

Equivalent Conicity

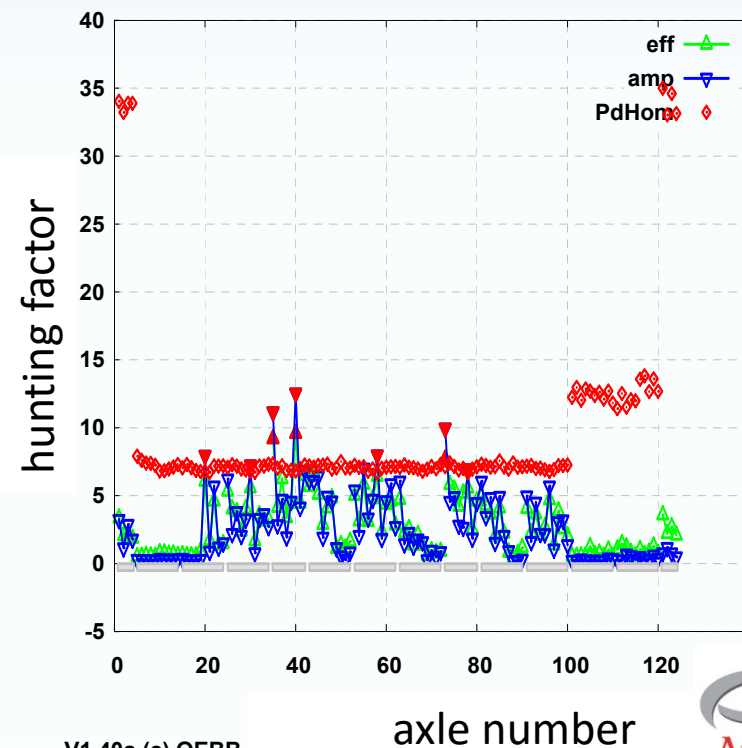
Measurement, Calculation and Robustness

Bernhard Barkow
Paul Mittermayr

Dr. Mittermayr Scientific
GmbH & Co KG (BAMM)



Hunting



V1.40a (c) OEGB



History

Kinematic	Stability	Contact mech.
Stephenson 1821 Redtenbacher 1855 Klingel 1883		Reynolds 1876 Hertz 1881
Heumann 1937 Nefzger 1974 Cooperrider 1975 Arnold 1994	Carter 1915 Matsudeira 1953 de Pater 1956 Wickens 1965 True 1993	Fromm 1926 Johnson 1958 Vermeulen 1964 Kalker 1964
Mauer	Knothe Polach	Sextro

cf: Knothe K., Böhm, F.: Stability of Railway and Road Vehicles. Vehicle System Dynamics, 31, 283-323 (1999).

Geometric task

Kinematic equivalence: four joint linkage

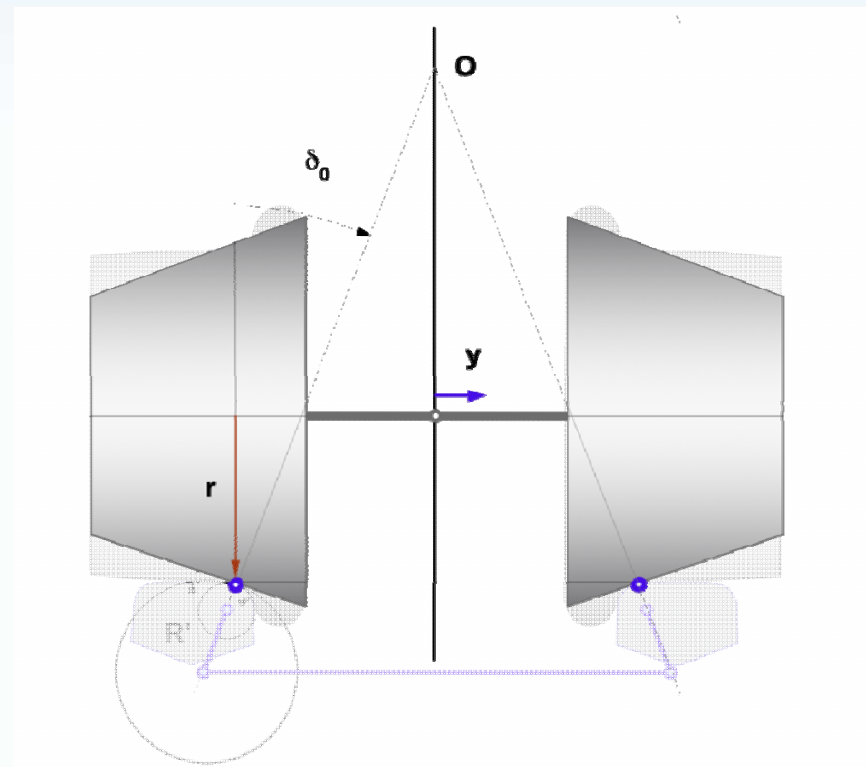
The origin **O** describes a cycloid

Requirements:

- Rigid wheel **R**
- Rigid Track **R'**
- Pure rolling
- Straight track

For each lateral displacement **y**

- Roll $\varphi = \phi \mathbf{y}$
- Height $\mathbf{h} = \mathbf{h}_0 + \zeta \mathbf{y}^2$
- Normal $\delta_l = \delta_0 + \xi \mathbf{y}$
- Rolling radii $\mathbf{r}_i = \mathbf{r}_0 \pm \gamma_e \mathbf{y}$



Parameters

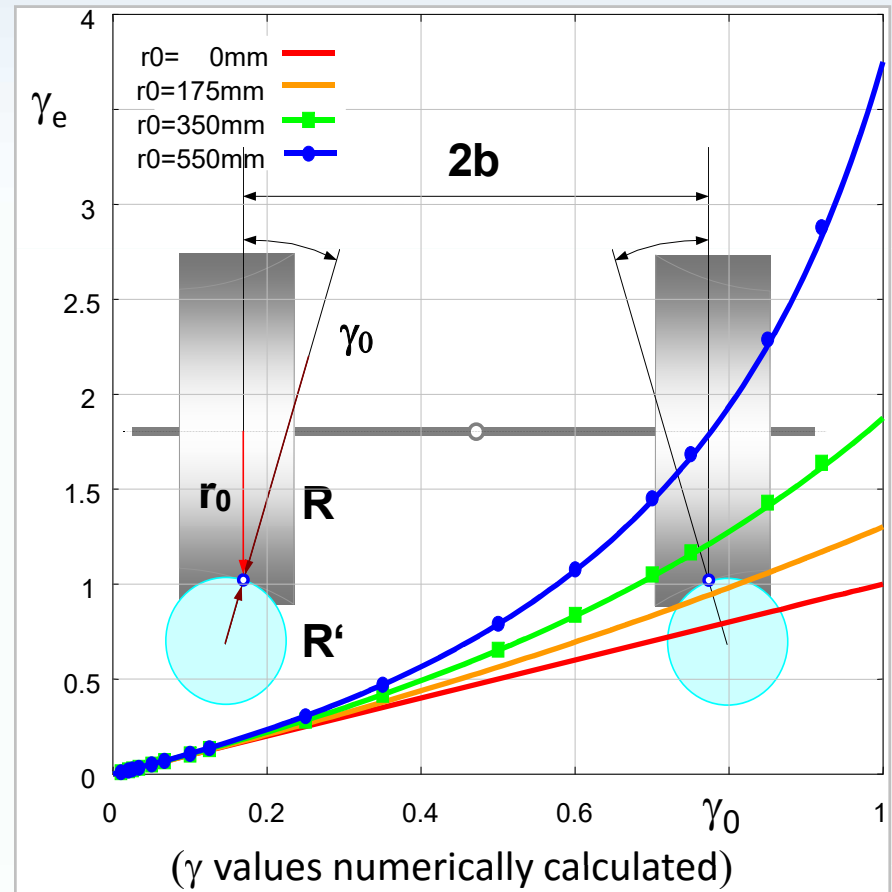
Kinematic equivalence according to the model of Klingel $\rightarrow \gamma_e$ effected by:

- wheel profile radius R
- rail profile radius R'
- track gauge $2b$
- rolling radius r_0

Linear approximation according to Joly:

$$\gamma_e = \frac{R}{R - R'} \cdot \frac{b + R'\gamma_0}{b - r_0\gamma_0} \cdot \gamma_0$$

