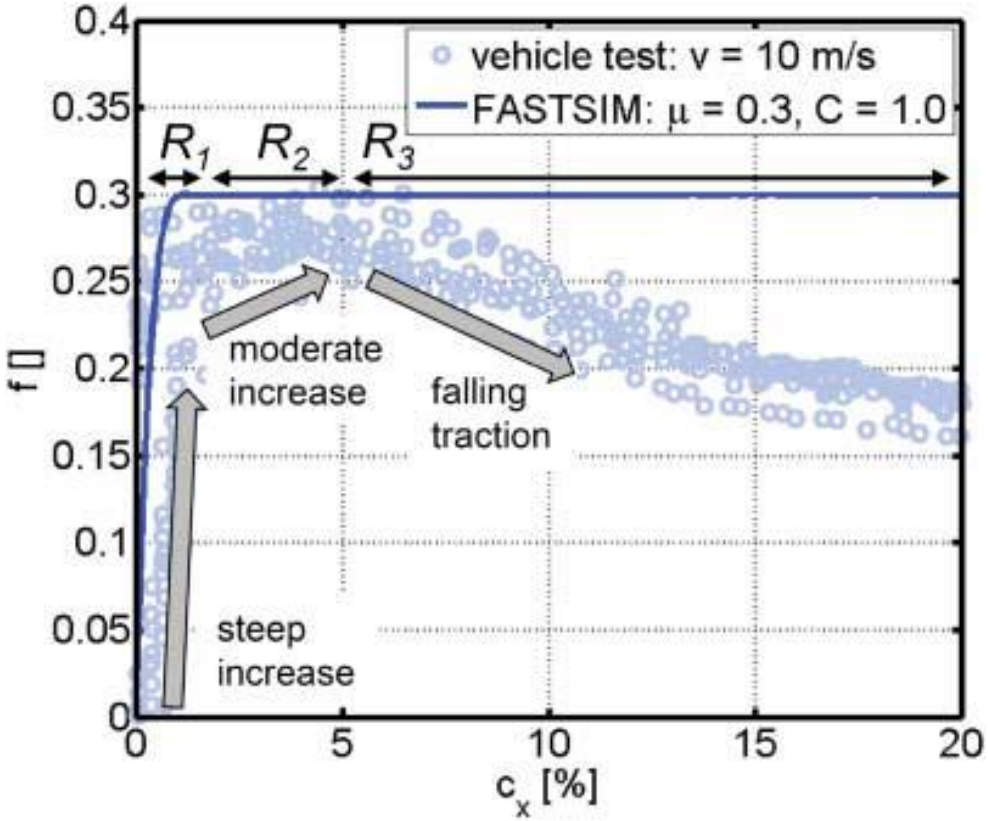
→Traction control

Load and contact geometry

→Curving

Contact conditions

→Traction control

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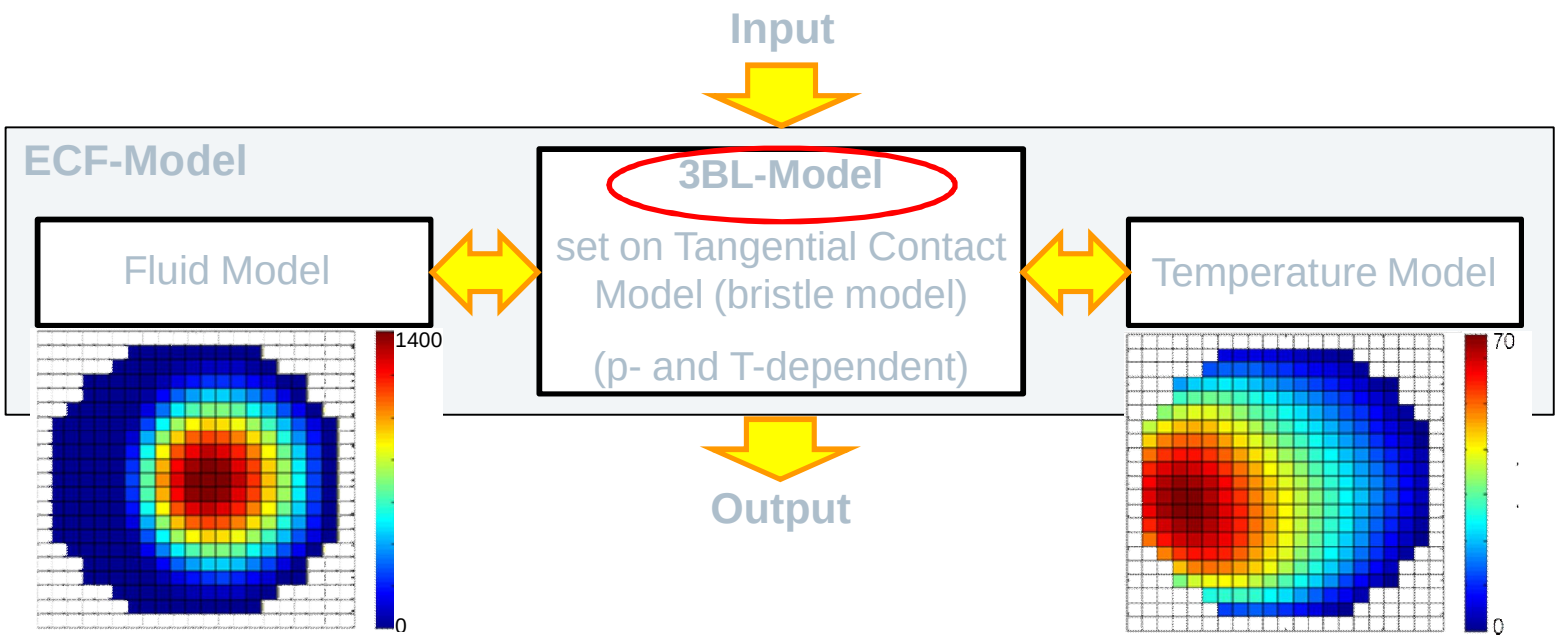
# The ECF-Model