$R'=0$, R arbitrary r_0 varied



Definition

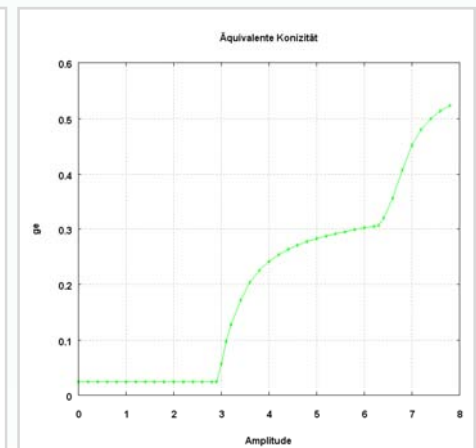
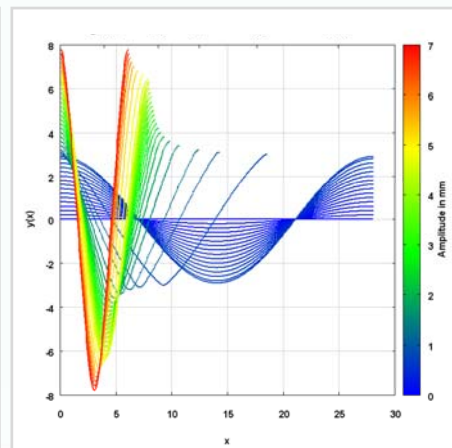
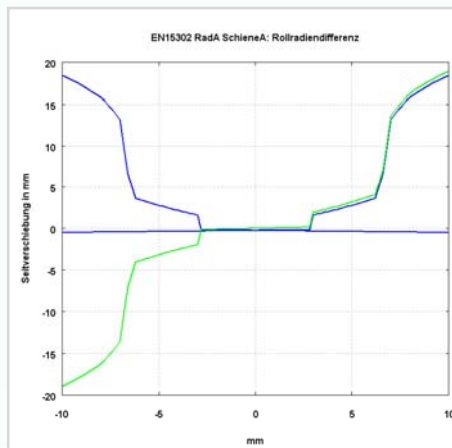
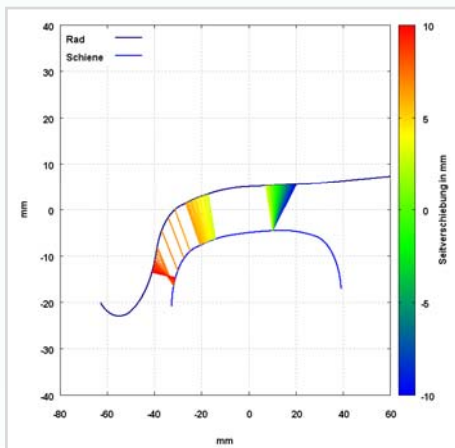
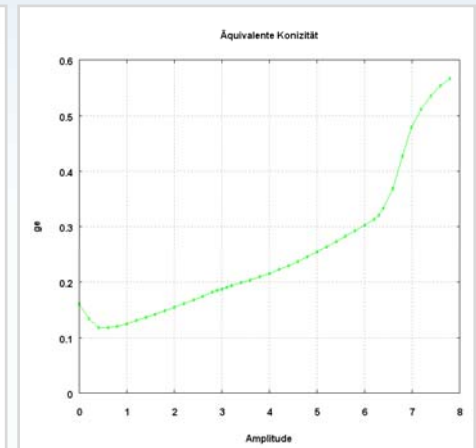
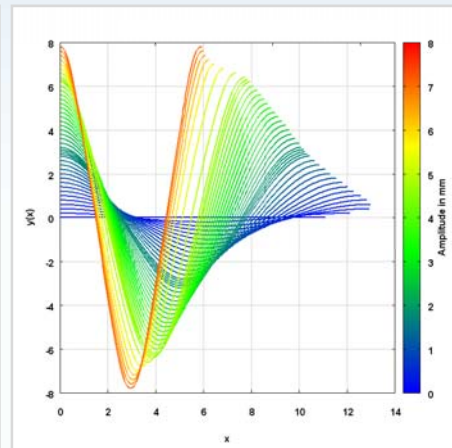
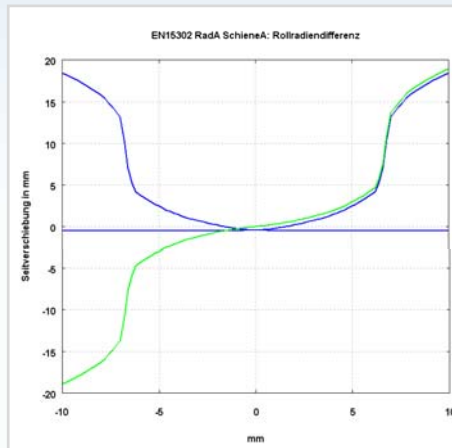
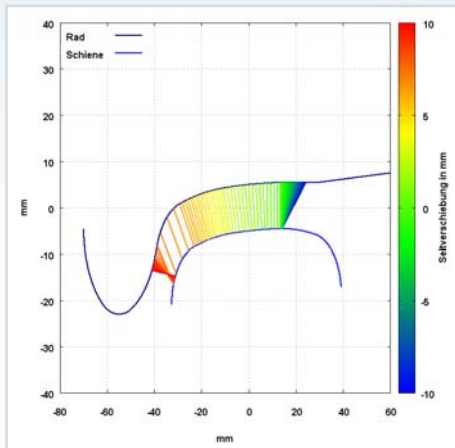
EN 15302: Rail profile A with rail profile A/B

Wheel/rail contact

Rolling radius difference

Hunting

Conicity



(New) Standard

EN 15302: Railway application – Method for determining the equivalent conicity

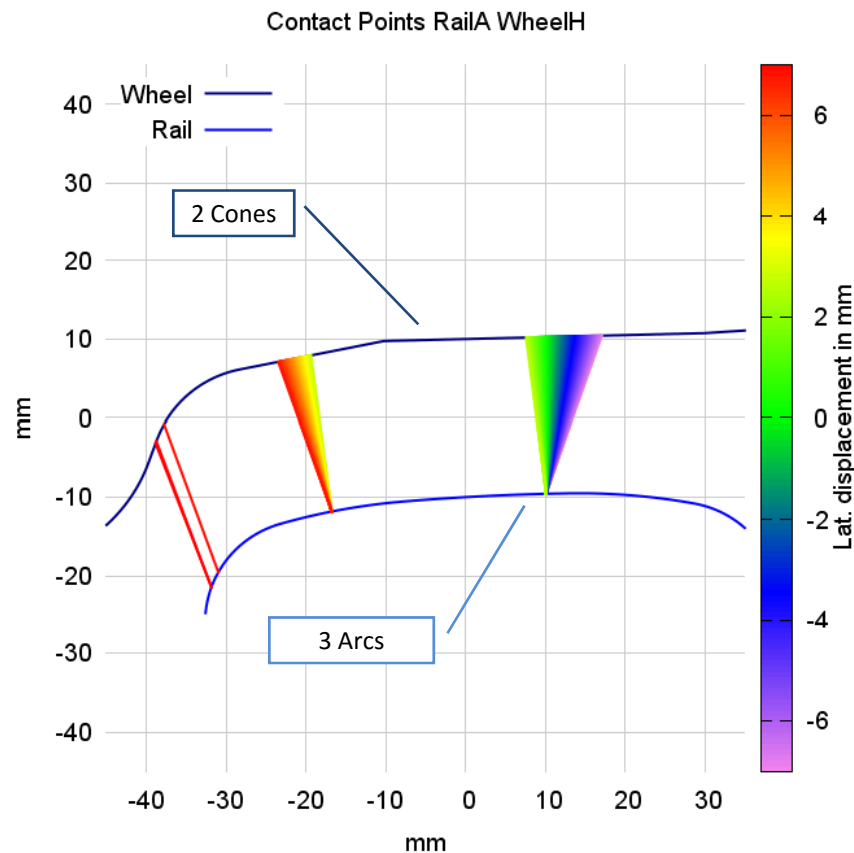
Table 1 — Combinations of profiles and their applications

Application	Wheelset	Track
Contribution to the assessment of vehicle's behaviour; relevant for vehicle's acceptance tests from the point of view of dynamic behaviour (EN 14363) ^a	Measured	Measured
Assessment of rail profiles (incl. gauge), check for need for track maintenance measures (reprofiling/grinding of the rails) ^{a,c}	Theoretical	Measured
Assessment of wheelset conditions, check for need for wheel profile maintenance measures (reprofiling of the wheel set) ^b	Measured	Theoretical
Theoretical evaluation during the design process (TSI HS RST and TSI HS IS) ^{b,c}	Theoretical	Theoretical
^a If possible these measurements of the rail profiles should be done with normal load on the track (e.g. by an inspection car), otherwise (especially on tracks with soft fastenings) the effects of the load may be taken into account in the interpretation of the results.		
^b The rail inclination and the gauge must be taken into account		
^c The distance between the active faces of the wheels must be taken into account		

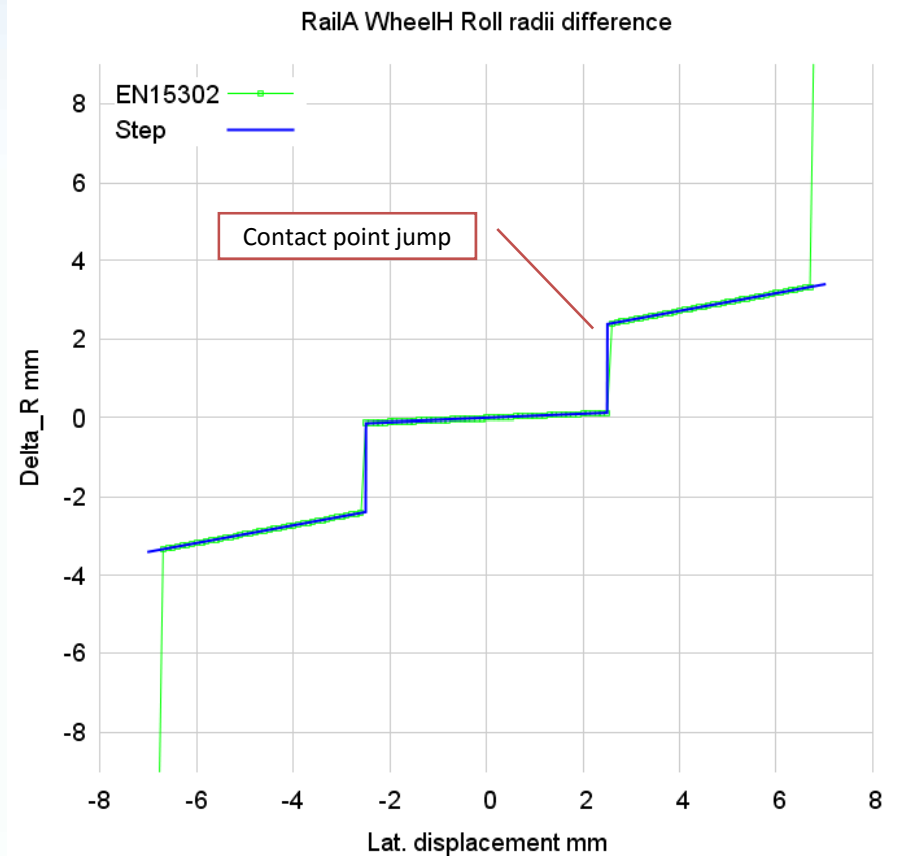


Examples of Standard

Rail A vs. Wheel H: Contact Points and ΔR



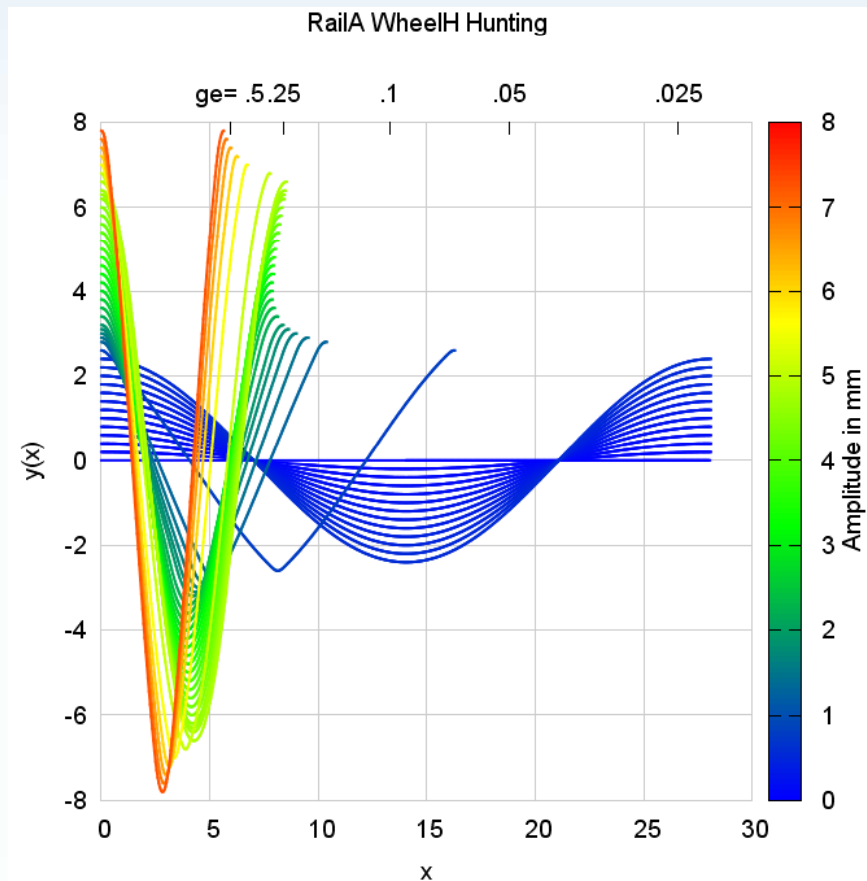
EN15302 (c) BAMM 2015



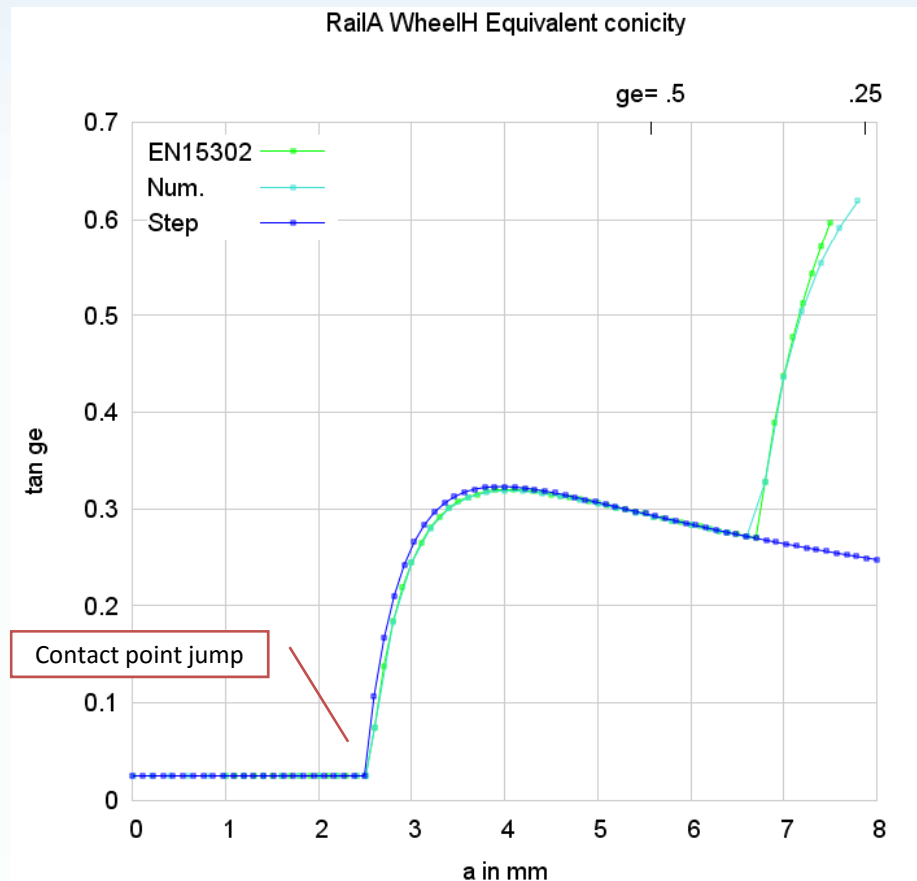
EN15302 (c) BAMM 2015

Examples of Standard

A/H: Wavelength and equivalent conicity



EN15302 (c) BAMM 2015



EN15302 (c) BAMM 2015

Profile measurement

What is measured for evaluating the wheel/rail geometry?

Measured data of the **rail**

Wear (wear of flank, wear of height, loss of area)

Track gauge

inclination

Rail cross-section

Measured data of the **wheel**

Diameter (deviation of roundness)

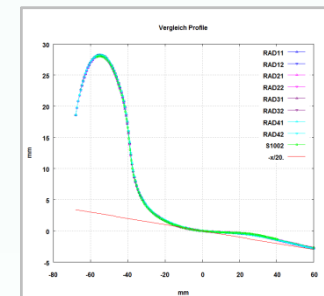
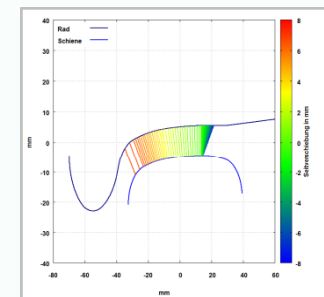
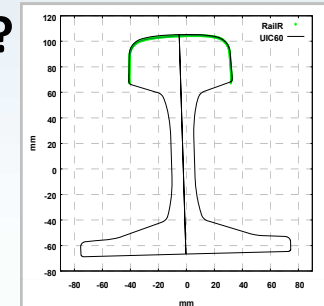
Wheel flange (thickness, height, gradient, wear)

Running surface: hollow tread

Wheel cross-section

Purpose: from single parameters to overall assessment!

Equivalent Conicity (dependent on the amplitude)



Measuring methods

Mechanical scanning of the profile

- Manual plotting instruments
- Various gauging tools
- Linear contour scanner
- Contour scanner with joint
- accurate
- Slow, frequently only single values



Optical methods

- Laser based (number of cameras)
- rapid, installable in measuring vehicles
- Reflexion effects (e.g. after milling or grinding)

Achievable accuracy

- Typical repeatability about 0.1 mm
- Higher accurateness desirable
(curvature R13 at 1 mm dot pitch: .038 mm)



Smoothing

Mathematical

Differentiability

Empirical

Curvature

Numerical

Smoothing index

Functions $f(x)$

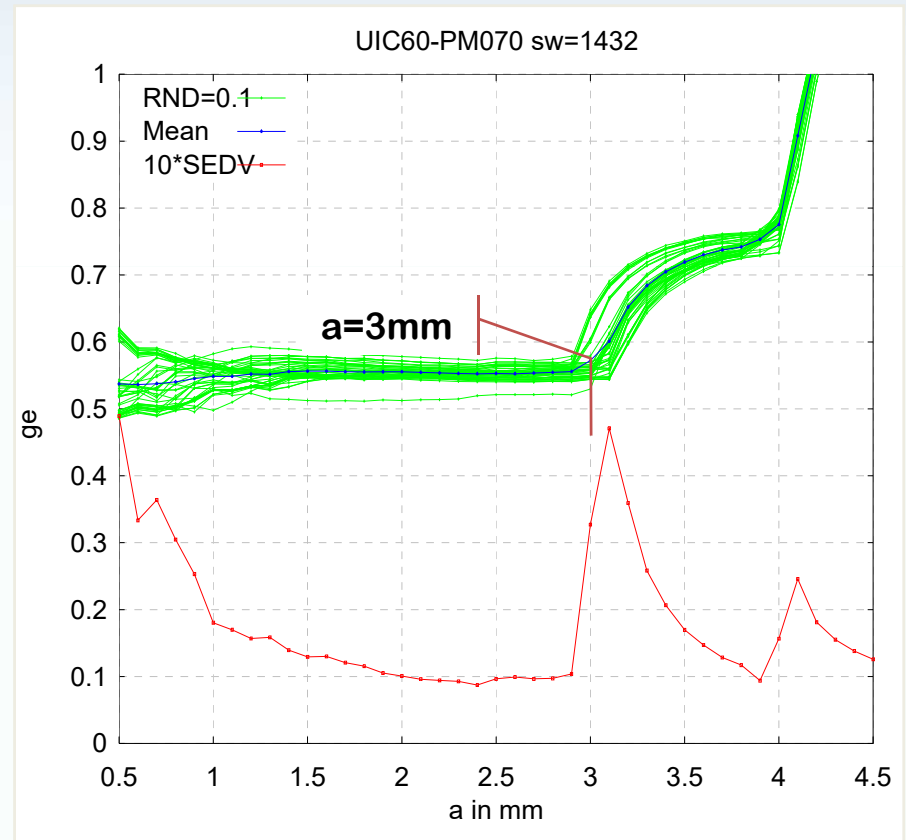
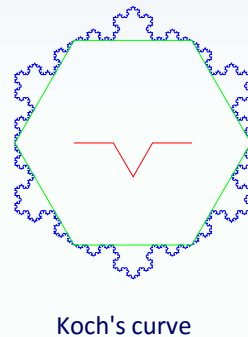
Polynomial regression (iterative)