Fluid pressure in contact [MPa]

Temperature in contact [C]

Model based on physical sub-models

⇒ Coefficient of friction μ is not an input ⇒ f is an output

⇒ 3BL

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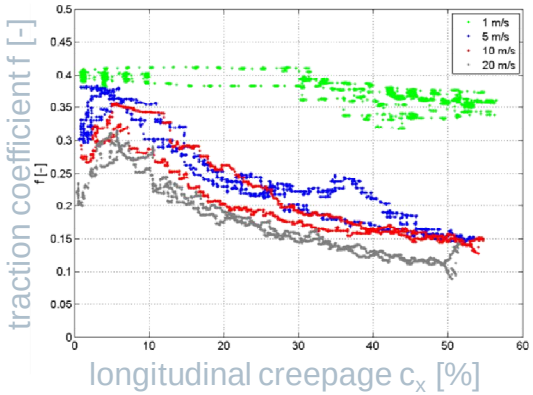
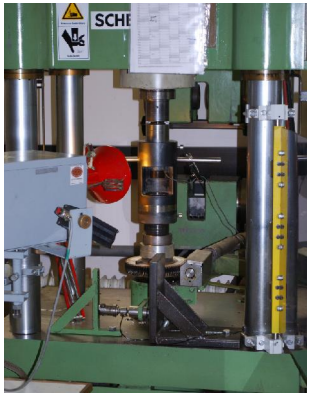
# The ECF-Model - Tests



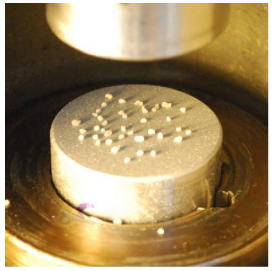

Loco tests

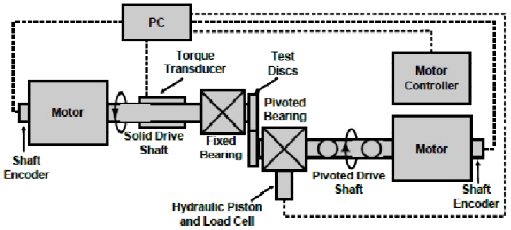
→ measurement of traction characteristics under different boundary conditions



HPT tests (High Pressure Torsion)

→ assessment of roughness, water, sand

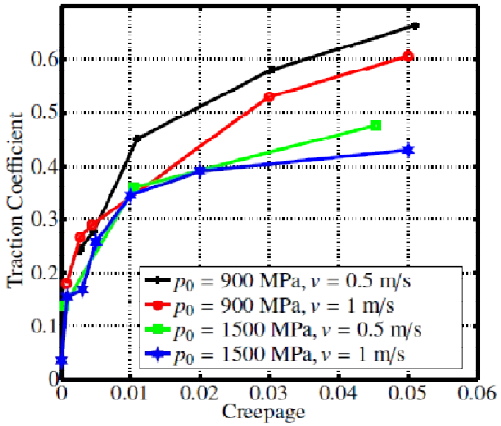





SUROS at University of Sheffield

Twin-disc tests

→ assessment of different contact conditions

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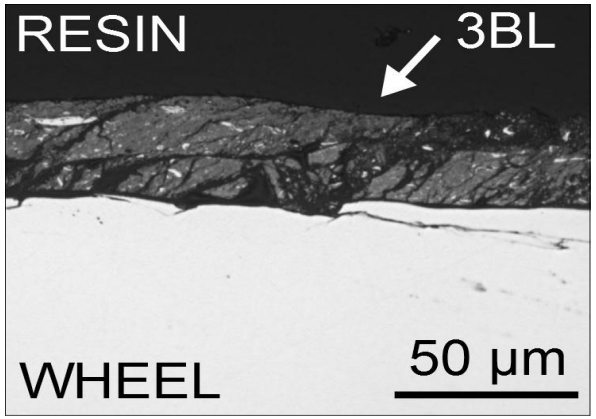
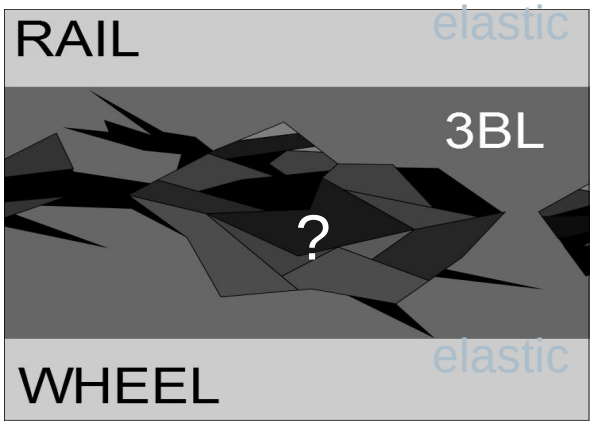
# The ECF-Model – Twin Disc Tests

Results from Twin Disc experiments




- 3BL found on specimens (steel particles, iron oxides)
- Also found in real railway operation

Includes effects from

- natural and artificially introduced solids like interfacial layers (granular materials under high pressure
- wheel-rail surface (roughness, micro-cracks, etc.)

⇒ Properties of 3BL?

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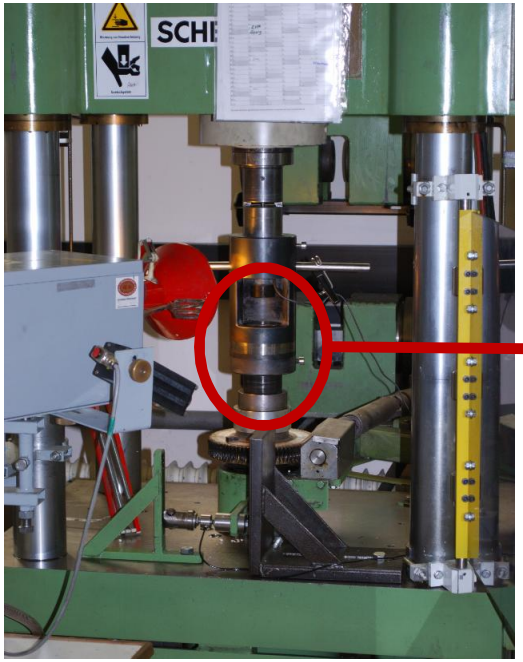
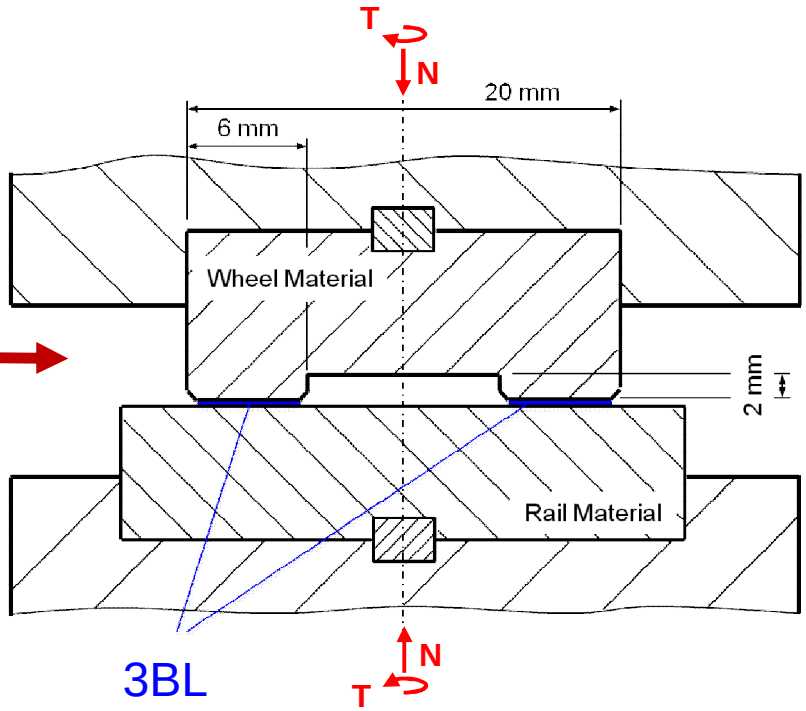
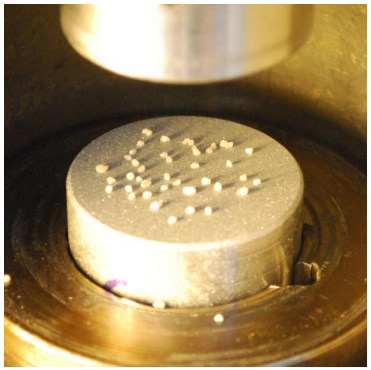
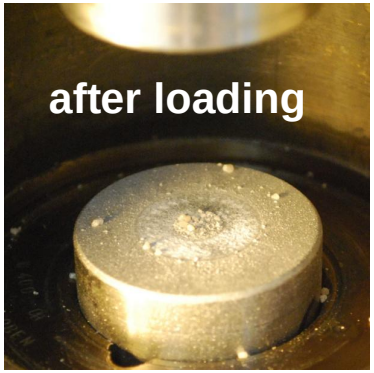
# The ECF-Model – HPT Tests








- Normal stresses comparable to wheel-rail contact (N)
- Rotation of discs and measurement of torque (T)