Linear filters (iterative)

Smoothing splines

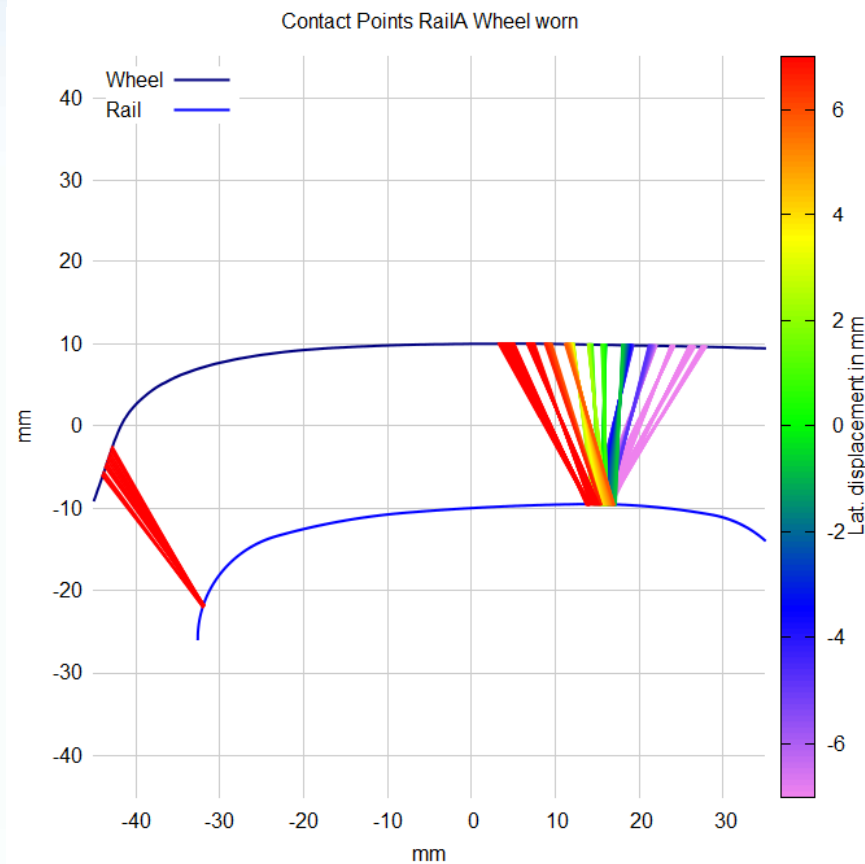
Curves $x(s)$, $y(s)$

Averaging curvature (iterative)

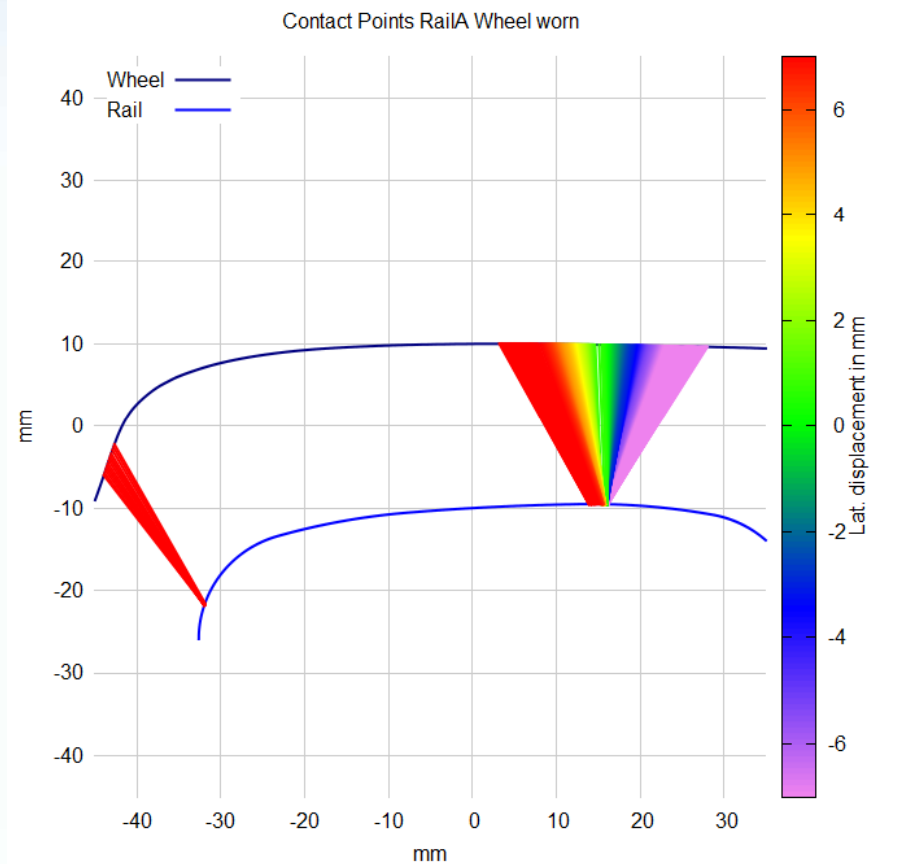


Worn Wheel

Rail A vs. worn Wheel (raw and smoothed)



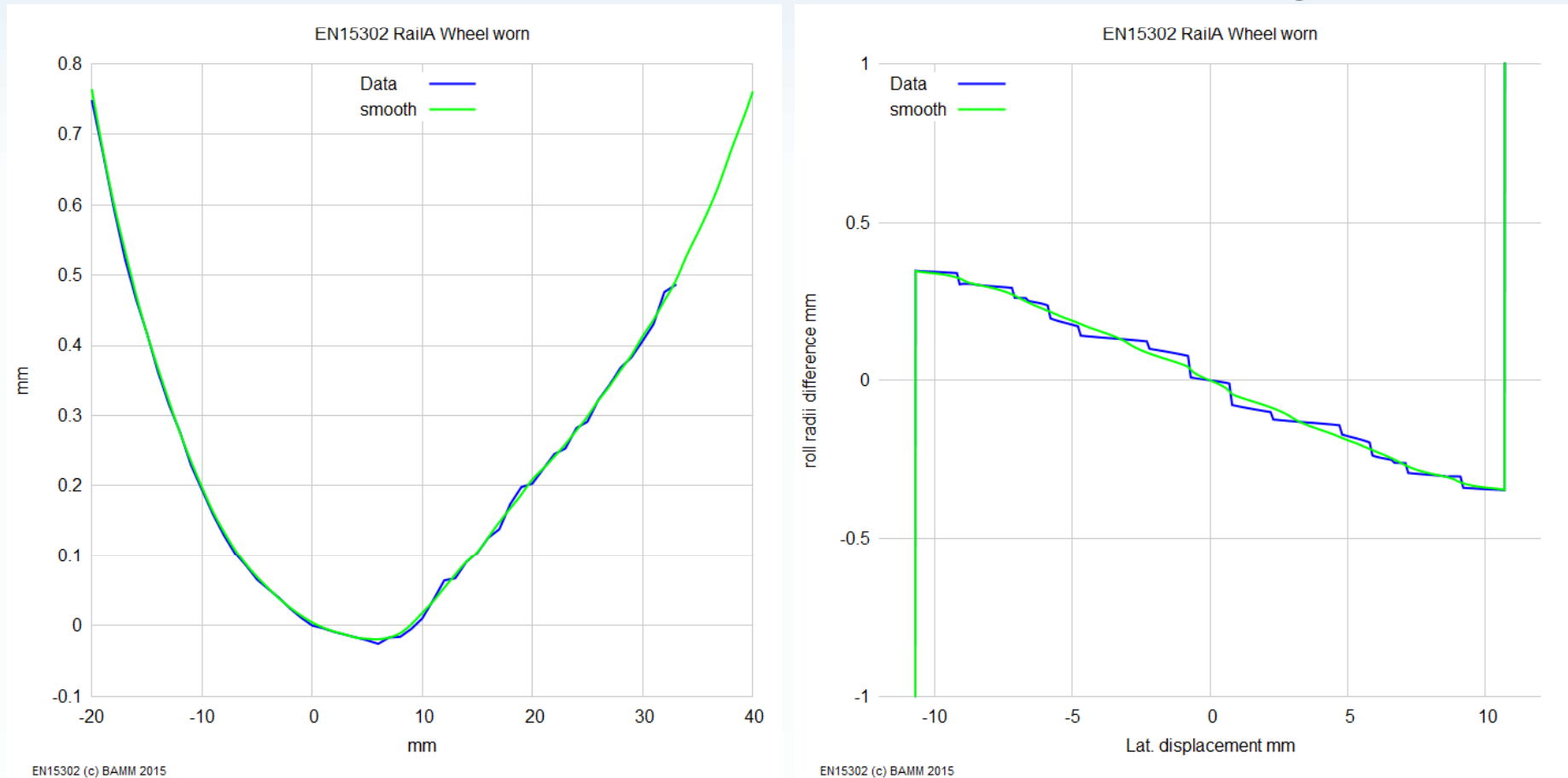
EN15302 (c) BAMM 2015



EN15302 (c) BAMM 2015

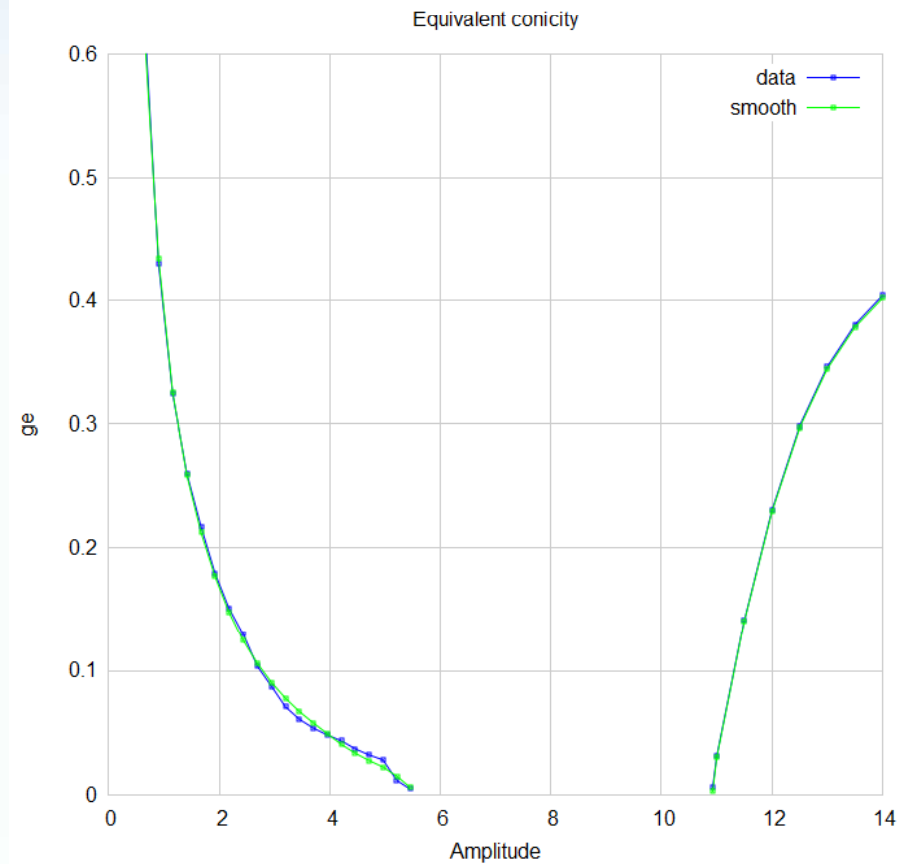
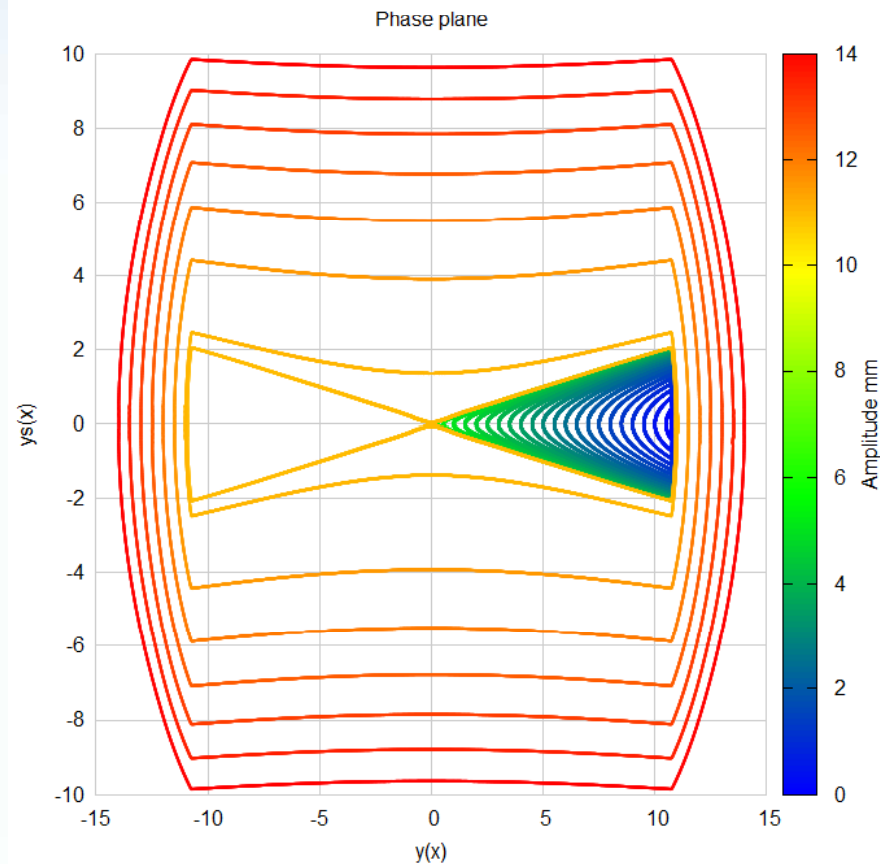
Worn Wheel

Rail A vs. worn Wheel A: influence of smoothing



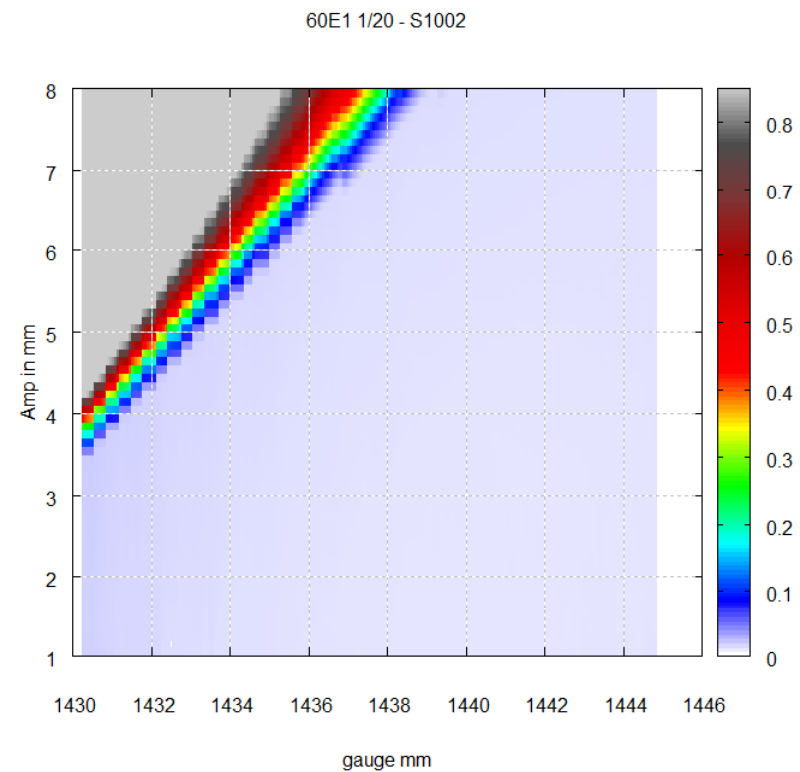
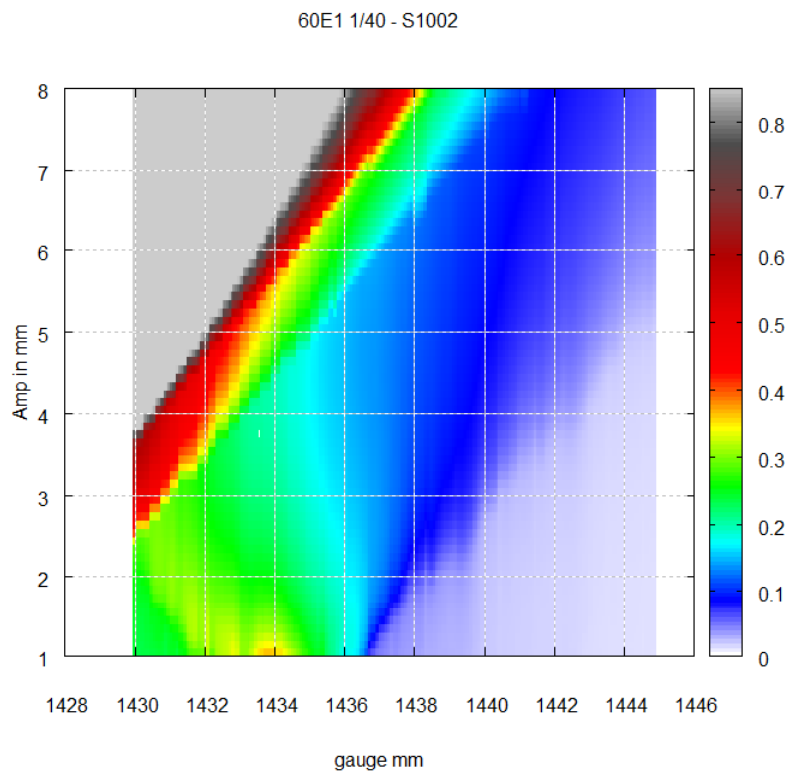
Worn Wheel

Rail A vs. worn Wheel A: not for all amplitudes defined!