⇒ Relationship between shear strain and shear stress

⇒ Influence of roughness, water, sand

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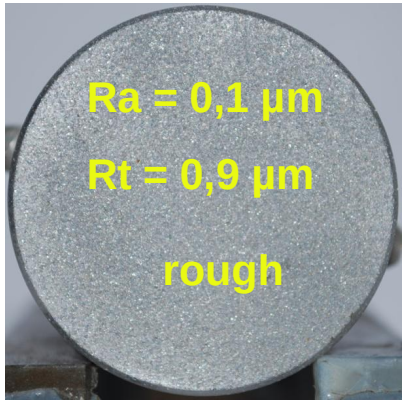
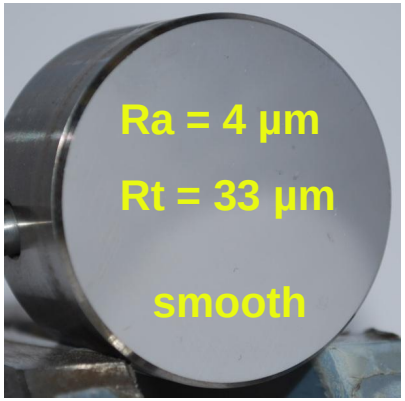
# The ECF-Model – HPT Tests

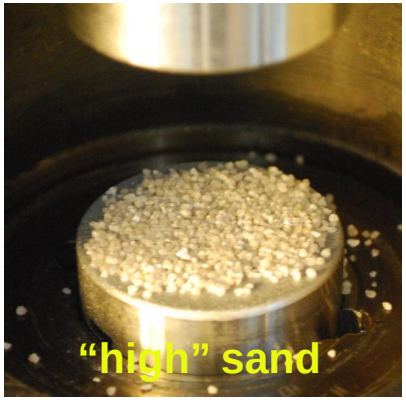
- Contact conditions
  - smooth / rough surfaces
  - „low“ / „high“ amount of sand
  - dry / wet

- Results
  - p-dependency of 3BL-Model parameter
    ⇒ low influence of roughness
    ⇒ low influence of amount of sand
    ⇒ water reduces the shear stress level
    ⇒ sand brings it back to original level

⇒ Behaviour at vehicle tests?



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# The ECF-Model – On Track Tests

Locomotive testing in Wildenrath/Germany

Measurement of traction characteristics

- with adapted traction control
- creepage: 0% - 50% - 0% in 8 seconds

| | vehicle velocity v [m/s] | | | |
|---|---|---|---|---|
| | **1** | **5** | **10** | **20** |
| **dry** | x | x | x | x |
| **wet** | x | x | x | x |
| **dry/sand** | x | x | x | x |
| **wet/sand** | x | x | x | x |

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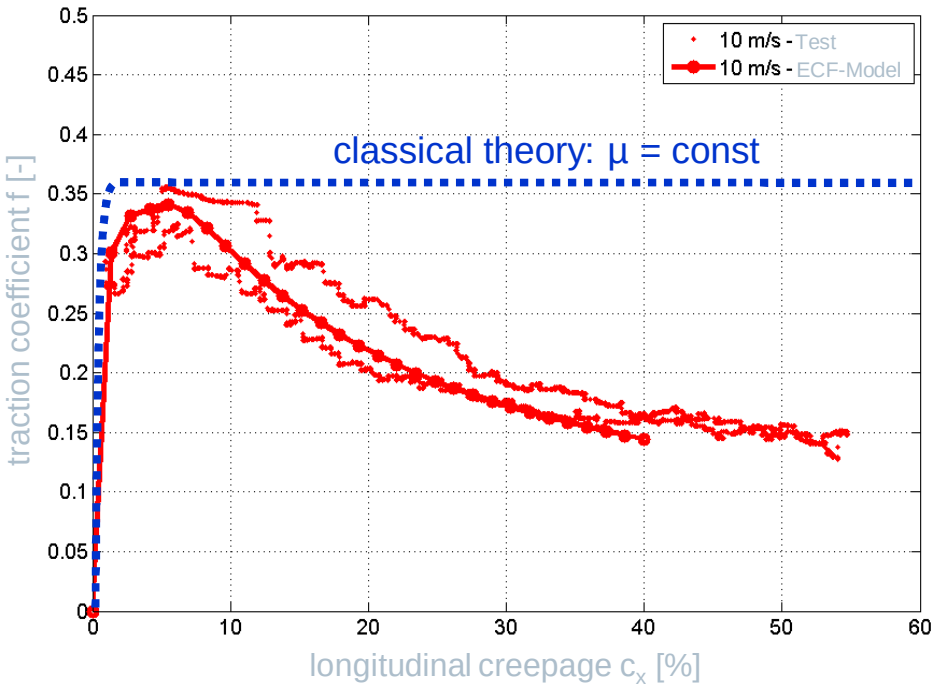
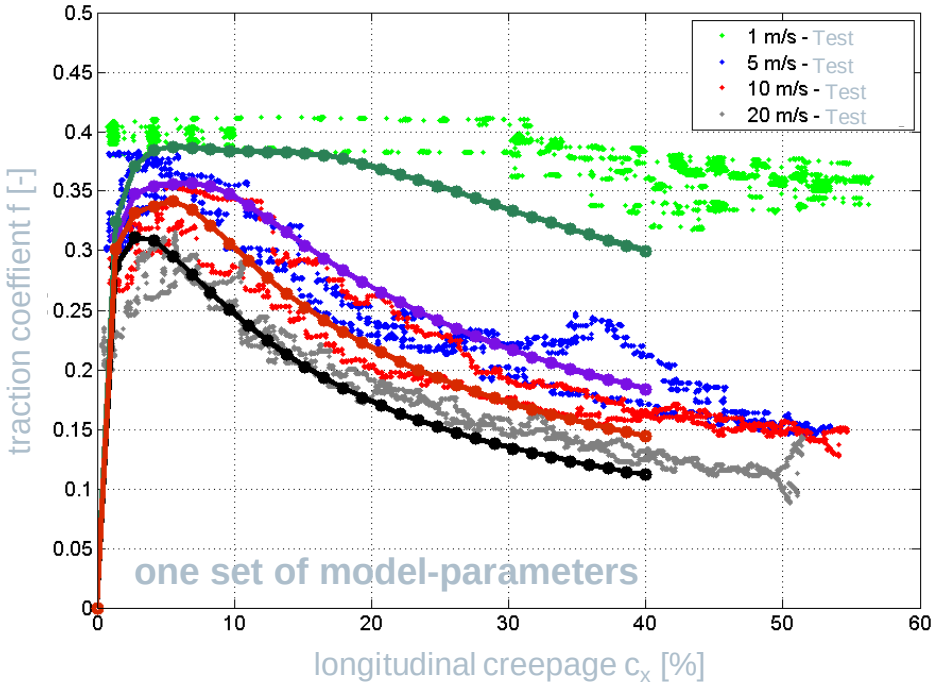
# The ECF-Model – On Track Tests