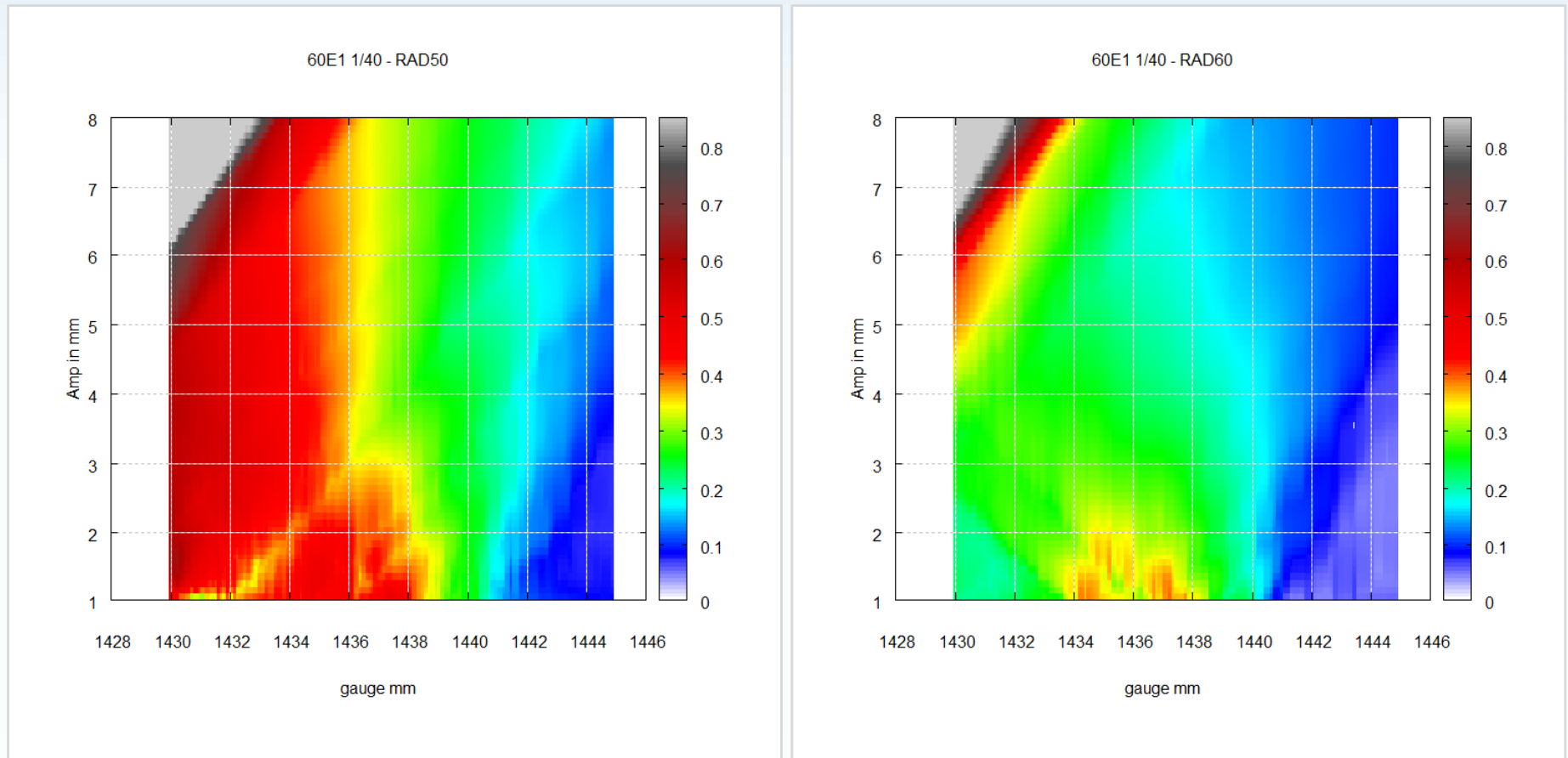
Combination of Profiles

Theoretical – theoretical: Rail 60E1 – S1002 (different inclination)



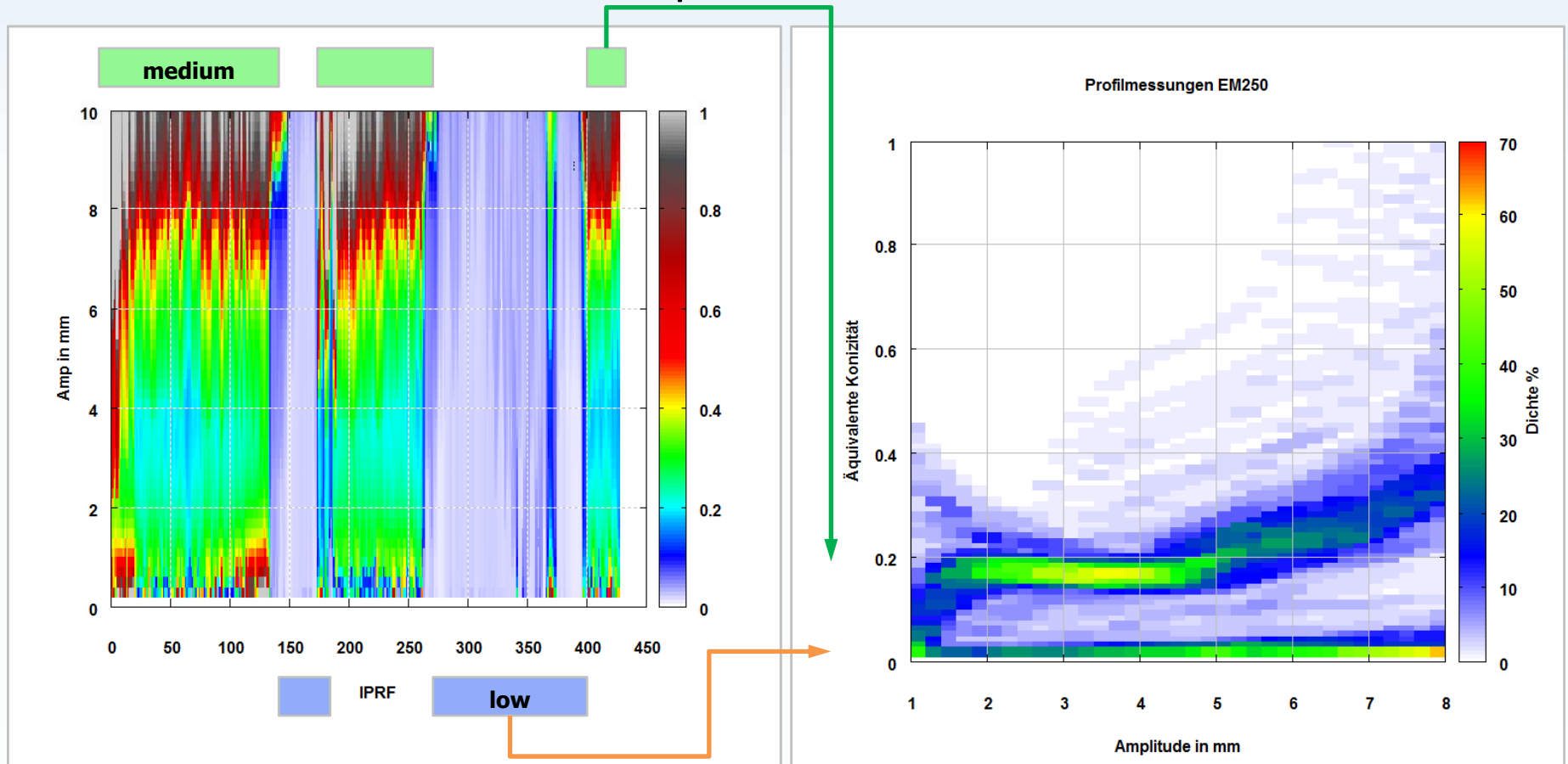
Combination of Profiles

Theoretical – measured: Profile 60E1 – wheel profile



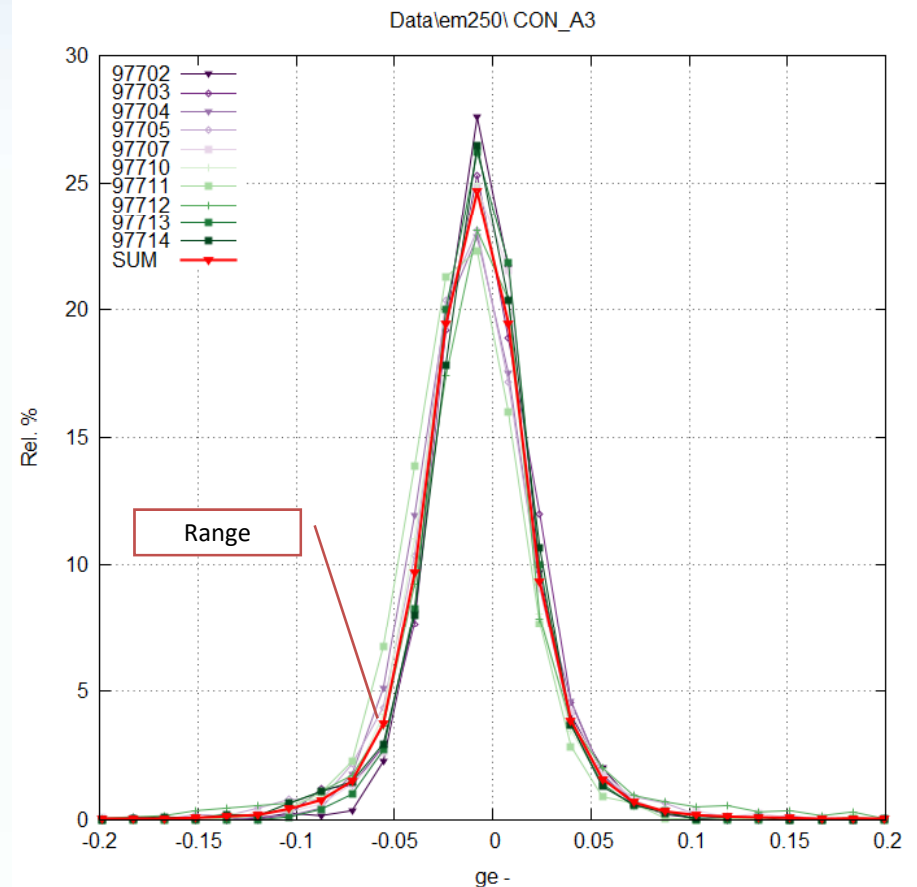
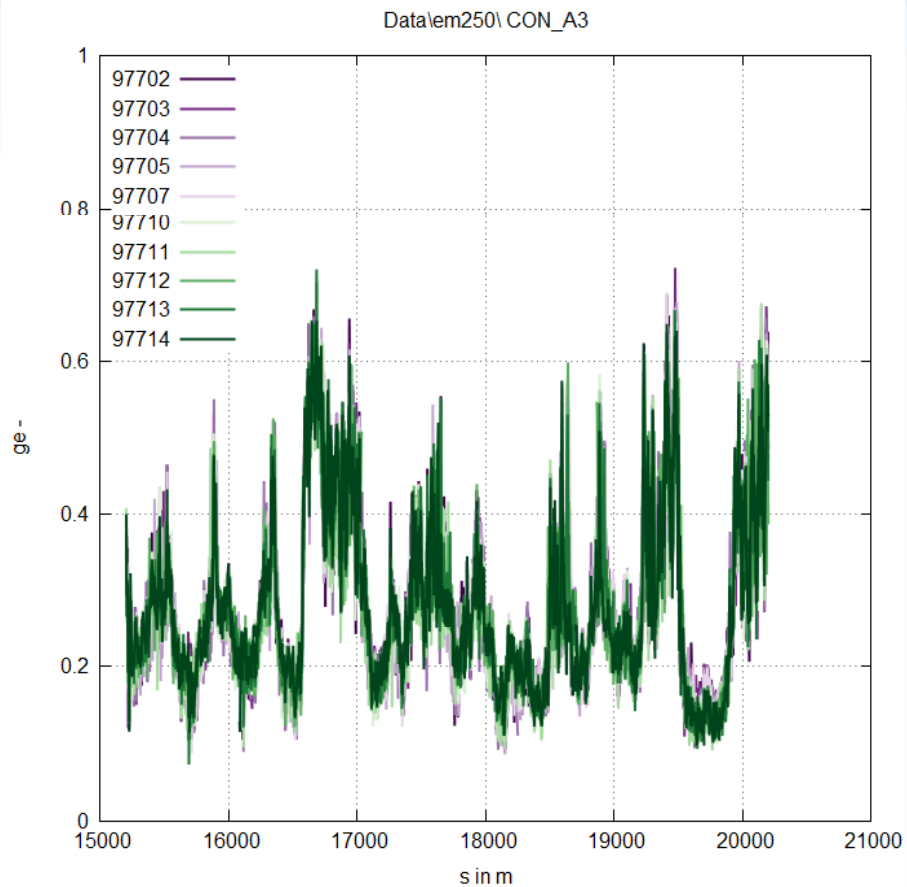
Field test