ECF-Model in good agreement with the vehicle test results

- Influence of creepage
- Influence of vehicle velocity
- ECF-parameter from HPT tests used for reproduction of vehicle test results

  ⇒ Estimation of traction characteristics by ‘simple’ HPT tests is possible

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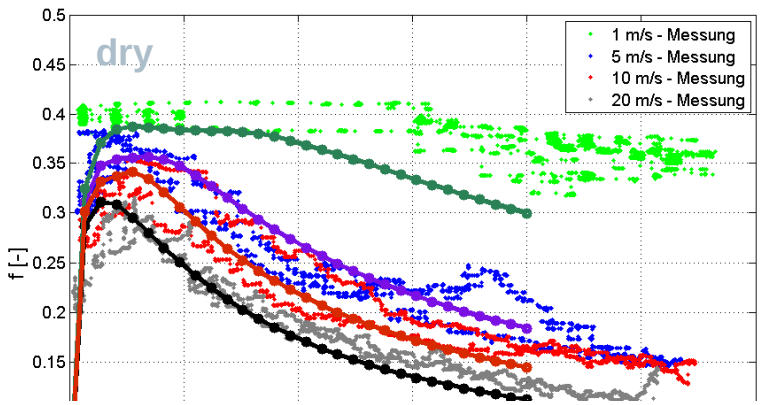
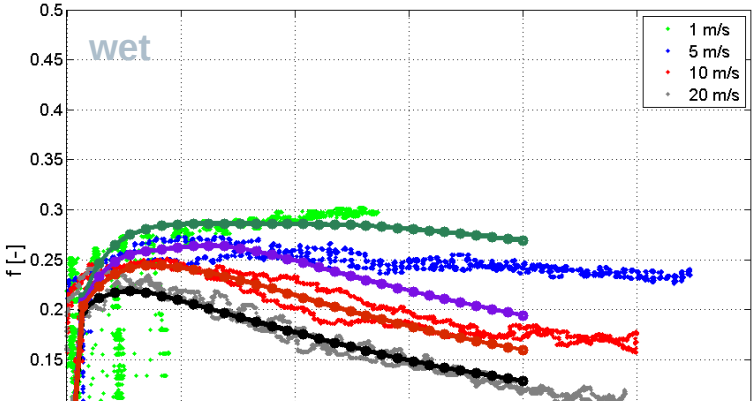
# The ECF-Model - Results

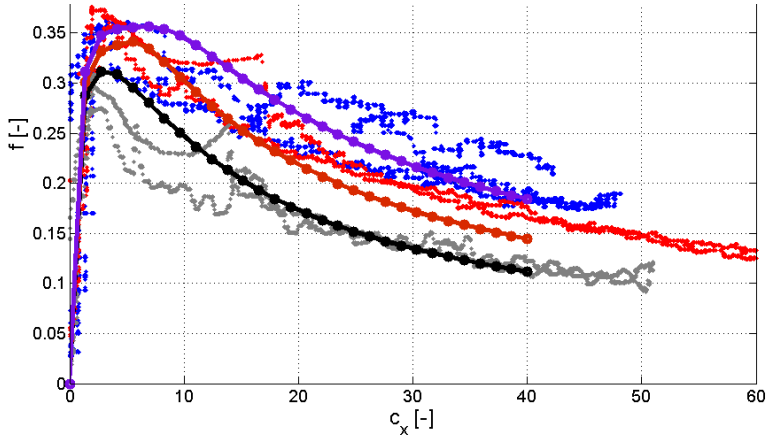


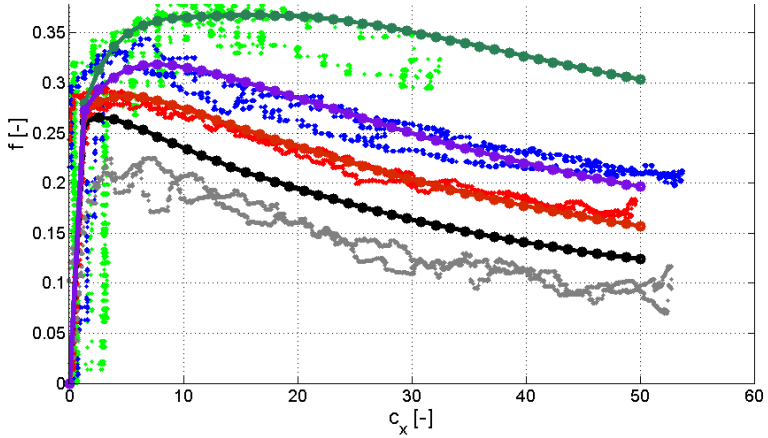




⇒ Good agreement for different contact conditions

⇒ ECF-parameter from HPT tests used for reproduction of vehicle test results

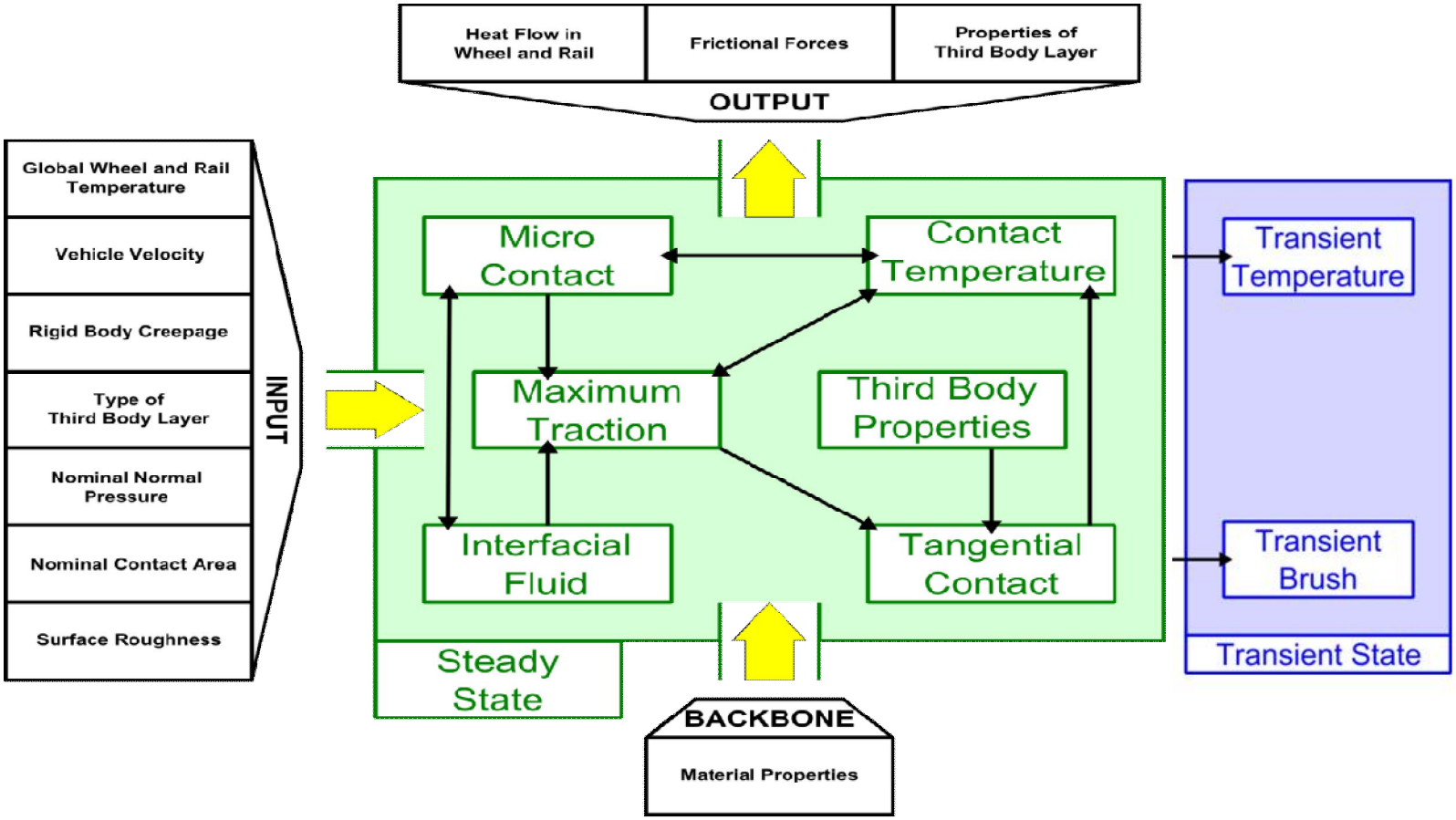
- ⇒ Water reduces traction level
- ⇒ All other contact conditions show similar traction level