Measured rail profiles of a track section



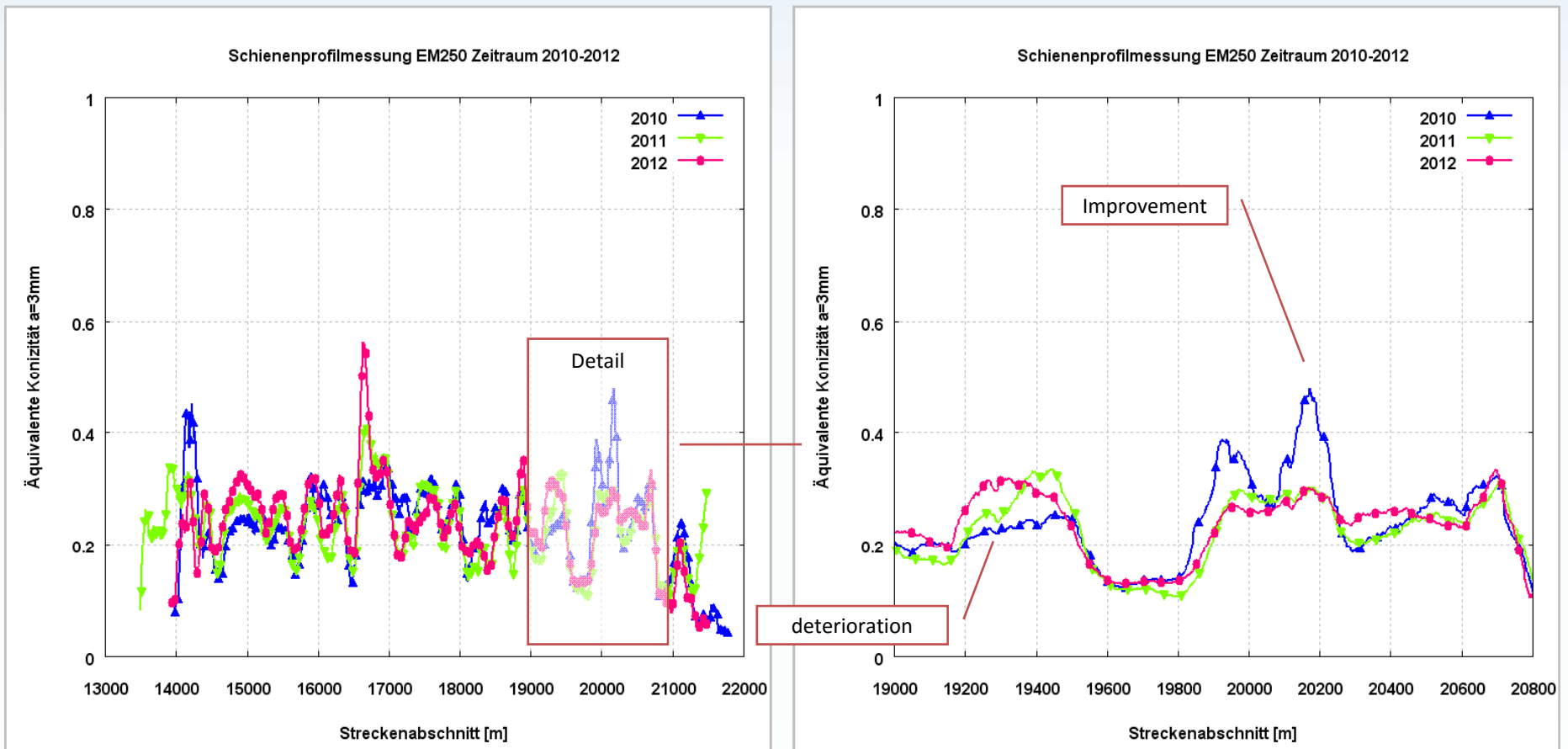
Repeatability

Same section, different velocities and orientation of vehicles



Time series

Variable trends: deteriorations but also improvements



Conclusio

Long-time evaluations and experience show:

- Estimate of tolerances possible (see standard)

- Repeatability given (proven by measurements)

- Measurable (indirect, but efficient real-time analysis possible)

- Simple evaluation of the interaction of wheel and rail

Measuring the in-service conicity is technically feasible and recommendable!



Dr. Paul Mittermayr

Bureau of applied Mechanics and Mathematic

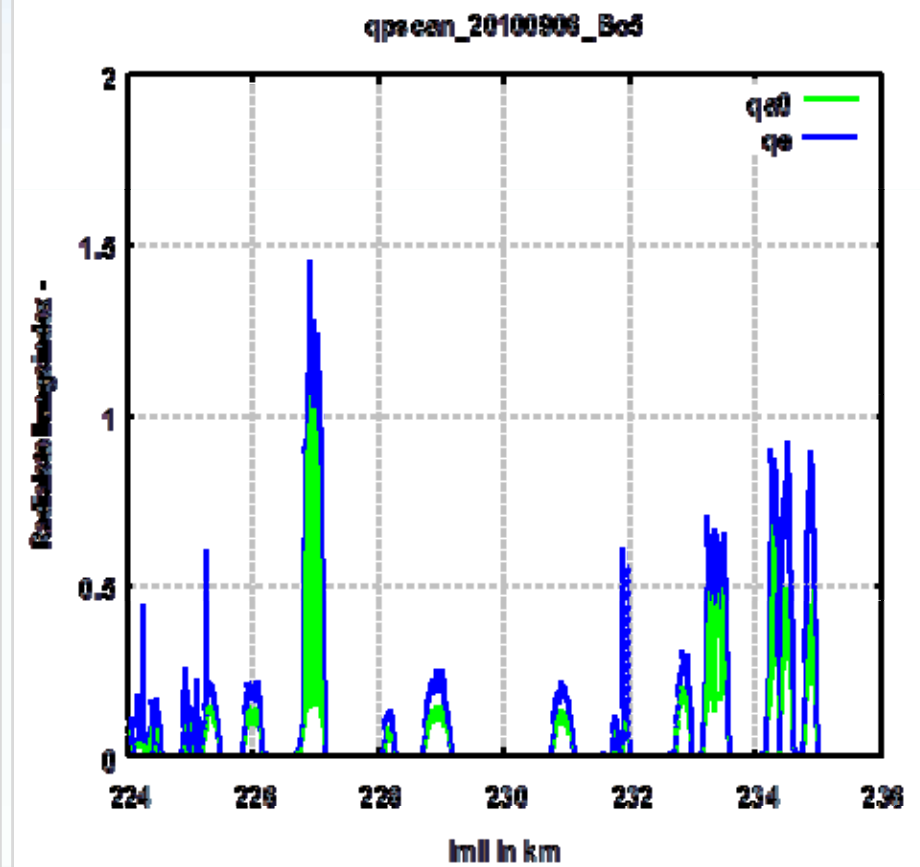
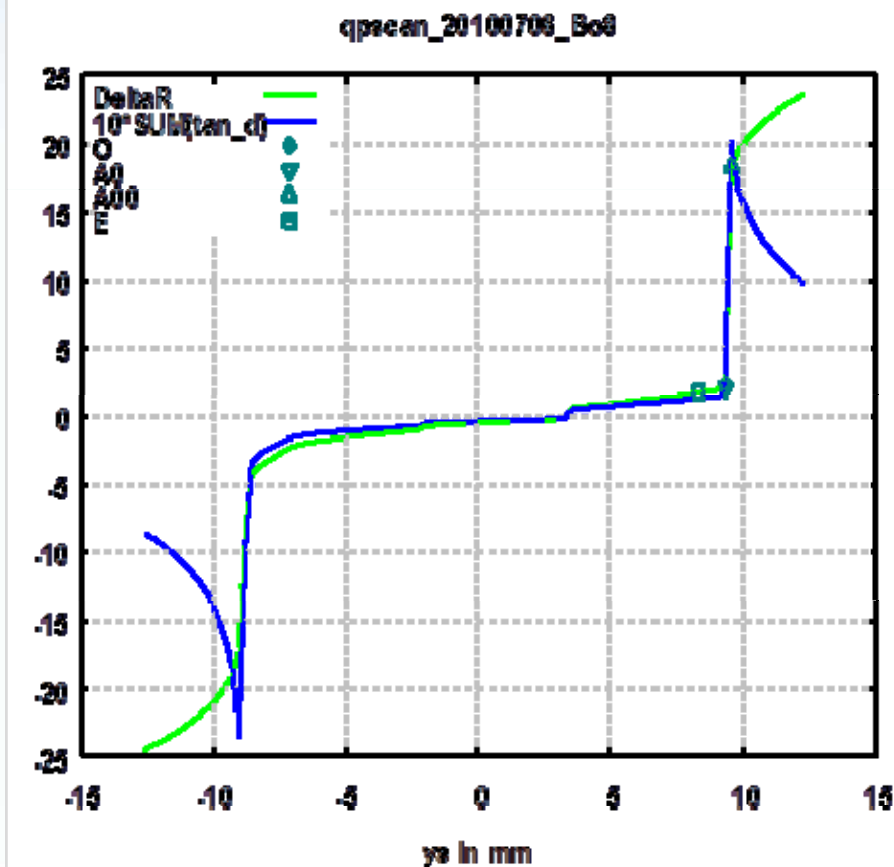
Dr. Mittermayr Scientific GmbH & Co KG

<http://www.bamm.at>

Thank you for your attention!

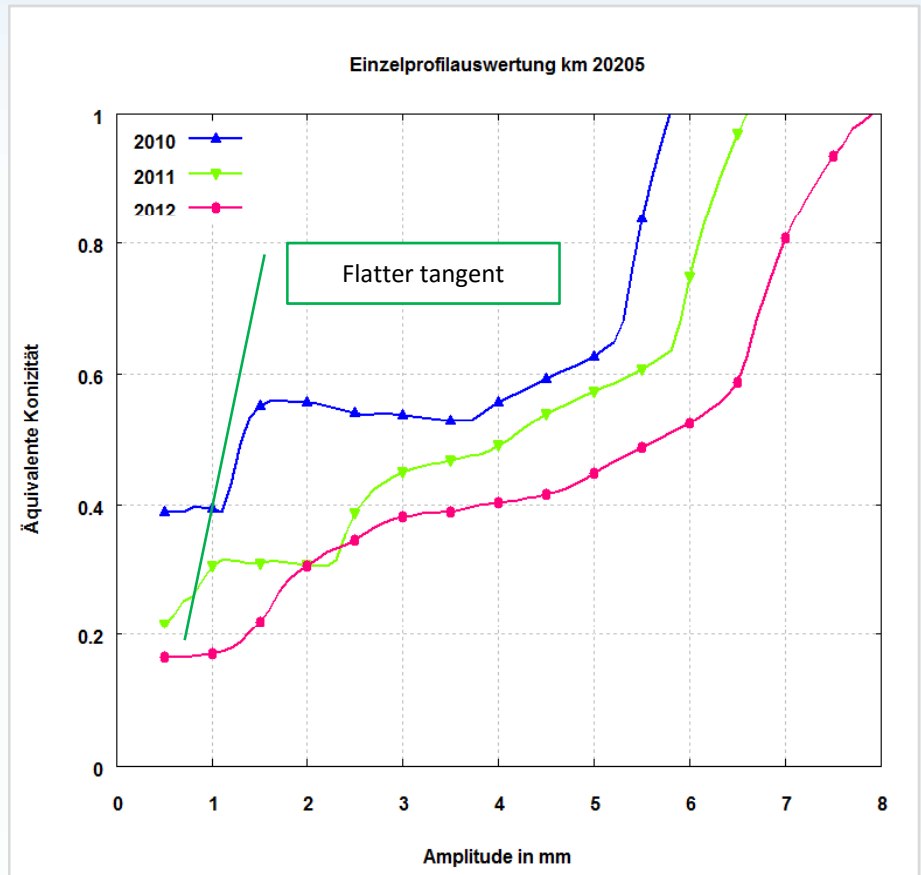
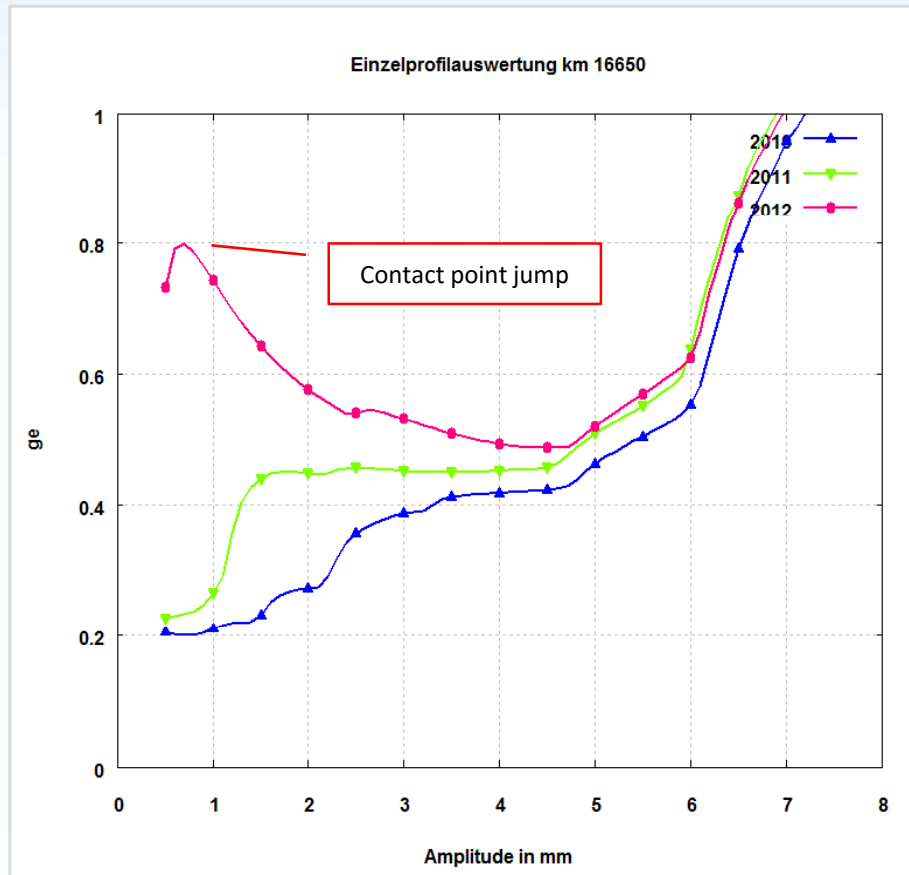
Radial Steering Index RSI

Parameter of the curvature: radial steering index RSI



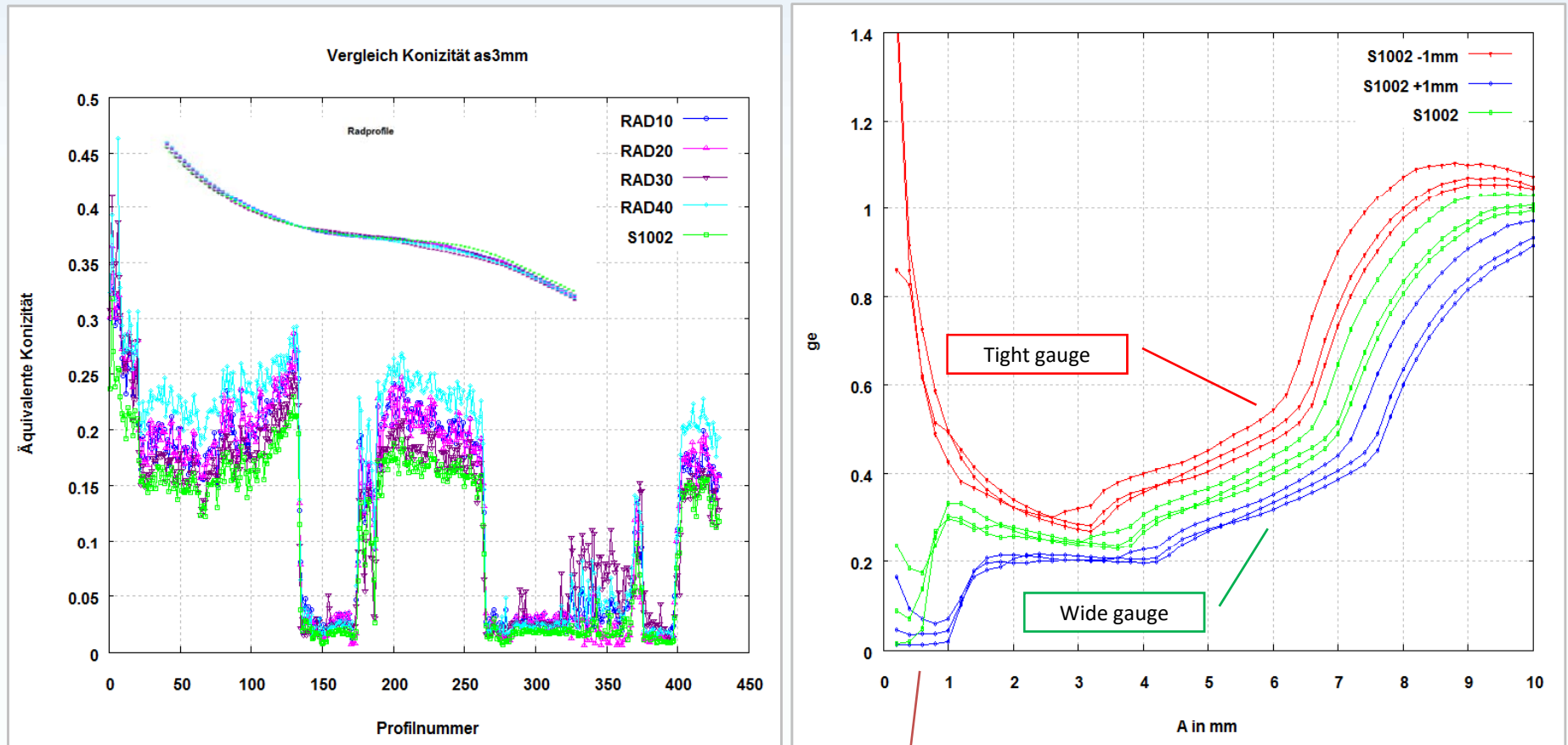
Time series

Isolated cases: deteriorations but also improvements



Variation

Measured rail profiles variation wheel profile and track gauge



Small amplitudes