# The ECF Model in Vehicle Dynamics

## ECF model: SIMPACK implementation

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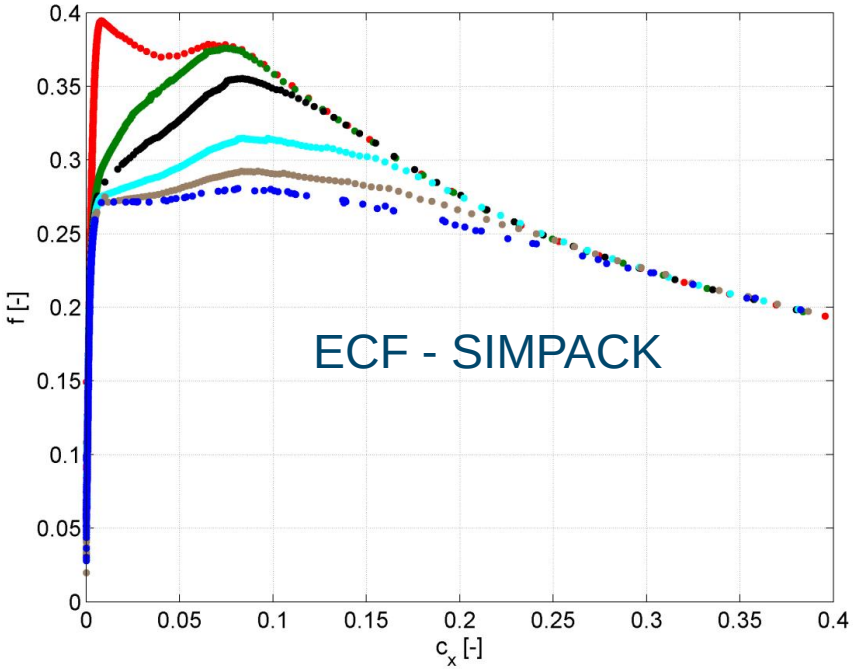
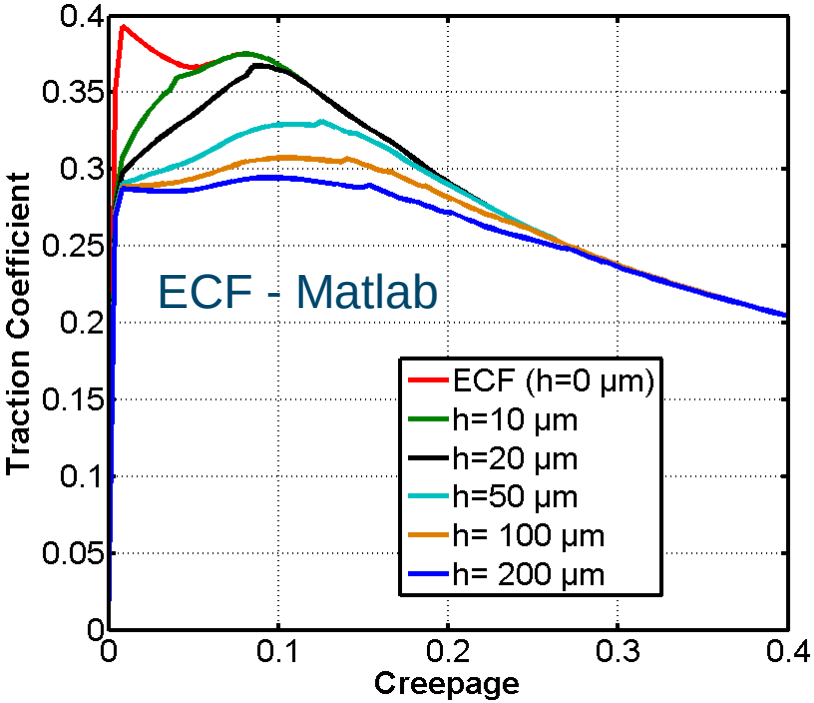
# The ECF Model in Vehicle Dynamics

## Validation of the User Routine

- Parameter variation: thickness of the 3rd Body Layer ($h_{3BL}$)




- Same set of input parameters used
- ECF model within SIMPACK gives practically the same results

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# The ECF Model in Vehicle Dynamics - Curving

## Traction in curves: FASTSIM vs. ECF-Model

- SIMPACK model
- traction in tangent and curved track ($f = T_x/Q$)
- leading truck, leading wheel set

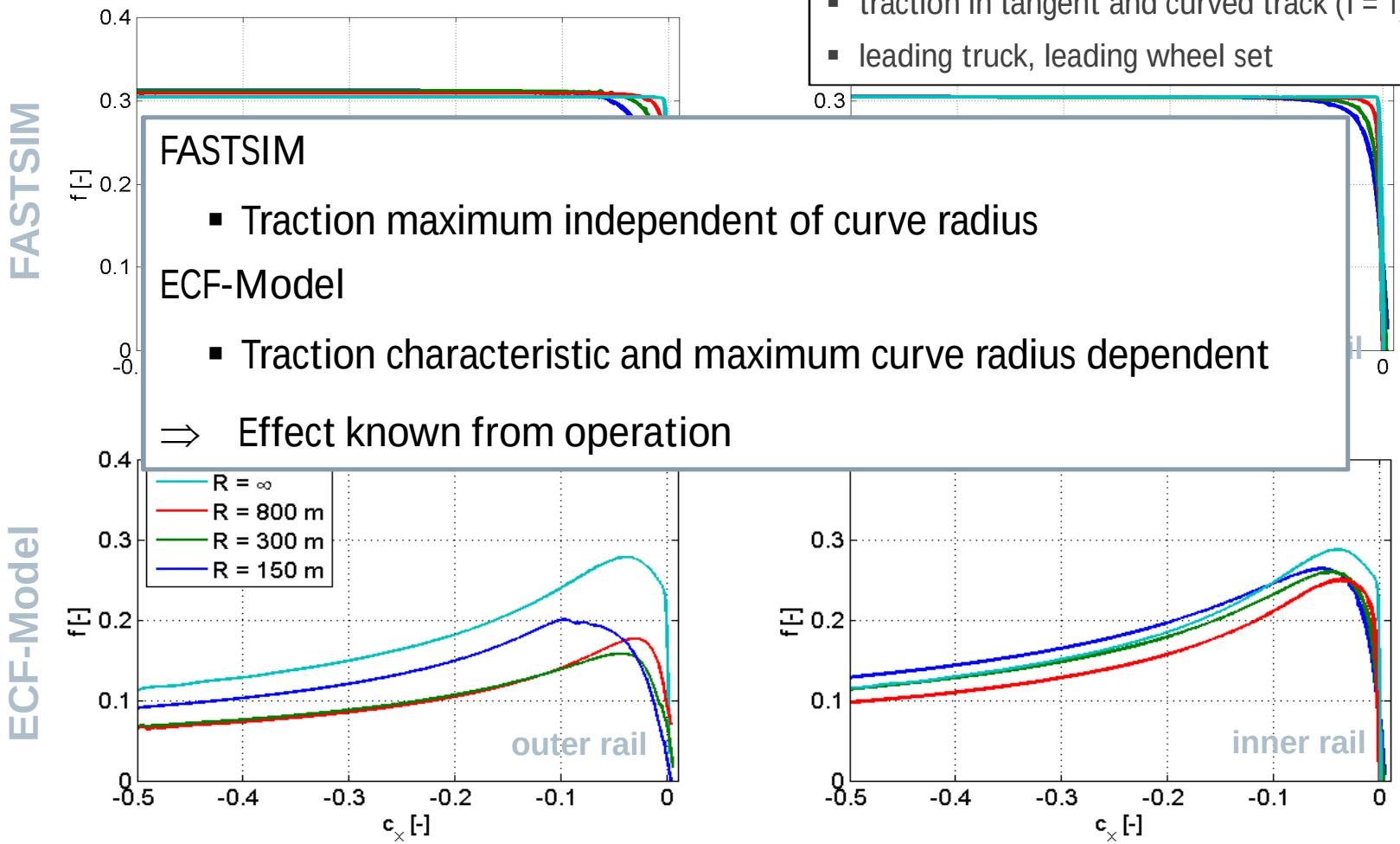
FASTSIM

- Traction maximum independent of curve radius

ECF-Model

- Traction characteristic and maximum curve radius dependent

⇒ Effect known from operation

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# The ECF Model in Vehicle Dynamics

- SIMPACK vehicle model
- Curving scenario (deviations from testing in %)
- Creep-Force-Models: 1 = FastSim table, 2 = FastSim online, 3 = FastSim with different μ inner/outer rail

| | 1 | 2 | 3 | ECF |
|---|---|---|---|---|
| COF | 0,39 | 0,39 | 0,53/0,25 | - |
| $L_{outer}$ | -8,38% | -9,14% | 18,10% | 12,95% |
| $V_{outer}$ | 3,93% | 5,76% | 6,81% | 12,04% |
| $L/V_{outer}$ | -12,41% | -12,41% | 9,49% | 0,73% |
| $L/V_{inner}$ | -27,59% | -27,59% | -3,45% | -8,62% |
| dz | 41,18% | 100,00% | 11,76% | 5,88% |

- The standard model does not predict the L/V value on the inner wheel correctly
- Only with the ad hoc assumption of two different COFs the measured values can be reproduced
- The ECF gives a good result without any such assumptions

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# Summary

Friction in wheel-rail contact is crucial for vehicle-track interaction

Classical creep force models are generally unable to explain the measurements

W/R-friction can not be described by only one number for the coefficient of friction dependent on vehicle velocity, normal load, contact geometry, etc.

Phenomenological models have no physical input

A physical creep force model has been developed (ECF-Model)

This model shows good agreement with test results. The ECF-Model offers new opportunities for more precise simulations in specific cases

- Curving (especially very narrow curves)
- Traction control
- Drive train dynamics
- Wear
- Fatigue & damage
- ...

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